Unprecedented studies of low-energy kaons interactions in nuclear matter by AMADEUS

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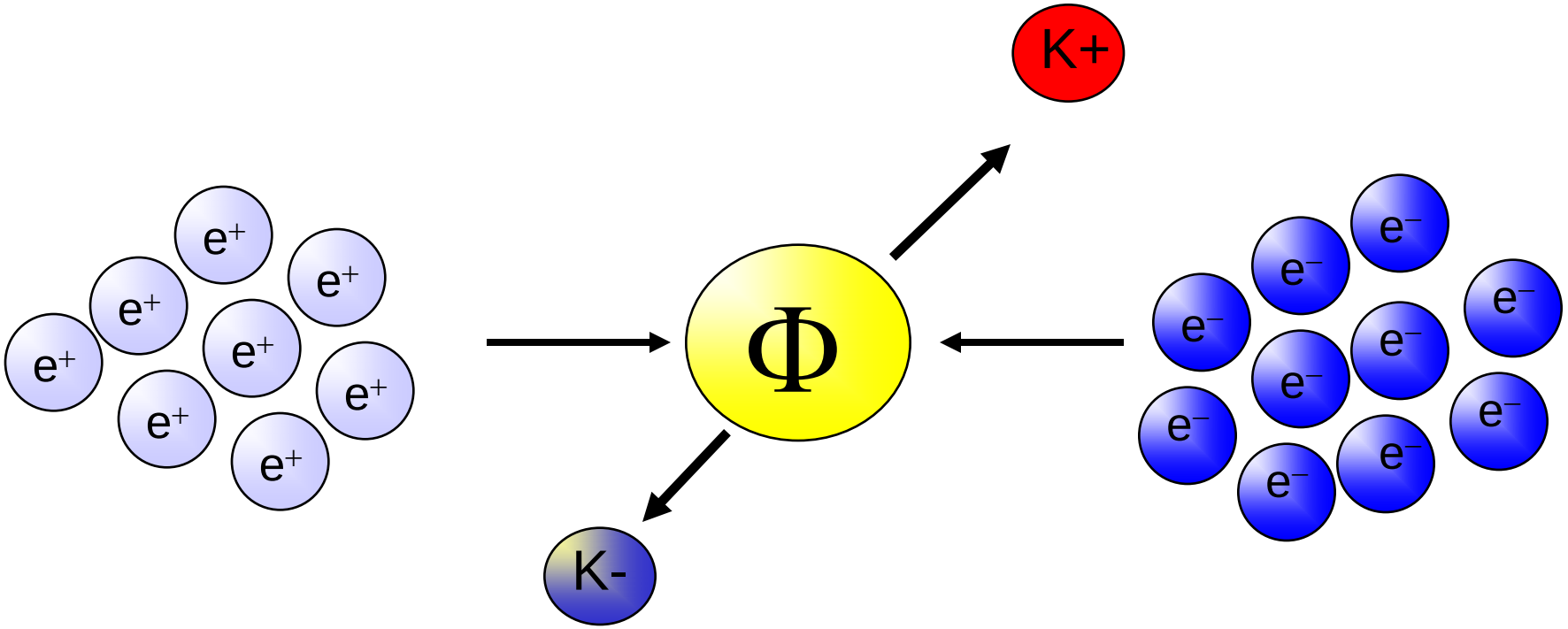
(On behalf of the AMADEUS collaboration)

II International Symposium on Mesic Nuclei

Krakow, 22-25 Sept. 2013

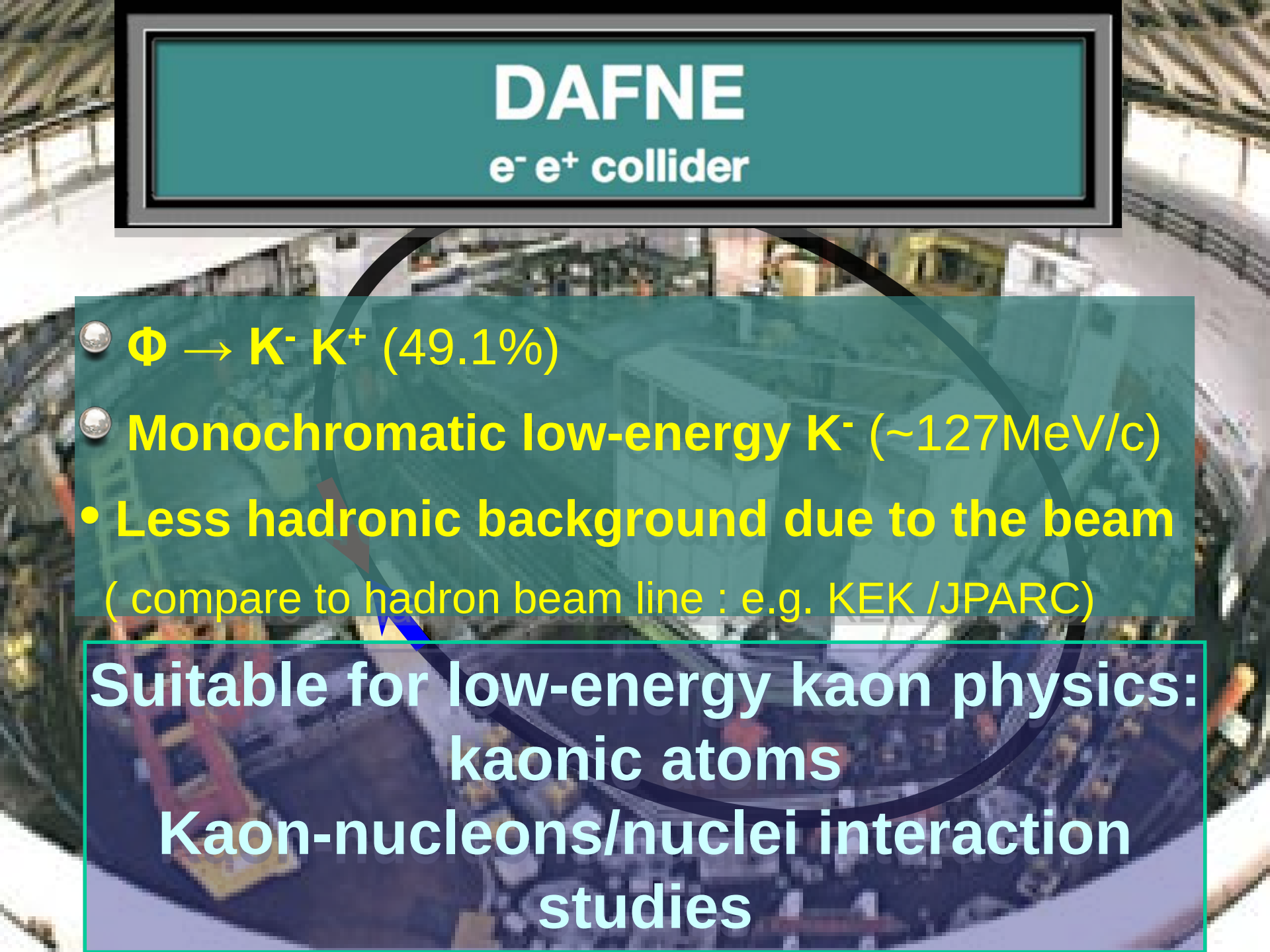
The DAFNE collider or the best possible beam of low energy kaons

The DAFNE principle



Flux of produced kaons: about 1000/second

DAΦNE, since 1998

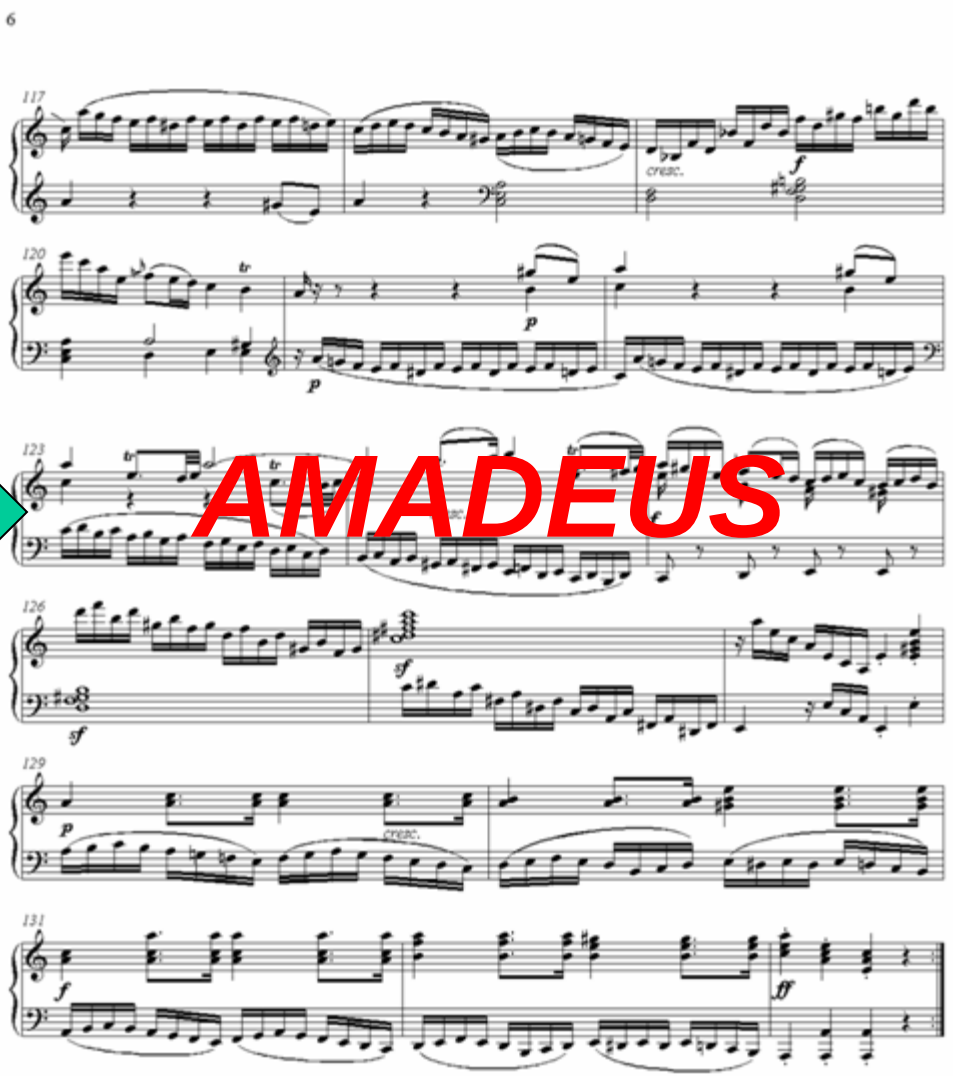


- **$\Phi \rightarrow K^- K^+$** (49.1%)
- **Monochromatic low-energy K^-** (~127MeV/c)
- **Less hadronic background due to the beam**

(compare to hadron beam line : e.g. KEK /JPARC)

Suitable for low-energy kaon physics:
kaonic atoms
Kaon-nucleons/nuclei interaction studies

Antikaonic Matter At DAΦNE: an Experiment Unraveling Spectroscopy



AMADEUS

Antikaon Matter At DAΦNE: Experiments with Unraveling 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

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

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 the first full acceptance, high precision measurement 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).

Either situations:

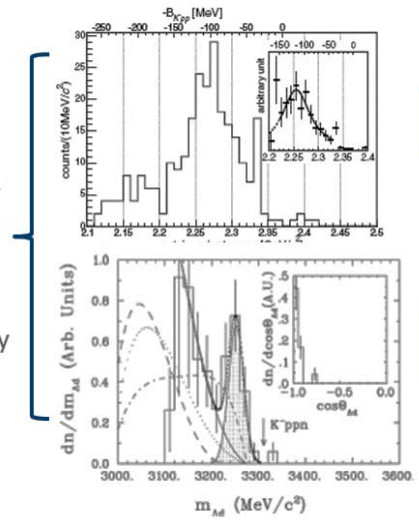
EXISTENCE or NON-EXISTENCE of the deeply bound kaonic nuclear clusters will have strong impact in kaon-nucleon/nuclei physics!!!

Status of the search for KNC

- KEK & FINUDA : same type of analysis but different target and detector specifications

Experimental results from **FINUDA**

K- stopped in light nuclei
Invariant mass spectroscopy



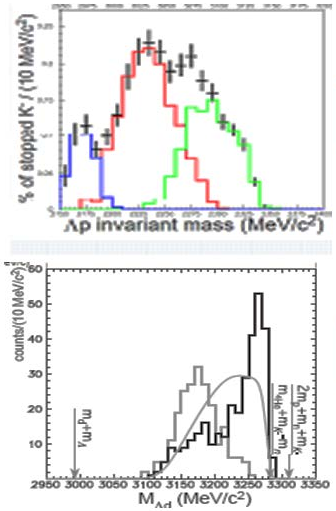
Λp

Λd

Results from **KEK**:

K- stopped in 4He
Invariant mass spectroscopy

-Reduced momentum acceptance
-Back to back Λp, Λd



Λp

Λd

- In the interpretation of these results there is a “flashback” by both theoreticians and experimentalists to the basics of stopped K- interactions in light nuclei:
  - New data suffers from reduced acceptance
  - Old bubble chamber data not specifically analyzed for this purpose and low statistics

Production methods of antikaon-mediated bound nuclear cluster

- stopped K^- reactions on light nuclei
- in-flight K^- reactions
- protons on proton (or light nuclei)
- heavy ion collisions

→ necessary:

- dedicated experiments
- exclusive measurement

Planned experiments

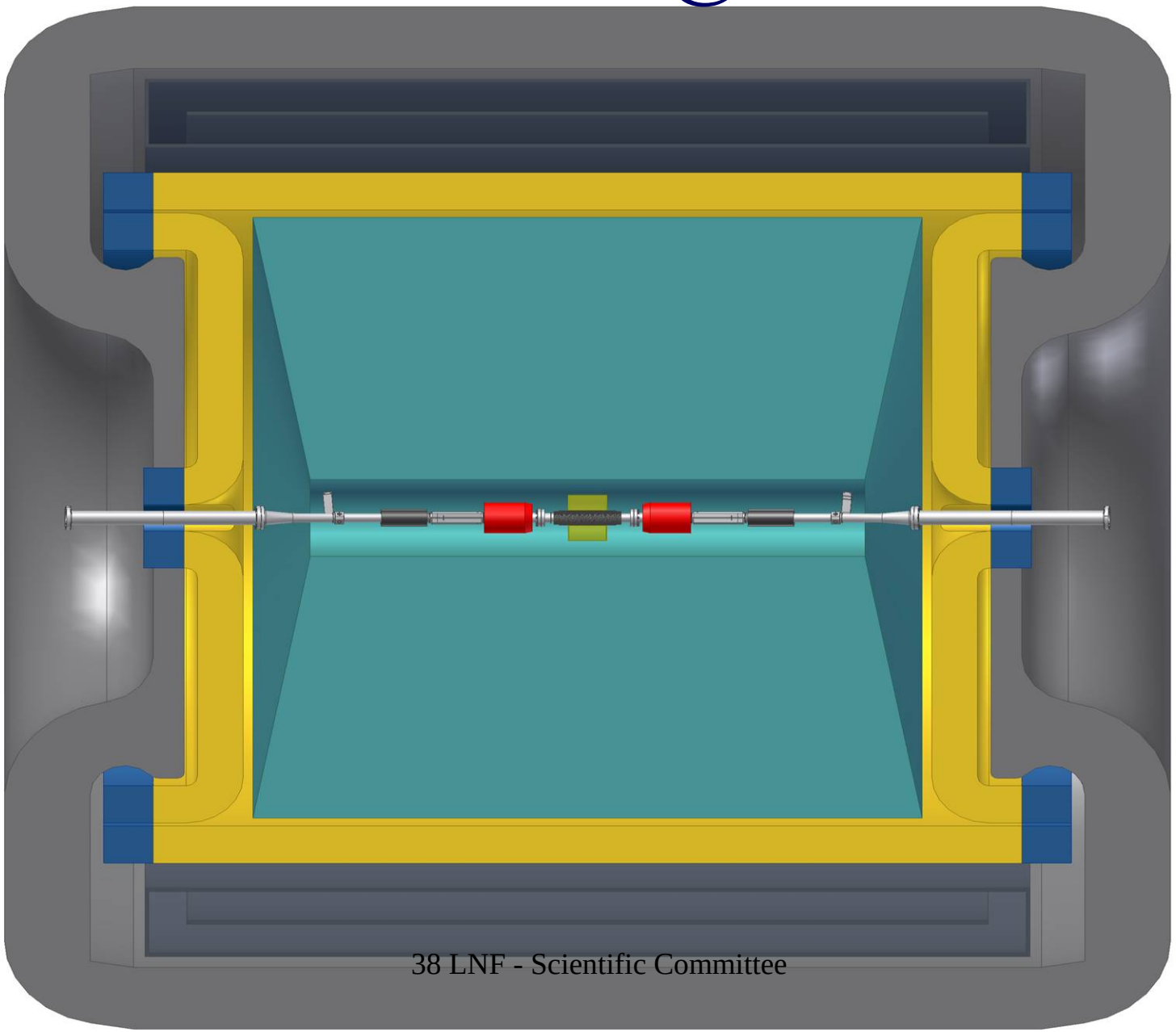
- ***the experiments in Japan*** **at J-PARC will produce kaonic nuclear states only with K^--induced reactions in-flight (E15)**

- ***alternative approaches followed*** **at GSI with FOPI using proton-nucleus collisions at beam energies close to the strangeness production threshold and with nucleus-nucleus collisions**

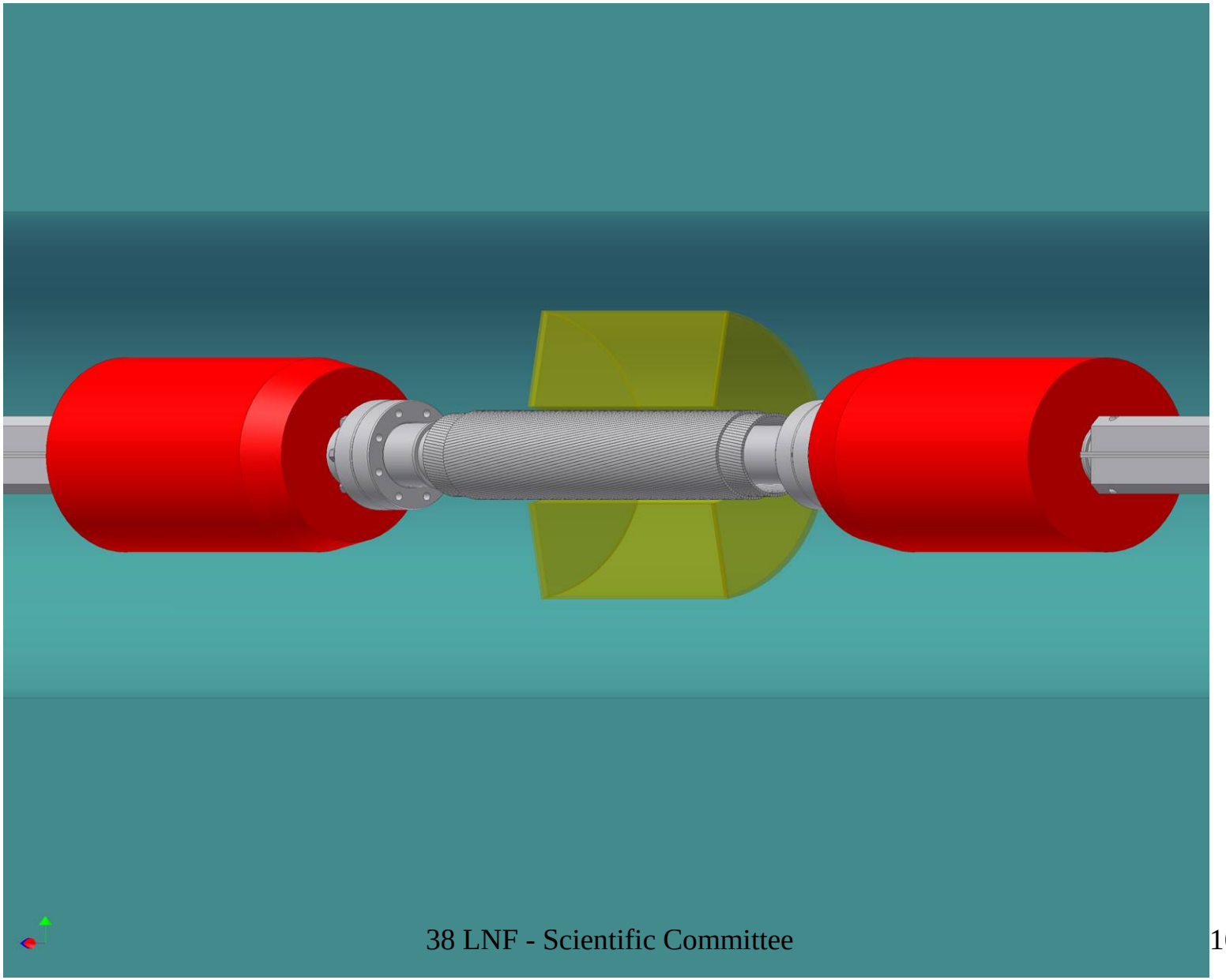
- **a dedicated facility – AMADEUS at DAΦNE will study antikaon-mediated bound nuclear systems with K^- induced reactions at rest**

AMADEUS setup

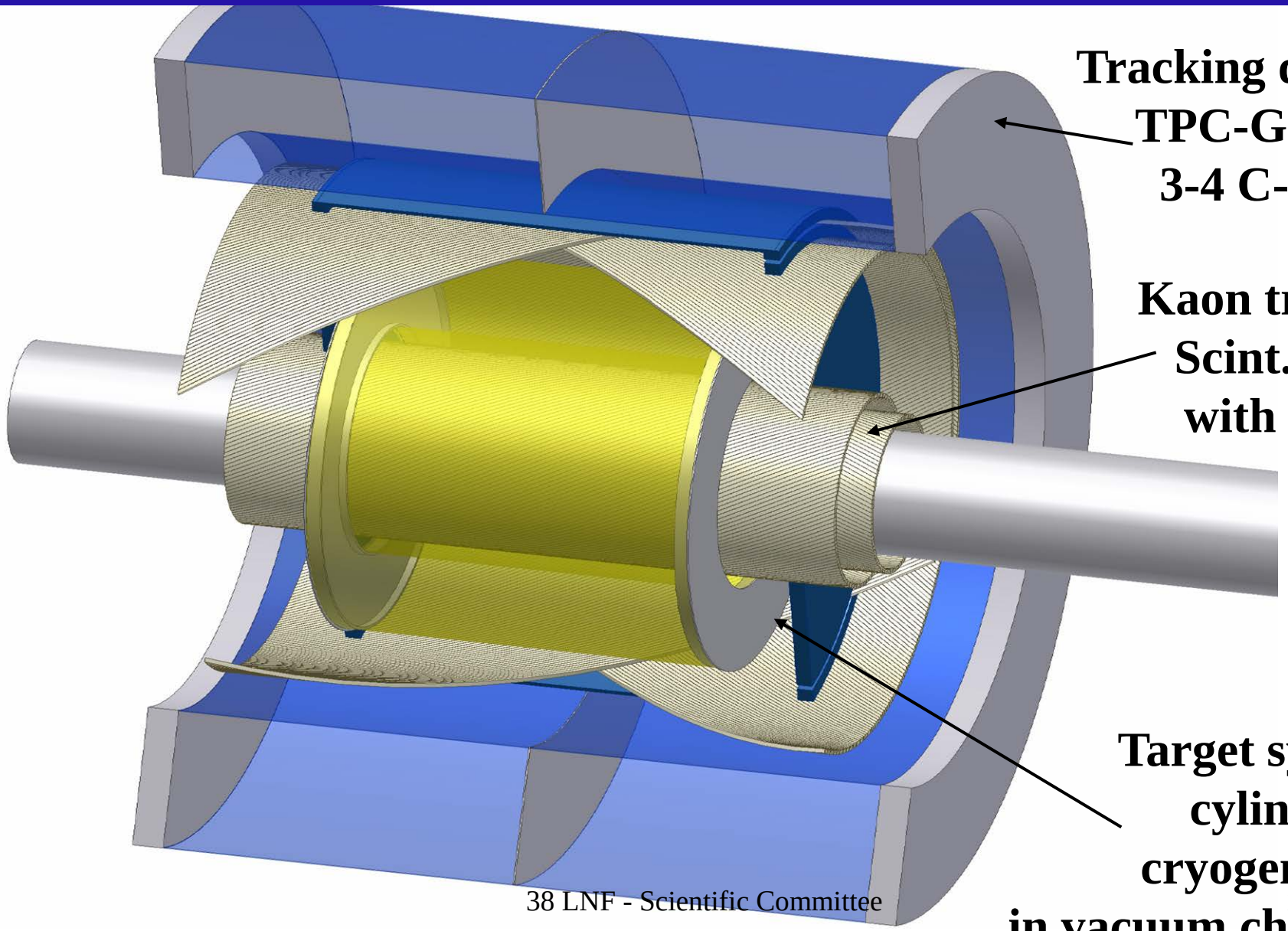
AMADEUS @ KLOE



AMADEUS @ KLOE



AMADEUS



Tracking device: TPC-GEM or 3-4 C-GEMs

Kaon trigger: Scint. fibers with SiPMs

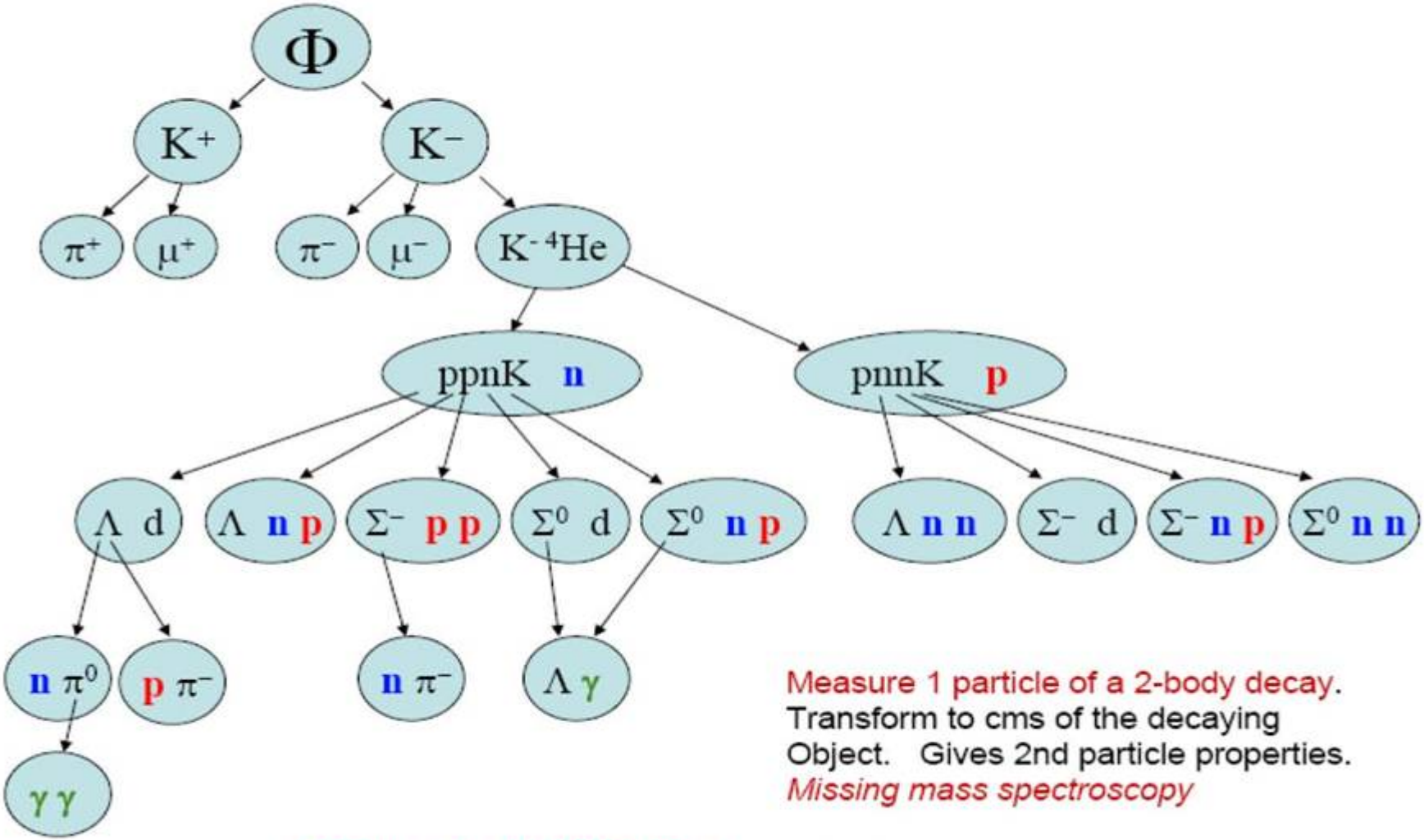
Target system: cylindrical cryogenic cell in vacuum chamber

Experimental program of AMADEUS

Unprecedented studies of the low-energy charged kaons interactions in nuclear matter: solid and gaseous targets (d, ^{3}He, ^{4}He) in order to obtain unique quality information about:

- Nature of the controversial **Λ(1405)**
- Possible existence of **kaonic nuclear clusters** (deeply bound kaonic nuclear states)
- Interaction of **K^-** with **one** and **two nucleons.**
- Low-energy charged kaon **cross sections** for momenta lower than 100 MeV/c (missing today)
- Many other processes of interest in the low-energy QCD in strangeness sector -> implications from particle and nuclear physics to astrophysics (dense baryonic matter in **neutron stars**)

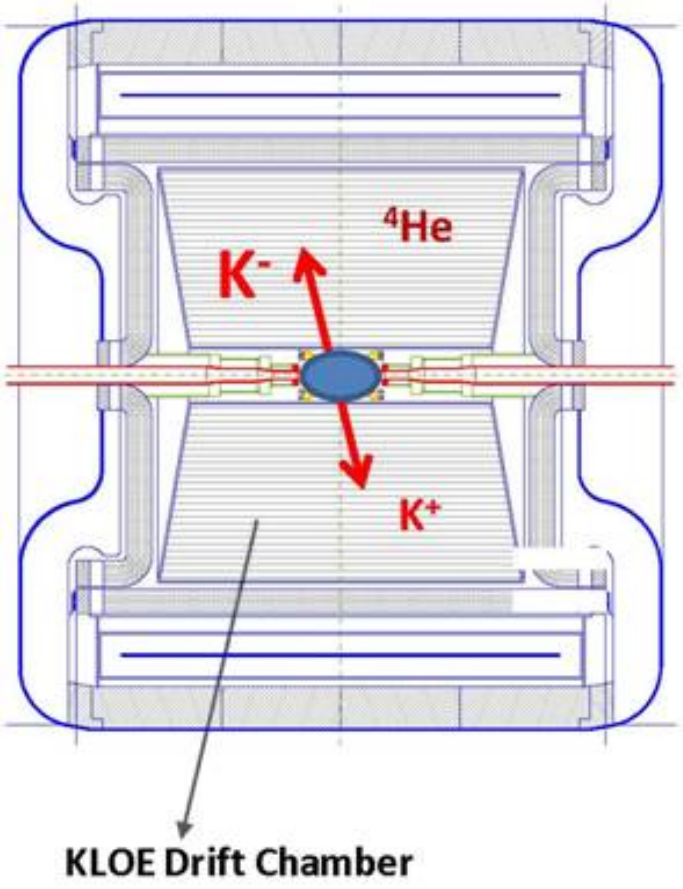
Reactions channels (simplified)



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*

Hadronic interactions of K^- in KLOE

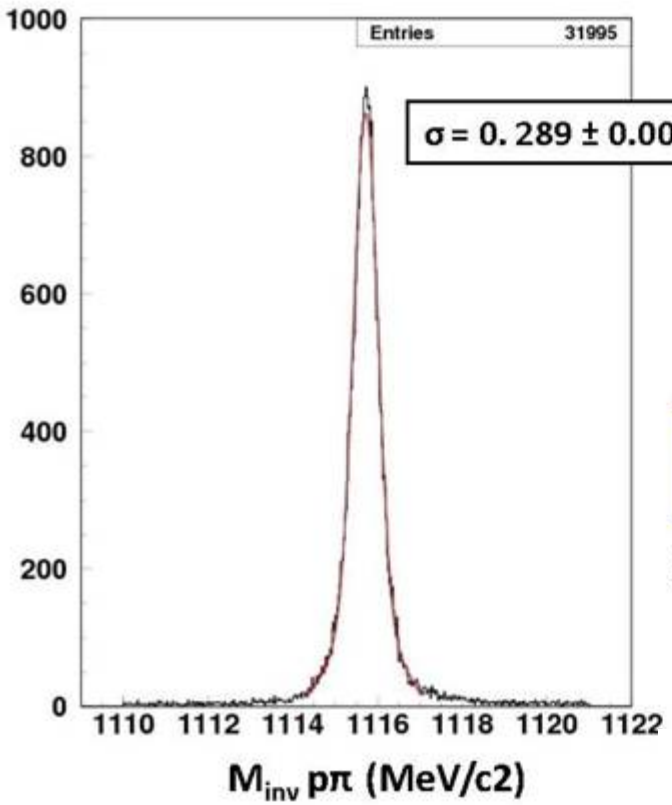


- The Drift Chambers of KLOE contain mailny **^{4}He**
- From analysis of KLOE data and Monte Carlo:
  0.1 % of K^- from daΦne should **stop in the DC volume**
- This would lead to hundreds of possible kaonic clusters produced in the 2 fb^{-1} of KLOE data.

AMADEUS status

- Analyses of the **2002-2005 KLOE data**:
- Dedicated **2012** run with pure **Carbon target** inside KLOE
  - Λp from 1NA or 2NA (single or multi-nucleon absorption)
  - Λd and Λt channels
  - $\Lambda(1405) \rightarrow \Sigma^0\pi^0$
  - $\Lambda(1405) \rightarrow \Sigma^+\pi^-$
  - $\Sigma N/\Lambda N$ internal conversion rates
- R&D for more refined setup
- Future possible scenario

Lambda invariant mass



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

-Dedicated event selection to avoid **Energy loss** in the DC wall

- Best $\chi 2$ tracks and vertices

PRELIMINARY

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

Preliminary evaluation with 2-body decay

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

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

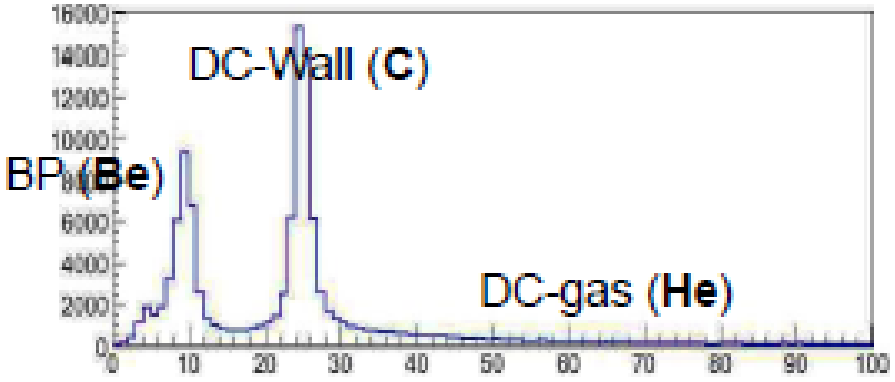
KLOE data on K^- nuclear absorption

Use of two different data samples:

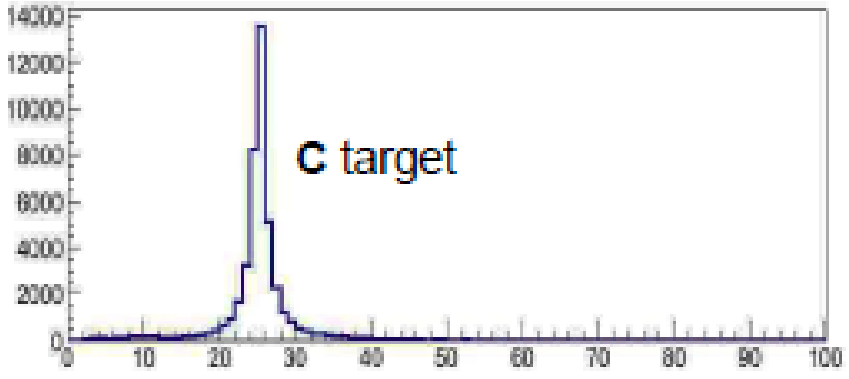
- KLOE data from 2004/**2005** (2.2 fb^{-1} total, 1.5fb^{-1} analyzed)

- Dedicated run in november/december **2012** with a **Carbon target** of 4/6 mm of thickness (~90 pb^{-1}; analyzed 37 pb^{-1}, x1.5 statistics)

Position of the K^- hadronic interaction inside KLOE:



2005 data



2012 with Carbon target

- Pure carbon target inserted in KLOE end of August 2012 ; data taking till December 2012

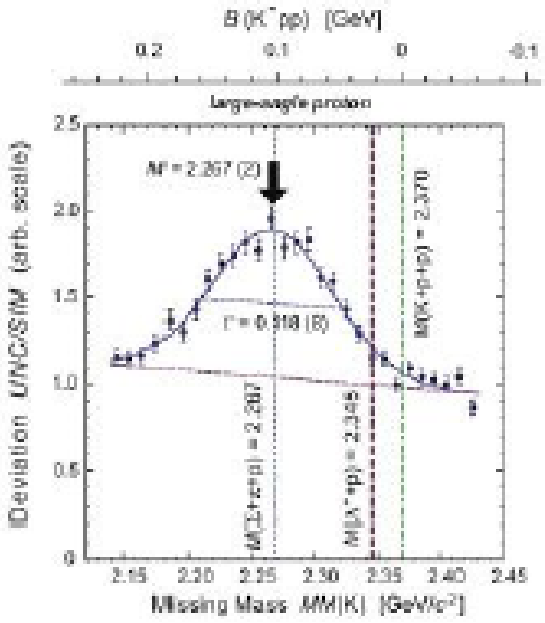
Λp analysis

Search for signal of bound states in the Λp channel: candidate to be a **K⁻pp** cluster. Observed and very debated (FINUDA, KEK, **DISTO**)

-Competing processes:

1NA: **K⁻N→Λπ⁻** (N from residual nucleus)

2NA: **K⁻NN→ΛN** (pionless)



Nucl.Phys.A835, 43 (2010)

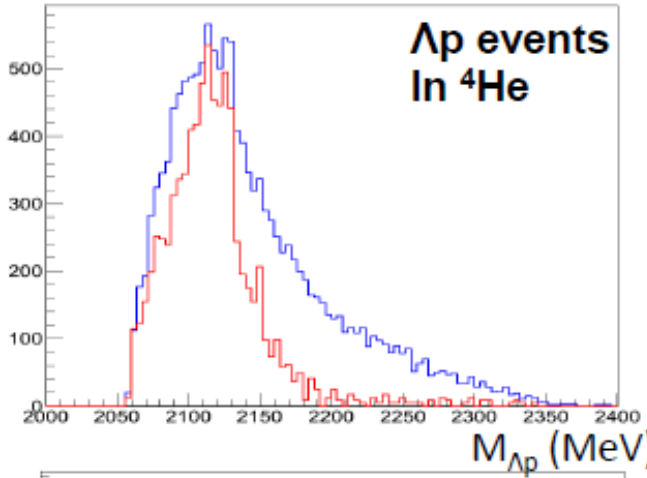
Λp analysis

-Competing processes:

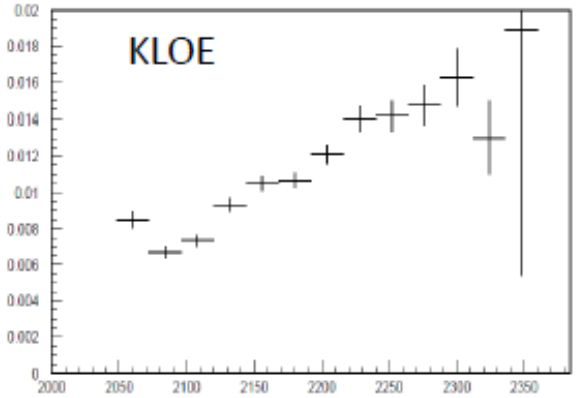
1NA: $K^-N \rightarrow \Lambda\pi^-$ (N from residual nucleus)

2NA: $K^-NN \rightarrow \Lambda N$ (pionless)

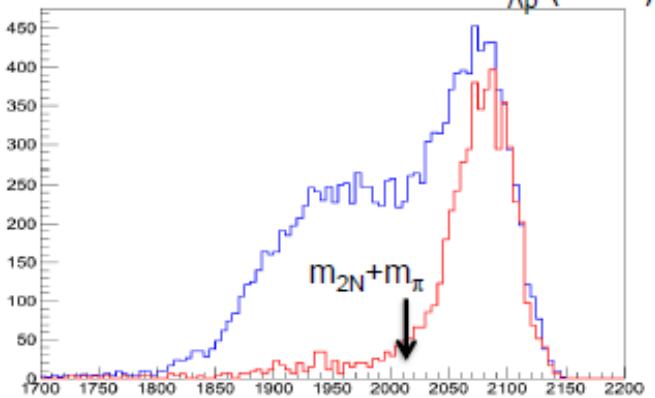
A perfect disentanglement between single and multi-nucleon absorption can be achieved thanks to the **nice acceptance:**



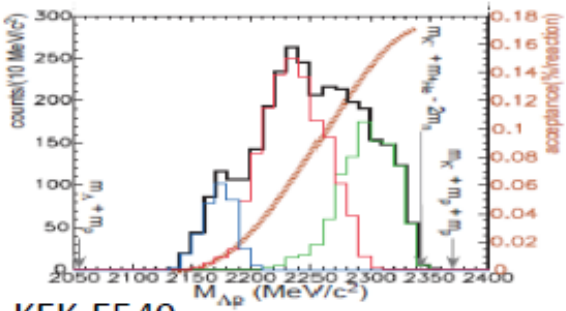
Λp all events
Λπ⁻(p) events
(arbitrary normalization)



Acceptance in $M_{\Lambda p}$ (MeV)
(arbitrary normalization)



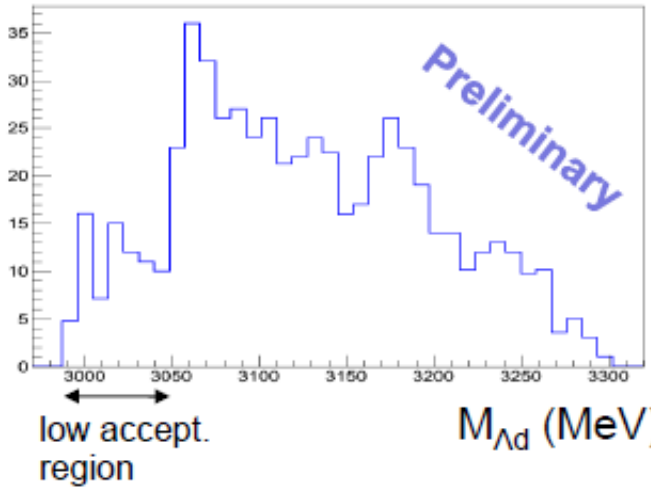
The Λp missing mass for the Λπ⁻(p) events lies exactly In the 2N+π⁻ mass region



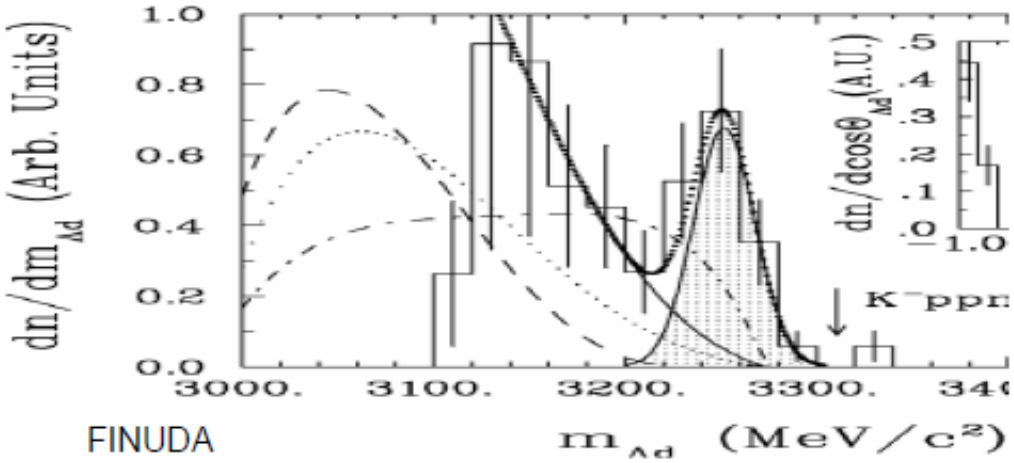
KEK-E549
Mod.Phys.Lett.A23, 2520 (2008)

Λd, Λt analyses

- Search for signal of bound states in the **Λd** channel. Candidate to be a **K⁻ppn** cluster. Observed spectra from FINUDA and KEK again showing possible bound states in the in the high invariant mass region.



Λd events
In ^{4}He



FINUDA
Nucl.Phys.A835, 43 (2010)

Λd, Λt analyses

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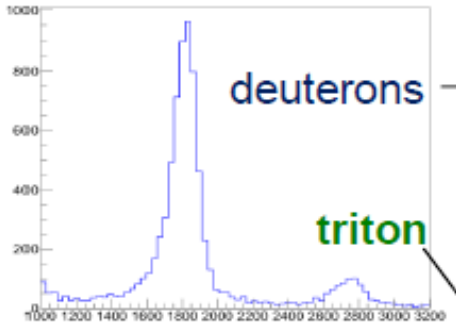
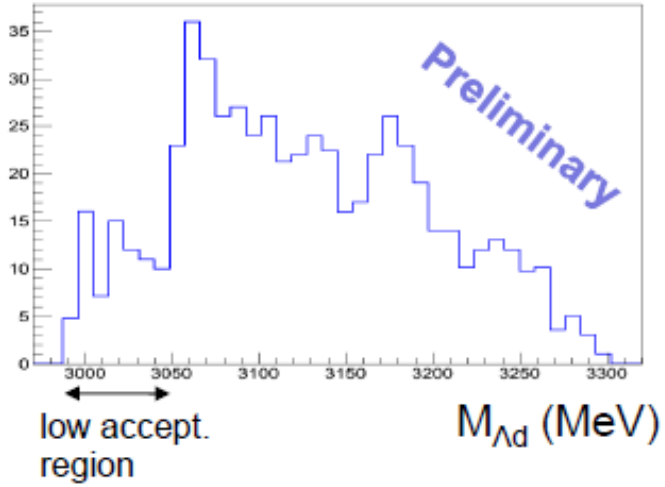
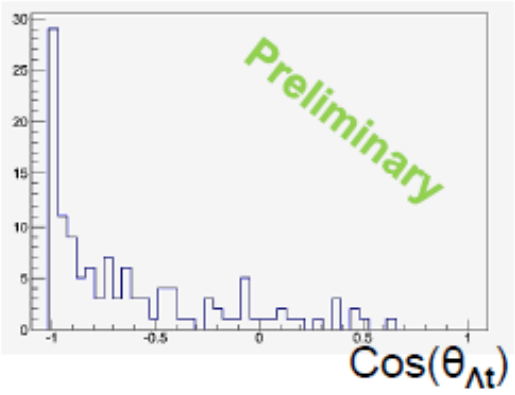


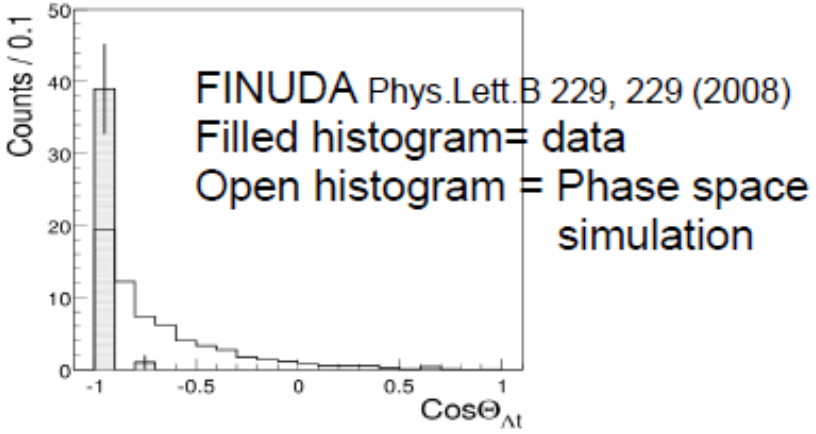


Λd events
In ^{4}He

Only FINUDA and an old experiment (with only 4 events!) have shown **Λt** spectra from K⁻ absorption

Λt events
In ^{4}He





Λ(1405) scientific case

$(M\ ,\ \Gamma)$ = $(1405.1^{+1.3}_{-1.0}\ ,\ 50 \pm 2)$ MeV, $I = 0$, $S = -1$, $J^p = 1/2^-$, Status: ****, strong decay into $\Sigma\pi$

Its **nature** is being a **puzzle now for decades**:

1) ***three quark state***: expected mass ~ 1700 MeV

2) ***penta quark***: more unobserved excited baryons

3) ***unstable* KN *bound state***

4) ***two poles***: $(z_1 = 1424^{+7}_{-23},\ z_1 = 1381^{+18}_{-6})$ MeV (Nucl. Phys. A881, 98 (2012))

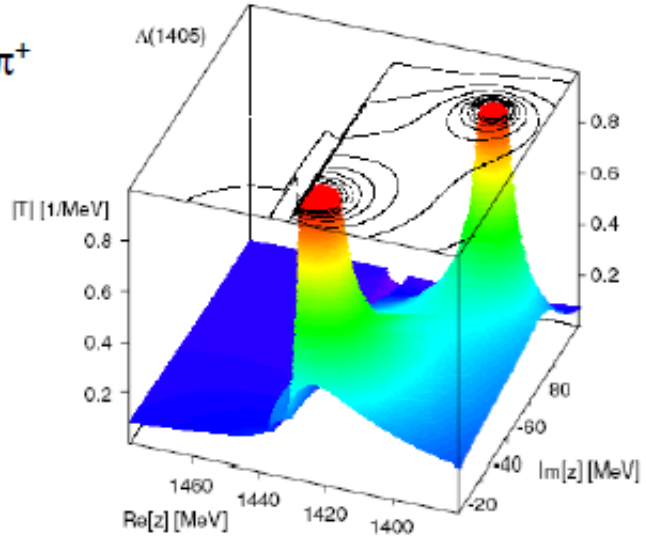
Higher mass pole mainly coupled to KN

mainly coupled to $\Sigma\pi$ -> **line-shape depends on production mechanism**

Line-shape also depends on the decay channel : $\Sigma^0\pi^0$ $\Sigma^+\pi^-$ $\Sigma^-\pi^+$

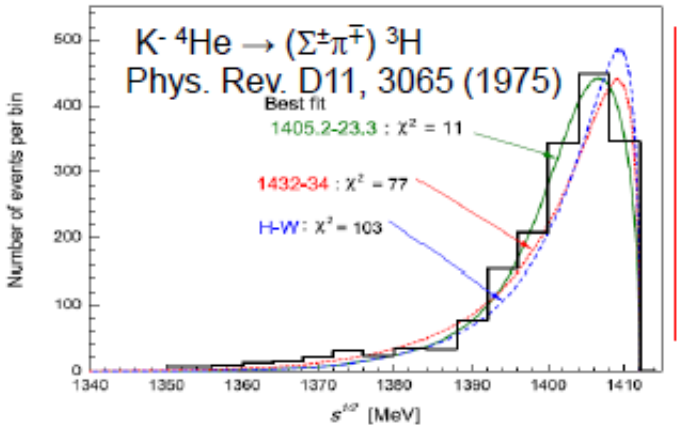
BEST CHOICE:

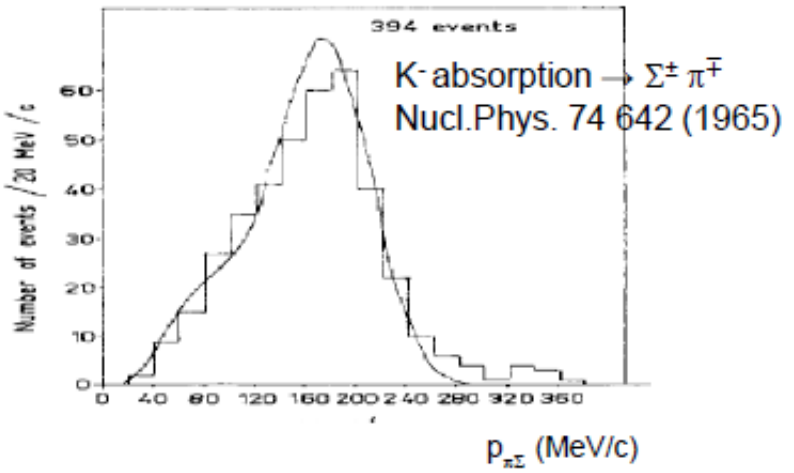
production in KN reactions (only chance to observe the high mass pole) **decaying in $\Sigma^0\pi^0$** (free from Σ(1385) background)



Λ(1405) previous experiments

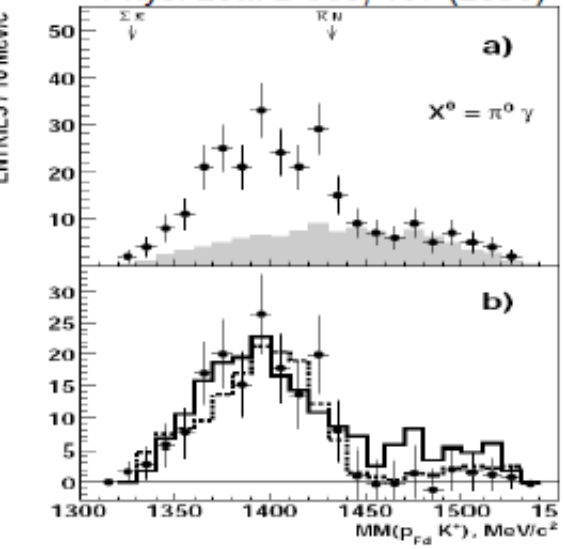
Old **absorption experiments:**
-$M_{\pi\Sigma}$ spectra always cut at the atrest limit
-$\Sigma^{\pm}\,\pi^{\mp}$ spectra suffer Σ(1385)contamination



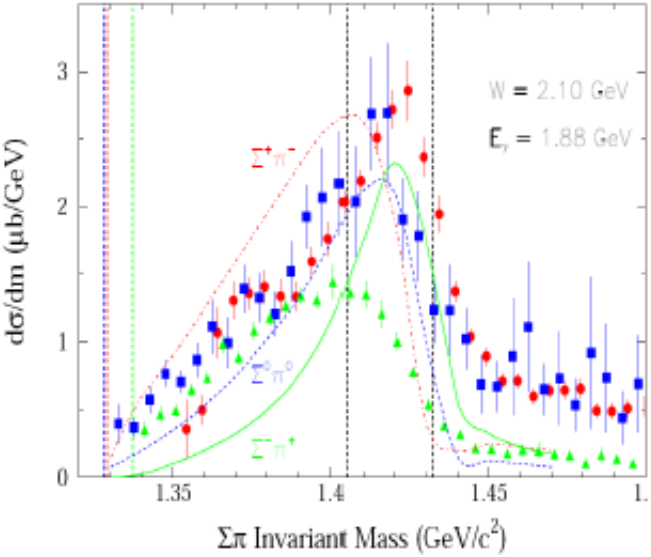


Other (**non-absorption**) experiments present spectra in the $\Sigma^0\,\pi^0$ channel (only three experiments…with different lineshapes!):

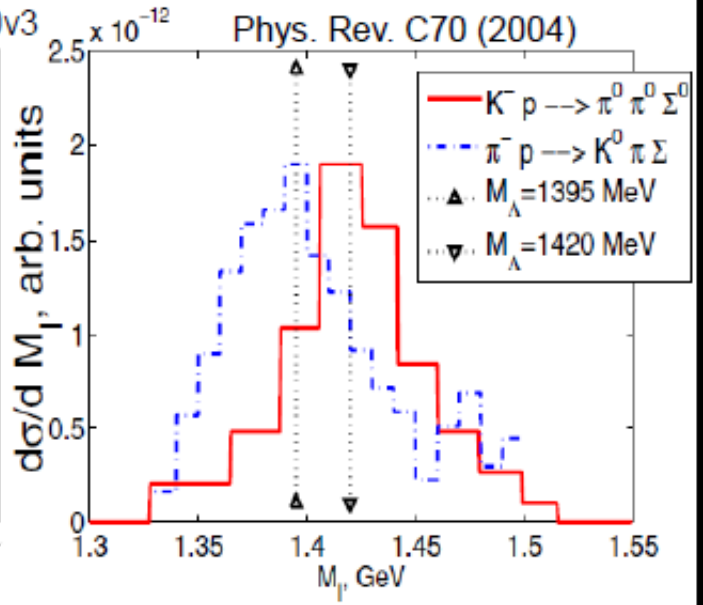
Phys. Lett. B 660, 167 (2008)



CLAS Collaboration, ArXiv:1301.5000v3



Phys. Rev. C70 (2004)

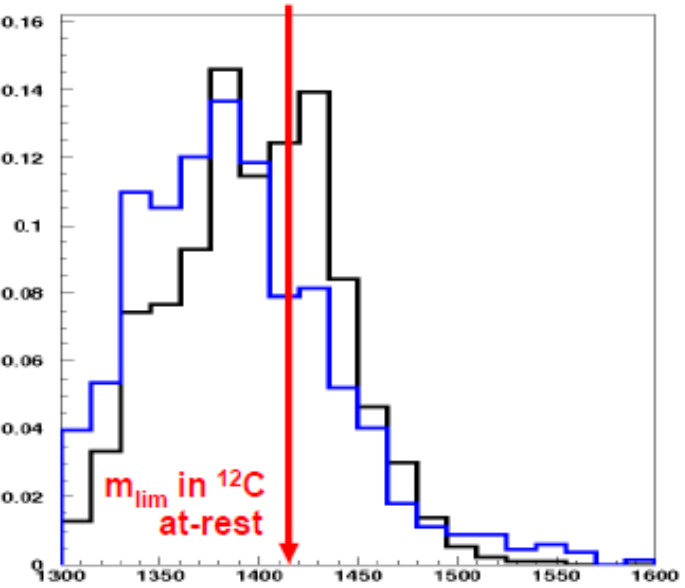


Analysis of $\Sigma^0\pi^0$ channel

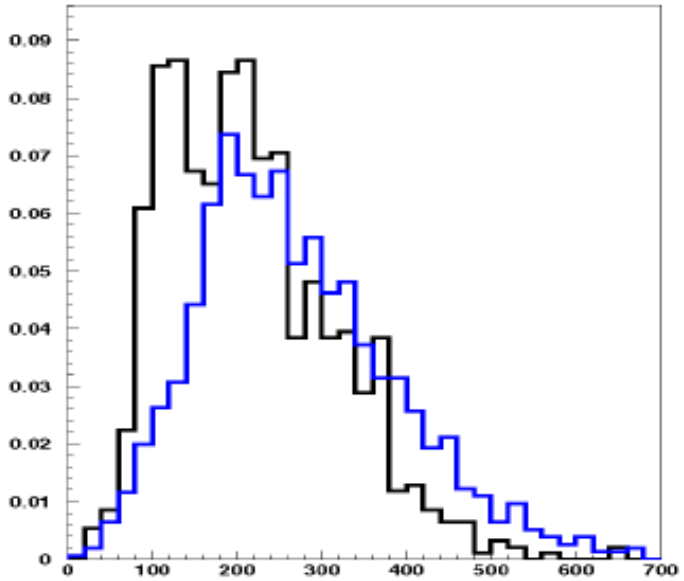
$\Lambda(1405)$ signal searched by K^- interaction with a **bound proton** in Carbon

$K^- p \rightarrow \Sigma^0 \pi^0$ detected via: $(\Lambda\gamma)\,(\gamma\gamma)$

K^- absorption in the DC wall (mainly ^{12}C with H contamination –epoxy-)



$M_{\Sigma 0\,\pi 0}$ (MeV)



$P_{\Sigma 0\,\pi 0}$ (MeV)

— 2005

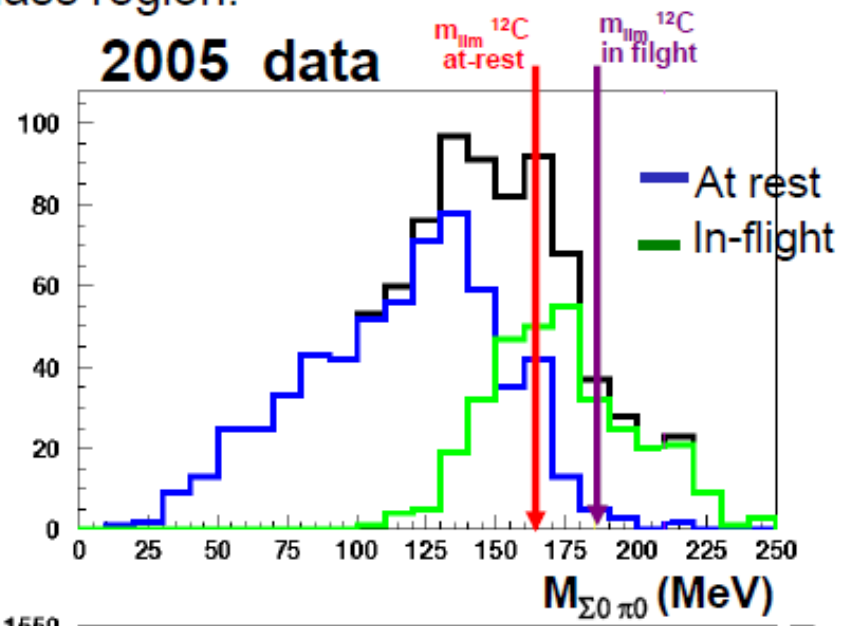
— 2012
Carbon target

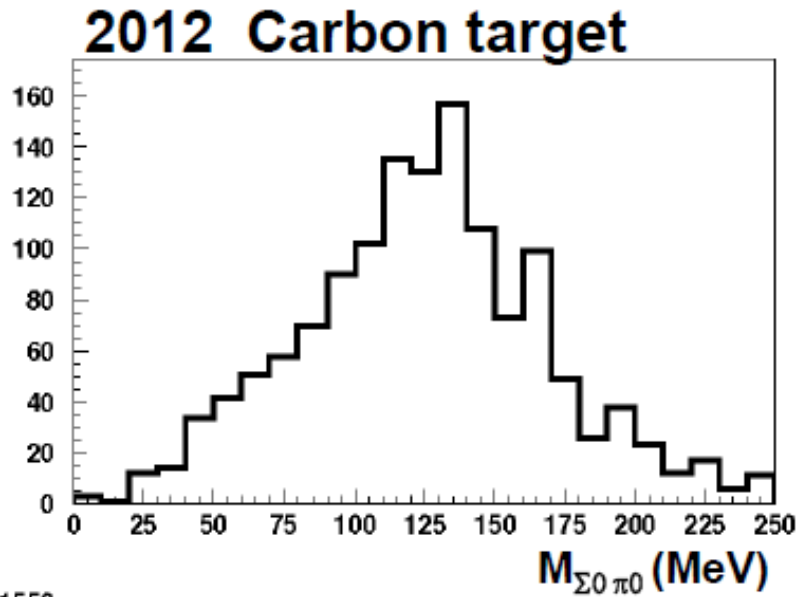
$m_{\pi 0 \Sigma 0}$ resolution $\sigma_m \approx 32$ MeV/c^2 ; $p_{\pi 0 \Sigma 0}$ resolution: $\sigma_p \approx 20$ MeV/c.

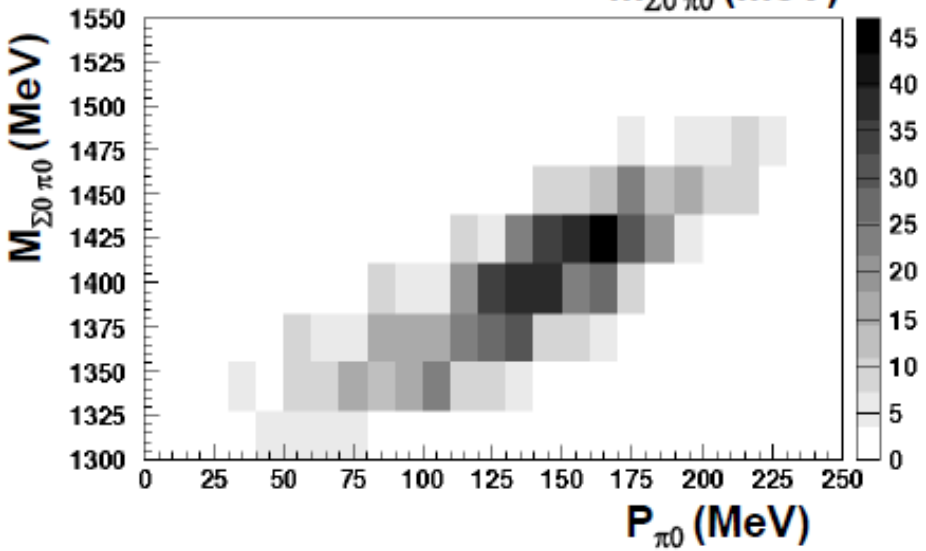
Negligible ($\Lambda\pi^0$ + internal conversion) background =(3±1)%, no I=1 contamination

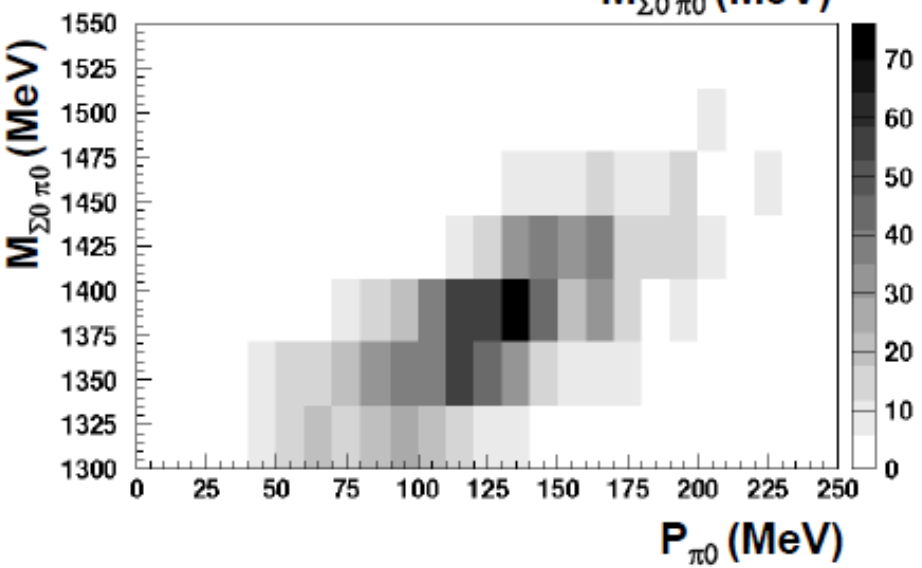
Analysis of $\Sigma^0\pi^0$ channel

A clear **in-flight** component (first evidence in K- absorption) open a higher invariant mass region.



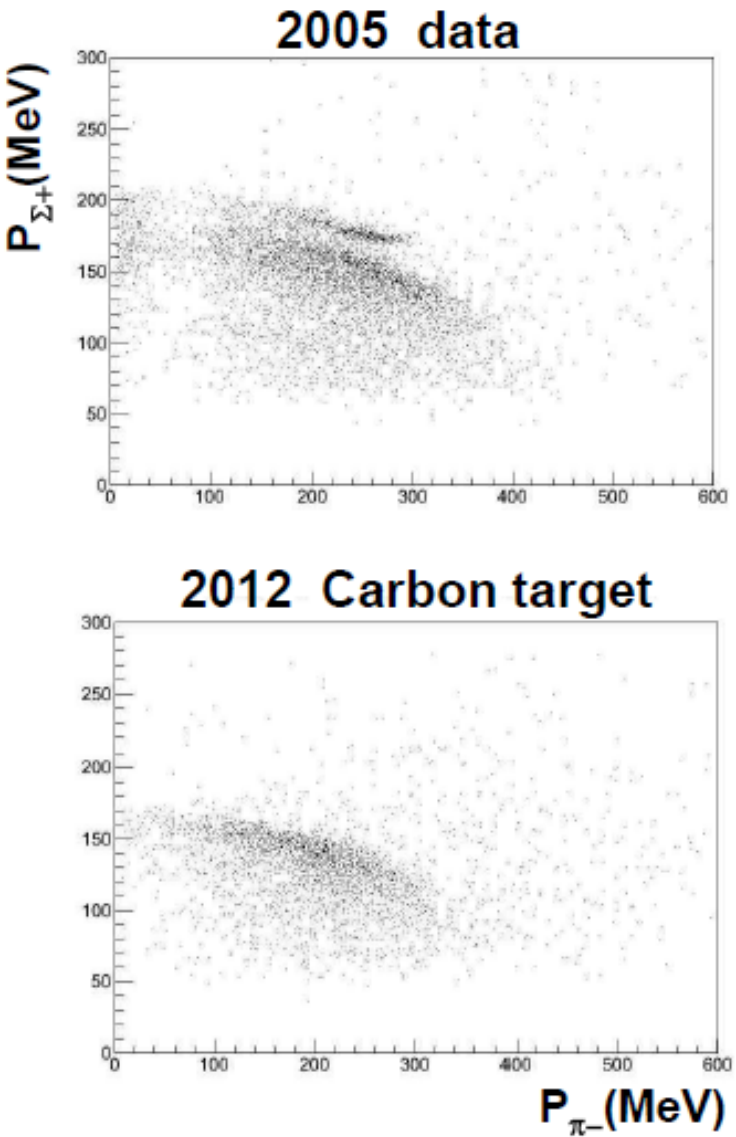






Λ(1405) charged channel: $\Sigma^+\pi^-$

Λ(1405) signal searched in $K^- p \rightarrow \Sigma^+ \pi^-$ detected via: $(p\pi^0)\pi^-$



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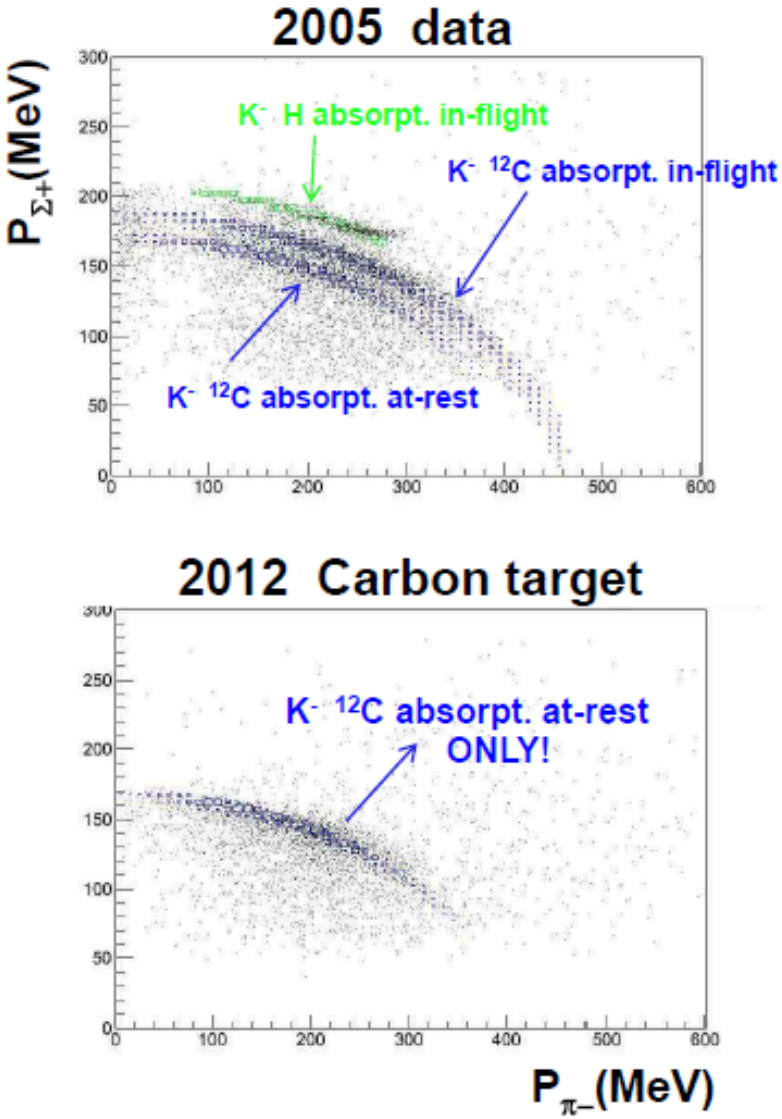

Λ(1405) charged channel: $\Sigma^+\pi^-$

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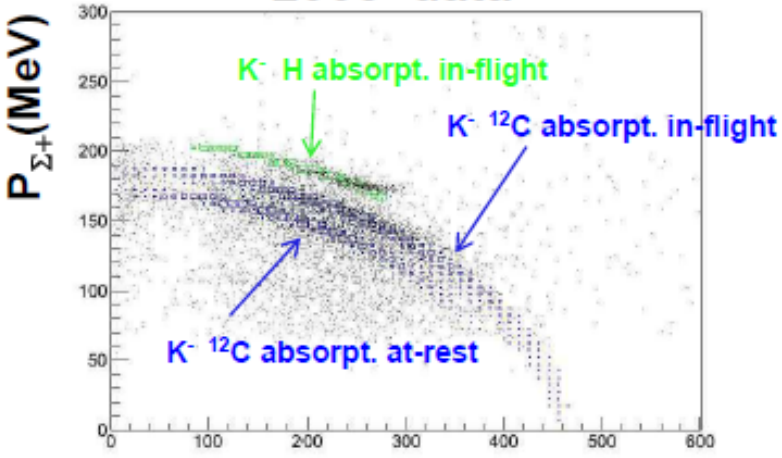
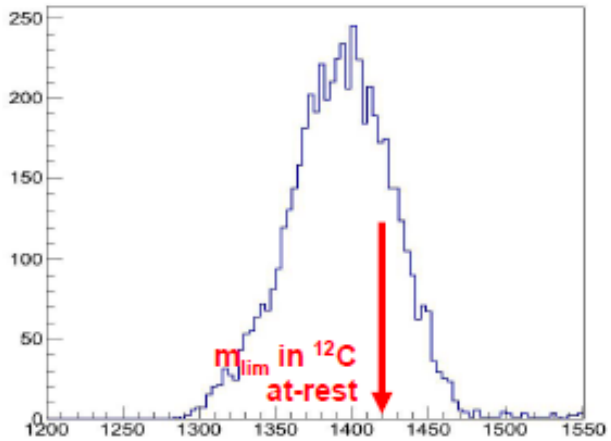
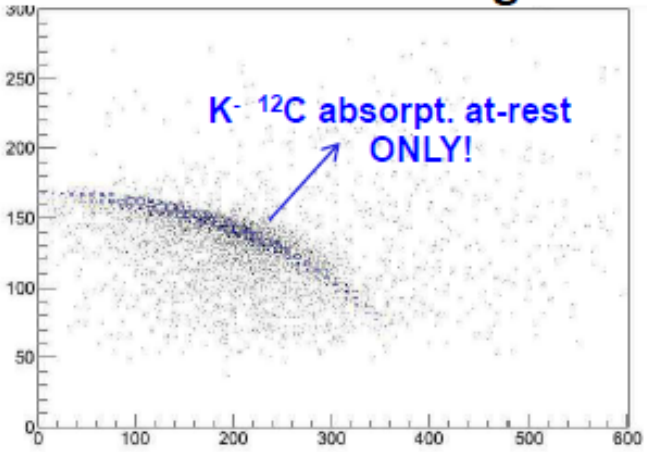
2005 data



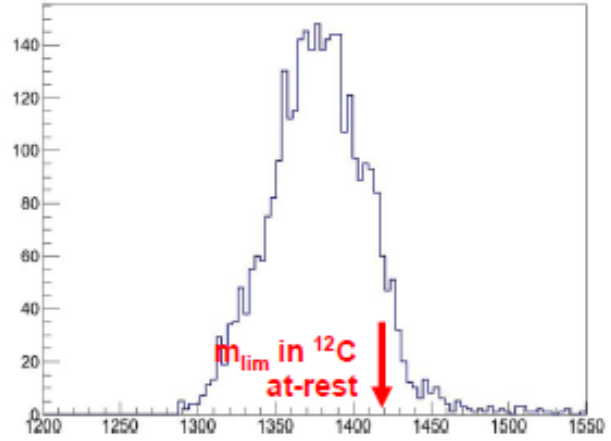
2005 data



2012 Carbon target



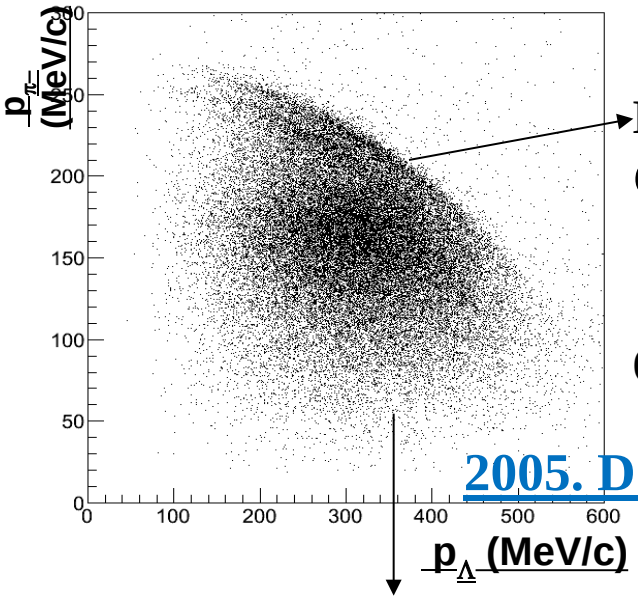
2012 Carbon target



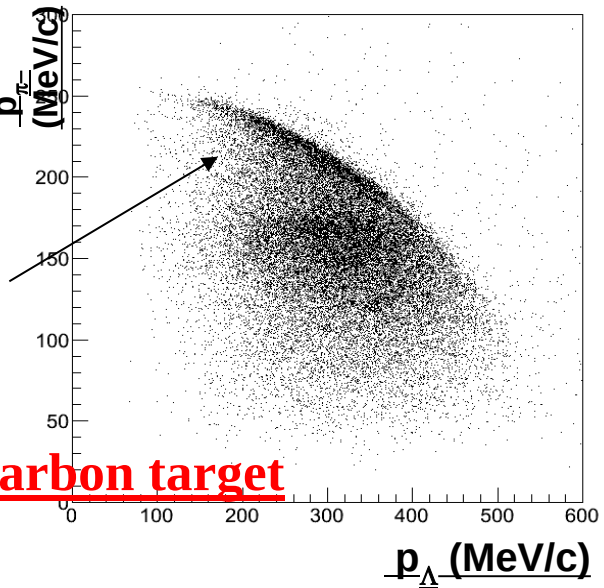
Σ/Λ conversion in the nuclear medium

- **Λπ⁻ analysis:** 1N absorption process **$K^- N \rightarrow Y\pi^-$**

Λπ channel: No possible formation of Λ(1405)
Well know resonance Σ(1385)



Direct formation $K^- n \rightarrow \Lambda\pi^-$
Clearly visible the 2 bands:
-in flight
-at rest
(only events at rest in Carbon Target)



2005. DC-wall carbon

2012 Carbon target

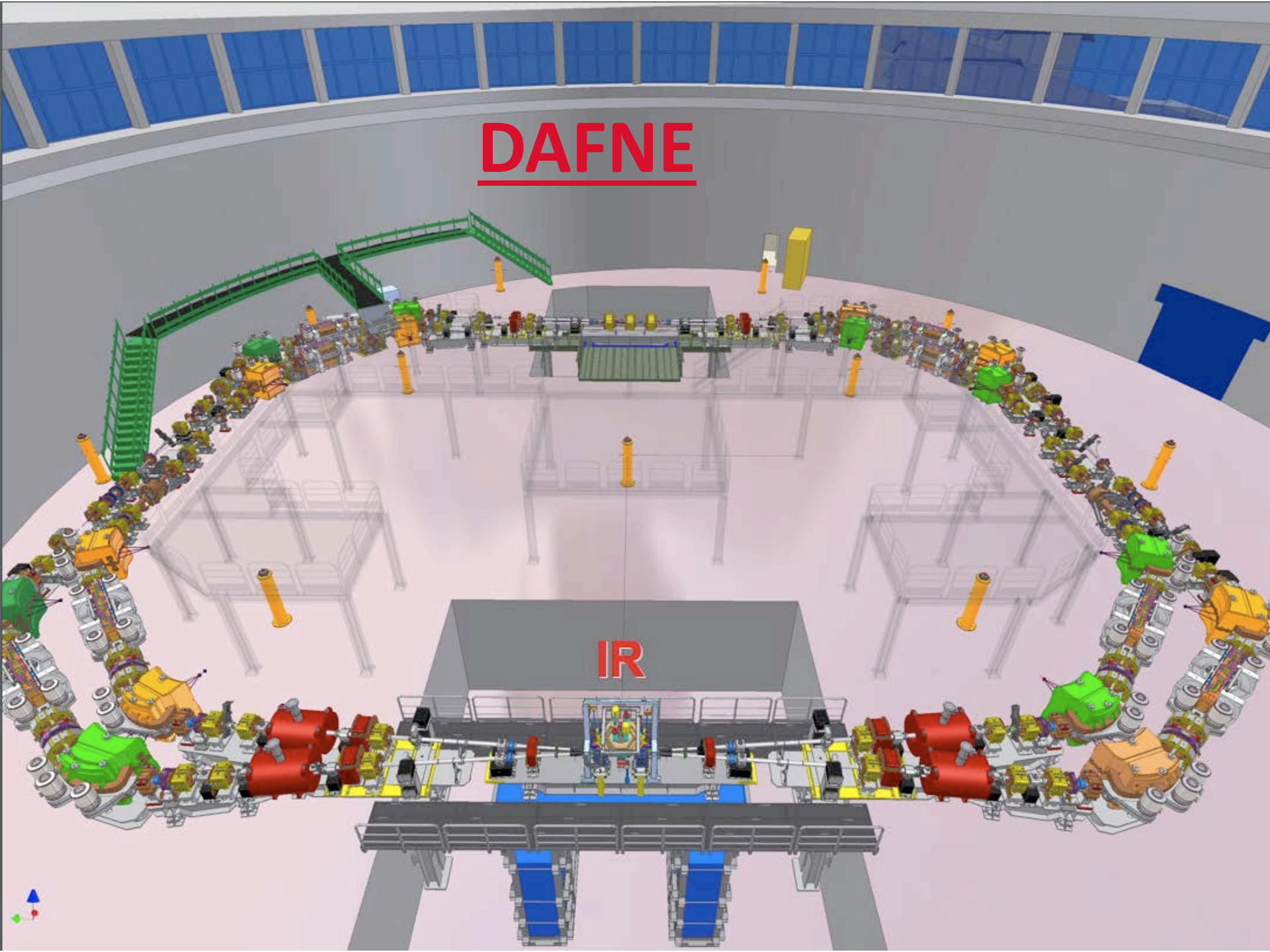
Two-step process involving sigma:

$K^- n \rightarrow \Sigma^0\pi^-$

- **Decay Λγ**
- **Undergo internal conversion within the residual nucleus ΣN->ΛN**

- The data in this channel is of great value to confirm the predicted branching ration modifications in medium for $^AZ(K^-,\pi^-)$

-Σ/Λ internal conversion rates can be obtained as well in function of the nucleus material


DAFNE
IR

KLOE-2 installation – completed

DAΦNE consolidation

Consolidation activities have been undertaken during the six month shut-down planned to install the new layers of the KLOE-2 detector and are completed!

What can be expected, at regime, from the DAΦNE consolidation?

- **Much lower fault rate -> uptime of the order of 80%**
- **Improved and faster injection due to:**
  - **better linac performances**
  - **enhanced diagnostic for Linac, TLs, A and MRs injection sections**
- **More stable operation**
  - **at low level due to:**
    - **reliable low-level control**
    - **fast and exhaustive diagnostic and fault analysis of the interlocks coming from magnet power supplies and vacuum gages**
    - **no mechanical vibration in the IR**
  - **at higher level:**
    - **new IP vacuum pipe**
    - **improved feedback system**
    - **orbit automatic control**
- **Higher positron current thanks to more efficient clearing electrodes**
- **More powerful diagnostics at the IP**
- **IR alignment from scratch**
- **Stable optics in the Main Rings**

C. Milardi, 46th LNF Sci. Comm., May 2013

DAFNE status

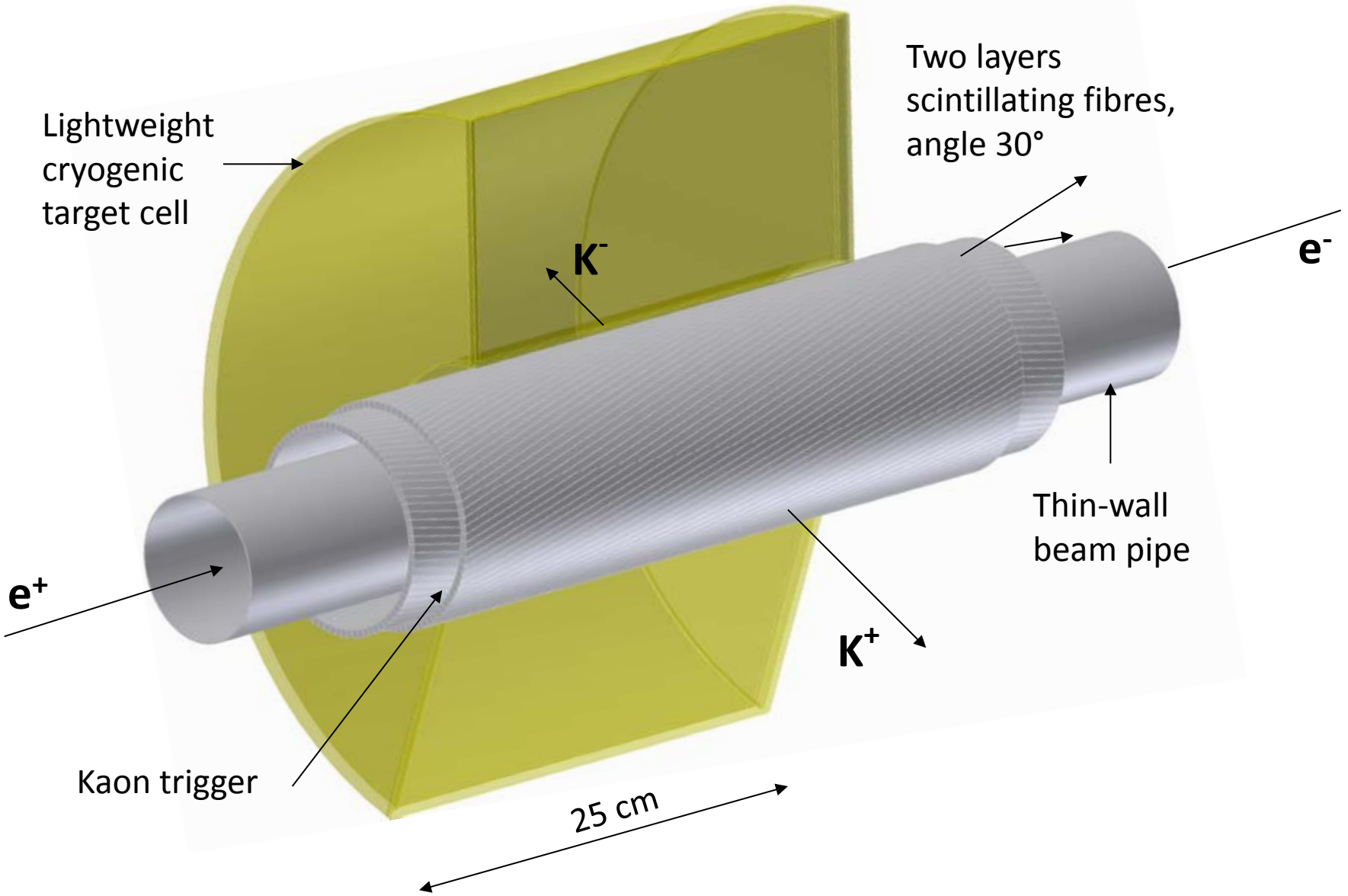
A new IR, based on large crossing angle, Crab-Waist compensation of the beam-beam interaction and compatible with a large detector, has been designed and implemented on DAΦNE

It satisfies the design requirement in terms of optics and betatron coupling compensation and beam-beam behaviour,

A general machine consolidation has been undertaken during the shut down required to install the new layers of the KLOE-2 detector

DAFNE restarted in September 2013 – plan to deliver in the coming 2 years 6 fb-1 to KLOE-2

AMADEUS stopped K- @ AMADEUS



Conclusions

- **AMADEUS has an enomous potential to perform complete measurements of low-energy kaon-nuclei interactions in various targets**
- **Data analyses ongoing**
- **For future: use of other dedicated targets (gas and solid)**


DAFNE represents an unique
opportunity to unveil the
secrets of the kaon-nucleon/nuclei
interaction at low energy