Advances and perspectives in the low-energy Kaon-nucleon/nuclei interaction studies At the DAFNE Collider

Catalina Curceanu

(On behalf of SIDDHARTA and AMADEUS collaborations)

LNF – INFN, Frascati

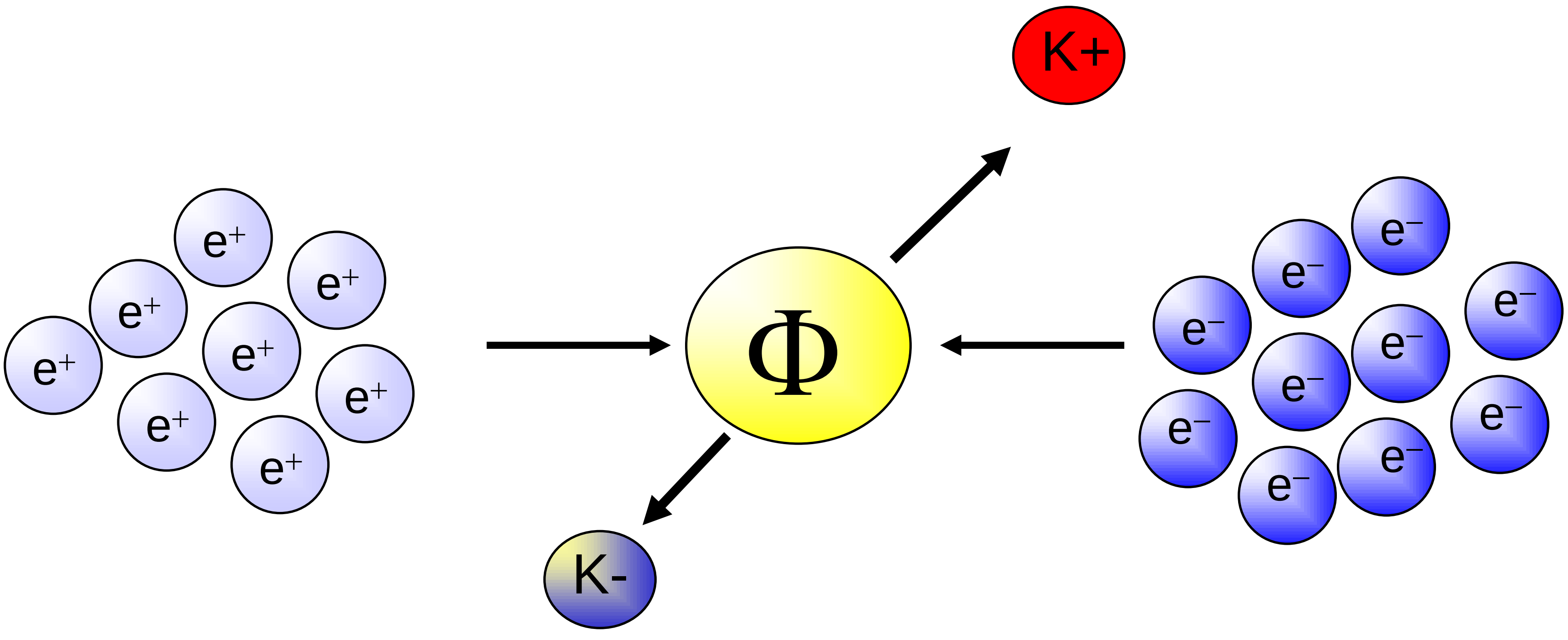
Hadrons in Nuclei, YITP, 30 October – 2 November 2013, Kyoto

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

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 /JPARC)

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

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
- AMADEUS carbon target and KLOE 2002-2005 data analyses in collaboration with KLOE

Support from : HP3 – WP9: WP24; WP28 is fundamental

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**

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*

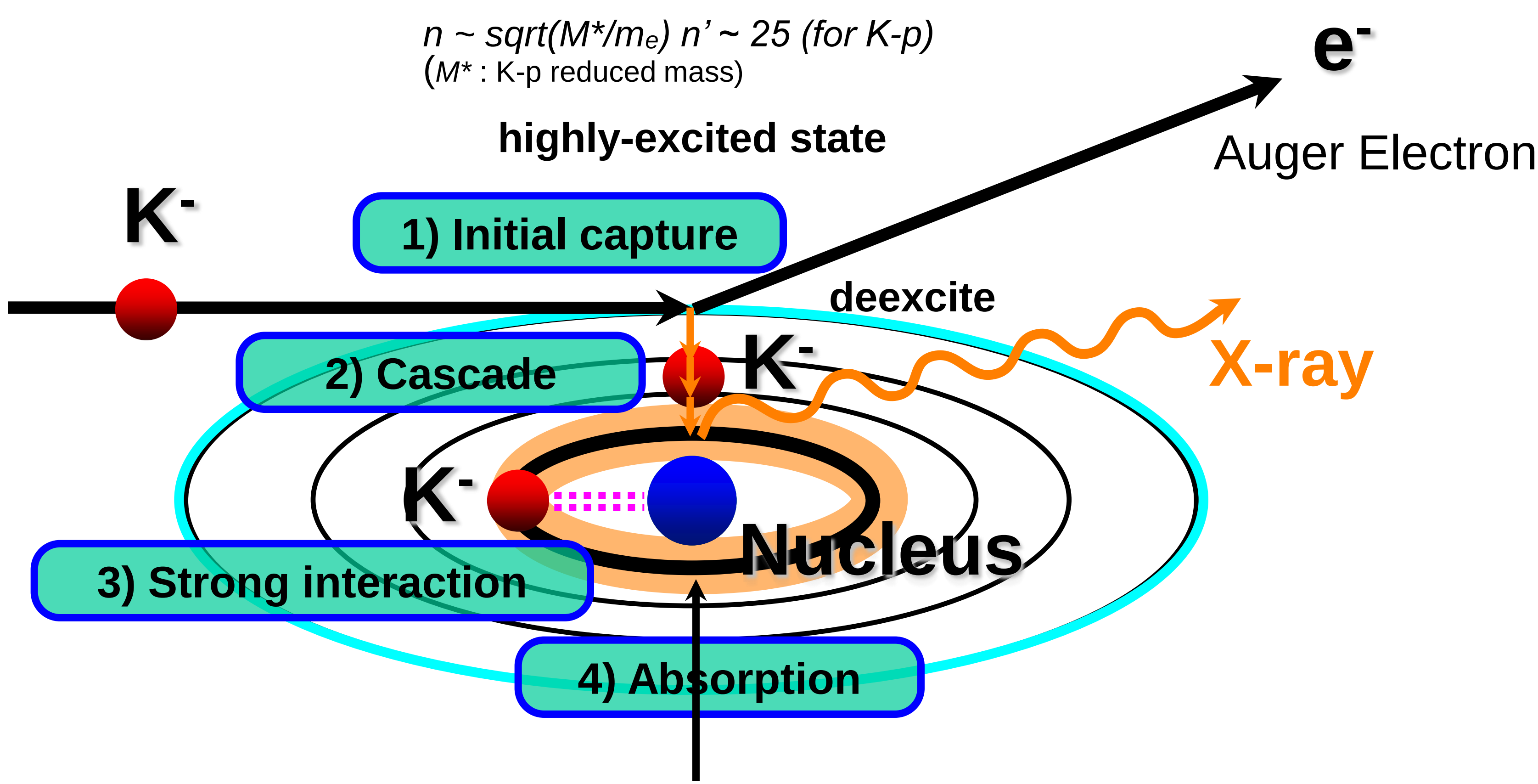
of the K_α line of **kaonic hydrogen**

and

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

Measurements of kaonic Helium 3 and 4 as well (2p level)

Kaonic atom formation



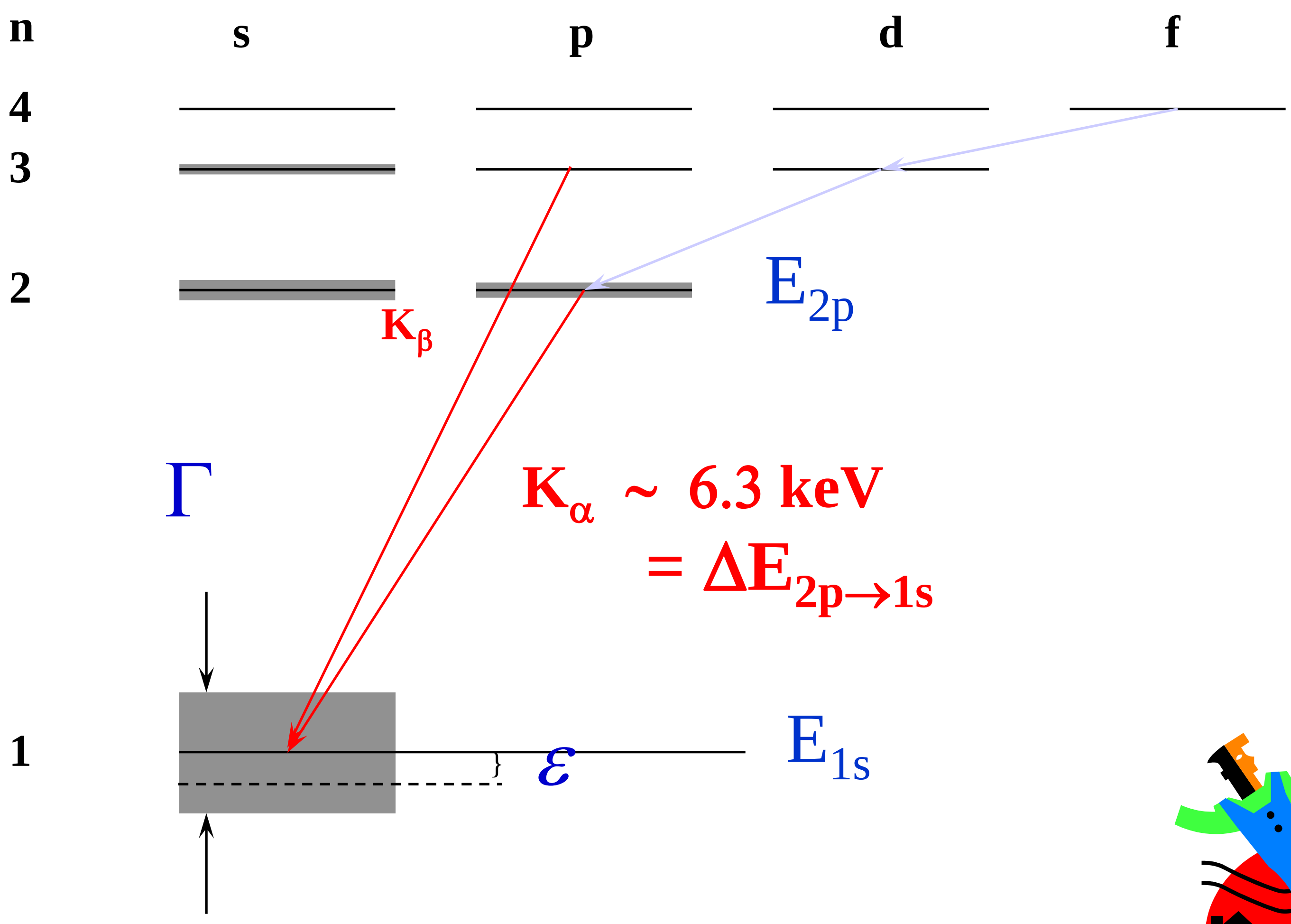
stopped in a target medium

Shift and Width of last orbit

· **1s** for K-p, K-d

· **2p** for K-He

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):

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

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

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

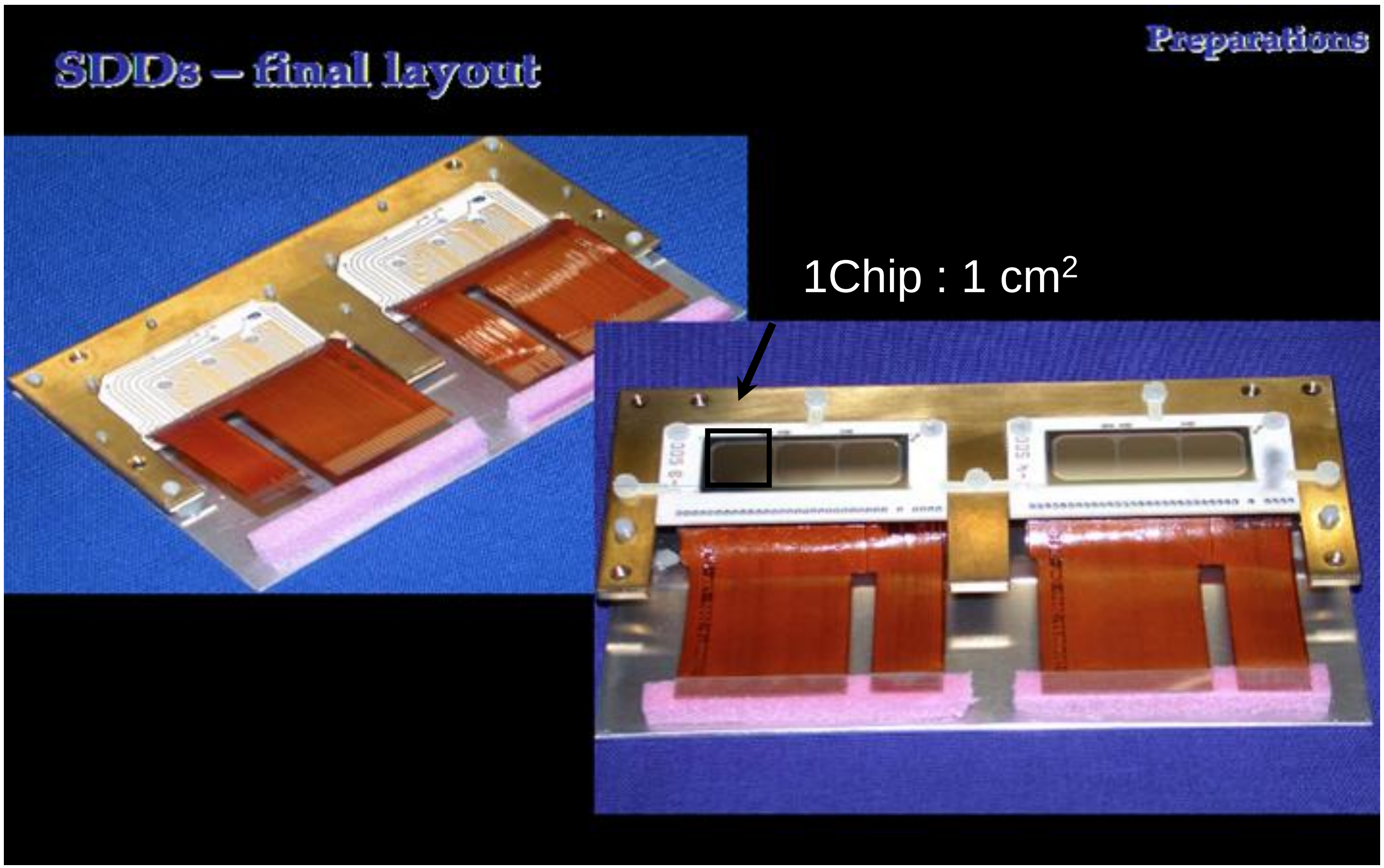
Measuring the $\bar{K}$N scattering lengths with the precision of a few percent will drastically change the present status of low-energy $\bar{K}$N phenomenology and also provide a clear assessment of the SU(3) chiral effective Lagrangian approach to low energy hadron interactions.

1. **Breakthrough in the *low-energy $\bar{K}N$ phenomenology*;**
2. **Threshold amplitude in QCD**
3. **Information on Λ(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**

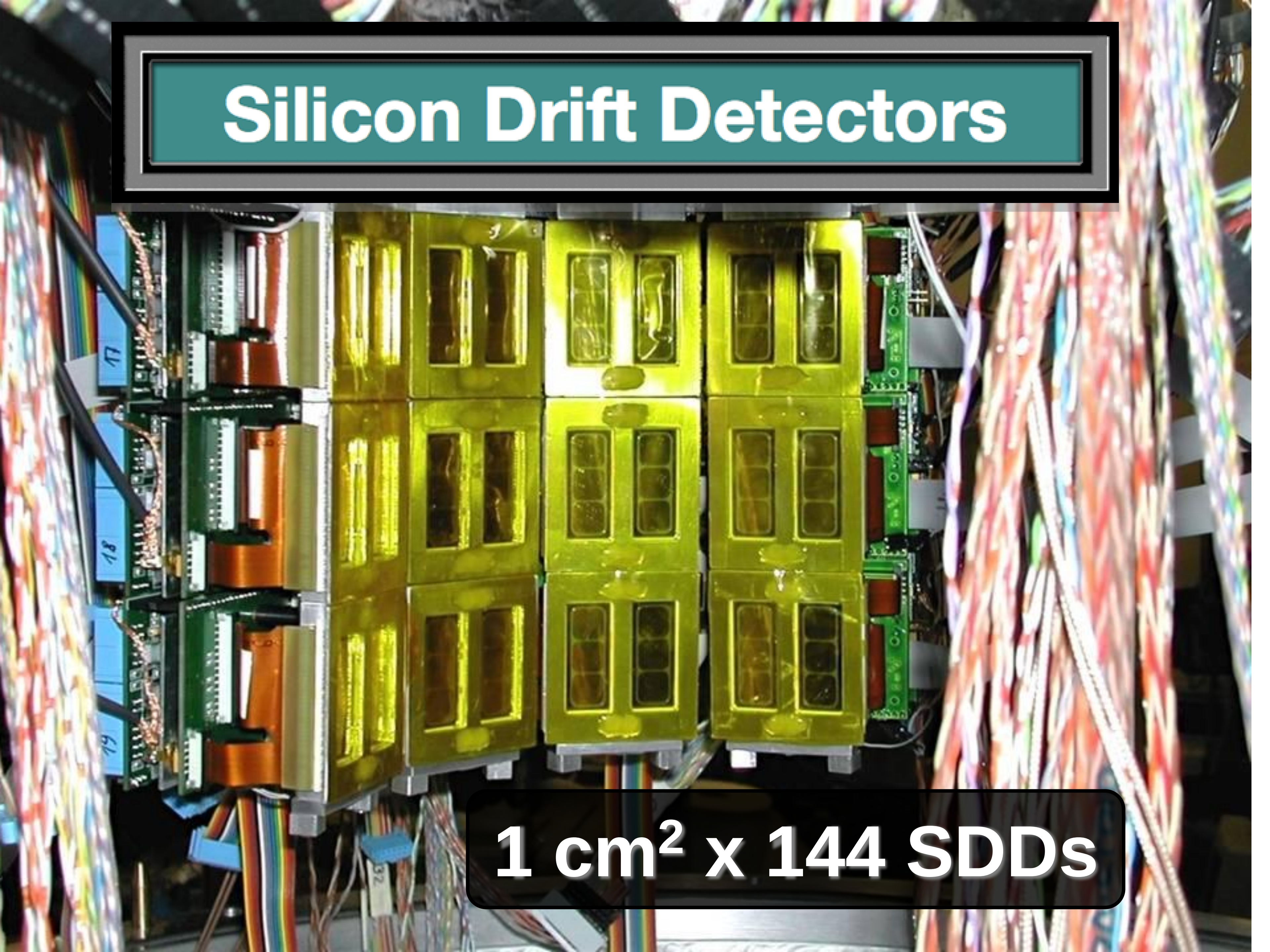
SIDDHARTA

Target cell

Silicon Drift Detector - SDD

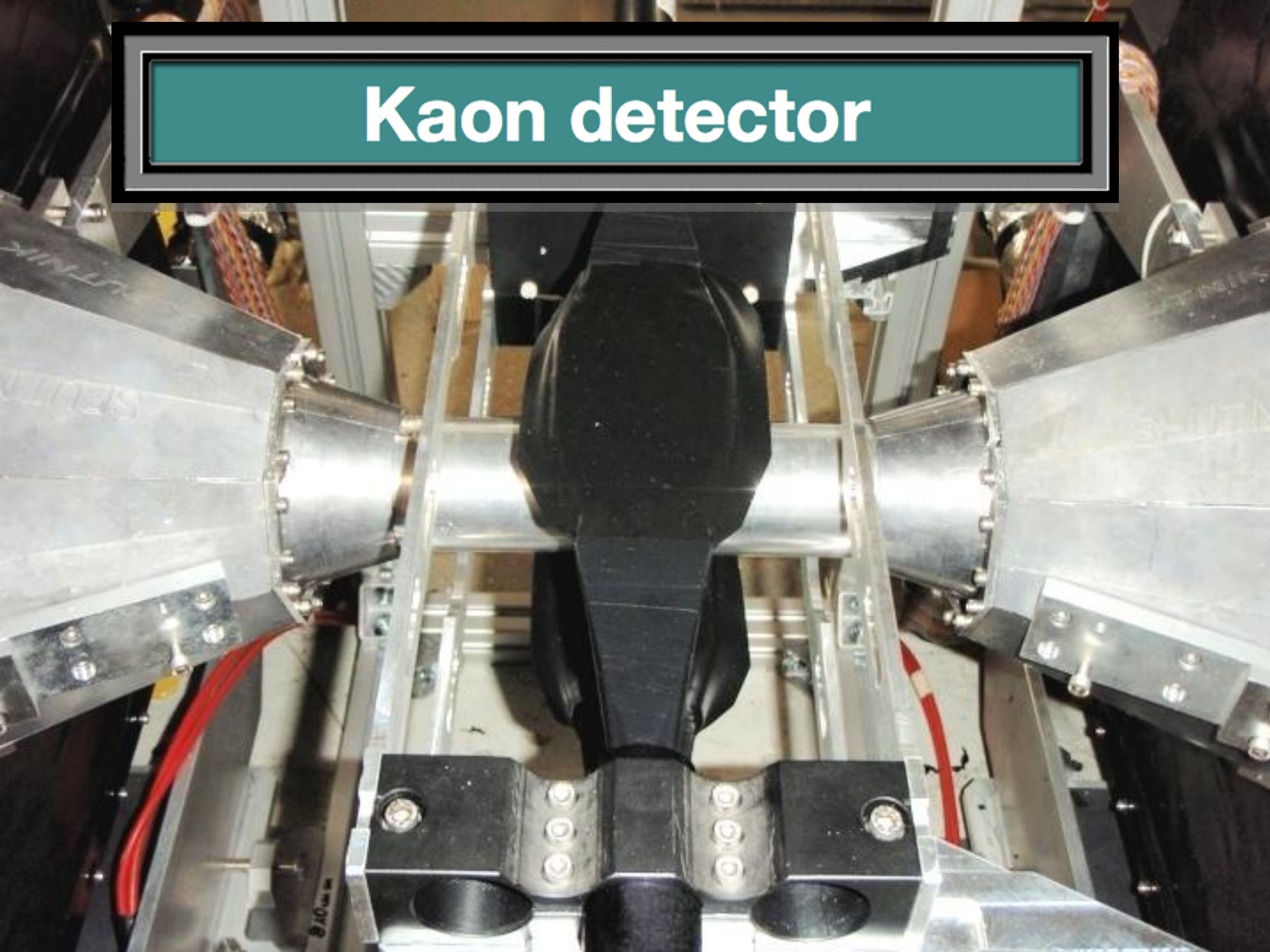


Silicon Drift Detectors

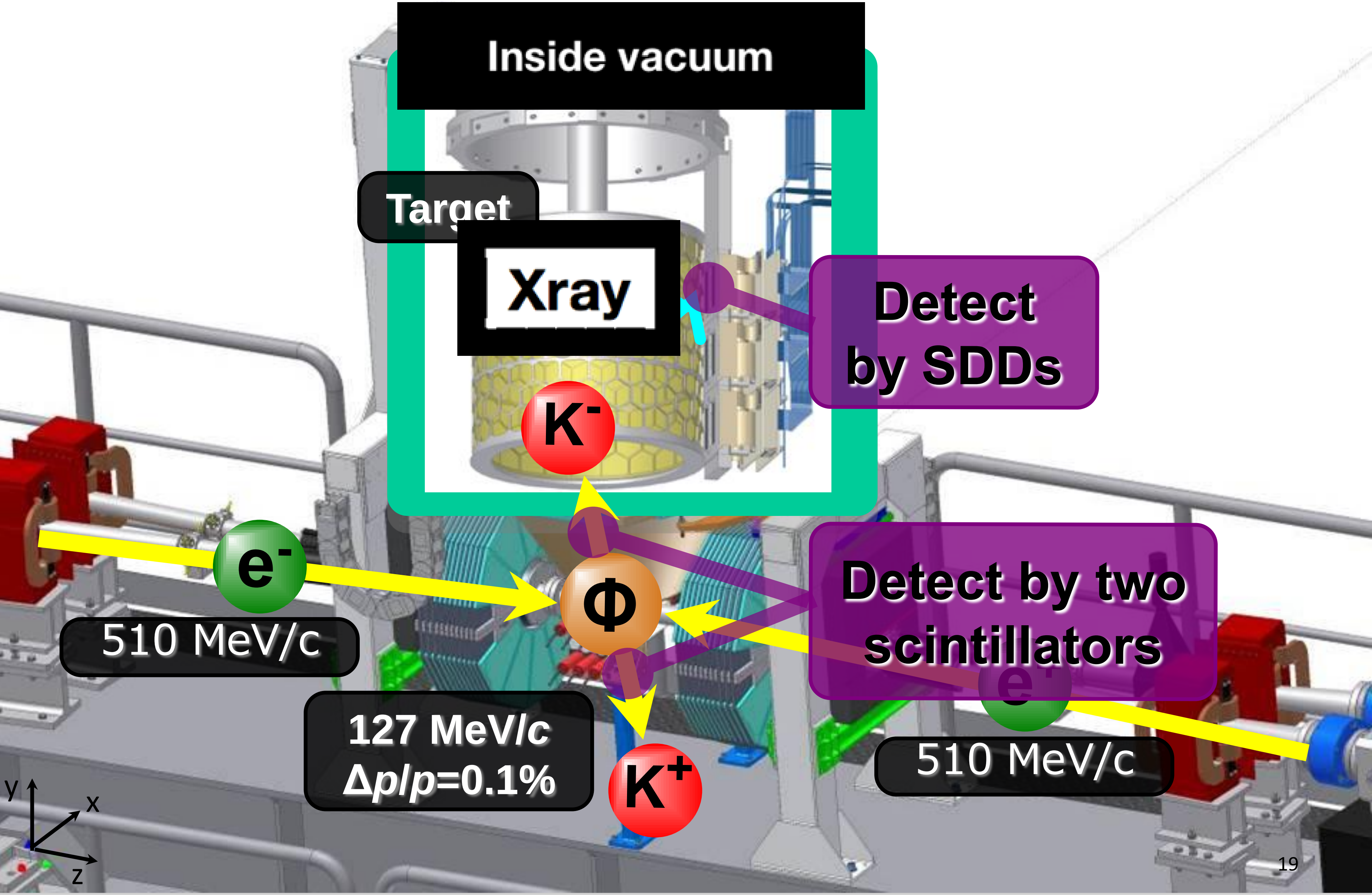


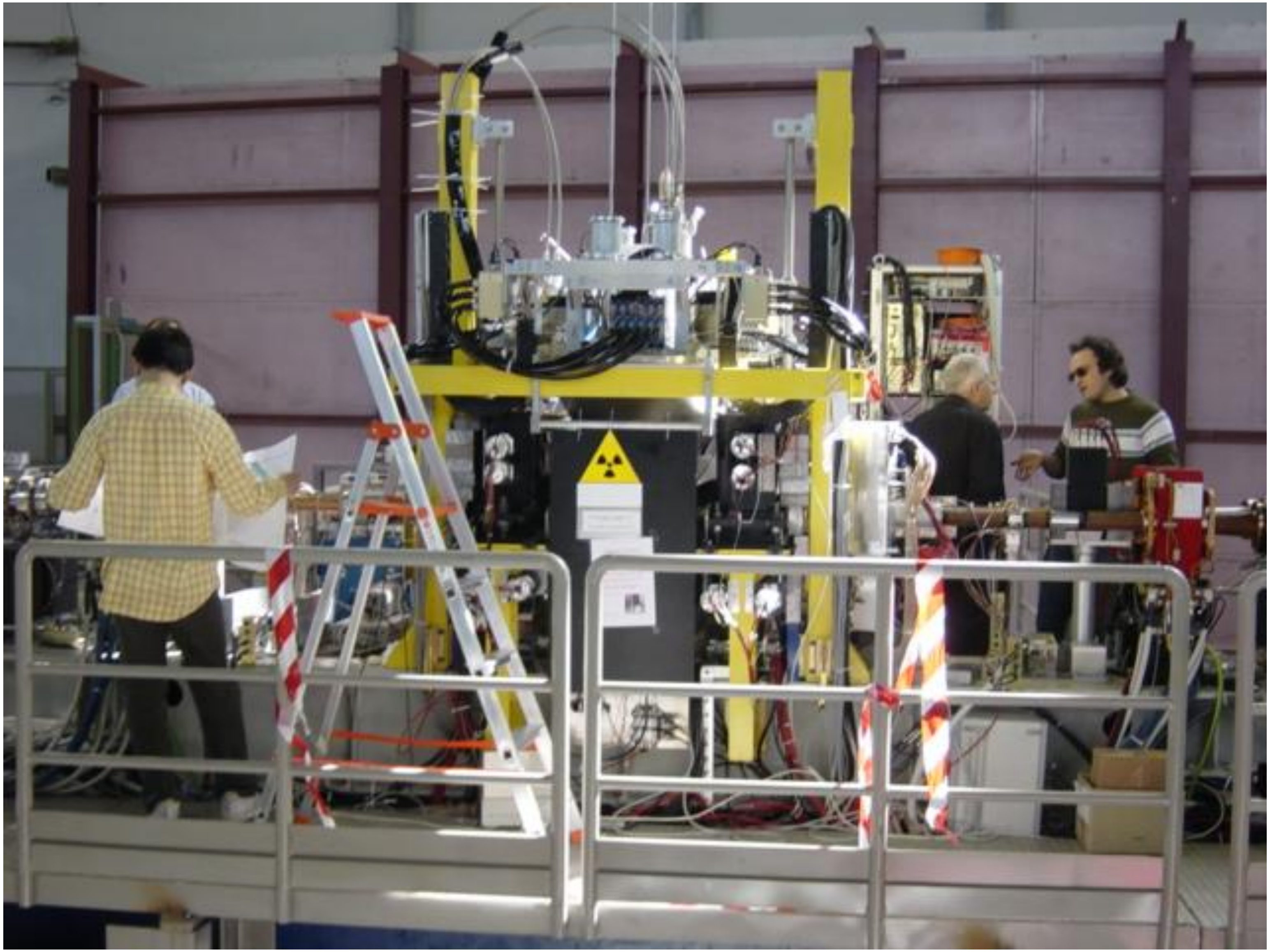
1 cm^2 x 144 SDDs

Kaon detector

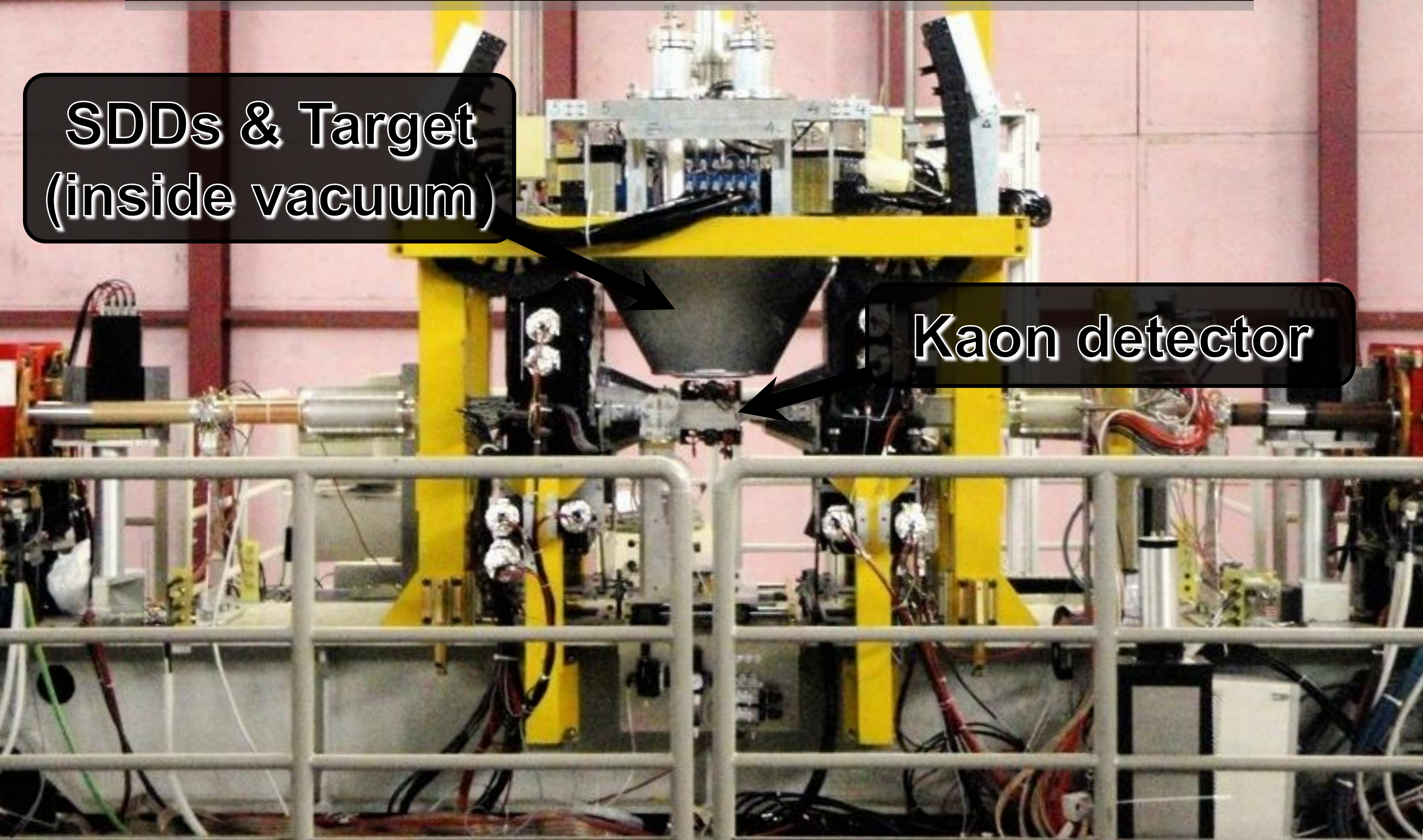


SIDDHARTA overview

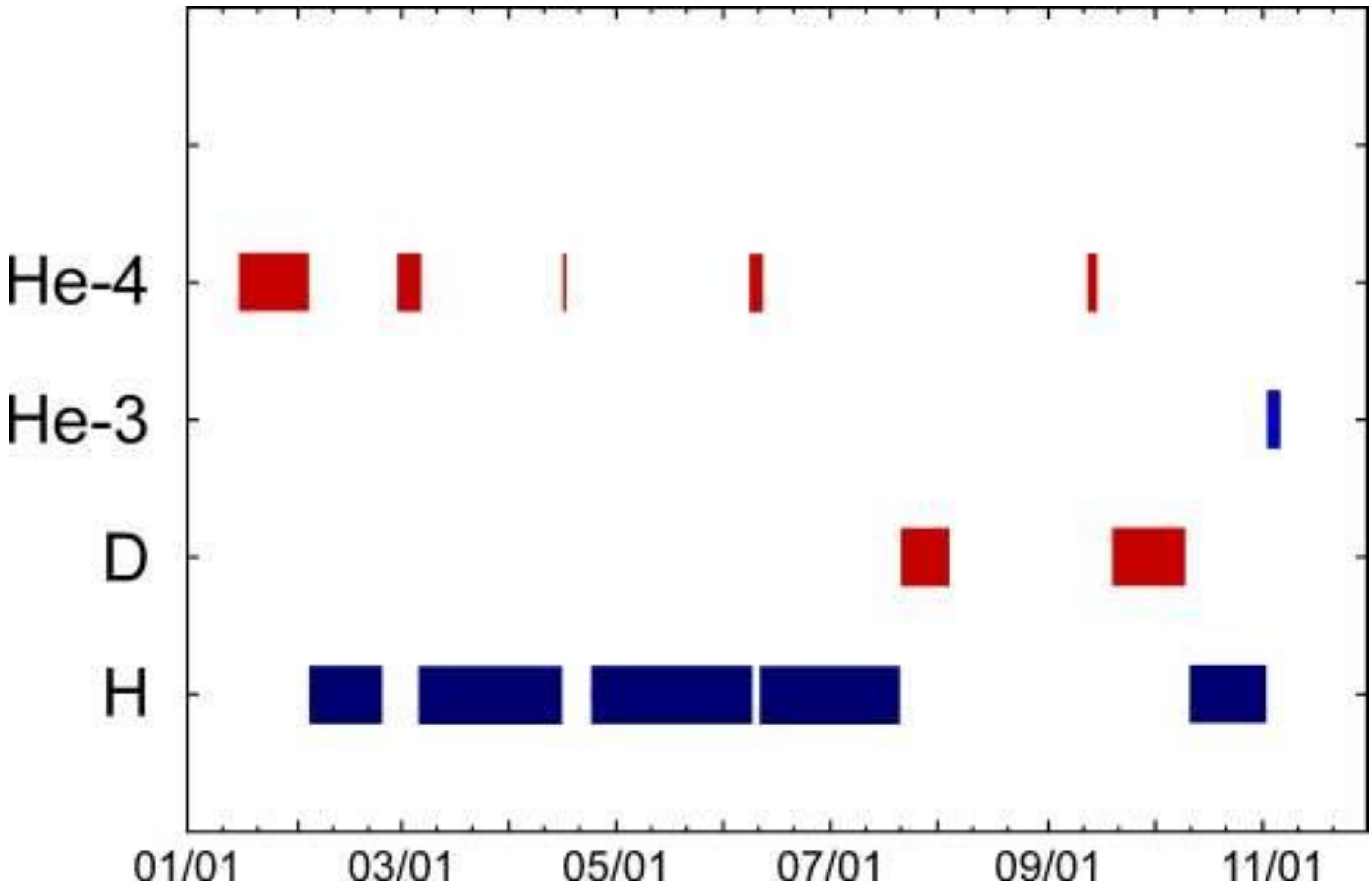




SIDDHARTA setup



SIDDHARTA data



SIDDHARTA results:

- Kaonic Hydrogen: 400pb^{-1}, most precise measurement ever,Phys. Lett. B 704 (2011) 113, Nucl. Phys. A881 (2012) 88; Ph D

- Kaonic deuterium: 100 pb^{-1}, as an exploratory first measurement ever, Nucl. Phys. A907 (2013) 69; Ph D

- Kaonic helium 4 – first measurement ever in gaseous target; published in Phys. Lett. B 681 (2009) 310; NIM A628 (2011) 264 and Phys. Lett. B 697 (2011);; PhD

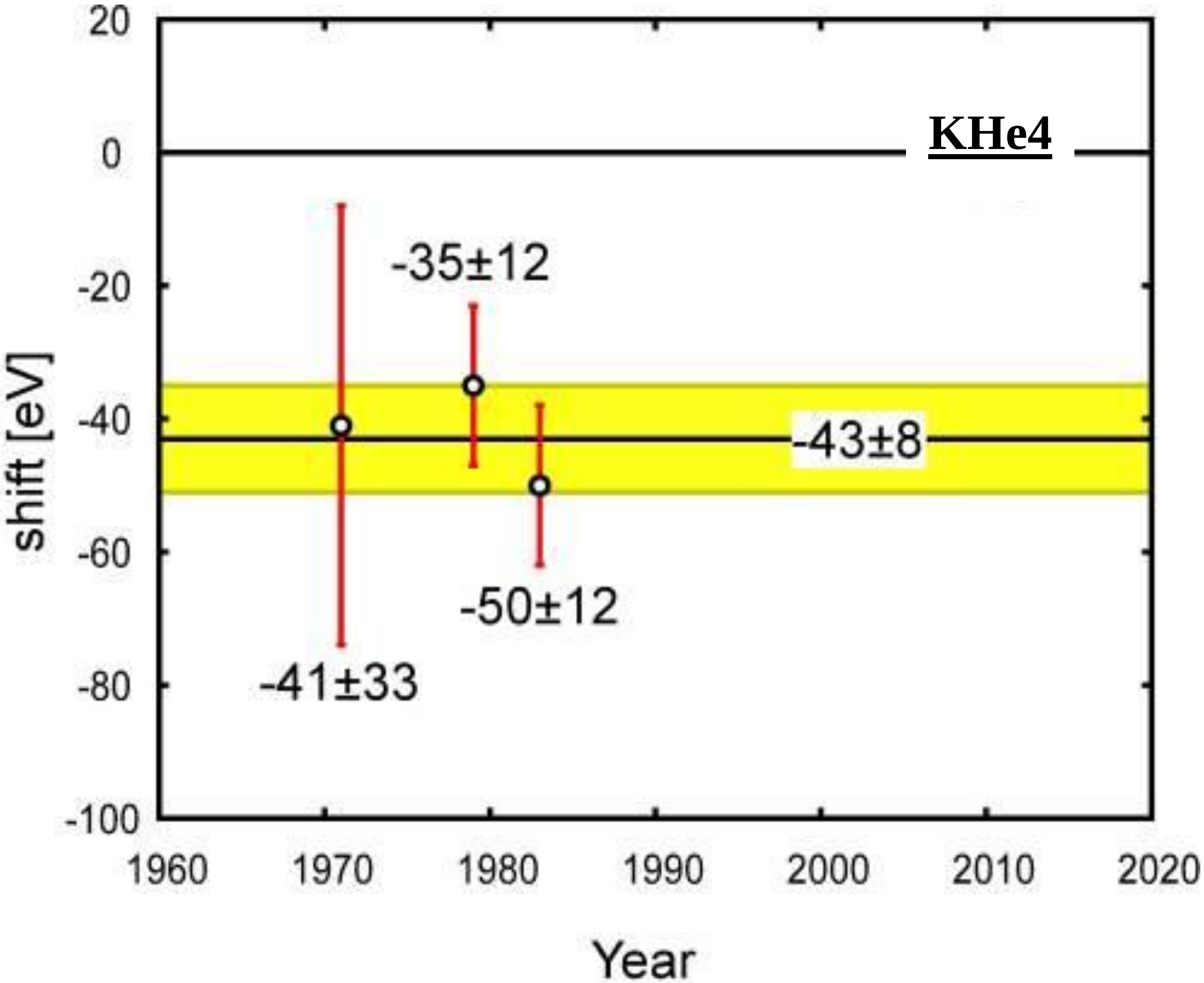
- Kaonic helium 3 – 10 pb^{-1}, first measurement in the world, published in Phys. Lett. B 697 (2011) 199; Ph D

- Widths and yields of KHe3 and KHe4 - Phys. Lett. B714 (2012) 40; ongoing: KH yields; kaonic kapton yields -> draft for publications

SIDDHARTA – important TRAINING for young researchers

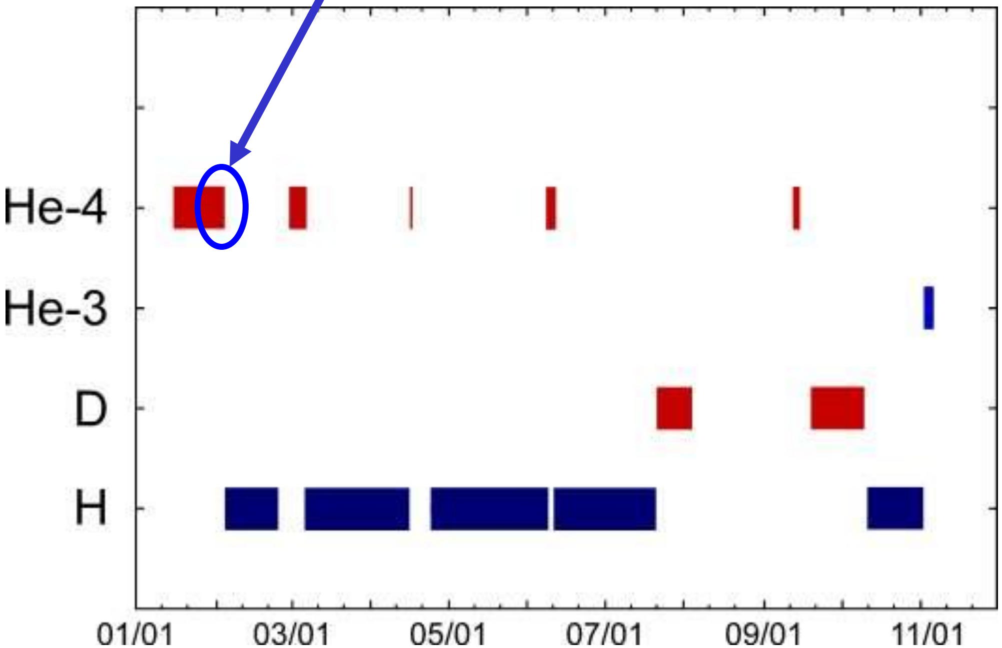
Kaonic Helium 3 and 4

Kaonic 4 old data

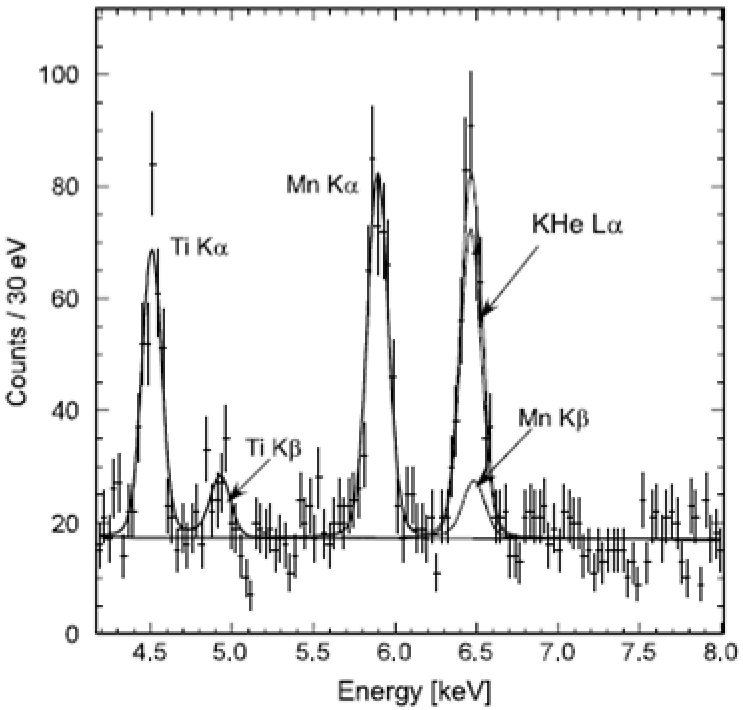


Data taking periods of SIDDHARTA in 2009

K-He4 data with Fe source



PLB681(2009)310



55Fe source:
Good for reduce sys. error on K-^{4}He
Bad for "background" events on K-H,K-D

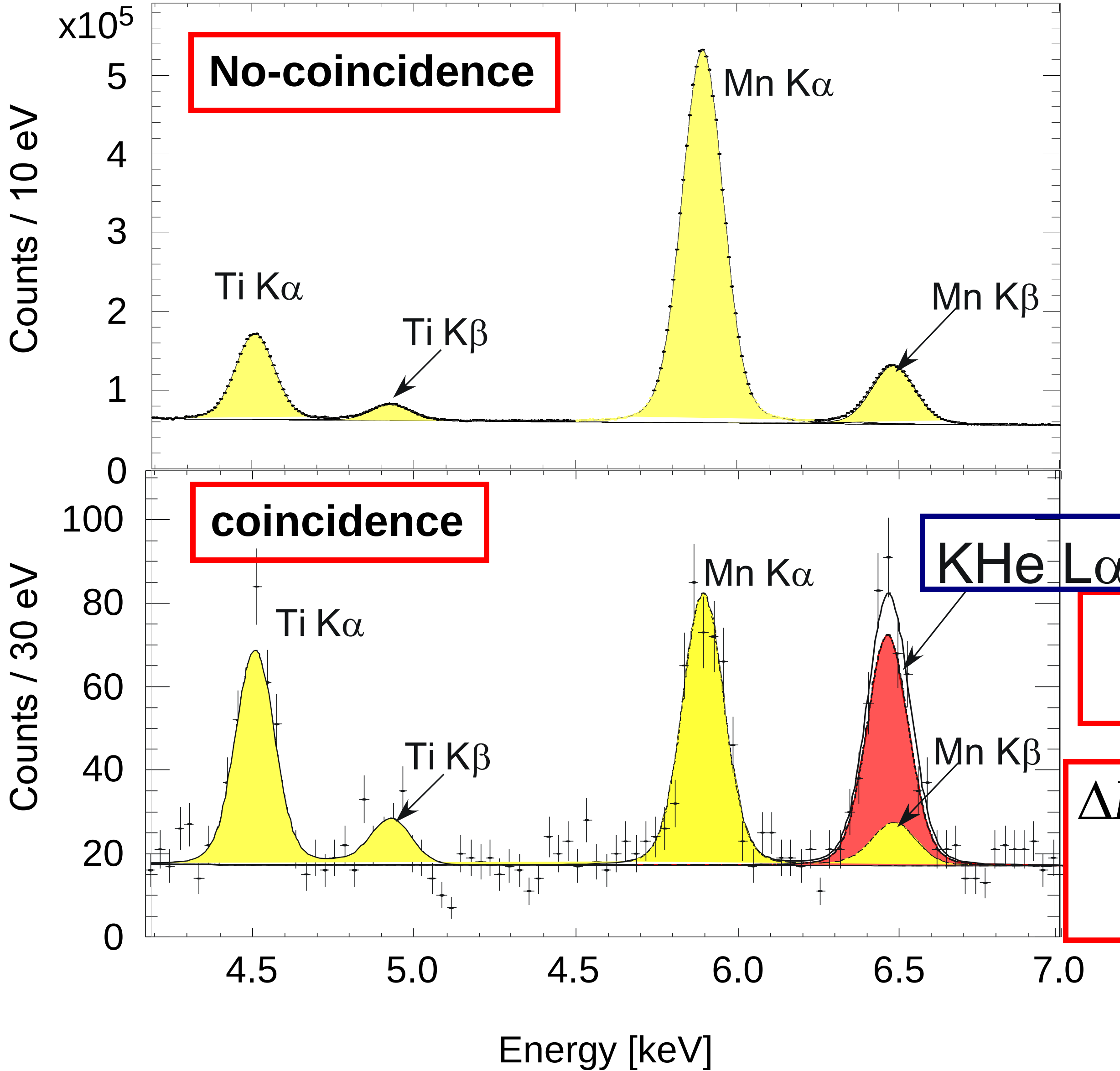
Removed ^{55}Fe source in other data

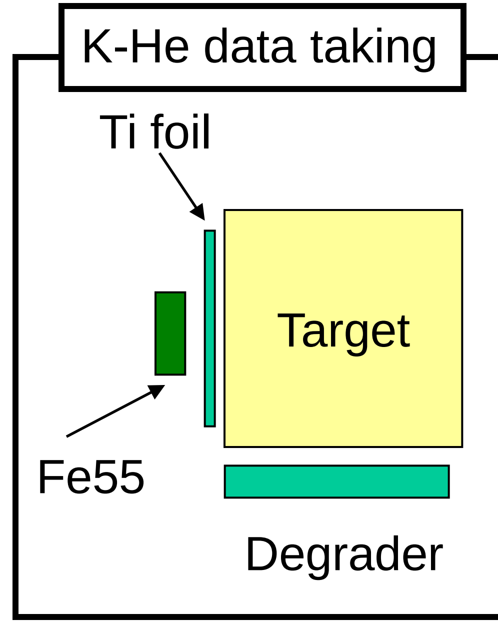
Use of
Mn Ka (5.9 keV) from ^{55}Fe

Systematic error = +/-2 eV

KHe-4 energy spectrum at SIDDHARTA

PLB681(2009)310; NIM A 628(2011)264





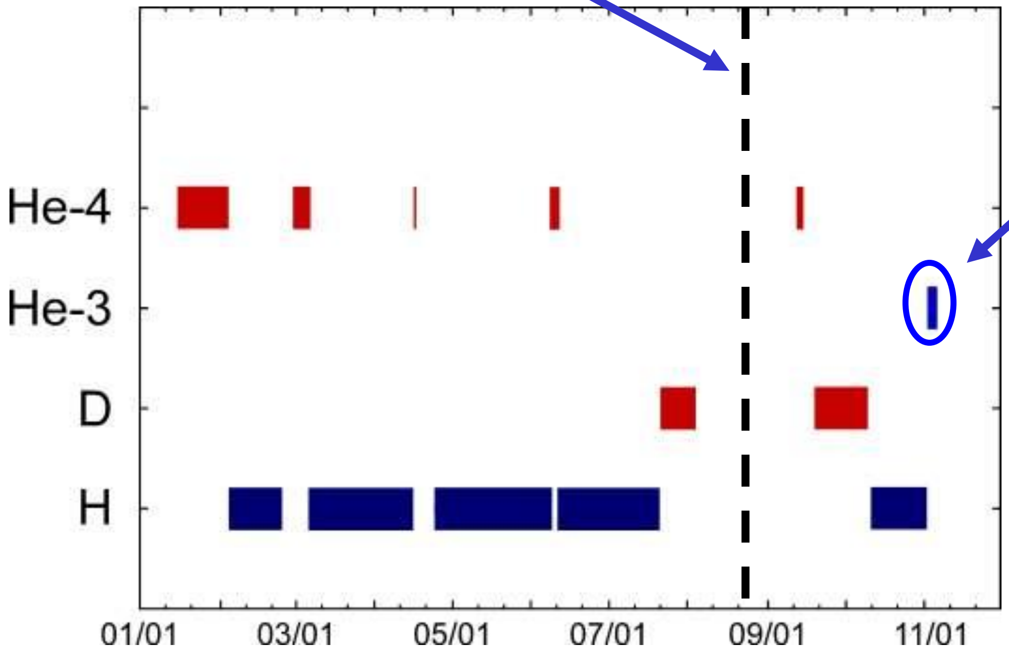
$$E_{\rm exp} = 6463.6 \pm 5.8 \text{ eV},$$

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

Data taking periods of SIDDHARTA in 2009

DAFNE shutdown in Summer → **New alignment of setup →Improve S/N ratio**

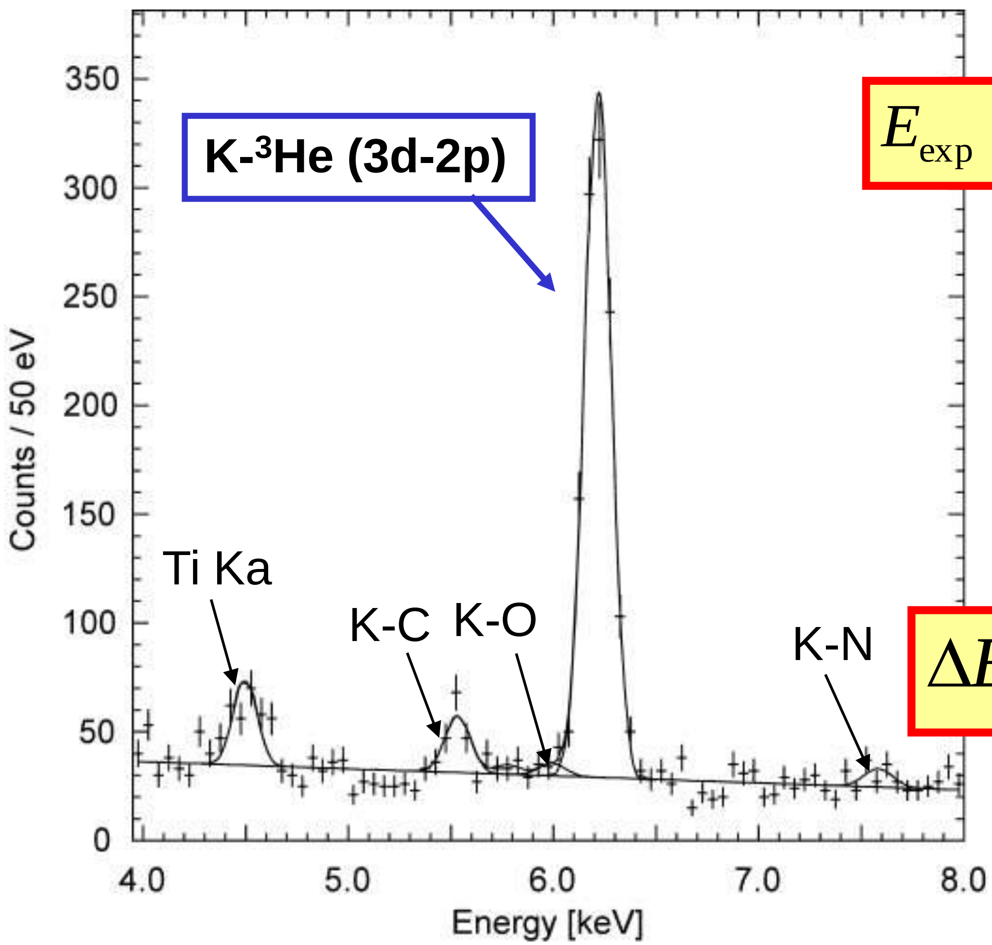
K-He3 data (~4days)



55Fe source:
Good for reduce sys. error on K-^{4}He
Bad   for "background" events on K-H,K-D

→ **Removed ^{55}Fe source in other data**

Kaonic Helium-3 energy spectrum



X-ray energy of K-3He 3d-2p

$$E_{\mathrm{exp}} = 6223.0 \pm 2.4(sta) \pm 3.5(sys)\ \mathrm{eV}$$

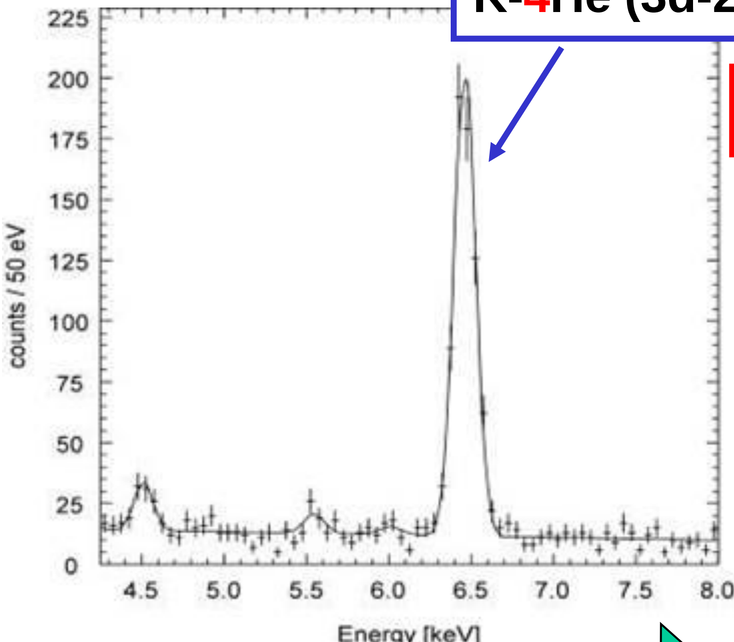
QED value: $E_{e.m.} = 6224.6\ \mathrm{eV}$

$$\Delta E_{2p} = E_{\mathrm{exp}} - E_{e.m.}$$

$$\Delta E_{2p} = -2 \pm 2(sta) \pm 4(sys)\ \mathrm{eV}$$

arXiv:1010.4631v1 [nucl-ex], PLB697(2011)199

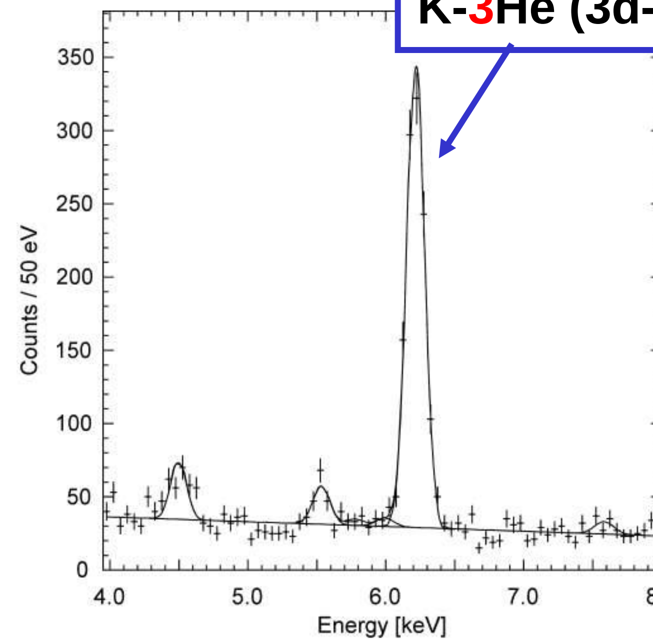
World First !
Observation of K-^{3}He X-rays
Determination of
strong-interaction shift



K-**4**He (3d-2p)

$$\Delta E_{2p} = +5 \pm 3(sta) \pm 4(sys)\ \text{eV}$$

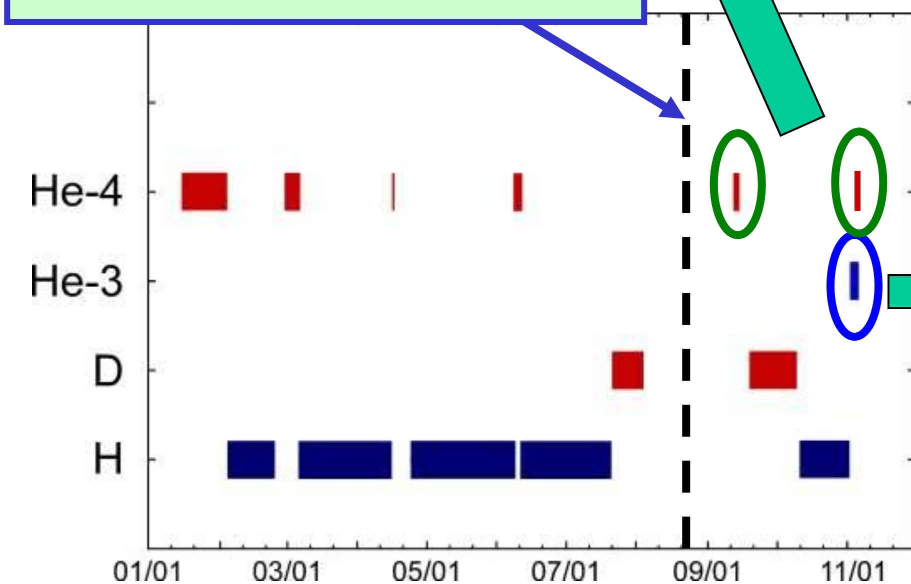
PLB697(2011)199



K-**3**He (3d-2p)

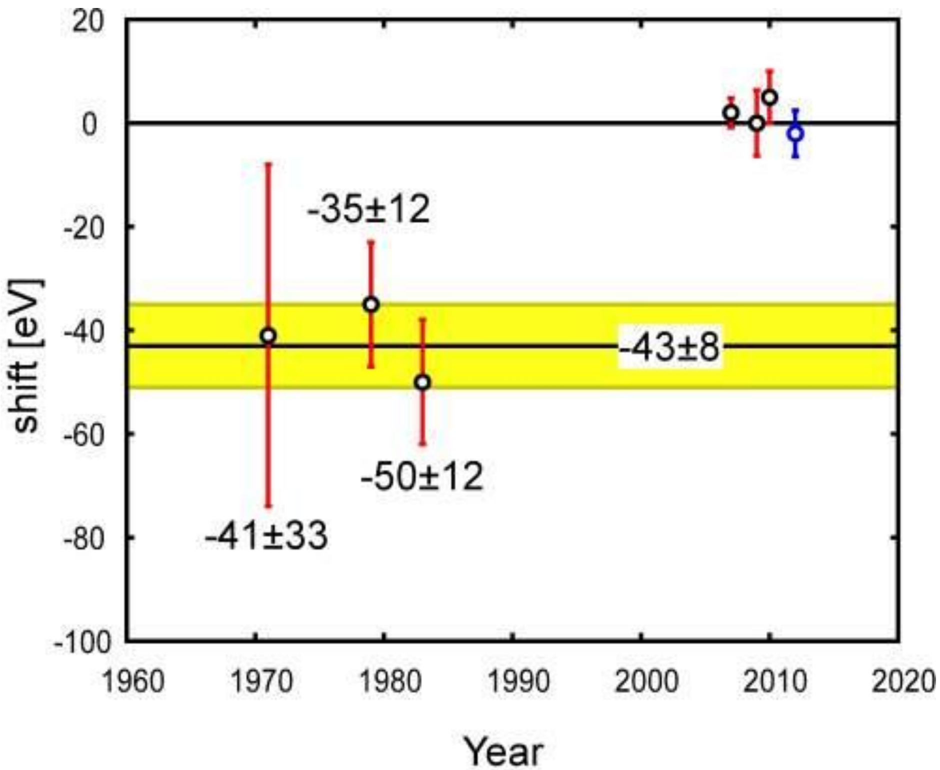
$$\Delta E_{2p} = -2 \pm 2(sta) \pm 4(sys)\ \text{eV}$$

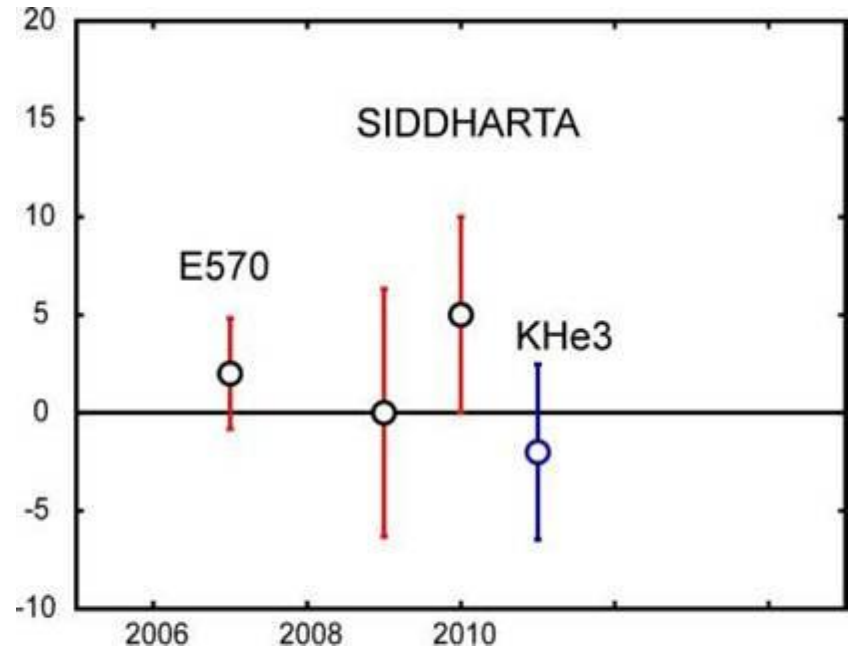
DAFNE shutdown in Summer



Comparison of results

	Shift [eV]	Reference
KEK E570	**+2±2±2**	**PLB653(07)387**
SIDDHARTA (He4 with 55Fe)	**+0±6±2**	**PLB681(2009)310**
SIDDHARTA (He4)	**+5±3±4**	**arXiv:1010.4631, PLB697(2011)199**
SIDDHARTA (He3)	**-2±2±4**	





***error bar** $= \pm\sqrt{(stat)^2 + (syst)^2}$

Phys. Lett. B714 (2012) 40

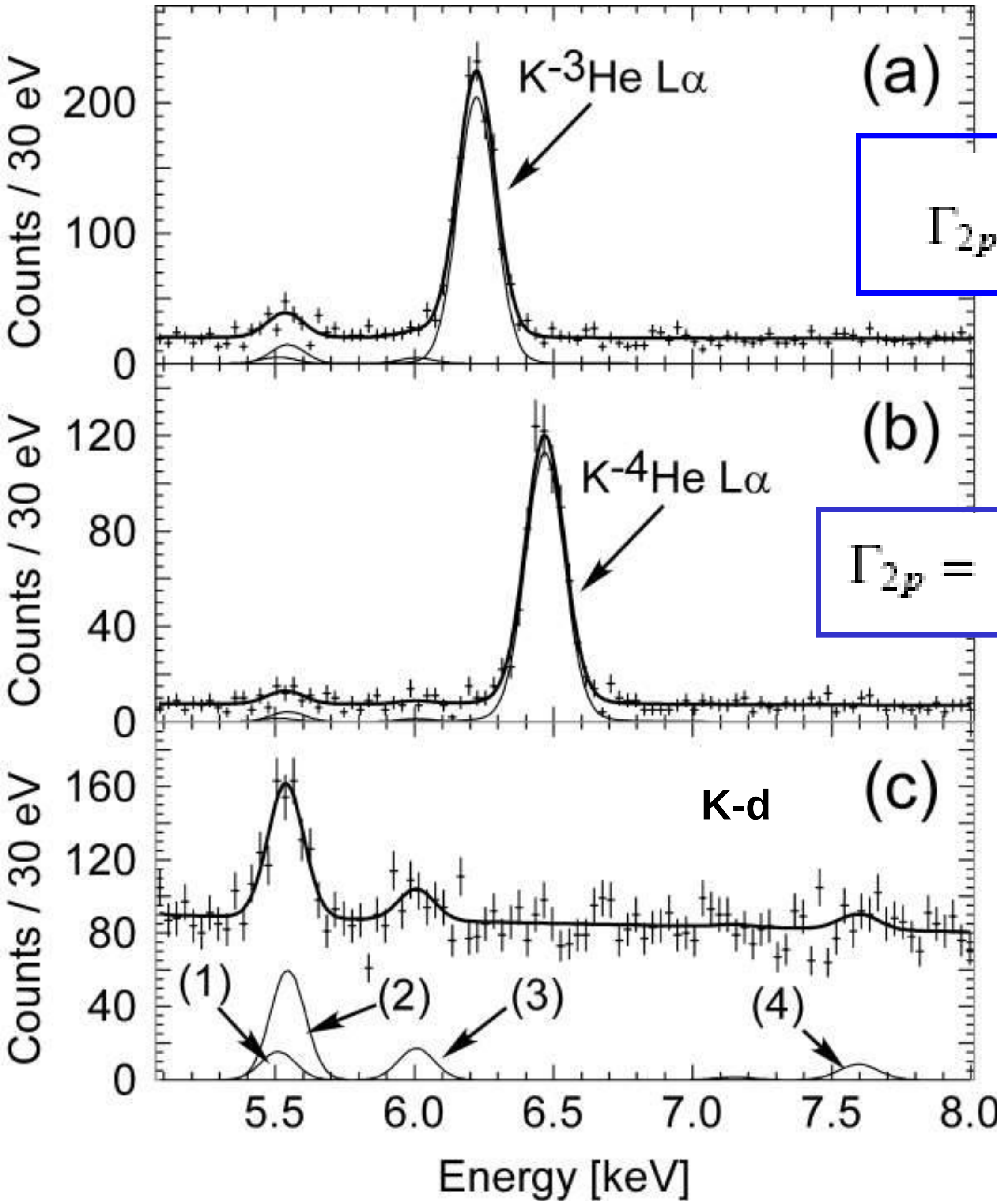
the strong-interaction width of the kaonic 3He and 4He 2p state

http://arxiv.org/abs/1205.0640v1

Old kaonic He4 measurements

	ΔE_{2p} (eV)	Γ_{2p} (eV)
	-41 ± 33	$-$
	-35 ± 12	30 ± 30
	-50 ± 12	100 ± 40
Average	-43 ± 8	55 ± 34

Theory: -0.13+-0.02 1.8+-0.05



$$\Gamma_{2p} = 6 \pm 6\ (\text{stat.}) \pm 7\ (\text{syst.})\ \text{eV},$$

$$\Gamma_{2p} = 14 \pm 8\ (\text{stat.}) \pm 5\ (\text{syst.})\ \text{eV},$$

Old average

$$\Gamma^{He4}{}_{2p} = 55 \pm 34 \text{ eV}$$

K-3He width

$$\Gamma_{2p} = 6 \pm 6 \text{ (stat.)} \pm 7 \text{ (syst.)}$$

K-4He width

$$\Gamma_{2p} = 14 \pm 8 \text{ (stat.)} \pm 5 \text{ (syst.) eV},$$

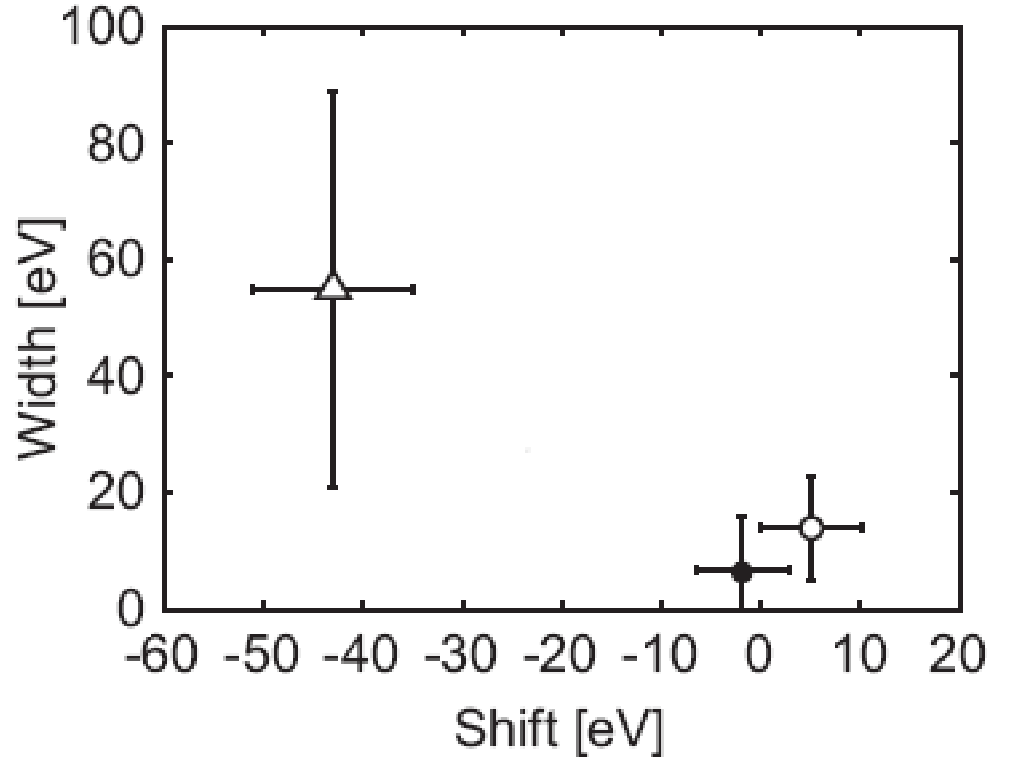


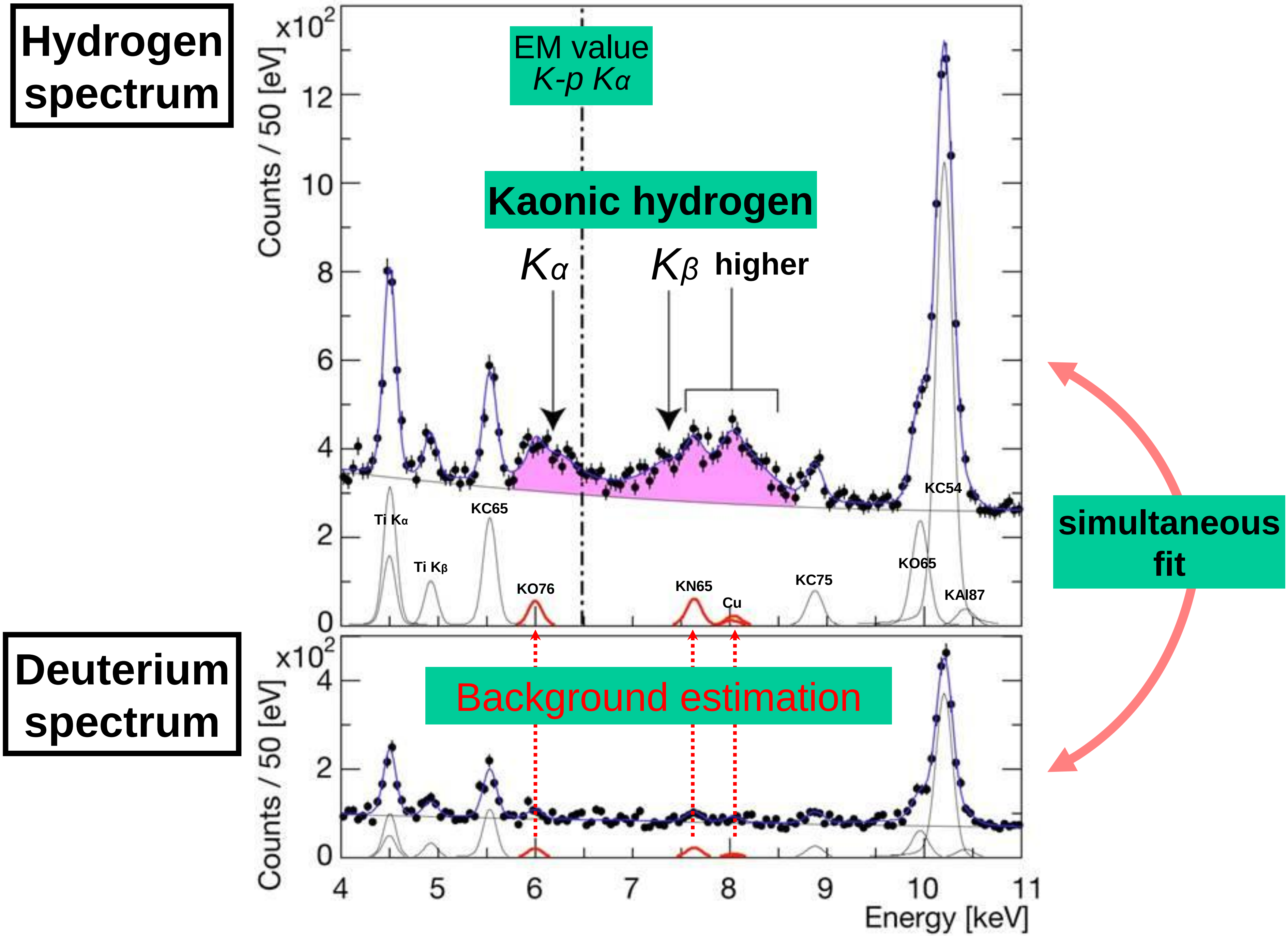
Figure 5: Comparison of experimental results. Open circle: K-4He 2*p* state; filled circle: K-3He 2*p* state. Both are determined by the SIDDHARTA experiment. The average value of the K-4He experiments performed in the 70's and 80's is plotted with the open triangle.

Kaonic Helium results:

- first measurements of KHe3 and in gas He4
- if any shift of 2 p level is present – is small
- KHe3 measurement took 3 days!!! – proves how EXCELLENT is SIDDHARTA-like method at DAFNE

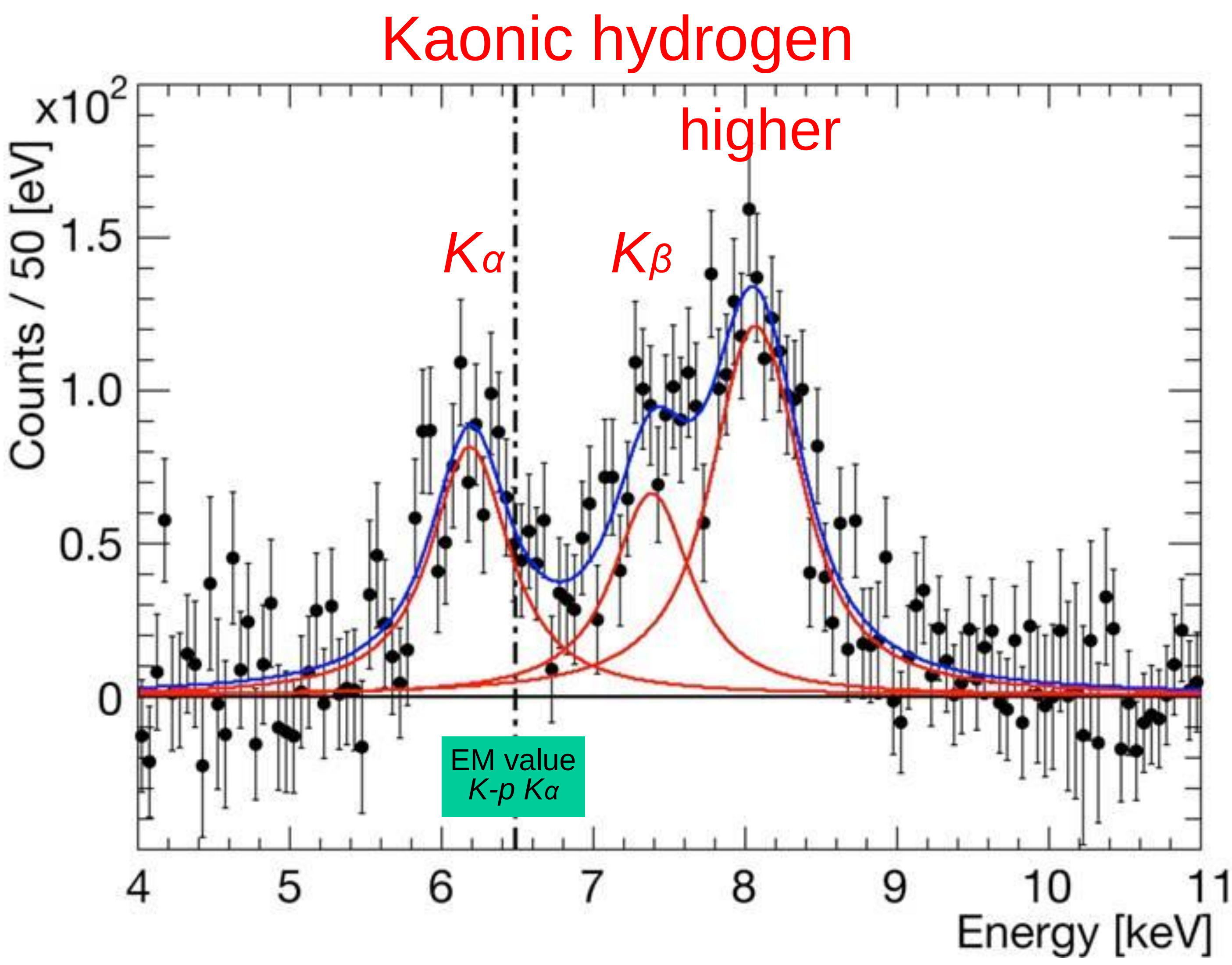
- SIDDHARTA-2 – can do much better: KHe3,4 at eV and try measurement of 1s levels!

Kaonic Hydrogen



Hydrogen spectrum
Deuterium spectrum
EM value
K-p Kα
Kaonic hydrogen
Kα
Kβ
higher
Ti Kα
Ti Kβ
KC65
KO76
KN65
Cu
KC75
KO65
KC54
KAl87
simultaneous fit
Background estimation
Counts / 50 [eV]
x10²
Energy [keV]

Residuals of K-p x-ray spectrum after subtraction of fitted background



KAONIC HYDROGEN results

$$\varepsilon_{1S} = -283 \pm 36(\mathrm{stat}) \pm 6(\mathrm{syst})\ \mathrm{eV}$$

$$\Gamma_{1S} = 541 \pm 89(\mathrm{stat}) \pm 22(\mathrm{syst})\ \mathrm{eV}$$

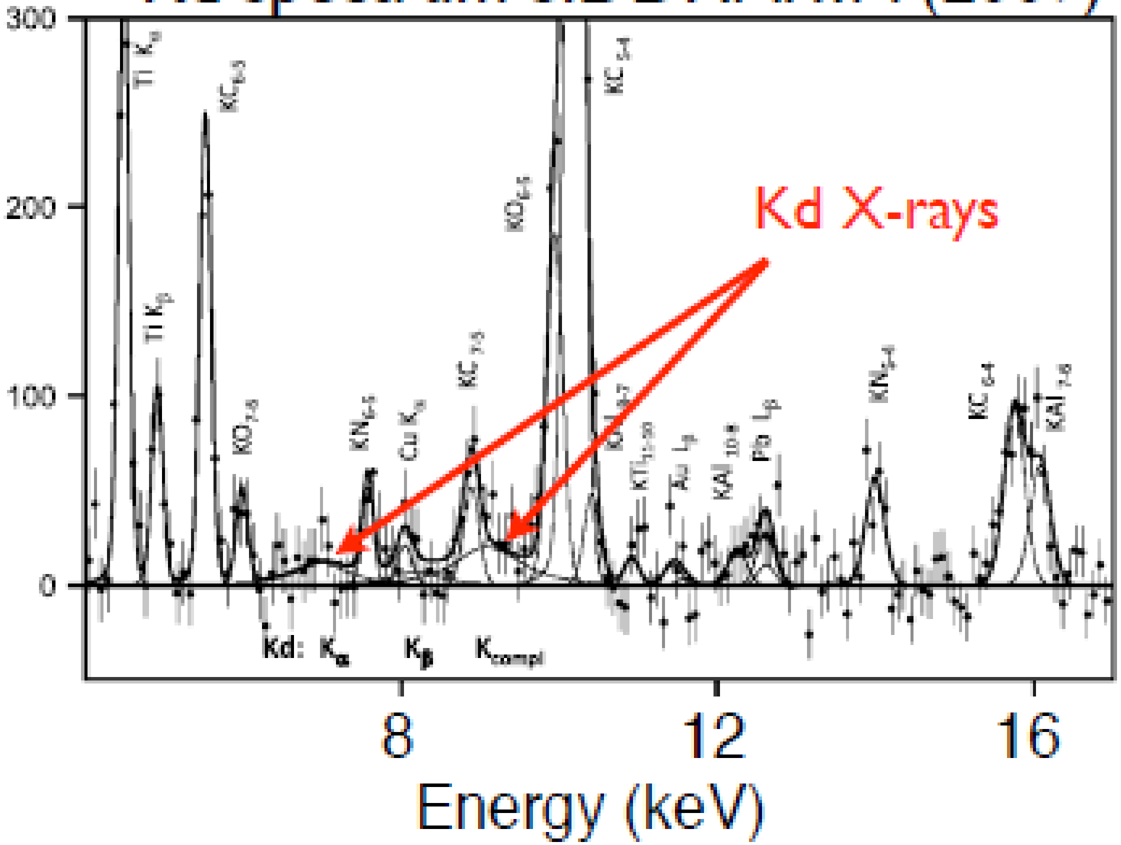
Kaonic Deuterium exploratory measurement

theoretical calculations

a_{K^-d} [fm]	ϵ_{1s} [eV]	Γ_{1s} [eV]	Ref.
$-1.58 + i\,1.37$	-887	757	Mizutani 2013 [4]
$-1.48 + i\,1.22$	-787	1011	Shevchenko 2012 [5]
$-1.46 + i\,1.08$	-779	650	Meißner 2011 [1]
$-1.42 + i\,1.09$	-769	674	Gal 2007 [6]
$-1.66 + i\,1.28$	-884	665	Meißner 2006 [7]

shift: ~ –800 eV   width: 700 - 1000 eV

Kd spectrum SIDDHARTA (2009)



fixed parameters in the fit

shift = -805 eV

Width = 750 eV

yield ratios of K transitions

continuous background was subtracted

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

The first Kd paper of SIDDHARTA

determined the upper limit of Kd K-transitions yields

Available online at www.sciencedirect.com

SciVerse ScienceDirect

NUCLEAR PHYSICS A

Nuclear Physics A 907 (2013) 69–77

www.elsevier.com/locate/nuclphysa

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,*], 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]

Kaonic Hydrogen results:

- most reliable and precise measurement ever

Our determination of the shift and width does provide new constraints on theories, having reached a quality which will demand refined calculations of the low-energy $\overline{K}N$ interaction.

- need to go for Kd! -> SIDDHARTA-2

DAΦNE represents (as always did) an (THE) EXCELLENT FACILITY in the sector of low-energy interaction studies of kaons with nuclear matter.

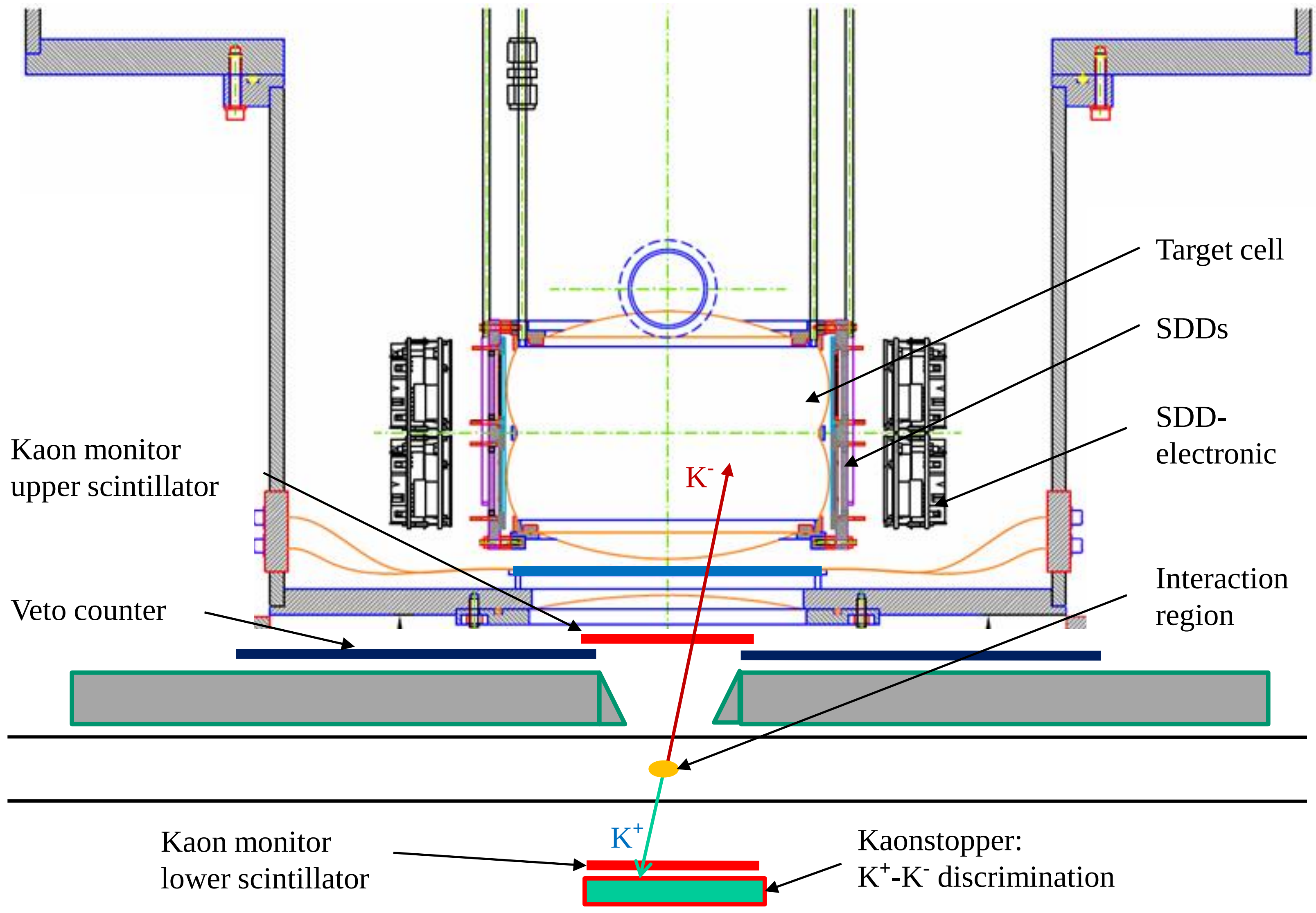
It is actually the IDEAL facility for kaonic atoms studies as SIDDHARTA has demonstrated

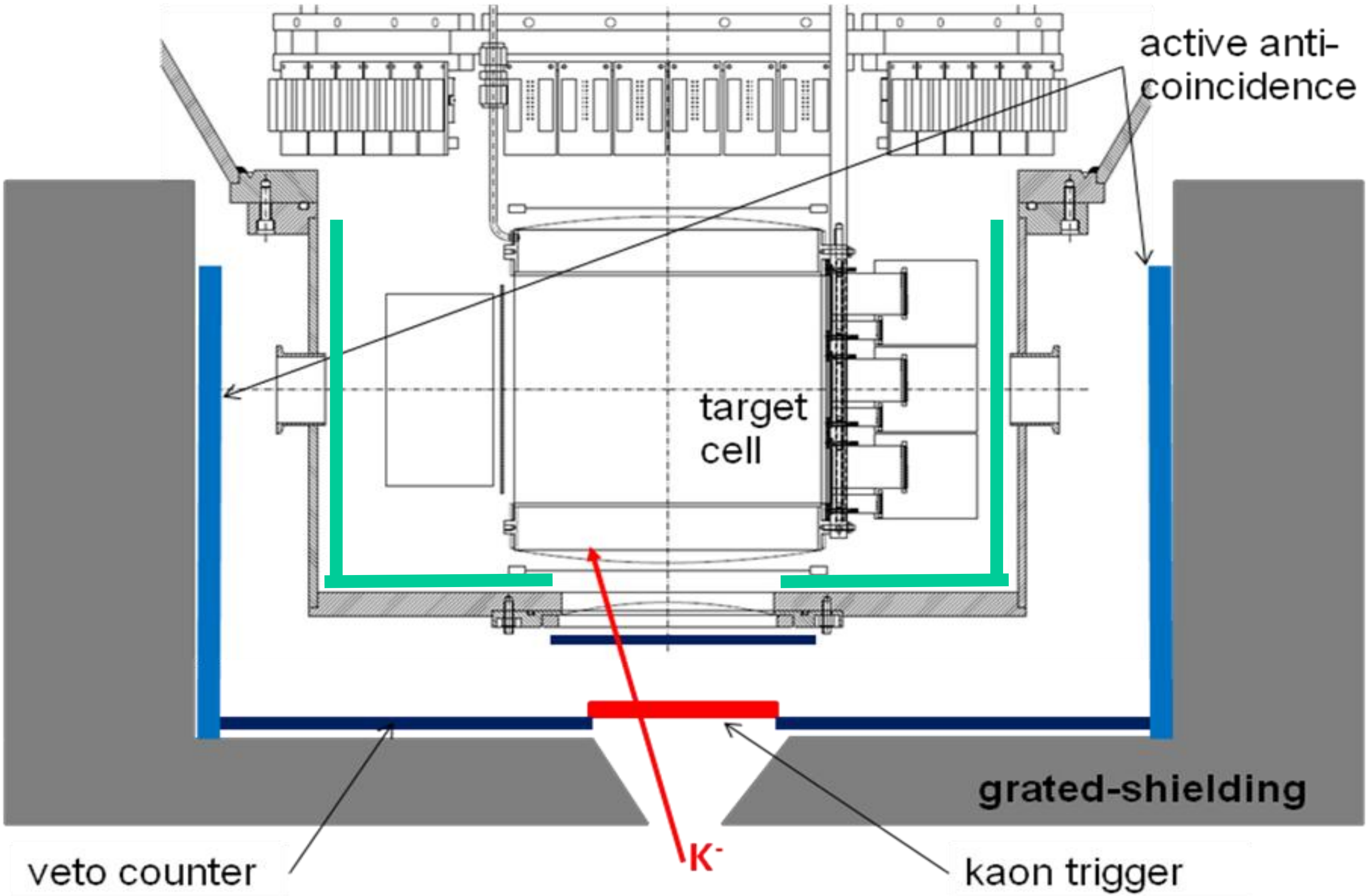
SIDDHARTA-2 team is ready to restart the measurements, having a multi-step strategy, strating with the Kaonic deuterium

SIDDHARTA–2

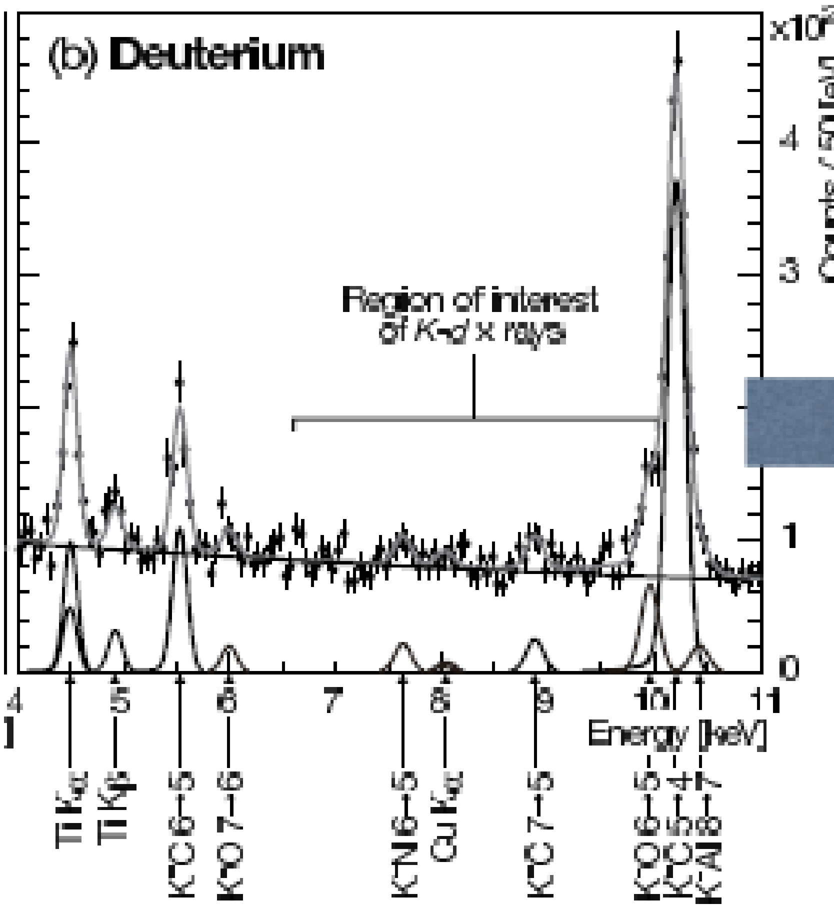
The SIDDHARTA-2 setup, essential improvements

- new target design
- new SDD arrangement
- vacuum chamber
- more cooling power
- improved trigger scheme
- shielding and anti-coincidence (veto)


Target cell
SDDs
SDD-
electronic
Kaon monitor
upper scintillator
K-
Veto counter
Interaction
region
K+
Kaon monitor
lower scintillator
Kaonstopper:
K+-K- discrimination

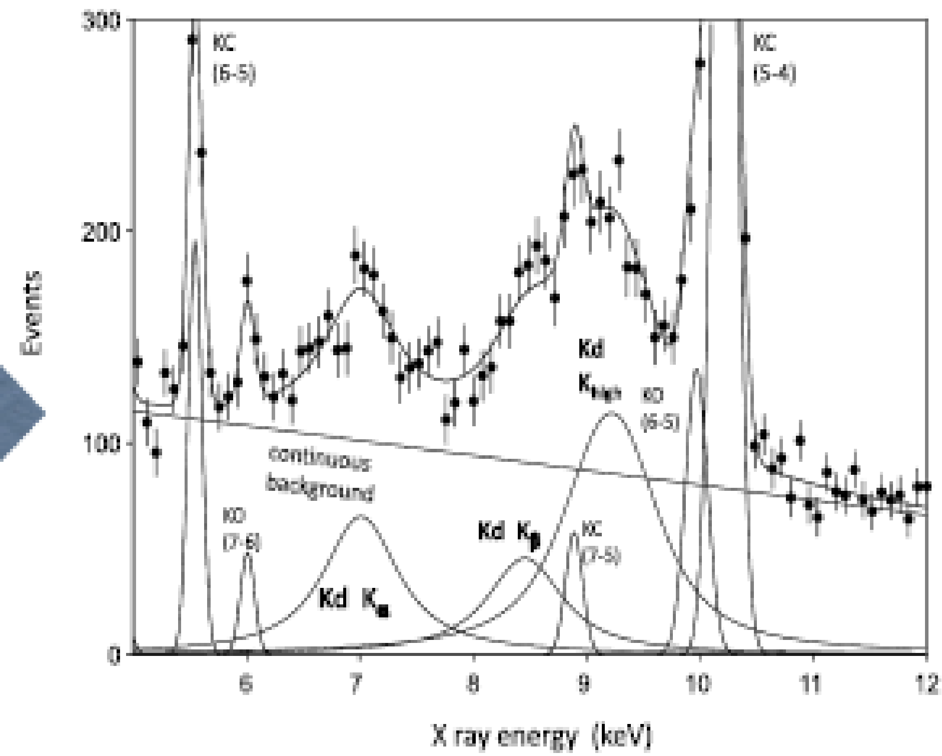

active anti-
coincidence
target
cell
grated-shielding
veto counter
K-
kaon trigger

SIDDHARTA(2009)



~100 pb^{-1}

SIDDHARTA2
(expected spectrum)



assuming

0.1% yield (1/10 of Kp)

800 pb^{-1}

fit result (all intensities free) sample 1
shift = -556+-86 eV width= 1284+-145 eV

New development of SDDs by Politecnico & FBK

- **Started in 2011 within a project supported by ESA**
- **Considered very suitable for the upgrade of the Siddharta-2 apparatus, with preliminary evaluation on prototypes in 2012/2013**

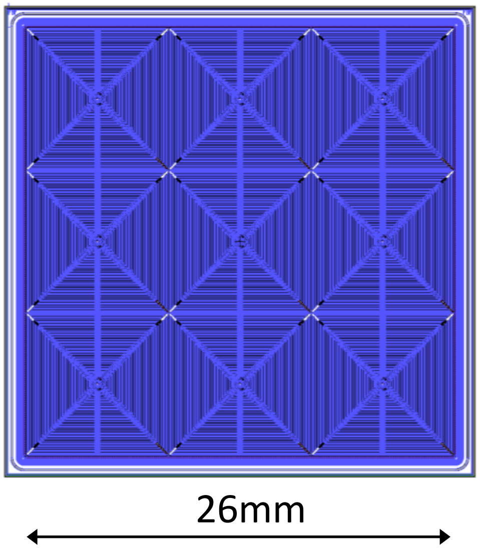
- **Key features of the proposed technological approach:**

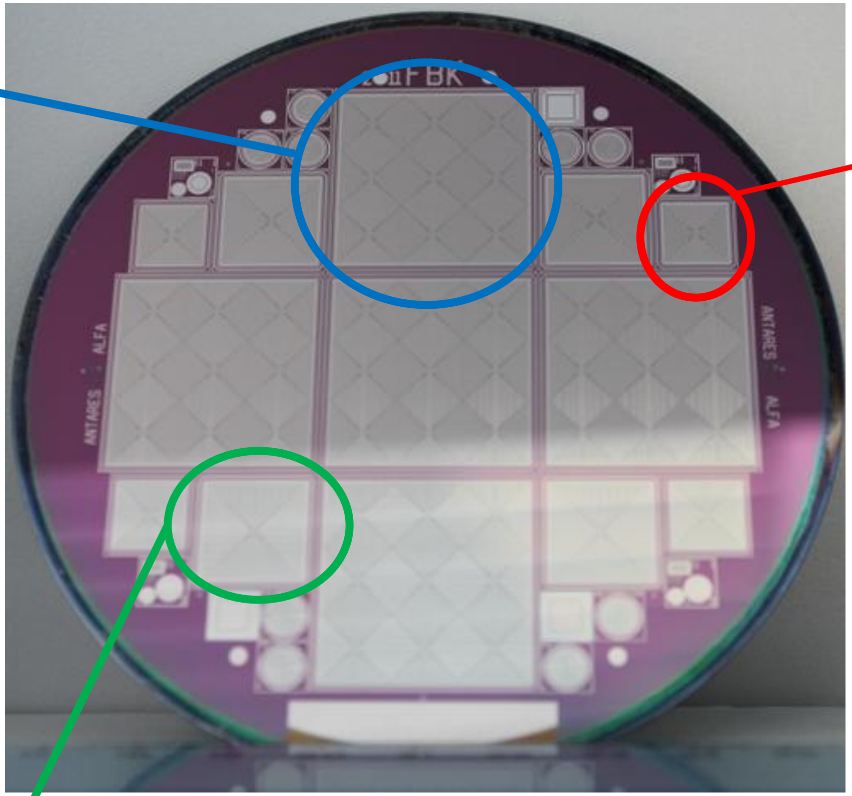
1) process of SDD detectors WITHOUT JFET integrated on the SDD itself (as used on current SIDDHARTA apparatus).
advantages:
- simplicity
- much lower production costs (much less techn. steps)
- faster production times (3-4 months vs. one year)
- much lower dependence of settings/performances on bias voltages than with the present detectors
- less sensitivity to latch-up during beam injection

2) SDD readout based on a new charge preamplifier "Cube" (recently developed at Politecnico di Milano):
- allows high performances in X-ray spectroscopy still using 'conventional' SDD technology (W/O integrated JFET)

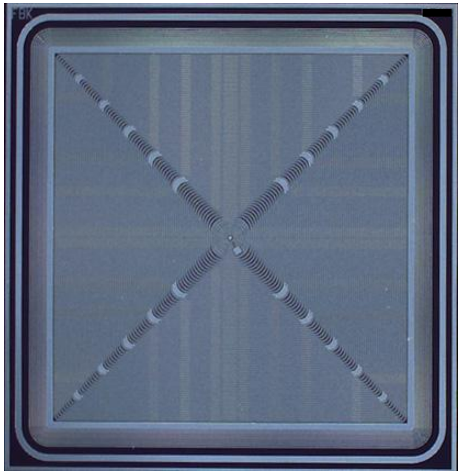
Present layouts of SDDs developed in the Polimi-FBK collaboration

Array: 9 SDDs (8 x 8 mm^2 each)





8 x 8 mm^2 single SDD

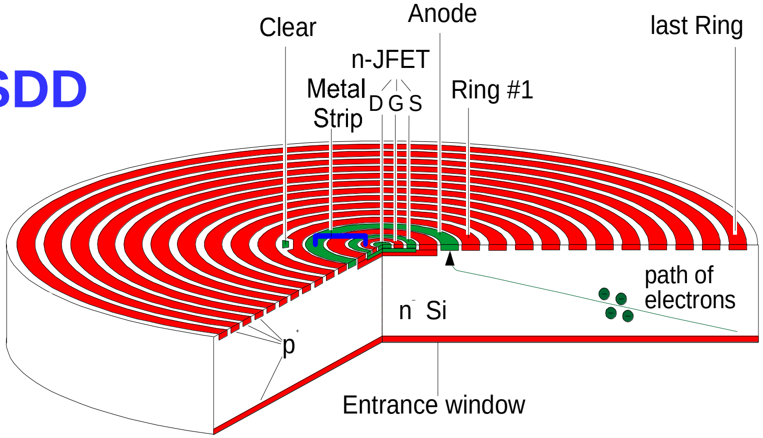


12 x 12 mm single SDD

FBK production:
- **4” wafer**
- **6” wafer upgrade just finished**

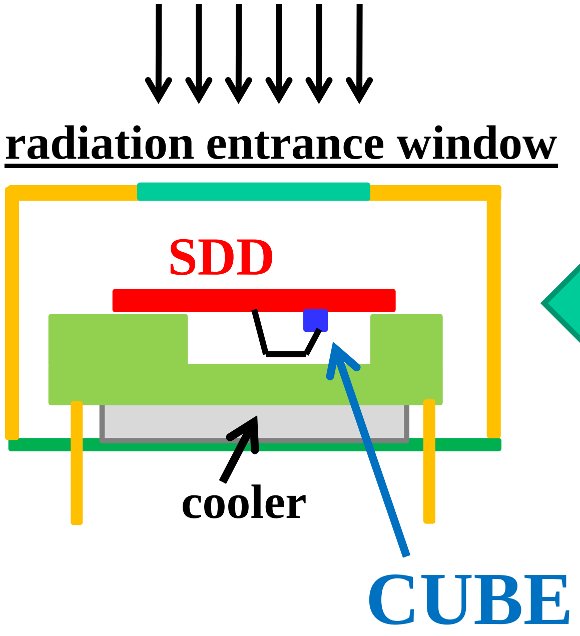
Front-end readout strategy

- **JFET integrated on the SDD**
  - **lowest total anode capacitance**
  - **limited JFET performances (gm, 1/f)**
  - **sophisticated SDD+JFET technology**

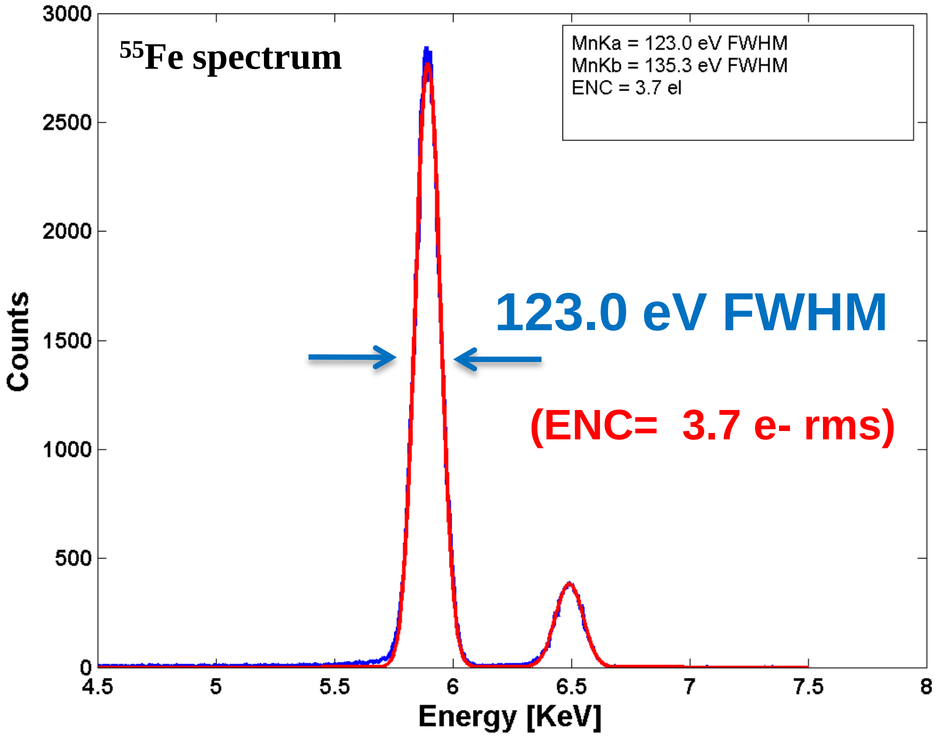


Now in Siddharta

- **external CUBE preamplifier (MOSFET input transistor)**
  - **larger total anode capacitance**
  - **better FET performances**
  - **standard SDD technology**



Proposed for Siddharta-2

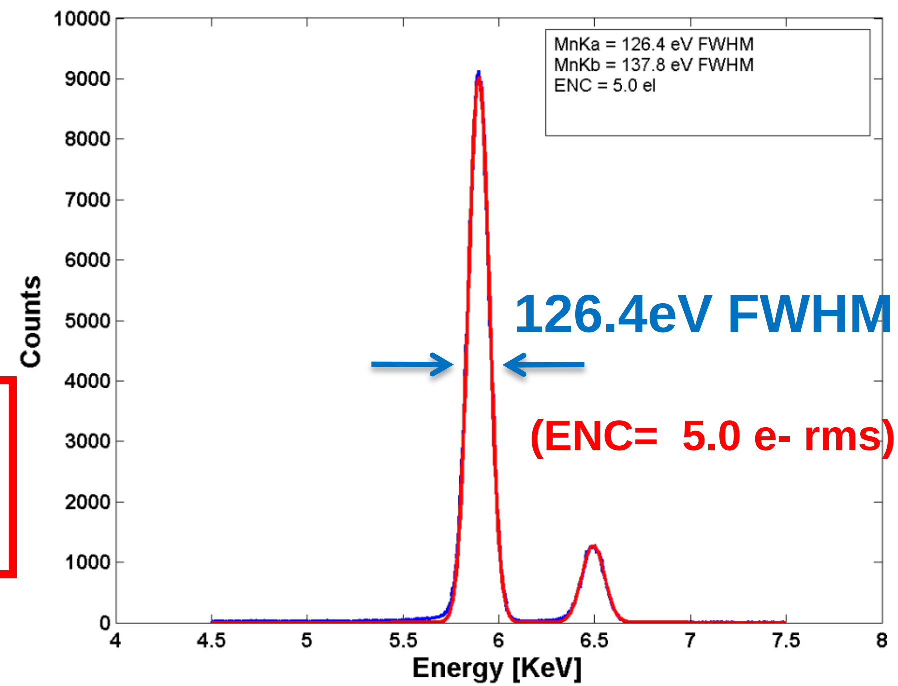


Best performances of new SDD technology and CUBE preamplifier

SDD characteristics:
- **Area = 10mm^2**
- **T= -40°C**

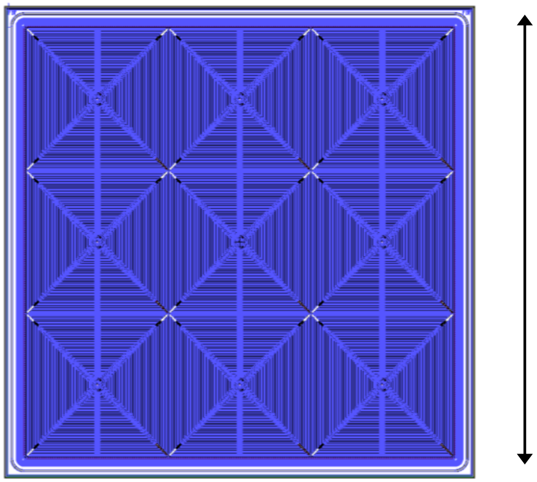
1.0 µs shaping time (optimum)

250ns shaping time

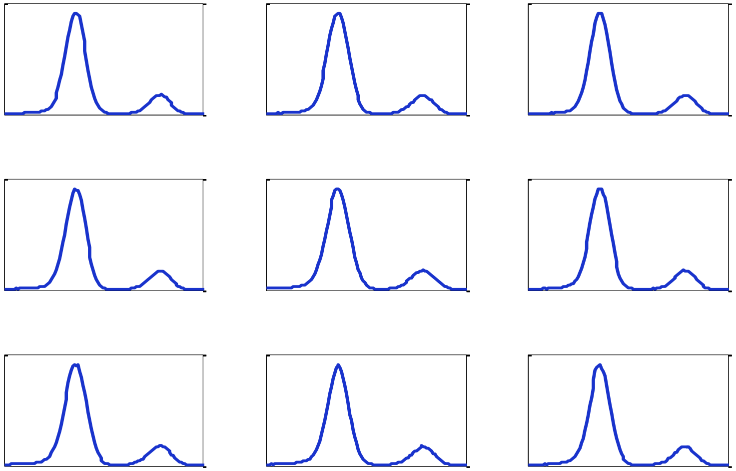


best resolution ever obtained with a SDD (even with integrated JFET) at this short shaping time

Monolithic array of 3x3 SDDs: an ideal detector for Siddharta-2 upgrade

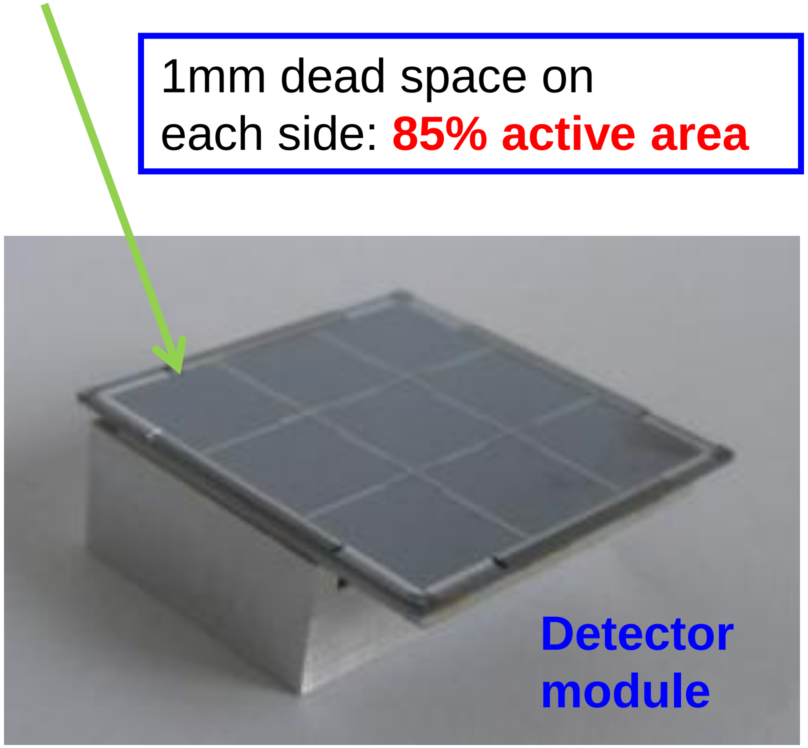


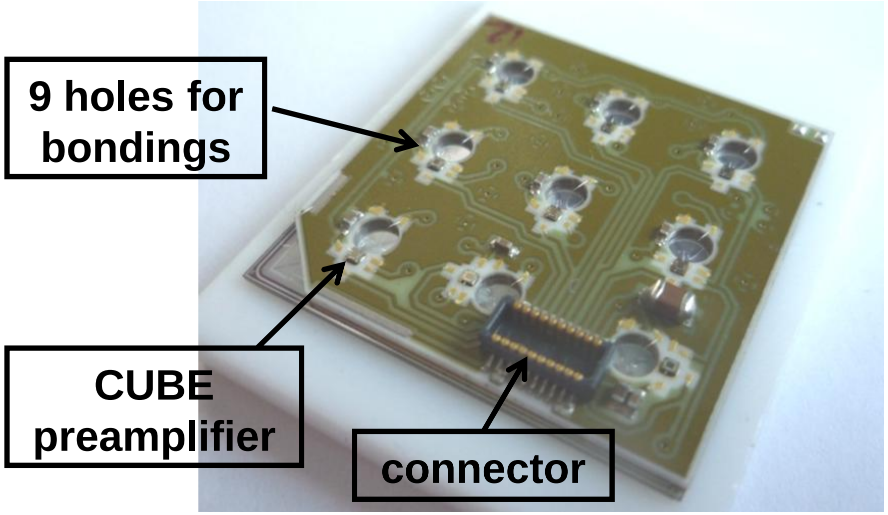
26mm



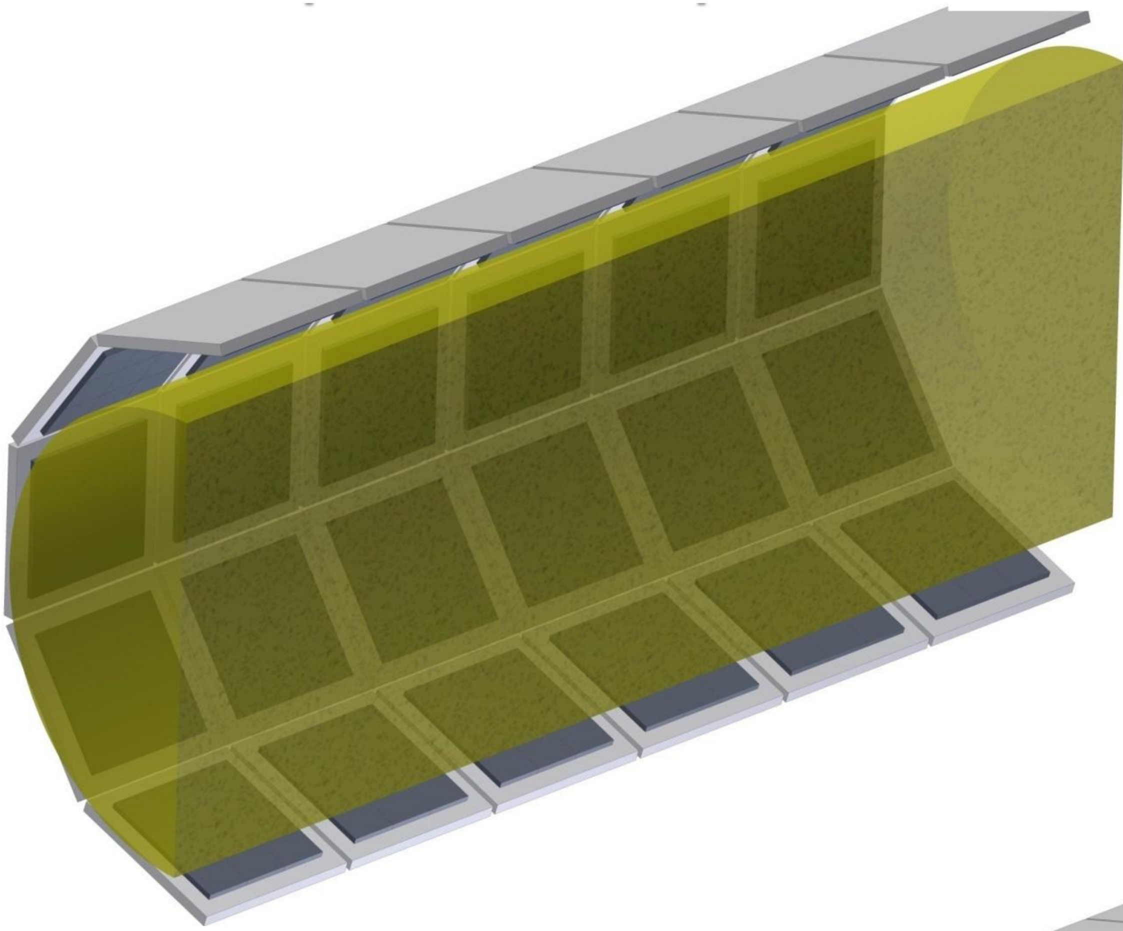
- ^{55}Fe spectra
- T=-20°C

1mm dead space on each side: **85% active area**





Ceramic carrier

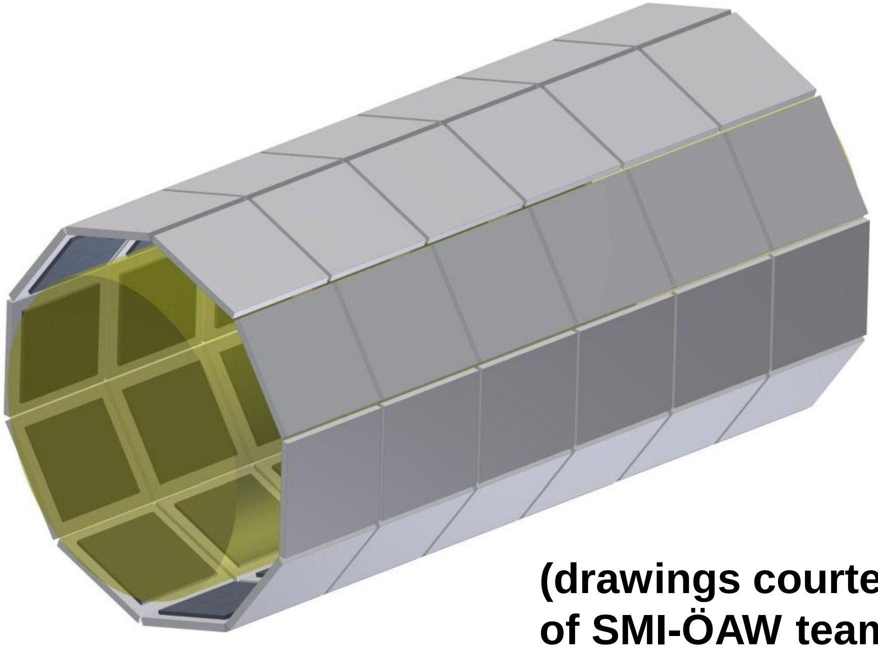


Upgrade of Siddharta-2 spectrometer based on:

- new SDDs development
- CUBE and ASICs readout
- low dead-area detection module design

Few numbers:

- 243cm^2 of SDDs arrays
- 36 SDDs monolithic arrays
- 324 readout channels



(drawings courtesy of SMI-ÖAW team)

What we gain with 200 cm2 new SDDs?**
(can be placed instead of present ones...)

Kaonic hydrogen at 7 eV with 100 pb – very important – tune threshold interaction

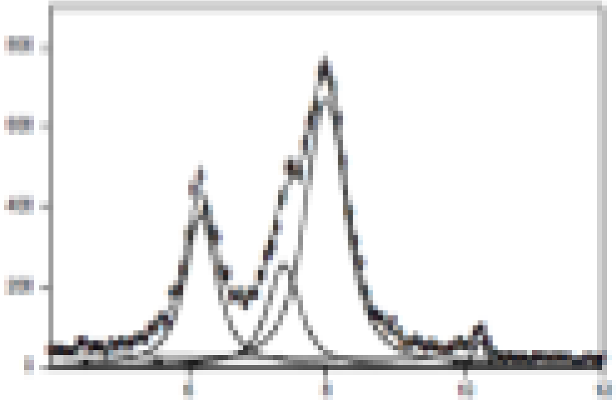
Kaonic deuterium at about 30 eV with 400 pb

Kaonic helium 2p at < 1 eV with 50 pb

Kaonic helium 1s – 150 events?

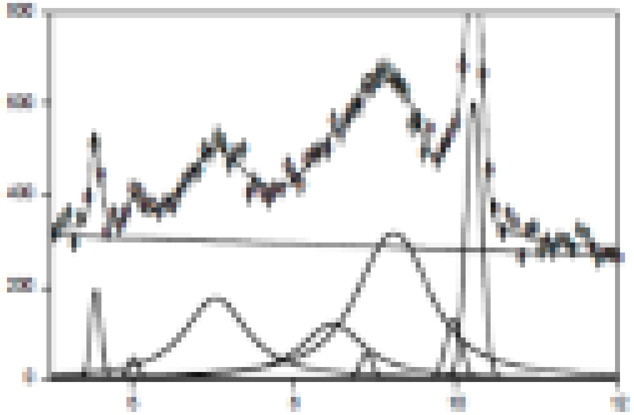
100 pb^{-1} hydrogen

K_α peak 4000 events
S/B 14:1
sigma(shift) = 7 eV sigma(width) = 13 eV



800 pb^{-1} deuterium

K_α peak 3000 events
S/B 1:1.5
sigma(shift) = 27 eV sigma(width) = 72 eV



SIDDHARTA-2 scientific program

1) Kaonic deuterium measurement - 1st measurement: and R&D for other measurements

2) Kaonic helium transitions to the 1s level – 2nd measurement, R&D

3) Other light kaonic atoms (KO, KC,…)

ECT* Workshop in Otctober 2013

Strangeness in the Universe?
Theoretical and experimental challenges and progress

7) Kaon mass precision measurement at the level of <10 keV

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

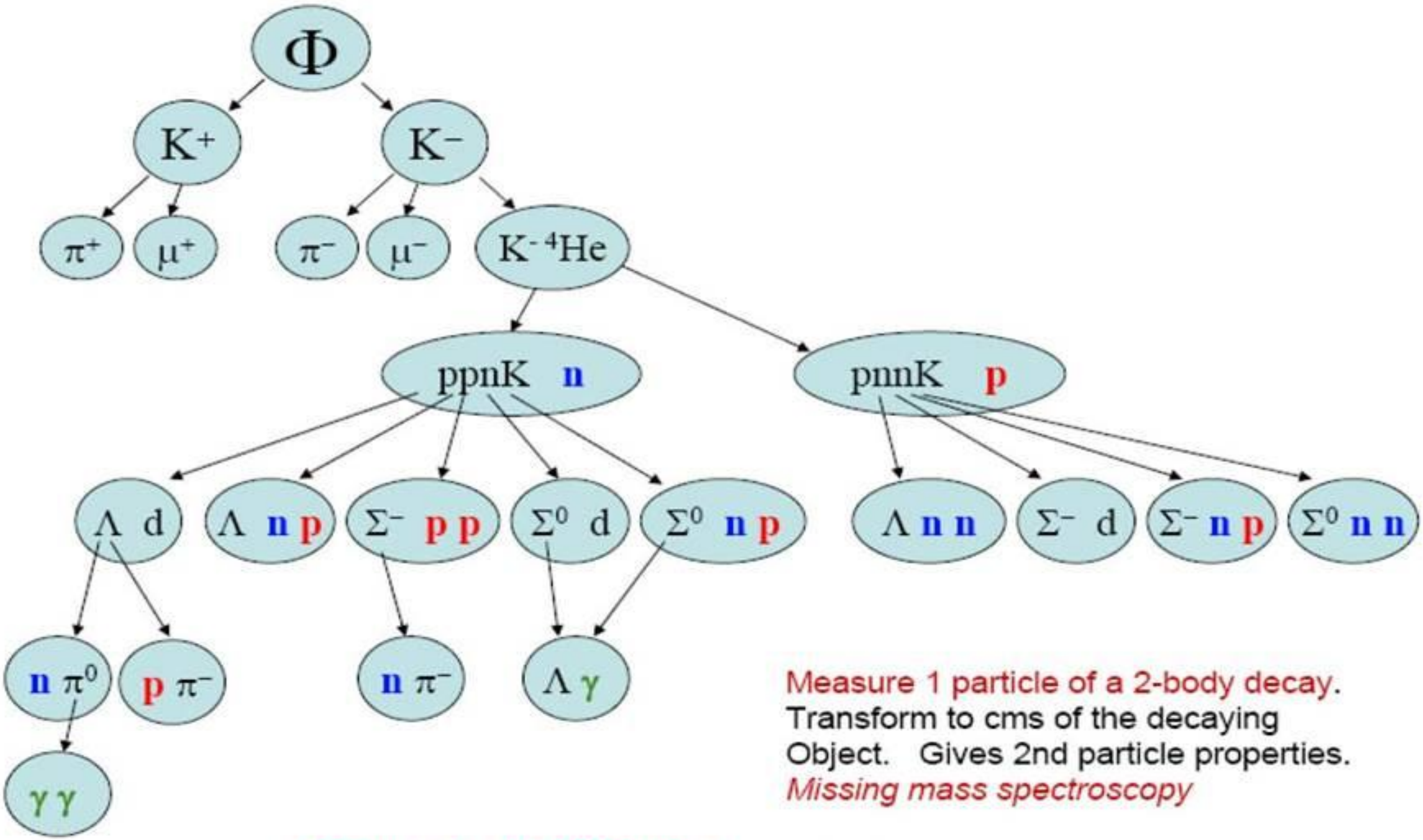
EU Fundings FP7 – I3HP2:
Network WP9 – LEANNIS;
WP24 (SiPM JRA);
WP28 (GEM JRA)

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**)

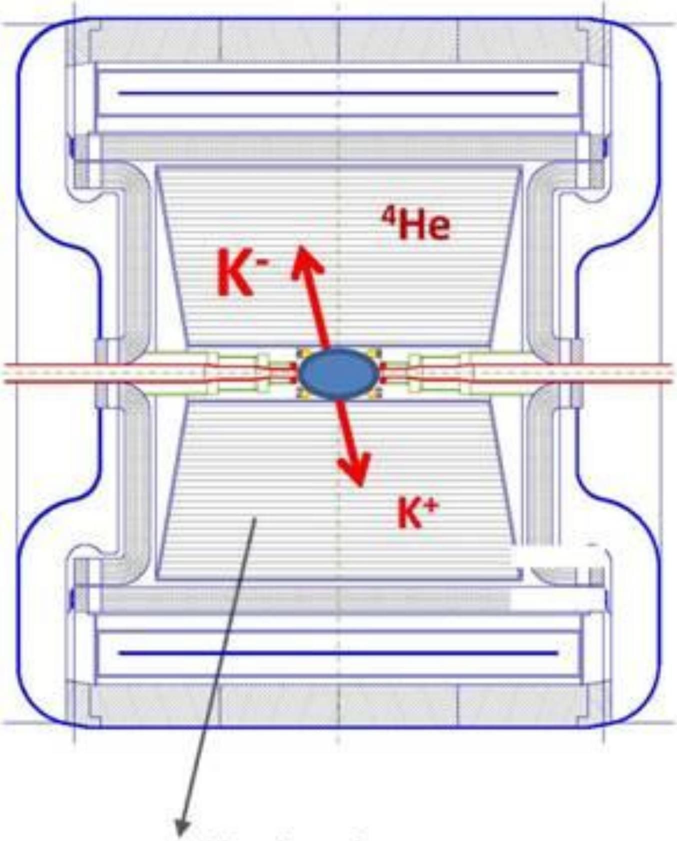
Reactions channels (simplified)



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*

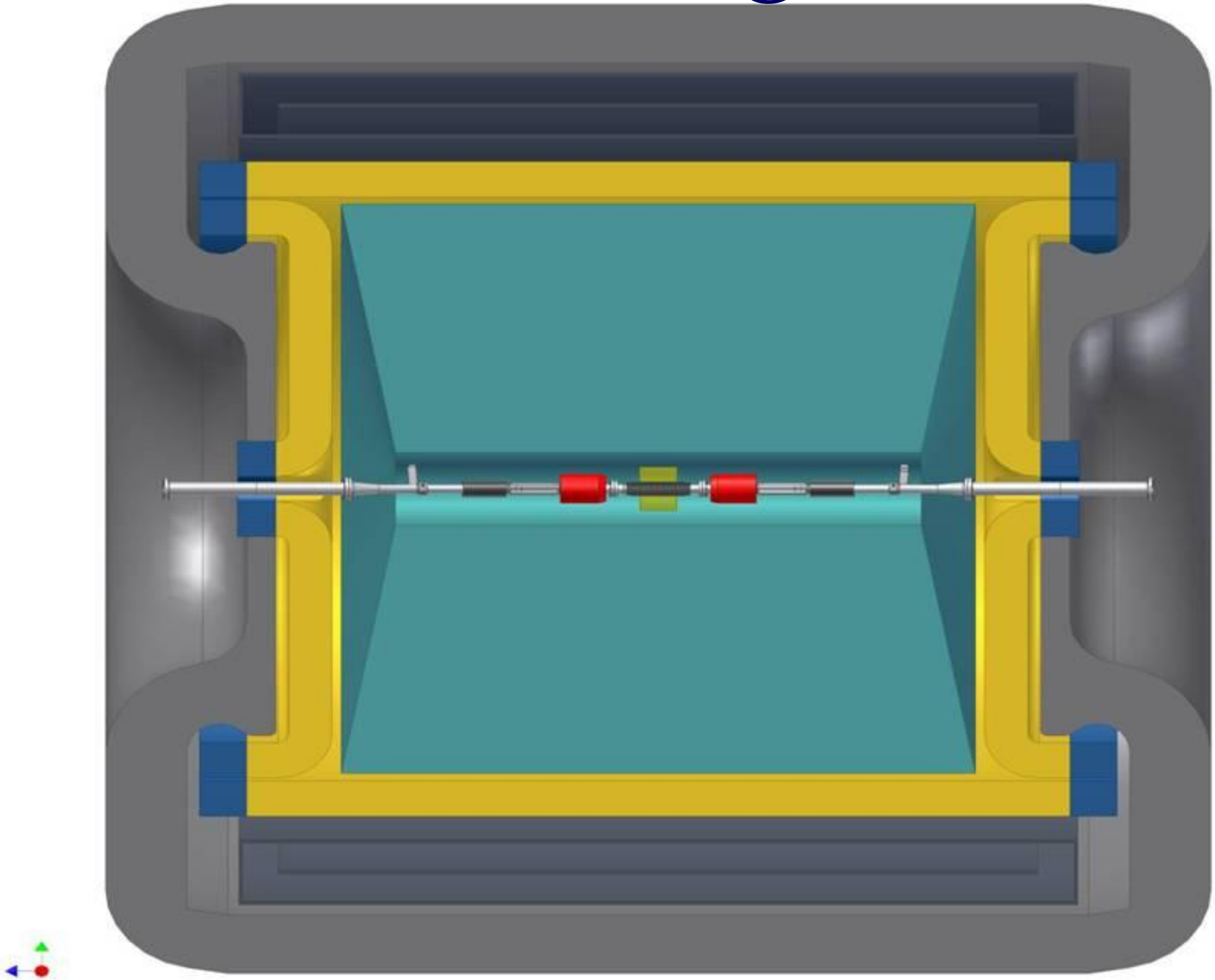
Hadronic interactions of K^- in KLOE



KLOE Drift Chamber

- 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 @ KLOE



AMADEUS status

- Analyses of the **2002-2005 KLOE data**:

- Dedicated **2012** run with pure **Carbon target** inside KLOE

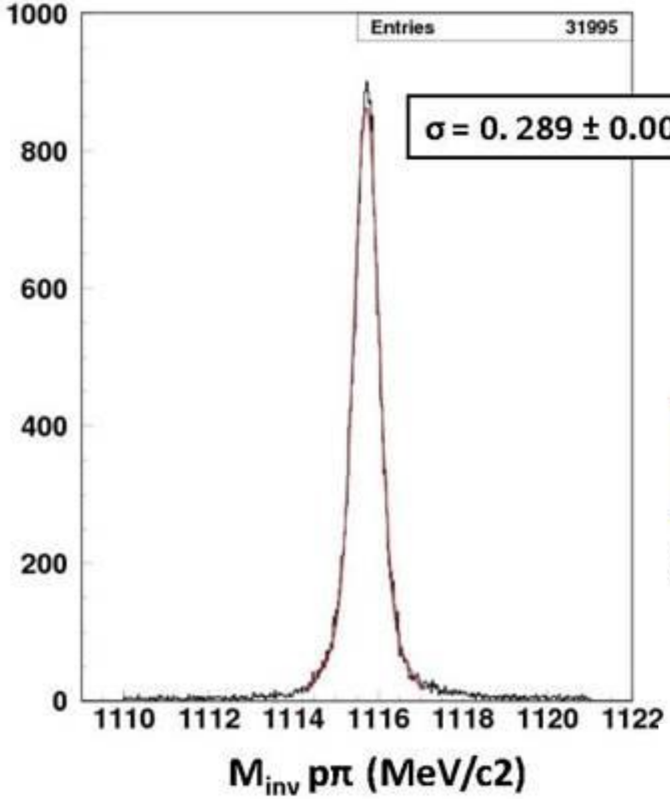
    - **Λp** from 1NA or 2NA (single or multi-nucleon absorption)
    - **Λd** and **Λt** channels
    - Λ (1405) -> $\Sigma^0\pi^0$
    - Λ (1405) -> $\Sigma^+\pi^-$
    - ΣN/ΛN internal conversion rates

- R&D for more refined setup

- Future possible scenario

Lambda invariant mass

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



σ = 0. 289 ± 0.003 MeV/c²

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

- Best χ2 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

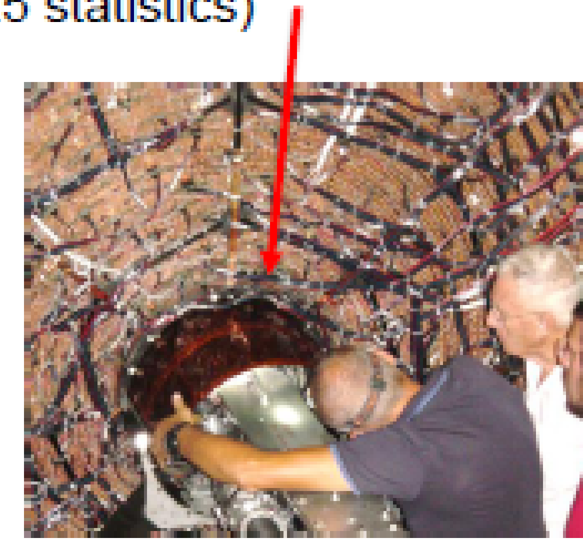
$K^\pm \rightarrow \mu^\pm \nu$

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

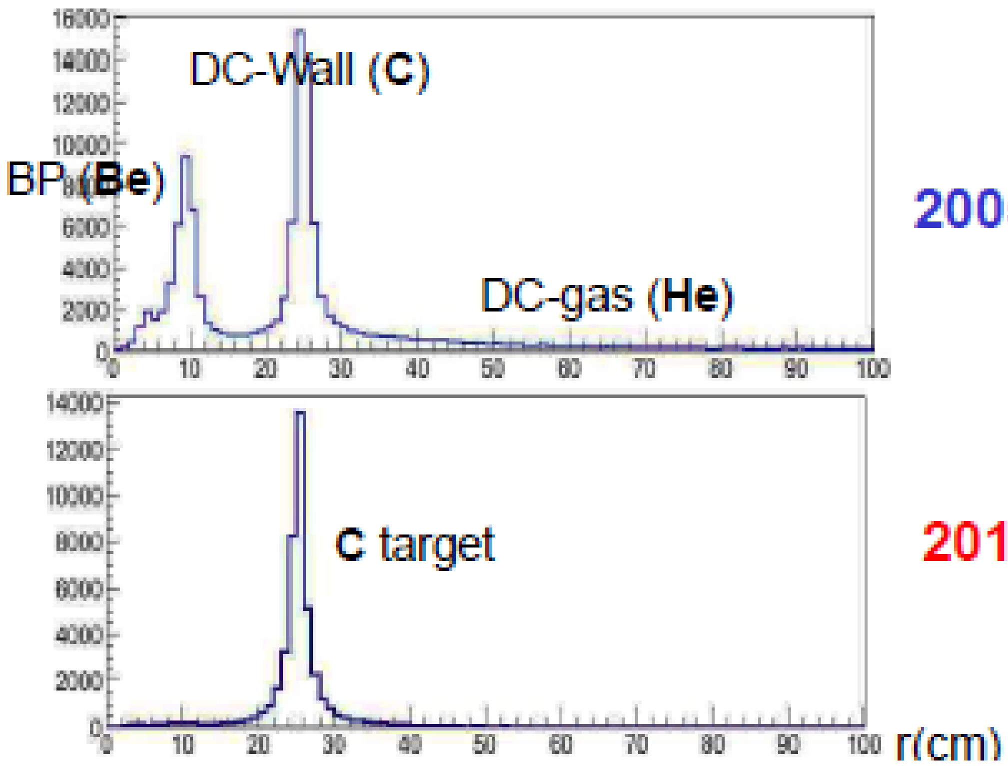
KLOE data on K^- nuclear absorption

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)



<u>Position of the K^- hadronic interaction inside KLOE:</u>



2005 data

2012 with Carbon target

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

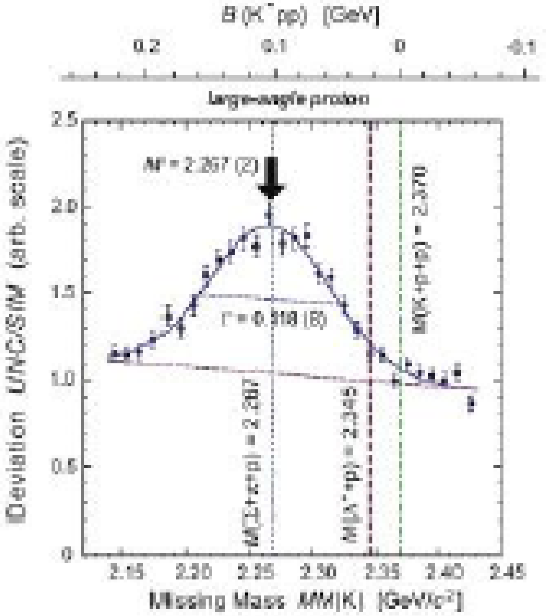
Λp analysis

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

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



Nucl.Phys.A835, 43 (2010)

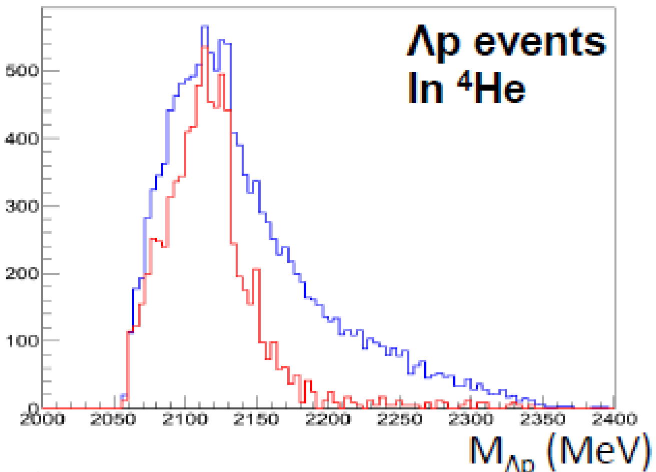
Λp analysis

-Competing processes:

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

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

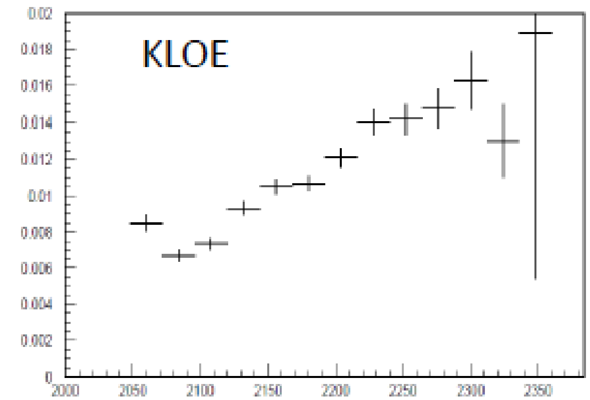
A perfect disentanglement between single and multi-nucleon absorption can be achieved thanks to the **nice acceptance:**



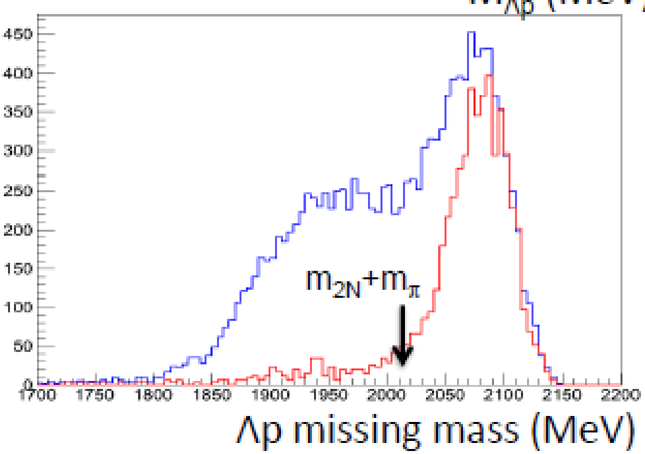
Λp all events

Λπ⁻(p) events

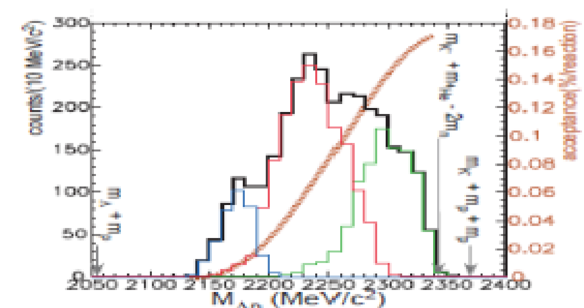
(arbitrary normalization)



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



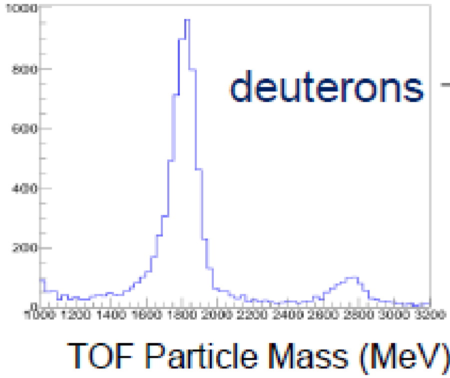
The Λp missing mass for the Λπ⁻(p) events lies exactly In the 2N+π⁻ mass region

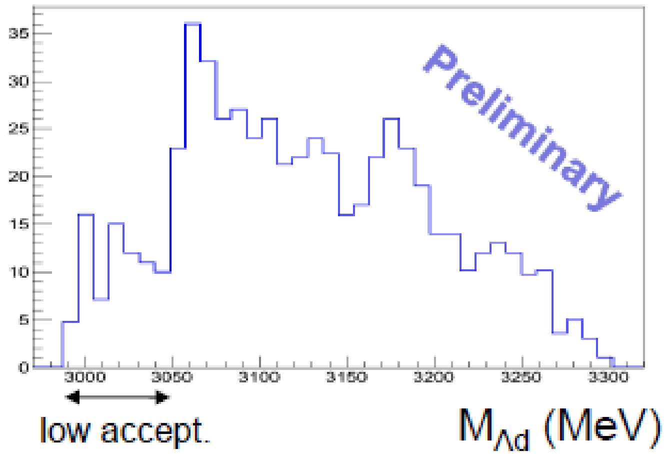


KEK-E549
Mod.Phys.Lett.A23, 2520 (2008)

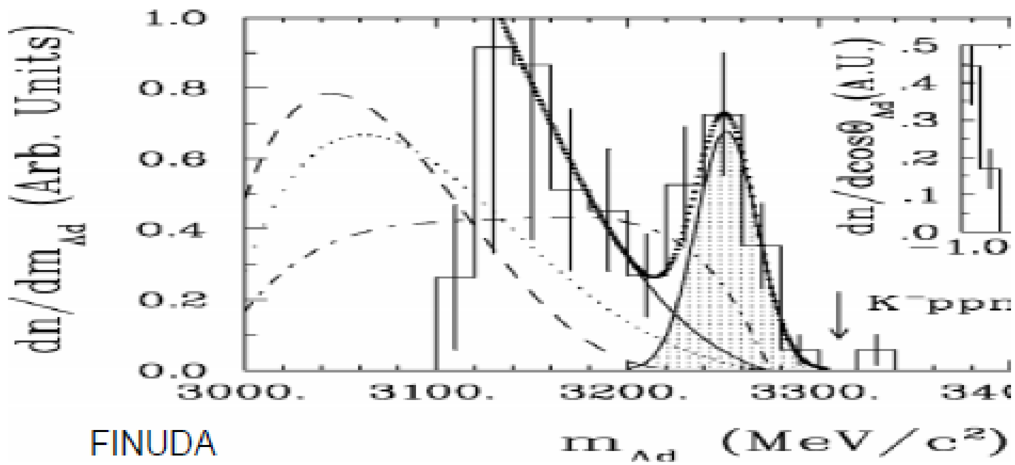
Λd, Λt analyses

- 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.





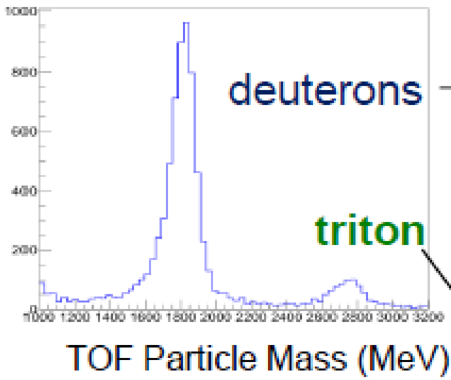
Λd events
In ^{4}He

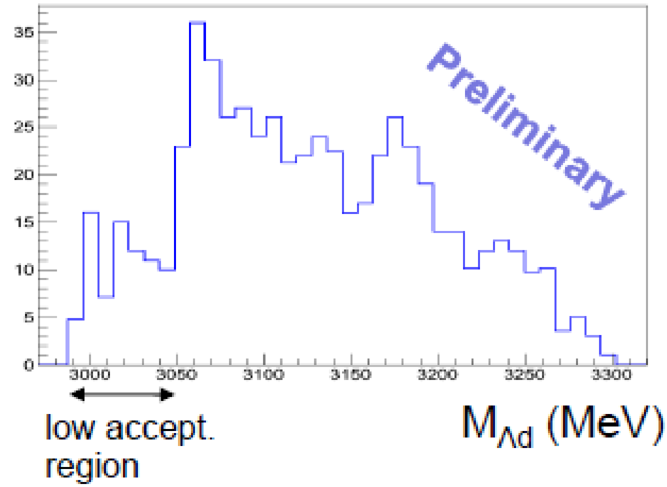


FINUDA
Nucl.Phys.A835, 43 (2010)

Λd, Λt analyses

- 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.

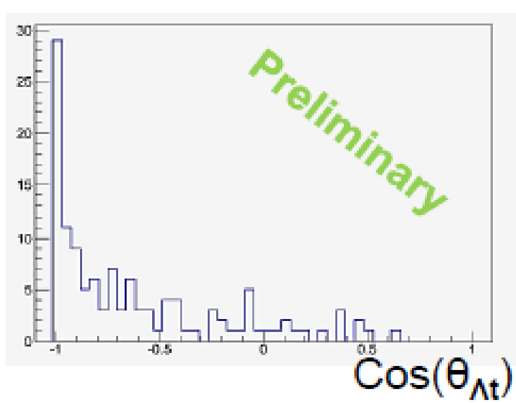


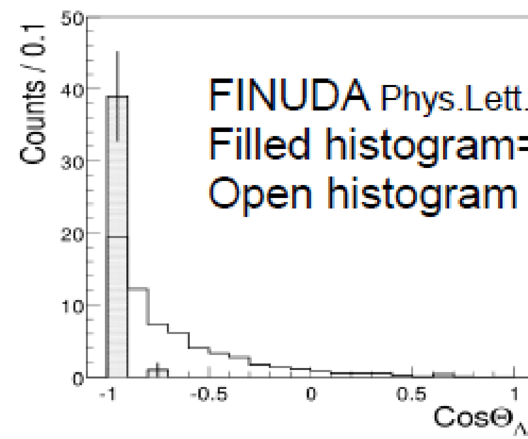


Λd events
In ^{4}He

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

$(M, \Gamma) = (1405.1^{+1.3}_{-1.0}, 50 \pm 2)$ 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

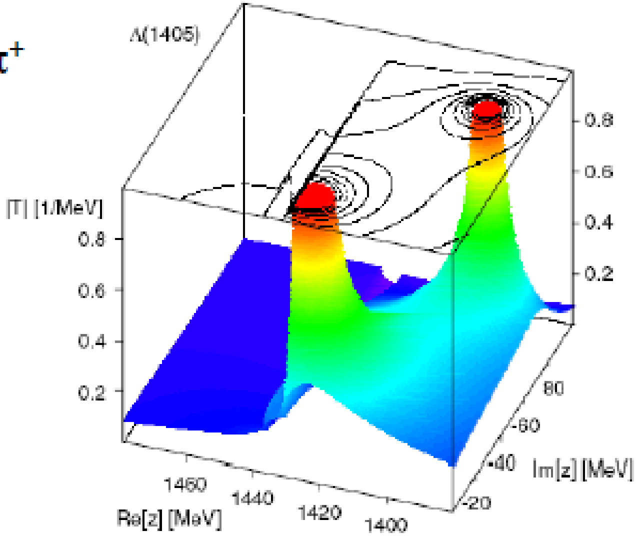
3) ***unstable* KN *bound state***

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:

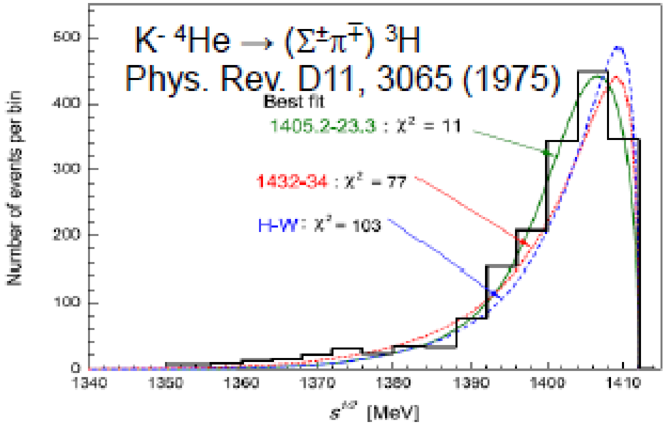
production in KN reactions (only chance to observe the high mass pole) **decaying in $\Sigma^0\pi^0$** (free from $\Sigma(1385)$ background)

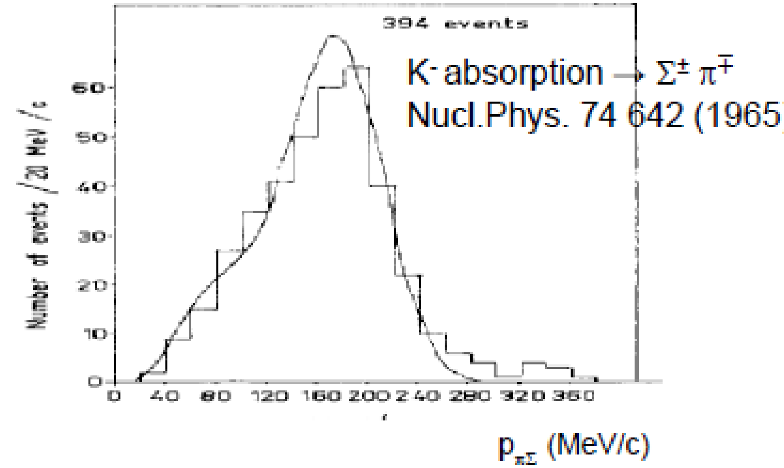
Λ(1405) previous experiments

Old **absorption experiments:**

-$M_{\pi\Sigma}$ spectra always cut at the atrest limit

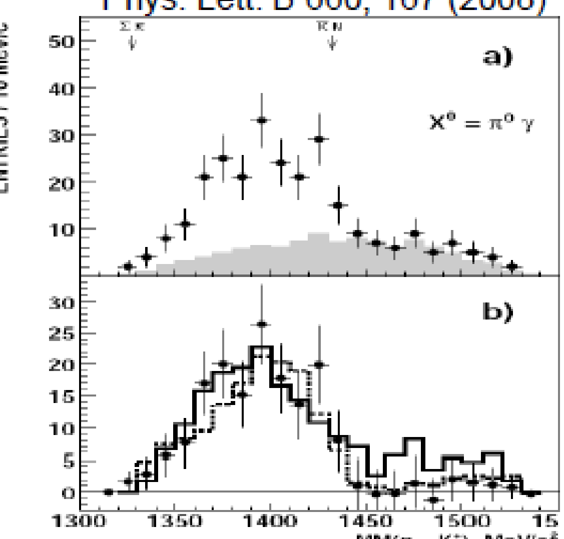
-$\Sigma^{\pm}\pi^{\mp}$ spectra suffer Σ(1385)contamination



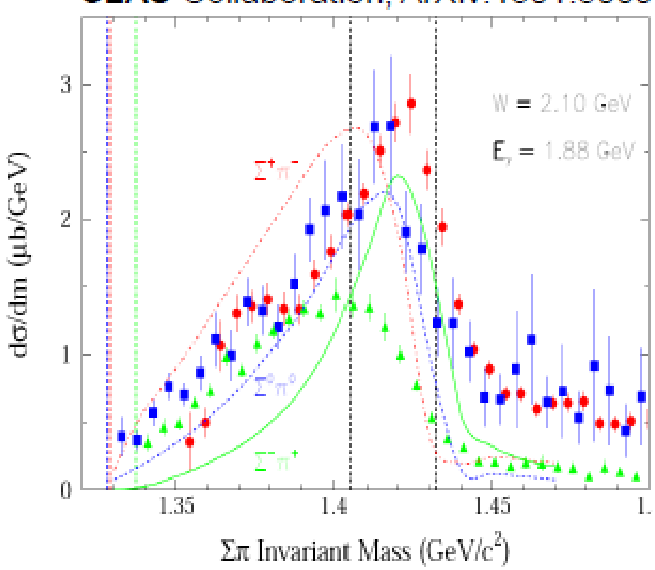


Other (**non-absorption**) experiments present spectra in the $\Sigma^0\pi^0$ channel (only three experiments…with different lineshapes!):

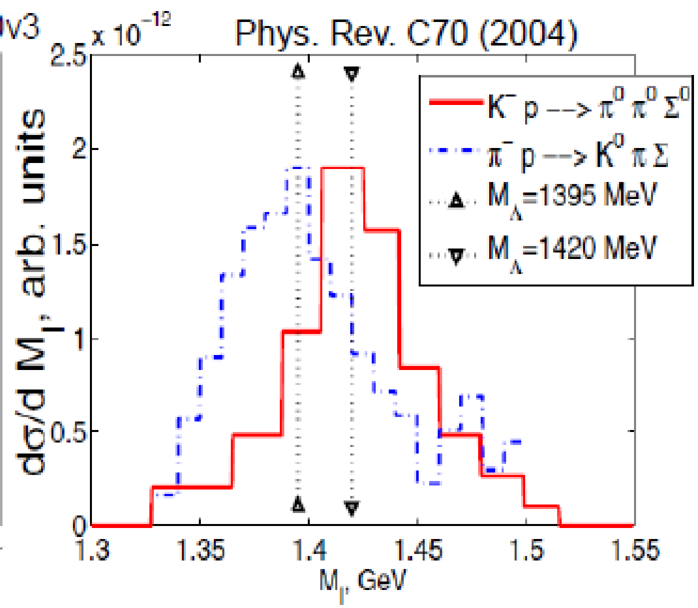
Phys. Lett. B 660, 167 (2008)



CLAS Collaboration, ArXiv:1301.5000v3



Phys. Rev. C70 (2004)

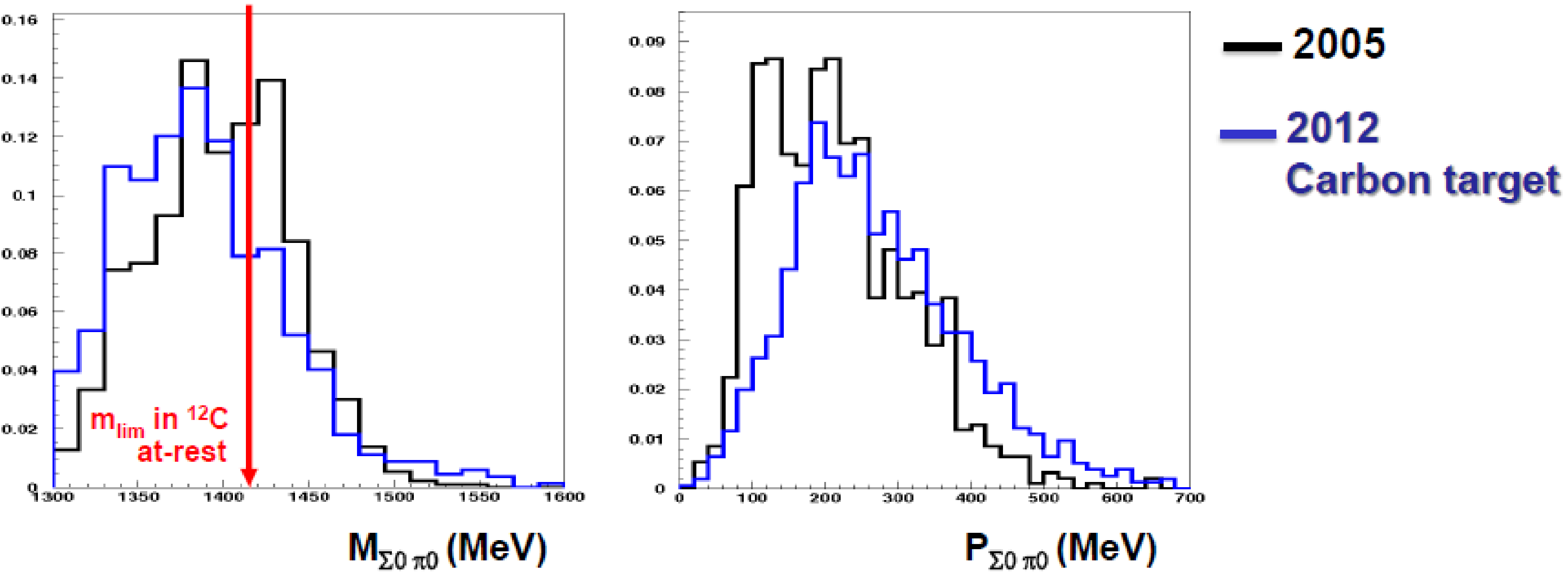


Analysis of $\Sigma^0\pi^0$ channel

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

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

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

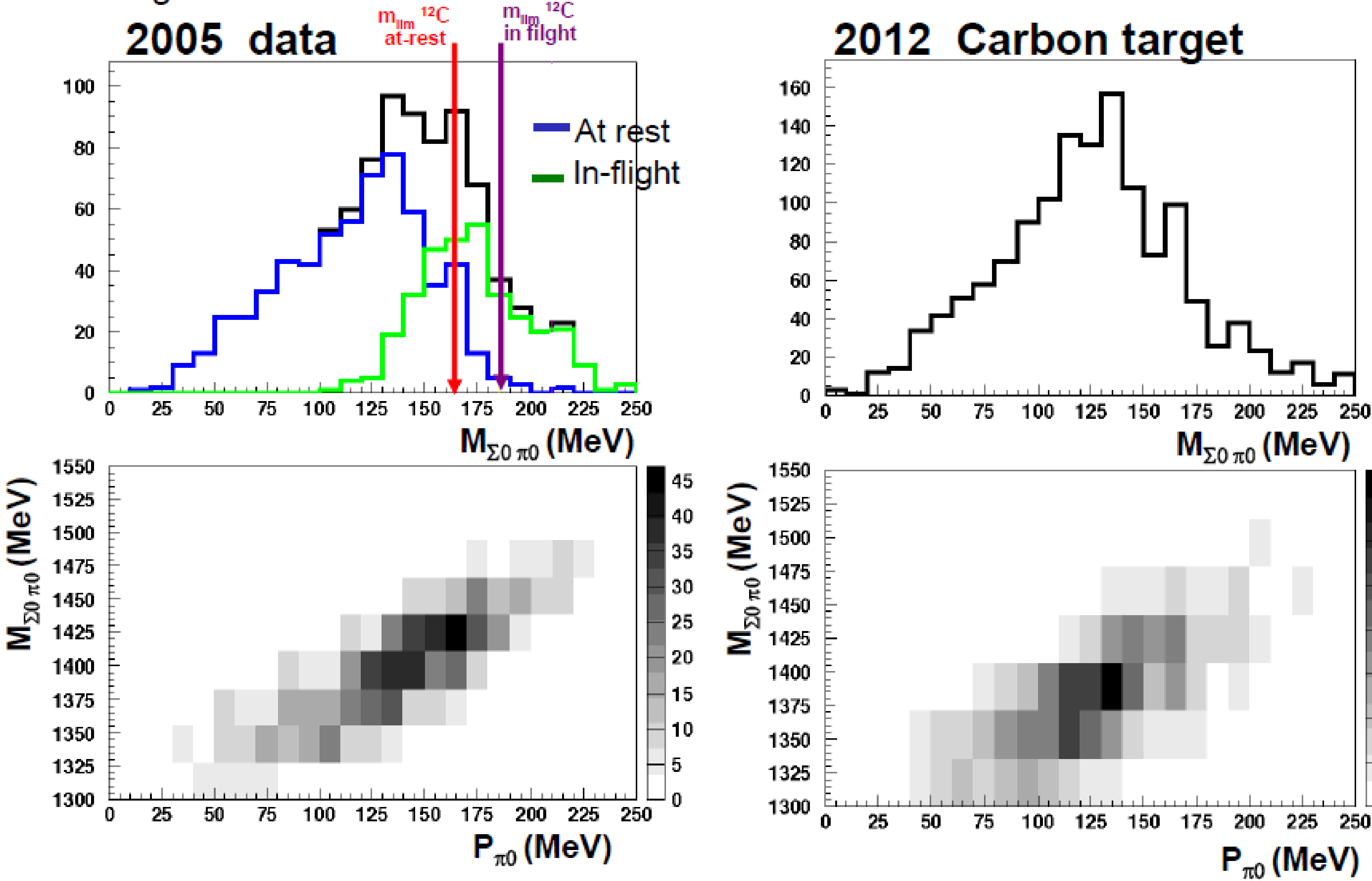


$m_{\pi 0 \Sigma 0}$ resolution $\sigma_m \approx 32$ MeV/c^2 ; **$p_{\pi 0 \Sigma 0}$ resolution:** $\sigma_p \approx 20$ MeV/c.

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

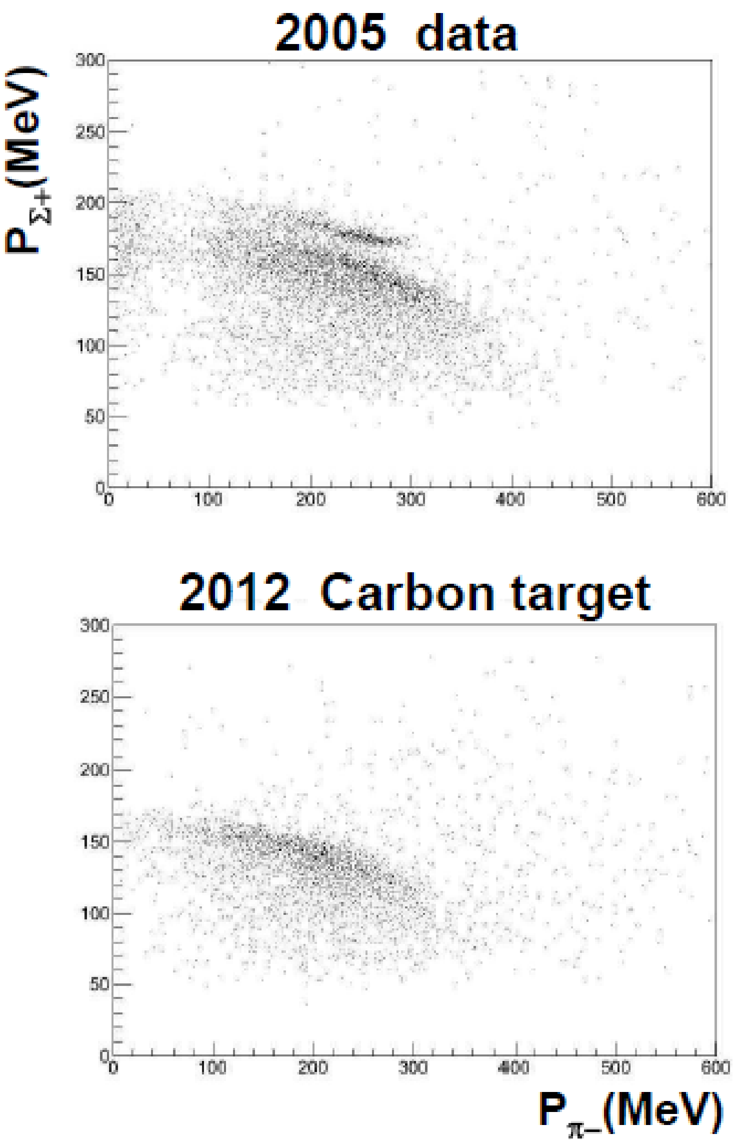
Analysis of $\Sigma^0\pi^0$ channel

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



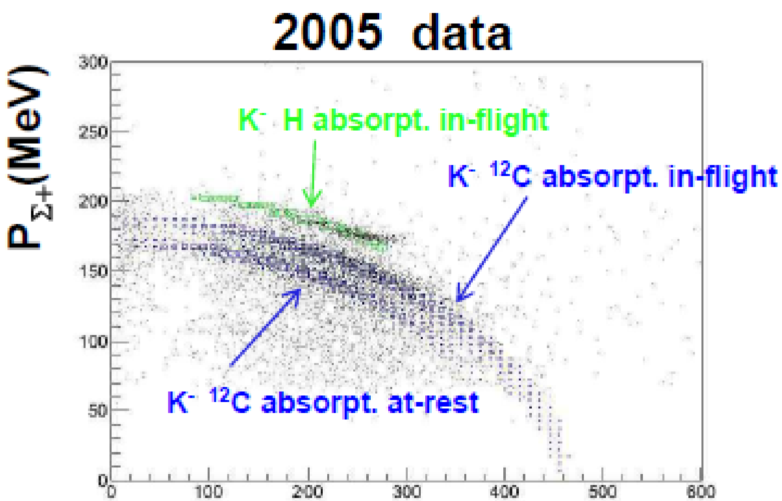
Λ(1405) charged channel: $\Sigma^+\pi^-$

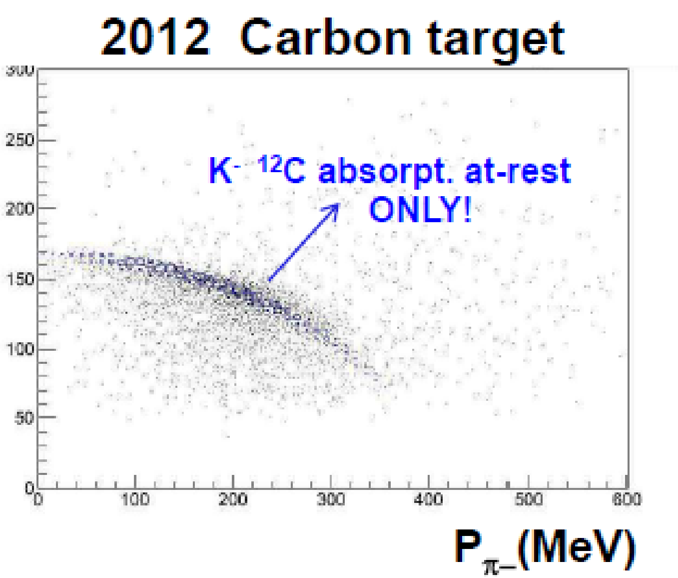
Λ(1405) signal searched in **$K^- p \rightarrow \Sigma^+ \pi^-$** detected via: **$(p\pi^0)\pi^-$**



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

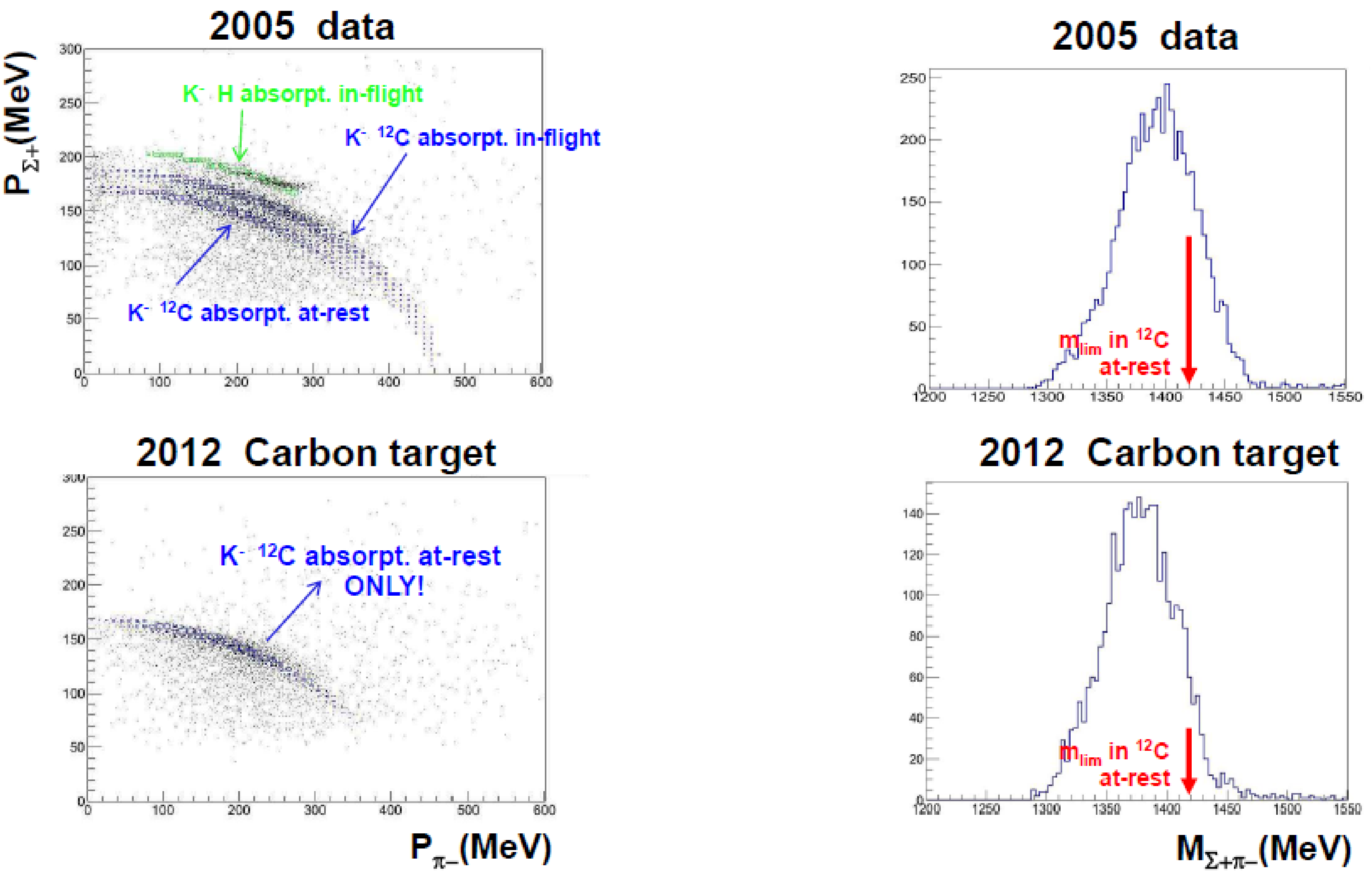
Λ(1405) signal searched in $\mathbf{K^- p \rightarrow \Sigma^+ \pi^-}$ detected via: $(\mathbf{p\pi^0})\pi^-$





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

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



Conclusions for AMADEUS

- **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)**

Epilogue

in memory of PK

- Reflections on the dialogue between experiment and theory

ECT*

Wolfram Weise
Trento and Technische Universität München

Dialogues on a blackboard in Garching (continued)

<u>QCD and the origin of mass:</u>

proton = u+u+d but 3+3+5 MeV = 938 MeV ??

answer:

almost all the of nucleon mass (and of the mass of the visible universe) does NOT come from the HIGGS ...

... but instead:

$$E = Mc^2$$

gluonic energy density <-> confinement
<-> spontaneous chiral symmetry breaking

PK 's secret love of Nambu-Goldstone bosons

PART II: about KAONS and ANTIKAONS

mass of strange quark ~ 100 MeV ->

kaon mass = 494 MeV

Spontaneous AND explicit

chiral symmetry breaking

attractive antikaon-nuclear unteraction -

sufficiently strong to produce

antikaon-nuclear quasi-bound states ??

... but first: kaonic hydrogen and SIDDHARTA


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