J-PARC
Japan Proton Accelerator Research Complex

The Extension Project of the J-PARC Hadron Experimental Facility

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on behalf of HEF-ex TF
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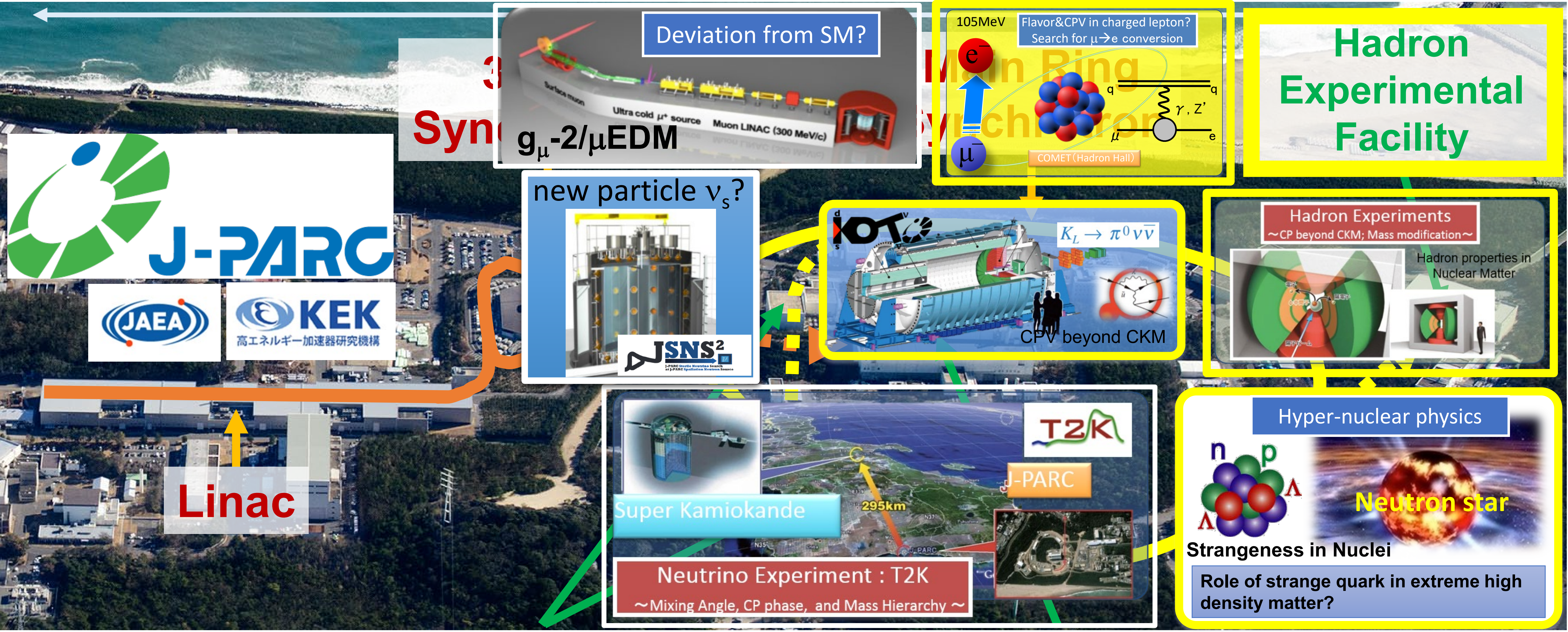
15th International Conference on Hypernuclear and Strange Particle Physics (HYP2025), 29 September 2025 to 3 October 2025, Tokyo

Particle and Nuclear Physics @ J-PARC



Neutrino Experimental Facility

Material and Life Science Experimental Facility

Origin & Evolution of Matter

Matter-Antimatter Symmetry

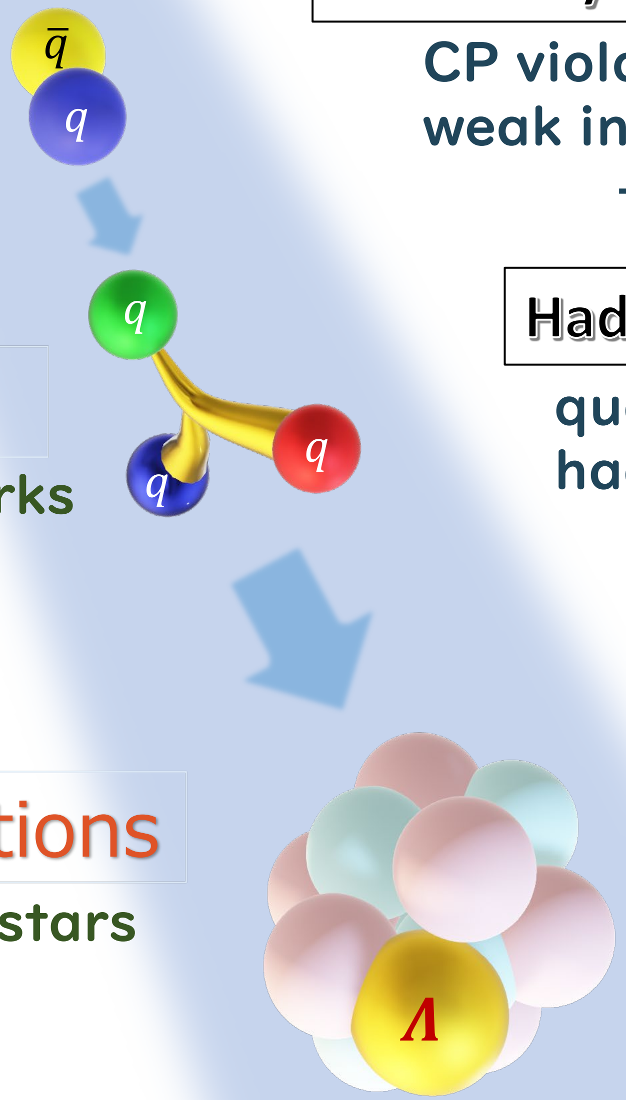
matter dominated universe

Origin of Matter Creation

formation of hadrons from quarks

Matter in Extreme Conditions

dense matter in neutron stars



Flavor Physics

CP violation
weak interaction
→ new physics

Kaon rare decays
$\mu \rightarrow e$ conversion

Hadron Physics

quark interactions
hadron mass-generation mechanism

Hadron spectroscopy
Meson in nuclei

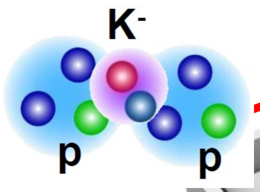
Strangeness Nuclear Physics

hadron interactions
hadronic many-body systems

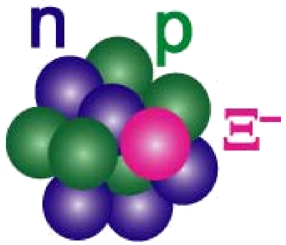
Hyperon-Nucleon scattering
Hypernuclear spectroscopy

Present Hadron Experimental Facility (HEF)

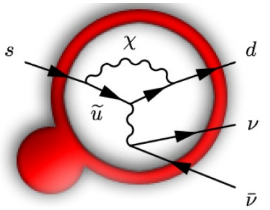
- < 1.1 GeV/c
- ~ 5x10^5 K$^-$/spill
- **Kaon in nuclei**

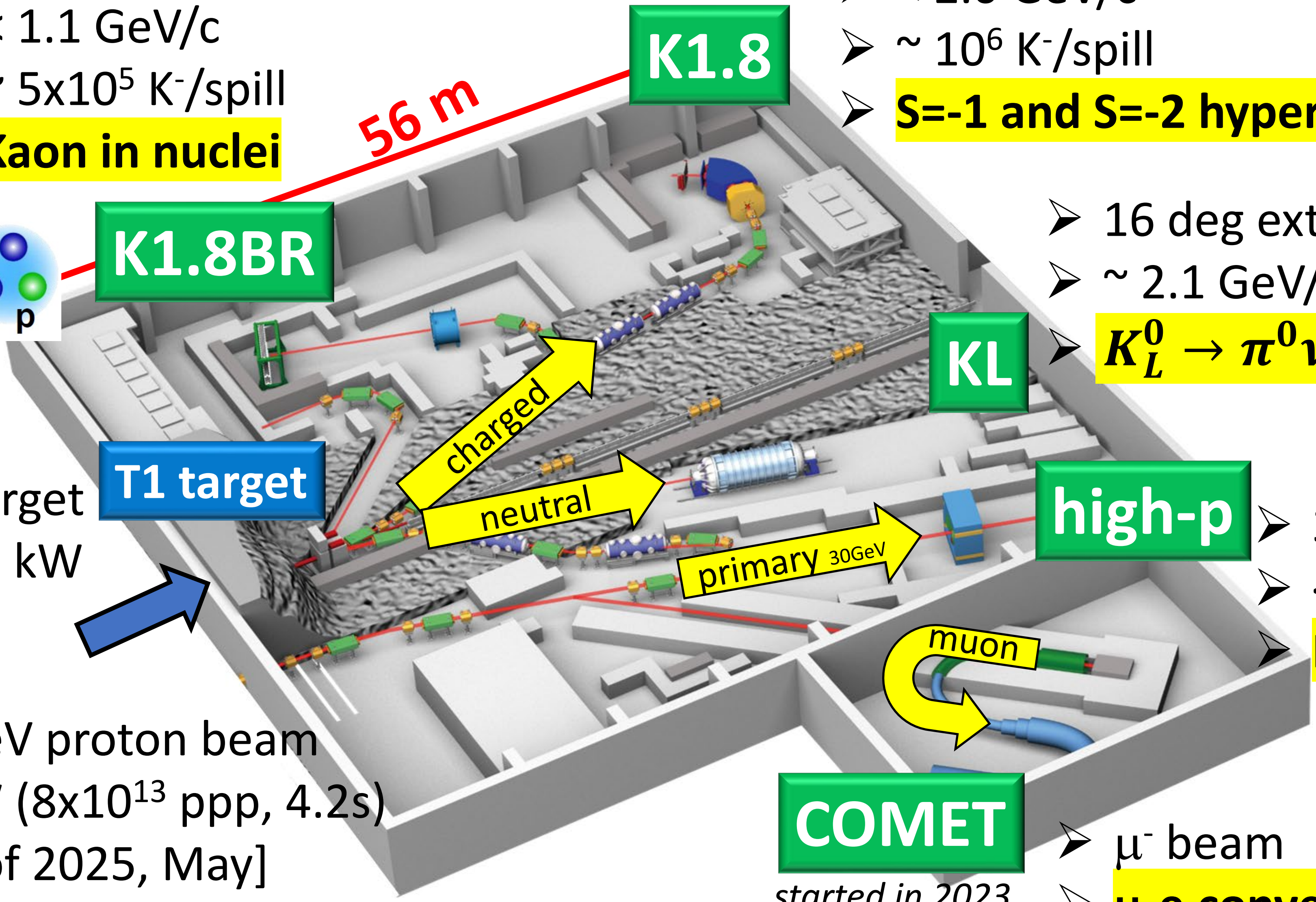


- < 2.0 GeV/c
- ~ 10^6 K$^-$/spill
- **S=-1 and S=-2 hypernuclei**



- 16 deg extraction
- ~ 2.1 GeV/c ~ 10^7 K^0_L/spill
- $K_L^0 \to \pi^0 \nu \bar{\nu}$

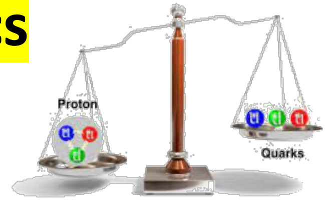




- Au Target
- < 115 kW

launched in 2020

- 30 GeV proton ~ 10^{10}
- < 31 GeV/c unsepa. π ~ 10^7
- **Hadron physics**



- 30 GeV proton beam
- 93kW (8x10^{13} ppp, 4.2s)
  [as of 2025, May]

started in 2023

- μ^- beam
- **μ-e conversion**

Achievements in Research at the Hadron Experimental Facility

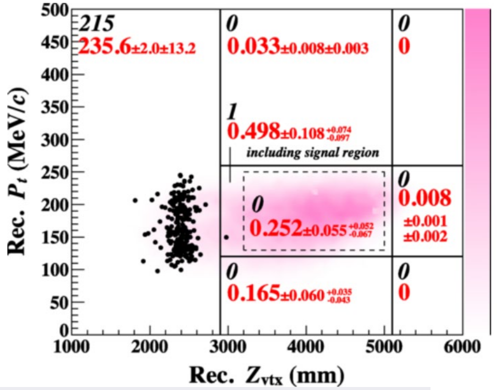
Flavor Physics

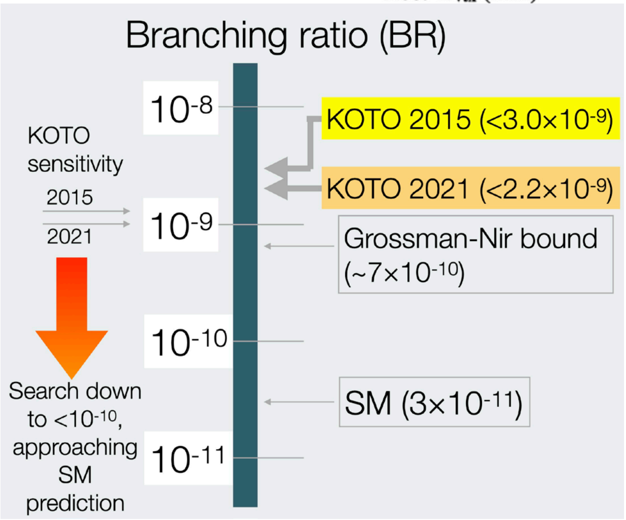
$K_L^0 \to \pi^0 \nu \bar{\nu}$ search @ KOTO

→ **Approaching the SM sensitivity for CP violation**

KOTO 2021

Single Event Sensitivity = 9×10^{-10}



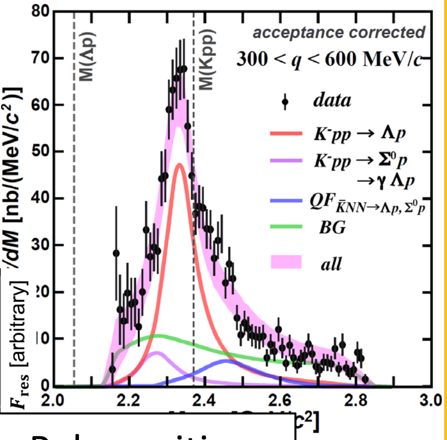


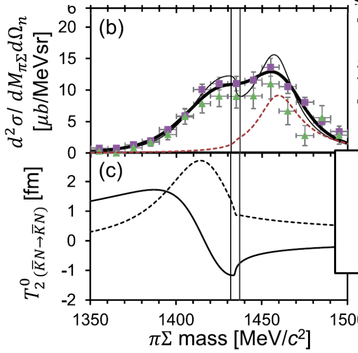
Hadron Physics

Observation of an exotic hadron bound system including K⁻ meson

→ **Established a new direction to understand meson-baryon int.**

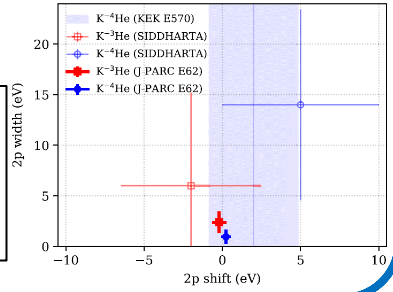
Kaonic nuclear state, "K-pp"





Pole position of $\Lambda(1405)$

Ultra-precise measurement of kaonic atoms

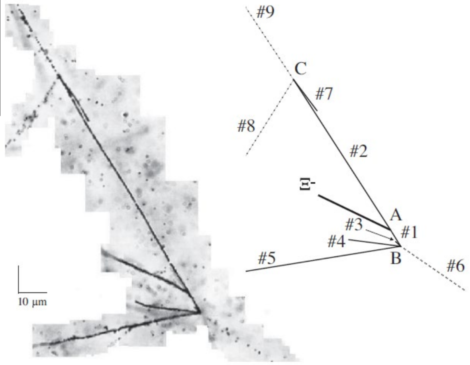


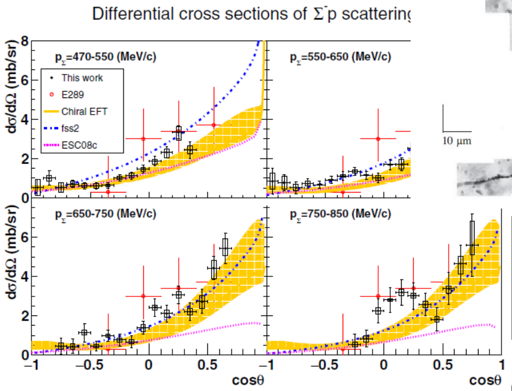
Strangeness Nuclear Physics

A lot of progress in hypernuclear research

→ **Clarified attractive S=–2 ΞN interaction and deepened S=–1 ΛN, ΣN interactions**

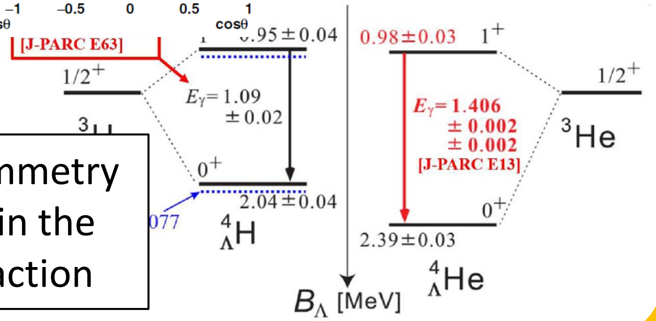
Observations of Ξ hypernuclei





First precise ΣN scattering

Charge-symmetry breaking in the ΛN interaction

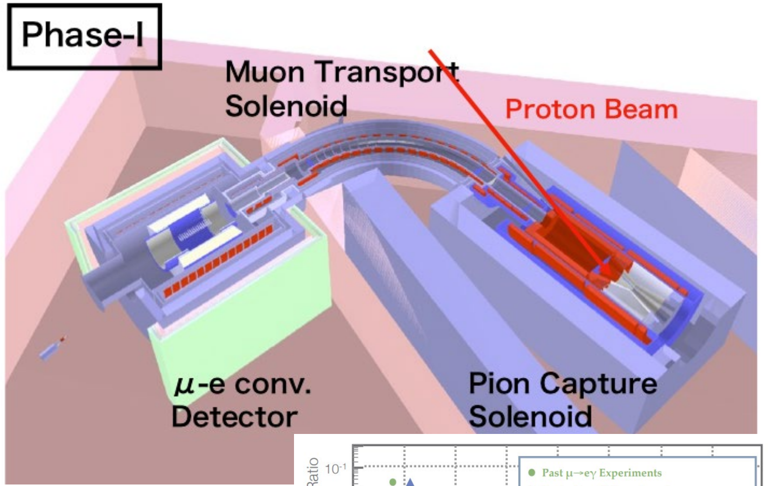


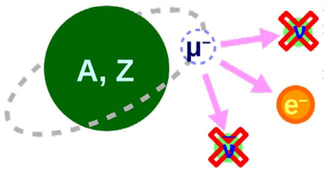
New Research Programs at the Hadron Experimental Facility

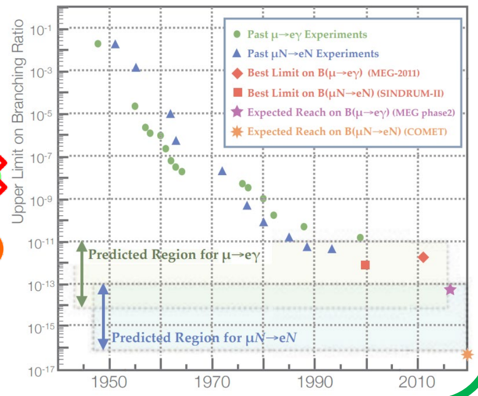
Flavor Physics

Search for μ→e conversion @ COMET (2023~)

→ **Search for charged lepton flavor violation**



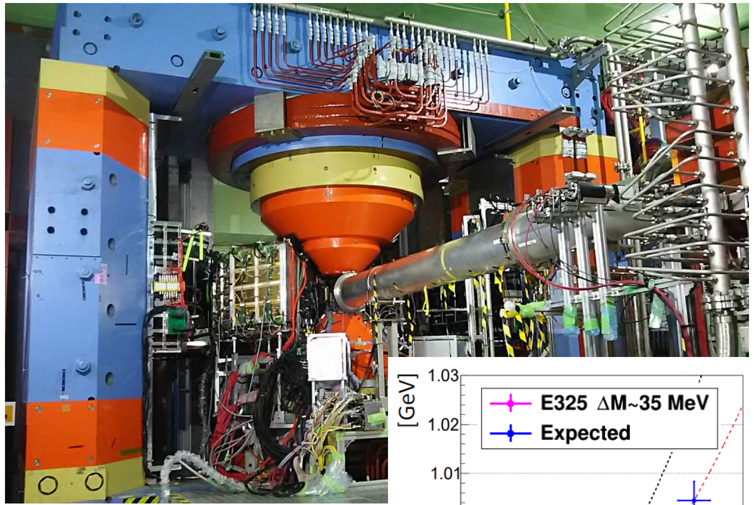


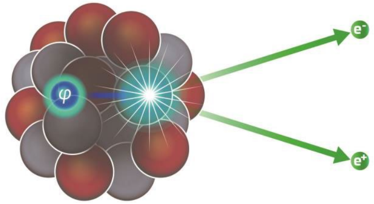


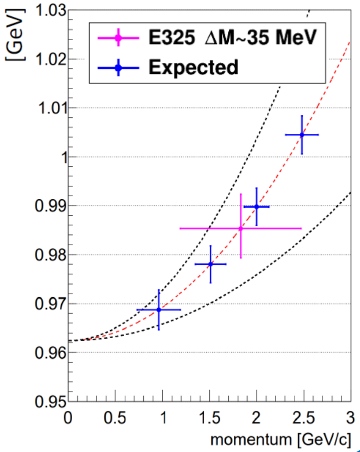
Hadron Physics

Measurement of spectral modification of ϕ meson in nuclei (2020~)

→ **Investigate mass-generation mechanism of hadrons**



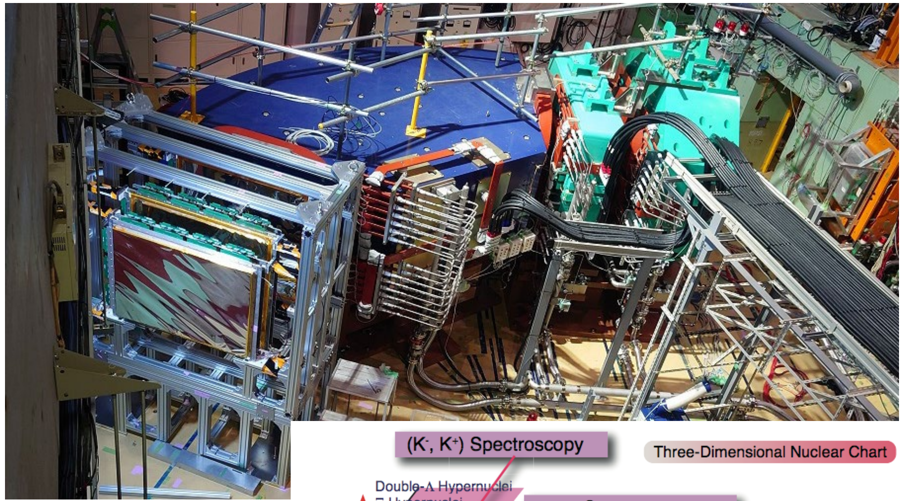


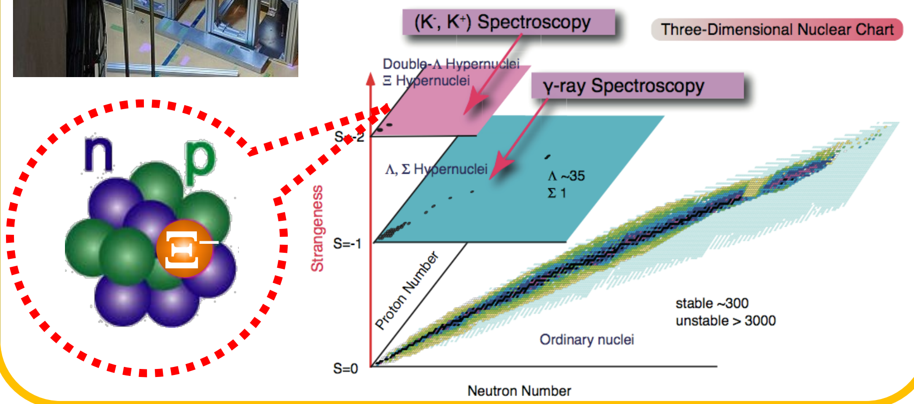


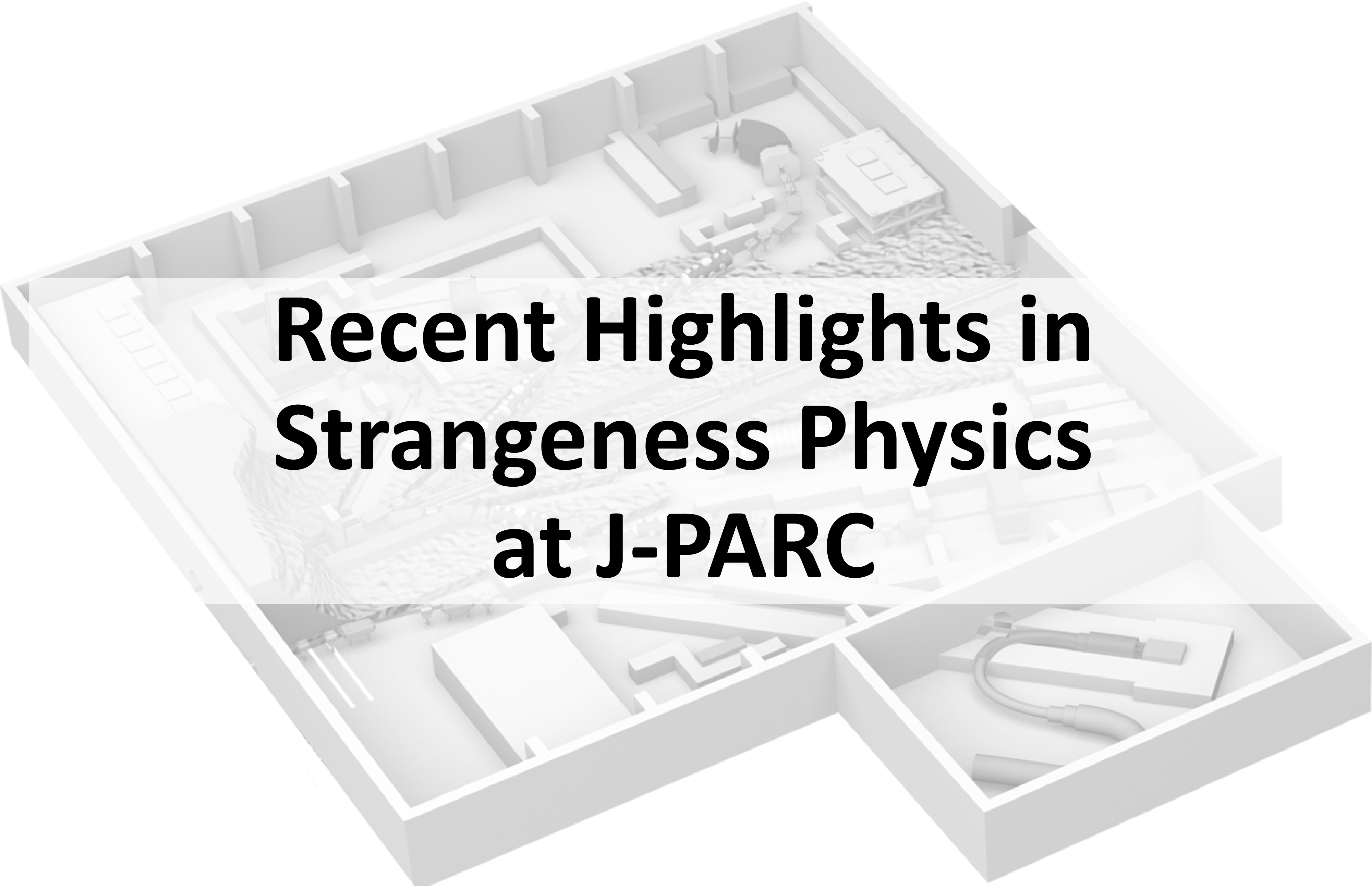
Strangeness Nuclear Physics

High-resolution spectroscopic study of S=–2 Ξ-hypernuclei (2023~)

→ **Provide accurate and systematic information on ΞN, ΛΛ interactions**







Recent Highlights in Strangeness Physics at J-PARC

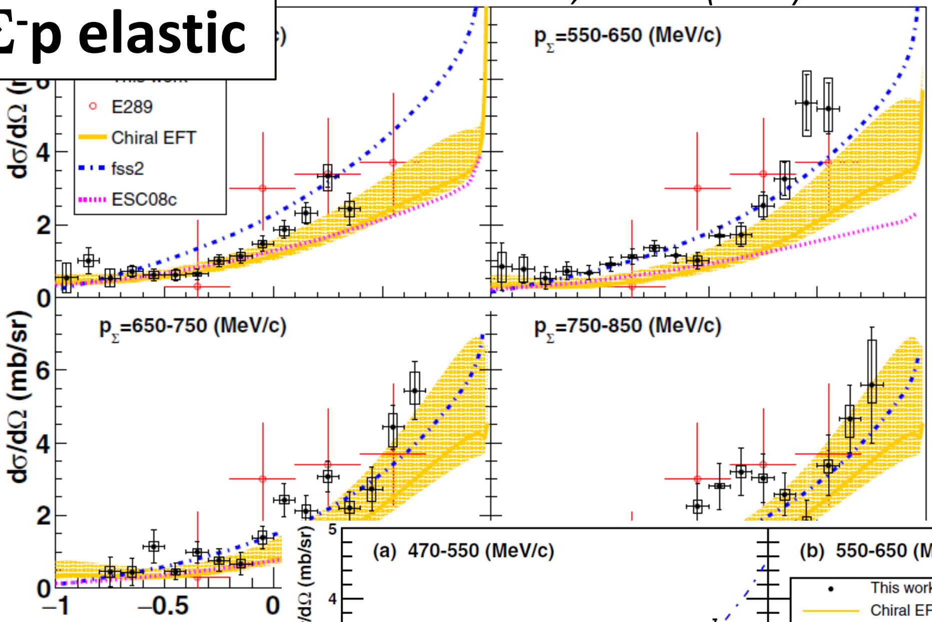
K.Miwa
Mon, Plenary 29a2

YN Scattering
– Extending NN to BB Interaction –

- Precision data of Σp scatterings obtained around 400-800 MeV/c (E40)
  - ✓Precise data allow detailed study of Σp interaction vs. theory

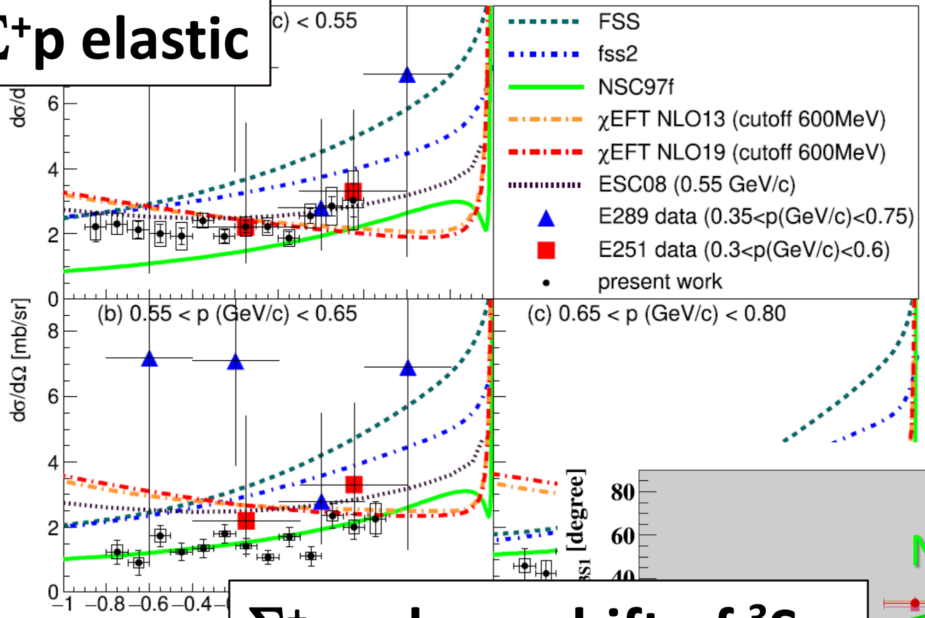
K. Miwa et al., PRC104(2021)045204

$\Sigma^- p$ elastic

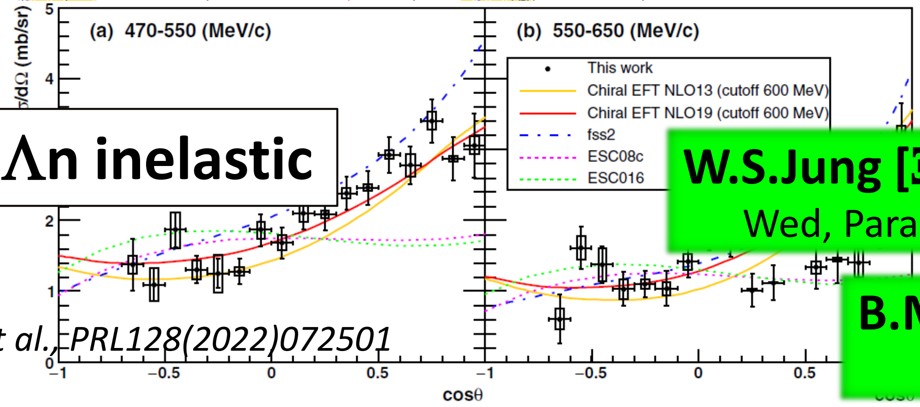


T. Nanamura et al., PTEP2022(2022)093D01

$\Sigma^+ p$ elastic

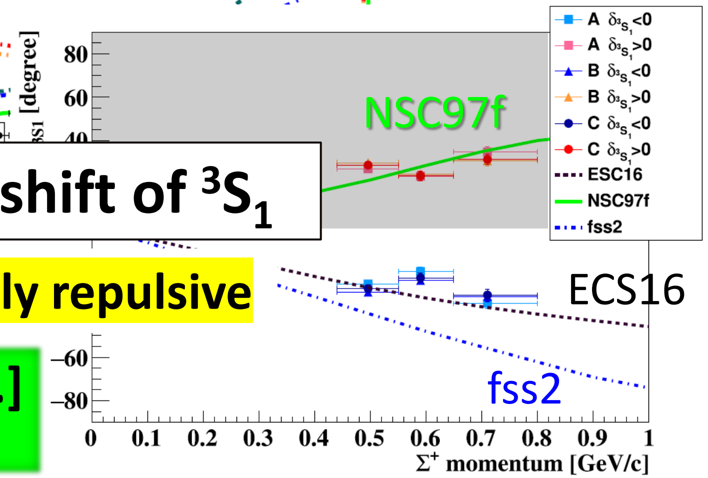


$\Sigma^- p \rightarrow \Lambda n$ inelastic



K. Miwa et al., PRL128(2022)072501

$\Sigma^+ p$, phase shift of $^3S_1$



→ moderately repulsive

W.S.Jung [$\Xi^- p \rightarrow \Lambda\Lambda$]
Wed, Parallel 1p2A

B.M.Kang [toward $\Xi^- p$ scatt.]
Mon, Parallel 29p1B

A.Kasagi
Tue, Parallel 30p2A

Hypertriton ($^{3}_{\Lambda}$H)

Y.Ma
Tue, Parallel 30p1A

T.Akaishi
Tue, Poster

– Important Benchmark in Hypernuclear Physics –

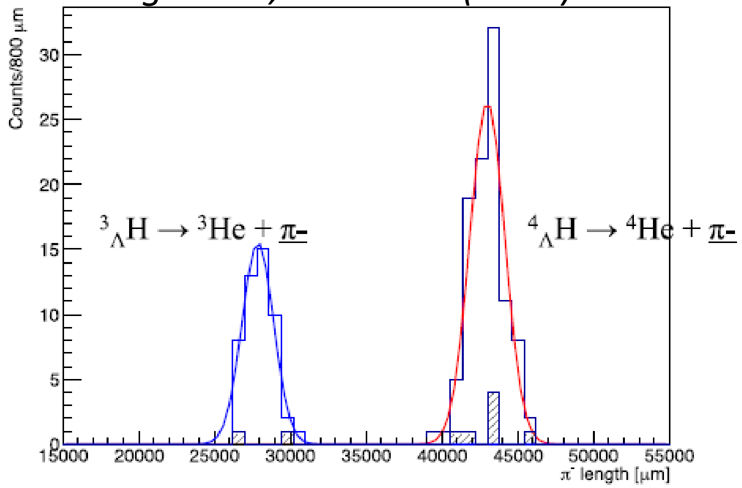
- Hypertriton binding energy measured by two experiments:
  - E07: Emulsion exposed to K⁻ beam, analyzed with machine learning
  - E73: Evaluated from $^{3,4}\mathrm{He}(K^-,\pi^0)^{3,4}_{\Lambda}\mathrm{H}$ cross sections (preliminary)

E07: Emulsion

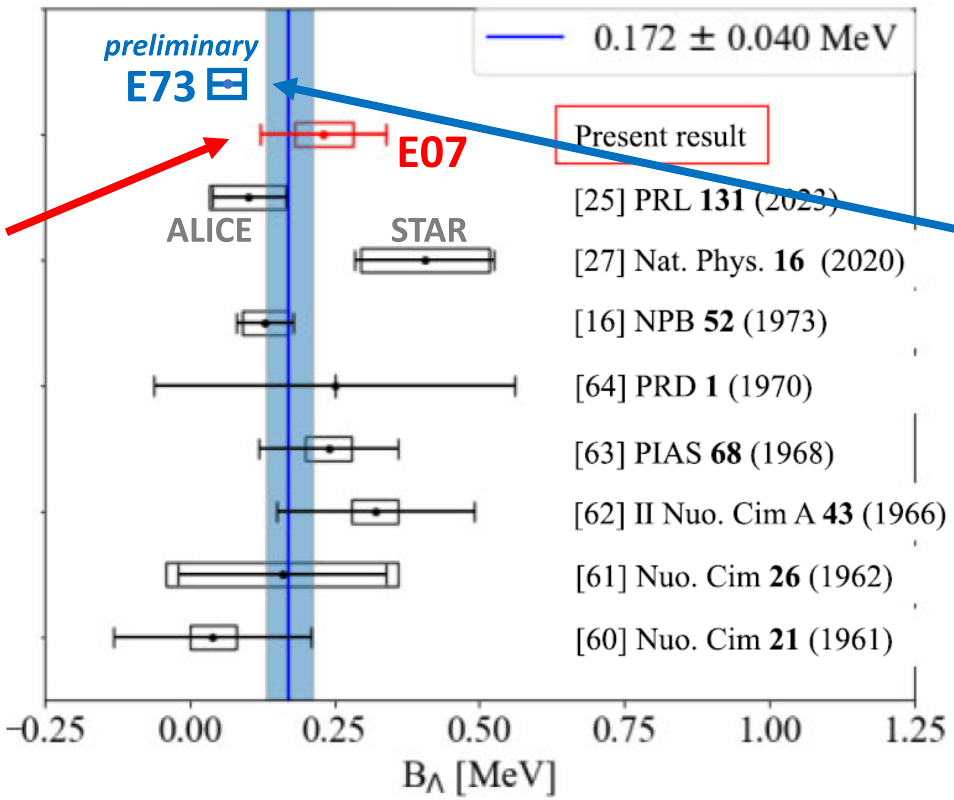
determined from π momentum obtained from π range

$B_\Lambda = 0.23 \pm 0.11 \pm 0.05$ MeV

A. Kasagi et al., PTEP2025(2025)083D01



A. Kasagi et al., PTEP2025(2025)083D01

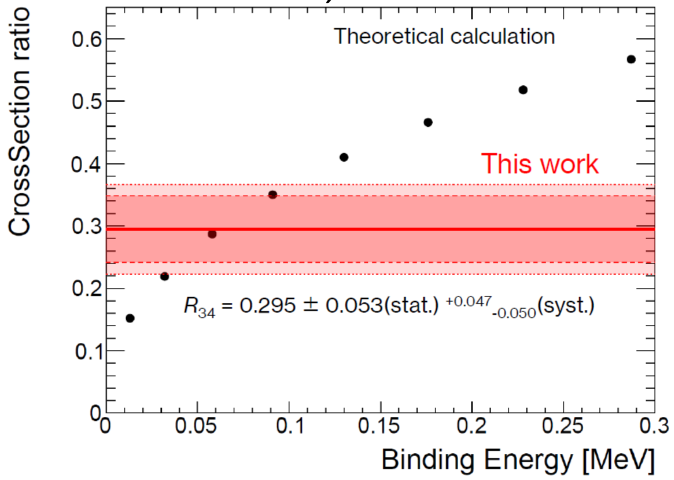


E73: $^{3,4}\mathrm{He}(K^-,\pi^0)^{3,4}_{\Lambda}\mathrm{H}$

evaluated from $\sigma_{^{3}_{\Lambda}H}/\sigma_{^{4}_{\Lambda}H}$ by comparison with theoretical calculation

$B_\Lambda = 0.061^{+0.028}_{-0.022}{}^{+0.024}_{-0.021}$ MeV

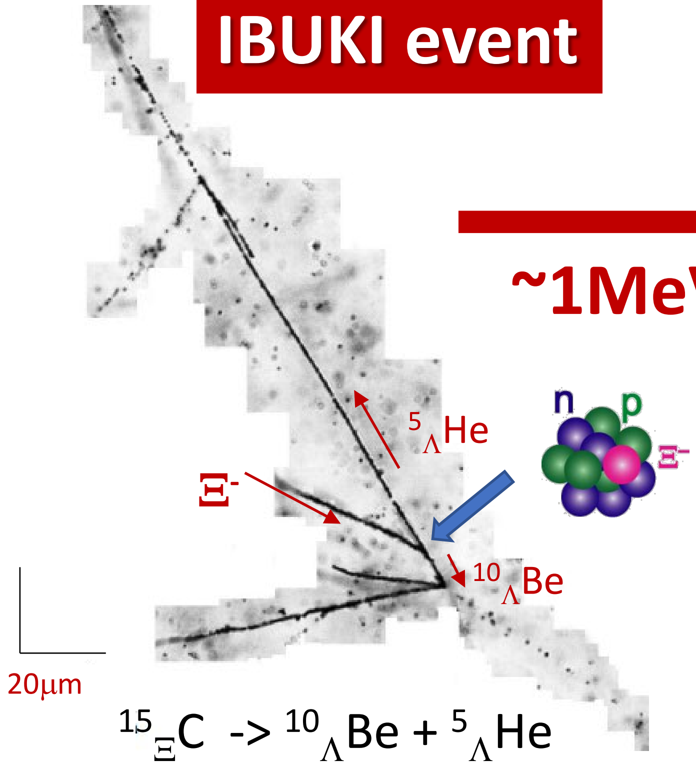
T. Akaishi et al., arXiv:2509.16967



Ξ-hypernuclei in Emulsion
– First Step to the ΞN Interaction –

- <u>Attractive Ξ-nuclear potential</u> was confirmed from observation of Ξ-hypernuclei in emulsion (E07)

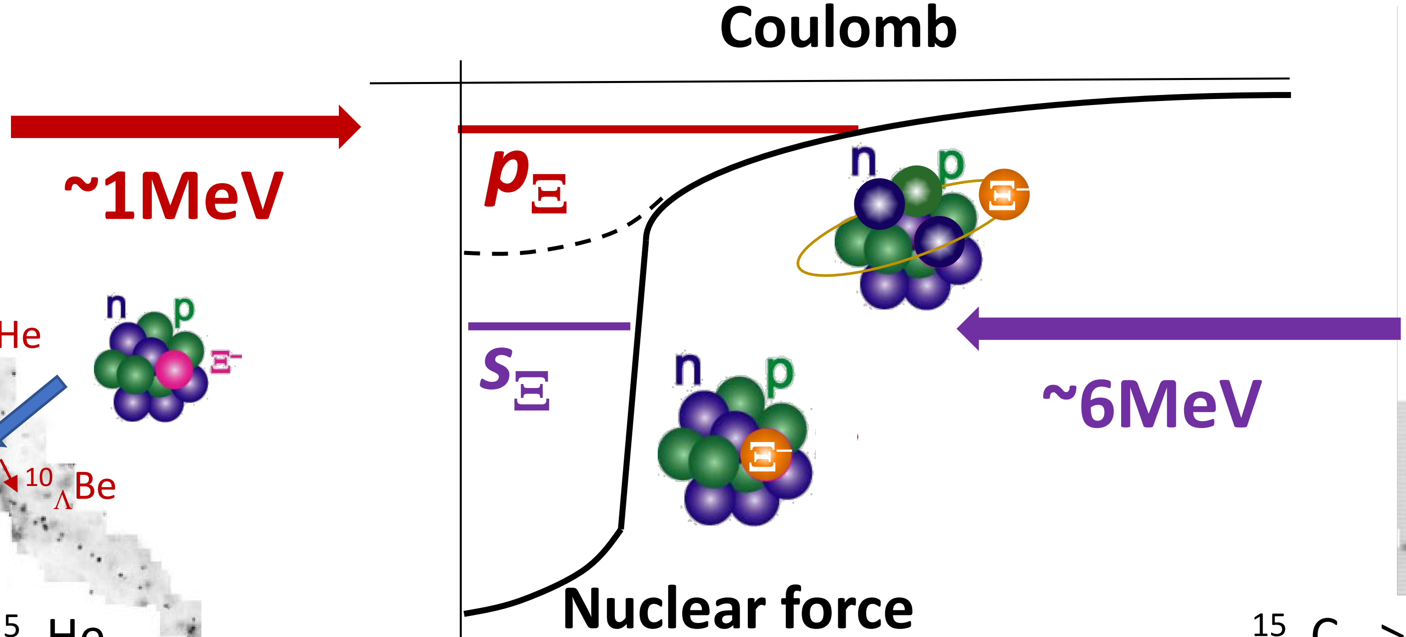
IBUKI event



$^{15}_{\Xi}\mathrm{C} \rightarrow {}^{10}_{\Lambda}\mathrm{Be} + {}^{5}_{\Lambda}\mathrm{He}$

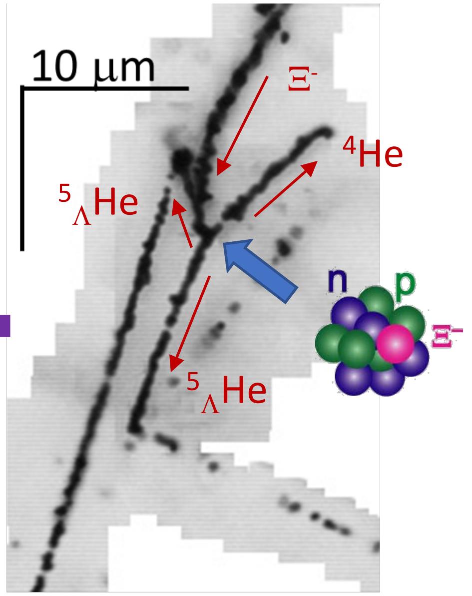
$\boxed{B_{\Xi^-} = 1.27 \pm 0.21\ \mathrm{MeV}}$

S. H. Hayakawa et al., PRL 126 (2021) 062501



$\boxed{\Xi^- + {}^{14}\mathrm{N} \rightarrow {}^{15}_{\Xi}\mathrm{C}}$

IRRAWADDY event



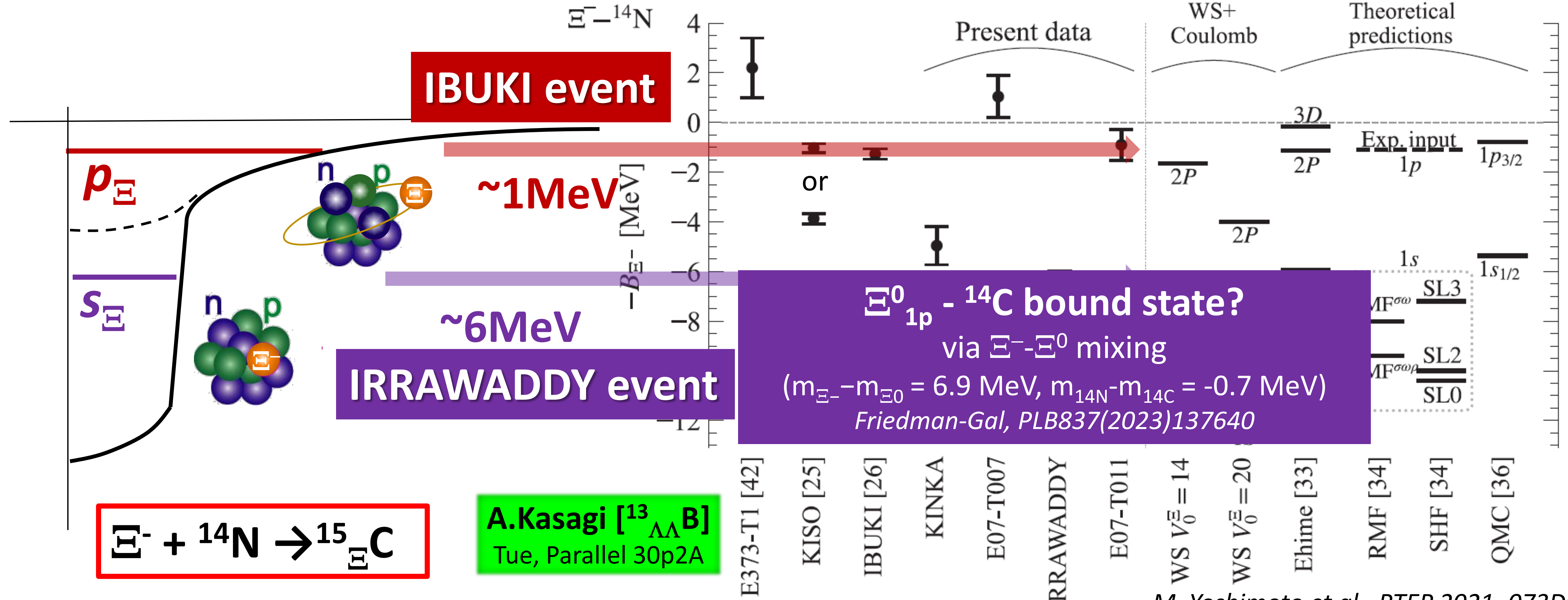
$^{15}_{\Xi}\mathrm{C} \rightarrow {}^{5}_{\Lambda}\mathrm{He} + {}^{5}_{\Lambda}\mathrm{He} + {}^{4}\mathrm{He} + n$

$\boxed{B_{\Xi^-} = 6.27 \pm 0.27\ \mathrm{MeV}}$

M. Yoshimoto et al., PTEP 2021, 073D02

Ξ-hypernuclei in Emulsion
– First Step to the ΞN Interaction –

- Attractive Ξ-nuclear potential was confirmed from observation of Ξ-hypernuclei in emulsion (E07)



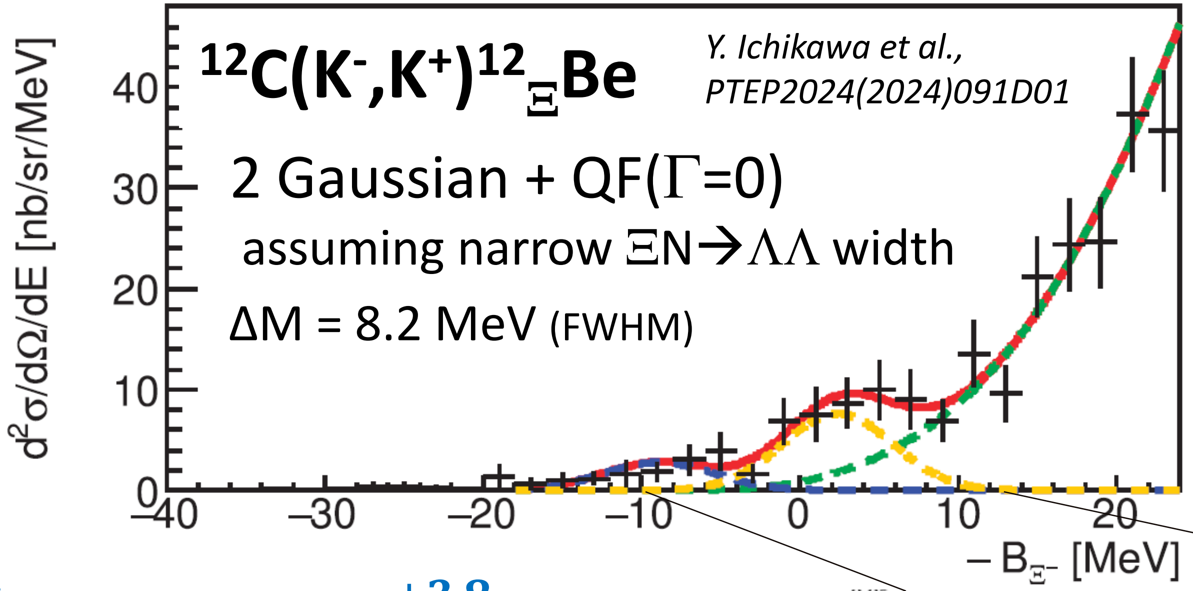
M. Yoshimoto et al., PTEP 2021, 073D02

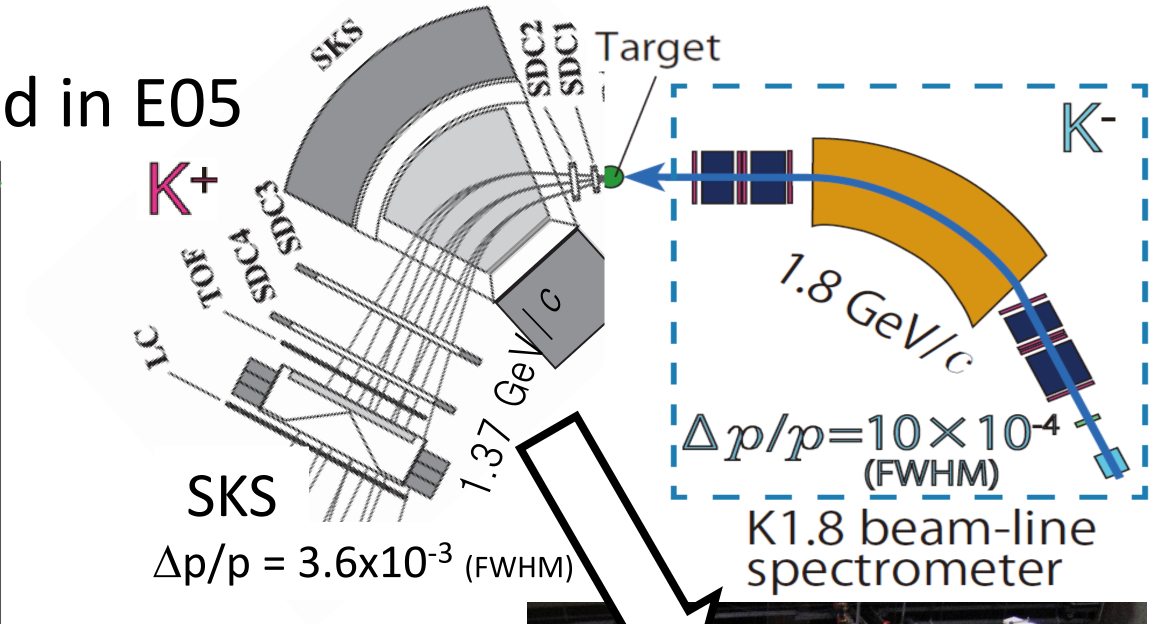
Y.Ichikawa
Wed, Plenary 1a1

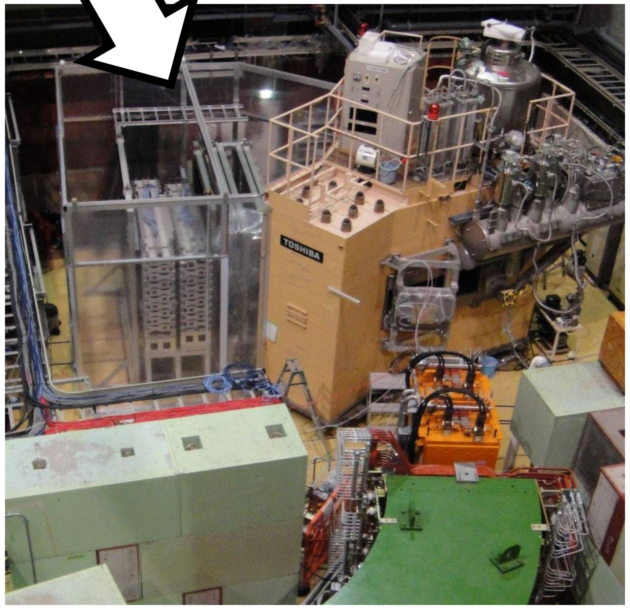
Ξ-hypernuclear Spectroscopy

– Toward a Precise Determination of the ΞN Interaction –

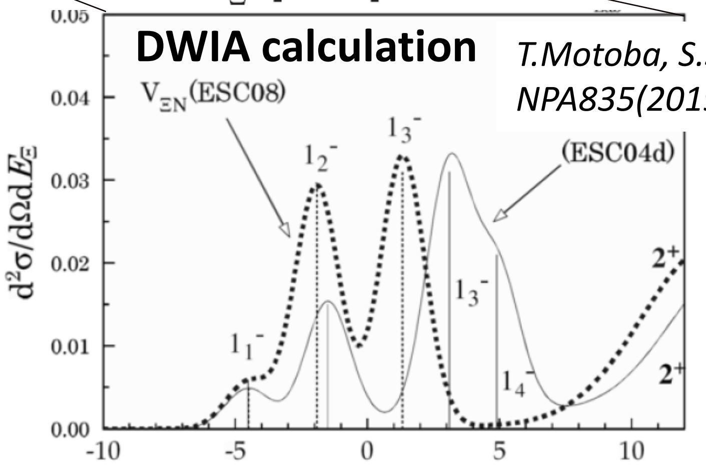
● Ξ-hypernuclear peaks were first observed in E05







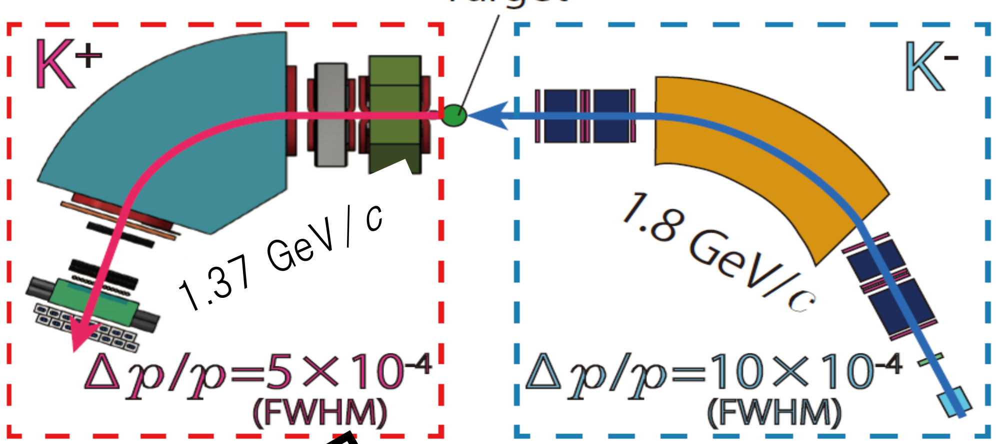
$$B_{\Xi^-}^{1st} = 8.9 \pm 1.4^{+3.8}_{-3.1}\ \mathrm{MeV}$$
$$B_{\Xi^-}^{2nd} = -2.4 \pm 1.3^{+2.8}_{-1.2}\ \mathrm{MeV}$$



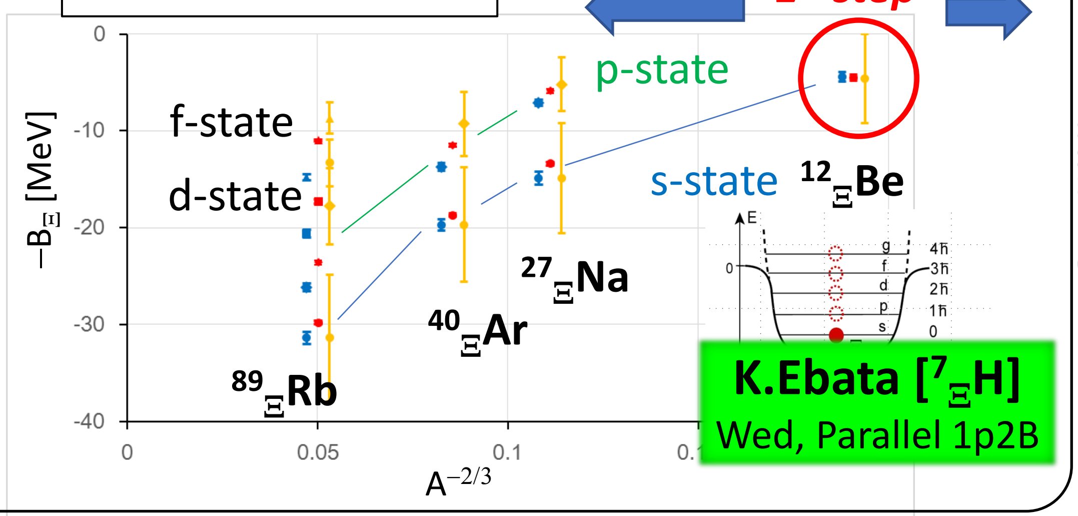
Need more precise measurements to investigate the detailed structure
→ E70 with ΔM = 2 MeV (FWHM) using S-2S

Ξ-hypernuclear Spectroscopy
– Toward a Precise Determination of the ΞN Interaction –

- Systematic measurements will be strongly promoted at J-PARC, starting from E70
- The precise Ξ-hypernuclear spectroscopy
  - Ξ potential – both Re(V_Ξ) and Im(V_Ξ)
  - isospin dependence ($\propto 1/A$)
  - ΞN-ΛΛ conversion



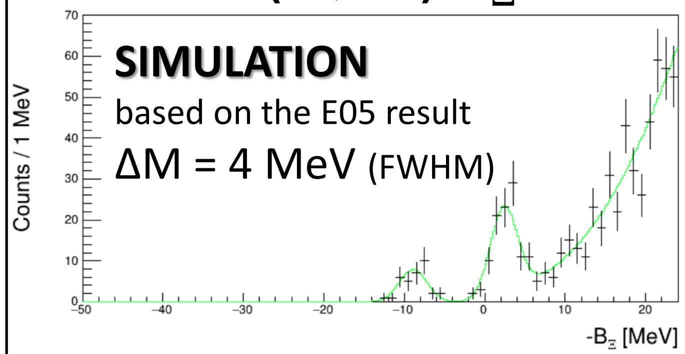
Calculated Ξ binding energy (and width)



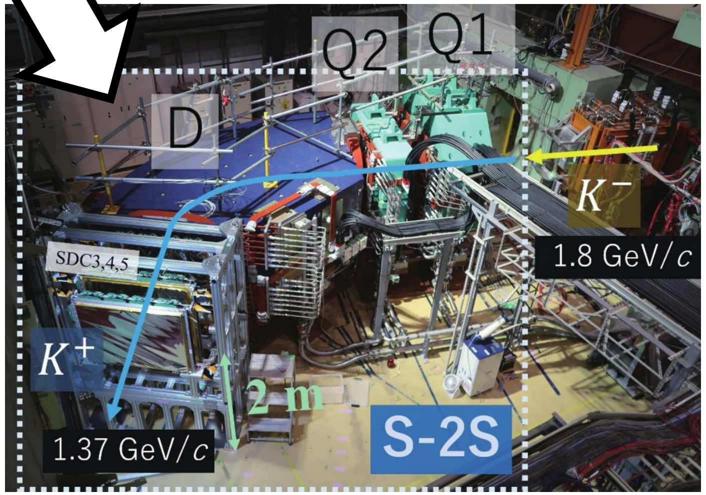
K.Ebata [$^{7}_{\Xi}$H]
Wed, Parallel 1p2B

1st step data-taking is completed

^{12}C (K$^-$, K$^+$) $^{12}_{\Xi}$Be



T. Gogami et al., The 38th J-PARC PAC (2024)



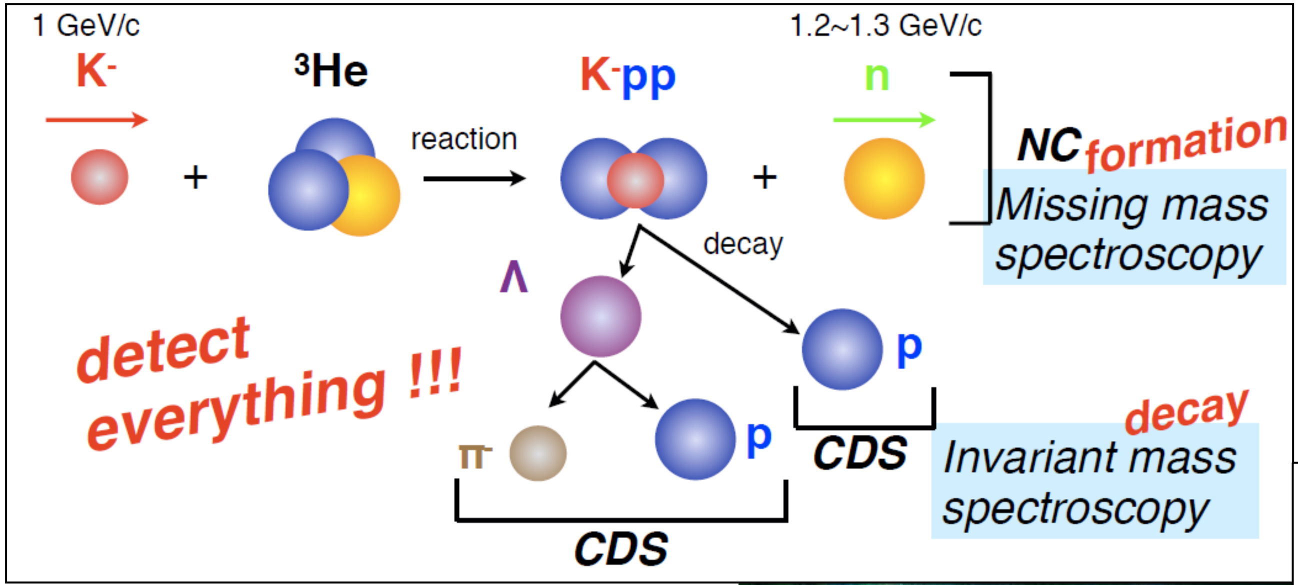
Results coming soon

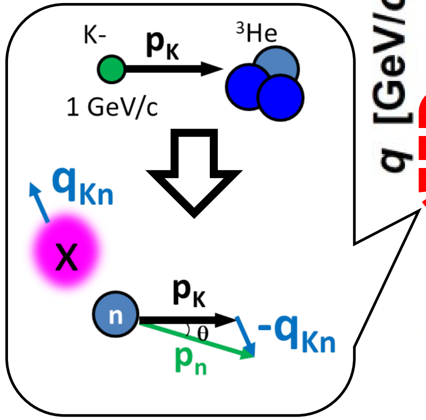
T.Hashimoto
Thu, Plenary 2a2

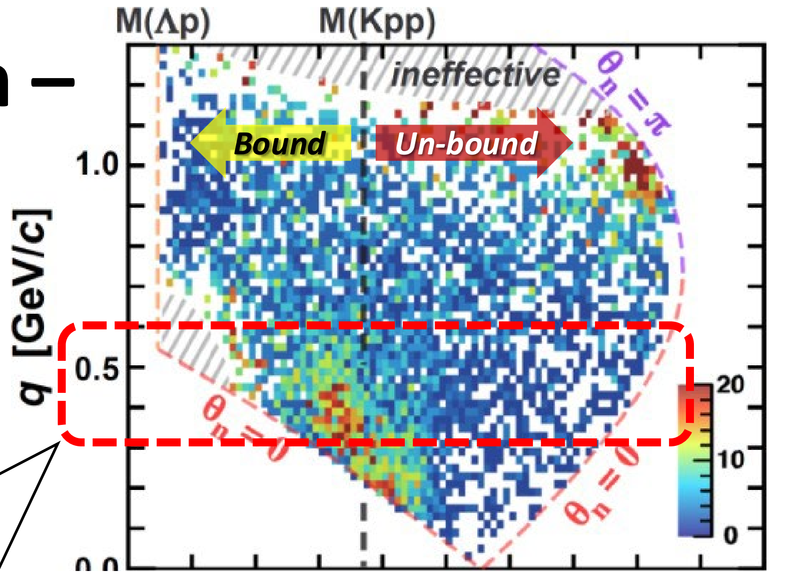
Kaonic Nuclei

– A New Form of Nuclei Composed of a Real Kaon –

- "K^-pp" bound state was observed via $^3He(K^-, \Lambda p)n$ in E15



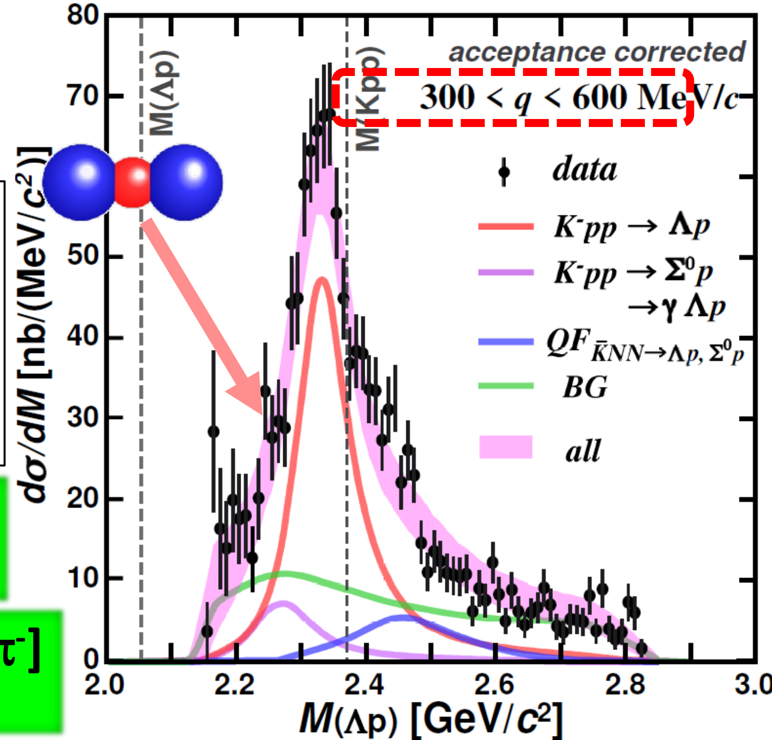


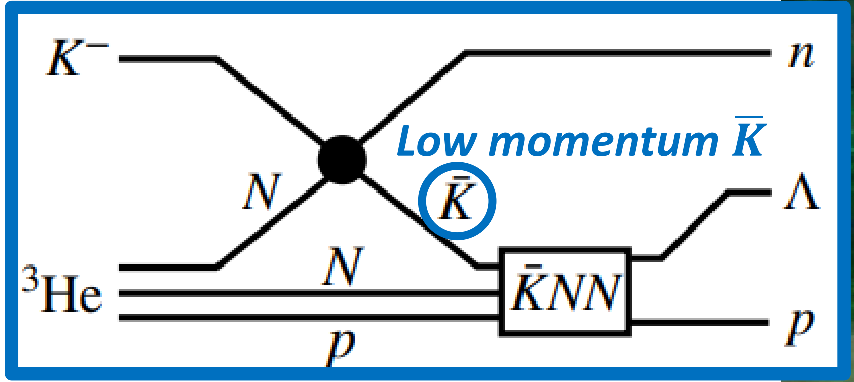


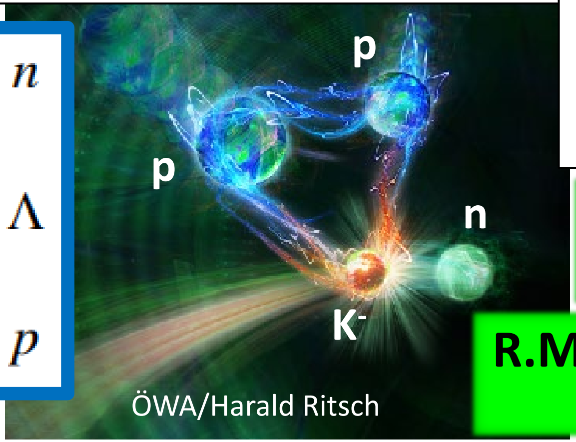
PLB789(2019)620., PRC102(2020)044002.

$$B_{Kpp} = 42 \pm 3^{+3}_{-4}$$
$$\Gamma_{Kpp} = 100 \pm 7^{+10}_{-9}$$

→ Compact system?







F.Oura [$^{12}C(K^-,p)X$]
Mon, Parallel 29p1C

R.Murayama [$K^-d \rightarrow \Lambda p \pi^-$]
Thu, Plenary 2a2

Y.Kimura
Mon, Parallel 29p1C

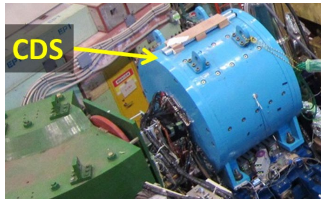
Kaonic Nuclei

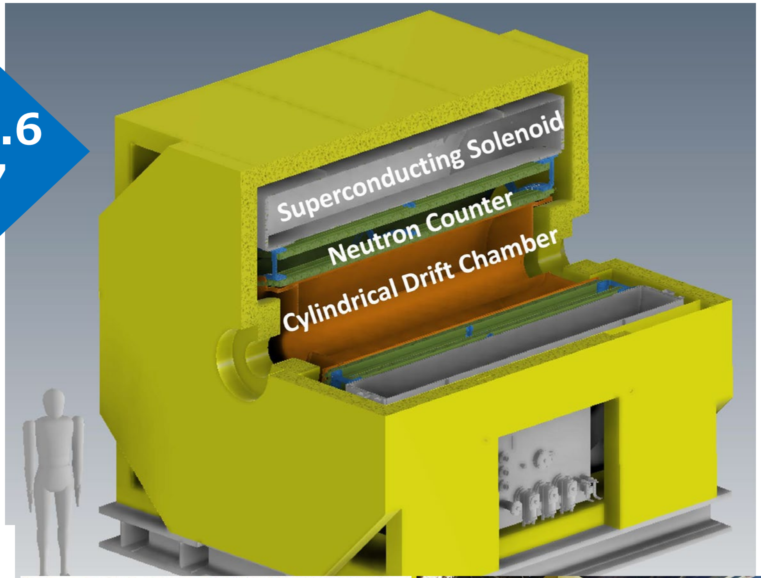
Y.Tsutsumi
Tue, Poster

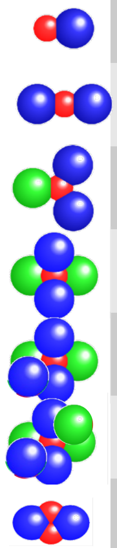
– Toward a Further Understanding of Kaonic Nuclei –

- Systematic measurements will be carried out at J-PARC, starting from E80
  - Mass number dependence
    - Binding energy, Branching ratio, *q* dependence, ..
  - Spin/parity determination
  - Internal structure extracted with theoretical investigations

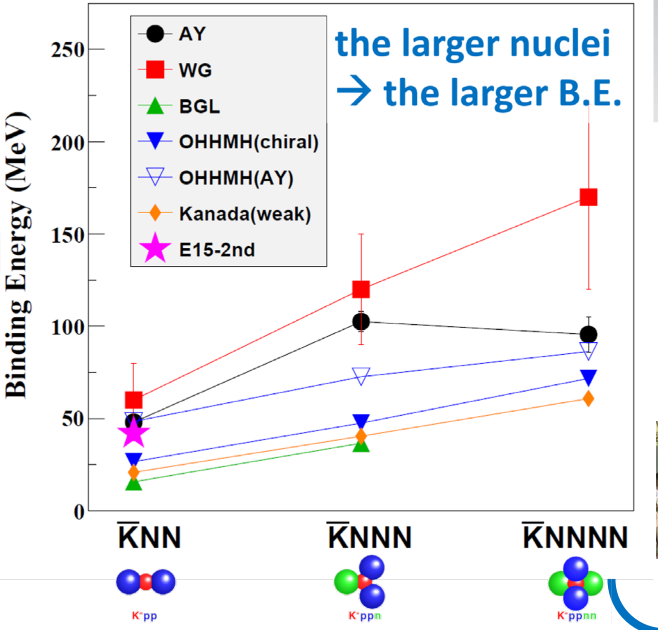
✓Solid angle: x1.6
✓Neutron eff.: x7







	Reaction	Decays
$\bar{K}N$	d(K⁻,n)	$\pi^{\pm 0}\Sigma^{\mp 0}$
$\bar{K}NN$	^{3}He(K⁻,N)	$\Lambda p/\Lambda n$
$\bar{K}NNN$	^{4}He(K⁻,N)	$\Lambda d/\Lambda pn$ ← first step
$\bar{K}NNNN$	^{6}Li(K⁻,d)	$\Lambda t/\Lambda dn$
$\bar{K}NNNNN$	^{6}Li(K⁻,N)	$\Lambda\alpha/\Lambda dd/\Lambda dpn$
$\bar{K}NNNNNN$	^{7}Li(K⁻,N)	$\Lambda\alpha n/\Lambda ddn$
$\bar{K}\bar{K}NN$	$\bar{p}$ + ^{3}He	$\Lambda\Lambda$



Will start in 2027

More Diverse Activities at the J-PARC Hadron Hall

– Discussed in HYP2025 –

Hyp-PTC@K1.8BR

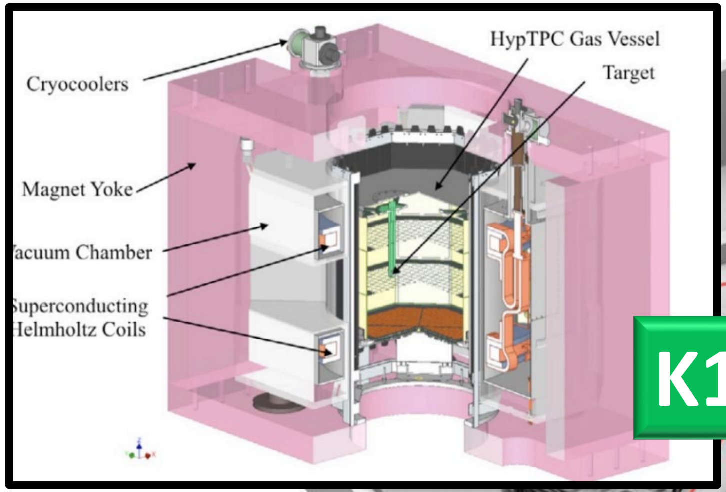
S.Hayakawa [physics w/HypTPC]
Tue, Parallel 30p2A

H.I.Lee [Λ*]
Thu, Parallel 3a1A

R.Saito [Λη Cusp]
Tue, Parallel 30p2B

S.H.Kim [N*Δ*]
Mon, Parallel 29p2B

J.J.Lee [N*Δ*]
Tue, Poster



Hyp-TPC@K1.8

J.K.Ahn [Θ^+]
Tue, Plenary 30a2

R.Sasaki [ΣN Cusp]
Tue, Poster

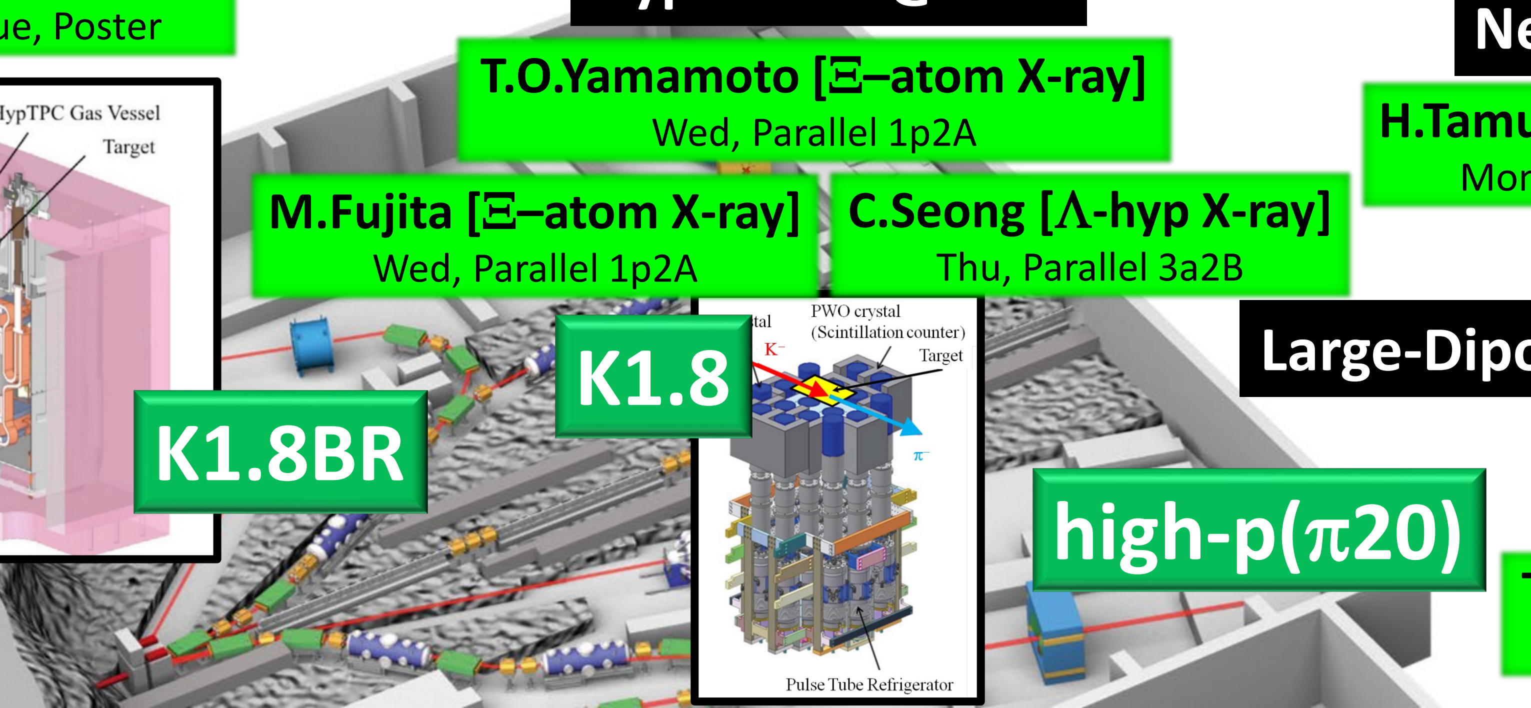
S.W.Choi [K*(892)]
Thu, Parallel 3a1A

Hyperball-J@K1.8

T.O.Yamamoto [Ξ–atom X-ray]
Wed, Parallel 1p2A

M.Fujita [Ξ–atom X-ray]
Wed, Parallel 1p2A

C.Seong [Λ-hyp X-ray]
Thu, Parallel 3a2B



S2-S@K1.8

T.Taniguchi [high-res. (π^+,K^+)]
Tue, Poster

D.Watanabe [high-res. (π^+,K^+)]
Wed, Parallel 1p2B

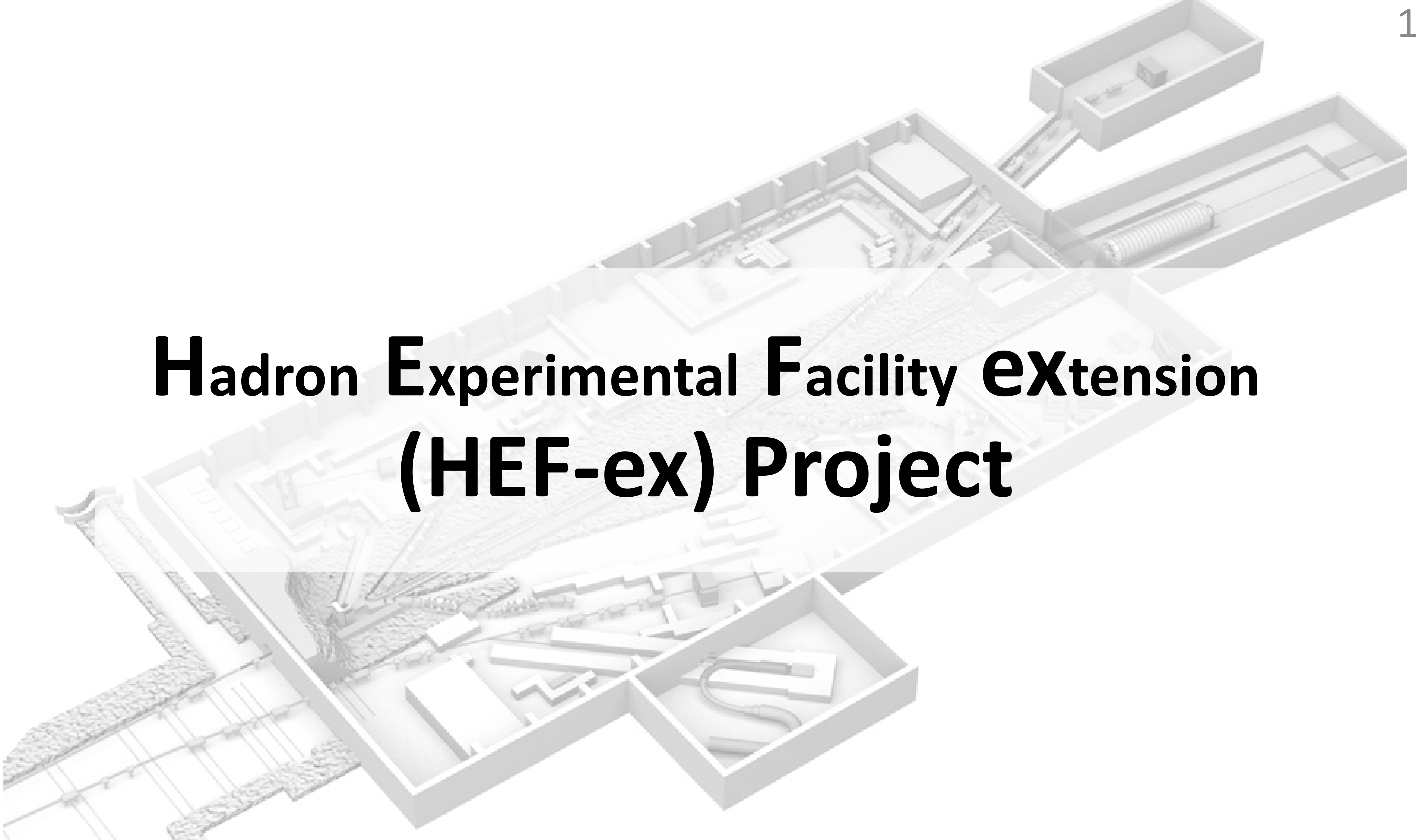
Near Future

H.Tamura [Λ's β-decay]
Mon, Parallel 29p2A

Large-Dipole@high-p(π20)

H.Sako [ϕ→KK]
Mon, Parallel 29p2C

T.Ishikawa [ϕN int.]
Tue, Parallel 30p1B

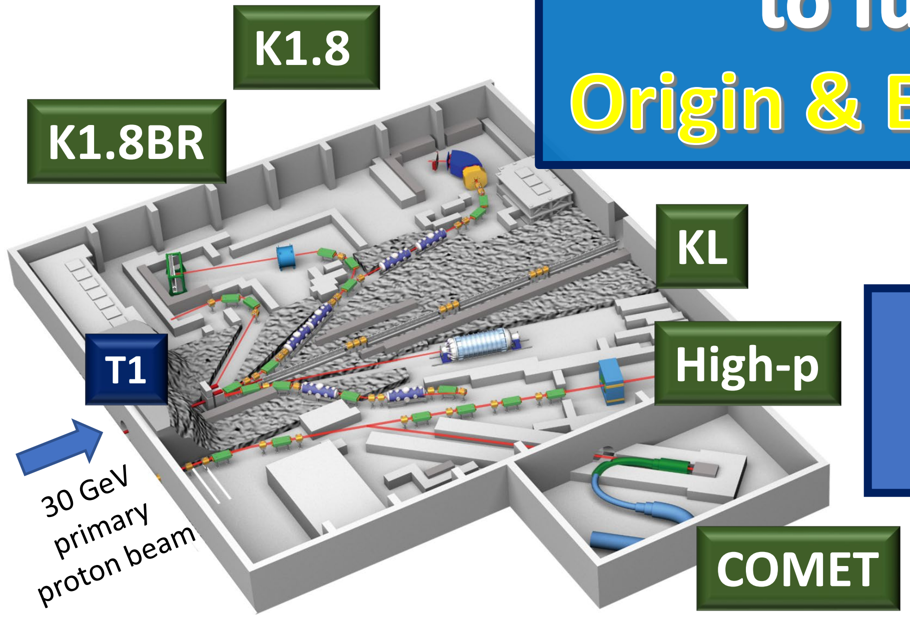


Hadron Experimental Facility extension (HEF-ex) Project

Hadron Experimental Facility extension (HEF-ex) Project

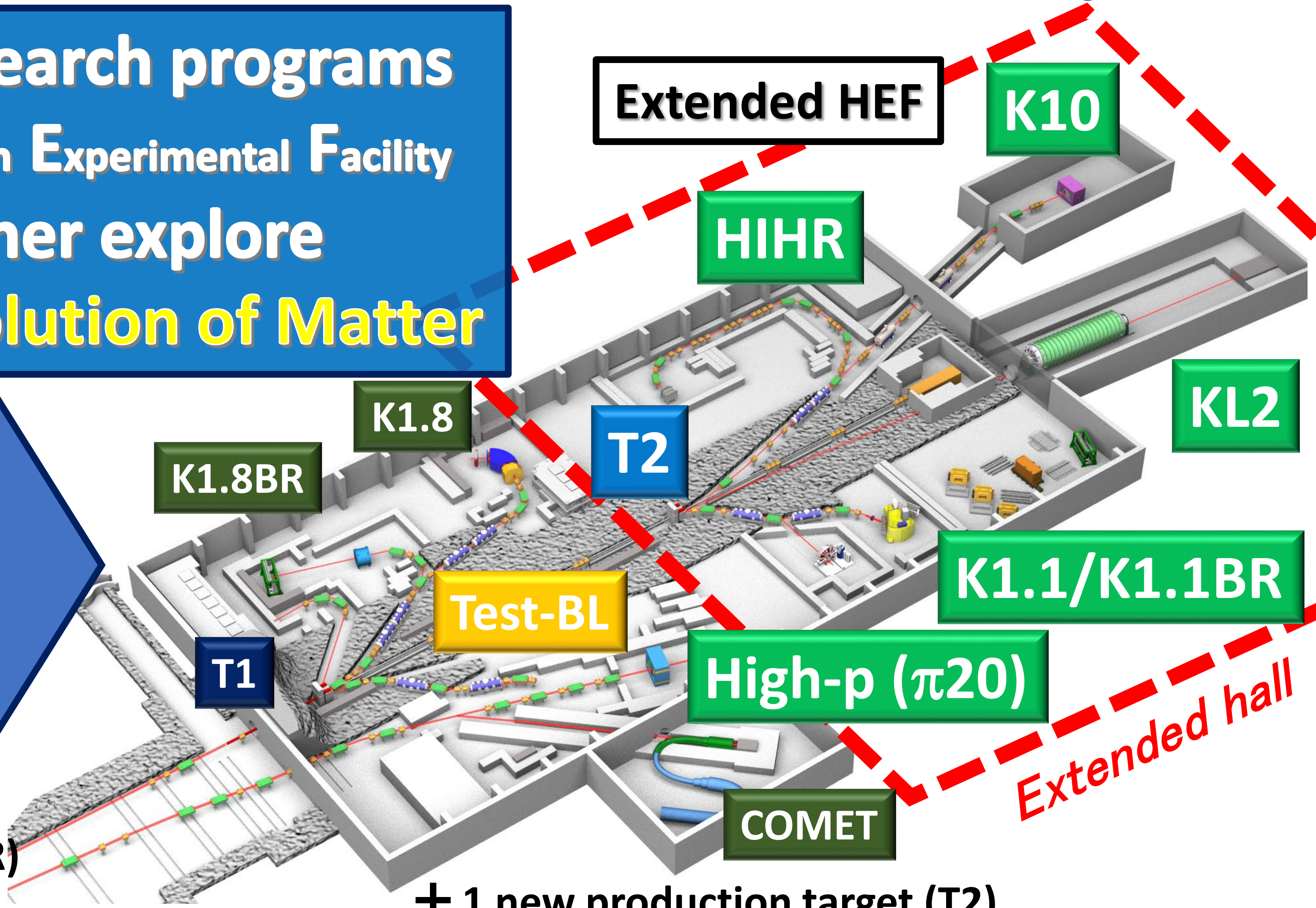
expand research programs
at the Hadron Experimental Facility
to further explore
Origin & Evolution of Matter

Present HEF (2009～)



1 production target (T1)
1 secondary-charged beamline (K1.8/K1.8BR)
1 neutral beamline (KL)
1 primary beamline (High-p)
1 muon beamline (COMET)

Extended HEF



＋1 new production target (T2)
＋4 new beamlines (HIHR, K1.1/K1.1BR, KL2, K10)
＋ 2 updated beamlines (High-p (π20), Test-BL)

Expanded Research Programs

at the Extended Facility

Determine density dependent ΛN interaction

HIHR **Ultra-high-resolution Λ hypernuclei spectroscopy**
- intense dispersion matched π beam

K1.1 **Systematic ΛN scattering measurement**
- intense polarized Λ beam

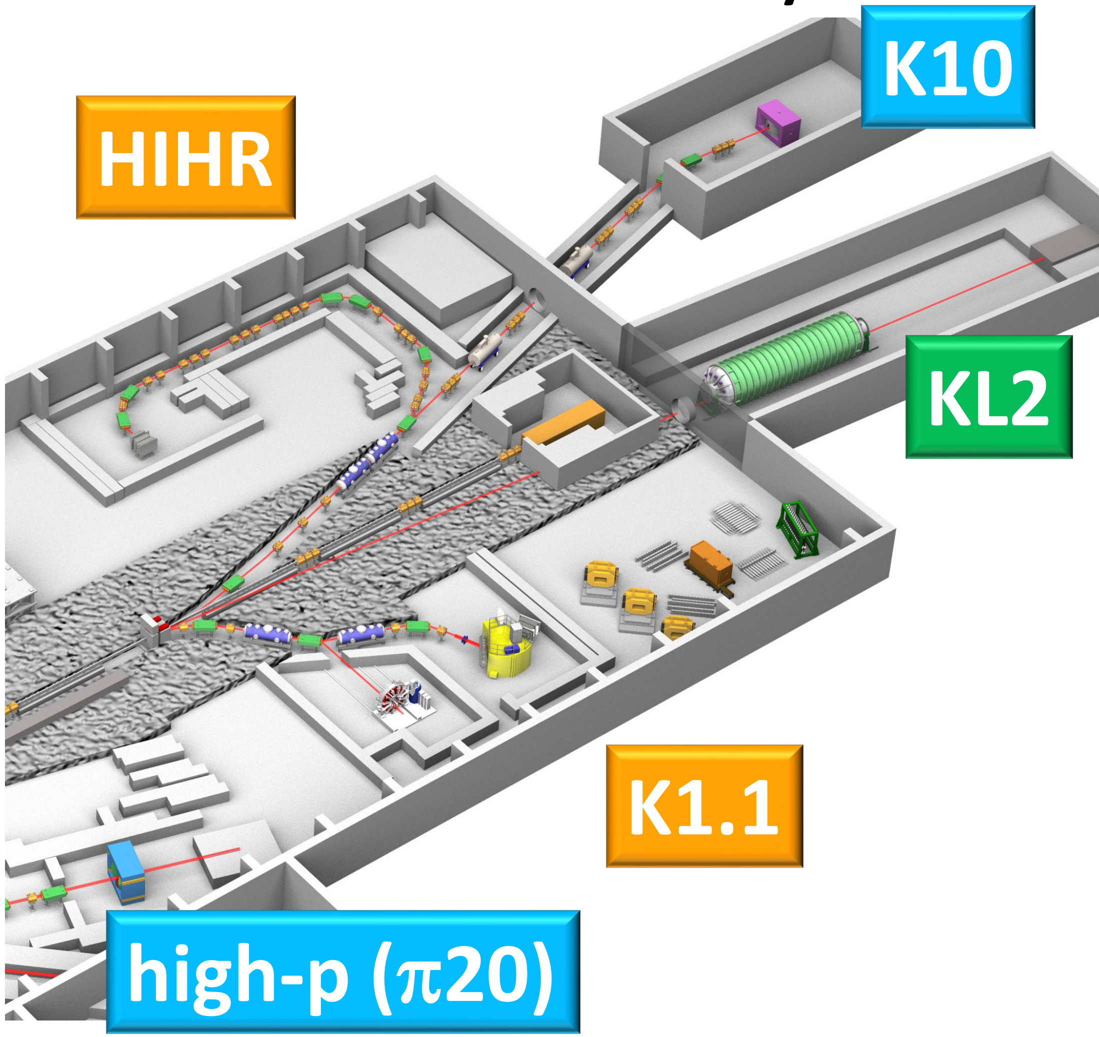
Investigate diquarks in baryons

high-p (π20) **High-resolution charm baryon spectroscopy**
- intense high-momentum π beam

K10 **High-resolution multi-strange baryon spectroscopy**
- intense high-momentum separated K beam

Search for new physics beyond the SM

KL2 **Most sensitive $K_L^0 \rightarrow \pi^0 \nu \bar{\nu}$ measurement**
- intense neutral K beam



Expanded Research Programs

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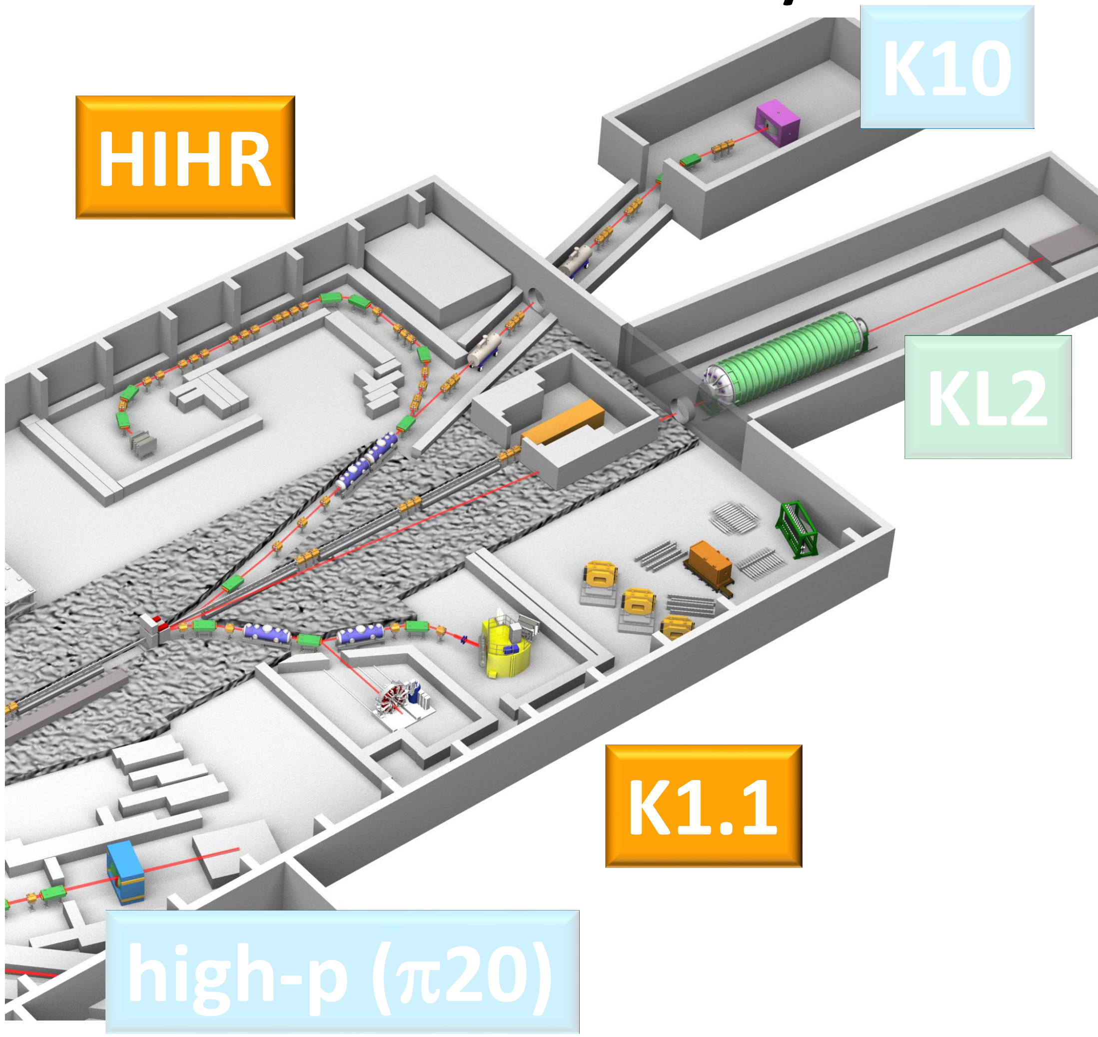
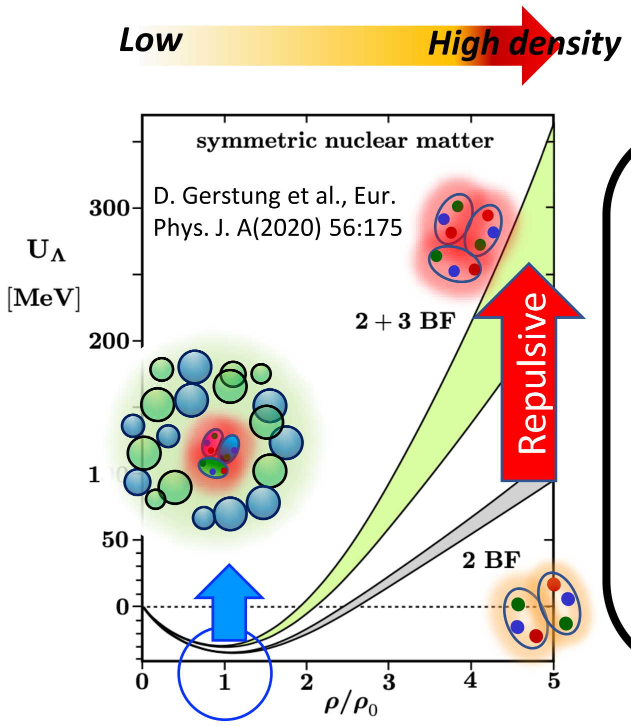


Strangeness Nuclear Physics: Hyperon in Dense Environment

Why can heavy neutron stars exist?

➢ **Hyperons (Λ, Ξ, ...) emerge in dense neutron star matter?**

ΛNN 3 Baryon Force is a key



We need to determine

a tiny fraction of 3 Baryon Force effects

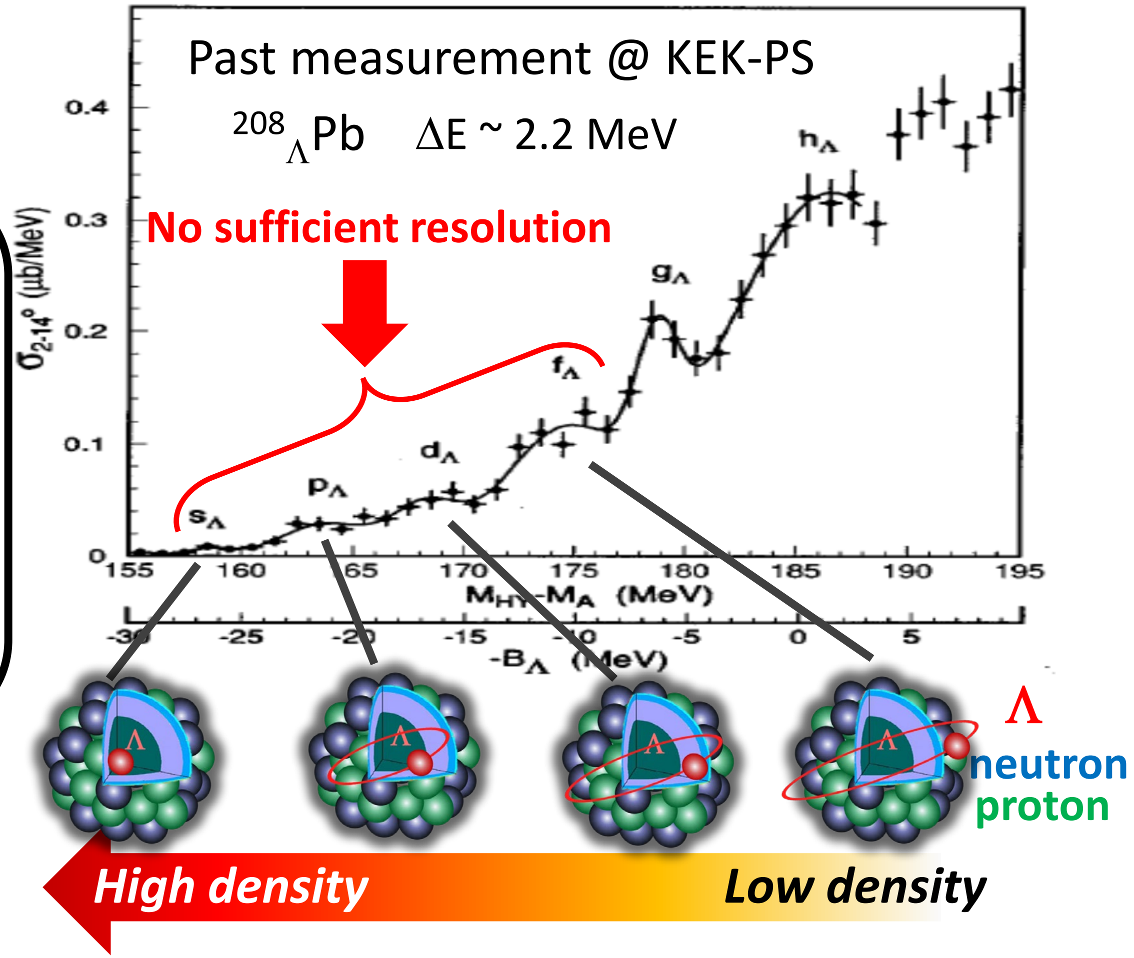
heavy Λ-hypernuclei :

Λ binding energies (B_Λ)

→ density dependent

ΛN interaction

→ We need precise measurements



Strangeness Nuclear Physics: Hyperon in Dense Environment

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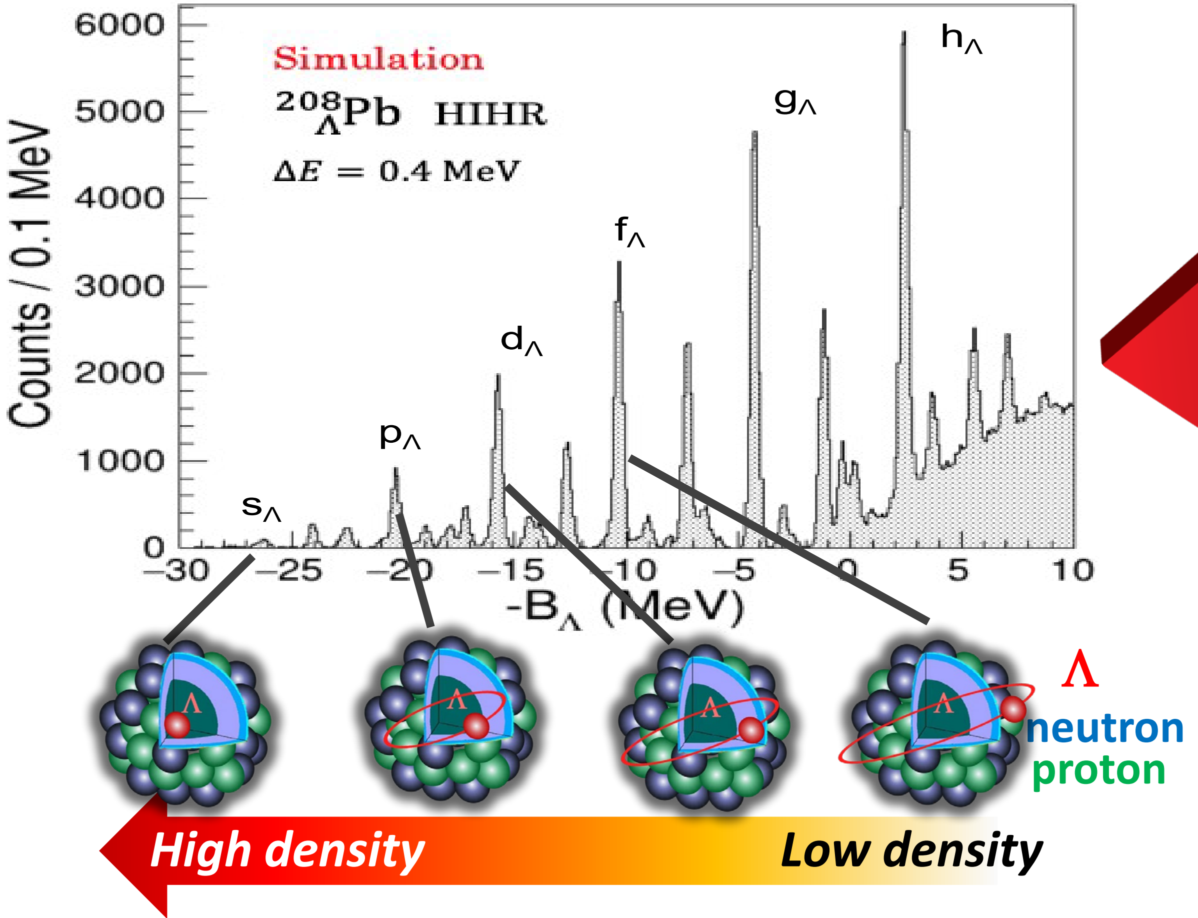
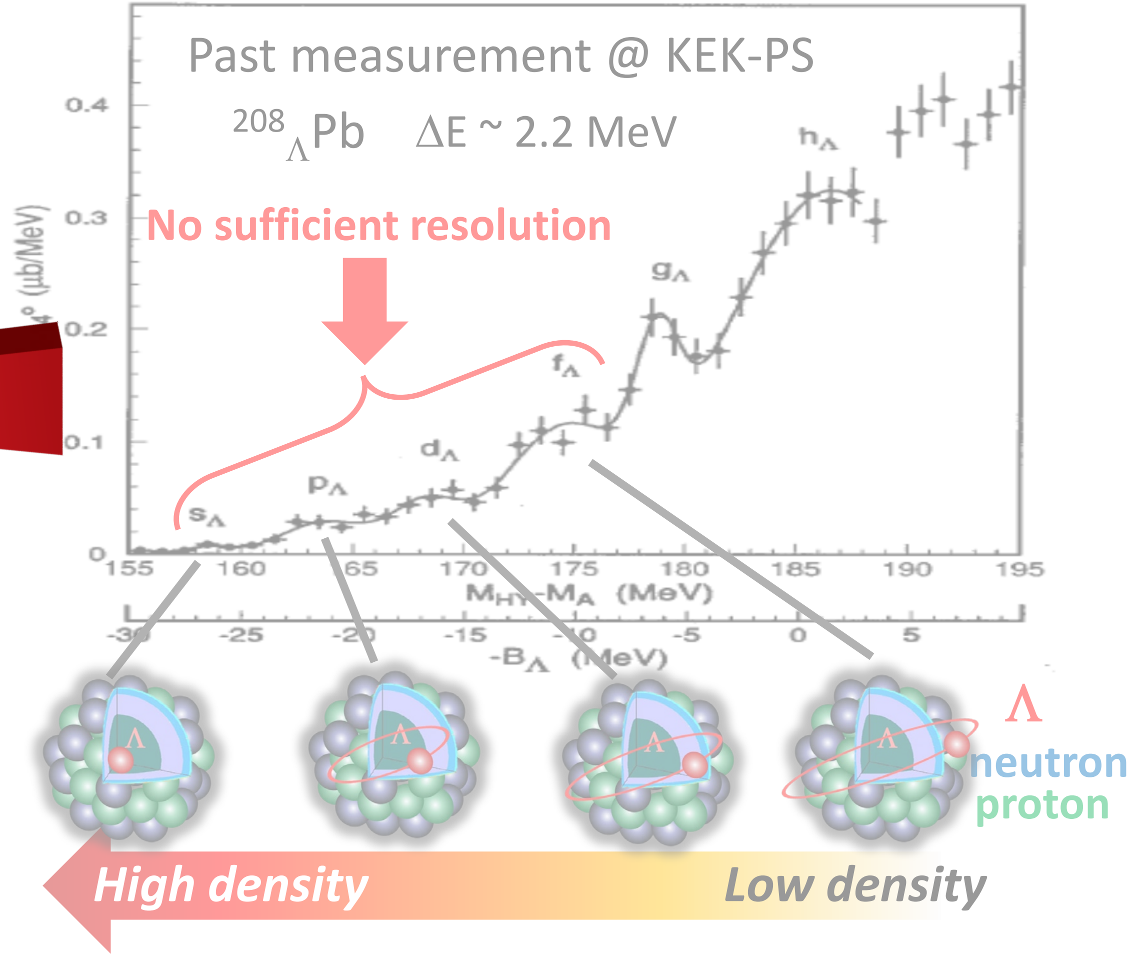
Need separation of each Λ orbital state





Strangeness Nuclear Physics: Hyperon in Dense Environment

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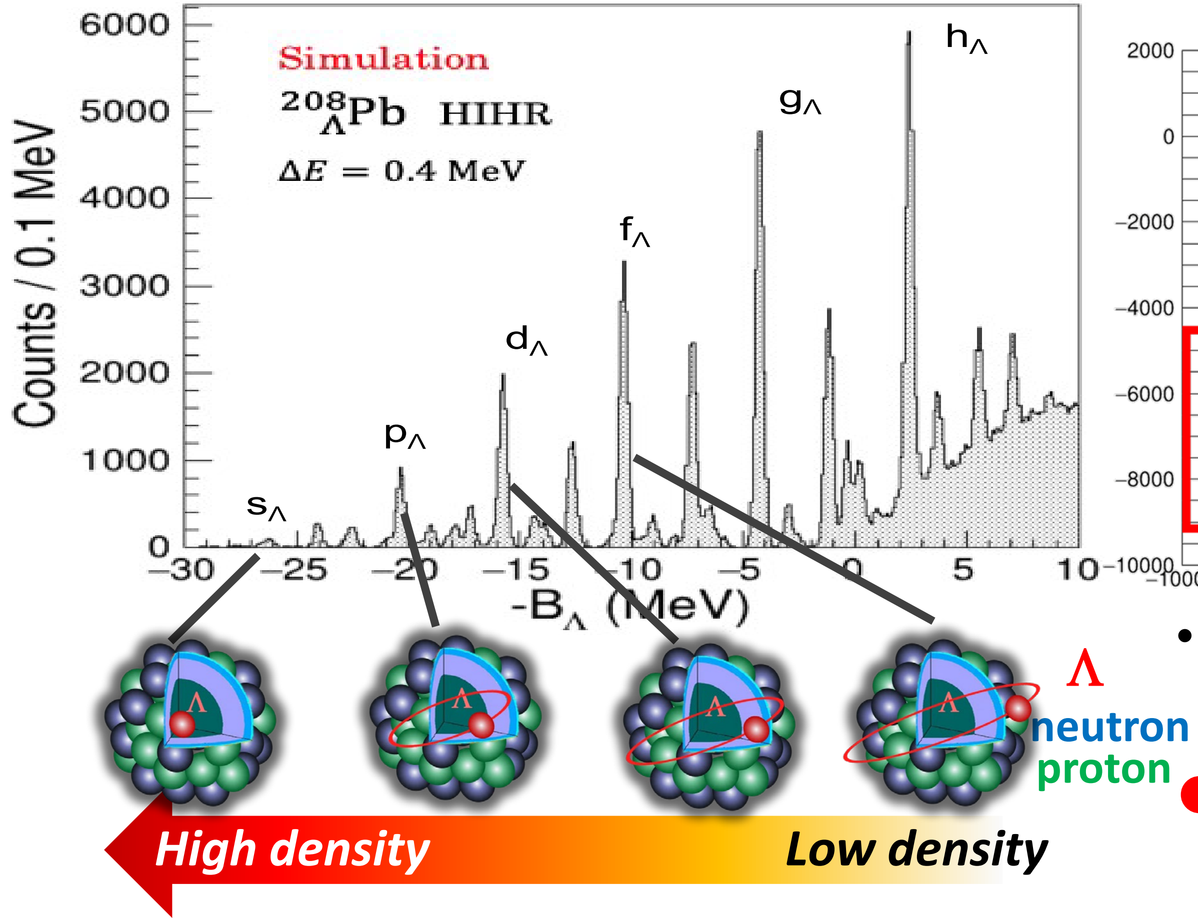
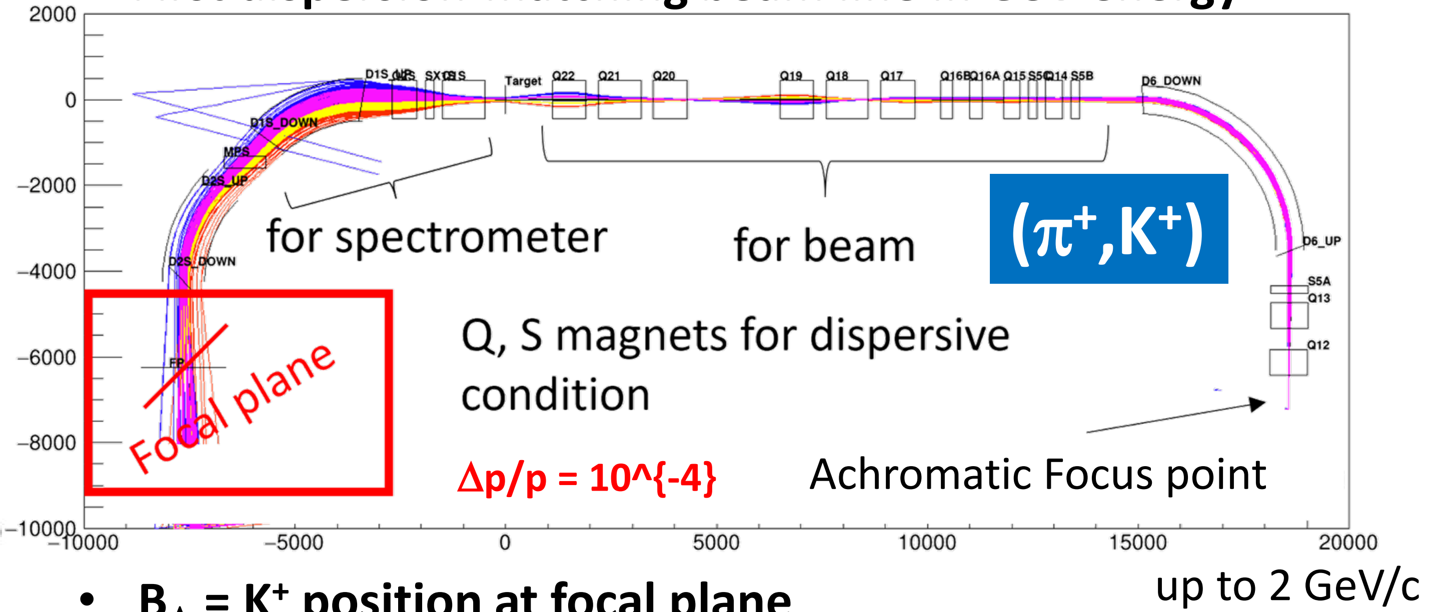
Ultra-high-resolution Λ-hyp. spectroscopy



HIHR beam line (High-Intensity High-Resolution)

First dispersion-matching beam line in GeV energy



- **B_Λ = K^+ position at focal plane**
  - ✓ No need for beam tracking → Intense π beam of > 10^8 /pulse
- **Break through the resolution limit:**

  ~2.2 MeV → **better than ~0.4 MeV** (FWHM)

Strangeness Nuclear Physics: Hyperon in Dense Environment

Why can heavy neutron stars exist?

➢ **Hyperons (Λ, Ξ, ...) emerge in dense neutron star matter?**

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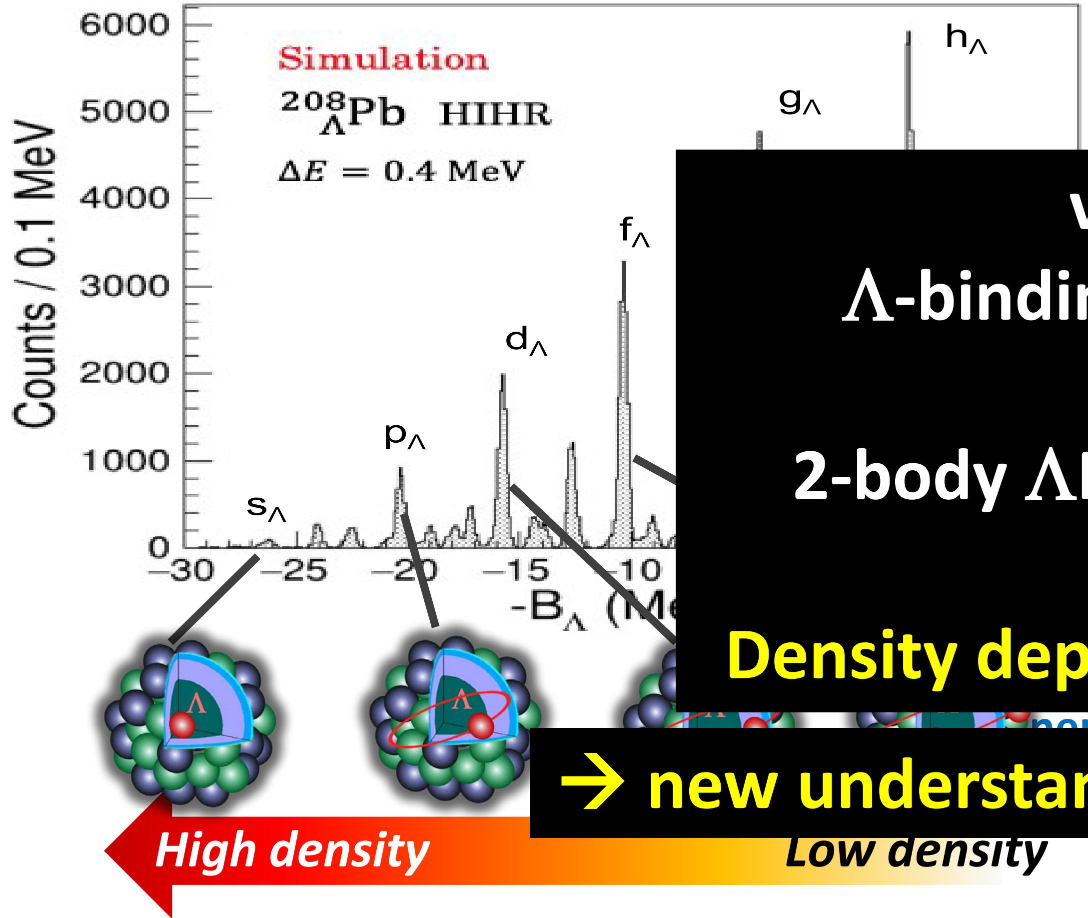
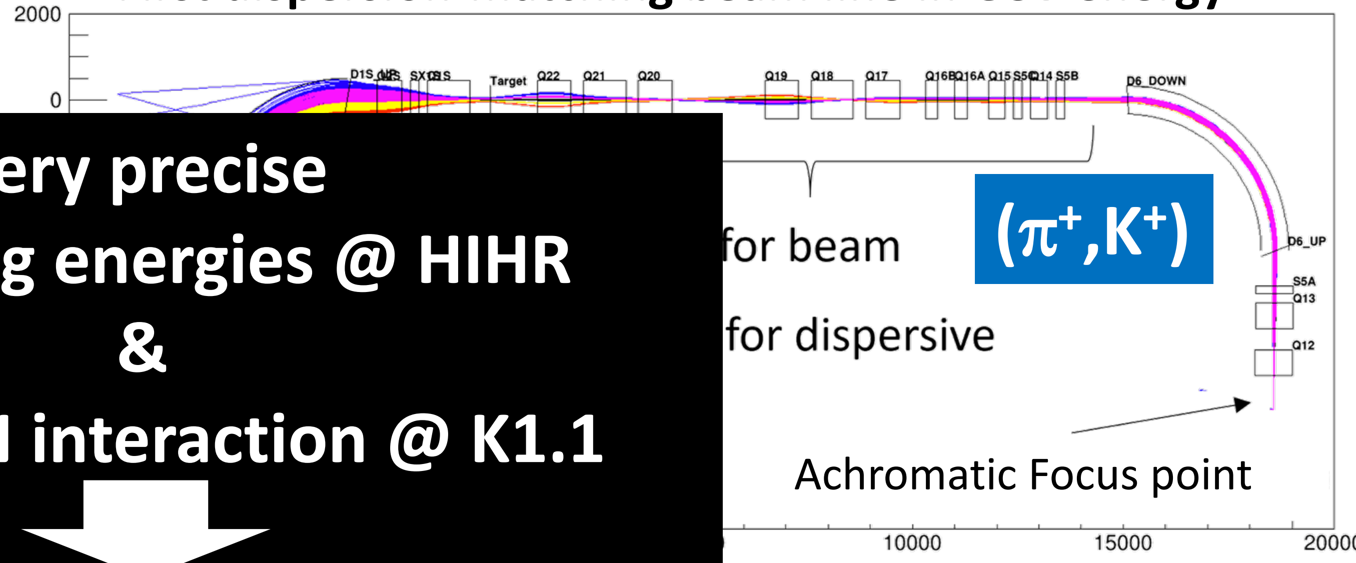


HIHR beam line (**H**igh-**I**ntensity **H**igh-**R**esolution)

First dispersion-matching beam line in GeV energy



up to 2 GeV/c

Intense π beam of > 10^8 /pulse

n limit:

~2.2 MeV → **better than ~0.4 MeV** (FWHM)

very precise

Λ-binding energies @ HIHR

&

2-body ΛN interaction @ K1.1

Density dependent ΛN interaction

→ new understanding of neutron star matter

Expanded Research Programs

at the Extended Facility

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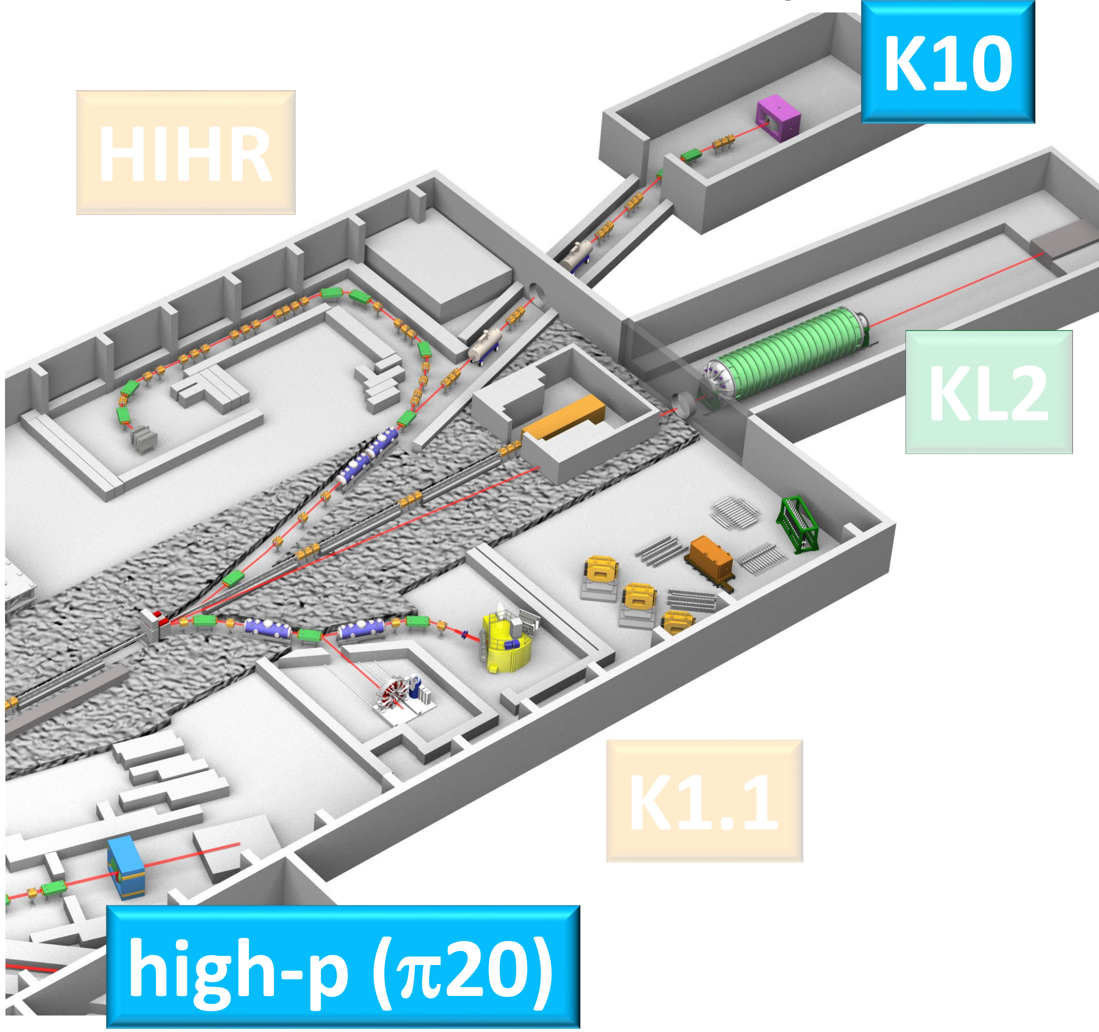


Behaver of non-perturbative QCD in low energy regime

Hadron Physics: Diquarks in Baryons

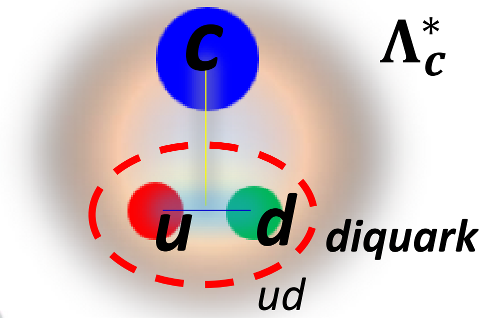
How quarks build hadrons?

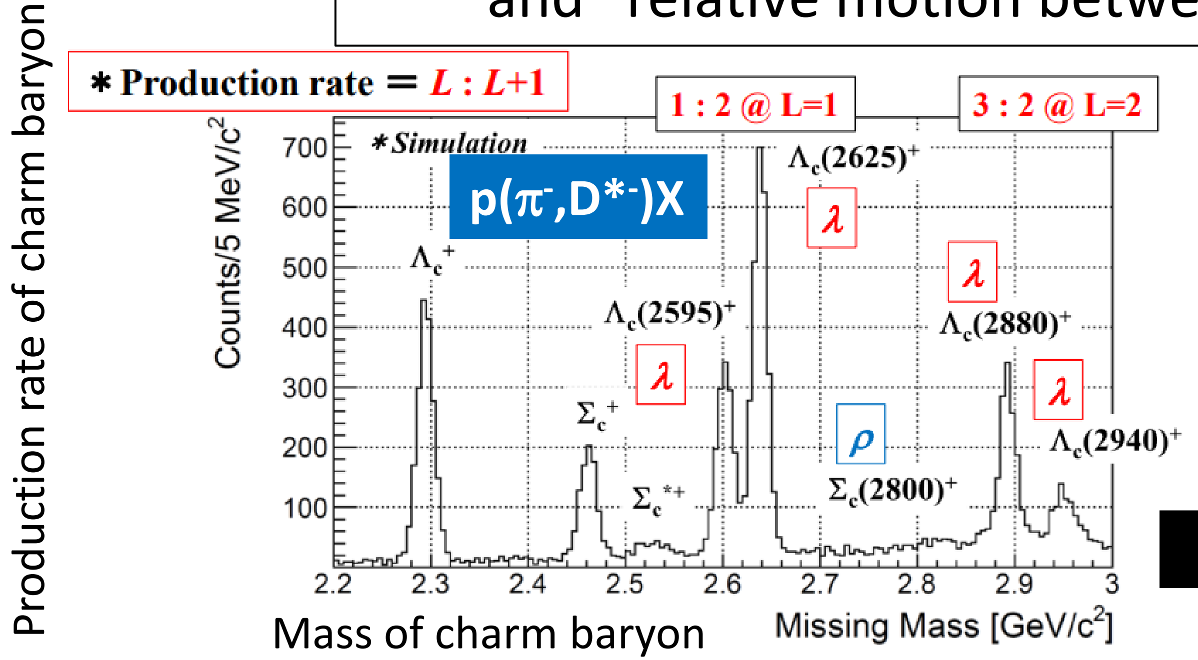
- Investigate **diquarks** in baryons **toward** understanding of **dense quark matter**

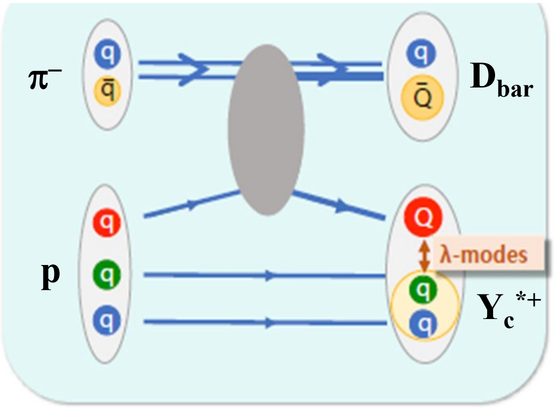
- **Charm Baryon Spectroscopy**
  using intense high-momentum π beam @ High-p (π20)

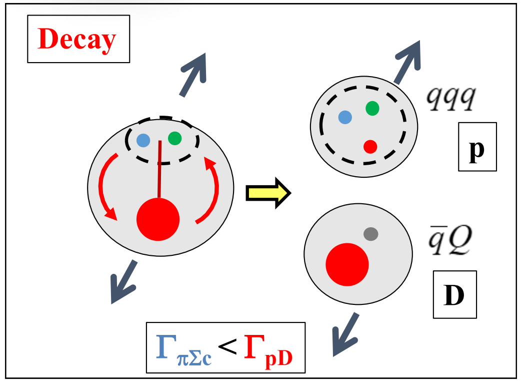
Establish a diquark (*ud*)

Λ_c^*: Disentangle "collective motion of *ud*"
and "relative motion between *u* and *d*"









"production rate" and "decay rate"
will give us information about diquark

Behaver of non-perturbative QCD in low energy regime

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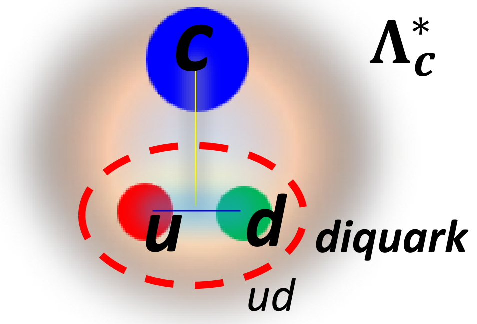


- **Multi-Strange Baryon Spectroscopy**
  using intense high-momentum K beam @ K10

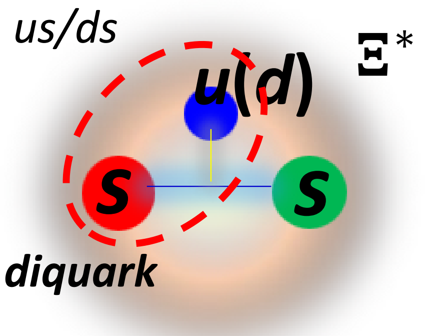
Diquarks in different systems

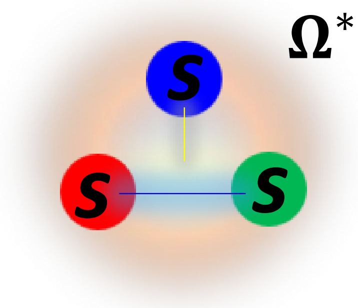
Ξ^*: *us/ds* diquark

Ω^*: the simplest *sss* system

→ diquark is expected to be suppressed

K.Shirotori [Ω*]
Thu, Parallel 3a2A





Systematic measurements will reveal the internal structure of baryons through the diquarks

Expanded Research Programs

at the Extended Facility

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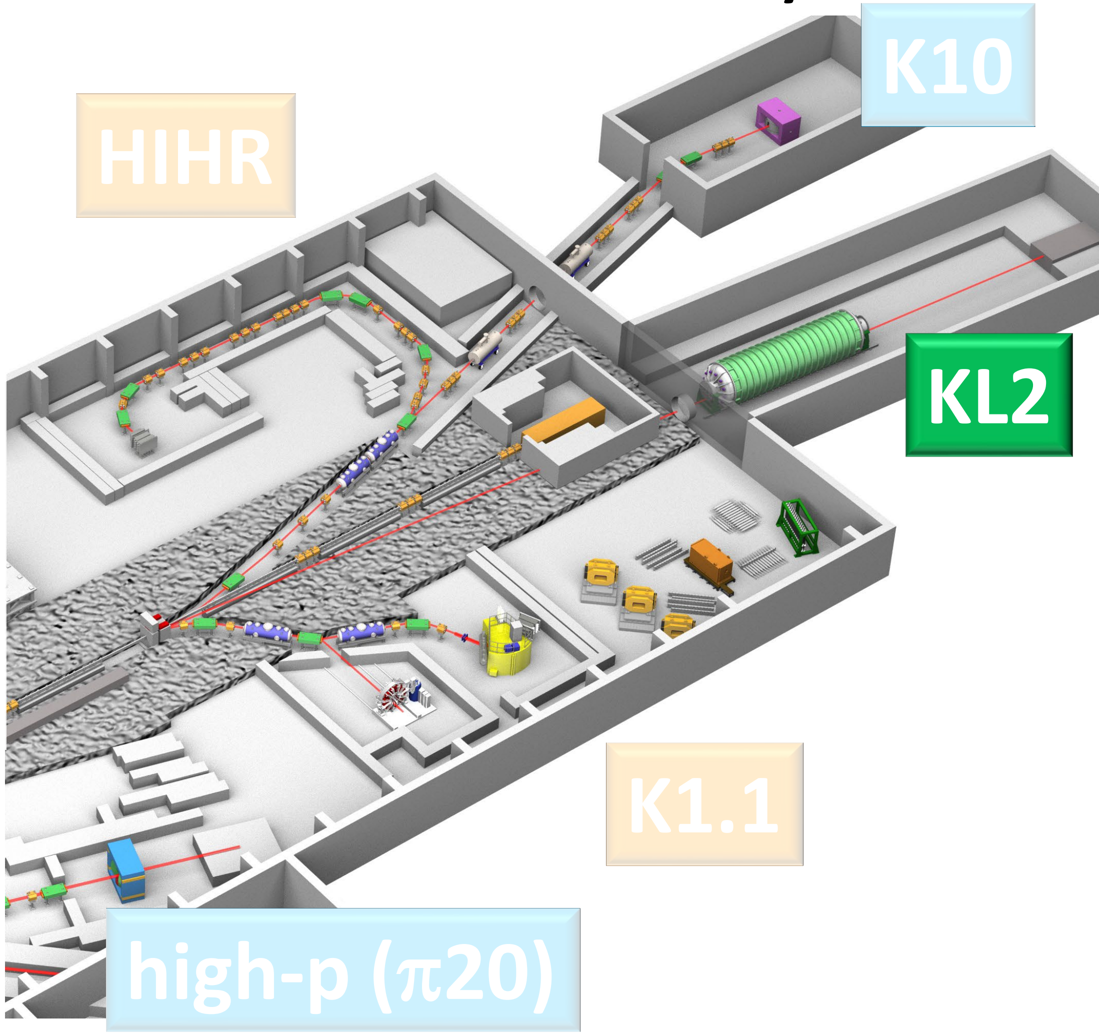


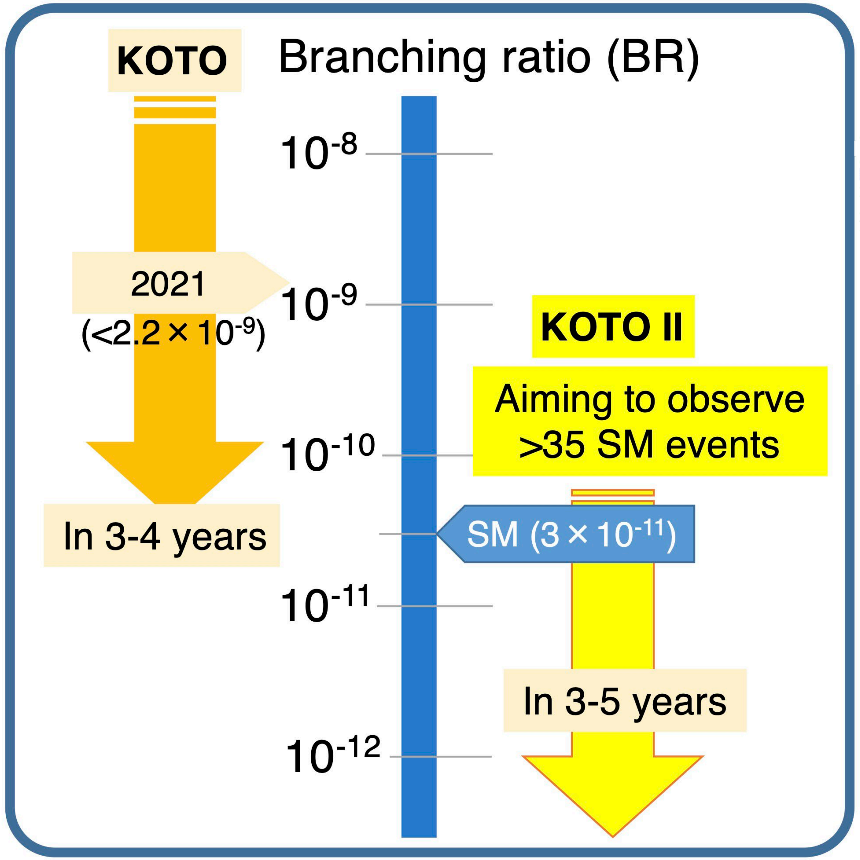
Flavor Physics: New Physics Search at KOTO II

Is there new physics beyond the Standard Model?

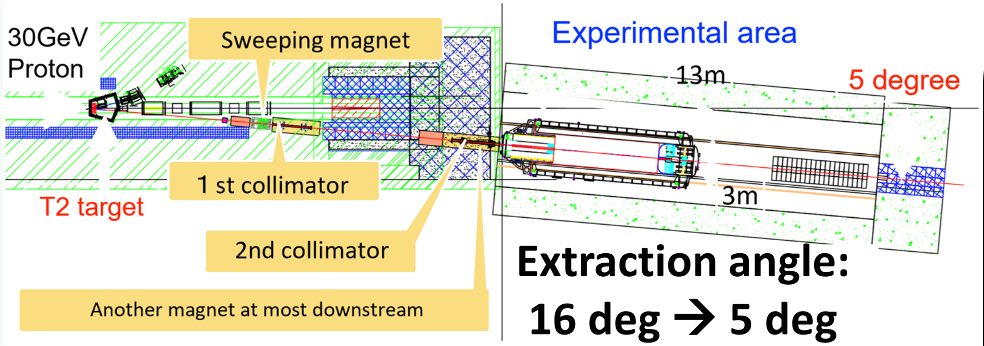
Rare kaon decay: $K_L^0 \rightarrow \pi^0 \nu \bar{\nu}$

One of the best probes for new physics searches

- Directly break CP symmetry
- Suppressed in the SM → Branching ratio ～ 3×10^{-11}
- Small theoretical uncertainties (～2%)

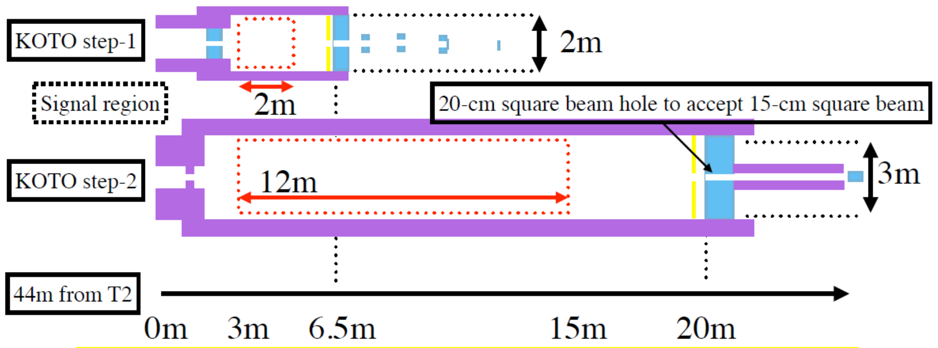


Sensitive to ~O(100) TeV physics



Extraction angle: 16 deg → 5 deg

Intense neutral kaon beam @KL2 (~x2.6)



Ultra-high sensitivity detector (x22)

KOTO II

New physics search with world's highest sensitivity more than 100 times

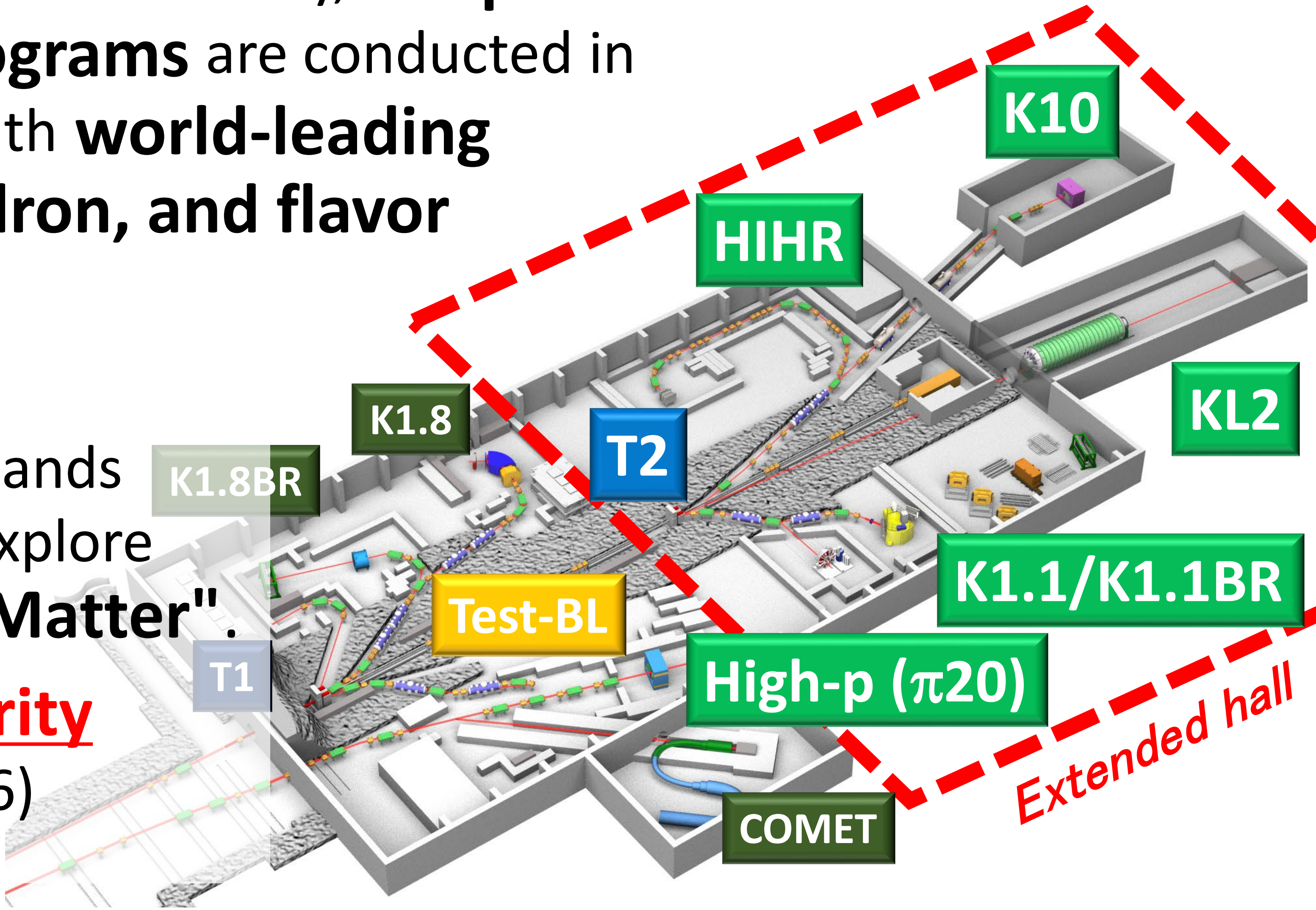
- Discover the $K_L^0 \rightarrow \pi^0 \nu \bar{\nu}$ signal with 5σ
- Measure the branching ratio with 30% accuracy

Indicate new physics, if deviation form the SM > 40%

Summary

- At the J-PARC Hadron Experimental Facility, **unique high-intensity research programs** are conducted in particle and nuclear physics, with **world-leading studies in strangeness, hadron, and flavor physics**.

- **The extension project** expands research programs to further explore the **"Origin & Evolution of Matter"**.
  - Selected as **KEK's top-priority project** (PIP2022, FY2022–26)



Project Refined with Communities

https://www.rcnp.osaka-u.ac.jp/~jparchua/en/hefextension.html

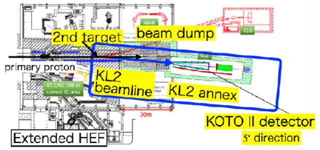

Many Encouraging Comments at the Town Meeting, HEF-ex 2025

https://kds.kek.jp/event/55177

Sep. 26-27, 2025

Comments from KL2

- 13 inputs from country groups, institutions, and theorists in the KOTO II collaboration
- Strong messages to realize KOTO II with KEK as a host institution
  - We will endeavour to realize KOTO II
  - We will do all we can to secure funding and contribute to the successful realization of KOTO II
  - We will make our best / all possible efforts to realize KOTO II



J-PARC KOTO II (E107) (scientifically approved)

77 members + 2 observers
34 institutions, 11 countries

Key Comments (1)

Catalina Oana Curceanu(INFN-LNF)

- J-PARC is an excellent hub for hadron and exotic atom physics.
- Reinforcing the Italy–Japan partnership will expand global collaboration.
  - Beyond physics, it will build a strong community and train the next generation.

Taku Gunji (CNS)

- The extension project has high complementarity with the science mission of the EIC, advancing both science and technology.
- Global collaboration is essential to raise J-PARC's profile and foster joint hadron experiments.

Key Comments (2)

Jung Keun Ahn (Korea U)

- Four beamline collaborations are active, but stronger platforms are needed to raise J-PARC's global recognition.
- K10 could become an iconic beamline for hadron spectroscopy, requiring higher momentum (up to 19 GeV/c) and additional budget.
- We could launch an Asia-Pacific Nuclear Physics Organization, starting with a Korea–Japan partnership and supported by government-level funding.
  - KEK should secure the primary beamline area to advance the HEF extension.

Key Comments (3)

Benjamin Doenigus(Goethe U)

- Complete current experiments and start proposed experiments in a timely manner to provide baselines for upcoming measurements elsewhere.
- Start the HEF extension smoothly, prioritizing HIHR and K1.1, with potential contributions feasible depending on timescales.

Karin Schönning(Uppsala U)

- J-PARC uniquely enables "tailor-made" experiments, bridging the gap from the delayed PANDA project.
- Uppsala group is exploring planned K1.1 scattering experiments with potential funding support.

Key Comments (4)

James Ritman (GSI)

- J-PARC Hadron Hall extension and FAIR have strong synergy potential, with broad physics scope and possibly staged timelines.
- A general-purpose detector (GPD) could attract international collaborators, and its feasibility should be explored.
  - But compromises are needed since no GPD can replace dedicated systems.

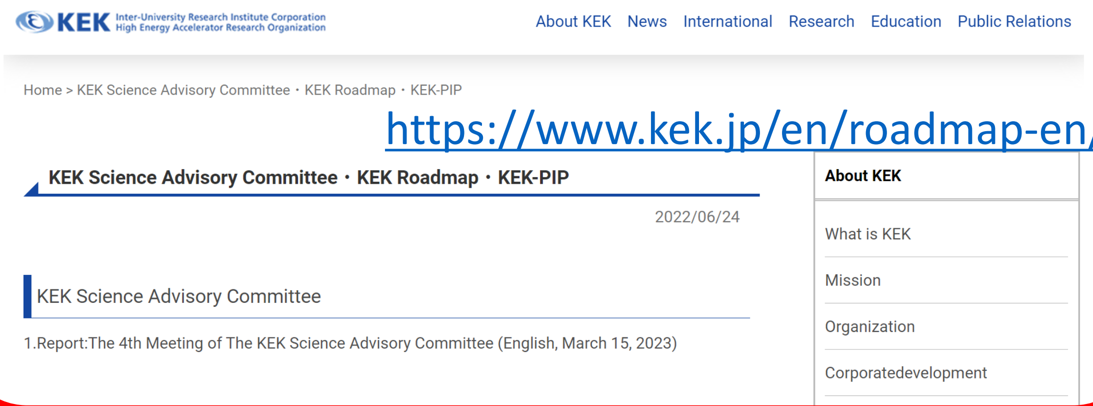
Thank you very much!

Status of the Extension Project

listed as a candidate for government funding:

- ➢**MEXT Roadmap 2020** (2012, 2014)
- ➢**Science Council of Japan Master Plan 2020** (2011, 2014, 2017)

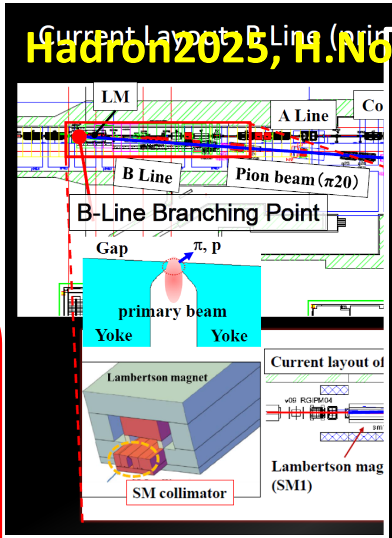
The project was selected as **the top-priority project** to be budgeted in the KEK mid-term plan (FY2022-26) at KEK-PIP2022 (Project Implementation Plan)

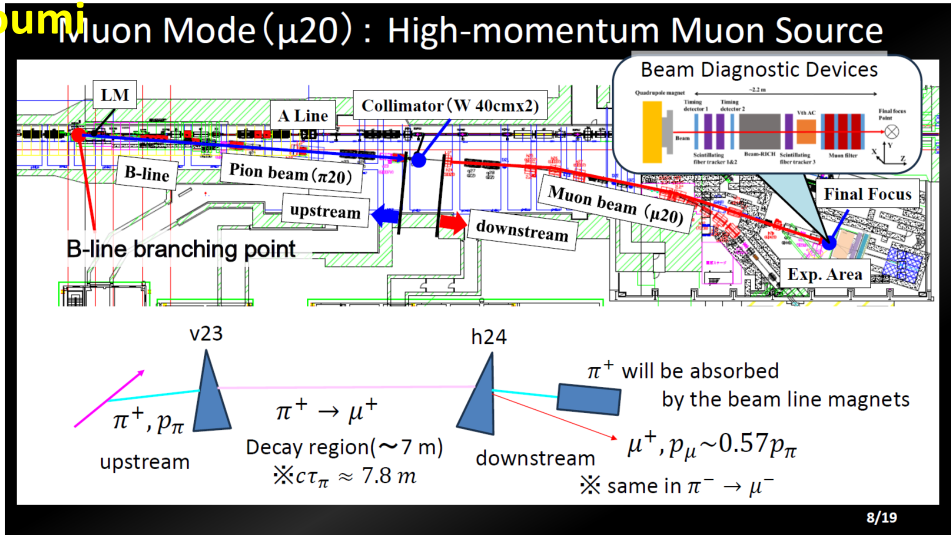


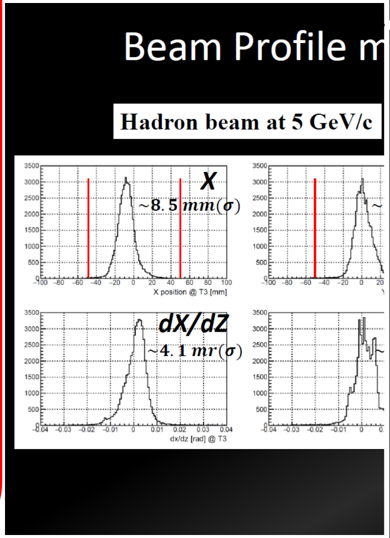
https://www.kek.jp/en/roadmap-en/

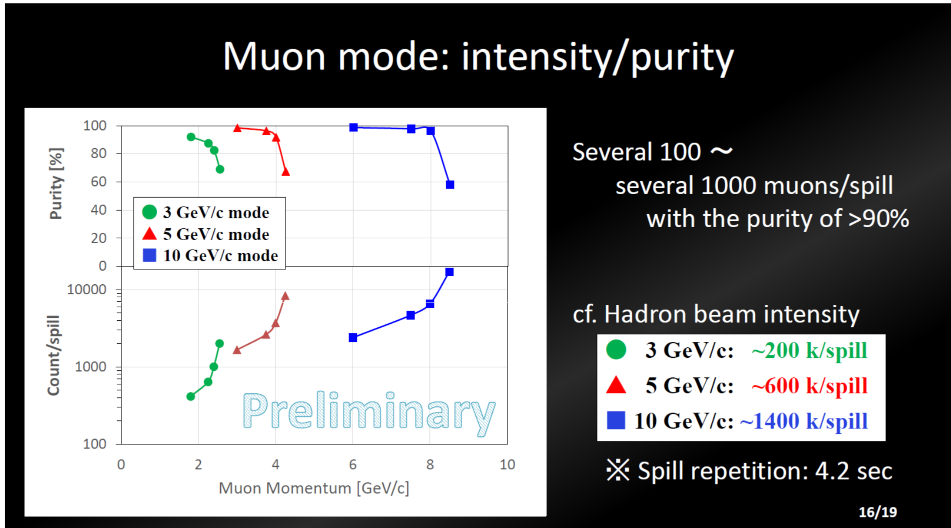
Toward π20, we successfully demonstrated positive secondary beam transport at the high-p BL.

Hadron2025, H.Noumi







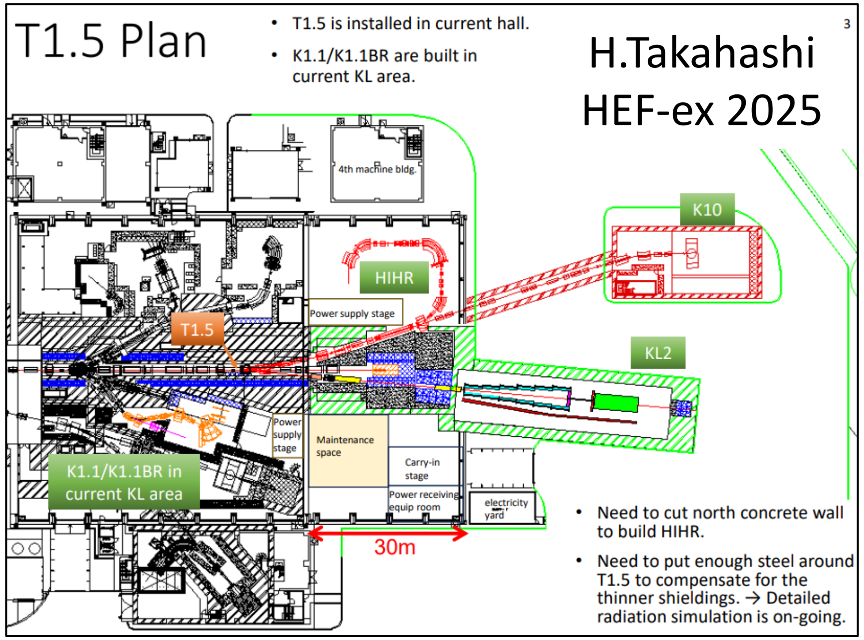


Status of the Extension Project

KEK-PIP2016 (2016-21)	
1^{st}	J-PARC upgrade for Hyper-K DONE
2^{nd}	HL-LHC/ATLAS DONE
3^{rd}	H-line and g-2/EDM
4^{th}	**HEF Extension**

KEK-PIP2022 (2022-27)	
1^{st}	**HEF Extension**
2^{nd}	Contribution to HL-LHC
3^{rd}	LiteBIRD
4^{th}	Transmission Muon Microscope

- Hadron Hall expansion is top budget priority at KEK.
  - ➢ Except for the g-2/EDM experiment = left over from PIP2016.
  - ➢ For g-2/EDM, funding for the detector has already started, while cost reduction for the building is still under consideration.
- Toward the early realization of the Hadron Hall expansion:
  1. cost reduction and optimization
  2. a step-by-step implementation plan with smaller phases
  3. exploring possible financial support from outside KEK
- **Your support is essential!**



Timeline of the Project

		1st Year	2nd Year	3rd Year	4th Year	5th Year	6th Year	7th Year	
Hadron Hall	Start of budget request								

construction parallel to beam operation in the first 4 years, beam-suspension in the next 2.5 years

The Extension Project of H*adron *E*xperimental *F*acility *(7 years)

Current Programs
with SX Power of ~100kW

Hall Extension

Expanded Programs

The project is ready to start!

→ We are working on getting the timeline consistent with current programs

Strangeness Nuclear Physics

	HIHR	JLab	Mainz
Reaction	(π^+, K^+)	(e,e'K+)	Decay π
Achievable Precision (keV)	◎ <100	◎ <100	◎ <100
Applicable hypernuclei	◎ All Z	○ Light – Medium Heavy (Larger Z, higher BG)	× Only Ground states of light hypernuclei
Availability of Neutron rich HY	◎ DCX $^{A}_{\Lambda}$(Z-2)	○ $^{A}_{\Lambda}$(Z-1)	○ Fragmentation only 2body-decay
Flexibility of beamtime	◎ Permanently Installed Beamline & Spectrometer	× Large-scale Installation (several months)	○ Kaon Spectrometer Installation (a few weeks)
Absolute Energy Calibration	△ $^{12}_{\Lambda}C$ $p(\pi^-, K^+)\Sigma^-$ Decay π	◎ $p(e, e'K^+)\Lambda, \Sigma^0$	○ Elastic e scattering

Systematic measurement can be performed @ HIHR

(π+,K+): n→Λ
(e,e'K+): p→Λ
=> Inf. on CSB

- 2-/3-body interactions via femtoscopy
- Huge data-set in Run3 (2022-25) ~
- Sensitive to S-wave (lower-mom. region)

Comple-mentary

Spin observables in ... scattering

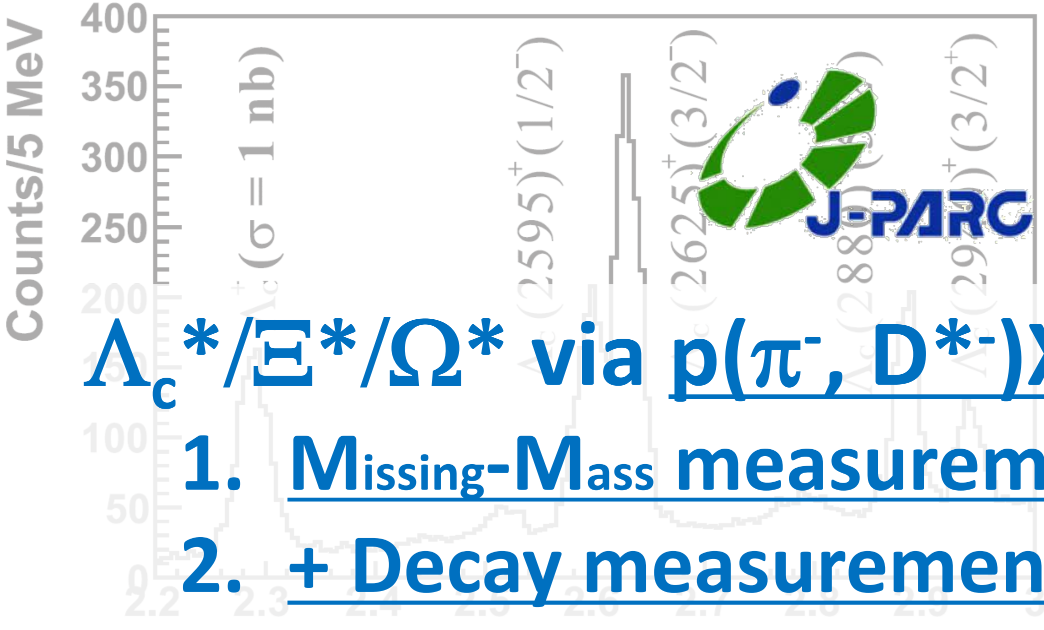
More detailed information @ K1.1

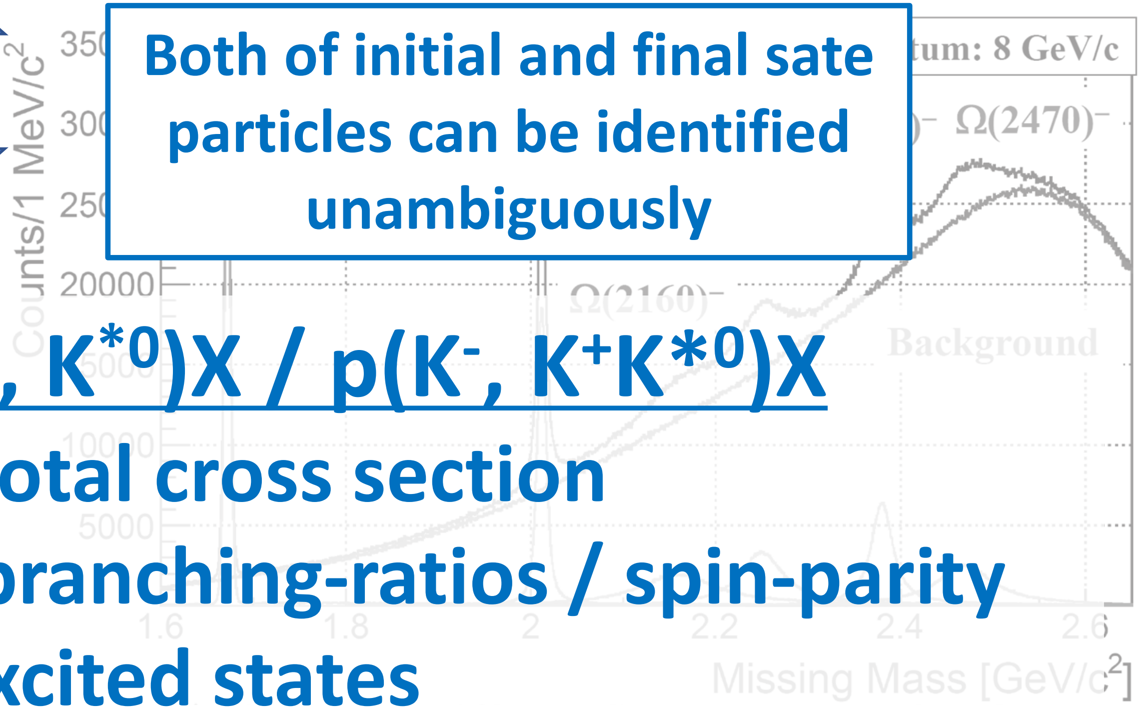
- **differential quantities (dσ/dΩ, etc.)**
- **spin observables**
- **Sensitive to higher partial wave in addition to S-wave**

Diquarks in Baryons

- High capabilities of hadron spectroscopy in *c*-sector, via inv. mass reconst.

Comple-mentary





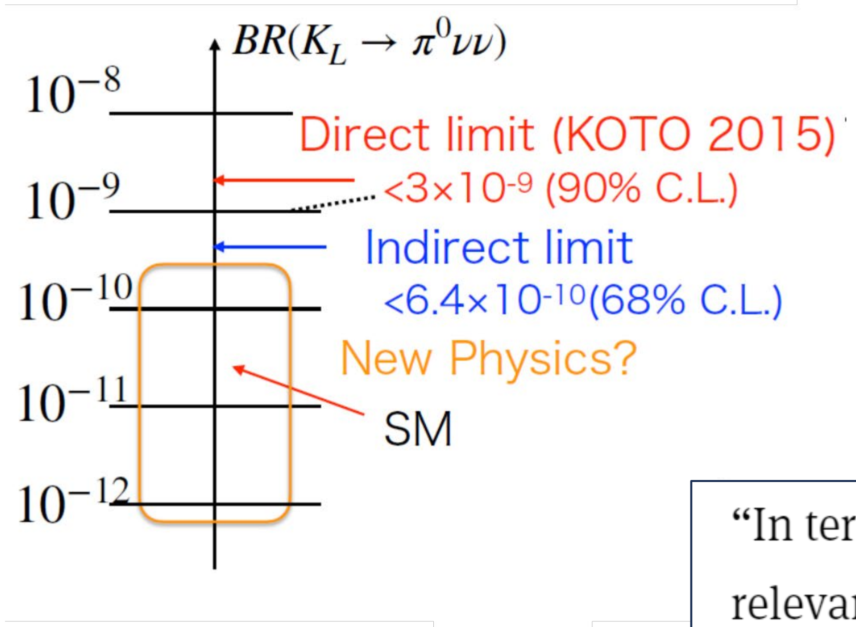
Both of initial and final sate particles can be identified unambiguously

Λ_c*/Ξ*/Ω* via p(π⁻, D*⁻)X / p(K⁻, K*⁰)X / p(K⁻, K⁺K*⁰)X

1. Missing-Mass measurement → total cross section
2. + Decay measurement → branching-ratios / spin-parity
3. Direct production of highly-excited states

K Rare Decays @ CERN

- NA62@CERN: $\boldsymbol{K^+ \to \pi^+ \nu\bar{\nu}}$ has been investigated
  - Run1: 2016-18, Run2: 2021-24 $\mathcal{B}\left(K^+ \to \pi^+ \nu\bar{\nu}\right) = \left(13.0^{+3.3}_{-3.0}\right) \times 10^{-11}$ JHEP 02 (2025) 191
- HIKE@CERN: $\boldsymbol{K^{+/0} \to \pi^{+/0} l^+ l^-, K_L^0 \to \pi^0 \nu\bar{\nu}}$ searches are planned as the next of NA62, but...



"In terms of their science, SHiP and HIKE/SHADOWS were ranked equally by the relevant scientific committees," explains CERN director for research and computing Joachim Mnich. "But a decision had to be made, and SHiP was a strategic choice for CERN."

$K_L^0 \to \pi^0\nu\bar{\nu}$ search @ KOTO/KOTO2

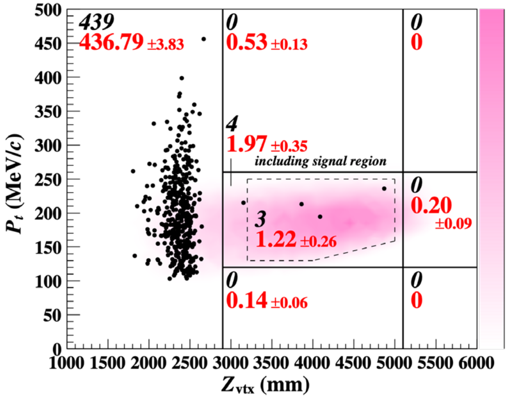
$K_L \to \pi^0\nu\bar{\nu}$ BR=3×10^{-11}

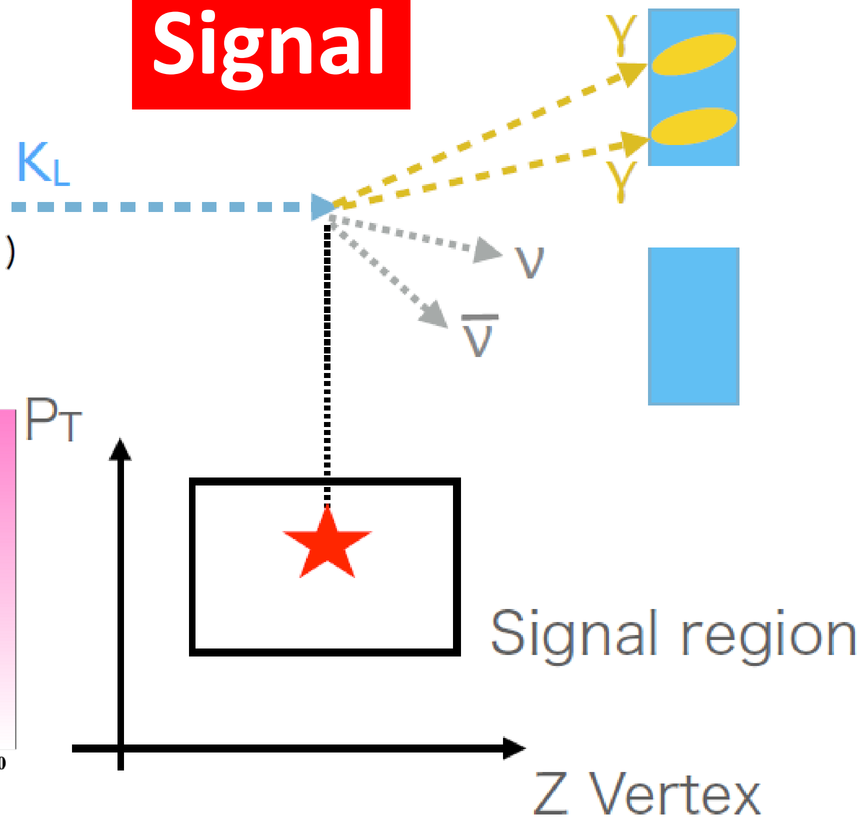
Signal

Assuming 2γ from π^0, Calculate z vertex.

$M^2(\pi^0)=2E_1E_2(1-\cos\theta)$

Calculate π^0 transverse momentum

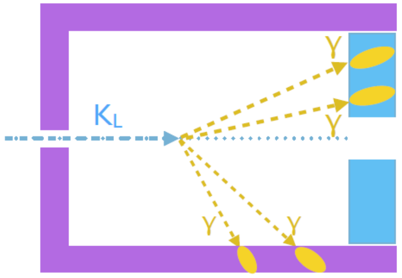




Backgrounds

$K_L \to \pi^0\pi^0$ BR=8.6×10^{-4}

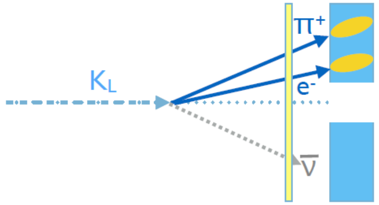
more photons



* Cover decay volume with veto detectors

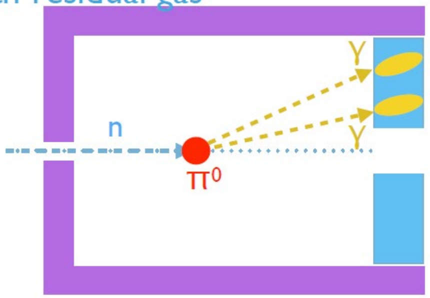
$K_L \to \pi^+e^-\bar{\nu}$ BR=4.0×10^{-1}

charged particles



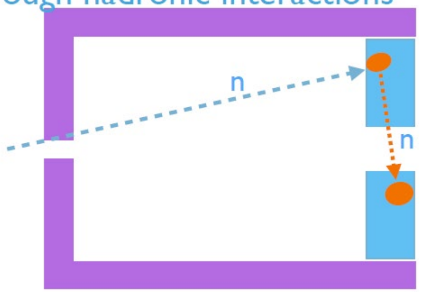
* Detect charged particles with plastic scintillators

π0 Production through the interaction with residual gas



* Keep the decay volume to be high vacuum

Neutron make 2 clusters through hadronic interactions



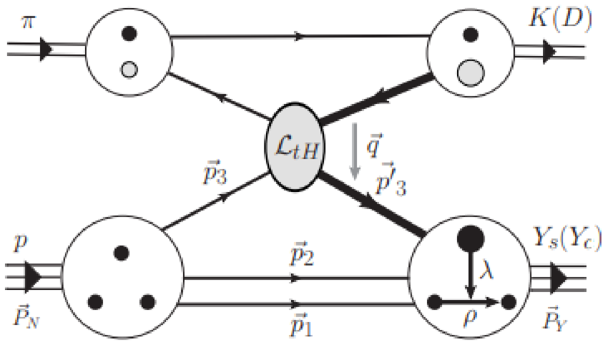
* Discriminate "neutron cluster" from "photon cluster"

Diquark Production and Decay

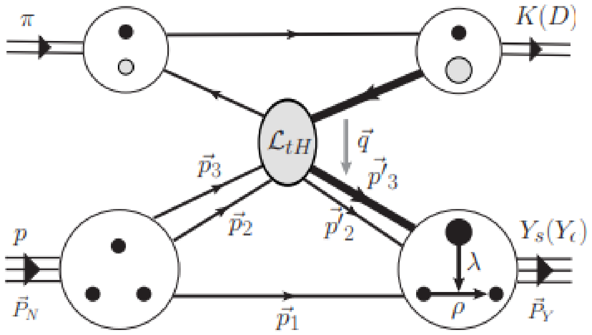
A. Hosaka

Productions

One-body → λ mode



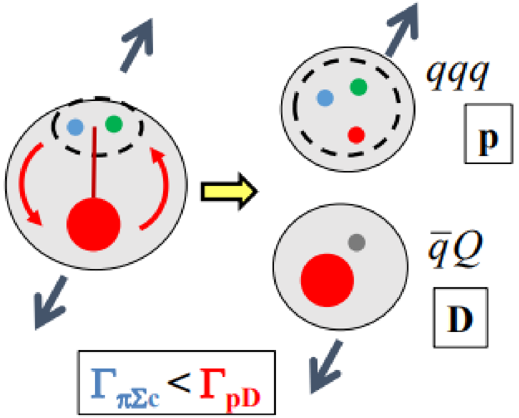
Tow-body → λ, ρ mode



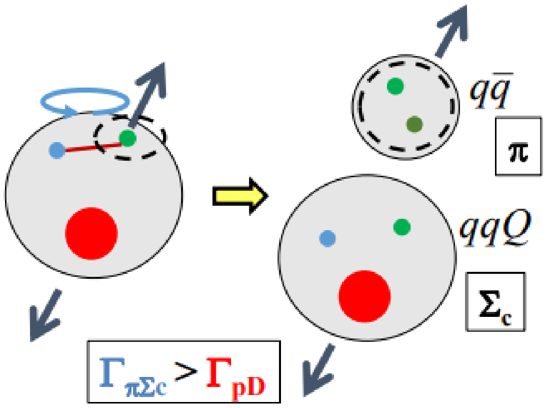
Shim, Hosaka, Kim, PTEP 2020 (2020) 5, 053D01

Decays

λ-mode decay: qqq + Qq$_{\text{bar}}$



ρ-mode decay: qqQ + qq$_{\text{bar}}$



Pictured by Shirotori & Noumi

E73: ${}^{3,4}\mathrm{He}(K^-,\pi^0)\,{}^{3,4}_{\ \Lambda}\mathrm{H}$

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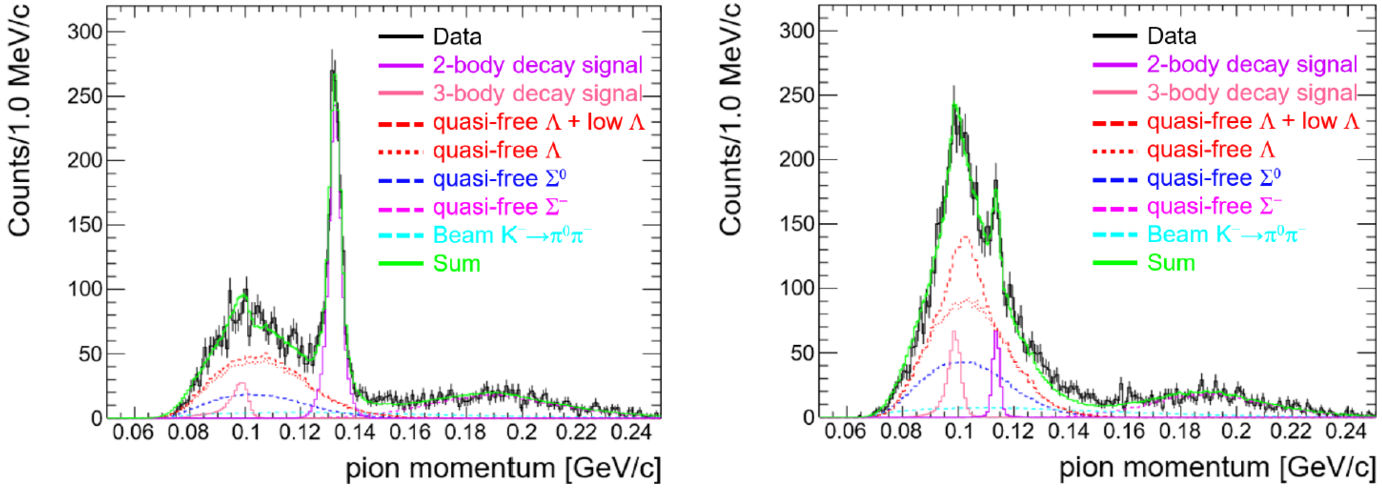
NPA1015(2021)122301

Production cross sections of ${}^{3,4}_{\ \Lambda}\mathrm{H}$ bound states in ${}^{3,4}\mathrm{He}(K^-,\pi^0)$ reactions at 1 GeV/c

Toru Harada [a,b,*], Yoshiharu Hirabayashi [c]

Fitting the π^- momentum spectra



- Fitted with almost the same elements
  - ✓Luminosity is almost same.
  - ✓2-body decay events: 1465(${}^{4}_{\Lambda}\mathrm{H}$), 225(${}^{3}_{\Lambda}\mathrm{H}$)

REIMEI Workshop at PKNU

Result of production cross section

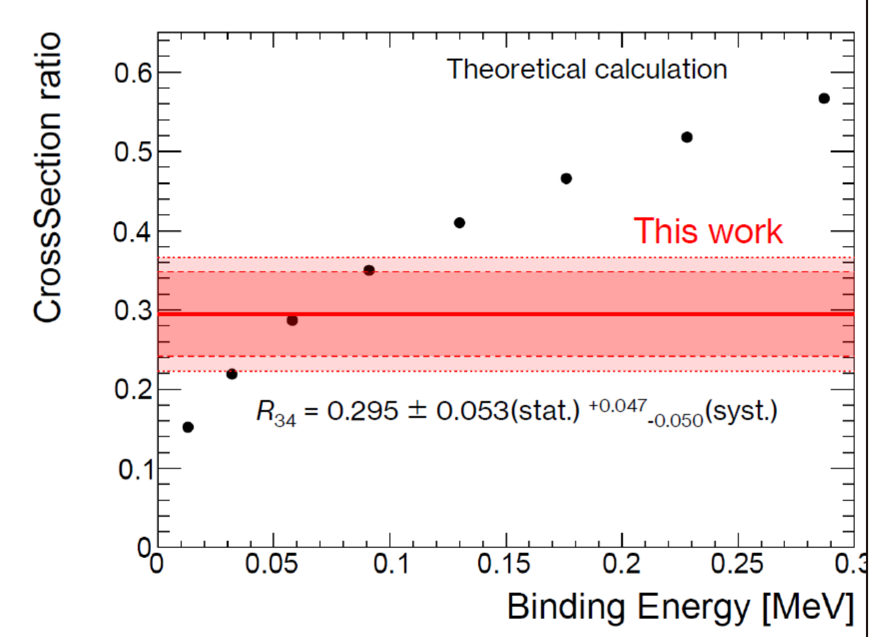
- Two-body decay branching ratio

$$\frac{\Gamma({}^{4,3}\mathrm{He}+\pi^-)}{\Gamma_{\mathrm{all}}} = \frac{\Gamma({}^{4,3}\mathrm{He}+\pi^-)}{\Gamma_{\pi^-}} \times \frac{1}{(1+\frac{\Gamma_{\pi^0}}{\Gamma_{\pi^-}}+\frac{\Gamma_{\mathrm{nm}}}{\Gamma_{\pi^-}})}$$

Fractional branching ratio	Helium-4	Helium-3
$\Gamma({}^{4,3}\mathrm{He}+\pi^-)/\Gamma_{\pi^-}$	0.690 ± 0.017	$0.357\,^{+0.028}_{-0.027}$
$\Gamma_{\pi^0}/\Gamma_{\pi^-}$	0.1	0.5
$\Gamma_{\mathrm{nm}}/\Gamma_{\pi^-}$	0.26 ± 0.13	0.025
$\Gamma({}^{4,3}\mathrm{He}+\pi^-)/\Gamma_{\mathrm{all}}$	0.51 ± 0.05	0.23 ± 0.02

$$\sigma^{\theta_{\mathrm{lab}}=0^\circ-20^\circ}_{{}^{4}_{\Lambda}\mathrm{H}} = 50.7 \pm 2.1\ (\mathrm{stat.})\ ^{+7.8}_{-8.3}\ (\mathrm{syst.})\ \mu\mathrm{b}$$

$$\sigma^{\theta_{\mathrm{lab}}=0^\circ-20^\circ}_{{}^{3}_{\Lambda}\mathrm{H}} = 15.0 \pm 2.6\ (\mathrm{stat.})\ ^{+2.4}_{-2.8}\ (\mathrm{syst.})\ \mu\mathrm{b}$$



T. Akaishi et al., arXiv:2509.16967

${}^{4}_{\Lambda}\mathrm{H}$ lifetime - PLB845(2023)138128
${}^{3}_{\Lambda}\mathrm{H}$ lifetime - analysis ongoing