Strangeness in the Universe?
Low-energy kaon-nuclei interaction studies with AMADEUS at the DAFNE Collider

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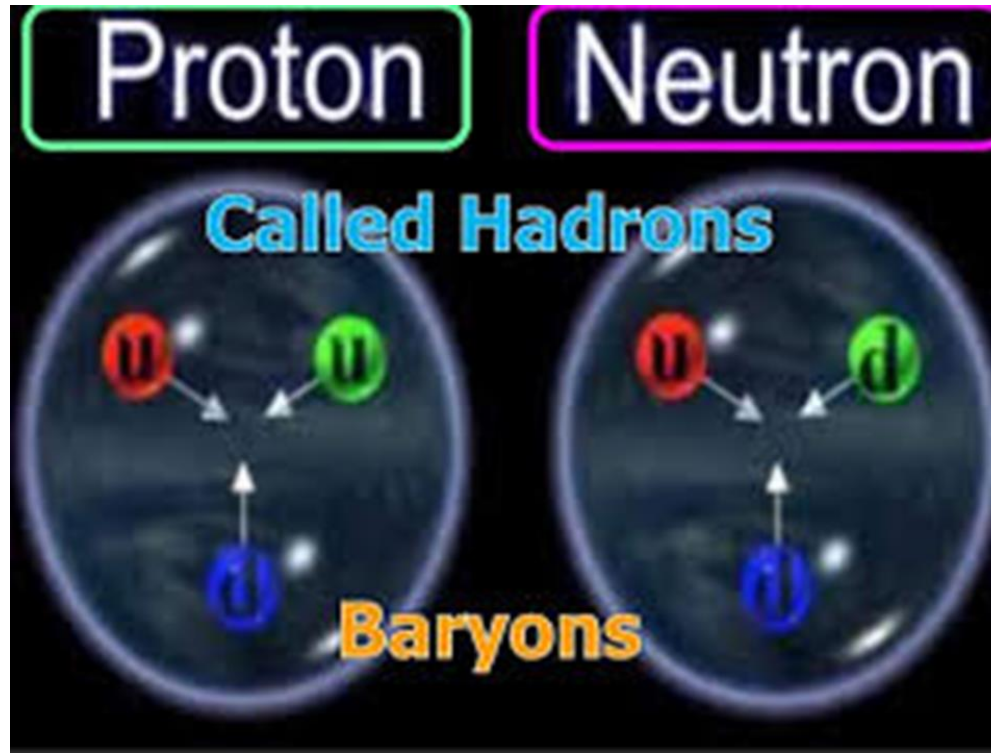
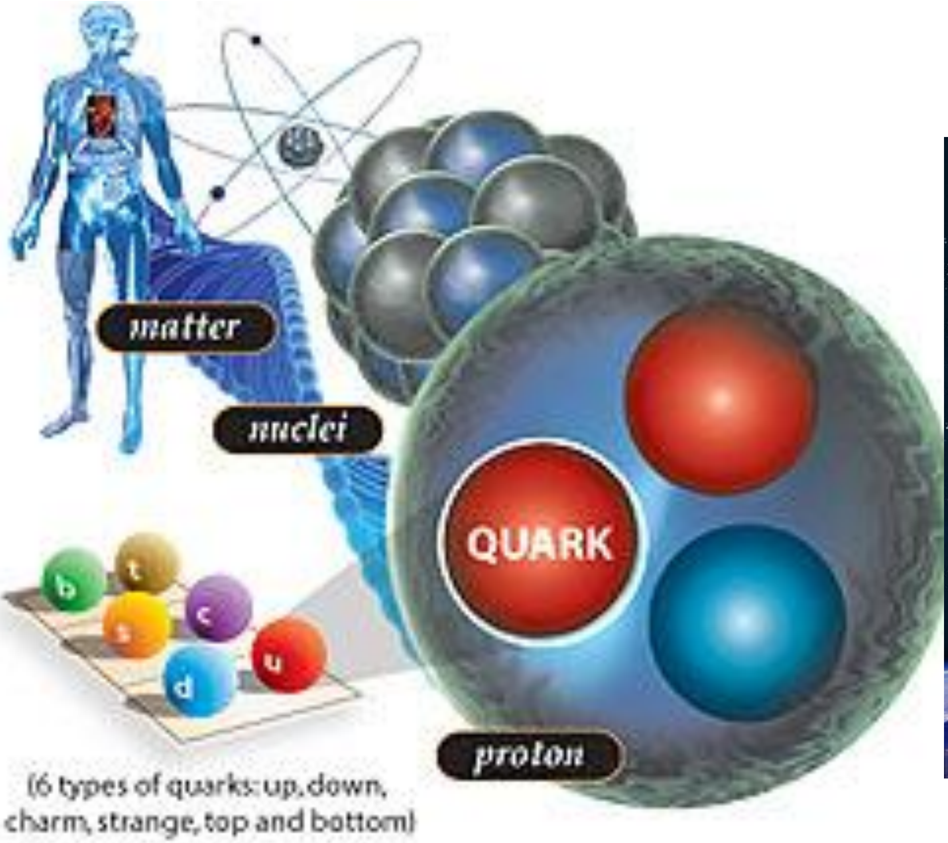
(On behalf of the AMADEUS collaboration)
LNF – INFN, Frascati
HYP2015, 7-12 September 2015, Sendai (Japan)

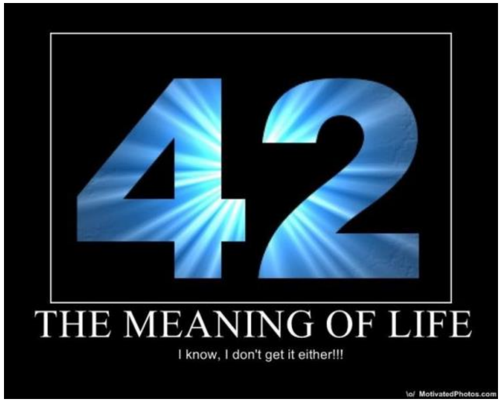
The Standard Mode and the "normal" matter



The Standard Model



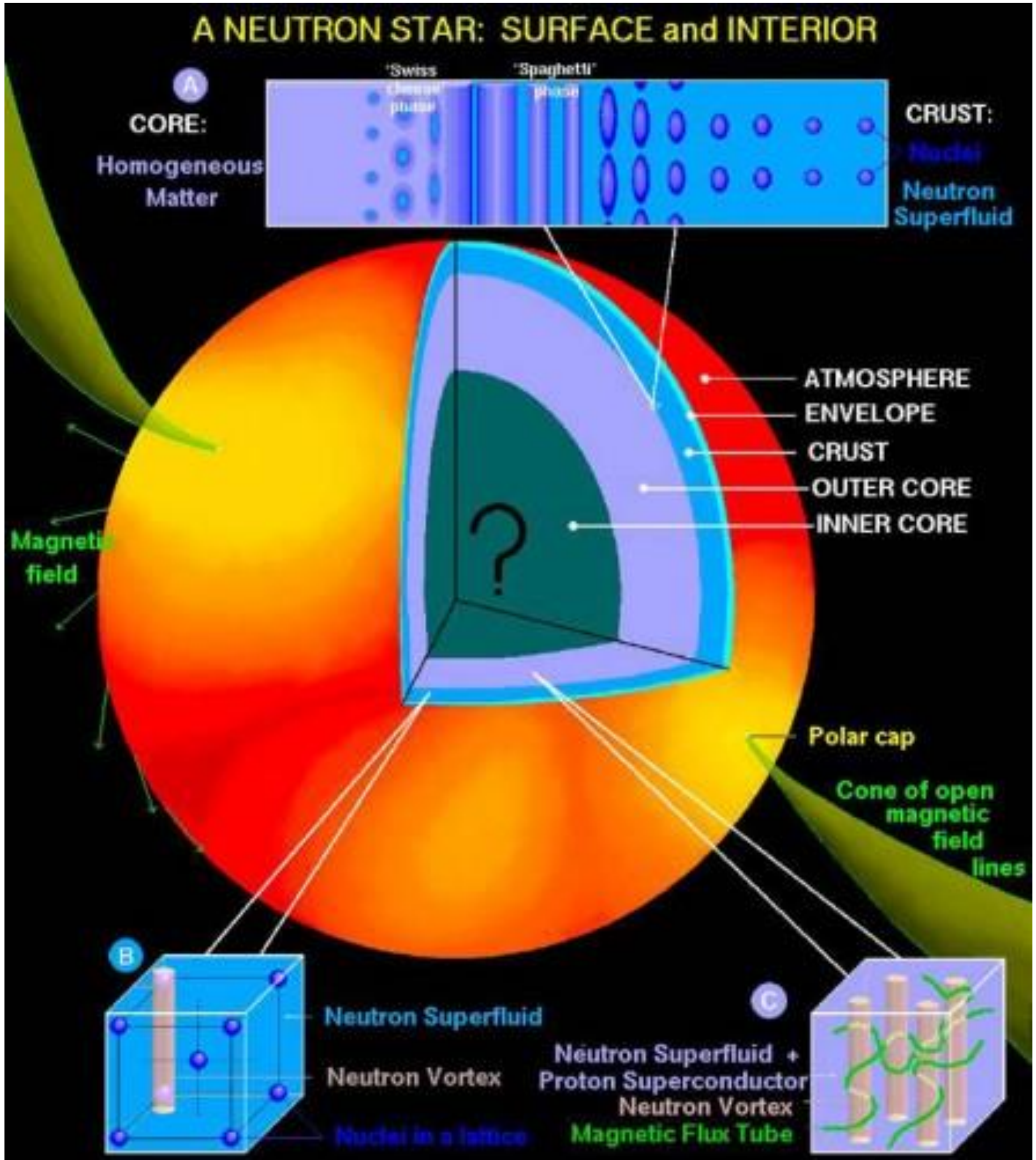
Is there any place for strangeness in the Universe?



There is no exquisite beauty without some STRANGENESS in the proportion.

Edgar Allan Poe

Could strangeness play a role in neutron stars?



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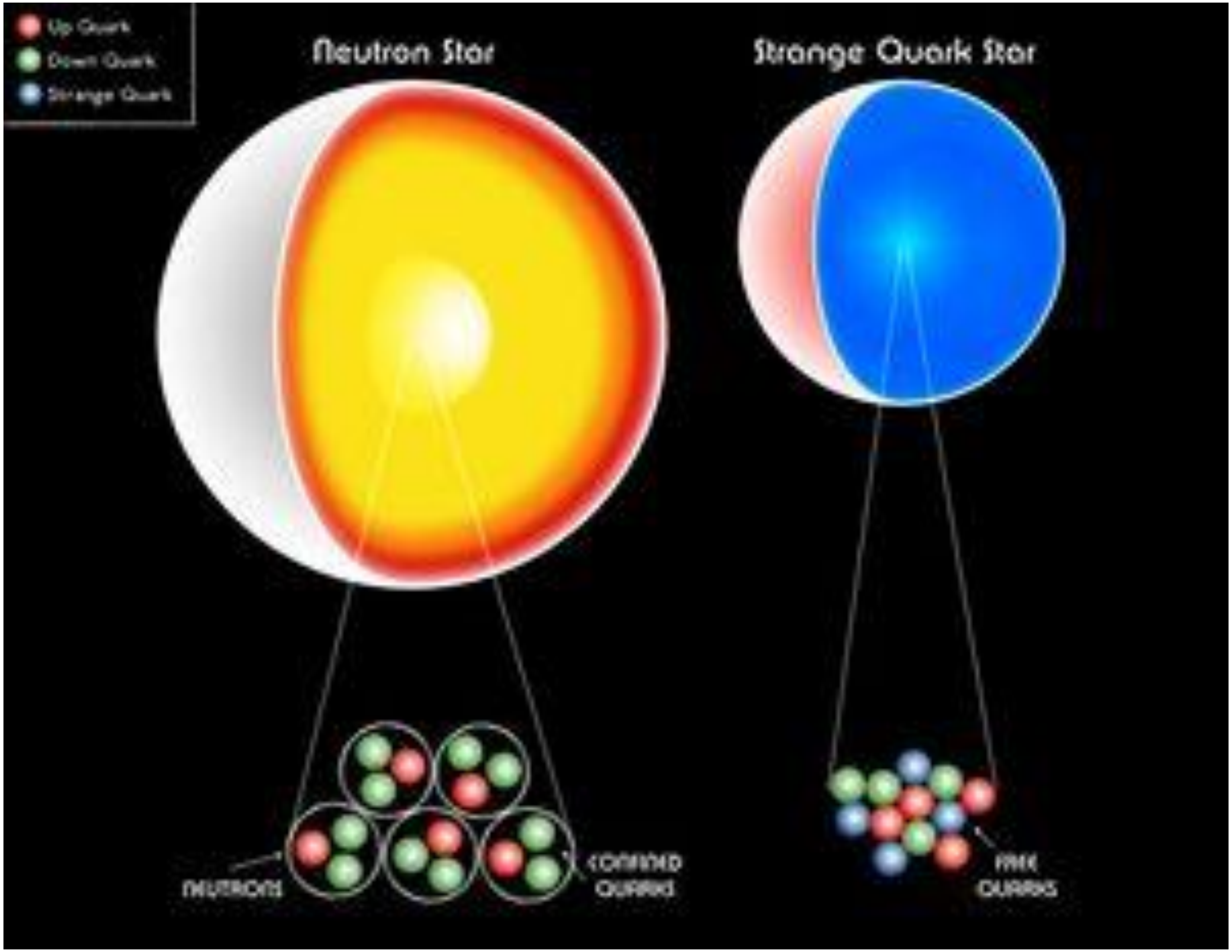
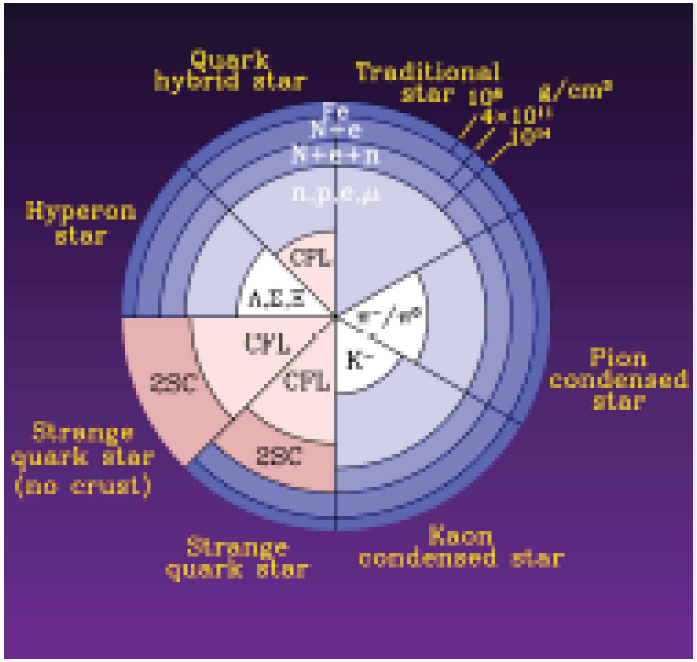


NEUTRON STARS and the EQUATION OF STATE of DENSE BARYONIC MATTER

J. Lattimer, M. Prakash: Astrophys. J. 550 (2001) 426

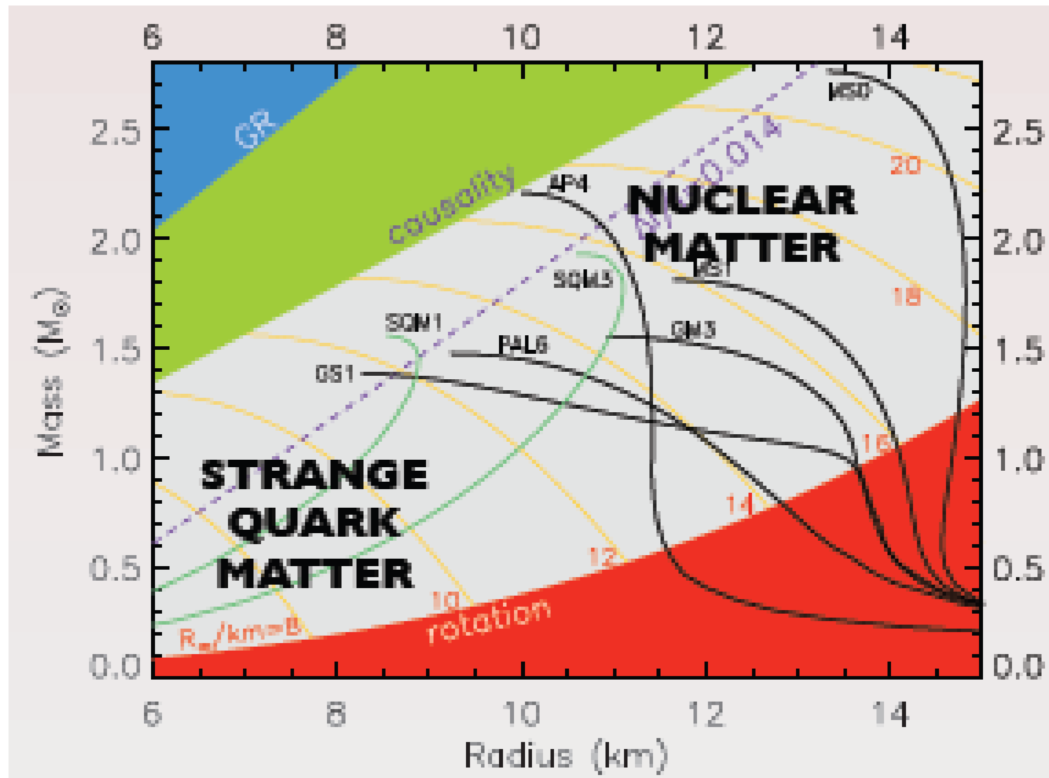


- **Neutron Star Scenarios**
-

$$\frac{dP}{dr} = -\frac{G}{c^2}\frac{(M + 4\pi P r^3)(\mathcal{E} + P)}{r(r - GM/c^2)}$$

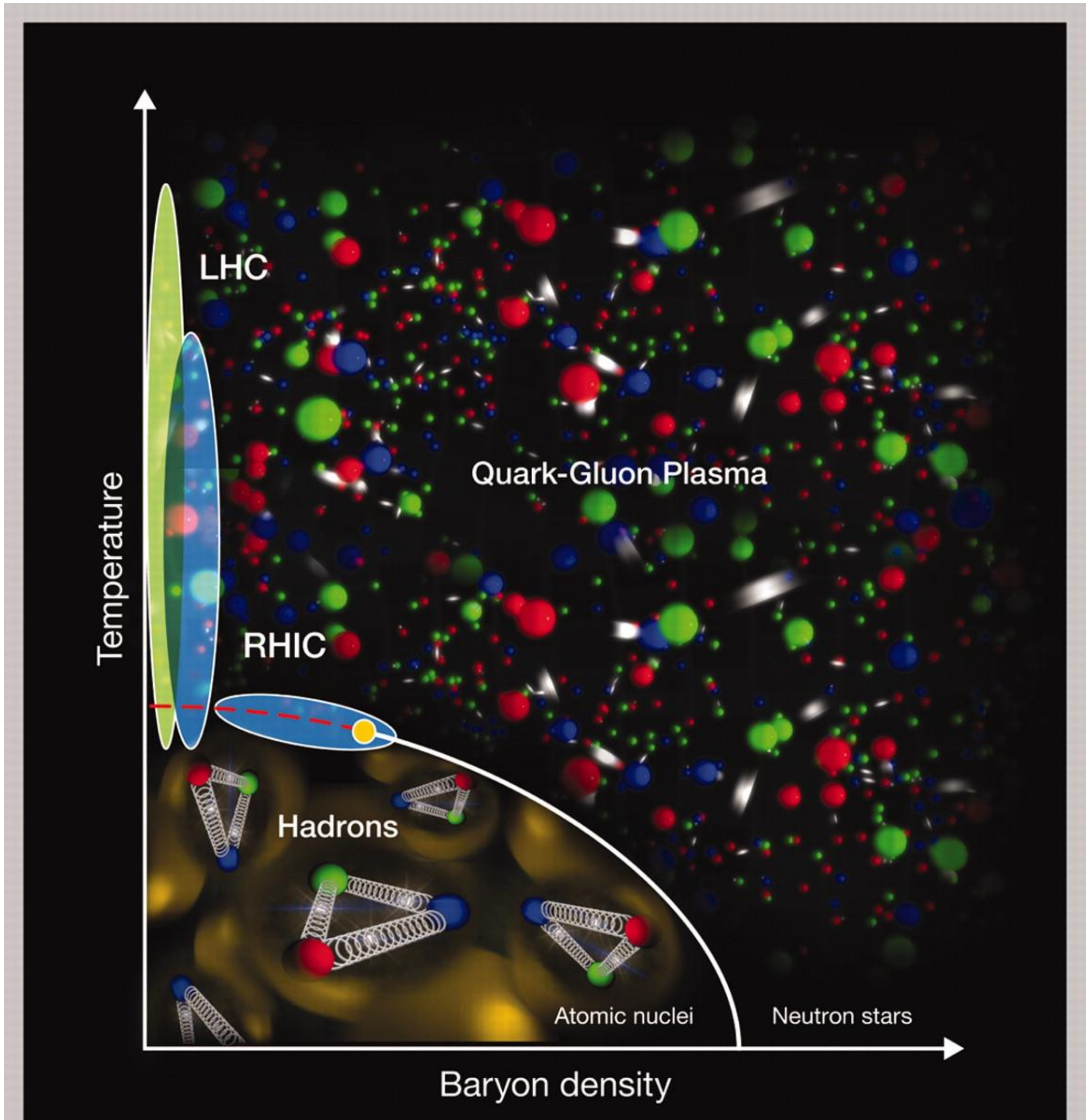
$$\frac{dM}{dr} = 4\pi r^2 \frac{\mathcal{E}}{c^2}$$

- **Mass-Radius Relation**



Technische Universität München

Low-energy kaon-nuclei Interactions studies



How strong is the interaction of kaons (strangeness) with nuclear matter?

How strong is the interaction of kaons (strangeness) with nuclear matter?

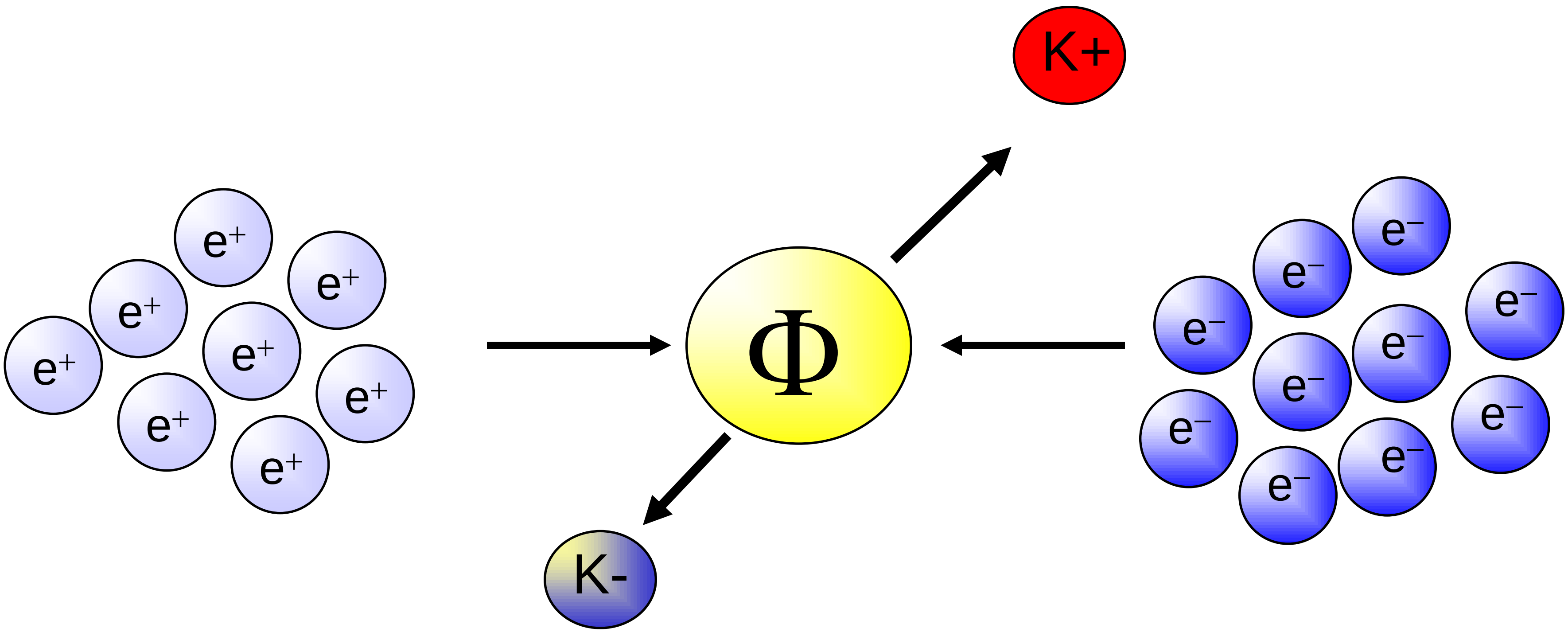
The low-energy kaon-nucleon/nuclei interaction studies are fundamental for understanding QCD in non-perturbative regime:

- **Explicit and spontaneous chiral symmetry breaking (mass of nucleons)**
- **Dense baryonic matter ->**
- **Neutron (strange?) stars EOS**
- **Dark matter with strangeness?**

Role of Strangeness in the Universe from particle and nuclear physics to astrophysics

The DAFNE collider or the best possible beam of low energy kaons

The DAFNE principle



Flux of produced kaons: about 1000/second

DAΦNE, since 1998

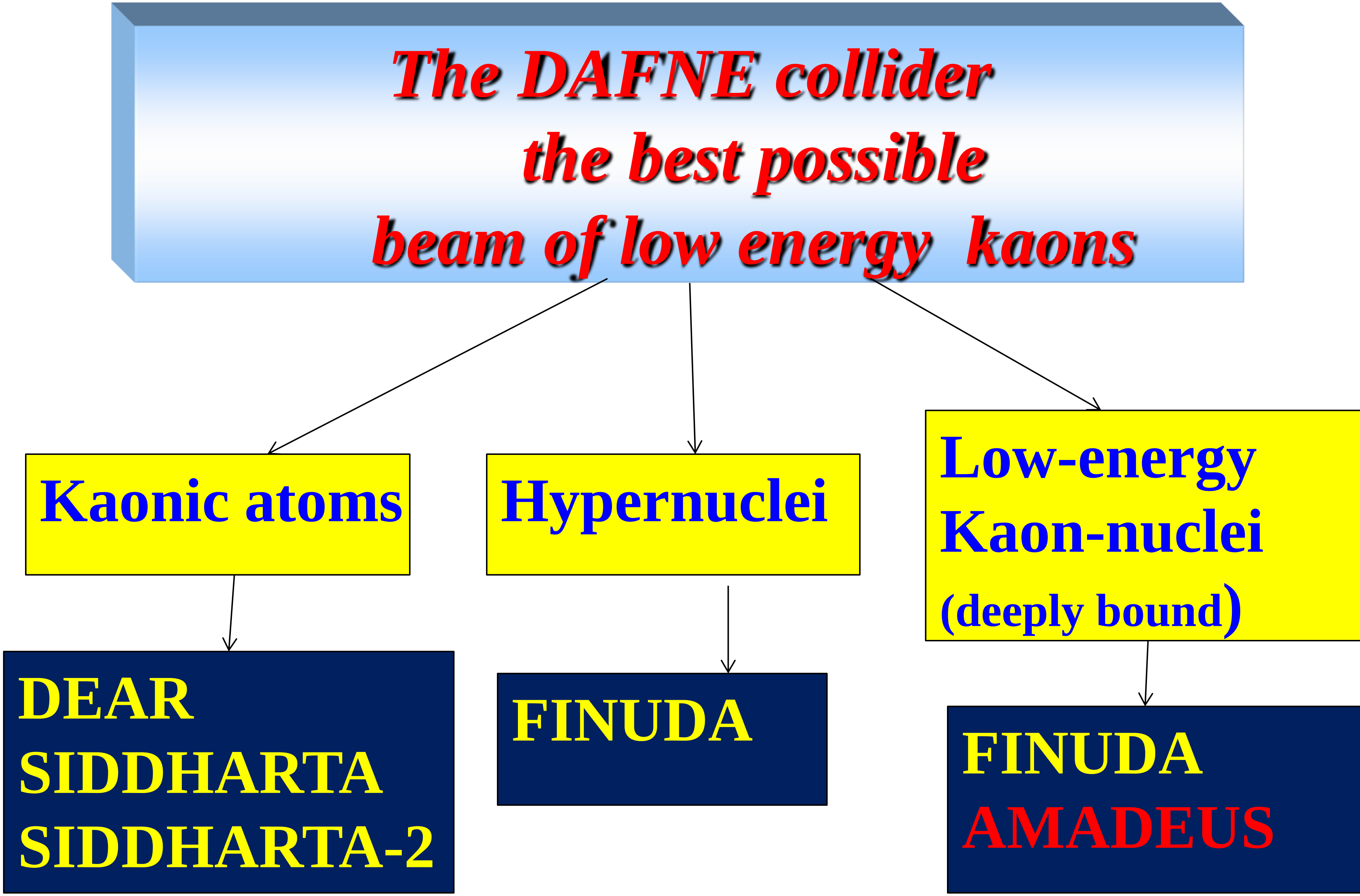
DAFNE

$e^- e^+$ collider

- **$\Phi \rightarrow K^- K^+$** (49.1%)
- **Monochromatic low-energy K^-** (~127MeV/c)
- **Less hadronic background due to the beam**

(compare to hadron beam line : e.g. KEK /JPARC)

Ideal for low-energy kaon physics:
kaonic atoms
Kaon-nucleons/nuclei interaction studies


The DAFNE collider
the best possible
beam of low energy kaons
Kaonic atoms
Hypernuclei
Low-energy
Kaon-nuclei
(deeply bound)
DEAR
SIDDHARTA
SIDDHARTA-2
FINUDA
FINUDA
AMADEUS

Antikaonic Matter At DAΦNE: an Experiment Unraveling Spectroscopy

AMADEUS

AMADEUS proposal

Antikaon Matter At DAΦNE: Experiments with Unraveling Spectroscopy

AMADEUS collaboration
116 scientists from 14 Countries and 34 Institutes

lnf.infn.it/esperimenti/siddharta
and
LNF-07/24(IR) Report on lnf.infn.it web-page (Library)

AMADEUS started in 2005 and was presented and discussed in all the LNF Scientific Committees

EU Fundings FP7 – I3HP2:
Network WP9 – LEANNIS;
WP24 (SiPM JRA);
WP28 (GEM JRA)

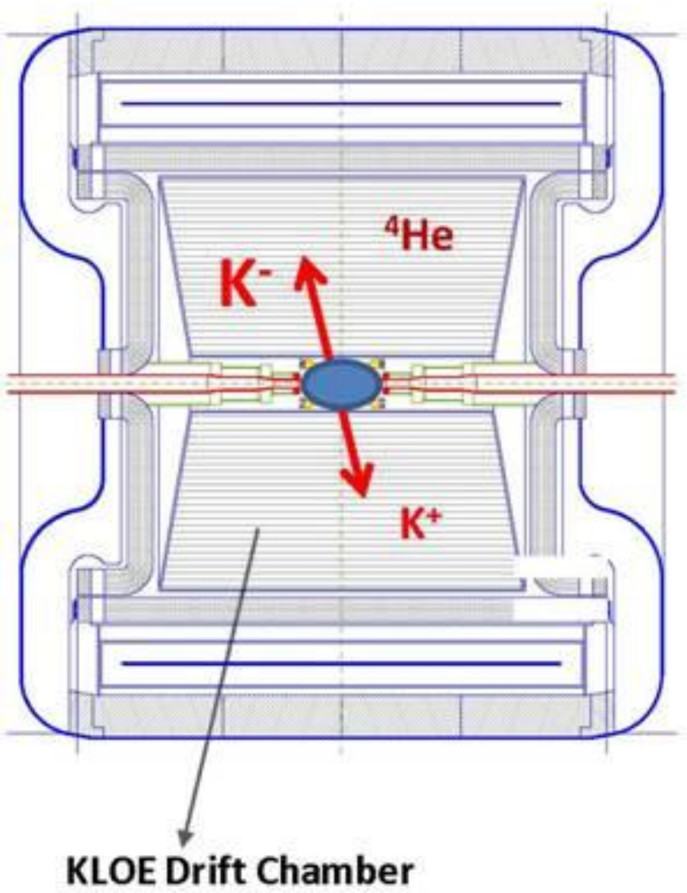
Experimental program of AMADEUS

Unprecedented studies of the low-energy charged kaons interactions in nuclear matter: solid and gaseous targets (d, ^{3}He, ^{4}He) in order to obtain unique quality information about:

- Nature of the controversial **Λ(1405)**
- Possible existence of **kaonic nuclear clusters** (deeply bound kaonic nuclear states)
- Interaction of K^- with **one** and **two nucleons.**
- Low-energy charged kaon **cross sections** for momenta lower than 100 MeV/c (missing today)
- Many other processes of interest in the low-energy QCD in strangeness sector -> implications from particle and nuclear physics to astrophysics (dense baryonic matter in **neutron stars**)

Hadronic interactions of K^- in KLOE

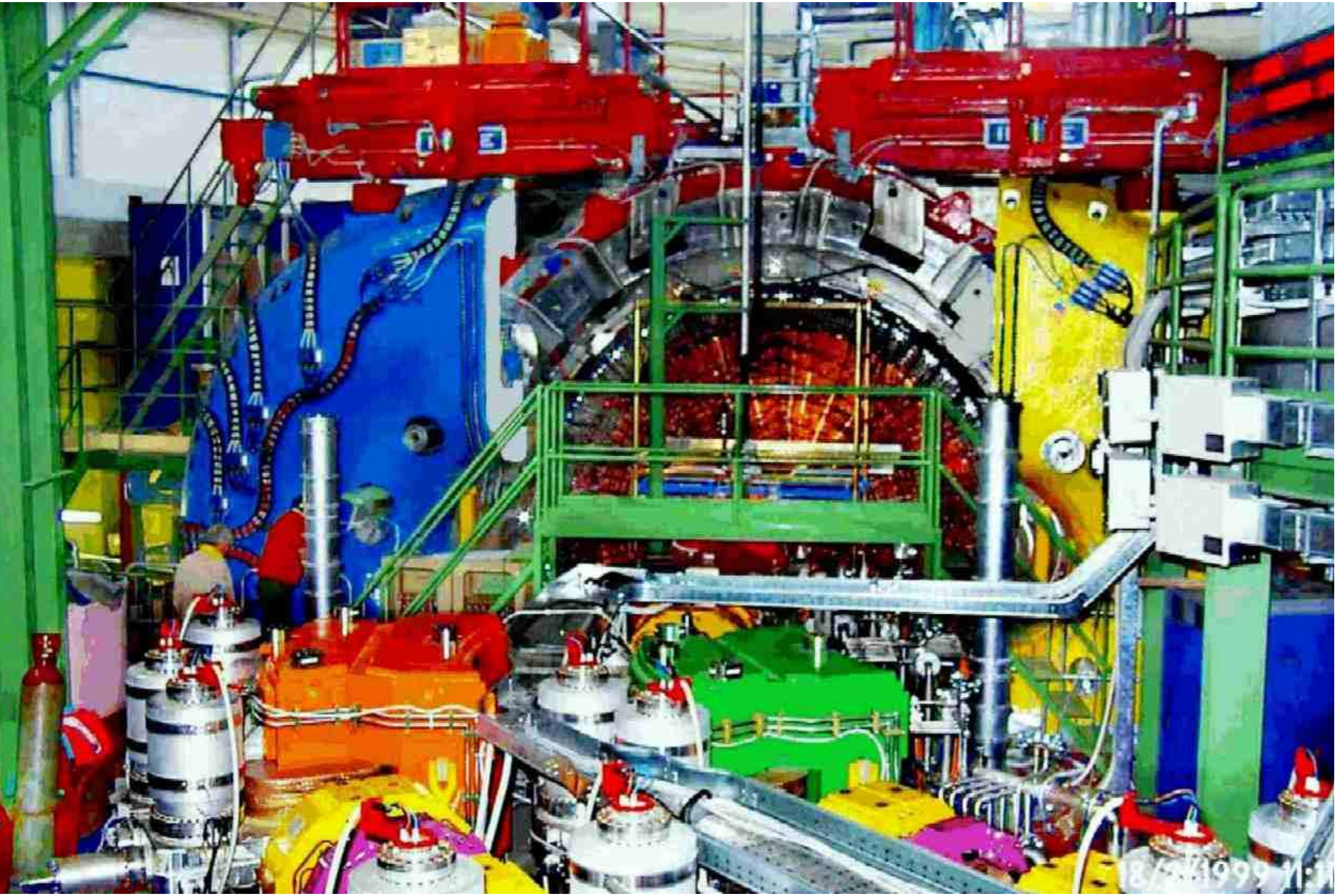
- ***AMADEUS – step 0 – feasibility studies***



•The Drift Chambers of KLOE contain mailny **^{4}He**

•From analysis of KLOE data and Monte Carlo:
0.1 % of K^- from daΦne should **stop in the DC volume**

•This would lead to hundreds of possible kaonic clusters produced in the 2 fb^{-1} of KLOE data.



AMADEUS status

- Analyses of the **2002-2005 KLOE data**:

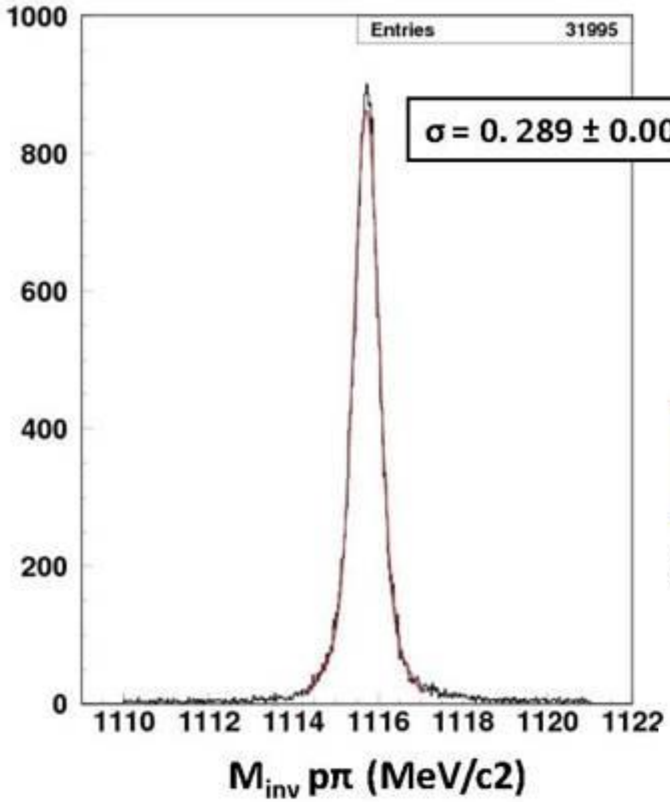
- Dedicated **2012** run with pure **Carbon target** inside KLOE

  - **Λp** from 1NA or 2NA (single or multi-nucleon absorption)
  - **Λd** and **Λt** channels
  - Λ (1405) -> $\Sigma^0\pi^0$
  - Λ (1405) -> $\Sigma^+\pi^-$
  - ΣN/ΛN internal conversion rates

- R&D for more refined setup

- Future possible scenario

Lambda invariant mass



$\Lambda \rightarrow p + \pi^-$

-Dedicated event selection to avoid **Energy loss** in the DC wall

- Best $\chi 2$ tracks and vertices

PRELIMINARY

M_{inv} = **1115,723 ± 0. 003 stat** (MeV/c²)

PDG: M_{Λ} = 1115,683 ± 0.006 stat ± 0.006 syst (MeV/c²)

-Sistematics dependent of momentum calibration

Preliminary evaluation with 2-body decay

$K^{\pm} \rightarrow \mu^{\pm} \nu$

$K^{\pm} \rightarrow \pi^{\pm} \pi^{0}$

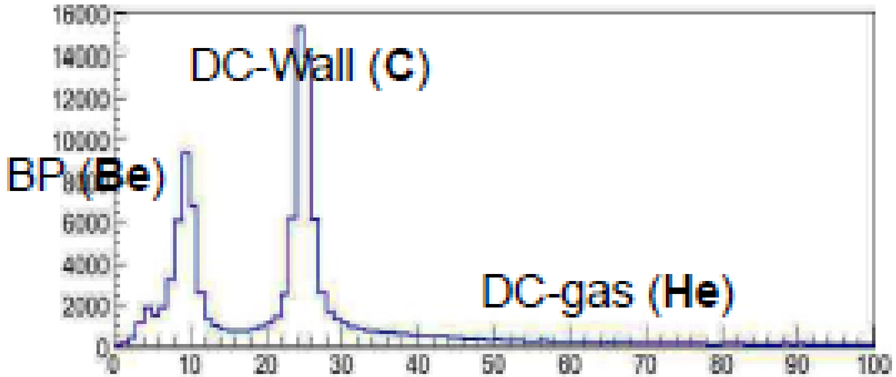
KLOE data on K^- nuclear absorption

Use of two different data samples:

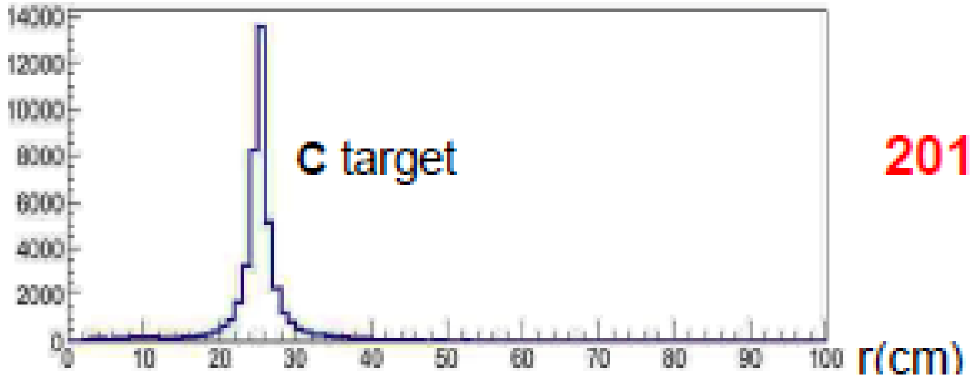
- KLOE data from 2004/**2005** (2.2 fb^{-1} total, 1.5fb^{-1} analyzed)

- Dedicated run in november/december **2012** with a **Carbon target** of 4/6 mm of thickness (~90 pb^{-1}; analyzed 37 pb^{-1}, x1.5 statistics)

Position of the K^- hadronic interaction inside KLOE:



2005 data



2012 with Carbon target

- Pure carbon target inserted in KLOE end of August 2012 ; data taking till December 2012

K^- absorption on light nuclei

1) $Y\pi$ CORRELATION

'p' , 'n' BOUND nucleons

- K^- 'n' $\rightarrow$ $\Lambda\pi^-$ (direct formation) $\rightarrow$ $\Sigma(1385)$ I=1

- K^- 'p' $\rightarrow$ $\Sigma^0\pi^0$ $\rightarrow$ $\Lambda(1405)$ I=0
- K^- 'p' $\rightarrow$ $\Sigma^+\pi^-$ $\rightarrow$ $\Lambda^* + \Sigma^*$

To measure the amount of resonant capture → position of the resonance

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To measure the amount of resonant capture → position of the resonance

2) Y N CORRELATION

- K^- 'pp' → Λ/Σ^0 p (without YN scattering) → $(K^-\ \text{'pp'})^{B.S.}$
- K^- 'ppn' → Λ d (without YN scattering) → $(K^-\ \text{'ppn'})^{B.S.}$
- K^- 'ppnn' → Λ t → rare 4NA

search for possible bound states

- with YN scattering → to get information on U_{YN}

K^-

PART 1

Y π CORRELATION

resonant VS non-resonant production study

Λ(1405) .. resonance or/and bound state?

- Chiral unitary models: Λ(1405) is an I = 0 quasibound state emerging from the coupling between the $\bar{K}N$ and the Σπ channels. Two poles in the neighborhood of the Λ(1405):

two poles: ($z_1 = 1424^{+7}_{-23} - i\ 26^{+3}_{-14}$; $z_1 = 1381^{+18}_{-6} - i\ 81^{+19}_{-8}$) MeV (Nucl. Phys. A881, 98 (2012))

mainly coupled to $\bar{K}N$ mainly coupled to Σπ → line-shape depends on production mechanism

- Akaishi-Esmaili-Yamazaki phenomenological potential

Phys. Lett. B 686 (2010) 23-28 Confirmation of single pole ansatz?

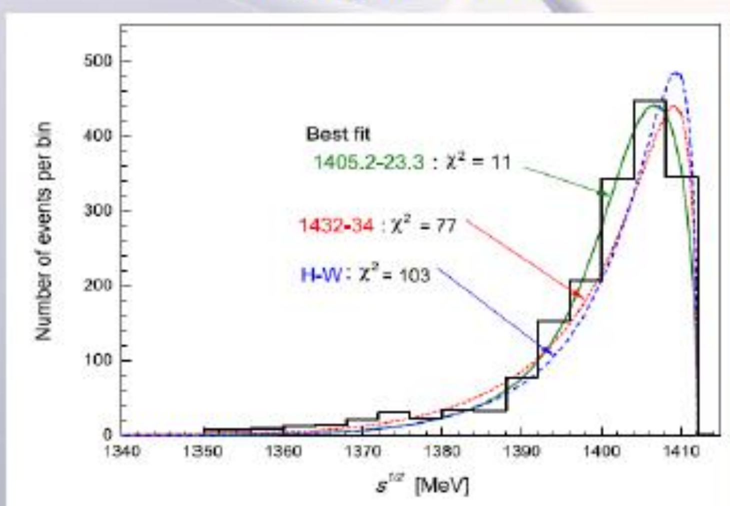
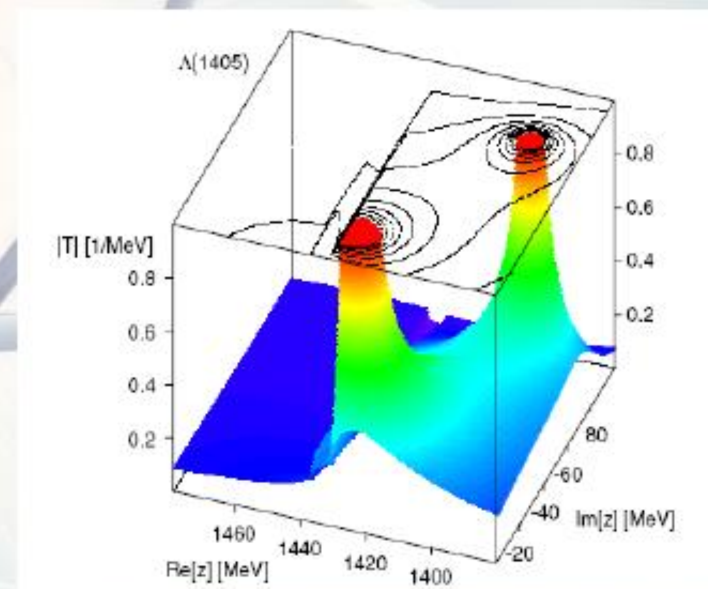


Fig. 6. Detailed differences in $M_{\Sigma\pi}$ spectra among the Hyodo–Weise prediction and the present model predictions.



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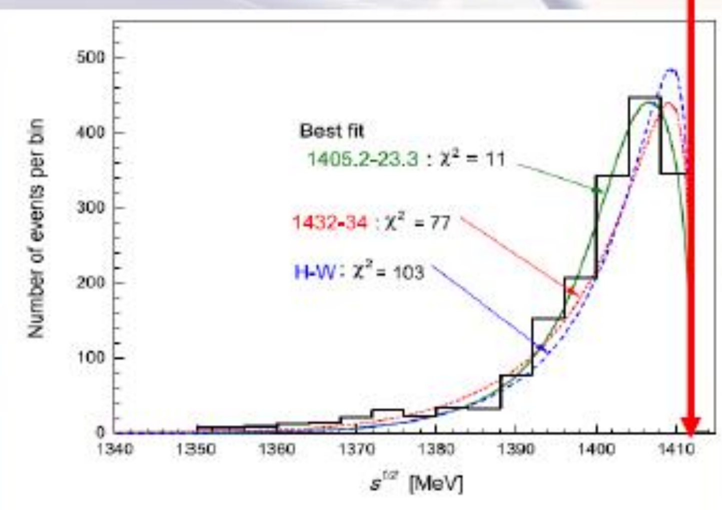

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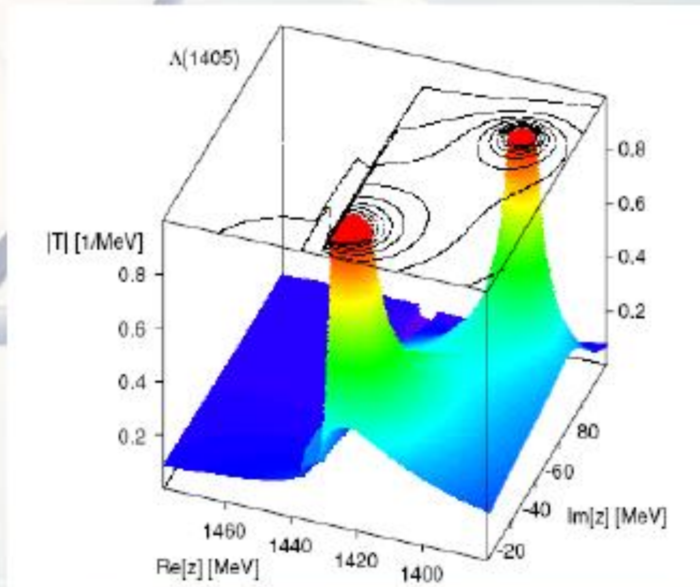


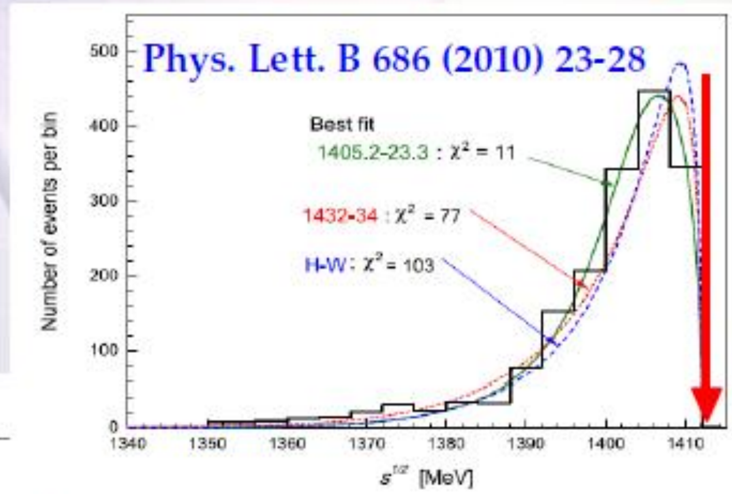
CUT AT THE <u>ENERGY LIMIT AT-REST</u> ?

<u>NON RESONANT SHAPE</u> ?

$\Sigma^+\pi^-$ correlation

$K^- p \rightarrow \Sigma^+\pi^-$ detected via: $(p\pi^0)\,\pi^-$

Possibility to disentangle: Hydrogen, in-flight, at-rest, K^- capture



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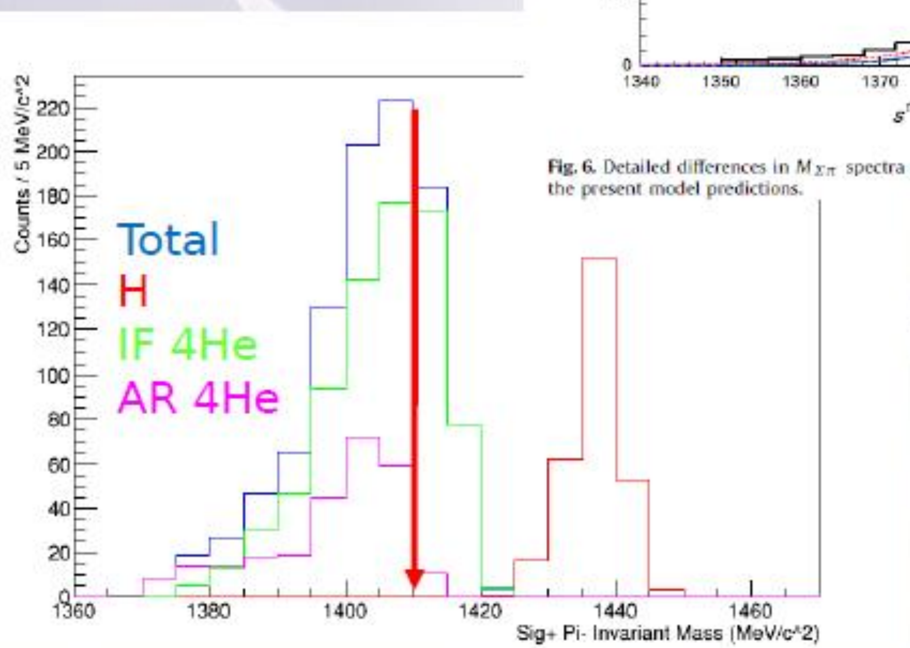

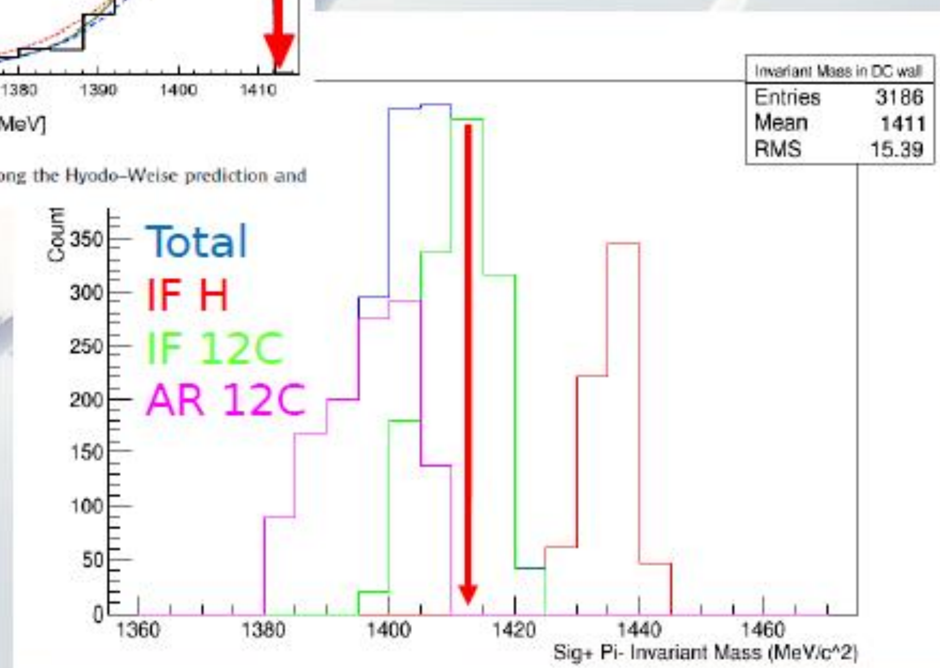

$\Sigma^+\pi^-$ correlation

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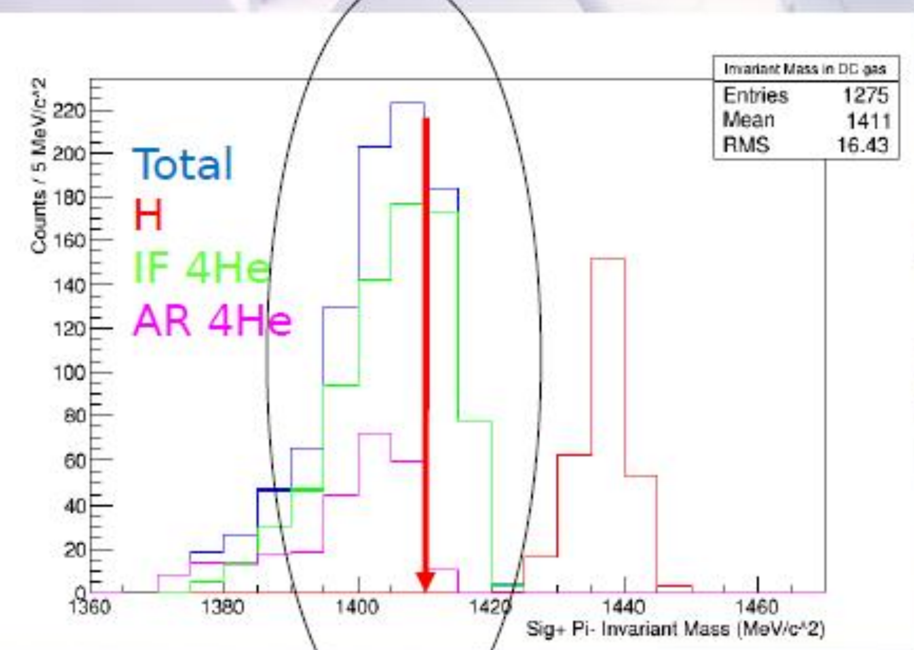
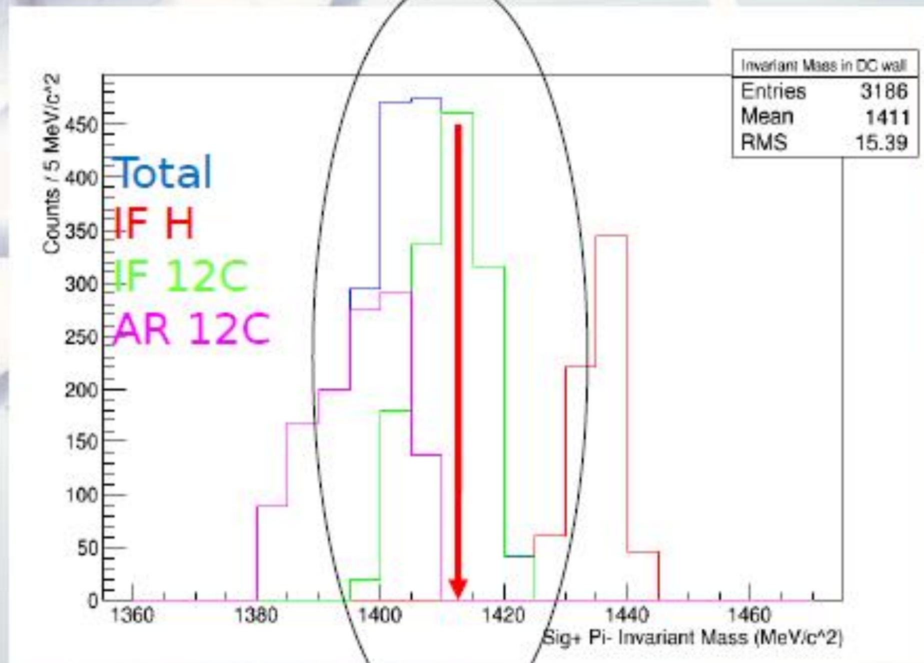
Possibility to disentangle: Hydrogen, in-flight, at-rest, K^- capture

if resonant production contribution is important a high mass component appears!



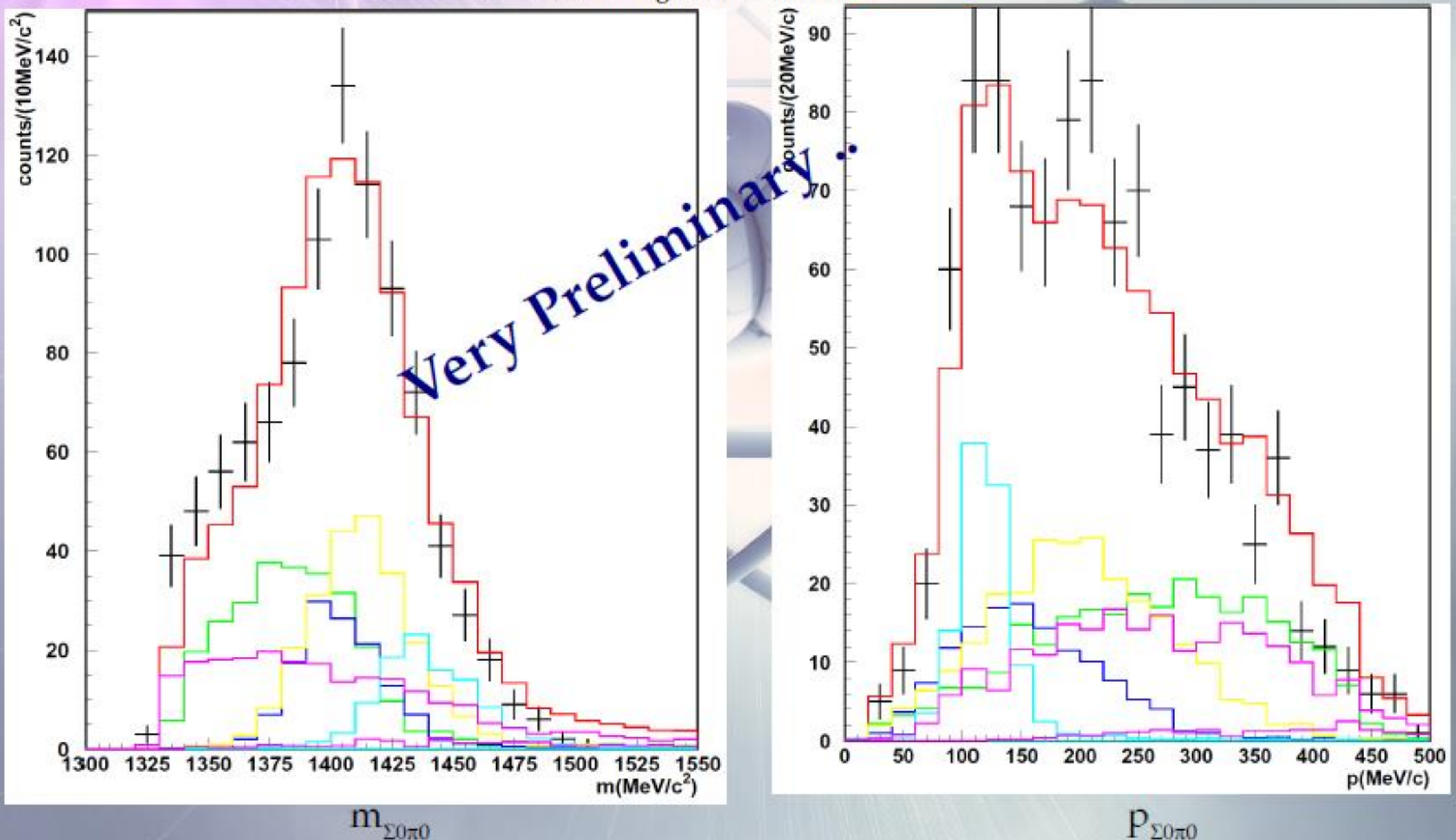


Fit of $\Sigma^0\pi^0$ spectrum in C

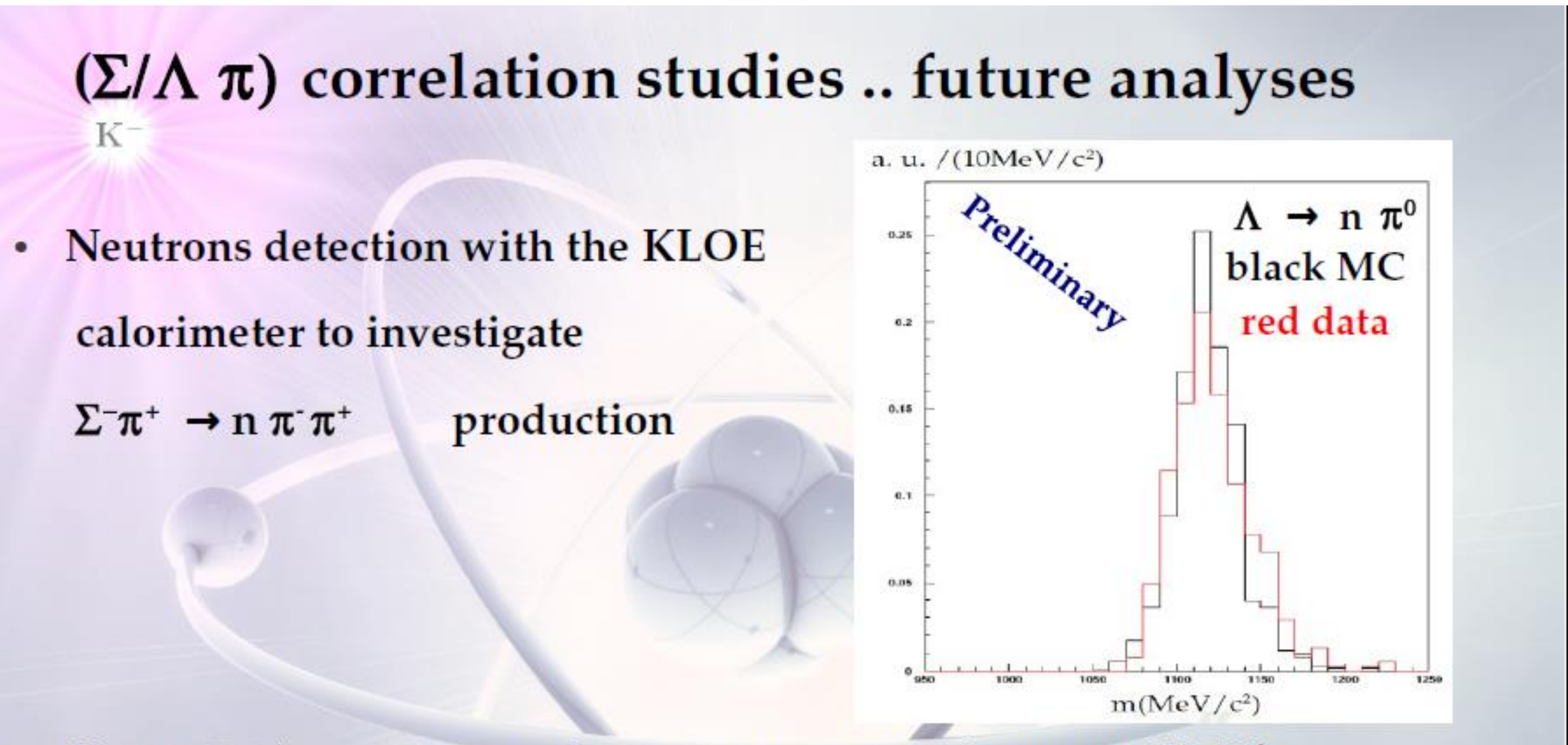
χ^2_{min} /ndf ~ 1.7 corresponding to $(M_{min}, \Gamma_{min}) = (1426, 52)$ MeV/c²

K^-

- **Global fit** (red) — **Resonant component K^-C at-rest** (green)
- **n. r. K^-C at-rest** (blue) — **n. r. K^-C in-flight** (yellow) — **n. r. K^-H in-flight** (cyan)
- **$\Lambda^0\pi^0$ background + n. r. m.** (magenta)



$\Sigma^{-}p^{+}$



($\Sigma/\Lambda\ \pi$) correlation studies .. future analyses
K^-
• Neutrons detection with the KLOE
calorimeter to investigate
$\Sigma^-\pi^+ \rightarrow n\ \pi^-\pi^+$ production
a. u. /(10MeV/c²)
Preliminary
$\Lambda \rightarrow n\ \pi^0$
black MC
red data
m(MeV/c²)

Resonant VS non-resonant

K^{-}

$K^{-} N \rightarrow (Y^{*}\ ?) \rightarrow Y \pi$

how much comes from resonance ?

Non resonant transition amplitude:

- Never measured before below threshold

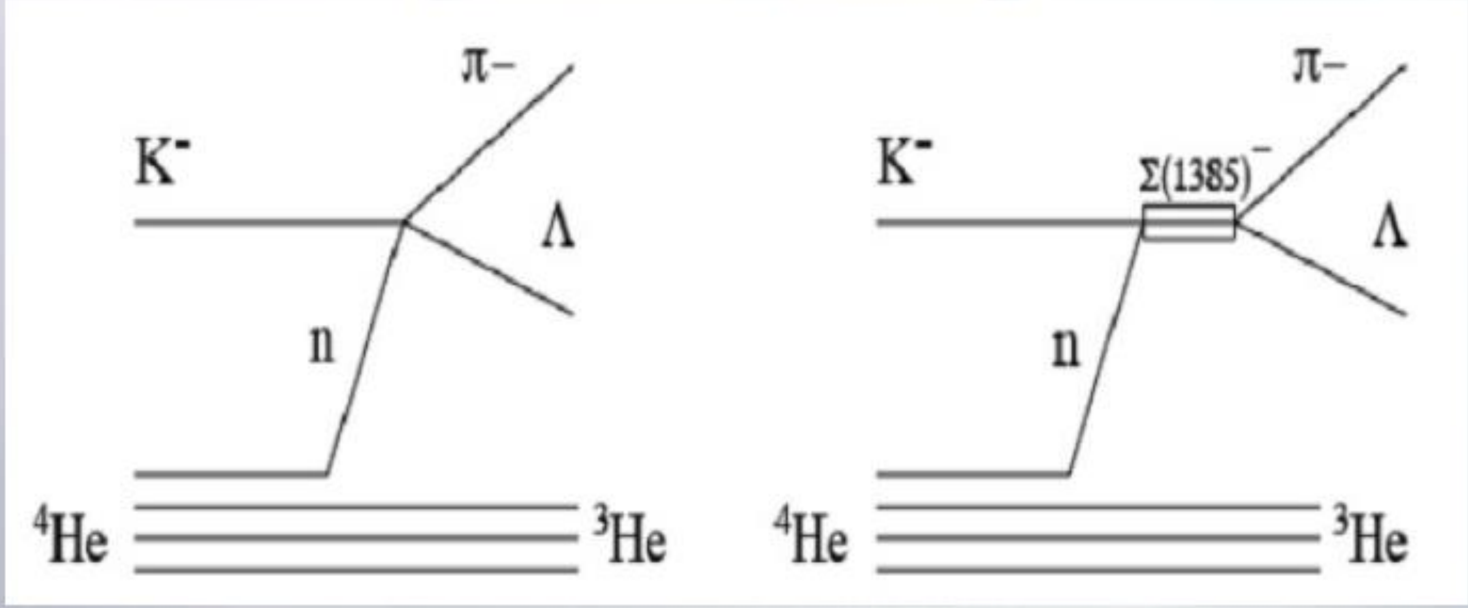
- few, old theoretical calculations (Nucl. Phys. B179 (1981) 33-48)

Resonant VS non-resonant

Investigated using:

$K^- "n" \rightarrow \Lambda\pi^-$ direct formation in ^4He

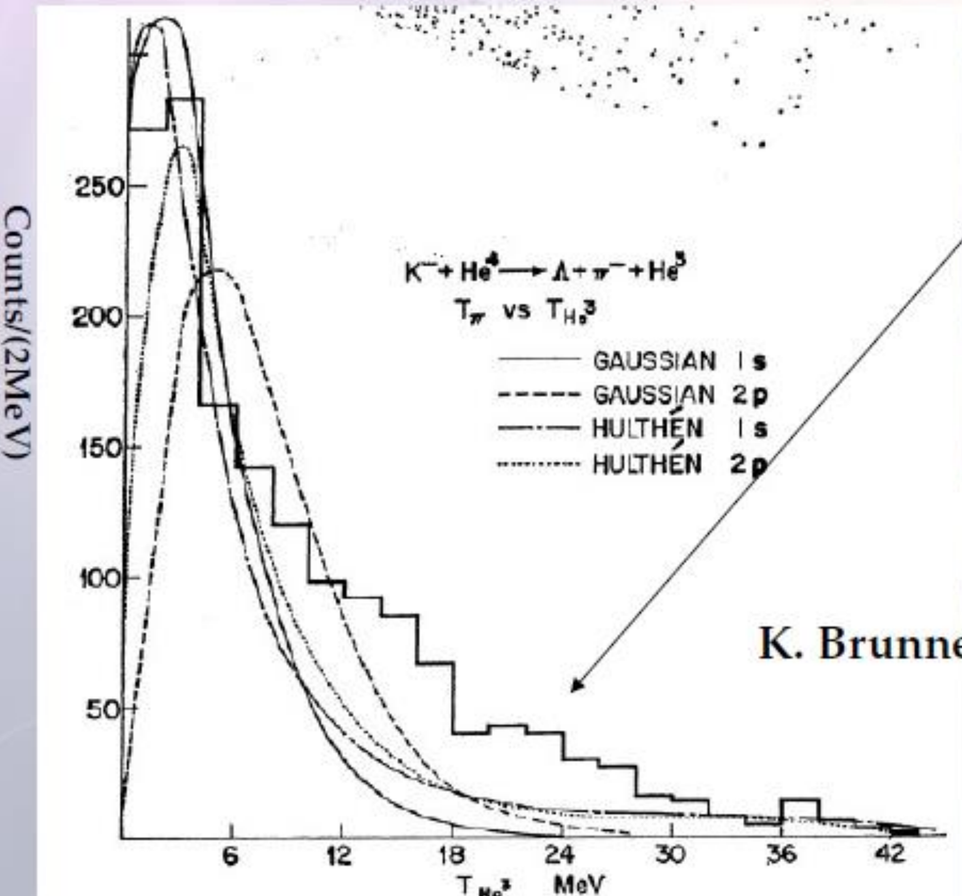
In collaboration with Prof. S. Wycech



Channel: $K^- \ ^4He \rightarrow \Lambda \pi^- \ ^3He$ … the idea

Bubble chamber experiments exhibit two components:

- Low momentum $\Lambda \pi^-$ pair → S-wave, I=1, non-resonant transition amplitude.
  - High momentum $\Lambda \pi^-$ pair → P-wave resonant formation ?



Also exsists in S-state K-mesic atom

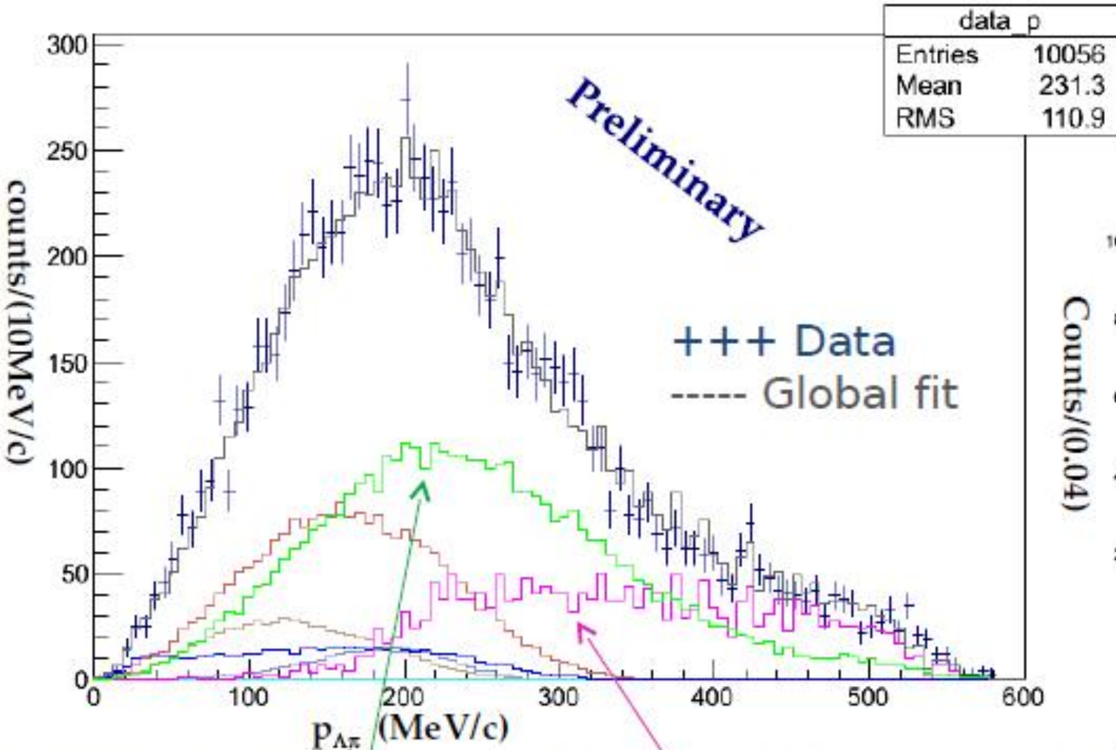
as a result of the

three body structure of the system

(K = 1, n=2, ^{3}He = 3)

K. Brunnel et al., Phys.Rev. D2 (1970) 98

$K^- \, {}^4He \rightarrow \Lambda \, \pi^- \, {}^3He$ preliminary fit

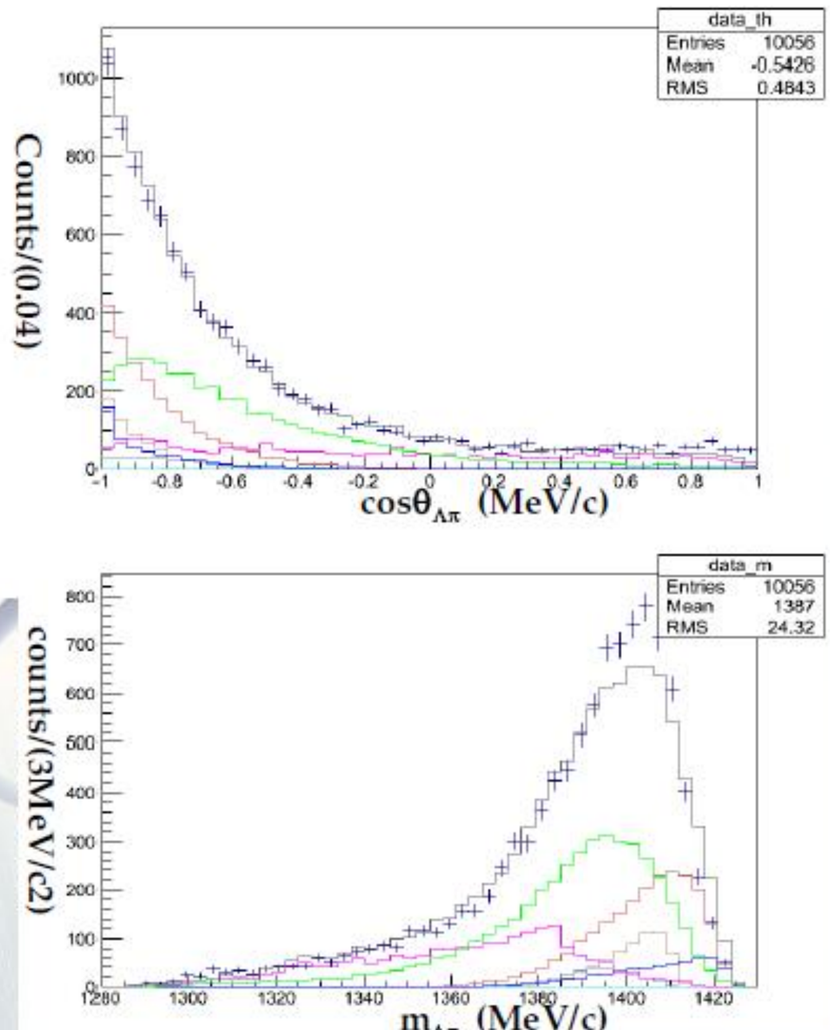


Absorptions in 12C
(from Carbon wall data)

Σ/Λ nuclear conversion
K-N→Σ π
→ΣN→ΛN

Simultaneous fit

$(p_{\Lambda\pi^-} - \theta_{\Lambda\pi^-})$



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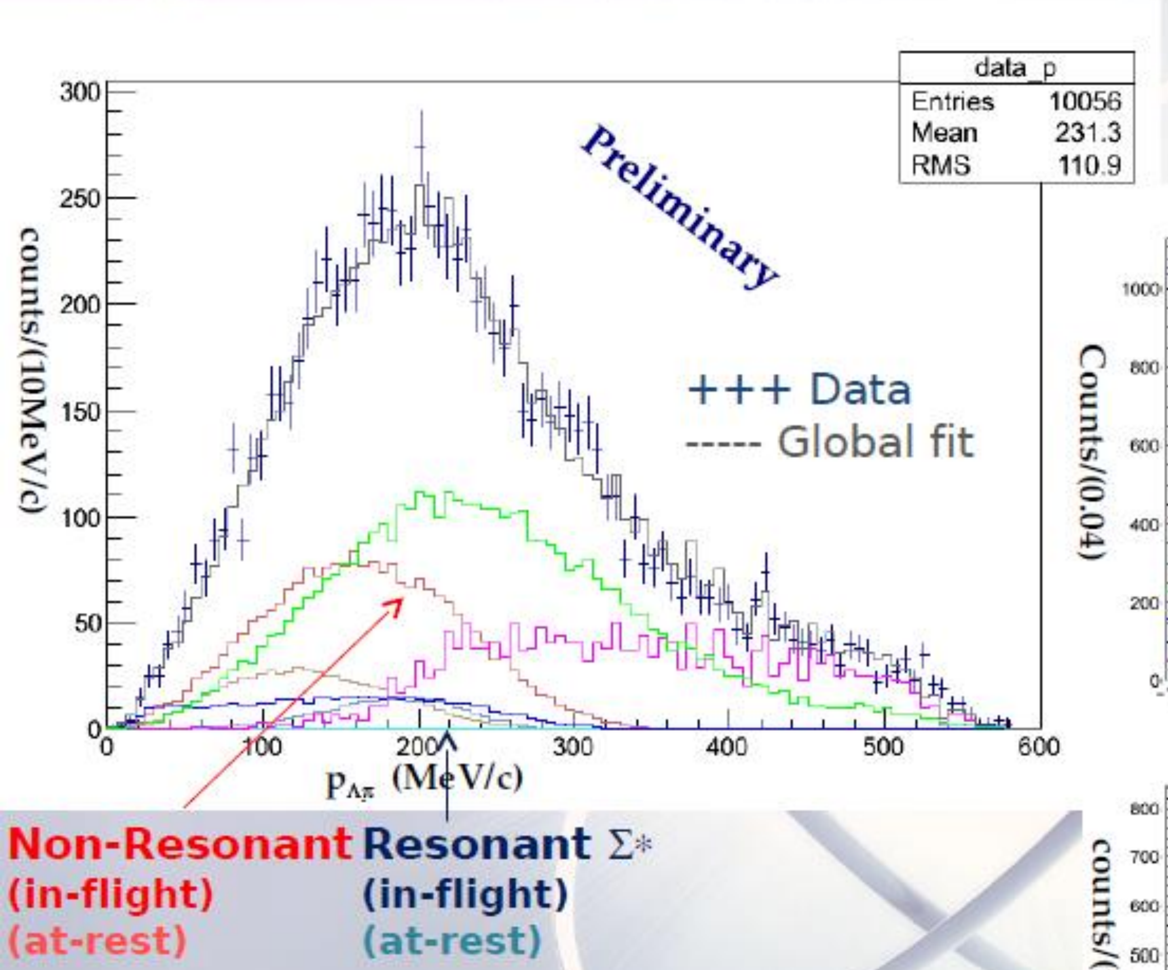
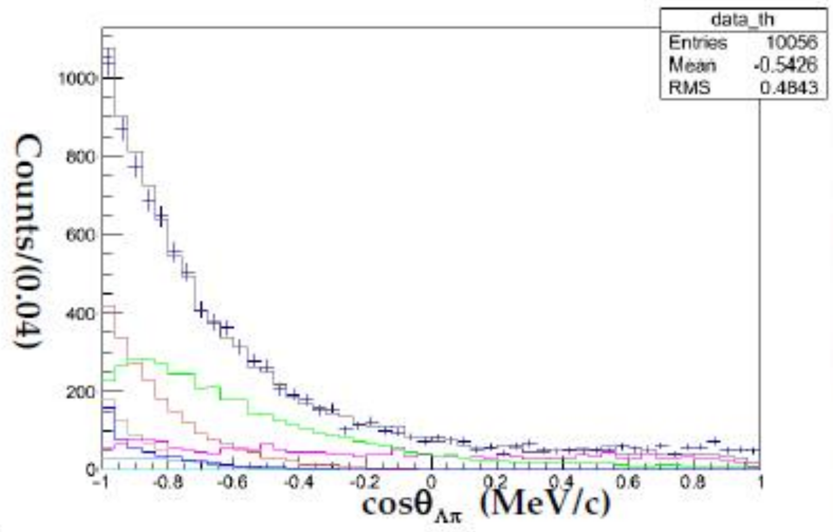
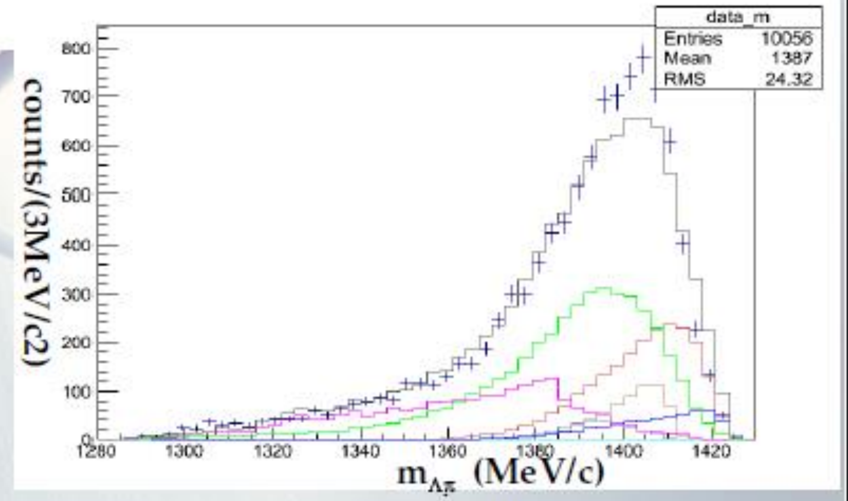


Simultaneous fit

($p_{\Lambda\pi-}$ - $\theta_{\Lambda\pi-}$)





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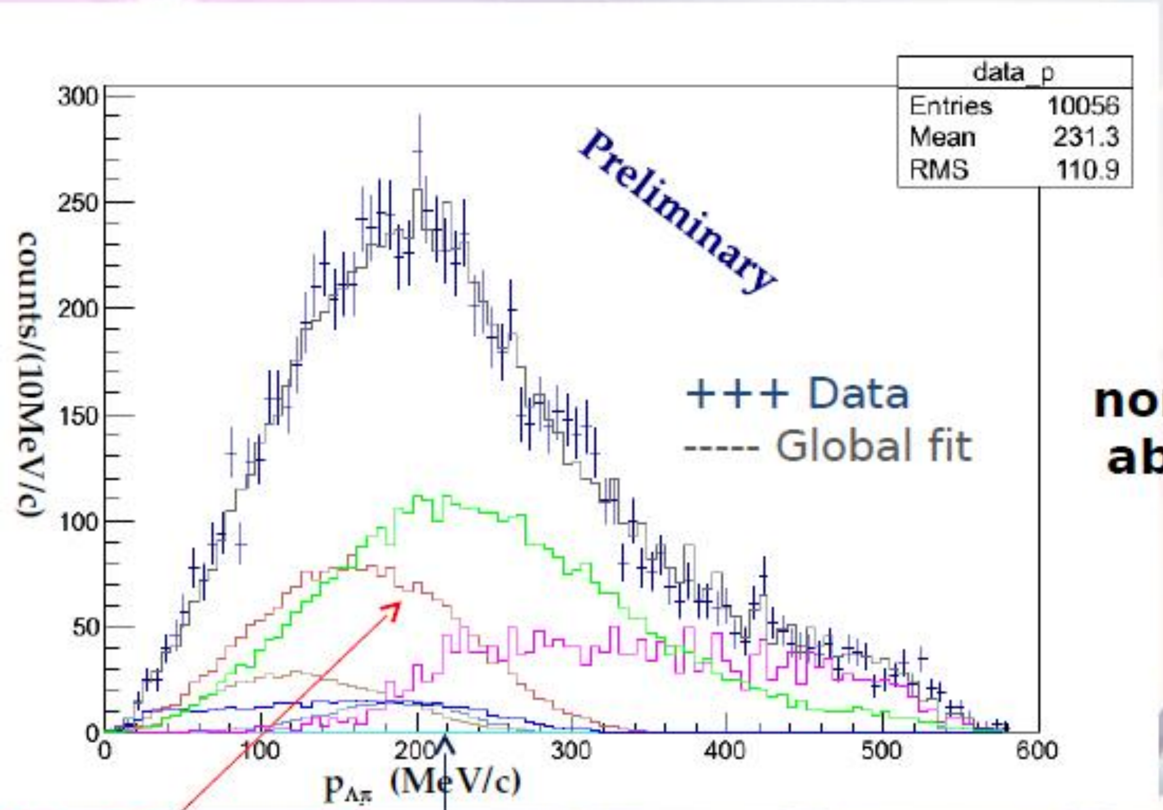


Non-Resonant (in-flight) (at-rest)

Resonant Σ^* (in-flight) (at-rest)

Simultaneous fit

$(p_{\Lambda\pi^-} - \theta_{\Lambda\pi^-})$

non-resonant / resonant absorption ratio:

- **at rest** ~ 2.3
- **in flight** ~ 4.1
- $\chi^2/(ndf - np) = 1.5$

K^-

PART 2

Single & multi – nucleon K^- absorption

kaonic nuclear clusters

investigation through

Λp,d,t / Σ^0p

correlation

Λp correlation study .. PART 2a

K^-

How deeply can an Antikaon be bound to a nucleus?

Possible bound states: K^-pp – K^-ppn

$K^-pp \rightarrow \Lambda/\Sigma\, p$ $\qquad$ $K^-ppn \rightarrow \Lambda d$

predicted due to the strong $\bar{K}N$ interaction in the I=0 channel. (Wycech (1986) - Akaishi & Yamazaki (2002))

Different theoretical approaches:

- Few-body calculations solving Faddeev equations
- Variational calculations with phenomenological $\bar{K}N$ potential
- $\bar{K}N$ effective interactions based on Chiral SU(3) dynamics

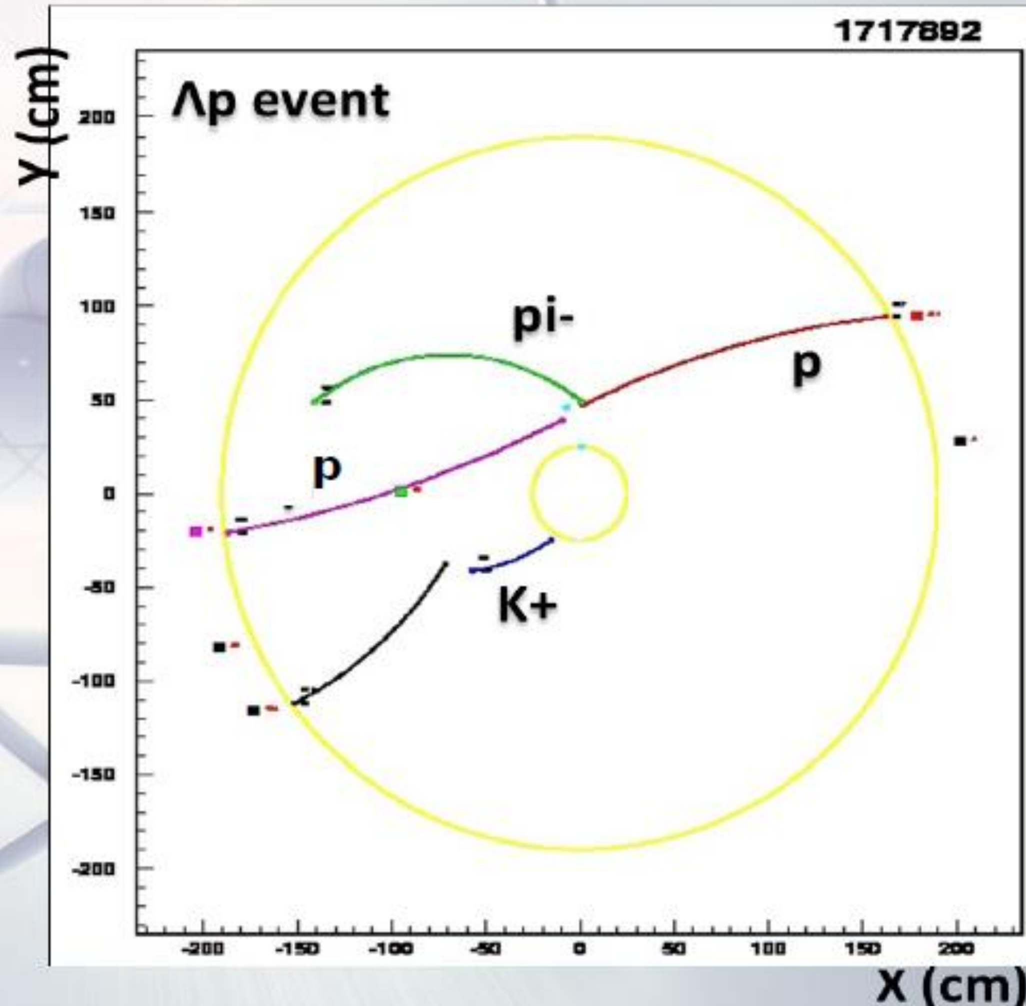
K^-pp bound state

	Theoretical prediction	B.E (MeV)	Γ (MeV)
PRC76, 045201 (2002)	T. Yamazaki and Y. Akaishi	48	61
arXiv:0512037v2[nucl-th]	A. N. Ivanov, P. Kienle, J. Marton, E. Widman	118	58
PRC76, 044004 (2007)	N. V. Shevchenko, A. Gal, J. Mares, J. Revai	50-70	~100
PRC76, 035203 (2007)	Y. Ikeda and T. Sato	60-95	45-80
NPA804, 197 (2008)	A. Dote, T. Hyodo, W. Weise	20±3	40-70
PRC80, 045207 (2009)	S. Wycech and A. M. Green	56.5-78	39-60
PRL B712, 132-137 (2012)	Barnea et al.	15.7	41.2

Λp correlation study

K- stopped + **X** → **Λ** **p** **X'**
(in-flight)
Λ → pπ−

(detected particles)



Resolutions for events in GAS:

p_Λ	$0.49 \pm 0.01\ MeV/c$
p_p	$2.63 \pm 0.07\ MeV/c$
$M_{\Lambda p}$	$1.10 \pm 0.03\ MeV/c^2$
r_{vertex}	$0.12 \pm 0.01\ cm$

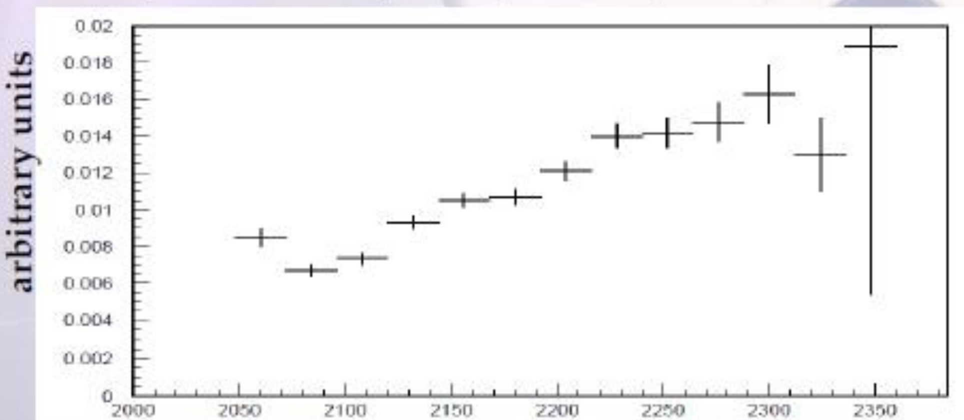
Λp correlation study

K^- stopped + X → Λ **p** X'
(in-flight)

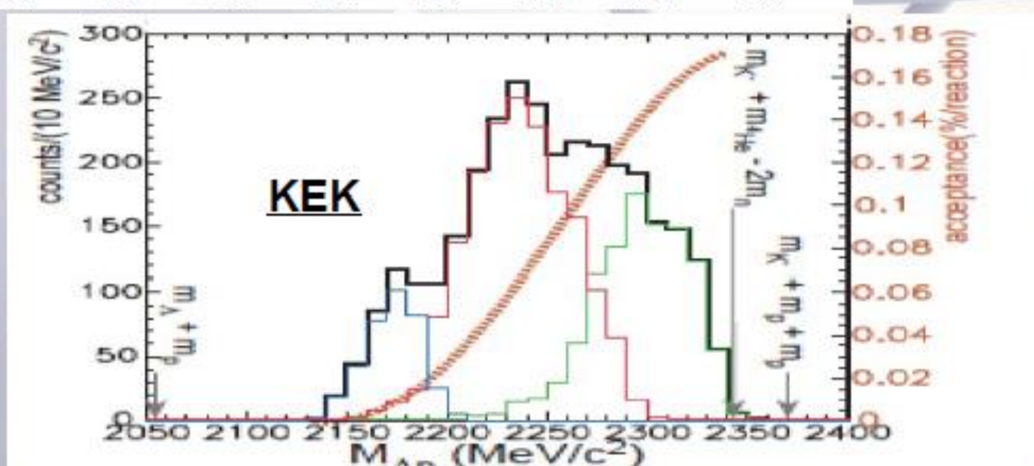
Λ → **pπ^-**

(detected particles)

Acceptance study with phase space **K- + 4He -> Λ p n n** MC simulation

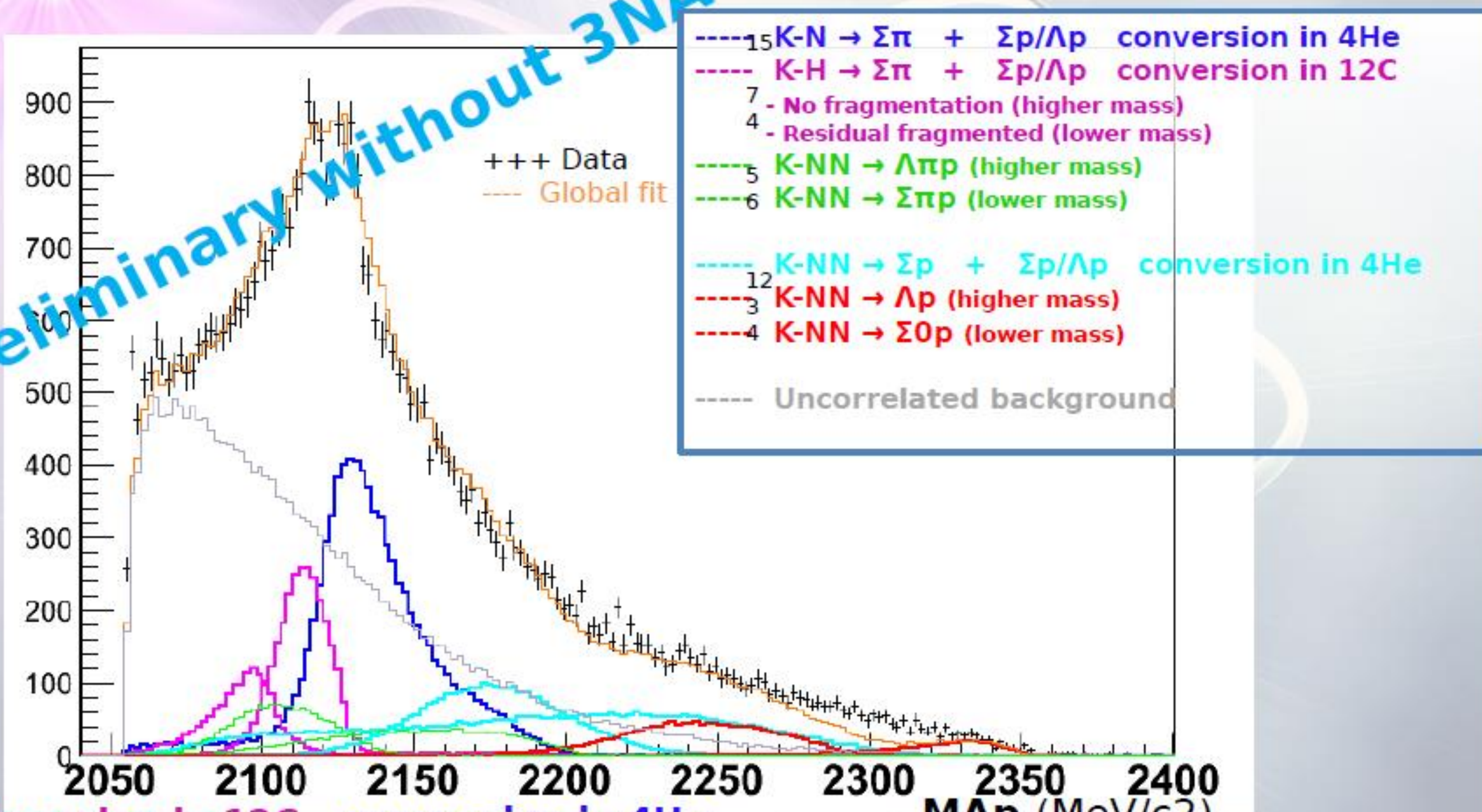


Projection of the acceptance function depending on : (PΛ,Pp,Minv Λp) on the Invariant mass plane



Λp correlation study

Fit 3D (P_Λ, P_p, $\theta_{\Lambda p}$)



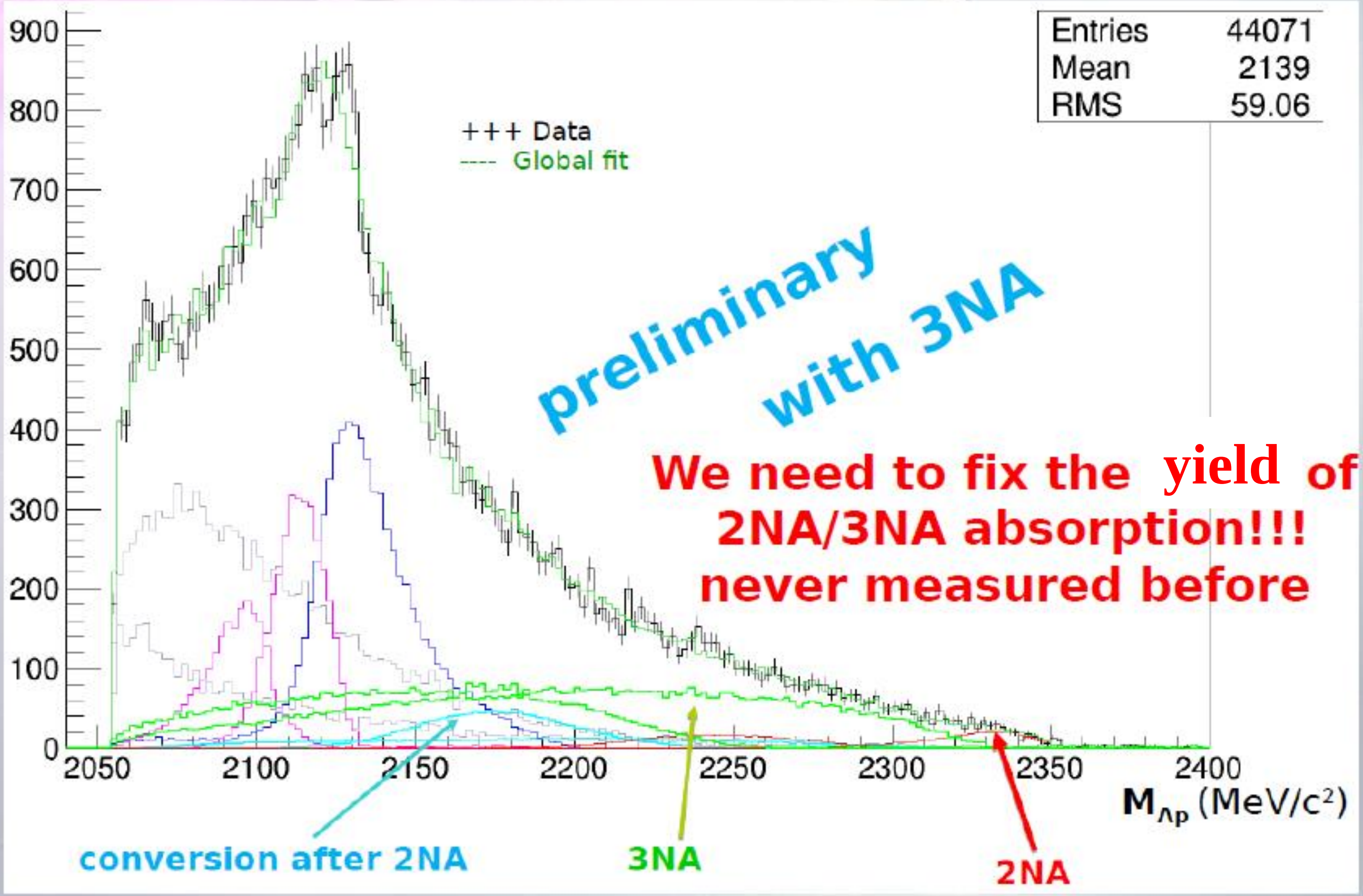
conversion in 12C   conversion in 4He

2NA direct production

conversion after 2NA: more energetic

Λp correlation study

Fit 3D (P_Λ, P_p, $\theta_{\Lambda p}$)



K⁻

2/3/4 NA yields

from

$\Sigma^0 p$ / Λt channels

Σ^0p correlation study .. PART 2b

K^-

$K^-_{\text{stopped / in-flight}} + X \rightarrow \Sigma^0\ \mathbf{p}\ X'$

$\Sigma^0 \rightarrow \Lambda\gamma$

$\Lambda \rightarrow p\pi^-$

(detected particles)

GOLDEN channel for K-pp cluster search

free from Σ N → Λ N' conversion process!!!

never measured before

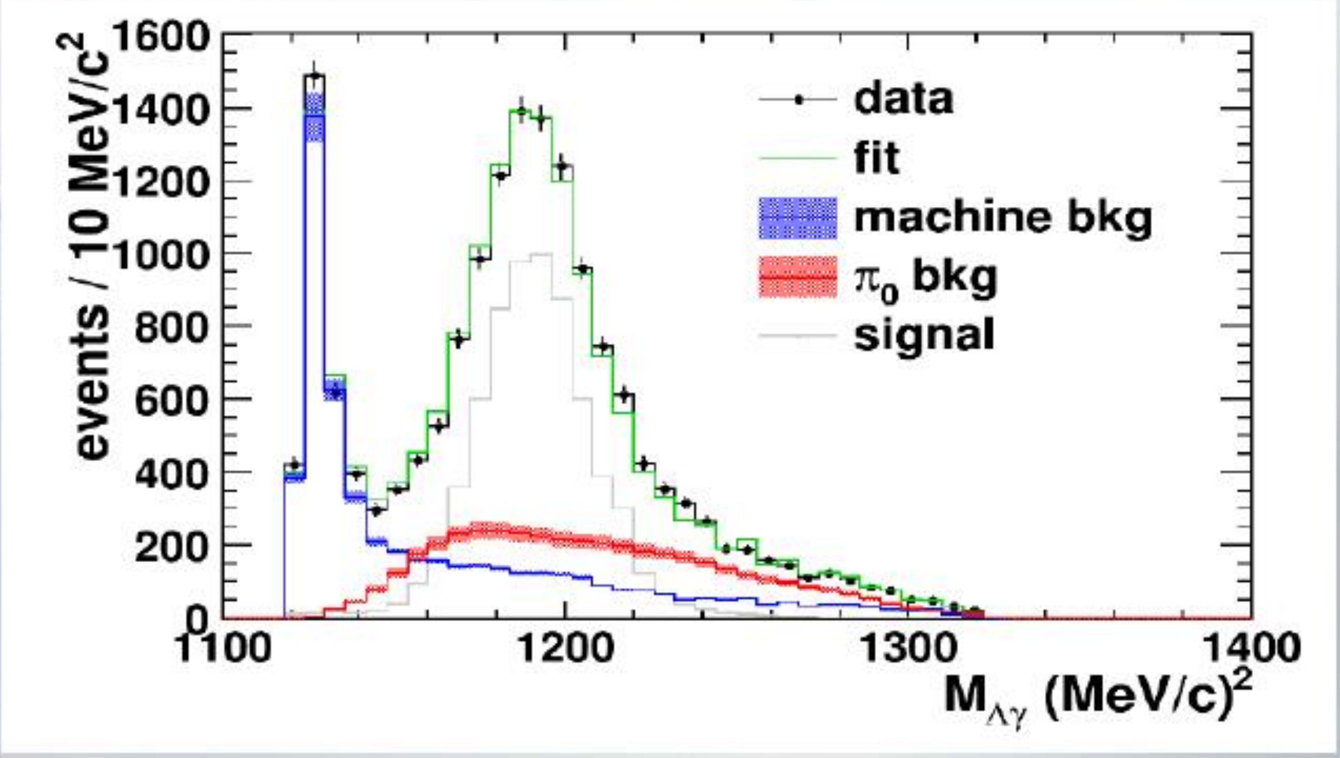
Σ^0p correlation study

$K^-_{\text{stopped / in-flight}} + X \rightarrow \Sigma^0 \; \mathbf{p} \; X'$

$\Sigma^0 \rightarrow \Lambda\gamma$, $\Lambda \rightarrow p\pi^-$

(detected particles)

Search for Σ^0 in the Λp sample (GAS events):

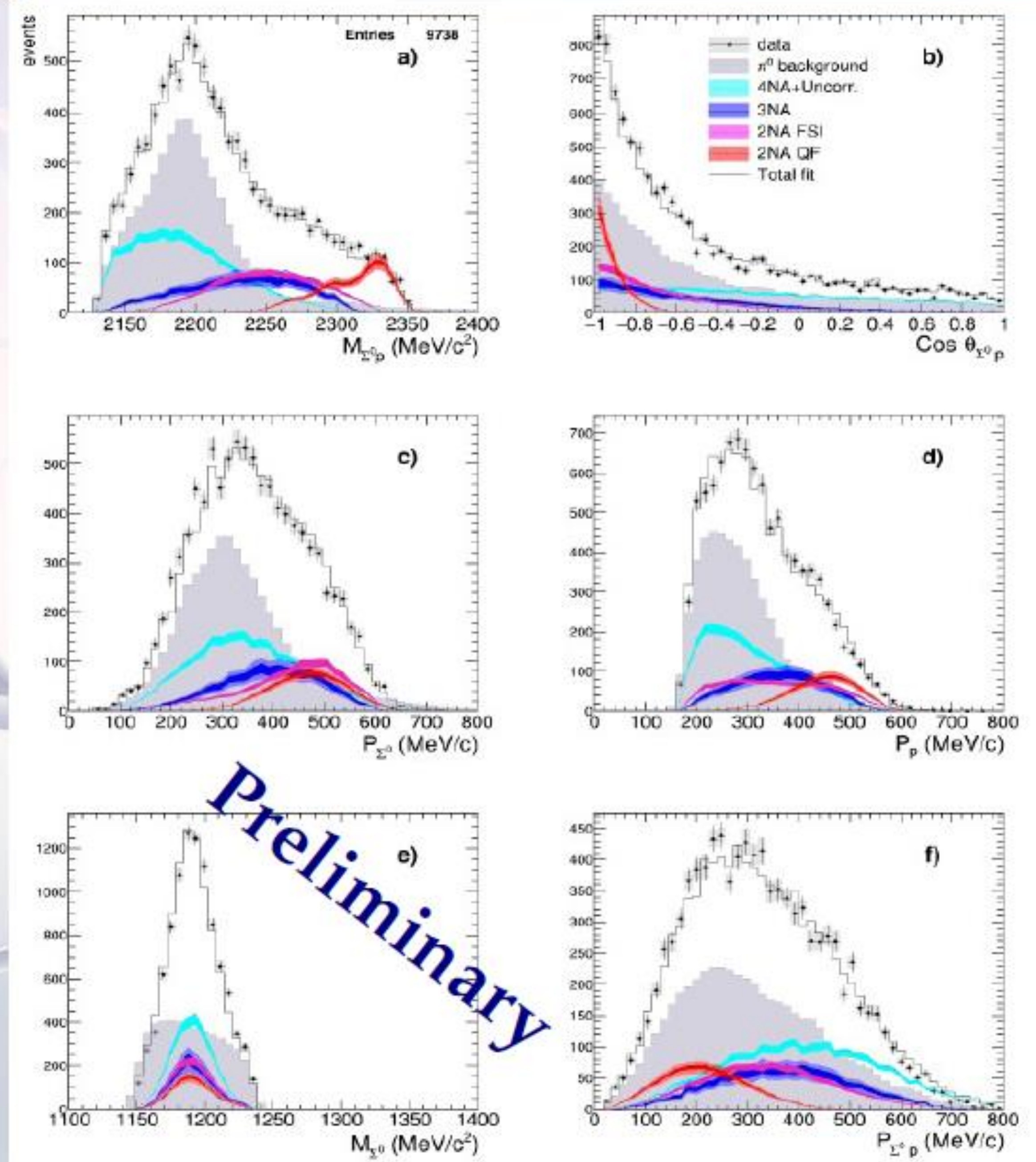


Σ^0p the fit

Simultaneous fit to the machine bkg subtracted spectra with simulated distributions for all the relevant physical quantities:

- Momentum of proton
- momentum of Σ^0
- Σ^0-p invariant mass
- angle Σ^0p

$\chi^2/\,(\text{ndf} - \text{np}) = 0.85$



Extracted yields

	yield / $K^-_{stop} \cdot 10^{-2}$	$\sigma_{stat} \cdot 10^{-2}$	$\sigma_{syst} \cdot 10^{-2}$
2NA-QF	0.124	± 0.019	+0.004 -0.008
2NA-FSI	0.265	± 0.027	+0.021 -0.022
Tot 2NA	0.366	± 0.032	+0.022 -0.031
3NA	0.267	± 0.067	+0.043 -0.020
Tot 3body	0.532	± 0.072	+0.047 -0.032
4NA + Uncorr. bkg.	0.753	± 0.052	+0.024 -0.074

Table 1. Production probability of the Σ^0p final state for different intermediate processes normalized to the number of stopped K^- in the DC wall. The statistical and systematic errors are shown as well.

Upper limit for K-pp bound state production

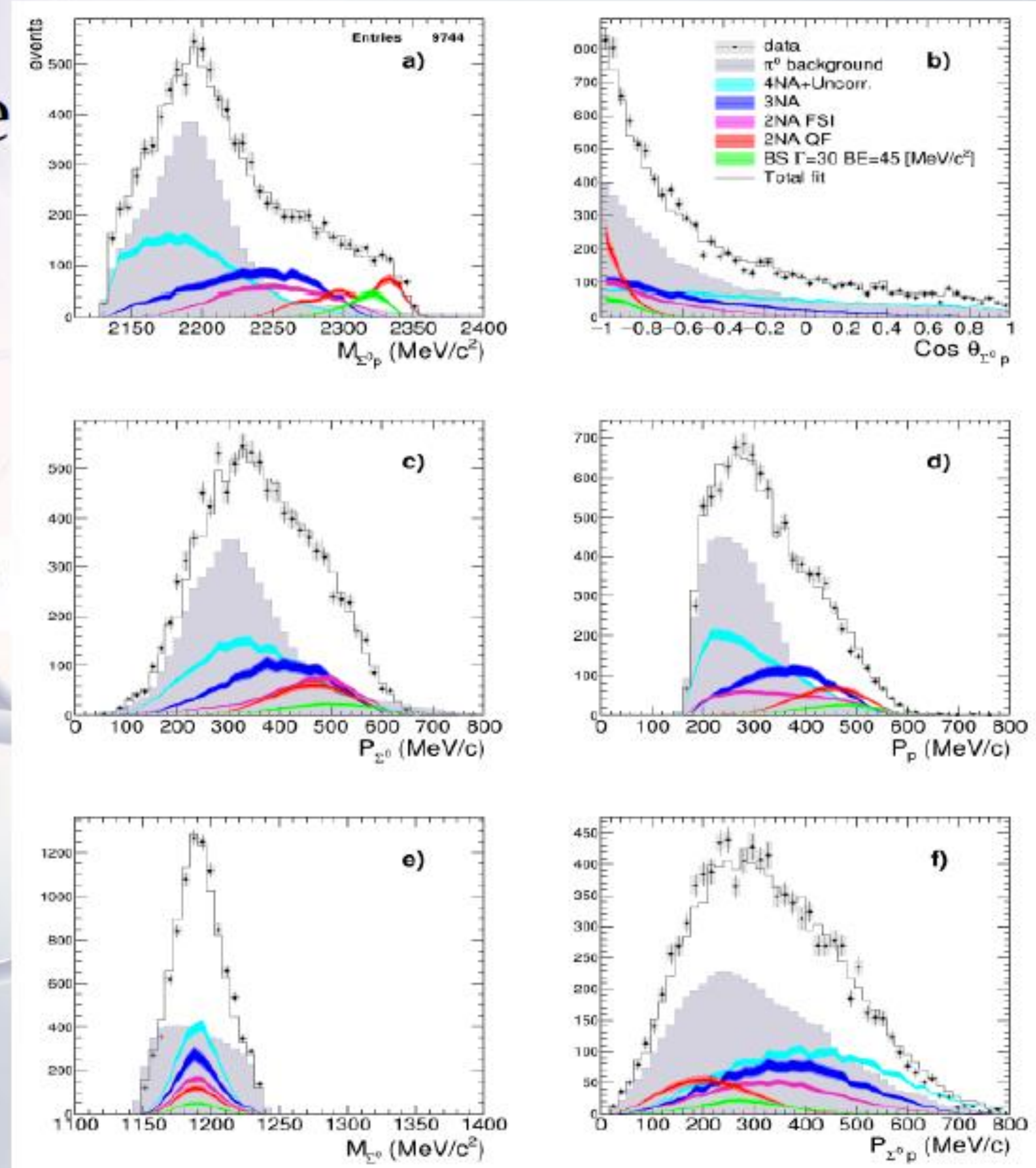
BE = 45 MeV

Width = 30 MeV

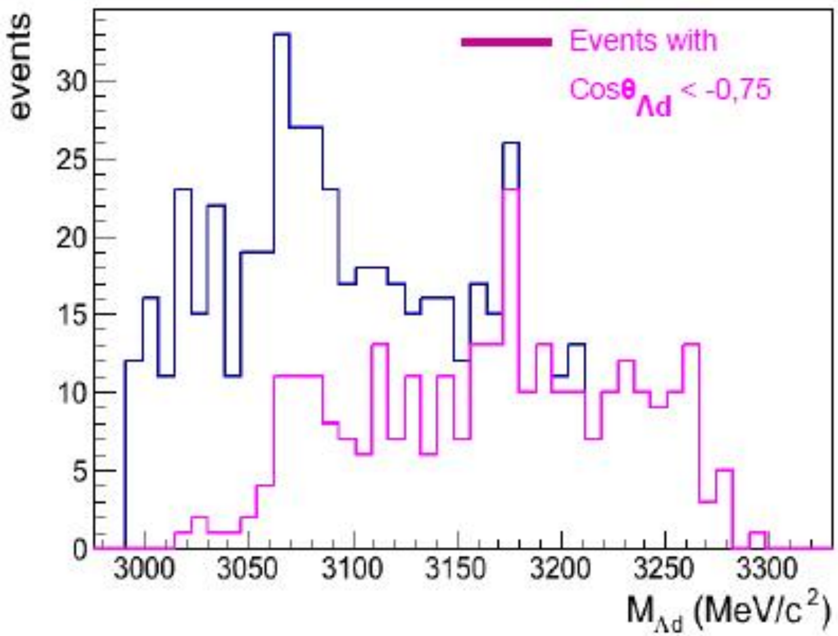
$$Yield/K^-_{stop} = (0.043 \pm 0.009\, stat^{+0.004}_{-0.005}\, syst) \cdot 10^{-2}$$

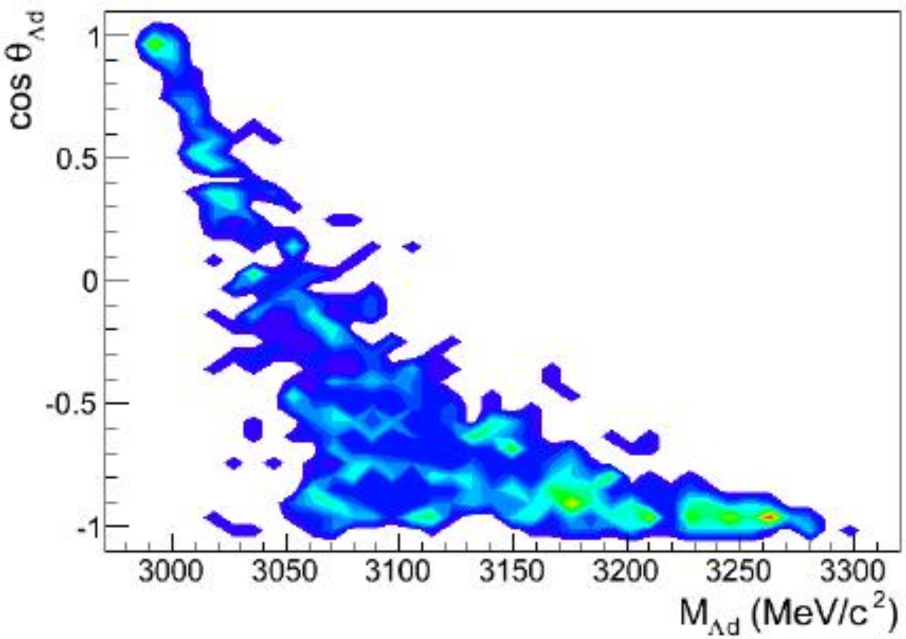
statistical significance = 1σ

Talk of O. Vazquez Doce



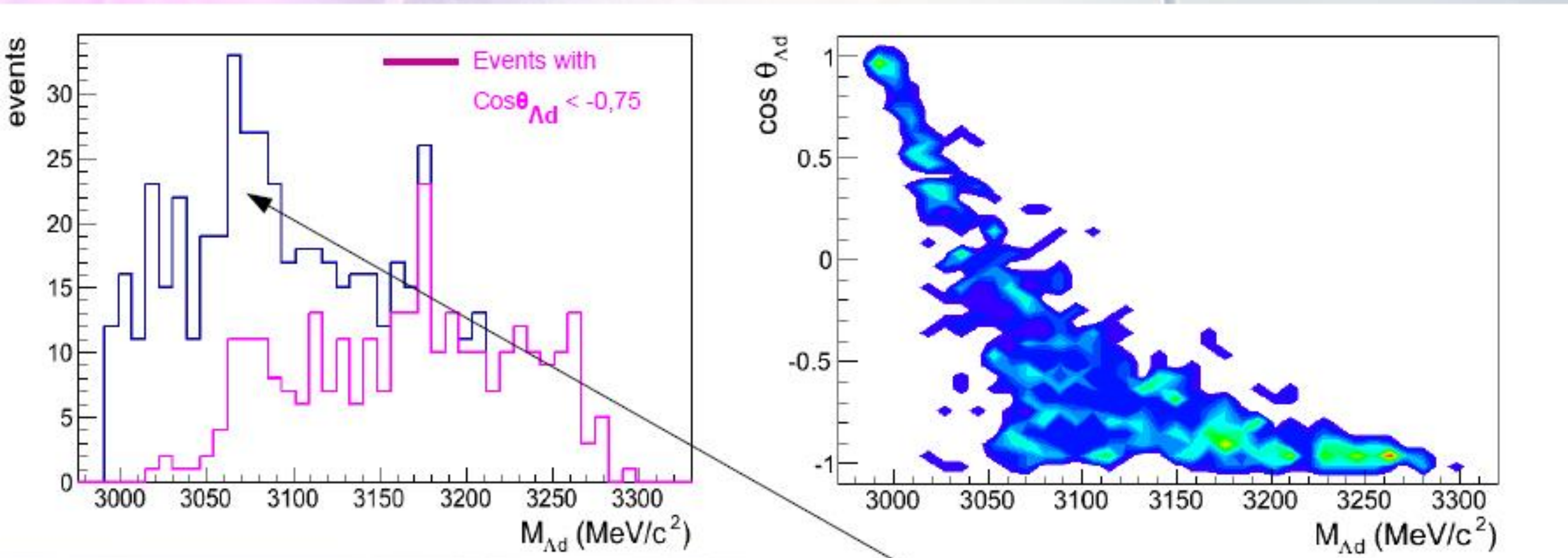
Λd search for a K-ppn cluster





- 572 Lambda-deuteron events in DC gas
- Structures at high Mass correlated with back-to-back events

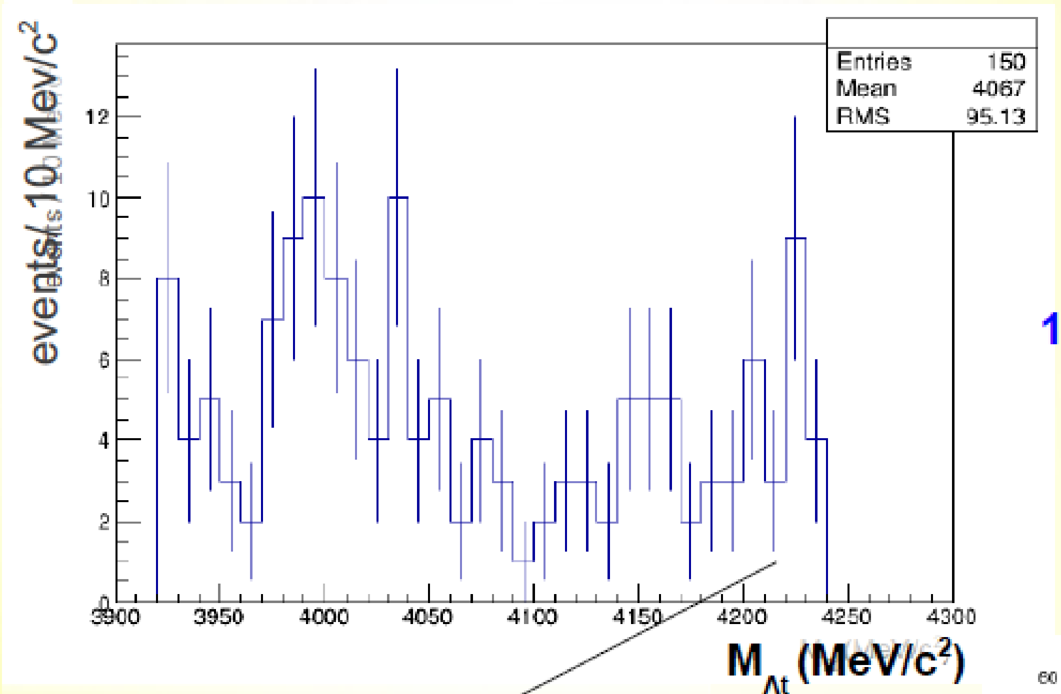
Λd search for a K-ppn cluster



- Fit to be performed

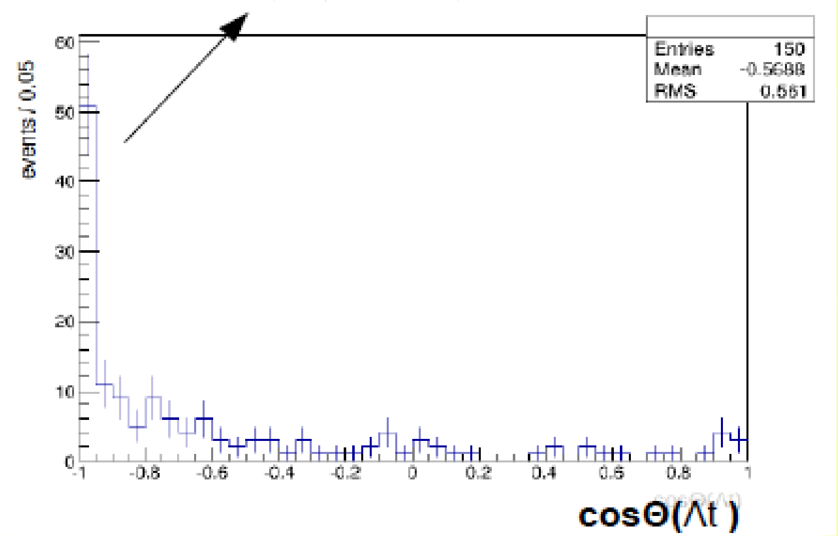
- Possibility to extract information on the cusp effect

Λt correlation studies in ^{4}He



150 events in gas of the DC (He + C_4H_{10})

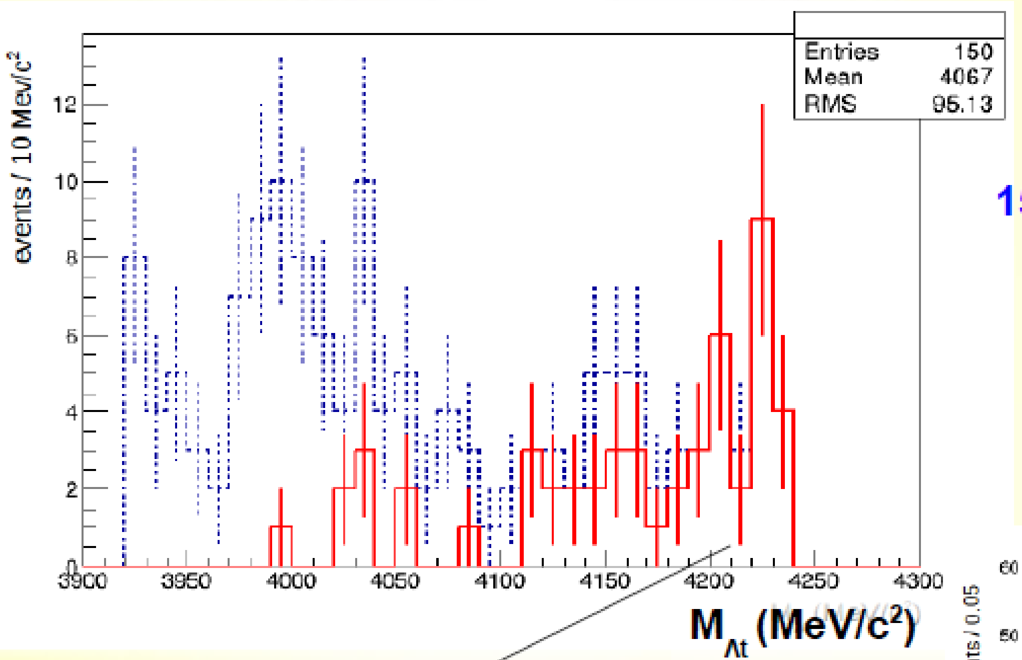
Clear back-to-back enhancement of Λt events



4NA process :

- highest part of invariant mass spectrum
- back-to-back topology

Λt correlation studies in ^{4}He

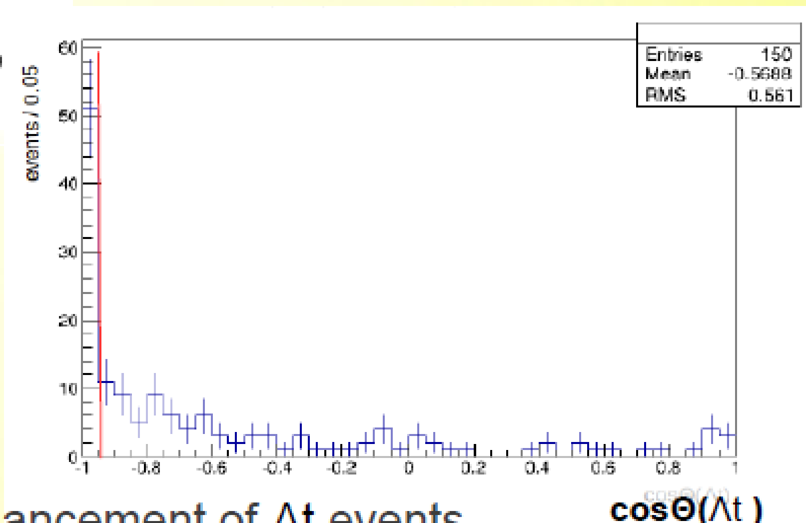


150 events in gas of the DC (He + C_4H_{10})

red line -
back to back events
($\cos\Theta_{\Lambda t}$) < -0.95

4NA process :

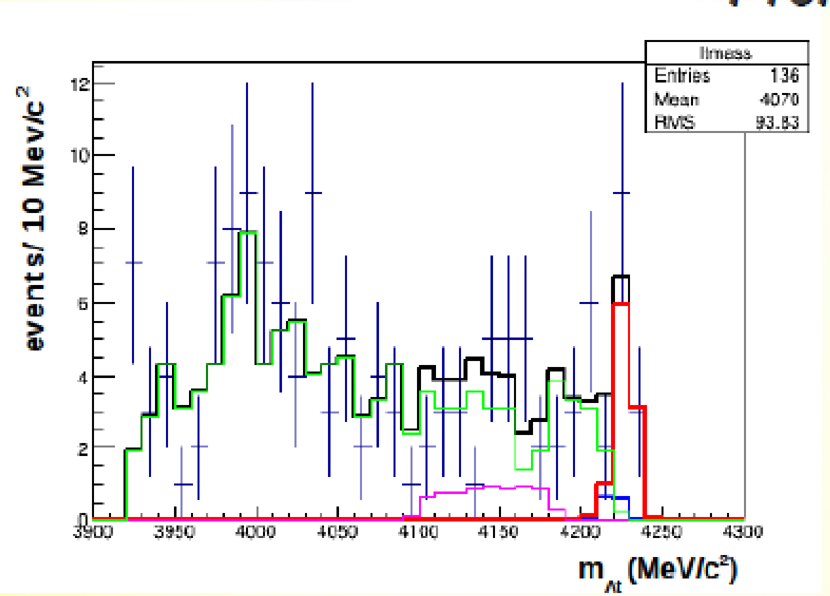
- highest part of invariant mass spectrum
- back-to-back topology



Clear back-to-back enhancement of Λt events

Λt correlation studies in ^{4}He: preliminary mass and angle simulataneous fit

Preliminary



Contribution to the spectra	Parameter value
K^{-4}He $\to \Lambda t$ at rest	0.01 ± 0.01
K^{-4}He $\to \Lambda t$ in-flight	0.09 ± 0.02
K^{-4}He $\to \Sigma^0 t$ in-flight	0.05 ± 0.03
K^{-12}C $\to \Lambda t$ experimental distribution from the carbon DC wall	0.85 ± 0.06
χ^2 / ndf	0.654

parameters giving the contribution of the each process

data

--- carbon data from DC wall

--- 4NA K^{-4}He → Λt in flight MC

--- 4NA K^{-4}He → Λt at rest MC

--- 4NA K^{-4}He → Σ^0t , Σ^0 → Λγ MC

--- 4NA K^{-4}He → Σ^0t , Σ^0 → Λγ MC

Total number of events = 136

4NA K^{-4}He → Λt at rest → 1 ± 1 events

4NA K^{-4}He → Λt in flight → 12 ± 3 events

BR(K^{-4}He(4NA) → Λt) **< 1.1 × 10^{-4} /K$_{stop}$**

σ(100 MeV/c) (K^{-4}He(4NA) → Λt) **=**
(0.41 ± 0.13 (stat) +0.01 -0.02 (sys)) mb

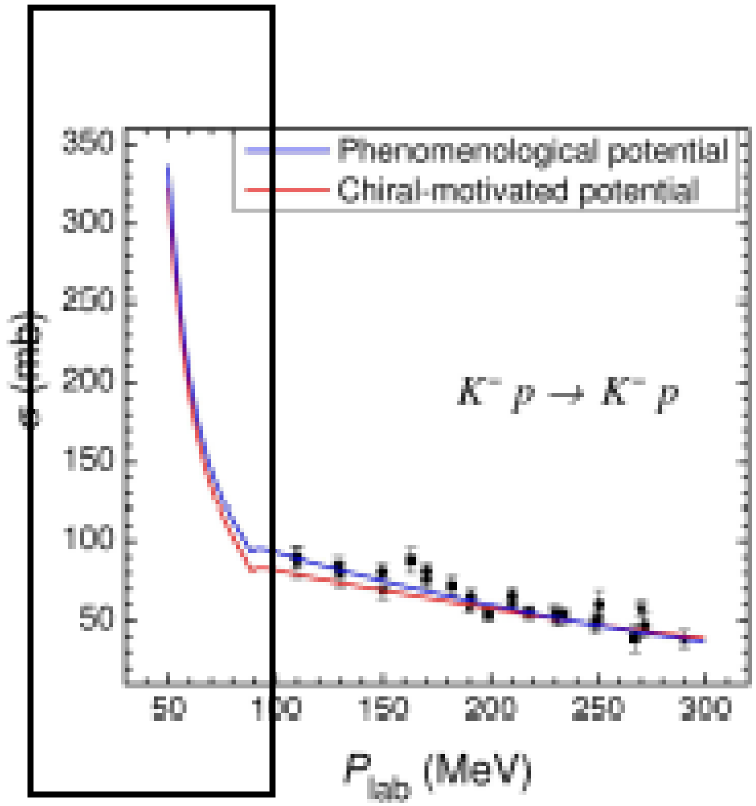
- Highest statistics ever in the Λt channel
- **4NA process** clearly seen for the first time
- **4NA Cross section & 100 MeV and upper limit on branching ratio extracted**

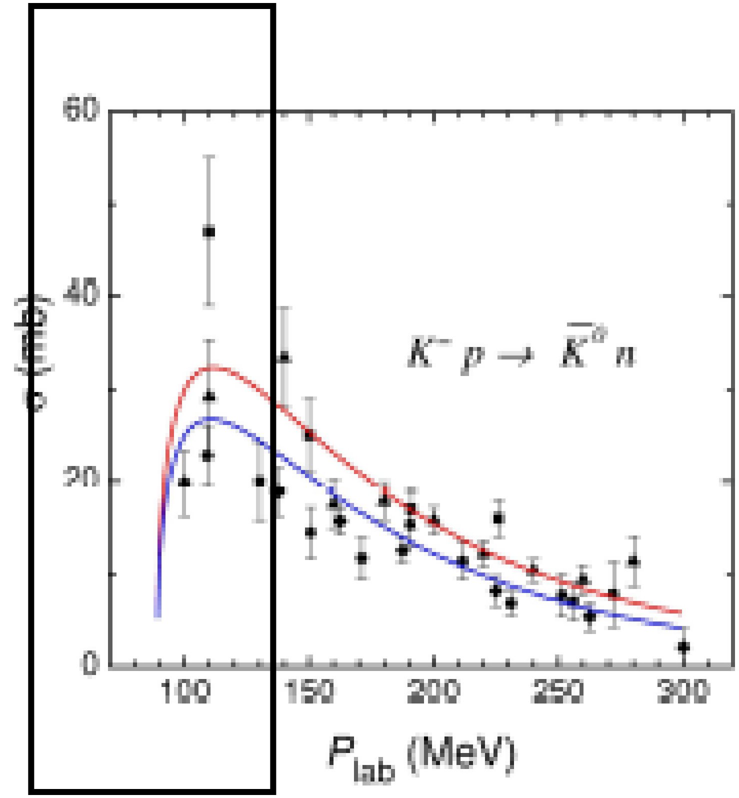
BR($K^{-4}He(4NA) \rightarrow \Lambda t$) **$< 1.1 \times 10^{-4} / K_{stop}$**

σ(100 MeV/c) ($K^{-4}He(4NA) \rightarrow \Lambda t$) =
(0.41 ± 0.13 (stat) +0.01 -0.02 (sys)) mb

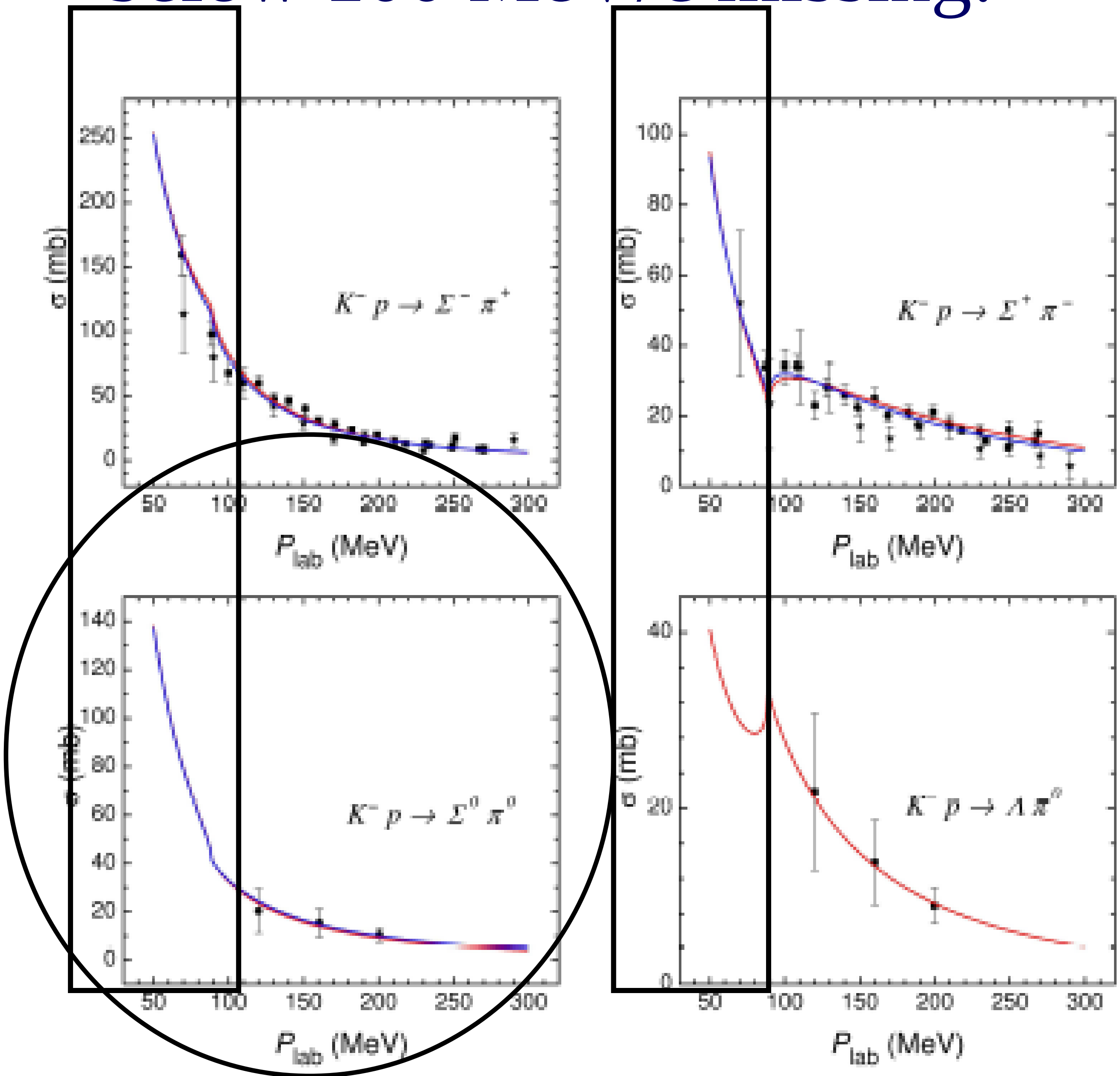
→ **paper in preparation**

Low-energy kaon scattering below 100 MeV/c missing:





Low-energy kaon processes below 100 MeV/c missing:



K^-

- 2 data sets from 2004/2005 KLOE data

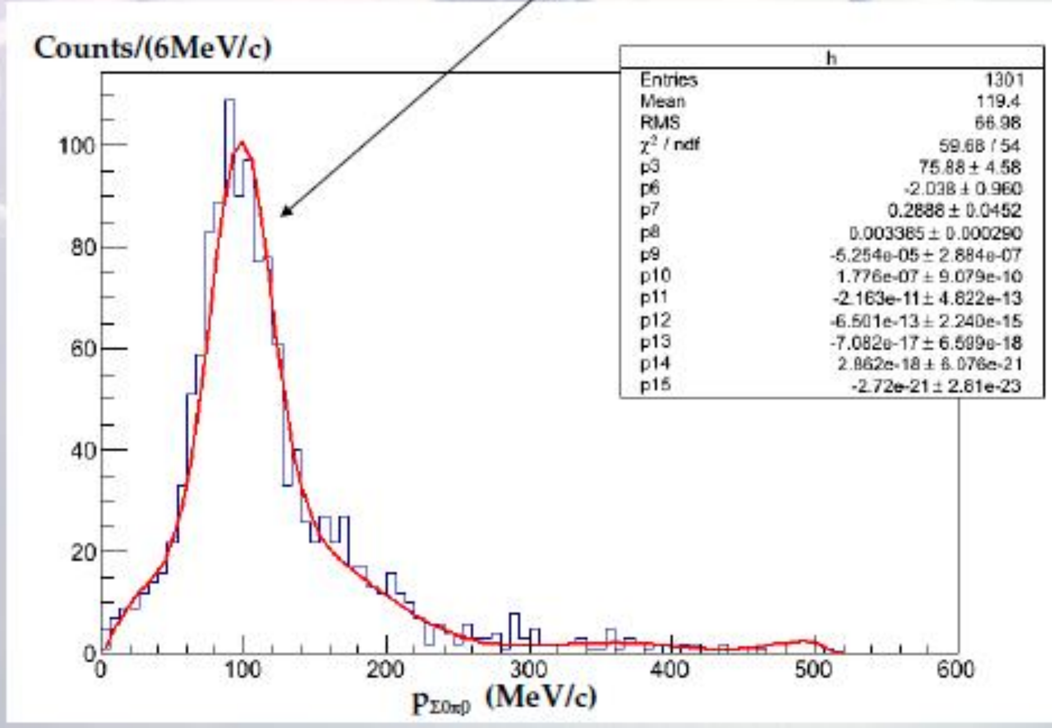
1) K- absorptions in the KLOE DC wall on H from the epoxy contained in the carbon fibre,

2) K- absorptions in the KLOE DC gas on H from isobutane C4H10 (10% in volume).

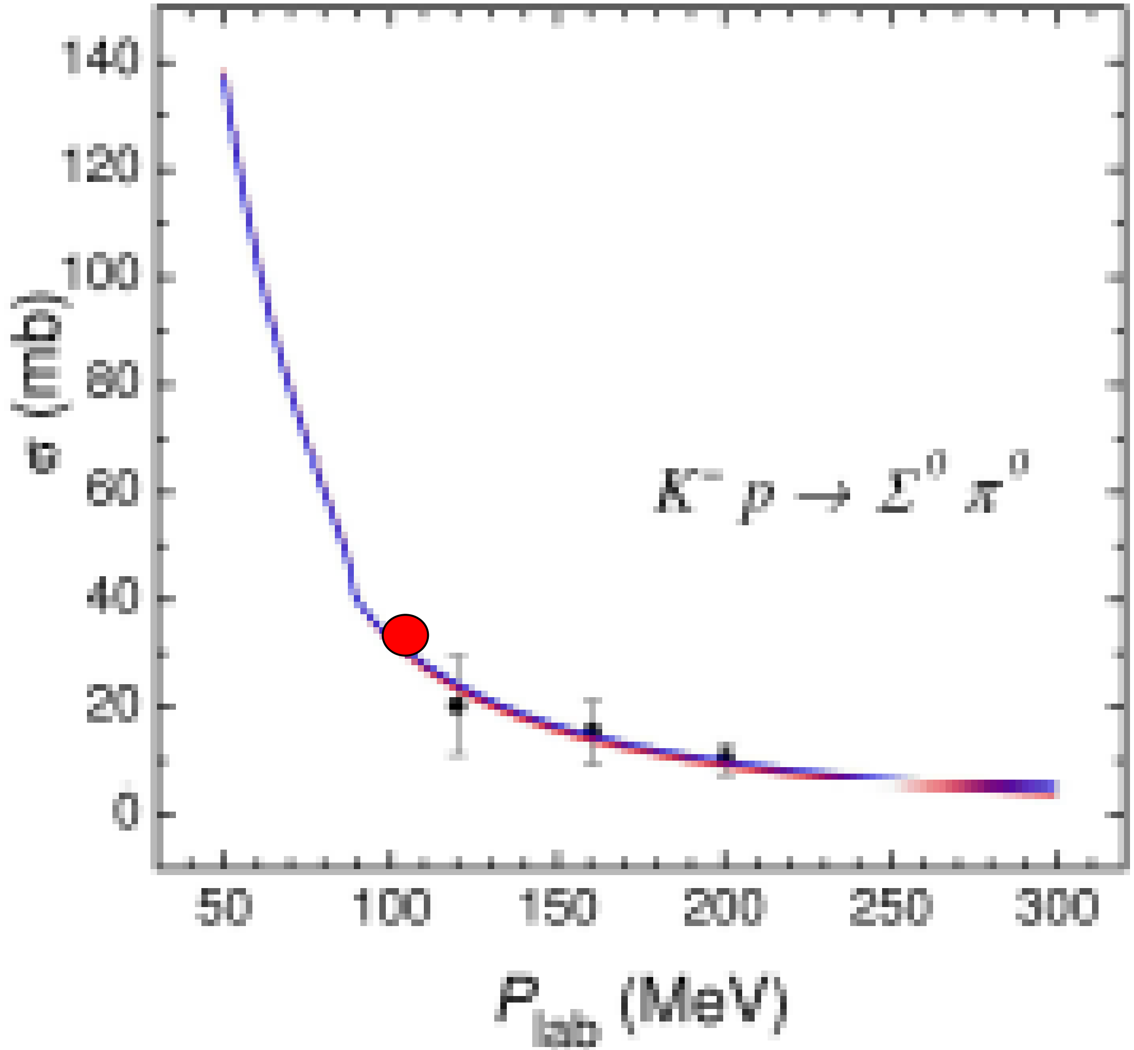
$\Sigma^0\pi^0$ momentum

Three component fit :

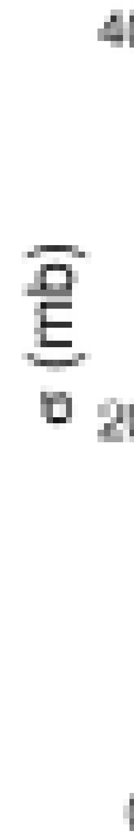
- K^- on H at rest + in flight
- K^- on ^{4}He and ^{12}C background



P_{lab} (MeV)

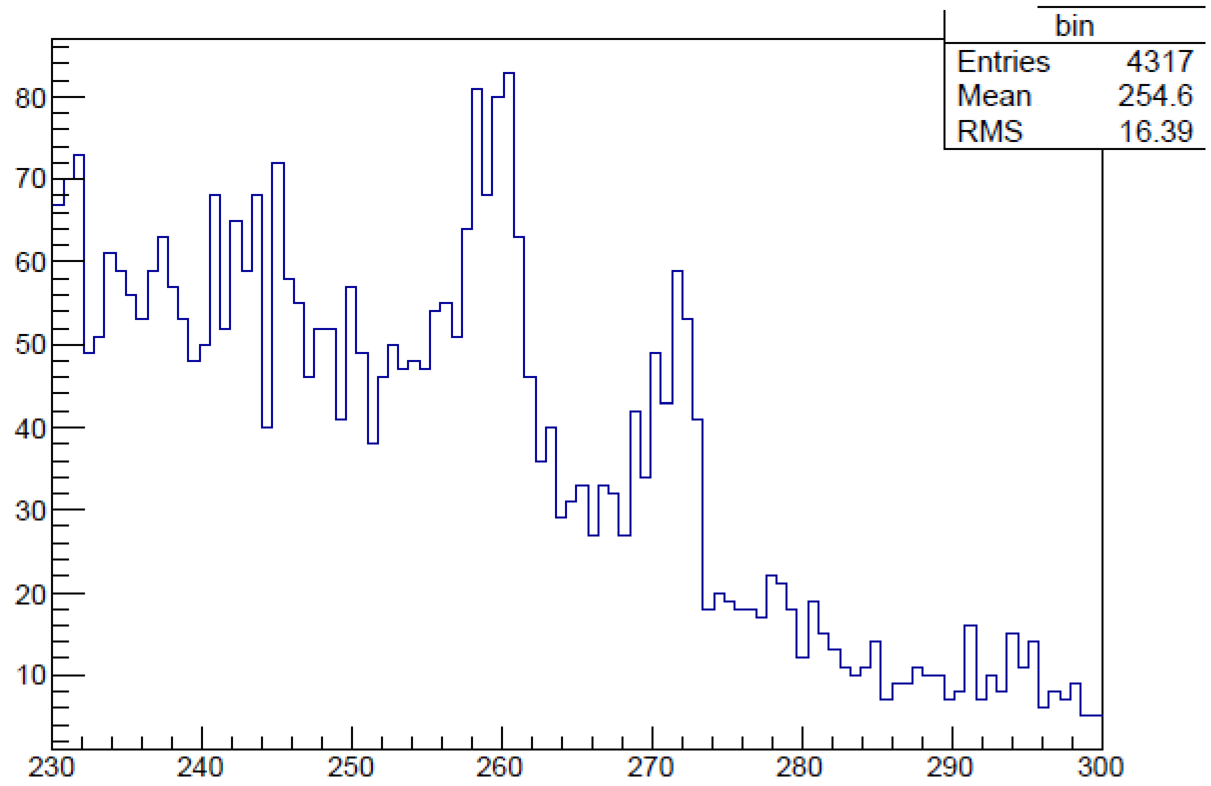


σ (mb)
140
120
100
80
60
40
20
0
50
100
150
200
250
300
$K^- p \to \Sigma^0 \pi^0$
P_{lab} (MeV)



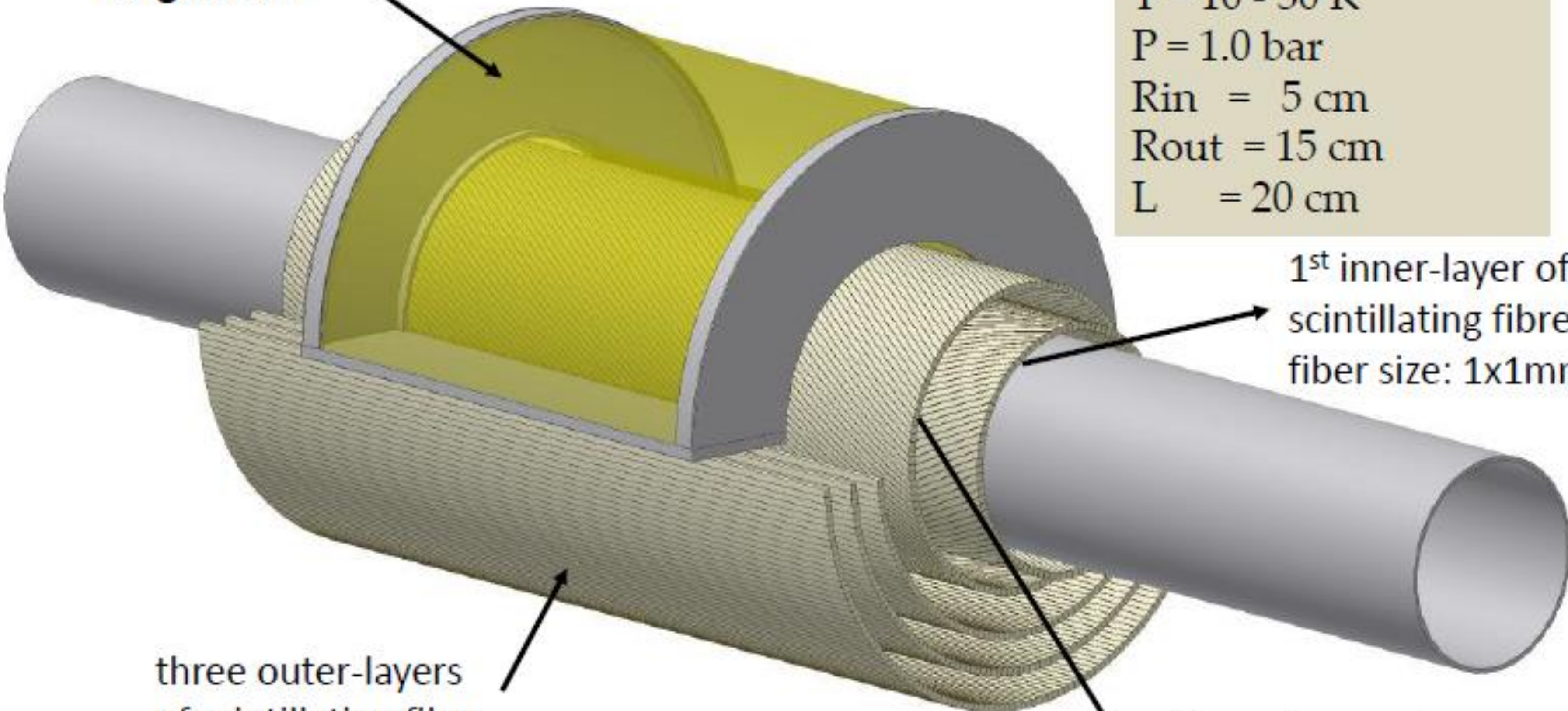
σ (mb)

Carbon hypernuclei signals (carbon) – very preliminary

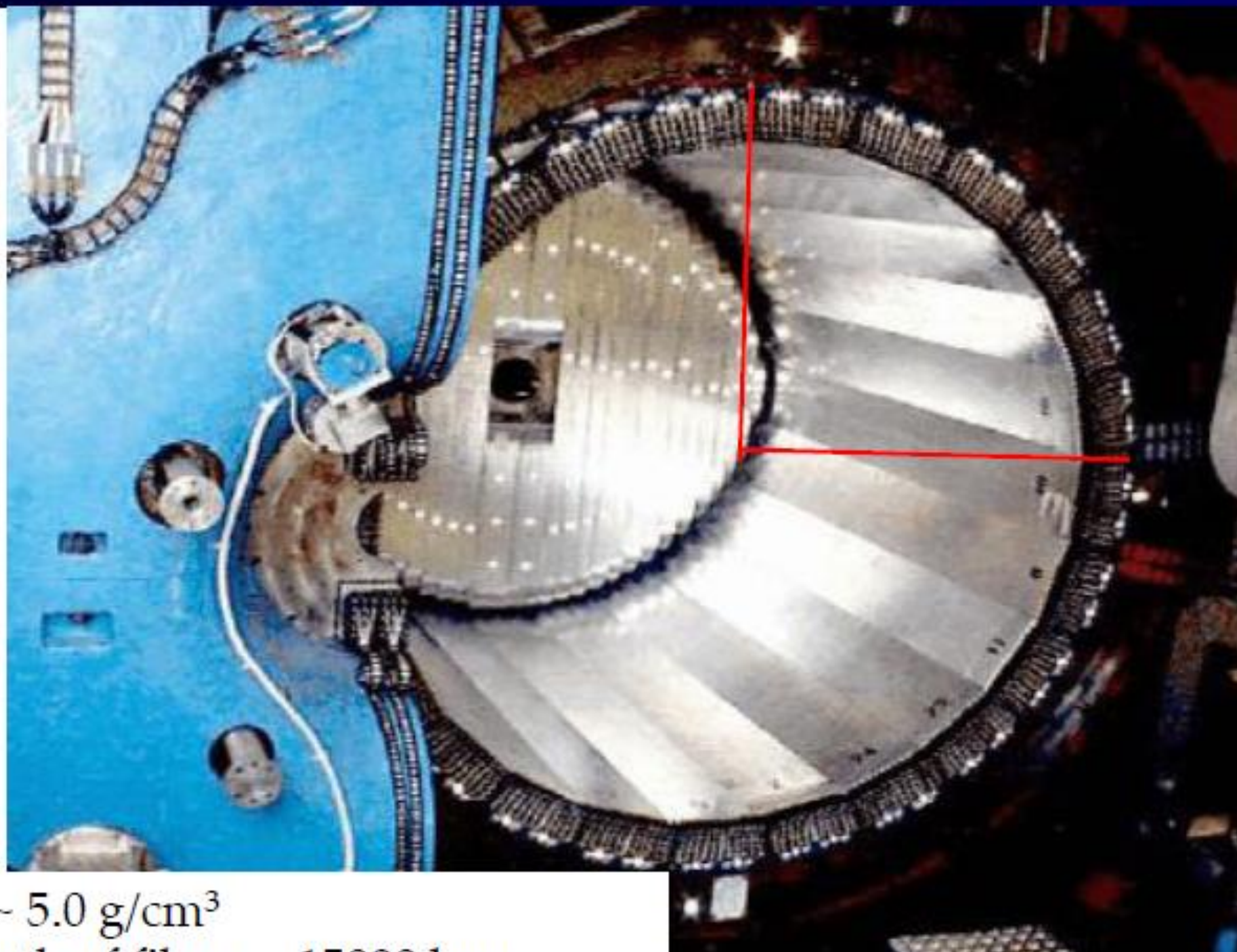


AMADEUS dedicated setup

Gaseous/liquid target cell:
T = 10 - 30 K
P = 1.0 bar
Rin = 5 cm
Rout = 15 cm
L = 20 cm

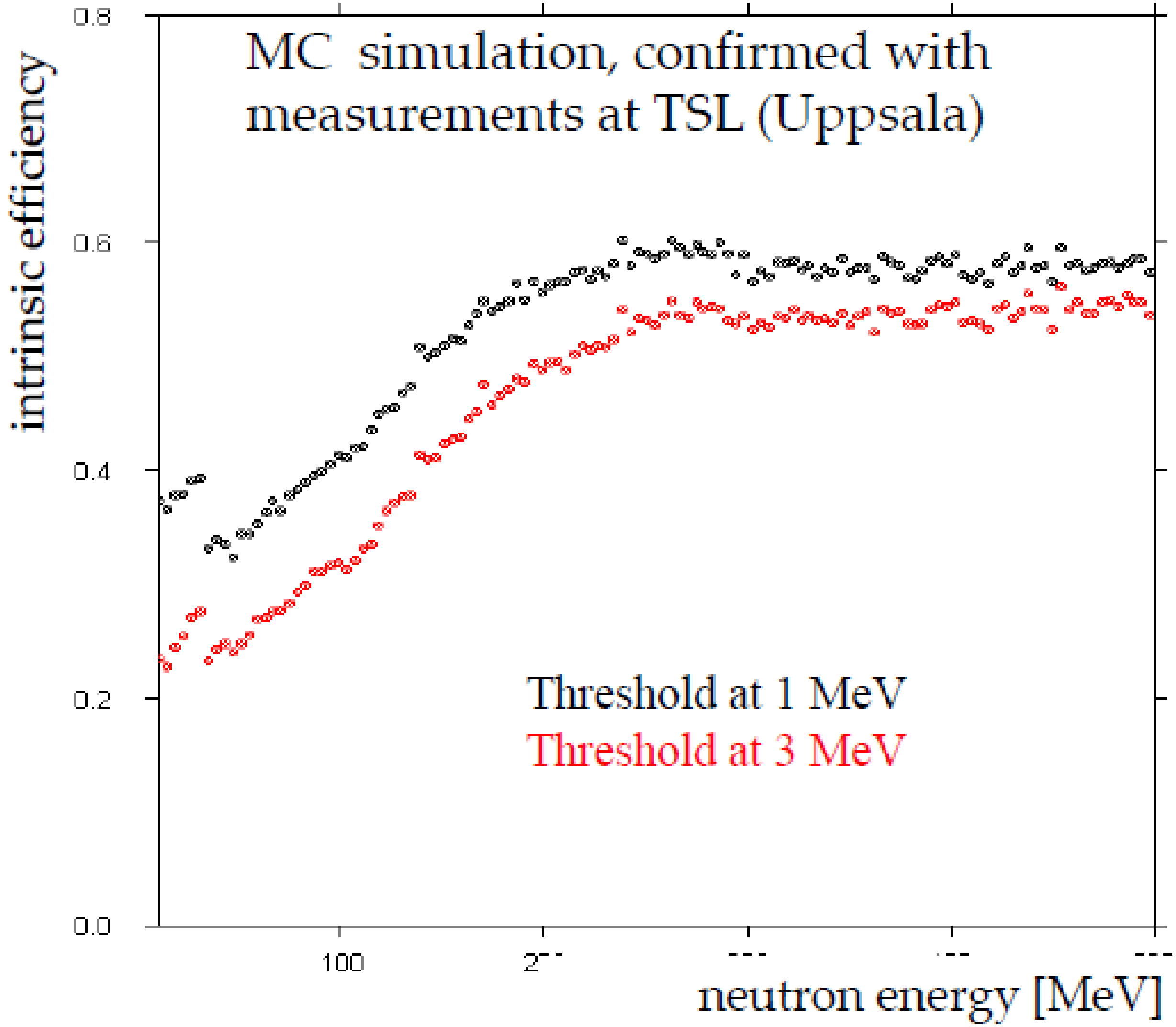


KLOE electromagnetic calorimeter



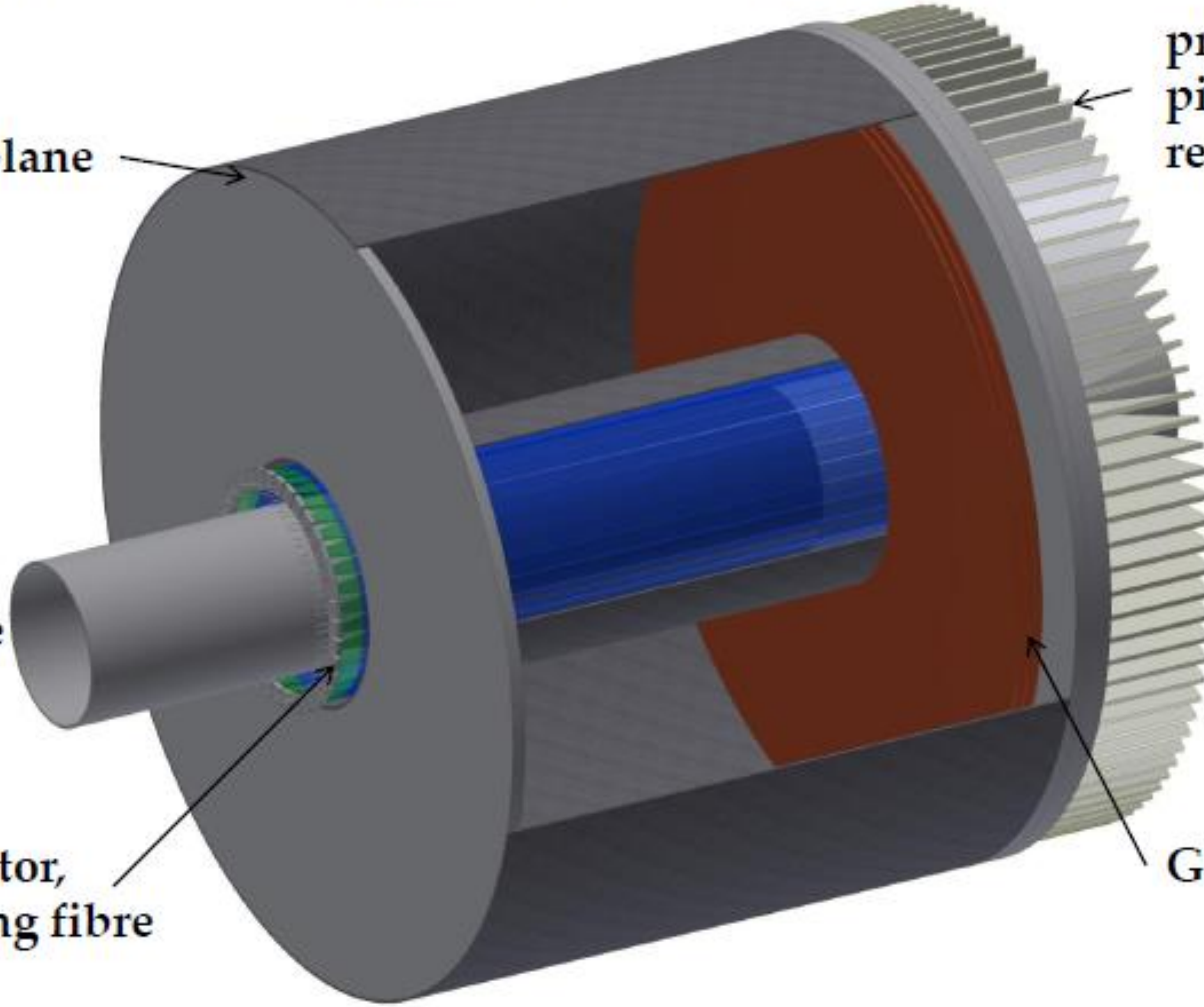
density ~ 5.0 g/cm^3
total length of fibres ~ 15000 km
read out by ~ 5000 mesh PM

Neutron detection efficiency



R&D – advanced setup

- **active target TPC with GEM technology, with 6000 pads**
  - R&D work within EU-FP7 HadronPhysics3

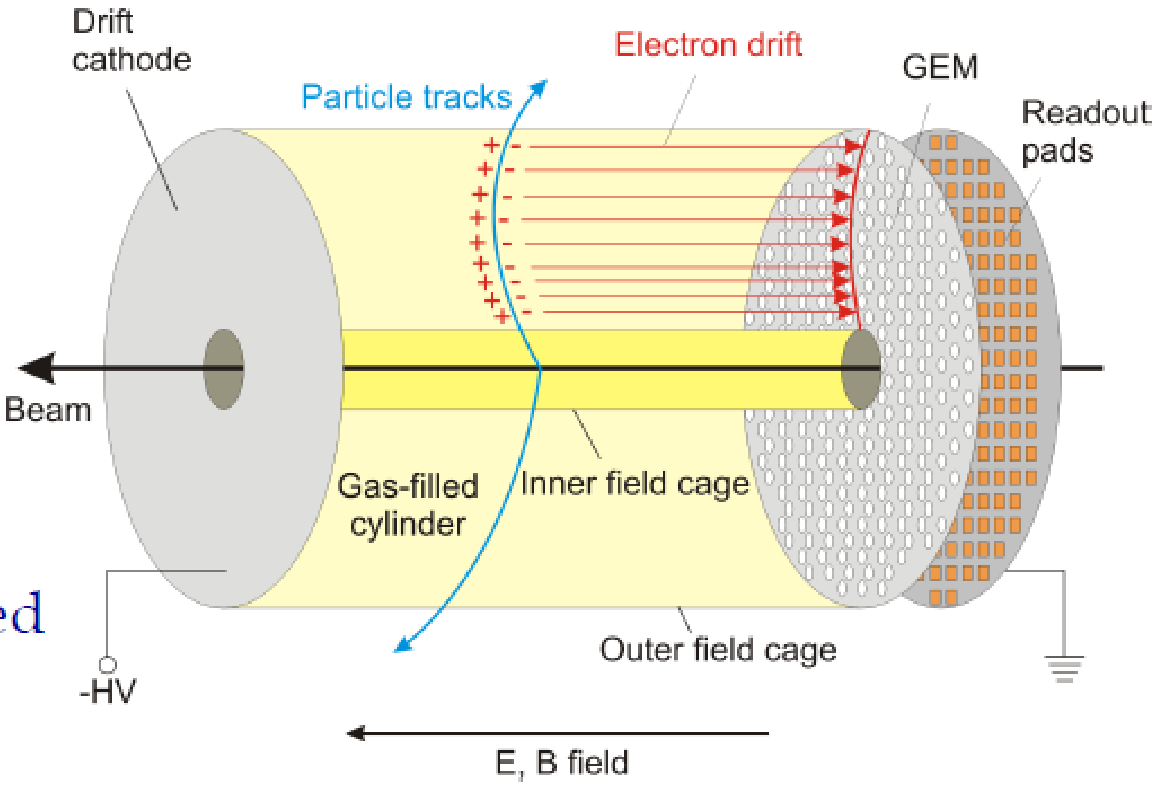


TPC with GEM Readout

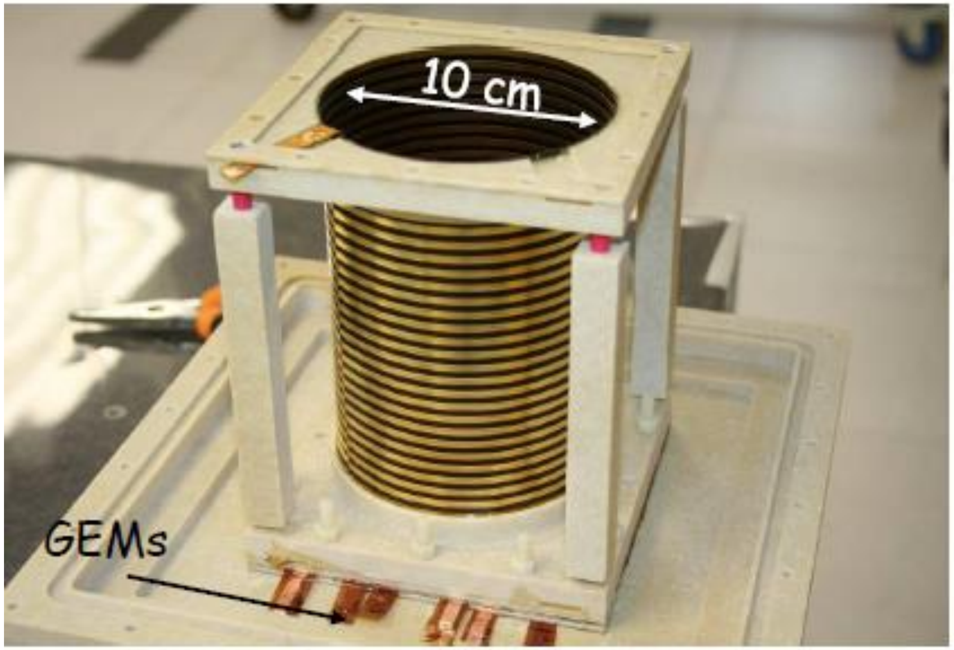
- EU-FP7 HadronPhysics2 WP24: JointGEM
  → **large TPC prototype**
- EU-FP7 HadronPhysics3 WP24: JointGEM
  → **active TPC**

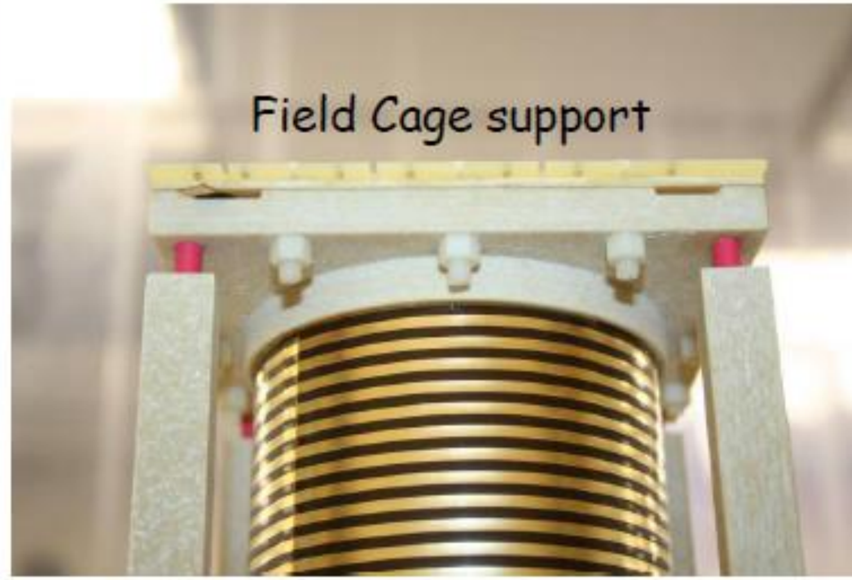
TPC with GEM readout:

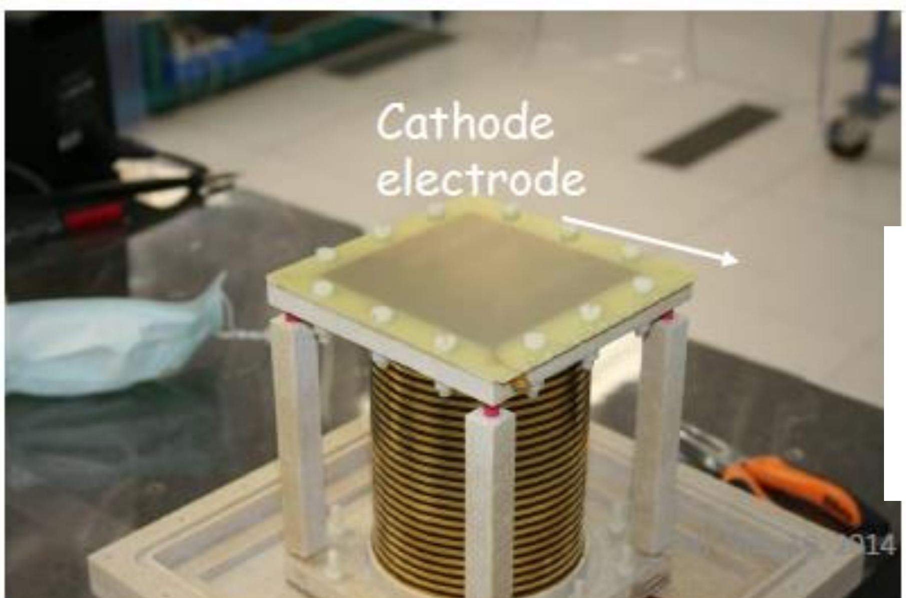
- High granularity
- Fast signal
- Multi-track resolution
- Ion feedback suppressed



“active” TPC-GEM test setup at LNF







Tests at PSI

Modern Instrumentation, 2015, 4, 32-41
Published Online July 2015 in SciRes. http://www.scirp.org/journal/mi
http://dx.doi.org/10.4236/mi.2015.43004

Performances of an Active Target GEM-Based TPC for the AMADEUS Experiment

M.Poli Lener

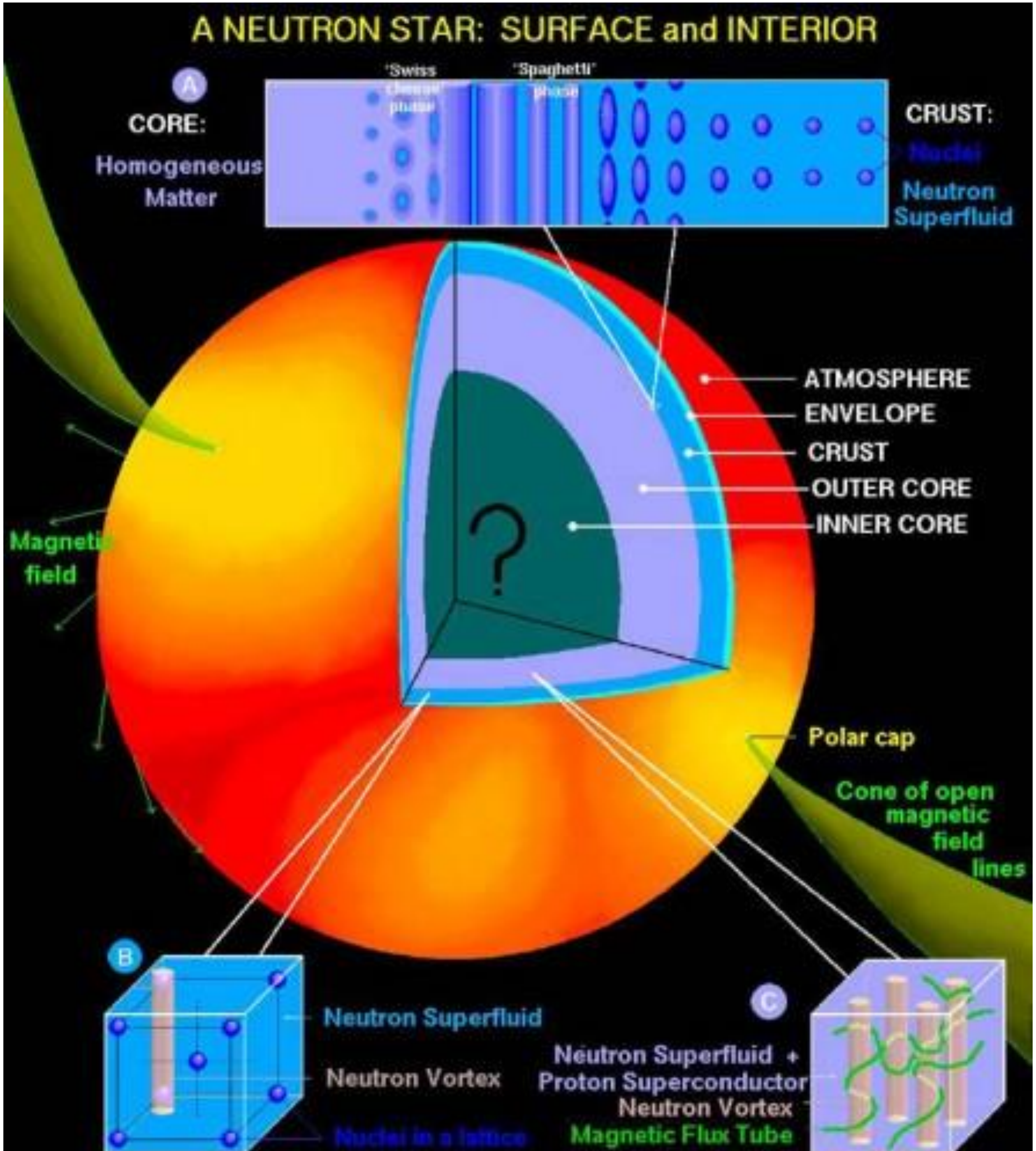
Conclusions

- **AMADEUS has an enormous potential to perform complete measurements of low-energy kaon-nuclei interactions in various targets**

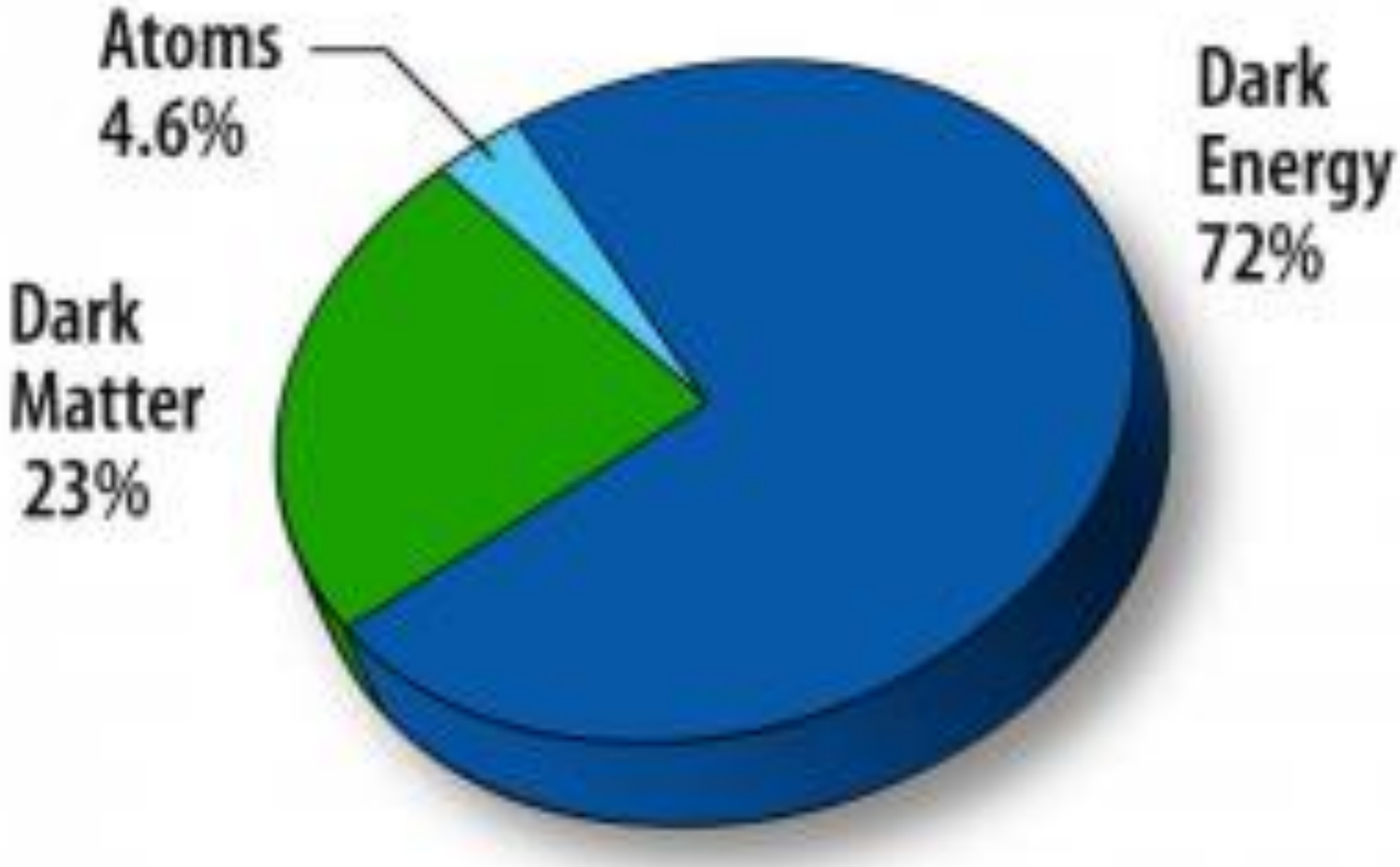
-> does strangeness play a role in the Universe?

- **Data analyses ongoing -> papers coming soon**

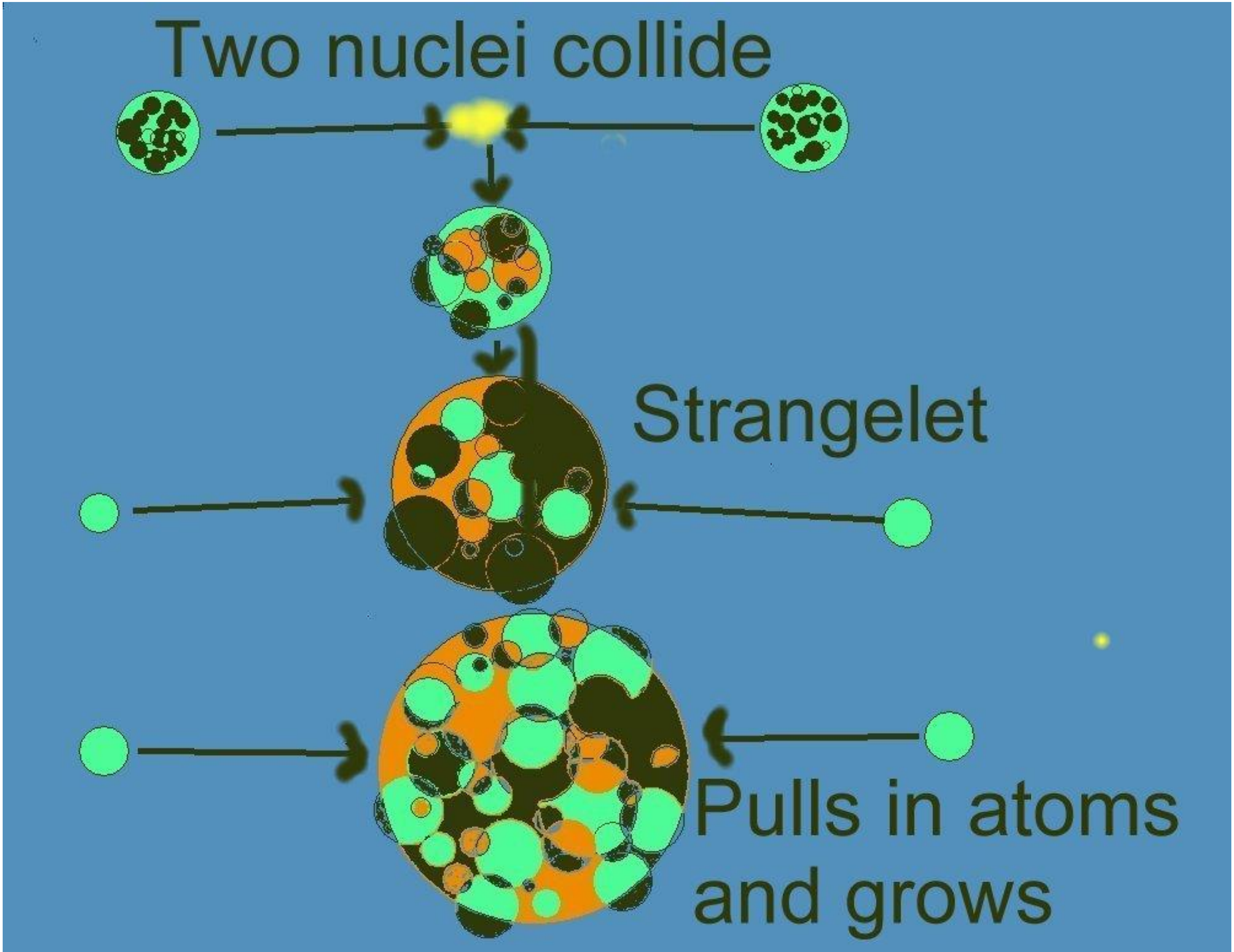
- **For future: AMADEUS dedicated setup with new active targets (gas and solid)**
- **-> WE INVITE YOU TO JOIN THE AMADEUS COLLABORATION**



A NEUTRON STAR: SURFACE and INTERIOR
A
CORE:
Homogeneous
Matter
'Swiss
"Spaghetti"
CRUST:
Neutron
Superfluid
ATMOSPHERE
ENVELOPE
CRUST
OUTER CORE
INNER CORE
?
Magneti
field
Polar cap
Cone of open
magnetic
field
lines
B
Neutron Superfluid
Neutron Vortex
C
Neutron Superfluid +
Proton Superconductor
Neutron Vortex
Magnetic Flux Tube



TODAY


Two nuclei collide
Strangelet
Pulls in atoms
and grows


AMADEUS @ DAFNE represents an unique
opportunity to unveil the
secrets of the kaon-nucleon/nuclei
interaction at low energy

Frontiers in hadron and nuclear physics with strangeness and charm

19 Oct 2015 to 23 Oct 2015

Organizers

Kai-Thomas Brinkmann (Univ. Giessen - Germany)
Catalina Curceanu (LNF – INFN Frascati)
Johann Marton (SMI-Vienna)
Ulf-G. Meissner (Universitat Bonn & FZ Juelich)
Bing-Song Zou (ITP/CAS - Beijing)

There is a theory which states that if ever anybody discovers exactly what the Universe is for and why it is here, it will instantly disappear and be replaced by something even more bizarre and inexplicable. There is another theory which states that this has already happened.

The scientific goal of AMADEUS

K^-

Low energy QCD in strangeness sector is still waiting for experimental conclusive constrains on:

1) $\overline{K}$-N potential → how deep can an antikaon be bound in a nucleus?

- U_{KN} strongly affects the position of the Λ(1405) state → we investigate it through $(\Sigma-\pi)^0$ decay --- Y π CORRELATION

- if U_{KN} is strongly attractive then possible K^- multi-N bound states → we investigate through (Λ/Σ–N) decay --- Y N CORRELATION

2) Y-N potential → extremely poor experimental information from scattering data

- U_{YN} determines the strength of the final state YN (elastic & inelastic) scattering in nuclear environment → could be tested by Y N CORRELATION

3) K-N → Λ/Σ π cross section below 100 MeV/c

Ongoing fit of $\Sigma^0\pi^0$

K^-

8 component fit :

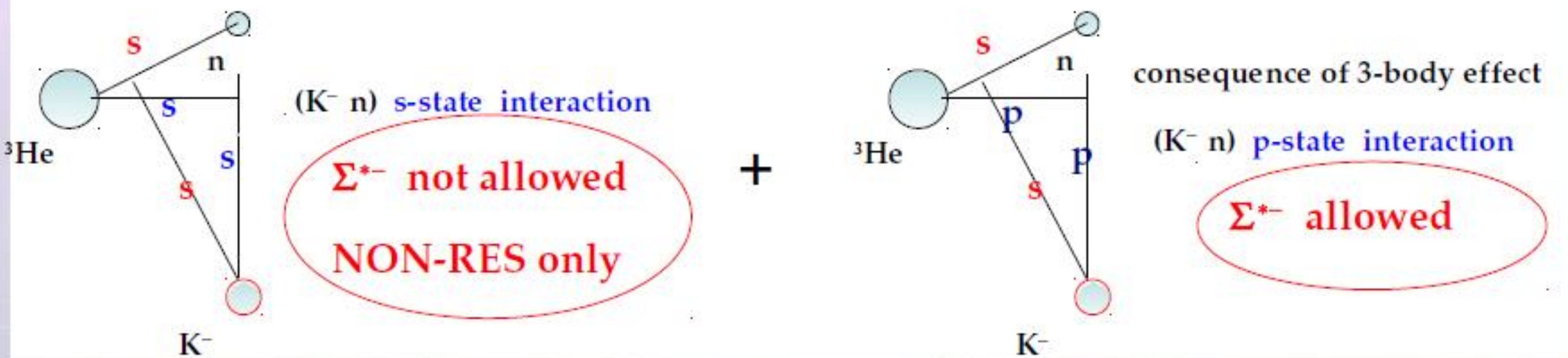
- Resonant component K^- C at-rest/in-flight. $(M,\Gamma) = (1405 \div 1430 , 5 \div 52)$
- Non resonant $\Sigma^0\pi^0$ K^- H production at-rest/in-flight
- Non resonant $\Sigma^0\pi^0$ K^- C production at-rest/in-flight
- $\Lambda\pi^0$ background (Σ(1385) + I.C.)
- non resonant misidentification (*n.r.m.*) background

Channel: $K^- \ ^4He \rightarrow \Lambda \pi^- \ ^3He$ ... the idea

K⁻

$K^-(s=0)$ $^4He(s=0)$ $n(s=1/2)$ $\Sigma^{*-}(s=3/2) \rightarrow$ resonance p-wave only

atomic s-state capture:



$(K^- \ ^4He \rightarrow \Lambda \pi^- \ ^3He)$ absorptions from (n s) - atomic states dominate $\rightarrow$

consistent with ^4He bubble chamber data (Fetkovich, Riley interpreted by Uretsky, Wienke)

- Coordinates recupling enables for P-wave resonance formation

Channel: $K^- \, {}^4He \rightarrow \Lambda \, \pi^- \, {}^3He$ ... the strategy

K^-

- To determine *for the first time* the ratio resonant/non-res

  33 MeV below threshold

$|f^{N\text{-}R}_{\Lambda\pi}|$ given the fairly well known $|f^{\Sigma*}_{\Lambda\pi}|$

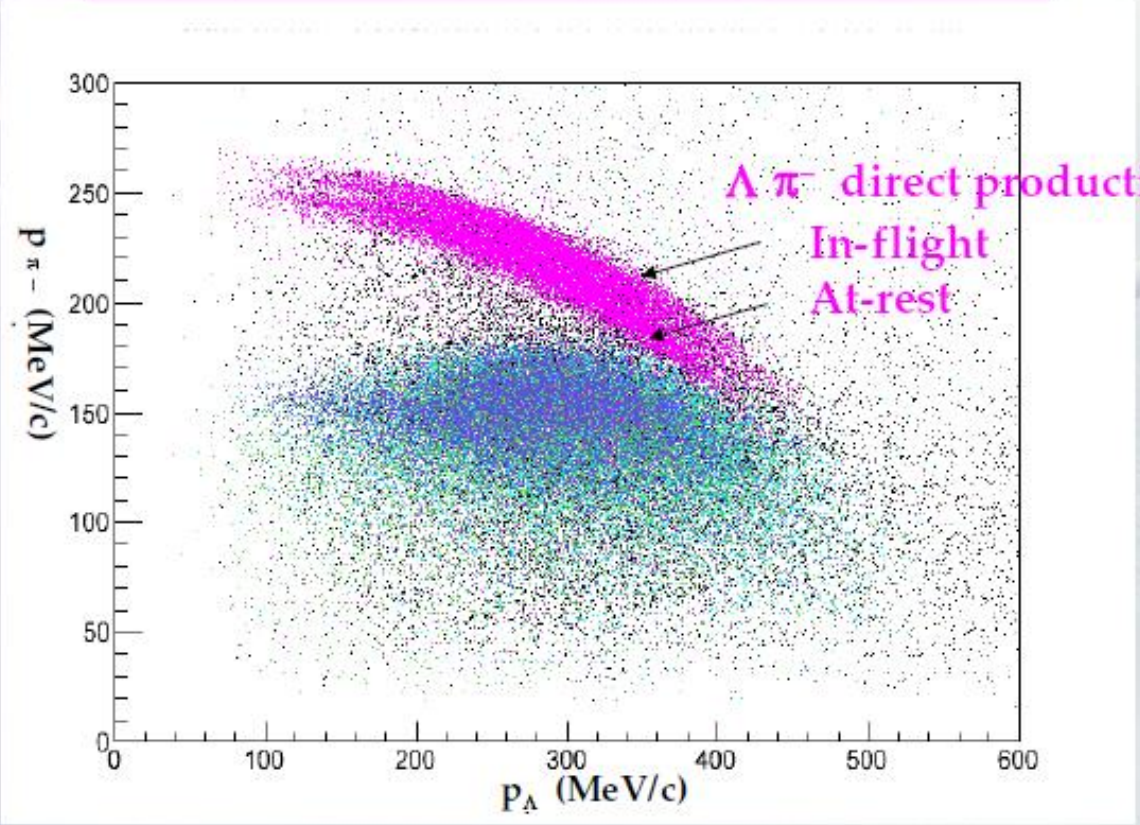
Theoretical paper under finalization

Channel: $K^- \, {}^4He \rightarrow \Lambda \pi^- \, {}^3He$ … <u>calculated reactions</u>

$K^- \, {}^4He \rightarrow \Lambda \pi^- \, {}^3He$

- At-rest : S-wave non-Res / P-wave Σ(1385) Res
- In-flight : S-wave non-Res / P-wave Σ(1385) Res

Direct $\Lambda \pi^-$ production .. SIGNAL

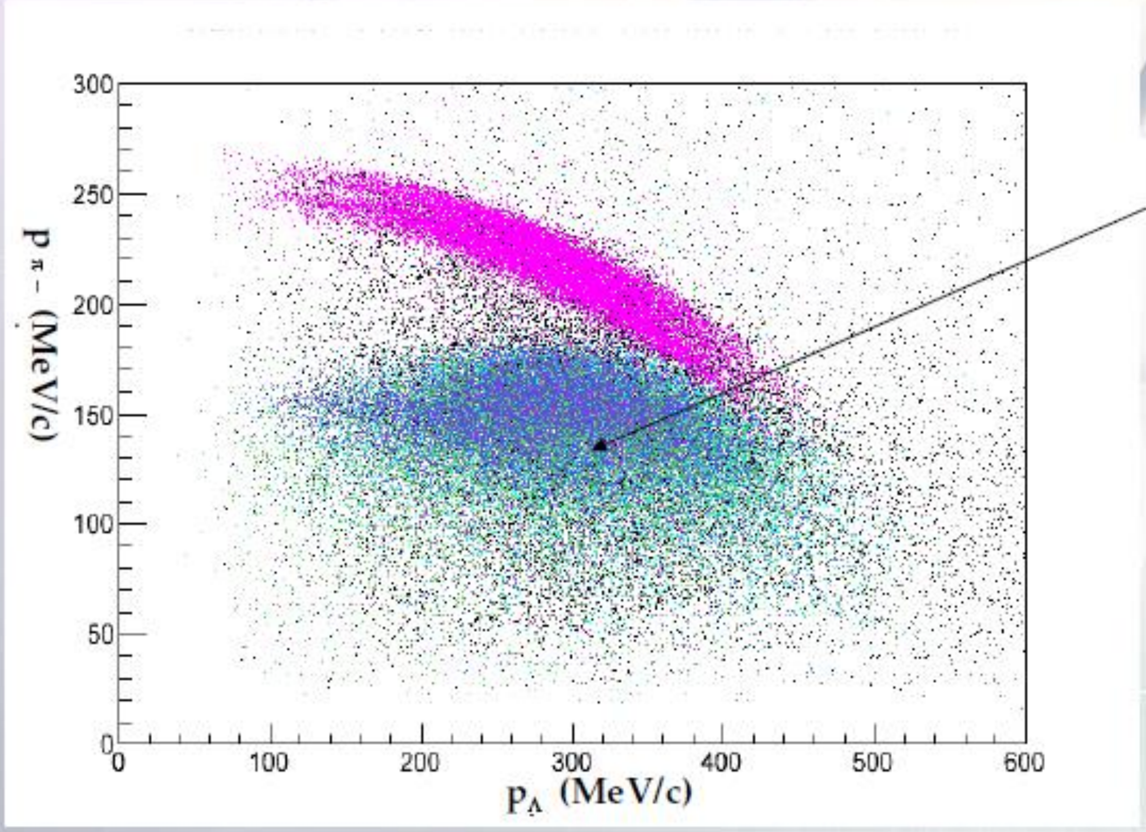


Channel: $K^- \, {}^4He \rightarrow \Lambda \, \pi^- \, {}^3He$ … calculated reactions

NOT Direct $\Lambda \pi^-$ production .. BACKGROUND

Λ comes from the Σ hyperon conversion on residual nucleons

$K^- N \rightarrow \Sigma^0\pi^- / \Sigma^+\pi^-$; $\Sigma N \rightarrow \Lambda N'$



NOT direct

$\Lambda \pi^-$ production

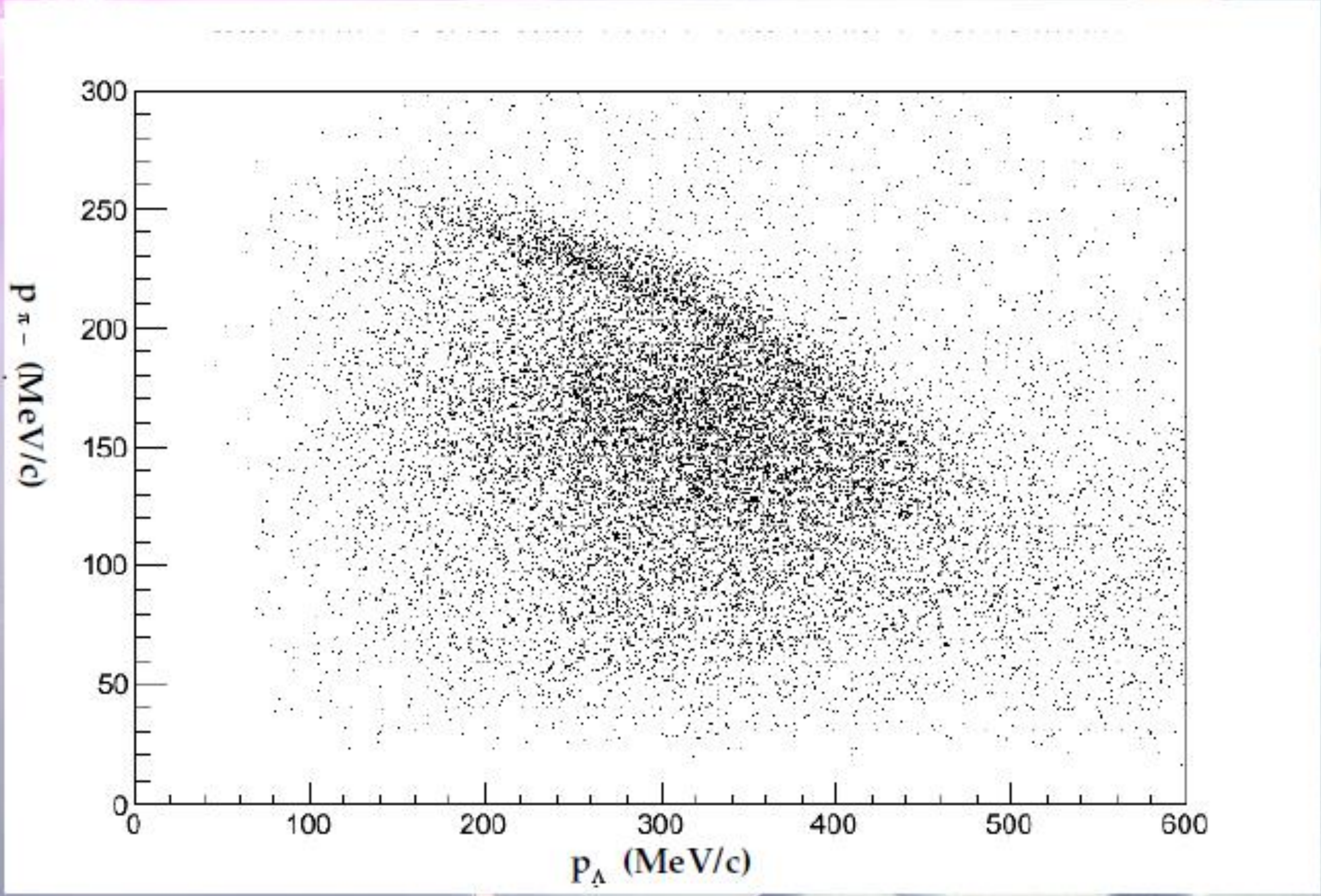
Σ^0 p conversion

Σ^0 n conversion

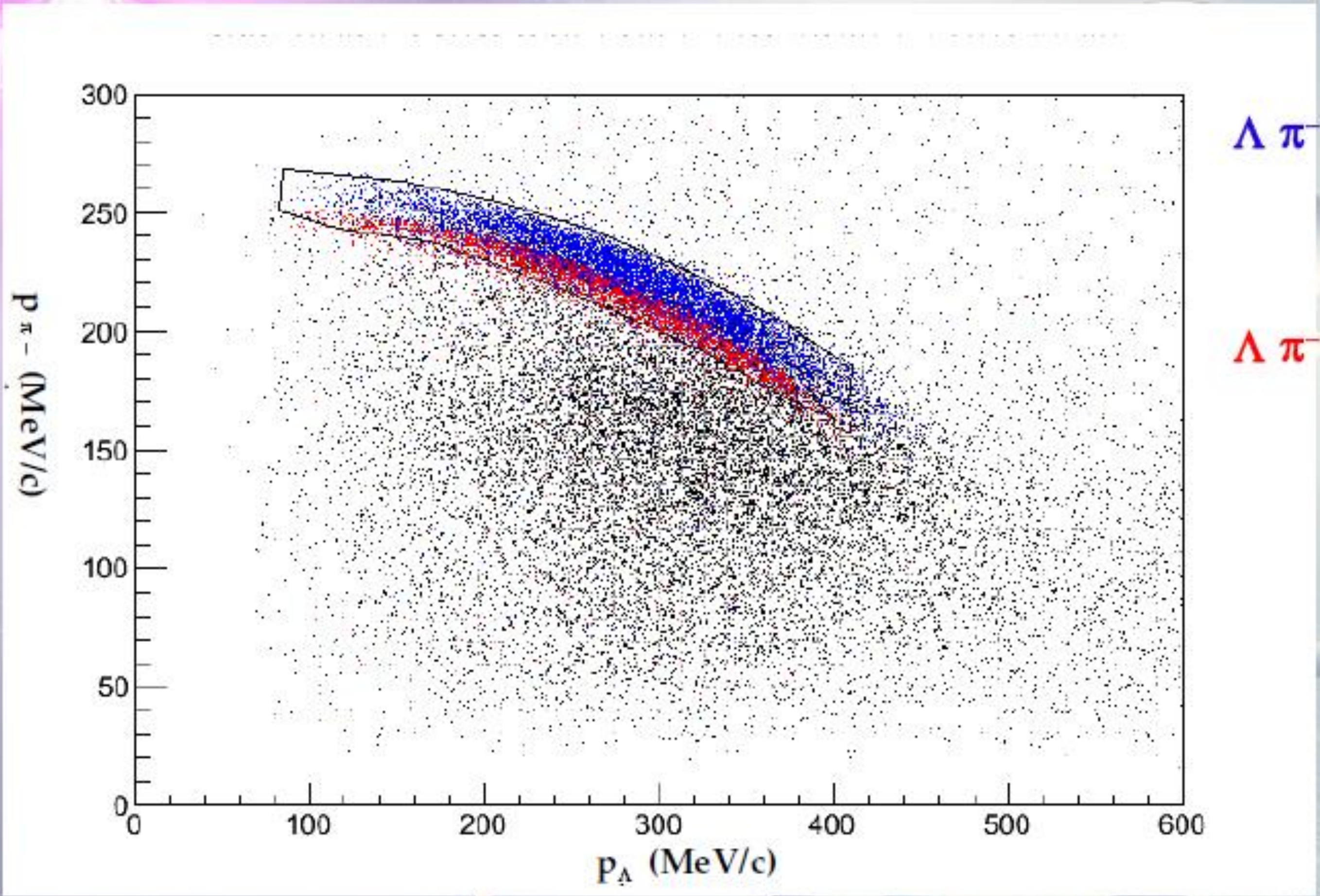
Σ^+ n conversion

$K^- \ {}^4He \rightarrow \Lambda \pi^- \ {}^3He$ events selection

K⁻



K^- $^4He \rightarrow$ $\Lambda\,\pi^-$ ^3He <u>events selection</u>



$\Lambda\,\pi^-$ direct production
In-flight RES +
N-R

$\Lambda\,\pi^-$ direct production
At-rest RES +
N-R

Background sources: - $\Lambda\,\pi^-$ events from Σ p/n $\rightarrow$ Λ p/n conversion

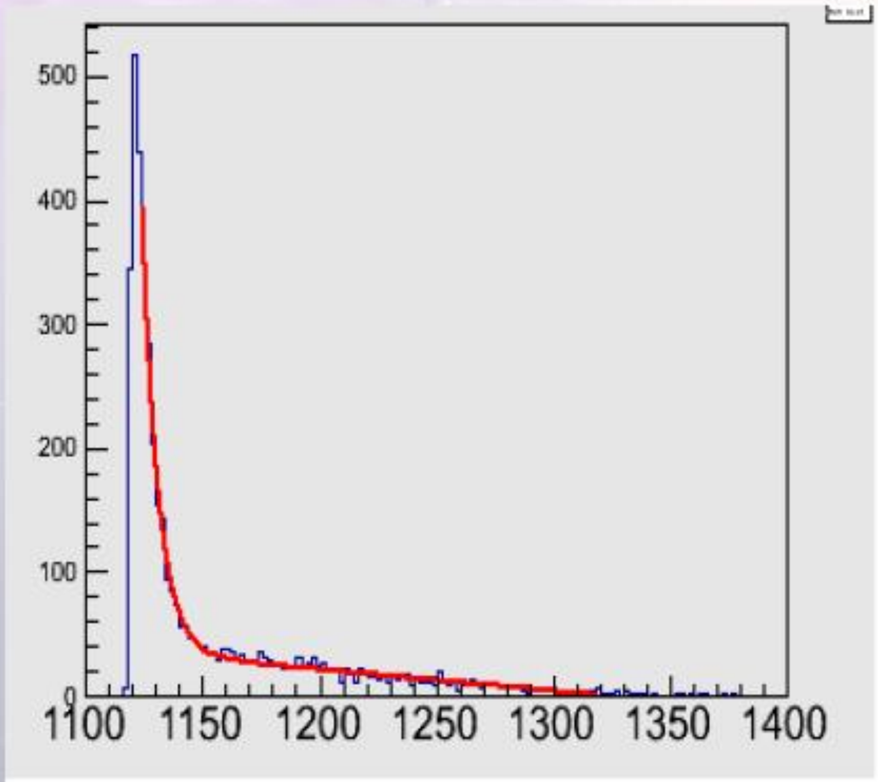
- $\Lambda\,\pi^-$ events from K^- ^{12}C absorptions in Isobutane

$\Sigma^0 p$ correlation study

K⁻

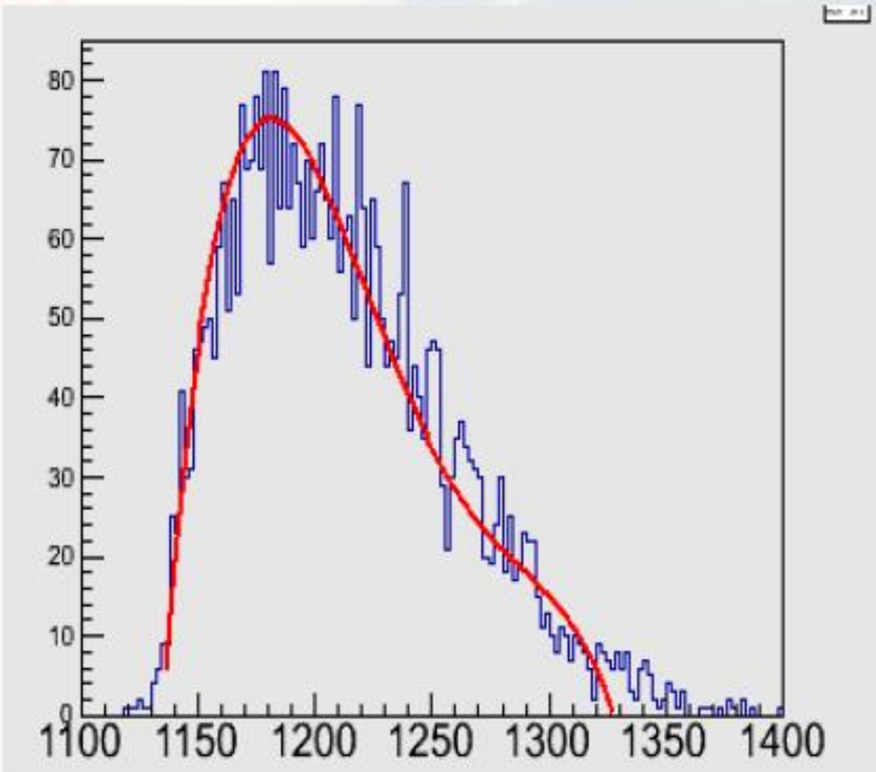
Two background sources:

Asynchronous background
(entering in the time selection window)



$M_{\Lambda\gamma}$(MeV/c²)

Events with π^0 (double counting for those!)

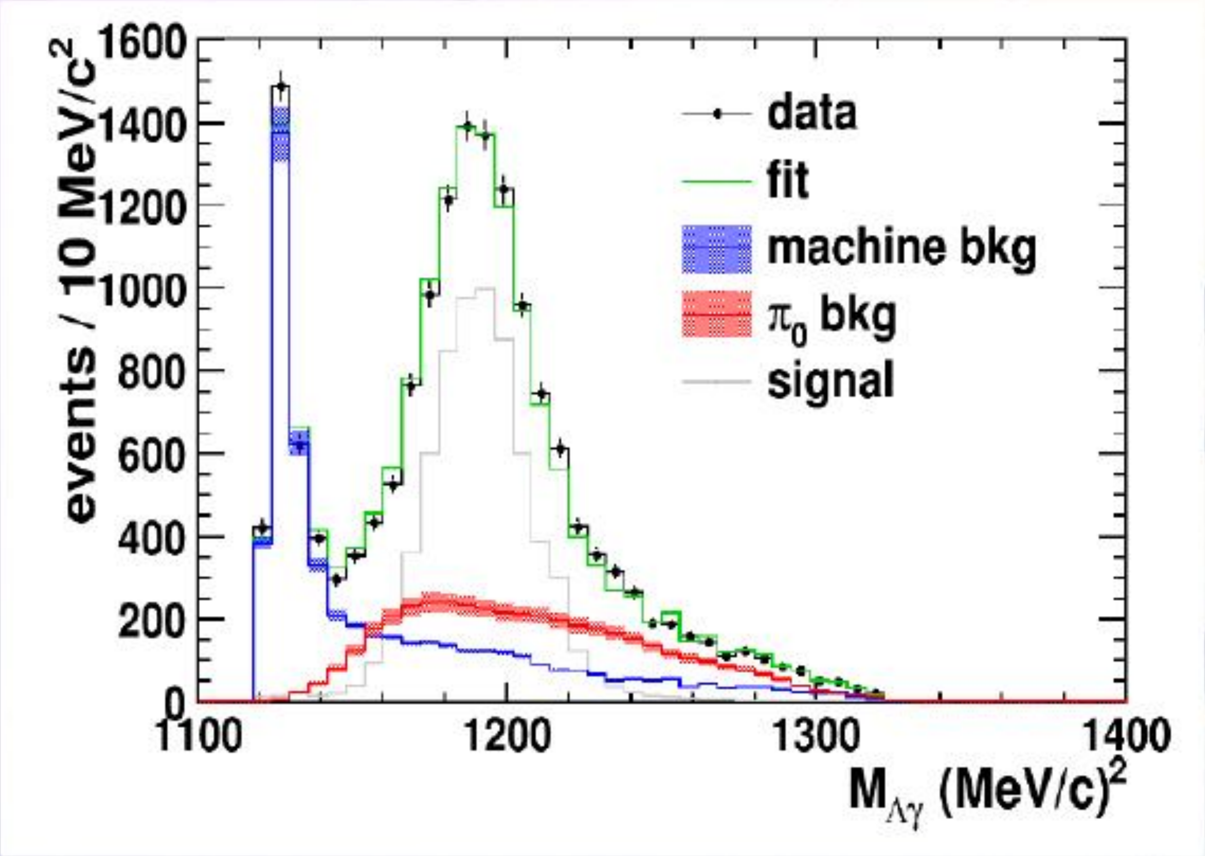


$M_{\Lambda\gamma}$(MeV/c²)

$\Sigma^0 p$ correlation study

Two background sources:

- Asynchronous background (entering in the time selection window)
- Events with π^0 (double counting for those!)



--- Data
--- Gaussian signal
--- Machine bkg
--- Pi0 bkg

Σ^0mass resolution
σ~15 MeV/c²
(compatible with MC simulations)

Λt correlation studies in ^4He: possible processes of K^- interaction

single nucleon absorption (1NA) – **K^-** absorbed by a **p**

$$K^- \, ^4He \rightarrow \Lambda \, \pi^0 \, t_{res}$$

$$K^- \, ^4He \rightarrow \Sigma^0 \pi^0 \, t_{res} \quad , \quad \Sigma^0 \rightarrow \Lambda \gamma$$

conversion on triton:

$$K^- \, ^4He \rightarrow \Sigma^0 \pi^0 \, t \quad , \quad \Sigma^0 t \, / \, \Lambda t$$

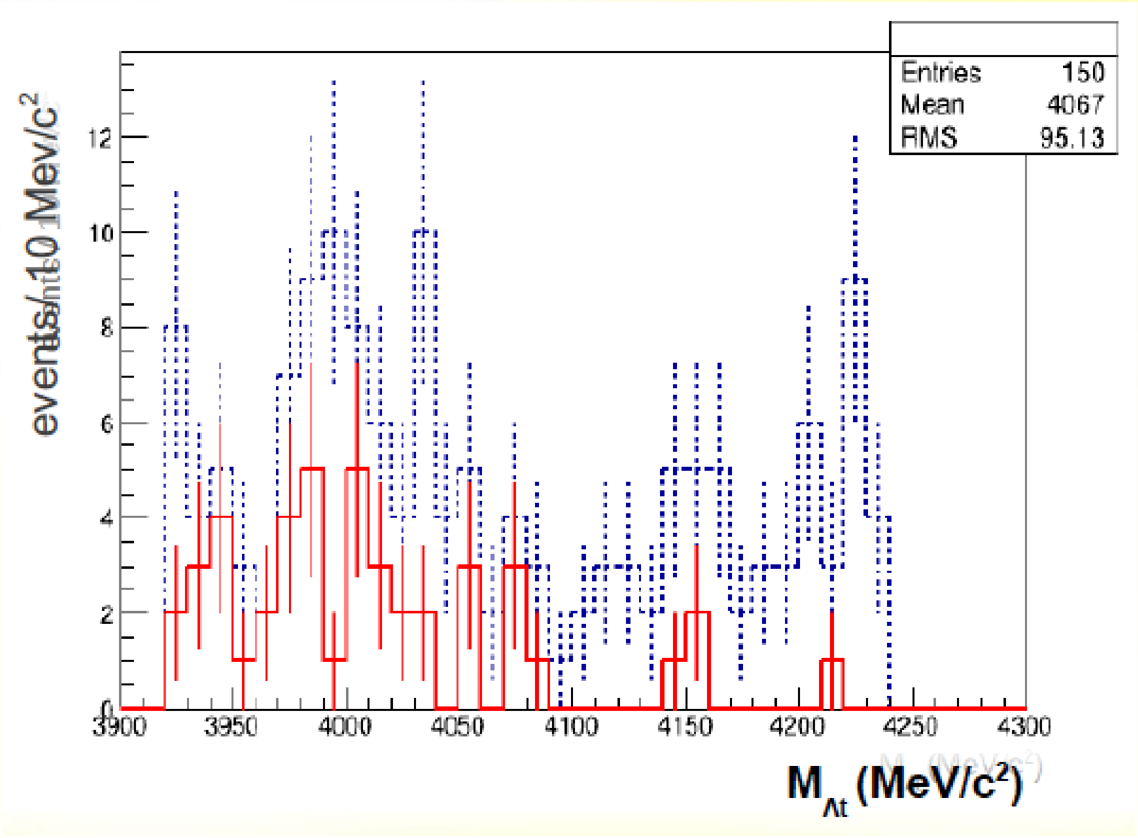
Residual tritons have **too low momentum** to be observed in KLOE
(tritons are required to have a cluster in EMC (i.e. P>500 MeV))

exclusive 4NA processes – K^- absorbed by an **α particle:**

$$K^- \, ^4He \rightarrow \Lambda t$$

$$K^- \, ^4He \rightarrow \Sigma^0 t \quad , \quad \Sigma^0 \rightarrow \Lambda \gamma$$

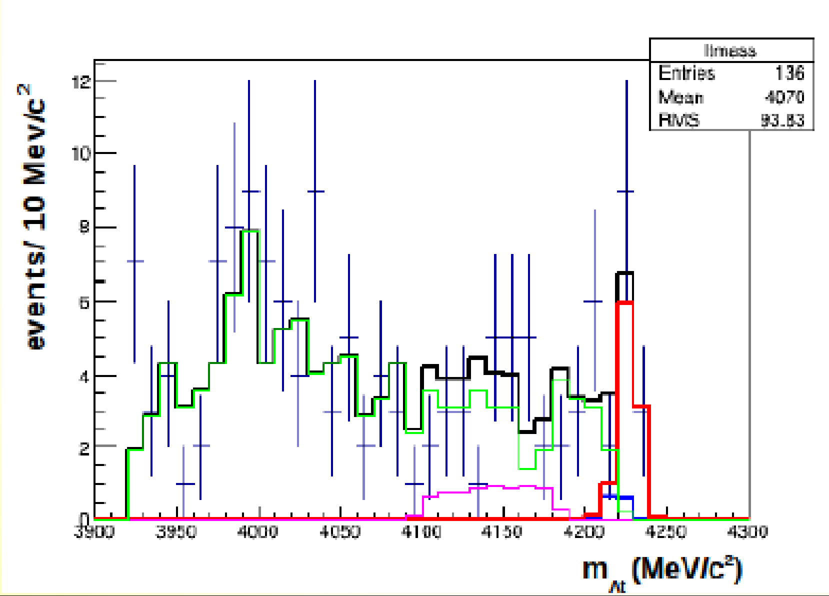
Λt correlation studies in ^{4}He

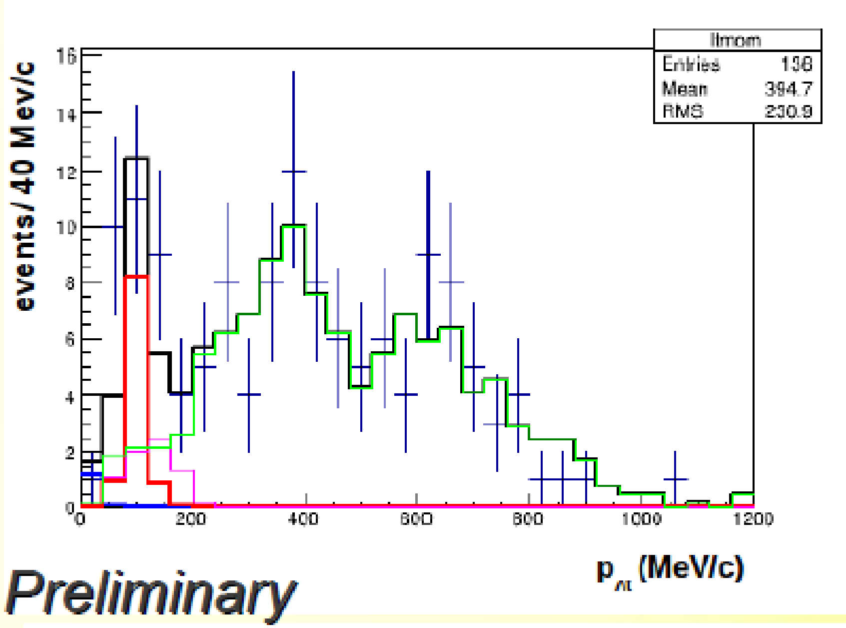


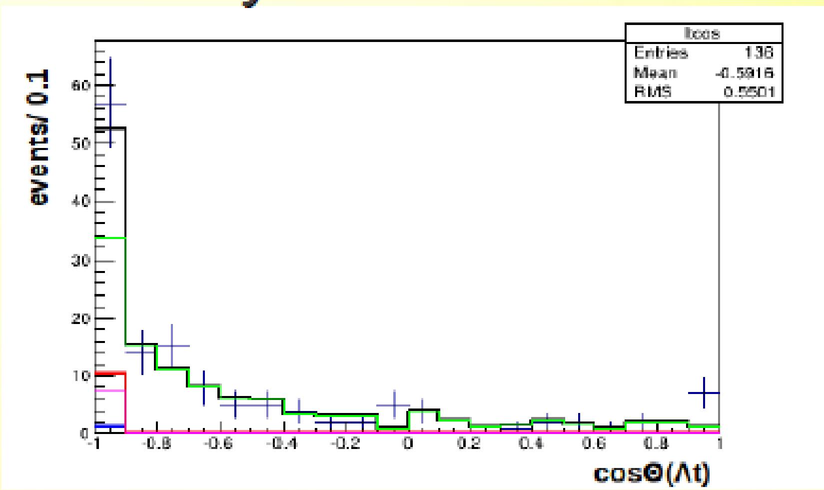
Red line – events containing an **extra proton** (not possible in pure ^{4}He)

→ **carbon contamination** in the gas mixture

Λt correlation studies in ^{4}He: mass, momentum and angle simulataneous fit







┼ data

--- carbon data from DC wall

--- 4NA K^- ^{4}He → Λt in flight MC

--- 4NA K^- ^{4}He → Λt at rest MC

--- 4NA K^- ^{4}He → Σ^0t , Σ^0 → Λγ MC

--- 4NA K^- ^{4}He → Σ^0t , Σ^0 → Λγ MC

Hadronic systems with STRANGENESS

Wolfram Weise (TU München)

Physics Issues and Keywords:

- **Mass hierarchy** of quarks in QCD
- **Strange** quark intermediate between "**light**" and "**heavy**"
- **Hadronic systems** with **strangeness**:

$$m_u = 1.7 - 3.3 \text{ MeV}$$
$$m_d = 4.1 - 5.8 \text{ MeV}$$
$$m_s = 101 \pm 25 \text{ MeV}$$

(at renorm. scale $\mu = 2$ GeV)

Excellent testing ground for studying interplay between
spontaneous and **explicit chiral symmetry breaking**
in low-energy QCD

Theoretical Framework with well-defined, symmetry-controlled input:

Chiral SU(3) Effective Field Theory
+ Coupled Channels
+ Few-Body Methods

Goals:

- **High-precision** constraints from K-N and K-NN **threshold measurements**
- Provide reliable basis for investigating **antikaon-nuclear quasibound states**

Framework:
Low-Energy QCD with Strange Quarks

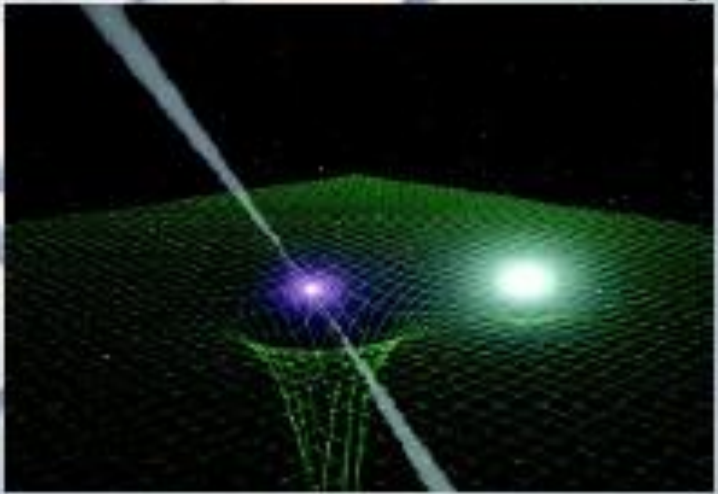
K⁻

Strangeness in baryonic matter:

- role of strangeness in EoS of neutron stars

- hyperon-nucleon and hyperon-hyperon interactions role in the investigation of dense baryonic matter

- new constraints from 2 solar masses neutron stars, very stiff Equation of State required!



But

- the basic ingredient .. namely $\bar{K}N$ interaction still unclear and mysterious from the experimental point of view.

K^-

Framework:
Low-Energy QCD
with Strange Quarks

Approached by the investigation of the antikaon-nucleon interaction

Important constraints:

- **K^-N threshold physics (shift and with of kaonic atoms levels measured by SIDDHARTA)**

? Deeply bound kaonic nuclei

- **$\Sigma\pi$ mass spectra**

- **Nature and properties of the $\Lambda(1405)$ considered as K^-N quasibound state embedded in the $\Sigma\pi$ continuum**

- Hypernuclear physics

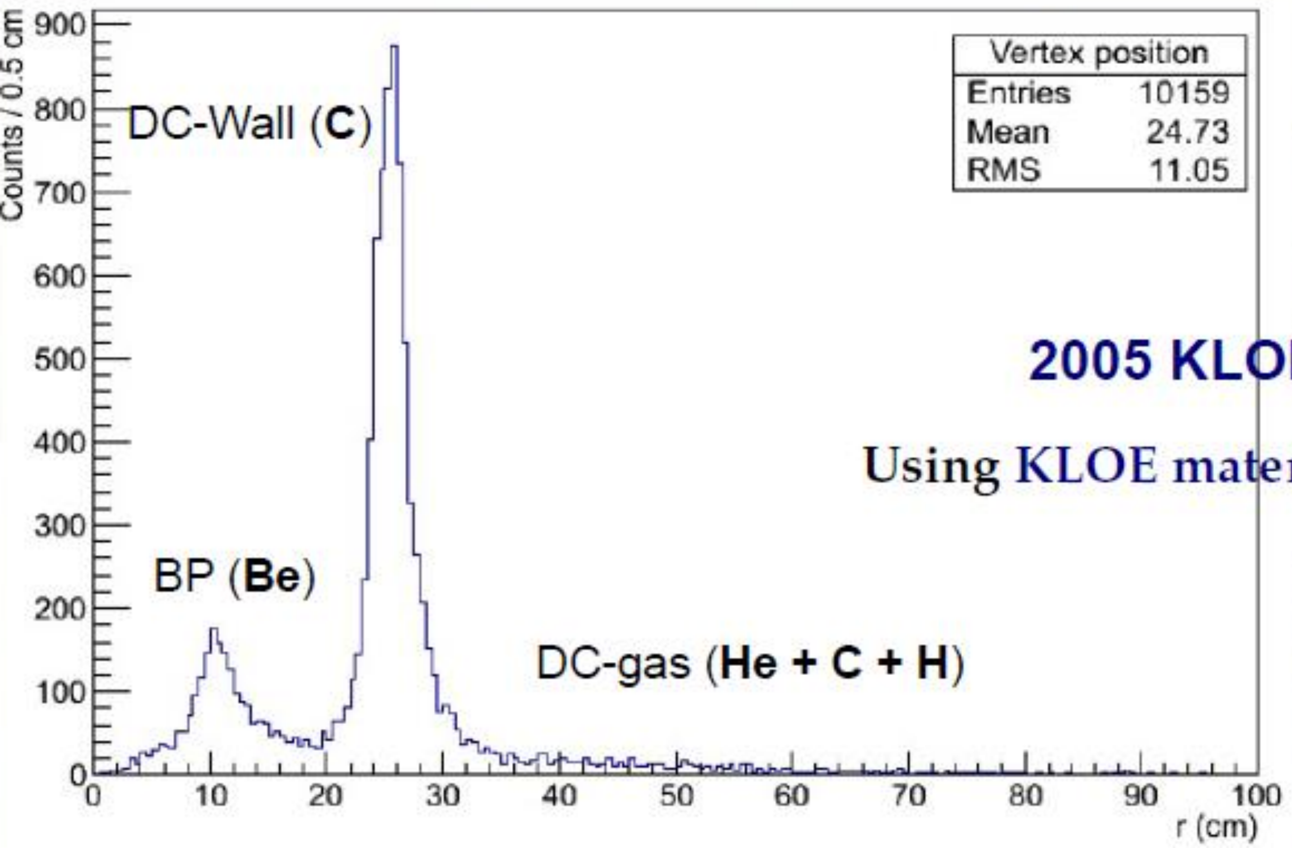
K^- absorption on light nuclei

K^-

We are lookin for K^- absorption in

(H, ^4He, ^9Be, ^{12}C)

<u>AT-REST</u> (K^- absorbed from atomic orbit) or <u>IN-FLIGHT</u> (p_K~100MeV)



2005 KLOE data A. R. + I. F.

Using KLOE materials as an active target