Low-energy kaon-nucleon/nuclei interaction studies at DAFNE (SIDDHARTA and AMADEUS)

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(On behalf of SIDDHARTA and AMADEUS)

LNF – INFN, Frascati

IFAE2011, Perugia, 27-29 April 2011

DAFNE

$e^- e^+$ collider

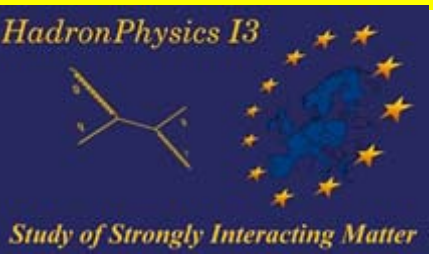
- $\Phi \rightarrow K^- K^+$ (49.1%)
- **Monochromatic low-energy K^-** (~127MeV/c)
- **Less hadronic background due to the beam**

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

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

SIDDHARTA

SIlicon Drift Detector for Hadronic Atom Research by Timing Applications



- LNF- INFN, Frascati, Italy
- SMI- ÖAW, Vienna, Austria
- IFIN – HH, Bucharest, Romania
- Politecnico, Milano, Italy
- MPE, Garching, Germany
- PNSensors, Munich, Germany
- RIKEN, Japan
- Univ. Tokyo, Japan
- Victoria Univ., Canada

EU Fundings: JRA10 – FP6 - I3HP
Network WP9 – LEANNIS – FP7- I3HP2

The scientific aim

the determination of the ***isospin dependent*** $\bar{K}N$ ***scattering lengths*** through a

~ precision measurement of the shift
and *of the width*

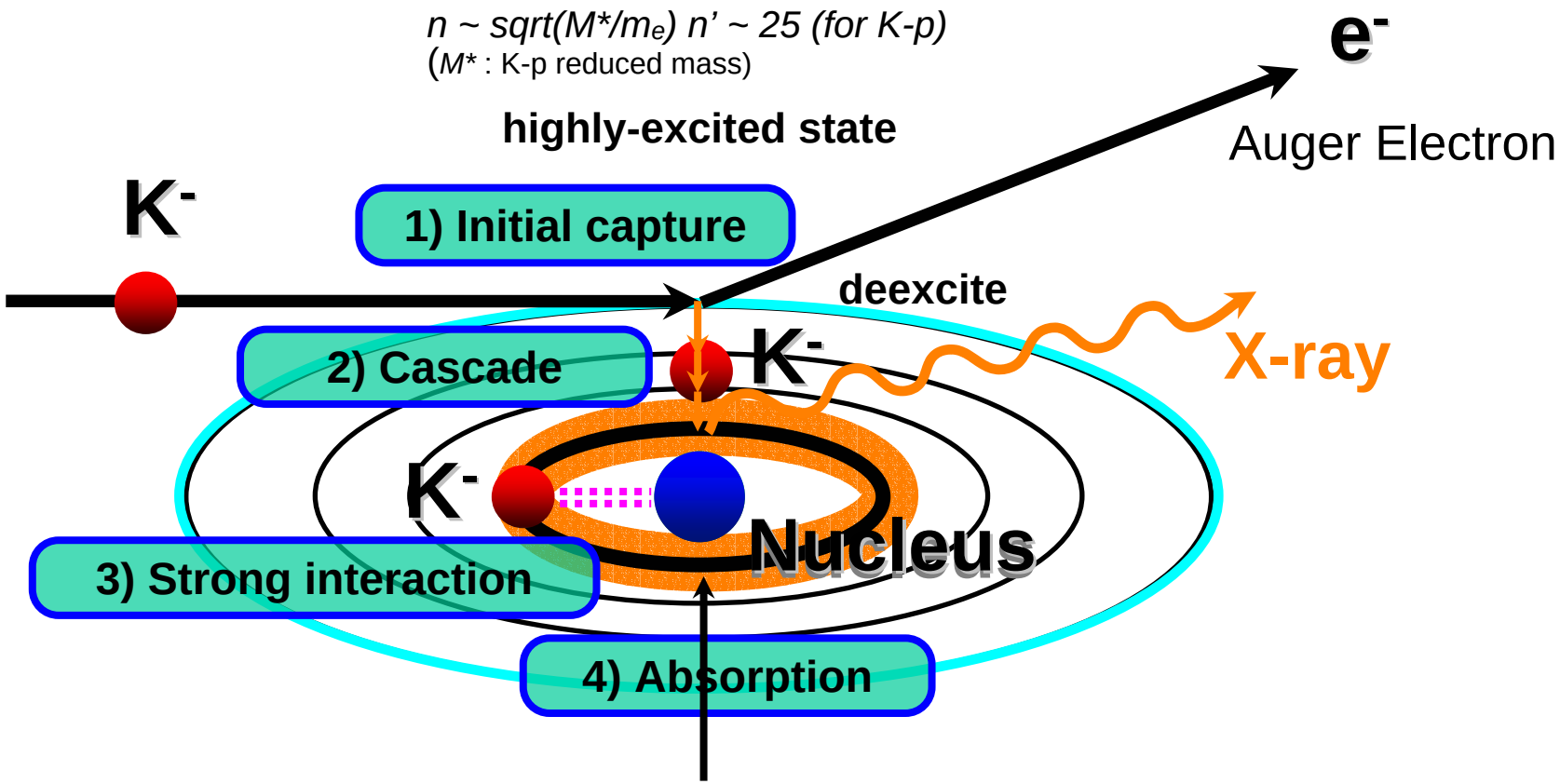
of the K_α line of **kaonic hydrogen**

and

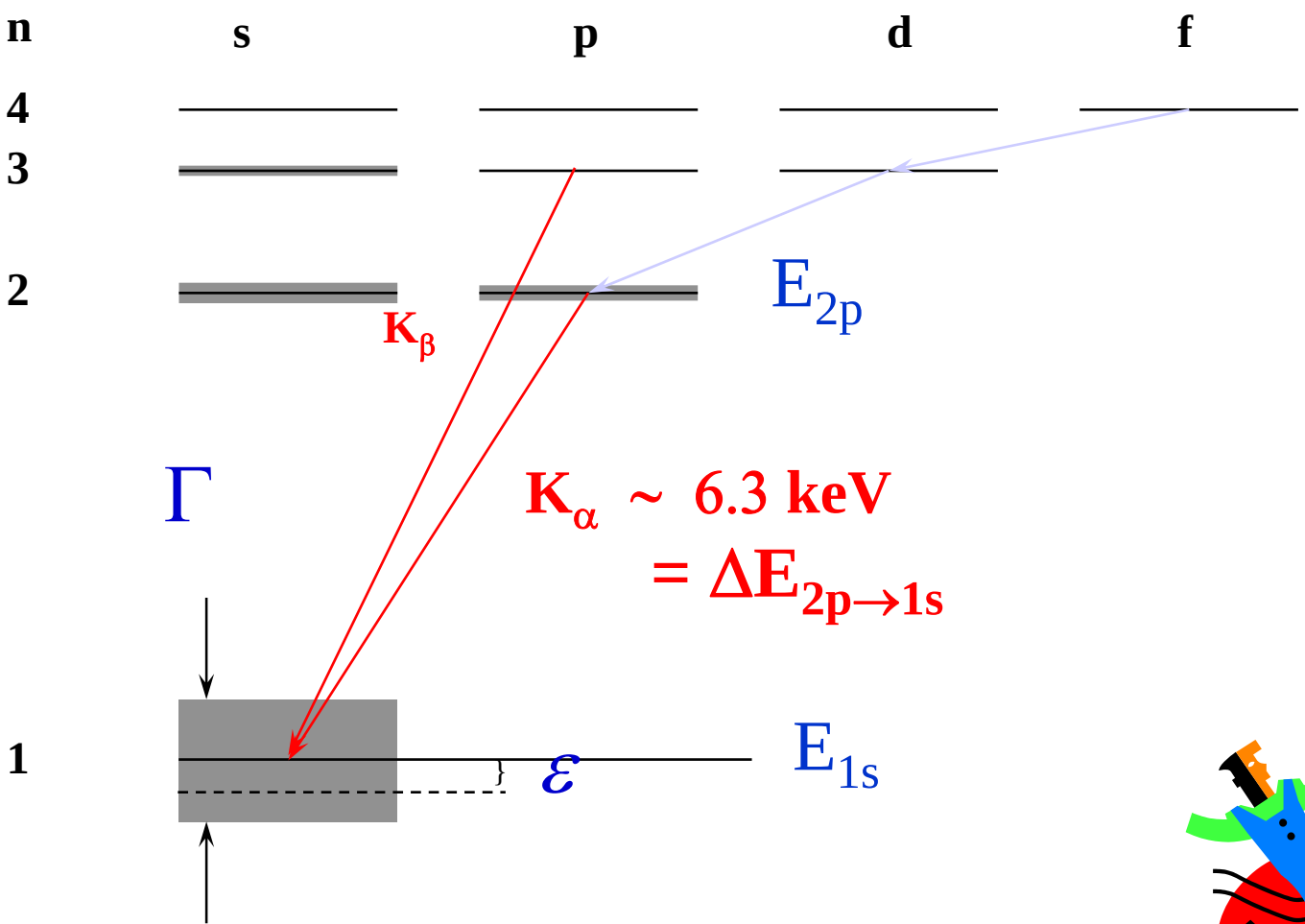
the *first measurement* of **kaonic deuterium**

Measurements of kaonic Helium as well (2p level)

Kaonic atom formation



Kaonic cascade and the strong interaction



Antikaon-nucleon scattering lengths

Once the shift and width of the 1s level for kaonic hydrogen and deuterium are measured -) scattering lengths

(isospin breaking corrections):

$$\varepsilon + i\,\Gamma/2 \Rightarrow a_{K^-p}\ \text{eV fm}^{-1}$$

$$\varepsilon + i\,\Gamma/2 \Rightarrow a_{K^-d}\ \text{eV fm}^{-1}$$

one can obtain the isospin dependent antikaon-nucleon scattering lengths

$$a_{K^-p} = (a_0 + a_1)/2$$

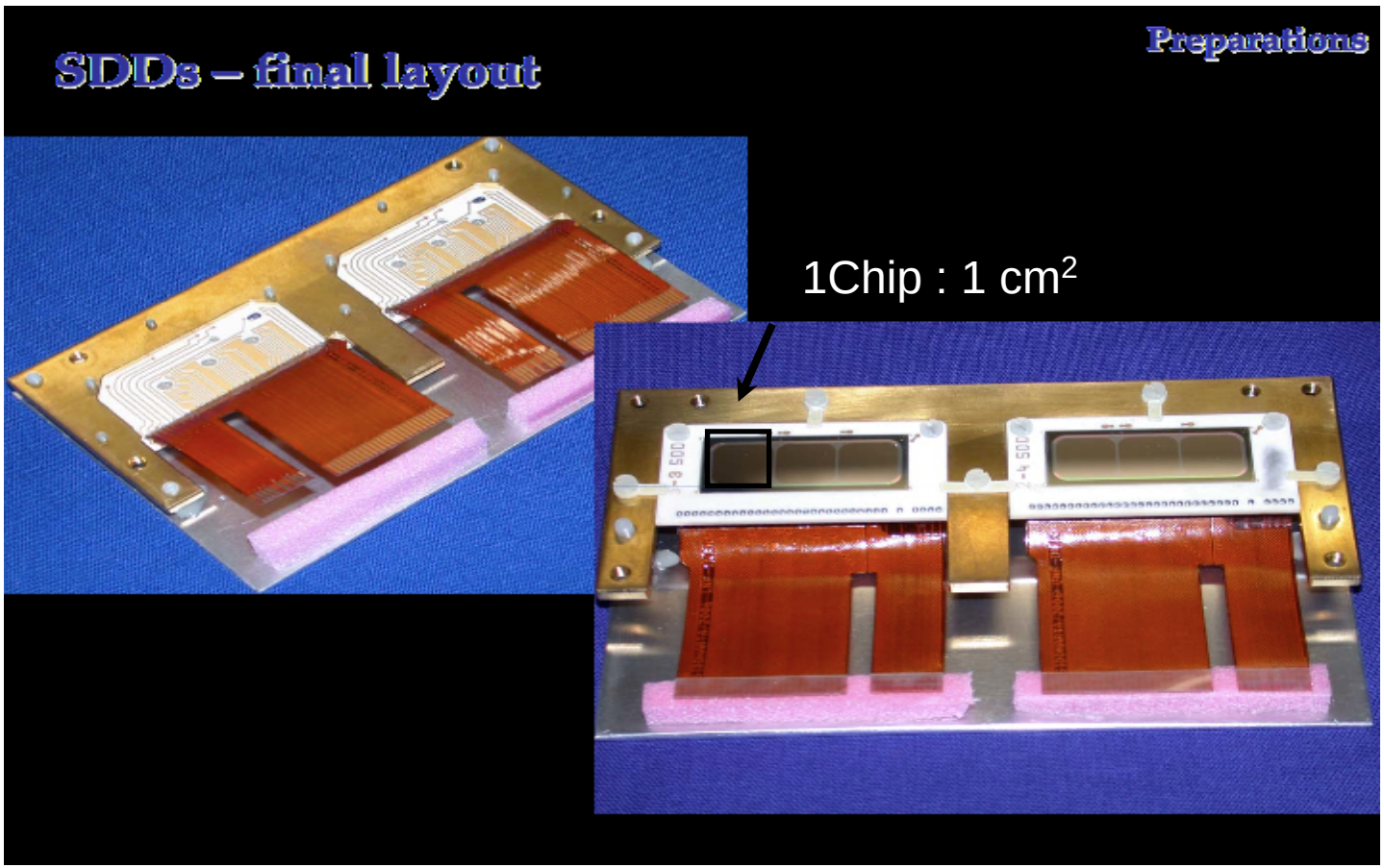
$$a_{K^-n} = a_1$$

SIDDHARTA Scientific program

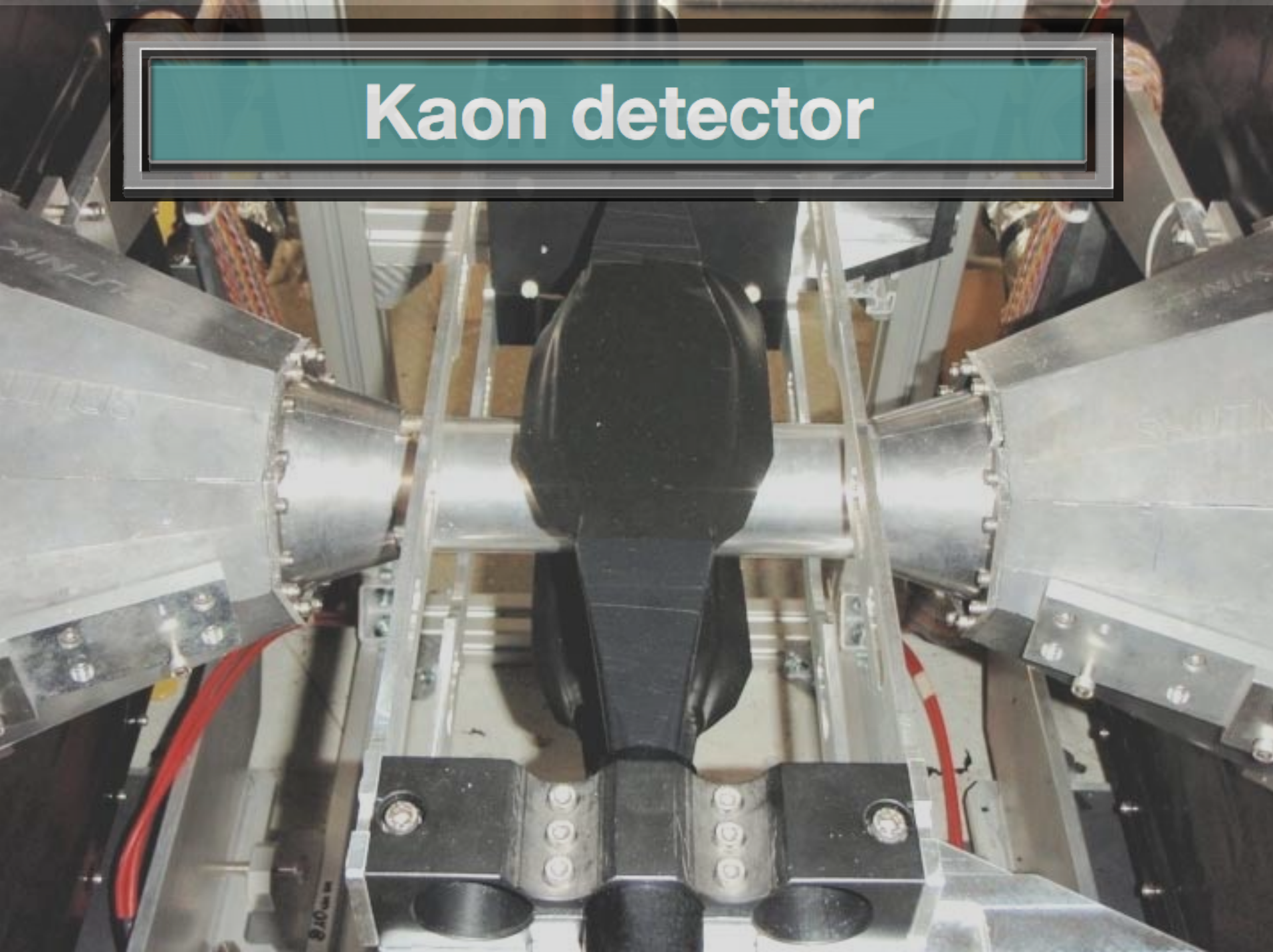
Measuring the $\bar{K}N$ scattering lengths with the precision of a few percent will drastically change the present status of low-energy $K\bar{N}$ phenomenology and also provide a clear assessment of the SU(3) chiral effective Lagrangian approach to low energy hadron interactions.

1. **Breakthrough in the *low-energy $\bar{K}N$ phenomenology*;**
2. **Threshold amplitude in QCD**
3. **Information on $\Lambda(1405)$**
4. **Contribute to the determination of the *KN sigma terms*, which give the degree of chiral symmetry breaking;**
5. **4 related alado with the determination of the *strangeness content of the nucleon* from the KN sigma terms**

Silicon Drift Detector - SDD



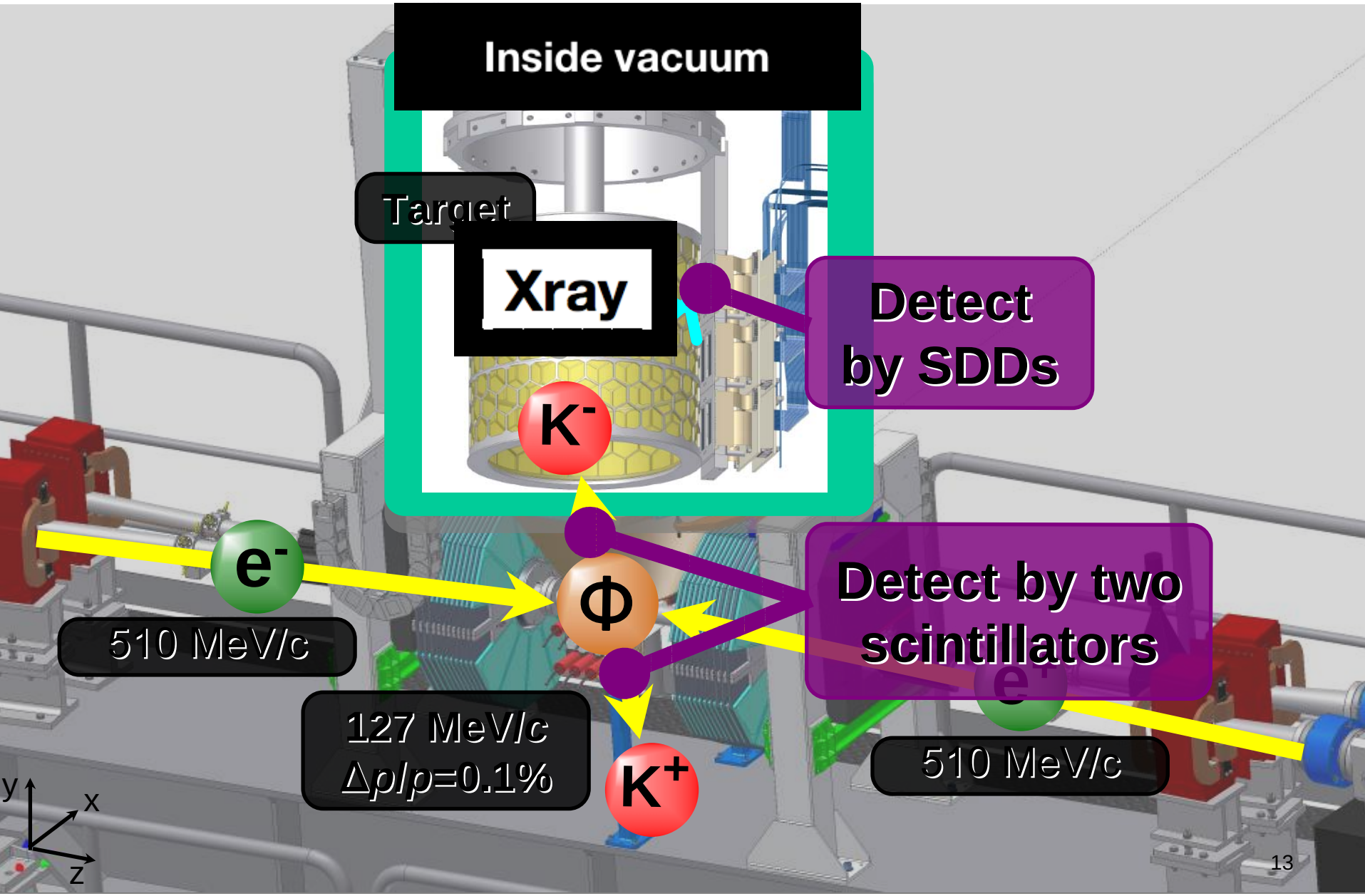
Kaon detector



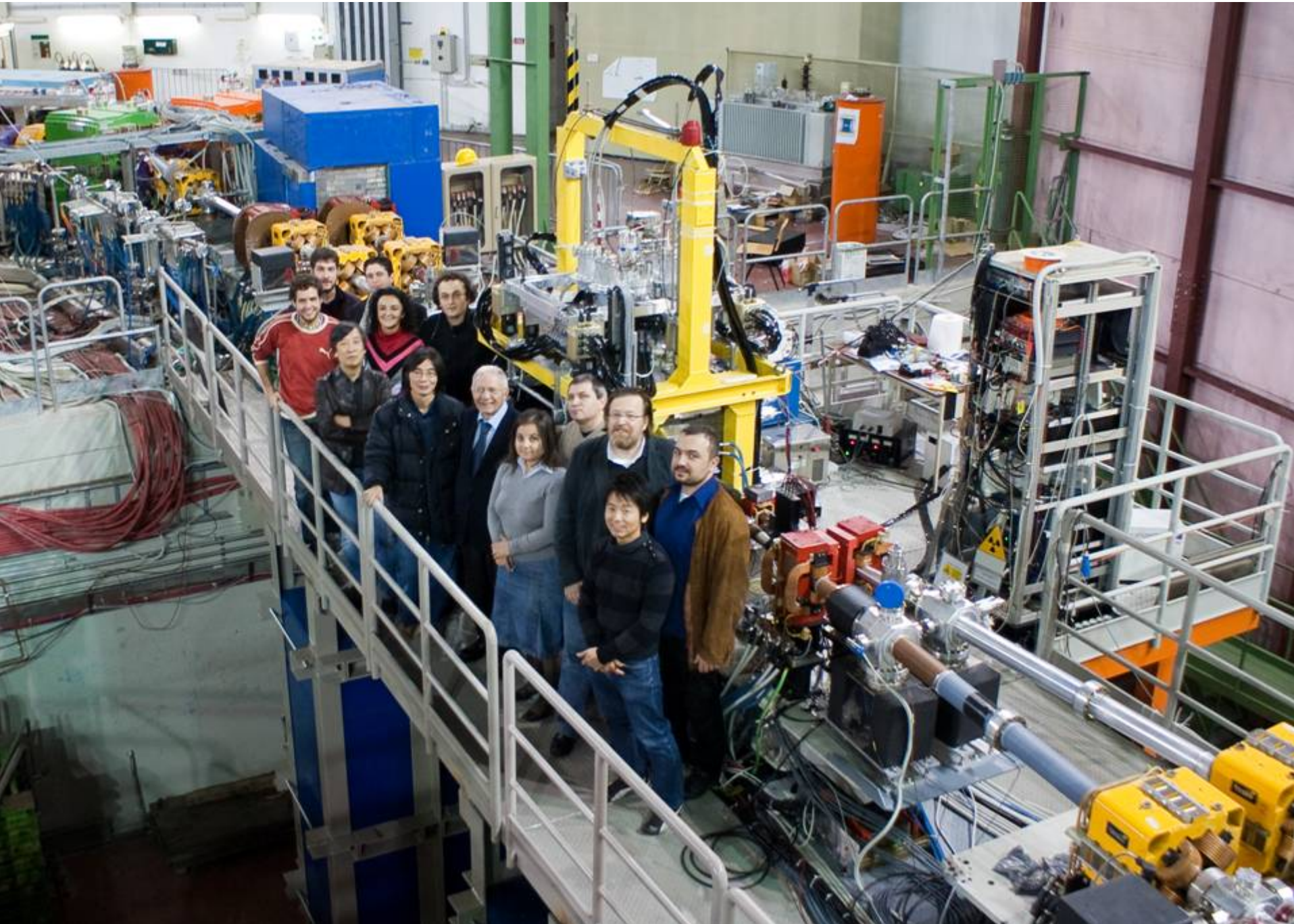
Target cell

Silicon Drift Detectors

SIDDHARTA overview




SIDDHARTA setup
SDDs & Target
(inside vacuum)
Kaon detector



SIDDHARTA measurements in 2009:

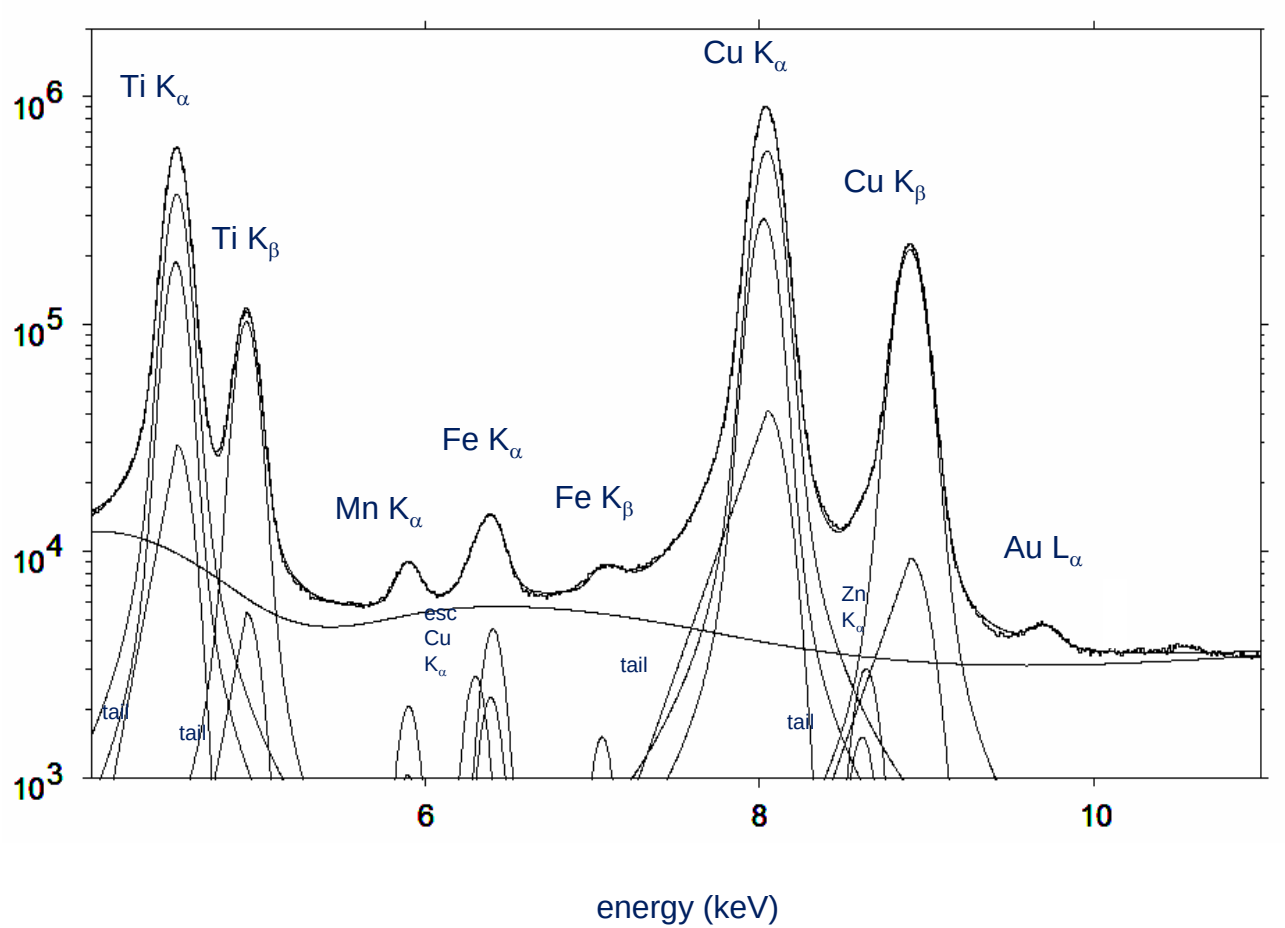
- Kaonic Hydrogen for about 400 pb^{-1} – under analysis – best measurement in the world (sensible improvement of the DEAR results)

- Kaonic deuterium for about 100 pb^{-1}, as an exploratory first measurement ever (under analysis)

- Kaonic helium 4 – published in Phys. Lett. B 681 (2009) 310; another paper in preparation

- Kaonic helium 3 – first measurement in the world, about 10 pb^{-1} (under analysis)

Energy calibration

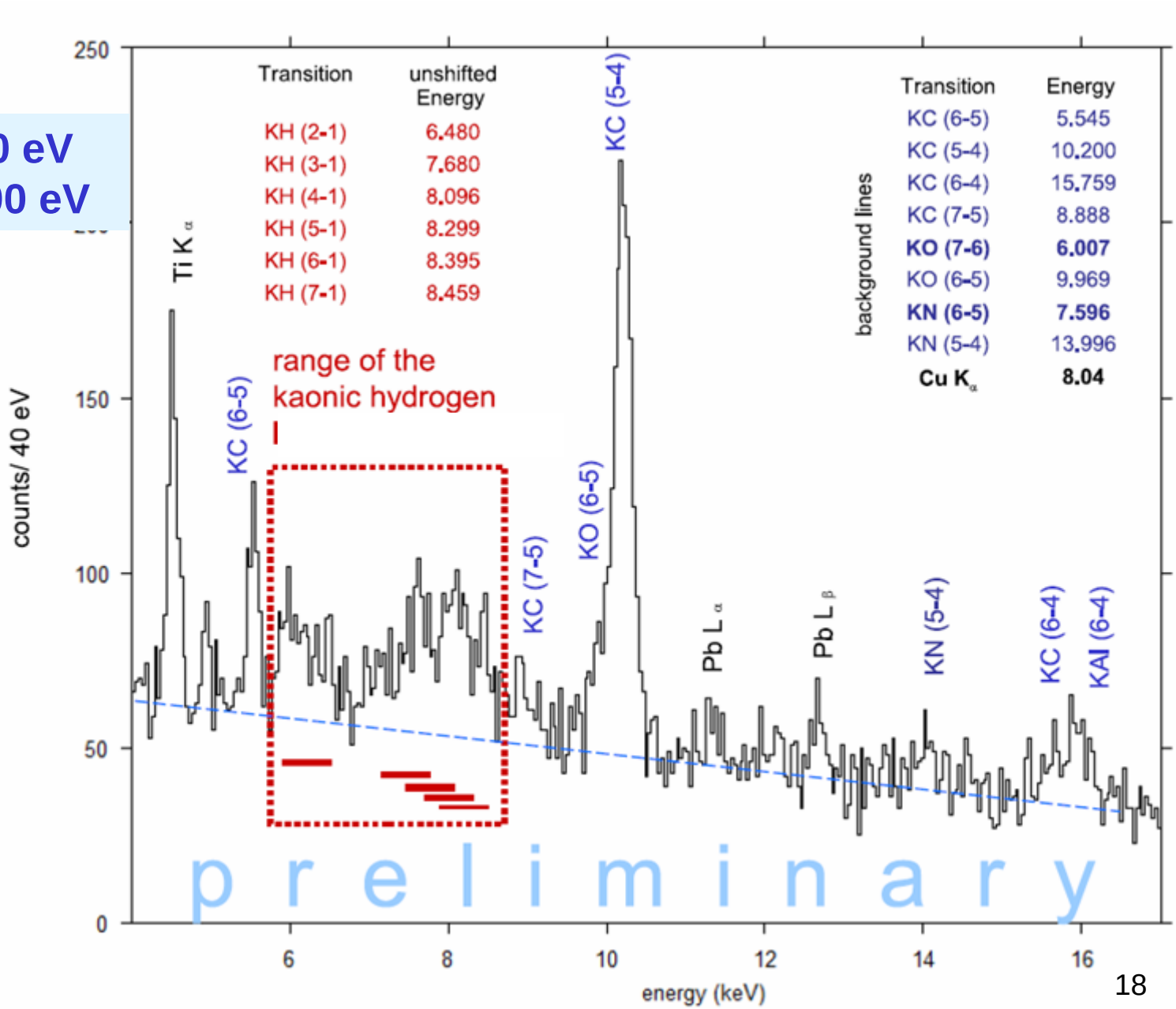


Calibration: periodic xray-tube switch on <u>during beam</u>
Ti + Cu K_α lines

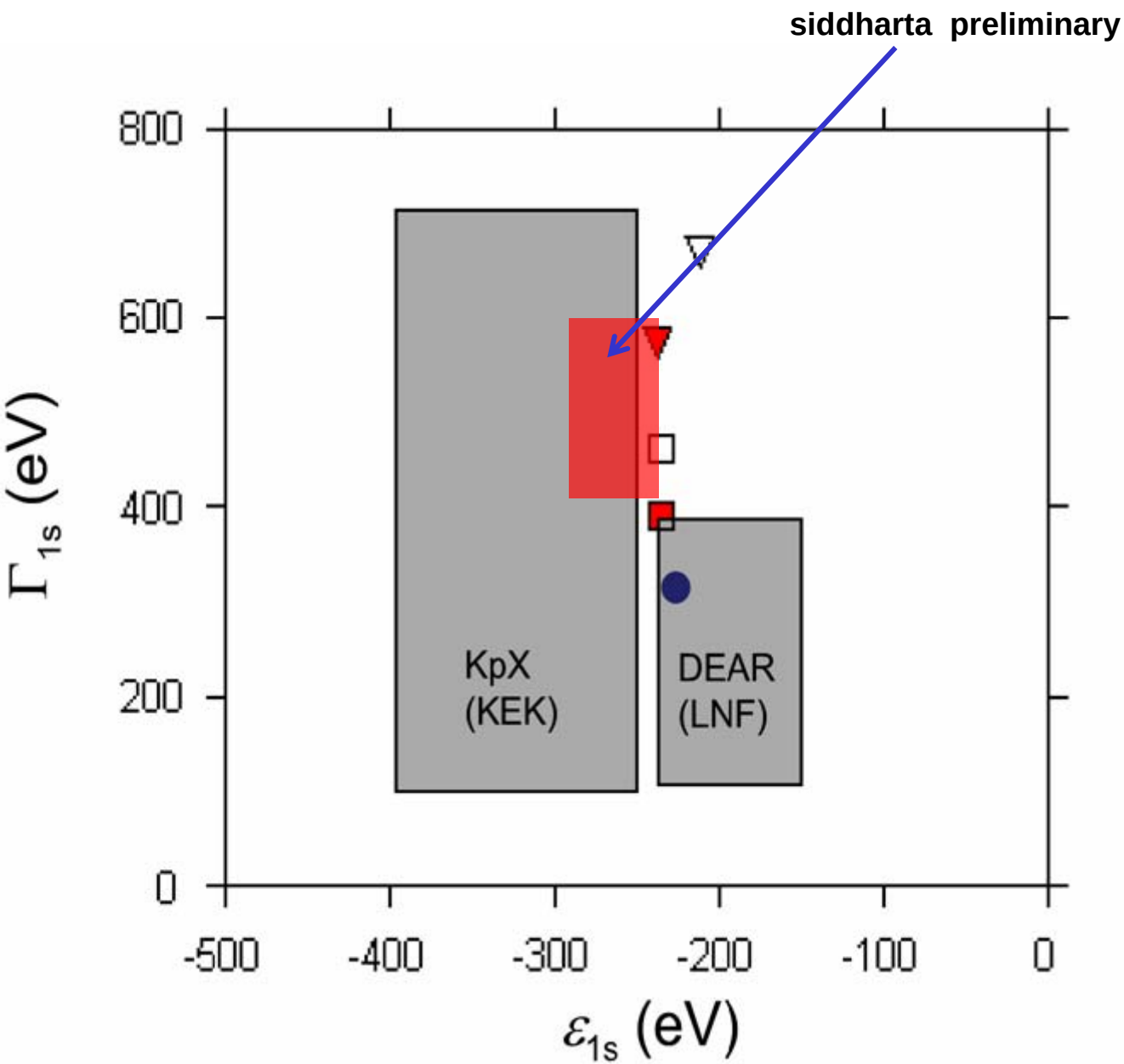
line shape to fit detector response (sum of 100 sdds with individual resolution, small asymmetry effect)

Kaonic hydrogen data

shift about 270 eV
Width about 500 eV

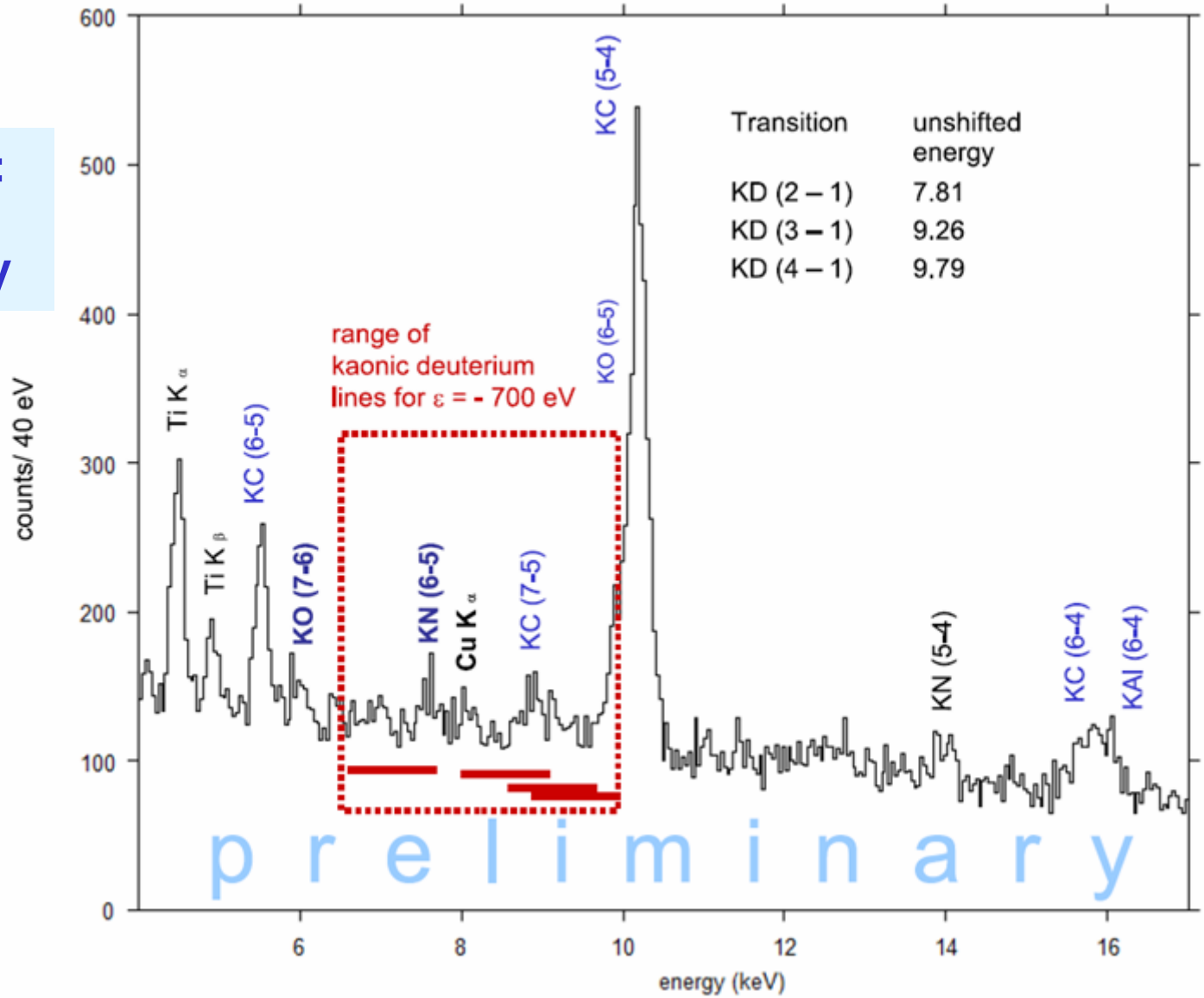


Kaonic hydrogen



Kaonic deuterium data

Hints (2 sigma) for:
shift about 700 eV
Width about 800 eV



First SIDDHARTA paper on Physics: KHe4
Phys. Lett. B 681 (2009) 310

$$\Delta E = E_{\text{exp}} - E_{\text{e.m.}}$$
$$= 0 \pm 6\ (\text{stat}) \pm 2\ (\text{syst})\ \text{eV}$$

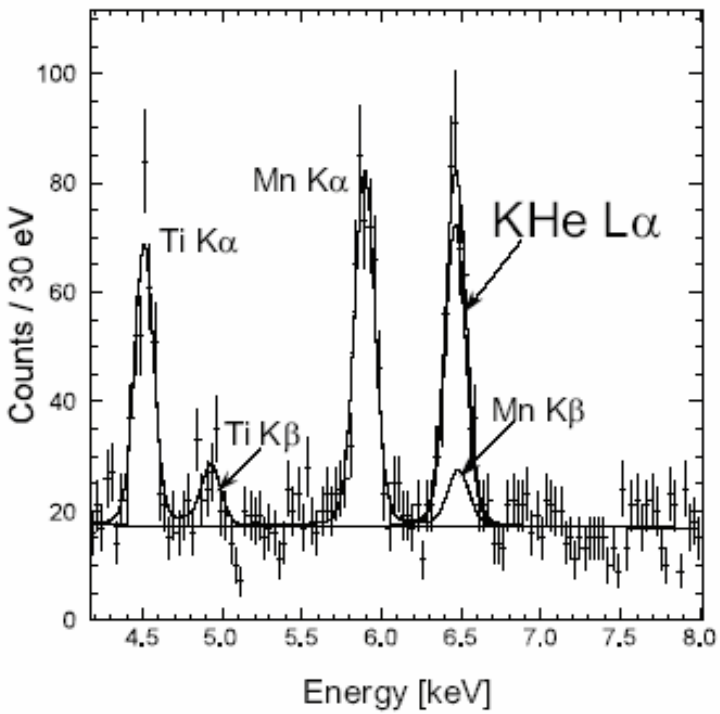
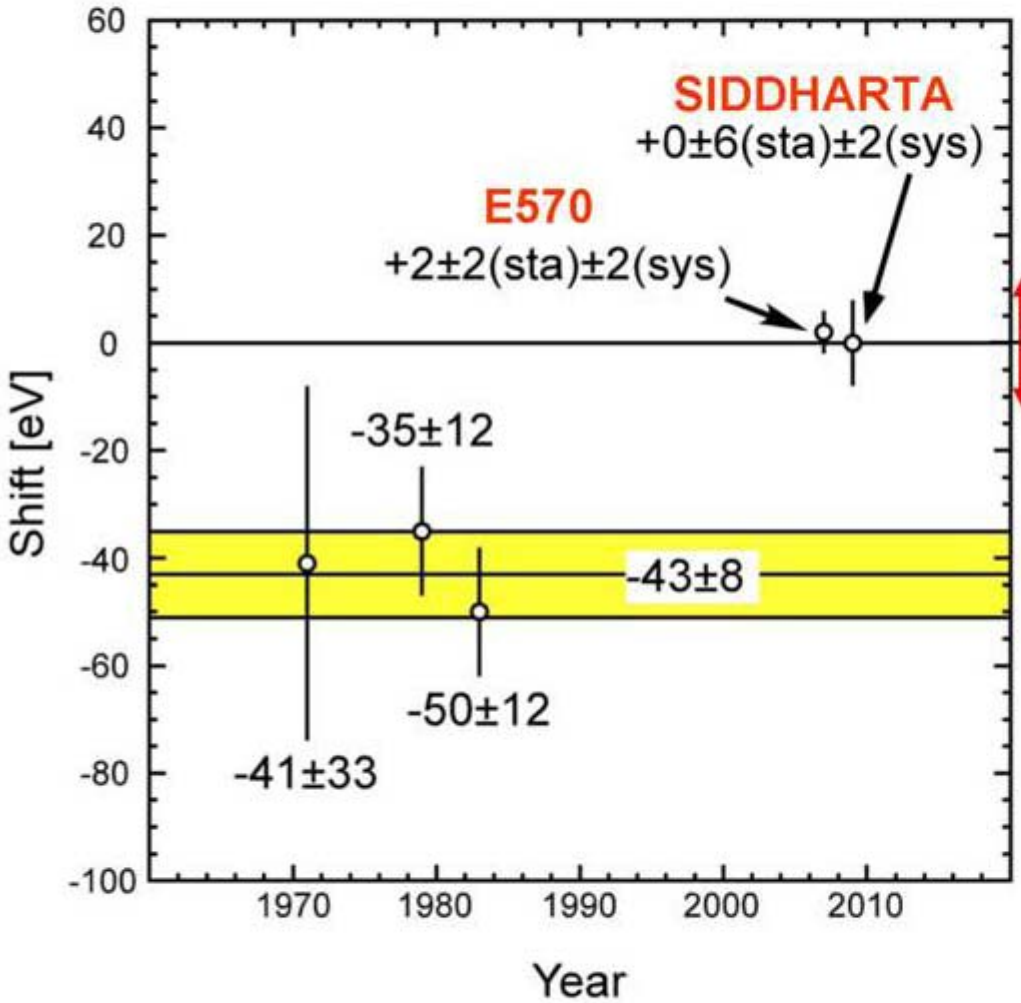


Fig. 5. Energy spectrum of the kaonic ^{4}He X-rays in coincidence with the K^+K^- events. Together with the accidental coincidence events of the Ti and Mn X-rays, the kaonic ^{4}He Lα line is seen at 6.4 keV.

Summary of KHe-4 shifts (up to 2007)



Akaishi Prediction
-10~ +10 eV

Optical model
~0eV

Optical model
Tiny (~ 0eV)

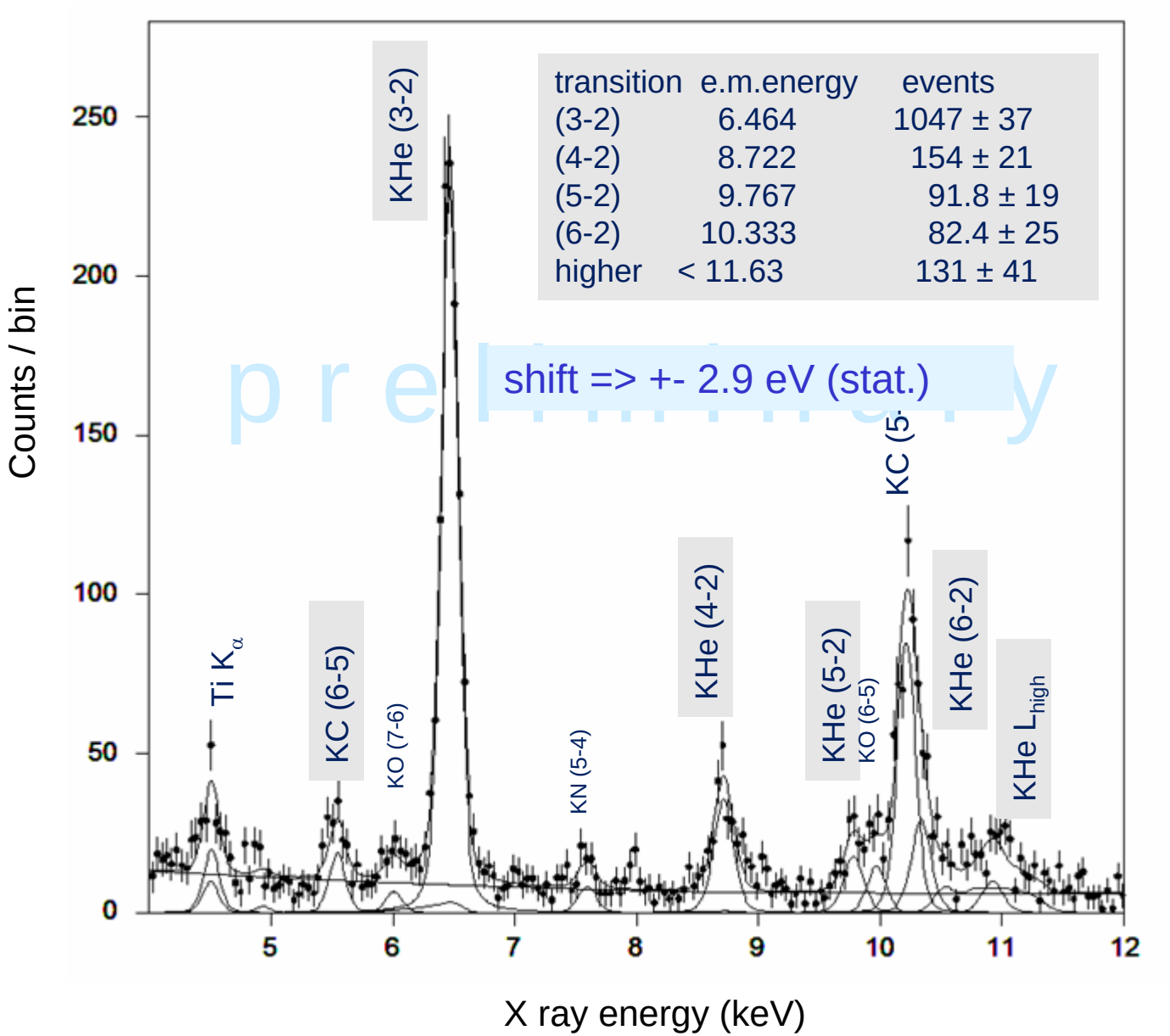
K-nucl model
Small (<±10 eV)

K-He4 exp
Large (-40 eV)

More data on Kaonic Helium 4

KHe used for **gasstop optimization** + physics interest[1])

data from setup 2 (no Fe55 source)



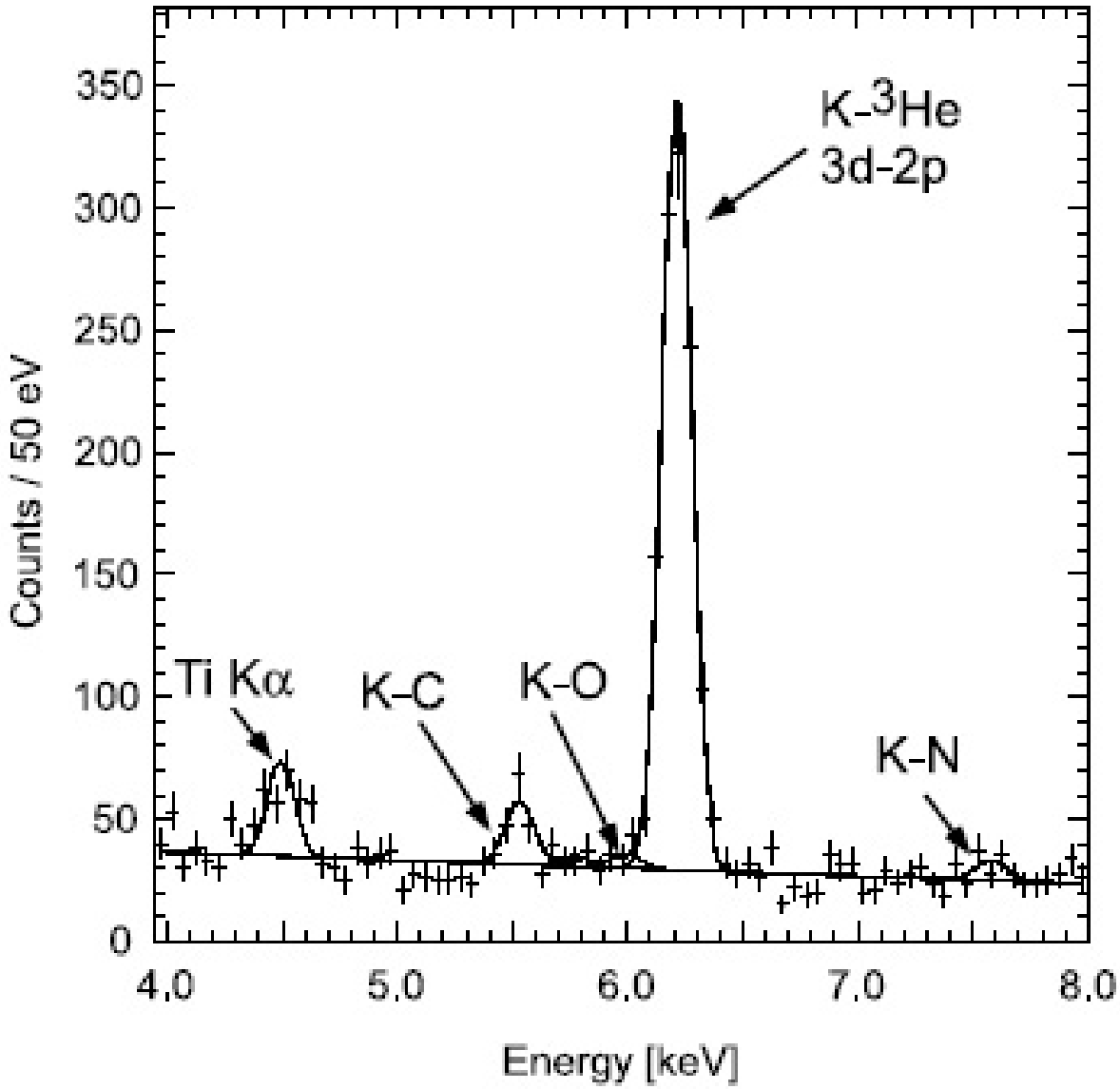
[1]) compare KEK E570 KHe L lines in liquid He, consistent result, first measurement in gas

Kaonic Helium 3
Phys. Lett. B 697 (2011) 199-202

data of ~ 15 pb^{-1}
taken 3.-7.11.2009

KHe3
never measured
before !

shift = - 2 eV
+- 2 eV (stat.)
+- 4 eV (syst.)



Summary of SIDDHARTA results

SIDDHARTA data taking finished Nov 2009.

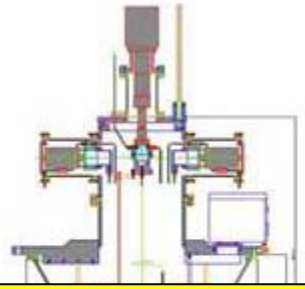
Preliminary results:

K^-p shift ~ 270 eV, width ~500 eV higher precision then in DEAR

K^-d first measurement ever, exploratory measurement, small signal, significance ~ 2σ

KHe4 measured for the first time in gaseous target,

KHe3 first time measurement



Kaonic deuterium,
KHe3,4 transitions to 1s,
heavier kaonic atoms,
Radiative capture of kaon....

The

an enriched scientific case

Exploring the (very) low-energy QCD in the strangeness sector by means of exotic atoms

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)

AMADEUS physics:

Antikaon Matter At DAΦNE: Experiments with Unraveling Spectroscopy

- Stopped kaons physics - ? Kaonic nuclear clusters (K-pp, K-ppn, K-pnn…) and interaction processes

- Low-energy kaon-nuclei interaction physics

-POSTER OF KRISTIAN PISCICCHIA

The scientific case of the so-called “deeply bound kaonic nuclear states” is hotter than ever, both in the theoretical

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

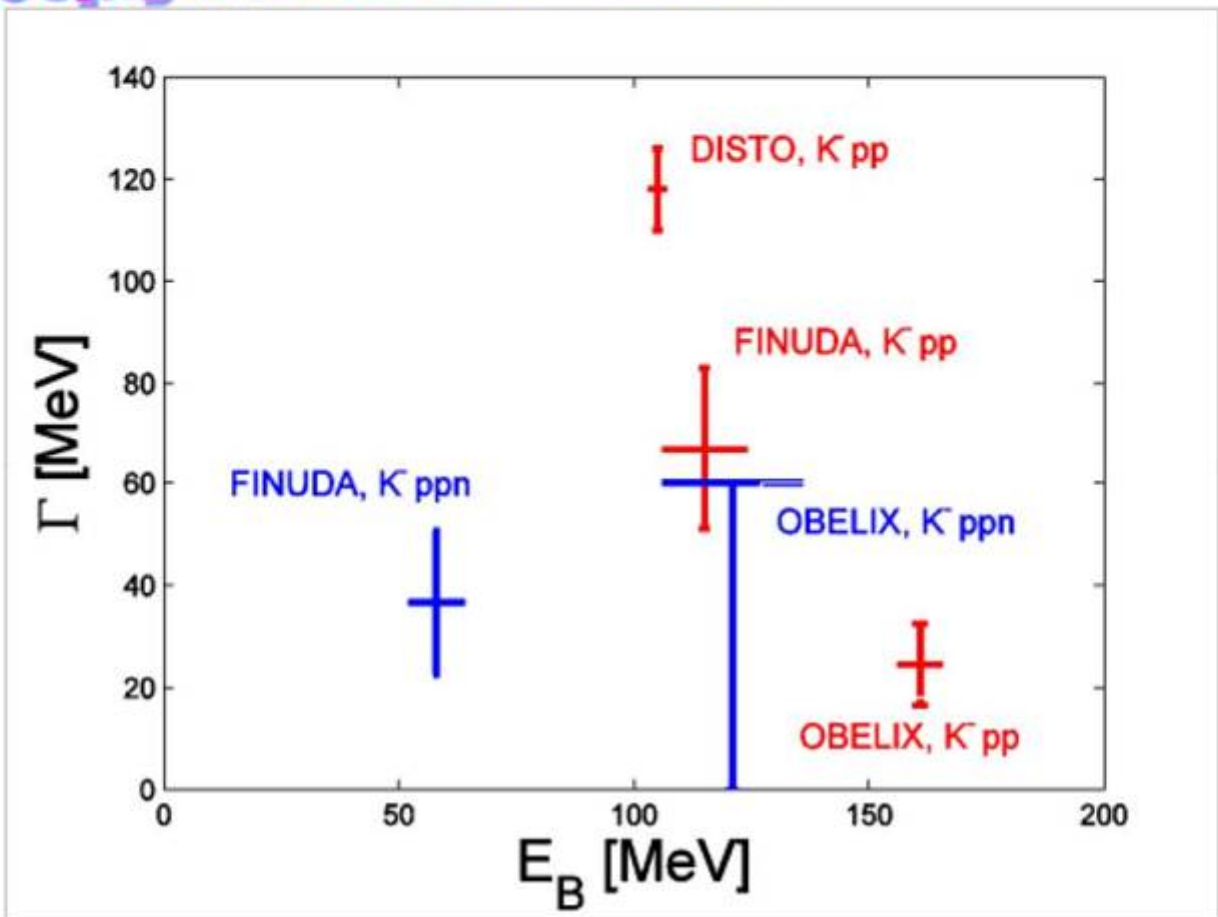
And even astrophysics (NEW!!!)

a second phase);

Present exprimental situation (J.Mares)

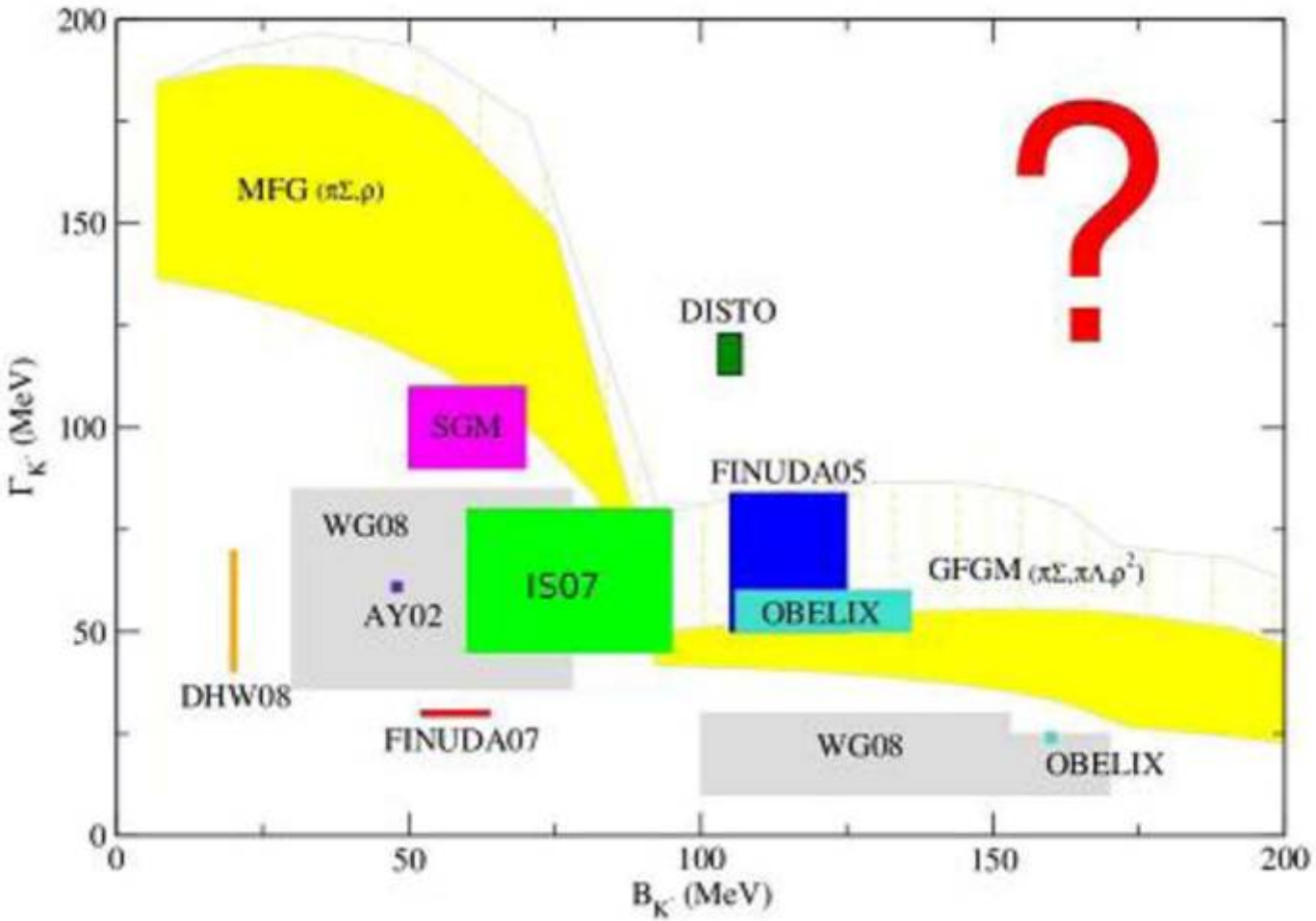
Int. Workshop on Hadronic Atoms and Kaonic Nuclei, ECT*
Trento, 26-Oct-09

Deeply bound antikaon states in nuclei



Present situation: exp and theory (J. Mares)

Int. Workshop on Hadronic Atoms and Kaonic Nuclei, ECT*
Trento, 26-Oct-09



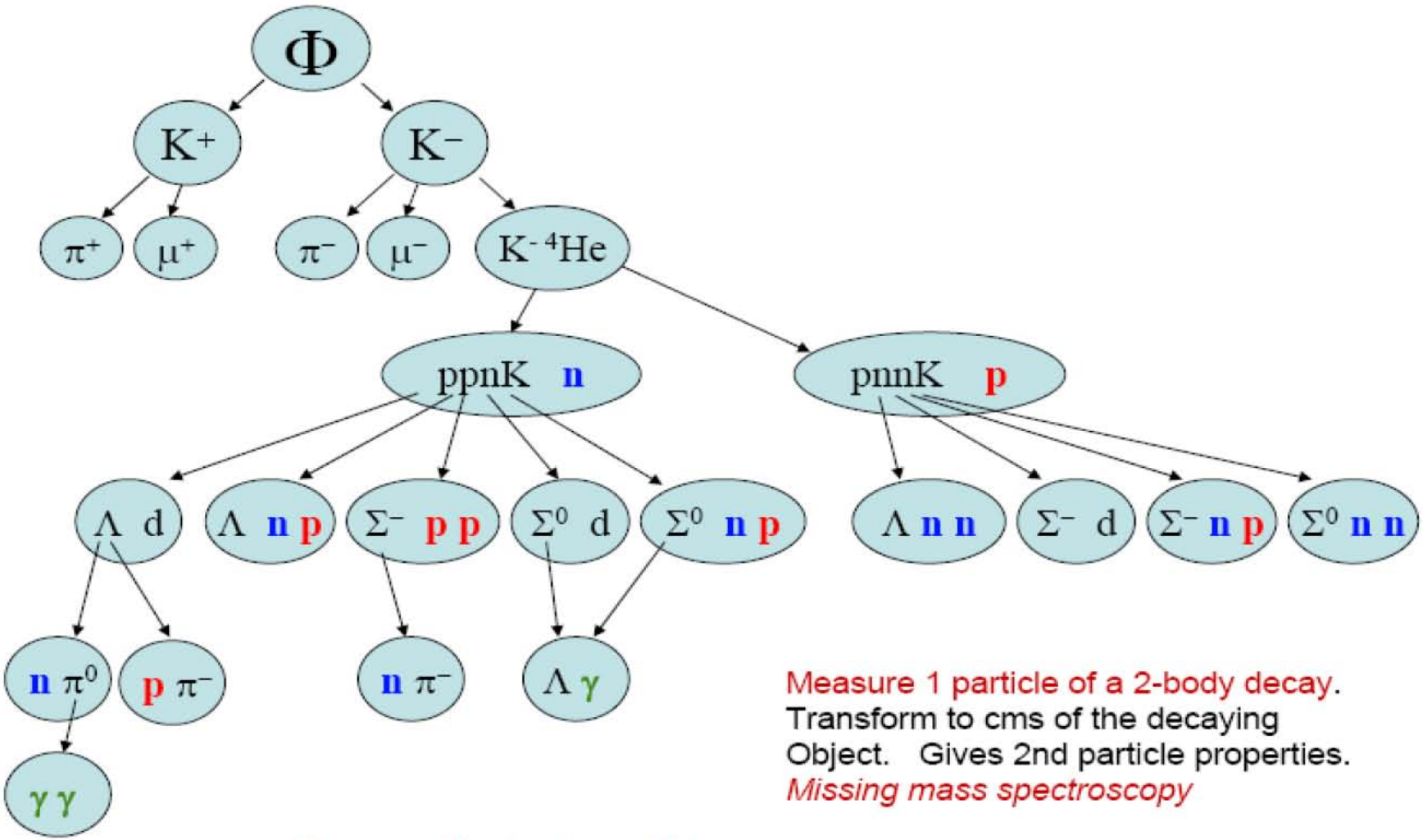
Planned experiments

- the future experiments in Japan at J-PARC will produce kaonic nuclear states only with K^--induced reactions in-flight (E15; E17)

- 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 reaction at rest

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*

Features of the experimental setup

The **complete** study of the characteristic features of the kaonic bound nuclear systems requires knowledge of: **binding energy, level width and partial widths, angular momenta, isospin, sizes, densities**, etc.

This can be done by *simultaneously observing* ***the production stage*** *of the* K^-*-clusters* via missing mass spectroscopy, *and their* ***decay products*** since their momentum correlations contain information on the internal structure of the exotic system.

It is therefore necessary to use a ***4π dedicated detector capable of detecting all particles created in both the formation and decay of the K-clusters***.

The detector satisfying all these features =>

The KLOE detector

Performance of the KLOE 4π detector:

-fully checked and exploited in the numerous measurements done already by KLOE;

-studies of processes with BR of $< 10^{-3}$ (10^{-6})

-acceptance 96%

-DC: $\sigma_p/p \sim 0.4\%$

-Spatial resolution of vertices in DC: 3 mm

-dE/dx capacity for particle ID implemented

-ECAL $dE/E_\gamma \sim 5.7\%/E^{1/2}$

–$\sigma_{t=}$ $(54/E^{1/2} + 50)$ ps

-$K_s \rightarrow \pi^+\pi^-$ at 0.8 MeV/c^2

–π^0 mass resolution to 2-3 % (reconstruction)

-Resol. for n of 500 MeV/c ~ 3%

……

Experimental programme
AMADEUS (1) – stopped kaons

- 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 next step, the
  kaonic 3-baryon states: $ppnK^-$ and $pnnK^-$
  produced in a ^4He gas target, in formation and decay processes

- Measure heavier targets (which?)

Experimental programme
AMADEUS (2) – low energy kaons

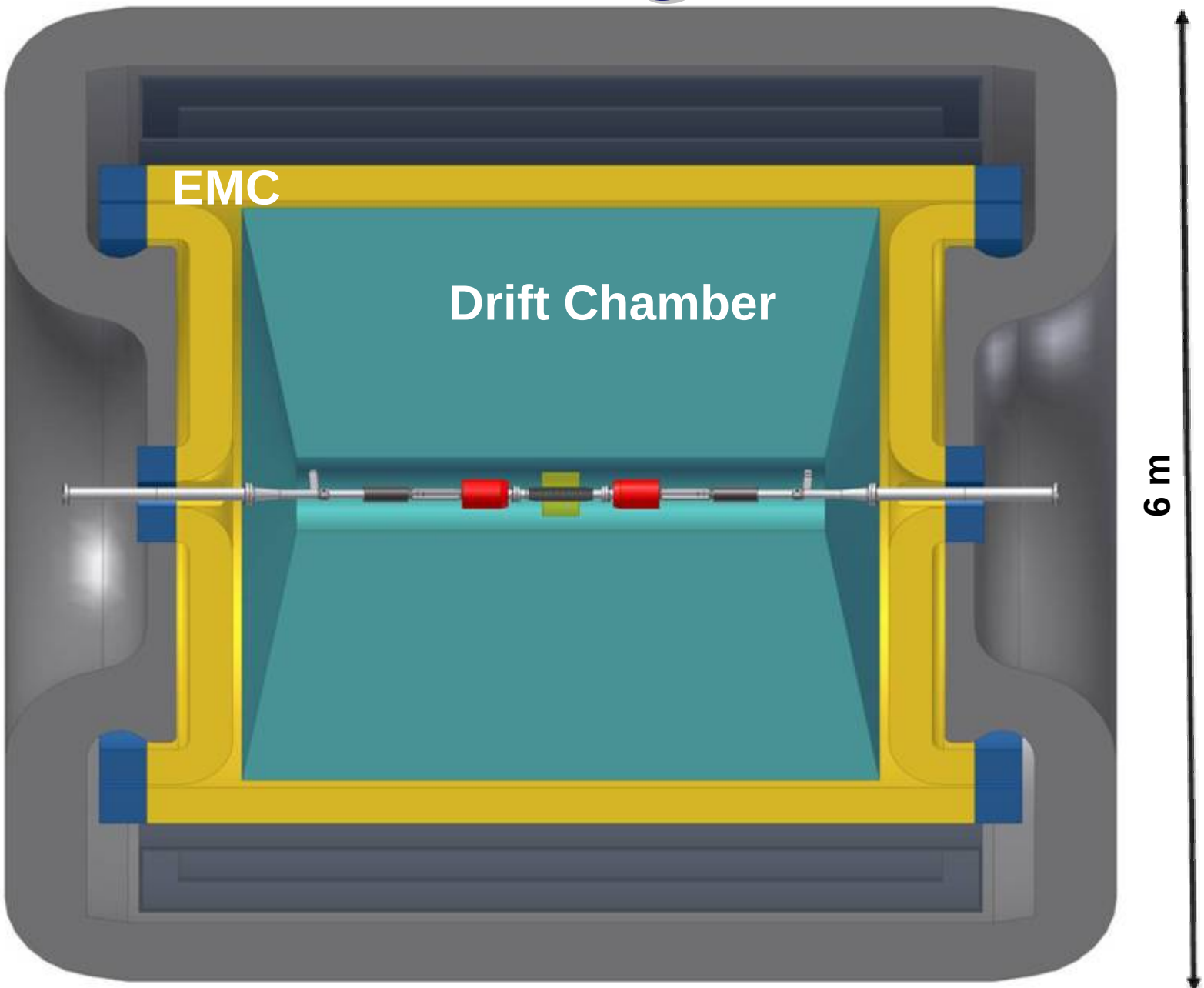
- Low-energy charged kaon cross sections and interactions on H, d, Helium(3 and 4), for K- momentum lower than 100 MeV/c (missing today);

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

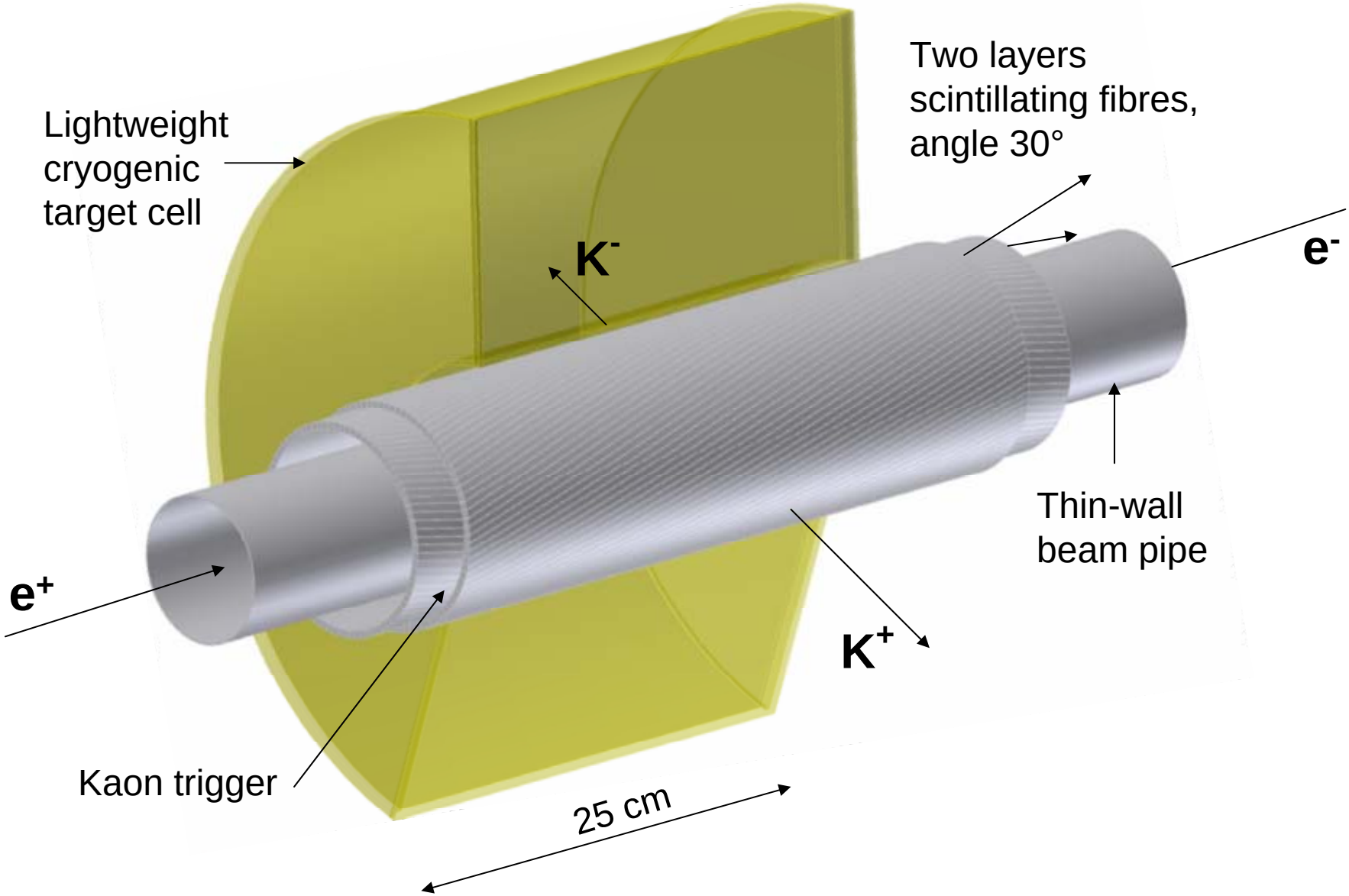
- Properties of $\Lambda(1116)$ and charged Σ – for example decays in channels with neutrino -> astrophysics implications (cooling of compact stars)

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

AMADEUS @ KLOE



AMADEUS stopped K- @ KLOE



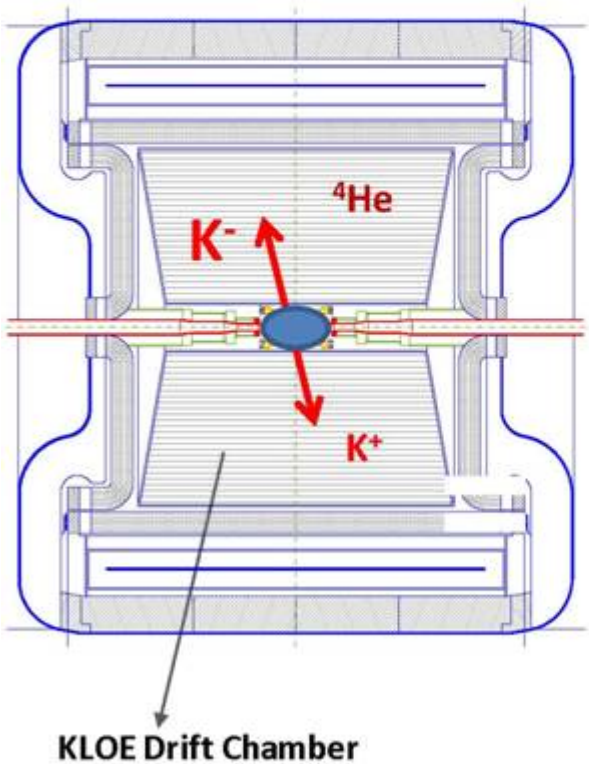
AMADEUS – to start after KLOE2 (2014?)

Presently: R&D for:

- trigger system (fibers read by SiPM)
- active traget TPC-GEM
- cryogenic target

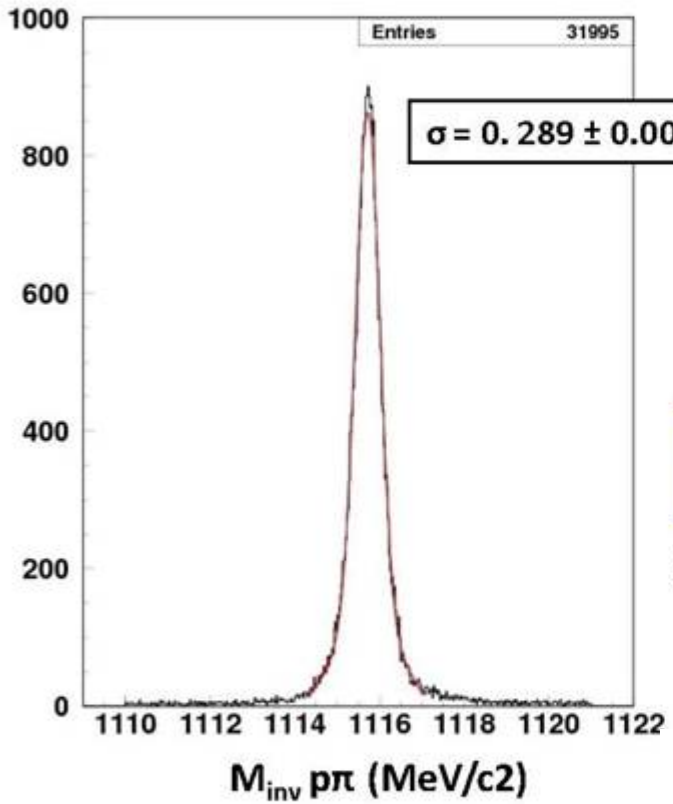
Excellent feasibility test –
analyses of the KLOE data

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.

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

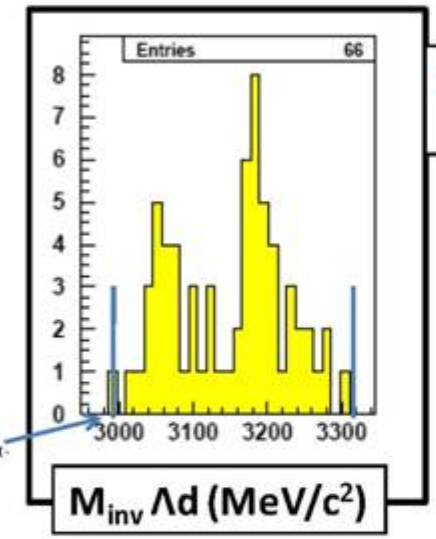
$K^\pm \rightarrow \mu^\pm \nu$

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

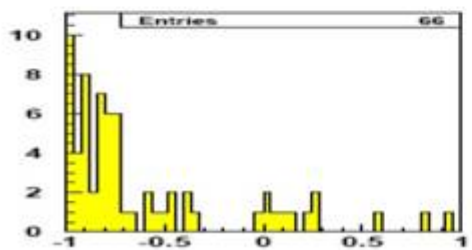
Lambda-d

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

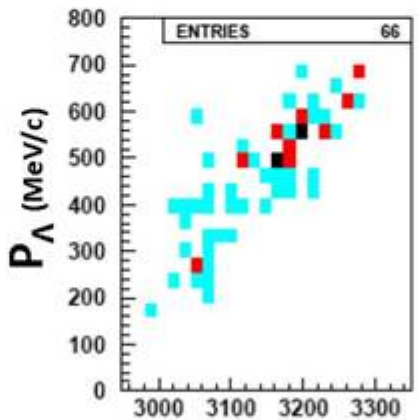
$\Lambda + d$



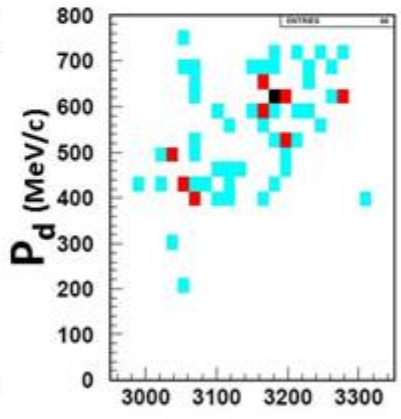
Events in the DC volume



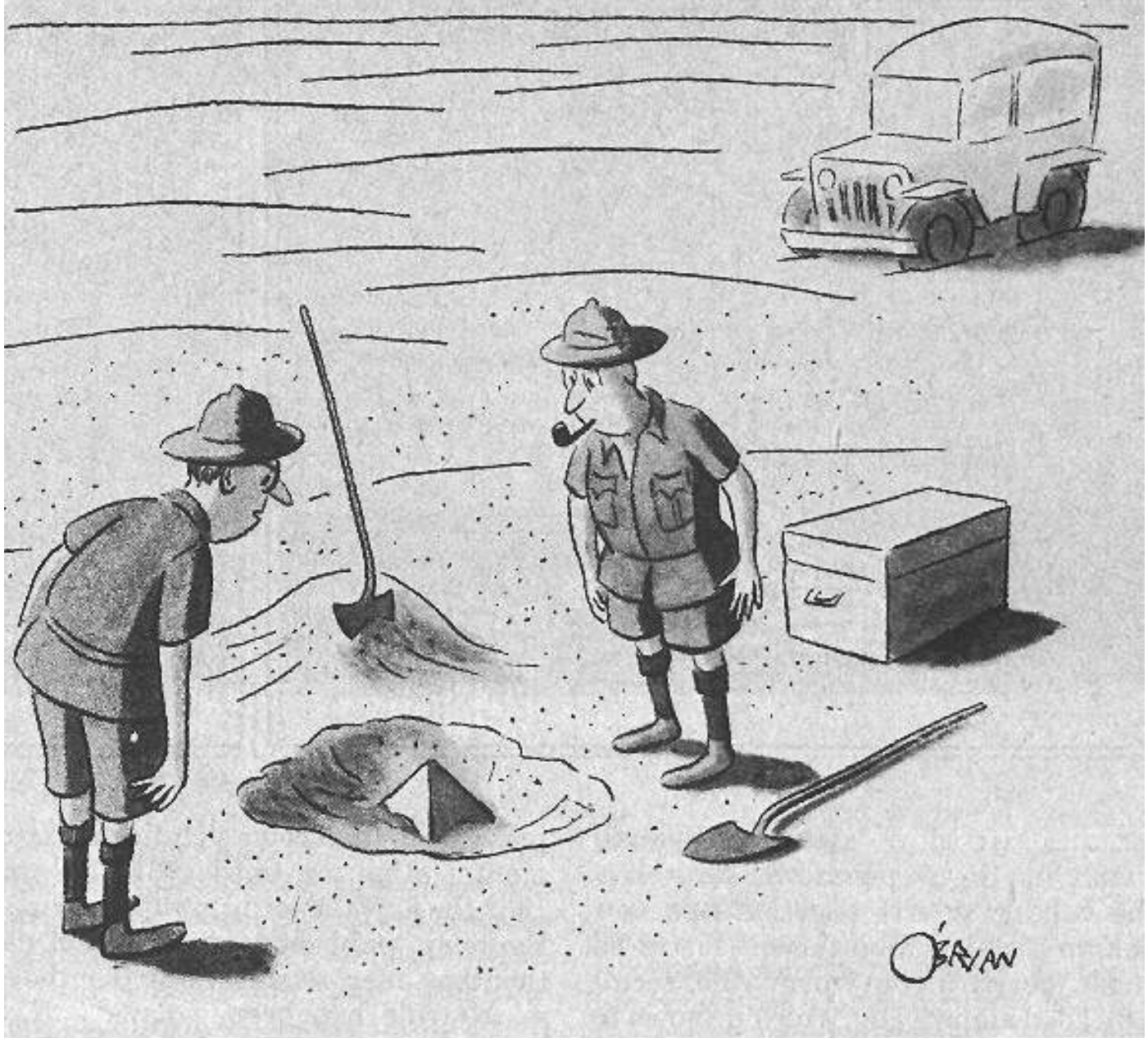
lambda momentum vs. Minv



deuteron momentum vs. Minv



M_{inv} Λd (MeV/c²)



"This could be the discovery of the century. Depending, of course, on how far down it goes."


DAFNE represents an unique
opportunity to study in a
complete way the kaon-nucleon/nuclei
physics at low energy

Published results

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JID:PLB AID:26267 /SCO Doctopic: Experiments [m50v1.3; v 1.21; Prn:21/10/2009; 8:36] P.1 (1-6)

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Kaonic helium-4 X-ray measurement in SIDDHARTA

SIDDHARTA Collaboration

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ED PROOF

- **Kaonic Helium-4 publication confirming the KEK E570 result using a gaseous target**

- **KHe4 publication concerning yields of the transitions: under preparation**

Table 1
Energy shift of the kaonic helium $2p$ state [4]

ΔE_{2p} (eV)	Ref.
-41 ± 33	Wiegand *et al.* [1]
-35 ± 12	Batty *et al.* [2]
-50 ± 12	Baird *et al.* [3]
-43 ± 8	Average of above [3,4]
$+2 \pm 2$ (stat) ± 2 (syst)	Okada *et al.* [5]
0 ± 6 (stat) ± 2 (syst)	This work

[1,2,3] liquid He, [5] liq. He, Compton scattering corrected, [This] gaseous He, Compton negligable