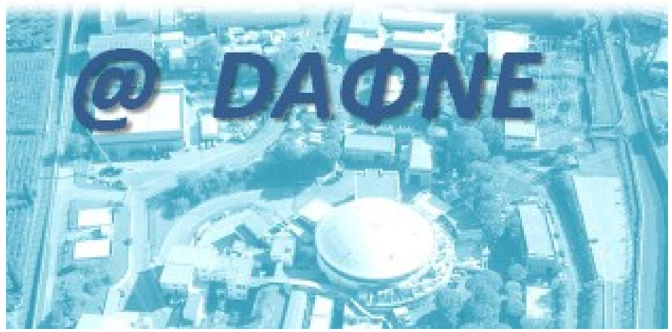
Antikaon-nucleon/nuclei interaction studies at low energies the AMADUES project

Dr. Kristian Piscicchia*
INFN, Laboratori Nazionali di Frascati
on behalf of the AMADEUS Collaboration

MESON 2012
12th International Workshop on Meson Production, Properties and Interaction
KRAKÓW, POLAND
31 May - 5 June 2012

*kristian.piscicchia@lnf.infn.it



ANTIKAONIC
MATTER
AT
DAΦNE: AN
EXPERIMENT
WITH **U**NRAVELING
SPECTROSCOPY

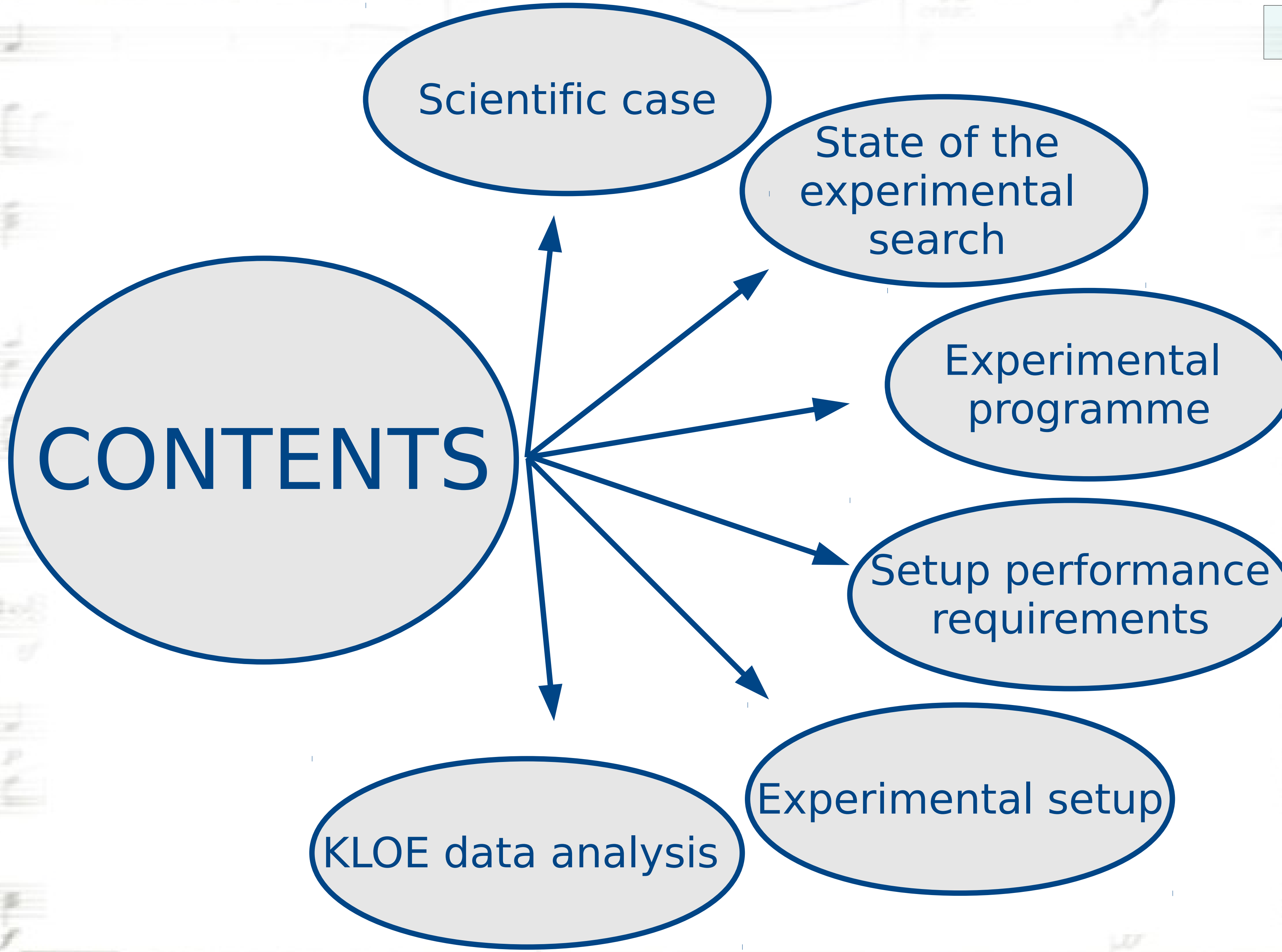
AMADEUS collaboration
116 scientists from 14 Countries and 34 Institutes

lnf.infn.it/esperimenti/siddharta
and
LNF-07/24(IR) Report on lnf.infn.it web-page (Library)

AMADEUS started in 2005 and was presented and discussed in all the LNF Scientific Committees

HadronPhysics2
Study of Strongly Interacting Matter

EU Fundings FP7 – I3HP2:
Network WP9 – LEANNIS;
WP24 (SiPM JRA);
WP28 (GEM JRA)


CONTENTS
Scientific case
State of the experimental search
Experimental programme
Setup performance requirements
Experimental setup
KLOE data analysis

Scientific case

- The experimental investigation of the low energy interaction of antikaons (S = -1) with nucleons and nuclei is fundamental in understanding how spontaneous and explicit breaking of chiral $SU(3)_L \times SU(3)_R$ symmetry in QCD occurs in nuclear environment.

- The isospin (I = 0) s-wave $\bar{K}N$ interaction is quite strongly attractive around the $\bar{K}N$ threshold (from kaonic hydrogen data), unlike the weakly repulsive kaon – nucleon (S = +1) interaction.

- Chiral perturbation theory is not directly applicable to the sector with baryon number (B = 1) and strangeness (S = -1) due to the formation of the $\Lambda(1405)$ about 30 MeV below the $K^- p$ threshold.

- Different theoretical approaches are followed ..

- conclusive **experimental data are necessary to set** more **stringent constraints**.

Scientific case

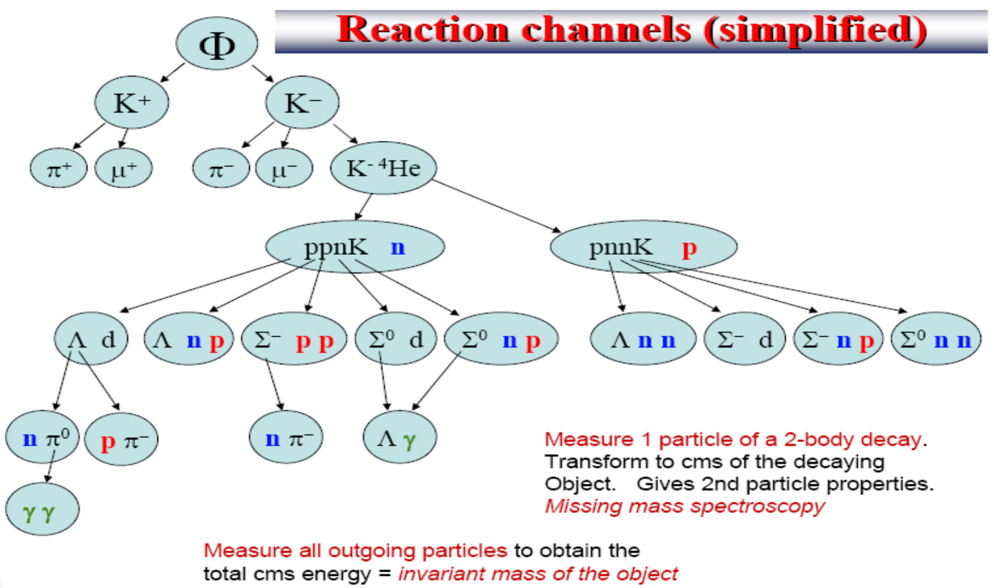
Deeply bound Kaonic nuclear states requires the presence of a strong attractive $\bar{K}N$ interaction in the isospin I=0 channel (Λπ channel closed for isospin selection, Σπ channel energetically closed)

The pillars of the existence of narrow $\bar{K}$ - nuclear states are:

- The low energy $\bar{K}N$ scattering data
- The kaonic hydrogen shift and with of the ground state
- The binding energy and decay with of Λ(1405) regarded as an isospin

  I = 0 bound state of $\bar{K}$ + N

Example of the possible formation of tribaryonic kaonic nuclear states by stopping K^- in ^4He →



<u>Scientific case</u> and state of the experimental search

- DBKNS were firstly suggested by **Wycech**.

- **Y. Akaishi and T. Yamazaki** '*nuclear bound states in light nuclei*' with binding energies (up to 120 MeV), and narrow with (about 20 MeV) (for K^-ppn systems).

(S. Wycech, Nucl. Phys. A450 (1986) 399c) *(Phys. Rev. C65 (2002) 044005)*

- **Possible experimental indications** of the formation of kaonic nuclear states have received **alternative explanations** in the framework of known processes

- Calculations of K^-pp systems suggests relatively moderate bindings and larger widths

N. V. Sevchenko, A. Gal, J. Mares, J. Revai, Phys. Rev. C 76, 044004 (2007)
A. Dote, T. Hyodo, W. Weise, Nucl. Phys. A 804, 197 (2008)

Performed experiments: E471, E549, E570 @ KEK, FINUDA @ DAΦNE, FOPI @ GSI, OBELIX

future experiments: FOPI @ GSI, E15 @ J-PARC, FAIR @ GSI … and AMADEUS

Scientific case

$\Lambda(1405)$ is a negative parity baryon resonance (spin = 1/2, isospin = 0, strangeness = -1) located slightly below the $\bar{K}N$ threshold, decaying into the $\Sigma\pi$ channel trough the strong interaction.

The quark model picture has some difficulties to reproduce the $\Lambda(1405)$. According to its negative parity, one of the quarks has to be exited to the $l = 1$ orbit. Similar to the nucleon sector, where one of the lowest negative parity baryon is the N(1535), the expected mass of the Λ^* is around 1700 MeV (since it contains one strange quark). Another difficulty is the energy splitting observed between the $\Lambda(1405)$ and the $\Lambda(1520)$, if is interpreted as the spin-orbit partner ($J^p = 3/2^-$).

The $\Lambda(1405)$ can be described as an $\bar{K}N$ quasibound state embedded in the $\Sigma\pi$ continuum.

R.H. Dalitz, T.C. Wong and G. Rajasekaran, Phys. Rev. **153** (1967) 1617.

In the context of chiral theories two poles emerge in the neighborhood of the $\Lambda(1405)$ 1) one pole ~1390 MeV/c^2 is strongly coupled to the $\Sigma\pi$ channel, 2) a second pole ~1420-1430 MeV/c^2 mostly couples to the $\bar{K}N$ channel.

Great importance to study the $\Lambda(1405)$ produced in $K^- p$ trough the $\Sigma^0\pi^0$ decay channel.

Kaon induced Lambda(1405) production on a deuteron target at DAFNE (D. Jido, E. Oset, T. Sekihara) arXiv:1008.4423v2 [nucl-th]

Experimental program

- AMADEUS aims to confirm or deny the existence of such exotic states performing a **full acceptance, high precision measurement of DBKNS both in formation and in the decay process**, implementing the KLOE detector with an inner AMADEUS dedicated setup:
  Study of the (most) fundamental antikaon deeply bound nuclear systems, the **kaonic dibaryon states: ppK^- and (pnK^-)** produced in a ^3He gas target, in formation and decay processes. As a next step **kaonic 3-baryon states: $ppnK^-$ and $pnnK^-$** produced in a ^4He gas target.

- The important state **Λ(1405)** and its behaviour in the nuclear medium could be better understood with high statistics.

- **Measurement of the low-energy charged kaon cross sections** on H, d, Helium(3 and 4), for K^- momentum lower than 100 MeV/c (missing today).

- Study of the **K^- nuclear interactions in Helium** (poorly known, based on one paper from 1970 …)

Setup performance requirements

Formation processes

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

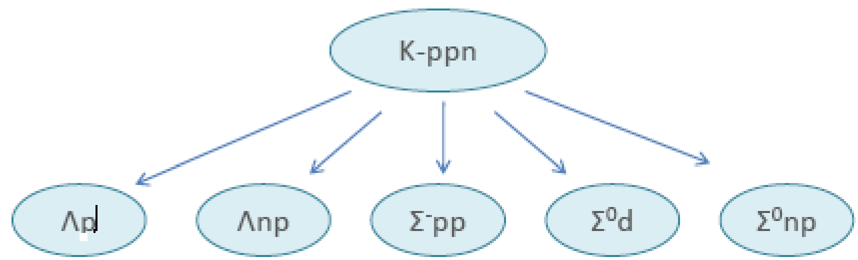
$K^-_{stopped} + {}^4He \rightarrow n + (K^-ppn)$

Study of the exotic states by the energy/momentum distribution of the ejected protons and neutrons. The setup should be able to measure:

- position of K^- stop: primary vertex and K^+ tracking (trigger)
- outgoing neutrons and protons

Setup performance requirements

Decay processes



Invariant mass spectroscopy

this requires:

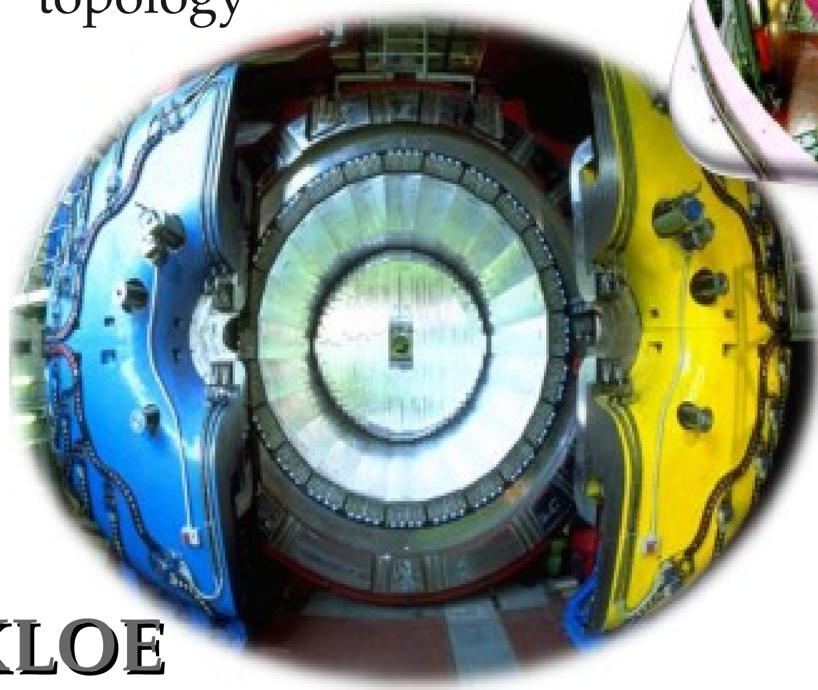
- identification of all decay products, including protons neutrons and pions from hyperons decay
- measurement of 4-momenta of charged and neutral particles
  - protons 200 – 800 Mev/c ; pions 50 – 200 Mev/c ; neutrons 200 – 800 Mev/c ; deuterons ...

requirements satisfied by..

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

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

DAΦNE



KLOE

- 96% acceptance,
- optimized in the energy range of all charged particles involved
- good performance in detecting neutrons checked by kloNe group

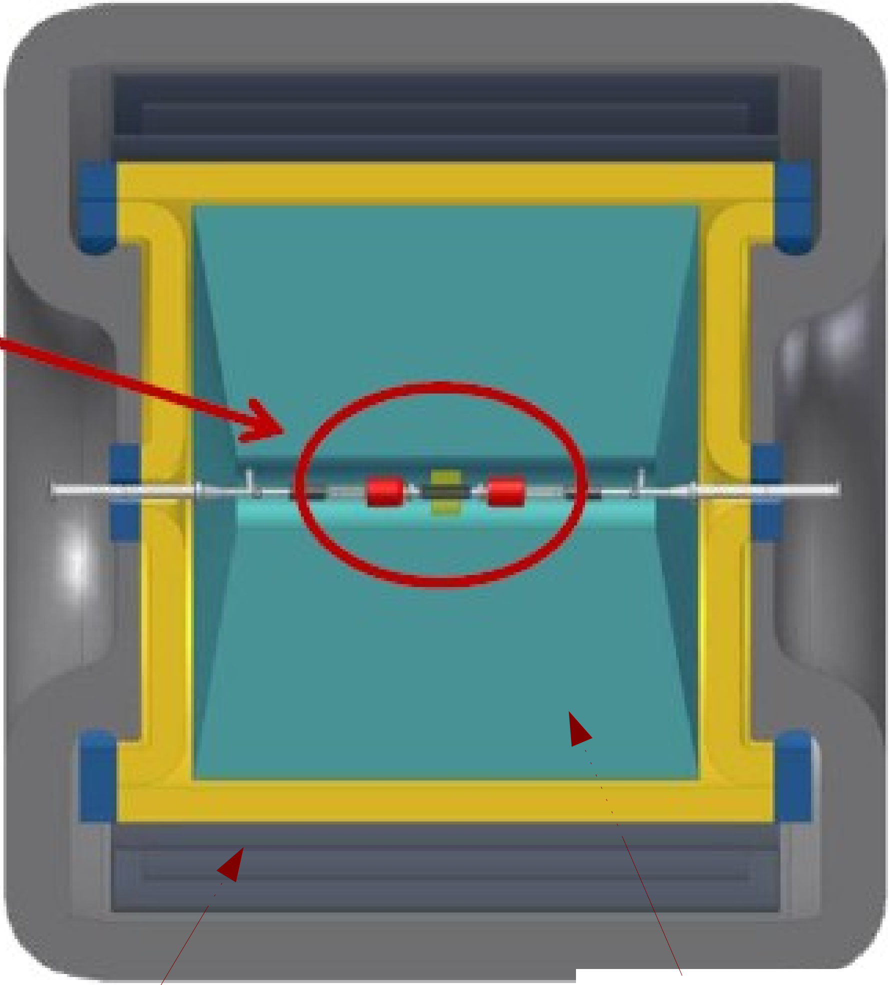
M. Anelli et al., Nucl. Instr. Meth. A 581, 368 (2007)

The experimental setup of AMADEUS

•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)

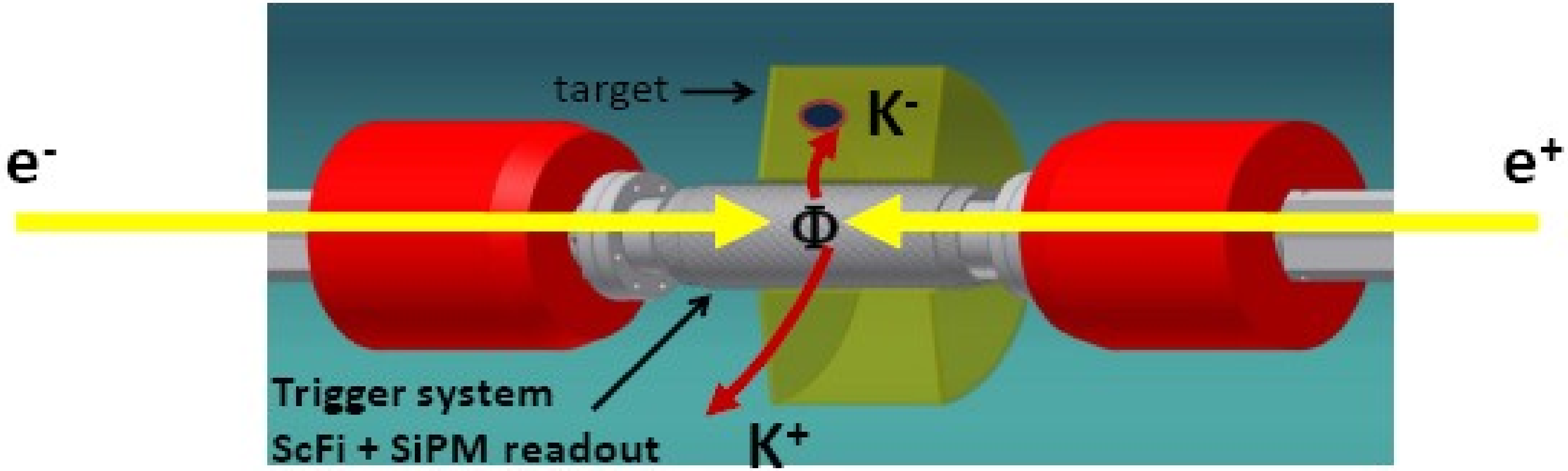


experimental setup: trigger system

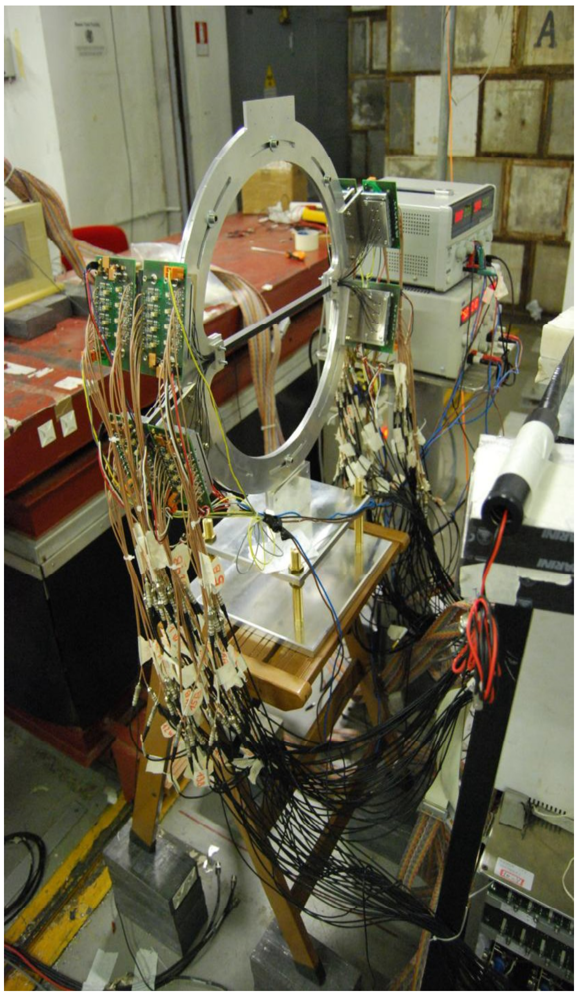
- **Cilindrical layer of scintillating fibers** surrounding the beam pipe to **trigger K^+ K^- in opposite directions**
- Single or double layer

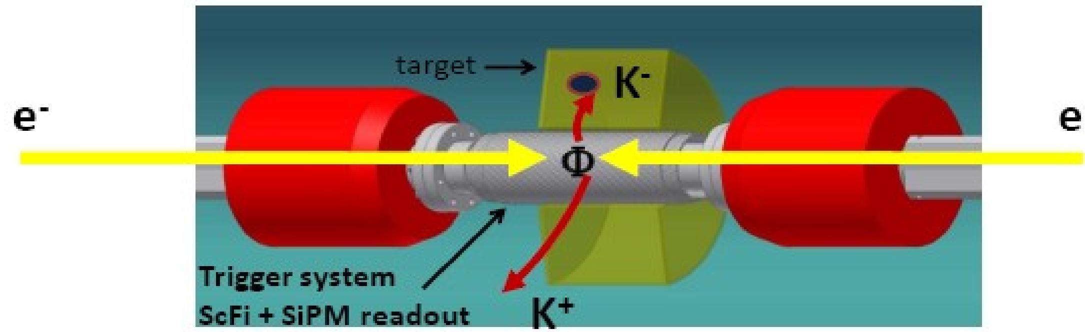
In this case possibility of perform tracking as well: X-Y measurement with high granularity layers

- **Readout** to be done by **SiPM (silicon photo-multipliers)**



experimental setup: trigger system



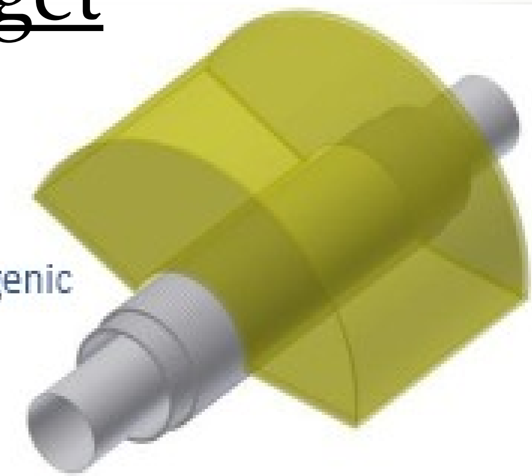


R&D activity is going on

prototipe of the trigger system
layers of BCF-10 fibers double cladded
free to rotate
read at both sides by Hamamatsu S10362-11-050-U SiPM

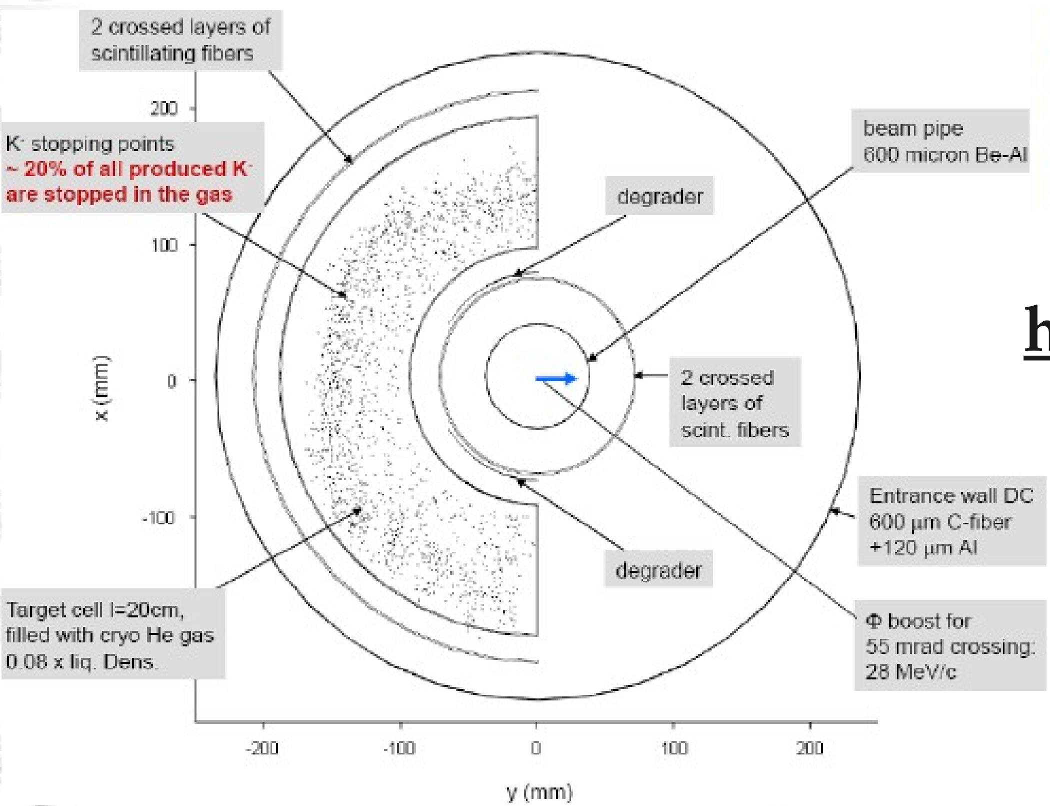
time resolution obtained (σ) for kaons 300ps
(Nuclear Inst. and Methods in Physics Research, A (2012), pp. 125-128).

experimental setup: target



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

AMADEUS Monte Carlo



half-toroidal cryogenic target cell

inside a vacuum chamber,
and
two more layers of fibers

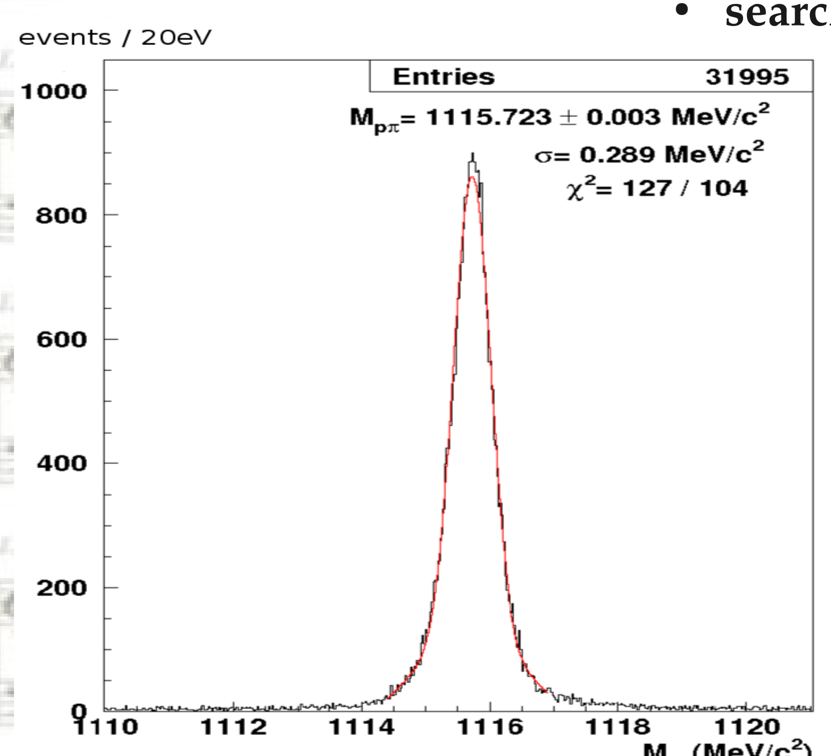
KLOE data analysis PRELIMINARY

… BUT much can be already done by analyzing the 2002-2005 collected KLOE data INDEED …

The **drift chamber** of KLOE **contains mainly ^{4}He**   (90% helium, 10% isobutane).

We can then study the interaction of K^- with ^{4}He filling the chamber (or with C from the drift chamber entrance wall carbon fiber). Present studies:

- **Λ(1116) + p** and **Λ(1116) + d** events
- **search for Λ(1405) → $\Sigma^0\pi^0$**



•The **reconstruction capability for Λ's and Σ's** was **already tested**

Hadronic interactions with a Λ(1116) are searched. The charged decay vertex $\Lambda \rightarrow p\pi^-$ (BR = 64%) is reconstructed.

The obtained invariant mass $m_{p\pi-}$ is shown left.

Study of K^- p interactions in the gas filling the DC of KLOE through the neutral channel $\Sigma^0\pi^0$

We are presently performing a study of **K^-** interaction with **protons** in the gas filling the Drift Chamber (DC) of the KLOE detector (90% ^{4}He , 10% isobutane) through the neutral channel **$\Sigma^0\pi^0$**

important still **poorly explored**:

- Crystall Ball collaboration in the $K^-p \rightarrow \Sigma^0\pi^0\pi^0$ reaction for kaon momentum in the range (514-750 MeV/c).

  [30] S. Prakhov, et al., Phys. Rev. C70 (2004) 034605.

- The p-p collision experiment COSY julich in the reaction pp $\rightarrow$ $pK^+ \Sigma^0\pi^0$. **(I. Zychor et al., Phys. Lett. B 660 (2008) 167).**

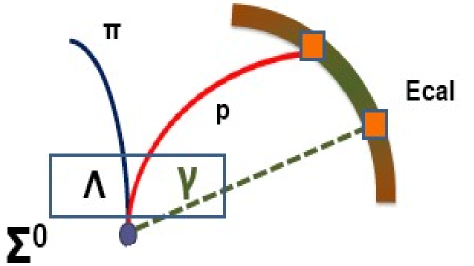
- Properties of the L(1405) Measured at CLAS **(K. Moriya et al. arXiv:1110.0469[nucl-ex]).**

We search for the reaction

$$K^- \; p \rightarrow \Sigma^0\pi^0 \rightarrow (\Lambda\gamma_3)\,(\gamma_1\gamma_2) \rightarrow (p\pi^-)\,\gamma_1\gamma_2\gamma_3$$

Steps of particles identification

1) As first we identify the $\Lambda(1116)$ reconstructing the charged decay vertex ($p\ \pi^-$) in the KLOE DC



2) only events occurring in the gas filling the chamber are selected by cutting on the Λ decay vertex position ($\mathbf{r}_\Lambda > 30$ cm) taking into account for the maximum path of the Λ and the error on the vertex position.

3) Three neutral clusters in the calorimeter (clusters with no associated tracks) in time from the point $\mathbf{r}_\Lambda$ are searched (photons from $K^+ \rightarrow \pi^+\pi^0$ decay are excluded) and identified as $\gamma_1\ \gamma_2\ \gamma_3$.

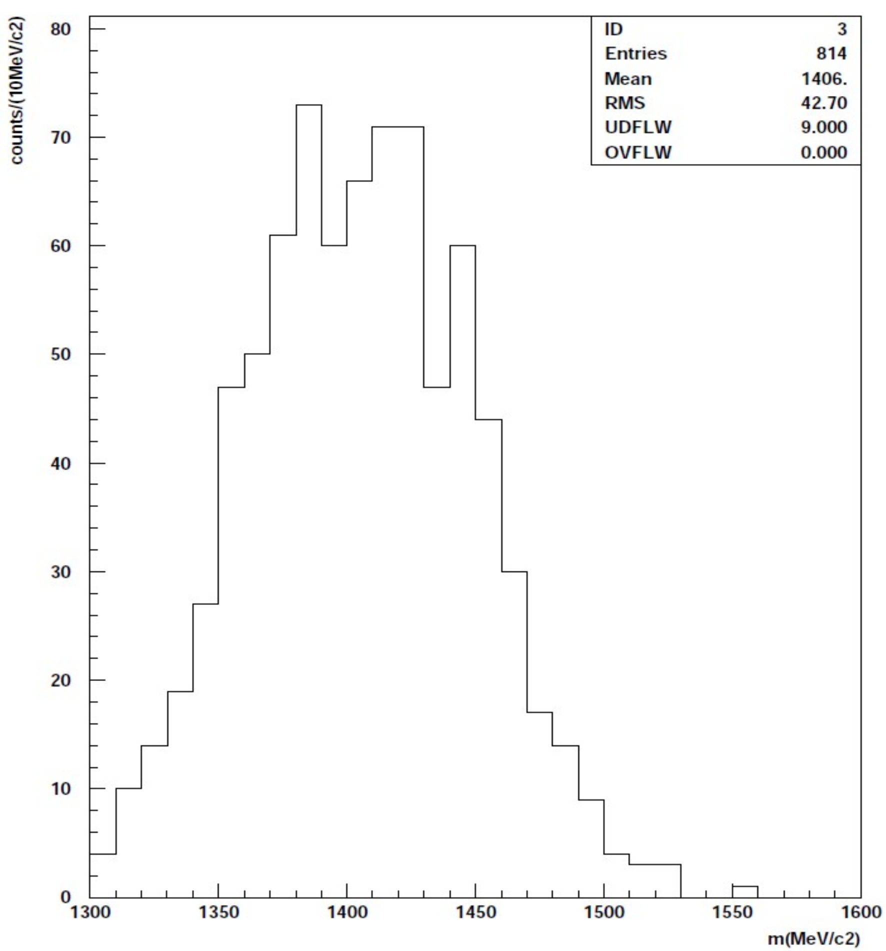
4) the couple of photons $\gamma_1\ \gamma_2$ coming from π^0 decay is identified by means of dedicated chi-squares optimized on MC simulations (and distinguished from γ_3 coming from $\Sigma^0 \rightarrow \Lambda\gamma_3$ decay).

The algorithm has (from true MC information) an efficiency > 80% to peack out the right triple of neutral clusters.

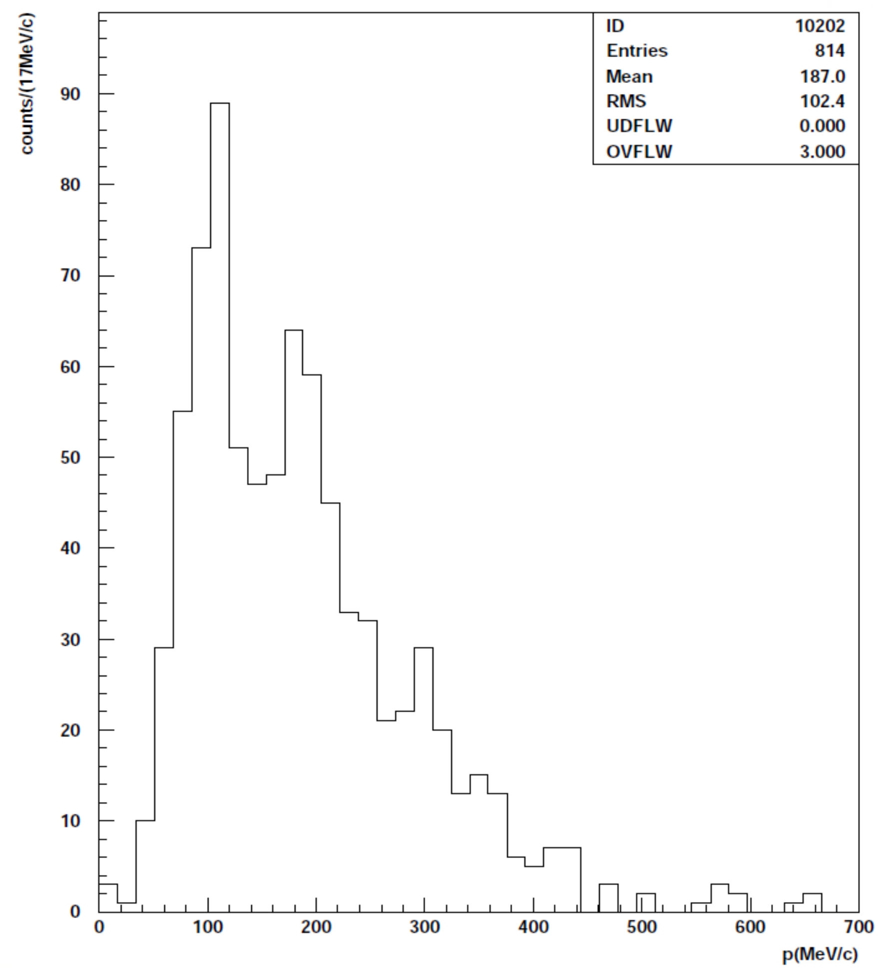
$m_{\pi0\Sigma0}$ and $p_{\pi0\Sigma0}$ distributions

Invariant mass $\mathbf{m}_{\pi0\Sigma0}$ **resolution**: ≈ 30 MeV/c², momentum $\mathbf{p}_{\pi0\Sigma0}$ **resolution**: ≈ 17 MeV/c

In $\mathbf{p}_{\pi0\Sigma0}$ a **lower momentum (LM) narrow** component and a **higher momentum (HM) broader** component emerge (corresponding to values of $p_{\pi0\Sigma0}$ around 100 MeV/c and 200 MeV/c).



Invariant mass: $m_{\pi0\Sigma0}$ (MeV/c²)



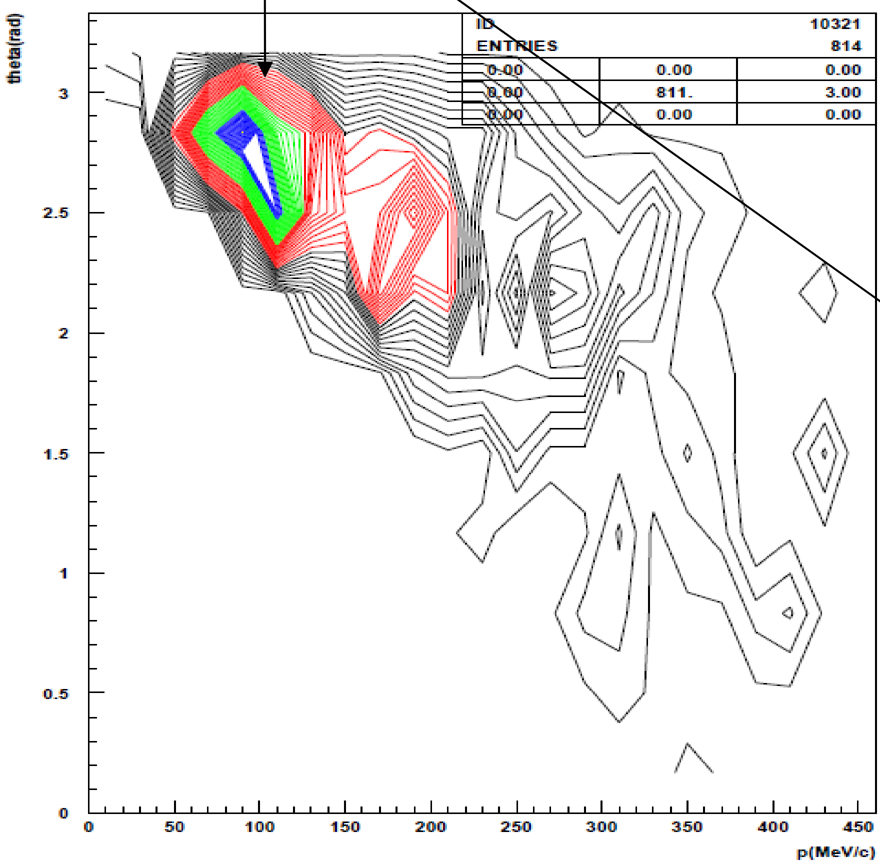
momentum: $p_{\pi0\Sigma0}$ (MeV/c)

$\theta_{\pi0\Sigma0}$ vs $p_{\pi0\Sigma0}$ and $m_{\pi0\Sigma0}$ vs $p_{\pi0\Sigma0}$ correlation

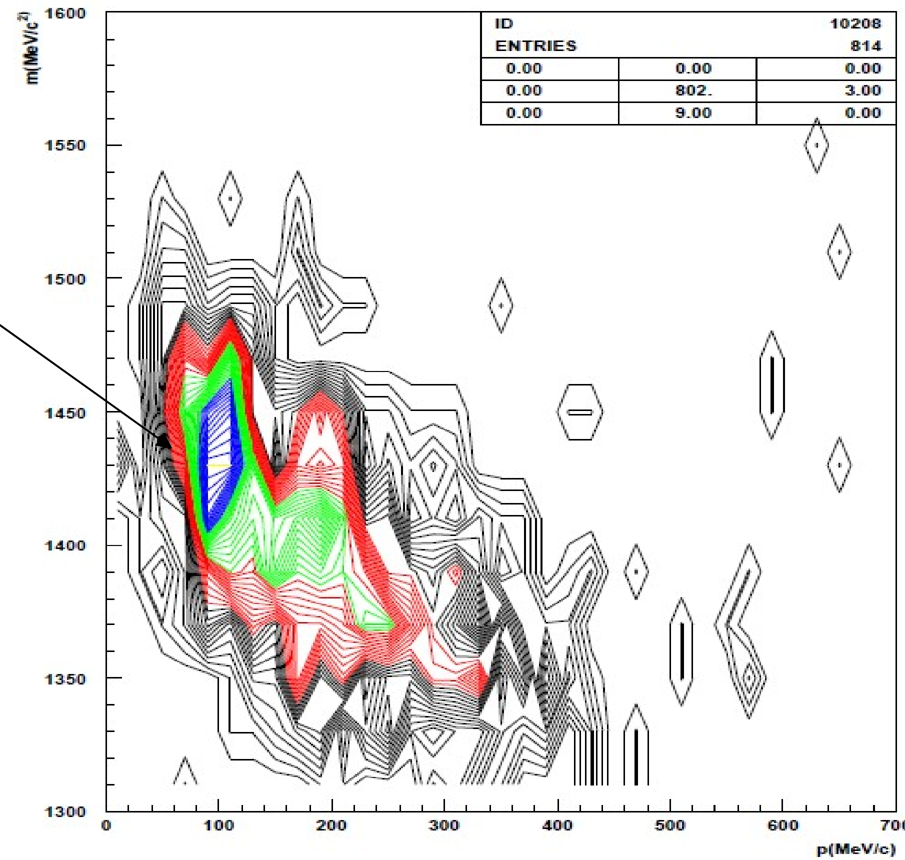
Correlations of (left) the angle $\theta_{\pi0\Sigma0}$ (angle between $\pi^0 - \Sigma^0$ in the lab. frame) and (right) of $m_{\pi0\Sigma0}$ with the momentum $p_{\pi0\Sigma0}$ (density grows from black to blue).

The LM component is correlated to higher $m_{\pi0\Sigma0}$ and greater $\theta_{\pi0\Sigma0}$ values.

The HM component is correlated to smaller $m_{\pi0\Sigma0}$ and $\theta_{\pi0\Sigma0}$ values.



$\theta_{\pi0\Sigma0}$ vs $p_{\pi0\Sigma0}$ (data)

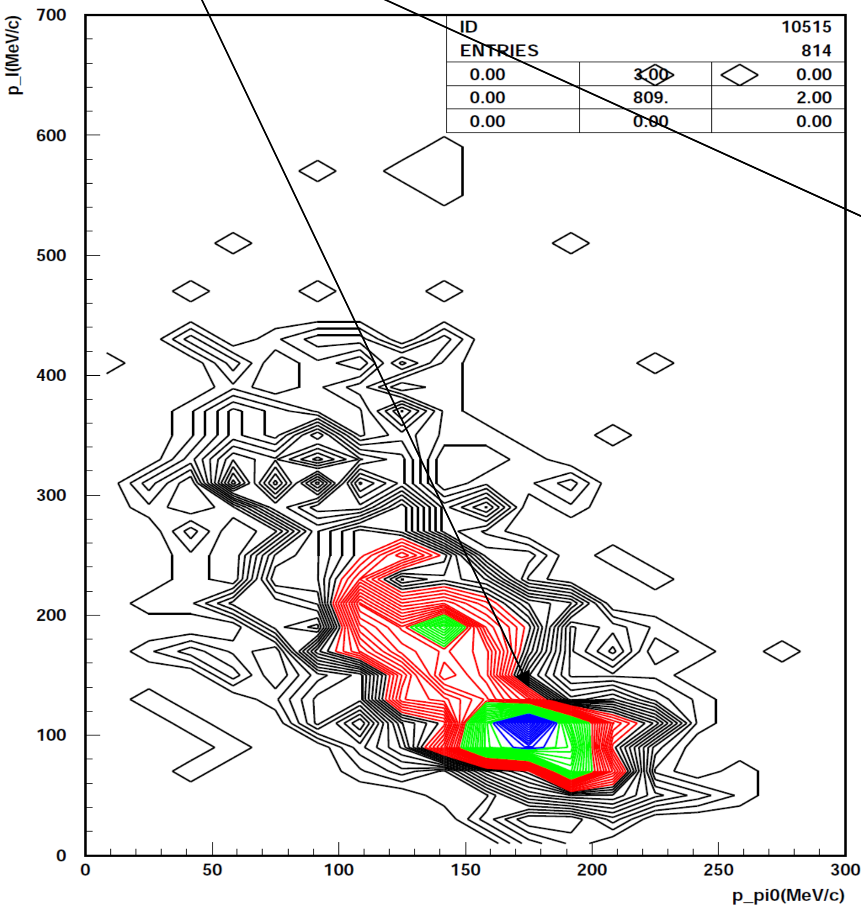


$m_{\pi0\Sigma0}$ vs $p_{\pi0\Sigma0}$ (data)

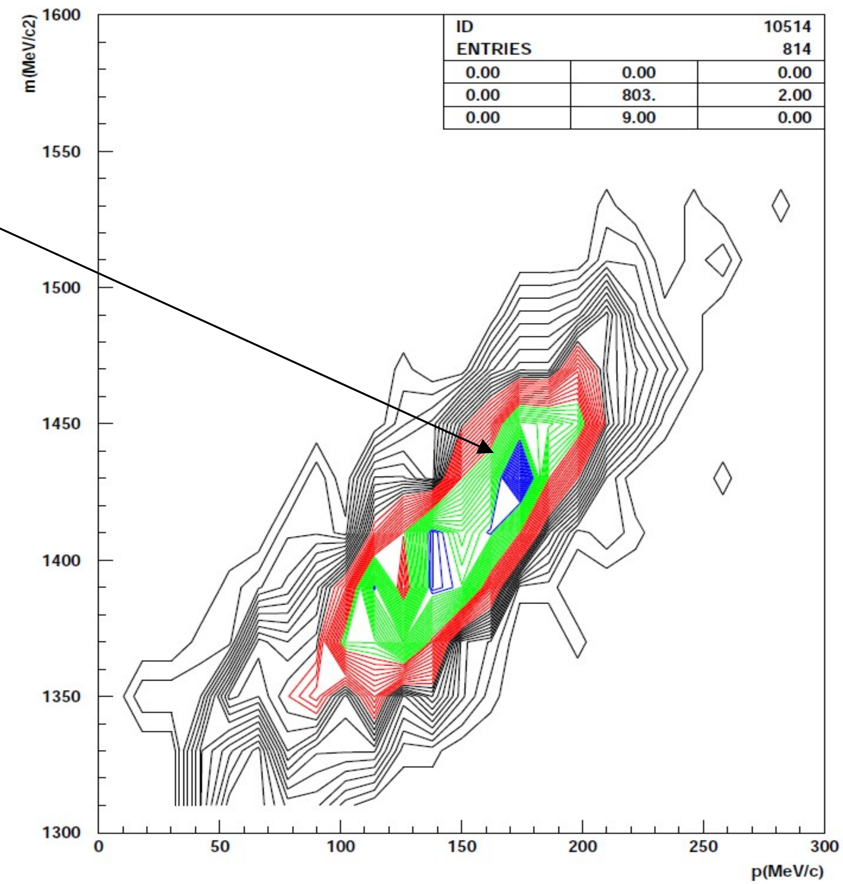
$p_{\pi0\Sigma0}$ vs $p_{\pi0}$ and $m_{\pi0\Sigma0}$ vs $p_{\pi0}$ correlation

Similar correlations between (left) $\mathbf{p_{\pi0\Sigma0}}$ ((right) $\mathbf{m_{\pi0\Sigma0}}$) **and** $\mathbf{p_{\pi0}}$ (density grows from black to blue)

The LM $p_{\pi0\Sigma0}$ (around 100 MeV/c) component is associated to π^0s with momentum around 170-180 MeV/c (an object with mass around 1425-1430 MeV/c² decays back-to-back in Σ^0–π^0 with $p_{\pi0}$ ~ 170-180 MeV/c).



$p_{\pi0\Sigma0}$ (MeV/c) vs $p_{\pi0}$ (MeV/c)



$m_{\pi0\Sigma0}$ (MeV/c²) vs $p_{\pi0}$ (MeV/c)

Study of the background

Dedicated MC simulations were created to study the following background sources:

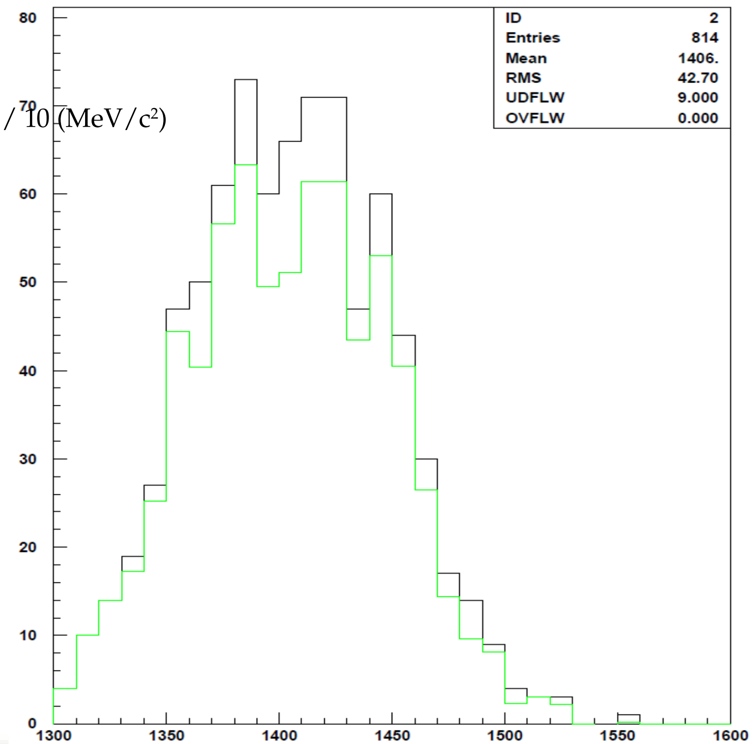
- contamination of $\Sigma(1385)$, such state can not decay in $\Sigma^0 \pi^0$ for isospin selection, but can decay in $\Lambda\pi^0$,
- internal conversion $\Sigma^0 N \rightarrow \Lambda N$ which could compete with the process $\Sigma^0 \rightarrow \Lambda \gamma$.

Σ(1385) + INTERNAL CONVERSION events were estimated to be **less than 5%** of the total observed events.

- A dedicated MC was made to simulate the background due to a misidentification of the correct neutral clusters triple (less than 20% from true MC information). The simulated $p_{\pi 0 \Sigma 0}$ and $m_{\pi 0 \Sigma 0}$ distributions follow those obtained in data.

- New MC simulations are presently under study in order to understand the non resonant $\Sigma^0\pi^0$ contribution and shape.

counts / 10 (MeV/c²)



Invariant mass: $m_{\pi 0\, \Sigma 0}$ (MeV/c²) observed distribution (black) subtracted spectrum (green)

Concluding remarks

- The AMADEUS collaboration aims to perform a **complete search for DBKNS** and to study the **low energy interaction of K^- with light nuclei**, by implementing a dedicated AMADEUS setup in KLOE.

- A **unic opportunity** is offered by the special features of the **DAΦNE** collider and the **KLOE** detector implemented with a specific **AMADEUS setup** !

- **R&D** activity is **presently going on** for the trigger and target system.

- The **KLOE reconstruction capability** for the AMADEUS channels was already tested by anlyzing 2002-2005 KLOE data,

preliminary results of the analysis already promise exciting prospectives.