IX International Conference on Hyperons, Charm and Beauty Hadrons

Kaon-nucleon/nuclei interaction studies by kaonic atoms measurements: the SIDDHARTA experiment at DAFNE

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on behalf of SIDDHARTA collaboration

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Perugia, Italy

SIDDHARTA

SIlicon Drift Detector for Hadronic Atom Research by Timing Applications

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

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

The scientific aim

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

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

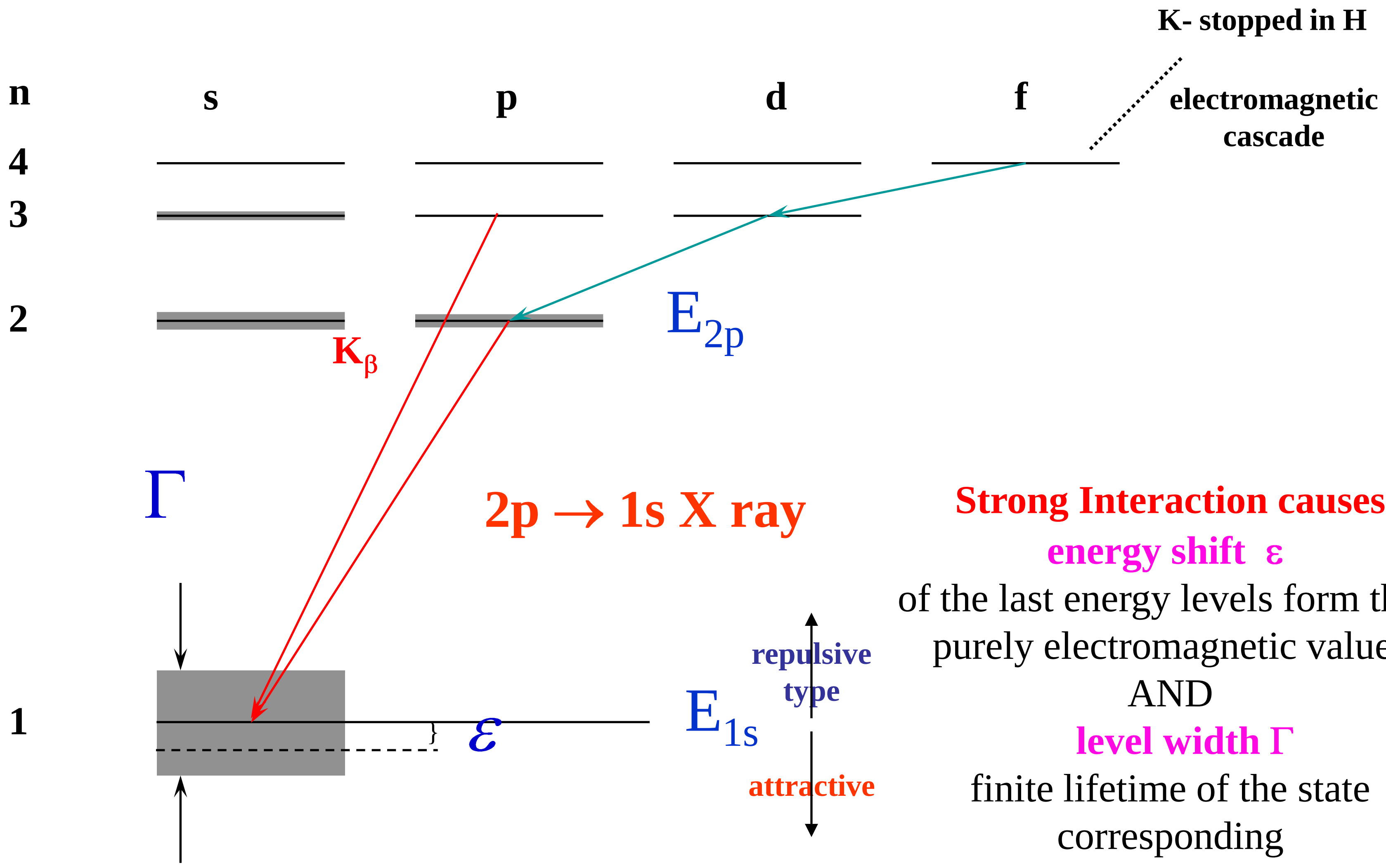
of the K_{α} line of **kaonic hydrogen (400 pb**-1)**

and

the *first measurement* of **kaonic deuterium (600 pb**-1)**

SIDDHARTA measures the X-ray transitions occurring in the cascade processes of kaonic atoms

Kaonic Hydrogen atoms



$$\varepsilon = E_{2p \to 1s}(\mathrm{exp}) - E_{2p \to 1s}(\mathrm{e.m.})$$

Strong Interaction causes:

energy shift ε

of the last energy levels form their purely electromagnetic values

AND

level width Γ

finite lifetime of the state corresponding to an increase in the observed level width

Kaonic Hydrogen – Deser formula

With a_0, a_1 standing for the I=0,1 S-wave $\bar{K}N$ complex scattering lengths in the isospin limit ($m_d = m_u$), μ being the reduced mass of the K^-p system, and neglecting isospin-breaking corrections, the relation reads:

$$\varepsilon + i\frac{\Gamma}{2} = \frac{2\pi}{\mu}2\alpha^3\mu^2 a_{K^-p} = 412\ fm^{-1}\cdot eV\cdot a_{K^-p}$$

$$a_{K^-p} = \frac{1}{2}(a_0 + a_1)$$

… a linear combination of the isospin scattering lengths a_0 and a_1
to disentangle them, also the kaonic deuterium scattering length is needed

For high precision checks, relations including isospin breaking corrections are needed

„By using the non-relativistic effective Lagrangian approach a complete expression for the isospin-breaking corrections can be obtained;
in leading order parameter-free modified Deser-type relations exist and can be used to extract scattering lenghts from kaonic atom data“[2]

[2]Meißner,Raha,Rusetsky, 2004

Kaonic deuterium

For the determination of the isospin dependent scattering lengths a_0 and a_1 the hadronic shift and width of kaonic hydrogen *and* kaonic deuterium are necessary !

Elaborate procedures needed to connect the observables with the underlying physics parameters.

$$a_{K^-p} = \frac{1}{2}[a_0 + a_1]$$

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

Impulse approximation term

$$a_{K^-d} = \frac{4[m_N + m_K]}{[2m_N + m_K]} \cdot a^{(0)} + C$$

larger then leading term

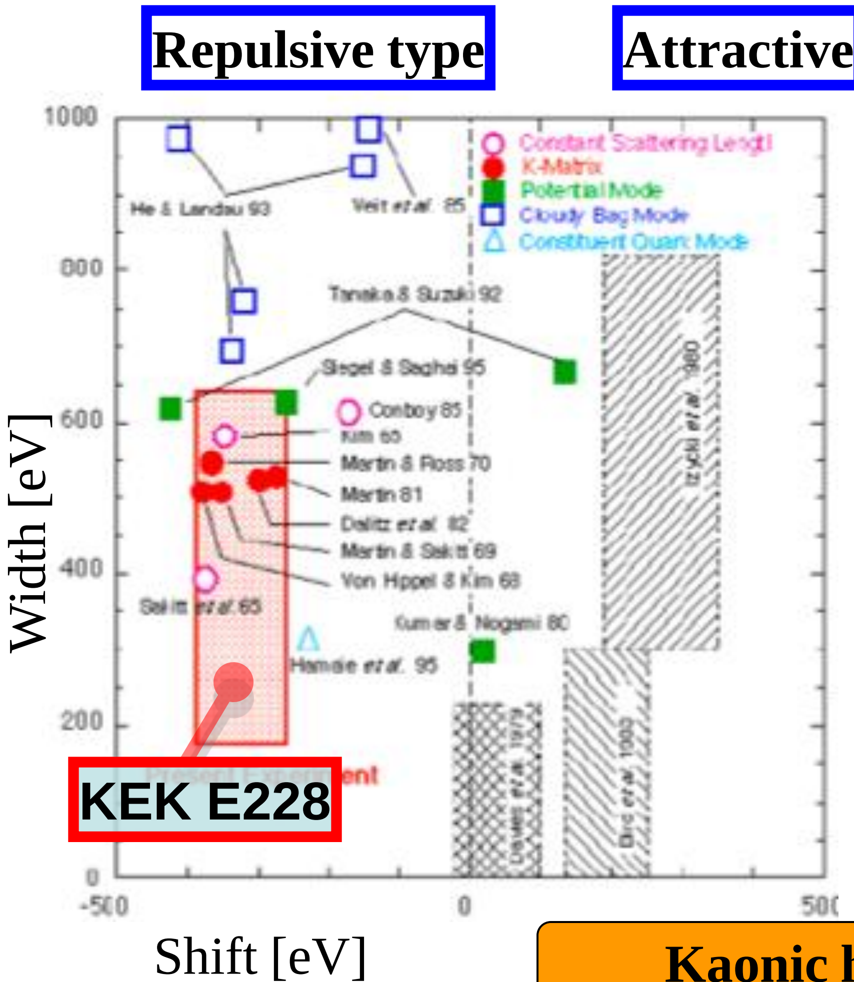
$$a^{(0)} = \frac{1}{2}\left[a_{K^-p} + a_{K^-n}\right] = \frac{1}{4}[a_0 + 3a_1]$$

"To summarize, one may expect that the combined analysis of the forthcoming high-precision data from DEAR/SIDDHARTA collaboration on kaonic hydrogen and deuterium will enable one to perform a stringent test of the framework used to describe low–energy kaon deuteron scattering, as well as **to extract the values of a0 and a1 with a reasonable accuracy.** However, in order to do so, **much theoretical work related to the systematic calculation of higher-order corrections within the non-relativistic EFT is still to be carried out."** (from: Kaon-nucleon scattering lengths from kaonic deuterium, **Meißner, Raha, Rusetsky, 2006,** arXiv:nucl-th/0603029)

Summary of the physics framework and motivation

- Exotic (kaonic) atoms – probes for strong interaction
  - hadronic shift ε_{1s} and width Γ_{1s} directly observable
  - experimental study of low energy QCD. Testing chiral symmetry breaking in strangeness systems
- Kaonic hydrogen
  - Kp simplest exotic atom with strangeness
  - kaonic hydrogen „puzzle“ solved – but: more precise experimental data important
  - kaonic deuterium never measured before
  - atomic physics: new cascade calculations (to be tested !)
- Information on Λ(1405) sub-threshold resonance
  - responsible for negative real part of scattering amplitude at threshold
  - important for the search for the controversial „deeply bound kaonic states” present / upcoming experiments (KEK,GSI,DAFNE,J-PARC)
- Determination of the isospin dependent KN scattering lengths
  - no extrapolation to zero energy

Kaonic Hydrogen puzzle



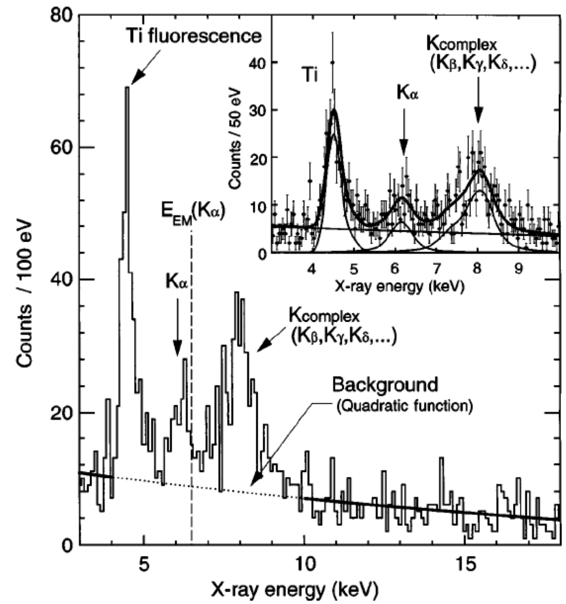


FIG. 3. Kaonic hydrogen x-ray spectrum. The inset shows the result of peak fitting and the components.

***Gas target**
***Si(Li) as x-ray detector**
***Hadron beamline**

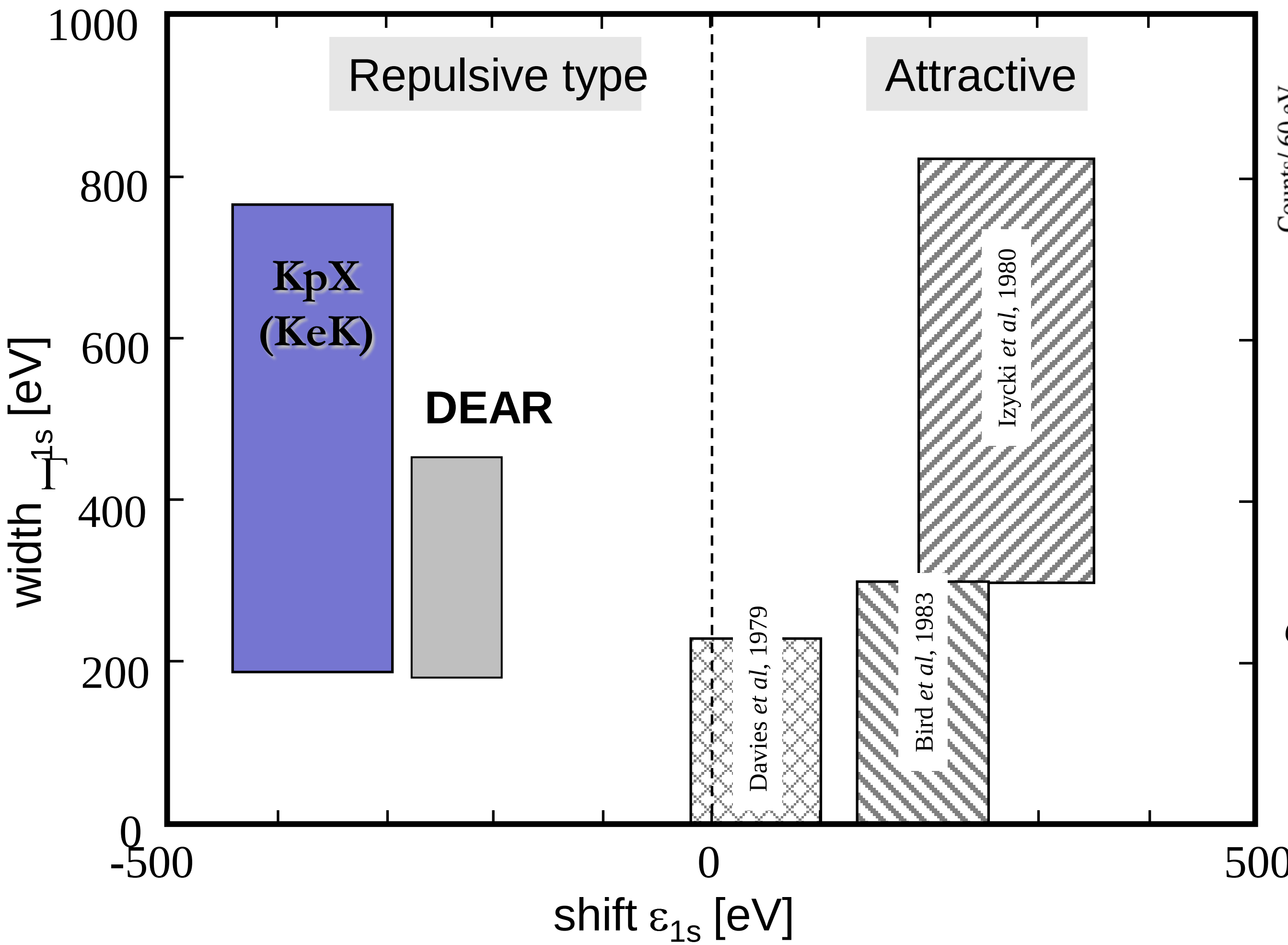
$$\Delta E_{1s} = E^{exp}_{2p\to 1s} - E^{E.M.}_{2p\to 1s}$$
$$= -323 \pm 63(\text{stat.}) \pm 11(\text{syst.})\ \text{eV}$$
$$\Gamma_{1s} = 407 \pm 208\ (\text{stat.}) \pm 100\ (\text{syst.})\ \text{eV}$$

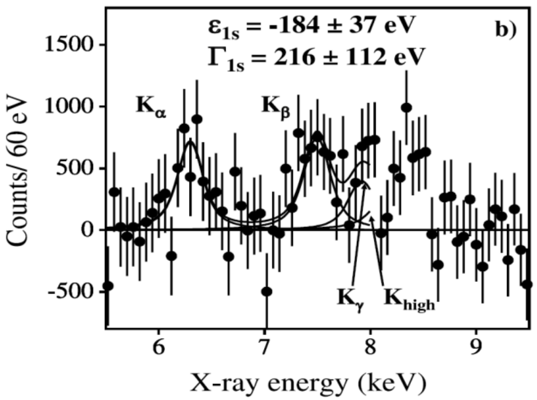
[T.M.Ito et al., Phys.Rev.C 58 (1997) 2366]

Kaonic hydrogen puzzle solved

Need a precise measurement!

DEAR results (2002-2005)





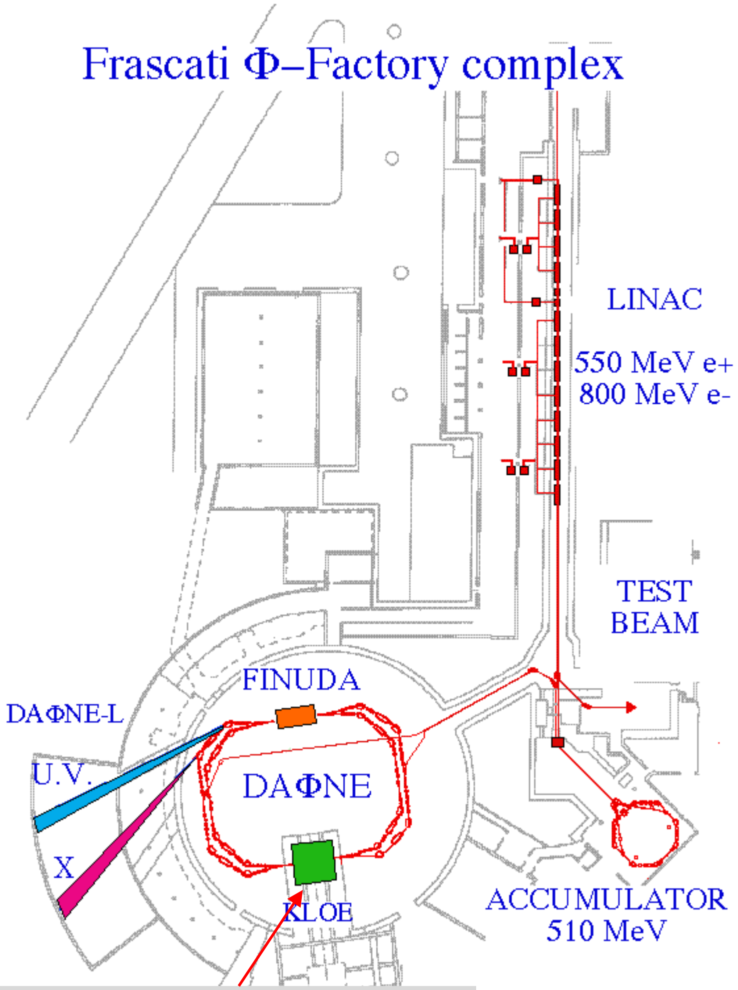
$$\varepsilon = -193 \pm 37(stat.) \pm 6(syst.) eV$$

$$\Gamma = 249 \pm 111(stat.) \pm 39(syst.) eV$$

G. Beer et al., PRL 94 (2005) 212302

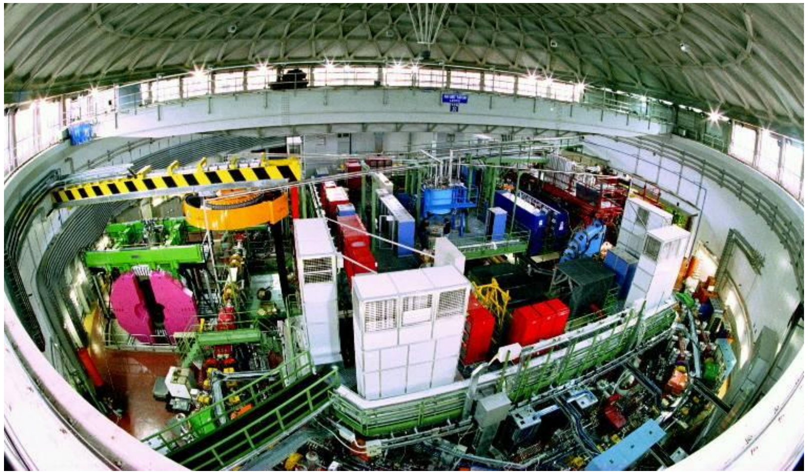
The best measurement published on Kaonic Hydrogen up to now

DAFNE accelerator



SIDDHARTA is set up here

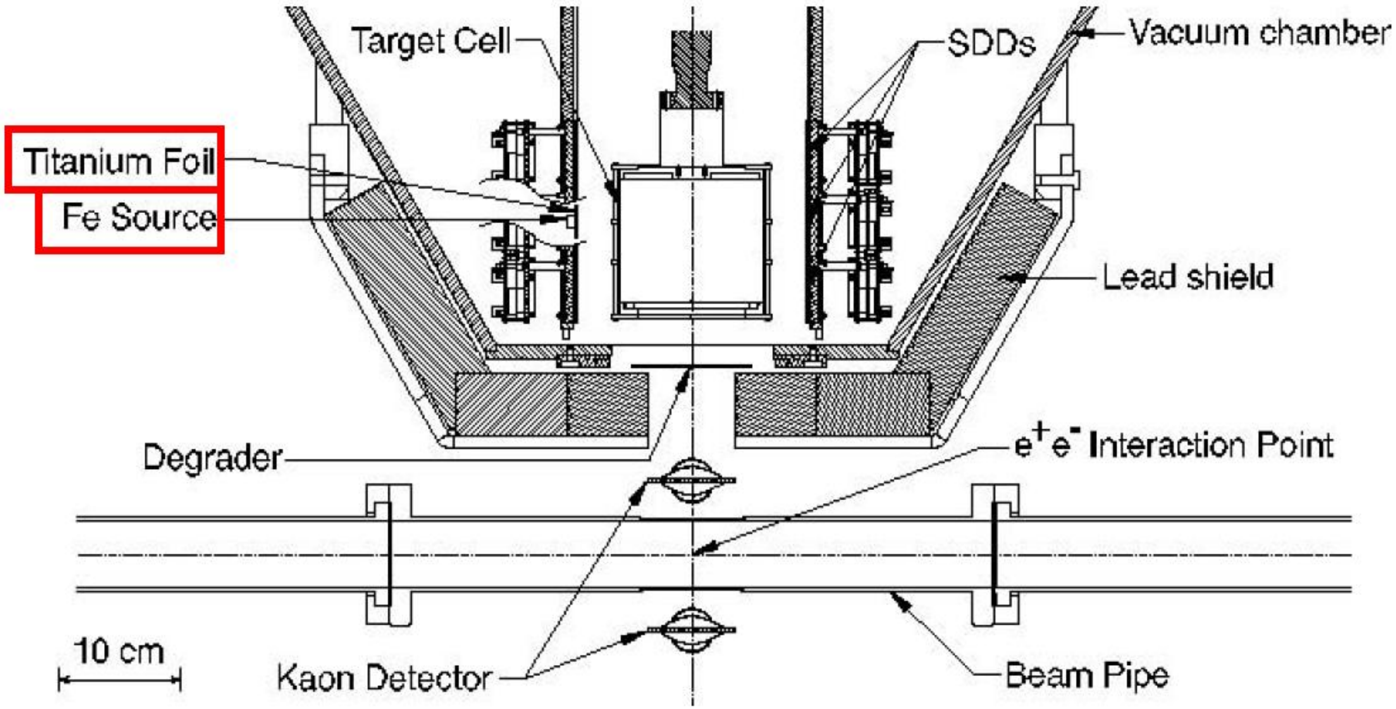
$$e^+ + e^- \rightarrow \phi \rightarrow K^+ + K^-$$

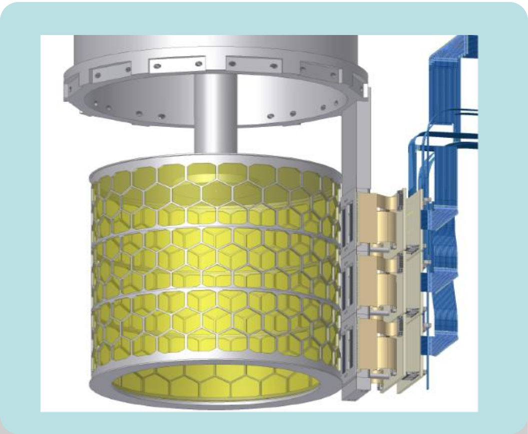


electron-positron collider, energy at phi resonance
phi produced nearly at rest.
(boost: 55 mrad crossing angle → 28 MeV/c)
charged kaons from phi decay: E_k = 16 MeV
degrade to < 4MeV to stop in gas target

Suitable for kaonic atoms measurements

The experimental setup





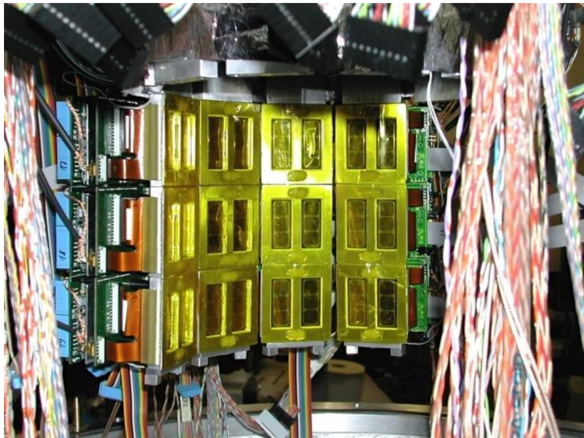
Target size: r=6 cm, height=12 cm

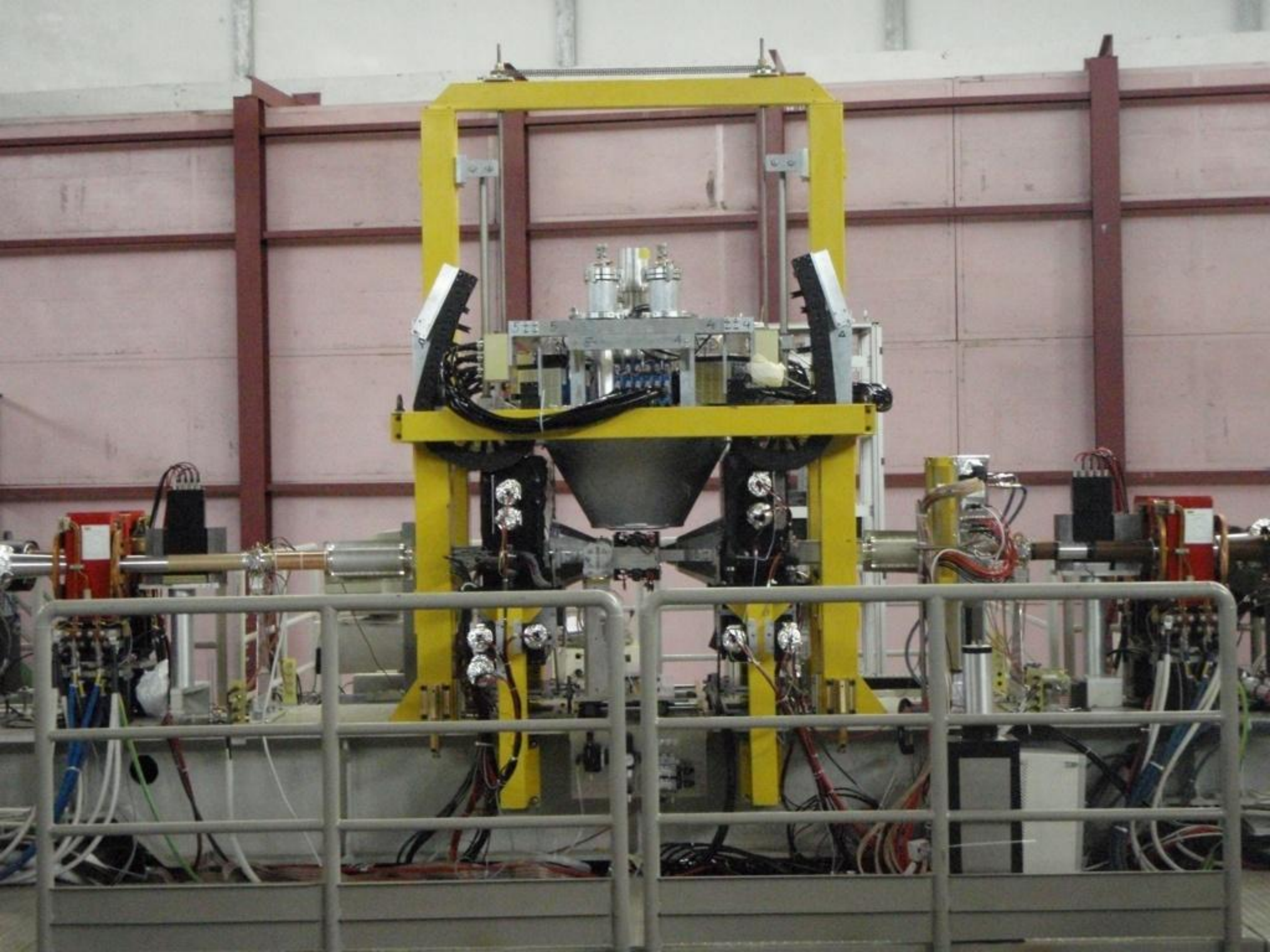
Target density: 0.01 of liquid hydrogen density (8.7 STP)

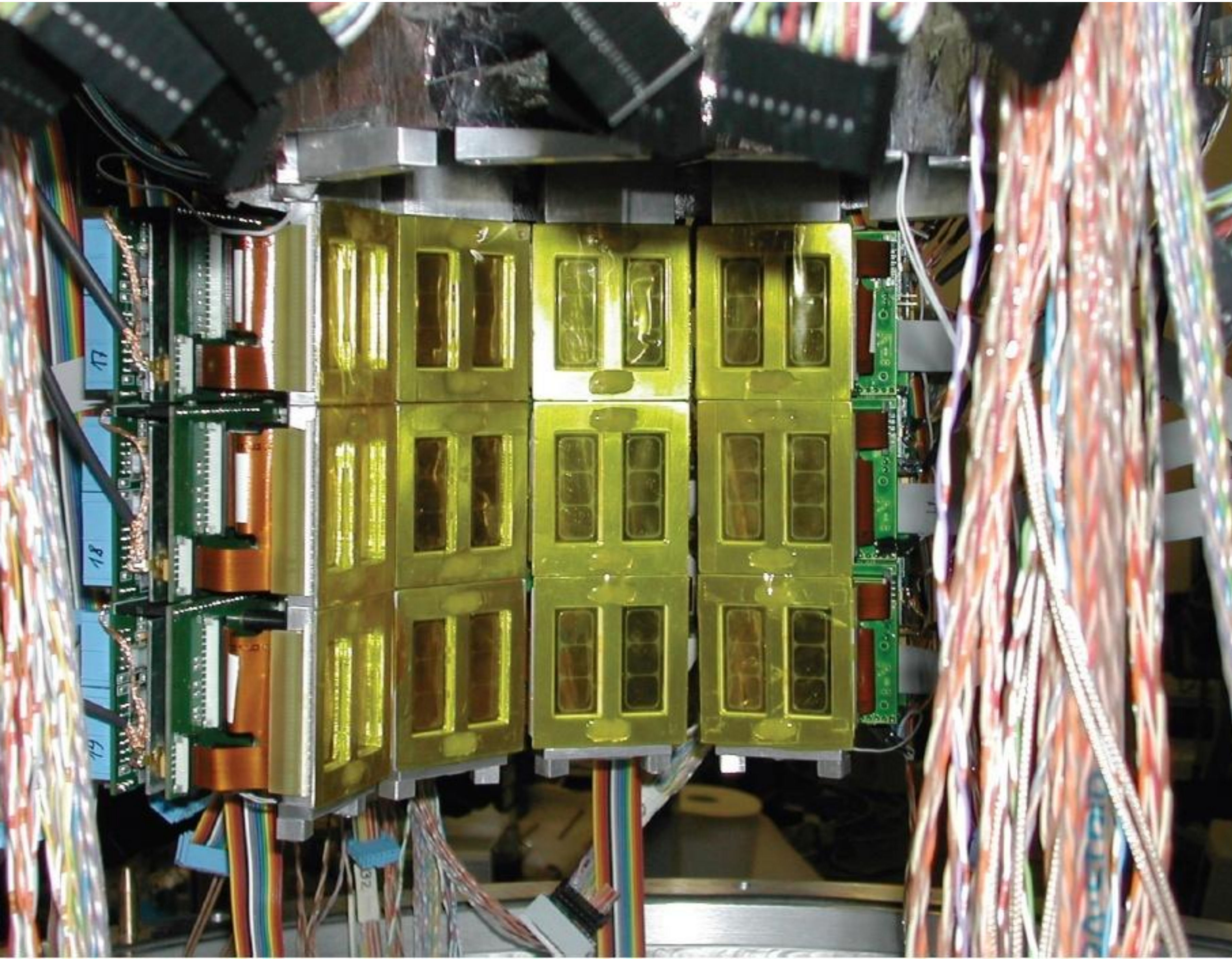
Installed SDD: 144 cm^2

SDD operation temp: 23 K

SDD Energy resolution: ≈150 eV (at 6 keV)



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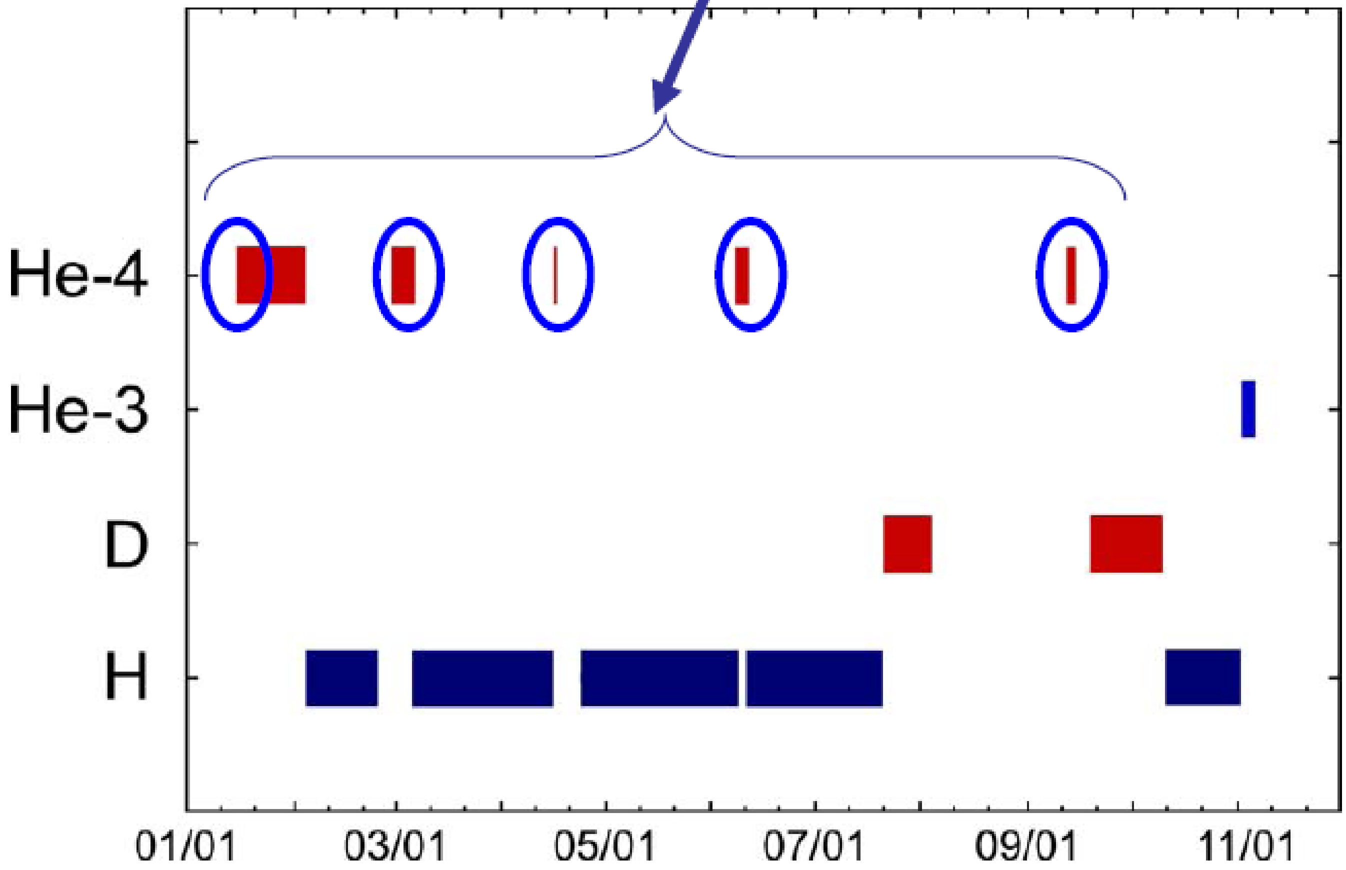
Data taking periods of SIDDHARTA in 2009

K-He4 data without Fe source



SIDDHARTA measurements in 2009

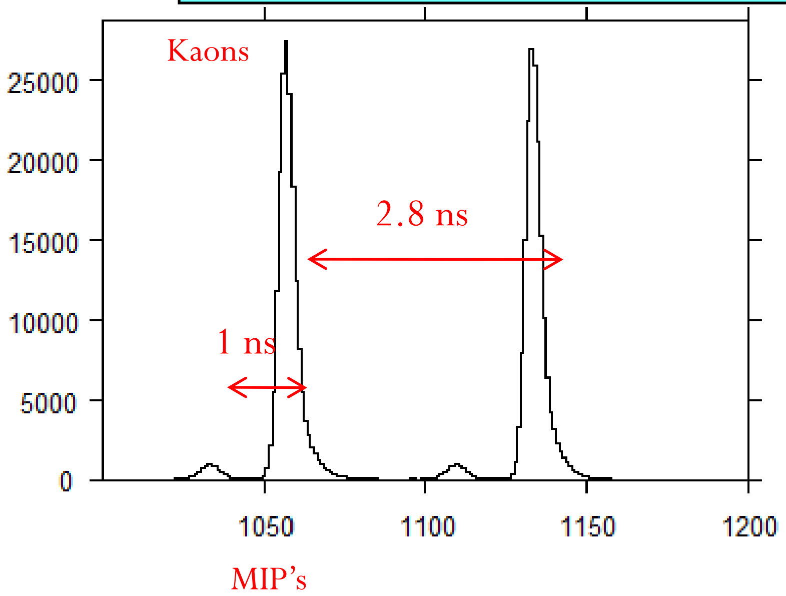
-Kaonic helium 4 – published in Phys. Lett. B 681 (2009) 310; another paper in preparation

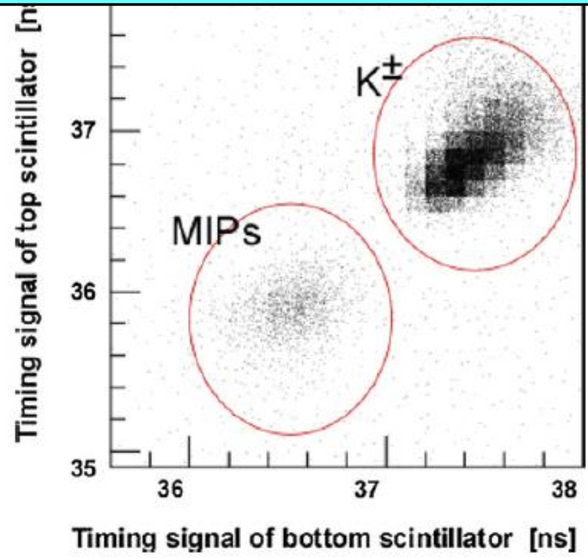
- Kaonic Hydrogen for about 400 pb^{-1} – under analysis – best measurement in the world (sensible improvement of the DEAR results)

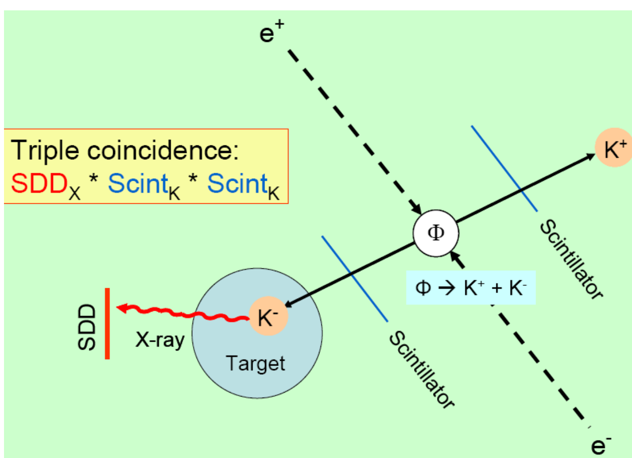
- Kaonic deuterium for about 100 pb^{-1}, as an exploratory first measurement ever (under analysis)

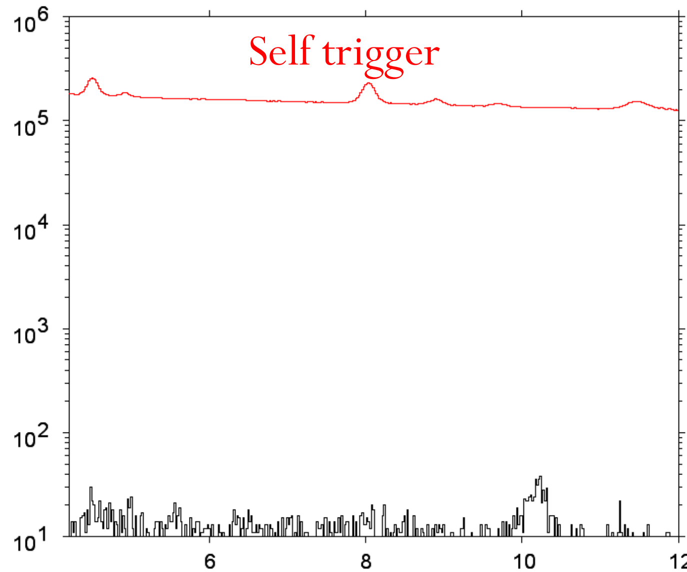
- Kaonic helium 3 – first measurement in the world, about 16 pb^{-1} (under analysis)

The Trigger (Triple coincidences)



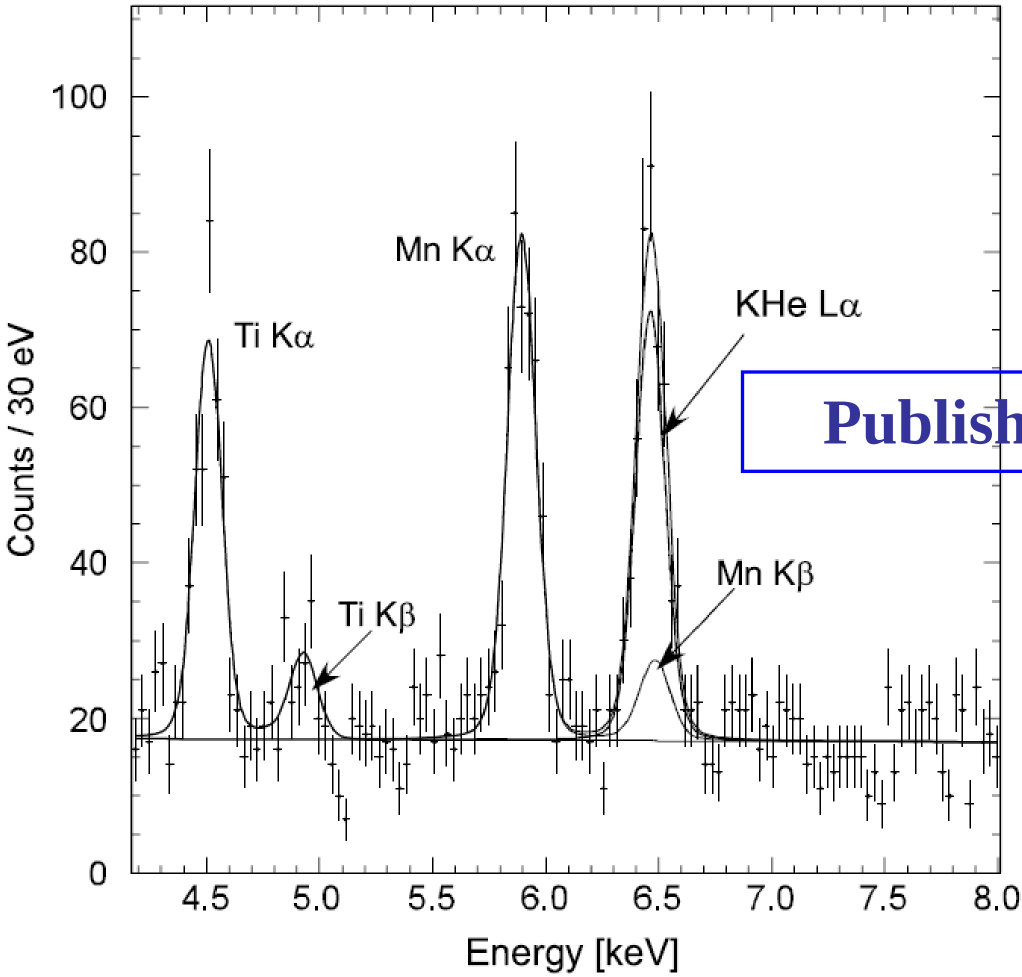






Background suppression more than 10^4

Energy spectrum of K-^{4}He X-rays



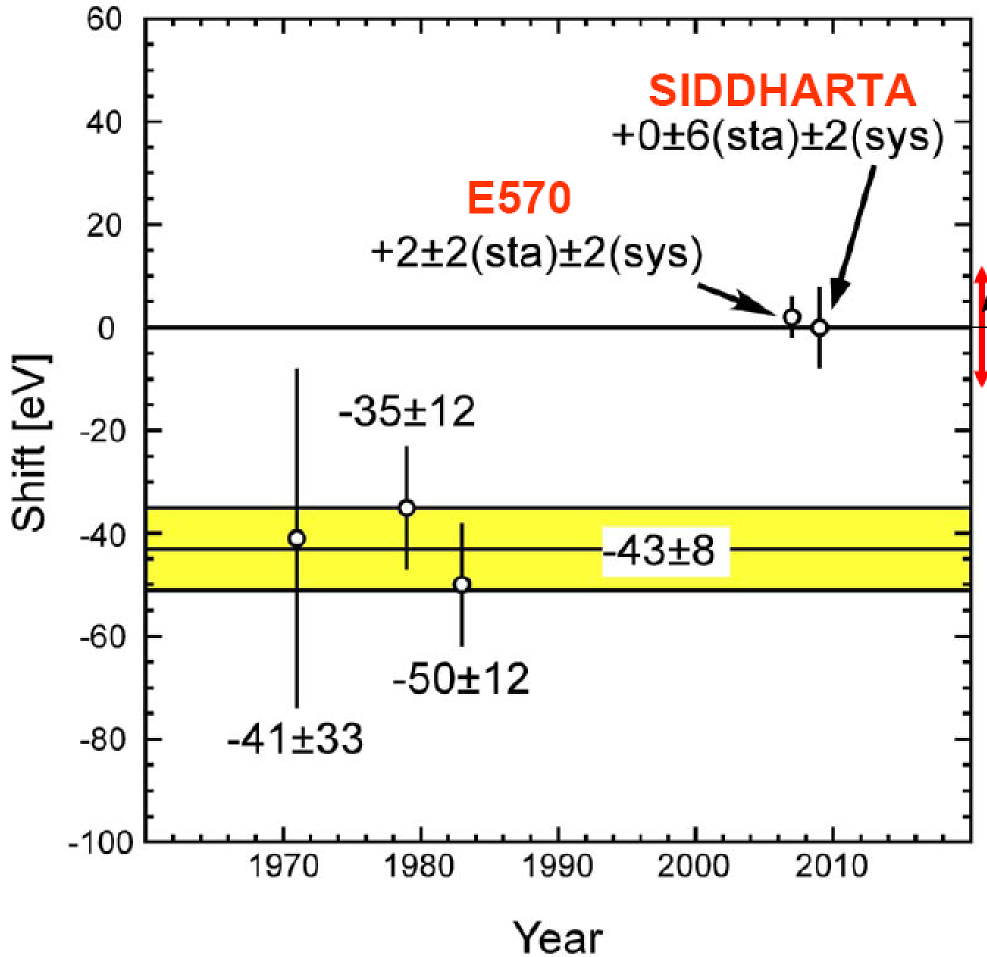
Energy of K^{4}He L$_\alpha$ (3d→2p) line:

E_{exp} = 6463.6 5.8 eV

Published in PLB 681(2009) 310-314

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

Summary of the K-^{4}He shifts



Akaishi Prediction
-10~ +10 eV

Optical model
~0eV

Optical model	Tiny (~ 0eV)	✓
K-nucl model	Small (<±10 eV)	✓
K-He4 exp	Large (-40 eV)	✗

Very preliminary K-^{4}He spectrum

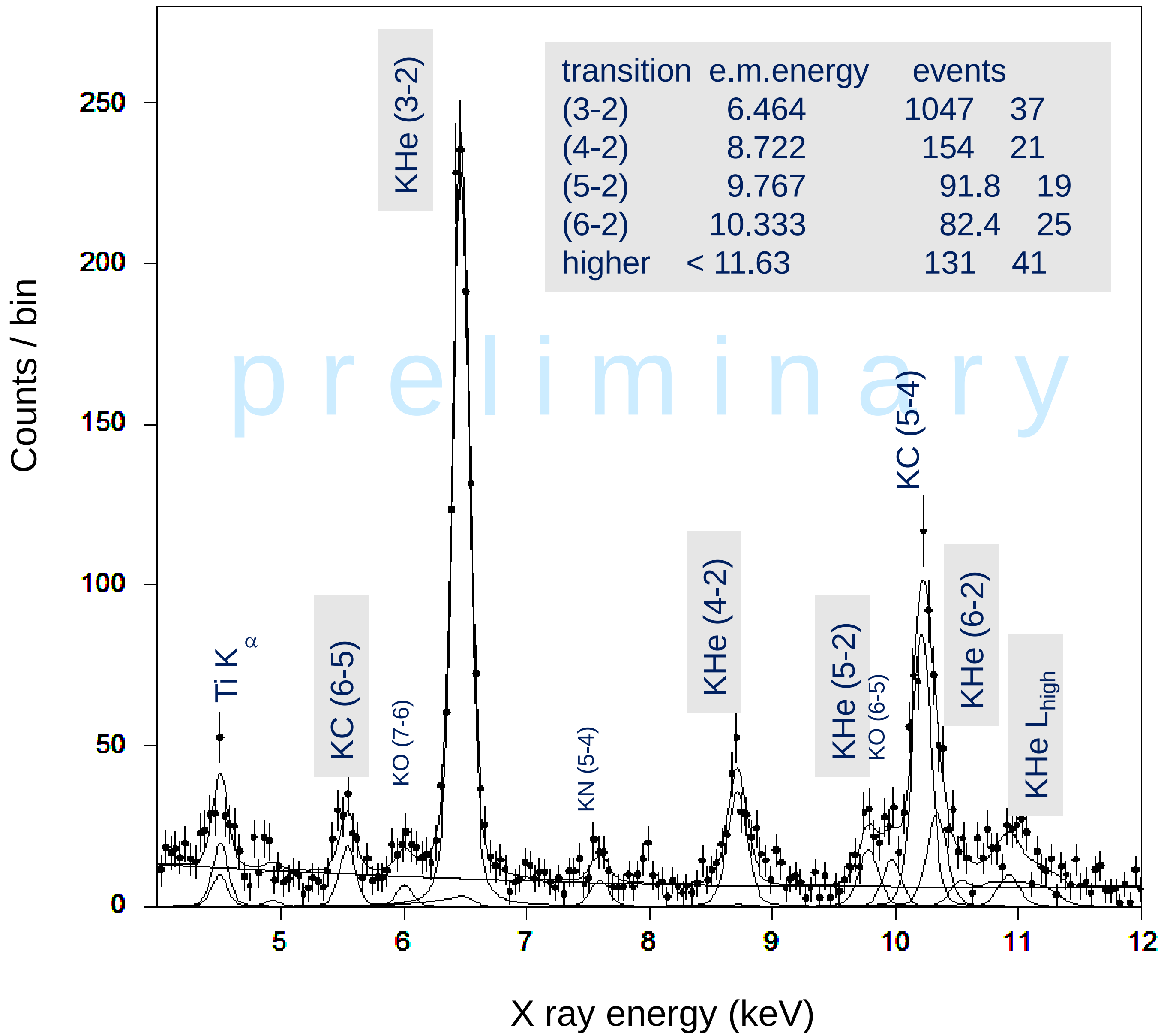
KHe used for
gasstop optimization
+ physics interest[1])

data from setup 2
(no Fe55 source)

Higher statistics of the K-^{4}He L lines (L_{α}, L_{β}, L_{γ})

Smaller statistics in shift, determination of width

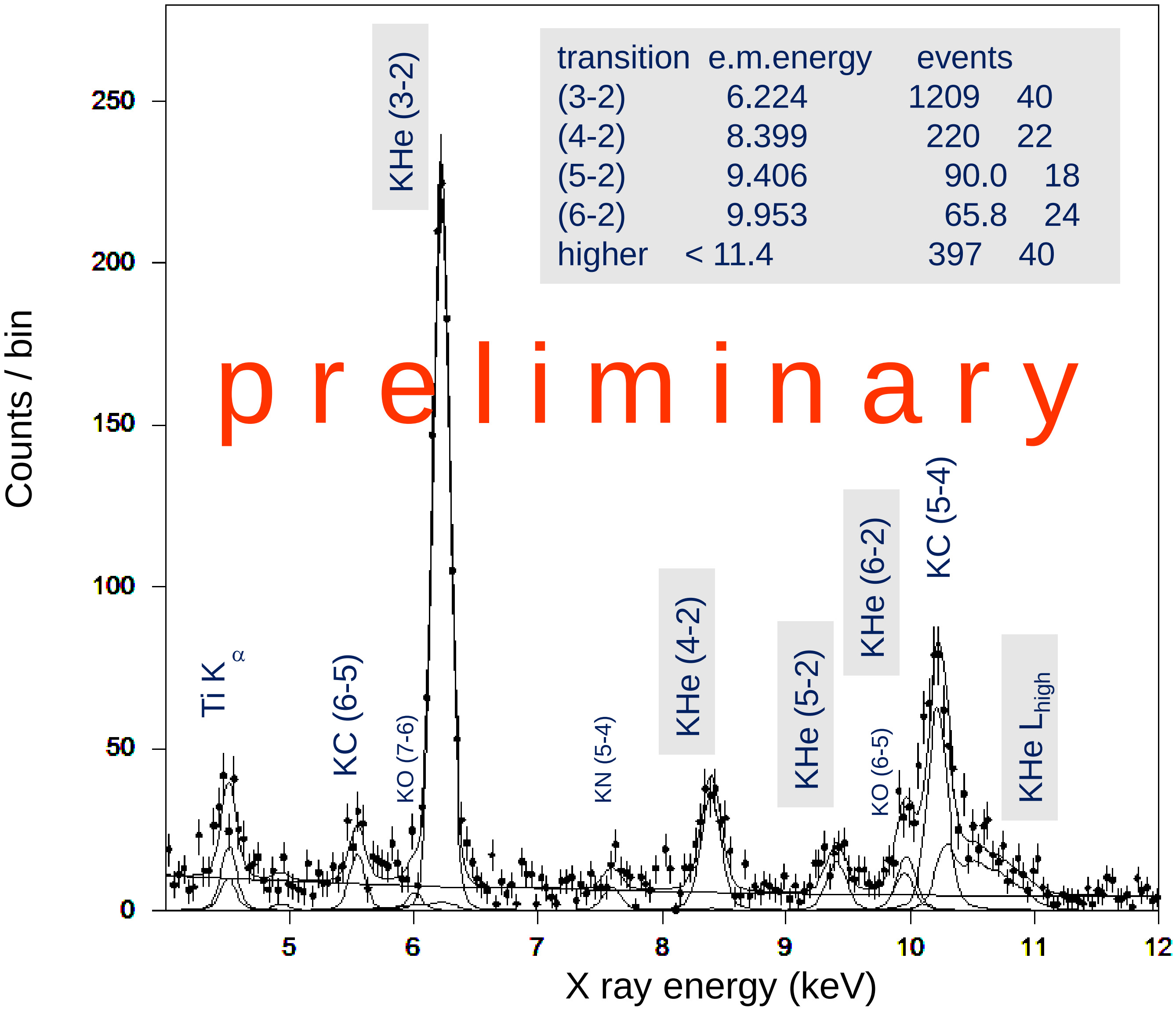
X-ray yield information in gas (for the first time)



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

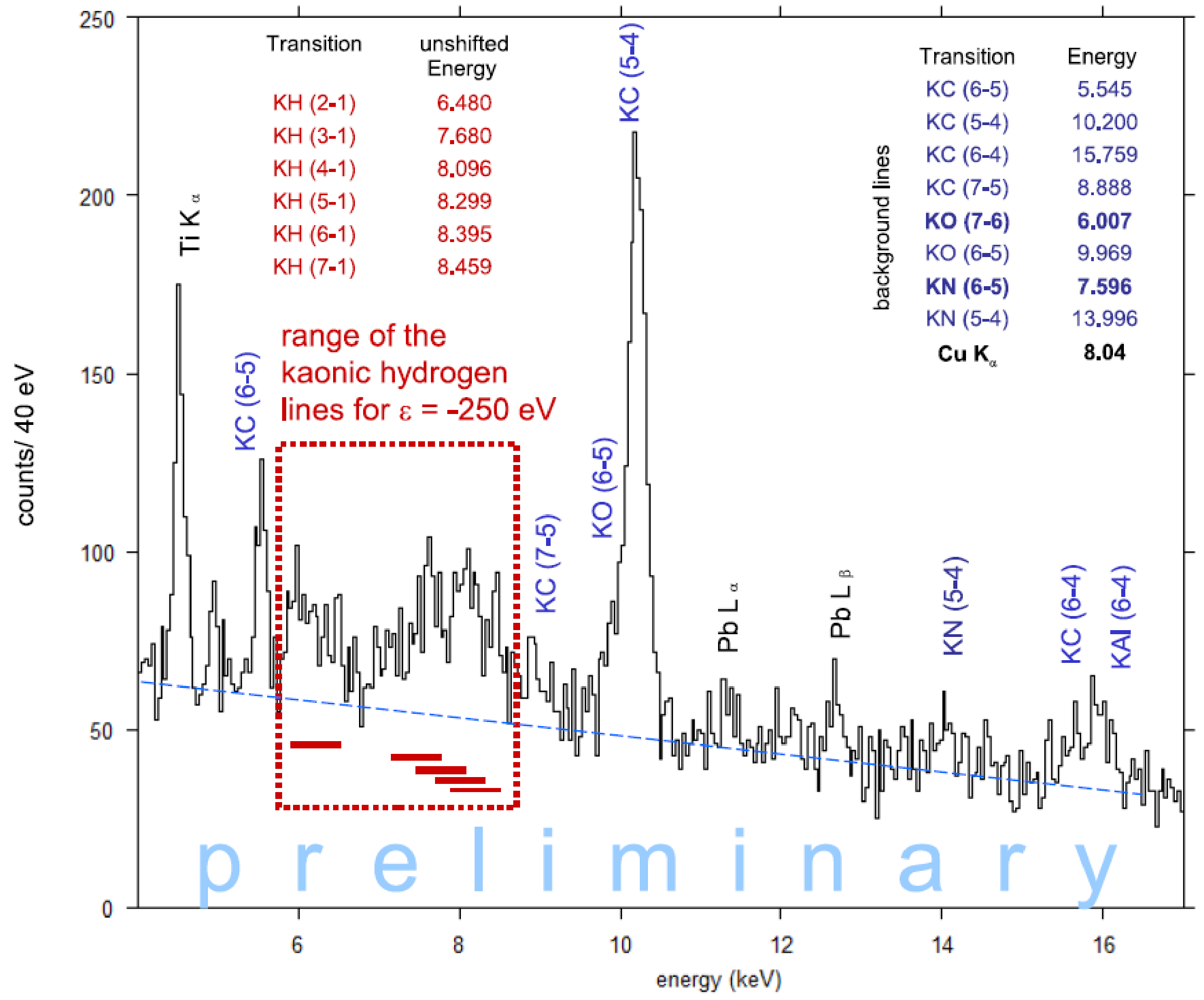
Very preliminary K-^{3}He spectrum

K-^{3}He never measured before !

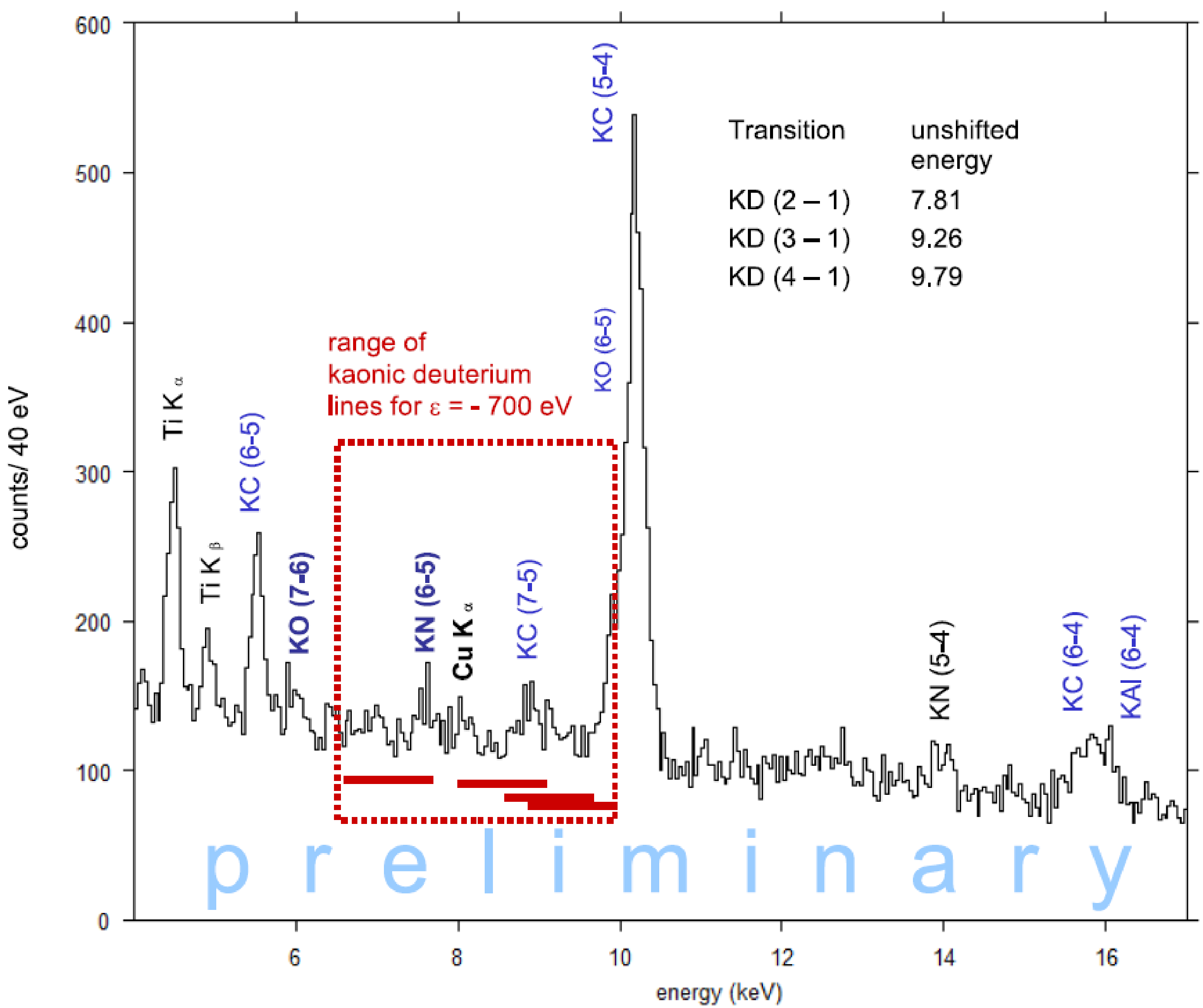


The statistical error for the transition 3d→2p in K ^{3}He is less than 3 eV.

Kaonic hydrogen data



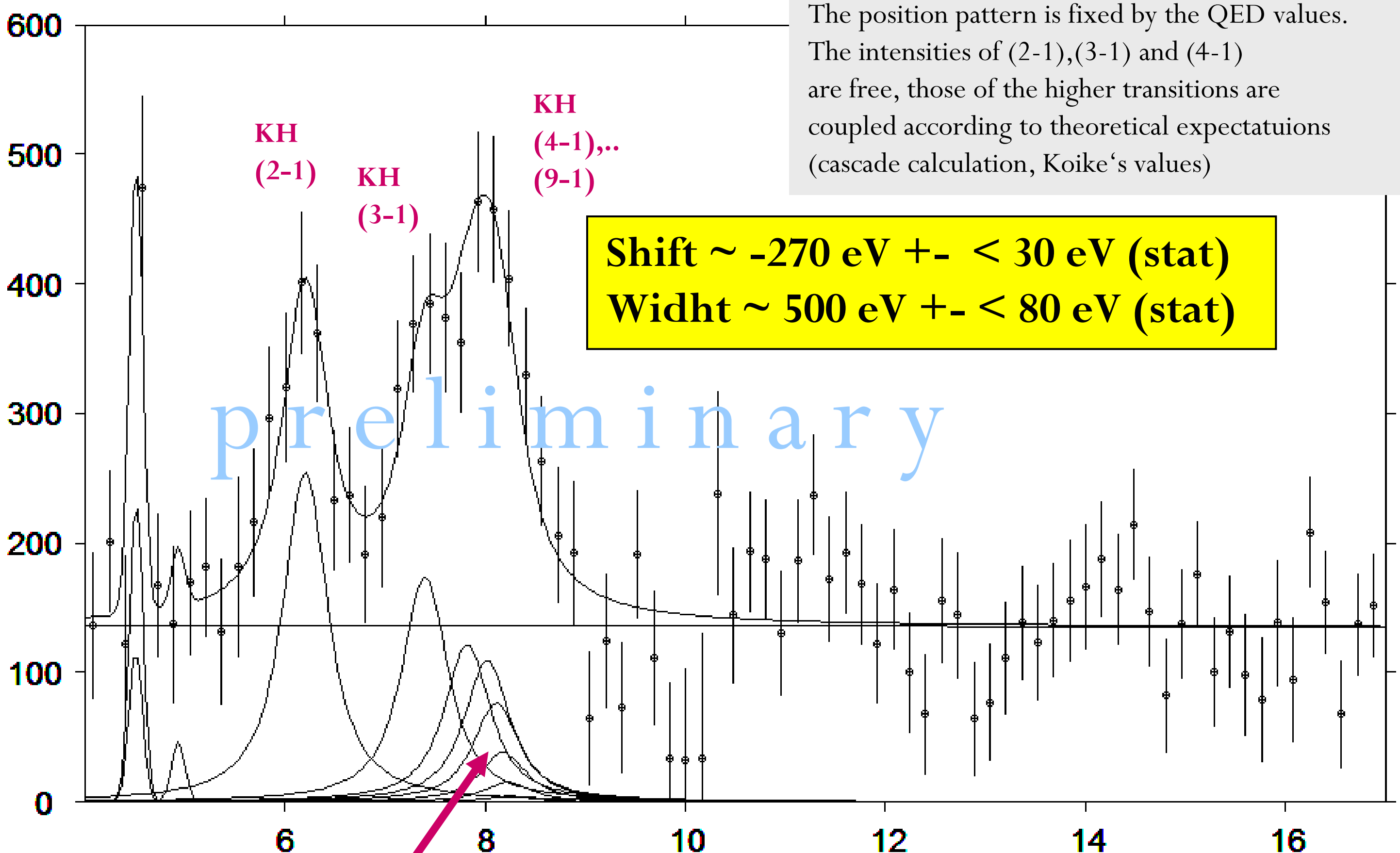
Kaonic deuterium data



Kaonic hydrogen fit

from the kaonic hydrogen spectrum the KD specturm was subtracted to get rid of the kaonic background lines KO, KN. 290 pb^{-1} KH

For the signal 8 voigtians with given gauss resolution and free identical lorentz width are used for (2-1),.. (9-1)
The position pattern is fixed by the QED values.
The intensities of (2-1),(3-1) and (4-1) are free, those of the higher transitions are coupled according to theoretical expectatuions (cascade calculation, Koike's values)



Note: K_{high} yield pattern

energy (keV)

In the final analysis the backgound can be determined from fitting the KD data and then include the pattren in the KH fit.

Conclusions

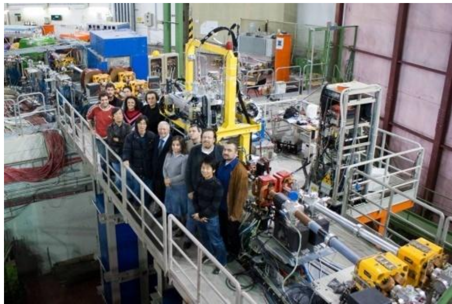
DAFNE proves to be a **real kaonic atom "factory",** representing an unique opportunity to study in a complete way the kaon-nucleon/nuclei physics at low energy.

SIDDHARTA experiment performed the following measurements:

- **the best measurement in the world, for kaonic hydrogen 2p→1s transitions (**shift ~ 270 eV, width ~500 eV, higher precision than in DEAR)

- **an exploratory first measurement ever for kaonic deuterium**

- **the kaonic helium 3d→2p transitions**:
  - for **the first time** in a **gaseous target for ^{4}He**
  - for the **first time ever for ^{3}He**



Future plans

The upgrade of the SIDDHARTA experimental setup

DAFNE 2012

Precise measurements for the X-ray transitions for kaonic hydrogen and kaonic deuterium

Measuring, with higher precision, the X-ray transitions for Kaonic ^{4}He and Kaonic ^{3}He to the 2p level and the first tentative to the 1s level

Other kaonic atoms (light and heavy) (ex: Si, Pb, etc)

Charged kaon mass precision measurement

DAFNE background

SYNCRONOUS: It's associated to K production, or Φ decays. It can be considered a hadronic background.

ASYNCRONOUS: It's dued to final products of electromagnetic cascade produced in the accelerator and to other materials activated by electrons lost from the beam. Moreover it also contains Touschek effect (same bunch particles' interactions)

The main contribute comes from the asyncronous background, wich can be reducted using a trigger and fast detectors:

SDD (Silicon Drift Detector)

Winning card of the SIDDHARTA experiment