Highlights of the low-energy kaon-nuclei interaction studies at DAΦNE

Oton Vázquez Doce (Universe Cluster Excellence, TUM)

on behalf of the AMADEUS and SIDDHARTA collaborations

KAONNIS (Integrated Initiative)

Unique studies of the low-energy kaon-nucleon/nuclei interactions
→ low-energy QCD in strangeness sector with implications from **particle,** Λ(1405), and **nuclear** (kaonic nuclear clusters) physics, to **astrophysics** (equation of state, role of strangeness).

- **Exotic atoms**: SIDDHARTA data analyses and **SIDDHARTA-2** experiment.
- **Kaon-nuclei interactions at low-energies**: **AMADEUS** Carbon target 2012 and KLOE 2002-2005 data analyses in collaboration with KLOE
- other activities related to strangeness physics (JPARC) with support from European projects: HP3 – WP9: WP24; WP28

Experimental program of AMADEUS

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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**)

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
  - Λ (1405) -> $\mathbf{\Sigma^0\pi^0}$
  - Λ (1405) -> $\mathbf{\Sigma^+\pi^-}$
  - ΣN/ΛN internal conversion rates

- R&D for more refined setup

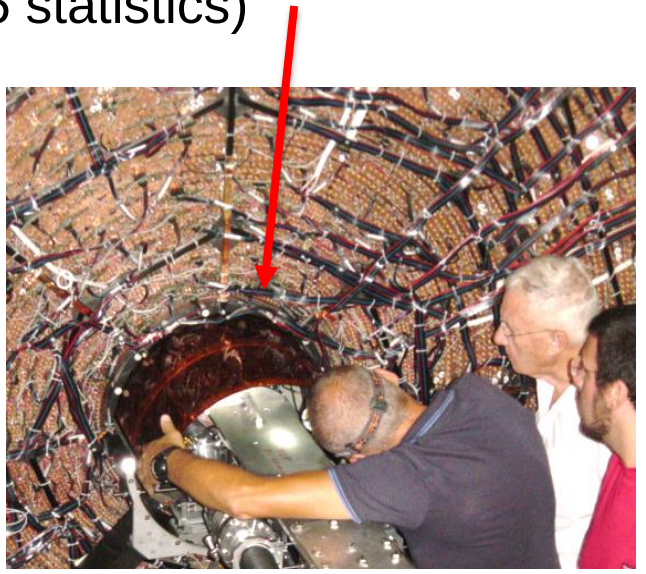
- Future possible scenario

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)



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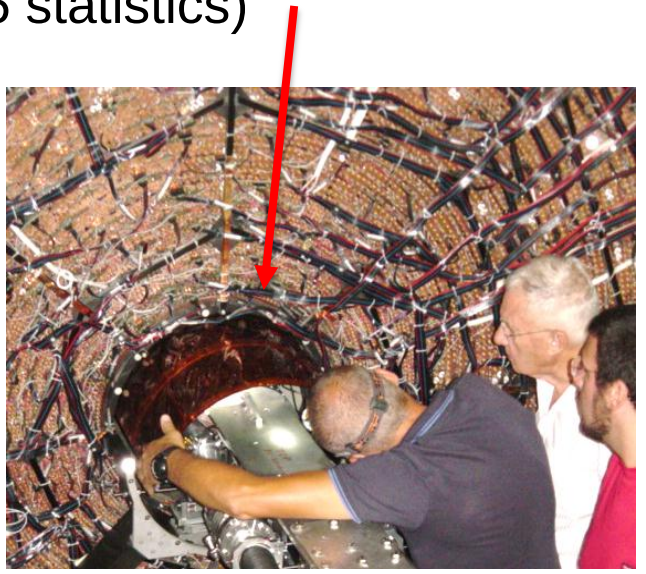
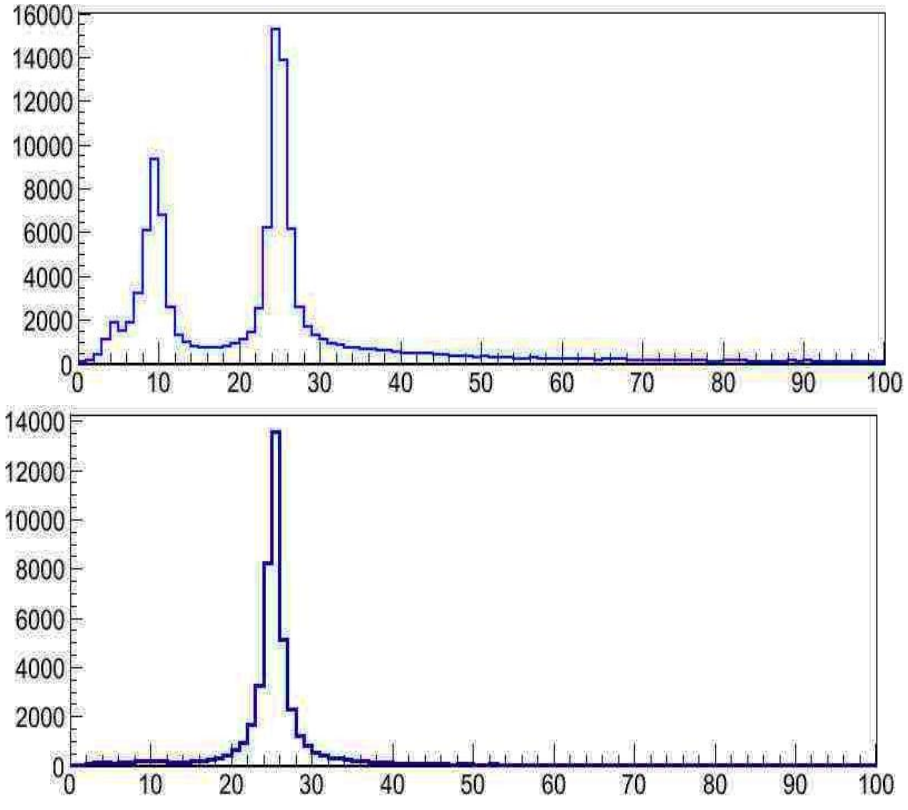


Position of the K^- hadronic interaction inside KLOE:



2005 data

2012 with Carbon target

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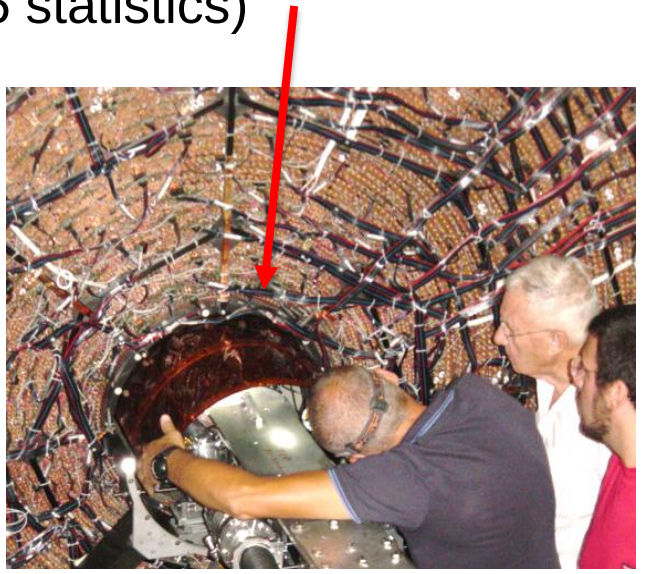

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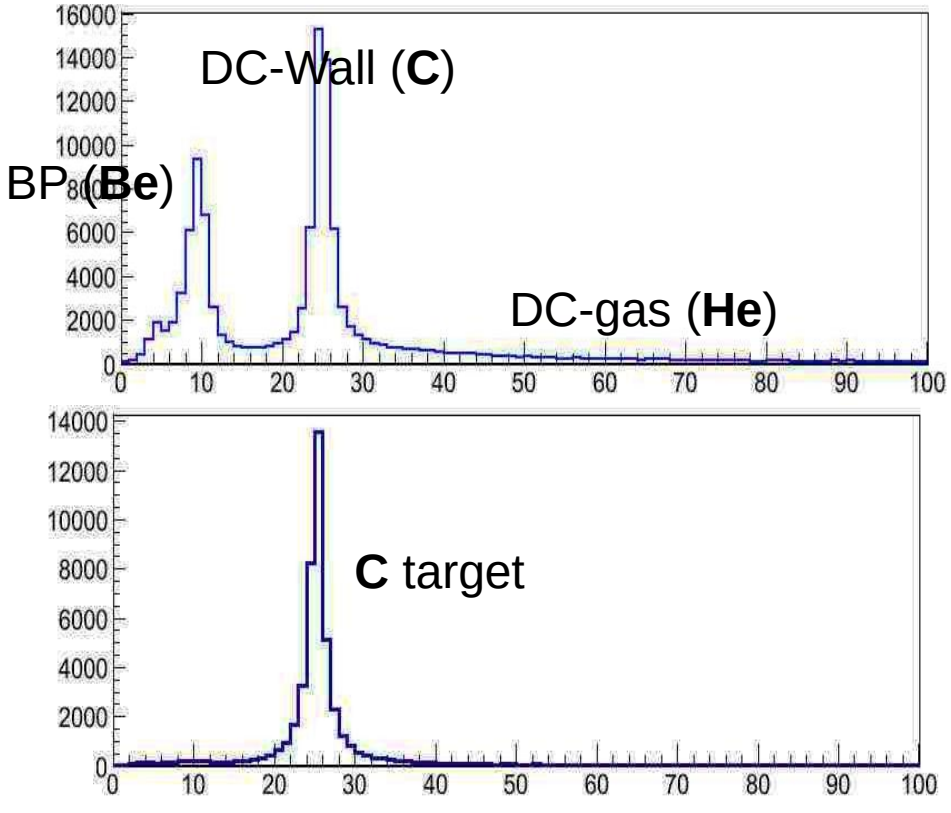


2005 data

2012 with Carbon target

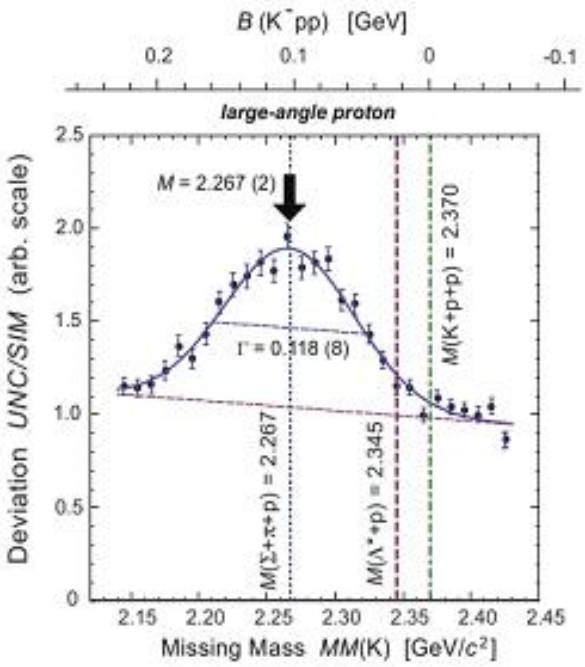
Λp analysis

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

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



Nucl.Phys.A835, 43 (2010)

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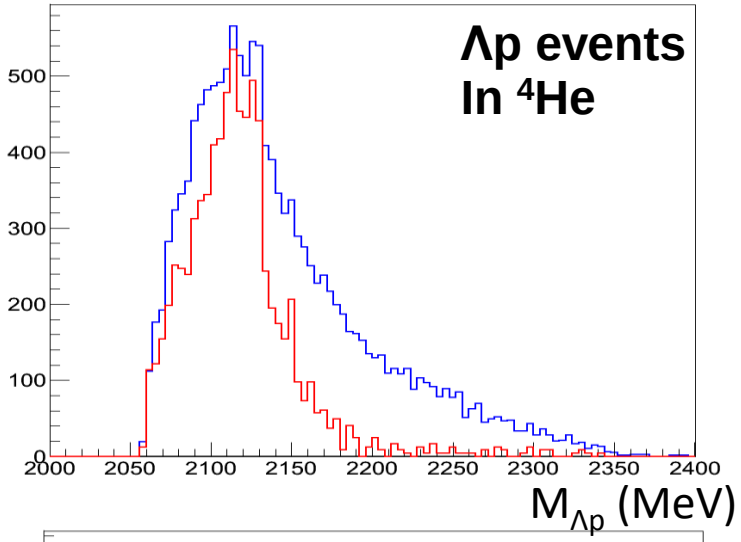
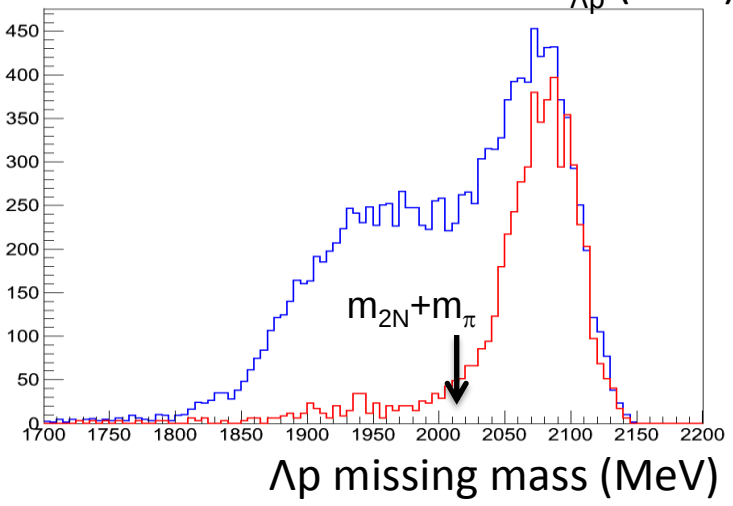
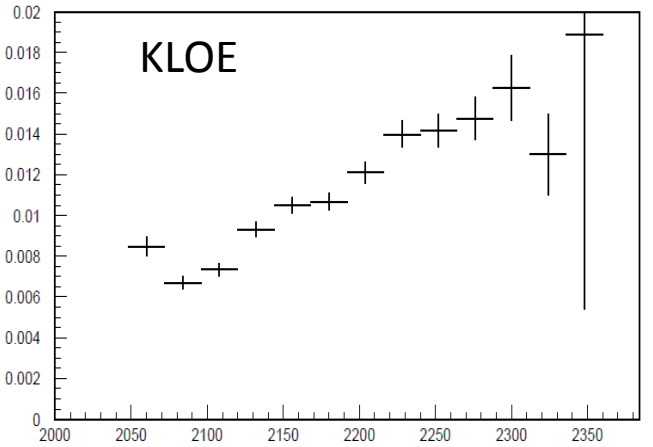


Λp all events
Λπ⁻(p) events
(arbitrary normalization)

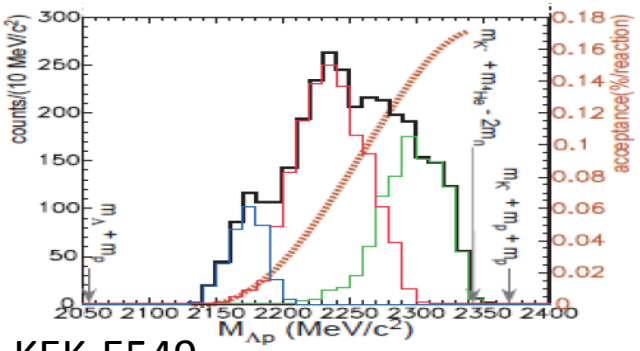


The Λp missing mass for the Λπ⁻(p) events lies exactly In the 2N+π⁻ mass region

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



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

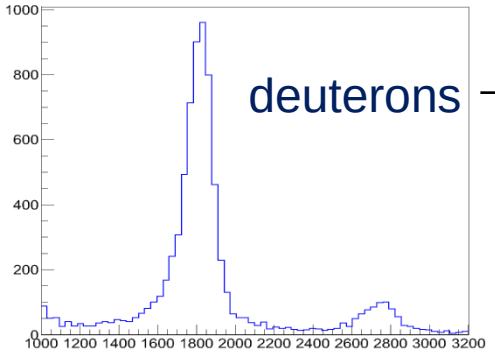


KEK-E549

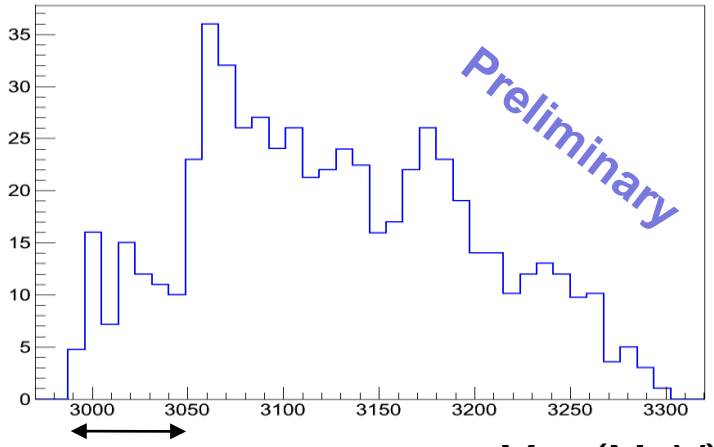
Mod.Phys.Lett.A23, 2520 (2008)

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.



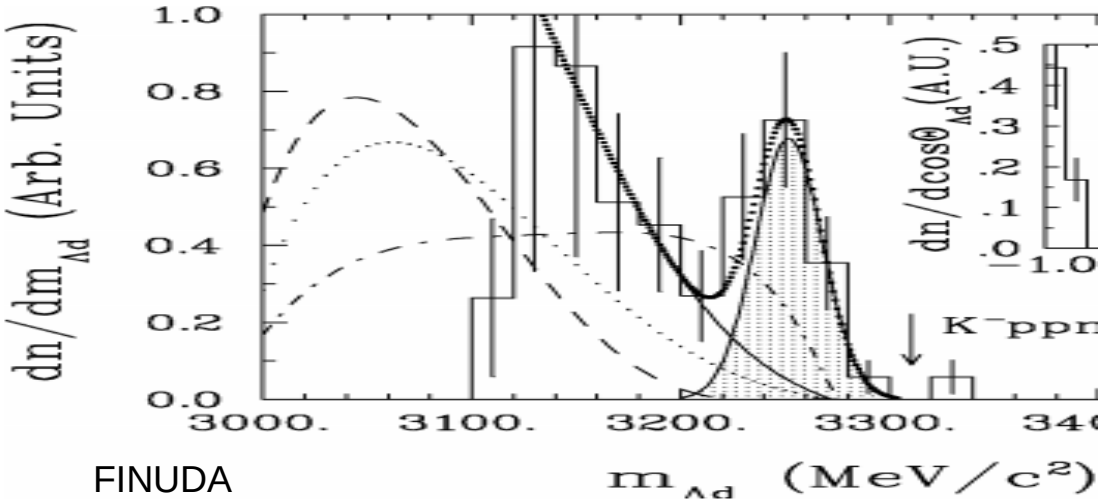
TOF Particle Mass (MeV)



low accept. region

$M_{\Lambda d}$ (MeV)

Λd events In ^{4}He



FINUDA
Nucl.Phys.A835, 43 (2010)

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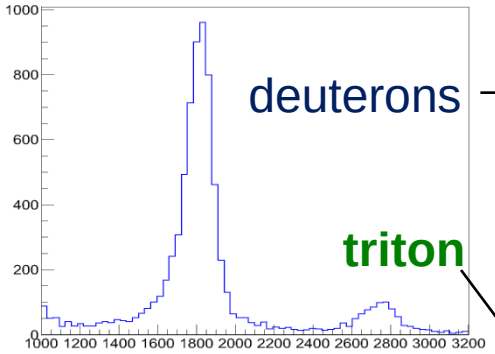
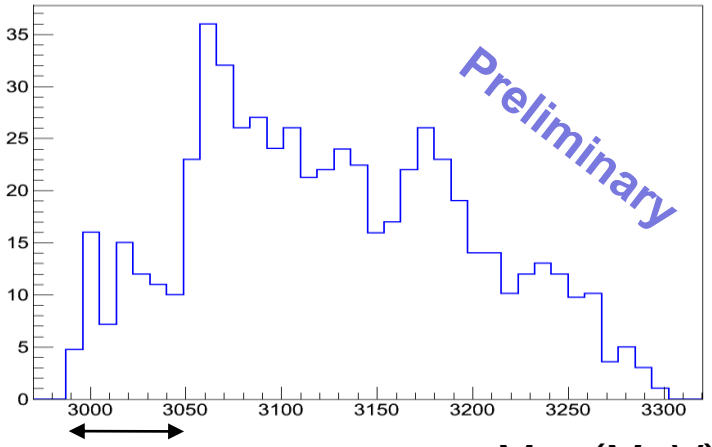
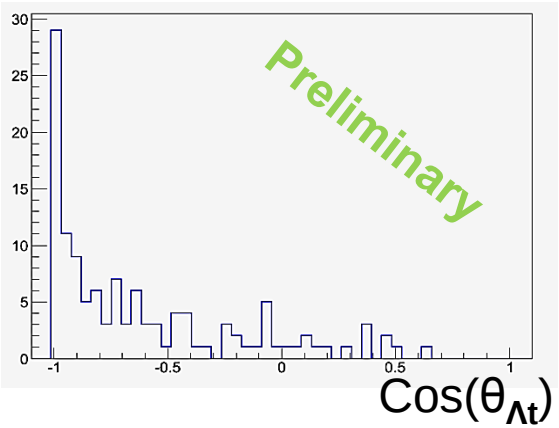


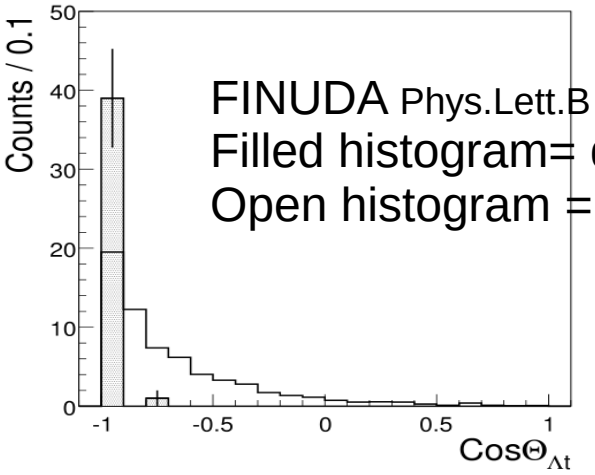


Λd events
In ^{4}He

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

Λt events
In ^{4}He





FINUDA Phys.Lett.B 229, 229 (2008)
Filled histogram= data
Open histogram = Phase space simulation

Λ(1405) scientific case

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

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

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

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

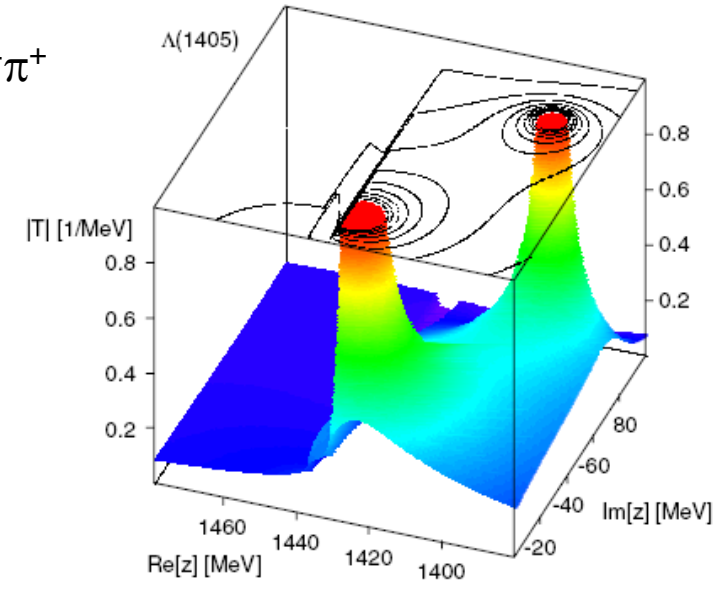
3) ***unstable* KN *bound state***

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 : $\Sigma^0\pi^0$ $\Sigma^+\pi^-$ $\Sigma^-\pi^+$



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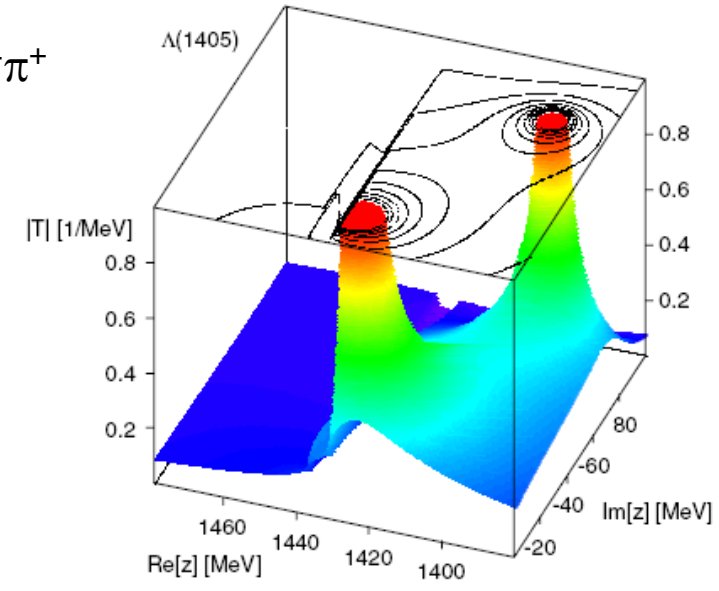
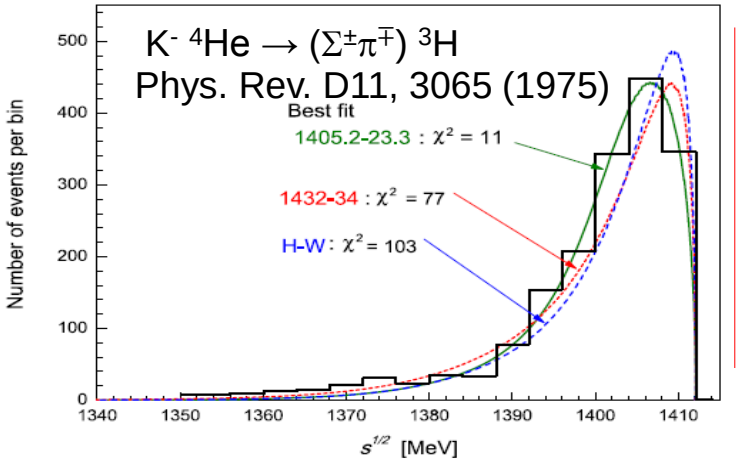
BEST CHOICE:

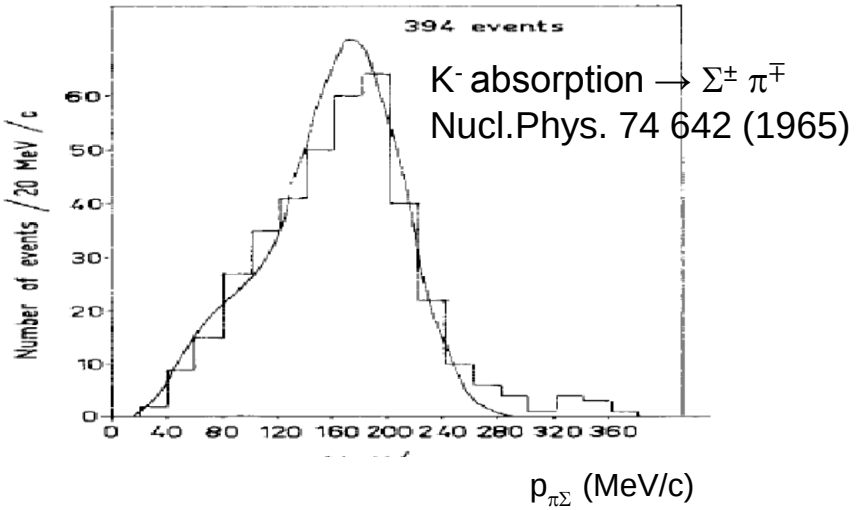
production in KN reactions (only chance to observe the high mass pole) **decaying in $\Sigma^0\pi^0$** (free from $\Sigma(1385)$ background)



Λ(1405) previous experiments

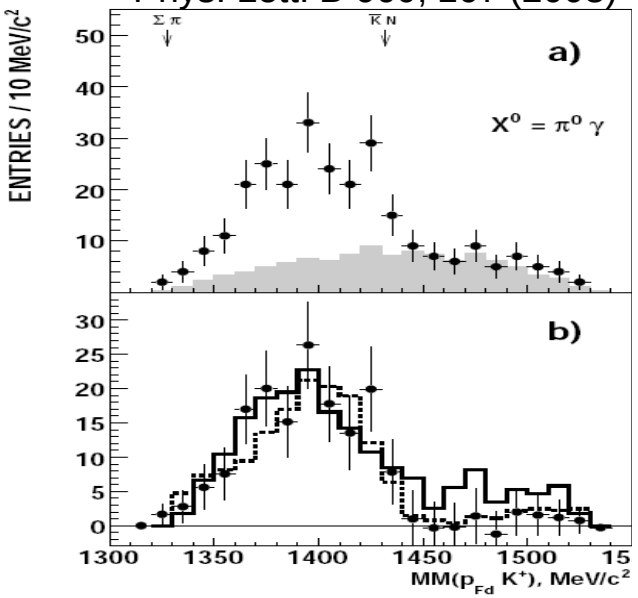
Old **absorption experiments:**
-$M_{\pi\Sigma}$ spectra always cut at the atrest limit
-$\Sigma^{\pm}\,\pi^{\mp}$ spectra suffer Σ(1385)contamination



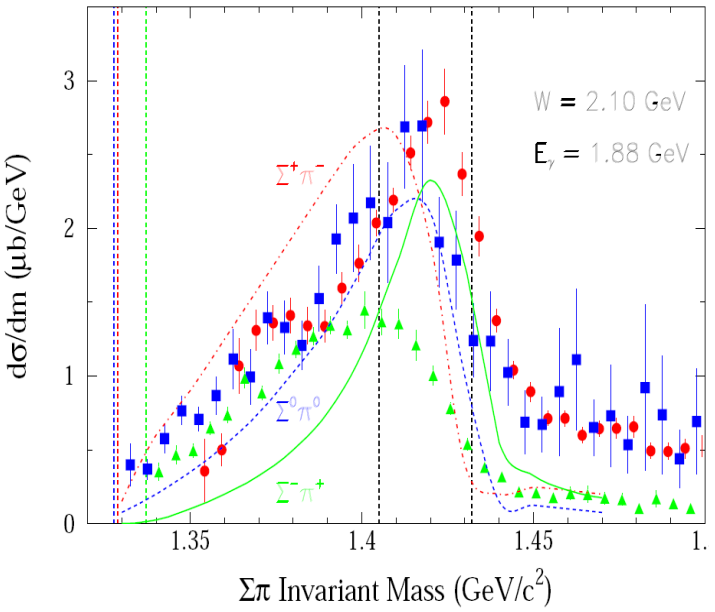


Other (**non-absorption**) experiments present spectra in the $\Sigma^0\,\pi^0$ channel (only three experiments…with different lineshapes!):

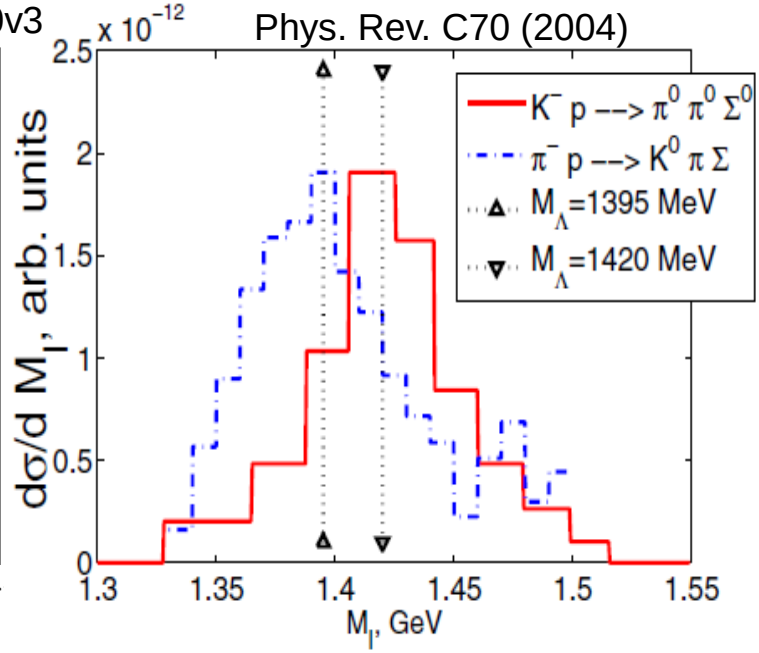
Phys. Lett. B 660, 167 (2008)



CLAS Collaboration, ArXiv:1301.5000v3



Phys. Rev. C70 (2004)

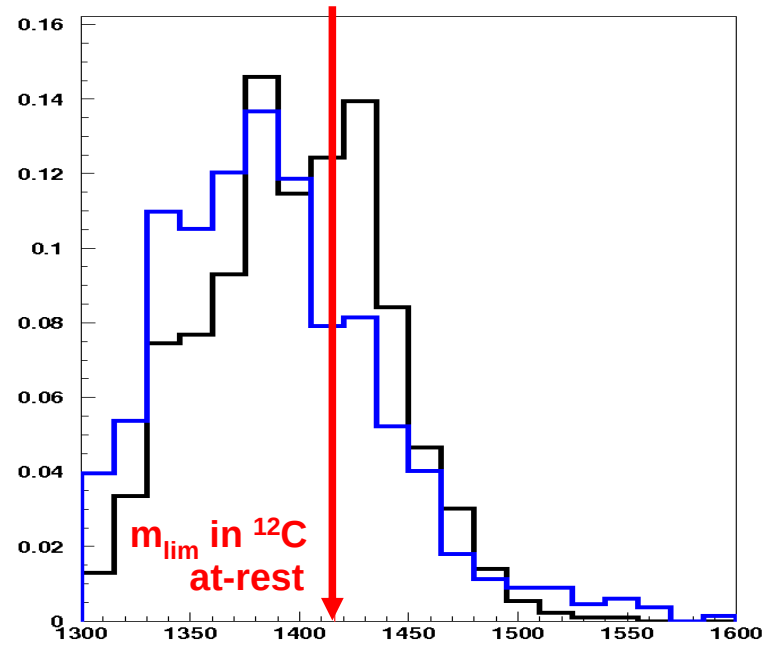


Analysis of $\Sigma^0\pi^0$ channel

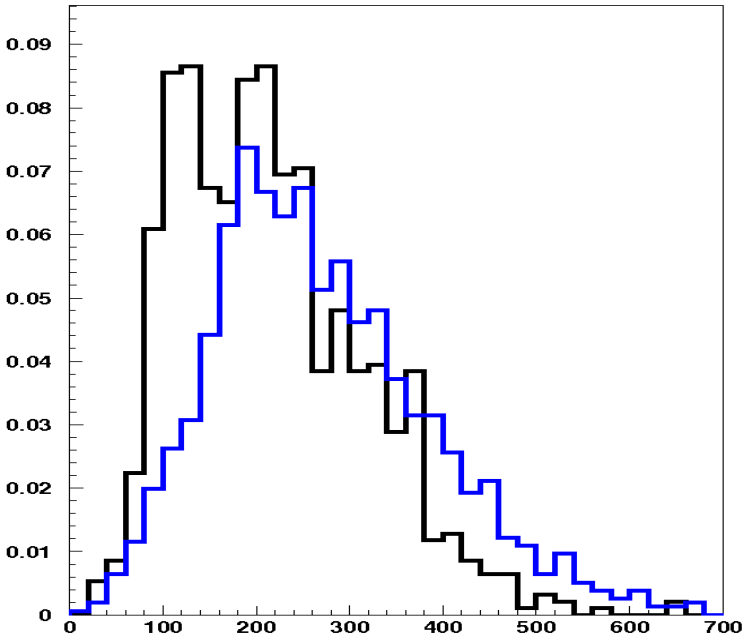
$\Lambda(1405)$ signal searched by K^- interaction with a **bound proton** in Carbon

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

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

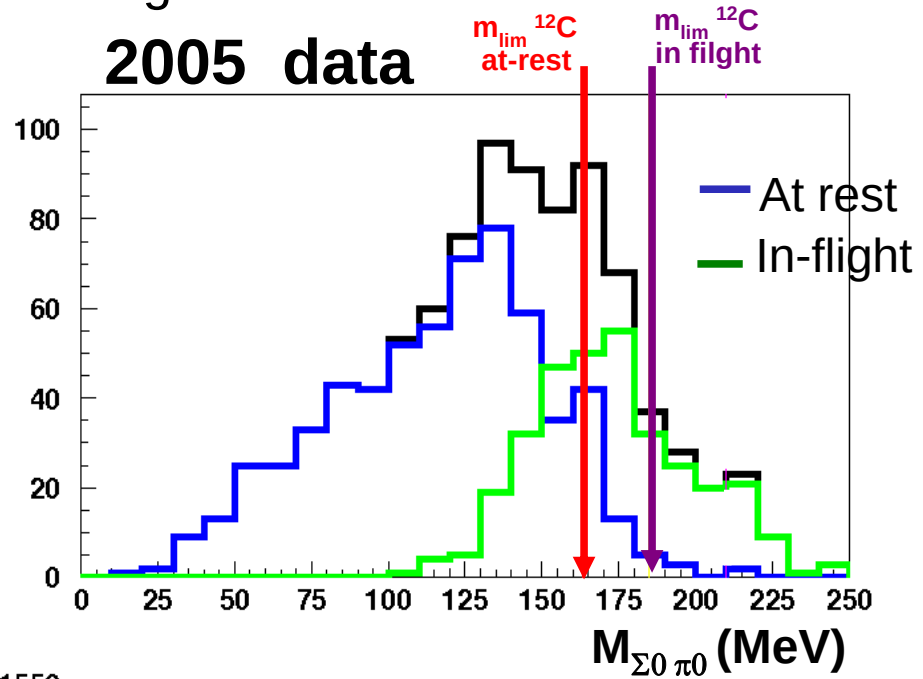
— 2012
Carbon target

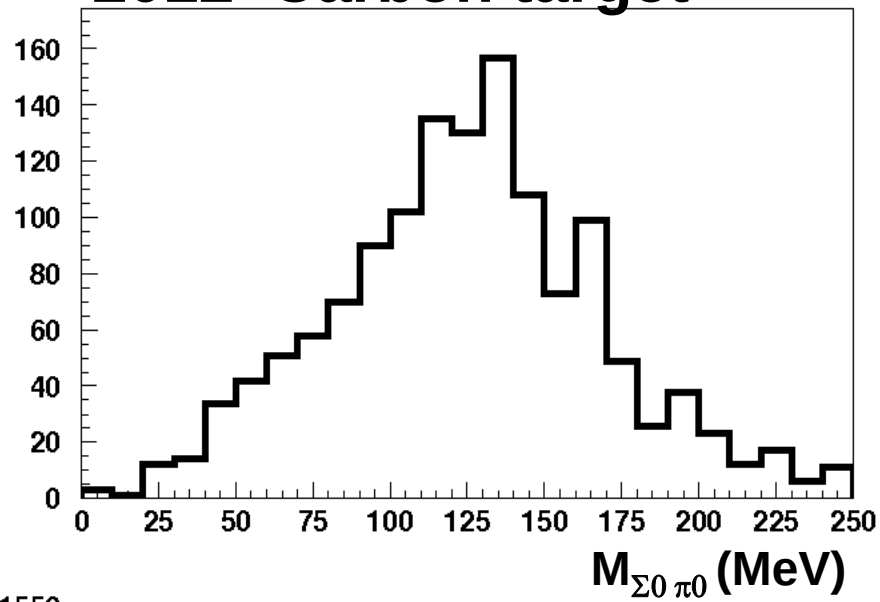
$m_{\pi 0 \Sigma 0}$ **resolution** $\sigma_m \approx 32$ MeV/c^2 ; $p_{\pi 0 \Sigma 0}$ **resolution**: $\sigma_p \approx 20$ MeV/c.

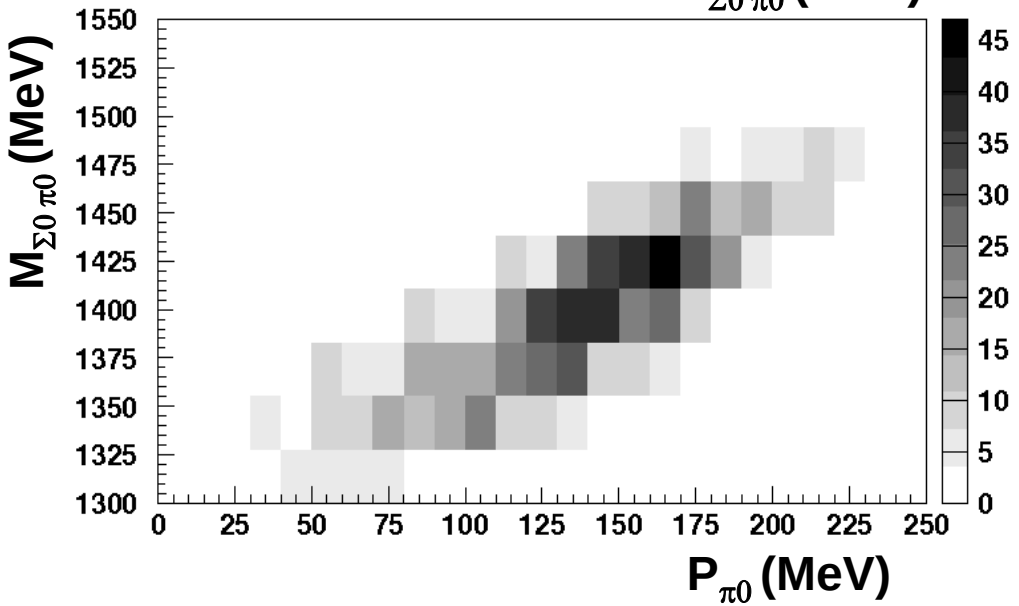
Negligible ($\Lambda\pi^0$ + internal conversion) background =(3±1)%, no I=1 contamination

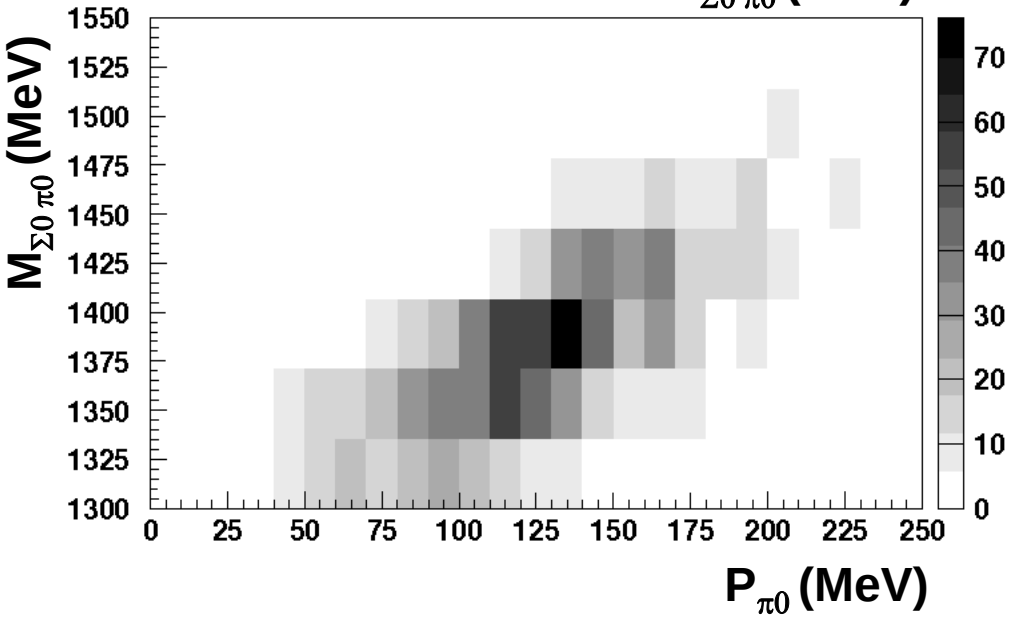
Analysis of $\Sigma^0\pi^0$ channel

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





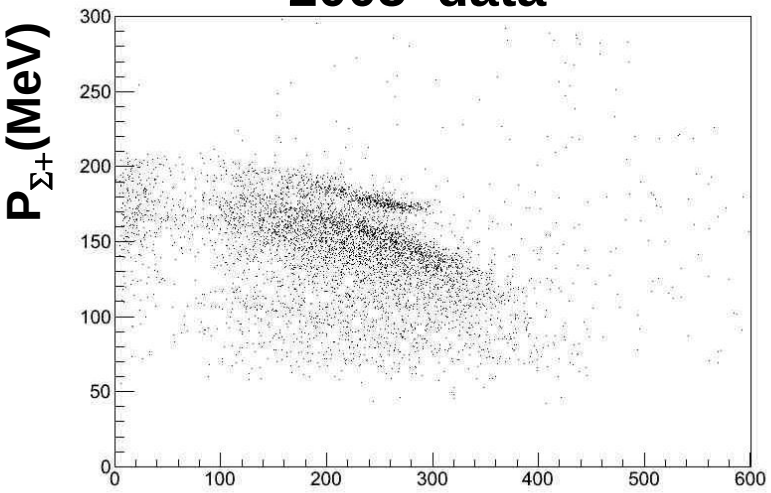




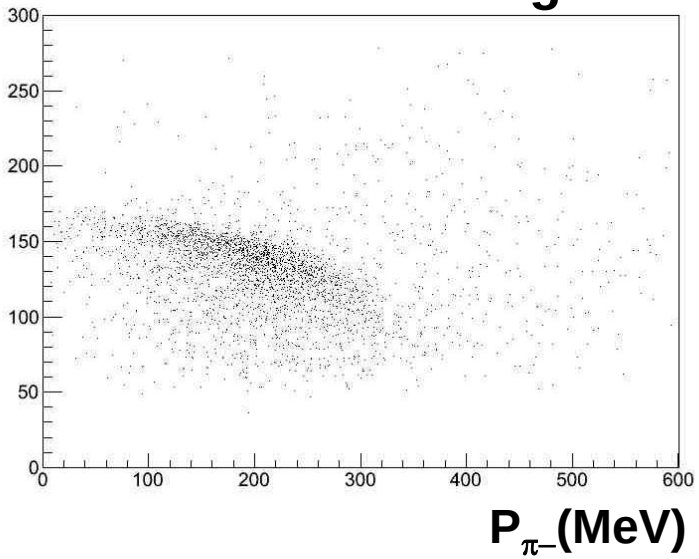
Λ(1405) charged channel: $\Sigma^+\pi^-$

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

2005 data



2012 Carbon target



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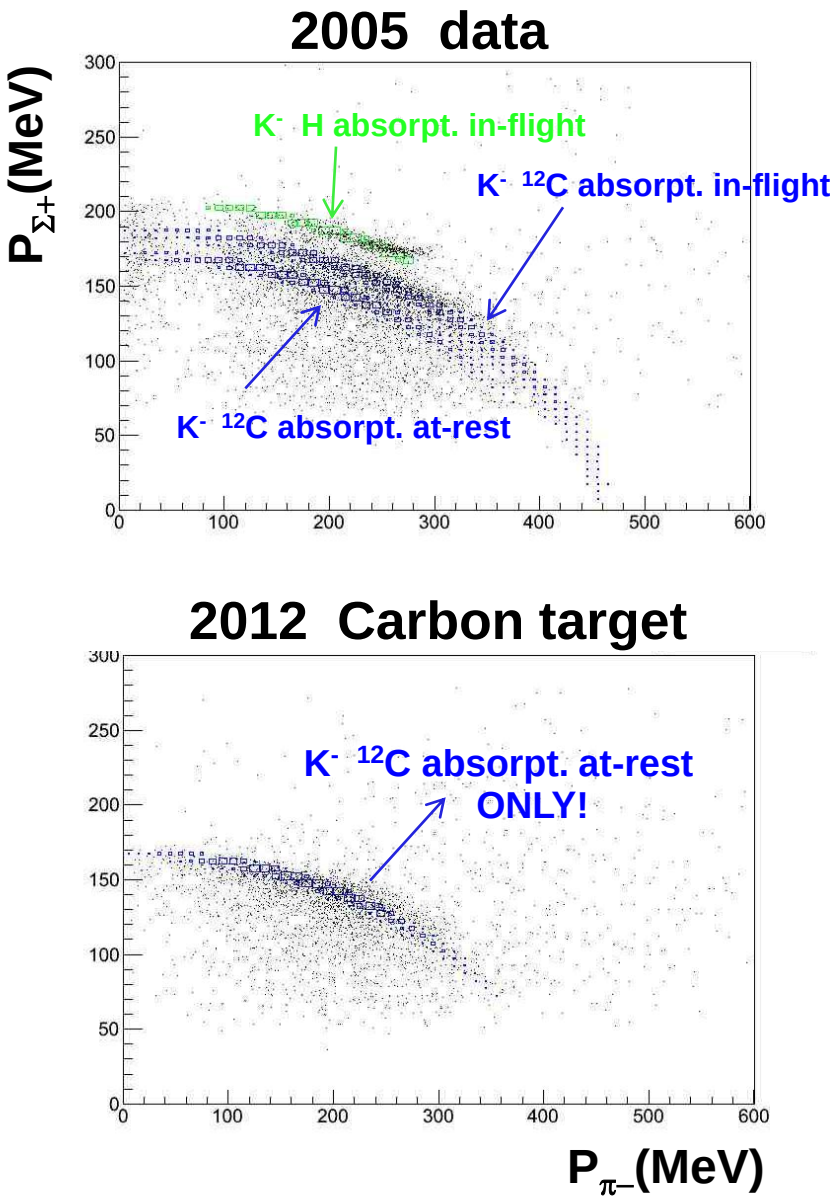

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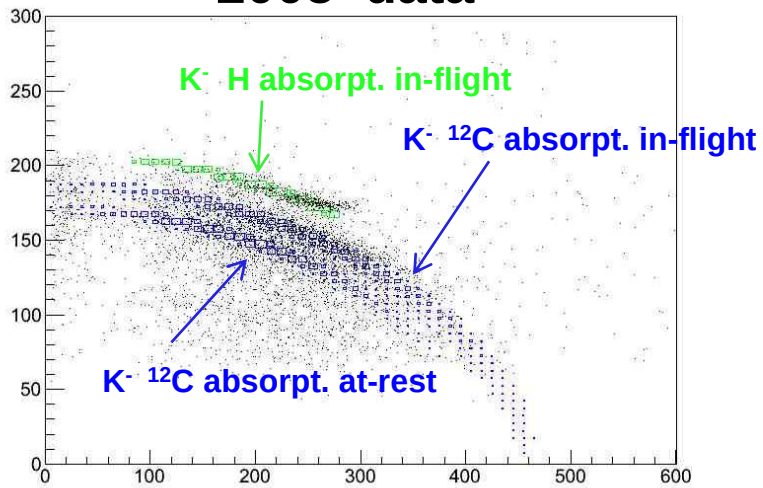

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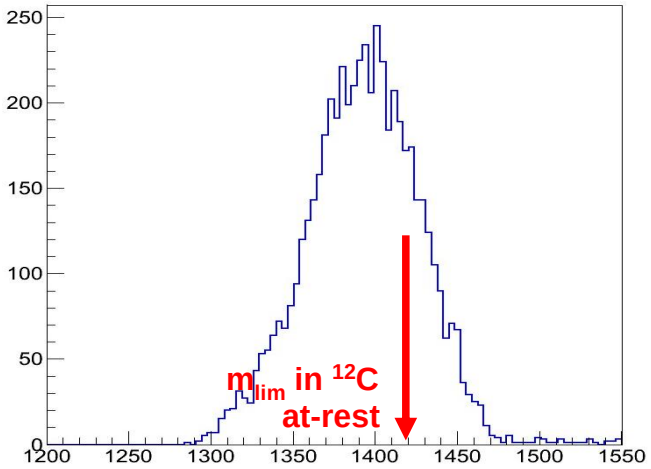

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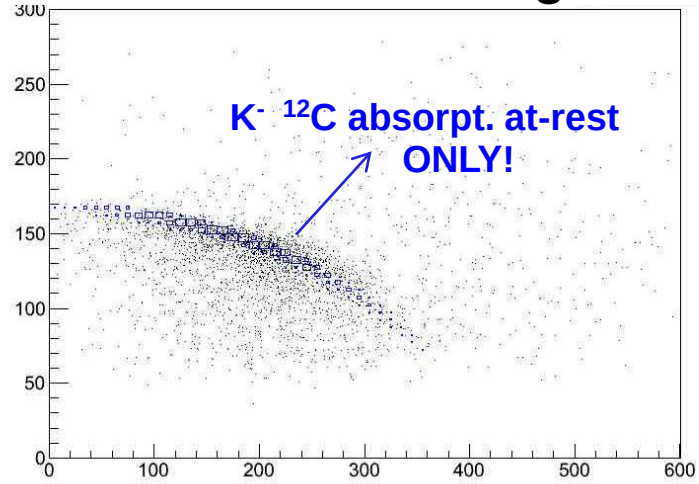

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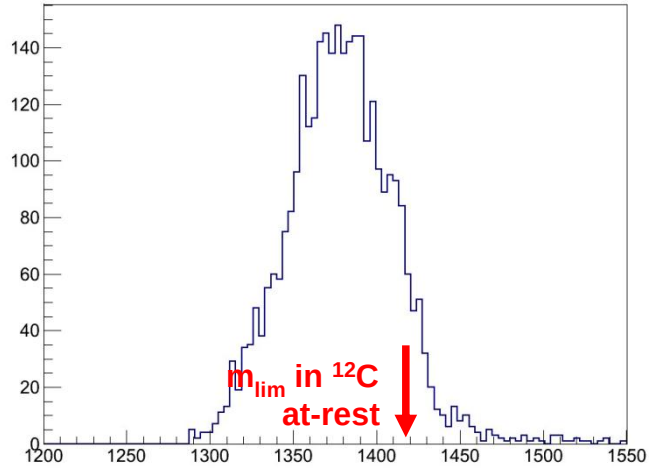
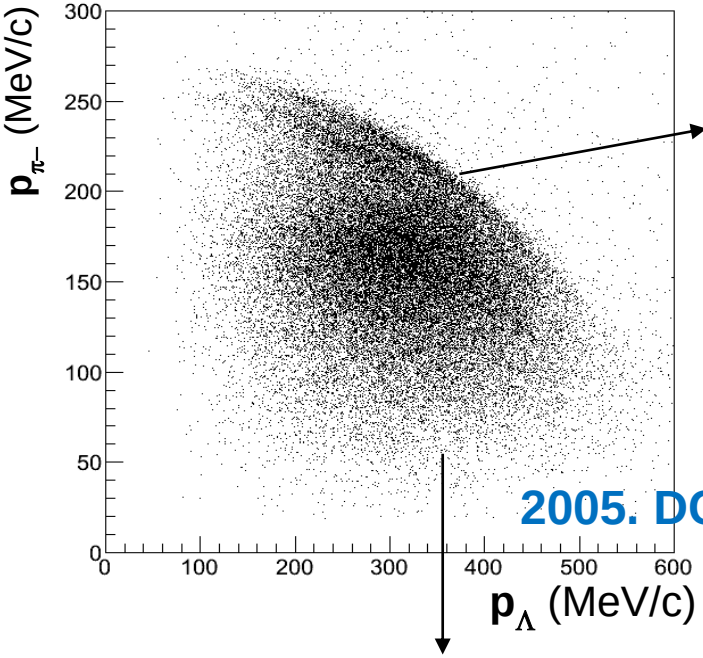


Σ/Λ conversion in the nuclear medium

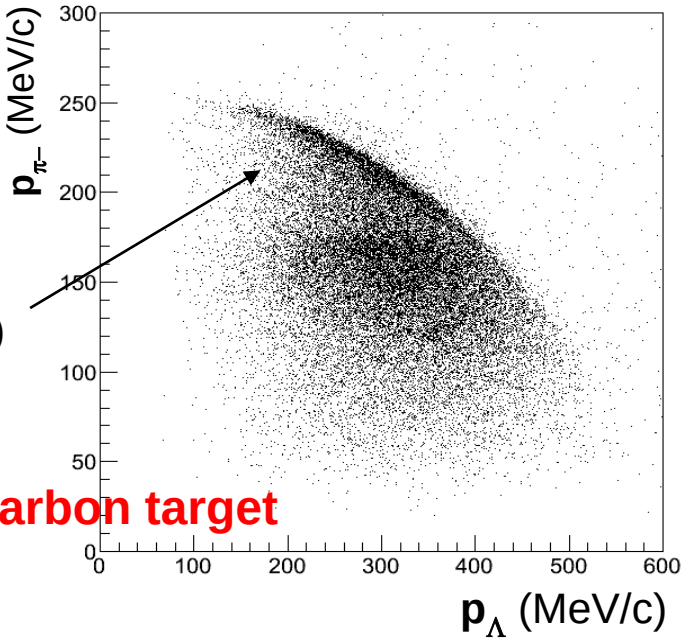
- **Λπ⁻ analysis:** 1N absorption process **$K^- N \rightarrow Y\pi^-$**

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

We thank to all the KLOE Collaboration for this great opportunity!

Special thanks to

Paolo Franzini, Juliet Lee Franzini, Antonio Di Domenico, Barbara Sciascia, Filippo Ceradini, Antonio de Santis, Erika de Lucia, Vincenzo Patera, Simona Giovannella, Paolo Santangelo

Fabio Bossi, Stefano Miscetti, Caterina Bloise

KLONE team

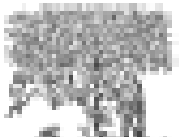
Many thanks also to:

- Alessandra Filippi and Stefano Piano
-The DAFNE team
-Giancarlo Sensolini

SIDDHARTA

The first Kd paper of SIDDHARTA

determined the upper limit of Kd K-transitions yields



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Upper limit of Kd(2→1) yield < 0.4% (CL 90%)

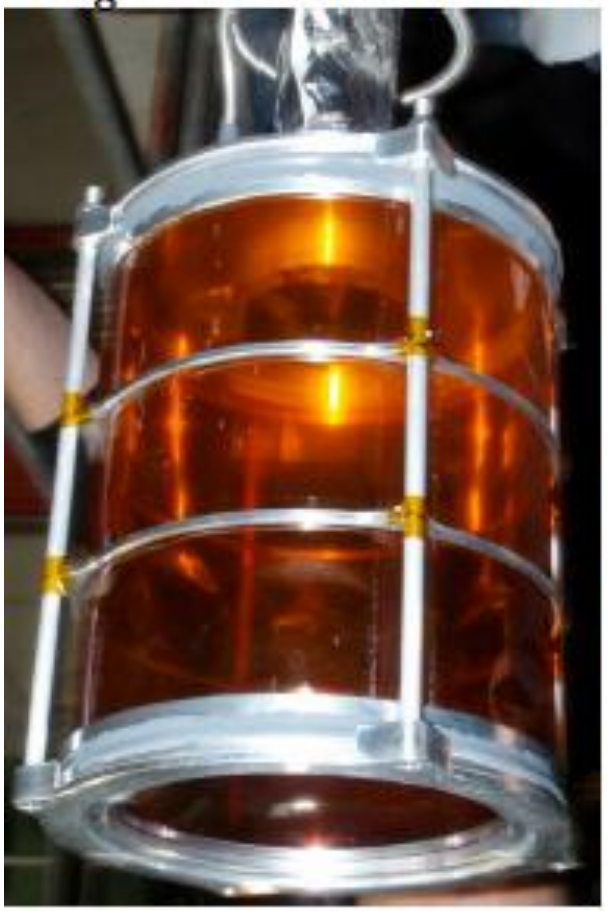
Preliminary study of kaonic deuterium X-rays by the SIDDHARTA experiment at DAΦNE

M. Bazzi [a], G. Beer [b], C. Berucci [c,a], L. Bombelli [d], A.M. Bragadireanu [a,e], M. Cargnelli [c,a], C. Curceanu (Petrascu) [a] A. d'Uffizi [a], C. Fiorini [d], T. Frizzi [d], F. Ghio [f], C. Guaraldo [a], R. Hayano [g], M. Iliescu [a], T. Ishiwatari [c], M. Iwasaki [h], P. Kienle [c,i,1], P. Levi Sandri [a], A. Longoni [d], J. Marton [c], S. Okada [h], D. Pietreanu [a,e], T. Ponta [e], A. Romero Vidal [j], E. Sbardella [a], A. Scordo [a], H. Shi [g], D.L. Sirghi [a,e], F. Sirghi [a,e], H. Tatsuno [a], A. Tudorache [e], V. Tudorache [e], O. Vazquez Doce [i], E. Widmann [c], J. Zmeskal [c]

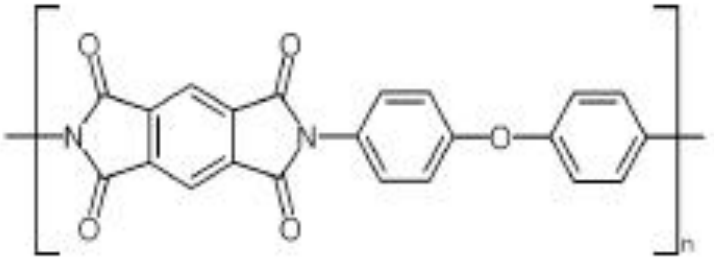
SIDDHARTA

X-ray yields of kaonic atoms in the Kapton polyimide

target cell of SIDDHARTA



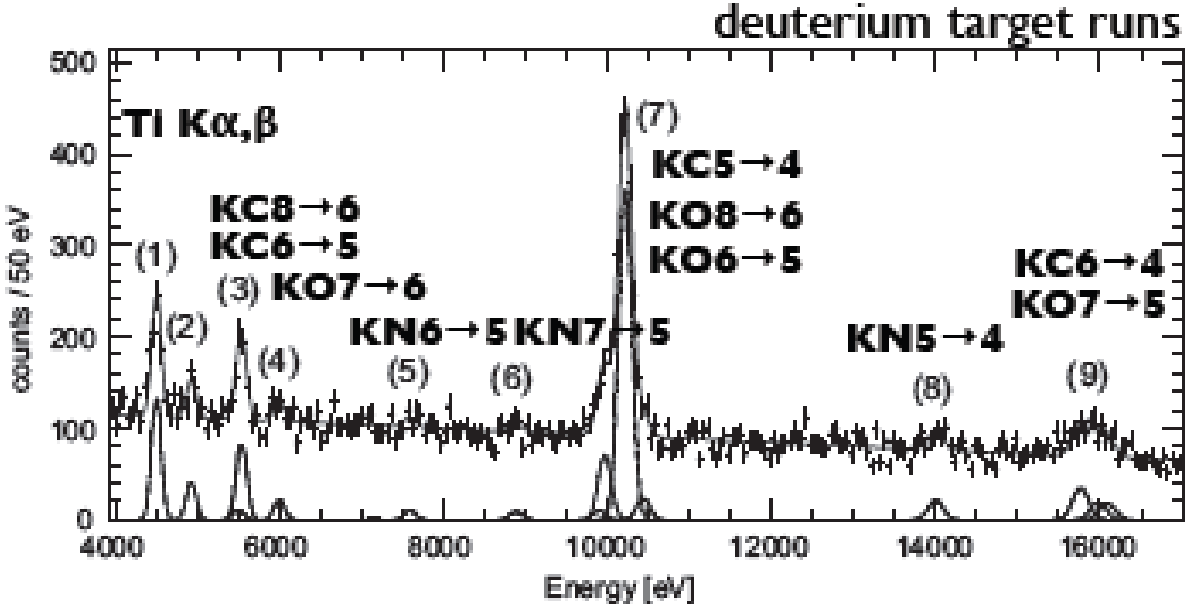
density 1.42 g/cm3 $C_{22}H_{10}O_5N_2$



kaonic Carbon, Oxygen, and Nitrogen

"solid target"

SIDDHARTA



kaonic atoms X-rays

principle number
n = 5 to 8

Δn=1 and 2

absolute yields per stopped-K on Kapton

Transition	Energy [keV]	Yield (Y) [%]
K^-C 5 → 4	10.2165	$9.7^{+0.7}_{-2.3}$
K^-C 6 → 5	5.5449	$2.2^{+0.6}_{-0.7}$
K^-C 6 → 4	15.7594	1.3 ± 0.3
K^-C 7 → 5	8.8858	0.2 ± 0.2
K^-C 8 → 6	5.5096	0.3 ± 0.6
K^-N 5 → 4	13.9959	0.7 ± 0.2
K^-N 6 → 5	7.5954	0.2 ± 0.2
K^-O 6 → 5	9.9687	$1.8^{+0.4}_{-0.5}$
K^-O 7 → 6	6.0068	0.5 ± 0.2
K^-O 7 → 5	15.9733	0.8 ± 0.3
K^-O 8 → 6	9.9027	0.3 ± 0.3

relative yields of successive lines

$$\frac{Y(K^-\text{C } 5 \to 4)}{Y(K^-\text{C } 6 \to 5)} = 4.4 \pm 1.2$$

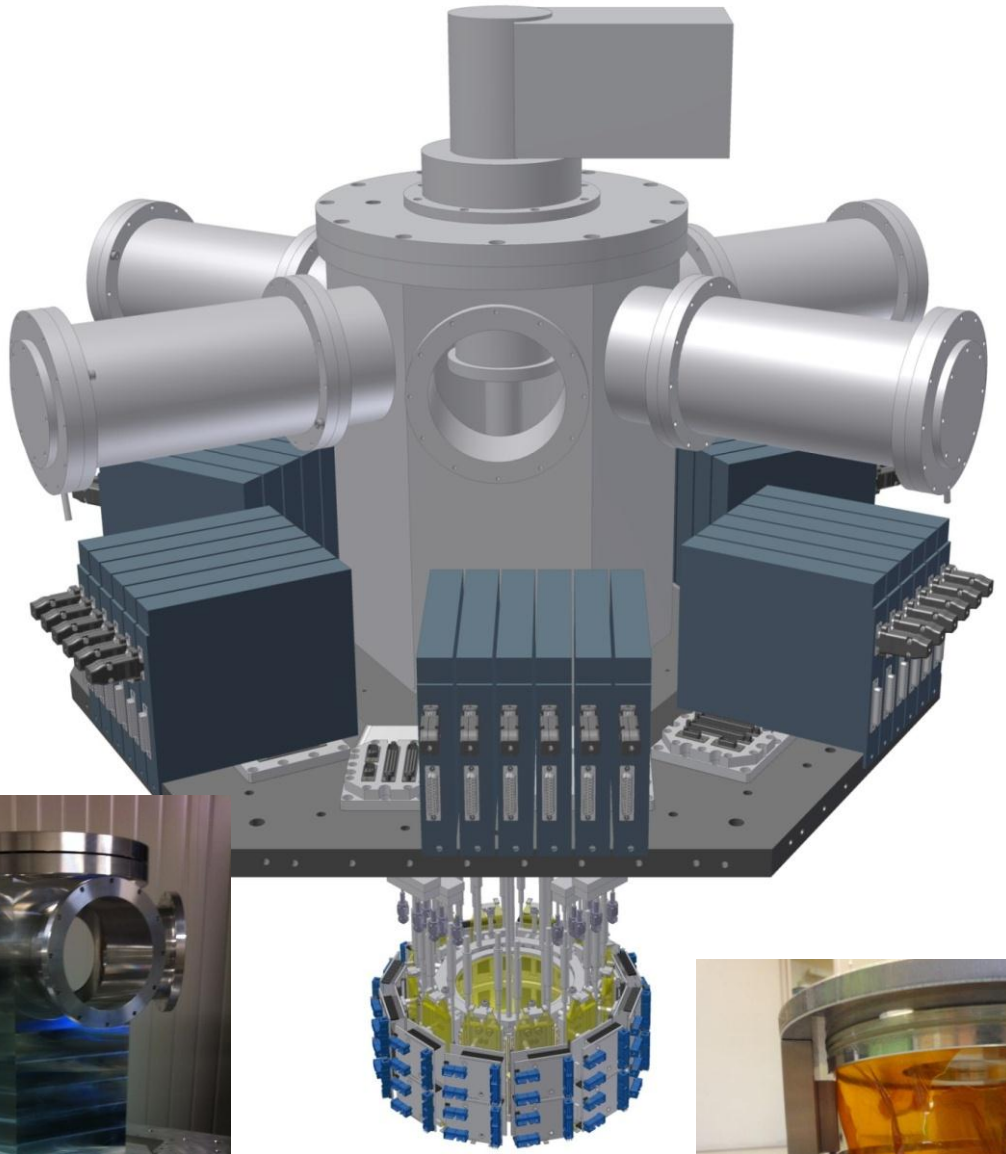
$$\frac{Y(K^-\text{N } 5 \to 4)}{Y(K^-\text{N } 6 \to 5)} = 3.0 \pm 2.1$$

$$\frac{Y(K^-\text{O } 6 \to 5)}{Y(K^-\text{O } 7 \to 6)} = 3.4 \pm 1.4$$

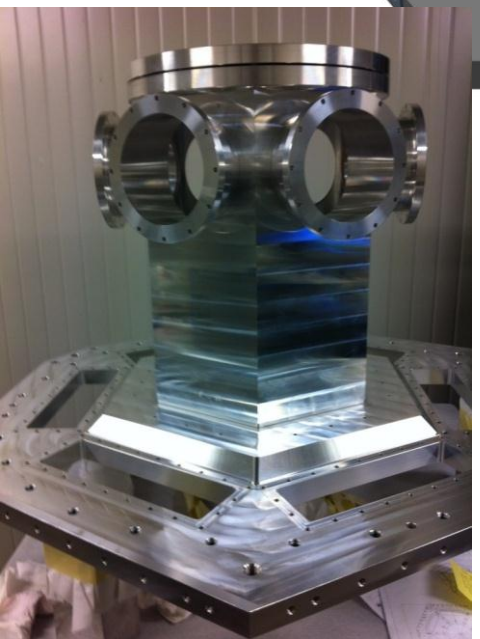
(preliminary)

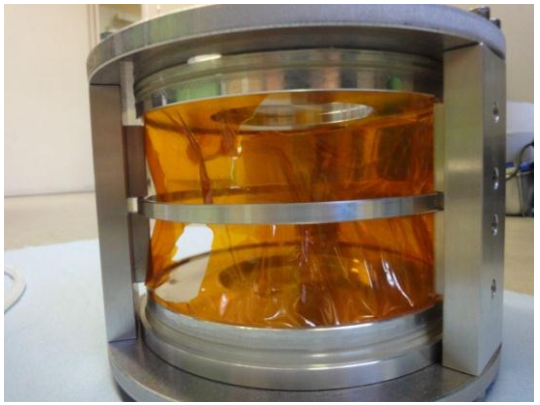
To be submitted for publication

SIDDHARTA-2: Status May 2013

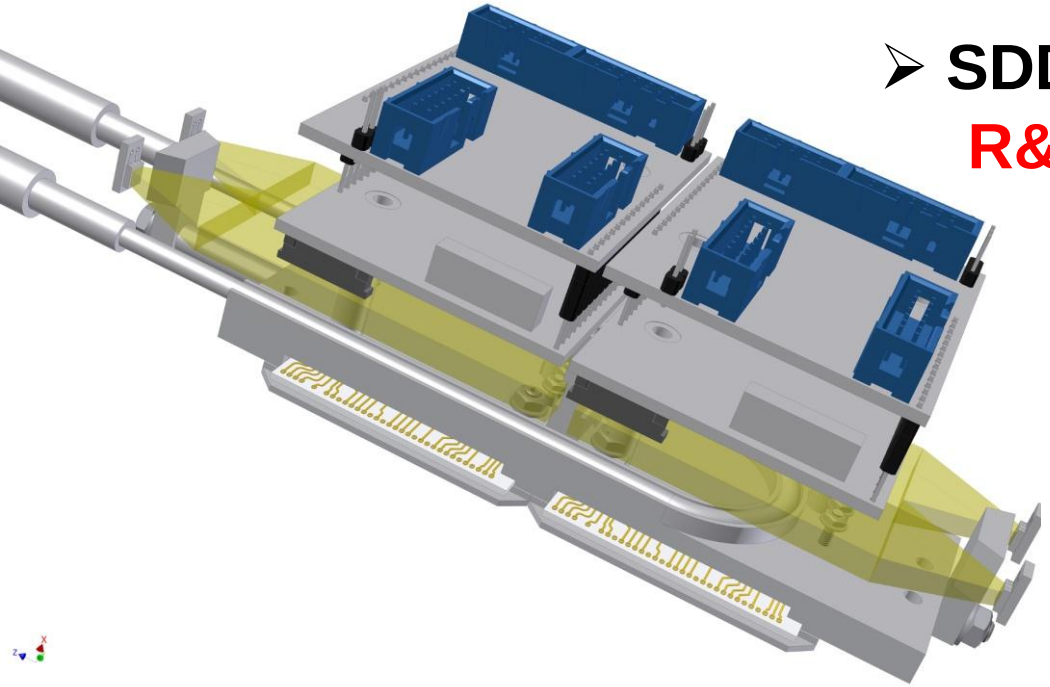


- **Vacuum chamber**
  ready and tested
- **Cryogenic target**
  ready and first cooling tests successfully
- **SDD cooling unit**
  prototype tested, components under construction

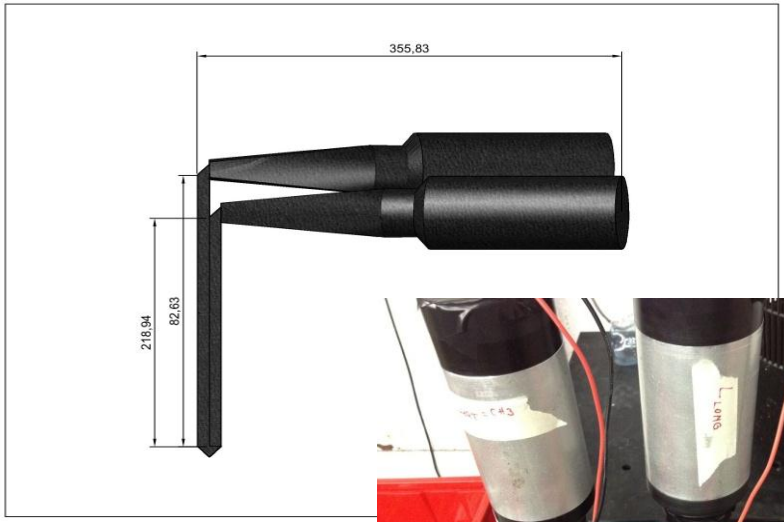


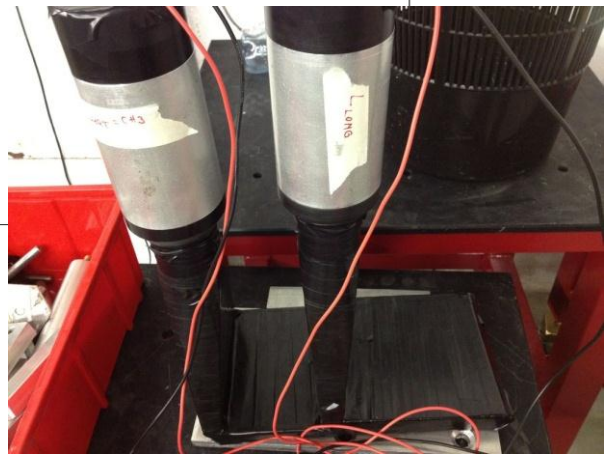


SIDDHARTA-2: Status May 2013



- SDD charge particle veto detector
  R&D finished, under construction





- VETO system
  R&D finished, under construction

SIDDHARTA-2 ready for testing with 1/3 of SDDs

- **summer 2013**

SIDDHARTA-2

Kd measurement:

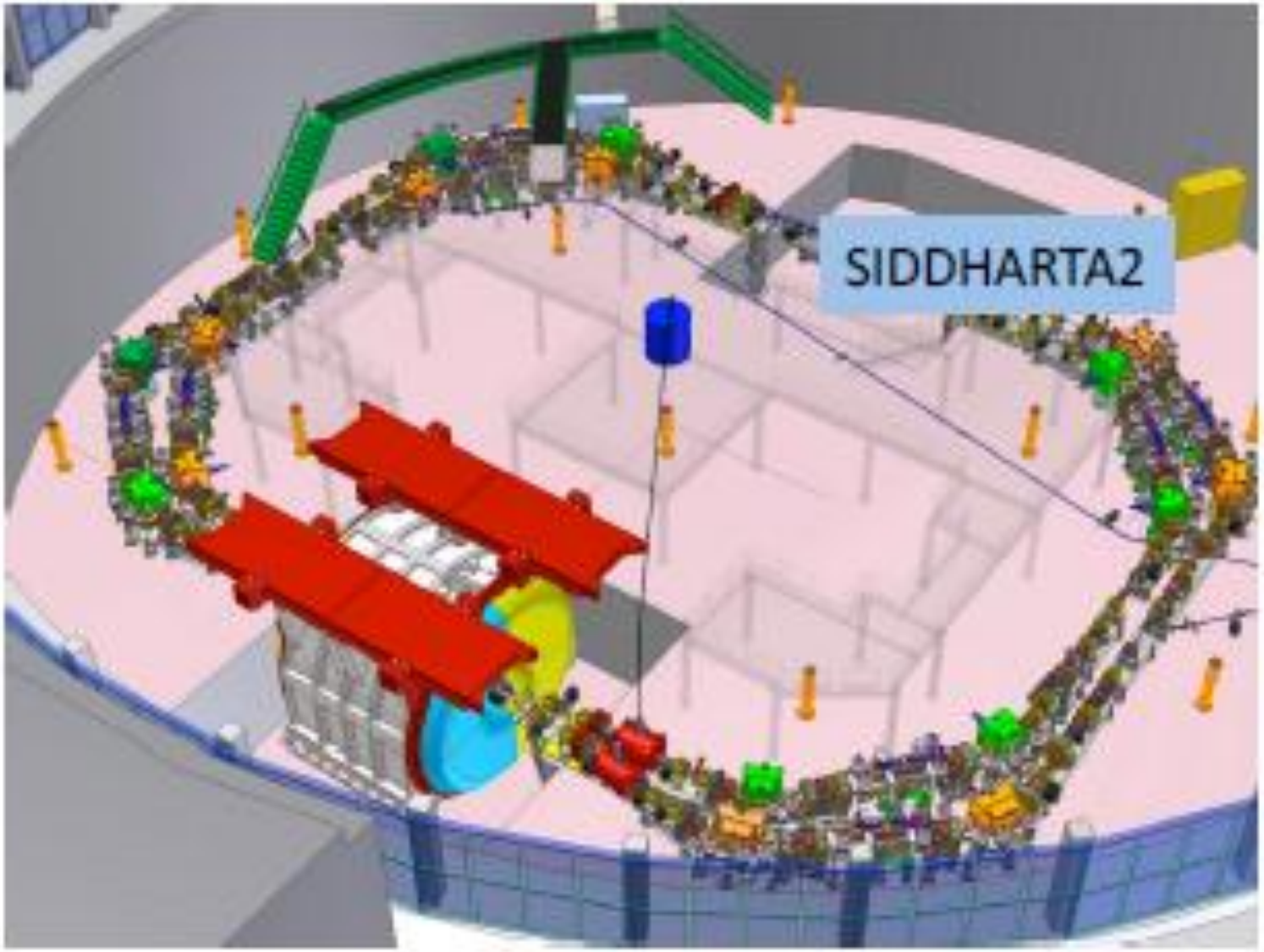
- SIDDHARTA-2 setup is going to be **ready within 2013** (compatible wit financing)
- We are confident that with an integrated luminosity of ***600 pb-1***, SIDDHARTA-2 will be able to perform a **first** X-ray measurement of the strong interaction parameters - the energy displacement and the width of the kaonic deuterium ground state, a **fundamental measurement** in low-energy strangeness QCD.
- In SIDDHARTA-like conditions this measurement would take about **4 months**

SIDDHARTA-2

REQUESTS

- to be **considered in the planning of LNF-INFN activities** (this includes support for fellowships and postdocs)
- a **concrete time schedule** for the installation of SIDDHARTA-2 at DAFNE and for the data taking

Where to install **SIDDHARTA-2**? A realistic possible scenario:



To (re)open the second IP with or without crab waist scheme