Studies of antikaon interactions with nucleons at DAΦNE

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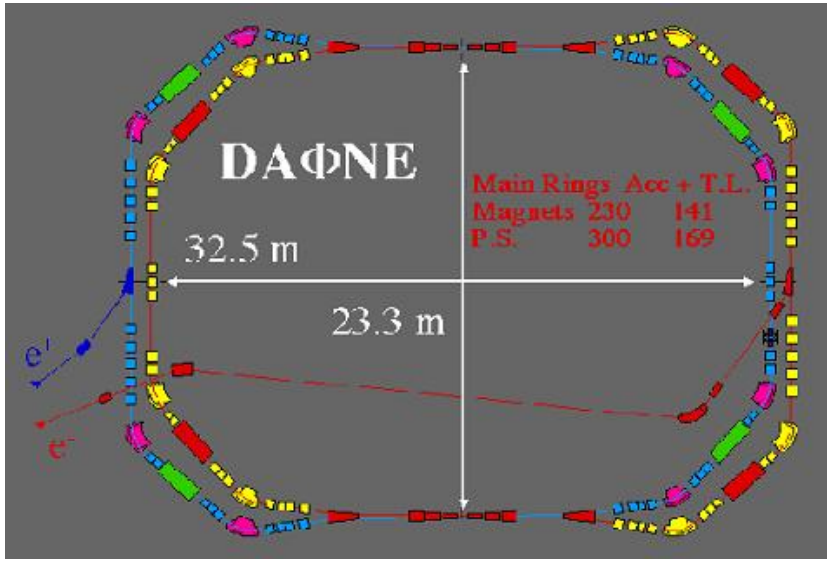
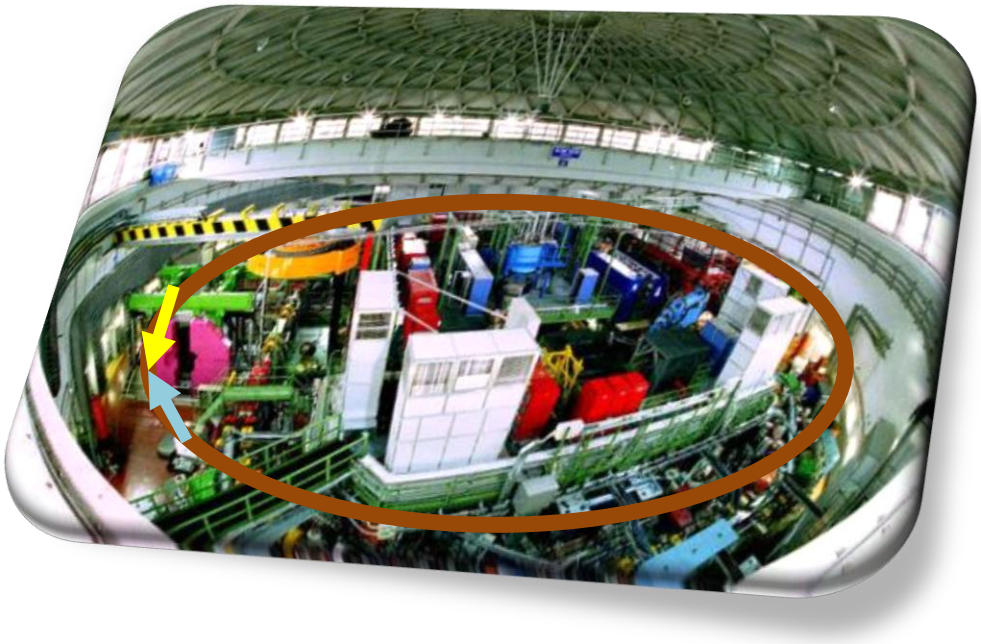
Laboratori Nazionali di Frascati

The DAΦNE e^+ e^- collider

- e+ e- beams at ~ 500 MeV/c
- Φ → K+ K- (49.1%)
- Monochromatic low-energy K- (~127 MeV/c)
- Low hadronic background due to beam characteristics (compared with hadron beam lines, as KEK)

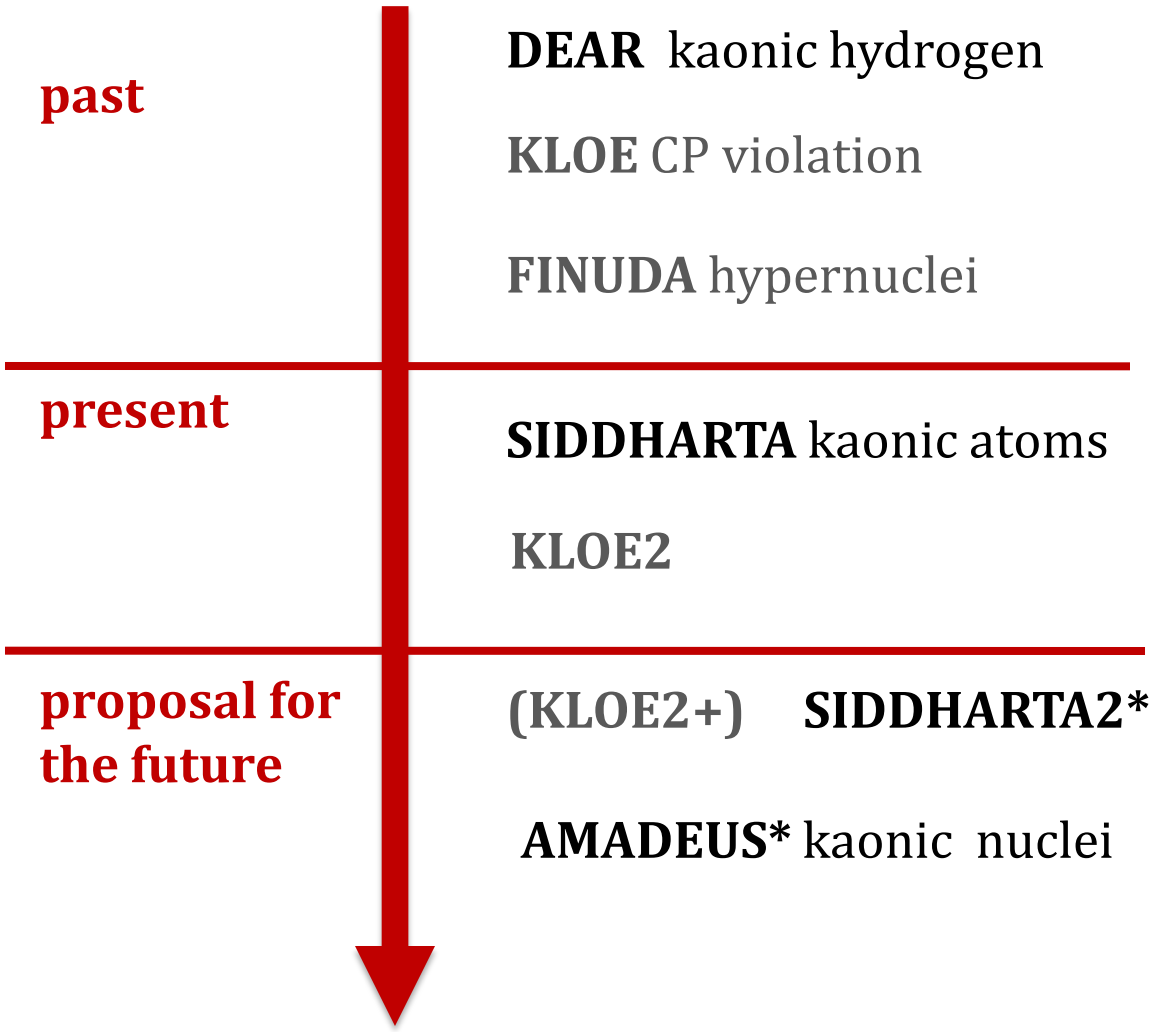




DAΦNE upgrade in 2008
Design of new interaction region scheme

Top luminosity reached during SIDDHARTA run:
$3x10^{32}$ pb-1 s-1

Experimental timeline at DAΦNE



Experimental timeline at DAΦNE

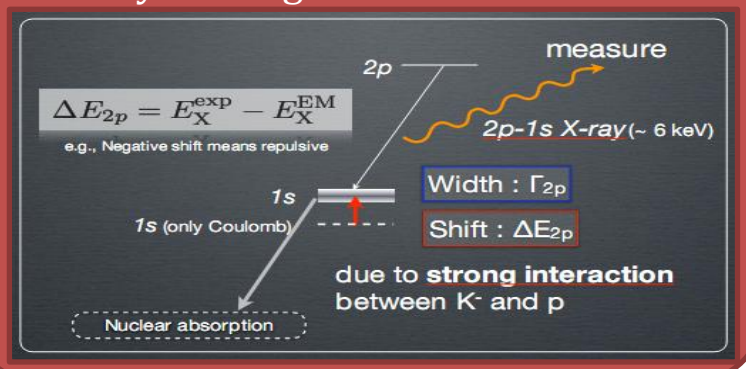
past

DEAR kaonic h

KLOE CP violati

FINUDA hyperr

talks by M. Cargnelli and T. Ishiwatari



present

SIDDHARTA kaonic atoms

KLOE2

proposal for the future

(KLOE2+) **SIDDHARTA2***

AMADEUS* kaonic nuclei

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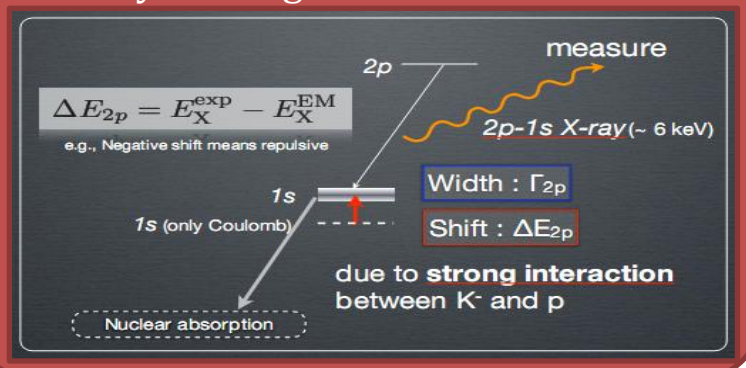

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The motivation

- Studying the properties of the **$\bar{K}$N potential** in the nuclear medium

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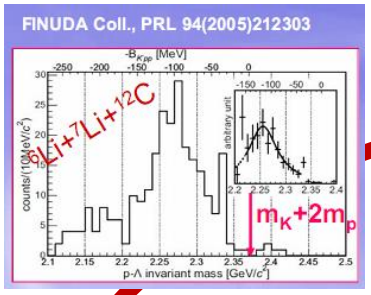
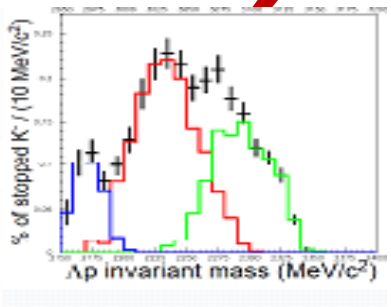
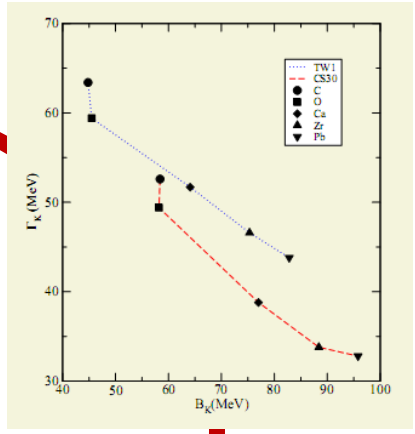
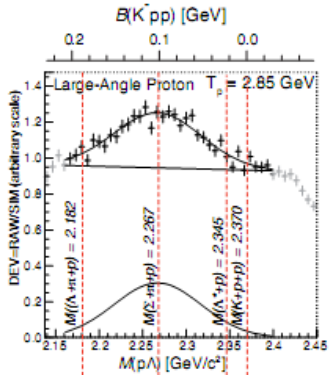
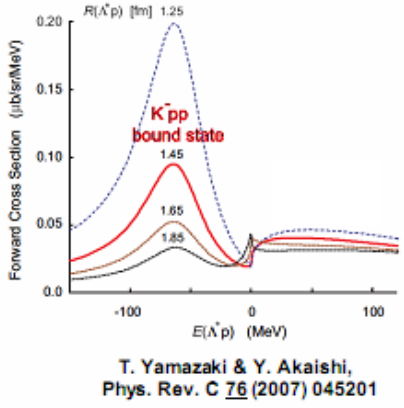




How deeply is a kaon bound in a nucleus?







T. Yamazaki & Y. Akaishi,
Phys. Rev. C 76 (2007) 045201

AMADEUS: the main program

- Search for fundamental kaonic nuclear systems in **formation** and **decay** processes:

kaonic dibaryon states:
ppK^- and pnK^-
produced by interacting K^- at rest
in a ^{3}**He** gaseous target

kaonic 3-baryon states:
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AMADEUS: extended program

Low-energy charged kaon cross section on p, d, He-3 and He-4, for K^- momentum lower than 100 MeV/c (missing today)

The K^- nuclear interactions in Helium (poorly known – based on one paper from 1970…)

Properties of Λ and charged Σ´s for example decays in channels with a neutrino → astrophysics implications (cooling of compact stars)

Resonance states as Λ(1405) or the Σ(1385) could be understood with high statistics; their behaviour in nuclear medium can be studied too

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AMADEUS for low-energy Kaon physics (scattering and interactions):

Use of the today's equivalent of bubble chambers
(all previous scattering meas. were done like this):
an Active Target: TPC-GEM filled with with H, d, He..

Kaonic production of Lambda(1405) off deuteron target

AMADEUS:

- Three key features

AMADEUS, full acceptancy
KLOE: 98% of 4π

AMADEUS, K- at rest in light nuclei (simplest case)

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ppK^- and pnK^-
produced in a ^3He gas target

kaonic 3-baryon states:
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produced in a ^4He gas target

AMADEUS, Full event reconstruction:

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

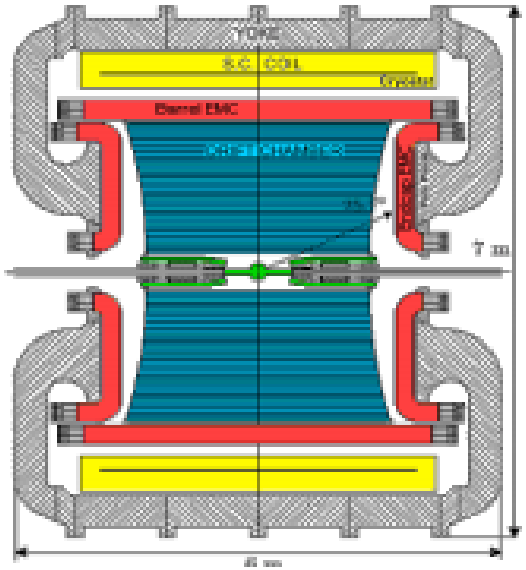
$(K^-ppn) \rightarrow \Lambda + d$

$\Lambda^*, \Sigma^* \rightarrow$ neutral/charged channels

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

The KLOE detector

- for CPT symmetry and QM tests, hadronic physics and more.



Almost full acceptancy 4π:

talk by M. Silarski @ EXA11

*** DRIFT CHAMBER**

- 90% He
- momentum resolution ~ 0.4%

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KLOE experiment @DAΦNE

- **Kaon physics: $|V_{us}|$ and CKM unitarity, CP and CPT violation, rare decays, χPT tests, quantum mechanics tests**
- **φ radiative decays: pseudoscalar and scalar mesons**
- **Hadron production in γγ collision**
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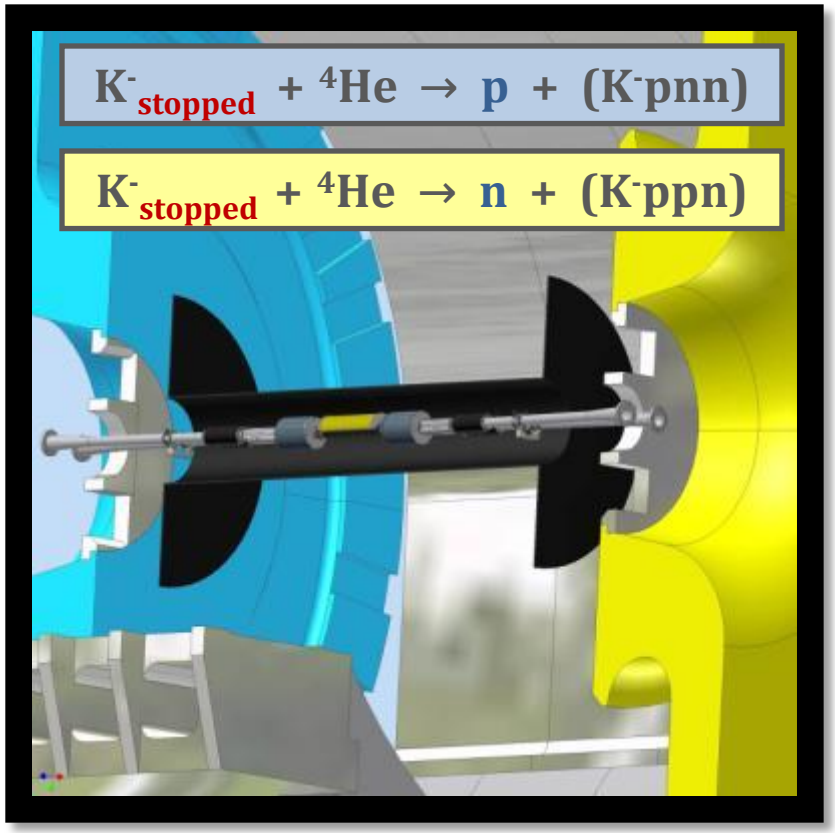
Status of KLOE2. arXiv:1001.3591, G. Venanzoni for the KLOE2 collaboration

From KLOE to AMADEUS

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



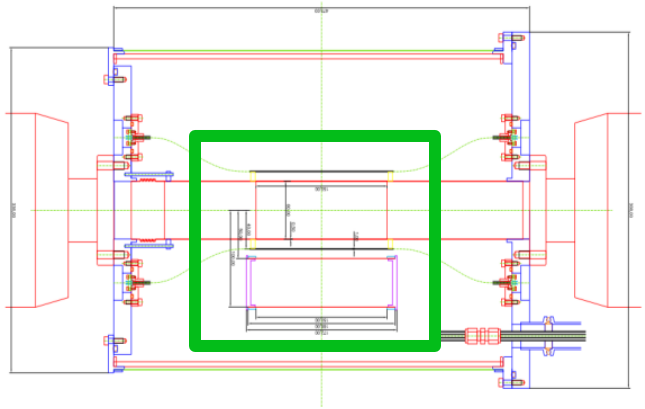
(50 cm. gap in KLOE DC around the beam pipe)

Setup for AMADEUSwithin KLOE:

- Modification of the **beam pipe** of KLOE-2 in order to allow access
- **Target** (A gaseous He target for a first phase of study)
- **Trigger** (1 or 2 layers of ScFi surrounding the interaction point)
- **Inner tracker** (eventually, a first tracking stage before the DC)

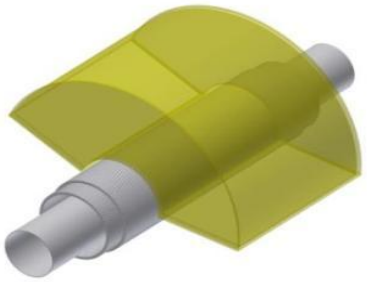
The implementation of the AMADEUS dedicated setup around the beam pipe will modify the topology of the events, stopping the K- in a target inner to the DC.

Target cell + interaction region



- Central region made of **CARBON FIBER**:
  - -Vacuum chamber
  - -External part of cryostate and target walls
  - -**Aluminium** for the peripheral part

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



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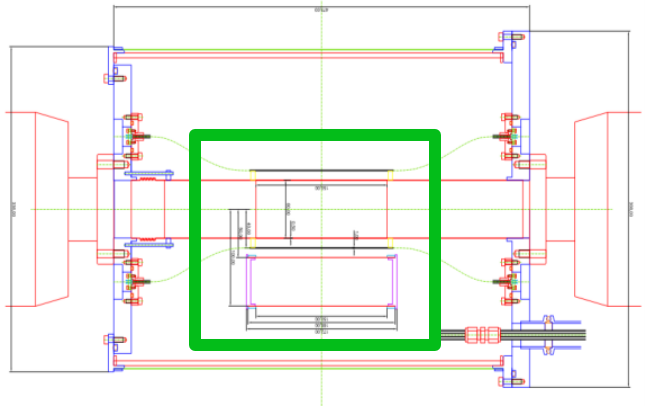

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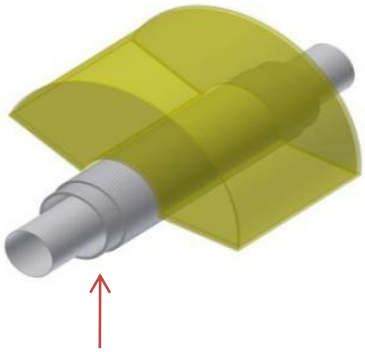
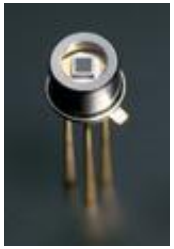


Trigger system

-Single or double layer of ScFi surrounding the interaction point

- Readout made by silicon photomultipliers:
  - - Ideal for ScFi couplin and high granularity detector
  - - Time resolution below 1 ns
  - -**Insensitive to strong magnetic fields**
  - - **no cooling needed**
  - - High gain (>10^6) and quantum efficiency

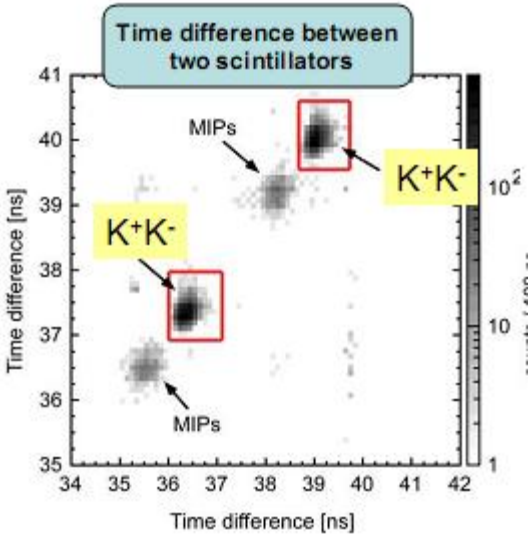


Hamamatsu S10362-11-050U,
efective area 1mm^2,400 pixel
wlorking biases ~ 70 V .

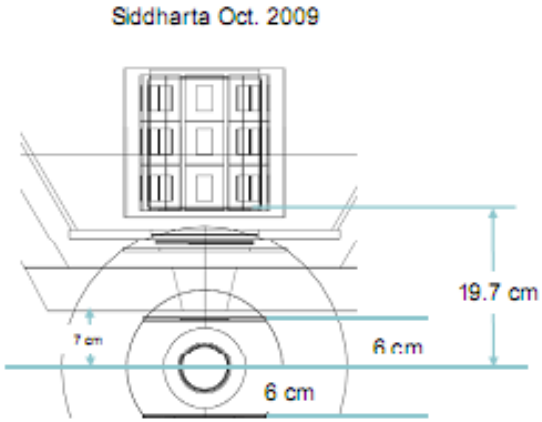
Trigger system: why?

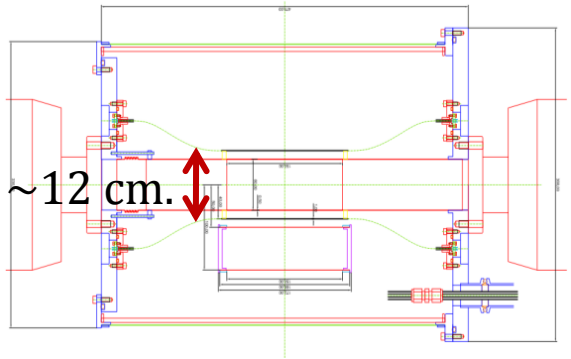
- KLOE data taking currently based on "tagging" in order to collect neutral and charged kaons, and e+ e- events as well
- The characteristics of the events will be changed by introducing the target, with the Kaons not likely entering in the DC

Time resolution requirements



SIDDHARTA vs AMADEUS

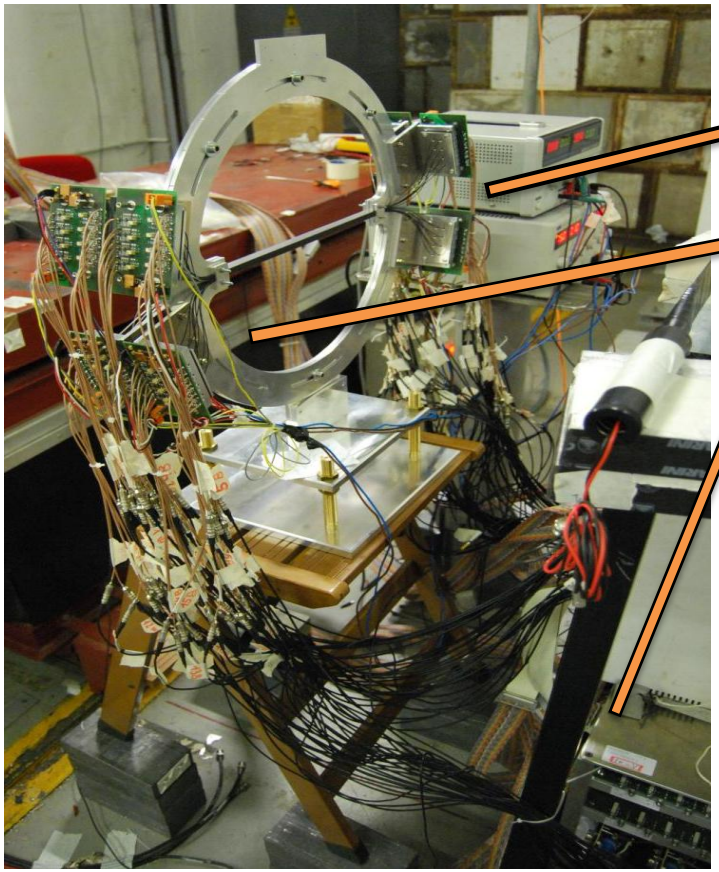




- Resolution needed for SIDDHARTA with a distance to the IP: **better than 1 ns**

Trigger system: R&D

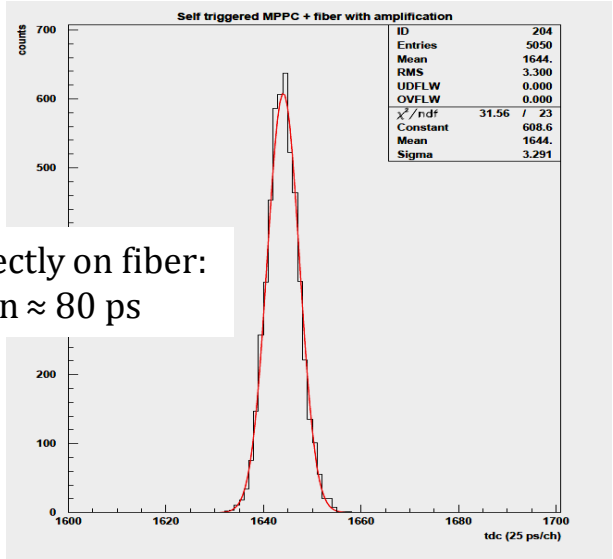
- test setup for SIPM+fiber coupling and reading electronics.



2-rings of double layer 16 fibres

64 fast pre-amplifiers (64x)

2 boards of 32 constant fraction discriminator with zero jitter



Laser directly on fiber:
Resolution ≈ 80 ps

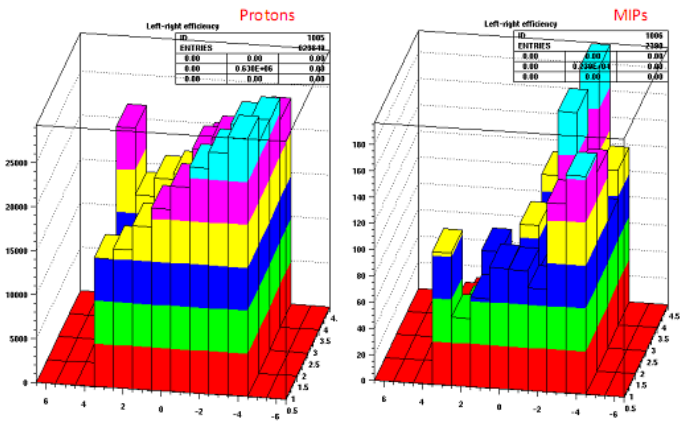
SiPM + Pre-amp + scintilliating fiber

time resolution study @ Roma3 University

Trigger system: R&D

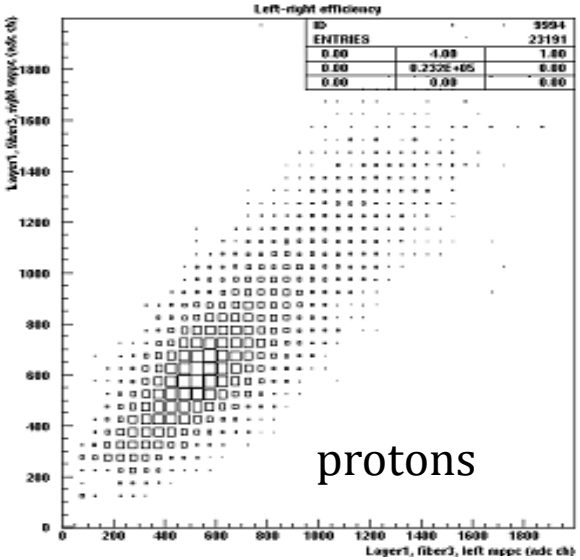
Test beam @ PSI πM1 beam
-continuous high-intensity secondary beam
10^7 π^-/s or 10^8 π^+/s a 170 MeV/c or 10^7 proton of 500 Mev for mA
Pions or proton sarrive in 1 ns-wide bunches every 20 ns.
Spot size on target (FWHM): 15 x 10

Beam profile

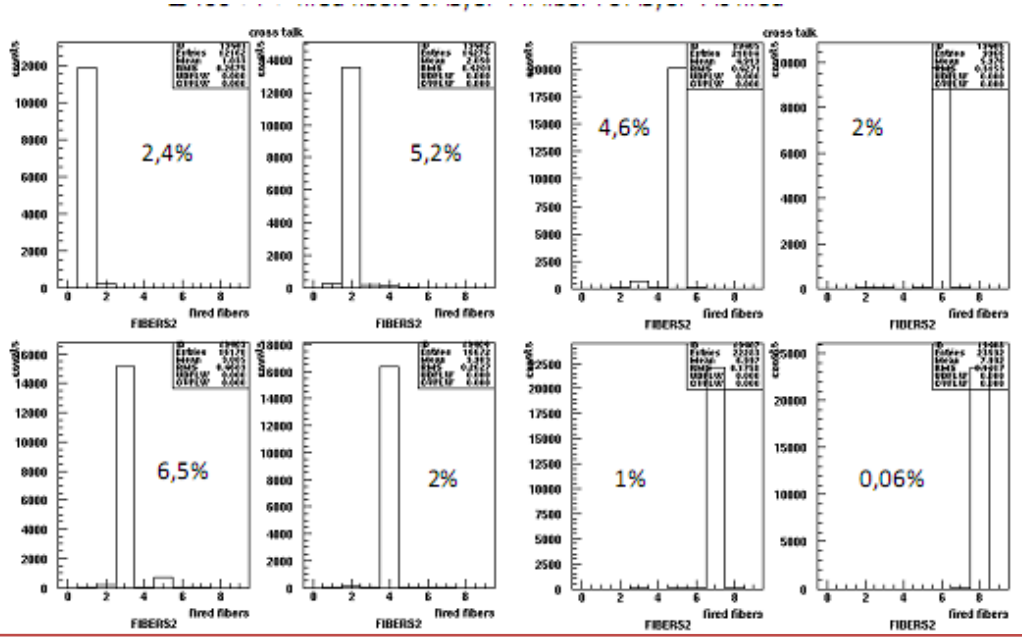


PROTONS MIPS

Study of efficiency for hadrons

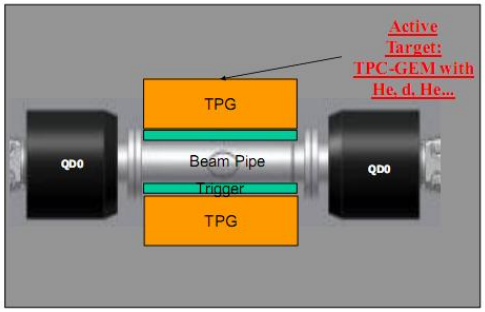


Crosstalk for adjacent fibers



TPG for inner tracking & active target

- AMADEUS for low-energy Kaon physics
  (scattering and interactions)
  Active target: TPC-GEM filled with H, d, He...



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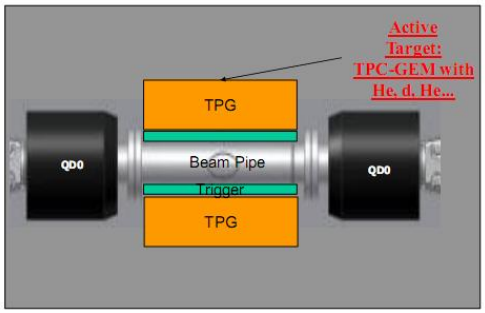
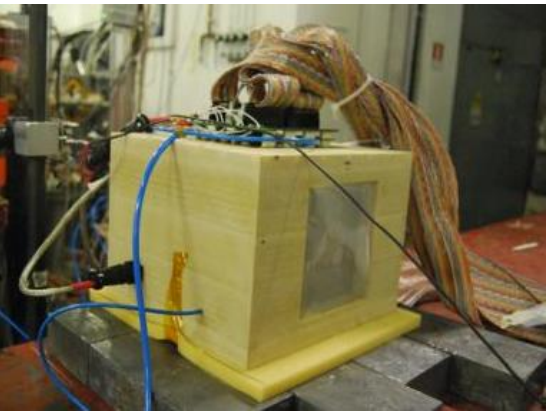


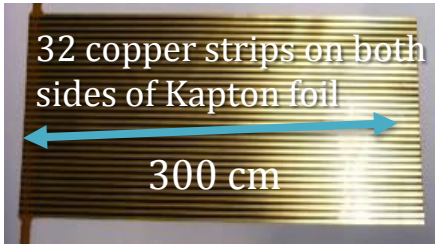


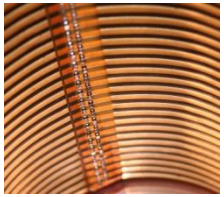
Prototype tested at BTF & PSI

The prototype is encapsulated inside a tight gas box (PERMAGLASS) which allow to simply change the geometry or replace new GEM.

The box has a leak of the order of 2 mbar/day corresponding to a humidity level of 100 ppm.

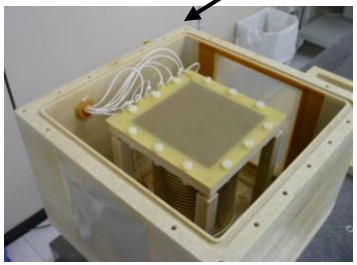
GEM-TPC construction: Field Cage

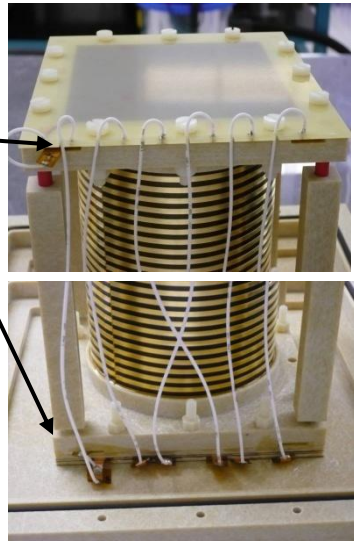




100 MΩ resistor

HV connection



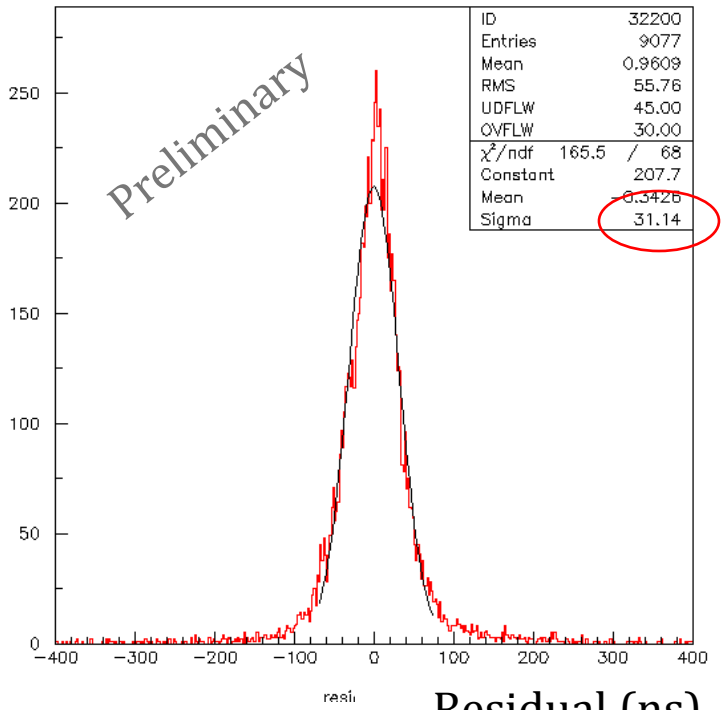


GEM-TPC construction: Assembly

TPG for inner tracking & active target

- Results from LNF & PSI tests with Ar/iso-C4H10 and Ar/CO2 gas mixtures

The track is performed fitting a **straight line** on a row **of 32 pads**



Residual (ns)

In the time space:

$\sigma^t_{residual} = \sqrt{32}*(\sigma^t_{track})^2$

→ σ^t_{track} **= 5,5 ns**

The time-space relationship is computed through the velocity drift ~ 2 cm/μs (Garfield simulation)

→Tracking resolution along z:

$\sigma^s_{track}(z) = v_{drift} * \sigma^t_{track}$ ~ **100 μm**

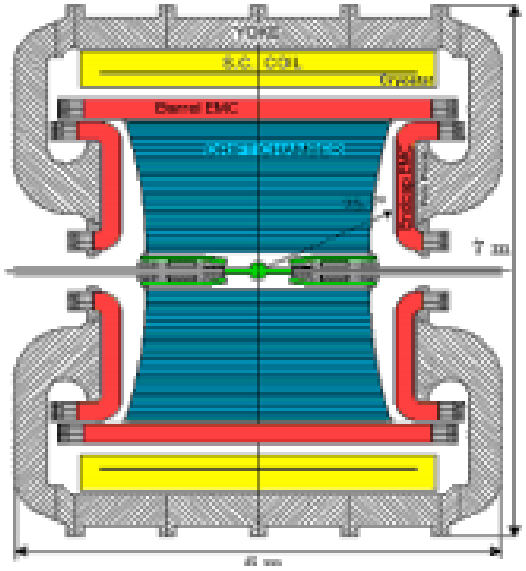
Tracking resolution along x-y:

$\sigma^s_{track}(x,y)$ **= 860 μm** (3x3 mm² pad size)

The KLOE detector

The KLOE detector

- for CPT symmetry and QM tests, hadronic physics and more.



Almost full acceptancy 4π:

*** DRIFT CHAMBER**

- 90% He
- momentum resolution ~ 0.4%

*** ELECTROMANETIC CALORIMETER**

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

KLOE experiment @DAΦNE

- **Kaon physics: $|V_{us}|$ and CKM unitarity, CP and CPT violation, rare decays, χPT tests, quantum mechanics tests**
- **φ radiative decays: pseudoscalar and scalar mesons**
- **Hadron production in γγ collision**
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Status of KLOE2. arXiv:1001.3591, G. Venanzoni for the KLOE2 collaboration

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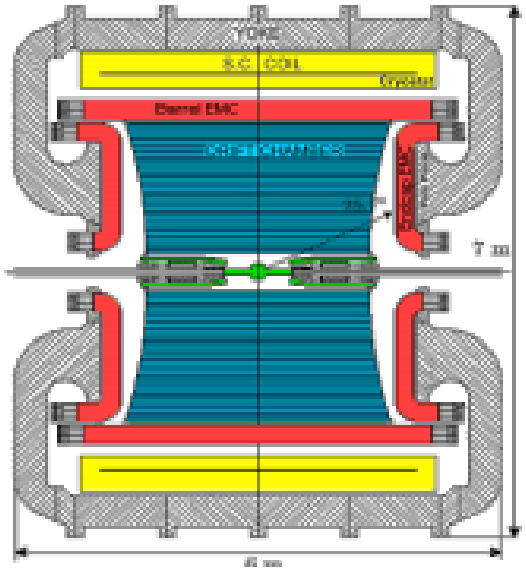

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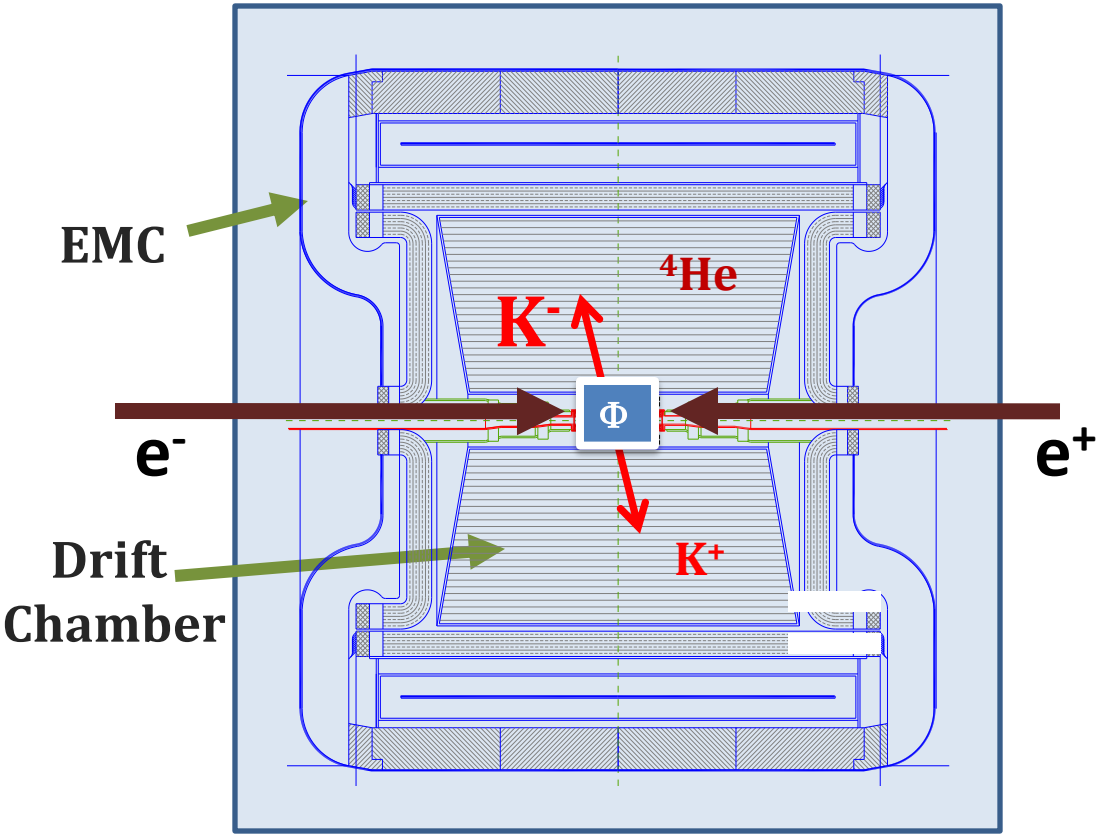
KLOE data analysis by the AMADEUS collaboration

- Test the behaviour of the KLOE detectorfor hadronic physics purposes
- Possibility to study the phenomenon with an active target

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



The implementation of the AMADEUS setup will modify the topology of the events

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

•From analysis of KLOE data and Monte Carlo: **0.1 % of K^- should stop in the DC volume**

•This would lead to hundreds of events with K- hadronic interactions at rest

"AMADEUS Step-0"

Selection of events

- Statistics: analyzing data up to an integrated luminosity of ~1,7 fb^{-1} (80% KLOE RUNS 2004/2005)
- Data analysis: search for hadronic interactions with Λ(1115):
  - $\Lambda \rightarrow p + \pi^-$ (64% BR)
  - Construct a vertex with Λ + an extra particle

$K^- + {}^4He \rightarrow n + n + (K^-pp) \rightarrow \Lambda + p$

$K^- + {}^4He \rightarrow n + (K^-ppn) \rightarrow \Lambda + d$

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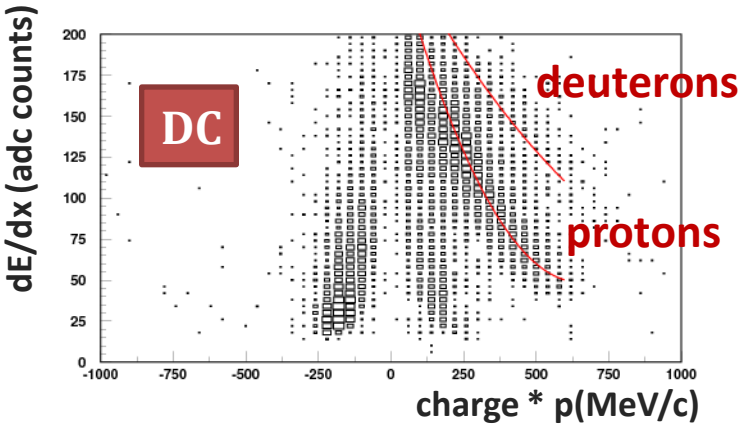
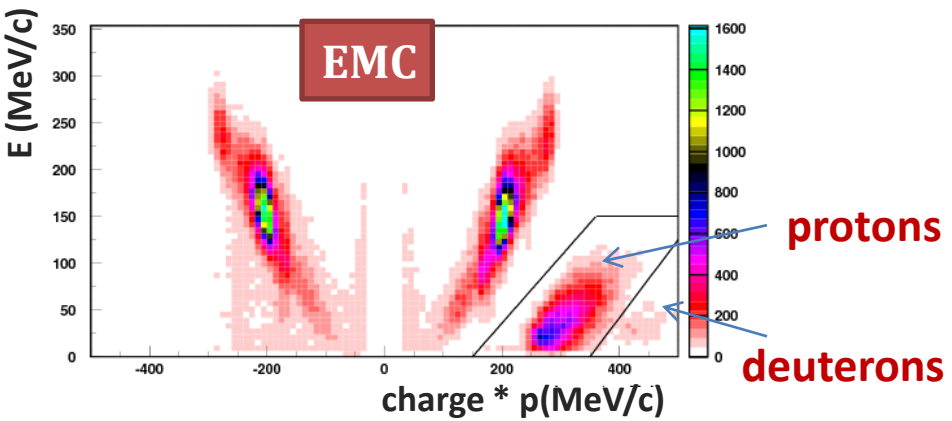
  - $\Lambda \rightarrow p + \pi^-$ (64% BR)
  - Construct a vertex with Λ + an extra particle

$K^- + {}^4He \rightarrow n + n + (K^-pp) \rightarrow \Lambda + p$

$K^- + {}^4He \rightarrow n + (K^-ppn) \rightarrow \Lambda + d$

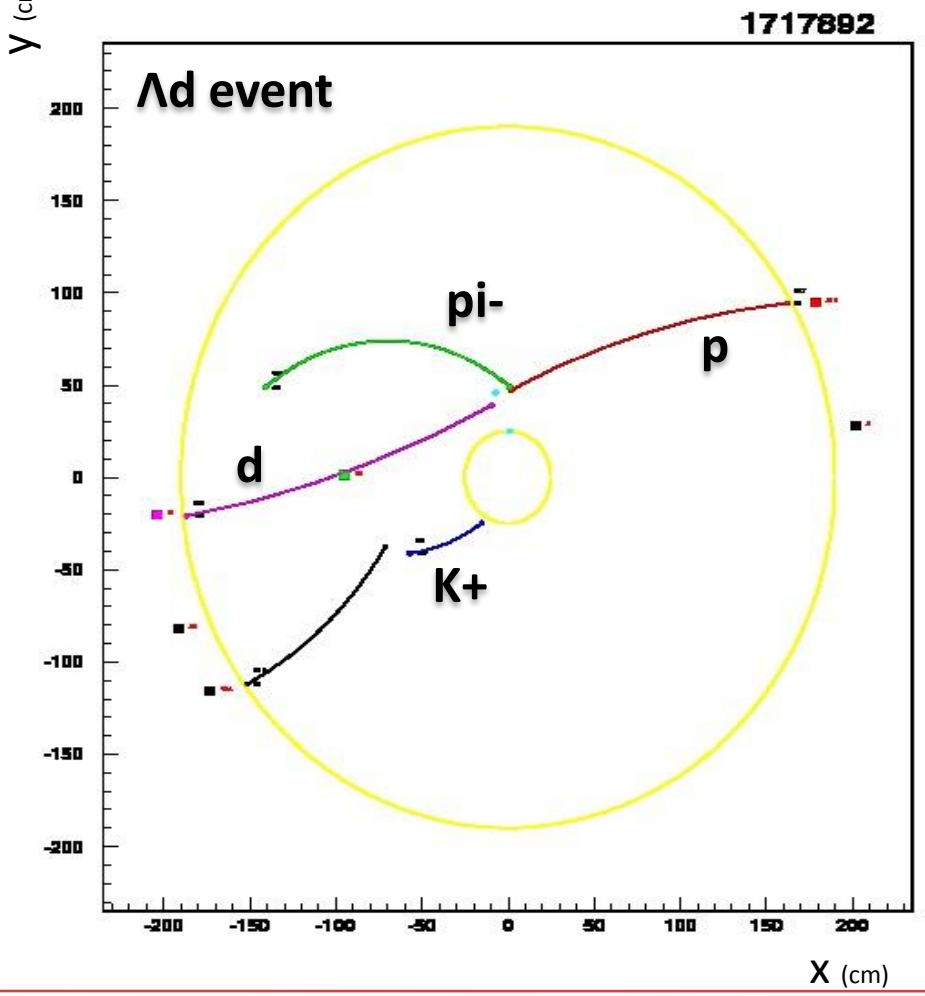
- PID: Protons and deuterons are **firstly** selected from the spectrum of particles near to the Lambda vertex **by dE/dx**





Events selection

-The use of the EMC clusters associated to tracks allows to calculate particle masses
-A good spatial resolution in essential to distinguish the “interaction” and “lambda” vertices .



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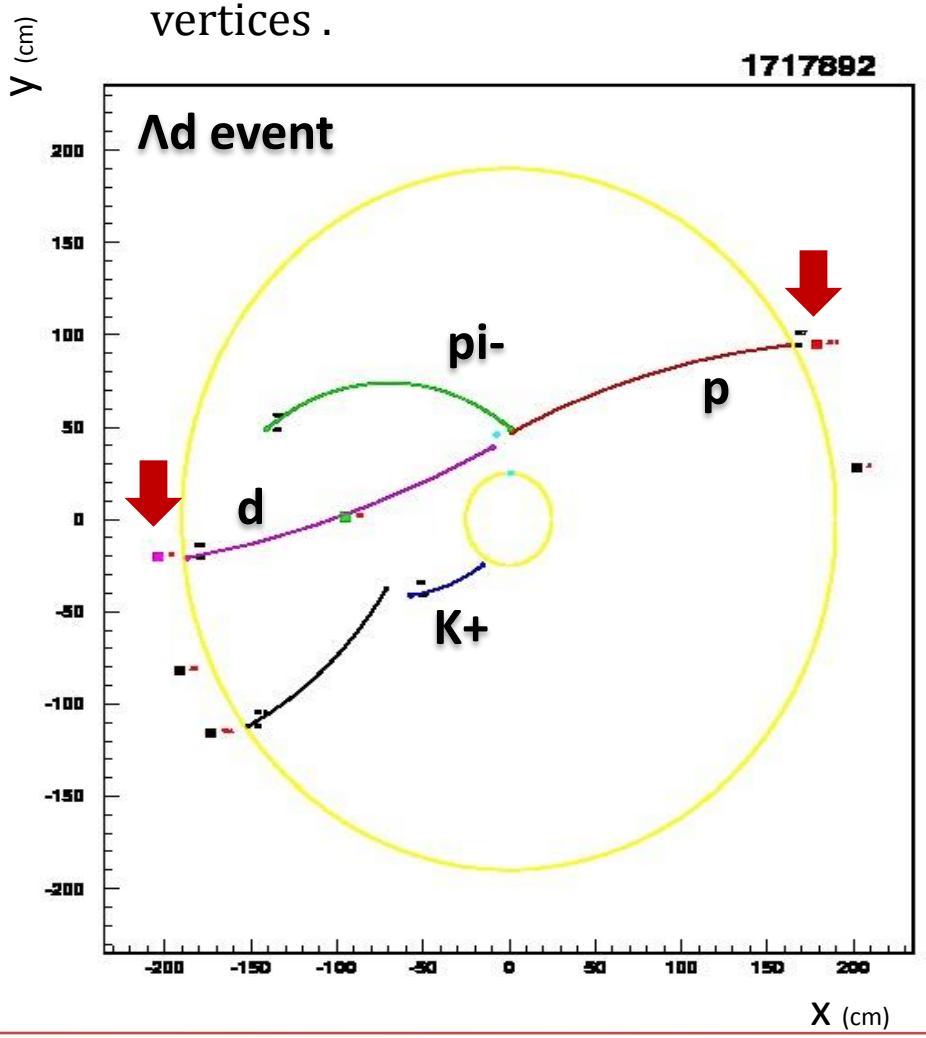
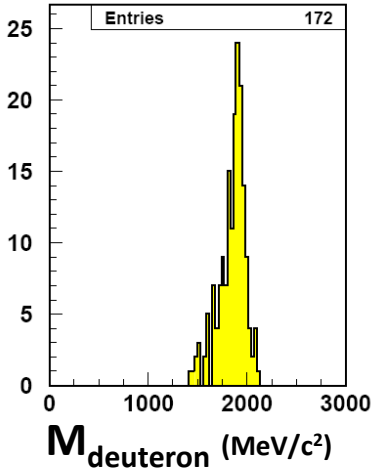
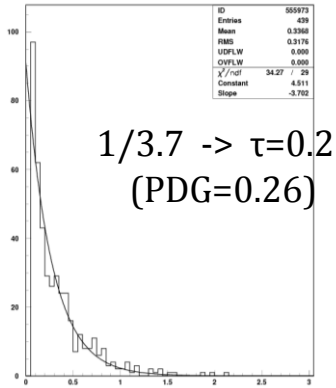


Time information from clusters used to:
- Calculate p/d mass by TOF
-Evaluate Σ^0 background
-Use Λ lifetime as quality cut





1/3.7 -> τ=0.25 ns
(PDG=0.26)

Lambda survival Time (ns)

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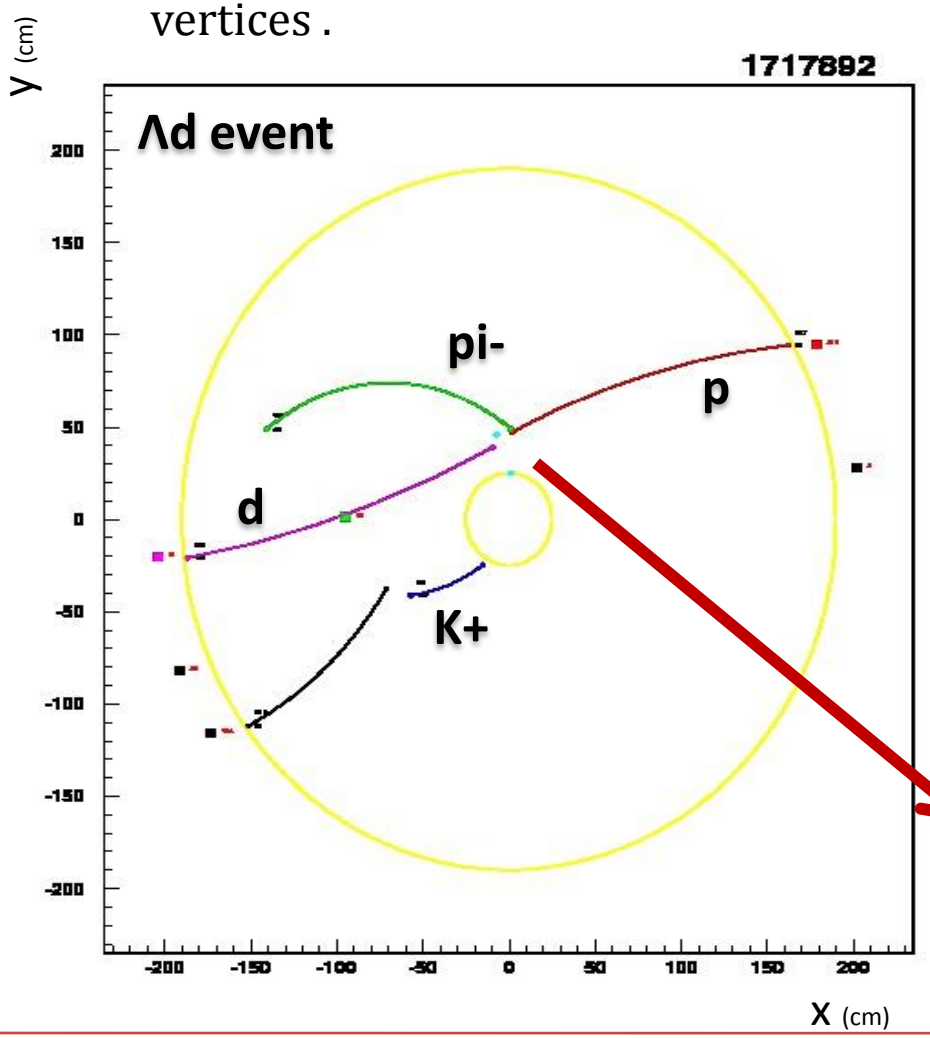

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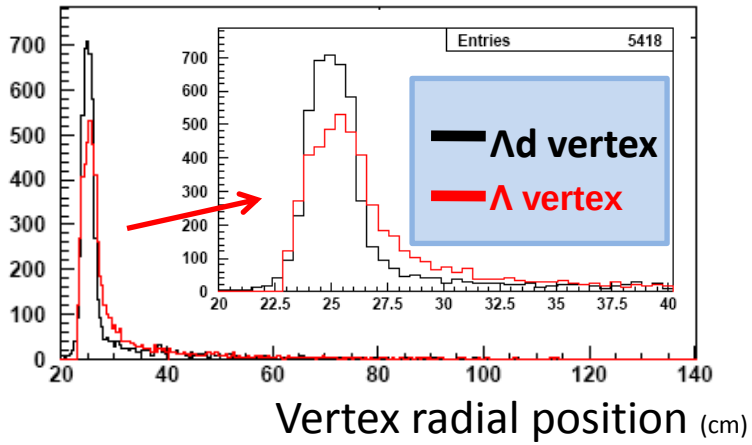


2 different vertices reconstrucion:

Λ -> p + pion

(K- + 4He) -> Λ + d

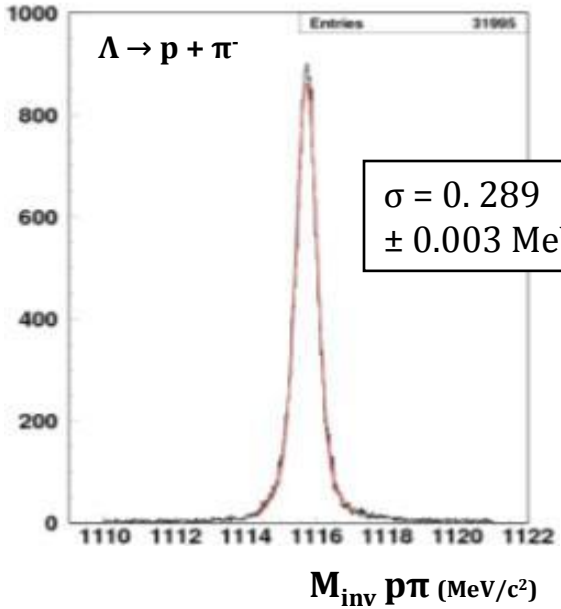
Invariant masses

-Lambda invariant mass from proton-pion pairs

KLOE: statistical error 0. 003 MeV/c2

PDG:

$M_\Lambda \pm 0.006$ stat ± 0.006 syst **(MeV/c²)**



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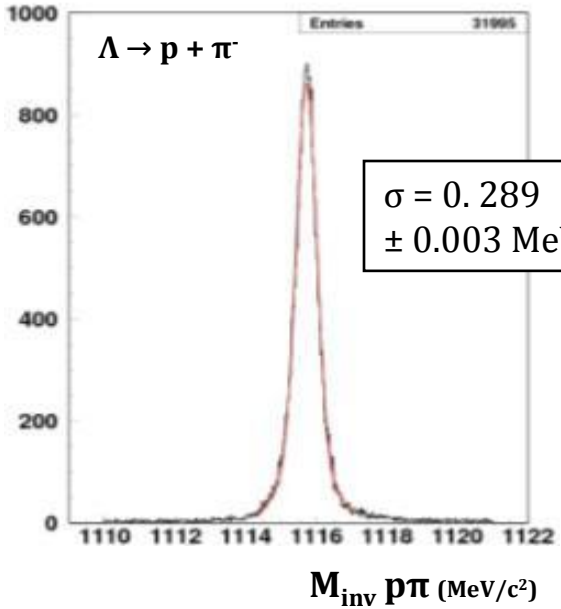
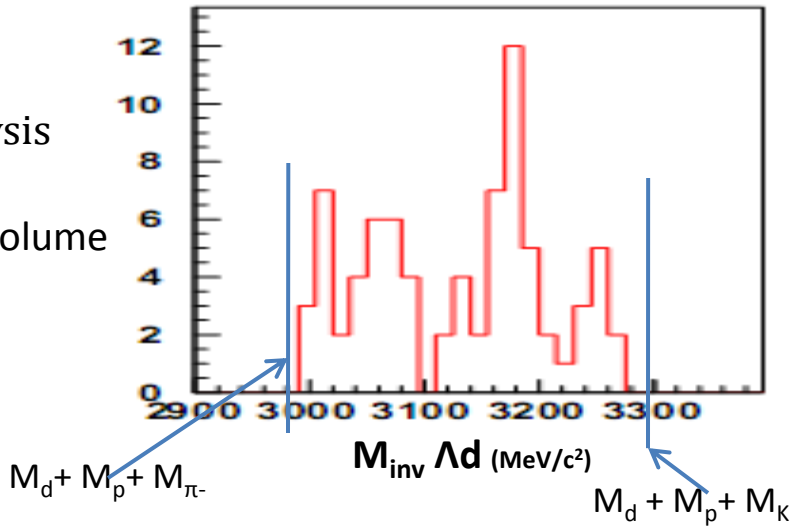


-**Lambda-deuteron** invariant mass and momentun spectra

Λd analysis
78 events
in the DC volume



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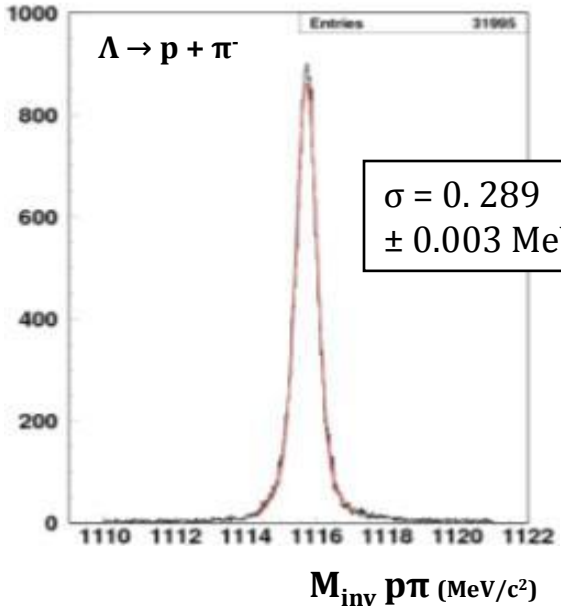

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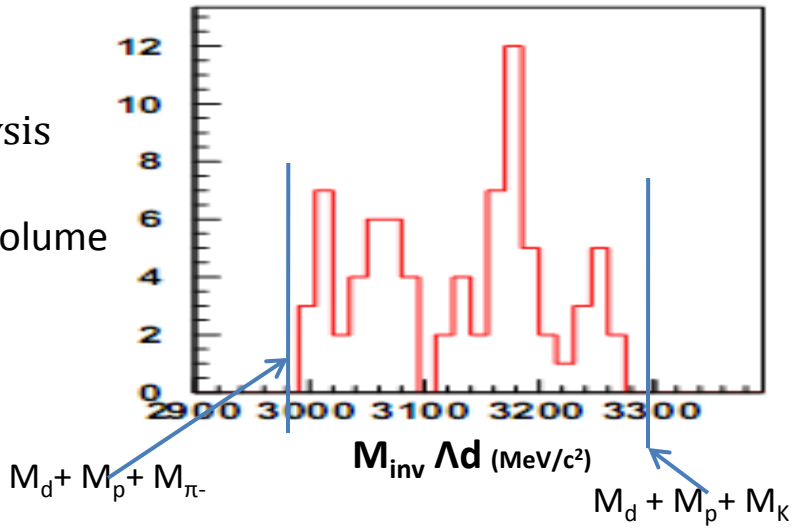
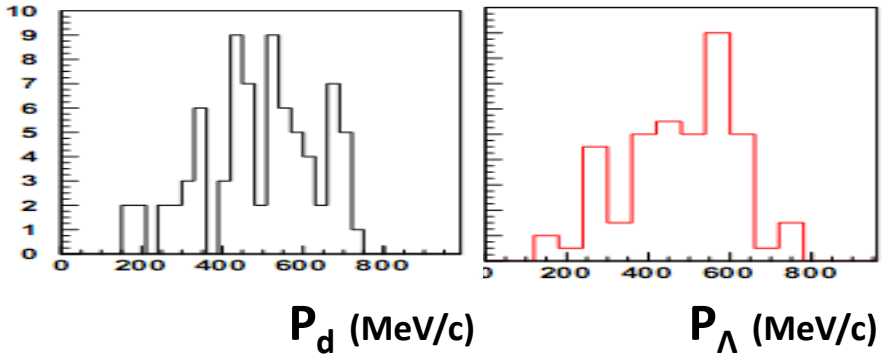
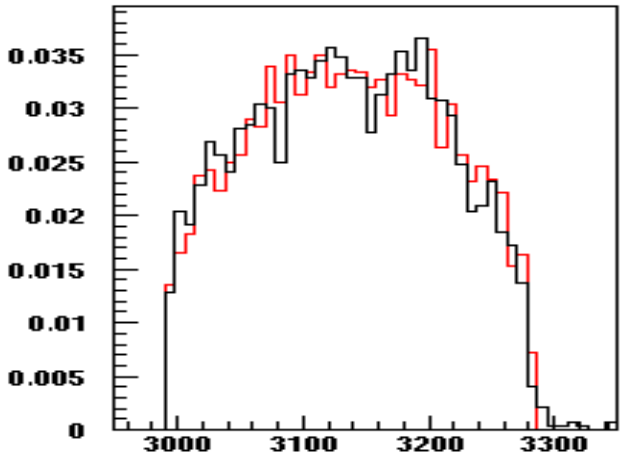


Efficency for tracks with P < 400 MeV
improved **increased acceptancy**



Acceptance

- Use of the standard KLOE Monte Carlo implementing the desired interaction of stopped K- in the gas volume
- Evaluation of the momentum and invariant masses reconstruction acceptance
- Simulation: $K^- + {}^4He \rightarrow \Lambda\, d\, n$ events (phase space)

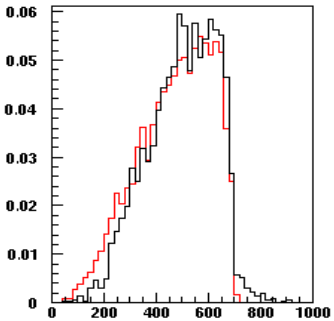


$M_{inv}\ \Lambda d$ (MeV/c²)

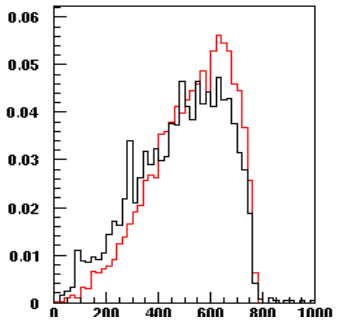
With the previously described reconstruction we expect to obtain an unbiased invariant mass spectra in the whole kinematically allowed range

True phase space MC
Reconstructed MC

Normalization 1:1
(no efficiency evaluation)



P_Λ (MeV/c)



P_d (MeV/c)

Neutral particles detection

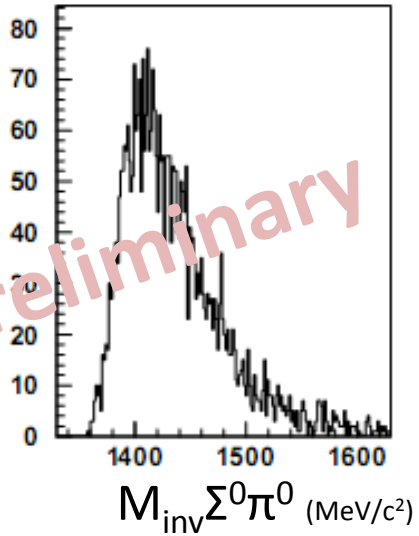
The EMC capabilities allows for:

D. Jido, E. Oset and T. Sekihara,
``Kaonic production of Lambda(1405) off deuteron target in chiral dynamics''
arXiv:0904.3410 [nucl-th]

Photon detection

- eliminate Σ^0 contamination of Λ events
- Analysis of $\Sigma^0\pi^0$ events

$$K^- p \to \Sigma^0 \pi^0$$
$$\Sigma^0 \to \Lambda \gamma$$



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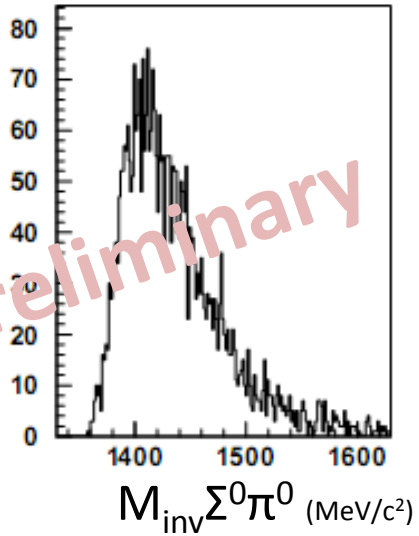
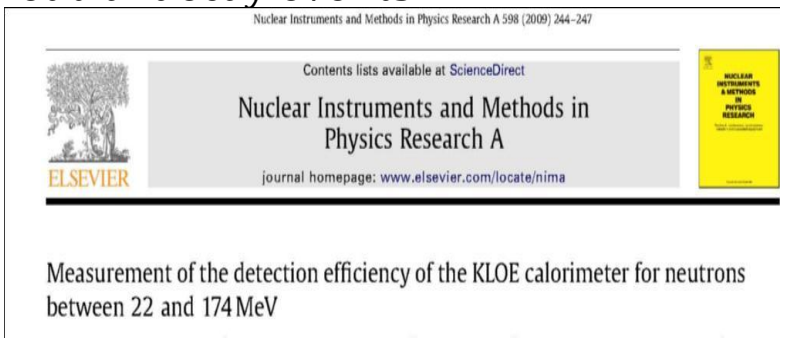


$M_{inv}\Sigma^0\pi^0$ (MeV/c²)

Neutron detection

- proved efficiency for the neutrons in EMC ~40% by KLONE
- being evaluated with copious lambda neutral decay events

$$K^- + {}^4He \to n + (K^-ppn) \to \Lambda + d$$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journal homepage: www.elsevier.com/locate/nima

Measurement of the detection efficiency of the KLOE calorimeter for neutrons between 22 and 174 MeV

Summary

- AMADEUS is a well defined proposal for continuing the studies on the antikaon-nucleon interactions at DAΦNE after SIDDHARTA.
- R&D for the realization of the experiment is ongoing preparing the target, and inner systems to be implemented in KLOE: trigger and tracking.
- The analysis of the KLOE data shows the capabilities of the detector for performing unbiased studies.

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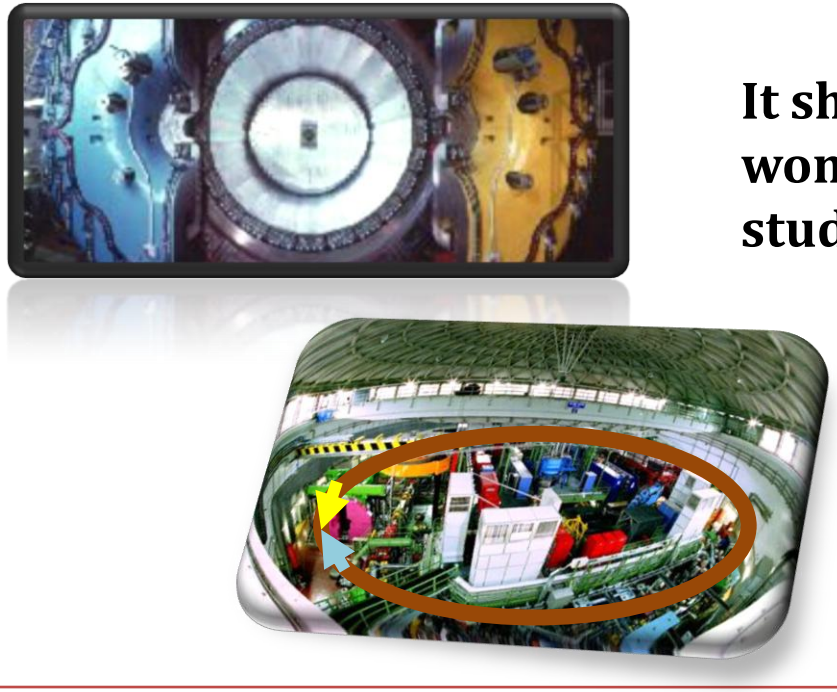

It should be a pitty not to use this wonderful detector @ DAΦNE for studying this physics case