Strangeness in the nuclear medium: experimental studies with the KLOE Drift Chamber.

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Excellence Cluster Universe, TU-Munich

Quark Confinement and the Hadron Spectrum XI
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Strangeness in medium: KN potential

- **ChPT** is not aplicable for systems with strangeness S=-1 (KN, πΣ, …)
  - the resonance Λ(1405) lies just below the K^-p threshold
  - Non-perturbative techniques, **requiring an indeterminated number of free parameters**, must be used.

Strangeness in medium: KN potential

- **Strong modifications** of the (anti)kaon properties in **dense** hadronic enviroments.
  - A **repulsive** KN potential of few MeV for **K+** is expected
  - For **K-** is **attractive** up to 100 MeV depending on the model. Kaonic atom data and K- yield in heavy ion collisions favour an attractive K- nucleus interaction.

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→ Kaon condensate in the core of neutron stars?

- Recent measurements of the mass of two neutron stars M ~ 2 x solar mass impose strict constraints on the strange matter contribution.

- The EoS has to be rather stiff but with a strong repulsion in **YN interaction** **would allow 2 solar mass NS.**

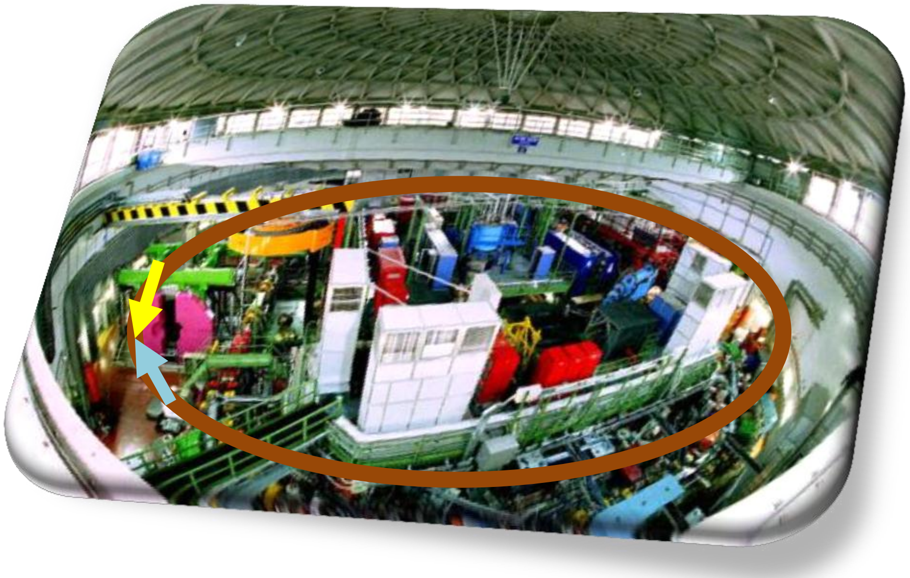
A two-solar-mass neutron star measured using Shapiro delay

P. B. Demorest[1], T. Pennucci[2], S. M. Ransom[1], M. S. E. Roberts[3] & J. W. T. Hessels[4,5] — Nature, Oct. 28, 2010

Science **340** (2013) 6131 — arXiv:1304.6875 [astro-ph.HE]

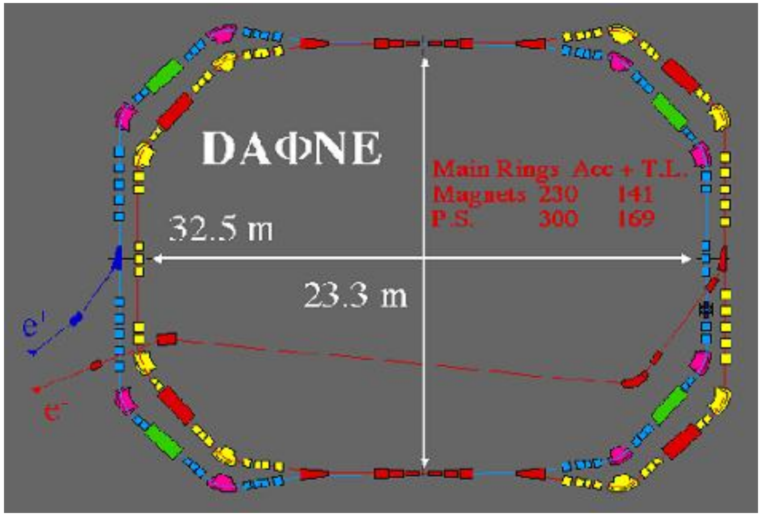
$$M = 2.01 \pm 0.04 \ M_\odot$$

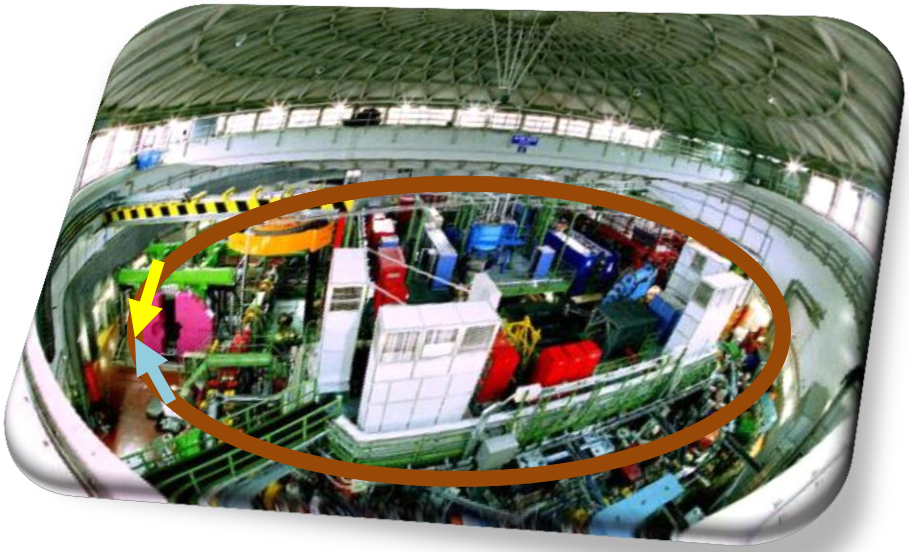
The DAΦNE collider



The DAΦNE collider

- e+ e- beams at ~ 500 MeV/c
- Φ → K+ K- (49.1%)
- **<u>Almost monochromatic low-energy K^- (~127 MeV/c)</u>**
- Low hadronic background due to beam characteristics (compared with hadron beam lines)





Top luminosity reached during SIDDHARTA run: $4x10^{32}$ pb-1 s-1

DAΦNE timeline

past

KLOE

FINUDA hypernuclei / kaonic clusters

present

SIDDHARTA kaonic hydrogen

KLOE2

future

SIDDHARTA-2 kaonic deuterium

AMADEUS kaonic clusters

SIDDHARTA: kaonic atoms

Deser-Truman Formula

$$\Delta E_1^{s} - \frac{i}{2}\Gamma_1 = -2\alpha^3\mu_c^2\, a_{K-p}$$

Kaonic hydrogen
SHIFT & WIDTH

$$a_{K-p} = \frac{1}{2}(a_0 + a_1)$$

S-wave scattering length "a_{K-p}" expressed with isospin dependent scattering lengths a_0 (I=0), a_1 (I=1)

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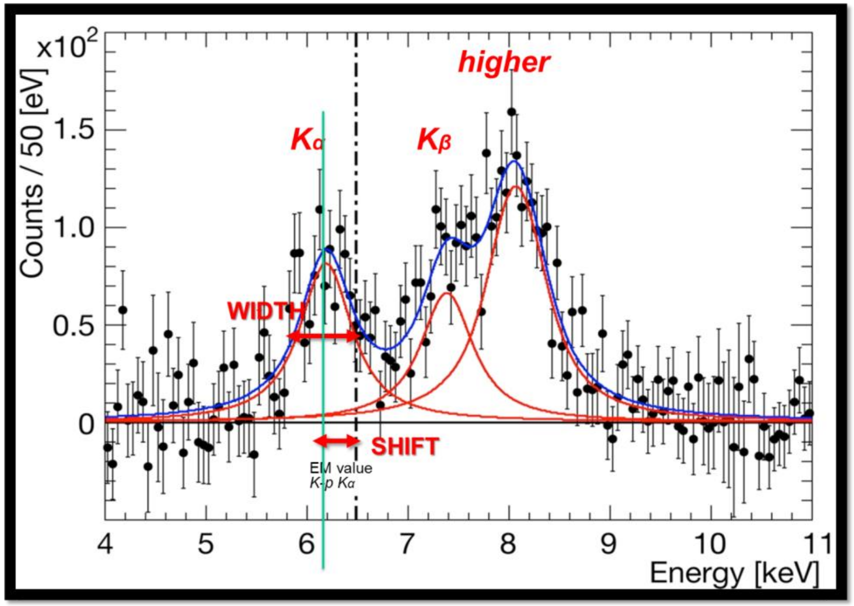
ε_{1s} = -283 ± 36(stat) ± 6(syst) eV
Γ_{1s} = 541 ± 89(stat) eV ± 22(syst)eV



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S-wave scattering length “$a_{K\text{-}p}$” expressed with isospin dependent scattering lengths a_0 (I=0), a_1 (I=1)

Together with shift & width of K-d atom, a_0 and a_1 can be disentangled

SIDDHARTA-2 in preparation

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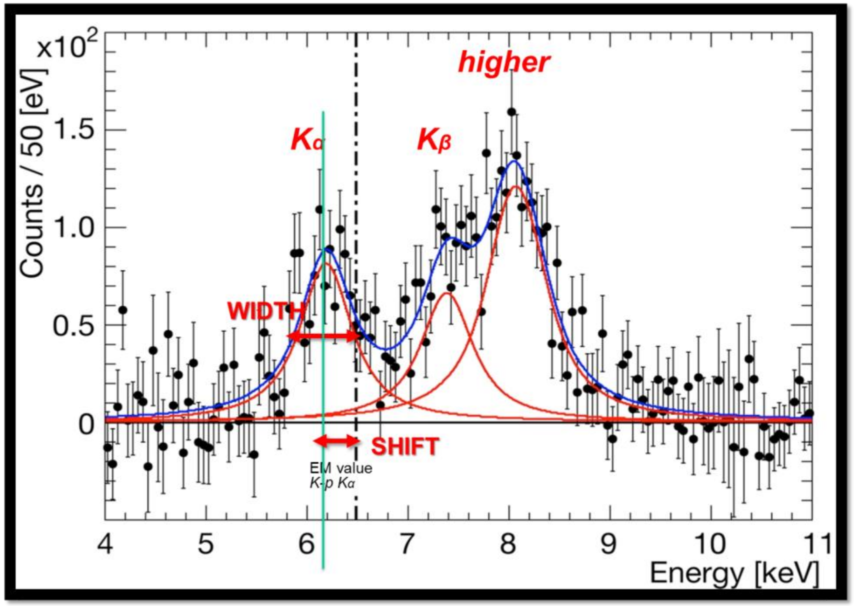
Γ_{1s} = 541 ± 89(stat) eV ± 22(syst)eV



The Λ(1405)

$(M\,,\,\Gamma) = (1405.1^{+1.3}_{-1.0}\,,\,50 \pm 2)$ MeV, $I = 0$, $S = -1$, $J^P = 1/2^-$, Status: ****, strong decay into $\Sigma\pi$

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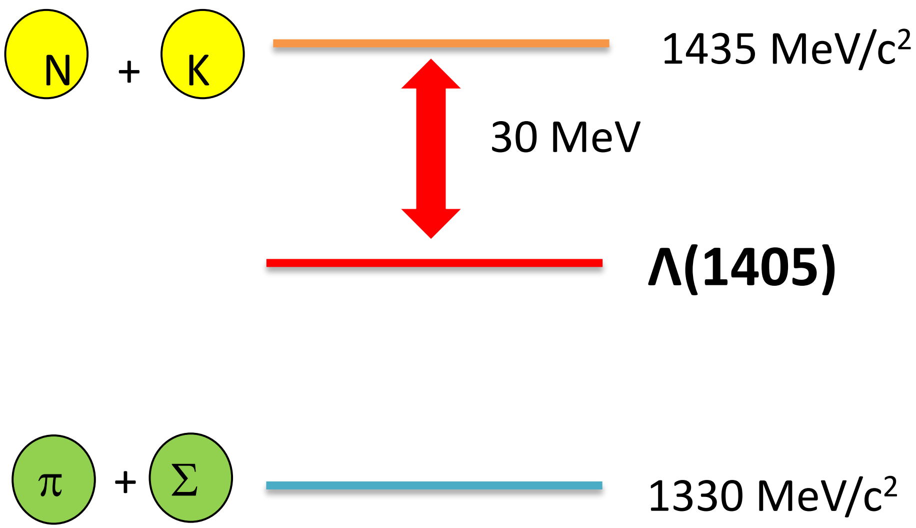
Understanding its nature will give us a key to the meson-baryon interaction



- The shape of the resonance and the **pole(s) position** is calculated with different models **extrapolating** the K^-p scattering amplitudes and K^-p scattering lengths at threshold.

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$(M, \Gamma) = (1405.1^{+1.3}_{-1.0}, 50 \pm 2)$ MeV, $I = 0$, $S = -1$, $J^P = 1/2^-$, Status: ****, strong decay into Σπ

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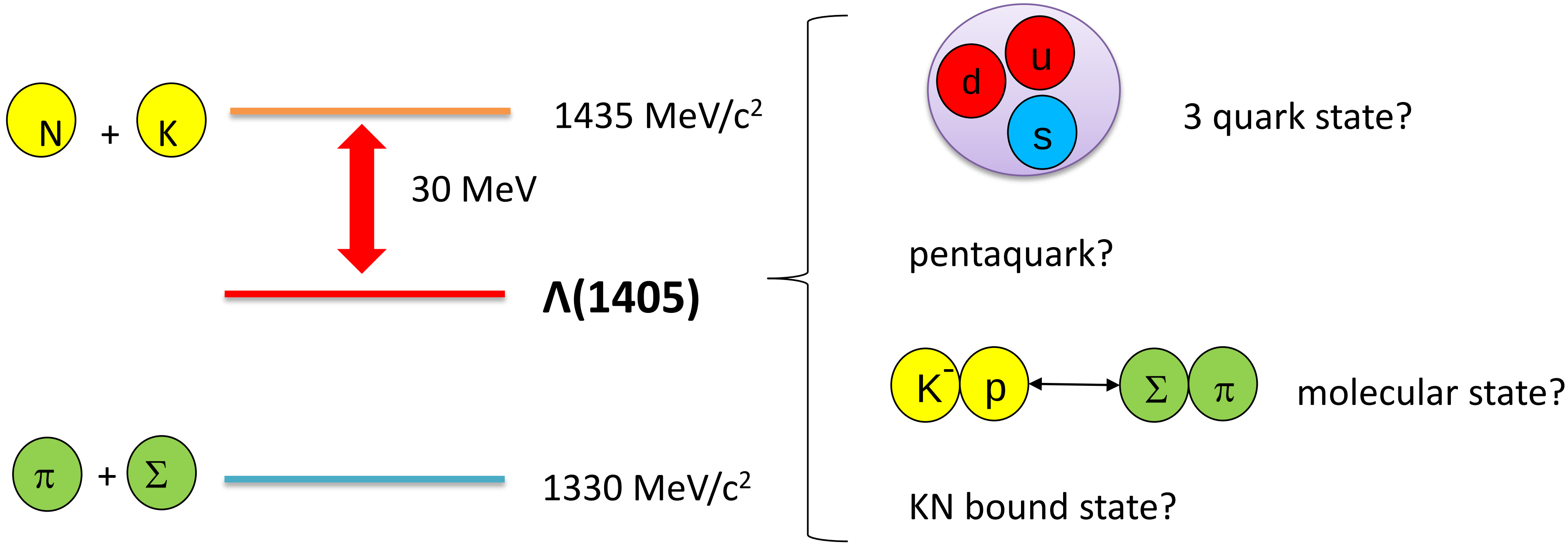
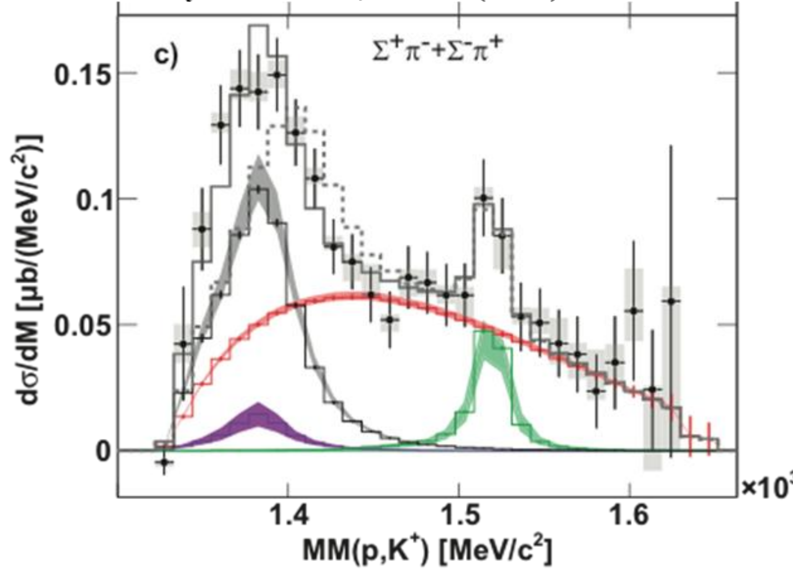


The Λ(1405)

HADES $p + p \rightarrow \Sigma^{\pm} + \pi^{\mp} + K^{+} + p$

Phys. Rev. C 87, 025201 (2013)

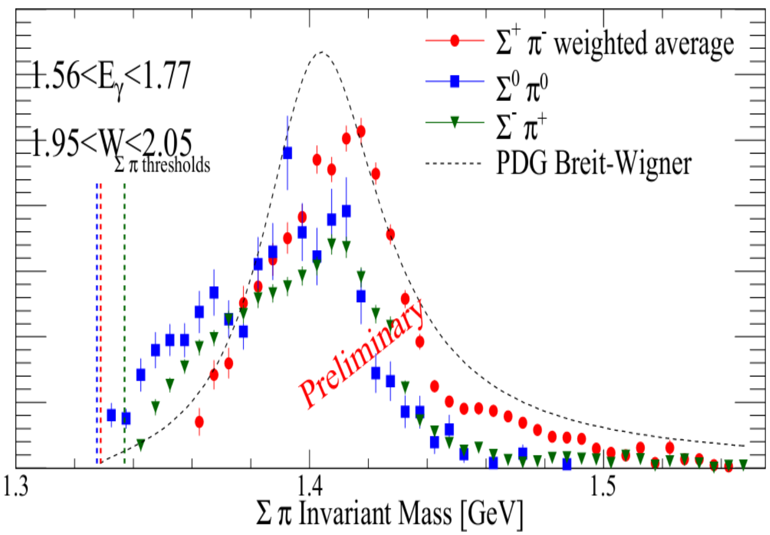


Experimental studies

Line shape influenced by the production mechanism:

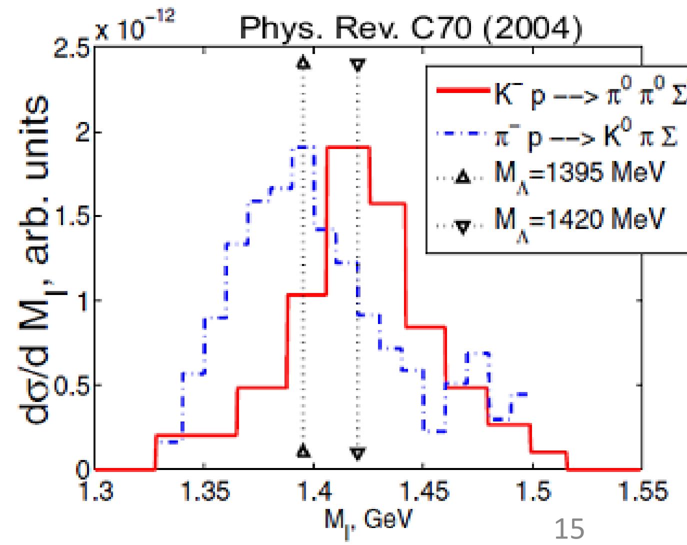
CLAS $\gamma + p \rightarrow K^{+}\Sigma\pi$

Phys. Rev. C 87, 035206 (2013)

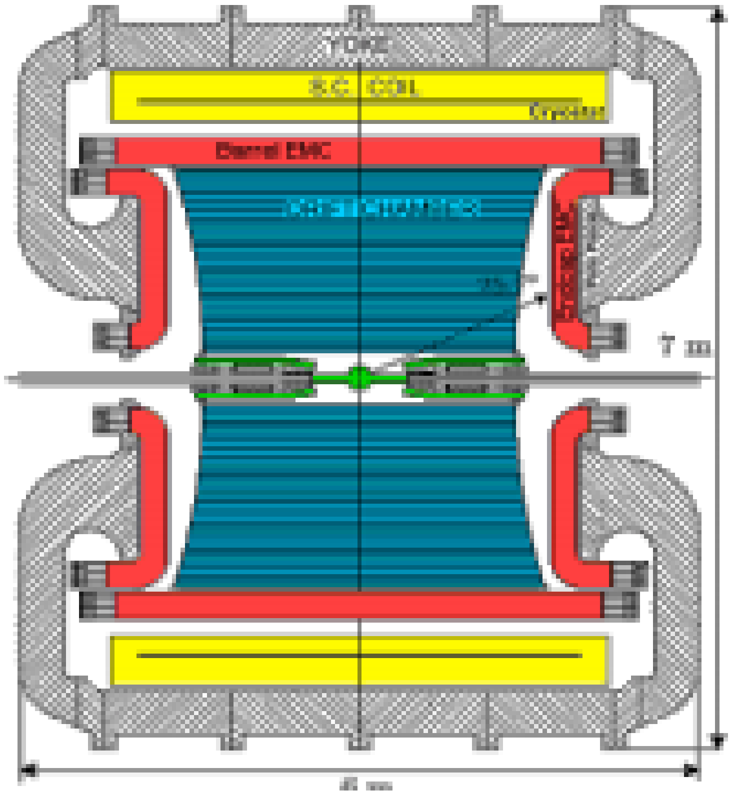


$K^- p \rightarrow \pi^0\pi^0\Sigma^0$

$\pi^- p \rightarrow K^0\, \pi\, \Sigma$



The KLOE detector



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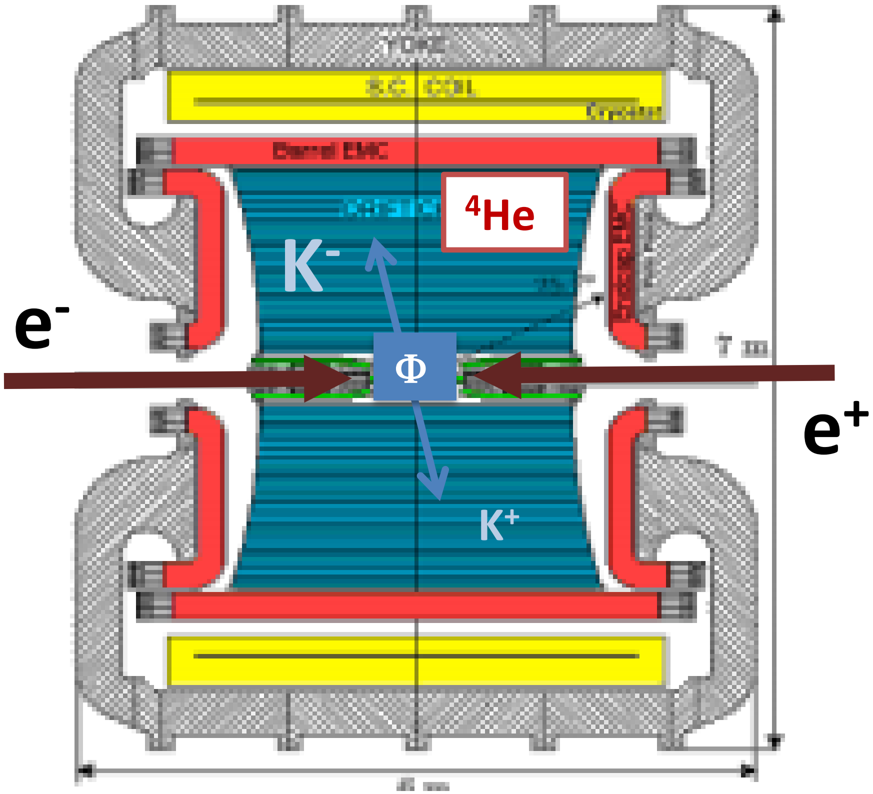

•0.1 % of K$^-$ stop in the **^{4}He**

•x10 times in the **^{12}C**

2004/2005 data: ~2.2 fb^{-1} (95% analized)

Almost full acceptancy 4π:

*** DRIFT CHAMBER**

- **90% ^{4}He**, 10% isobutane
- entrance wall in carbon fiber (**^{12}C**)
- momentum resolution ~ 0.4%

*** ELECTROMANETIC CALORIMETER**

- $\sigma_E/E = 5.7\%/\sqrt{E}$ (GeV)

Active detector:

THE GOOD:

\+ **Excellence acceptance**
\+ **Excellence resolution**
\+ **Charged+neutrals**

THE BAD

\- **low statistics**
\- **interacting nuclei difficult to identify**

KLOE: Study of $\Sigma\pi$ in ^{12}C

Analysis of events in the **^{12}C entrance wall** of the DC

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Analysis of events in the **^{12}C entrance wall** of the DC

K^-_{stopped} + ^{12}C → $\Sigma^+\pi^-$ X
in-flight abs.

$\quad \hookrightarrow p\pi^0$

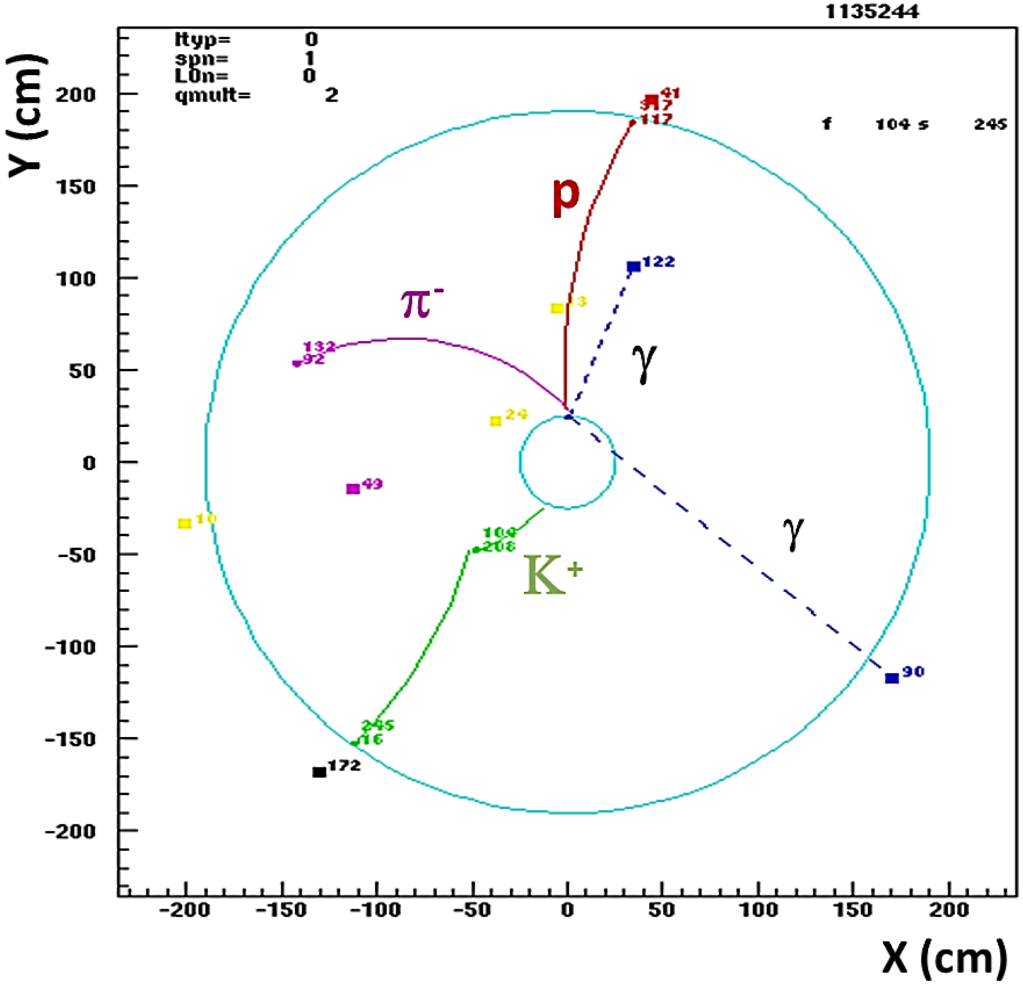
$\quad\quad \hookrightarrow \gamma\gamma$

→ $\Sigma^0\pi^0$ X

$\quad \hookrightarrow \gamma\gamma$

$\quad \hookrightarrow \Lambda\gamma$

$\quad\quad \hookrightarrow p\pi^-$



KLOE: Study of $\Sigma\pi$ in ^{12}C

Analysis of events in the ^{12}**C entrance wall** of the DC

K^-_{stopped} (stopped / in-flight abs.) $+ {}^{12}C \rightarrow \Sigma^+\pi^- X$

$\Sigma^+ \rightarrow p\pi^0$, $\pi^0 \rightarrow \gamma\gamma$

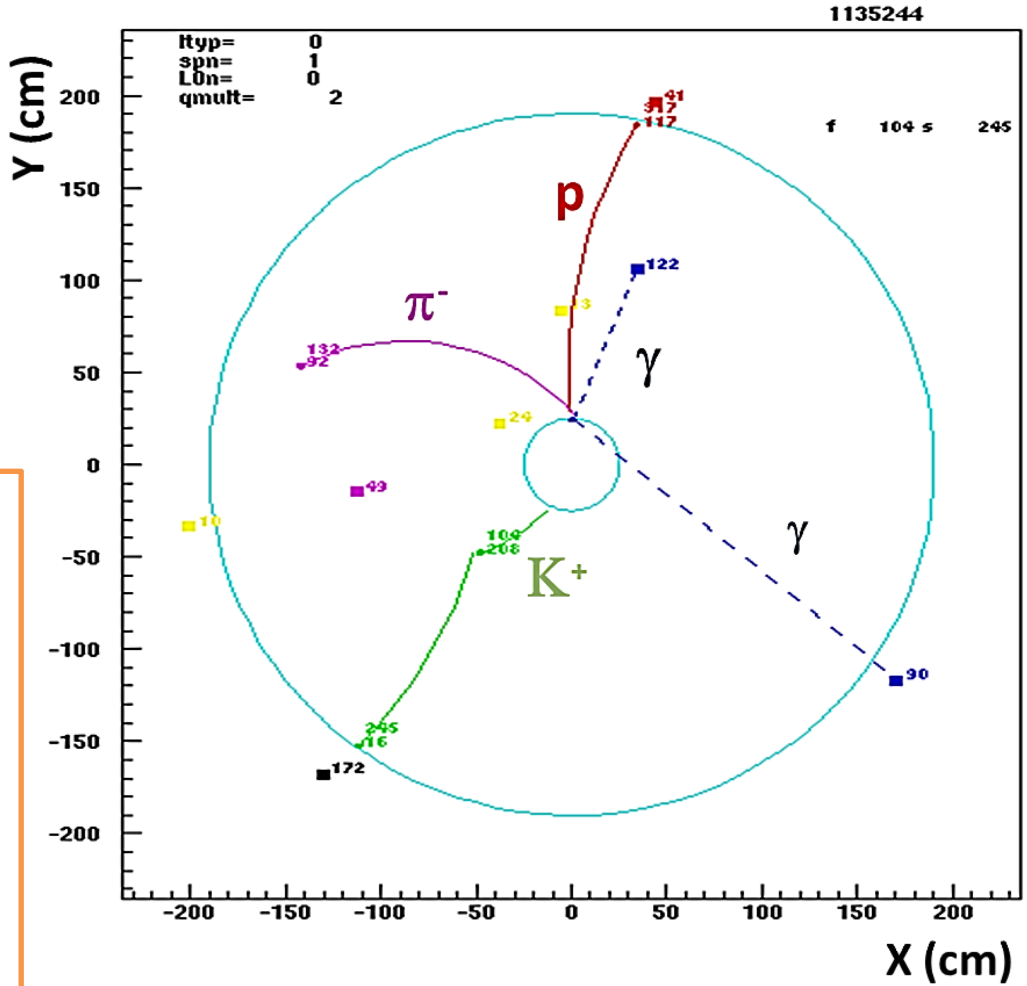
$\rightarrow \Sigma^0\pi^0 X$

$\pi^0 \rightarrow \gamma\gamma$

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

I=0, free from Σ^* background

$$\frac{d\sigma(\Sigma^0\pi^0)}{dM} \propto \frac{1}{3}\left|T^0\right|^2$$



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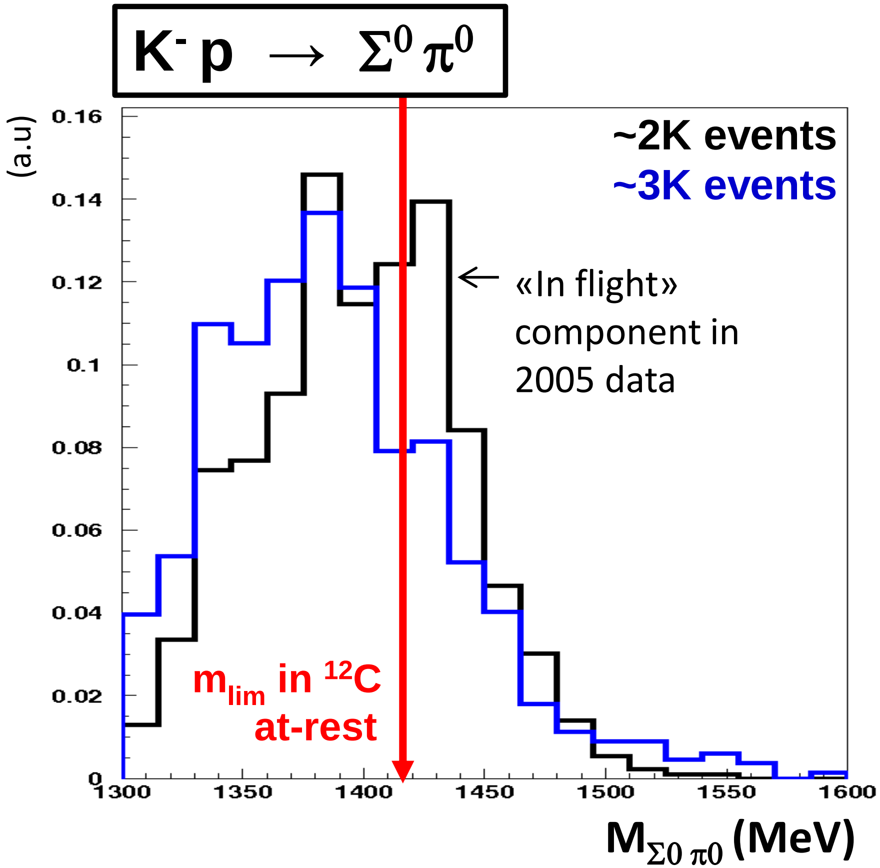

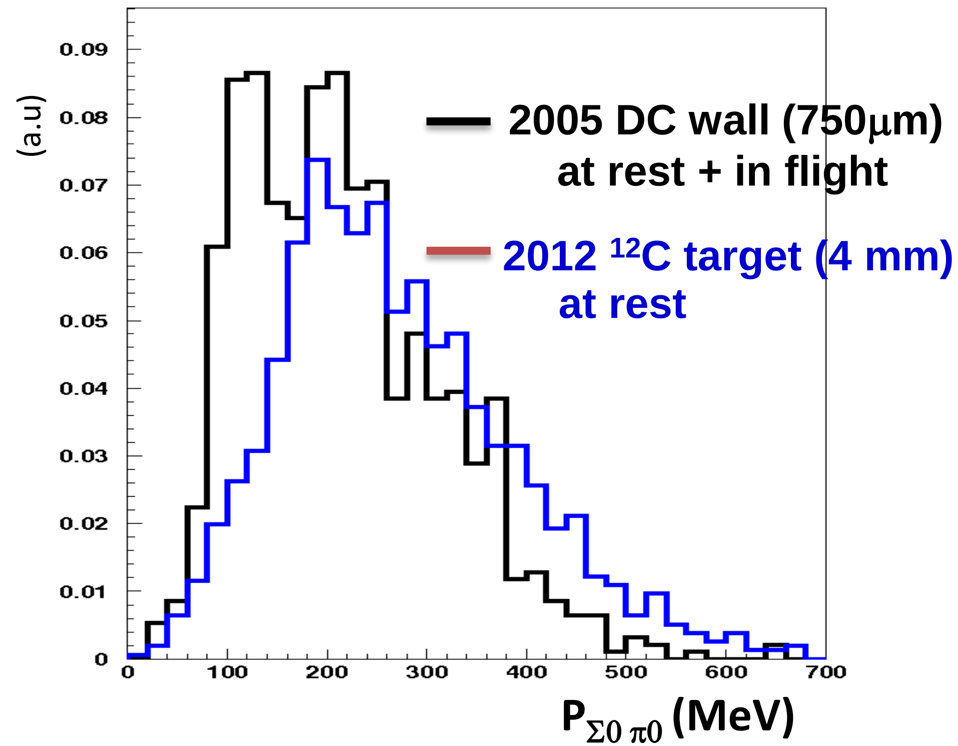

$M_{\pi\Sigma}$ **resolution** $\sigma_m \approx 32$ MeV/c^2

$p_{\pi\Sigma}$ **resolution**: $\sigma_p \approx 20$ MeV/c.

Negligible ($\Lambda\, \pi^0$ + internal conversion) background =(3±1)%

- The in-flight component opens a new kinematical region, that favors resonant events.

$Y\pi$: Resonant VS Non-Resonant

- Another unsolved question ...

  KN→ (Y*?) → Yπ how much comes from resonance ?

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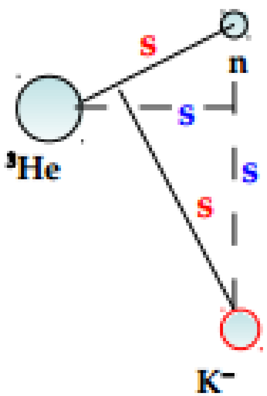
- Investigated using:

$K^-_{stopped/in\ flight}$ + $^4He \rightarrow \Lambda\pi\ ^3He$
- S-wave non-resonant
- P-wave resonant $\Sigma(1385)$

Atomic s-state capture assumed:

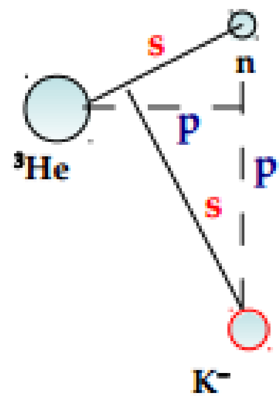


(K⁻ n) s-state interaction

Σ^{*-} not allowed

NON-RES only

+



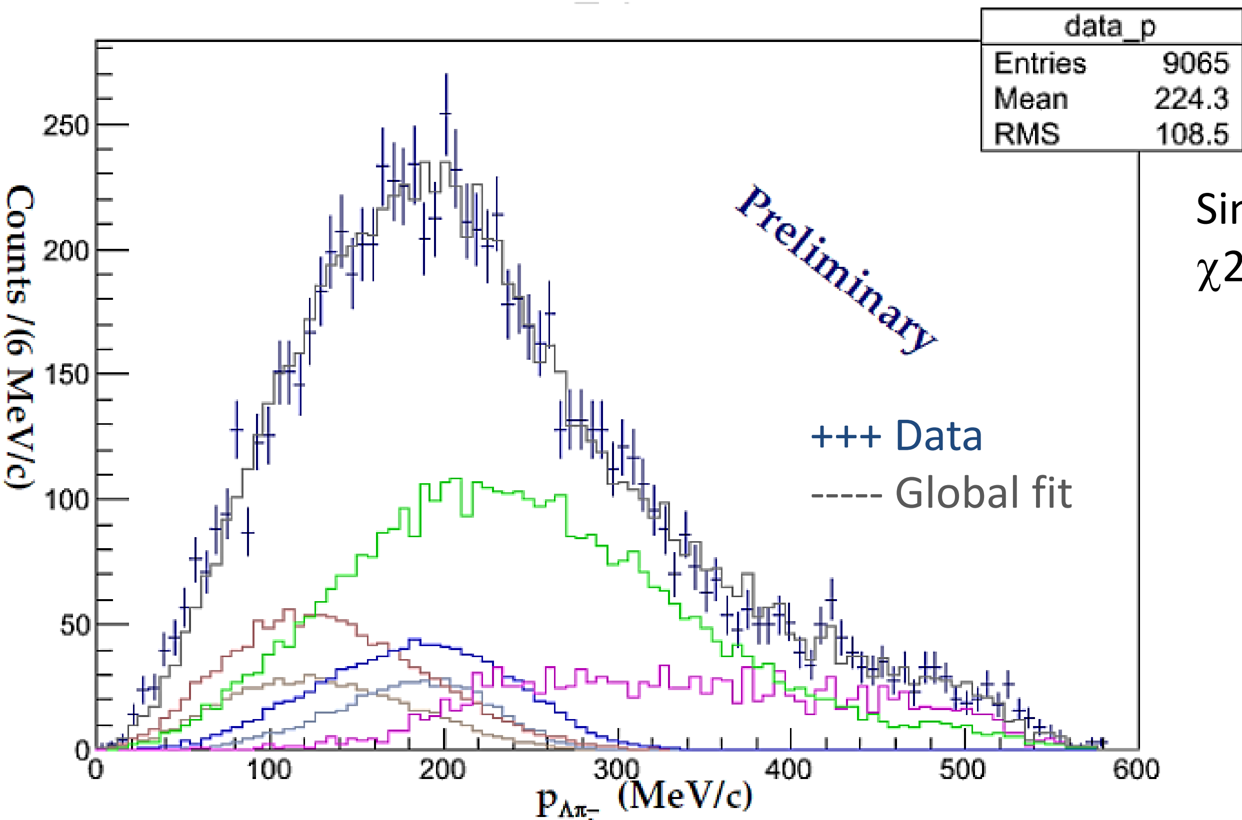
consequence of 3-body effect

(K⁻ n) p-state interaction

Σ^{*-} allowed

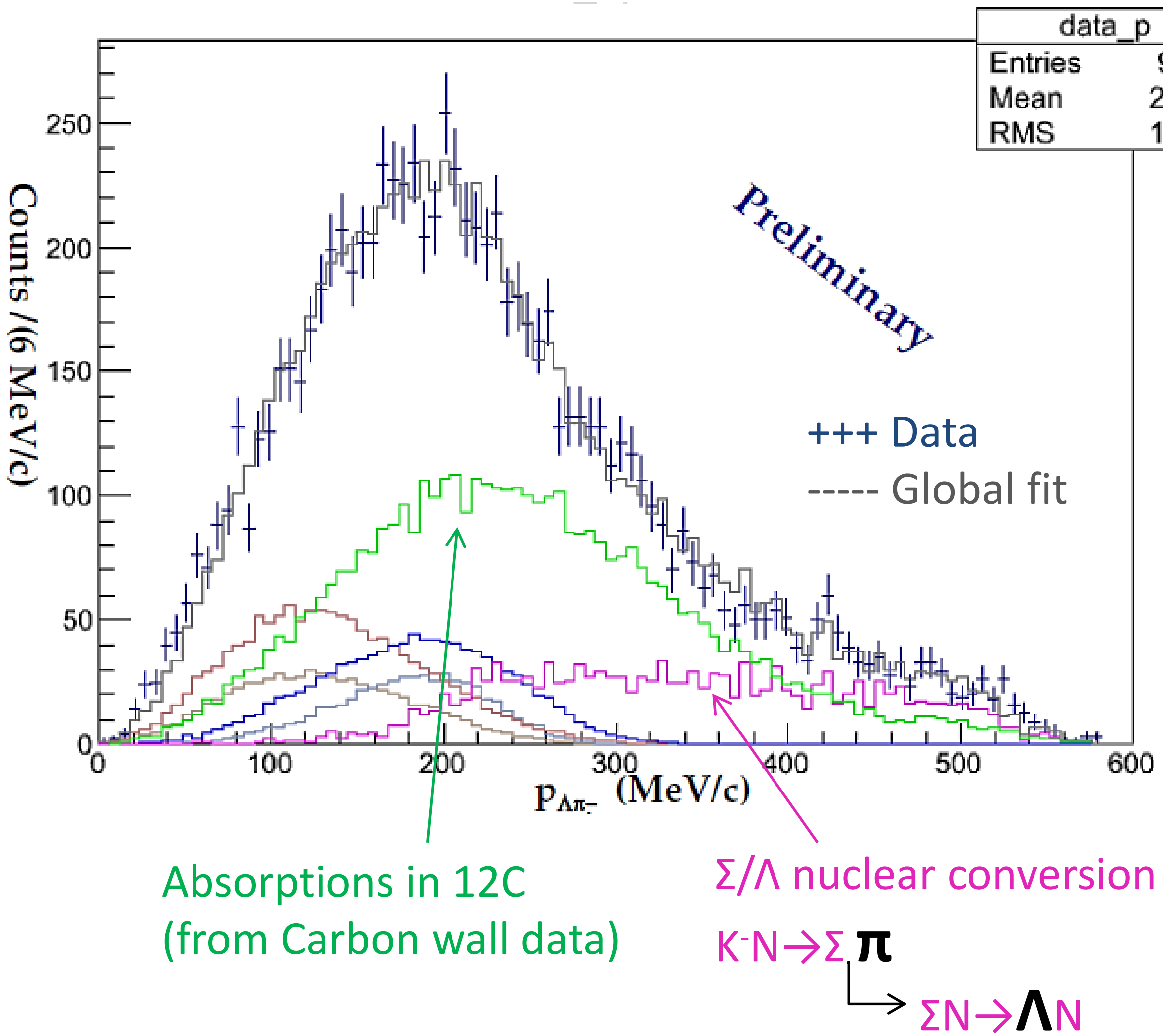
In collaboration with **Prof. S. Wycech**

$\Lambda\pi$: Resonant VS Non-Resonant



Simultaneous fit **($p_{\Lambda\pi}$, $m_{\Lambda\pi}$, $\theta_{\Lambda\pi}$)**
$\chi 2$/ (ndf – np) = 1.6

$\Lambda\pi$: Resonant VS Non-Resonant



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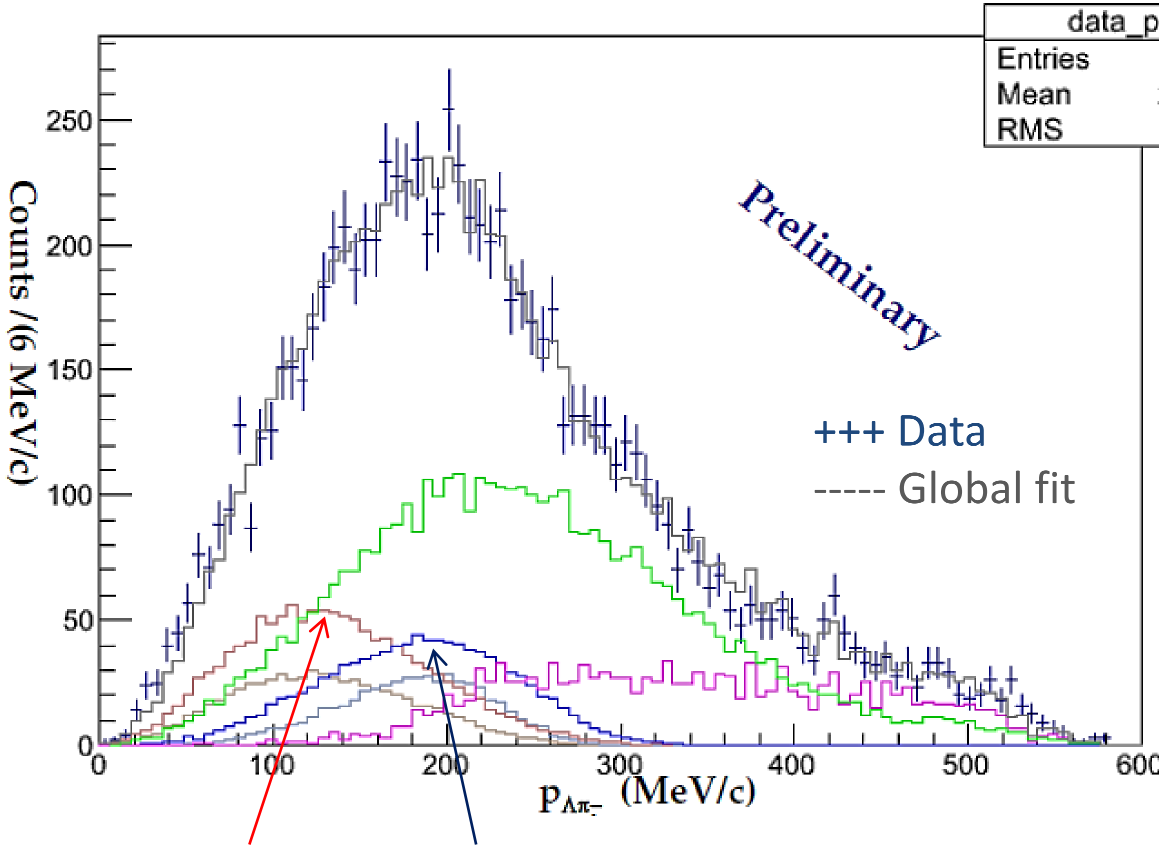

Simultaneous fit **($p_{\Lambda\pi}$, $m_{\Lambda\pi}$, $\theta_{\Lambda\pi}$)**
$\chi 2$/ (ndf – np) = 1.6

Resonant/non-resonant absorption ratio:

- at rest = 1.26 ± 0.06 (stat)

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

Resonant Σ*
(in-flight)
(at-rest)

In-fight/at-rest ratio = 1.9 ± 0.4 (stat)
(consistent with Σ+π- momentum estimation = 2.2)

Kaonic clusters

How deeply is bound a kaon in a nucleus?

Kaonic clusters

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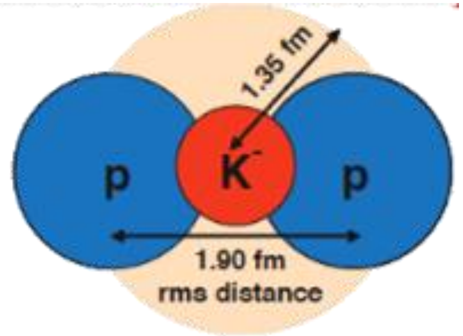

Strong attractive I=0 KN interaction favors discrete nuclear states **high B** and **small Γ** .

Different theoretical approaches:

-Few-body calculations solving Faddeev equations

-Variational calculations with phenomenological KN potential

-KN effective interactions based on Chiral SU(3) dynamics

Experimental studies for the **K-pp** the **Λp** decay channel

K-ppn Λd

Kaonic clusters

Theoretical work

$K^{-}pp$ **...**it does exsist

... a K^{-}pp puzzle

Reference	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
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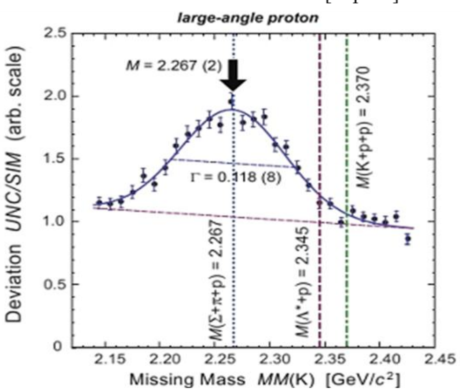
Experiments:

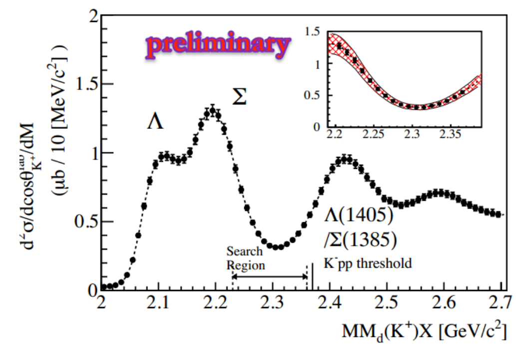
arXiv:0912.5116 [hep-ex]



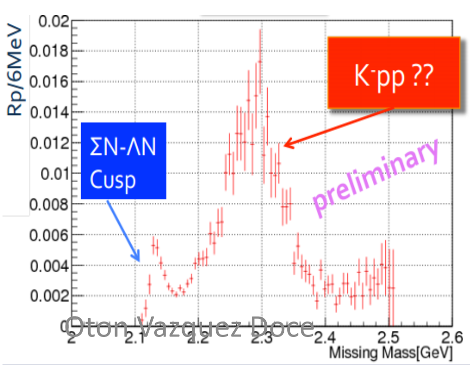
Production via $pp \to pK^+\Lambda$ (2,85 GeV)

B = 105 ± 2 ± 5 MeV
Γ = 118 ± 8 ± 10 MeV

DISTO

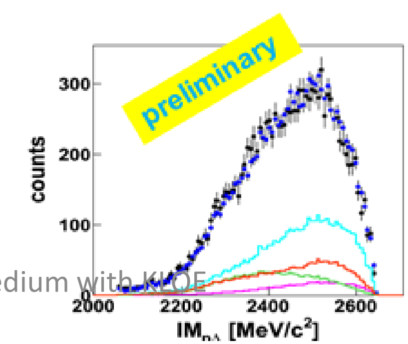


LEPS-Spring8



E27 @ J-Parc

HADES



Contributions from N*, interferences using PWA

Kaonic clusters

Theoretical work

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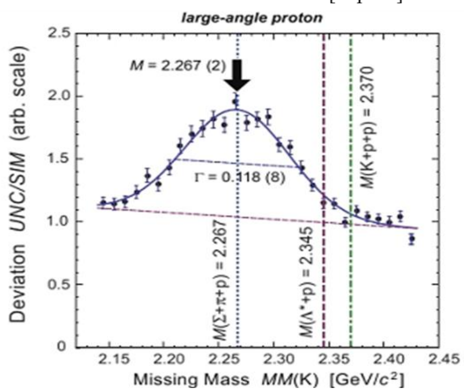

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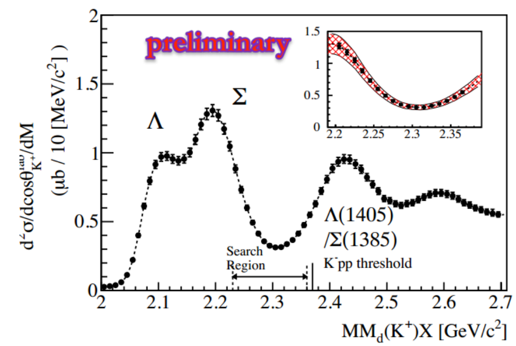

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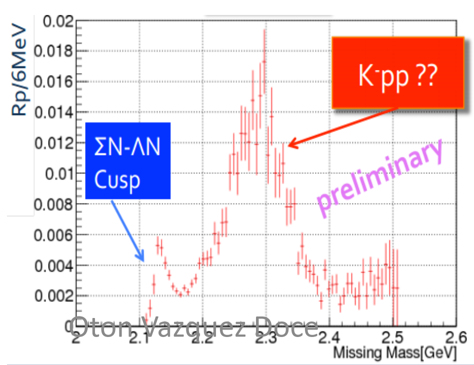

E27 @ J-Parc

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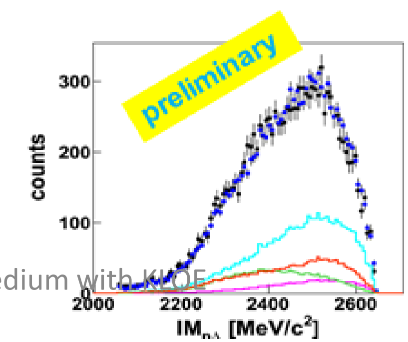
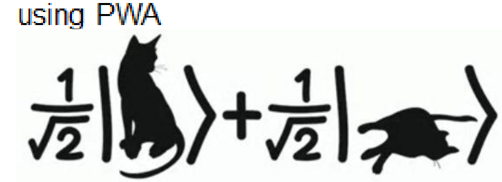


Contributions from N*, interferences using PWA



KLOE data: Λ-proton events

Analysis of events in the DC gas volume

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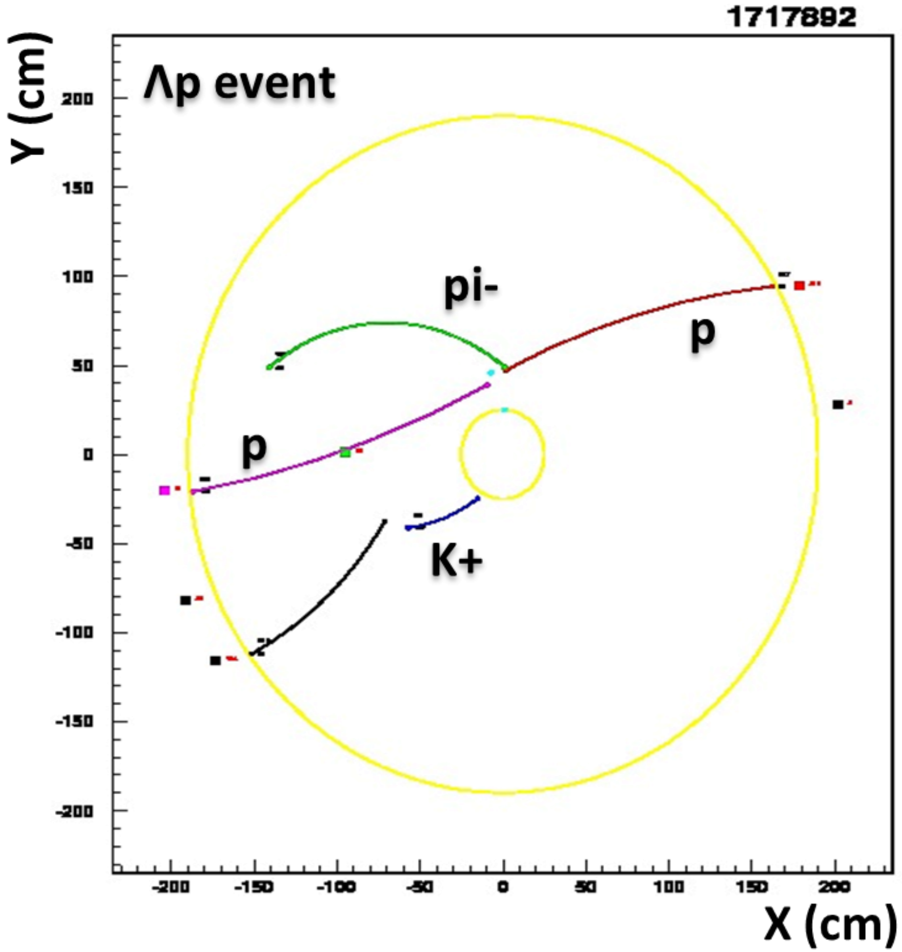
Analysis of events in the DC gas volume

$$K^-_{\substack{\text{stopped} \\ \text{in-flight abs.}}} + {}^4He \rightarrow \Lambda p\, X$$

$\Lambda \rightarrow p\pi^-$



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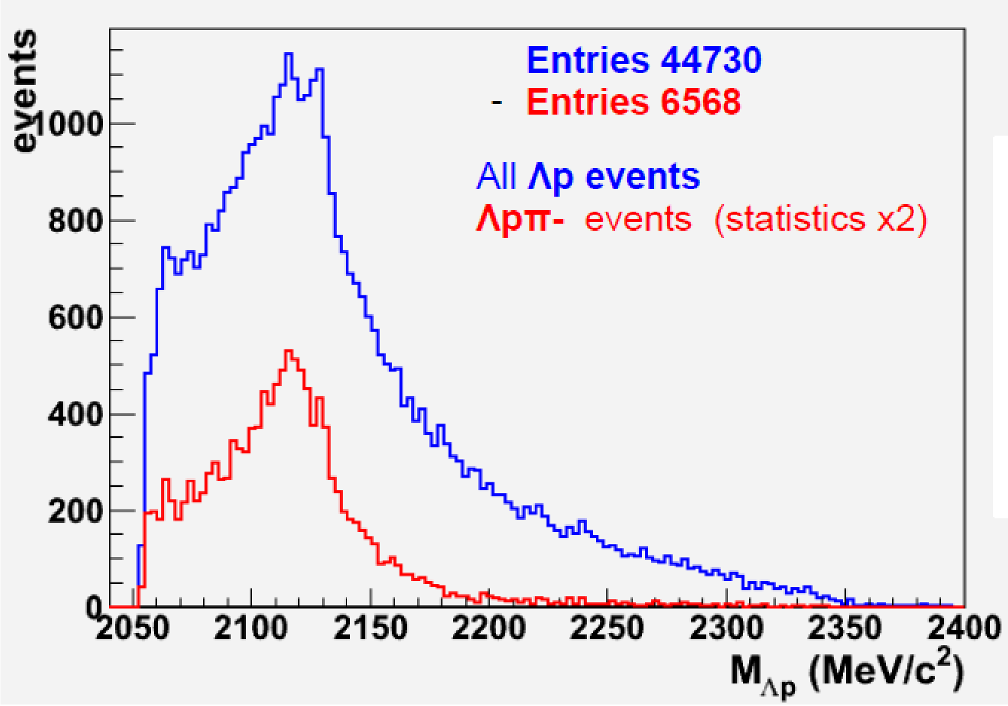

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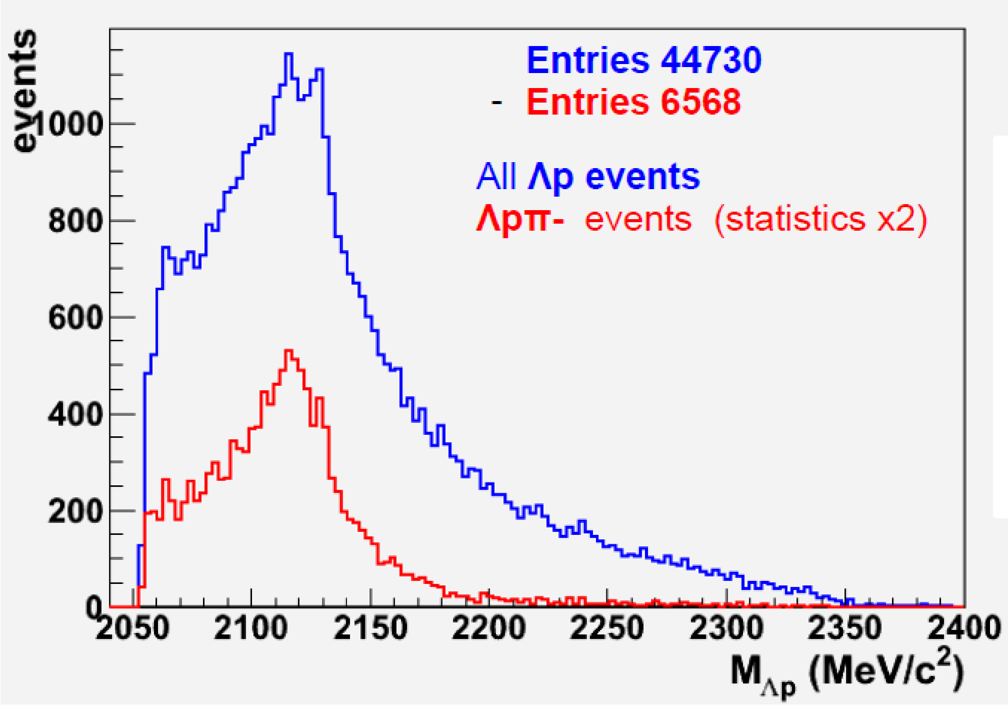
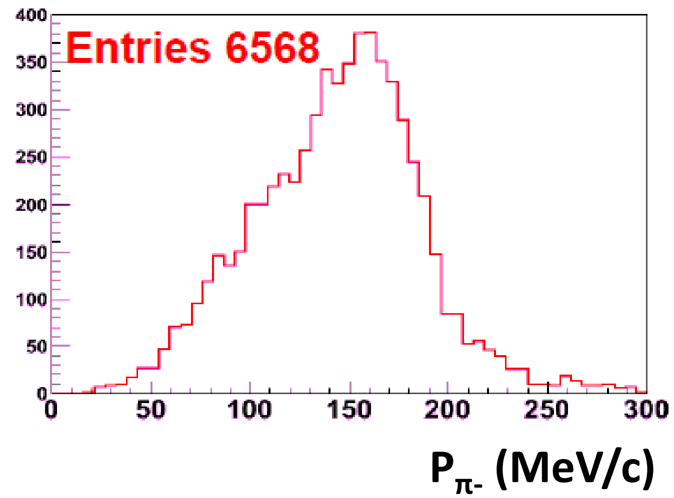




- Low invariant mass: 1 Nucleon absorption followed by Σ/Λ nuclear conversion

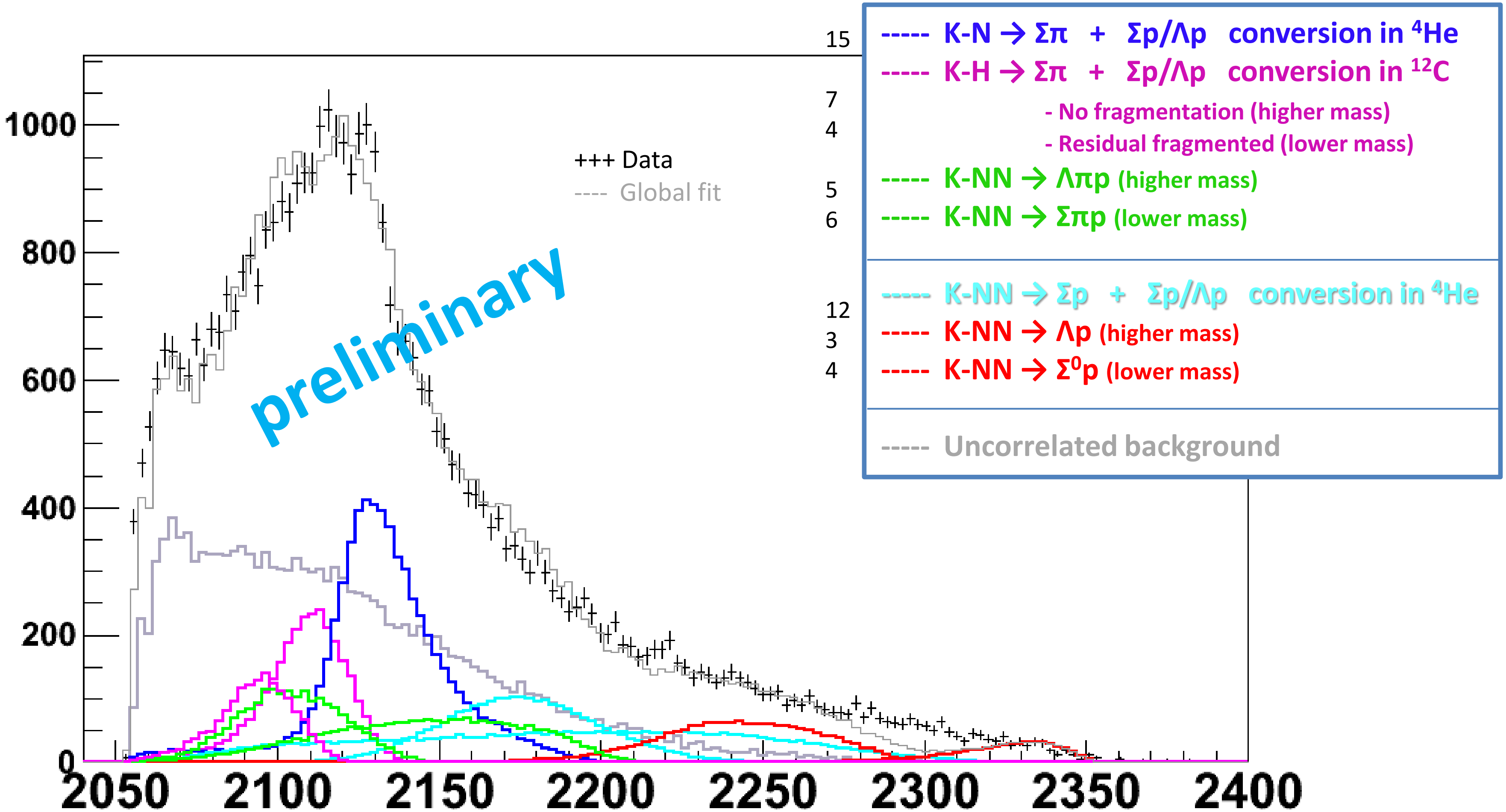
1NA: $K^-N \rightarrow \Sigma$ **π**

$\hookrightarrow$ $\Sigma N \rightarrow$ **ΛN**

- High invariant mass: **2NA**: $K^-NN \rightarrow$ **ΛN** (pionless?)

Λp preliminary fit

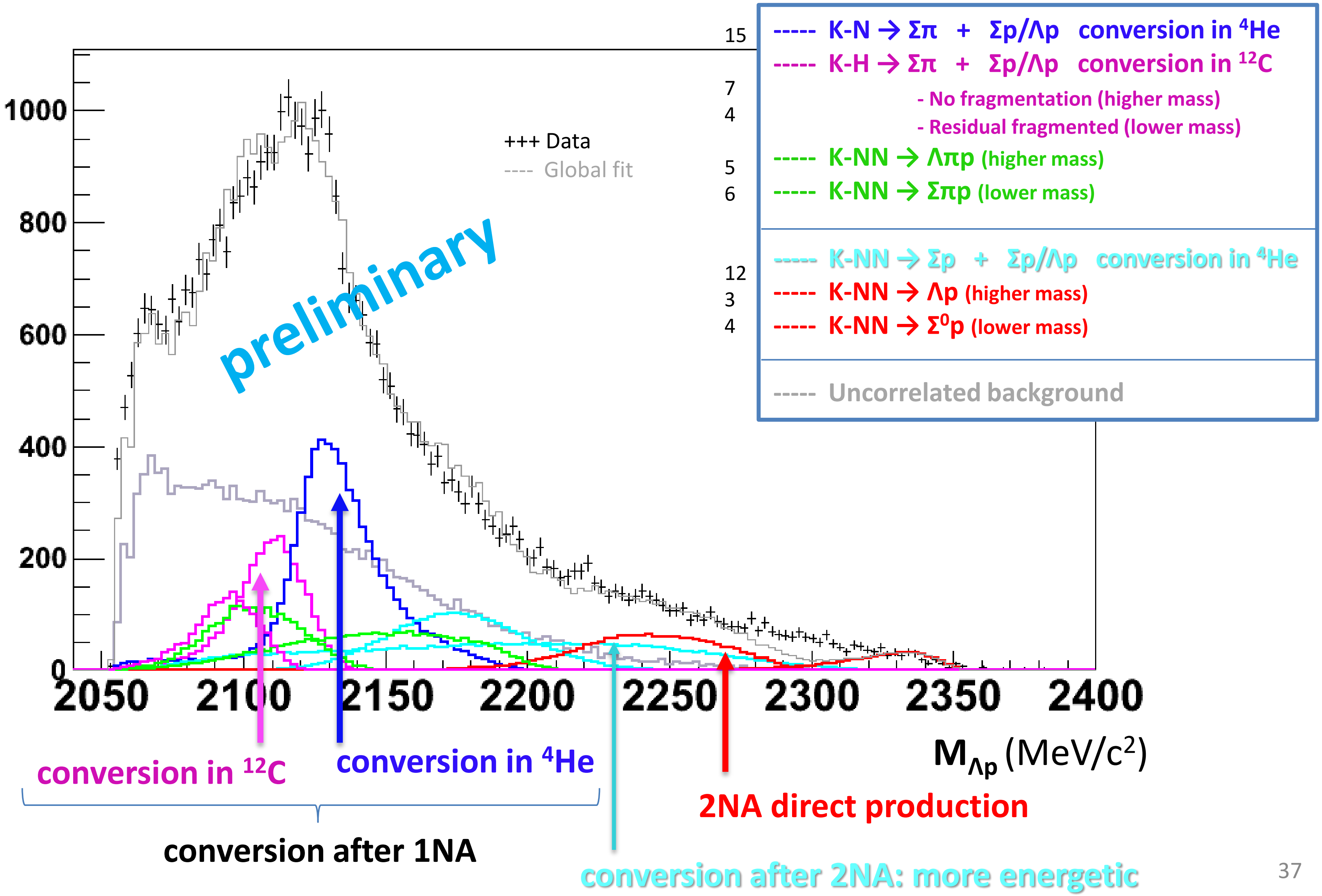
Fit 3D (P_Λ, P_p, $\theta_{\Lambda p}$)



$M_{\Lambda p}$ (MeV/c^2)

Λp preliminary fit

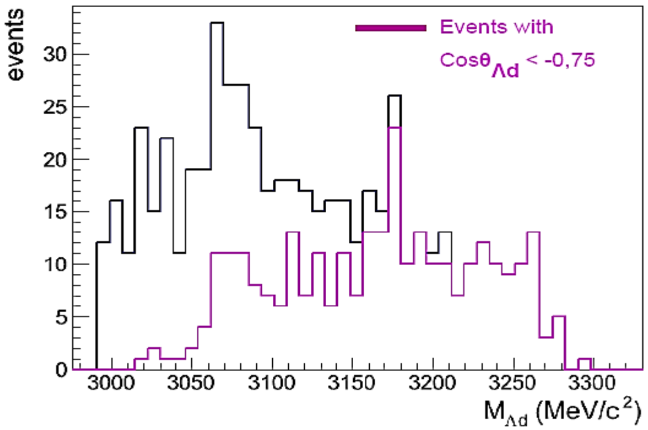
Fit 3D (P_Λ, P_p, $\theta_{\Lambda p}$)

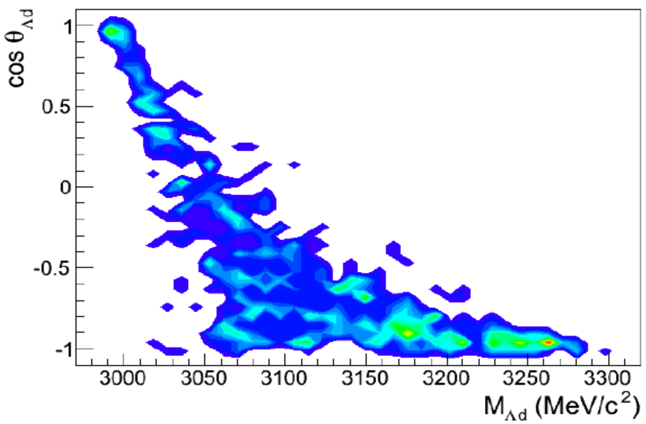


KLOE data: Λd, Λt events

Λd sample in ^{4}He

572 events





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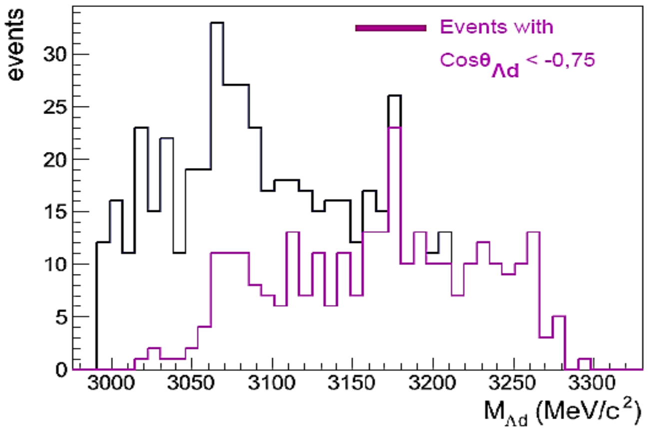
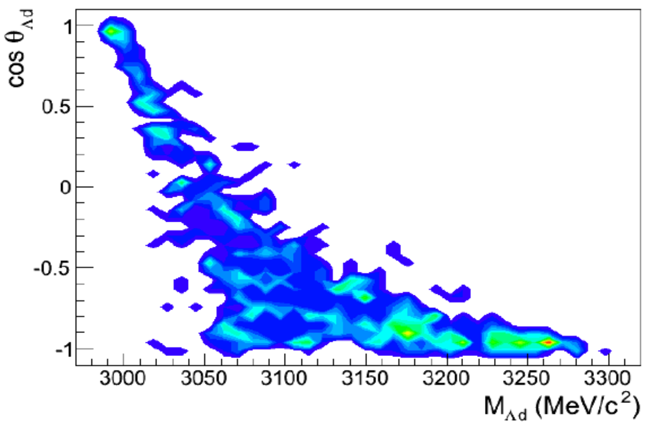
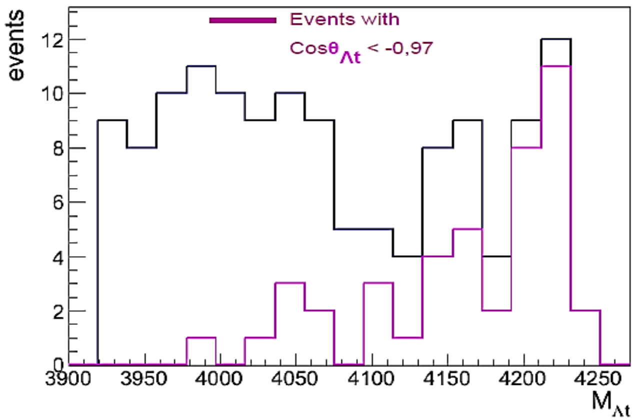
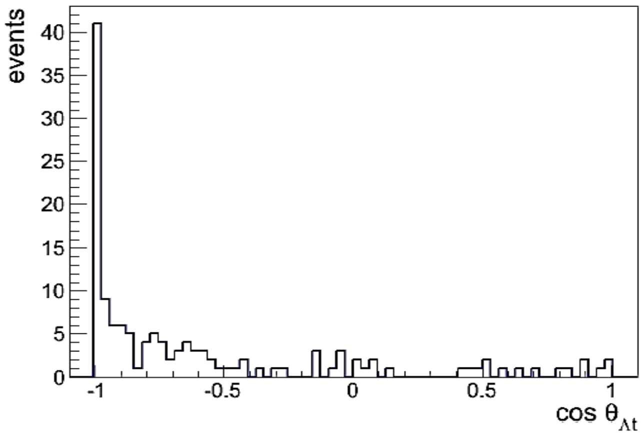




Λt sample in ^{4}He

134 events





Conclusions (I)

Λp analysis

- The extraction of the signal of a bound state in processes involving more than 1 nucleon is very **difficult** unless it is very **narrow** and with **high** formation rate.
- **ΣN/ΛN** conversion process **dominates** both low and high invariant mass regions. This process can be described quantitatively and qualitatively exploring the YN interaction.

Λd / Λt analyses

- 3- and 4-nucleon absorption processes clearly seen.
- Additional structures must be investigated.:
  - **Σ^0** contamination?
  - Bound state?

Conclusions (II)

$\Sigma\pi$ analysis

- The spectra $M_{\Sigma\pi}$ show a **high invariant mass** component associated to in-flight K^- capture.
- The «higher pole» region is accessible thanks to the in-flight events.

$\Lambda\pi$ analysis

- Detailed calculation of the absorption process and $\Lambda\pi$ resonant and non-resonant formation have been performed
- $\Lambda\pi$ first measurement of **resonant/non-resonant ratio** in nuclear K^- absorption
- The method will be used for the $\Sigma\pi$ channels

Conclusions (II)

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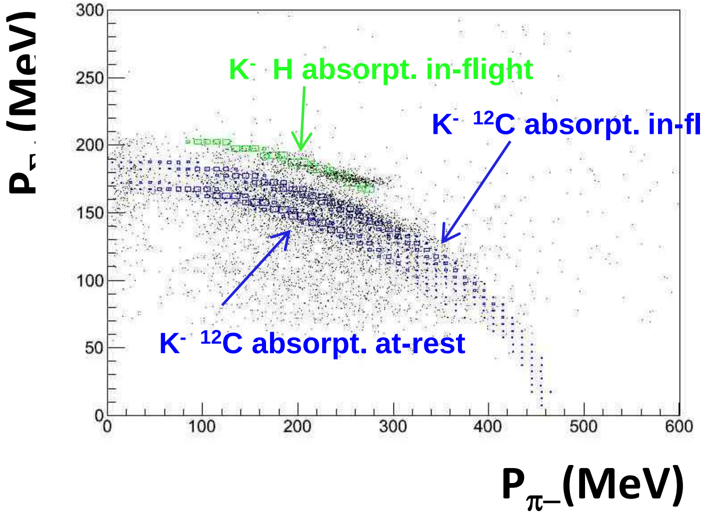
Thank you for your attention!

SPARE

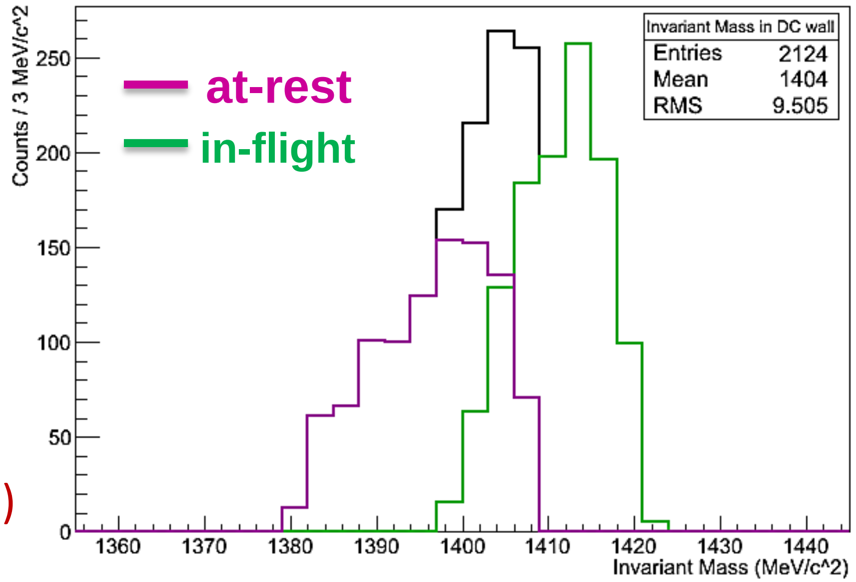
KLOE: Study of $\Sigma\pi$ in ^{12}C

$K^- p \rightarrow \Sigma^+ \pi^-$

2005 DC-wall



- Evaluation of the contamination from H in the DC wall and in-flight/at-rest splitting can be performed thanks to the good momentum resolution of the charged channels



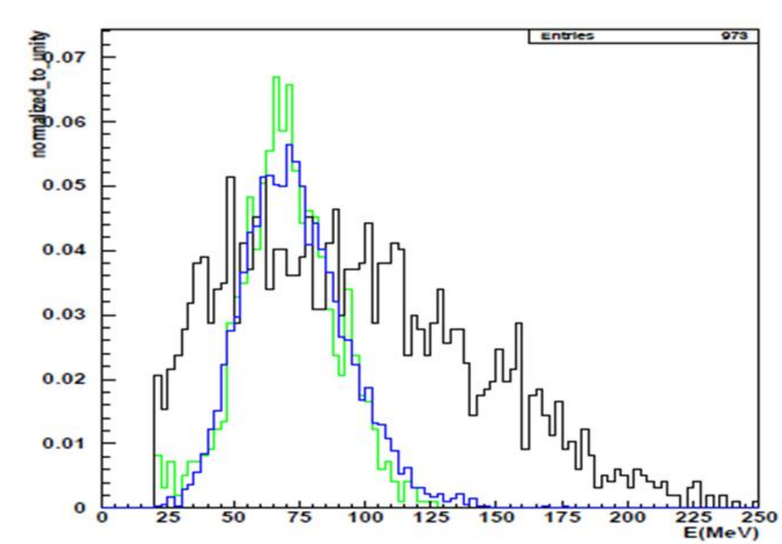
$R_{in\text{-}flight/at\text{-}rest} = 1.16 \pm 0.05$ (statistic)

$M_{\pi\Sigma}$ resolution $\sigma_m \approx 14$ MeV/c^2

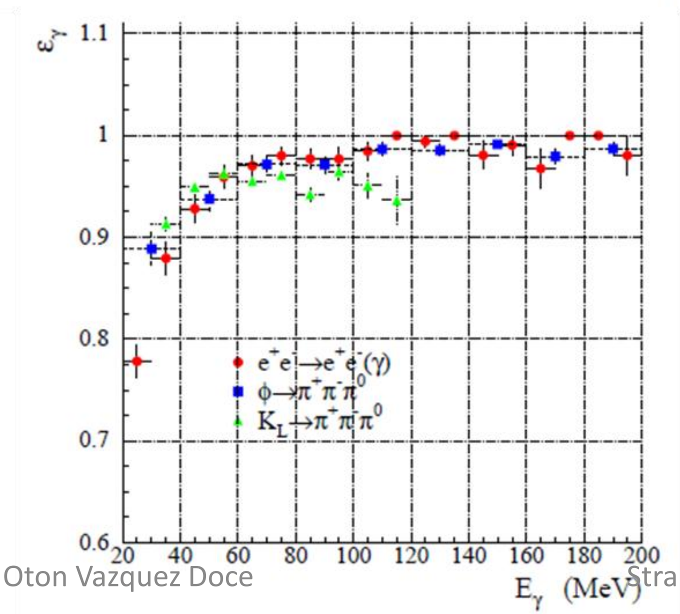
Missidentification background =1 $\pm$ 0.2 %

KLOE: Study of $\Sigma\pi$ in ^{12}C

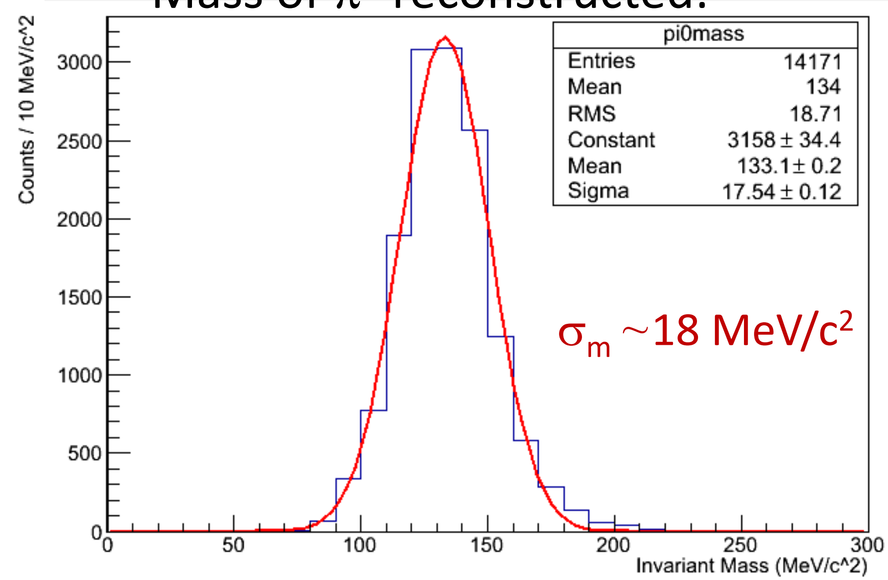
Use of the calorimeter: Photon detection



Black -> energy of photons from π^0
Blue -> energy of photons from $\Sigma^0 \to \Lambda\gamma$



Mass of π^0 reconstructed:

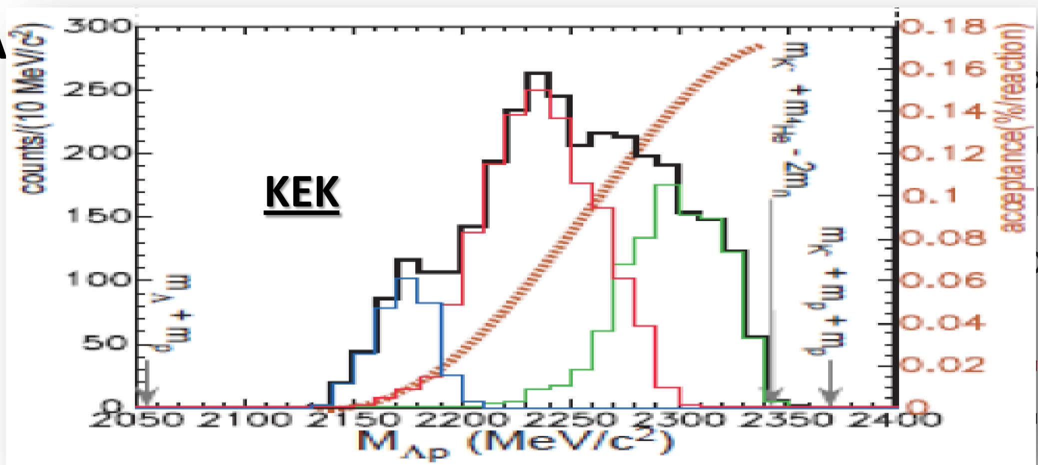


KLOE data: Λp analysis

- Resolution study with MC simulation and charged kaons decays:

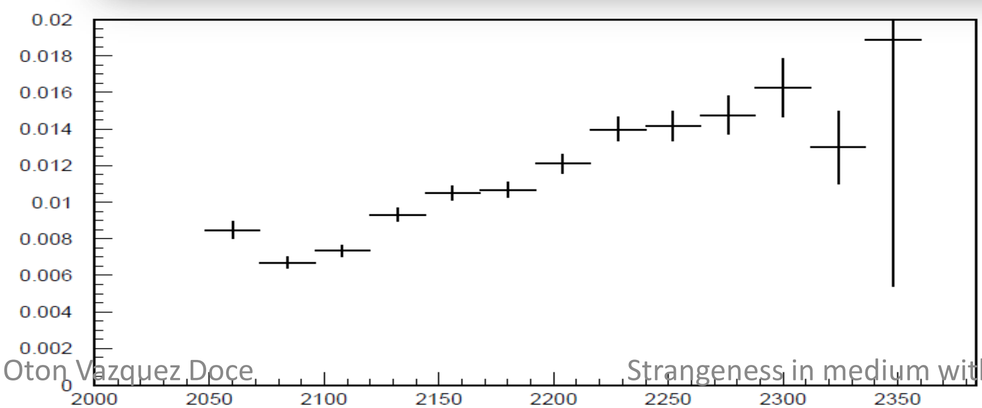
p_Λ	$0.49 \pm 0.01\ MeV/c$
p_p	$2.63 \pm 0.07\ MeV/c$
$M_{\Lambda p}$	$1.10 \pm 0.03\ MeV/c^2$
r_{vertex}	$0.12 \pm 0.01\ cm$

- A



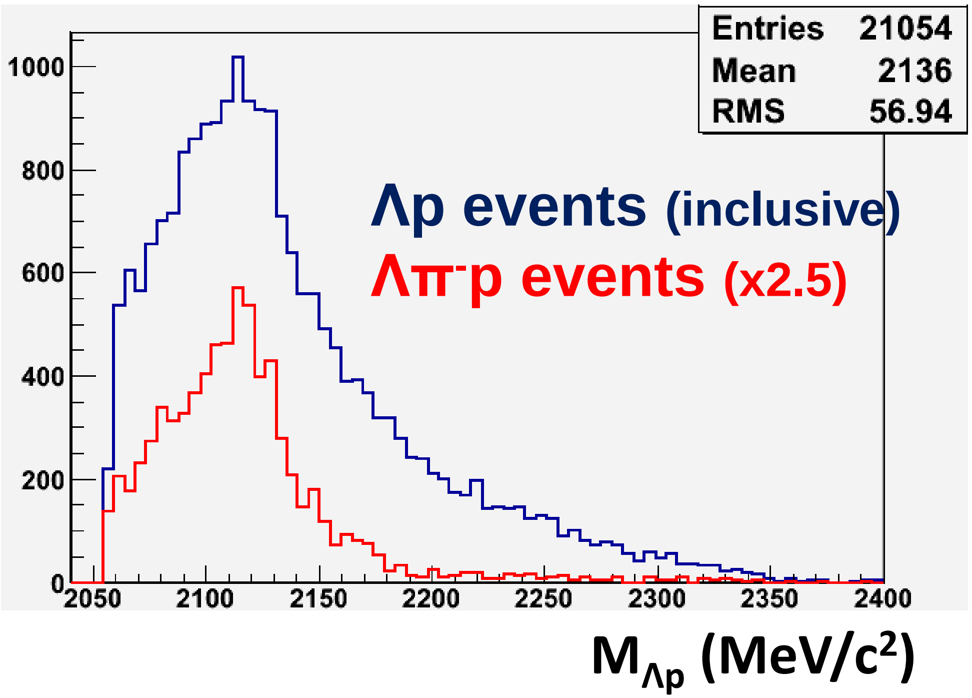
MC simulation
rojection of acceptance
unction depending on
P_Λ,P_p,Minv Λp)
n the Invariant mass plane

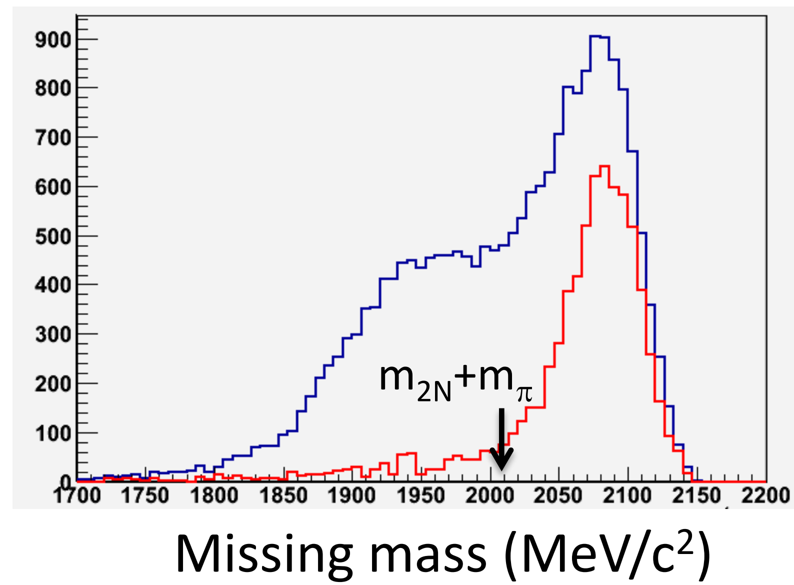
True phase space MC
Reconstructed MC
Corrected MC with acc. Corr.



Normalization 1:1
(no efficiency evaluation)

KLOE data: Λp analysis





- 2NA: **$K^-NN \rightarrow \Lambda N$** (pionless)

↓ alternative process: **<u>ΣN/ΛN conversion</u>**

1NA: **$K^-N \rightarrow \Sigma\pi$**

└→ **$\Sigma N \rightarrow \Lambda N$**