L'odissea degli atomi esotici a DAFNE

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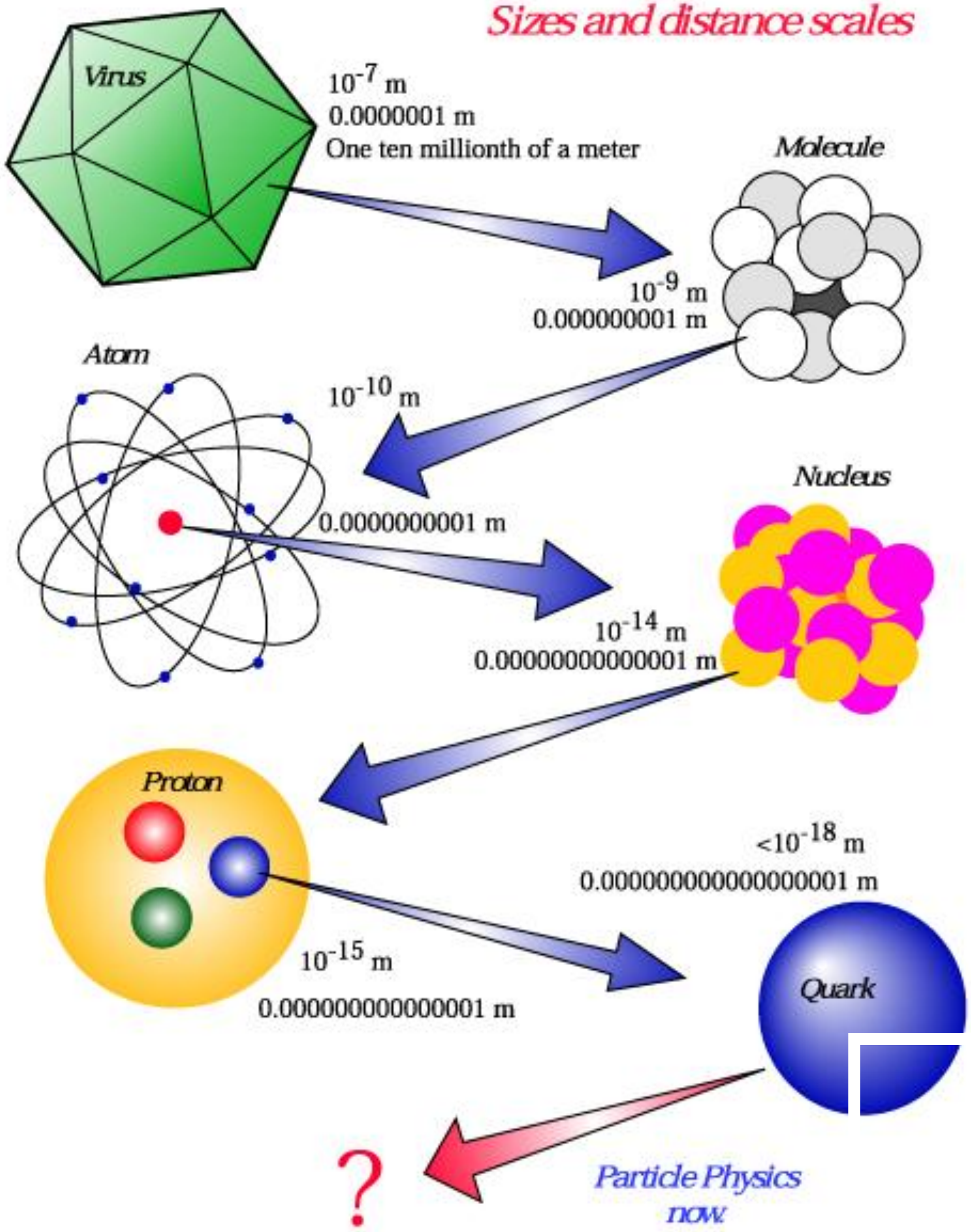
Scuola per dottorato
16-19 Giugno 2014 LNF-INFN

Sizes and distance scales



Virus

10^{-7} m
0.0000001 m
One ten millionth of a meter

Molecule

10^{-9} m
0.000000001 m

Atom

10^{-10} m
0.0000000001 m

Nucleus

10^{-14} m
0.00000000000001 m

Proton

10^{-15} m
0.000000000000001 m

$<10^{-18}$ m
0.000000000000000001 m

Quark

?

Particle Physics
now.

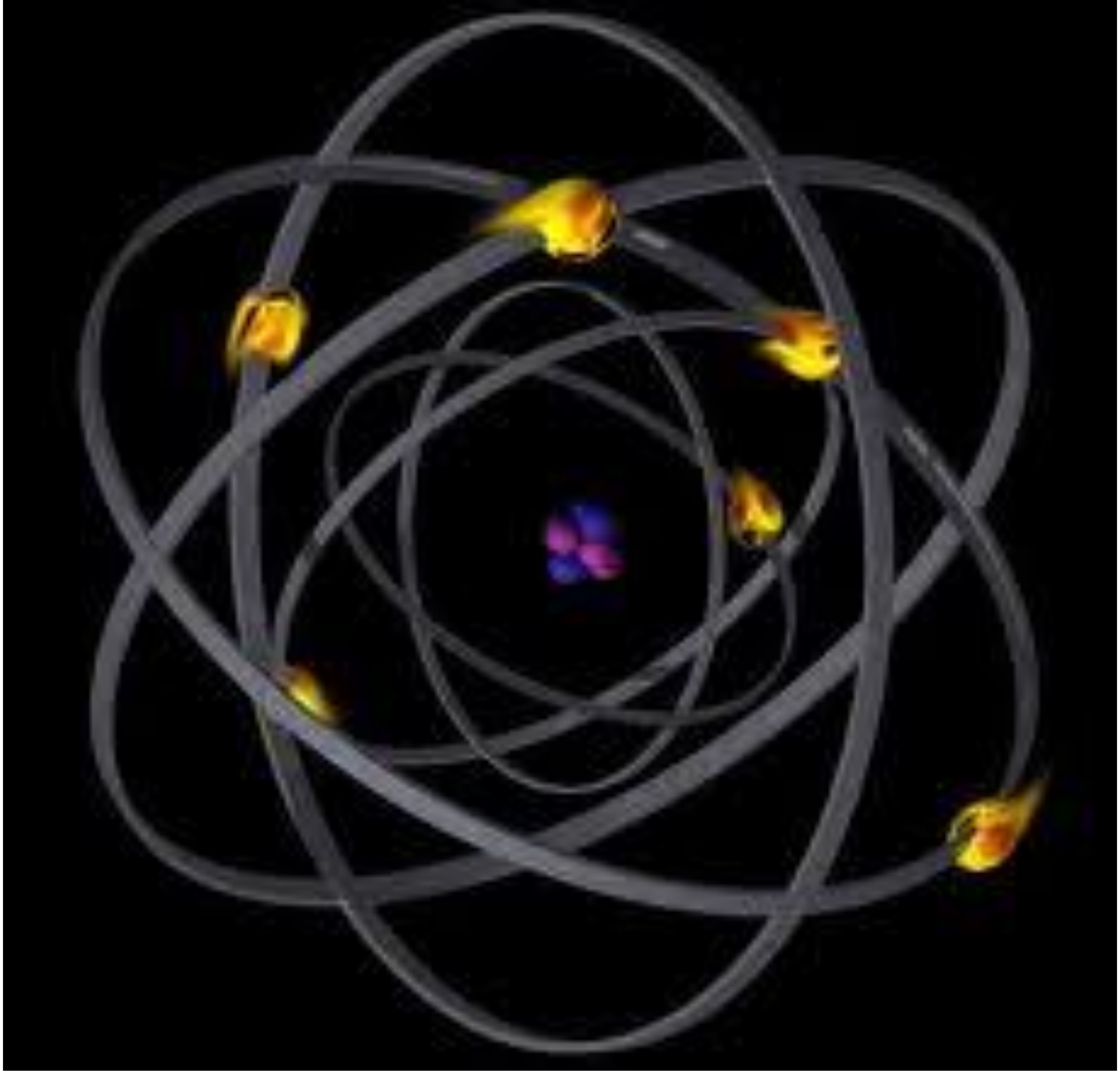
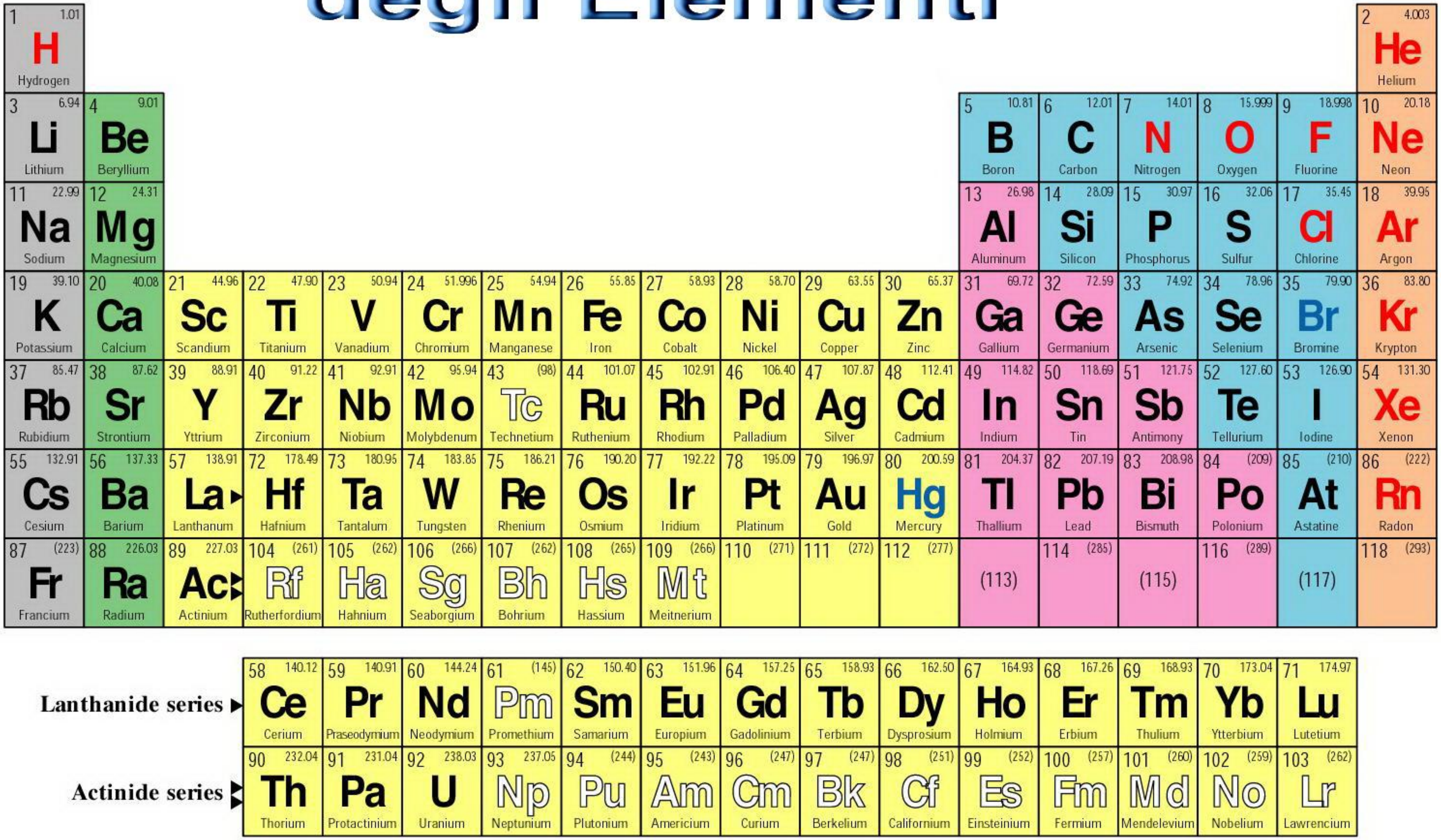


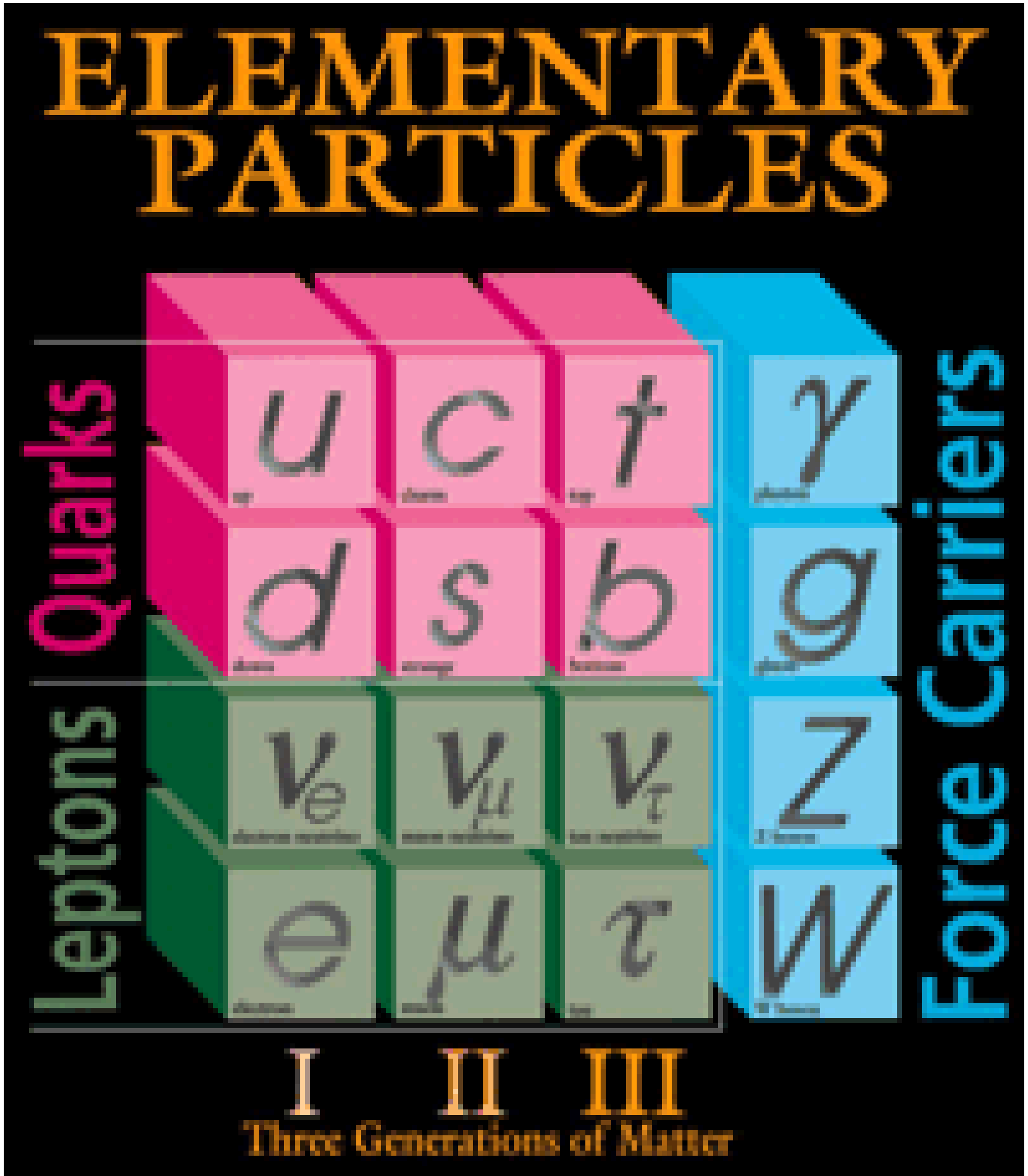
Tavola Periodica degli Elementi



1 1.01 H Hydrogen																	2 4.003 He Helium
3 6.94 Li Lithium	4 9.01 Be Beryllium											5 10.81 B Boron	6 12.01 C Carbon	7 14.01 N Nitrogen	8 15.999 O Oxygen	9 18.998 F Fluorine	10 20.18 Ne Neon
11 22.99 Na Sodium	12 24.31 Mg Magnesium											13 26.98 Al Aluminum	14 28.09 Si Silicon	15 30.97 P Phosphorus	16 32.06 S Sulfur	17 35.45 Cl Chlorine	18 39.95 Ar Argon
19 39.10 K Potassium	20 40.08 Ca Calcium	21 44.96 Sc Scandium	22 47.90 Ti Titanium	23 50.94 V Vanadium	24 51.996 Cr Chromium	25 54.94 Mn Manganese	26 55.85 Fe Iron	27 58.93 Co Cobalt	28 58.70 Ni Nickel	29 63.55 Cu Copper	30 65.37 Zn Zinc	31 69.72 Ga Gallium	32 72.59 Ge Germanium	33 74.92 As Arsenic	34 78.96 Se Selenium	35 79.90 Br Bromine	36 83.80 Kr Krypton
37 85.47 Rb Rubidium	38 87.62 Sr Strontium	39 88.91 Y Yttrium	40 91.22 Zr Zirconium	41 92.91 Nb Niobium	42 95.94 Mo Molybdenum	43 (98) Tc Technetium	44 101.07 Ru Ruthenium	45 102.91 Rh Rhodium	46 106.40 Pd Palladium	47 107.87 Ag Silver	48 112.41 Cd Cadmium	49 114.82 In Indium	50 118.69 Sn Tin	51 121.75 Sb Antimony	52 127.60 Te Tellurium	53 126.90 I Iodine	54 131.30 Xe Xenon
55 132.91 Cs Cesium	56 137.33 Ba Barium	57 138.91 La ▸ Lanthanum	72 178.49 Hf Hafnium	73 180.95 Ta Tantalum	74 183.85 W Tungsten	75 186.21 Re Rhenium	76 190.20 Os Osmium	77 192.22 Ir Iridium	78 195.09 Pt Platinum	79 196.97 Au Gold	80 200.59 Hg Mercury	81 204.37 Tl Thallium	82 207.19 Pb Lead	83 208.98 Bi Bismuth	84 (209) Po Polonium	85 (210) At Astatine	86 (222) Rn Radon
87 (223) Fr Francium	88 226.03 Ra Radium	89 227.03 Ac ▸ Actinium	104 (261) Rf Rutherfordium	105 (262) Ha Hahnium	106 (266) Sg Seaborgium	107 (262) Bh Bohrium	108 (265) Hs Hassium	109 (266) Mt Meitnerium	110 (271)	111 (272)	112 (277)	(113)	114 (285)	(115)	116 (289)	(117)	118 (293)

Lanthanide series ▸	58 140.12 Ce Cerium	59 140.91 Pr Praseodymium	60 144.24 Nd Neodymium	61 (145) Pm Promethium	62 150.40 Sm Samarium	63 151.96 Eu Europium	64 157.25 Gd Gadolinium	65 158.93 Tb Terbium	66 162.50 Dy Dysprosium	67 164.93 Ho Holmium	68 167.26 Er Erbium	69 168.93 Tm Thulium	70 173.04 Yb Ytterbium	71 174.97 Lu Lutetium
Actinide series ▸	90 232.04 Th Thorium	91 231.04 Pa Protactinium	92 238.03 U Uranium	93 237.05 Np Neptunium	94 (244) Pu Plutonium	95 (243) Am Americium	96 (247) Cm Curium	97 (247) Bk Berkelium	98 (251) Cf Californium	99 (252) Es Einsteinium	100 (257) Fm Fermium	101 (260) Md Mendelevium	102 (259) No Nobelium	103 (262) Lr Lawrencium

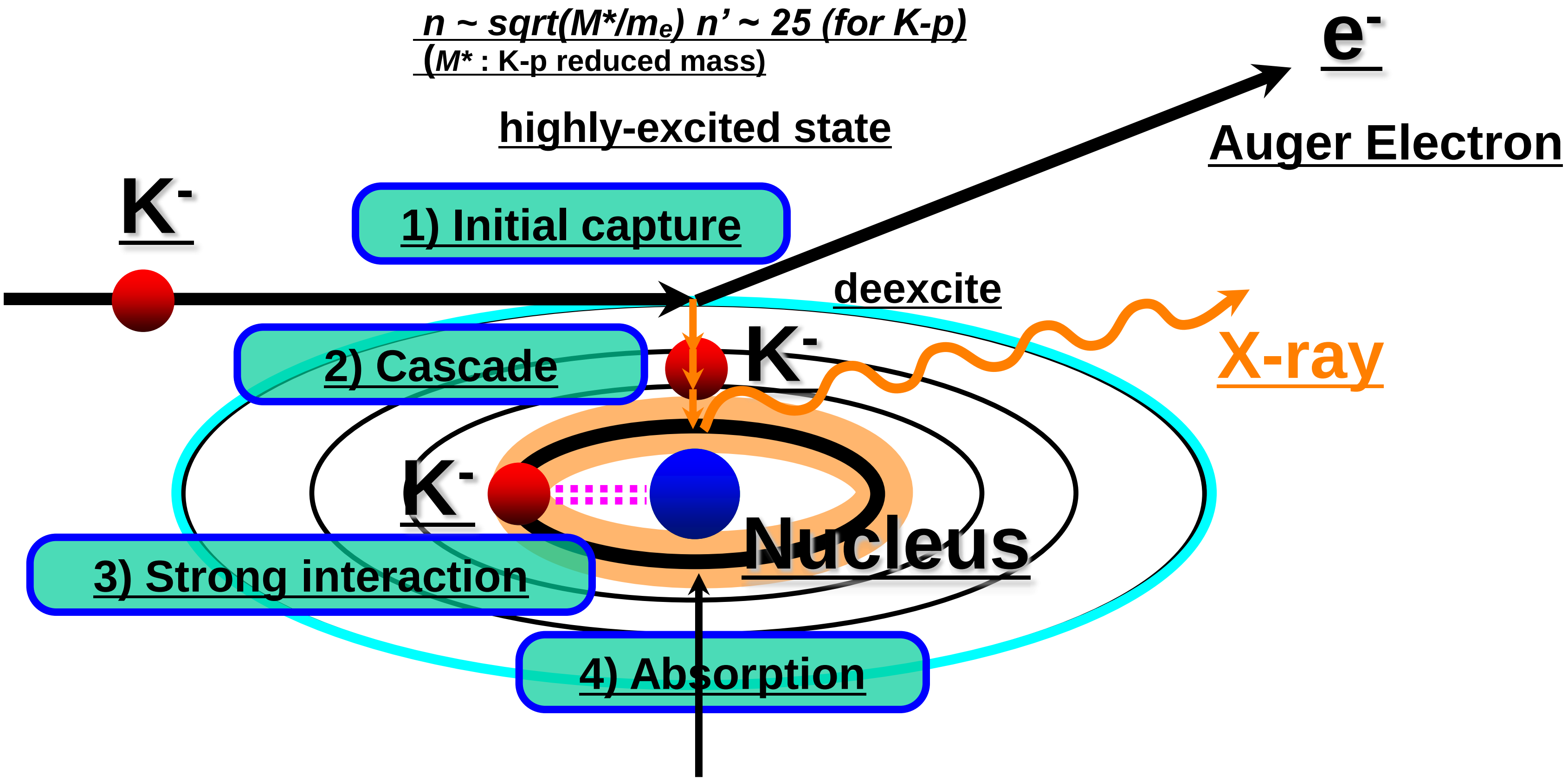
The Standard Model



Formazione di un atomo esotico (atomo kaonico)

$n \sim \mathrm{sqrt}(M^*/m_e)\ n' \sim 25$ (for K-p)

(M^* : K-p reduced mass)



stopped in a target medium

Shift and Width of last orbit

The strong int. width > [illegible] width

- 1s for K-p, K-d
- 2p for K-He

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

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**:

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

(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:

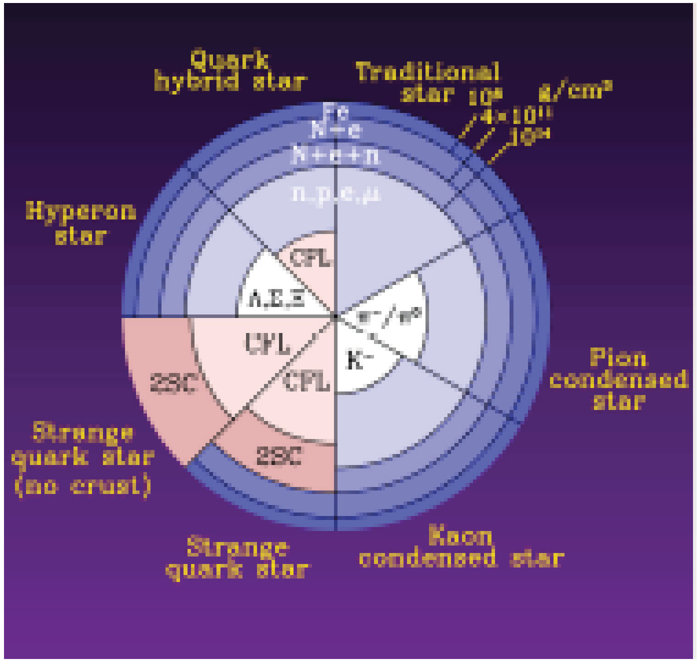
Chiral SU(3) Effective Field Theory
+ Coupled Channels
+ Few-Body Methods

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

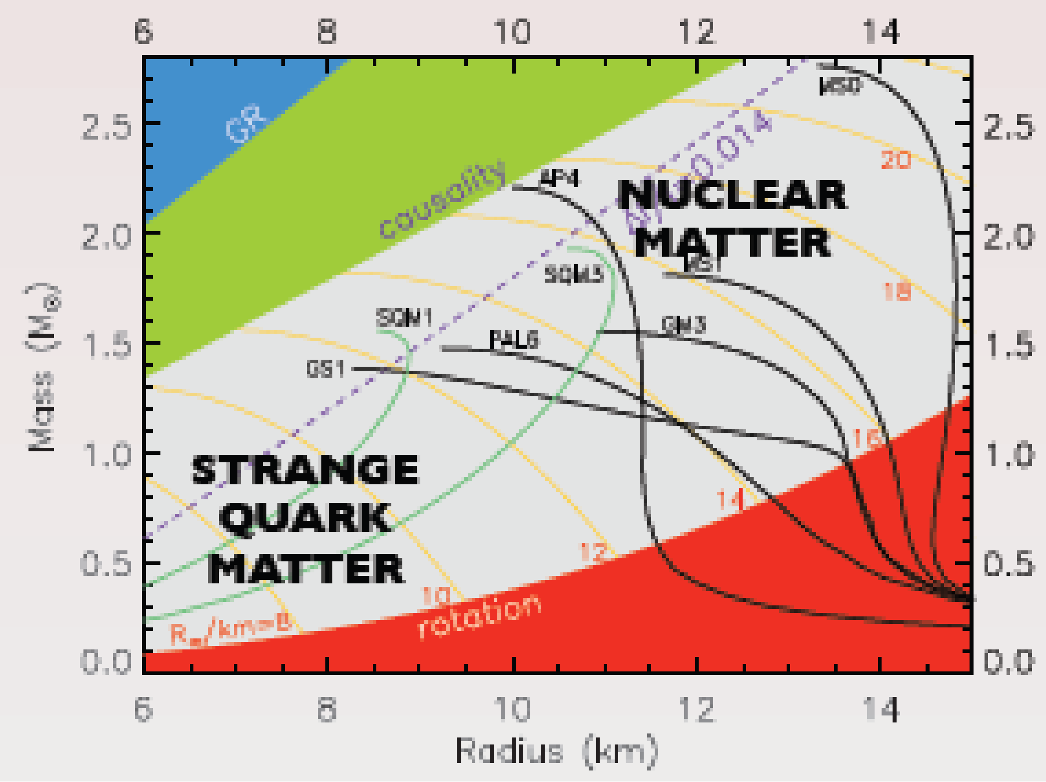


- **Neutron Star Scenarios**
-

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

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

- **Mass-Radius Relation**



Low-Energy QCD with Strange Quarks

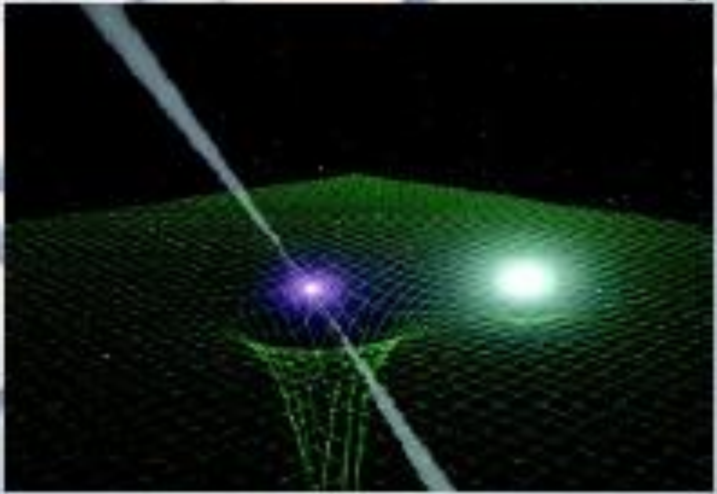
K^-

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!

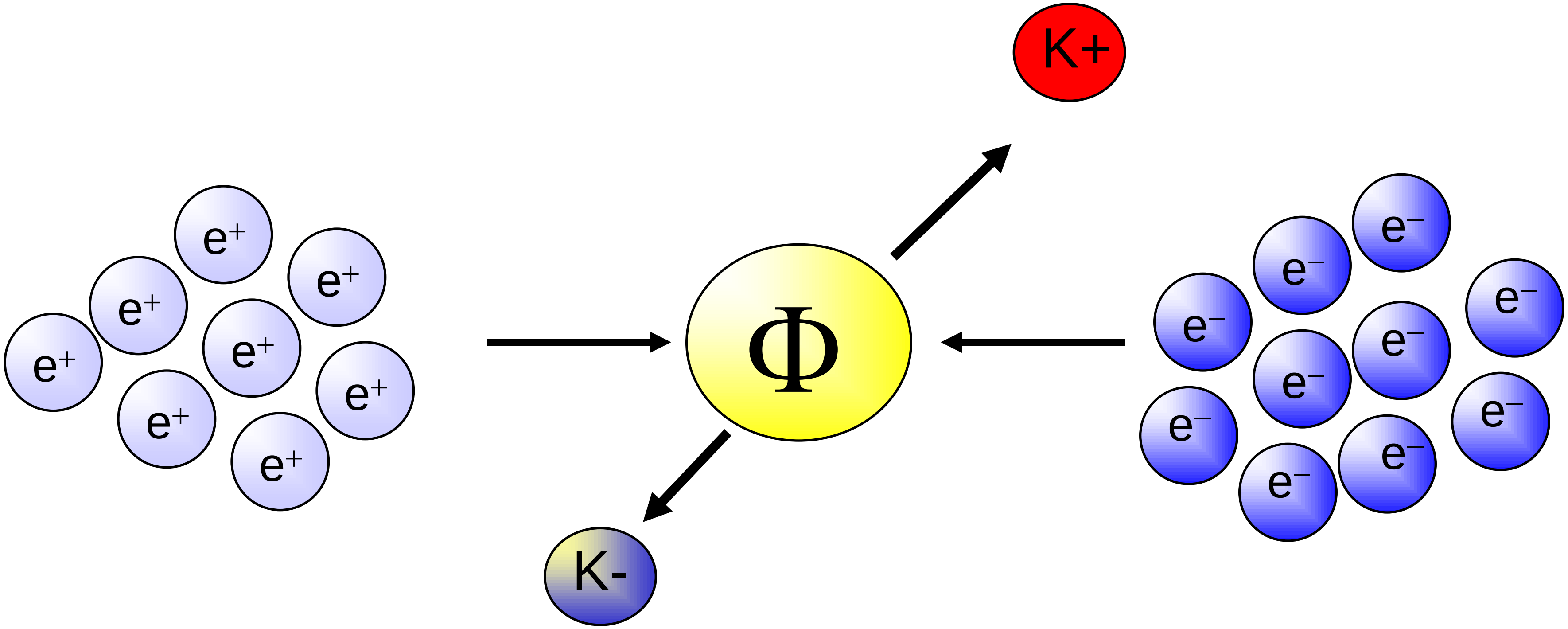


But

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

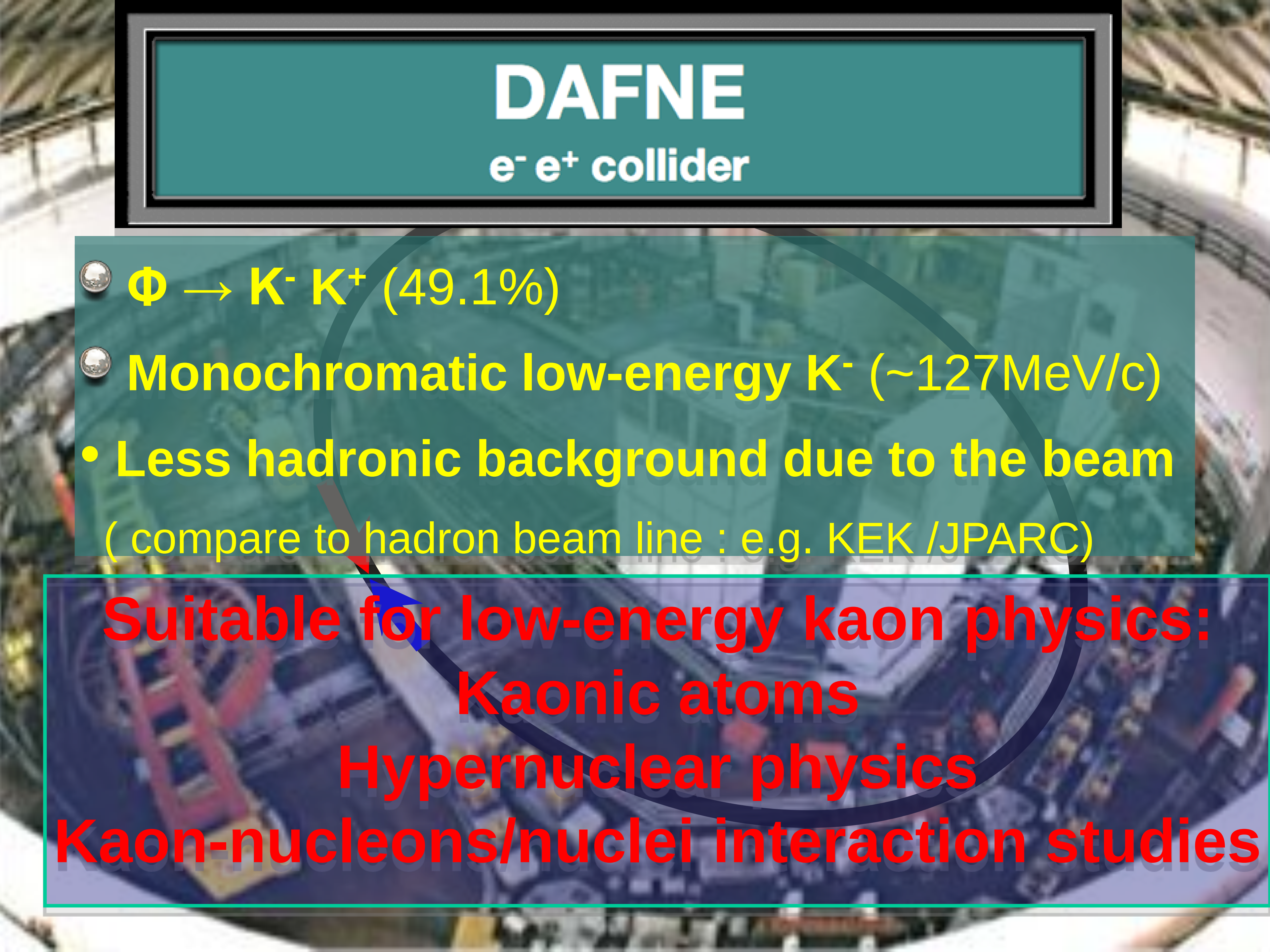
DAFNE Collider at LNF-INFN

The DAFNE principle



Flux of produced kaons: about 1000/second

DAΦNE, since 1998



DAFNE

$e^- e^+$ collider

- **Φ → $K^- K^+$** (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*

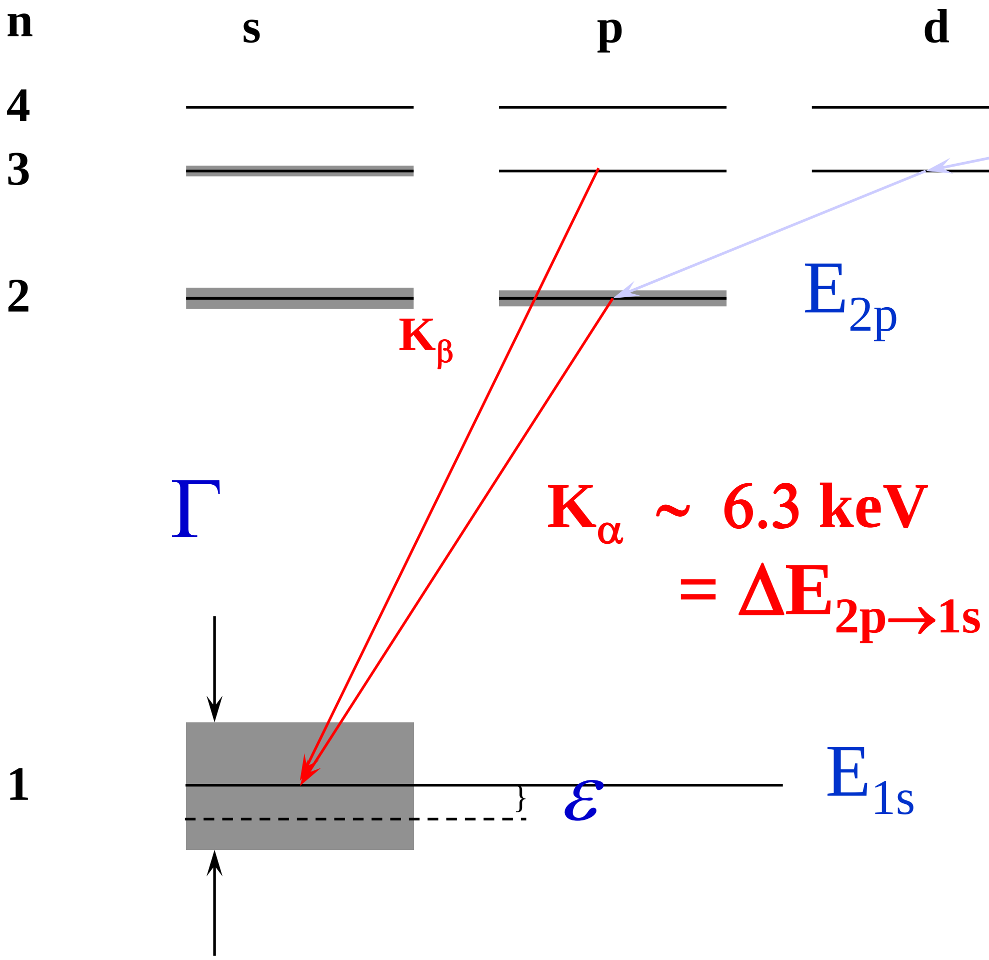
of the K_α line of **kaonic hydrogen**

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



K_α ~ 6.3 keV

$= \Delta E_{2p \to 1s}$

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):

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

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

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.

↓

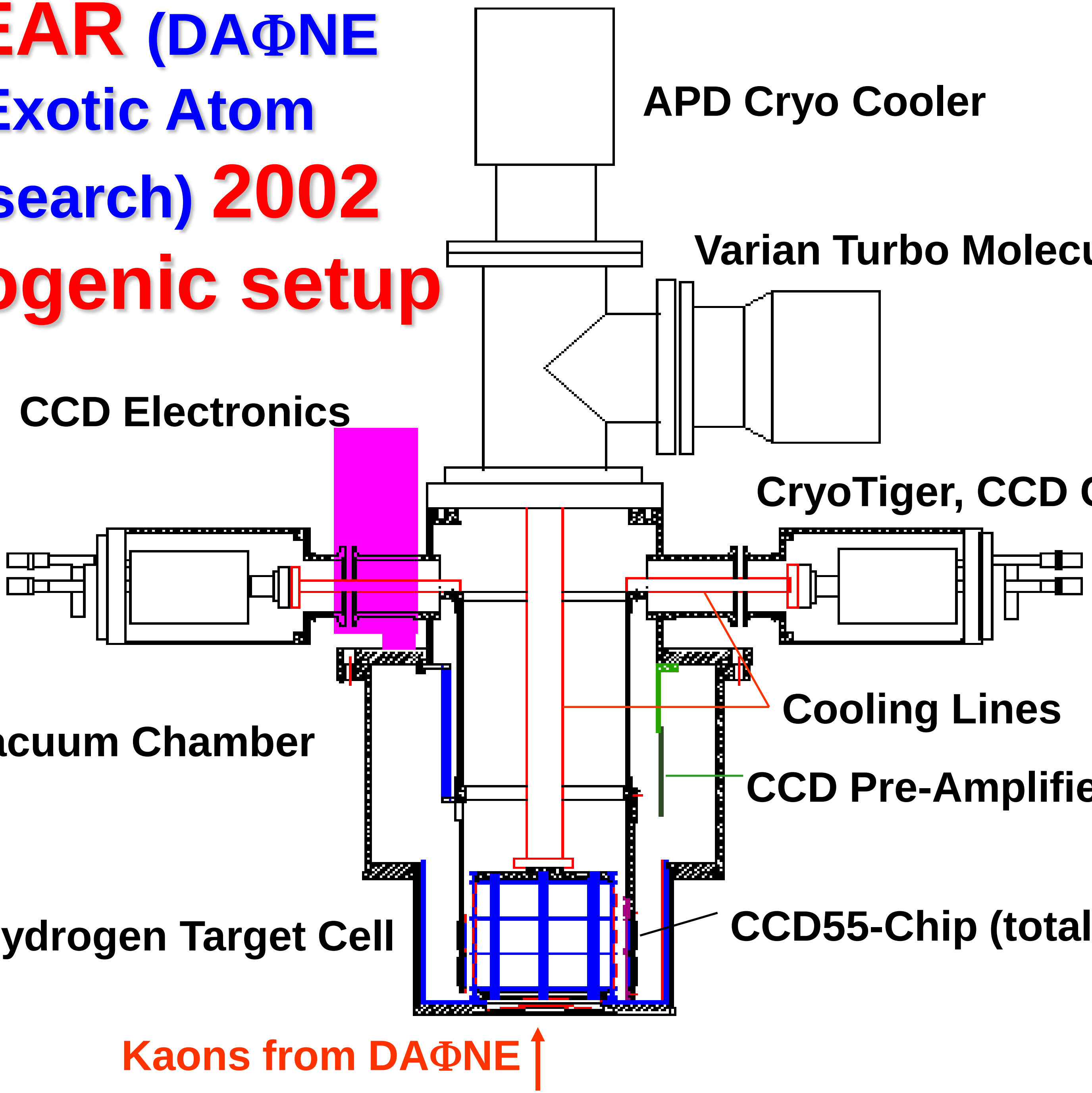
1. **Breakthrough in the *low-energy $\bar{K}N$ phenomenology*;**
2. **Threshold amplitude in QCD**
3. **Study of the Λ(1405)**
4. **Contribute to the determination of the *KN sigma terms*, which give the degree of chiral symmetry breaking;**
5. **4 related alado with the determination of the *strangeness 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 x10^{32}
- Average luminosity (cm -2 s -1) ˜ 2 x10^{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



APD Cryo Cooler

Varian Turbo Molecular Pump

CCD Electronics

CryoTiger, CCD Cooling

Cooling Lines

Vacuum Chamber

CCD Pre-Amplifier Boards

Hydrogen Target Cell

CCD55-Chip (total of 16 chips)

Kaons from DAΦNE

DEAR on DAΦNE (2002)

October – December 2002 DAQ

Collected data:

-Kaonic Nitrogen:

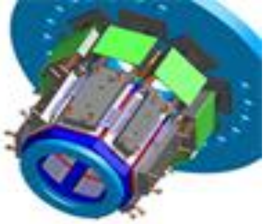
6 – 28 October (about 17 pb^{-1} – 10 pb^{-1} in stable conditions);

-Kaonic Hydrogen:

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

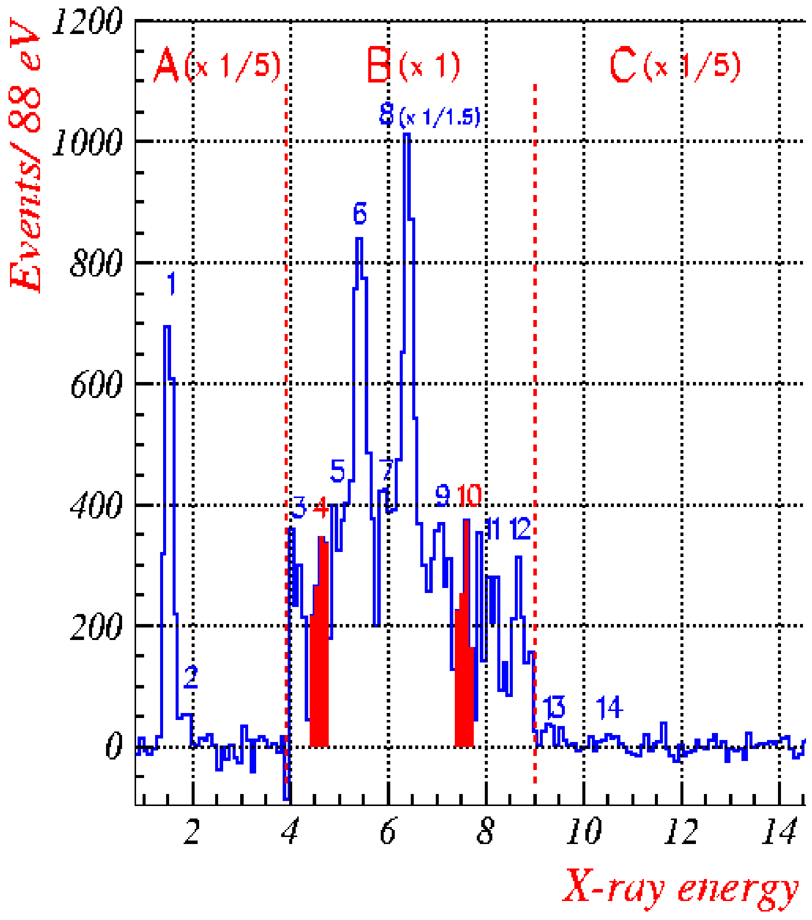
-Background data (no collisions) for KH:

16 – 23 December

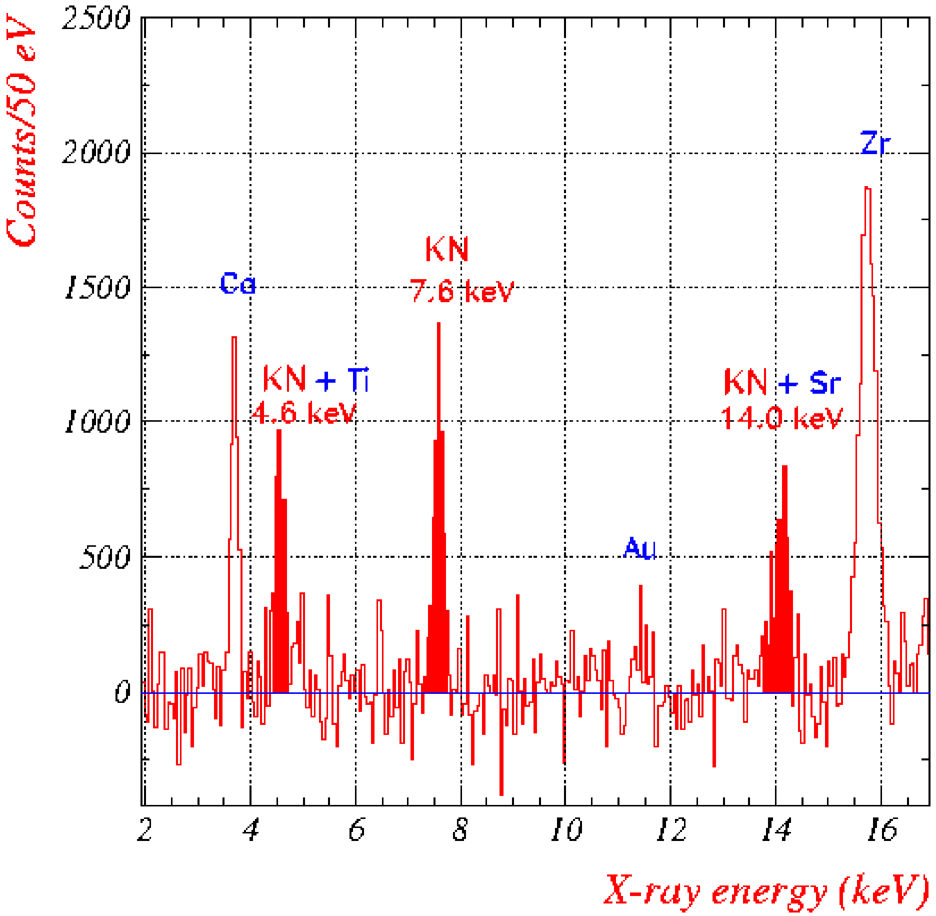


Kaonic Nitrogen

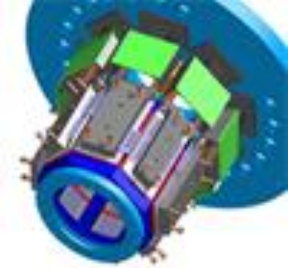
Kaonic Nitrogen, 2001, ~ 3 pb^{-1}
Background subtracted spectrum



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:

-Kaonic Nitrogen:

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

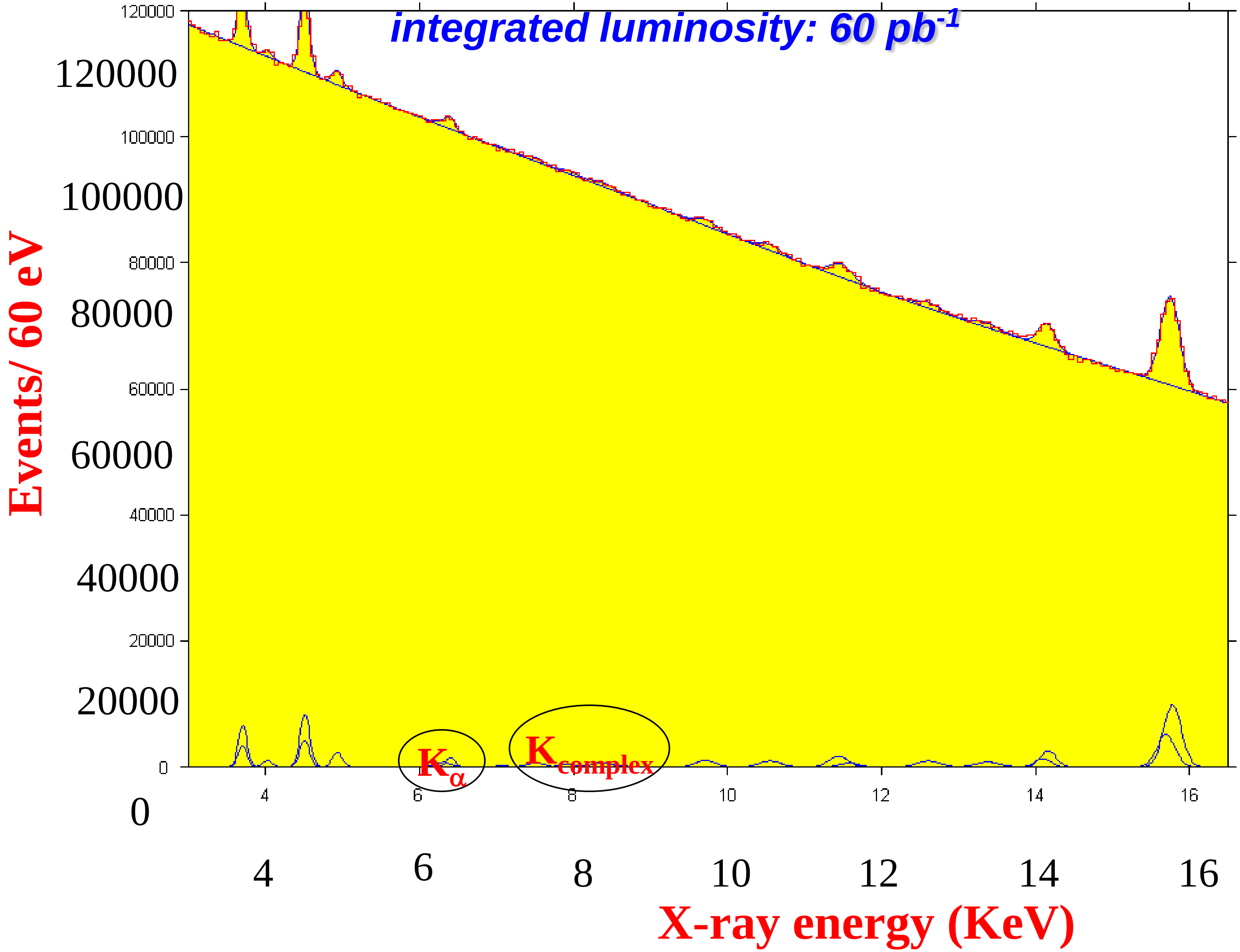
-Kaonic Hydrogen:

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

-Background data (no collisions) for KH:

16 – 23 December

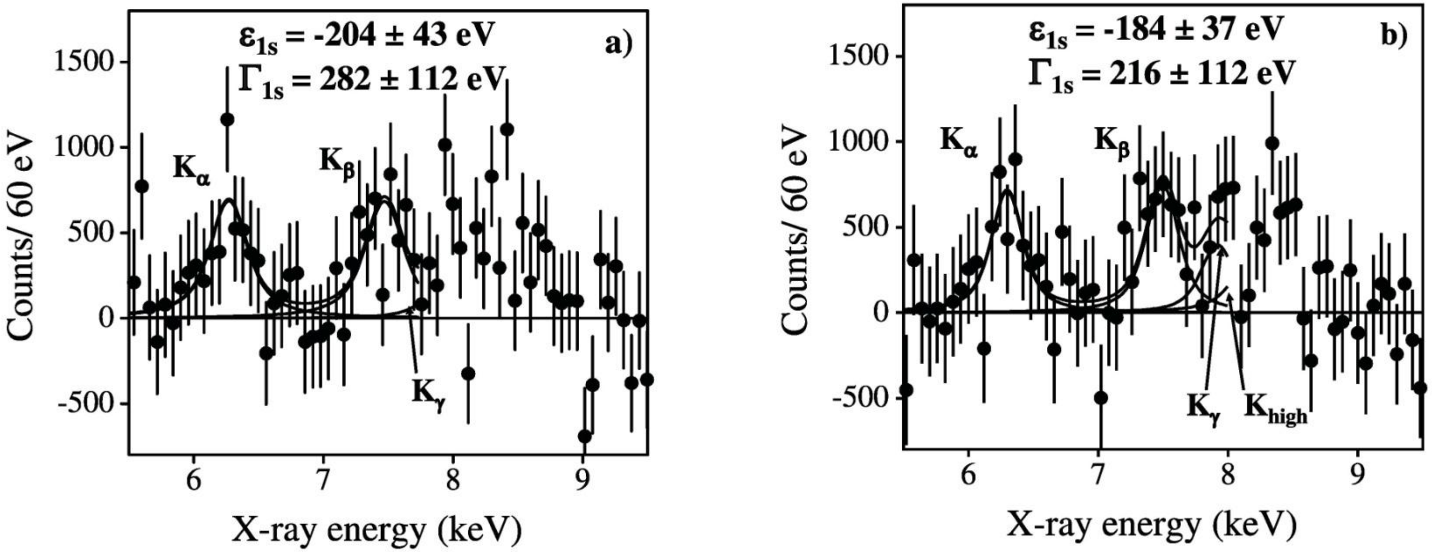
Kaonic Hydrogen (2002 data)- global fit



integrated luminosity: 60 pb^{-1}

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

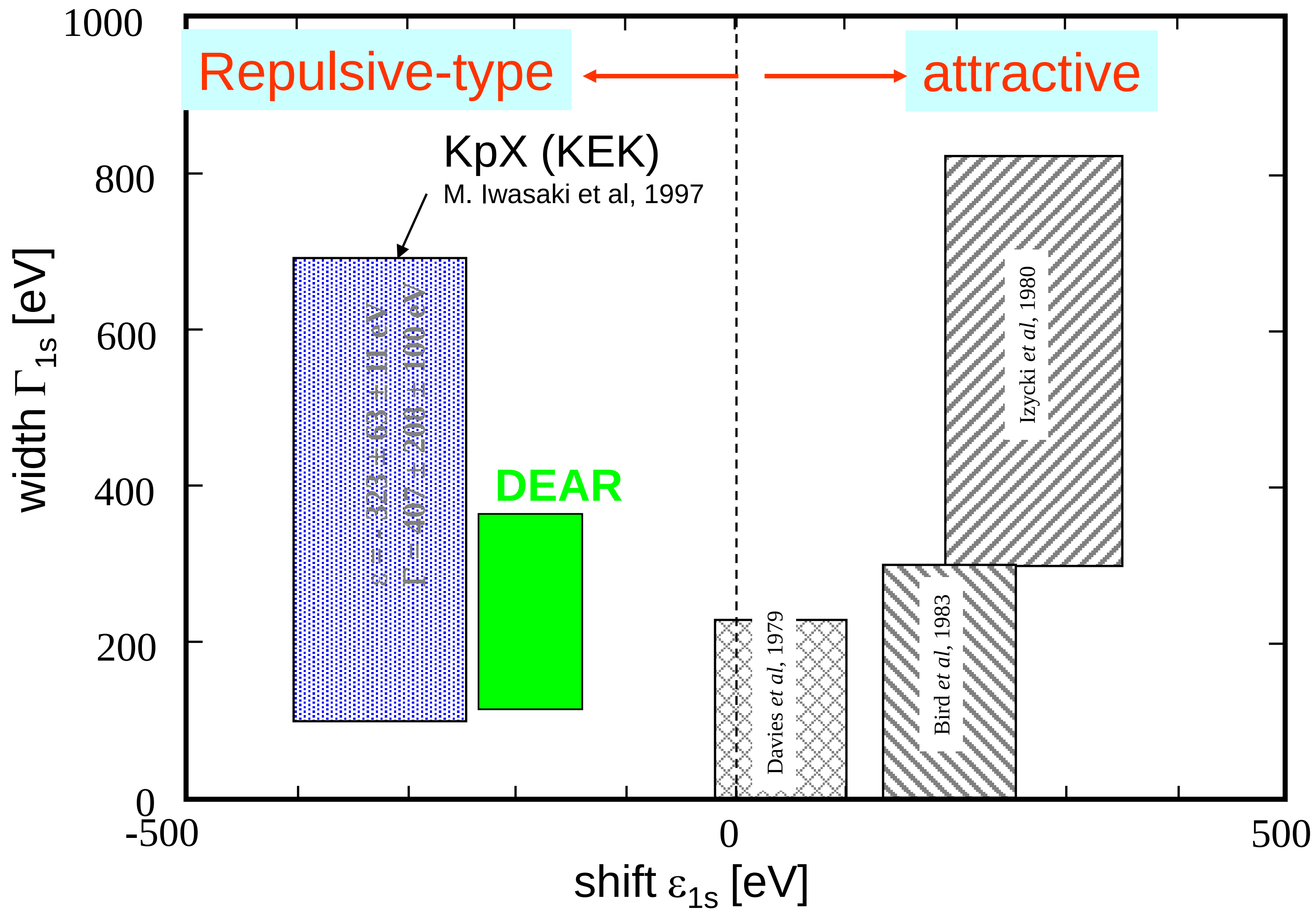
2 independent analyses starting from the raw data
giving consistent results

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

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

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

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***

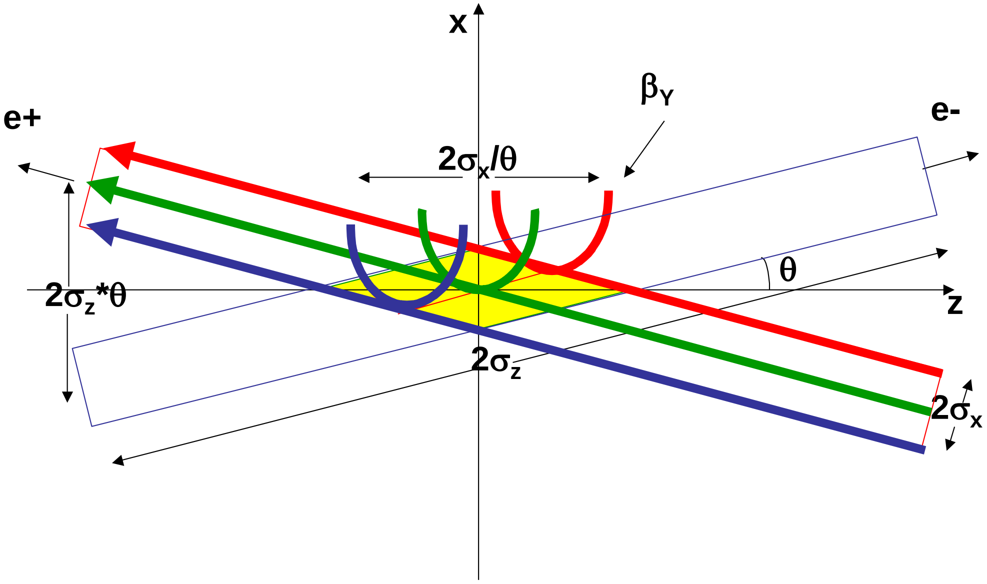
  This will allow to determine the isospin dependent antikaon nucleon scattering lengths at percent level precision

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



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

P. Raimondi,
November 2005

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

- **LNF- INFN, Frascati, Italy**
- **SMI- ÖAW, Vienna, Austria**
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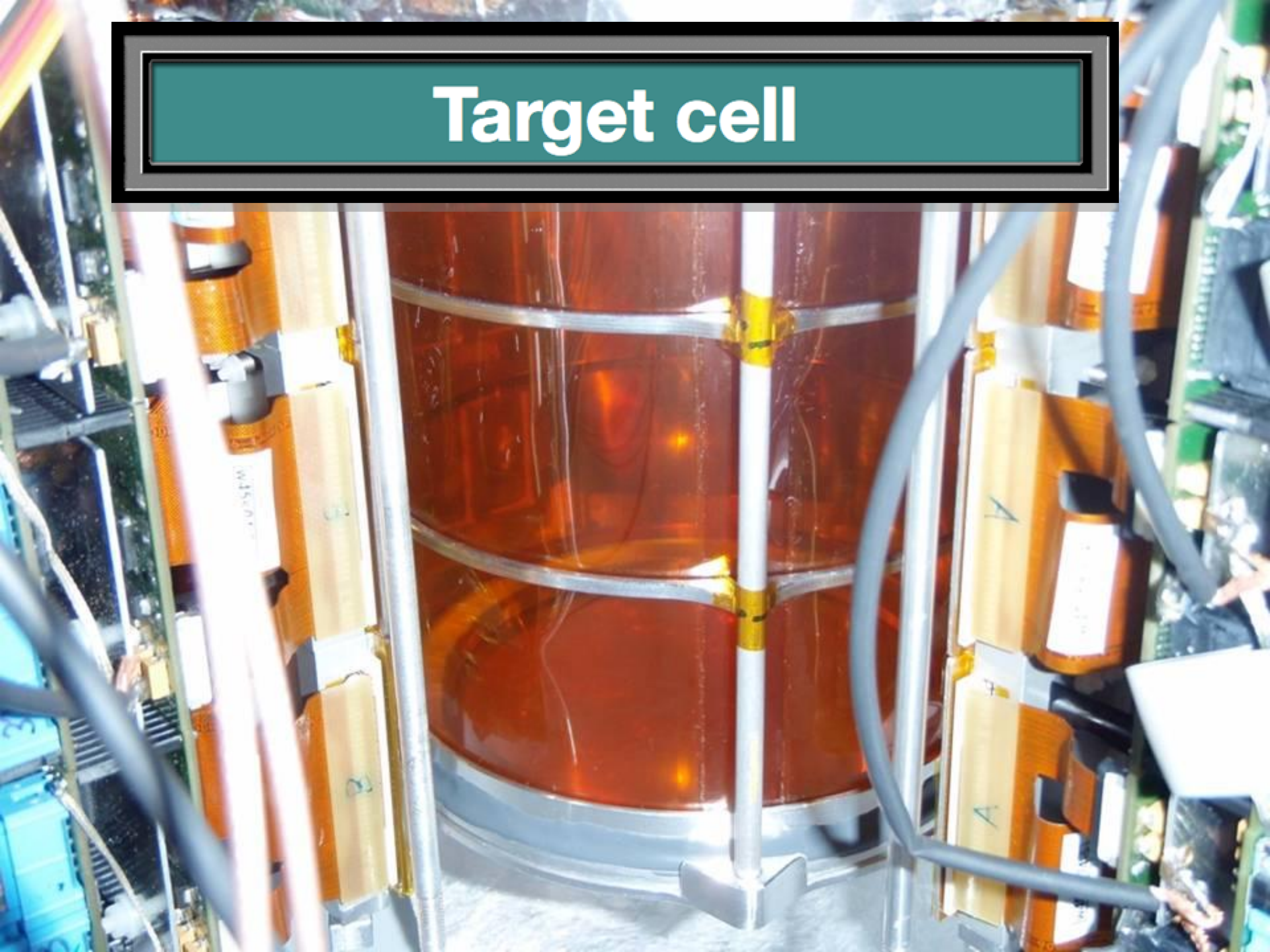
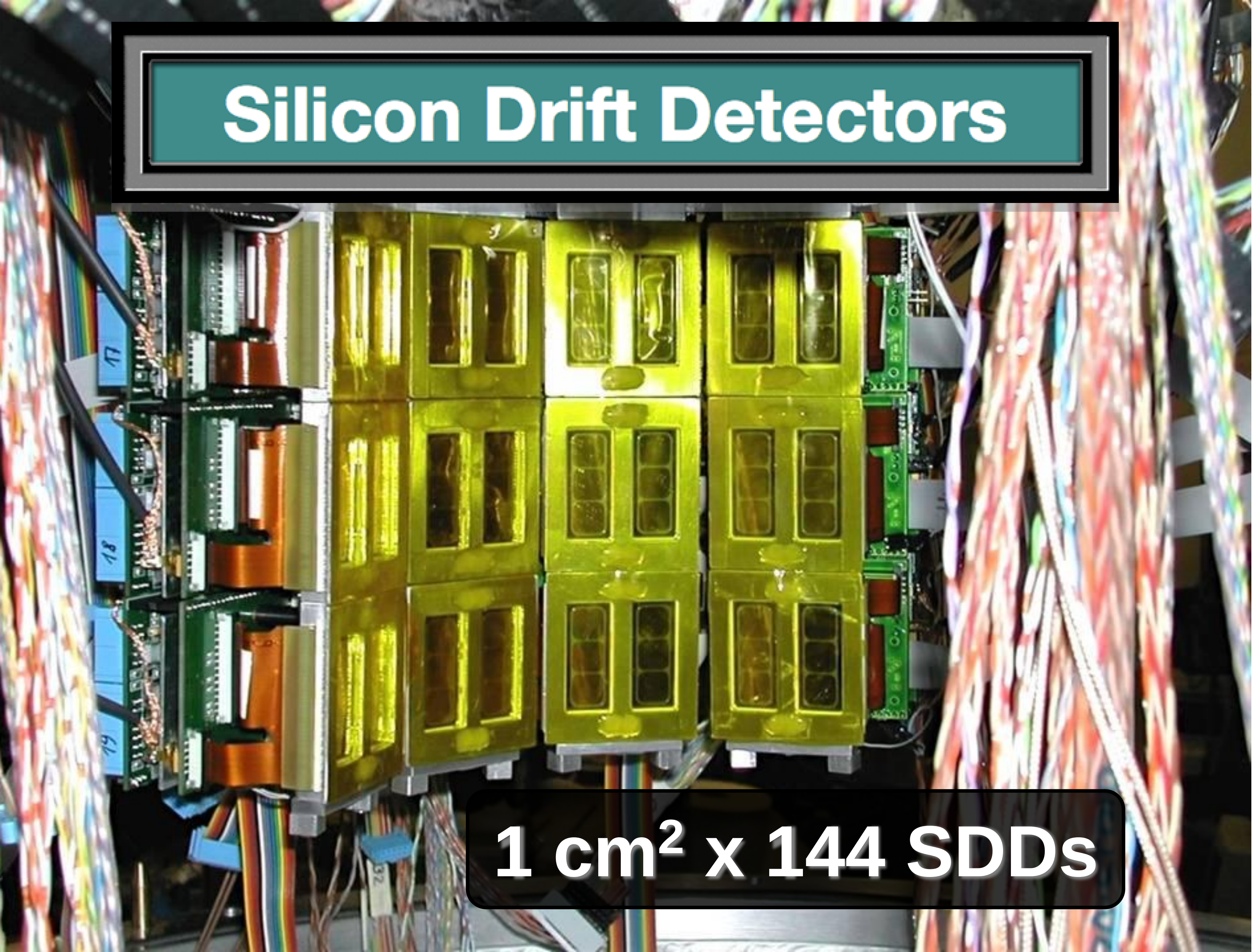
- **RIKEN, Japan**
- **Univ. Tokyo, Japan**
- **Victoria Univ., Canada**

EU Fundings: JRA10 – FP6 - I3H
FP7- I3HP2

Target cell

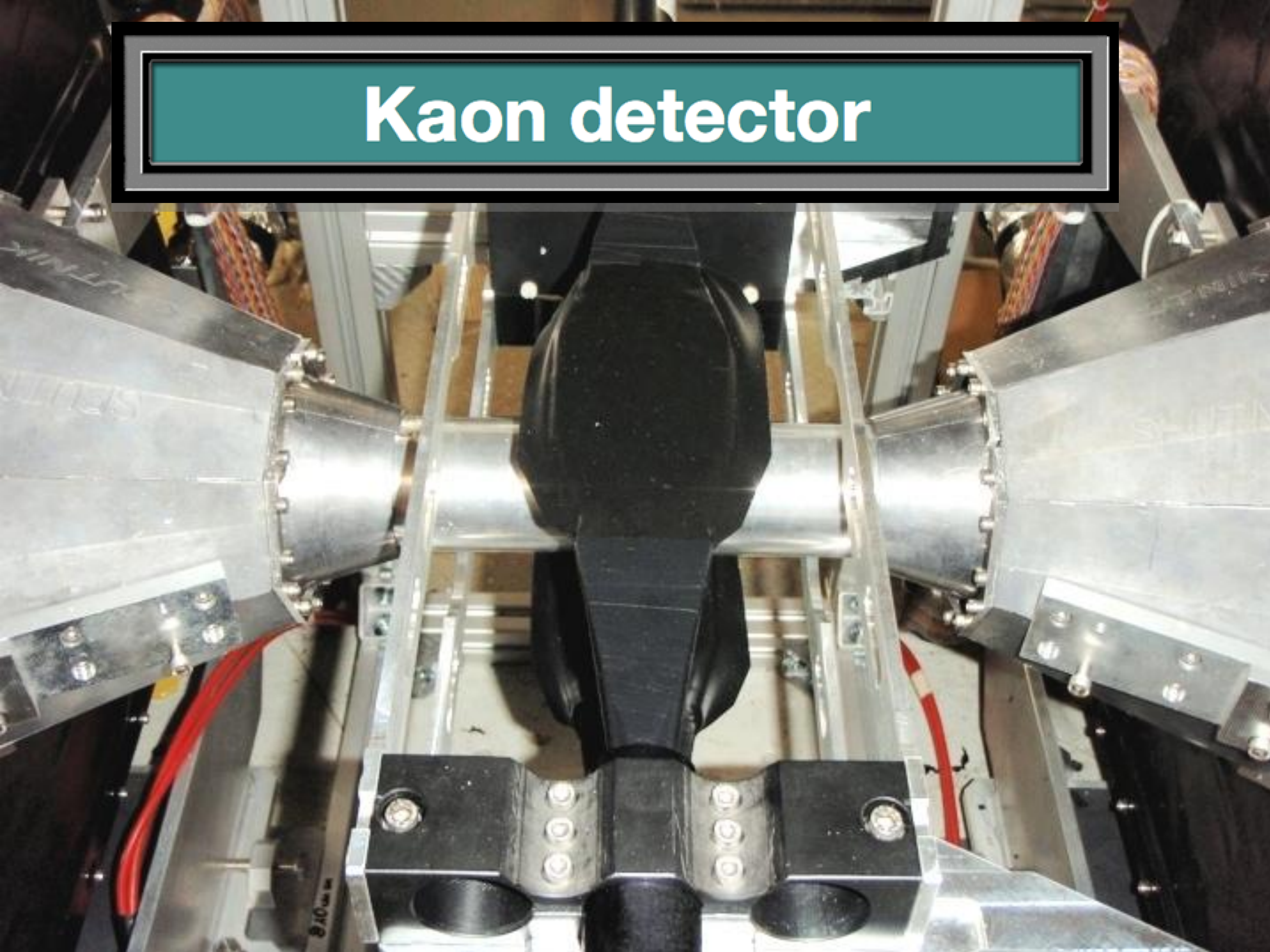


Silicon Drift Detectors

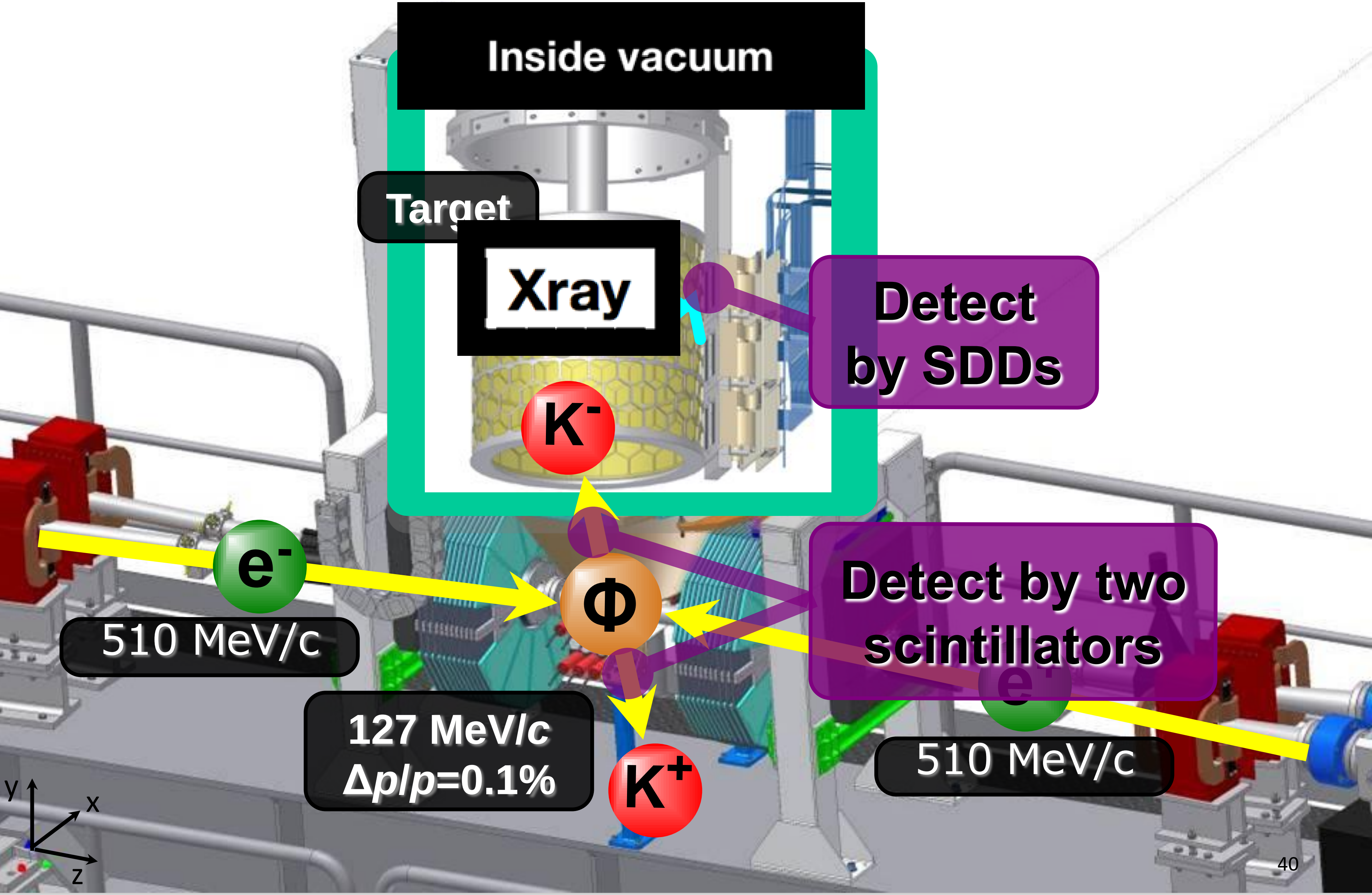


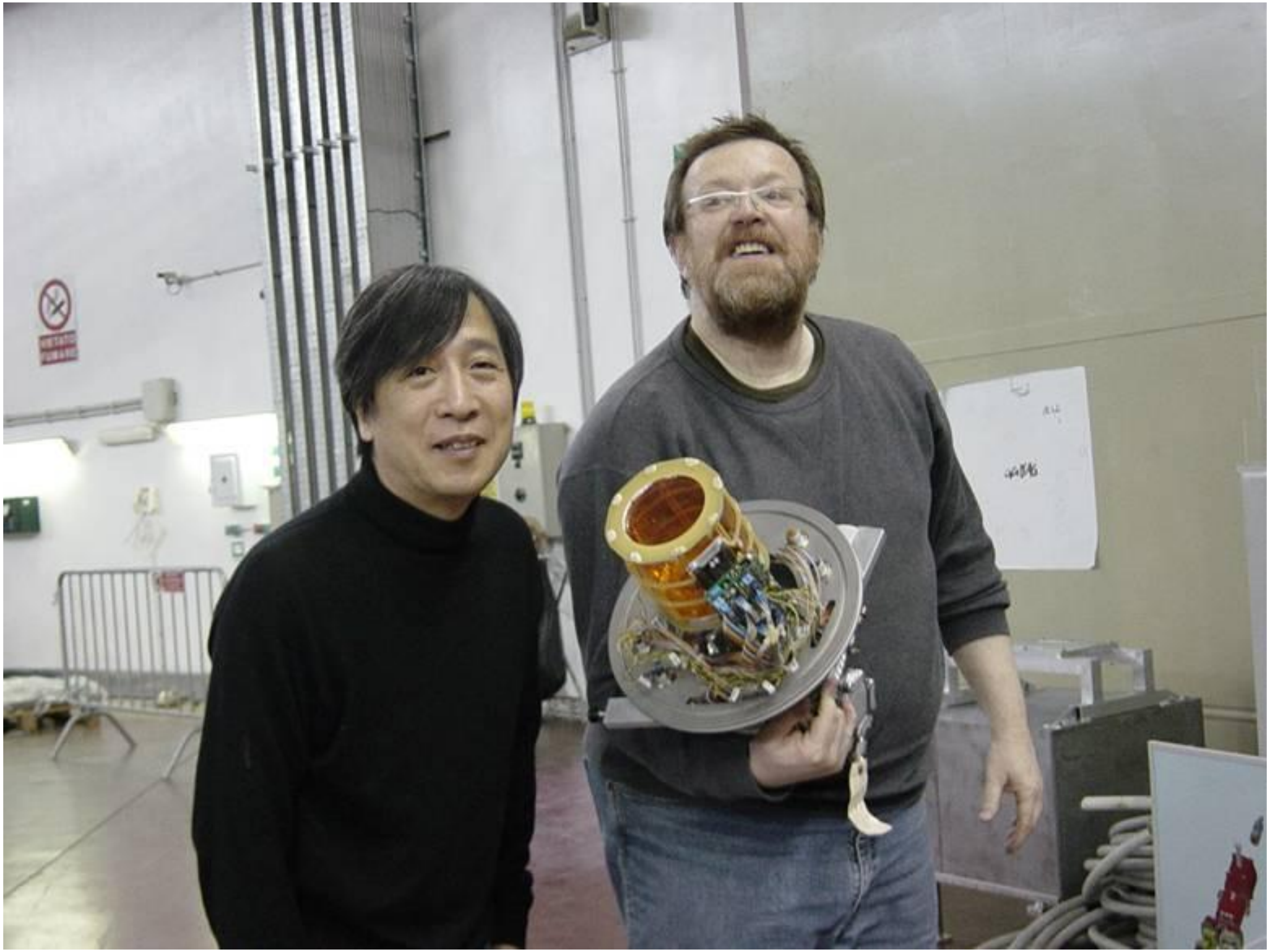
1 cm^2 x 144 SDDs

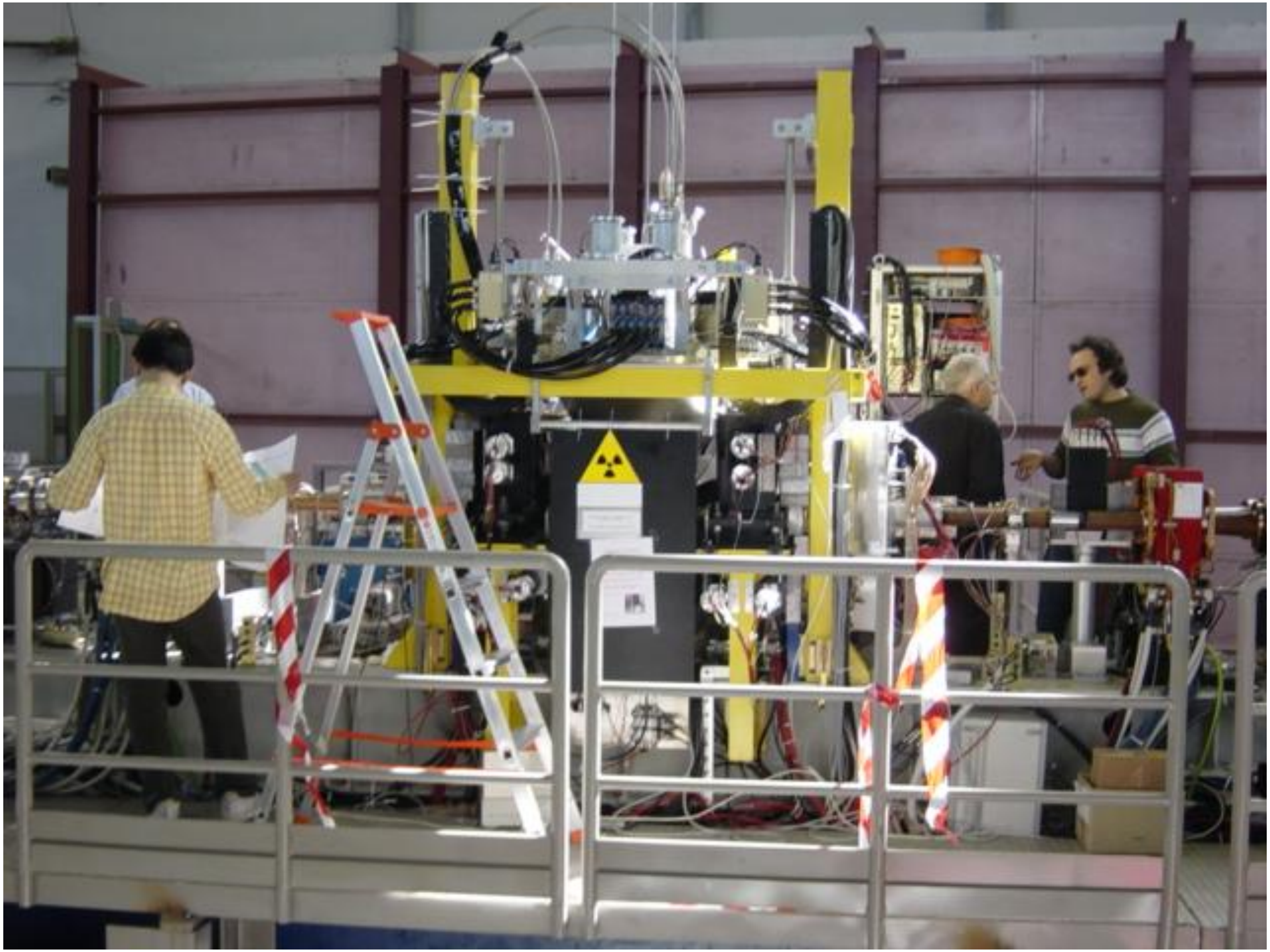
Kaon detector



SIDDHARTA overview





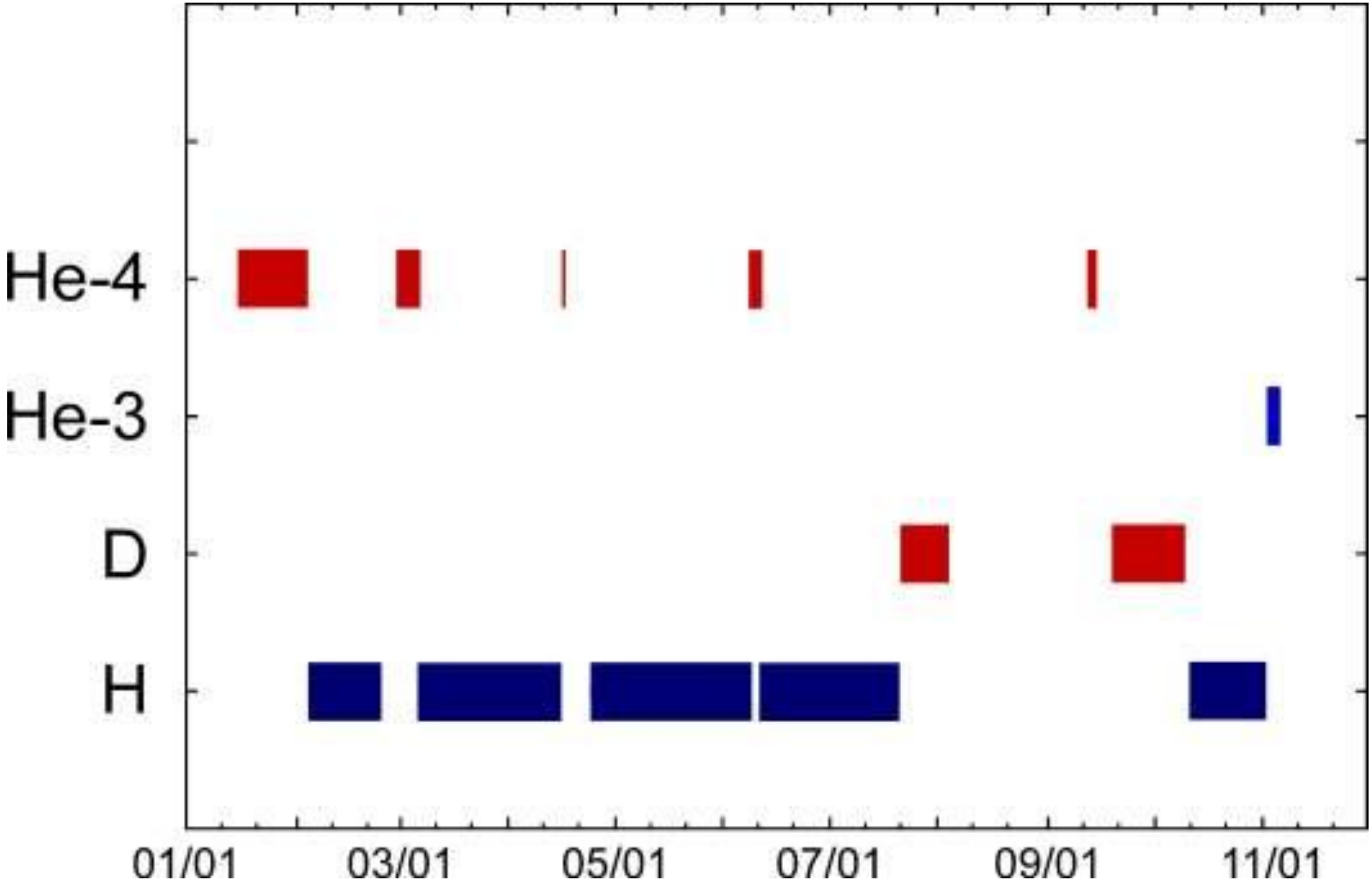


SIDDHARTA setup

SDDs & Target (inside vacuum)

Kaon detector

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

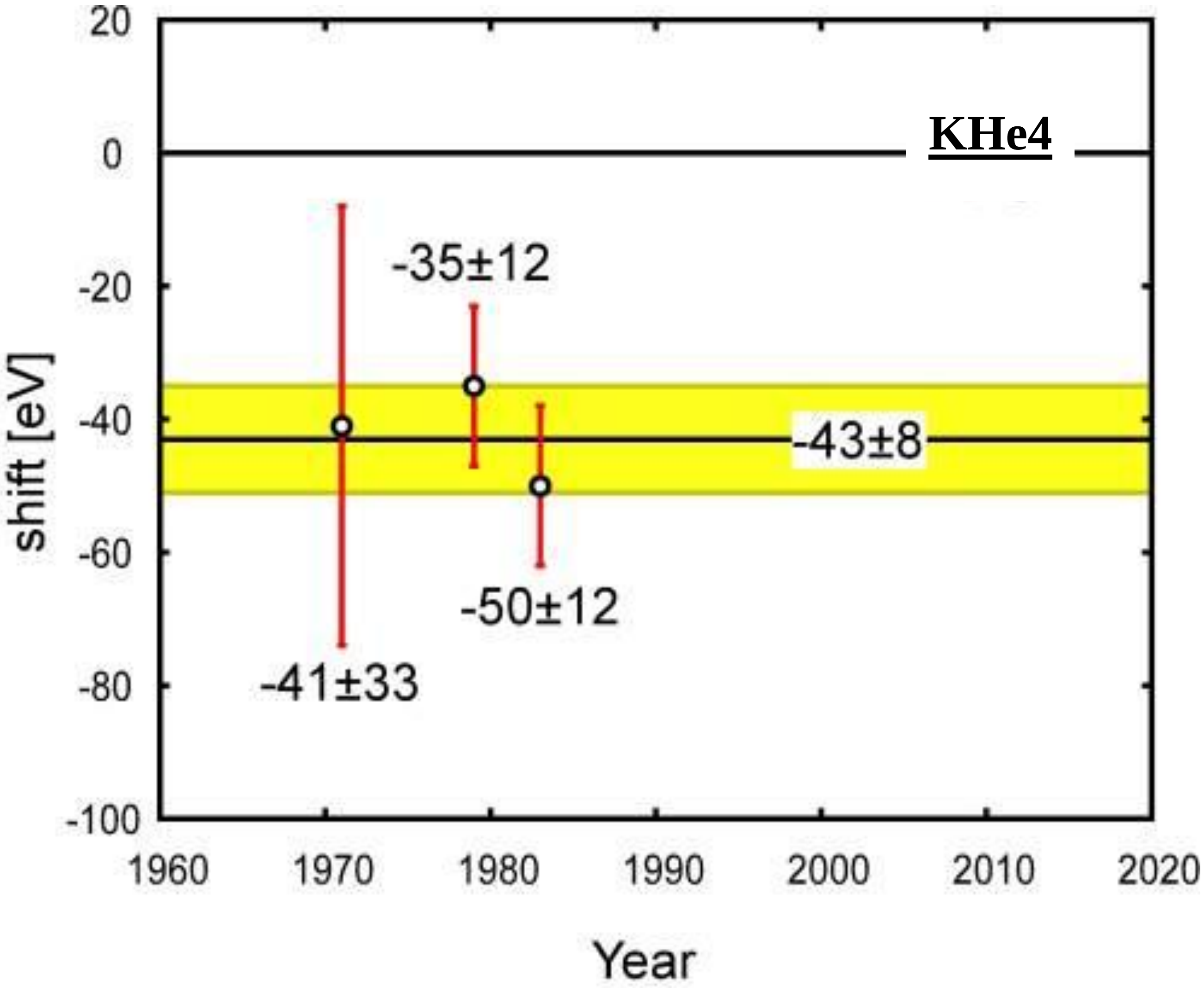
- **Kaonic helium 3** – 10 pb^{-1}, first measurement in the world, published in Phys. Lett. B 697 (2011) 199; Ph D

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

SIDDHARTA – important TRAINING for young researchers

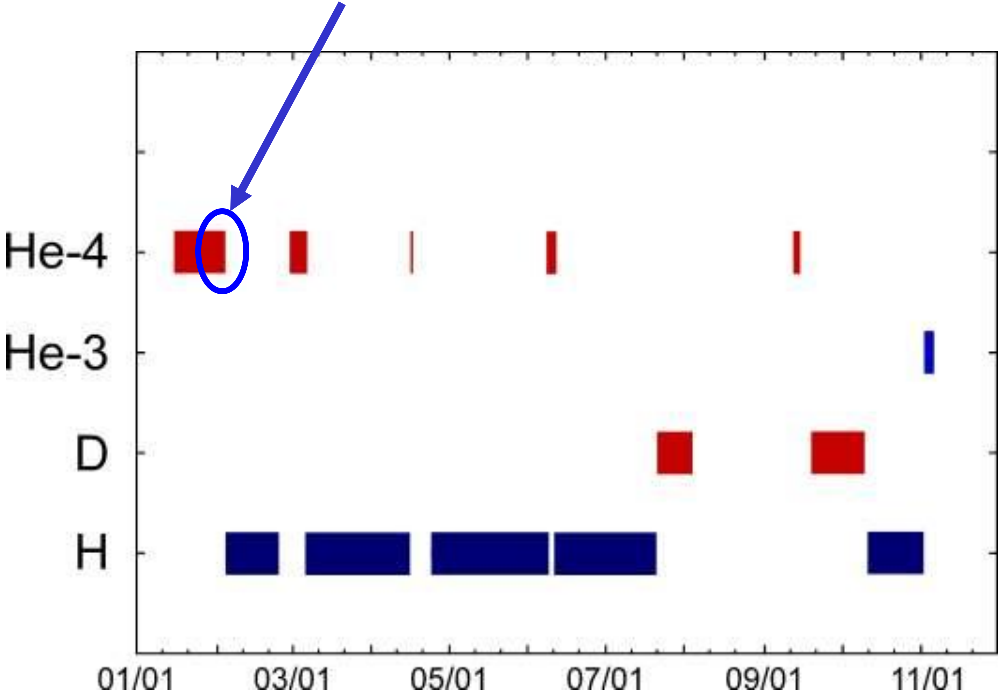
Kaonic Helium 3 and 4

Kaonic 4 old data

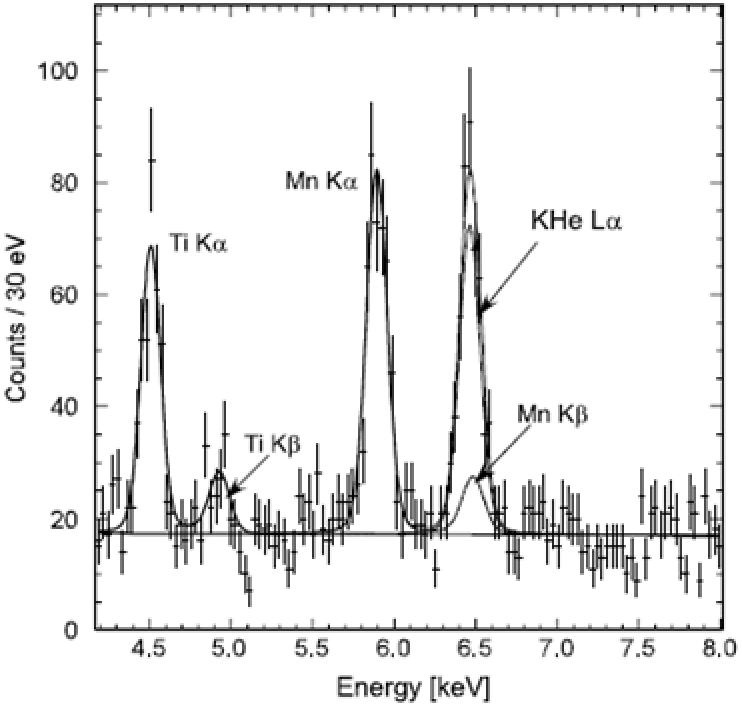


Data taking periods of SIDDHARTA in 2009

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

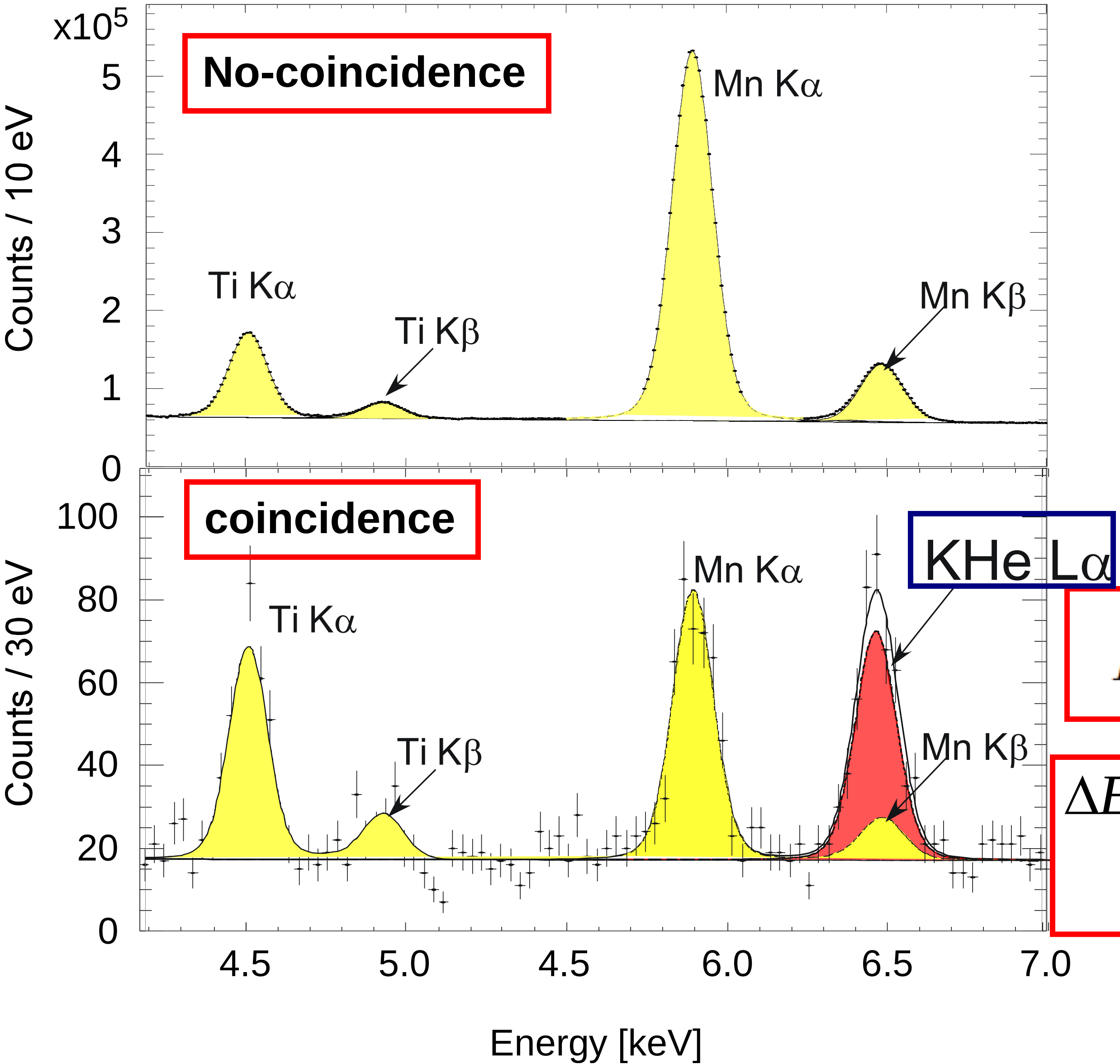
Removed ^{55}Fe source in other data

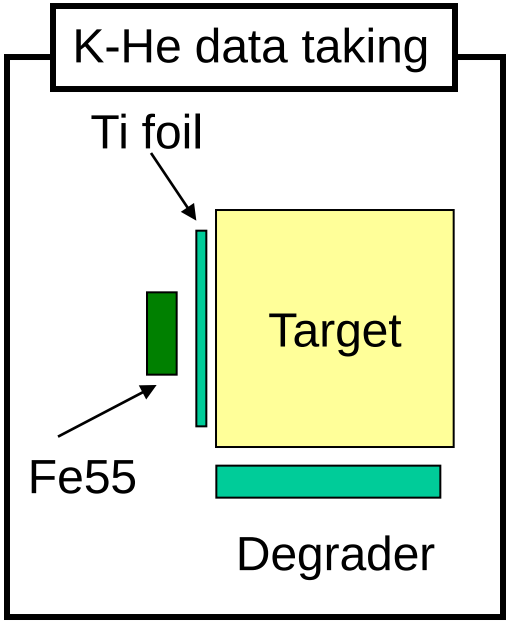
Use of
Mn Ka (5.9 keV) from ^{55}Fe

Systematic error = +/-2 eV

KHe-4 energy spectrum at SIDDHARTA

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





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

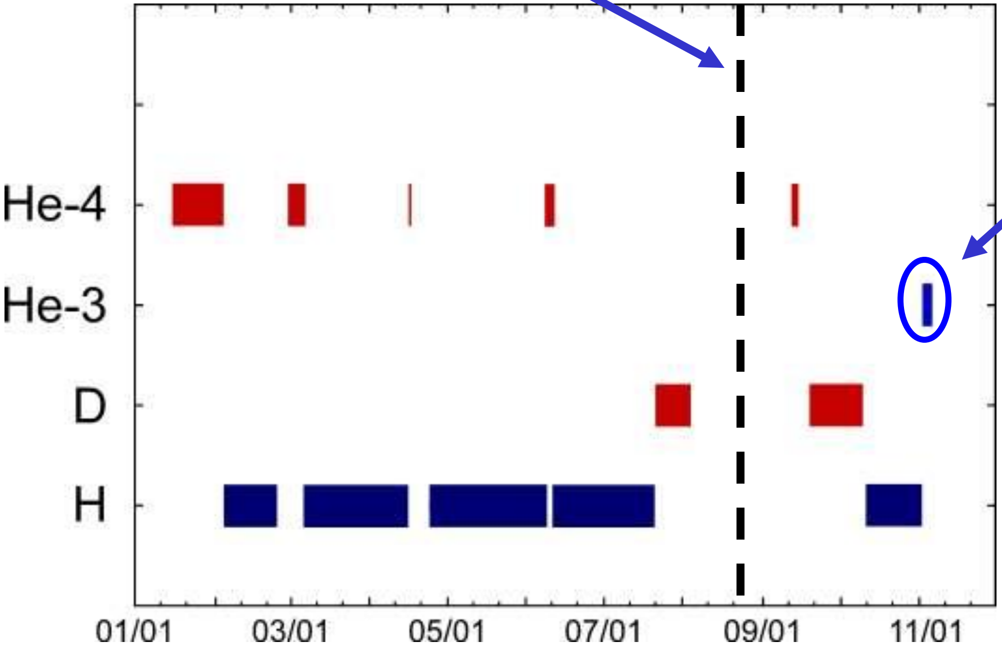
$$\Delta E = E_{\text{exp}} - E_{e.m.}$$
$$= 0 \pm 6(\text{stat}) \pm 2(\text{syst})\,\text{eV}$$

Data taking periods of SIDDHARTA in 2009

DAFNE shutdown in Summer

New alignment of setup
→Improve S/N ratio

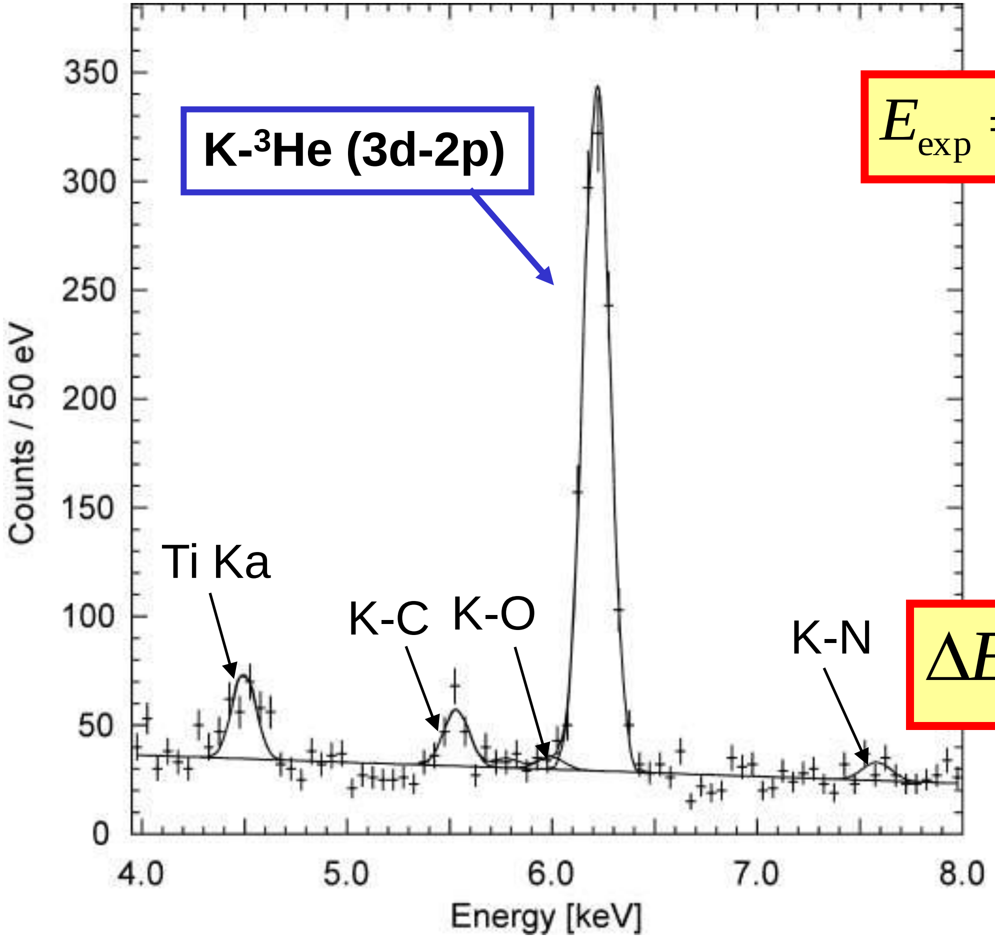
K-He3 data (~4days)



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

Removed ^{55}Fe source in other data

Kaonic Helium-3 energy spectrum



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

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

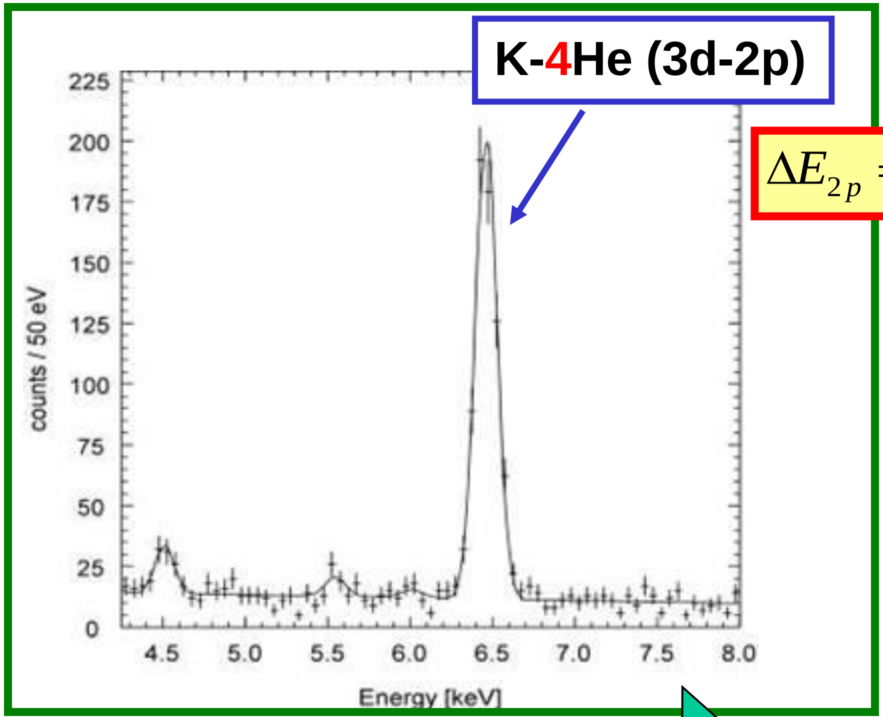
QED value: $E_{e.m.} = 6224.6\ \mathrm{eV}$

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

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

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

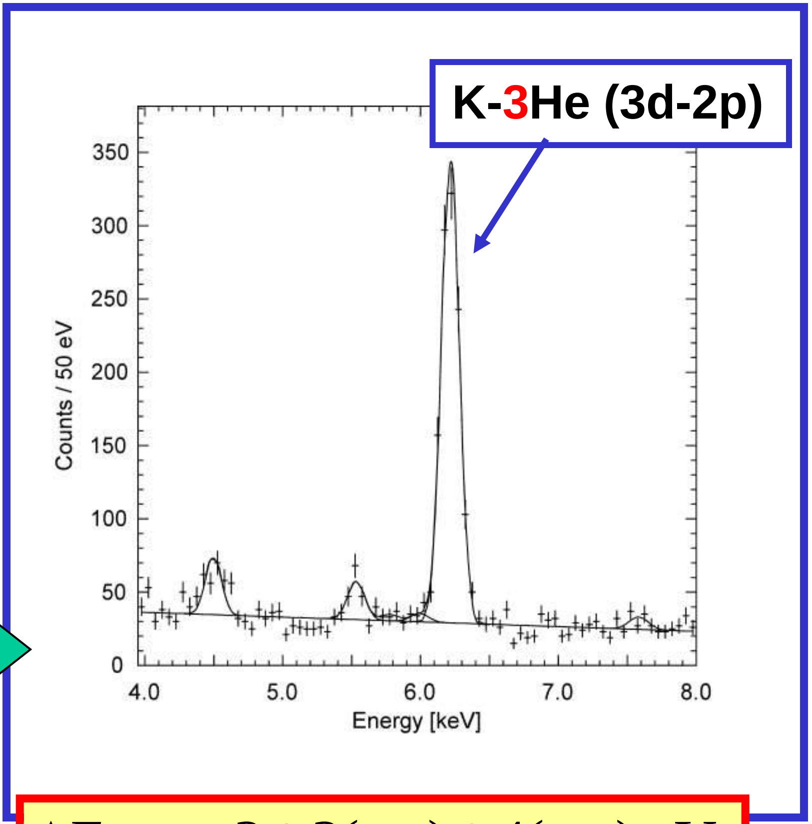
arXiv:1010.4631v1 [nucl-ex], PLB697(2011)199



K-4He (3d-2p)

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

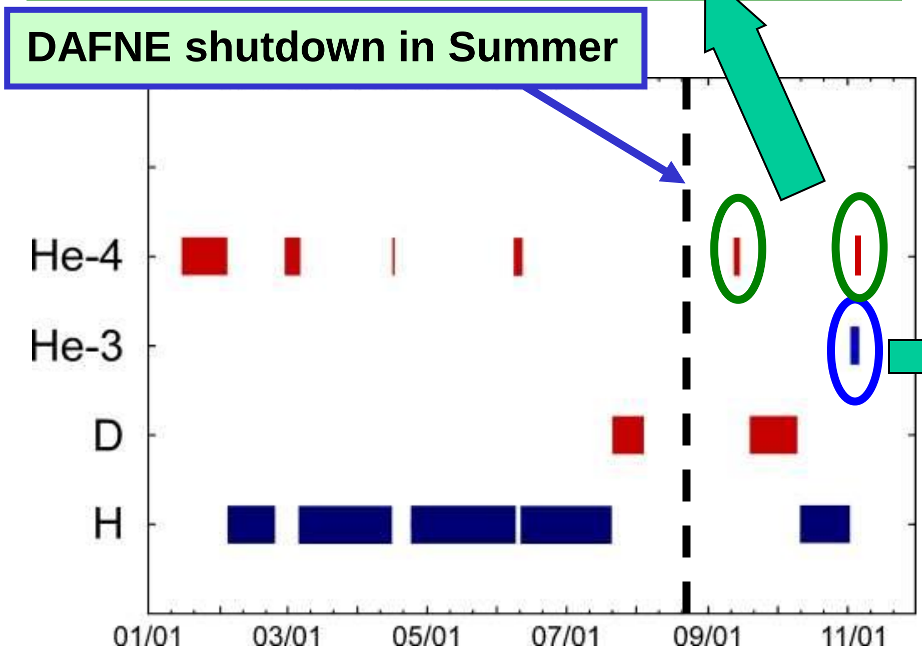
PLB697(2011)199



K-3He (3d-2p)

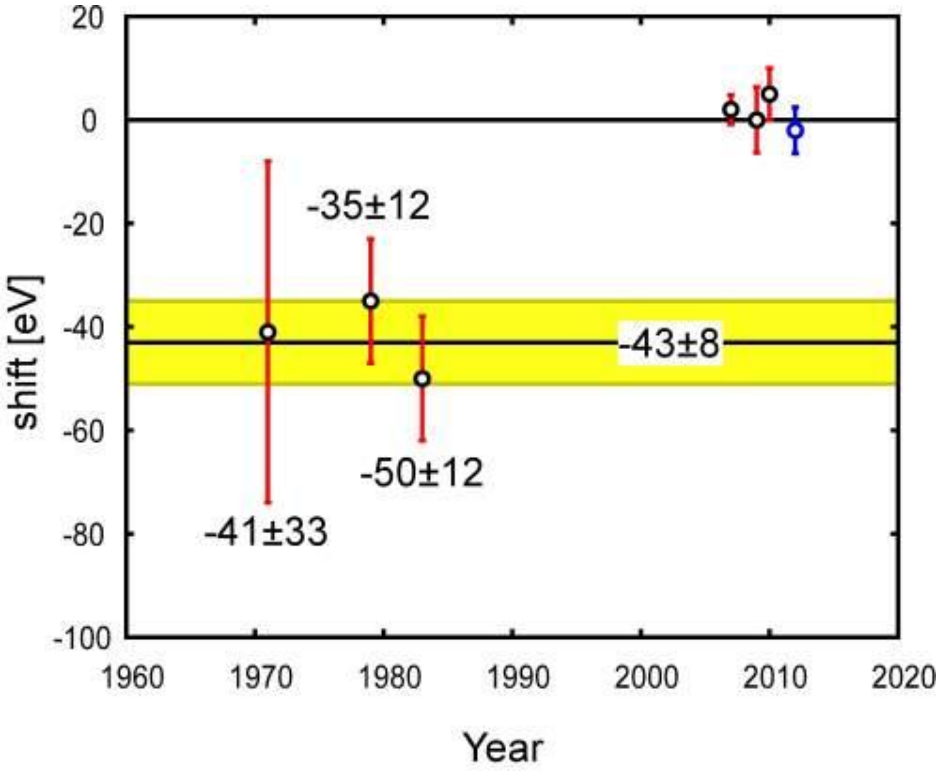
$$\Delta E_{2p} = -2 \pm 2(sta) \pm 4(sys)\ \text{eV}$$

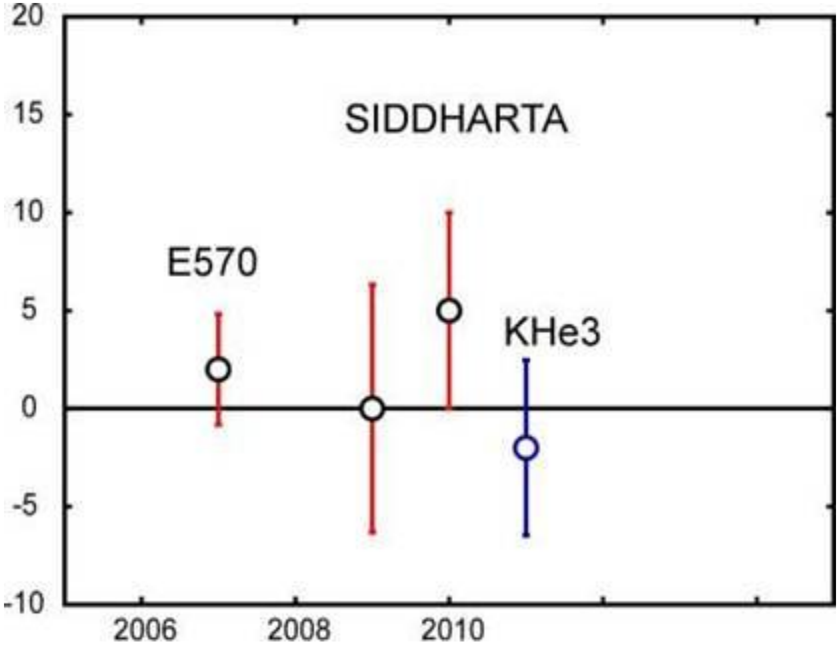
DAFNE shutdown in Summer



Comparison of results

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





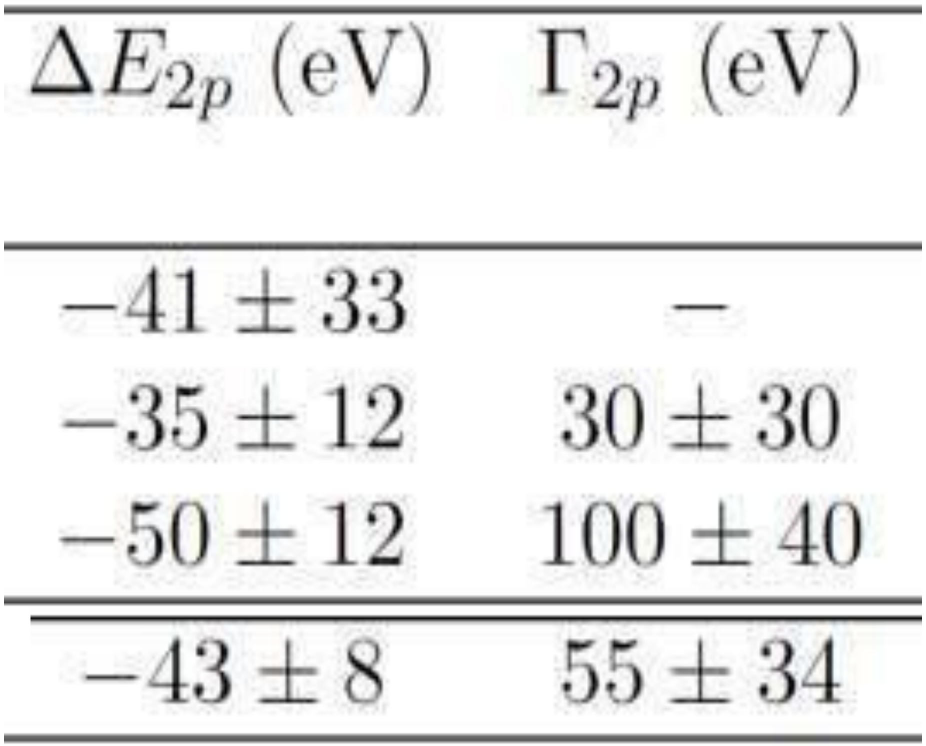
***error bar** $= \pm\sqrt{(stat)^2 + (syst)^2}$

Phys. Lett. B714 (2012) 40

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

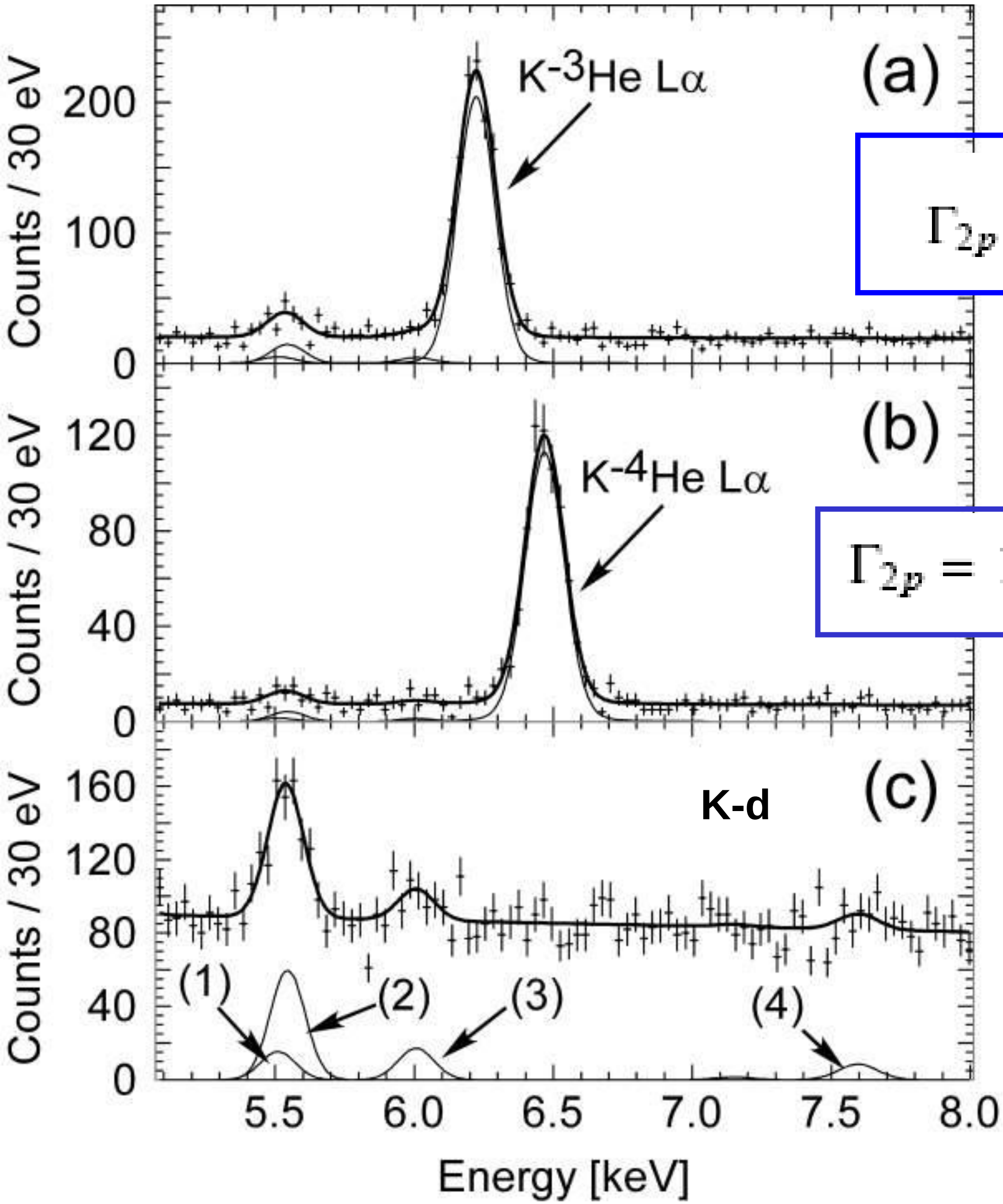
http://arxiv.org/abs/1205.0640v1

Old kaonic He4 measurements



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

Theory: -0.13+-0.02 1.8+-0.05



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

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

Old average

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

K-3He width

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

K-4He width

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

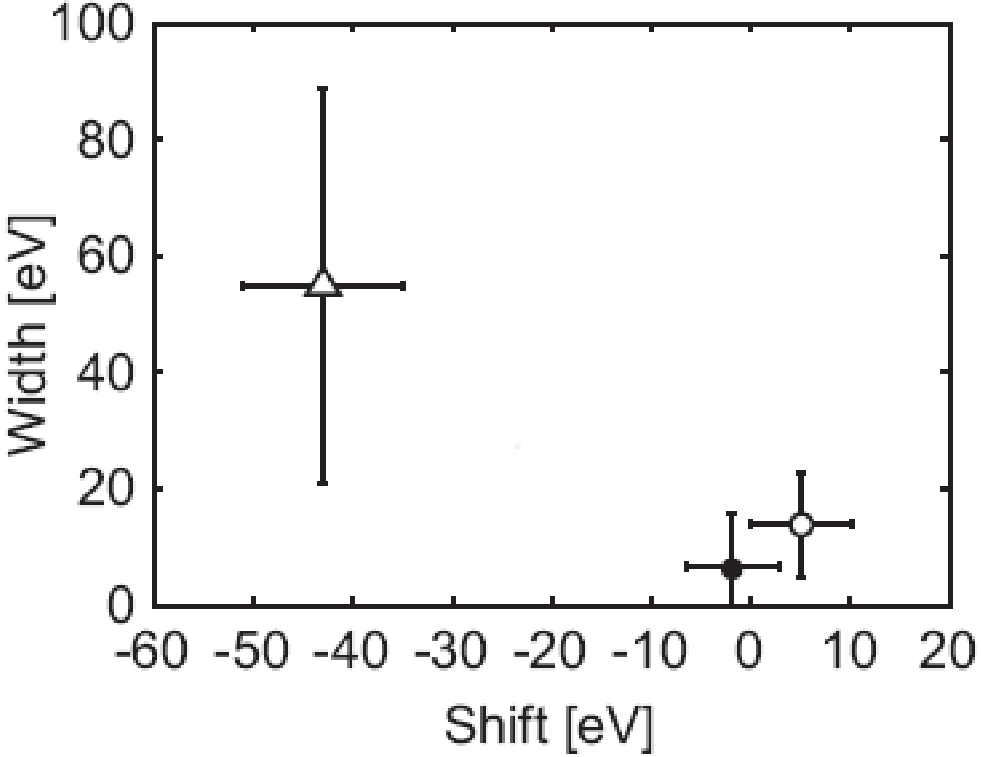


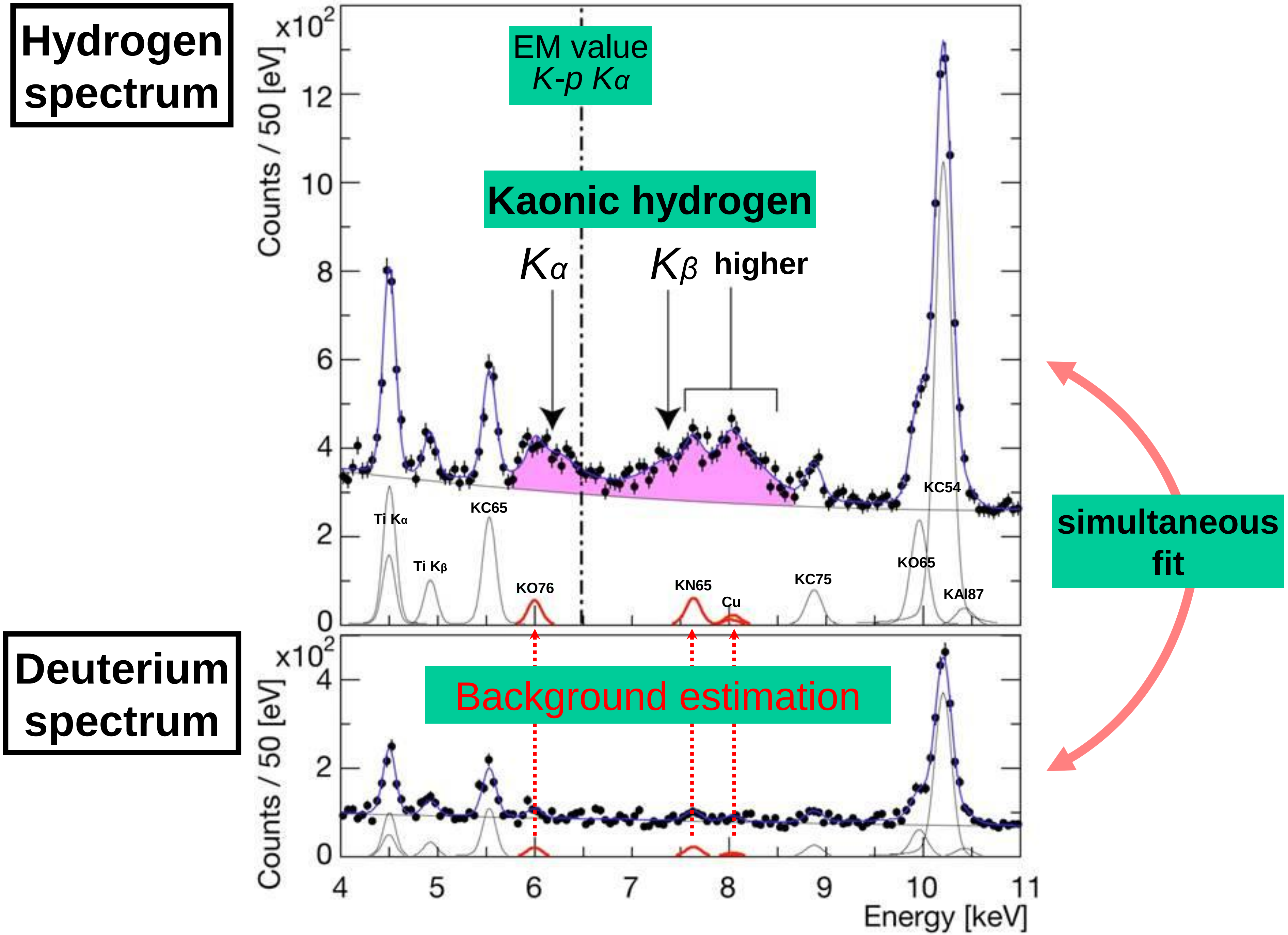
Figure 5: Comparison of experimental results. Open circle: K-4He 2*p* state; filled circle: K-3He 2*p* state. Both are determined by the SIDDHARTA experiment. The average value of the K-4He experiments performed in the 70’s and 80’s is plotted with the open triangle.

Kaonic Helium results:

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

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

Kaonic Hydrogen



Hydrogen spectrum

EM value
K-p Kα

Kaonic hydrogen

Kα

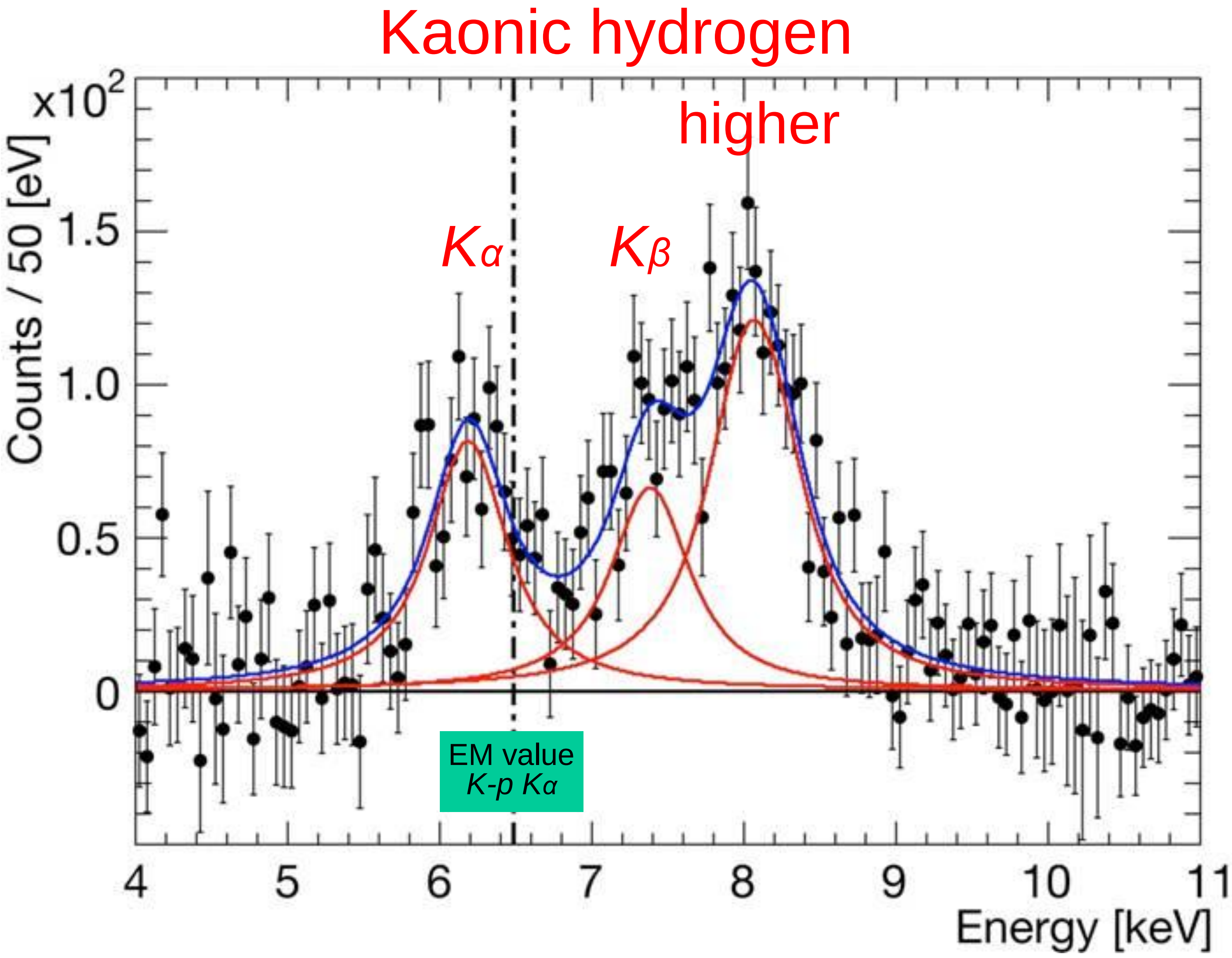
Kβ **higher**

simultaneous fit

Deuterium spectrum

Background estimation

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



KAONIC HYDROGEN results

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

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

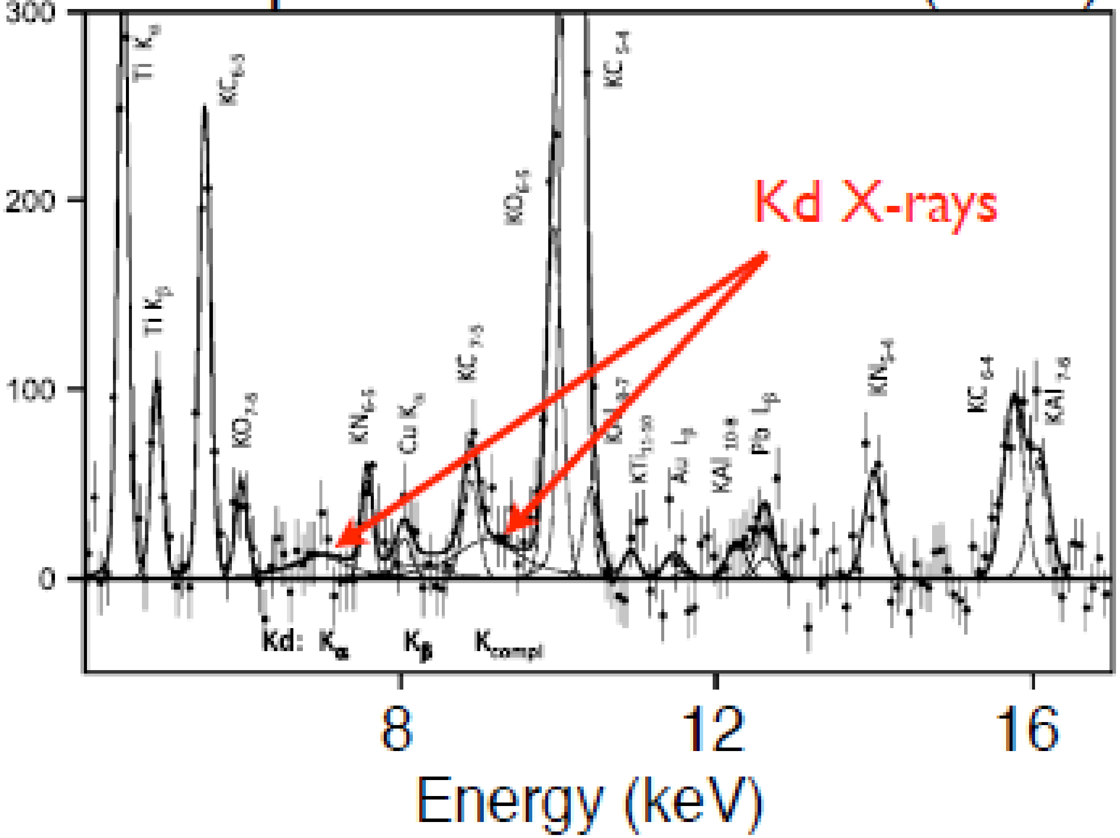
Kaonic Deuterium exploratory measurement

theoretical calculations

$a_{K^- d}$ [fm]	ϵ_{1s} [eV]	Γ_{1s} [eV]	Ref.
$-1.58 + i1.37$	-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

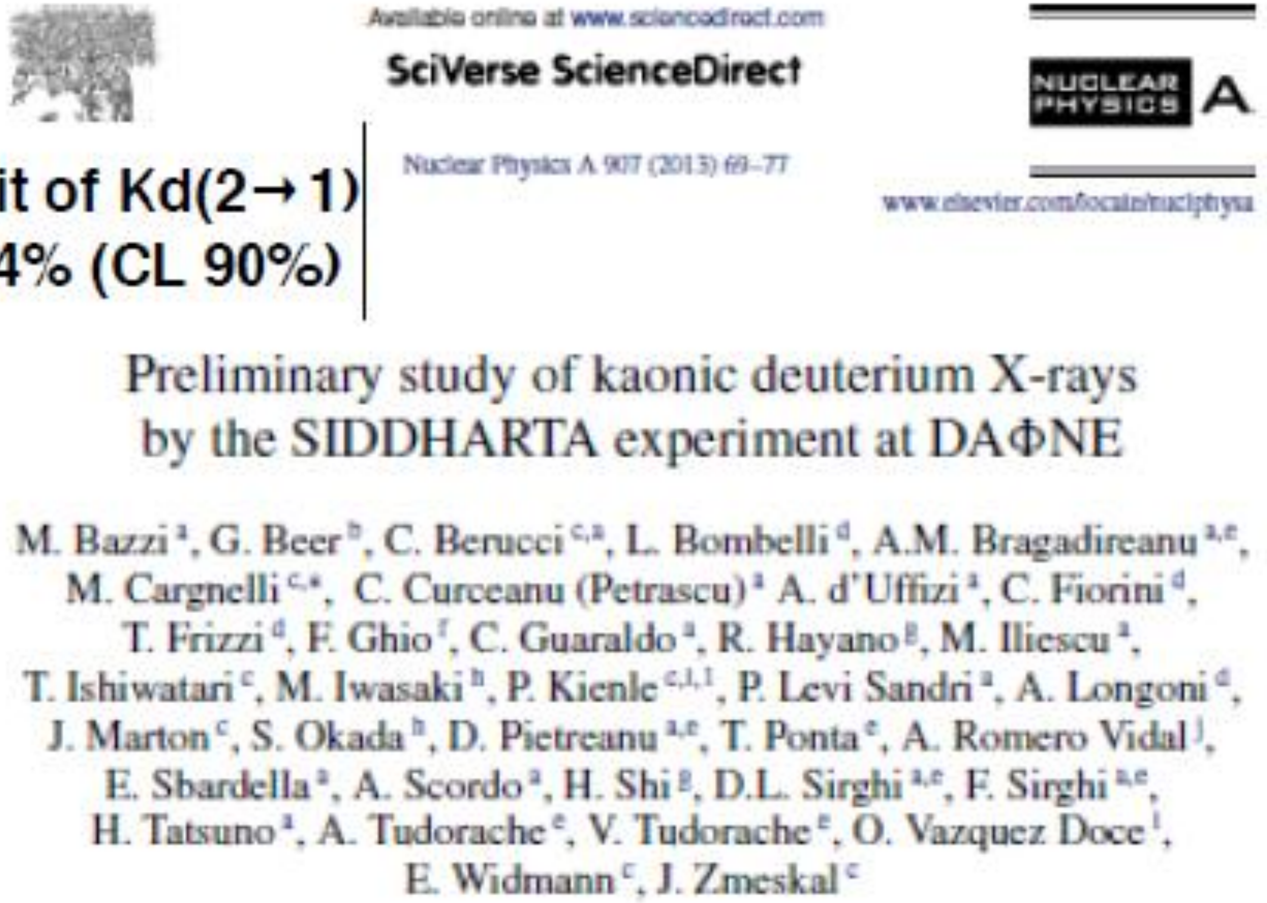
continuous background was subtracted

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

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



Available online at www.sciencedirect.com

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Nuclear Physics A 907 (2013) 69–77

NUCLEAR PHYSICS A

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]

CERN Courier, November 2011

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 cm^2) 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].

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

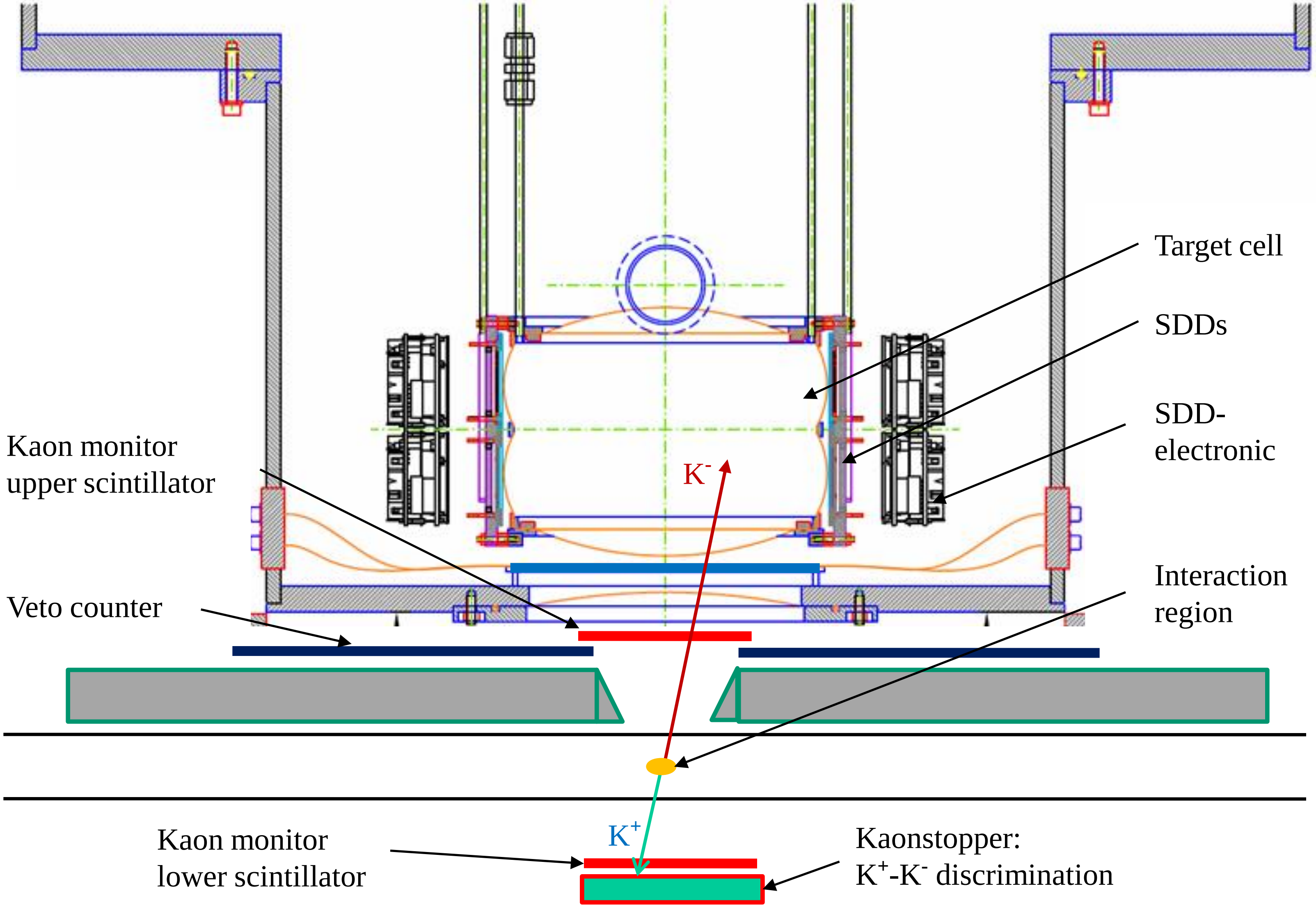
It is actually the IDEAL facility for kaonic atoms studies as SIDDHARTA has demonstrated

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

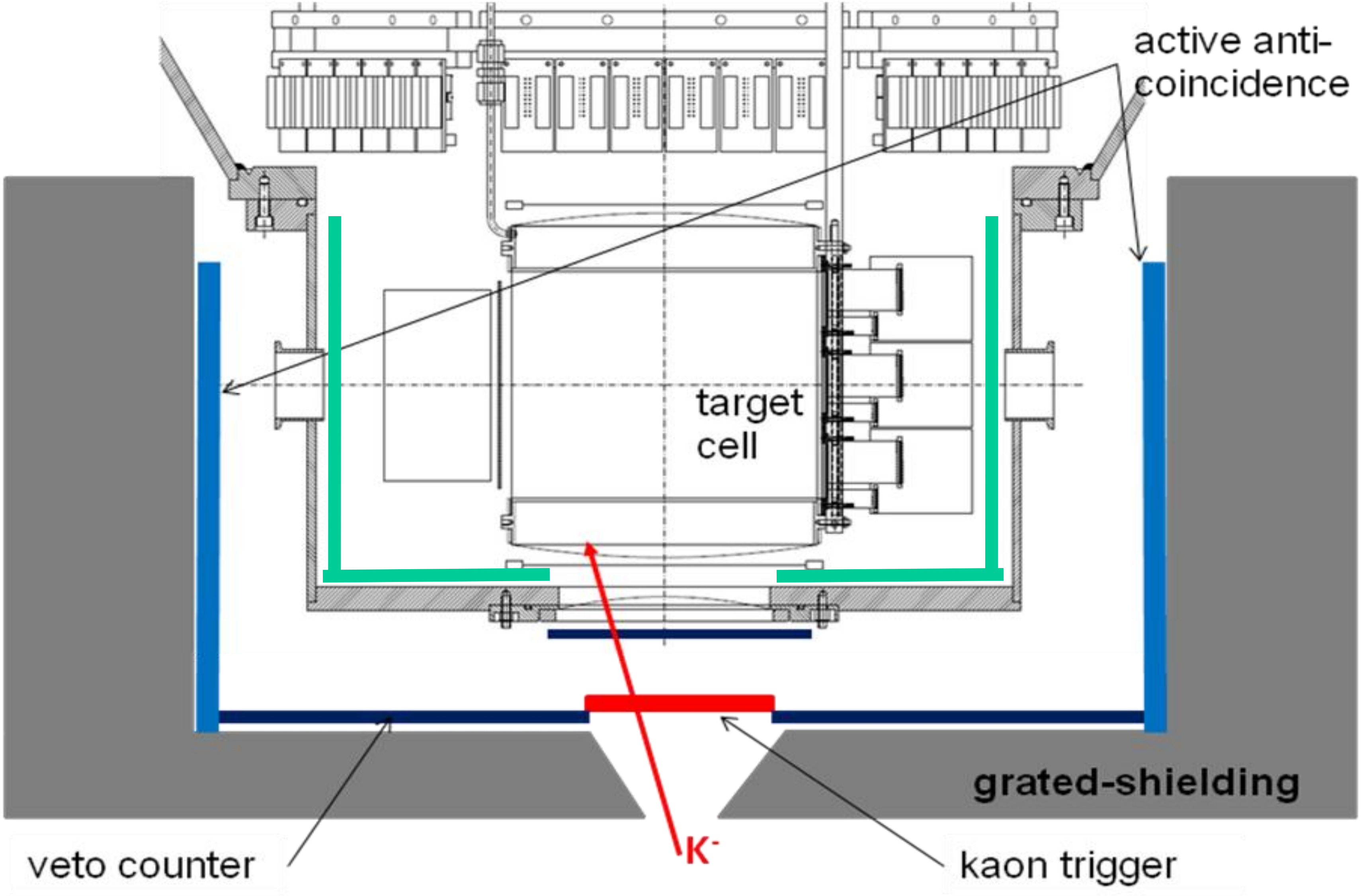
Kaon monitor
upper scintillator

Veto counter

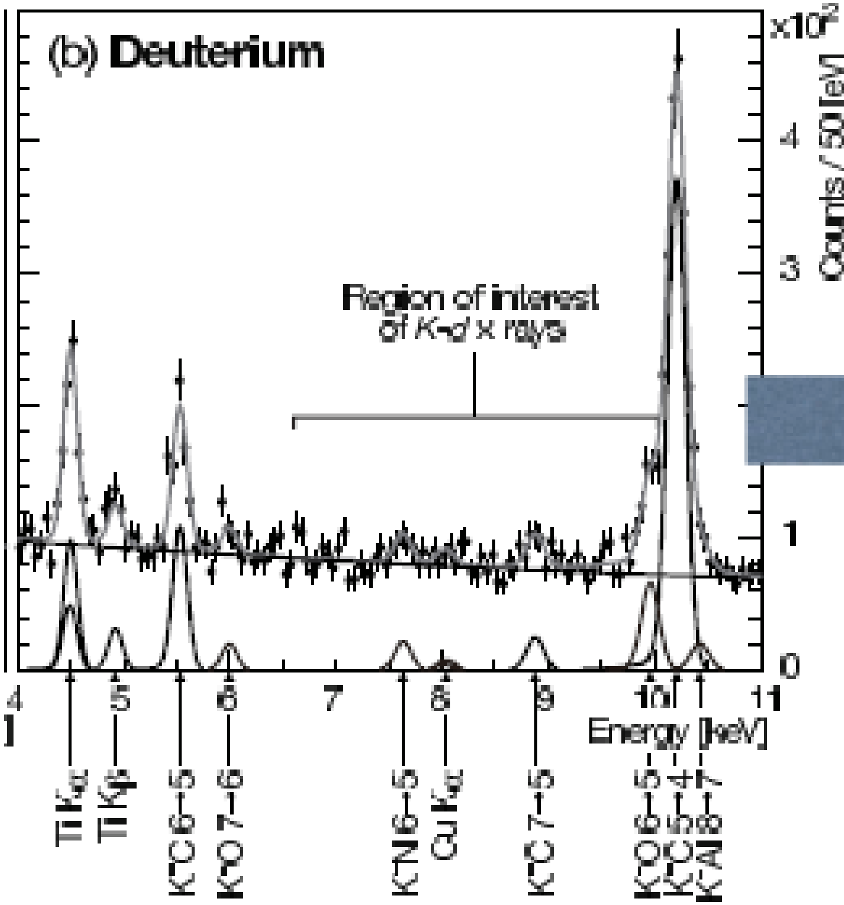
Interaction
region

Kaon monitor
lower scintillator

Kaonstopper:
K^+-K^- discrimination

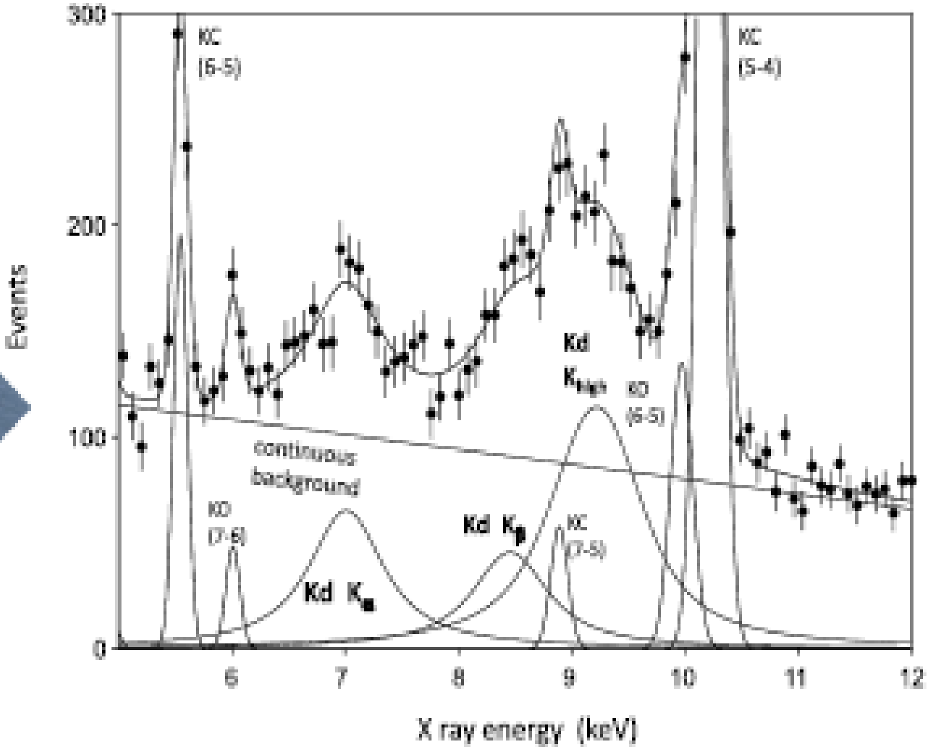

active anti-coincidence
target cell
grated-shielding
veto counter
K⁻
kaon trigger

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 – $\Lambda(1405)$ 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

HYP2012

Concluding Remarks

Tomofumi NAGAE,

Kyoto University

HIGHLIGHTS

HYP2012 — HYP-X

3-year progress

HYP
2012
BARCELONA

HYP-X
@J-PARC

160 participants form 20 countries !

HIGHLIGHTS

HYP2012

(e,e'K$^+$)

$^{6}_{\Lambda}$H

SIDDHARTA & Λ(1405)

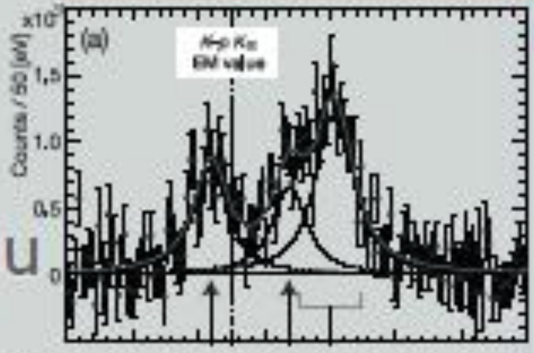
B-B Int. & H With LQCD & EFT

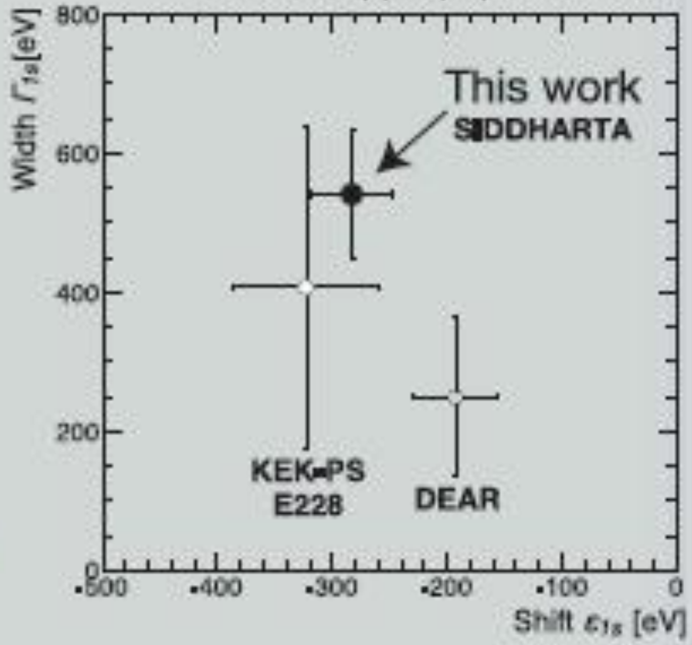
... And a lot of intensive discussions.

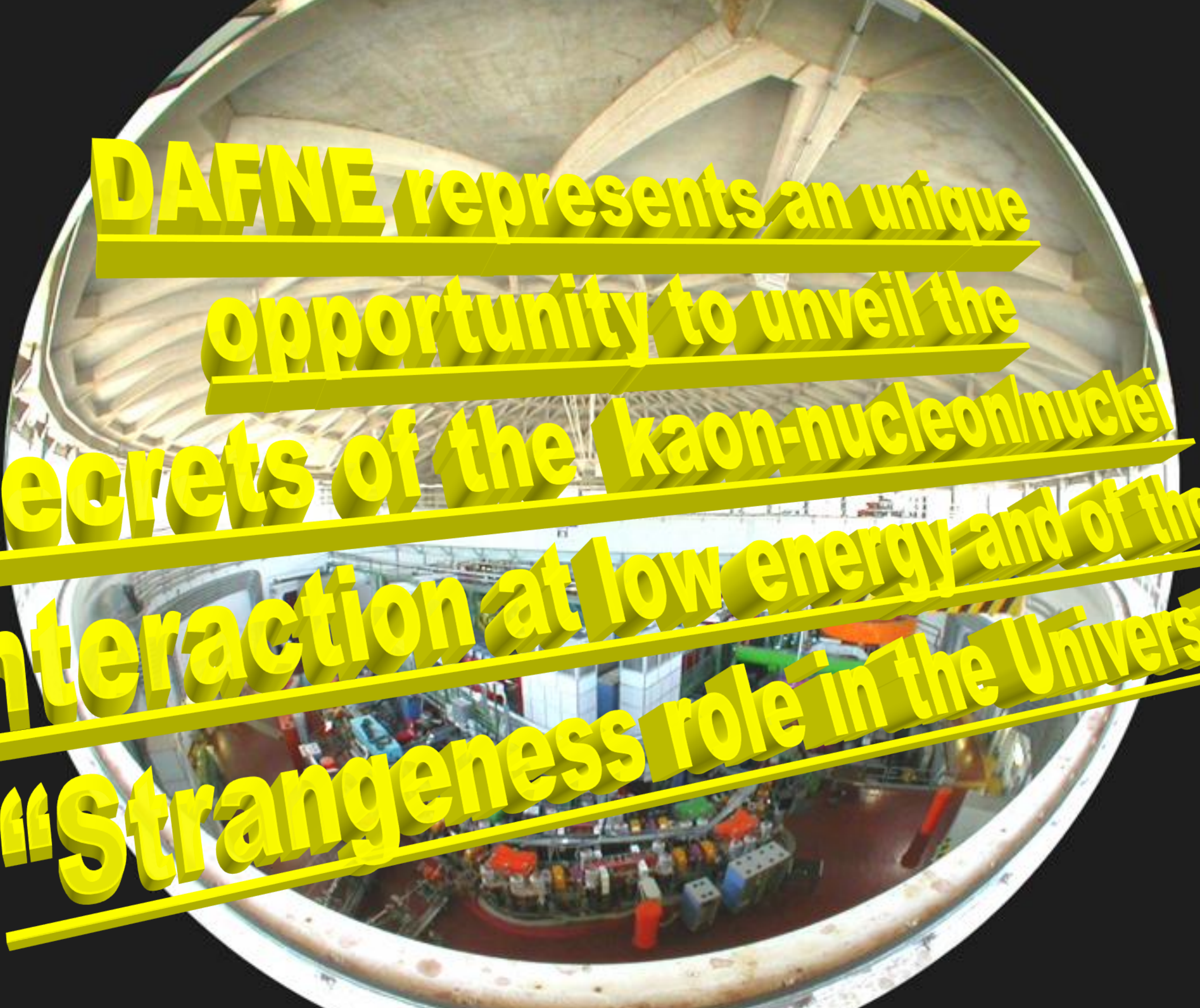
Nuclear Kaonic Systems

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”

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

Dialogues on a blackboard in Garching (continued)

QCD and the origin of mass:

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

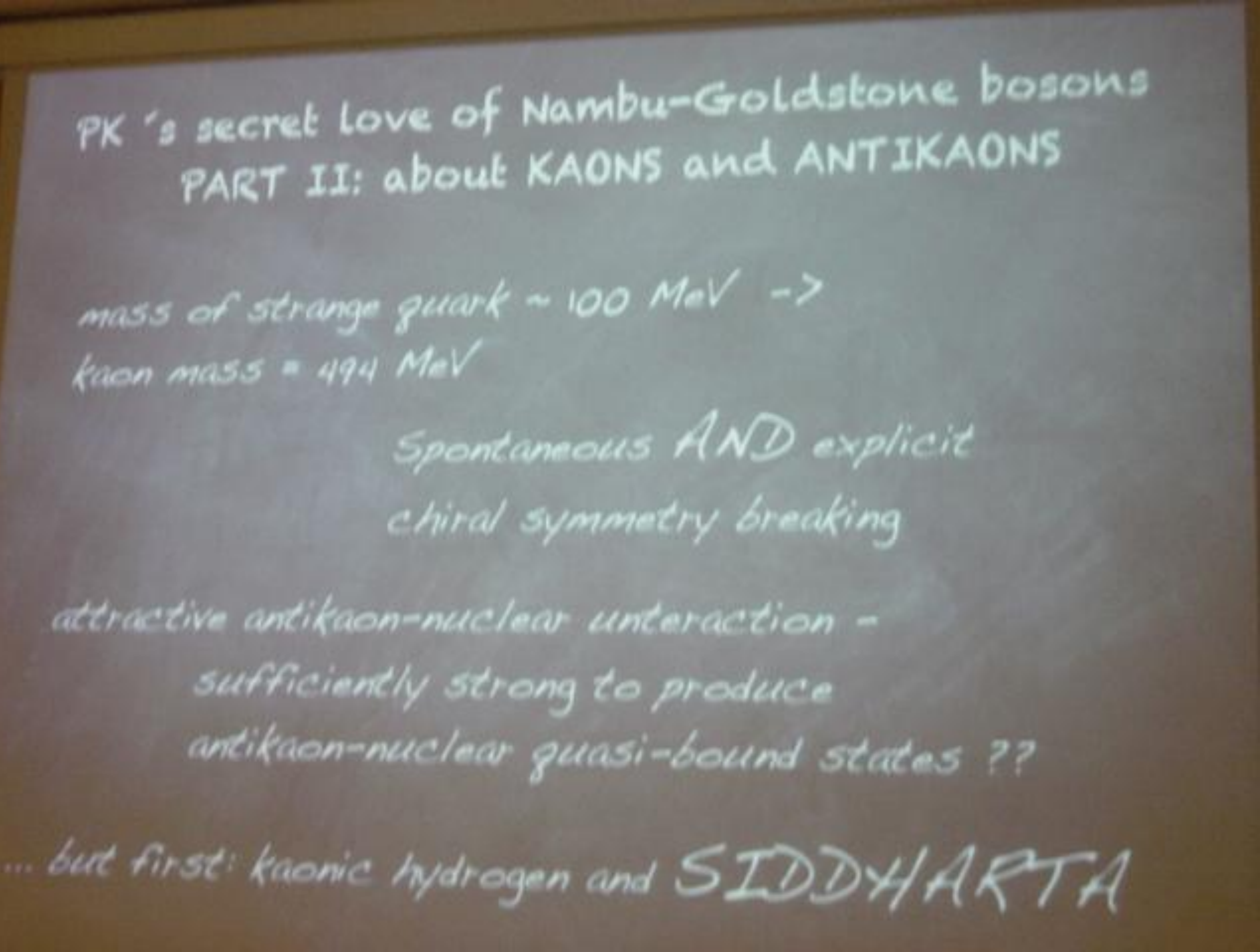
answer:

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

“Se in un cataclisma andasse distrutta tutta la conoscenza scientifica, e soltanto una frase potesse essere trasmessa alle generazioni successive, quale affermazione conterrebbe la massima quantità di informazioni nel numero minimo di parole? Io credo che sarebbe l'ipotesi atomica (o dato di fatto atomico, o comunque vogliamo chiamarlo) secondo cui tutte le cose sono fatte di atomi, piccole particelle che si agitano con un moto perpetuo, attraendosi quando sono un po’ distanti una dall'altra, ma respingendosi quando sono schiacciate una contro l'altra. In questa singola frase c'è un'enorme quantità di informazione sul mondo che ci circonda, se soltanto ci si riflette sopra con un po’ di immaginazione.”

Richard Feynman, *Sei pezzi facili*

.