Low energy Kaon-nucleon/nuclei interaction studies at DAΦNE by AMADEUS

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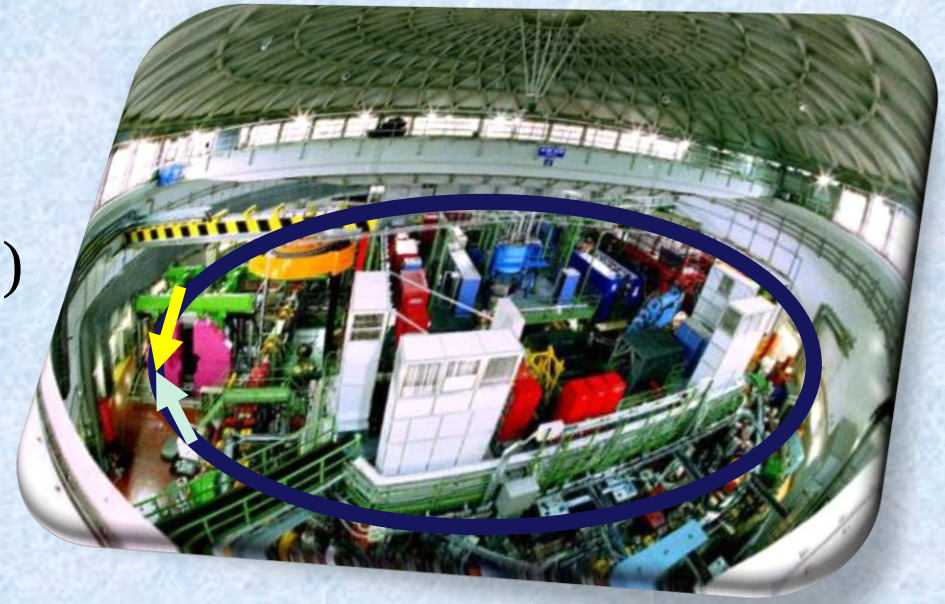
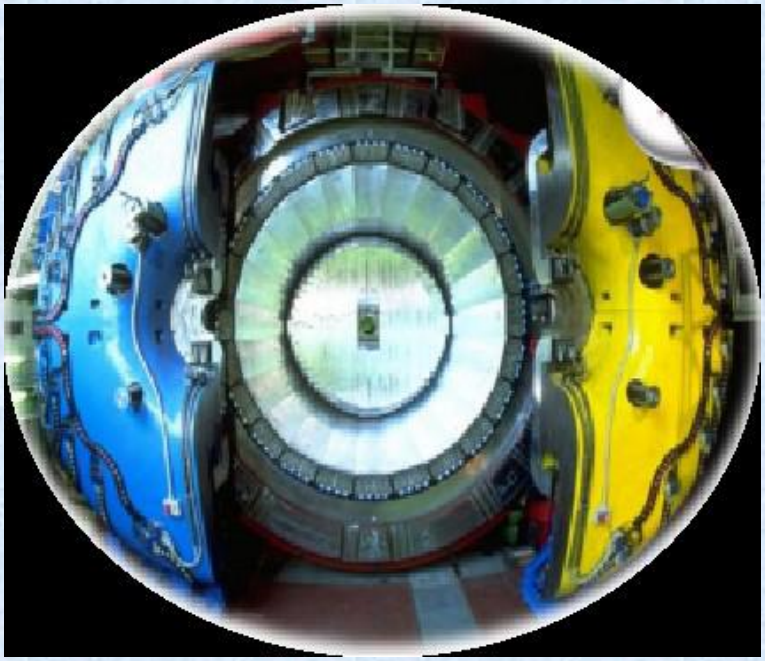
AMADEUS at the DAΦNE e^+e^- collider

DAΦNE

- Double ring e^+ e^- collider working in C.M. energy of Φ (≈ 500 MeV/c)
- $\Phi \rightarrow K^+ K^-$ (49.1%) (≈ 600 $K^+ K^-$ /s)
- low momentum Kaons (≈ 127 MeV/c)
- back to back $K^+ K^-$ topology (about 1000/second)





AMADEUS using KLOE

- **96% acceptance**,
- optimized in the energy range of all charged particles involved
- good performance in detecting photons (and neutrons checked by kloNe group (M. Anelli et al., Nucl Inst. Meth. A 581, 368 (2007)))

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, ^{8}Be, ^{12}C …) in order to obtain unique quality information about:

- possible existence of **kaonic nuclear clusters** (deeply bound kaonic nuclear states – DBKNS) ***** **-** search in the Λp, Λd, and Λt final channels
- Interaction of **K^-** with **one** and **more nucleons (single and multi – nucleon K^- absorption)**
- **Λ(1405) in all 3 decay channels (which is its nature?)**
- 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**)

*** DBKNS: Λp channel - Kpp bound by about 60-90 MeV!!! (in a normal nucleus the BE/nucleon is about 6-7 MeV) – a role in neutron stars**?

Investigation of K^- absorption on light nuclei

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

AT REST (K absorbed from atomic orbit) or

IN FLIGHT (p_K~100 MeV)

Reactions we investigate:

Prelim results

- **Λp, Λd and Λt final state channels from single or multi-nucleon absorption processes**
- **K^- 'p' → $\Sigma^0\pi^0$**
- **K^- 'p' → $\Sigma^+\pi^-$**
- K^- ' n' → **$\Lambda\pi^-$ (direct formation) or**

K^- N → **$\Sigma^0\pi^0$/ $\Sigma^+\pi^-$; $\Sigma N \rightarrow \Lambda\pi$ (internal conversion processes)**

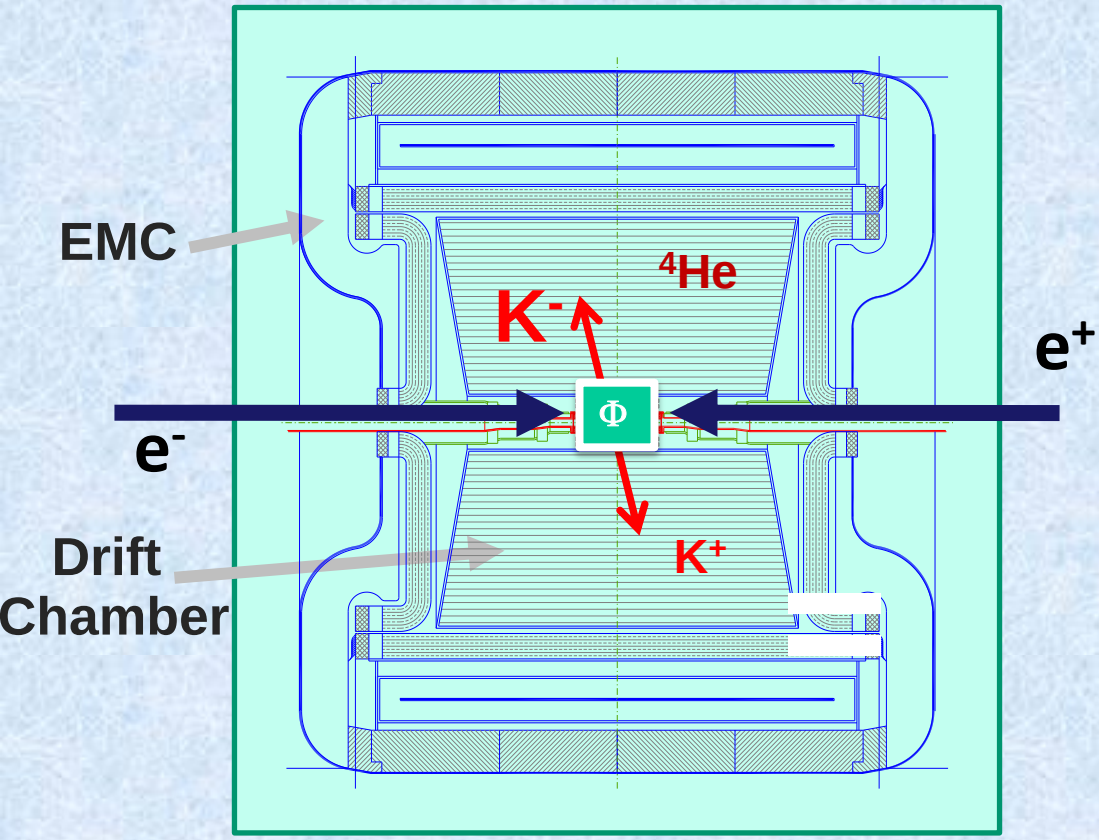
R&D for more refined setup: ScFi + SiPM (trigger system) TPC – GEM (inner tracker)

Experimental tests of the trigger prototype for the AMADEUS experiment based on SciFi read by MPPC, Nucl.Instrum.Meth. A671 (2012) 125128
Performances of a GEMbased TPC prototype for new highrate particle experiments, Nucl.Instrum.Meth. A617 (2010) 183185

Step 0: Low energy K^- hadronic interaction studies with KLOE existent data

The Drift Chamber (DC) of KLOE contains mailny **^{4}He (**90%, 10% *isobutane* C_4H_{10})

how K+/K- events looks like nowadays in **KLOE:**



Monte Carlo simulations show:

- ~ **0.1 % of K^- stop in the DC volume**
- **~ 2% stop in the Carbon** entrance wall of the DC

= thousands of events with K^- hadronic interactions

↓

Possibility to use KLOE materials as an active target

Advantage:

excellent resolution ..

$\sigma_{p\Lambda}$ = 0.49±0.01 MeV/c in DC gas

$\sigma_{m\gamma\gamma}$ = 18.3±0.6 MeV/c2

Disadvantage:

Non dedicated target → different nuclei contamination → complex interpretation .. but → new features .. K in flight absorption

Data samples analysed

- **2004/2005 KLOE data**: K^- absorption in light nuclei of KLOE materials **(H, ^{9}Be, ^{12}C, ^{4}He)** ~ 2.2 fb^{-1} in total analysed luminosity

- Dedicated **2012** run with pure graphite **Carbon target** inside KLOE 4/6 mm of thickness (~90 pb^{-1}collected; at disposition with good calibration and analyzed 37 pb^{-1})

  → K^- ^{12}C absorptions AT - REST

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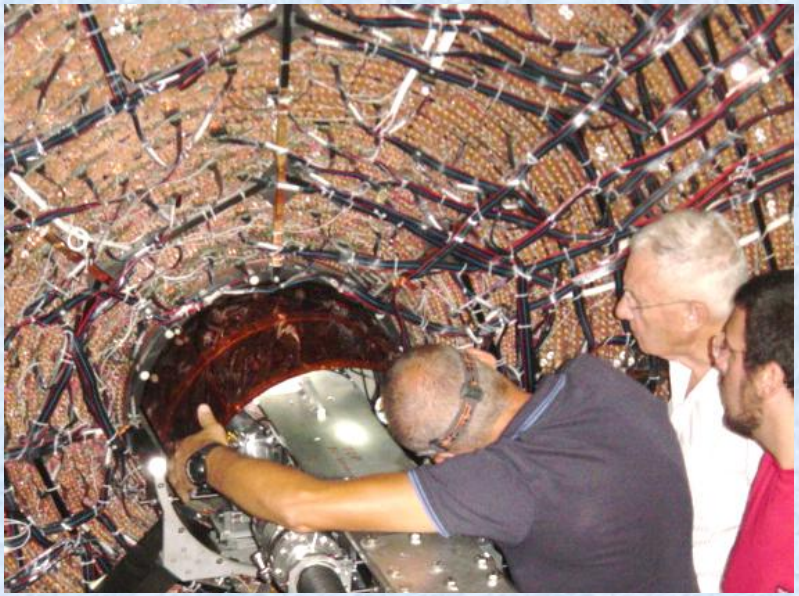
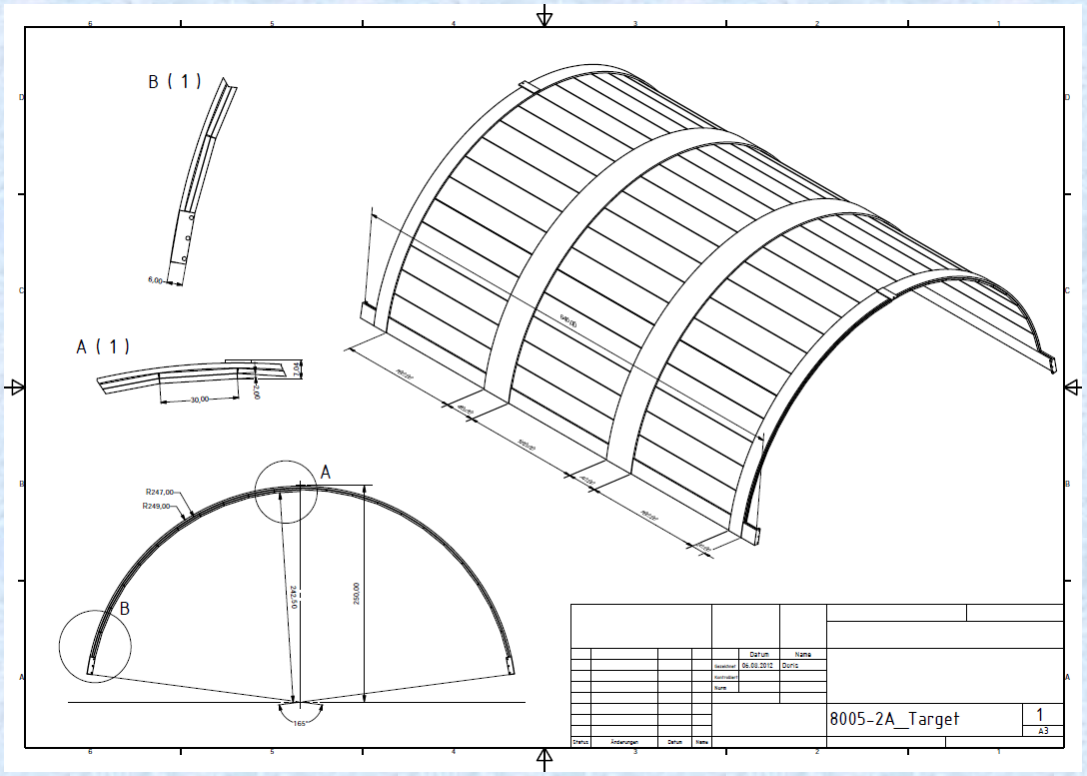




Λp / Λd / Λt scientific case

- study important for the further understanding of aspects of **low-energy QCD in strangeness sector**
- possibility to gain information on the modification of the hadron mass and interaction in nuclear medium
- possibility to study very interesting and in this moment hot topic of **kaonic nuclear clusters** also called …
- **Deeply Bound Kaonic Nuclear States** (as for ex. K^-pp in **Λp** channel and K^-ppn in **Λd** channel are predicted due to the strong KN interaction in the I=0 channel by Wycech (1986) and Akaishi & Yamazaki (2002)
- interpretation strongly depends on **single and multi – nucleon absorption process** which can be studied in this channels

Theoretical and experimental studies

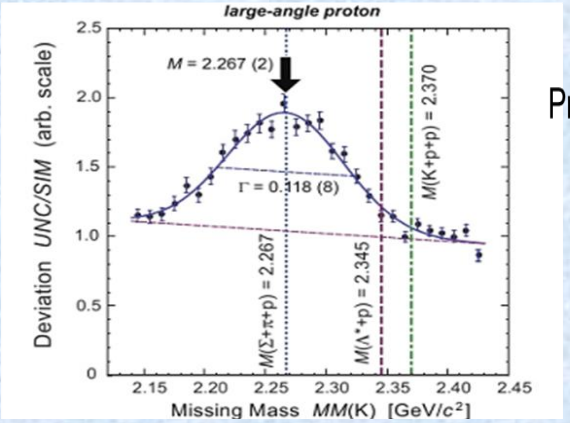
Theoretical work on *K⁻pp*
- It **does** exsist

(MeV)	ATMS Yamazaki & Akaishi, PLB535 (2002) 70.	Variational Dote, Hyodo, Weise, PRC79 (2009) 014003.	Faddeev Shevchenko, Gal, Mares, PRL98 (2007) 082301.	Faddeev Ikeda & Sato, PRC79 (2009) 035201.	Variational Wycech & Green, PRC79 (2009) 014001.
B	48	17-23	50-70	45-80	40-80
Γ	61	40-70	90-110	45-75	40-85

... a K⁻pp puzzle

Experiments:

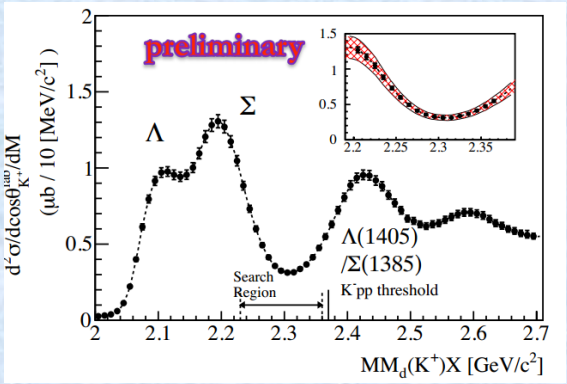
arXiv:0912.5116 [hep-ex]



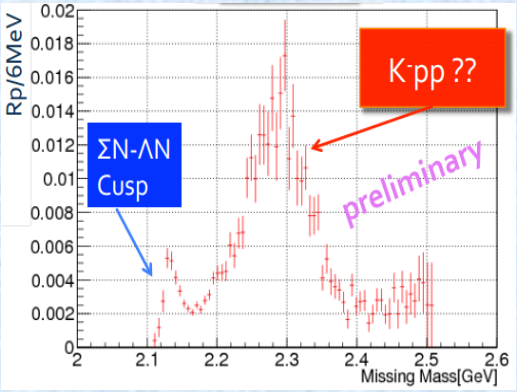
Production via $pp \to pK^+\Lambda$ (2,85 GeV)

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

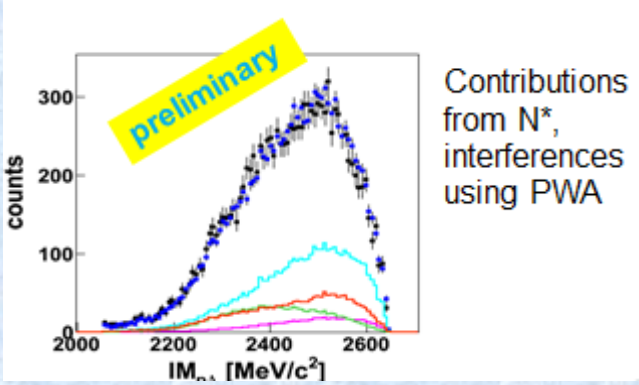
DISTO



LEPS-Spring8



E27 @ J-Parc

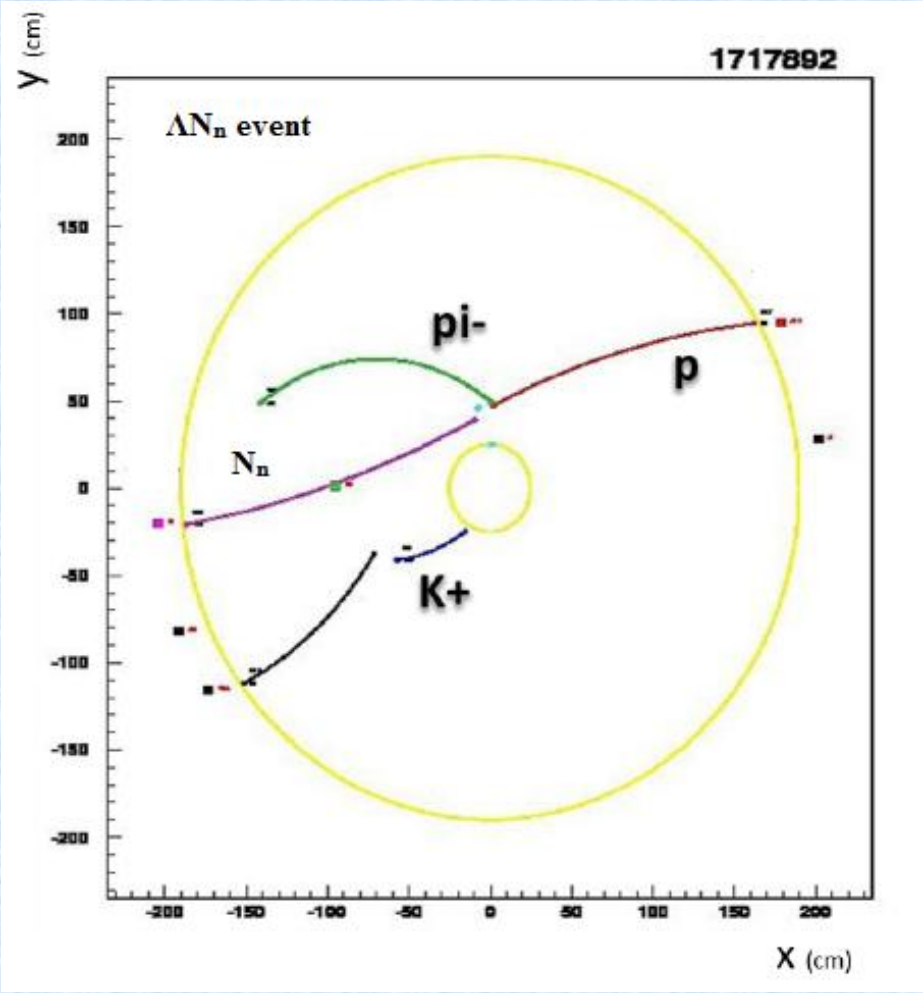


HADES

Λp/d/t channel:
brief info about event selection

Analysis of events in the DC gas volume:

N_n – higher mass particle **= p, d or t**

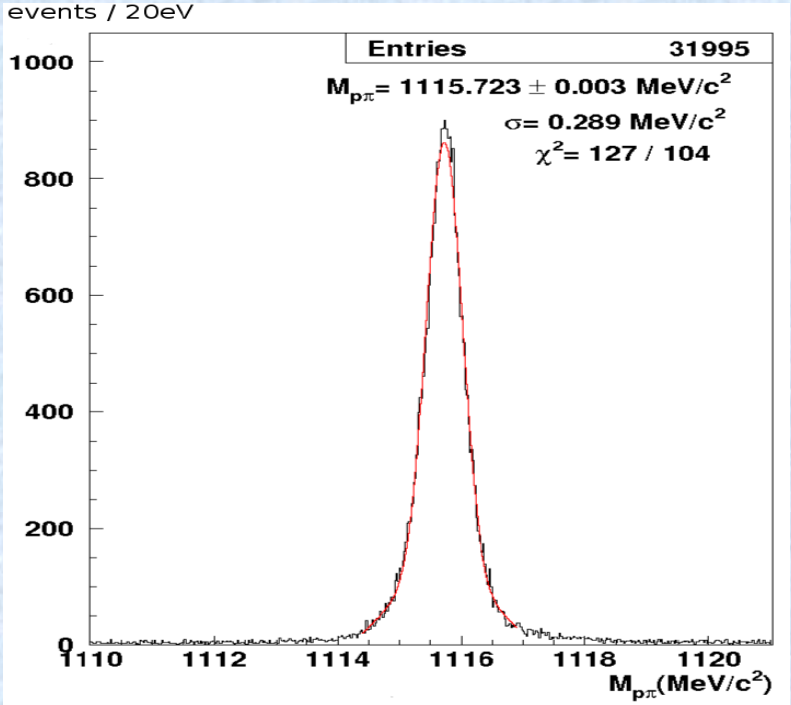


Particle identification via:

- **dE/dx** information in the DC wires
- **E** deposited in the **EMC**

Mass by TOF

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

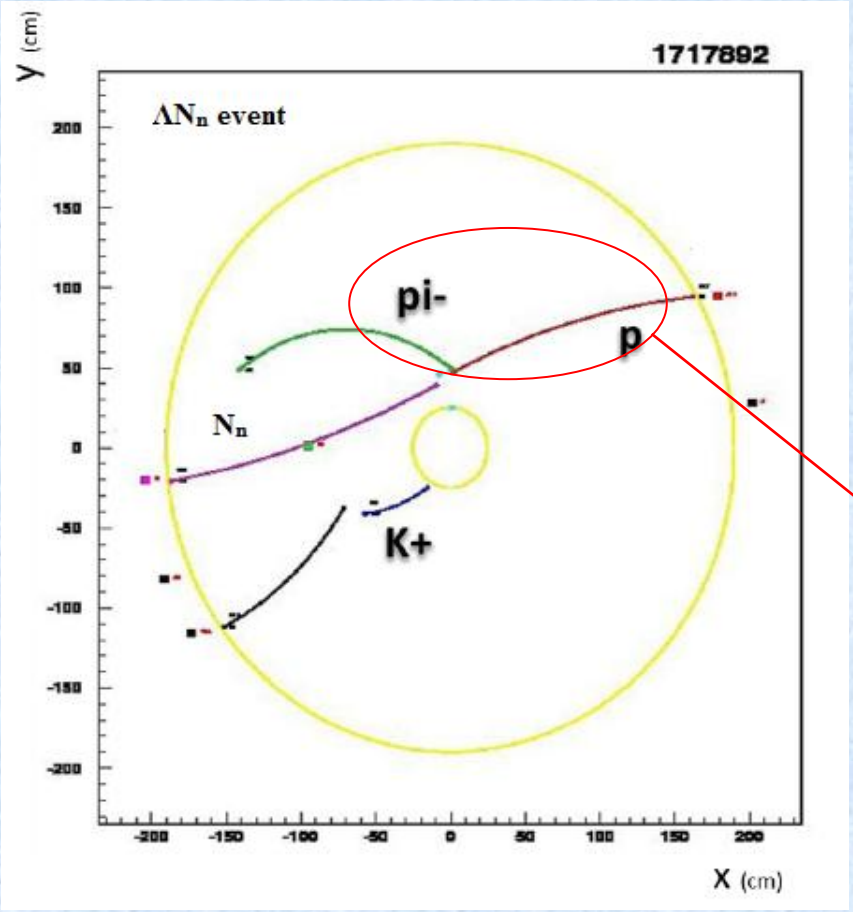


M_{inv} pπ (MeV/c²)

Λp/d/t channel:
brief info about event selection

Analysis of events in the DC gas volume:

N_n – higher mass particle **= p, d or t**



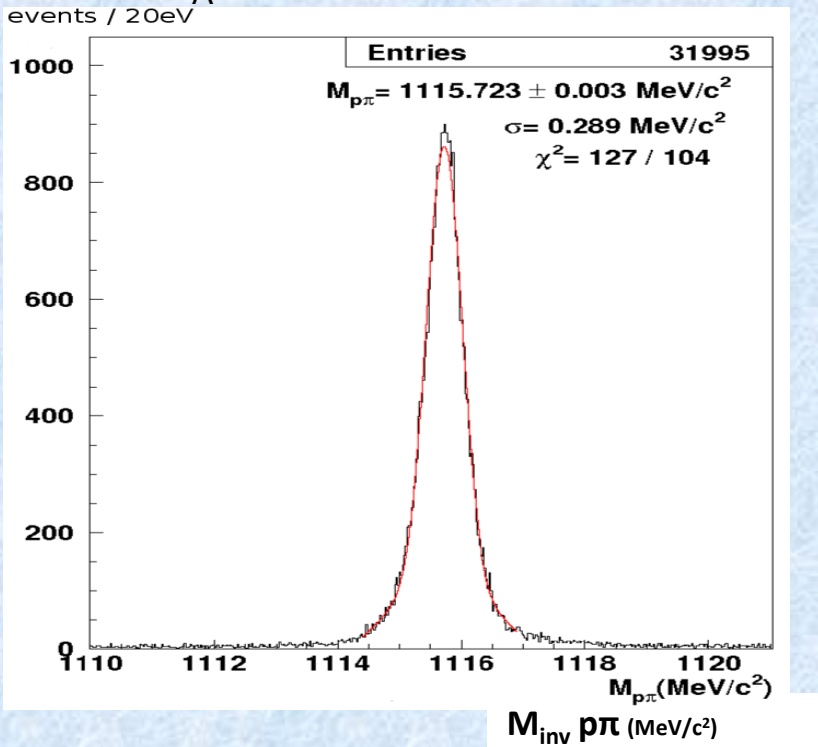
Particle identification via:

- **dE/dx** information in the DC wires
- **E** deposited in the **EMC**

Mass by TOF

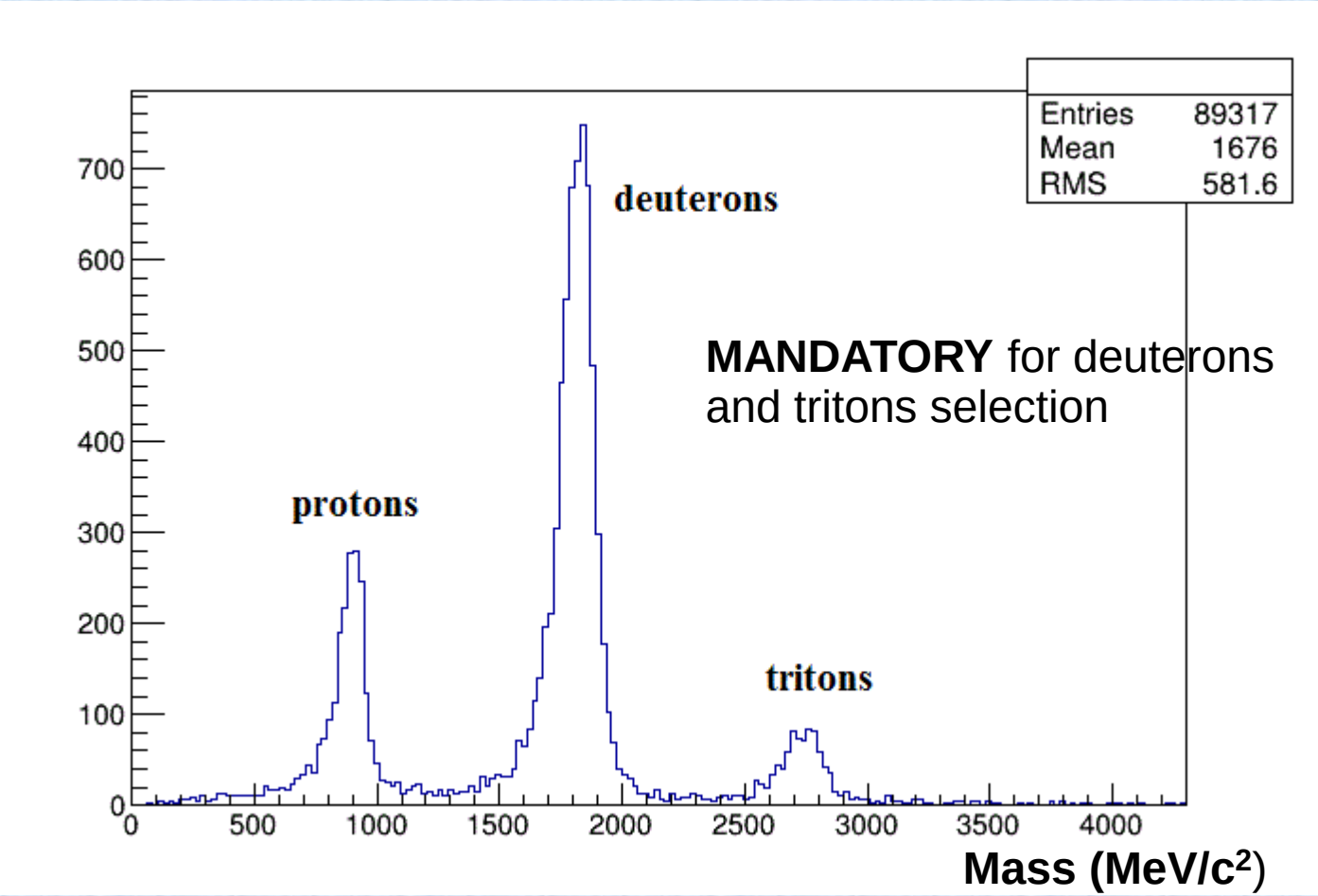
PDG: $M_\Lambda = 1115.683 \pm 0.006 \pm 0.006$

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



Λp/d/t channel:
brief info about event selection – particle ID

Selection in masses obtained by Time of Flight

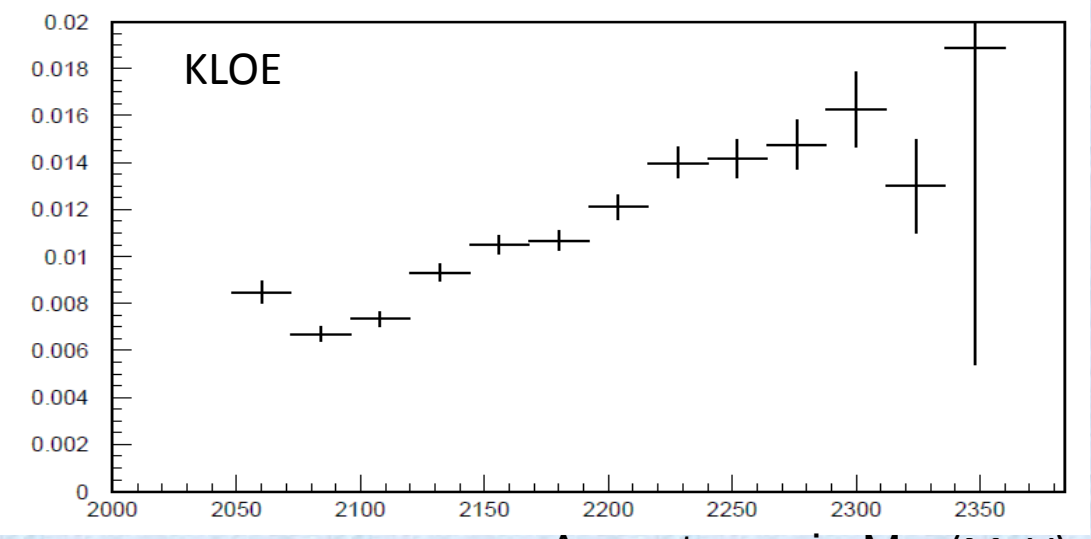


NOT NECCESSARY FOR PROTON SELECTION :

- Protons are associated with EMC cluster, or if no cluster associated
- track reaching the calorimeter region + “proton signature” in the dE/dx of DC gas is requested

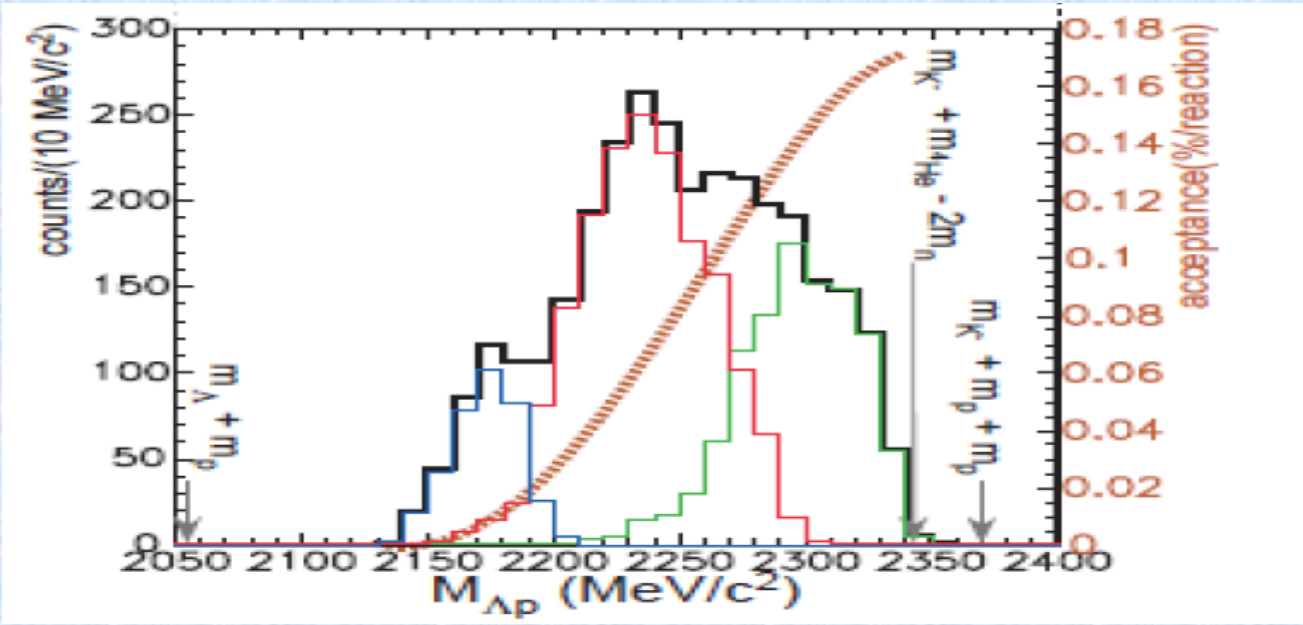
KLOE is the highest acceptance apparatus for these type of studies :

Excellent acceptance of the KLOE detector:



Acceptance in $M_{\Lambda p}$ (MeV)
(arbitrary normalization)

Acceptance study done with phase space
$K^- + {}^4He \rightarrow \Lambda\, p\, n\, n$
MC simulation

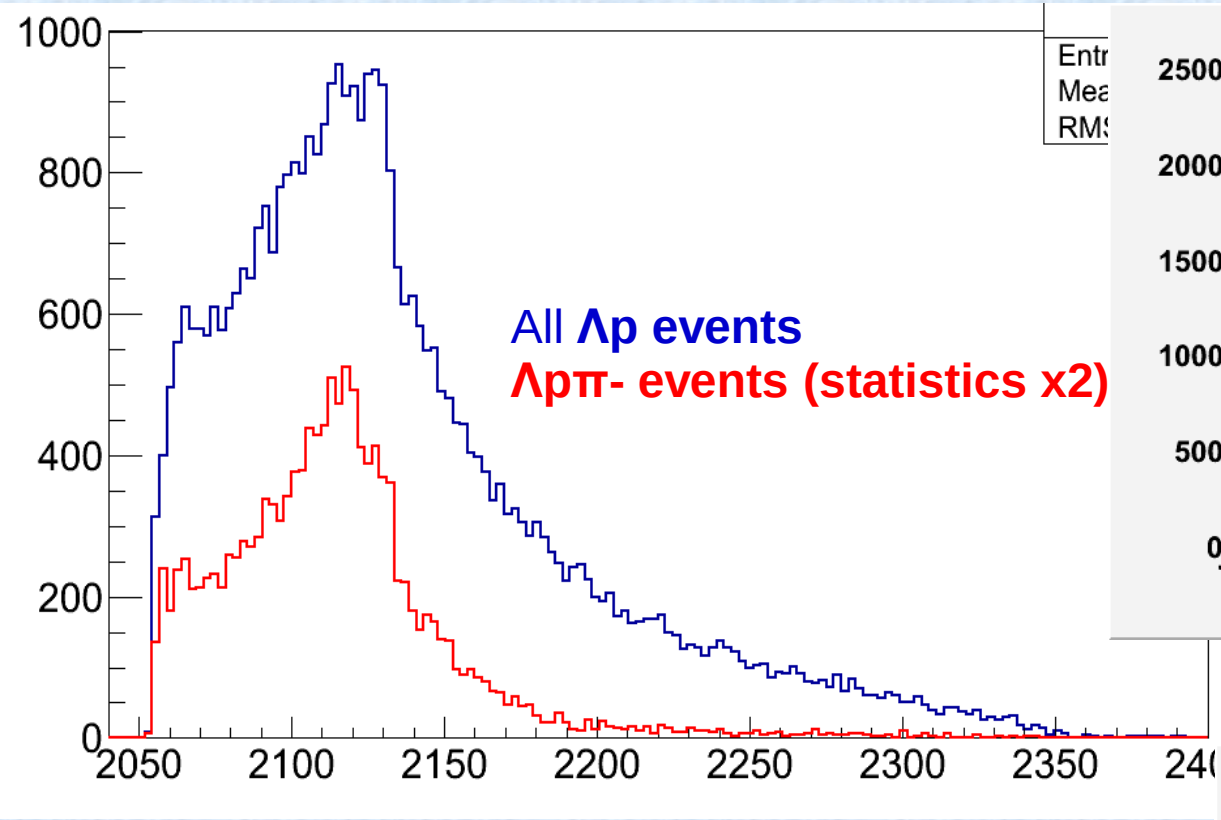


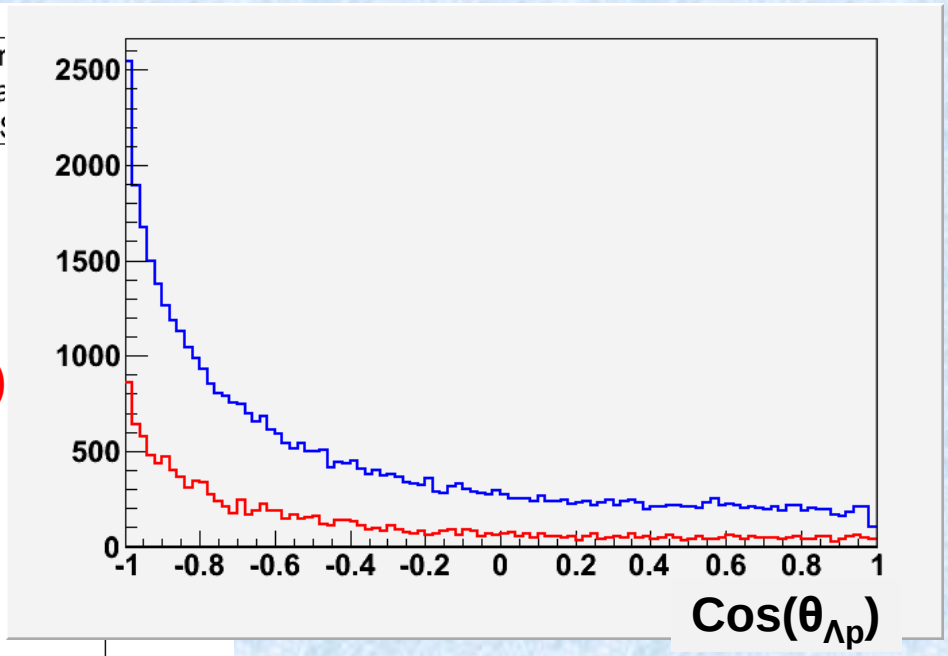
1NA
ΣN/ΛN –DBKS
2NA

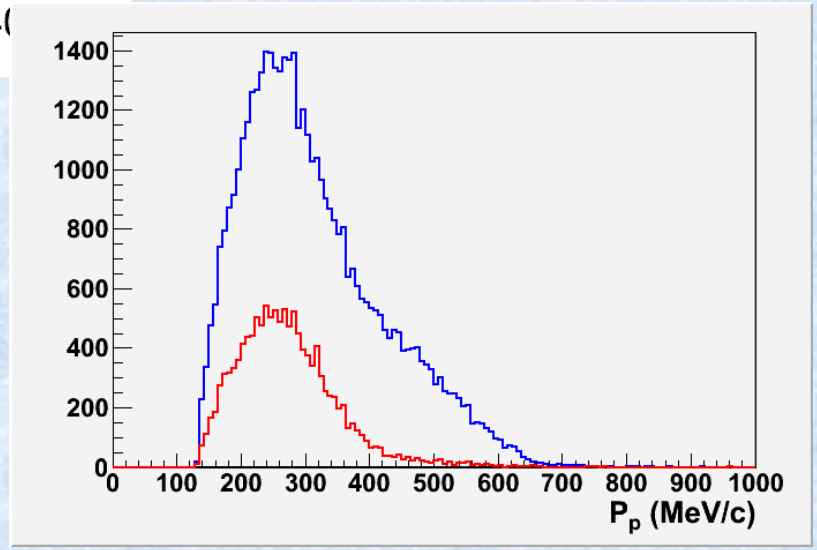
KEK-E549

Mod.Phys.Lett.A23, 2520 (2008)

Λp analysis with KLOE







The presence of a pion is the characteristic signal of a single nucleon absorption:

$K^-n \rightarrow \Sigma\, \pi^-$ + conversion process Σp/Λp

Simulated contributing channels

FINAL PRODUCED PARTICLES

1NA with Σ/Λ conversion:

$K^-N \rightarrow \Sigma\pi + \Sigma p/\Lambda p$ conversion in ^4He

$K^-H \rightarrow \Sigma\pi + \Sigma p/\Lambda p$ conversion in ^{12}C (molecular!)

↓

with the possibility of fragmentation in the conversion process

2NA processes:

$K^-NN \rightarrow \Lambda p$

$K^-NN \rightarrow \Sigma^0 p$ (lost photon)

$K^-NN \rightarrow \Sigma^0 p + \Sigma p/\Lambda p$ conversion in ^4He

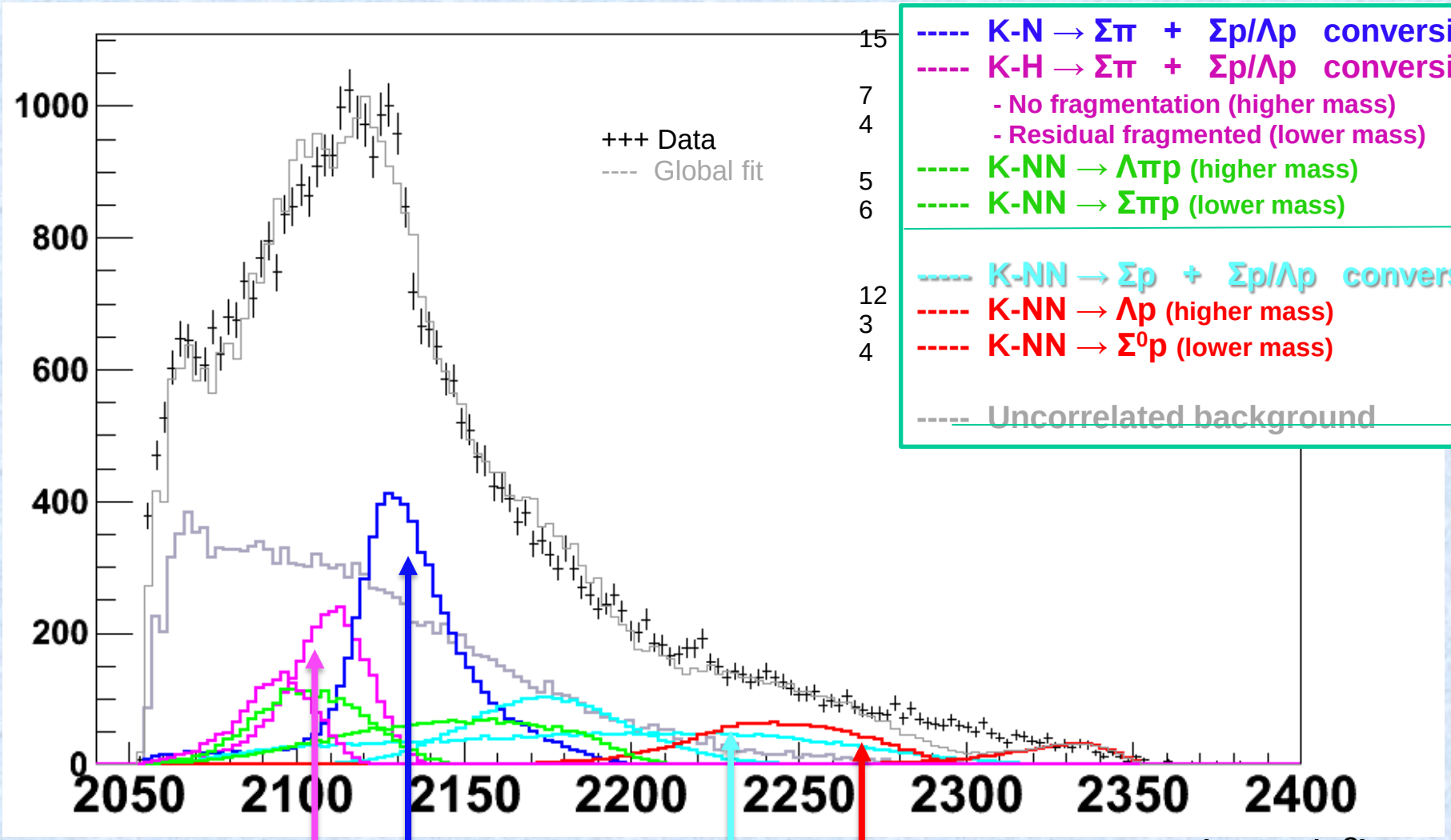
Pionic 2NA modes: $K^-NN \rightarrow Y\pi N$

Uncorrelated processes:

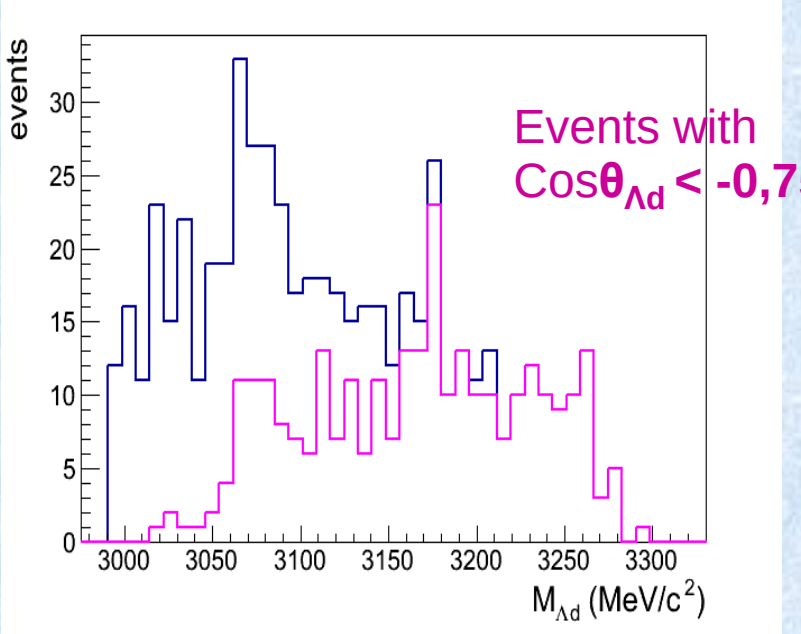
Simulation based in «spectator» protons from Λd correlated events in ^{12}C

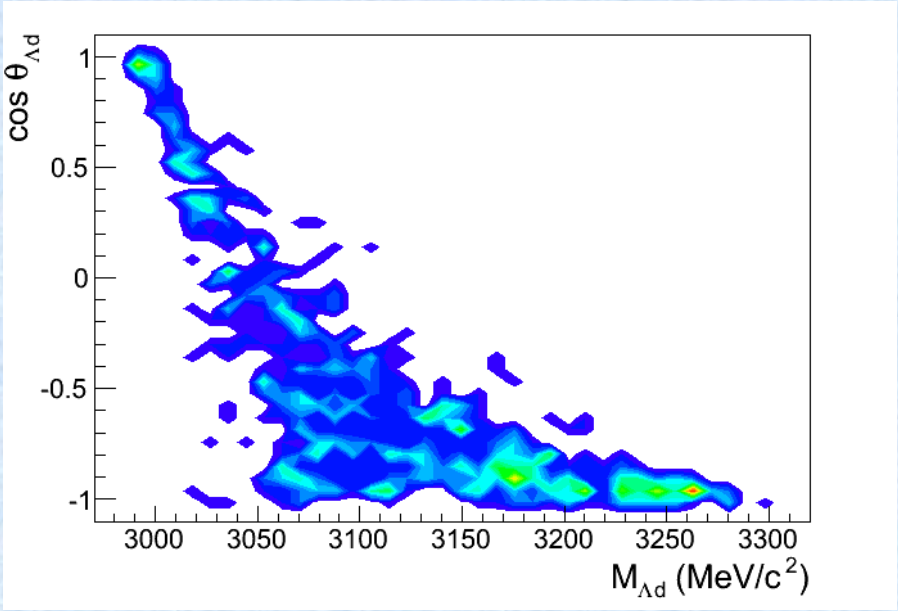
Λp preliminary fit

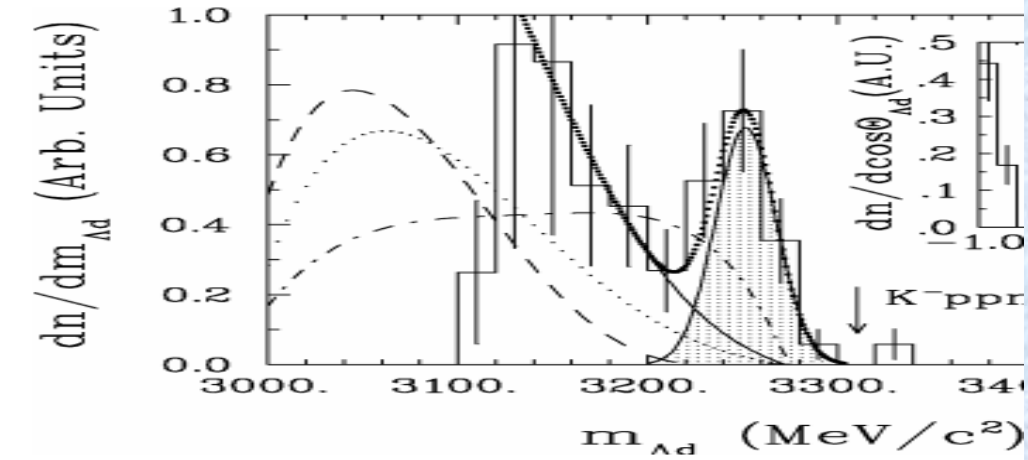
2D fit ($M_{\Lambda p}$, $\cos\theta_{\Lambda p}$)



KLOE data Λd analysis







FINUDA
Phys. Lett. B 654 (2007) 80

572 **Λd** events in the DC gas

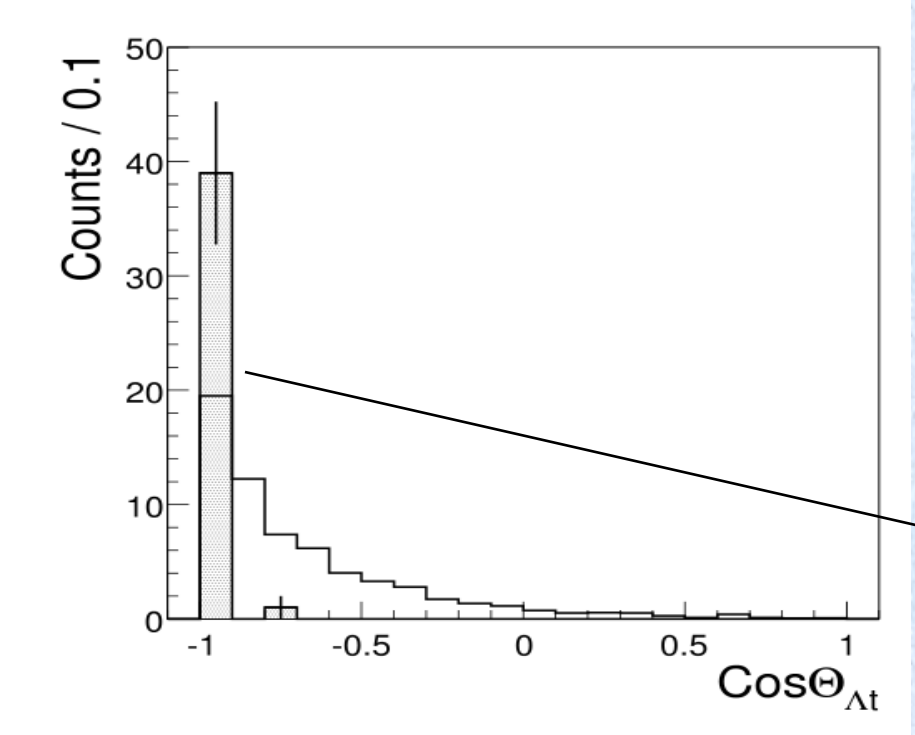
Structures at high mass clearly correlated with back-to-back events

Previous experiments on Λt channel

Only FINUDA and an old bubble chamber experiment [M.Roosen, J.H. Wickens, Il Nuovo Cimento 66, (1981), 101] (**with only 3 events!)** have **published Λt** spectra from K^- absorption

FINUDA presented:

- a study of Λ vs t momentum correlation and an opening angle distribution
- **40 events** collected and added together coming from different targets (Li, Be, C, D_2O)



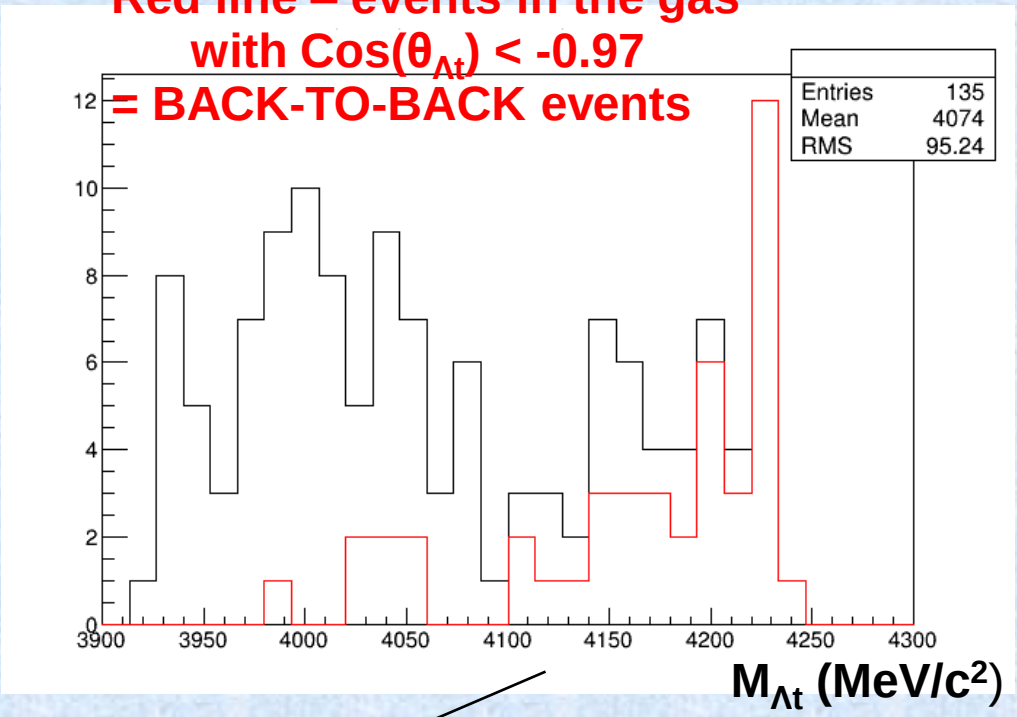
FINUDA Phys.Lett.B 229, 229 (2008)
Filled histogram= data
Open histogram = Phase space simulation

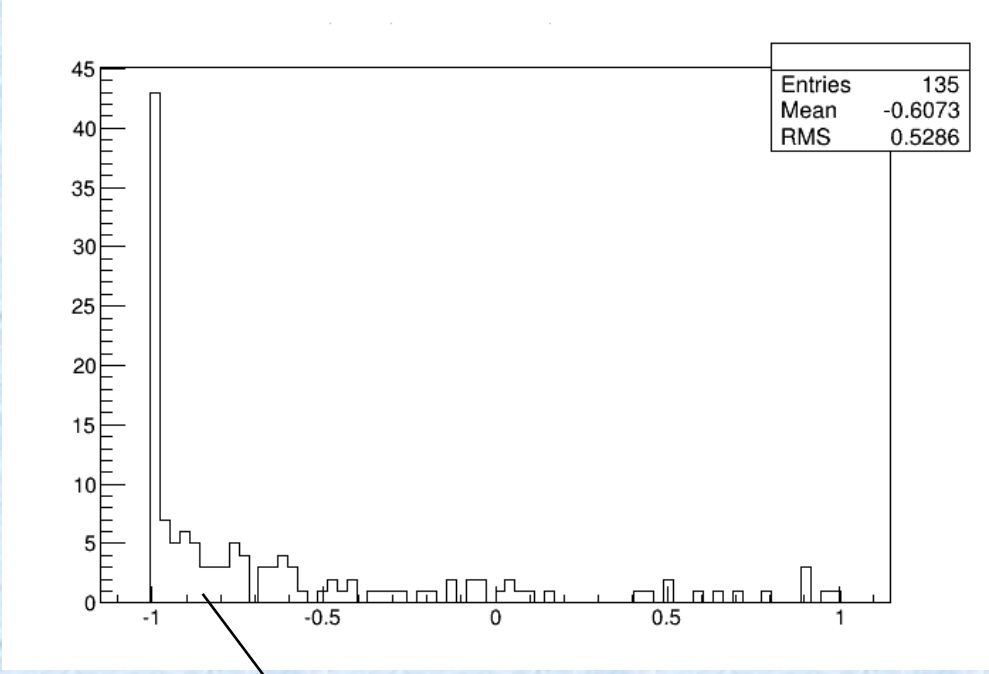
Experimental data showing only back-to-back events

Λt channel analyses with KLOE

Invariant mass spectrum and opening angle distribution of Λt pairs in DC gas

Red line – events in the gas with $Cos(\theta_{\Lambda t}) < -0.97$ = BACK-TO-BACK events





High energy tritons expected to come from the rare **4 NA process**

Clear back-to-back enhancement of the **Λt events**

135 events in gas - highest statistics ever

Λt channel analyses

Processes contributing the Λt spectrum

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

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

→ Most probable processes to contribute the spectra, but…
have too low momentum to be obseved
(tritons are required to have a cluster in EMC (i.e. P>500 MeV))

exclusive pionless 4NA processes:

$K^- {}^4He \rightarrow \Lambda t$

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

Conversion on triton:

$K^- {}^4He \rightarrow \Sigma^0 \pi^{-0} t$, $\Sigma^0 t$ / Λt

When the spectra will be fitted we shall see if there is still room for a possible **K^-ppnn** kaon nuclear cluster signal

Λ(1405) scientific case

Λ(1405) : mass = $1405.1^{+1.3}_{-1.0}$ MeV, width = 50 ± 2 MeV

I = 0, S = 1 , J^p = ½⁻ , **Status: **** , strong decay into Σπ**

Its nature has been a puzzle for decades: three quark state, unstable KN bound state, pentaquark, two poles??

Chiral unitary models: Λ(1405) is an I = 0 quasibound state emerging from the coupling between the KN and the Σπ channels. Two poles in the neighborhood of the Λ(1405) :

two poles: (z1 = 1424+7-23– i 26+3-14 ; z2 = 1381+18-6– i 81+19-8) MeV

mainly coupled to KN mainly coupled to Σπ → line-shape depends on production mechanism

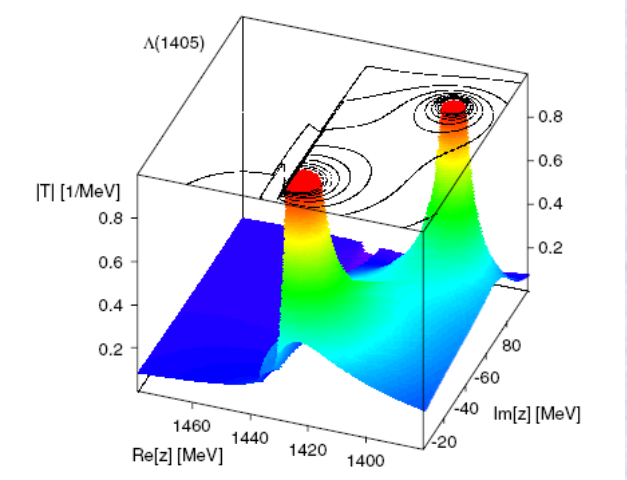
$$\frac{d\sigma(\Sigma^-\pi^+)}{dM} \propto \frac{1}{3}|T^0|^2 + \frac{1}{2}|T^1|^2 + \frac{2}{\sqrt{6}}Re(T^0T^{1*})$$

$$\frac{d\sigma(\Sigma^+\pi^-)}{dM} \propto \frac{1}{3}|T^0|^2 + \frac{1}{2}|T^1|^2 - \frac{2}{\sqrt{6}}Re(T^0T^{1*})$$

Line-shape also depends on the decay channel

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

observed in only
3 experiments …
with different line-shapes!



Pure I=0 (free from Σ(1385) background)

Latest results: CLAS & HADES

Measurement of the Σπ photoproduction line shapes near the Λ(1405)

CLAS Collaboration (K. Moriya *et al.*) *Visualizza tutti i 155 autori*

Jan 2013 - 24 pages

Phys.Rev. C87 (2013) 035206
(2013-03-15)
DOI: 10.1103/PhysRevC.87.035206
JLAB-PHY-13-1690
e-Print: arXiv:1301.5000 [nucl-ex] | PDF

Investigation of the Lambda(1405) line shape observed in pp collisions

Johannes Siebenson, Laura Fabbietti (Munich, Tech. U., Universe)

Jun 21, 2013 - 8 pages

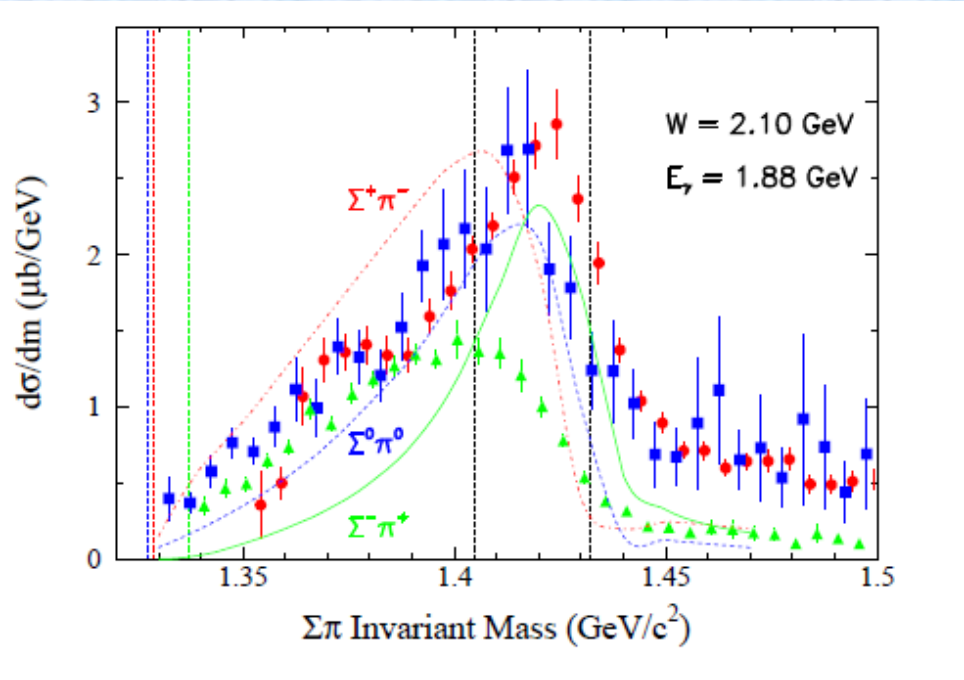
e-Print: arXiv:1306.5183 [nucl-ex] | PDF

Determination of the $\Sigma(1385)^0/\Lambda(1405)$ ratio in p+p collisions at 3.5 GeV

E. Epple, L. Fabbietti (Munich, Tech. U.)

Feb 2012 - 7 pages

Hyperfine Interact. 210 (2012) 45-51



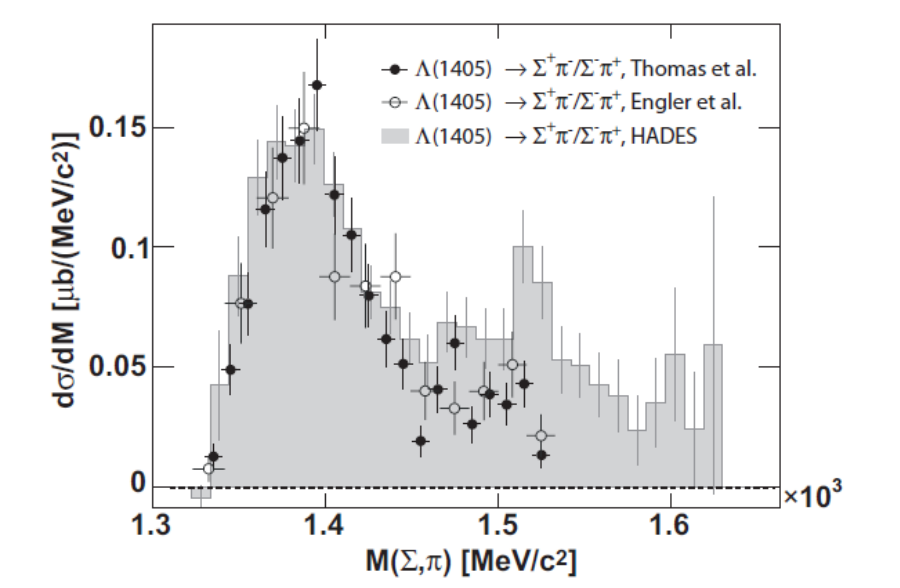


FIG. 1. Comparison between the HADES data and the data of [6] and [7], measured in $\pi^- + p$ reactions. All three spectra show the sum of the $\Sigma^+\pi^-$ and $\Sigma^-\pi^+$ data samples.

First parallel measurement of Λ(1405) lineshape in all 3 Σπ channels

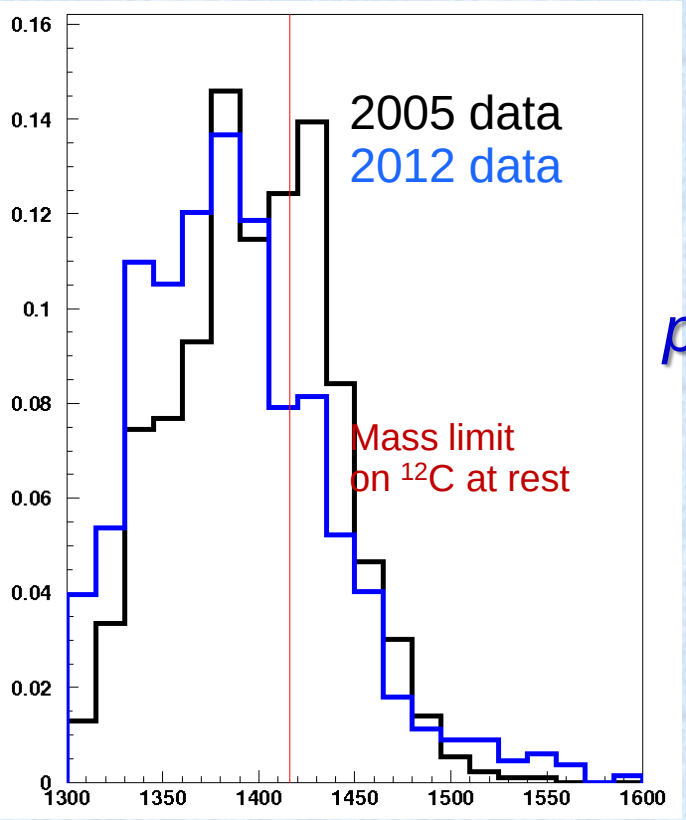
different reactions
and higher momentum

Measurement of the Isospin interference contribution via the $\Sigma^+\pi^-$ / $\Sigma^-\pi^+$ ratio and of the Σ*/Λ* ratio

$\Sigma^0\ \pi^0$ channel

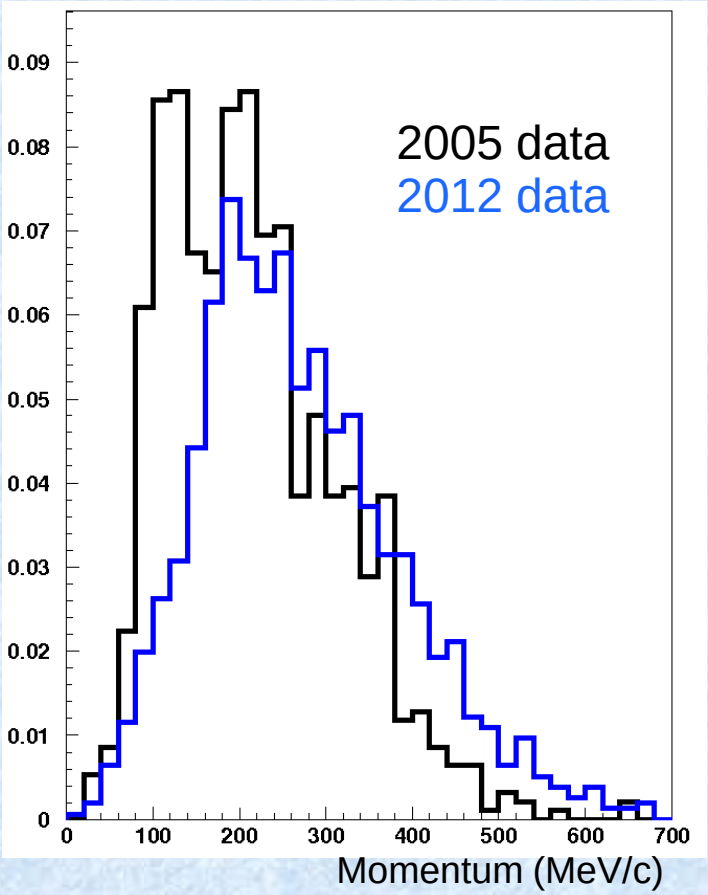
$\Lambda(1405)$ signal searched by K^- interaction with a bound proton in Carbon
$K^-\ p \rightarrow \Sigma^0\pi^0$ detected via: $(\Lambda\gamma)(\gamma\gamma)$
Strategy : K^- absorption in the DC entrance wall, mainly 12C with H contamination (epoxy)

N.U.



preliminary

N.U.



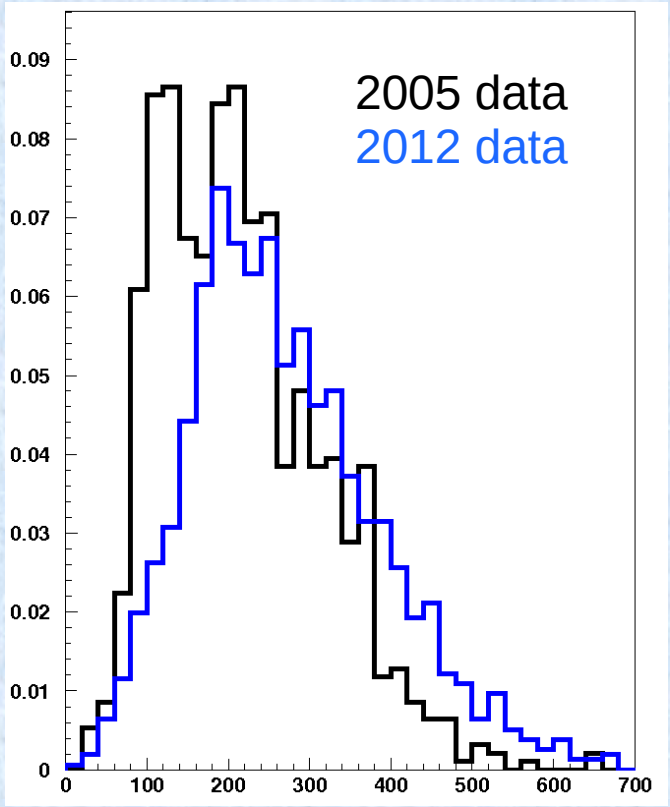
$m_{\pi 0 \Sigma 0}$ **resolution** $\sigma_m \approx 32\ \mathrm{MeV/c^2}$; $p_{\pi 0 \Sigma 0}$ **resolution:** $\sigma_p \approx 20\ \mathrm{MeV/c}$.

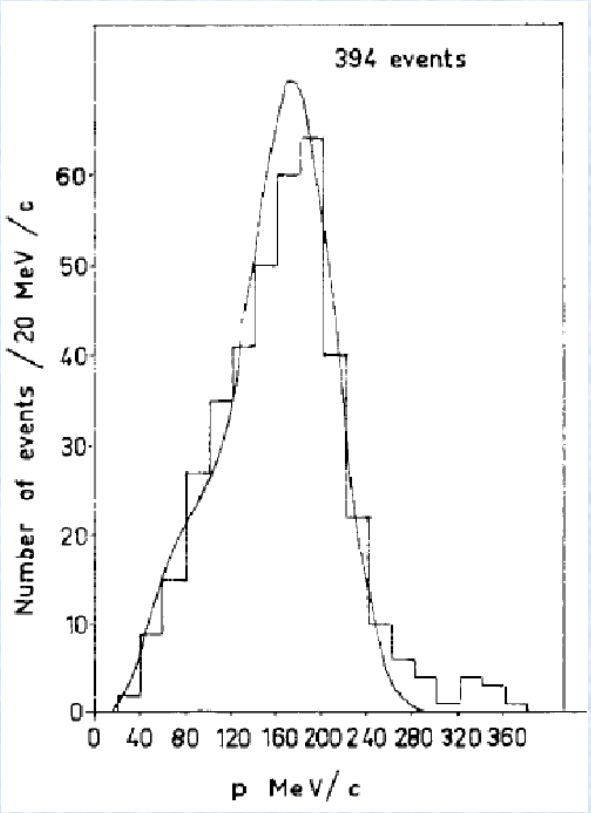
Negligible $(\Lambda\,\pi^0$ **+ internal conversion) background = (3±1) % → no I=1 contamination**

Comparison with K^- absorption in emulsion

A higher invariant mass region is opened

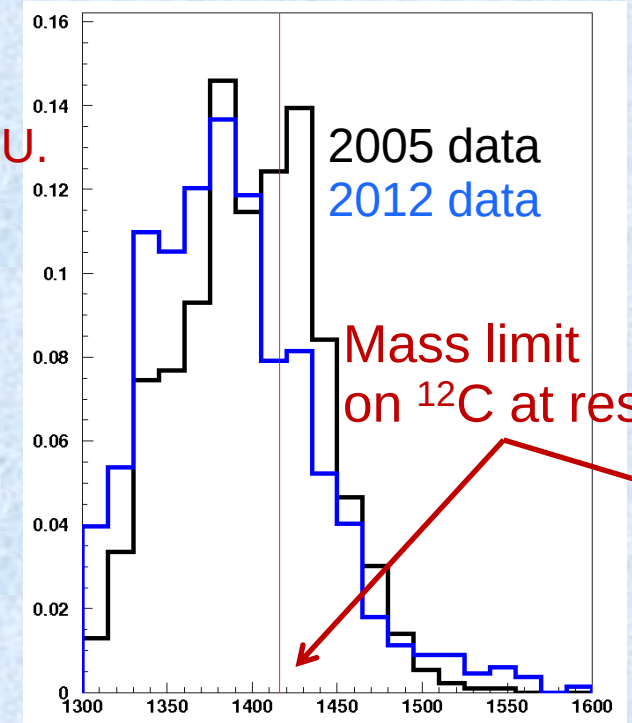
N.U.



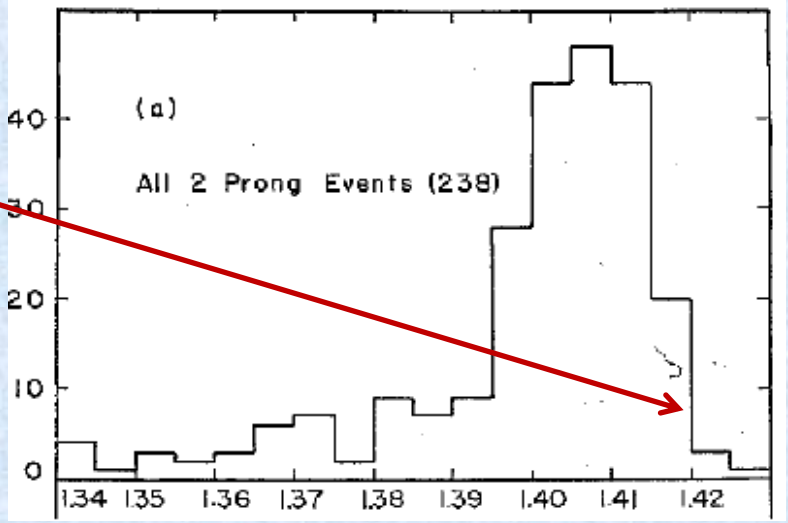


Momentum (MeV/c)

N.U.



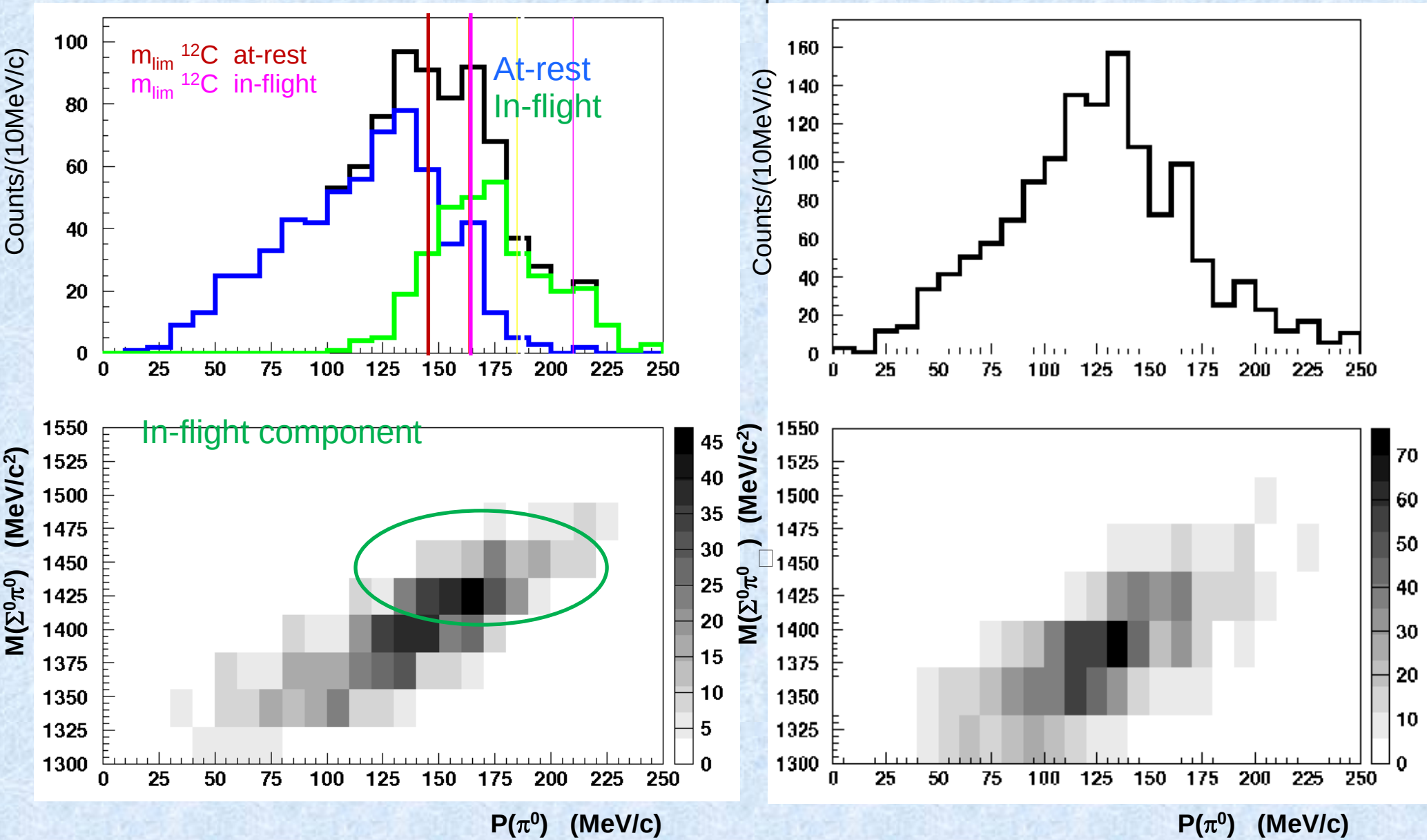
Mass limit on ^{12}C at rest



Invariant Mass (MeV/c^2)

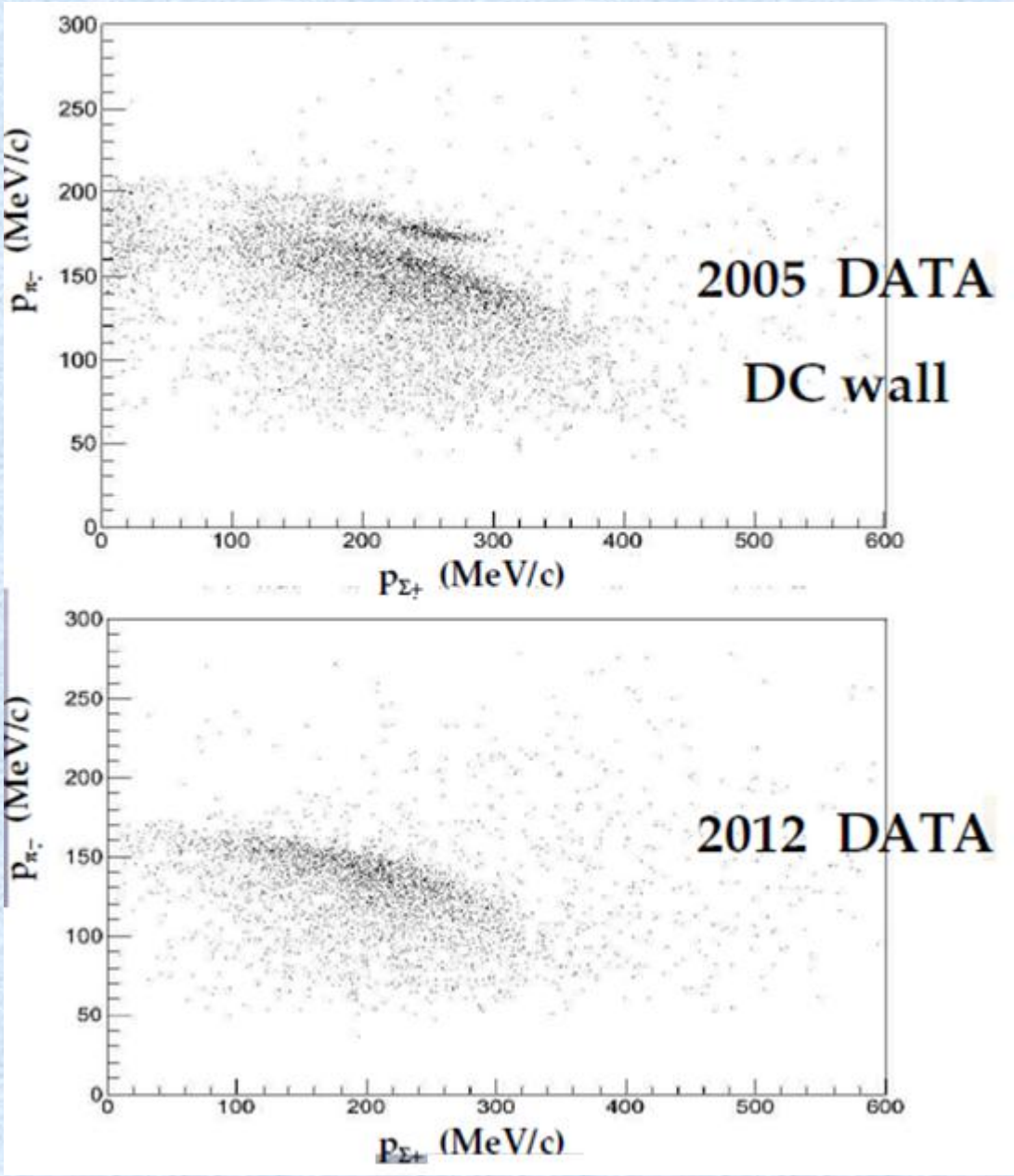
$\Sigma^0\ \pi^0$ channel : the π^0 momentum

$P(\pi^0)$ resolution: $\sigma_p \approx 12$ MeV/c



$P(\pi^0)$ could be used for in-flight/at-rest separation

$\Sigma^+ \pi^-$ channel



$K^- H \rightarrow \Sigma\pi$
Is peaked at around 1430 MeV

K^- H interaction probability estimate based on **K^- interaction**
AT REST in hydrocarbons mixture data (Lett. Nuovo Cimento, C 1099 (1972))

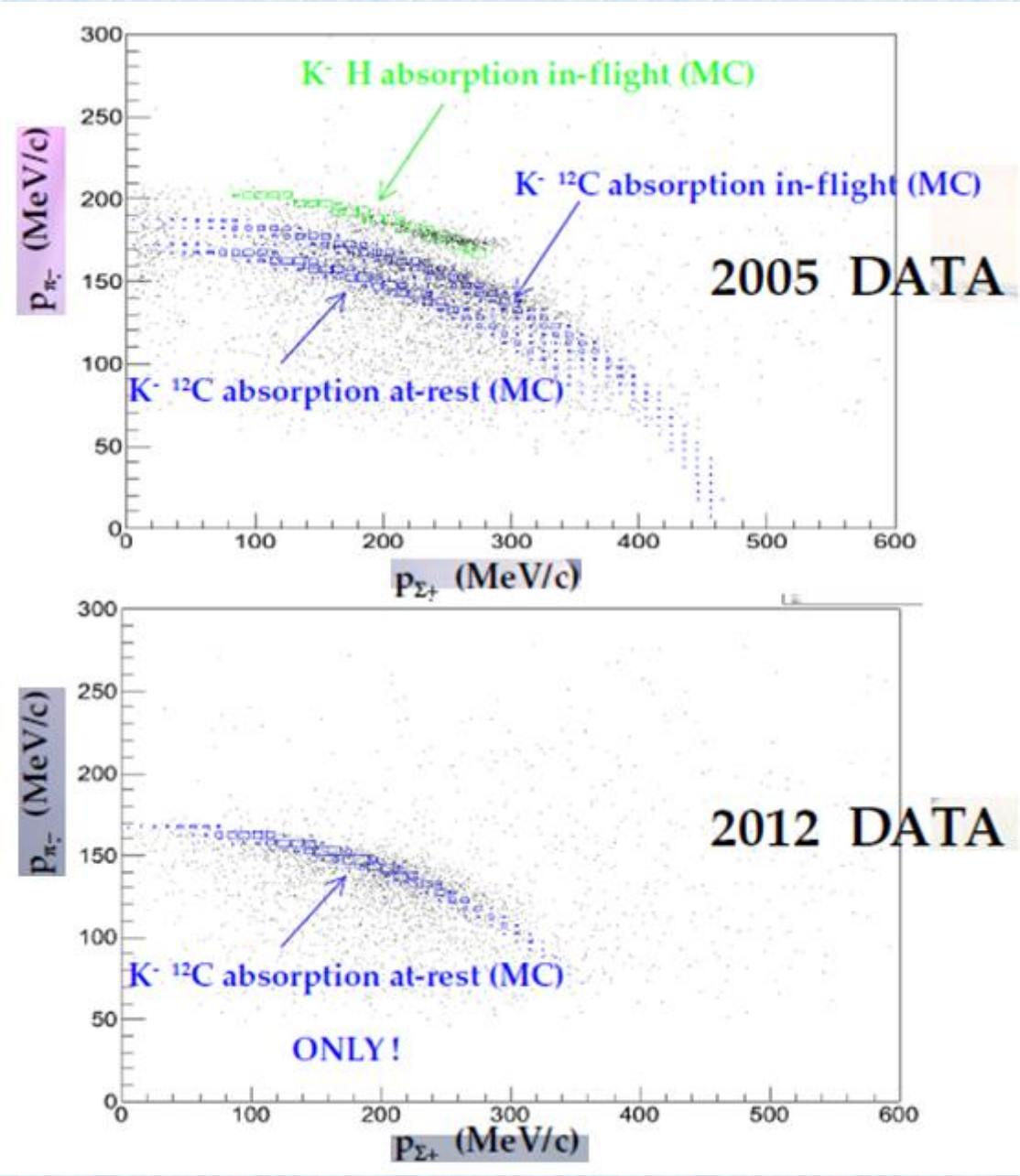
= **order of 1%**

Thanks to the excellent p_{π^-} resolution

< 1 MeV

. . .

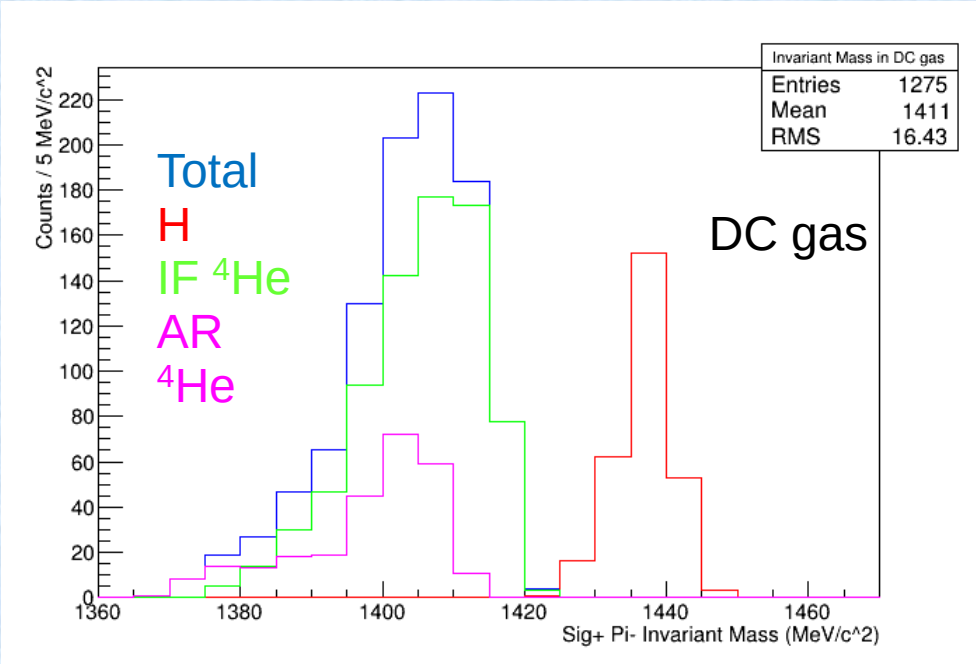
$\Sigma^+ \pi^-$ channel

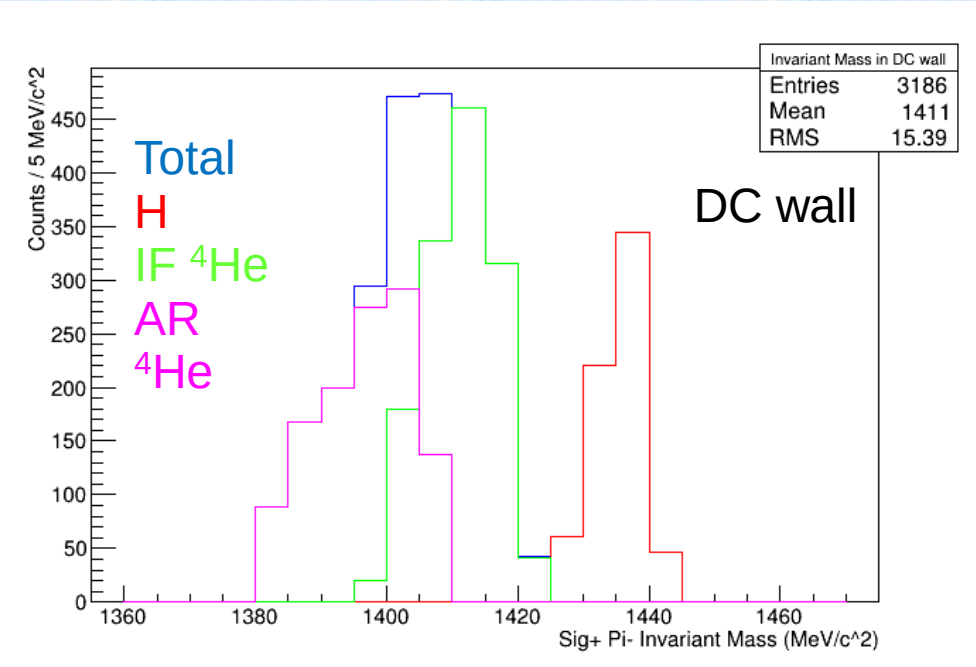


K^- H contribution ~ 20%

… in flight absorption is extremely different!

$\Sigma^+ \pi^-$ invariant mass spectra: at rest / in flight





Removing the H component is fundamental since it behaves like a high mass pole

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

If resonant component is important a high mass component appears

Conclusions and perspectives

- Search for the kaonic nuclear clusters:

  fit of the **Λp** spectrum close to conclusive, refinement in the analyses in **Λd** channel ongoing, **Λt** channel – highest statistic ever

- Excellent possibility to make a **study of single and multi nucleon absorption processes** in these channels

- **Quantitative information that can be extracted:**
  - 1NA/2NA absolute rate per stopped kaon in ^{4}He
  - 1NA/2NA Σ-Λ conversion rates

- **Qualitative information:**

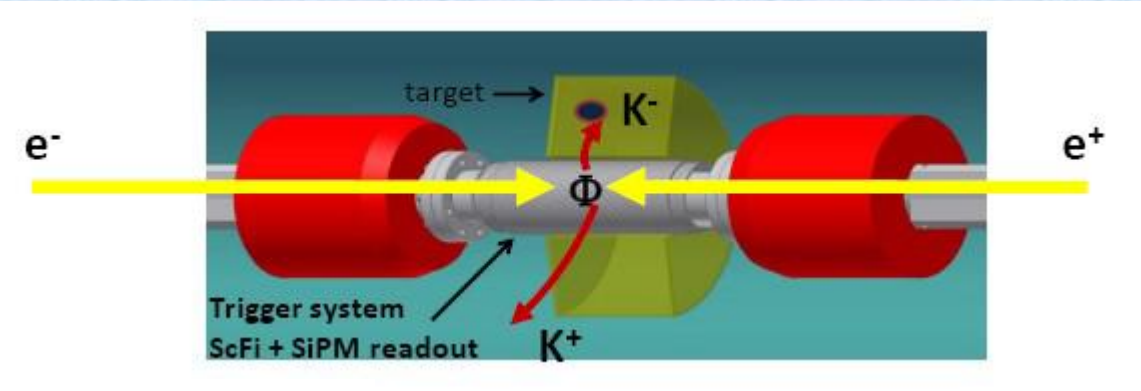
  1NA shape

  - m(Σπ) spectra show a high invariant mass component → associated to in-flight K^- capture
  - Preliminary **$\Lambda\pi^-$** first measurement of RES/NON-RES ratio in nuclear K- absorption

Conclusions and perspectives

AMADEUS experiment:

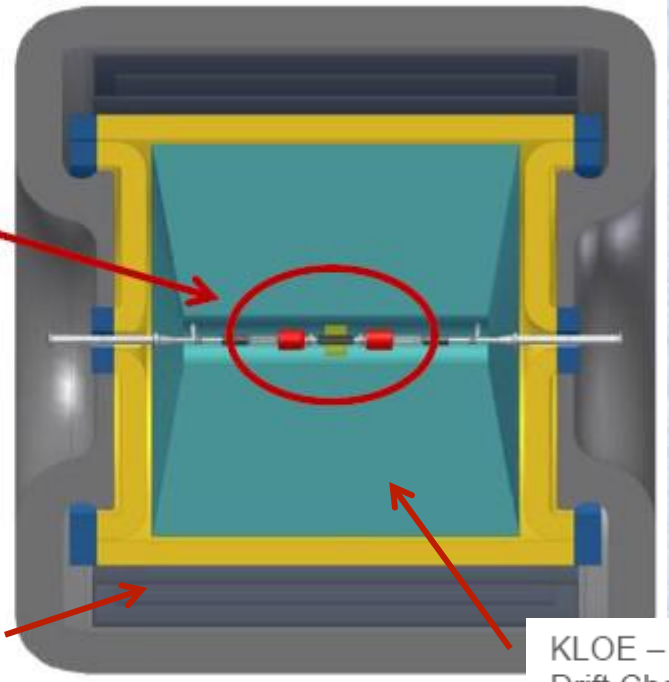
Implementation of dedicated solid targets & cryogenic gaseous targets (H, d, ^{3}He, ^{4}He) inside the KLOE DC

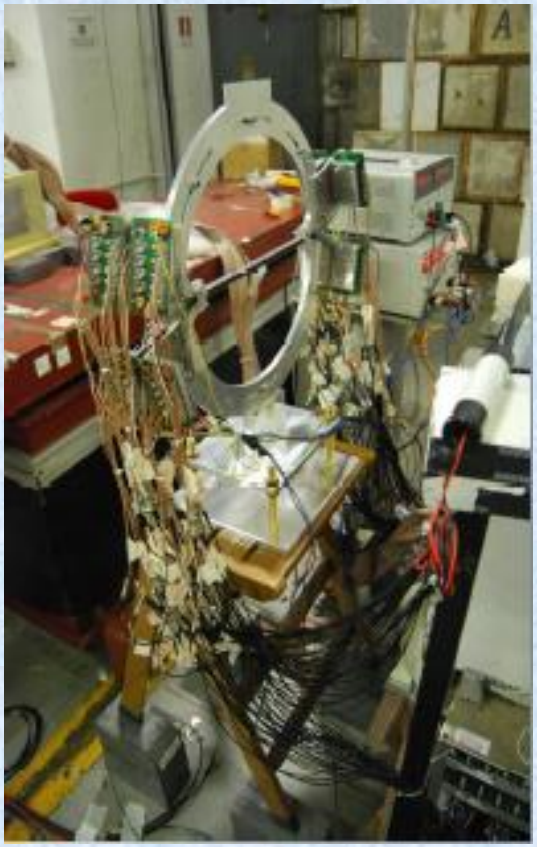


•The AMADEUS setup will be implemented in the 50 cm. gap in KLOE DC around the beam pipe:

•Target (A gaseous He target for a first phase of study)

•Trigger (1 or 2 layers of ScFi surrounding the interaction point)





R&D activity ongoing:
more refined setup: ScFi + SiPM (trigger system) TPC – GEM (inner tracker)

Thank you

Spare slides

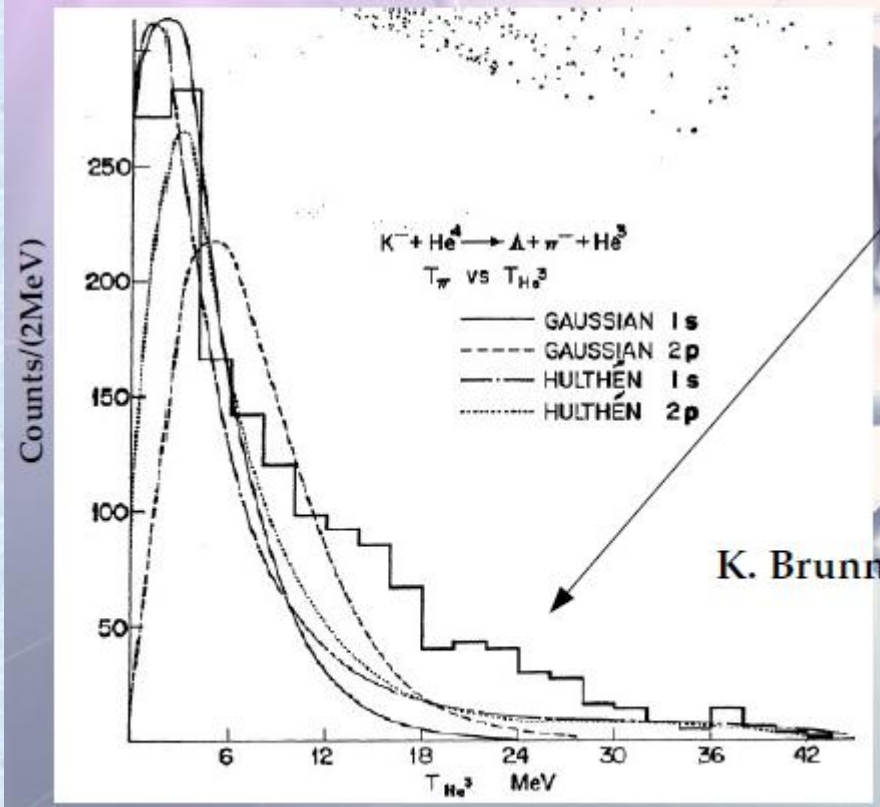
Resonant vs non-resonant issue:

How much comes from resonance : $K^-N \rightarrow (Y^* \ ?) \rightarrow Y\pi$

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)

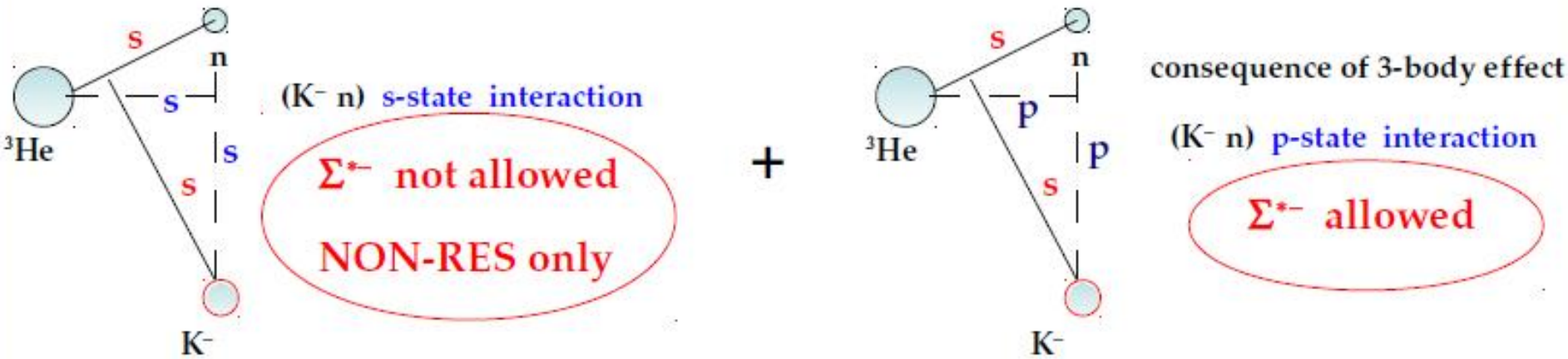
K. Brunnel et al., Phys.Rev. D2 (1970) 98

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 are assumed →

${}^4He$ 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^-

- Fit of the $p_{\Lambda\pi^-}$ observed distribution using calculated distributions :

$$P_s^{\,s}(p_{\Lambda\pi}) = |\Psi_N(p_{\Lambda\pi})|^2 \; |f^{\,s}(p_{\Lambda\pi})|^2 \; \rho \qquad \text{non-resonant}$$

$$P_s^{\,p}(p_{\Lambda\pi}) = |\Psi_N(p_{\Lambda\pi})|^2 \; c^2 \; |2f^{\,\Sigma*}(p_{\Lambda\pi})|^2 \; \rho/3 \; (kp_{\Lambda\pi})^2 \qquad \text{resonant}$$

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

↓

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

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

Calculated primary hadronic interactions:

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

- At-rest : S-wave non-Res / P-wave $\Sigma(1385)$ Res
- In-flight : S-wave non-Res / P-wave $\Sigma(1385)$ Res

$K^- \, {}^4He \rightarrow \Sigma^0 \, \pi^- \, {}^3He$

- At-rest : S-wave non-Res / P-wave $\Sigma(1385)$ Res
- In-flight : S-wave non-Res / P-wave $\Sigma(1385)$ Res

$K^- \, {}^4He \rightarrow (\Sigma \, \pi)^0 \, {}^3H$

- At-rest : S-wave non-Res / S-wave $\Lambda(1405)$ Res / P-wave $\Sigma(1385)$ Res
- In-flight : S-wave non-Res / S-wave $\Lambda(1405)$ Res / P-wave $\Sigma(1385)$ Res

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

K^-

Simultaneous fit ($p_{\Lambda\pi^-}$ - $m_{\Lambda\pi^-}$ - $\theta_{\Lambda\pi^-}$) leaving the ratio At-rest /In-flight and ^{12}C contamination to vary around the estimated values within errors:

Global fit

$\Lambda \pi^-$ At-rest N-R

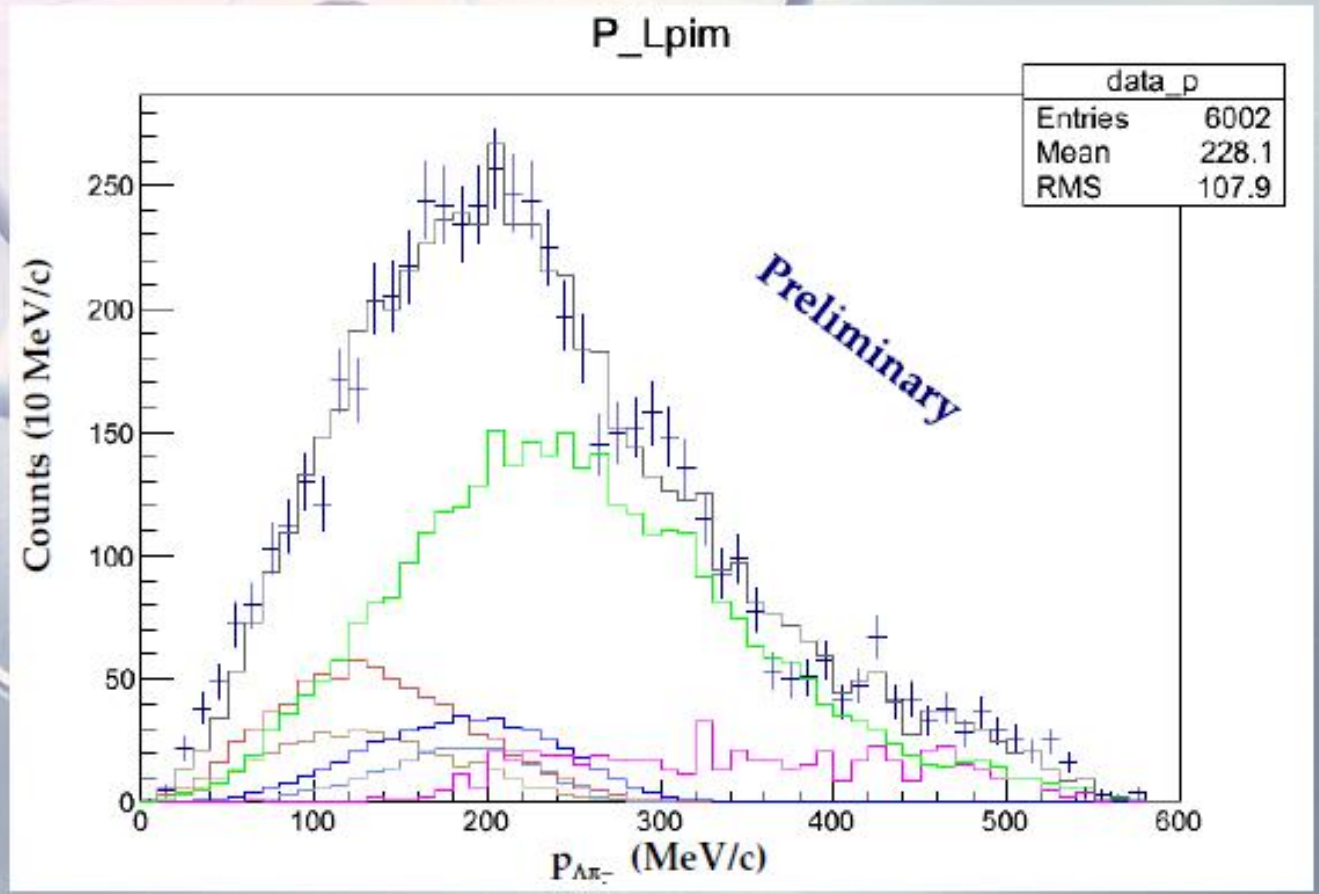
$\Lambda \pi^-$ At-rest RES

$\Lambda \pi^-$ In-flight N-R

$\Lambda \pi^-$ In-flight RES

$\Lambda \pi^-$ events from $K^- \ ^{12}C$

Σ p/n $\rightarrow$ Λ p/n conversion



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

Simultaneous fit ($p_{\Lambda\pi^-}$ - $m_{\Lambda\pi^-}$ - $\theta_{\Lambda\pi^-}$) leaving the ratio At-rest /In-flight and ^{12}C contamination to vary around the estimated values within errors:

- χ^2/ (ndf – np) = 1.2
- **(At-rest RES)/(At-rest N-R) = 0.6 ± 0.06**
- **(In-flight RES)/(In-flight N-R) = 0.6 ± 0.3**

Preliminary

- (In-flight) / (At-rest) = 1.9 ± 0.5
- Σ p/n → Λ p/n conversion = (9.6 ± 0.8)%
- $\Lambda \pi^-$ events from $K^- \ ^{12}C$ = (57 ± 1)%

Ongoing

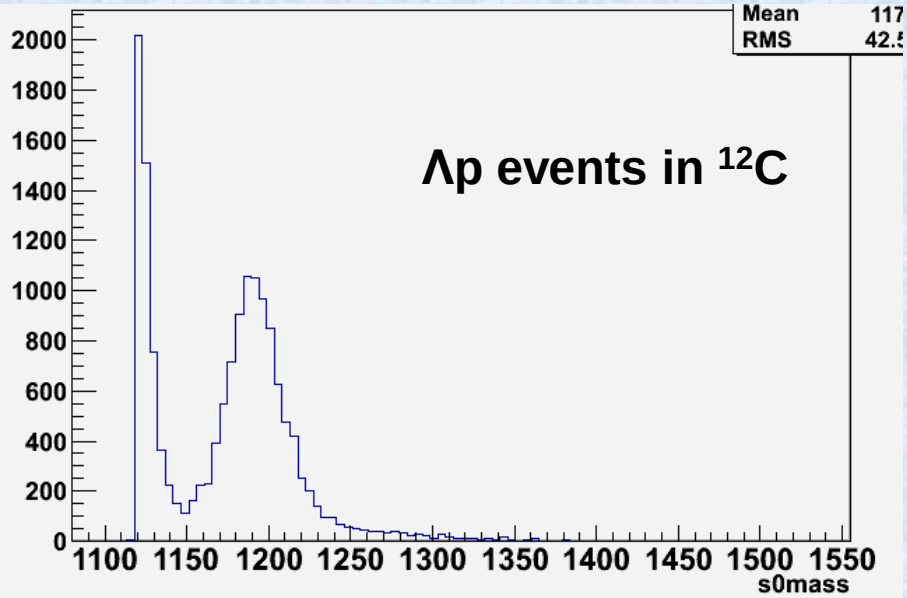
Is there room for a 2NA pionic mode?

$K^-NN \rightarrow Y\pi N$

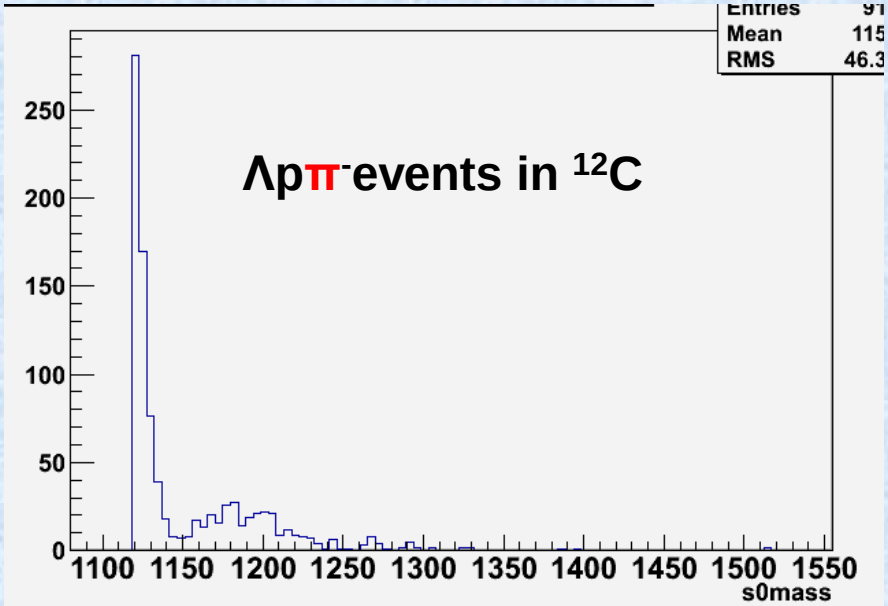
The preliminary fits find possible contribution for this processes (~ 5%)

$\Sigma^0 p$ – signature of the 2NA process

$\Lambda\gamma$ invariant mass spectra



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



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

Acceptance study with phase space
$K^- + {}^4He \rightarrow \Lambda\, p\, n\, n$ MC simulation

$$A = A(P_{\Lambda p}, \theta_{\Lambda p}, M_{\Lambda p})$$

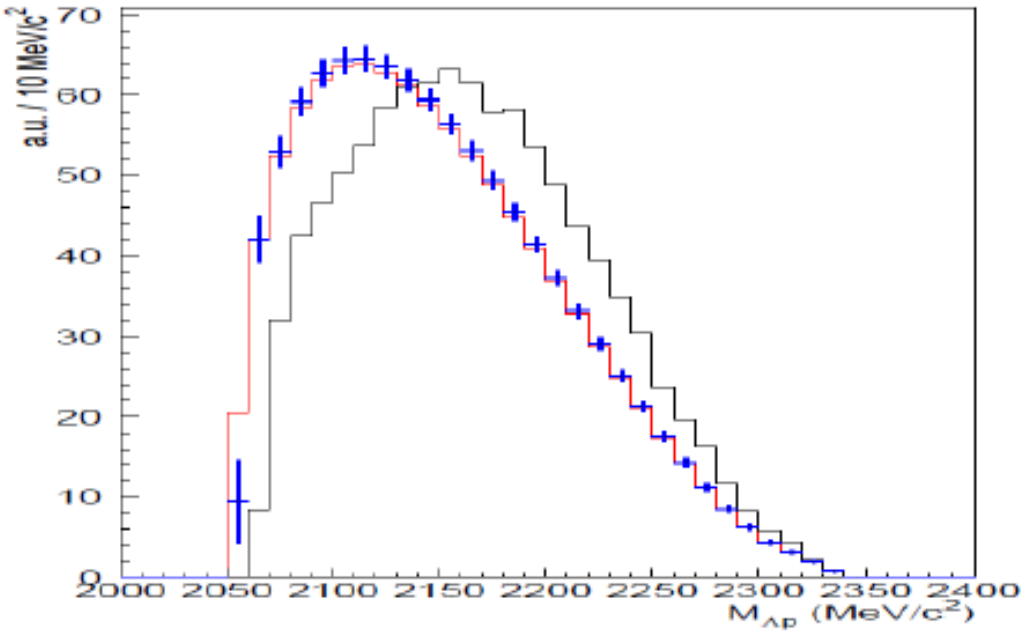
where $P_{\Lambda p}$ is the added momentum for the Lambda and the proton, $\theta_{\Lambda p}$ is the angle between the two particles, and $M_{\Lambda p}$ is its invariant mass. A sample of 5×10^6 MC events has been produced and reconstruted in order to obtain the acceptance function, that is evaluated in 8 intervals of $P_{\Lambda p}$ (between 0 and 800 MeV/c) and $\theta_{\Lambda p}$ (between 0 and 180 degrees) , and 40 intervals for $M_{\Lambda p}$

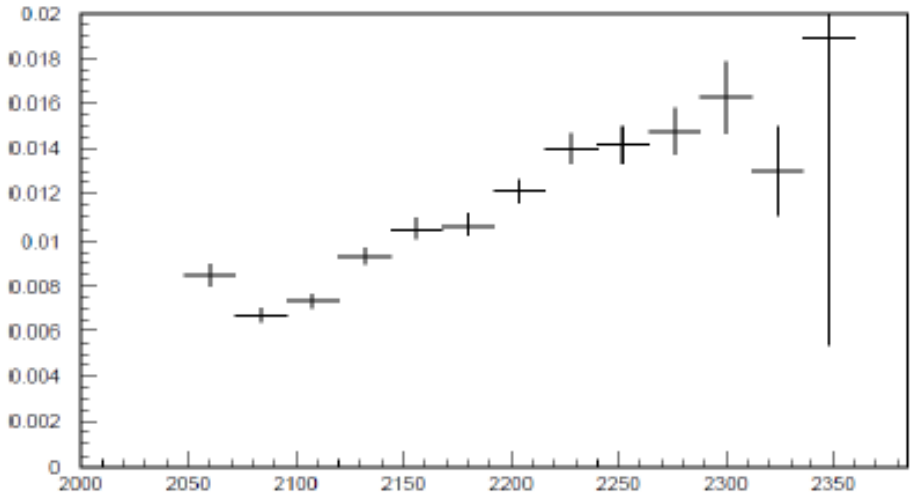
$$A^{i,j,k} = MC(P^i_{\Lambda p}, \theta^j_{\Lambda p}, M^k_{\Lambda p})/REC(P^i_{\Lambda p}, \theta^j_{\Lambda p}, M^k_{\Lambda p})$$

with i,j=1,8 and k=1,40.

Acceptance study with phase space

$K^- + {}^4He \rightarrow \Lambda\, p\, n\, n$ MC simulation





Minv Λp (MeV)

Projection of acceptance function depending on (P_Λ,P_p,Minv Λp) on the Invariant mass plane

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

Normalization 1:1
(no efficiency evaluation)

Calculation of the $K^- \, {}^4He \rightarrow \Lambda\pi^- \, {}^3He$ resonant and non-resonant production

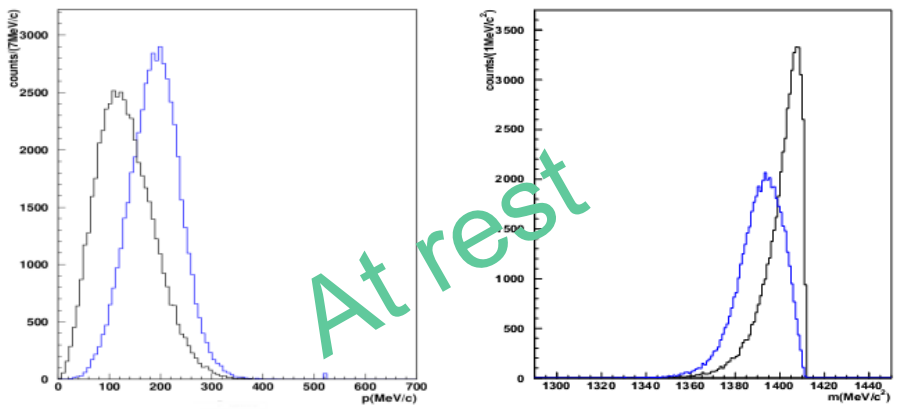


Figura 1: *Left:* $\Lambda\pi^-$ *momentum distributions* $P_s^s(p_{\Lambda\pi})$ *black,* $P_s^p(p_{\Lambda\pi})$ *blue. Right:* $\Lambda\pi^-$ *mass distributions* $P_s^s(m_{\Lambda\pi})$ *black,* $P_s^p(m_{\Lambda\pi})$ *blue.*

Performed by Kristian Piscicchia in collaboration with prof. Wycech

RESONANT
NON-RESONANT

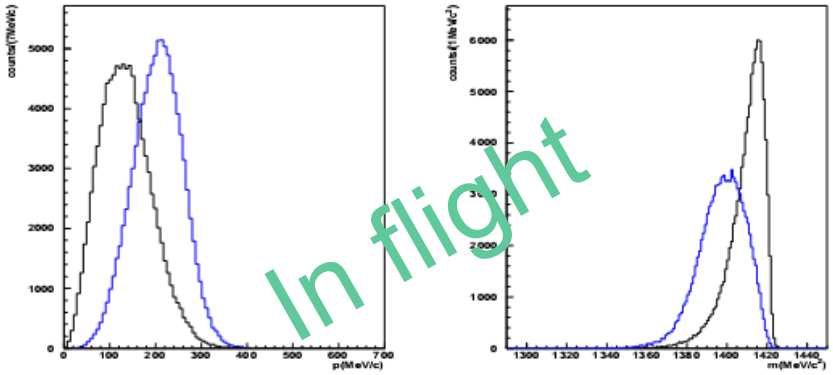


Figura 1: *Left:* $\Lambda\pi^-$ *momentum distributions* $P_{if}^s(p_{\Lambda\pi})$ *black,* $P_{if}^p(p_{\Lambda\pi})$ *blue. Right:* $\Lambda\pi^-$ *mass distributions* $P_{if}^s(m_{\Lambda\pi})$ *black,* $P_{if}^p(m_{\Lambda\pi})$ *blue.*

Λp analysis

Simulations made and data to be studied for the following processes:
(gas of the DC ^{4}He 90%, 10% isobutane C_4H_{10})

Single nuclear absorption (1NA)

1) $\mathbf{K^- H} \rightarrow \Sigma^+ \pi^-$ Σ^+ n/Λp (conversion on neutron from C)

$\hookrightarrow$ **Λp**

2) $\mathbf{K^- n} \rightarrow \Sigma^0 \pi^-$ Σ^0 p/Λp (^{4}He ; 1NA)

$\hookrightarrow$ **Λp(d)**

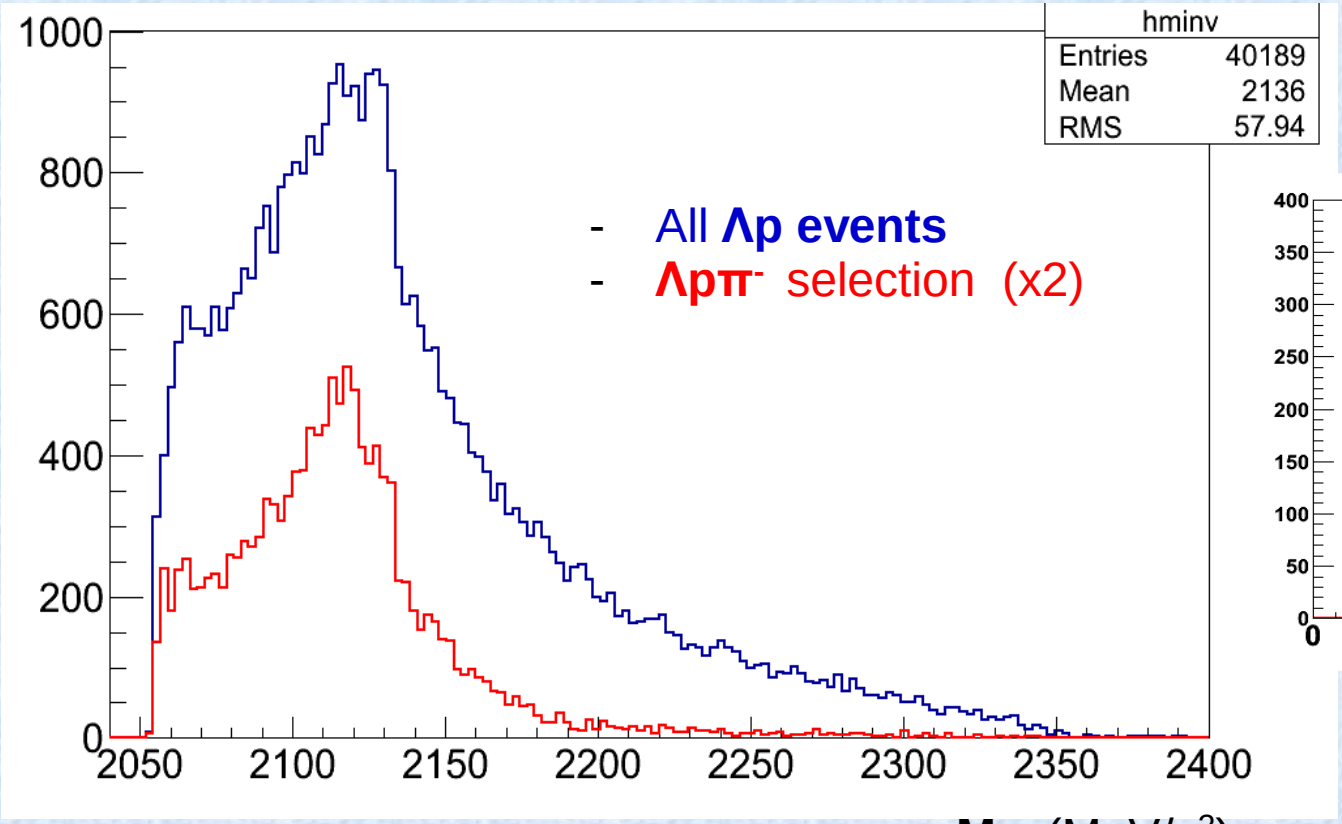
3) $\mathbf{K^- p} \rightarrow \Sigma^+ \pi^-$ Σ^+ n/Λp (^{4}He ; 1NA)

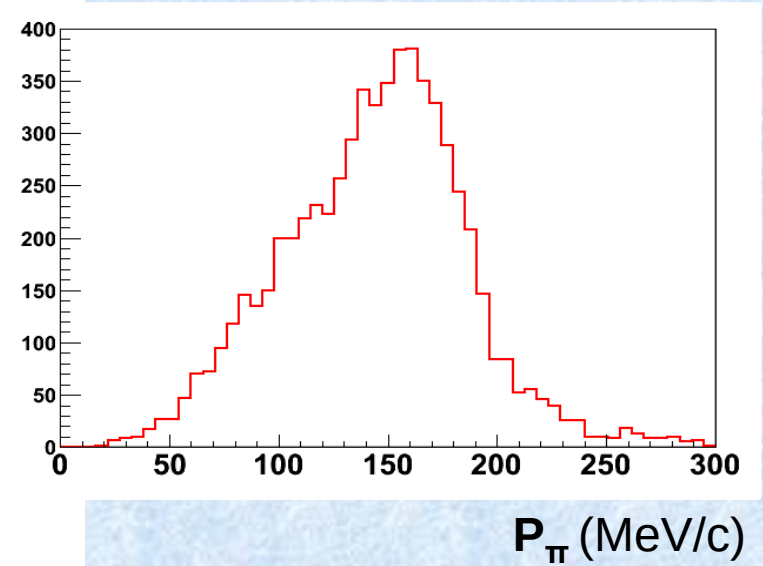
$\hookrightarrow$ **Λp(d)**

4) $\mathbf{K^- n} \rightarrow \Sigma^0 \pi^-$ Σ^0 n/Λn (^{4}He ; 1NA)

$\hookrightarrow$ **Λn(p)(p)**

Λp and **Λpπ**$^-$ samples





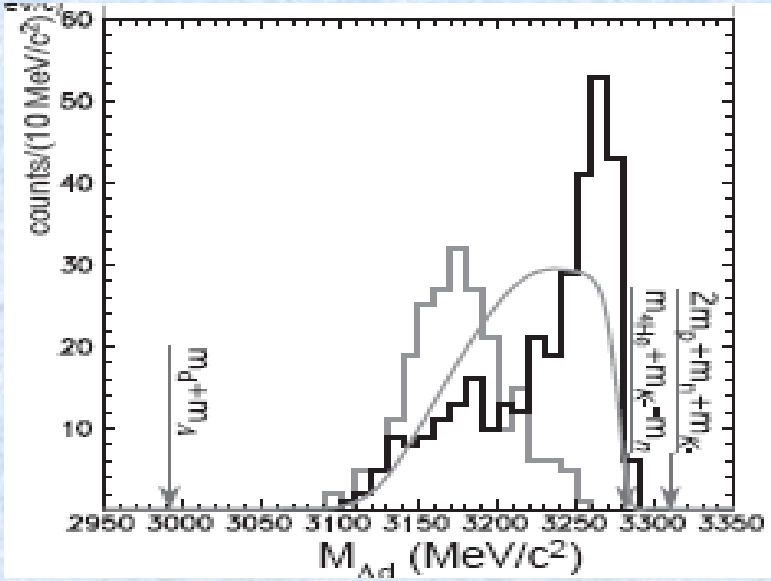
The presence of a pion is the characteristic signal of an absorption by a single nucleon:

Absorption: $K^-N \rightarrow \Sigma\pi$ + **<u>conversion</u>** process: $\Sigma p/\Lambda p$

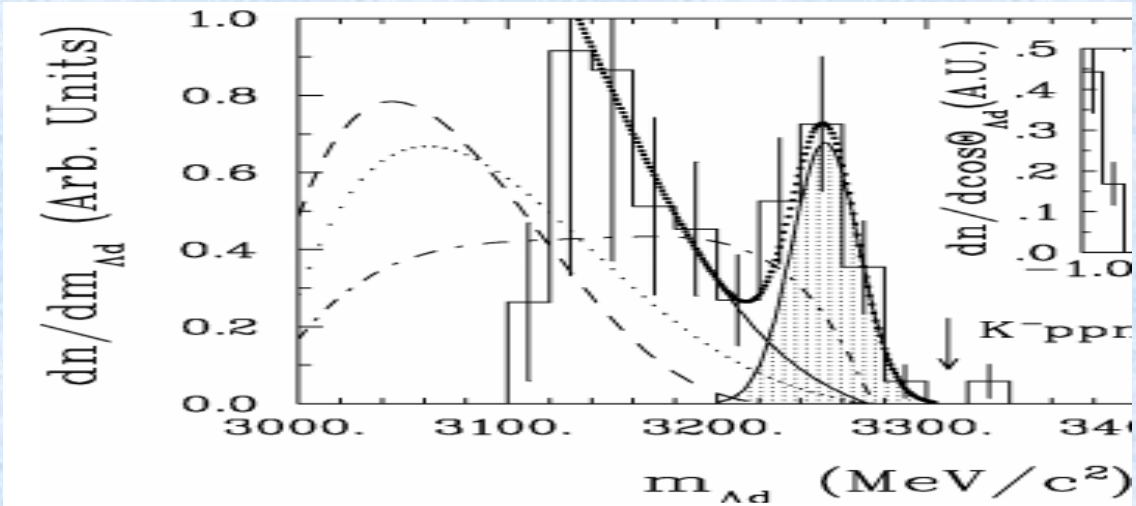
detected particles

Previous experiments on Λd channel

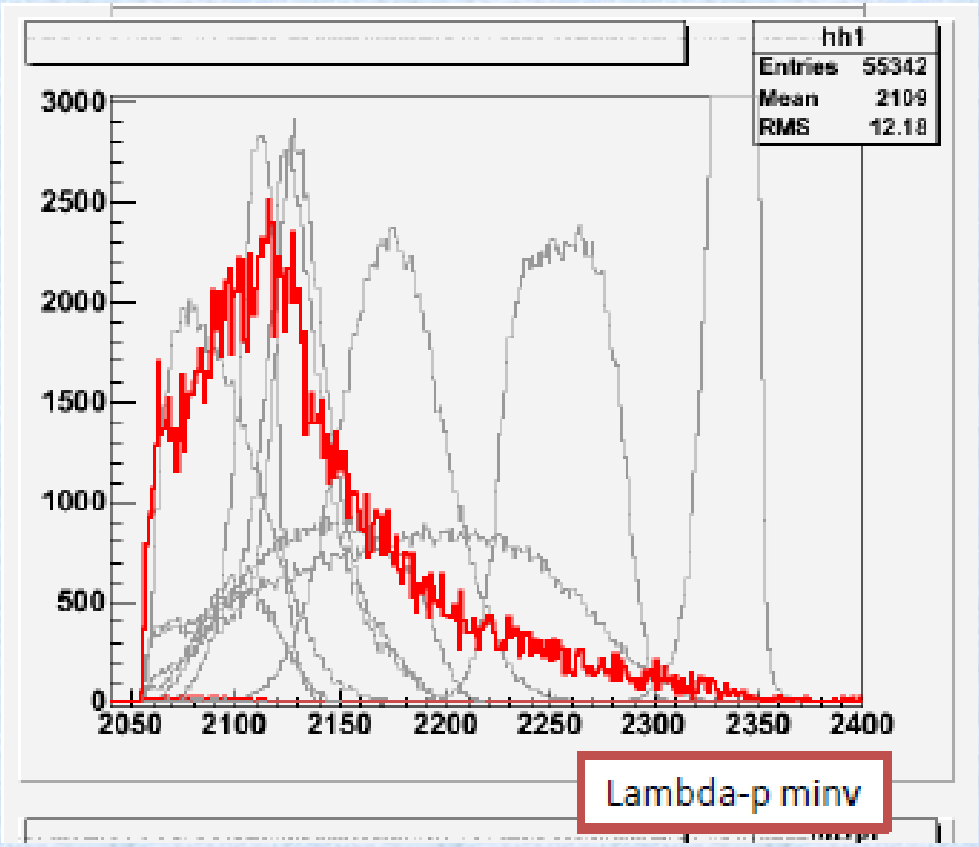
- Observed spectra from FINUDA and KEK showing possible bound states in the in the high invariant mass region – a “bump” around 3250 MeV/c^2



KEK
Phys.Rev. C76 (2007) 068202

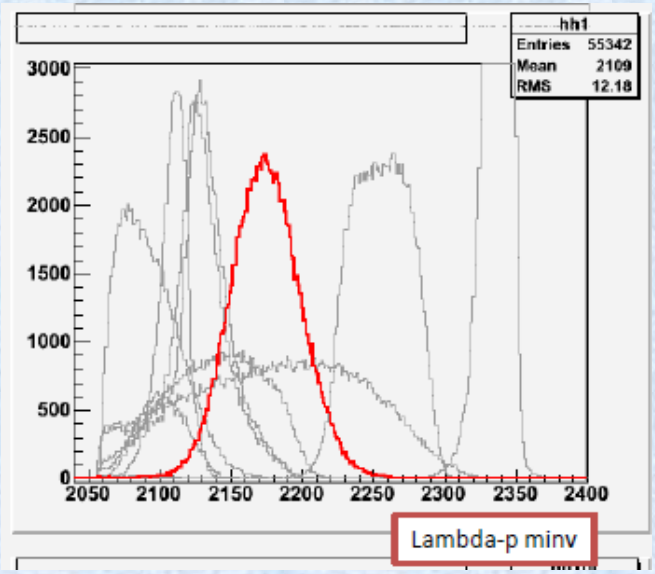


FINUDA
Nucl.Phys.A835, 43 (2010)

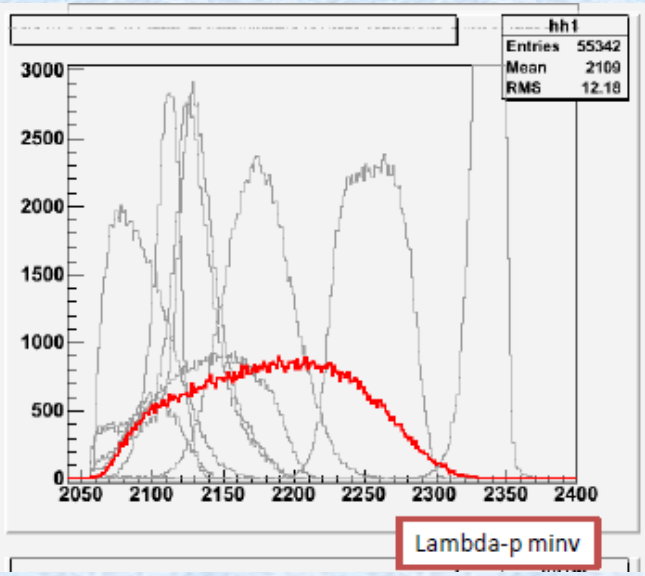


DATA

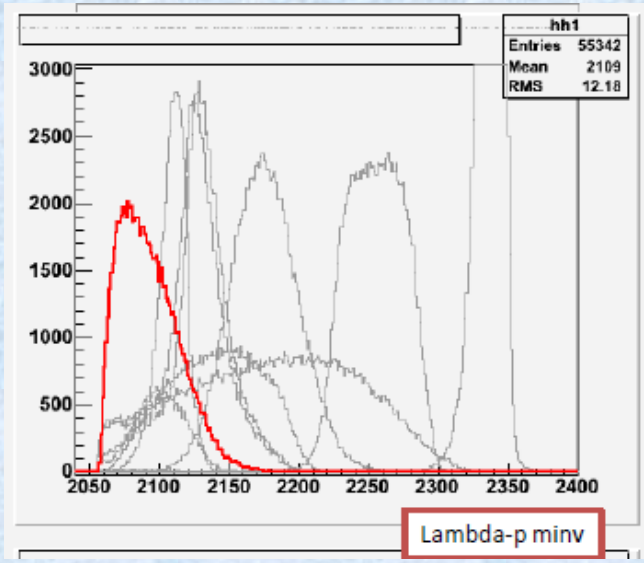
2 NA with conversion



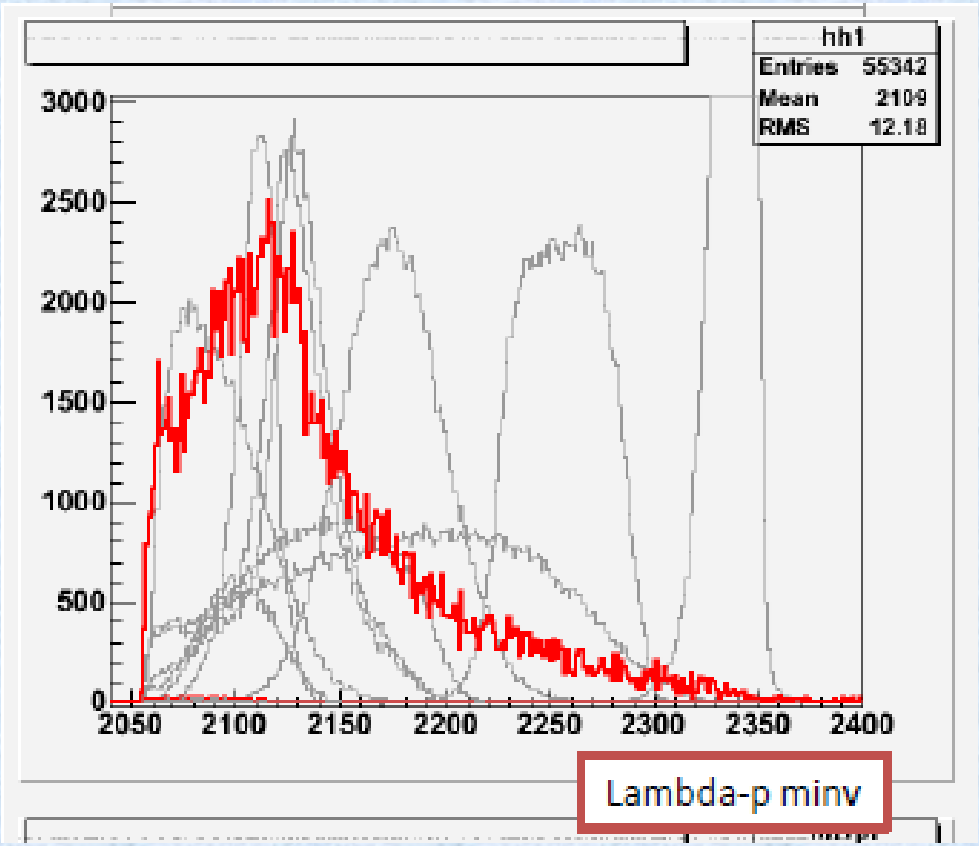
7)



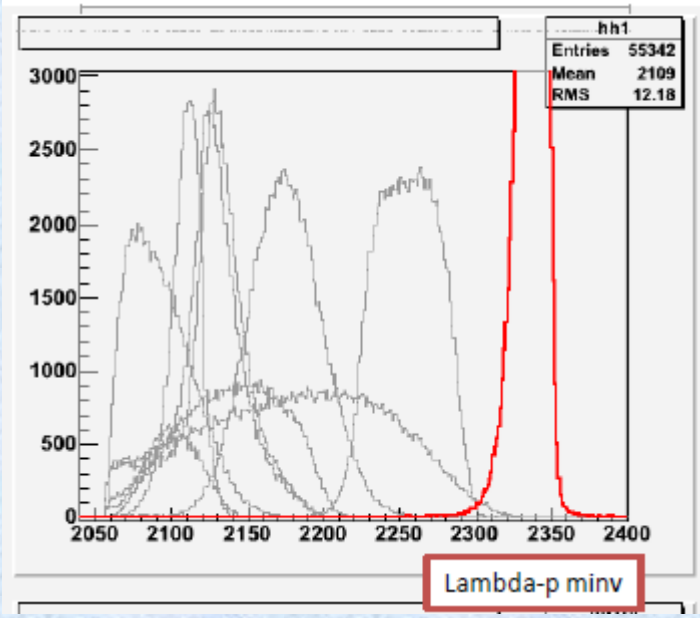
8)



9)

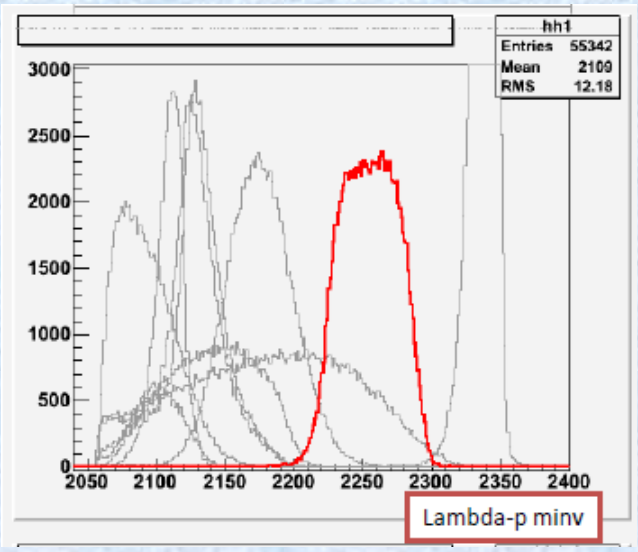


DATA

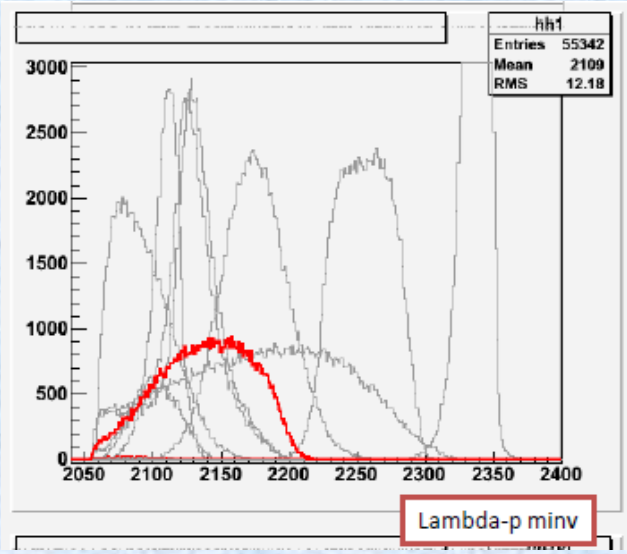


5)

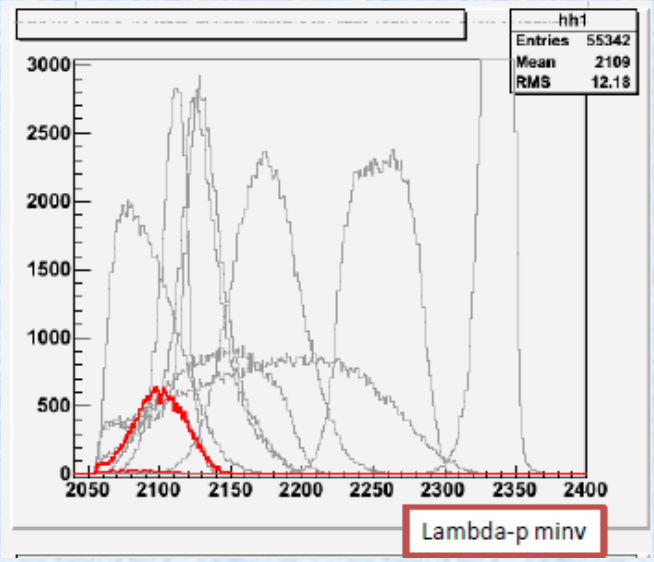
2NA direct formation of Σ^0 or Λ with p



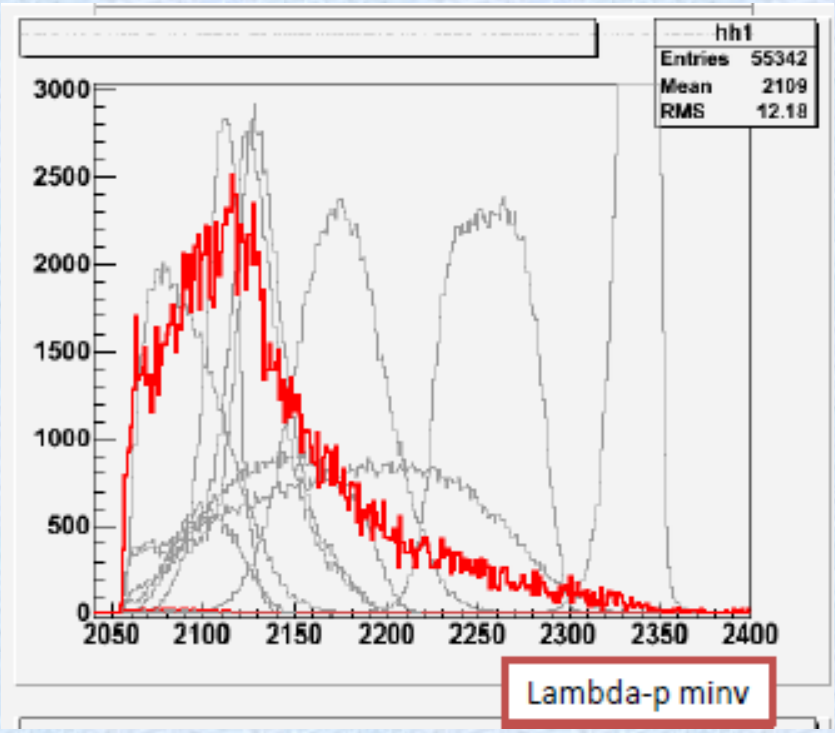
6)



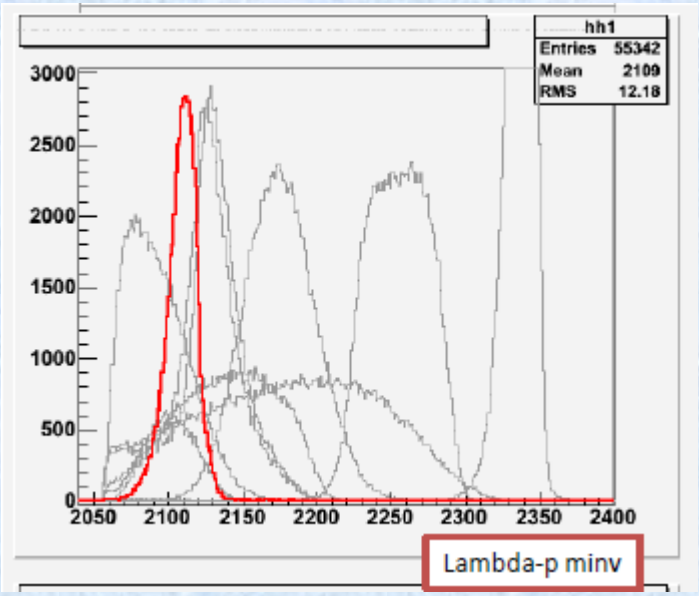
10)



11)

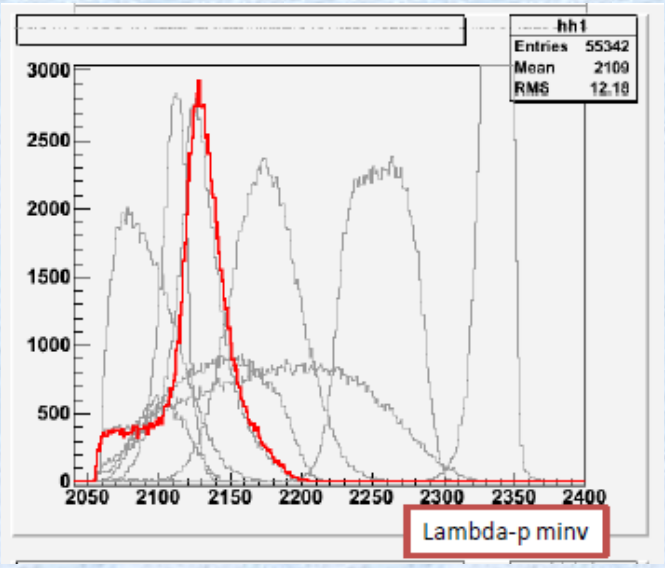


DATA

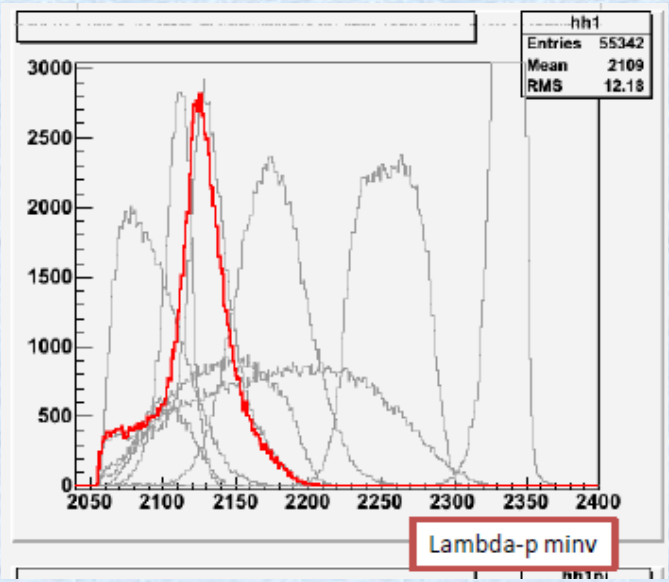


1)

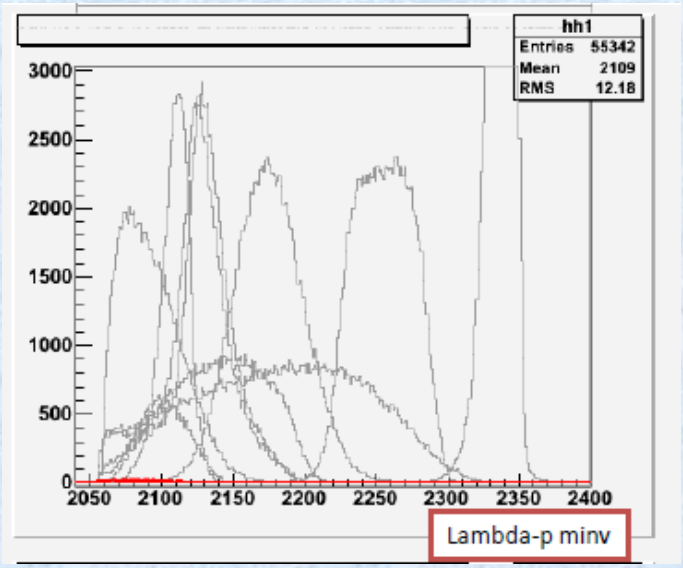
1NA with conversion



2)



3)



4)

Λp analysis

Simulations made and data to be studied for the following processes:
(gas of the DC ^{4}He 90%, 10% isobutane C_4H_{10})

Double nuclear absorption (2NA)
(all on ^{4}He)

5) $\mathbf{K^- pp \rightarrow \Lambda p(n)(n)}$

6) $\mathbf{K^- pp \rightarrow \Sigma^0 p(n)(n)}$

7) $\mathbf{K^- pn} \rightarrow \Sigma^0 n$ $\quad \Sigma^0 p/\Lambda p$
$\rightarrow$ **Λp(n)**

8) $\mathbf{K^- pp} \rightarrow \Sigma^0 \mathbf{p}$ $\quad \Sigma^0 n/\Lambda n$
$\rightarrow$ **Λn(n)**

9) $\mathbf{K^- pn} \rightarrow \Sigma^0 n$ $\quad \Sigma^0 n/\Lambda n$
$\rightarrow$ **Λn(p)**

10) $\mathbf{K^- pn \rightarrow \Lambda \pi^- p(d)}$ (mesonic)

11) $\mathbf{K^- pn \rightarrow \Sigma^0 \pi^- p(d)}$ (mesonic)

Λp analysis

quantitative output: 2NA absorption rate per stopped Kaon

Katz et al.,
Phys.Rev.D1 (1970) 1267. **0.16 ± 0.03 (in He)**

Vander Velde-Wilquet et al.,
Il Nuovo Cimento,Vol.49A, N.2 (1979) **0.19 ± 0.03 (in C)** ← No Σ–Λ rate

FINUDA and KEK has not published this number

Description of ΣN→ΛN in medium

High quality experimental data challenges available models

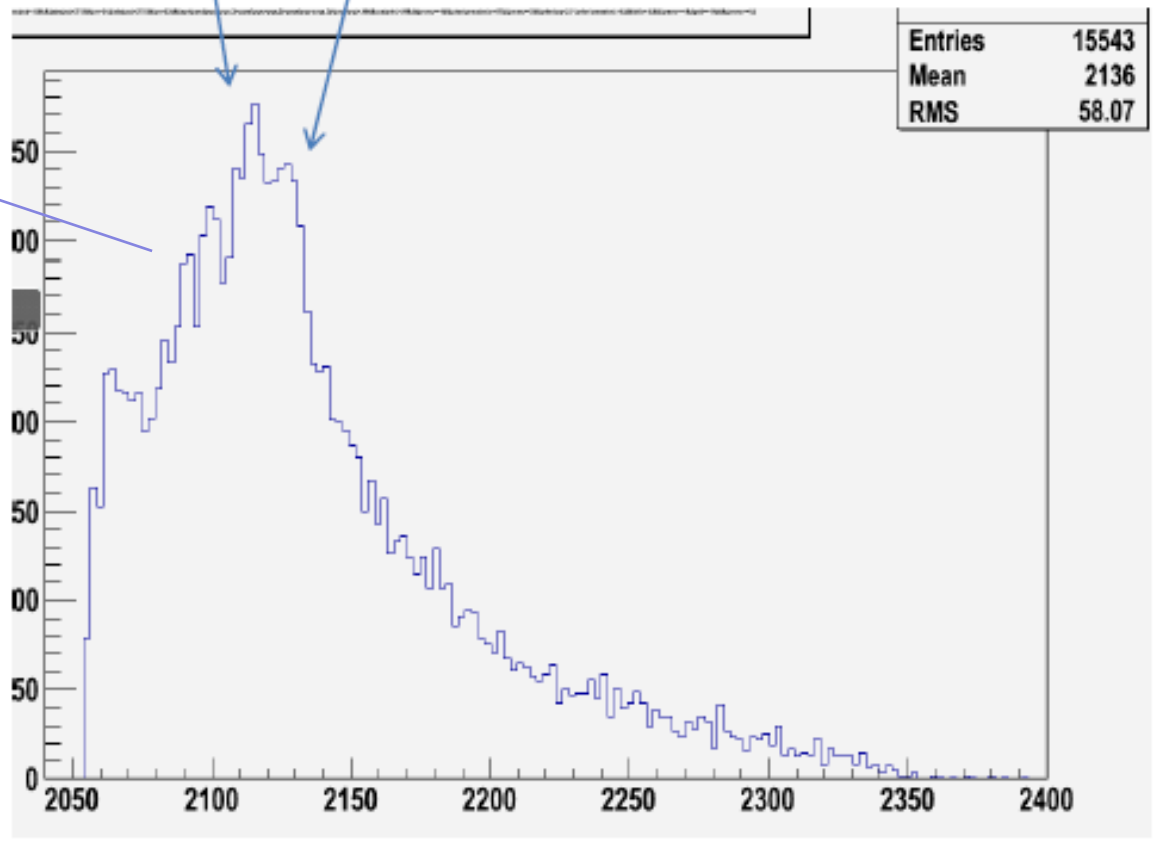
New detailed theoretical models for YN interaction

Very important astrophisical implications: presence of hyperons in neutron stars

Λp analysis

The 2 peaks: - hydrogen absorption + 12C conversion
- 4He conversion

Still to discuss

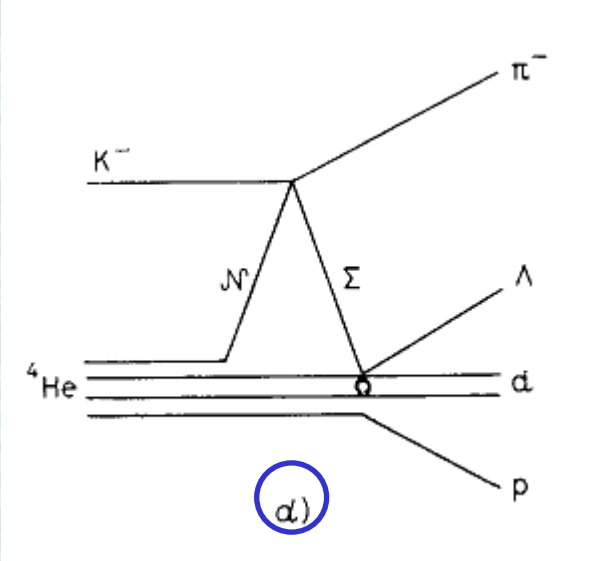


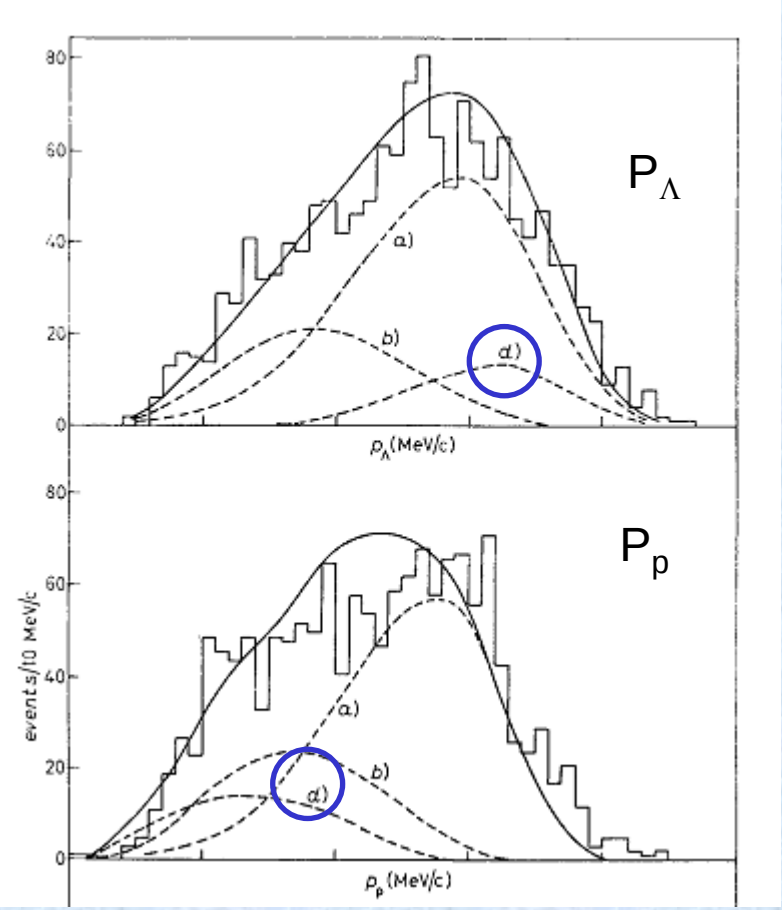
$M_{\Lambda p}$ (MeV/c^2)

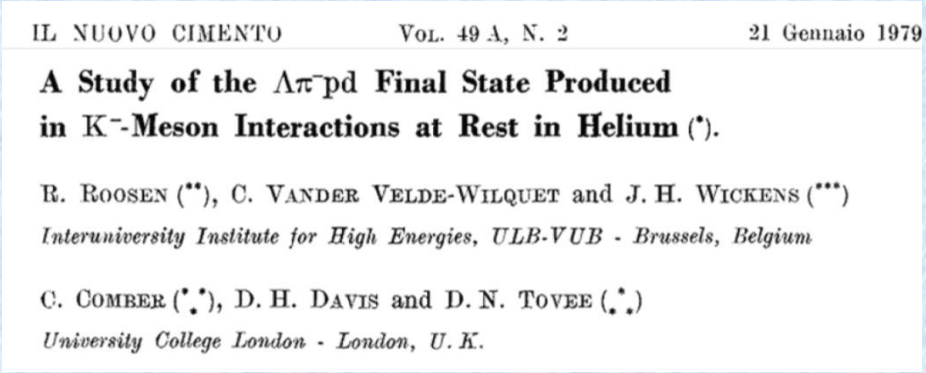
Λp analysis

Another process to take into account:

- Low momentum proton process: **'double nucleon conversion'**





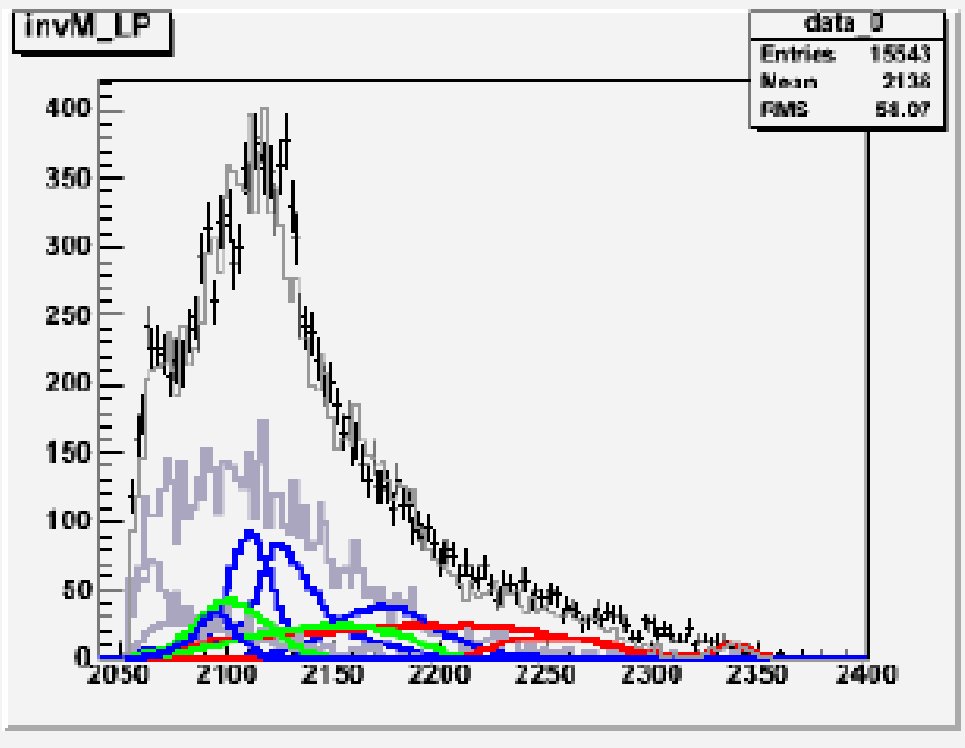


IL NUOVO CIMENTO Vol. 49 A, N. 2 21 Gennaio 1979

A Study of the $\Lambda\pi^-pd$ Final State Produced in K^--Meson Interactions at Rest in Helium (*).

R. Roosen (**), C. Vander Velde-Wilquet and J. H. Wickens (***)
Interuniversity Institute for High Energies, ULB-VUB - Brussels, Belgium

C. Comber (***), D. H. Davis and D. N. Tovee (***)
University College London - London, U. K.



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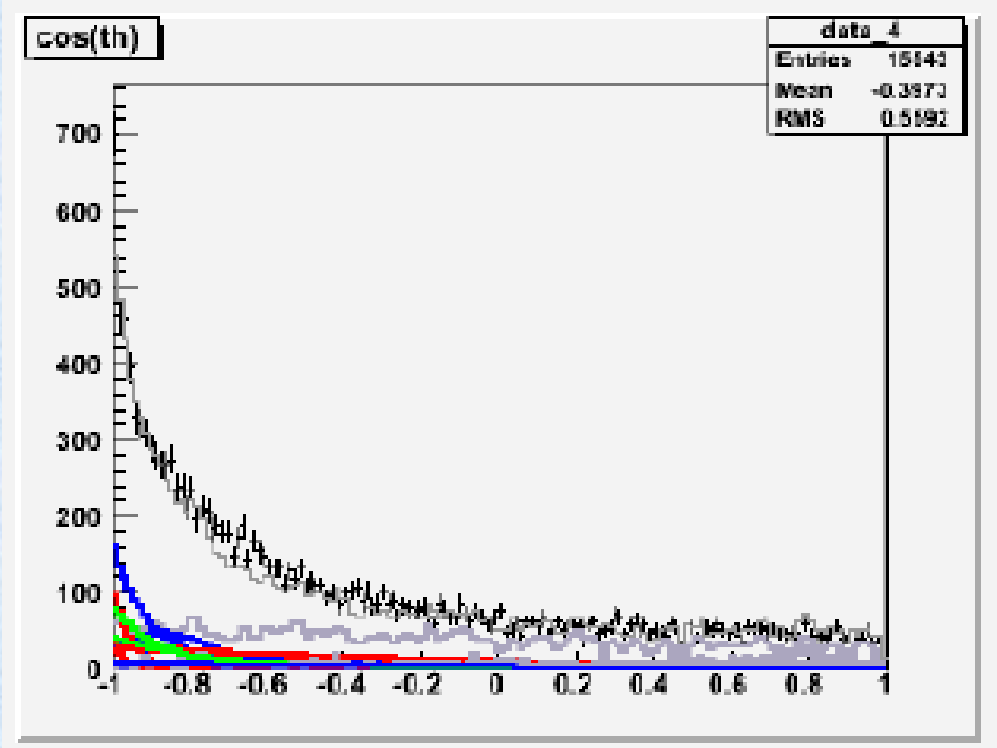
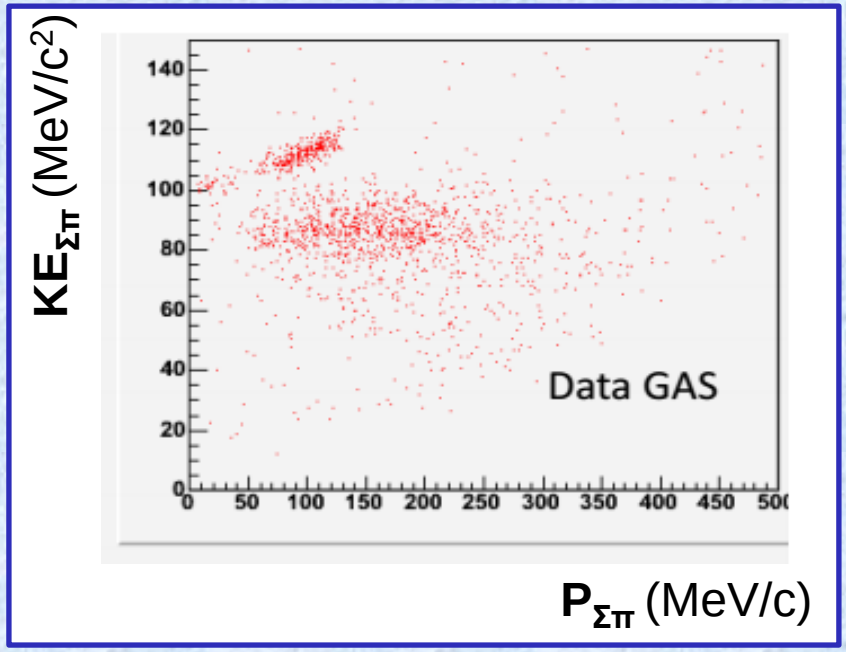




Cos($\theta_{\Lambda p}$)

Scientific case for the Λp / Λd / Λt and Λp + π^- channels:

Scientific case for the Λp / Λd / Λt and Λp + π^- channels:

How hadron masses and interactions change in nuclear medium .. approach by means of **kaonic nuclear clusters**.

Deeply Bound Kaonic Nuclear States:

$K^-pp \rightarrow \Lambda p$

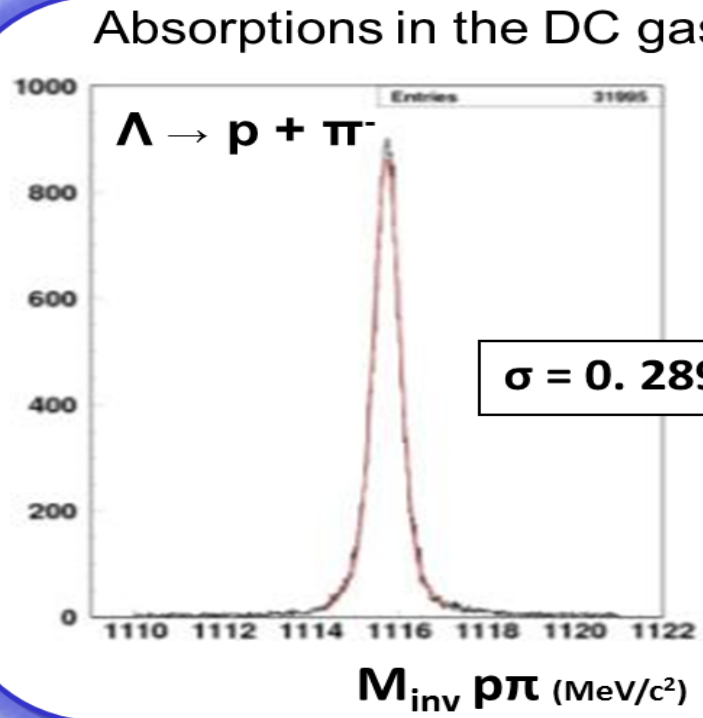
$K^-ppn \rightarrow \Lambda d$

$K^-ppnn \rightarrow \Lambda t$

predicted due to the strong KN interaction in the I=0 channel.

interpretation strongly depends on single and multi – nucleon absorption processes - they can be well studied in this channels

Λ(1116) mass measurement



σ = 0. 289 ± 0.003 MeV/c²

KLOE: statistical error 0. 003 MeV/c2

PDG: M_Λ = 1115,683 ± 0.006 stat ± 0.006 syst **(MeV/c²)**

PDG measurement: **PhysRevLett.72.1322 (1994)**

- pp collisions. 6 DC's. B=1,17 Tm.
- Momentum resolution: Δp(FWHM)/p=0.01
- Callibrated with $K_s^0 \to \pi^+\pi^-$decay
- 60K events

KLOE Memo 231

Momentum Calibration of the KLOE Drift Chamber

A. Antonelli, M. Antonelli, L. Passalacqua

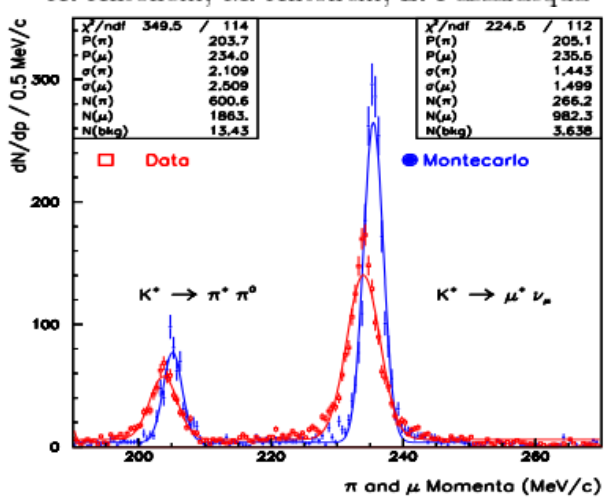


Figure 10: Comparison between the MC and data spectra of daughter track momentum in the kaon center-of-mass frame for two-body charged kaon decays

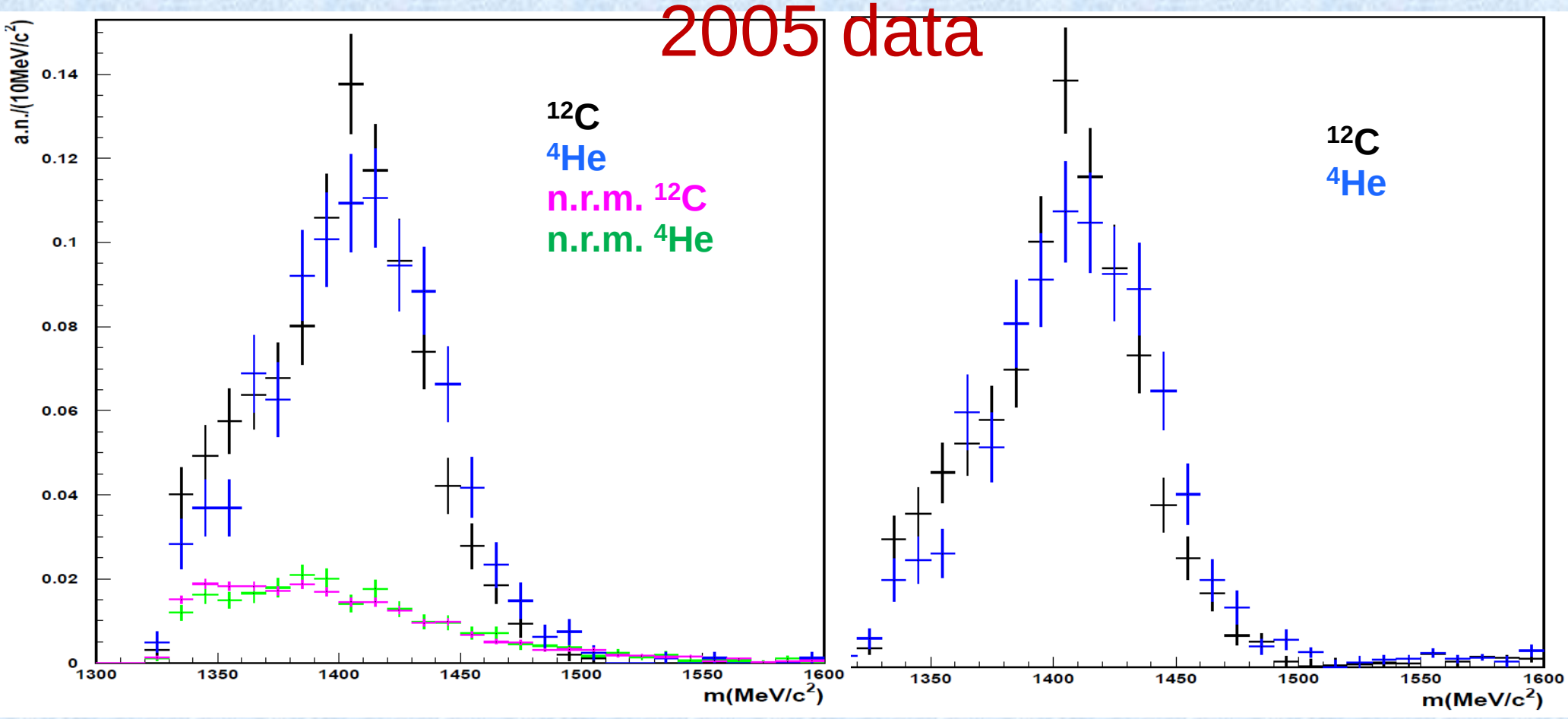
- Using K+ decays for callibration in KLOE the systematic error in the Λ mass can be reduced down to ~**0.013** MeV (optimistic...)

$\Sigma^0\ \pi^0$ channel

Invariant mass spectra with mass hypotesis on Σ^0 and π^0 non resonant misidentification background subtracted (left)

$\sigma_m \approx 17$ MeV/c^2 (^{12}C) $\sigma_m \approx 15$ MeV/c^2 (^{4}He)

Similar m($\Sigma^0\pi^0$) shapes due to the similar kinematical thresholds for ^{4}He and ^{12}C.



Λ(1405) scientific case

Long history of K^- nuclear absorption experiments

1) $m_{\Sigma\pi}$ **spectra cut at the energy limit at-rest**

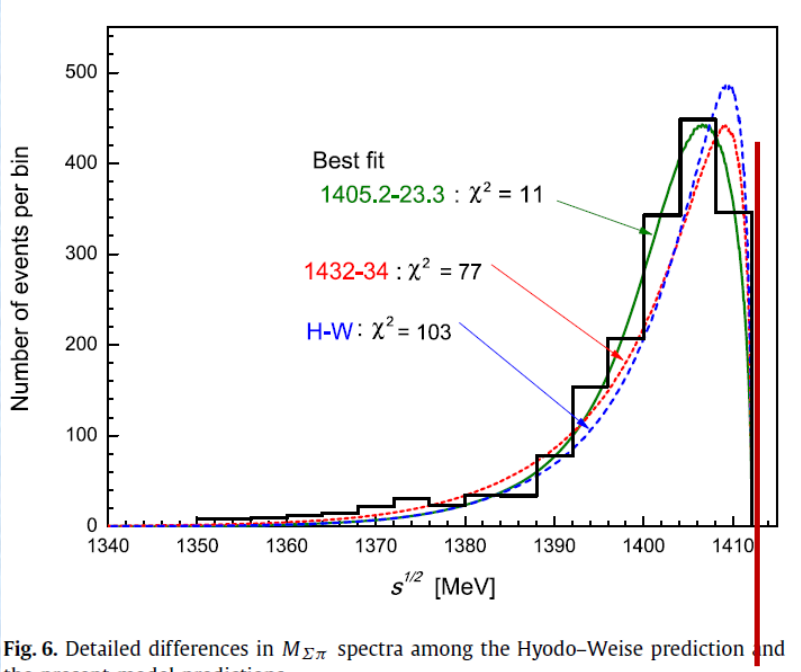
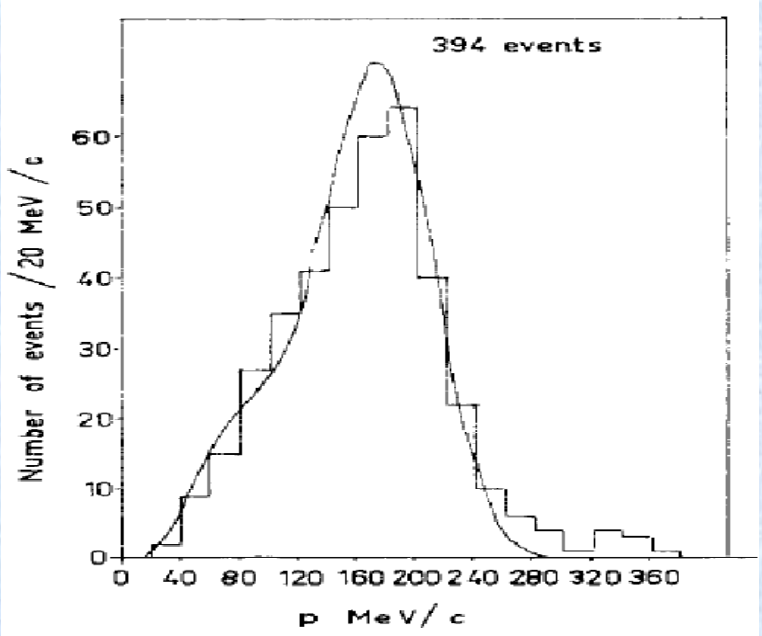


Fig. 6. Detailed differences in $M_{\Sigma\pi}$ spectra among the Hyodo–Weise prediction and the present model predictions.

Phys.Lett. B (2010) 23-28

Akaishi-Esmaili-Yamazaki phenomenological potential

2) ($\Sigma^{\pm}\pi^{-+}$) with **Σ(1385) contamination**



P.J. Carlson et al., Nucl. Phys. 74 642

To test the higher mass pole:

- production in KN reactions (only chance to observe it)
- decaying in **$\Sigma^0\pi^0$ (free from Σ(1385) background I=1)**