Kaon-nuclei interaction studies at low energies:
the AMADEUS experiment

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BEACH 2010
The IX International Conference on Hyperons Charm and Beauty Hadrons
Perugia, June, 2010

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

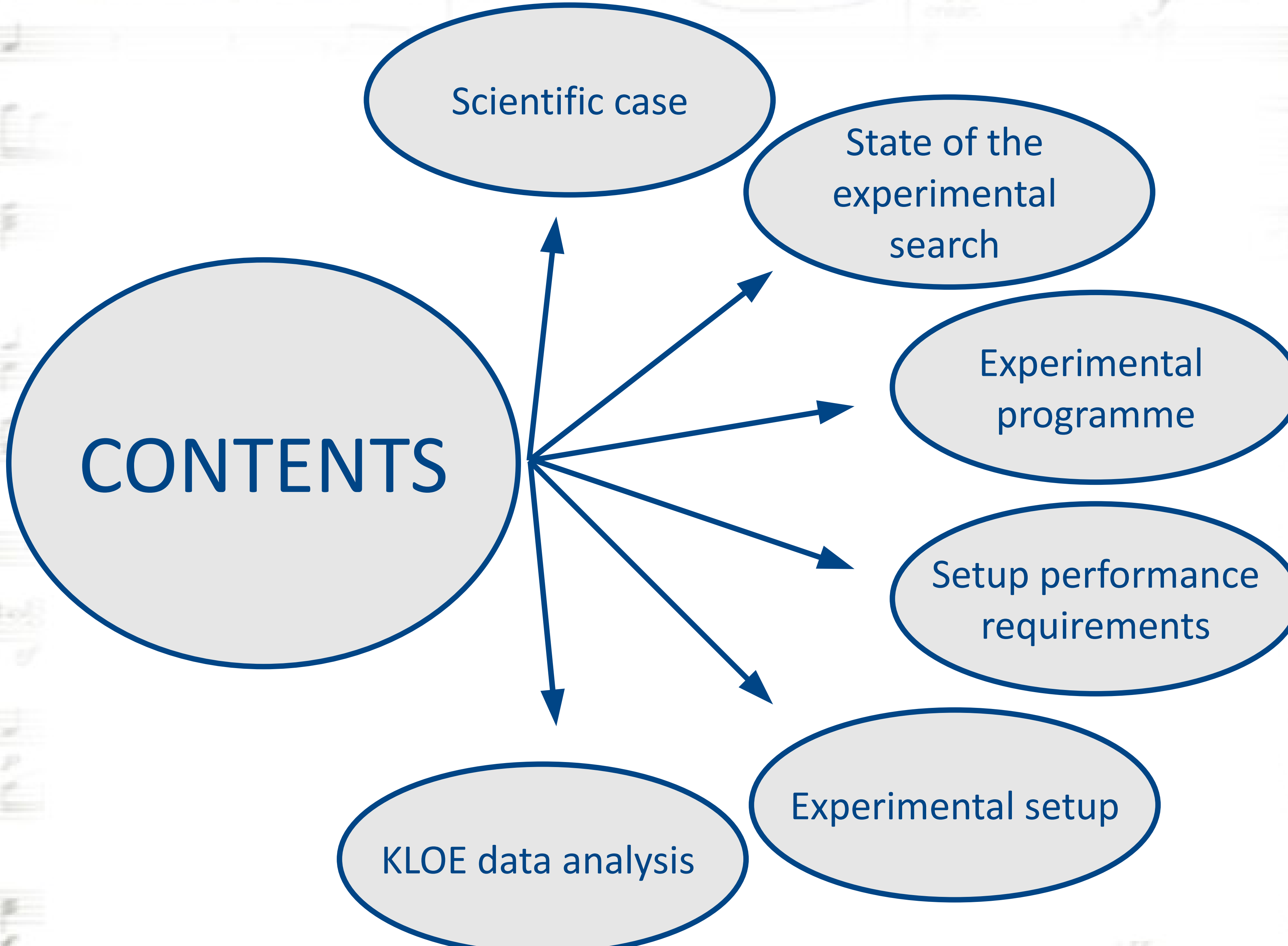
AMADEUS collaboration
116 scientists from 14 Countries and 34 Institutes

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

HadronPhysics2
Study of Strongly Interacting Matter

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

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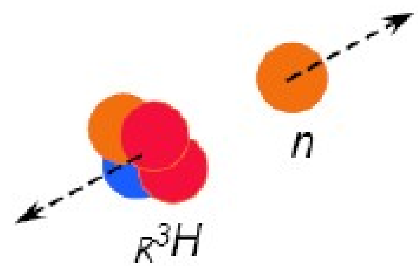
KLOE data analysis

AMADEUS scientific case

An important hadron physycs unresolved problem:

- how hadron masses and interactions change in nuclear medium

Approach by means of the predicted **kaonic nuclear clusters**



- from which to deduce the **hadron-nucleus potential** and the

in-medium hadron mass

AMADEUS scientific case

Deeply bound Kaonic nuclear states:

- In presence of strong KN attractive potential were firstly suggested by Wycech

  (S. Wycech, Nucl. Phys. A450 (1986) 399c)

- Y. Akaishi and T. Yamazaki 'nuclear bound states in light nuclei'

  (Phys. Rev. C65 (2002) 044005)

K^- cluster	M (MeV/c^2)	$-E_B$ (MeV)	Γ_B (MeV)	$\rho(0)$ (fm^{-3})	R_{rms} (fm)
pK^-	1407	27	40	0.59	0.45
ppK^-	2322	48	61	0.52	0.99
$pppK^-$	3211	97	13	1.56	0.81
$ppnK^-$	3192	118	21	1.50	0.72
ppK^-K^-	2747	117	35	–	–
$ppnK^-K^-$	3582	221	37	2.97	0.69

State of the experimental search and theoretical debate for DBKS

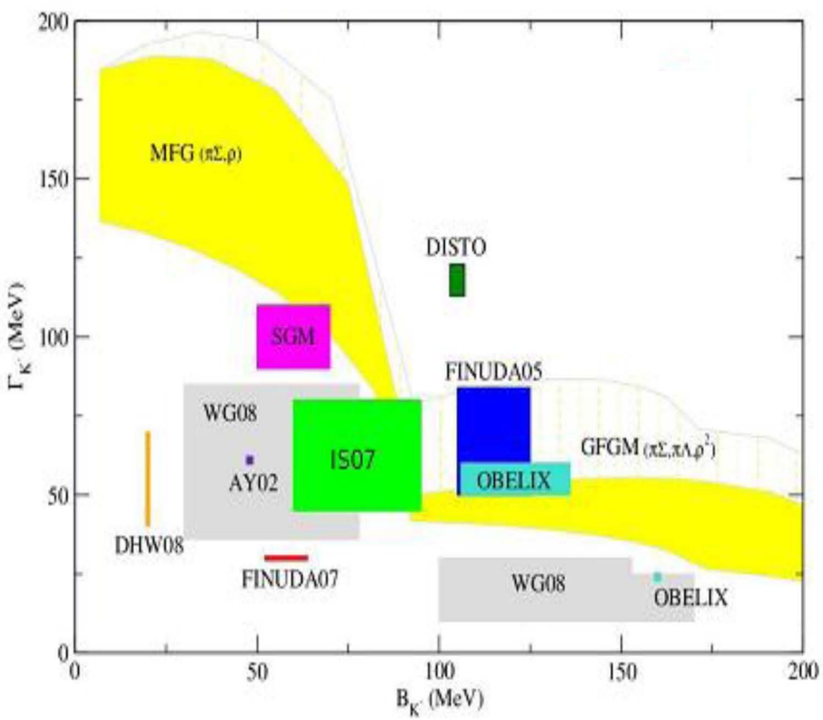
- E471, E549, E570 @ KEK
- FINUDA @ DAΦNE
- FOPI @ GSI
- OBELIX

future experiments

- FOPI @ GSI
- E15 @ J-PARC
- FAIR @ GSI

... and AMADEUS

International workshop on Hadronic Atoms and Kaonic Nuclei, ECT* Trento,
26-Oct-09
present experimental/theorical sitauation (J. Mares)



State of the experimental search and theoretical debate for DBKS

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

•Recent calculations of k^-pp systems suggests relatively moderate bindings and large 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)

↓

new complete experimental results are needed

Experimental programme

- The scientific case of the so-called "deeply bound kaonic nuclear states" is hotter than ever, both in the theoretical (intensive debate) and experimental sectors.

- What emerges is the strong need for a complete experimental study of the scientific case, i.e. a clear and clean experiment (so without the need to make hypothesis on involved physics processes), measuring kaonic clusters both in formation and in the decay processes.

- AMADEUS's main aim is to perform a full acceptance, high precision measurement of DBKNS both in formation and in the decay processes, by implementing the KLOE detector with an inner AMADEUS-dedicated setup, containing a cryogenic target and a trigger system (and an inner tracker in a second phase).

Experimental programme

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Either situations: **existence** or **not exsistence** of DBKNS will have strong impact in kaon-nucleon/nuclei physics!

Experimental programme

study of the (most) fundamental antikaon deeply bound nuclear systems,

the **kaonic dibaryon states: ppK^- and (pnK^-)**

produced in a ^{3}He gas target, in formation and decay processes

as next step, the **kaonic 3-baryon states: $ppnK^-$ and $pnnK^-$**

produced in a ^{4}He gas target, in formation and decay processes

Experimental programme

- Low-energy charged kaon cross sections and interactions on H, d, Helium(3 and 4), for K^- momentum lower than 100 MeV/c (missing today);

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

- Resonance states as the elusive in-nature but so important Λ(1405) or the Σ(1385) could be better understood with high statistics; their behaviour in the nuclear medium can be studied too.

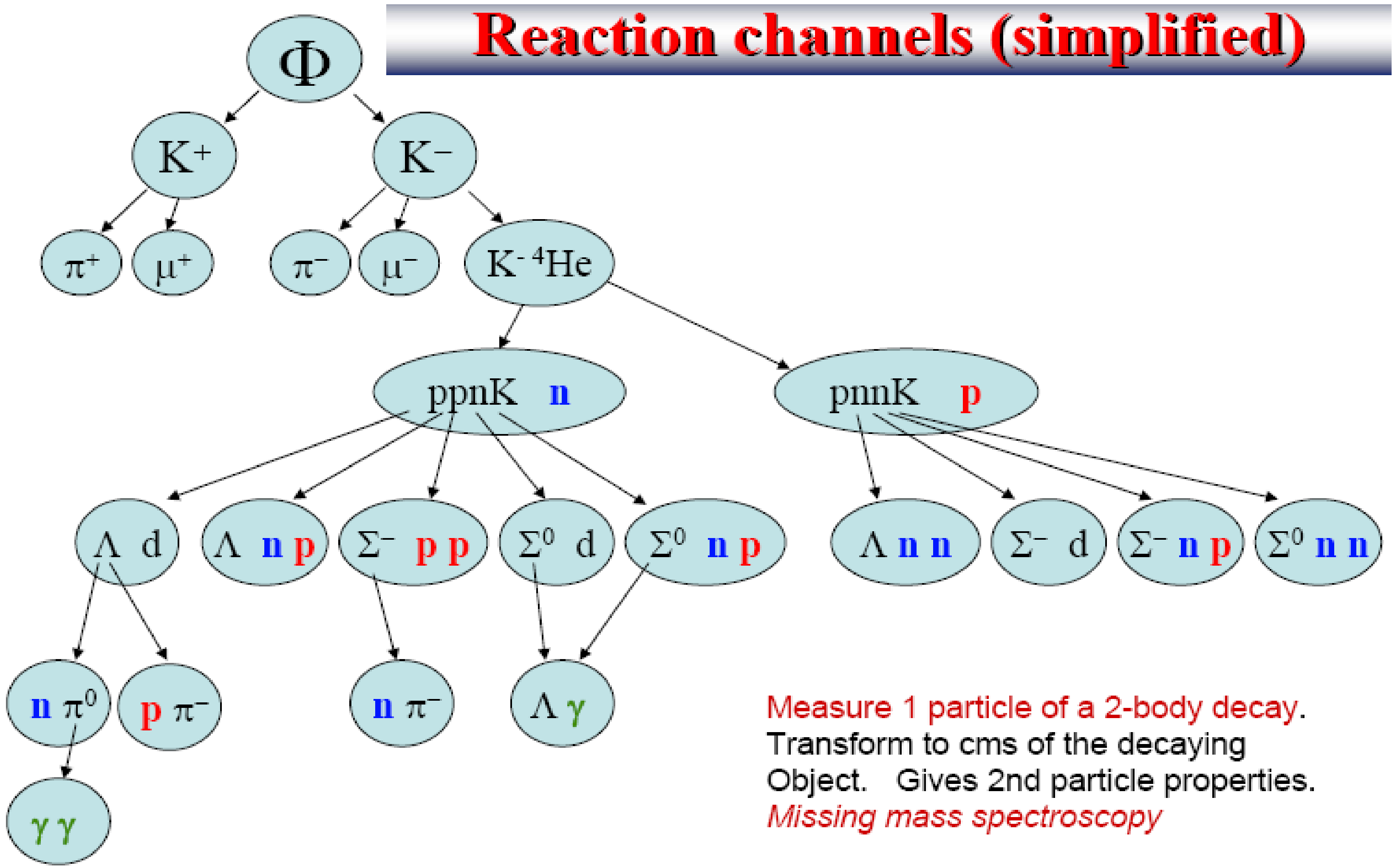
The search for antikaon-mediated deeply bound nuclear states with AMADEUS

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.

This requires the detection of:

- charged and neutral particles
- up to about 800 Mev/c
- in a 4π geometry
- with high efficiency and resolution

The search for antikaon-mediated deeply bound nuclear states with AMADEUS



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*

Setup performance requirements

Formation processes

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

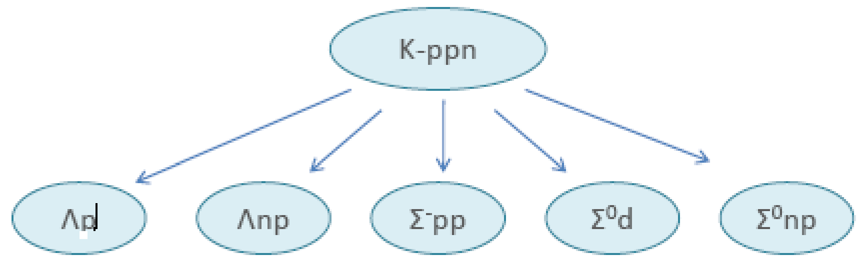
$$\boxed{K^-_{stopped} + {}^4He \rightarrow n + (K^-ppn)}$$

Study of the exotic states by the energy 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:

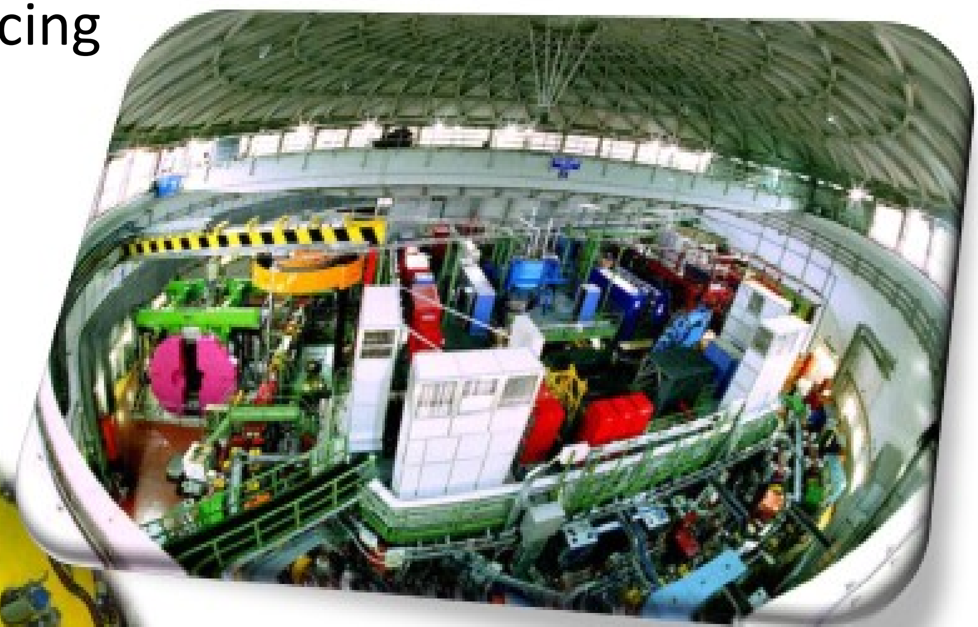
- identification of all decay products, including protons neutrons and pions from hyperons decay
- measurement of 4-momenta of charged and neutral particles
  - protons 200 – 800 Mev/c ; pions 50 – 200 Mev/c ; neutrons 200 – 800 Mev/c ; deuterons ...

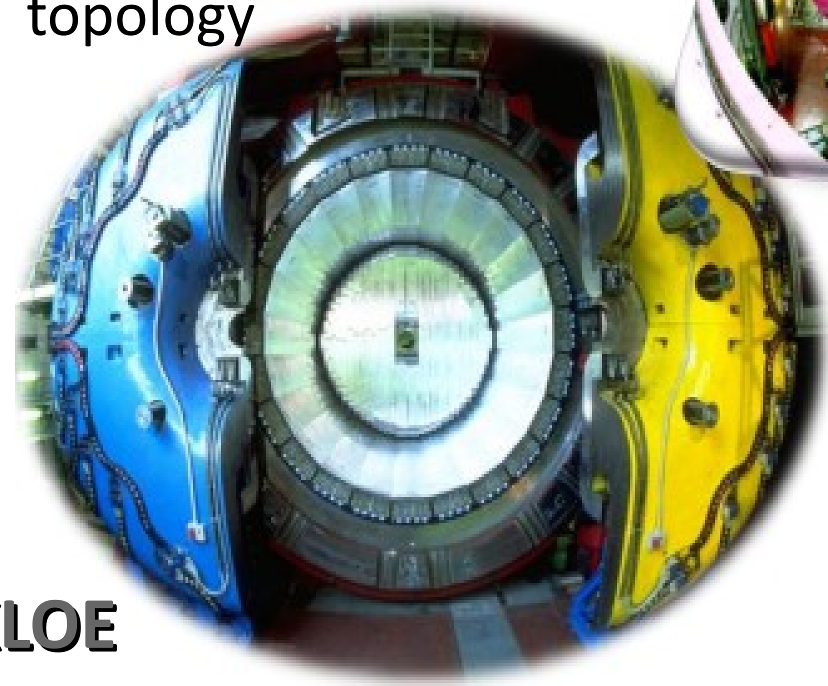
requirements satisfied by..

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

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

DAΦNE upgrade





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)

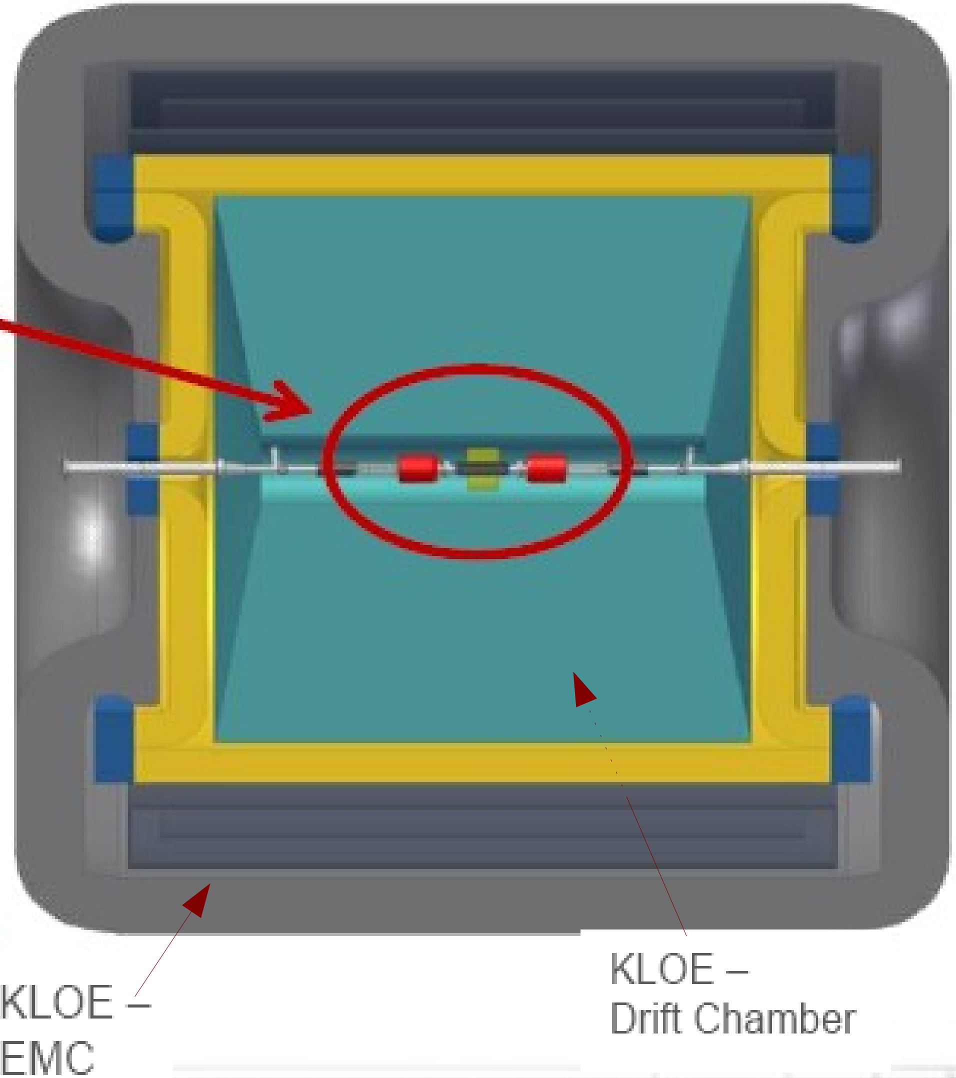
The experimental setup of AMADEUS

•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)

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

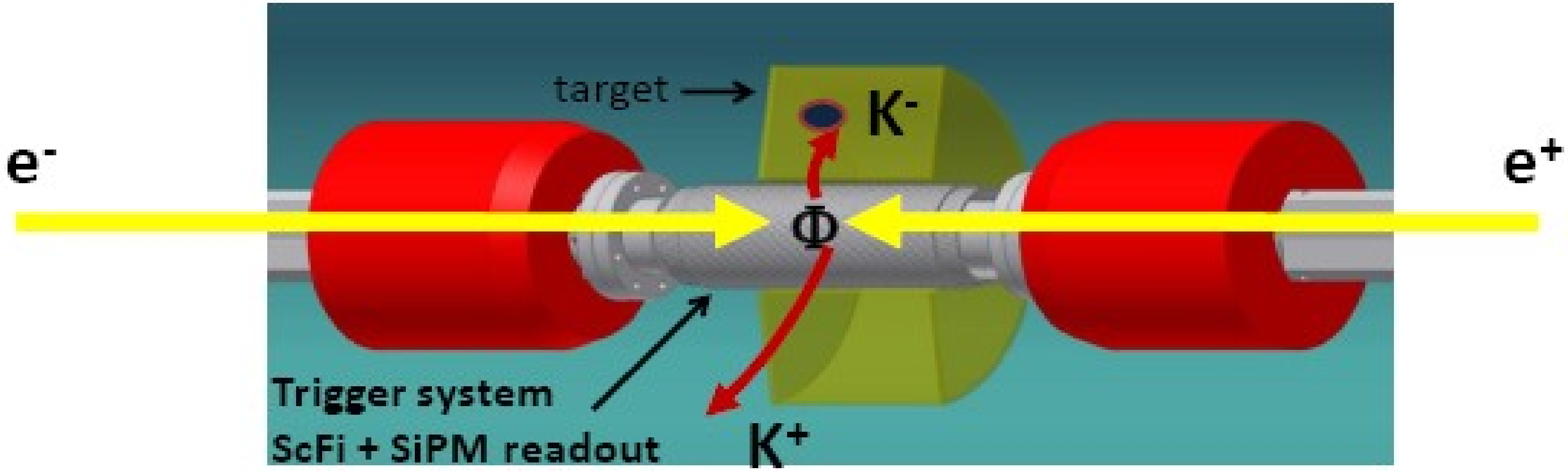


experimental setup: trigger system

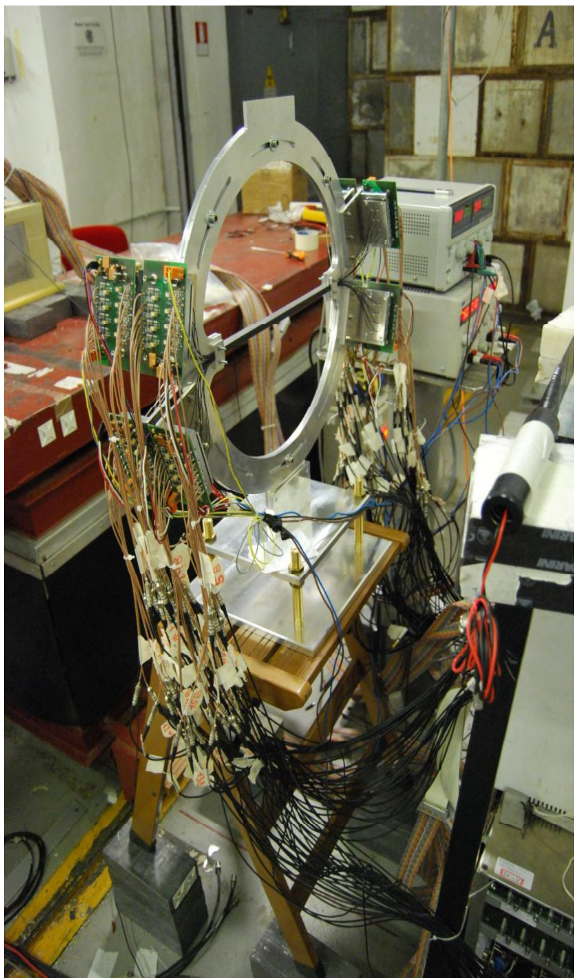
- **Cilindrical layer of scintillating fibers** surrounding the beam pipe to **trigger K^+ K^- in opposite directions**
- Single or double layer

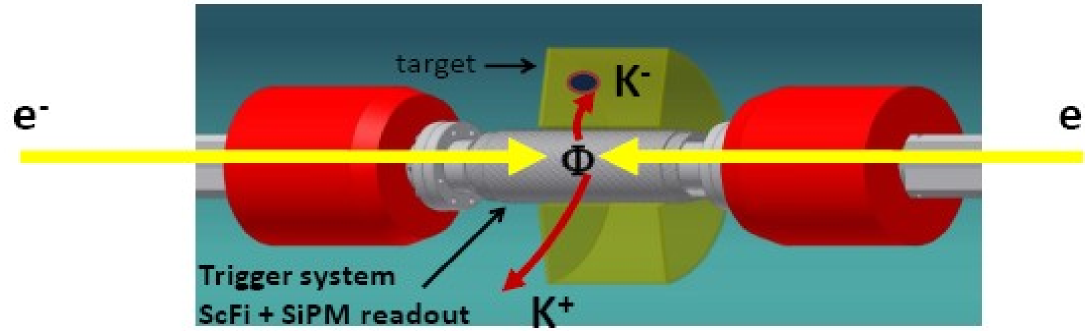
In this case possibility of perform tracking as well: X-Y measurement with high granularity layers

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



experimental setup: trigger system





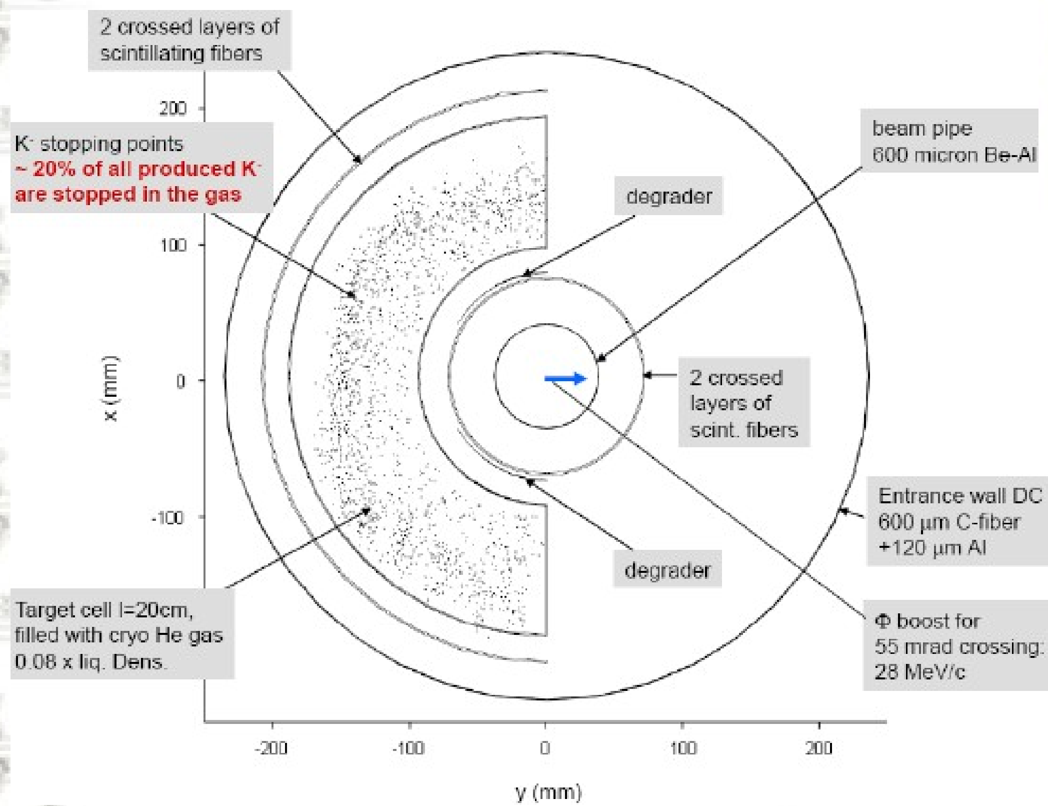
prototipe of the trigger system

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

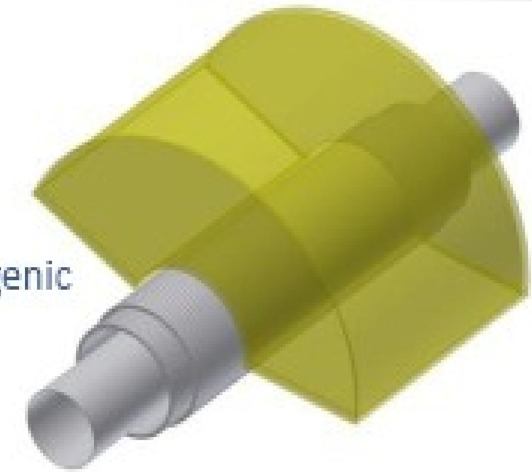
is now under test

experimental setup: target

AMADEUS Monte Carlo



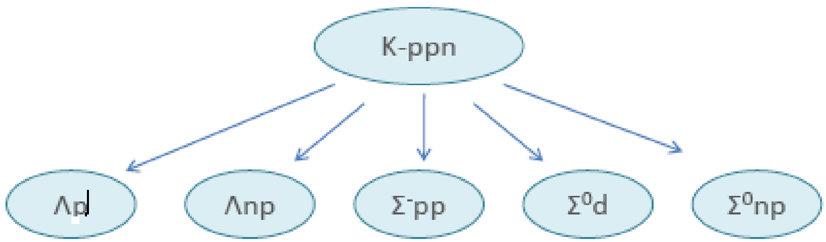
Low-mass cryogenic gas target cell:
T = 10 K
P = 1.0 bar
Rin = 5 cm
Rout = 15 cm
L = 20 cm



half-toroidal cryogenic target cell
inside a vacuum chamber,
and
two more layers of fibers

Analysis of K$^-$ He interactions in the KLOE drift chamber

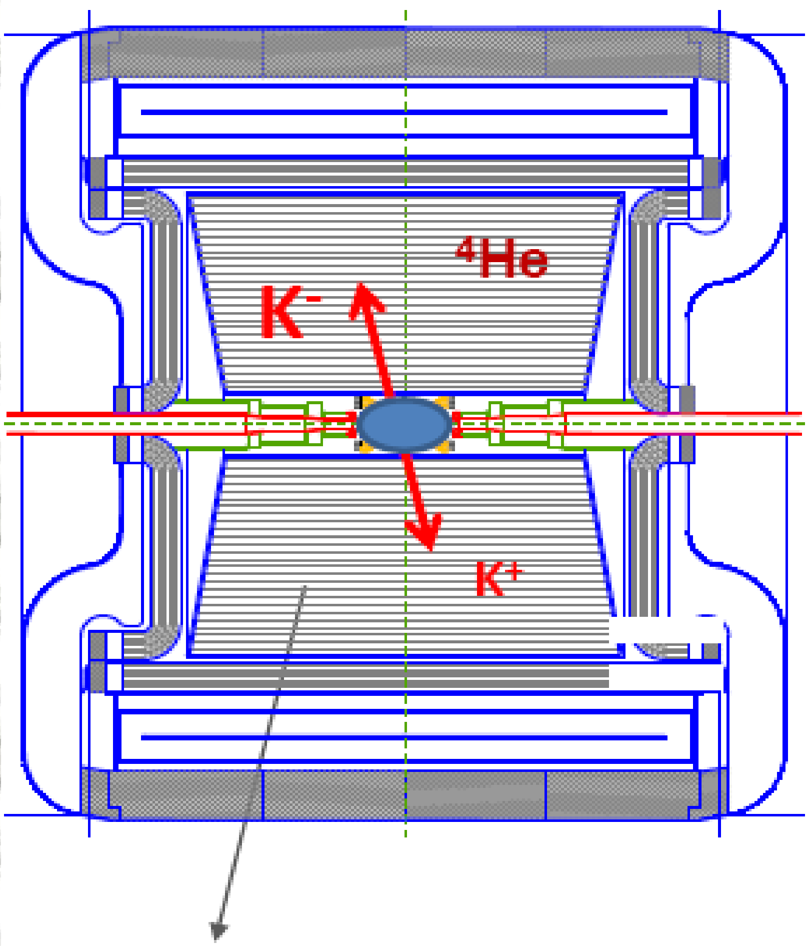
Exotic states are expected to predominantly decay into final states containing Σ, Λ, p, n, d, as an example the decay channels of the kaonic tribaryon state are:



important feature of the **detector** and the **tracking procedure** is the **reconstruction capability for Λ's and Σ's**

main source of background comes from classical hadronic interactions of K$^-$ in ^{4}He (poorly known based on one paper from 1970)

Analysis of K⁻ He interactions in the KLOE drift chamber



KLOE Drift Chamber

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

•From analysis of KLOE Monte Carlo **0.1% of K⁻** from DAΦNE should **stop in the DC volume**

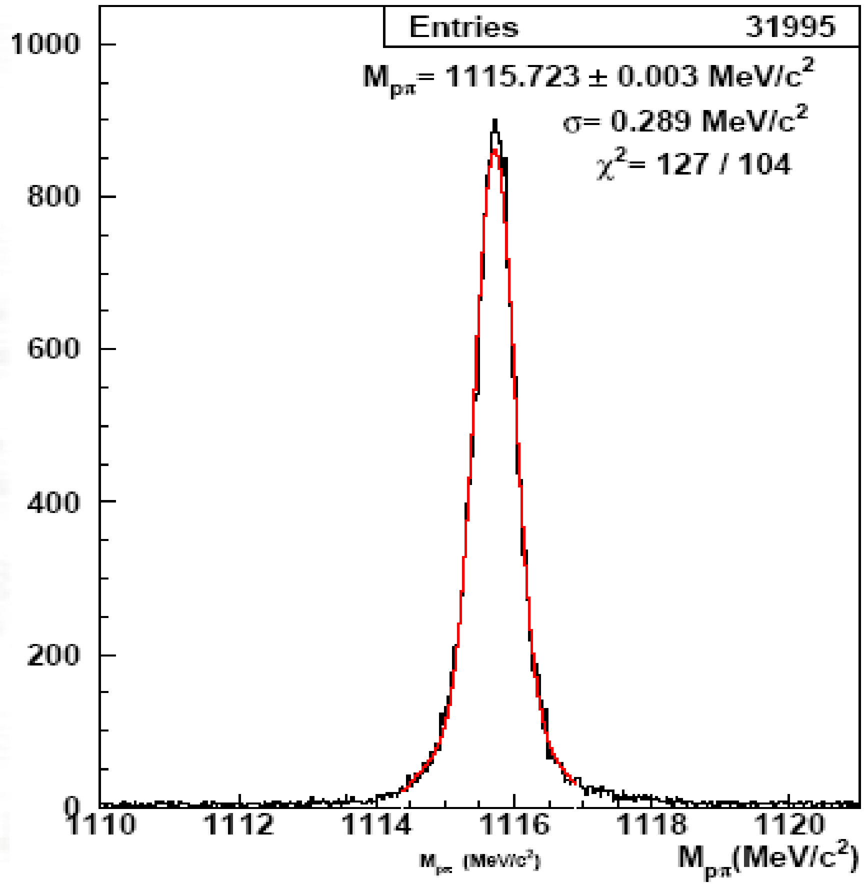
•total amount of analyzed data up to a luminosity of ≈ 1.1 fb^{-1} from KLOE data (K charged group)

•kaons tag system: 2-body decay and/or dE/dx signature in the DC gas.

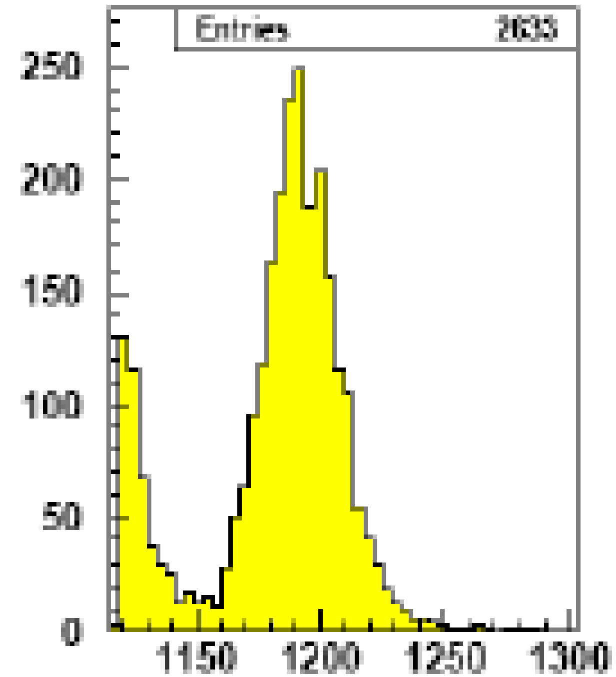
Strategy

•search for hadronic interactions with Λ(1116) as product $\Lambda \rightarrow p + \pi^-$ (64% BR), vertex made by KLOE reconstruction

Analysis of K^- He interactions in the KLOE drift chamber



Λ invariant mass reconstruction.



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

Σ^0 Invariant mass reconstruction

Conclusions

•The AMADEUS collaboration aims to perform a complete search for deeply bound kaonic nuclear states, and study of low energy K^- light nuclei interaction

•To this end an AMADEUS dedicated setup will be implemented in KLOE (data taking to start after KLOE2)

•All charged and neutral particles involved in formation and decay processes will be detected in a 4π geometry

•The reconstruction capabillity for Λ's and Σ's was tested analyzing KLOE data

•Continuing analysis of KLOE data in view of KLOE2 data taking to increase statistics

AMADEUS scientific case

Deeply bound Kaonic nuclear states:

- In presence of strong KN attractive potential were firstly suggested by Wycech

  (S. Wycech, Nucl. Phys. A450 (1986) 399c)

- Y. Akaishi and T. Yamazaki 'nuclear bound states in light nuclei'

  (Phys. Rev. C65 (2002) 044005)

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  - strong attractive I=0 interaction KN interaction favours discrete nuclear states, bound 100-200 Mev, narrow 20-30 Mev
  - shrinkage effect of a K on core nuclei forming unusual dense nuclear medium

AMADEUS scientific case

Deeply bound Kaonic nuclear states requires the presence of a strong attractive KN interaction in the isospin I=0 channel.

From experimental data:

- S-wave K^- nucleon scattering length is negative at treschold
- K_α line shift of kaonic hydrogen is negative

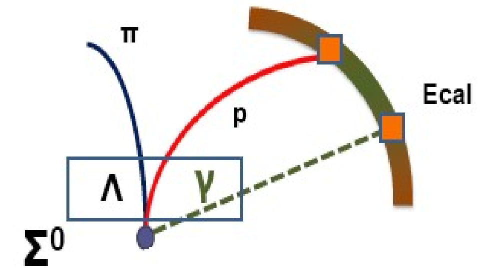
Repulsive type interaction

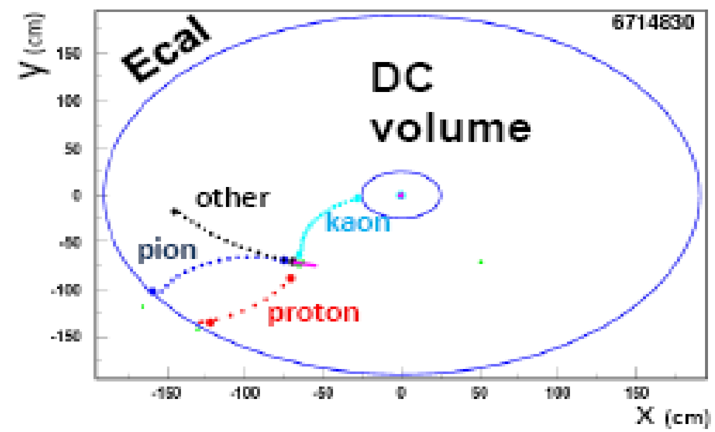
KN potential strongly dependent on density:
- **repulsive** in **free space**
- **attractive** in **nuclear matter**

Selection criteria for Λ

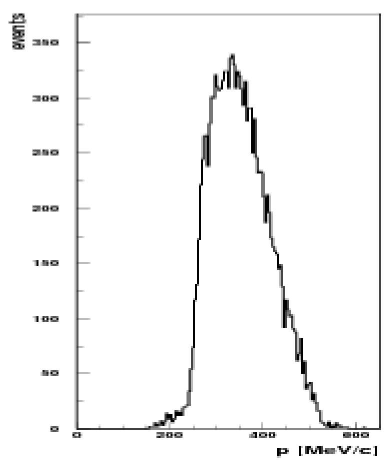
requests:

- vertex with at last two opposite charged particles
- spatial position of vertex inside DC, or in DC entrance wall
- negative tracks with dE/dx < 95 ADC_{counts}





protons having right E-p relation using energy released in the calorimeter



cut because treshold of calorimeter

selection with energy loss in DC