理研で取り組んだ物理・学んだこと（失敗談を交えて）

Physical Researches conducted at RIKEN
— as a Chief Scientist —

次世代研究者へ：失敗を恐れず挑戦的な研究を！

IWASK2024 — 05/03/2024

Masahiko IWASAKI

Meson Science Laboratory

A Slide from Interim Review of Institute Laboratory Assessment in 2006

研究者としての来歴：決して成功ばかりじゃない…

nuclear physics

PhD student **UT** big leader T. Yamazaki *1982*

heavy neutrino search (particle physics) NG

hypernuclear study NG

TRIUMF pionic atom NG *PhD in 1987*

Σ-hypernucleus ! $^{4}_{\Sigma}He$

atomic meta-stable state in exotic helium! (atomic physics) → p̄ physics @ ASAKUSA

original

PhD student

muon science

UT-MSL vigorous leader K. Nagamine

Staff Scientist

research associate

construction

contribution to JHF — stalled

← (*RIKEN-RAL construction*)

DAQ

μ-CF

slow-μ

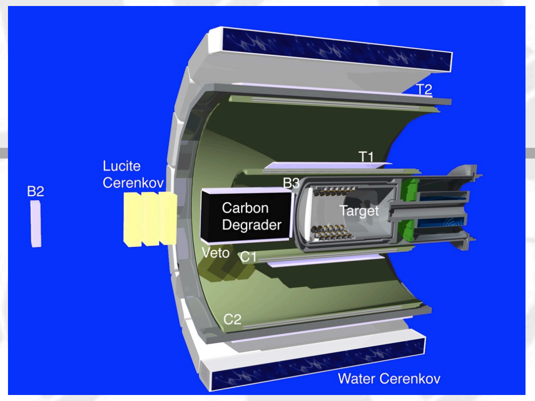
μ-radiography

完全オリジナル実験成功

KEK KpX E228

kaonic hydrogen atom

1990-1997



大失敗 enthusiastic promoter K. Nakai

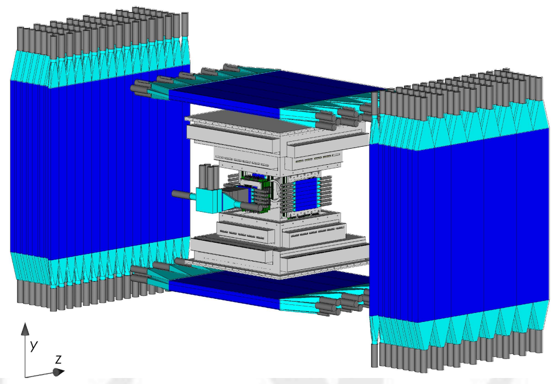
NG

TI-Tech *1997*

associate professor

PI

KEK - E471, E549, E570



INFN / SMI (DEAR) kaonic atom

GSI pionic atom

TI-Tech visiting professor

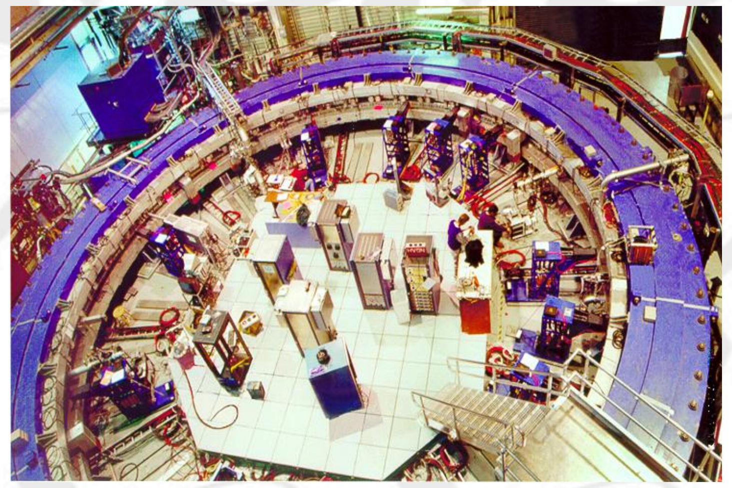
E471 kaonic nucleus search NG *2002*

BNL E821 muon g-2 measurement

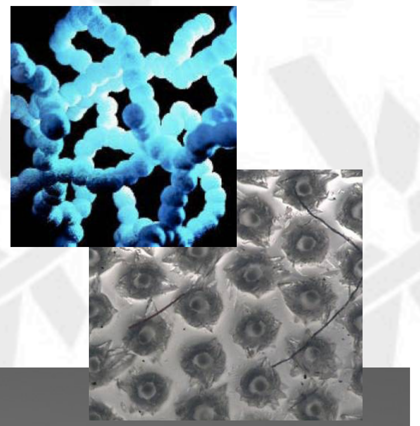
muon CBO (particle physics)

2002

BNL E821



laser-drilled aerogel



INFN (SIDDHARTA) kaonic atom

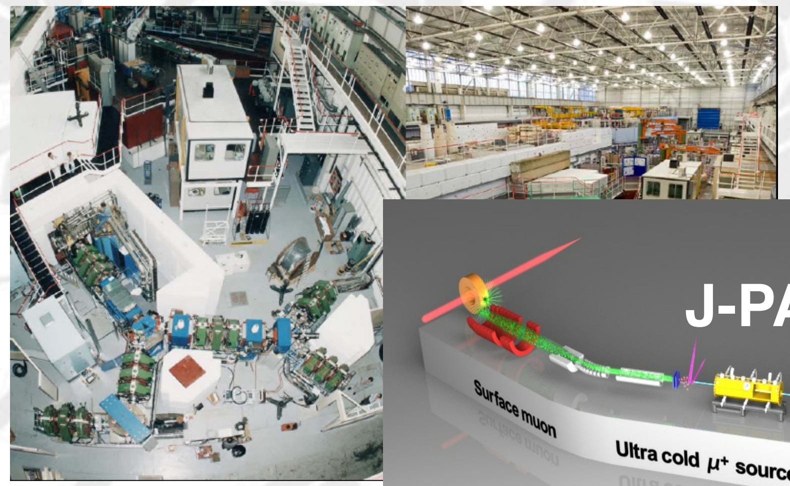
E549, E570 kaonic nucleus search kaonic helium-4 atom

RIKEN chief scientist

last 22 years in RIKEN

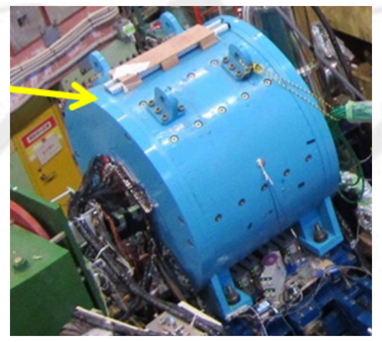
RIKEN-RAL operation

RIKEN-RAL muon facility



RNC inauguration → RIBF pionic atom

K中间子核観測成功



J-PARC E15 / E17

kaonic nucleus "Kpp" search

kaonic helium-3 atom

2006-2019

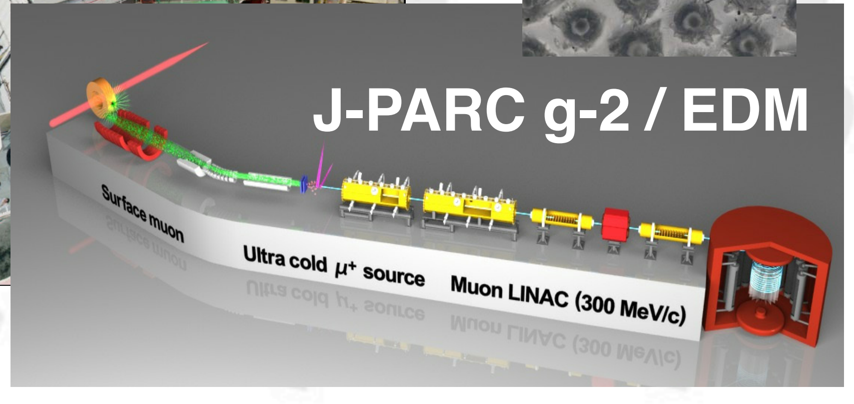
ϕ & KK in nuclei

J-PARC P34 muon g-2 / EDM

μ magnetic microscope

based on cold-μ

J-PARC g-2 / EDM



Meson Science Laboratory

– covers wide variety of field by the variety of researchers –

nuclear physics

- mesonic atoms (atomic physics / nuclear physics)
- mesons in nuclei (nuclear physics) – today!
- Λ in nuclei (nuclear physics)

IWASK2024 ではここの話を

muon science

- μCF : muon catalyzed fusion (chemistry / atomic physics / nuclear physics)
- μSR : muon spin rotation / resonance … (condensed matter physics)
- μA* : muonic atoms (nuclear physics)
- cold-μ : muon magnetic microscope / muon g-2 (particle physics / atomic physics / condensed matter physics)

Mössbauer

- in-beam M : RI-beam Mössbauer spectroscopy (condensed matter physics)

IWASK2024 ··············

Interdisciplinary Workshop for Advanced Science of Kaon and related topics

日時：2024年3月5日 (火) 9:30 - 18:00

場所：理化学研究所 大河内記念ホール

先ごろJ-PARCで生成・分光に成功した K^-pp 束縛核に関する一連の研究は、粒子描像があやうくなるほどコンパクトな陽子間距離を示唆し、高密度物質である原子核内におけるハドロンの粒子性と量子性という本質的問題を提起しています。ここで提起された問題は、原子核という舞台においてのみならず、固体凝縮物質中の電子が示す量子相転移とも密接な関係にあります。K中間子研究はハドロン研究の一分野としての位置づけを超え、物質の階層性をまたいだ新たな学際研究へと広がる可能性を秘めています。この好機に、K中間子および関連するトピックをあつめたワークショップを開催し、未来の中間子科学が取り組むべき課題は何か、指針を探る機会としたいと思います。

講演者

松田恭幸、石田勝彦、神田聡太郎、渡邊功雄、藤山茂樹、馬越、橋本直、西隆博、板橋健太、四日市悟、岡田信二、岩崎雅彦 (順不同)

申し込み方法

https://indico2.riken.jp/e/iwask2024

問い合わせ先 iwask2024@ml.riken.jp（板橋・藤山・山本）

全ての参加者に感謝を

— IWASK2024 —

To organizers, thank you for giving me a chance to talk.

To speakers, all the participants and secretaries, thank you for joining.

named and organized by K. Itahashi and S. Fujiyama
with helps from researchers who have been contributed
Meson Science Laboratory in RIKEN

I apologize for not being able to cover my contributions as Chief Scientist at RIKEN due to time constraints.

I hope the missing parts are well covered by the other speakers of IWASK2024.

A Typical Experimental Research Cycle

Objective:
Unsolved Problem
Why and How?

→

Ansatz
Assumption
Methodology

→

Experiment

A Typical Experimental Research Cycle

Objective:
Unsolved Problem
Why and How?

→

Ansatz
Assumption
Methodology

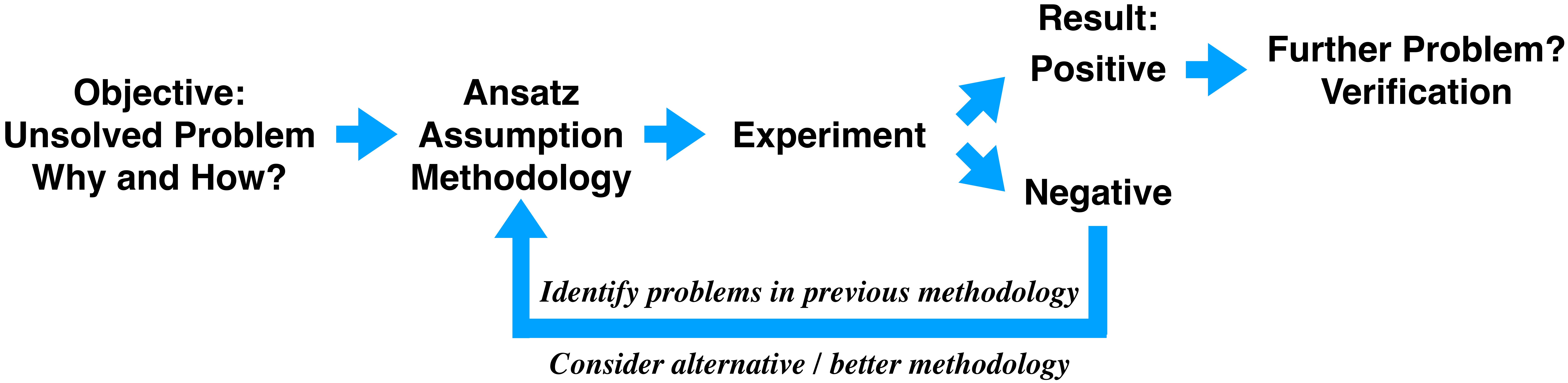
→

Experiment

→ **Result:**
Positive → **Further Problem?**
Verification

→ **Negative**

A Typical Experimental Research Cycle



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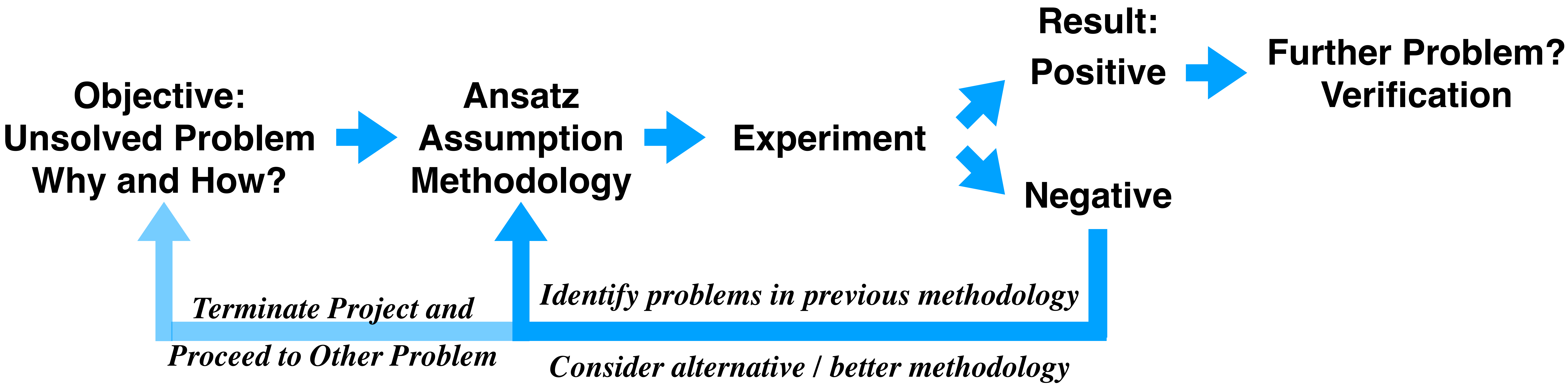
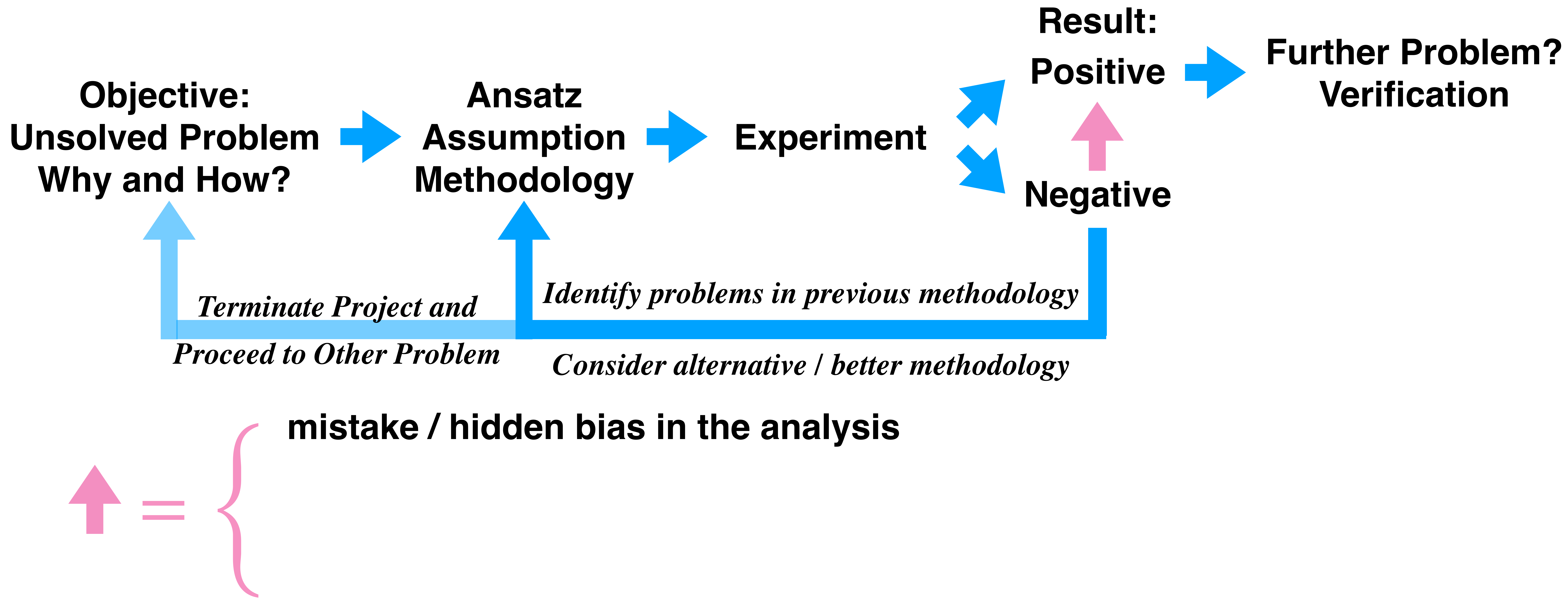
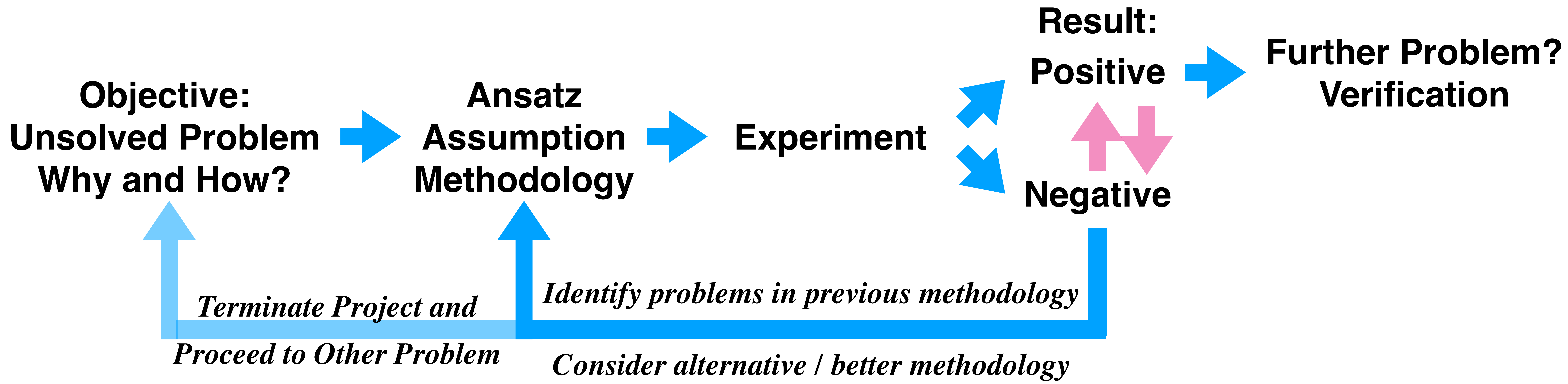


A Typical Experimental Research Cycle

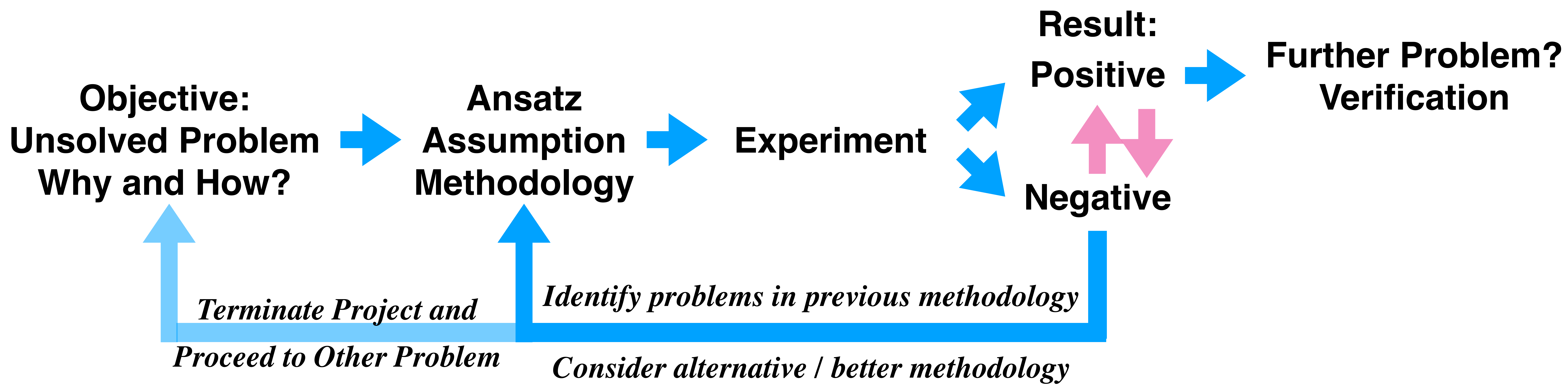


A Typical Experimental Research Cycle



= { **mistake / hidden bias in the analysis** — *Must be corrected, and open that to public.*

A Typical Experimental Research Cycle



↑ = {

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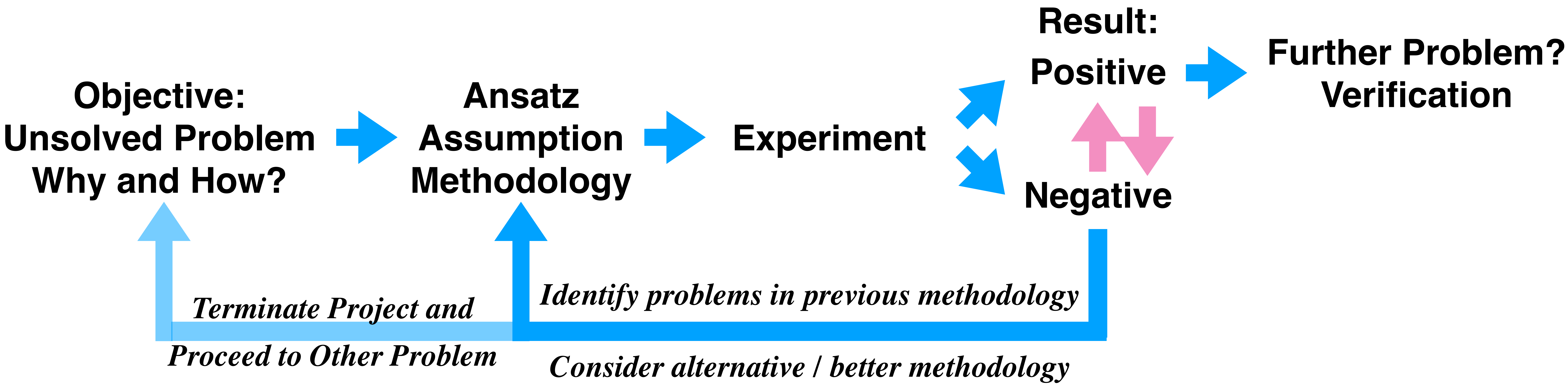
— *To encourage ambitious research, failure must be embraced.*

完全にミスを防ぐことは不可能。間違いは許容されるべき

実験研究のサイクルの紹介

A Typical Experimental Research Cycle



↑ = {

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— *To encourage ambitious research, failure must be embraced.*

完全にミスを防ぐことは不可能。間違いは許容されるべき

pretend to be positive — **unacceptable scientific misconduct**

決して許容できない。過度な倫理教育・研究者の引き締めは愚策

研究者としての最初の大成功

Let me start from a mile-stone experiment, which makes me to be a Principal Investigator (PI)

The KpX experiment

"It takes three years from gaining PhD in 1987 to develop original research ideas in 1990, and another seven years to get the first results reported in 1997."

… 本質的革新を齎すための手段を真摯に模索 …

… 良い研究は10年位は平然とかかる …

K中間子水素原子パズル

My first success as a researcher

Resolving the kaonic hydrogen puzzle is a must

PHYSICAL REVIEW D

VOLUME 50

1 AUGUST 1994

THE $\Lambda(1405)$ by R.H. Dalitz, Oxford University

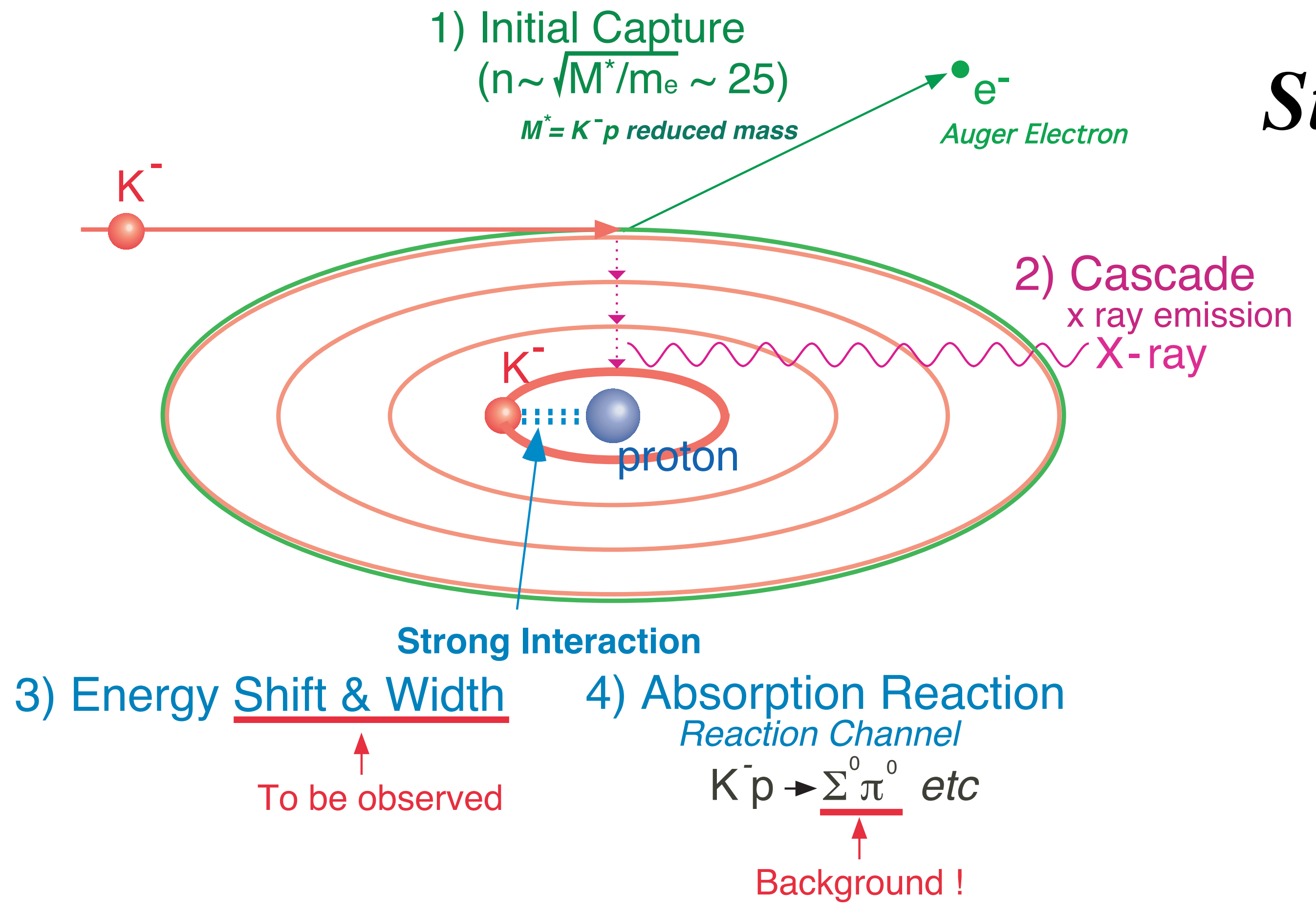
....

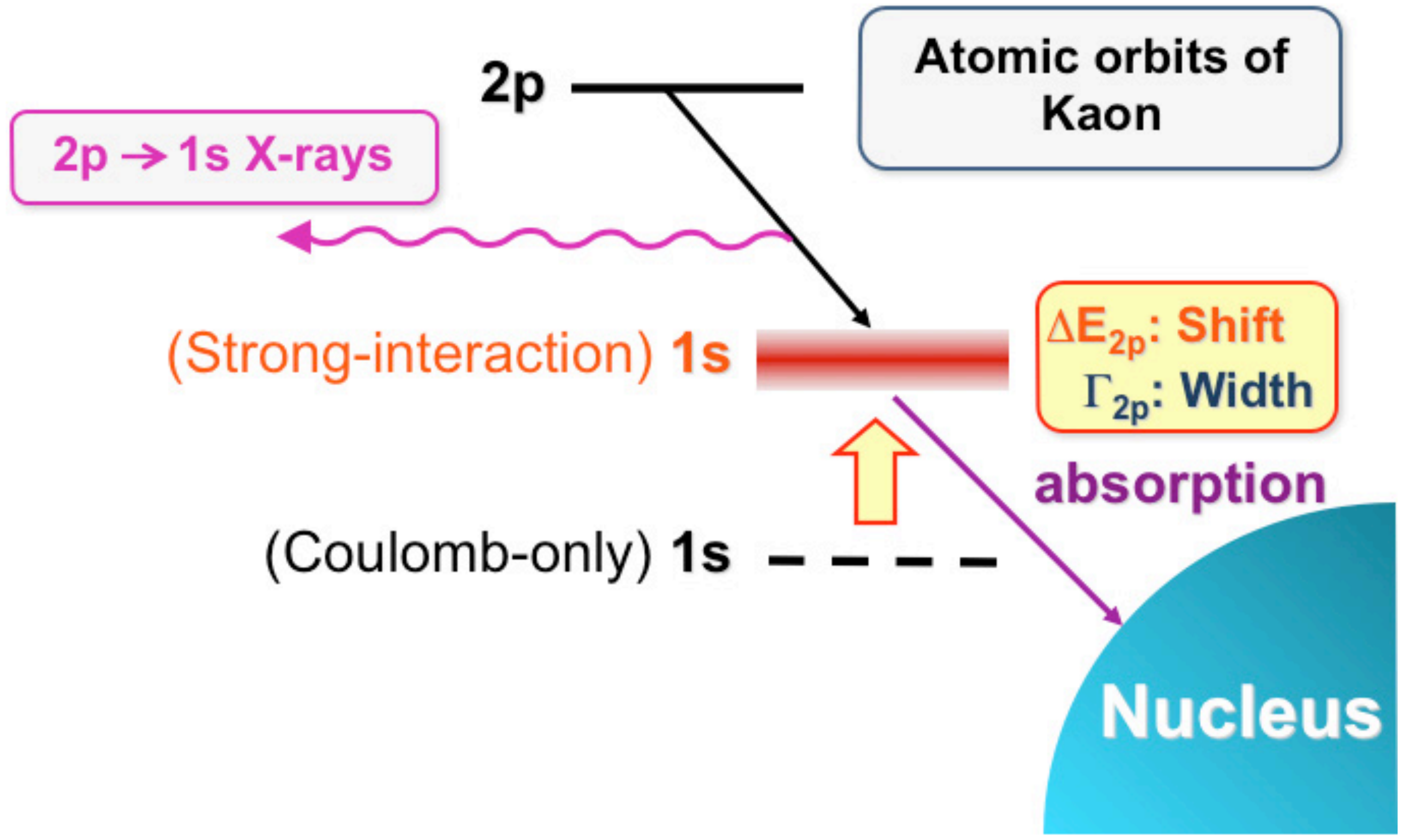
The present status of the $\Lambda(1405)$ thus depends heavily on theoretical arguments, a somewhat unsatisfactory basis for a four-star rating. Nevertheless, there is no known reason to doubt its existence or quantum numbers. A measurement of the energy-level shifts and widths for the atomic levels of kaonic hydrogen (and deuterium) would give a valuable check on analysis of the $(\Sigma\pi, N\bar{K})$ amplitudes, since the energy of the K^-p atom lies roughly midway between those for the two sets of data. The three measurement of $(\Delta E\text{-}i\Gamma/2)$ for kaonic hydrogen are inconsistent with one another and require that the sign of $\mathrm{Re}(A_{I=0} + A_{I=1})$ be opposite that deduced from $N\bar{K}$ reaction data (see BATTY 89). Accurate measurements of $(\Delta E\text{-}i\Gamma/2)$ values for kaonic hydrogen are badly needed, but may not be possible until the KAON factory becomes operational.

....

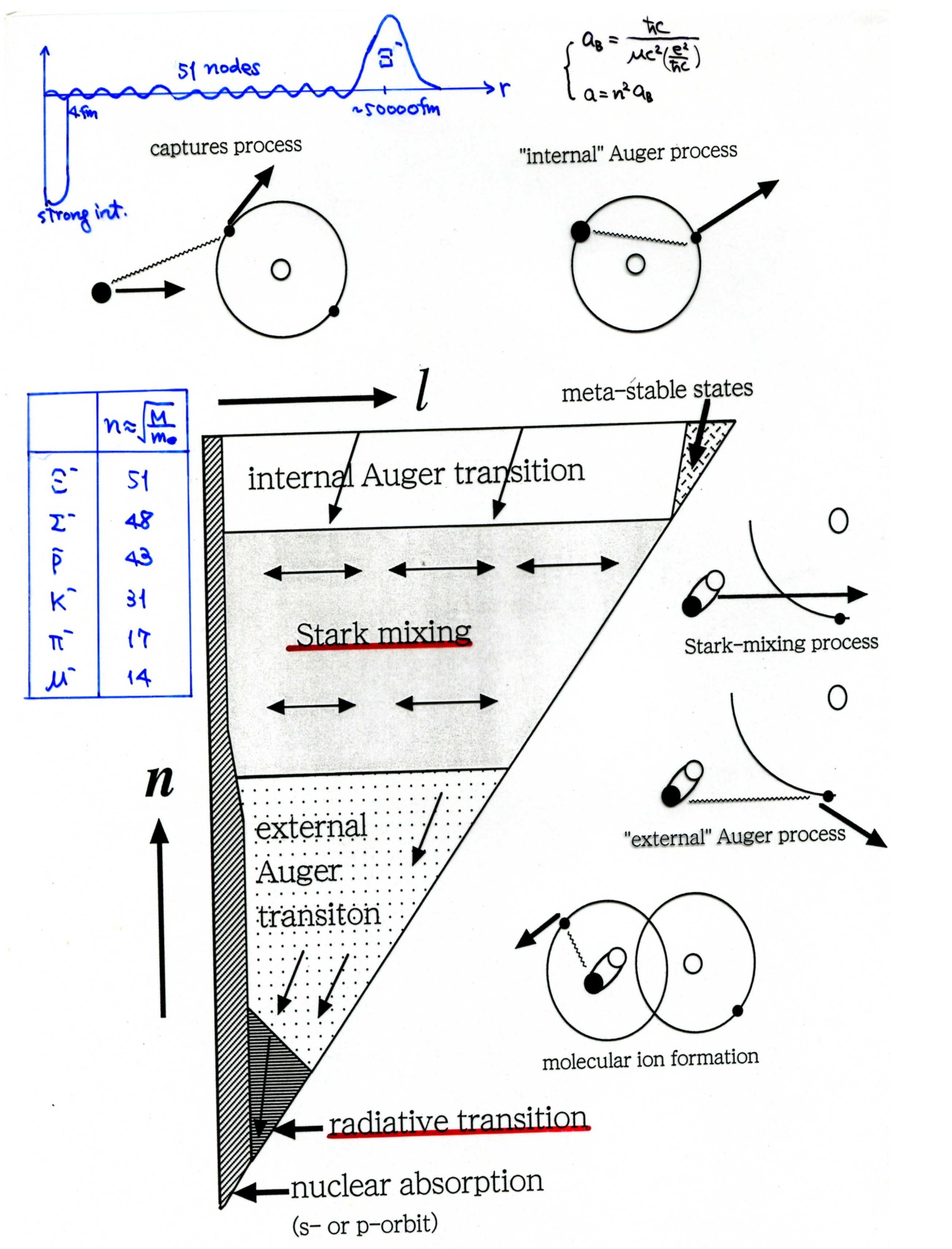
→ Kaonic Hydrogen Puzzle!

Kaonic Atom Formation

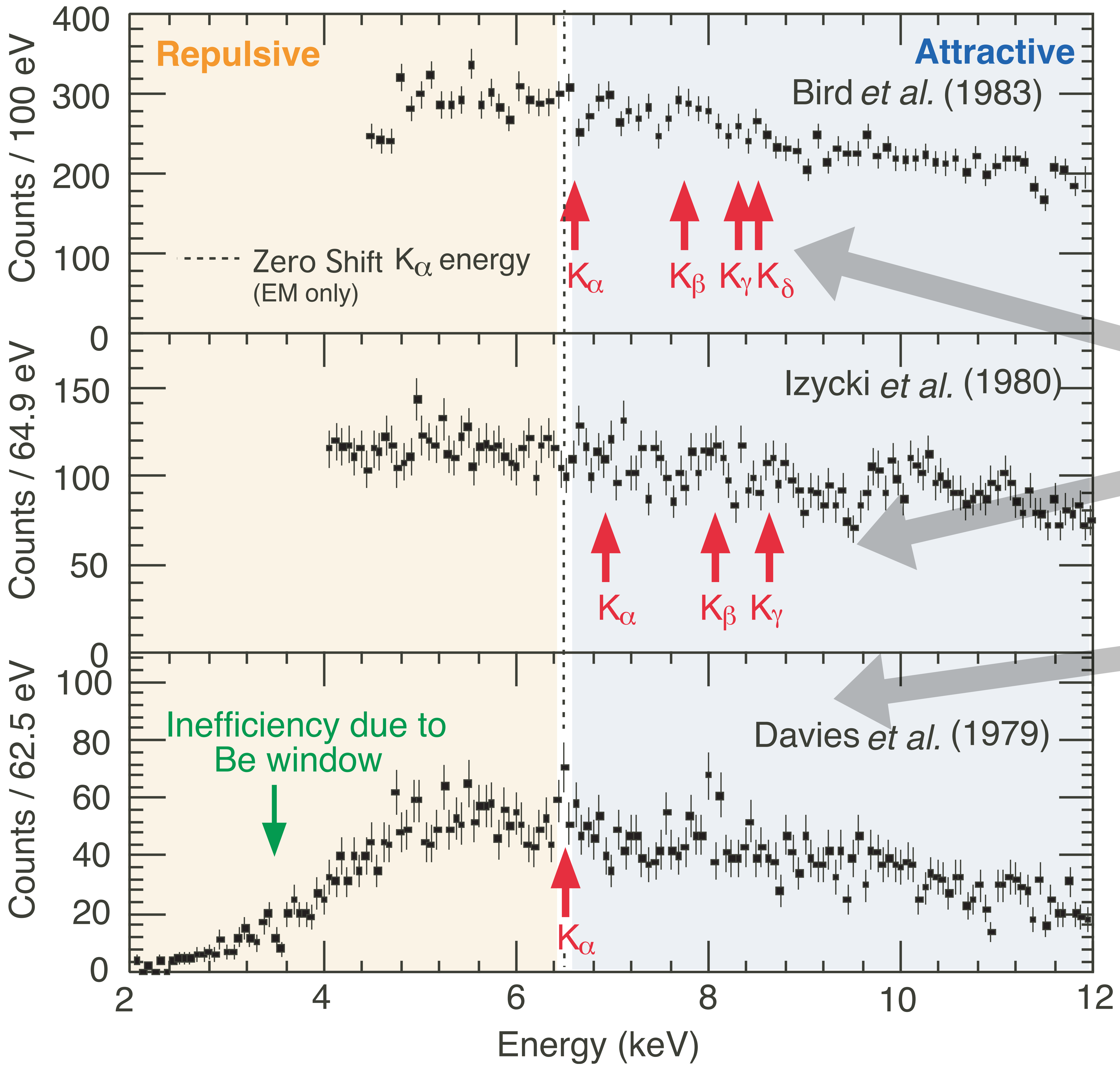




Stark-effect prevents x-ray observation

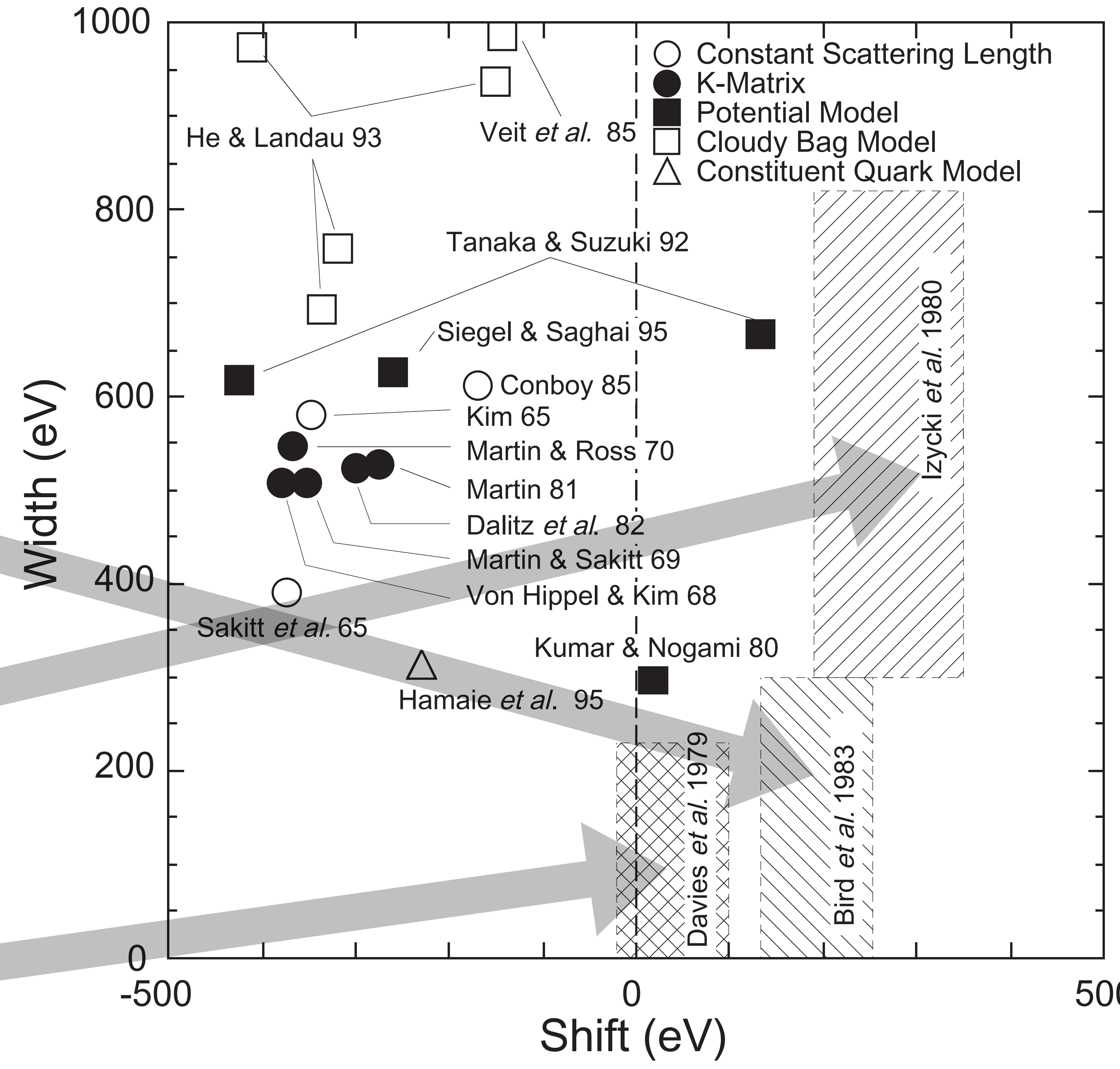


Previous data on the kaonic hydrogen



Can you really see signals in these spectra?

Theories and Experimental results are inconsistent



Most probably the applied experimental methods are insufficient!

How to improve?

過去の実験困難をどう乗り越える？

困難解決に向けた方策

My first proposal to PAC (実験課題審査会):

*Simply **REJECTED** … Insufficient to convince reviewers*

Consider more about how to initiate the break through to overcome experimental difficulties?

Second proposal to PAC: … break through ideas

- **Gas Target (liquid previously)**
  Stark Free (drastically improve S/N)
- **Background Free (reduce noise)**
  Final state tagging / Specify reaction point
  Require kaonic hydrogen atom formation
- **X-ray detector in Hydrogen Gas**
  Si(Li) without x-ray window
  Drastically improve signal

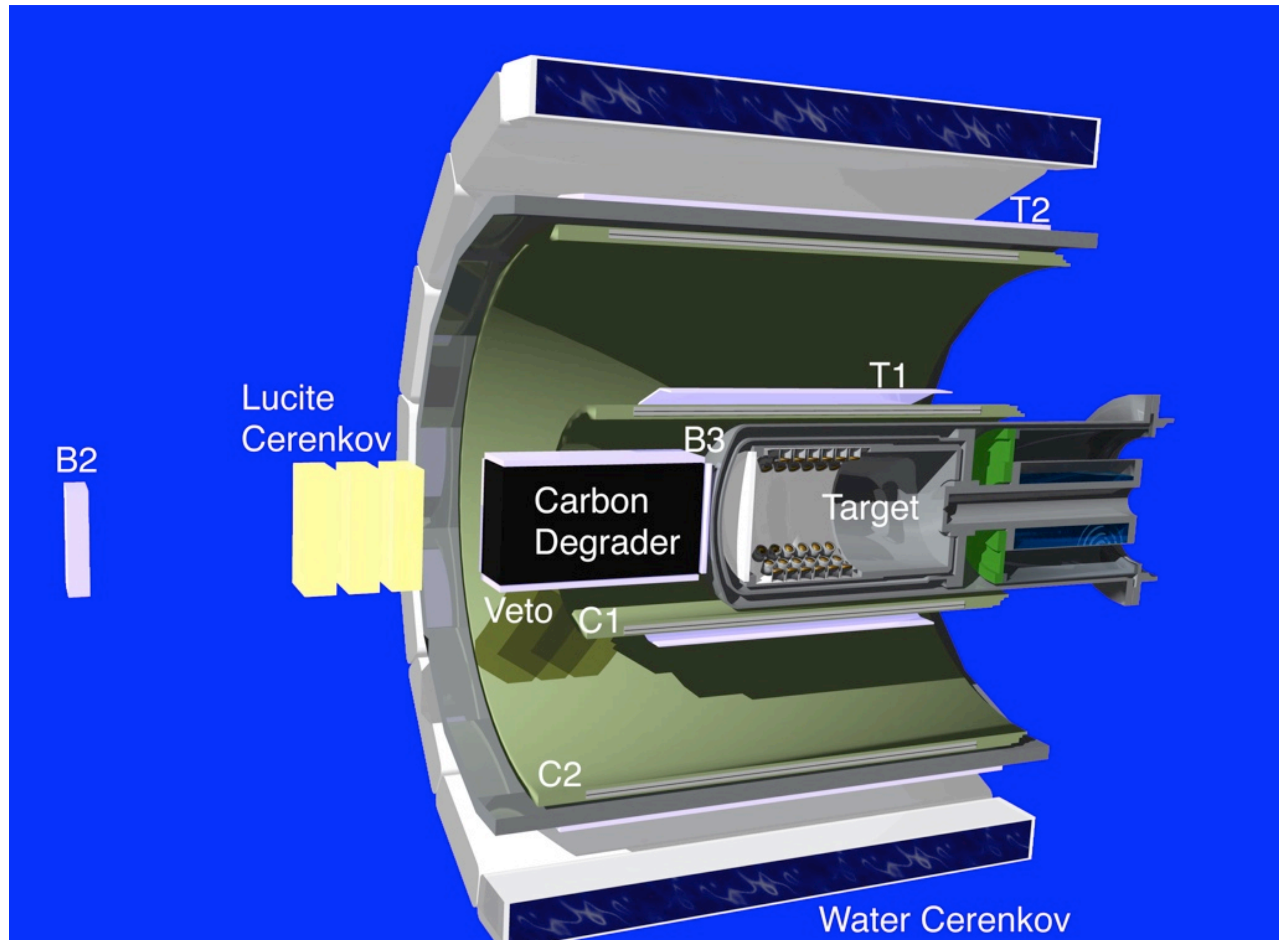
ACCEPTED by fully convincing reviewers …

Won a strong budgetary support from KEK (K. Nakai)

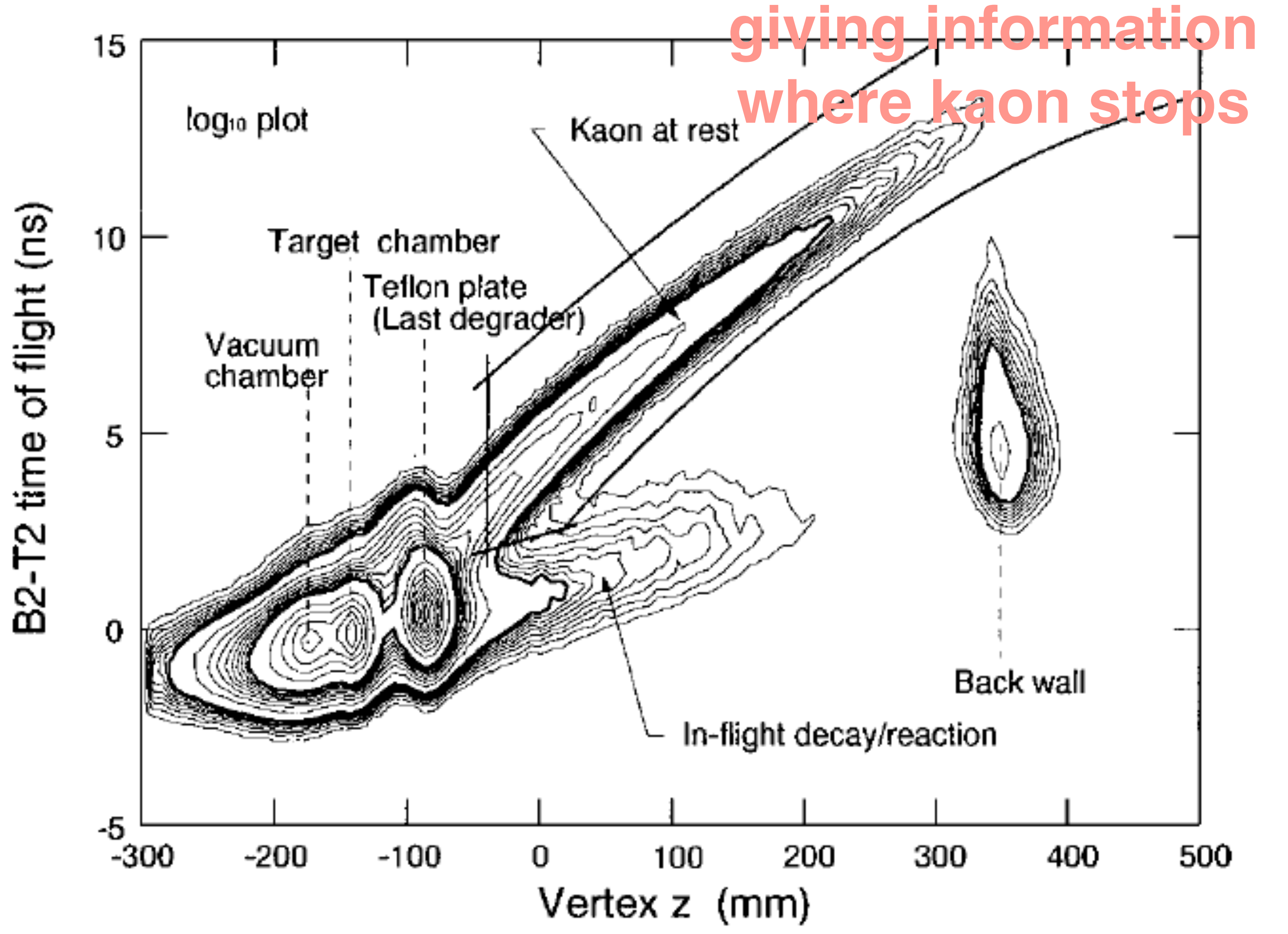
two charged pion tagging

Reaction	Produced Particles	Branching Ratio	$\pi/\mu/e$ Multiplicity (>150 MeV/c)	γ Multiplicity
Free Decay of K^-				
$\mu^-\nu$	$\mu^-\nu$	63.5 %	1	0
$\pi^-\pi^o$	$\pi^-2\gamma$	21.2 %	1	2
$\pi^-\pi^-\pi^+$	$\pi^-\pi^-\pi^+$	5.59 %	0	0
$e^-\pi^o\nu$	$e^-2\gamma$	4.82 %	1	2
$\mu^-\pi^o\nu$	$\mu^-2\gamma$	3.18 %	1	2
$\pi^-\pi^o\pi^o$	$\pi^-4\gamma$	1.73 %	0	4
K^-p Reaction				
$\Sigma^+\pi^-$	$\pi^-2\gamma p$	10 %	1	2
$\Sigma^+\pi^-$	$\pi^-\pi^+n$	10 %	2	0
$\Sigma^-\pi^+$	$\pi^+\pi^-n$	46 %	2	0
$\Sigma^o\pi^o$	$\pi^-3\gamma p$	18 %	0	3
$\Sigma^o\pi^o$	$5\gamma n$	10 %	0	5
$\Lambda\pi^o$	$\pi^-2\gamma p$	4 %	0	2
$\Lambda\pi^o$	$4\gamma n$	2 %	0	4

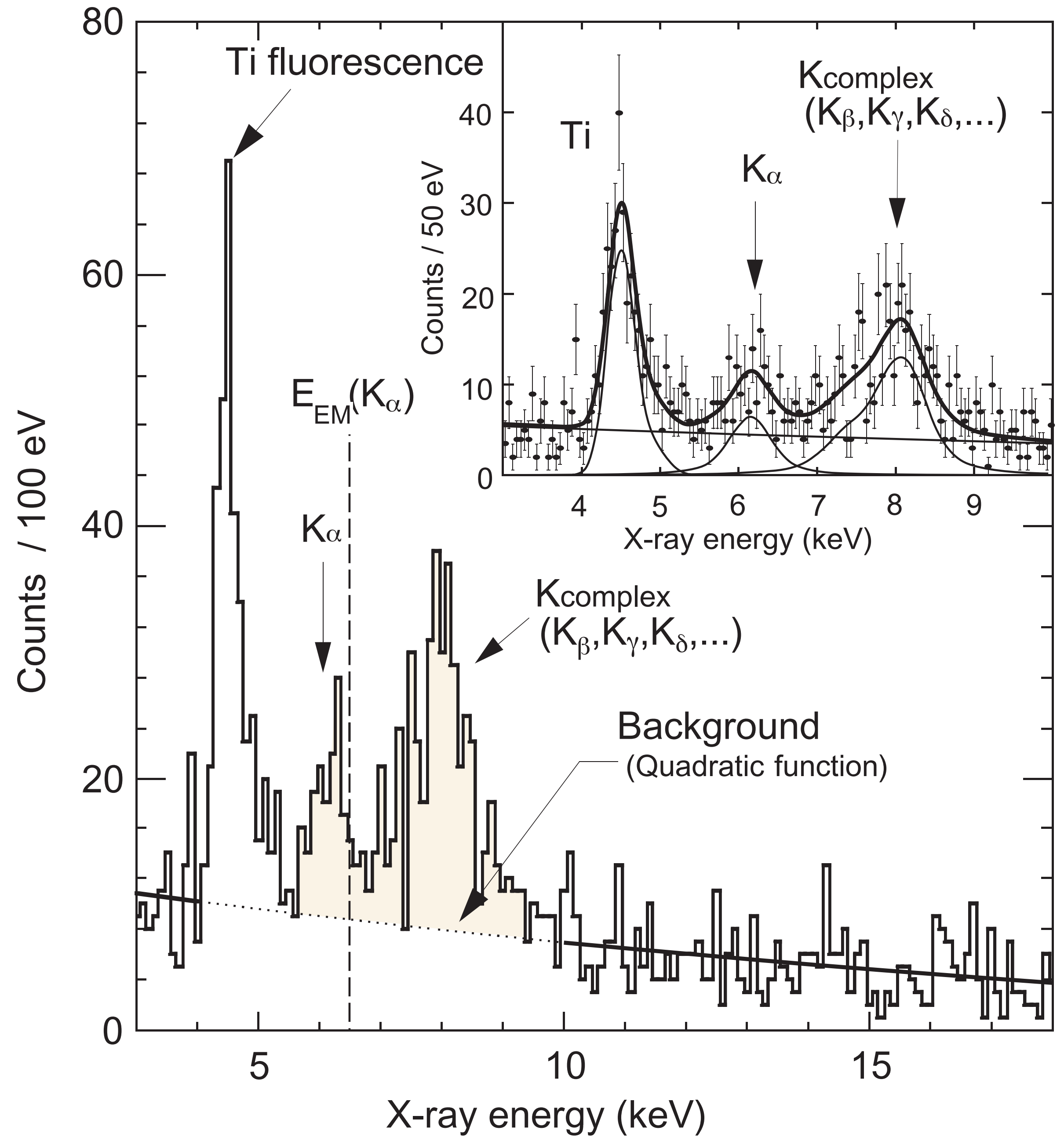
giving no γ as a background source

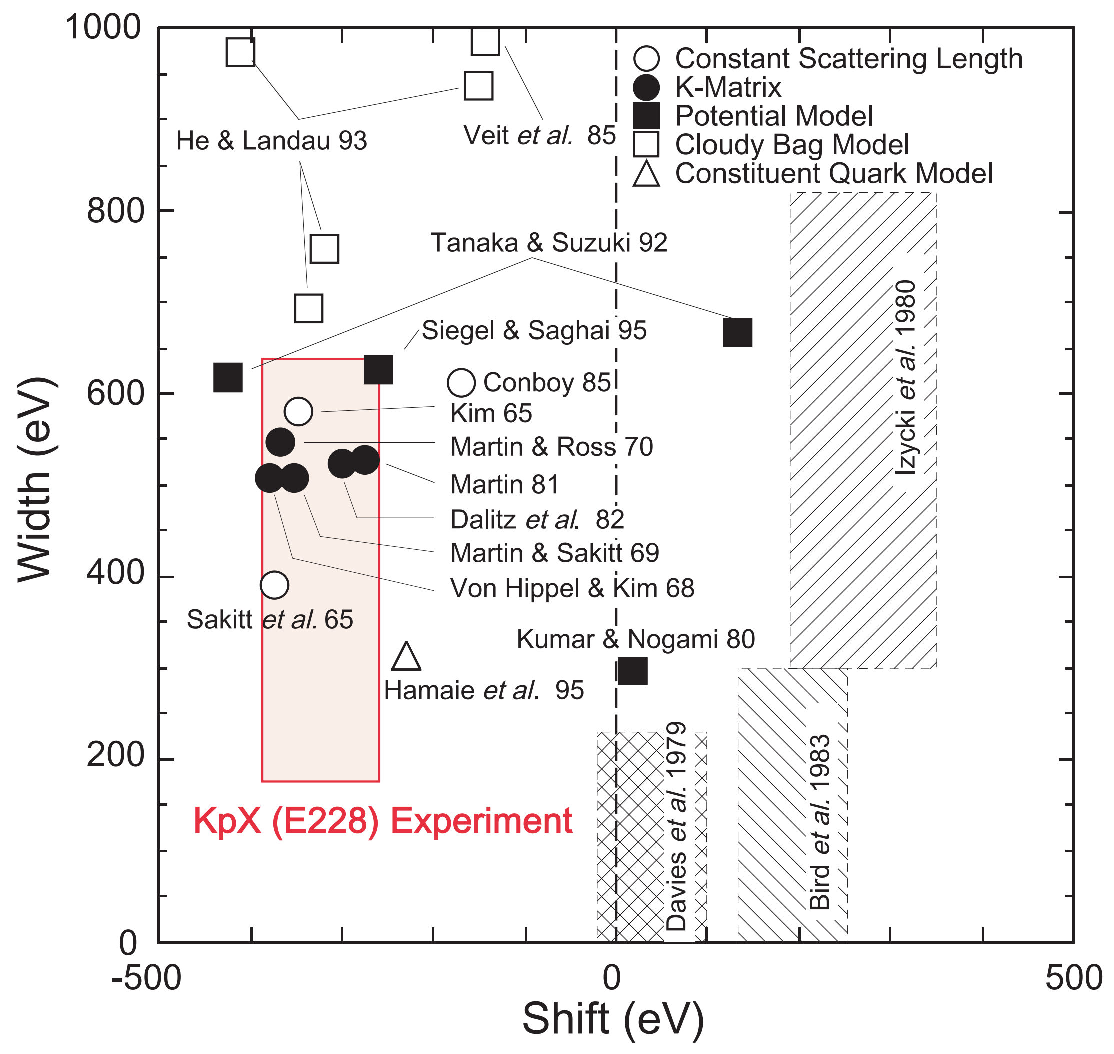


giving information where kaon stops



Succeeded in Kaonic Hydrogen x-ray Measurement





The European Physical Journal C

Volume 15 · Number 1-4 · 2000

THE Λ(1405)

Revised March 1998 by R.H. Dalitz, Oxford University

....

From the measurement of $2p - 1s$ x rays from kaonic-hydrogen, the energy-level shift ΔE and width Γ of its 1s state can give us two further constraints on the ($\bar{\Sigma}\pi$, NK) system, at an energy roughly midway between those from the low-energy hydrogen bubble chamber studies and those from qR(Σπ) observations below pK⁻ threshold. IWASAKI 97 have reported the first convincing observation of this x ray, with a good initial estimate:

$$\Delta E - i\Gamma/2 = (-323 \pm 63 \pm 11) - i(204 \pm 104 \pm 50) \text{ eV}. \quad (2)$$

the errors here encompass about half of the predictions made following various analyses and/or models for the in-flight K^-p and sub-threshold qR(Σπ) data. Better measurements will be needed to discriminate between the analyses and predictions. ..., perhaps from the DAΦNE storage ring at Frascati, information vital for our quantitative understanding of the ($\Sigma\pi$, NK) system in this region. .....

Kaonic hydrogen puzzle was resolved!

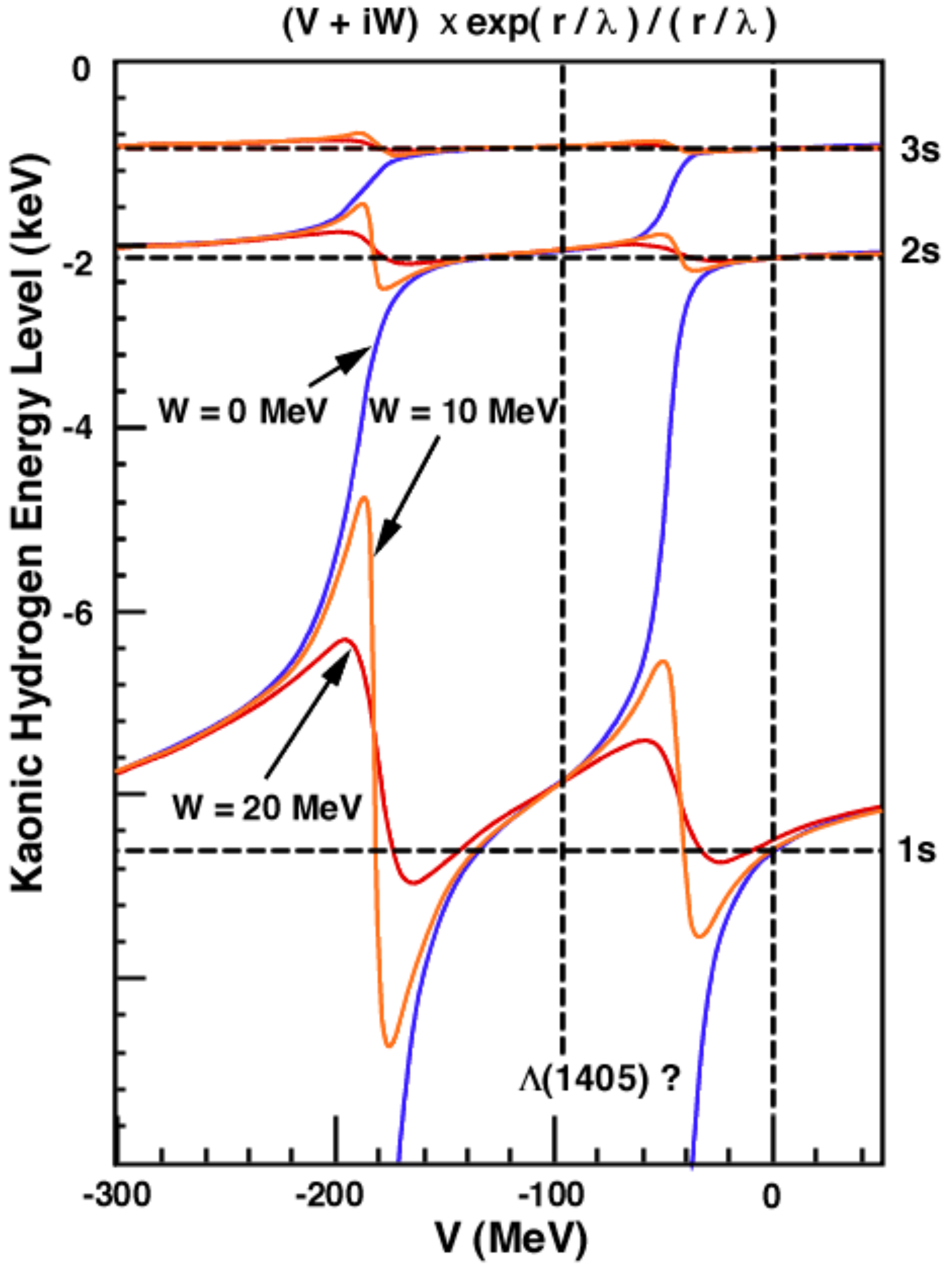
... leads Associate Professor position in TITech, and successively to Chief Scientist position in RIKEN

What's next in physics?

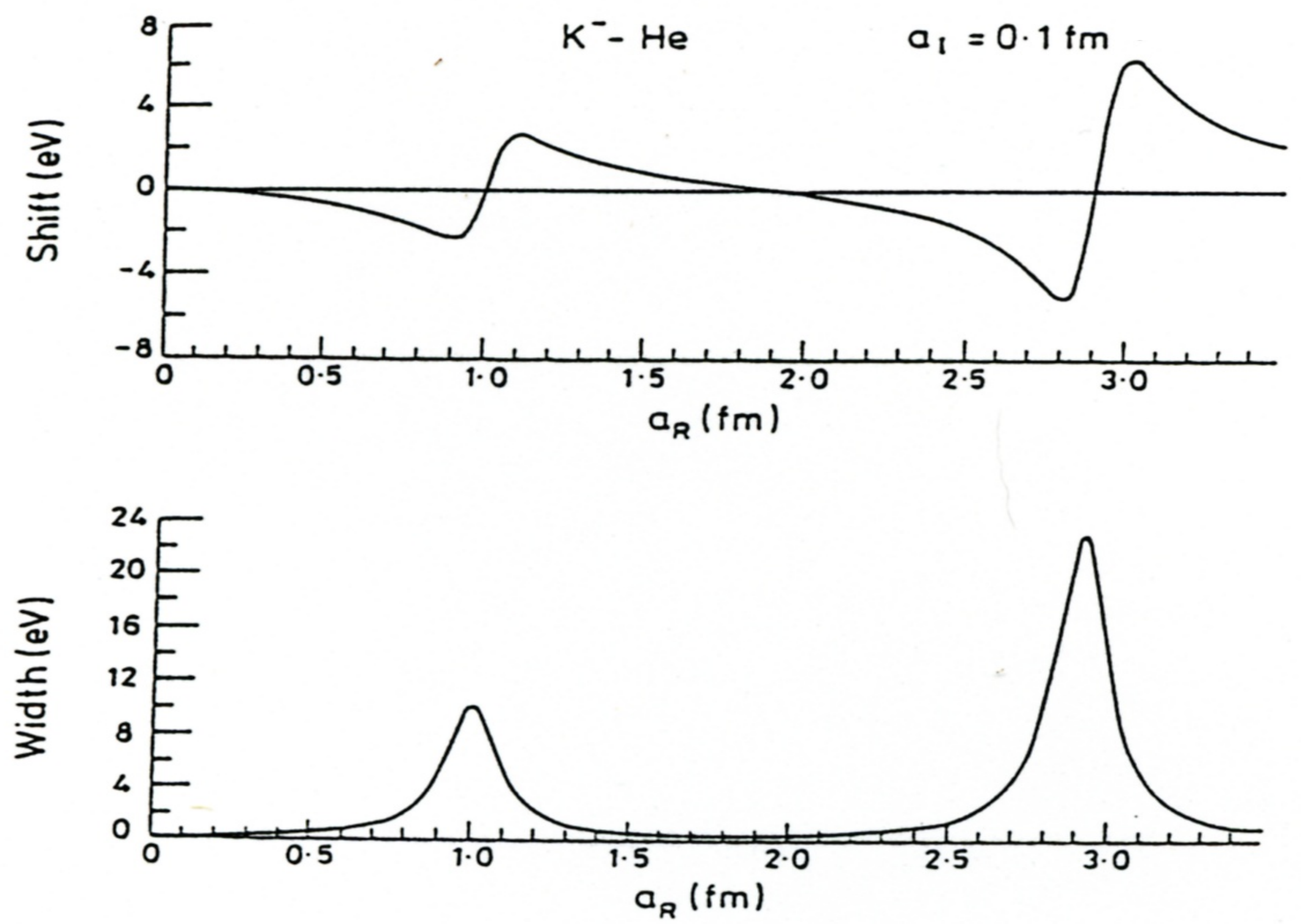
実験困難を越えた先?

Does $\bar{K}N$ interaction repulsive?

実験結果が示すもの？



$W_0 = -277$ MeV fm^{-1} × $\bar{a} = -30$ MeV



R. Seki, Phys. Rev. C5 (1972) 1196

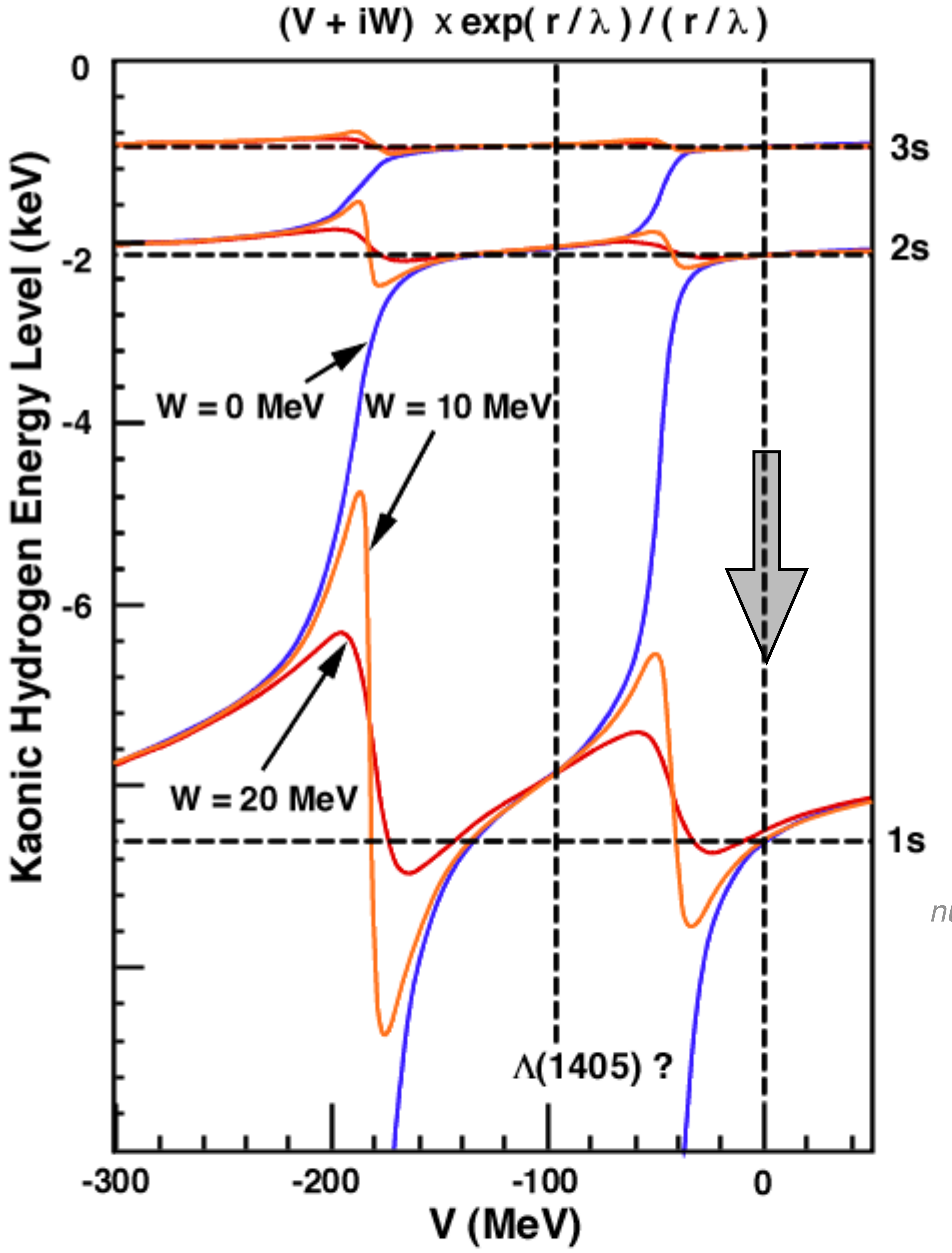
S. Baird et al., Nucl. Phys. A392 (1983) 297

C.J. Batty, Nucl. Phys. A508 (1990) 89c

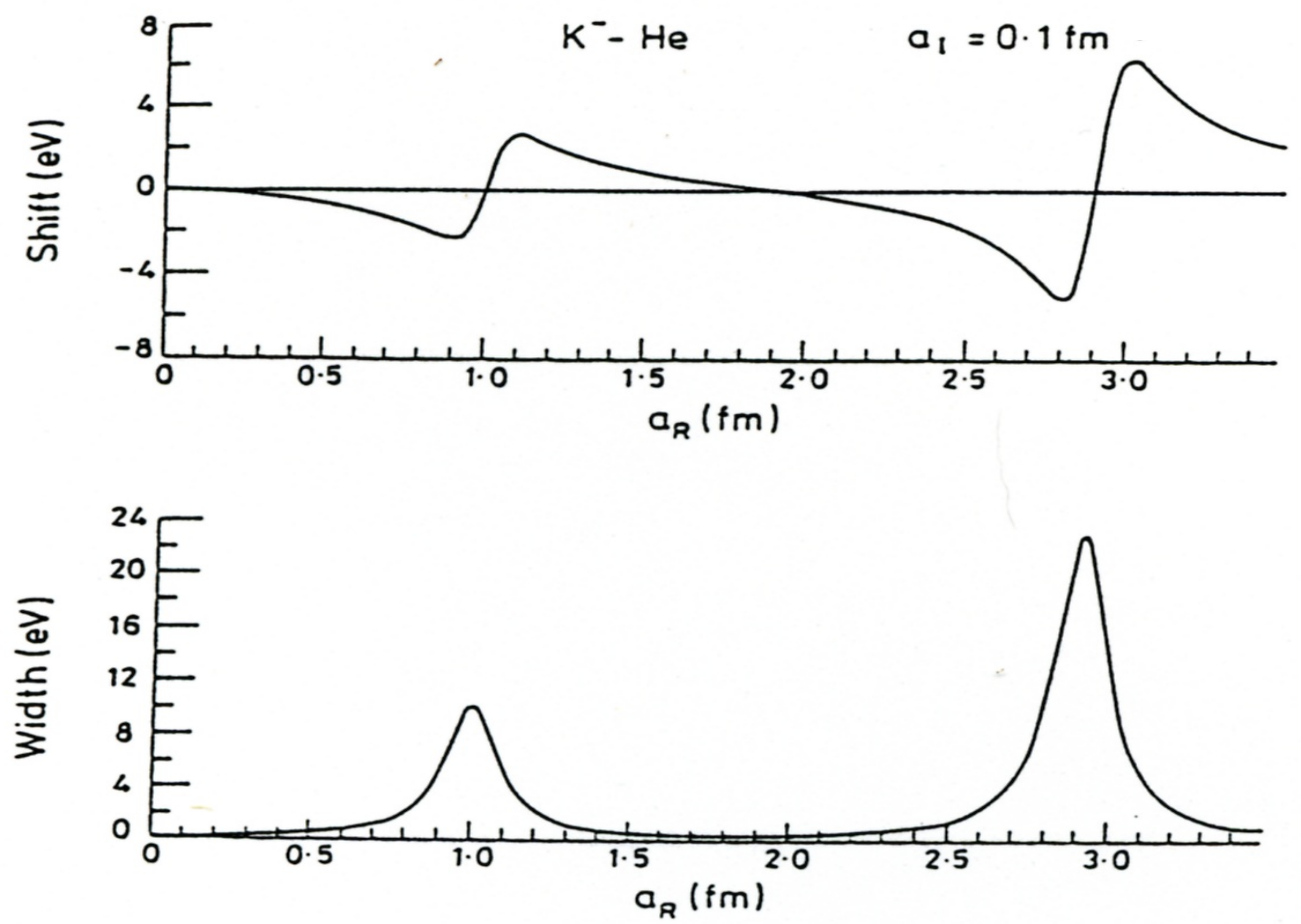
K束縛核の存在？!

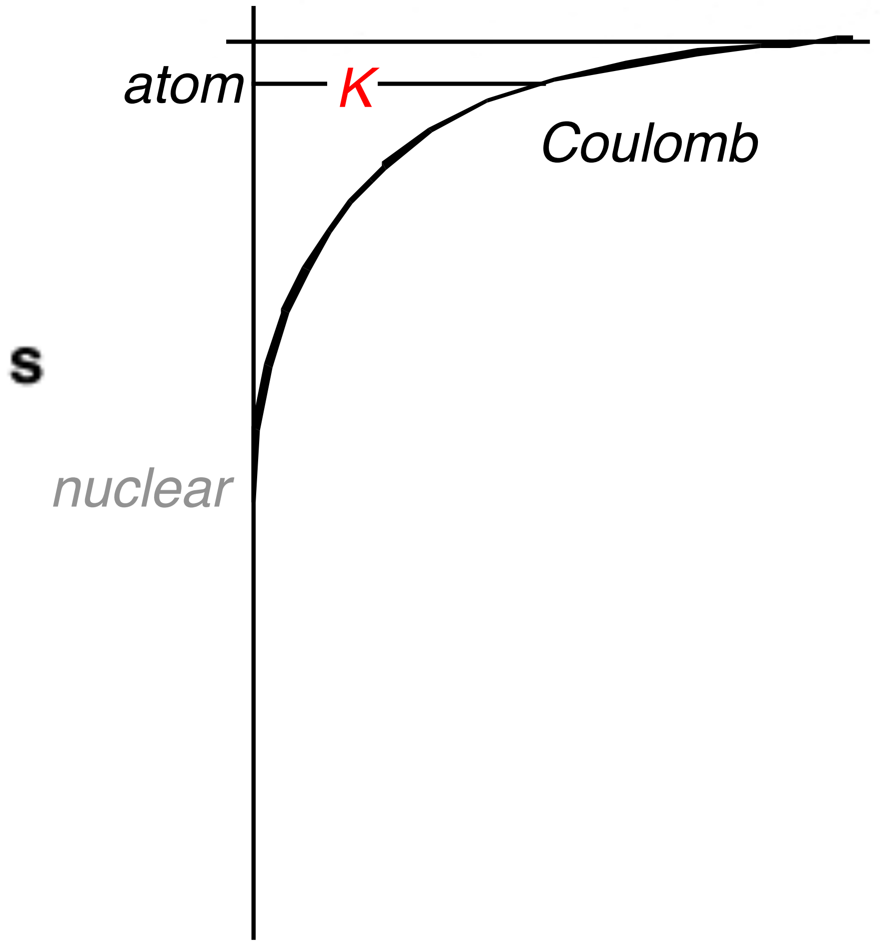
Does $\bar{K}N$ interaction repulsive?

実験結果が示すもの?



$W_0 = -277$ MeV fm^{-1} $\times$ $\bar{a} = -30$ MeV





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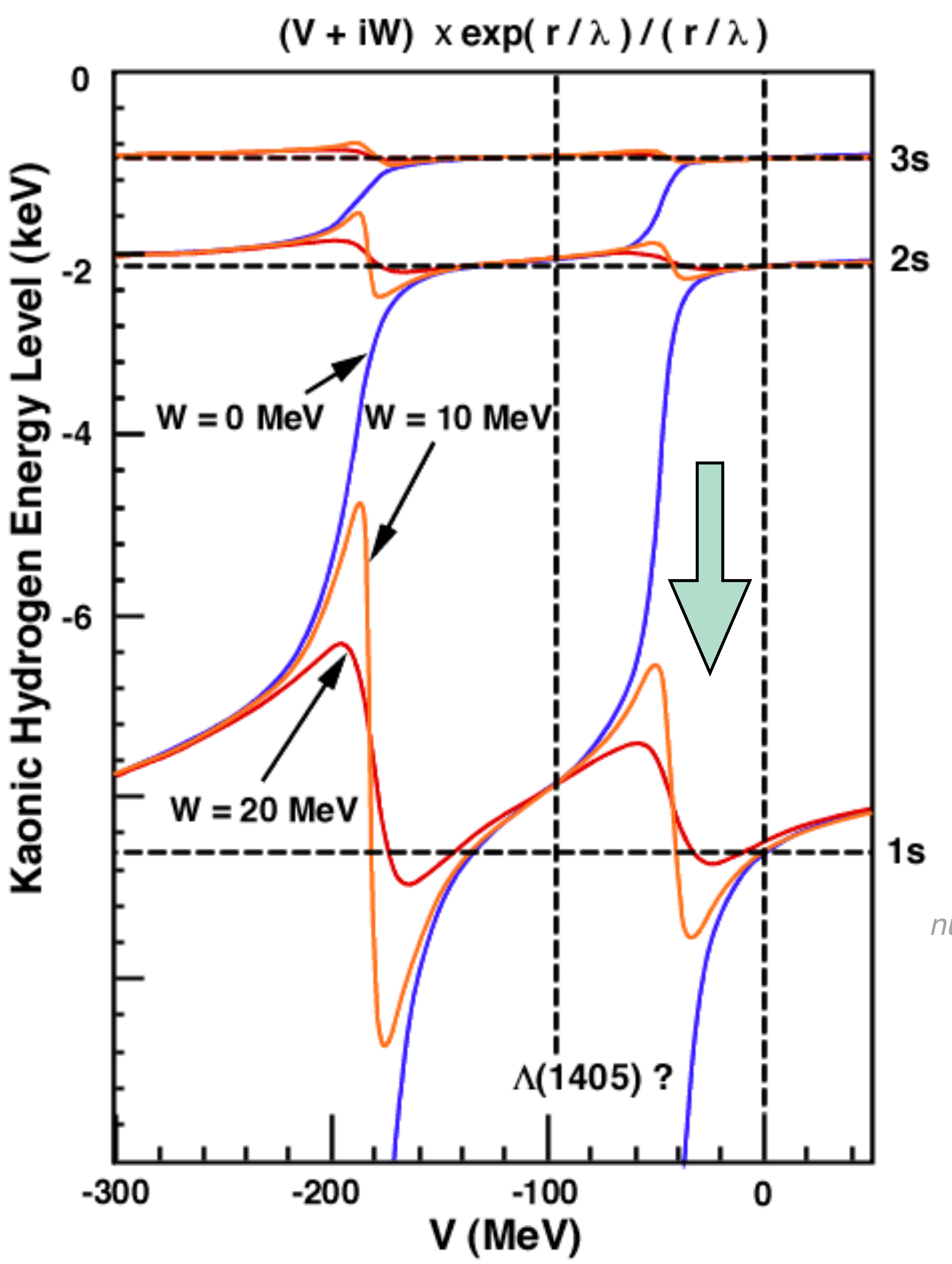
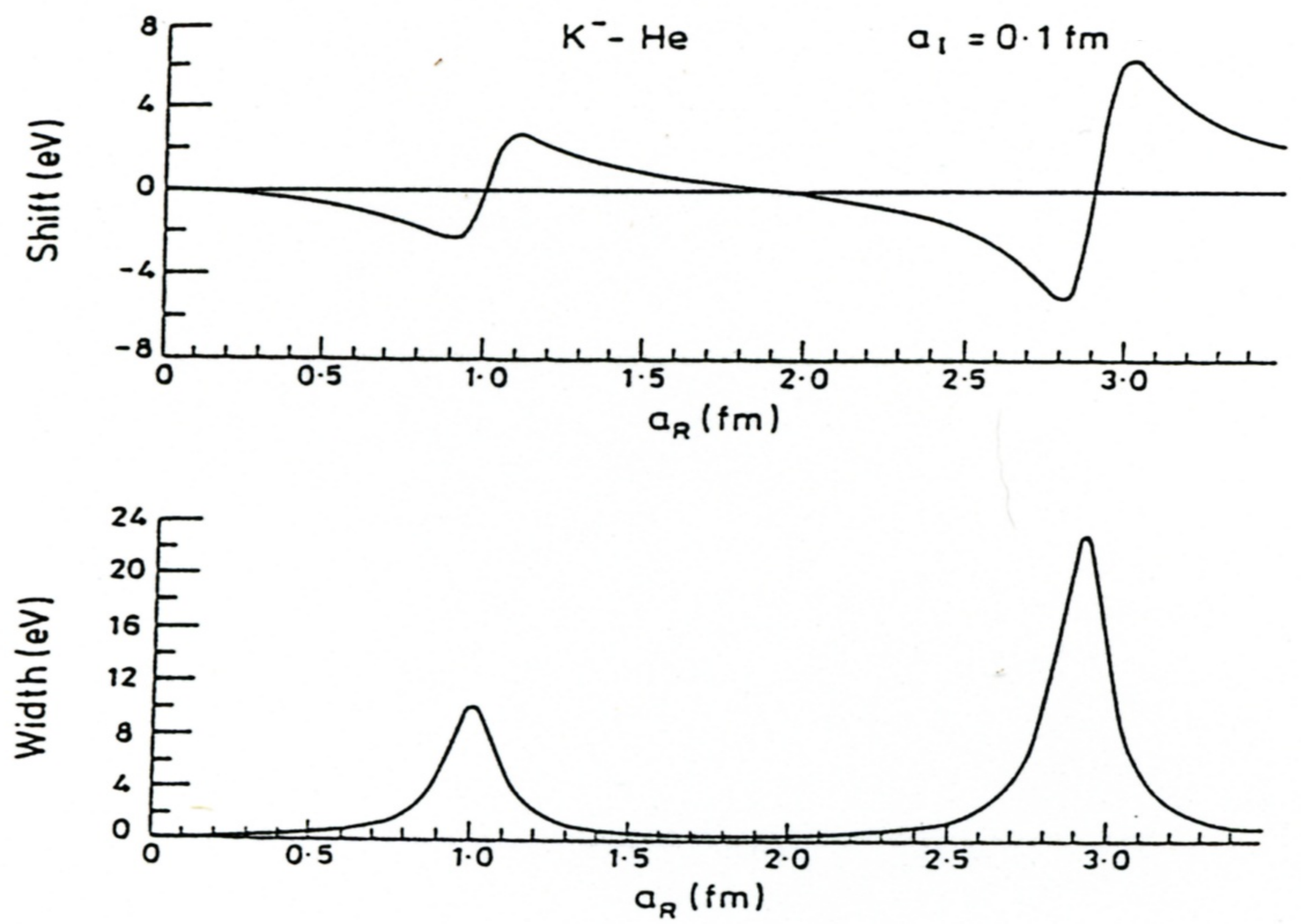
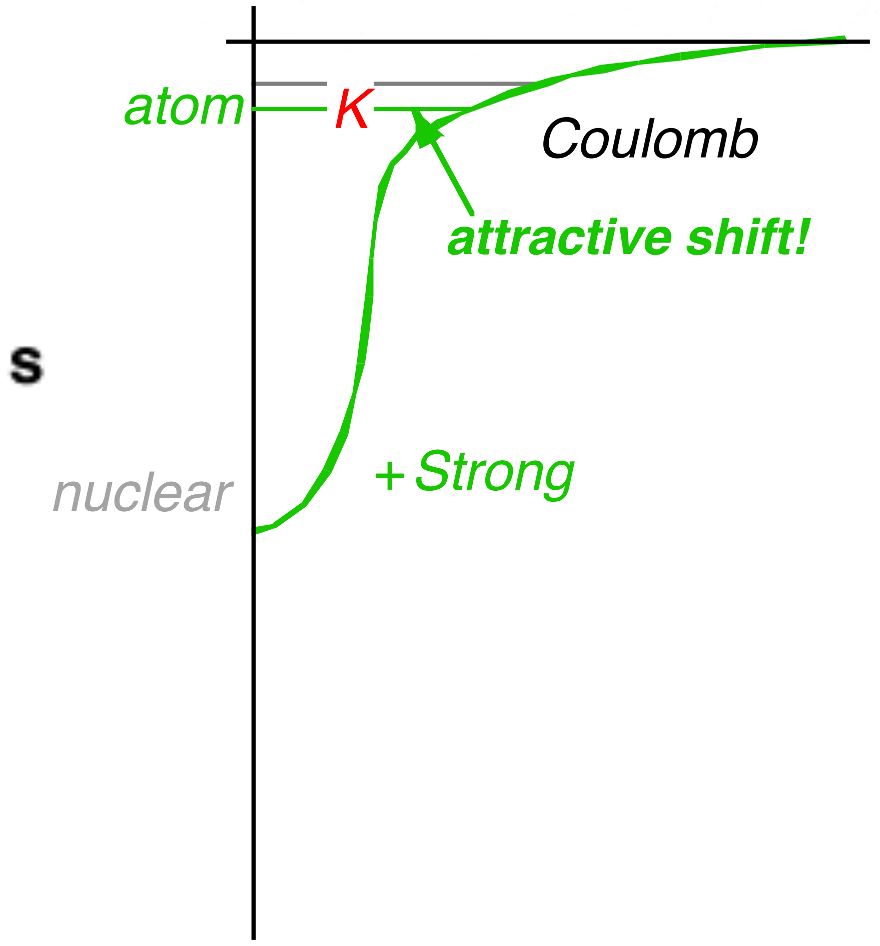


$W_0 = -277 \text{ MeV fm}^{-1} \times \bar{a} = -30 \text{ MeV}$





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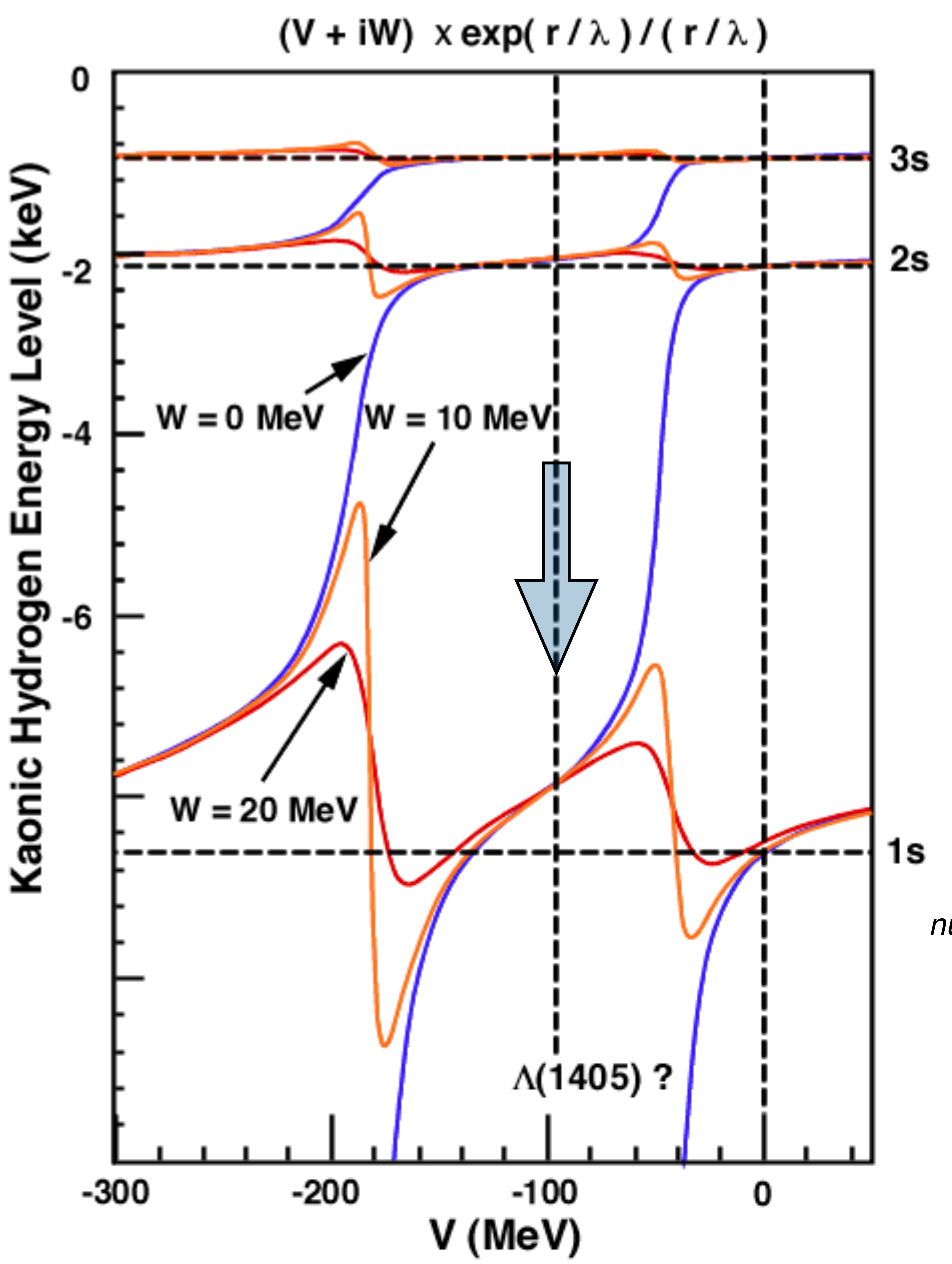

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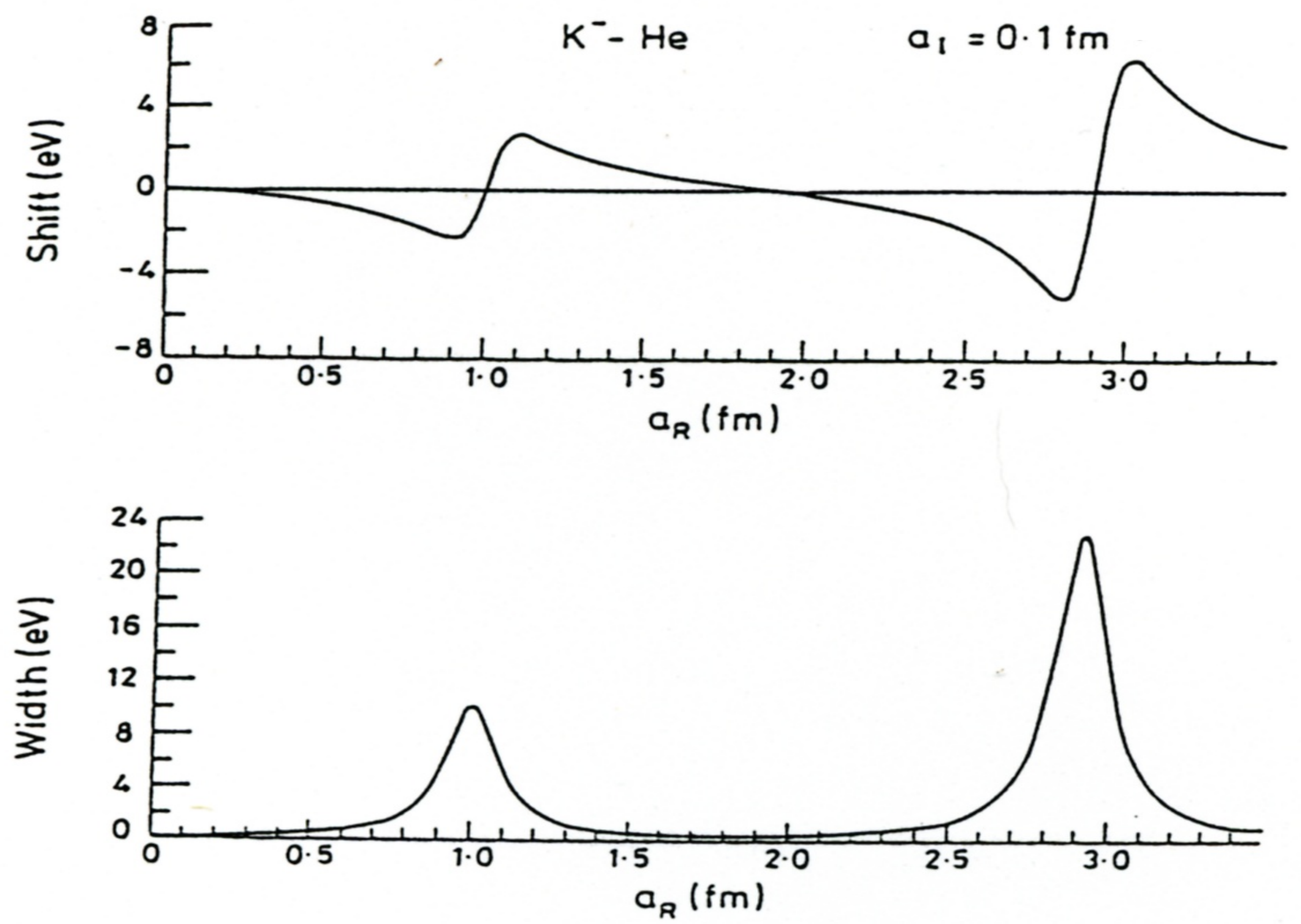

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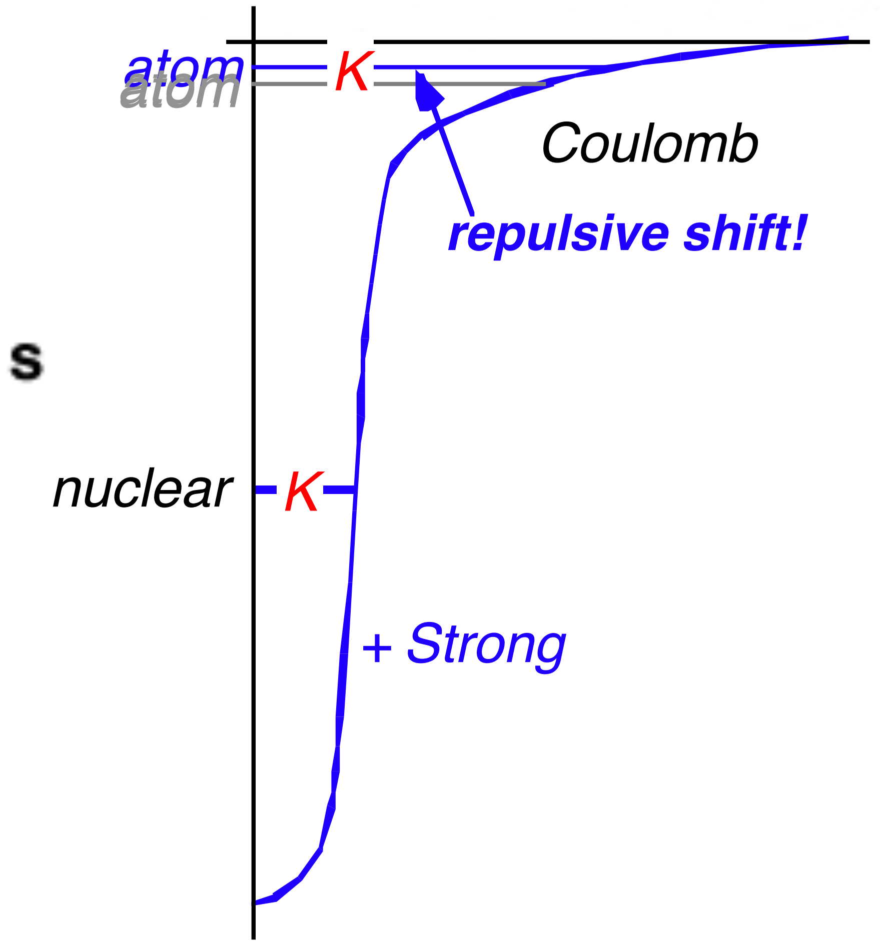
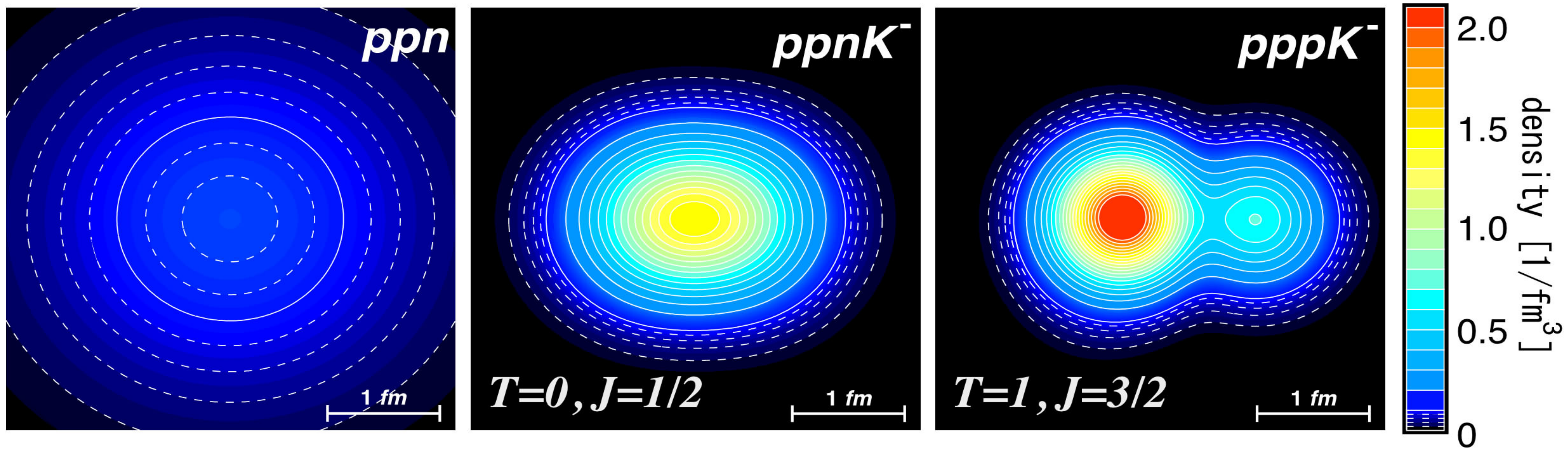


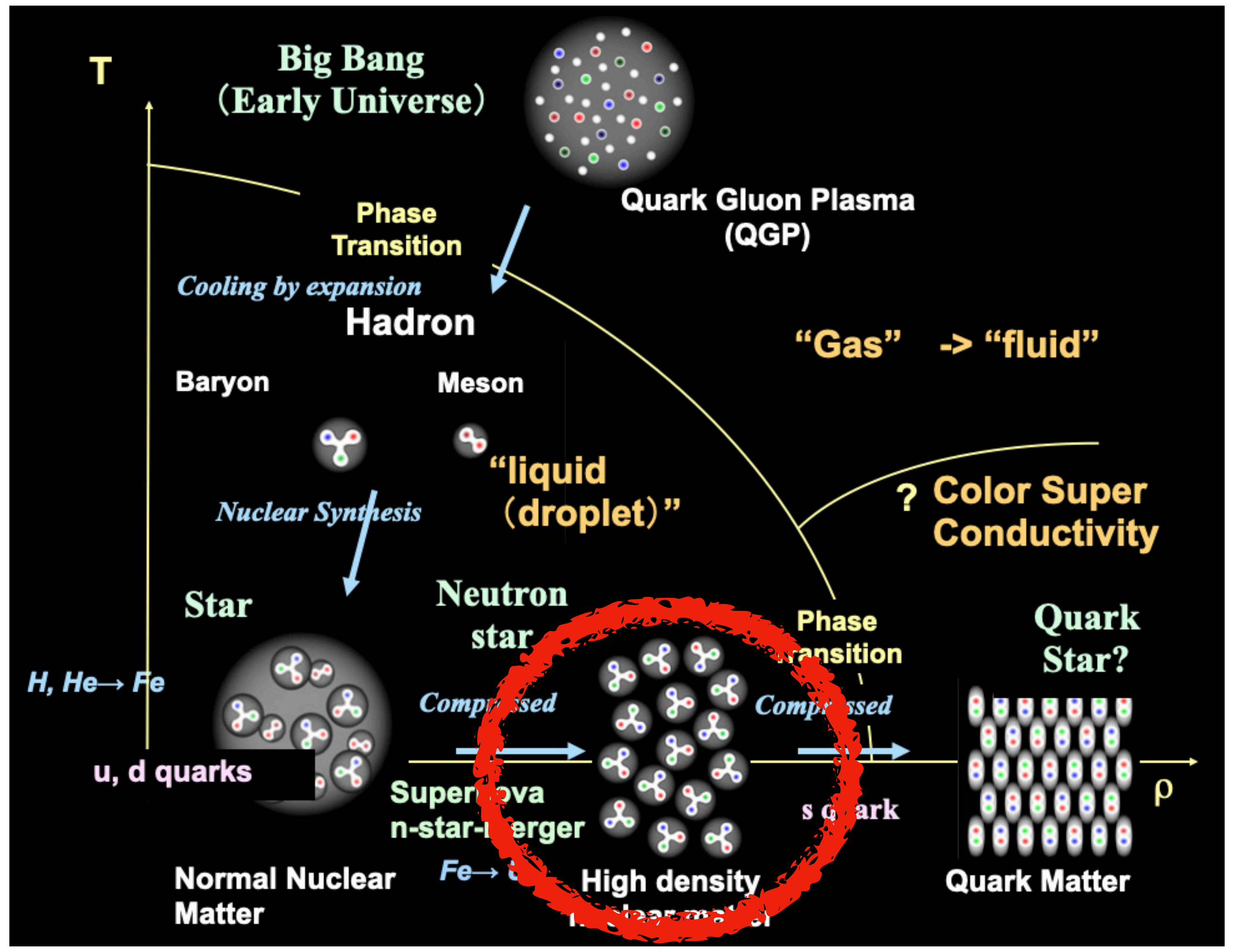
No! strongly attractive!

Kaonic Nuclear state exists?

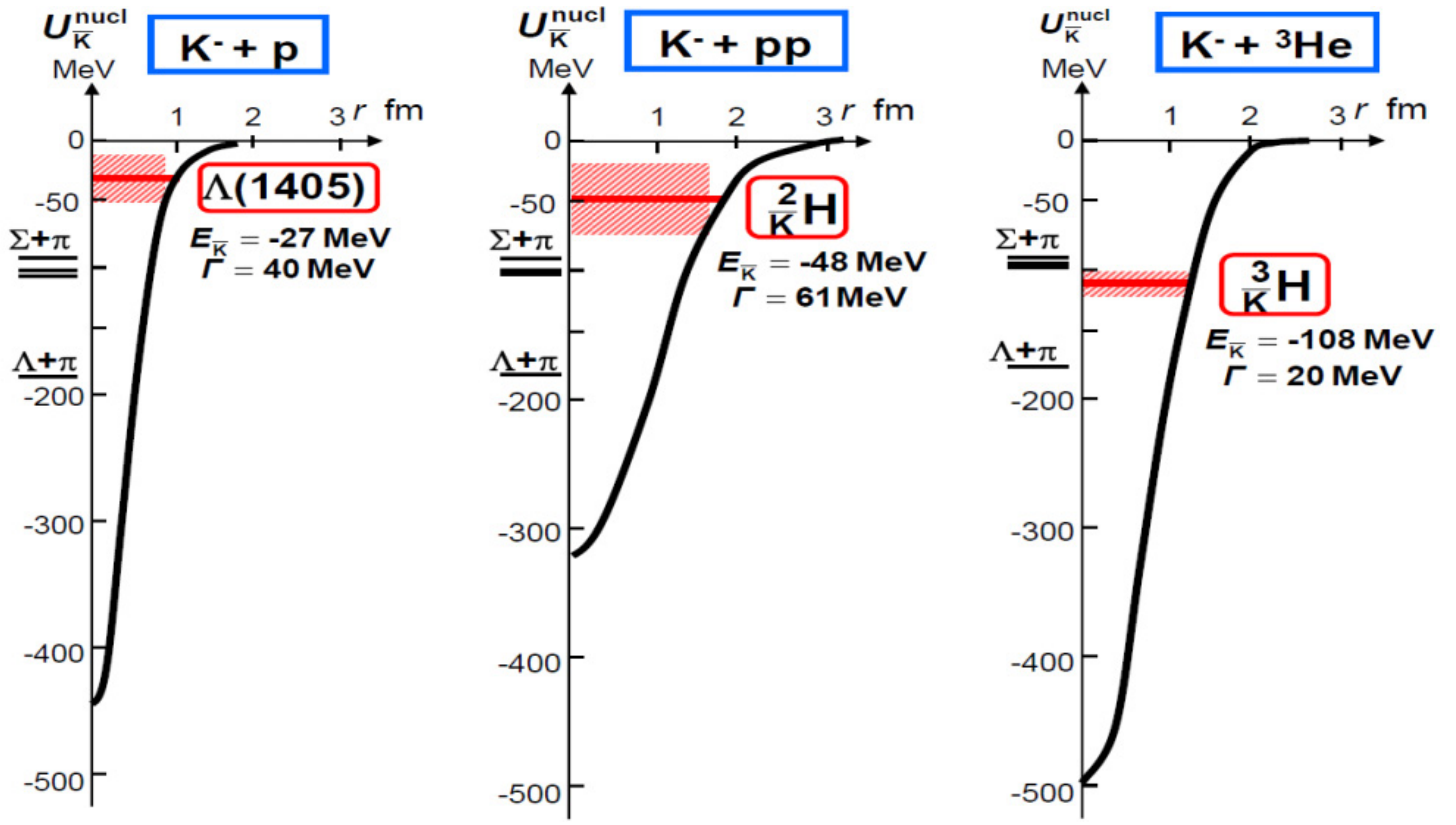
K束縛核の存在？！



探査競争



The KpX experiment triggers kaonic nuclear bound state search, world wide



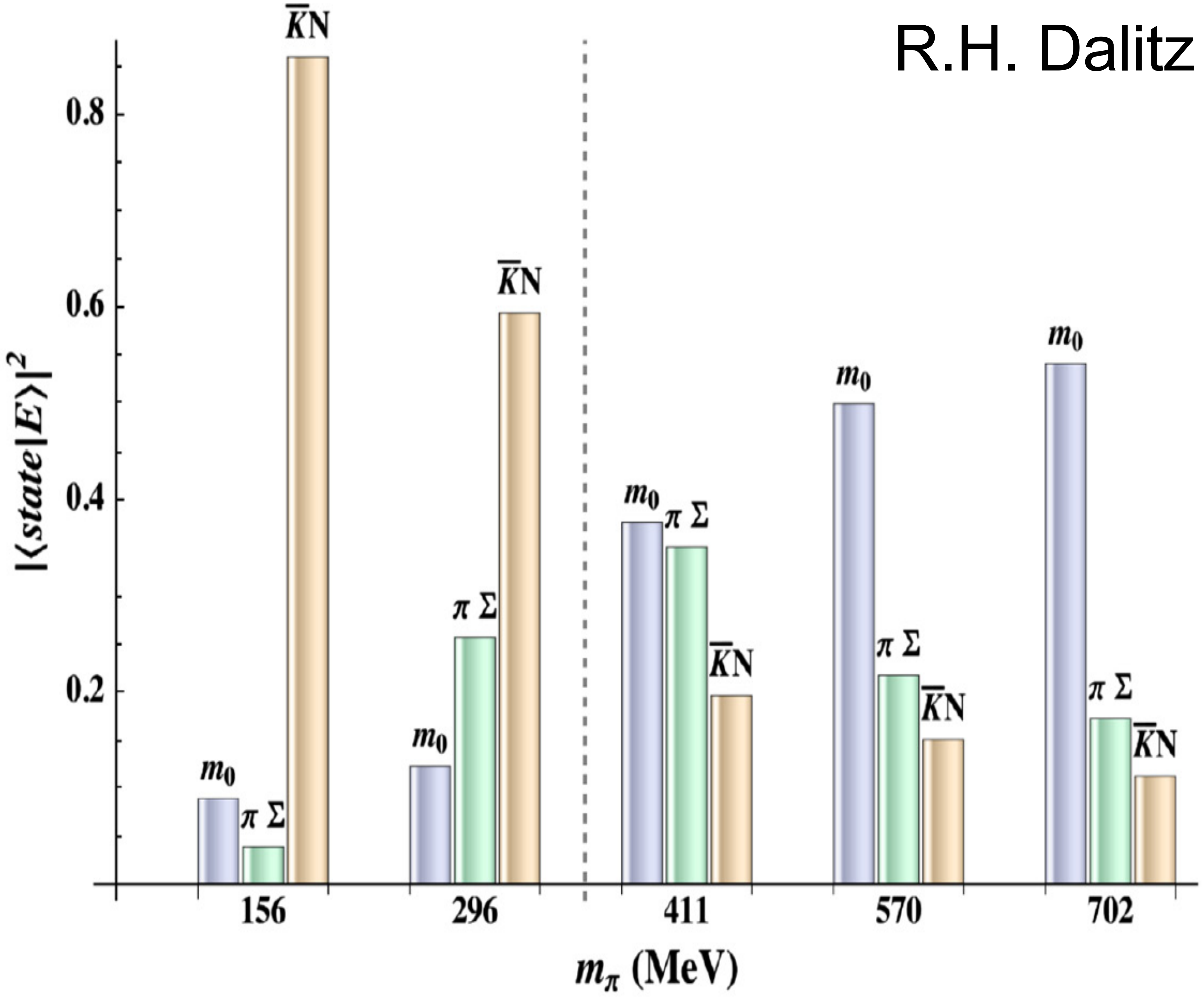
… K中間子原子核探査競争の時代へ …

Λ(1405)ってどういうもの？

What is Λ(1405)?

- Is it quark excited state of Λ baryon (*uds*)?

Λ(1405) = $\bar{K}N$ … a "molecule-like hadron composite"



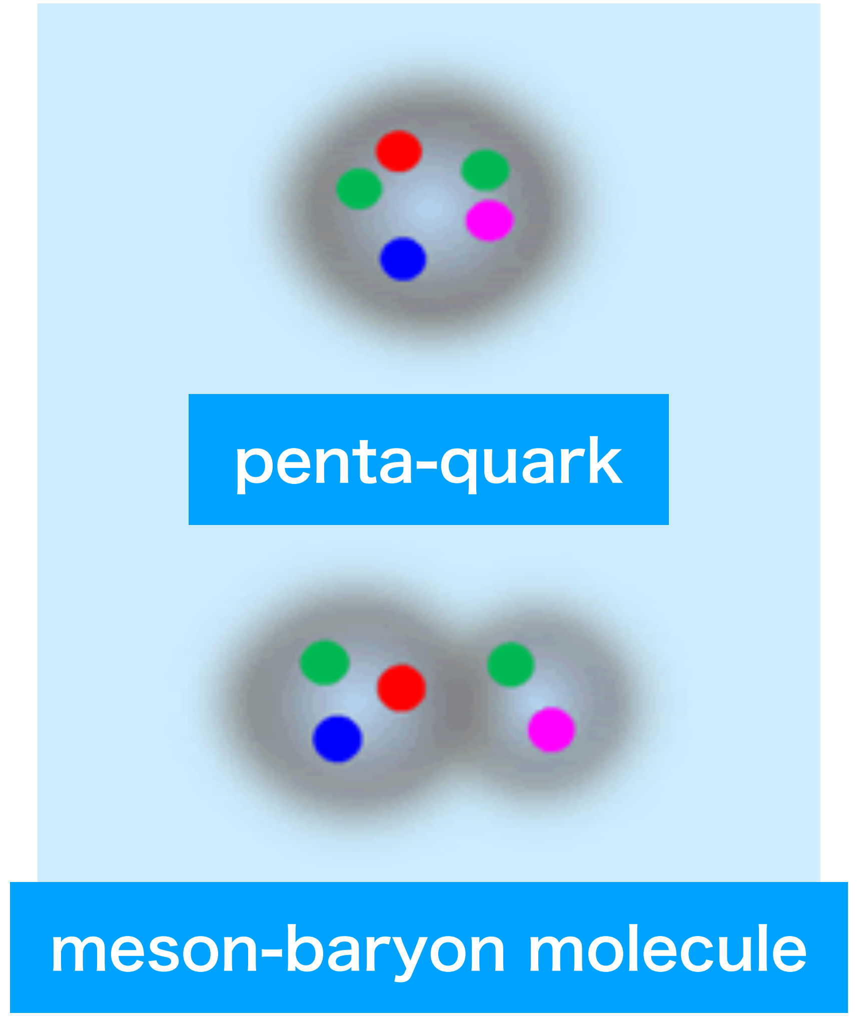
R.H. Dalitz and S.F. Tuan, Ann. Phys., 3, 307 (1960)

- **supported by kaonic hydrogen data**

Phys. Rev. Lett., 78, 3067 (1997)

- **supported by Lattice QCD**

J.M.M. Hall et al., Phys. Rev. Lett. 114(2015)132002.



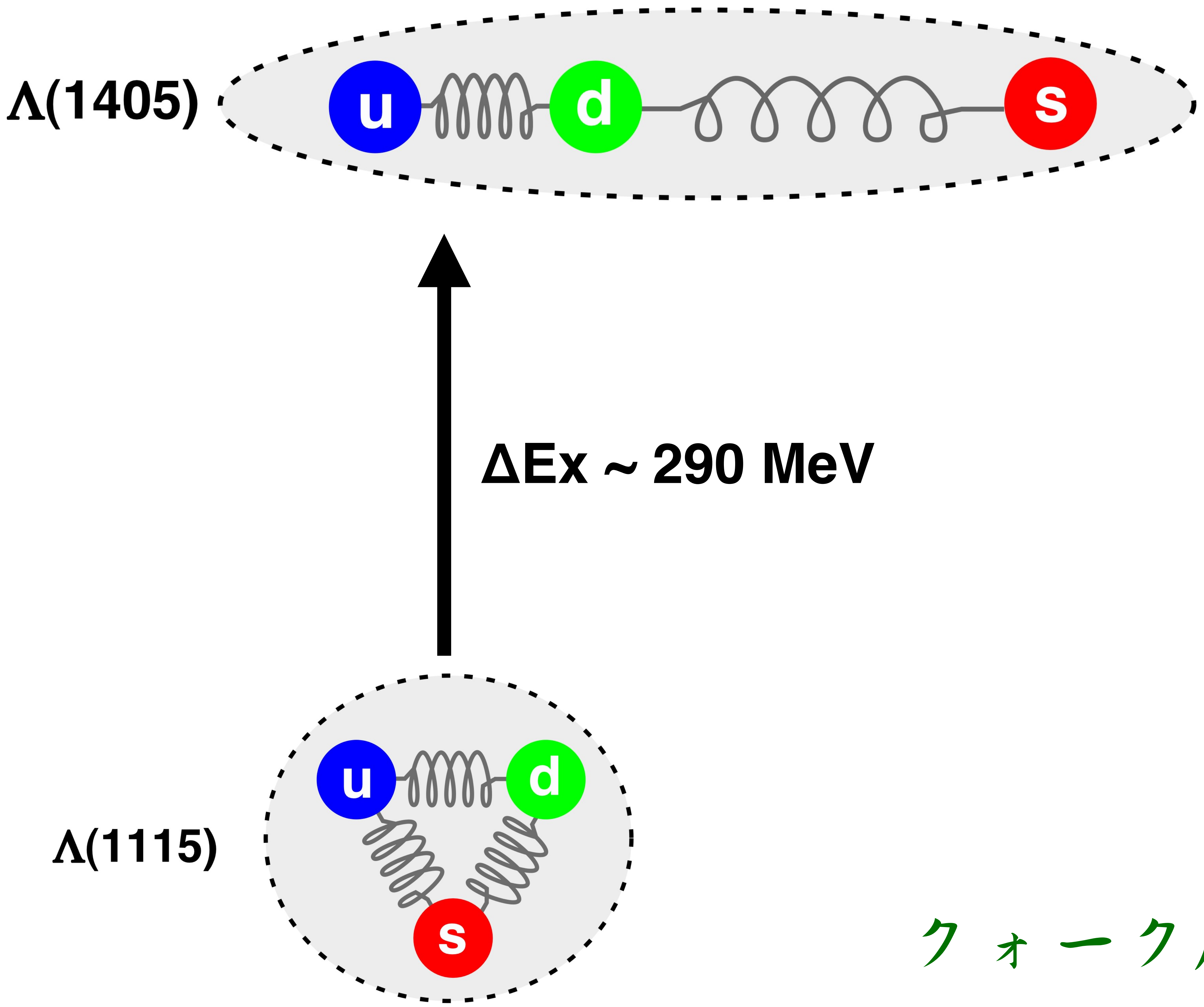
why not $\bar{K}NN$?

forming a nuclear bound state

From Λ(1405) to kaonic nuclei

クォーク励起状態?

Is Λ(1115) an excited state of *uds*?

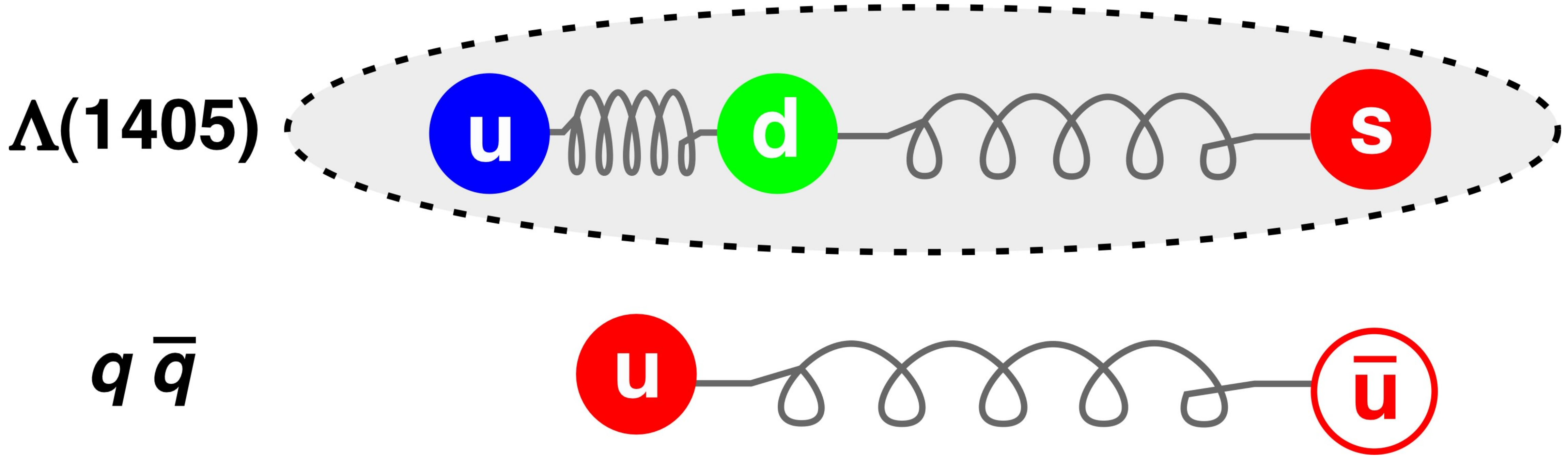


クォーク励起状態としてのΛ(1405)描像

From Λ(1405) to kaonic nuclei

カイラル凝縮との結合?

with $\bar{q}q$ (χ-condensate) in vacuum



真空は何もない空間ではなく、
$\bar{q}q$が対となって凝縮している
と思われている

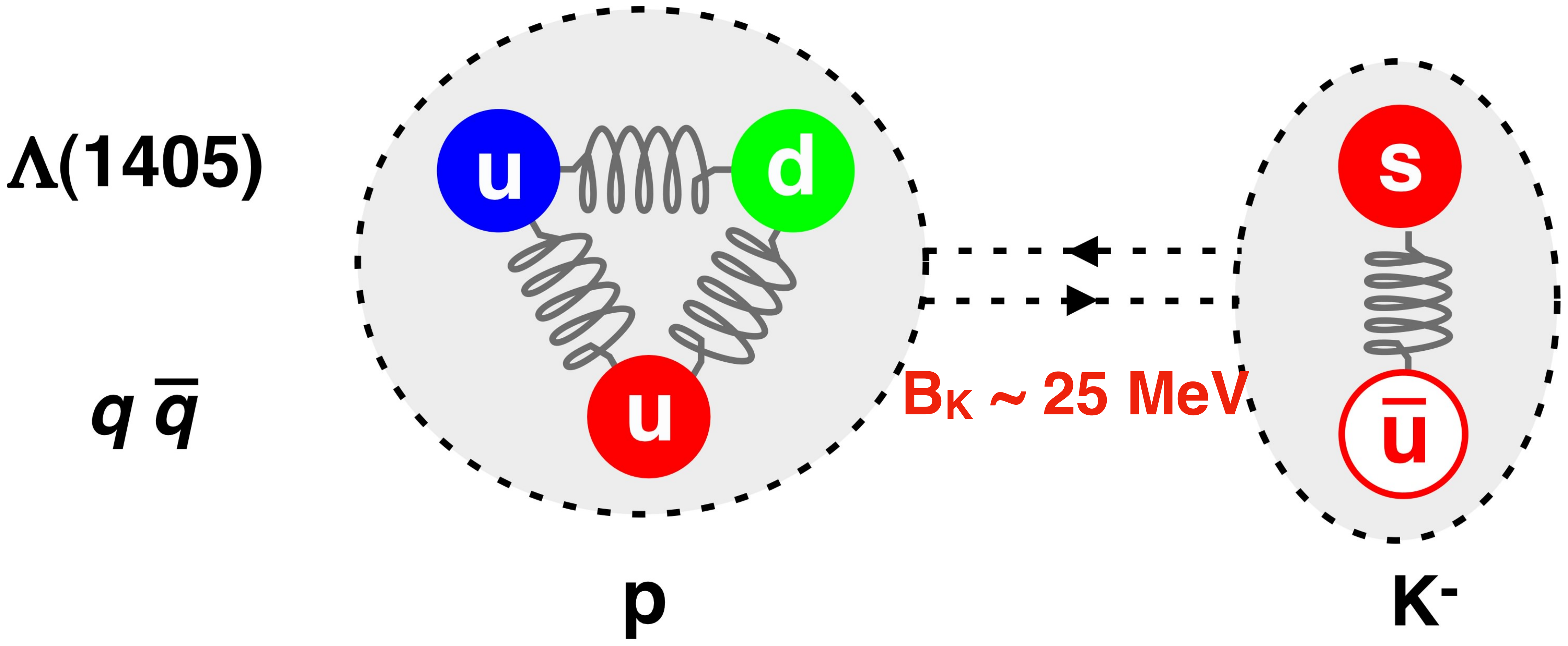
真空の $\overline{q}q$ 凝縮と Λ(1405)

From Λ(1405) to kaonic nuclei

分子的ハドロン結合状態?

two color-singlet objects bound by meson exchange :

p = K^-

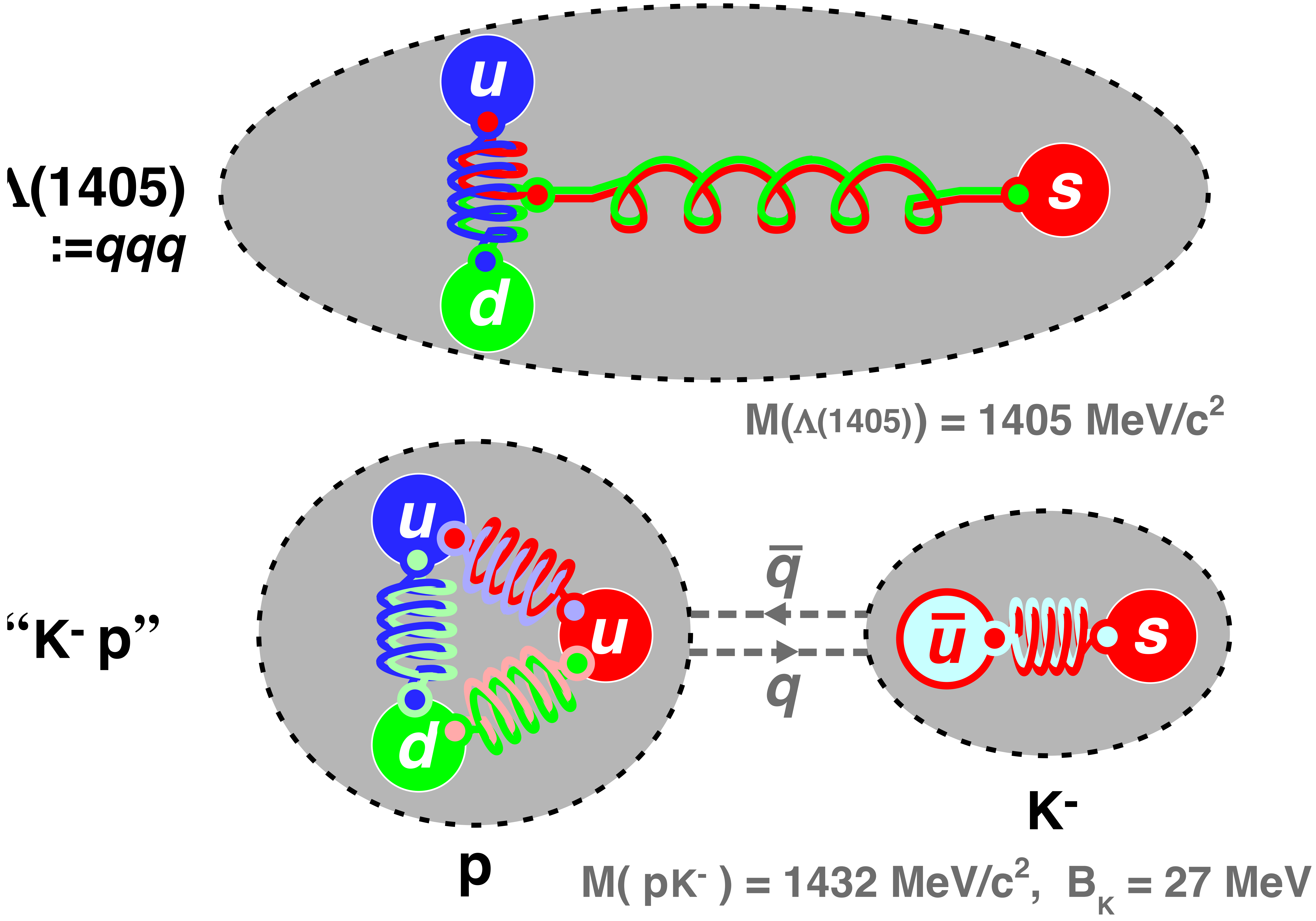


M(pK^-) = 1432 MeV/c^2

分子的ハドロン結合状態としてのΛ(1405)描像

Λ(1405) in *qqq* & meson-baryon

多彩なK中間子核の存在?



Λ(1405) is on-site of "hadronization", where stretched-gluon capture $\bar{q}q$ from vacuum

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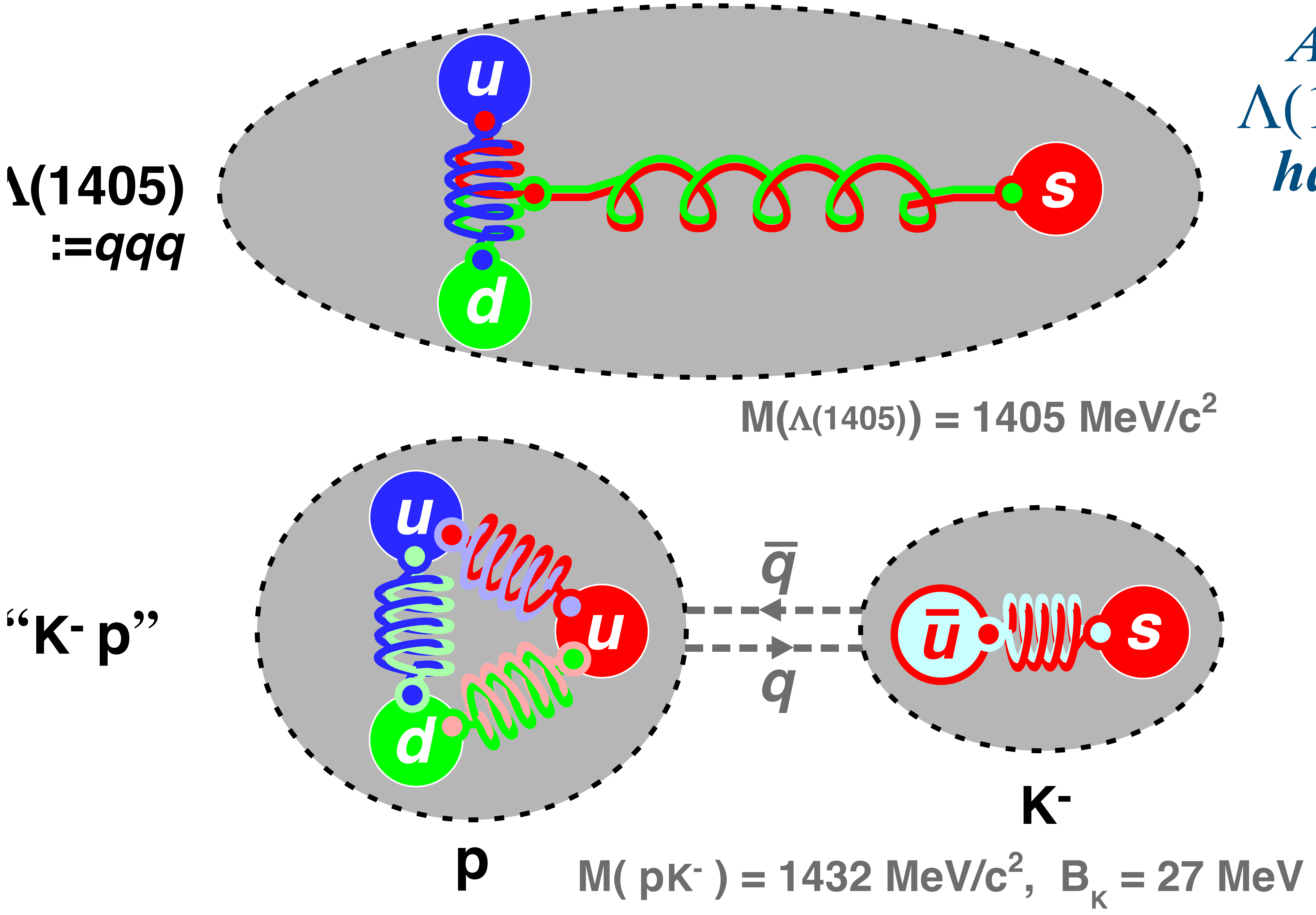

A quantum state known as Λ(1405) can be molecule-like hadron cluster composed of "$K^{-}p$"

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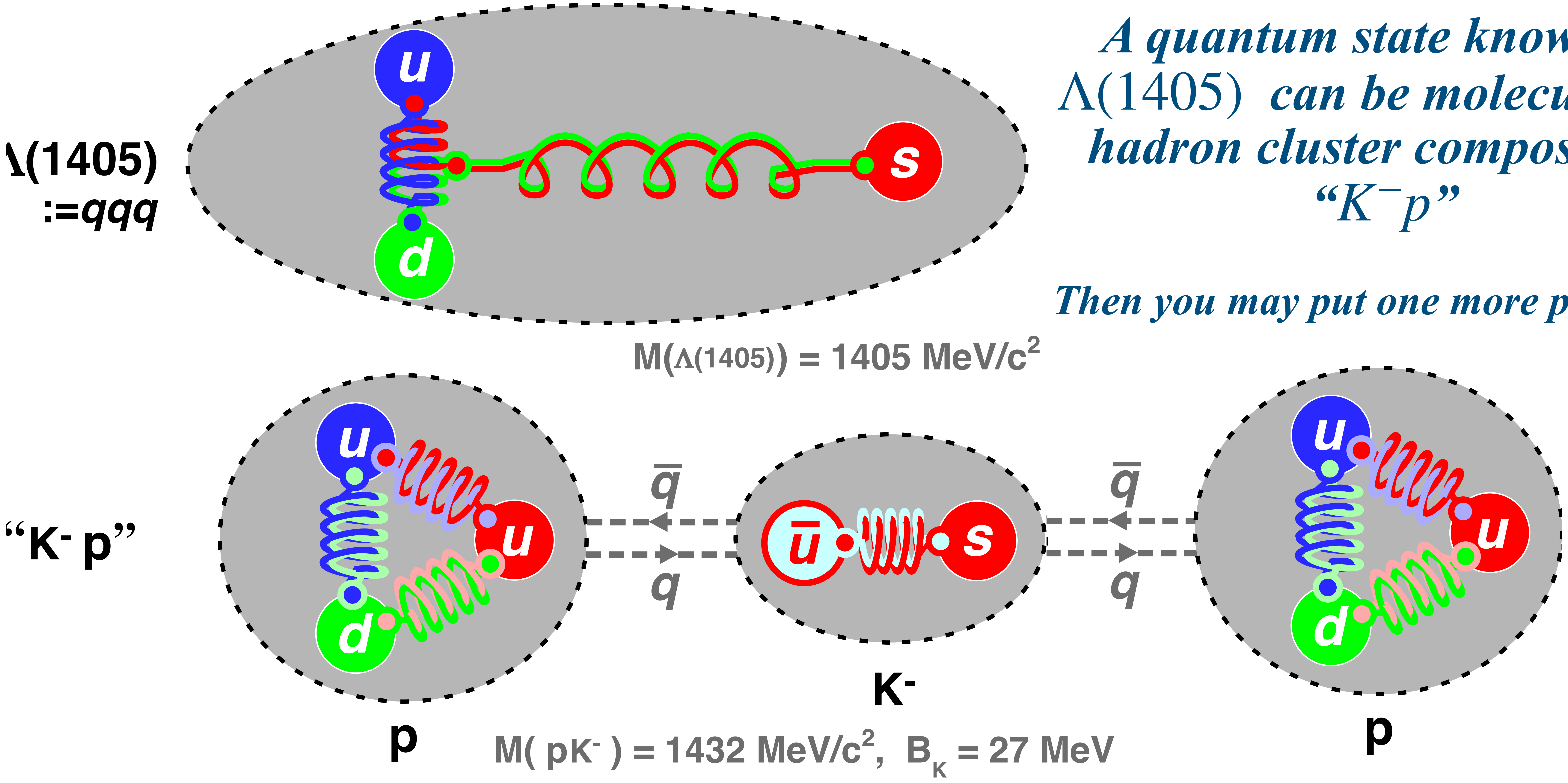
Then you may put one more proton …



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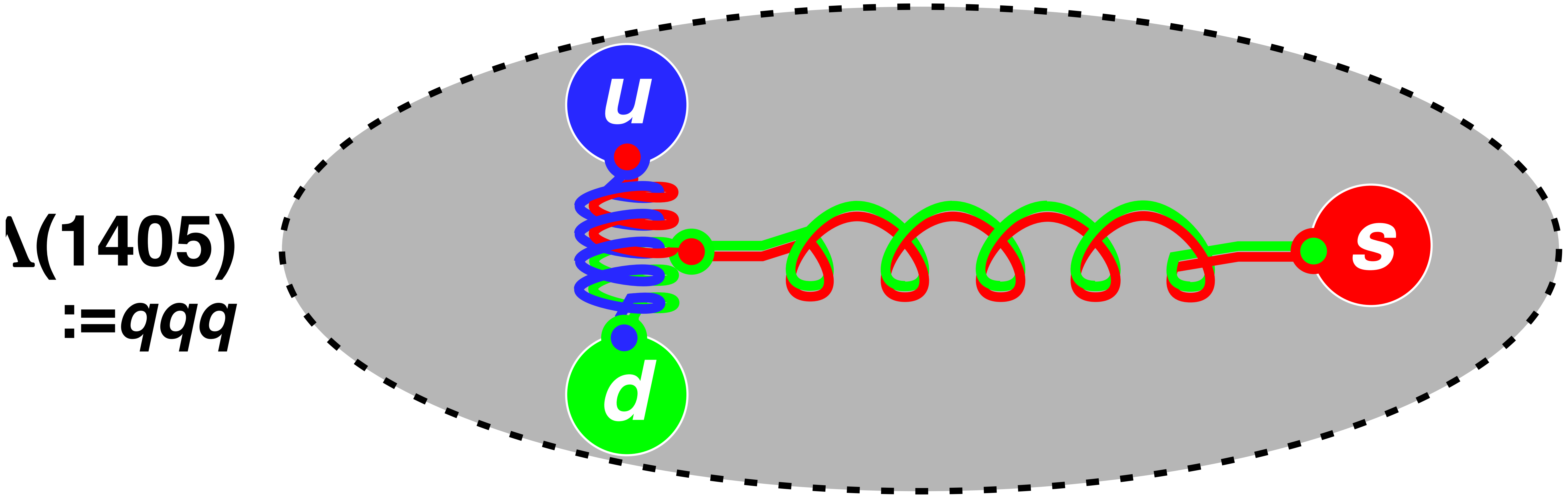

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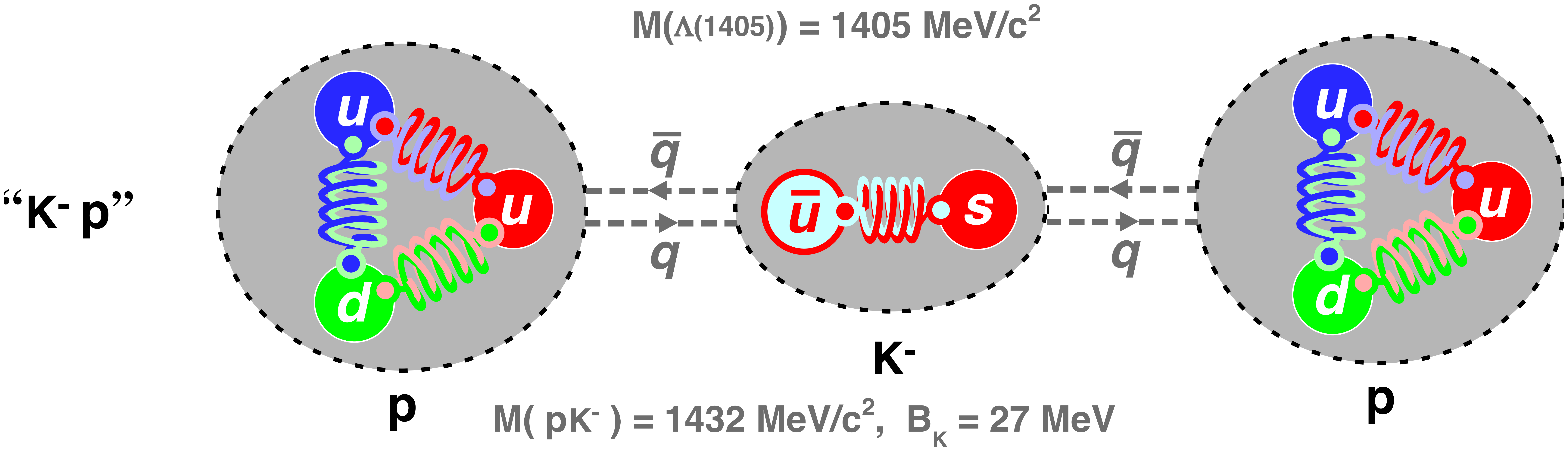


Λ(1405) is on-site of "hadronization", where stretched-gluon capture $\bar{q}q$ from vacuum

"K^-pp" will exist

研究における最大の失敗

First trial to search for Kaonic Nuclei resulted in wrong interpretation in 2004.

The biggest Failure

“It was very difficult to overcome the challenges caused by the mistake.”

… 間違いに気がついた時は悪夢・問題特定とその
公表に3年・観測成功(汚名返上?)に11年 …

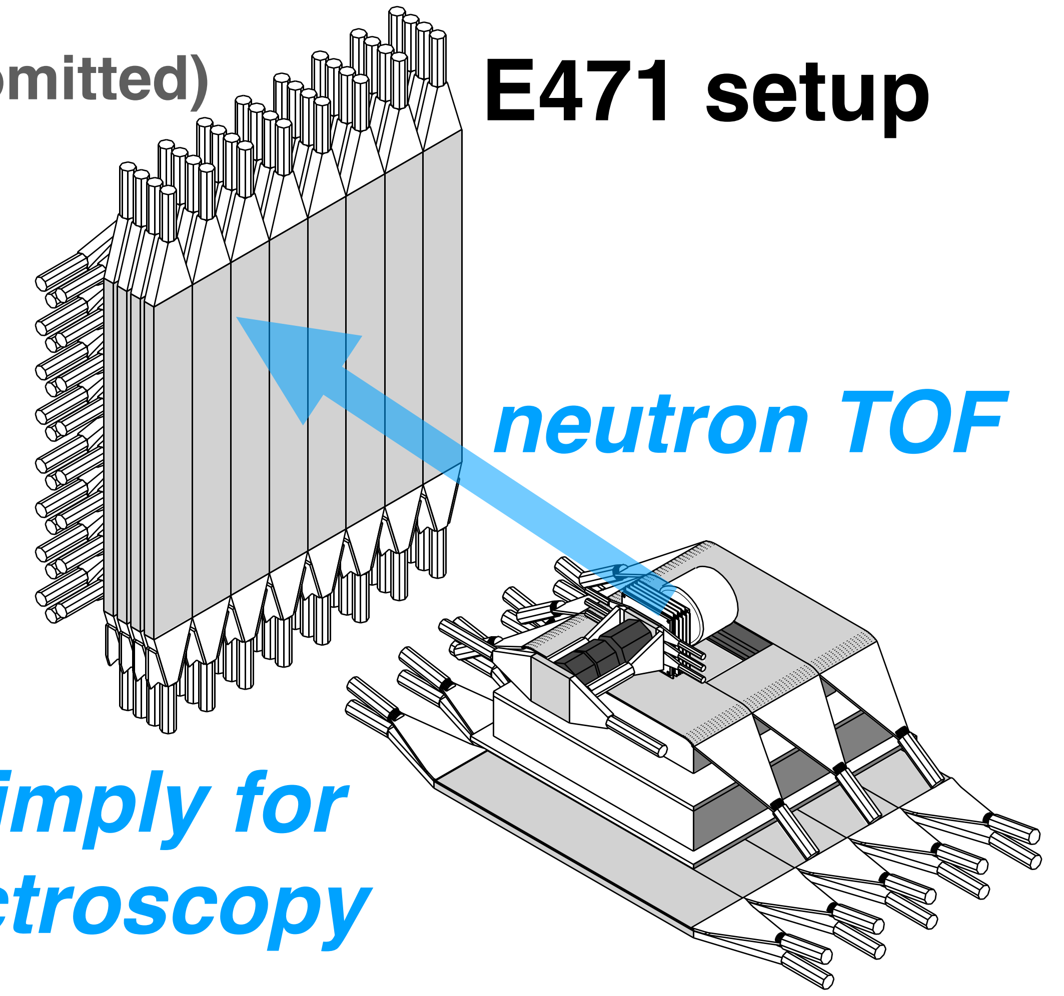
最初のK中間子核探査研究

First trial to search for Kaonic Nuclei

via kaon absorption at-rest in ^{4}He target

Reaching wrong conclusion faked by data

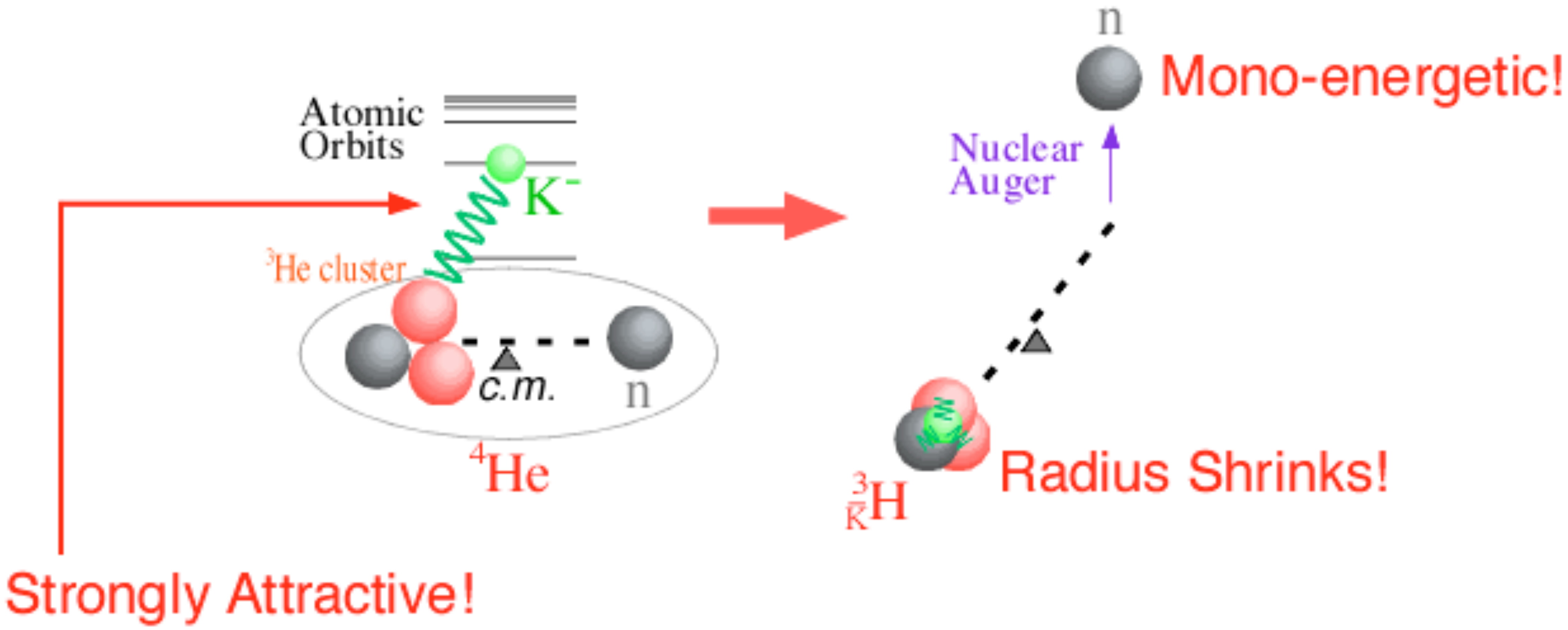
(top and right detectors are omitted)



dedicative simply for neutron spectroscopy

Ansatz in E471

If kaonic nuclear bound state $K^- \oplus {}^3\mathrm{He}$ exist as it is predicted,



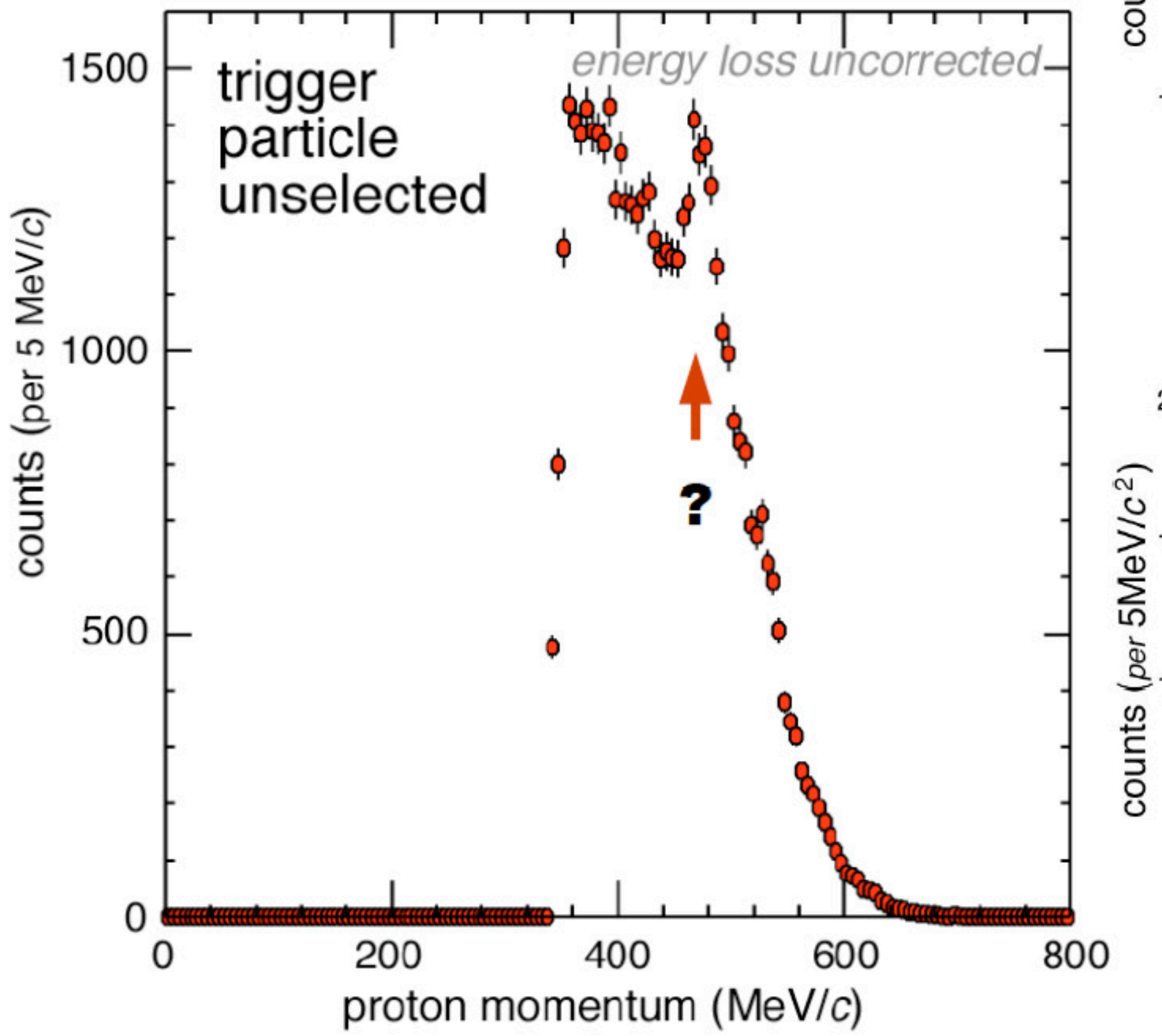
mono-energetic **neutron** will be emitted from kaon absorption reaction from kaonic helium atom via nuclear Auger effect by substituting neutron with kaon

^{4}He(stopped K-, p) spectrum

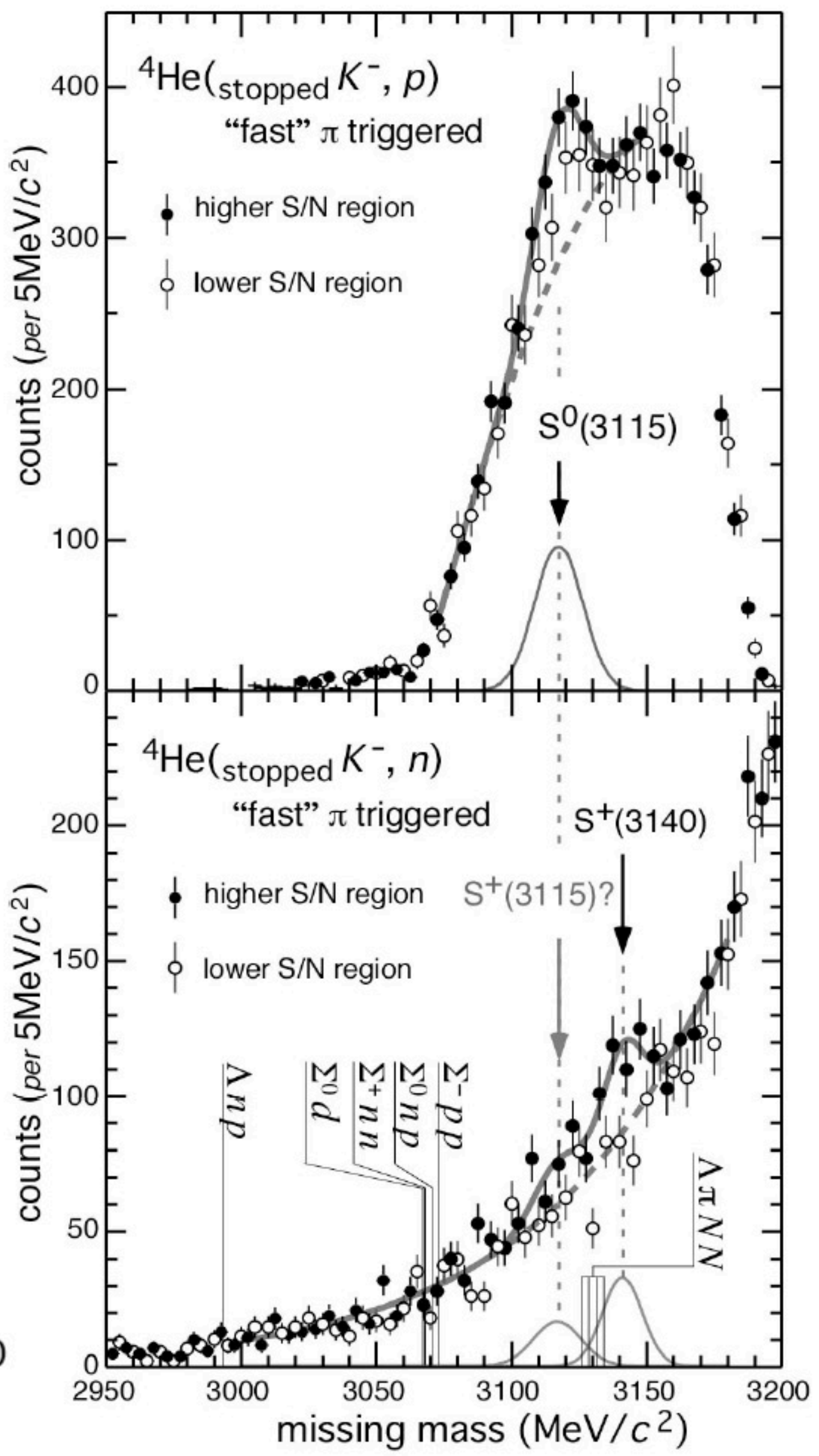
previous result from E471

mono-energetic proton observed, instead

Proton TOF spectrum



nucl-ex/0310018



K中間子核検証研究

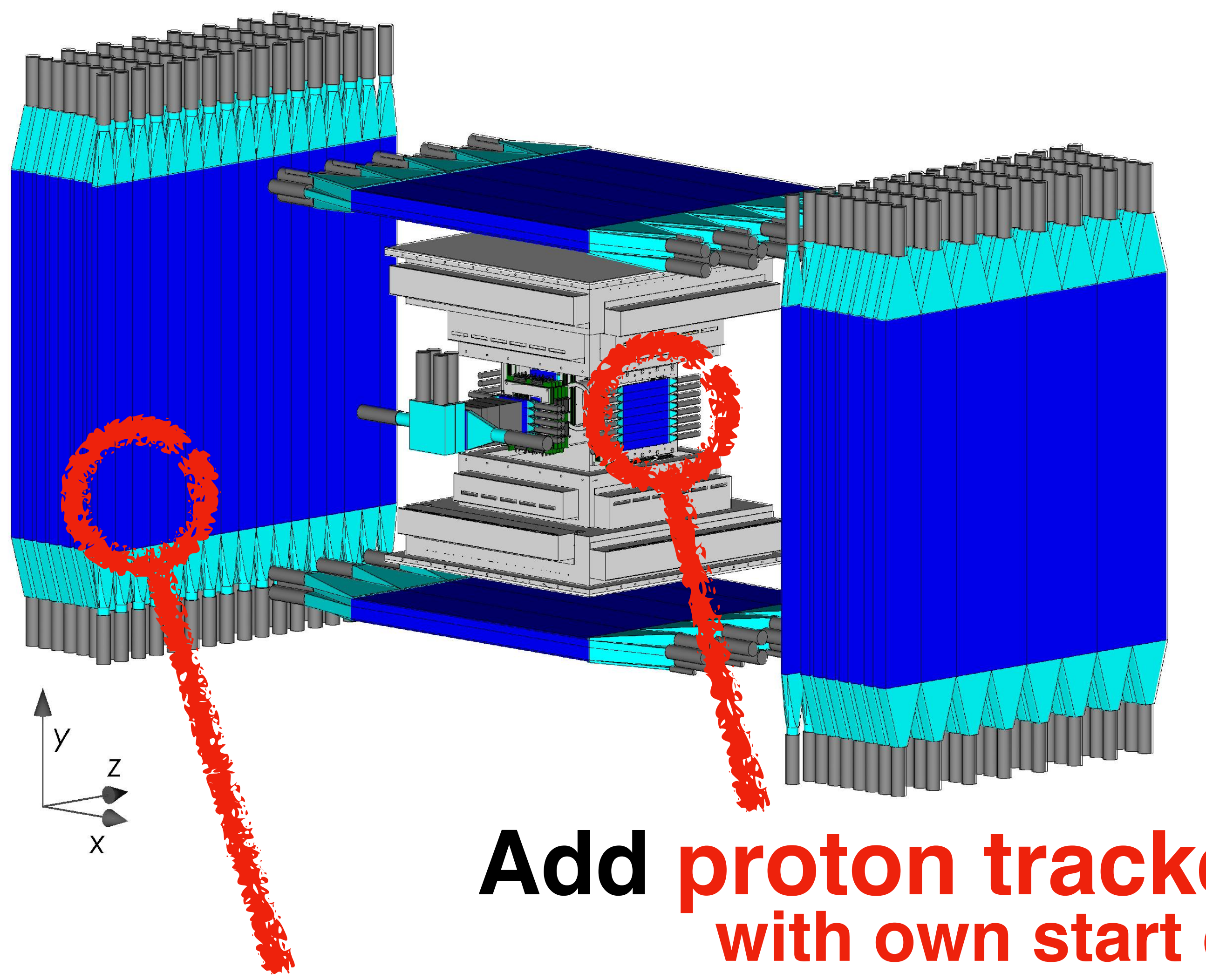
Verification Study by ourselves gave Negative Result!

Obviously, we were in BIG BIG trouble …

¡¿ What Happened ?!

Ansatz in E549 / E570

If we upgrade our setup dedicative for proton spectroscopy, we can get confirmative proton spectrum.



Add proton tracker
with own start counter

Replace thin charge-veto counters to high resolution (thicker) counters for proton TOF

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何を間違ったか？

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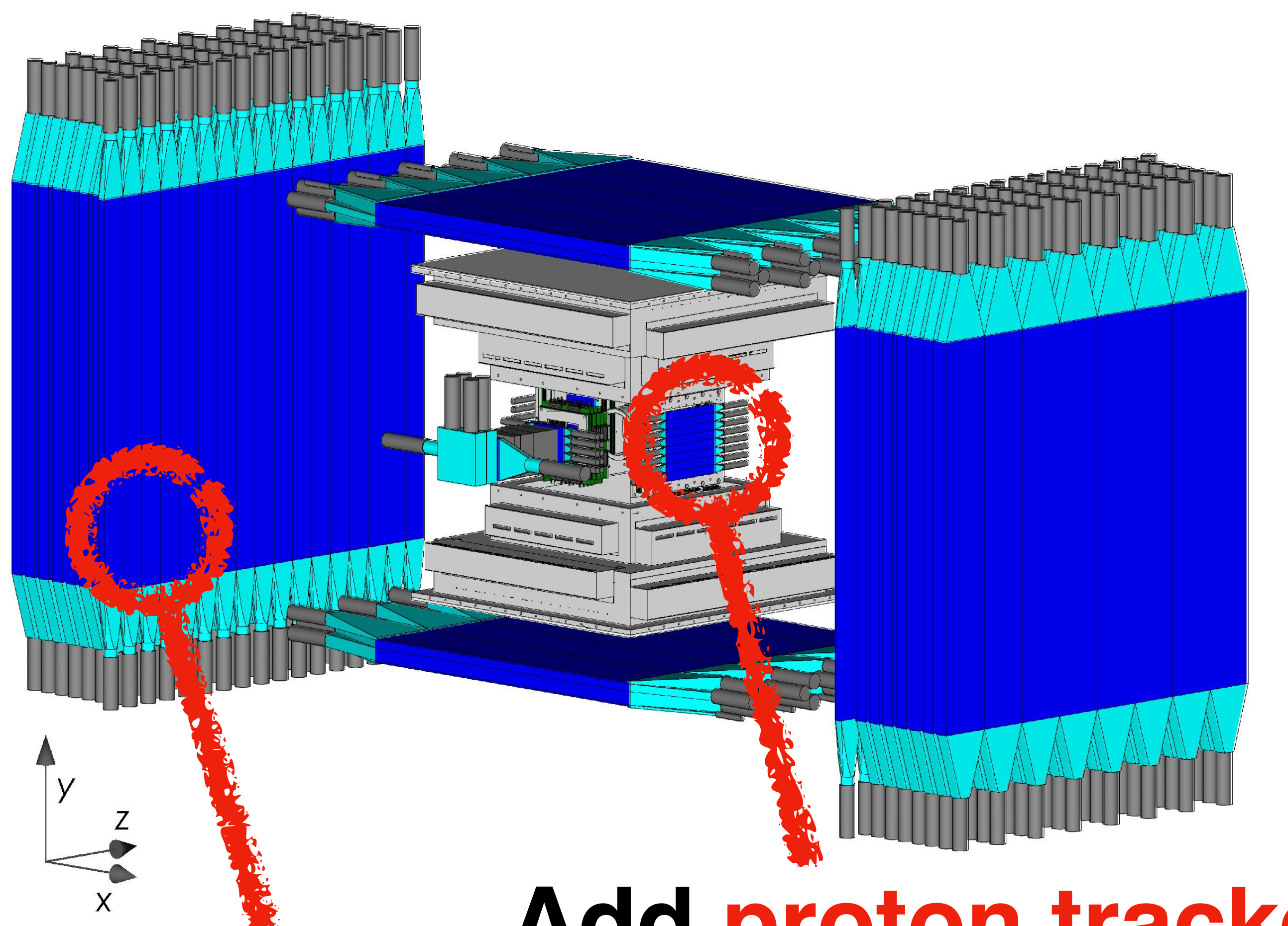

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The answer is:

"The imperfect analysis hidden in insufficient experimental setup"

More specifically, imperfect sluing correction

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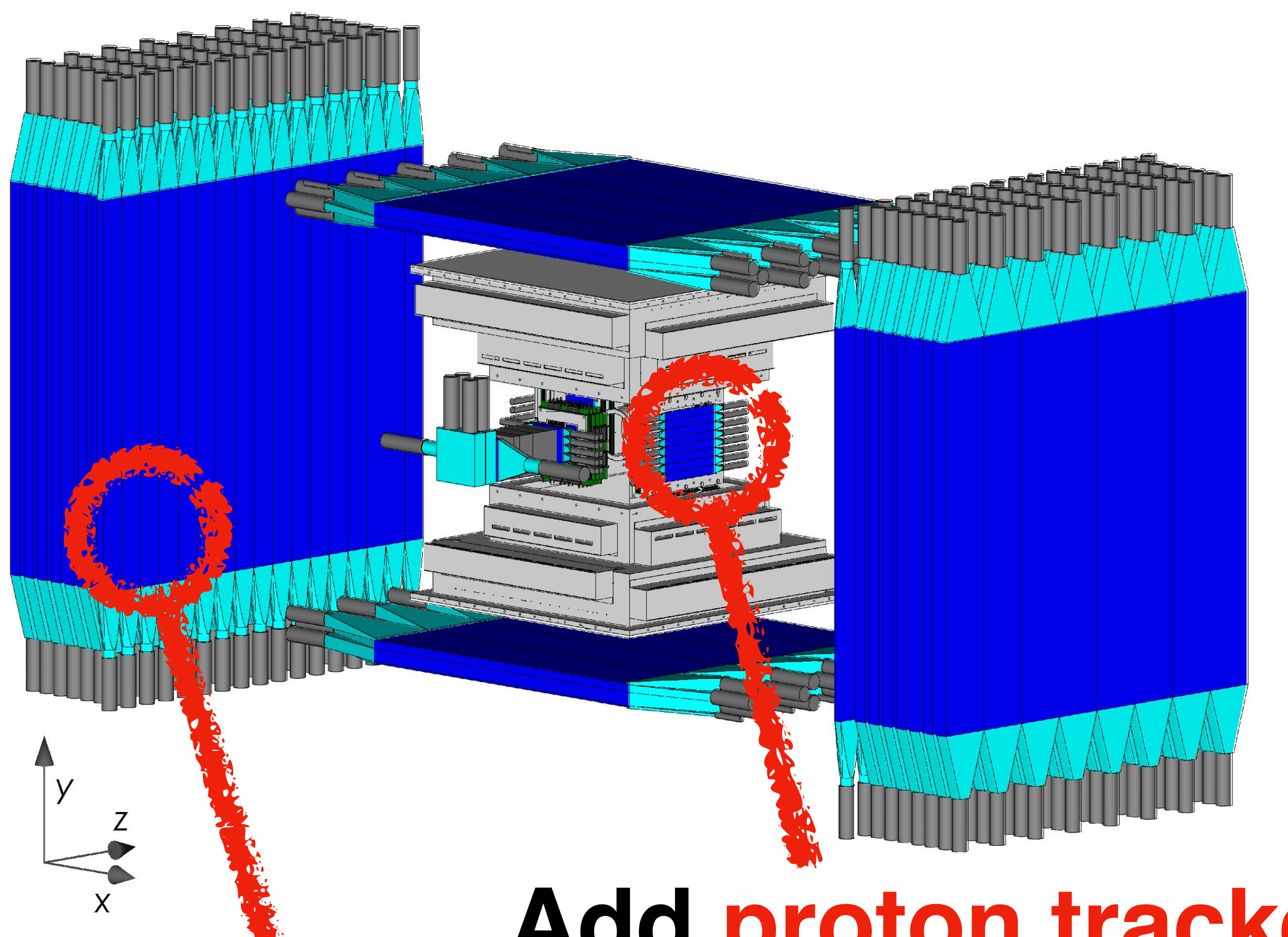

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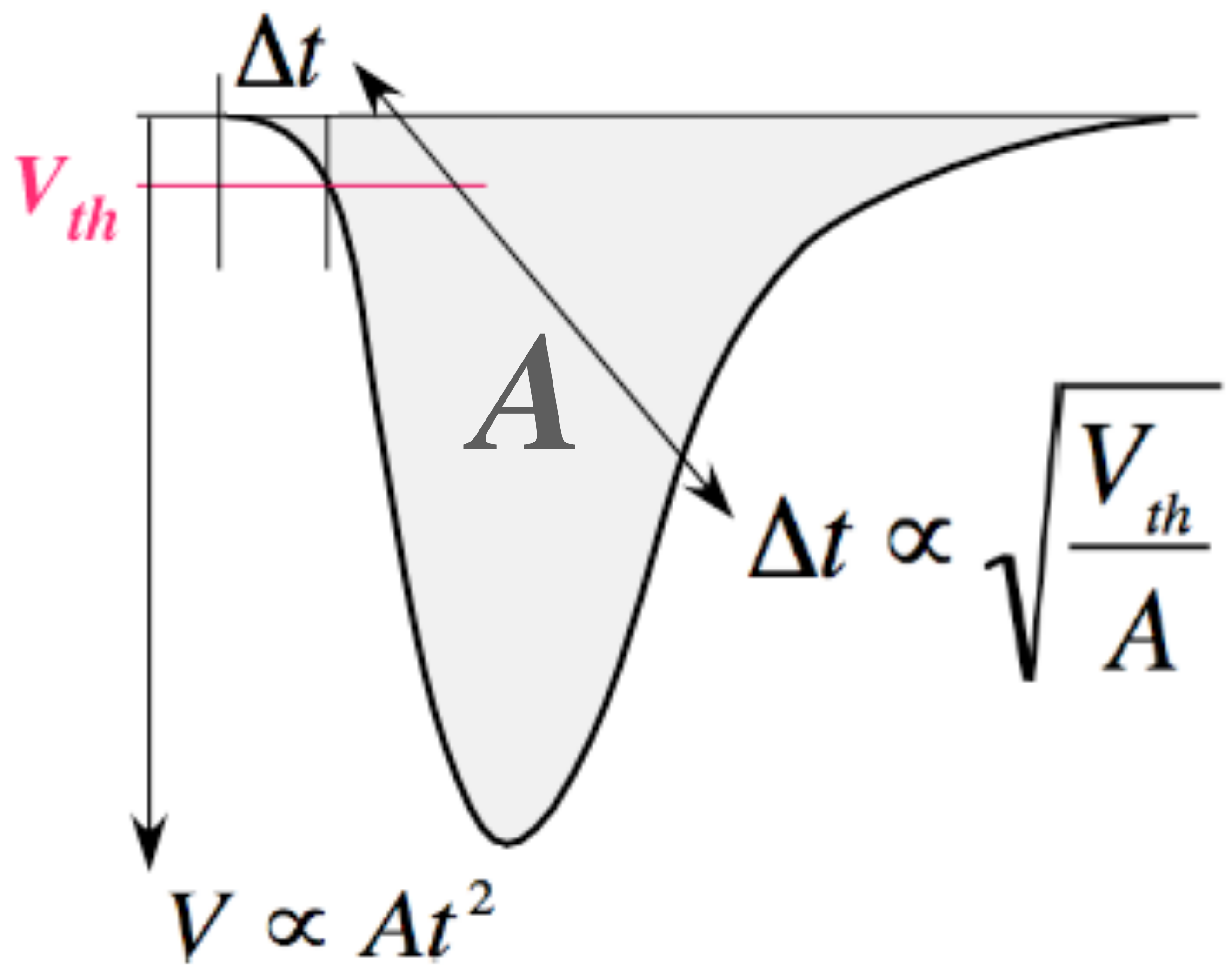

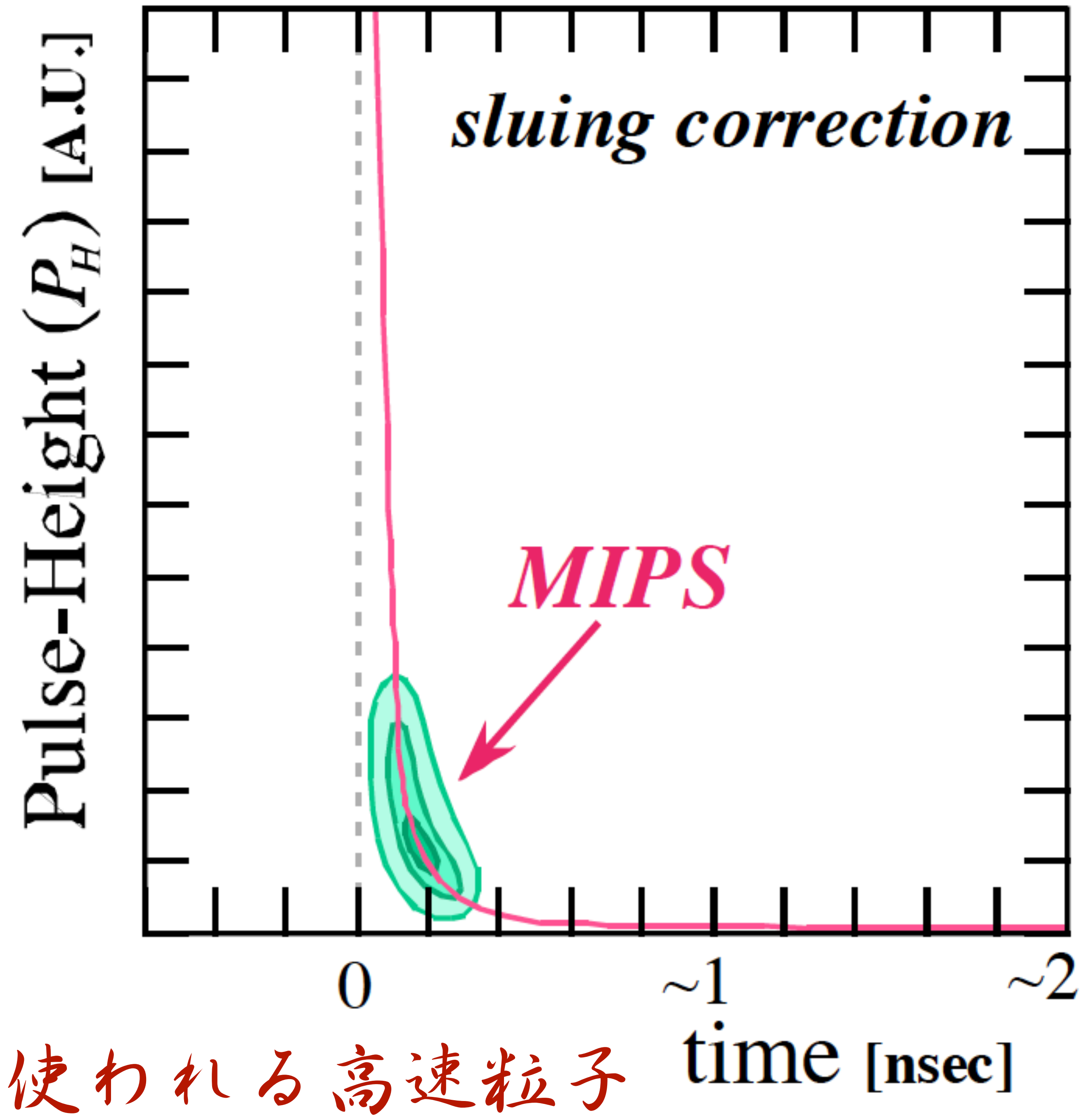

MIPS: 標準的に較正に使われる高速粒子

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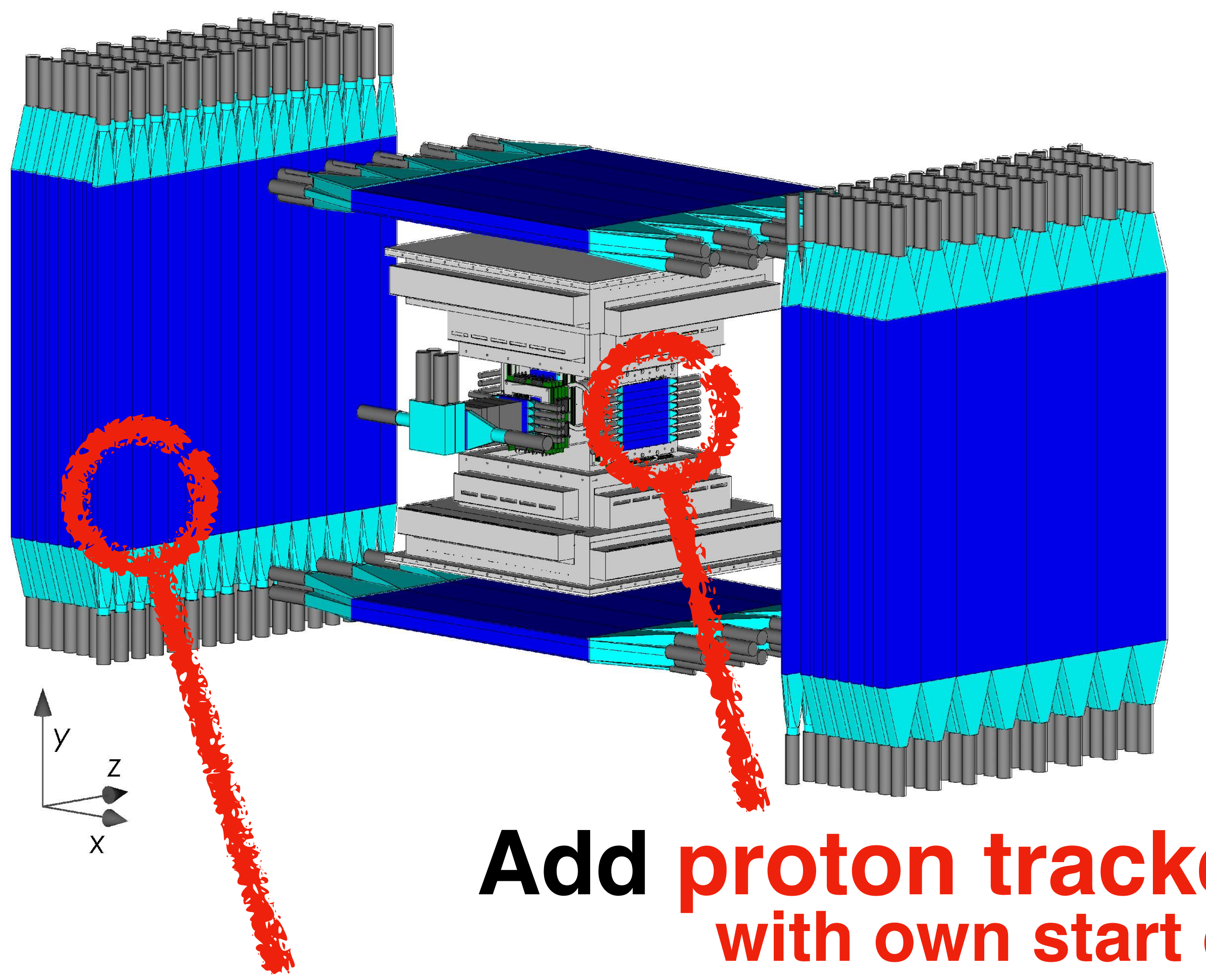

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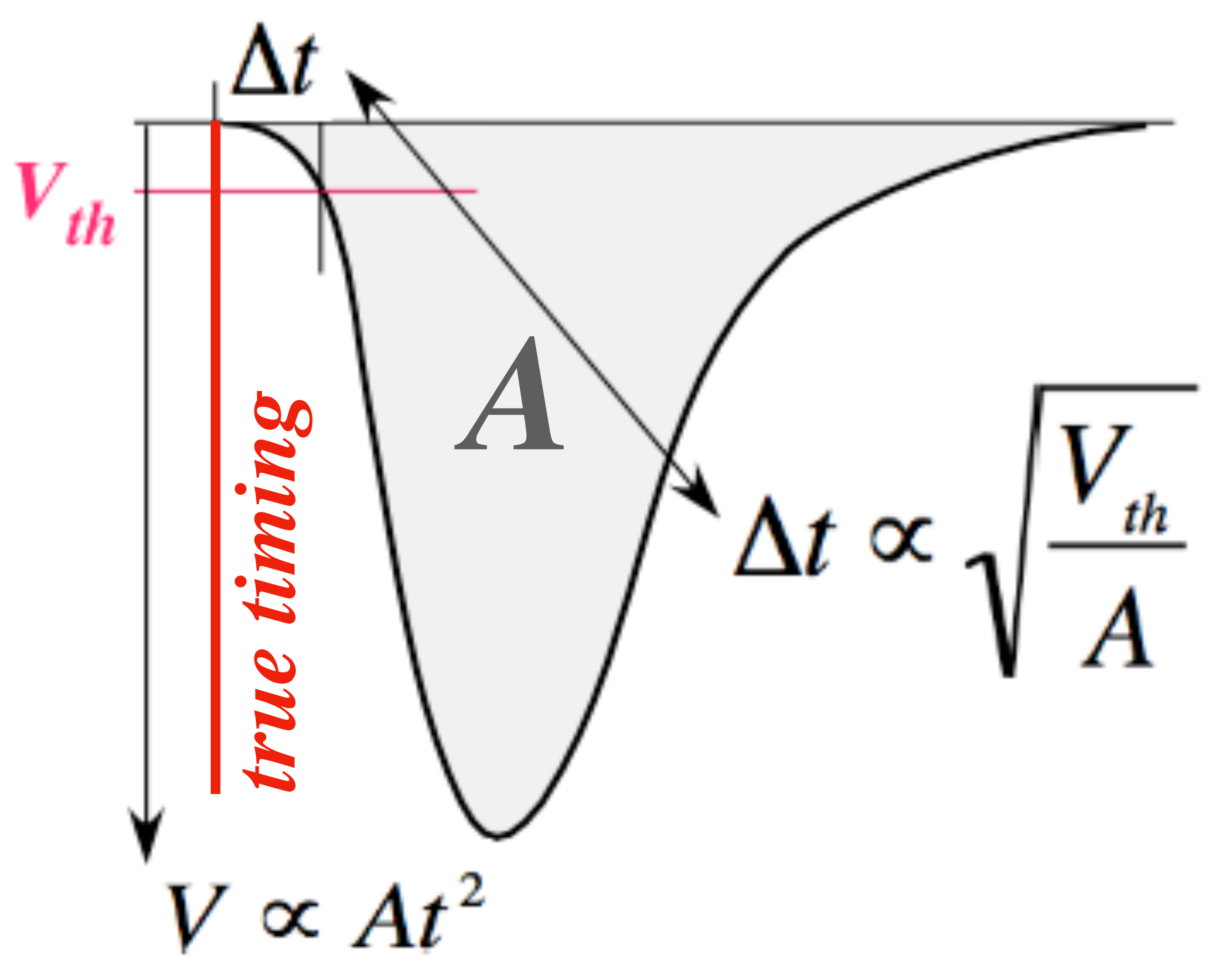

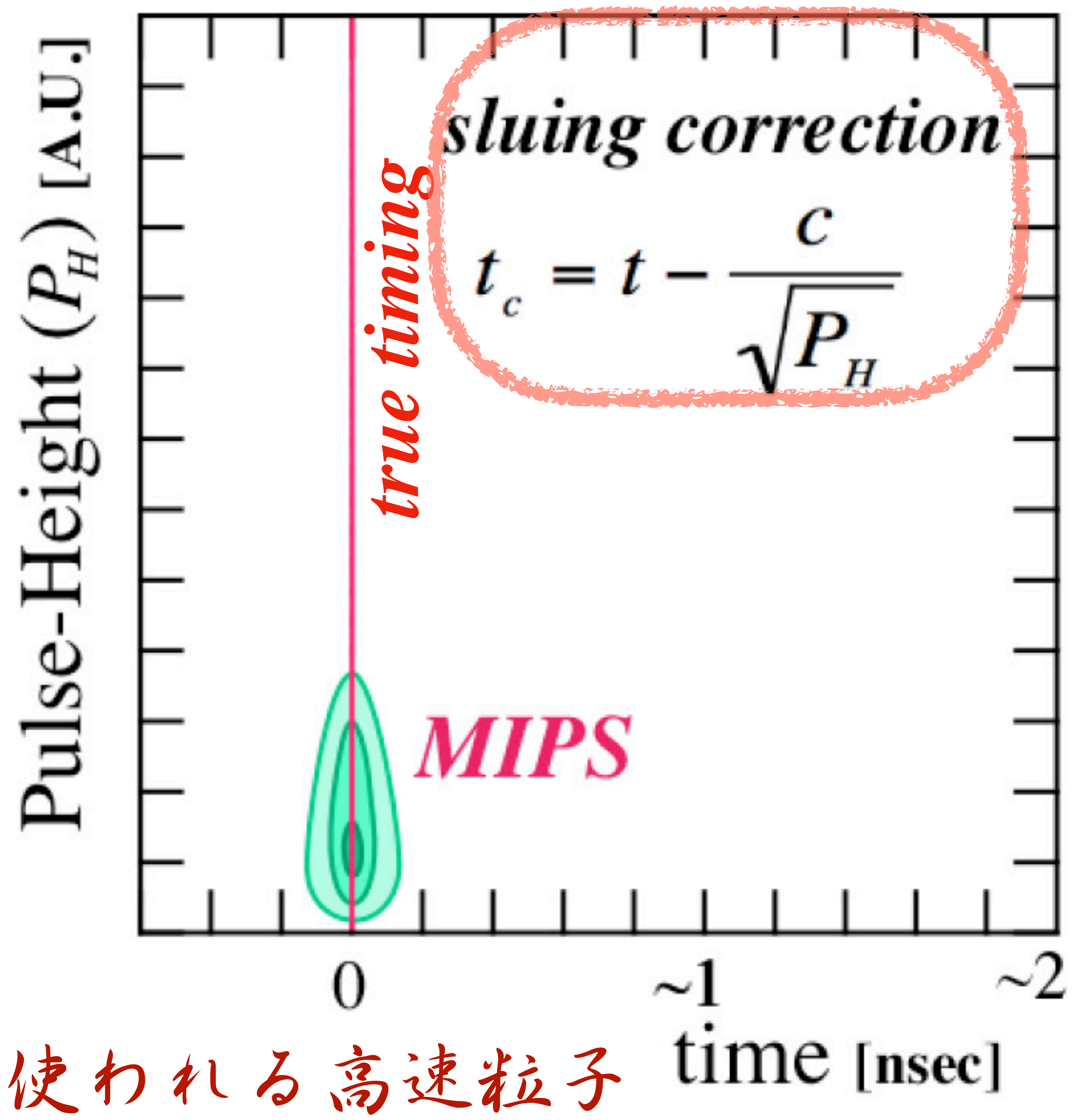

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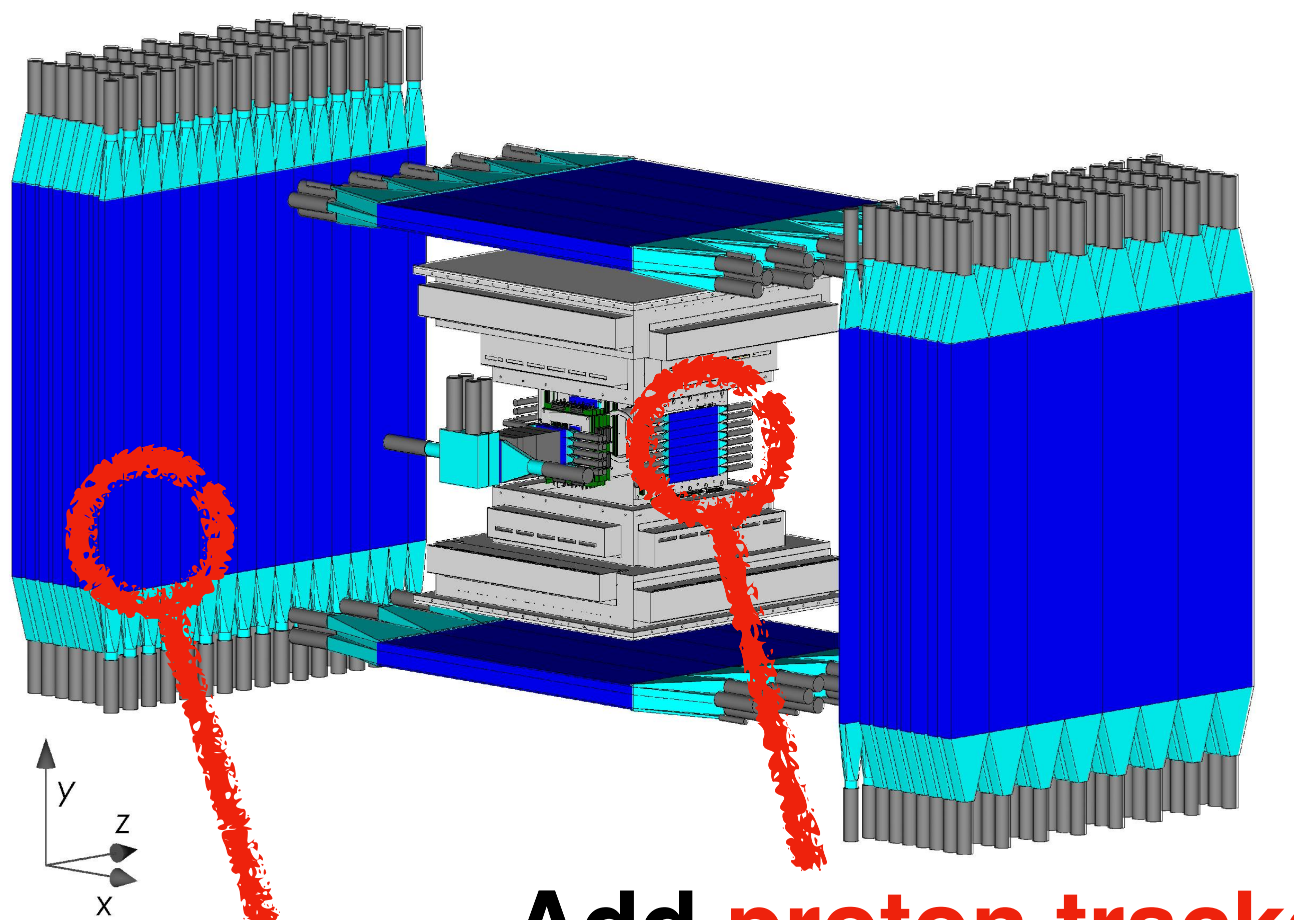

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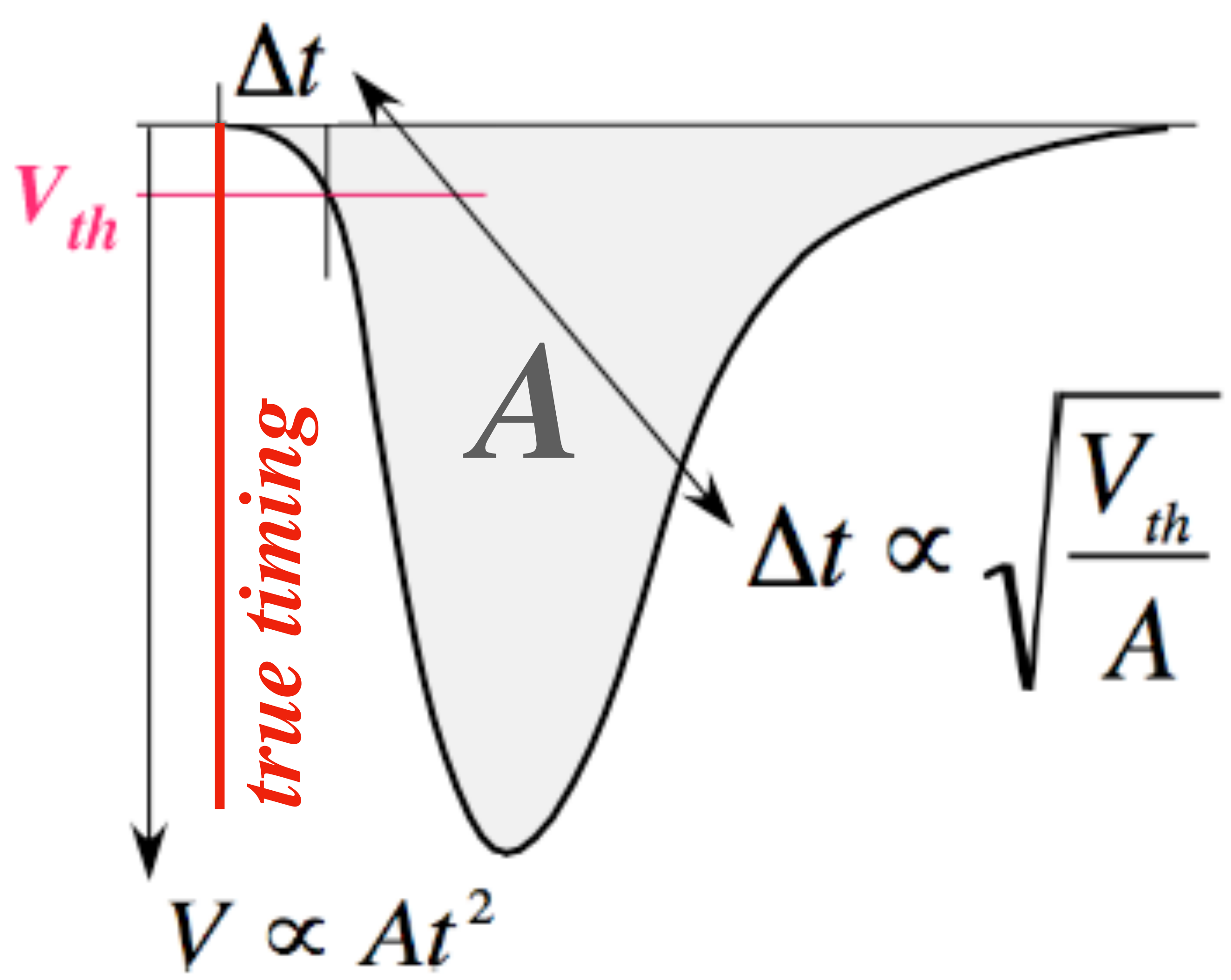
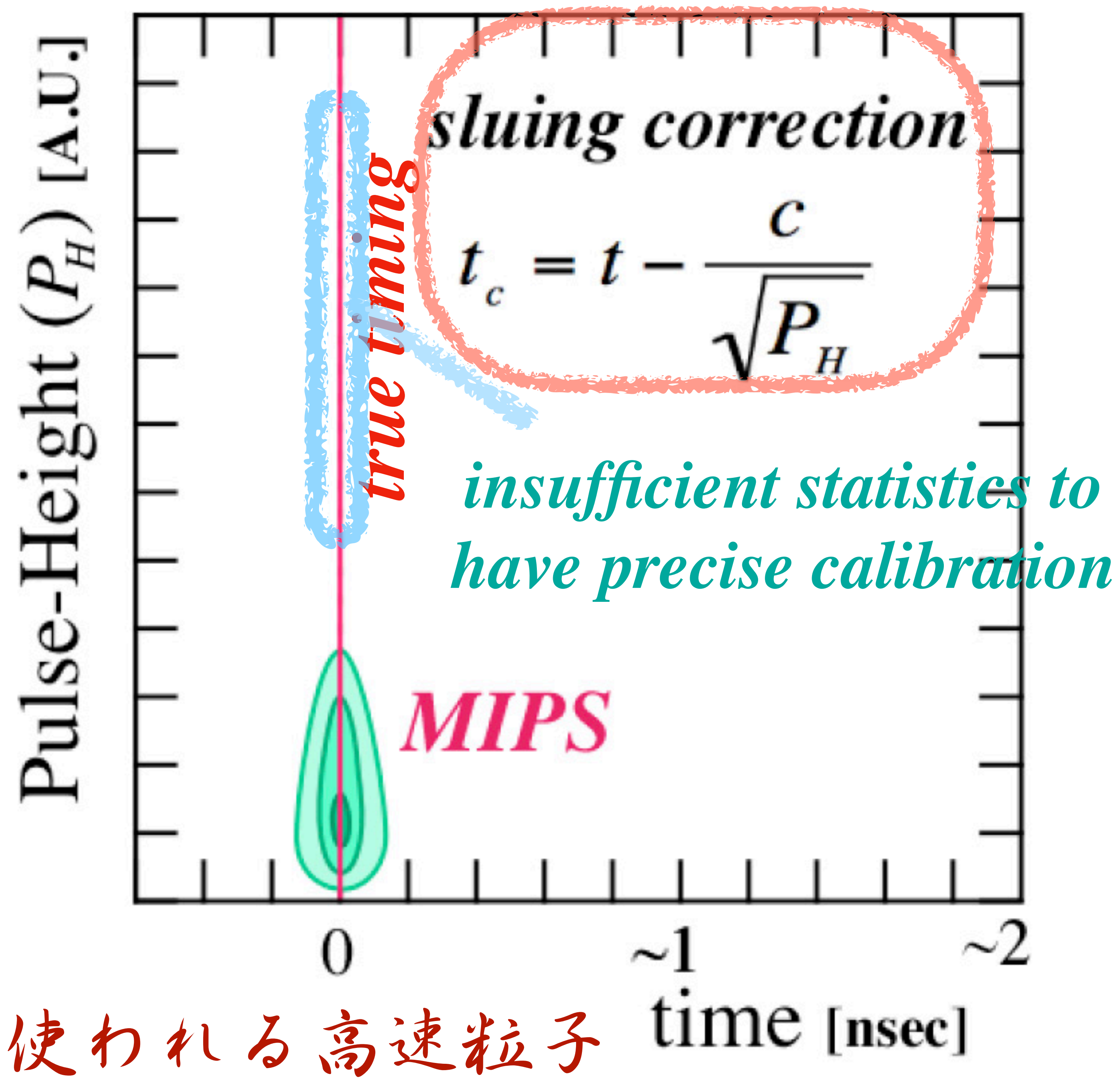




MIPS: 標準的に較正に使われる高速粒子

Why we were FAKED…

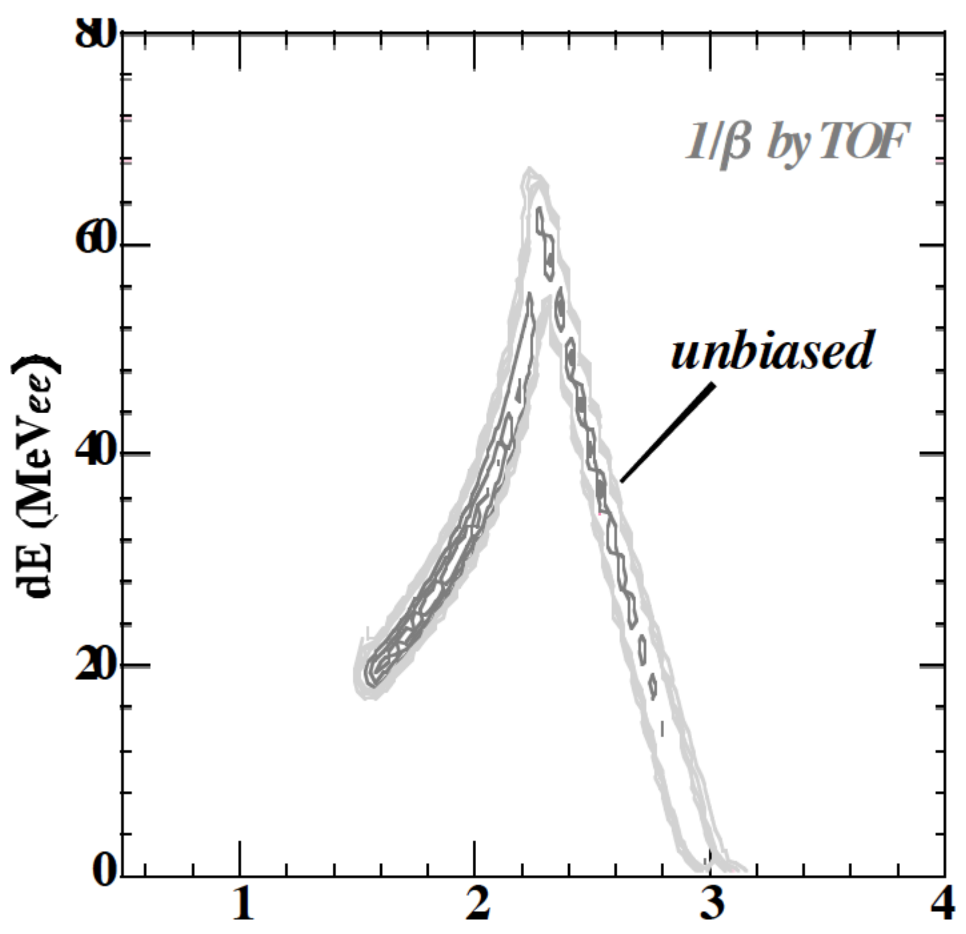
We shall publish the reason why we were faked, because we found our mistake by ourselves.

identified by M. Sato (the one who cannot come today) …

What will happen if sluing correction is slightly mistuned by 5 ps / MeV ?

much smaller than the resolution

simulation

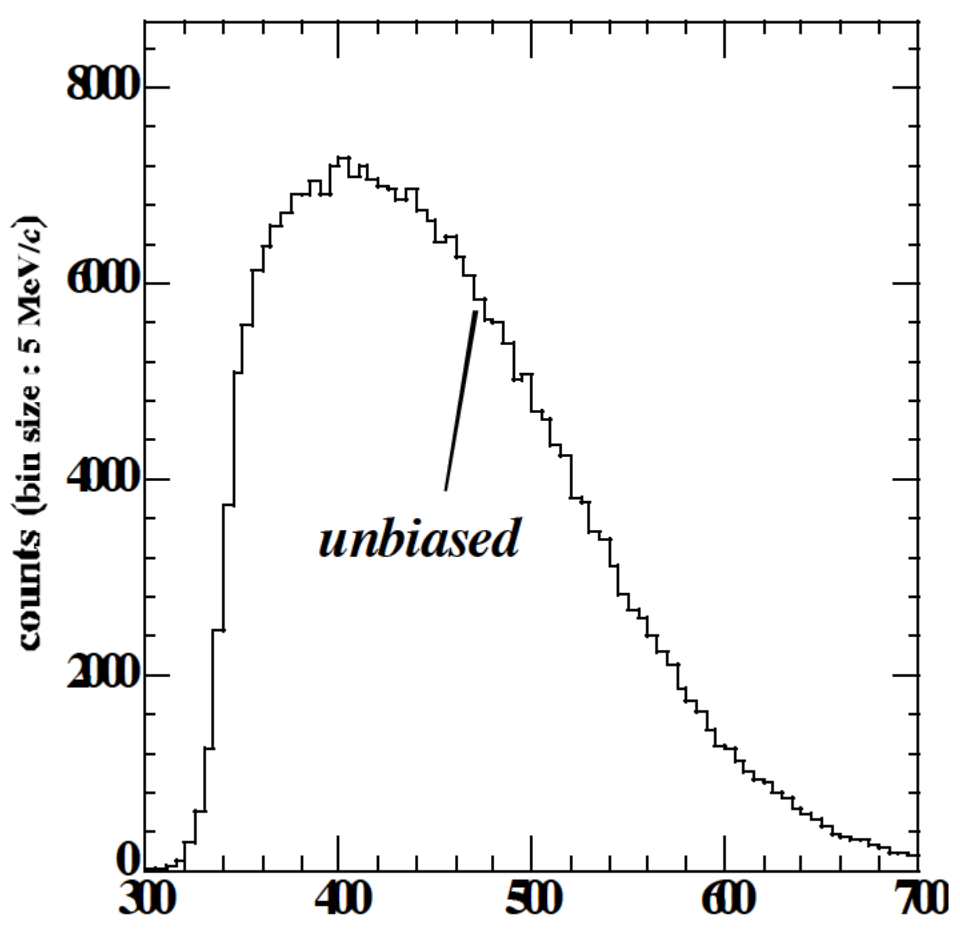


Pulse Hight (A) for sluing correction

1/β by time-of-flight

∝ 1 / proton momentum

simulation



proton momentum (MeV/c)

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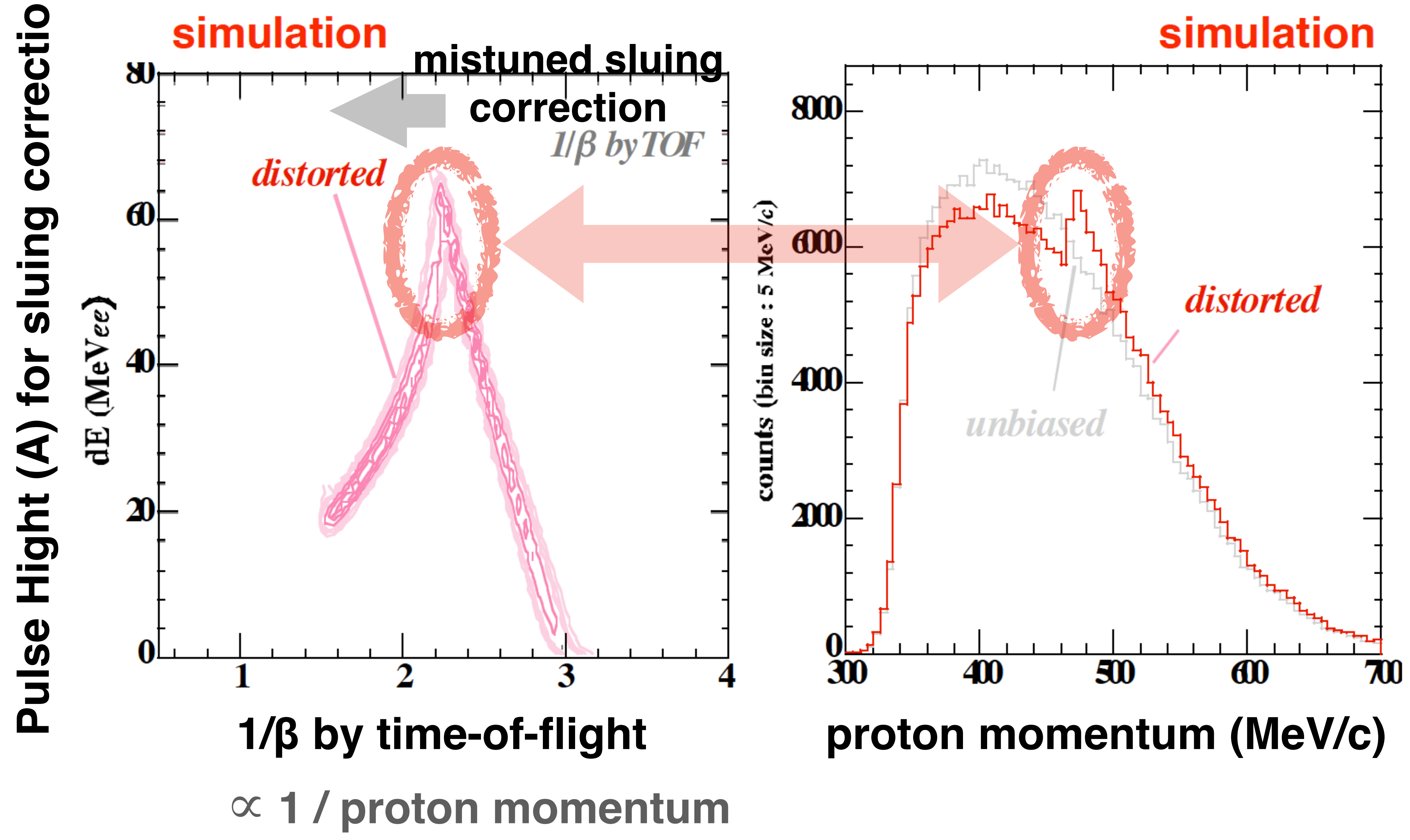

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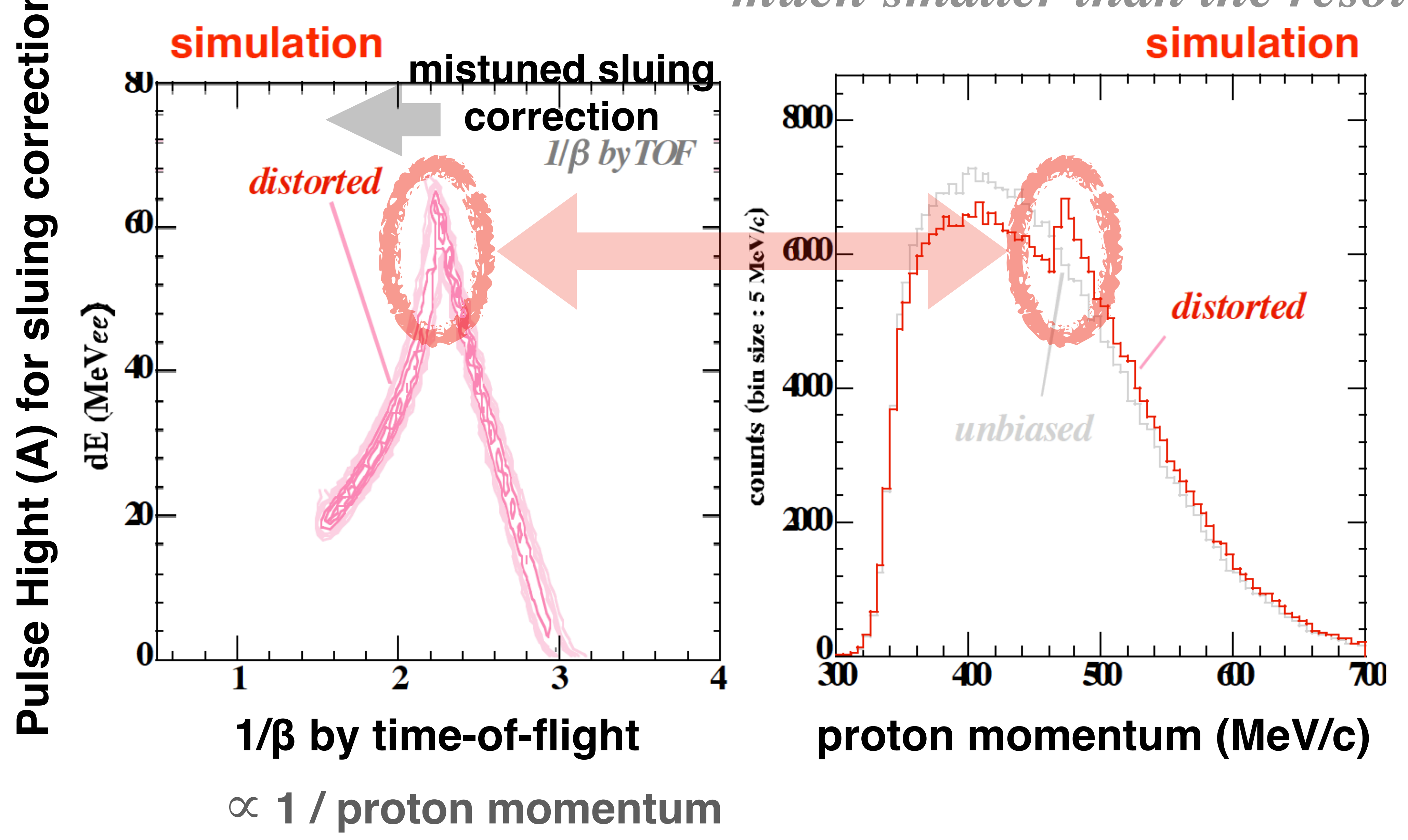


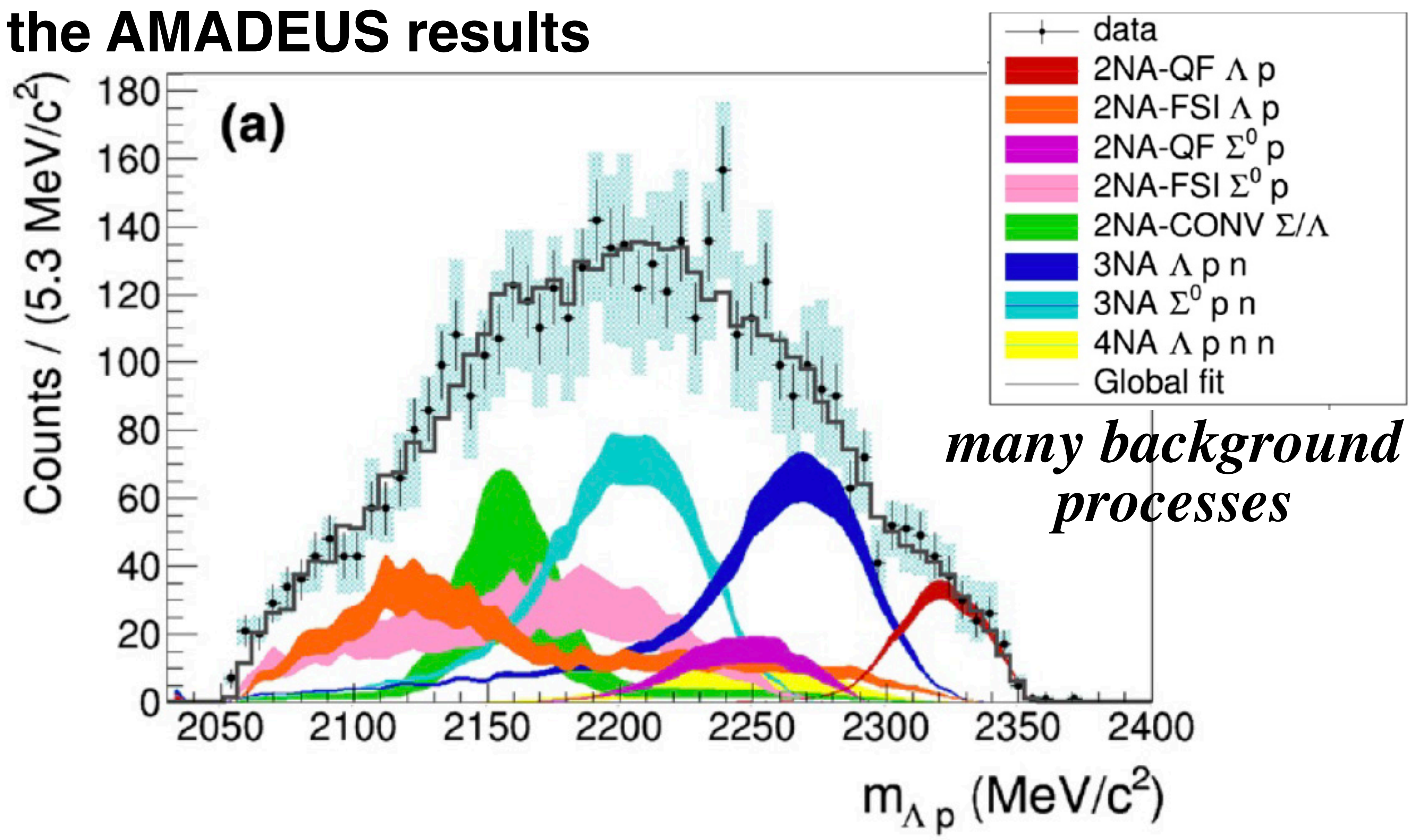
Pulse Hight anomaly forms a spurious peak in the momentum spectrum at exactly the same place where we found a fake signal

This is a very hard lesson for us.

This doesn't mean there's non-existence of kaonic nuclear bound state.

Background is very severe in kaon reaction at-rest.

Eur. Phys. J. C 79, 190 (2019)



How to discriminate K-nucl. formation signal out from severe backgrounds?

シグナルは巨大バックグランドの中に …

閑話休題：今一度どう取り組むべきか根本的に考える…

Let me digress on what I learned as a researcher on

What is the most important point as a researcher to realize break through achievement

如何に革新的成果を導くか?

理研で研究者と切磋琢磨しながら感じたこと

What questions to be addressed …

Why?

is the source of research

Differentiate from previous approach

様々な角度からベストを探る

Looking at the same problem from a different angle can make it easier.

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Nobody can do anything alone (at least for experimental research). Communication is the starting point for the collaboration. Diversity can be a source of unique idea.

一人じゃ何も出来ない
人との関わりによる相互触発

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Having several strengths to be proud of as a researcher

Collaboration through division of speciality / role in the collaboration.

研究者としての強み

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Perspective view

Summarize situation eventually… To escape from local optimum. Not to loose the way to go.

俯瞰的に考える

Having several strengths to be proud of as a researcher

Collaboration through division of speciality / role in the collaboration.

研究者としての強み

To researchers:

To administrators:

To researchers:

Keep asking why even to textbooks (common sense) … I hope you aim for discoveries that change the world or demand a rewrite of the textbooks.

世の中を変える、あるいは教科書の書き換えを迫るような発見を目指して!

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Please prioritize securing research resources for researchers, including ***time for meditation****, to maximize research outcomes, rather than strictly enforcing rules.*

研究者が創造的であるためには常に忙しいことはNG

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*Please streamline lengthy documents and rulebooks, and **explain the reason why these policies and regulations are essential by using the 5W1H method.** Otherwise it won't be respected so efficiently.*

所の政策や規定は出来るだけ省略・簡潔化(5W1H)。「何故不可避か」の説明

閑話休題：今少しの脱線…

Let me digress more in the context of scientific mistake and misconduct

研究上の間違い　研究不正

What everyone knows …

Scientific misconduct never pay off !!

研究不正は割に合わない

*The motivation for misconduct is the desire **to be recognized as a researcher for significant scientific contributions**.*

*Significant academic achievements **will extensively be verified / examined.***

Result of misconduct will never be verified, though…

承認欲求・不可避な検証・不正の露見

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Why can't research misconduct be completely eradicated?

People could consider ***even a short-lived glory to be glory.***

Without outstanding achievements, fixed-term researchers can't secure their next position. — This fact also makes it difficult to eradicate research misconduct.

三日天下でも天下は天下？けど、三日天下の先は奈落…

過度な成果創出ストレスも不正誘引事象（五神理事長の主導で緩和）

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No matter how challenging, one should take essential efforts with a holistic perspective; otherwise, you may wandering around local (or selfish) optimum.

例え困難だろうと、俯瞰的視野を持ち「本質的取り組みは何か」を常に意識

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Excessive ethics simply waste valuable research time *for sincere researchers.*

Ethics are of ***no help to the fundamental solution****, as all the people already understand that misconduct is unacceptable.*

研究倫理教育拡充は本質的には愚策

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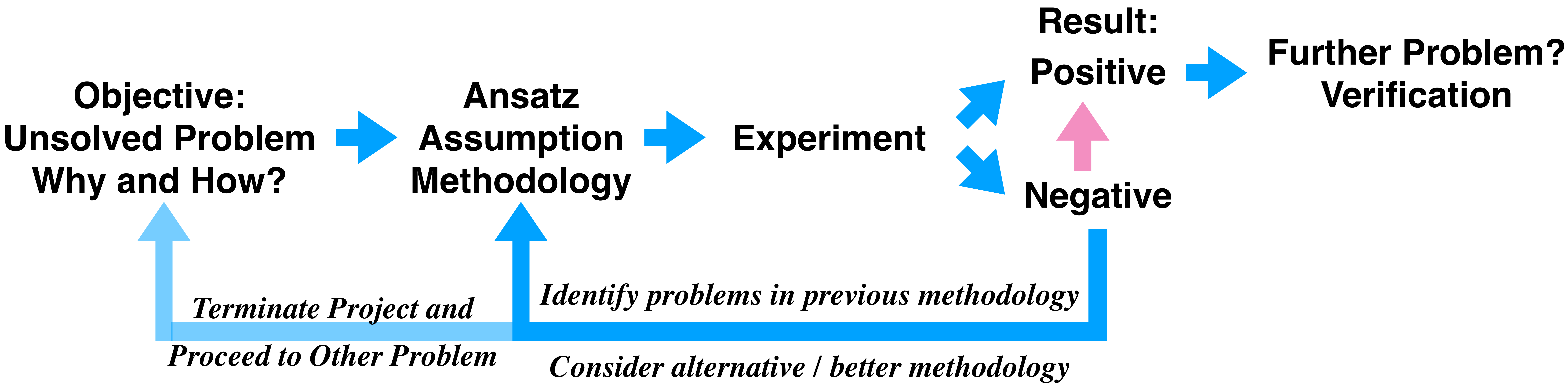
研究倫理教育拡充は本質的には愚策

Communication between research labs (or organizations) and creating an ***open minded atmosphere*** *where people freely express their opinions are essential for preventing misconduct — expanding projects that involve multiple research labs, such as* ***exploring new research areas****, is important for this purpose.*

本音をぶつけ合える環境を!! 矯正より開放的環境・新領域開拓課題の拡充等が有益

諦めない限り完全失敗ではない
失敗の訂正は大事
どう取り組む?

A Typical Experimental Research Cycle



↑ = {
- mistake / hidden bias in the analysis — *Must be corrected, and open that to public.* — *To encourage ambitious research, failure must be embraced.*
  完全にミスを防ぐことは不可能。間違いは許容されるべき
- pretend to be positive — unacceptable scientific misconduct
  決して許容できない。過度な倫理教育・研究者の引き締めは愚策

諦めない限り完全失敗ではない
失敗の訂正は大事
どう取り組む?

A Typical Experimental Research Cycle

Back to the kaonic nuclear search

How to discriminate K-nucl. formation signal out from severe backgrounds?

How to breakthrough the experimental difficulty?

K中間子原子核探査で如何に革新的成果を導くか?

完全実験を目指そう!

閑話休題：今一度どう取り組むべきか根本的に考える …

"The opposite of success is not failure. It's not trying."

- Attributed to F.C. Farmer, sometime mistakenly attributed to T. Edison.

"Failure happens when you stop challenge. If you keep going until succeed, that's success."

- Attributed to K. Matsushita, probably inspired by words of T. Edison.

Further challenges based on deeper insights on what we shall do for ideal experiment!

Complicated dynamics

Insufficient information

→

Simplify formation channel: $K^- N \to \bar{K} N'$

Specify decay channel: $\bar{K} NN \to \Lambda p$

Study on multi-dimensional kinematics: $(m_{\Lambda p}, q_{\Lambda p})$

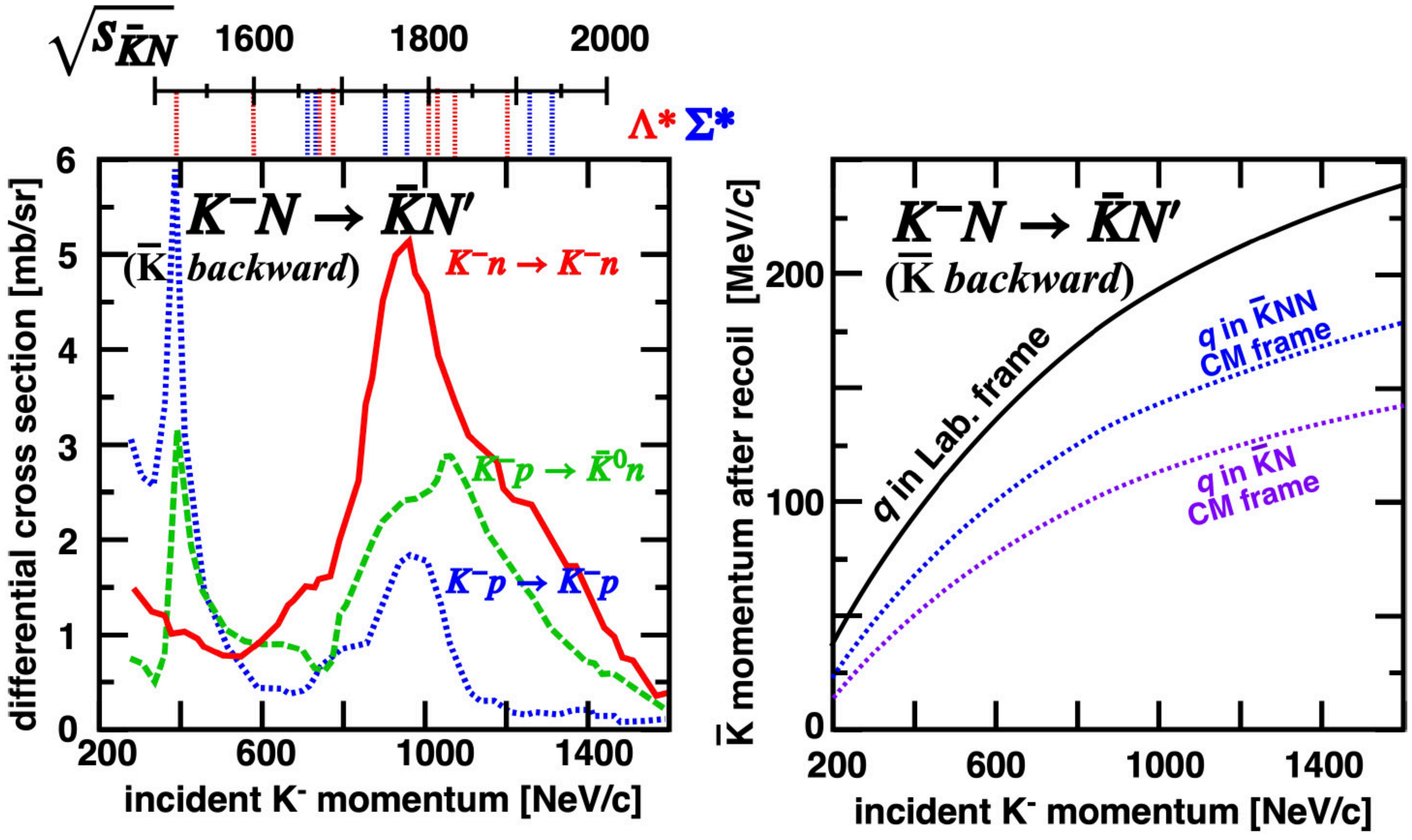
… improve information in ideal manner

Nucleon knockout reaction $K^-N \rightarrow \bar{K}N'$

理想的実験手法のヒント
核子反跳プロセス

Introduced by T. Kishimoto 1999

Why don't we knockout nucleon by kaon so as to form anti-kaon close to at-rest near residual nuclei?



Nucleon knockout reaction $K^- N \rightarrow \bar{K} N'$

理想的実験手法のヒント
核子反跳プロセス

Introduced by T. Kishimoto 1999

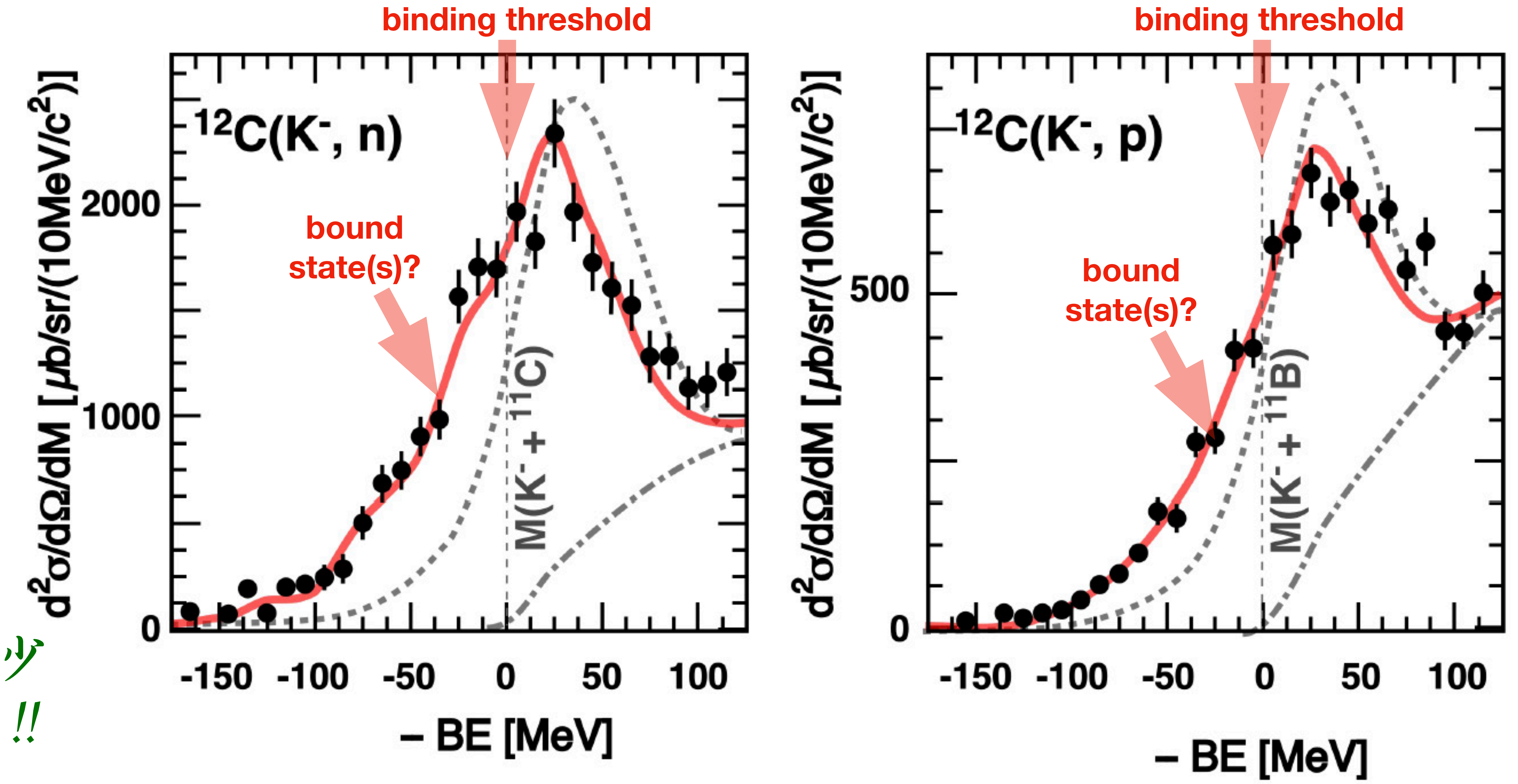
KEK-PS E548 led by T. Kishimoto: observe forward going nucleon produced by $K^- N \rightarrow \bar{K} N'$ reaction on carbon target. (missing mass spectroscopy)

The result suggests kaonic nuclear bound state formation, but the signal is not distinct to be identified as a peak

大変魅力的だけど
全体的になだらか
で確信には遠い

どうすれば良い?

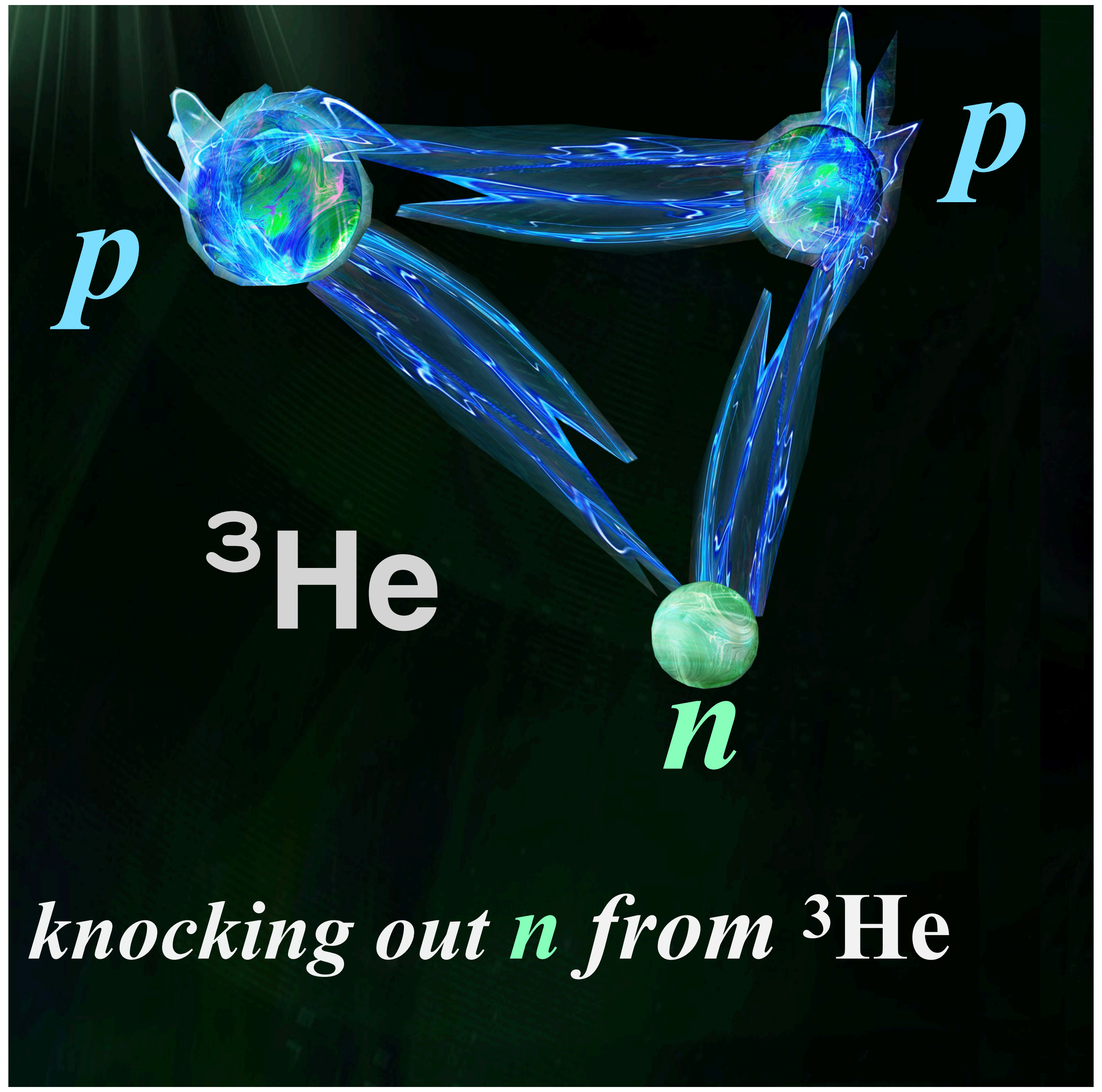
バックグランド除去可能な少
数系・完全実験を目指そう!!



J-PARC E15: “K⁻pp” Exploration

理想的実験を目指して

K^- + ^{3}He (ppn)



(K^- + pp) + n

substitute n in ^{3}He by K^-

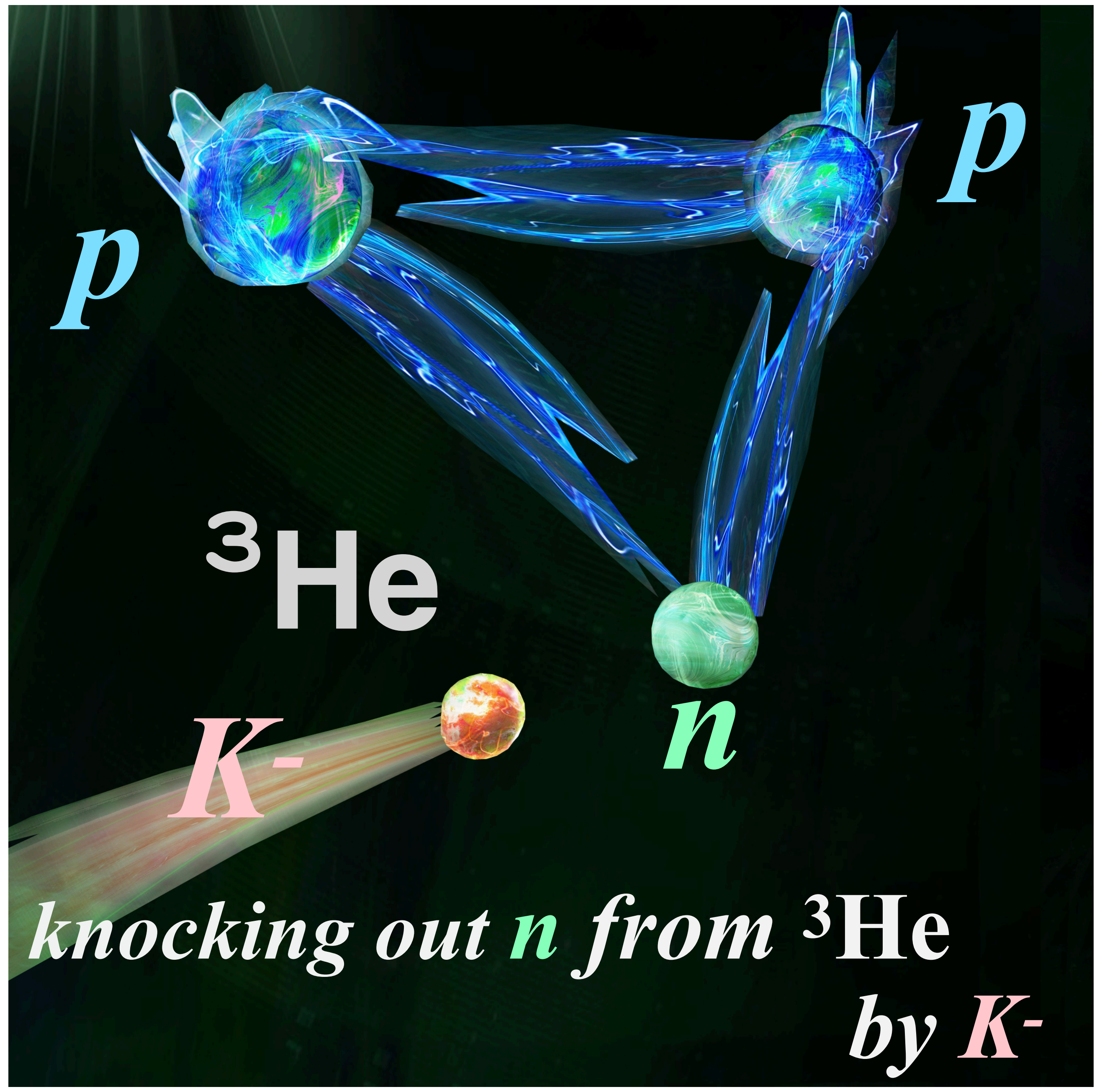
minimize number
of particles

provides multi-dimensional kinematical information

J-PARC E15: “K⁻pp” Exploration

理想的実験を目指して

K^- + ^{3}He (ppn)



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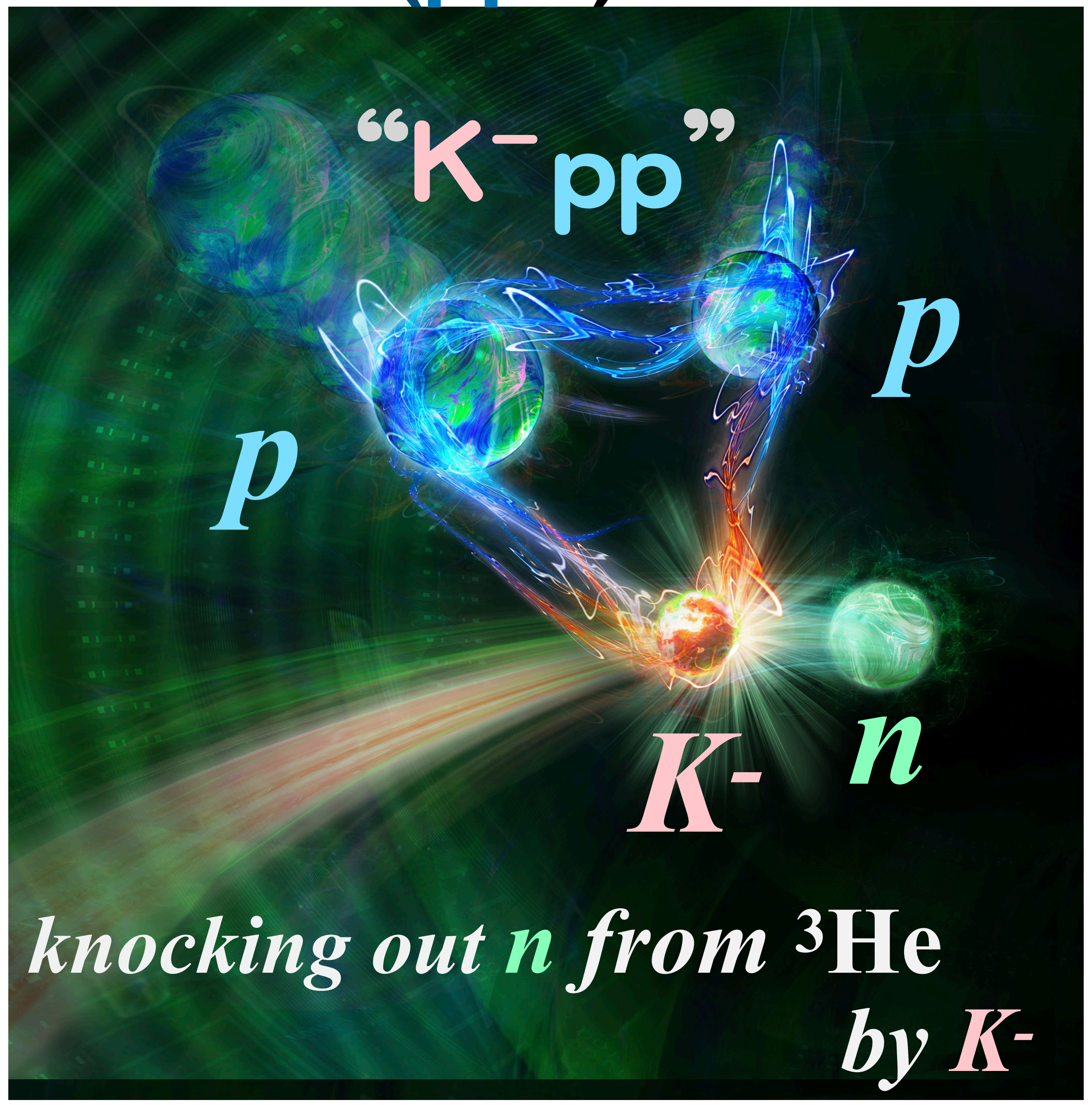


$(K^- + pp) + n$

substitute n in ^{3}He by K^-

minimize number of particles

$$K^- + {}^3He \rightarrow (K^- + pp) + n$$

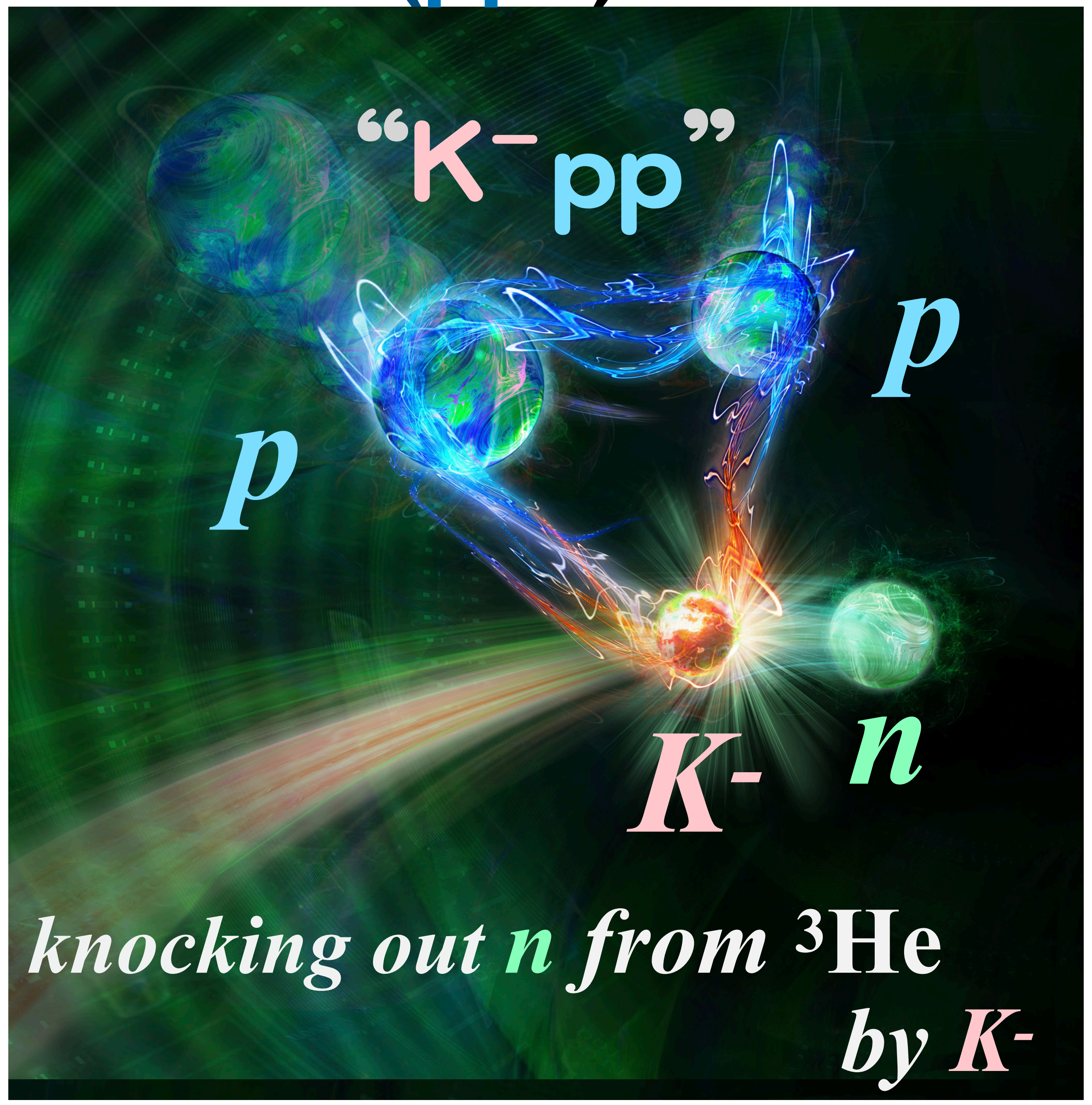
: formation

provides multi-dimensional kinematical information

J-PARC E15: "K^-pp" Exploration

理想的実験を目指して

K^- + ^{3}He (ppn)



(K^- + pp) + n

substitute n in ^{3}He by K^-

minimize number
of particles

If "K^-pp" exits, a peak will be formed in invariant mass spectrum below M(K^-pp)

$$M(K^-pp) \equiv m_{K^-} + 2m_p$$

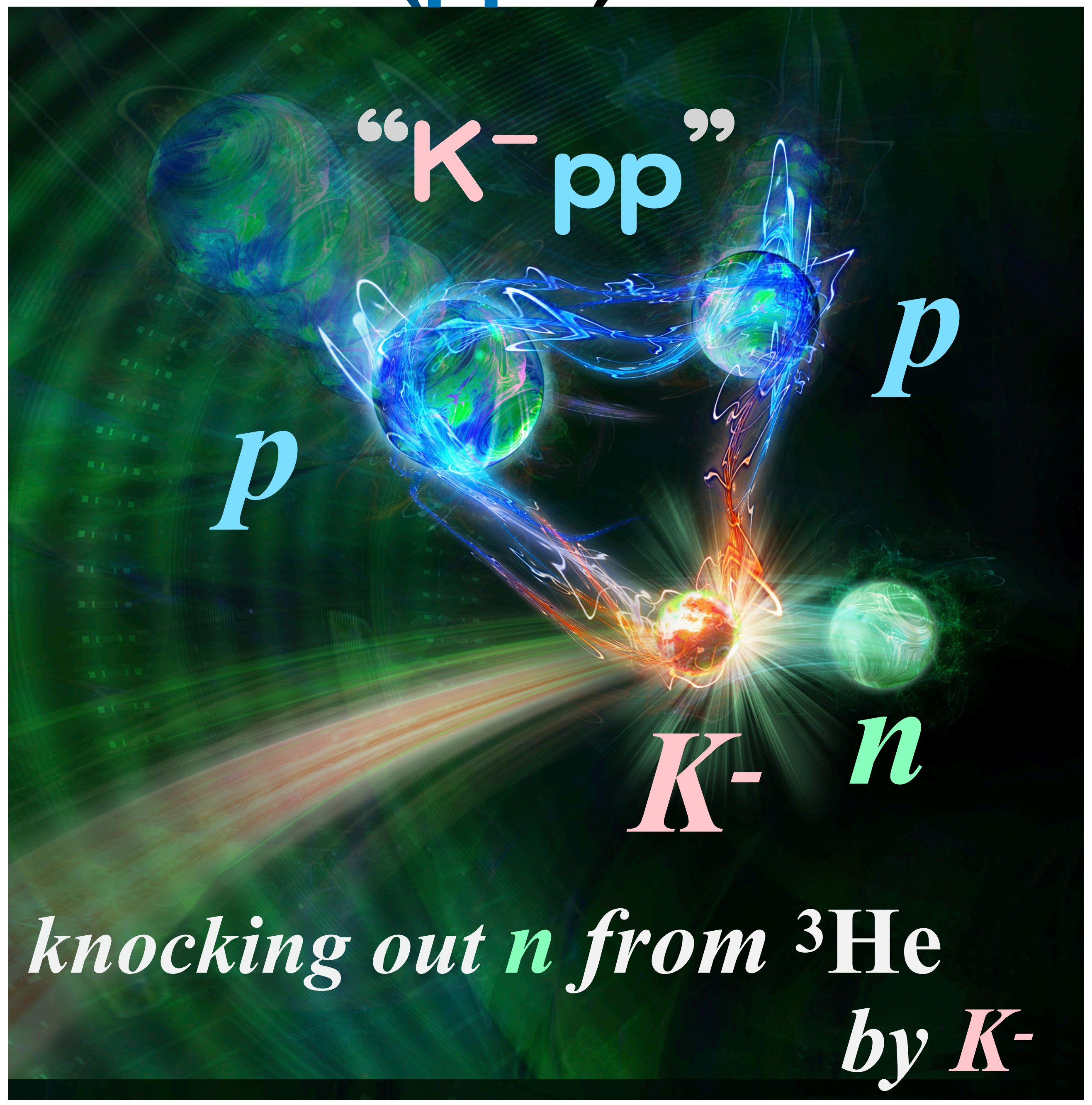
K^- + ^{3}He → (K^- + pp) + n : formation

provides multi-dimensional kinematical information

J-PARC E15: "K^-pp" Exploration

理想的実験を目指して

K^- + ^{3}He (ppn)



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If "K^-pp" exits, a peak will be formed in invariant mass spectrum below M(K^-pp)

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K^- + ^{3}He → (K^- + pp) + n : formation

(K^- + pp) → Λ + p : decay (*M, q*)

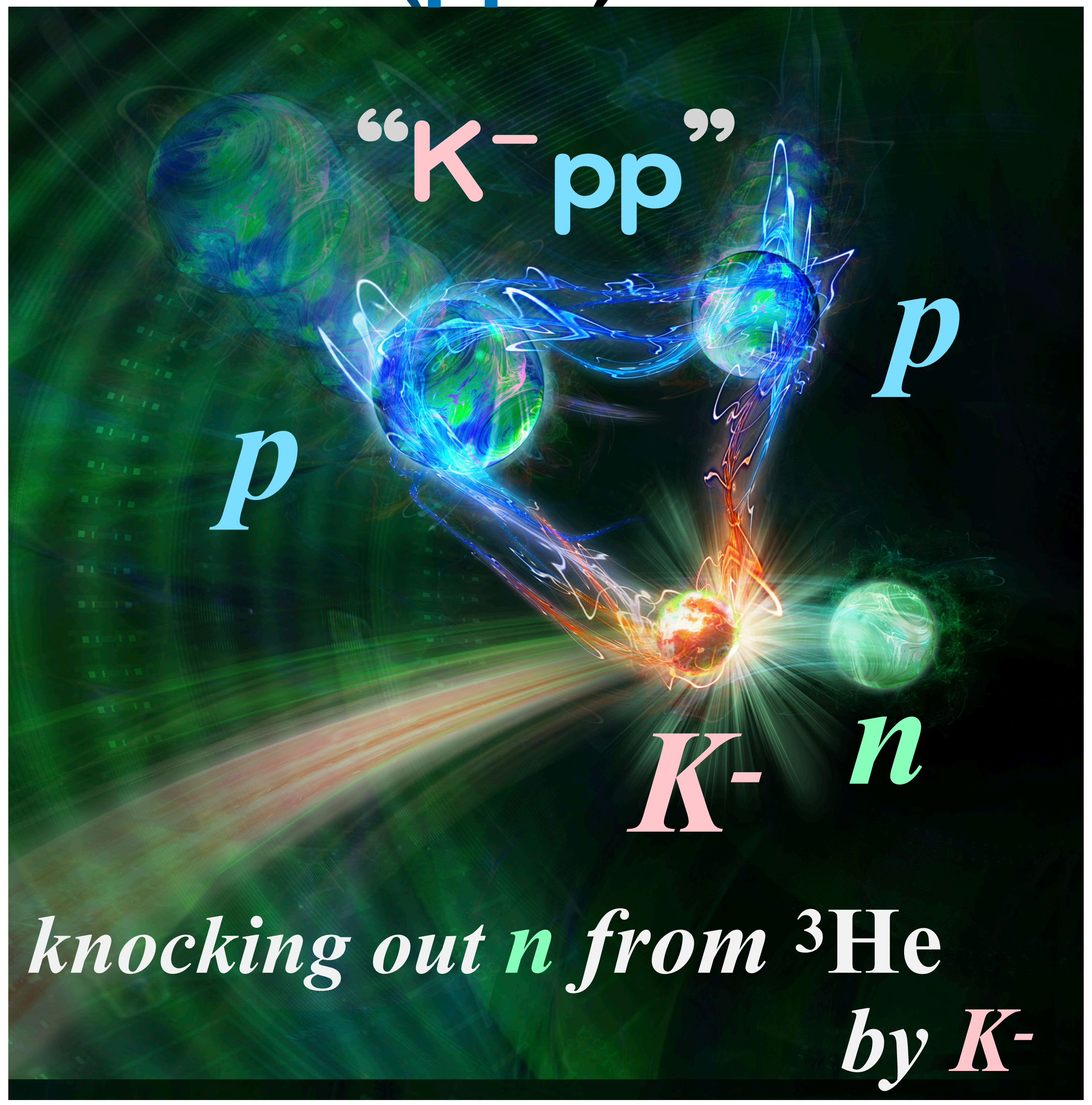
provides multi-dimensional kinematical information

J-PARC E15: "K^-pp" Exploration

理想的実験を目指して

反応生成粒子の数を減らして、生成と崩壊の両チャネルから
反応力学を多次元的かつ詳細に観測!

K^- + ^{3}He (ppn)



(K^- + pp) + n

substitute n in ^{3}He by K^-

minimize number of particles

If "K^-pp" exits, a peak will be formed in invariant mass spectrum below M(K^-pp)

$$M(K^-pp) \equiv m_{K^-} + 2m_p$$

kinematically identified

K^- + ^{3}He → (K^- + pp) + n : formation

(K^- + pp) → Λ + p : decay (*M*, *q*)

identified as charged particles

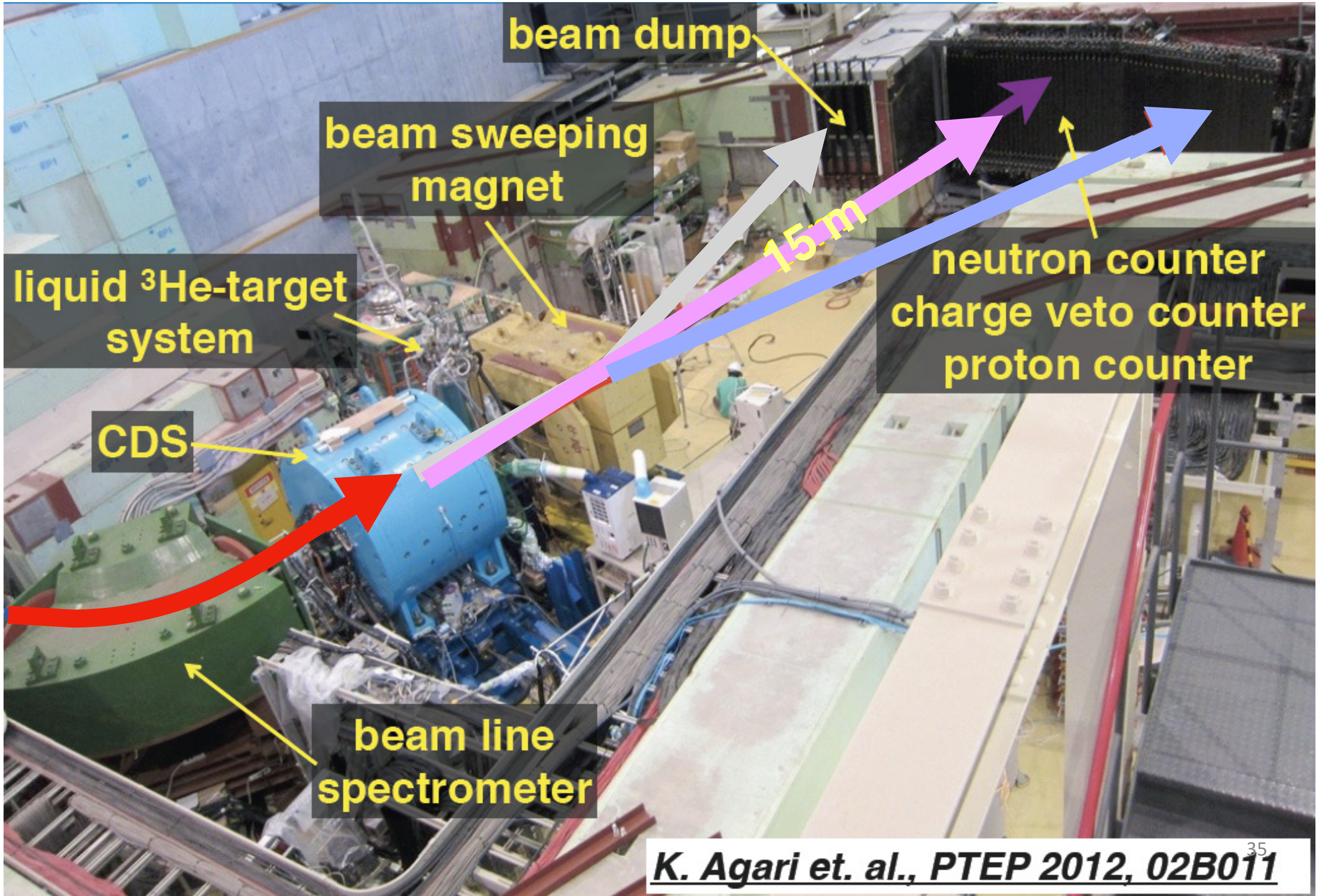
select K^- + ^{3}He → (Λ+p)+n events,

analyze *invariant mass M* of (K^- + pp)-system

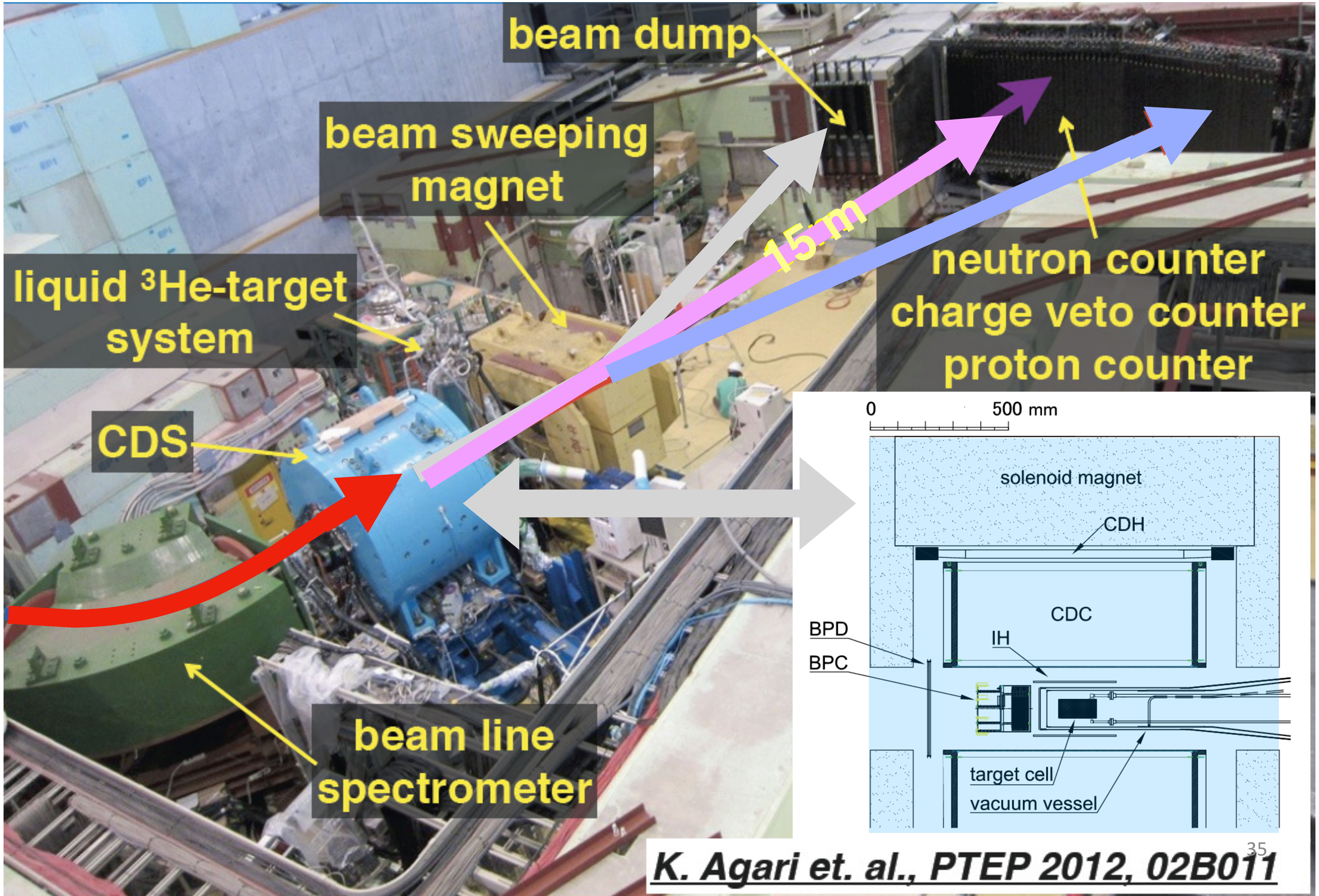
and *momentum transfer q* to the system

provides multi-dimensional kinematical information

Experimental Setup for E15

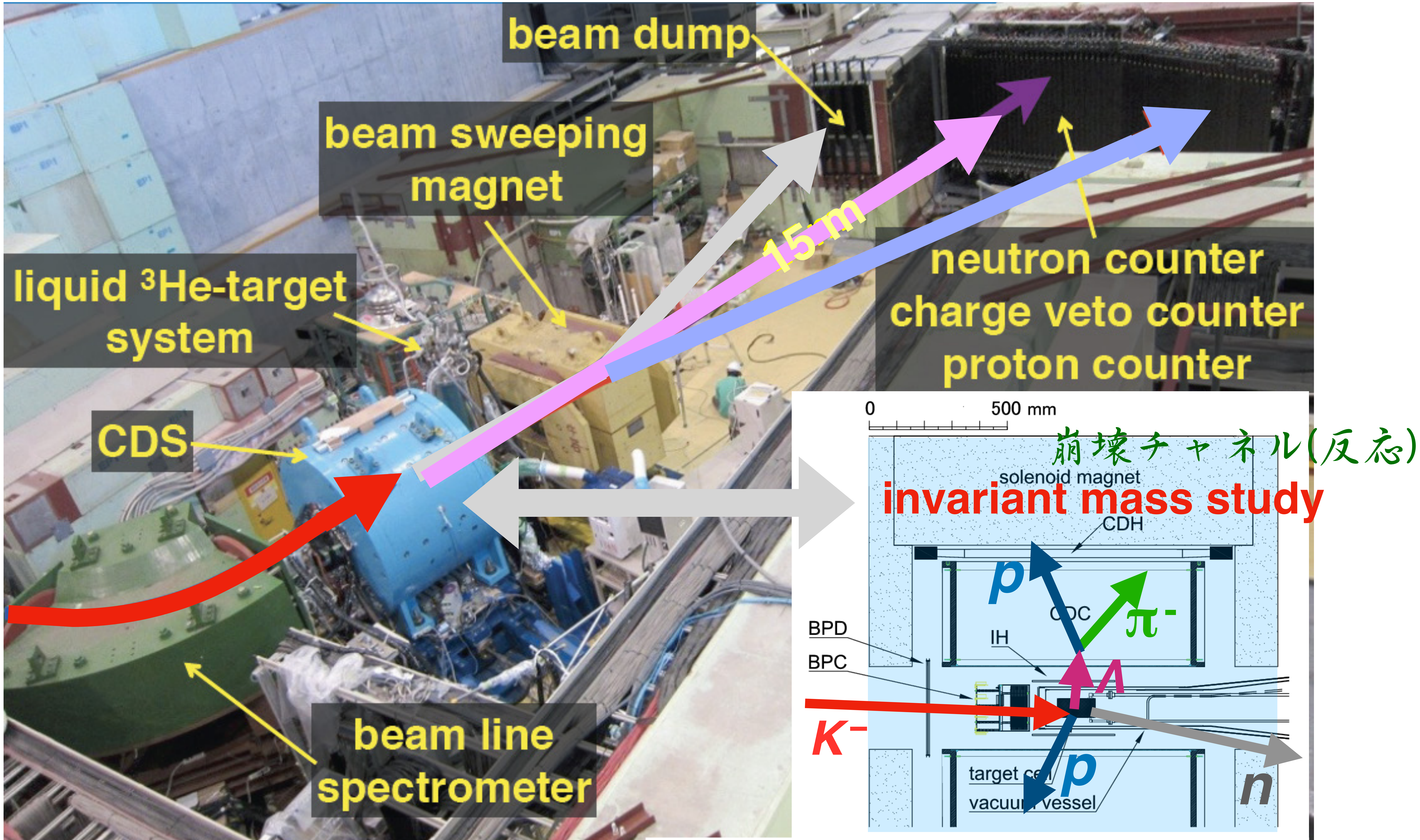


Experimental Setup for E15



K. Agari et. al., PTEP 2012, 02B011

Experimental Setup for E15



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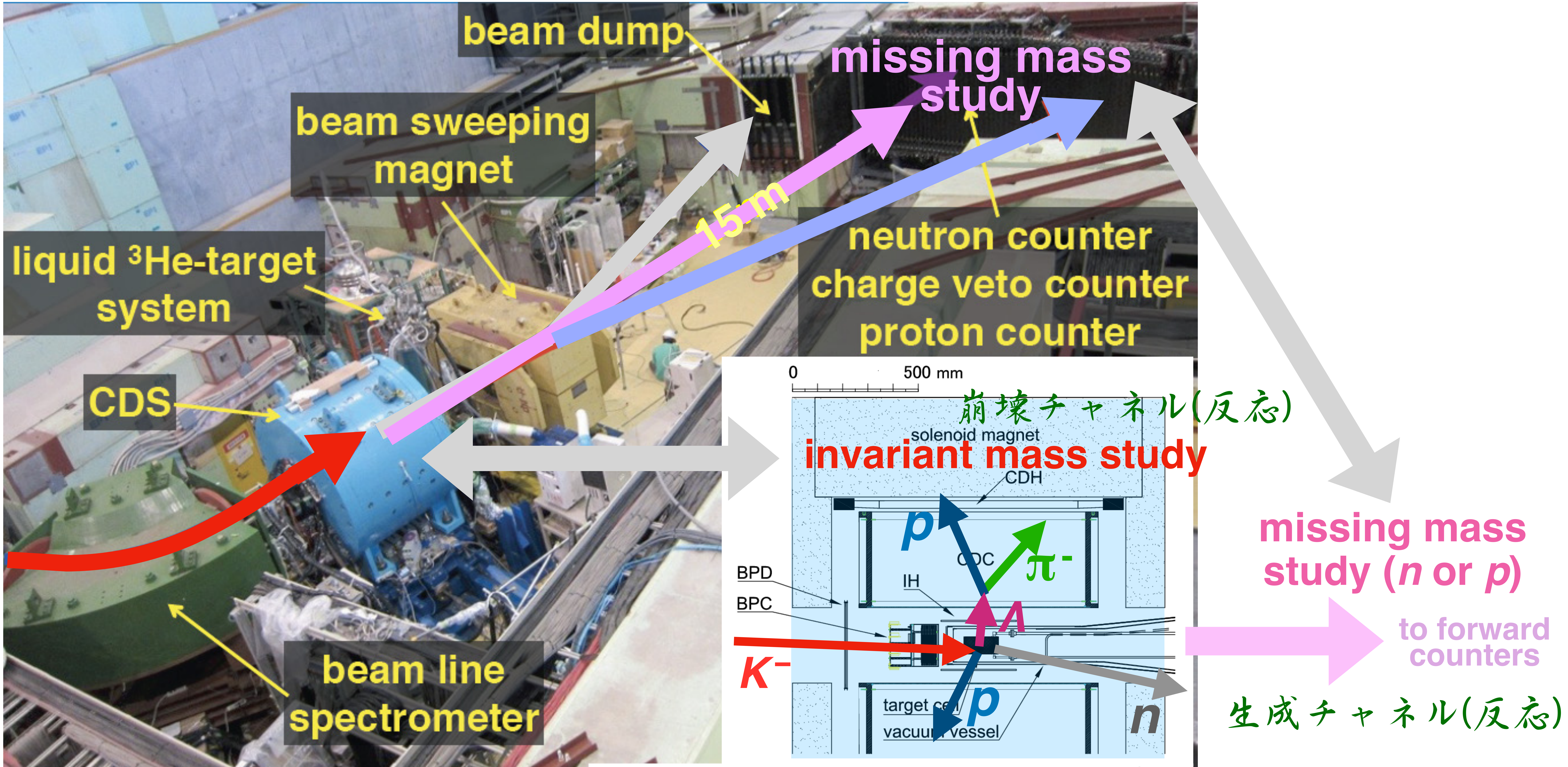
Experimental Setup for E15

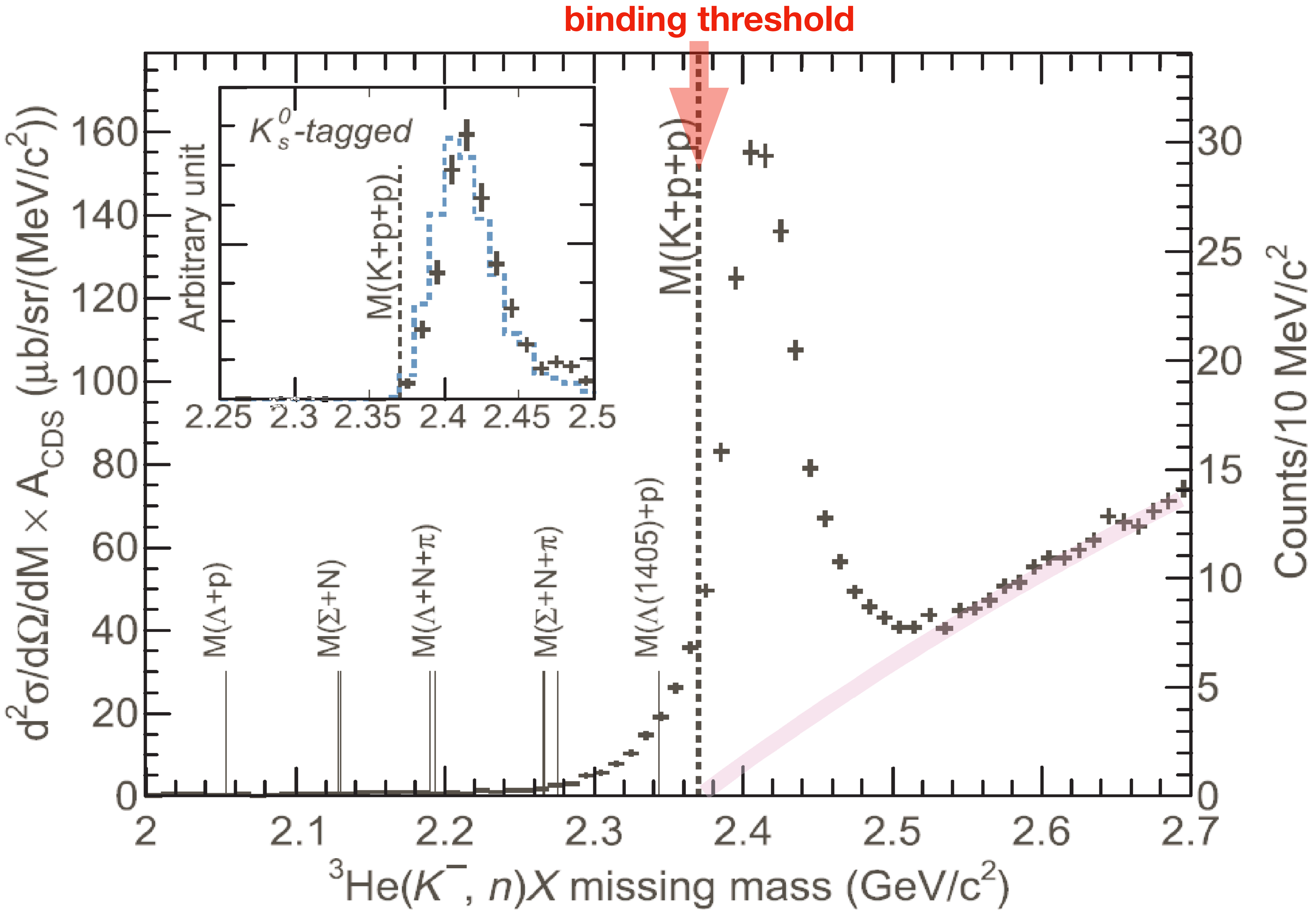


K. Agari et. al., PTEP 2012, 02B011

^{3}He(K$^-$, n$_{NC}$)X — missing mass study

$$K^- + {}^3\mathrm{He} \rightarrow (\bar{K} + NN) + n'$$

K中間子が前方に核子を蹴り出すことで、反跳Kが遅くなり、容易に残核とK束縛状態を作ることが期待される



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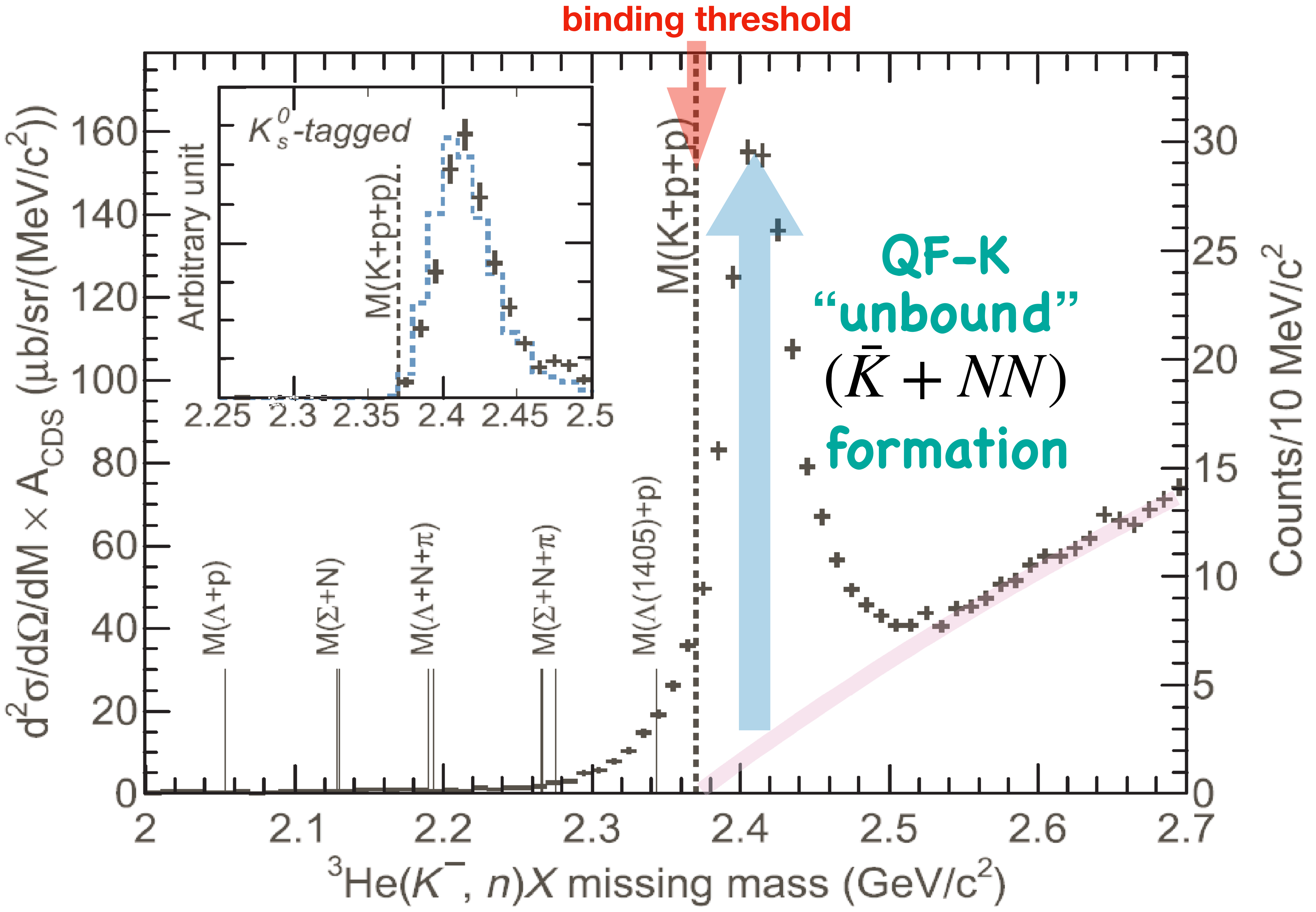
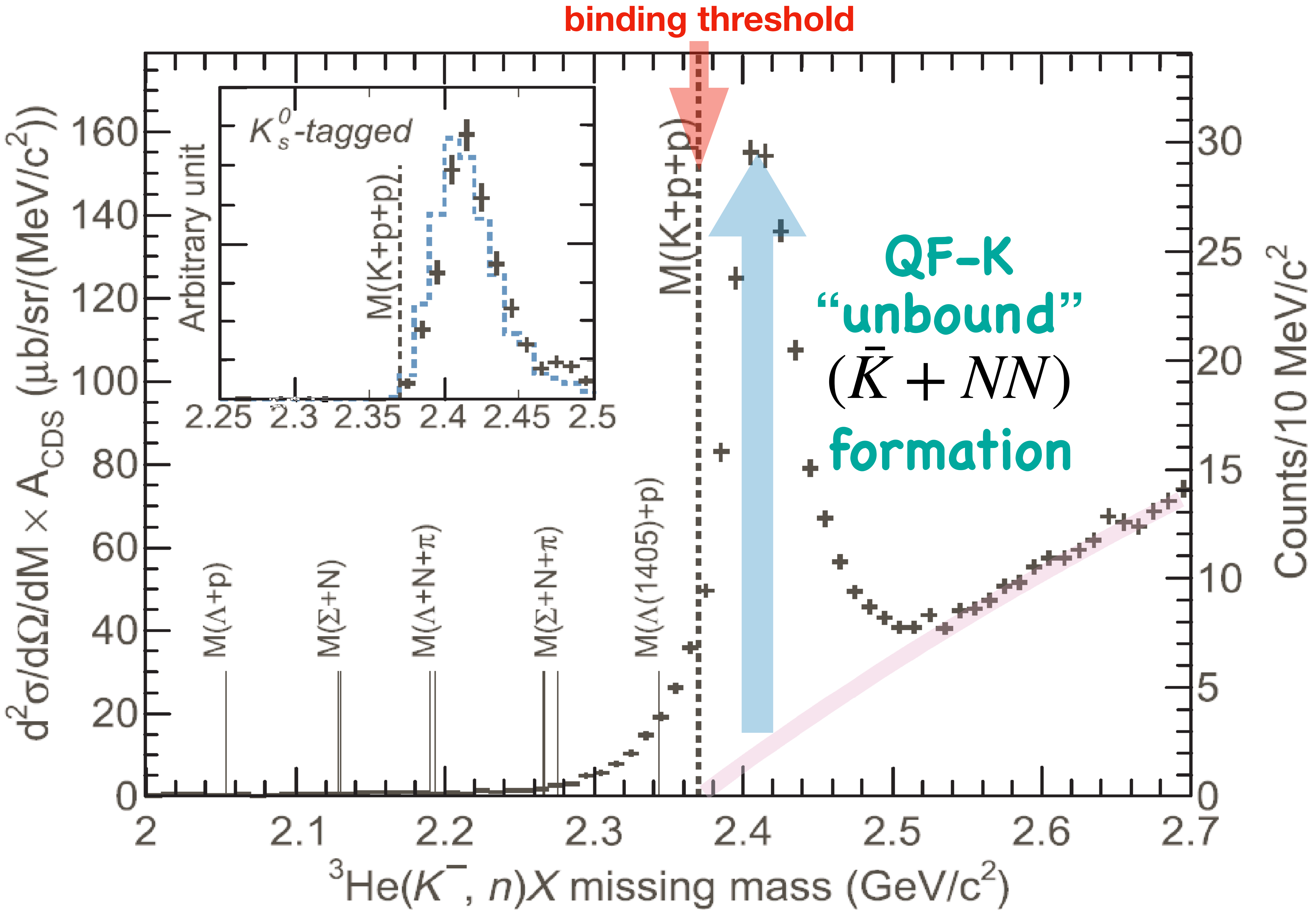


Dominance of nucleon knockout reaction, $K^-N \to \bar{K}n'$, is confirmed as a doorway

^{3}He(K$^-$, n$_{NC}$)X — missing mass study

$$K^- + {}^3\text{He} \rightarrow (\bar{K} + NN) + n'$$

想定通りKN交換反応が主要成分:
K中間子が前方に核子を蹴り出すことで、反跳Kが遅くなり、容易に残核とK束縛状態を作ることが期待される



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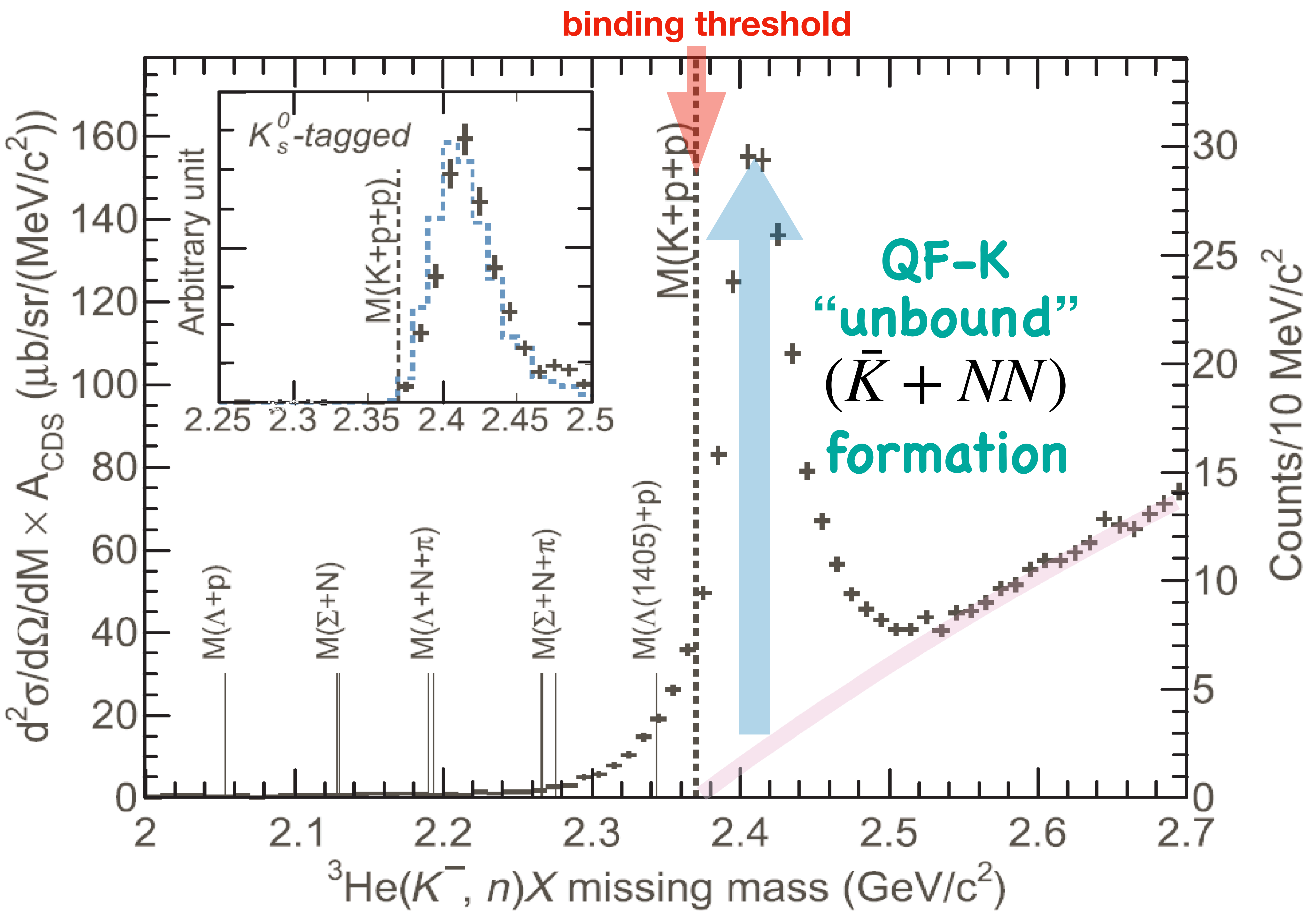

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missing mass spectroscopy is insufficient to isolate K^-pp signal from QF-K leakage

生成チャネルの解析(missing mass)だけでは不十分

Dominance of nucleon knockout reaction, $K^-N \rightarrow \bar{K}n'$, is confirmed as a doorway

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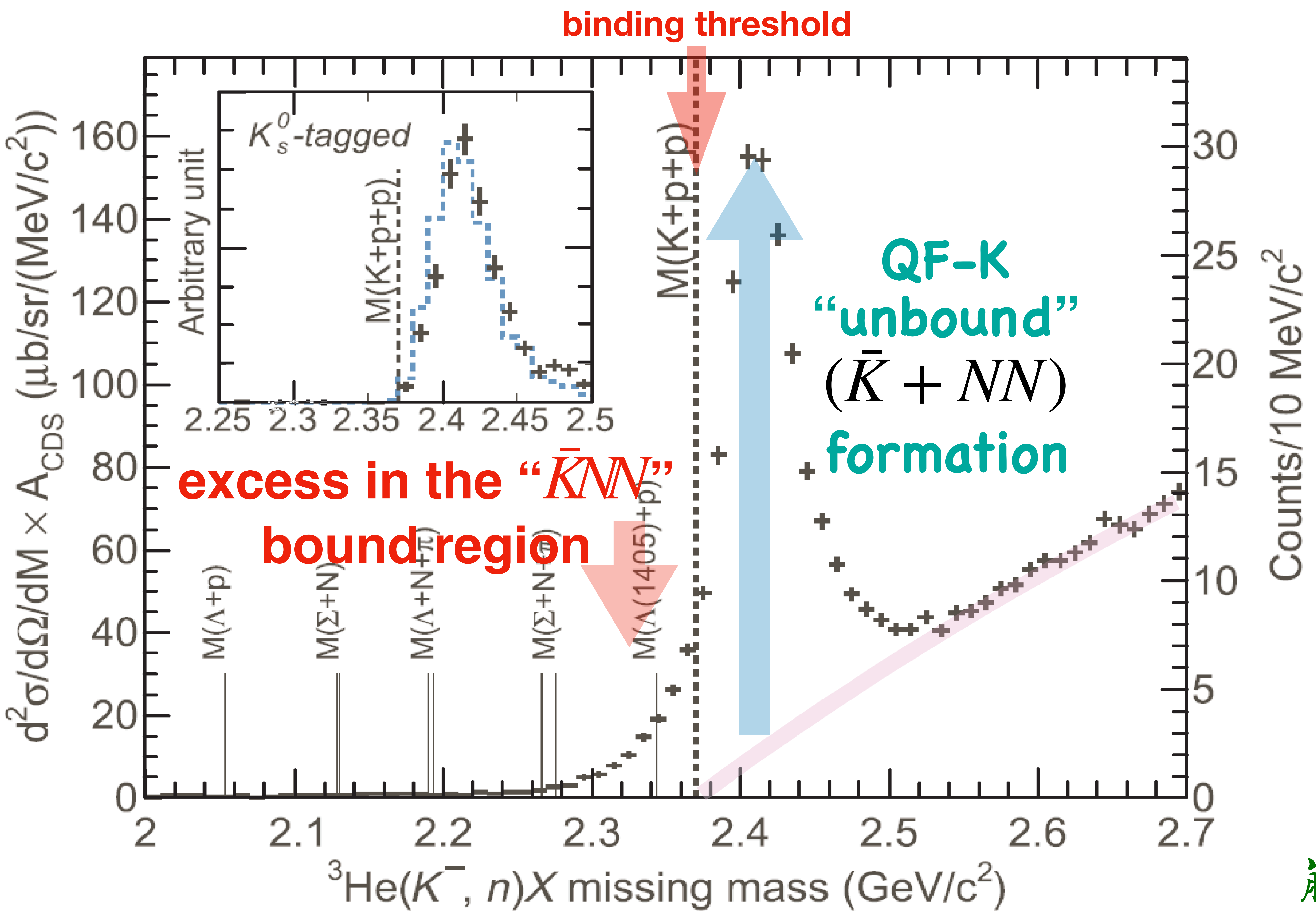

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missing mass spectroscopy is insufficient to isolate K$^-$pp signal from QF-K leakage

生成チャネルの解析 (missing mass) だけでは不十分

How to study the excess?

The ideal decay channel is:

$$\bar{K} + NN \to \Lambda p.$$

Because it is the most simple reaction easy to analyze

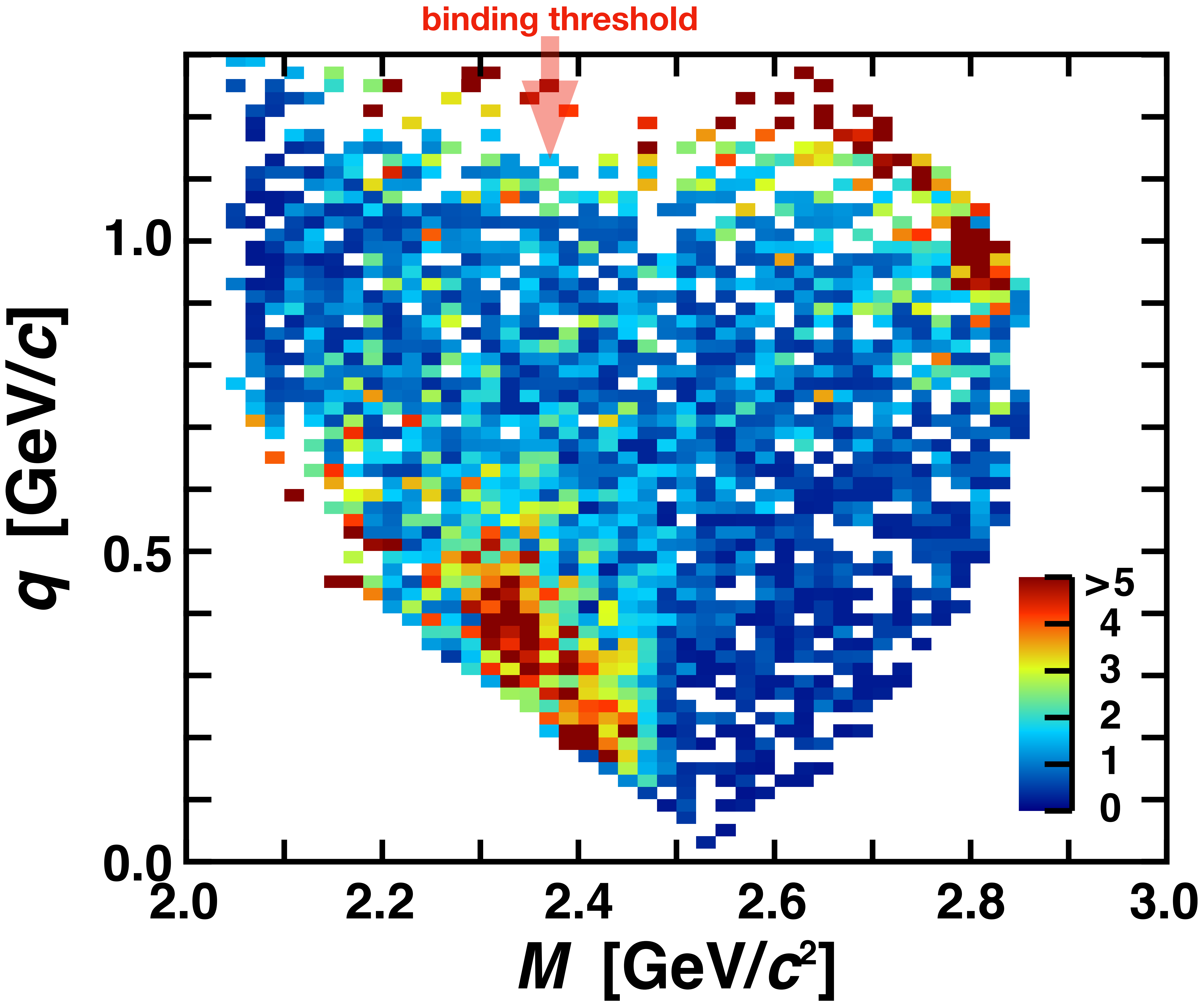
崩壊チャネルの解析 (invariant mass) へ

Dominance of nucleon knockout reaction, $K^-N \to \bar{K}n'$, is confirmed as a doorway

Λp 不変質量解析が示したもの

Λp $+n$ events on (M, q)-plane

Acceptance corrected event distribution on (M, q)



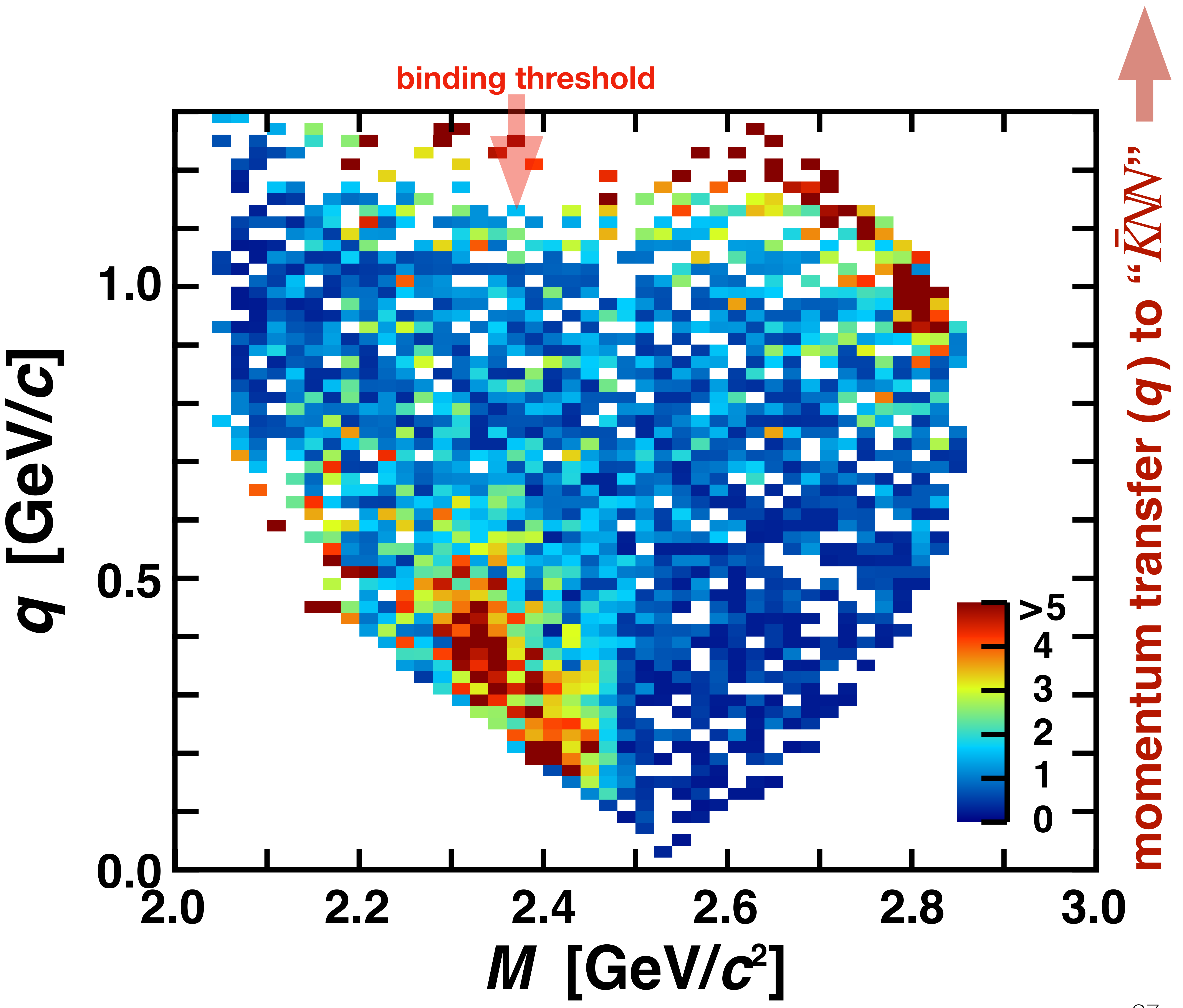
Λp 不変質量解析が示したもの

Λp $+n$ events on (*M*, *q*)-plane

Acceptance corrected event distribution on (M, q)

q-distribution: system size

— sticking probability: high-q capture happens if the system is compact —



Λp $+n$ events on (*M*, *q*)-plane

Λp 不変質量解析が示したもの

Acceptance corrected event distribution on (M, q)

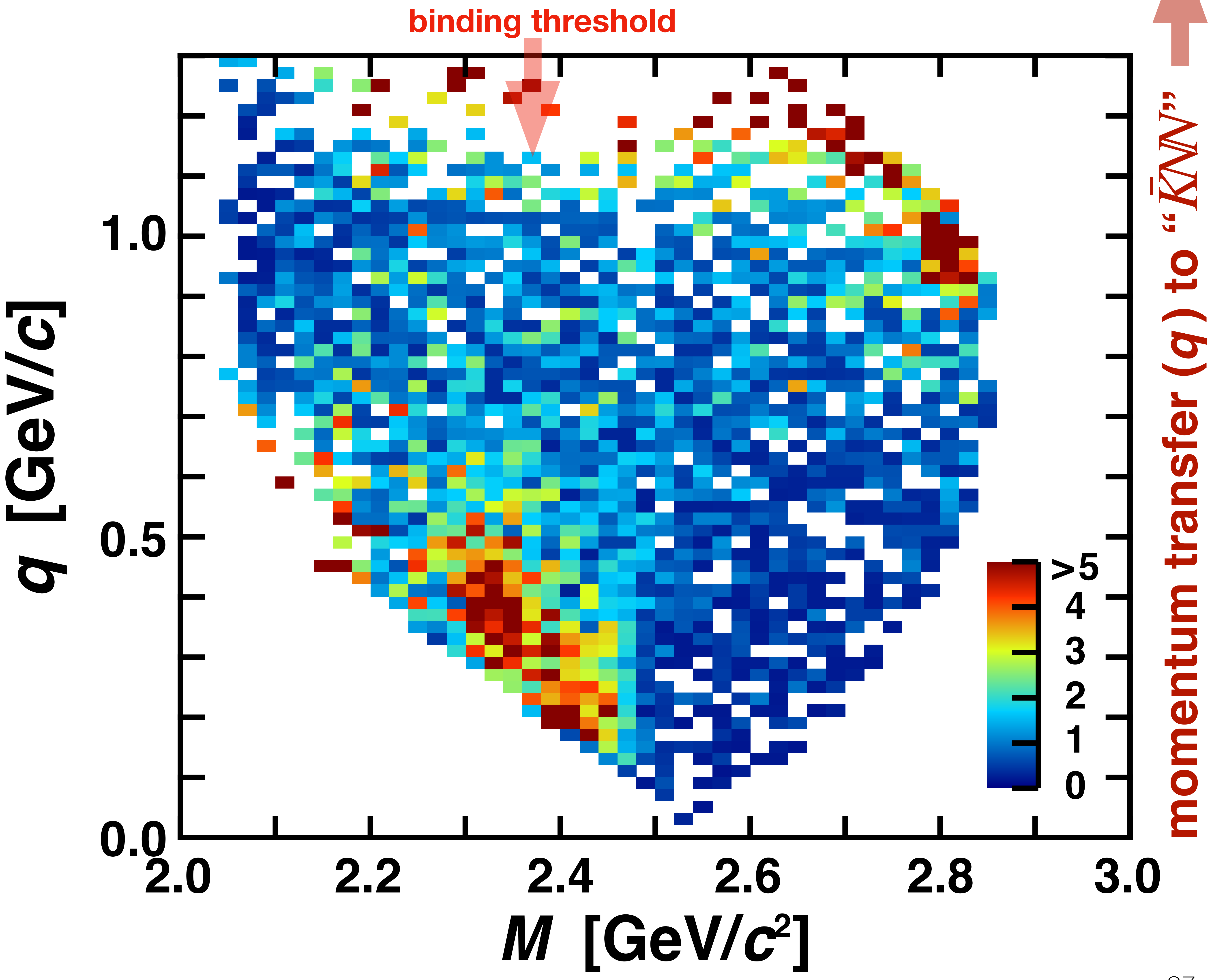
reconstructed "$\bar{K}NN$" mass (*M*)

q-distribution: system size

— sticking probability: high-q capture happens if the system is compact —

M-distribution: binding energy & absorption width

—both information gives $\bar{K}N$ interaction strength —



Λp 不変質量解析が示したもの

Λp $+n$ events on (*M*, *q*)-plane

Acceptance corrected event distribution on (M, q)

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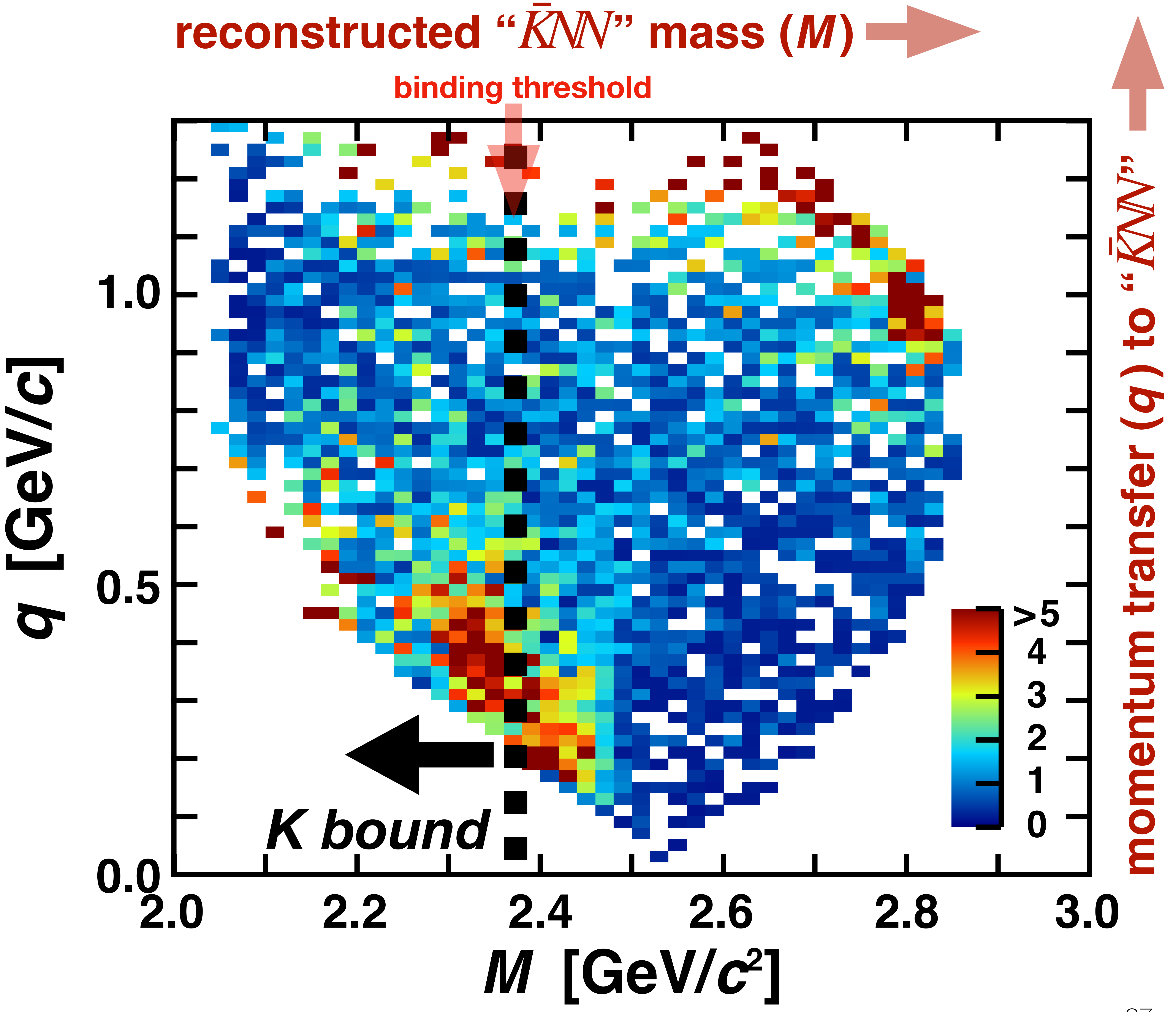


Λp 不変質量解析が示したもの

Λp $+n$ events on (*M, q*)-plane

Acceptance corrected event distribution on (M, q)

q-distribution: system size

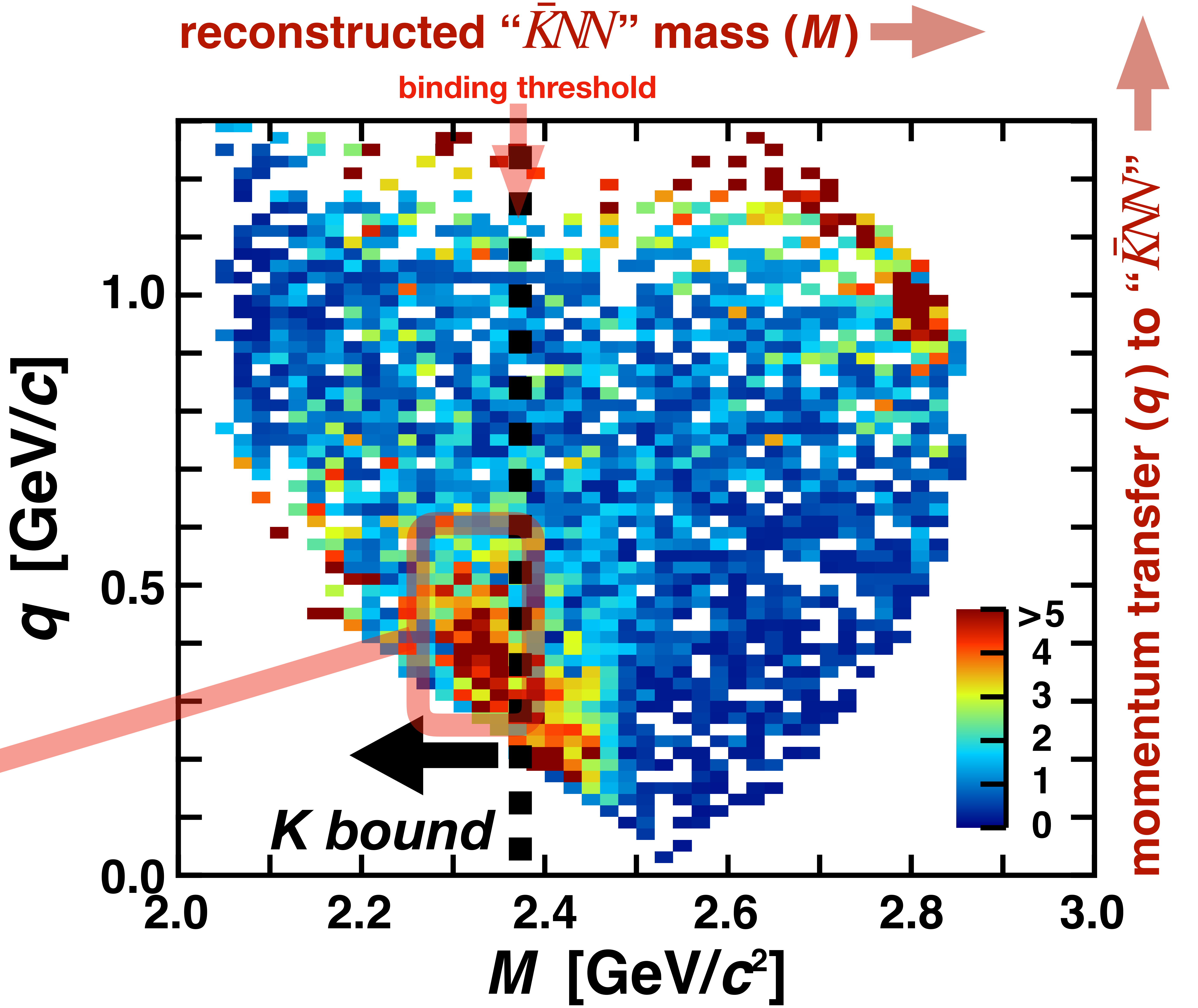
— sticking probability: high-*q* capture happens if the system is compact —

M-distribution: binding energy & absorption width

— both information gives $\bar{K}N$ interaction strength —

The K⁻pp signal is clearly seen on (M, q)-plane!

— relatively deep and wide, and extended to high-*q* region —

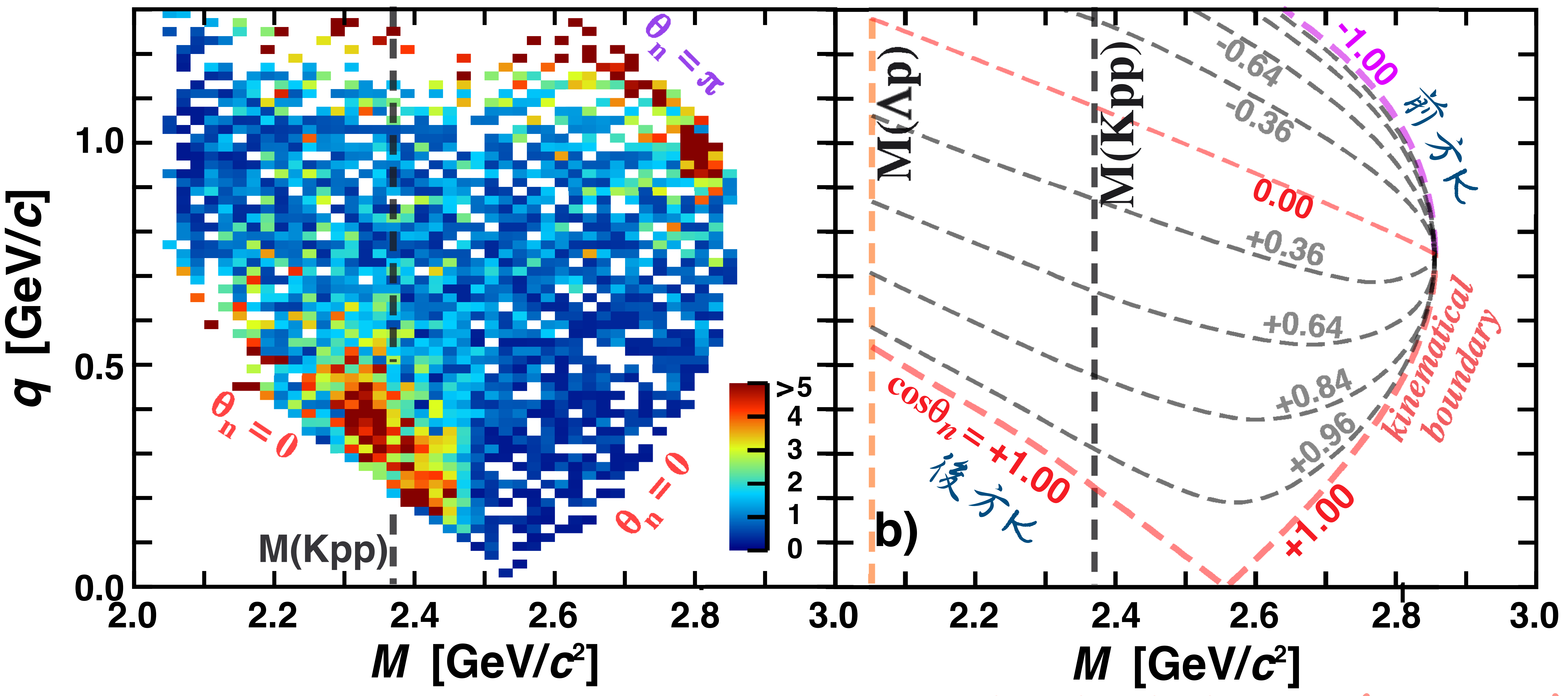


M & *q* defines kinematics ⟷ (or *M* & θ_n) 運動量移行qと反跳角度θの関係

$K^- + {}^3He \rightarrow$ "K^-pp" + n

$$\tan\theta_n^{Lab.} = \frac{-q\sin\theta}{p_K - q\cos\theta}$$

$$\begin{pmatrix}\sqrt{m_K^2+p_K^2}\\ p_K\\ 0\end{pmatrix} + \begin{pmatrix}M_{^3\mathrm{He}}\\ 0\\ 0\end{pmatrix} = \begin{pmatrix}\sqrt{M^2+q^2}\\ q\cos\theta\\ q\sin\theta\end{pmatrix} + \begin{pmatrix}\sqrt{m_n^2+p_K^2-2p_K q\cos\theta+q^2}\\ p_K-q\cos\theta\\ -q\sin\theta\end{pmatrix}$$



cosθn in Fig. is in CM (K⁻ + ³He)

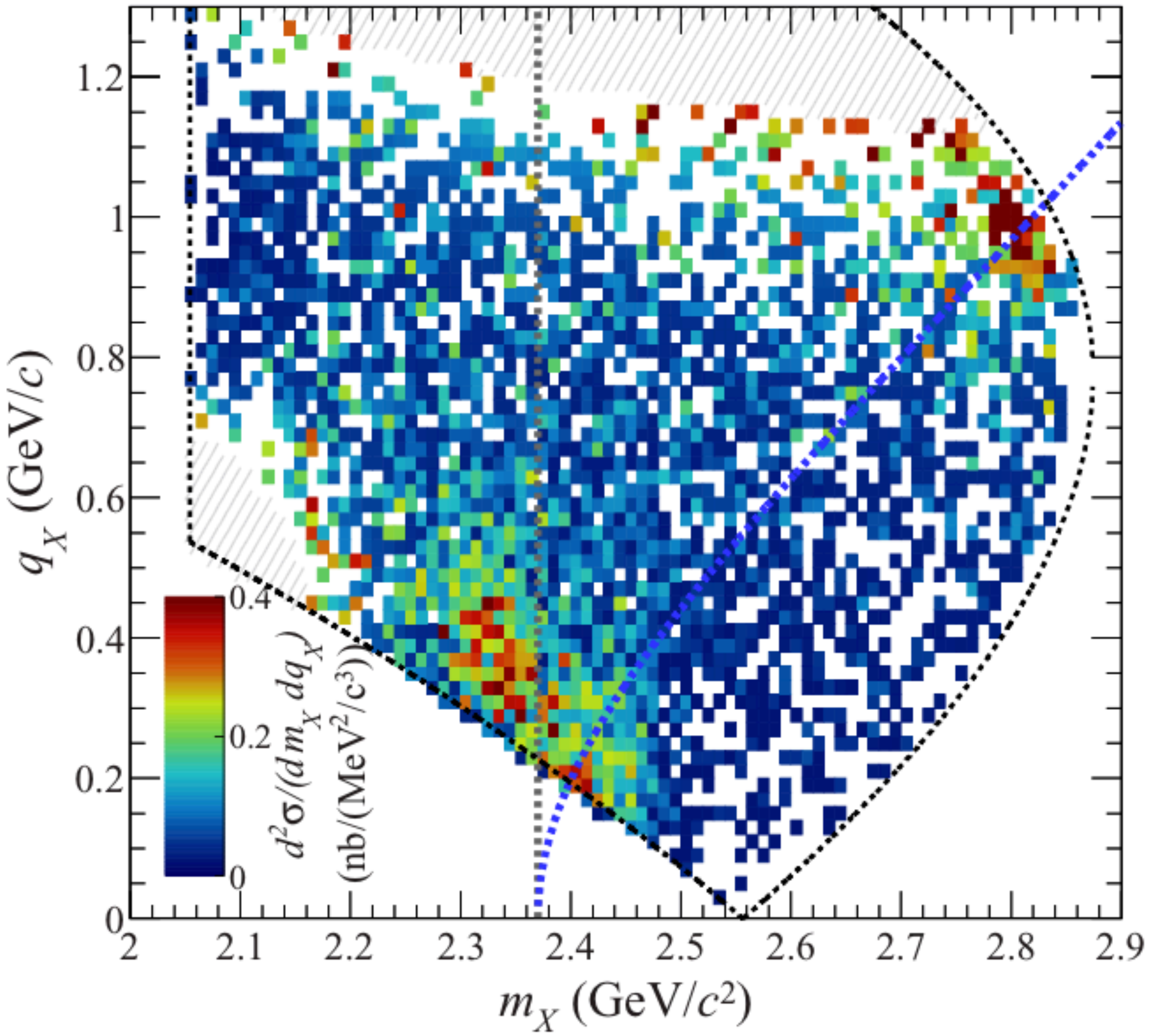
$\Lambda p + n_{miss}$

model fitting function in (m, q)-plane

フィット関数

ρ : Lorentz-invariant phase-space

$$f_{\bar{K}NN}(m,q) \times \rho_{\{\Lambda pn\}}(m,q) \qquad f_{QF\text{-}\bar{K}}(m,q) \times \rho_{\{\Lambda pn\}}(m,q)$$



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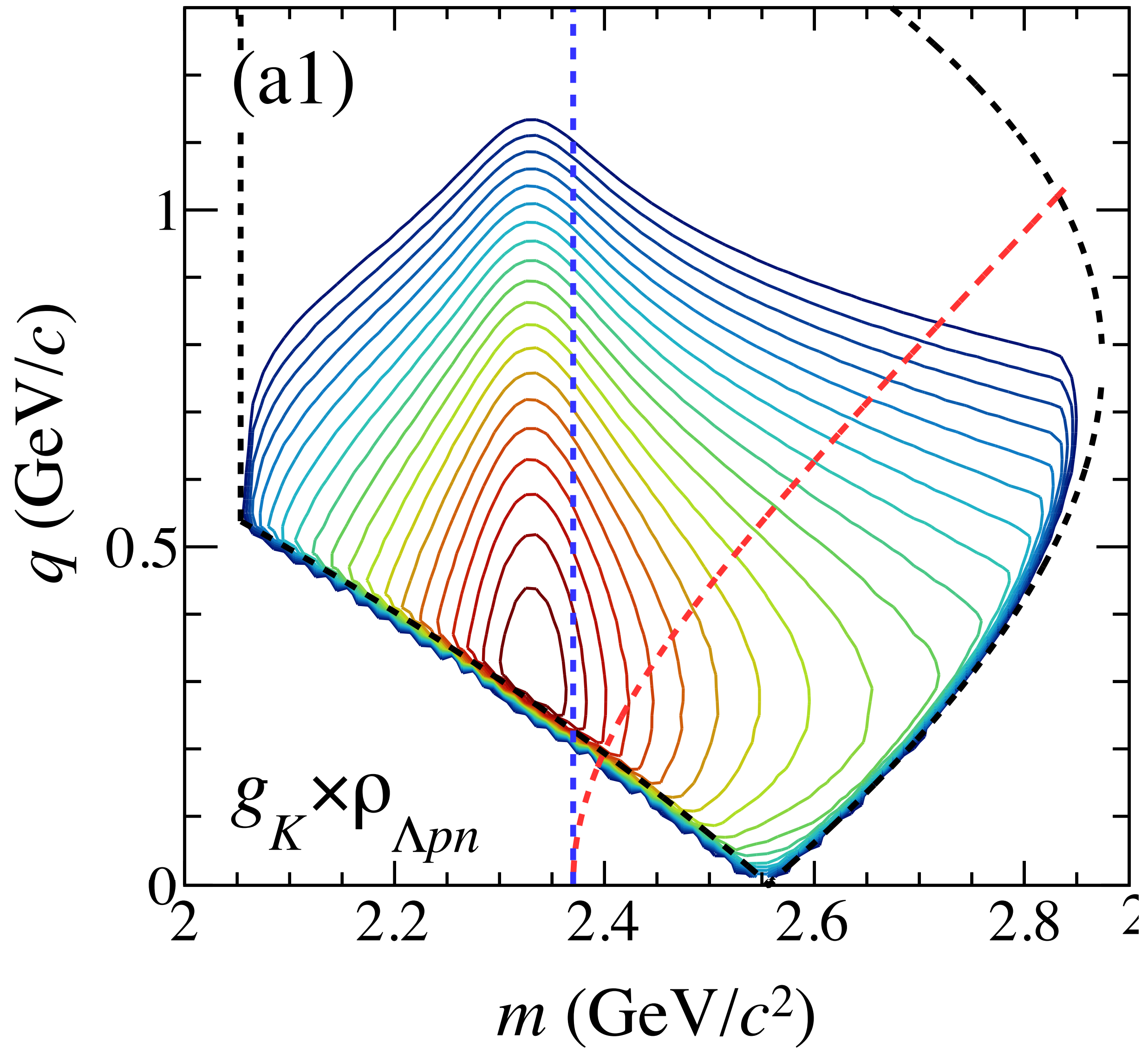
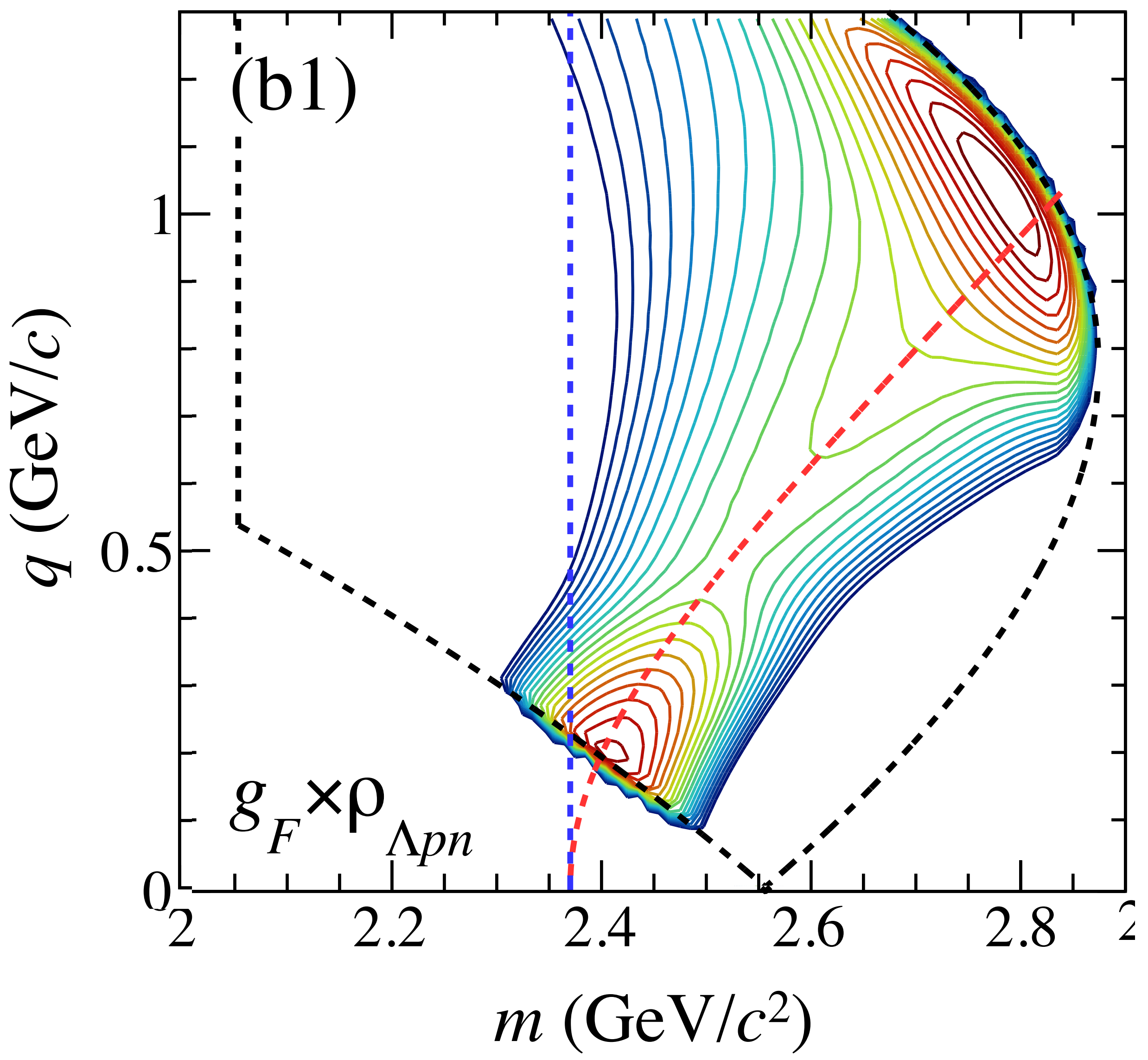
$\bar{K}NN$ production



+

QF-$\bar{K}$ absorption



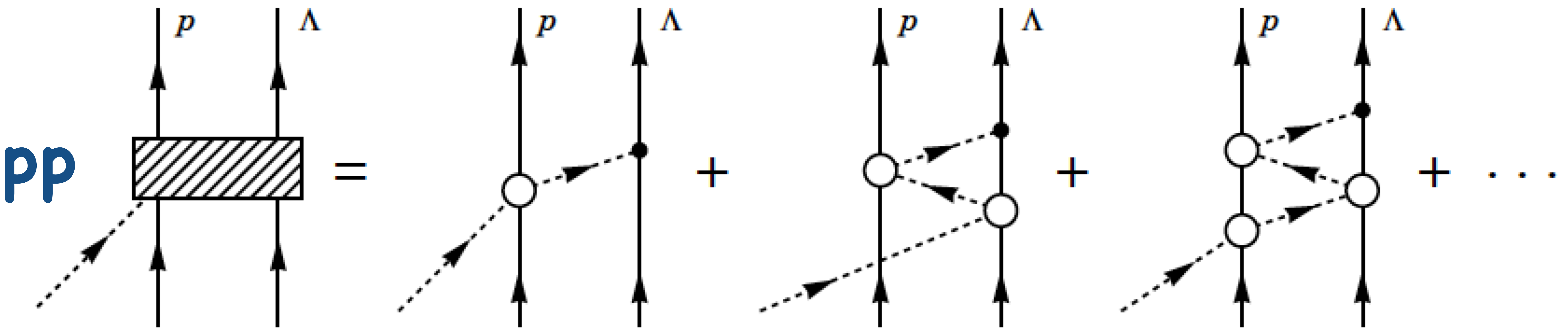
$f_{\bar{K}NN}(m,q)$: $B.W.(m) \times$ *form factor*(q)

$f_{QF\text{-}\bar{K}}(m,q)$: *quasi-free (on mass-shell) K abs.*

Λp + $n_{mis.}$ vs. theory

Structure in E15[1st] can be explained with quasi-free K absorption ($QF_{\bar{K}A}$) & Kpp @ χ-UM?

Kpp



Sekihara Oset Ramos

PTEP

Prog. Theor. Exp. Phys. 2016, 123D03 (27 pages)
DOI: 10.1093/ptep/ptw166

On the structure observed in the in-flight ^{3}He(K^-, Λp)n reaction at J-PARC

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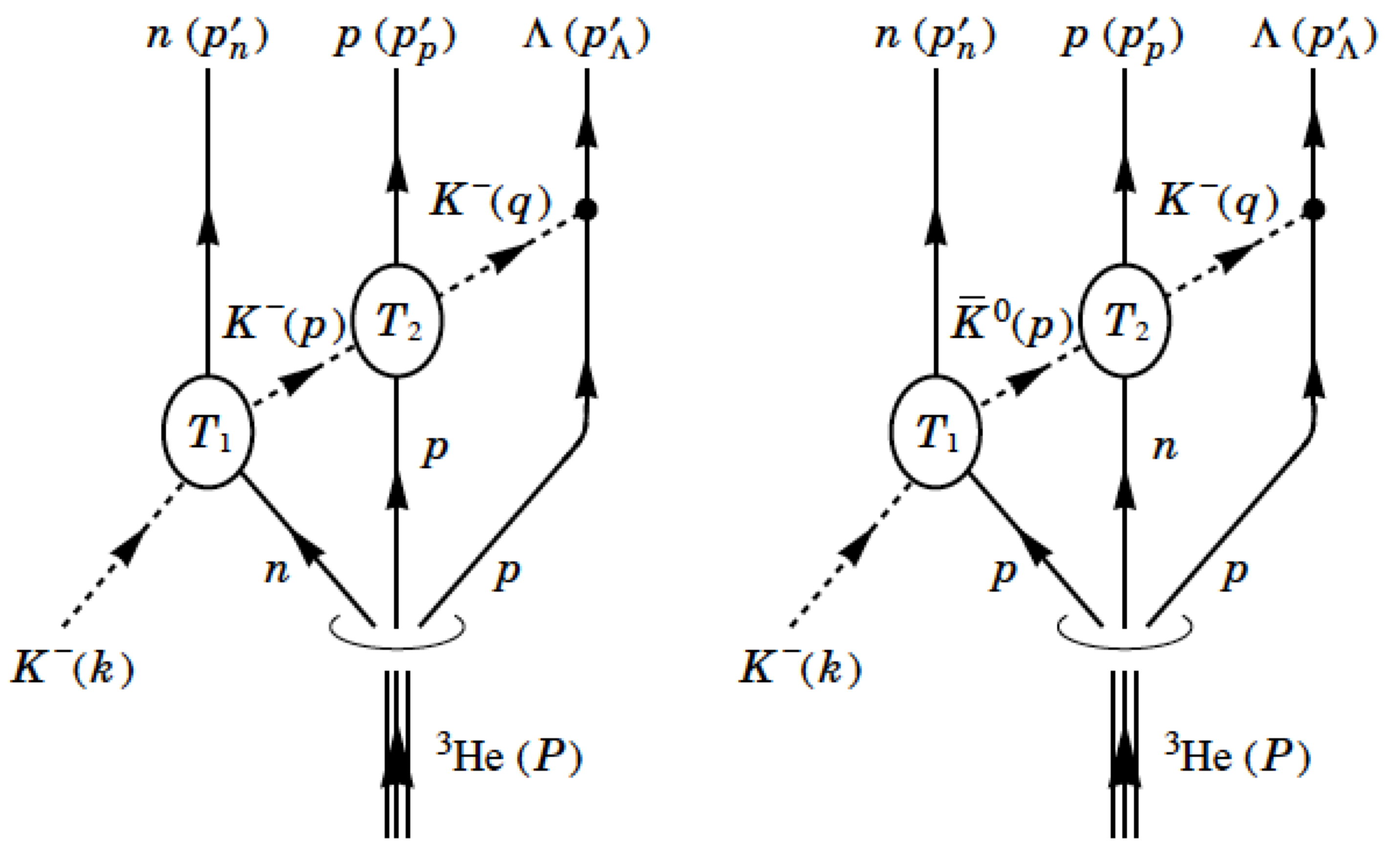


$QF_{\bar{K}A}$

PWIA based interpretation

(plane wave impulse approximation)

— from time integral —

B.W. / Lorentzian

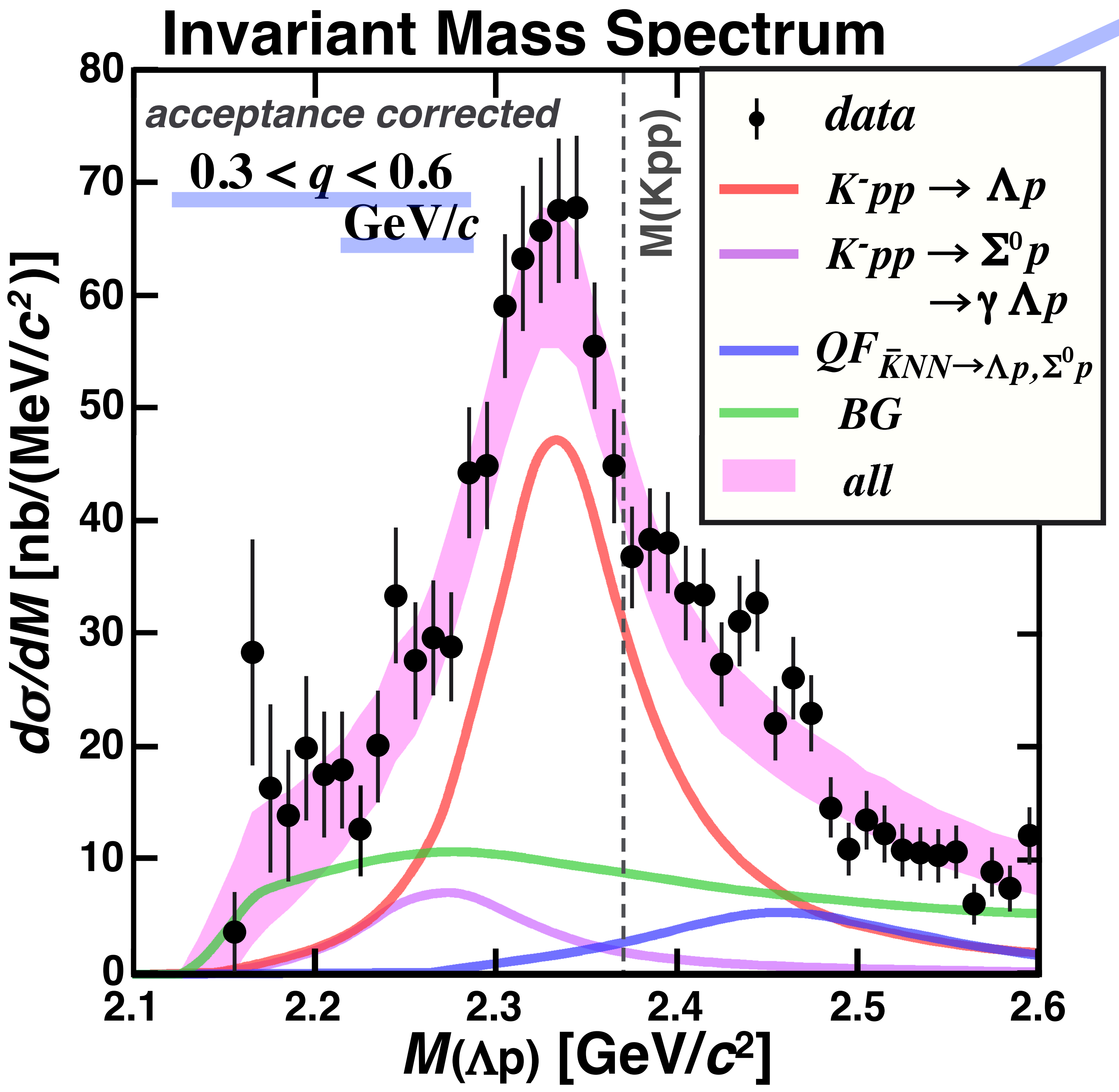
form factor / structure factor

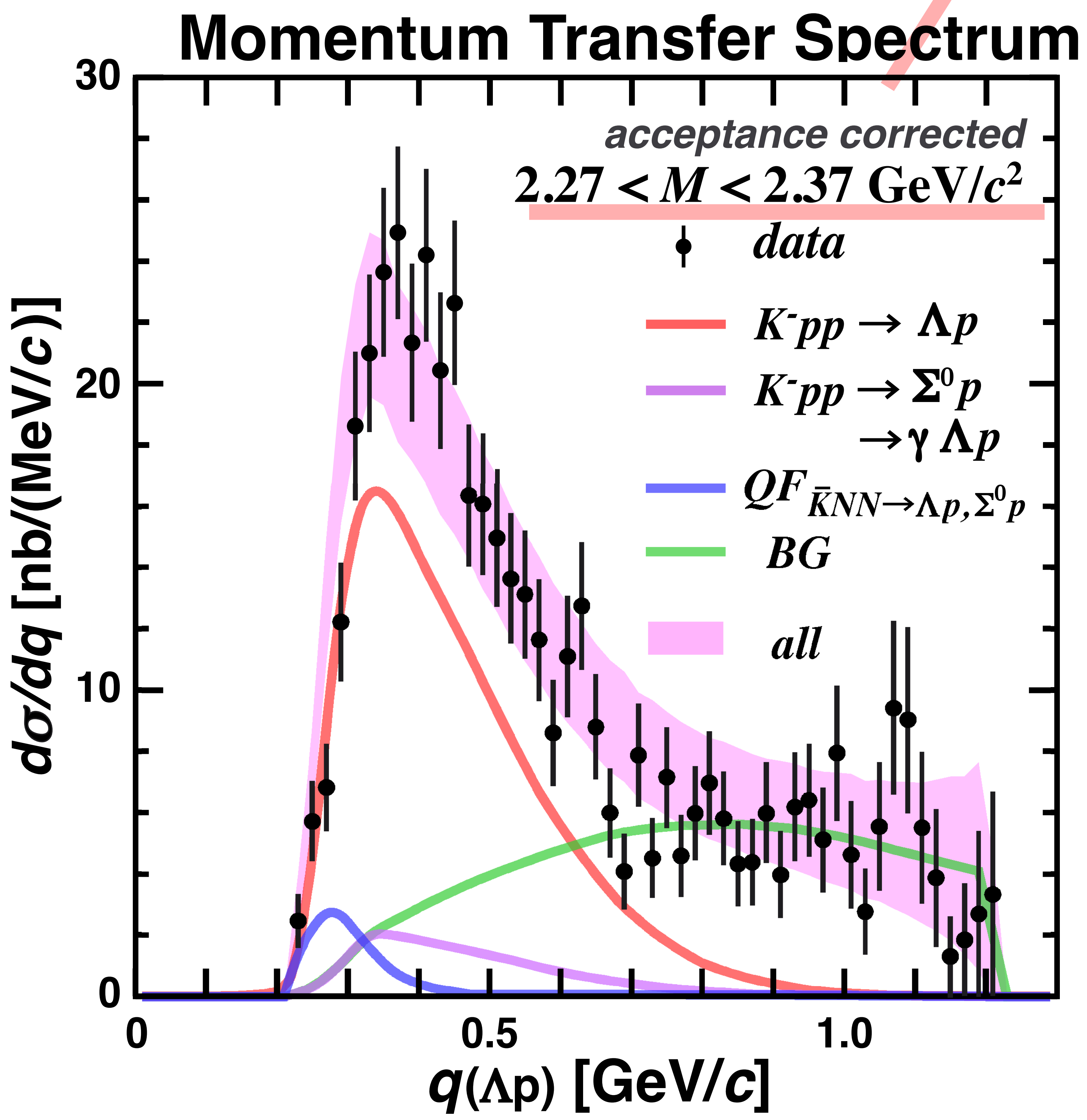
$$\sigma\,(M,\,q) \propto \rho_{3B}(M,q) \times \frac{(\Gamma_{Kpp}/2)^2}{(M - M_{Kpp})^2 + (\Gamma_{Kpp}/2)^2} \times \exp\left(-\frac{q^2}{Q^2_{Kpp}}\right)$$

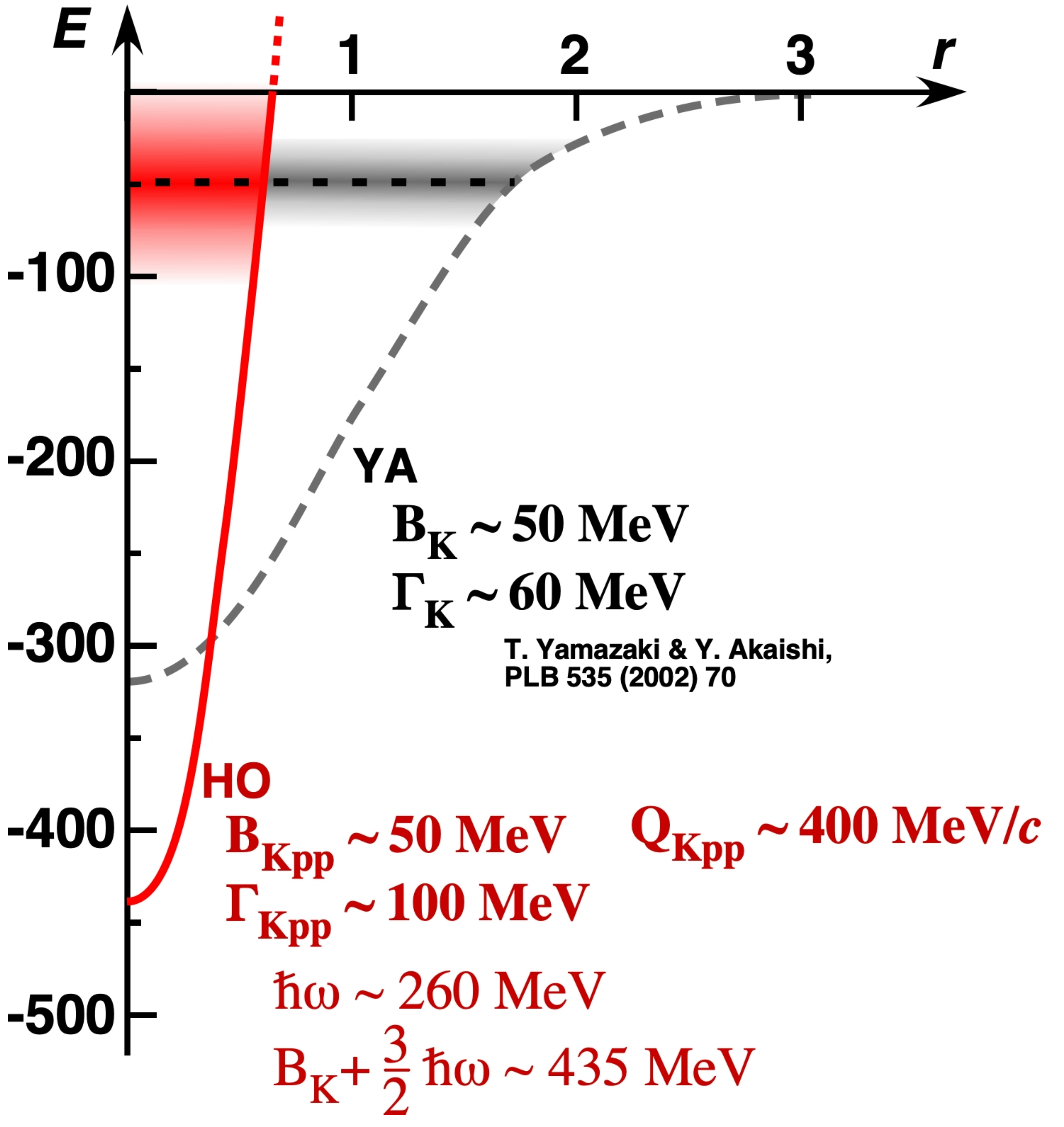
Differential cross section

Lorentz invariant phase space (Λpn)

Fourier Transformation of S-wave Harmonic Oscillator (HO) — from spatial integral —







strong binding ($\bar{K}$N attraction)

$B_{Kpp} \sim 40$ MeV, $\Gamma_{Kpp} \sim 100$MeV

wide momentum width

$Q_{Kpp} \sim 400$ MeV/c

… could be quite compact …

($R_{Kpp} \sim 0.6$ fm (H.O.)) コンパクト？

E15 result

Succeeded in Observing First Clear "K^- pp" Signal

Strong binding ($\bar{K}N$ attraction)

Large width (very unstable)

Large Q (could be very compact)

K中間子核探査研究の最近のレビュー

https://doi.org/10.1007/978-981-15-8818-1_37-1

The detail can be found:

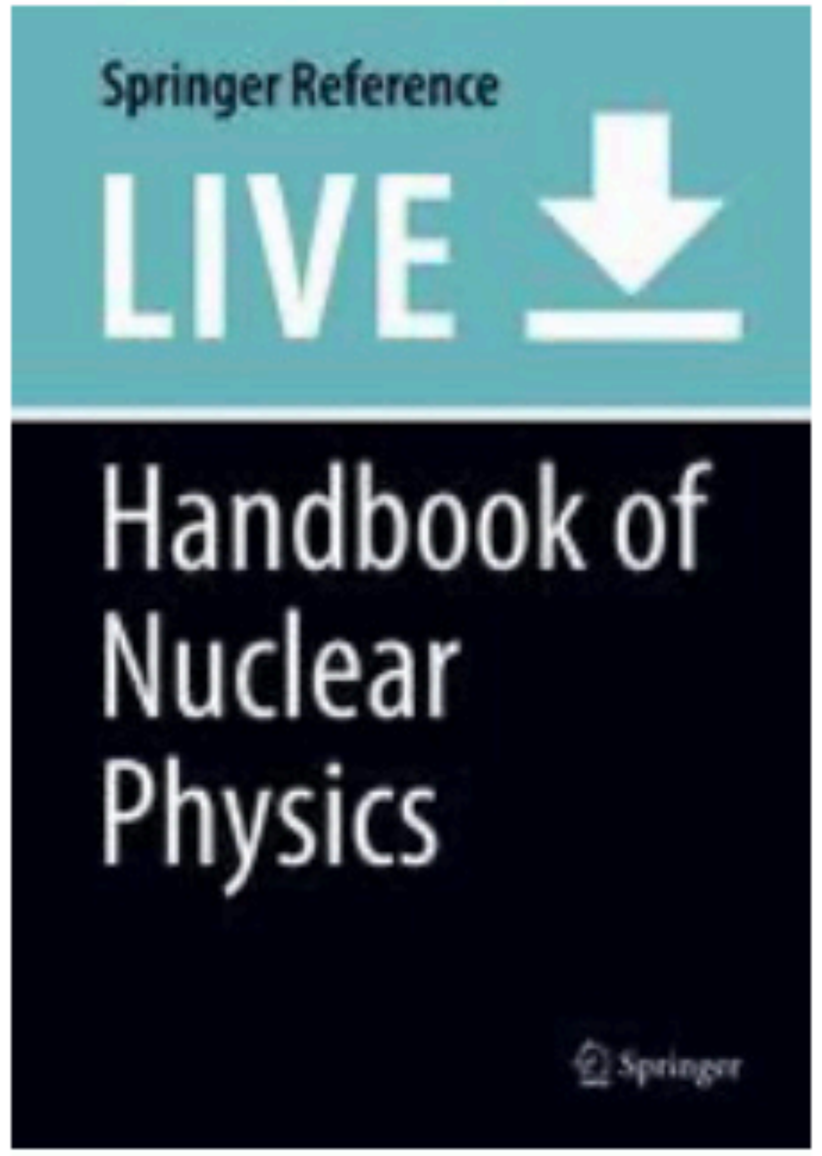
— in a review —

$\bar{K}N$ interaction study via kaonic atom

Search for $\bar{K}NN$ nuclear bound state as a natural extension of $\Lambda(1405) \equiv \bar{K}N$

Recent results on $\bar{K}$ bound state

Future direction of $\bar{K}$ (ϕ) bound state study



Kaonic Nuclei from the Experimental Viewpoint

Research on kaonic nuclear bound states is a completely new field. This nuclear system consists of

補足: PWIAでの形状(構造)因子計算

$\bar{K}N \rightarrow$ Y*(~1700) $\rightarrow \bar{K}N$

$$f(\mathbf{p}_K, \mathbf{p}_n) \propto \langle f|\, V\, |i\rangle + \langle f|\, V \frac{1}{E - H_0 + i\epsilon} V\, |i\rangle + \ldots$$

$\bar{K}N_sN_s \rightarrow$ "K-pp" S-wave resonance?

$$f_0(\mathbf{p}_K, \mathbf{p}_n) \propto \left\langle \exp\left(-i\frac{\mathbf{p}_n \cdot \mathbf{x}'}{\hbar}\right) \exp\left(-\frac{\mathbf{x}'^2}{2{R_{Kpp}}^2}\right) \middle| V \middle| \exp\left(i\frac{\mathbf{p}_K \cdot \mathbf{x}}{\hbar}\right) \exp\left(-\frac{\mathbf{x}^2}{2{R_{He}}^2}\right) \right\rangle$$

$$\frac{V_0}{4\pi}\delta(\mathbf{x}' - \mathbf{x})$$ PWIA

$$\propto \frac{V_0}{4\pi} \int d^3x \exp\left(-i\frac{(\mathbf{p}_K - \mathbf{p}_n)\cdot \mathbf{x}}{\hbar}\right) \exp\left(-\left(\frac{1}{{R_{Kpp}}^2} + \frac{1}{{R_{He}}^2}\right)\frac{\mathbf{x}^2}{2}\right)$$

$$= \frac{V_0}{4\pi} \int d^3x \exp(i\,\mathbf{k}\cdot\mathbf{x}) \exp\left(-\frac{\mathbf{x}^2}{2R^2}\right), \qquad R = R_{Kpp}\left(1 + \left(\frac{R_{Kpp}}{R_{He}}\right)^2\right)^{-1/2}$$

$$= \sqrt{\frac{\pi}{2}} V_0 R^3 \exp\left(-\frac{R^2k^2}{2}\right)$$

運動量の広がりはサイズの逆数

$$\frac{d\sigma_0}{d\Omega} \propto |f_0(q)|^2 \propto \exp\left(-\frac{R^2q^2}{\hbar^2}\right) = \exp\left(-\frac{q^2}{Q^2}\right), \qquad Q = \frac{\hbar}{R}$$

$\bar{K}NN$のπ中間子放出を伴う崩壊

π中間子放出を伴う崩壊チャネル分岐比は？

Mesonic decay branch of $\bar{K}NN$?

核子密度の2乗に比例? vs. 核子密度の1乗に比例?

for example:

$K^- + {}^3He \rightarrow (K^- + pp) + n$ vs. $K^- + {}^3He \rightarrow ((K^- + n)p) + p$

$(K^- + pp) \rightarrow \Lambda + p$ $((\pi^- \Lambda) + p) \rightarrow \pi^- \Lambda + p$

— will be sensitive to the internal structure (compactness) of $\bar{K}NN$.

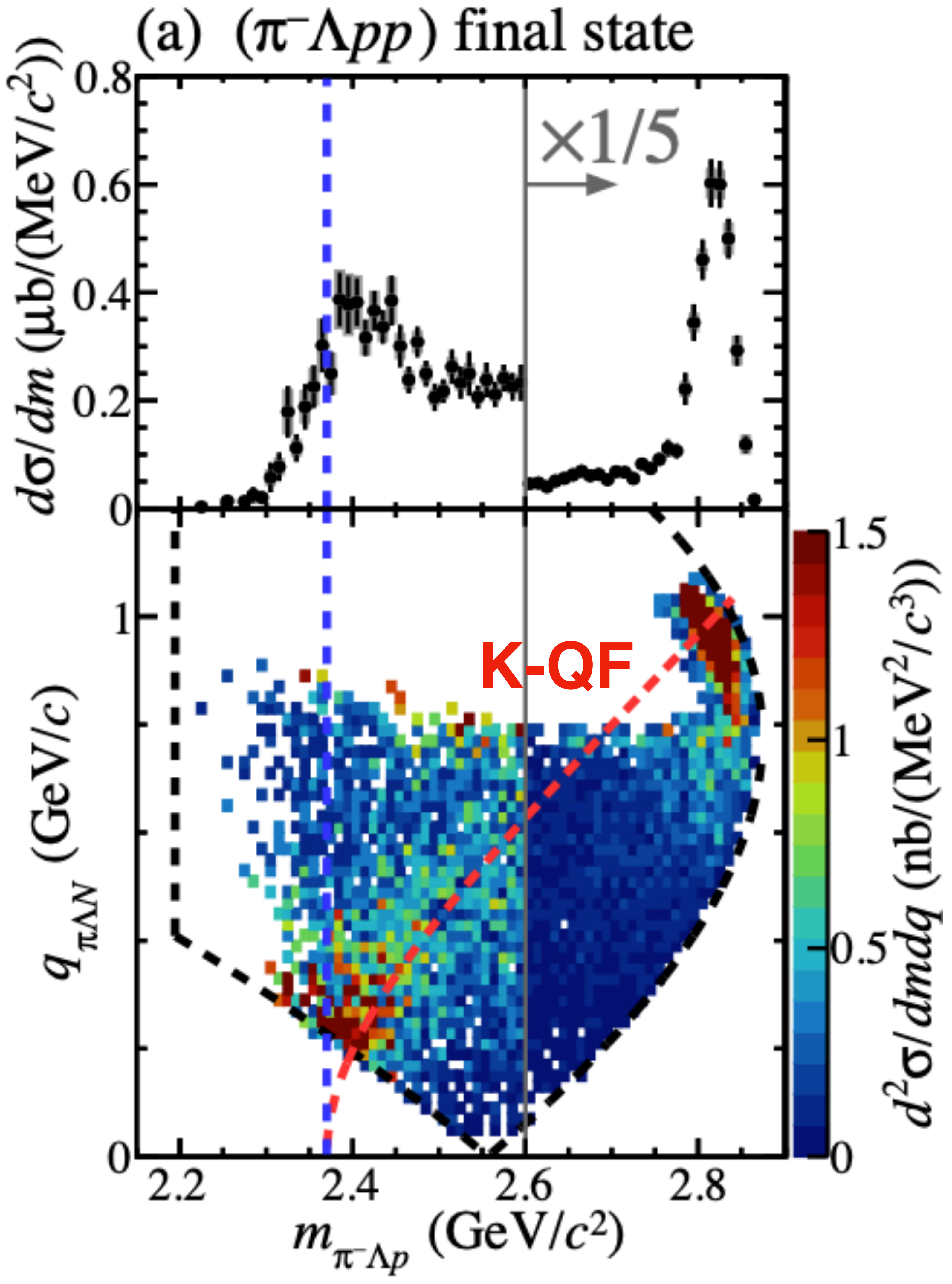
— will be sensitive to the isospin partner of $\bar{K}NN$.

$((K^- + n)p) \equiv (\bar{K}^0 + nn)$

$\bar{K}NN$ isospin partner: $K^- pp \leftrightarrow \bar{K}^0 nn$ — 鏡像核の存在は必須!

… done by T.Yamaga

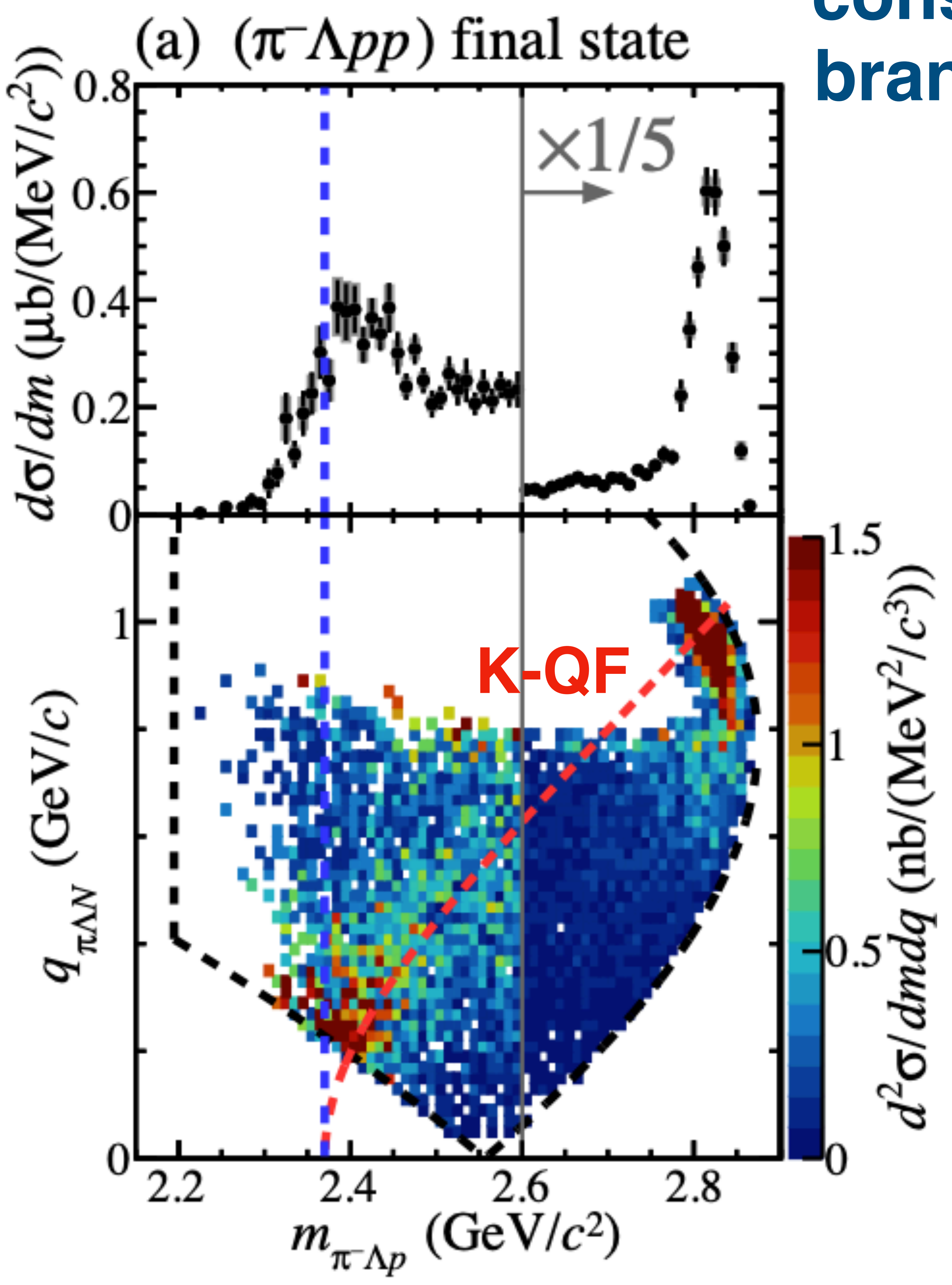
$K^- + {}^3He \rightarrow \pi^-\Lambda pp$ reaction



… *analyzed by T. Yamaga*

$K^- + {}^3He \rightarrow \pi^-\Lambda pp$ reaction

consistent with $K^- + {}^3He \rightarrow \Lambda pn$ reaction
branch seems to be oder bigger



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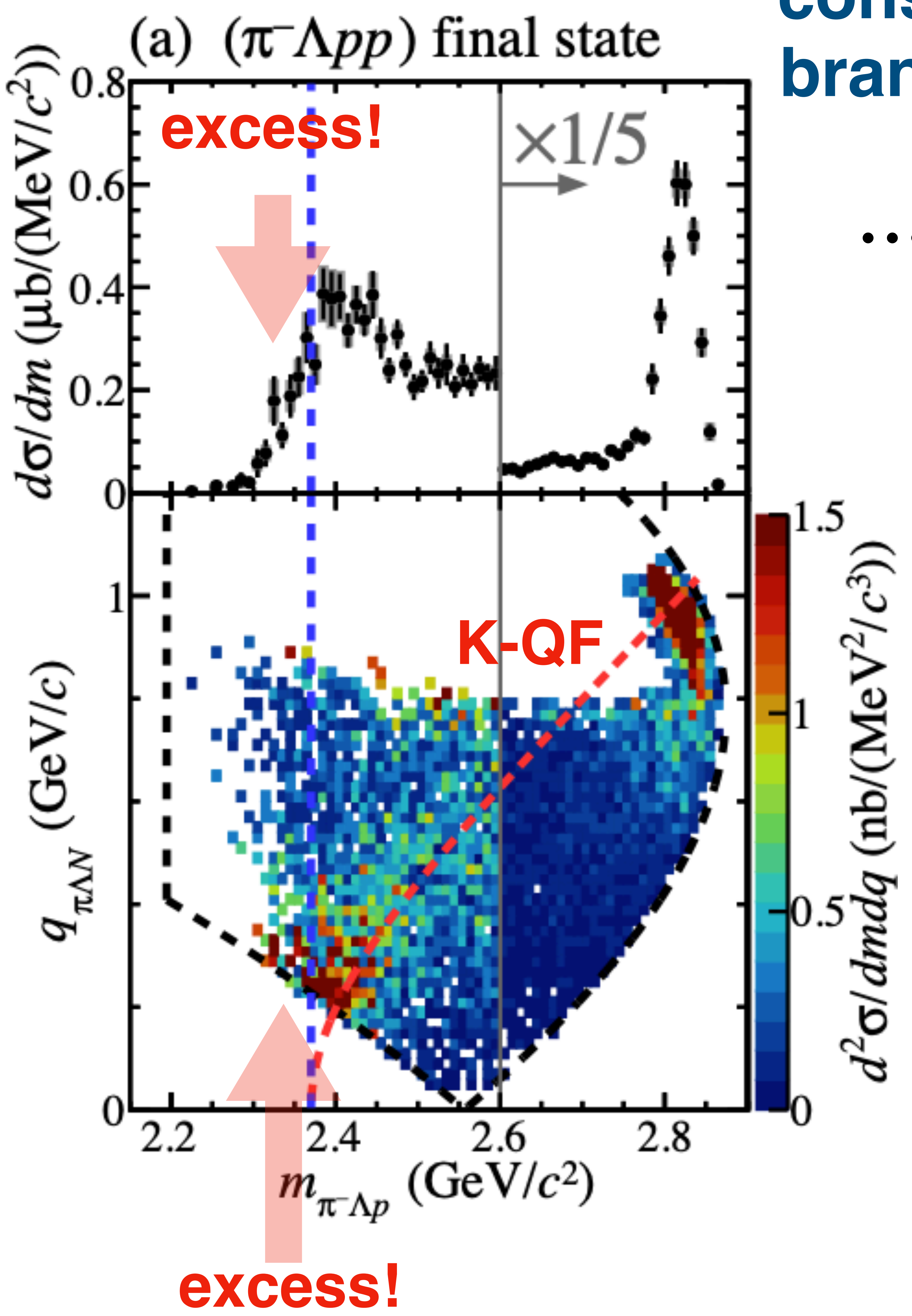

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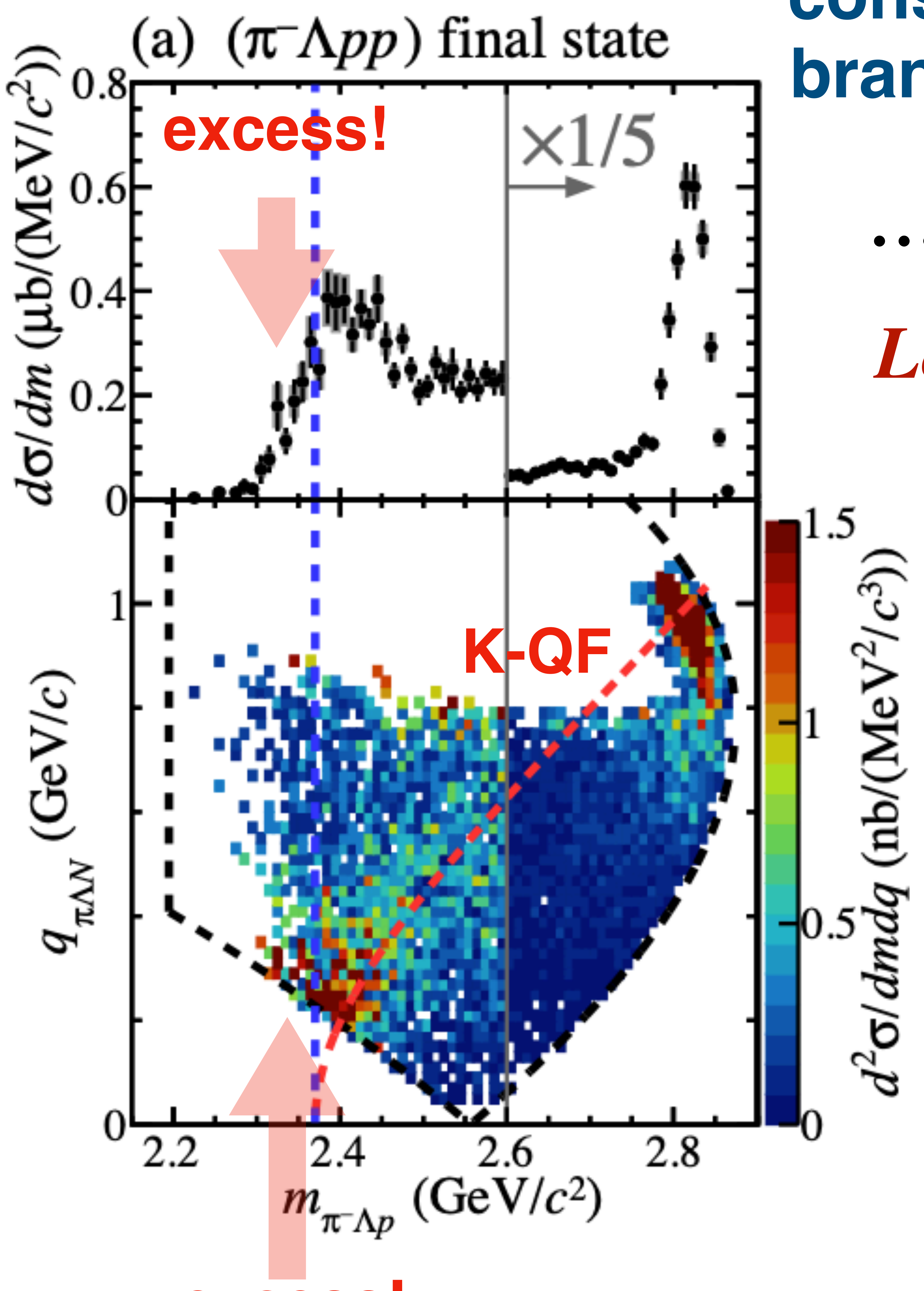
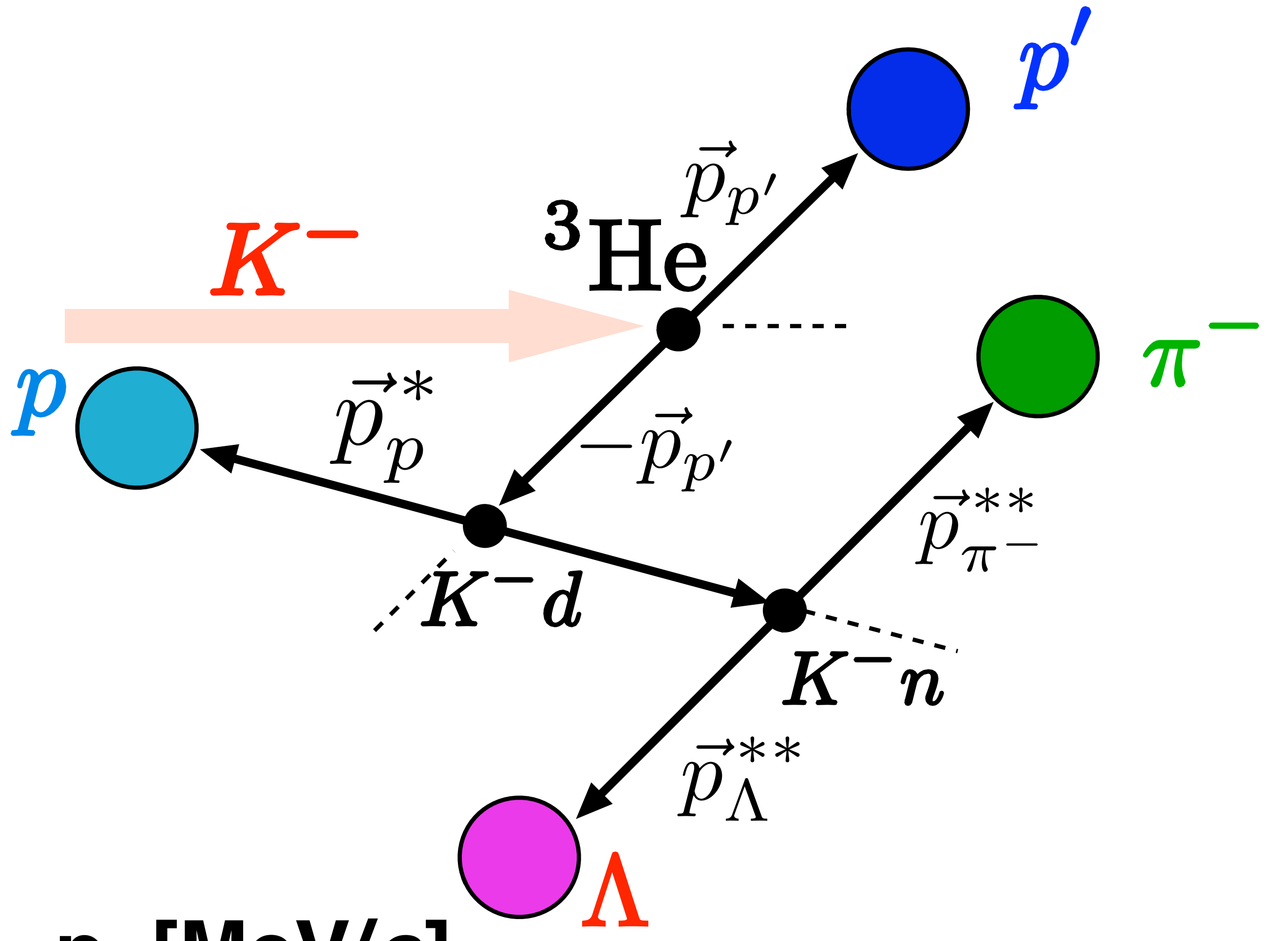
… excess is not easy to see …

… analyzed by T. Yamaga

$K^- + {}^3He \rightarrow \pi^-\Lambda pp$ reaction





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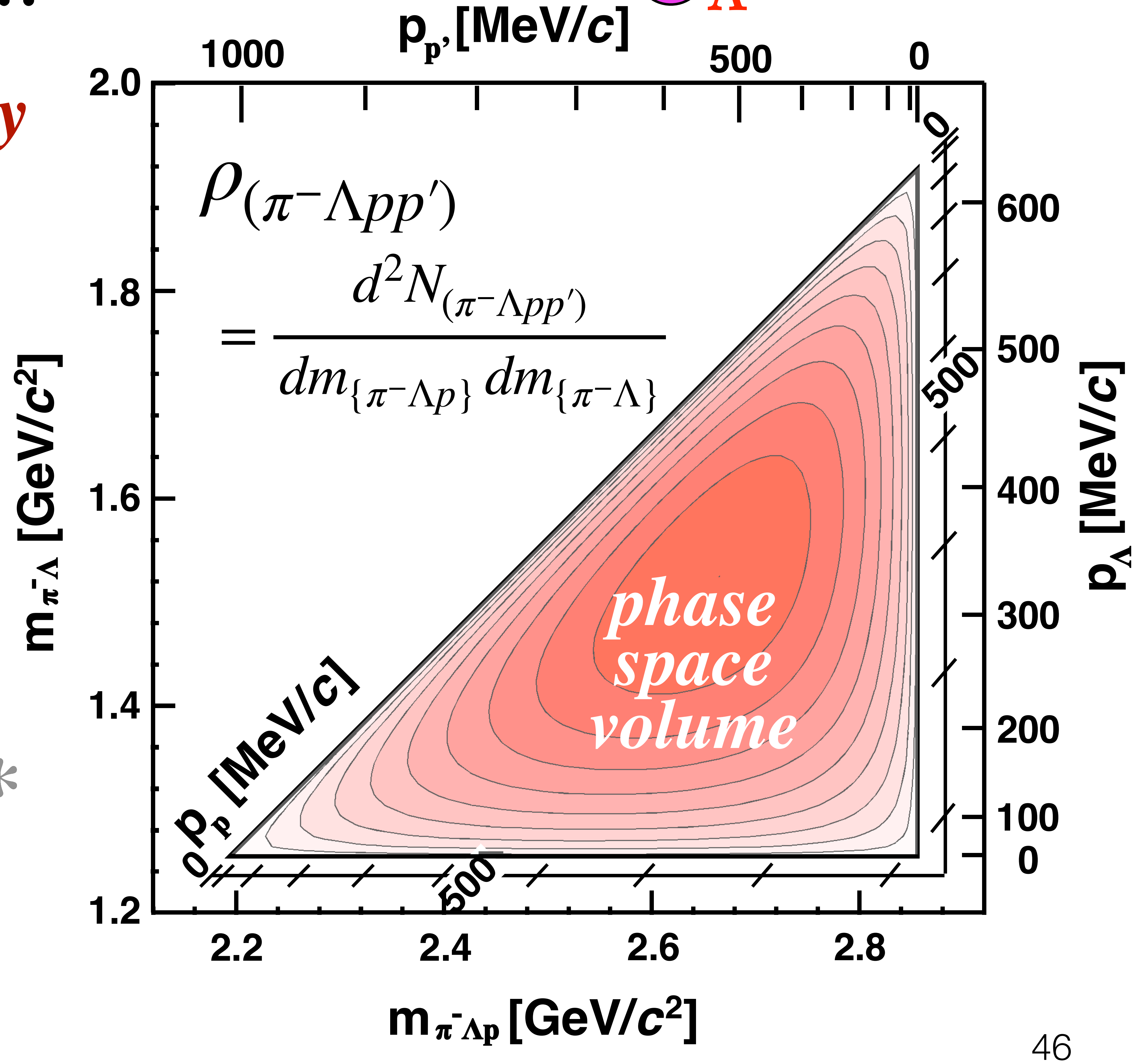
Let's normalize event density by 4-body phase space

The normalization by 4-body phase space, i.e., final-state-density

$$\rho_{(\pi^-\Lambda pp')} = \frac{d^2N_{(\pi^-\Lambda pp')}}{dm_{\{\pi^-\Lambda p\}}\, dm_{\{\pi^-\Lambda\}}}$$

$$\propto p_{p'} \times p_p^* \times p_\Lambda^{**}$$



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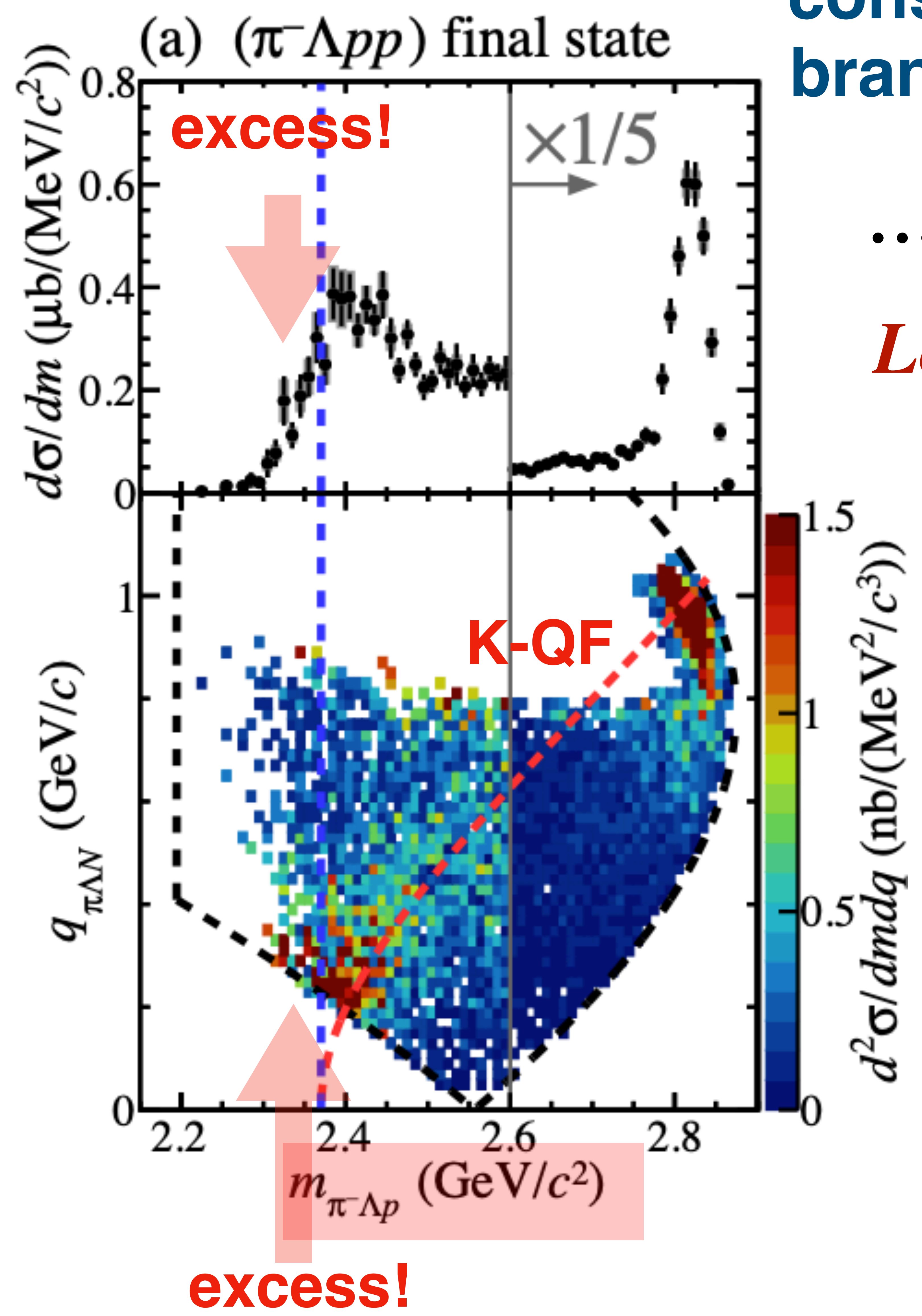

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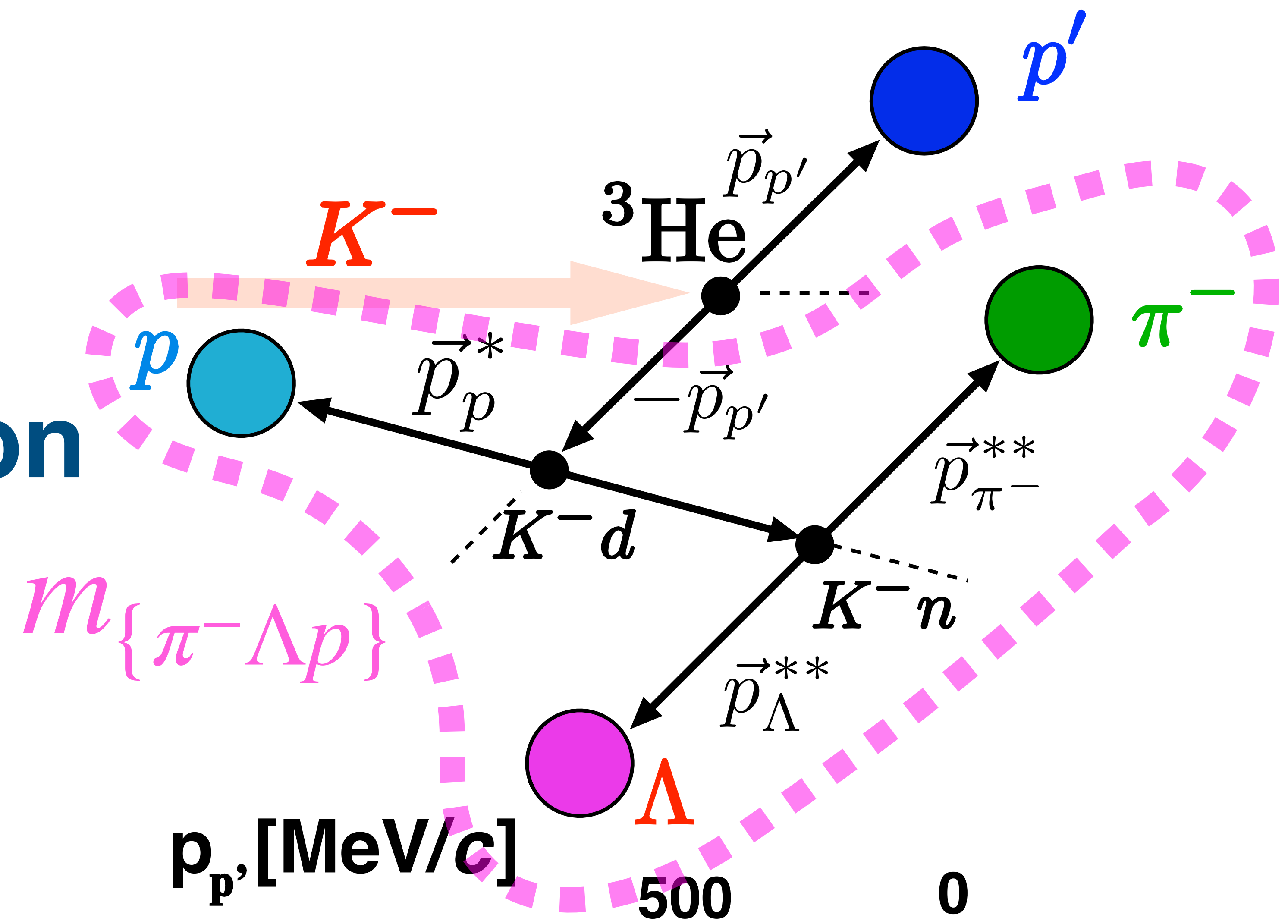
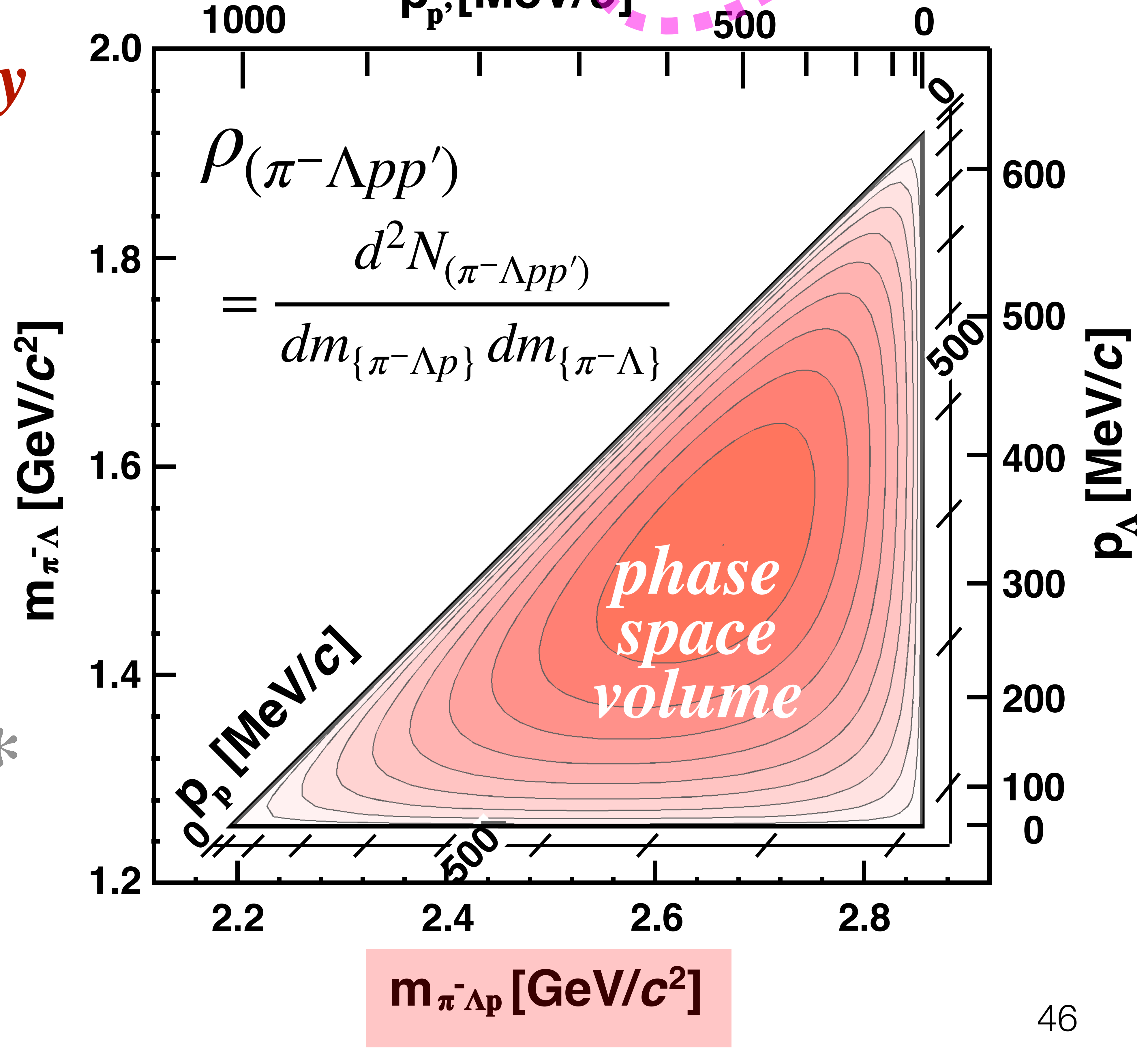
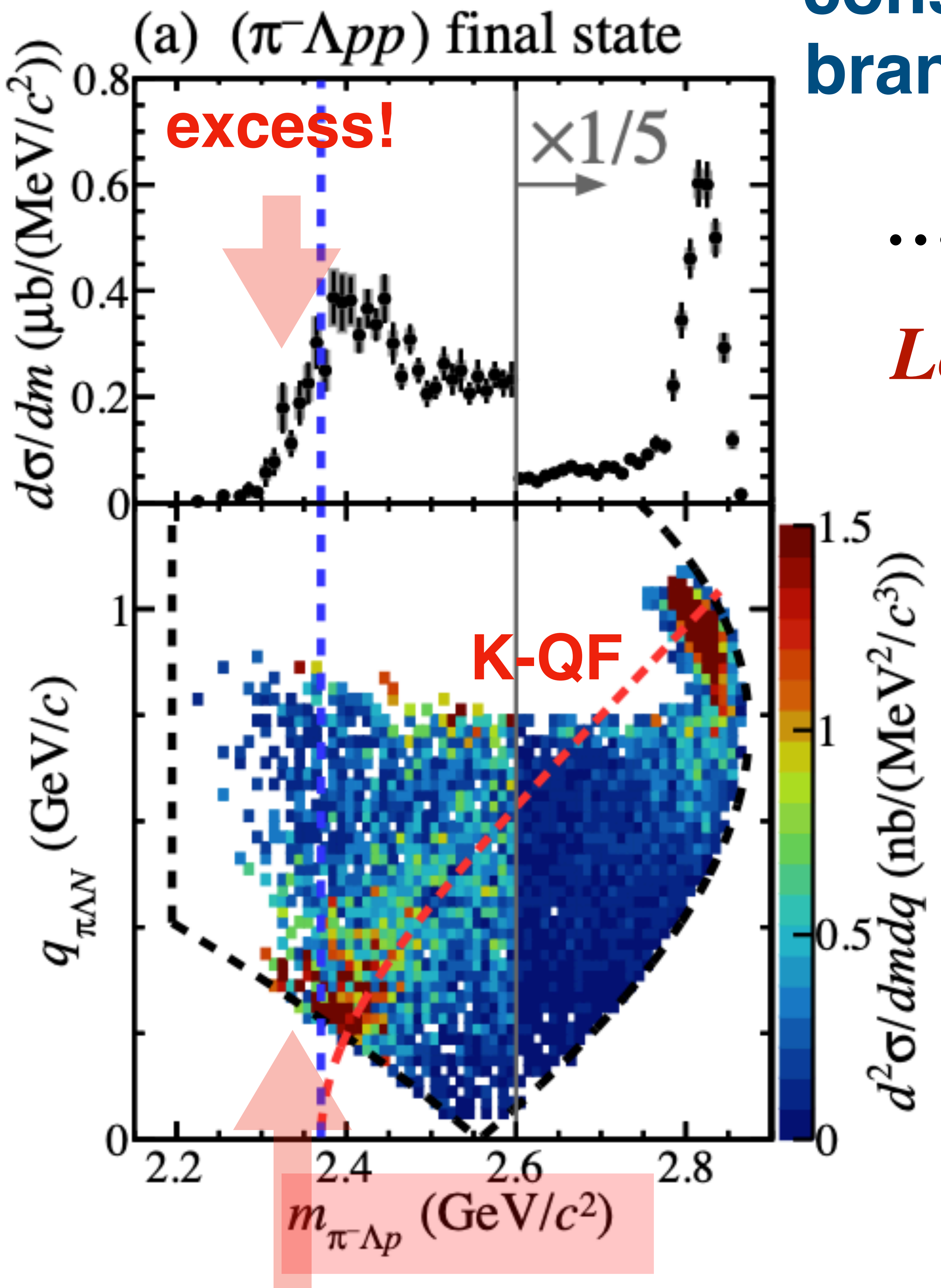


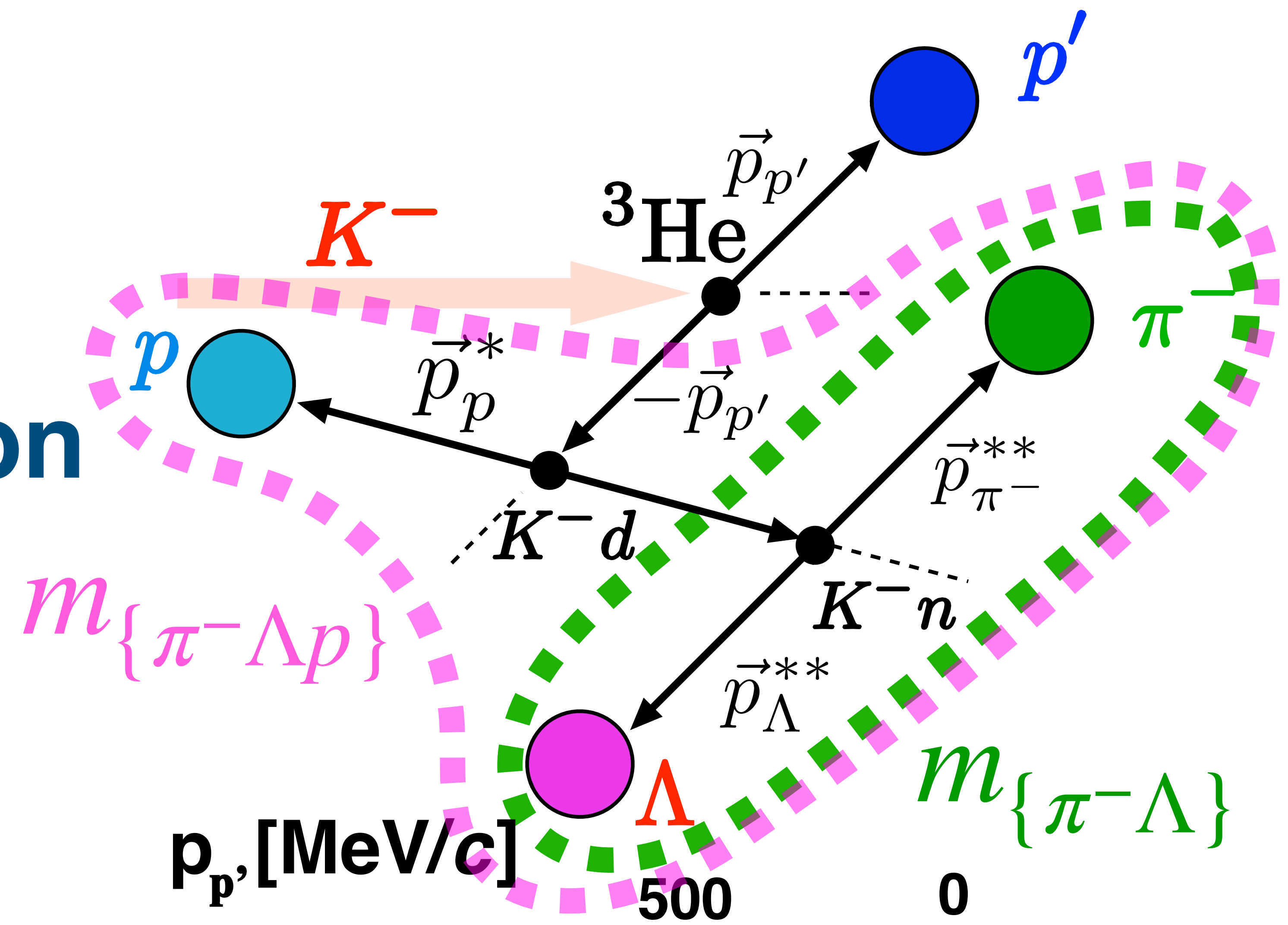


… analyzed by T. Yamaga

K⁻ + ³He → π⁻Λpp reaction



consistent with K⁻ + ³He → Λpn reaction
branch seems to be oder bigger



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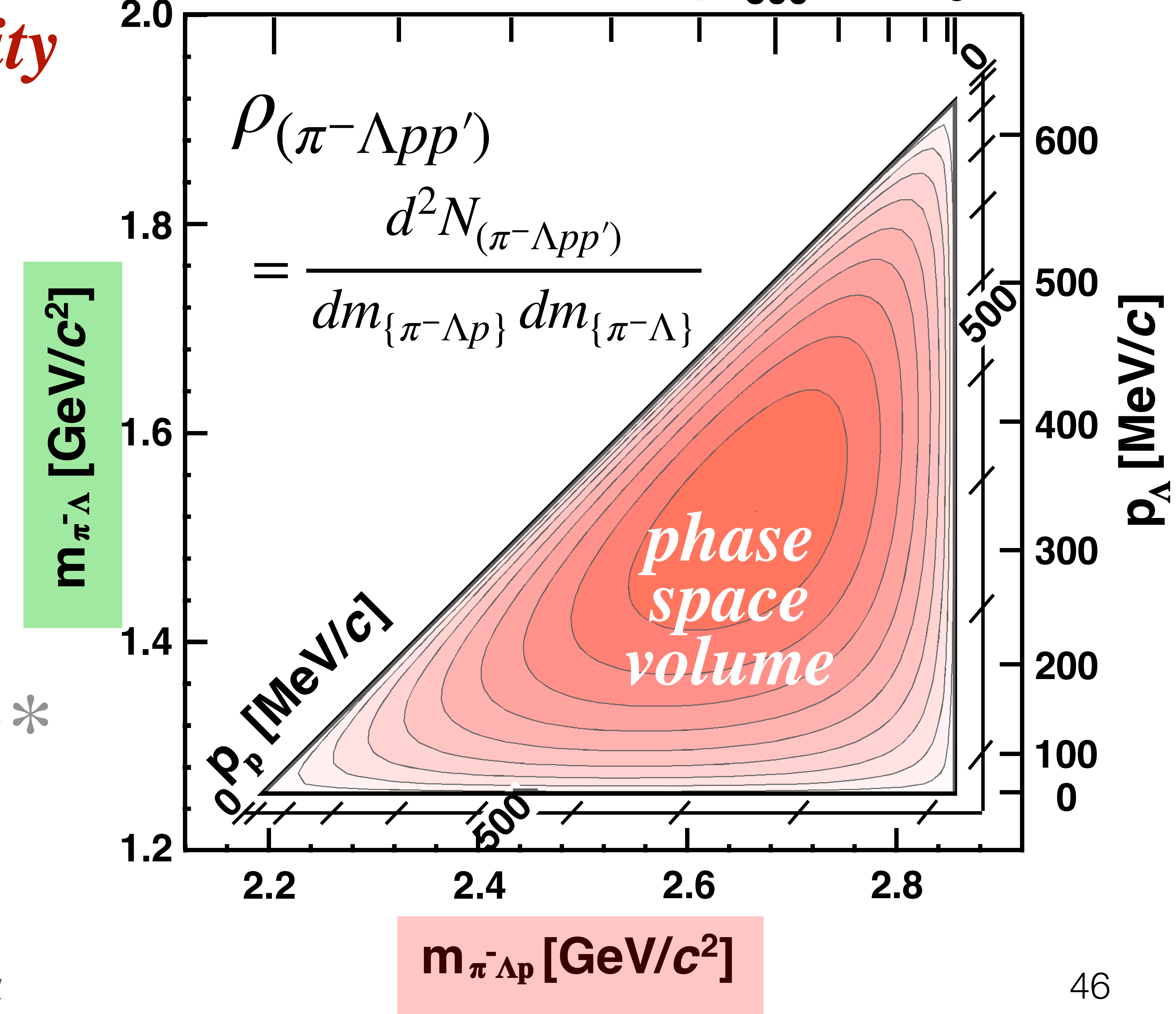

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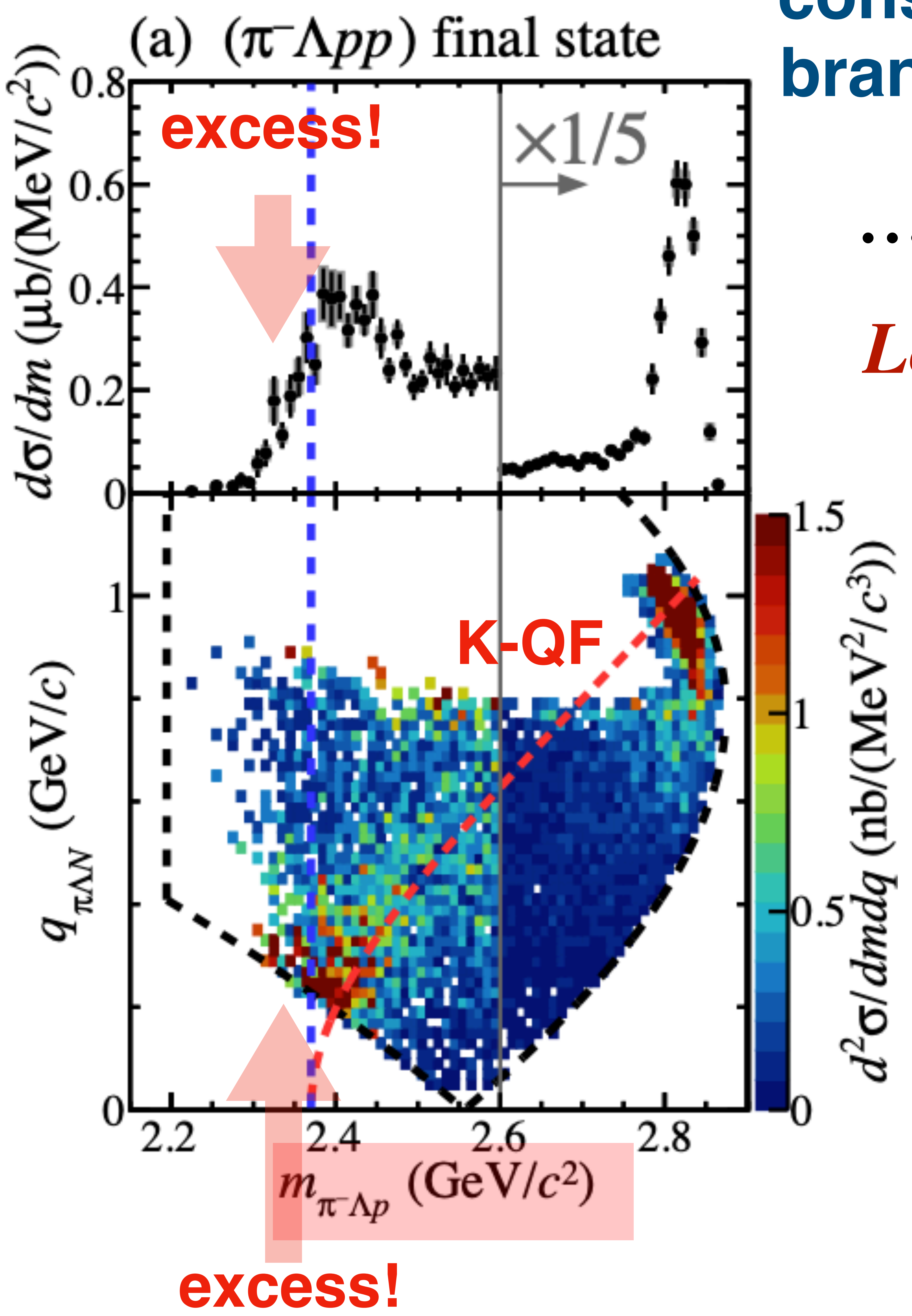

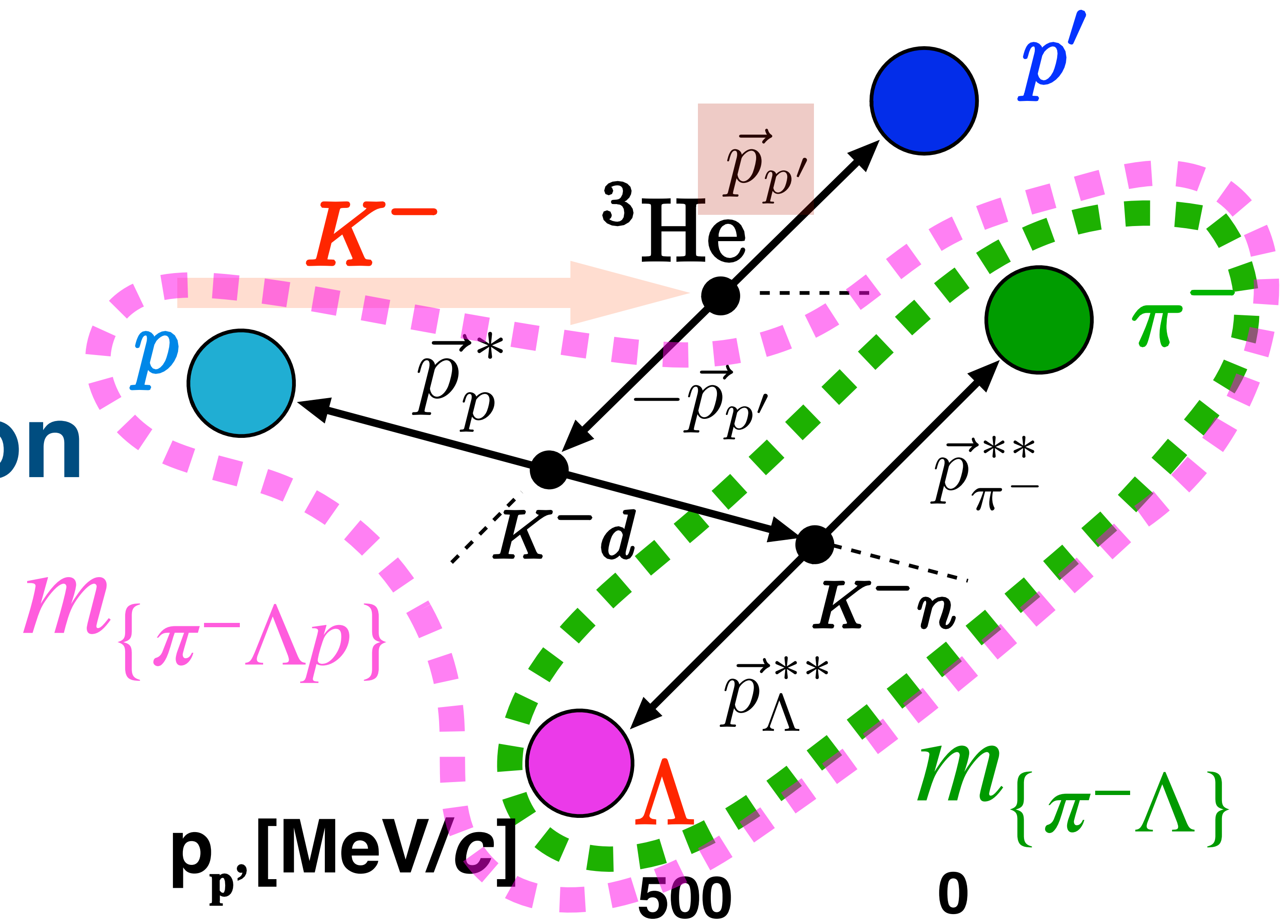

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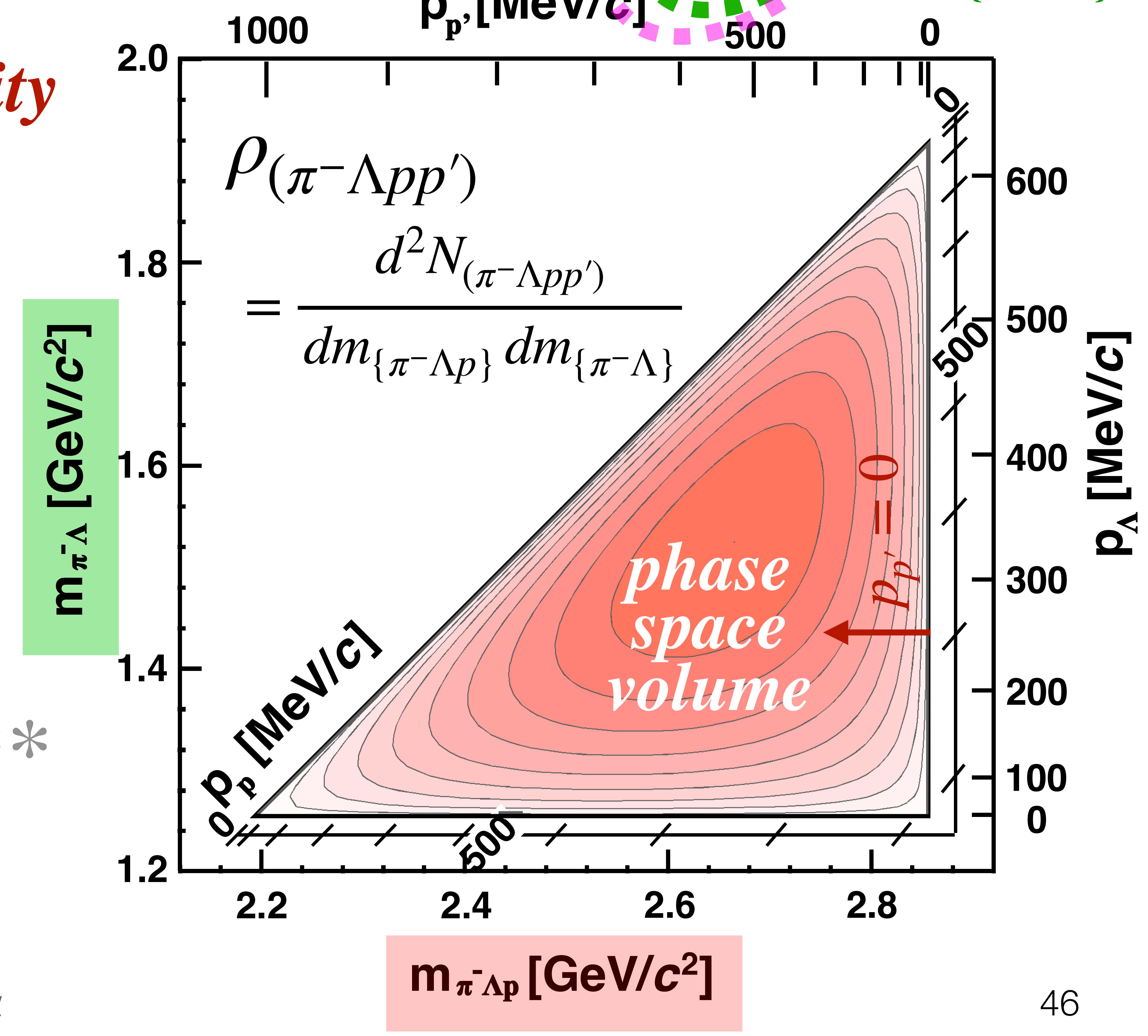

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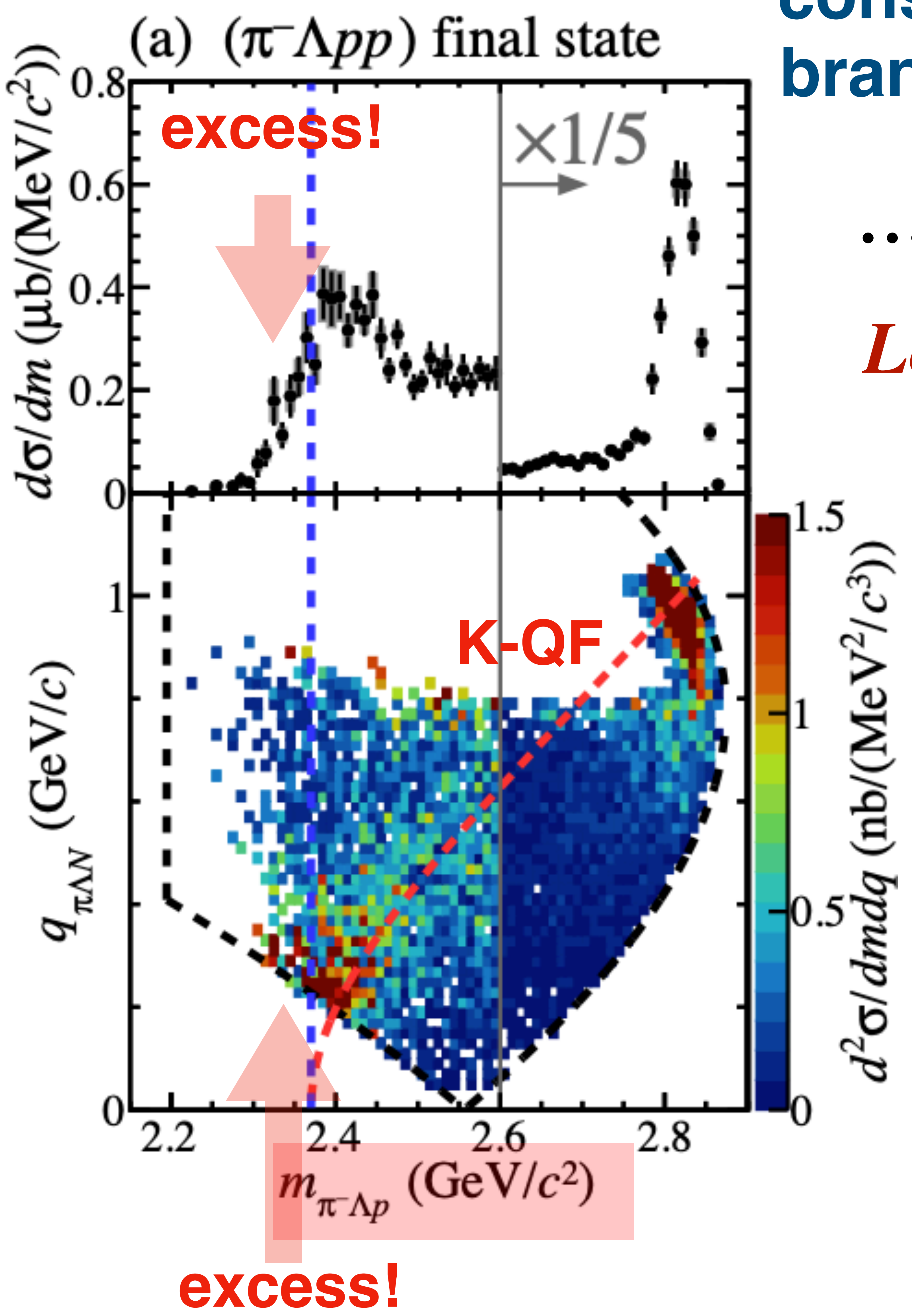

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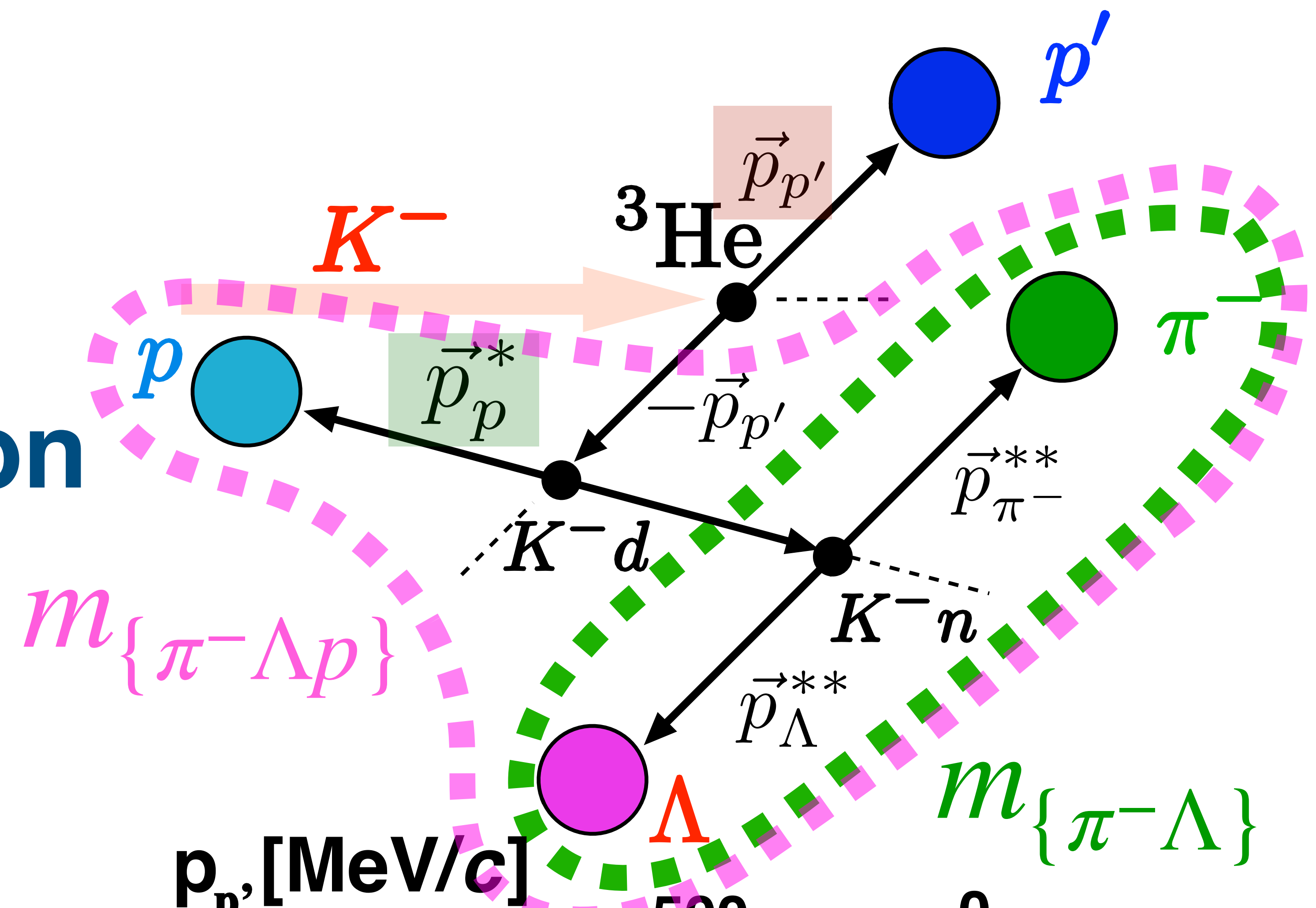

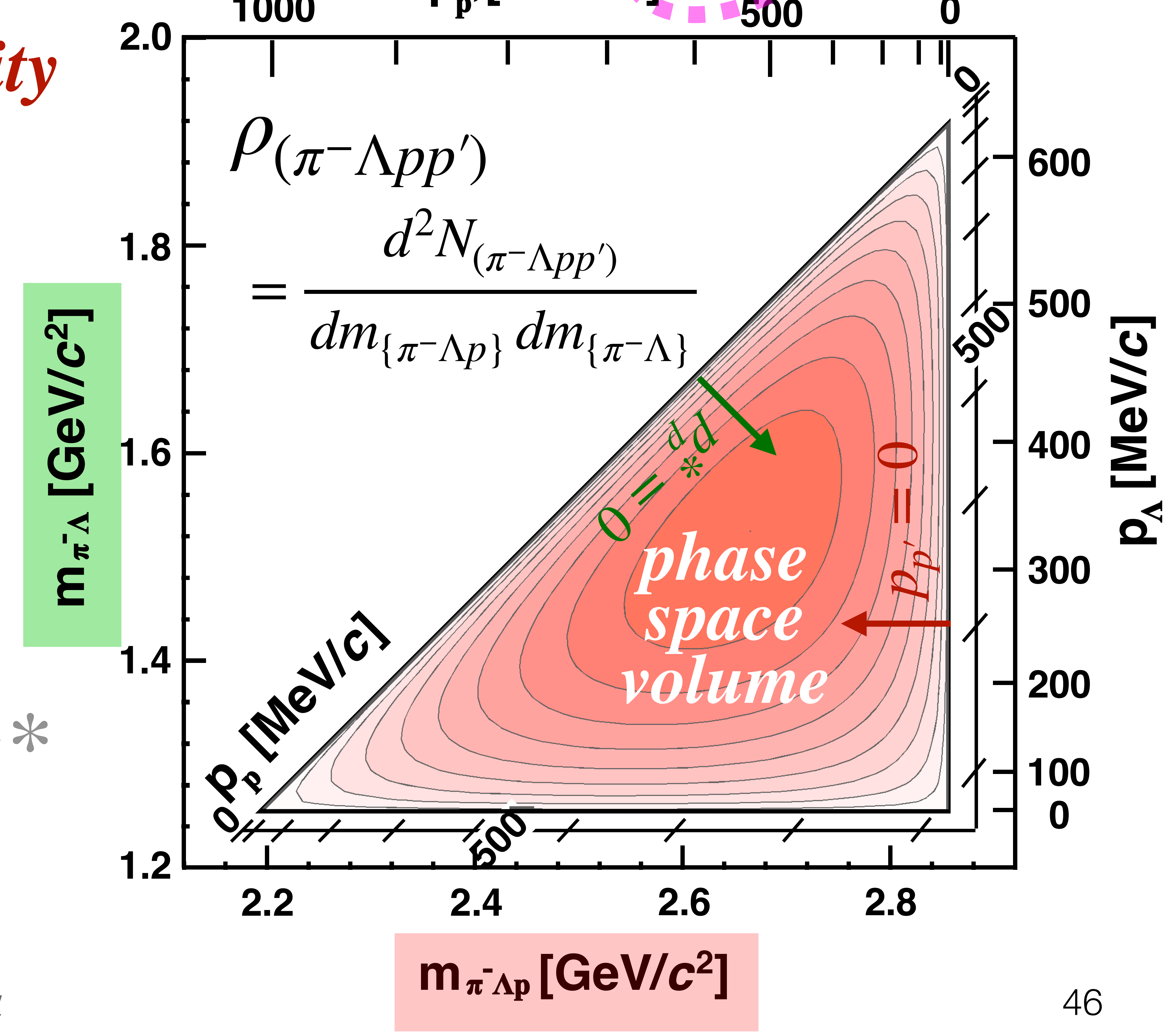

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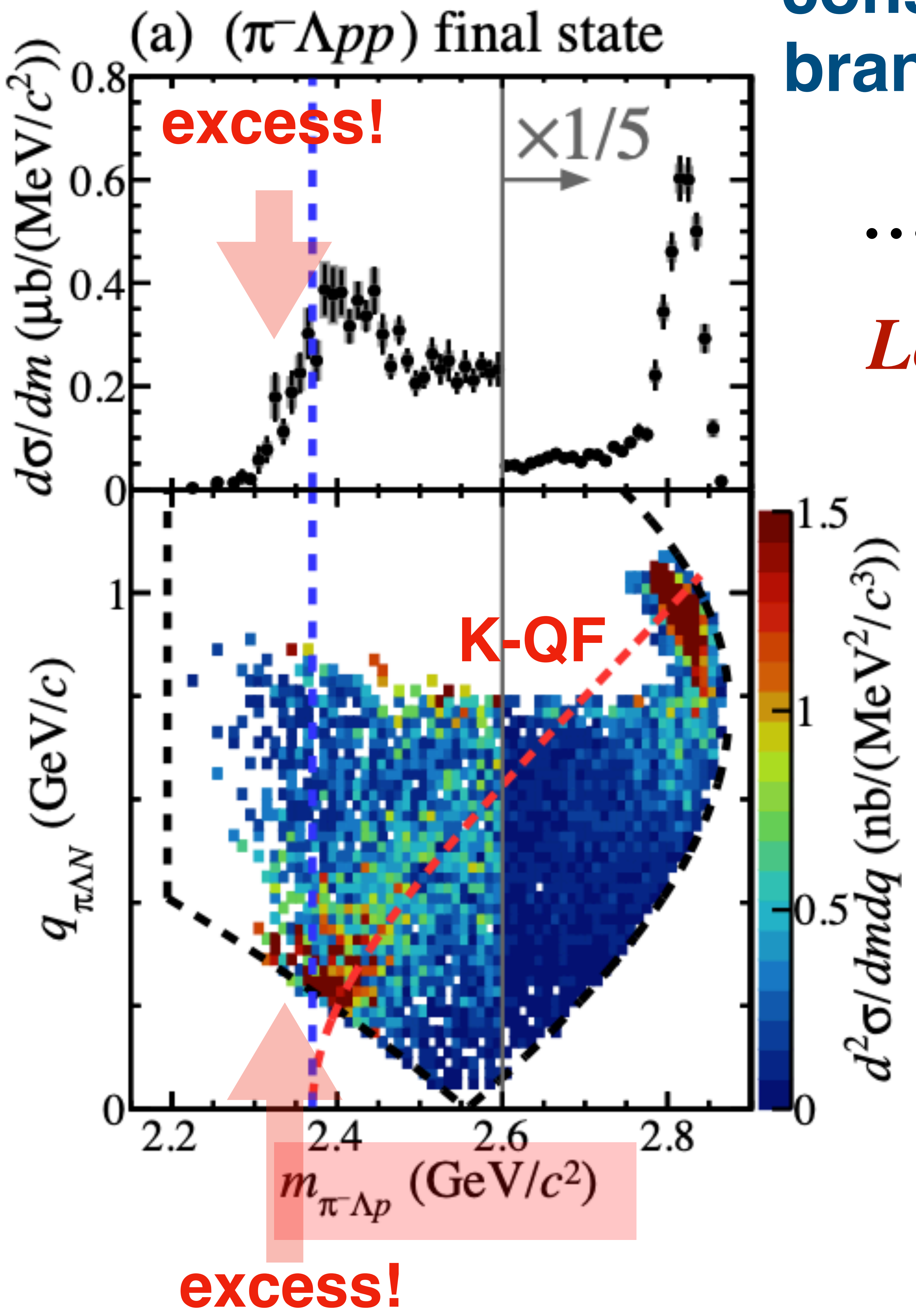

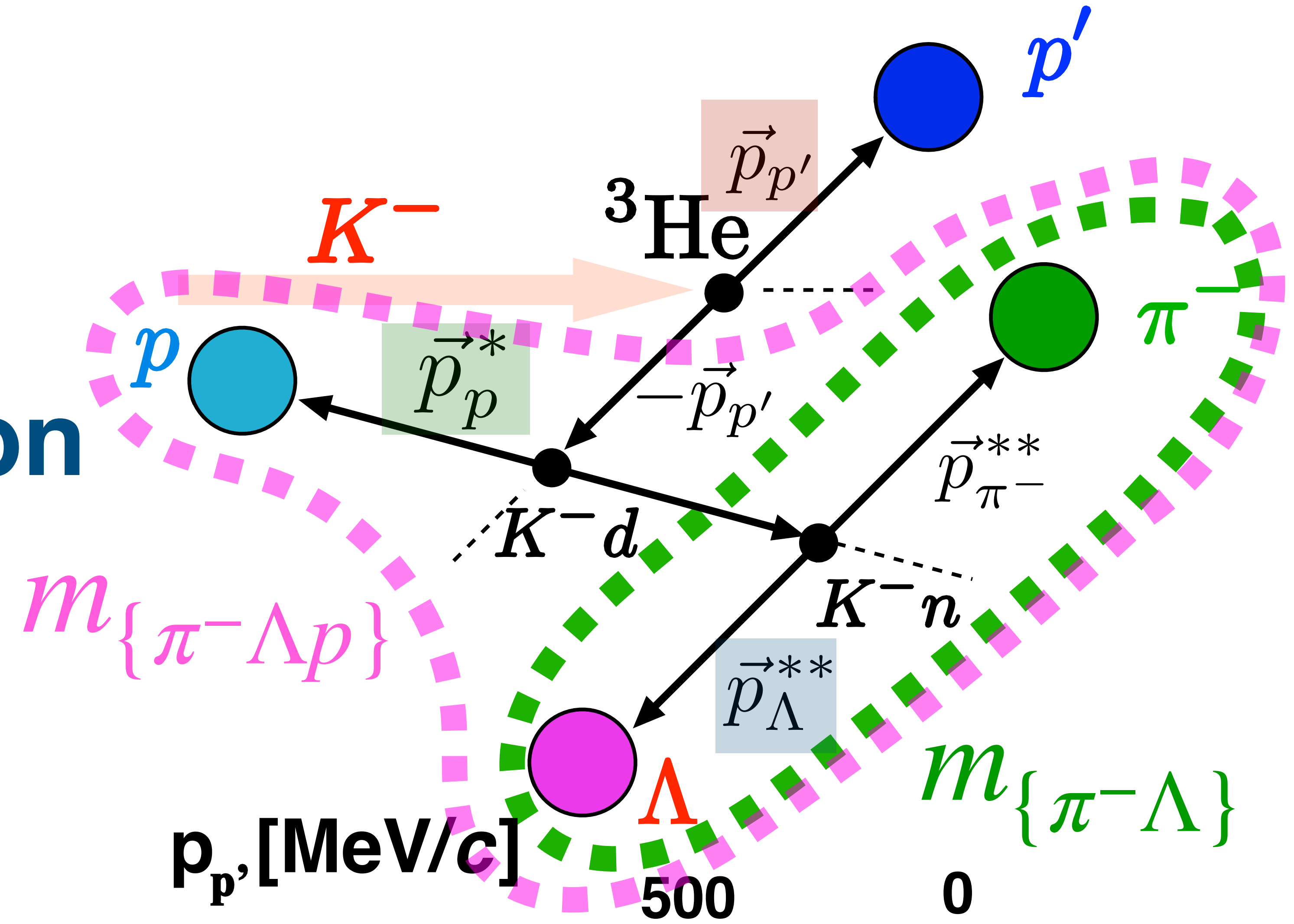

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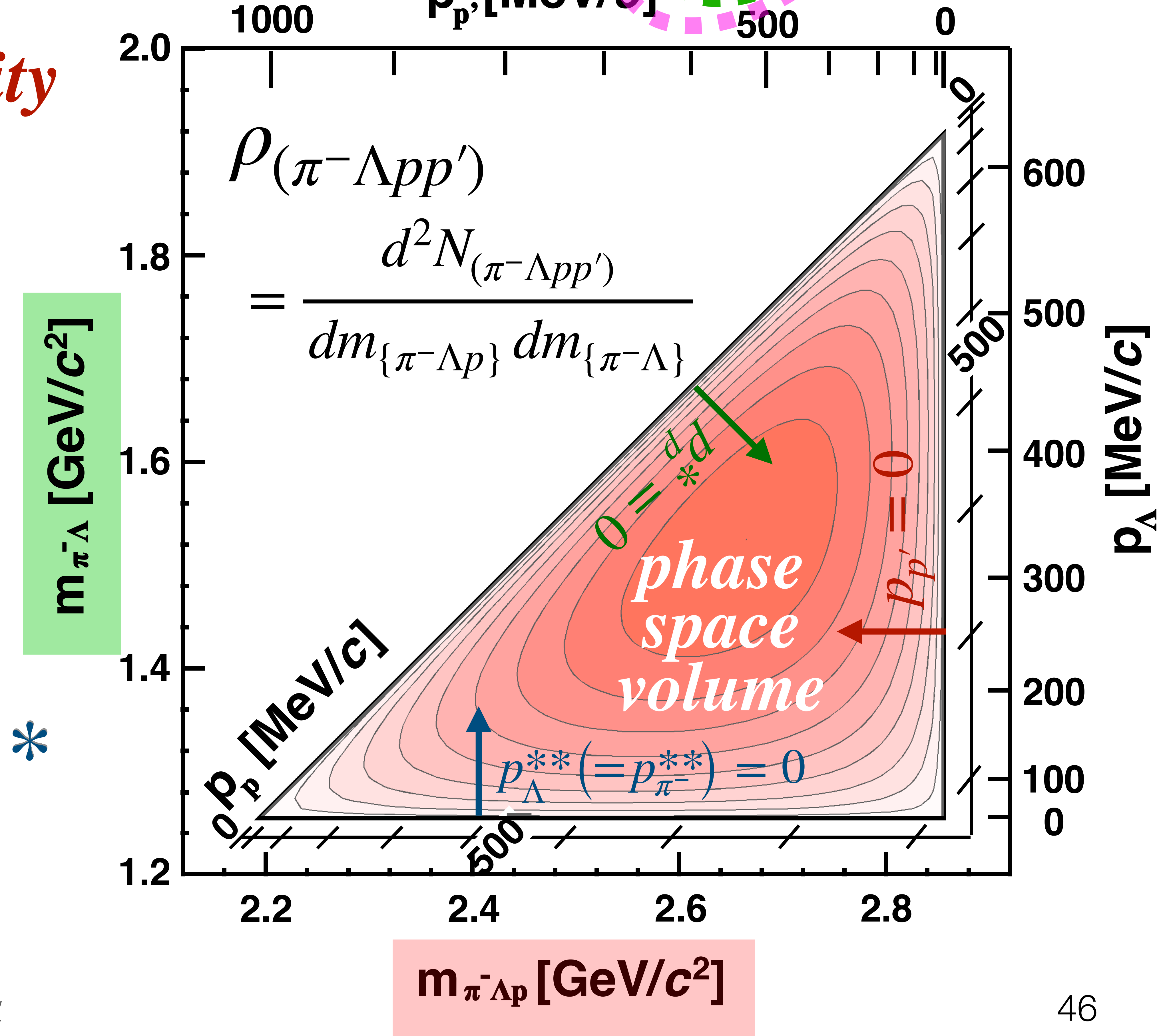
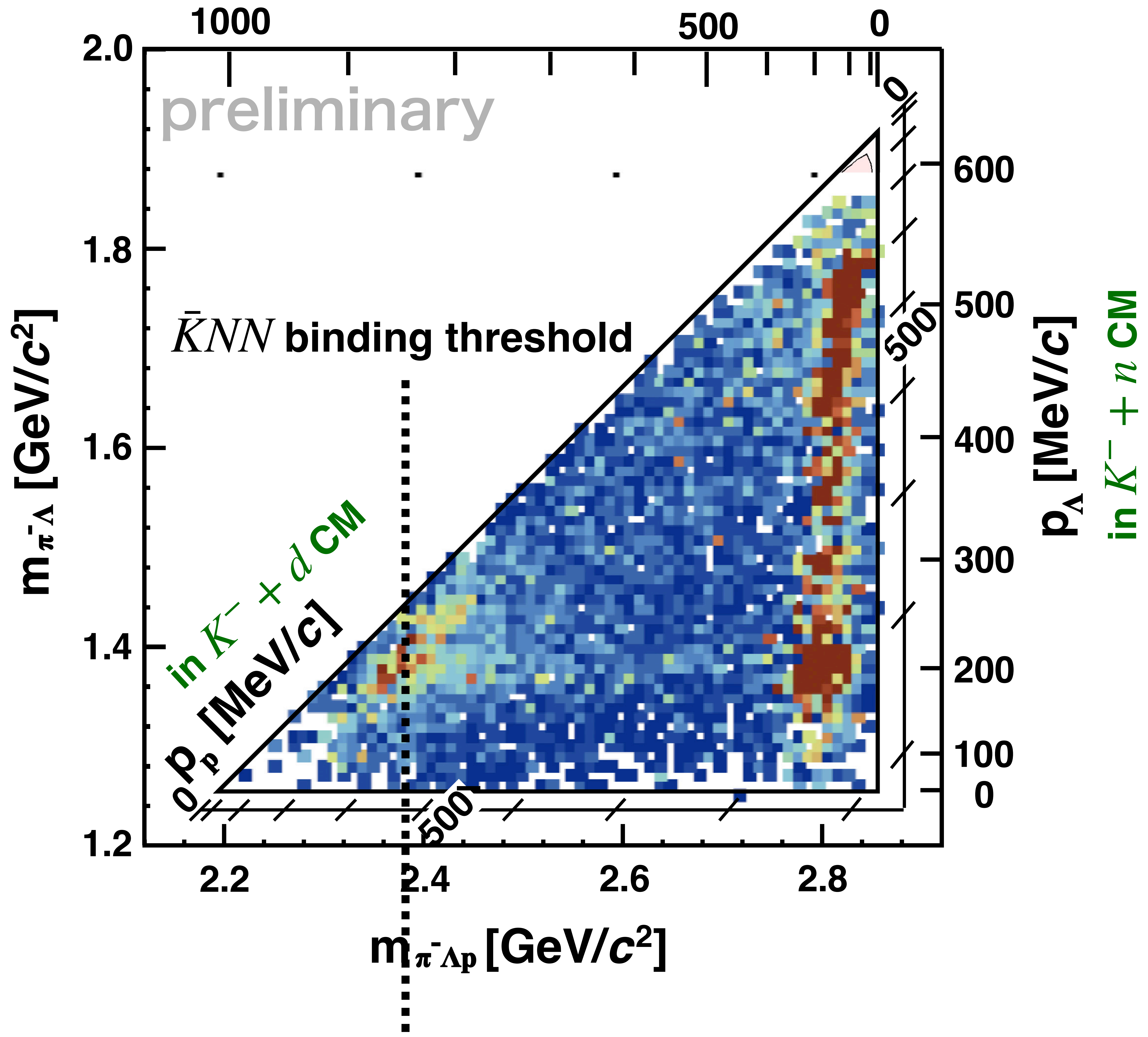
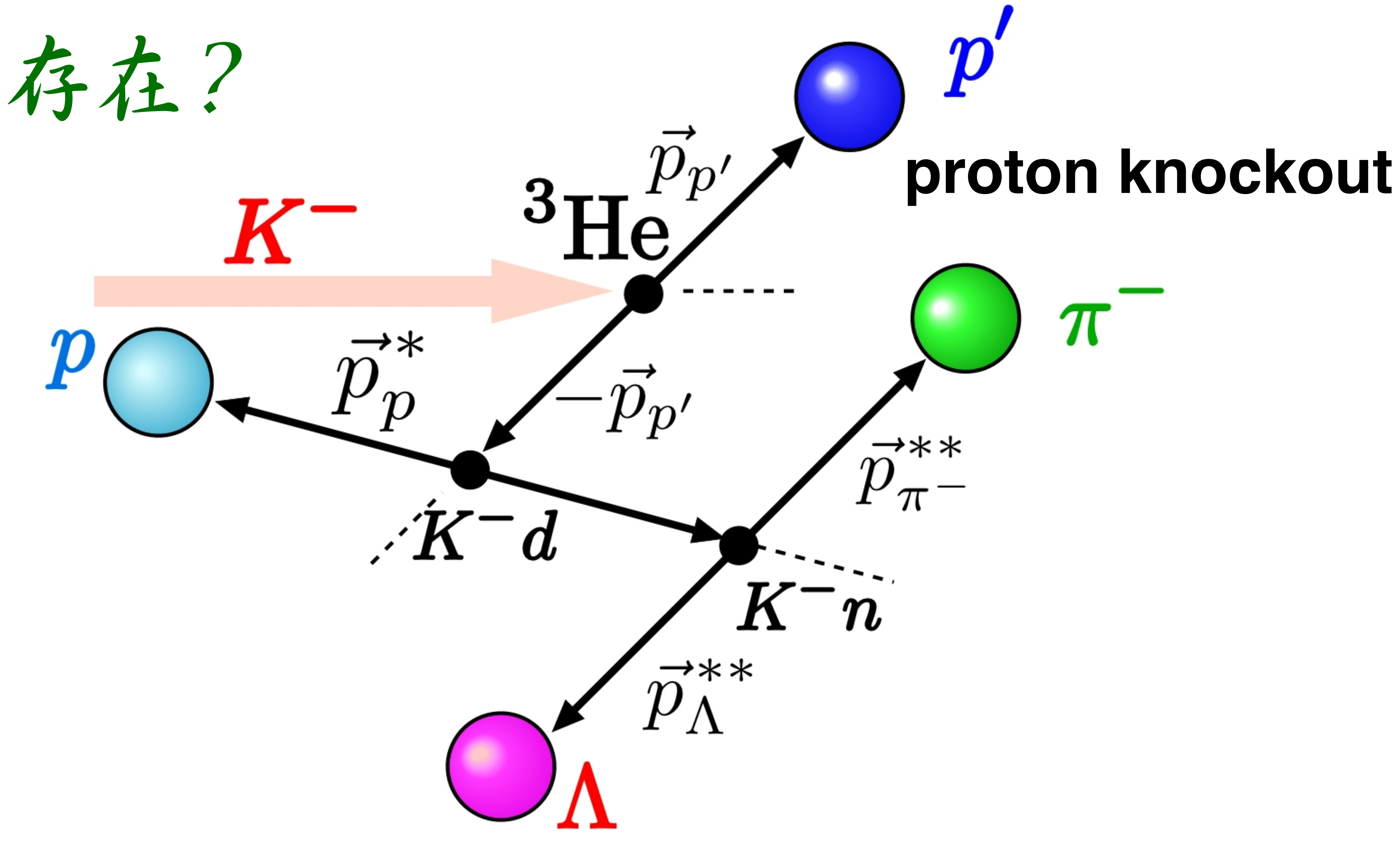


… analyzed by T. Yamaga

“K^-pp”鏡像核“$\bar{K}^0nn$”の存在？



$M(\bar{K}^0nn) \sim 2377\,\mathrm{MeV}/c^2$



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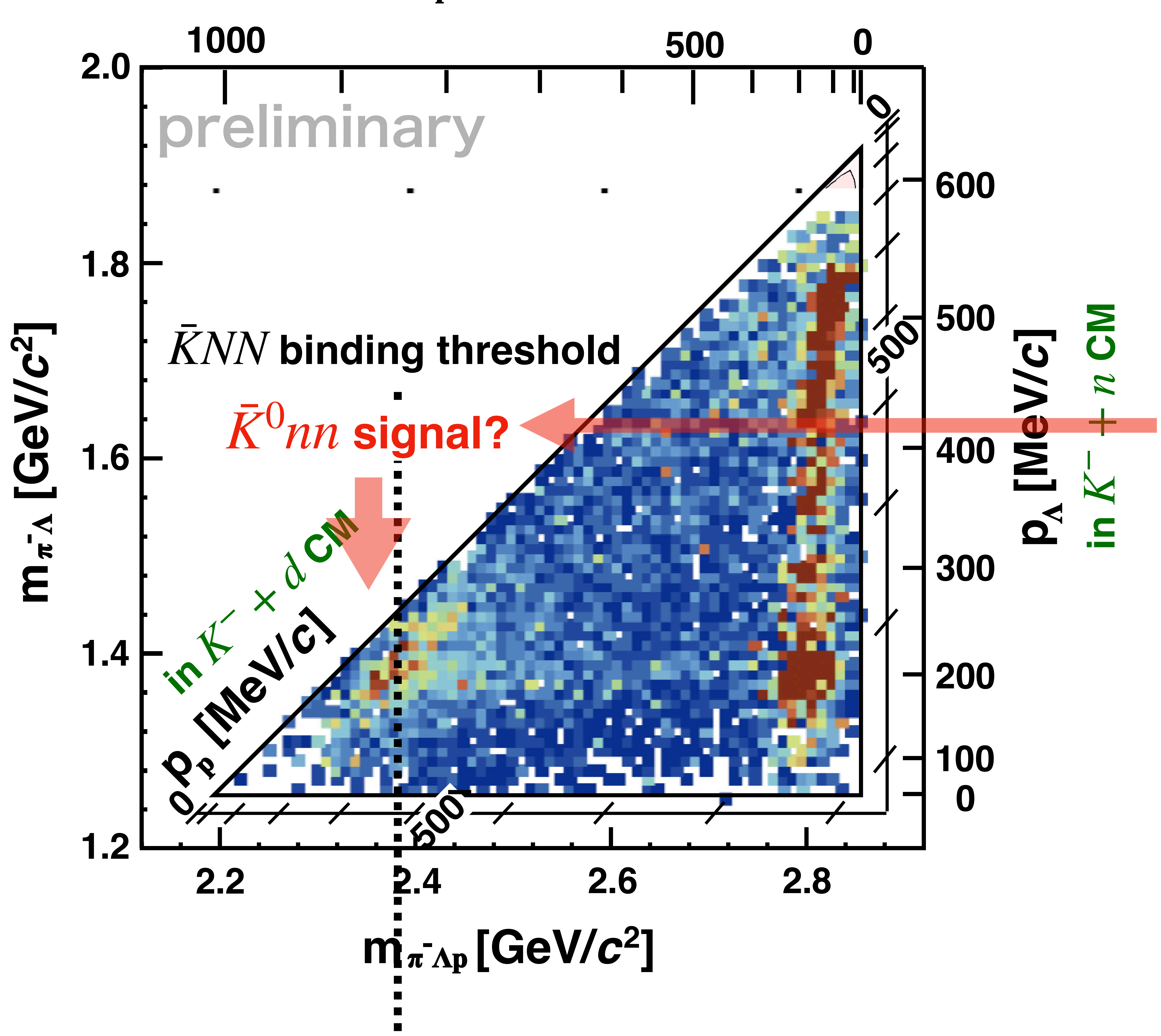

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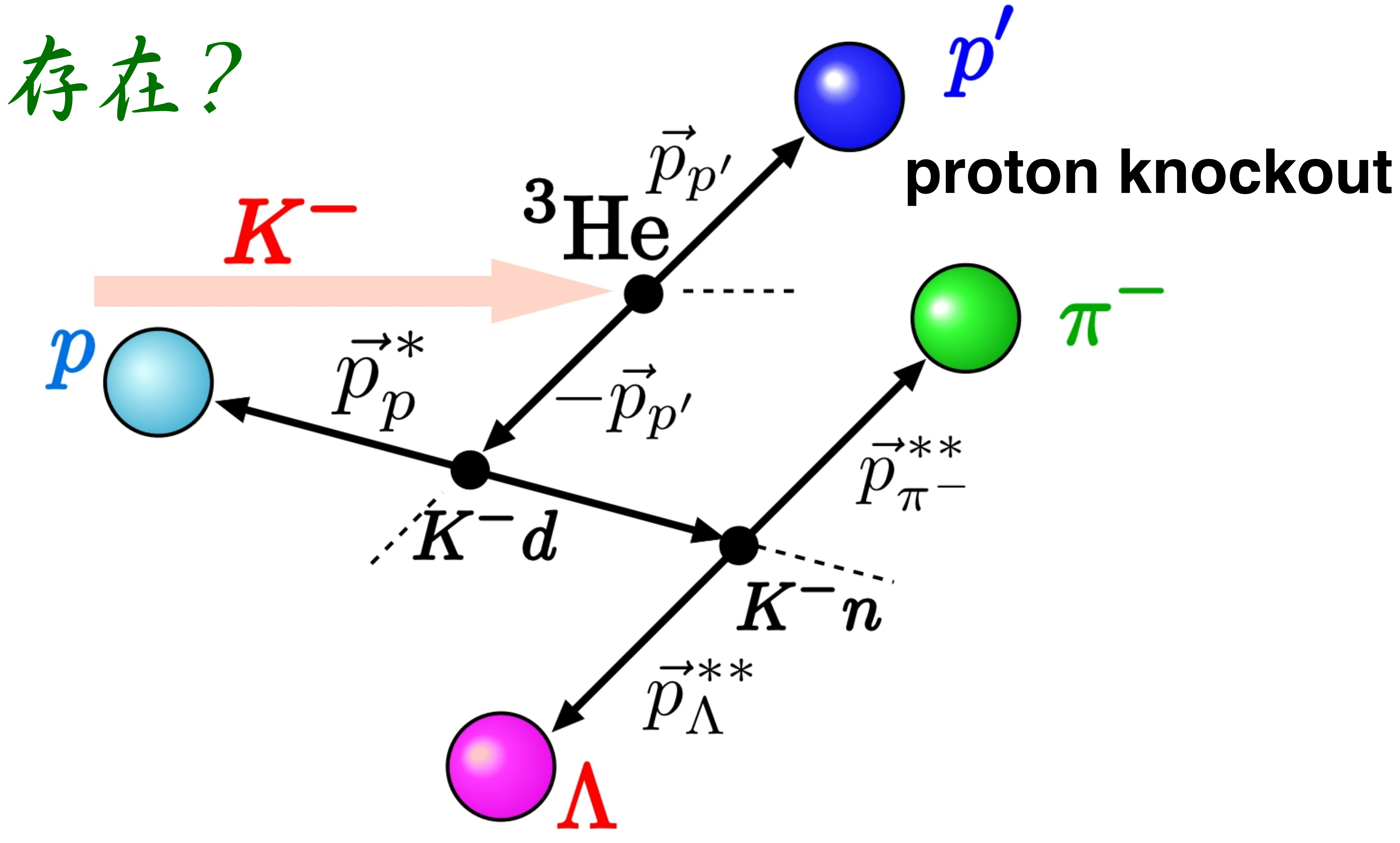
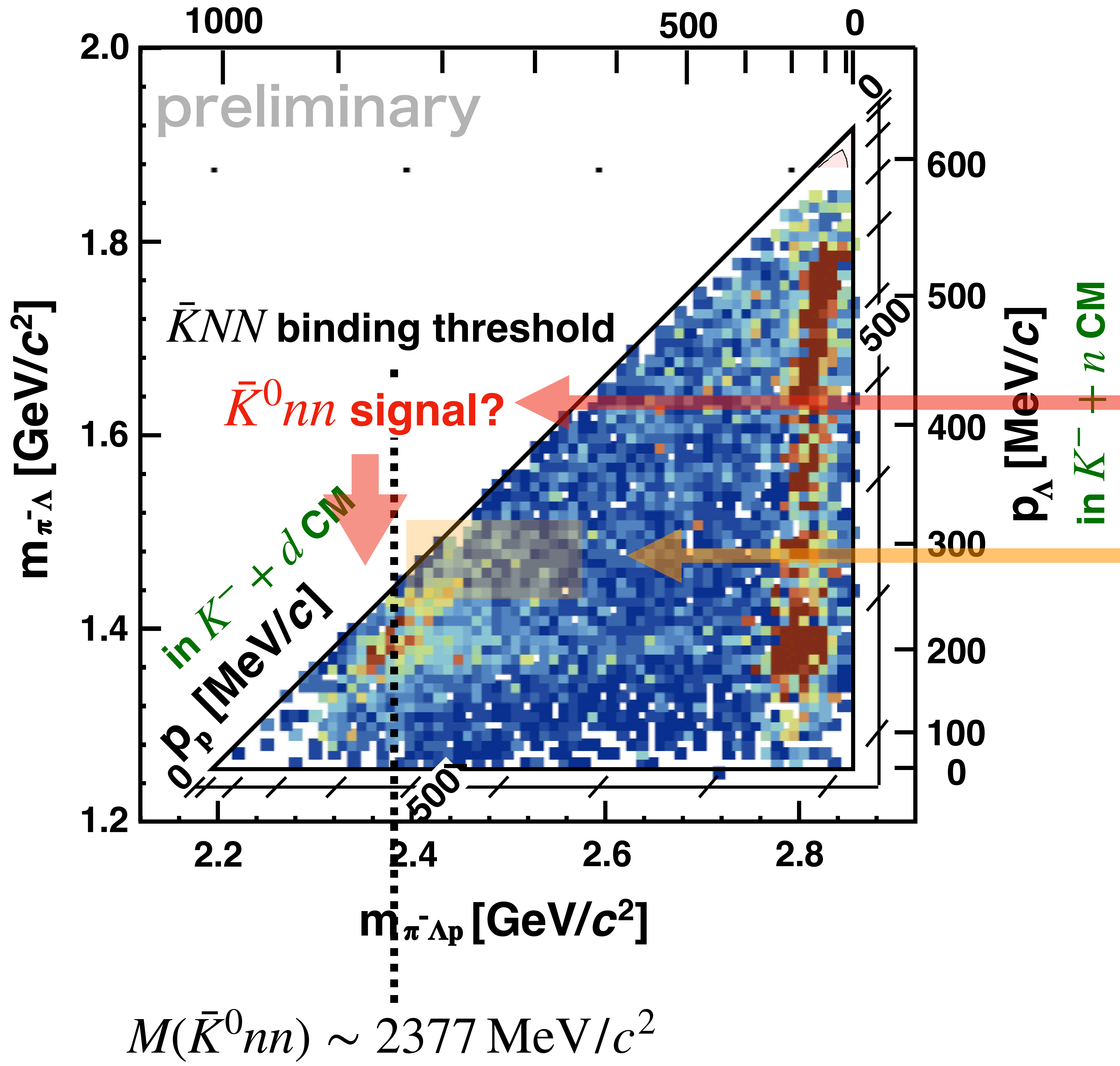
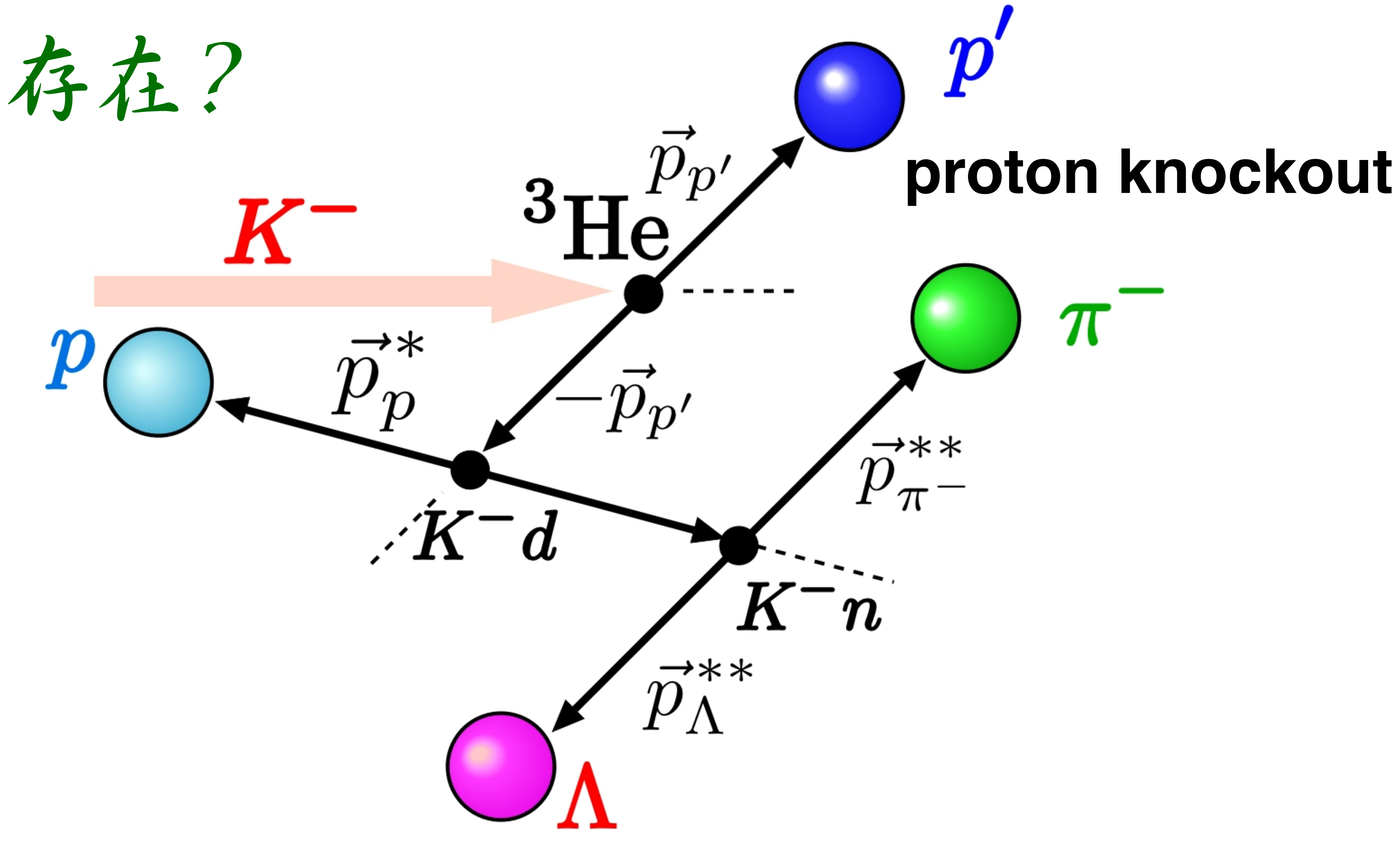


$\bar{K}^0nn$ signal-like event concentration below $\bar{K}$-bound threshold is seen?

— twice more data become available in April —

"K^-pp"鏡像核"$\bar{K}^0nn$"の存在？





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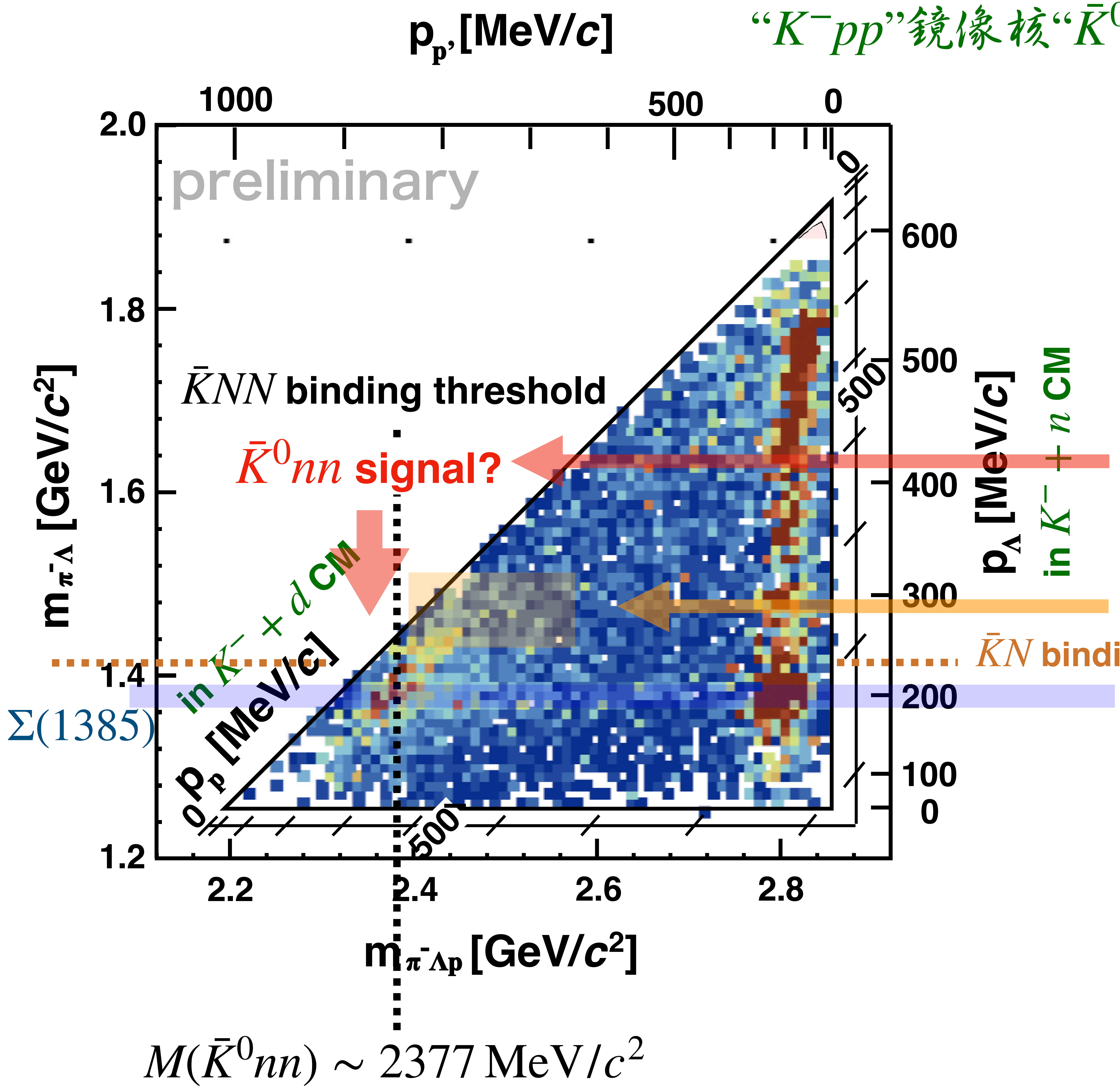
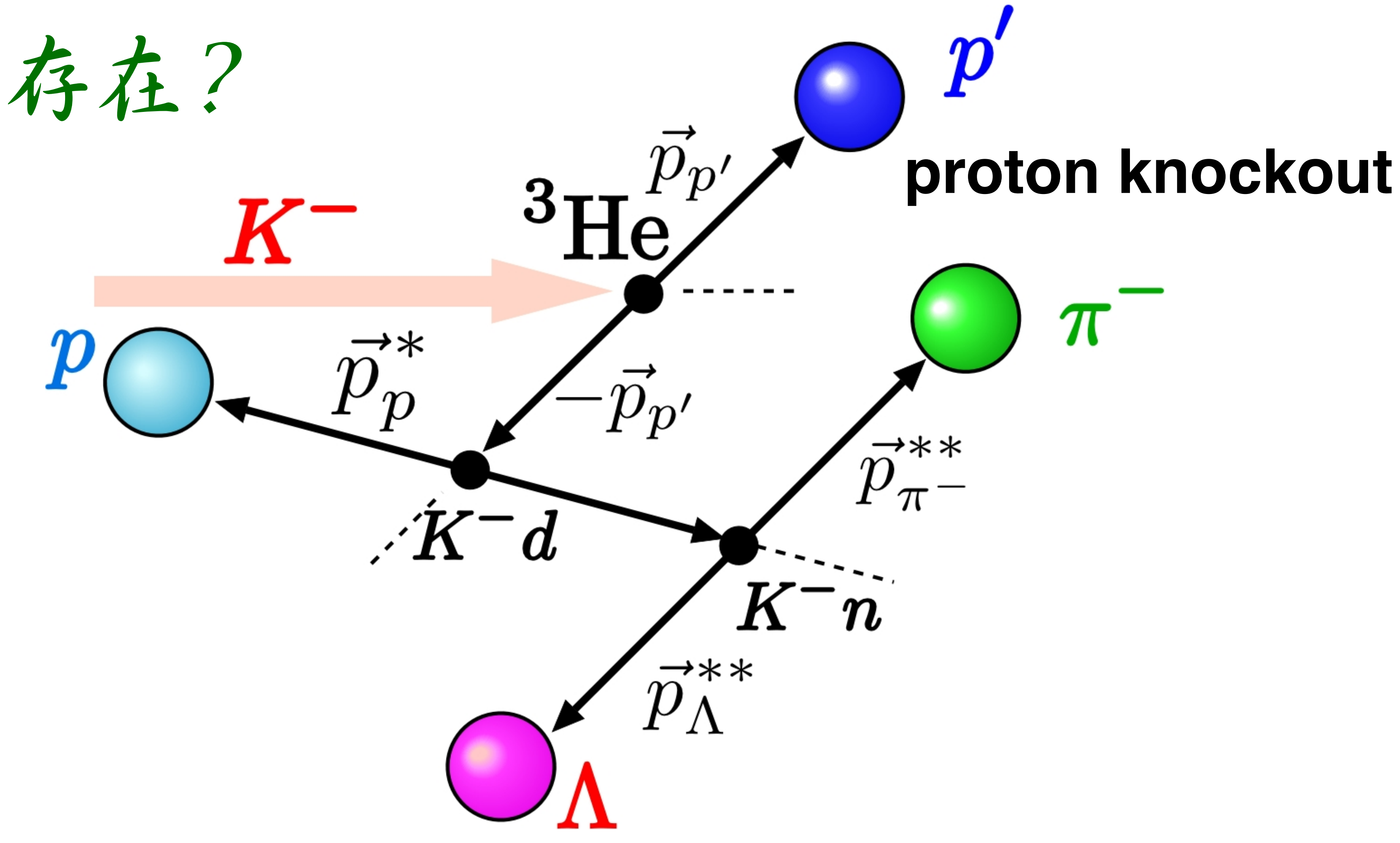
QF-K induced reaction?

“K^-pp”鏡像核“$\bar{K}^0nn$”の存在？





$\bar{K}^0nn$ signal-like event concentration below $\bar{K}$-bound threshold is seen?

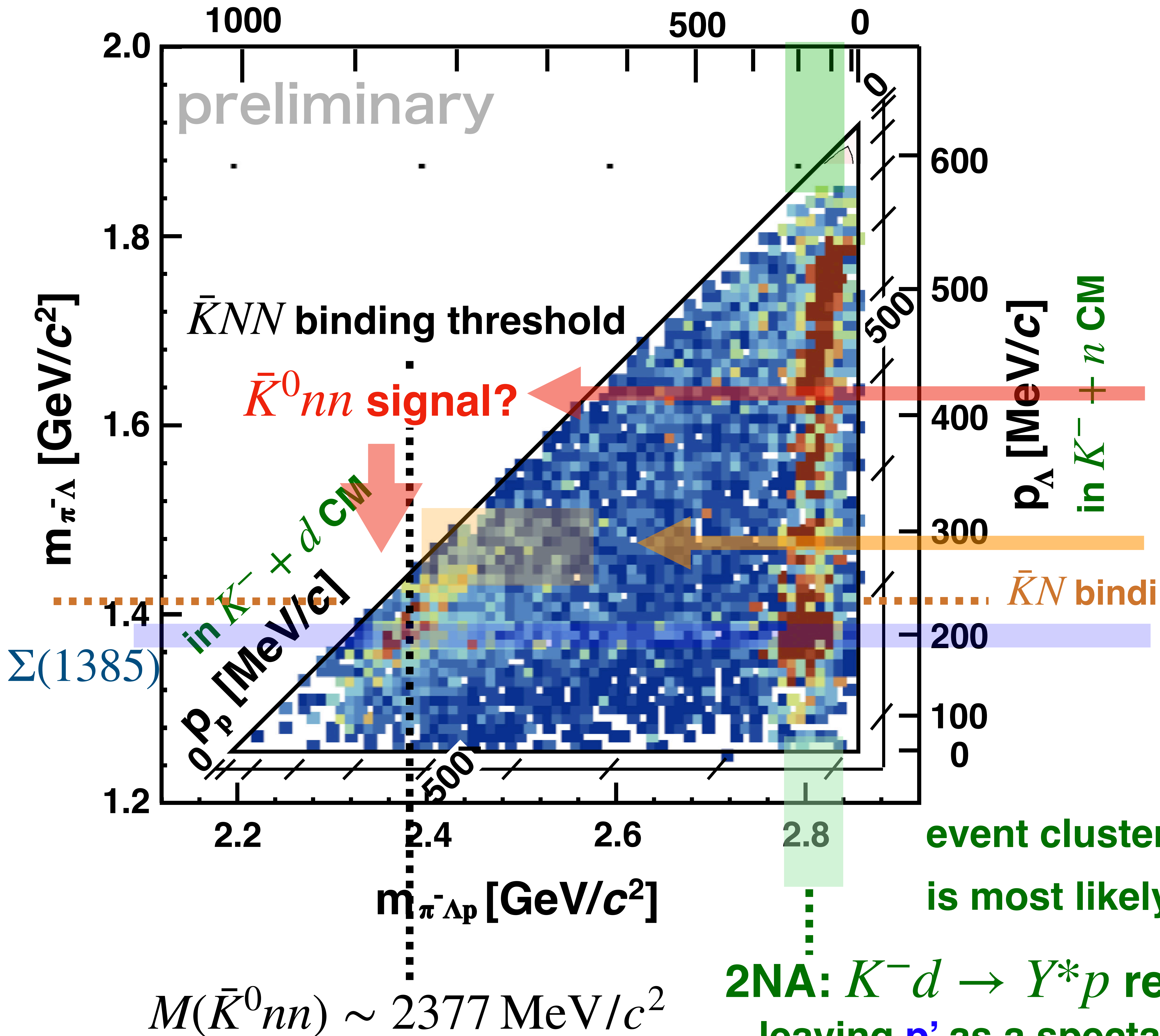
— *twice more data become available in April* —

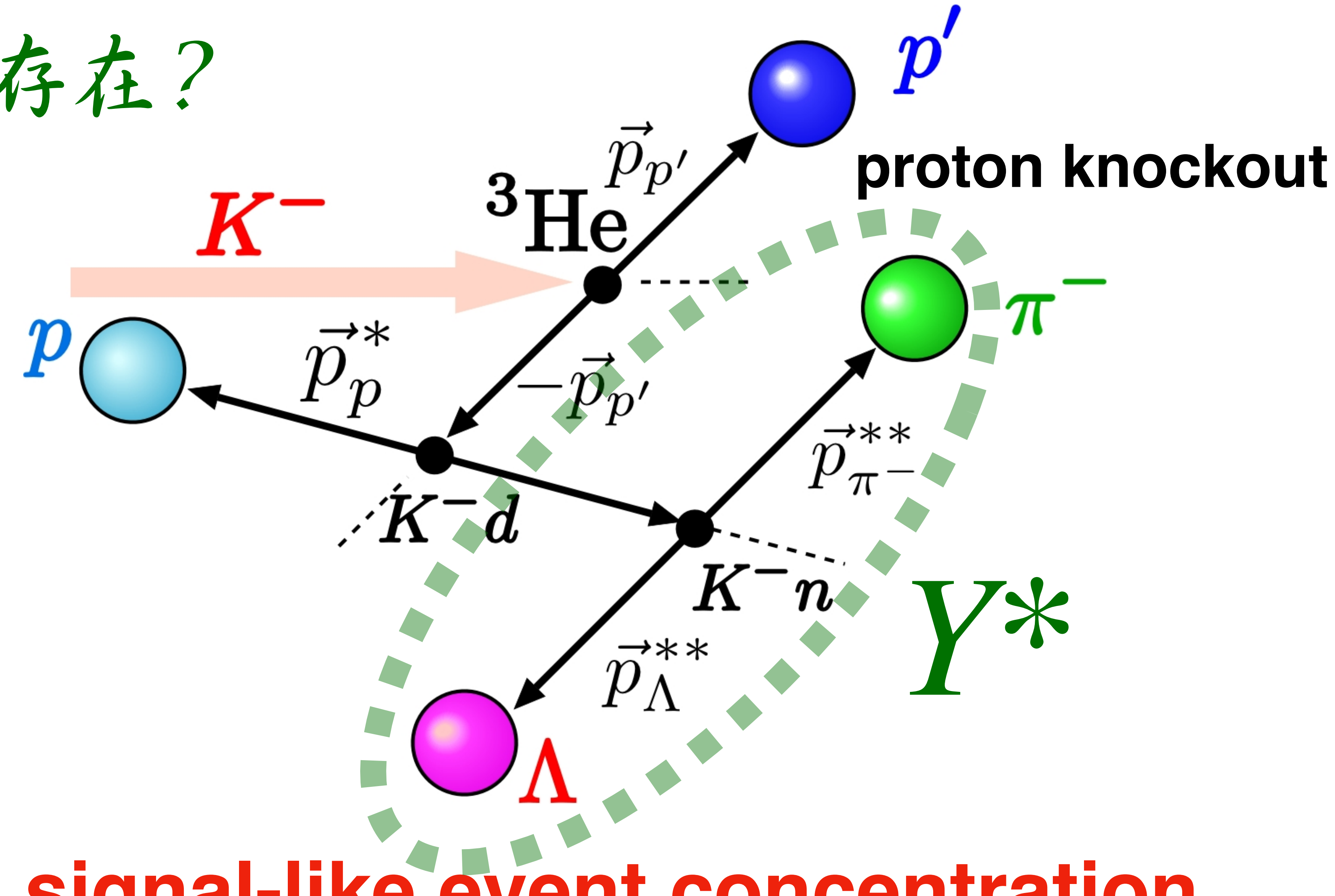
QF-K induced reaction?

$\bar{K}N$ **binding threshold**

$\Sigma(1385)$ contribution is not negligible compared to $(\Lambda p) + n$ final state.

“K^-pp”鏡像核“$\bar{K}^0nn$”の存在？





$\bar{K}^0nn$ signal-like event concentration below $\bar{K}$-bound threshold is seen?

— *twice more data become available in April* —

QF-K induced reaction?

Σ(1385) contribution is not negligible compared to $(\Lambda p) + n$ final state.

event cluster at $m_{\pi^-\Lambda p} \sim \sqrt{s_{K^-d}} \approx 2.83\,\mathrm{GeV}$ is most likely …

2NA: $K^-d \to Y^*p$ reaction leaving p’ as a spectator

核内クラスター構造の存在？

— K^- seems to be sensitive to the deuteron cluster in ^{3}He —

Further analysis on other data

もっと重いK中間子原子核はないのか?

Signal of $\bar{K}NNN$?

系統的研究への第一歩

$K^- + {}^3He \rightarrow (K^- + pp) + n$
$(K^- + pp) \rightarrow \Lambda + p$

➡

$K^- + {}^4He \rightarrow (K^- + ppn) + n$
$(K^- + ppn) \rightarrow \Lambda + d$

Preliminary data analysis for $\bar{K}NNN$ formation study utilizing ${}^4_\Lambda\mathrm{He}$ lifetime measurement via $K^- + {}^4\mathrm{He} \rightarrow \pi^0 + {}^4_\Lambda\mathrm{He}$ reaction giving us a very interesting result

… done by T. Hashimoto

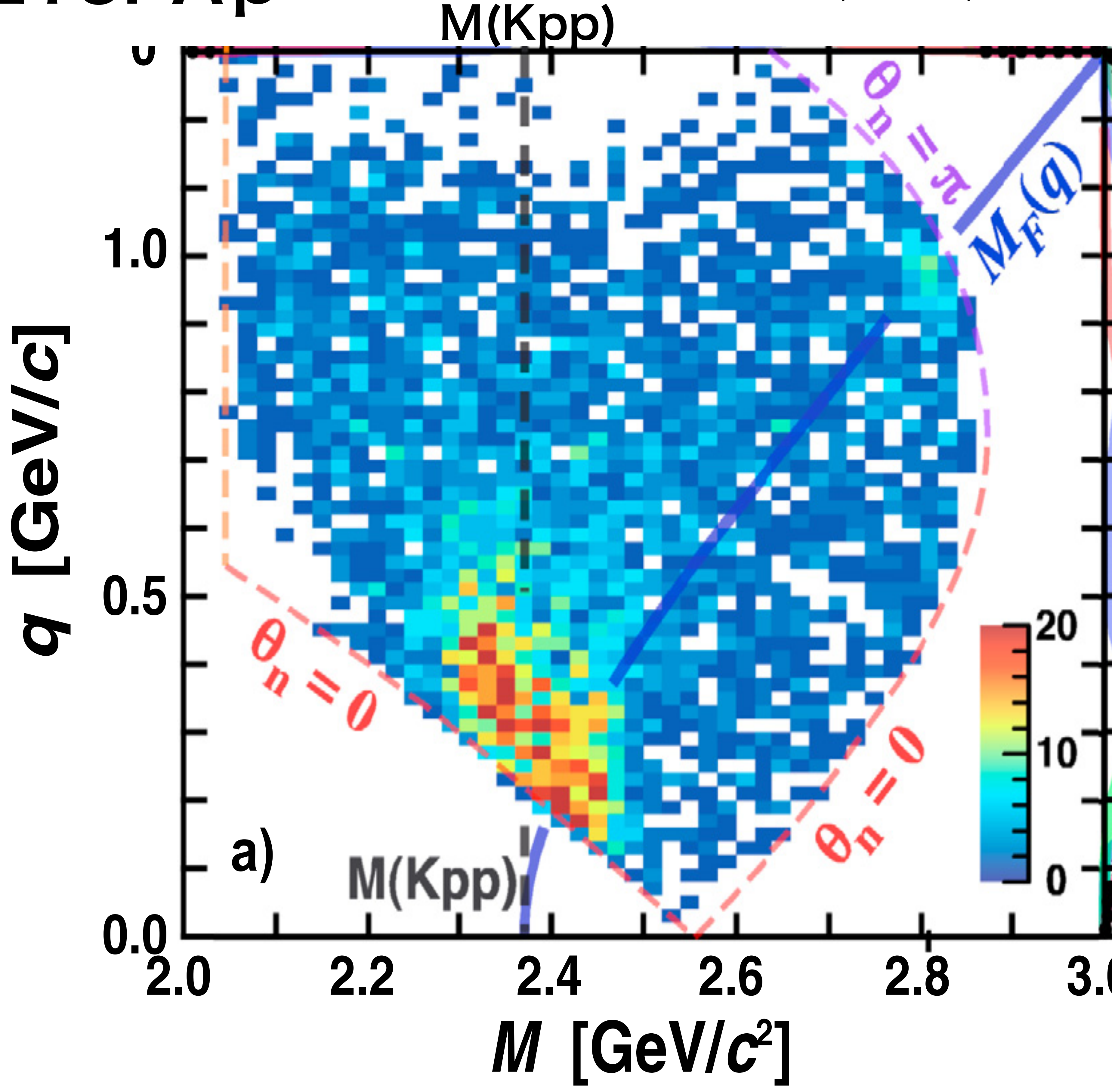
標的核を変えて

Λp on ^{3}He target

Λd on ^{4}He target

E15: Λp

PLB789(2019)620

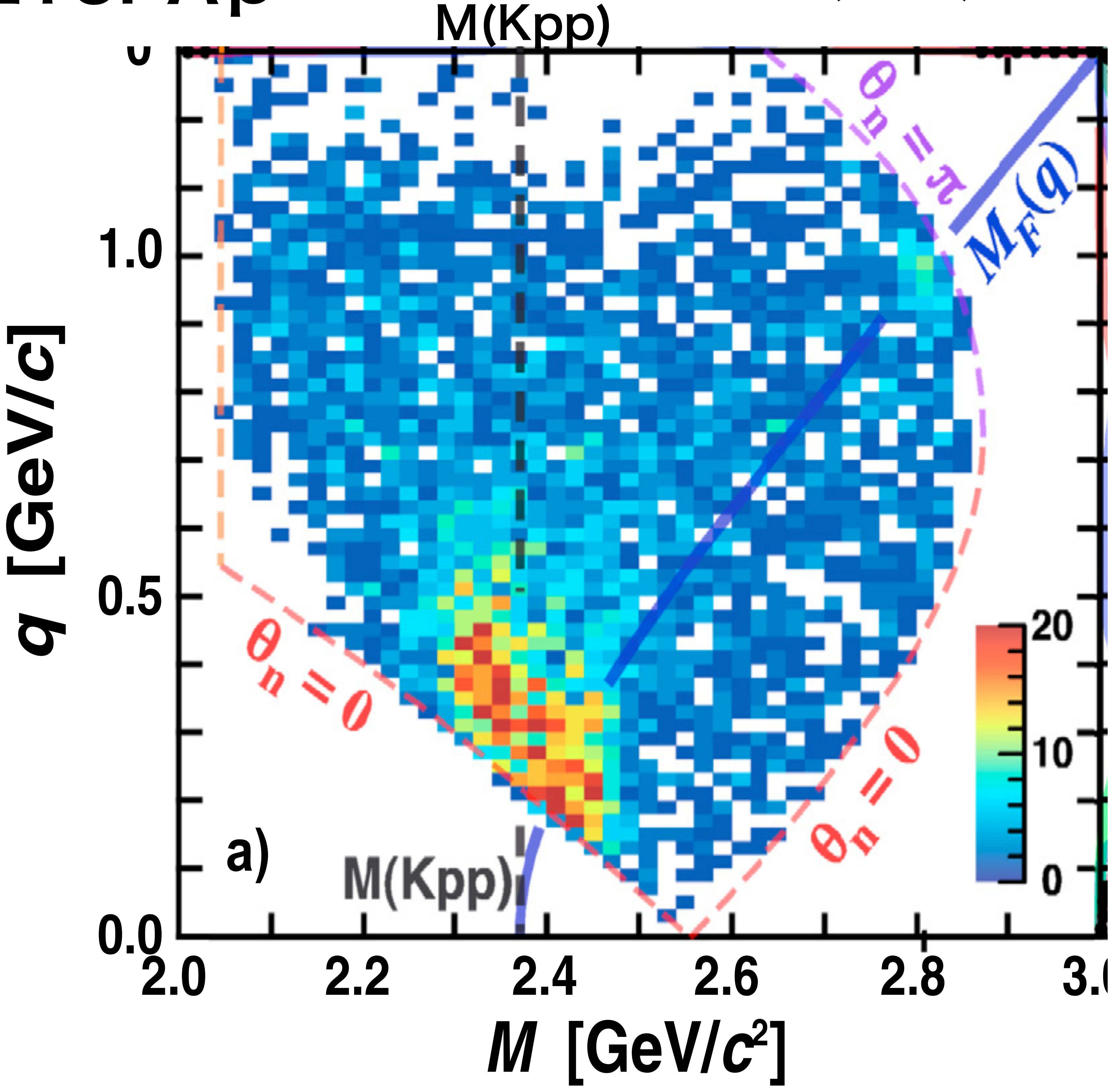


標的核を変えて

Λp on ³He target

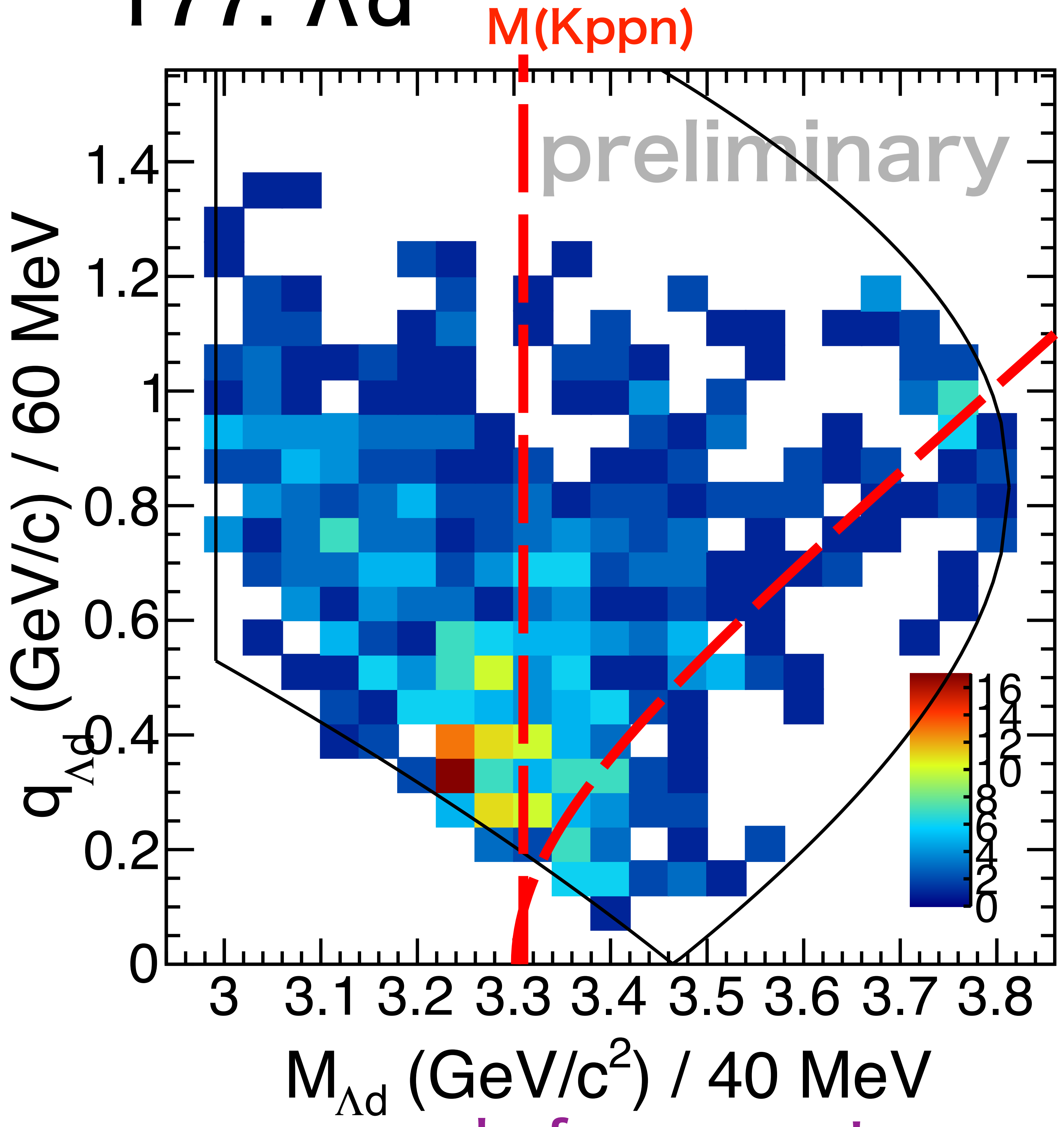
E15: Λp

PLB789(2019)620



Λd on ⁴He target

T77: Λd



before acceptance correction

T. Hashimoto

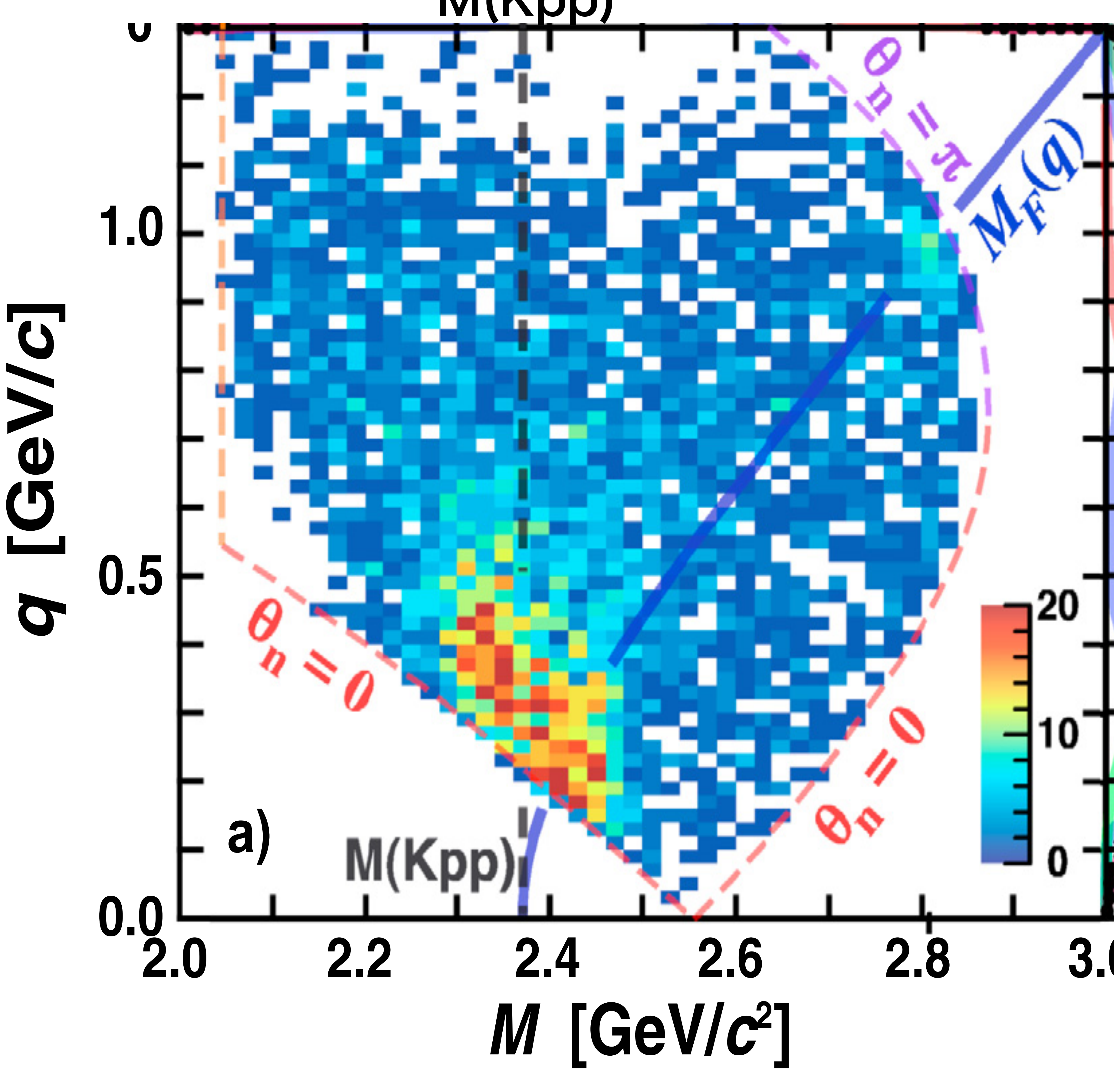
標的核を変えて

Λp on ^{3}He target

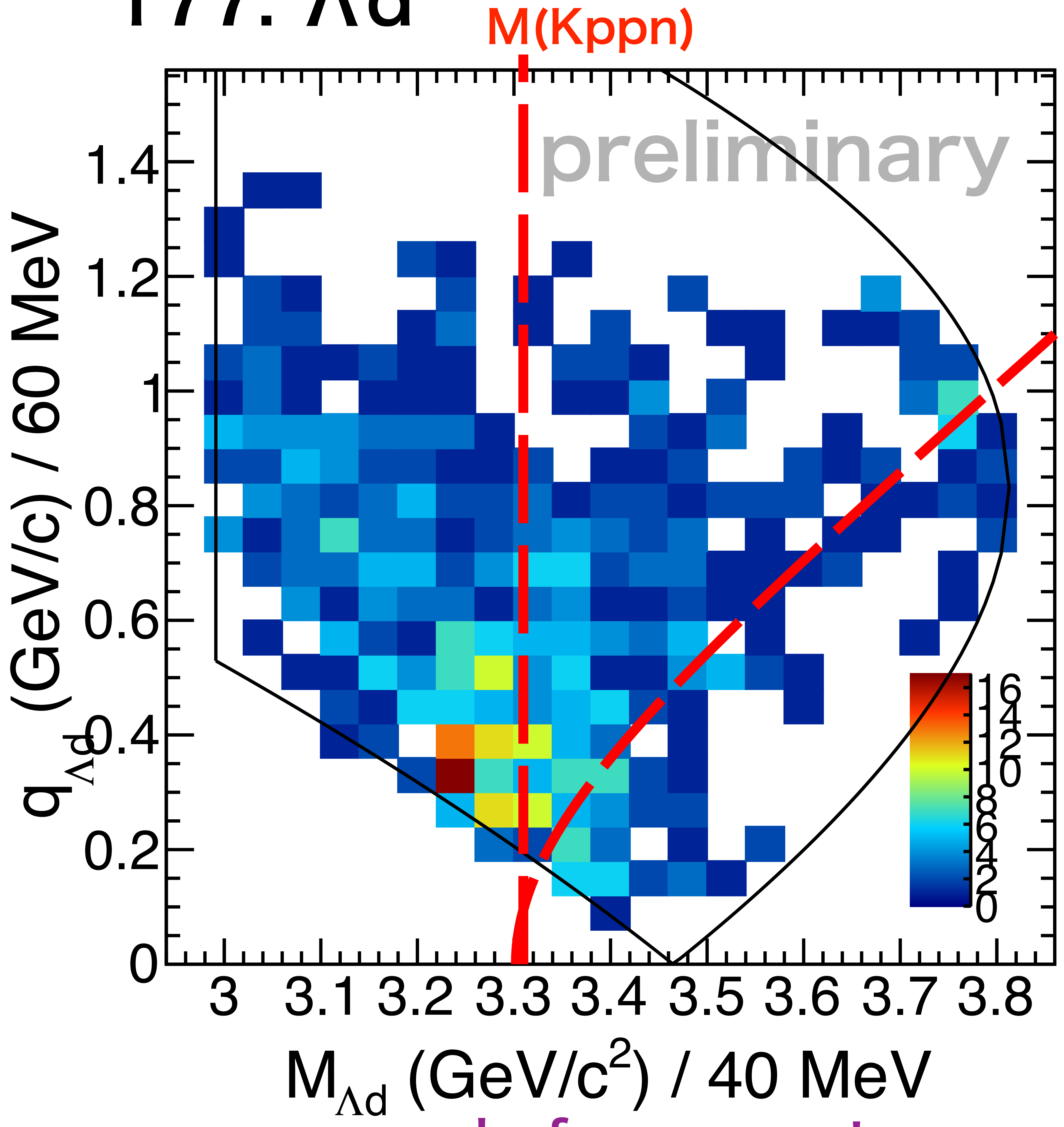
Λd on ^{4}He target

E15: Λp

PLB789(2019)620



T77: Λd



before acceptance correction

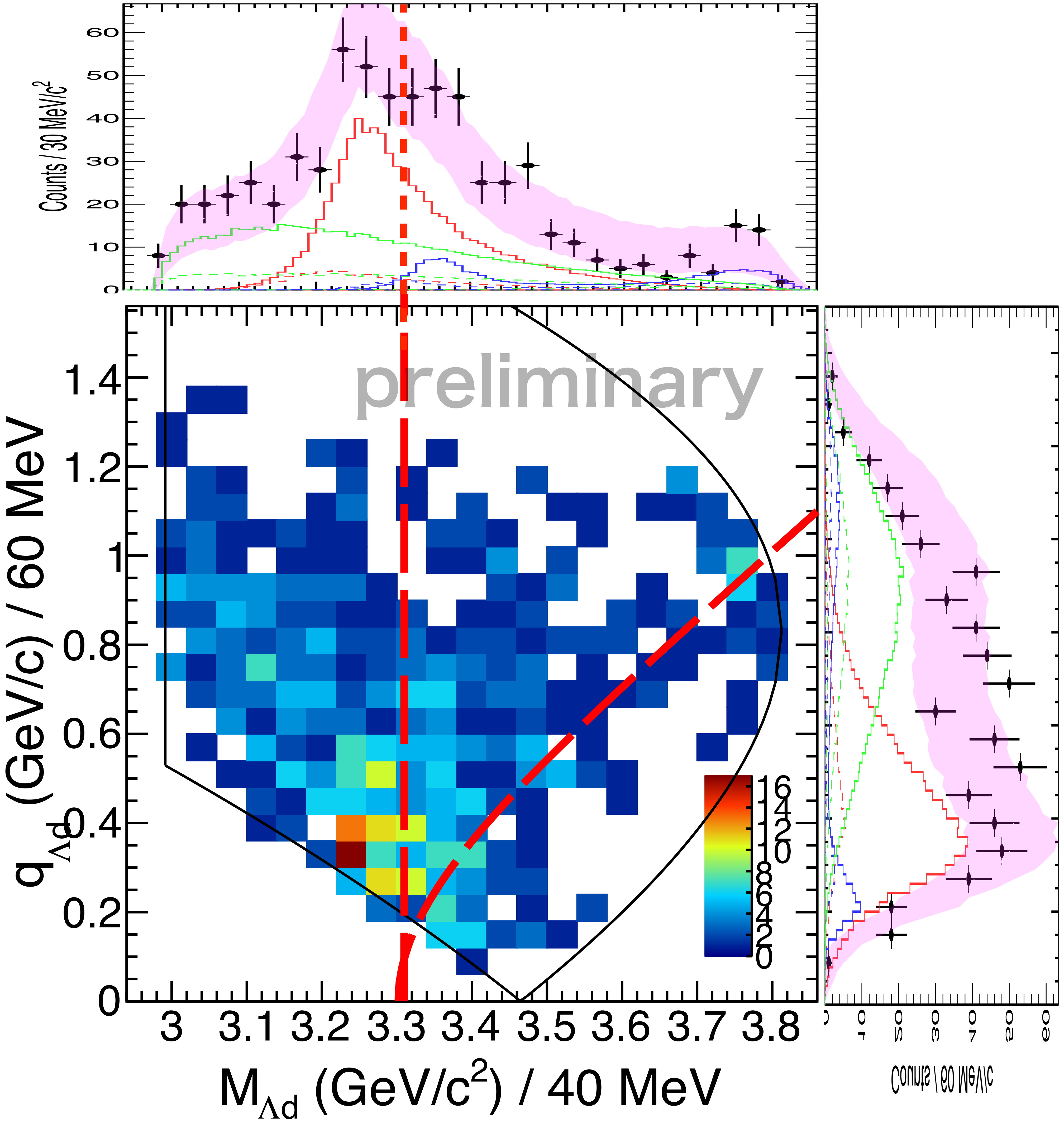
- Two distributions are quite similar
- structure below the threshold, QF-K, and broad background

T. Hashimoto

Λd decay

Promising signal observed similar to $\bar{K}NN \rightarrow \Lambda p$

3核子状態の存在?



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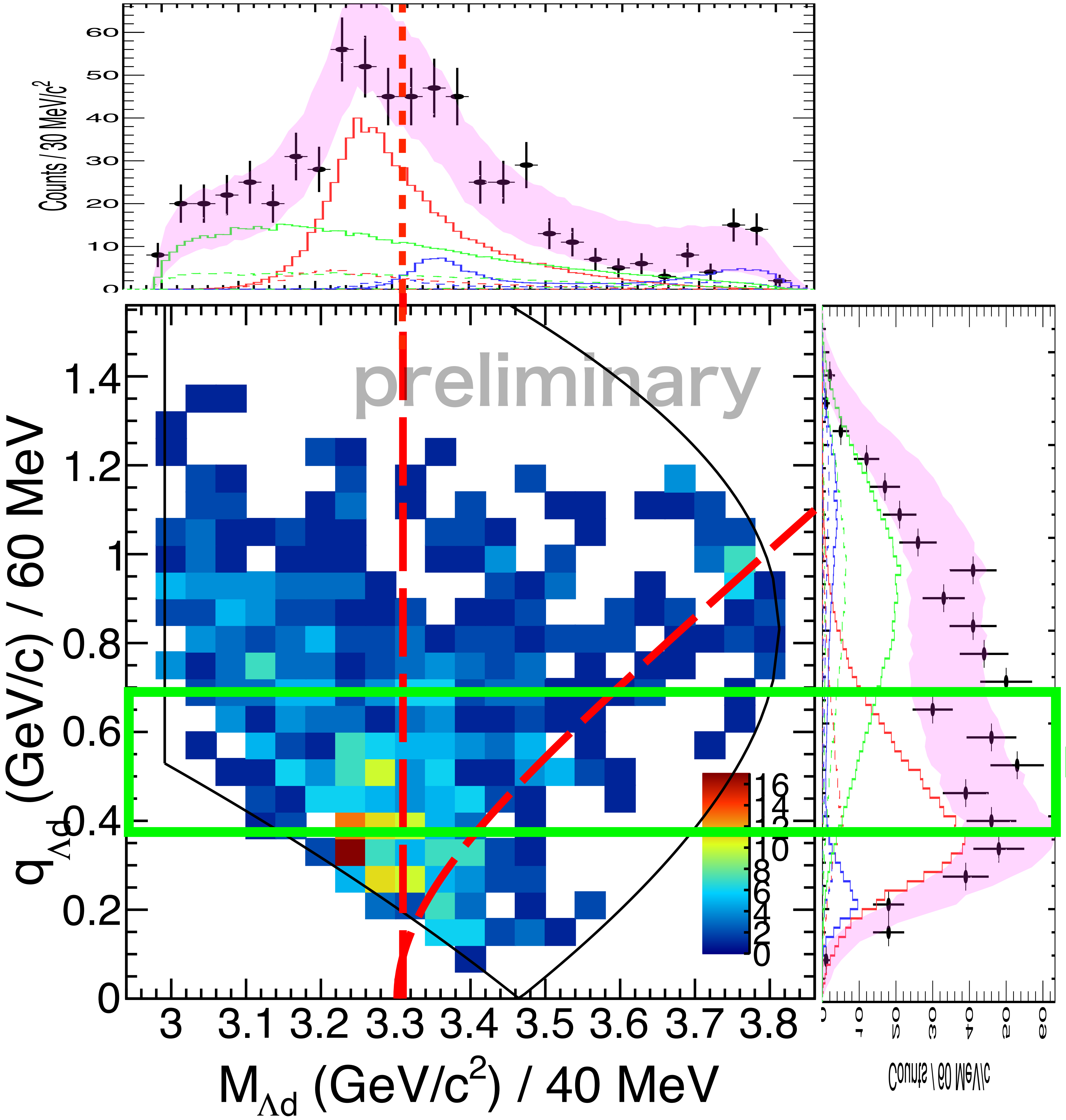
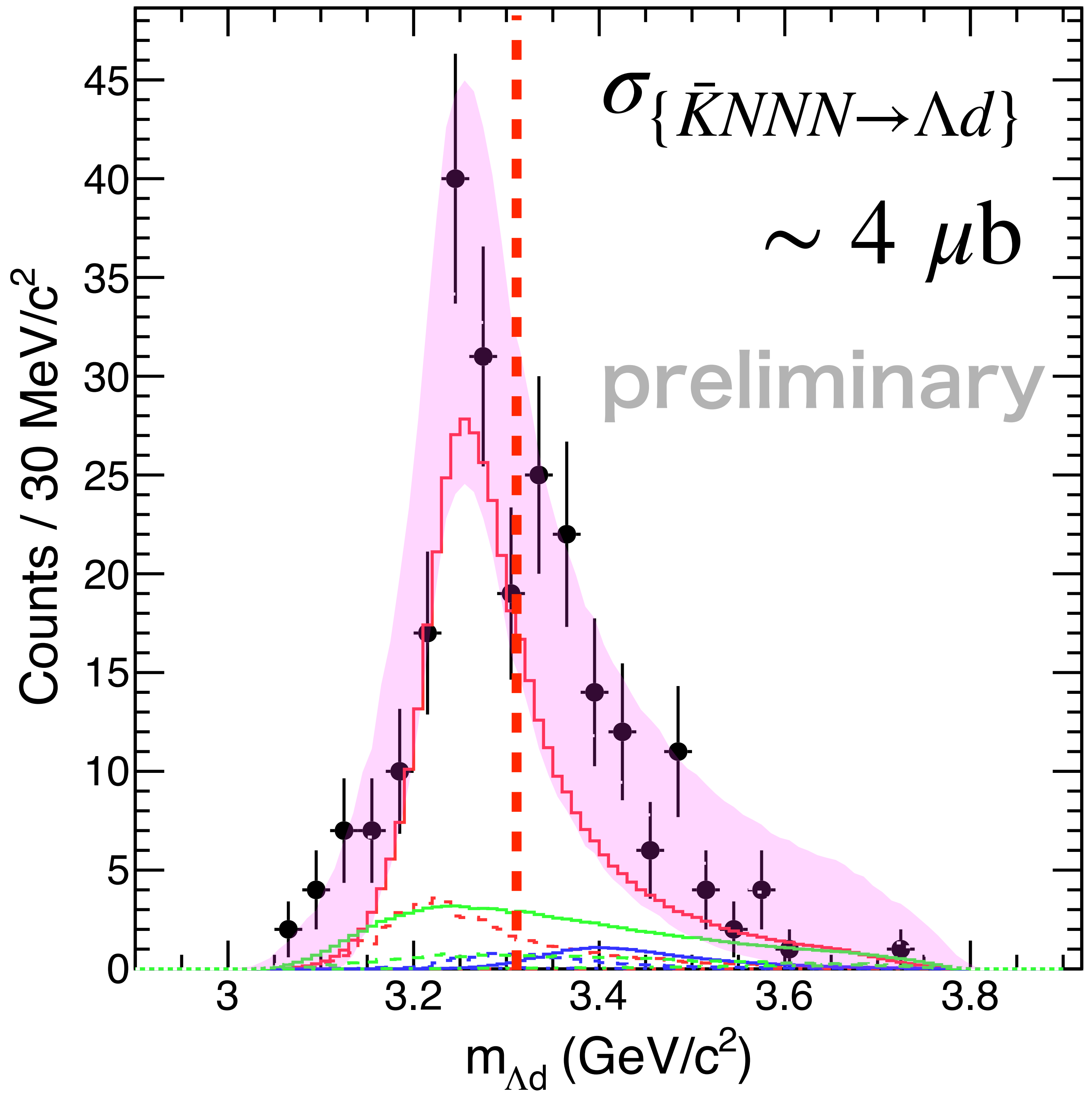


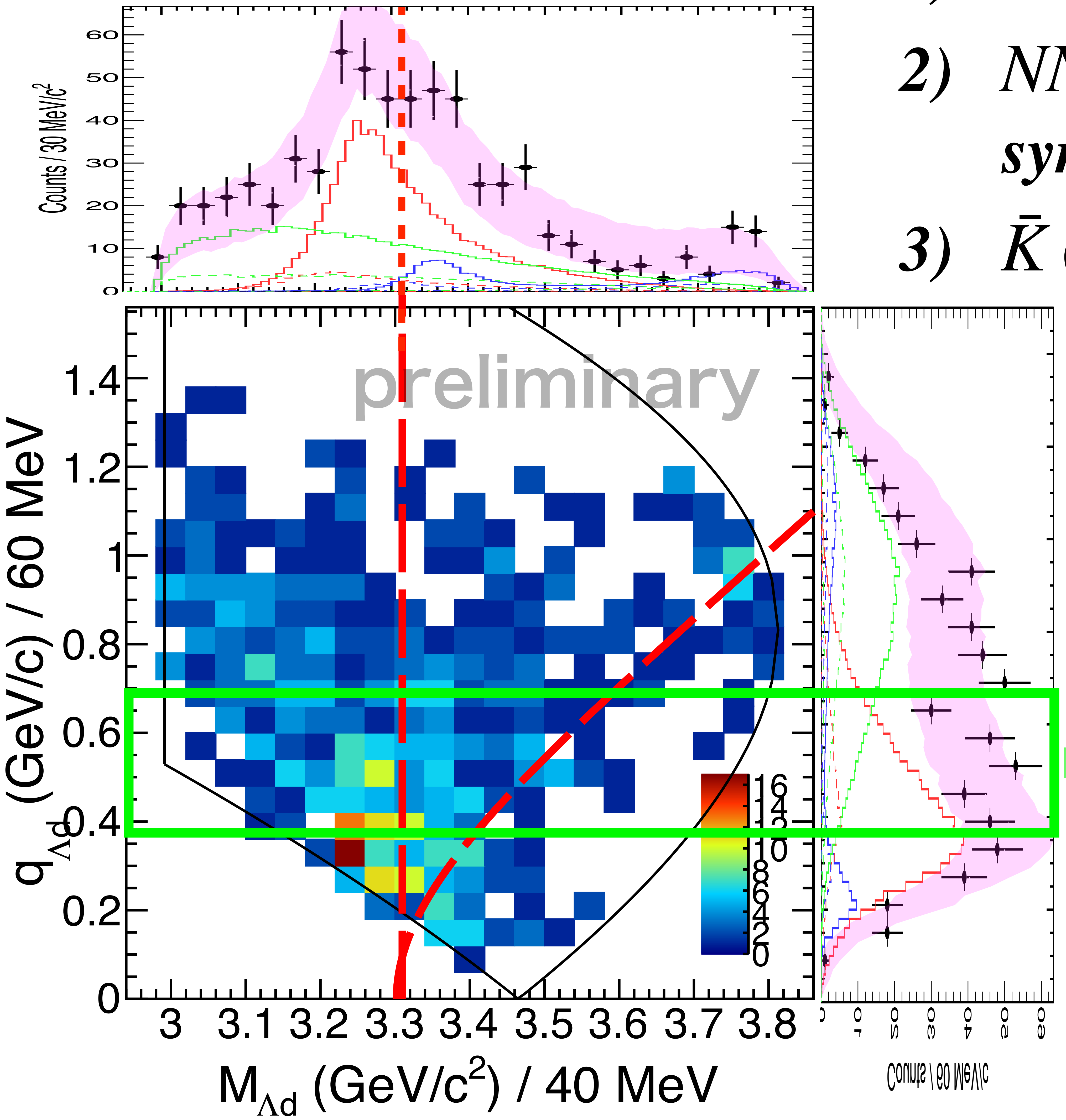
$0.3 < q_{\Lambda d} < 0.6$ GeV/c window



Λd decay – $\bar{K}NNN$ Spin-parity is FIXED to be $I(J^P) = 0\left(\frac{1}{2}^-\right)$.

Promising signal observed similar to $\bar{K}NN \to \Lambda p$

1) *Λd decay requires isospin $I_{\bar{K}NNN} = 0$* 3核子状態の存在?
2) *NNN must be either $(pp)n$ or $p(nn)$, thus the nucleons' symmetry requires $J_{NNN} = 1/2$ and $J_{\bar{K}NNN} = 1/2$*
3) *$\bar{K}$ (pseudo-scaler) presence requires negative parity (P)*



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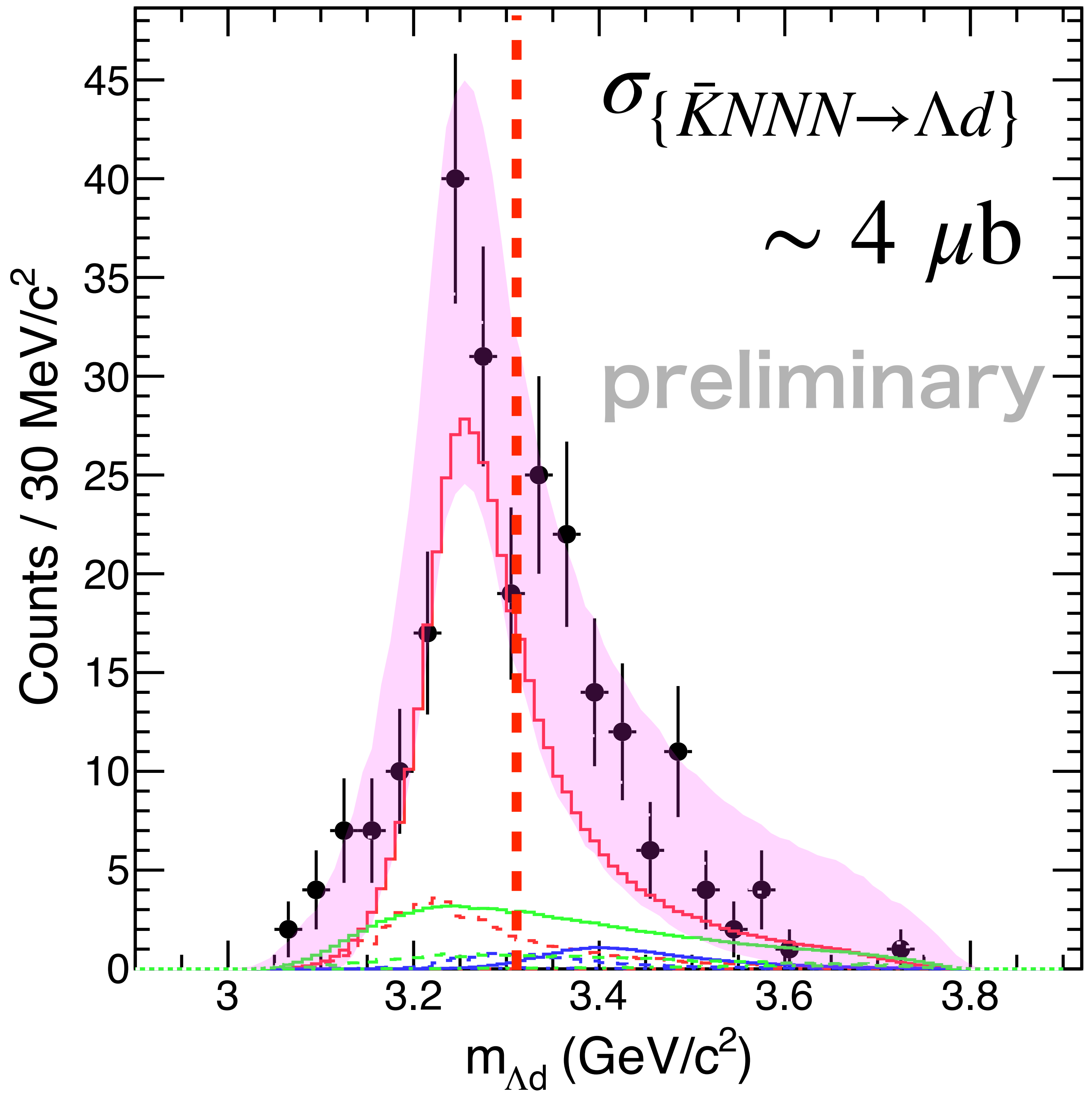


What we learned for kaonic nuclear bound state:

K束縛核についてわかったこと

- $\bar{K}NN$ $\left(I(J^P) = \frac{1}{2}(0^- \text{ or } 1^-?)\right)$ **identified in** $\bar{K}NN \to \Lambda p$ **analysis**

"K^-pp" $\to \Lambda p$ decay requires the isospin to be $I_{\bar{K}NN} = 1/2$.

Phys. Lett. B789, 620-625 (2019)
Phys. Rev. C102, 044002 (2020)

- $\bar{K}NN \to \pi Y p$ **decay dominance** $Br_{\pi Yp} > 10 \times Br_{\Lambda p}$
- $\bar{K}NN$ **isospin partner could be identified in** $\pi^- \Lambda p$ **decay** *twice more data available in April*

$\bar{K}N$ interaction is also strong in $I_{\bar{K}N} = 1$, at least for absorption

Will be published soon… T.Yamaga

- $\bar{K}NNN$ $\left(I(J^P) = 0\left(\frac{1}{2}^-\right)\right)$ **identified in** $\bar{K}NNN \to \Lambda d$ *one more data available in April*

Spin-Parity automatically FIXED!

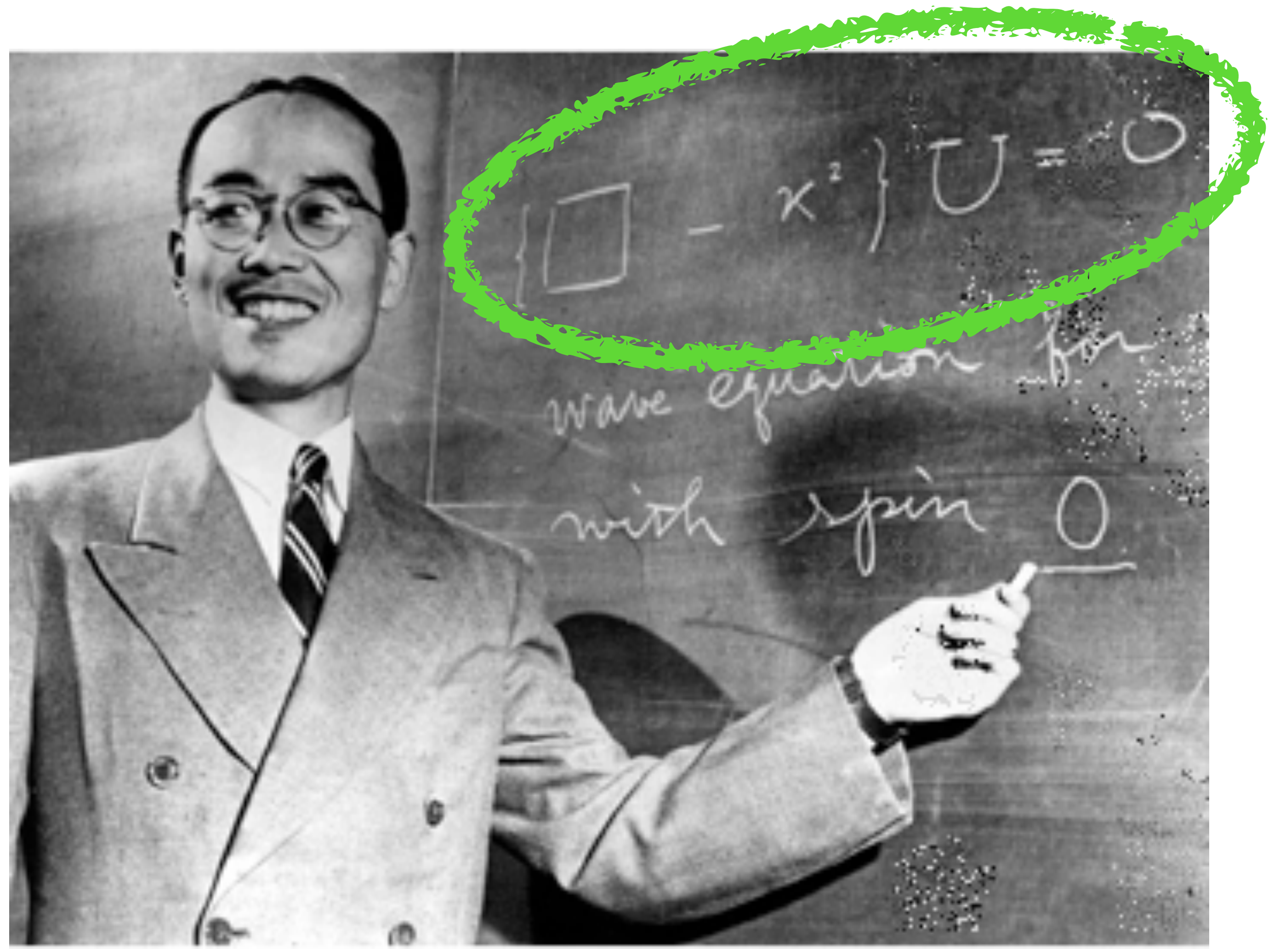
Preliminary analysis → Three nucleon bound state!

Higher statistics is needed to be conclusive… T. Hashimoto

Basic understanding of nuclei

Z [e]	ist	2nd	3rd
$+\frac{2}{3}$	***u***	*c*	*t*
$-\frac{1}{3}$	***d***	*s*	*b*

quark flavor



- Nuclei consist of nucleons bound by nuclear force

nucleons (*N*): ***qqq*** ← → **meson:** $\bar{q}q$

q* = *u* or *d

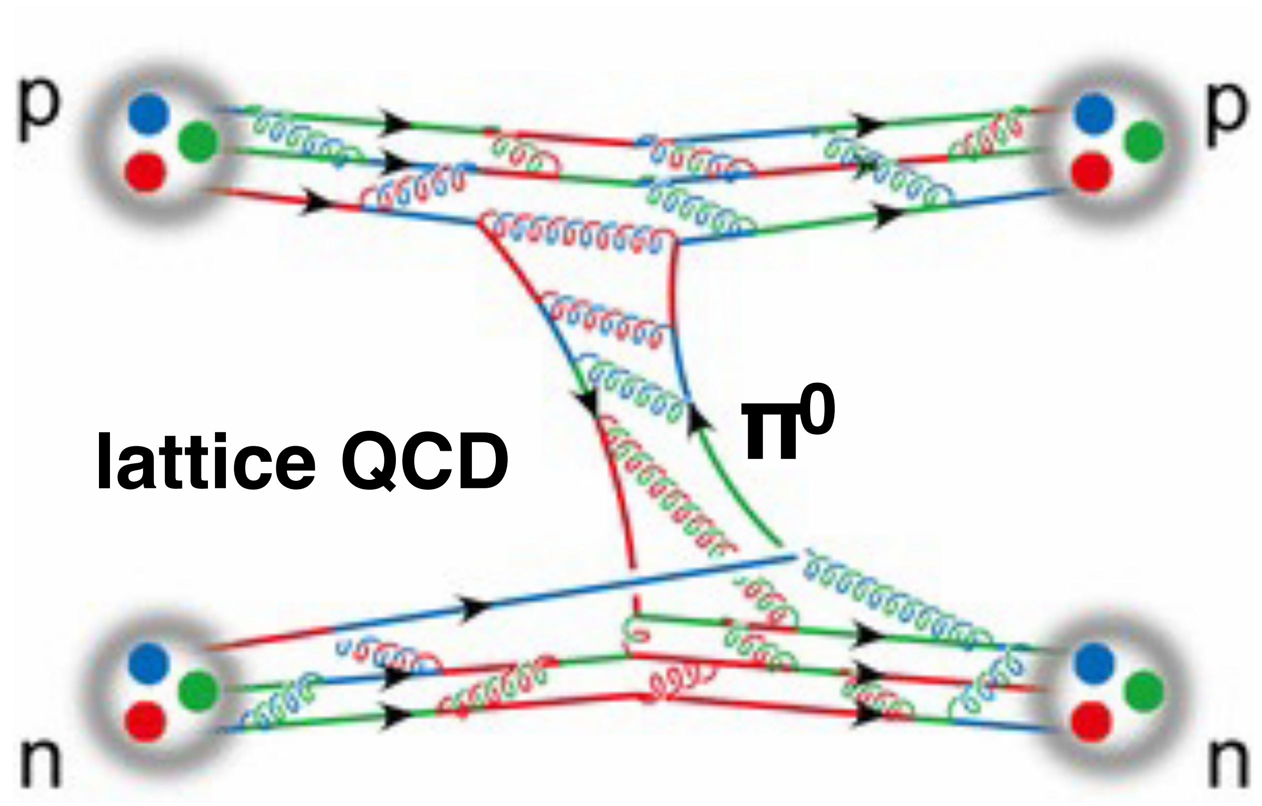
Fermion: Pauli exclusion

Boson: particles can share a quantum state

Yukawa Theorem tells：

- in nuclei, mesons are virtual particles and form nuclear potential

$$\phi \propto \frac{1}{r}\exp(-mr)$$



従来の理解を超えて

Basic understanding of nuclei

- Nuclei consist of nucleons bound by nuclear force

nucleons (N): qqq ⟵ meson: $\bar{q}q$ ⟶

$q = u$ or d

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Z [e]	ist	2nd	3rd
$+\frac{2}{3}$	u	c	t
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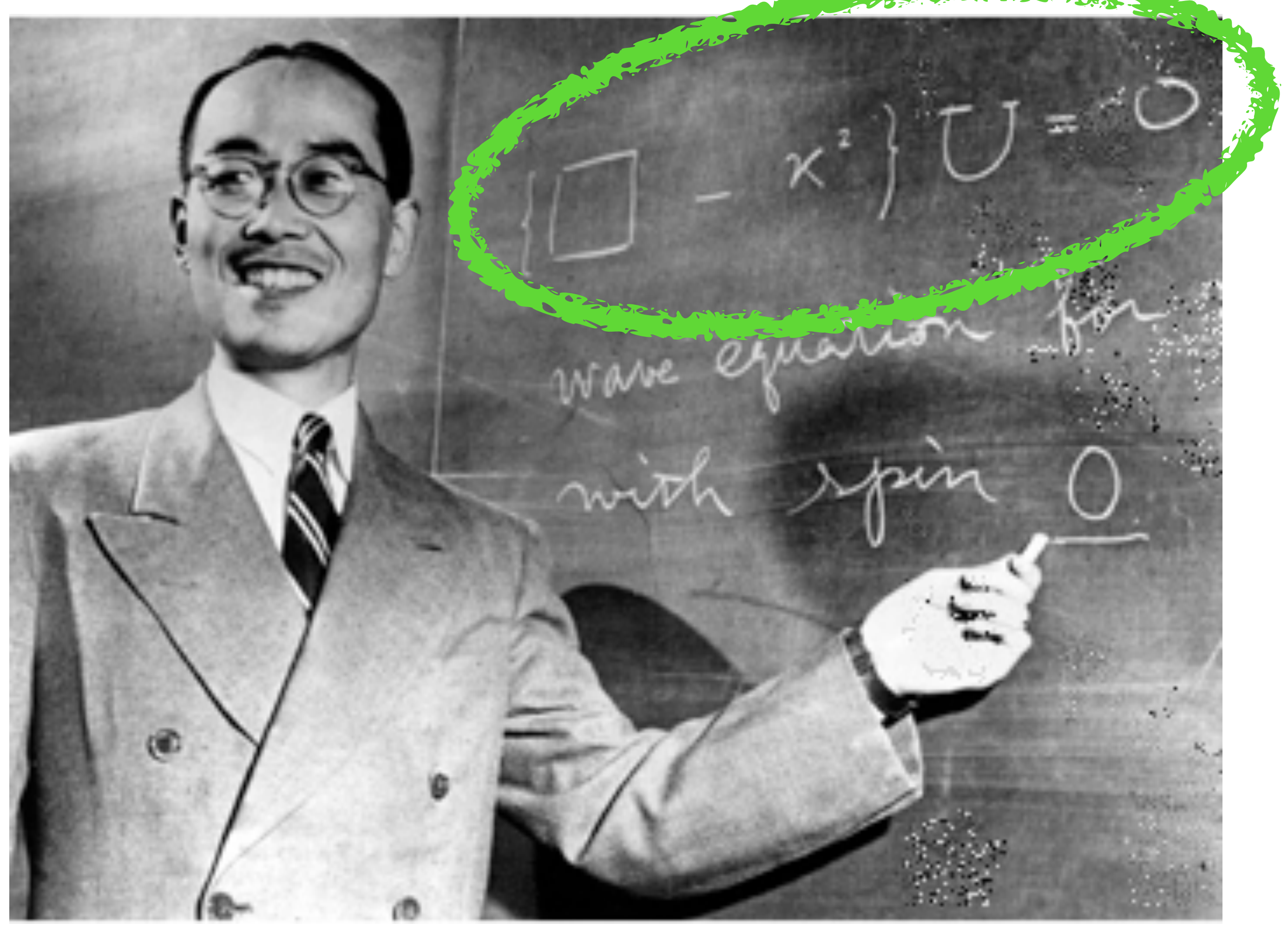
quark flavor



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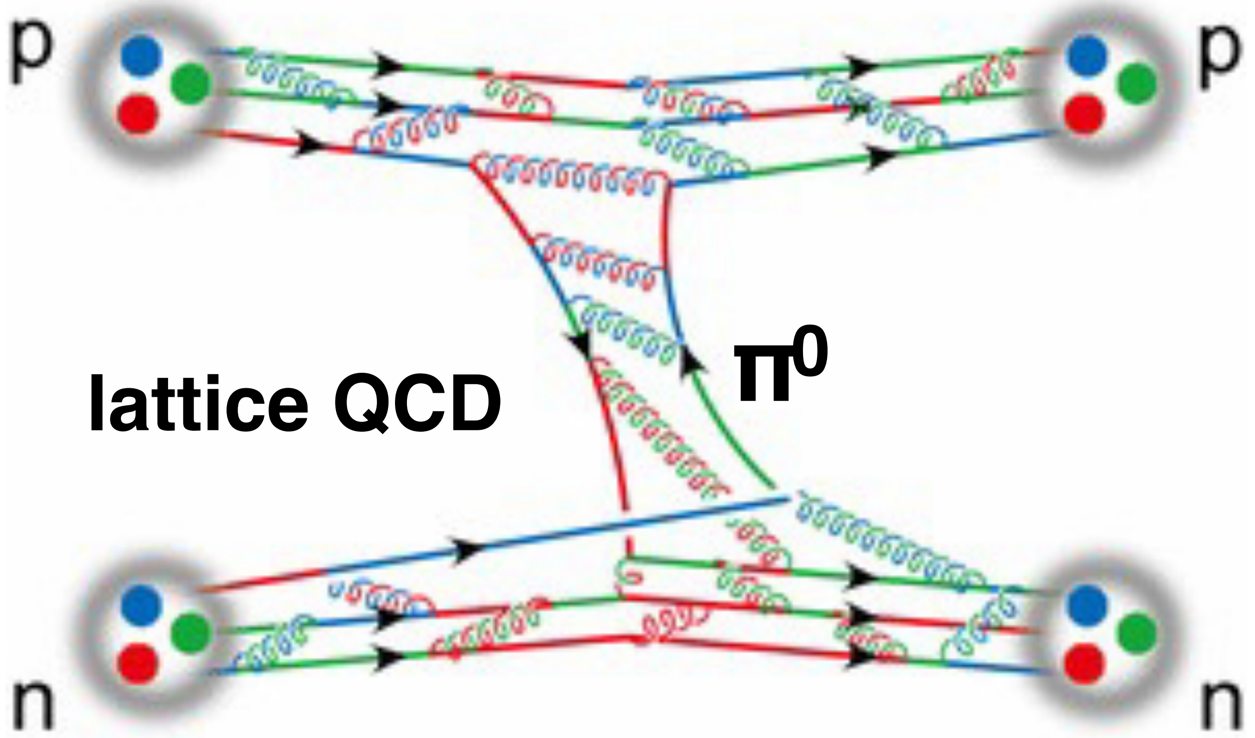

Long standing question：

Can meson be a constituent particle forming nuclei?

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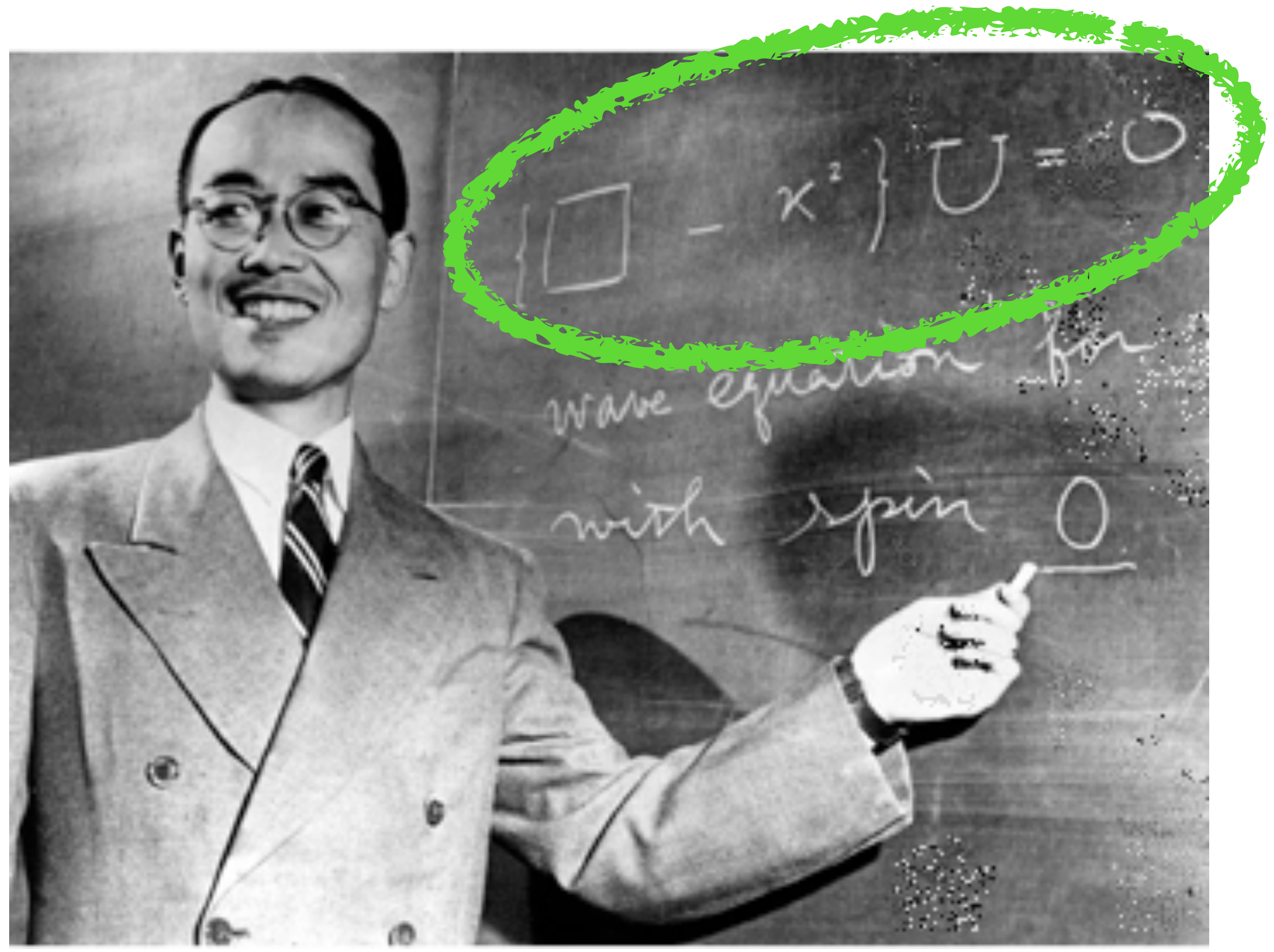

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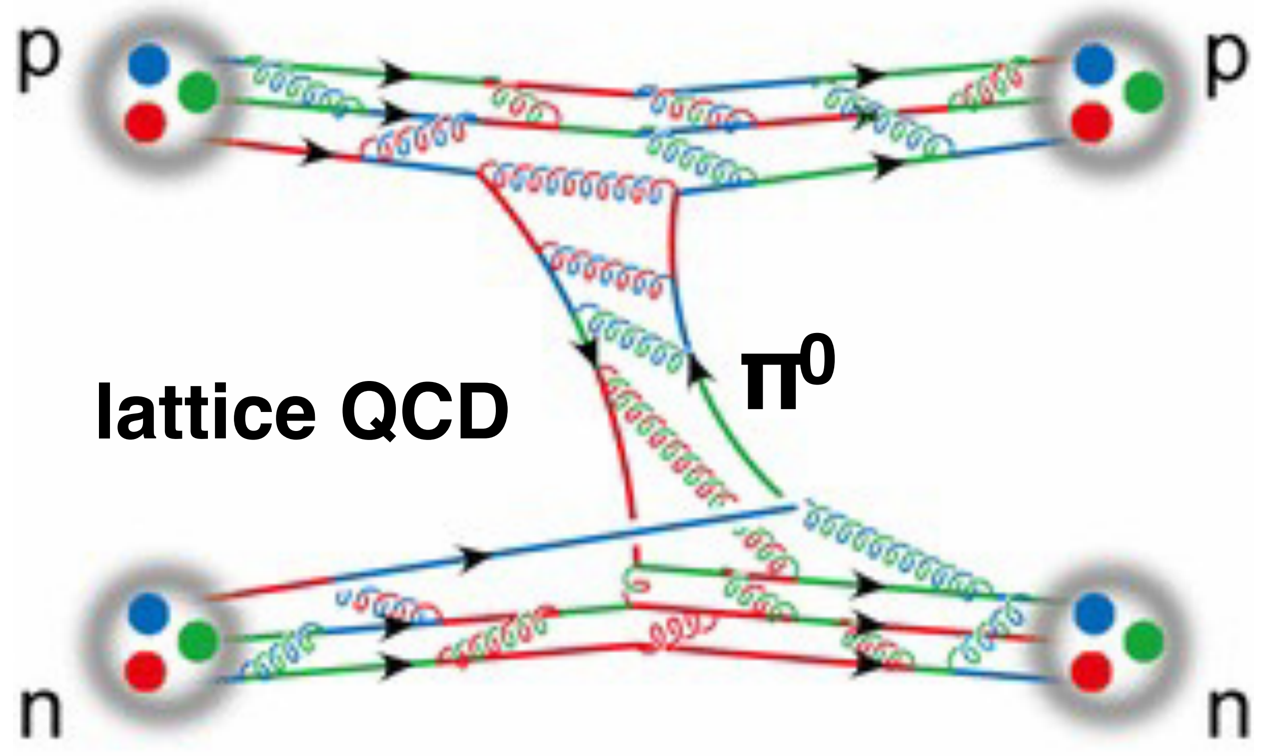

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$\bar{K}$ ($\bar{q}s$) forms a bound state with two nucleons

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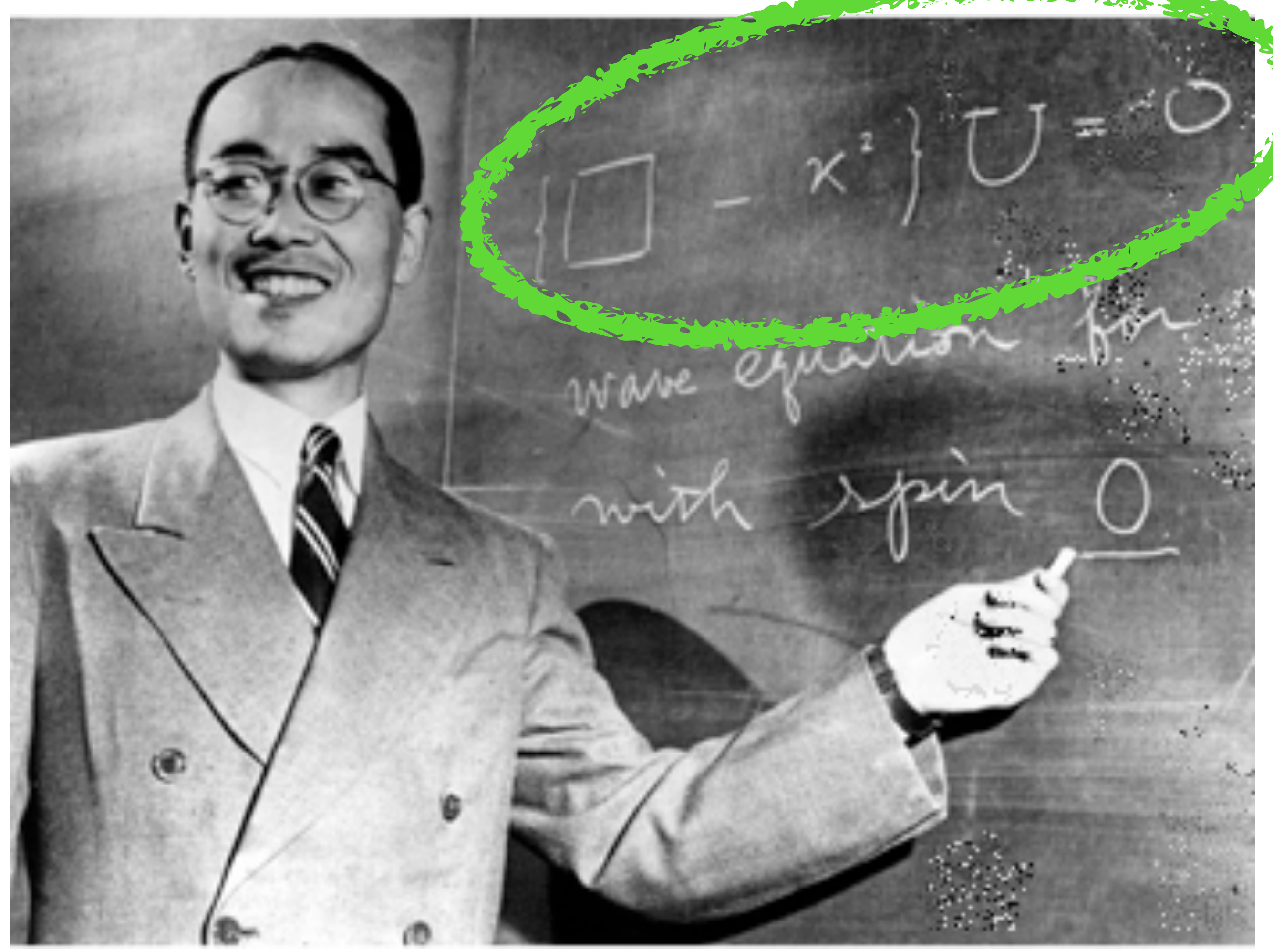

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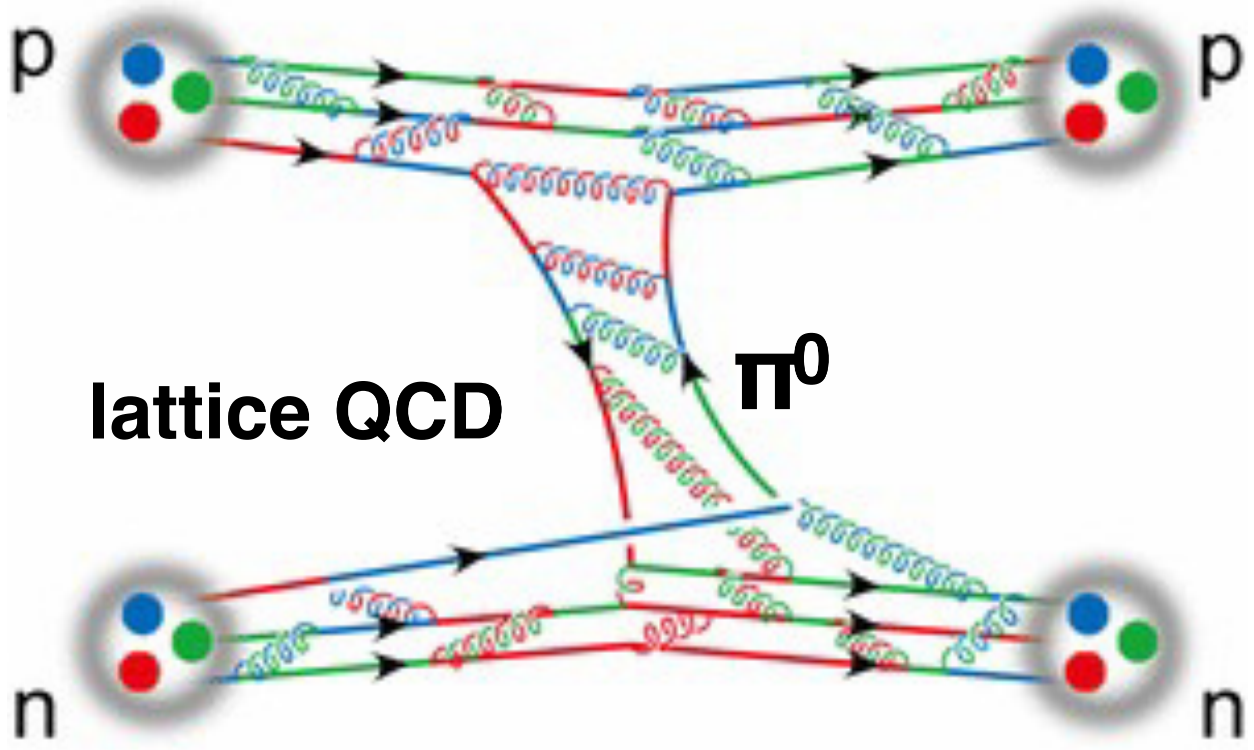

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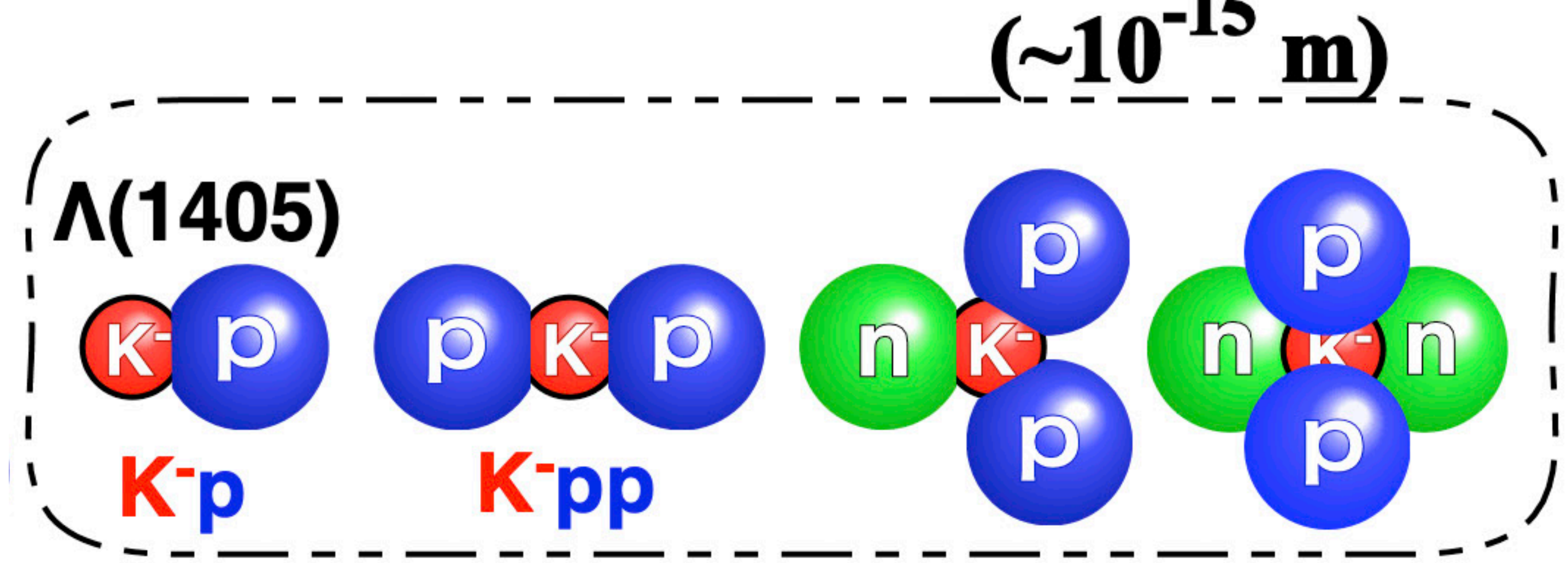
⇒ **totally new probe (impurity) to study inside nuclei**

$\bar{K}$ meson (K^- : $\bar{u}s$, $\bar{K}^0$: $\bar{d}s$)

$I(J^P)$

発展的研究に何を求めるか?



— essential verification for transitioning from “observation” to “discovery” —

Further Verification Study is Required

“Charge Mirror State (isospin partner) exists?”

“What is the Quantum Number $I(J^P)$ *of* $\bar{K}NN$*?”*

“Is the system really compact?”

“Systematic study of Kaonic Nuclei in Heavier System?”

… やることまだまだ山積み … 次世代に期待 …
… 大きな成果ほど、厳しい視線 orz …

Toward next generation experiments!

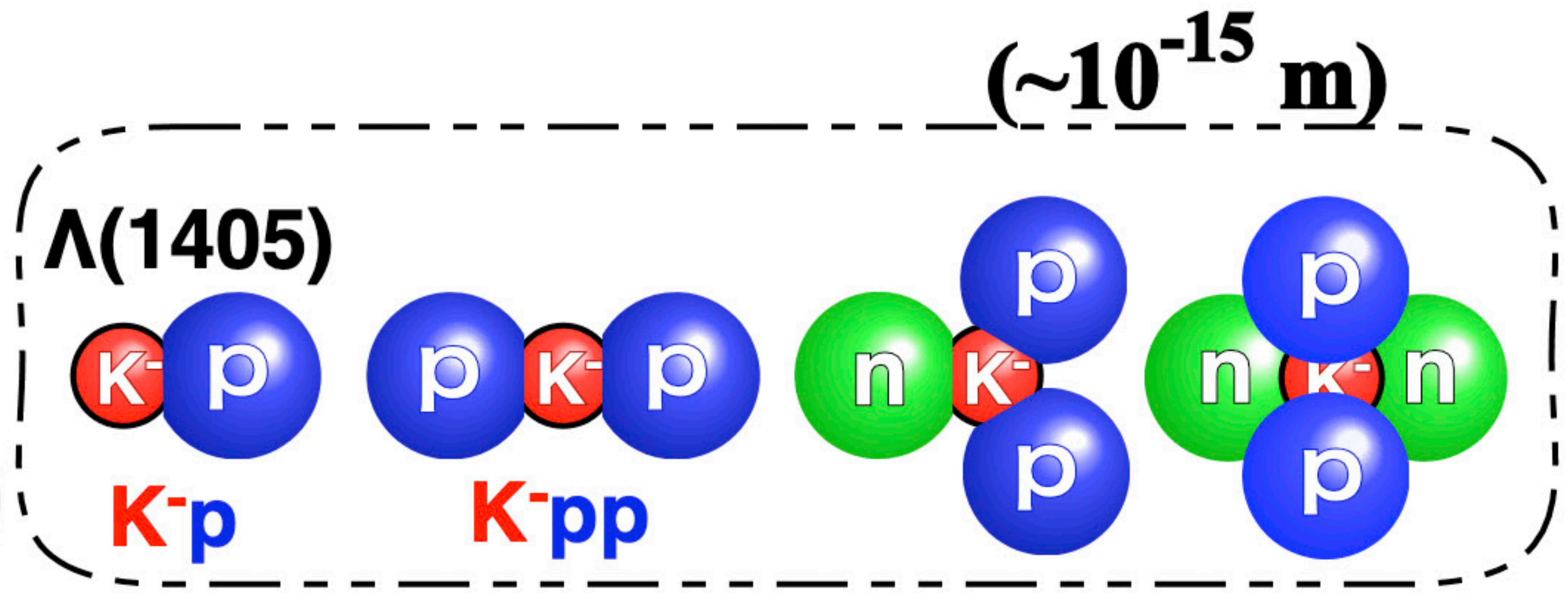
新型スペクトロメータ

Are kaonic nuclei really compact?

Isospin-partner "$\bar{K}^0 nn$" exist?

What is the spin-parity I(J^P)?

Systematic study on



molecule-like hadronic nuclear cluster

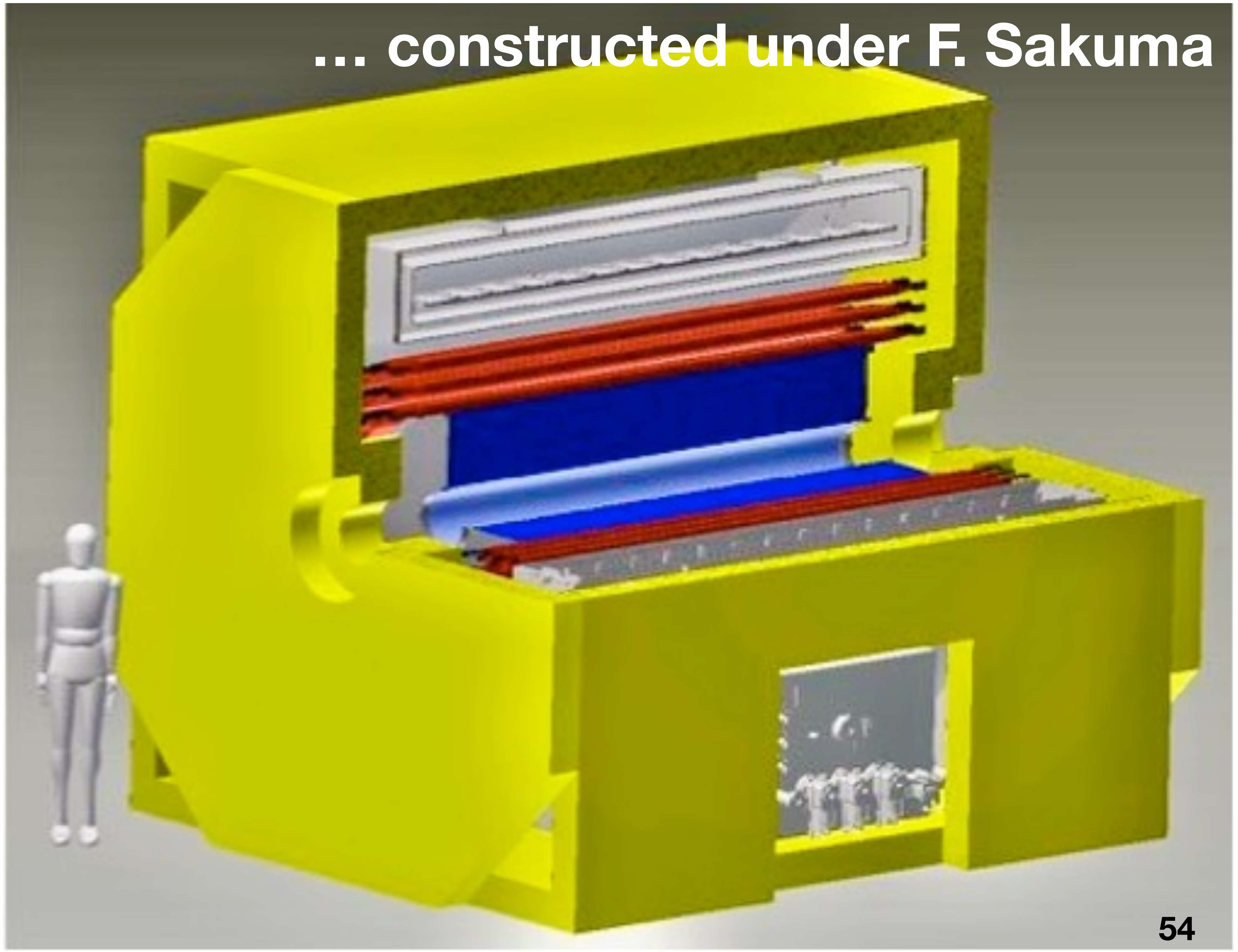
"Does it have a unique shape like a chemical molecule?"

New spectrometer based on Grant-in-Aid (MEXT)

for Specially Promoted Research … M. Iwasaki — 2022-2026

for Scientific Research (S) … F. Sakuma — 2024-2028

expecting collaborative inputs from international collaborators



How to study the size?

系のサイズ研究をどう進めるか?

Simple method for $\bar{K}NN$:

— **Reaction Form(structure)-Factor**

In PWIA, reaction dynamics is ignored, and simply applied delta function.

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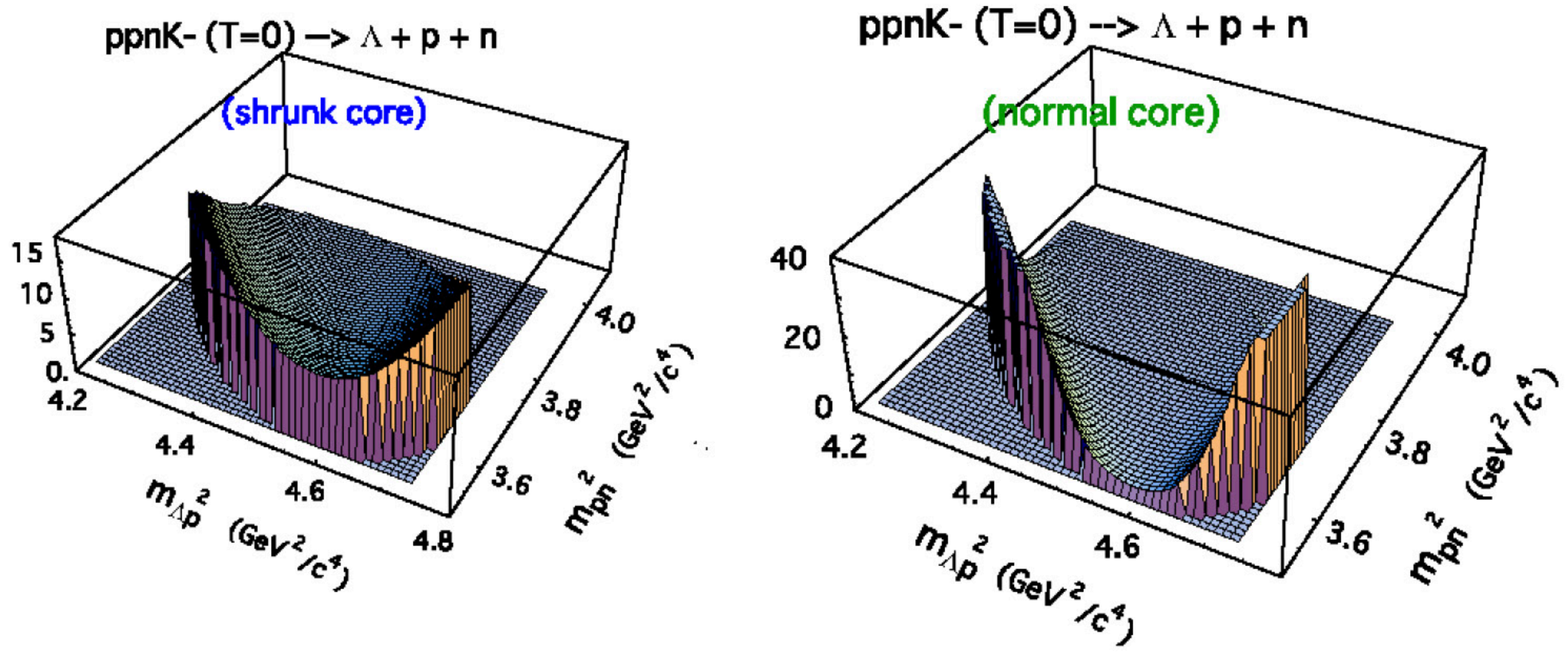
P. Kienle, Y. Akaishi, T. Yamazaki: Phys. Lett. B 632 (2006) 187



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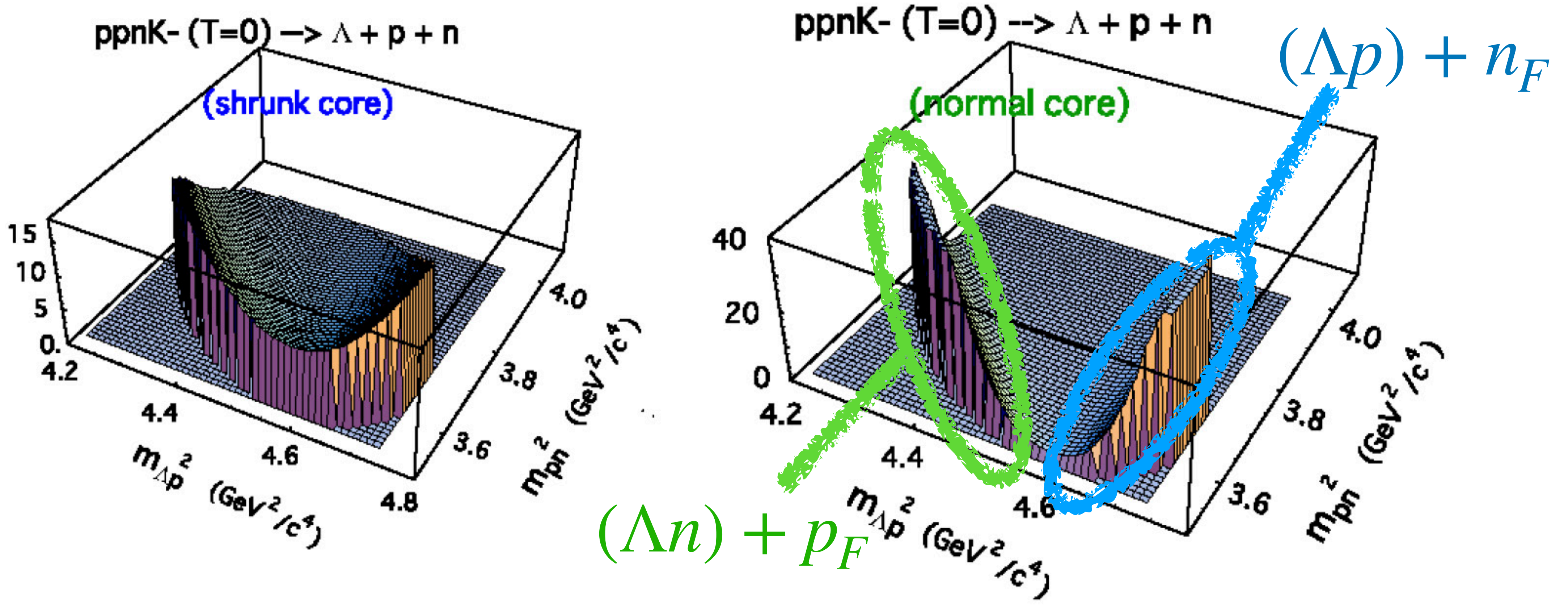

If it decays in kaon-2NA process, $(\bar{K}NN)N \to (\Lambda N) + N_F$, *then the* N_F *should have Fermi-momentum of the system.*

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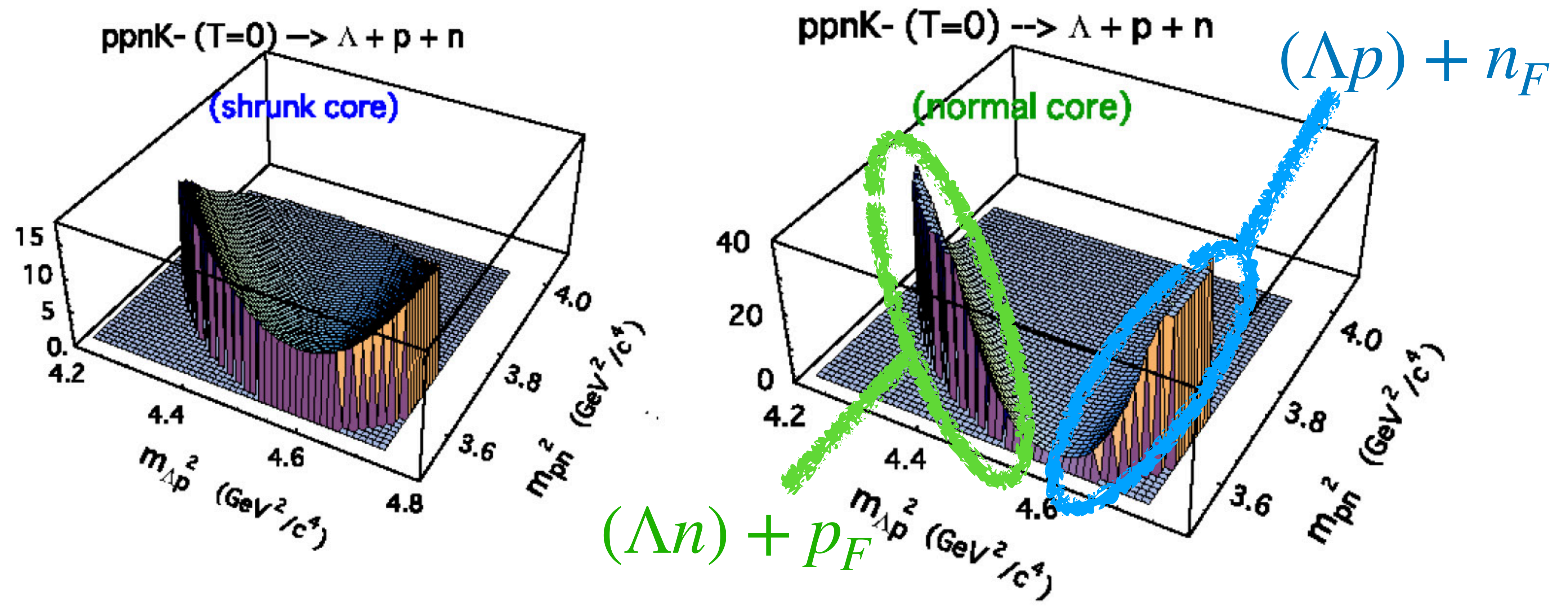

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It would be more easy to understand to form deuteron in 3NA with coalescence $\bar{K}NNN \rightarrow (\Lambda NN) \rightarrow \Lambda + d$ or the system size is compatible as $R = \hbar / p_F \sim 0.4\,\mathrm{fm}$?

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— Substantial theoretical progress is needed —

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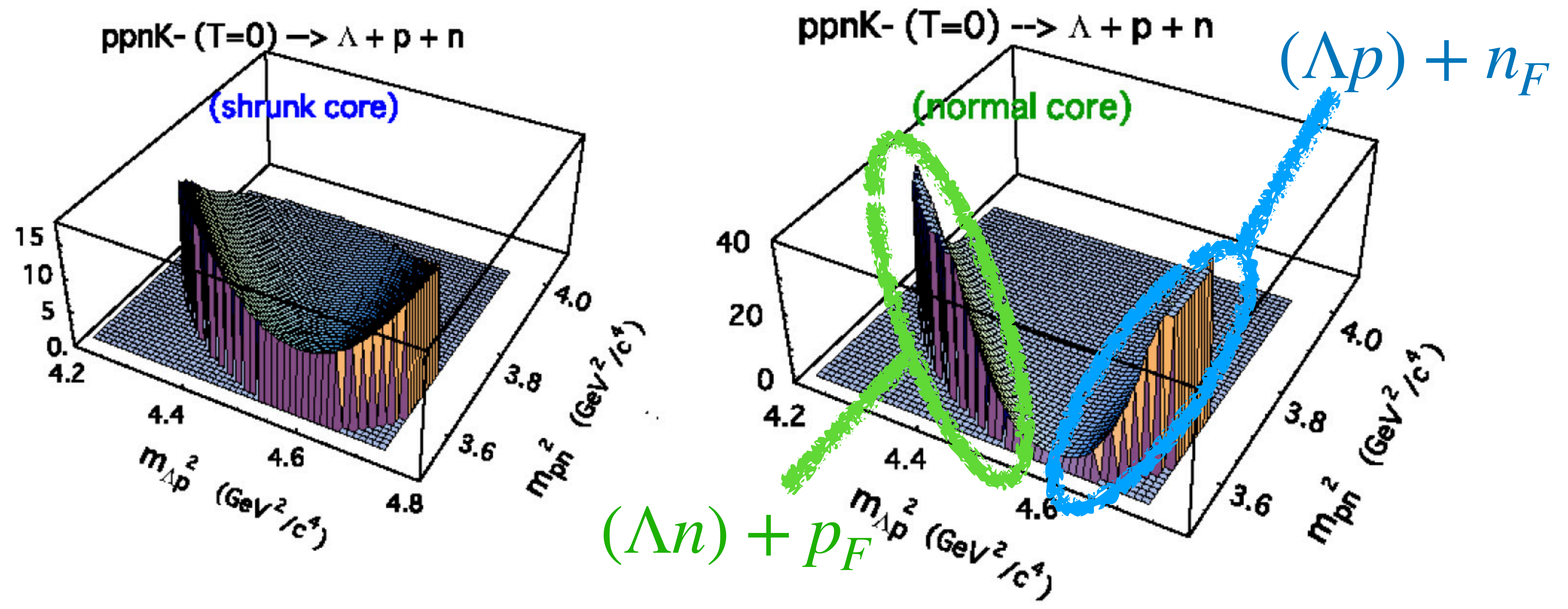

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Spin-Parity I(J^P) Assignment for $\bar{K}NN$

… 量子状態の性質を決める最も基本的な量子数 …

… $I_{\bar{K}N} = 0$ チャネルが引力的なので、ほぼ間違いなく $I(J^P) = 1/2(0^-)$ であろう。ただし、本質的な理解のために実験的に決めることが重要。しかし、その決定は極めて困難…

Two possible internal structures: I(J^P) ?

スピンパリティ状態の2つの可能性

$\bar{K}NN$: $I = 1/2$, $J^P = 0^-$: $I_{NN} = 1$, $S_{NN} = 0$, $L_{\bar{K}} = 0$

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Thus, $J^P = 0^-$ or 1^-

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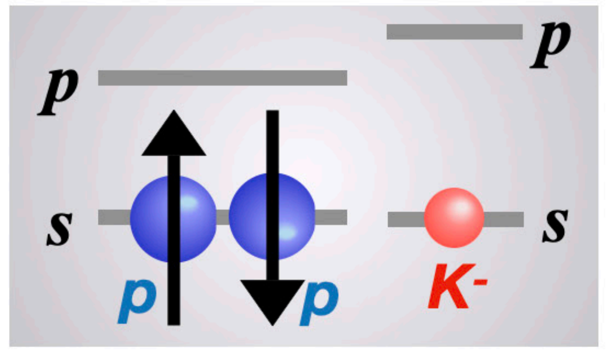
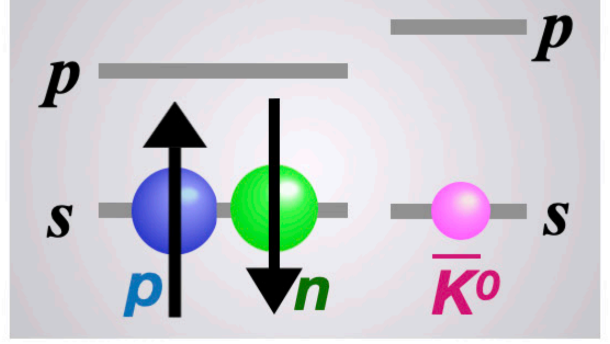
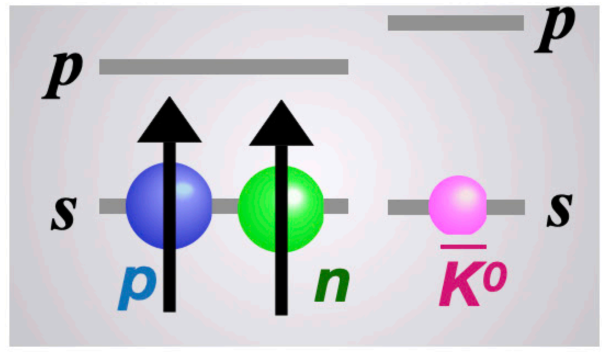
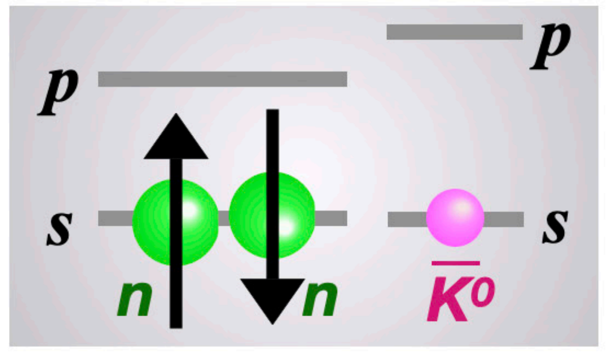
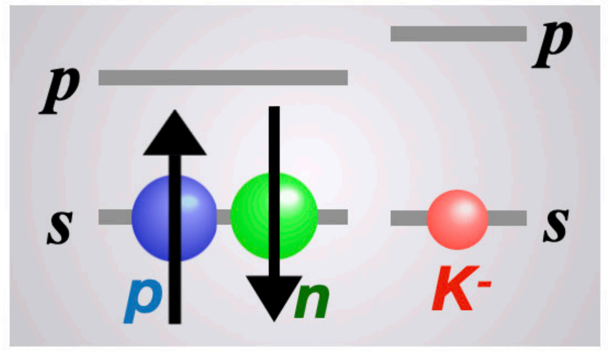
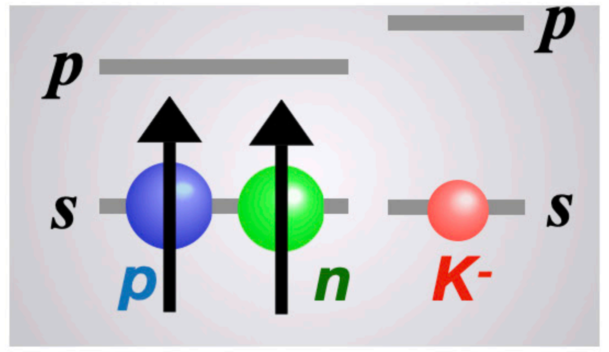
"K^-pp" $I_3(\bar{K}NN) = +\frac{1}{2}$	 +  $-\sqrt{\frac{1}{3}}\left(\sqrt{2}K^-pp + \bar{K}^0\frac{pn+np}{\sqrt{2}}\right) \otimes \left(\frac{\uparrow\downarrow - \downarrow\uparrow}{\sqrt{2}}\right)$	 $\bar{K}^0\frac{(pn-np)}{\sqrt{2}} \otimes \left(\uparrow\uparrow, \frac{\uparrow\downarrow + \downarrow\uparrow}{\sqrt{2}}, \downarrow\downarrow\right)$
"$\bar{K}^0nn$" $I_3(\bar{K}NN) = -\frac{1}{2}$	 +  $-\sqrt{\frac{1}{3}}\left(\sqrt{2}\bar{K}^0nn + K^-\frac{pn+np}{\sqrt{2}}\right) \otimes \left(\frac{\uparrow\downarrow - \downarrow\uparrow}{\sqrt{2}}\right)$	 $-K^-\frac{(pn-np)}{\sqrt{2}} \otimes \left(\uparrow\uparrow, \frac{\uparrow\downarrow + \downarrow\uparrow}{\sqrt{2}}, \downarrow\downarrow\right)$
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$\frac{\sigma_{\bar{K}^0nn}}{\sigma_{K^-pp}}$	$0.13 \sim 0.15$	~ 0.75

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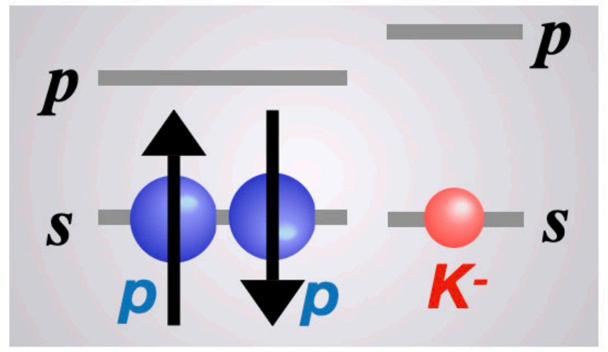
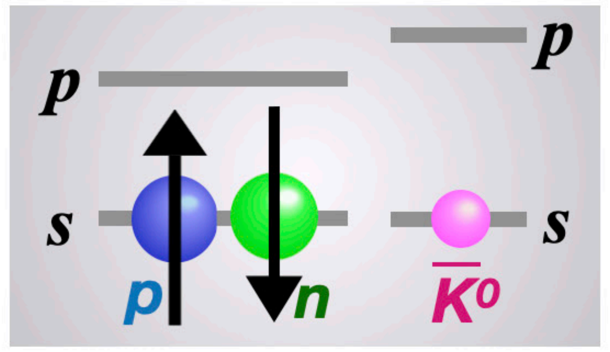
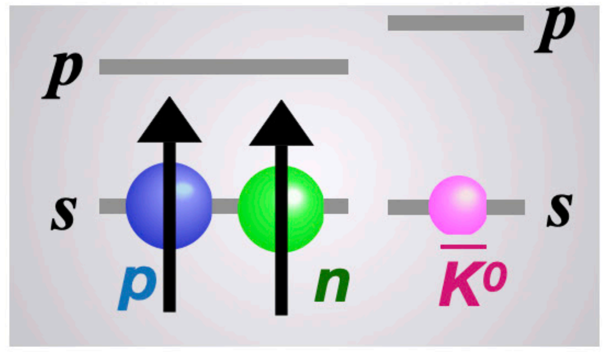
"K^-pp" $I_3(\bar{K}NN) = +\frac{1}{2}$	 + 	
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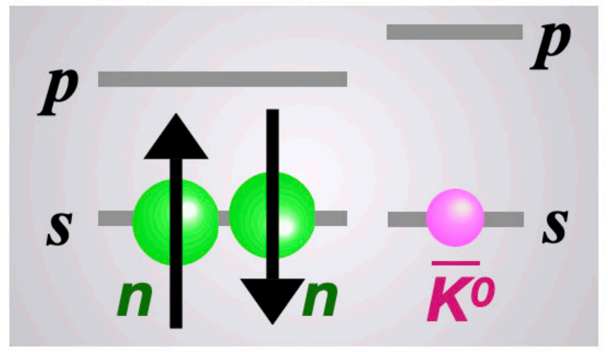
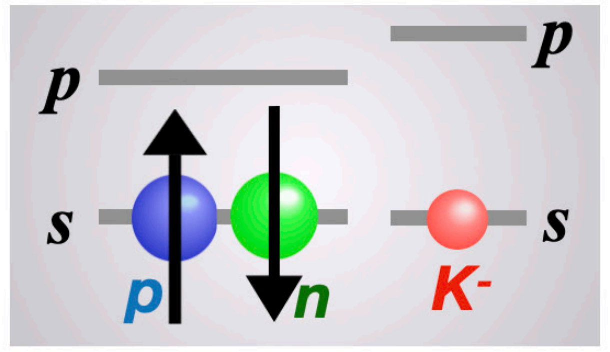
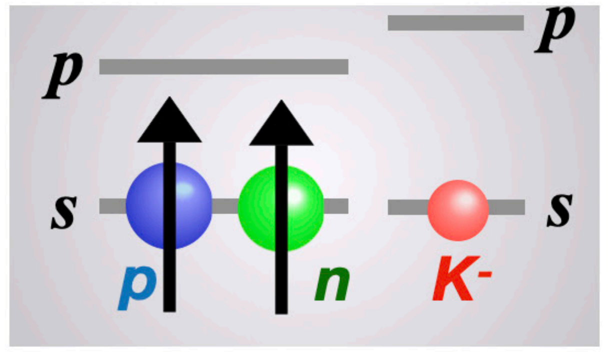
"$\bar{K}^0nn$" $I_3(\bar{K}NN) = -\frac{1}{2}$	 + 	
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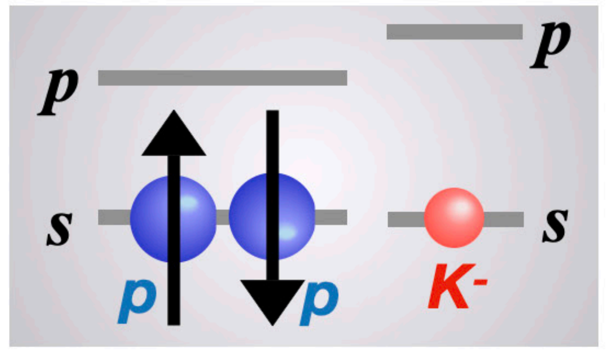
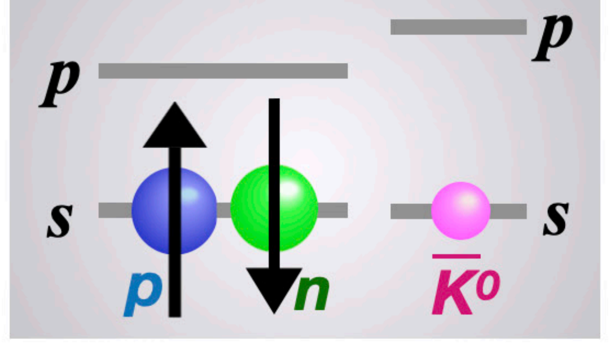
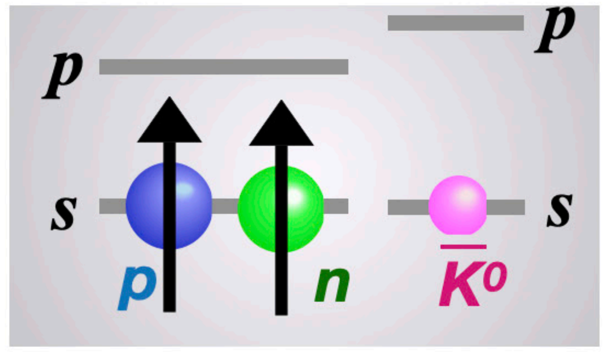
"K^-pp" $I_3(\bar{K}NN) = +\frac{1}{2}$		+ 	
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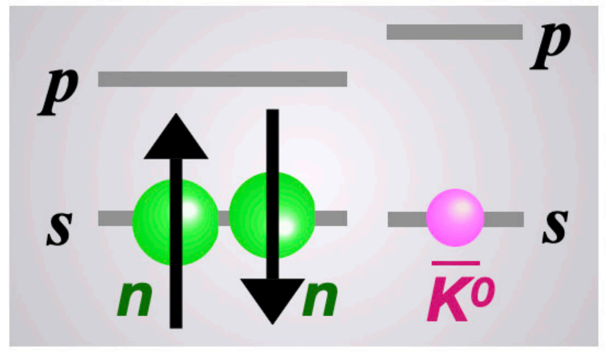
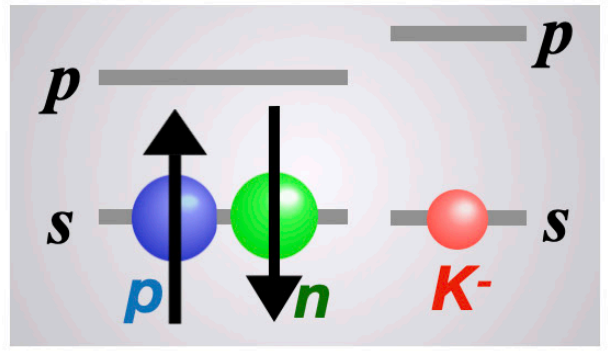
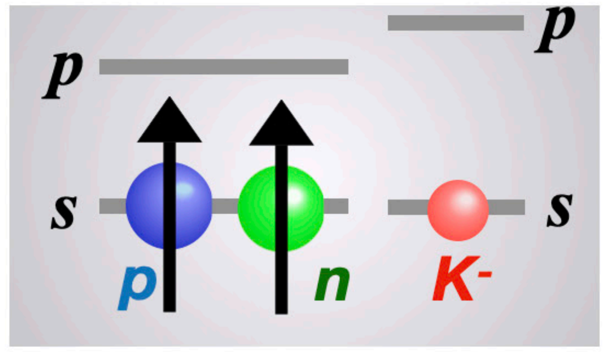
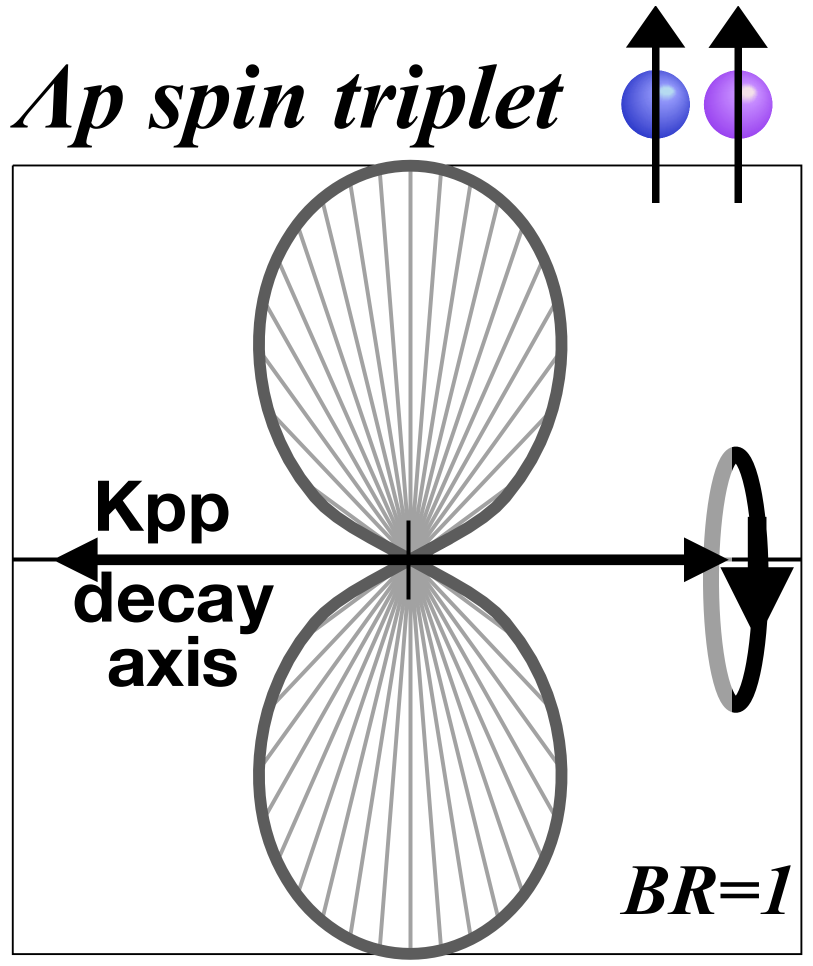
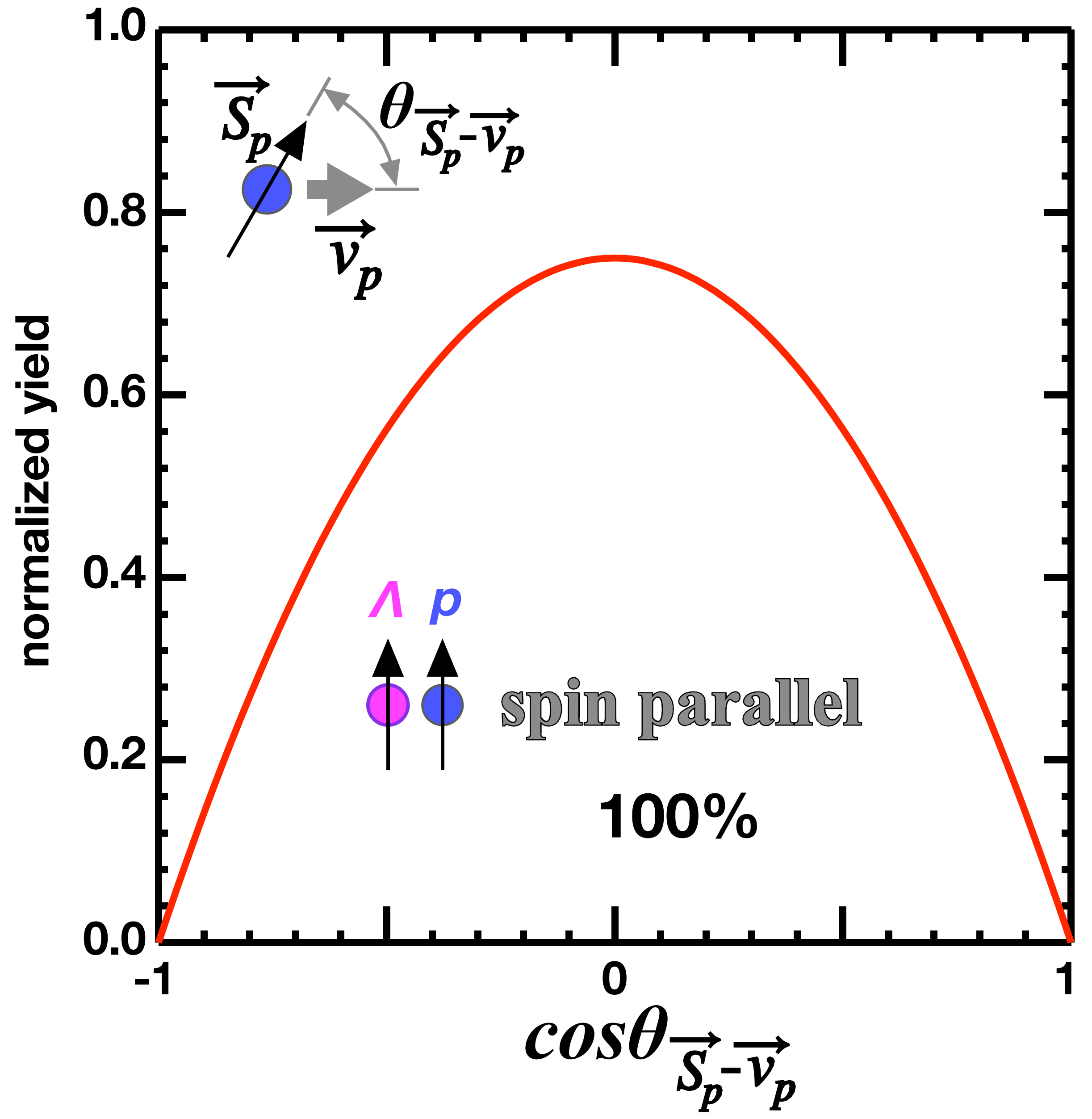
"$\bar{K}^0nn$" $I_3(\bar{K}NN) = -\frac{1}{2}$		+ 	
	$-\sqrt{\frac{1}{3}}\left(\sqrt{2}\bar{K}^0nn + K^-\frac{pn+np}{\sqrt{2}}\right) \otimes \left(\frac{\uparrow\downarrow - \downarrow\uparrow}{\sqrt{2}}\right)$		$-K^-\frac{(pn-np)}{\sqrt{2}} \otimes \left(\uparrow\uparrow, \frac{\uparrow\downarrow + \downarrow\uparrow}{\sqrt{2}}, \downarrow\downarrow\right)$
$\bar{K}N$ *coupling*	$\frac{\lvert I_{\bar{K}N} = 0\rvert^2}{\lvert I_{\bar{K}N} = 1\rvert^2} = \frac{3}{1}$		$\frac{\lvert I_{\bar{K}N} = 0\rvert^2}{\lvert I_{\bar{K}N} = 1\rvert^2} = \frac{1}{3}$
$\frac{\sigma_{\bar{K}^0nn}}{\sigma_{K^-pp}}$	$0.13 \sim 0.15$		~ 0.75

Λp decay axis and spin axis of $\bar{K}NN$ J^P 崩壊軸とスピン軸

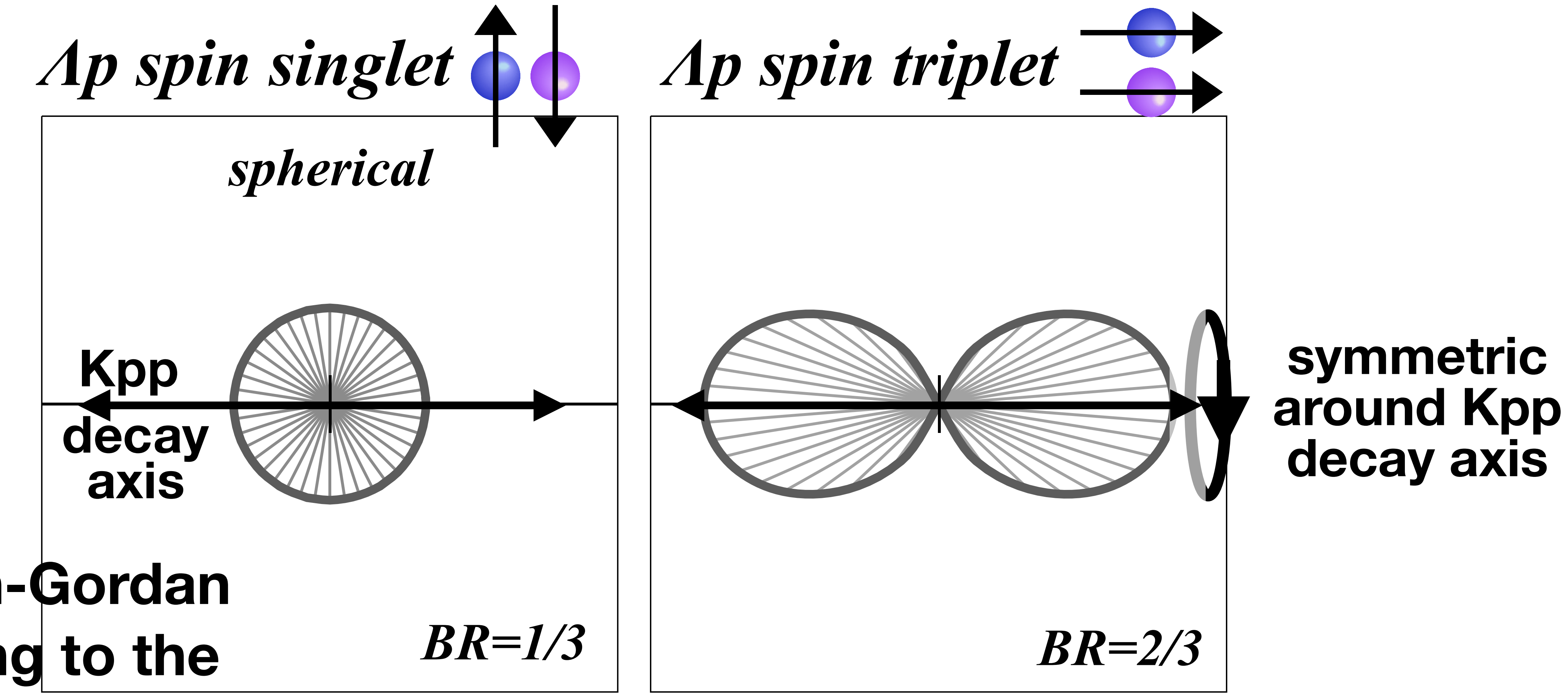
proton spin orientation referring to the decay axis

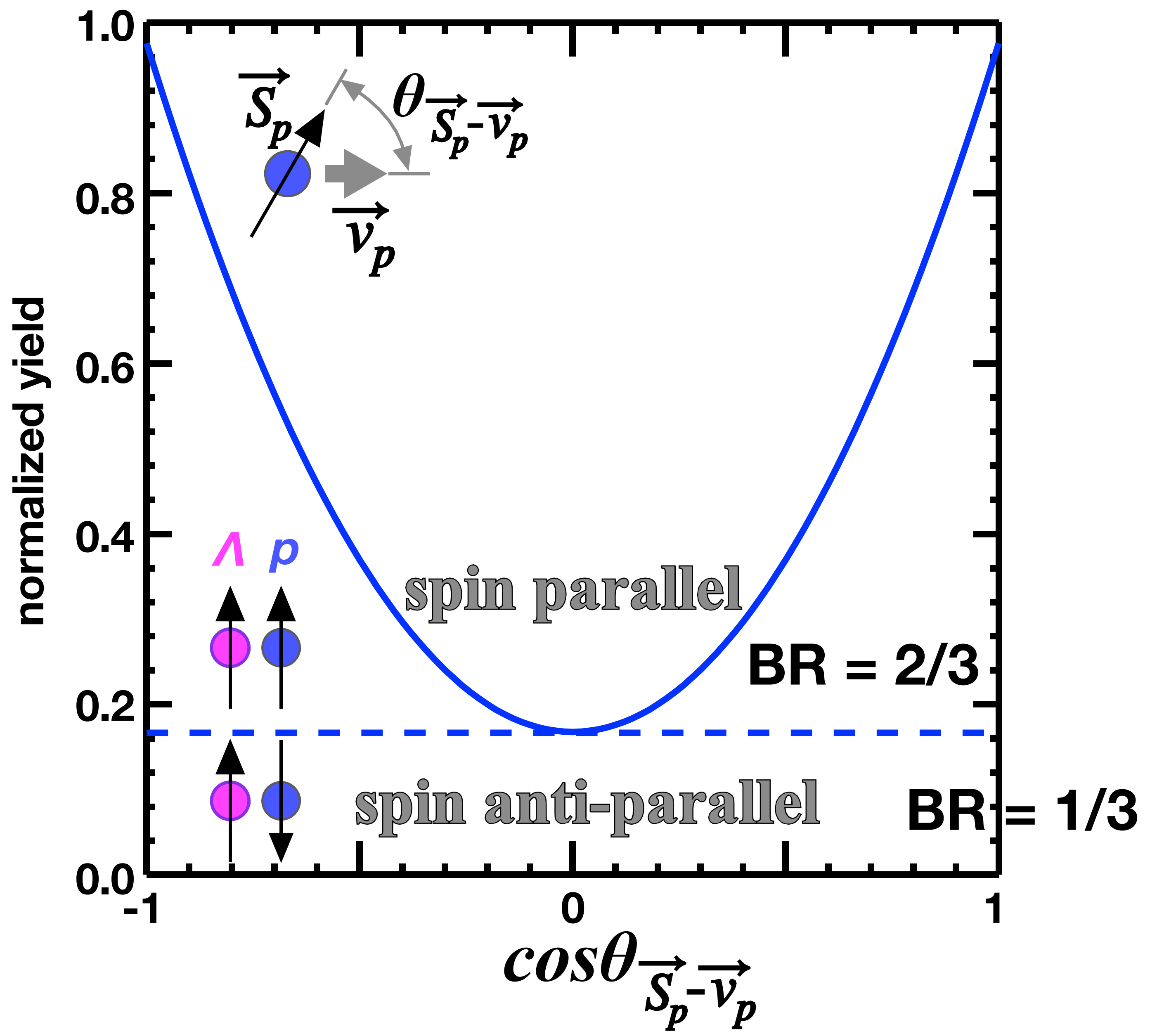
$\bar{K}NN$: I = 1/2, J^P = 0^-: I_{NN} = 1, S_{NN} = 0, $L_{\bar{K}}$ = 0





$\bar{K}NN$: I = 1/2, J^P = 1^-: I_{NN} = 0, S_{NN} = 1, $L_{\bar{K}}$ = 0





Angular momentum & Clebsch-Gordan define spin orientation referring to the decay axis.

Orthogonal spin (referring to its motion cosθ=0) can be efficiently measured.

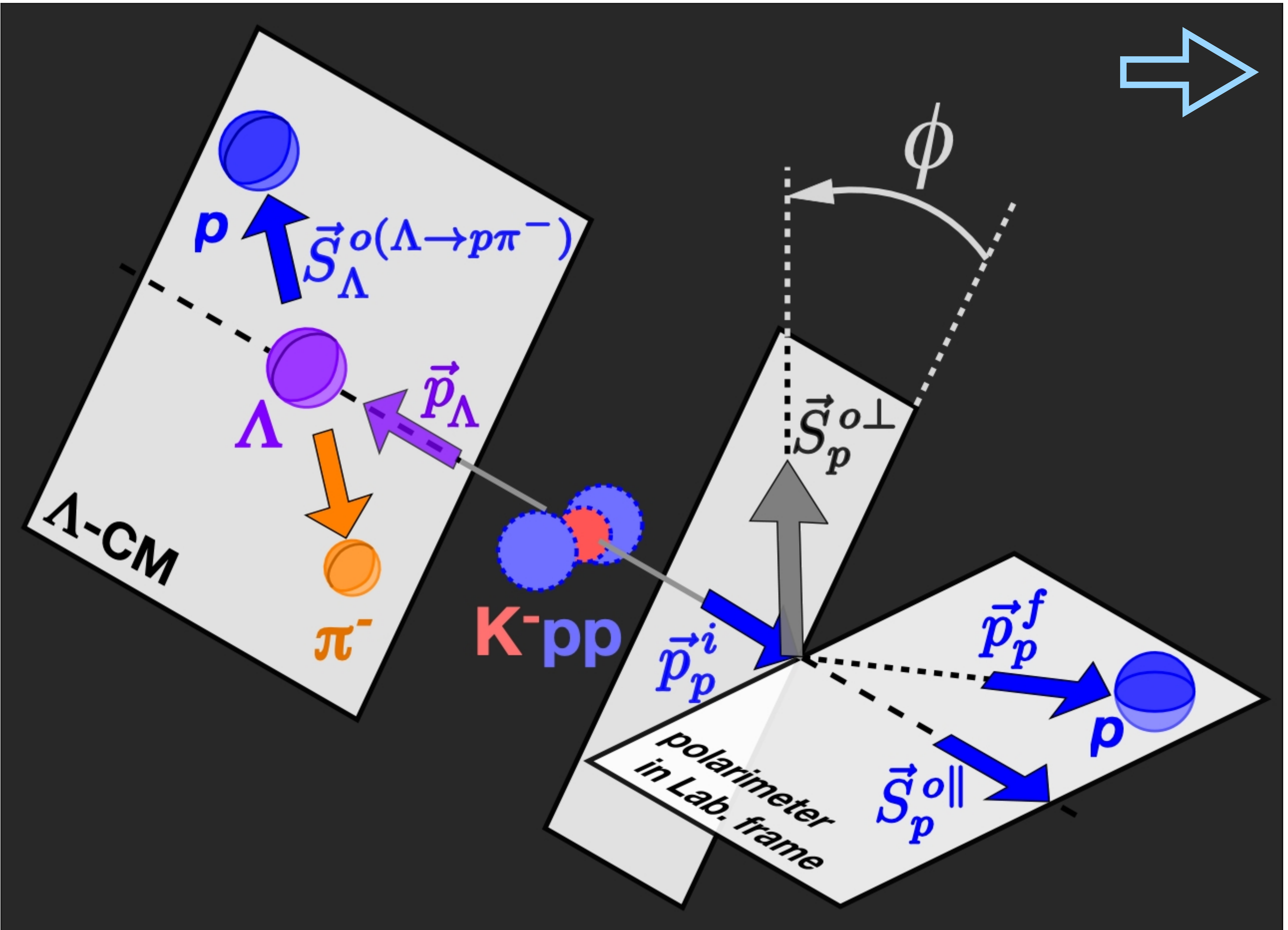
Strong Λp spin-spin correlation can be measured in J^P = 0^-, not in 1^-.

How to measure spin-spin correlation 崩壊軸と反跳軸の相対角度ϕで測定

– spin asymmetry measurement using $\Lambda \to p\pi^-$ & p-C(H) scattering–

p-C(H) scattering sensitive only on ϕ asymmetry

$\vec{S}_{\Lambda}^{o(\Lambda\to p\pi^-)} \approx \vec{v}_p^{(\Lambda\to p\pi^-)}(in\ \Lambda\text{–}CM)$



$$N(\phi)\,d\phi \propto (1 + r\cdot\alpha_{\Lambda p}\cos\phi)\,d\phi$$

r : scaling factor

$$r = A_{\Lambda}\cdot A_{pC}\cdot \vec{S}\cdot\vec{S}^{\parallel}\cdot c_{conv}$$

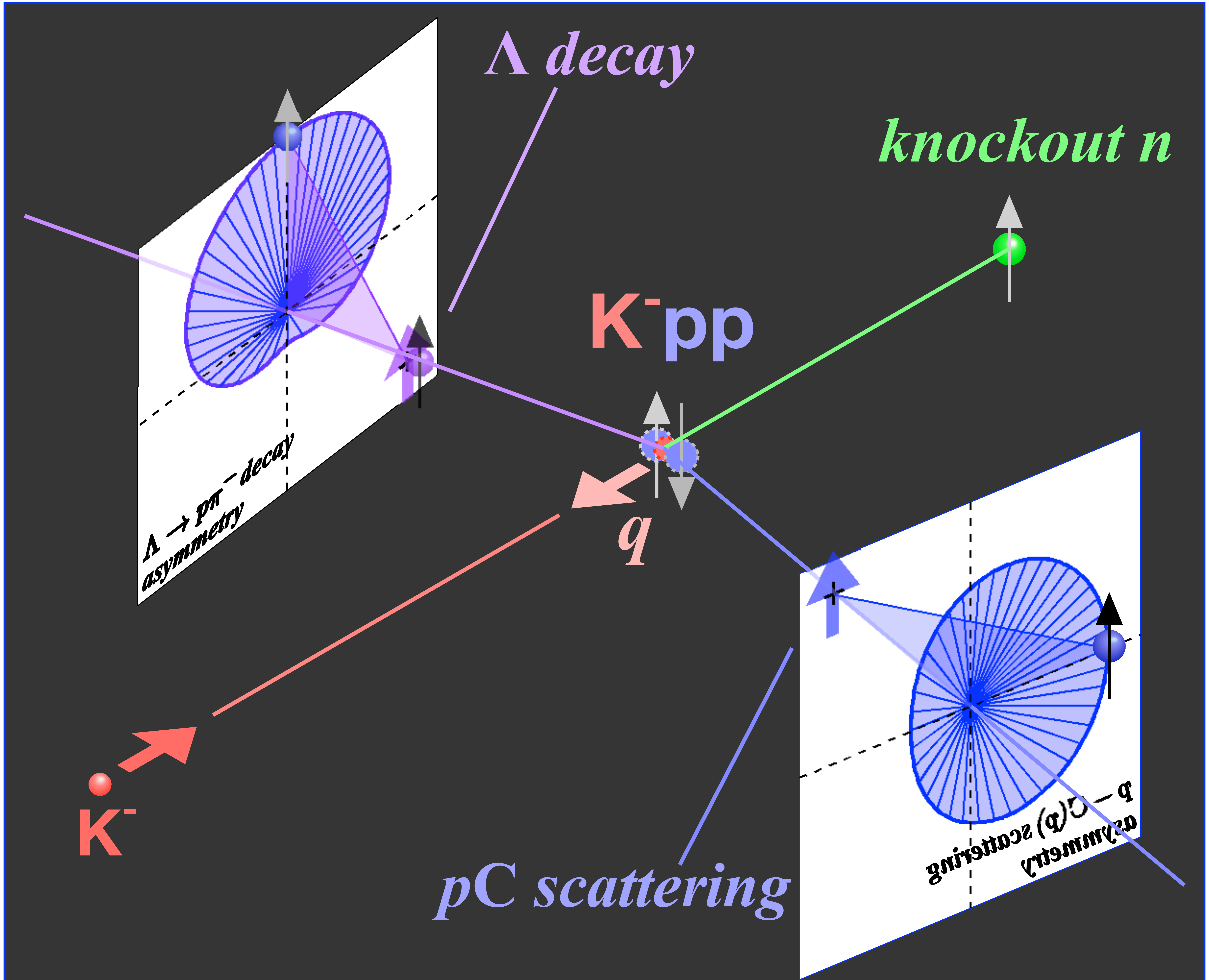
A_{Λ} : Λ asymmetry parameter

A_{pC} : proton spin-analyzing-power on carbon (and on p)

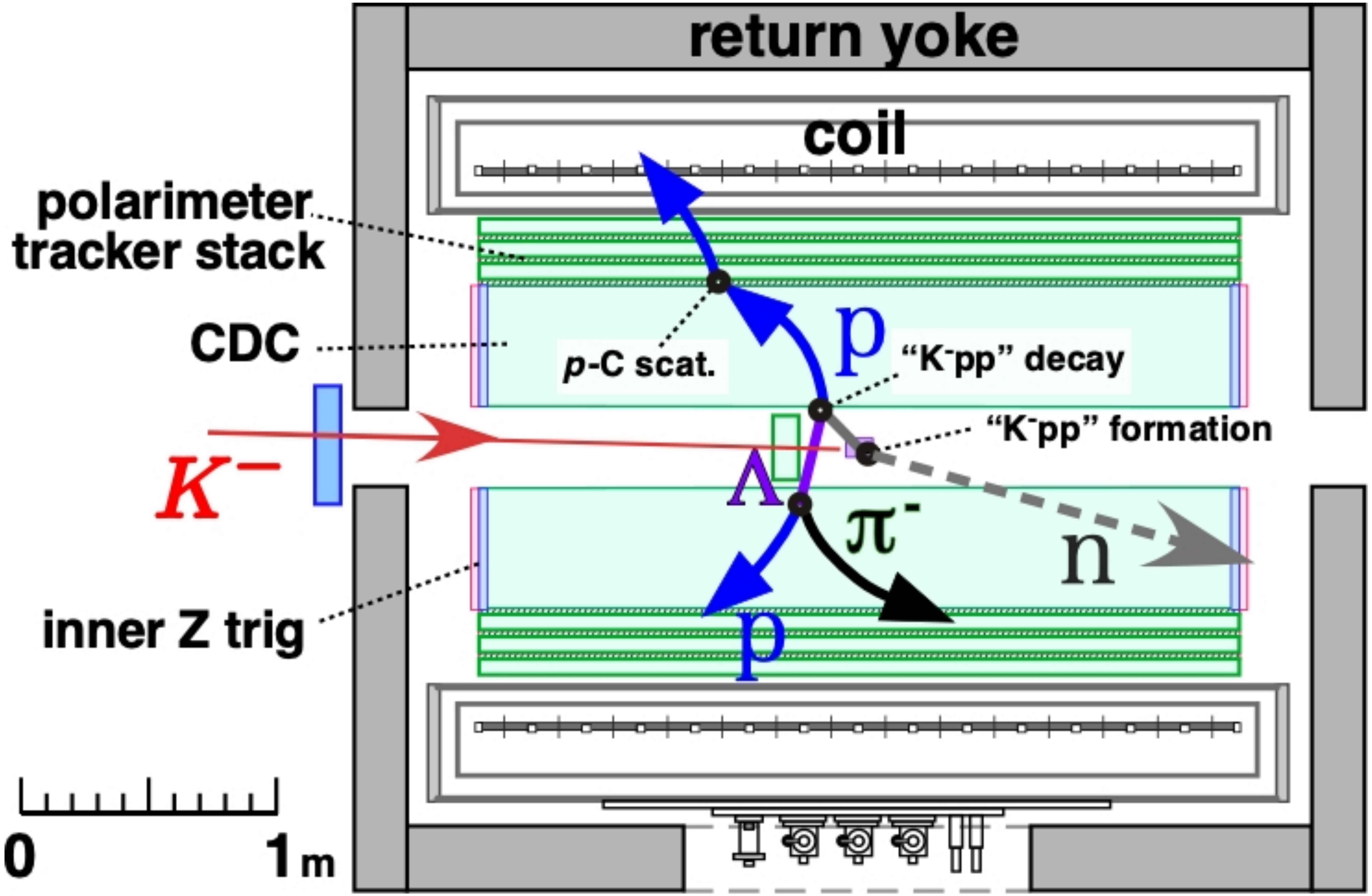
$\vec{S}\cdot\vec{S}^{\parallel}\ (\equiv \vec{S}_p\cdot\vec{S}_p^{\parallel})$: spin sensitivity referring to motional axis

c_{conv} : convolution coefficient between two asymmetries

非対称度計測概念図

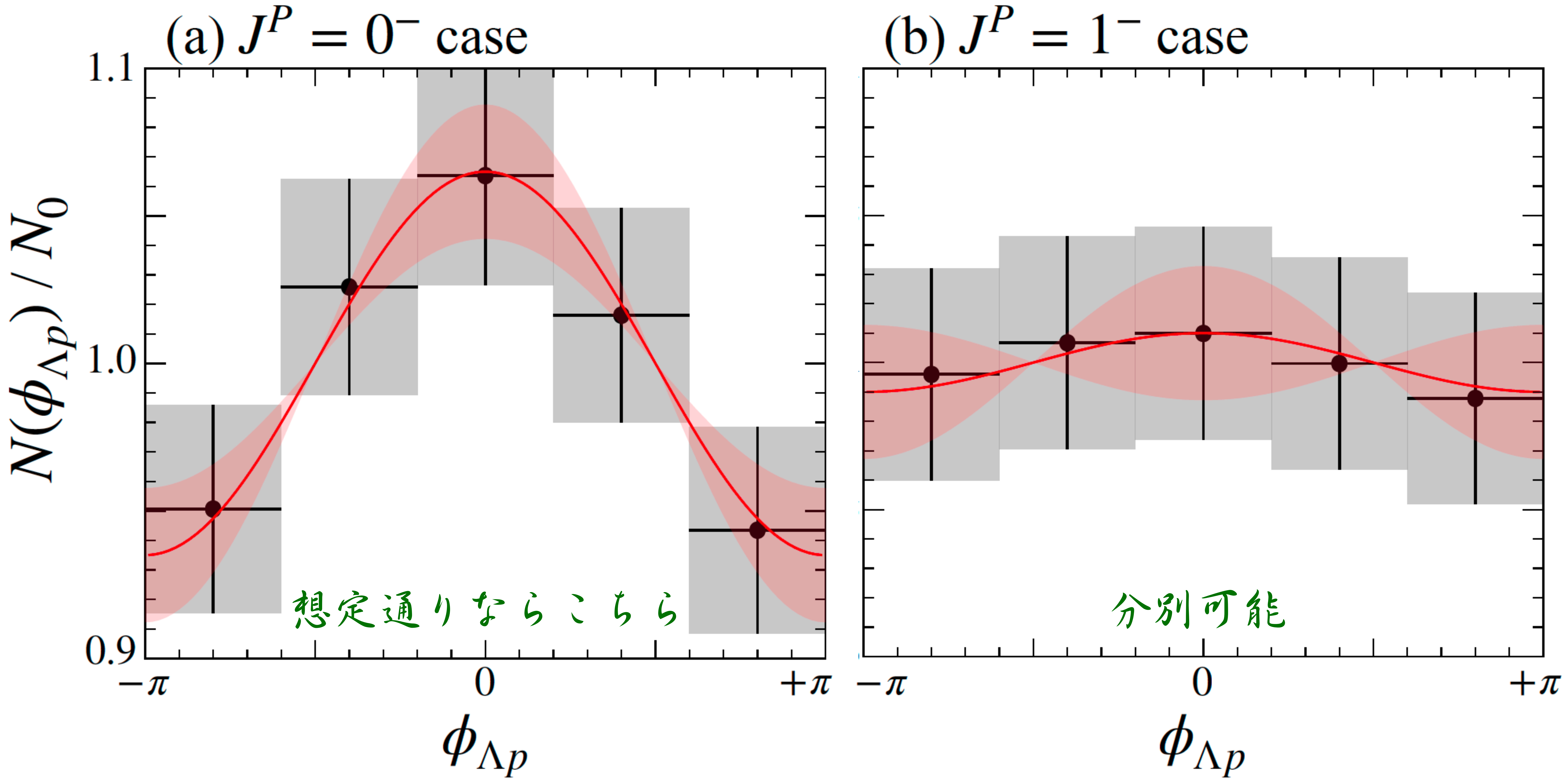


Toward J^P (spin・parity) study of K^-pp with ^3He target



非対称度計測想定スペクトル

Λp spin-spin asymmetry

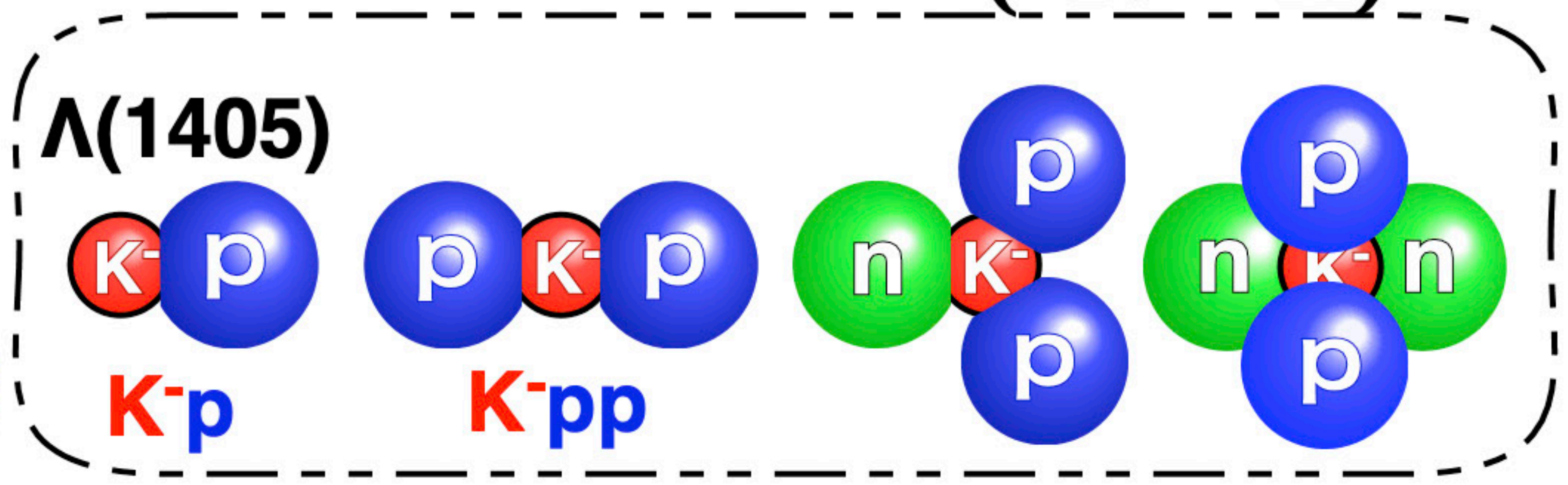


新型スペクトロメータで目指すもの

With new spectrometer, we will conduct

— a systematic study on light kaonic nuclei —

(~10^{-15} m)

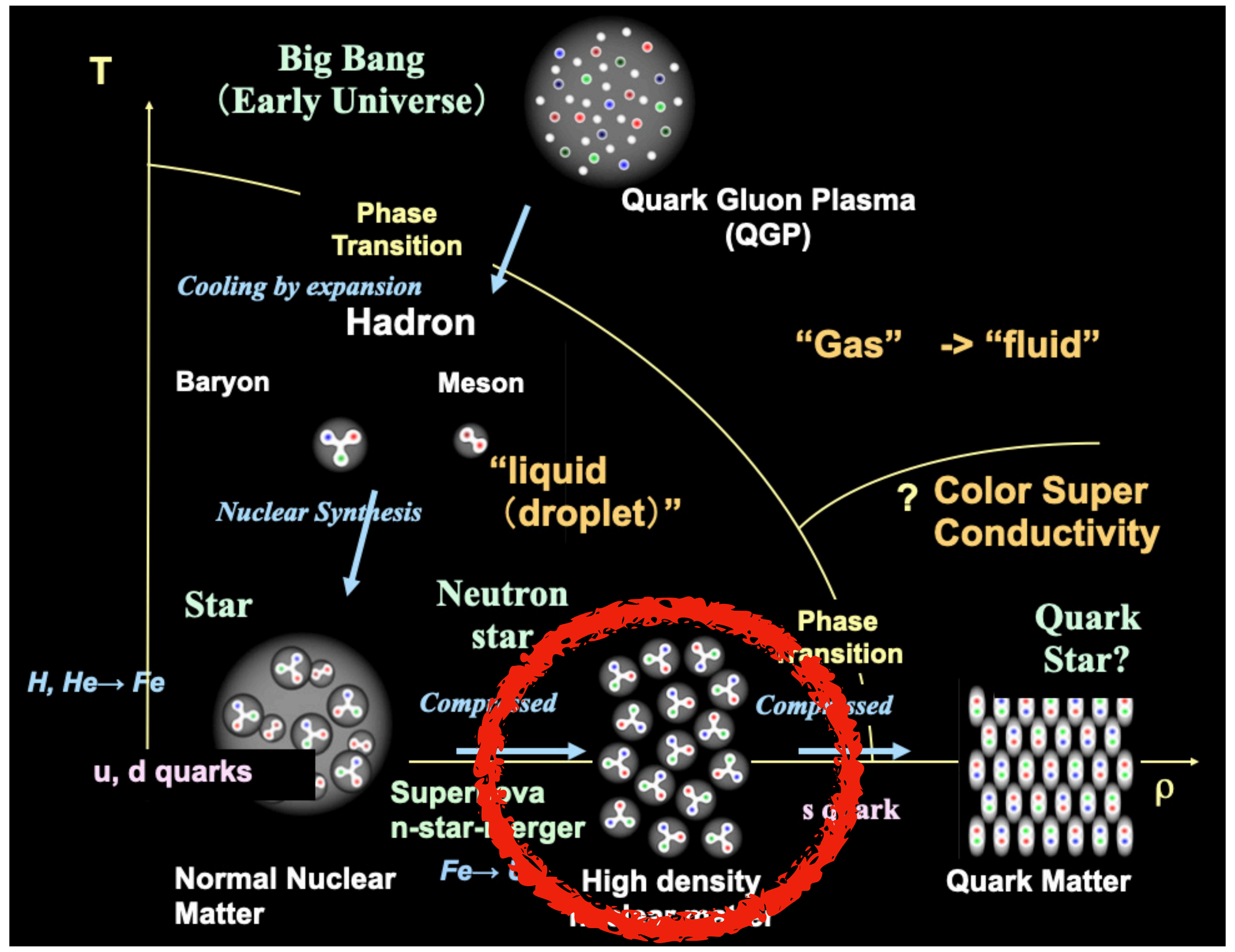


粒子数が多いと不変質量法は厳しい

中重核へは質量欠損法への橋渡し？

molecule-like hadronic nuclear cluster

"Does it have a unique shape like a chemical molecule?"



— in future —

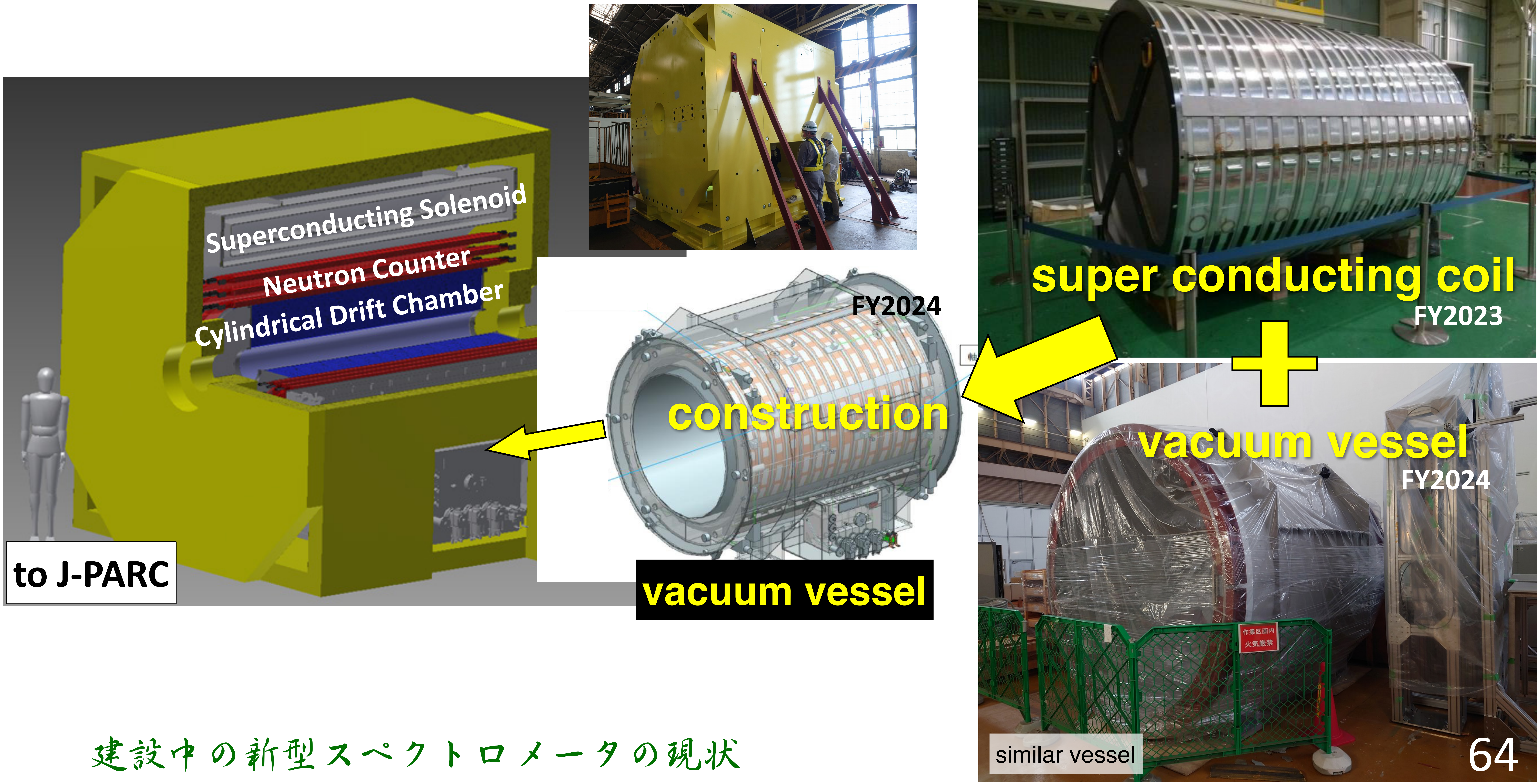
We wish to know

how hadron mass is generated

and

physics at high density

Superconducting Solenoid Magnet

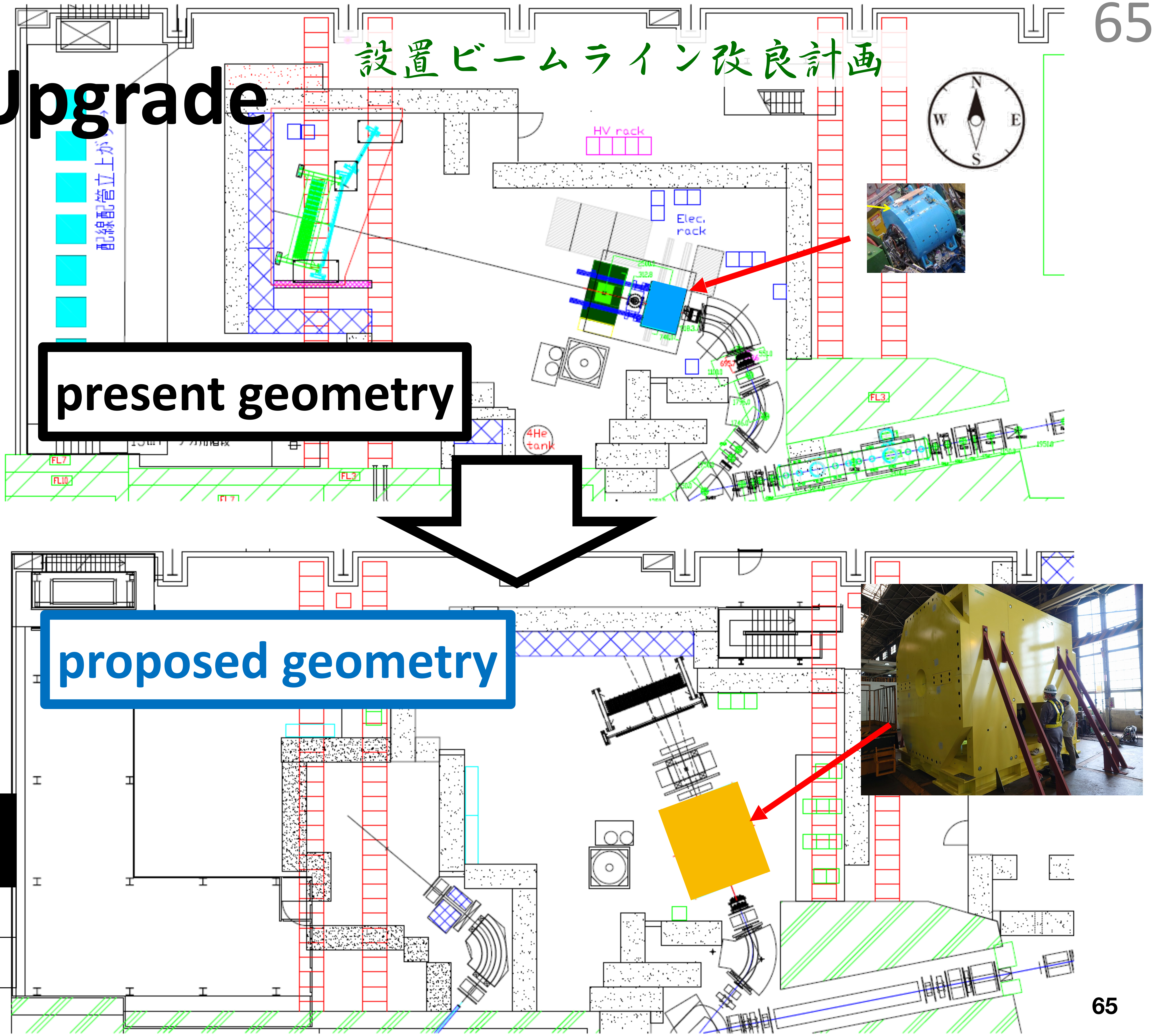


Proposed K1.8BR Upgrade

- **Shortened beam line to enhance Kaon yield**
  - ➢ K- yield will increase by **~ 1.4 times @ 1.0 GeV/c**

with π/K ratio ~ 2

— realize additional test beam line



Shorten the beam line (~2.5m) by removing the final D5 magnet

Relative beam-line length (m)	D5	D4
Present CDS	0	-3.7
New CDS	+1.2	**-2.5**

Please collaborate with us, if you are interested in.

… ここでの物理や実験装置に興味があったら是非協力しませんか？…

… という訳で、私は「普通の研究員に戻ります」…

I'm going back to being an ordinary researcher for three years to conduct a Grant-in-Aid for Specially Promoted Research — as a play on the Candy's retirement in 1977 —

… なんと50年近く前 … 今どきの若者には通用しないか …

Yet Another Extension:

$\bar{K}\bar{K}$ bound state via $\bar{p}$ annihilation?

ϕN bound state via $\bar{p}$ annihilation?

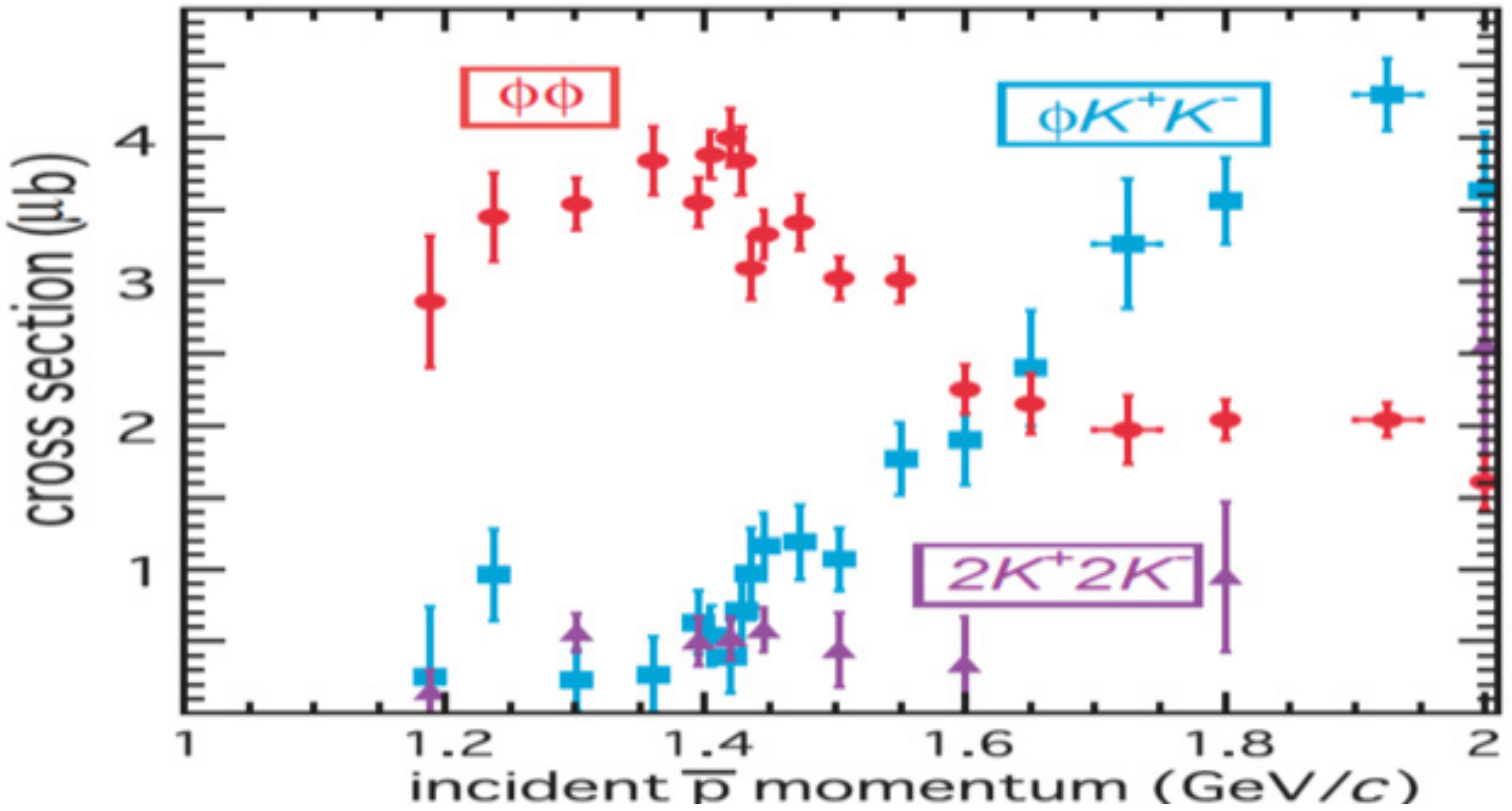
さらなる発展の可能性?

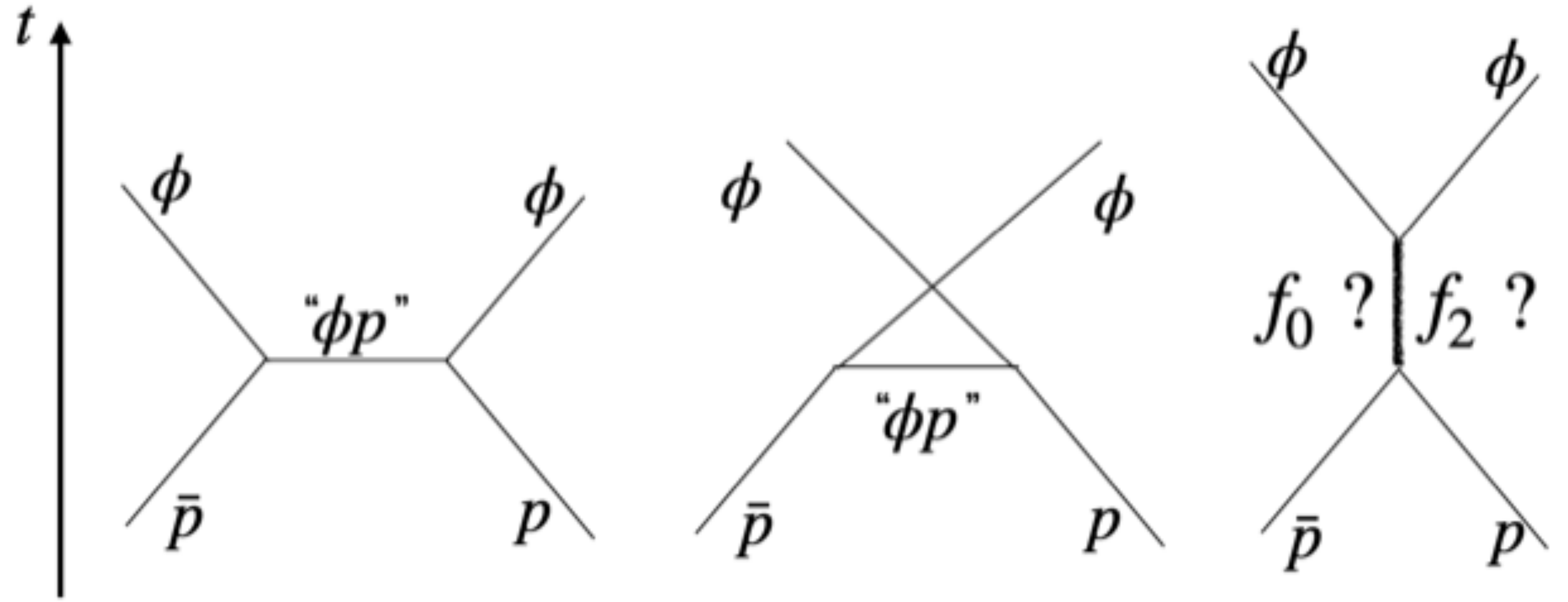
arXiv:2212.12690

Evidence of a p–ϕ bound state

Emma Chizzali[a,b,*], Yuki Kamiya[c,d,**], Raffaele Del Grande[b], Takumi Doi[d], Laura Fabbietti[b], Tetsuo Hatsuda[d], and Yan Lyu[d,e]

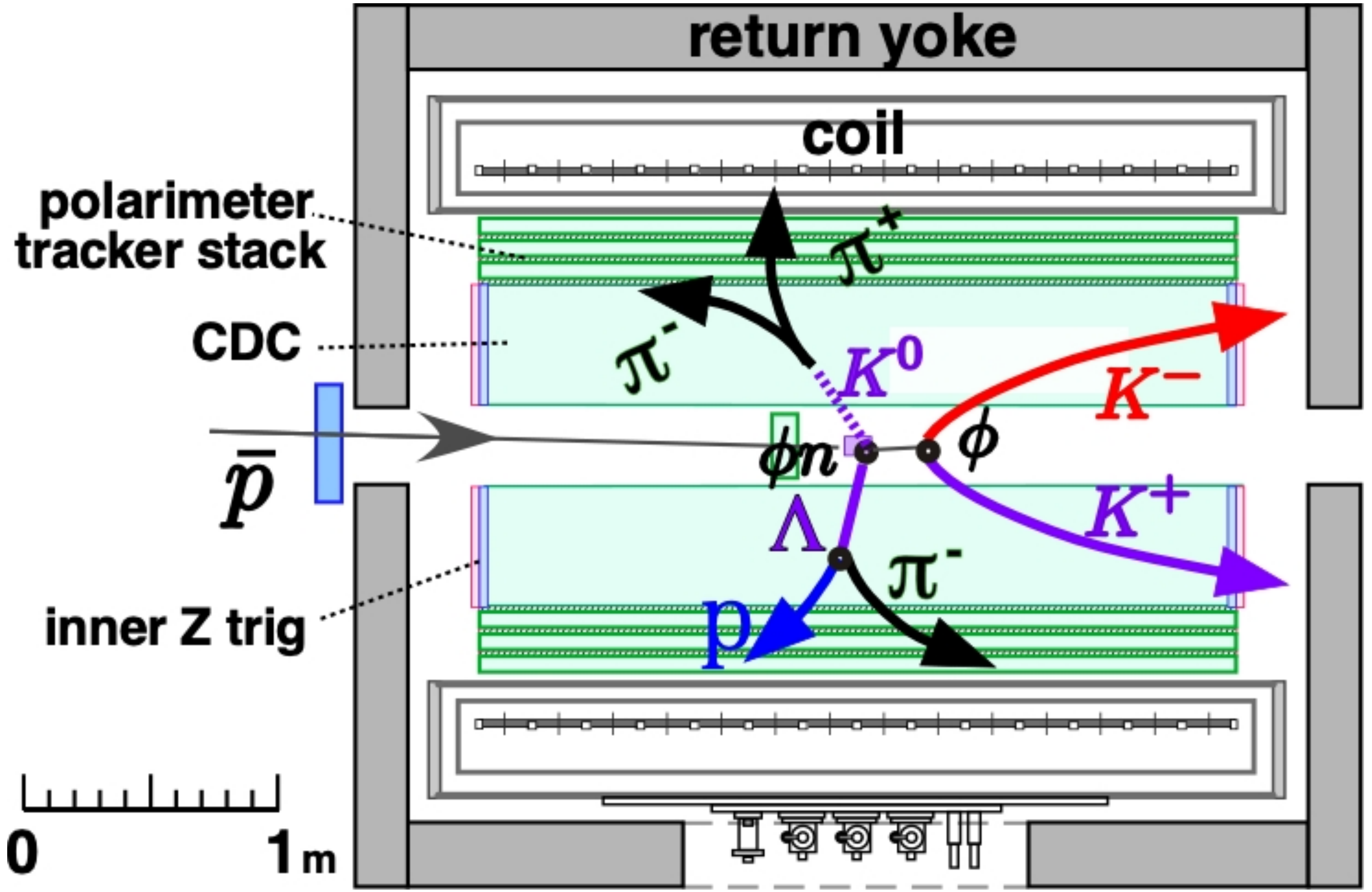
The possibility of the existence of a ϕN bound state ($J = 1/2$) as a novel molecular hadron cluster has been pointed out. This is consistent with $\phi\phi$ dominance near the production threshold of the $\bar{p}p$ reaction channel.





… H. Onishi

If exist, nuclear ϕ bound states search is of interest



ϕN bound state search?

分子状ハドロン等更なる
エキゾチックハドロン探査?

… *H. Onishi*

Thank You for Attention!

次世代に更なる面白い物理の発展を期待します!

Bonus topics:

— What I learned with the Talk —

おまけ：トークを通して気づけたこと等

Bonus topic 1:

トークすることで気づけたことなど
トークをすることで俯瞰的視野を持てる

It is important:

When you make matters clear and organized, you may realize the essence of a problem that you were not aware of, and you may also have more perspective view to identify a better way to resolve a problem.

In the talk, I realized that my materials in not sufficiently clear and organized, so I updated the this materials.

問題を整理し人に伝える必要のあるトークをすることは、
問題を俯瞰的に捉える視野を醸成し本質を捉えるのに役立つ。 十分整理されていなかった点は以下にまとめ直す。

批判的意見も力に

Bonus topic 2:

The critical questions:

En'yo-san raised question: "What will you do, if the charge mirror state $\bar{K}^0 nn$ do not exist?"

鏡像核が存在しなかったらどうするのか？

As the sign of the existence already seen in the analysis, speculating about the non-existent is a pointless exercise, often termed the devil's proof as it is impossible to prove.

存在の兆候が見えている以上、存在しない可能性に思い煩うのは無為

Instead, we aim to verify the signs of existence that we have seen in our experimental study of the $\pi^-\Lambda p + p'$ final state.

むしろ$\pi^-\Lambda p + p'$終状態研究で見えた鏡像核の存在兆候を検証したい

トークで受けた気が付きにくい実験バイアスに関する指摘

Bonus topic 3:

実験家への有用な情報

Possible bias generated in mixed-trigger:

— mentioned by K. Itahashi

To study the systematic error, we often utilize Mixed Trigger, but it may fake us on DAQ efficiency.

To study the systematic error, we usually utilize Mixed Trigger, but it may fake us on DAQ efficiency. Y. Tanaka realized that the DAQ efficiency is not a general number, but it differs for trigger conditions. — Self-inefficiency for pre-scaled trigger is very low by definition, but the inefficiency caused by pre-scaled trigger to the crucial one is not. Thus, the stability of the DAQ efficiency shall be studied as a function of pre-scaling factors in a systematic manner, if one wish to apply mixed-trigger on an experiment. It may fake us on the total cross section!

隠れたバイアスの例…

研究者に成果を挙げさせるために
管理対象という認識を排し、如何に活用するか

Bonus topic 4:

事務部門への期待

To improve effectiveness in enforcing compliance with the rules:

One needs a reason to follow, especially for Scientist who trained to raise question even to the textbook or supervisor, and requested not to follow blindly.

Ex. Rule: Never cross a crosswalk at a red light.

I followed the rule ever since I was asked "what ethical responsibility can you take, if some children imitates you in time and involved in a car accident?"

ルールは強制ではなく共感を …


μCF理論計算との相互発展
MuCF Theory
Prof Kamimura, Dr Kino, Dr Hiyama, Dr Koike,
Prof Shimamura, Prof Akaishi, ...
Precise calculation of μα-sticking
by Prof Kamimura
更なる理論計算の発展(4体計算)
木野氏:ミュオン分子過程の考察
上村氏:α付着の高精度計算
発展@J-PARC
原子分子過程に関わるミュオン原子・分子X線精密測定
木野、岡田、...
This exp.
Solid
Liquid
Effective Sticking

懇親会での集合写真