Kaonic hydrogen x rays experiments at DAΦNE

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The DEAR collaboration:

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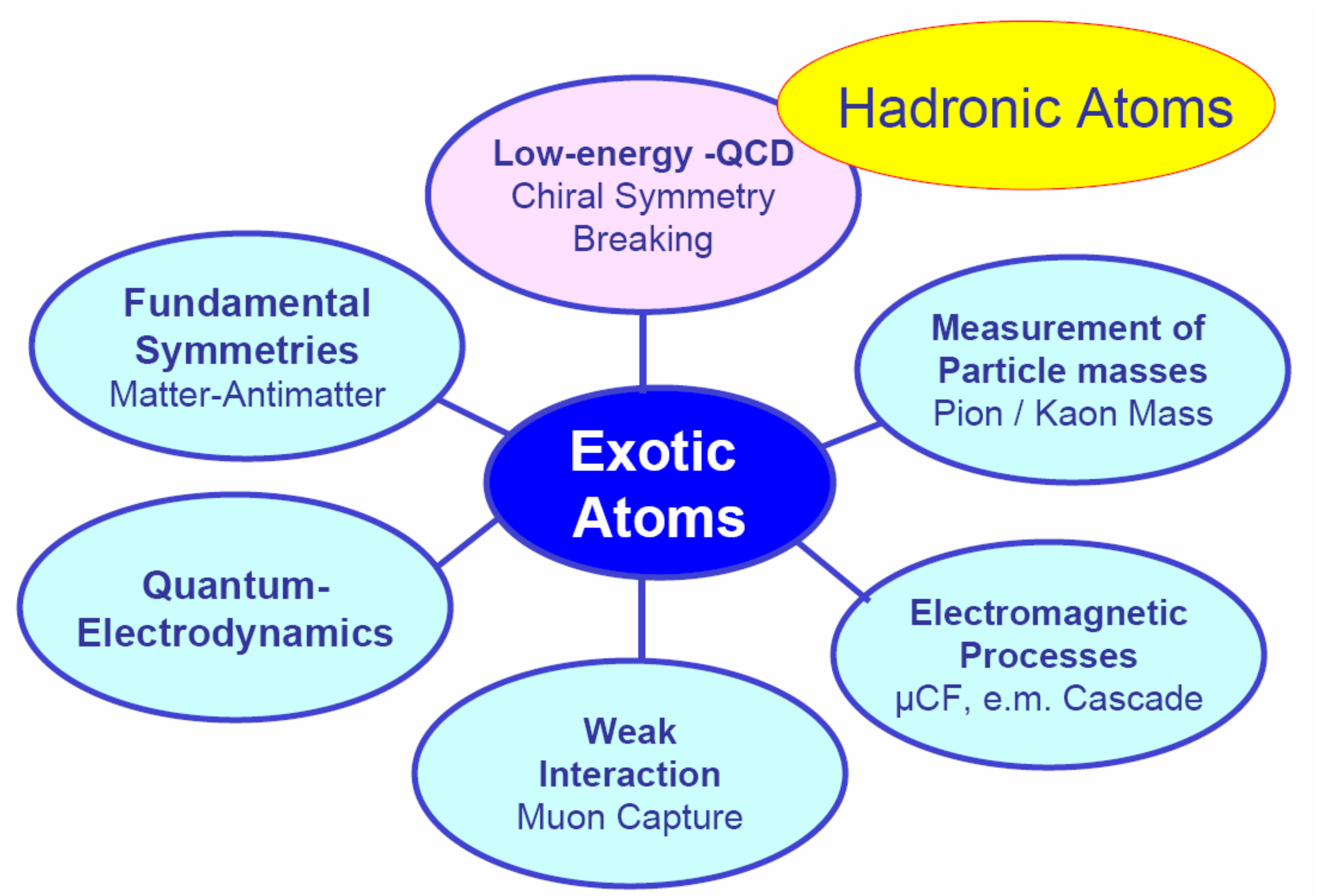
The SIDDHARTA collaboration

Some of us @ coll. meeting in Frascati

Exotic atoms – a broad research field

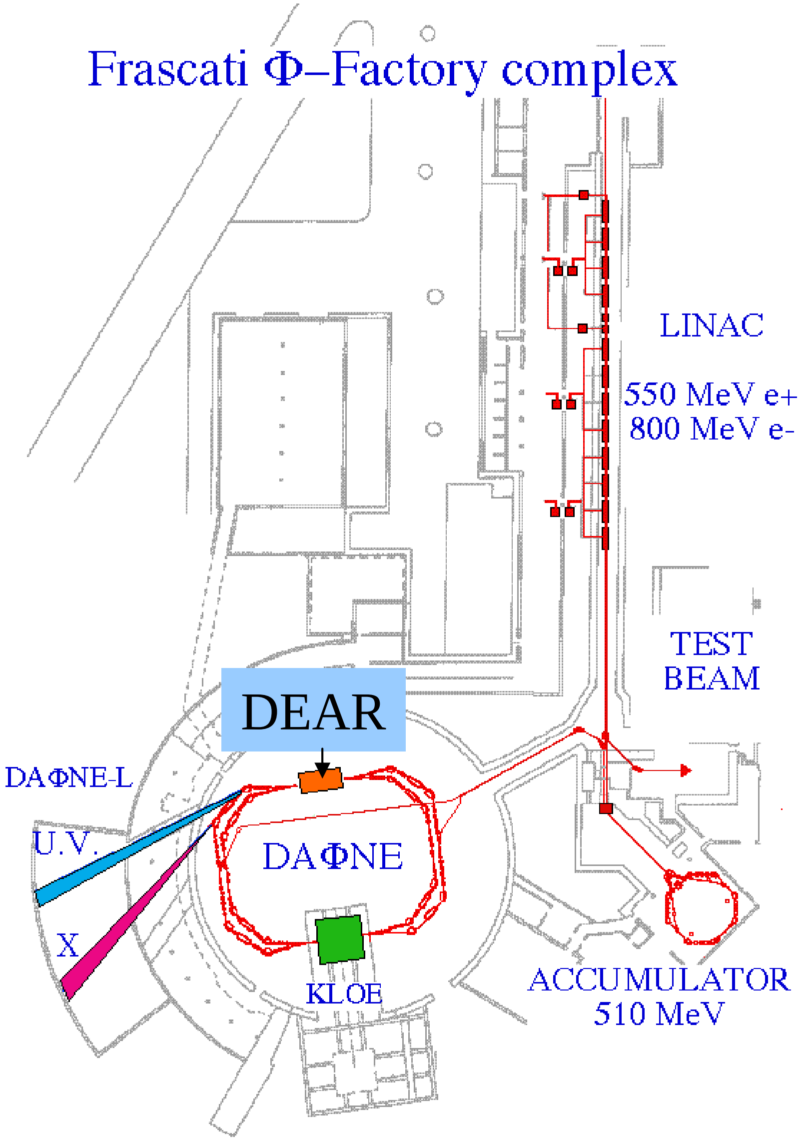


K^-p, K^-d
π^-p, π^-d
….

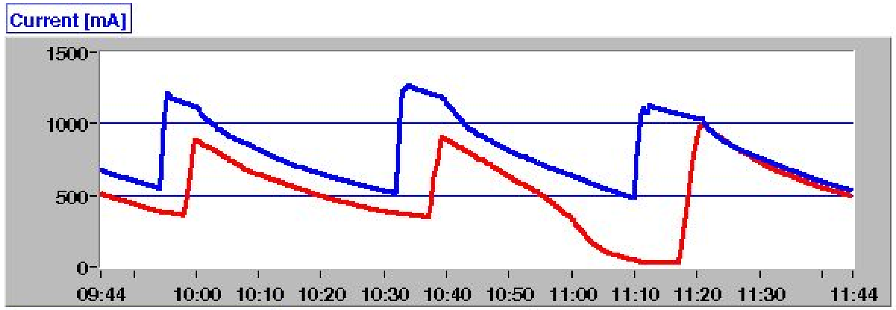
Motivation

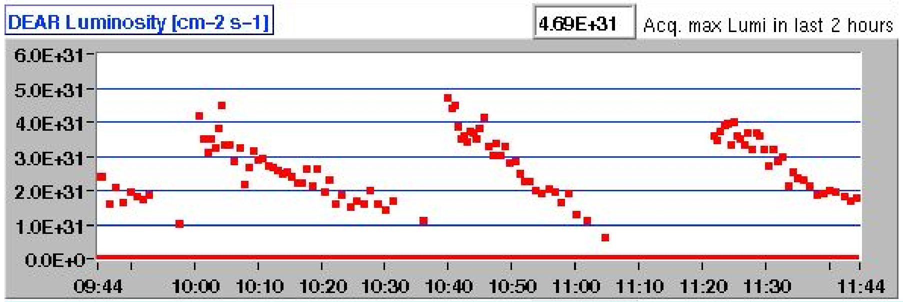
- Exotic (kaonic) atoms – probes for strong interaction
  - hadronic shift ε_{1s} and width Γ_{1s} directly observable
  - experimental study of low energy QCD
- Kaonic hydrogen
  - Kp simplest exotic atom with strangeness
  - kaonic hydrogen „puzzle“ solved – but: precision data missing
  - kaonic deuterium never measured before
  - atomic physics: new cascade calculations (to be tested !)
- Information on $\Lambda(1405)$ sub-threshold resonance
  - responsible for repulsive interaction
  - important for research on 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
- Testing chiral symmetry breaking in systems with strangeness

DAΦNE (LN Frascati)



electron – positron collider with collision energy tuned to the Φ resonance at 1.02 GeV c.m.

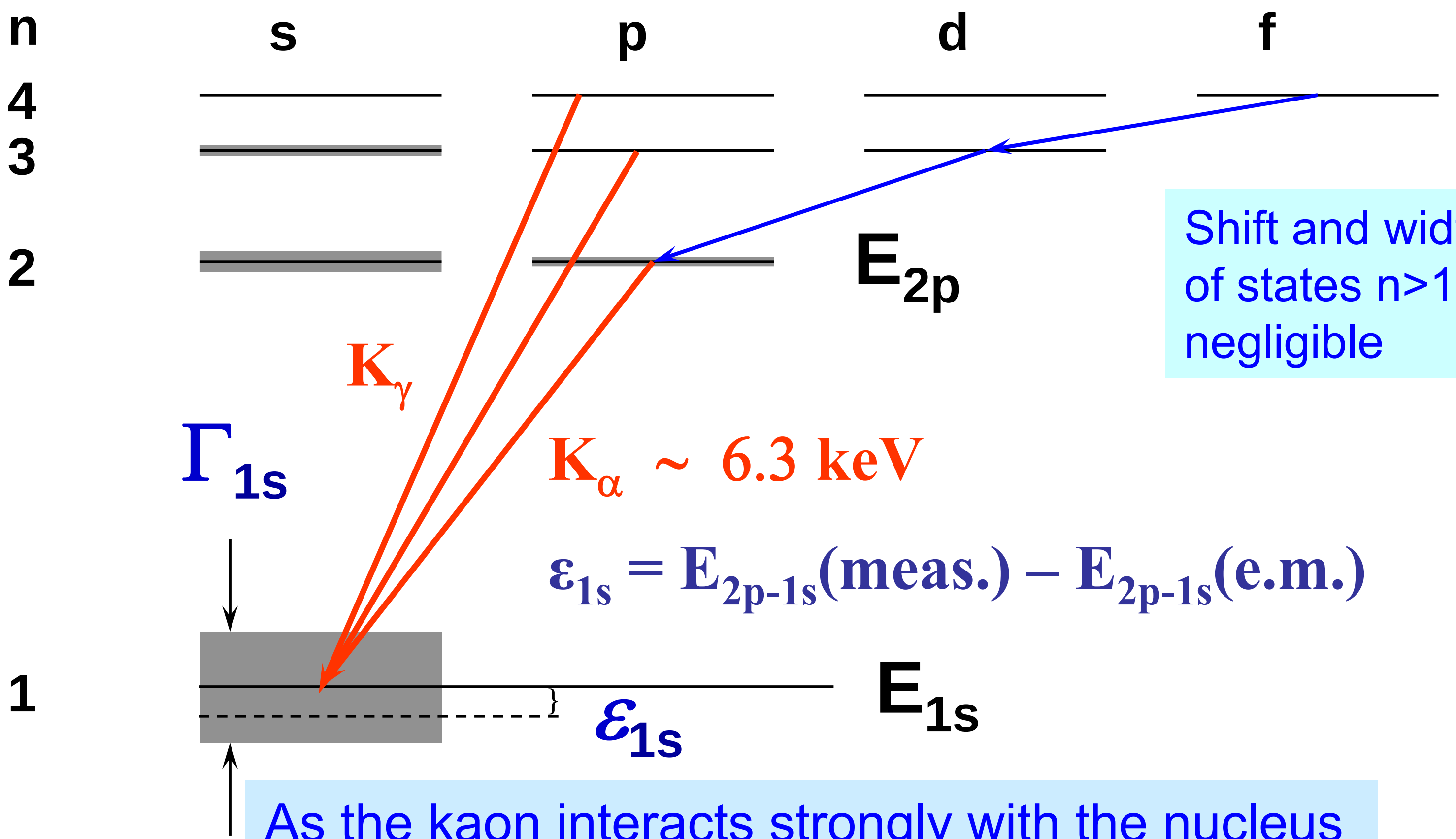




Φ production cross section ~ 3000nb (corrected for radiative losses)
Integrated luminosity ~ 2 pb^{-1} per day
~ 3×10^6 K^- per day

Kaonic hydrogen

Negative kaons stopped in H_2 → initial atomic capture →
→ electromagnetic cascade → X-ray transitions



Shift and width of states n>1 negligible

As the kaon interacts strongly with the nucleus the 1s energy level is shifted and broadened

Scattering lengths

Relation of strong interaction shift and width
to the complex Kp scattering length a_{K^-p}

$$\varepsilon + i\frac{\Gamma}{2} = \frac{2\pi}{\mu}\left|\psi_{1s}(0)\right|^2 a_{K^-p} = 2\alpha^3\mu^2 a_{K^-p} = 412\ fm^{-1}\cdot eV\cdot a_{K^-p}$$

$$(\,Deser - Goldberger - Baumann - Thirring\,)$$

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

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

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

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

Impulse approximation term

Correction term (3body calc.)

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

The challenge

to do low energy X ray spectroscopy at an accelerator !

The radiation environment produces **a lot of charge** in Si detectors

„Beam background" – Touschek scattering – stray 510 MeV $e^{\pm}$ - **Showers** (not correlated to $e^{\pm}$ collisions)

Babha scattering - Showers

Pions from Phi or K^0 decay

Muons, pions, electrons **from charged K decay** - hadronic background –
- trigger signal – remains in triggered setup

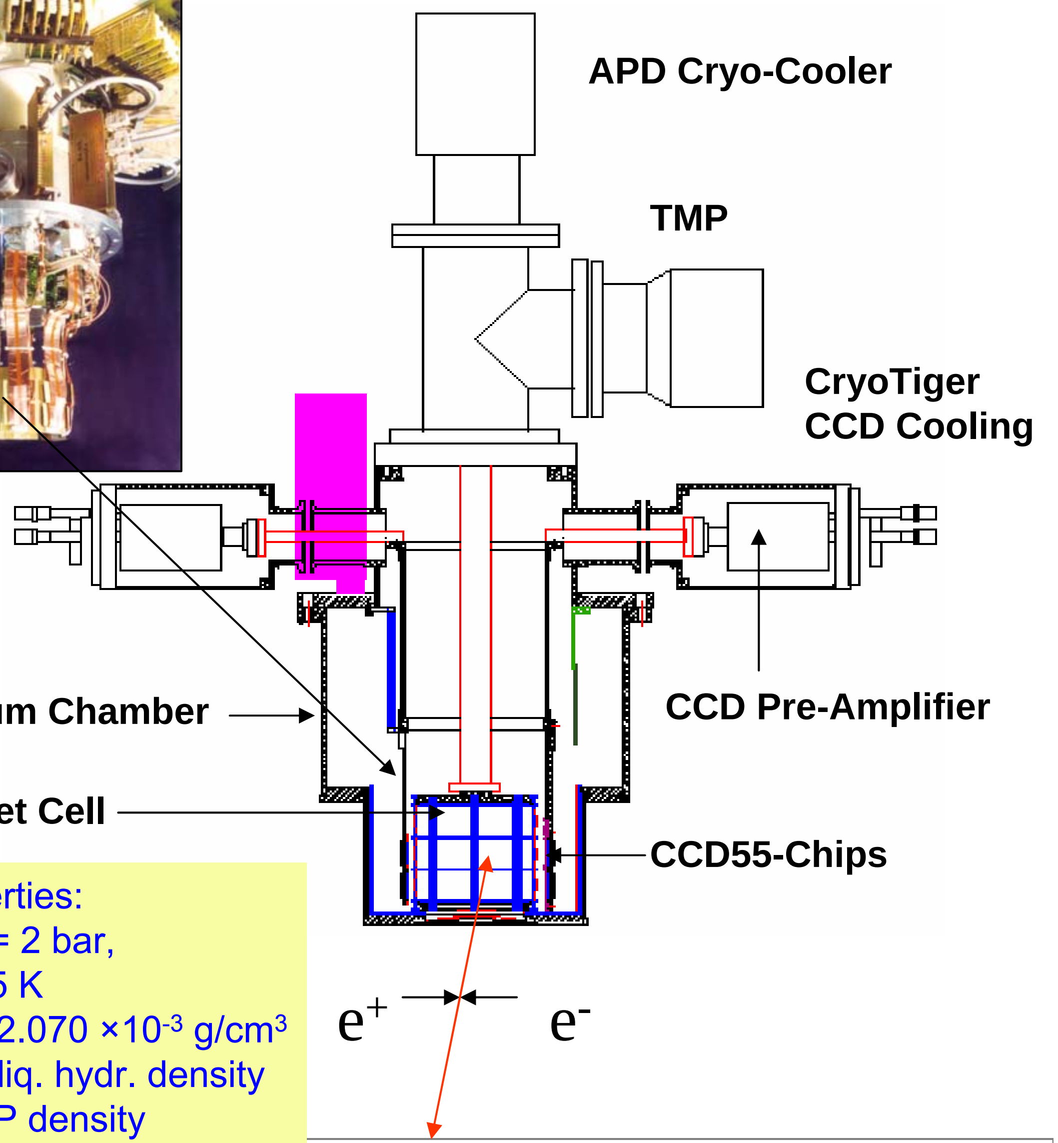
The DEAR experimental precision was in fact limited by the Signal vs. Background ratio. The yield for deuterium is ~ 10 times smaller then for hydrogen, so a powerfull background suppression is needed!

Actual background intensities (beam- and kaon correlated) known from DEAR

DEAR Experimental Set-up

Energy measurement of kaonic K lines with an array of 16 CCD X-ray detectors

- pixel size 22.5x22.5 μm
- total area per chip 7.24 cm^2
- depletion depth ~30 μm
- read-out time per CCD 2 min.
- energy resolution ~140 eV @ 5.9keV



volume: 1150 cm^3 cryogenic H_2 gas
side: 75 μm Kapton
entrance: 125 μm Kapton
grid structure: glass fiber reinforced epoxy

Gas properties:
Pressure = 2 bar,
Temp = 25 K
Density = 2.070 $\times 10^{-3}$ g/cm^3
= 0.029 × liq. hydr. density
= 23 × STP density

Kaonic hydrogen data analysis

- Set noise threshold
- Select single and double pixel events
- Reject frames with large noise peak width and high occupancy
- Correction of charge transfer efficiency
- Energy calibration with fluorescence background lines
- Determine detector resolution

The same procedure was applied on

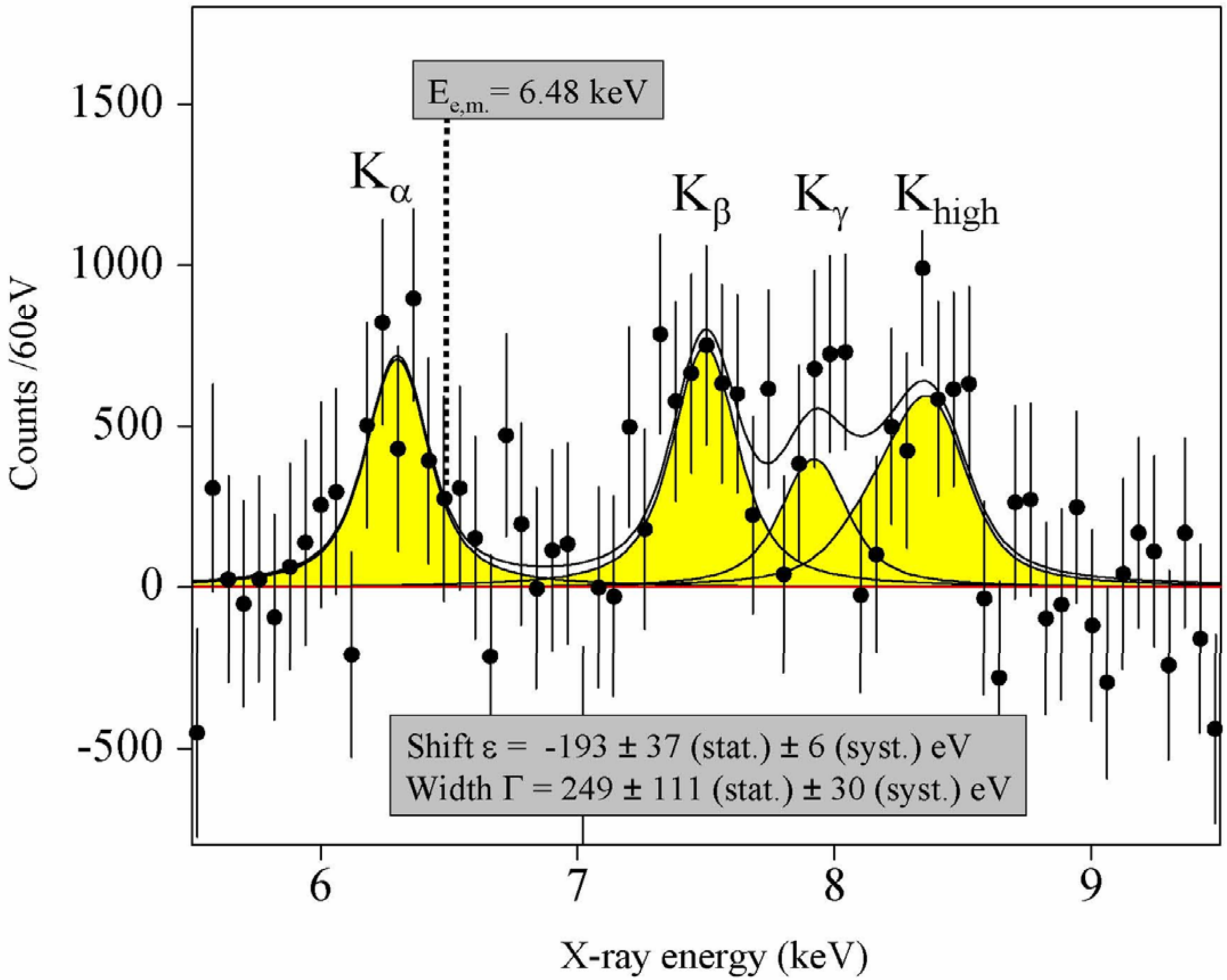
- Data from hydrogen with collisions (H)
- Background (B) data
  1) data measured in hydrogen with separatec beams (no collisions, no kaons produced)
  2) kaonic nitrogen data

Normalization of H vs. Background measurement (using Si fluorescence X-ray intensity)

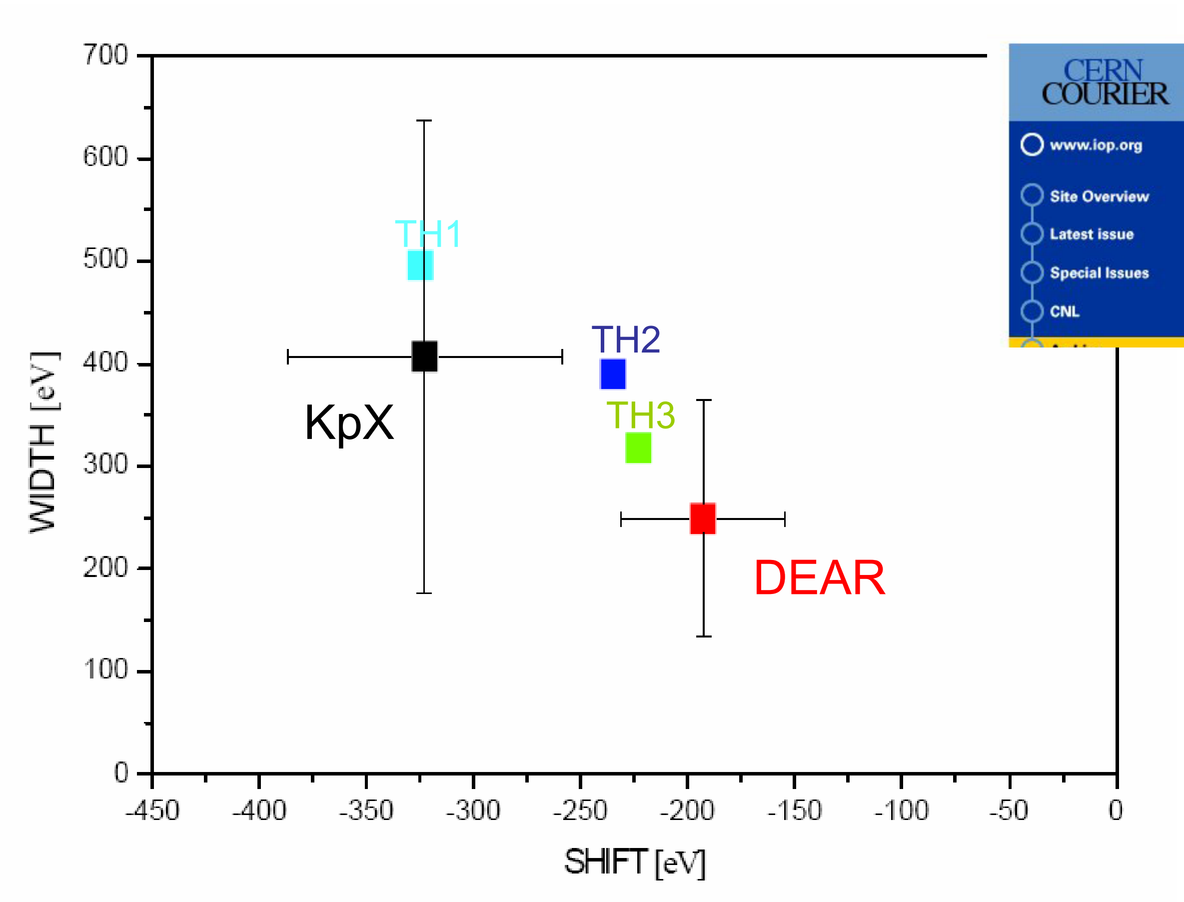
Components of the X-ray spectra:
- Continuous background due to bremsstrahlung
- Fluorescence lines from structure materials
- Kaonic X-ray lines (only in H)

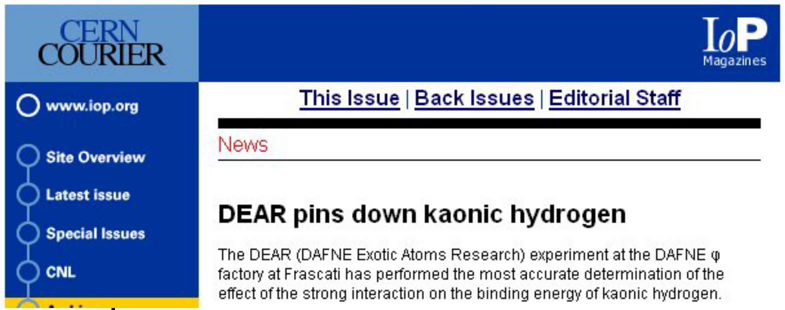
Challenges:
- Fit of the continuous background
- Disentangling of the kaonic K_{α} line from the Fe fluorescence line
- Effect of Kp (n>4) line yields

Kaonic hydrogen results from DEAR



Comparison of results

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News

DEAR pins down kaonic hydrogen

The DEAR (DAFNE Exotic Atoms Research) experiment at the DAFNE φ factory at Frascati has performed the most accurate determination of the effect of the strong interaction on the binding energy of kaonic hydrogen.

→ better experimental data needed

TH1: U.G. Meißner et al.,
Eur. Phys. J. C 35 (2004)349

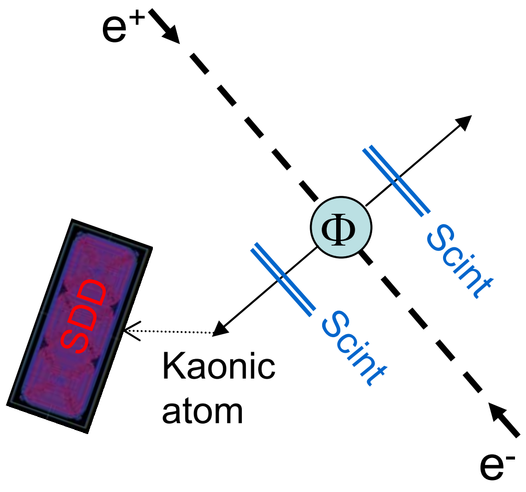
TH2: B. Borosoy et al.,
Phys. Rev. Lett. 94 (2005) 213401

TH3: SMI-TU Vienna
A.N. Ivanov et al.,
Eur. Phys. J. A21 (2004) 11
J. Phys. G 31 (2005) 769
Eur. Phys. J. A25 (2005) 329

From DEAR to SIDDHARTA

Need new X-ray detectors providing

- timing capability → background suppression
  by using the kaon - X ray time correlation
- excellent energy resolution
- high efficiency, large solid angle
- performance in accelerator environment



SDD (silicon drift detectors)

arrays of large SDDs in development

I3 Hadron Physics EU FP6 –

Joint Research Activity: **SIDDHARTA**

in cooperation with LNF, MPG, PNSensor, Politecnico Milano, IFIN-HH.

Triple coincidence:
$SDD_X * Scint_K * Scint_K$

Test measurements

Design of the new Setup

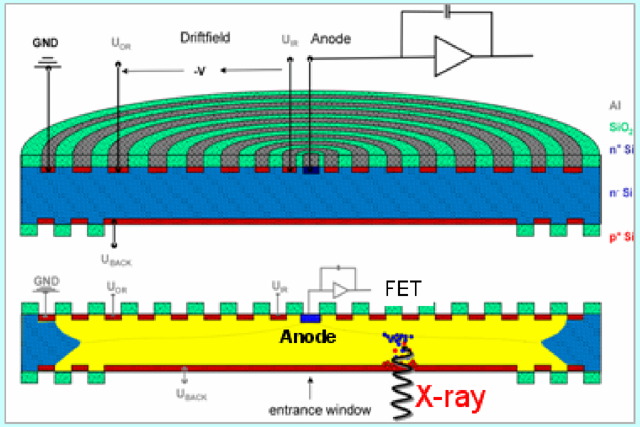
Monte Carlo studies

In the next stage of the experiment we will achieve an improvement in the signal / background ratio of ~ 2 – 3 orders of magnitude !

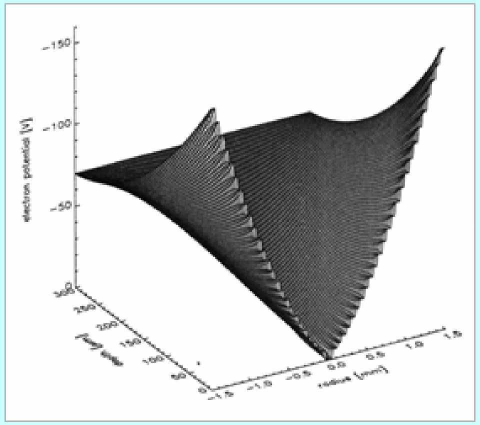
Principle

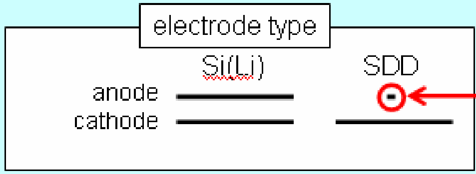
SDD (Silicon Drift Detector)

Schematic drawing



potential distribution



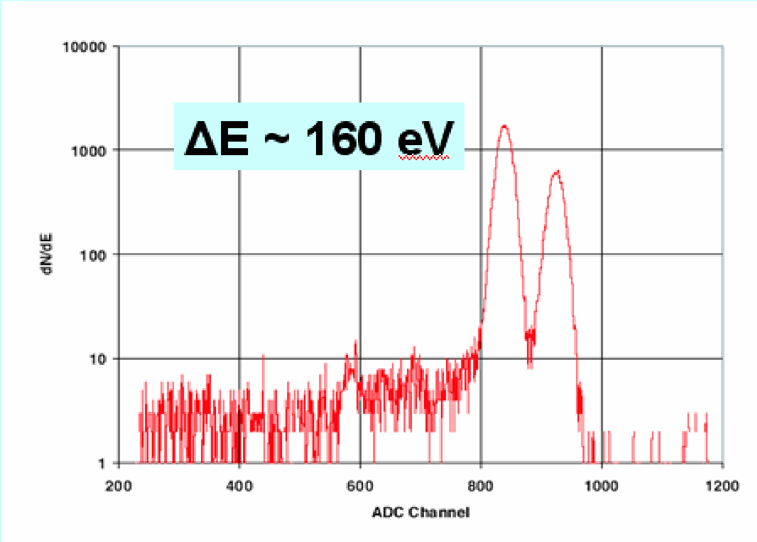


$$Q = CV$$
$$= (\varepsilon_0 S / d)\, V$$

Small capacitance

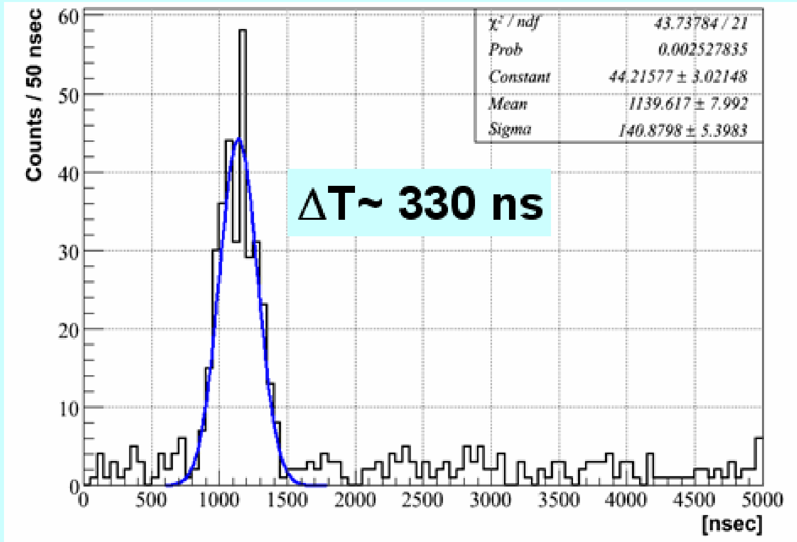
Performance

Energy resolution



Energy spectrum of 100 mm² SDD with ^{55}Fe source

Time resolution

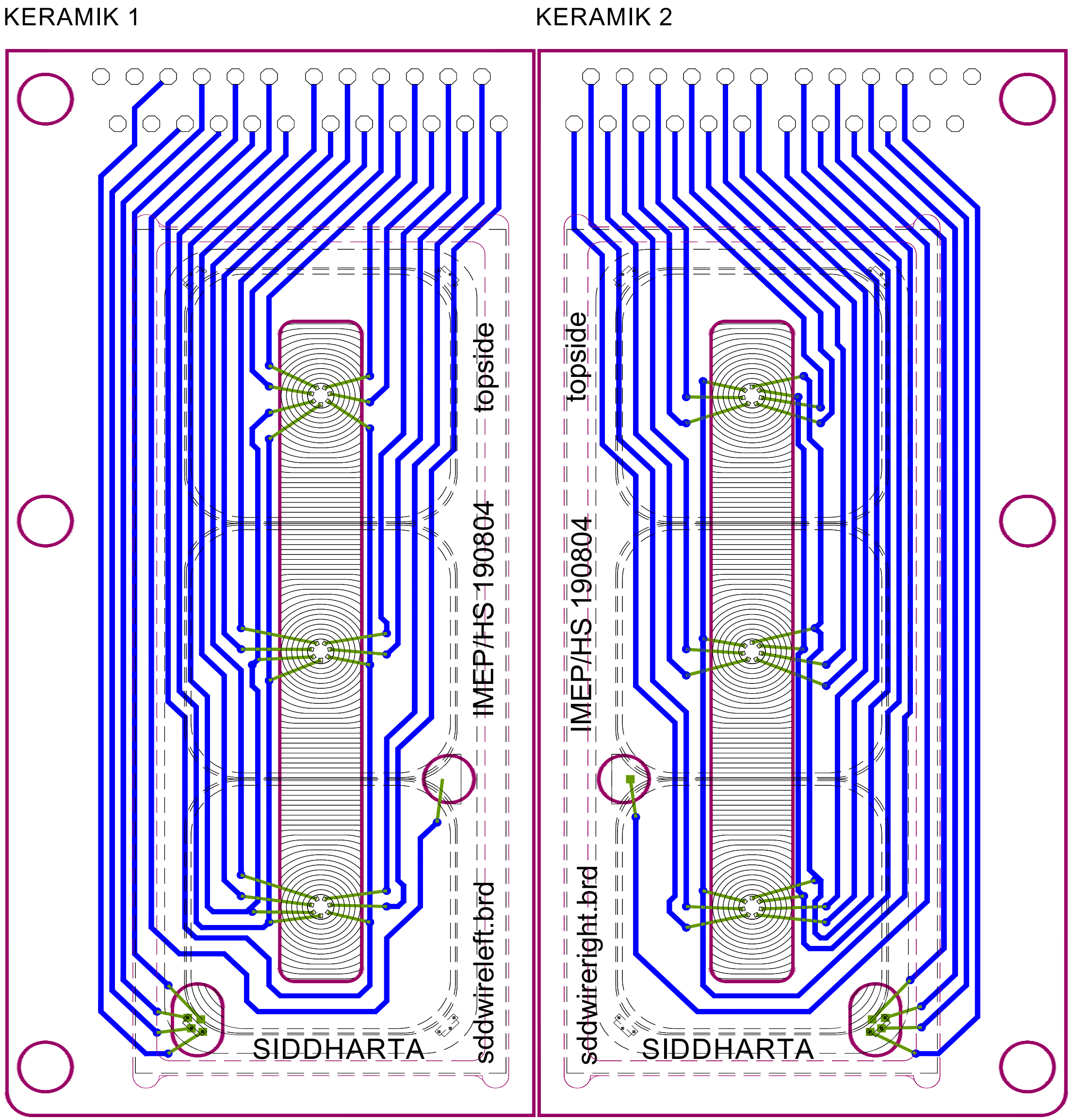


Time difference between SDD signal and Kaon signal

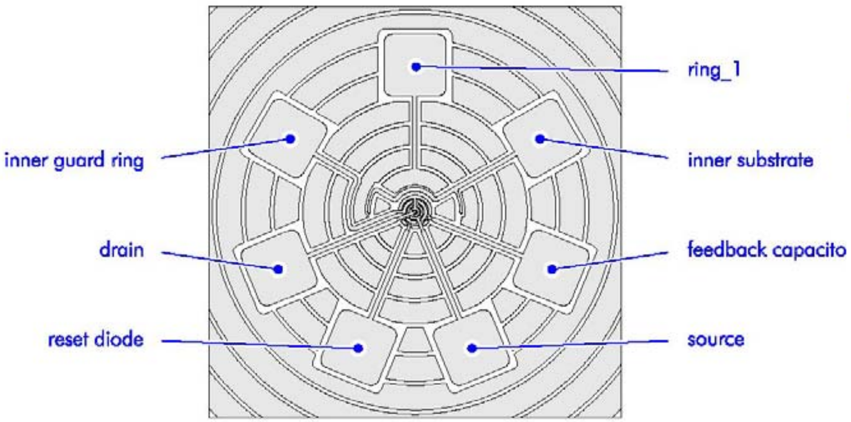
Wiring & bonding

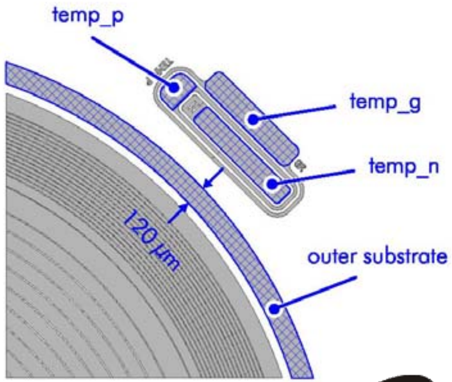
different from standard electronic devices:

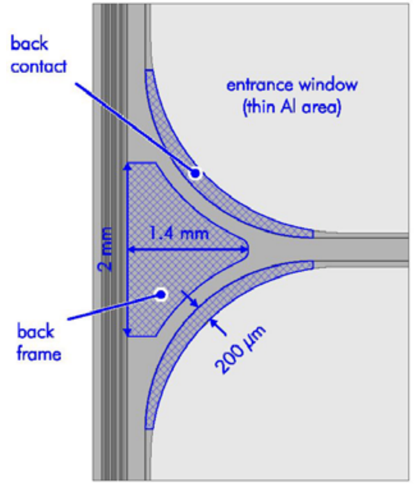
- double sided structure
- not passivated
- large area chips
- arrangement of bond pads in the center, on insulator over sensitive area



Wireing & bonding (cont.)

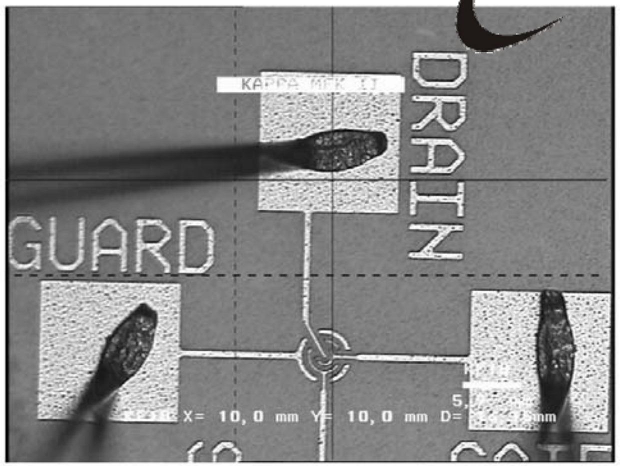






PNSensor

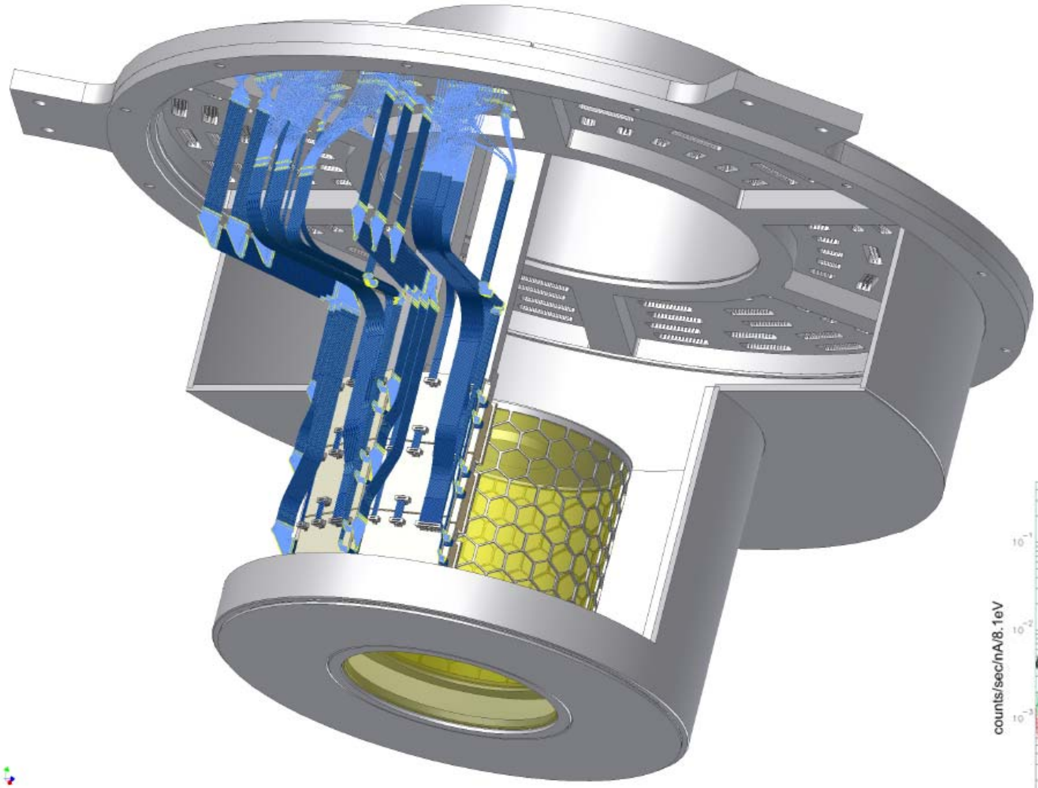
MPE



all chips will be inspected and tested at SMI !

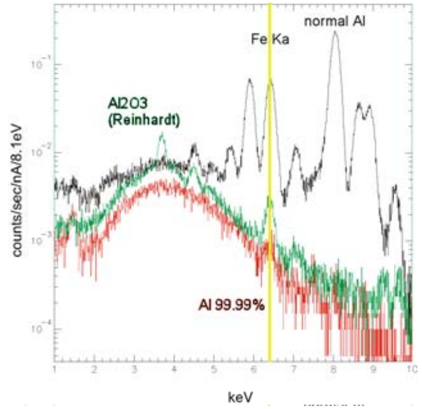
Target and SDD setup

Cryogenic target cell



Target cell – SDD array assembly

Carefully selected structure materials analyzed by PIXE

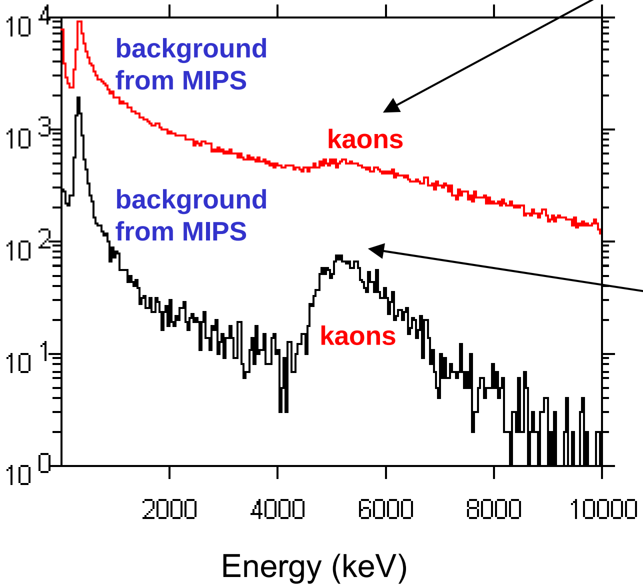


Monte Carlo results

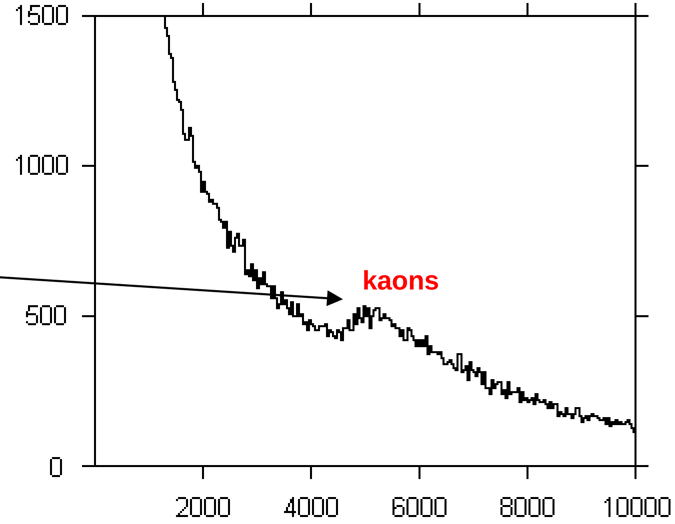
The trigger

Scintillators
2 x 1.5 mm plastic

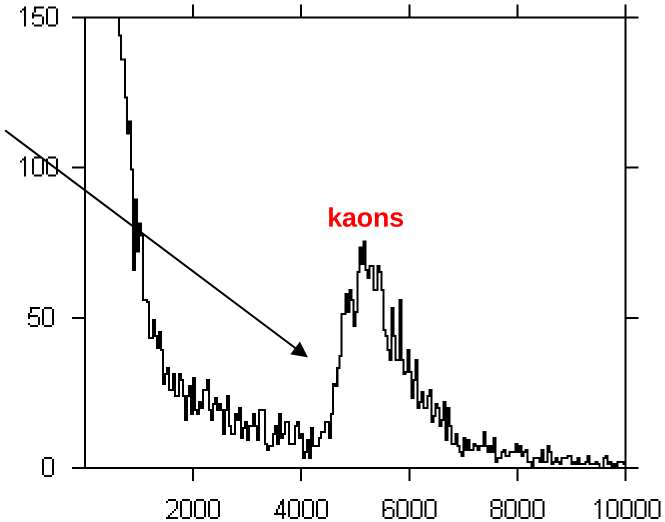
All vertical axes: counts per bin



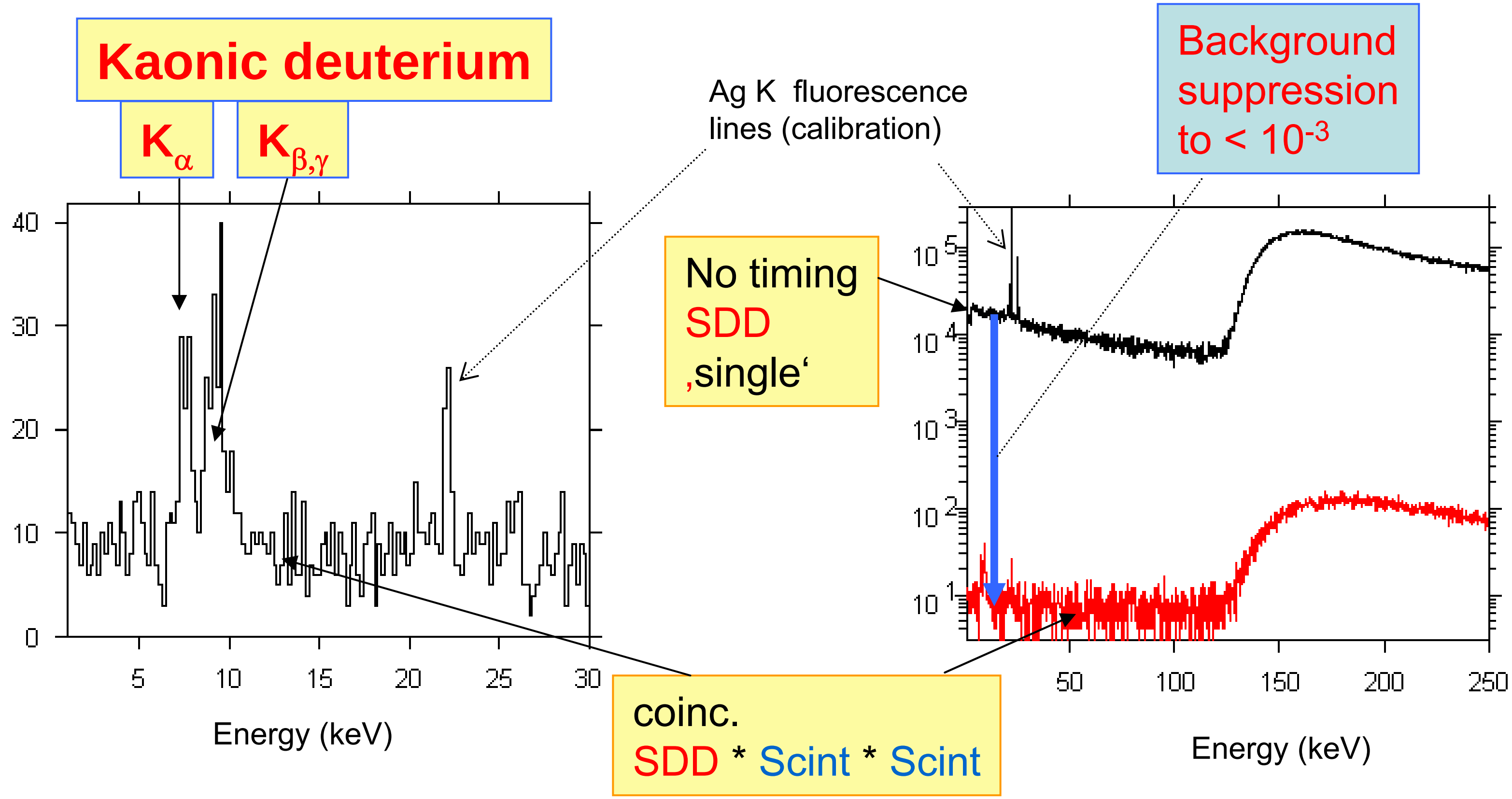
single
Scint.



coinc.
Scint. * Scint.

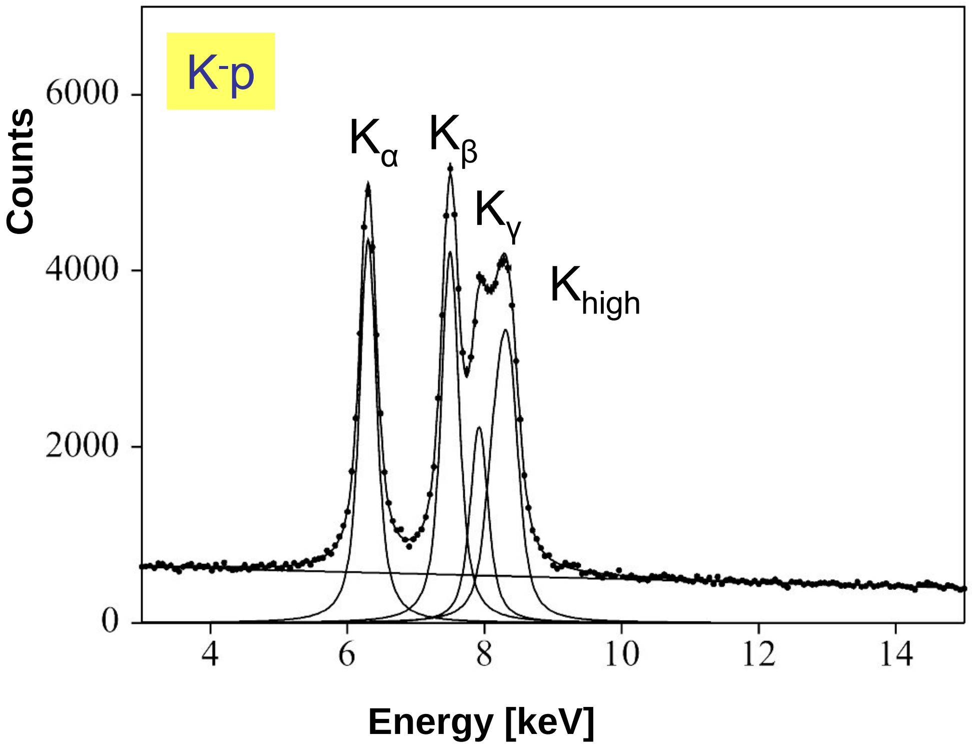


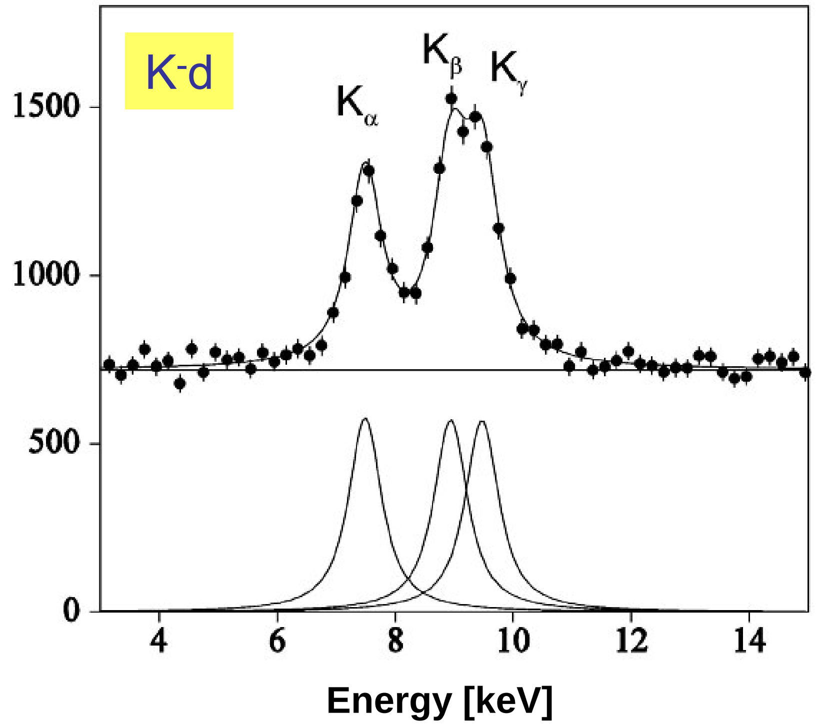
Monte Carlo results



Expected quality of data with SIDDHARTA

Monte Carlo simulated X-ray spectra for data of 30 days. SDD array and kaon trigger.





K^-p: ε_{1s} = 193 eV, Γ_{1s} = 249 eV, $Y(K_\alpha)$=2%
precision: ε_{1s} ± 2eV Γ_{1s} ± 4 eV

K^-d: ε_{1s} = 325 eV, Γ_{1s} = 630 eV, $Y(K_\alpha)$=0.2%
precision: ε_{1s} ± 18 eV Γ_{1s} ± 45 eV

Conclusions

DEAR finished sucessfully –
delivered most precise result on K^-p shift an width.
Theoretical efforts continue

SIDDHARTA well under way,
will start physics measuremets in 2007:
K^-d K^-p K^-He

Further perspectives at DAFNE: LOI for a search of kaonic nuclear clusters using KLOE plus additional components