Low-energy strangeness studies by AMADEUS to understand the Neutron Stars

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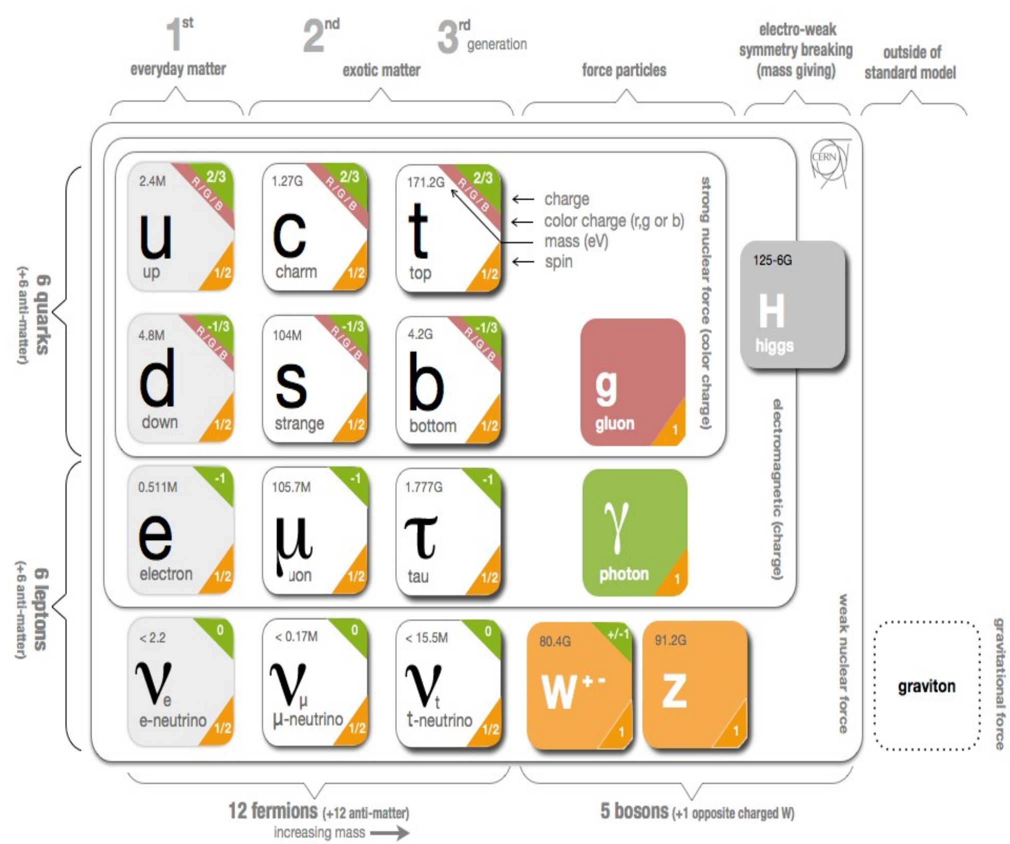
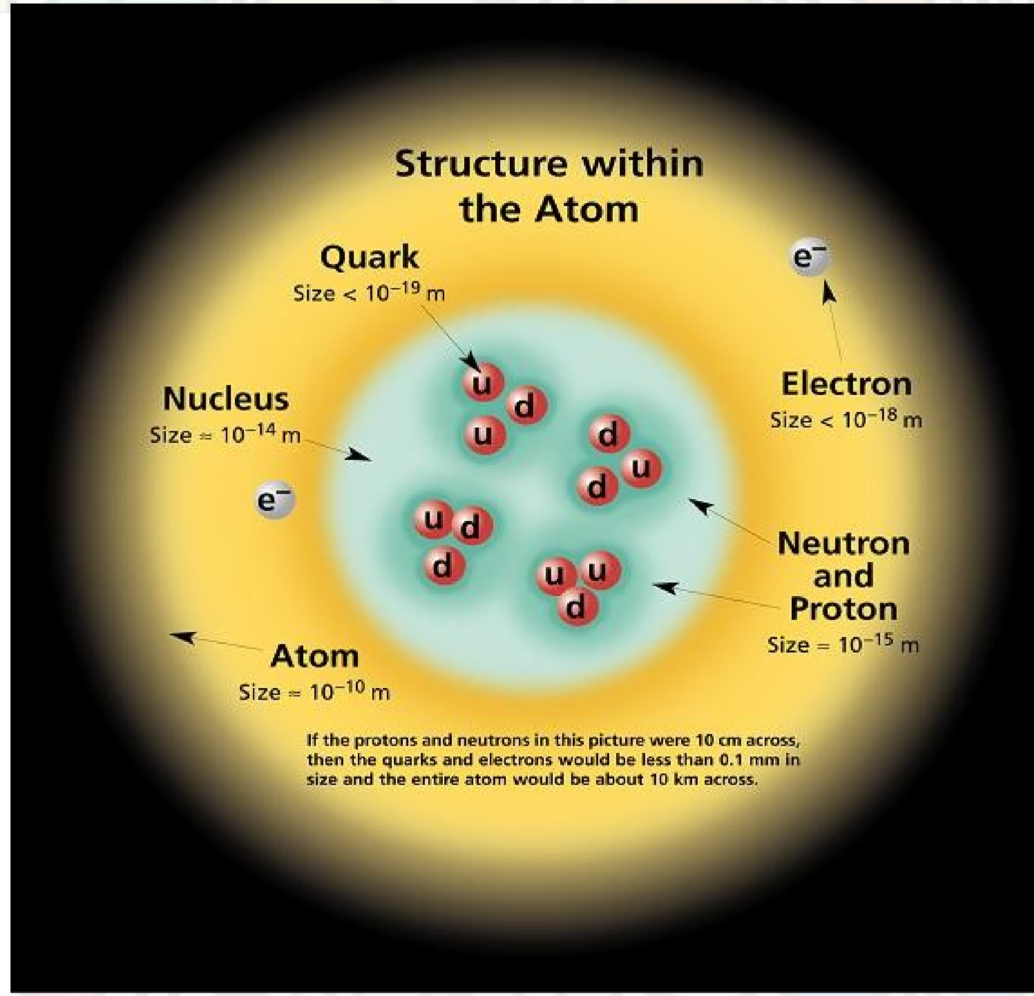
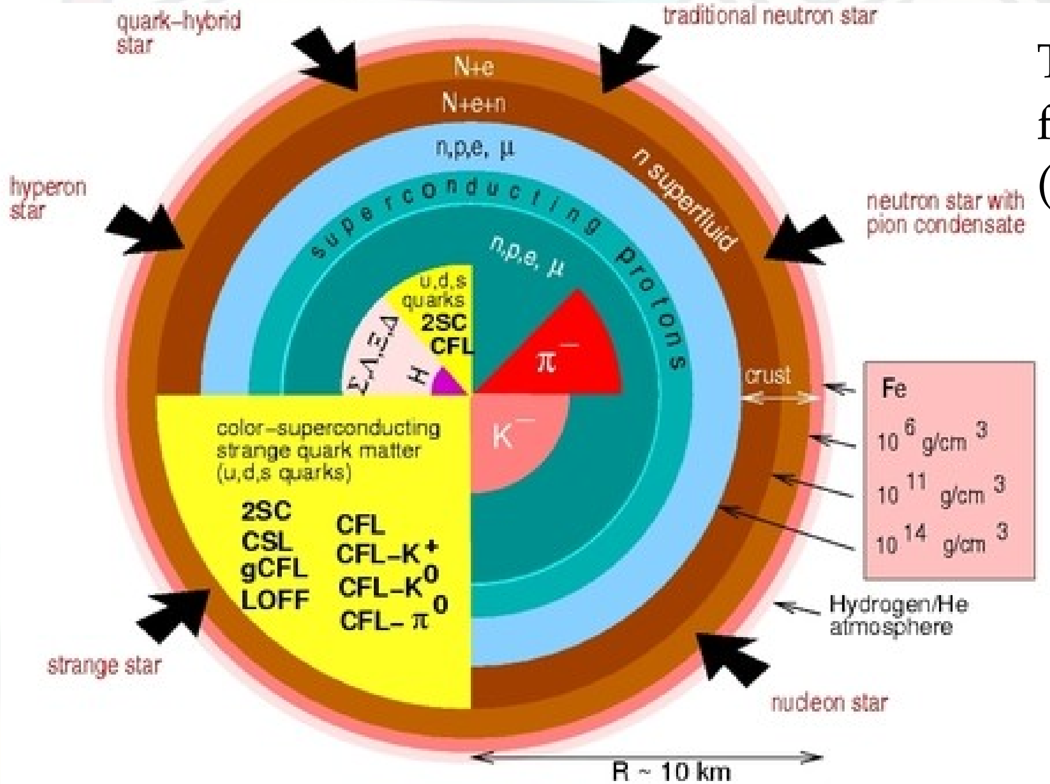
Ordinary matter → 1st generation of foundamental particles





WHAT ABOUT THE OTHER PARTICLES?

Stangeness in Neutron Stars?



The largest well-measured mass is 1.97±0.04 M⊙ for **PSR J1614-2230**.
(Annu. Rev. Nucl. Part. Sci. 2012. 62; 485-515)

Some models predict hadrons with $S \neq 0$ inside 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**

K-N potential U_{KN} → **how deep can an antikaon be bound in a nucleus?**

AMADEUS: Anti-kaonic Matter At Daϕne: Experiments with Unrevealing Spettrocopy

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:

- Interaction of **K^-** with **one** and **more nucleons (single and multi – nucleon K^- absorption)**

- possible existence of **kaonic nuclear clusters** (deeply bound kaonic nuclear states – DBKNS) * - search in the **Λp**, Σp, Λd, and Λt final channels

- Low-energy charged kaon **cross sections** for momenta lower than 100 MeV/c

- Controversial nature of the Λ(1405)

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

* **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**?

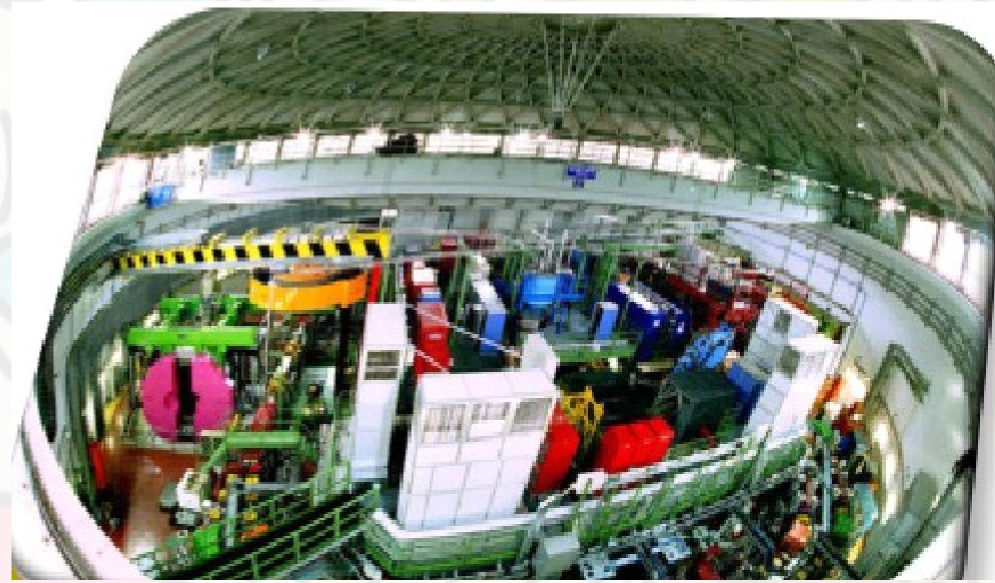
AMADEUS & DAΦNE

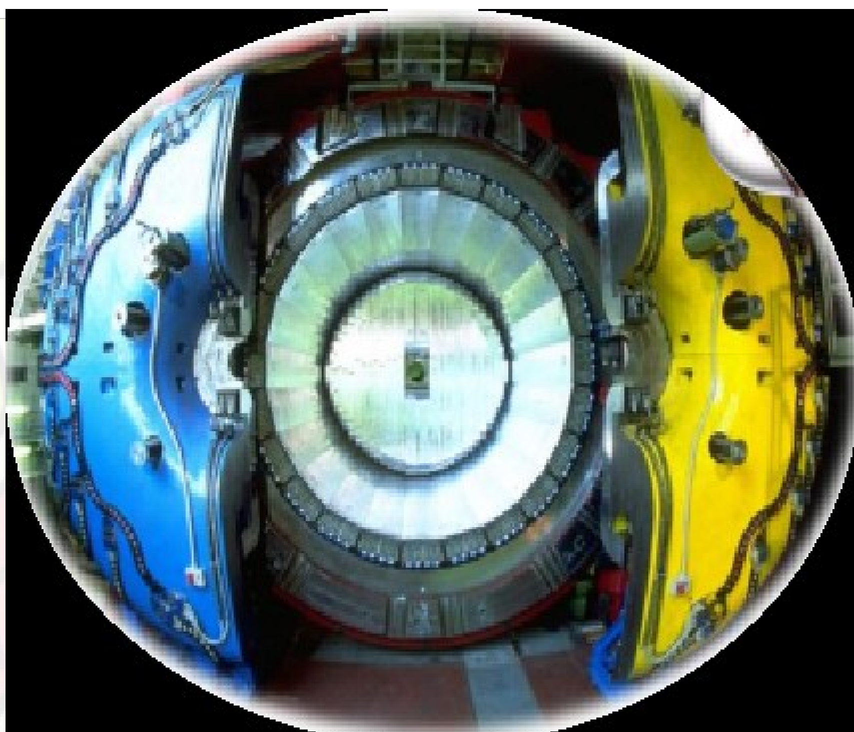
DAΦNE

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





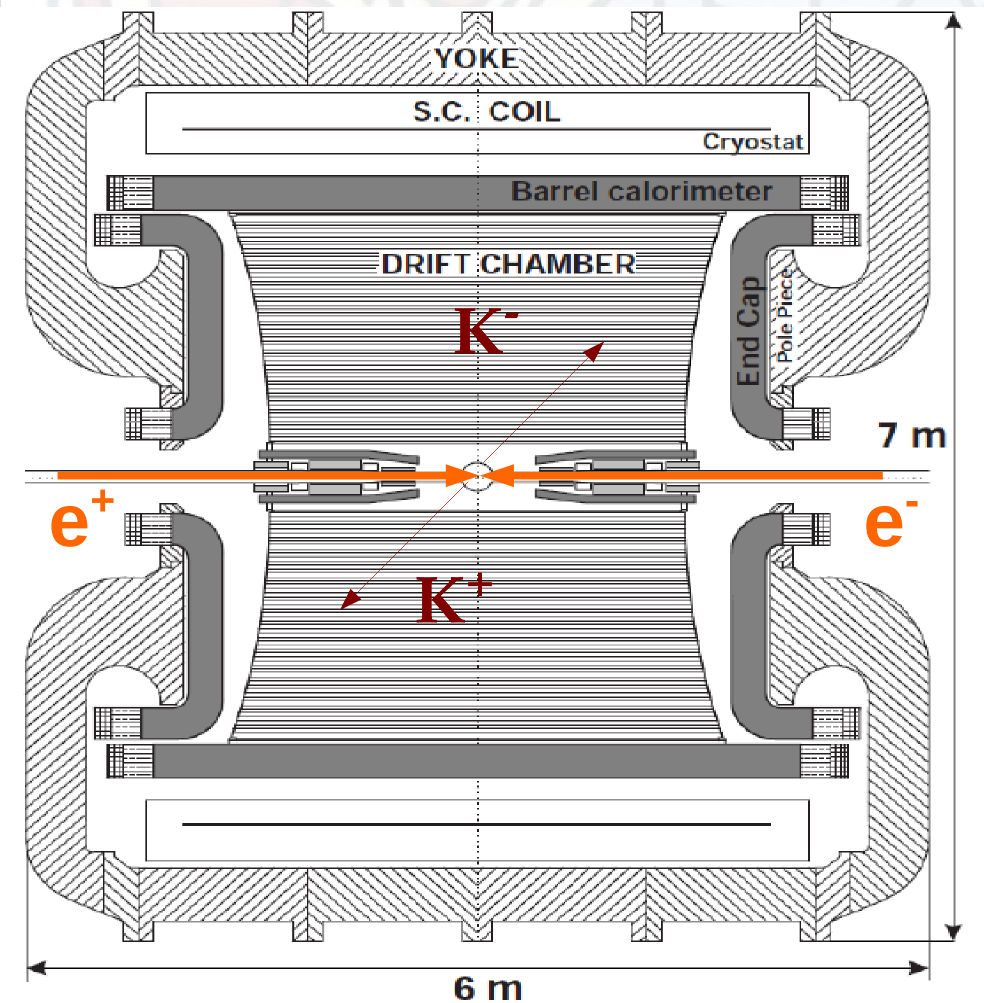
AMADEUS STEP 0: KLOE 2004-2005 data

- 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)))

Low-energy K^- hadronic interactions studies with KLOE, why?

Possibility to use KLOE materials as an active target

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



Advantage:
excellent resolution ..

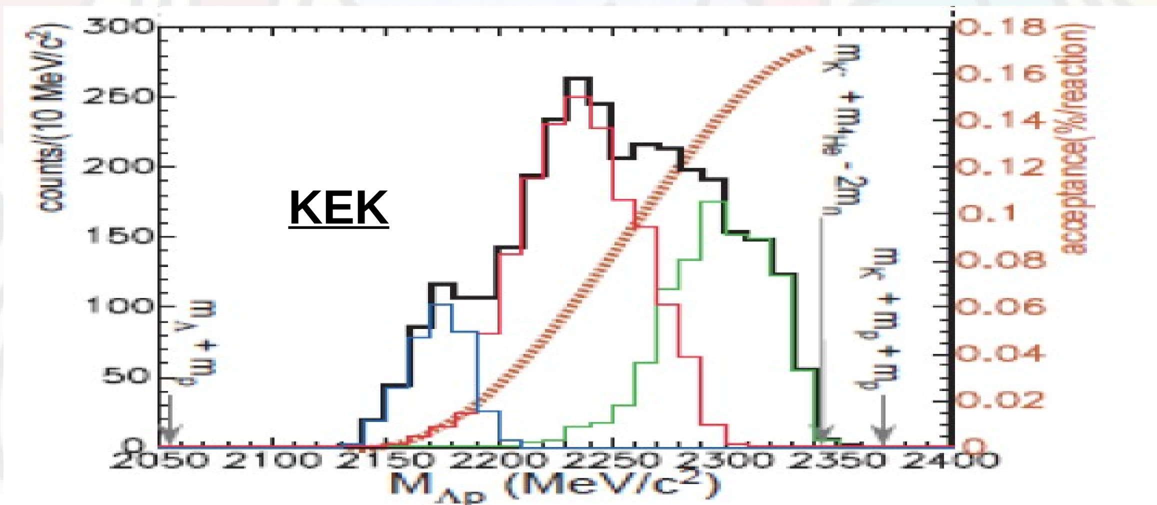
$\sigma_{p\Lambda}$ = 0.49±0.01 MeV/c in DC gas

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

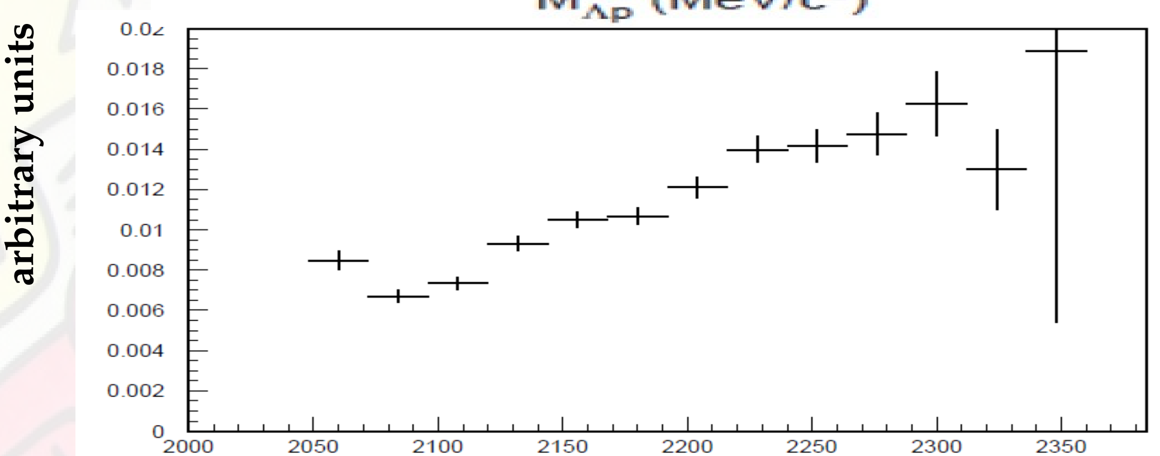
Disadvantage:
Not dedicated target → different nuclei contamination → complex interpretation.

Search for the K^-pp bound state through the Λp correlation study

K^- stopped + X → Λ p X' (detected particles)
(in-flight)
Λ → $p\pi^-$



1NA
ΣN/ΛN - DBKS
2NA

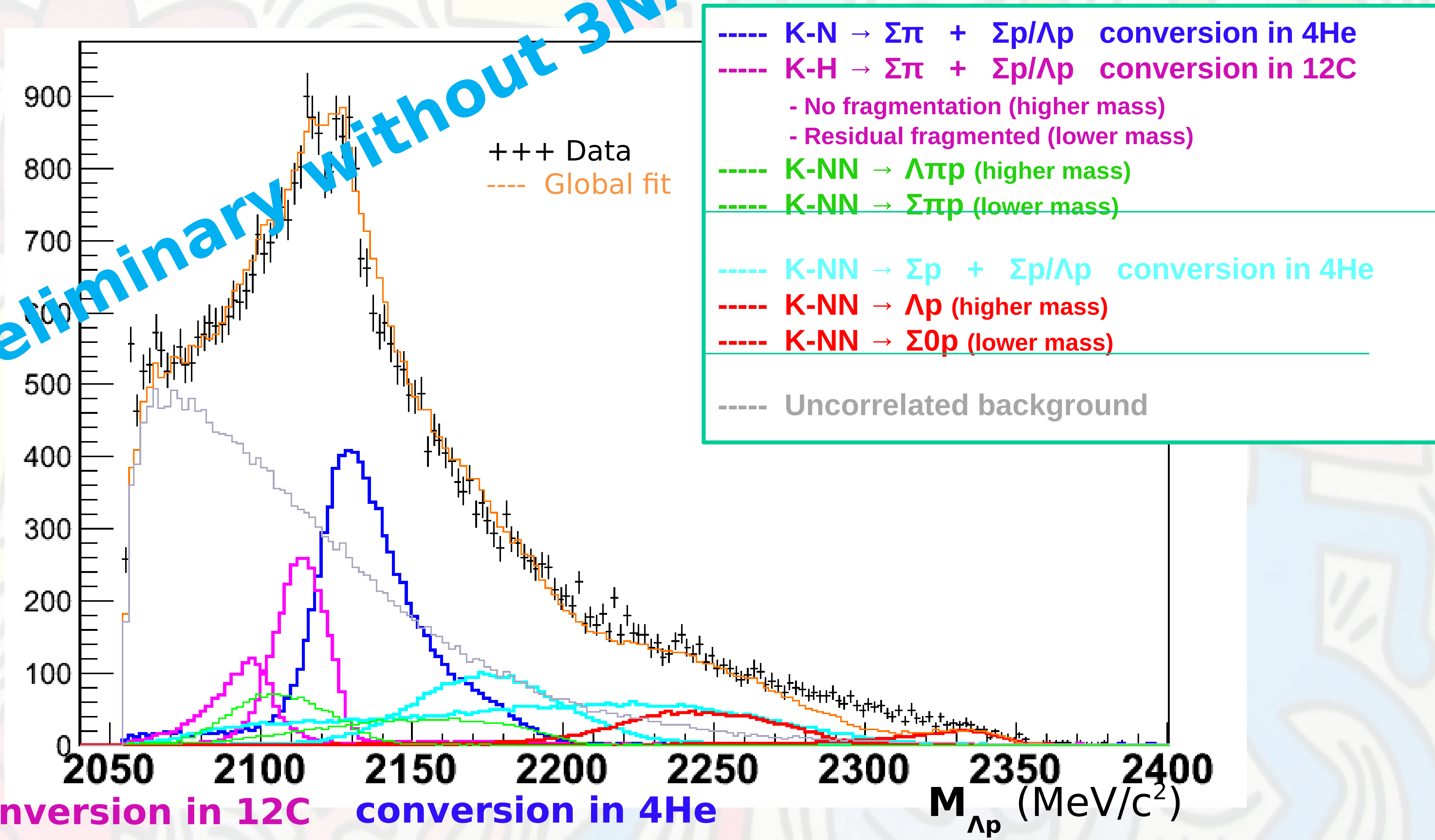


Projection of the acceptance function depending on : (P_Λ,P_p,M_{inv} Λp) on the Invariant mass plane

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

Λp correlation study

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



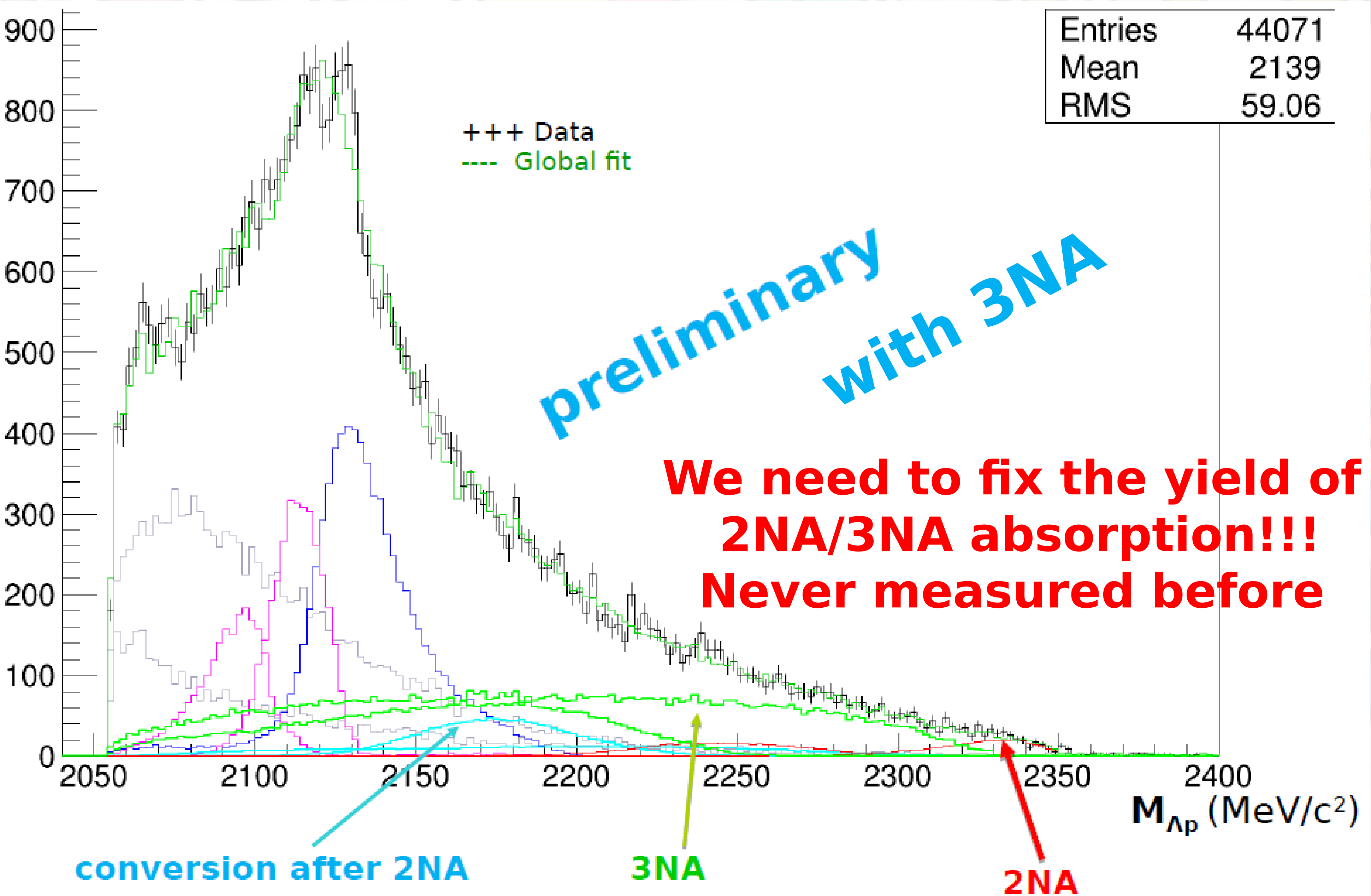
conversion in 12C   conversion in 4He

2NA direct production

conversion after 2NA: more energetic

Λp correlation study

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



Conclusions & Future Perspectives

- Λp analysis to be finalized:

  *No clear peak structure excludes the possibility of a high formation rate and/or narrow width resonance.
  *The signal from the decay of a K^-pp bound state is masked by the Σ/Λ conversion process.
  *Clear evidence of 3NA in Λp channel.

- Try to extract $\sigma_{YN \rightarrow YN}$ to give quantitative informations about U_{YN}

THANKS

Single & multi-nucleon K^- absorption. Kaonic nuclear cluster investigation through Λp, Λd, Λt and $\Sigma^0 p$ correlation.

- Single nucleon absorption (**1NA**):

$$K^- + \text{'p'} \rightarrow \Lambda + \pi^0$$

- Double nucleons absorption (**2NA**):

$$K^- + \text{'pp'} \rightarrow \Lambda + p$$

$$K^- + \text{'pp'} \rightarrow \Sigma^0 + p$$

- Three nucleons absorption (**3NA**):

$$K^- + \text{'ppn'} \rightarrow \Lambda + d$$

- Four nucleons absorption (**4NA**):

$$K^- + \text{'ppnn'} \rightarrow \Lambda + t$$

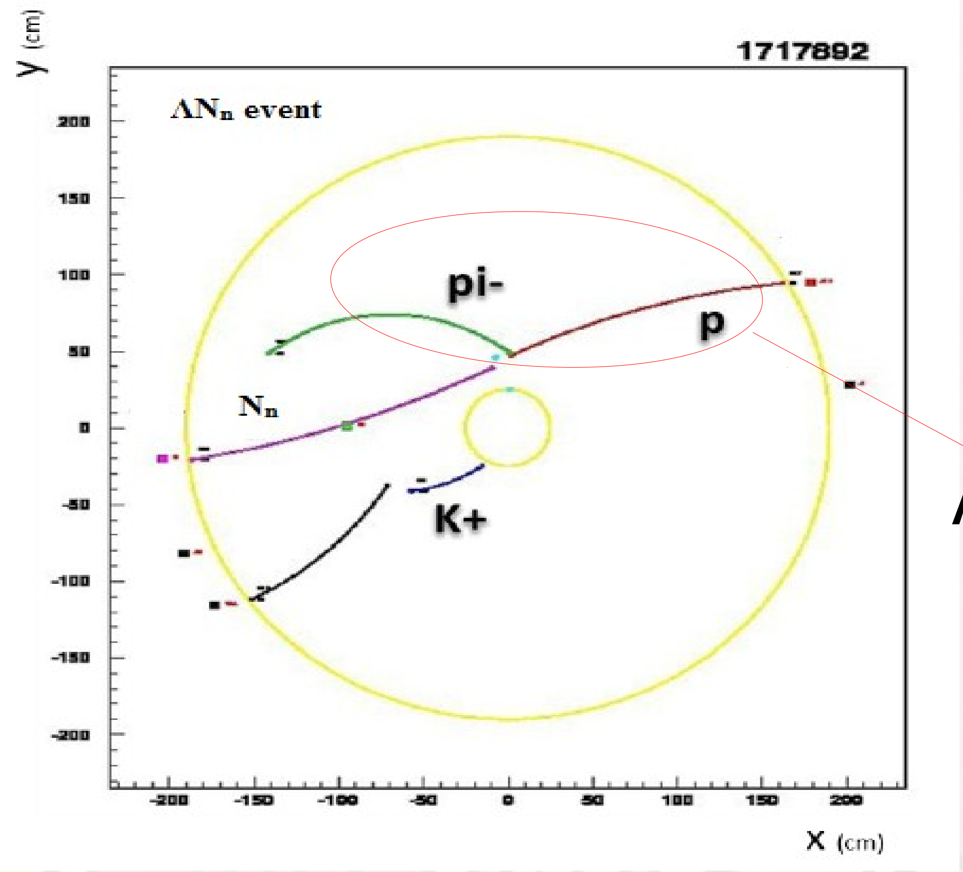
Different theoretical approaches:
- Few-body calculations solving Faddeev equations
- Variational calculations with phenomenological KN potential
- KN effective interactions based on Chiral SU(3) dynamics

K^-pp bound state

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
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

Events reconstruction in KLOE

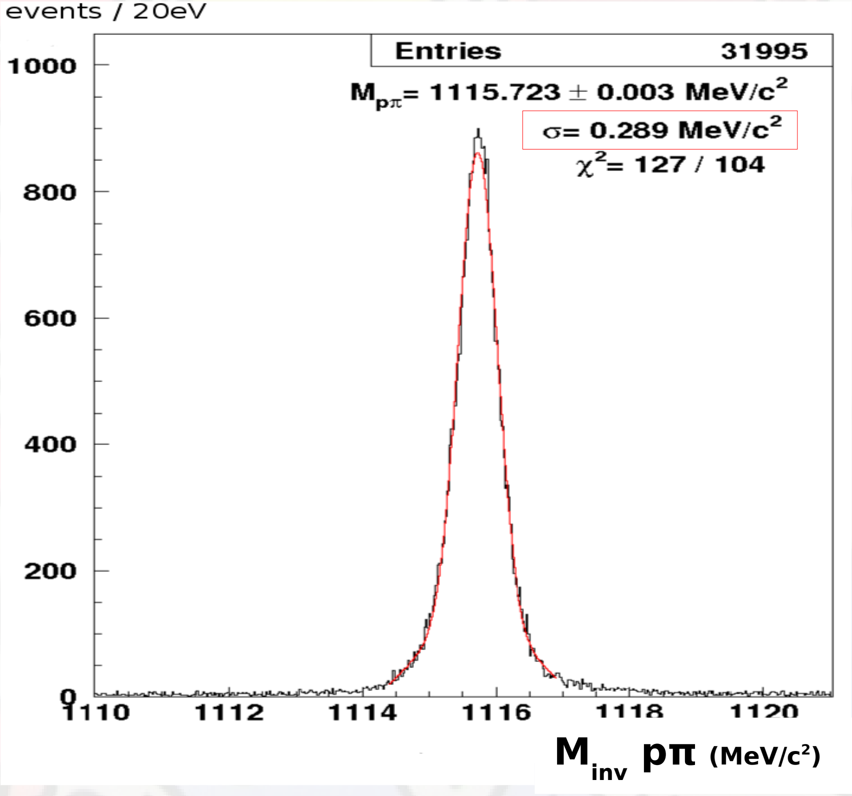
N_n – higher mass particle p,d **or t**



Particle identification via:

- **dE/dx** information in the DC wires
- Mass by TOF

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



KLOE: $M_{inv} = 1115.723 \pm 0.003$ (stat.) MeV/c²

PDG: $M_{\Lambda} = 1115.683 \pm 0.006$ MeV/c²

Λp events, preliminary fit

- 1NA with Σ/Λ conversion:

$K^-N \rightarrow \Sigma\pi$ + $\Sigma p/\Lambda p$

FINAL PRODUCED PARTICLES

- 2NA processes:

$K^-NN \rightarrow \Lambda\, p$

$K^-NN \rightarrow \Sigma^0\, p$ + $\Sigma^0 \rightarrow \Lambda\, \gamma$

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

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

- Uncorrelated processes:

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