Search for kaons 2/3 nucleon absorption and hyperon-nucleon scattering cross section by AMADEUS

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On behalf of the AMADEUS collaboration

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ISU2015: "Quest for visible and invisible strange stuff in the Universe"

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OUTLINE

- **The AMADEUS (Anti-kaonic Matter At DAΦNE: Experiments with Unravelling Spectroscopy) collaboration;**

- **Low-energy K^- interaction with light nuclei (^3He, ^4He, ^8Be, ^{12}C …)**

$$K^- X \rightarrow \Lambda\, p\, X'$$

$$K^- X \rightarrow \Sigma^0\, p\, X'$$

1) ⟶ Search for K^-pp bound state
2) ⟶ Fix the 2/3NA yield

- **How to extract YN scattering cross section;**

- **Results and Conclusions.**

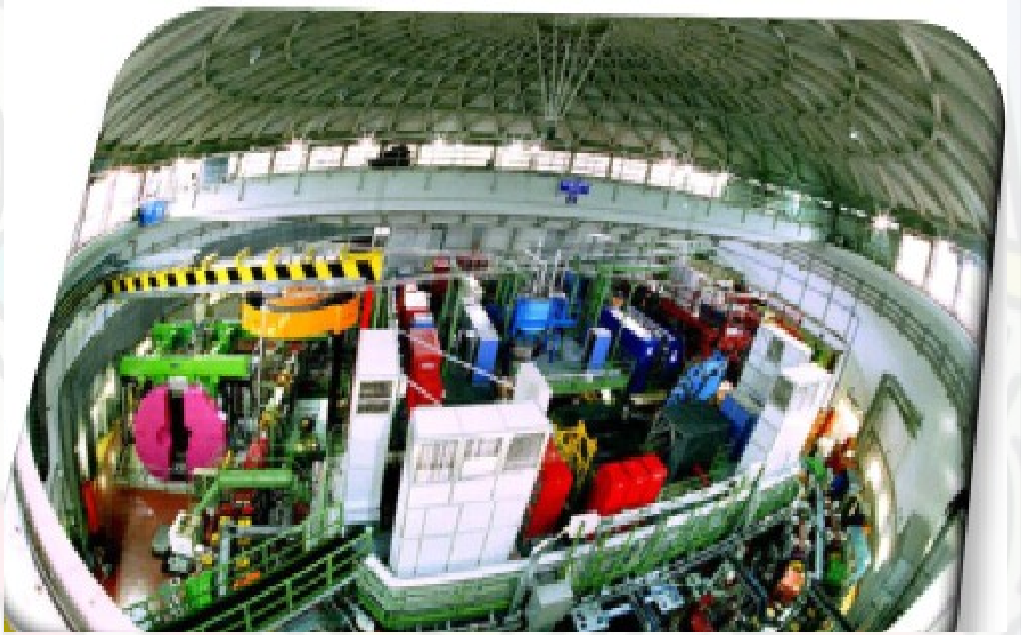
AMADEUS & DAΦNE

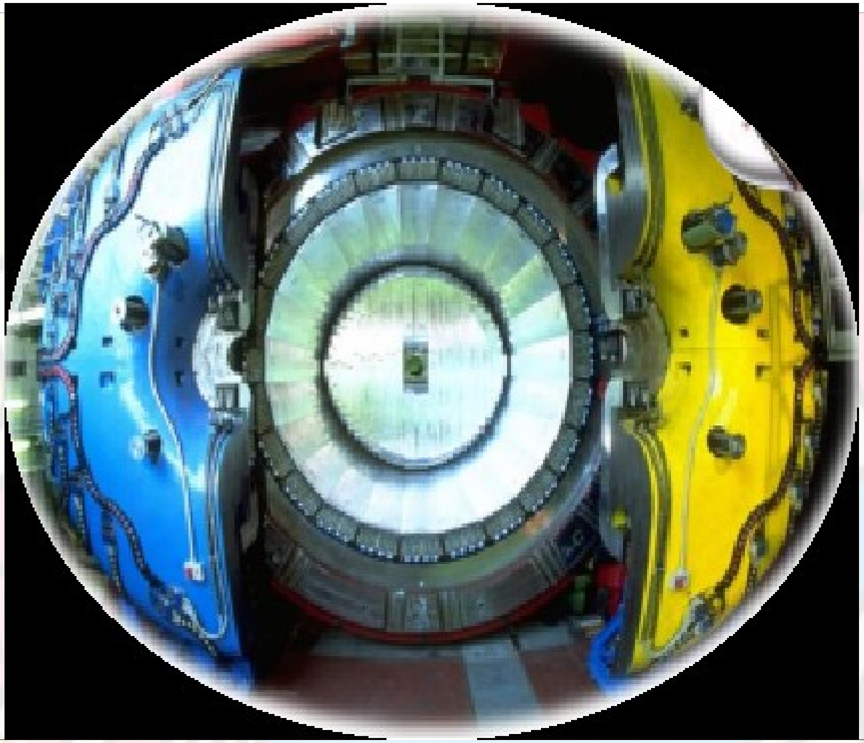
DAΦNE

Double ring e^+e^- collider working in C.M. energy of ϕ, producing ≈ 600 K^+K^-/s

$\phi \rightarrow K^+K^-$ (BR = (49.2 ± 0.6)%)

- low momentum Kaons ≈ 127 Mev/c
- back to back K^+K^- topology





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)))

The scientific goal of AMADEUS

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?

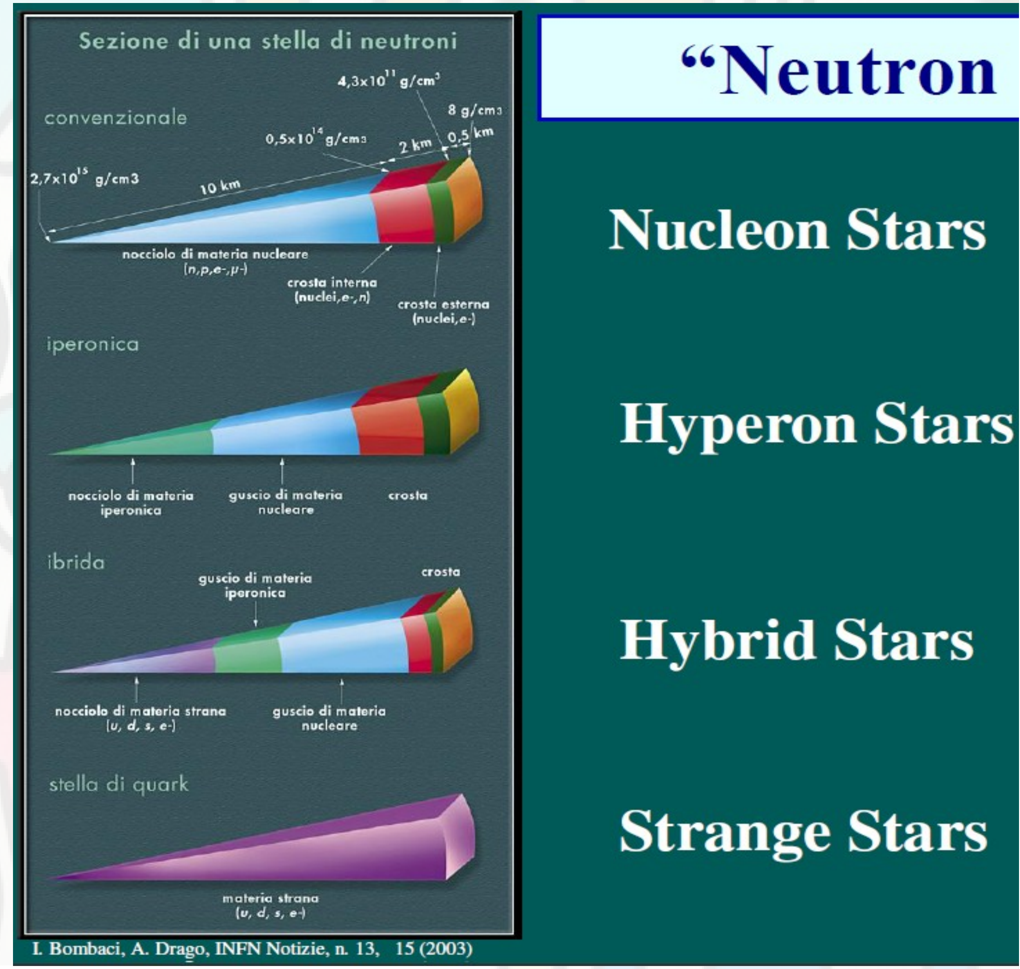
- $U_{\overline{K}N}$ strongly affects the position of the $\Lambda(1405)$ state → we investigate it through $(\Sigma-\pi)^0$ decay --- $Y\,\pi$ CORRELATION

- if $U_{\overline{K}N}$ is strongly attractive then possible K^- multi-N bound states → we investigate through $(\Lambda/\Sigma-N)$ 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

Essential impact on the case of NEUTRON STARS



Microscopic approach to hyperonic matter EOS

input

2BF: nucleon-nucleon (NN), nucleon-hyperon (NY), hyperon-hyperon (YY)

e.g. Nijmegen, Julich models

3BF: NNN, NNY, NYY, YYY

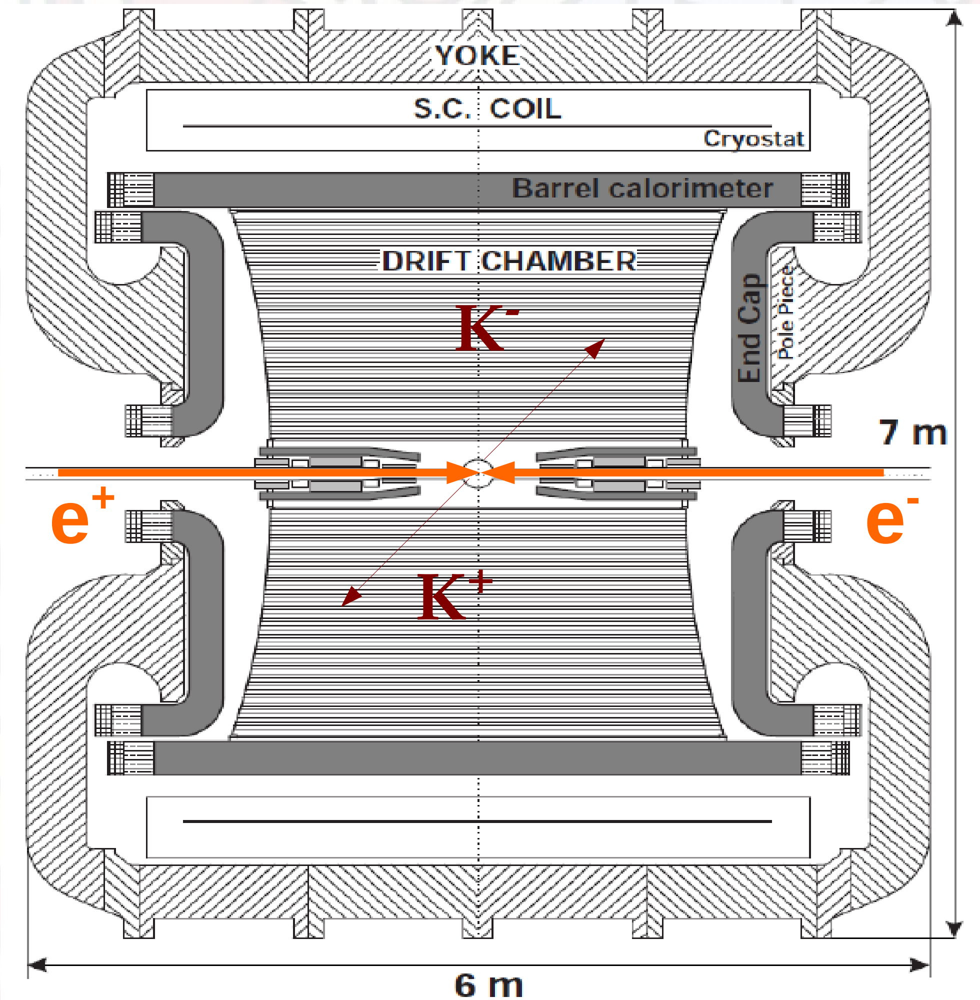
Hyperonic sector: experimental data

1. YN scattering (very few data)
2. Hypernuclei

Low-energy K^- hadronic interactions studies with KLOE

Possibility to use KLOE materials as an active target

- DC wall (750 μm C foil, 150 μm Al foil);
- DC gas (90% He, 10% C_4H_{10}).



Advantage:
excellent resolution ..

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

$\sigma_{m\gamma\gamma}$ = 18.3±0.6 MeV/c^2

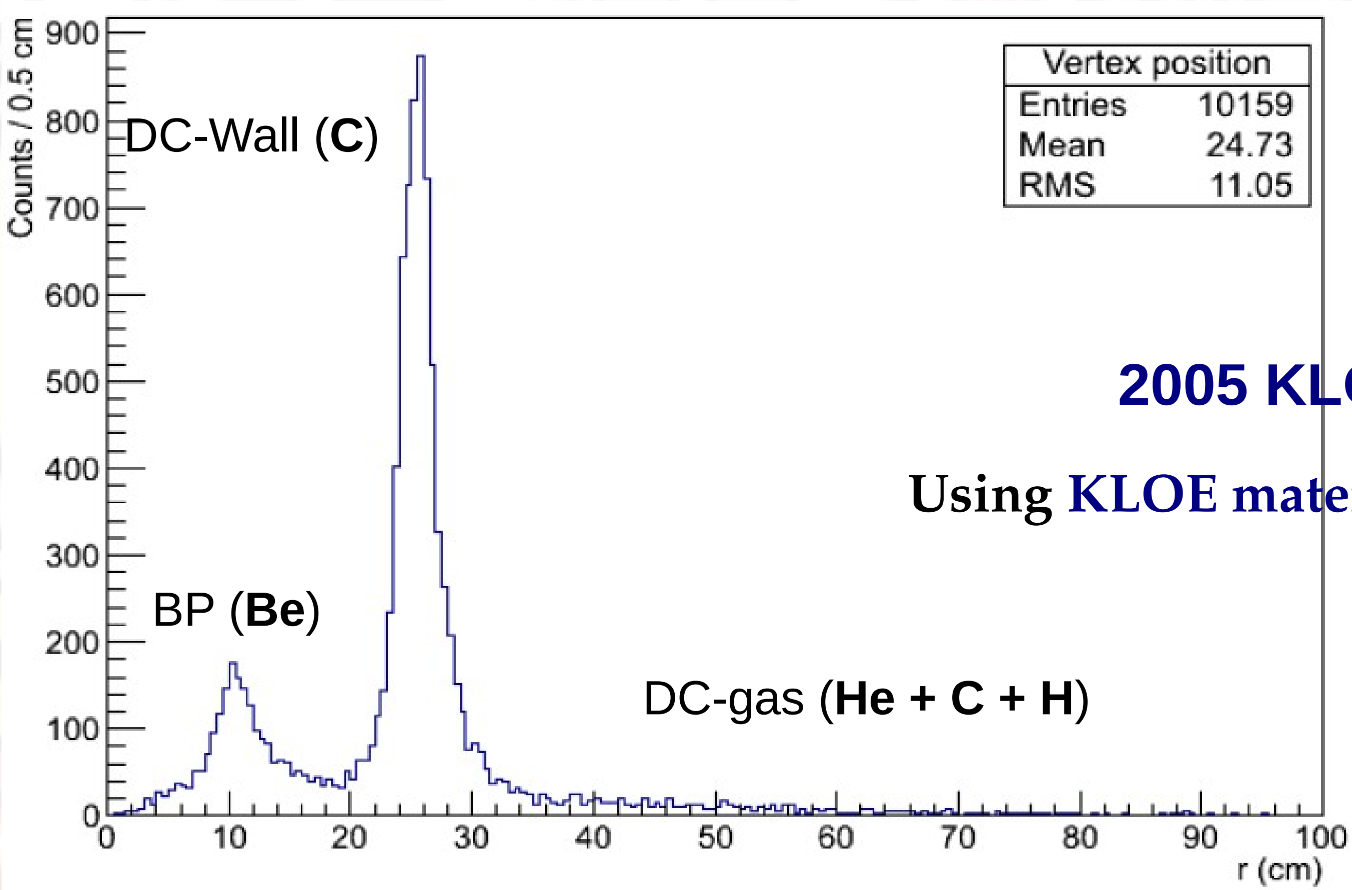
Disadvantage:
Not dedicated target → different nuclei contamination → complex interpretation.

How to do that? ... K^- absorption on light nuclei

We are lookin for K^- absorption in

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

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



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

Using KLOE materials as an active target

Search for the K^-pp bound state

$K^- + \text{"pp"} \rightarrow \Lambda/\Sigma^0 + p$ **genuine 2NA process;**

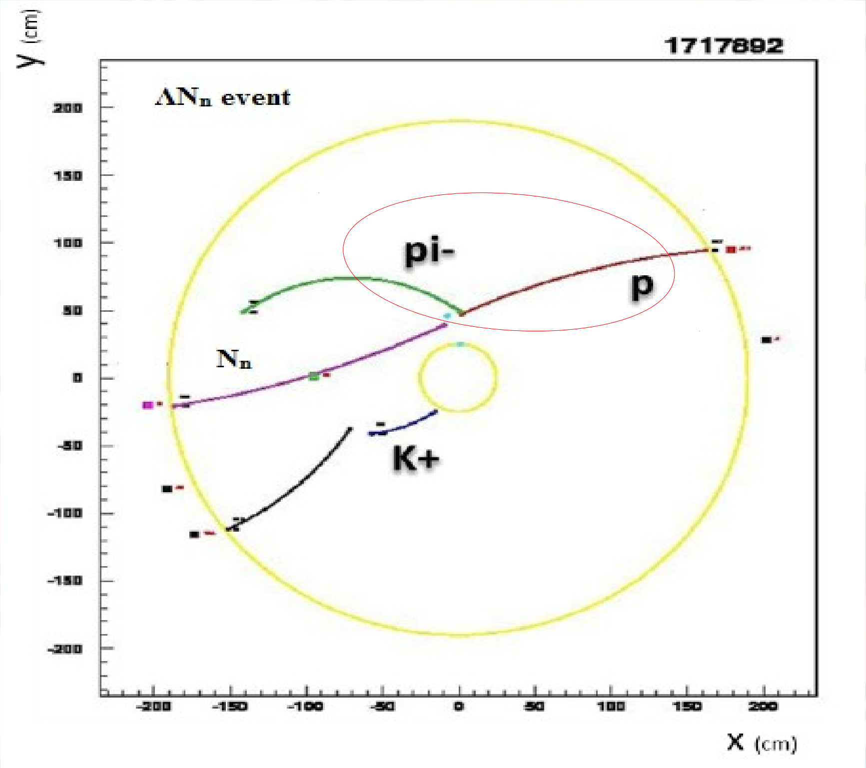
$K^- + \text{"pp"} \rightarrow \text{"}K^-pp\text{"} \rightarrow \Lambda/\Sigma^0 + p$ **kaonic bound state.**

predicted due to the strong KN interaction in the I=0 channel.
(Wycech (1986) - Akaishi & Yamazaki (2002))

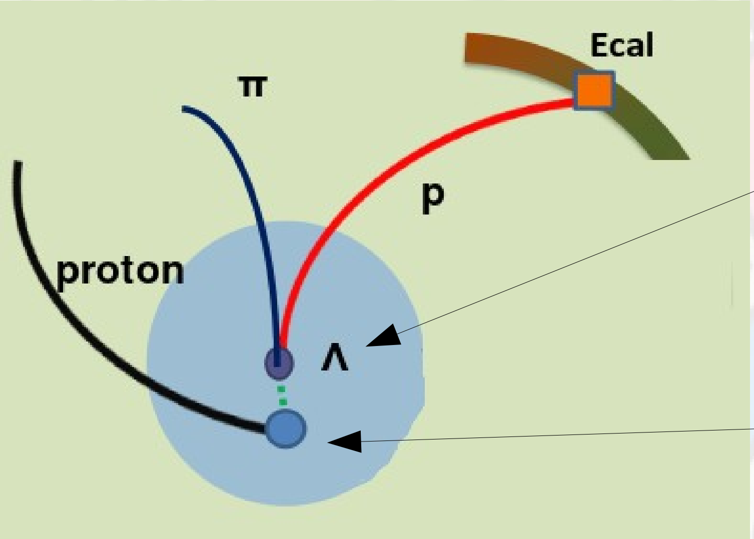
	Theoretical prediction	B.E (MeV)	Γ (MeV)
PRC76, 045201 (2002)	T. Yamazaki and Y. Akaishi	48	61
arXiv:0512037v2[nucl-th]	A. N. Ivanov, P. Kienle, J. Marton, E. Widman	118	58
PRC76, 044004 (2007)	N. V. Shevchenko, A. Gal, J. Mares, J. Revai	50~70	~100
PRC76, 035203 (2007)	Y. Ikeda and T. Sato	60~95	45~80
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

Λ(1116): the signature of K⁻ hadronic interaction

1st Step: $\Lambda \rightarrow p + \pi^-$ identification
(BR = 63.9 ± 0.5 %)



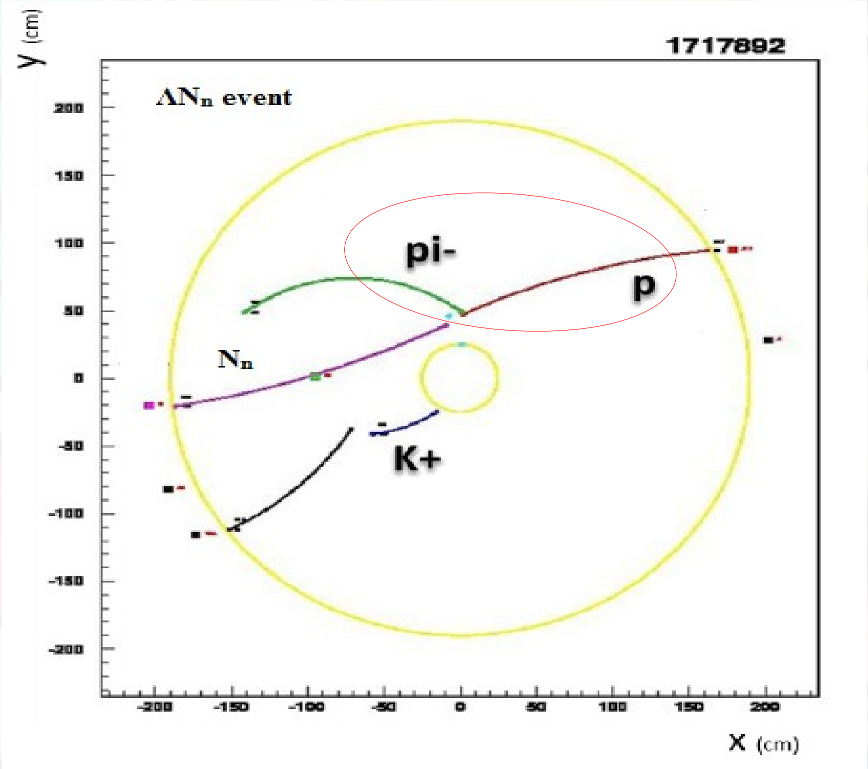
2nd Step: **hadronic interaction vertex** searched extrapolating backwards the Λ path and an extra positive track



Λ decay vertex

hadronic vertex

Λ(1116): the signature of K^- hadronic interaction



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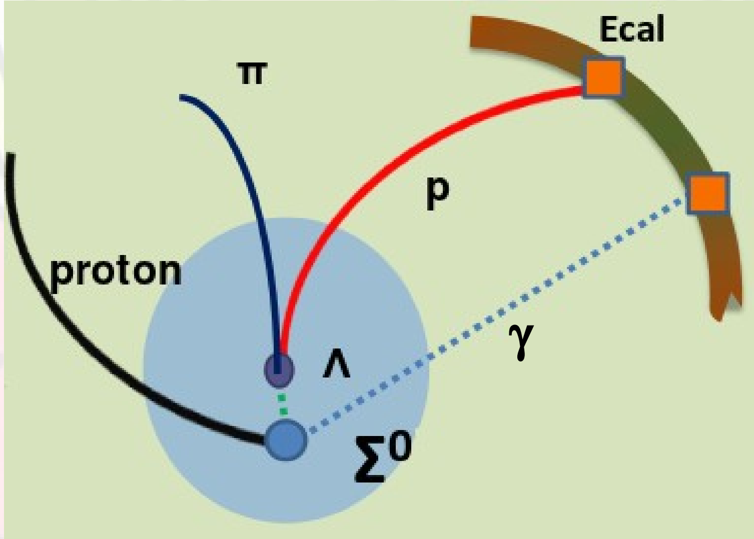


$\Sigma^0 p$ events:
Additional photon track due to

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

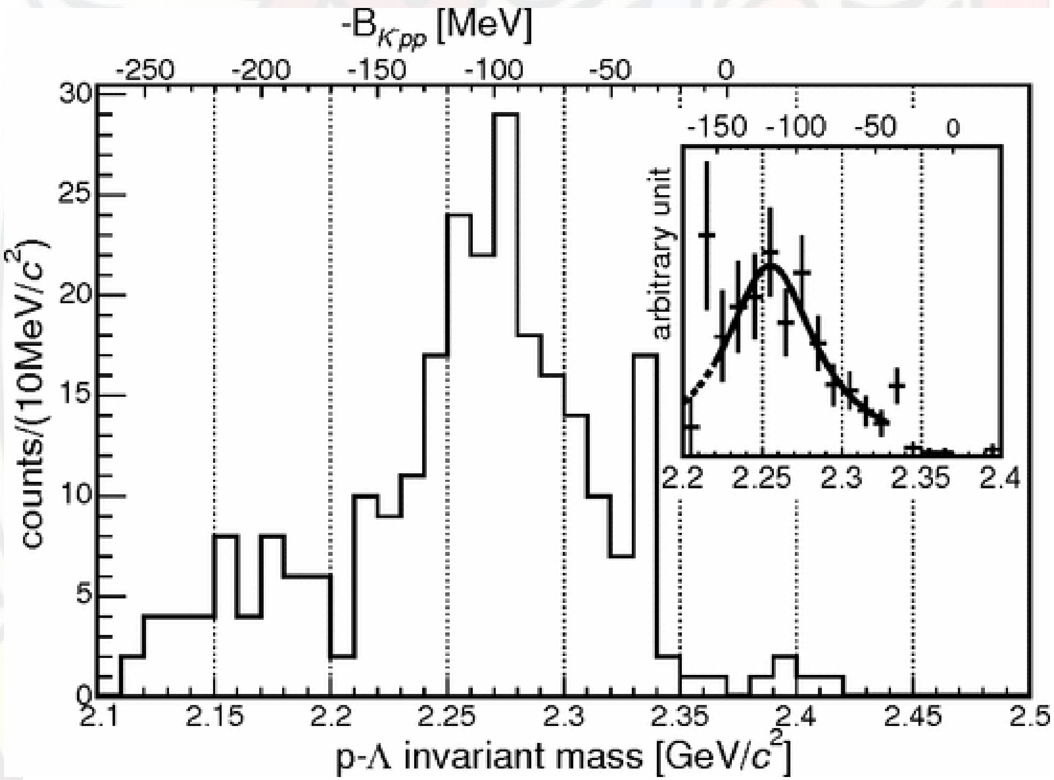
electromagnetic decay.

Λ p channel

Experimental studies in the Λp decay channel through K⁻ nucleons/nuclei absorption

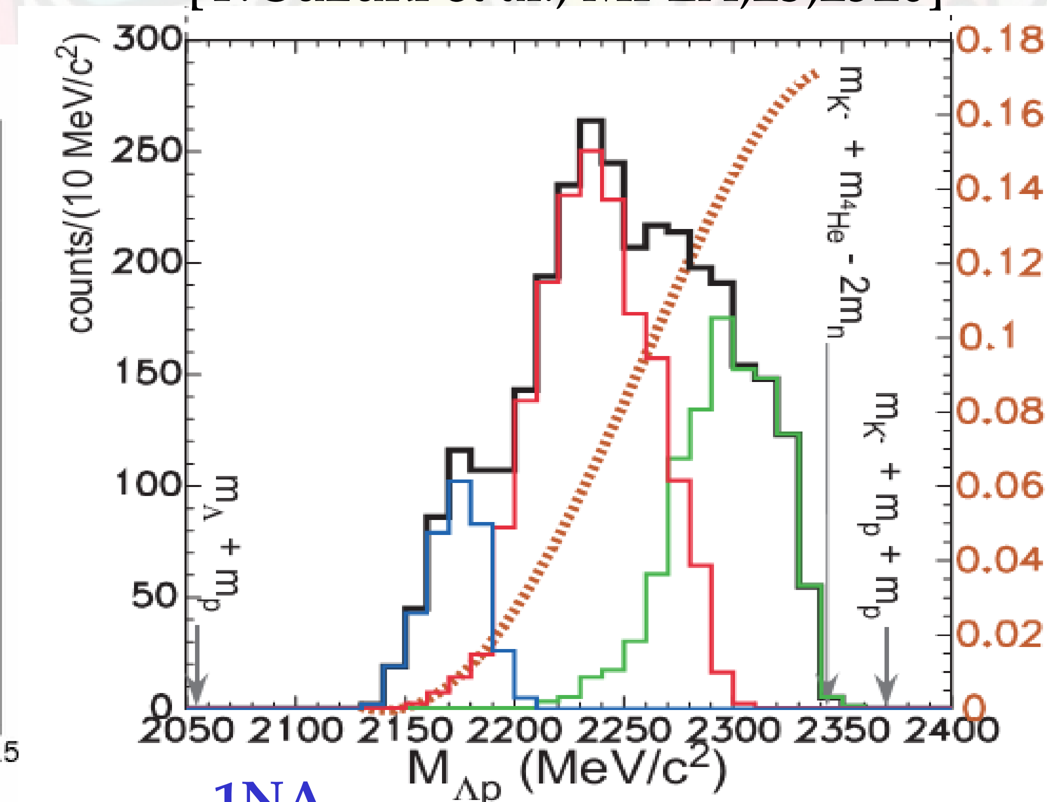
$$K^- X \rightarrow \Lambda\, p\, X'$$

FINUDA at DAΦNE (X= ^{6}Li, ^{7}Li, ^{9}Be)
[M. Agnello et al., PRL94, 212303]



$B = 115^{+6}_{-5}(\mathrm{stat})^{+3}_{-4}(\mathrm{sys})$ MeV
$\Gamma = 67^{+14}_{-11}(\mathrm{stat})^{+2}_{-3}(\mathrm{sys})$ MeV

E-549 at KEK (X= ^{4}He)
[T. Suzuki et al., MPLA,23,2520]

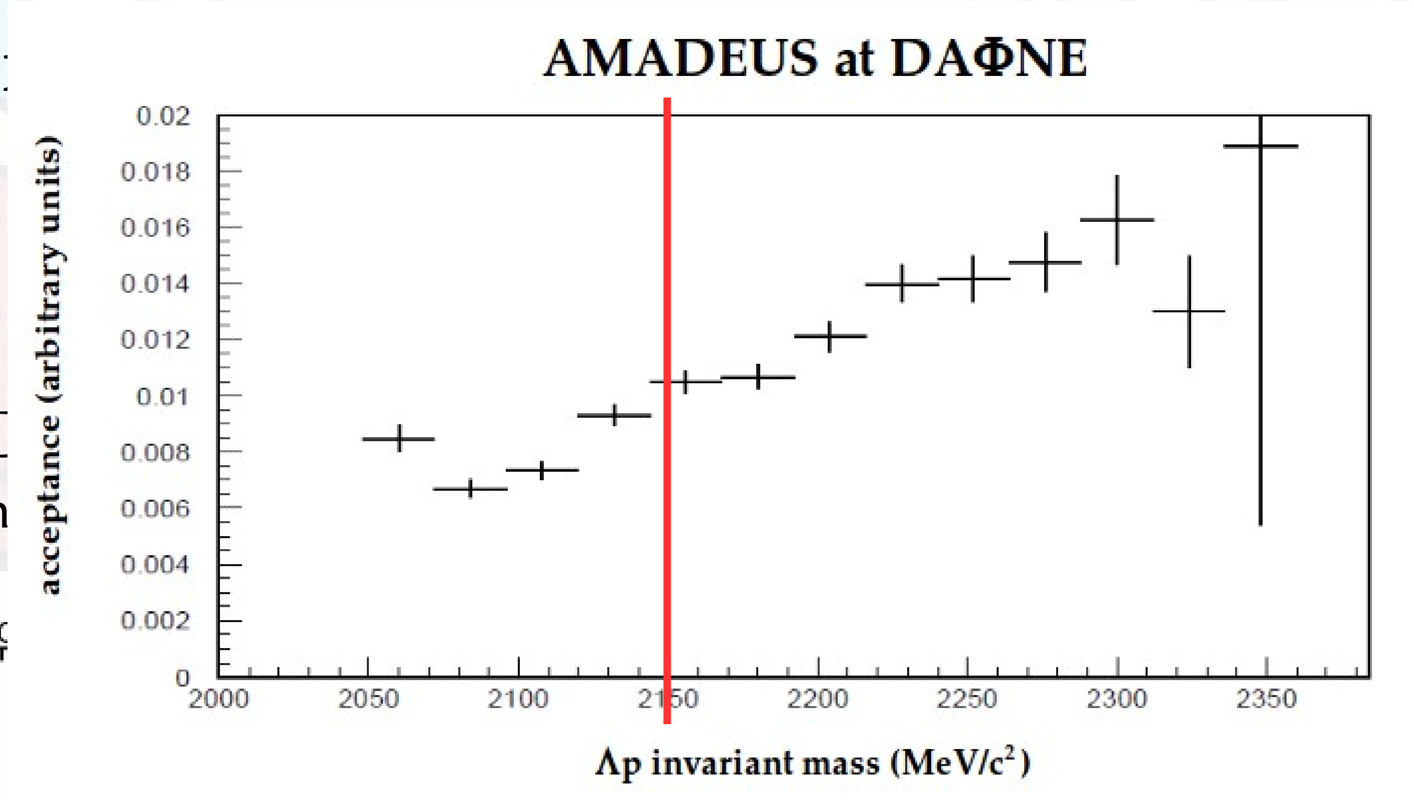


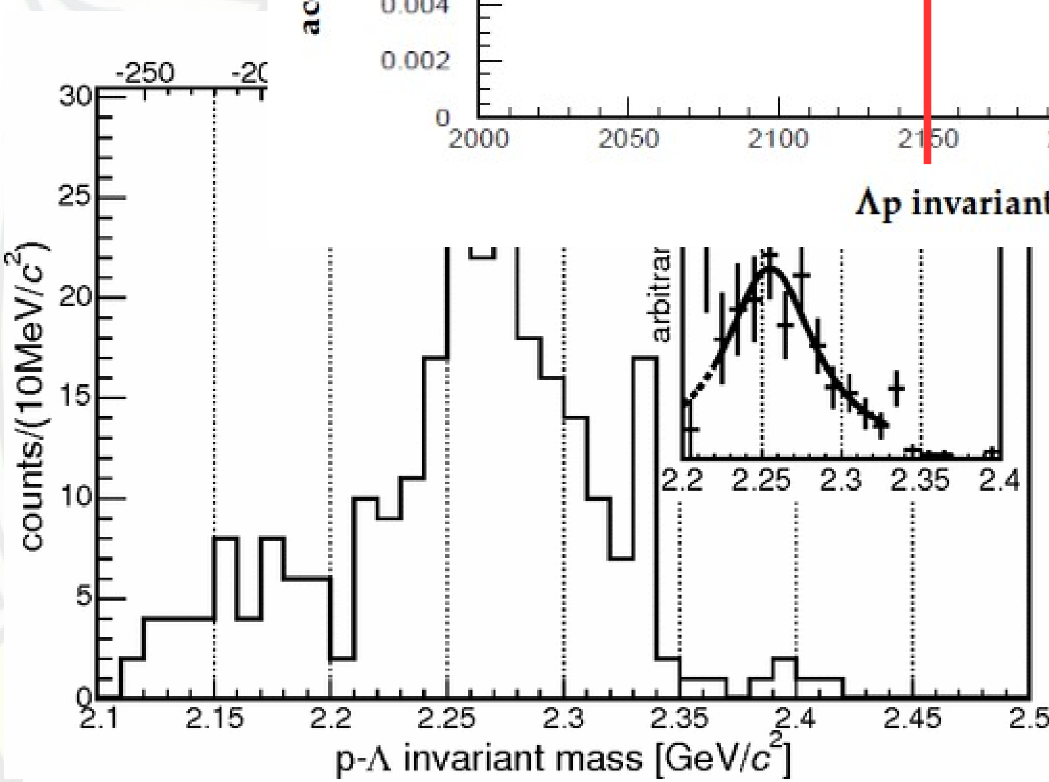
1NA
ΣN/ΛN - DBKS
2NA

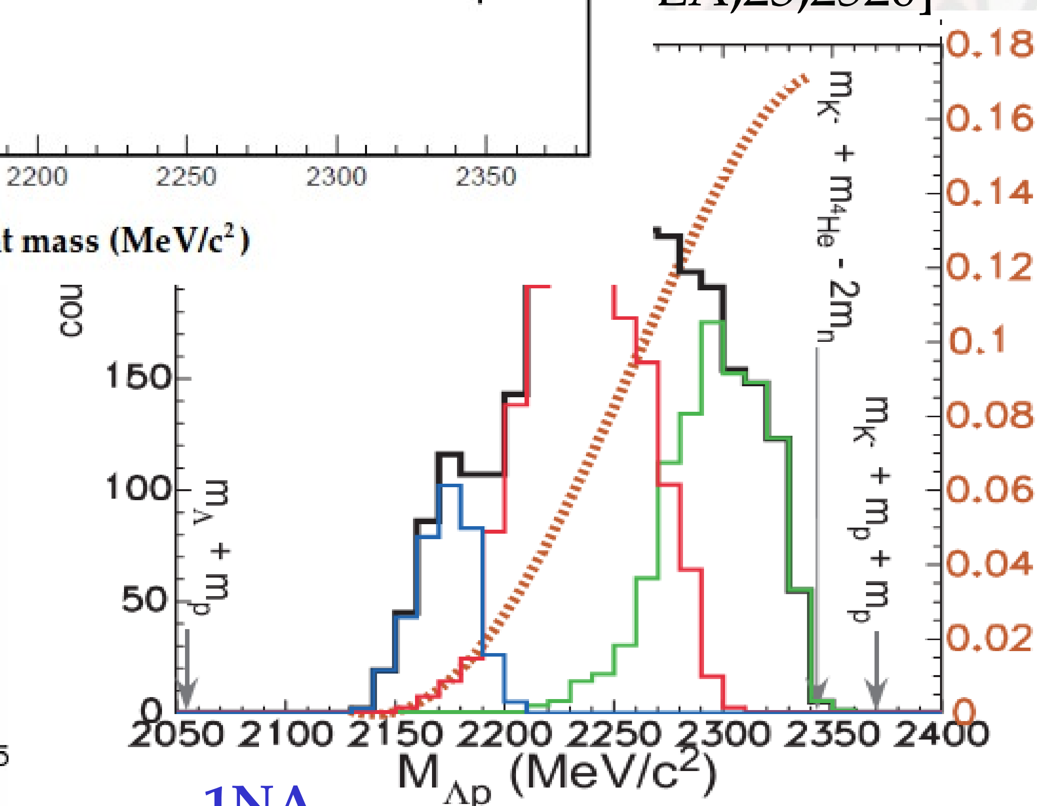
E... annel ... n

FINUD... (X= ^{4}He)

[M. Agn... LA,23,2520]







1NA

ΣN/ΛN - DBKS

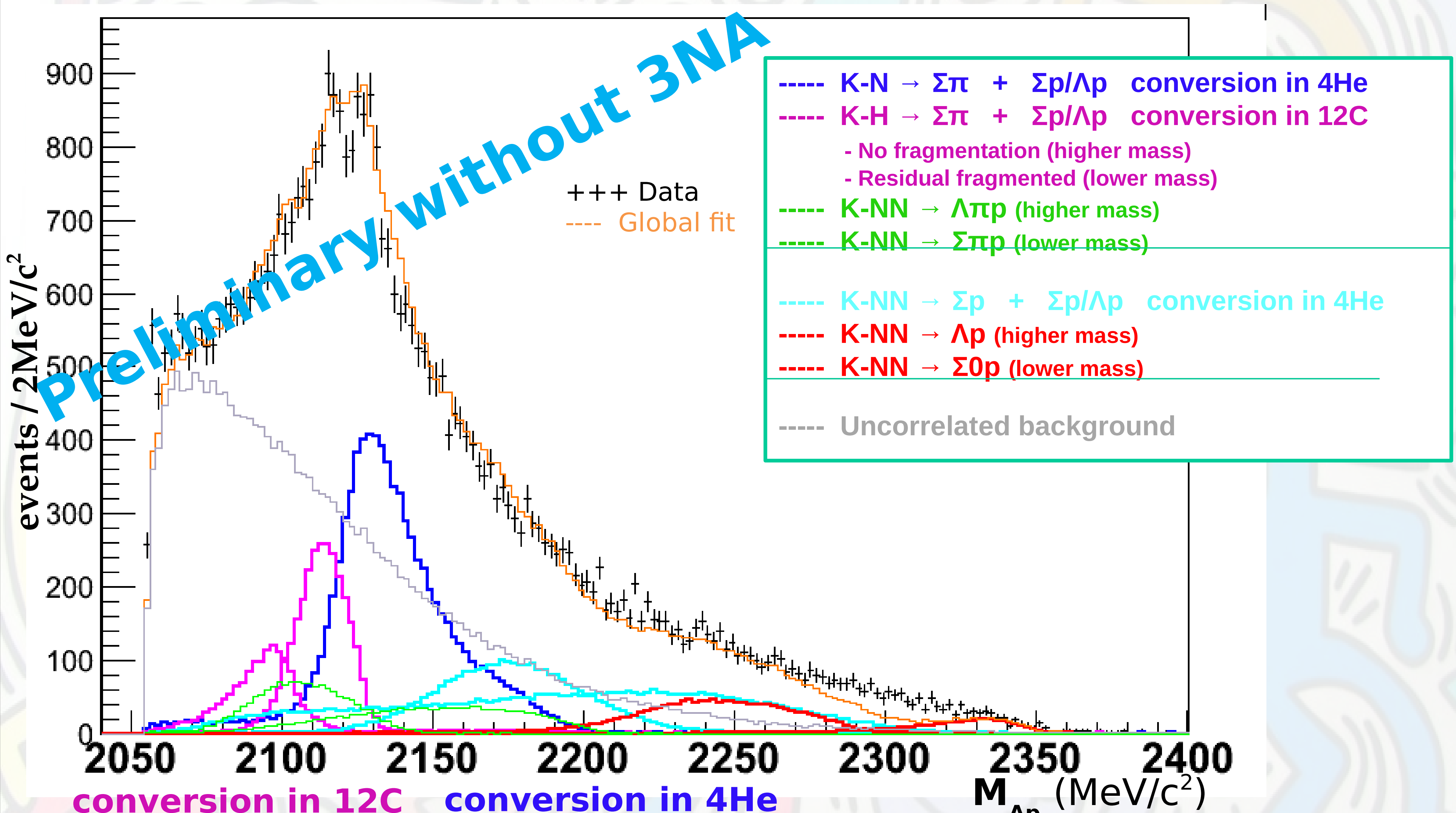
2NA

$B = 115^{+6}_{-5}\,(stat)^{+3}_{-4}\,(sys)$ **MeV**

$\Gamma = 67^{+14}_{-11}\,(stat)^{+2}_{-3}\,(sys)$ **MeV**

Λp correlation study

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



conversion in 12C

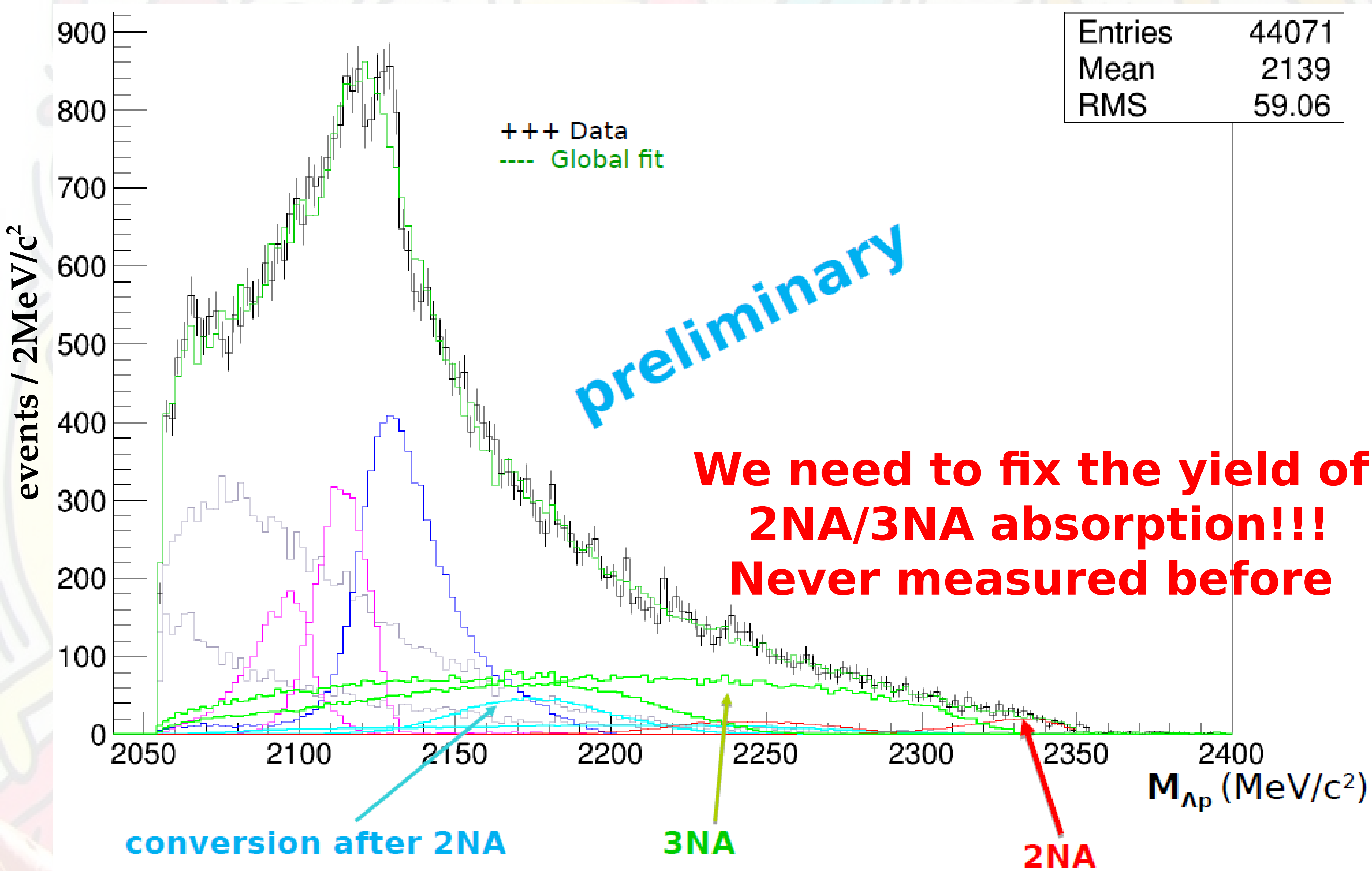
conversion in 4He

2NA direct production

conversion after 2NA: more energetic

Λp correlation study

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



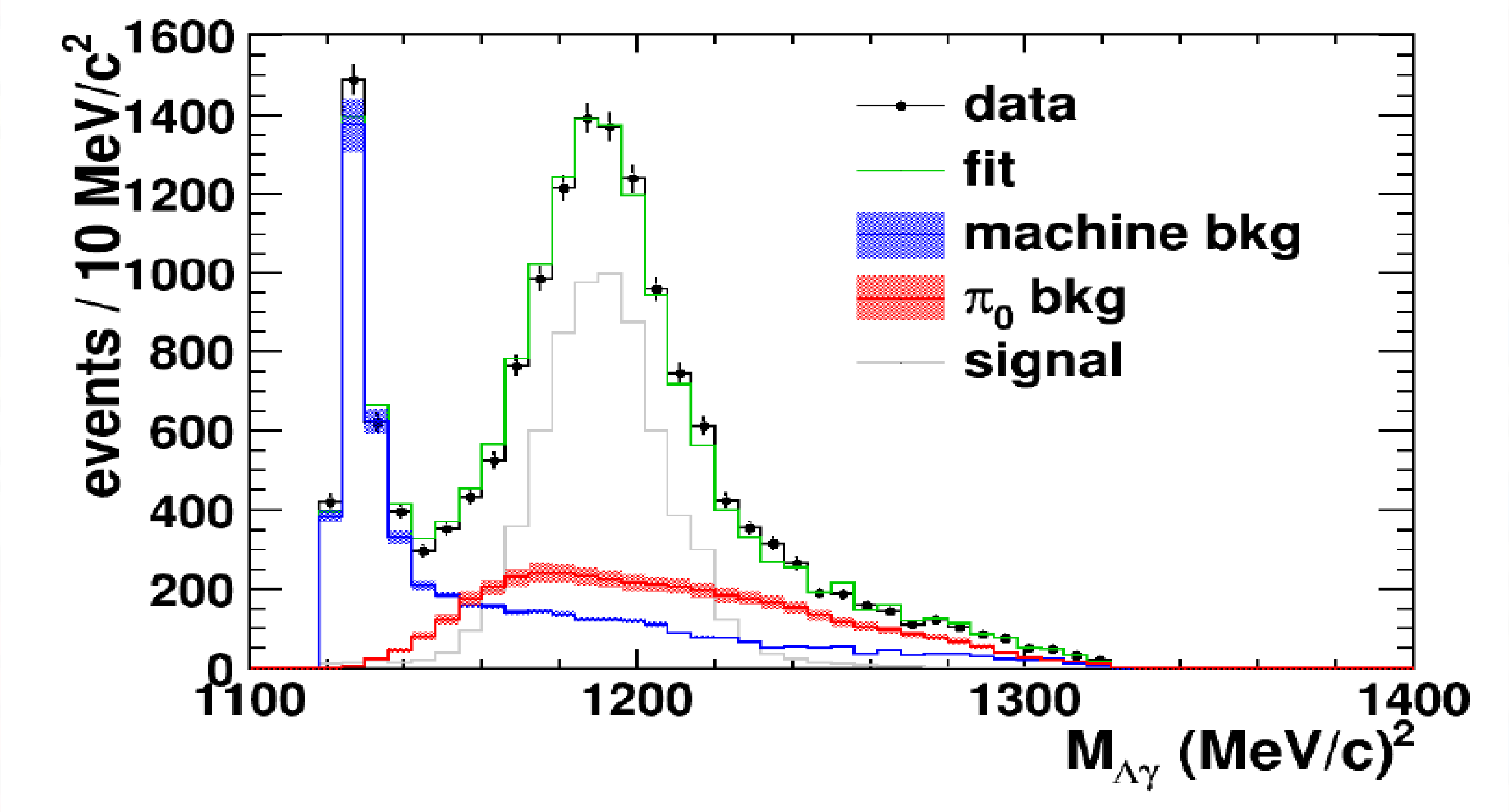
Σ^0 p channel

GOLDEN channel for K-pp cluster search
free from Σ N → Λ N' conversion process!!!

$\Sigma^0 p$ correlation study

Two background sources:

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



$\Sigma^0 p$ the fit

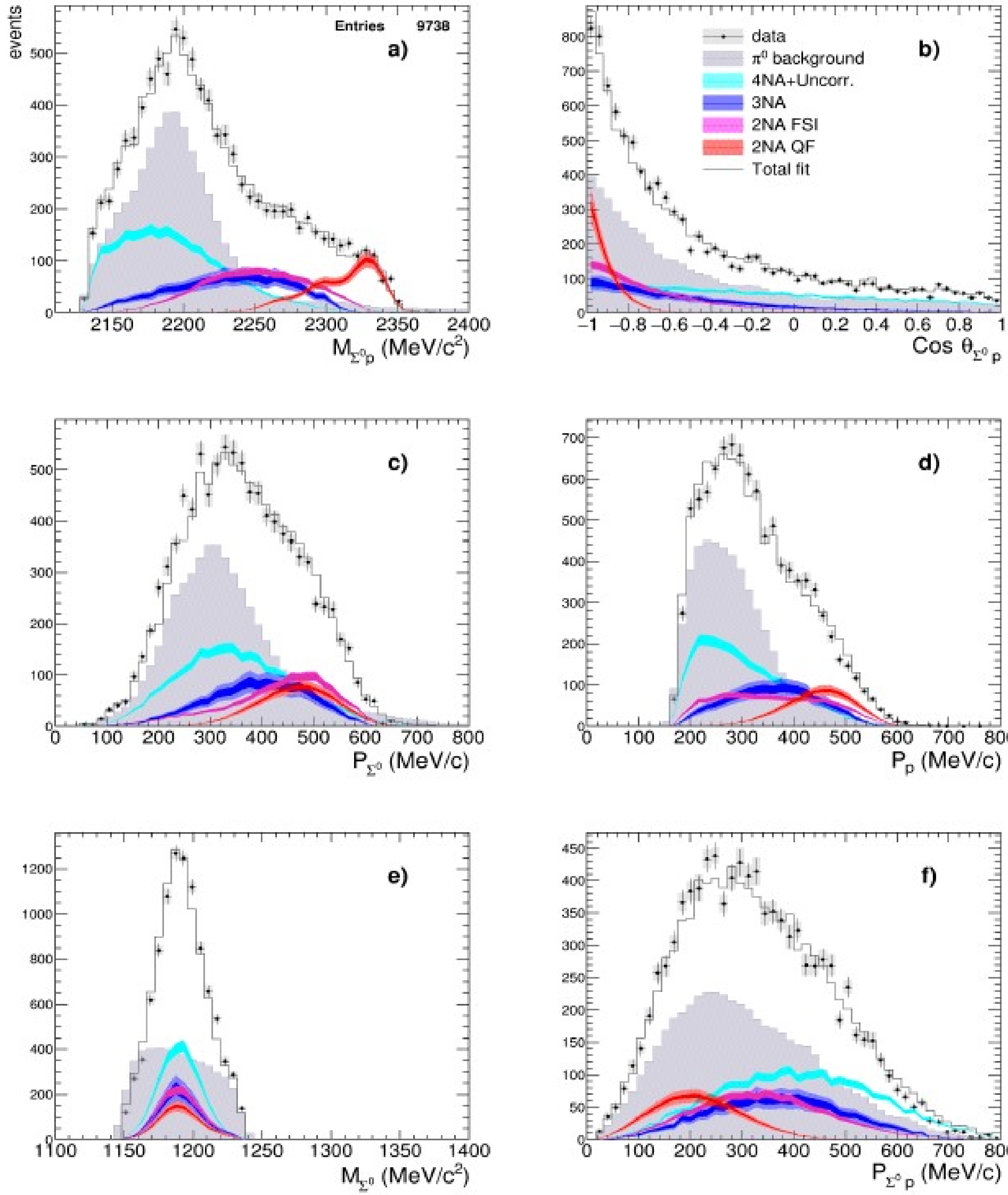
Simultaneous fit for all The relevant physical Quantities:

- **momentum of proton**
- **momentum of Σ^0**
- **Σ^0-p invariant mass**
- **angle $\Sigma^0 p$**

$\chi^2/(ndf - np) = 0.85$

Uploaded on arXiv:1511.04496

Submitted to PLB



Extracted yields

	yield / $K^-_{stop} \cdot 10^{-2}$	$\sigma_{stat} \cdot 10^{-2}$	$\sigma_{syst} \cdot 10^{-2}$
2NA-QF	0.127	± 0.019	$^{+0.004}_{-0.008}$
2NA-FSI	0.272	± 0.028	$^{+0.022}_{-0.023}$
Tot 2NA	0.376	± 0.033	$^{+0.023}_{-0.032}$
3NA	0.274	± 0.069	$^{+0.044}_{-0.021}$
Tot 3 body	0.546	± 0.074	$^{+0.048}_{-0.033}$
4NA + bkg.	0.773	± 0.053	$^{+0.025}_{-0.076}$

Table 2. Production probability of the Σ^0p final state for different intermediate processes normalised to the number of stopped K^- in the DC wall. The statistical and systematic errors are shown as well.

Uploaded on arXiv:1511.04496

Submitted to PLB

Upper limit for K-pp bound state production

BE = 45 MeV

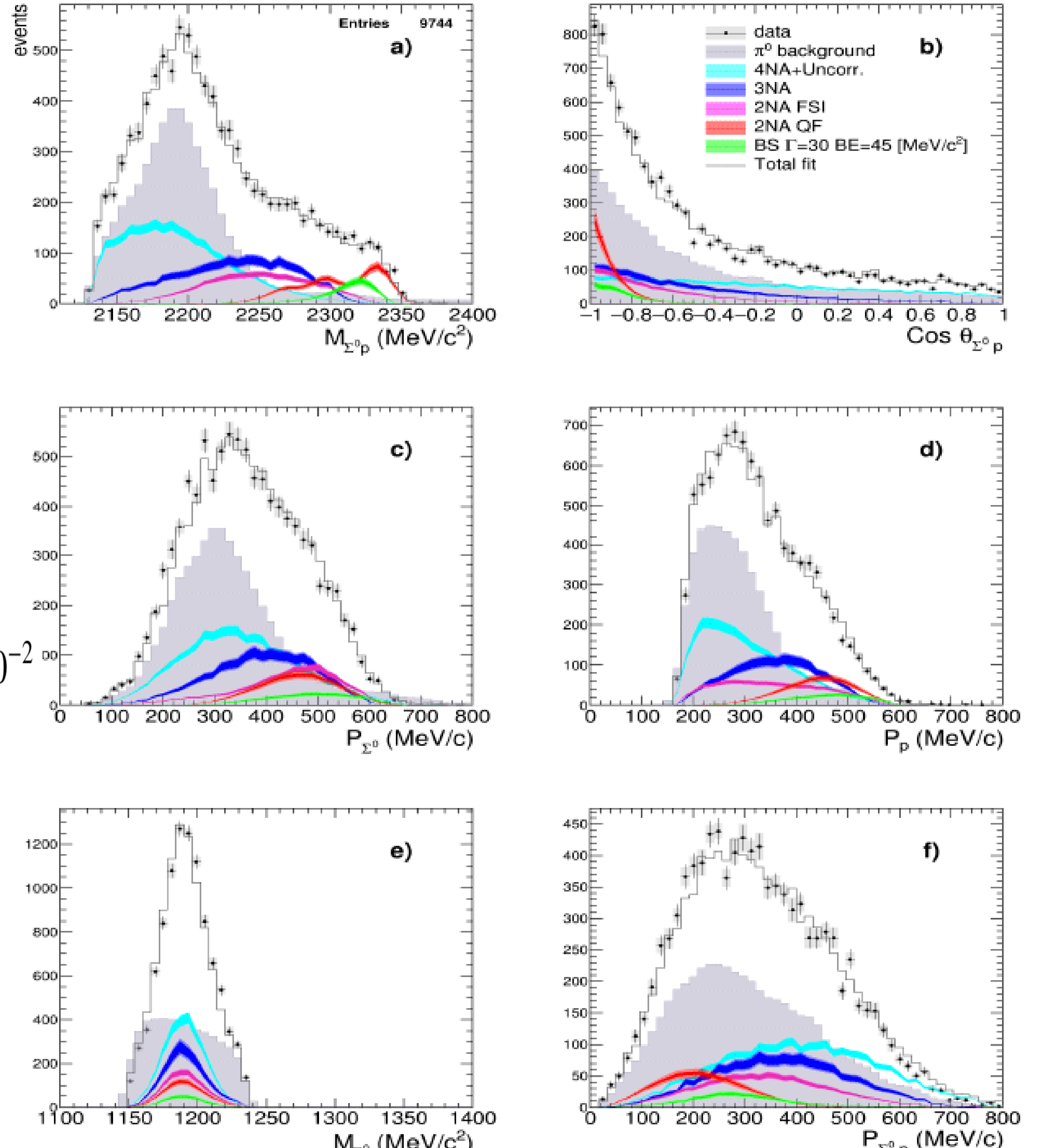
Width = 30 MeV

$$ppK^-/K^-_{stop} = (0.044 \pm 0.009\,stat^{+0.004}_{-0.005}\,syst) \cdot 10^{-2}$$

with a significance of 1σ

Uploaded on arXiv:1511.04496

Submitted to PLB



YN scattering cross section

Σ^0d correlation study

If we consider **helium target** we have:

1NA: $K^- + {}^4He \rightarrow (K^-p)pnn \rightarrow \Sigma^0 + \pi^0 + n + d$
2NA: $K^- + {}^4He \rightarrow (K^-pn)pn \rightarrow \Sigma^0 + n + d$

} Σ^0 and d are uncorrelated

3NA: $K^- + {}^4He \rightarrow (K^-ppn)n \rightarrow \Sigma^0 + d + n$ $\rightarrow$ we know 2NA/3NA

The FSI processes are:

1) $\Sigma^0 + n \rightarrow \Sigma^0 + n$ $\rightarrow$ $\sigma(YN \rightarrow YN)$
2) $\Sigma^0 + d \rightarrow \Sigma^0 + d$ $\rightarrow$ $\sigma(YNN \rightarrow YNN)$
3) $d + n \rightarrow d + n$ $\rightarrow$ known

Conclusions

- Λp correlation study to be finalized:

* No clear peak for the dibarionic kaonic cluster (K^-pp);
* Contaminations due to the Σ /Λ conversion processes and to the Σ^0 decay, necessary to fix the 2/3NA yield;

- Σ^0p correlation study:

* $2NA/K^-_{stop} = (0.127 \pm 0.019\ stat\ ^{+0.004}_{-0.008}\ syst) \times 10^{-2}$
  $3NA/K^-_{stop} = (0.274 \pm 0.069\ stat\ ^{+0.044}_{-0.021}\ syst) \times 10^{-2}$

* K^-pp bound state (BE = 45 MeV and Width= 30 MeV):

$ppK^-/K^-_{stop} = (0.044 \pm 0.009 stat^{+0.004}_{-0.005} syst) \cdot 10^{-2}$ with a significance of 1σ

- YN cross section:

* Σ^0d → only elastic scattering in FSI processes;
* We can try to extract σ(YN → YN) and σ(YNN → YNN)

THANKS