The AMADEUS experiment and the analysis of K$^-$He KLOE data

Oton Vázquez Doce
on behalf of the AMADEUS Collaboration

Excited QCD 09

Zakopane, February 12, 2009

The AMADEUS experiment

- The AMADEUS experiment at **DAΦNE**
- Experimental case: **Deeply bound kaonic nuclear states**
- The AMADEUS setup

KLOE data analysis

- KLOE experiment data, hadronic interactions of K^-
- **Lambda** identification
- Lambda correlations: **Λ+p, Λ+d, Λ(1405)**...and more to come

Introduction

- Letter of Intend, March 2006
- Day 1 proporsal, November 2007

Study of deeply bound kaonic nuclear states at DAΦNE2

- **The main aim of AMADEUS is to confirm or deny the existance of Kaonic Clusters**, studying it in the formation and decay processes

- Either situations: EXISTENCE or NON-EXISTENCE of the deeply bound kaonic nuclear clusters will have strong impact in kaon-nucleon/nuclei physics

Kaonic Clusters

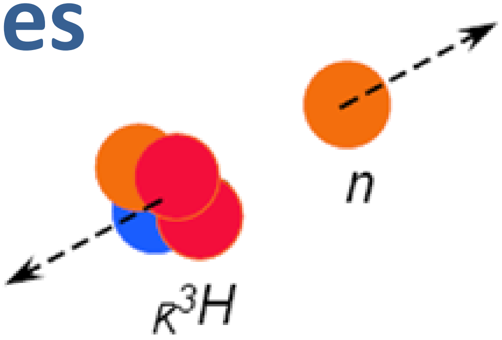
A hadron physics important and unresolved topic: **How the hadronic masses and interactions change in nuclear medium**

Deeply bound kaonic nuclear states

firstly suggested by S. Wycech (1986)

Y. Akaishi and T. Yamazaki *(Phys. Rev. C65 (2002) 044005)*

"Nuclear bound states in light nuclei"



Strong attractive I=0 KN interaction favors discrete nuclear states **bound ~100** and **Γ ~ 30 MeV**.

- Prediction based on the interpretation of the s-wave, isospin I=0 **Λ(1405)** resonance as a **K^-p bound state**
- Creation of a KN potential as to similtaneously reproduce data from KN **scattering lenghts** and binding energy and width of **kaonic hydrogen**

Theoretical debate

- Alternative interpretations of the present data: double nucleon absorption followed by FSI of the produced particles with daughter nucleus

- Theoretical development of $\bar{K}N$ interaction in free space in the framework of SU(3) Chiral unitary model, and modification due to many-body efects in nuclear medium

- Nature of the Λ(1405) resonance

- Bound kaon approach in the Skyrme model also predicts Kaonic Clusters

- Interpretations with not-so-strongly attractive $\bar{K}N$ potentials

- Nucleon-Nucleon repulsion

- Deeply bound states only in heavy nucleus

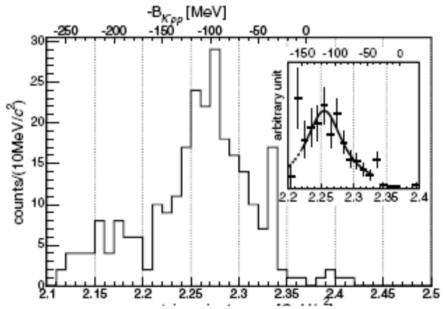
⇩

theoreticians demand new complete experimental results!

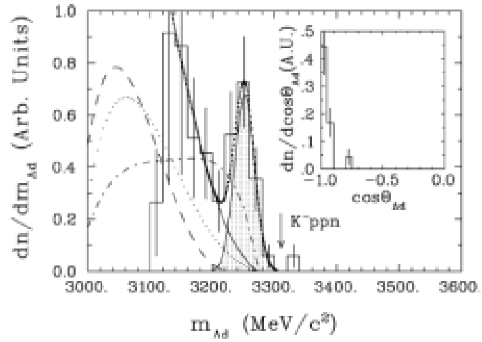
Experimental data

Experimental results from **FINUDA**

K- stopped in light nuclei
Invariant mass spectroscopy



Λp

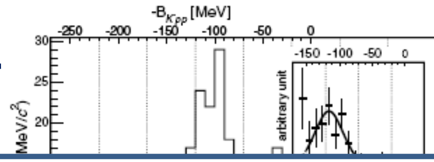


Λd

Experimental data

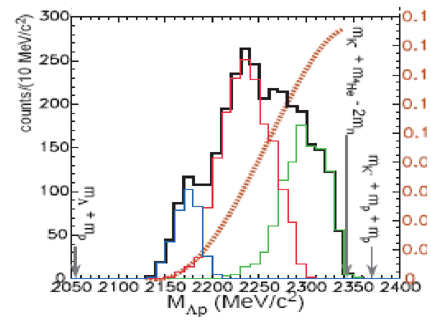
Experimental resu
from **FINUDA**

K- stopped in light nuc
Invariant mass spectro

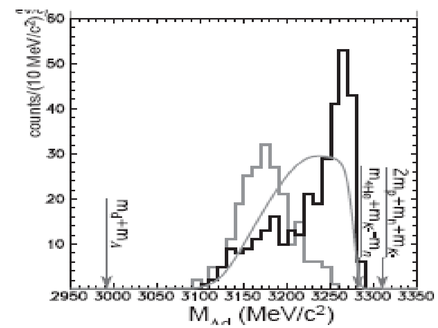


Results from **KEK**:

K- stopped in 4He
Invariant mass spectroscopy



Λp



Λd

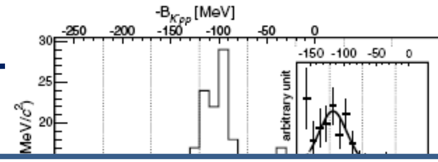
Experimental data

Experimental resu

from **FINUDA**

K- stopped in light nuc

Invariant mass spectro



Λp

Results from **KEK**:

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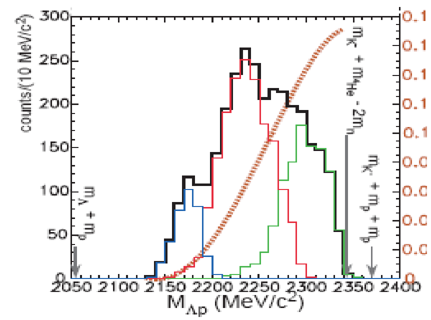
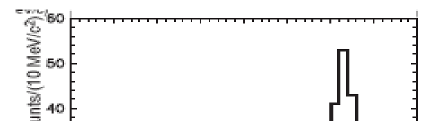


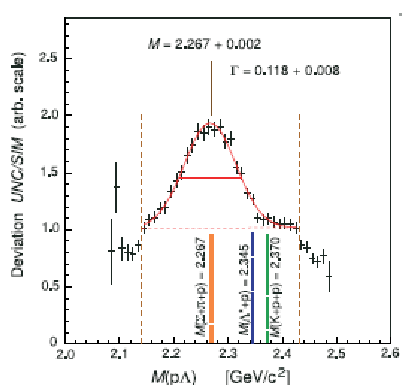
Λp



Λd

DISTO

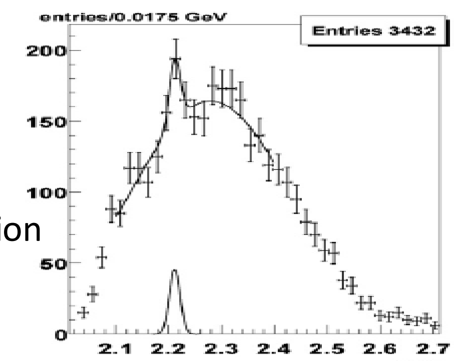
p+p → K^{+}+X



Λp

OBELIX

$\bar{p}^{4}$He annihilation



Λp

(Λd)

The AMADEUS experiment

AMADEUS phase-1: start in 2010/2011 (after KLOE2 step-0), study di- and tri – baryon kaonic nuclei and low-energy kaon-nucleon/nuclei interactions

AMADEUS phase-2: after 2012, higher integrated luminosity, refined study; extend to other nuclei (kaonic nuclei spectroscopy along the periodic table)

The AMADEUS experiment

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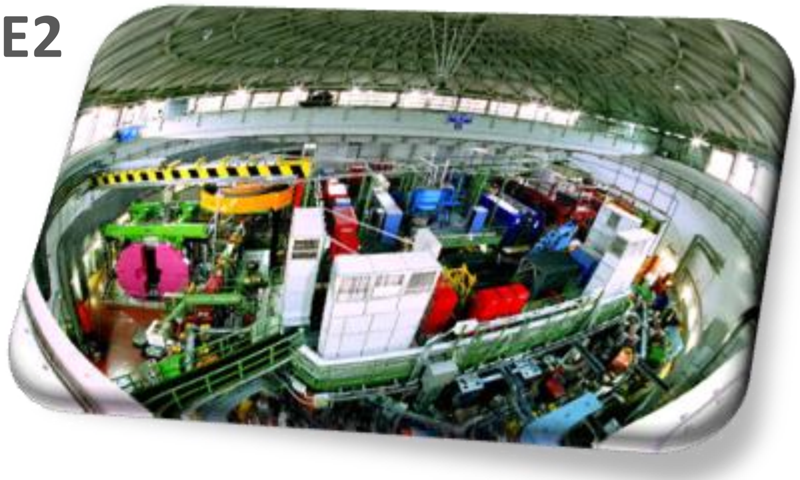
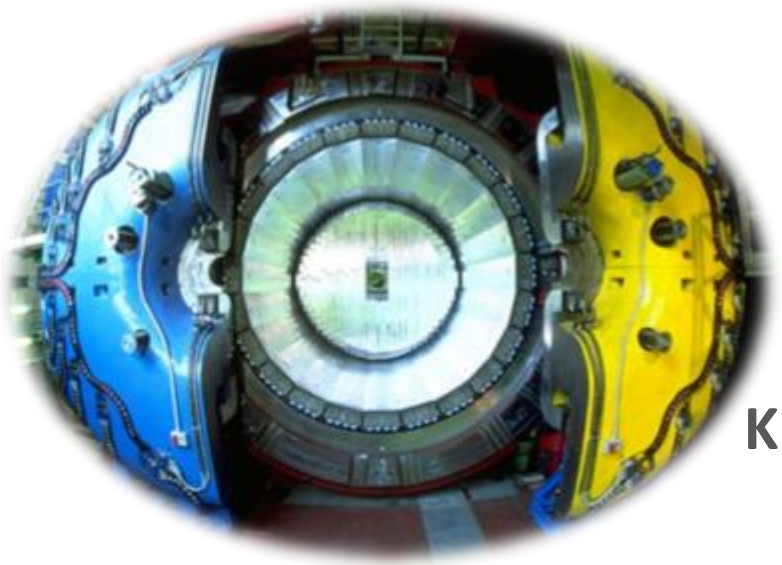
AMADEUS phase-2: after 2012, higher integrated luminosity, refined study; extend to other nuclei (kaonic nuclei spectroscopy along the periodic table)

Requirements satisfied by…

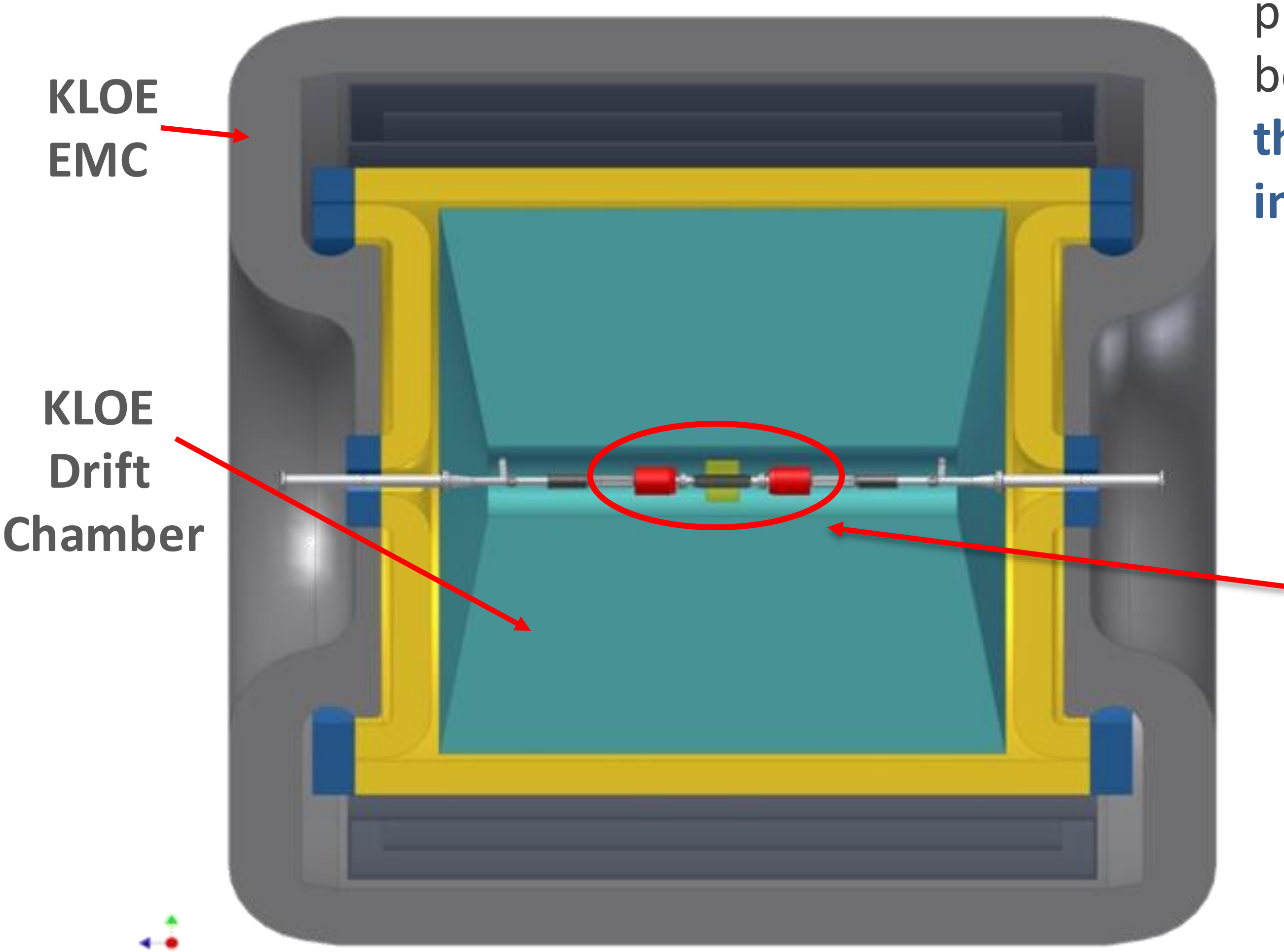
DAΦNE2





KLOE

The AMADEUS setup



Full acceptance and high precision measurements will be made by **implementing the KLOE detector with an inner AMADEUS setup**

(50 cm. gap in KLOE DC around the beam pipe)

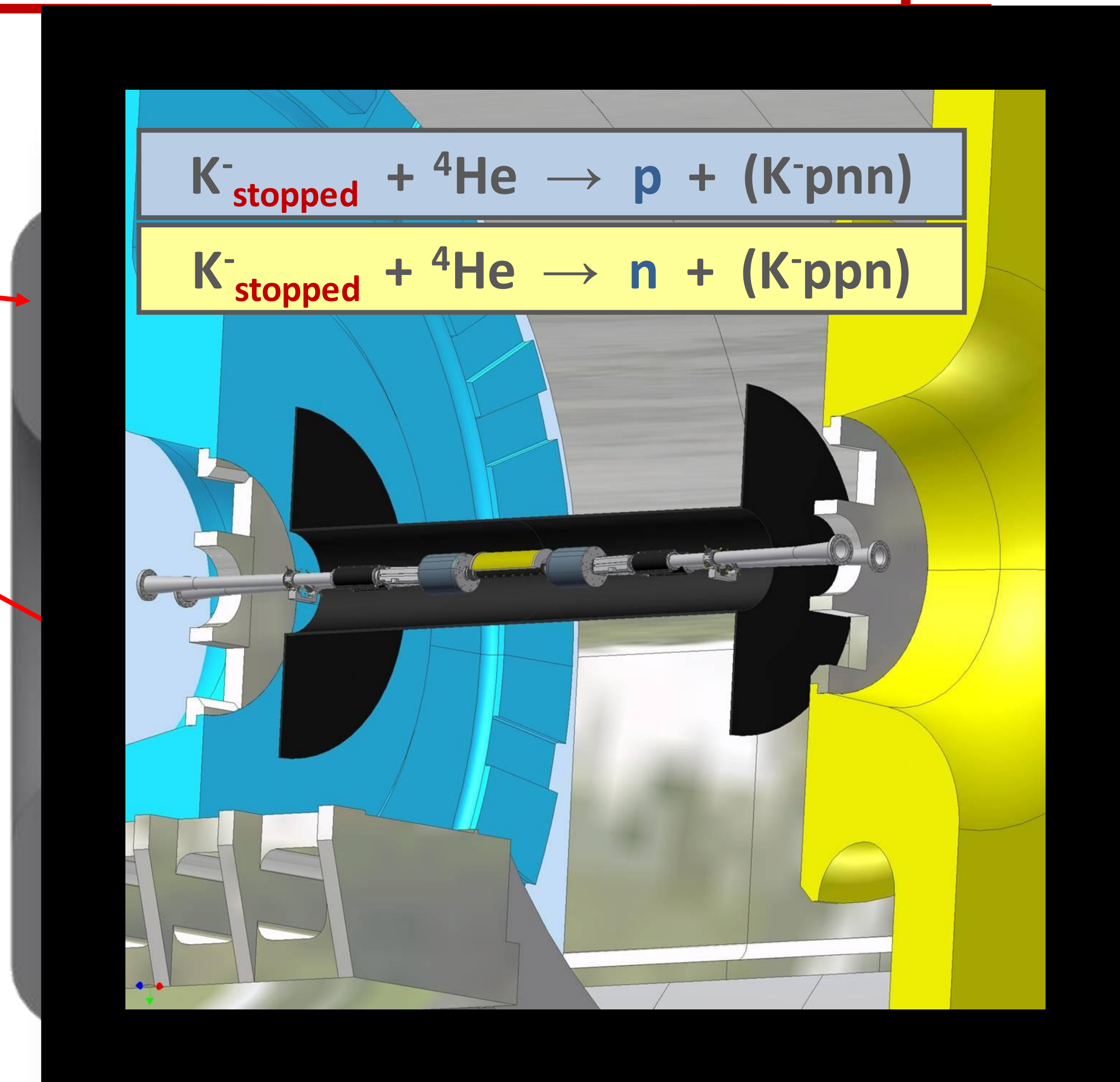
Setup for AMADEUS within KLOE

- **Cryogenic target**
- **Inner tracker**
- **Kaon trigger**

The AMADEUS setup

KLOE EMC

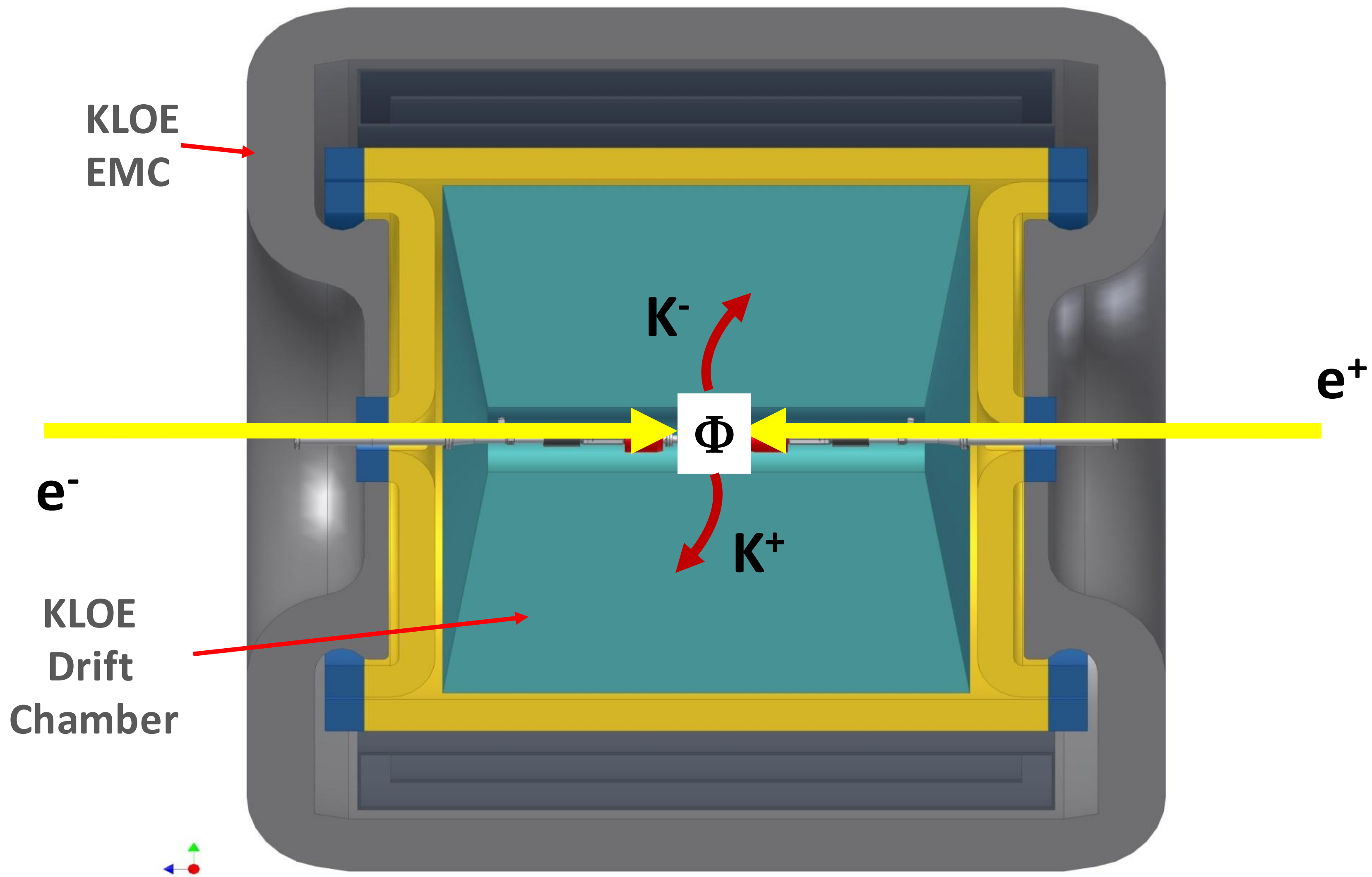
KLOE Drift Chamber



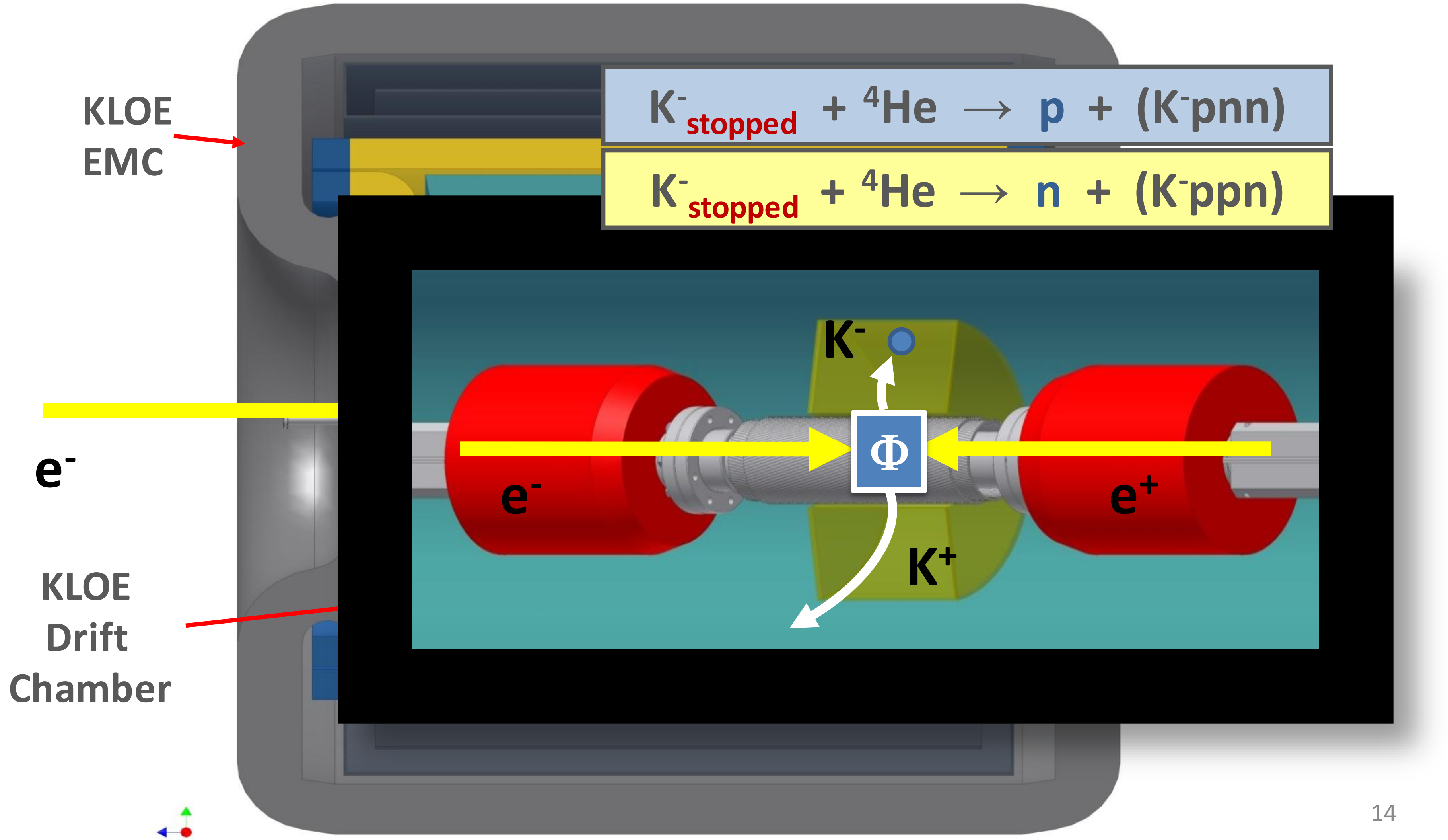
ptance and high
measurements will
by **implementing**
detector with an
ADEUS setup
gap in KLOE DC
the beam pipe)

for AMADEUS
n KLOE
yogenic target
ner tracker
on trigger

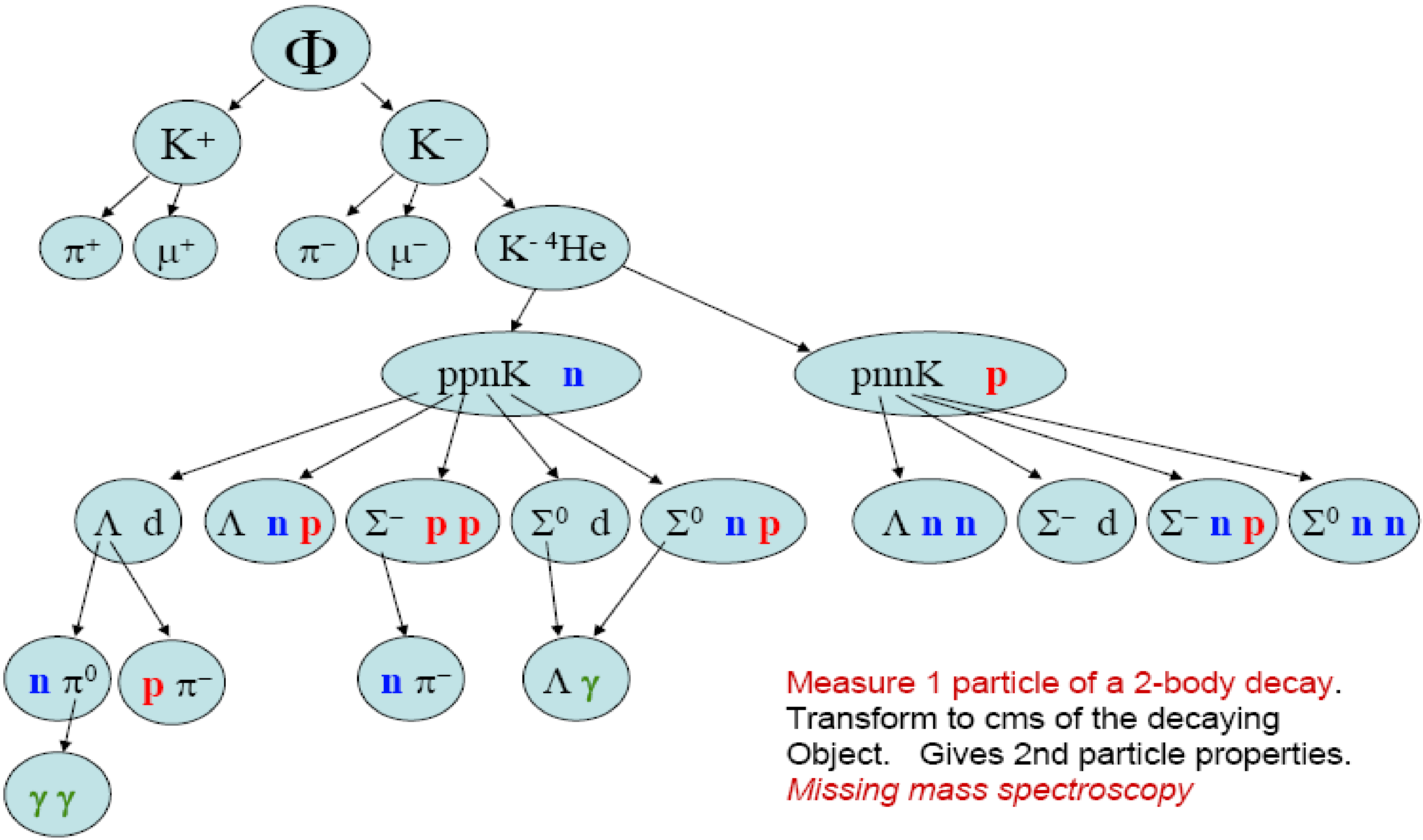
KLOE without AMADEUS



KLOE with AMADEUS



Reactions channels (simplified)



Measure 1 particle of a 2-body decay.
Transform to cms of the decaying Object. Gives 2nd particle properties.
Missing mass spectroscopy

Measure all outgoing particles to obtain the total cms energy = *invariant mass of the object*

Performance requirements

Formation processes

$$K^-_{stopped} + {}^4He \rightarrow p + (K^-pnn)$$

$$K^-_{stopped} + {}^4He \rightarrow n + (K^-ppn)$$

Exotic states produced with (K^-, N) reactions will be observed by the energy distribution of the **ejected protons and neutrons** via the **missing mass spectra** of the (K^-, p) and (K^-, n) reactions.

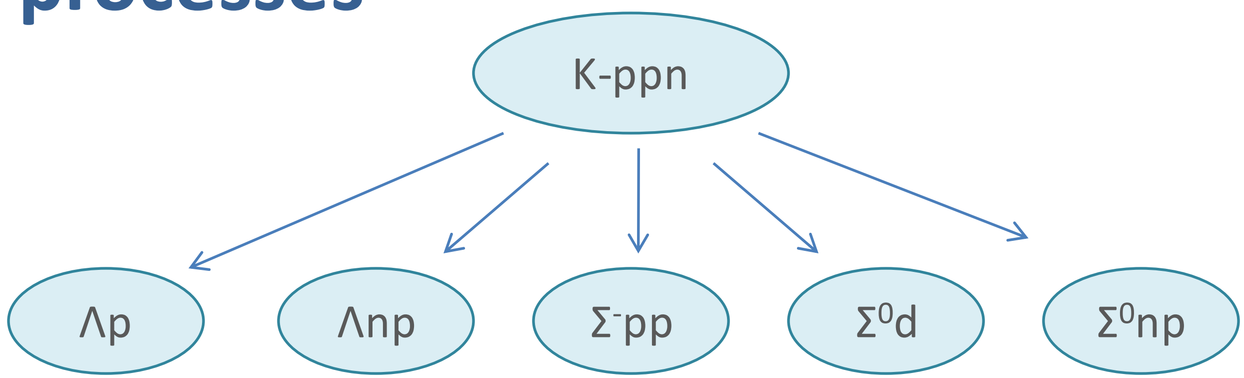
⇒ **The setup should be capable to measure:**

- Position of K^- stop: primary vertex and K^+ tracking (trigger)
- Outgoing **neutrons** and **protons 400 - 600 MeV/c**

→ KLOE has an experimentally proved capability for neutron detection (KLOnE)

Performance requirements

Decay processes



Invariant mass spectroscopy

→ all decay products have to be identified, including hyperons decay products

→ 4-momenta of **charged an neutral** particles must be determined

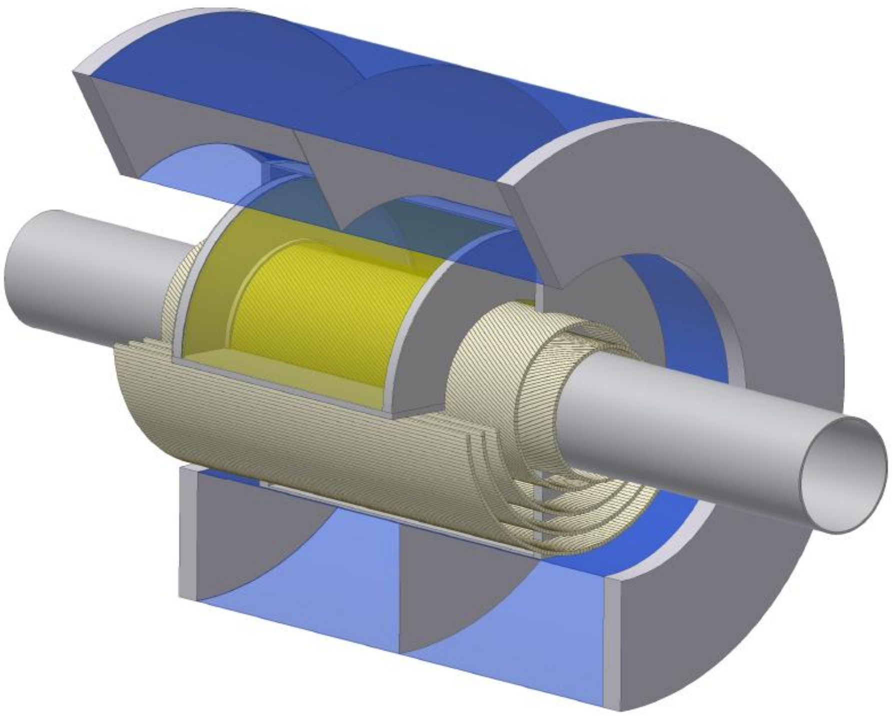
- **protons** 200 - 500 MeV
- **pions** 50 -200 MeV
- **neutrons** 200 -500 MeV
- **deuterons**...

The AMADEUS setup

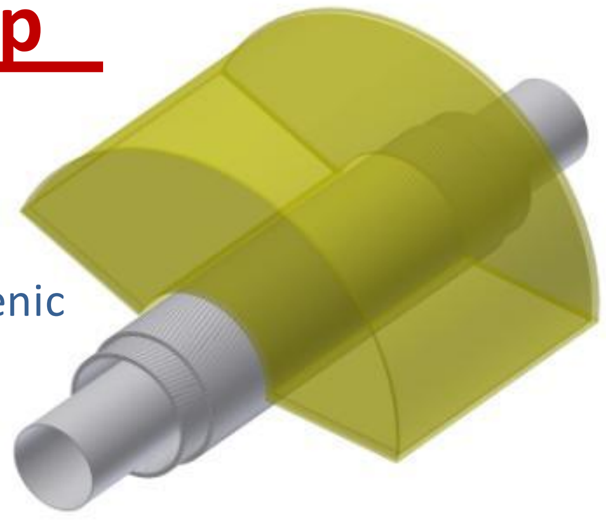
- **Inner tracker** (eventually, a first tracking stage before the DC)

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

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



The AMADEUS setup



AMADEUS

Low-mass cryogenic gas target cell:
T = 10 K
P = 1.0 bar
Rin = 5 cm
Rout = 15 cm
L = 20 cm

•**Inner tracker** (eventually, a first tracking stage before the DC)

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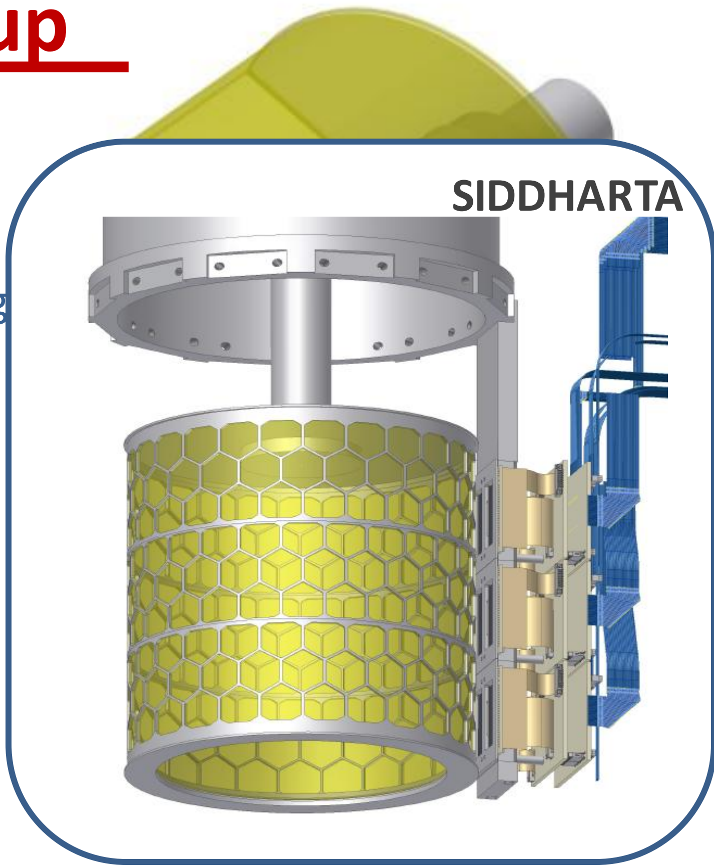


working T 22 K working P 1.5 bar
Alu-grid
Side wall: Kapton 50 µm
Entrance window: Kapton 50 µm

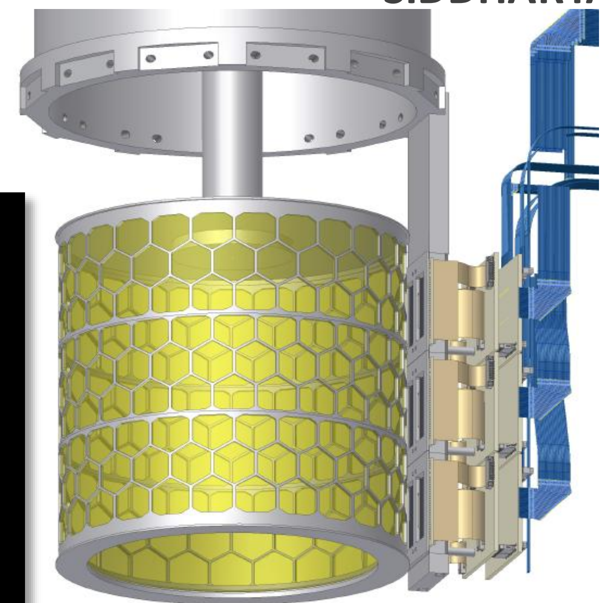
Current target installed at DAΦNE

The AMADEUS setup

AMADEUS

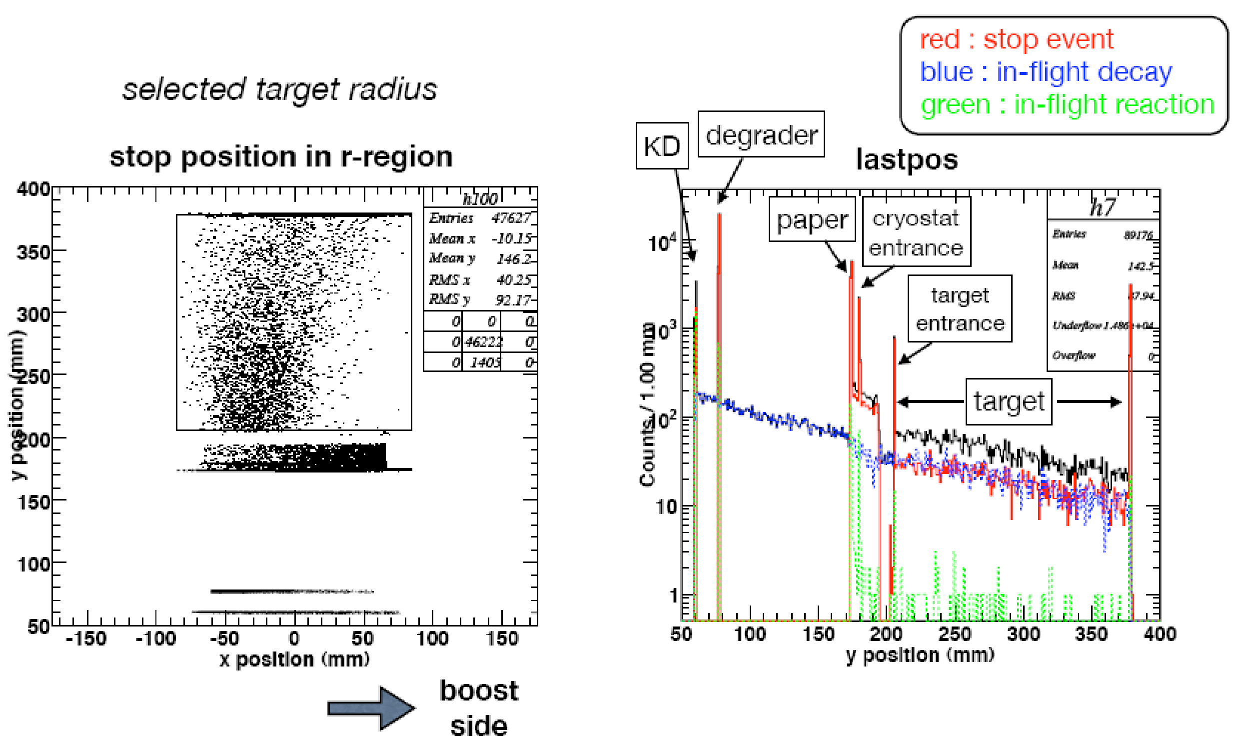
Low-mass cryog
gas target cell:

SIDDHARTA



•Inner tracker (eventually, a

SIDDHARTA Monte Carlo



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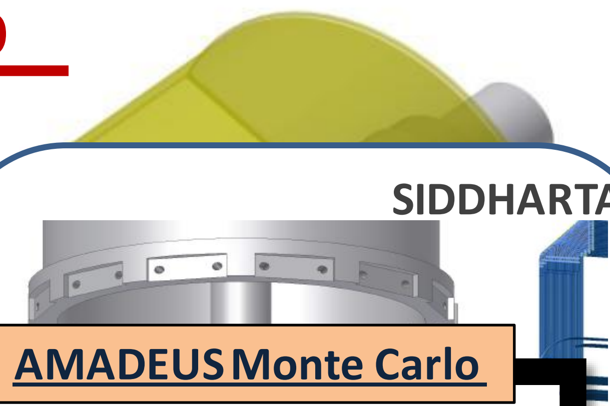
The AMADEUS setup

AMADEUS

SIDDHARTA



Low-mass cryog

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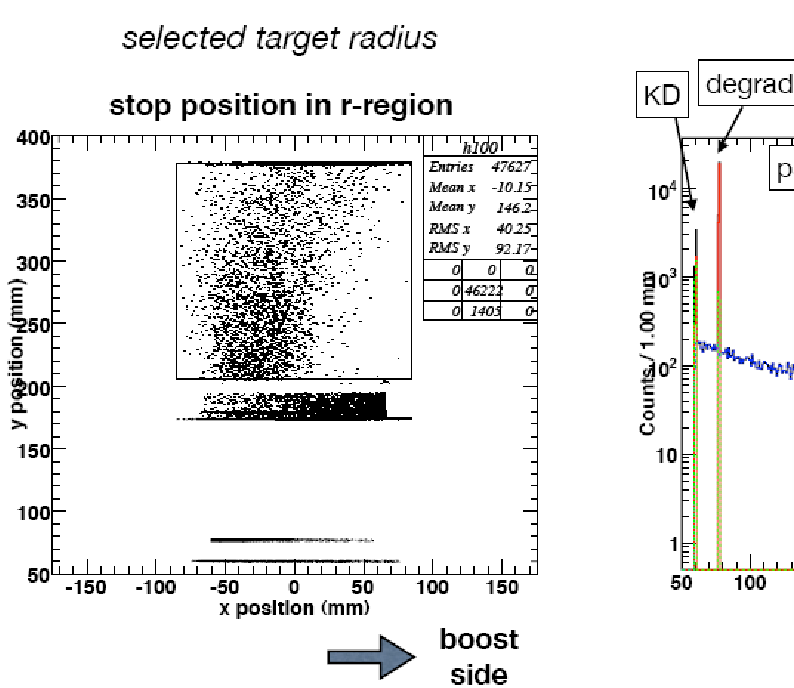
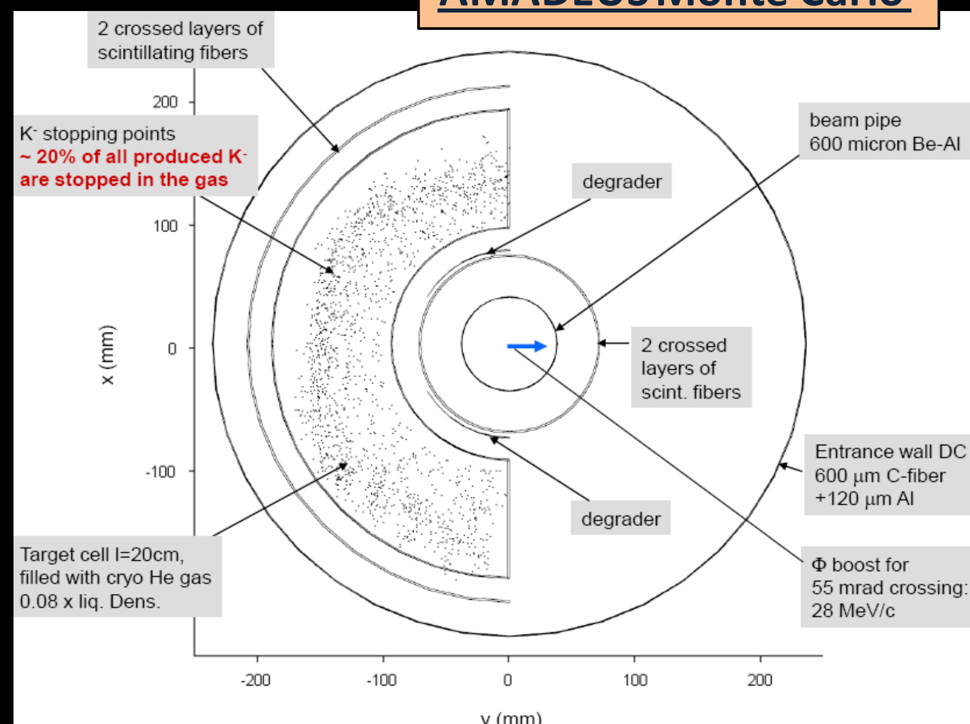


AMADEUS Monte Carlo



target installed at DAΦNE

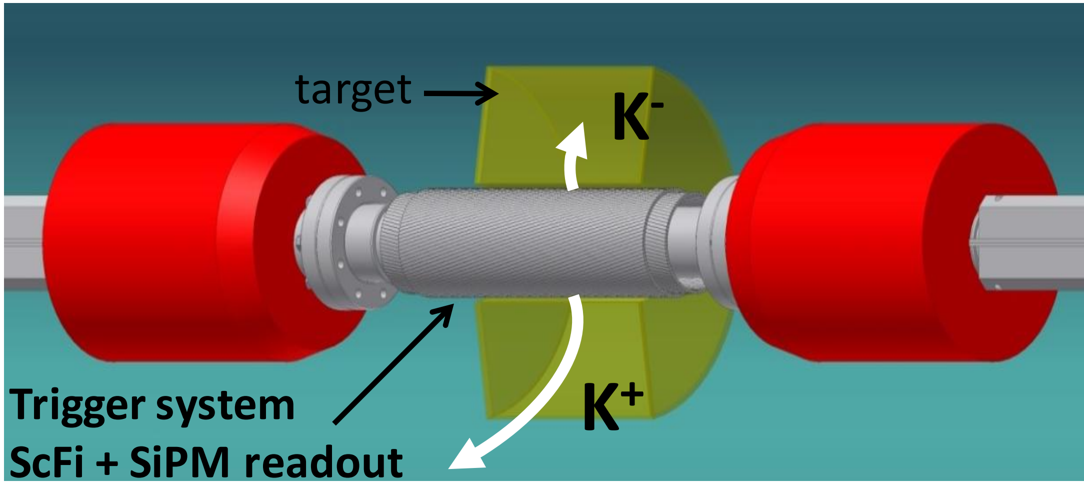
The AMADEUS setup

- **Cilindrical layer of scintillating fibers** surrounding the beam pipe to **trigger K^+ K^- in opposite directions**
- Readout to be done by **SiPM**

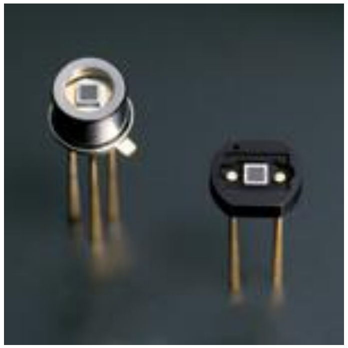
•Inner tracker (eventually, a first tracking stage before the DC)

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

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

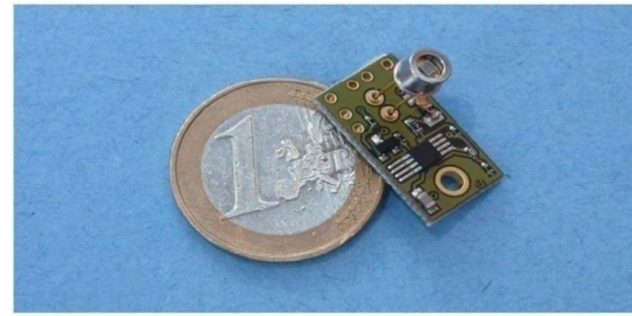


Trigger system: SiPM tests



SiPM (HAMAMATSU U50) (400 pixels)
Operating voltage ~70V

Dedicated fast pre-amplifiers design
Gain x20 – x100
Small size



For a good behavior stability in the applied voltage with great precision is needed for every single detector.

Electronics: New CAMAC modules providing:

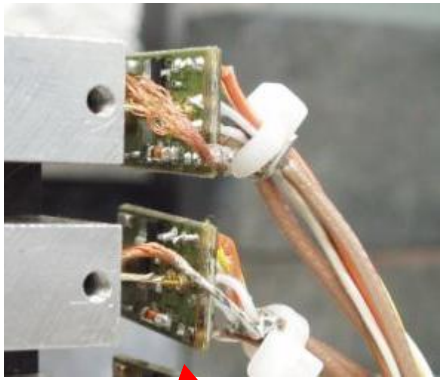
- Variable V_{bias} for 5 channels with a **stability for nominal voltages below 1 mV**
- 2 output / channel:
  - -Amplified (x50-x100) signal
  - -Discriminated signal (variable threshold)

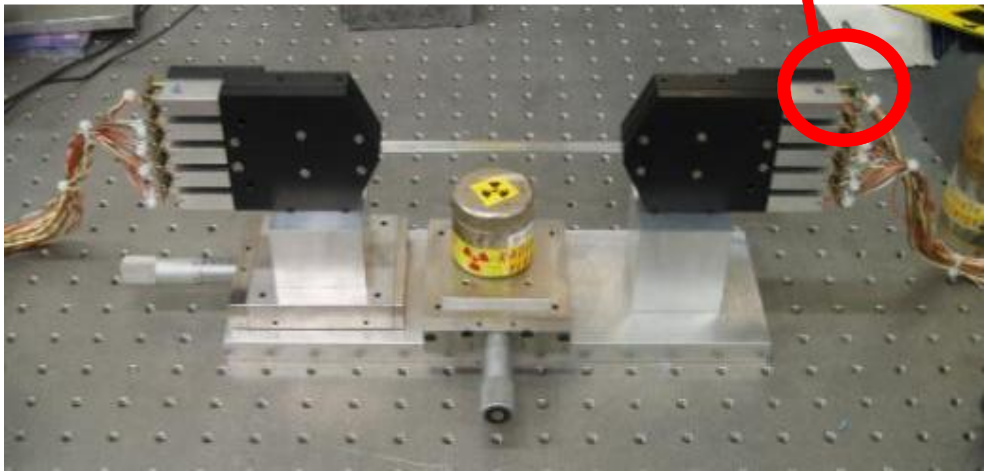
Designed by G. Corradi, D. Tagnani, C. Paglia

Trigger system: ScFi + SiPM setup

New mechanical support for
5 ScFi read from both sides
10 SiPM + readout card

Precission support for
efficiencies studies





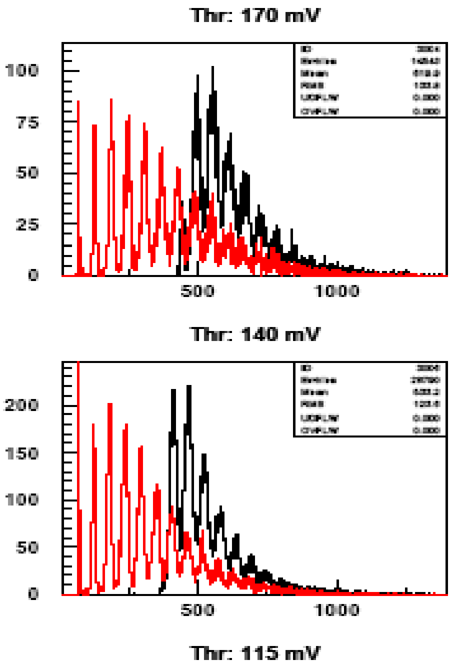
November, 2008

Instrumented fibers:

- Pol.Hi.Tech 46 (Blue)
- Saint Gobain BCF- 10 single cladding:
  - -Emission peak 432 nm
  - -Decay time 2,7 ns
  - -1/e 2.2 m
  - -80000 ph./MeV

90Sr β source tests:

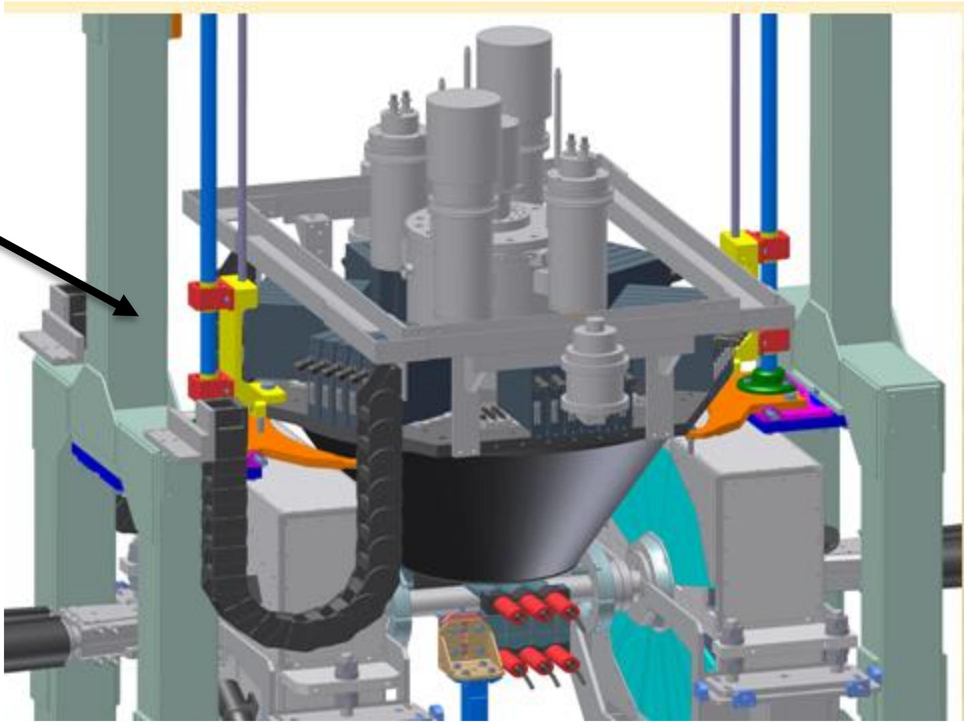
Trigger SiPM
Signal SiPM



Trigger system tests: installation at DAΦNE

SIDDHARTA setup

DAΦNE beam pipe



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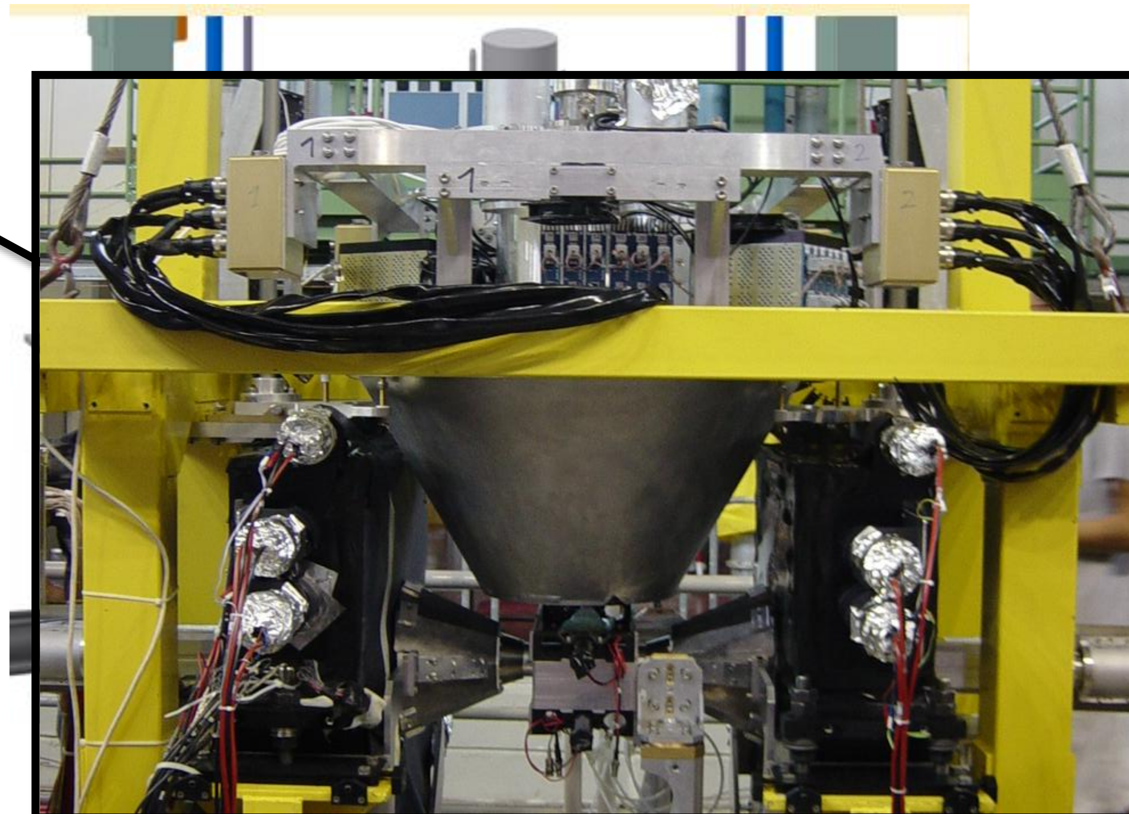
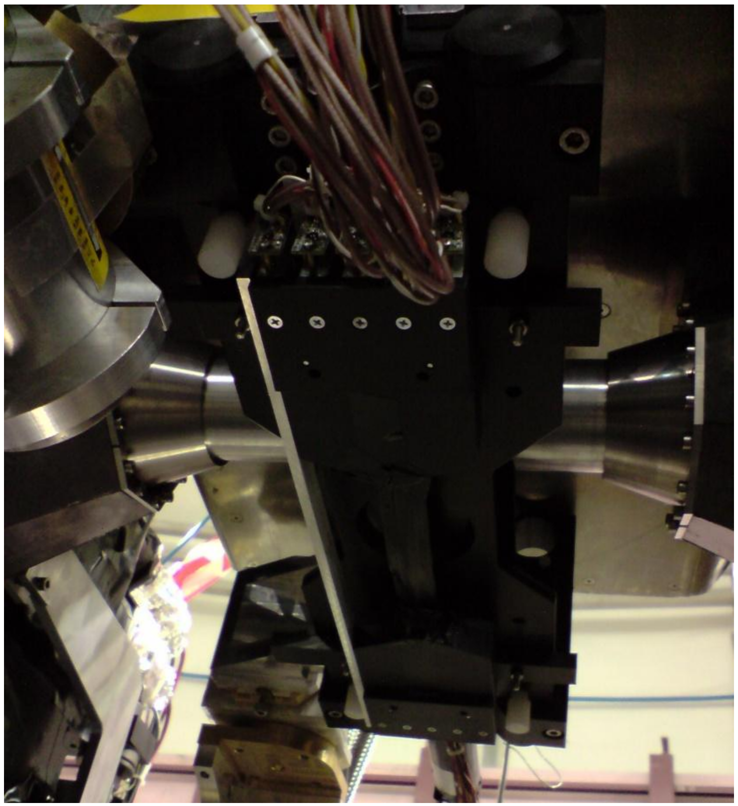
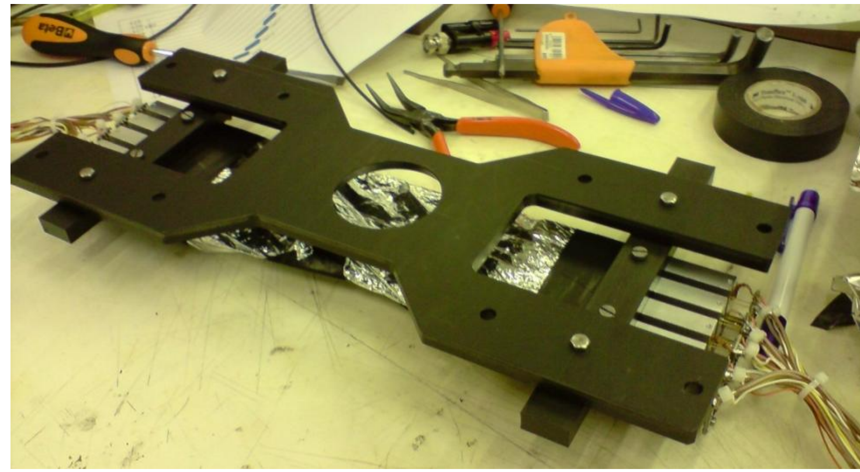
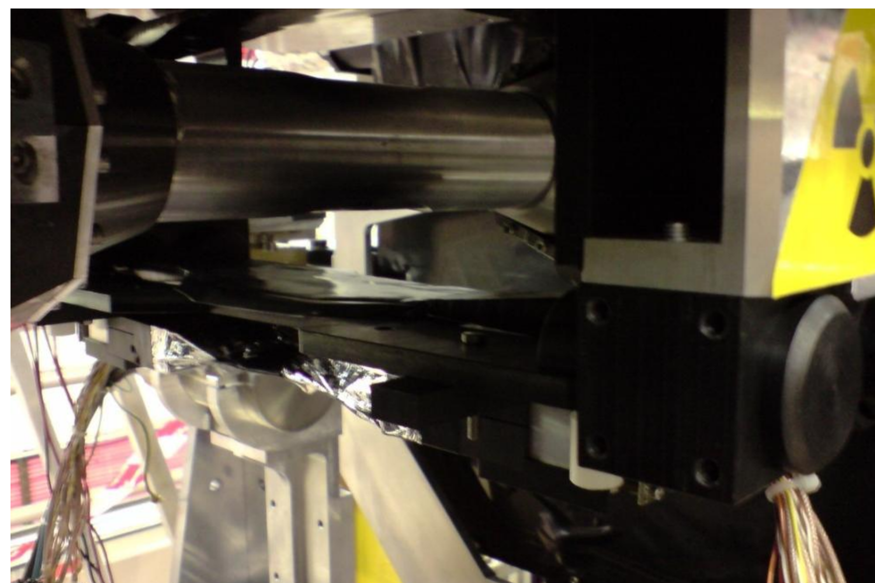


DAΦNE
beam pipe

Trigger system tests: installation at DAΦNE

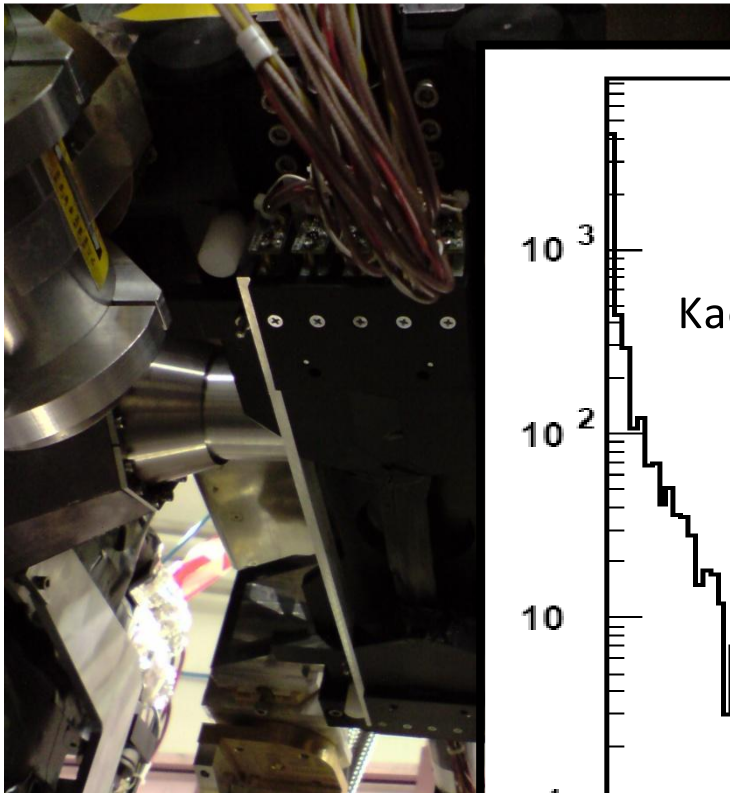


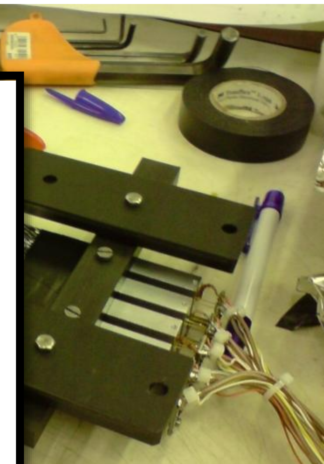


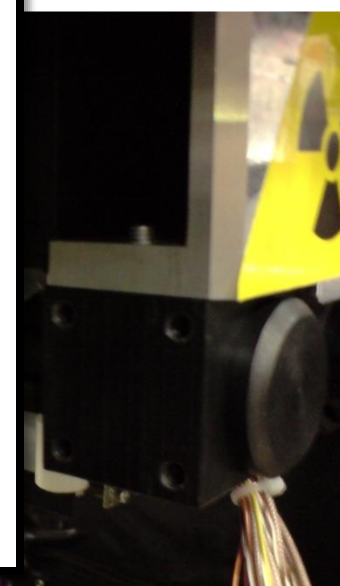


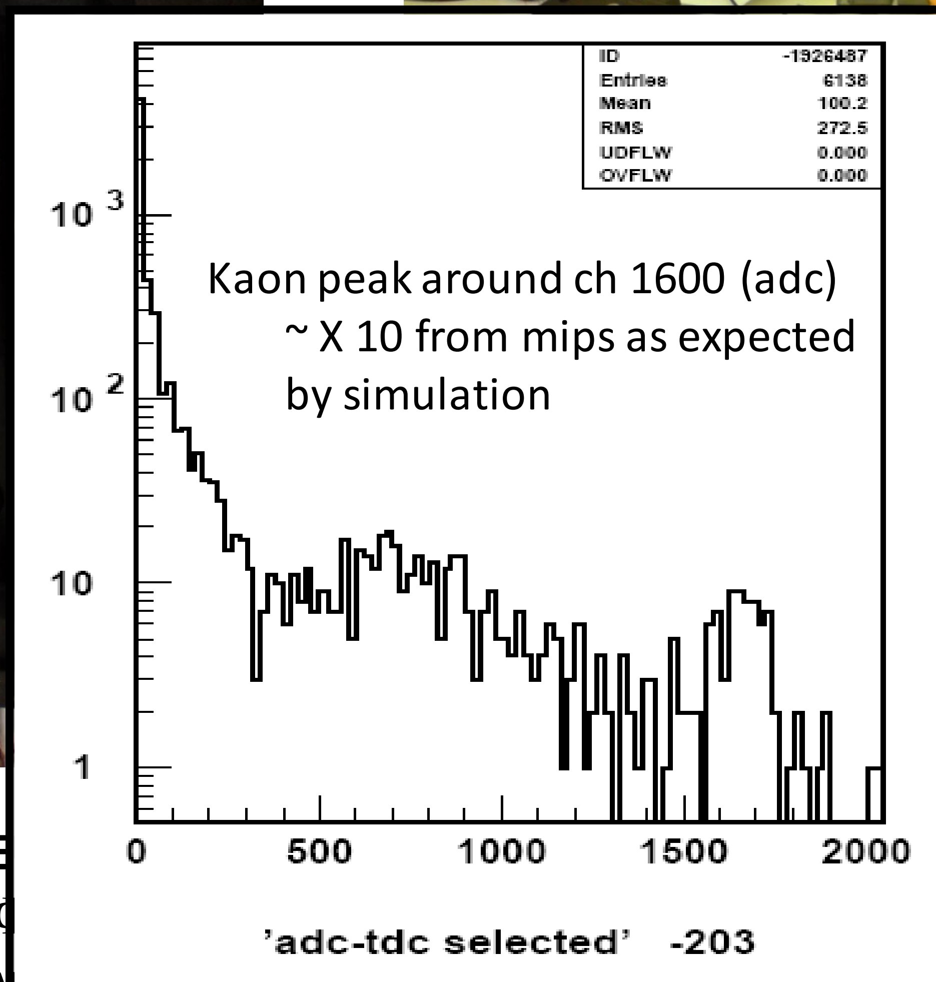
Installation of AMADEUS trigger test setup in DAΦNE
22-24 January 2009

Trigger system tests: installation at DAΦNE









Installation of AMADE
setup in DA
22-24 January

Conclusions

"In conclusion, an initial programme based on the study of the ^{3}He and the ^{4}He targets, to investigate dibaryonic and tribaryonic states, would require an integrated luminosity from 2 to 6 fb^{-1}, according to depth of the investigation"

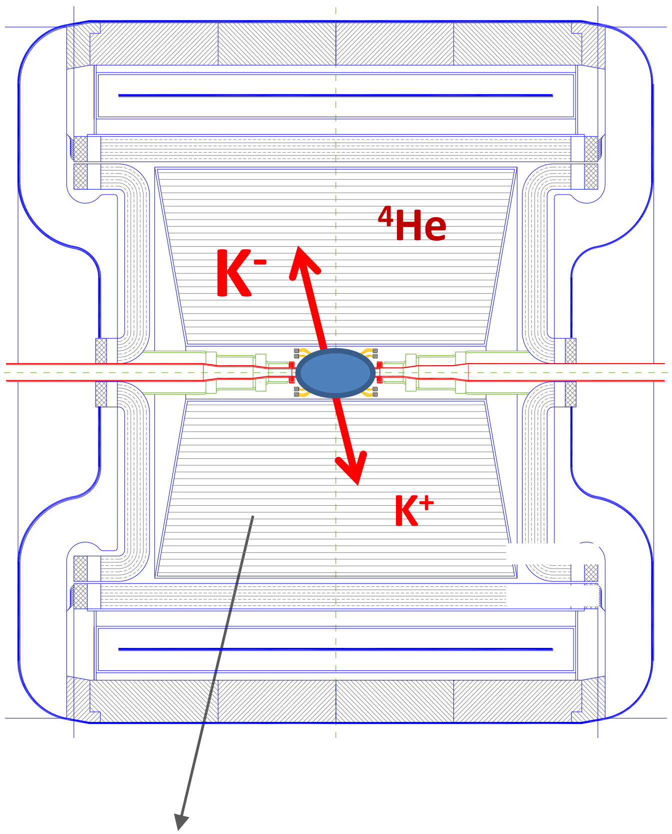
A complete determination of all **formation and decay channel** measuring, binding energies, widths, angular momentum, isospin, sizes…

Detection of: - charged and neutral particles
- high efficiency and resolution
- **in 4π geometry (full acceptance)**

- The goal is to **definitely clarify the existence of Kaonic Clusters**

Analysis of K^{-}He KLOE data

Hadronic interactions of K^- in KLOE



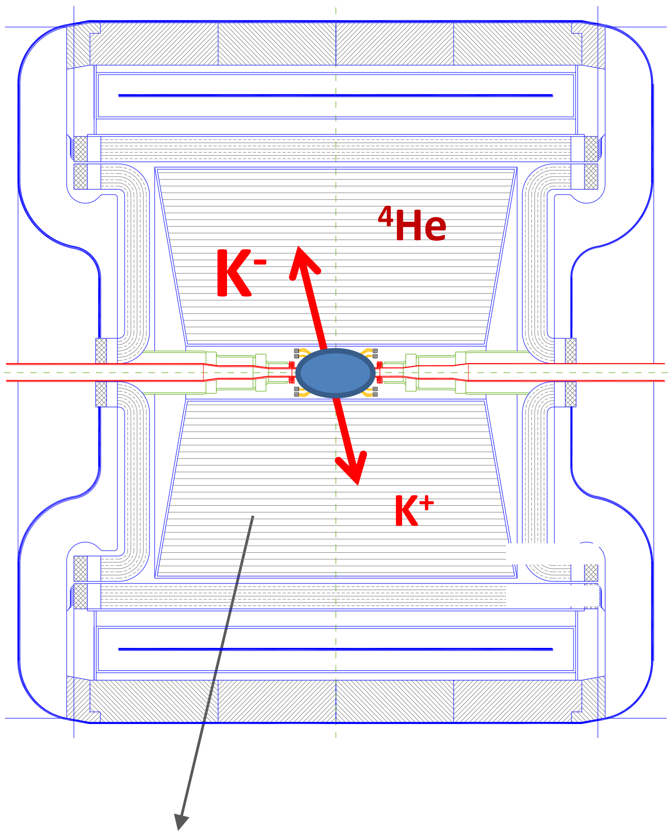
KLOE Drift Chamber

•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.

Strategy of the analysis



KLOE Drift Chamber

•**Statistics:**

•Total amount of data analyzed up to an integrated luminosity of **~1,1 fb^{-1}** from KLOE data (K-charged group).

•Special ntuples of KLOE data were created, with kaons tagged by **2-body decay** or by the **dE/dx** signature in the DC gas.

•**Strategy:**

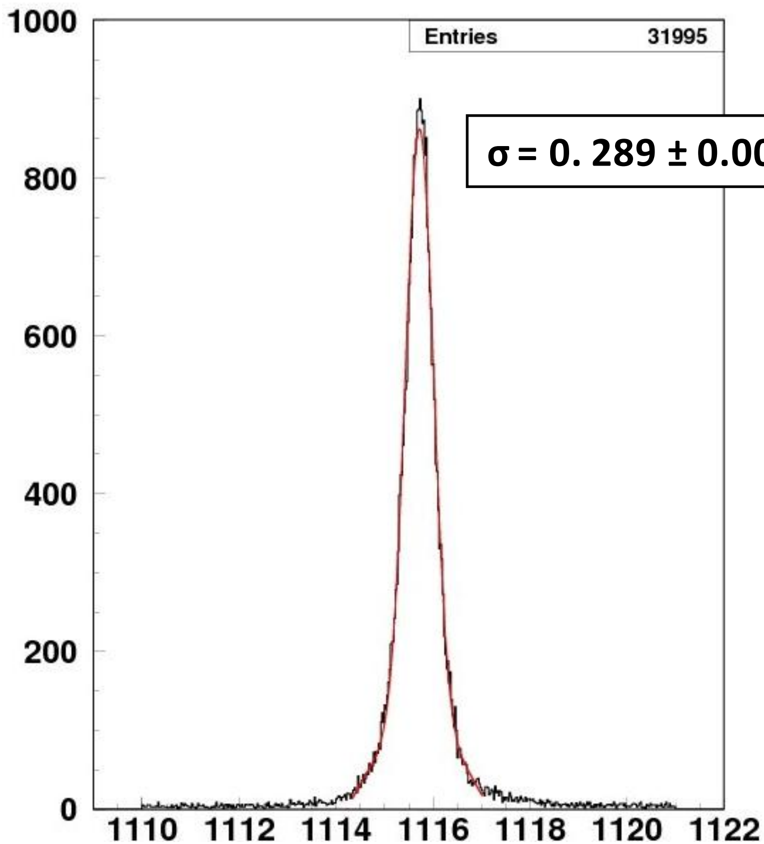
Search for hadronic interactions with Λ(1115) as products:

• **$\Lambda \rightarrow p + \pi^-$** (64% BR) vertex made by KLOE reconstruction

• Construct a vertex with **Λ + an extra particle**

Lambda invariant mass

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



σ = 0. 289 ± 0.003 MeV/c²

M_{inv} pπ (MeV/c2)

-Dedicated event selection to avoid Eloss in the DC wall

- Best $\chi 2$ tracks and vertices

KLOE:

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

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

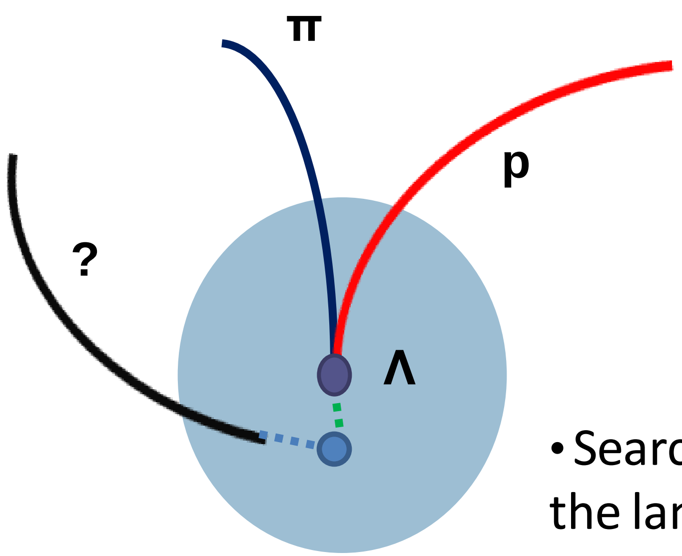
-Sistematics dependent of momentum calibration

-Evaluated by 2-body decay of $K^\pm$:

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

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

Particle identification



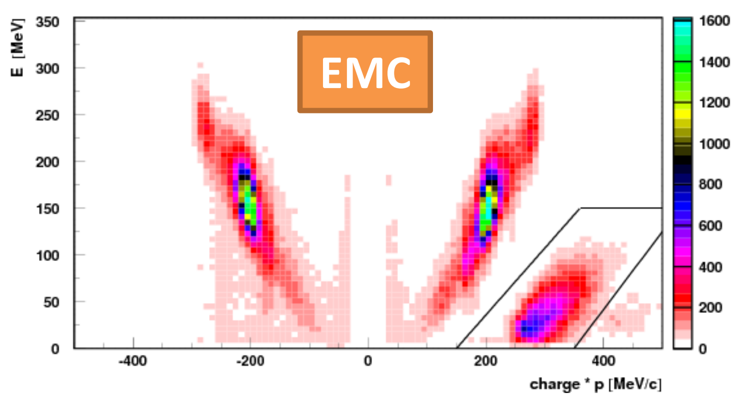
$K^{-}_{stopped} + {}^{4}He \rightarrow n + n + (\underline{K^{-}pp})$

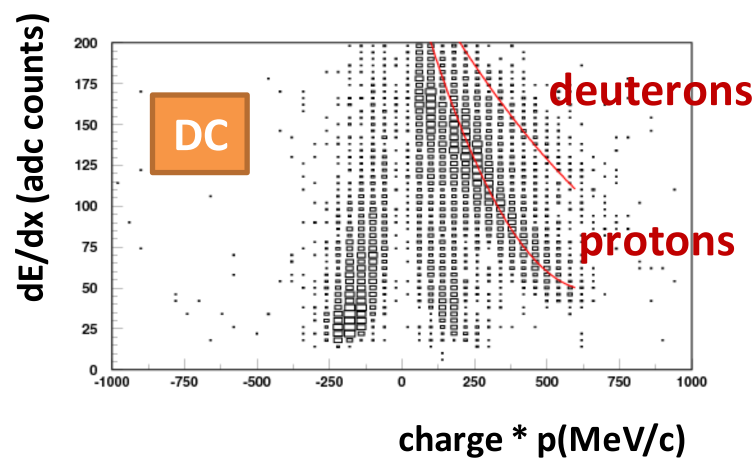
$\rightarrow \Lambda + p$

$K^{-}_{stopped} + {}^{4}He \rightarrow n + (\underline{K^{-}ppn})$

$\rightarrow \Lambda + d$

- Search for the proton with first DC measurement around the lambda vertex (30 cm. cylinder)
- Vertex lambda+(proton or deuteron) assumption



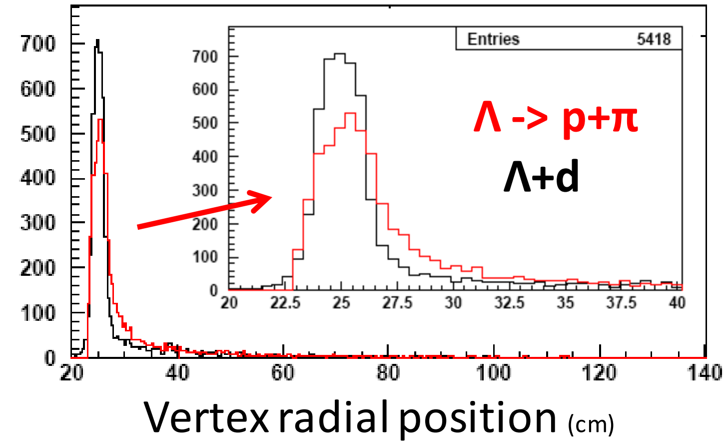


Correlations with Lambda

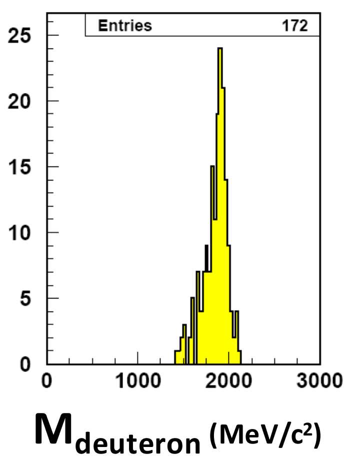
Improved **Λd vertex** reconstruction

Improved mass recognition (PID) of deuterons and protons

Improved selection of events in DC-gas

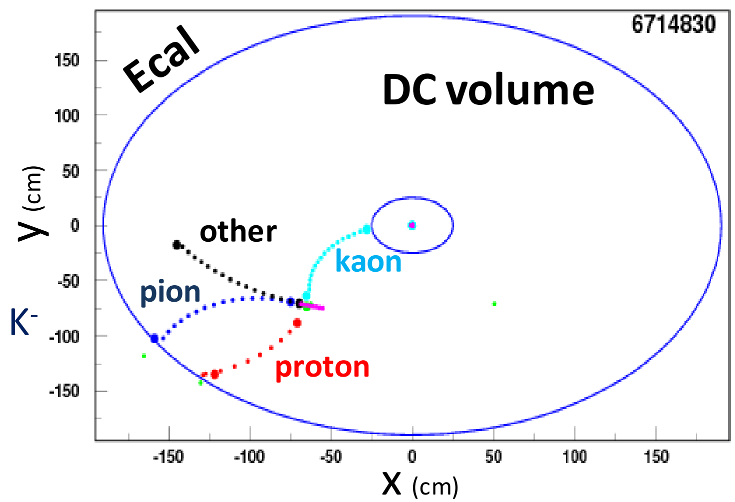


- **Proton/deuteron candidates are required to have an associated cluster in the EMC and its mass is measured by time of flight.**



-Require the presence of the tracked/extrapolated K^-

-Check event display

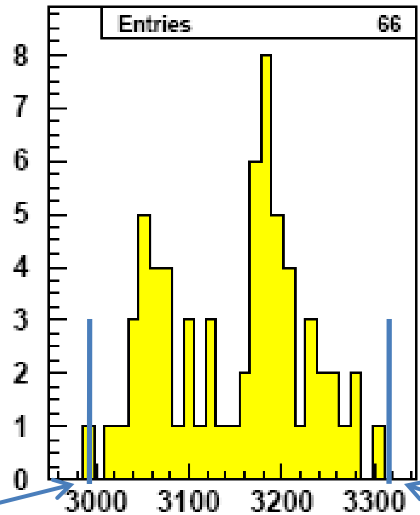


Λd analysis

Lambda-d

$K^-_{stopped} + {}^4He \rightarrow n + (K^-ppn)$

$(K^-ppn) \rightarrow \Lambda + d$

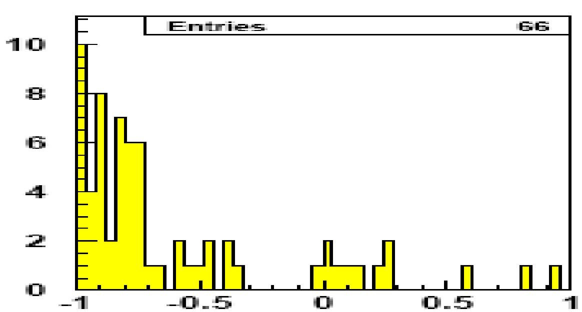


Events in the DC volume

$M_d + M_p + M_{\pi^-}$

$M_d + M_p + M_K$

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



Cos θ (Λd)

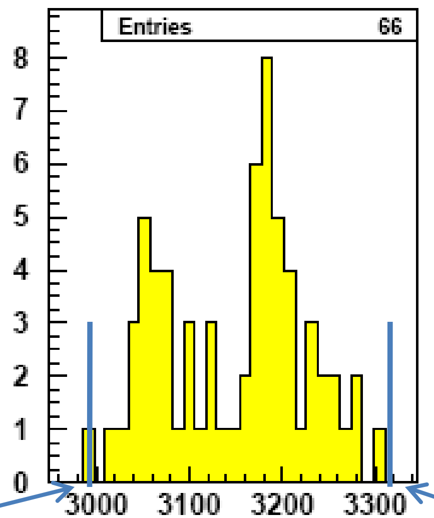
Λd analysis

Lambda-d

$$K^-_{stopped} + {}^4He \rightarrow n + (K^-ppn)$$

$$(K^-ppn) \rightarrow \Lambda + d$$

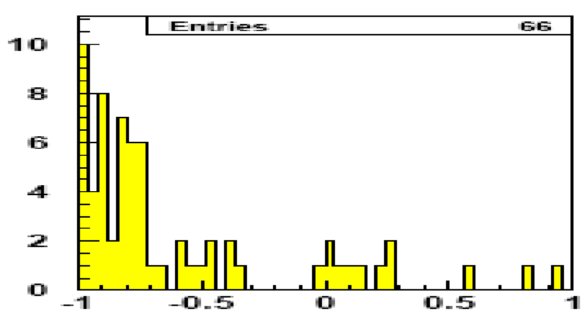
Events in the DC volume



$M_d + M_p + M_{\pi^-}$

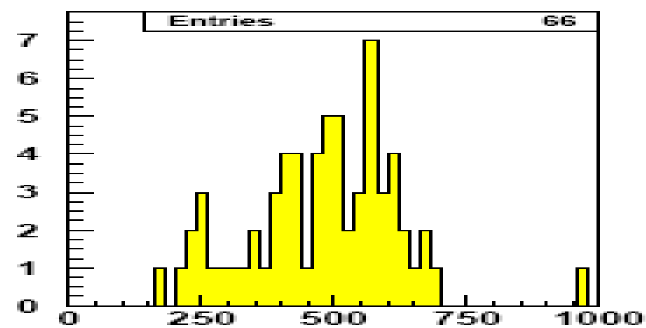
$M_d + M_p + M_K$

M_{inv} Λd (MeV/c²)

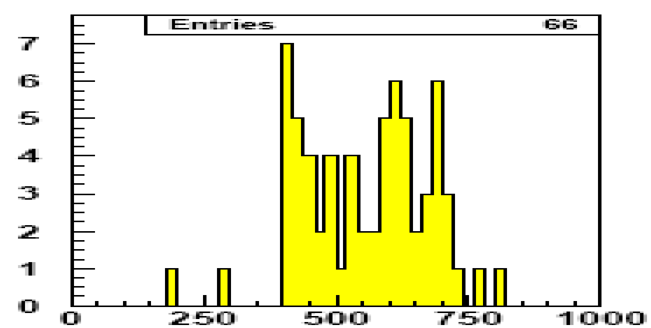


Cos θ (Λd)

Momentum of lambda and deuteron:



P_Λ (MeV/c)



P_d (MeV/c)

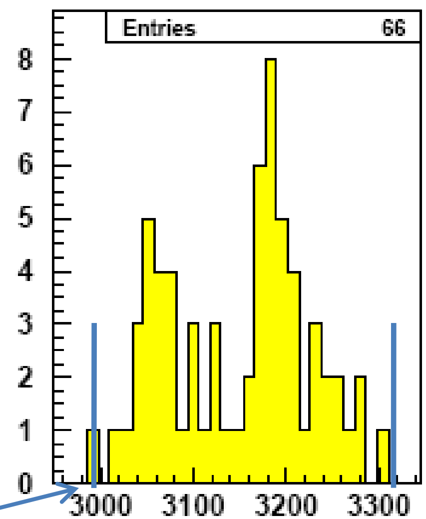
Oton Vázquez Doce

Λd analysis

Lambda-d

$$K^-_{stopped} + {}^4He \rightarrow n + (K^-ppn)$$

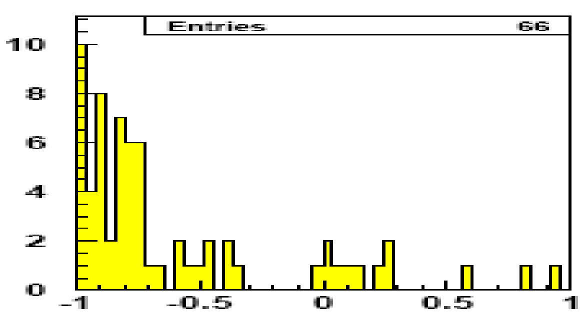
$$(K^-ppn) \rightarrow \Lambda + d$$



Events in the DC volume

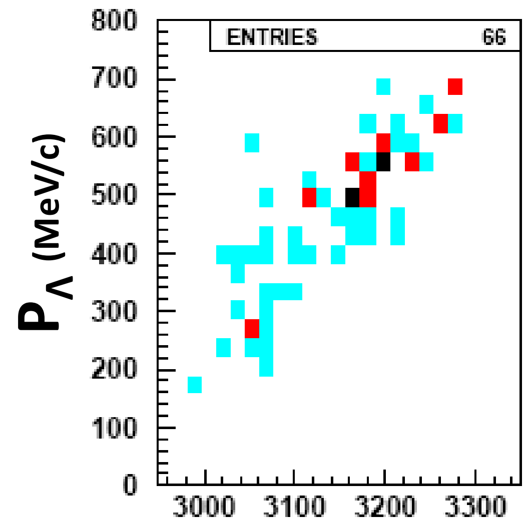
$M_d + M_p + M_{\pi^-}$

M_{inv} Λd (MeV/c²)

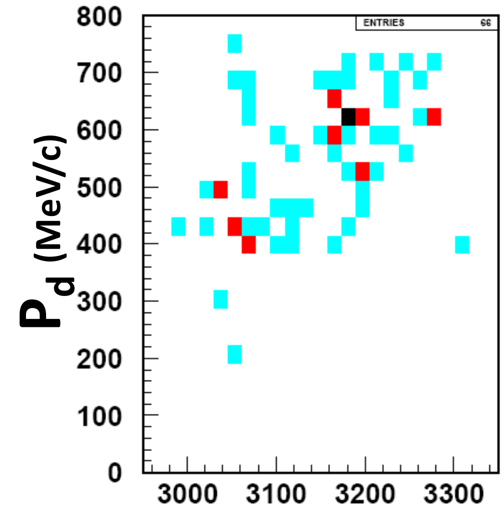


Cos θ (Λd)

lambda momentum vs. Minv



deuteron momentum vs. Minv



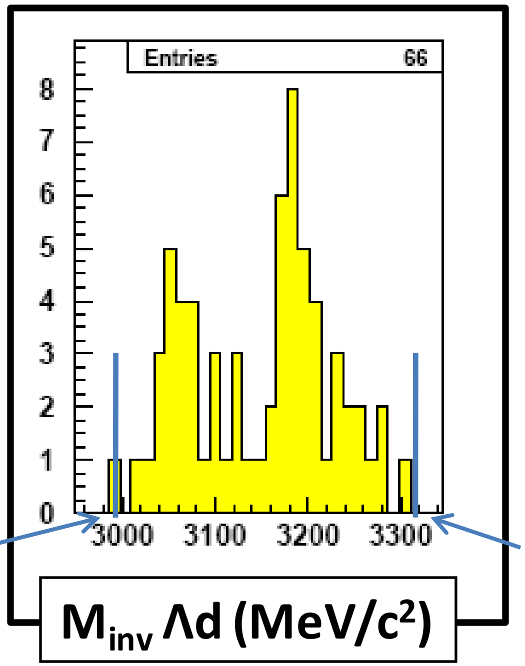
M_{inv} Λd (MeV/c²)

Λd analysis

Lambda-d

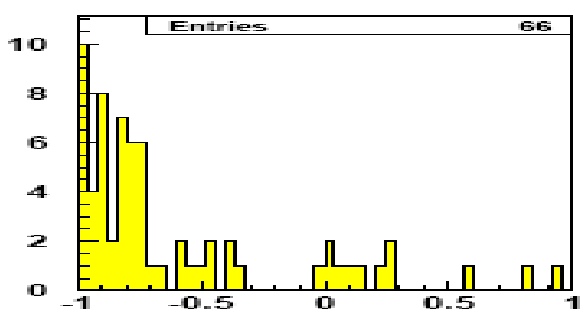
$K^{-}_{stopped} + {}^{4}He \rightarrow n + (K^{-}ppn)$

$\Lambda + d$

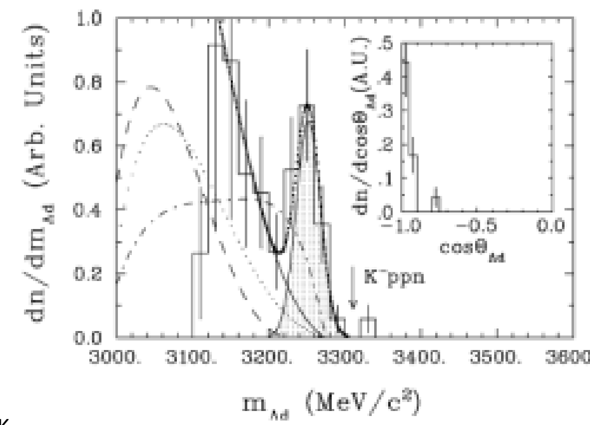


$M_d + M_p + M_{\pi-}$

$M_d + M_p + M_K$

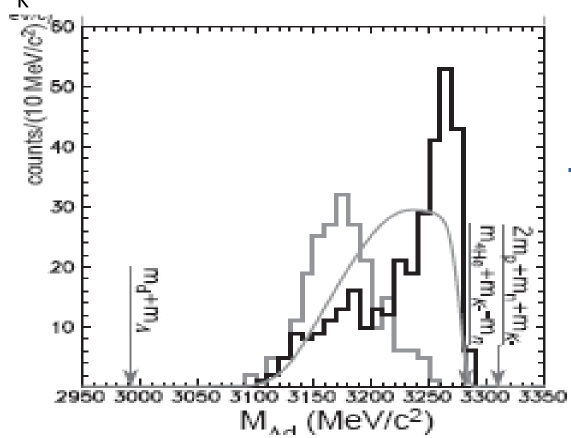


Cos θ (Λd)



FINUDA

K- stopped in light nuclei



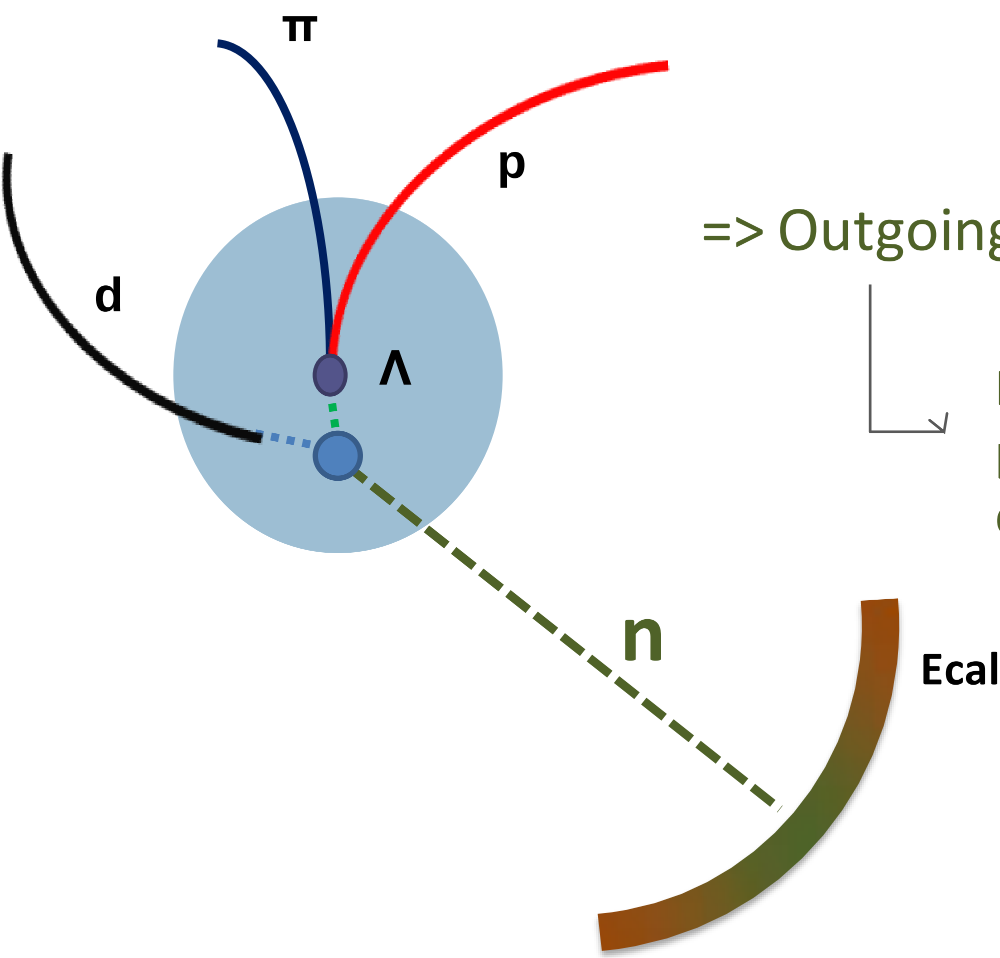
KEK

K- stopped in 4He

Neutron search

$K^{-}_{stopped} + {}^{4}He \rightarrow n + (K^{-}ppn)$

$(K^{-}ppn) \rightarrow \Lambda + d$



=> Outgoing **neutrons 400-600 MeV/c**

KLOE has an experimentally proved capability for neutron detection (KLOnE)

$\Sigma^0\pi^0$

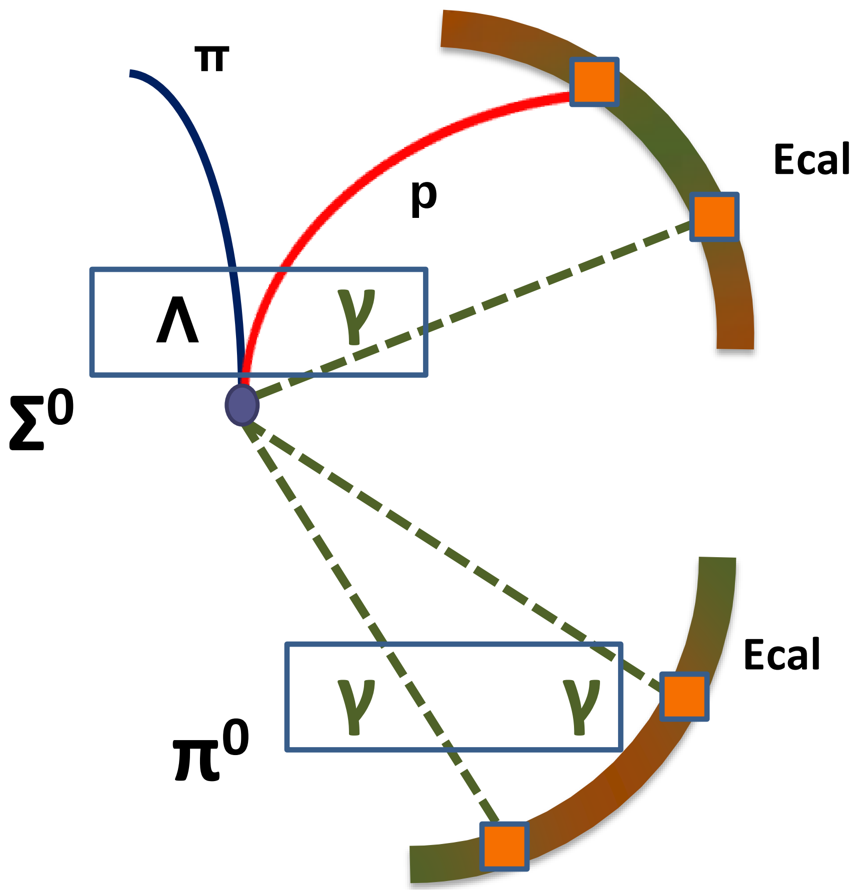
Λ(1405)/Λ(1420) search

- Strongly related with the deeply bound kaonic states prediction
- Lack of experimental data

$\Sigma^0\pi^0$

$\Lambda(1405)/\Lambda(1420)$ search

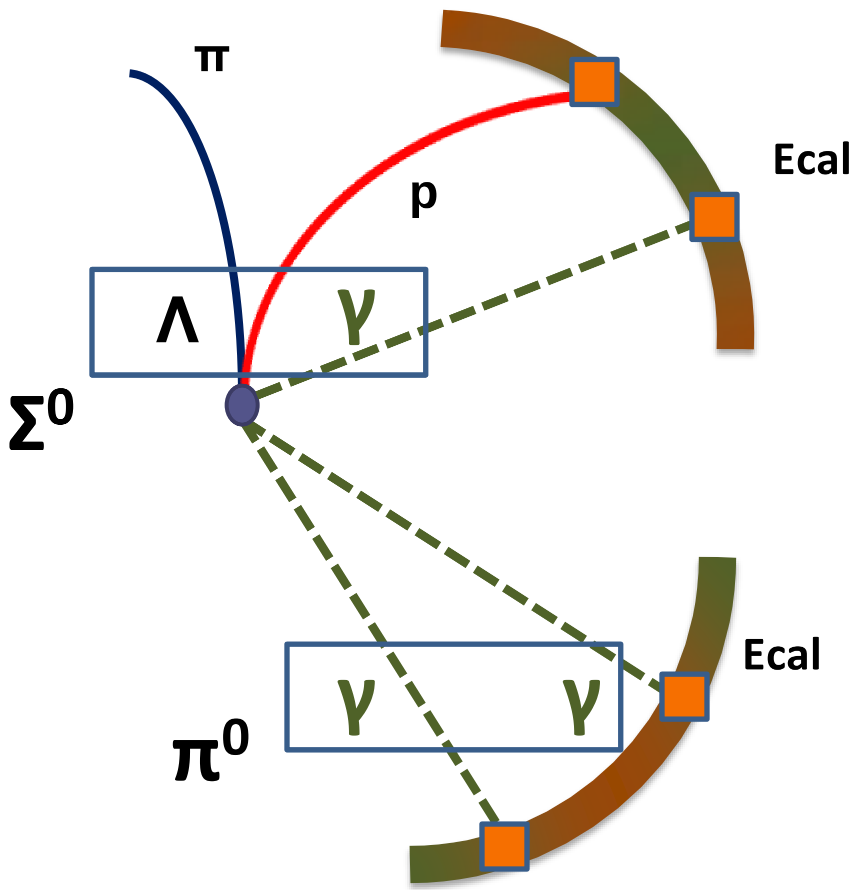
- Strongly related with the deeply bound kaonic states prediction
- Lack of experimental data



$\Sigma^0\pi^0$

Λ(1405)/Λ(1420) search

- Strongly related with the deeply bound kaonic states prediction
- Lack of experimental data



Kinematic fit:

•χ2 computing:

-momentum of proton and pion

-Covariance matrix elements for every track

-time and positions plus resolutions for photons

•Allows to reject background selecting the right combination of photons

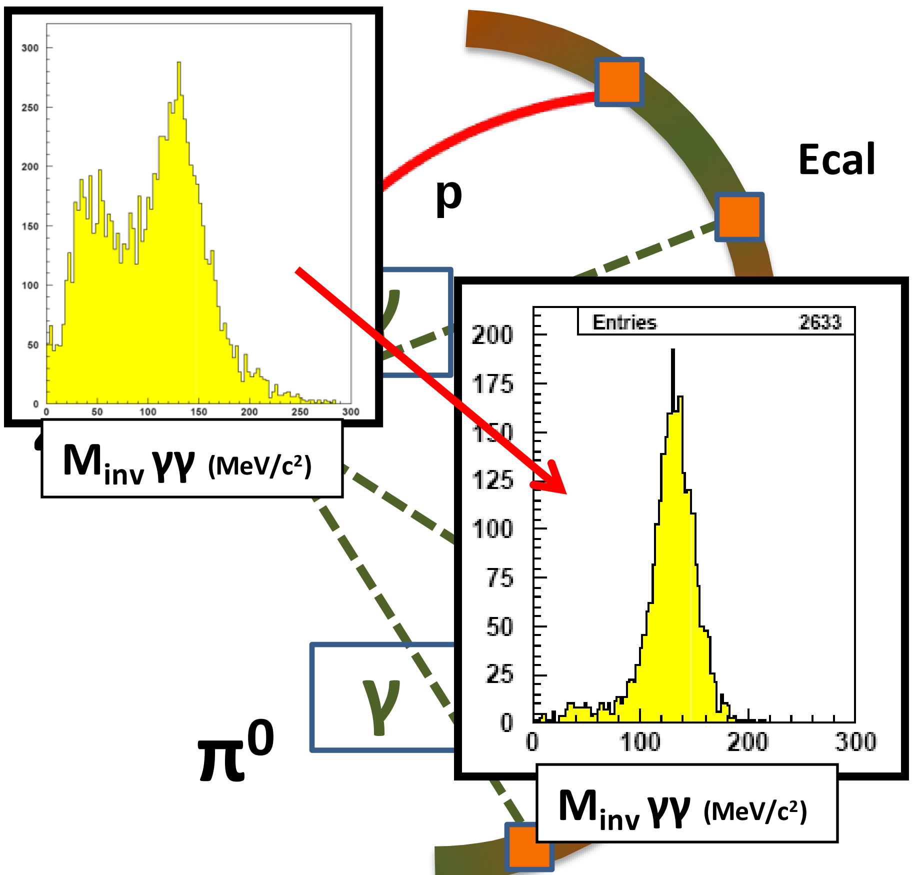
•Constraints: Δt for the arrival time of photons

•No mass assumption -> unbiased mass spectras

$\Sigma^0\pi^0$

Λ(1405)/Λ(1420) search

- Strongly related with the deeply bound kaonic states prediction
- Lack of experimental data



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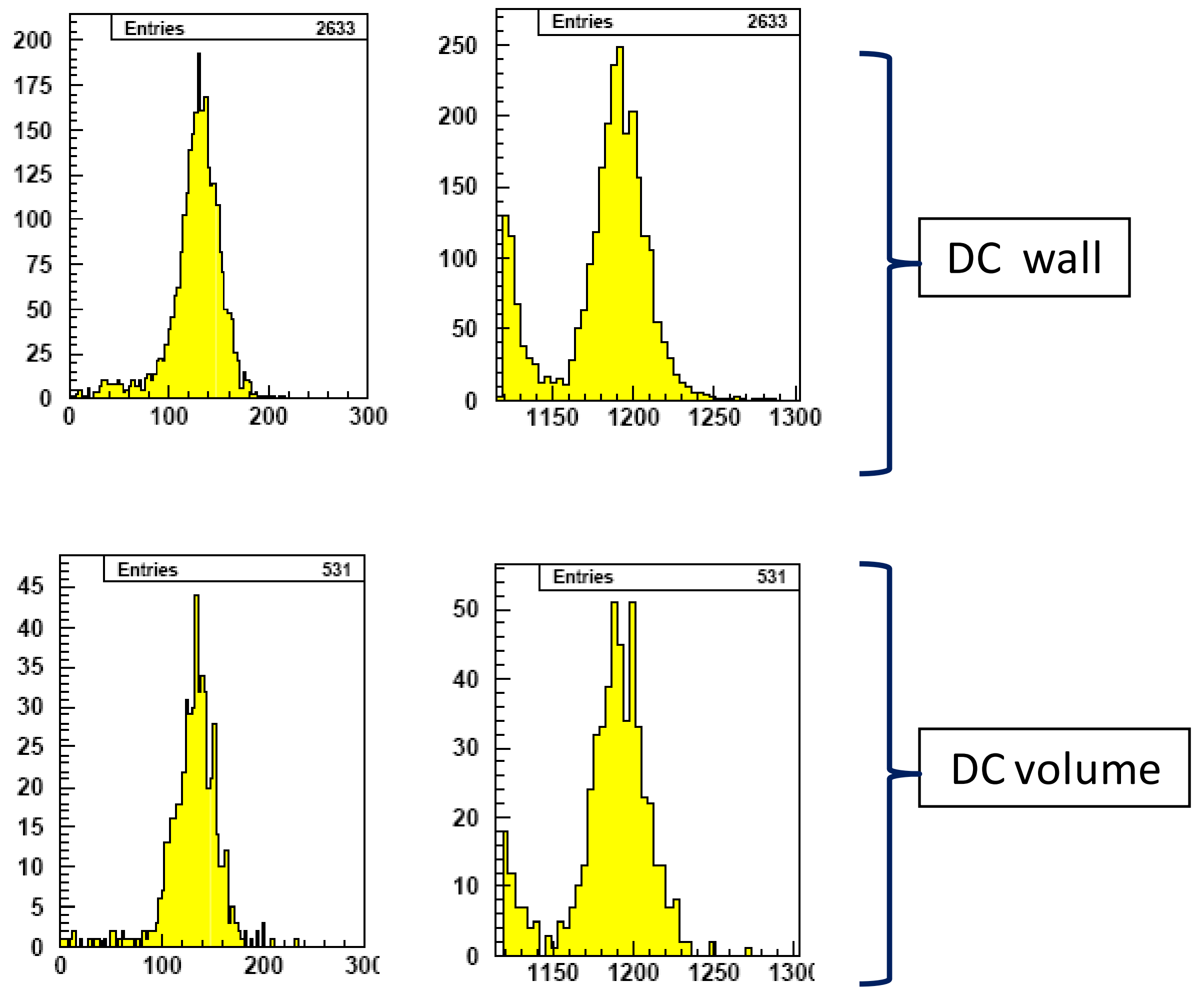
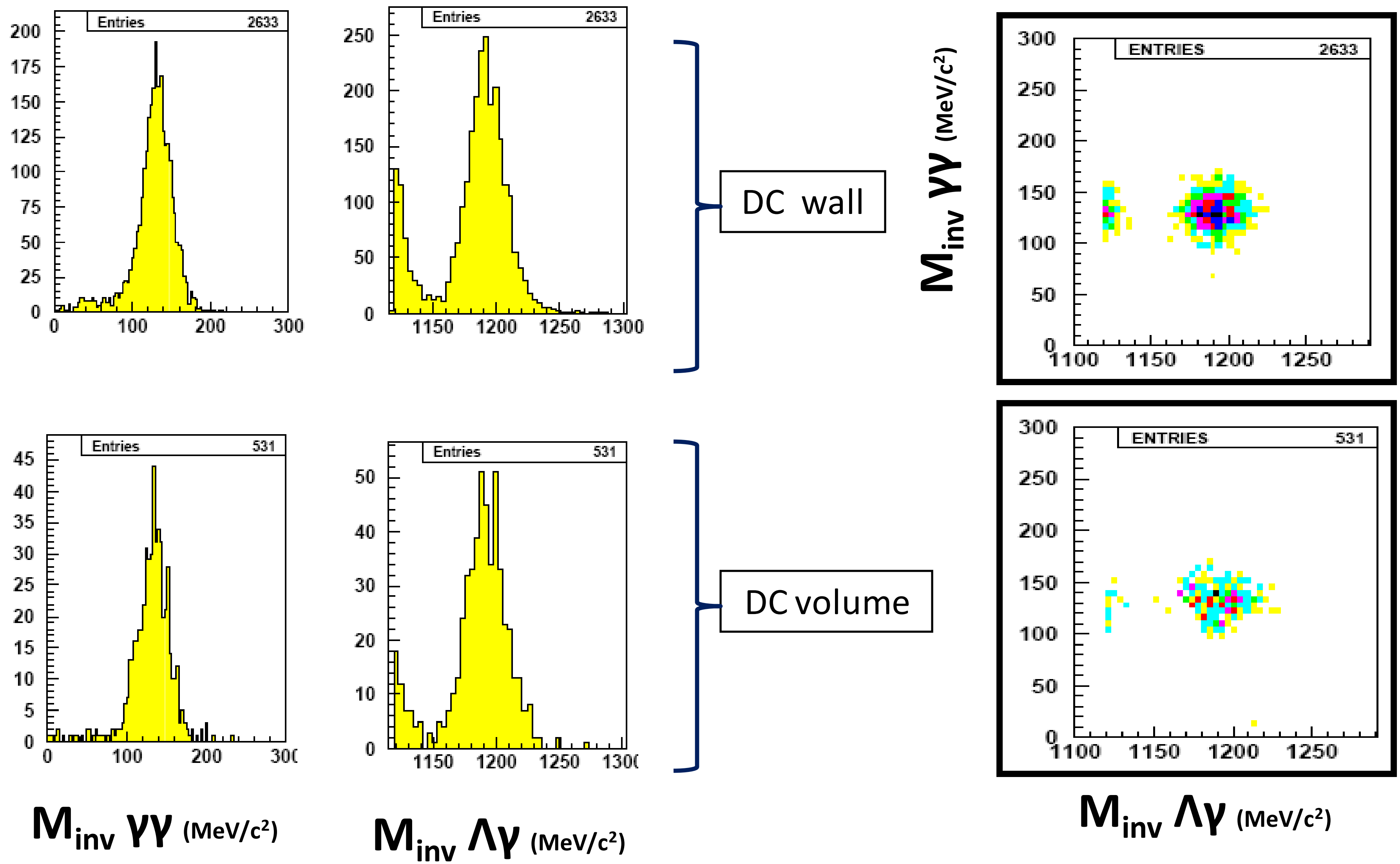
$\Sigma^0\pi^0$



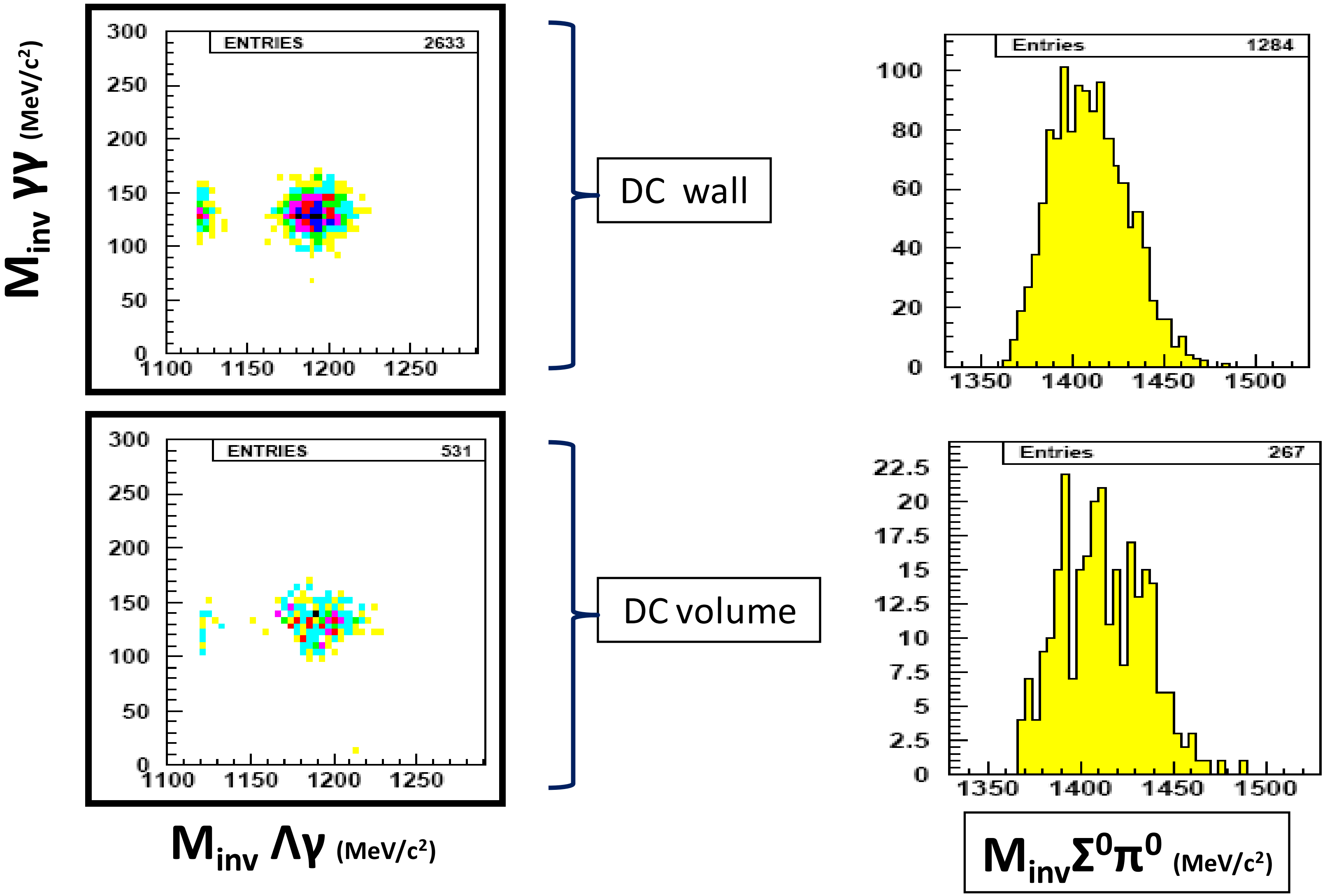
M_{inv} $\gamma\gamma$ (MeV/c^2)

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

$\Sigma^0\pi^0$


Entries 2633
Entries 2633
DC wall
ENTRIES 2633
Entries 531
Entries 531
DC volume
ENTRIES 531
M_{inv} γγ (MeV/c²)
M_{inv} Λγ (MeV/c²)
M_{inv} γγ (MeV/c²)
M_{inv} Λγ (MeV/c²)

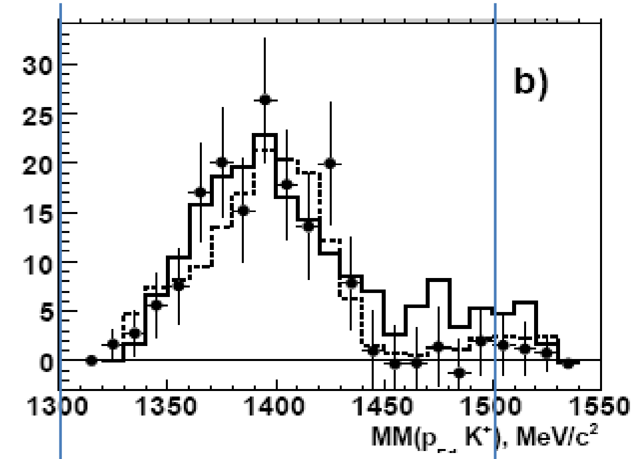
$\Sigma^0\pi^0$



M_inv γγ (MeV/c²)
ENTRIES 2633
ENTRIES 531
DC wall
DC volume
Entries 1284
Entries 267
M_inv Λγ (MeV/c²)
M_inv Σ0π0 (MeV/c²)

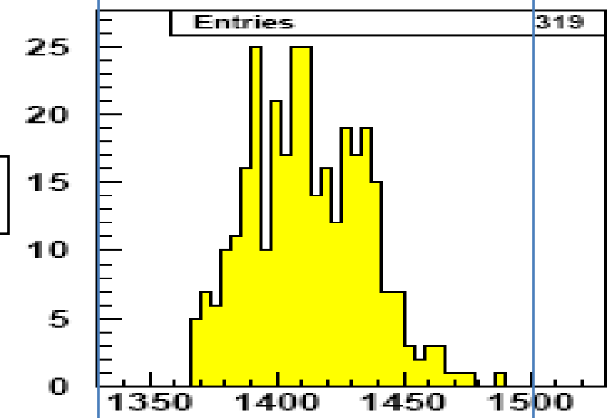
$\Sigma^0\pi^0$

$\pi^- p \rightarrow K^0\, \Sigma^0\, \pi^0$ (solid line) PDG
$K^- p \rightarrow \pi^+\, \pi^-\, \Sigma^+\, \pi^-$ (dotted line) PDG
$pp \rightarrow p\, K^+\, Y^0$ (points with errors) 2007

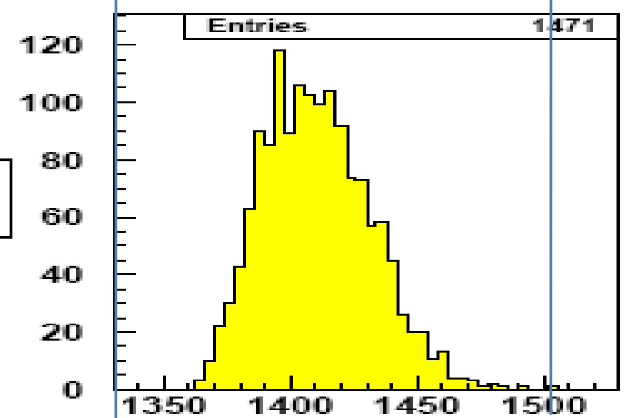


Comparison with available experimental data

DC volume



DC wall



Conclusions

•**1.1 fb^{-1}** of the KLOE data have been **analyzed** looking for physics generated by the 0.1 % of K^- stopped in the DC volume (no target).

•Excellent **Λ(1115) measurement** has been performed showing the **KLOE capabilities** to study KN interactions at low E.

•Capacity to analyze **Λd** in a broad kinematic range with **high acceptance** representing key ingredients for AMADEUS success.

Future goals

•Refine selection criteria for **Λp** and **Λt**

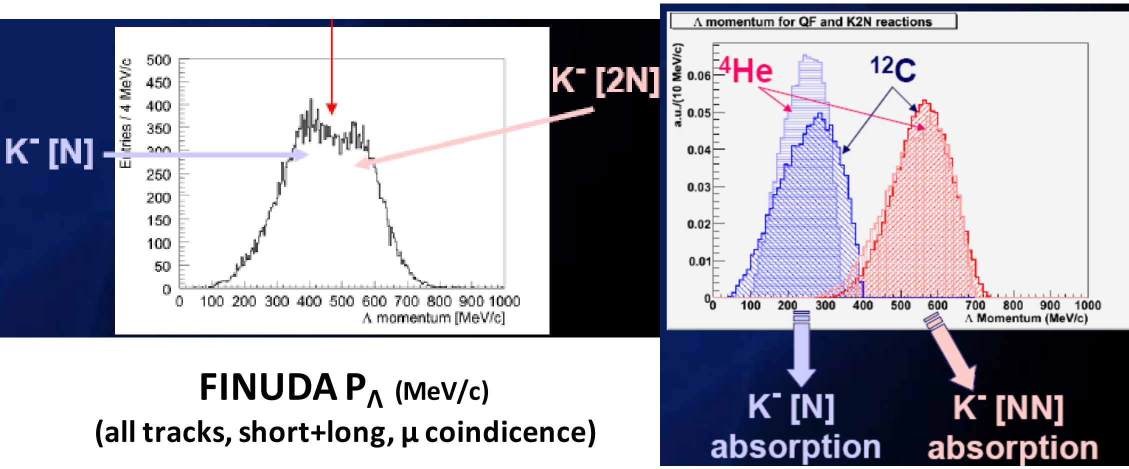
•Analyze **neutron**-events in the Λd case

•Improve the algorithm for Kinematical fit in the search for **Λ(1405)**

•Increase the **statistics** to the whole 2004-2005 KLOE data set **(x2)**

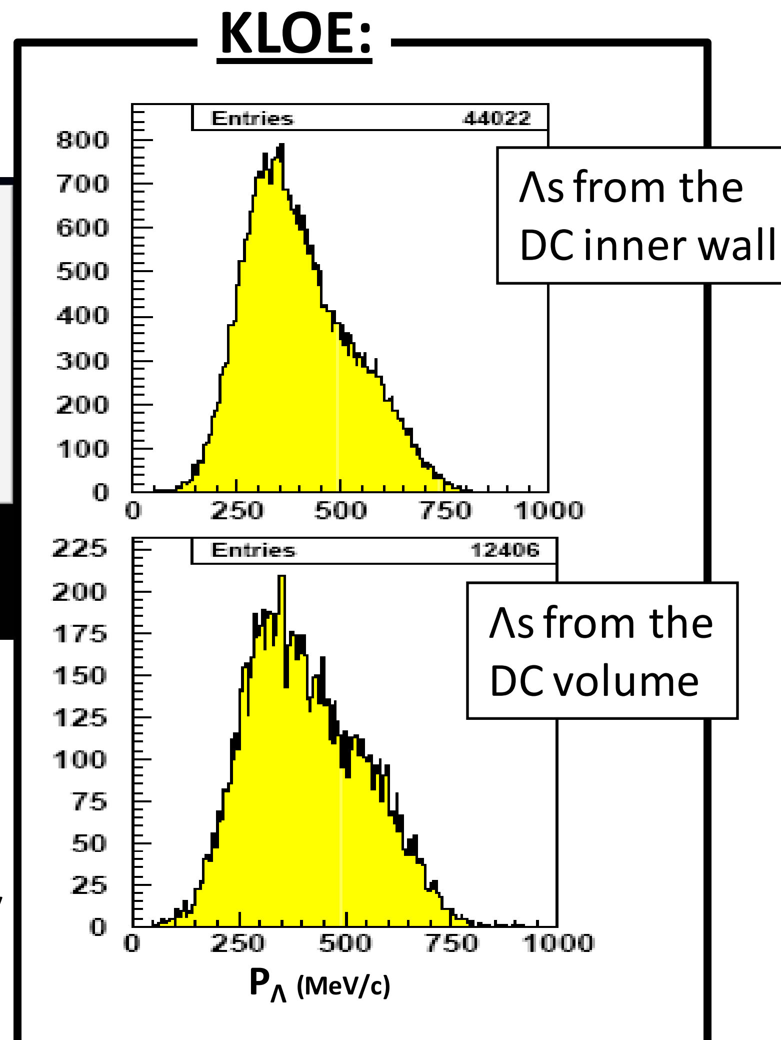
Lambda momentum

Simulation: expected signals for inclusive Λ production in ^{4}He and ^{12}C



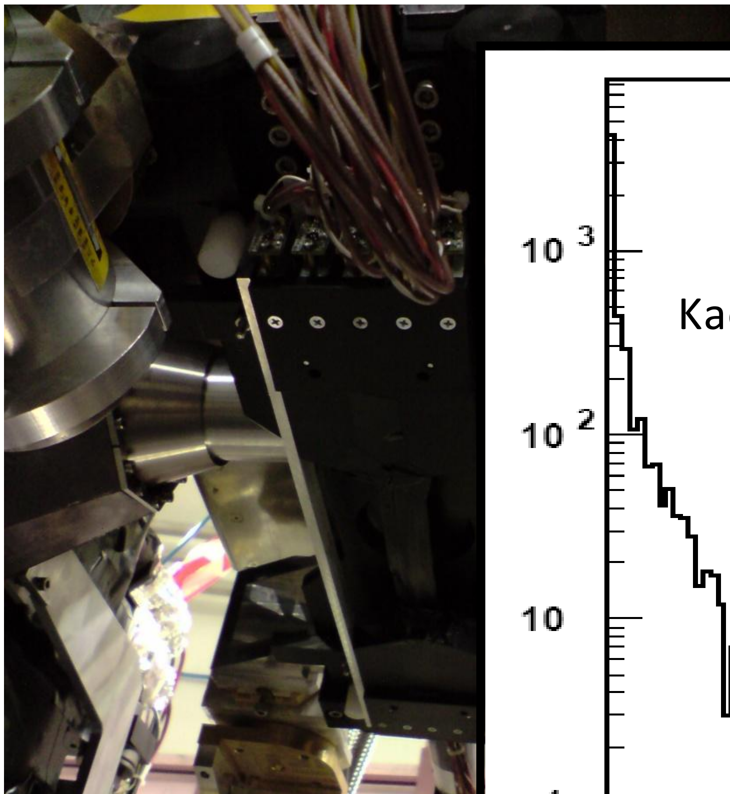
FINUDA P_Λ (MeV/c)
(all tracks, short+long, μ coindicence)

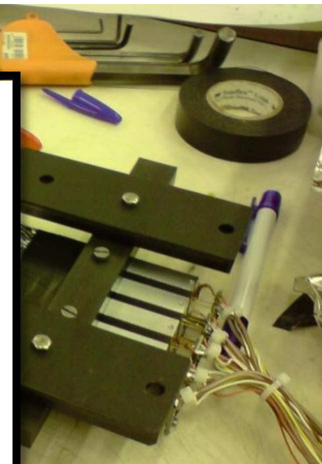
Thanks to S. Piano, A. Filippi

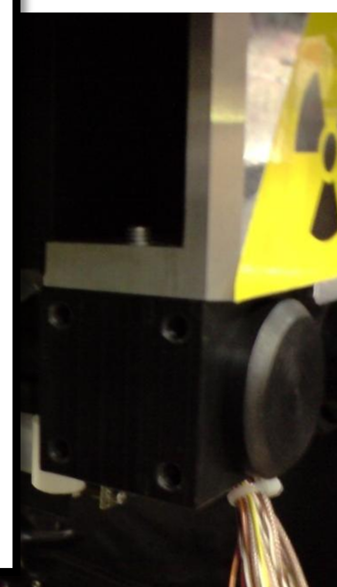


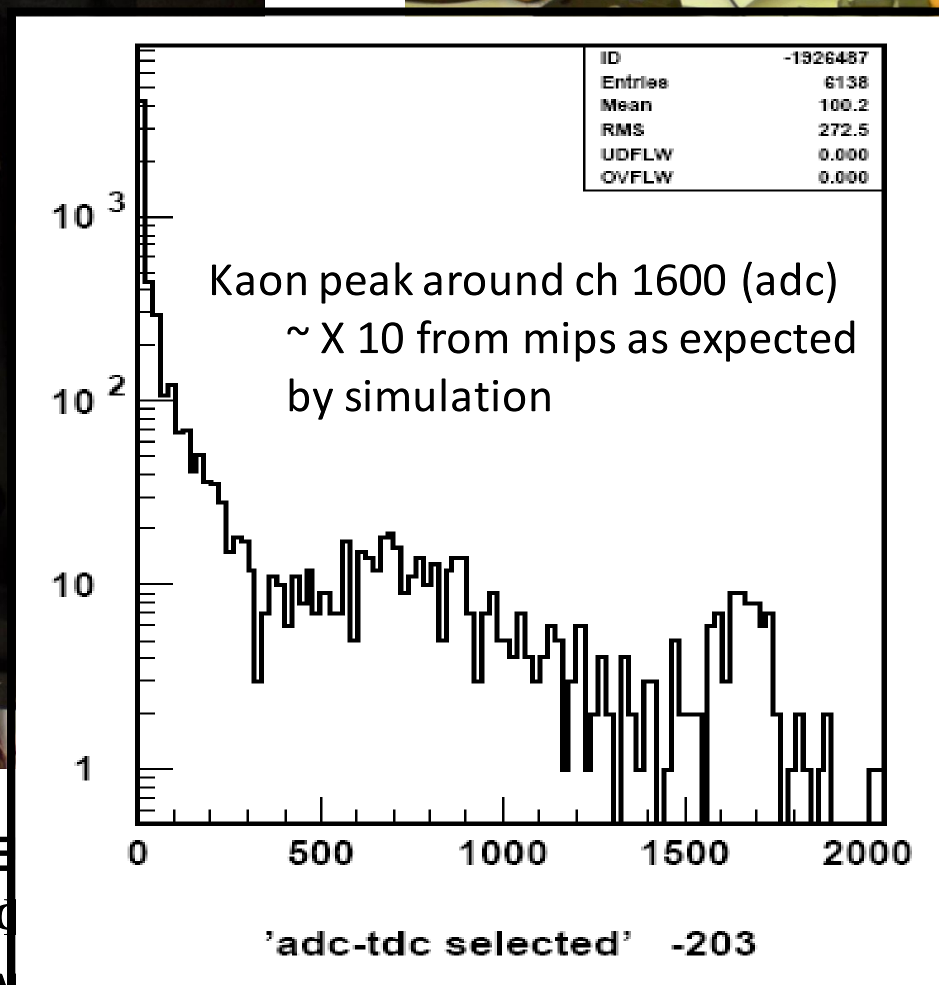
- -Well defined double structure in both cases
- -Similar momentum range
- -Differences at lower momentum due to acceptancy
- -**Perfectly compatible!!!**

Trigger system tests: installation at DAΦNE



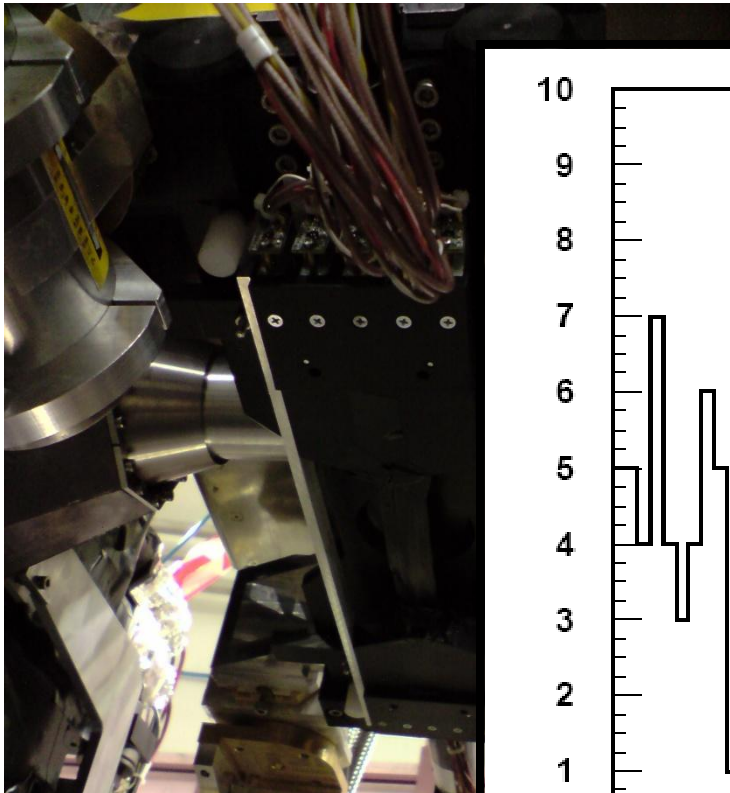


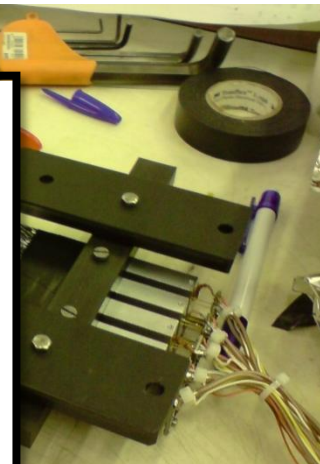


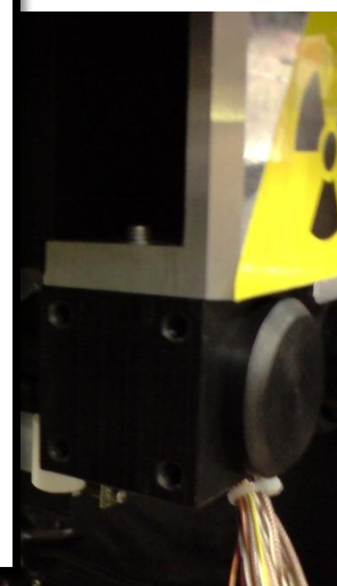


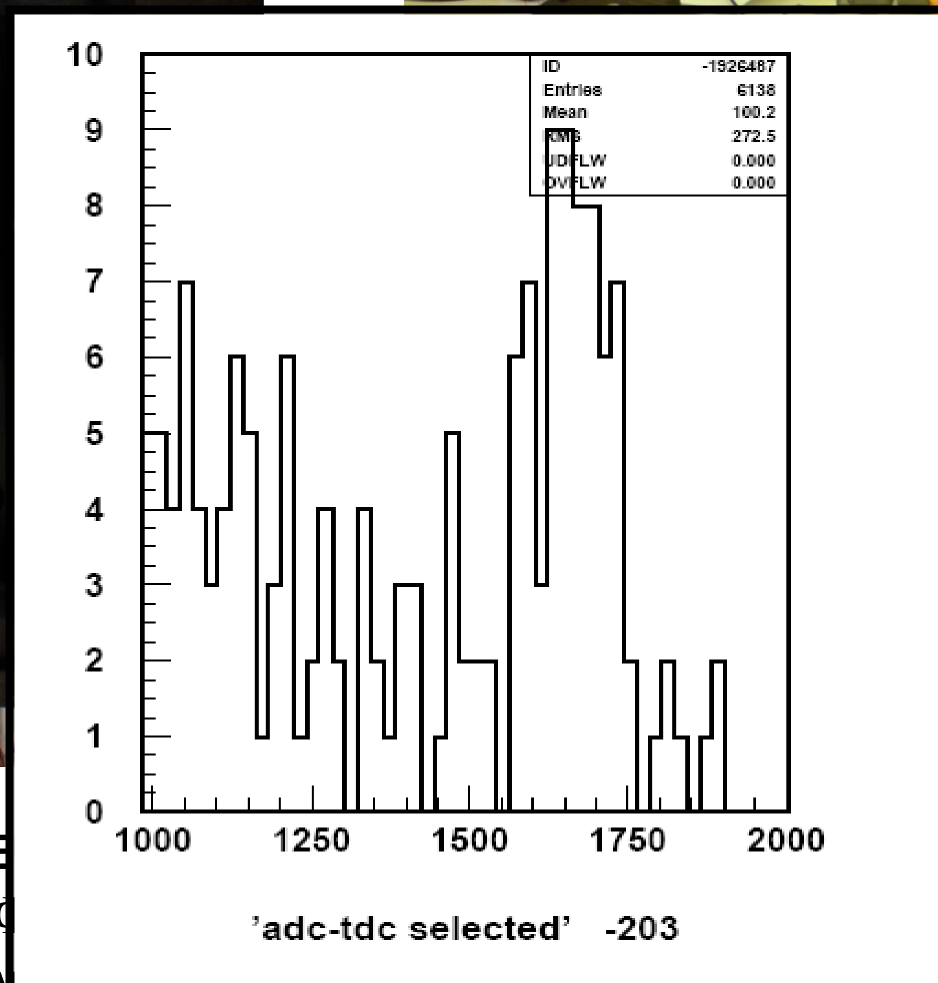
Installation of AMADE
setup in DA
22-24 January

Trigger system tests: installation at DAΦNE









Installation of AMADE
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22-24 January