X-ray Spectroscopy of Kaonic Atoms at DAΦNE

Antonio Romero Vidal
Laboratori Nazionali di Frascati, Rome, Italy

on behalf of the SIDDHARTA collaboration

SIDDHARTA collaboration

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

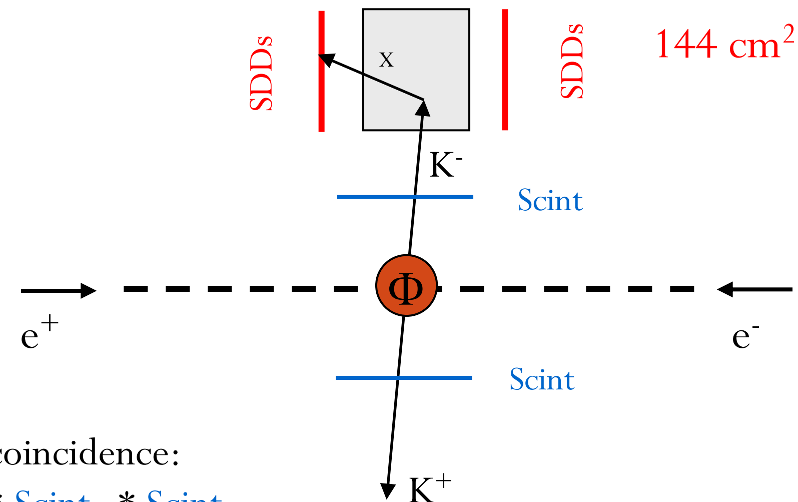
Univ. Tokyo, Japan

Victoria Univ., Canada

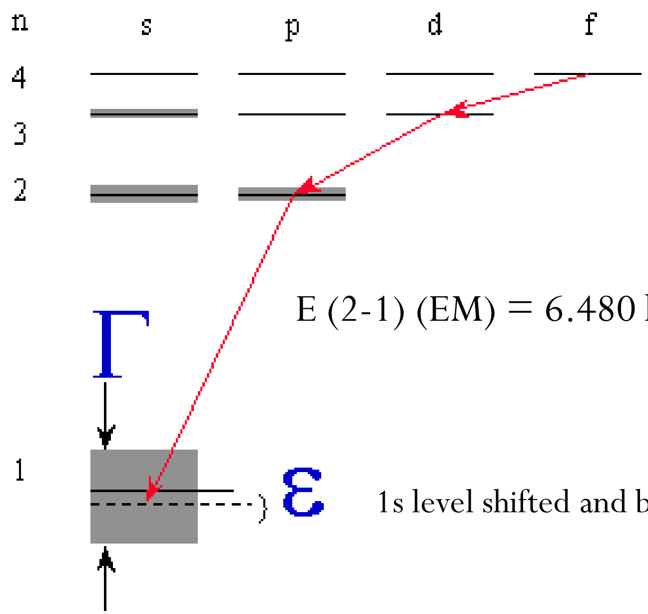
EU Fundings: JRA10 – FP6 - I3HP
Network WP9 – LEANNIS – FP7- I3HP2

SIDDHARTA - What is it ?

- Goal: measure the shift and broadening of the X ray transition of light kaonic atoms.
- The ground state is affected by the strong interaction of the kaon and the nucleus.
- Delivers input for effective theories in low energy QCD.



Triple coincidence:
$SDD_X * Scint_K * Scint_K$



E (2-1) (EM) = 6.480 keV

1s level shifted and broadened

New X-ray detectors (SDD Silicon Drift Detectors)

- timing capability → trigger for background suppression
- excellent energy resolution (140 eV at 6.0 KeV)
- high efficiency, large solid angle.
- performance in accelerator environment

Hadronic atoms in QCD

Objects of type $(\bar{K}\ X)$, (π^-, X) with X = p, d, ^{3}He, ^{4}He,.. or $\pi^+\pi^-$ $\pi\bar{K}$

Bound electromagnetically, binding well known

Strong interaction (mediated by QCD) → modify binding

→ decay of object

in some cases: small perturbation

→ energy shift and width can be related to T-matrix elements at threshold (Deser[1] type formulas)

compare to results from low energy scattering experiments[2]

Low energy phenomena in strong interaction can not be described in terms of quarks and gluons, instead *effective theories* are used (they have some degrees of freedom to accomodate experimental data)

[1] Deser relation in some cases not sufficient to compare to high precision experimental data

[2] Problems: extrapolation to E=0 and quality of old experimental data

QCD predictions

Chiral perturbation theory was extremely successful in describing systems like πH, but ***can not be used for KH***. Main reason is the presence of the Λ(1405) resonance only 25 MeV below threshold.

Effective field theory ↔

- scattering data
- atomic X ray data
- energy, width of resonances

There exist non-perturbative coupled channel techniques which are able to generate the Λ(1405) dynamically as a Kbar N quasibound state and as a resonance in the π Σ channel

Kaonic hydrogen – Deser formula

With a_0, a_1 standing for the I=0,1 S-wave $\overline{KN}$ 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

"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 underlaying 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 than 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 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

- Information on $\Lambda(1405)$ 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

AIMS OF SIDDHARTA

- Improve the previous measurements of the Kaonic hydrogen shift and width.
- First observation of the Kaonic deuterium K lines.
- Precise measurement of the Kaonic He^4 L_α transition.
- First observation and precise measurement of the Kaonic He^3 L_α transition.

Kaon-nucleon interaction at low energies

Experimental data are available for:

1) K^- p cross section for elastic and inelastic processes.

2) Branching ratios for K^- p absorption at rest.

3) $\pi\Sigma$ invariant mass distribution below K^- p threshold, wich exhibits the $\Lambda(1405)$ resonance.

4) 1s level shift and width of K^- p atom determined through Xray measurements. (SIDDHARTA)

Scattering data vs X-ray measurements

Analyises on scattering data have been usually made by using a K-matrix formulation with the assumption that its elements are smooth functions of energy, allowing extrapolation down to threshold and below

S-wave $\bar{K}N$ scattering lengths (fm)

Reference	I = 0 a_0	I = 0 b_0	I = 1 a_1	I = 1 b_1
Sakitt *et al.* (1965)	- 1.63±0.07	0.51±0.05	- 0.19±0.08	0.44±0.04
Kim *et al.* (1967)	- 1.67±0.04	0.71±0.04	- 0.07±0.06	0.68±0.03
von Hippel *et al.* (1968)	- 1.65±0.04	0.73±0.02	- 0.13±0.02	0.51±0.03
Martin & Ross (1970)	- 1.74±0.04	0.70±0.01	- 0.05±0.04	0.63±0.06
Martin *et al.* (1981)	- 1.70±0.07	0.68±0.04	0.37±0.09	0.60±0.07

The energy shift ΔE_{1S} and width Γ_{1S} of the K^-p 1S state as obtained from kaonic hydrogen X-ray measurements and scattering analyses

Method	Experiment	ΔE_{1S} (eV)	Γ_{1S} (eV)
Kaonic hydrogen X-ray measurements	Davies *et al.* (1979)	+ 40 ± 60	0^{+230}_{-0}
	Izycki *et al.* (1980)	+370 ± 80	560 ± 80
	Bird *et al.* (1983)	+193 ± 60	80^{+220}_{-80}
K^-p scattering analyses	Sakitt *et al.* (1965)	- 375 ± 21	396 ± 25
	Kim *et al.* (1967)	- 358 ± 16	568 ± 25
	von Hippel *et al.* (1968)	- 367 ± 8	511 ± 16
	Martin & Ross (1970)	- 367 ± 12	544 ± 25
	Martin *et al.* (1981)	- 272 ± 21	527 ± 33

The K^-p scattering lengths determined from kaonic hydrogen X-ray measurements and those from scattering analyses

Method	Reference	a_{K^-p} (fm)
Kaonic hydrogen X-ray measurements	Davies *et al.* (1979)	$(0.10\pm0.14) + i(0.00^{+0.28}_{-0.00})$
	Izycki *et al.* (1980)	$(0.65\pm0.19) + i(0.68\pm0.31)$
	Bird *et al.* (1983)	$(0.47\pm0.14) + i(0.10^{+0.27}_{-0.10})$
K^-p scattering analyses	Sakitt *et al.* (1965)	$(-0.91\pm0.05) + i(0.48\pm0.03)$
	Kim *et al.* (1967)	$(-0.87\pm0.04) + i(0.69\pm0.03)$
	von Hippel *et al.* (1968)	$(-0.89\pm0.02) + i(0.62\pm0.02)$
	Martin & Ross (1970)	$(-0.89\pm0.03) + i(0.66\pm0.03)$
	Martin *et al.* (1981)	$(-0.66\pm0.05) + i(0.64\pm0.04)$

Scattering data lead to a negative shift, wich means that strong interaction is repulsive type and shifts the EM level to a less bound energy.

Scattering data -> $\varepsilon<0$

Old X-ray measurements -> $\varepsilon>0$

"Kaonic Hydrogen puzzle"

Kaonic Hydrogen Puzzle

KeK results

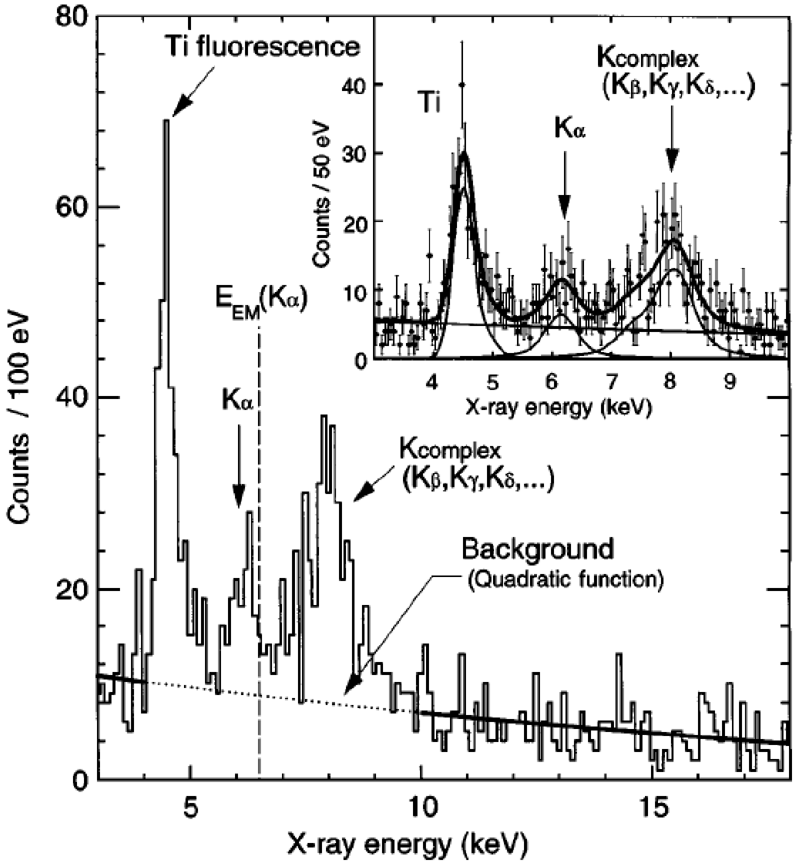


FIG. 3. Kaonic hydrogen x-ray spectrum. The inset shows the result of peak fitting and the components.

$$\Delta E(1s) = E(K_\alpha) - E_{\rm EM}(K_\alpha) = -323 \pm 63 \pm 11 \text{ eV}$$

$$\text{and} \quad \Gamma(1s) = 407 \pm 208 \pm 100 \text{ eV},$$

KpX at KEK results [6],

Solved !!

[6] M.Iwasaki et al., Phys. Rev. Lett. 78 (1997) 3067
T.M.Ito et al., Phys. Rev. A58 (1998) 2366.

DEAR results [2002-2005]

collision   Non collision

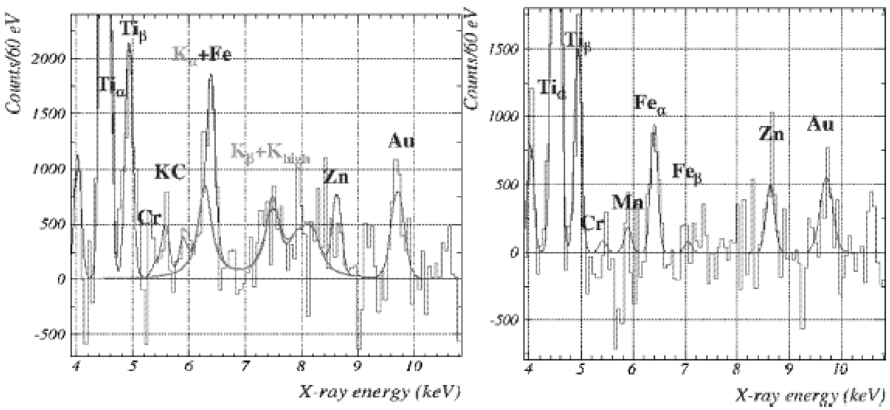
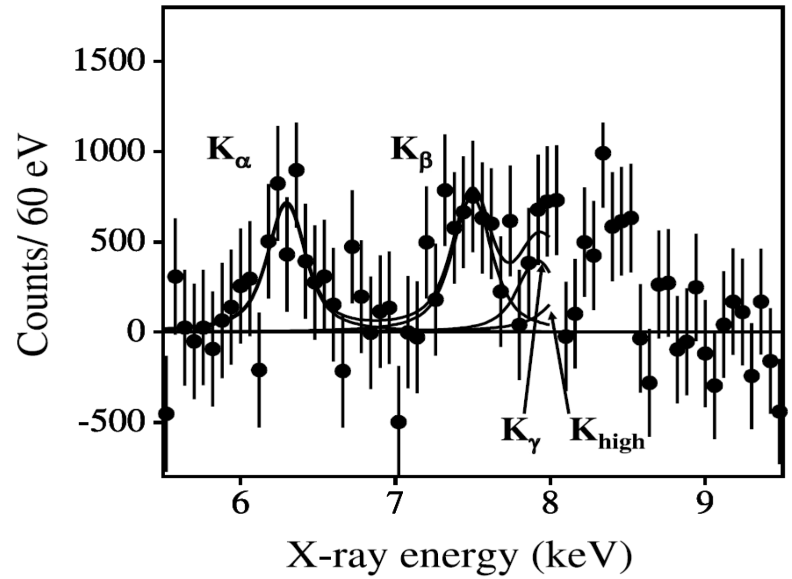


Fig. 6. – *The kaonic hydrogen (left) and no-collision (right) continuous background subtracted spectra. The kaonic hydrogen transitions are visible in the kaonic hydrogen spectrum. The electronic transition are due to setup materials excited by the background particles.*



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

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

Confirming the results found at KeK.

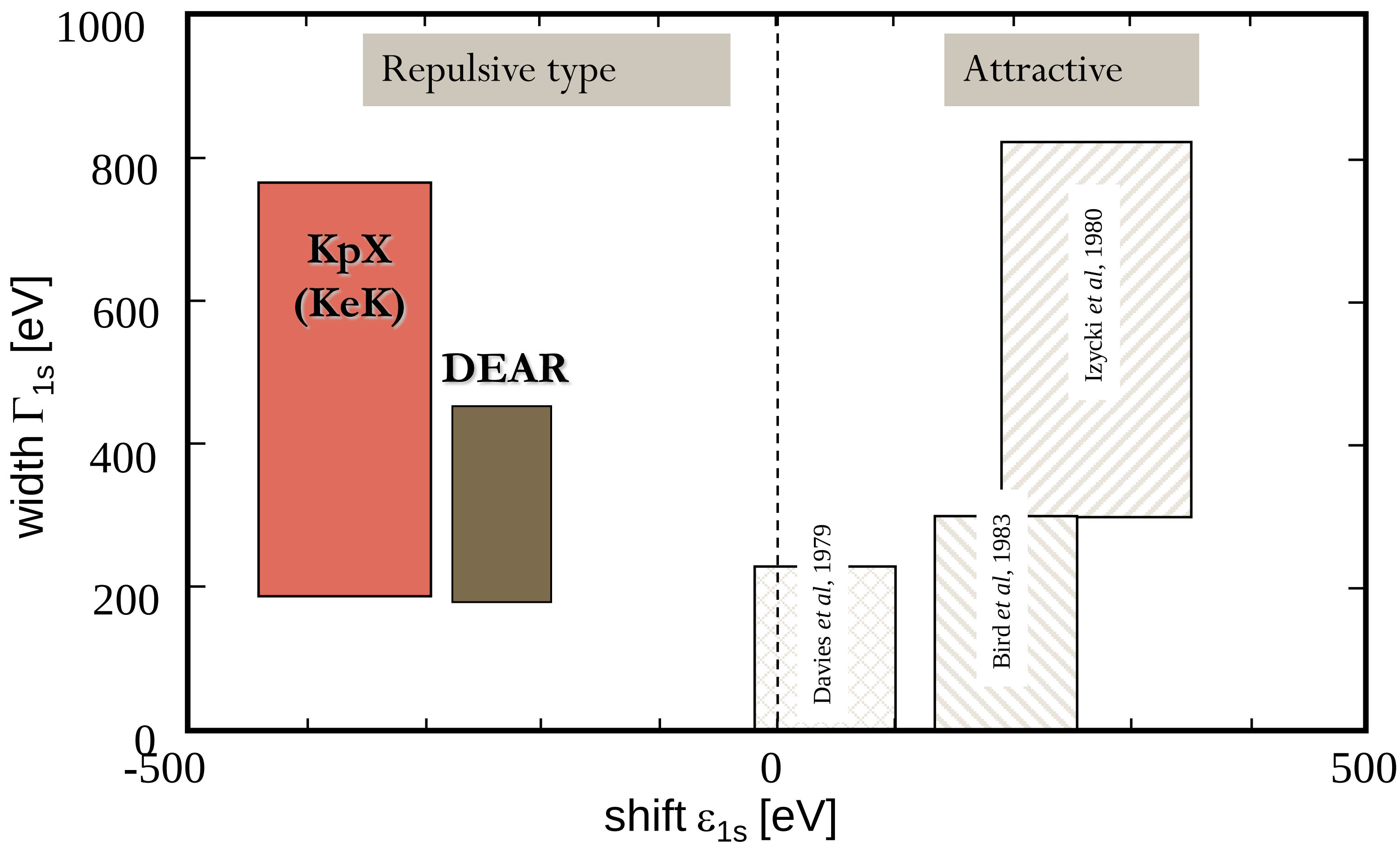
No deuterium measurements due to the too much high background

(KeK)

$$\Delta E(1s) = E(K_\alpha) - E_{\mathrm{EM}}(K_\alpha) = -323 \pm 63 \pm 11 \text{ eV}$$

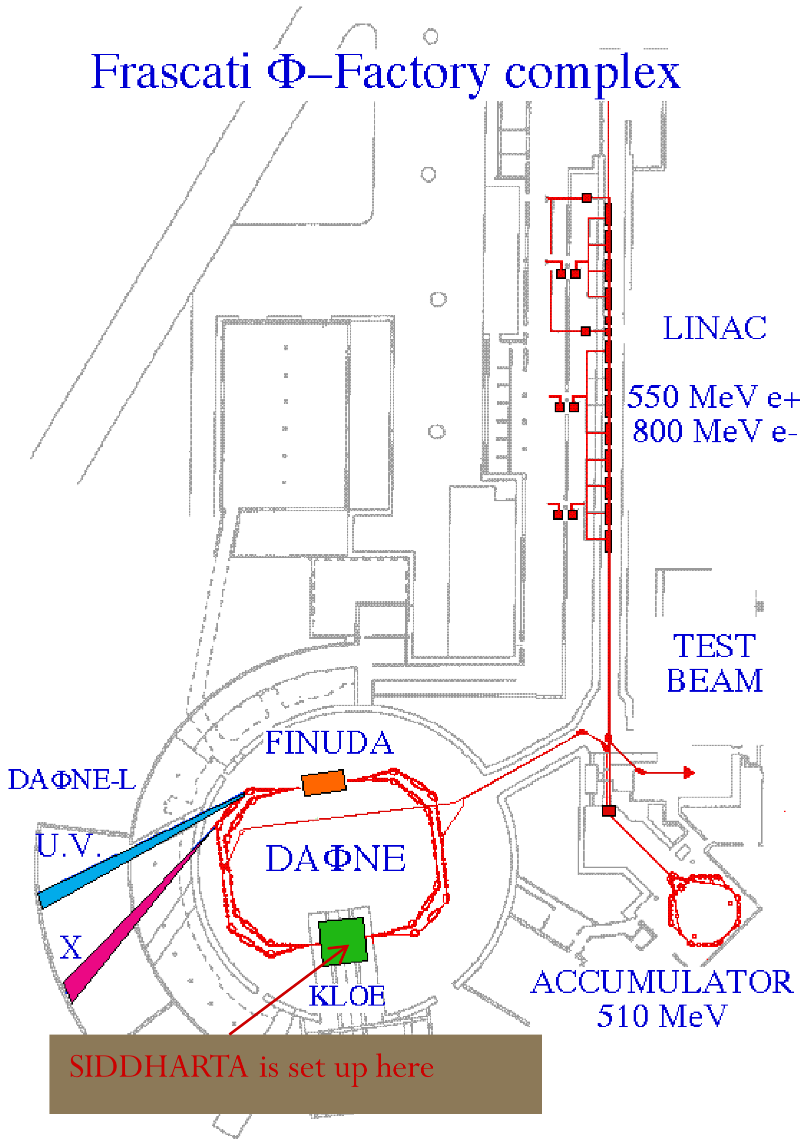
$$\text{and} \quad \Gamma(1s) = 407 \pm 208 \pm 100 \text{ eV},$$

Previous X-ray measurements summary

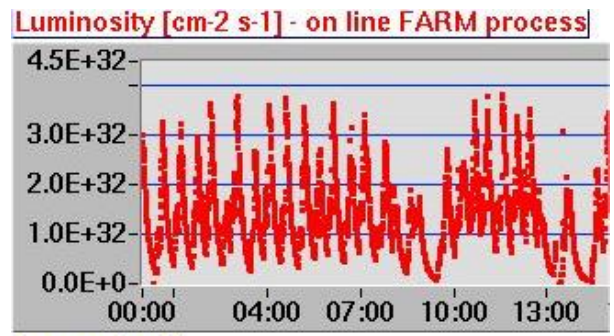


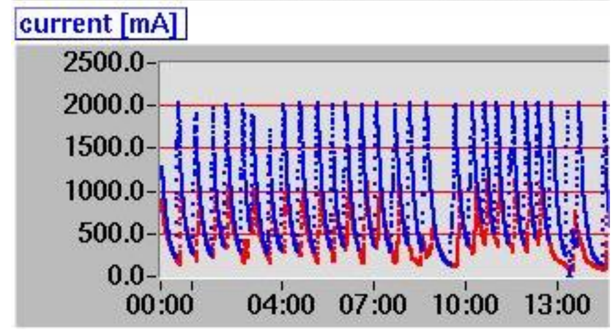
DAΦNE UPGRADE, 2008

DAΦNE



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





Φ production cross section ~ 3000 nb (loss-corrected)
Integr. luminosity 2009 **~ 6 pb^{-1} per day** [1] (~ 10^7 $K^\pm$)
(increased by crabbed waist scheme)
Peak luminosity ~ 3 × 10^{32} cm^{-2} s^{-1} = 450 Hz $K^\pm$
[1] we can not use kaons produced during injections.

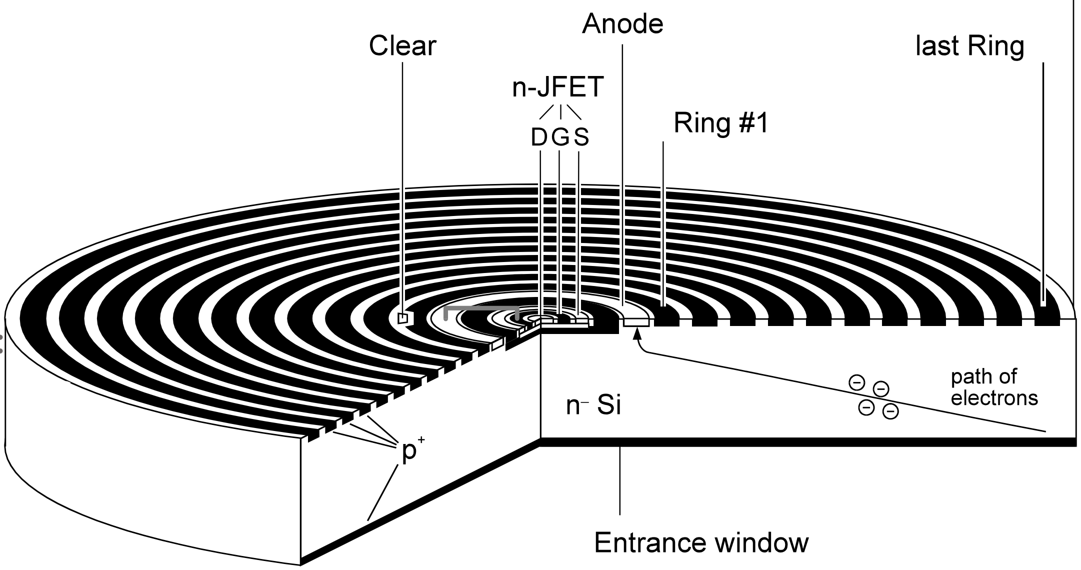
compare situation during DEAR data taking **(2002)**
currents ~ 1200/800 ~ 1 pb^{-1} per day, peak ~ 3×10^{31} cm^{-2} s^{-1}

DAFNE background

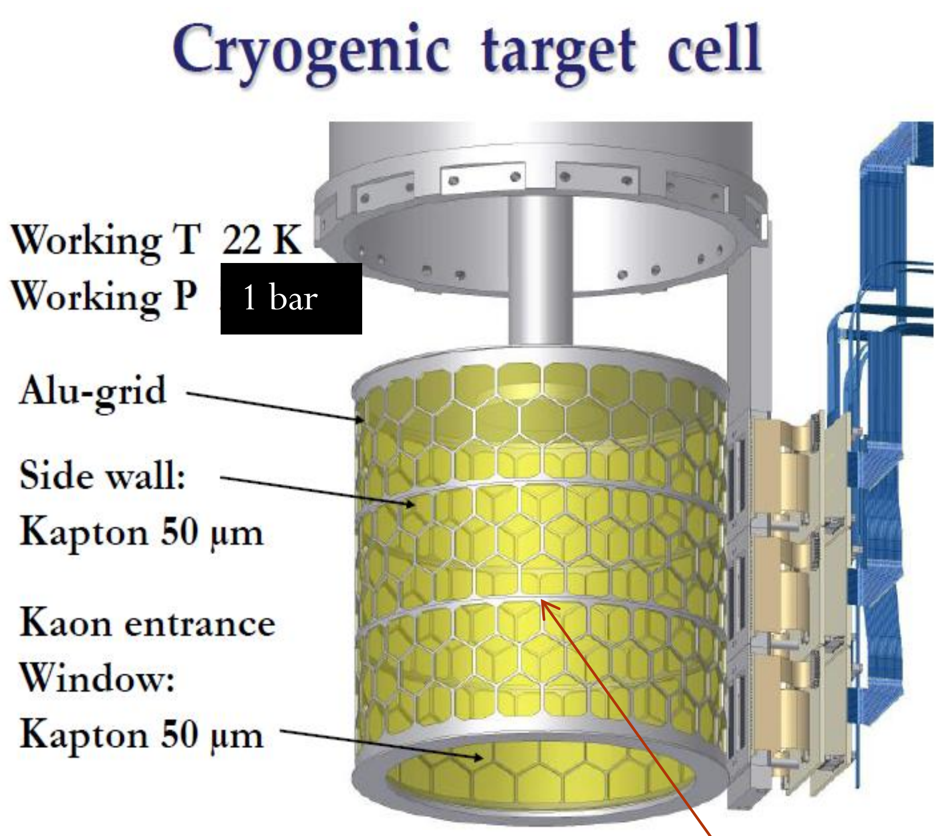
SYNCRONOUS: It's associated to K production, or Φ decays. It can be considered a hadronic background.

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)

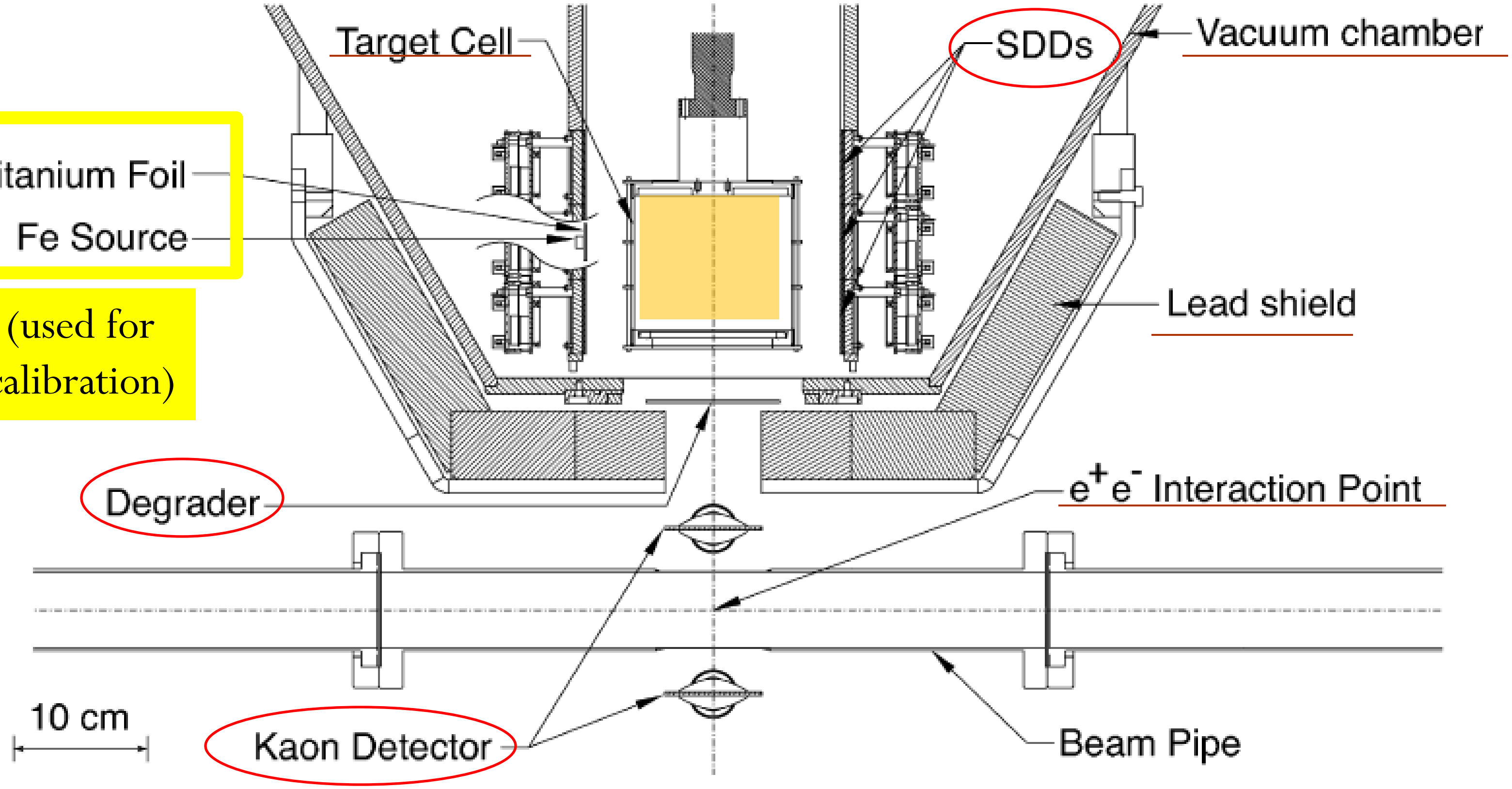


Target



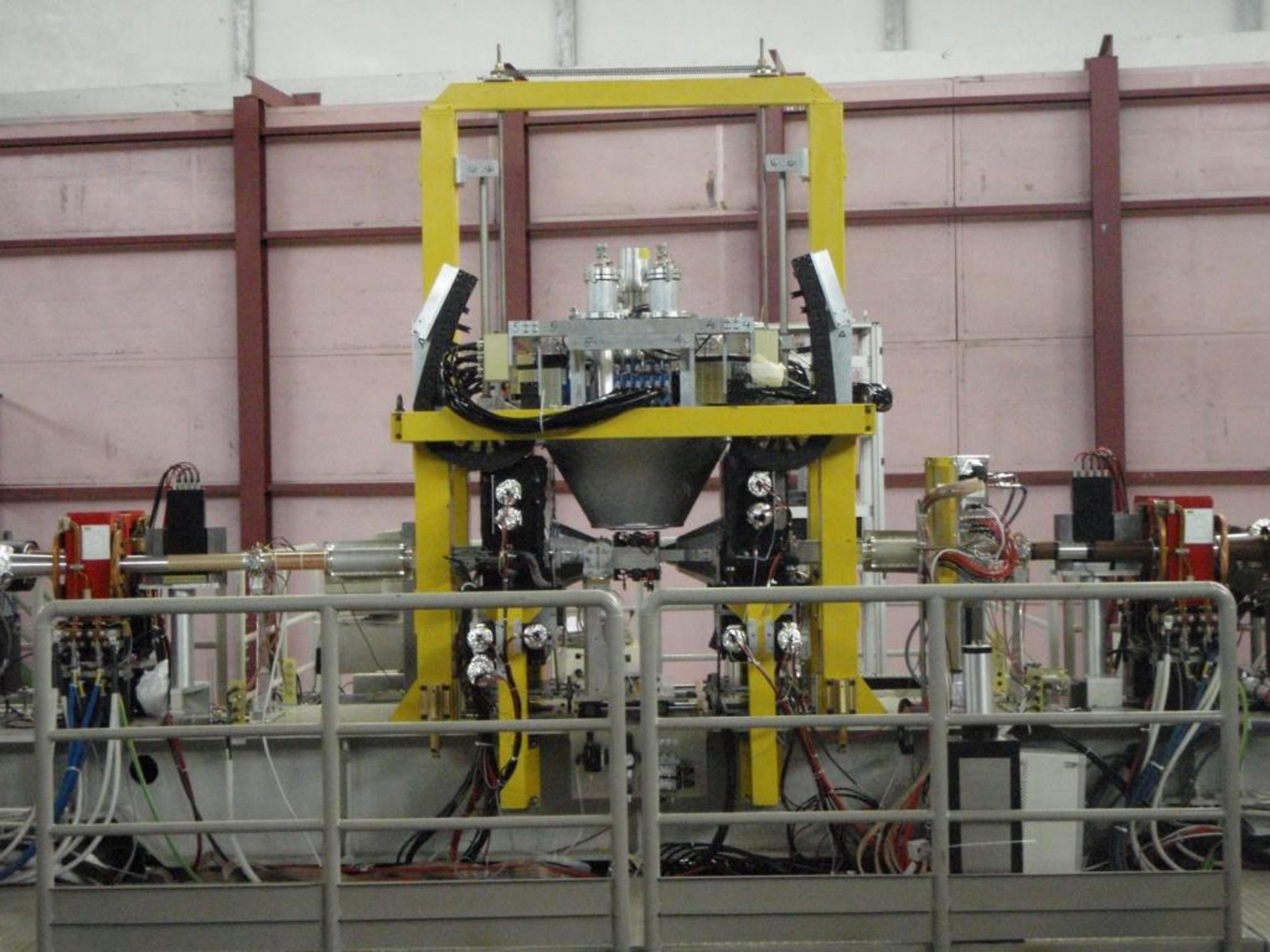
Low density gas
- Hydrogen
- Deuterium
- Helium4, Helium3

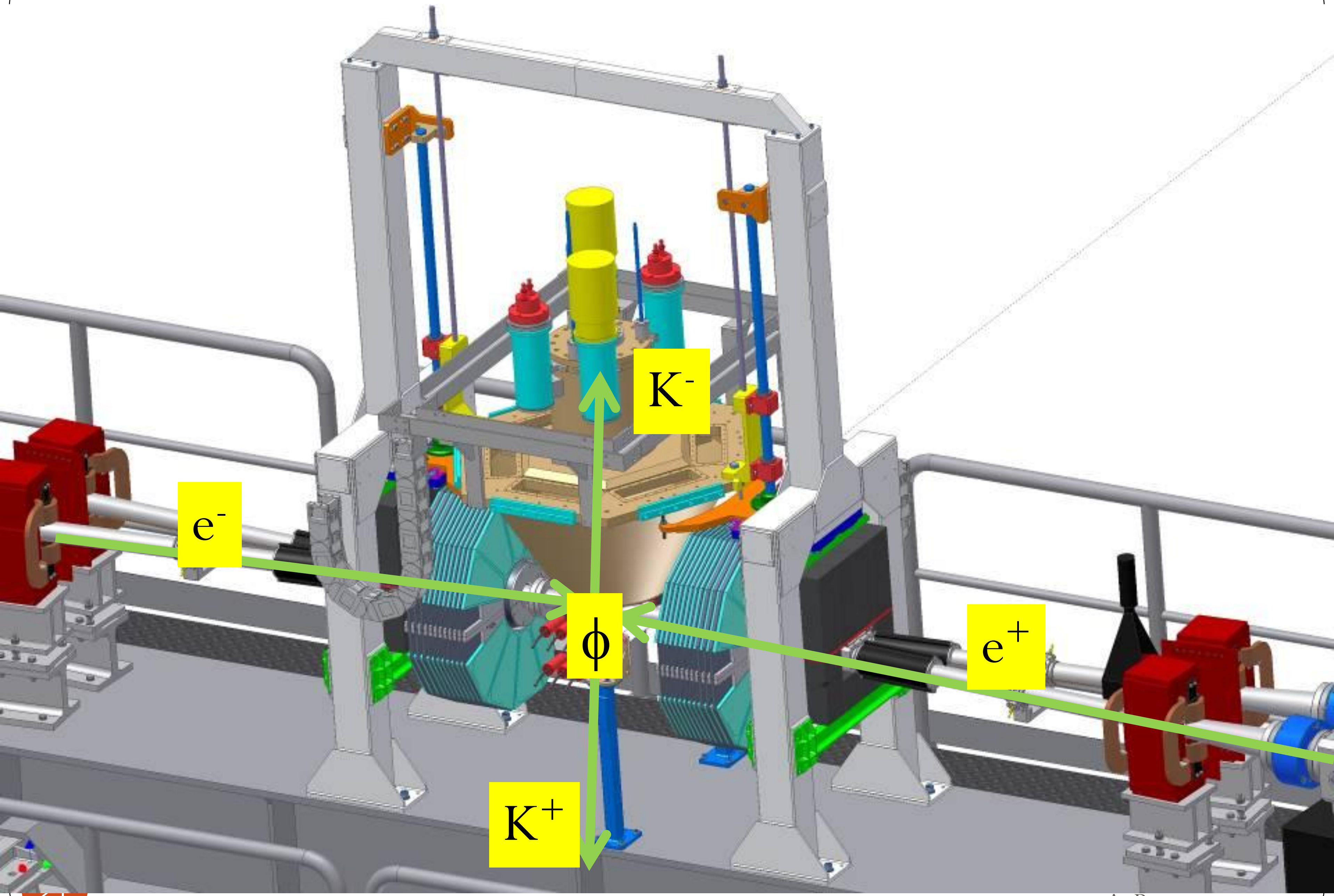
SIDDHARTA SETUP

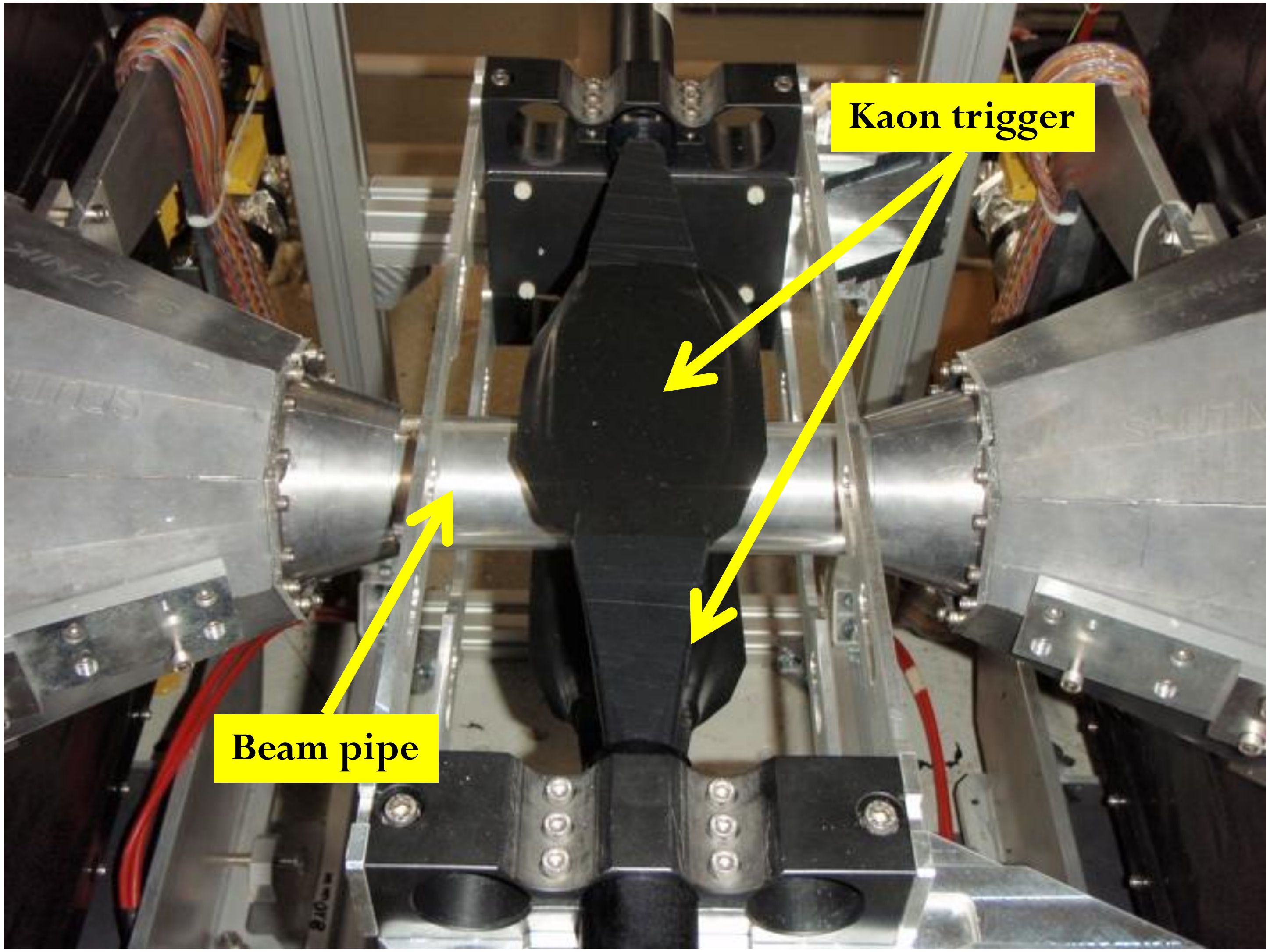


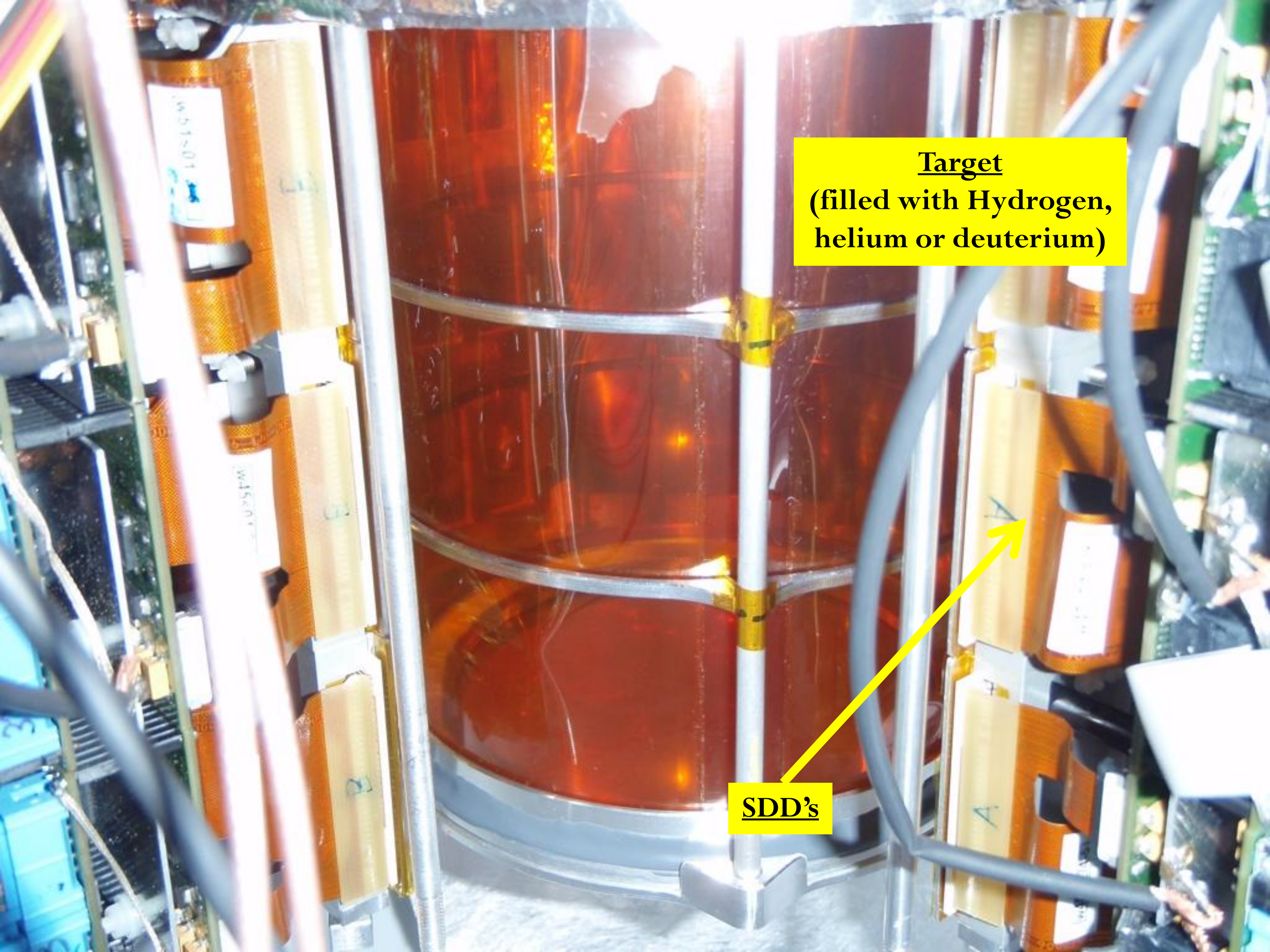
(used for calibration)

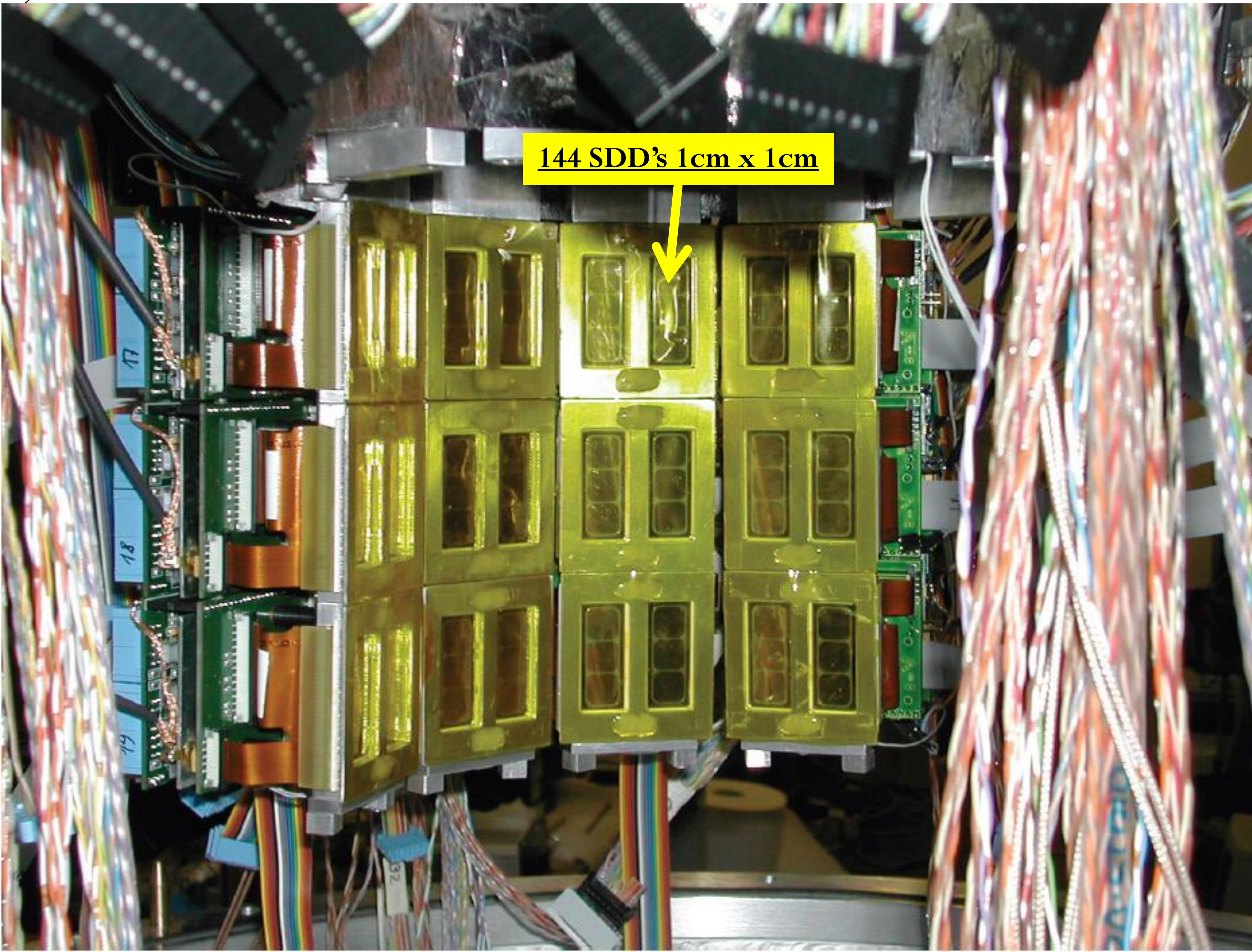
(two scintillators
In coindidence with the
DAFNE RF)



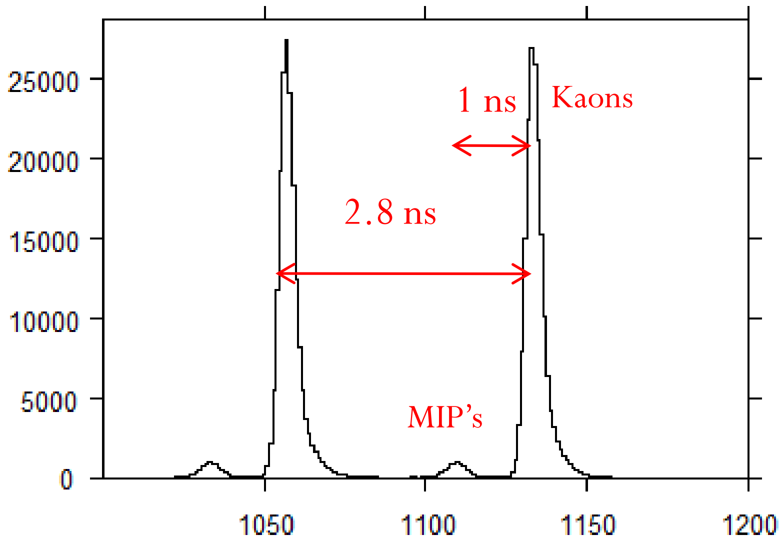

K-
e-
ϕ
e+
K+


Kaon trigger
Beam pipe

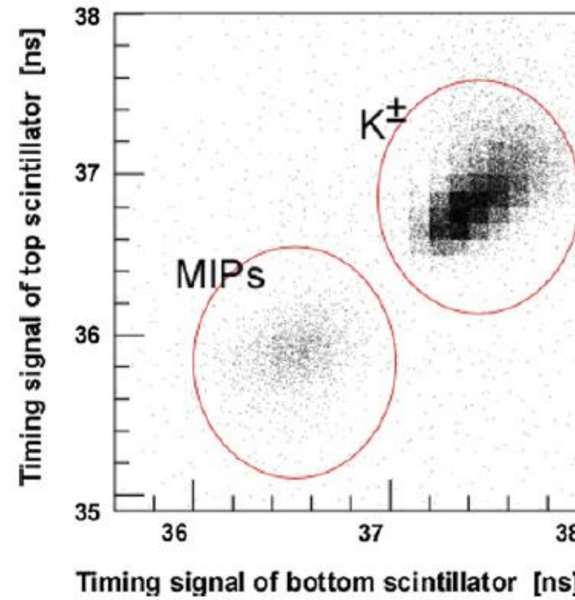

Target
(filled with Hydrogen, helium or deuterium)
SDD's

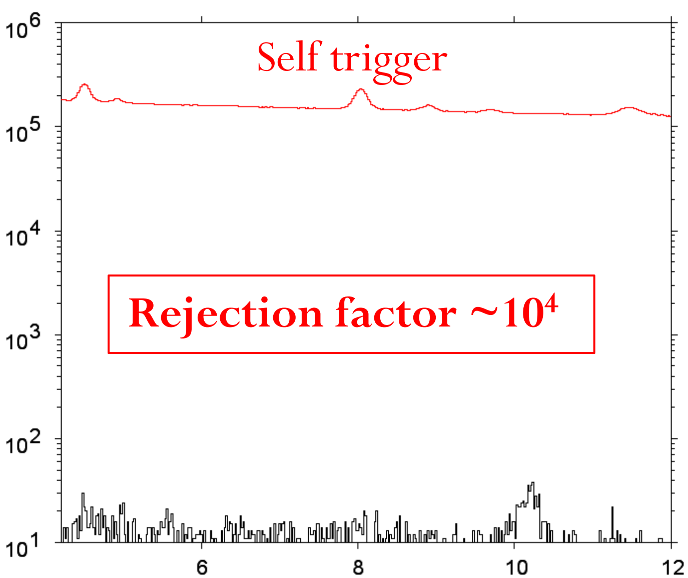

144 SDD's 1cm x 1cm

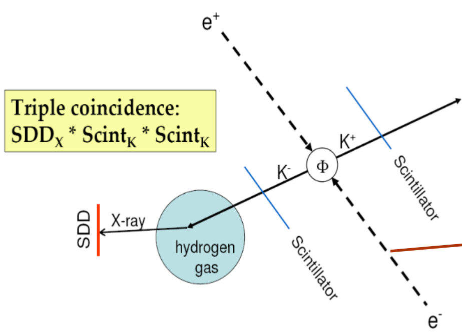
Trigger

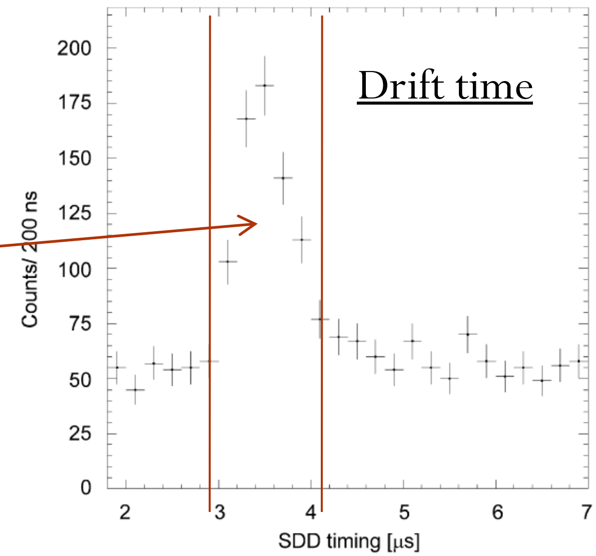


Kaons are detected by TOF. Two scintillators in coincidense with the collission.



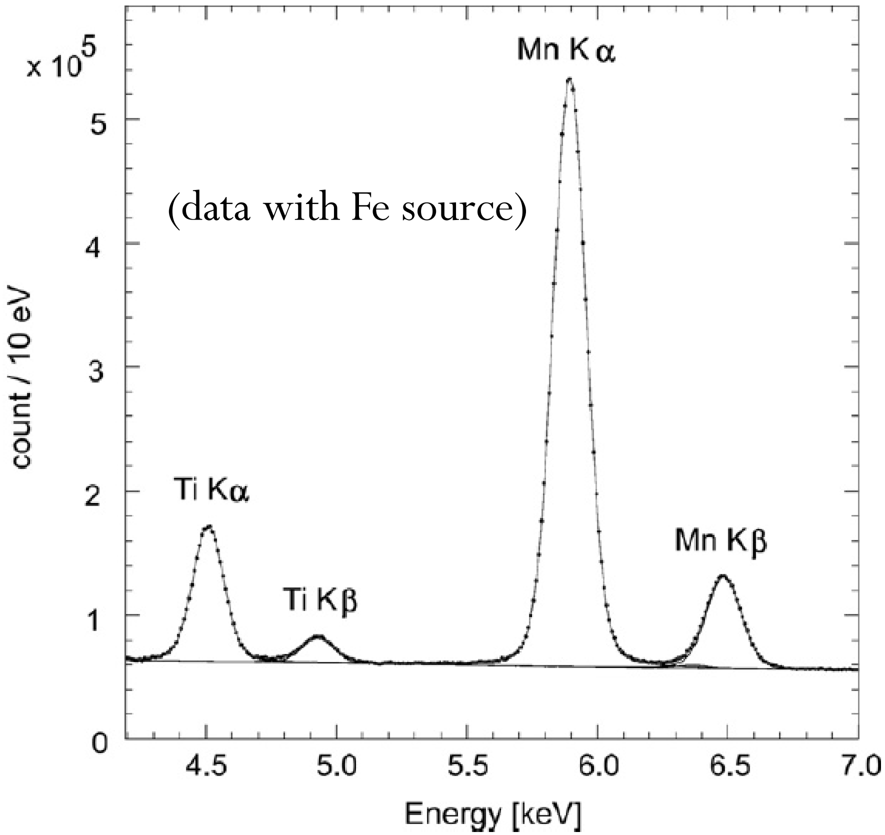




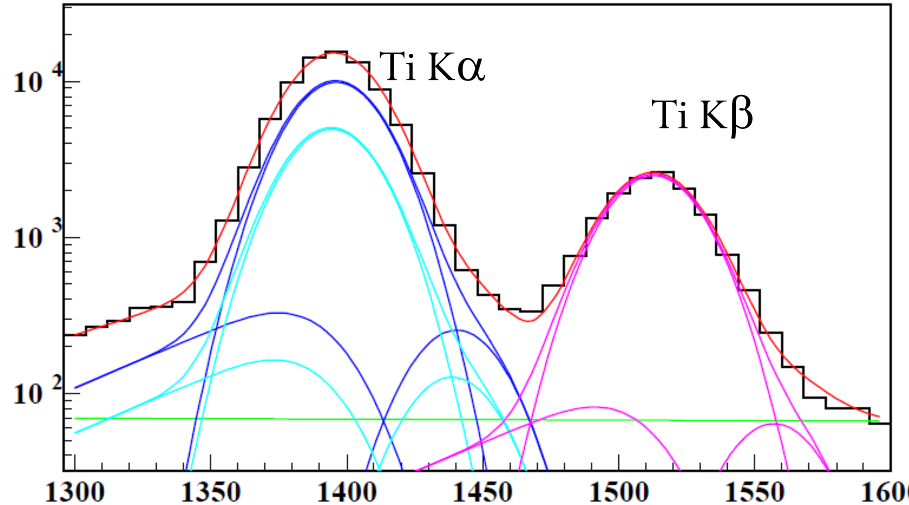


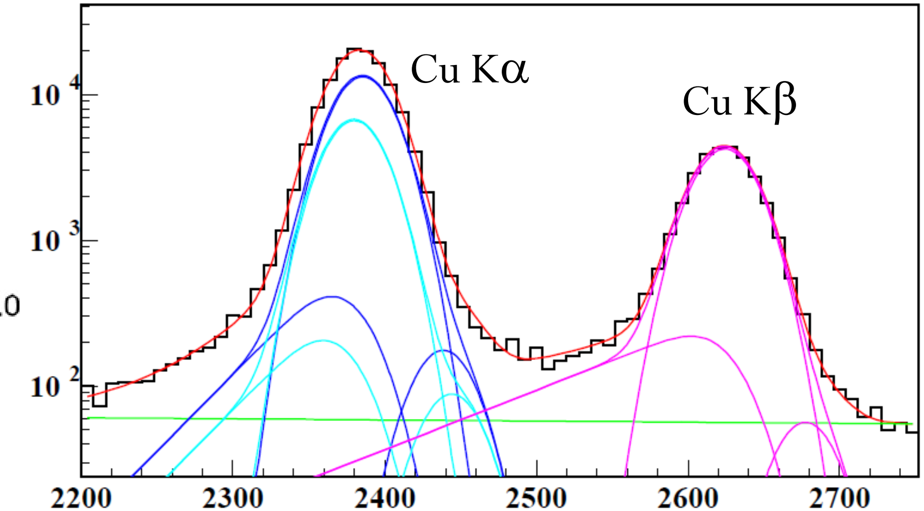
Calibration runs

Every 10 normal runs, a calibration run is done using a X-ray tube which activates the Ti and Cu foils, in order to check the setup stability.



Resolution at 6.4 KeV (FWHM) ~ 140 eV

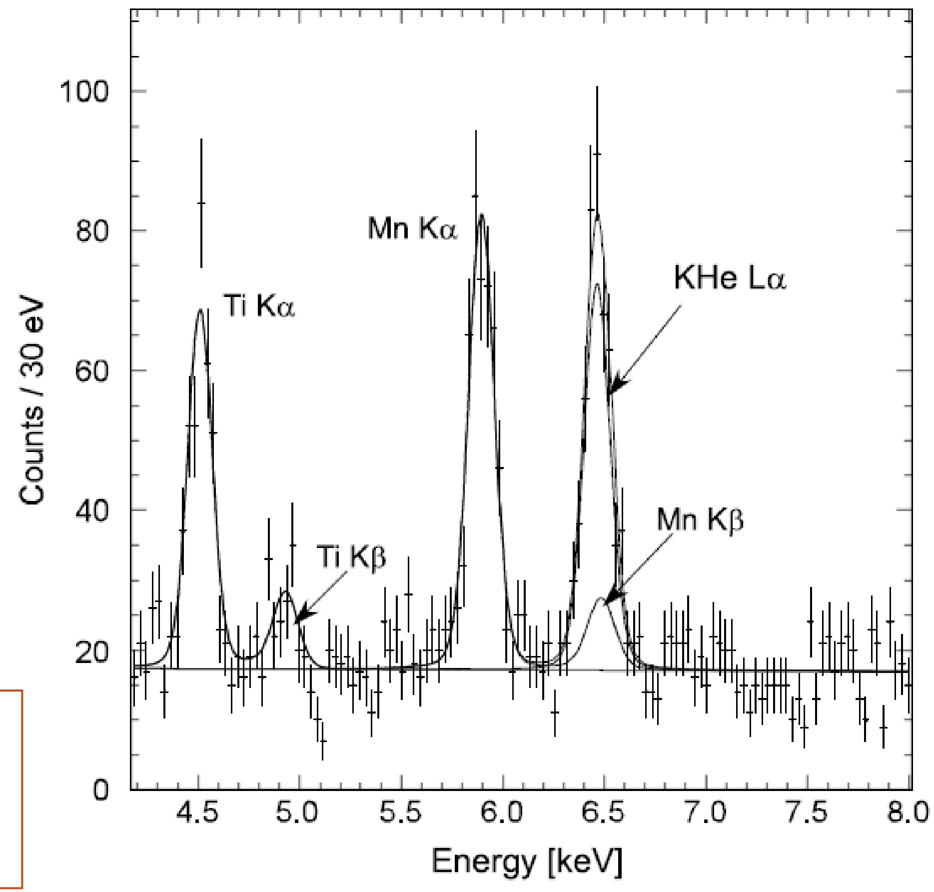




Kaonic He4. First results

Table 1
Energy shift of the kaonic helium 2*p* state.

ΔE (eV)	Ref.
−41 ± 33	Wiegand et al. [5]
−35 ± 12	Batty et al. [6]
−50 ± 12	Baird et al. [7]
−43 ± 8	Average of above [1,7]
+2 ± 2 (stat) ± 2 (syst)	Okada et al. [10]
0 ± 6 (stat) ± 2 (syst)	This work



Physics Letters B 681 (2009) 310-314

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

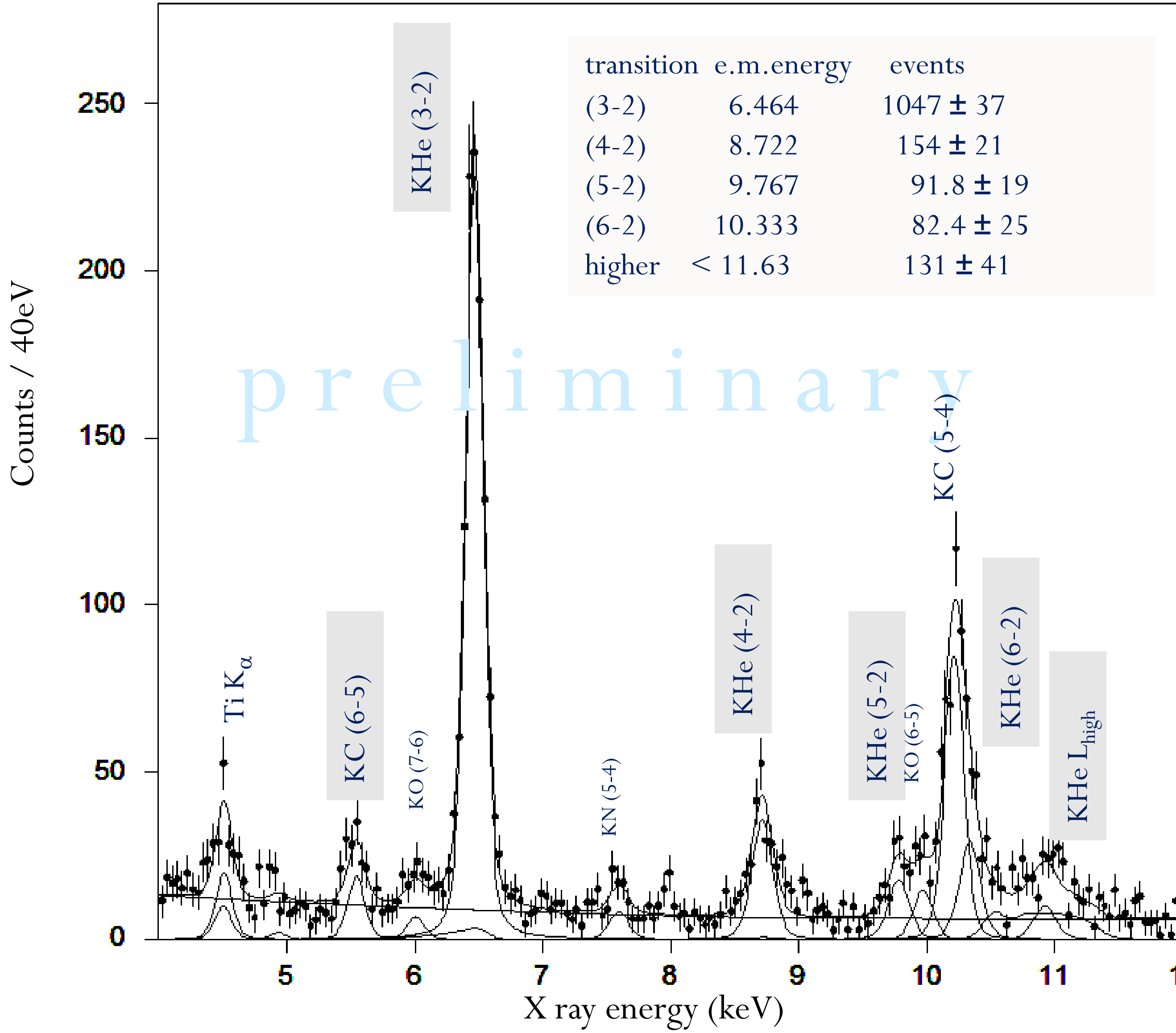
(Diana Laura Sirghi talk about Kaonic Helium)

Fit of Kaonic Helium 4. New data

KHe used for
gas stop optimization
+ physics interest[1])

data from setup 2
(no Fe55 source)

Shift compatible with zero

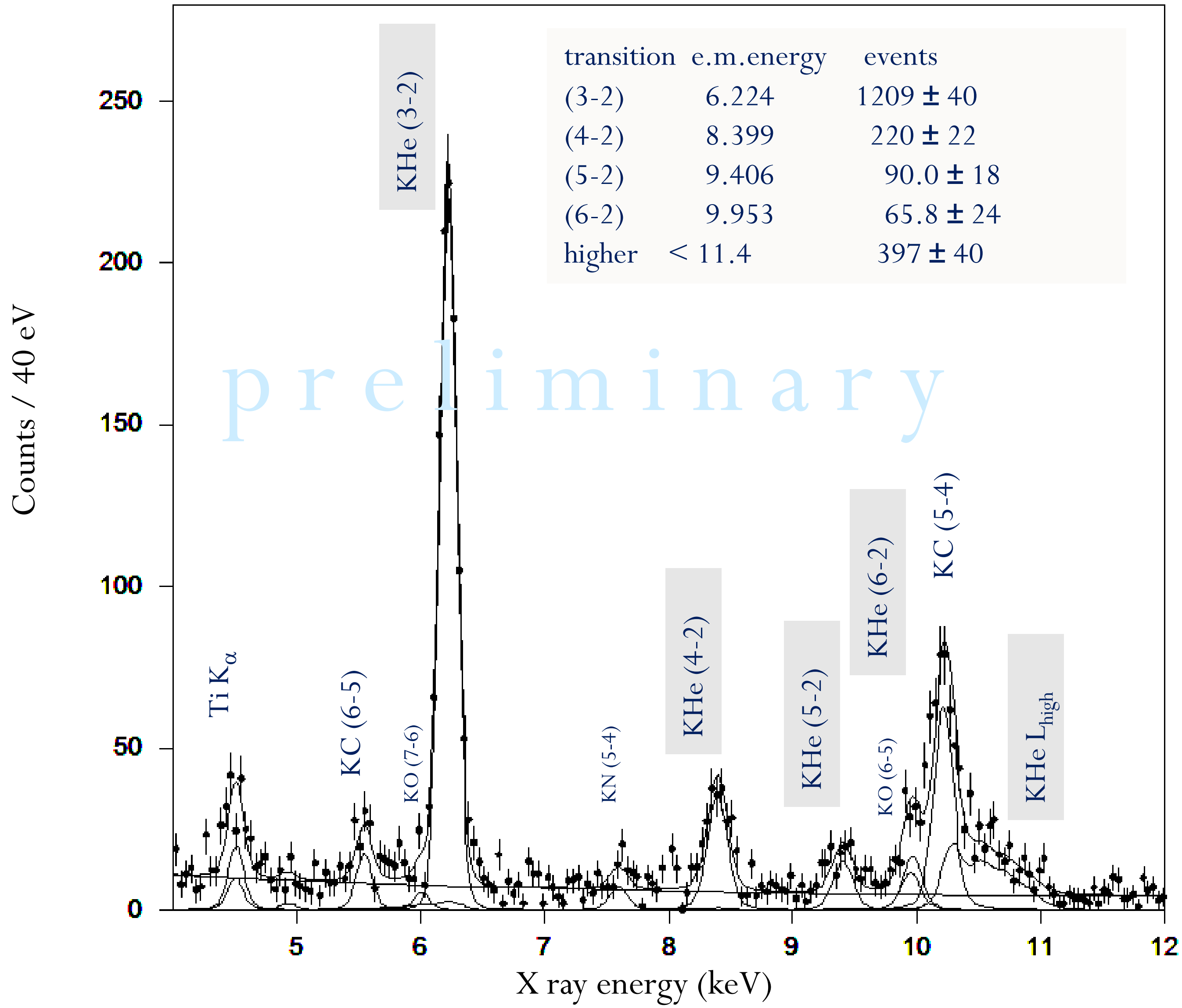


[1]) compare KEK E570
KHe L lines in liquid He,
consistent result,
first measurement in gas

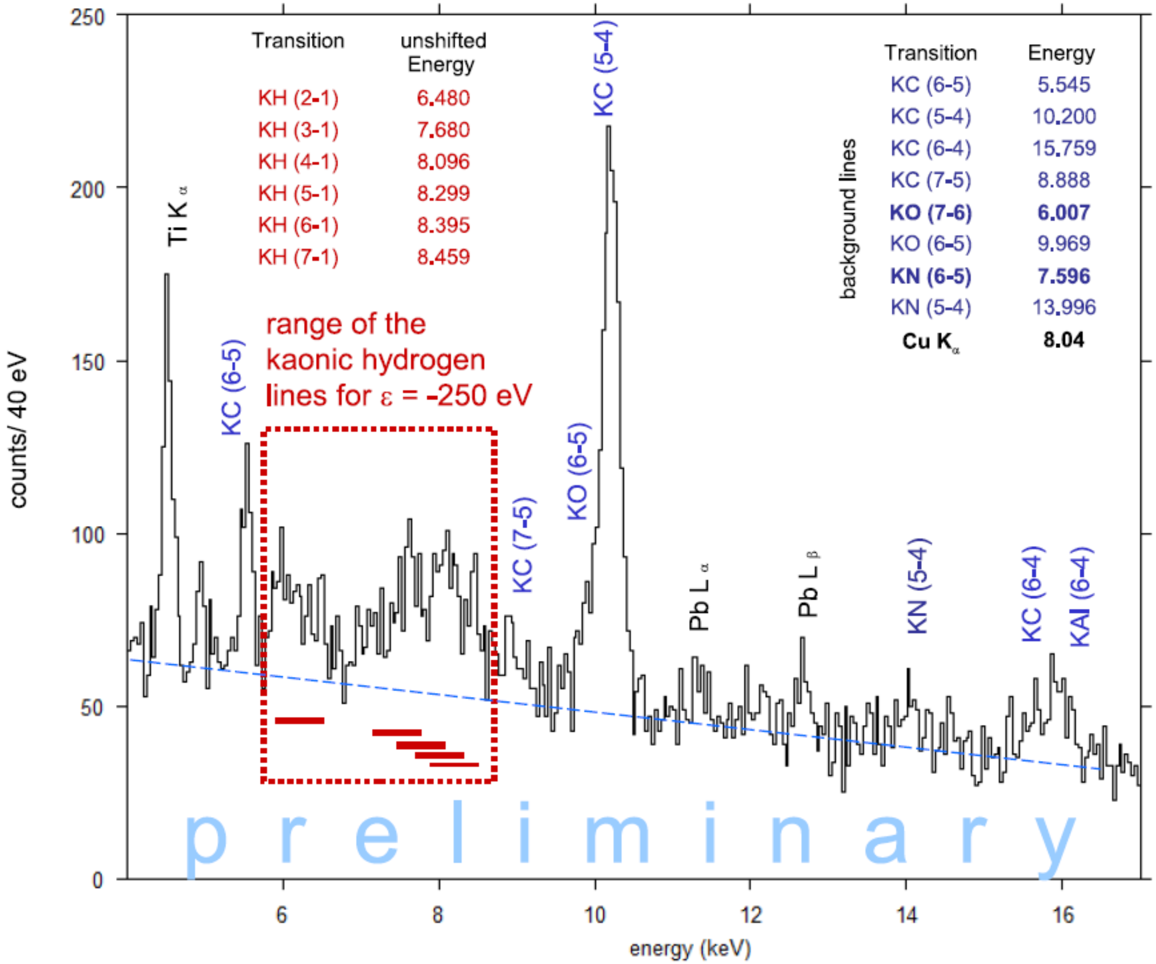
Fit of Kaonic Helium 3

KHe3
never measured
before !

Shift compatible
with zero

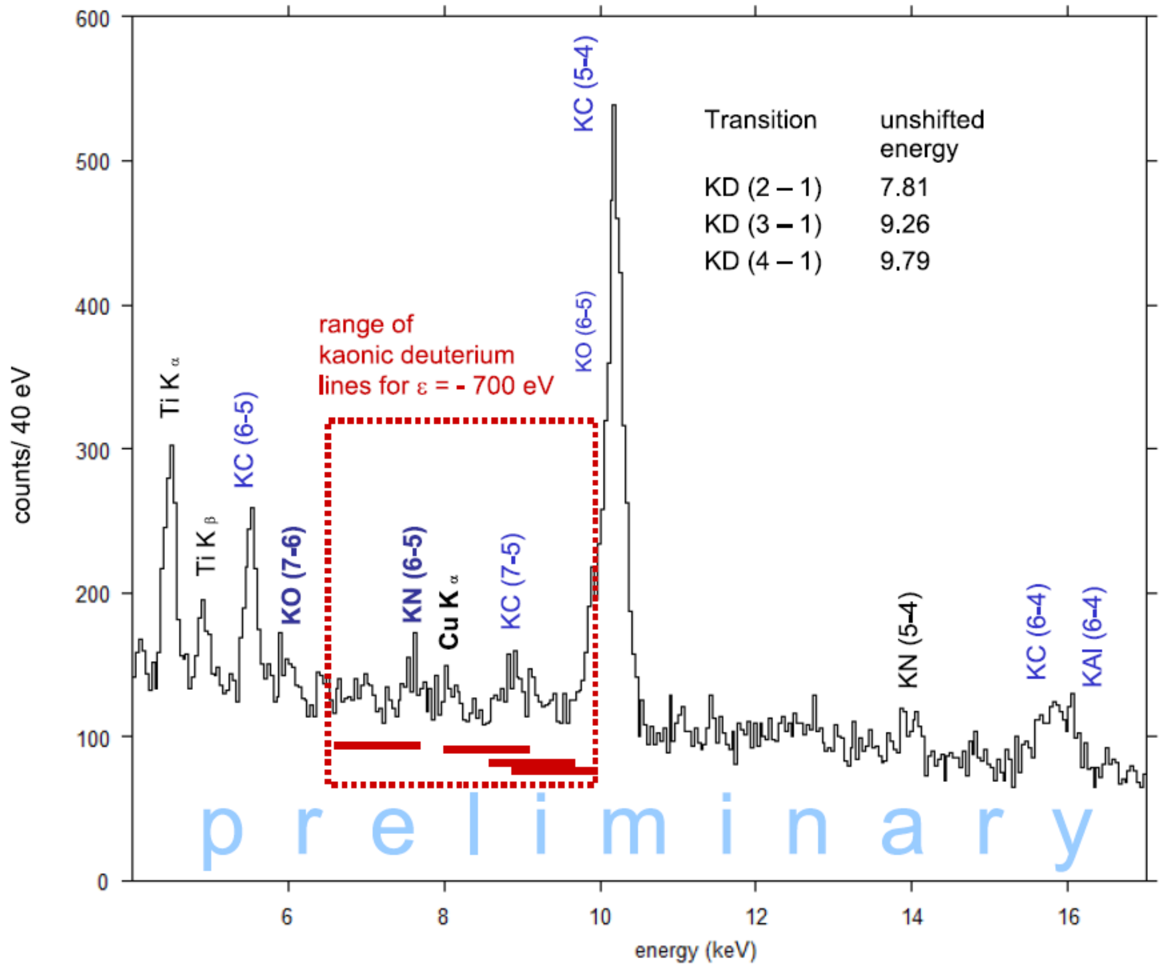


Kaonic hydrogen data



---- MESON 2010 , 12/06/2010 , A. Romero ----

Kaonic deuterium data

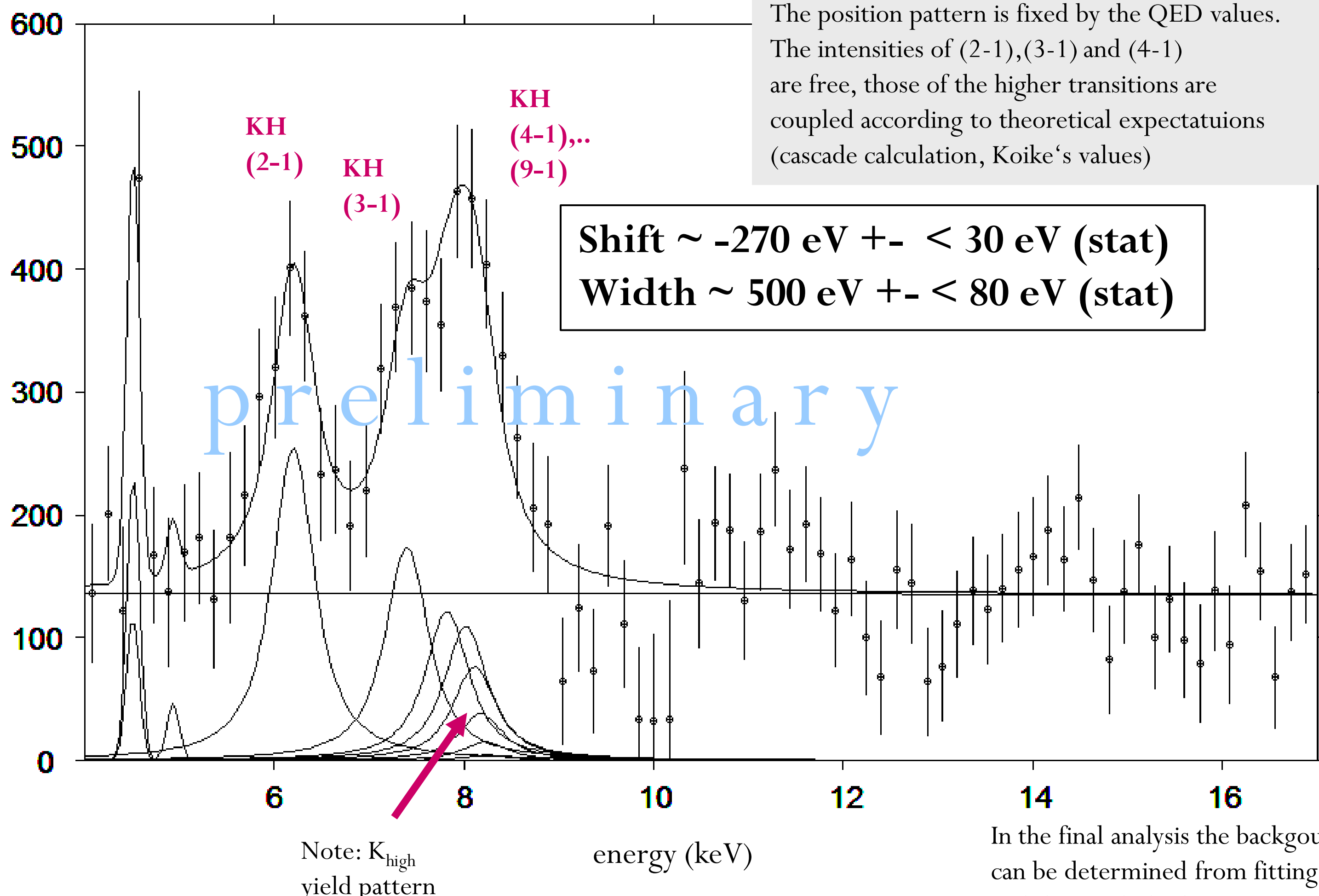


---- MESON 2010 , 12/06/2010 ,
A. Romero ----

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)



Shift ~ -270 eV +- < 30 eV (stat)
Width ~ 500 eV +- < 80 eV (stat)

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

Future plans

SIDDHARTA2

- **SIDDHARTA upgrade (from 2012) for :**
  - **Kaonic deuterium precision measurement**
  - **Other kaonic atoms (light and heavy) (Si,Pb …)**
  - **Charged kaon mass precision measurement.**
  - **Feasibility study for Sigmonium atoms.**
  - **Kaonic Helium transitions to the 1s level.**

Conclusions

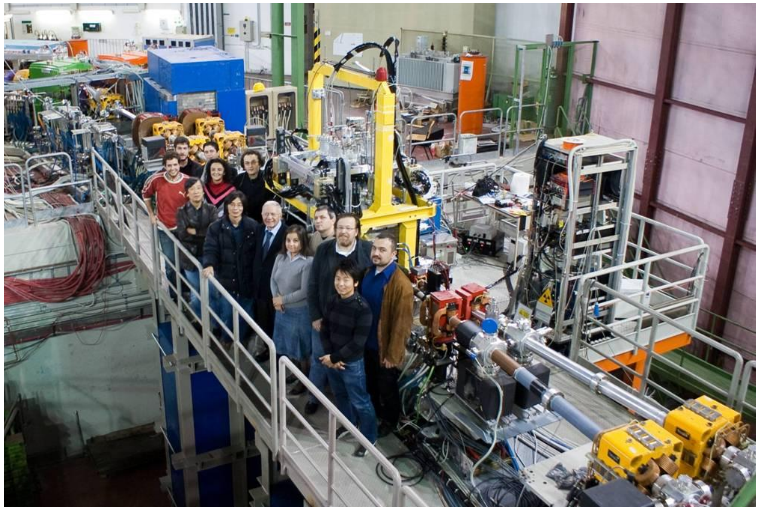
• **SIDDHARTA** has performed first class measurements of kaonic atoms.

• **K^-p** shift ~ -270 eV, width ~500 eV higher precision than in DEAR. Preliminary results.

• **SIDDHARTA2** plans solving kaonic atoms campaign (2012).

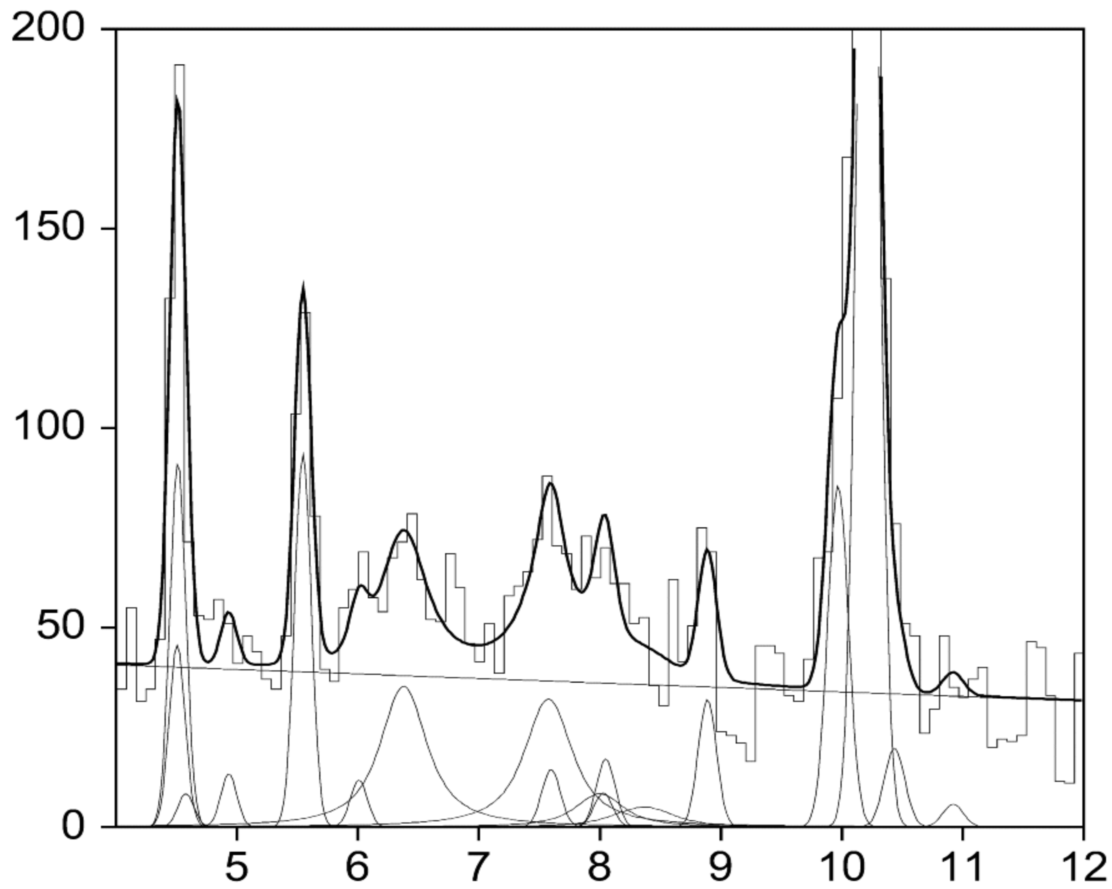
• **K^-d** exploratory measurement, small signal, significance ~ 2σ.

• **DAFNE** represents an unique opportunity to study in a complete way the kaon-nucleon/nuclei physics at low energy.

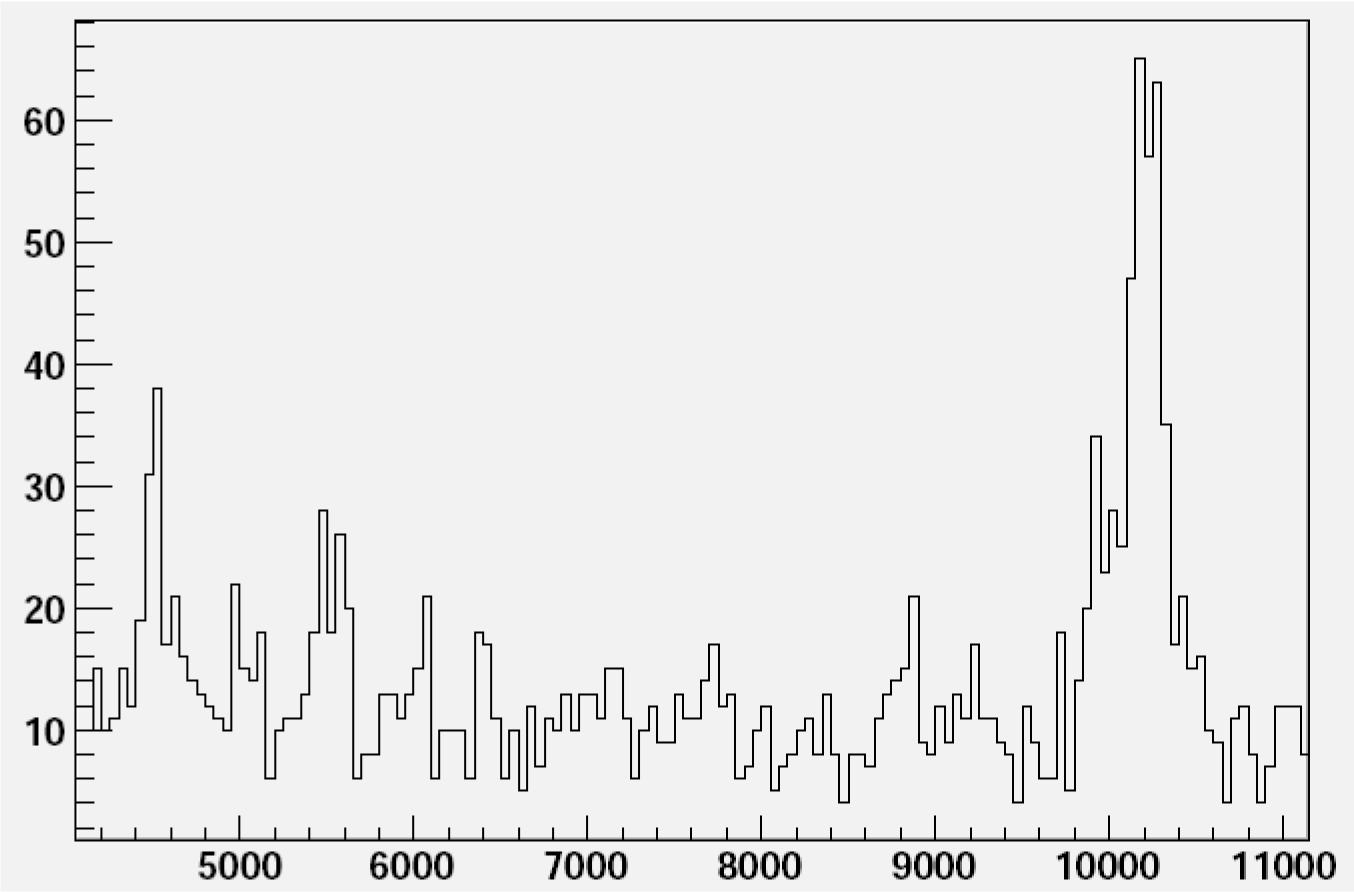


Thank you very much !

SPARES


200
150
100
50
0
5
6
7
8
9
10
11
12

Kaonic Deuterium



Summary and Outlook

SIDDHARTA data taking finished Nov 2009. *Preliminary results:*

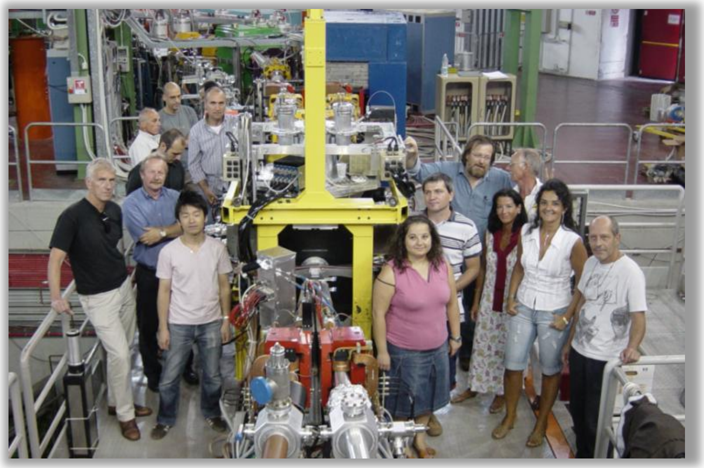
KHe4 measured in gaseous target, shift zero within errors (confirming E570)

KHe3 first time measurement, shift zero within errors (σ = 2.7 eV stat. 4 eV syst.)

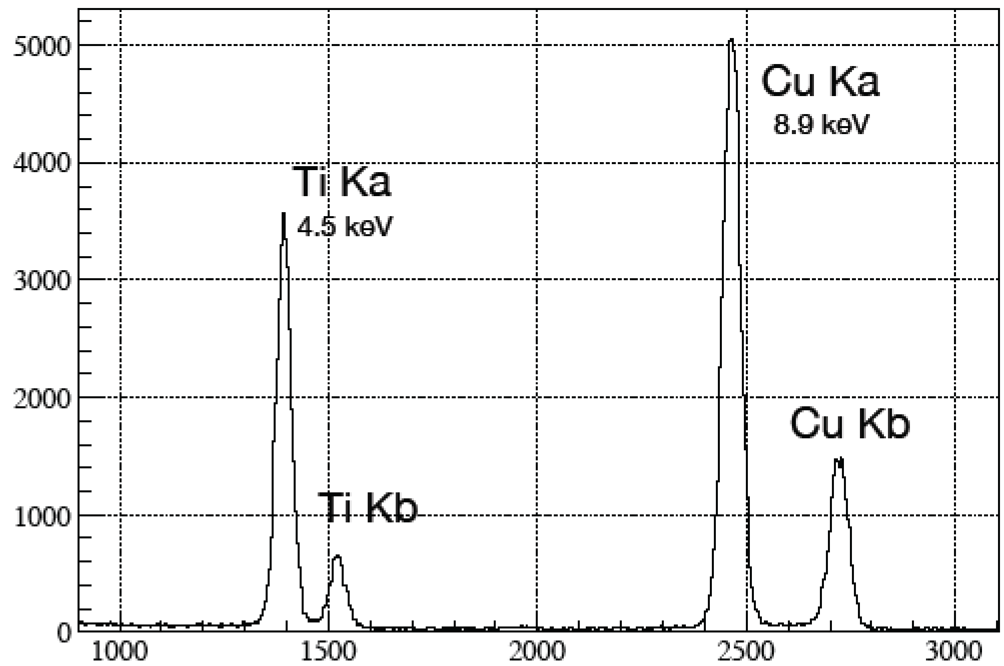
K^-p shift ~ 270 eV, width ~500 eV higher precision then in DEAR

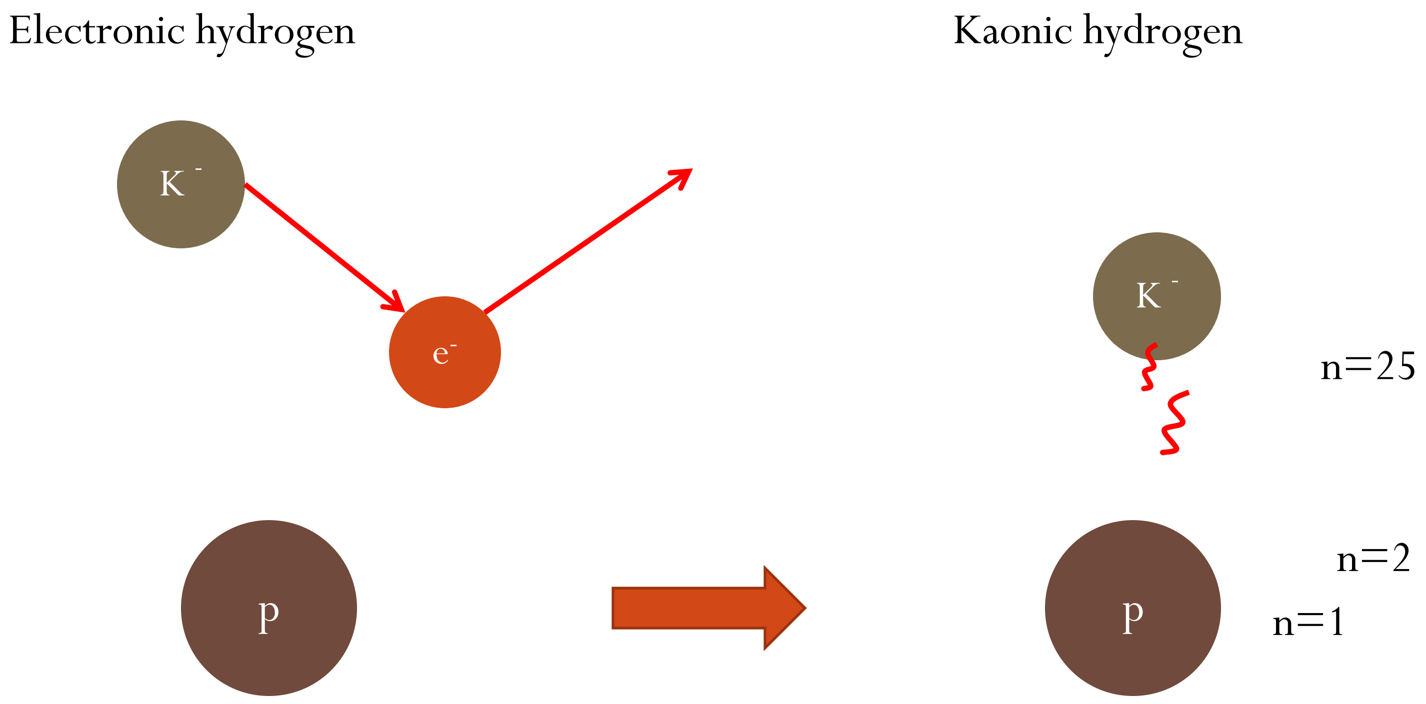
K^-d first measurement ever, exploratory measurement, small signal, significance ~ 2σ

hopefully extension of the experimental program ~2012-
with improved technique - remeasure Kd, other light atoms, heavys, $Kp \rightarrow \gamma\ \Lambda^*$



Thanks for your attention !


5000
4000
3000
2000
1000
0
1000
1500
2000
2500
3000
Ti Ka
4.5 keV
Ti Kb
Cu Ka
8.9 keV
Cu Kb



Finaly, the Kaon is absorved by the nucleus

Kaon-nucleon interaction at low energies

Anti(K)-N interaction at low energies has complex dynamical aspects due to several πY channels opening at K- p threshold (1432 MeV):

$$K^-p \to K^-p$$

$$K^-p \to \overline{K}^0 n - 5\,MeV$$

$$K^-p \to \pi\Sigma + 100\,MeV$$

$$K^-p \to \pi^0\Lambda + 180\,MeV$$

This region is also dominated by the s-wave Λ(1405) resonance, wich only decays in Σπ.

This resonance also couples to the anti(K)-N system but it doesn't decay to it since it's ~ 30 MeV below the threshold

Exotic atoms

In order to determine the energy shift , the E.M. energy of the unshifted line must first be calculated

Klein-Gordon equation with Coulomb potential with second order perturbation theory corrections
Corrections include vacuum polarization, electron screening, relativistic corrections to reduced mass, nuclear polarization and Lamb shift

Kaonic hydrogen and deuterium level energies (KeV)

Line	kaonic hydrogen	kaonic deuterium
K_α	6.46	7.81
K_β	7.66	9.26
K_γ	8.07	9.79
K	8.61	10.41

KpX at KEK, Japan

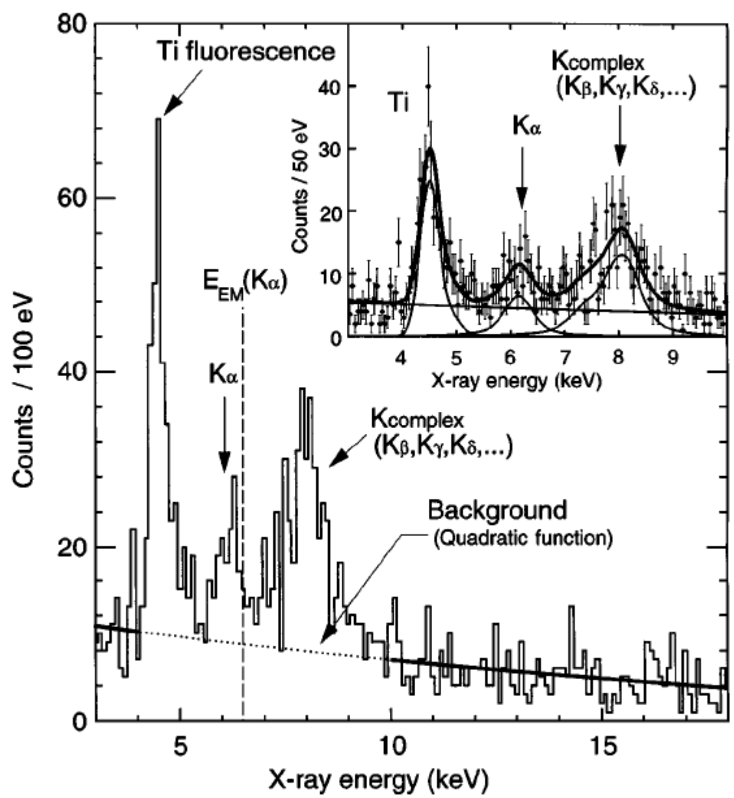
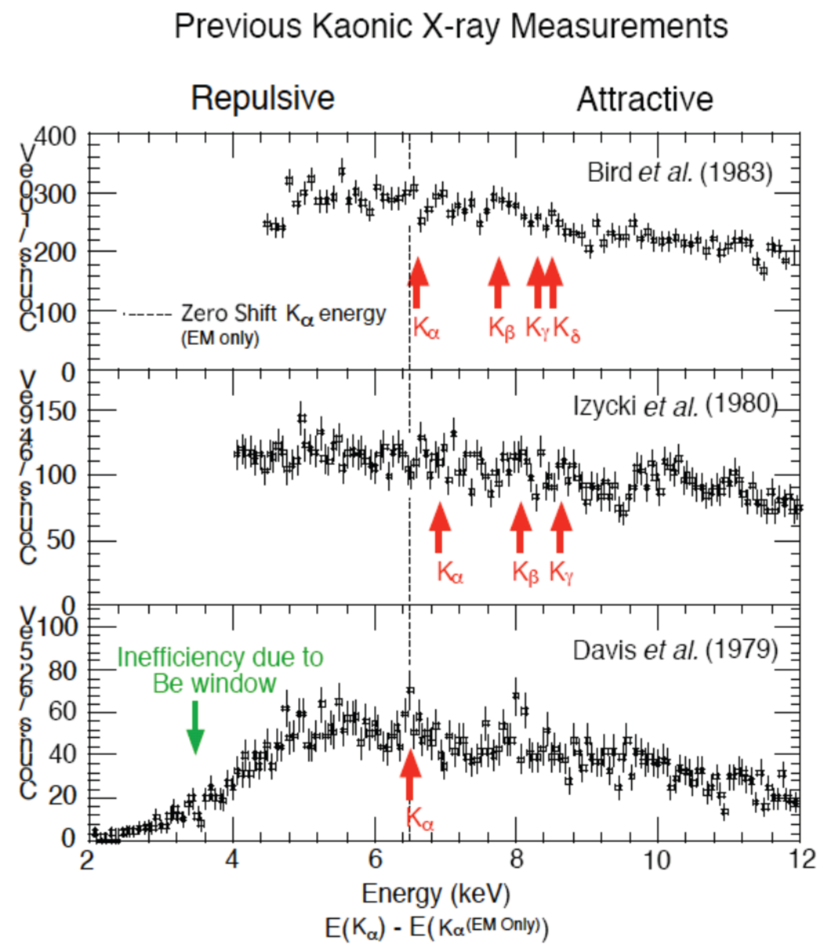


FIG. 3. Kaonic hydrogen x-ray spectrum. The inset shows the result of peak fitting and the components.

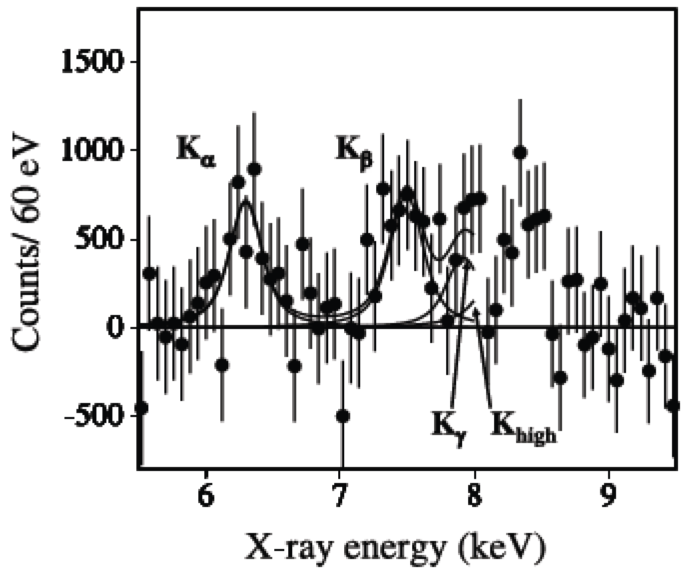
Old experiments



[6] M.Iwasaki et al., Phys. Rev. Lett. 78 (1997) 3067
T.M.Ito et al., Phys. Rev. A58 (1998) 2366.

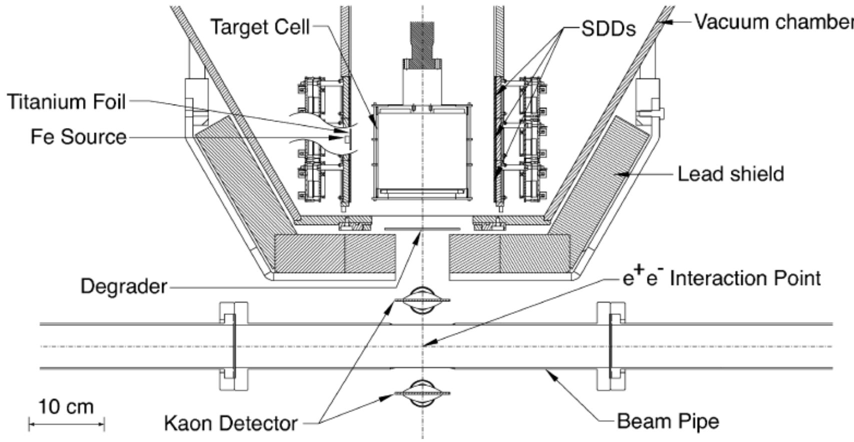
DEAR

- Experiment at DAFNE before SIDDHARTA.
- It used CCD detectors (slow time response)

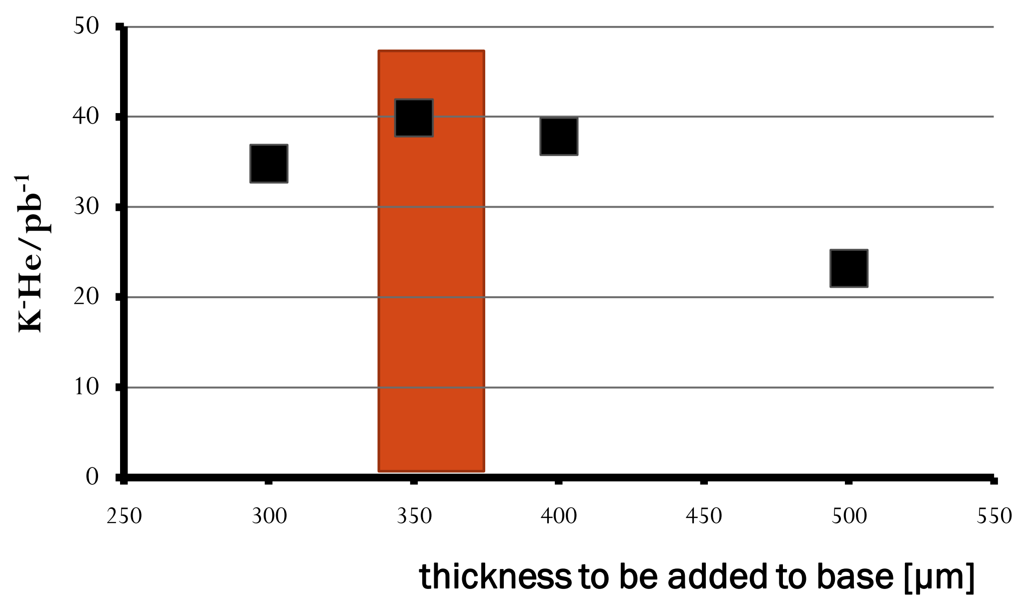


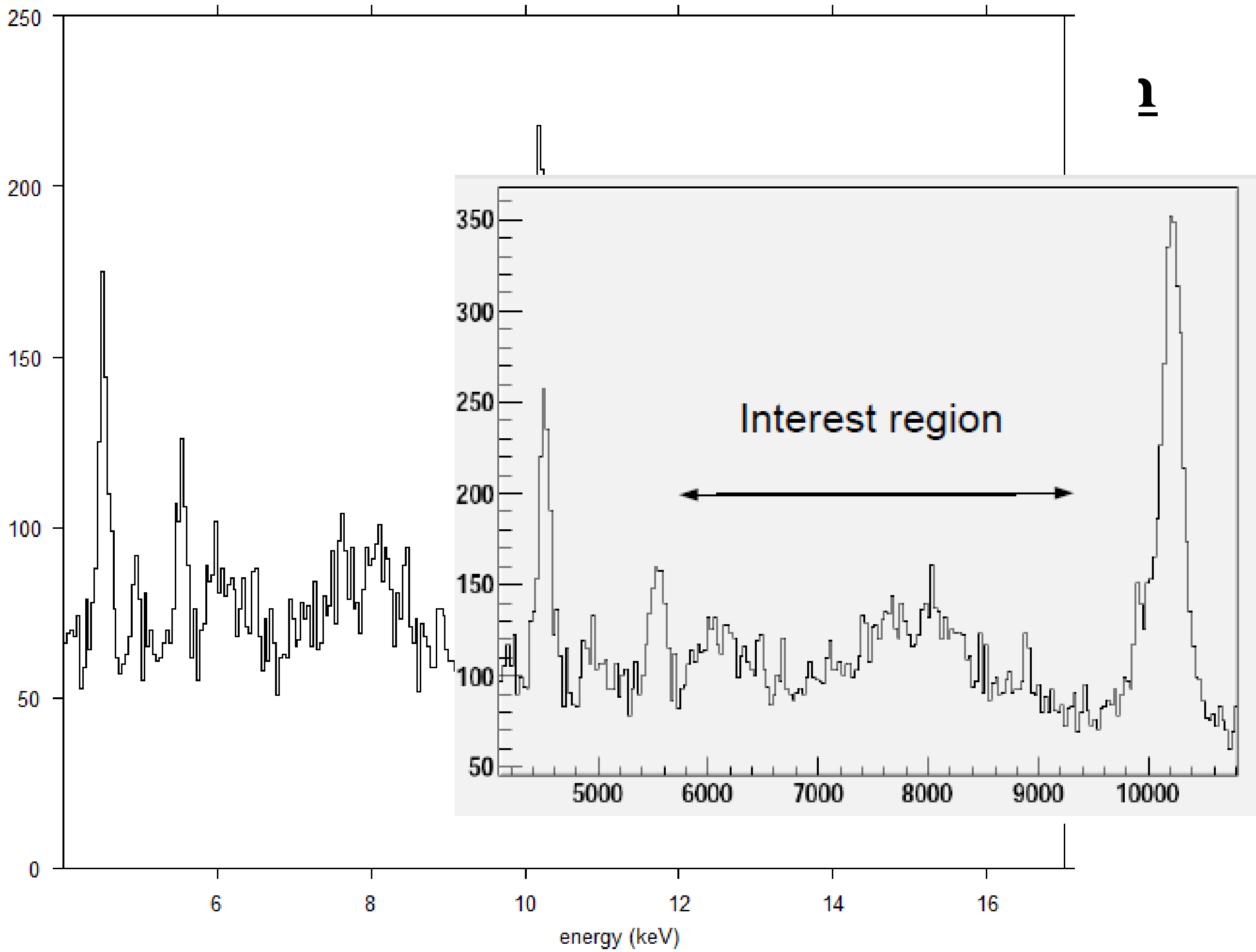
$$\varepsilon = -193 \pm 37(stat.) \pm 6(syst.) eV$$
$$\Gamma = 249 \pm 111(stat.) \pm 39(syst.) eV$$

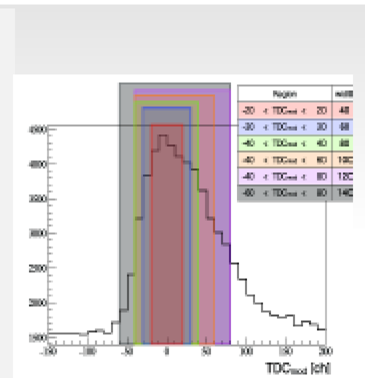
Degrader optimization



Degrader thickness is changed to optimize the number of kaons inside the target

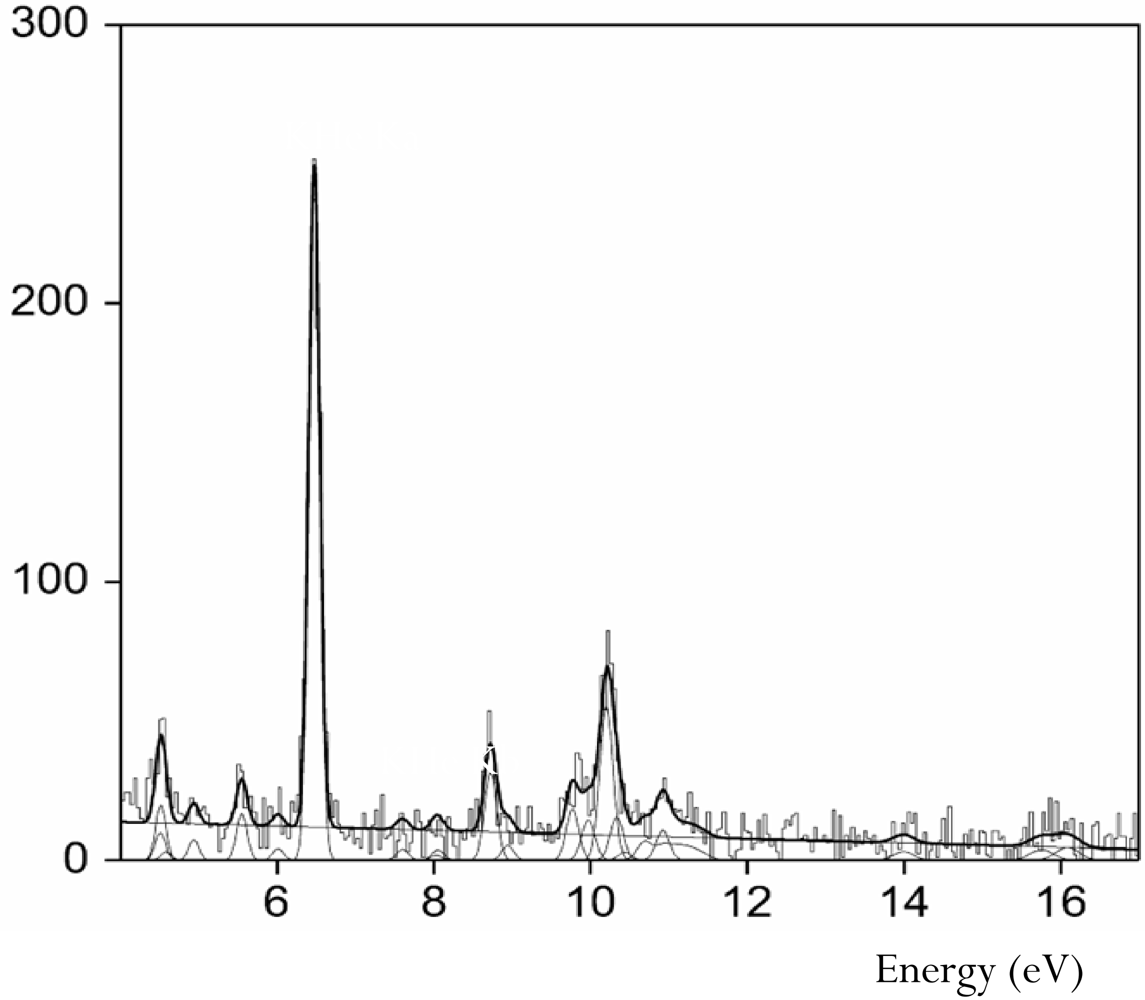



Interest region
energy (keV)

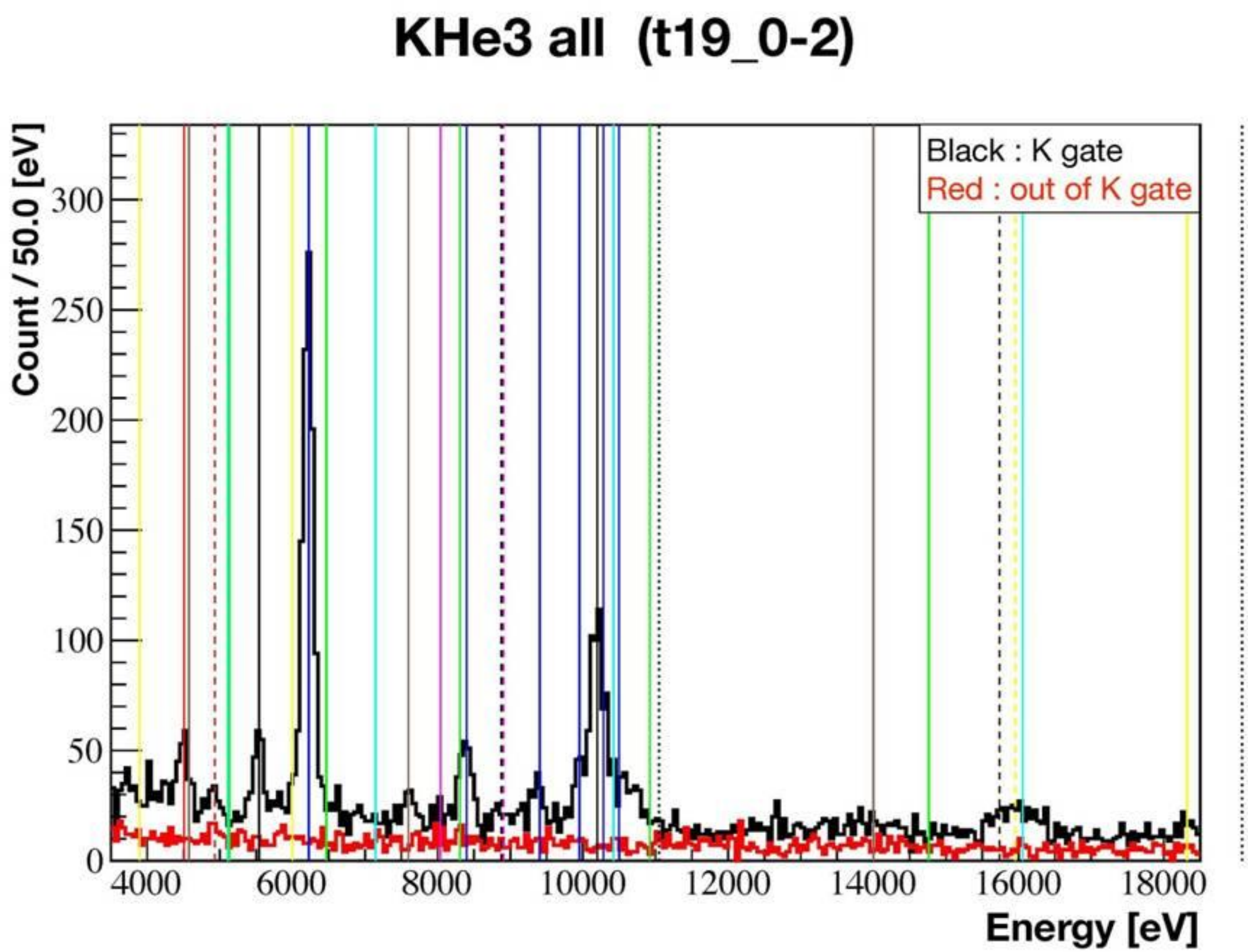


Kaonic He^4

More data under analysis



Kaonic He^3


KHe3 all (t19_0-2)
Count / 50.0 [eV]
0
50
100
150
200
250
300
4000
6000
8000
10000
12000
14000
16000
18000
Energy [eV]
Black : K gate
Red : out of K gate

Kaonic atoms

- Energy shift ε and line width Γ of 1s state are related to real and imaginary part of the S-wave scattering length:

a_{K^-p}

- Neglecting isospin-breaking corrections Deser-Trueman formula [1] for kaonic hydrogen and deuterium state:

$$\varepsilon + \frac{i\Gamma}{2} = 2\alpha^3\mu^2 a_{K^-p} = 412\,\tfrac{eV}{fm}\,a_{K^-p}$$
$$\varepsilon + \frac{i\Gamma}{2} = 2\alpha^3\mu^2 a_{K^-d} = 601\,\tfrac{eV}{fm}\,a_{K^-d}$$

Scattering lengths can be expressed in terms of antiK-N isospin dependent scattering lengths:

$$a_{K^-p} = \frac{a_0(I=0) + a_1(I=1)}{2}$$
$$a_{K^-d} = \frac{1}{2}\frac{m_N + m_K}{m_N + \frac{m_K}{2}}(3a_1 + a_0) + C$$

Includes all higher contributions related to the pysics associated to the K- d three body problem.
It can be numerically calculated solving Faddeev equation

[1] S.Deser et al., Phys.Rev. 96 (1954) 774;
T.L.Trueman, Nucl. Phys. 26 (1961) 57;
A.Deloff, Phys. Rev. C13 (1976) 730.

Kaon-nucleon interaction at low energies

Experimental data are available for:

1) K- p cross section for elastic and inelastic processes;
2) Branching ratios for K- p absorption at rest

$$\gamma = \lim_{k \to 0} \frac{\sigma(K^- p \to \pi^+ \Sigma^-)}{\sigma(K^- p \to \pi^- \Sigma^+)} = 2.36 \pm 0.04$$

$$R_c = \lim_{k \to 0} \frac{\sigma(K^- p \to charged\ particle)}{\sigma(K^- p \to all\ final\ states)} = 0.664 \pm 0.011$$

$$R_n = \lim_{k \to 0} \frac{\sigma(K^- p \to \pi^0 \Lambda)}{\sigma(K^- p \to all\ neutral\ states)} = 0.189 \pm 0.015$$

3) $\pi\Sigma$ invariant mass distribution below K- p threshold, wich exibits the $\Lambda(1405)$ resonance
4) 1s level shift of K- p atom determined through Xray measurement

The importance of a new Xray measurement

Wich is the scientific meaning of an Xray measurement on kaonic hydrogen?

1) Confirming the puzzle'resolution understanding the Kaon-Nucleon interaction
2) Studying the structure of the $\Lambda(1405)$ (composite, elementary 3q-state, anti(K)-N bound state….)
3) Xray results represent the only direct experimental evidence on the near-zero energy anti(K)-N interaction
4) Better understanding of the K-matrix
5) Reconcile Xray and scattering data (already attempted)

Contents

KAONIC HYDROGEN

The importance of a new Xray measurement

Wich is the scientific meaning of an Xray measurement on kaonic hydrogen?

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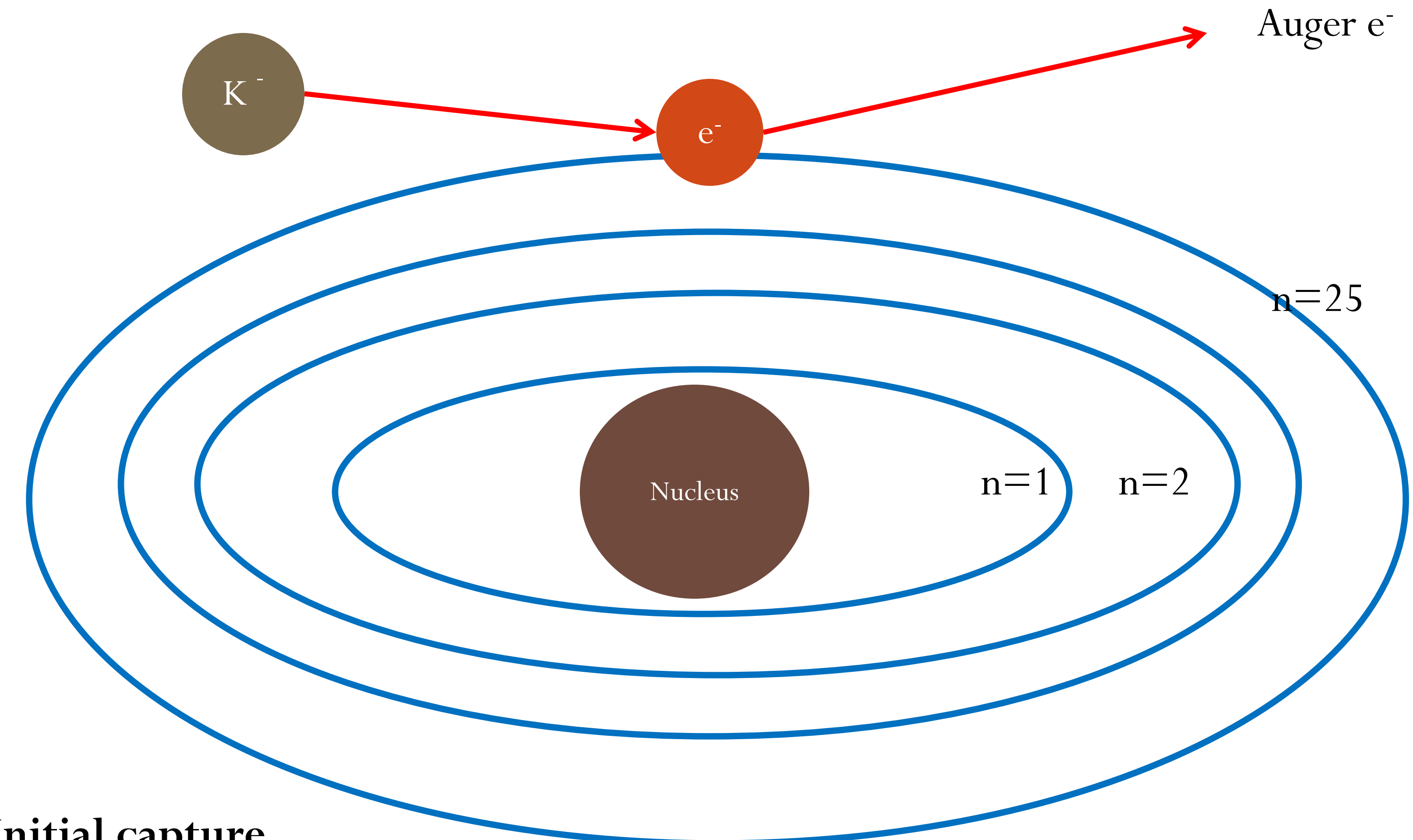
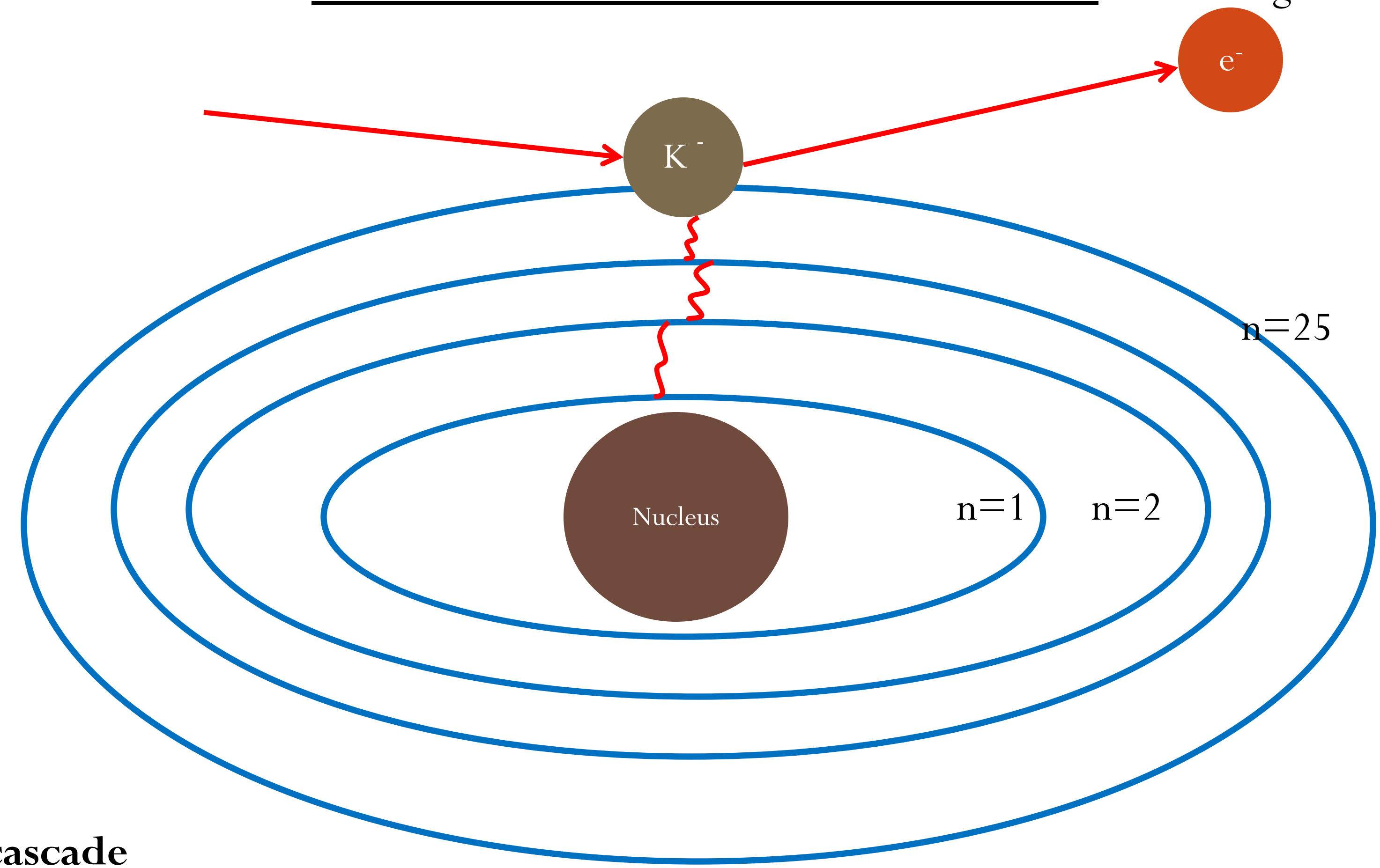
4) Reconcile Xray and scattering data (already attempted)

Kaonic atom formation



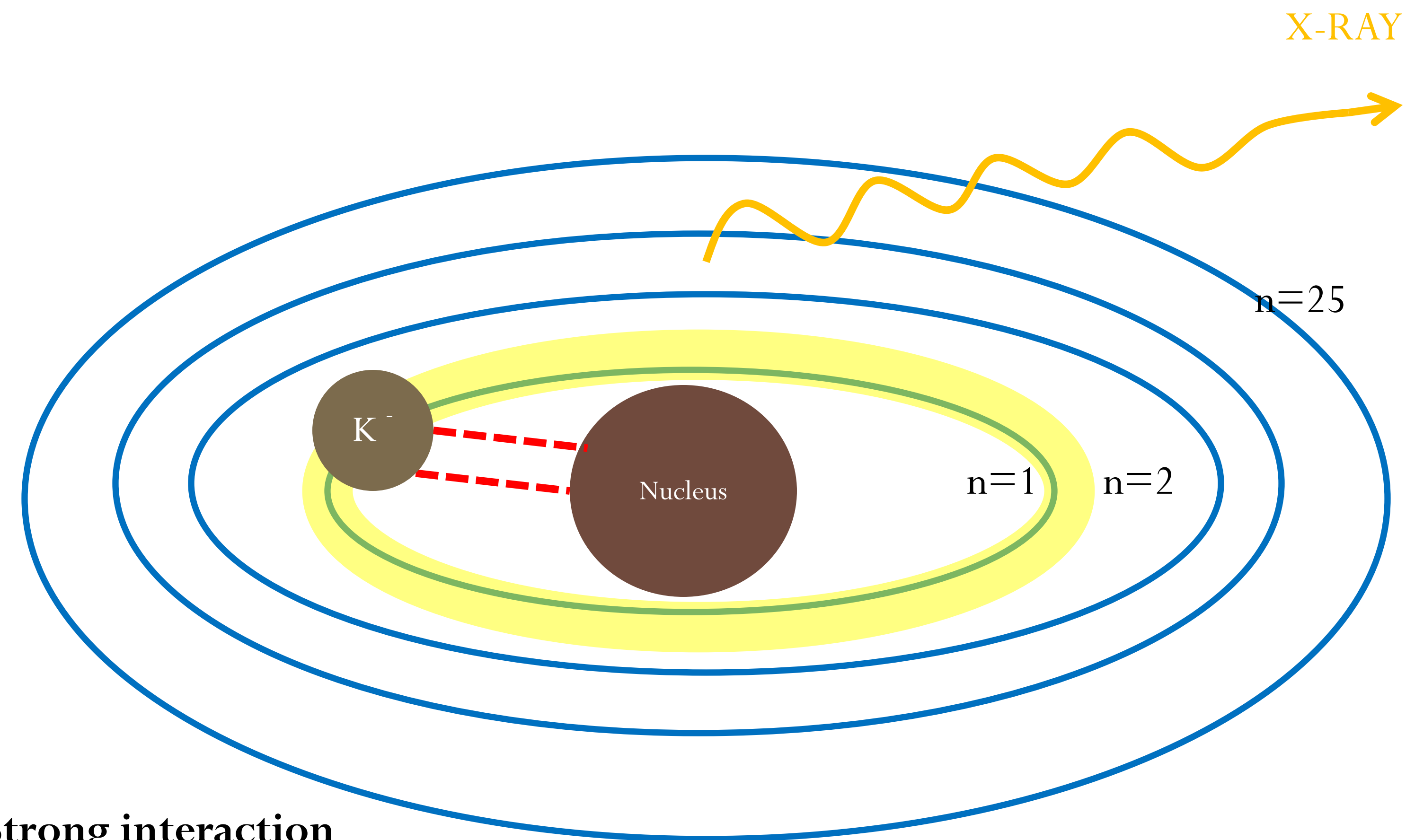
Initial capture

Kaonic atom formation



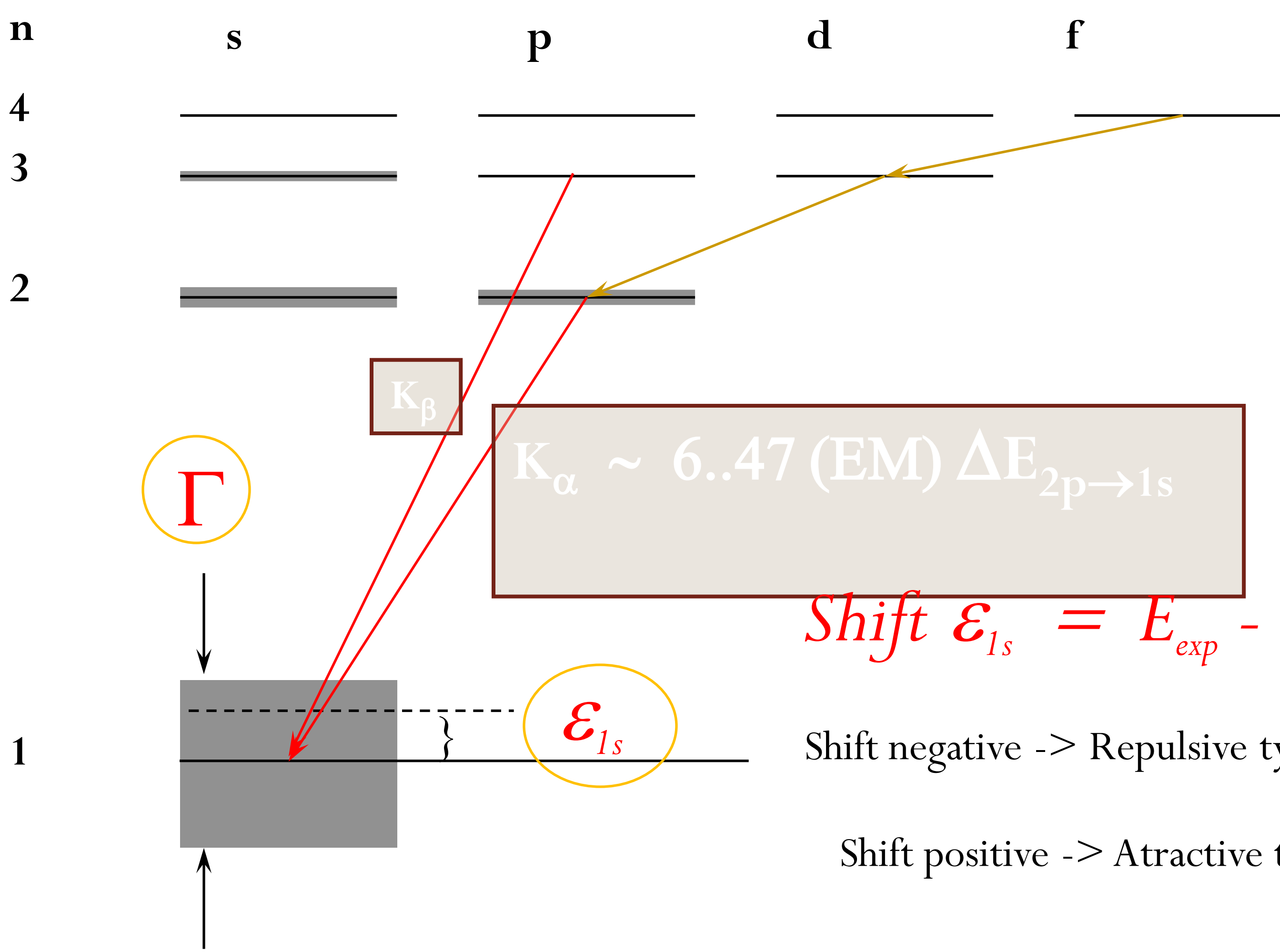
cascade

Kaonic atom formation



Strong interaction

Energy levels for Kaonic Hydrogen



$$\text{Shift } \varepsilon_{1s} = E_{exp} - E_{EM}$$

Shift negative -> Repulsive type

Shift positive -> Atractive type

Kaonic Hydrogen Puzzle

1979-1983: first kaonic hydrogen measurements[5]

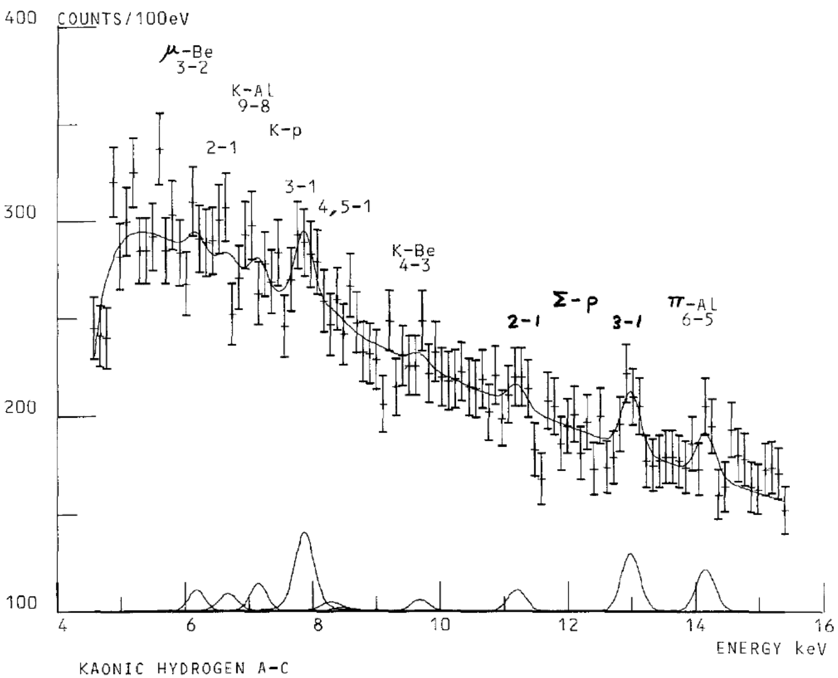


Fig. 3. X-ray spectrum obtained from data set A–C for energies less than 20 keV.

TABLE 2

Results for kaonic hydrogen

Transition	Electro-magnetic energy (keV)	Previously measured [3]) $\sim 9\times10^7$ K-stops: measured energy (keV)	peak area	yield per atom	This expt. $(1.4\pm0.7)\times10^8$ K-stops: measured energy (keV)	peak area	yield per atom (relative yield)
2–1	6.482	6.96 ± 0.09	78 ± 34	0.00021	6.675 ± 0.060	36^{+48}_{-36}	$0.0008^{+0.0010}_{-0.0008}$ (23^{+32}_{-23})
3–1	7.679	7.99 ± 0.07	102 ± 34	0.00025	7.872	164 ± 51	0.0033 ± 0.0014 (100 ± 31)
4–1	8.098	8.64 ± 0.10	64 ± 33	0.00015	8.291	20^{+50}_{-20}	$0.0004^{+0.0010}_{-0.0004}$ (12^{+30}_{-12})
5–1	8.288				8.481	8 ± 3	0.0002 ± 0.0002 (5 ± 2)

TABLE 4

Strong interaction effects in kaonic hydrogen

Experiment	Shift ε (eV)	Width Γ (eV)
Davies *et al.* [2])	40 ± 60	0^{+230}_{-0}
Izycki *et al.* [3])	370 ± 80	560 ± 260
Present work	193 ± 60	80^{+220}_{-80}

[5] J.D.Davies et al., Phys Lett 83 (1979) 55;
M.Izycki et al., Z.Phys. A297 (1980) 11;
P.M.Bird et al., Nucl.Phys. A404 (1983) 482.

Dreser-Trueman Formula

Energy shift **ε** and line width **Γ** of **1s** state are related to real and imaginary part of the S-wave scattering length:

$$\varepsilon_{K^-p} + \frac{i\Gamma_{K^-p}}{2} = 2\alpha^3 \mu^2_{K^-p} a_{K^-p} = 412 \frac{eV}{fm} a_{K^-p}$$

$$\varepsilon_{K^-d} + \frac{i\Gamma_{K^-d}}{2} = 2\alpha^3 \mu^2_{K^-d} a^2_{K^-d} = 601 \frac{eV}{fm} a_{K^-d}$$

(Papers)

Contents

- Introduction
- Previous results
- The SIDDHARTA experiment
- Kaonic Hydrogen analysis
- Near future
- Conclusions

Dreser-Trueman Formula

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(Papers)

Isospin dependent scattering lengths

Scattering lengths can be expressed in terms of antiK-N isospin dependent scattering lengths:

$$a_{K^-p} = \frac{a_0(I=0) + a_1(I=1)}{2}$$

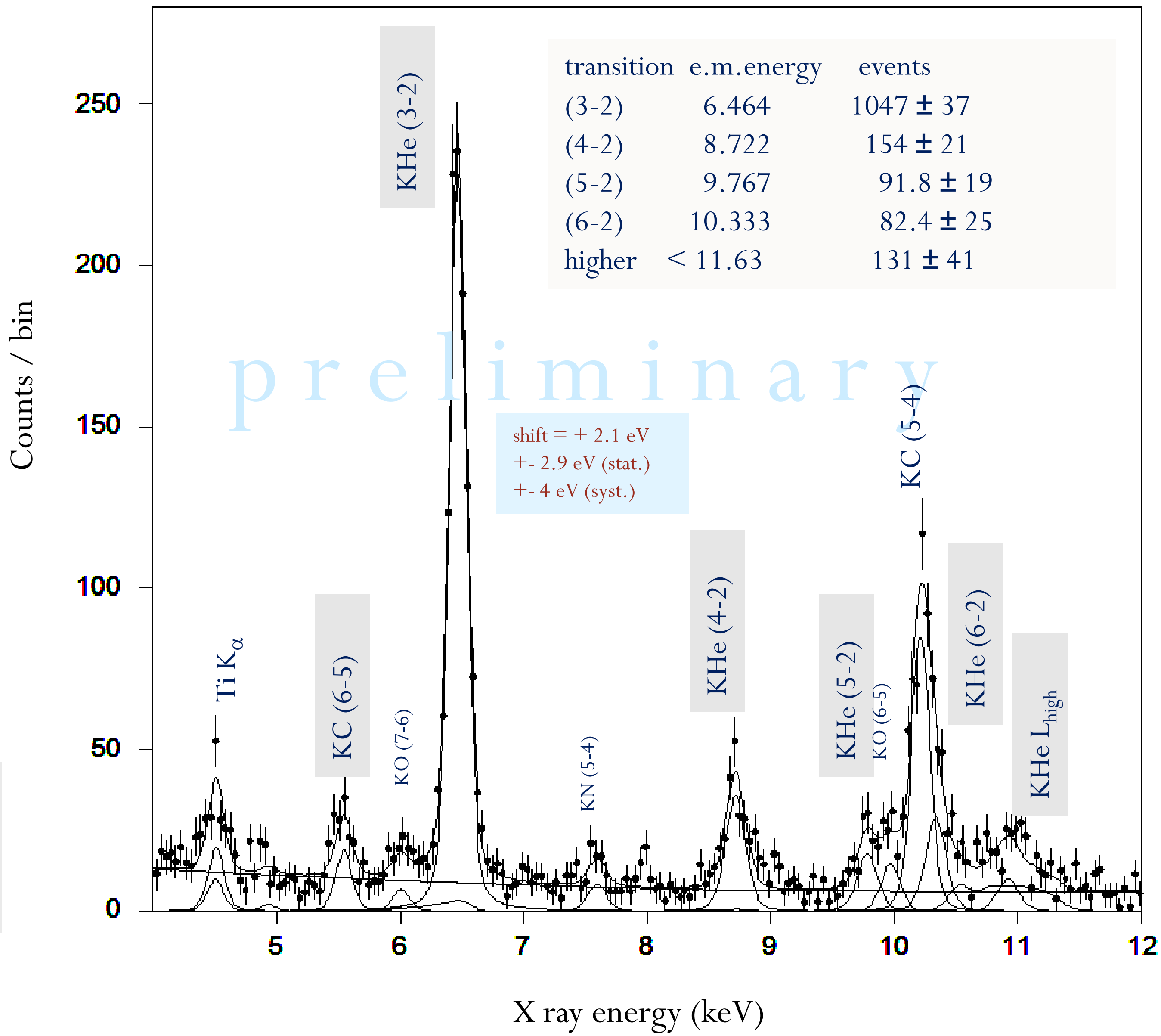
$$a_{K^-d} = \frac{1}{2}\frac{m_N + m_K}{m_N + \frac{m_K}{2}}(3a_1 + a_0) + C$$

Includes all higher contributions related to the pysics associated to the K$^-$d three body problem. It can be numerically calculated solving Faddeev equation

Fit of Kaonic Helium 4

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

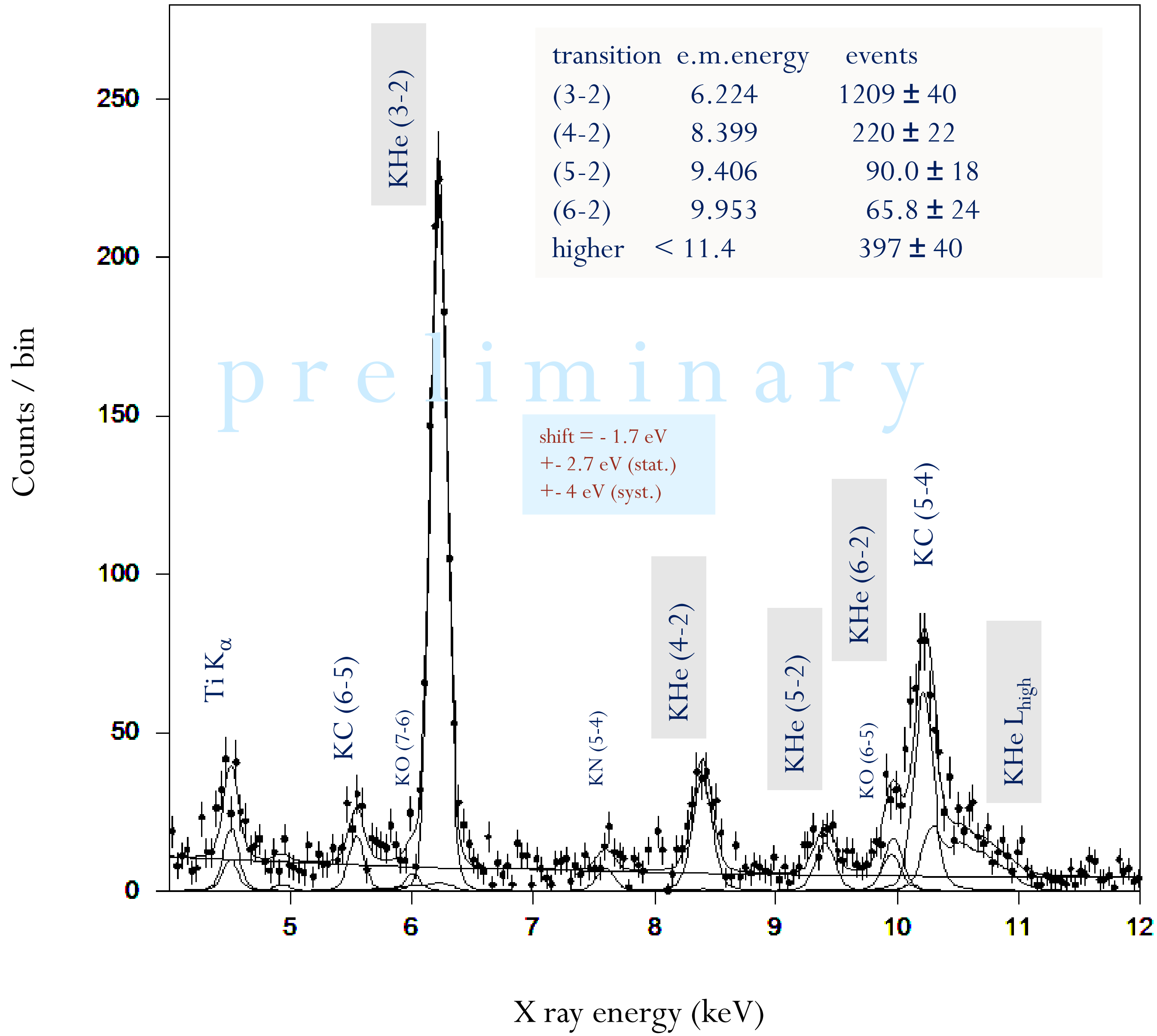
data from setup 2
(no Fe55 source)



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

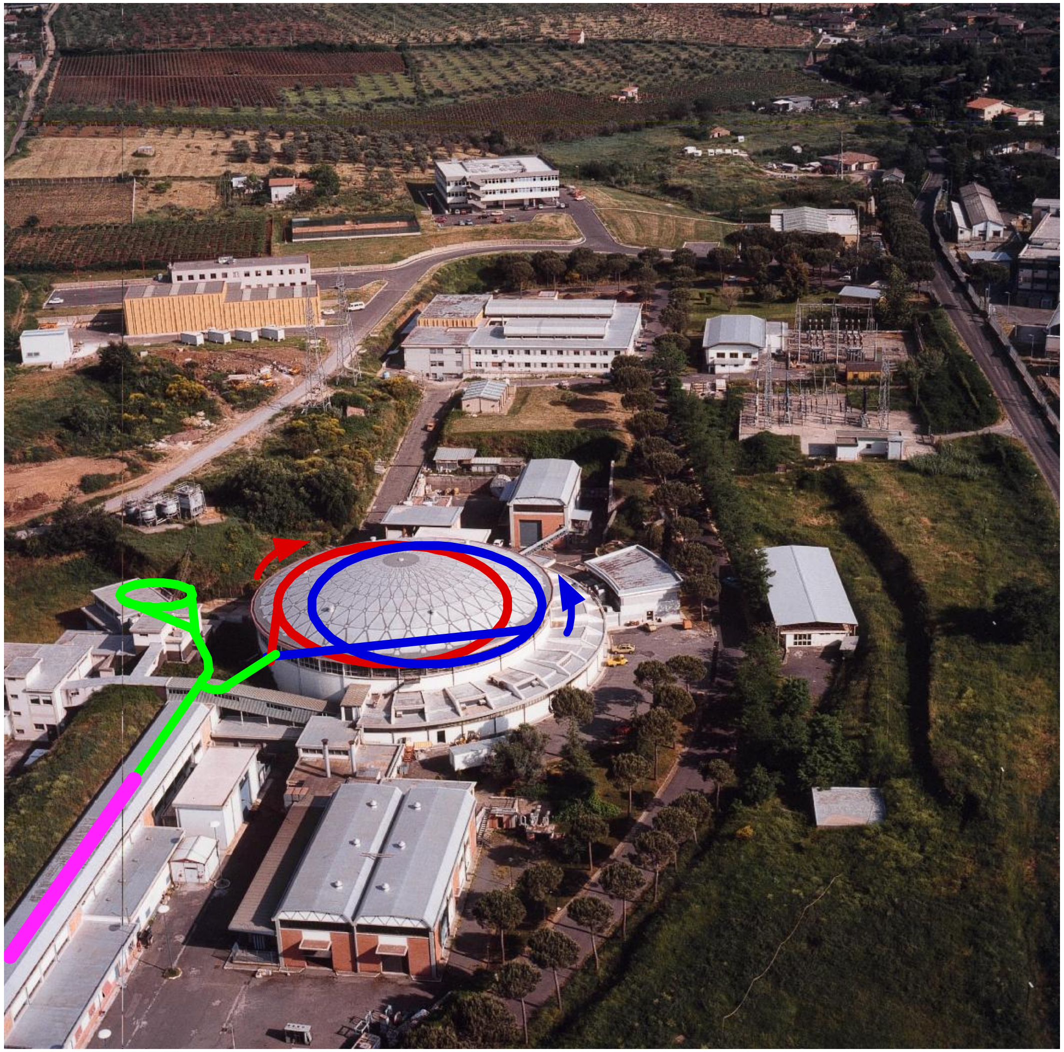
Fit of Kaonic Helium 3

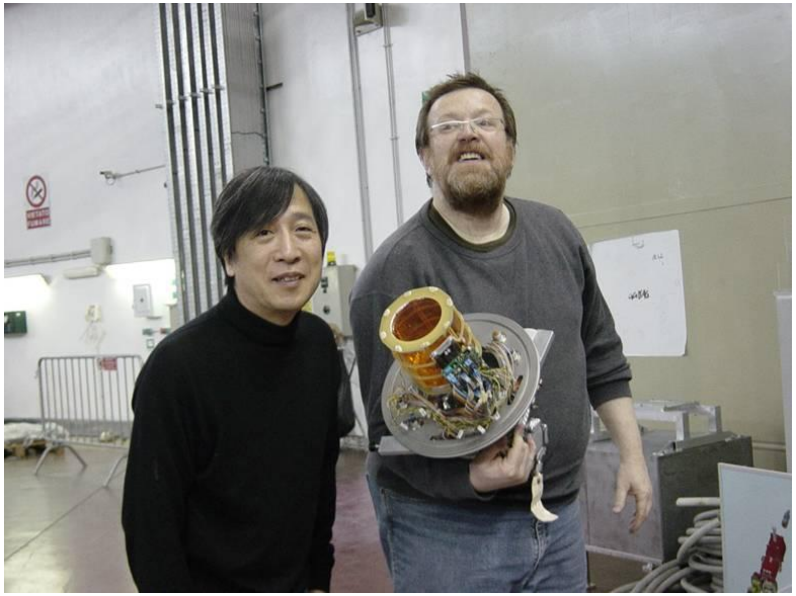
KHe3
never measured
before !

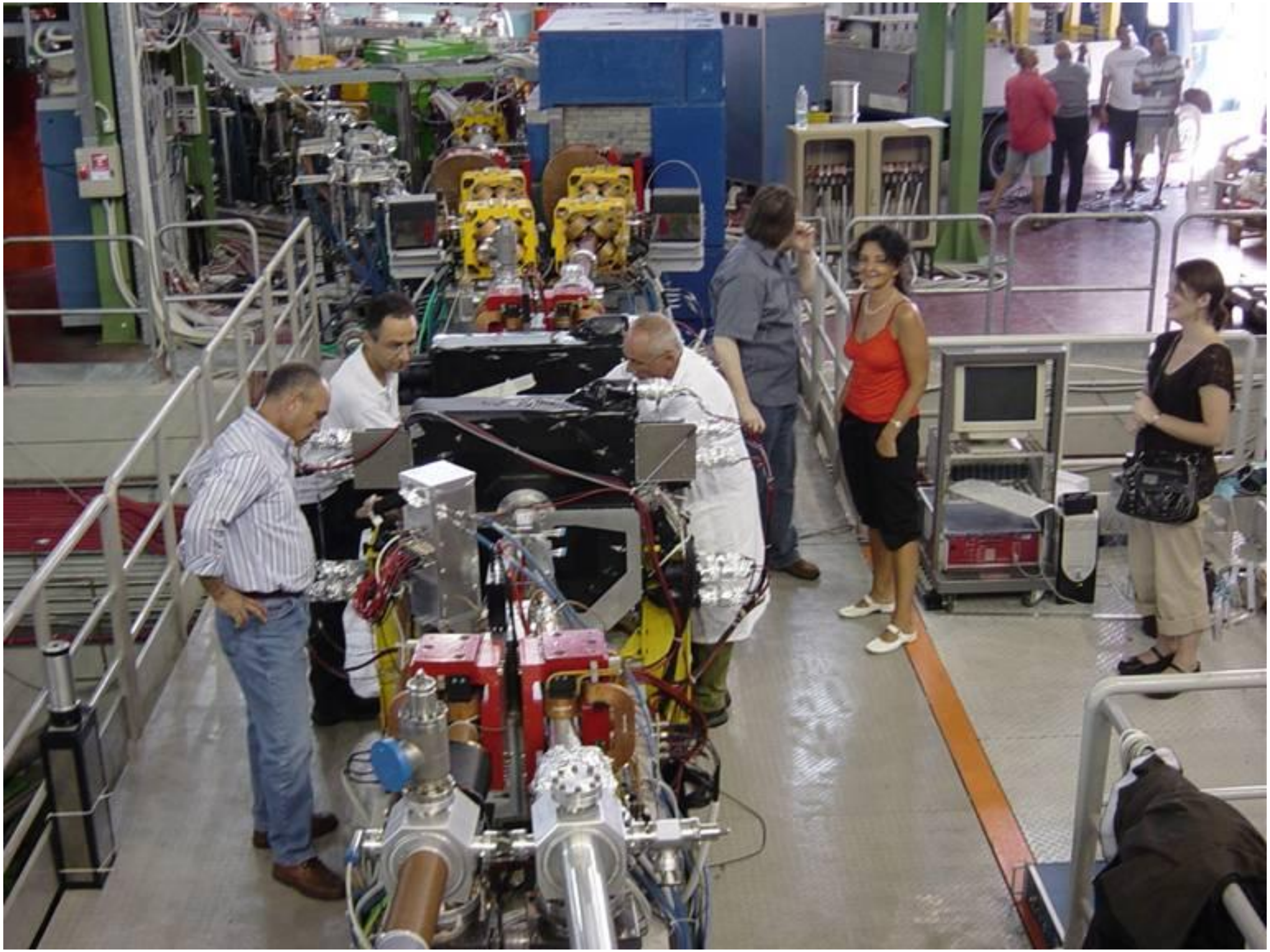


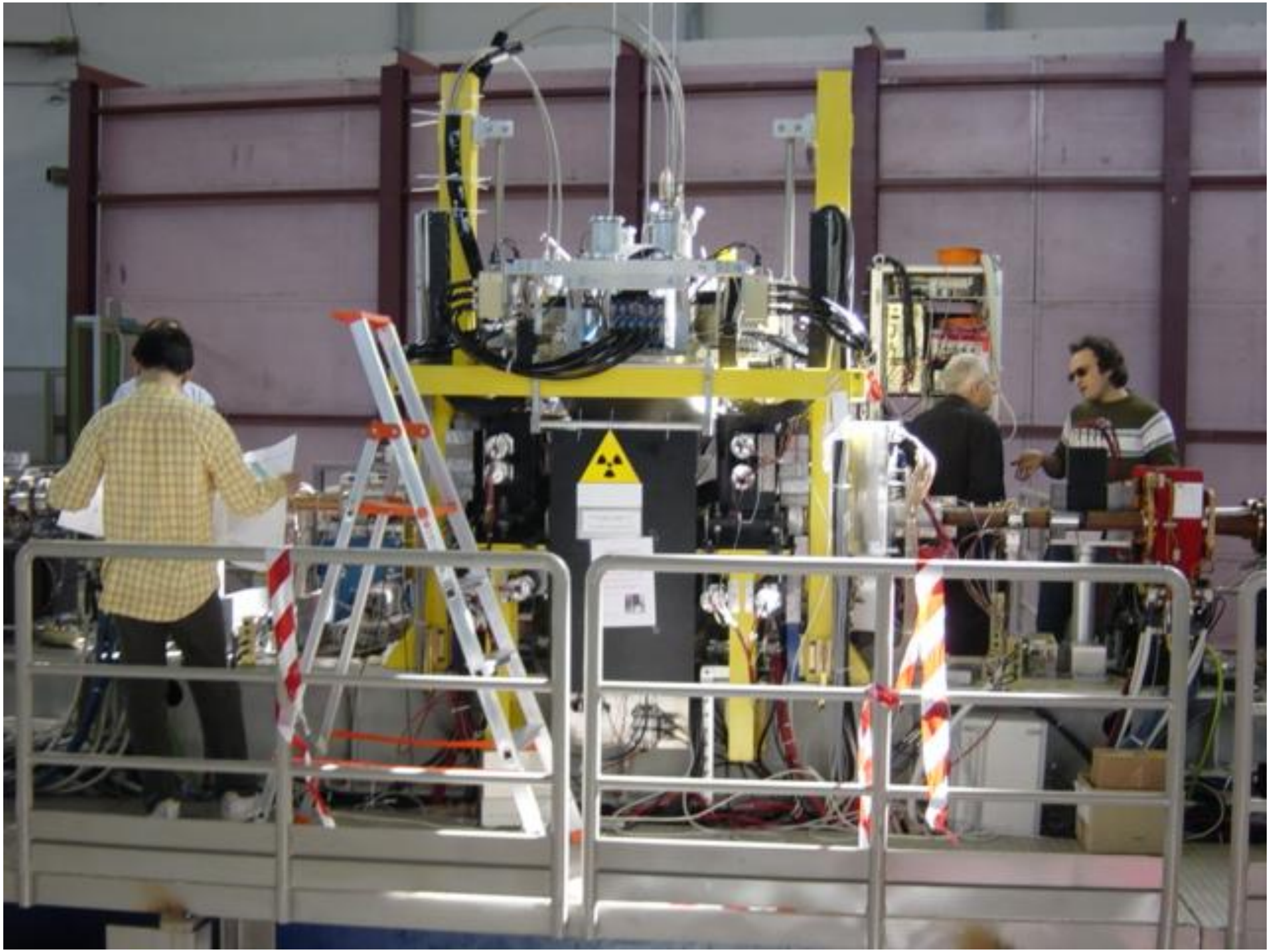
DAFNE

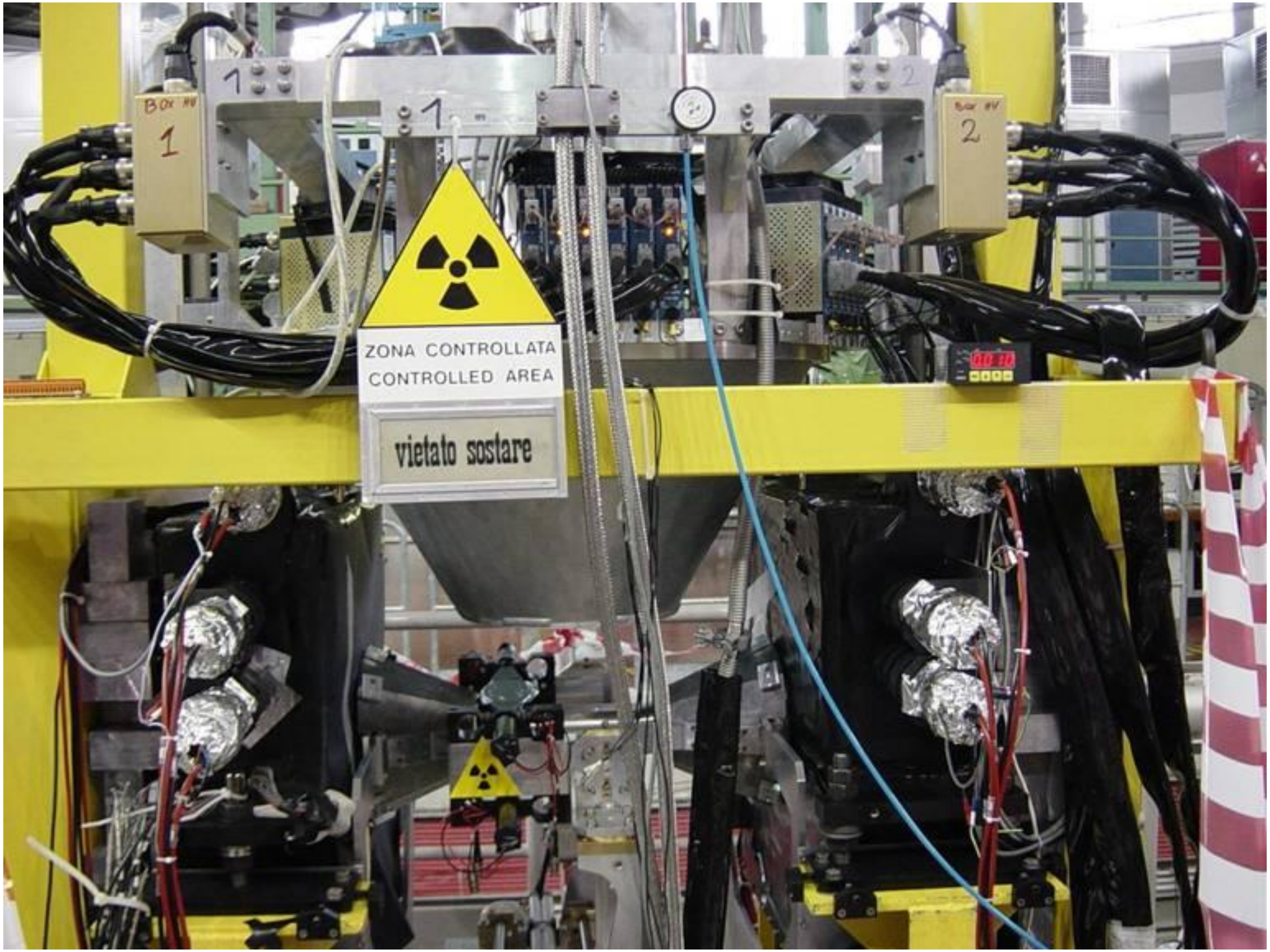
- Phi factor at Frascati (Rome)
- e+ - e- beam collider

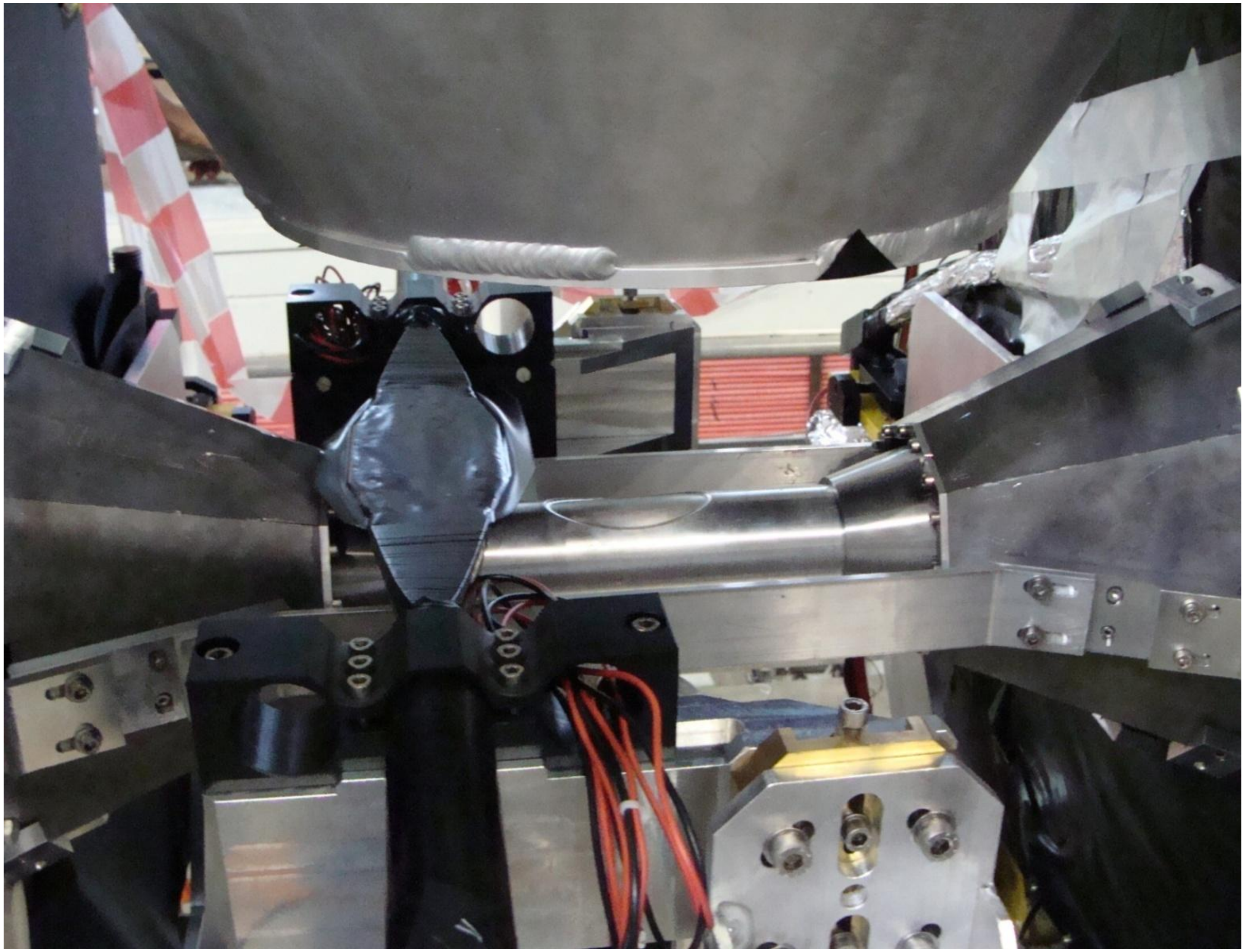




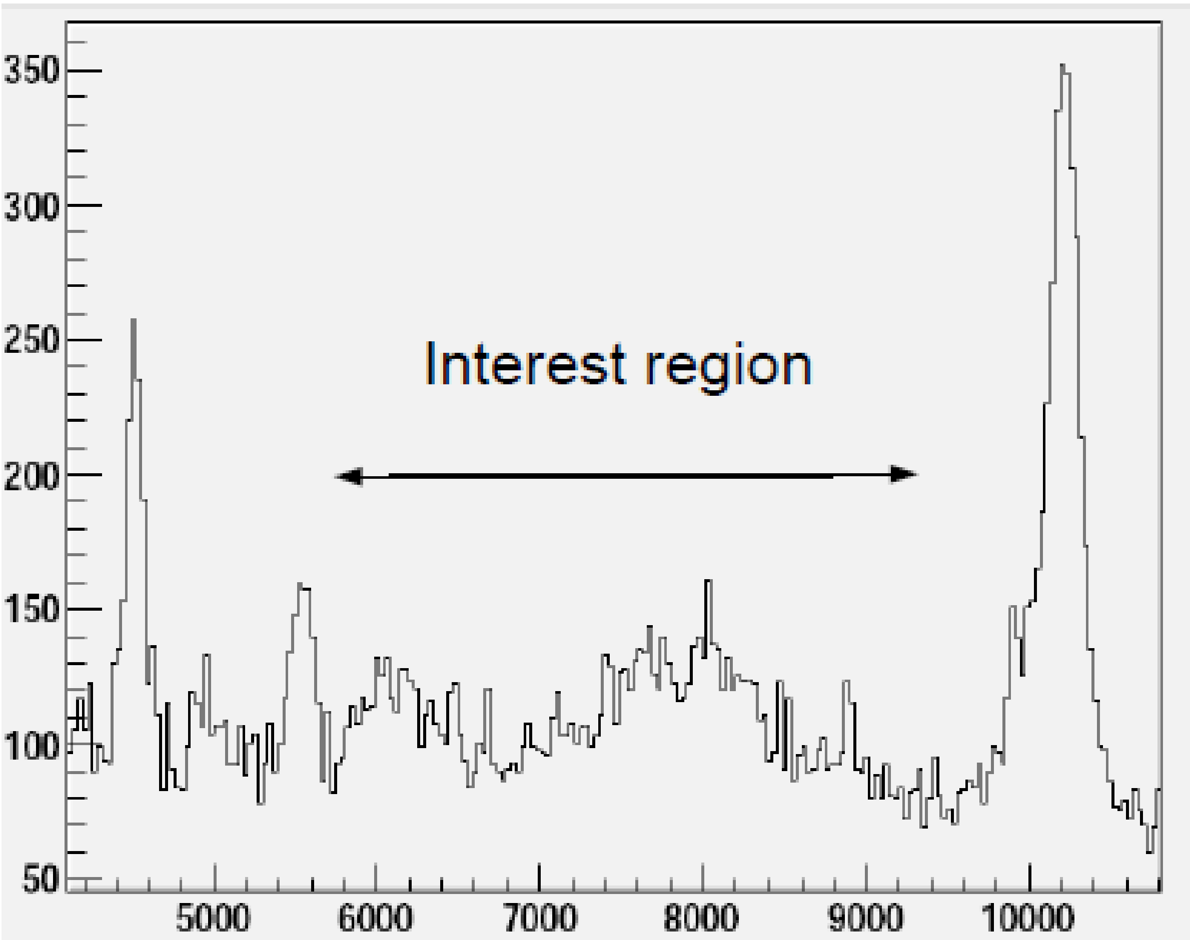


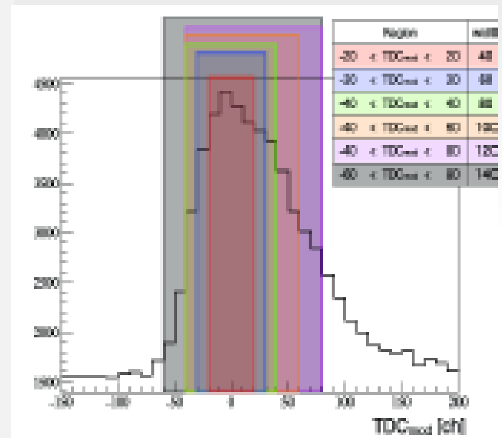


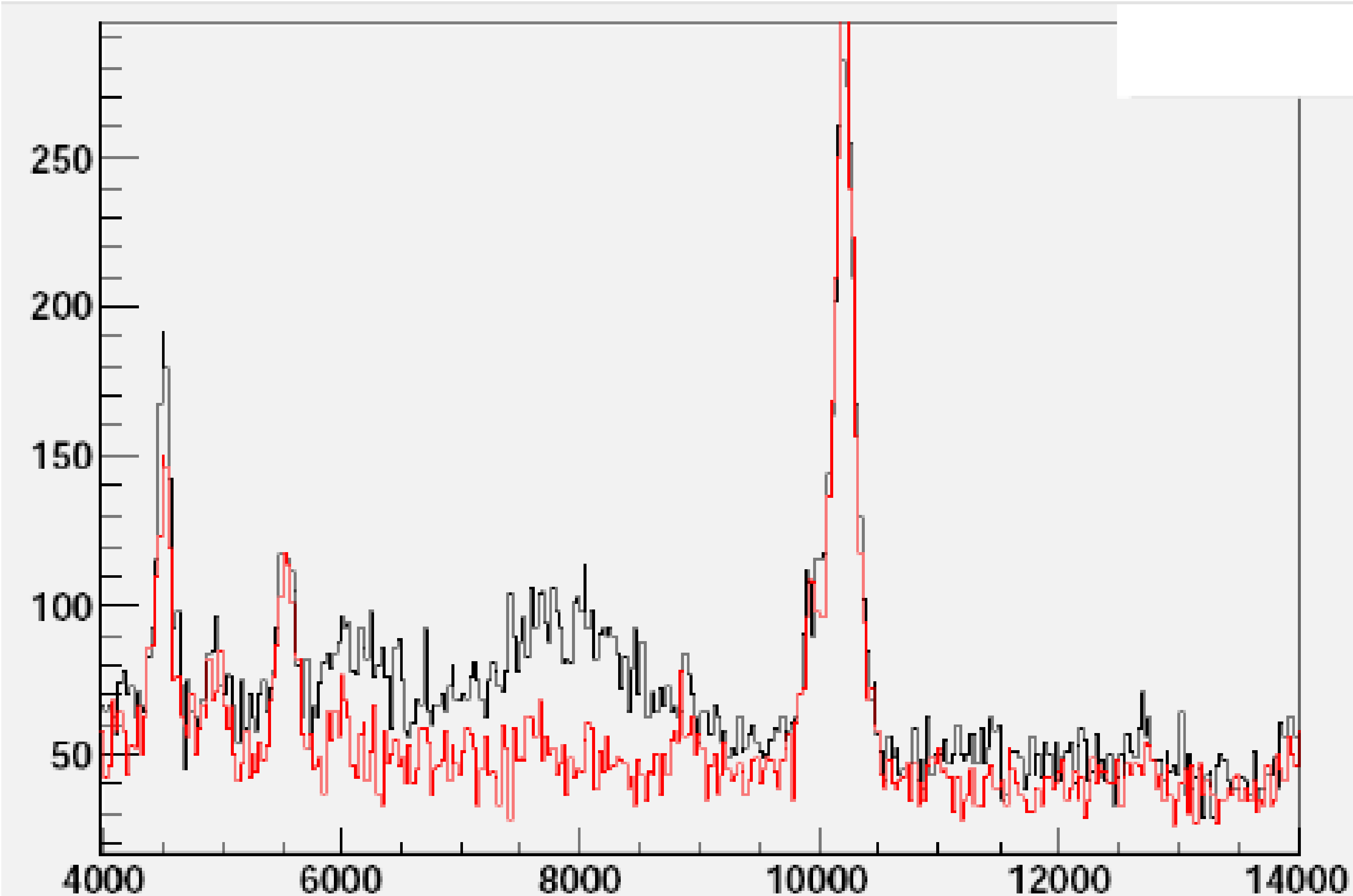

Box HV
1
Box HV
2
ZONA CONTROLLATA
CONTROLLED AREA
vietato sostare



Kaonic Hydrogen



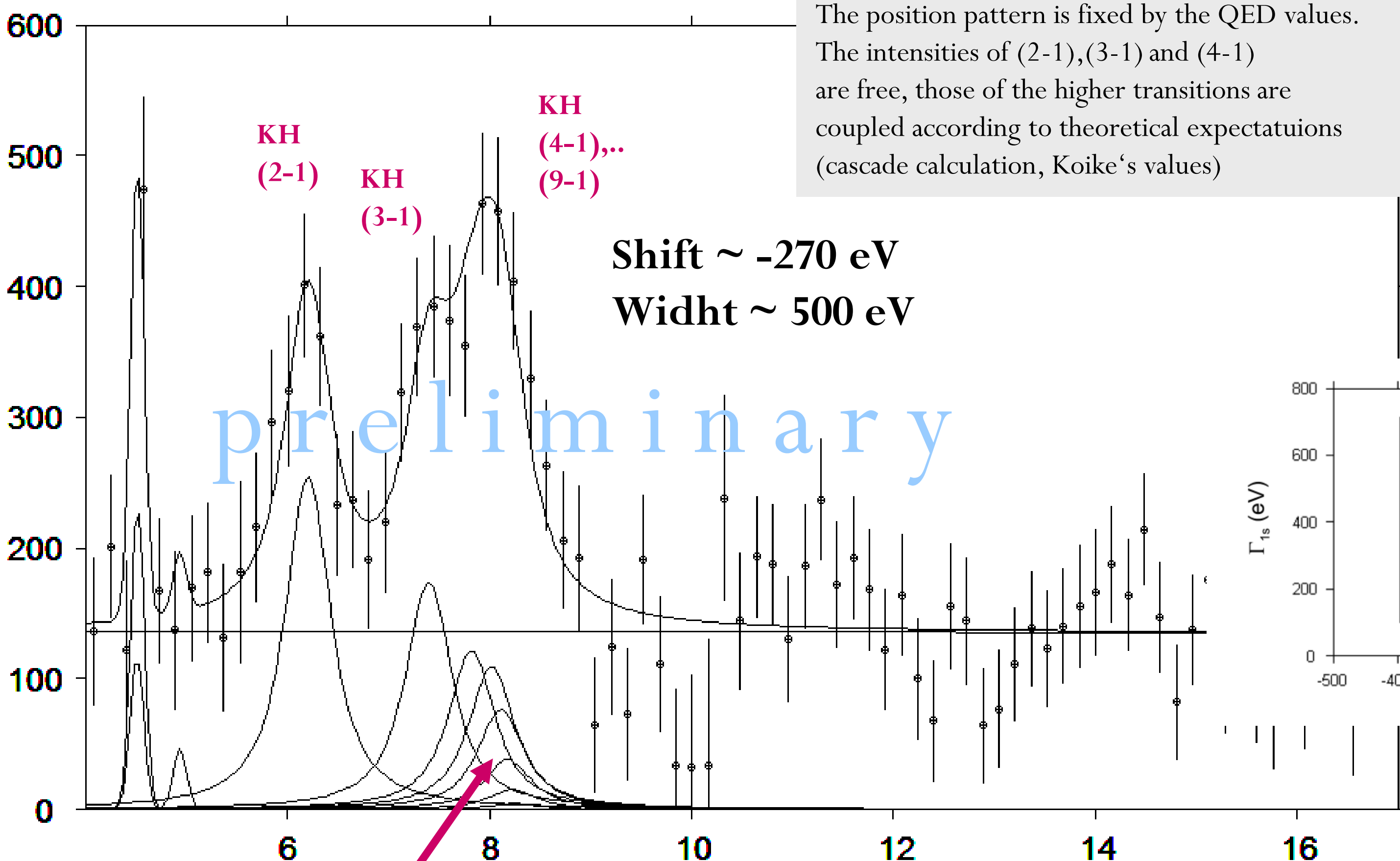



250
200
150
100
50
4000
6000
8000
10000
12000
14000

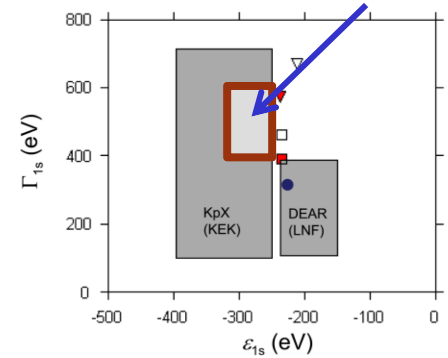
Kaonic hydrogen fit

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)



siddharta preliminary



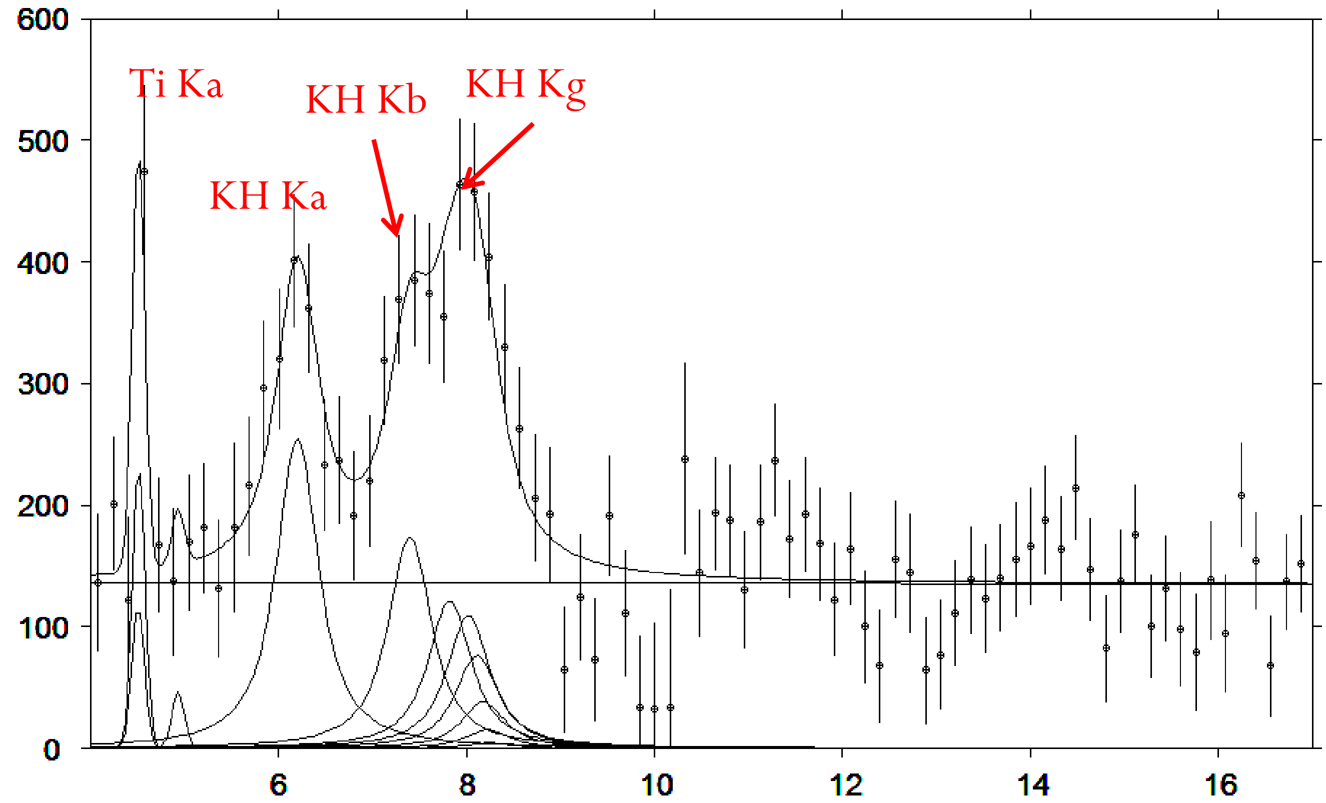
Note: K_{high} yield pattern

energy (keV)

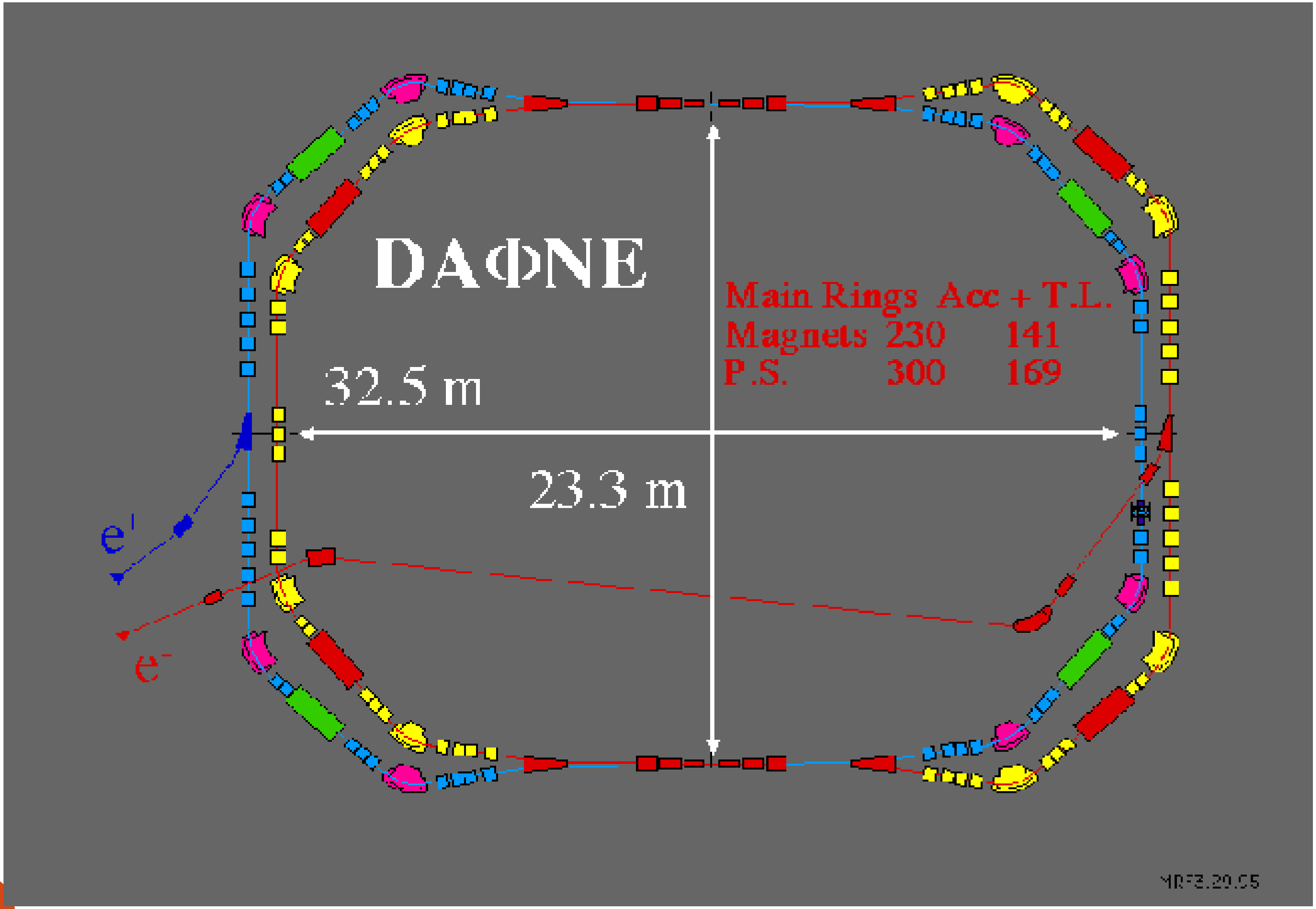
In the final analysis the backgound can be determined from fitting the KD data and then include the pattren in the KH fit.

Kaonic Hydrogen

- Systematics are being studied.
- Publication coming soon.



Shift ~ -270 eV
Widht ~ 500 eV


DAΦNE
Main Rings Acc + T.L.
Magnets 230 141
P.S. 300 169
32.5 m
23.3 m
e+
e-
MRF3.20.55

The "Kaonic Hydrogen Puzzle"

All Xray experiments done until today are in agreement abut the sign of ε:

$\varepsilon > 0$

This is in direct contradiction with the repulsive strong interaction found from scattering data analyses!!!

The K^-p scattering lengths determined from kaonic hydrogen X-ray measurements and those from scattering analyses

Method	Reference	a_{K^-p} (fm)
Kaonic hydrogen X-ray measurements	Davies *et al.* (1979)	$(0.10\pm0.14) + i(0.00\ ^{+0.28}_{-0.00})$
	Izycki *et al.* (1980)	$(0.65\pm0.19) + i(0.68\pm0.31)$
	Bird *et al.* (1983)	$(0.47\pm0.14) + i(0.10\ ^{+0.27}_{-0.10})$
K^-p scattering analyses	Sakitt *et al.* (1965)	$(-0.91\pm0.05) + i(0.48\pm0.03)$
	Kim *et al.* (1967)	$(-0.87\pm0.04) + i(0.69\pm0.03)$
	von Hippel *et al.* (1968)	$(-0.89\pm0.02) + i(0.62\pm0.02)$
	Martin & Ross (1970)	$(-0.89\pm0.03) + i(0.66\pm0.03)$
	Martin *et al.* (1981)	$(-0.66\pm0.05) + i(0.64\pm0.04)$

SIDDHARTA2 physics – enriched case

SIDDHARTA2:

1) Kaonic deuterium measurement

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

3) Kaonic helium transitions to the 1s level

4) Other light kaonic atoms (KO, KC,…)

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

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

6) Kaon capture in hydrogen – L(1405) study

Kaon-nucleon interaction at low energies

Experimental data are available for:

1) K^- p cross section for elastic and inelastic processes.

2) Branching ratios for K^- p absorption at rest.

$$\gamma = \lim_{k\to 0} \frac{\sigma(K^-p \to \pi^+\Sigma^-)}{\sigma(K^-p \to \pi^-\Sigma^+)} = 2.36 \pm 0.04$$

$$R_c = \lim_{k\to 0} \frac{\sigma(K^-p \to charged\ particle)}{\sigma(K^-p \to all\ final\ states)} = 0.664 \pm 0.011$$

$$R_n = \lim_{k\to 0} \frac{\sigma(K^-p \to \pi^0\Lambda)}{\sigma(K^-p \to all\ neutral\ states)} = 0.189 \pm 0.015$$

3) $\pi\Sigma$ invariant mass distribution below K^- p threshold, wich exhibits the $\Lambda(1405)$ resonance.

4) 1s level shift and width of K^- p atom determined through Xray measurements.

Trigger

Triple coincidence:
SDD_X * $Scint_K$ * $Scint_K$