KAONIC DEUTERIUM AT J-PARC - PROBING LOW ENERGY QCD

Johann Zmeskal for the E57 collaboration
SMI, Vienna, Austria

2nd Jagiellonian Symposium on Fundamental and Applied Subatomic Physics
Kraków June 5-9, 2017

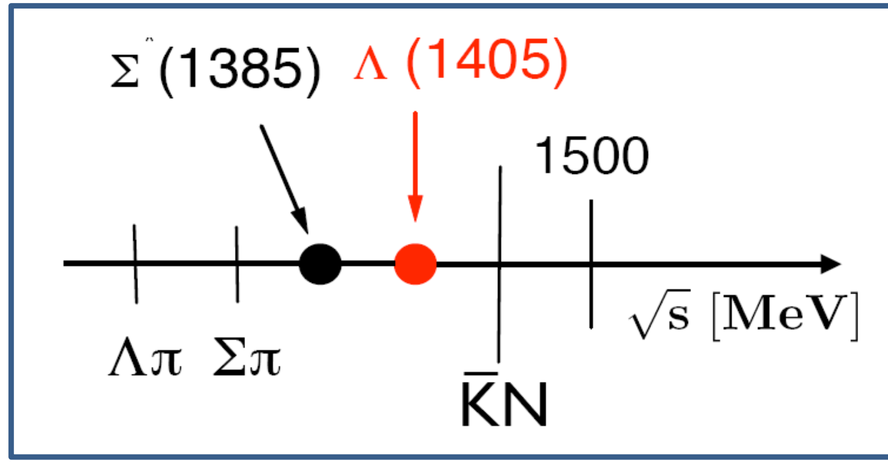
OUTLINE

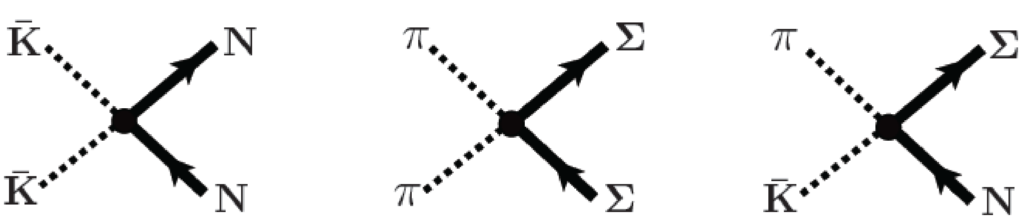
- Motivation
- short overview $K^{-}p$
- $K^{-}d$ setup at J-PARC
- first tests at J-PARC
- Summary

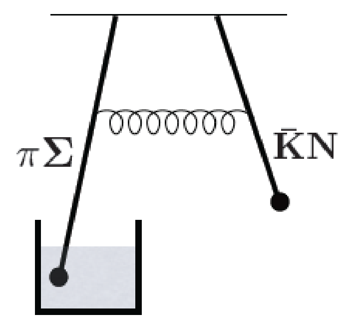
LOW-ENERGY $\bar{K}N$ INTERACTION

Chiral perturbation theory developed for πp, ππ **not** applicable for KN systems

non-perturbative coupled channels approach based on **chiral SU(3) dynamics**





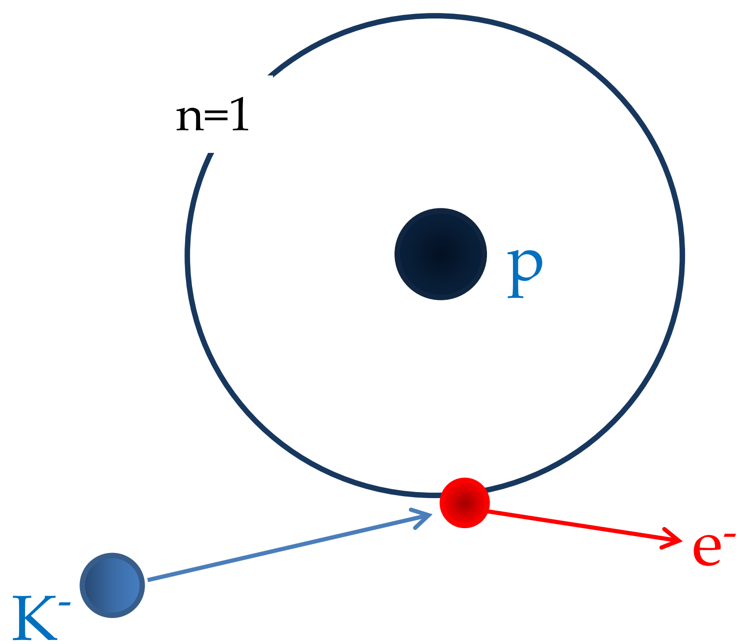


channel coupling

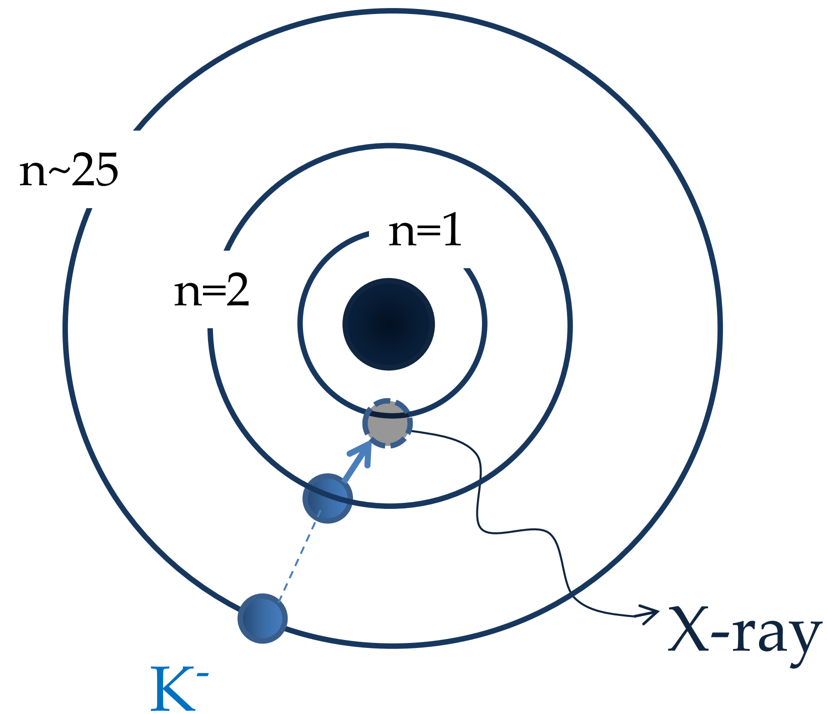
Review:
T. Hyodo, D. Jido
Prog. Part. Nucl. Phys. 67 (2012) 55

FORMING "EXOTIC" ATOMS

"normal" hydrogen



"exotic" (kaonic) hydrogen

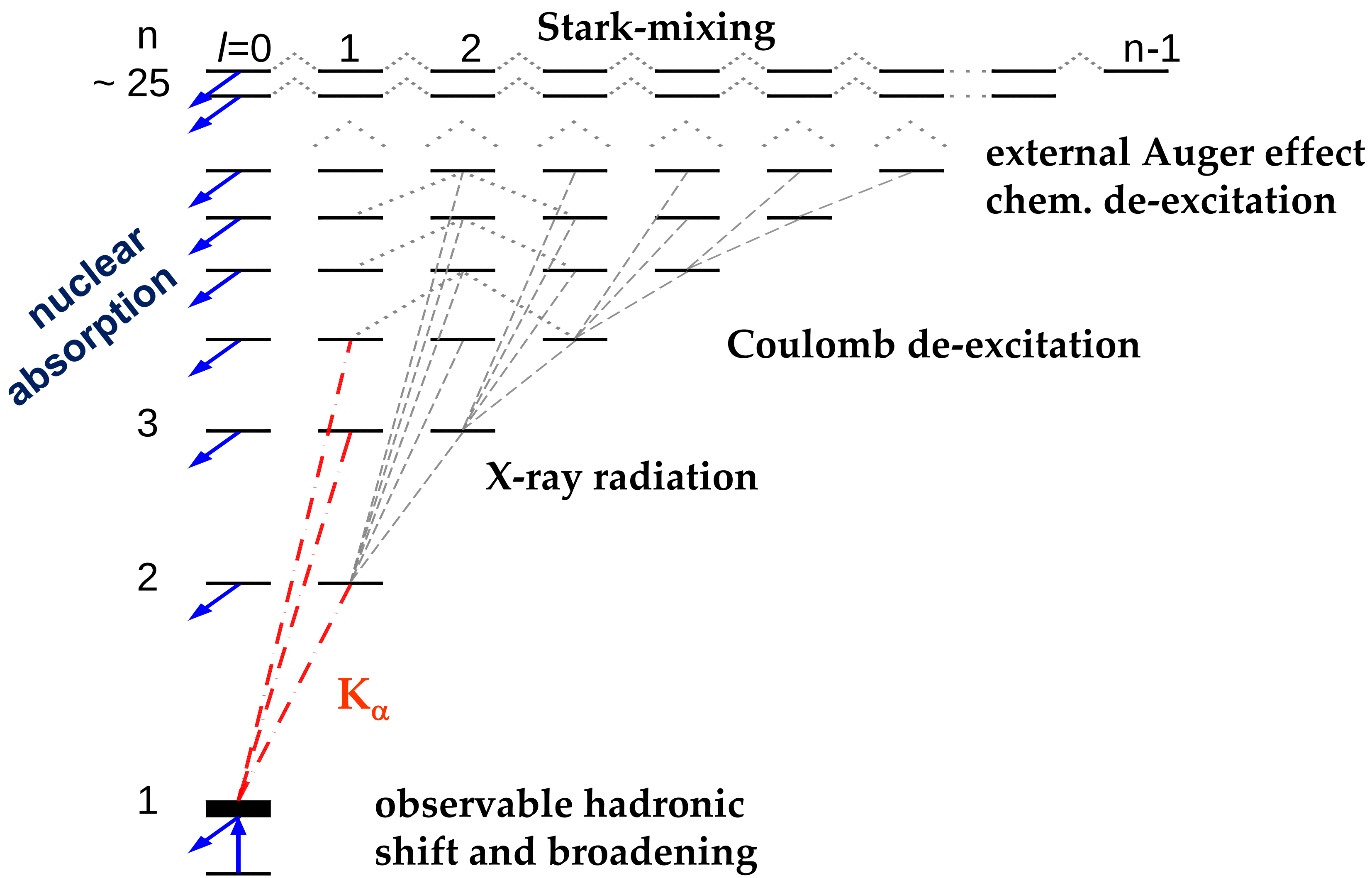


$$n \approx \sqrt{\frac{m_{\text{red}}}{m_e}} \cdot n_e$$

$2p \rightarrow 1s$

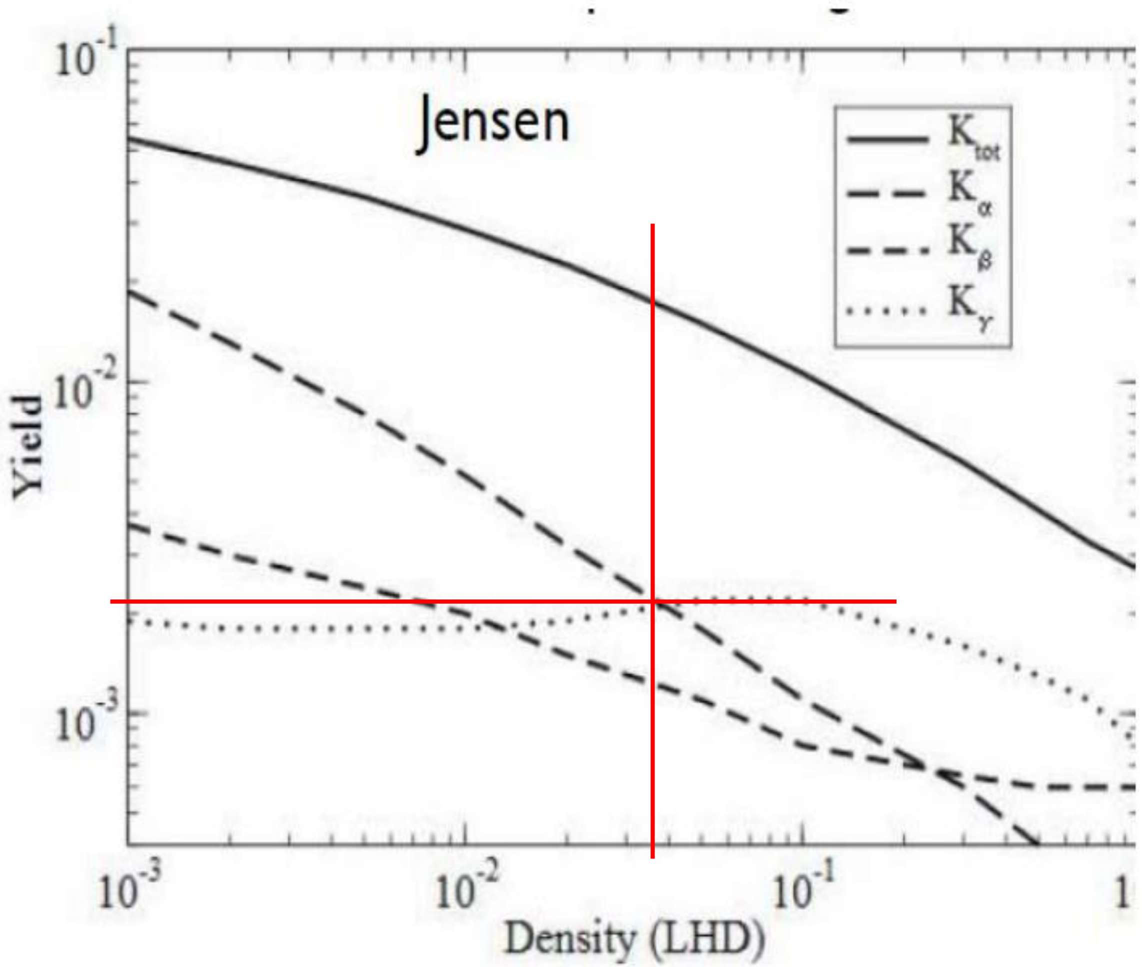
K_α transition

CASCADE PROCESSES



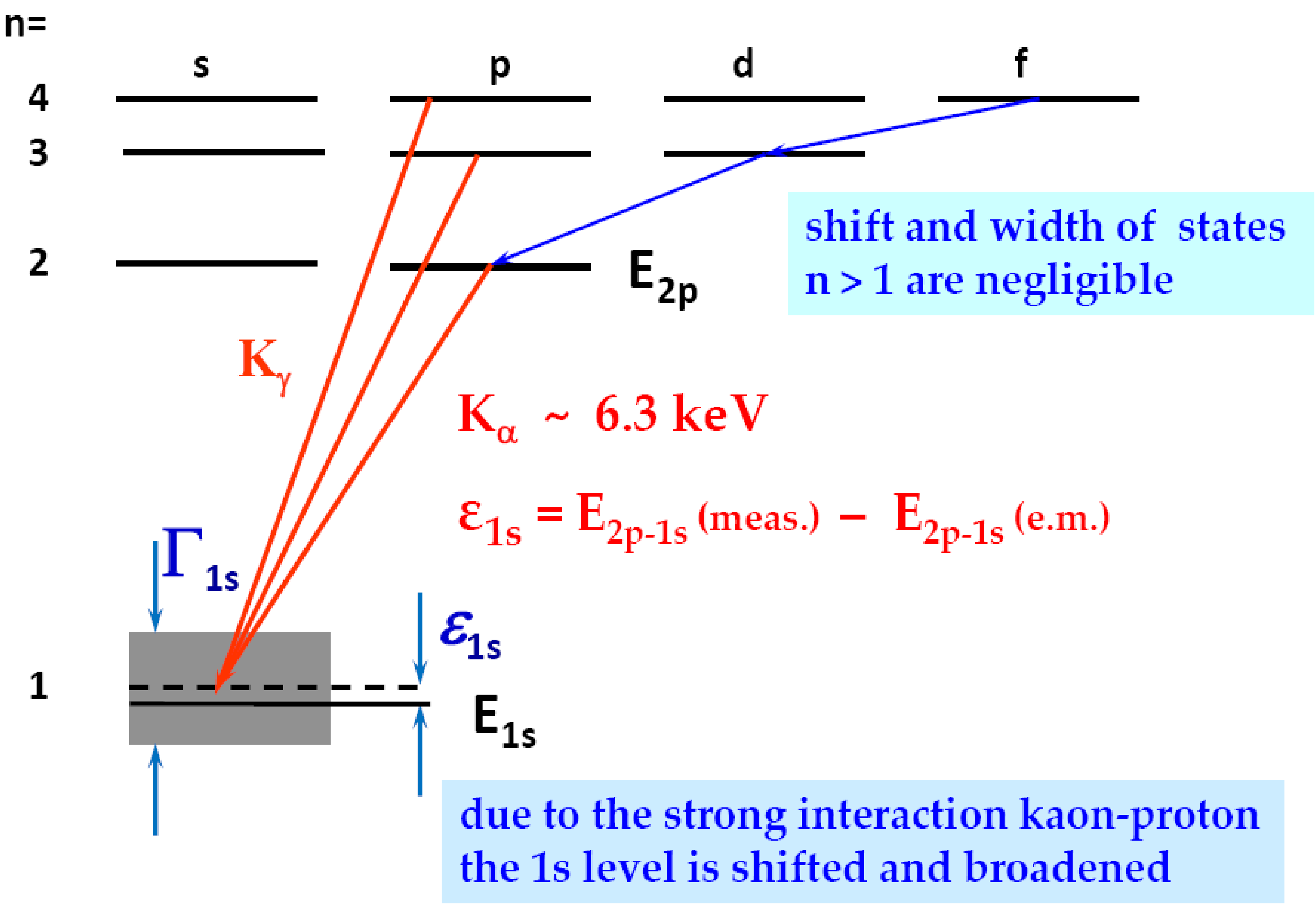
Kaonic deuterium yields

Kaonic deuterium cascade calculations for X-ray yields of K_α , K_β , K_γ and K_{tot}



$Y(K_\alpha) \sim 2 \cdot 10^{-3}$

X-RAY TRANSITIONS TO THE 1s STATE



SCATTERING LENGTHS

Deser-type relation connects shift ε_{1s} and width Γ_{1s} to the real and imaginary part of $a_{K\text{-}p}$

$$\varepsilon_{1s} - \frac{i}{2}\Gamma_{1s} = -2\alpha^3\mu_c^2 a_{K^-p}\left(1 - 2\alpha\mu_c(\ln\alpha - 1)a_{K^-p}\right)$$

(μ_C reduced mass of the K⁻p system, α fine-structure constant)

U.-G. Meißner, U.Raha, A.Rusetsky, Eur. phys. J. C35 (2004) 349
next-to-leading order, including isospin breaking

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

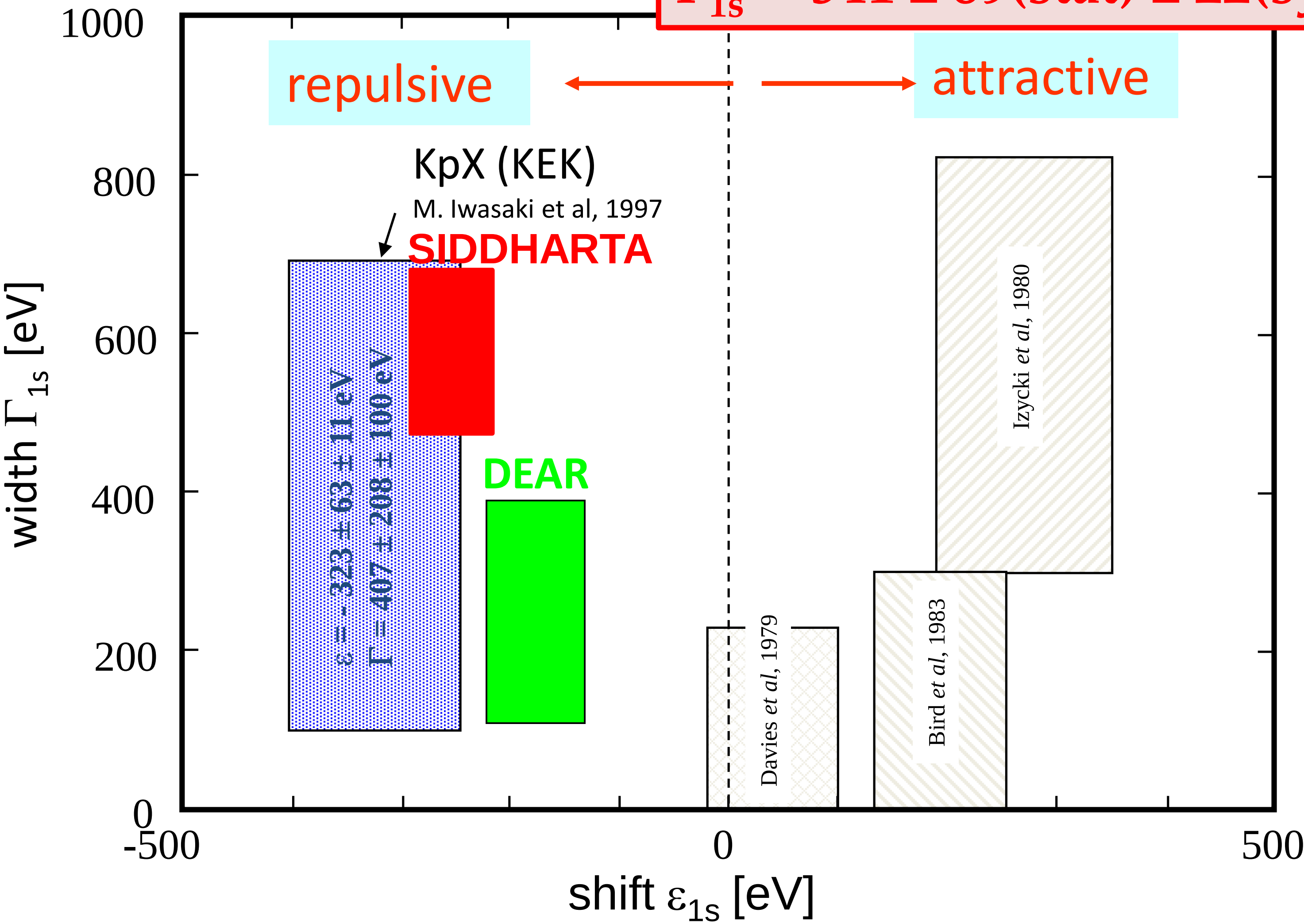
$$a_{K^-n} = a_1$$

$$a_{K^-d} = \frac{k}{2}\left[a_{K^-p} + a_{K^-n}\right] + C = \frac{k}{4}\left[a_0 + 3a_1\right] + C$$

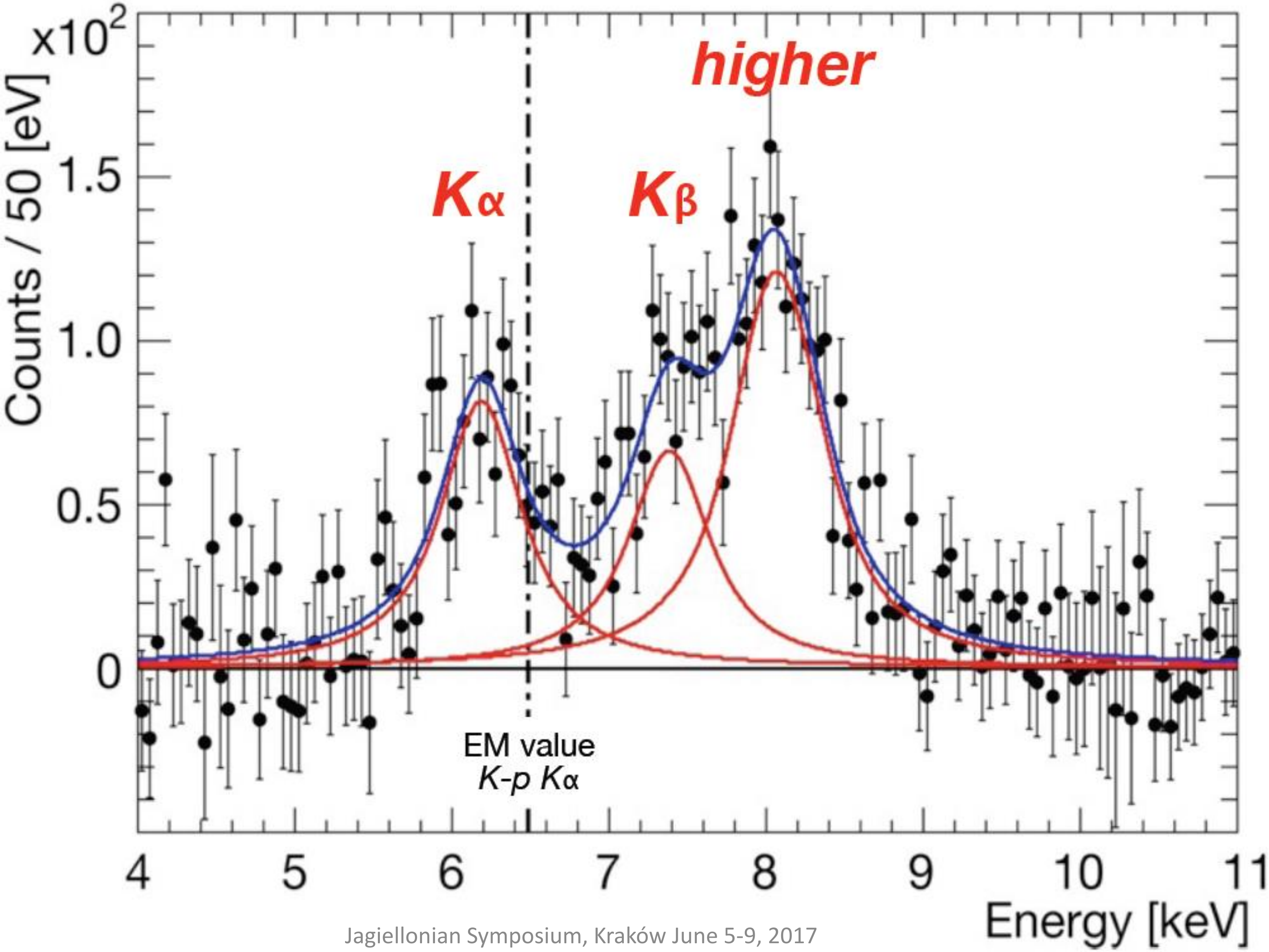
$$k = \frac{4\left[m_n + m_K\right]}{\left[2m_n + m_K\right]}$$

KAONIC HYDROGEN: KpX, DEAR and SIDDHARTA

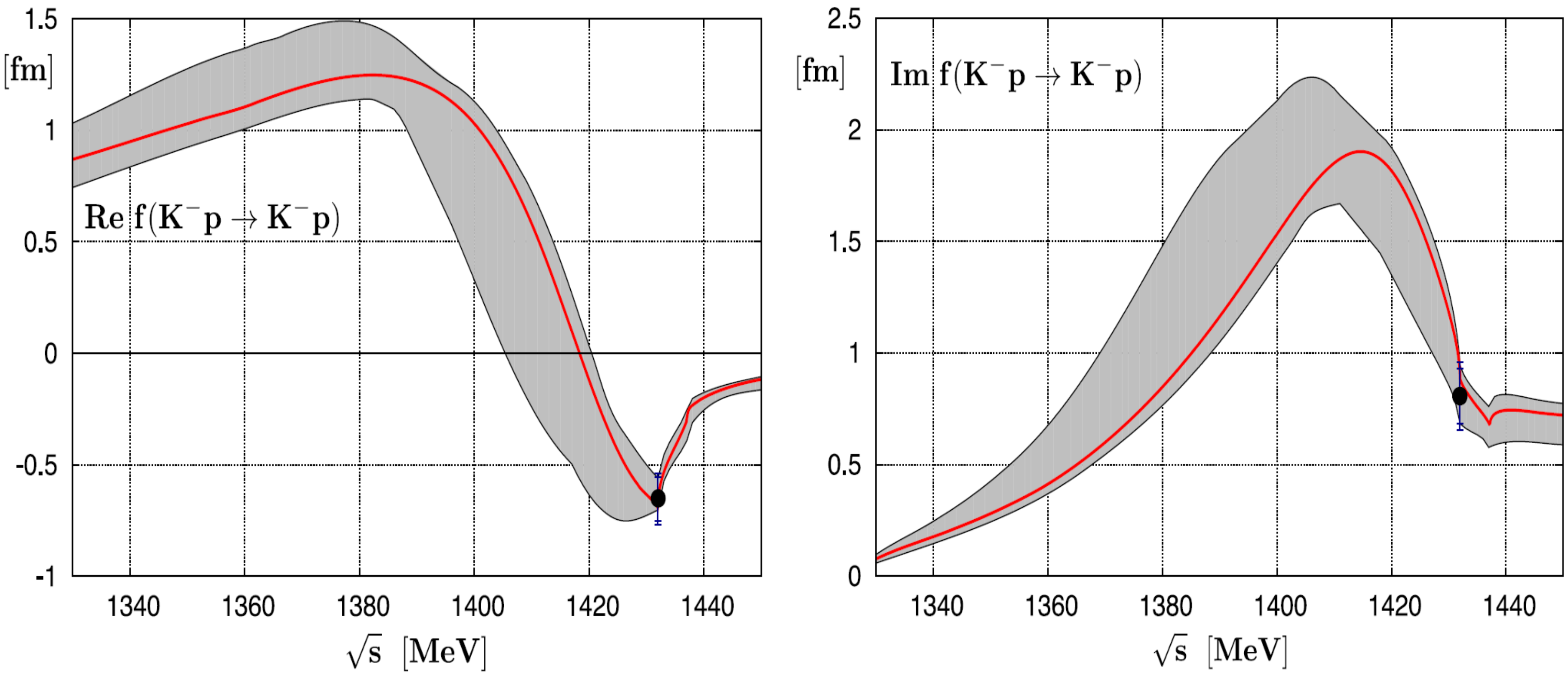
ε_{1s} = -283 ± 36(stat) ± 6(syst) eV
Γ_{1s} = 541 ± 89(stat) ± 22(syst) eV



K⁻p SPECTRUM, BG SUBTRACTED



Improved constraints on chiral SU(3) dynamics from kaonic hydrogen:
Y. Ikeda, T. Hyodo and W. Weise, PLB 706 (2011) 63



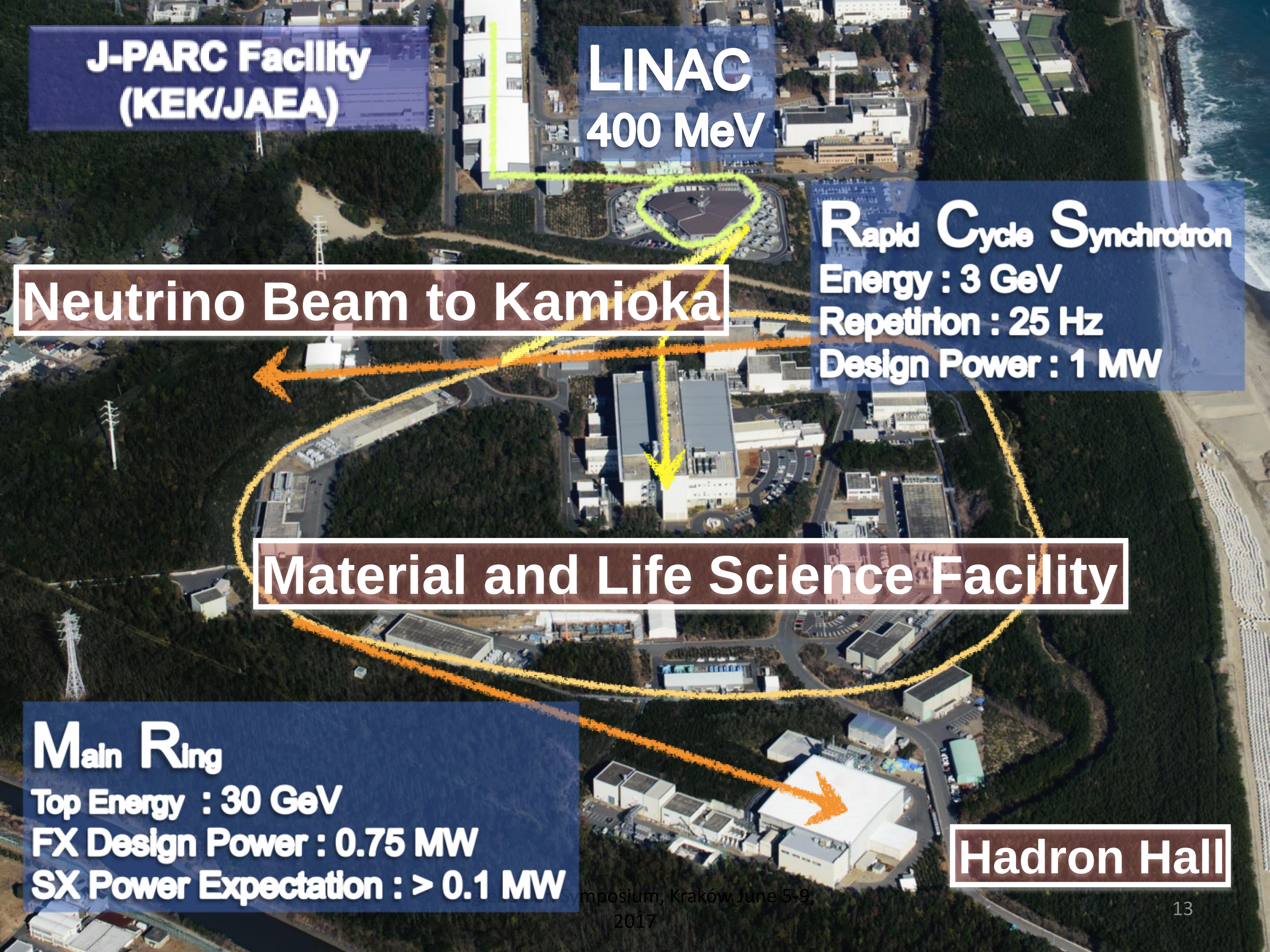
Real part (left) and imaginary part (right) of the $K^-p \to K^-p$ forward scattering amplitude extrapolated to the subthreshold region, deduced from the SIDDHARTA kaonic hydrogen measurement.

K-d at J-PARC

K–d collaboration

LNF- INFN, Frascati, Italy
SMI- ÖAW, Vienna, Austria
IFIN – HH, Bucharest, Romania
Politecnico, Milano, Italy
RIKEN, Japan
Tokyo Univ., Japan
Victoria Univ., Canada
KEK, Tsukuba, Japan
RCNP, Osaka, Japan
Seoul Univ., South Korea
Zagreb Univ., Croatia
INFN, Torino, Italy
Osaka Univ., Japan
TUM, Garching, Germany
Kyoto Univ., Japan
Jagiellonian Univ., Poland
RCJ, Juelich, Germany
Santiago de Compostela Univ., Spain
Tohoku Univ., Japan
KIRAMS, Seoul, South Korea

20 Institutes / 10 Countries


J-PARC Facility
(KEK/JAEA)
LINAC
400 MeV
Rapid Cycle Synchrotron
Energy : 3 GeV
Repetirion : 25 Hz
Design Power : 1 MW
Neutrino Beam to Kamioka
Material and Life Science Facility
Main Ring
Top Energy : 30 GeV
FX Design Power : 0.75 MW
SX Power Expectation : > 0.1 MW
Hadron Hall

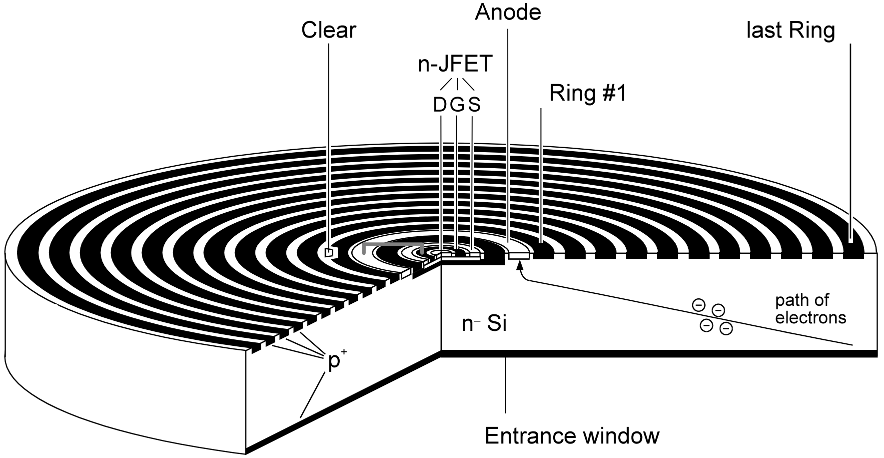
K^-d AT J-PARC

- X-ray detection → large active area
- charge particle tracking → BG supression
- light-weight cryogenic target → X-ray transmission
- high momentum K^- beam → degrader

Development of new SDD-chips

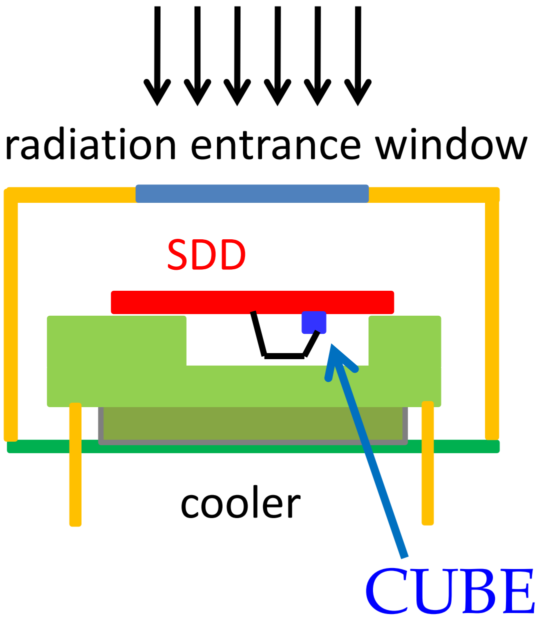
➢ SIDDHARTA

- JFET integrated on SDD
- lowest total anode capacitance
- limited JFET performance
- sophisticated SDD+JFET technology



➢ $K^{-}d$ @ J-PARC / DAΦNE

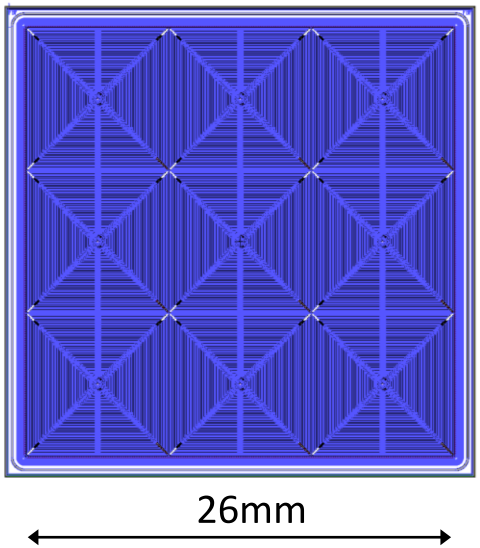
- external CUBE preamplifier (MOSFET input transistor)
- larger total anode capacitance
- better FET performances
- standard SDD technology

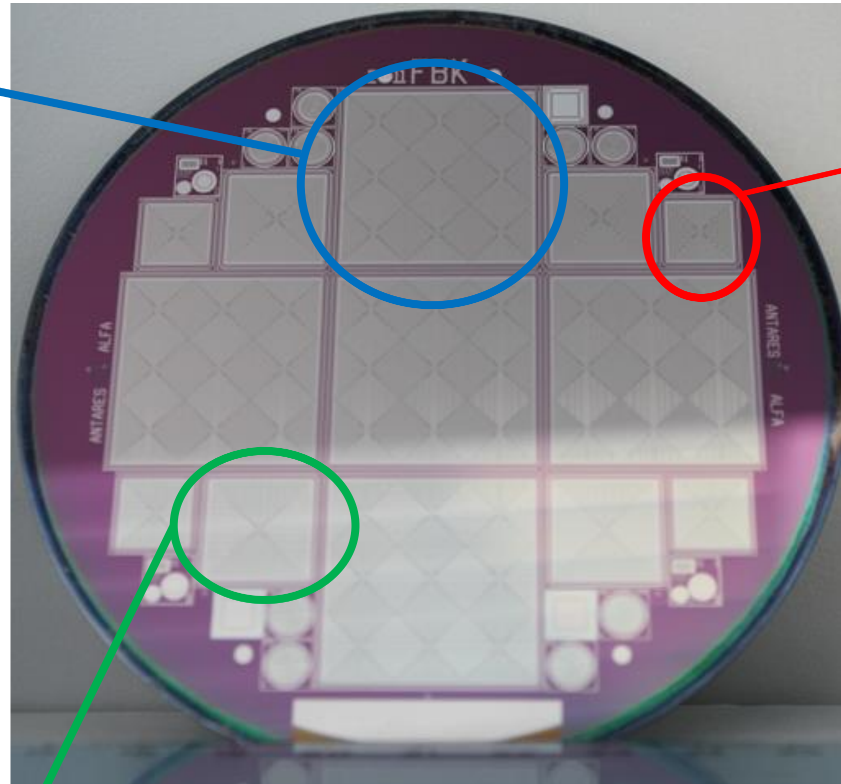


Large area Silicon Drift Detector

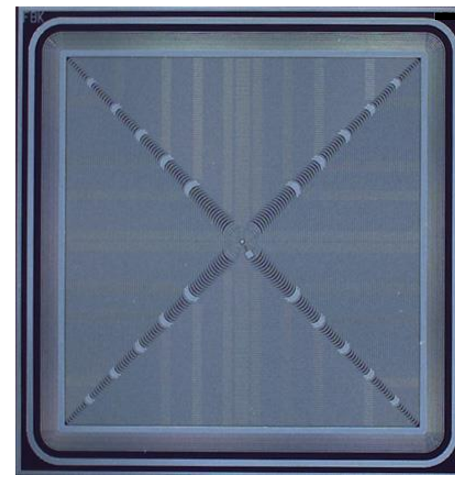
developed by Politech Milano and FBK-Trento, Italy

Array: 9 SDDs
(8 x 8 mm^2
each)





8 x 8 mm^2
single SDD

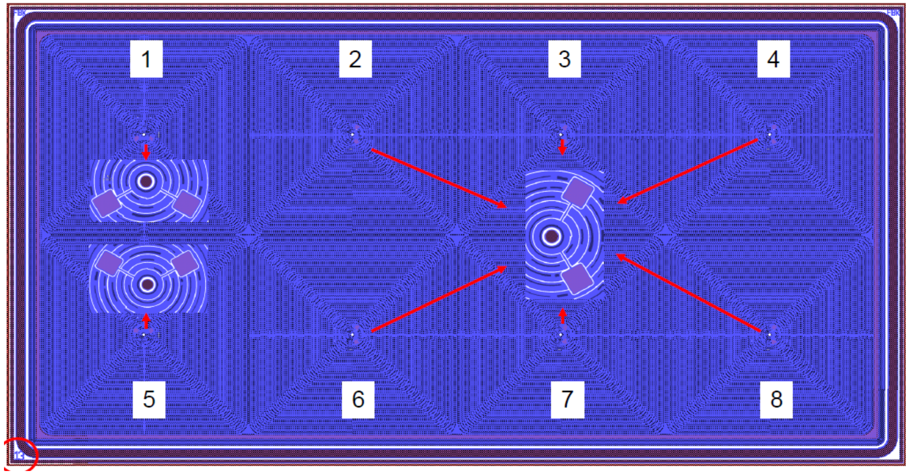


12 x 12 mm
single SDD

FBK production:

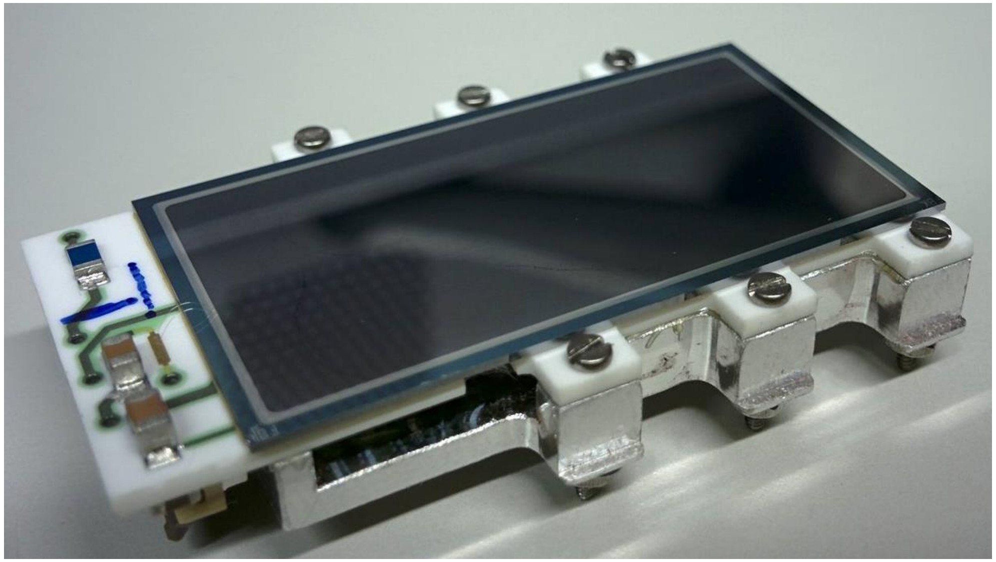
- 4" wafer
- 6" wafer upgrade just finished

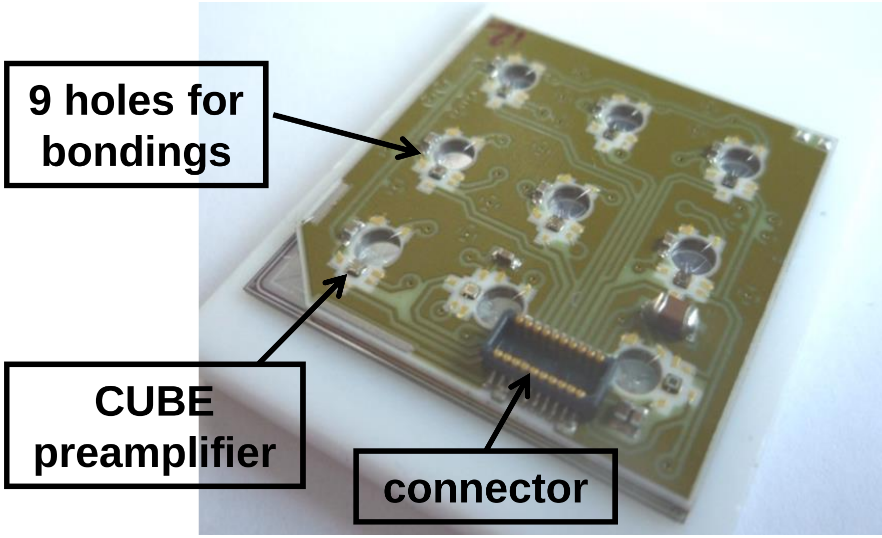
The new 4x2 SDD array for K⁻d



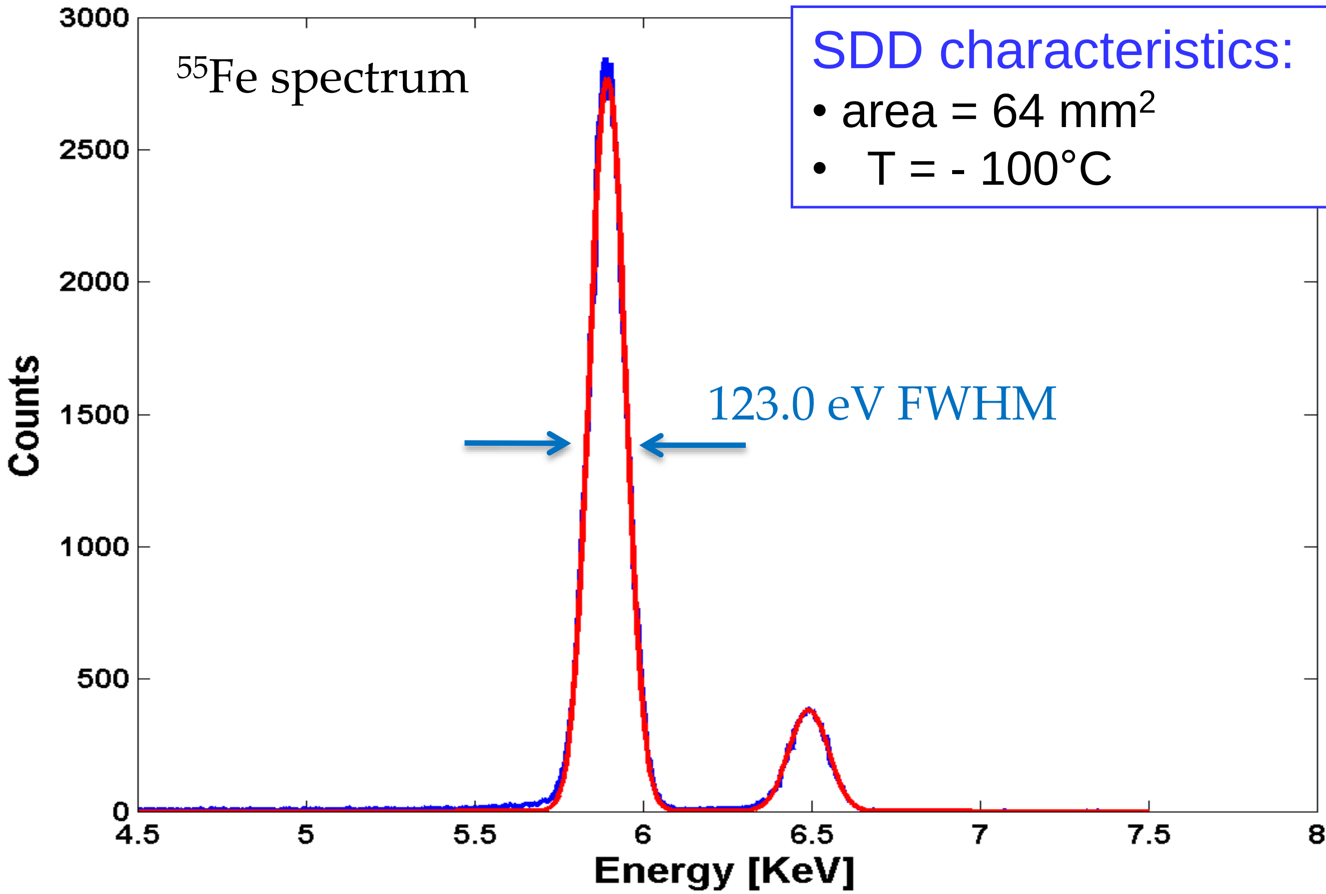
SDD-chip back side with bonding pads

SDD-chip glued to ceramic board, bonded to CUBE preamplifier





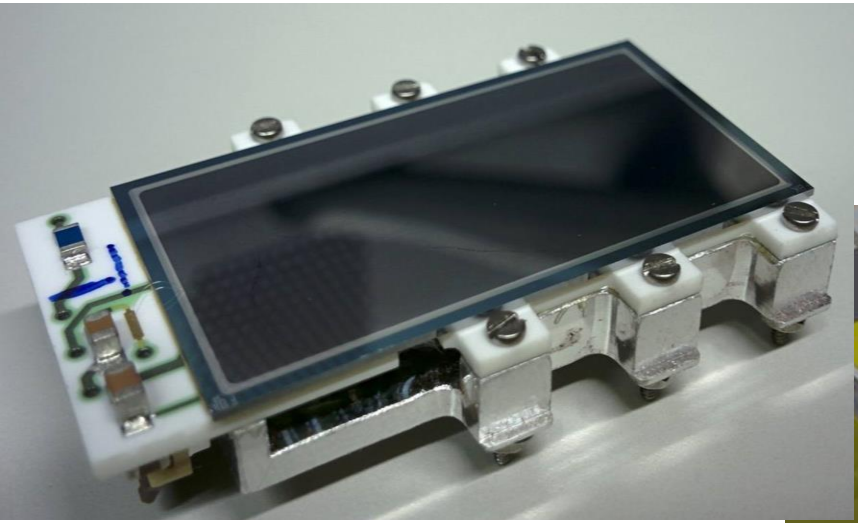
New SDD technology with CUBE preamplifier

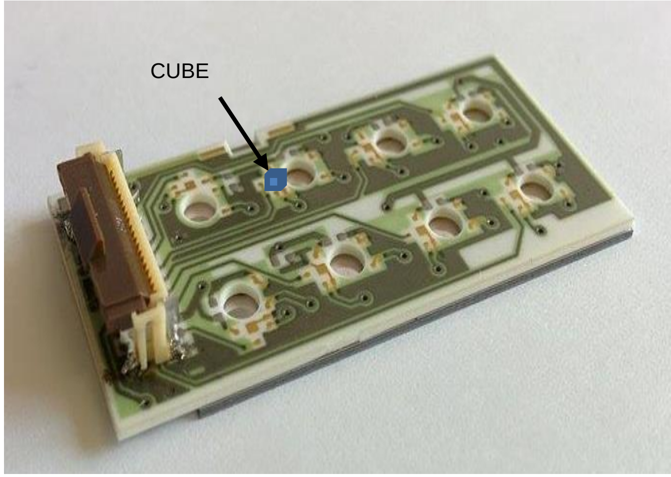


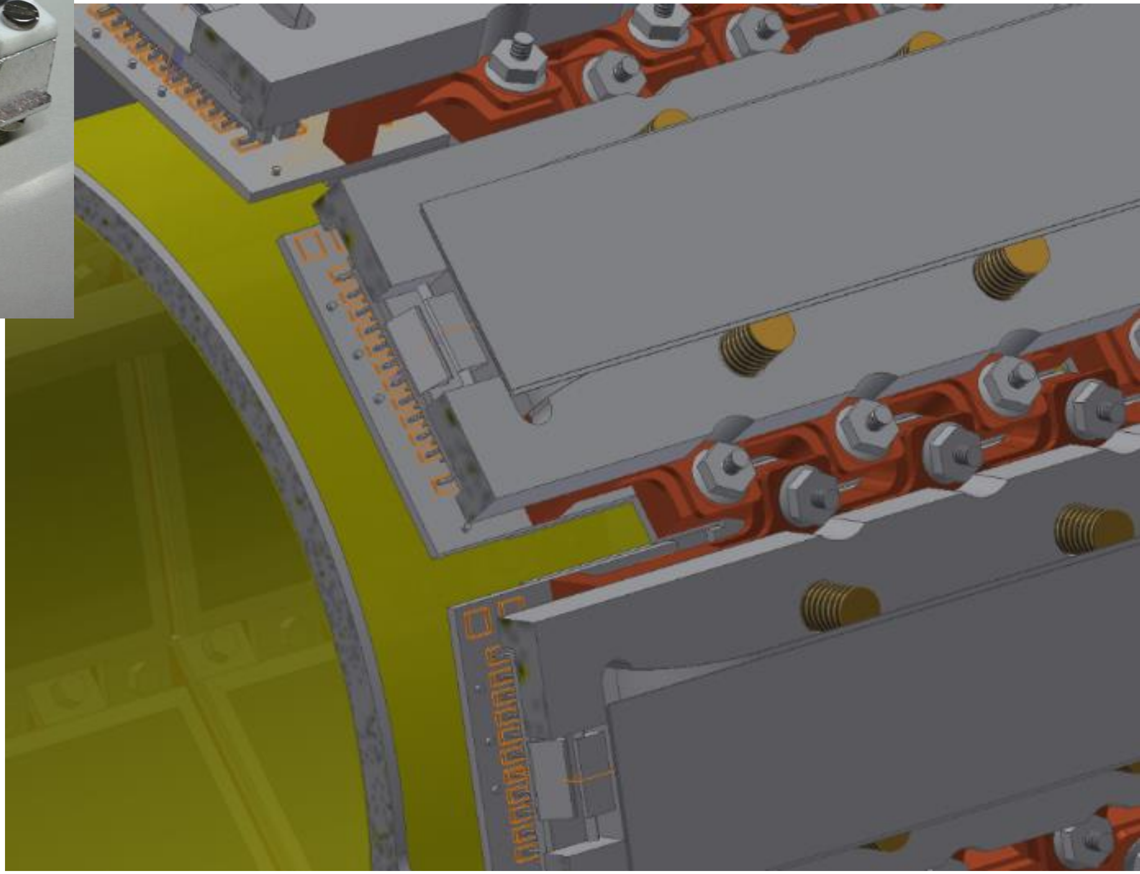
SDD characteristics:
- area = 64 mm^2
- T = - 100°C

first series of new SDD-chips available

4x2 SDD array – layout + arrangement around target

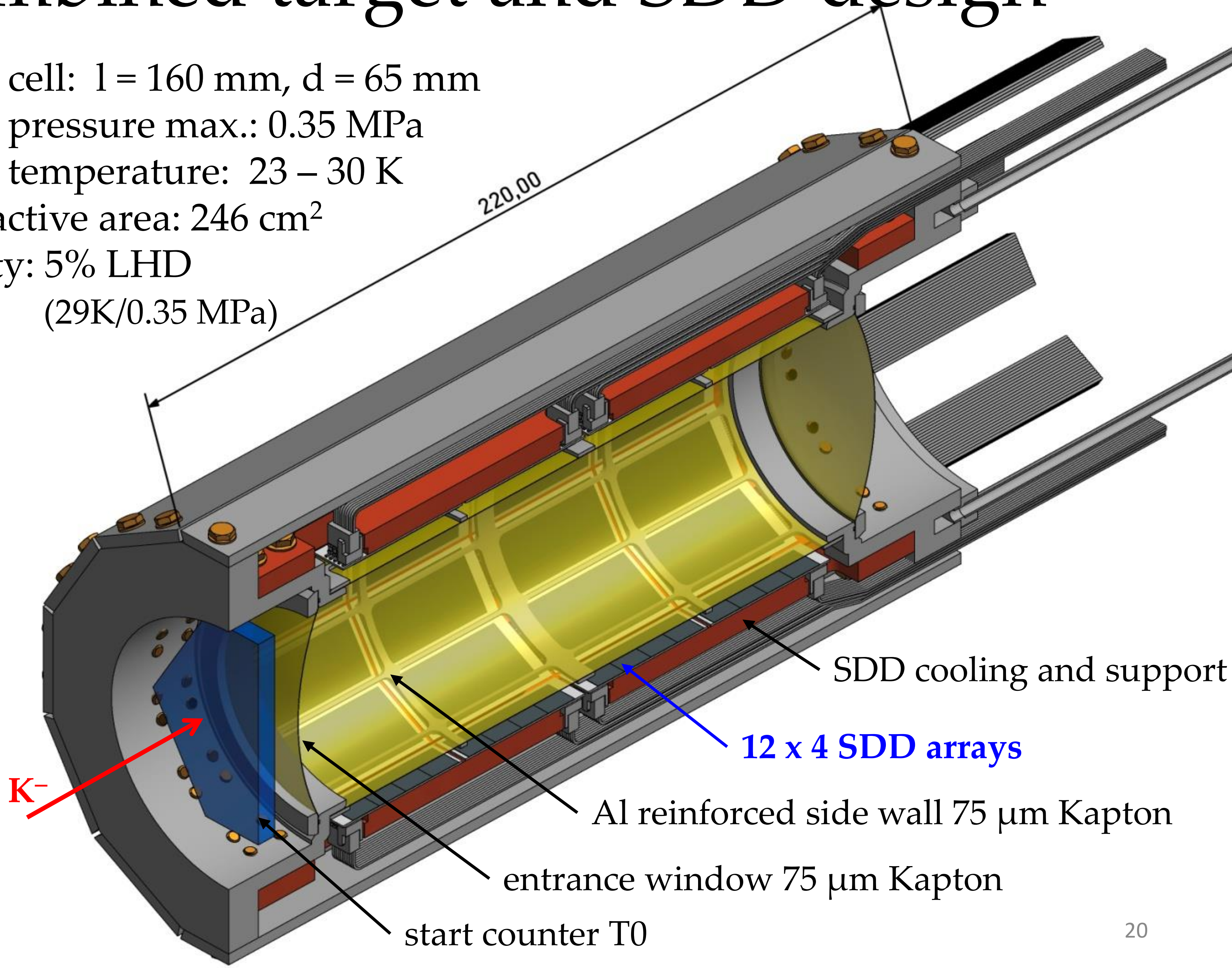




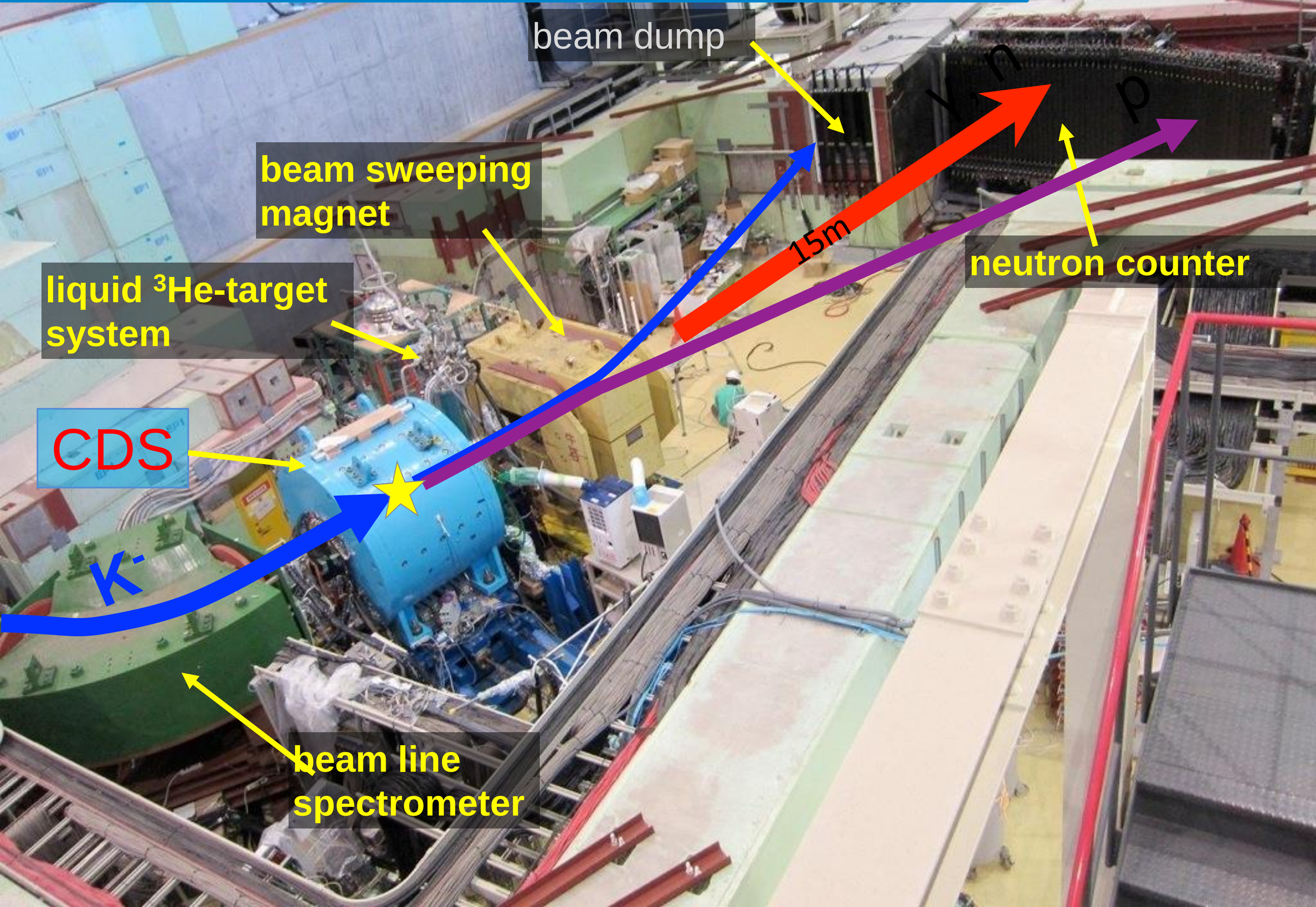


Combined target and SDD design

target cell: l = 160 mm, d = 65 mm
target pressure max.: 0.35 MPa
target temperature: 23 – 30 K
SDD active area: 246 cm^2
density: 5% LHD
(29K/0.35 MPa)

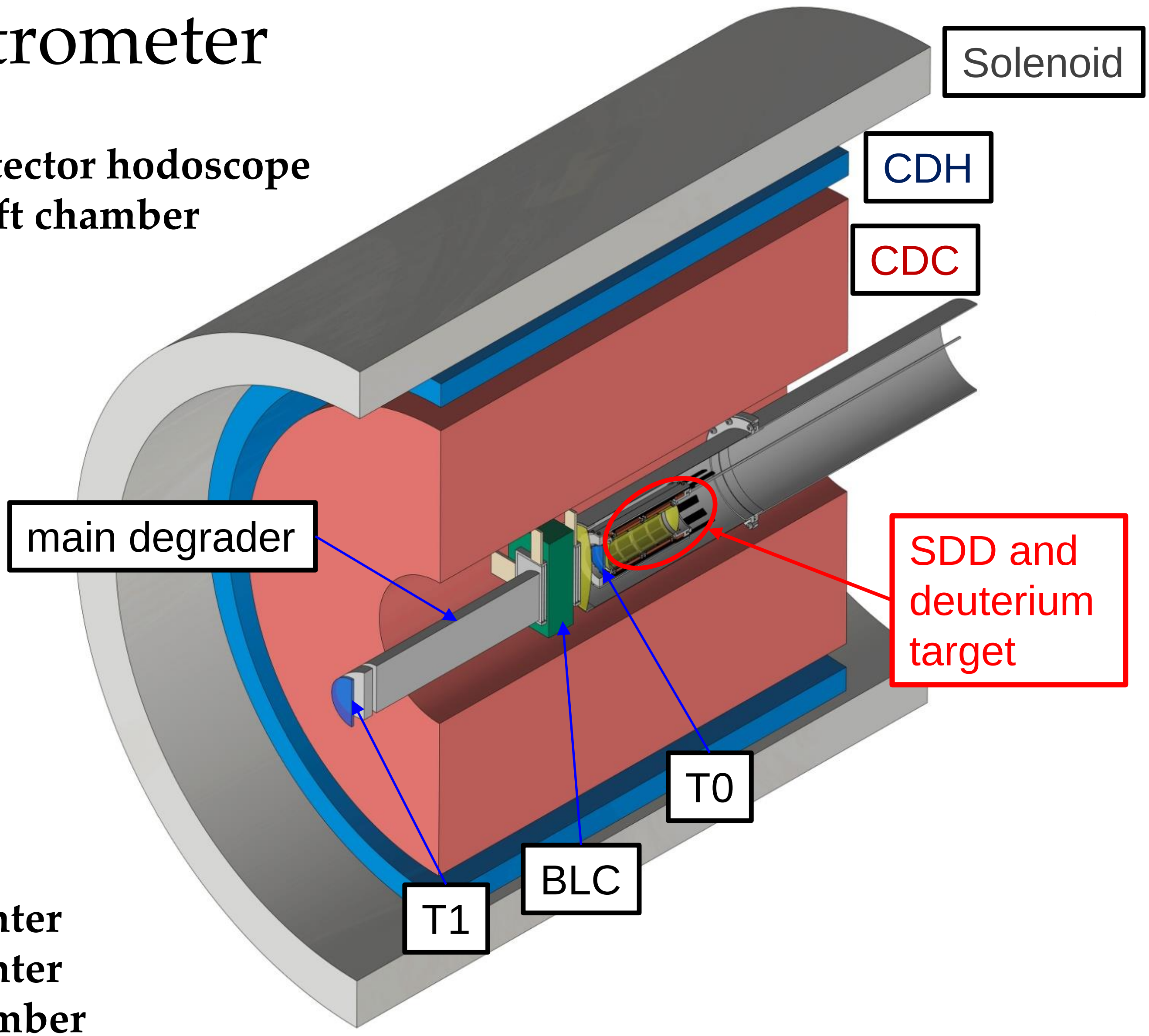


J-PARC K1.8BR spectrometer for E15



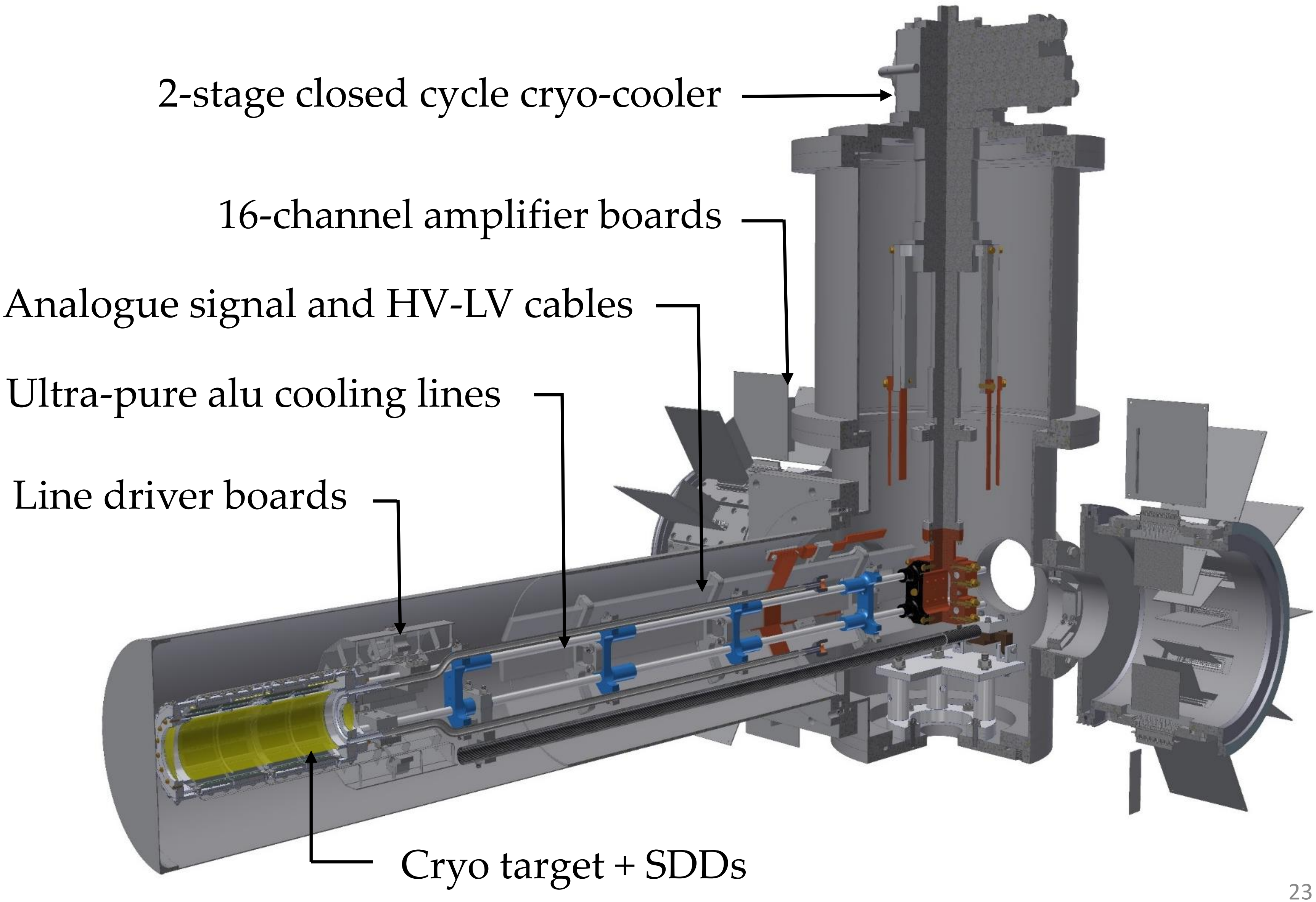
Charged particle tracking with the K1.8BR spectrometer

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



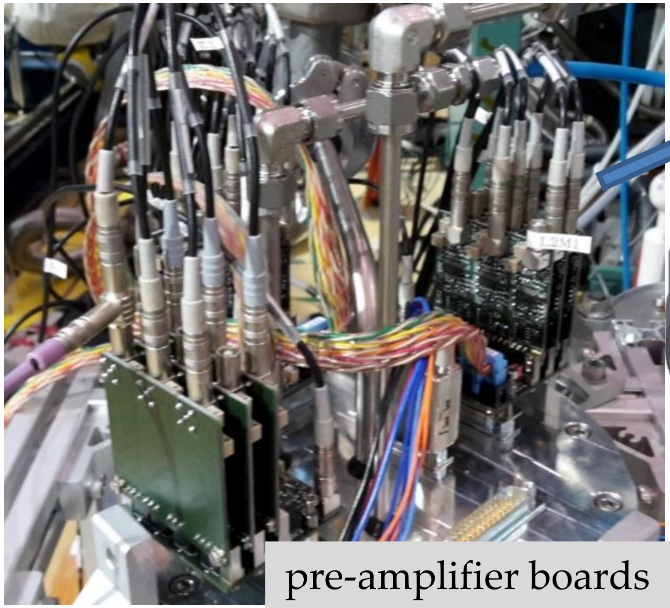
T0.......beam line counter
T1.......beam line counter
BLC....beam line chamber

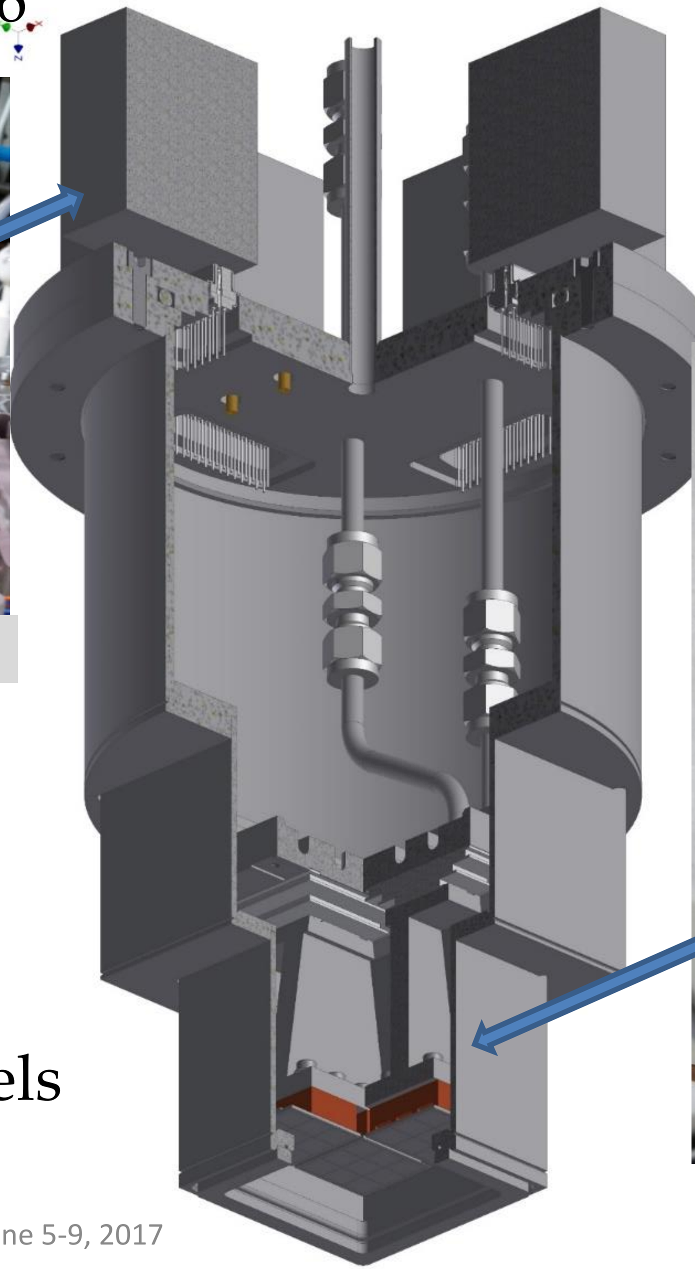
K$^-$d cryogenic target and SDD detector setup



E57 - SDD test setup

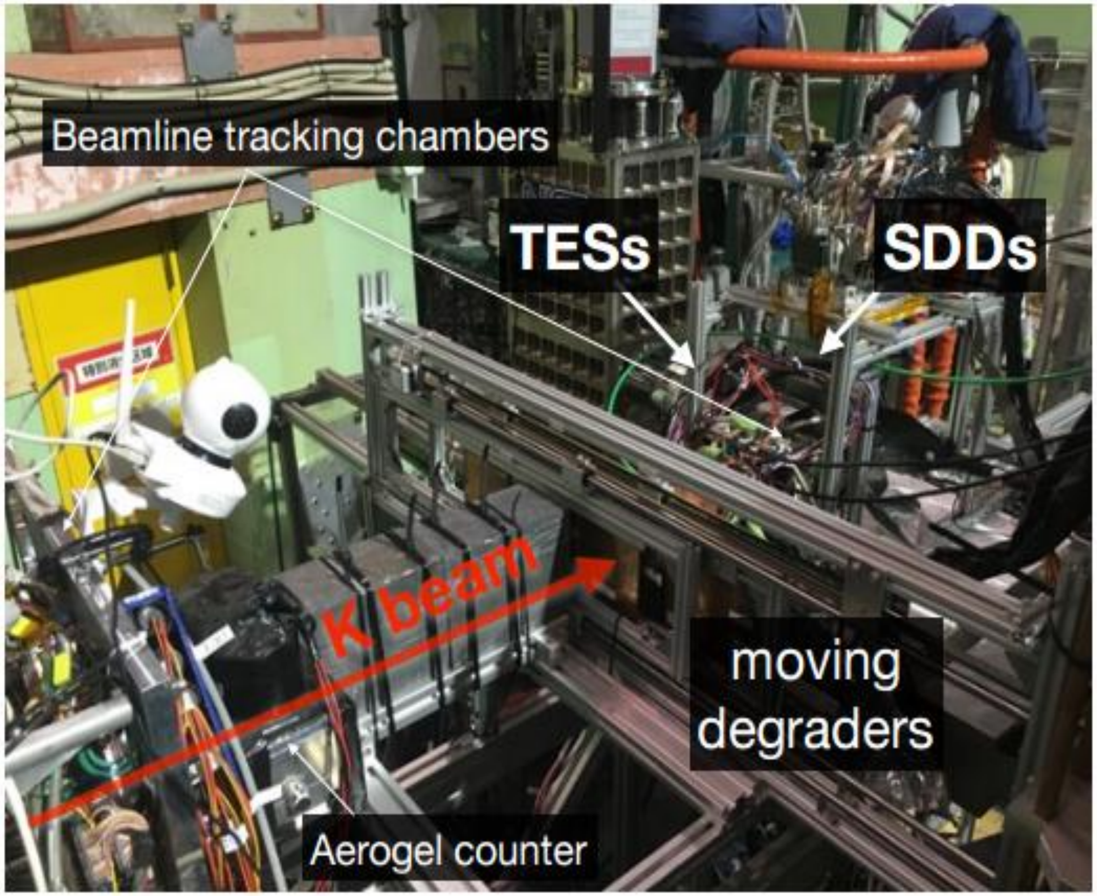
beam time June, 2016

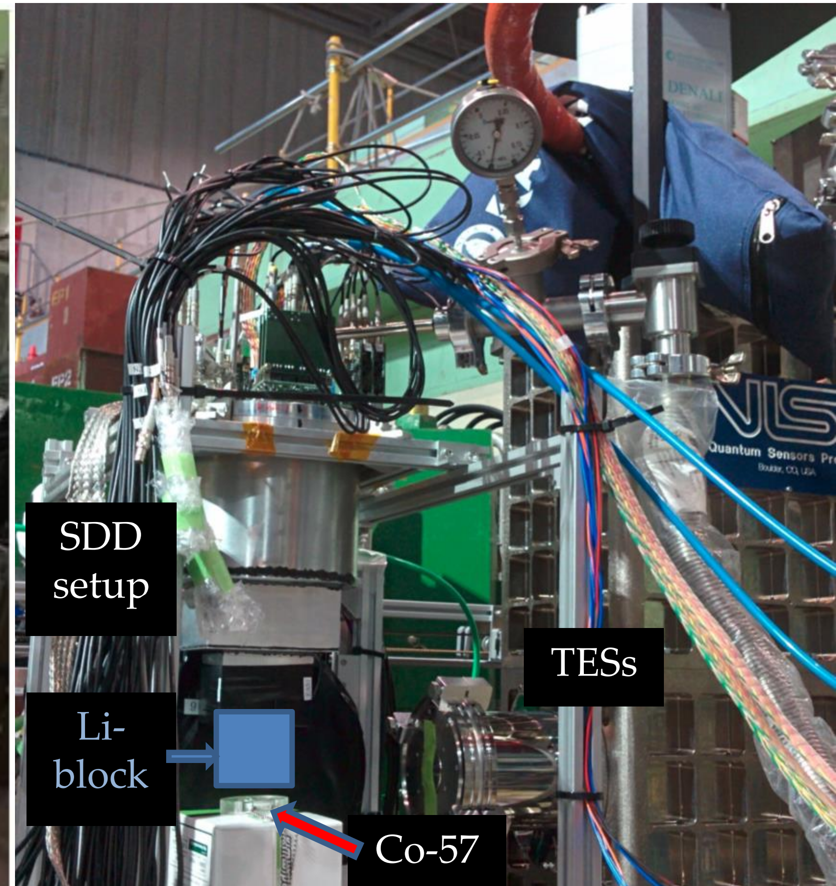




- 28 working channels

Setup of E57 and E62 in K1.8BR area





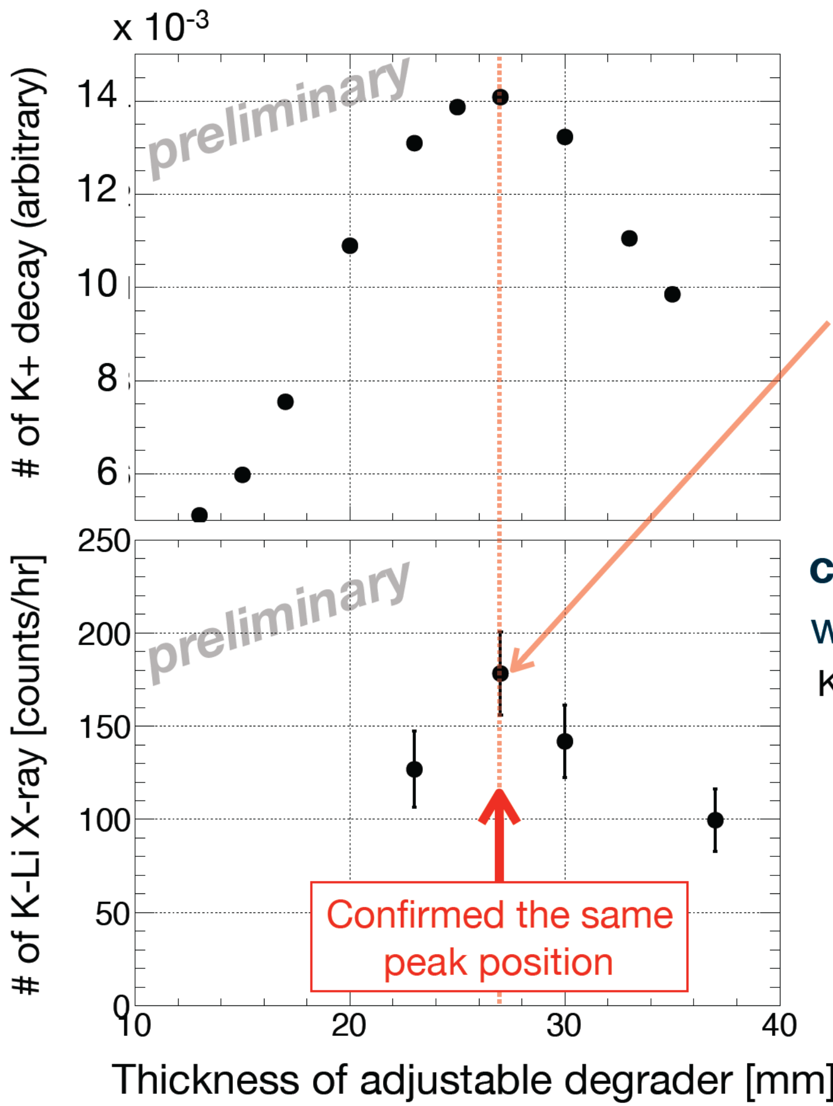
- ✓ optimisation of stopped kaons in low mass targets
- ✓ K^{-}Li X-ray intensity to background ratio and range tuning in agreement with MC simulation

STOPPED KAONS

RANGE CURVE MEASURED @ J-PARC – June 2016

with tracking chamber system for **0.9 GeV/c** **K⁺**

with SDDs for **0.9 GeV/c** **K⁻**



K-Li x-ray yield :
~180 counts / hr
(with 24 good SDDs)

consistent with G4 sim

within error of ref. value:

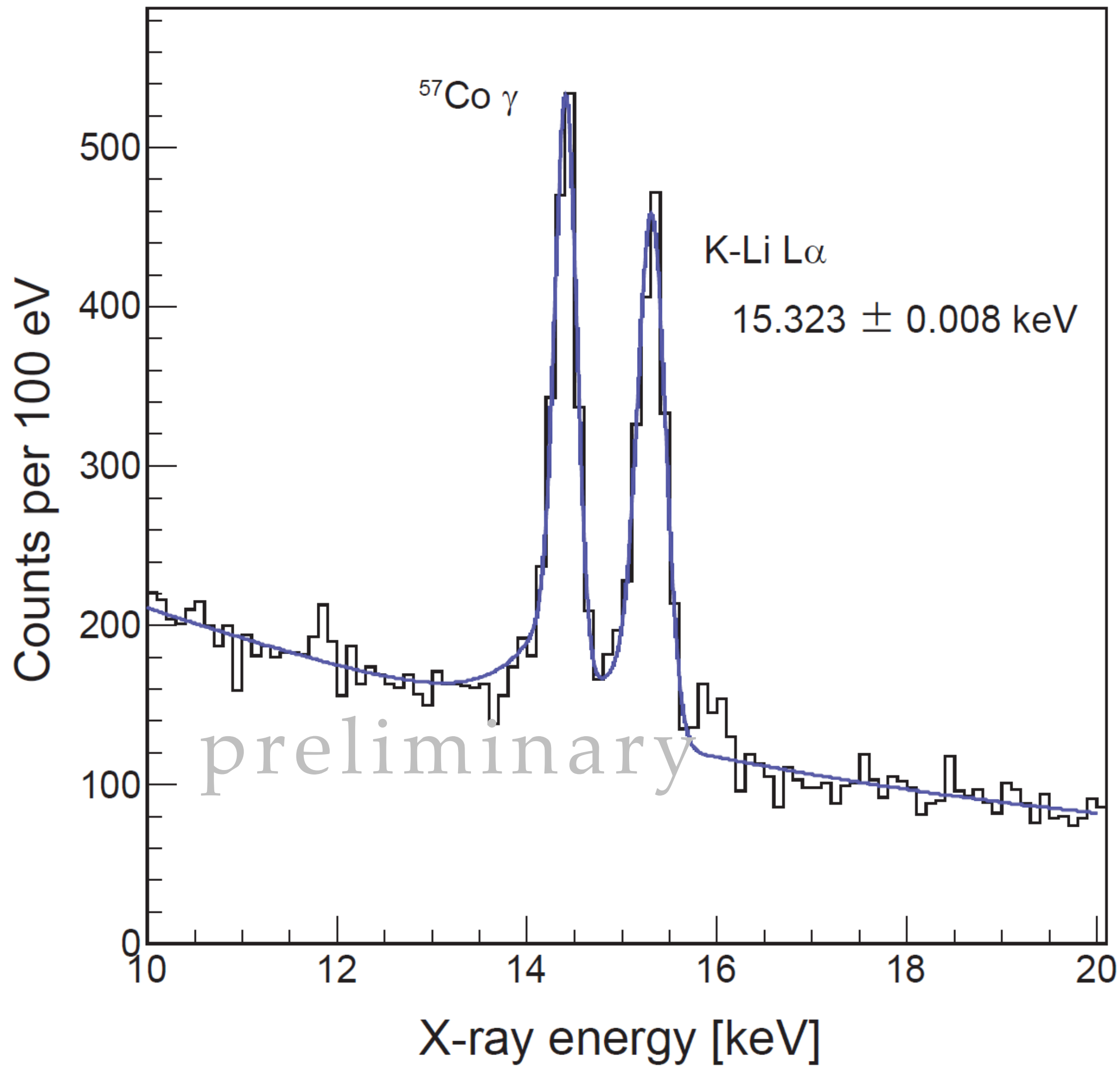
K-Li yield = 15 ± 3 % / stop K
[PRA 9 (1974) 2282]

Note that the simulation was performed again with obtained beam profile & actual geometrical inputs.

KAONIC LITHIUM 3→2

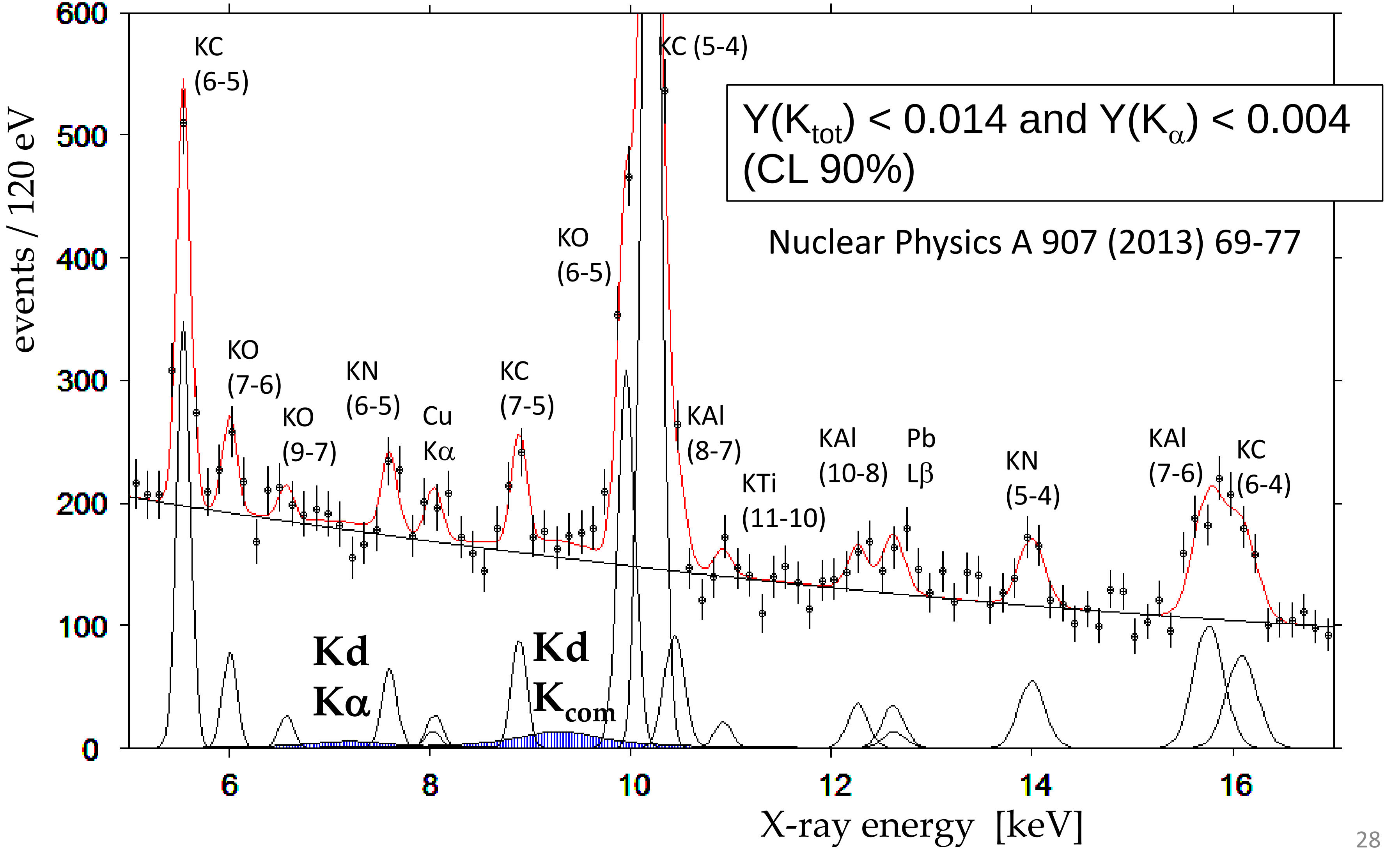
- ✓ Sum of K^- runs
  (0.7 and 0.9 GeV/c)
- ✓ 15.323 ± 0.008 keV
  ~ 1200 counts
  resolution 160 eV

$K^-Li_{L\alpha}$ transition:
15.330 keV (pure QED)
J.P.Santos et al.
Phys. Rev. A 71 (2005) 032501

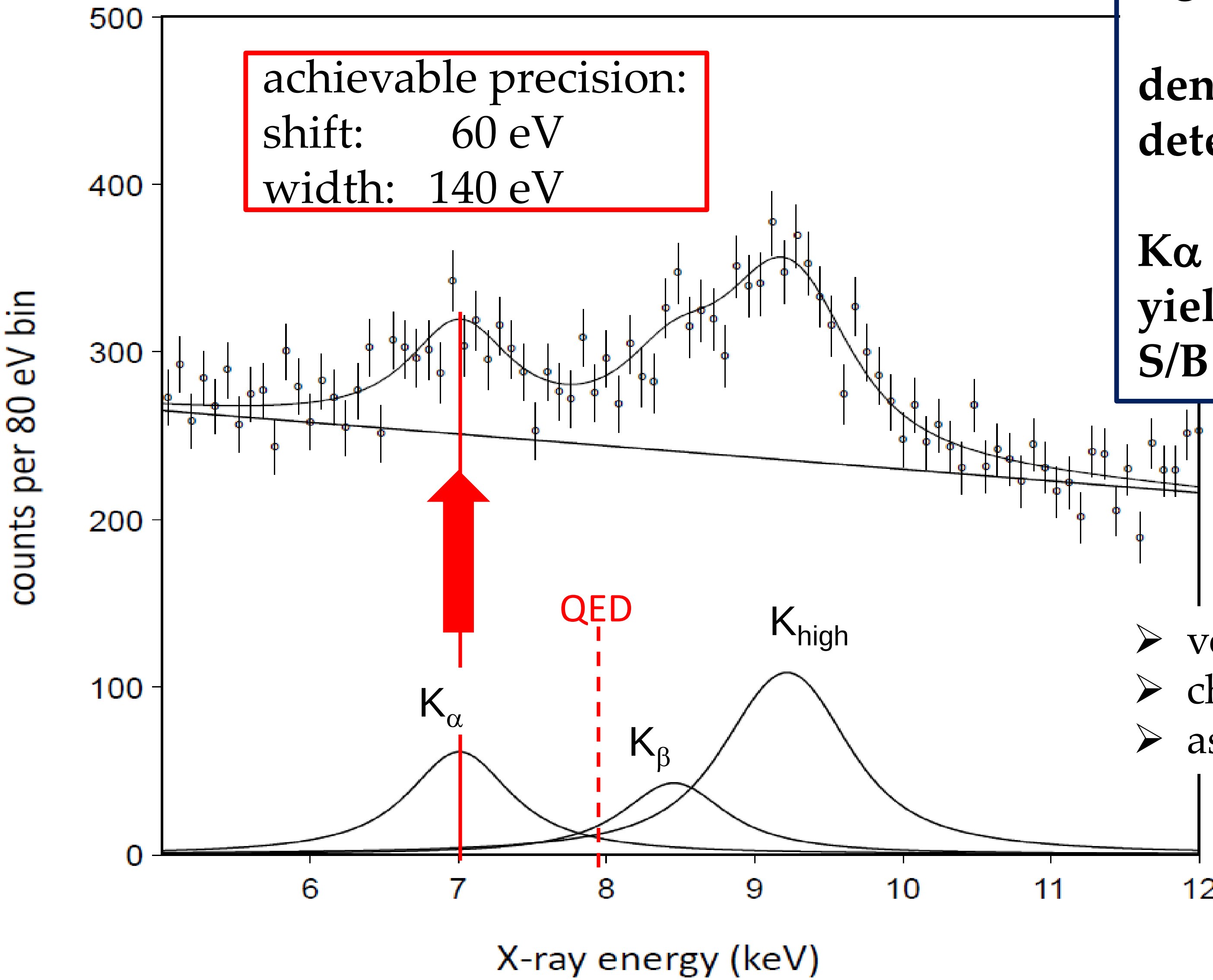


SIDDHARTA – deuterium target

fit constraints: shift: -500 eV
width: 1000 eV



Geant4 simulated $K^{-}d$ X-ray spectrum



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

Kα yield: 0.1 %
yield ratio as in $K^{-}p$
S/B ~ 1 : 4

- vertex cut
- charged particle veto
- asynchronous BG

K^-d scattering lengths - theory

a_{Kd} [fm]	ε_{1s} [eV]	Γ_{1s} [eV]	Reference
-1.55 + *i* 1.66	- 969	938	Weise 2015 [2]
-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]
-1.62 + *i* 1.91	- 1080	1024	Oset 2001 [3]

ε_{1s} = (-800 ± 60) eV

Γ_{1s} = (800 ± 140) eV

[1] M. Döring, U.-G. Meißner, Phys. Lett. B 704 (2011) 663

[2] W. Weise, arXiv:1412.7838[nucl-theo]2015

[3] S.S. Kamakov, E. Oset, A. Ramos, Nucl. Phys. A 690 (2001) 494

[4] T. Mizutani, C. Fayard, B. Saghai, K. Tsushima, Phys. Rev. C 87, 035201 (2013), arXiv:1211.5824[hep-ph]

[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

arXiv:1705.06857v1 [nucl-th] 19 May 2017

Constraining the $\bar{K}N$ interaction from the $1S$ level shift of kaonic deuterium

Tsubasa Hoshino,[1] Shota Ohnishi,[1] Wataru Horiuchi,[1] Tetsuo Hyodo,[2] and Wolfram Weise[2,3]

[1] *Department of Physics, Hokkaido University, Sapporo 060-0810, Japan*
[2] *Yukawa Institute for Theoretical Physics, Kyoto University, Kyoto 606-8502, Japan*
[3] *Physik-Department, Technische Universität München, 85748 Garching, Germany*

Motivated by the precise measurement of the $1S$ level shift of kaonic hydrogen, we perform accurate three-body calculations for the spectrum of kaonic deuterium using a realistic antikaon-nucleon ($\bar{K}N$) interaction. In order to describe both short- and long-range behavior of the kaonic atomic states, we solve the three-body Schrödinger equation with a superposition of a large number of correlated Gaussian basis functions covering distances up to several hundreds of fm. Transition energies between $1S$, $2P$ and $2S$ states are determined with high precision. The complex energy shift of the $1S$ level of kaonic deuterium is found to be $\Delta E - i\Gamma/2 = (670 - i\,508)$ eV. The sensitivity of this level shift with respect to the isospin $I = 1$ component of the $\bar{K}N$ interaction is examined. It is pointed out that an experimental determination of the kaonic deuterium level shift within an uncertainty of 25 % will provide a constraint for the $I = 1$ component of the $\bar{K}N$ interaction significantly stronger than that from kaonic hydrogen.

SUMMARY

Status of E57 at J-PARC

- first successful test run
- New robust SDDs developed – assembling is ongoing
- K-d target system under construction

- SIDDHARTA-2 at DAΦNE

- experiments at J-PARC E62, E15, E31, E27

Supported by

HadronPhysics I3 FP6 European Community program: Contract No. RII3-CT-2004-506078

European Community Research Infrastructure Integrating Activity "Study of Strongly Interacting Matter" (HadronPhysics2, Grant Agreement No. 227431) under the Seventh Framework Programme of EU

Austrian Federal Ministry of Science and Research BMBWK [650962/0001 VI/2/2009]

Romanian National Authority for Scientific Research [2-CeX 06-11-11/2006]

Grant-in-Aid for Specially Promoted Research (20002003), MEXT, Japan

Austrian Science Fund (FWF): P24756-N20

Thank you