Dalle particelle alle stelle: il ruolo della stranezza nell'Universo? Studio dell'interazione dei kaoni con la materia nucleare

Catalina Curceanu
LNF – INFN, Frascati

INFN2014, Padova 24-26 Marzo 2014

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)

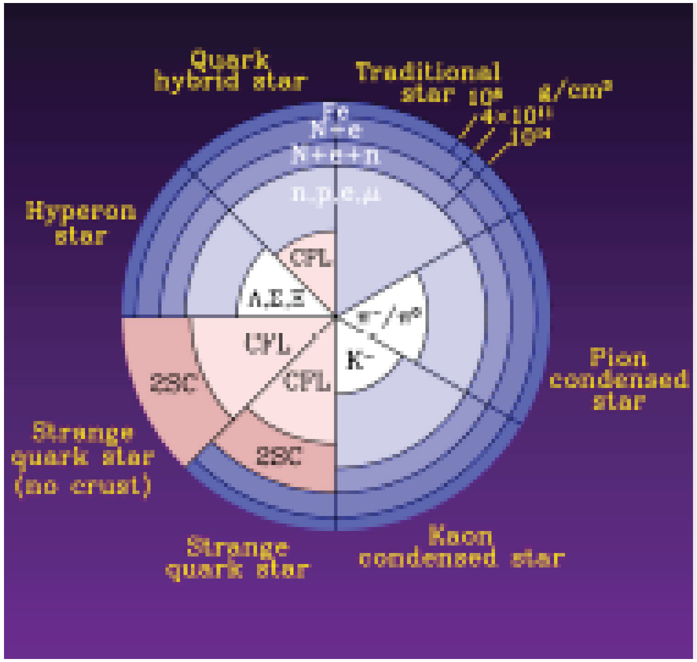
Excellent testing ground for studying interplay between **spontaneous** and **explicit chiral symmetry breaking** in low-energy QCD

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**



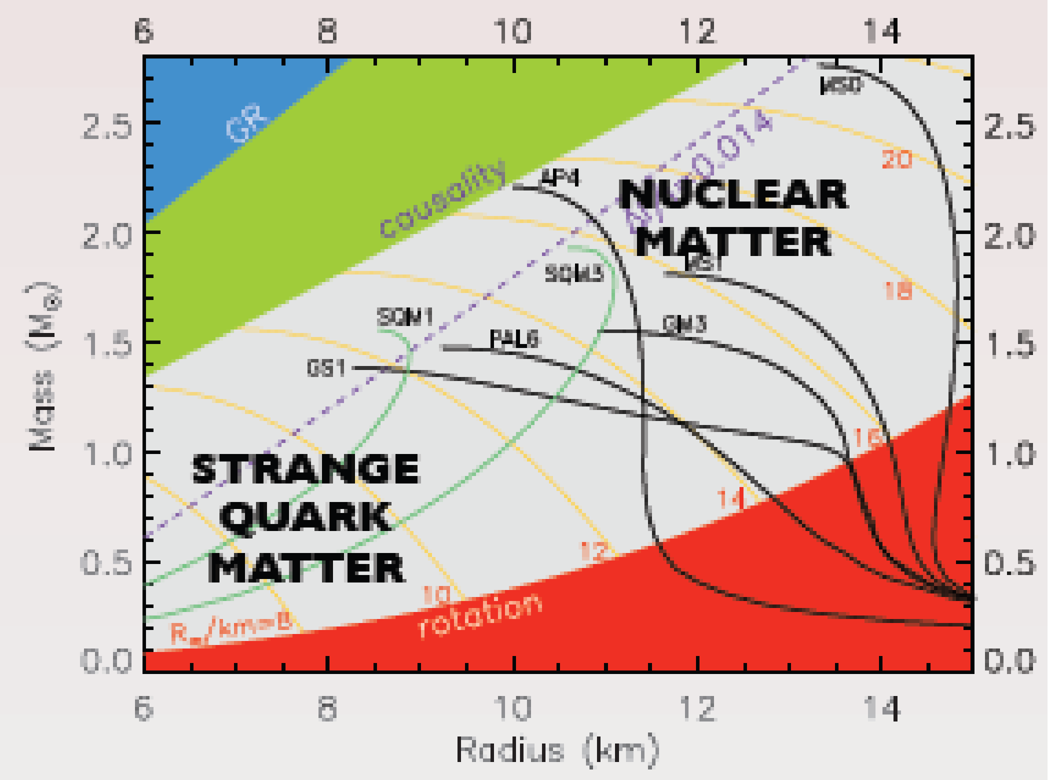
NEUTRON STARS and the EQUATION OF STATE of DENSE BARYONIC MATTER

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

- Neutron Star Scenarios
- Mass-Radius Relation

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

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

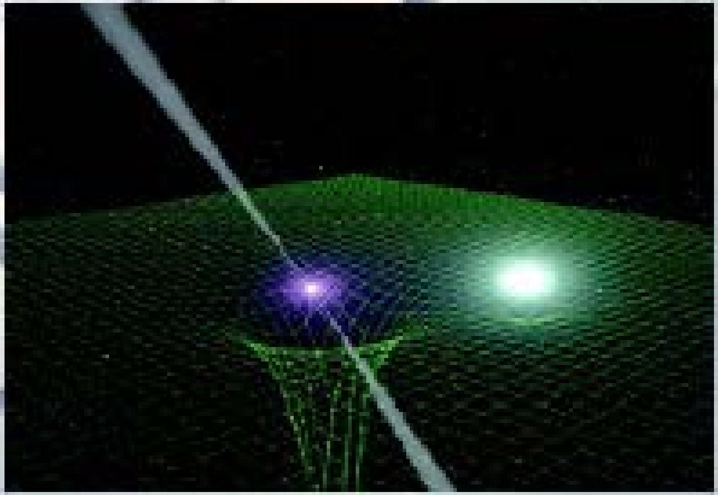


Low-Energy QCD with Strange Quarks

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 **$\bar{K}N$ 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

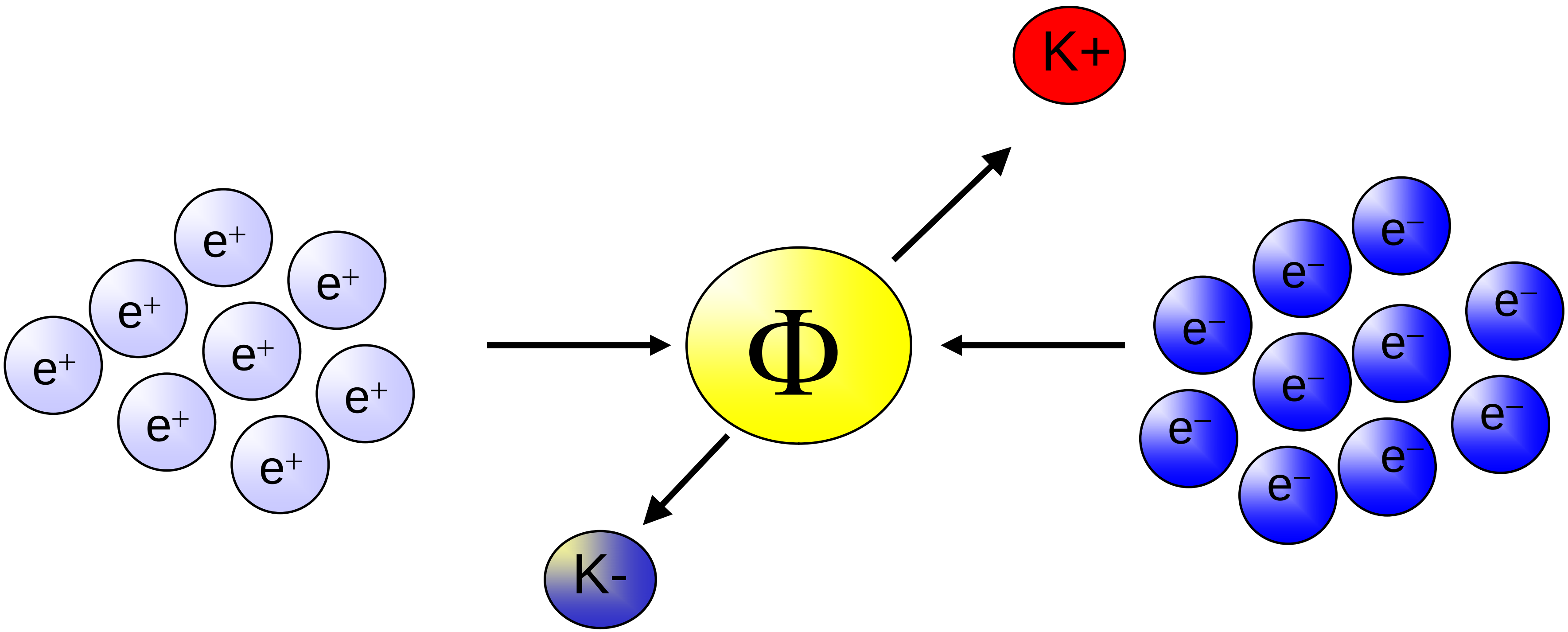
- $\Sigma\pi$ mass spectra

- 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*

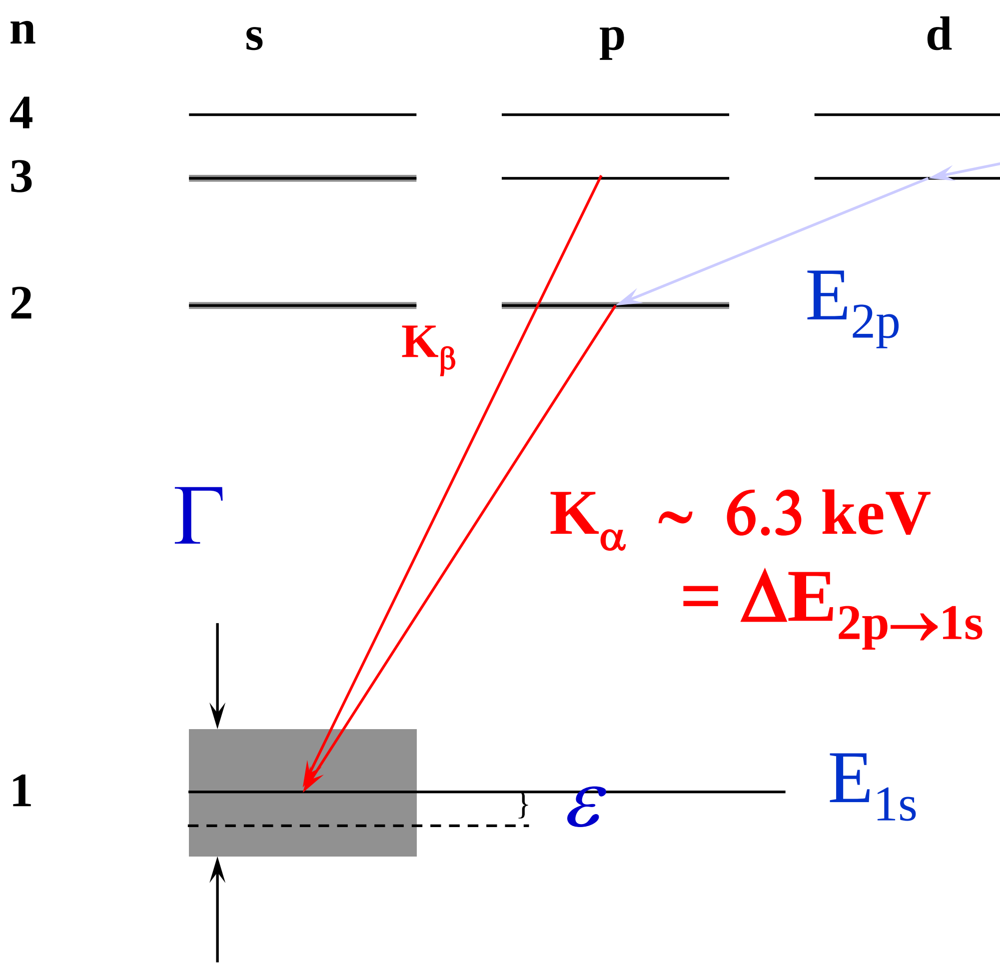
of the K_α line of **kaonic hydrogen**

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):

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

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

one can obtain the isospin dependent antikaon-nucleon scattering lengths

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

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

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.

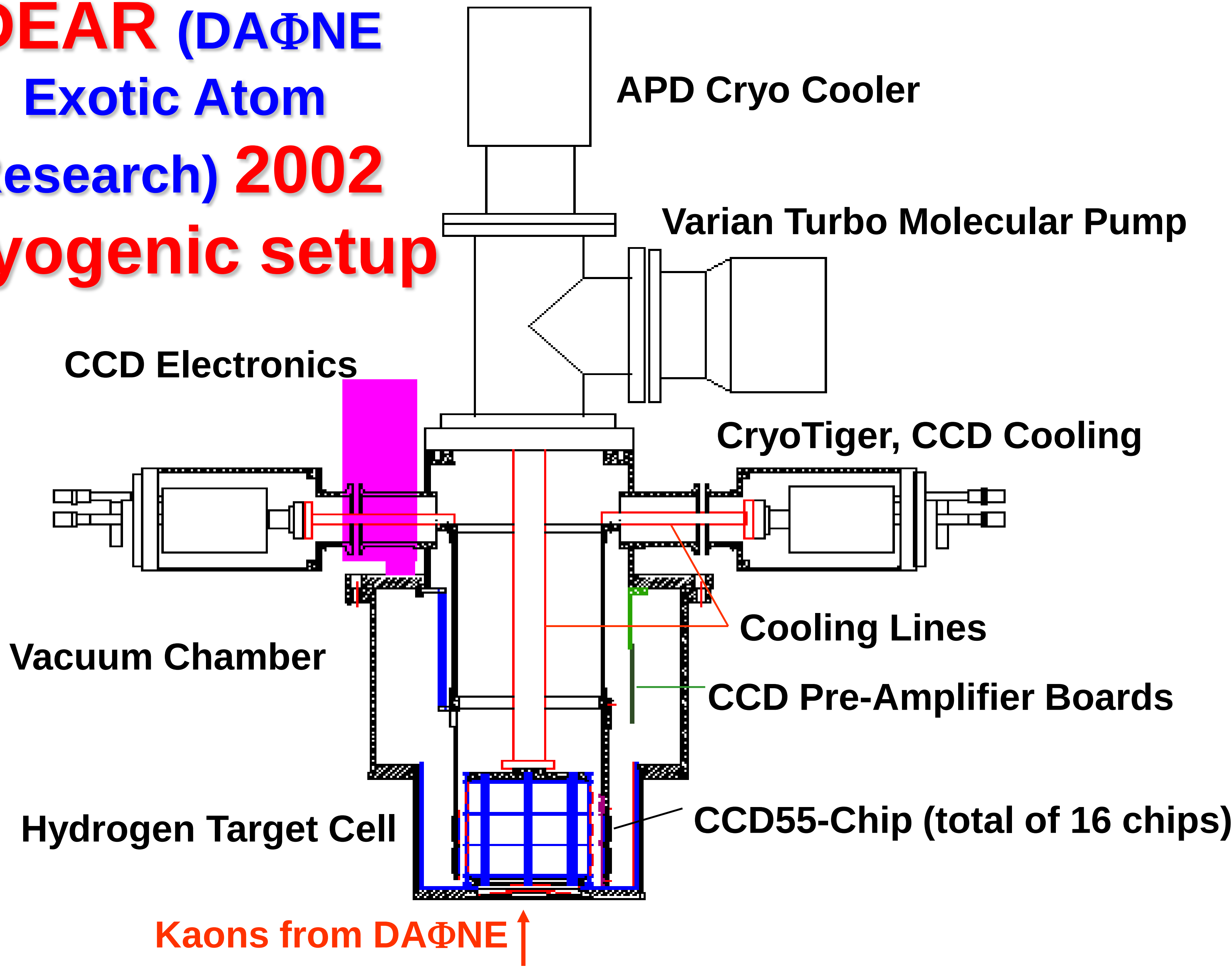
1. **Breakthrough in the *low-energy $\bar{K}N$ phenomenology*;**
2. **Threshold amplitude in QCD**
3. **Study of the Λ(1405)**
4. **Contribute to the determination of the *KN sigma terms*, which give the degree of chiral symmetry breaking;**
5. **4 related alado with the determination of the *strangeness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

Performances obtained in 2002 in the DEAR I.P.

- Number of bunches per beam 95 + 95
- Total current per beam e-/e+ (A) ˜ 1.3/1
- Peak luminosity($cm^{-2} s^{-1}$) 0.7×10^{32}
- Average luminosity ($cm^{-2} s^{-1}$) ˜ 2×10^{31}
- Integrated luminosity per day (pb^{-1}) 2.2 (best)
- Luminosity lifetime (h) ˜ 0.6
- Number of fillings per hour ˜ 1.7
- Injection frequency e-/e+ (Hz) 2/1
- Data acquisition during injection off

Total integrated luminosity in 2002 about 70 pb^{-1}

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);

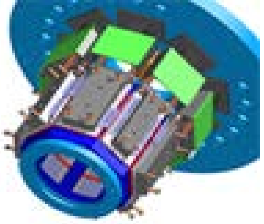
-Kaonic Hydrogen:

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

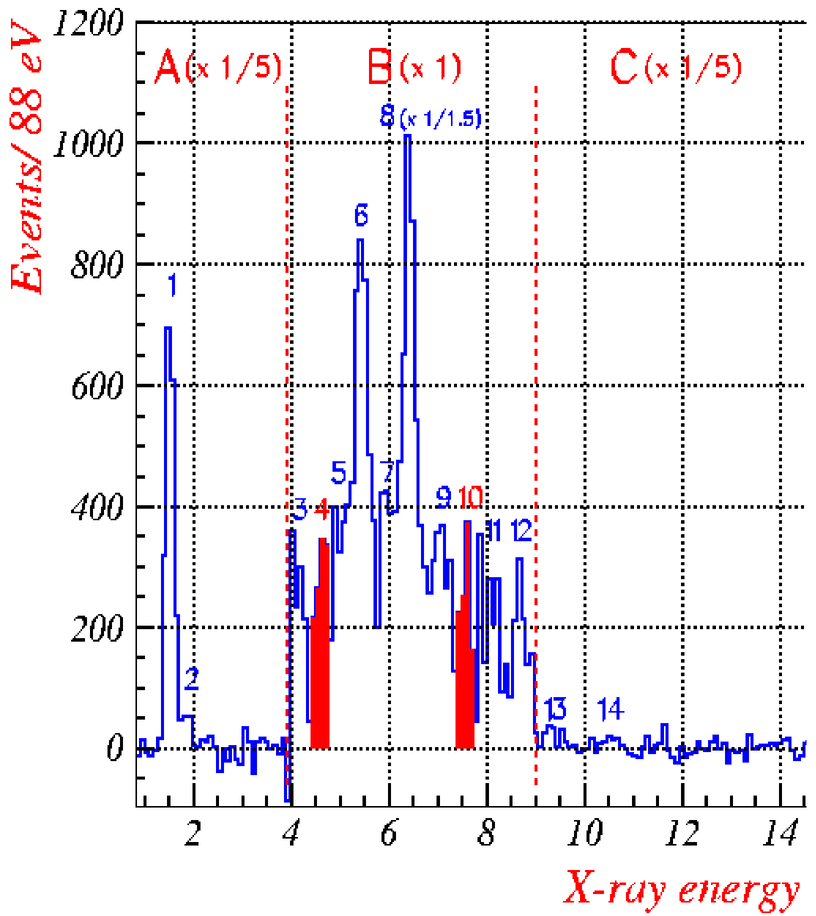
-Background data (no collisions) for KH:

16 – 23 December

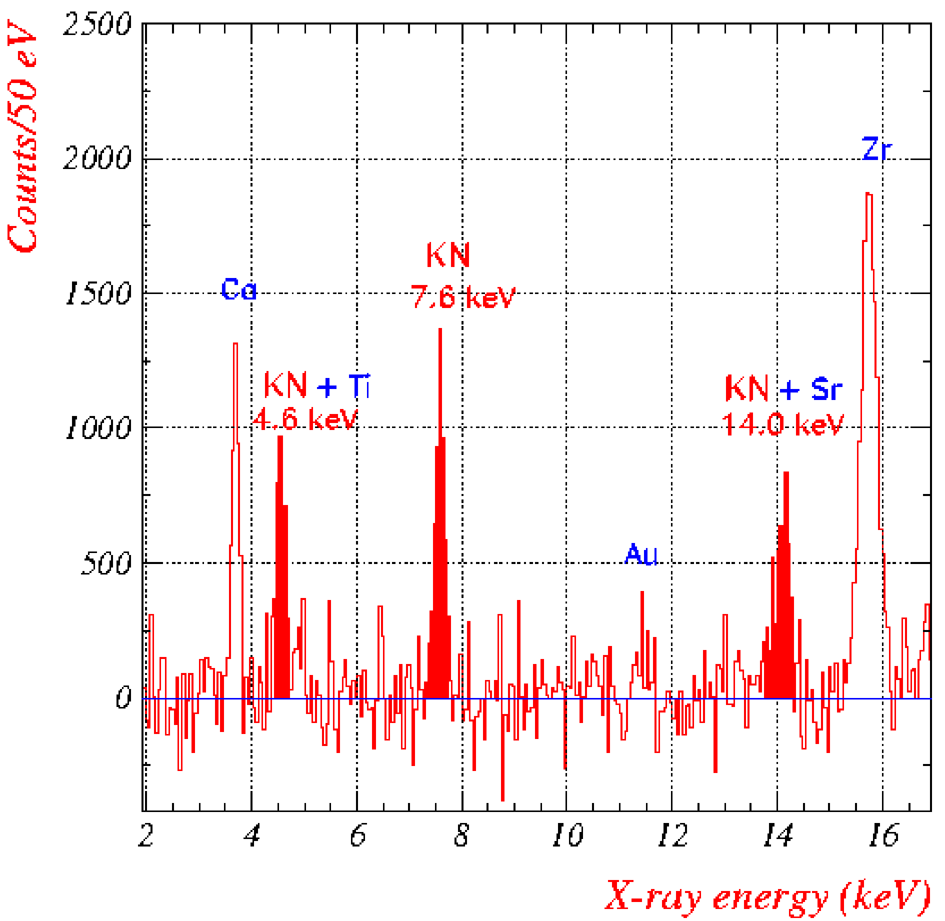
Kaonic Nitrogen



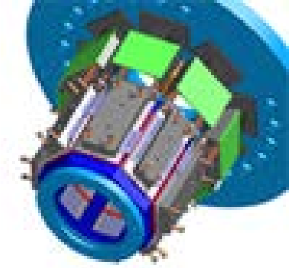
Kaonic Nitrogen, 2001, ~ 3 pb^{-1}
Background subtracted spectrum



Kaonic Nitrogen, 10 pb^{-1} (October 2002)
Background subtracted spectrum



Kaonic Nitrogen Physics



- ***First determination*** **of the yield of 3 Kaonic Nitrogen X-ray transitions:**

7 → 6 (41.5 +/- 7.4 +/- 4.1)%
6 → 5 (55.0 +/- 3.9 +/- 5.5)%
5 → 4 (57.4 +/- 15.2 +/- 5.7)%

stimulated activity in the the field of atomic **cascade** ***for exotic atoms***

- ***Mass of the kaon*** – **as a test measurement:**
- **m_{K^-} = 493.884 +/- 0.314 MeV**

(Ph. D. thesis, Tomo Ishiwatari, Phys. Lett. B593 (1-4), (2004), pag. 48.)

October – December 2002 DAQ

Collected data:

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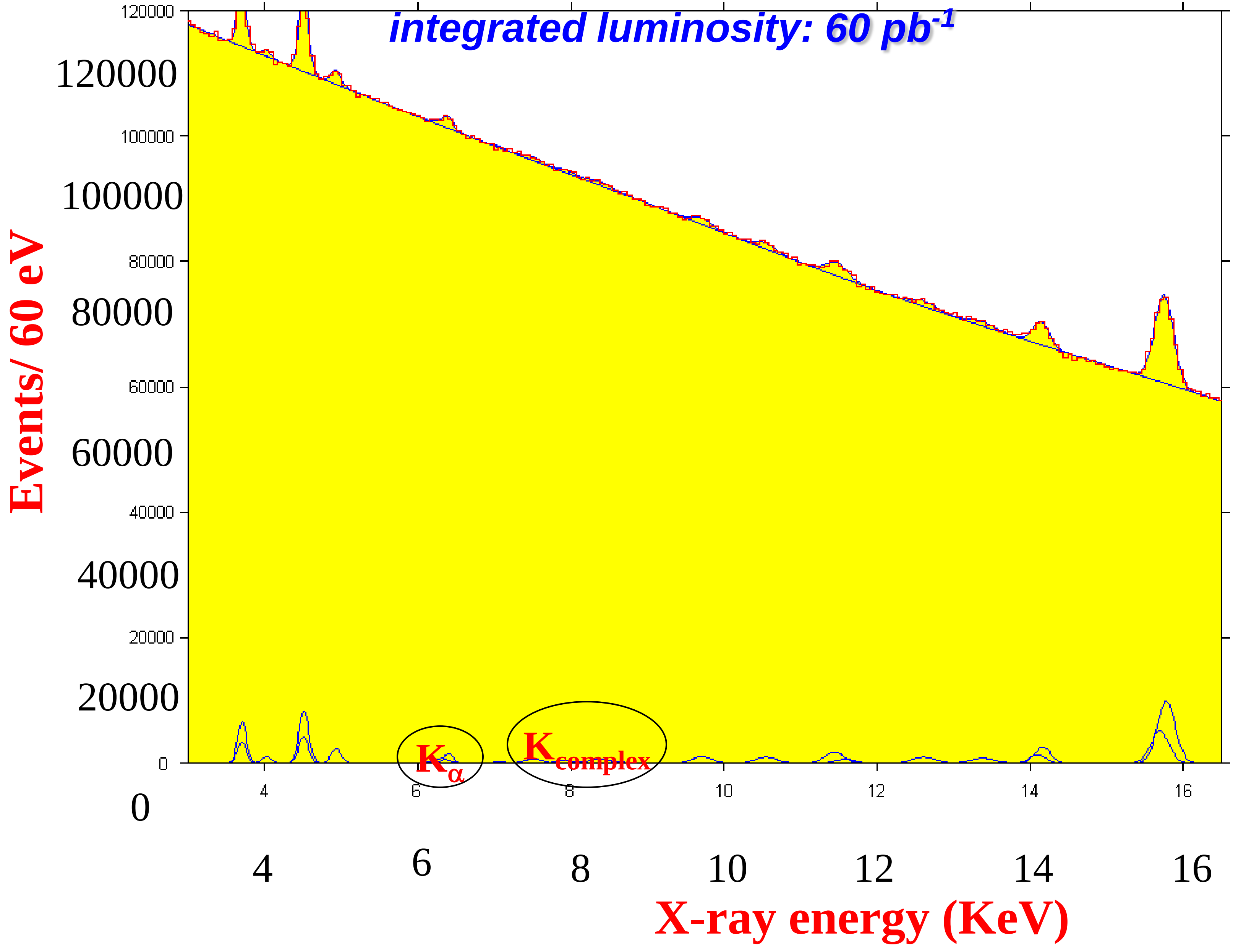
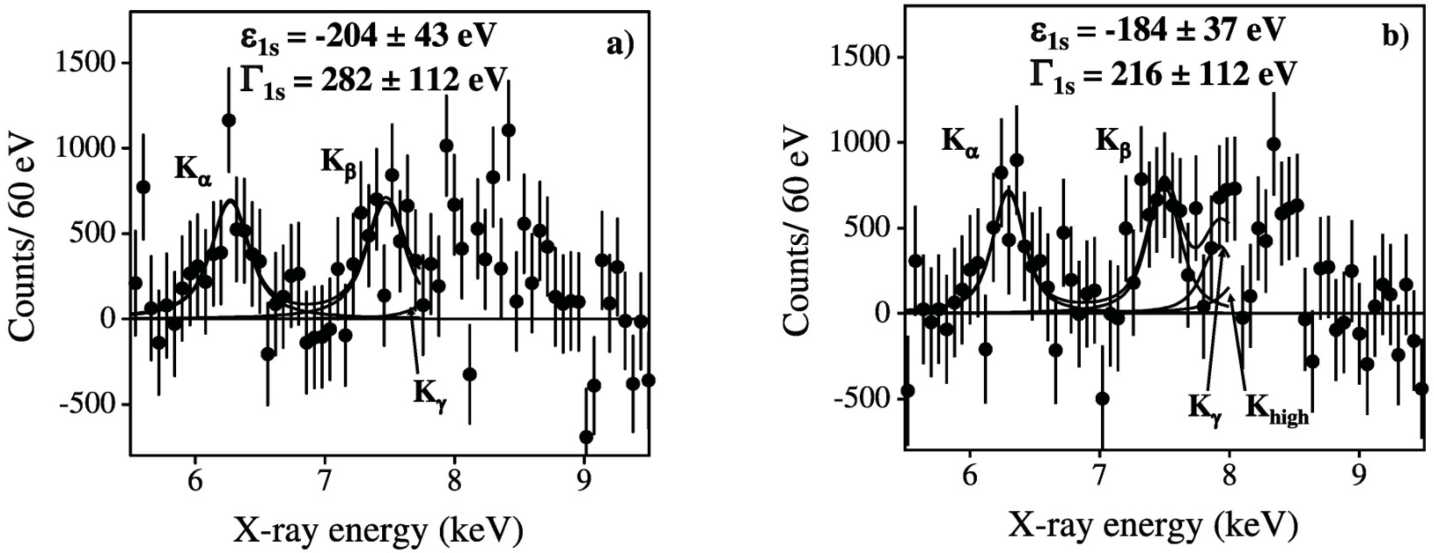
Kaonic Hydrogen (2002 data)- global fit



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.

Technische Universität München

DEAR Results on the Shift and Width

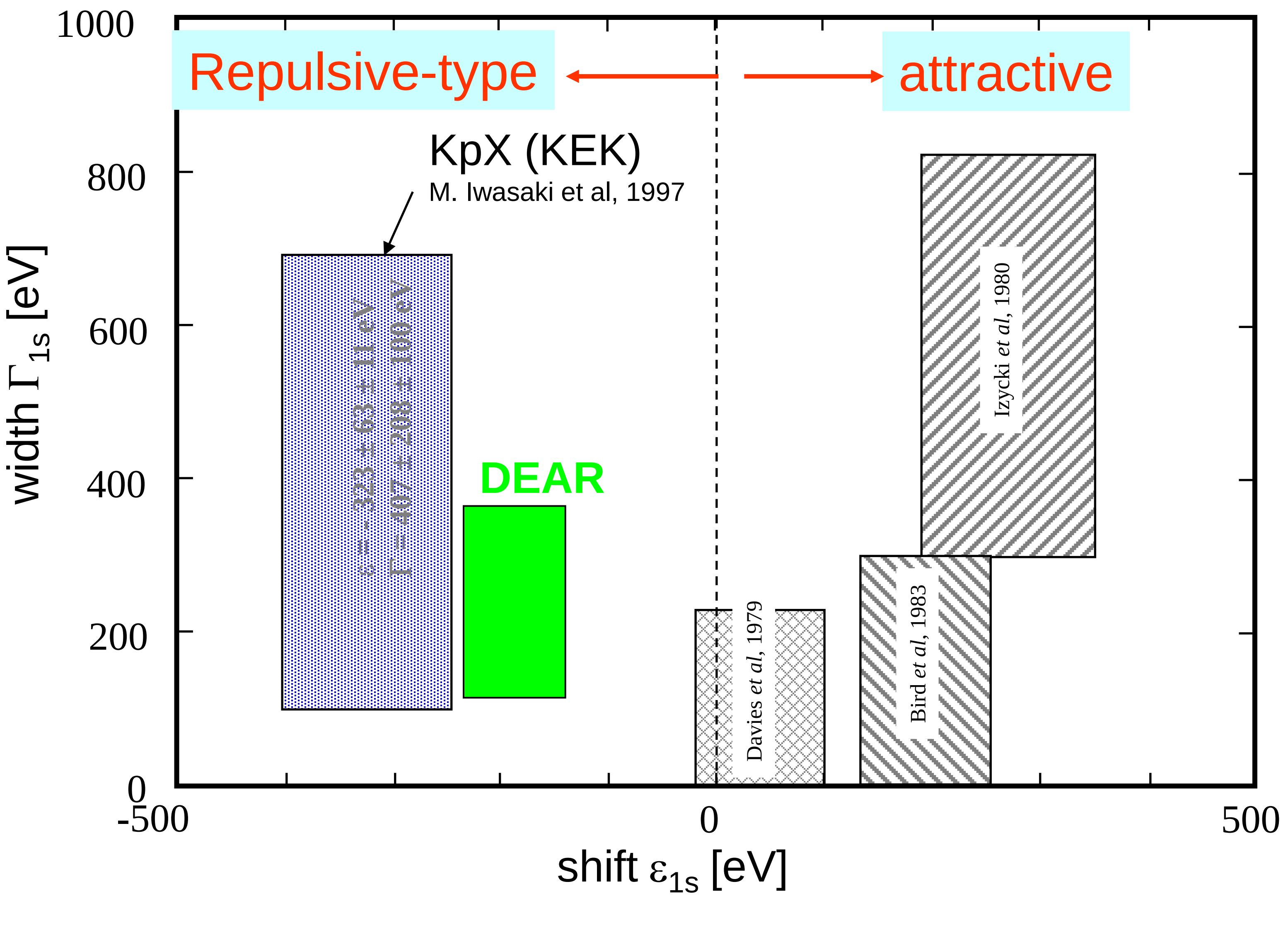
2 independent analyses starting from the raw data giving consistent results

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

Shift: ε_{1s} = - 193 ± 37 (stat.) ± 6 (syst.) eV

Width: Γ_{1s} = 249 ± 111 (stat.) ± 30 (syst.) eV

DEAR Results on kaonic hydrogen



SIDDHARTA principal goal:

- ✓ **Improve the precision of the measurement of *kaonic hydrogen* 1s level shift and width;**
- ✓ **Perform the first measurement of *kaonic deuterium***

This will allow to determine the isospin dependent antikaon nucleon scattering lengths at percent level precision

=> Achieved by improving drastically the S/B ratio, while keeping the excellent DEAR energy resolution

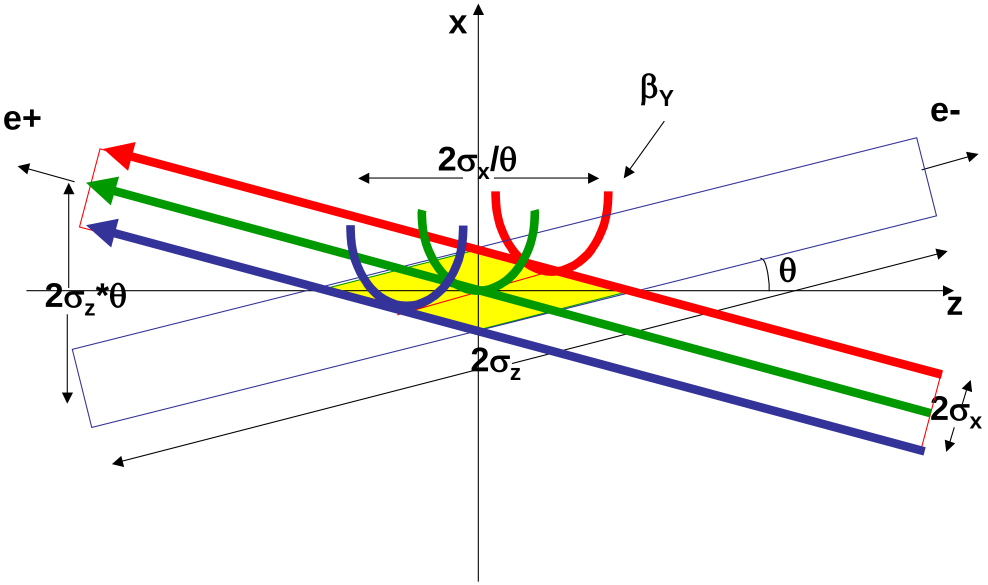
DAFNE UPGRADE

Crabbed Waist in 3 Steps

1. Large Piwinski's angle $\Phi = tg(\theta)\sigma_z/\sigma_x$

2. Vertical beta comparable with overlap area $\beta_y \approx \sigma_x/\theta$

3. Crabbed waist transformation $y = xy'/(2\theta)$



P. Raimondi,
November 2005

Crabbed waist is realized with a sextupole in phase with the IP in X and at $\pi/2$ in Y

Crabbed Waist Advantages

1. Large Piwinski's angle

$$\Phi = tg(\theta)\sigma_z/\sigma_x$$

a) Geometric luminosity gain

b) Very low horizontal tune shift

2. Vertical beta comparable with overlap area

$$\beta_y \approx \sigma_x/\theta$$

a) Geometric luminosity gain

b) Lower vertical tune shift

c) Vertical tune shift decreases with oscillation amplitude

d) Suppression of vertical synchro-betatron resonances

3. Crabbed waist transformation

$$y = xy'/(2\theta)$$

a) Geometric luminosity gain

b) Suppression of X-Y betatron and synchro-betatron resonances

SIDDHARTA

SIlicon Drift Detector for Hadronic Atom Research by Timing Applications

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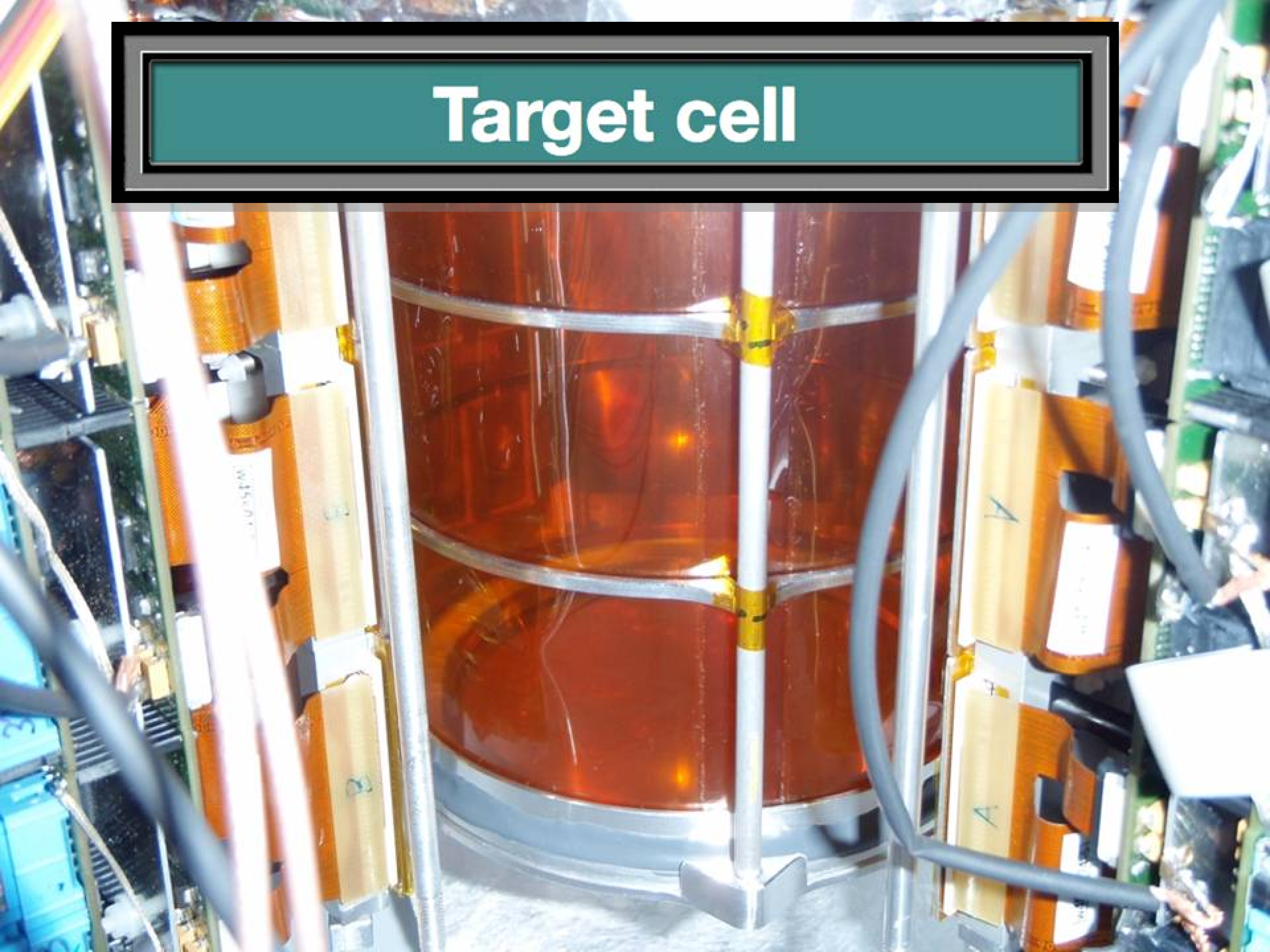
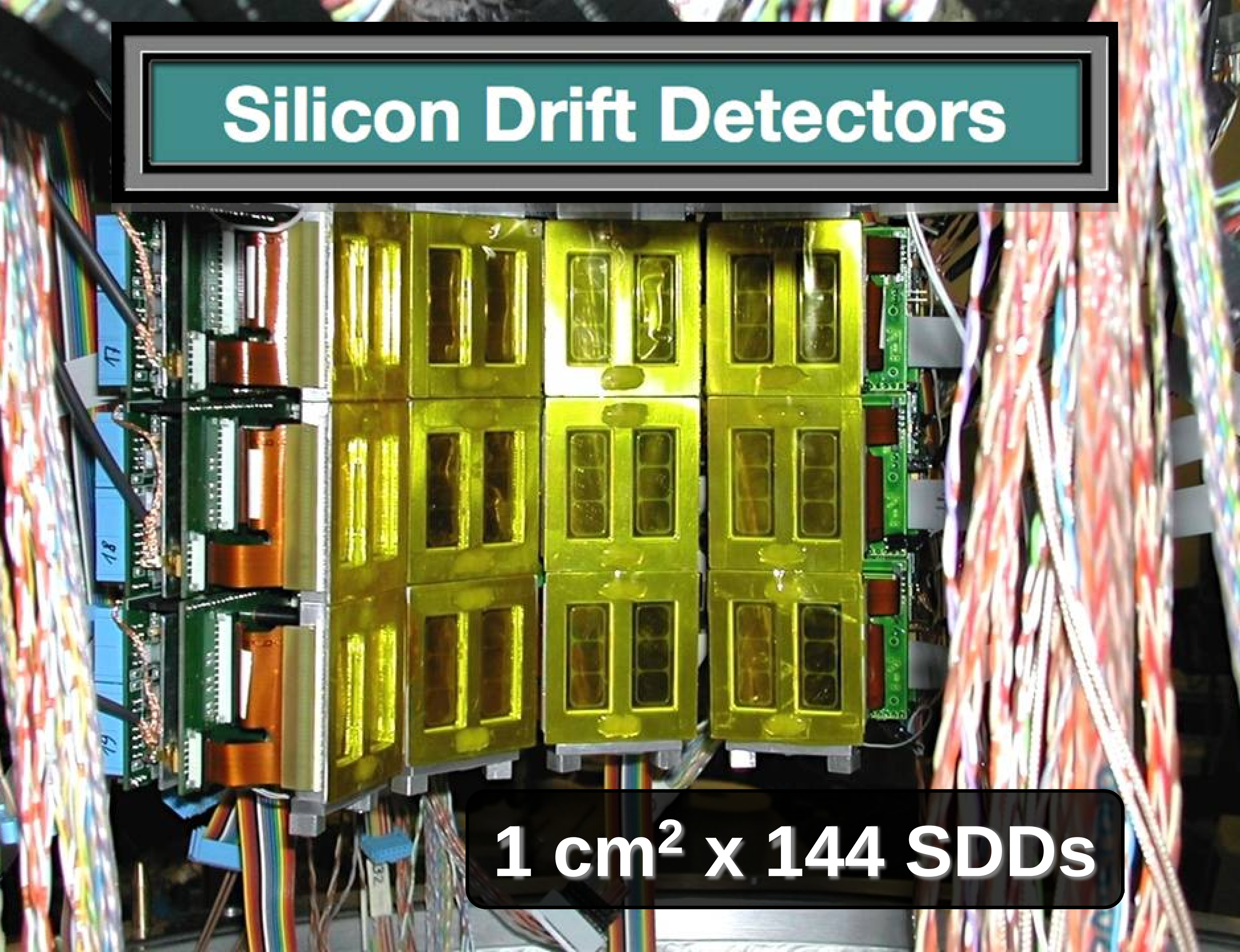
FP7- I3HP2

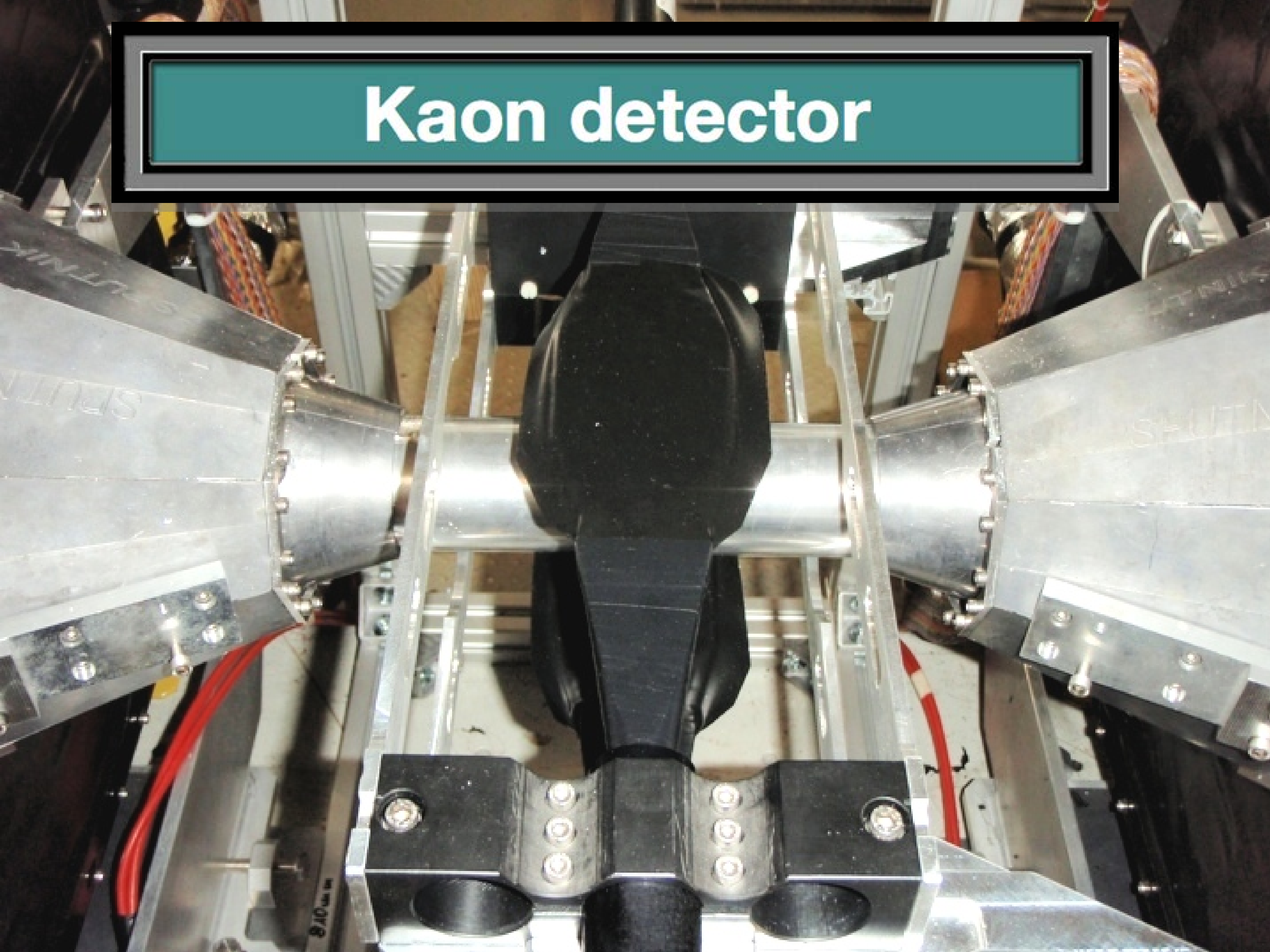
Target cell



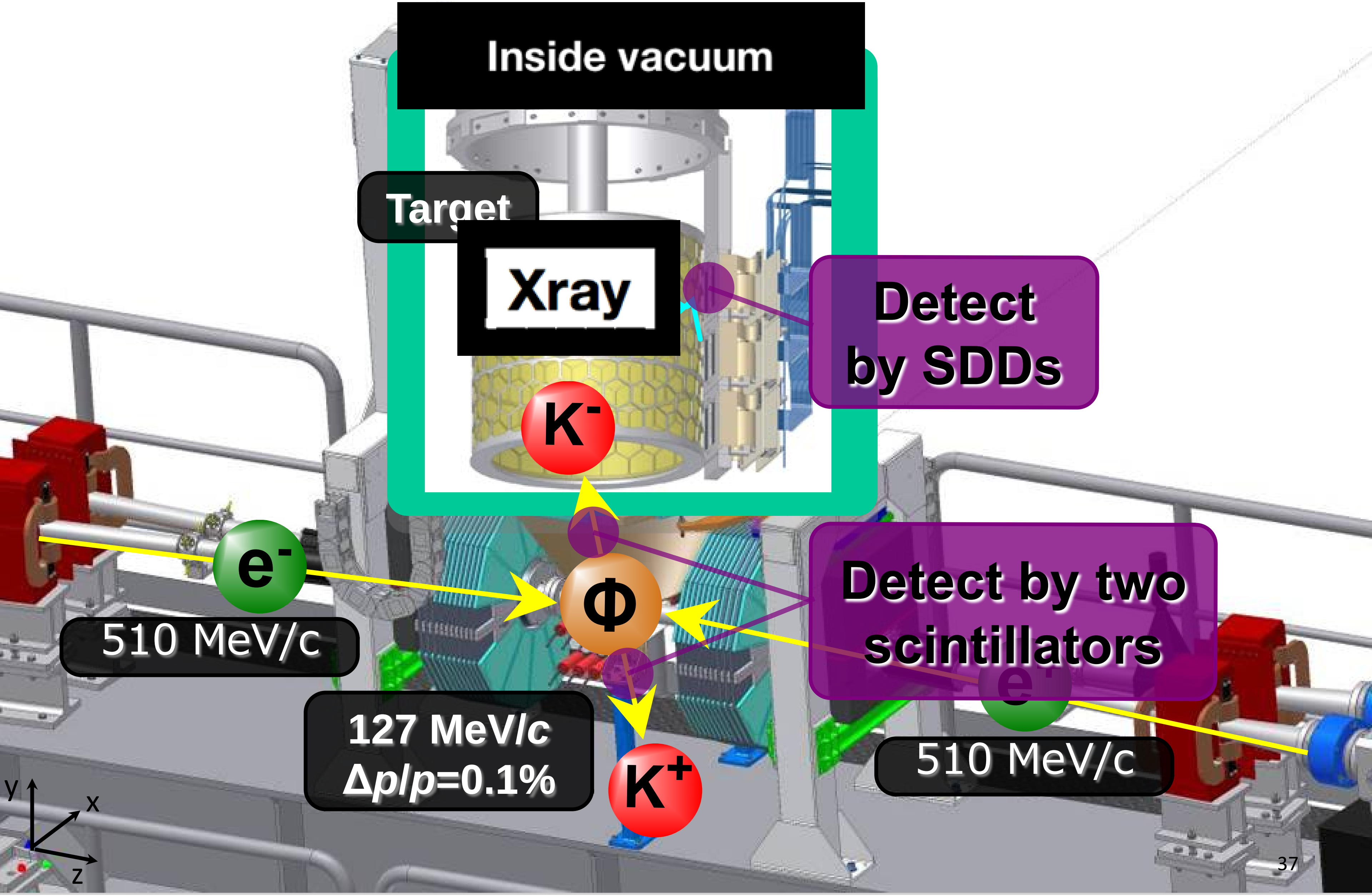
Silicon Drift Detectors

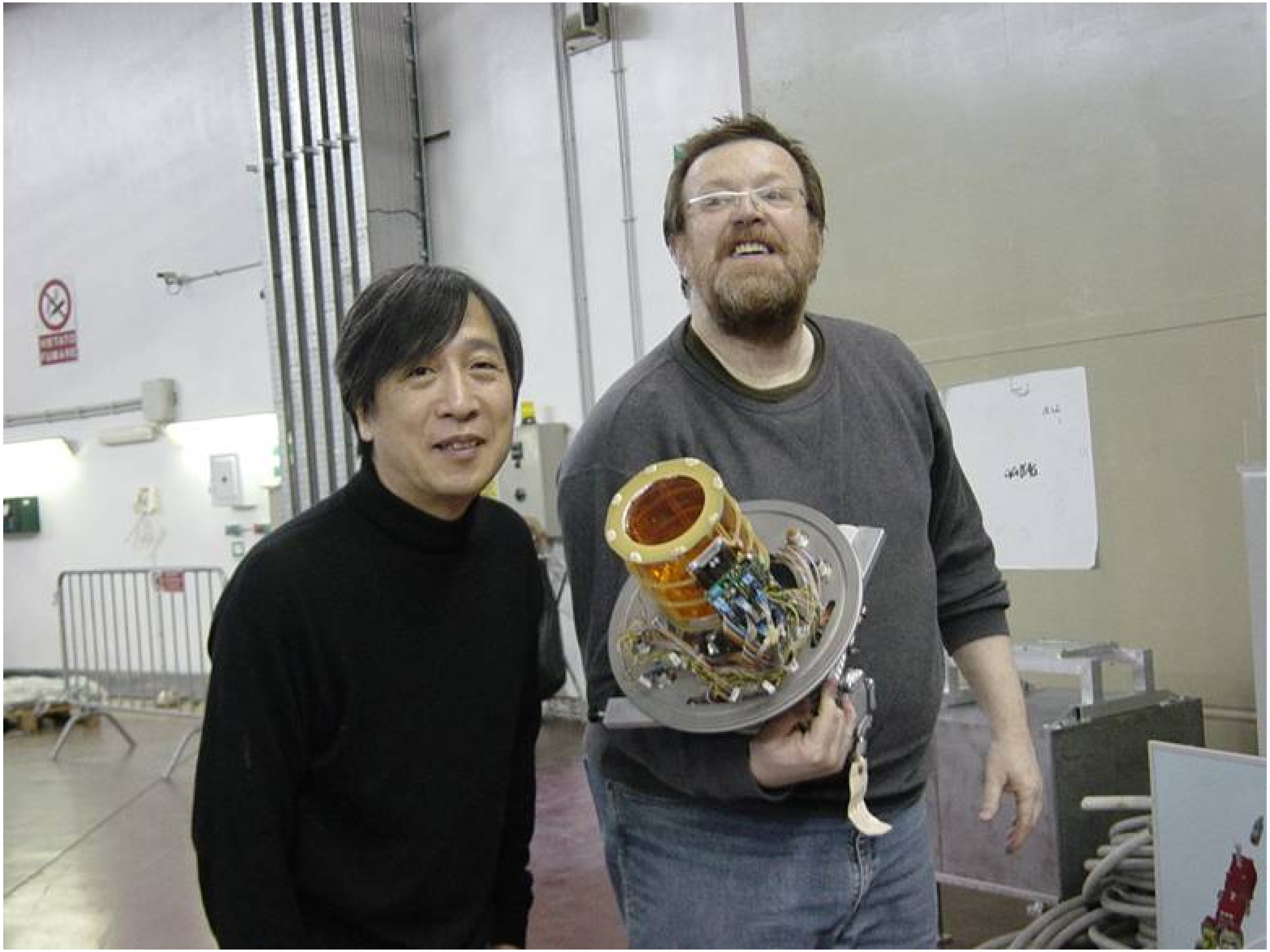


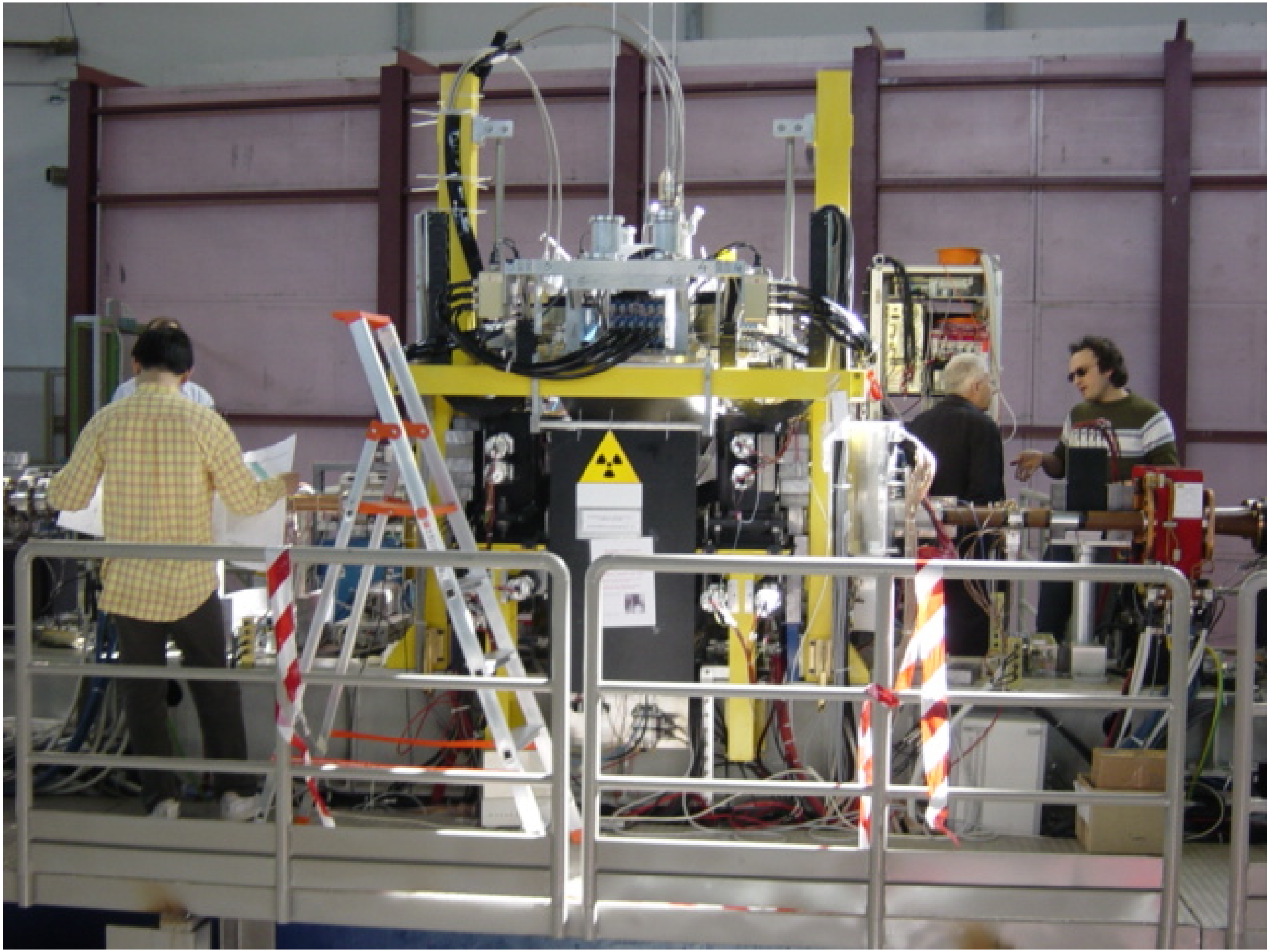
Kaon detector

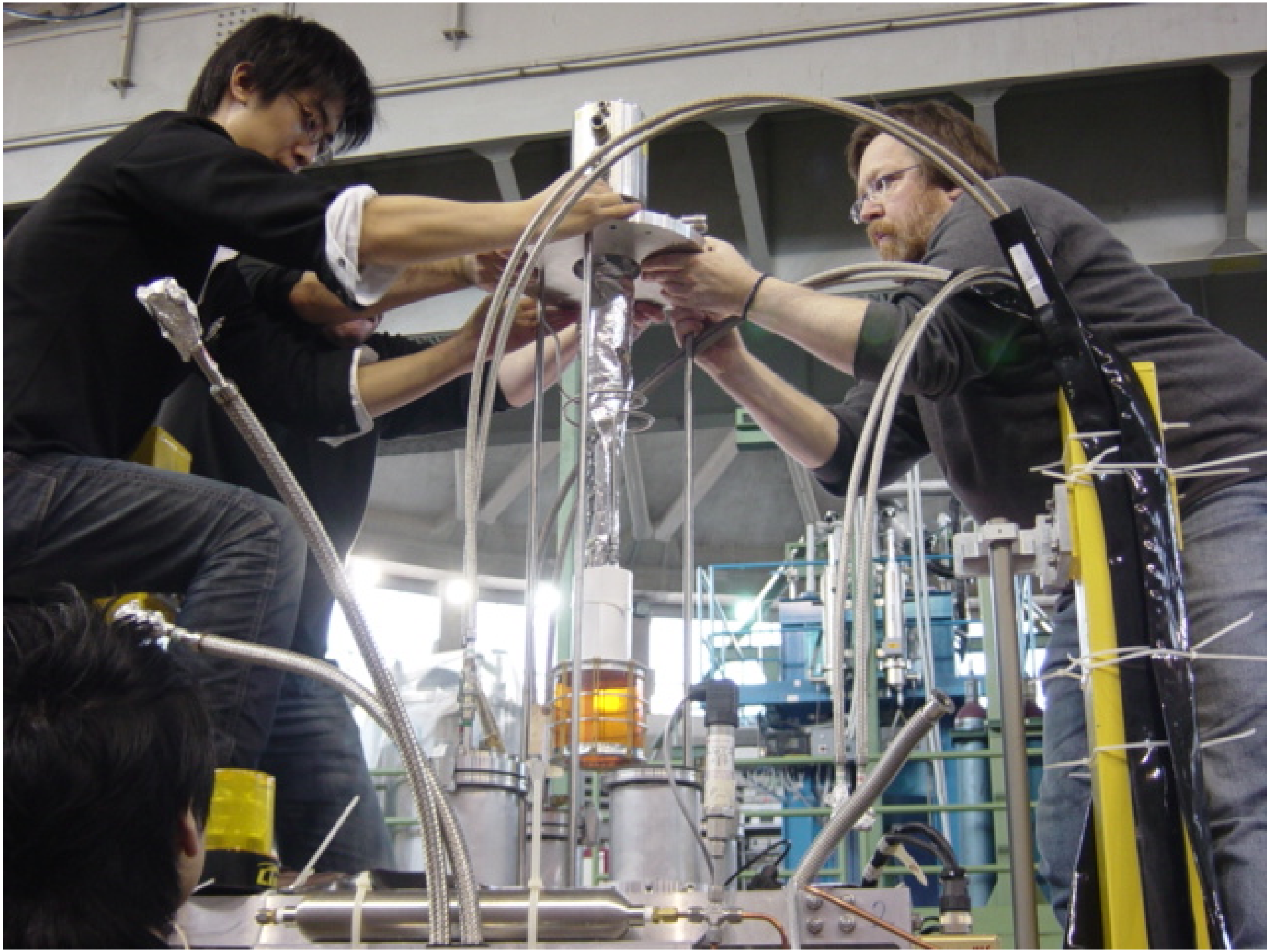


SIDDHARTA overview

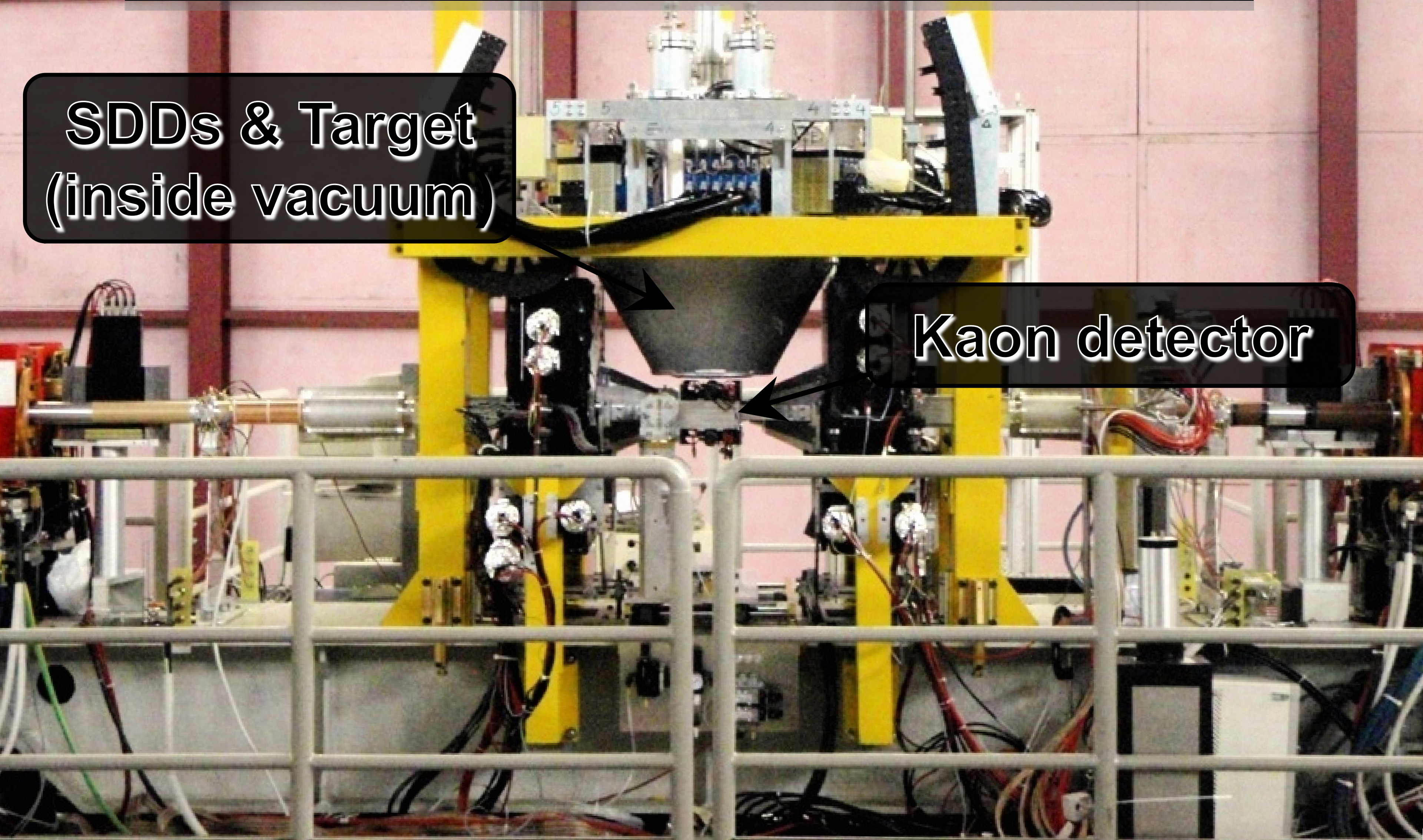


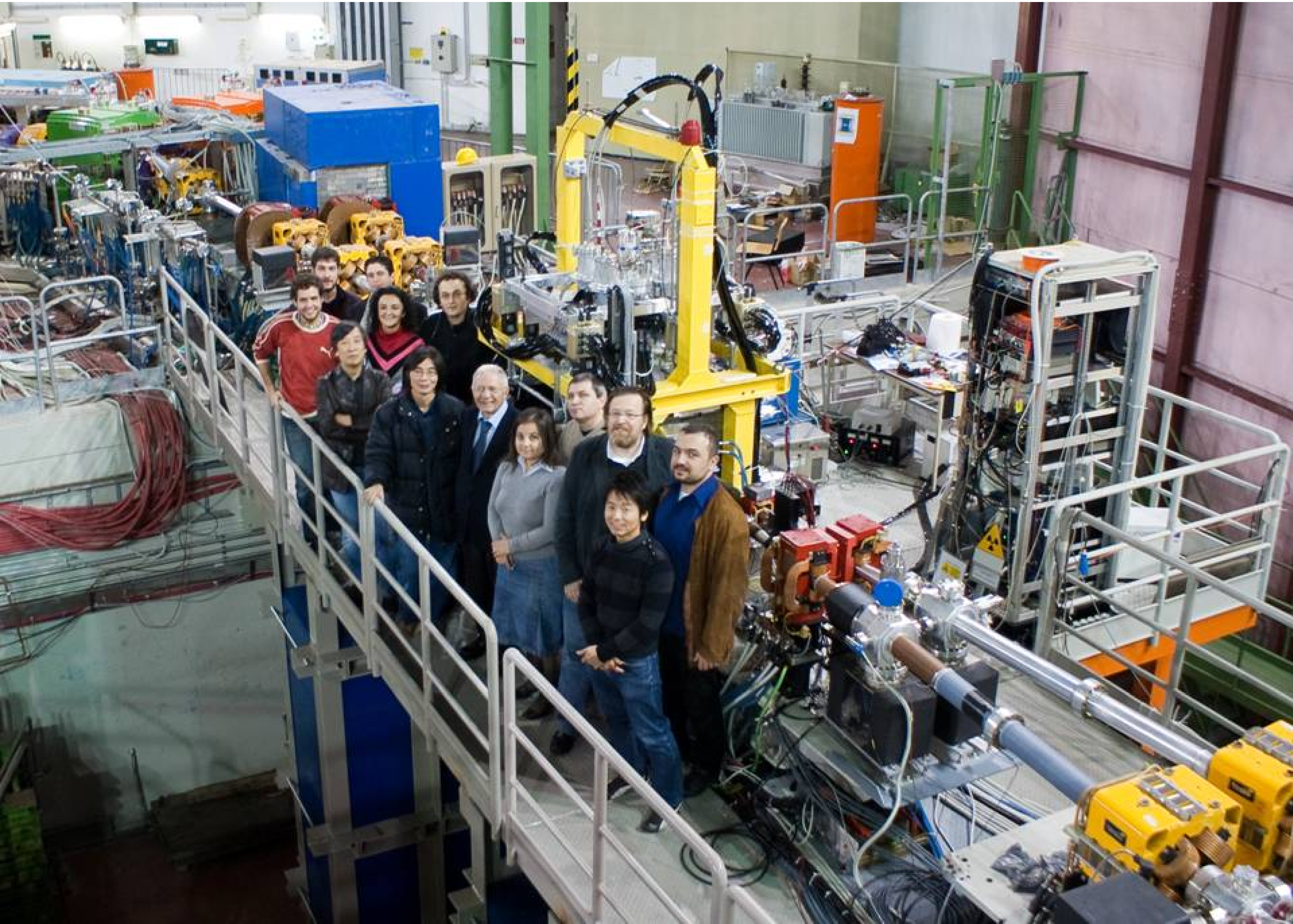




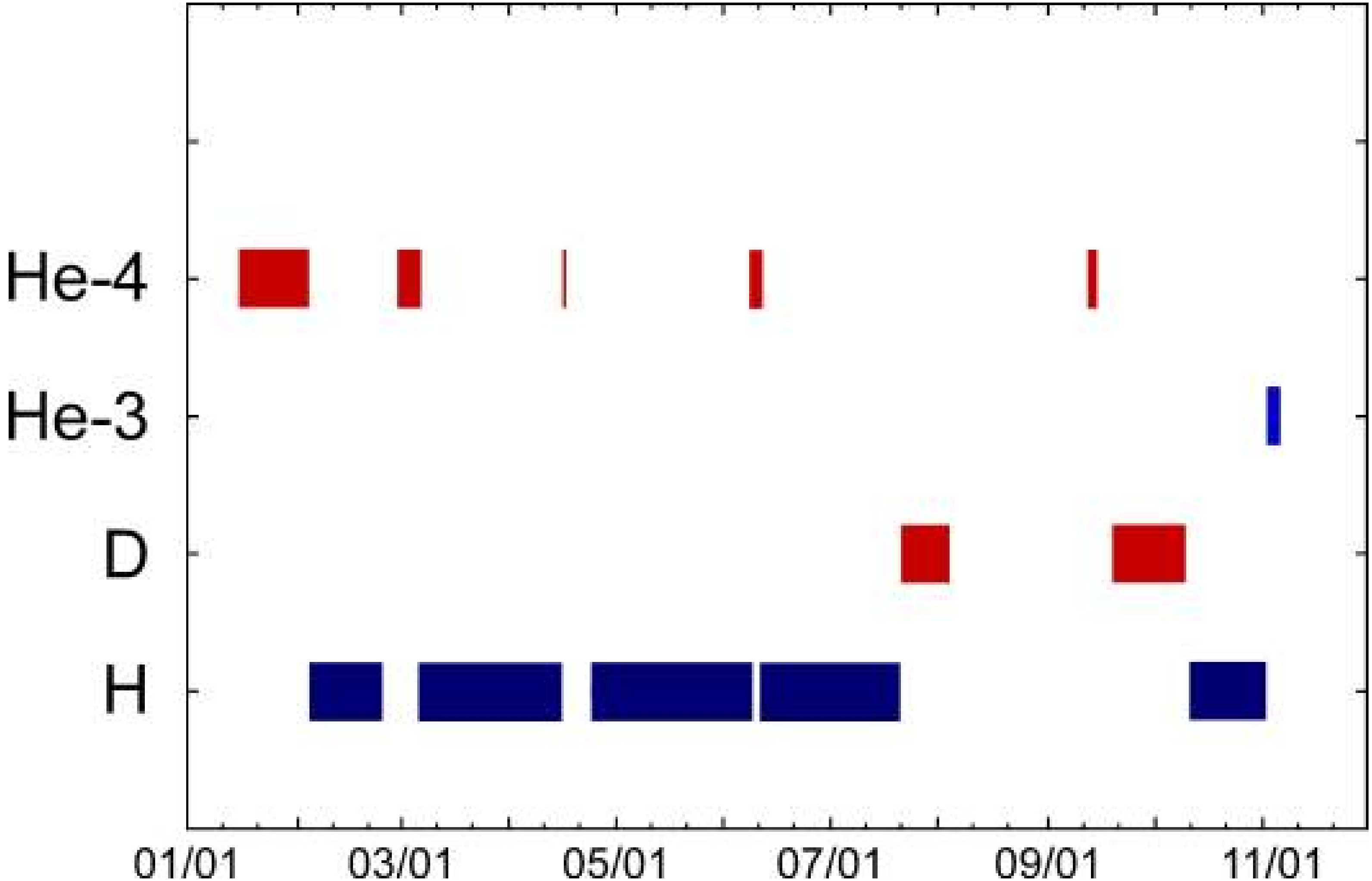


SIDDHARTA setup





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

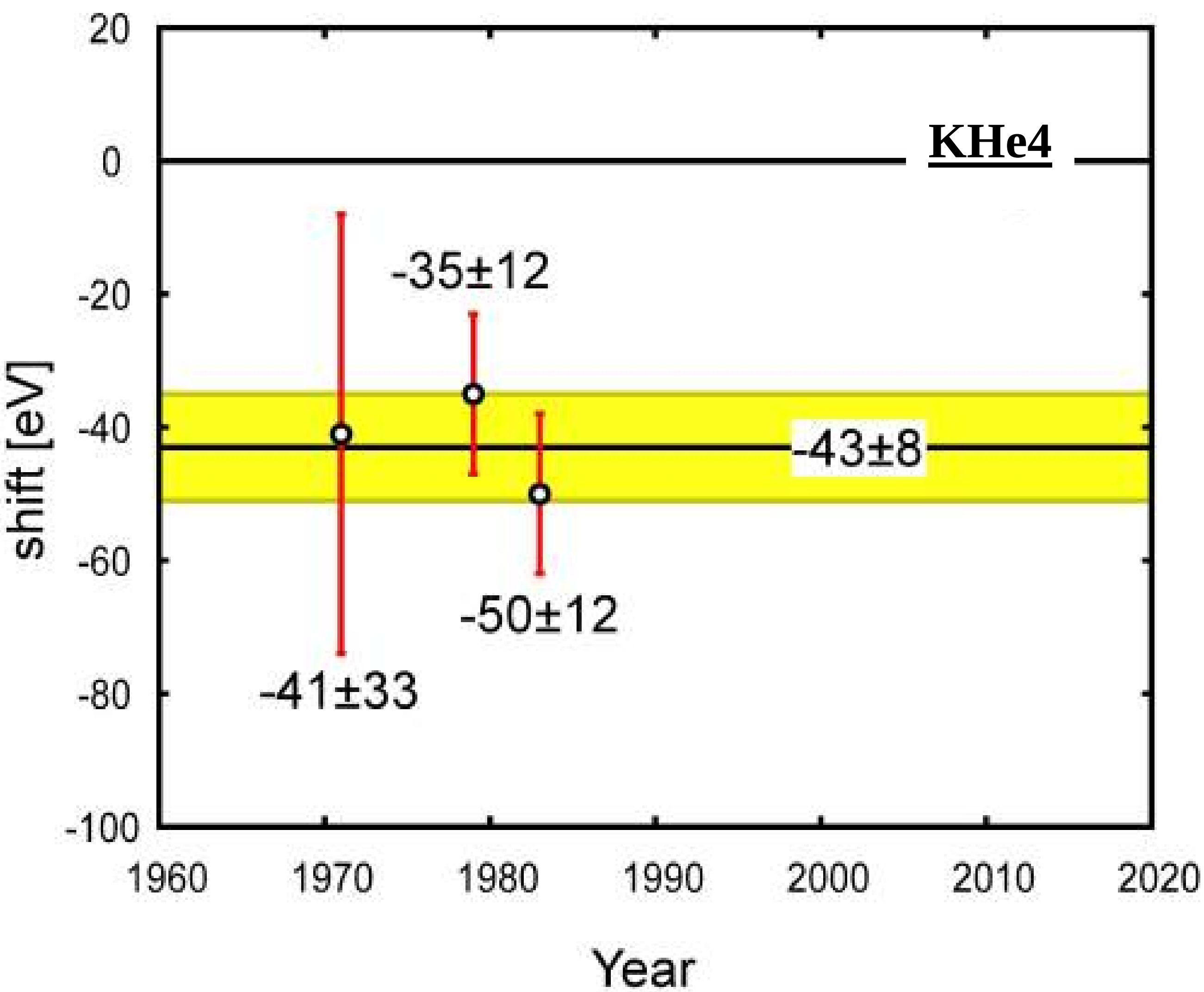
- Kaonic helium 3 – 10 pb^{-1}, first measurement in the world, published in Phys. Lett. B 697 (2011) 199; Ph D

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

SIDDHARTA – important TRAINING for young researchers

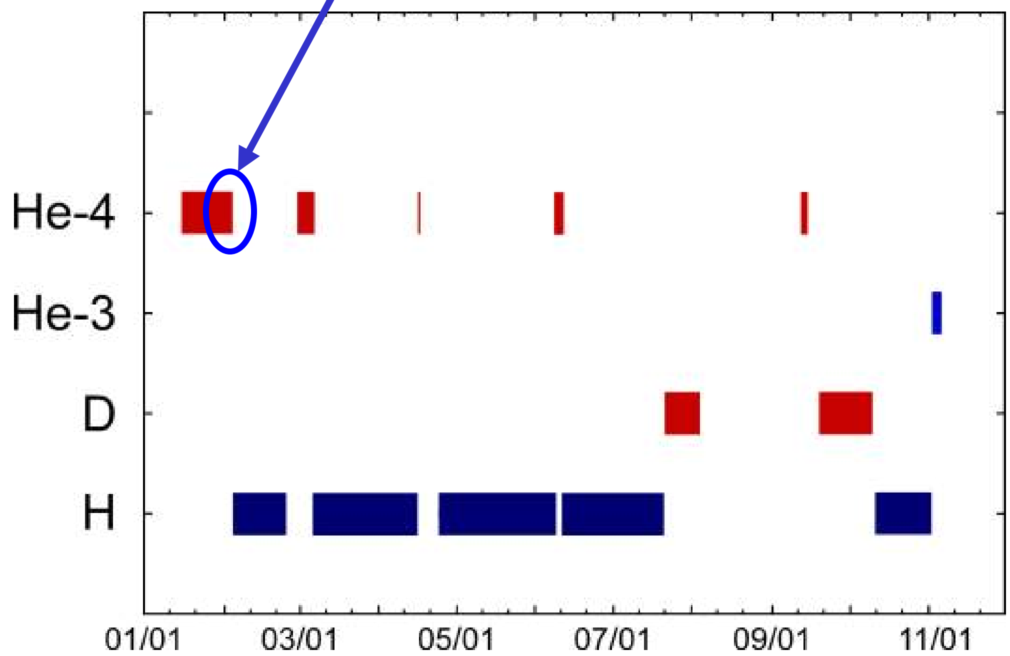
Kaonic Helium 3 and 4

Kaonic 4 old data

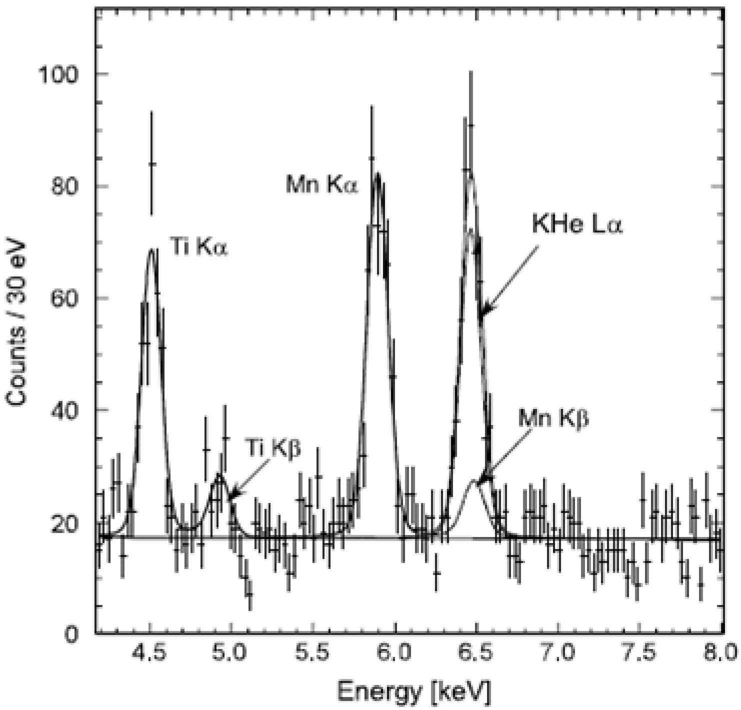


Data taking periods of SIDDHARTA in 2009

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

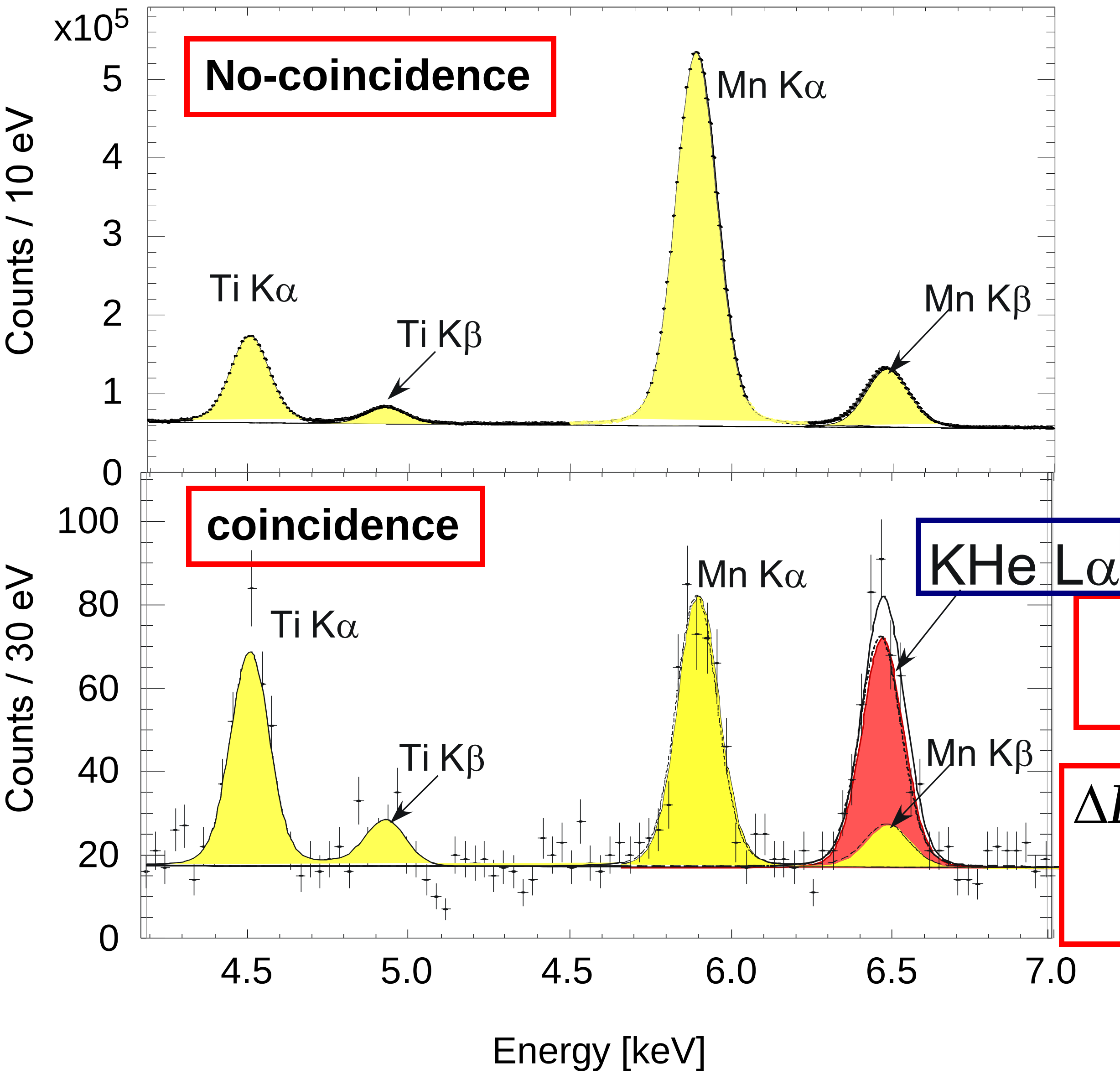
Removed ^{55}Fe source in other data

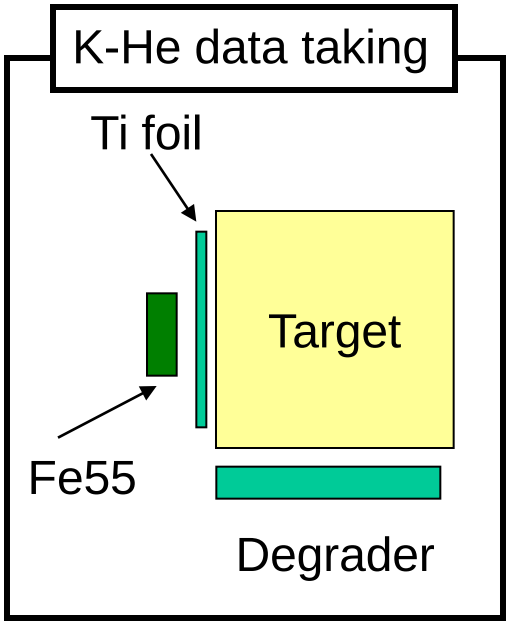
Use of
Mn Ka (5.9 keV) from ^{55}Fe

Systematic error = +/-2 eV

KHe-4 energy spectrum at SIDDHARTA

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





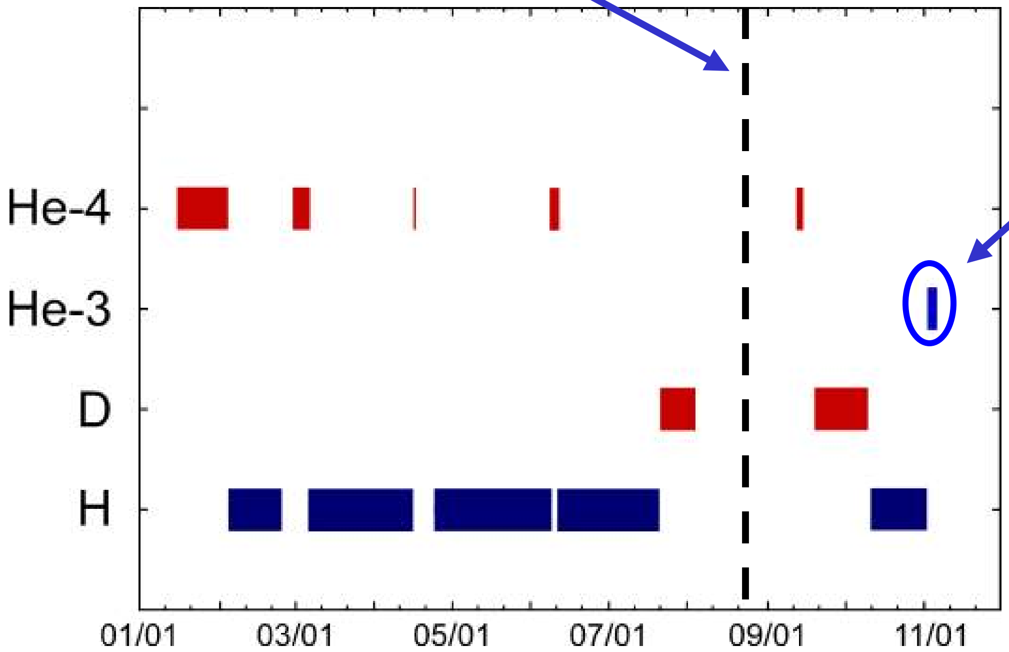
$$E_{\mathrm{exp}} = 6463.6 \pm 5.8\ \mathrm{eV},$$

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

Data taking periods of SIDDHARTA in 2009

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

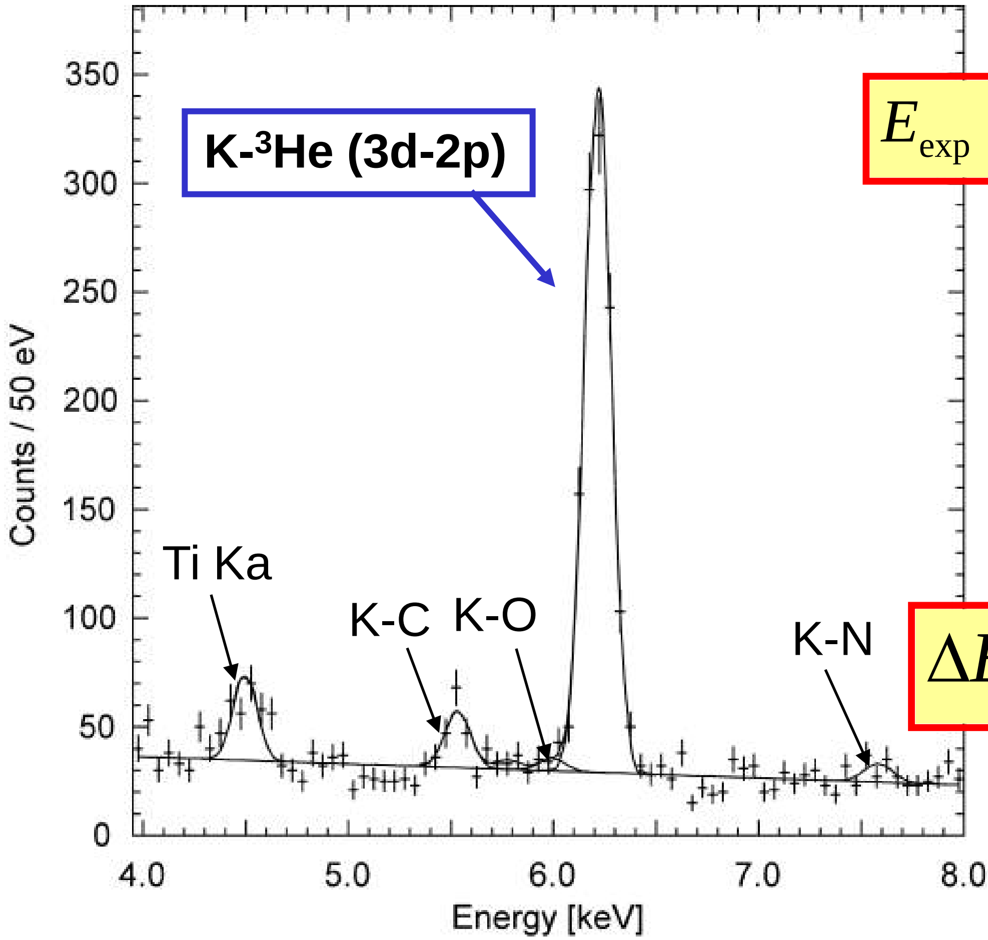
K-He3 data (~4days)



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

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

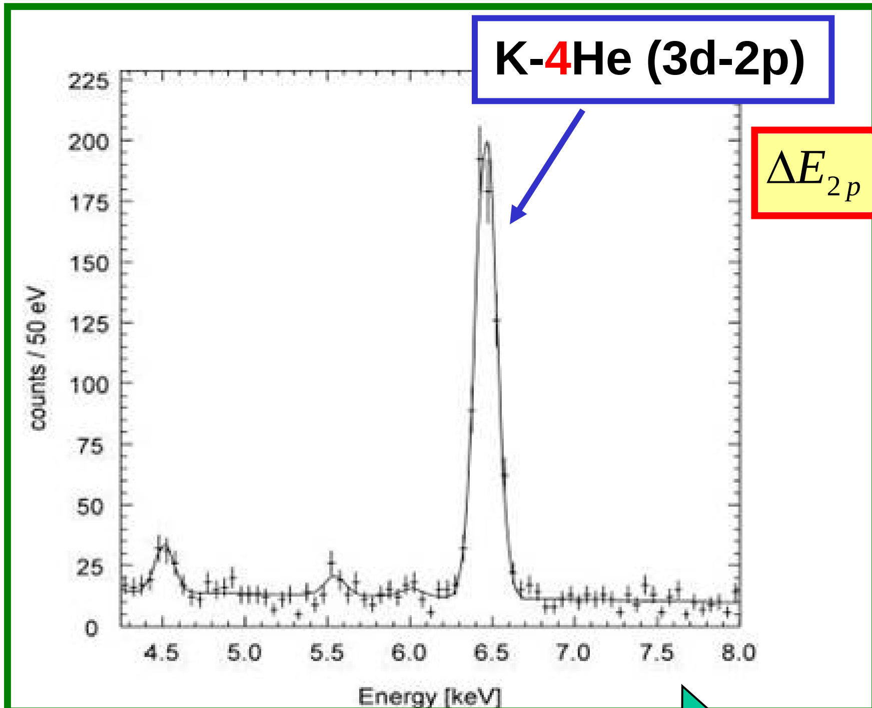
QED value: $E_{e.m.} = 6224.6\ \text{eV}$

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

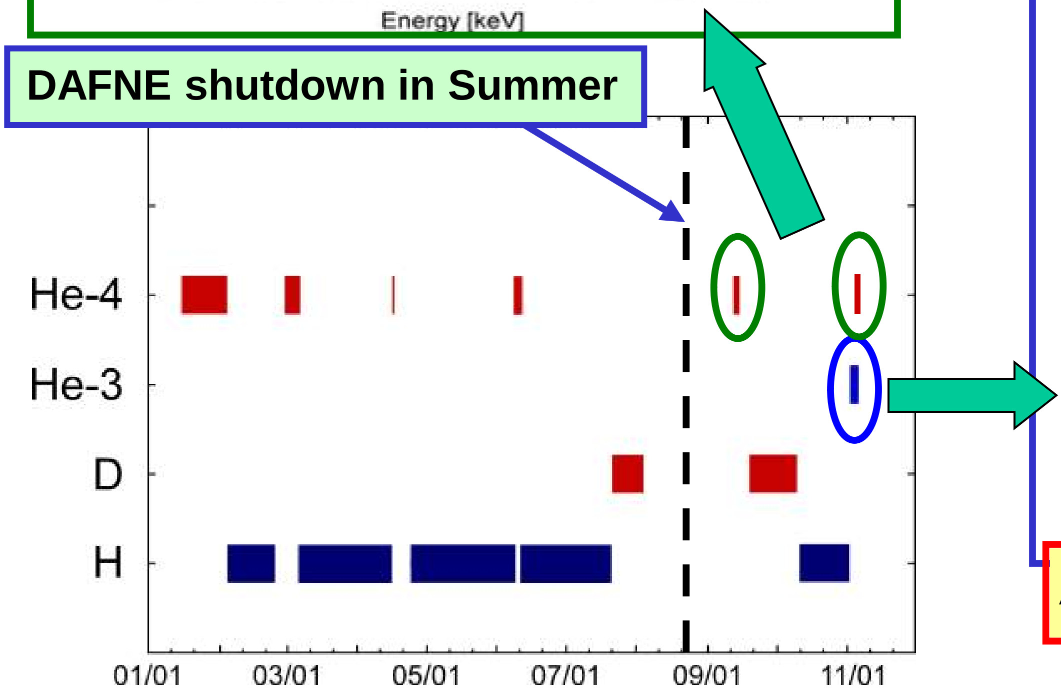
$$\Delta E_{2p} = -2 \pm 2(sta) \pm 4(sys)\ \text{eV}$$

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

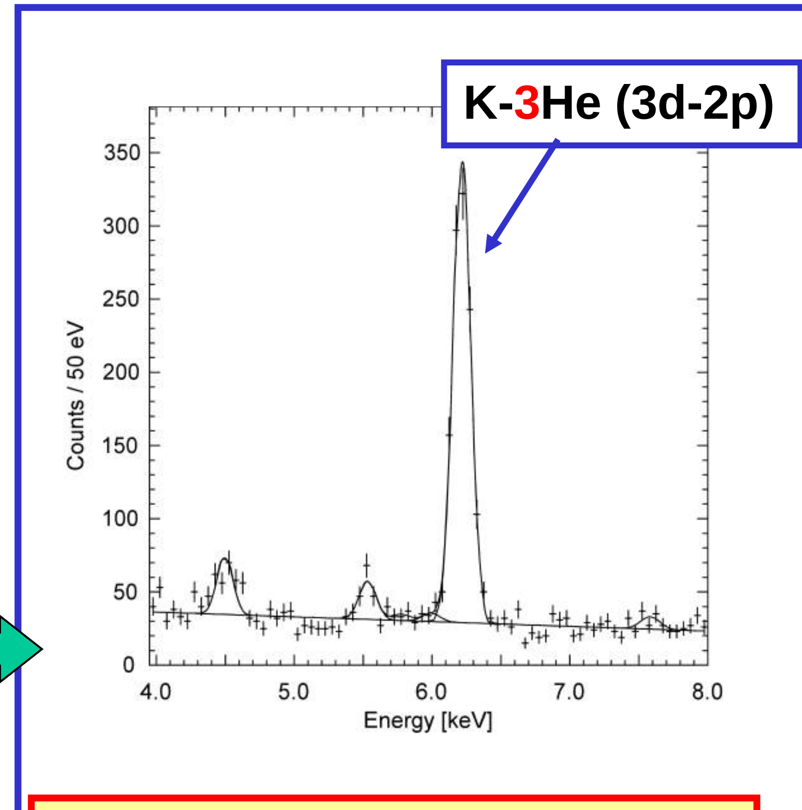
arXiv:1010.4631v1 [nucl-ex], PLB697(2011)199



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



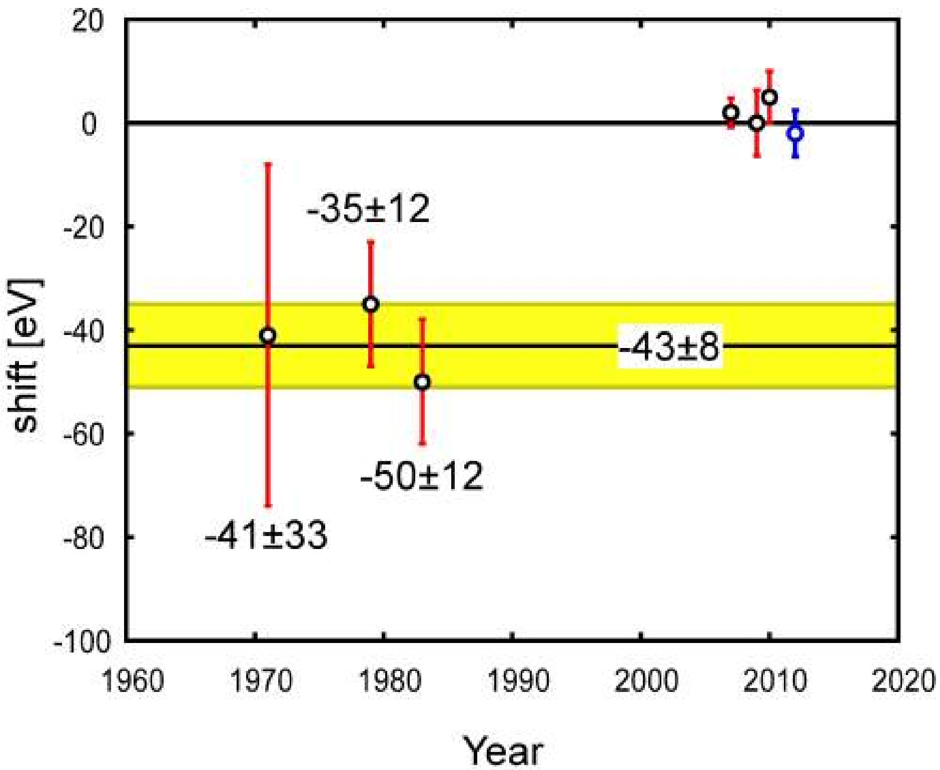
PLB697(2011)199

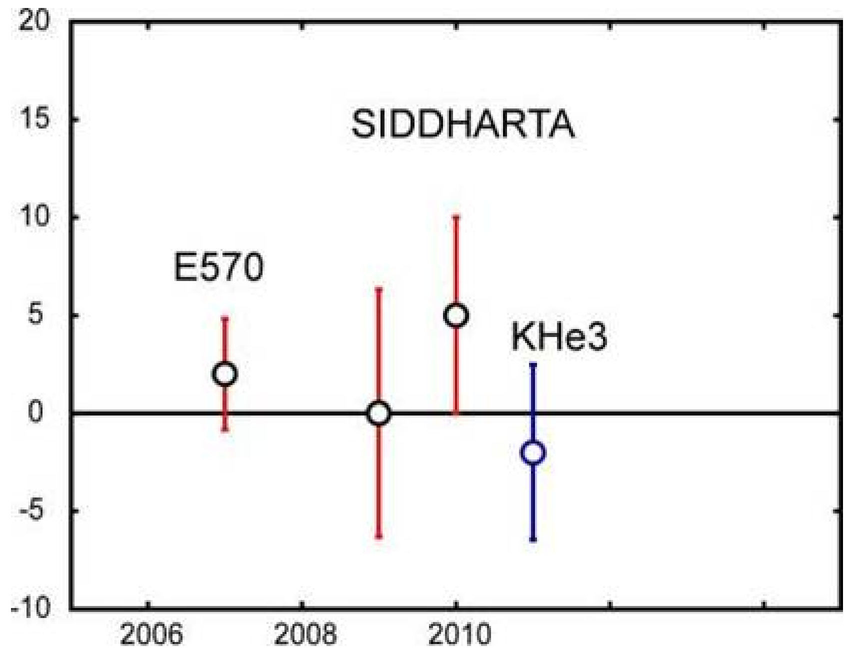


$$\Delta E_{2p} = -2 \pm 2(sta) \pm 4(sys)\ \text{eV}$$

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

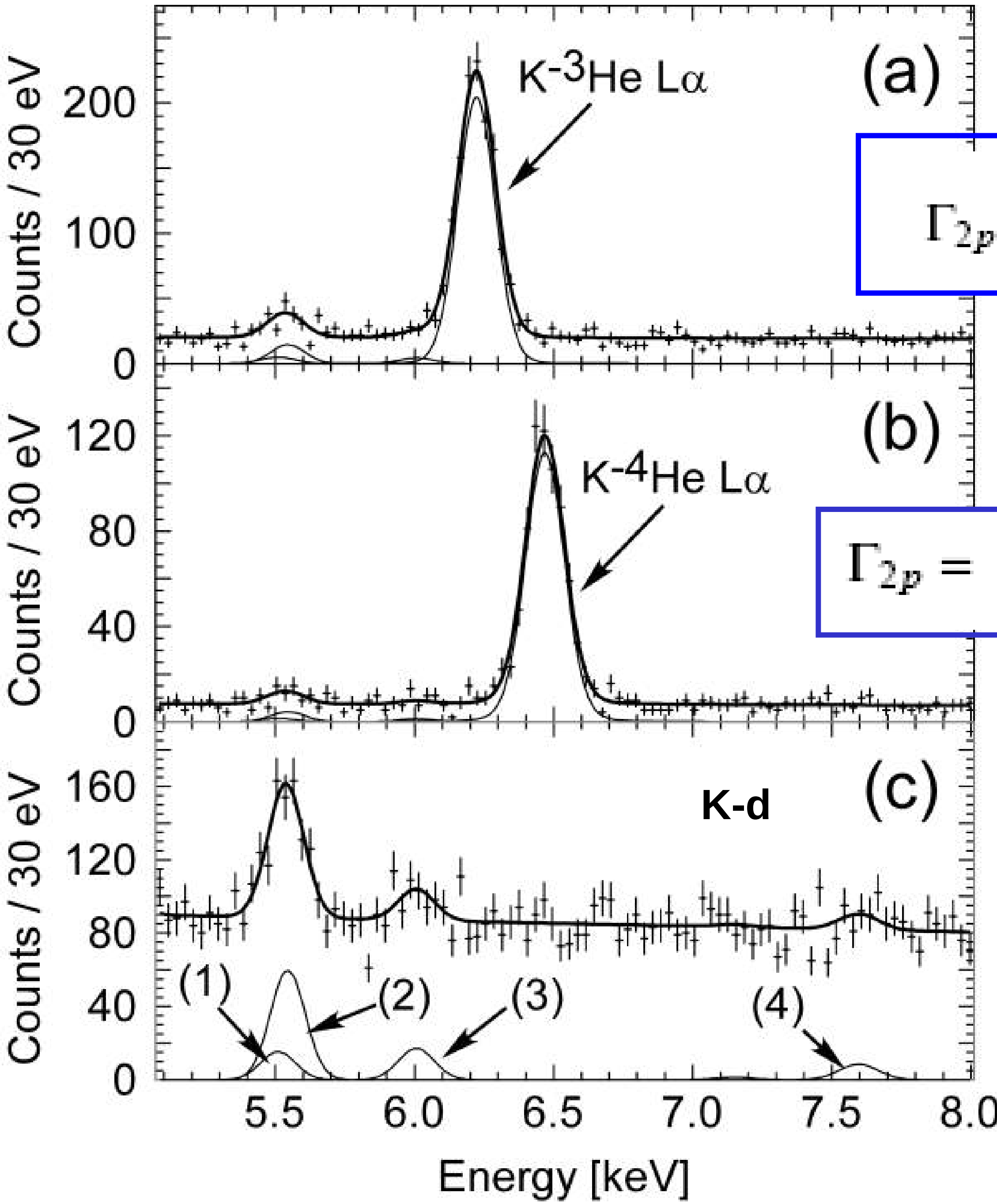
the strong-interaction width of the kaonic 3He and 4He 2p state

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

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

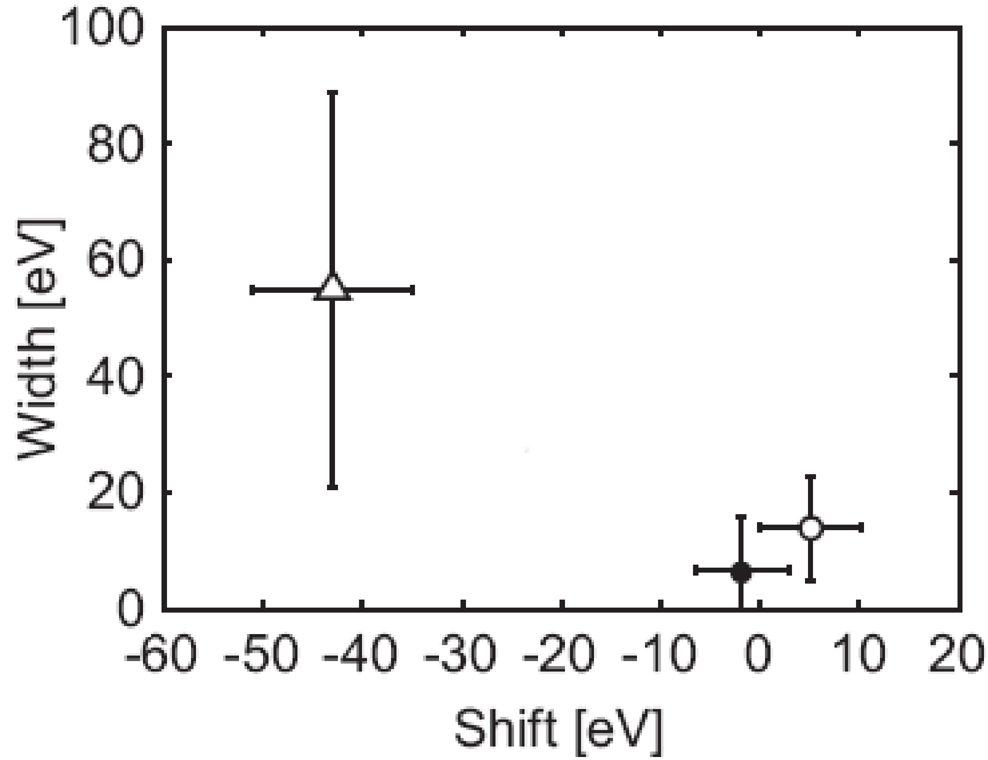


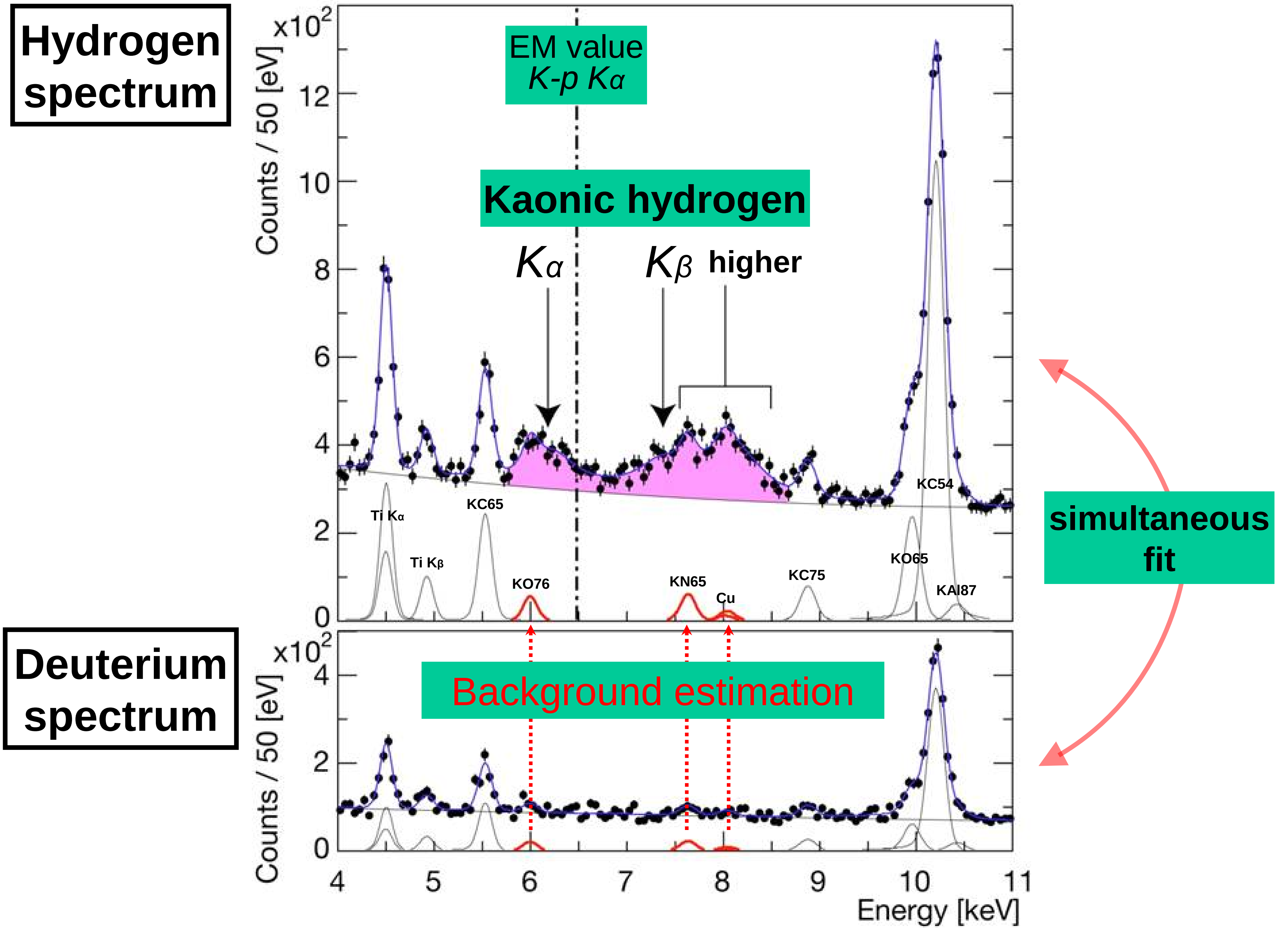
Figure 5: Comparison of experimental results. Open circle: K-4He 2*p* state; filled circle: K-3He 2*p* state. Both are determined by the SIDDHARTA experiment. The average value of the K-4He experiments performed in the 70’s and 80’s is plotted with the open triangle.

Kaonic 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

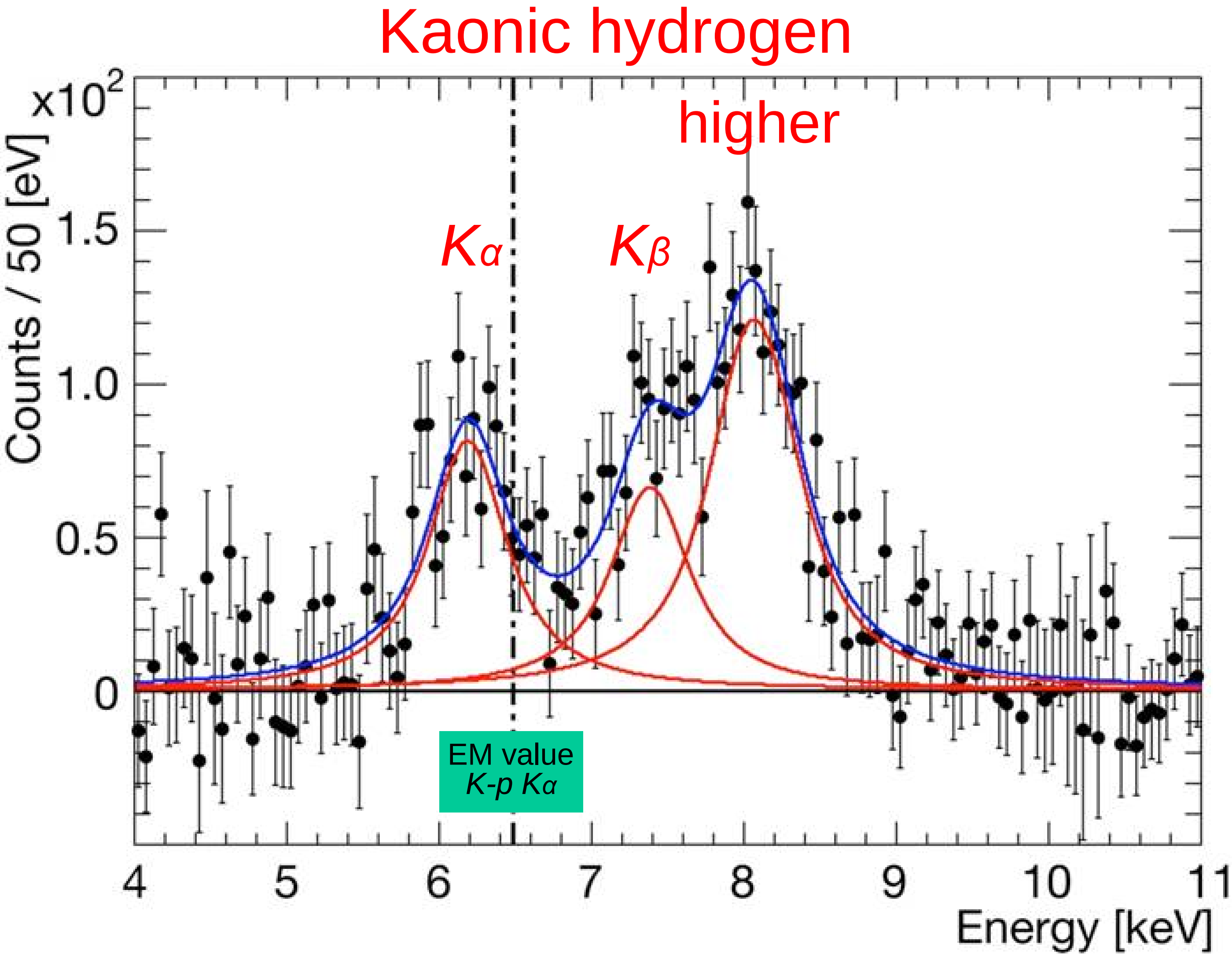
- SIDDHARTA-2 – can do much better: KHe3,4 at eV and try measurement of 1s levels!

Kaonic Hydrogen



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

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



KAONIC HYDROGEN results

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

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

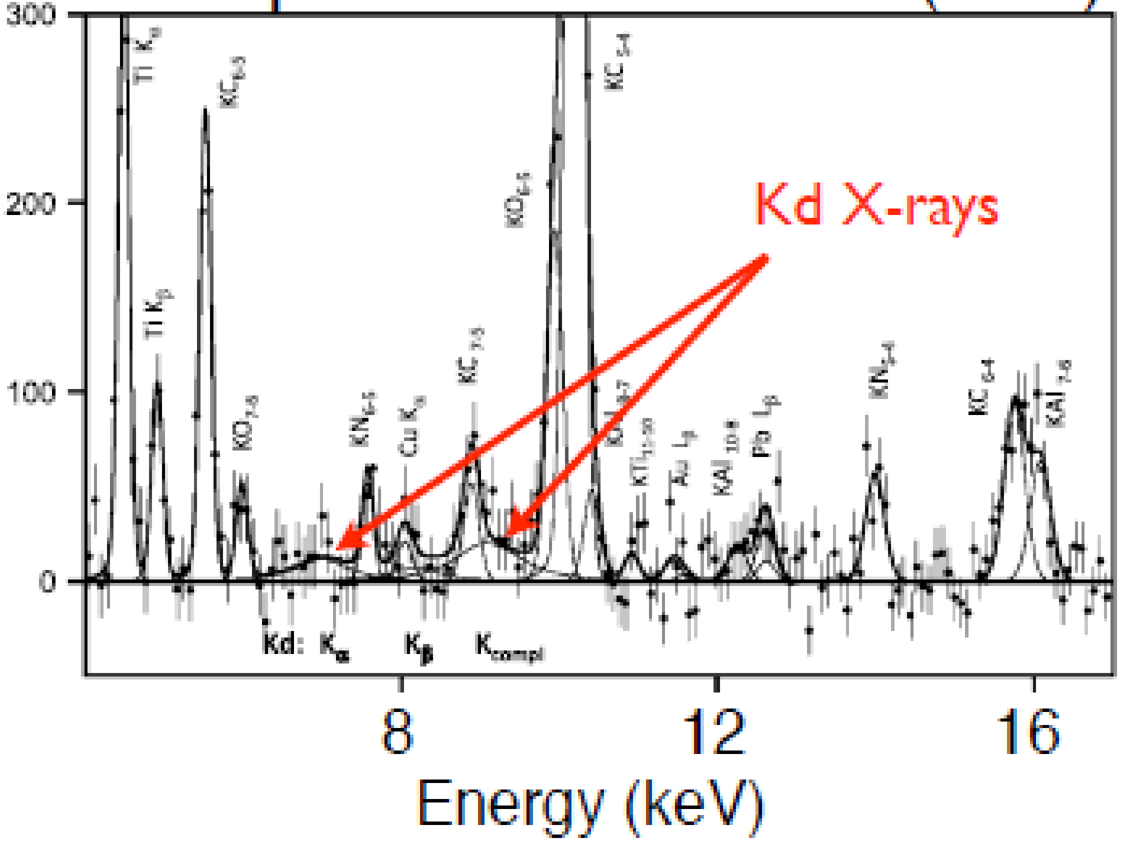
Kaonic Deuterium exploratory measurement

theoretical calculations

a_{K^-d} [fm]	ϵ_{1s} [eV]	Γ_{1s} [eV]	Ref.
$-1.58 + i1.37$	-887	757	Mizutani 2013 [4]
$-1.48 + i1.22$	-787	1011	Shevchenko 2012 [5]
$-1.46 + i1.08$	-779	650	Meißner 2011 [1]
$-1.42 + i1.09$	-769	674	Gal 2007 [6]
$-1.66 + i1.28$	-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 907 (2013) 69–77
NUCLEAR PHYSICS A
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]

EXOTIC ATOMS

Kaonic hydrogen casts new light on strong dynamics

Hadronic bound systems with strange quarks, such as kaonic hydrogen, are well suited for testing chiral dynamics, especially in view of the interplay between spontaneous and explicit symmetry breaking. Effective field theories with coupled channels based on chiral meson–baryon Lagrangians have become well established as a framework for describing $\bar{K}$–nucleon interactions at threshold, including much disputed Λ(1405) resonances and deeply bound antikaonic nuclear clusters lying just below the respective thresholds.

A recent precision measurement at the Laboratori Nazionali di Frascati of the strong-interaction-induced shift and width of the 1s level in kaonic hydrogen sheds new light on these basic problems in strong-interaction binding and dynamics. Kaonic hydrogen, in which a $\bar{K}$ replaces the electron, is produced by the capture of stopped $\bar{K}$ from the decay of ϕ mesons in hydrogen gas. The ϕ mesons are generated nearly at rest at the DAΦNE e^+e^- collider, operating in a new, high-luminosity collision mode.

The SIDDHARTA collaboration with the apparatus. (Image credit: C Curceanu.)

The shift and width of the kaonic 1s state is deduced from precision X-ray spectroscopy of the K-series transitions in the kaonic hydrogen. The emitted K-series X-rays, with energies of 6–9 keV, were detected by the recently developed Silicon Drift Detector for Hadronic Atom Research by Timing Application (SIDDHARTA) experiment, which performs X-ray–kaon coincidence spectroscopy using microsecond timing and the excellent energy resolution of about 180 eV FWHM at 6 keV of 144 large-area (1 cm²) silicon drift detectors that surround the hydrogen target cell. This method reduces the large X-ray background from beam losses by orders of magnitude. It has led to the most precise values for the 1s level shift, $\varepsilon_{1s} = -283 \pm 36(\text{stat.}) \pm 6(\text{syst.})$ eV, and width $\Gamma_{1s} = 541 \pm 89\ (\text{stat.}) \pm 22\ (\text{syst.})$ eV for kaonic hydrogen (Bazzi *et al.* 2011).

A recent study using next-to-leading-order chiral dynamics calculations of the shift and the width has shown excellent agreement with these measurements (Ikeda *et al.* 2011). Further measurements with similar accuracy are planned for the K-series X-rays from kaonic deuterium, using an improved SIDDHARTA-2 set-up to disentangle the isoscalar and isovector scattering lengths.

● Further reading

M Bazzi *et al. Phys. Lett.* **B704** (2011) 113.
Y Ikeda, T Hyodo and W Weise 2011 arXiv:1109.3005[nucl-th].

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

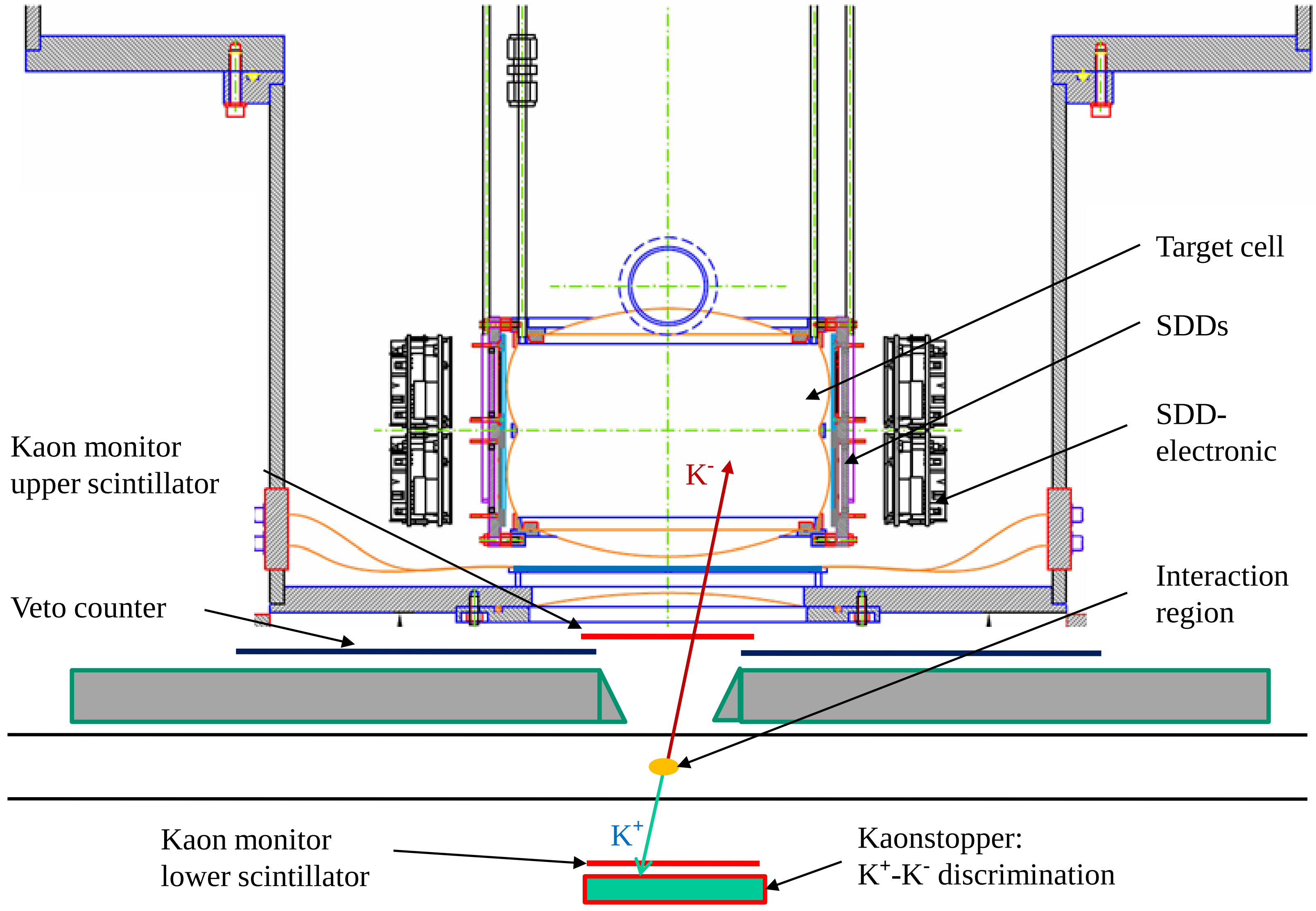
It is actually the IDEAL facility for kaonic atoms studies as SIDDHARTA has demonstrated

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

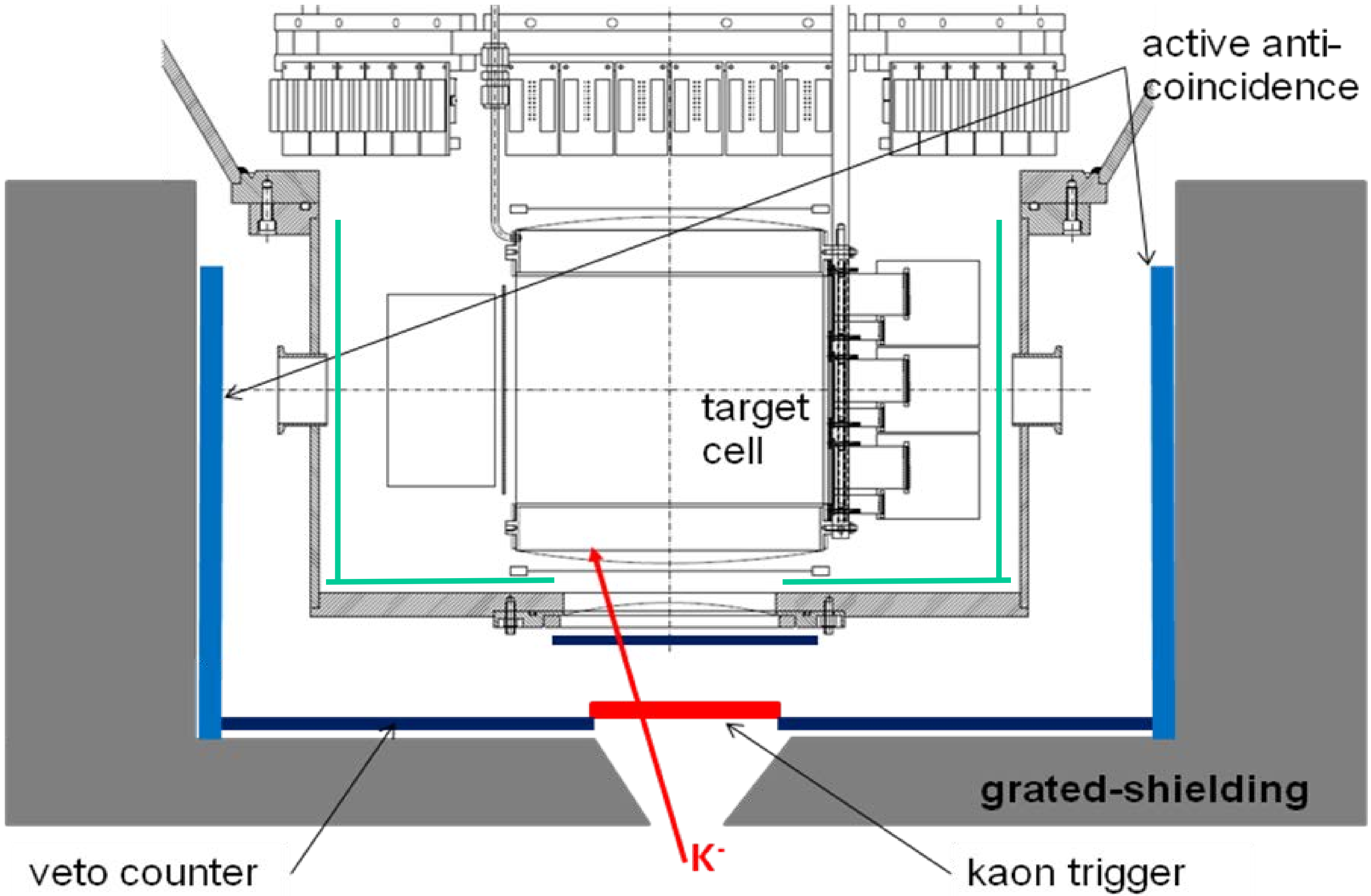
SIDDHARTA–2

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)
- new SDD detectors (FBK)

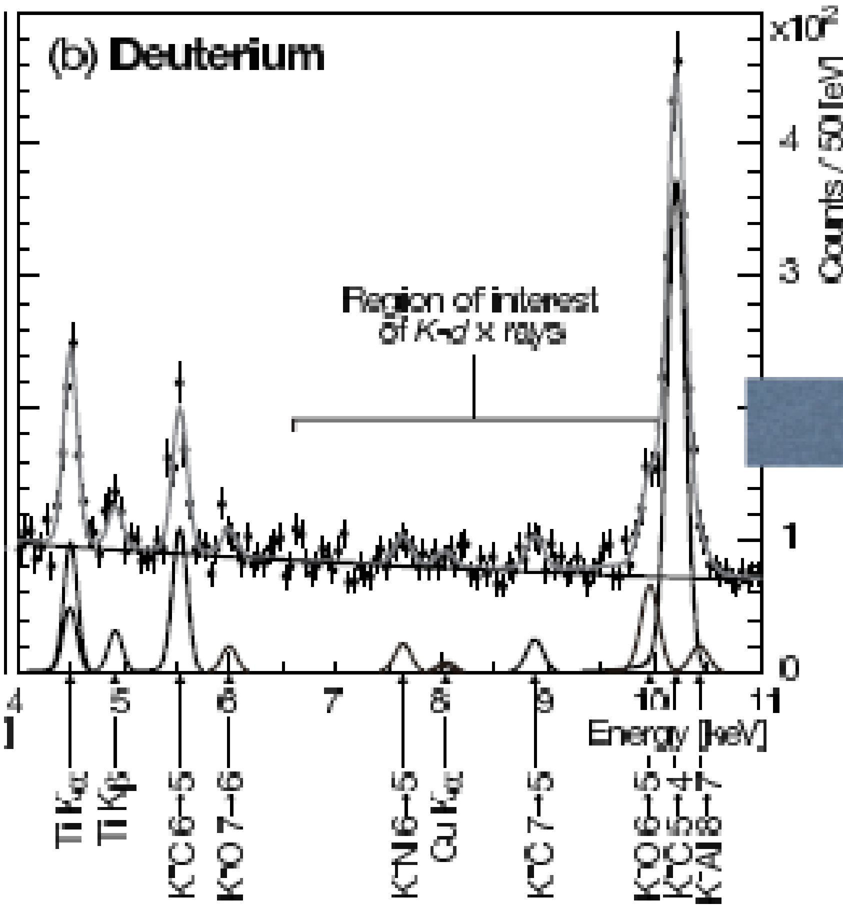


Target cell
SDDs
SDD-
electronic
Kaon monitor
upper scintillator
Veto counter
Interaction
region
K^-
K^+
Kaon monitor
lower scintillator
Kaonstopper:
K^+-K^- discrimination



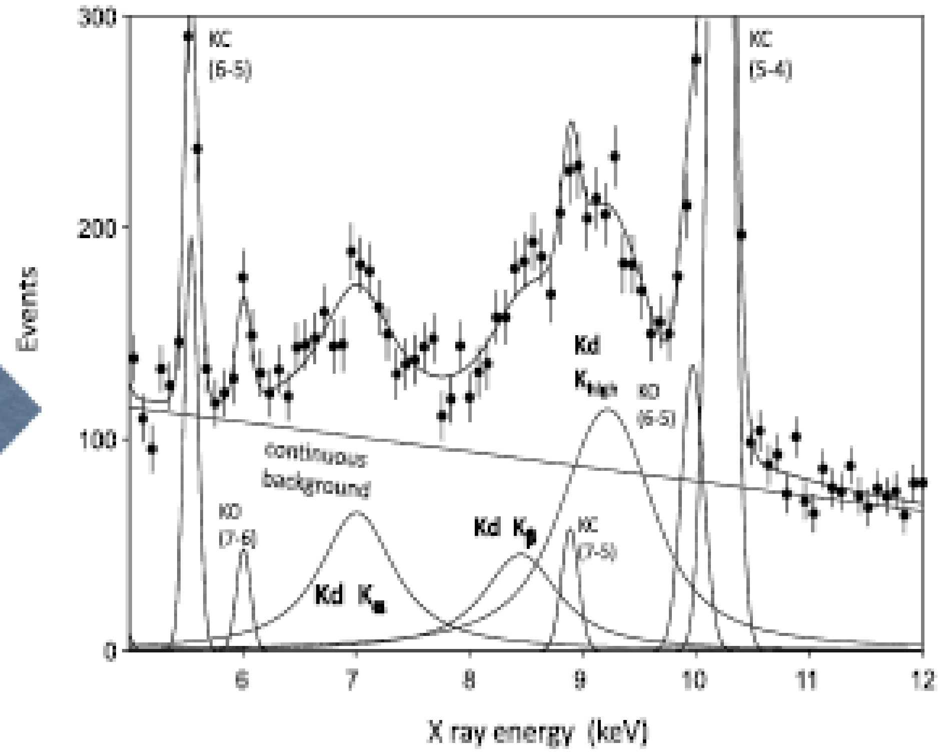
active anti-coincidence
target cell
grated-shielding
veto counter
K-
kaon trigger

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

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,…)

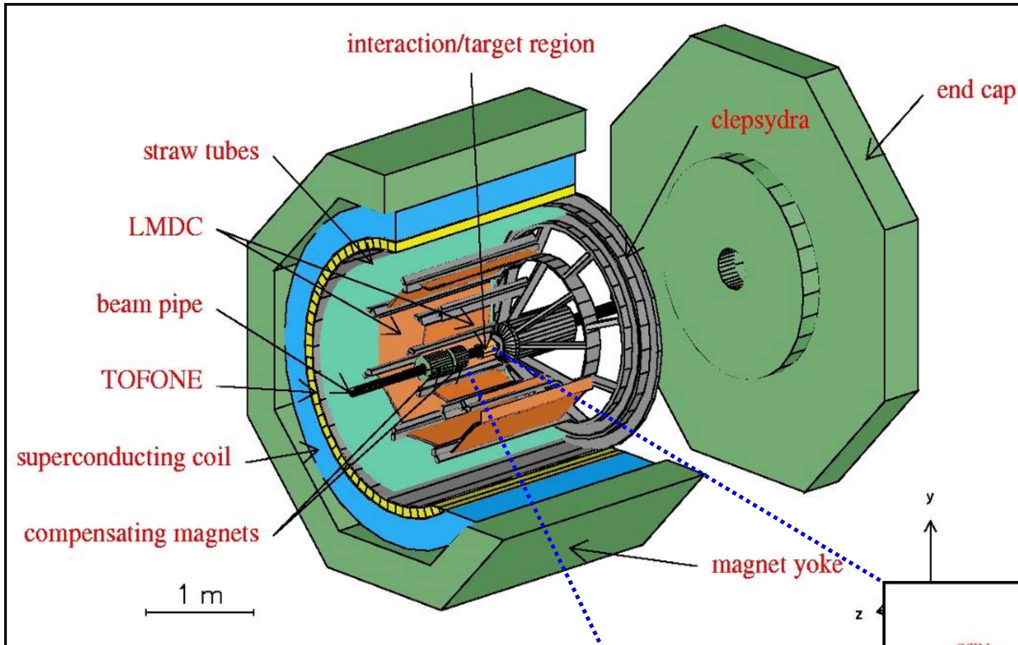
4) Heavier kaonic atoms measurement (Si, Pb…)

5) Kaon radiative capture – Λ(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

FINUDA @ DAΦNE



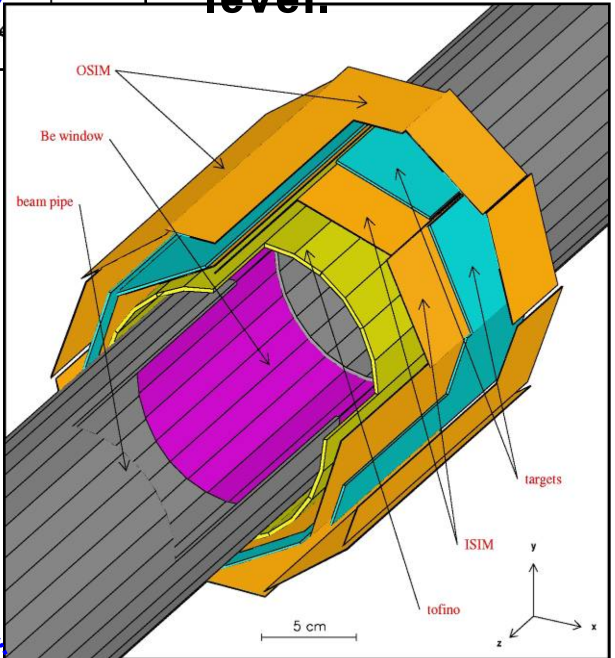
$$e^- + e^+ \rightarrow \phi \rightarrow K^- K^+$$

$$K^-_{stop} + {}^{A}Z \rightarrow {}^{A}_{\Lambda}Z + \pi^-$$

Measuring precisely the momentum of this pion you can infer on the hypernuclear level.

$$ {}^{A}_{\Lambda}Z \rightarrow \begin{cases} {}^{A}(Z+1) + \pi^- \\ {}^{(A-2)}(Z-1) + p + n \\ {}^{(A-2)}Z + n + n \end{cases} $$

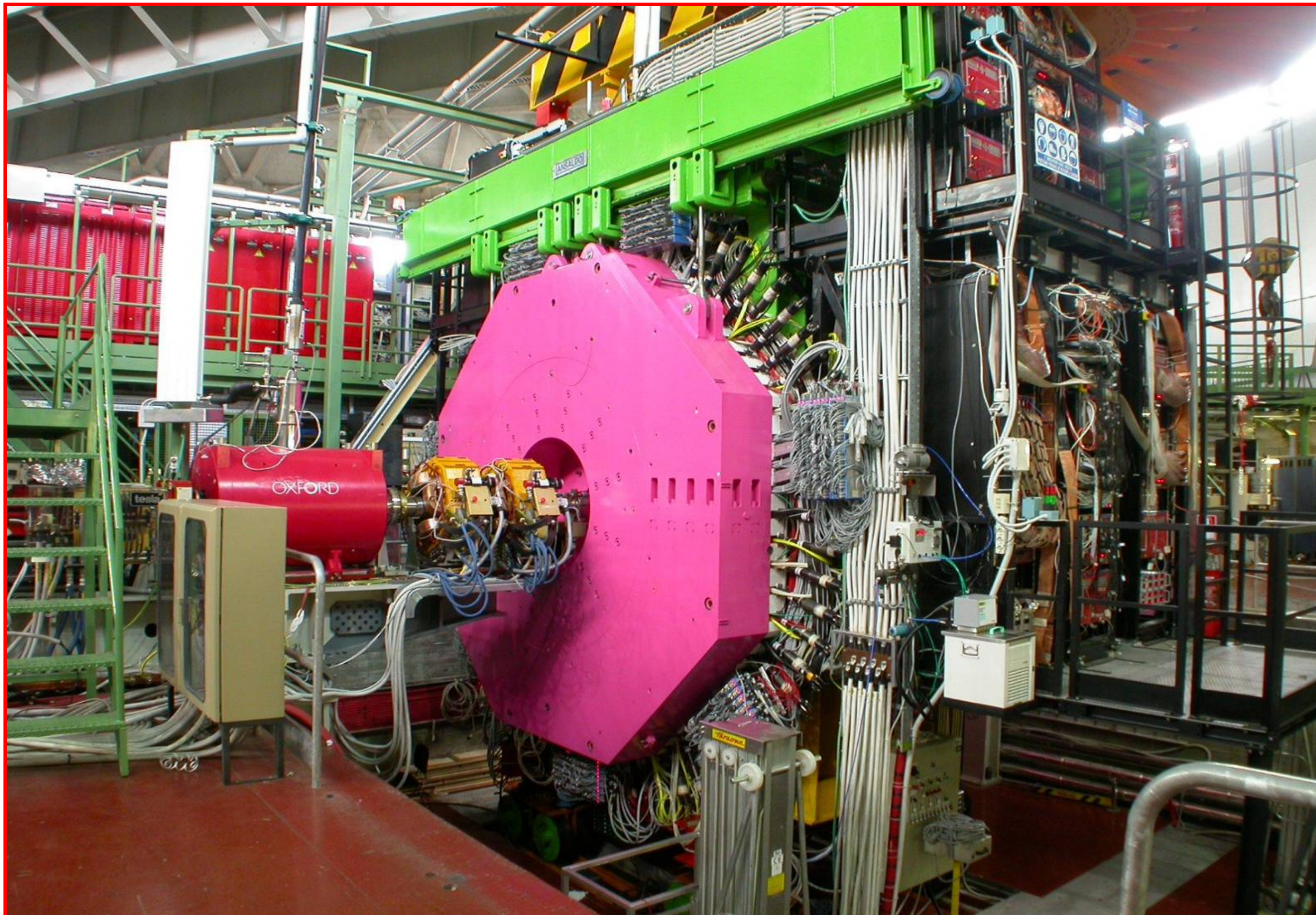
Measuring precisely the hypernuclear decay products you can study weak-interaction in the medium.



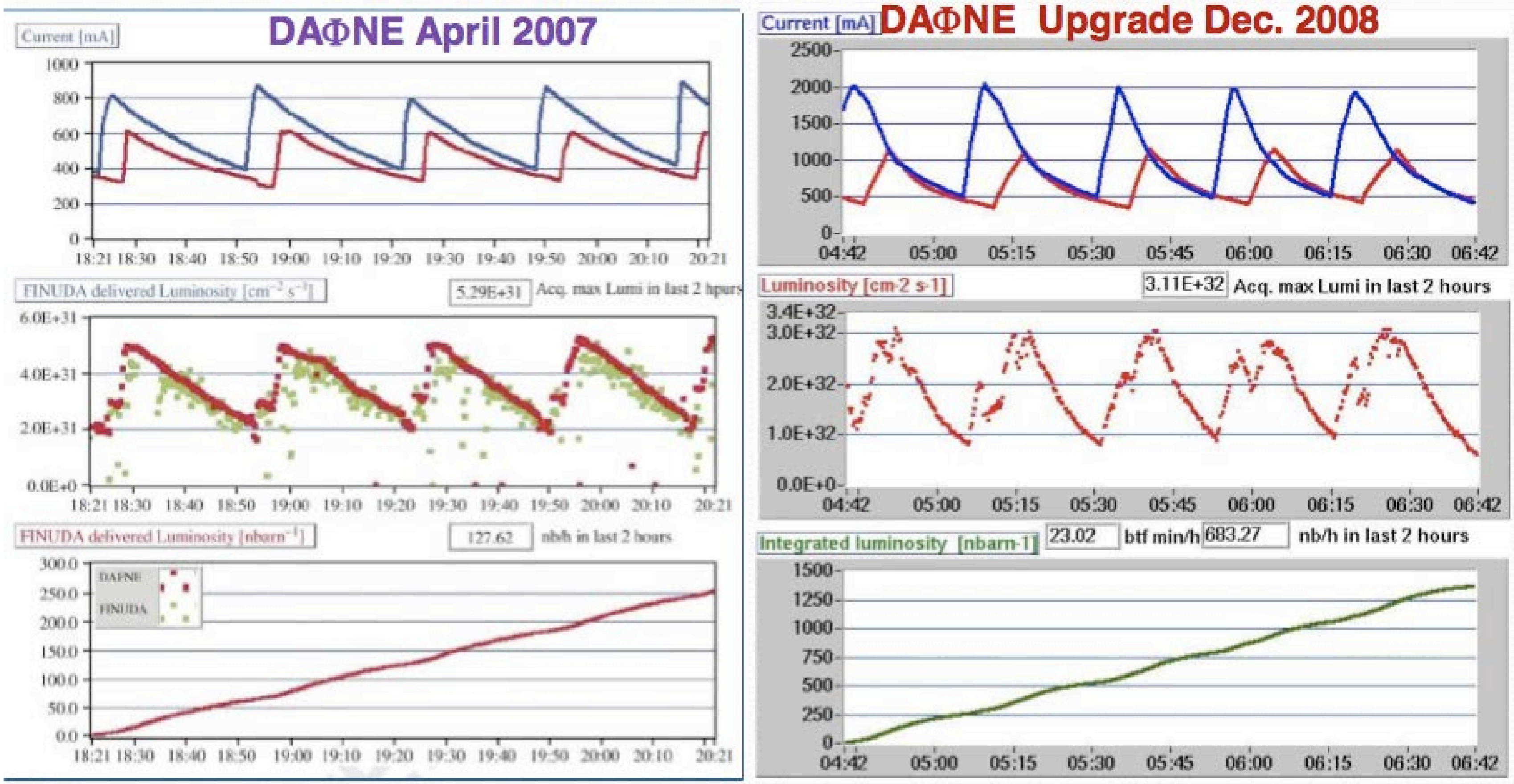
The FINUDA Collaboration

- Bari University and I.N.F.N. Bari
- Brescia University and I.N.F.N. Pavia
- KEK
- L.N.F. / I.N.F.N. Frascati
- Pavia University and I.N.F.N. Pavia
- RIKEN
- Seoul National University
- Teheran Shahid Beheshty University
- Torino University and I.N.F.N. Torino
- Torino Polytechnic and I.N.F.N. Torino
- Trieste University and I.N.F.N. Trieste
- TRIUMF

FINUDA @ DAΦNE



K-beam @ DAΦNE e^+e^- collider



Φ peak production cross section

Φ≈ 4 x 10^{-30}cm^2

Beam Intensity:

≈ 2 x 10^6 $K^{\pm}$pairs / pb^{-1}

FINUDA key features

- ☺ very thin nuclear targets (0.1 ÷ 0.3 g/cm^2)

  → **high resolution spectroscopy**

- ☺ **coincidence measurement with large acceptance**

  → **decay mode study**

- ☺ **different targets in the same run**

  → **high degree of flexibility**

FINUDA Physics program

Λ-HYPERNUCLEAR SPECTROSCOPY
essential tool for testing :
- theoretical models of Λ-N potentials
- single particle nuclear model predictions
- bound states with strangeness

simultaneously on different targets

HYPERNUCLEAR DECAYS
- study of baryon-baryon weak processes in nuclear matter
- Neutron-rich hypernuclei
- Λ lifetime

and, moreover

SEARCH FOR:
- K-multi-nucleon absorption
- Deeply bound kaonic nuclei
- Final states with Λ & other Hyperons

FINUDA Data Takings

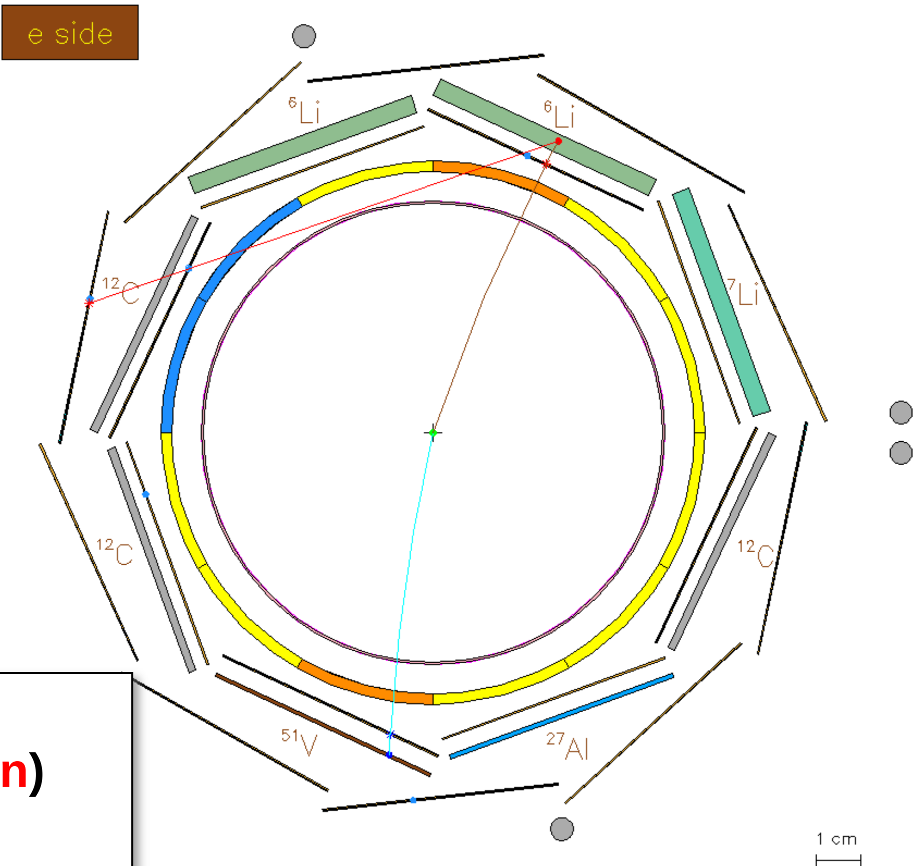
2003-04 **The first, mainly exploratory, and started four years later than planned due to the time needed to tune DAΦNE, and to run other experiments.**
Collected *Luminosity ≈220pb^{-1} on 3 x^{12}C, 2 x^{6}Li, 1 x^{7}Li, 1 x^{27}Al, 1 x^{51}V nuclear targets.*

2006-07 **The second, with a collected *Luminosity of ≈966pb^{-1}on 2 x^{6}Li, 2 x^{7}Li, 2 x^{9}Be, 1 x^{13}C, 1xD$_2$O nuclear targets.***

Target setup of the first data taking

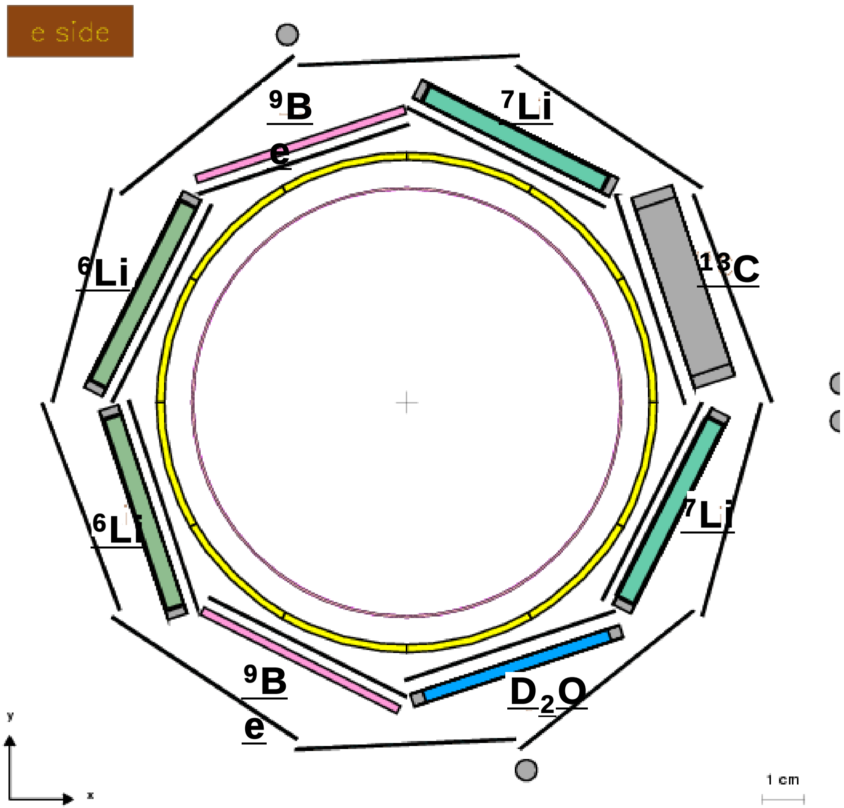
- Choice: 2x ^{6}Li, 1x ^{7}Li, 3x ^{12}C, 1x ^{27}Al, 1x ^{51}V

- We focused on known material (^{12}C) to check detector performance with an eye to heavier materials
  - Hypernucelar spectroscopy
  - Hypernuclei decay modes
  - Bound kaonic states
  - Rare hypernuclear decay



Hypernuclear trigger:
- 2 hits on tofino over threshold (kaon)
- extended back to back
- multiplicity (>2) on tofone
- Time correlation tofino-tofone (<10ns)

Target setup of the second data-taking



- Choice: 2x ^{6}Li, 2x ^{7}Li, 1x D_2O, 2x ^{9}Be, 1x ^{13}C
- We focused on medium-light target to allow a wider spectrum of analyses
  - Hypernucelar spectroscopy
  - Hypernuclei decay modes
  - Bound kaonic states
  - Rare hypernuclear decay

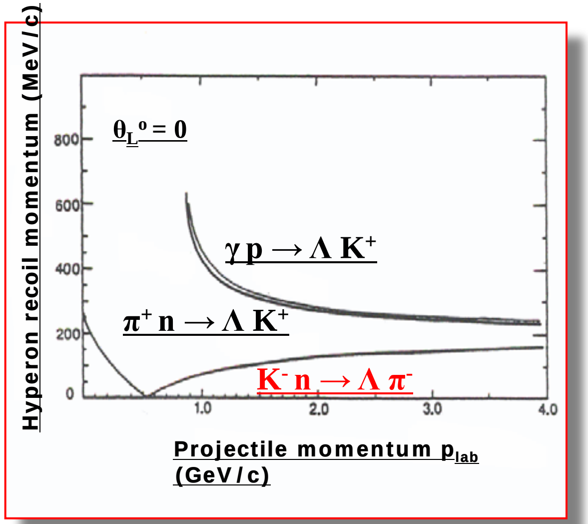
Target's thickness evaluated taking into account the narrower (1.8 mm) TOFINO with respect to the first data taking:

Hypernuclear spectroscopy

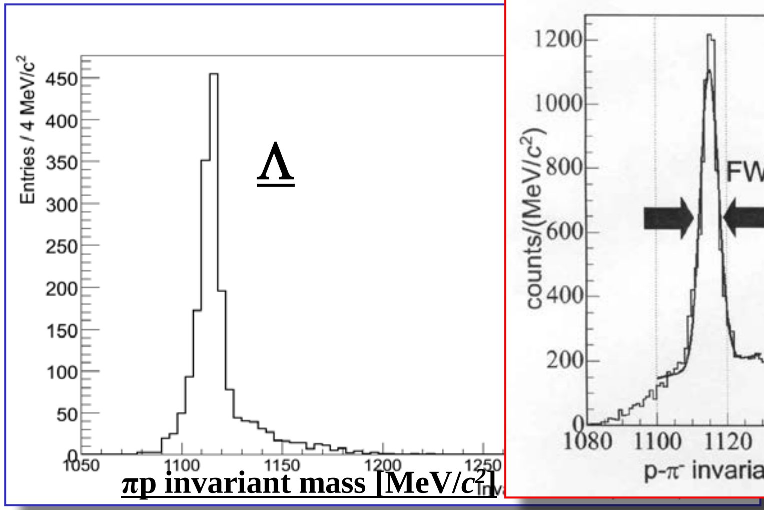
Hypernuclei are produced following Φ decay via **strangeness exchange reaction**

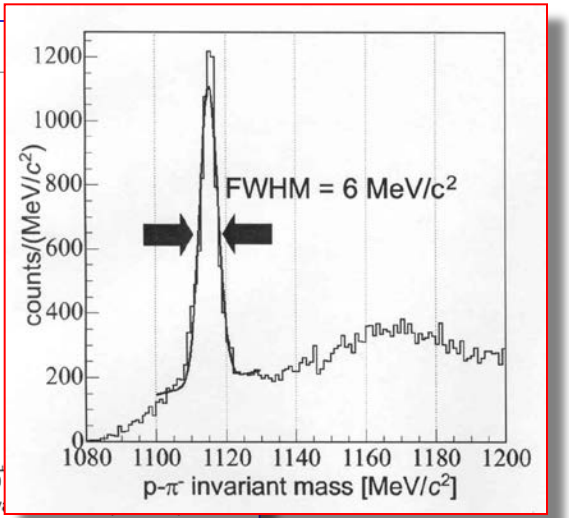
$$\Phi \rightarrow K^+ K^- \ (49\%)$$

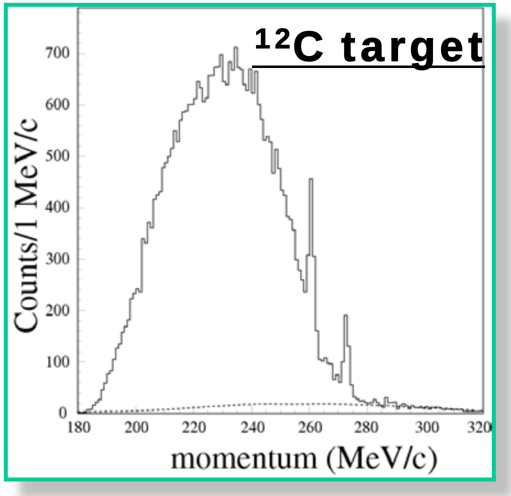
$$\rightarrow K^- + {}^{A}Z \ \rightarrow {}^{A}_{\Lambda}Z + \pi^- \quad (\sim 10^{-3})$$



FINUDA, being a high acceptance magnetic spectrometer, can detect **all the particles** produced and following K^- interaction with the target

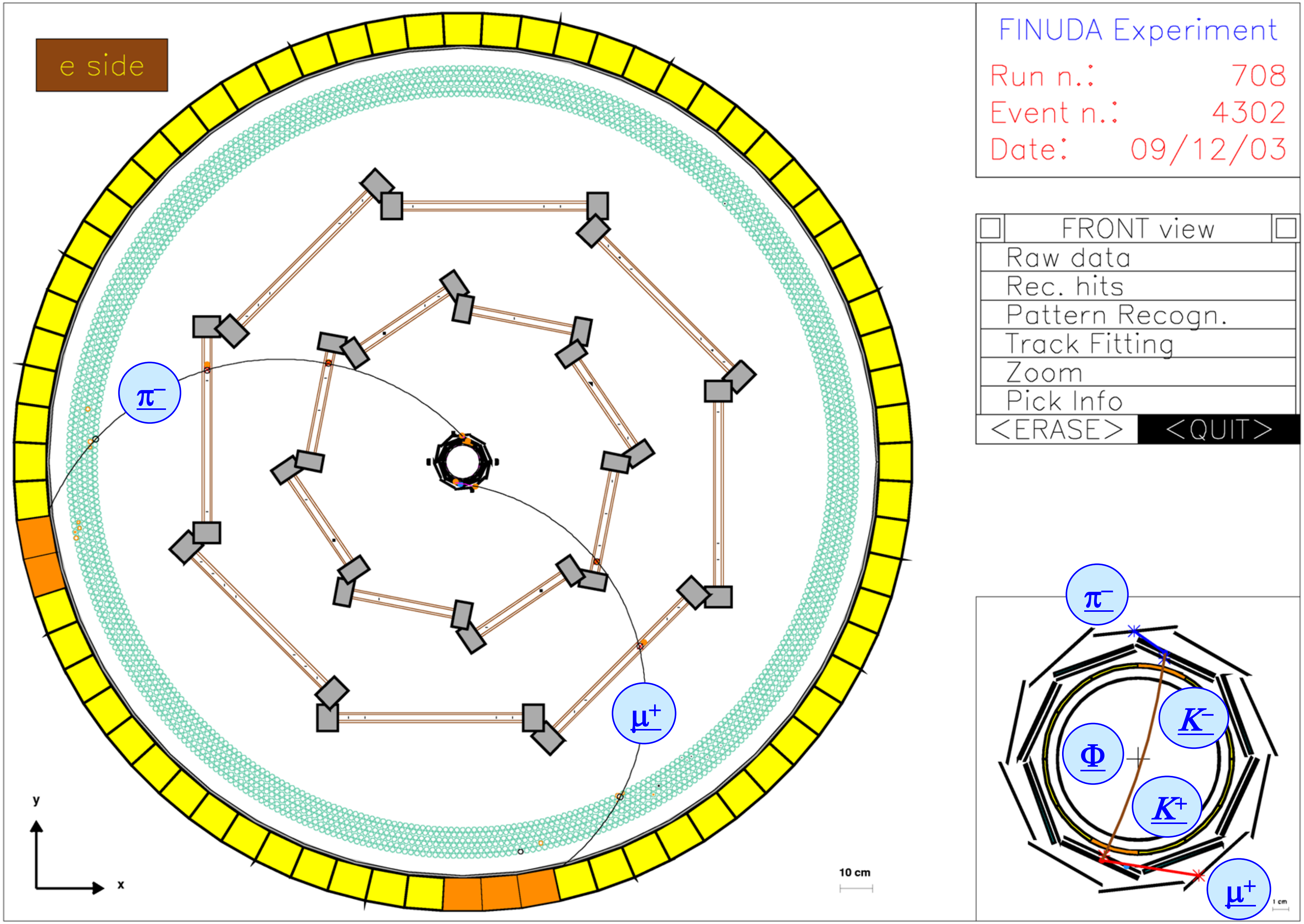






Not only hypernuclear systems can be studied

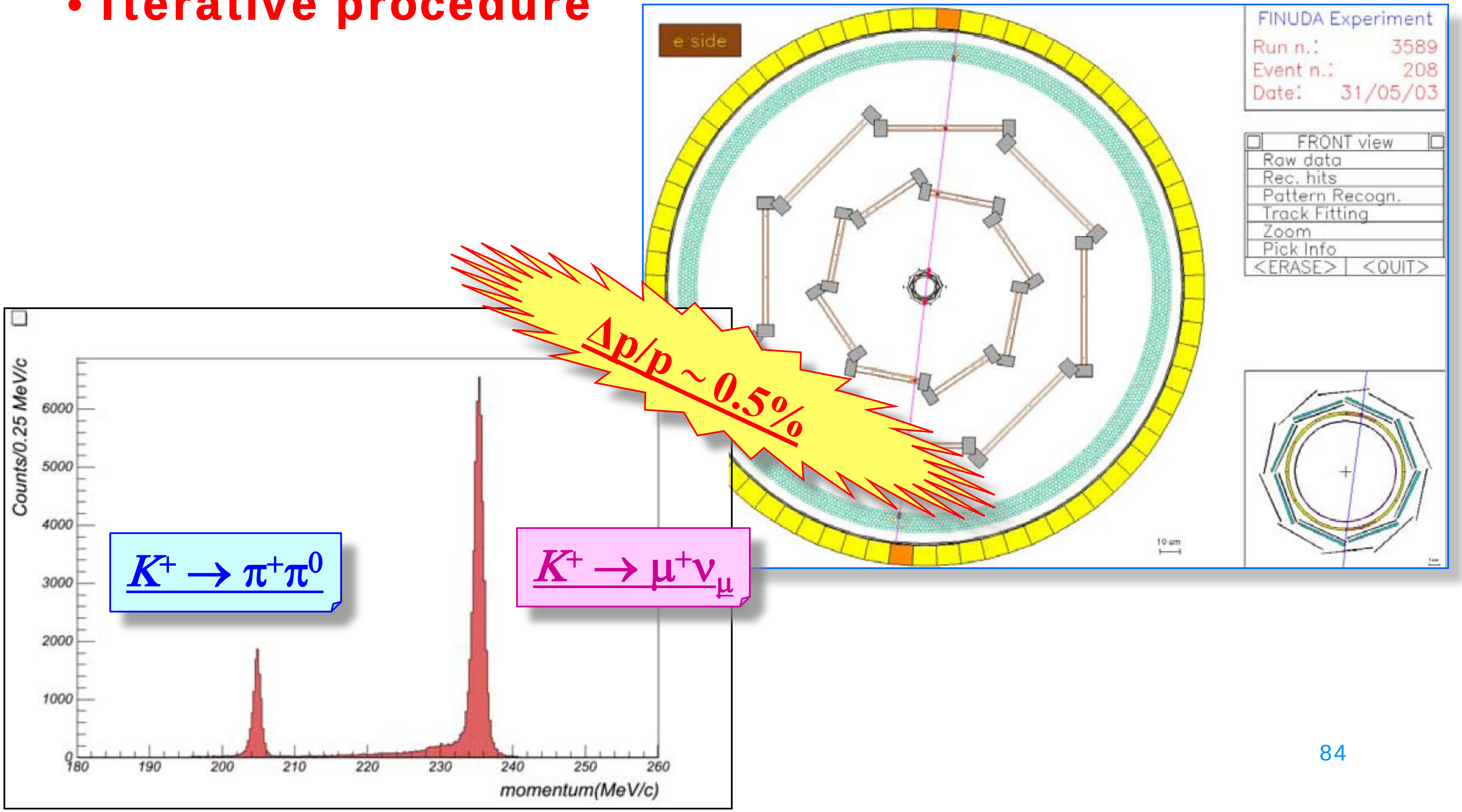
The hypernuclear event



Momentum resolution

FINUDA is a composite detector ⇒ alignment procedure is crucial

- **straight cosmic rays, collected during and after data taking, are used**
- **Iterative procedure**



FINUDA scientific results

Hypernuclear physics

Hypernuclear spectroscopy: PLB 622 (2005) 32: $^{12}{}_{\Lambda}C$

PLB 698 (2011) 219: $^{7}{}_{\Lambda}Li$, $^{9}{}_{\Lambda}Be$, $^{13}{}_{\Lambda}C$, $^{16}{}_{\Lambda}O$

Weak Decay: NPA 804 (2008) 151: NMWD $^{5}{}_{\Lambda}He$, $^{7}{}_{\Lambda}Li$, $^{12}{}_{\Lambda}C$

PLB 681 (2009) 139: MWD ($^{5}{}_{\Lambda}He$,) $^{7}{}_{\Lambda}Li$, $^{9}{}_{\Lambda}Be$, $^{11}{}_{\Lambda}B$

PLB 685 (2010) 247: NMWD&2N $^{5}{}_{\Lambda}He$, $^{7}{}_{\Lambda}Li$, $^{9}{}_{\Lambda}Be$, $^{11}{}_{\Lambda}B$, $^{12}{}_{\Lambda}C$, $^{13}{}_{\Lambda}C$, $^{15}{}_{\Lambda}N$, $^{16}{}_{\Lambda}O$

PLB 701 (2011) 556: NMWD&2N $^{5}{}_{\Lambda}He$, $^{7}{}_{\Lambda}Li$, $^{9}{}_{\Lambda}Be$, $^{11}{}_{\Lambda}B$, $^{2}{}_{\Lambda}C$, $^{13}{}_{\Lambda}C$, $^{15}{}_{\Lambda}N$, $^{16}{}_{\Lambda}O$

NPA 881 (2012) 322 : (n, n, p) events from 2N

Rare Decays: NPA 835 (2010) 439: $^{4}{}_{\Lambda}He$, $^{5}{}_{\Lambda}He$ 2-body decays

Neutron-rich Hypernuclei: PLB 640 (2006) 145: upper limits $^{6}{}_{\Lambda}H$, $^{7}{}_{\Lambda}H$, $^{12}{}_{\Lambda}Be$

PRL 108 (2012) 042501, NPA 881 (2012) 269: $^{6}{}_{\Lambda}H$ observation

FINUDA scientific results

Other physics topics

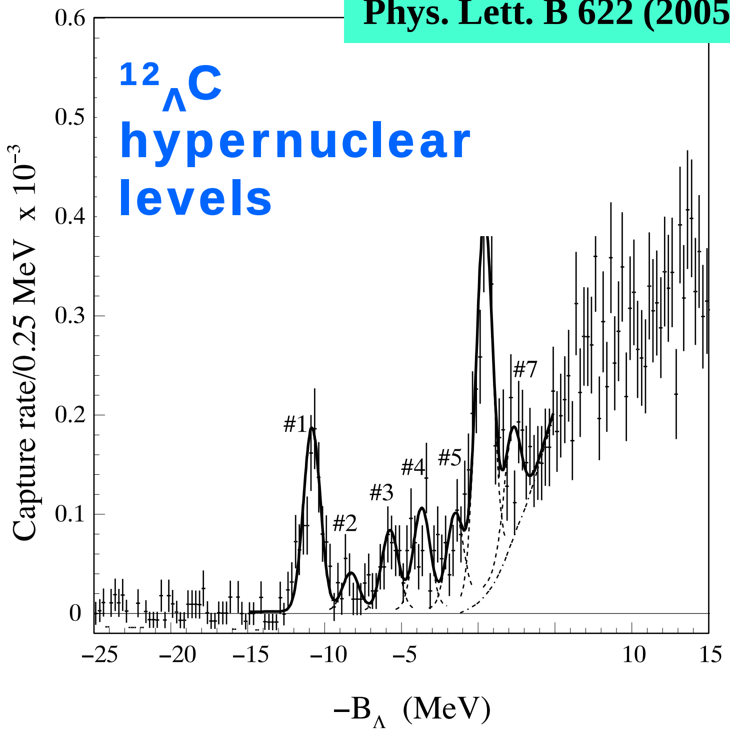
Kaon nuclei interaction: PRL 94 (2005) 212303 **first evidence of a K^--nucleons state**

NPA 914 (2013) 310 **recent update of K^--nucleons state**

Hypernuclear Spectroscopy

FINUDA has performed a rich program of spectroscopy thanks to the possibility to have different target at the same time

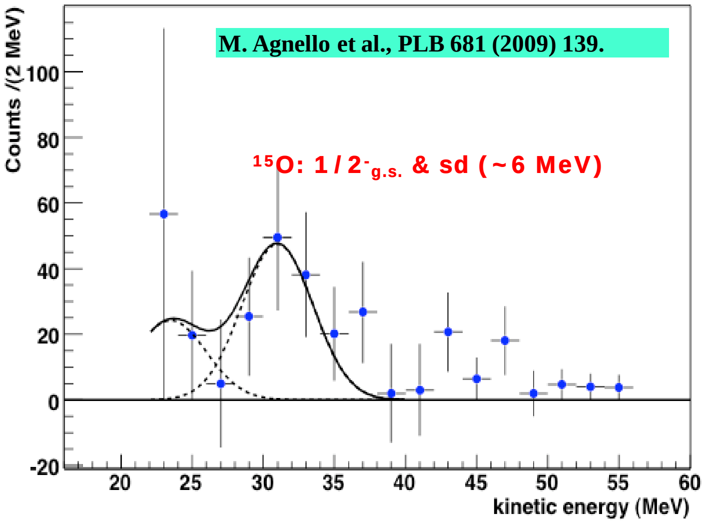
Phys. Lett. B 622 (2005) 35



New states were identified, spin-parity assignment has been done

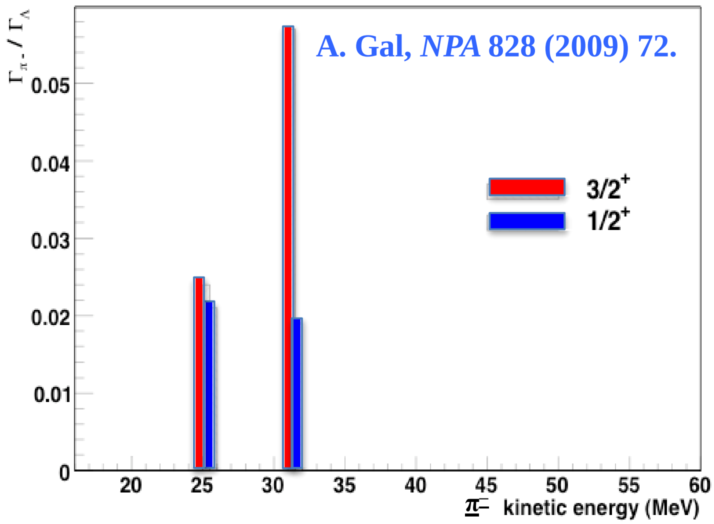
We achieved an energy resolution of 1.3 MeV, the best obtained in hadronic environment

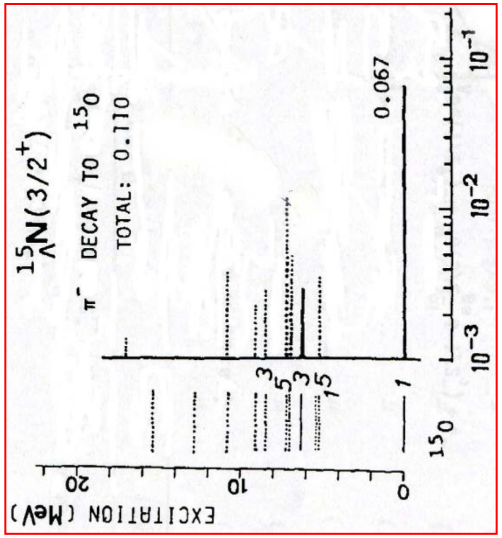
J^{π} assignment



$^{15}N_{\Lambda}$ J^{π} assignment has been experimentally determined:

J^{π} ($^{15}N_{\Lambda\ g.s.}$) = 3/2$^{\pm}$

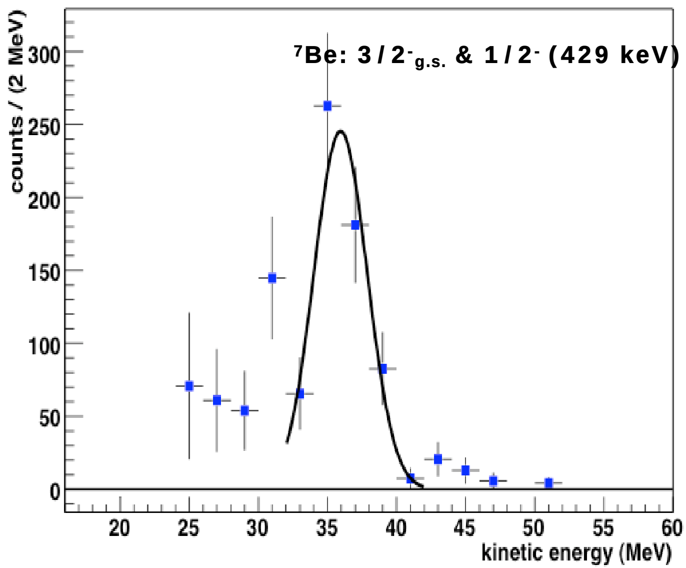




T. Motoba, *NPA* 489 (1988) 683

Theoretical expectations

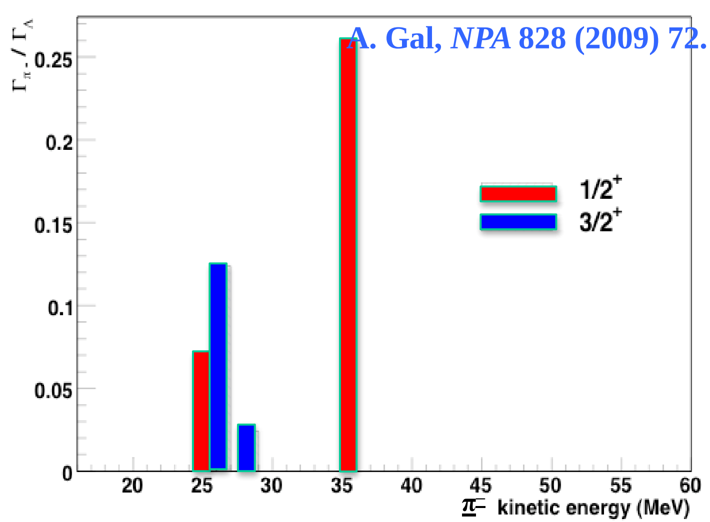
J^π assignment

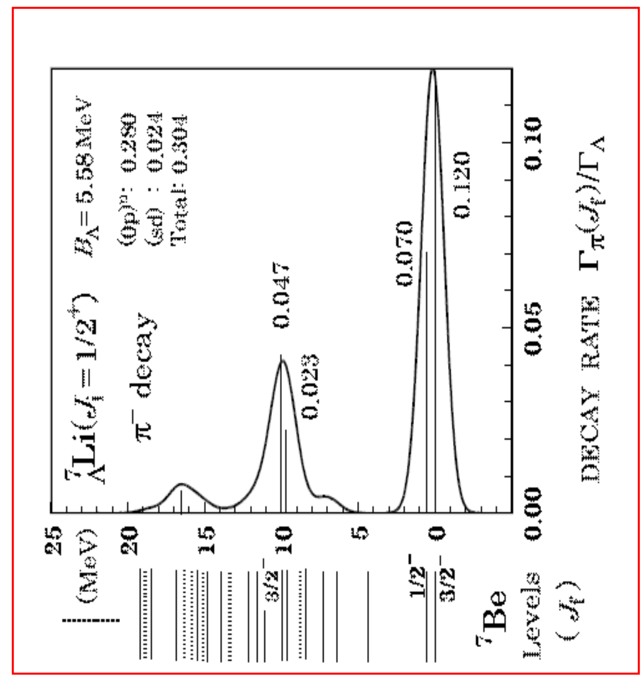


$^{7}Li_{\Lambda}$ J^{π} assignment has been confirmed:

J^{π} ($^{7}Li_{\Lambda\ g.s.}$) = 1/2^{+}

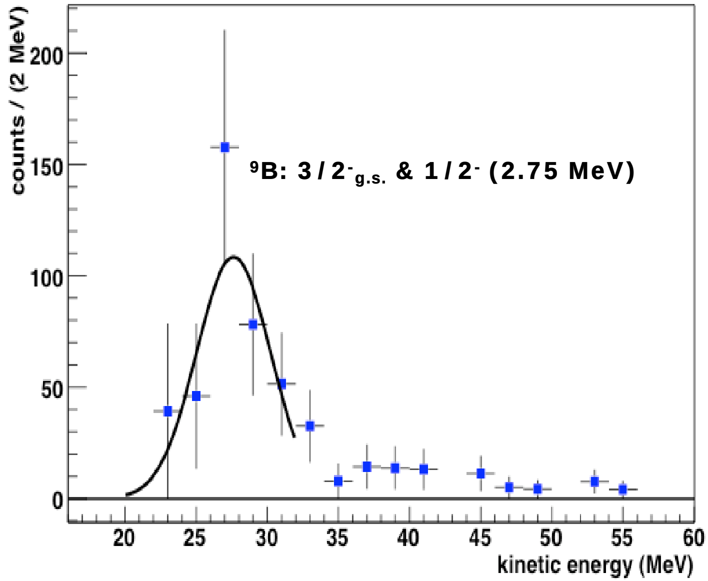
(J. Sasao, Phys. Lett. B 579 (2004) 258.)





Theoretical expectations

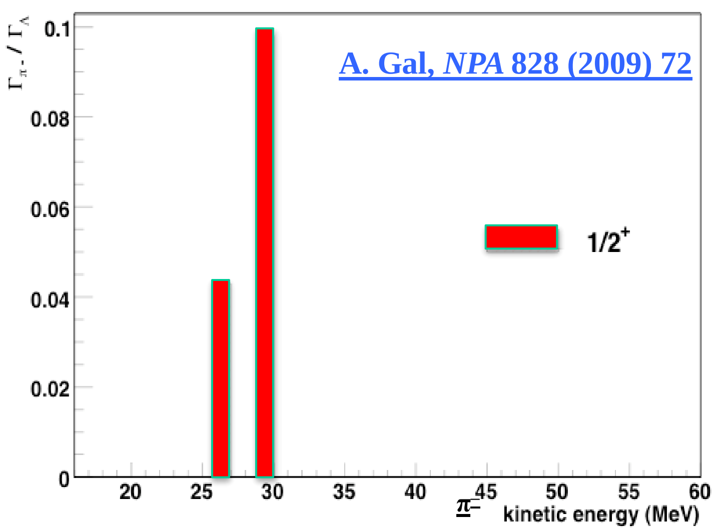
J^π assignment

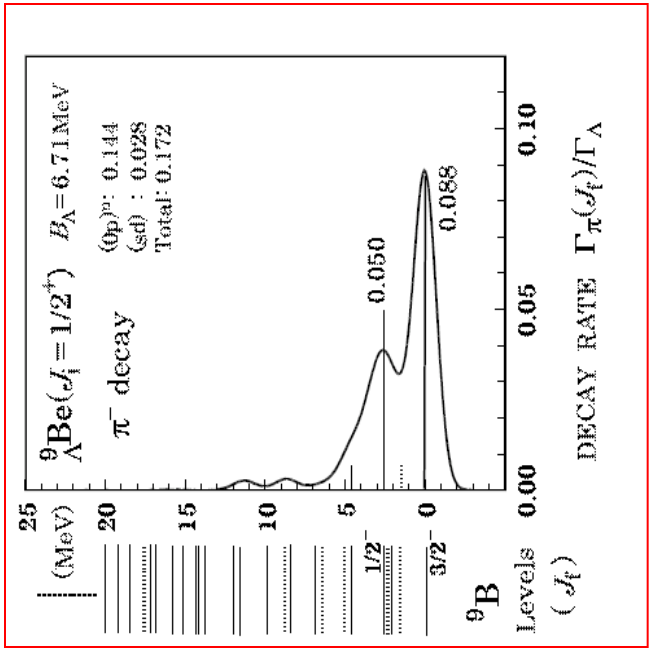


$^9Be_\Lambda$ J^π assignment has been confirmed:

J^π ($^9Be_{\Lambda\ g.s.}$) = 1/2$^+$

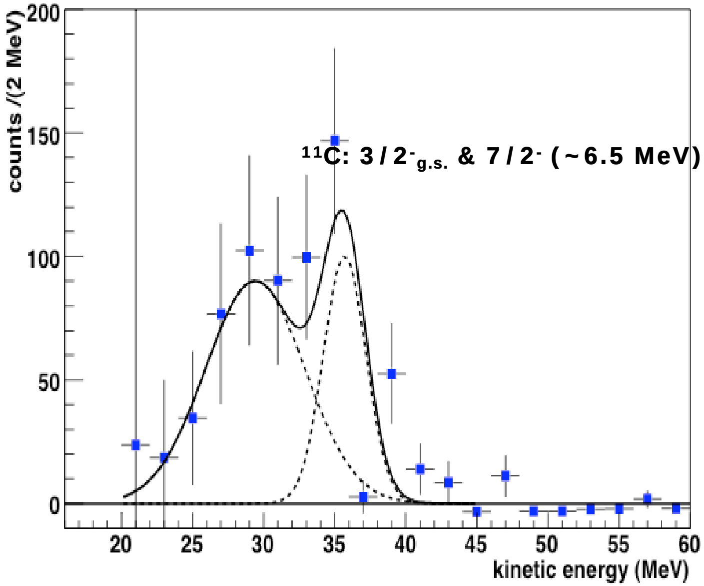
(O.Hashimoto *et al.*, Nucl. Phys. A 639 (1998) 93c.)

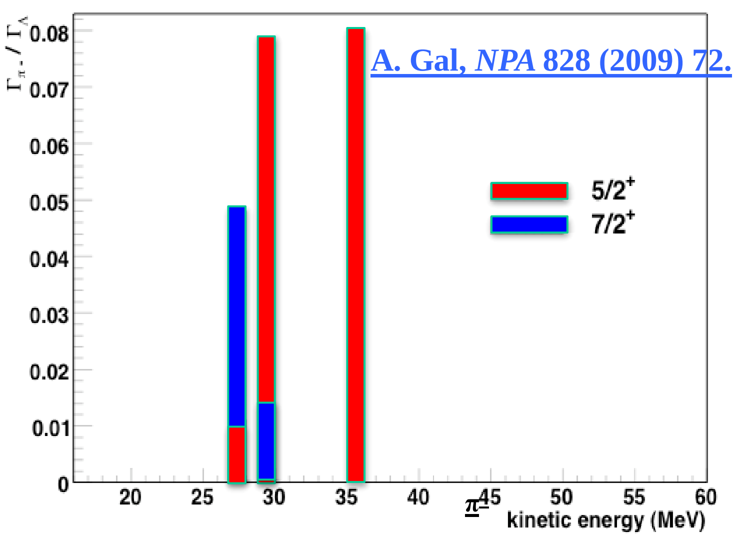




Theoretical expectations

J^{π} assignment

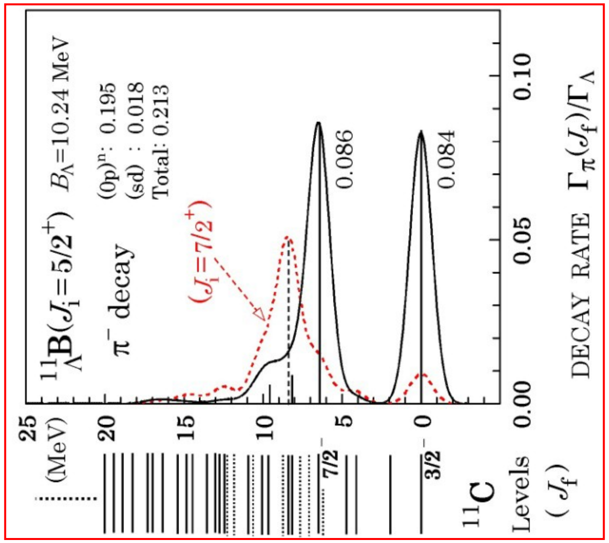




$^{11}B_{\Lambda}$ J^{π} **assignment has been confirmed:**

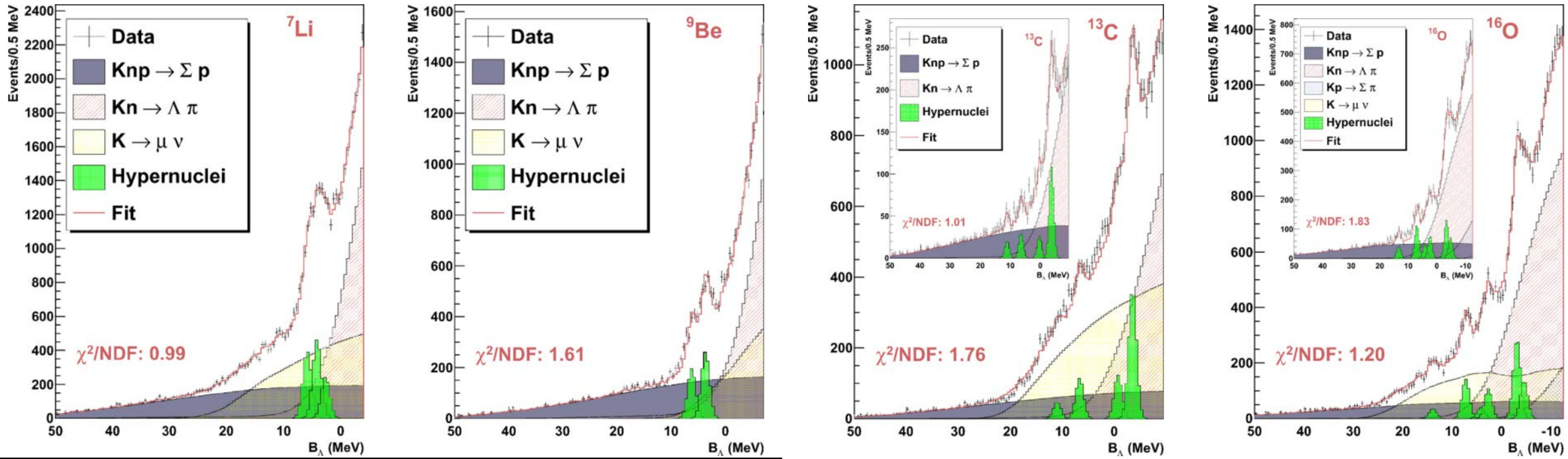
J^{π} ($^{11}B_{\Lambda\,g.s.}$) = 5/2$^+$

(Y. Sato et al., Phys. Rev. C 71 (2005) 025203)



Theoretical expectations

Hypernuclear Spectroscopy

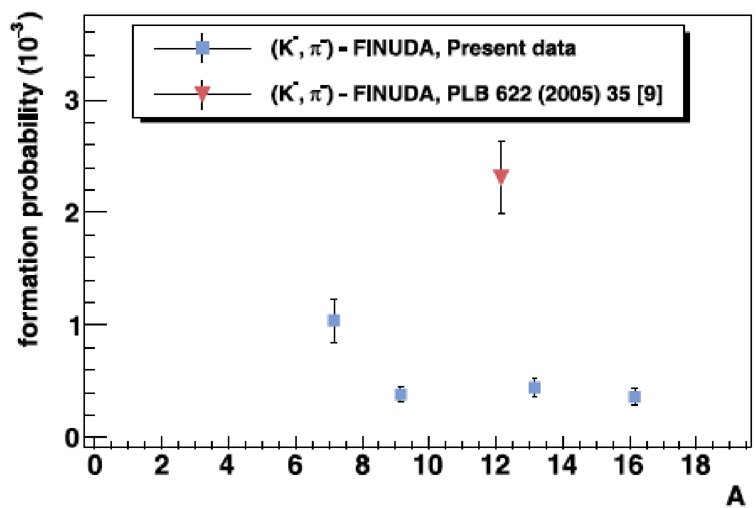


^{7}Li	B_Λ (MeV)	E_X (MeV)	Formation probability per stopped K^- (10^{-3})
1	5.8 ± 0.4	–	$0.37 \pm 0.04 \pm 0.05$
2	4.1 ± 0.4	1.7	$0.46 \pm 0.05 \pm 0.06$
3	2.6 ± 0.4	3.2	$0.21 \pm 0.03 \pm 0.03$

^{13}C	B_Λ (MeV)	E_X (MeV)	Formation probability per stopped K^- (10^{-3})
1	11.0 ± 0.4	–	$0.10 \pm 0.02 \pm 0.01$
2	6.4 ± 0.4	4.6	$0.19 \pm 0.02 \pm 0.03$
3	0.3 ± 0.4	10.7	$0.16 \pm 0.02 \pm 0.02$
4	-3.7 ± 0.4	14.7	$0.47 \pm 0.04 \pm 0.07$

^{9}Be	B_Λ (MeV)	E_X (MeV)	Formation probability per stopped K^- (10^{-3})
1	6.2 ± 0.4	–	$0.16 \pm 0.02 \pm 0.02$
2	3.7 ± 0.4	2.5	$0.21 \pm 0.02 \pm 0.03$

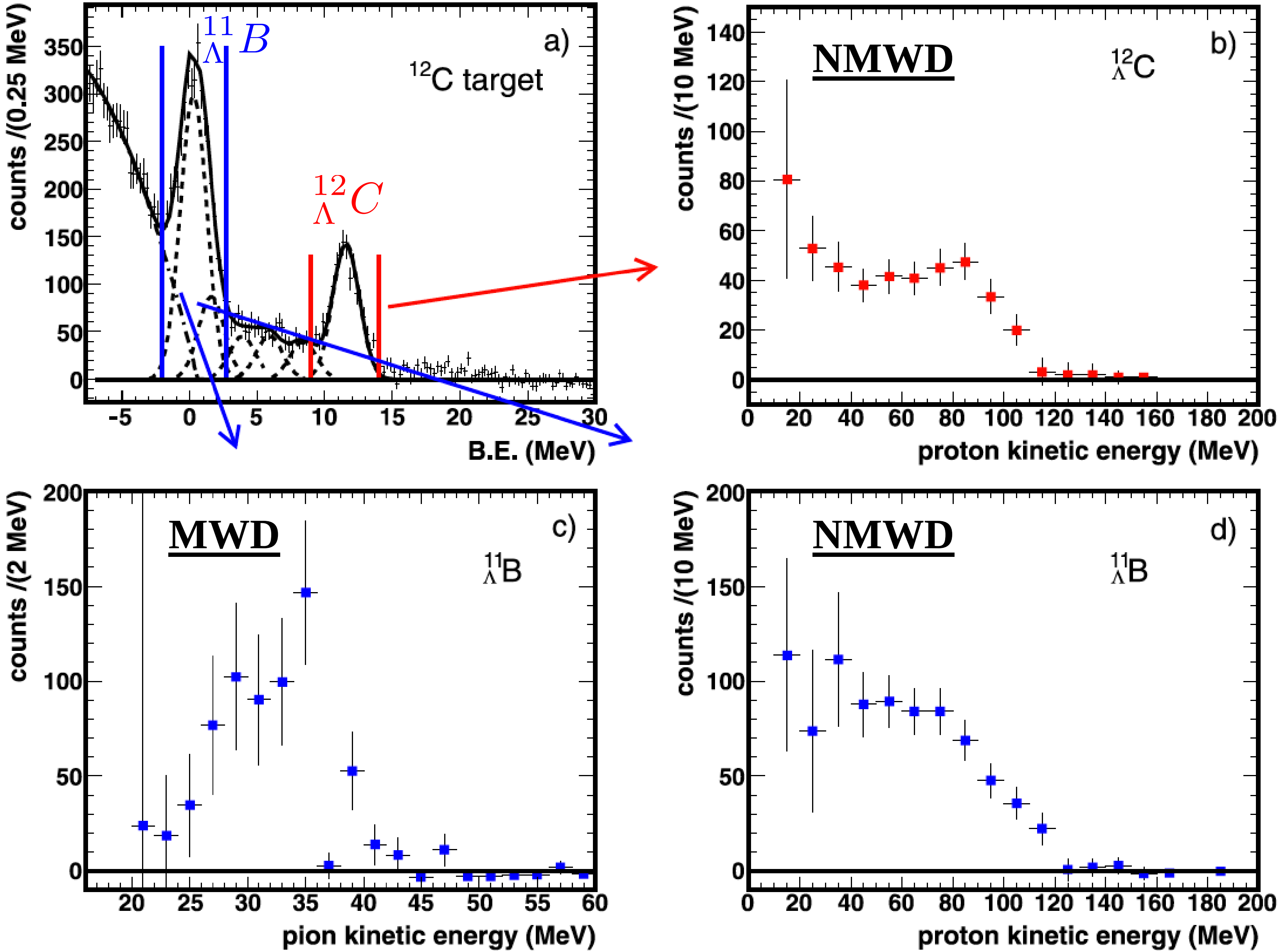
^{16}O	B_Λ (MeV)	E_X (MeV)	Formation probability per stopped K^- (10^{-3})
1	13.4 ± 0.4	–	$0.10 \pm 0.02 \pm 0.01$
2	7.1 ± 0.4	6.3	$0.26 \pm 0.04 \pm 0.04$
3	4.3 ± 0.4	9.1	$0.13 \pm 0.03 \pm 0.02$
4	2.4 ± 0.4	11.0	$0.15 \pm 0.03 \pm 0.02$
5	-3.3 ± 0.4	16.7	$0.55 \pm 0.07 \pm 0.08$
6	-4.7 ± 0.4	18.1	$0.28 \pm 0.06 \pm 0.04$



Formation rates

Phys. Lett. B 698 (2011) 219

Hypernuclear decay

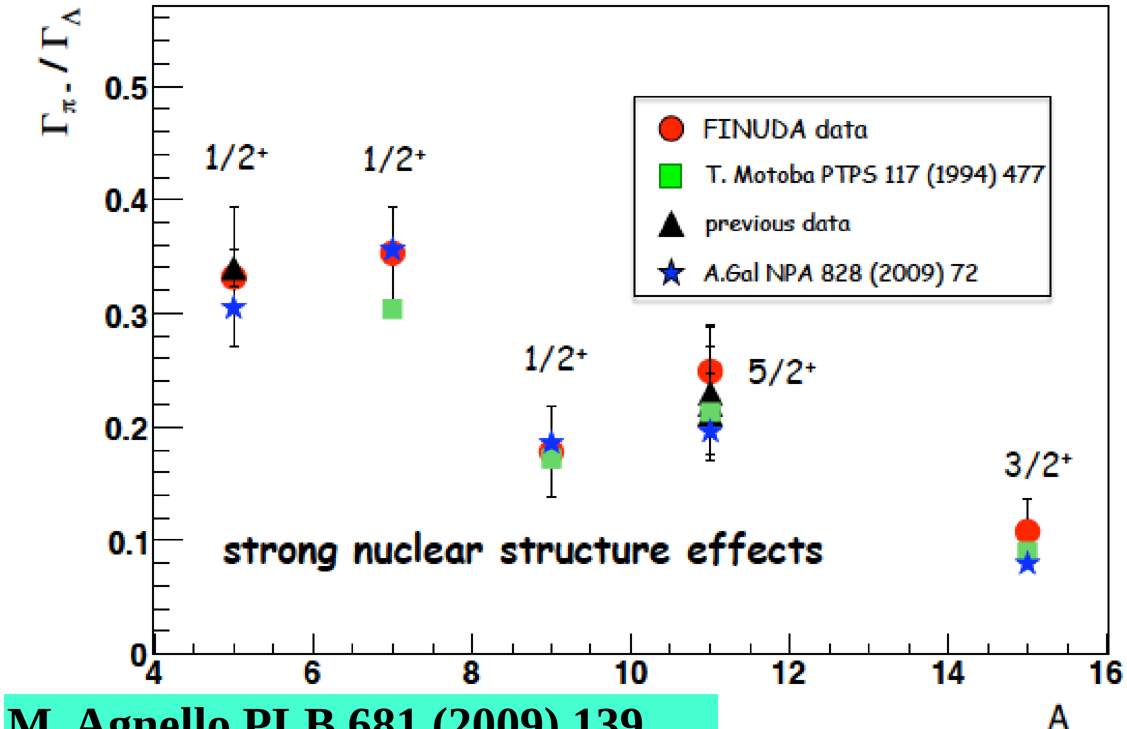


Mesonic decay rate

$$\Gamma_{\pi-} / \Gamma_{\Lambda} = \Gamma_{tot} / \Gamma_{\Lambda} \bullet \; BR_{\pi-}$$

$$\Gamma_{tot} / \Gamma_{\Lambda} = (0.990 \pm 0.094) + (0.018 \pm 0.010) \bullet A$$

π distortion, MWD enhancement proved

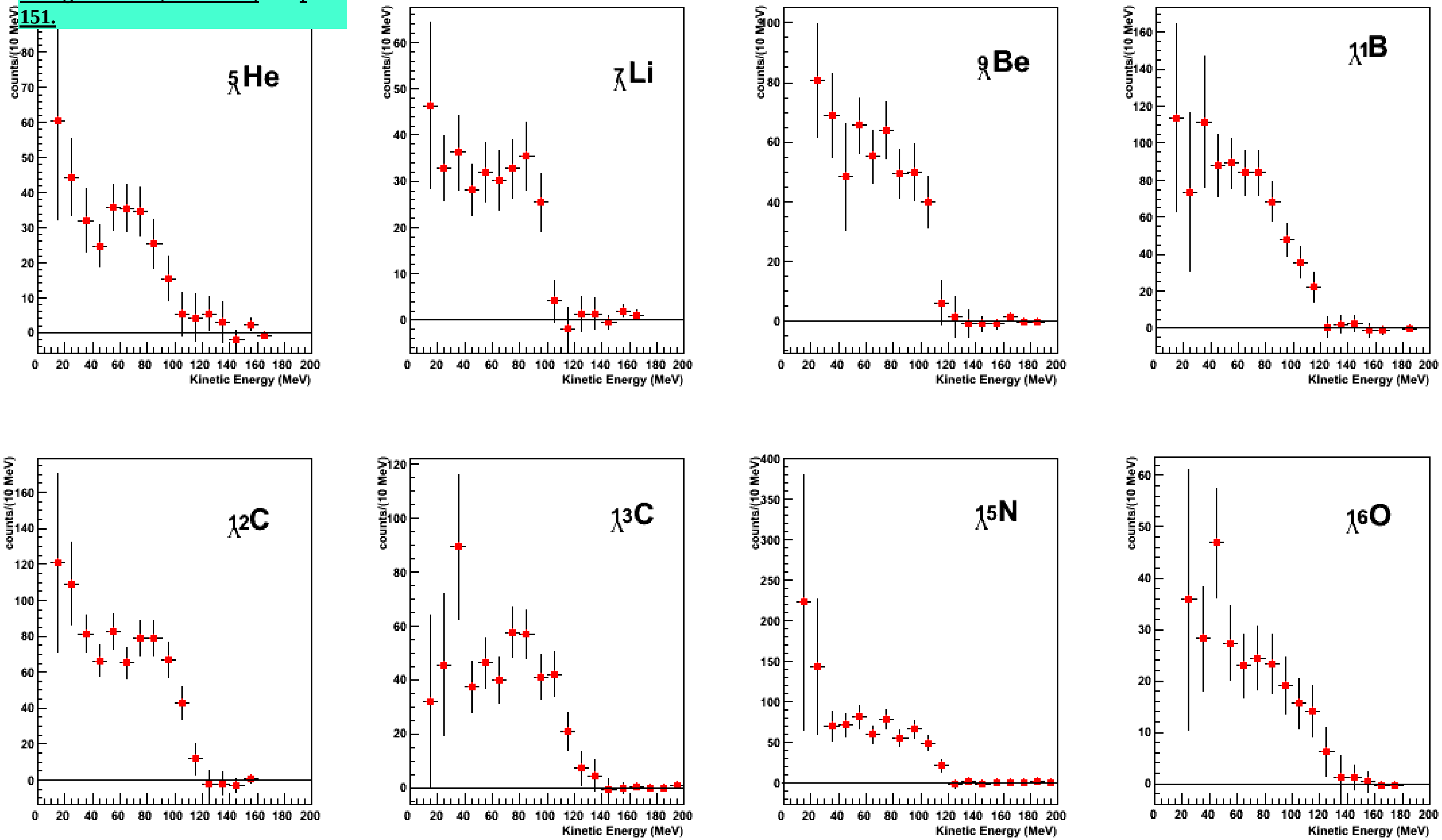


M. Agnello PLB 681 (2009) 139

NMWD of Hypernuclei

***p* spectra *K⁻(np)* background subtracted**

M. Agnello *et al.*, *NPA* 804 (2008) 151.



common features:

- **low energy rise**
- **structure at ~80 MeV**

M. Agnello *et al.*, *PLB* 685 (2010) 247.

$^{6}H_{\Lambda}$ production rate

First neutron-rich hypernucleus ever seen $K^{-}_{stop} + {}^{6}Li \rightarrow {}^{6}_{\Lambda}H + \pi^{+}$

$${}^{6}_{\Lambda}H \rightarrow {}^{6}He + \pi^{-}$$

background sources

- **accidentals: π⁺ (250 ÷ 255 MeV/c) and π⁻ (130 ÷ 137 MeV/c)** — **0.27 ± 0.27 ev.** BGD2

$K^{-}_{stop} + {}^{6}Li \rightarrow \Sigma^{+} + \pi^{-} + {}^{4}He + n$, $\Sigma^{+} \rightarrow n + \pi^{+}$ — **end point ~190 MeV/c end point ~282 MeV/c** — **0.16 ± 0.07 ev.** BGD1

$K^{-}_{stop} + {}^{6}Li \rightarrow {}^{4}_{\Lambda}H + n + n + \pi^{+}$, ${}^{4}_{\Lambda}H \rightarrow {}^{4}He + \pi^{-}$ — **end point ~252 MeV/c p(π⁻) = 133 MeV/c** — **negligible**

signal events

- **total background on ^{6}Li:** **BGD1 + BGD2 = 0.43 ± 0.28 ev.**

- **Poisson statistics:** **3 events DO NOT belong to pure background @ C.L. = 99%**

Production rate = (2.9 ± 2.0) × 10^{-6}/ K^{-}_{stop}

FINUDA Coll. and A. Gal, *PRL* 108 (2012) 042501

Bound Kaonic States

- **Akaishi-Yamazaki** — deep potentials → large B.E. small widths → a few nucleon aggregate

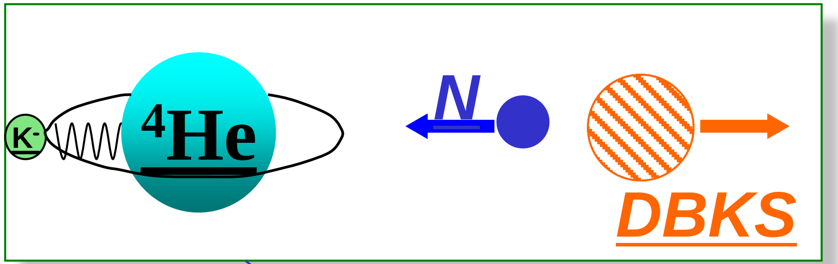
- **Weise et al.**
- **Gal et al.**
- **Oset, Ramos et al.**
- **Wycech et al.**
- **Schäffner-Bielich et al.**

} shallow potentials → moderate-large B.E. large widths(>50 MeV), → more visible on heavy systems

EXP. SITUATION

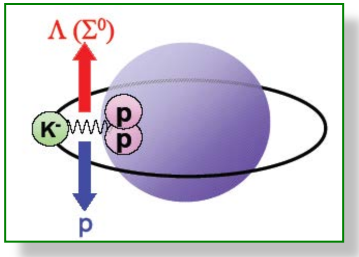
Scarce information → Missing mass / Invariant mass

Missing mass:



KEK, AGS, FINUDA

Invariant mass:



FINUDA, FOPI

Experimental results

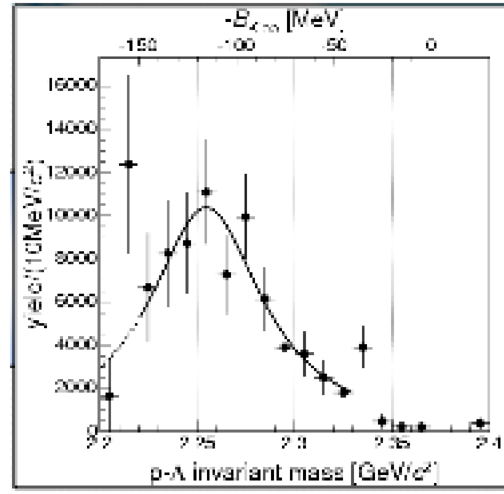
PRL 94(2005)212303

A(K-,Λp)X

B = 115^{+6}_{-5} (stat)$^{+3}_{-4}$ (sys) MeV

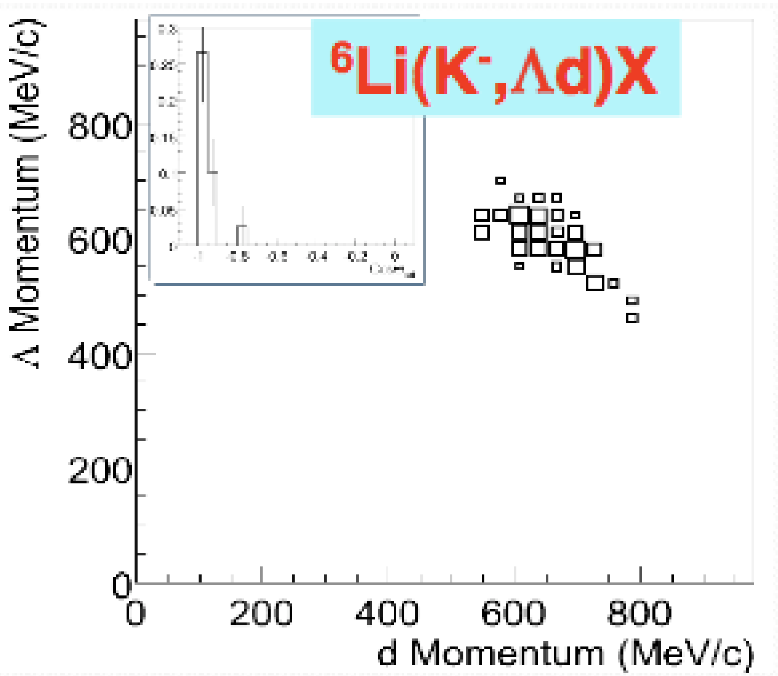
Γ = 67^{+14}_{-11} (stat)$^{+2}_{-3}$ (sys) MeV

Yield ≈ 0.1%/stopped K$^-$



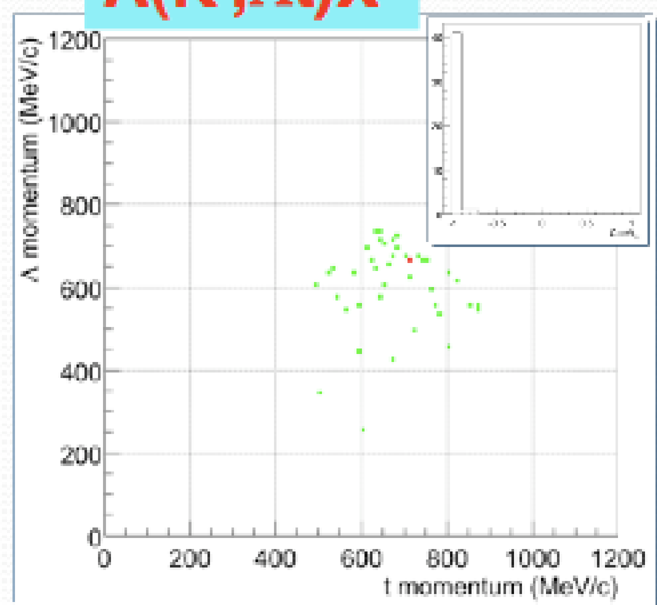
PLB 654(2007)80

^{6}Li(K$^-$,Λd)X



A(K$^-$,Λt)X

PLB 669(2008)229



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

KAONNIS (Integrated Initiative):

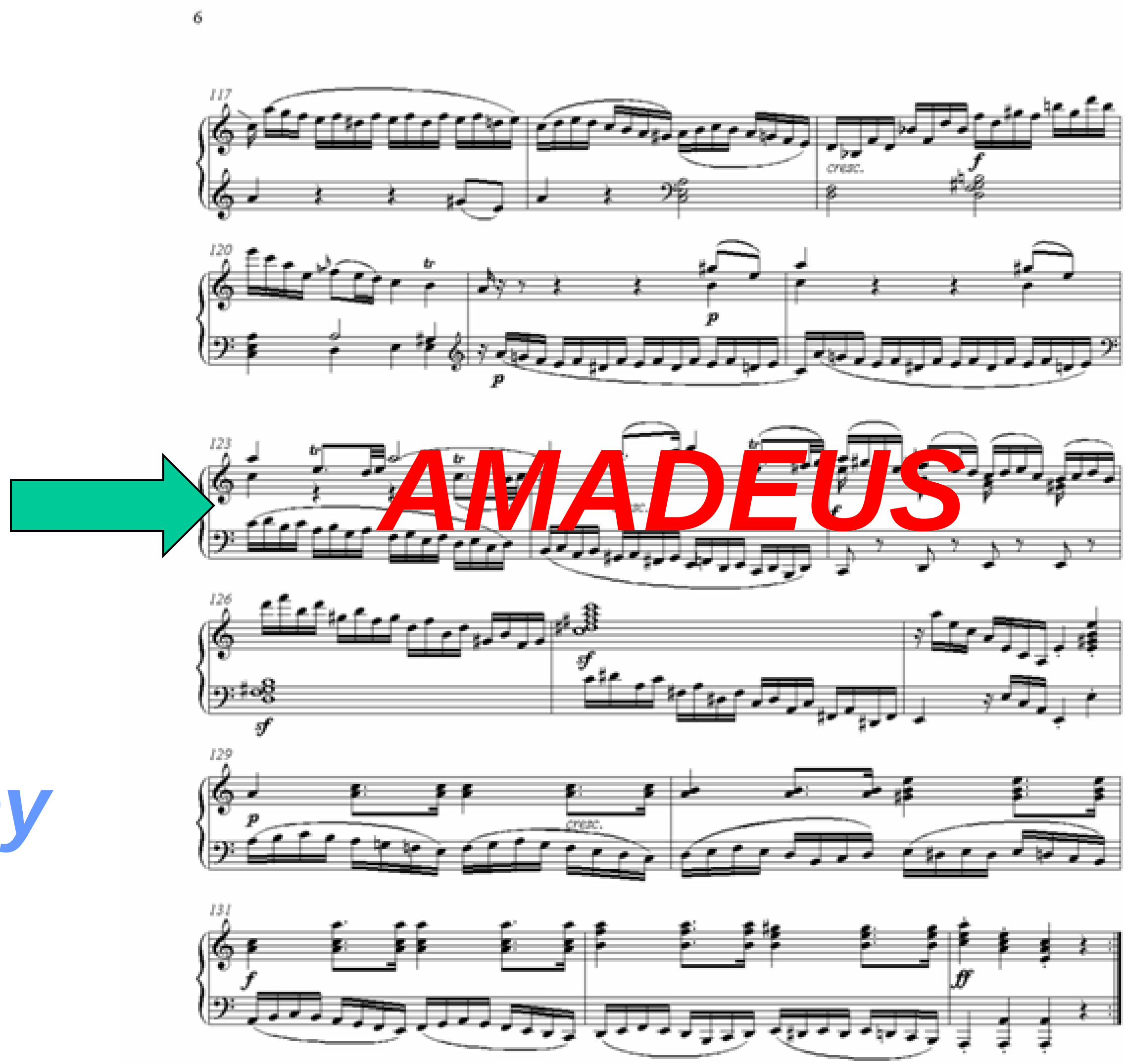
Unique studies of the low-energy kaon-nucleon/nuclei interactions -> low-energy QCD in strangeness sector with implications from particle (Λ(1405)) and nuclear (kaonic nuclear clusters?) physics to astrophysics (equation of state -> role of strangeness)

- 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)

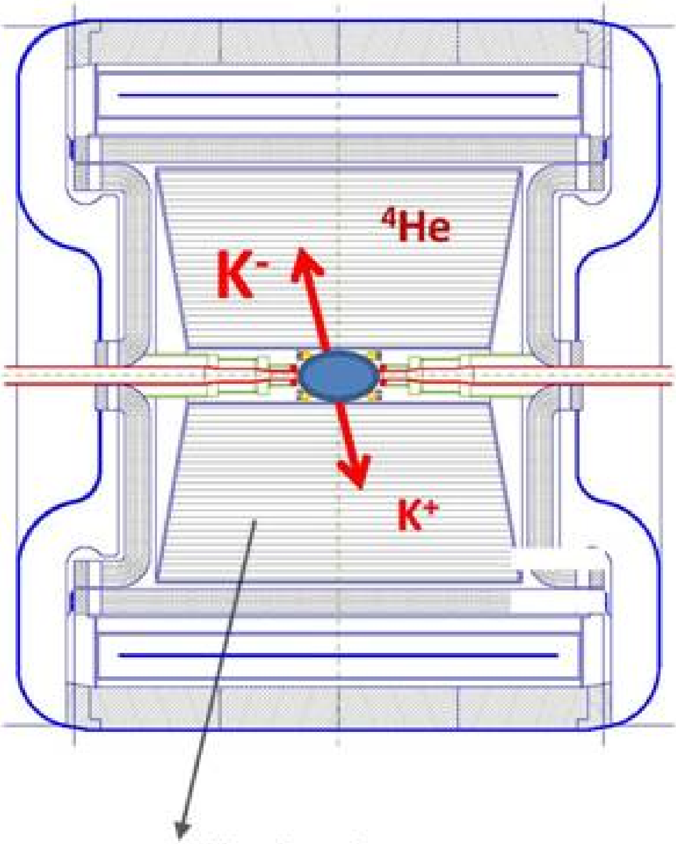
HadronPhysics2
Study of Strongly Interacting Matter

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**)

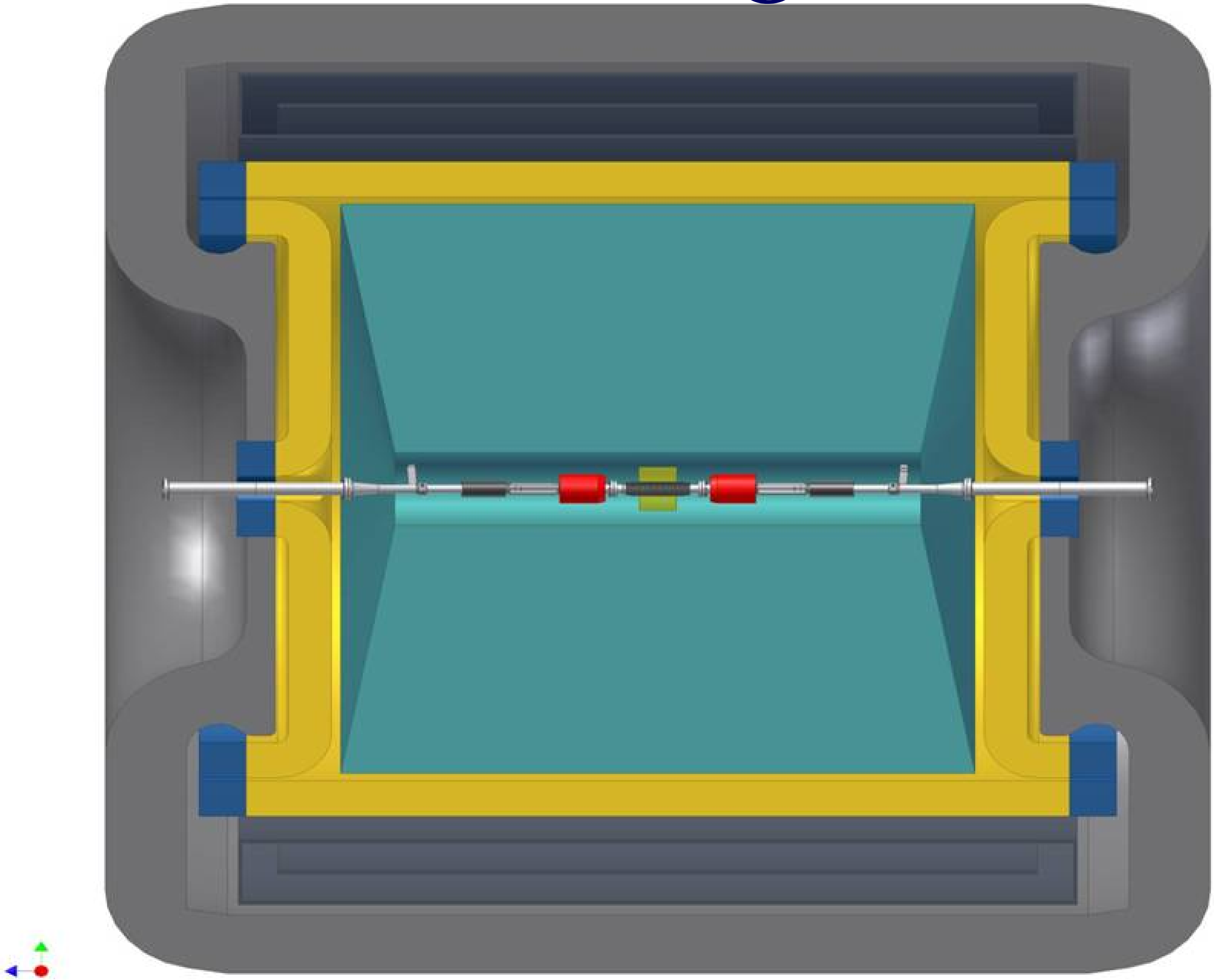
Hadronic interactions of K^- in KLOE



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

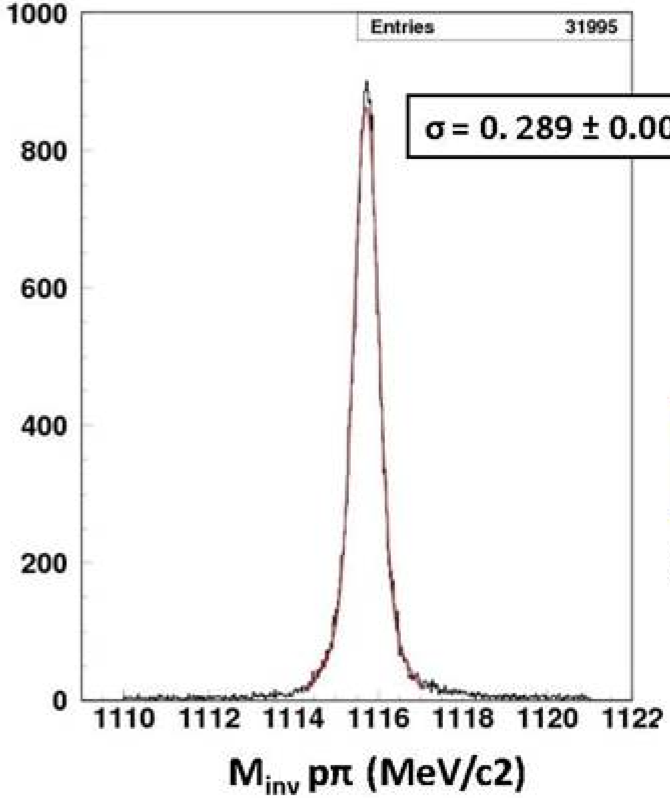
    - **Λp** from 1NA or 2NA (single or multi-nucleon absorption)
    - **Λd** and **Λt** channels
    - Λ (1405) -> **$\Sigma^0\pi^0$**
    - Λ (1405) -> **$\Sigma^+\pi^-$**
    - $\Sigma N/\Lambda N$ internal conversion rates

- R&D for more refined setup

- Future possible scenario

Lambda invariant mass

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



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

- Best $\chi 2$ tracks and vertices

PRELIMINARY

M_{inv} = 1115,723 ± 0. 003 stat (MeV/c²)

PDG: M_Λ = 1115,683 ± 0.006 stat ± 0.006 syst (MeV/c²)

-Sistematics dependent of momentum calibration

Preliminary evaluation with 2-body decay

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

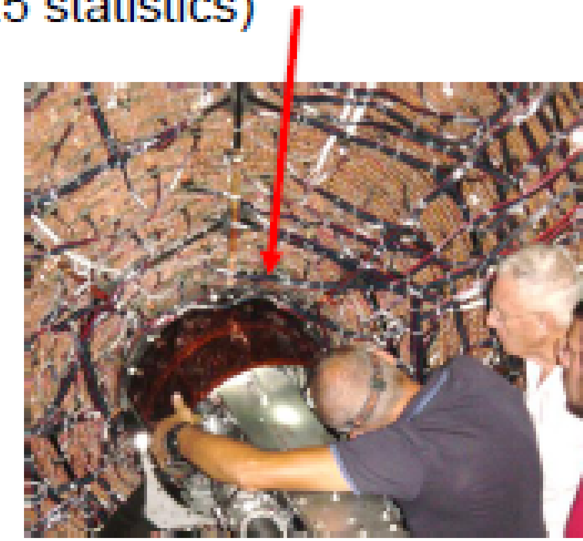
$K^\pm \rightarrow \pi^\pm \pi^0$

KLOE data on K⁻ nuclear absorption

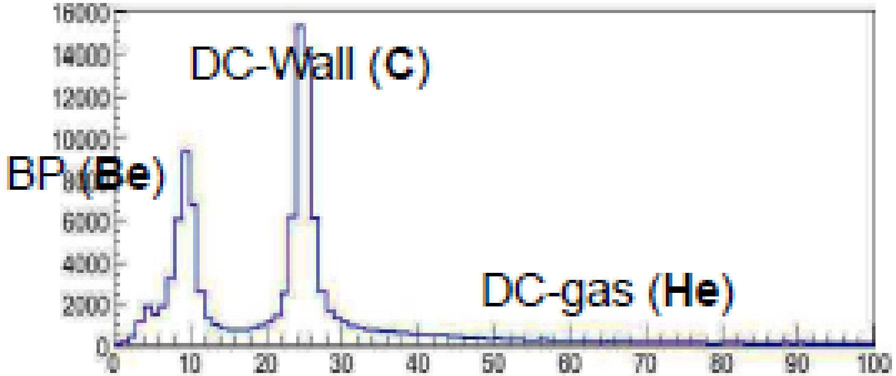
Use of two different data samples:

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

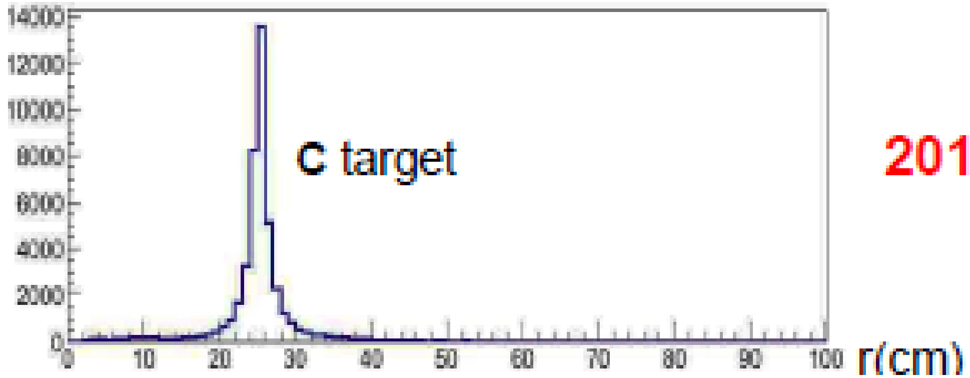
- Dedicated run in november/december **2012** with a **Carbon target** of 4/6 mm of thickness (~90 pb^{-1}; analyzed 37 pb^{-1}, x1.5 statistics)



Position of the K^- hadronic interaction inside KLOE:



2005 data



2012 with Carbon target

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

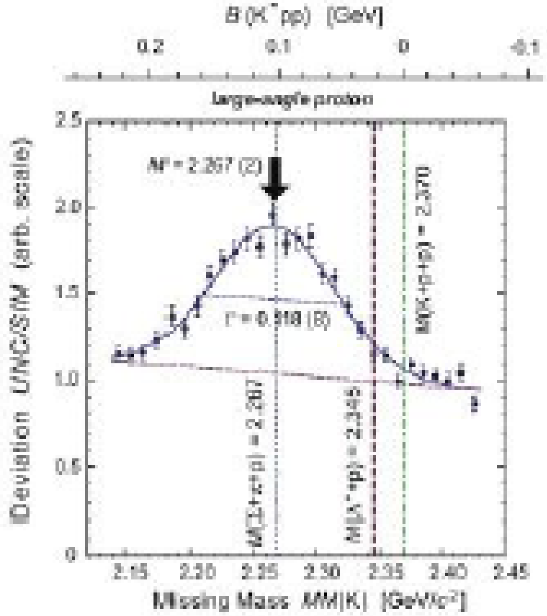
Λp analysis

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

-Competing processes:

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

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



Nucl.Phys.A835, 43 (2010)

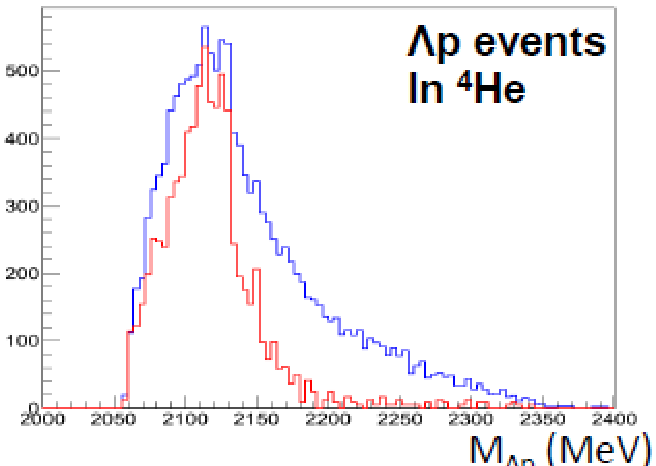
Λp analysis

-Competing processes:

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

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

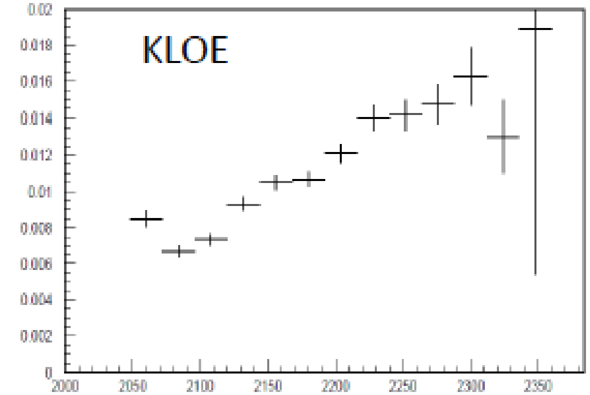
A perfect disentanglement between single and multi-nucleon absorption can be achieved thanks to the **nice acceptance:**



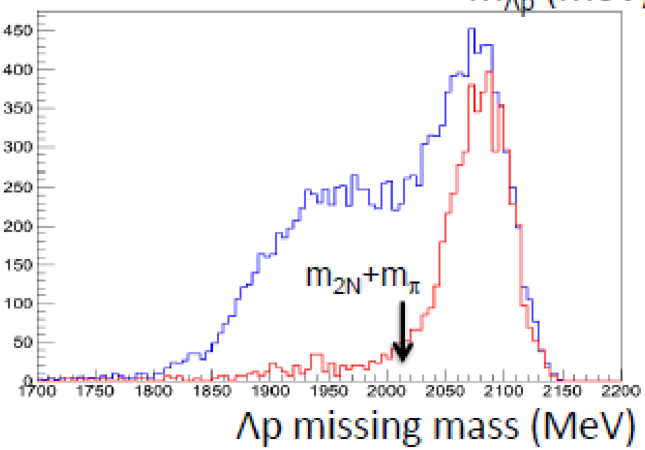
Λp all events

Λπ⁻(p) events

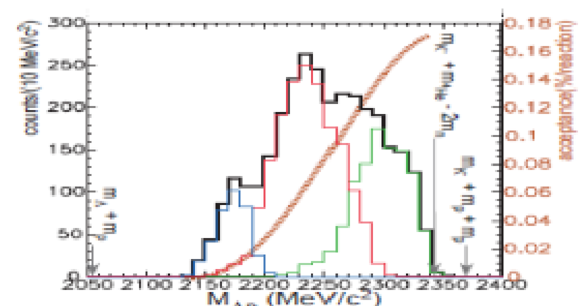
(arbitrary normalization)



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



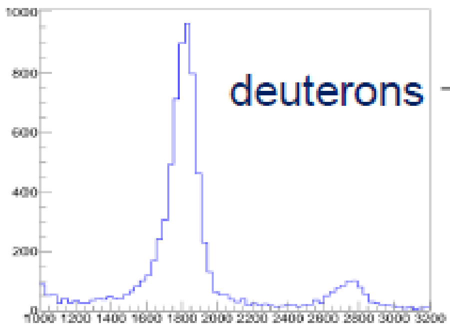
The Λp missing mass for the Λπ⁻(p) events lies exactly In the 2N+π⁻ mass region



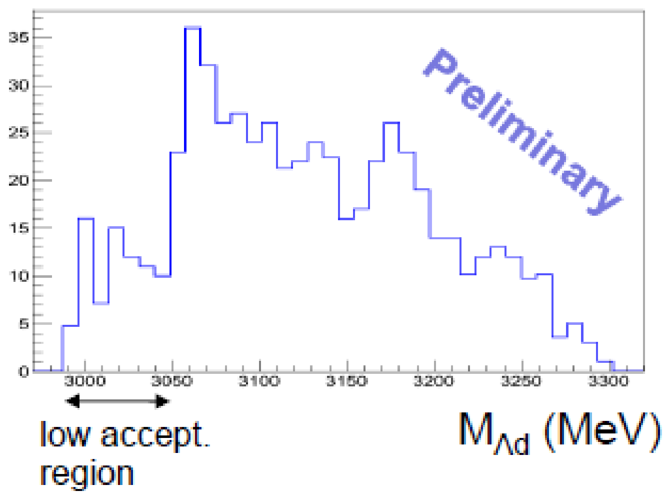
KEK-E549
Mod.Phys.Lett.A23, 2520 (2008)

Λd, Λt analyses

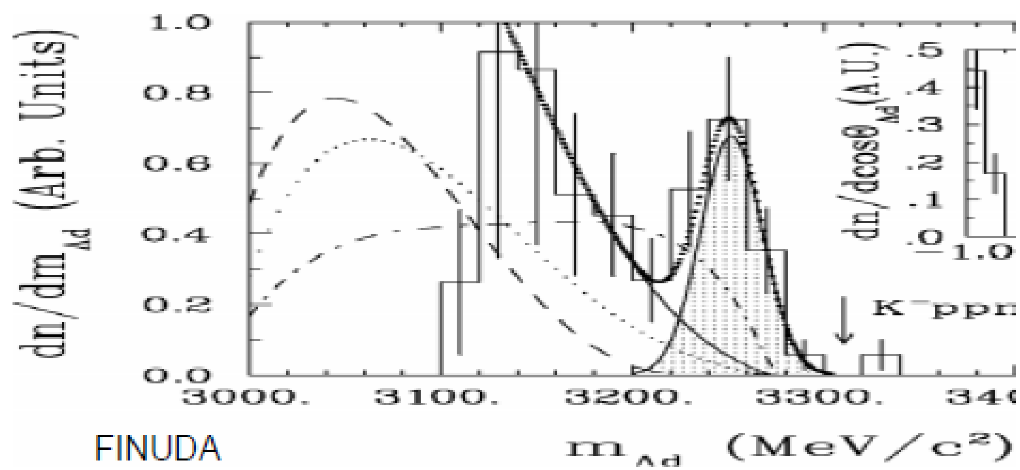
- Search for signal of bound states in the **Λd** channel. Candidate to be a **K^-ppn** cluster. Observed spectra from FINUDA and KEK again showing possible bound states in the in the high invariant mass region.



TOF Particle Mass (MeV)



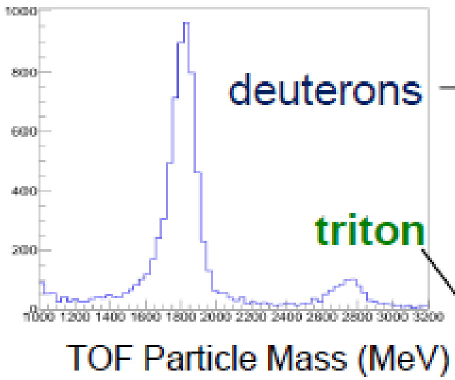
Λd events
In ^{4}He

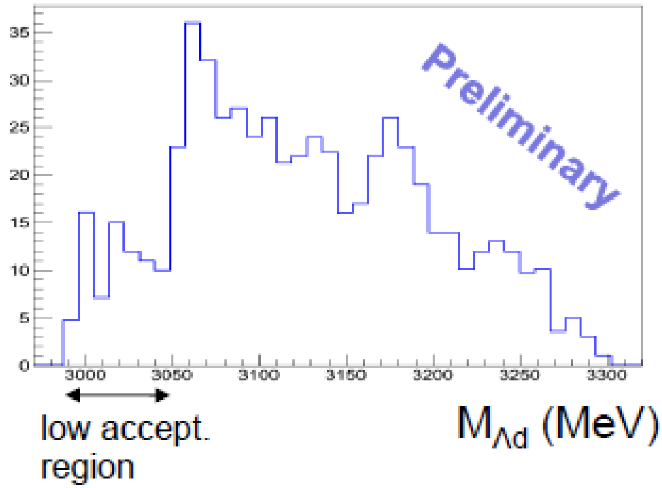


FINUDA
Nucl.Phys.A835, 43 (2010)

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.

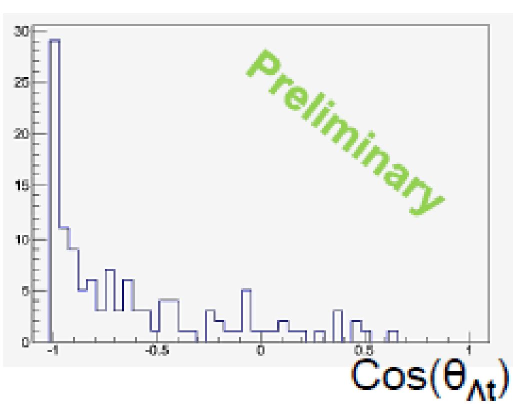


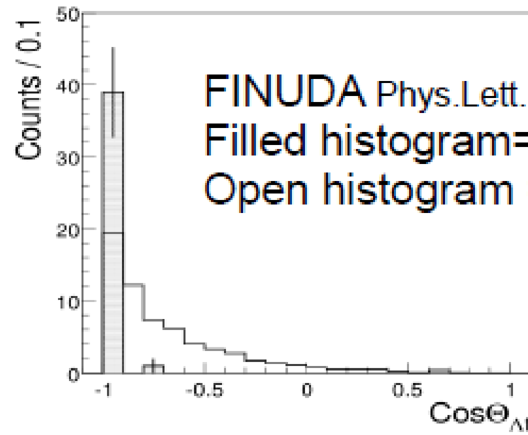


Λd events
In ^{4}He

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

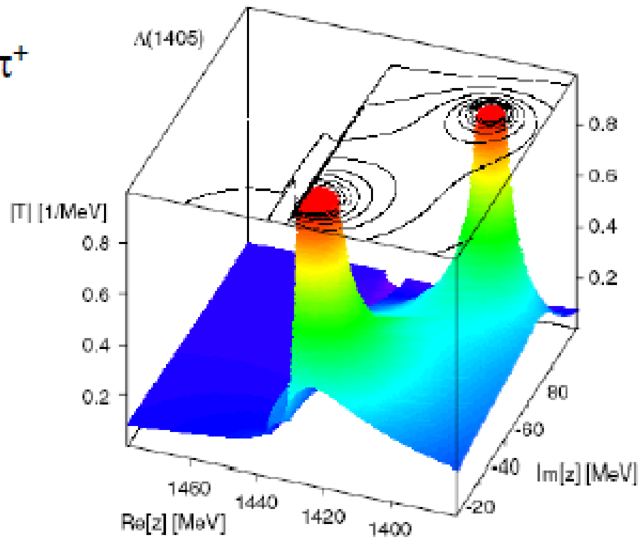
3) ***unstable* KN *bound state***

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:

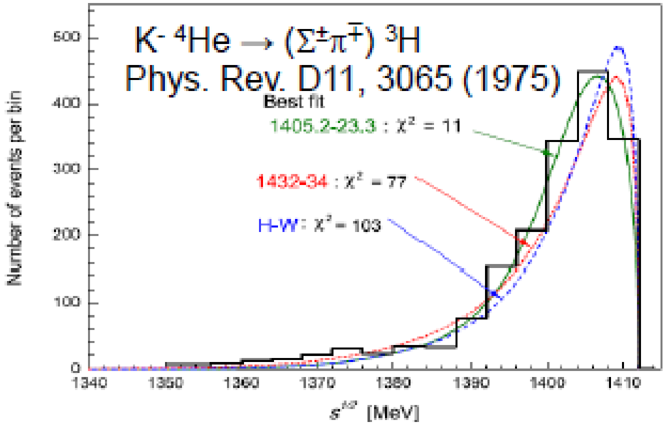
production in KN reactions (only chance to observe the high mass pole) **decaying in $\Sigma^0\pi^0$** (free from $\Sigma(1385)$ background)

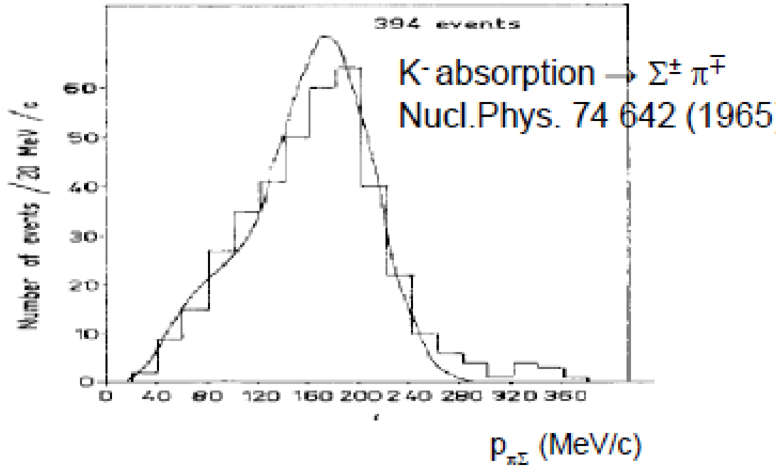
Λ(1405) previous experiments

Old **absorption experiments:**

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

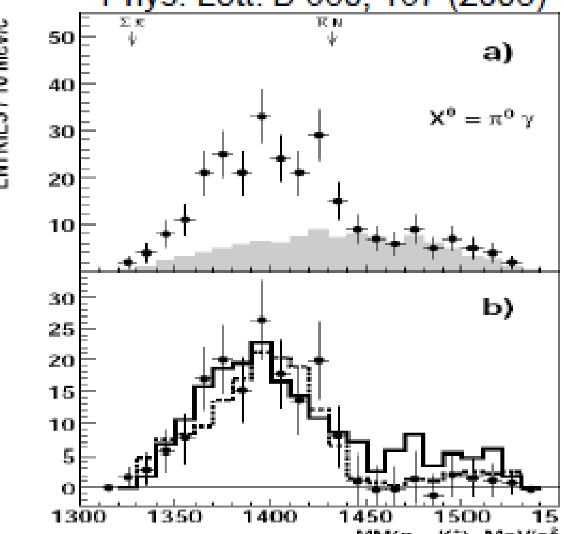
-$\Sigma^{\pm}\pi^{\mp}$ spectra suffer Σ(1385)contamination



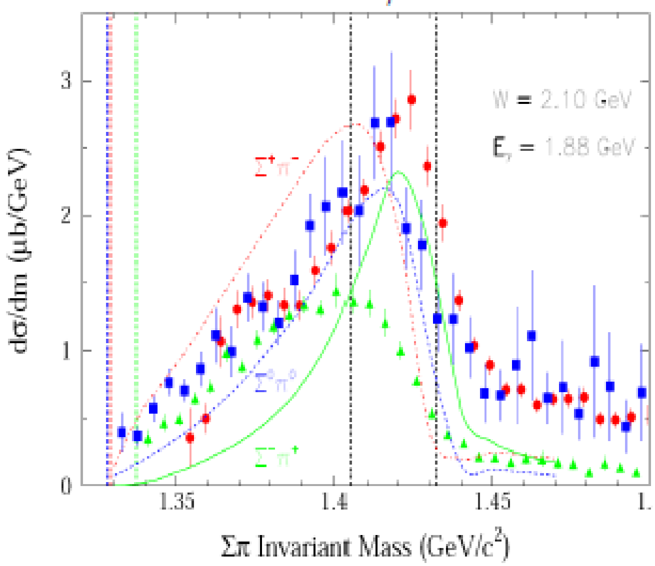


Other (**non-absorption**) experiments present spectra in the $\Sigma^0\pi^0$ channel (only three experiments…with different lineshapes!):

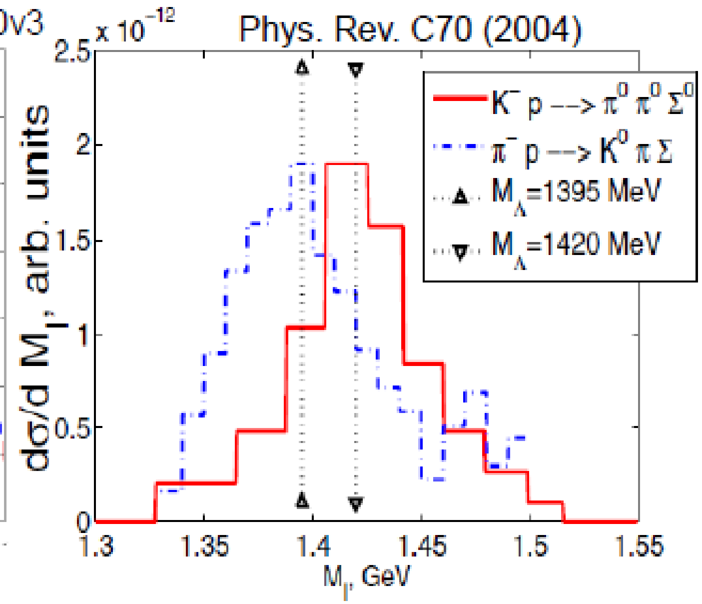
Phys. Lett. B 660, 167 (2008)



CLAS Collaboration, ArXiv:1301.5000v3



Phys. Rev. C70 (2004)

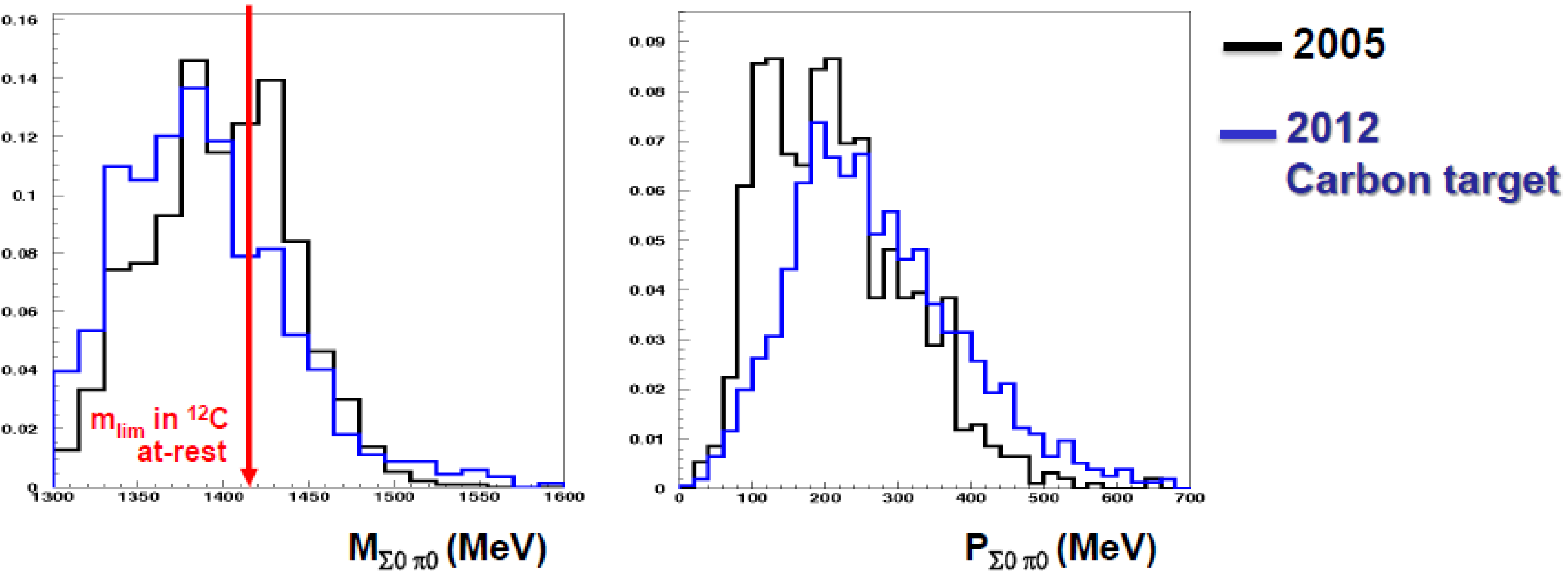


Analysis of $\Sigma^0\pi^0$ channel

$\Lambda(1405)$ 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

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)**

HYP2012

Concluding Remarks

Tomofumi NAGAE,

Kyoto University

HIGHLIGHTS

HYP2012 — HYP-X

3-year progress

160 participants form 20 countries !

HIGHLIGHTS

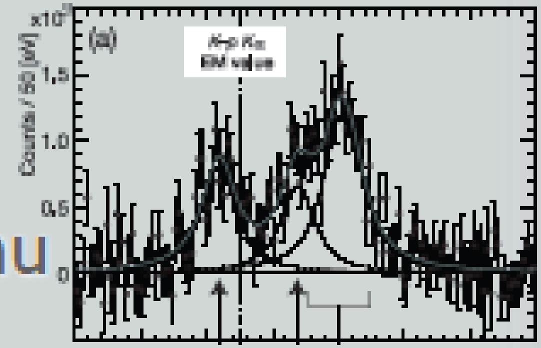
HYP2012

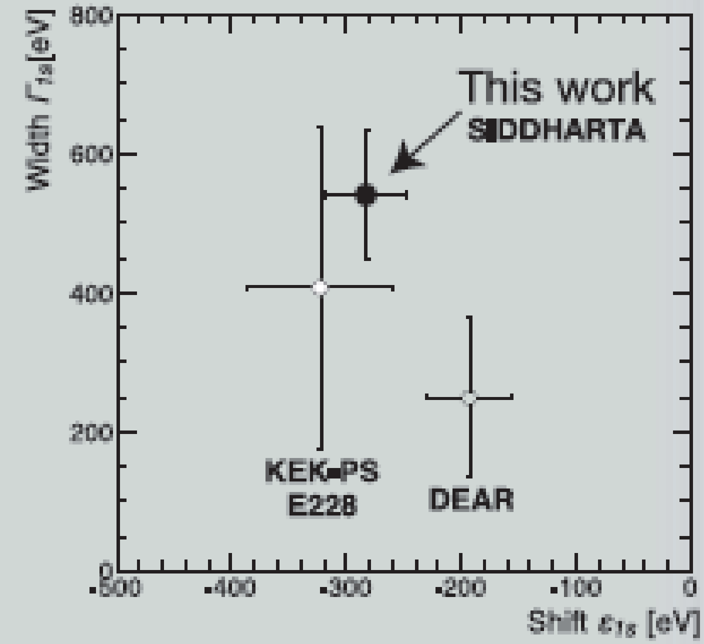
... And a lot of intensive discussions.

Nuclear Kaonic Systems

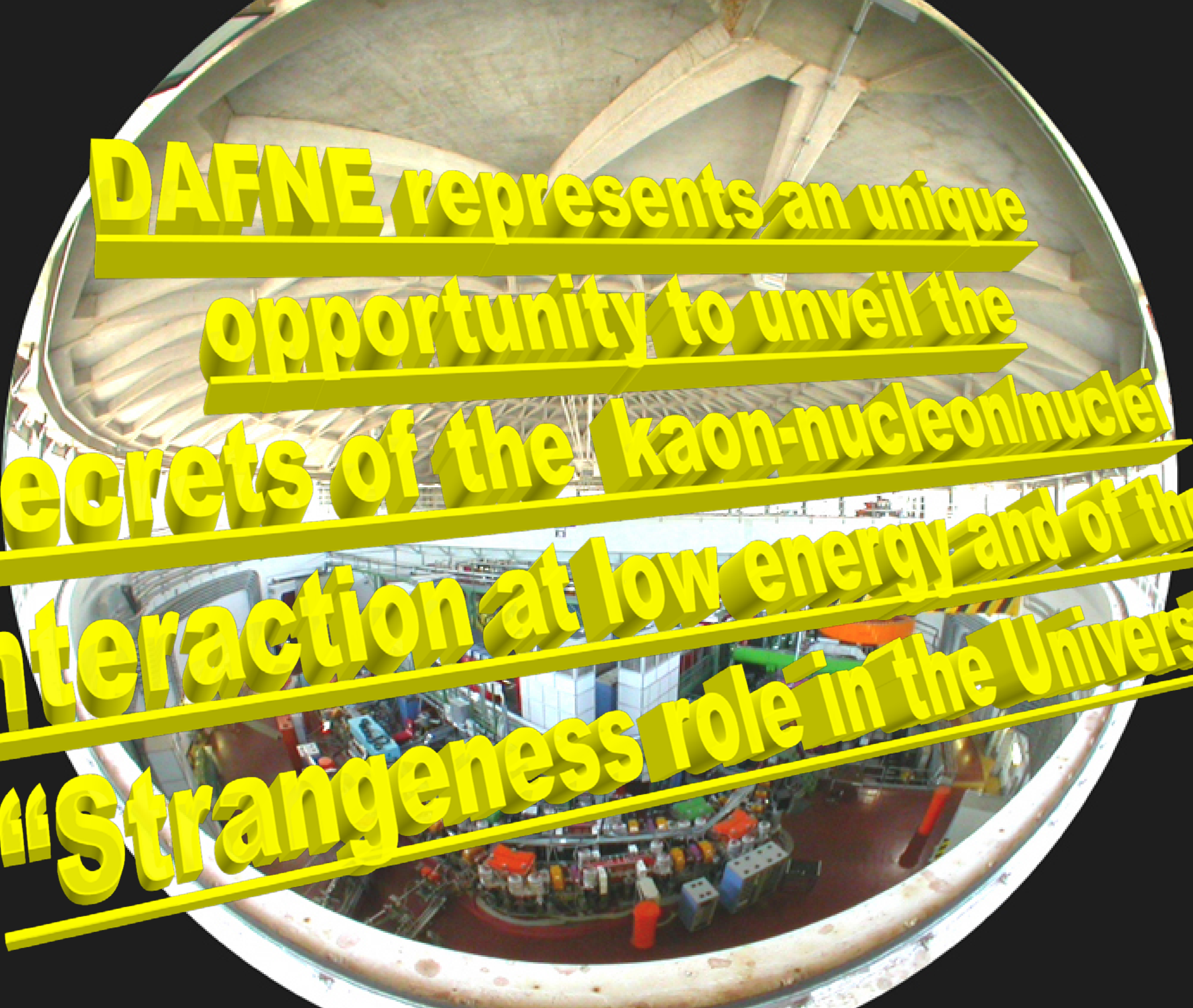
HYP2012

- SIDDHARTA and AMADEUS : C. Curceanu





- Kaonic hydrogen
  - Consitent with low Energy scatt.
- Kaonic ^{3,4}He puzzle for Shifts & Widths solved: T. Ishiwatari
- SIDDHARTA-2 for K^-d



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”

Dialogues on a blackboard in Garching (continued)

QCD and the origin of mass:

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