Strangeness in the Universe? Advances and perspectives in the low-energy kaon-nucleon/nuclei studies at the DAFNE collider

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PANIC2014, 24-29 August 2014, Hamburg (Germany)

The low-energy kaon-nucleon/nuclei interaction studies
are fundamental for understanding QCD in non-perturbative regime:

- **Explicit and spontaneous chiral symmetry breaking (mass of nucleons)**
- **Dense baryonic matter ->**
- **Neutron (strange?) stars EOS**

Role of Strangeness in the Universe from particle and nuclear physics to astrophysics

Strangeness in the Universe?
Theoretical and experimental progress and challenges in the antikaon nuclear physics, ECT* 21-25 October 2013

Hadronic systems with STRANGENESS

Wolfram Weise (TU München)

Physics Issues and Keywords:

- **Mass hierarchy** of quarks in QCD
- **Strange** quark intermediate between "**light**" and "**heavy**"
- **Hadronic systems** with **strangeness**:

$$m_u = 1.7 - 3.3 \text{ MeV}$$
$$m_d = 4.1 - 5.8 \text{ MeV}$$
$$m_s = 101 \pm 25 \text{ MeV}$$

(at renorm. scale $\mu = 2$ GeV)

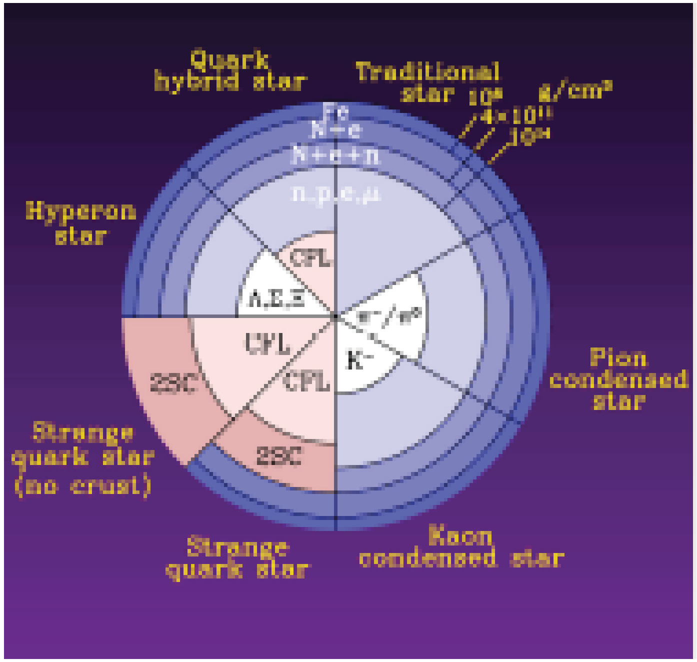
Excellent testing ground for studying interplay between **spontaneous** and **explicit chiral symmetry breaking** in low-energy QCD

Theoretical Framework with well-defined, symmetry-controlled input:

Chiral SU(3) Effective Field Theory
+ Coupled Channels
+ Few-Body Methods

Goals:

- **High-precision** constraints from K-N and K-NN **threshold measurements**
- Provide reliable basis for investigating **antikaon-nuclear quasibound states**



NEUTRON STARS and the EQUATION OF STATE of DENSE BARYONIC MATTER

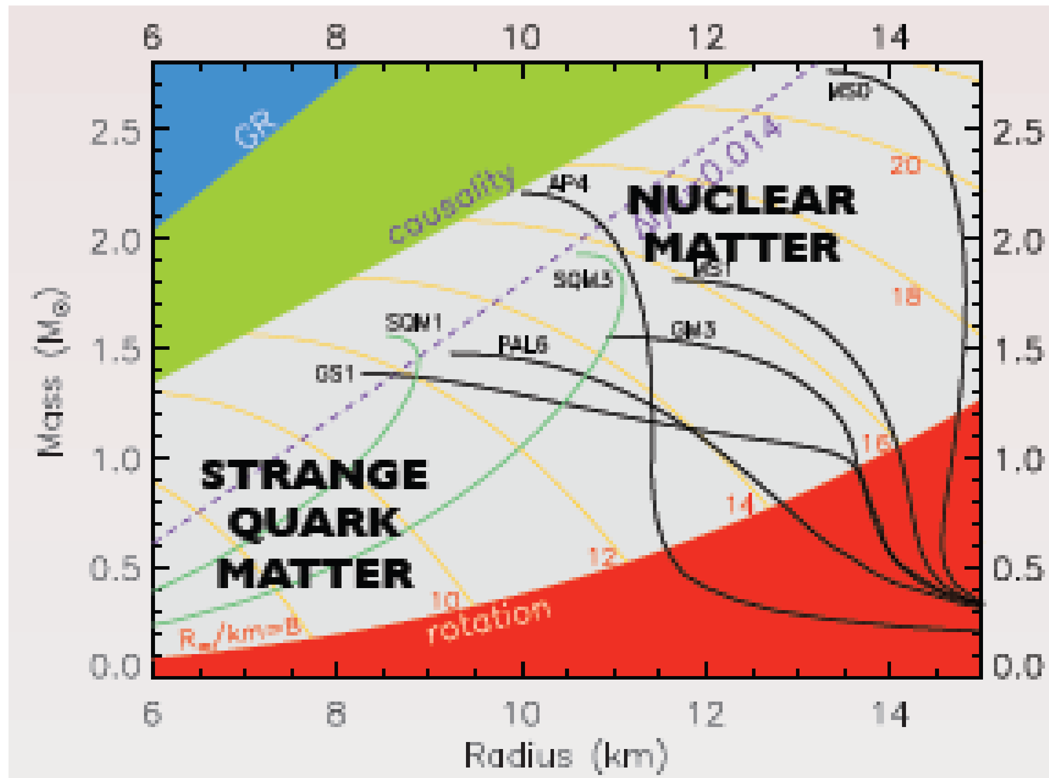
J. Lattimer, M. Prakash: Astrophys. J. 550 (2001) 426

- **Neutron Star Scenarios**
-

$$\frac{dP}{dr} = -\frac{G}{c^2}\frac{(M + 4\pi P r^3)(\mathcal{E} + P)}{r(r - GM/c^2)}$$

$$\frac{dM}{dr} = 4\pi r^2 \frac{\mathcal{E}}{c^2}$$

- **Mass-Radius Relation**



Framework:
Low-Energy QCD with Strange Quarks

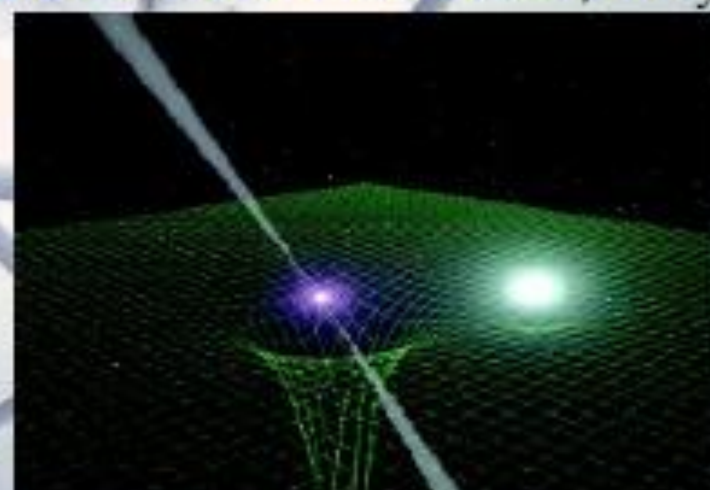
K⁻

Strangeness in baryonic matter:

- role of strangeness in EoS of neutron stars

- hyperon-nucleon and hyperon-hyperon interactions role in the investigation of dense baryonic matter

- new constraints from 2 solar masses neutron stars, very stiff Equation of State required!



But

- the basic ingredient .. namely $\overline{K}N$ interaction still unclear and mysterious from the experimental point of view.

Framework:
Low-Energy QCD
with Strange Quarks

Approached by the investigation of the antikaon-nucleon interaction

Important constraints:

- **K^-N threshold physics (shift and with of kaonic atoms levels measured by SIDDHARTA)**

? Deeply bound kaonic nuclei

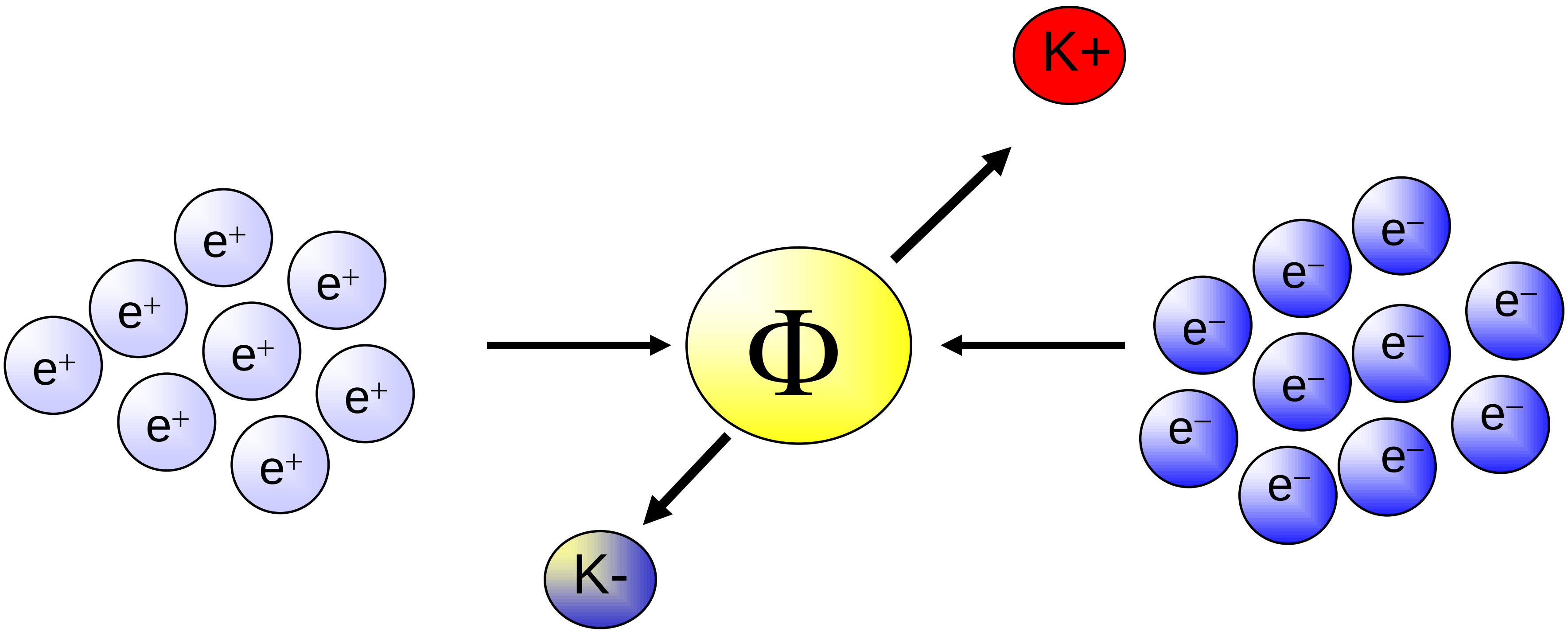
- **$\Sigma\pi$ mass spectra**

- **Nature and properties of the $\Lambda(1405)$ considered as K^-N quasibound state embedded in the $\Sigma\pi$ continuum**

- Hypernuclear physics

DAFNE Collider at LNF-INFN

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

Hypernuclear physics

Kaon-nucleons/nuclei interaction studies

The DAFNE collider the best possible beam of low energy kaons

Kaonic atoms

- DEAR
- SIDDHARTA
- SIDDHARTA-2

Hypernuclei

- FINUDA

Low-energy Kaon-nuclei (deeply bound)

- FINUDA
- AMADEUS

DEAR and 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 - I3H
FP7- I3HP2

Kaonic atoms: the scientific aim

the determination of the ***isospin dependent***
KN scattering lengths through a

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

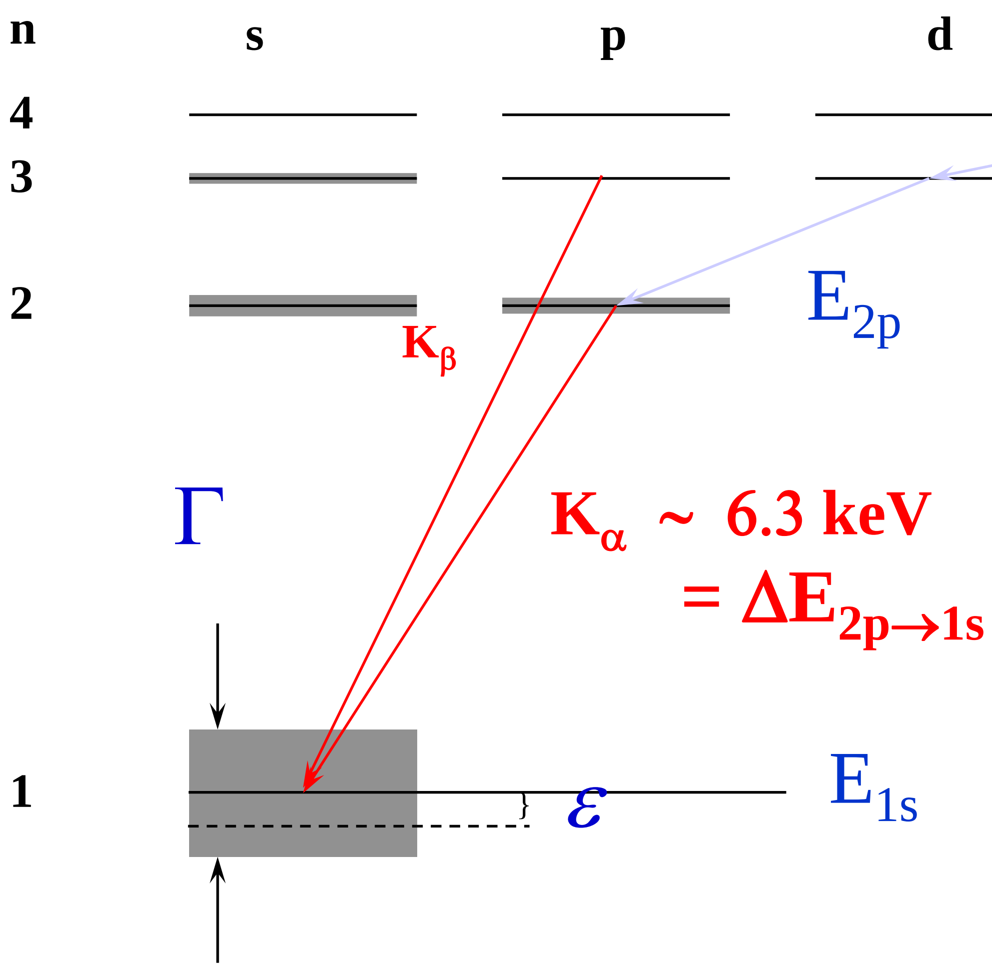
of the K_α line of **kaonic hydrogen**

and

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

Measurements of kaonic Nitrogen (kaon mass) and kaonic Helium 3 and 4 as well (2p level – deeply bound kaonic nuclei)

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

⇓ ⇓

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

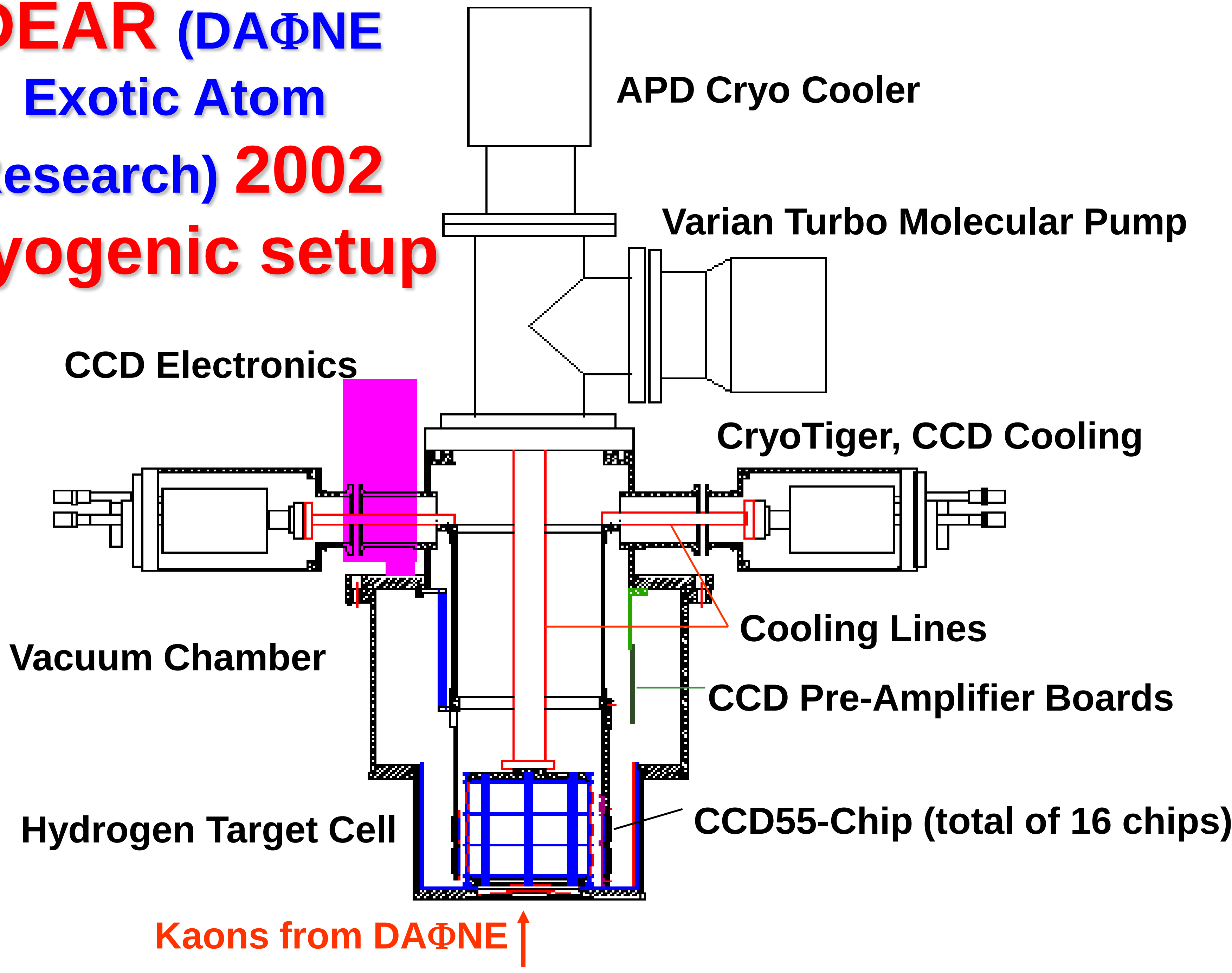
$$a_{K^-n} = a_1$$

The 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. **Study of the 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**

DEAR (DAΦNE Exotic Atom Research) 2002 Cryogenic setup



DEAR on DAΦNE (2002)

October – December 2002 DAQ

Collected data:

-Kaonic Nitrogen:

6 – 28 October (about 17 pb^{-1} – 10 pb^{-1} in stable conditions);

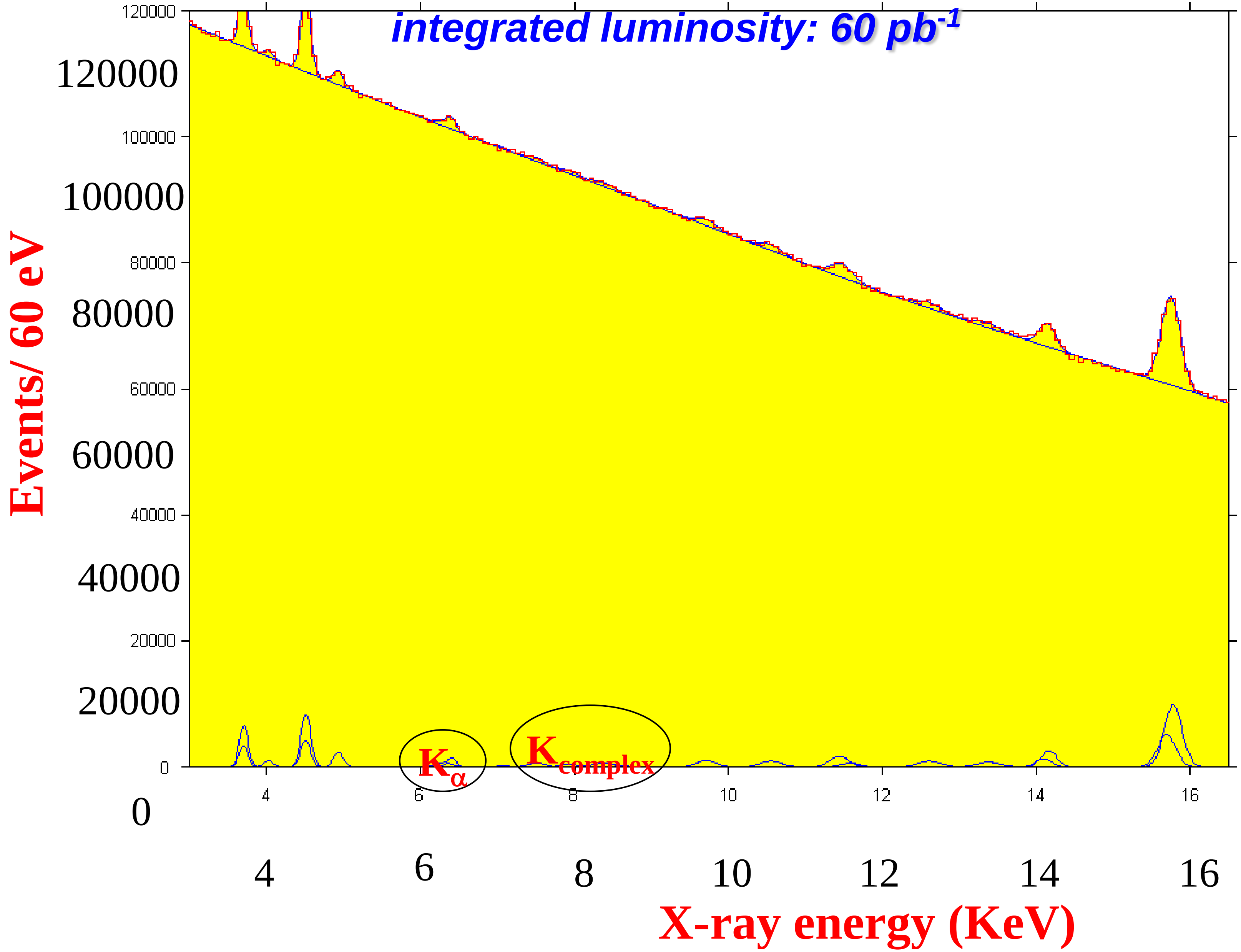
-Kaonic Hydrogen:

30 October – 16 December: about 60 pb^{-1}

-Background data (no collisions) for KH:

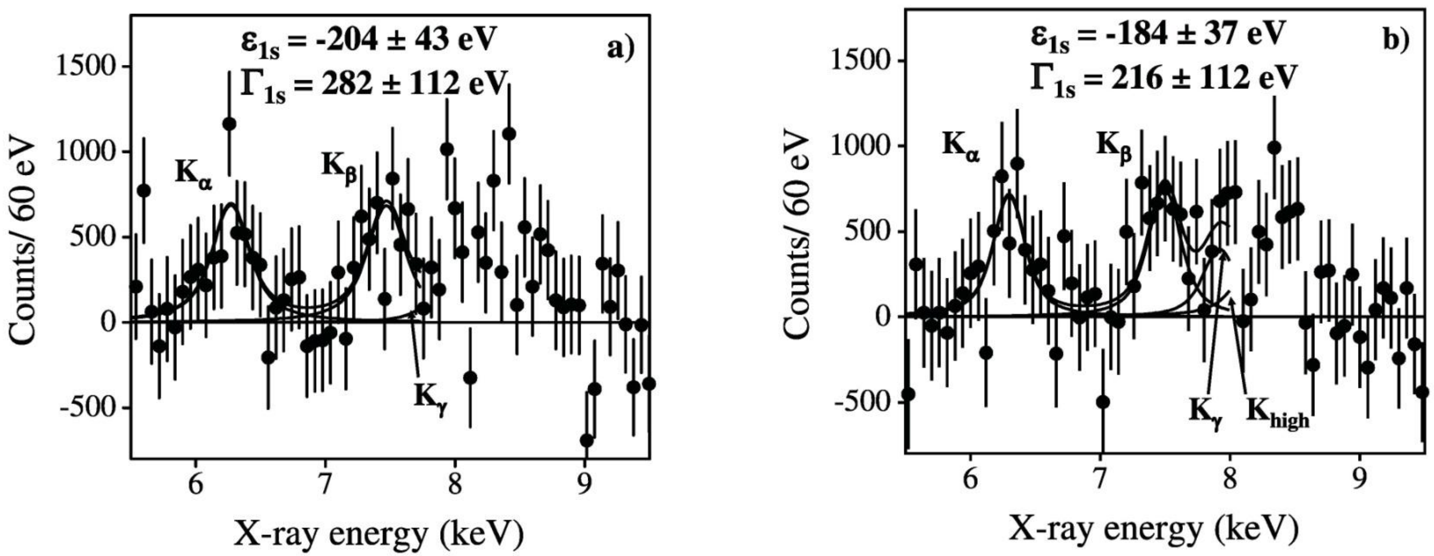
16 – 23 December

Kaonic Hydrogen (2002 data)- global fit



KAONIC HYDROGEN

DEAR (Frascati); G. Beer et al., Phys. Rev. Lett. 94 (2005) 212302



- **K^-p SCATTERING LENGTH**

$$\varepsilon + \frac{i\Gamma}{2} = 2\alpha^3\mu^2\, a_{K^-p}\left[1 - 2\alpha\mu(\ln\alpha - 1)\, a_{K^-p}\right]$$

Deser & Trueman

Rusetsky et al.

DEAR Results on the Shift and Width

2 independent analyses starting from the raw data giving consistent results

(Phys.Rev.Lett. 94, 212302 (2005))

Shift: $\varepsilon_{1s} = -193 \pm 37\ (\text{stat.}) \pm 6\ (\text{syst.})\ \text{eV}$

Width: $\Gamma_{1s} = 249 \pm 111\ (\text{stat.}) \pm 30\ (\text{syst.})\ \text{eV}$

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**
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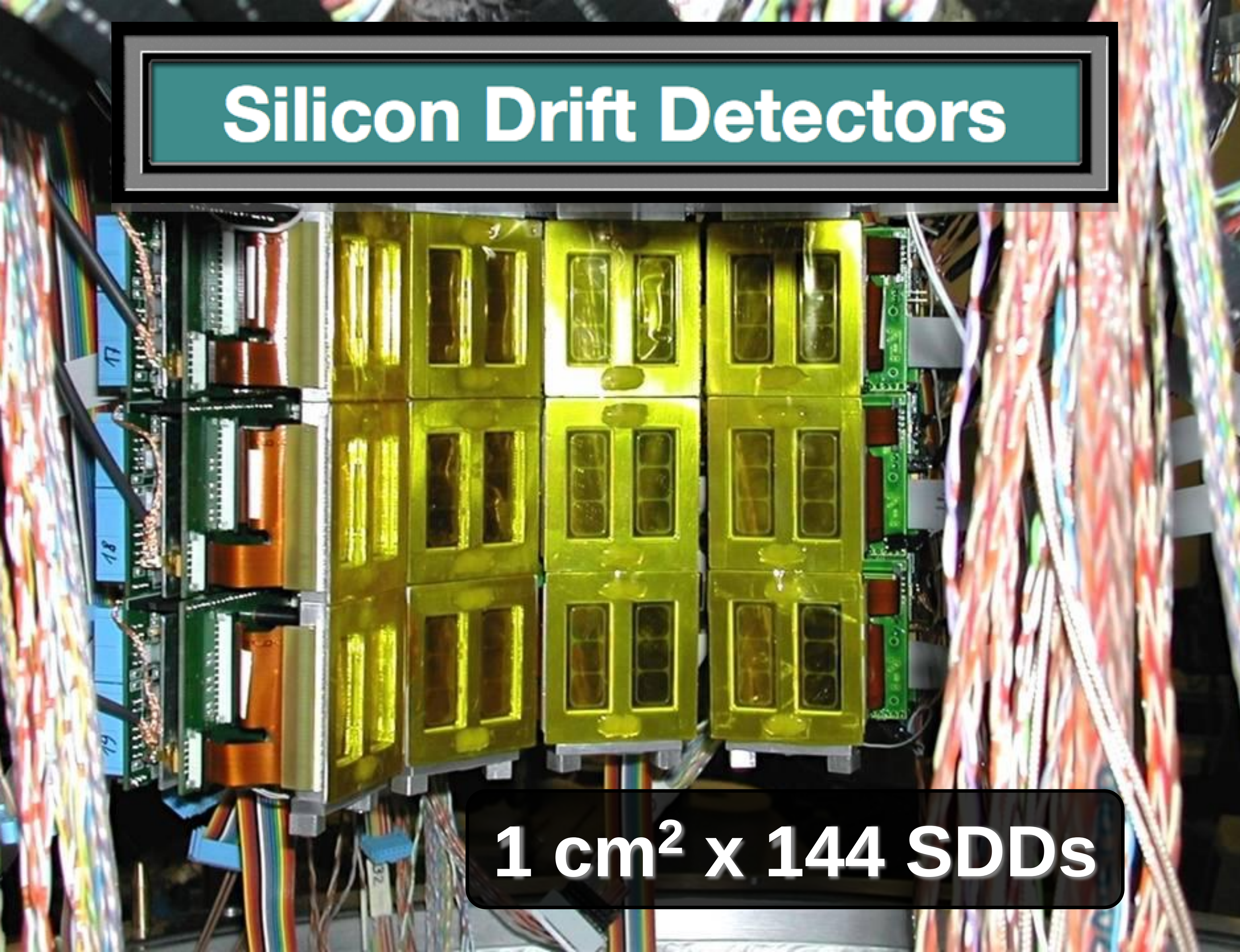
- **PNSensors, Munich, Germany**
- **RIKEN, Japan**
- **Univ. Tokyo, Japan**
- **Victoria Univ., Canada**

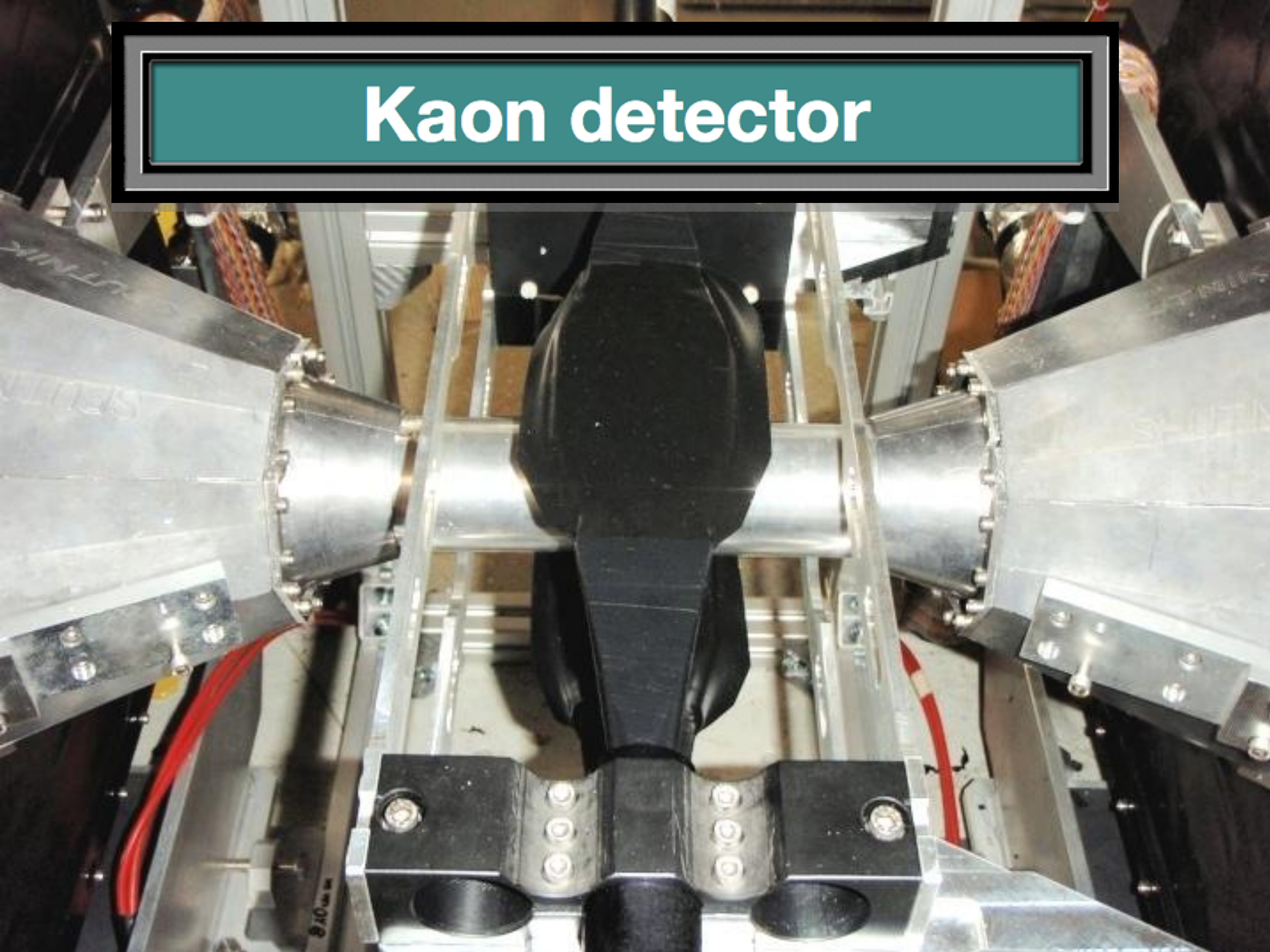
EU Fundings: JRA10 – FP6 - I3H
FP7- I3HP2

Target cell

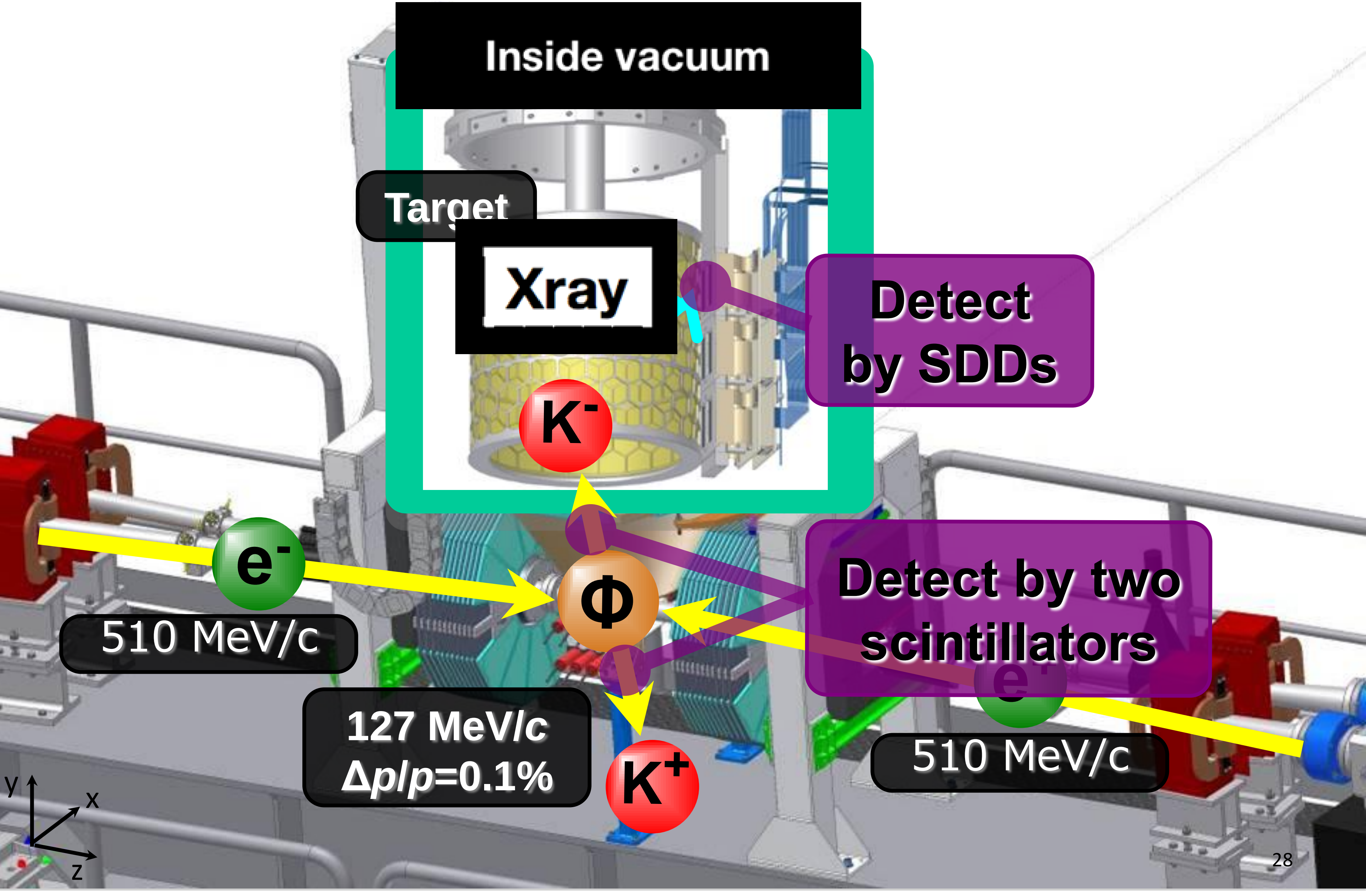
Silicon Drift Detectors

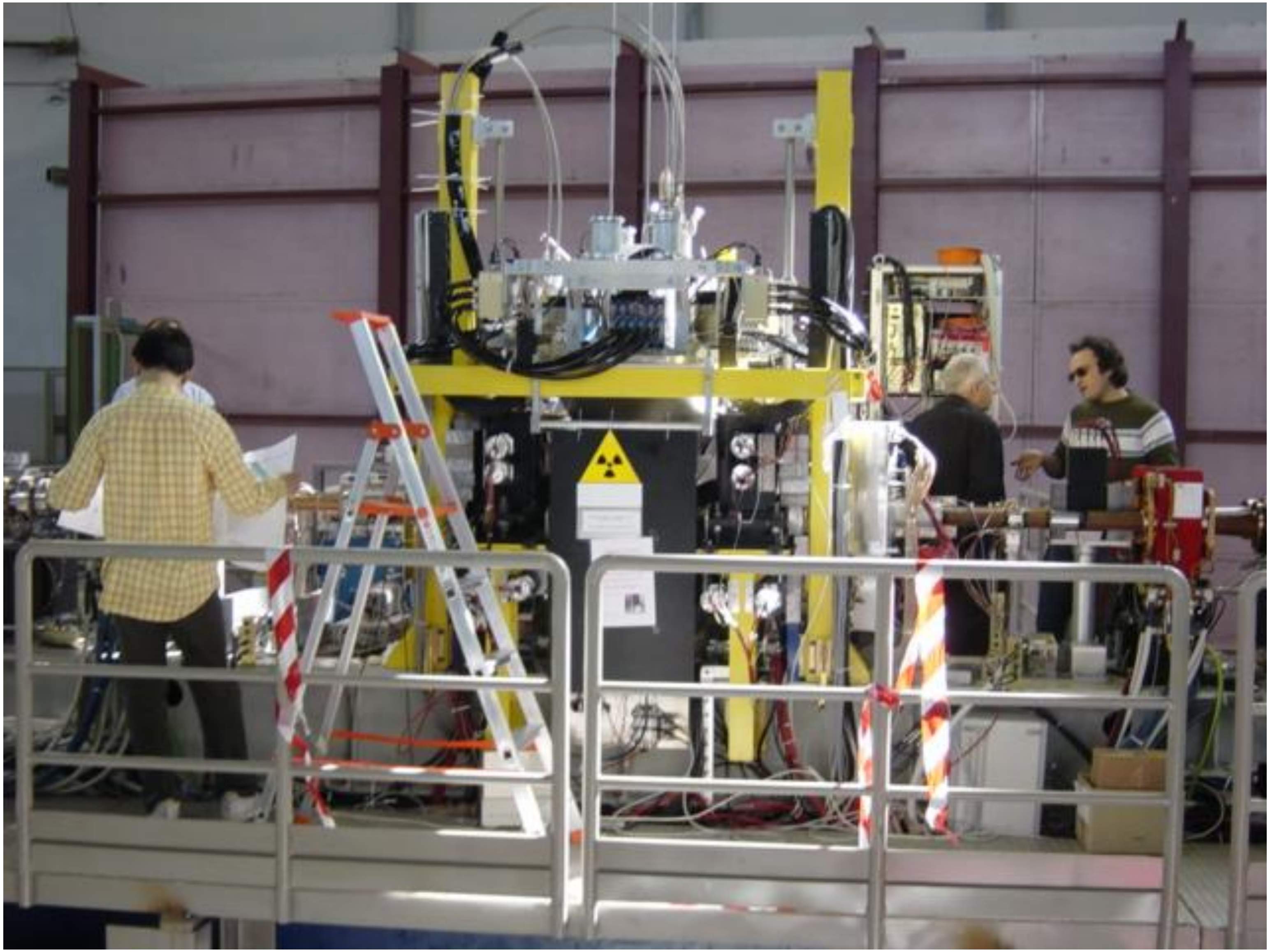


Kaon detector

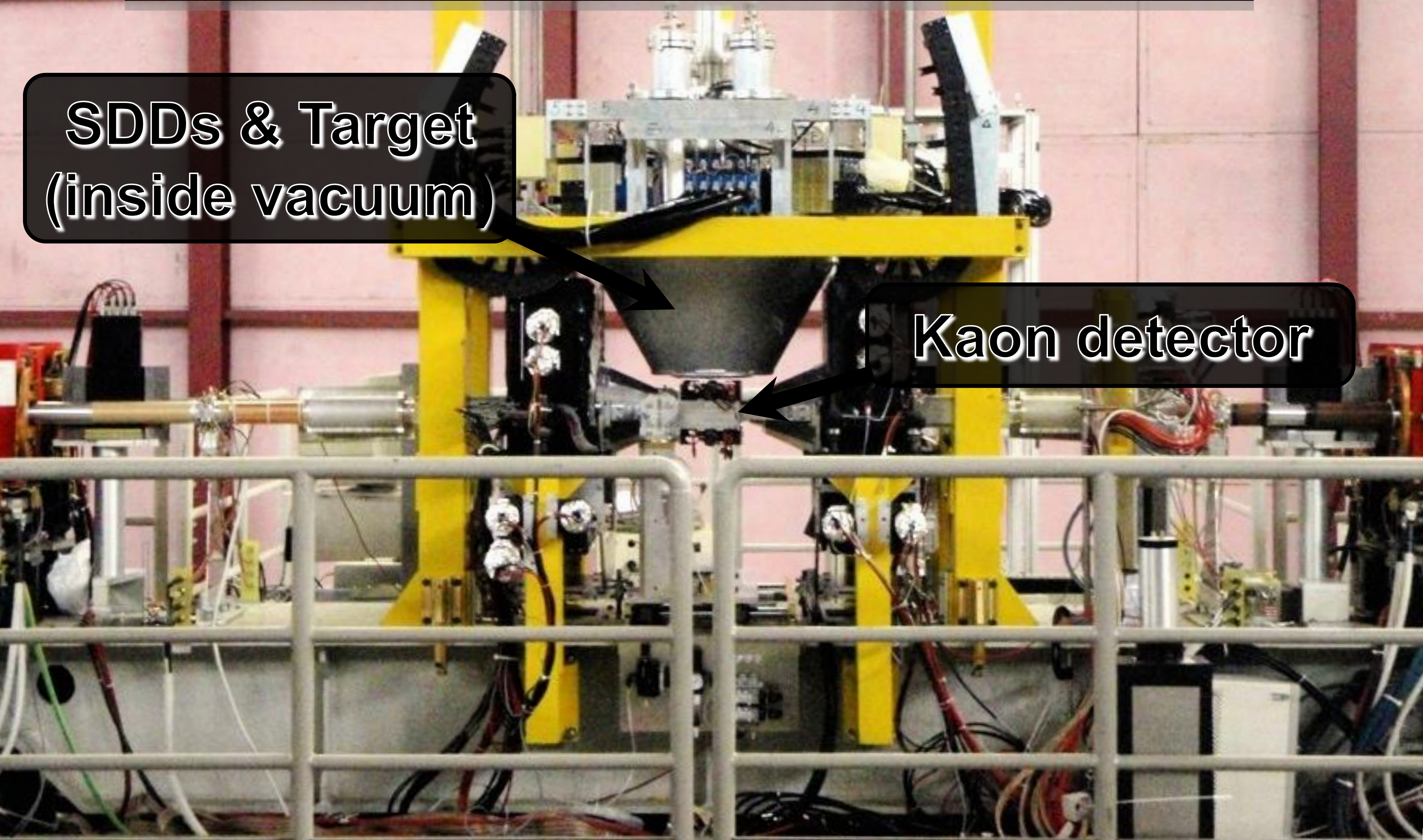


SIDDHARTA overview

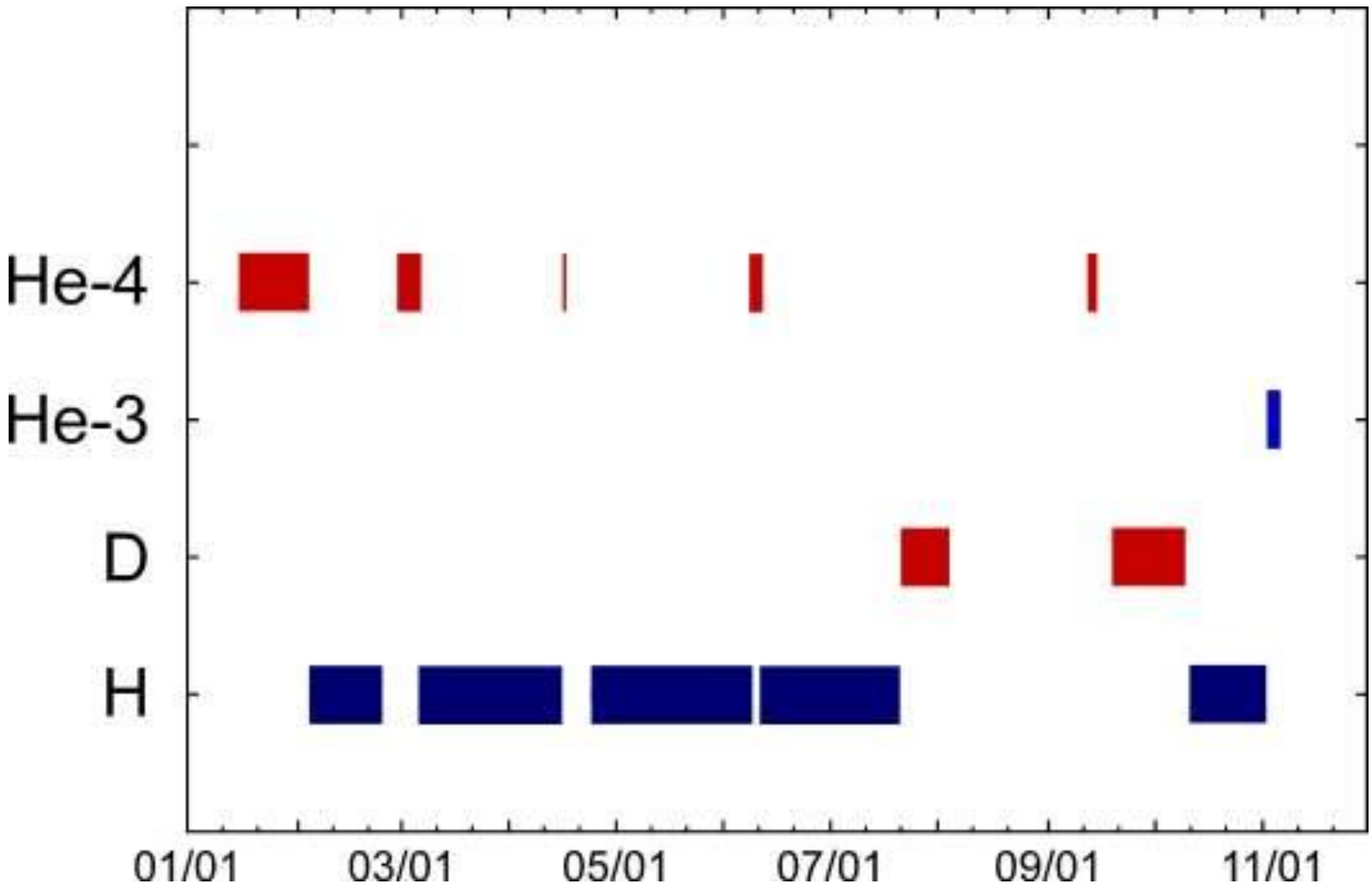




SIDDHARTA setup



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

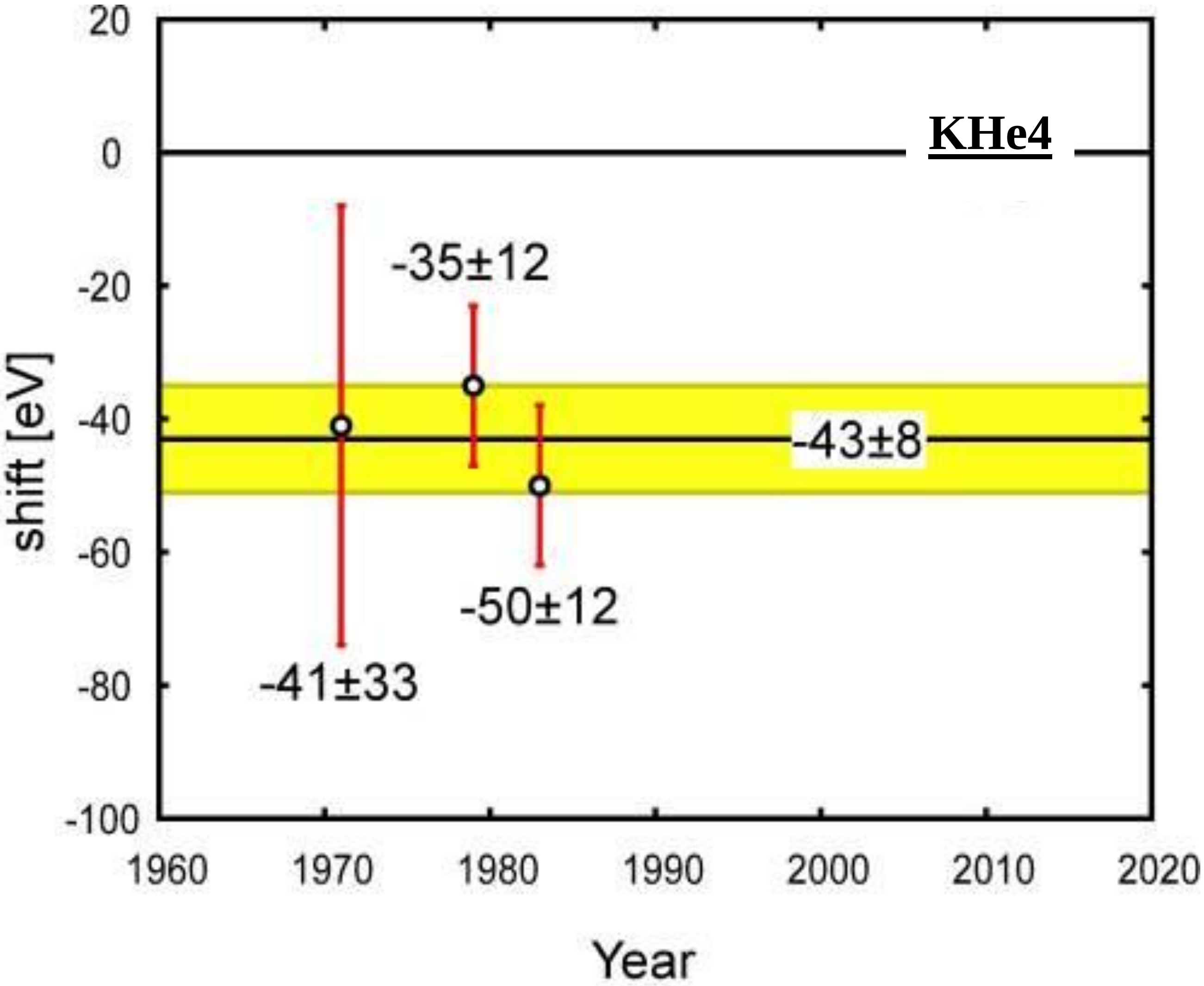
- Kaonic helium 3 – 10 pb^{-1}, first measurement in the world, published in Phys. Lett. B 697 (2011) 199; Ph D

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

SIDDHARTA – important TRAINING for young researchers

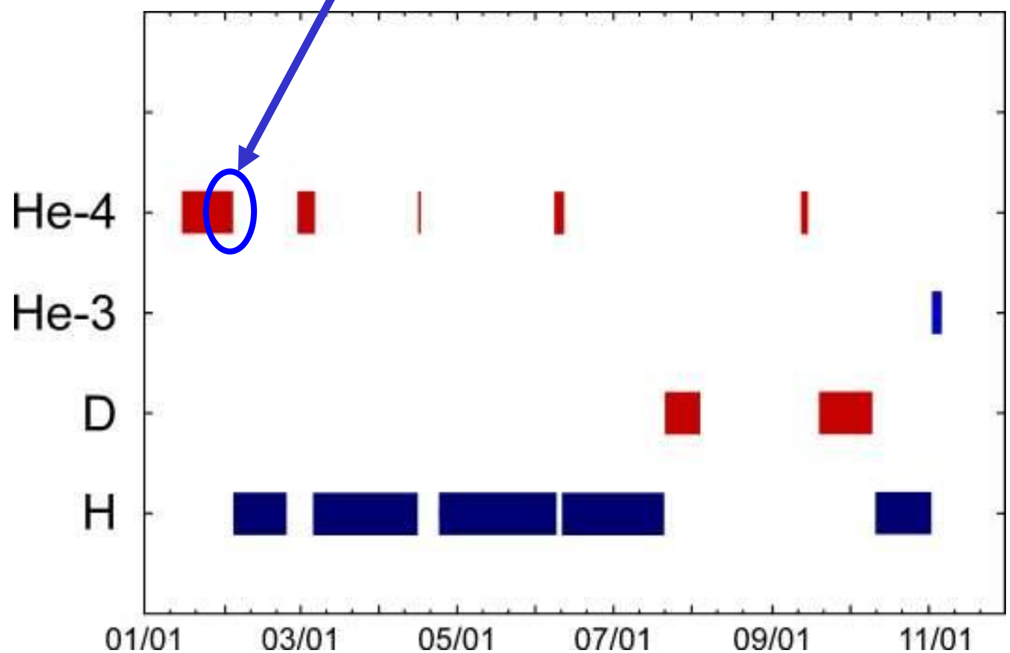
Kaonic Helium 3 and 4

Kaonic 4 old data

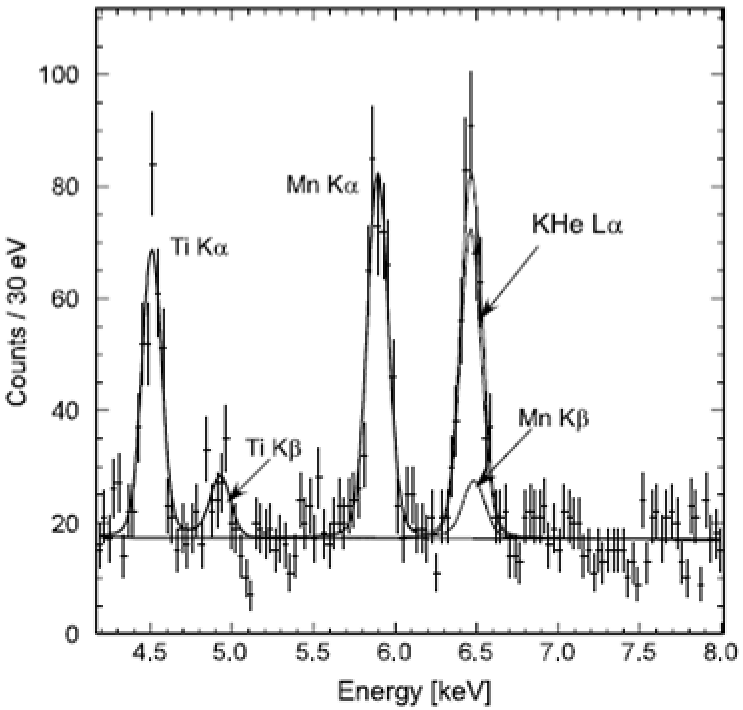


Data taking periods of SIDDHARTA in 2009

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

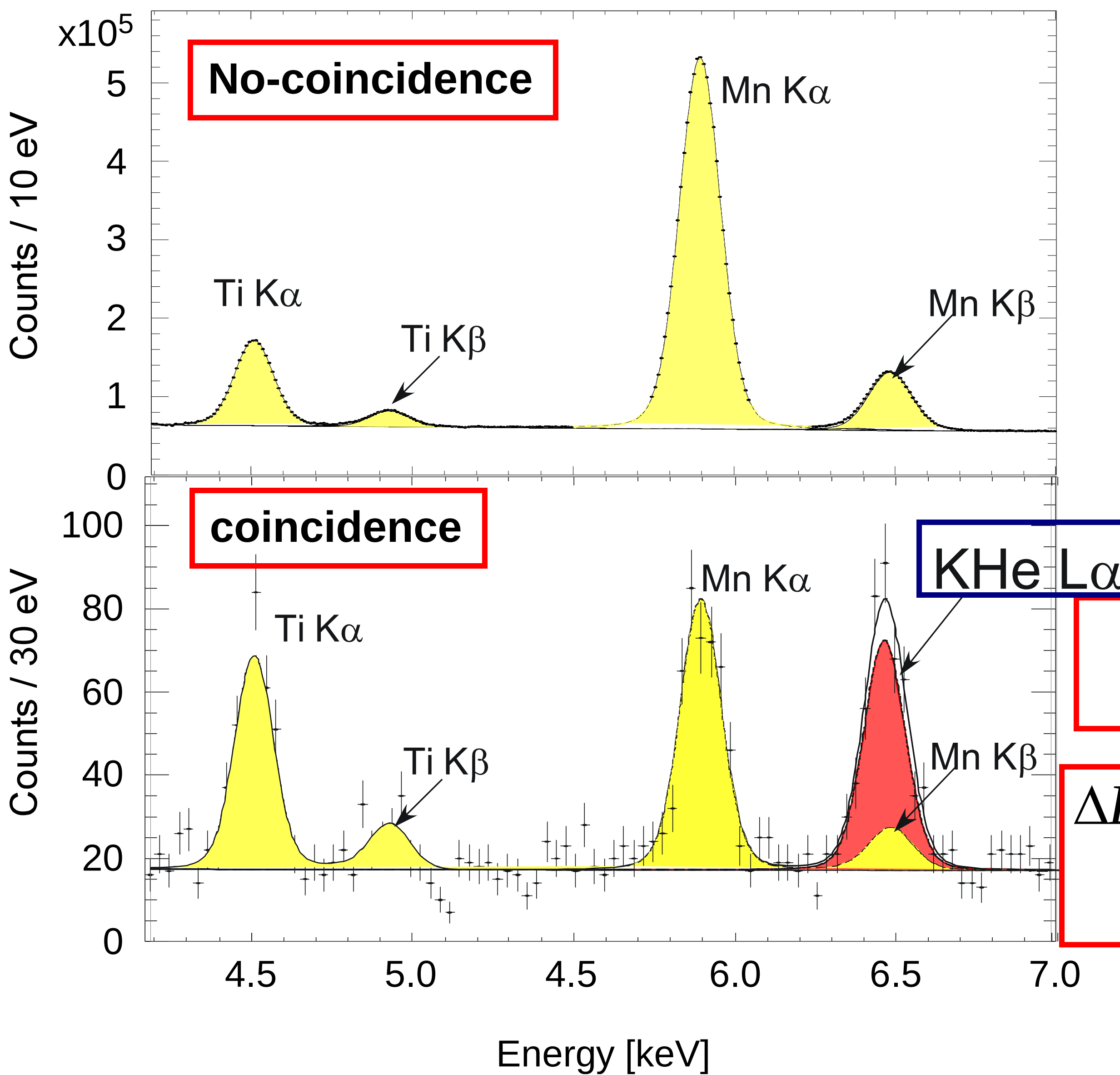
Use of
Mn Ka (5.9 keV) from ^{55}Fe

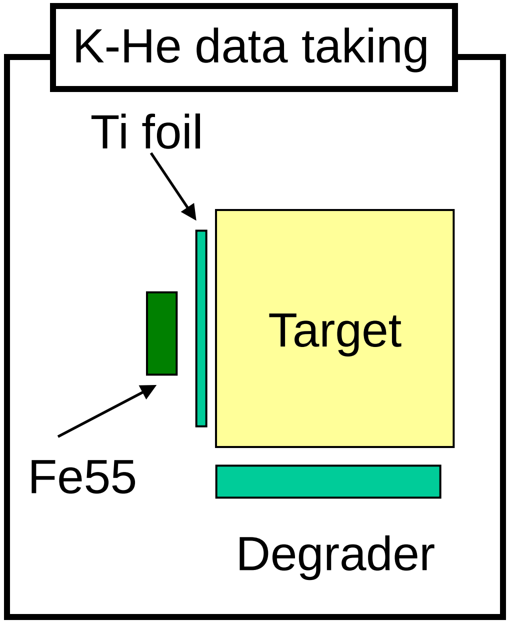
Systematic error = +/-2 eV

Removed ^{55}Fe source in other data

KHe-4 energy spectrum at SIDDHARTA

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





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

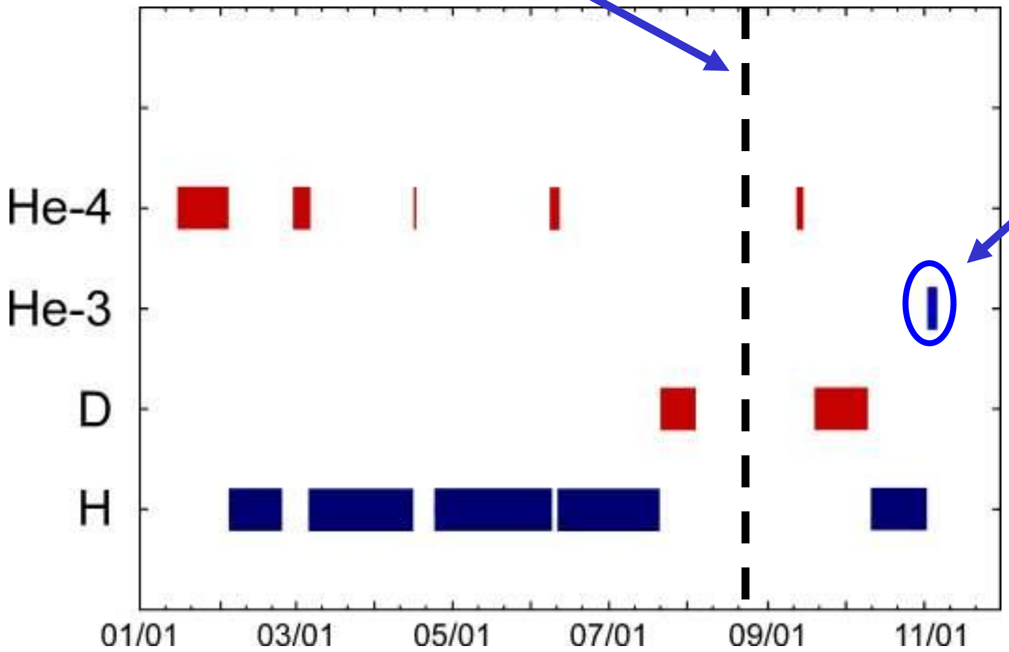
$$\Delta E = E_{\rm exp} - E_{e.m.}$$
$$= 0 \pm 6(\mathrm{stat}) \pm 2(\mathrm{syst})\,\mathrm{eV}$$

Data taking periods of SIDDHARTA in 2009

DAFNE shutdown in Summer

New alignment of setup
→Improve S/N ratio

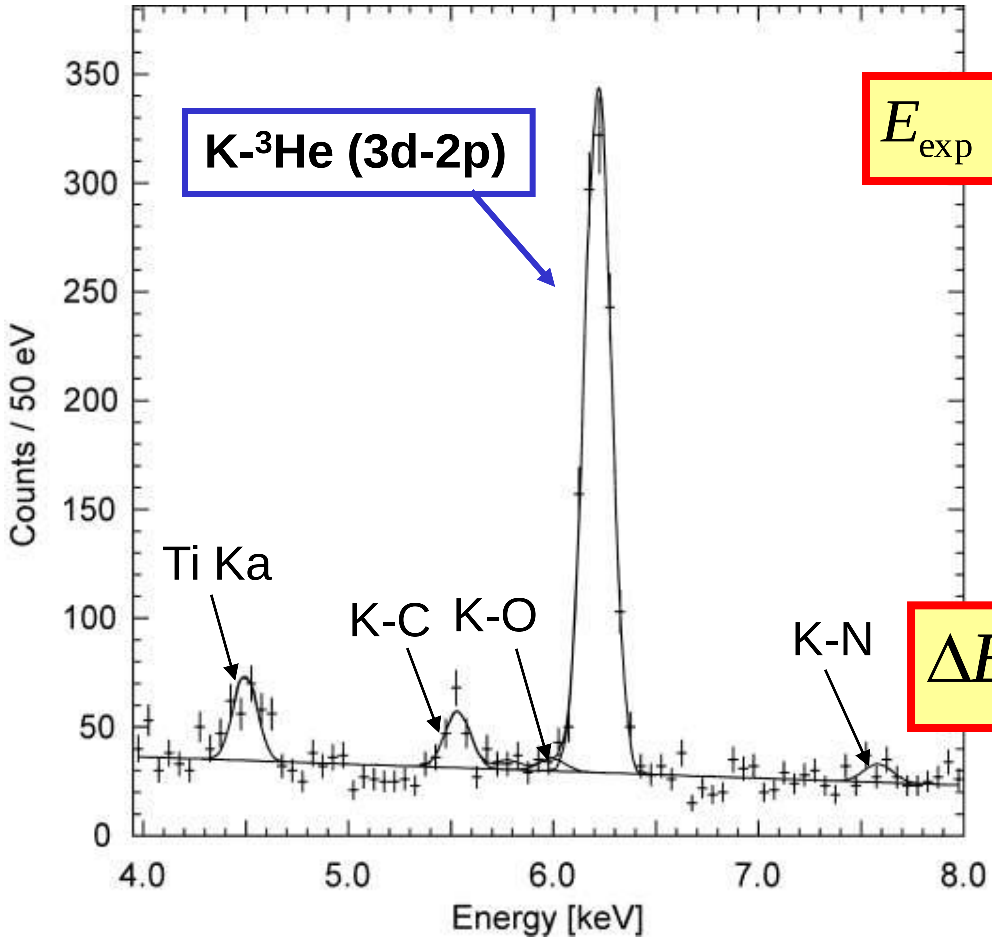
K-He3 data (~4days)



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

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

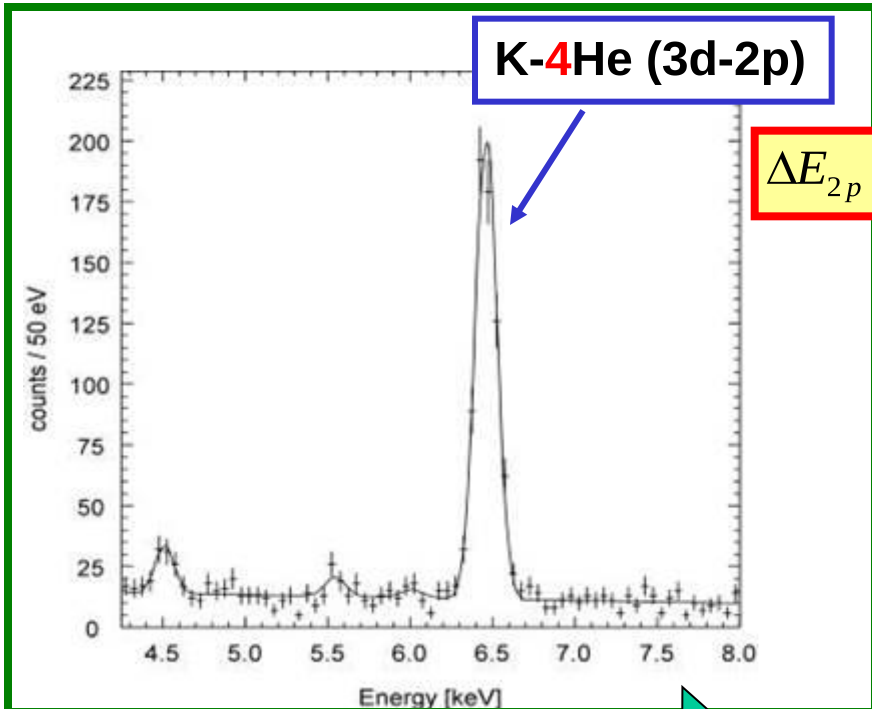
QED value: $E_{e.m.} = 6224.6\ \text{eV}$

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

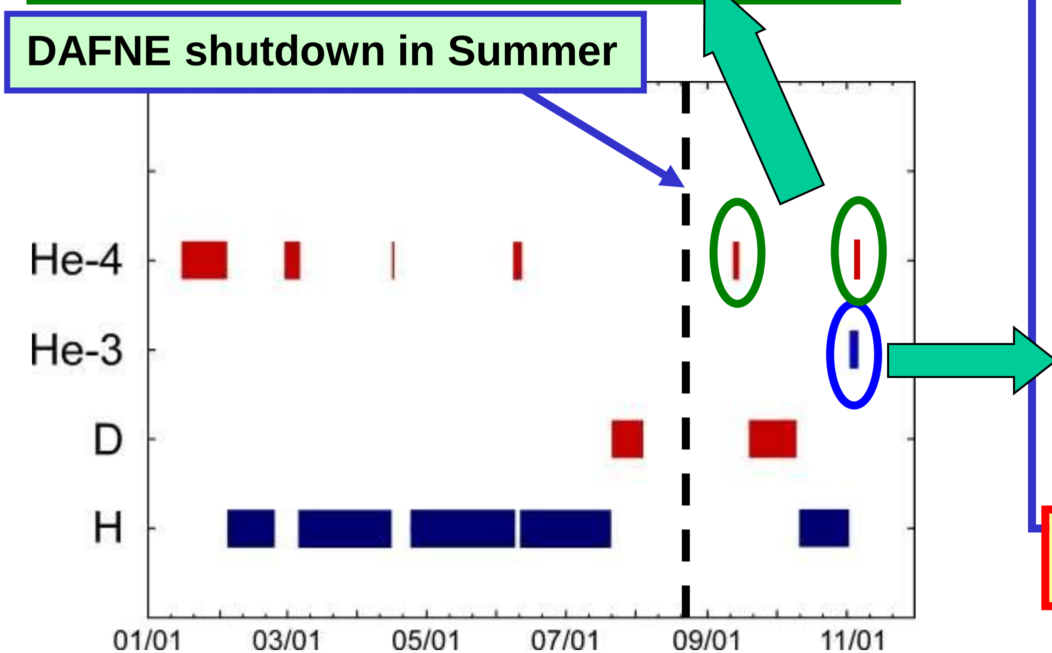
$$\Delta E_{2p} = -2 \pm 2(sta) \pm 4(sys)\ \text{eV}$$

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

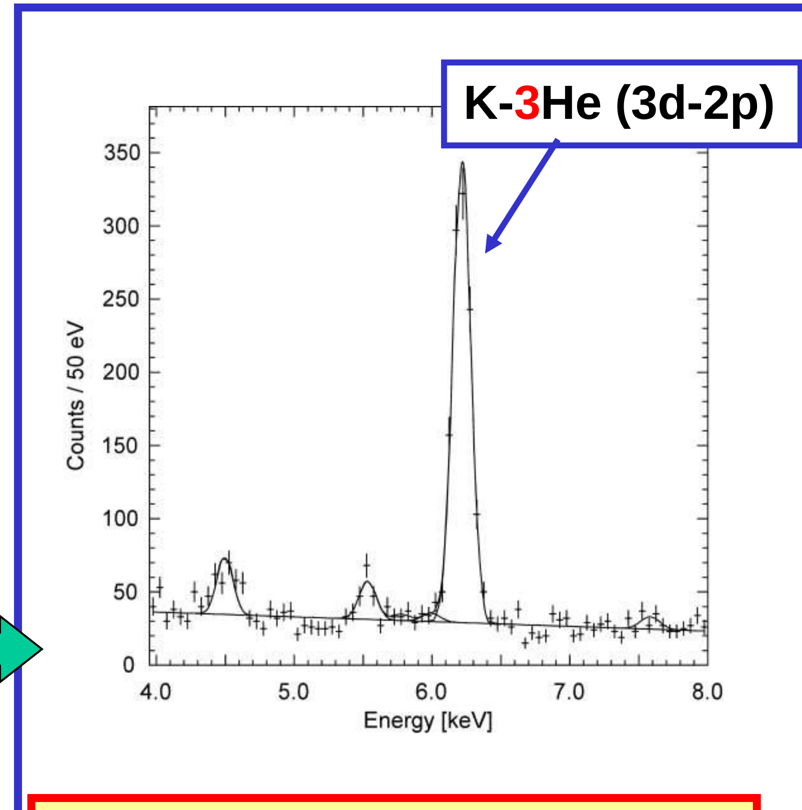
arXiv:1010.4631v1 [nucl-ex], PLB697(2011)199



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



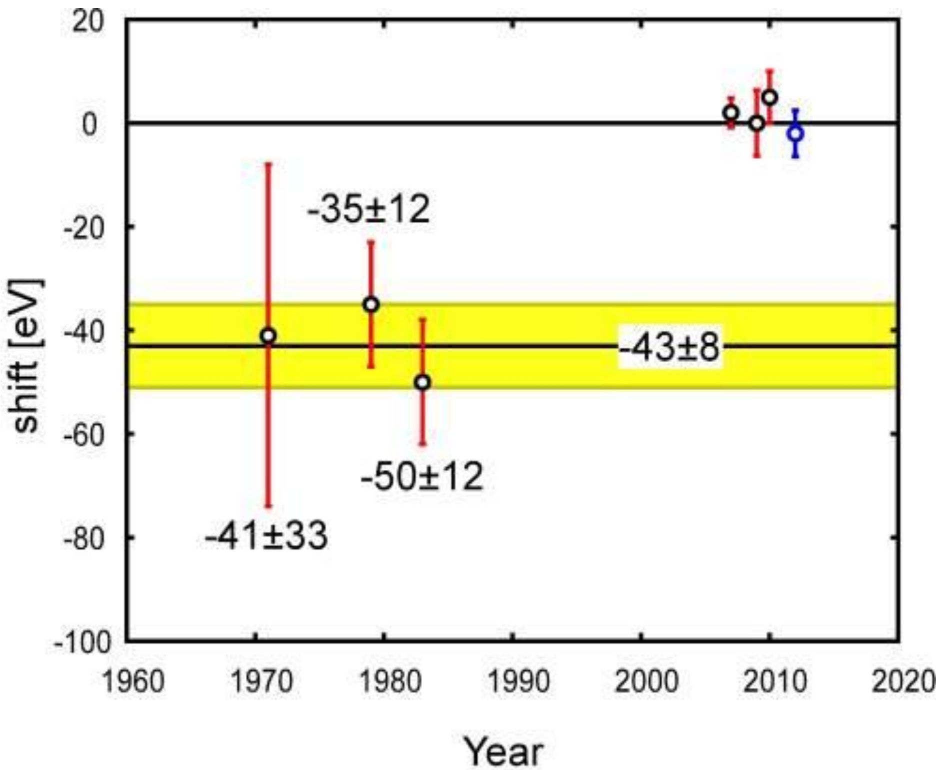
PLB697(2011)199

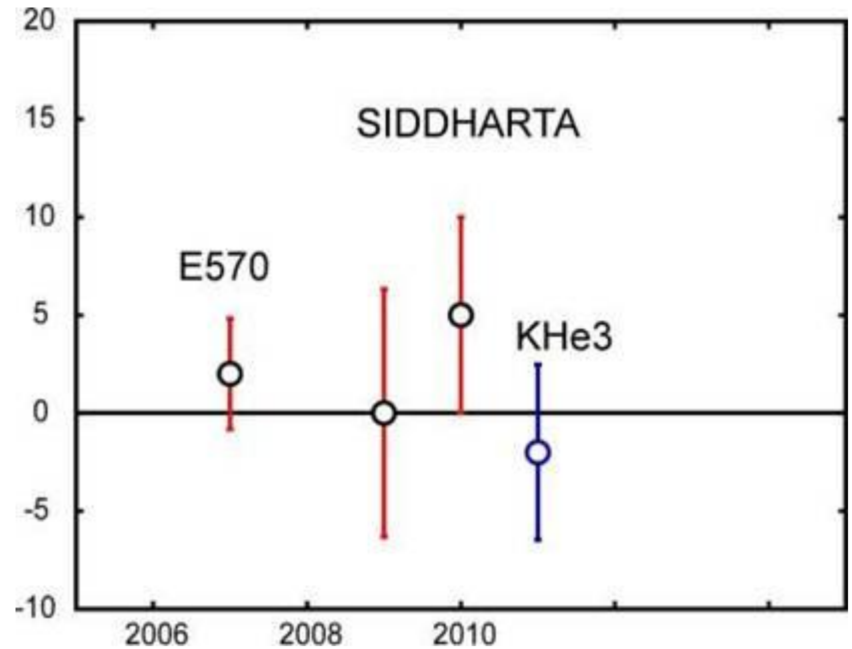


$$\Delta E_{2p} = -2 \pm 2(sta) \pm 4(sys)\ \text{eV}$$

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

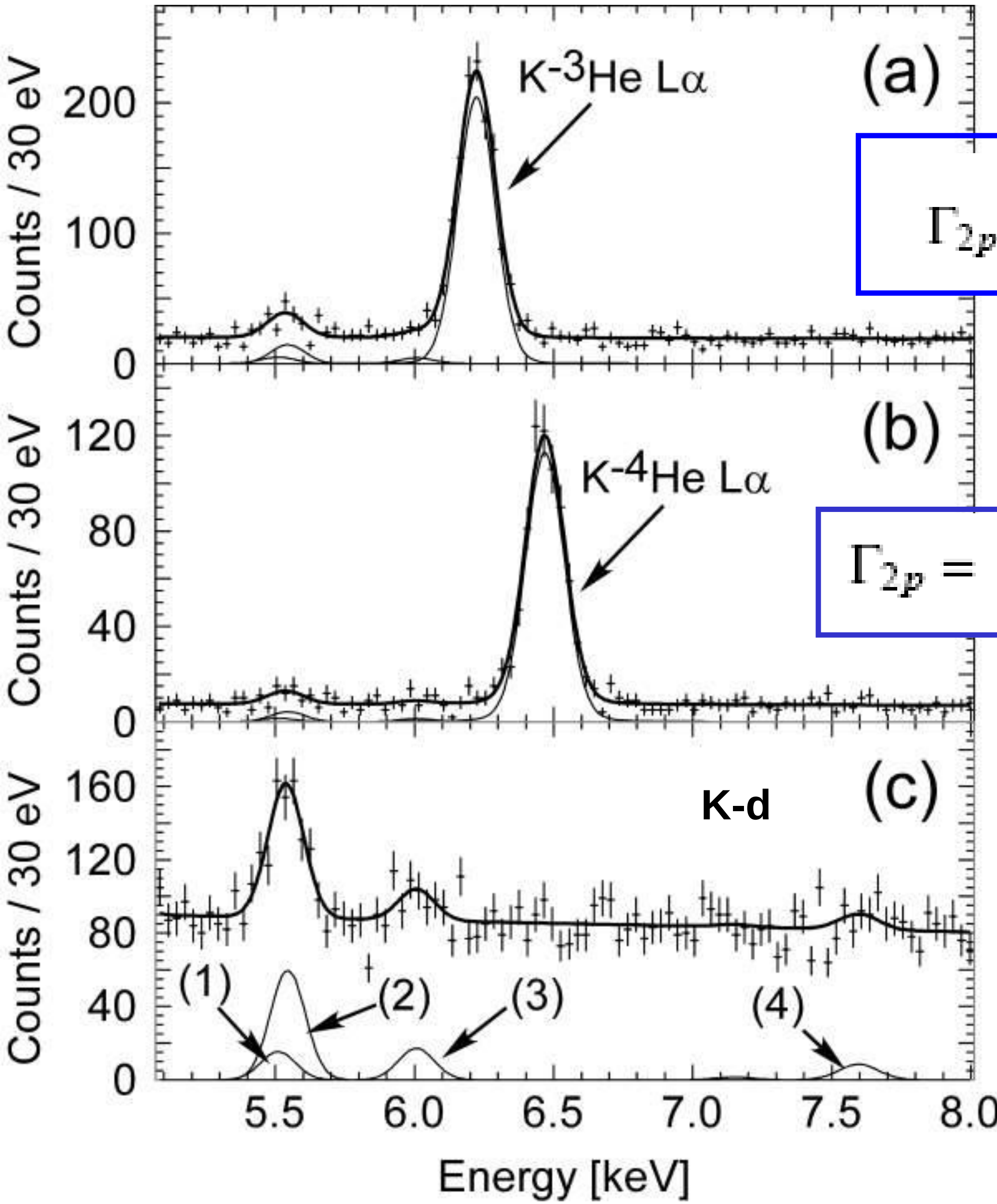
the strong-interaction width of the kaonic 3He and 4He 2p state

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

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

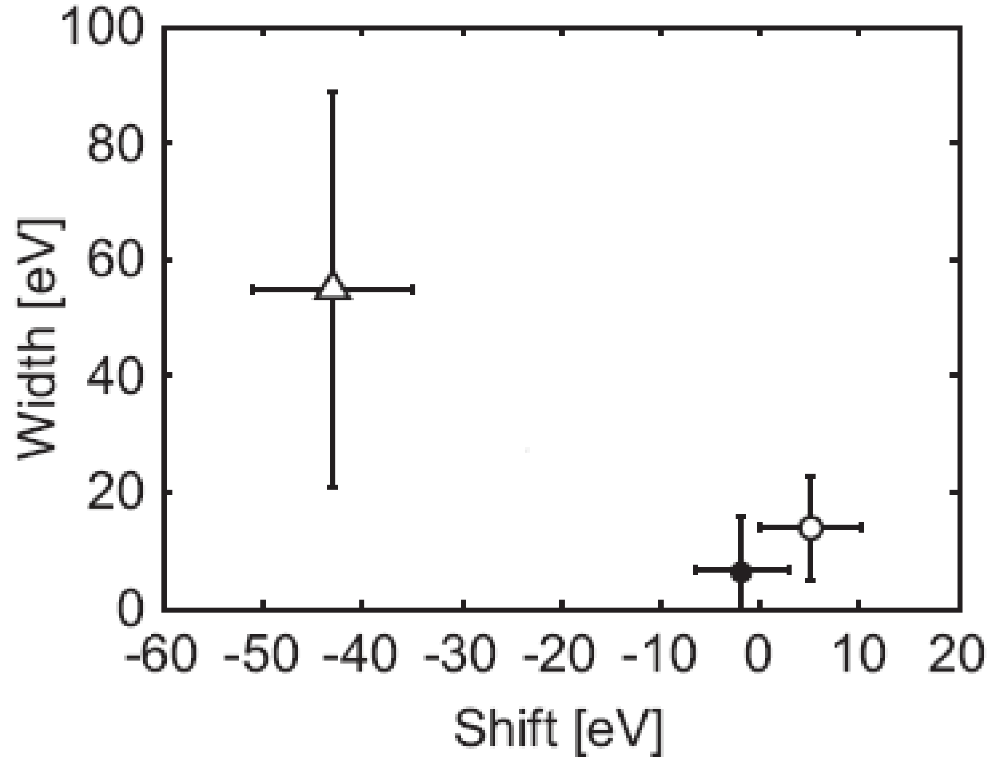
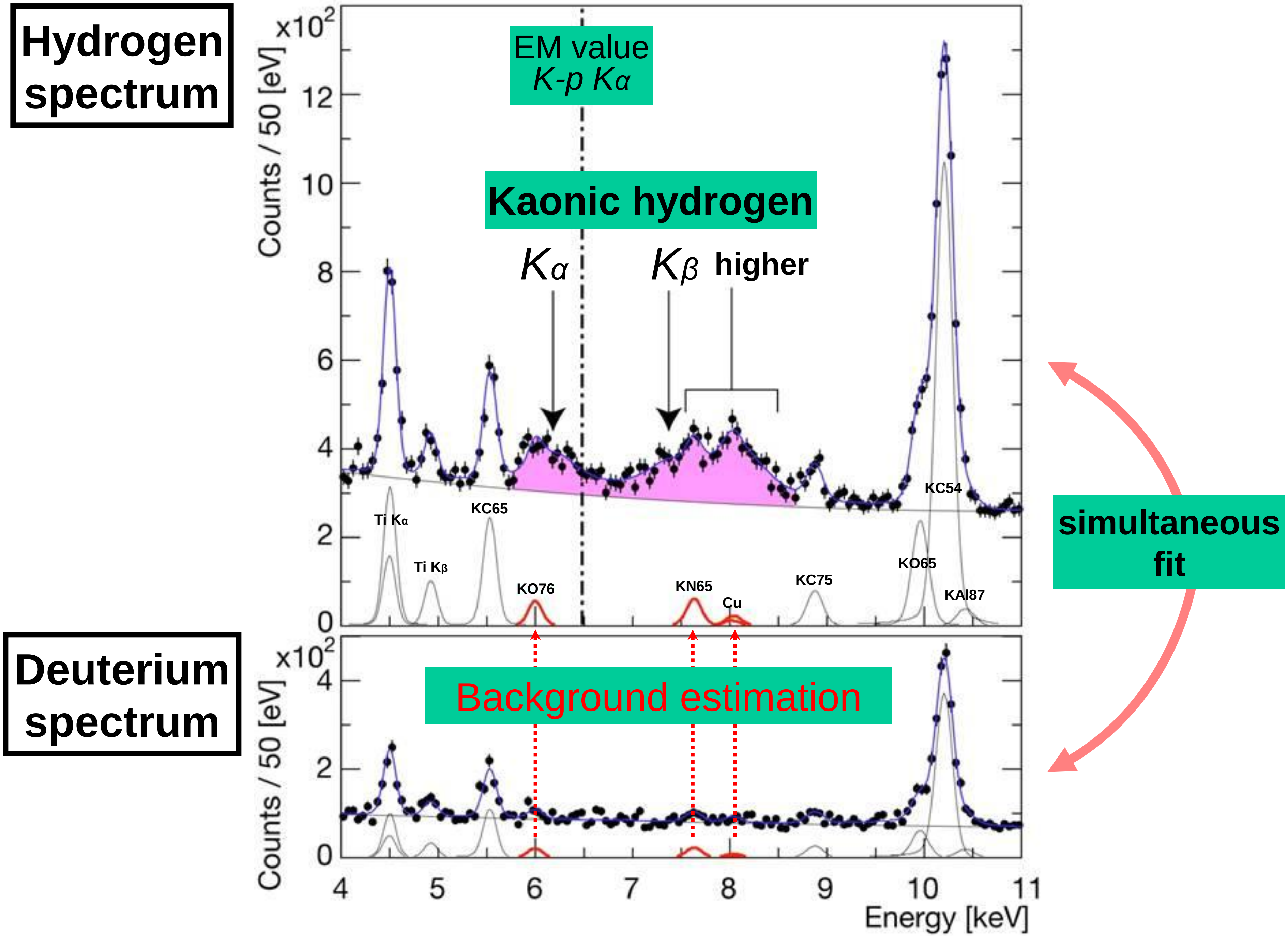
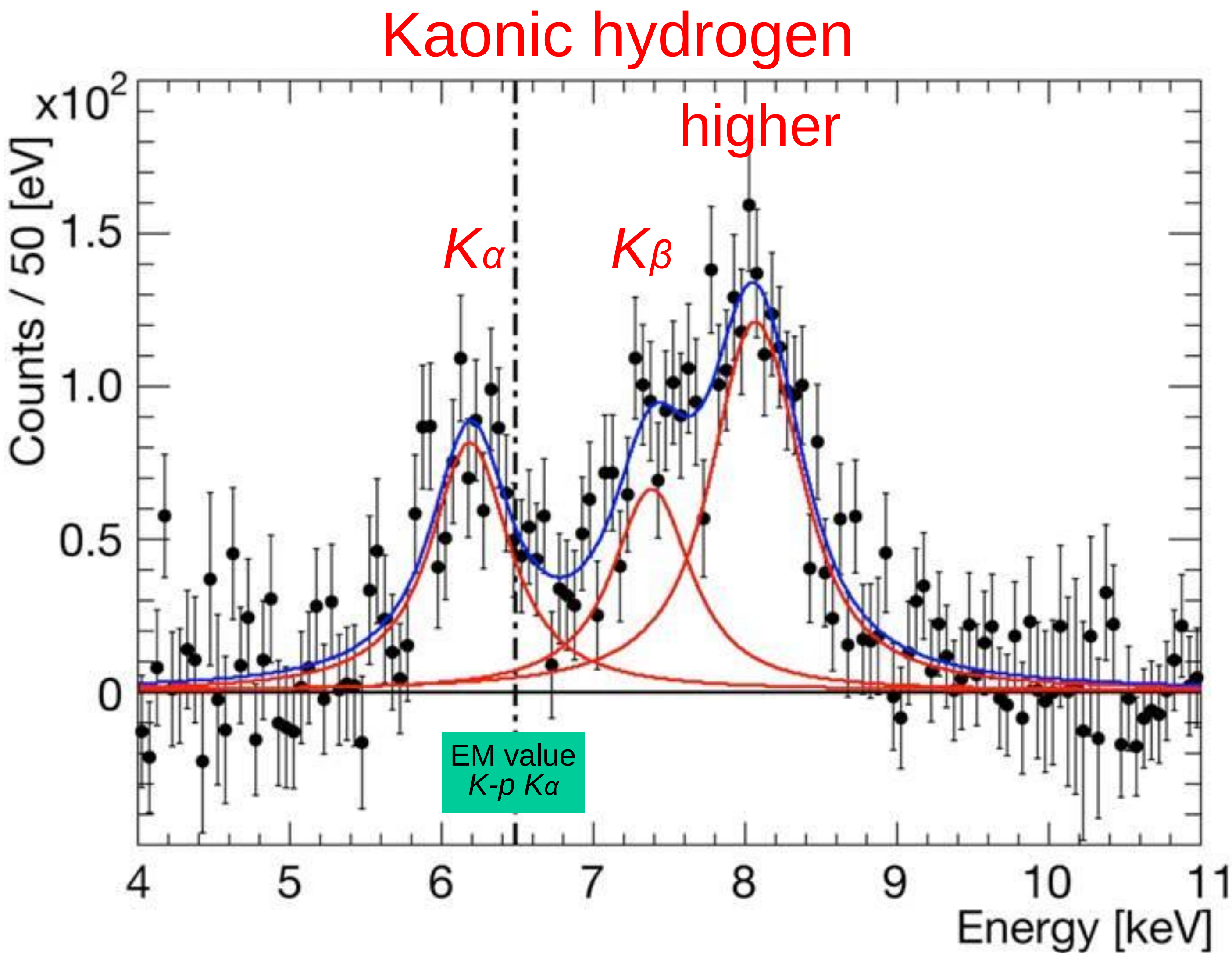


Figure 5: Comparison of experimental results. Open circle: K-4He 2*p* state; filled circle: K-3He 2*p* state. Both are determined by the SIDDHARTA experiment. The average value of the K-4He experiments performed in the 70's and 80's is plotted with the open triangle.

Kaonic 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
Background estimation
simultaneous fit
Counts / 50 [eV]
x10²
Energy [keV]
0
2
4
6
8
10
12
4
5
6
7
8
9
10
11

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



KAONIC HYDROGEN results

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

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

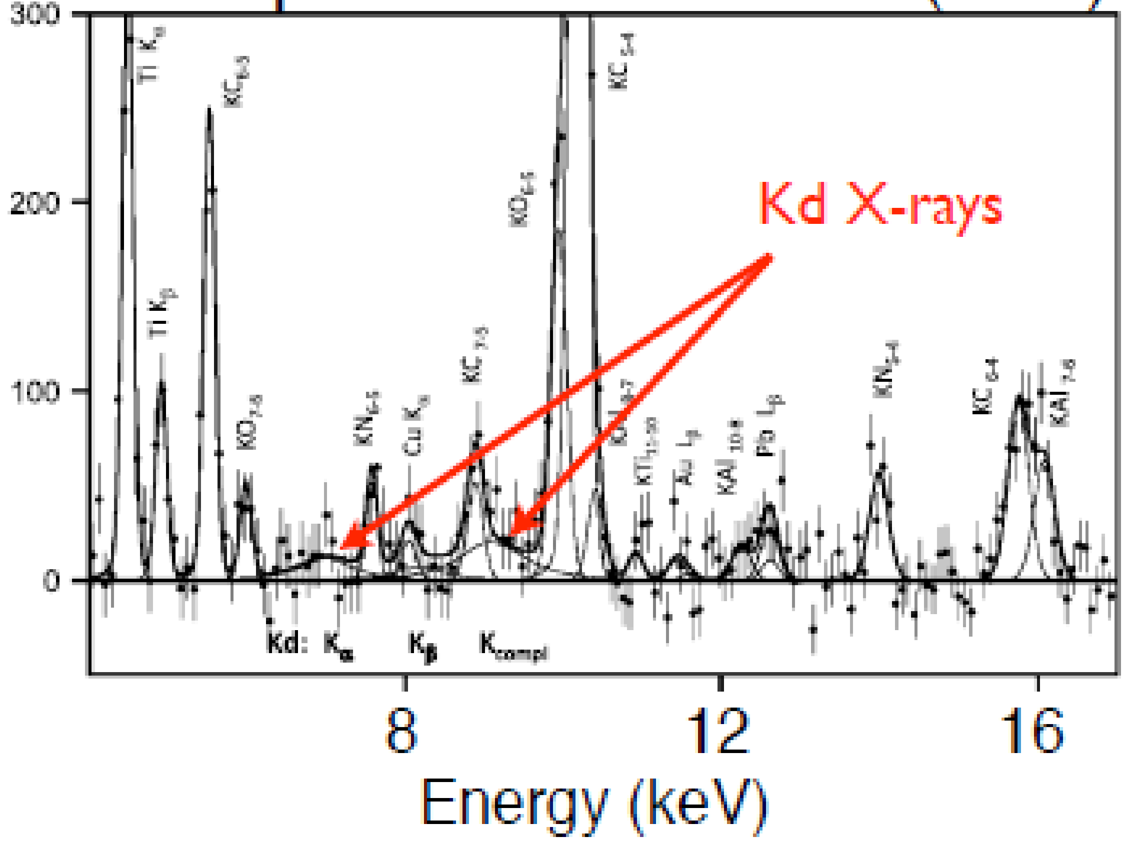
Kaonic Deuterium exploratory measurement

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

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

Available online at www.sciencedirect.com

SciVerse ScienceDirect

NUCLEAR PHYSICS A

Nuclear Physics A 907 (2013) 69–77

www.elsevier.com/locate/nuclphysa

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]

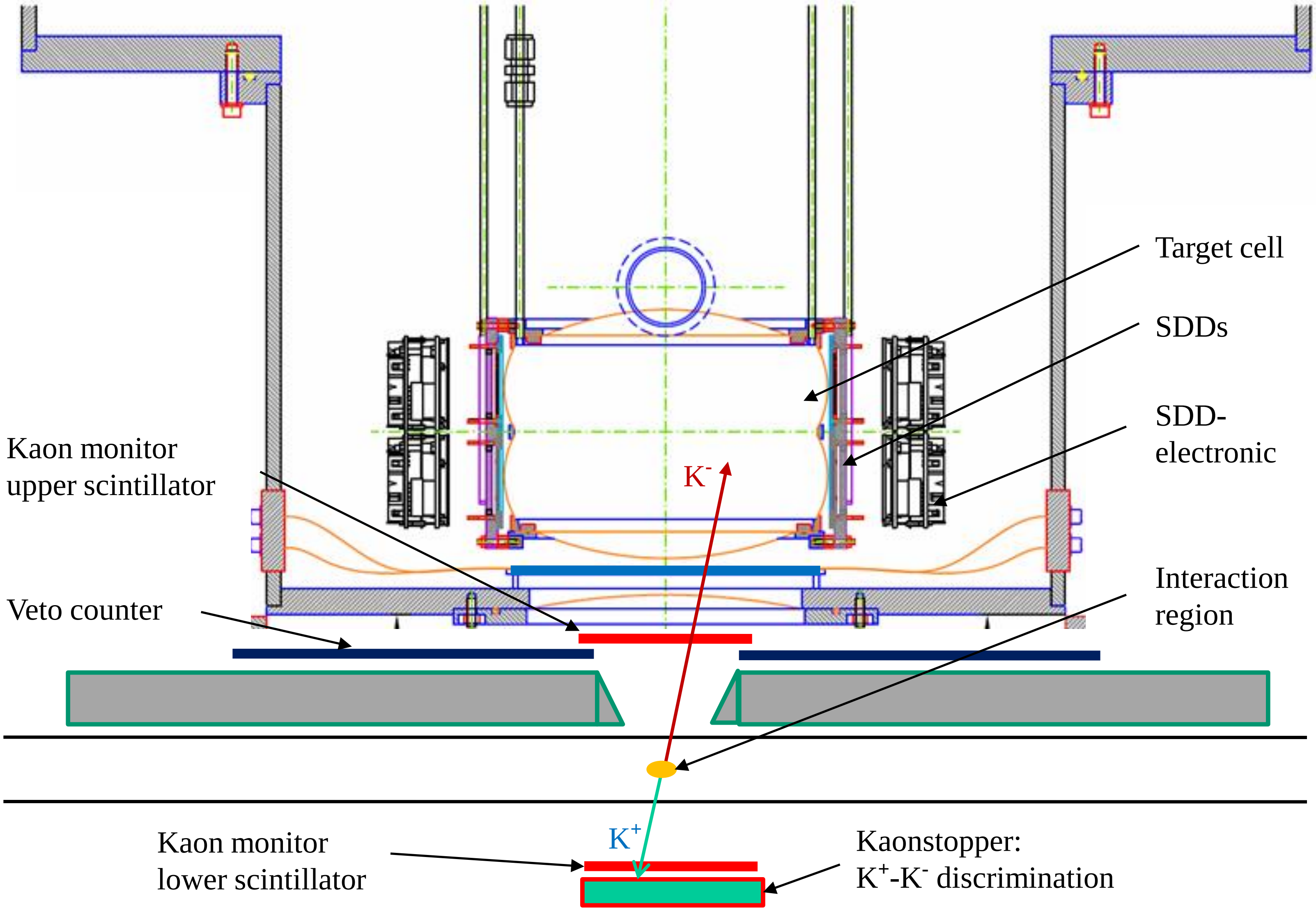
DAΦNE represents (as always did) an (THE) EXCELLENT FACILITY in the sector of low-energy interaction studies of kaons with nuclear matter.

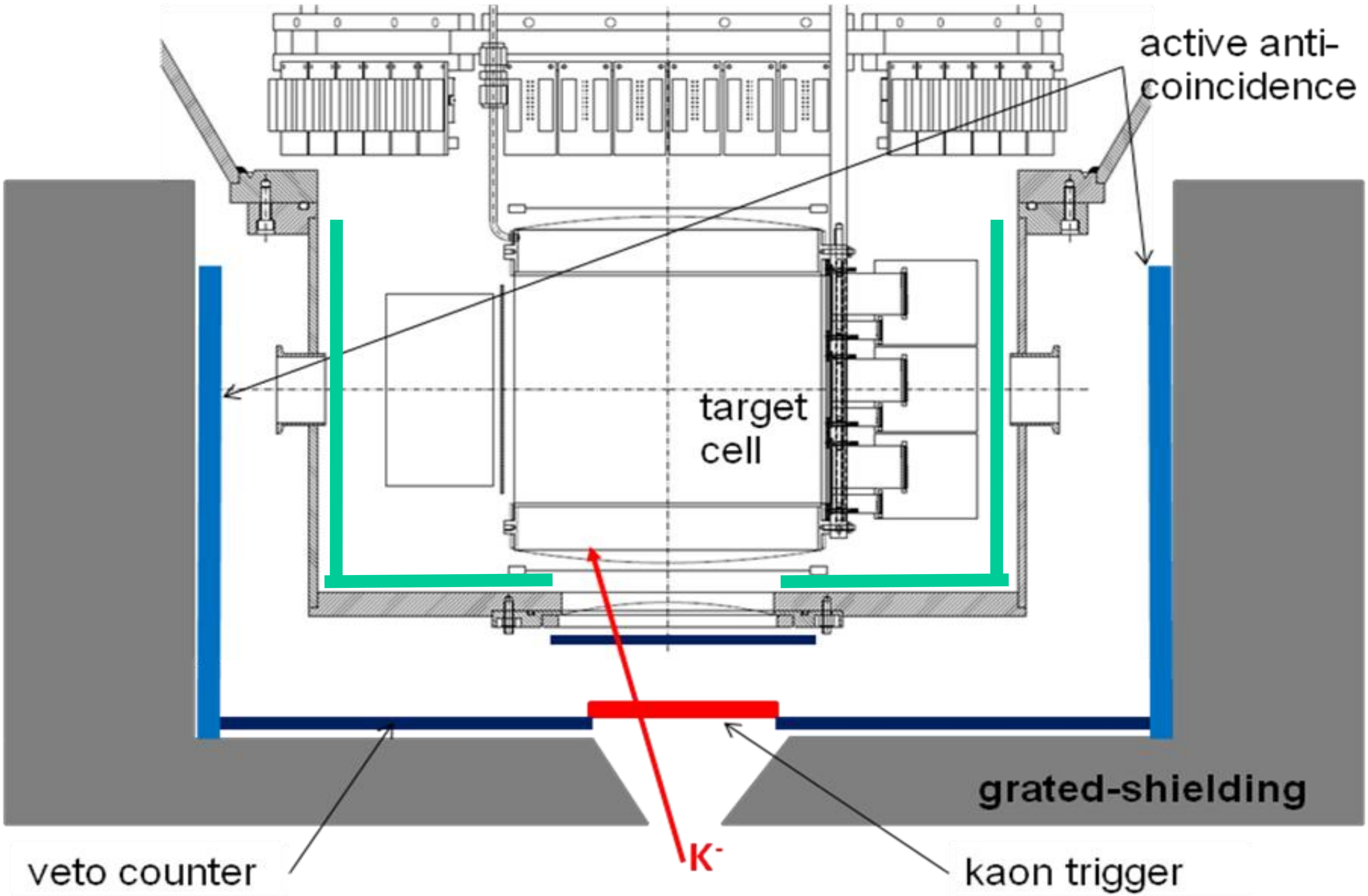
It is actually the IDEAL facility for kaonic atoms studies as SIDDHARTA has demonstrated

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

The SIDDHARTA-2 setup, essential improvements

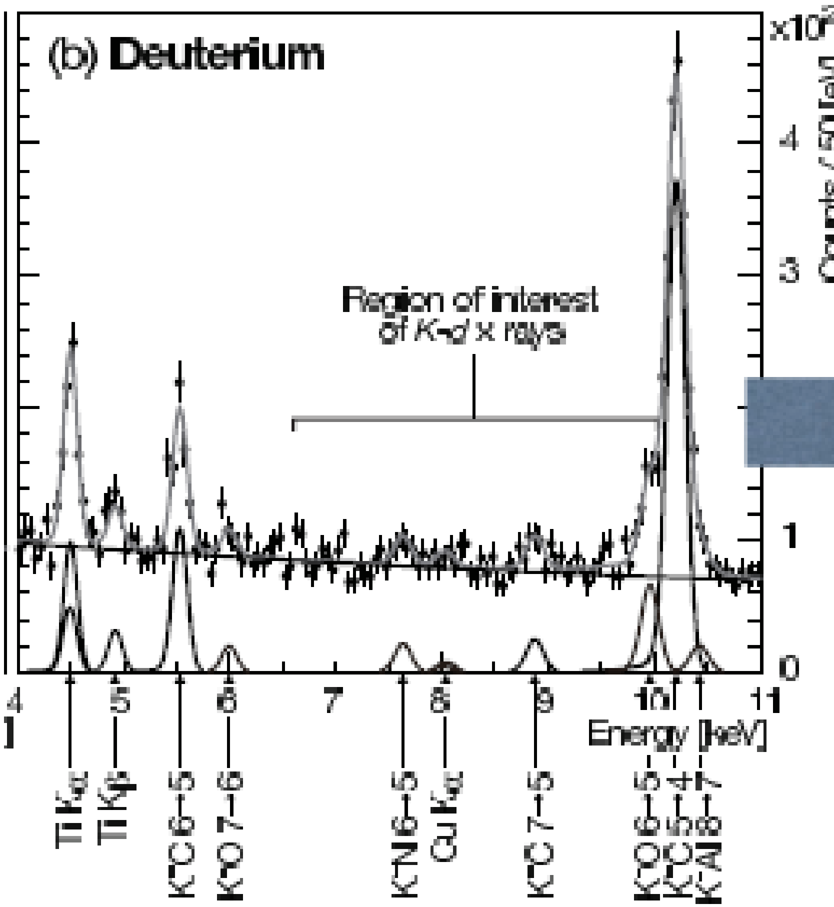
- new target design
- new SDD arrangement
- vacuum chamber
- more cooling power
- improved trigger scheme
- shielding and anti-coincidence (veto)
- new SDD detectors (FBK)

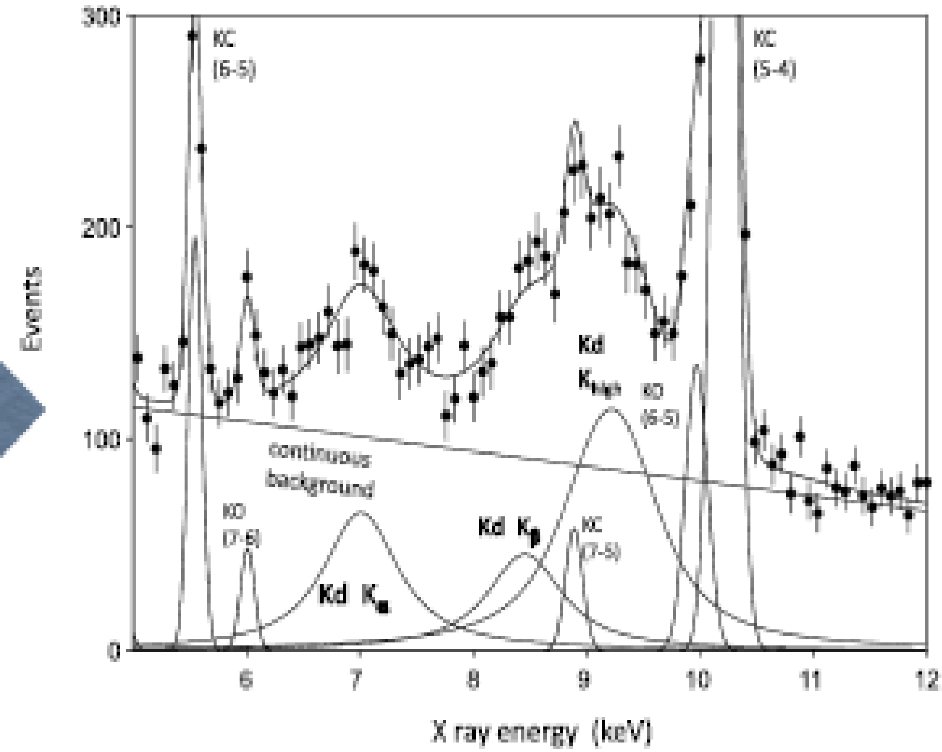

Target cell
SDDs
SDD-
electronic
Kaon monitor
upper scintillator
K-
Veto counter
Interaction
region
K+
Kaon monitor
lower scintillator
Kaonstopper:
K+-K- discrimination


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

SIDDHARTA(2009)

SIDDHARTA2
(expected spectrum)





~100 pb^{-1}

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

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,…)

4) Heavier kaonic atoms measurement (Si, Pb…)

5) Kaon radiative capture – $\Lambda(1405)$ study

6) Investigate the possibility of the measurement of other types of hadronic exotic atoms (sigmonic hydrogen ?)

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

KAONNIS (Integrated Initiative):

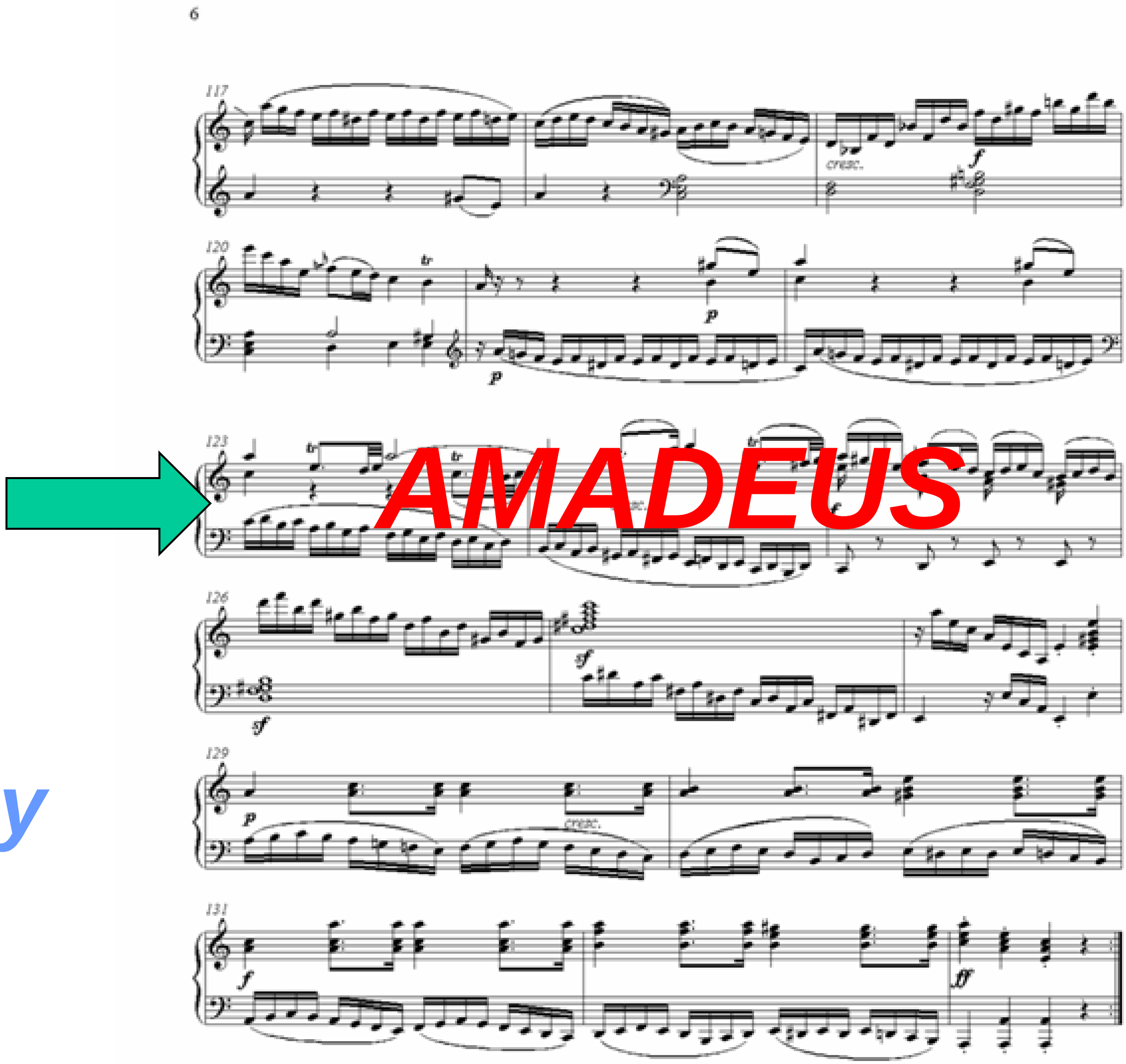
Unique studies of the low-energy kaon-nucleon/nuclei interactions -> low-energy QCD in strangeness sector with implications from particle (Λ(1405)) and nuclear (kaonic nuclear clusters?) physics to astrophysics (equation of state -> role of strangeness)

- ***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

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)

HadronPhysics2
Study of Strongly Interacting Matter

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**)

Deeply Bound Kaonic Nuclei?

Kaonic nuclei

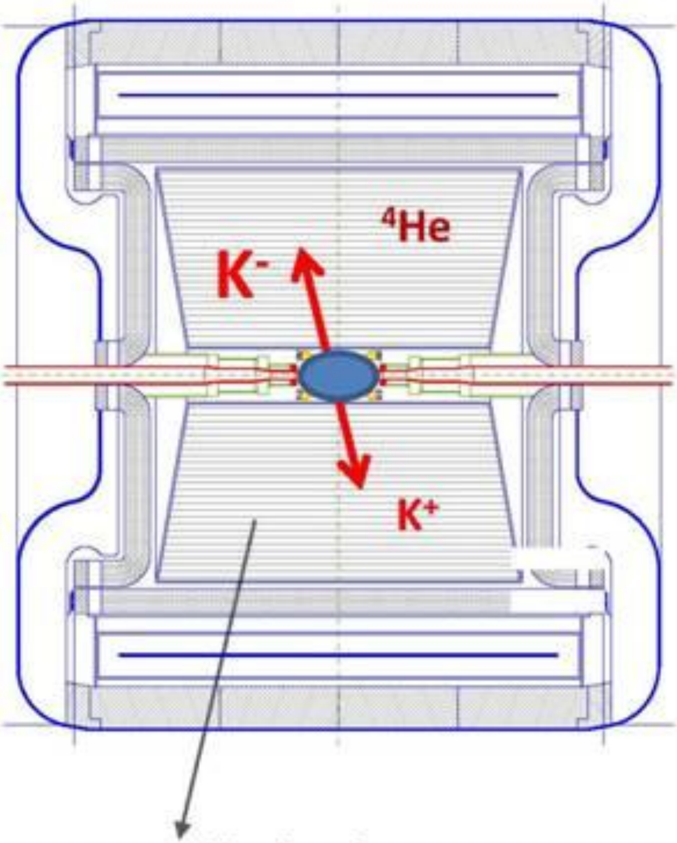
- Deeply bound state by strong interaction.
- Strong attraction of the I =0 $\bar{K}N$ interaction ($\bar{K}N^{I=0}$) plays an important role in kaonic nuclei.

K^-pp bound state

- The simplest kaonic nuclei.
- Theoretical prediction of B.E. and Γ depend on the $\bar{K}N$ interaction and the calculation method .

	Theoretical prediction	B.E (MeV)	Γ (MeV)
PRC76, 045201 (2002)	T. Yamazaki and Y. Akaishi	48	61
arXiv:0512037v2[nucl-th]	A. N. Ivanov, P. Kienle, J. Marton, E. Widman	118	58
PRC76, 044004 (2007)	N. V. Shevchenko, A. Gal, J. Mares, J. Revai	50~70	~100
PRC76, 035203 (2007)	Y. Ikeda and T. Sato	60~95	45~80
NPA804, 197 (2008)	A. Dote, T. Hyodo, W. Weise	20±3	40~70
PRC80, 045207 (2009)	S. Wycech and A. M. Green	56.5~78	39~60
PRL B712, 132-137 (2012)	Barnea et al.	15.7	41.2

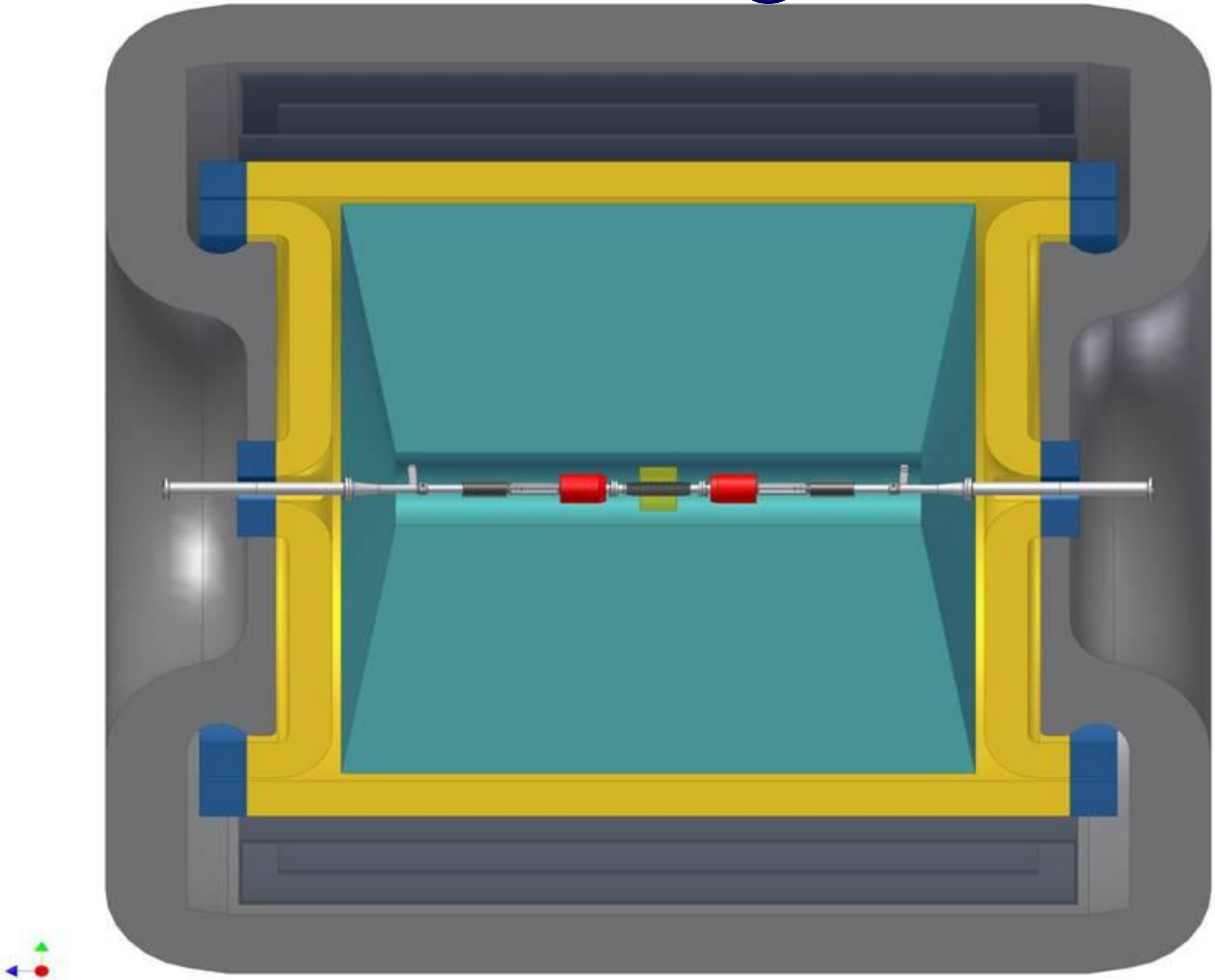
Hadronic interactions of K^- in KLOE



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

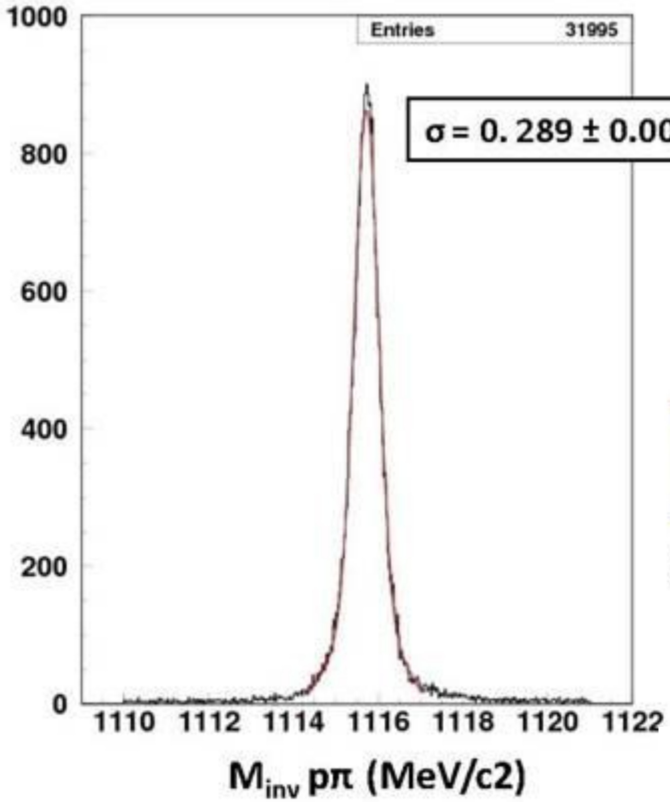


AMADEUS status

- 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

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



-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

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

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

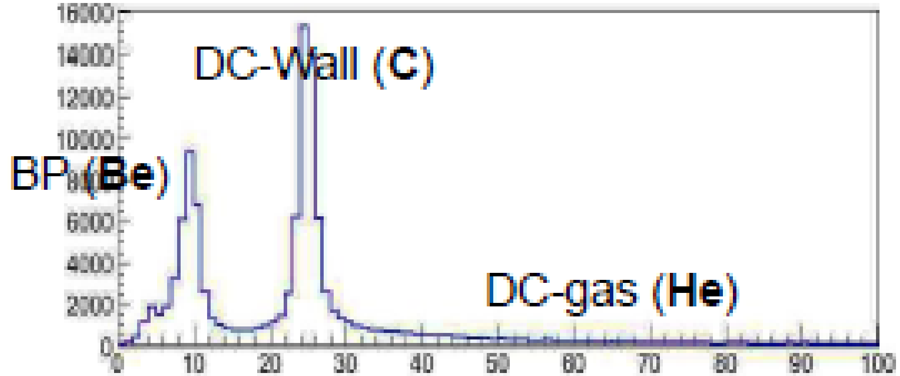
KLOE data on K^- nuclear absorption

Use of two different data samples:

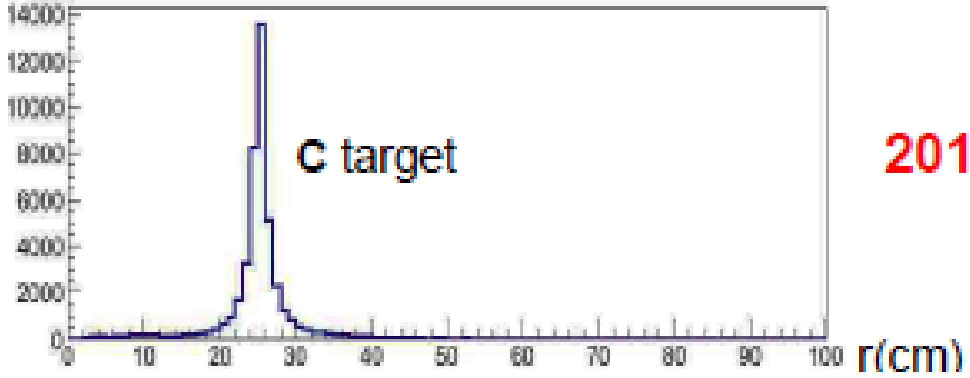
- KLOE data from 2004/**2005** (2.2 fb^{-1} total, 1.5fb^{-1} analyzed)

- 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)

<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

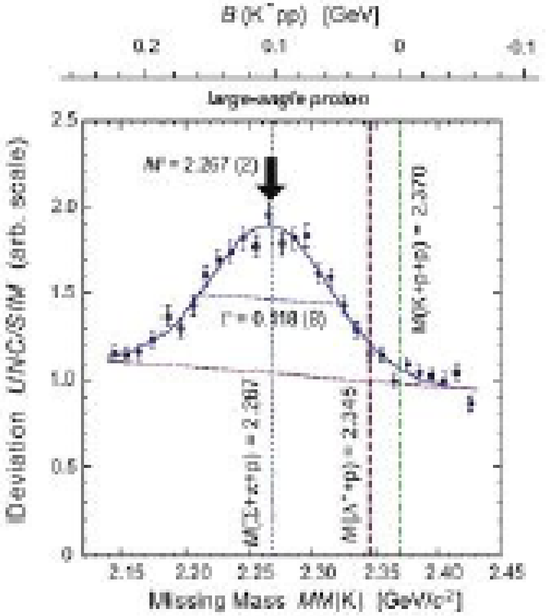
Λp analysis

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)

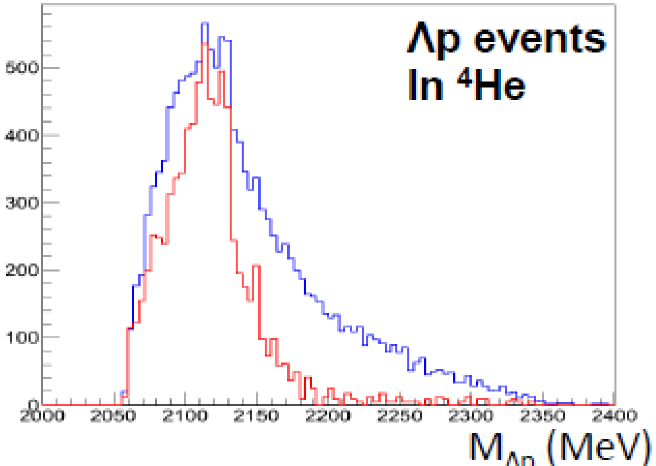
Λp analysis

-Competing processes:

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

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

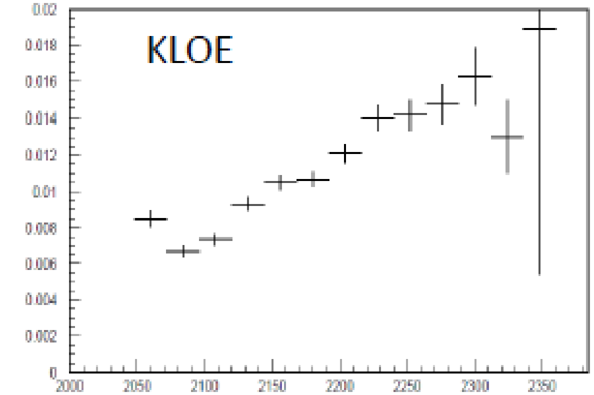
A perfect disentanglement between single and multi-nucleon absorption can be achieved thanks to the **nice acceptance:**



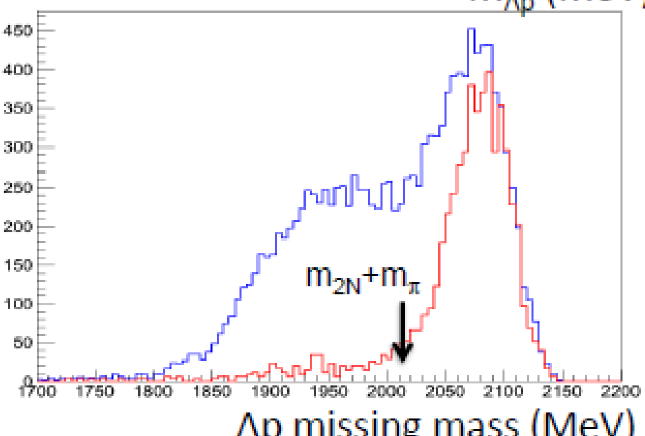
Λp all events

$\Lambda\pi^-$(p) events

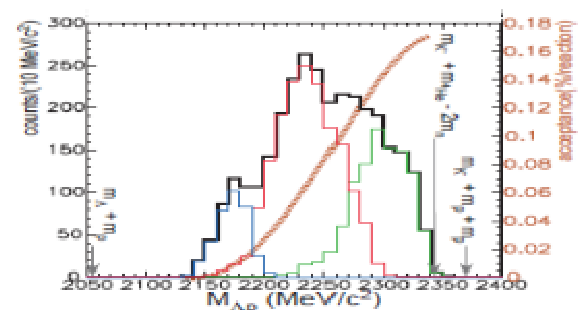
(arbitrary normalization)



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



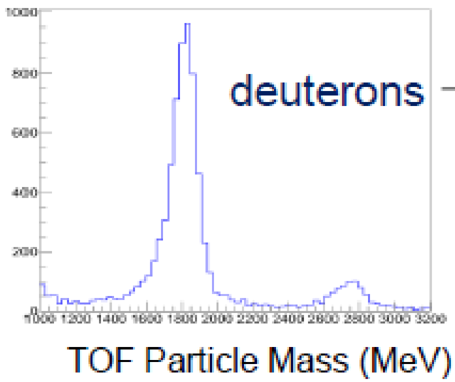
The Λp missing mass for the $\Lambda\pi^-$(p) events lies exactly In the $2N+\pi^-$ mass region

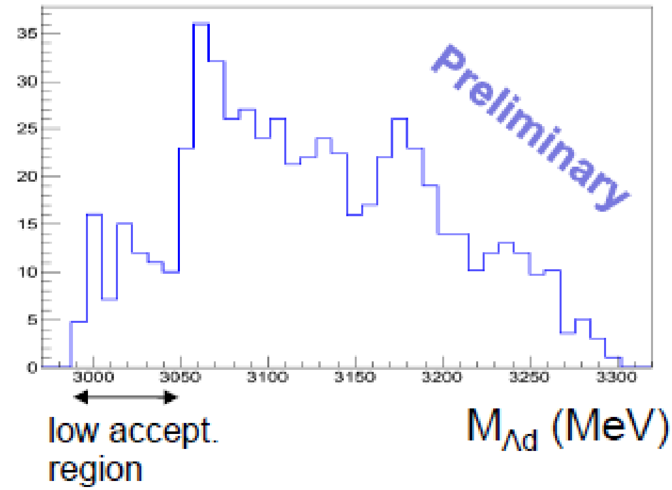


KEK-E549
Mod.Phys.Lett.A23, 2520 (2008)

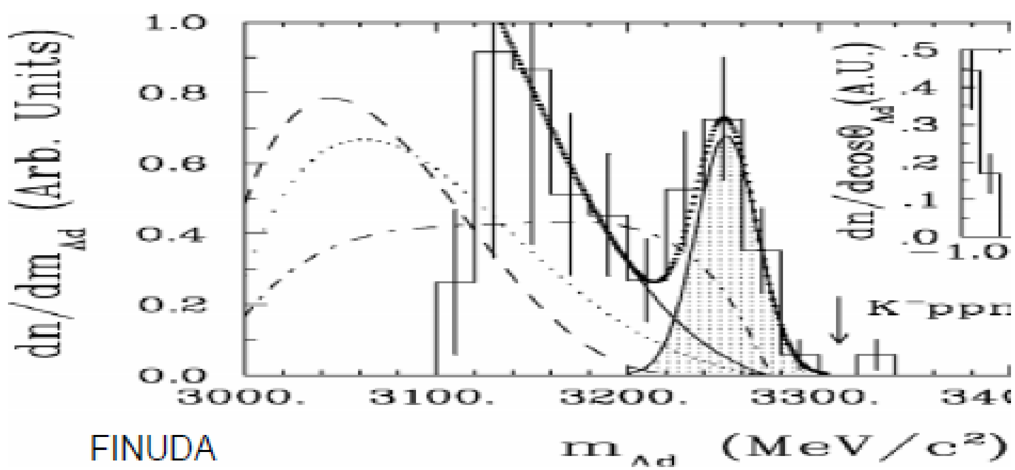
Λd, Λt analyses

- 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.





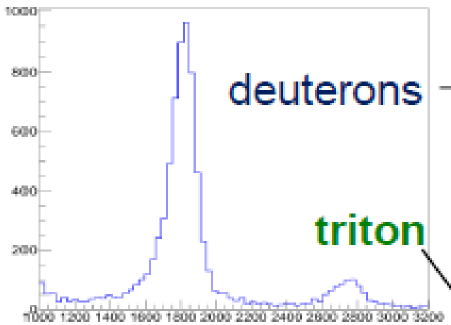
Λd events In ^{4}He

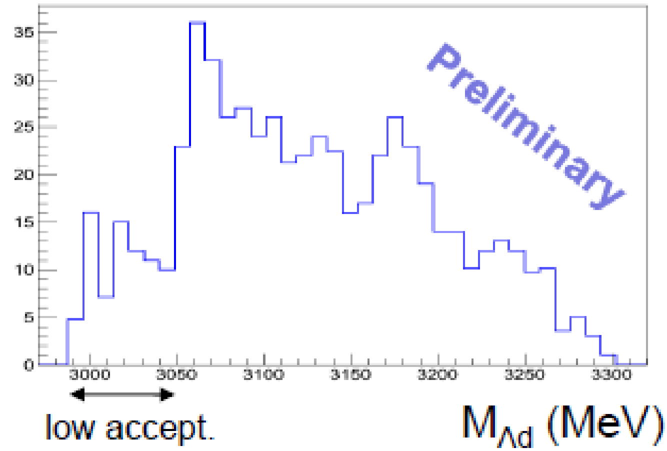


FINUDA
Nucl.Phys.A835, 43 (2010)

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.

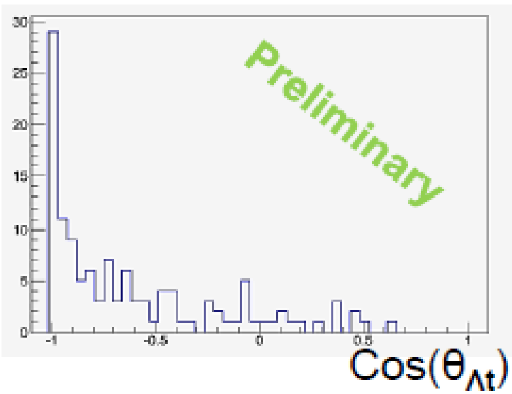


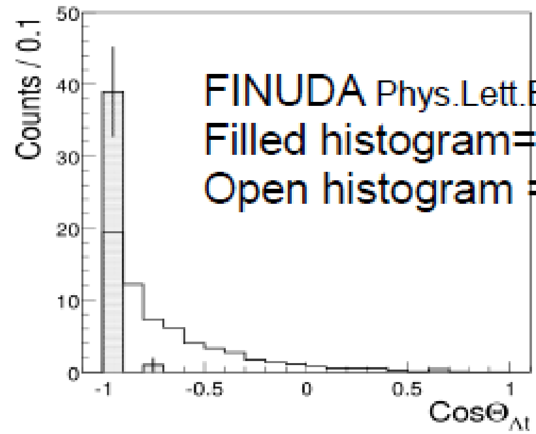


Λd events
In ^{4}He

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

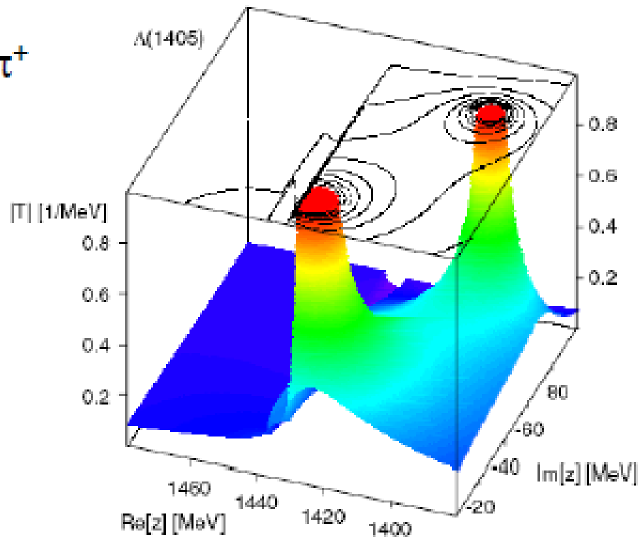
3) ***unstable* KN *bound state***

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:

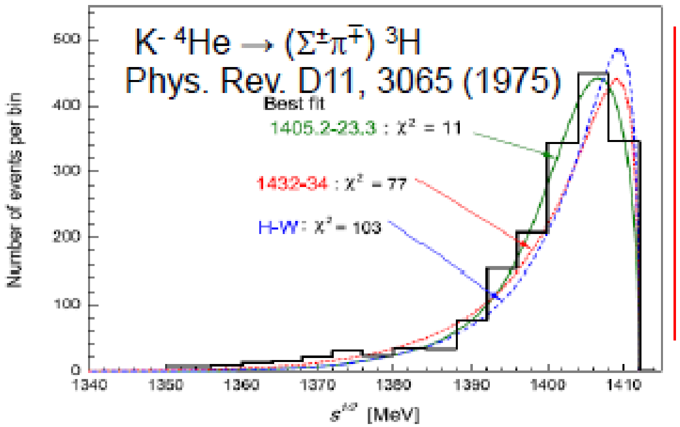
production in KN reactions (only chance to observe the high mass pole) **decaying in $\Sigma^0\pi^0$** (free from $\Sigma(1385)$ background)

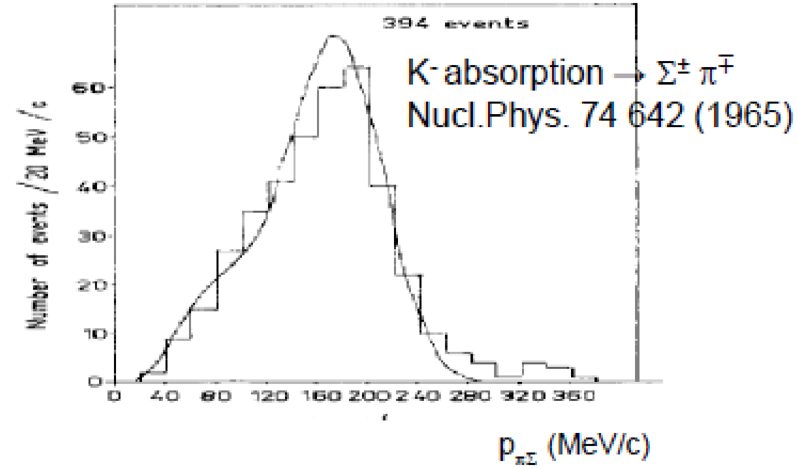
Λ(1405) previous experiments

Old **absorption experiments:**

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

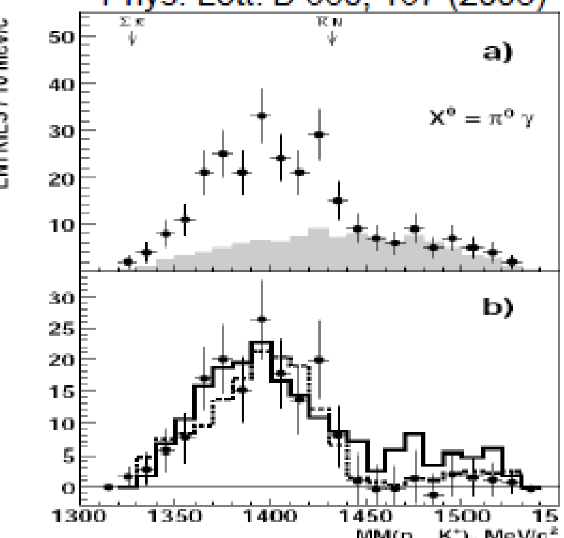
-$\Sigma^{\pm}\pi^{\mp}$ spectra suffer Σ(1385)contamination



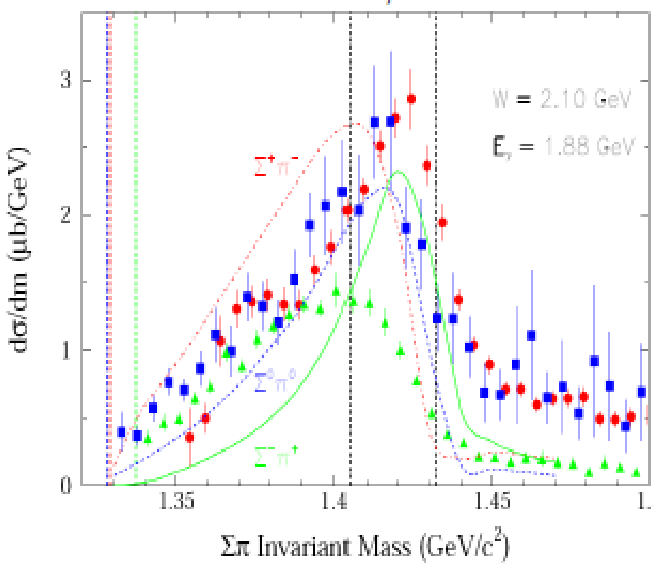


Other (**non-absorption**) experiments present spectra in the $\Sigma^0\pi^0$ channel (only three experiments…with different lineshapes!):

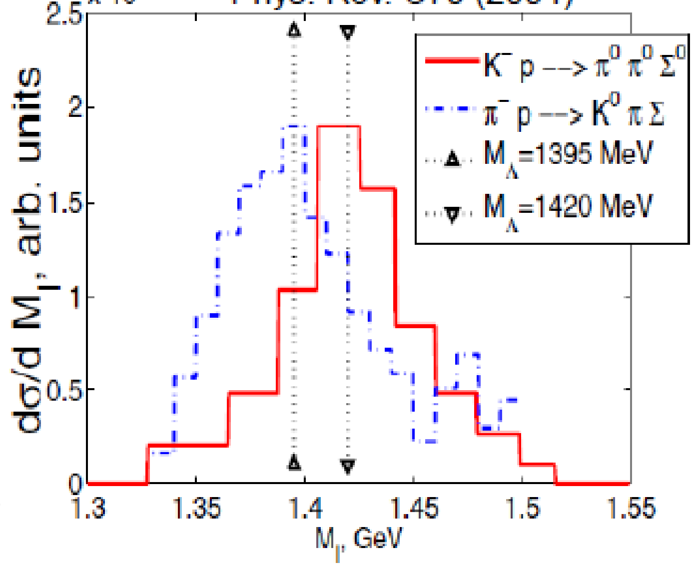
Phys. Lett. B 660, 167 (2008)



CLAS Collaboration, ArXiv:1301.5000v3



Phys. Rev. C70 (2004)

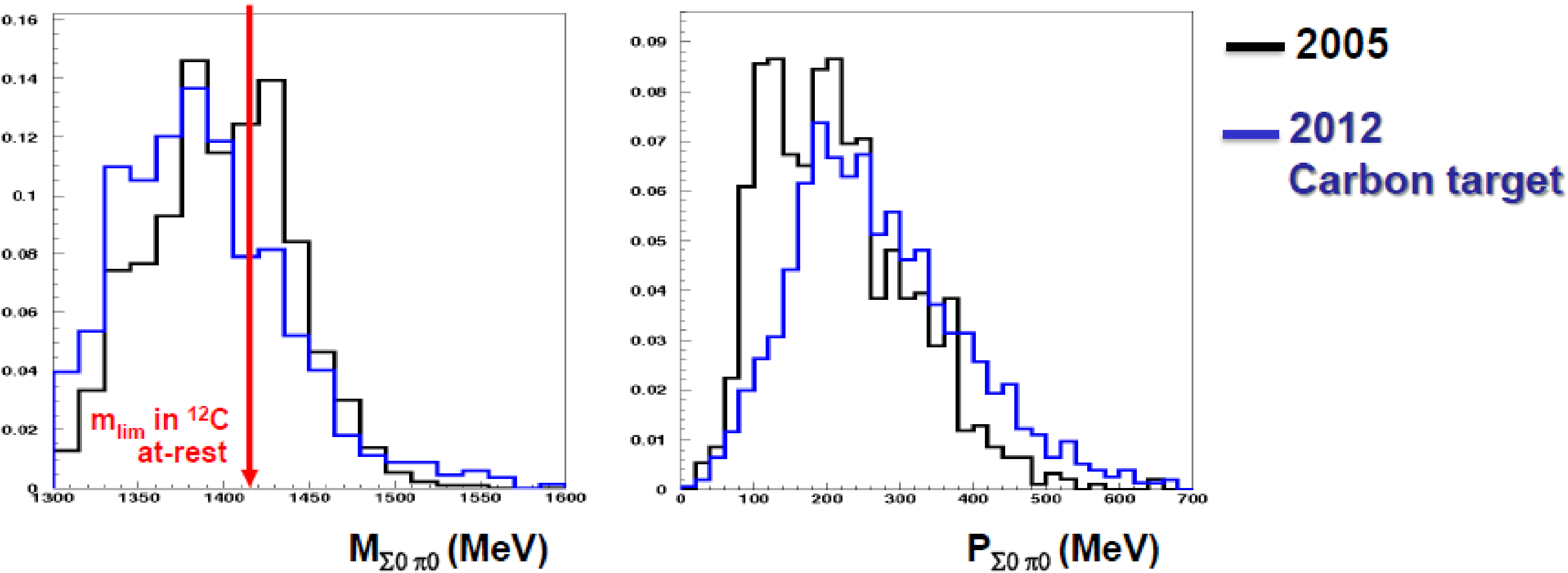


Analysis of $\Sigma^0\pi^0$ channel

$\Lambda(1405)$ 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-)



$m_{\pi0\Sigma0}$ resolution $\sigma_m \approx 32$ MeV/c^2 ; **$p_{\pi0\Sigma0}$ resolution:** $\sigma_p \approx 20$ MeV/c.

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

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)**

DAFNE represents an unique opportunity to unveil the secrets of the kaon-nucleon/nuclei interaction at low energy and of the "Strangeness role in the Universe"

Achievements and Perspectives in Low-Energy QCD with Strangeness

27 October - 31 October 2014

Infos at:

http://www.ectstar.eu/node/791