Kaonic atoms – studies of the strong interaction with strangeness

J. Marton on behalf SIDDHARTA/SIDDHARTA2
Stefan Meyer Institute, Vienna

P24756-N20

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

HadronPhysics I3

Study of Strongly Interacting Matter

HadronPhysics2

HadronPhysics3

INFN Istituto Nazionale di Fisica Nucleare

Laboratori Nazionali di Frascati

IFIN-HH

MPE

RIKEN

SMI

POLITECNICO MILANO

PNSensor

THE UNIVERSITY OF TOKYO

University of Victoria

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

FWF

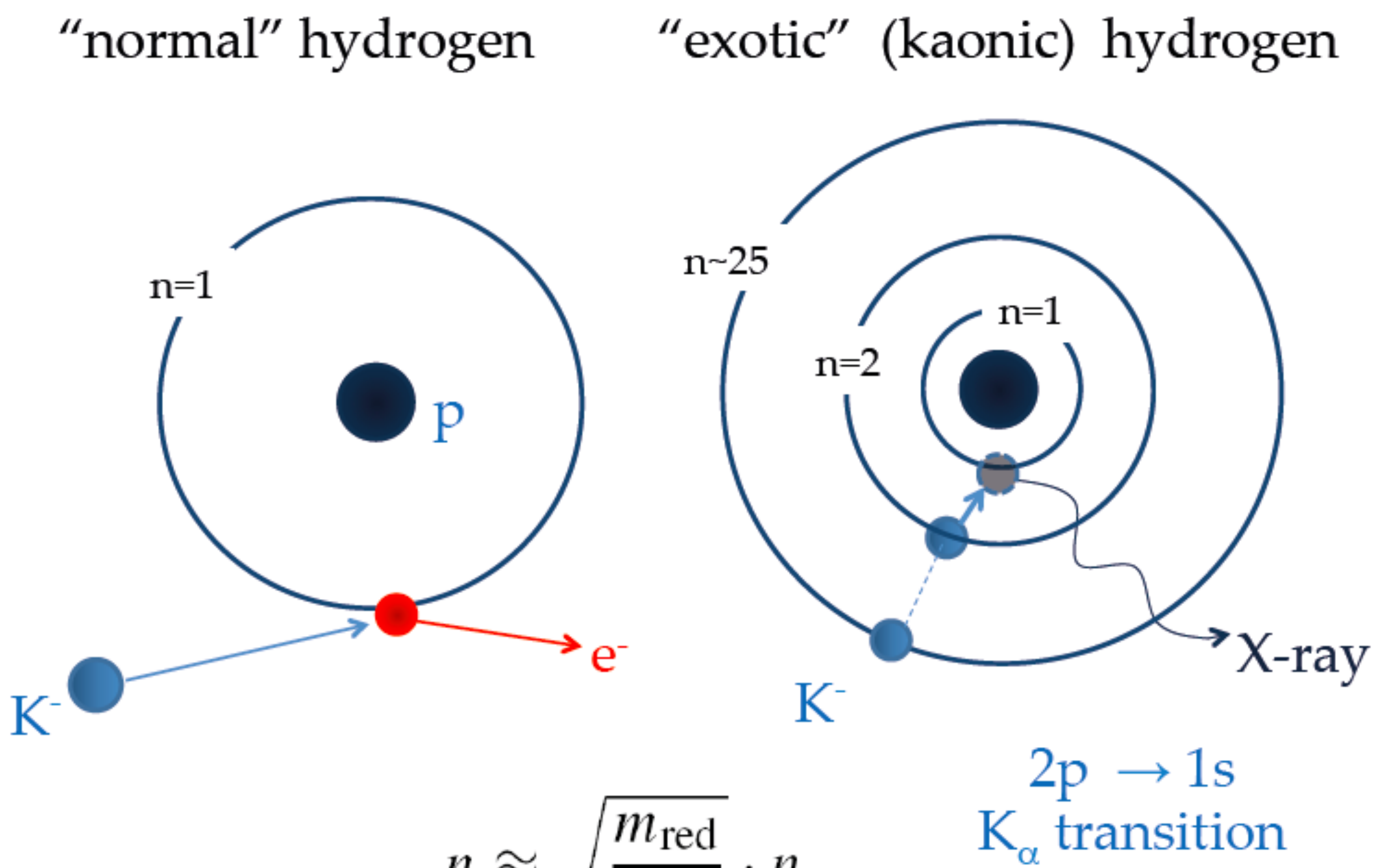
Austrian Science Fund (FWF):

[P24756-N20]

Content

- Exotic atoms as probes for fundamental interactions
- Results of KH, $K^{3,4}He$ experiments
- Open issues: $K^{-}D$ measurement, high resolution experiments
- Experimental challenges (yield, background)
- Target and Instrumentation
- Summary and Outlook

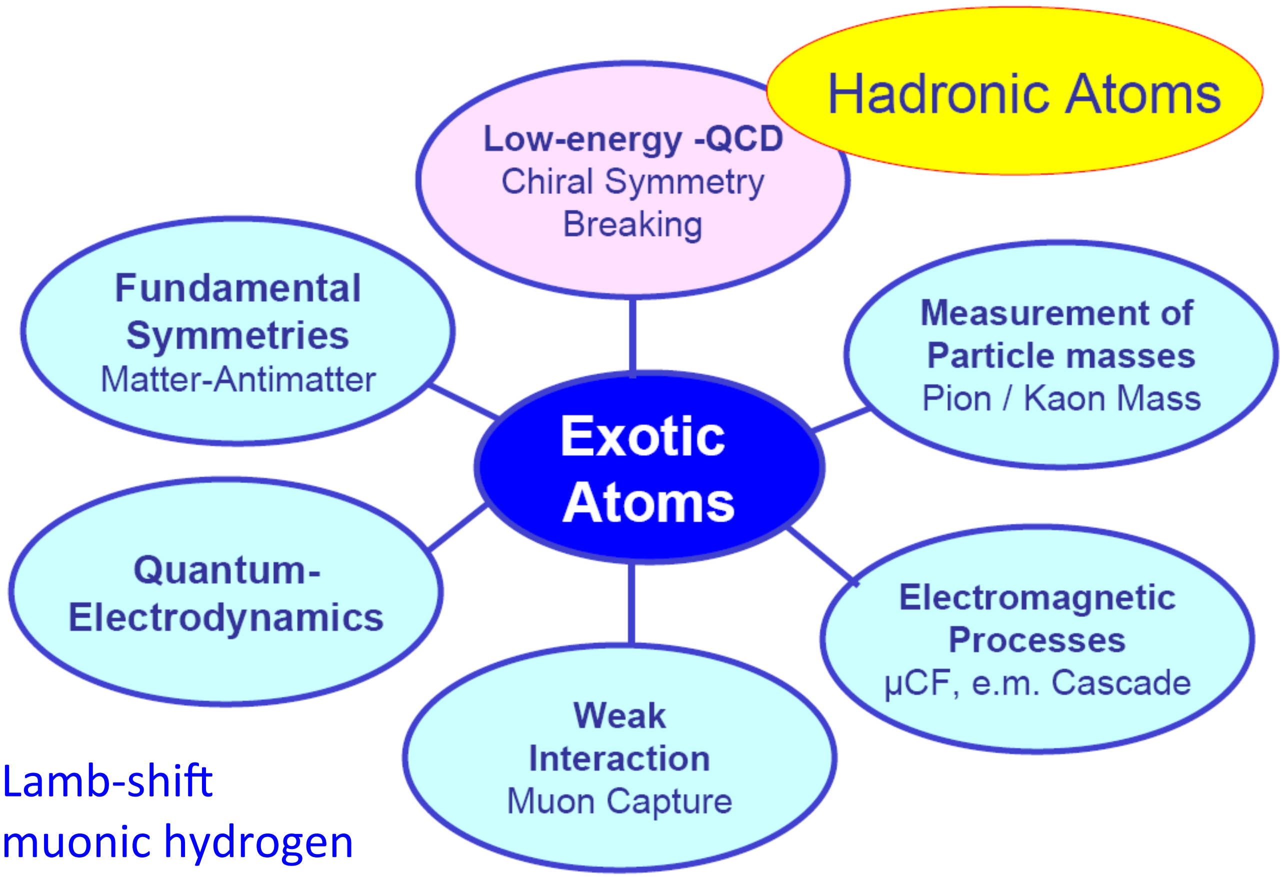
What is a exotic (kaonic) atom?



$$n \approx \sqrt{\frac{m_{\text{red}}}{m_e}} \cdot n_e$$

Exotic atoms

- Studies of fundamental interactions and symmetries with exotic atomic bound systems

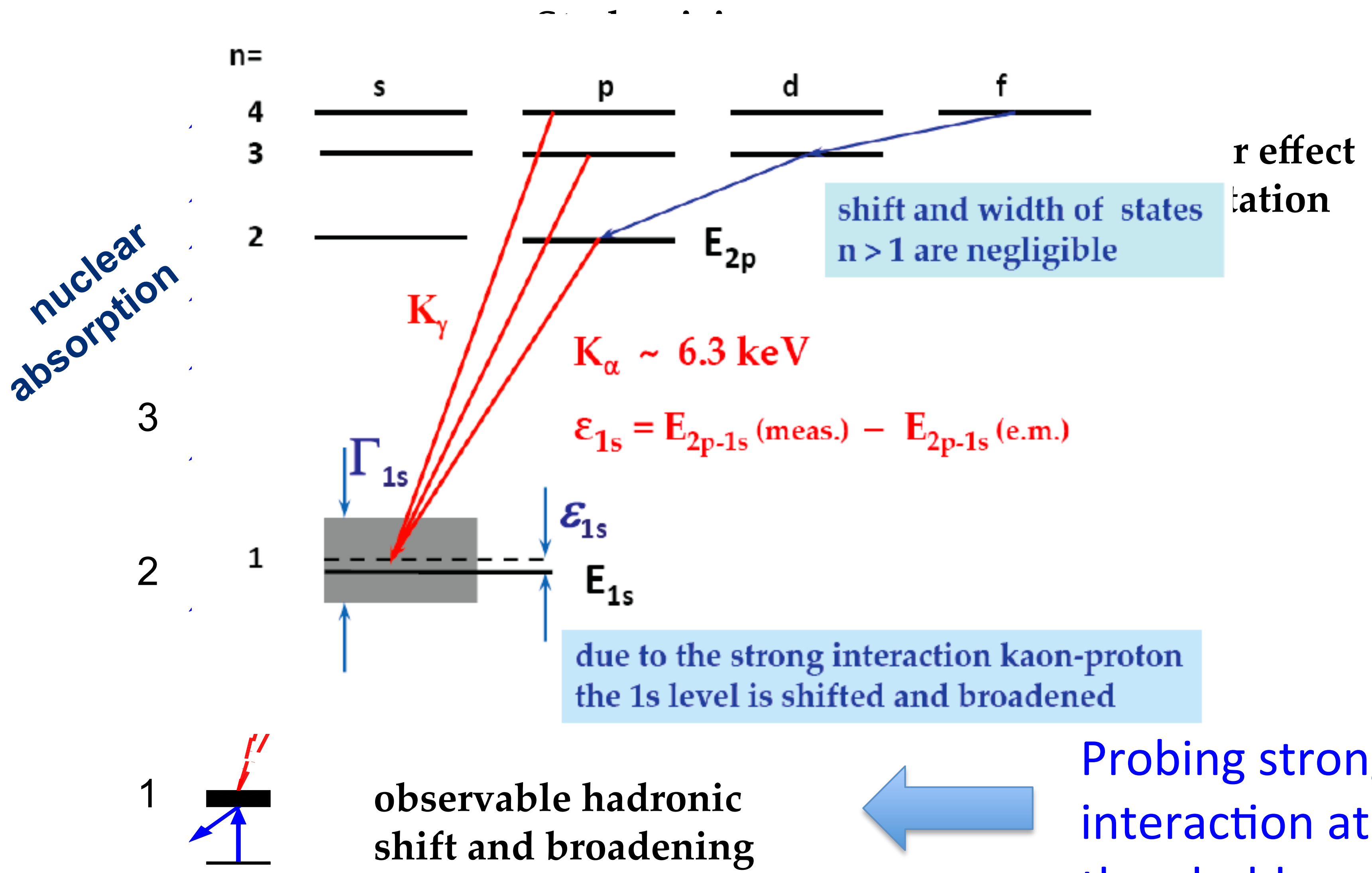


K^-p, K^-d
π-p, π-d
….

Hadronic atoms are sensitive probes for the strong interaction at lowest energy (direct study of strong interaction at threshold)

Lamb-shift
muonic hydrogen
→ Proton radius

Cascade in hadronic atoms (KH,KD)



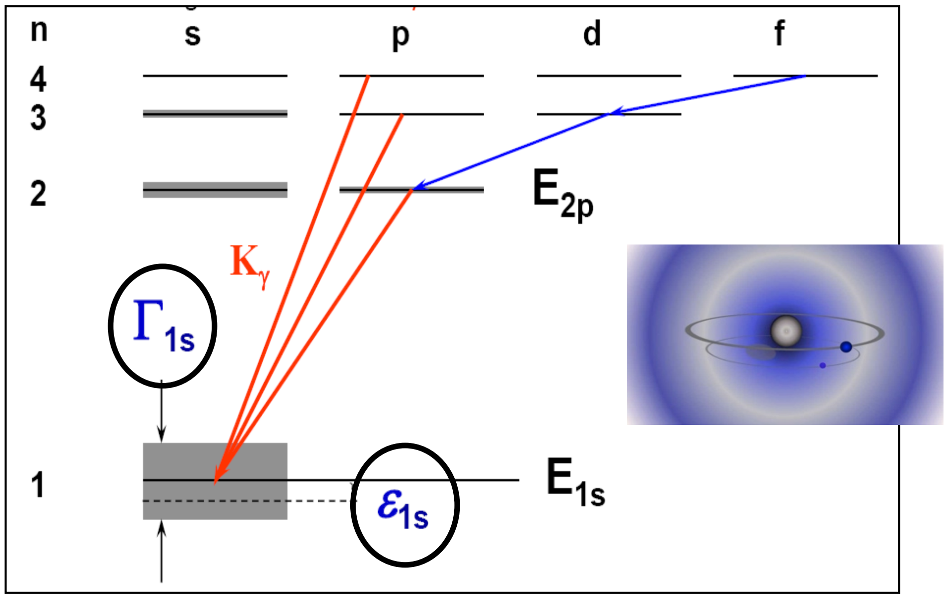
Probing strong interaction at threshold

Kaonic hydrogen and deuterium

- Principal interaction = electromagnetic.
- Strong interaction manifests in hadronic shift and width of the 1s state → **energy displacement** from the electromagnetic value of the 1s state and **broadening** due to K^- absorption

$$\varepsilon_{1s} = E_{1s}^{meas.} - E_{1s}^{e.m.(calc.)}$$

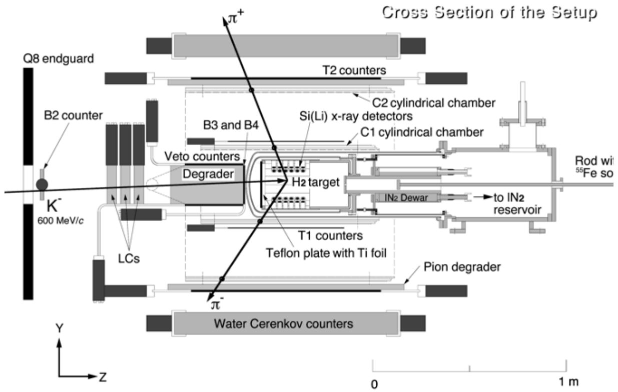
$$E_{1s}^{e.m(calc.)} = E_{KG} + E_{VP} + E_{FS}$$

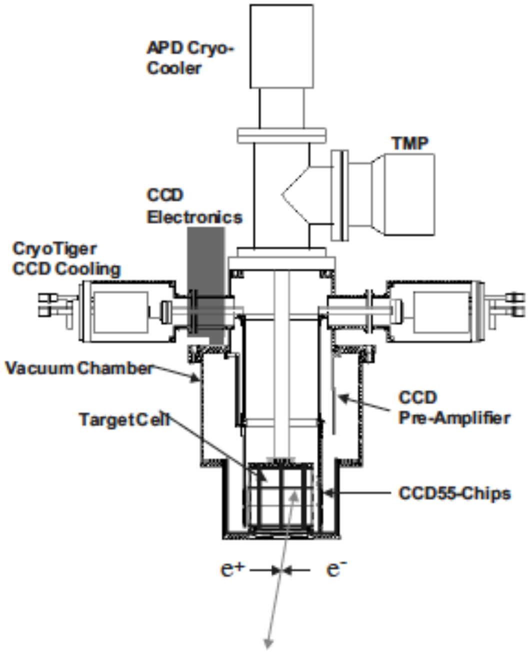


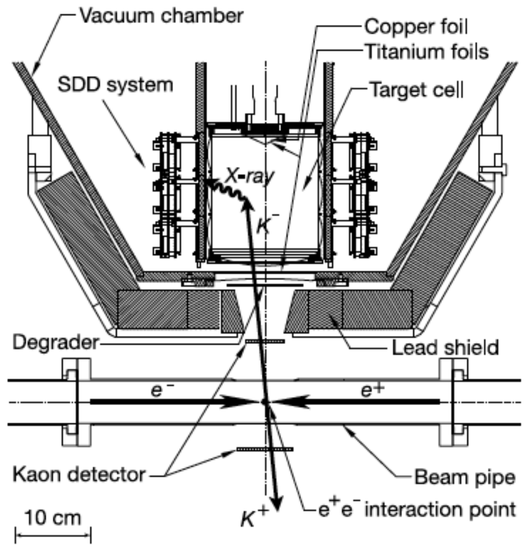
- calculated solving the Klein-Gordon (KG) equation and taking into account vacuum polarization (VP) and final size (FS) effect (accuracy ~1eV).
- Strong interaction effect on 2p state is weak (meV) and experimentally undetermined, nevertheless has severe consequences for the x-ray yield.

Experiments on kaonic hydrogen

Older experiments used liquid targets which have the disadvantage of lower yields (Stark effect)





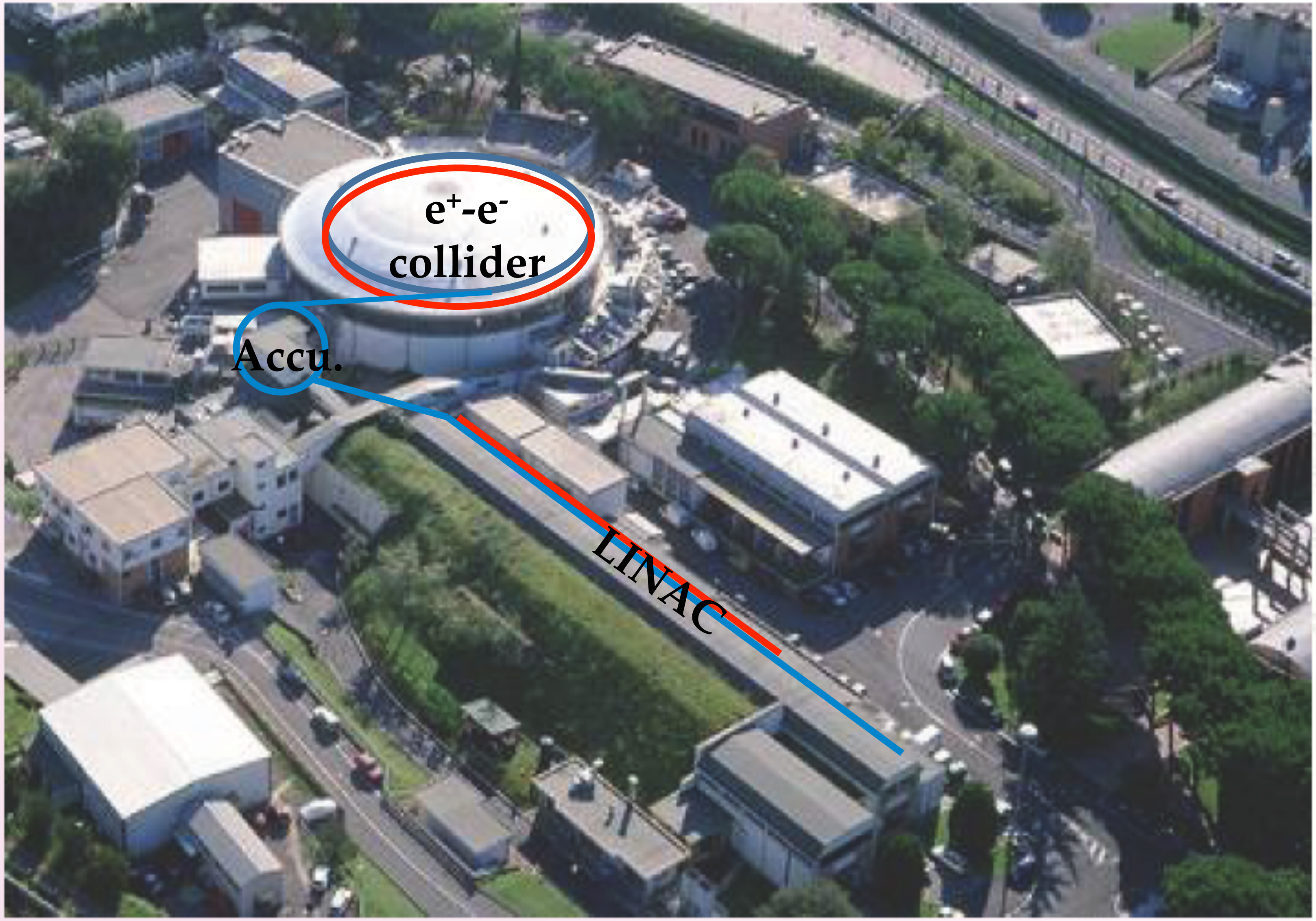


KpX, PRL1997
KEK (K beam)
Gas target
Si(Li) detectors

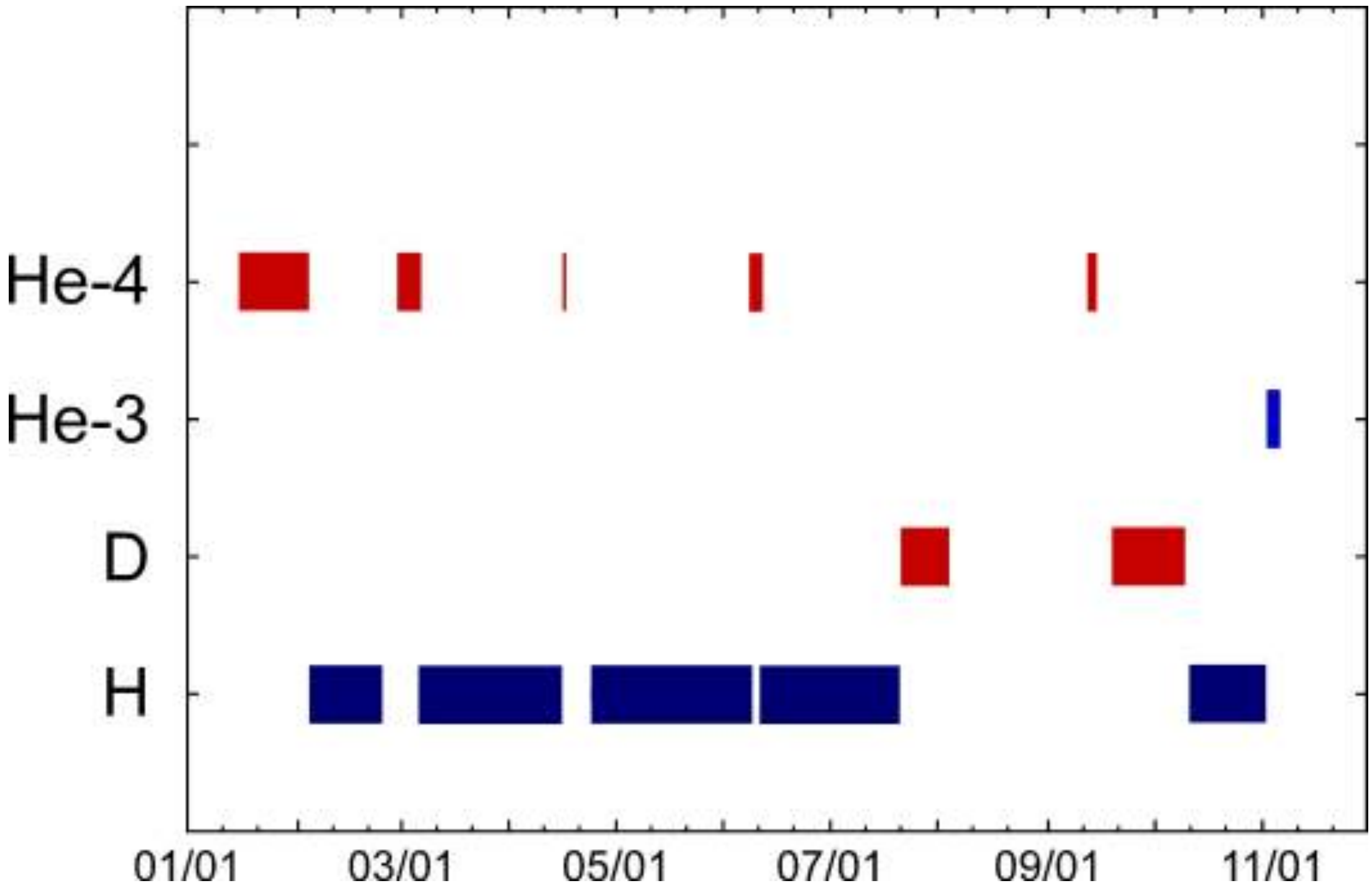
DEAR, PRL2005
DAFNE (e^+ e^- collider)
Gas target
CCD detectors

SIDDHARTA, PLB 2011
DAFNE (e^+ e^- collider)
Gas target
SDD detectors

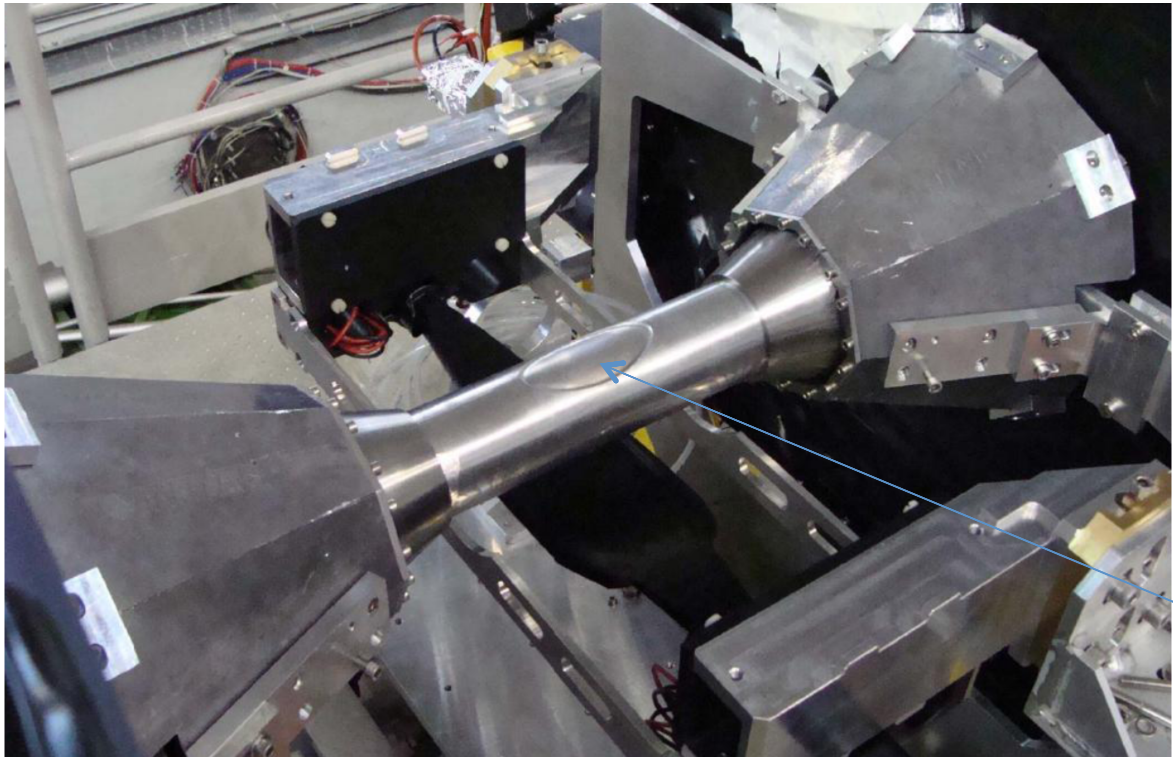
Kaonic atoms at DAΦNE/Frascati



SIDDHARTA data overview



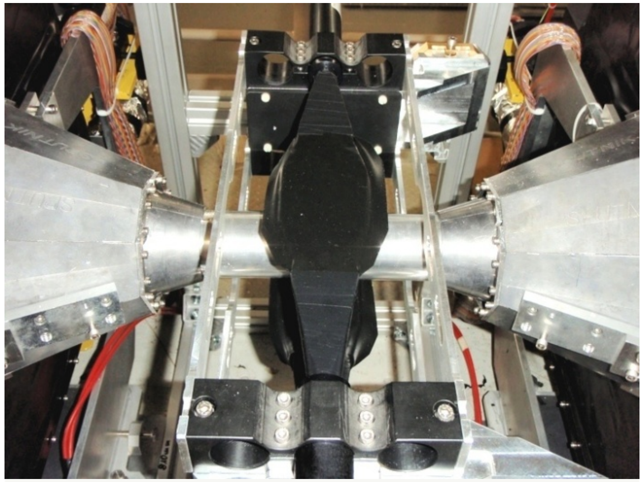
Beam pipe in e^+e^- intersection of SIDDHARTA



SIDDHARTA used the KLOE intersection of DAFNE

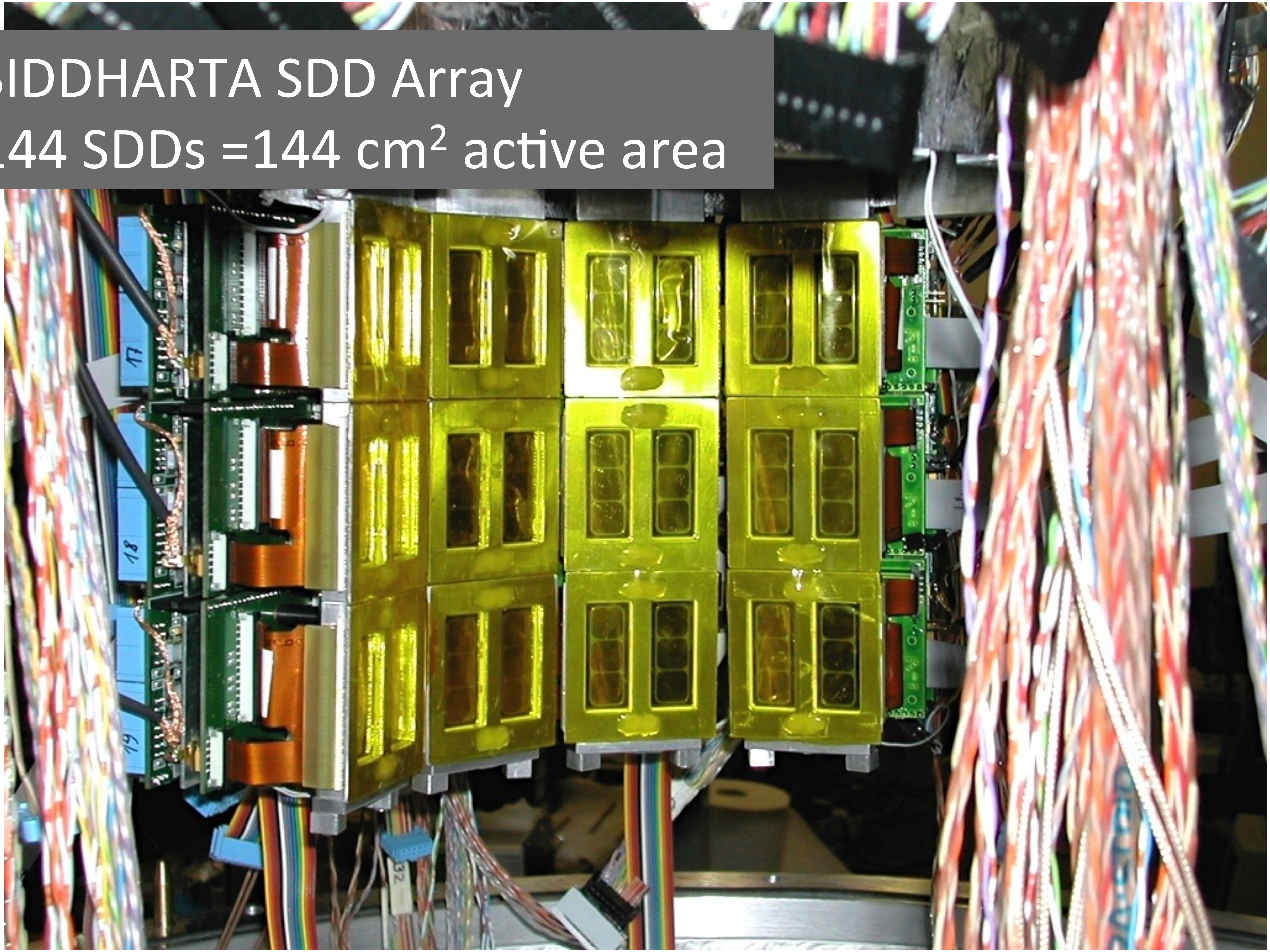
Luminosity increased with new system providing a large crossing angle (crab waist system)

Kaon window

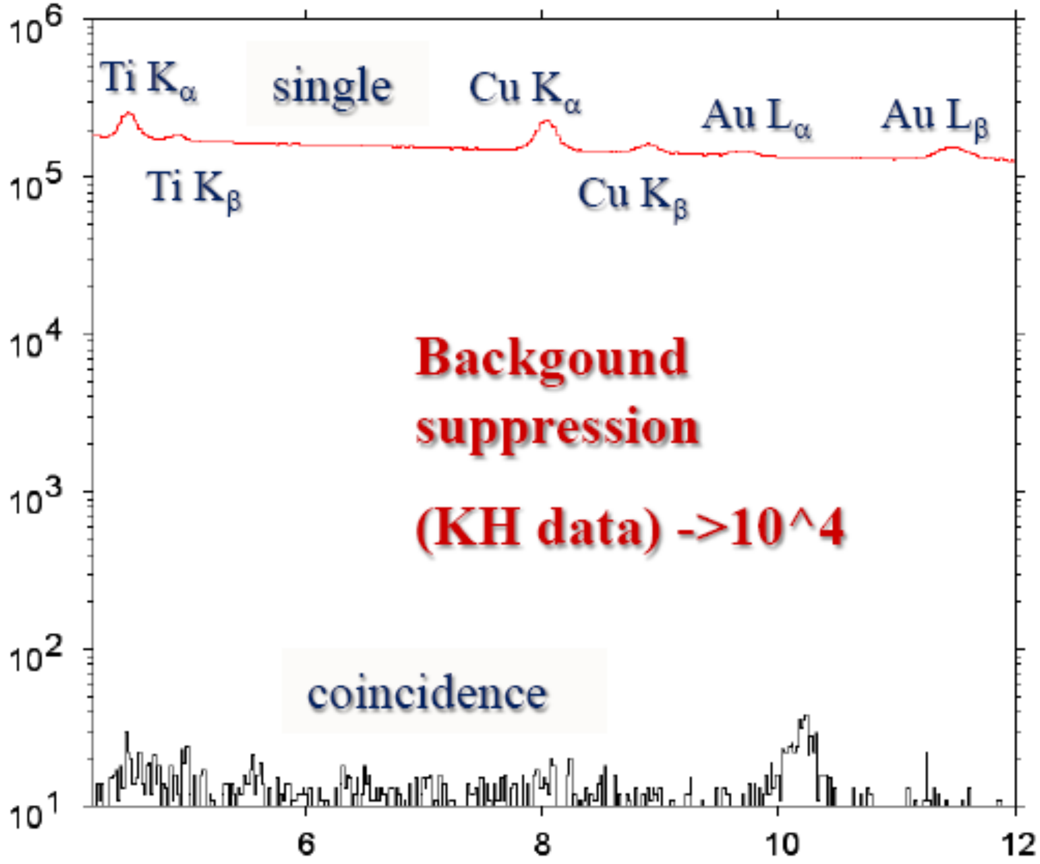


Kaon detectors sitting below and above the intersection

SIDDHARTA SDD Array
144 SDDs =144 cm^2 active area

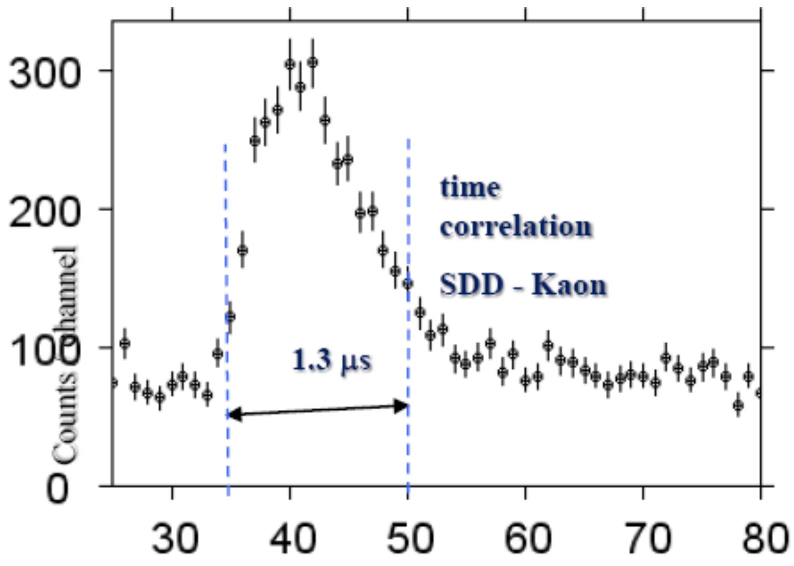


Background suppression in SIDDHARTA



X-ray energy [keV]

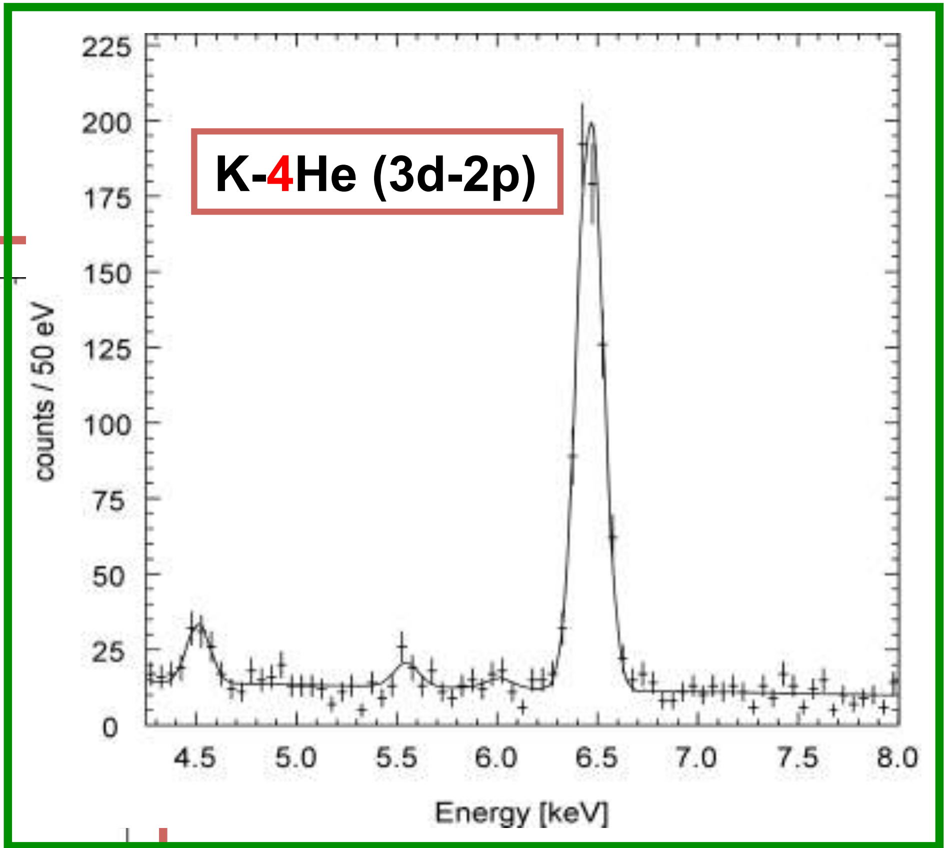
Efficient background suppression by using the kaon - x-ray correlation



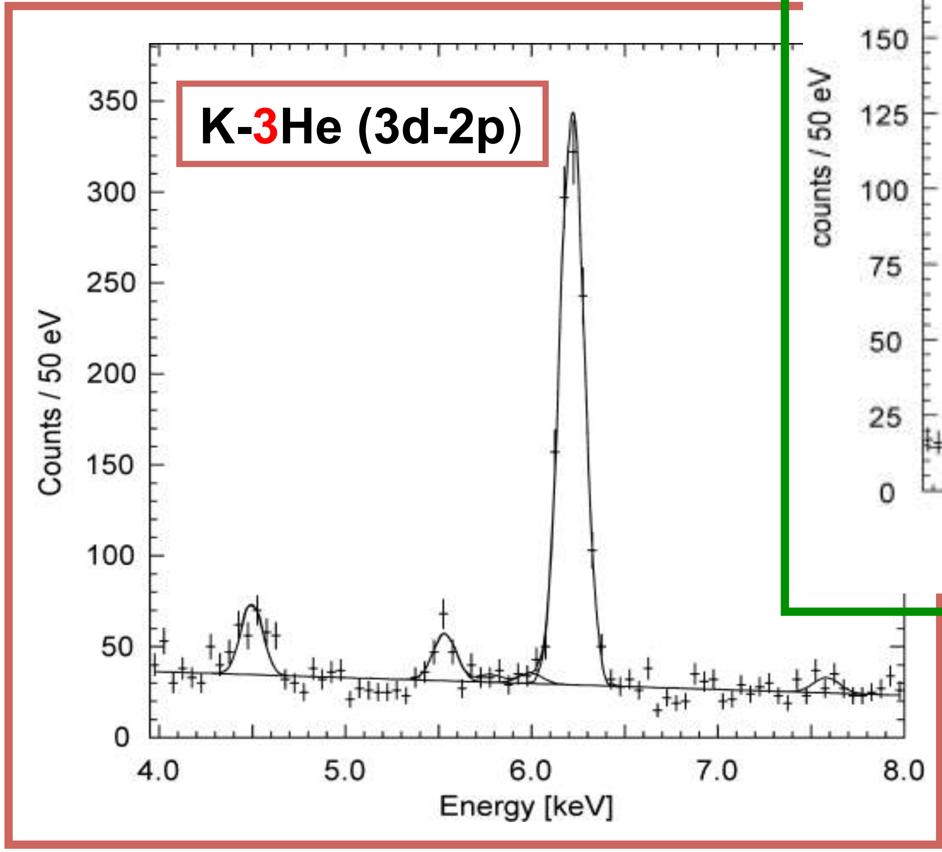
time [83 ns/ch]

Comparison kaonic ^{3}He and ^{4}He

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



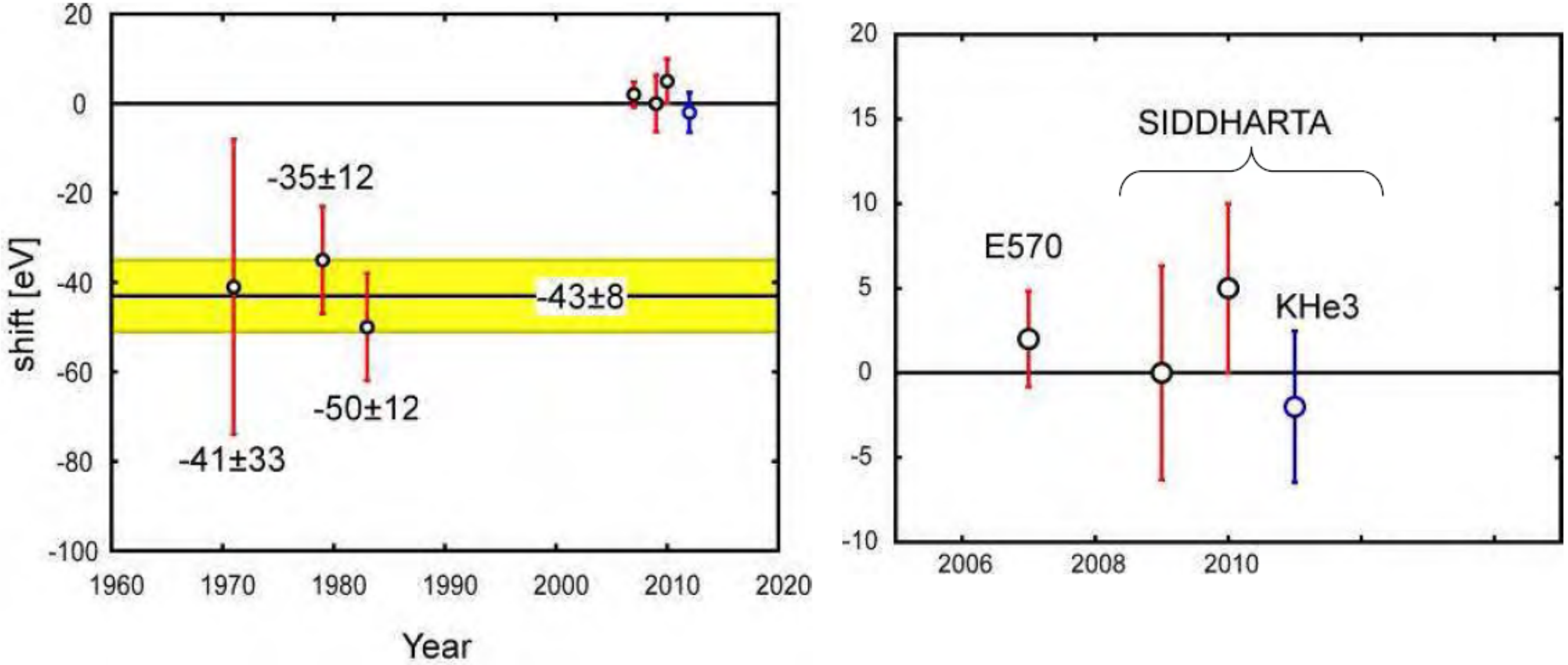
$$\Delta E_{2p} = -2 \pm 2(sta) \pm 4(sys)\ \text{eV}$$



PLB697(2011)199

Kaonic helium results

	Shift [eV]	Reference
KEK E570	+2±2±2	PLB653(2007)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	



➢ **calibration under control within several eV**

Yields in kaonic helium atoms

Eur. Phys. J. A (2014) **50**: 91
DOI 10.1140/epja/i2014-14091-0

THE EUROPEAN PHYSICAL JOURNAL A

Letter

**L-series X-ray yields of kaonic ³
targets**

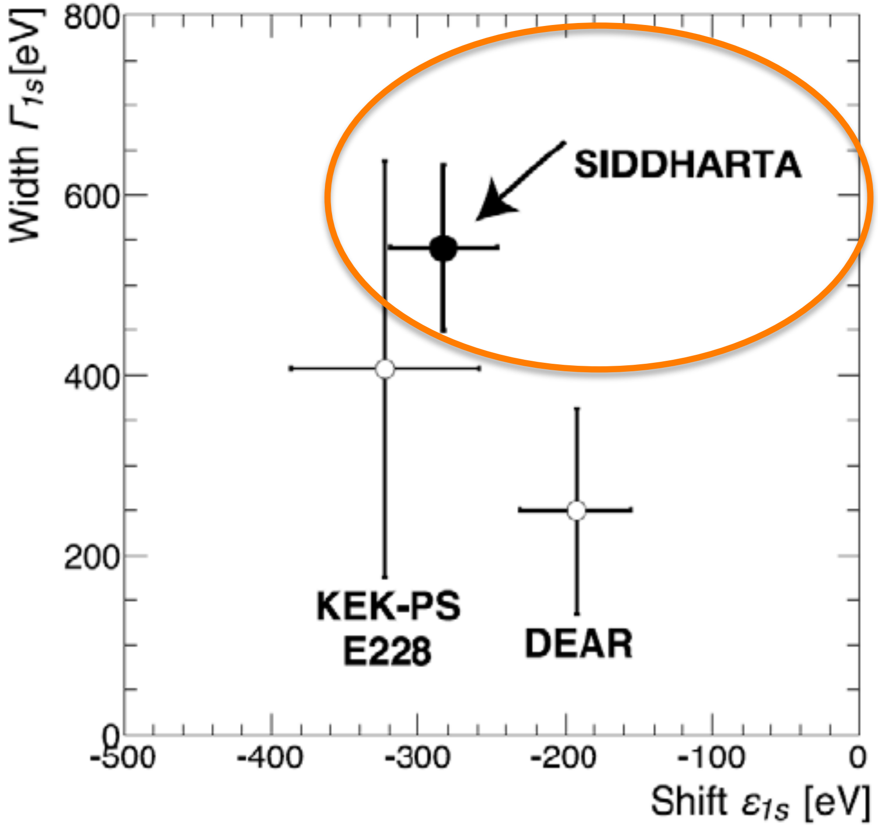
The SIDDHARTA Collaboration

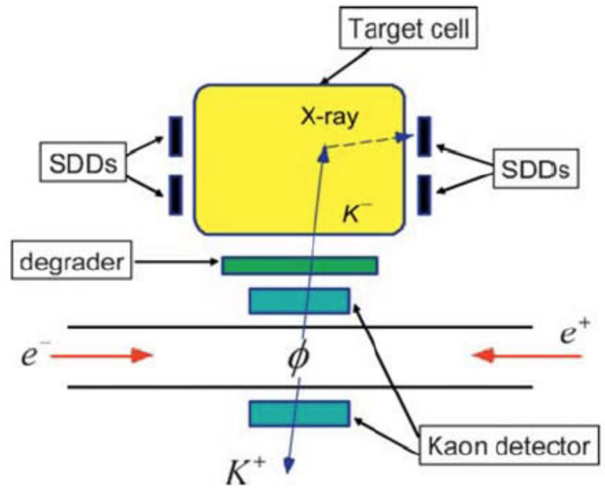
M. Bazzi[1], G. Beer[2], C. Berucci[1,3], A.M. Bragadireanu[1,
F. Ghio[7], C. Guaraldo[1], R.S. Hayano[8], M. Iliescu[1], T. I
S. Okada[9], D. Pietreanu[1,4], T. Ponta[4], R. Quaglia[5,6], A
D.L. Sirghi[1,4], F. Sirghi[1,4], H. Tatsuno[1,b], O. Vazquez D

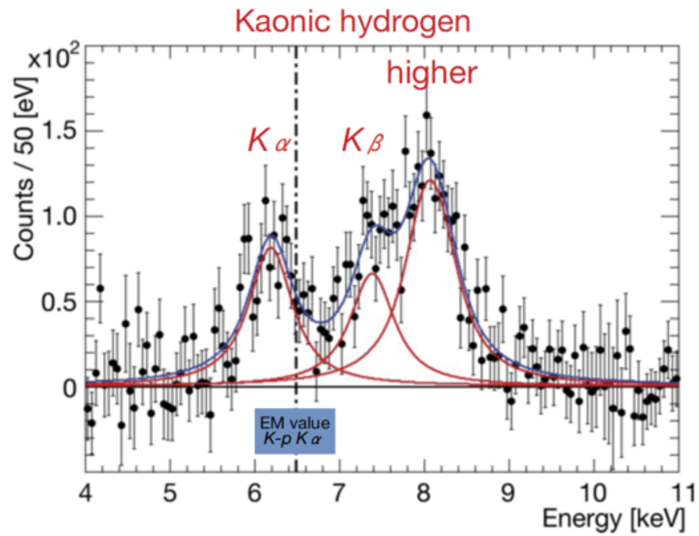
- Study of the x-ray pattern in kaonic helium atoms (transitions to the 2p state)
- First determination of the absolute yields
- Indications of weak molecular Stark mixing
- Data are calling for improved cascade calulations

Transition	^{3}He (0.96 g/l)	^{4}He (1.65 g/l)	^{4}He (2.15 g/l)	^{4}He (Liquid) [1]	^{4}He (Liquid) [3]
$L\alpha$	$25.0^{+6.7}_{-5.8}$	$23.1^{+6.0}_{-4.2}$	$17.2^{+2.6}_{-9.5}$	9.2 ± 2.4	8.9 ± 4.5
$L\beta$	$3.6^{+1.3}_{-0.7}$	4.2 ± 1.1	$3.1^{+0.6}_{-1.6}$	5.2 ± 1.3	2.3 ± 1.2
$L\gamma$	$1.3^{+0.5}_{-0.4}$	1.3 ± 0.6	$0.7^{+0.3}_{-0.5}$	2.4 ± 0.7	1.6 ± 0.8
L_{high}	5.2 ± 2.1	$6.9^{+2.0}_{-1.9}$	$4.1^{+1.1}_{-2.1}$	–	$0.4 \pm 0.3^*$

K^-p result SIDDHARTA







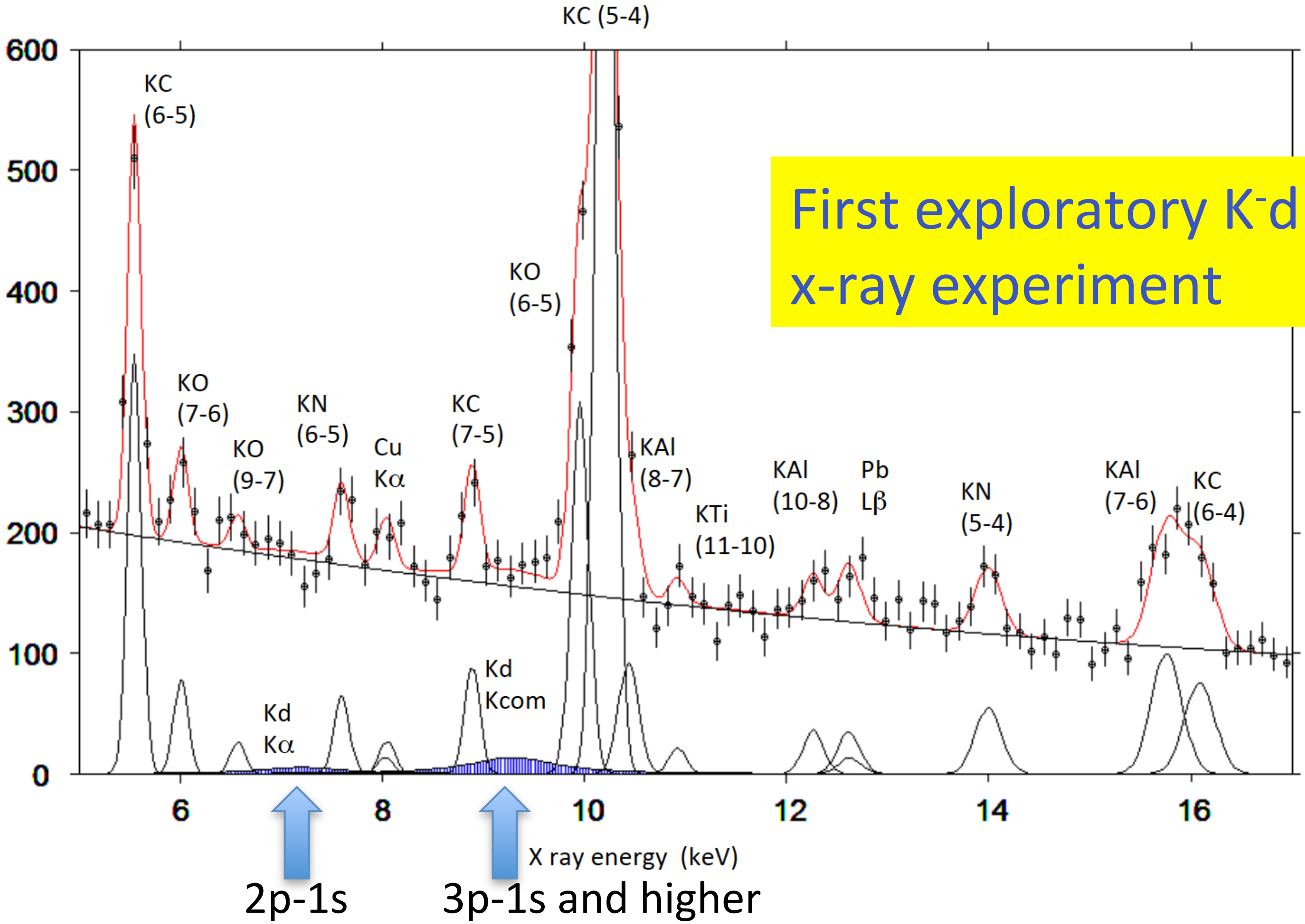
$\varepsilon_{1S} = -283 \pm 36(\text{stat}) \pm 6(\text{syst})$ eV

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

Physics Letters B704 (2011) 113

Kaonic atoms with deuterium gas (SIDDHARTA)

fit for shift about 500 eV, width about 1000eV, Kα / Kcomplex = 0.4



First exploratory K⁻d x-ray experiment

Yield of K-series in KD

ELSEVIER

Available online at www.sciencedirect.com

SciVerse ScienceDirect

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]

Upper limits (90 C.L.) for the x-ray yield (SIDDHARTA)

$Y(K_{tot}) < 0.0143$

$Y(K_{\alpha}) < 0.0039$

Results of SIDDHARTA

Kaonic Hydrogen: 400pb^{-1}, most precise measurement, Physics Letters B704 (2011) 113

Kaonic deuterium: 100 pb^{-1}, exploratory first measurement ever, Nucl. Phys.A907 (2013)69

- 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)

- Kaonic helium 3: 10 pb^{-1}, first measurement, published in Phys. Lett. B 697 (2011) 199

Physics Letters B 704 (2011) 113–117

Contents lists available at SciVerse ScienceDirect

Physics Letters B

www.elsevier.com/locate/physletb

A new measurement of kaonic hydrogen X-rays

SIDDHARTA Collaboration

M. Bazzi[a], G. Beer[b], L. Bombelli[c], A.M. Bragadireanu[a,d], M. Cargnelli[e,*], G. Corradi[a], C. Curceanu (Petrascu)[a], A. d'Uffizi[a], C. Fiorini[c], T. Frizzi[c], F. Ghio[f], B. Girolami[f], C. Guaraldo[a], R.S. Hayano[g], M. Iliescu[a,d], T. Ishiwatari[e], M. Iwasaki[h], P. Kienle[e,i], P. Levi Sandri[a], A. Longoni[c], V. Lucherini[a], J. Marton[e], S. Okada[a,*], D. Pietreanu[a,d], T. Ponta[d], A. Rizzo[a], A. Romero Vidal[a], A. Scordo[a], H. Shi[g], D.L. Sirghi[a,d], F. Sirghi[a,d], H. Tatsuno[g,1], A. Tudorache[d], V. Tudorache[d], O. Vazquez Doce[a], E. Widmann[e], J. Zmeskal[e]

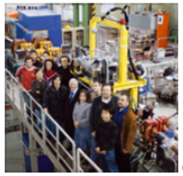
Kaonic hydrogen casts new light on strong dynamics – CERN Courier 26.10.11 17:10

CERN Courier

CERN COURIER

Oct 25, 2011

Kaonic hydrogen casts new light on strong dynamics

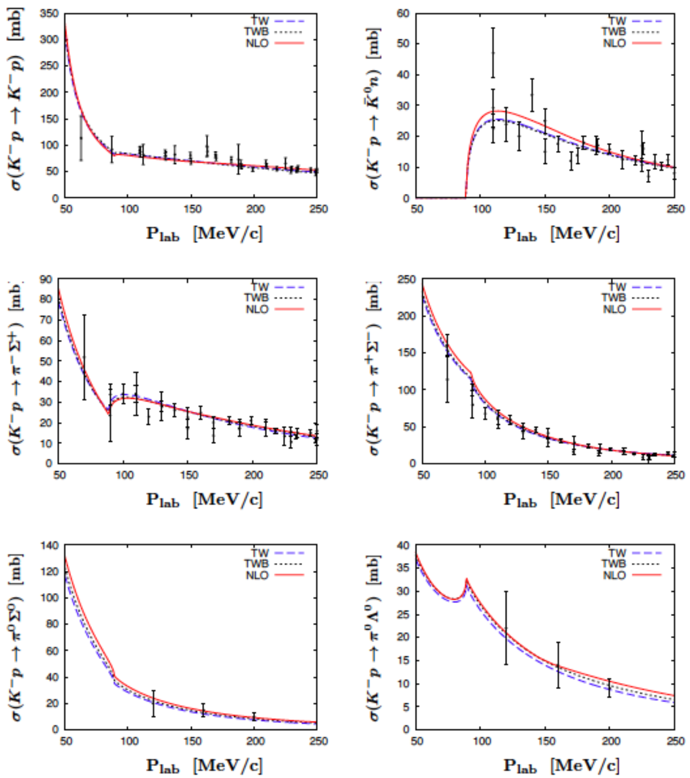


(http://images.iop.org/objects/ccr/cern/51/9/6/CCnew3_09_11.jpg)

SIDDHARTA (http://images.iop.org/objects/ccr/cern/51/9/6/CCnew3_09_11.jpg)

Sources of experimental information on $K_{bar}N$ interaction

K-p scattering data
for threshold data extrapolation necessary



Threshold branching ratios

threshold branching ratios
$\frac{\Gamma(K^-p \to \pi^+\Sigma^-)}{\Gamma(K^-p \to \pi^-\Sigma^+)}$
$\frac{\Gamma(K^-p \to \pi^+\Sigma^-, \pi^-\Sigma^+)}{\Gamma(K^-p \to \text{all inelastic channels})}$
$\frac{\Gamma(K^-p \to \pi^0\Lambda)}{\Gamma(K^-p \to \text{neutral states})}$

Kaonic atom data

Kaonic hydrogen
Kaonic Deuterium

1s state shift
1s state width

→ x-ray spectroscopy

Constraints from precise kaonic hydrogen measurements → sub-threshold extrapolations of the KbarN amplitude with strongly reduced uncertainties

Chiral SU(3) theory of antikaon-nucleon interactions with improved threshold constraints
Y. Ikeda, T. Hyodo and W. Weise, Nucl. Phys. A881 (2012) 98-114.

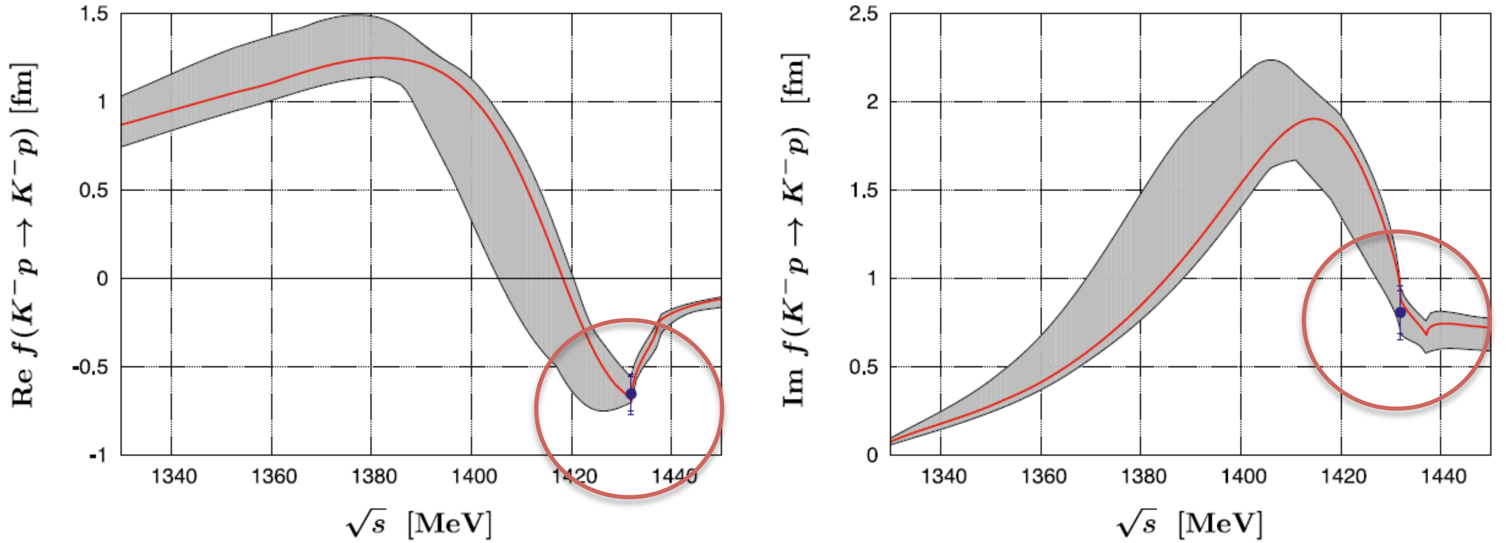
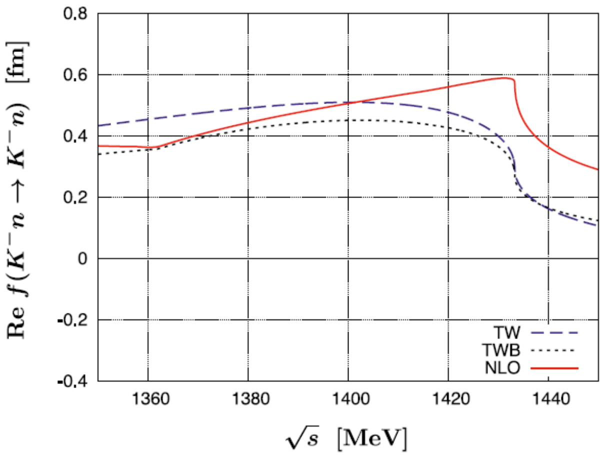
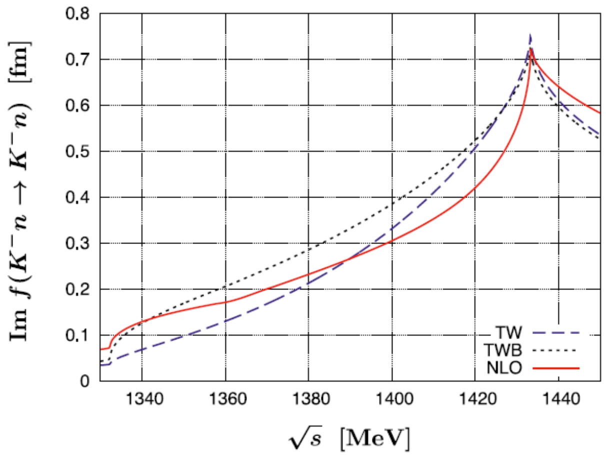


Fig. 4. Real part (left) and imaginary part (right) of the $K^-p \to K^-p$ forward scattering amplitude obtained from the NLO calculation and extrapolated to the subthreshold region. The empirical real and imaginary parts of the K^-p scattering length deduced from the recent kaonic hydrogen measurement (SIDDHARTA [15]) are indicated by the dots including statistical and systematic errors. The shaded uncertainty bands are explained in the text.

Predictions

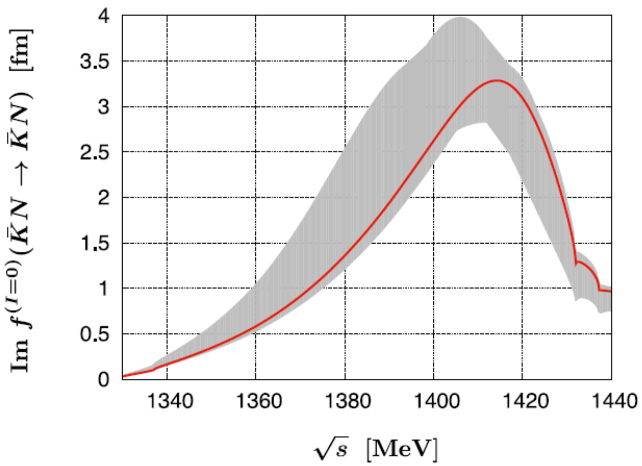
Real and imaginary part of the K⁻n → K⁻n forward scattering amplitude in the sub-threshold region

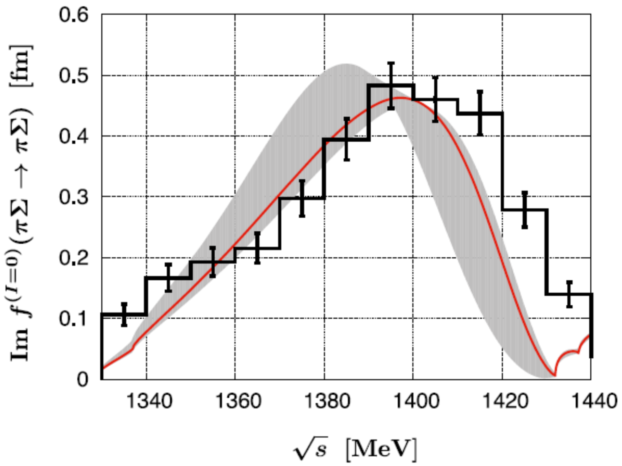




Imaginary part of the I=0 KbarN and Σπ amplidudes

Error bands due to constraints by SIDDHARTA





Motivation for new experiments

- SIDDHARTA – K-p strong interaction observables
- SIDDHARTA – First exploratory experiment on K^-D

But: No data on hadronic shift and width of 1s state of kaonic deuterium

→ still to be measured

- ➢ Study of K-n interaction: Isospin-dependent scattering lengths from KH and KD → K^-p interaction at low energy is well understood, but the case of K^-d represents the most important missing information
- ➢ High resolution studies of kaonic atoms (e.g. K-He, heavier kaonic atoms)

Expected shift and width

a_d [fm]	ε_{1s} [eV]	Γ_{1s} [eV]	Reference
-1.58 + *i* 1.37	- 887	757	Mizutani 2013 [4]
-1.48 + *i* 1.22	- 787	1011	Shevchenko 2012 [5]
-1.46 + *i* 1.08	- 779	650	Meißner 2011 [1]
-1.42 + *i* 1.09	- 769	674	Gal 2007 [6]
-1.66 + *i* 1.28	- 884	665	Meißner 2006 [7]

=>
shift = -800 eV
width = 800 eV
used in simulation

Modified Deser formula next-to-leading order in isospin breaking (Meißner, Raha, Rusetsky 2004 [3])
(μ_c reduced mass of K^-d, α finestructure constant)

$$\epsilon_{1s} - \frac{i}{2}\Gamma_{1s} = -2\alpha^3\mu_c^2 a_d \left(1 - 2\alpha\mu_c\left(\ln\alpha - 1\right)a_d\right) \quad (1)$$

[1] M. Döring, U.-G. Meißner, Phys. Lett. B 704 (2011) 663.
[3] U.-G. Meißner, U.Raha, A.Rusetsky, Eur. phys. J. C35 (2004) 349.
[4] T. Mizutani, C. Fayard, B. Saghai, K. Tsushima, arXiv:1211.5824[hep-ph] (2013).
[5] N.V. Shevchenko, Nucl. Phys. A 890-891 (2012) 50-61.
[6] A. Gal, Int. J. Mod. Phys. A22 (2007) 226
[7] U.-G. Meißner, U. Raha, A. Rusetsky, Eur. phys. J. C47 (2006) 473

Isospin scattering lengths

- The isospin scattering lengths a_0 and a_1 for I=0,1 cannot be determined from ε_{1s} and Γ_{1s} from kaonic hydrogen.
- The (modified) Deser-type formula
U.G.Meißner,U.Raha,A.Rusetsky,Eur.Phys.J.C35(2004)349,arXiv:hep-ph/0402261.

$$\epsilon_{1s} - \frac{i}{2}\Gamma_{1s} = -2\alpha^3\mu_c^2 a_p\left(1 - 2\alpha\mu_c(\ln\alpha - 1)a_p\right)$$

$a_p = ½(a_0+a_1)$

- Kaonic deuterium provides the lacking information

$a_n = a_1$

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

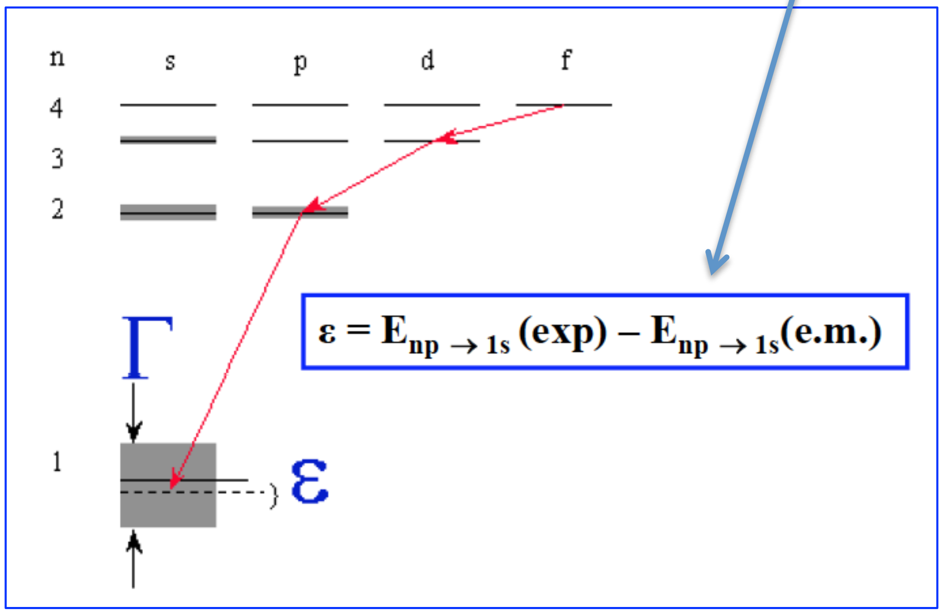
$$a_{K^-n} = a_1$$

$$a_{K^-d} = [a_0 + 3a_1]Q + C$$

$$Q = \frac{[m_N + m_K]}{[2m_N + m_K]}$$

Goal

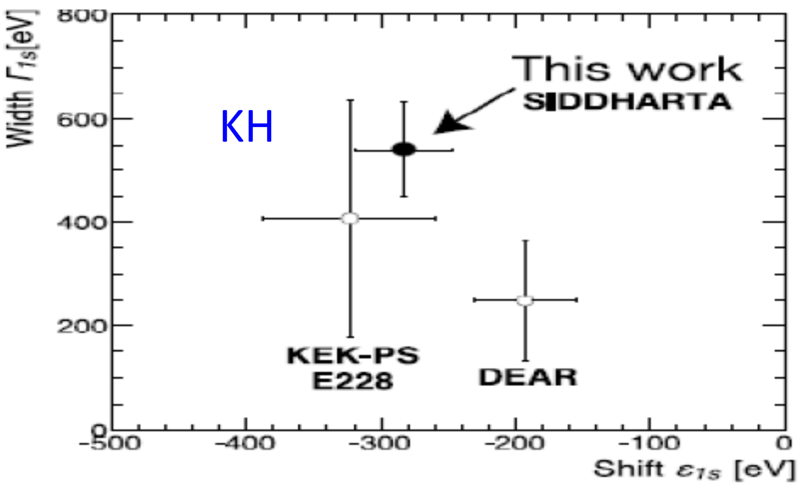
- Measurement of the shift ε_{1s} and width (broadening) Γ_{1s} of the ground state 1s
- Since only the 1s state is measurably affected by strong interaction → measured K line energies compared to calculated e.m transition energies yield ε_{1s} and Γ_{1s}

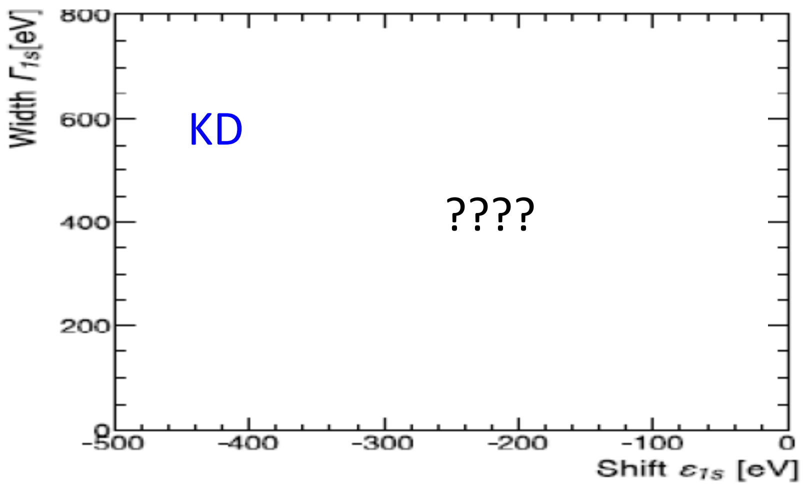


Transition	e.m. energy (keV) (calculated, without strong interaction)
KD (2-1)	7.808
KD (3-1)	9.255
KD (4-1)	9.765
KD (5-1)	9.994
KD (6-1)	10.119
..	..
KD (∞)	10.41

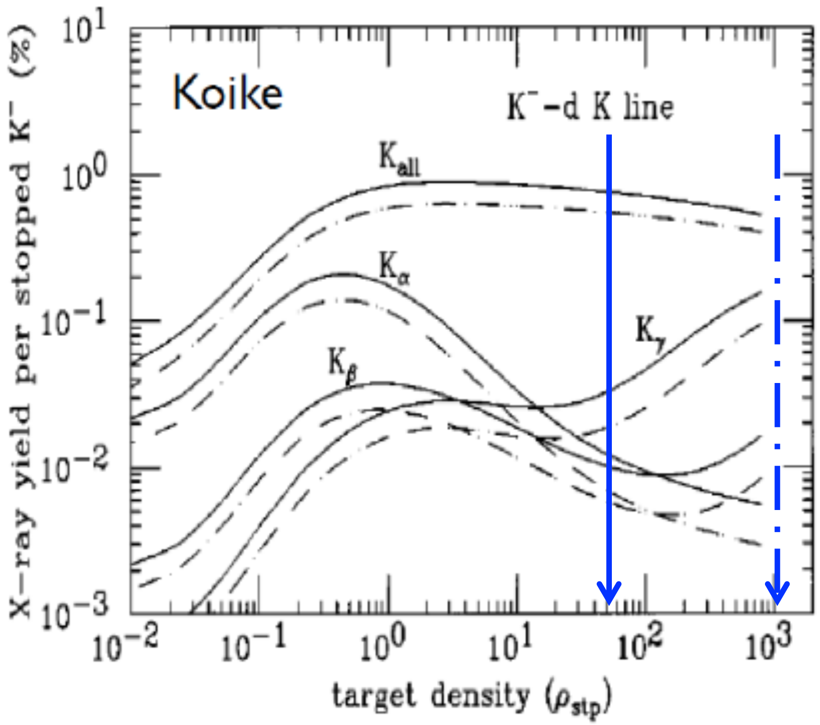
Comparison KH-KD

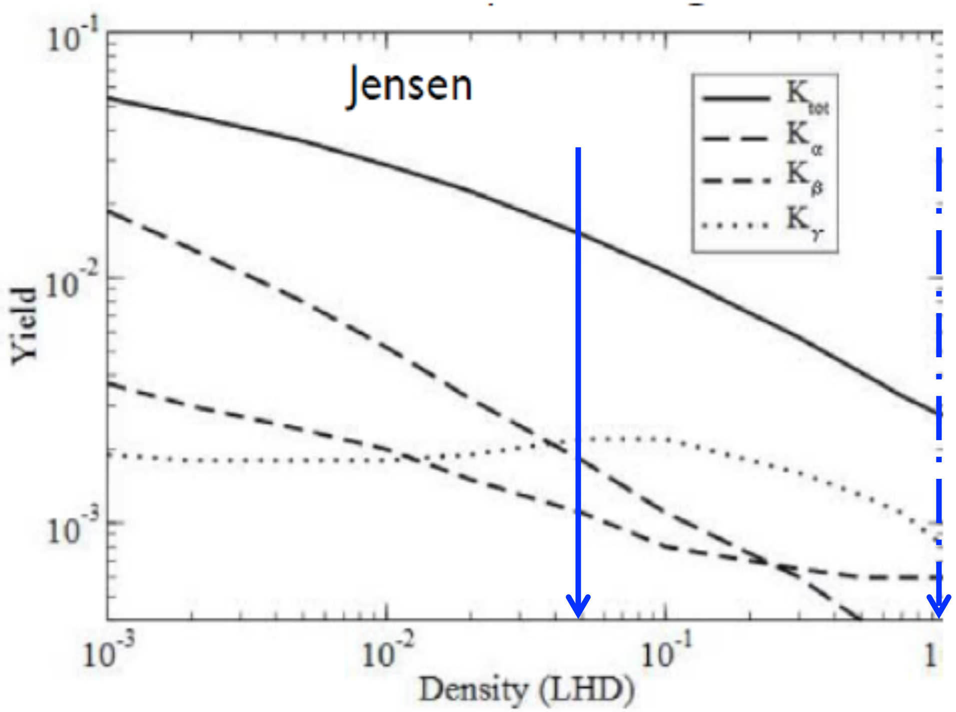
	Kaonic hydrogen	Kaonic deuterium
Yield (Kα) estimates	3%	0.3% (depending on 2p state width)
Energy (Kα) e.m.	6.5 keV	7.8 keV
Shift (1s)	-283±36(stat)±6(syst)	-800 ? (estimate)
Width (1s)	541±89(stat)±22(syst)	800 ? (estimate)





X-ray yields in $K^{-}D$





T.Koike, T. Harada, "calculation of K-p and K-d atoms", Phys. Rev. C 53 (1996) 79

T. S. Jensen, "Atomic Cascade in Kaonic Hydrogen and Deuterium", Proceedings of DAFNE 2004: Physics at meson factories, June 2004.

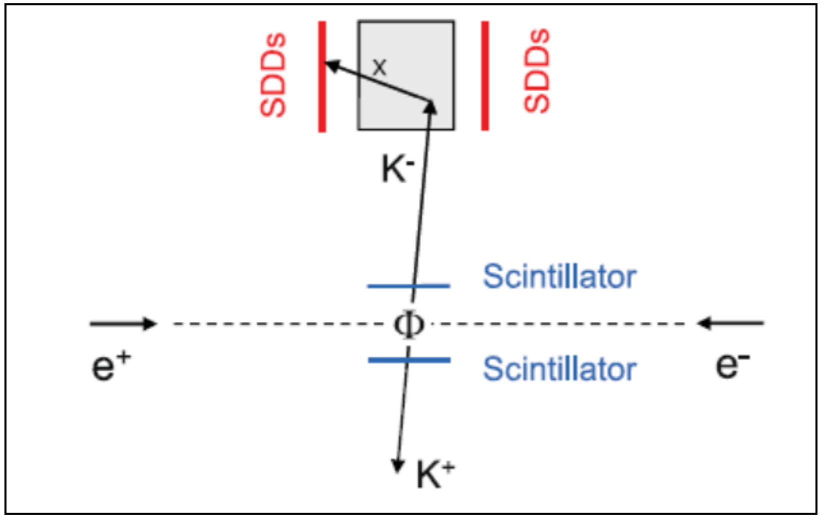
KD experiments employing new instrumentation

From SIDDHARTA to SIDDHARTA2

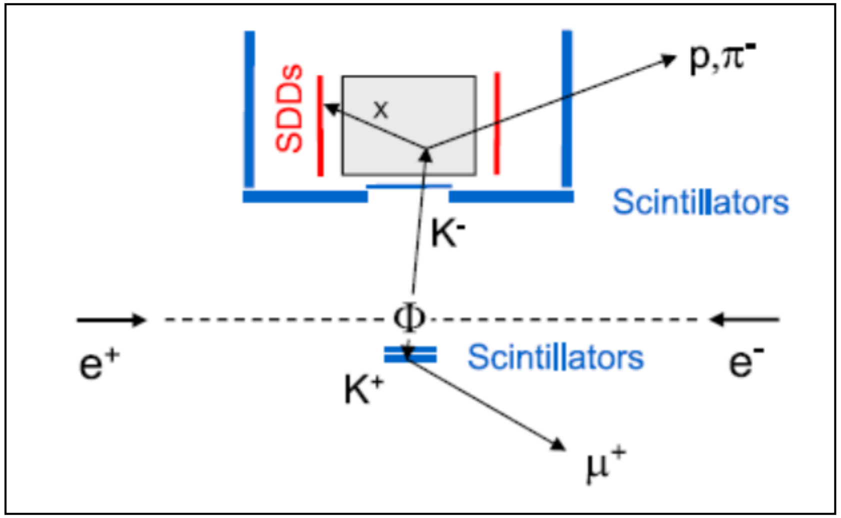
Changes

- Factor 2 in density of deuterium gas
- Kaon trigger geometry and arrangement
- Discrimination K^+/K^- by lifetime detector
- Active shielding of apparatus
- Higher timing resolution of SDDs by cooling

SIDDHARTA



SIDDHARTA2



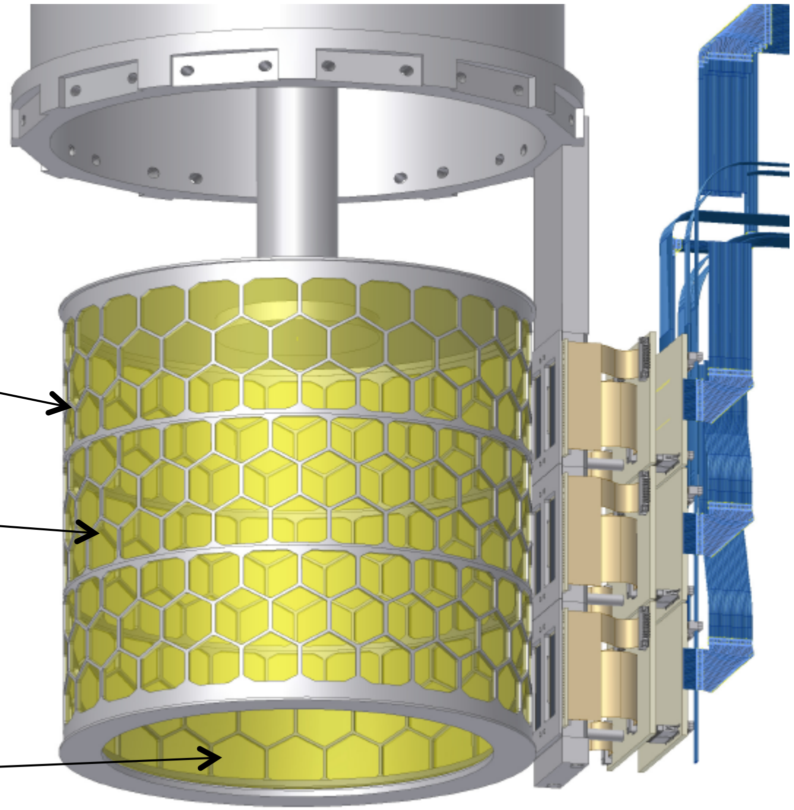
Lightweight cryogenic target (used for KH)

working T 22 K
working P 1.5 bar

Alu-grid

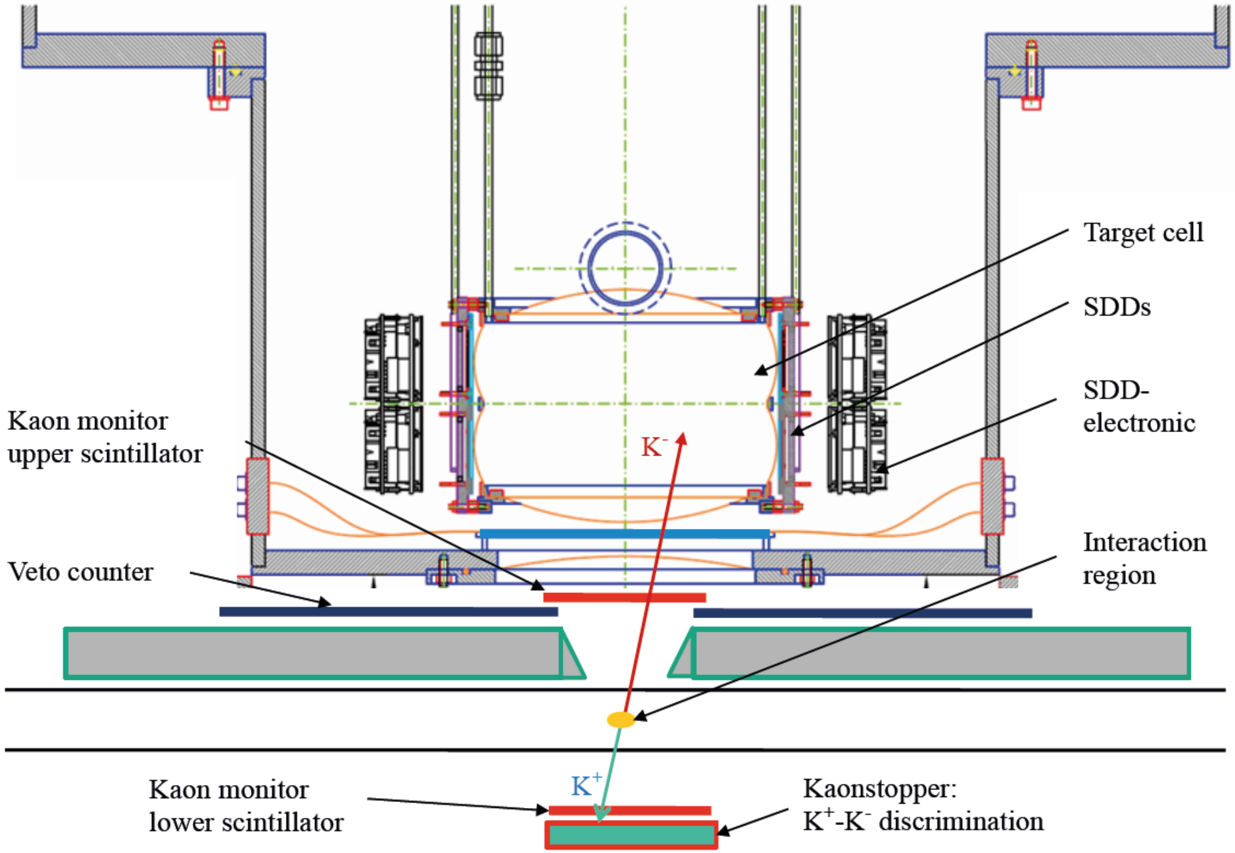
Side wall:
Kapton 50 μm

Kaon entrance
Window:
Kapton 75 μm



Plans for SIDDHARTA2 at DAFNE

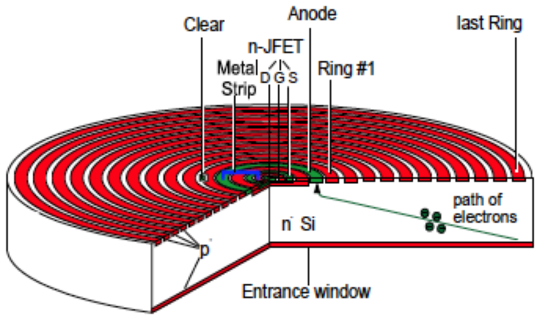
- new target design
- new SDD arrangement
- vacuum chamber
- more cooling power
- improved trigger scheme
- shielding and anti-coincidence (veto)



New x-ray detectors

- JFET integrated on the SDD

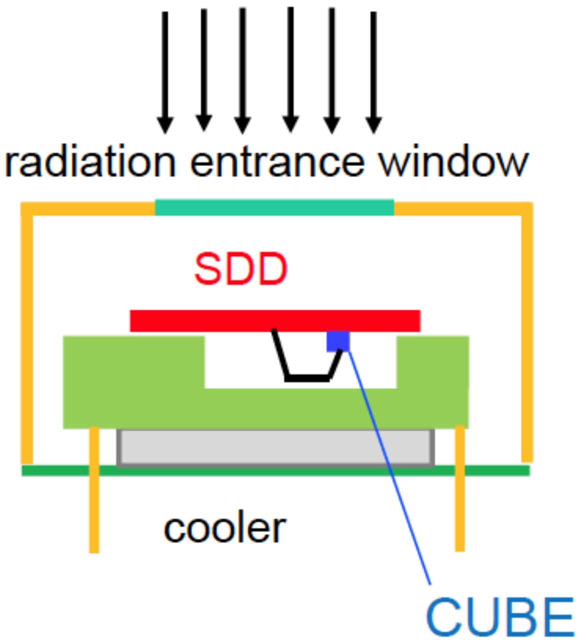
- lowest total anode capacitance
- limited JFET performances
- sophisticated SDD+JFET technology



Used in Siddharta

- external CUBE preamplifier (MOSFET input transistor)

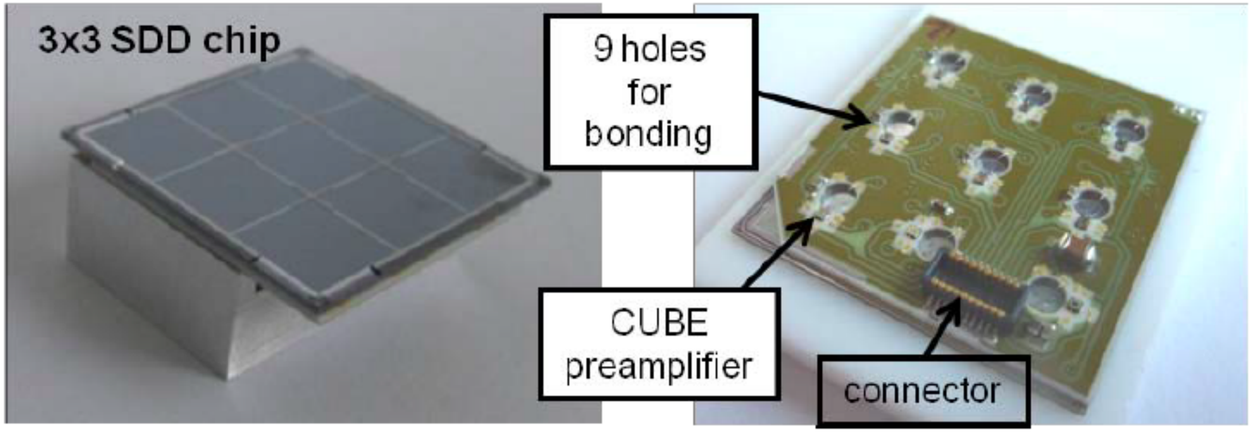
- larger total anode capacitance
- better FET performances
- standard SDD technology



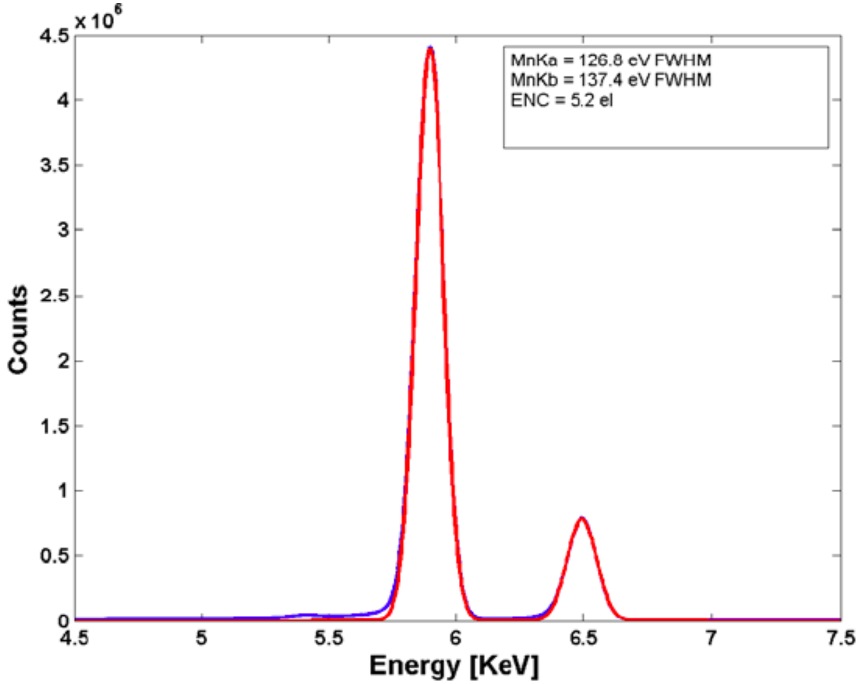
Proposed for kaonic deuterium measurement

New SDDs for x-ray detection

(FBK and Politecnico Milano)



Excellent active to total area 85%
→ Large solid angle



Test with Fe-55 Source
Mn Kα
127 eV (FWHM)

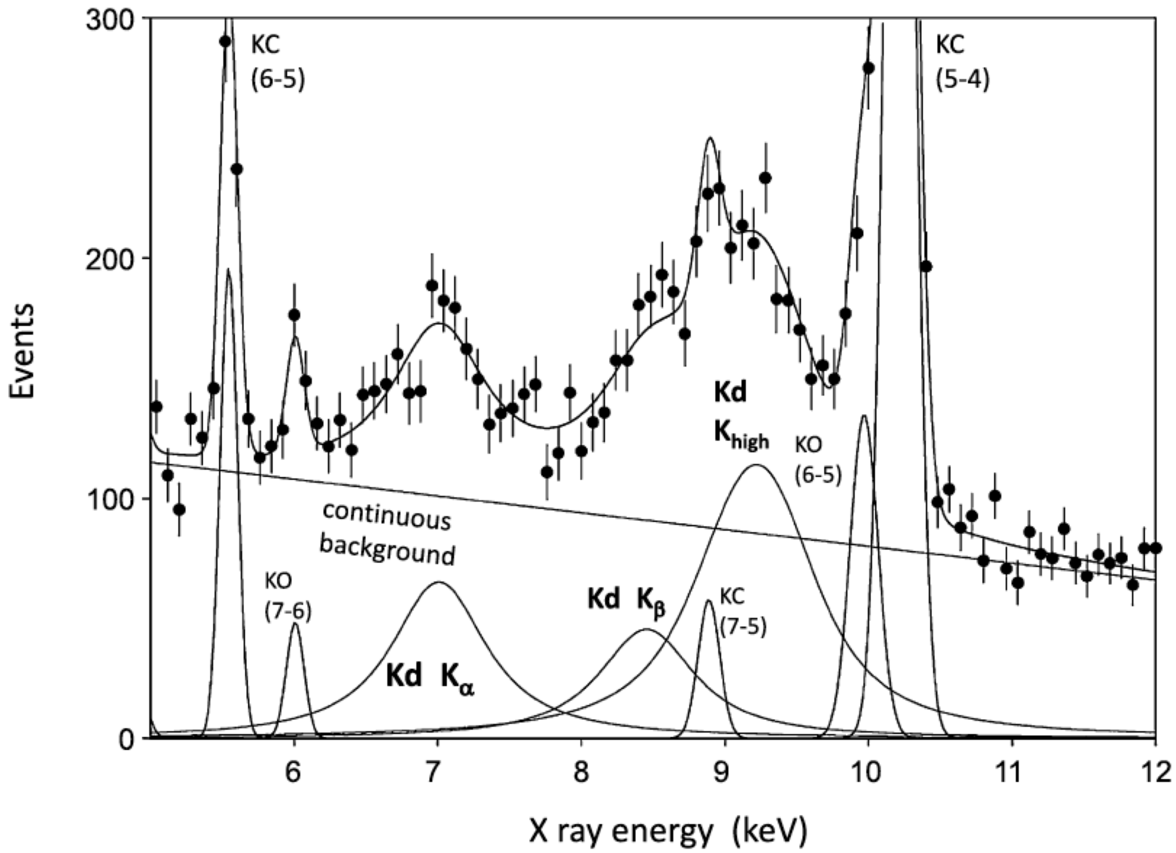
Very good energy resolution

Very good timing at low T

SDD Characterization

- Extremely important for precision x-ray spectroscopy
  - Stability
    - Long term monitoring gain and offset
    - Stability under small temperature variations
    - Gain stability at different x-ray rates
  - Linearity
  - SDD time response at various temperatures
  - SDD operation at low temperatures
  - Radiation hardness

Kaonic deuterium with SIDDHARTA2 at DAFNE



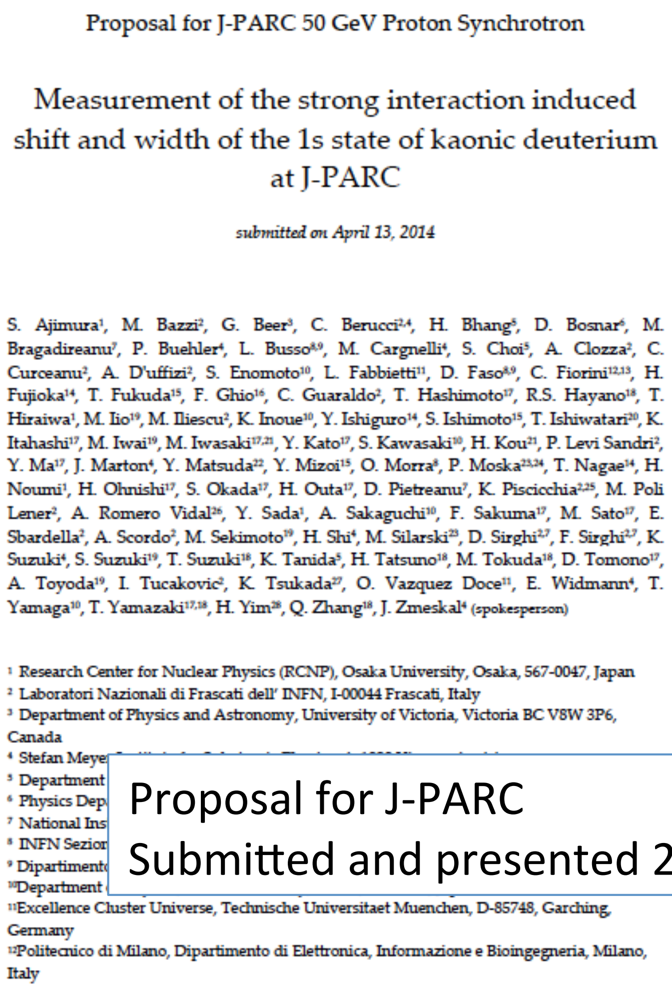
Monte Carlo Simulation for KD in SIDDHARTA2:
Shift: -805 eV
Width: 750 eV
Yield (Kα)=0.001
Luminosity: 800 pb-1

Presision from MC
Shift: 70 eV
Width 150 eV

M. Bazzi et al. (SIDDHARTA Coll.), Nucl.Phys. A907 (2013) 69.

We expect to measure shift and width of kaonic deuterium with a sinilar relative precision like kaonic hydrogen

Option:
kaonic deuterium @ J-PARC



Proposal for J-PARC 50 GeV Proton Synchrotron

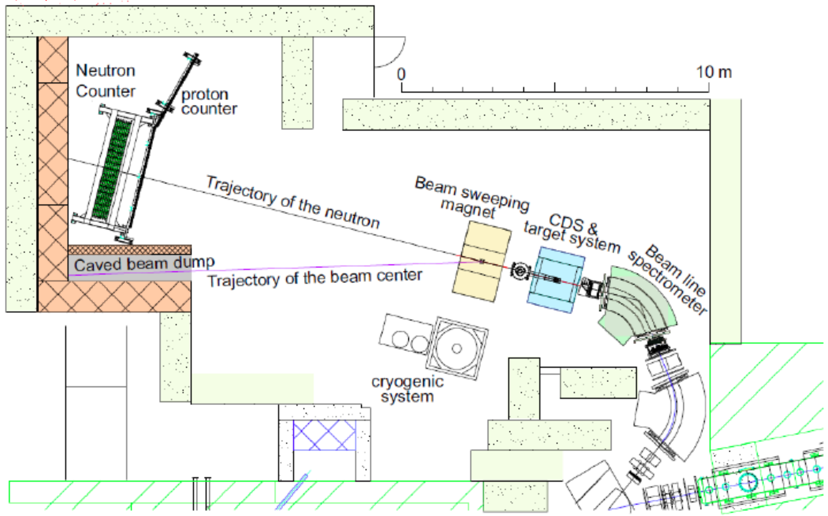
Measurement of the strong interaction induced shift and width of the 1s state of kaonic deuterium at J-PARC

submitted on April 13, 2014

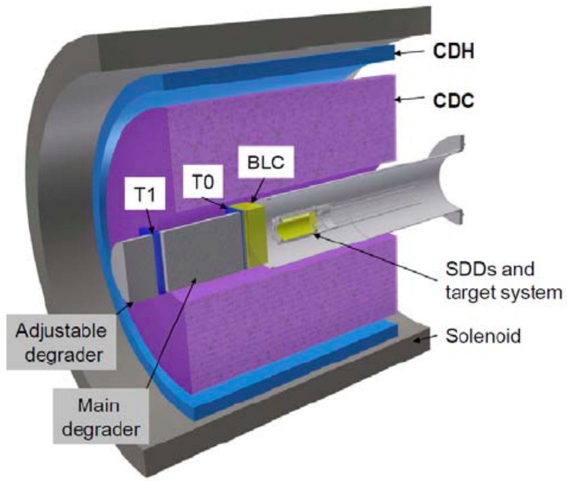
S. Ajimura[1], M. Bazzi[2], G. Beer[3], C. Berucci[2,4], H. Bhang[5], D. Bosnar[6], M. Bragadireanu[7], P. Buehler[4], L. Busso[8,9], M. Cargnelli[4], S. Choi[5], A. Clozza[2], C. Curceanu[2], A. D'uffizi[2], S. Enomoto[10], L. Fabbietti[11], D. Faso[8,9], C. Fiorini[12,13], H. Fujioka[14], T. Fukuda[15], F. Ghio[16], C. Guaraldo[2], T. Hashimoto[17], R.S. Hayano[18], T. Hiraiwa[1], M. Iio[19], M. Iliescu[2], K. Inoue[10], Y. Ishiguro[14], S. Ishimoto[15], T. Ishiwatari[20], K. Itahashi[17], M. Iwai[19], M. Iwasaki[17,21], Y. Kato[17], S. Kawasaki[10], H. Kou[21], P. Levi Sandri[2], Y. Ma[17], J. Marton[4], Y. Matsuda[22], Y. Mizoi[15], O. Morra[8], P. Moska[23,24], T. Nagae[14], H. Noumi[1], H. Ohnishi[17], S. Okada[17], H. Outa[17], D. Pietreanu[7], K. Piscicchia[2,25], M. Poli Lener[2], A. Romero Vidal[26], Y. Sada[1], A. Sakaguchi[10], F. Sakuma[17], M. Sato[17], E. Sbardella[2], A. Scordo[2], M. Sekimoto[19], H. Shi[4], M. Silarski[23], D. Sirghi[2,7], F. Sirghi[2,7], K. Suzuki[4], S. Suzuki[19], T. Suzuki[18], K. Tanida[5], H. Tatsuno[18], M. Tokuda[18], D. Tomono[17], A. Toyoda[19], I. Tucakovic[2], K. Tsukada[27], O. Vazquez Doce[11], E. Widmann[4], T. Yamaga[10], T. Yamazaki[17,18], H. Yim[28], Q. Zhang[18], J. Zmeskal[4] (spokesperson)

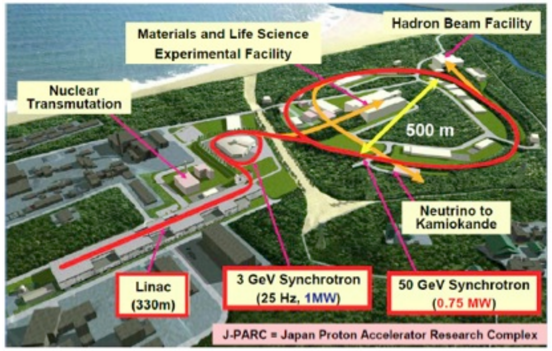
[1] Research Center for Nuclear Physics (RCNP), Osaka University, Osaka, 567-0047, Japan
[2] Laboratori Nazionali di Frascati dell' INFN, I-00044 Frascati, Italy
[3] Department of Physics and Astronomy, University of Victoria, Victoria BC V8W 3P6, Canada
[4] Stefan Meye
[5] Department
[6] Physics Dep
[7] National Ins
[8] INFN Sezion
[9] Dipartiment
[10] Department
[11] Excellence Cluster Universe, Technische Universitaet Muenchen, D-85748, Garching, Germany
[12] Politecnico di Milano, Dipartimento di Elettronica, Informazione e Bioingegneria, Milano, Italy

Proposal for J-PARC
Submitted and presented 2014



J-PARC K1.8BR spectrometer,
for E15, E17





SIDDHARTA2 @DAFNE

DAFNE – ideal for kaonic atoms

Kaon source (Φ decay in K^-K^+)

Low-energy kaons (127 MeV/c) ideal for stopping

No tracking

With 10 pb^{-1} per day

1.5 10^7 K- per day isotropically

2% per kaon pair stopping in gas

144 SDDs from SIDDHARTA

Kaonic deuterium @J-PARC ?

Kaon beam

Kaons at higher momentum (660-1000 MeV/c)

needs degrader

Tracking

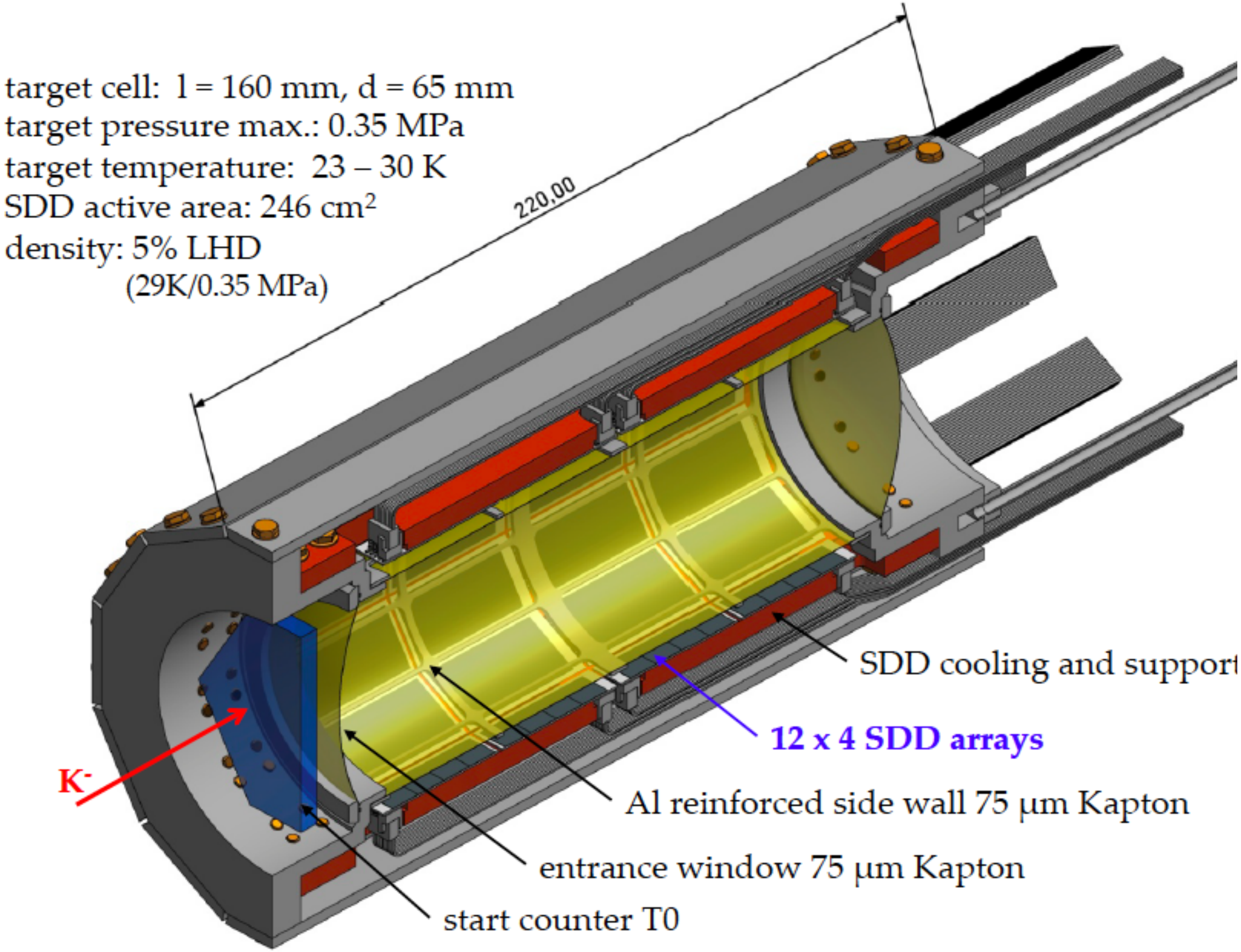
With 30 kW beam power

430 10^7 K^- per day

0.03% per kaon pair stopping in gas (660 MeV/c)

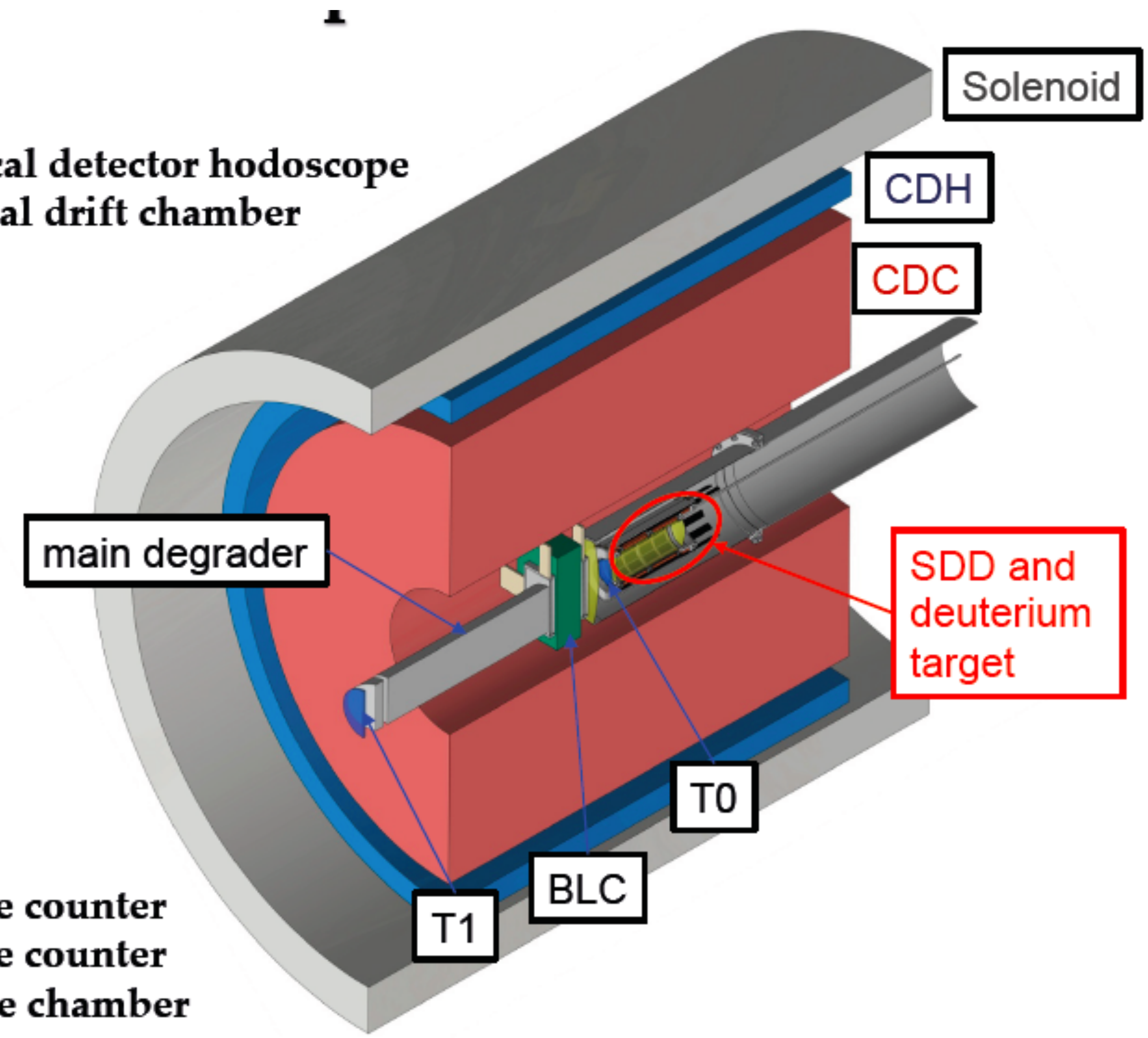
340 SDDs

Cryogenic target and SDDs



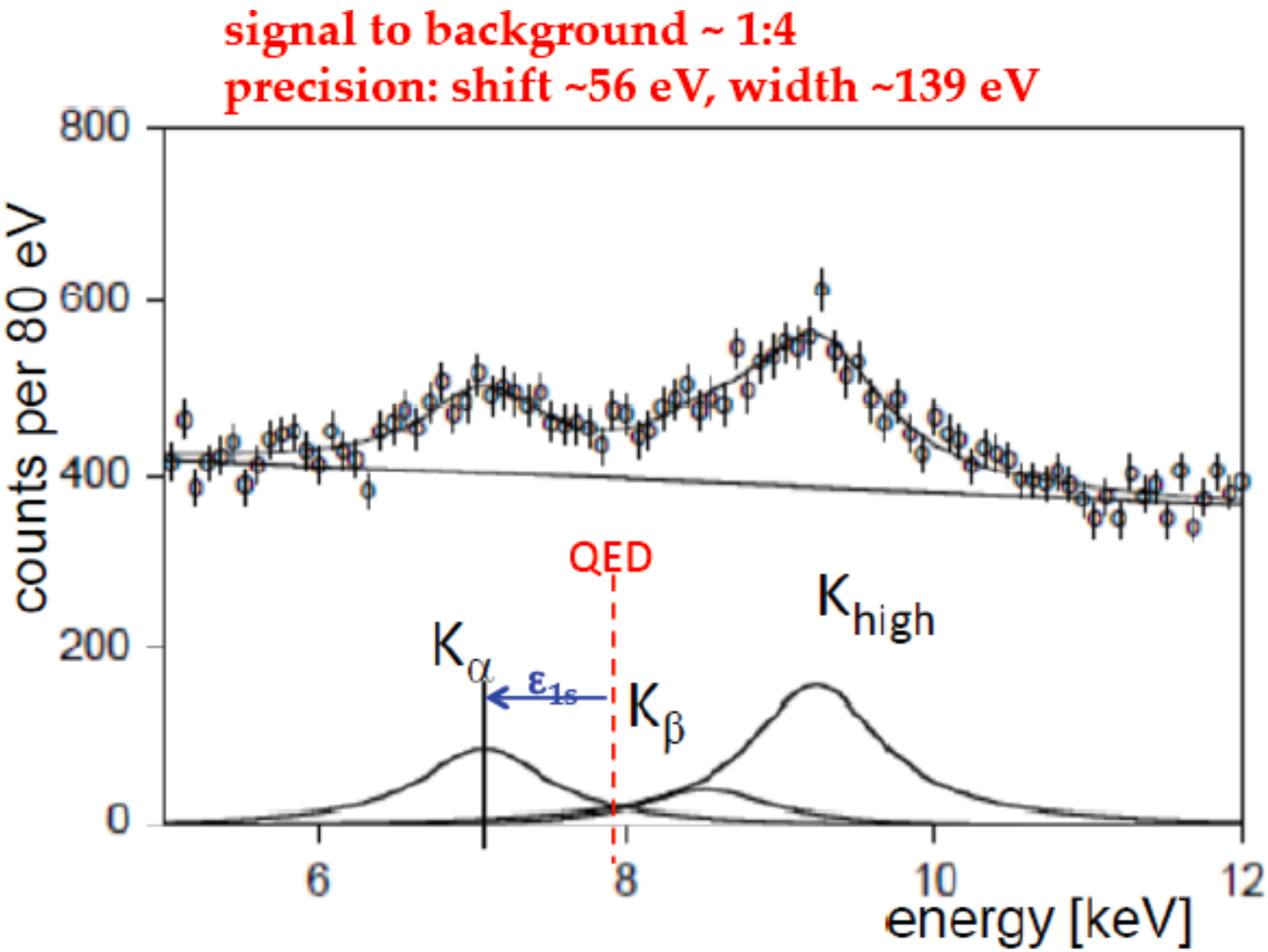
Setup at J-PARC K1.8BR

CDH...cylindrical detector hodoscope
CDC...cylindrical drift chamber



T0.......beam line counter
T1.......beam line counter
BLC....beam line chamber

Monte Carlo results Kd@J-PARC



signal: shift - 800 eV
width 750 eV
density: 5% (LHD)
detector area: 246 cm^2

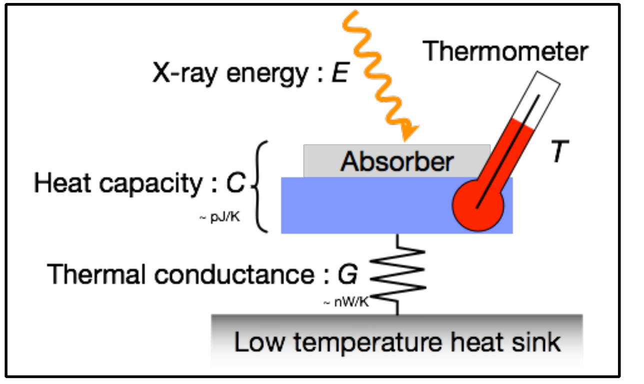
Kα yield: 0.1 %
yield ratio as in K$^-$p

Outlook: New precision studies with new technologies

- Kaonic helium 2p state shift/width
- 2 level studies in kaonic atoms

New experiments - microcalorimeter

Study of 2 transitions in the same kaonic atom for separating one-nucleon 1N) from multi-nucleon (mN) processes using micro-calorimeters



rms radii of potentials are characteristic features:

	r_m	Re(full)	Re(1N)	Re(mN)	Im(full)	Im(1N)	Im(mN)
Ni	3.72	3.34	3.82	2.86	3.73	4.46	3.12
Pb	5.56	5.21	5.71	4.78	5.46	6.23	5.00

(values in fm).

Radius difference 1N-mN real terms=0.95 fm.

Radius difference 1N-mN imag. terms=1.2-1.3 fm.

Further applications of microcalorimeters for precision x-ray studies:

- K-He-3,4 2p-shift/width
- Charged kaon mass

Feasibility of new experiments

Microcalorimeter detectors based on Transition Energy Sensors (TES) achieved 53 eV resolution for 100 keV X-rays for an array of 5cm^2.

Resolution stays constant in the linear region (up to 400 keV).

To model less favorable conditions we adopted also increase of energy spread with $\sqrt{E_X}$.

E.F. & S. Okada, NPA 915 (2013) 170.

Summary

- SIDDHARTA – important results on light kaonic atoms
- Impact for $K_{bar}N$ theory (see talk by W. Weise at this conference)
- SIDDHARTA – first exploratory experiment on $K^{-}d$
- SIDDHARTA2 with improved apparatus aiming at a first extraction of 1s state shift and width in kaonic deuterium
- SIDDHARTA2 at DAFNE/J-PARC
- Close collaboration of experimentalists and theoreticians extremely important → LEANNIS (HadronPhysics3 in EU FP7)

FWF
P24756-N20
HadronPhysics2 Study of Strongly Interacting Matter
LEANNIS

Thank you