



Kaonic Atoms

- KEK E570, SIDDHARTA, J-PARC E17 -

Ryugo S. Hayano
University of Tokyo

Experiments



E570	KEK	$K^- {}^4\text{He}$	Published
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Experiments



E570	KEK	$K^- {}^4\text{He}$	Published
SIDDHARTA	DAΦNE	$K^- p$, $K^- d$, $K^- {}^4\text{He}$, $K^- {}^3\text{He}$	Data taken

Experiments



E570	KEK	$K^- {}^4\text{He}$	Published
SIDDHARTA	DAΦNE	$K^- p$, $K^- d$, $K^- {}^4\text{He}$, $K^- {}^3\text{He}$	Data taken
E17	J-PARC	$K^- {}^3\text{He}$	“Day-1”

The E570 collaboration

G. Beer¹, H. Bhang², M. Cargnelli³, J. Chiba⁴, S. Choi²,
C. Curceanu⁵, Y. Fukuda⁶, T. Hanaki⁴, R. S. Hayano⁷, M. Iio⁸,
T. Ishikawa⁷, S. Ishimoto⁹, T. Ishiwatari³, K. Itahashi⁸, M. Iwai⁹,
M. Iwasaki⁸, B. Juhasz³, P. Kienle³, J. Marton³, Y. Matsuda⁸,
H. Ohnishi⁸, S. Okada⁸, H. Oota⁸, M. Sato⁶, P. Schmid³,
S. Suzuki⁹, T. Suzuki⁸, H. Tatsuno⁷, D. Tomono⁸,
E. Widmann³, T. Yamazaki⁸, H. Yim², J. Zmeskal³

Victoria Univ.¹, SNU², SMI³, TUS⁴, INFN(LNF)⁵,
Tokyo Tech⁶, Univ. of Tokyo⁷, RIKEN⁸, KEK⁹

The E15/E17 collaboration

S. Ajimura¹, G. Beer², H. Bhang³, P. Buehler⁴, L. Busso^{5,6}, M. Cargnelli⁴, J. Chiba⁷,
S. Choi³, C. Curceanu⁸, D. Faso^{5,6}, H. Fujioka⁹, Y. Fujiwara¹⁰, T. Fukuda¹¹,
C. Guaraldo⁸, R.S. Hayano¹², T. Hiraiwa¹³, A. Hirtl⁴, M. Iio⁹, M. Iliescu⁸, T. Ishikawa¹²,
S. Ishimoto¹⁴, T. Ishiwatari⁴, K. Itahashi⁹, M. Iwai¹⁴, M. Iwasaki^{9,10}, B. Juhasz⁴,
P. Kienle^{4,15}, J. Marton⁴, Y. Matsuda¹², Y. Mizoi¹⁰, O. Morra^{5,16}, T. Nagae¹³, H. Noumi¹,
H. Ohnishi⁹, S. Okada⁸, H. Oota⁹, D. Pietreanu⁸, A. Sakaguchi¹⁷, F. Sakuma⁹, M. Sato⁹,
M. Sekimoto¹⁴, D. Sirghi⁸, F. Sirghi⁸, P. Schmid⁴, S. Suzuki¹⁴, T. Suzuki¹², H. Tatsuno¹²,
M. Tokuda¹⁰, D. Tomono⁹, A. Toyoda¹⁴, K. Tsukada⁹, E. Widmann⁴, T. Yamazaki^{9,12},
H. Yim³, J. Zmeskal⁴

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⁵ INFN Sezione di Torino, Italy, ⁶ Università di Torino, Italy, ⁷ Tokyo University of Science, Japan,

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¹³ Kyoto University, Japan, ¹⁴ KEK, Japan, ¹⁵ Technische Universität München, Germany,

¹⁶ INAF-IFSI, Sezione di Torino, Italy, ¹⁷ Osaka University, Japan

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, 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, A. Tudorache^d, V. Tudorache^d, O. Vazquez Doce^a, E. Widmann^e, J. Zmeskal^e

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^c Politechno di Milano, Sez. di Elettronica, Milano, Italy

^d IFIN-HH, Magurele, Bucharest, Romania

^e Stefan-Meyer-Institut für subatomare Physik, Vienna, Austria

^f INFN Sez. di Roma I and Inst. Superiore di Sanita, Roma, Italy

^g Univ. of Tokyo, Tokyo, Japan

^h RIKEN, The Inst. of Phys. and Chem. Research, Saitama, Japan

ⁱ Tech. Univ. München, Physik Dep., Garching, Germany

Two more talks (session 3B)



Michael Cargnelli (Vienna)

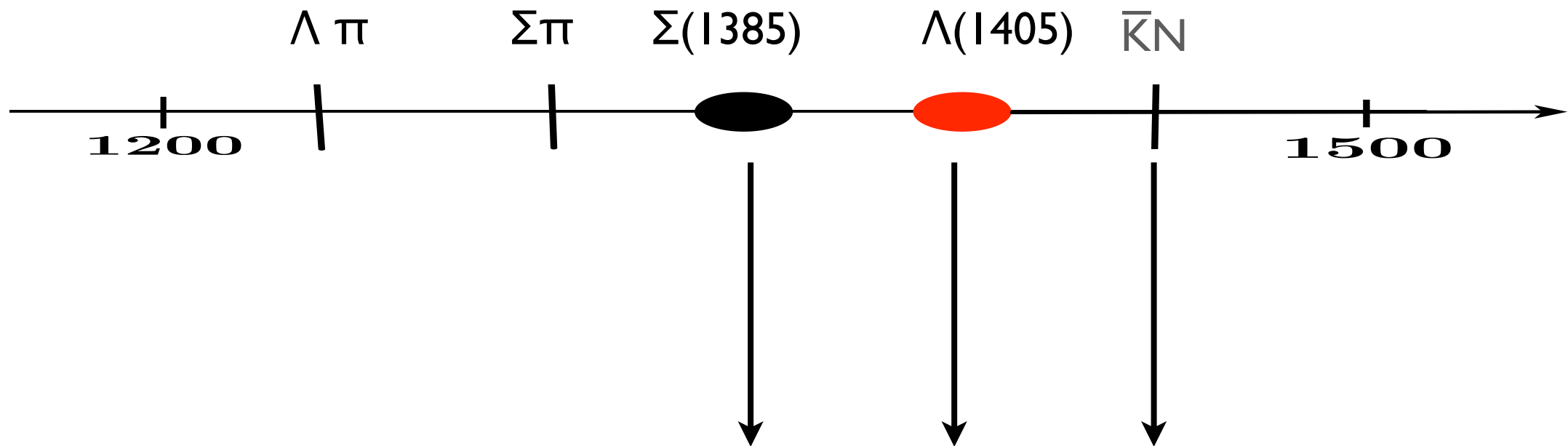
Precision spectroscopy of light kaonic atom X-rays in the **SIDDHARTA** experiment

Masaharu Sato (Tokyo)

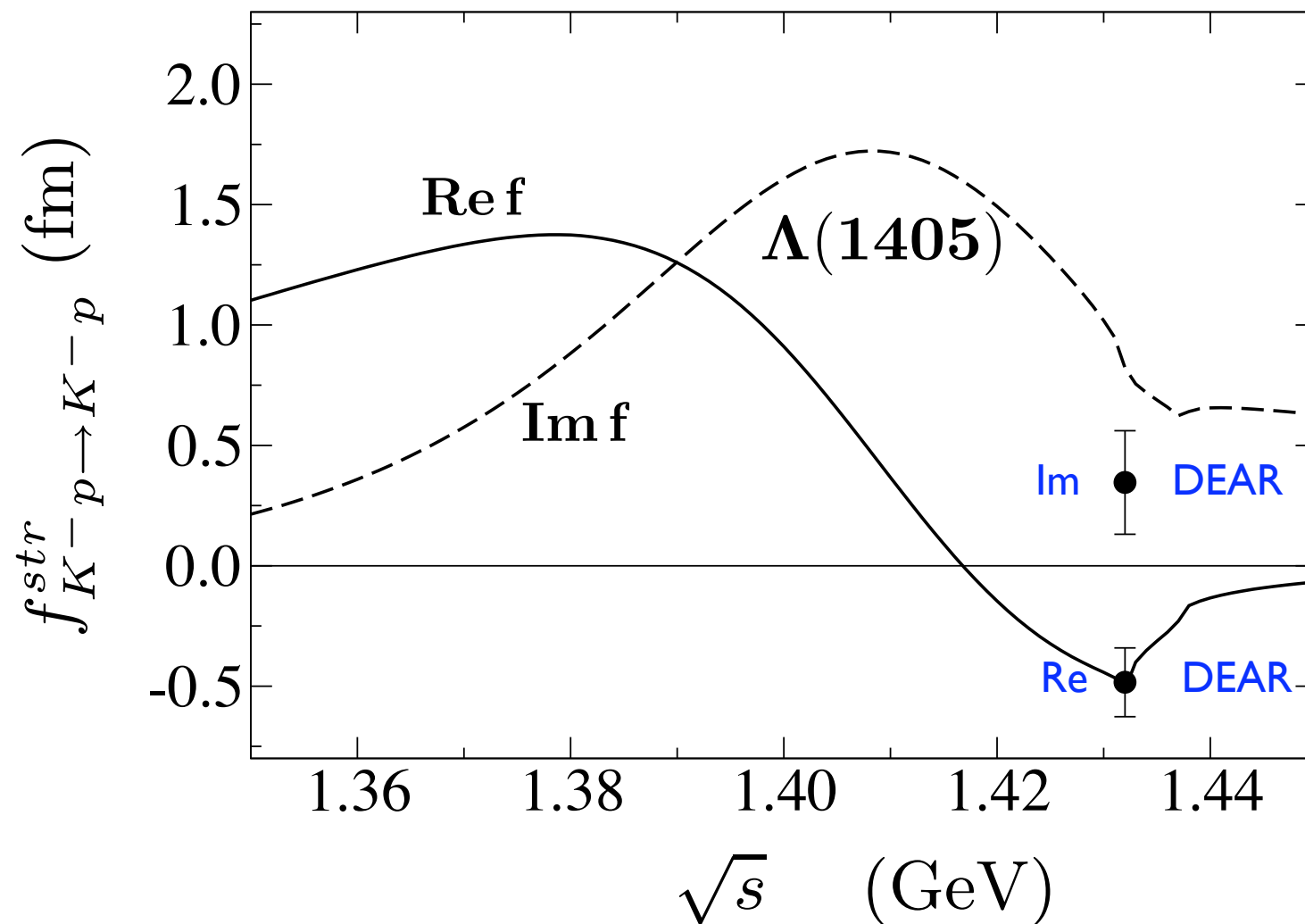
Precision spectroscopy of kaonic ^3He X-rays at **J-PARC**

何故
Why?

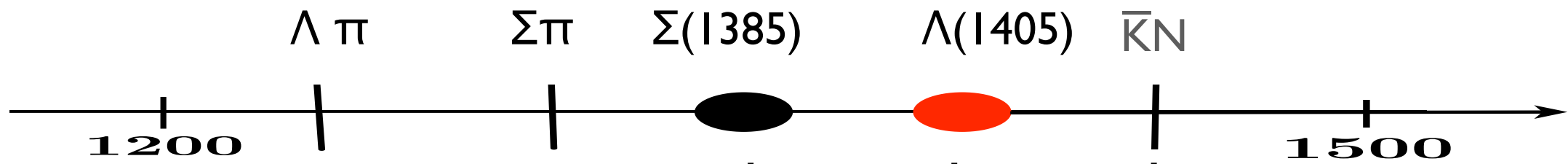
$\bar{K}N$ at threshold



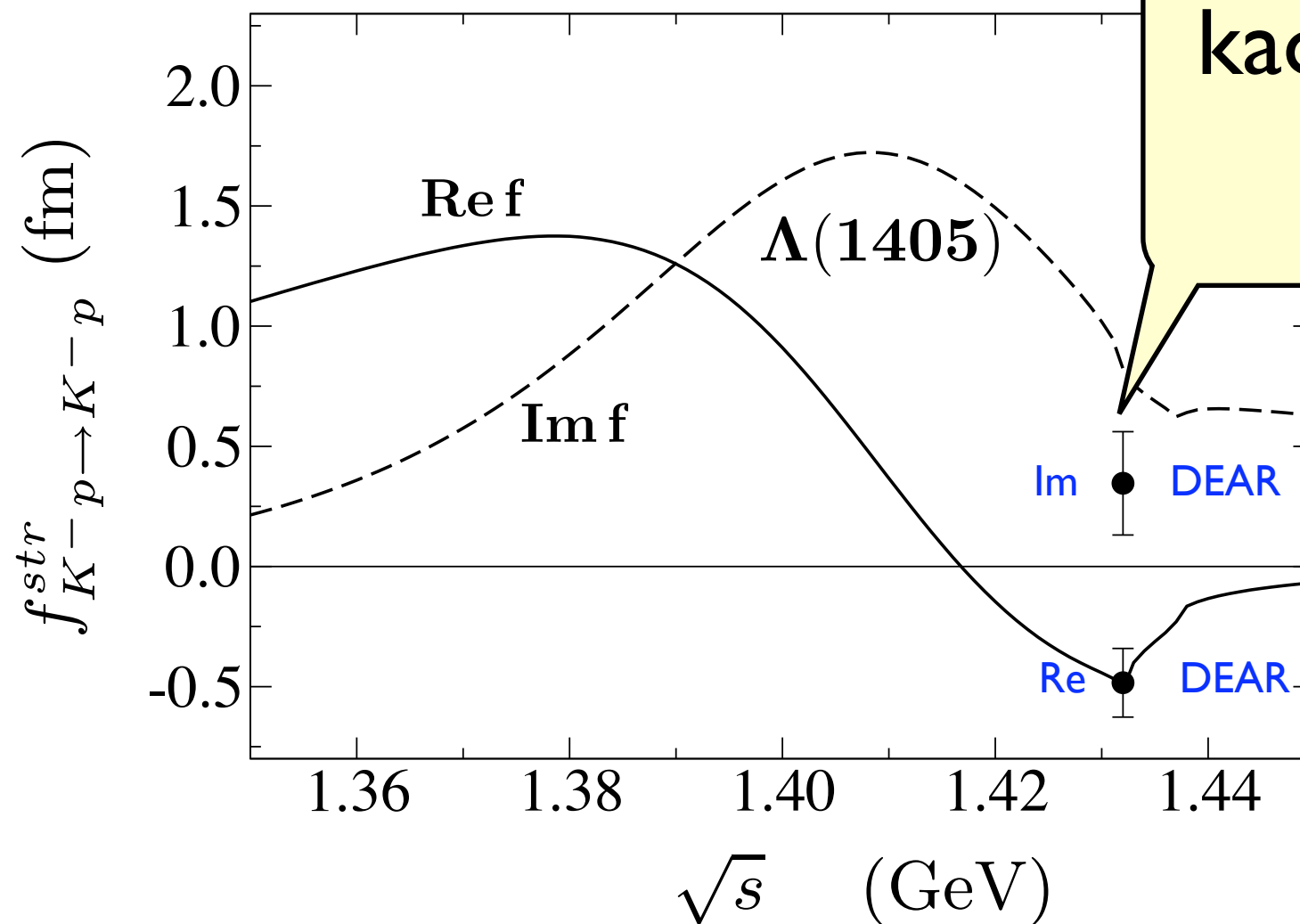
strong elastic amplitude



$\bar{K}N$ at threshold

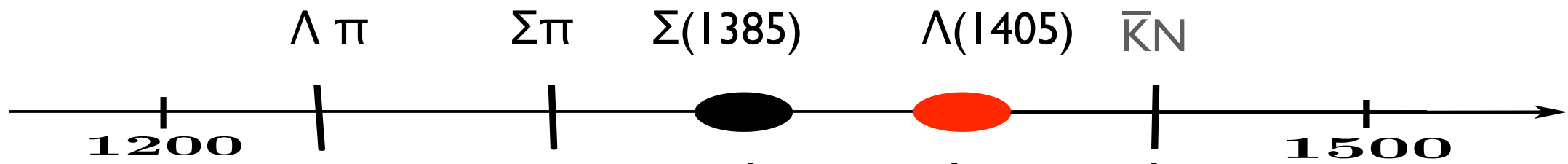


strong elastic amplitude

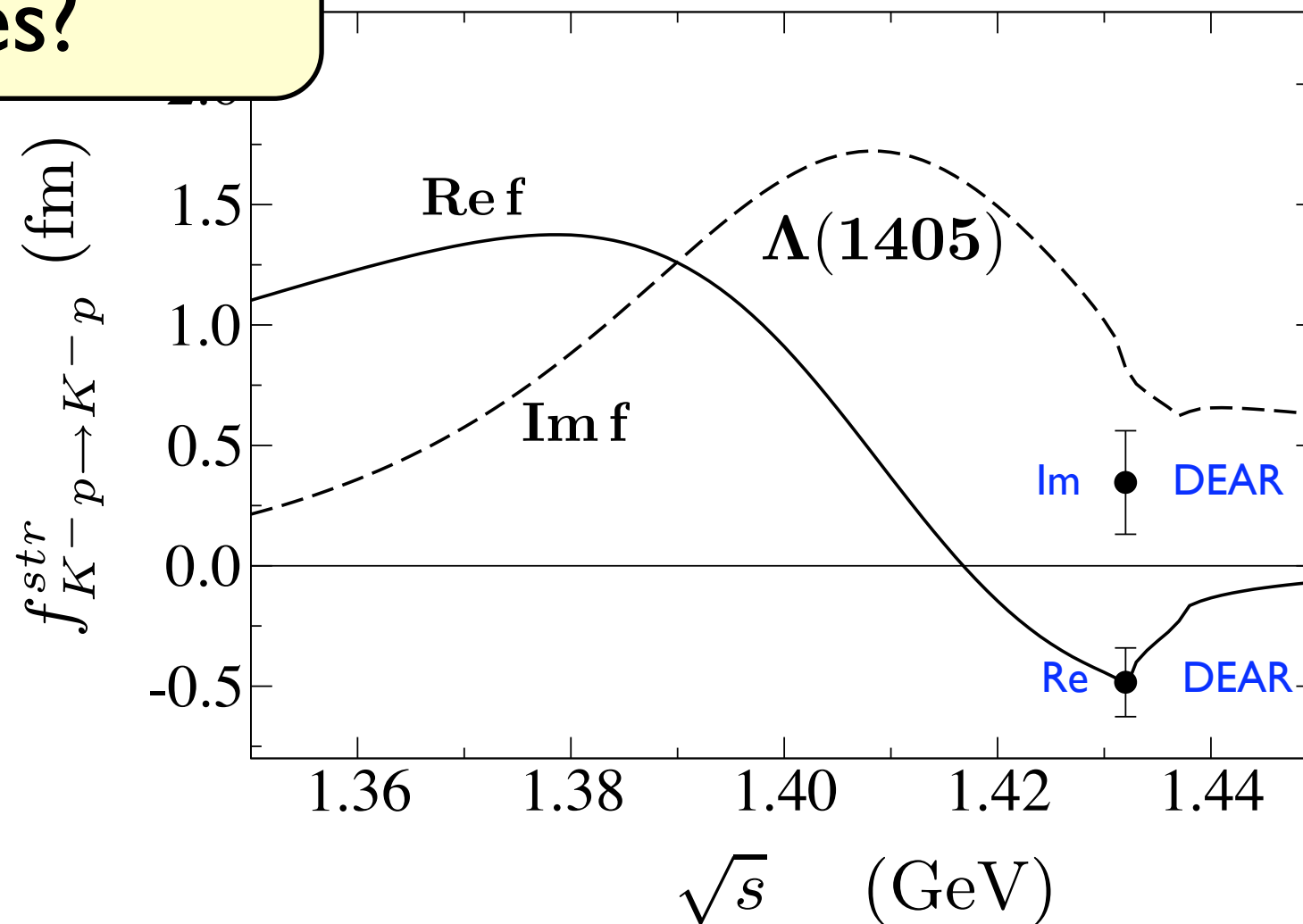


kaonic hydrogen
X-ray

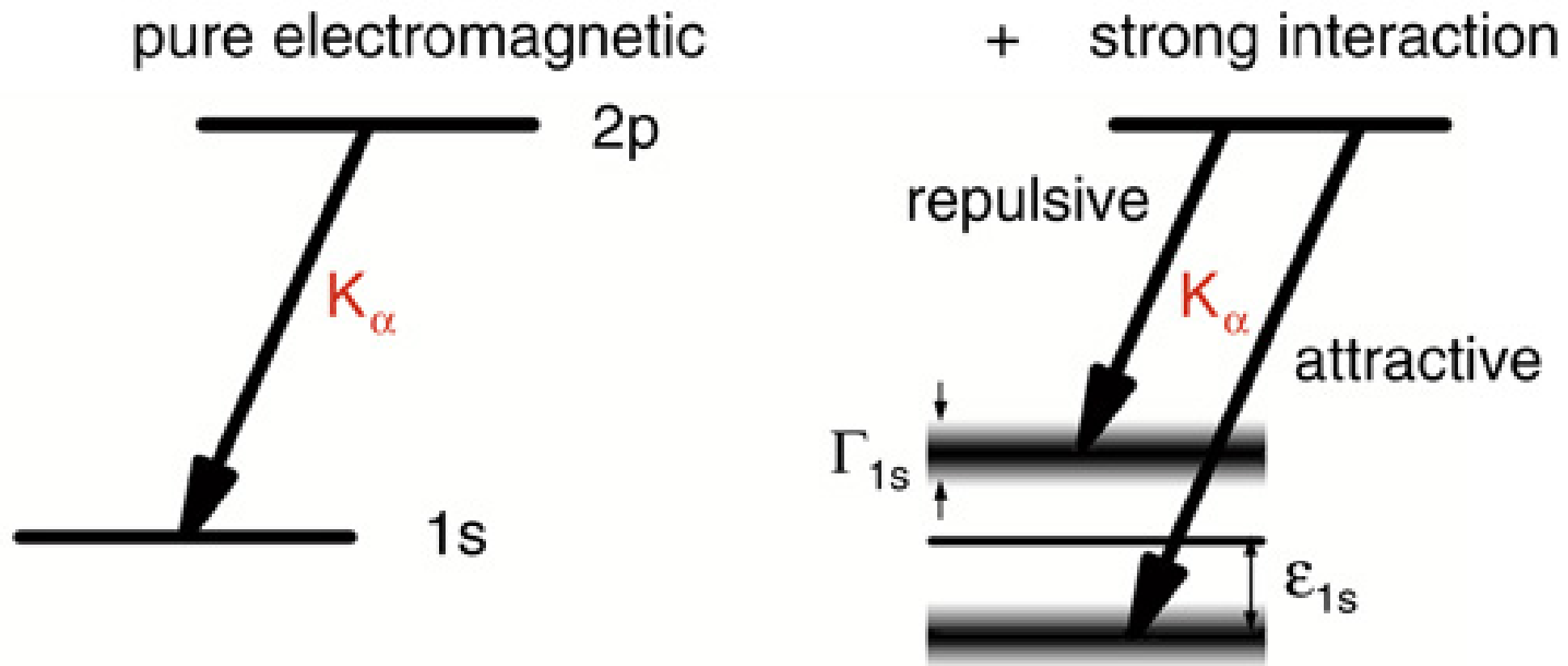
$\bar{K}N$ at threshold



kaon-nucleus
Deeply-bound
states?



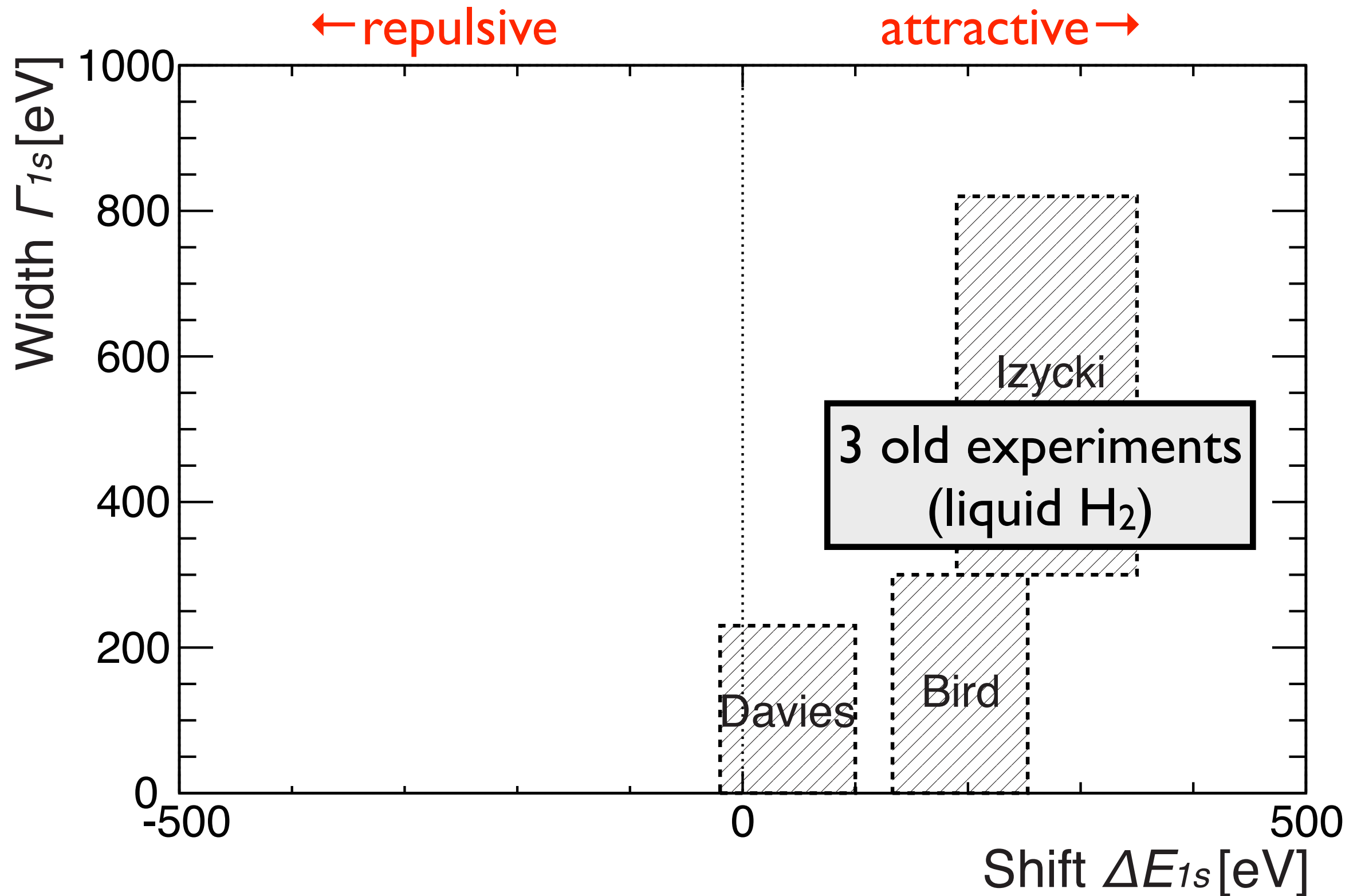
observables



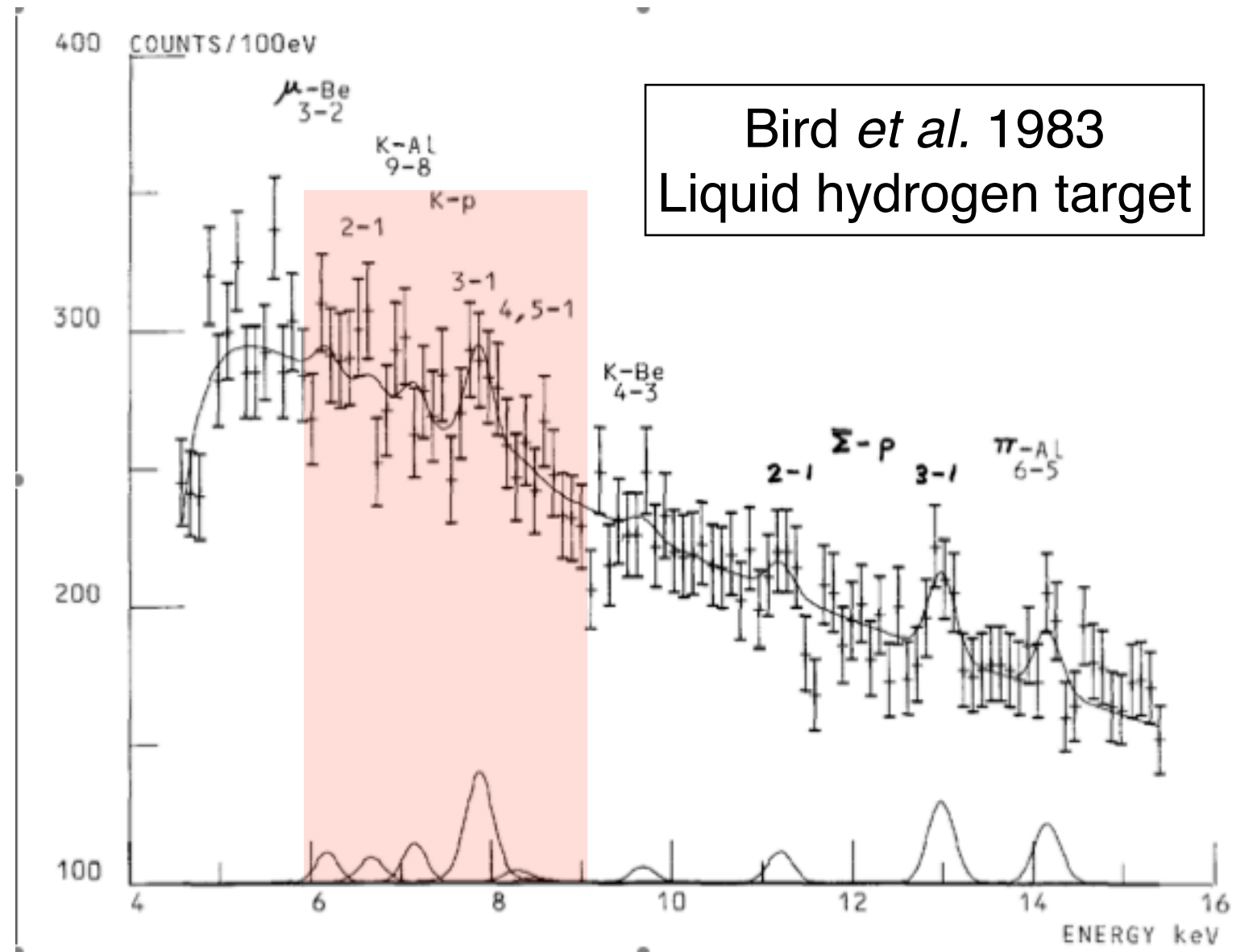
	transition	energy
Kaonic hydrogen	$2p \rightarrow 1s$	~ 6.5 keV
kaonic helium	$3d \rightarrow 2p$	~ 6.4 keV (K^- - ^4He)

① Kaonic Hydrogen

before KpX



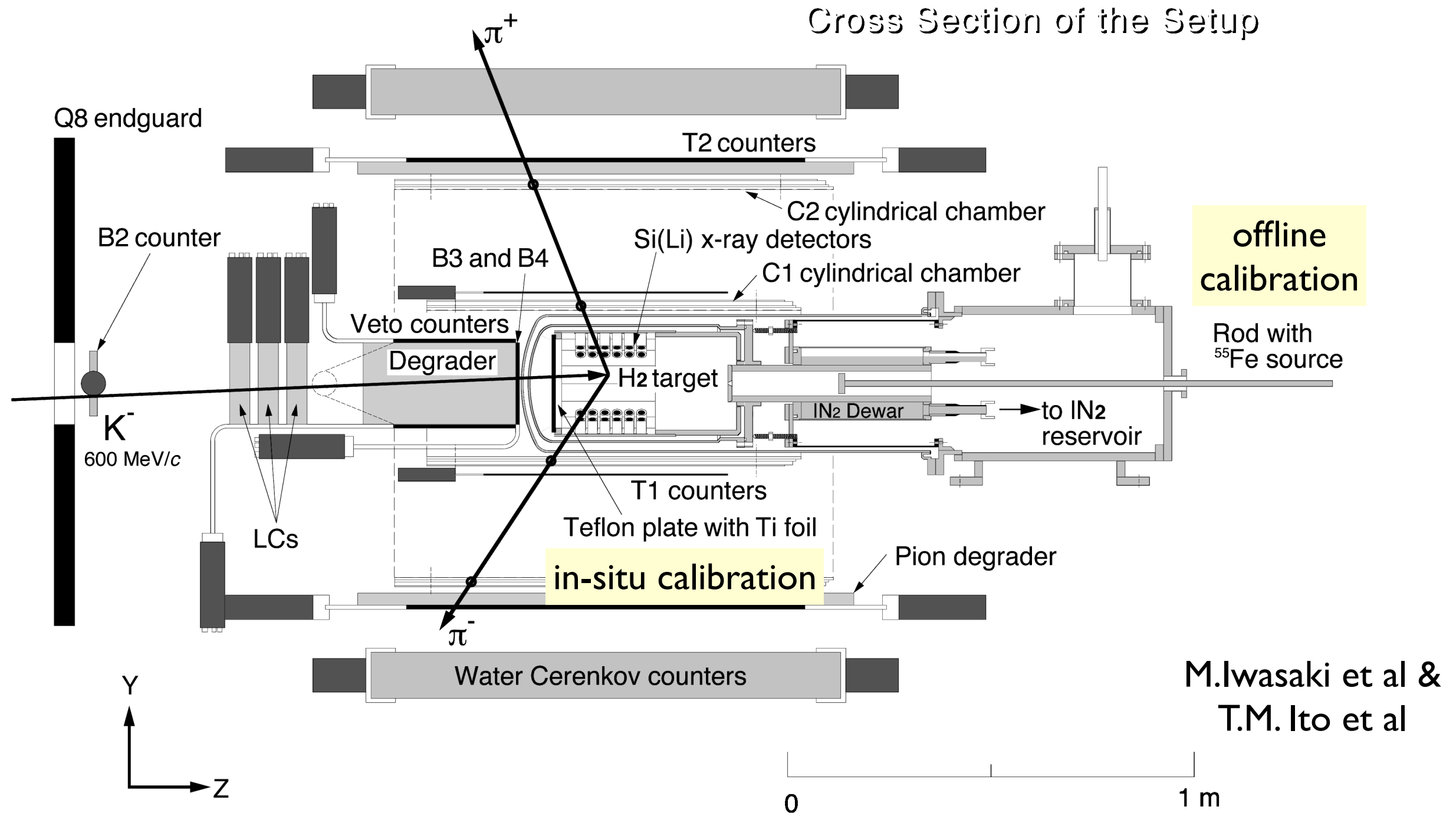
?????



KpX @ KEK

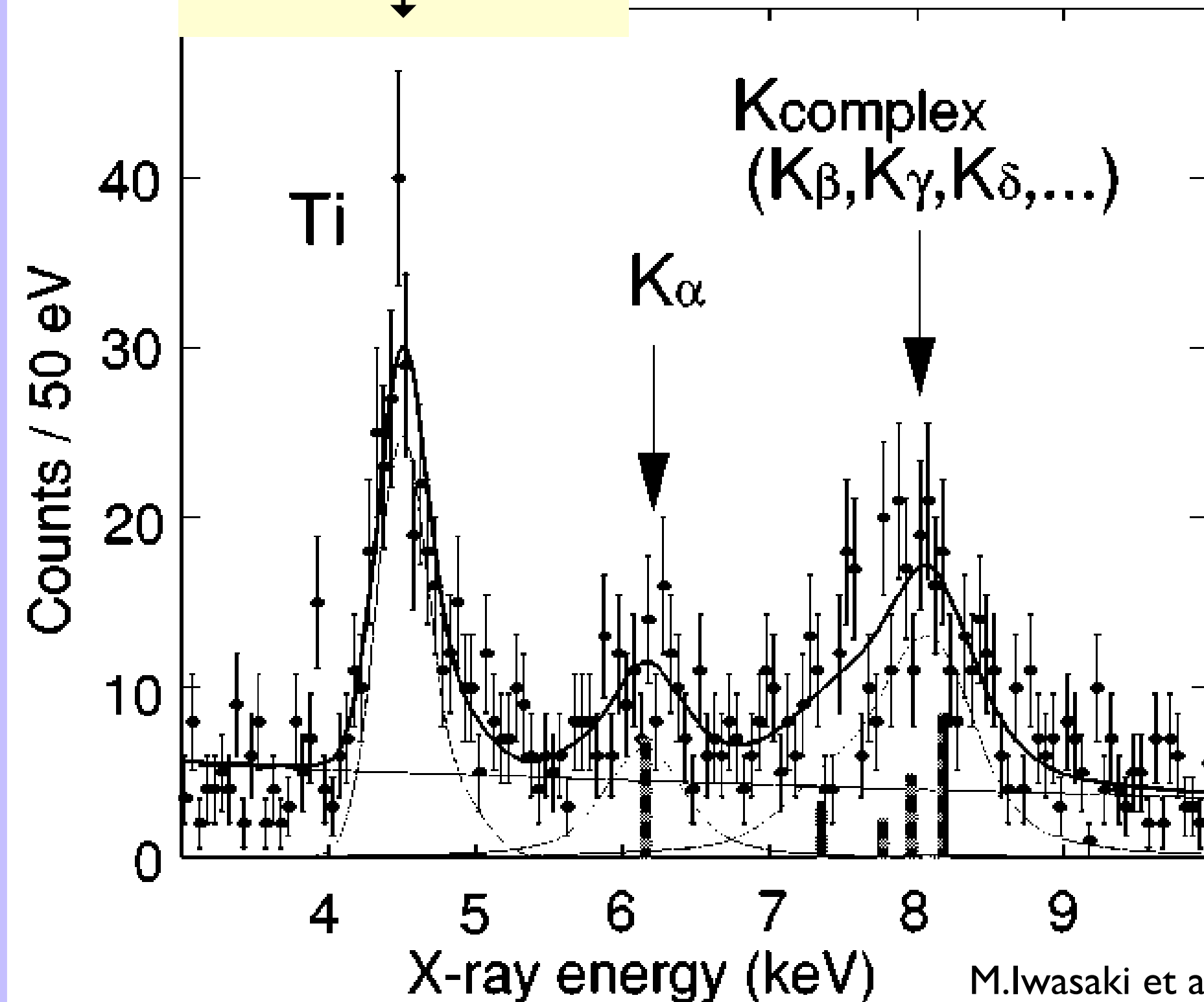


H₂ gas, tagging, 60 Si(Li) detectors (200 mm²)



M.Iwasaki et al &
T.M. Ito et al

in-situ calibration

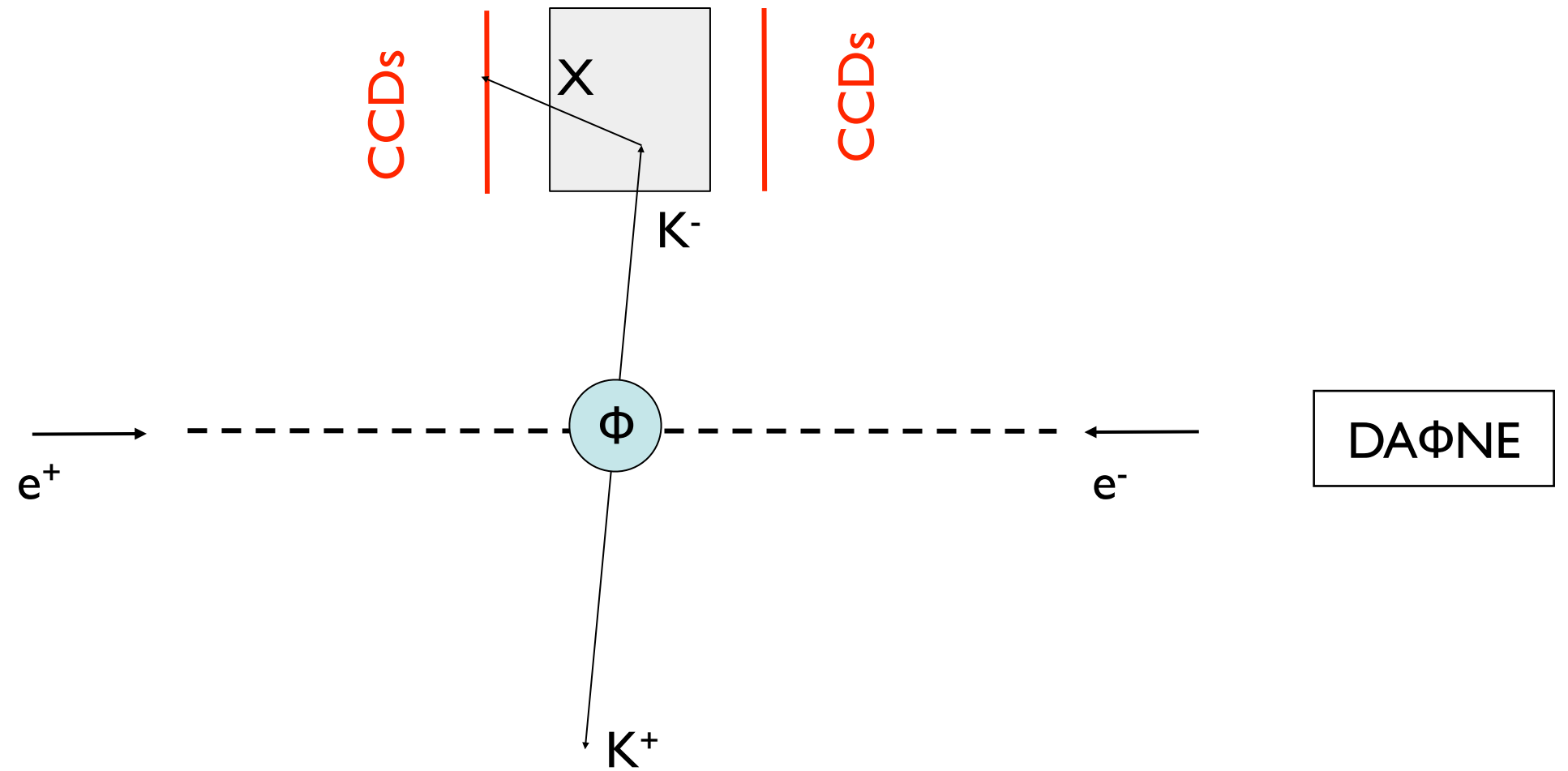


good S/N
but small # of events

resolution 407eV
FWHM@4.5 keV

M.Iwasaki et al &
T.M. Ito et al

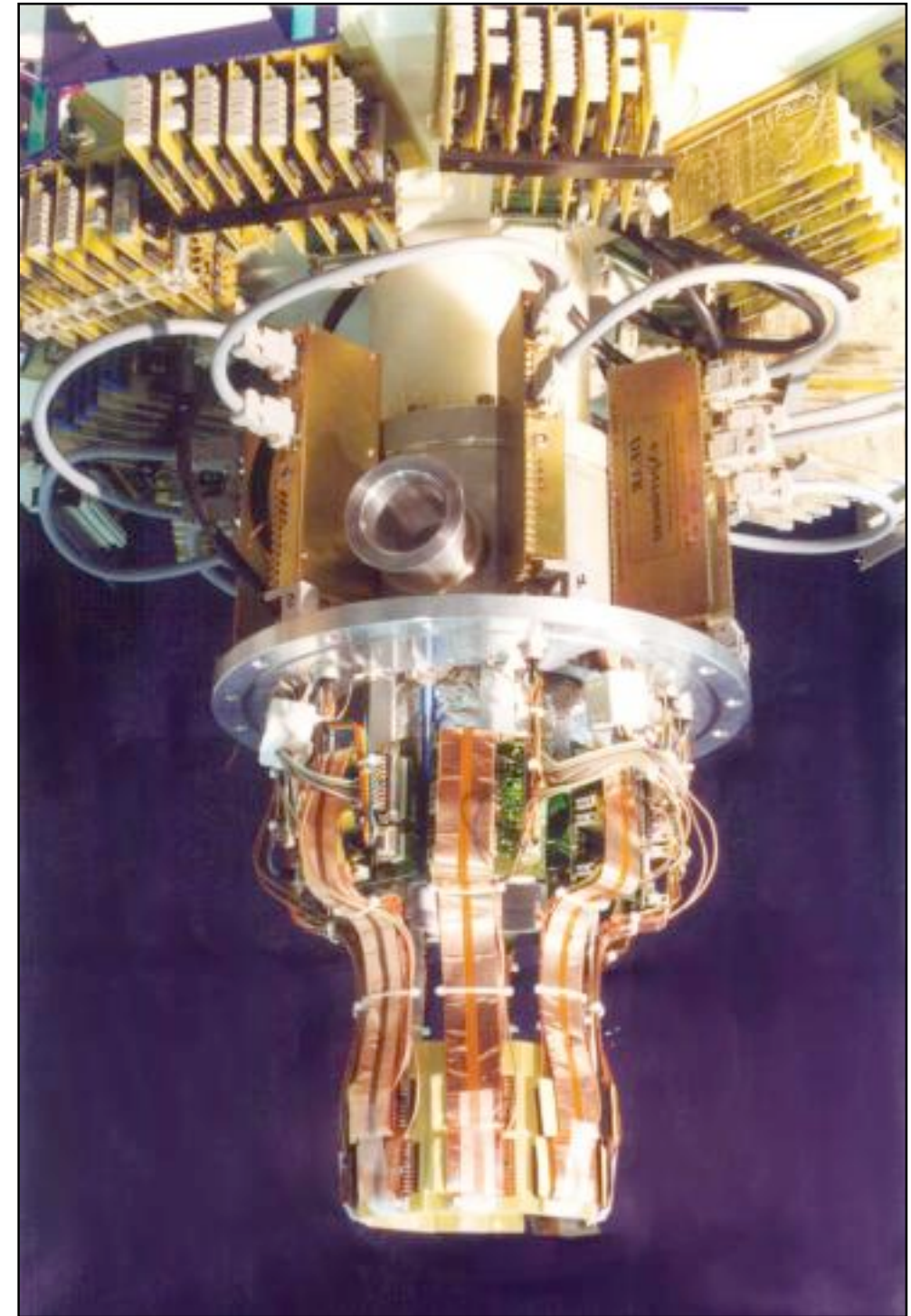
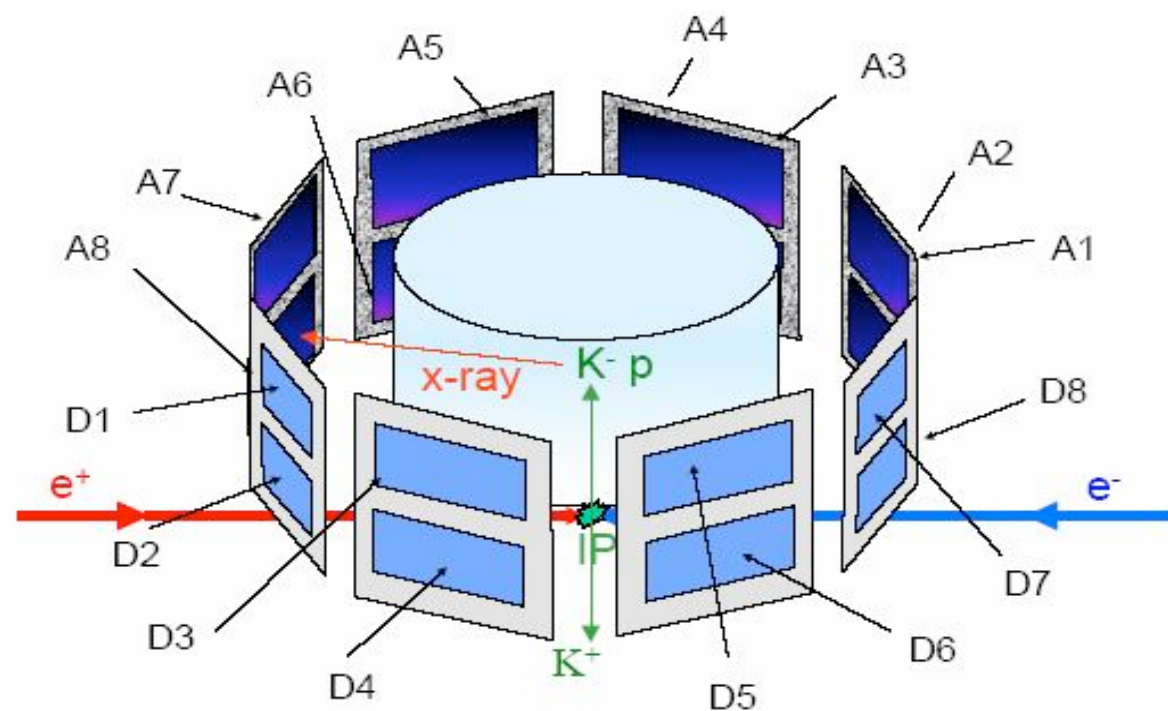
DEAR



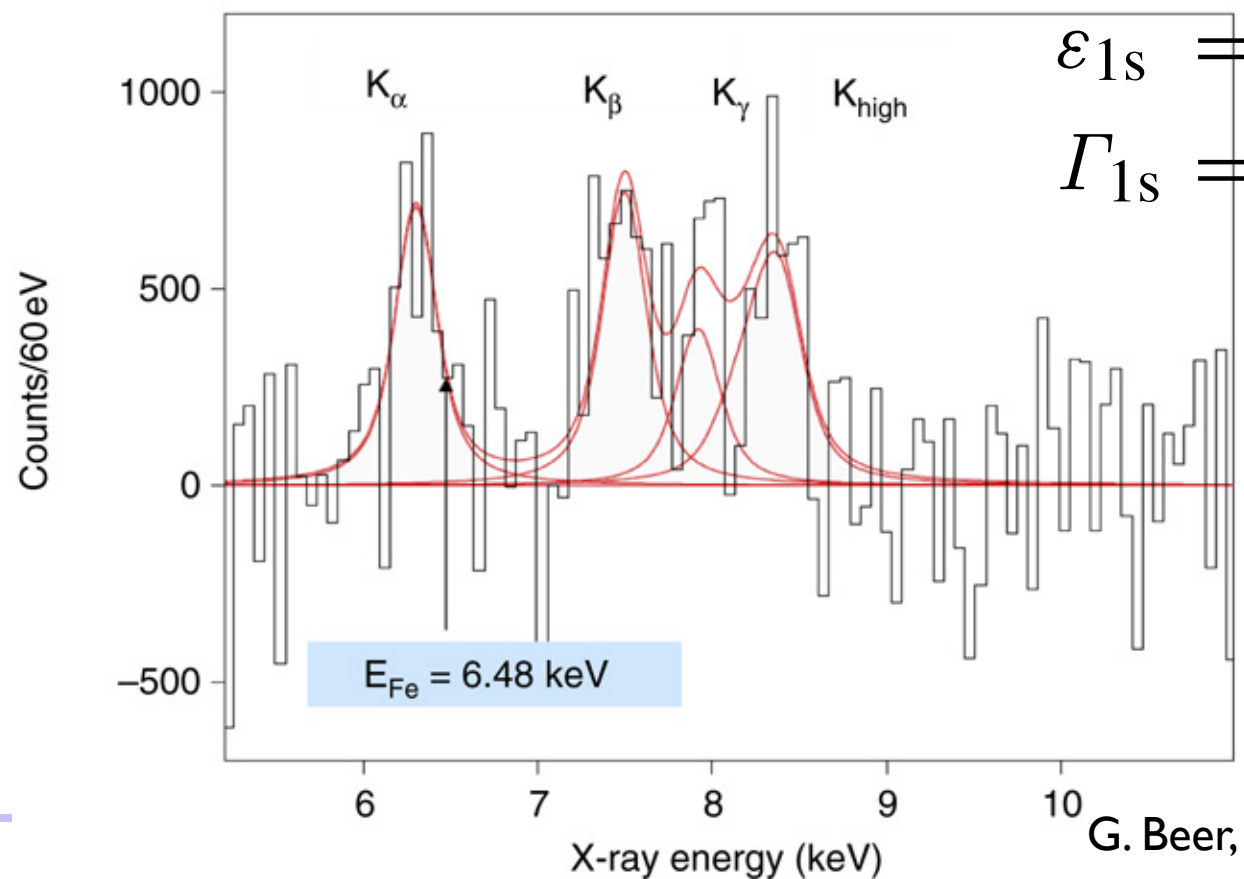
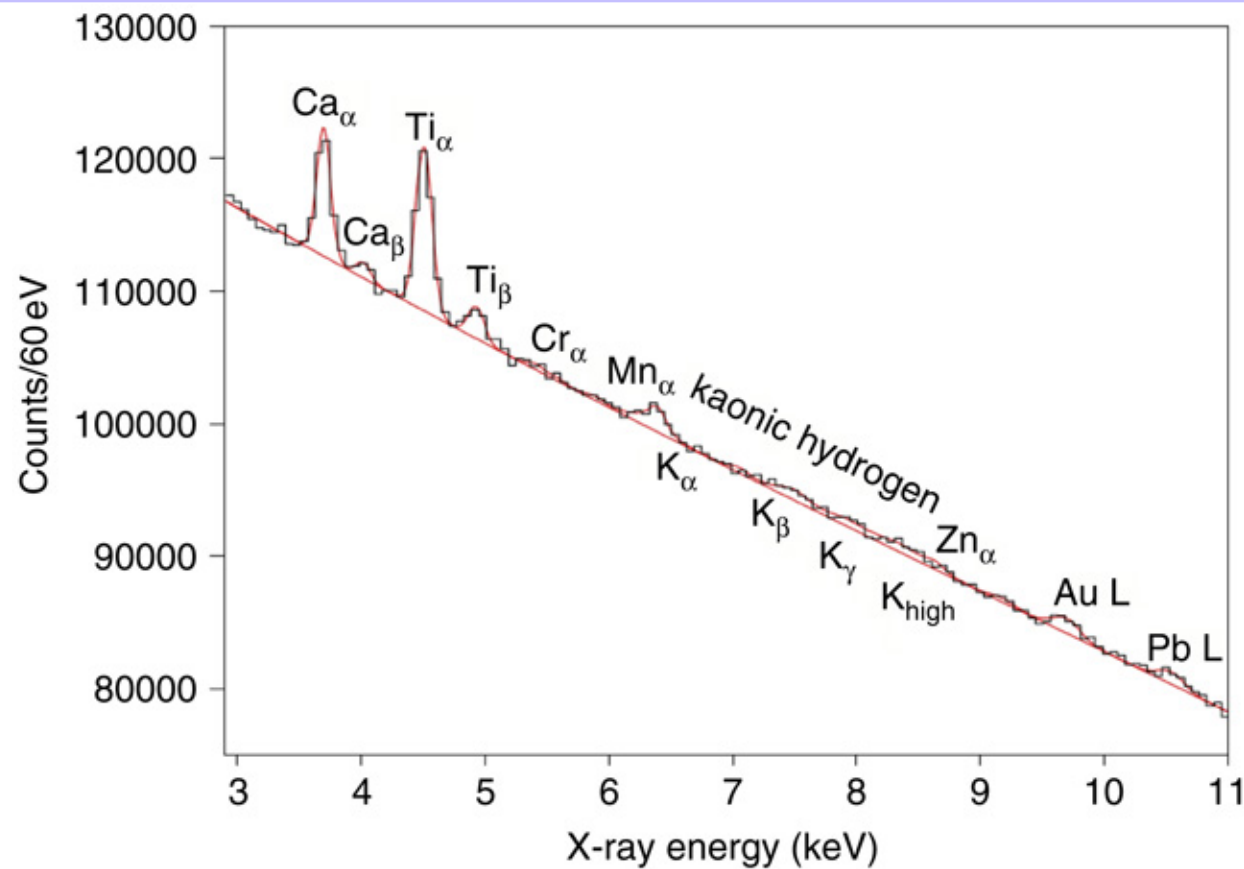
DEAR @ DAΦNE

CCD, good energy
resolution (150 eV @ 6 keV)

but no time resolution



DEAR spectrum



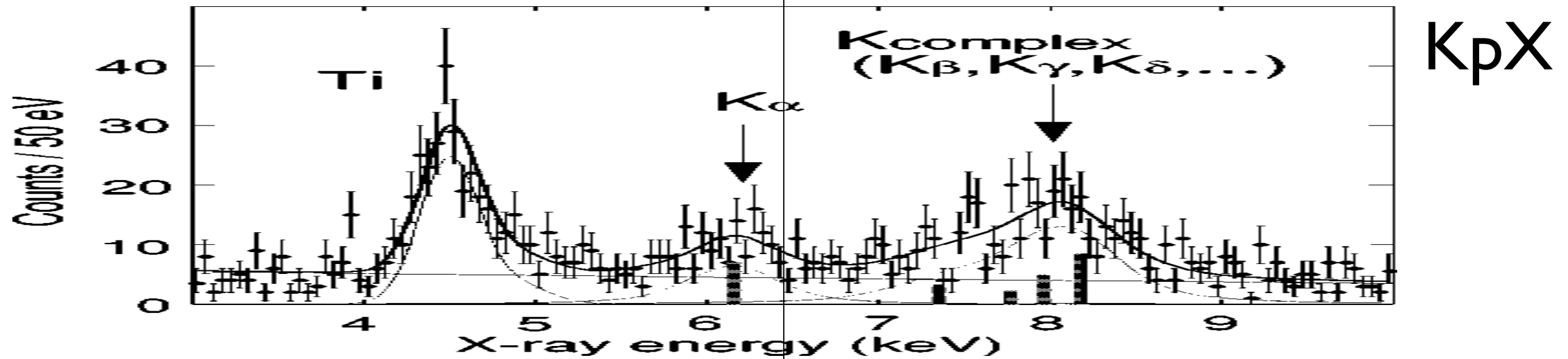
$$\varepsilon_{1s} = (-193 \pm 37_{stat} \pm 6_{sys}) \text{ eV}$$

$$\Gamma_{1s} = (249 \pm 111_{stat} \pm 30_{sys}) \text{ eV}.$$

G. Beer, et al., Phys. Rev. Lett. 94 (2005) 212302.

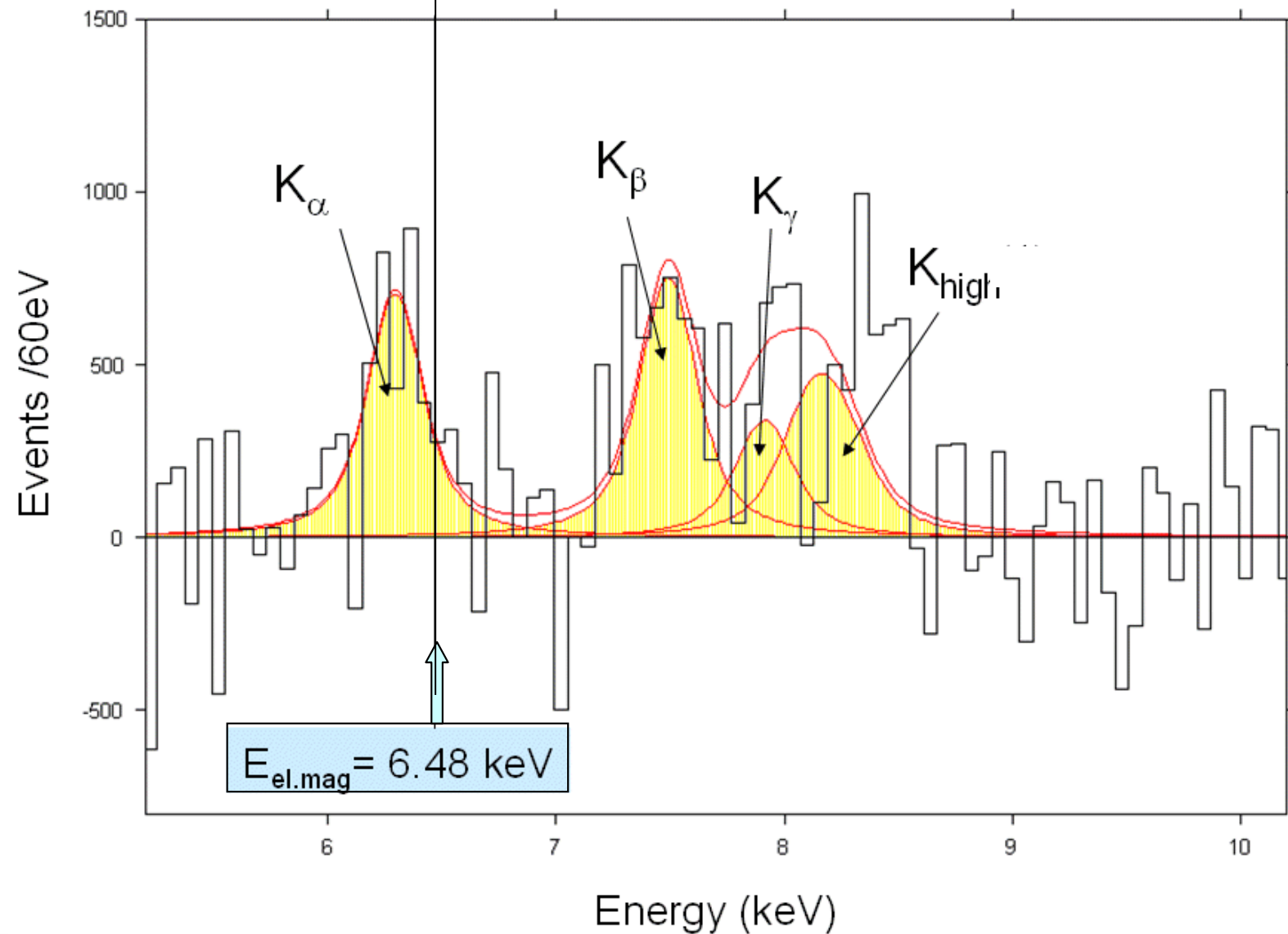
Ryu Hayano, MENU2010

repulsive

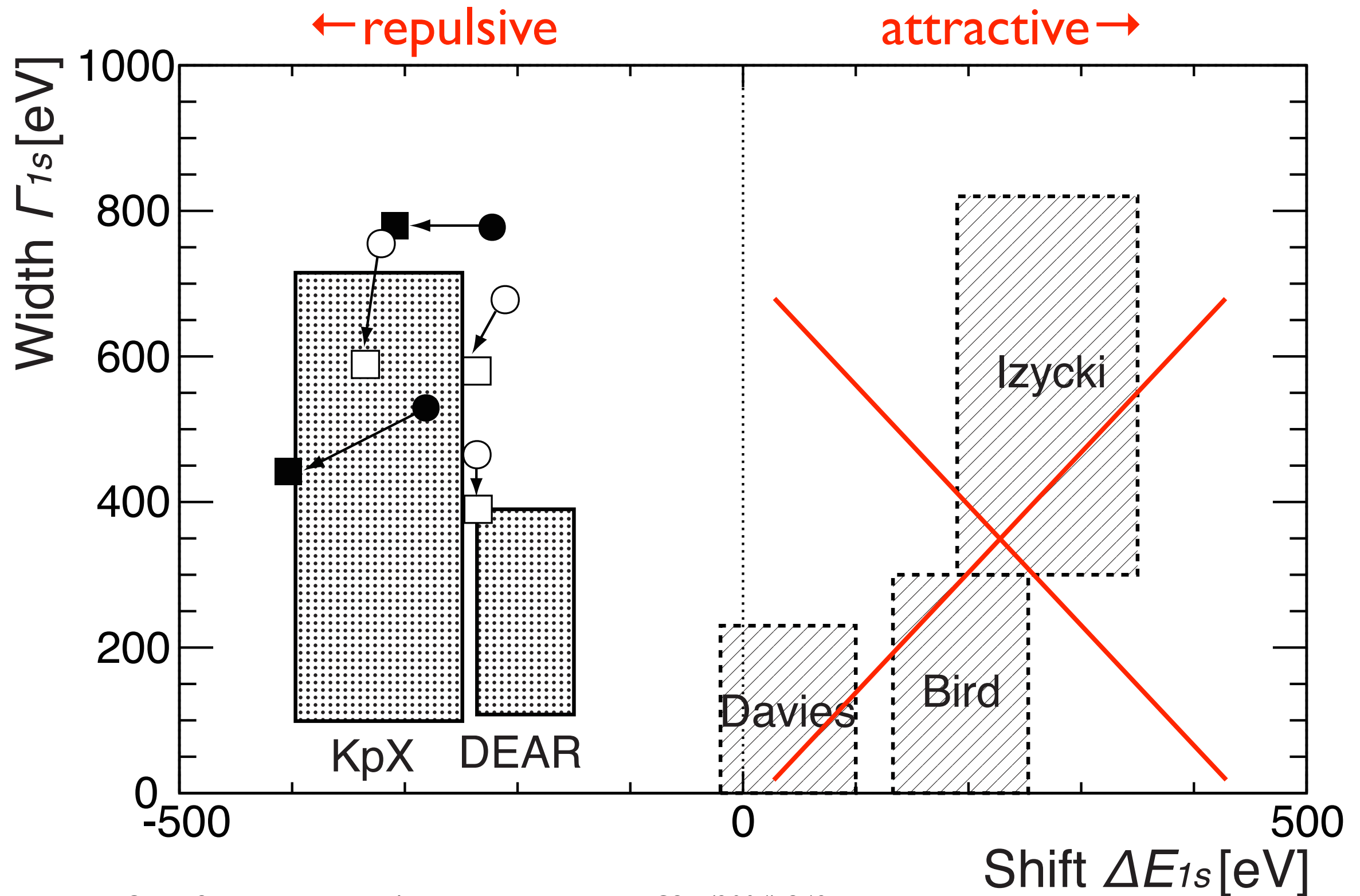


DEAR

after background subtraction



KpX & DEAR

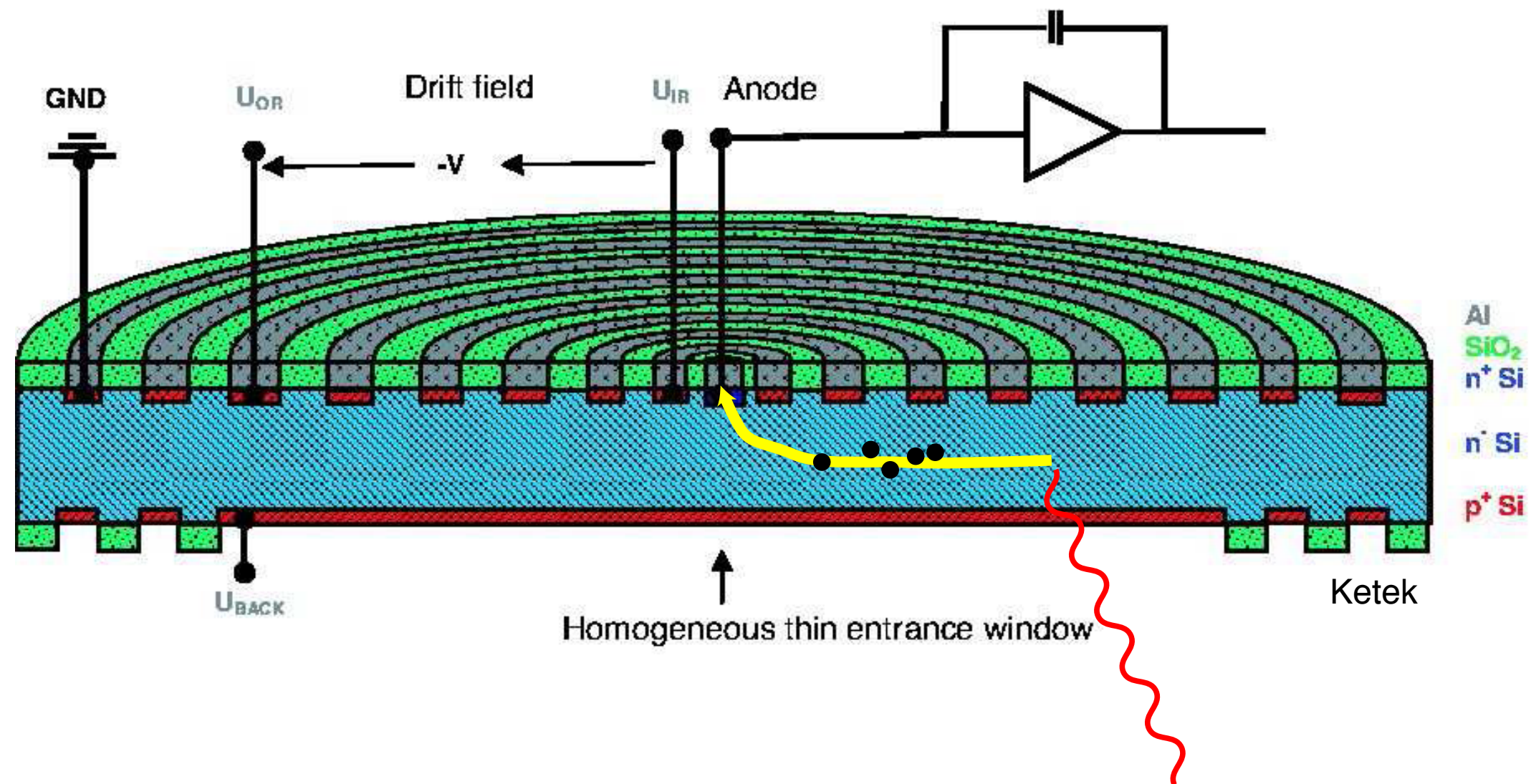


U.-G. Meißner, U. Raha and A. Rusetsky, Eur. Phys. J. C35 (2004) 349

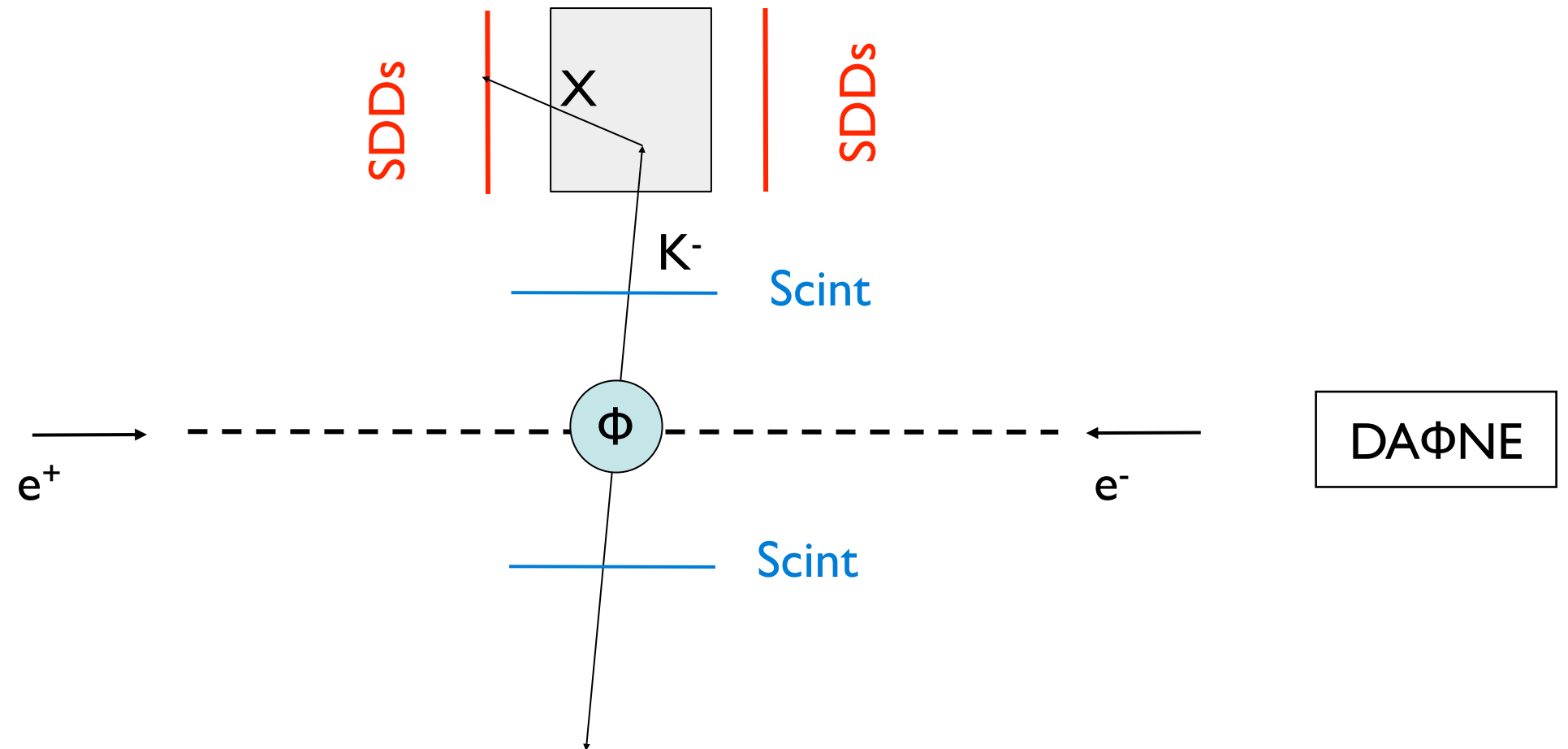
B. Borasoy, R. Nißler and W. Weise, Eur. Phys. J. A25 (2005) 79

- ▶ necessity for improved measurements
- ▶ K⁻p and K⁻d
- ▶ CCD is not an ideal detector
- ▶ X-ray detector(s) with good energy & time resolution necessary
- ▶ Silicon Drift Detector

Silicon Drift Detector (SDD)

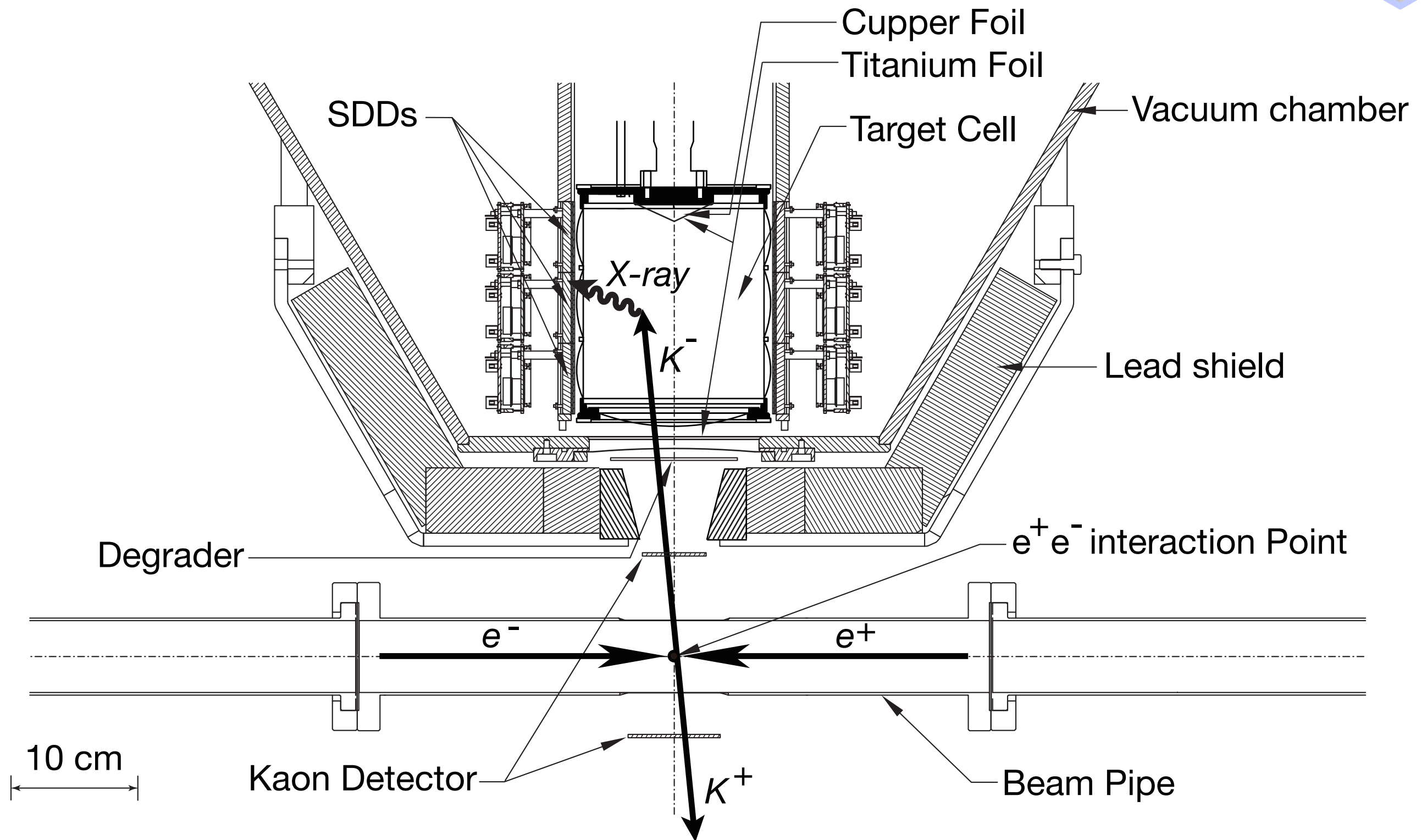


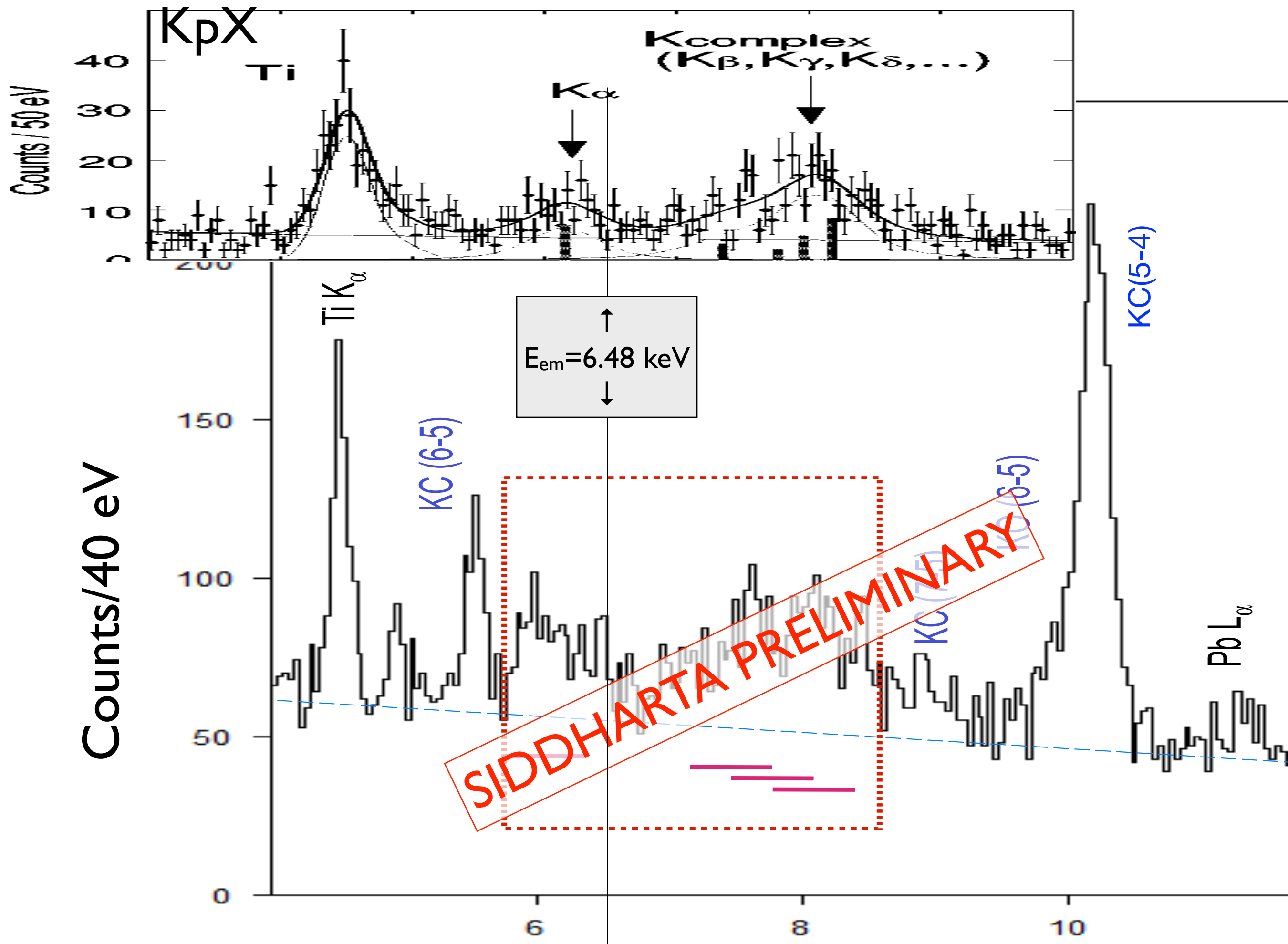
resolution $\Delta E/E \searrow$ detector capacitance \searrow
SDD - small capacitance, indep. of the detector area

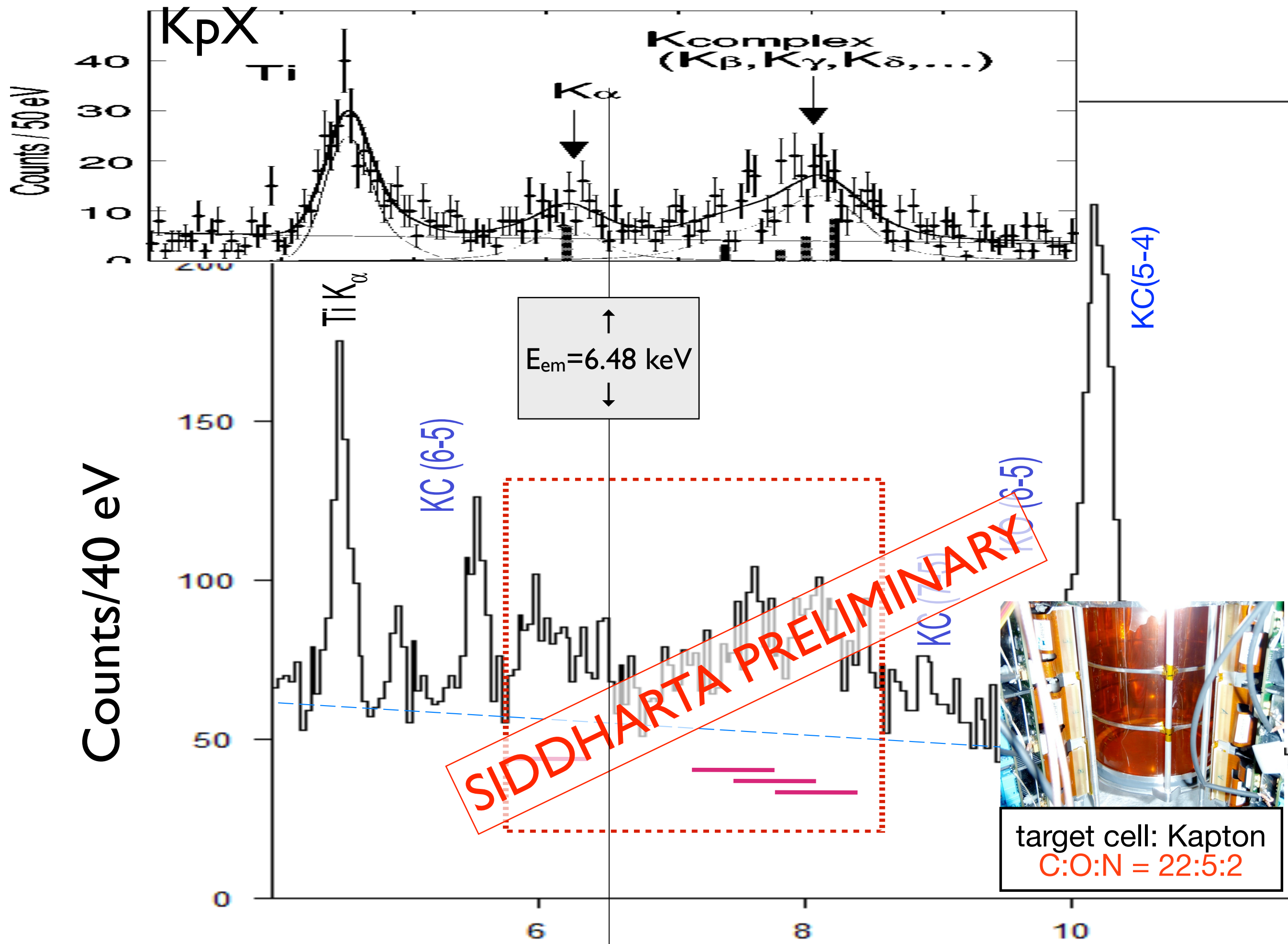


Triple coincidence:

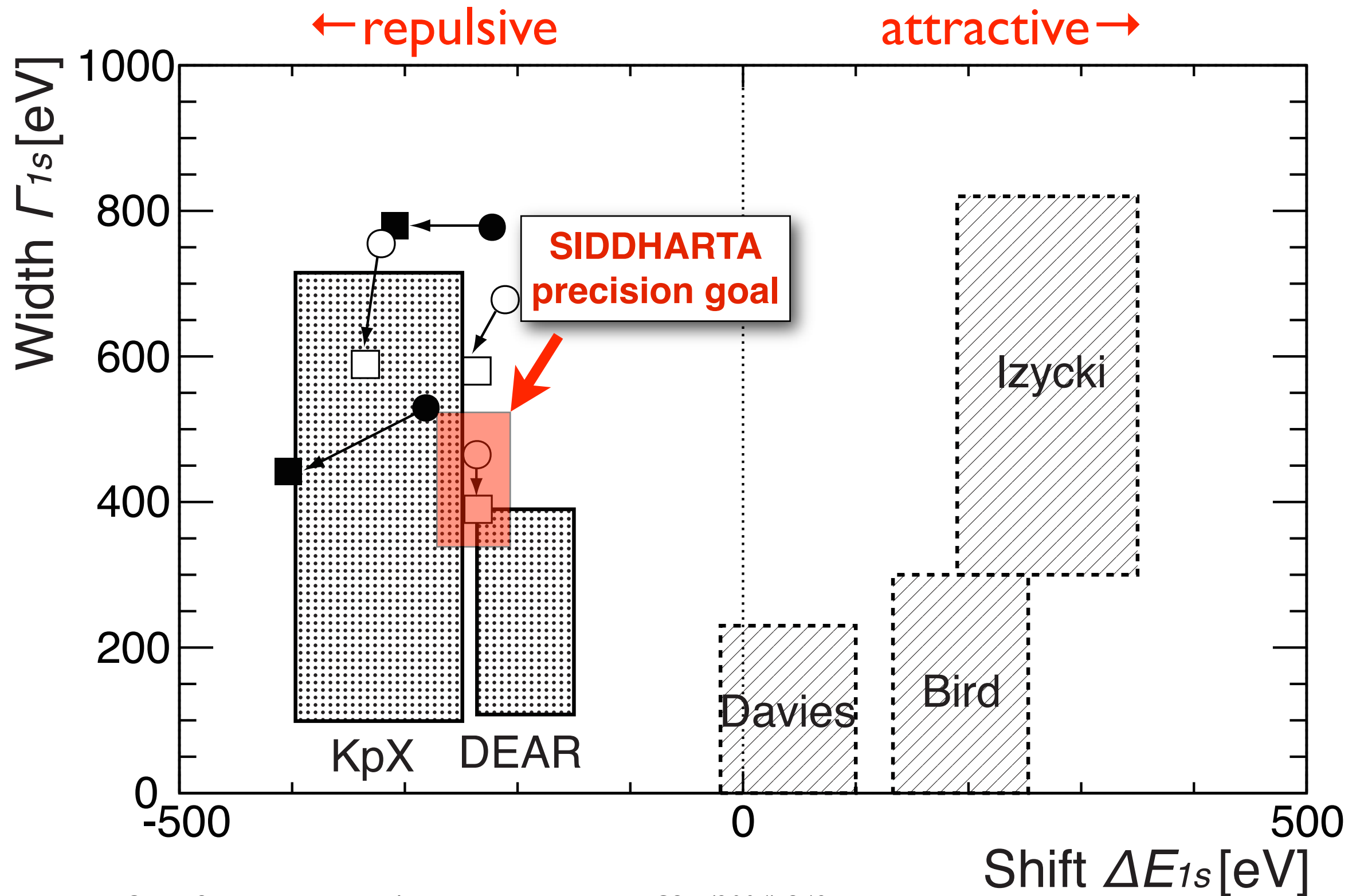
$$\text{SDD}_X * \text{Scint}_K * \text{Scint}_K$$







KpX & DEAR



U.-G. Meißner, U. Raha and A. Rusetsky, Eur. Phys. J. C35 (2004) 349

B. Borasoy, R. Nißler and W. Weise, Eur. Phys. J. A25 (2005) 79

② Kaonic Helium

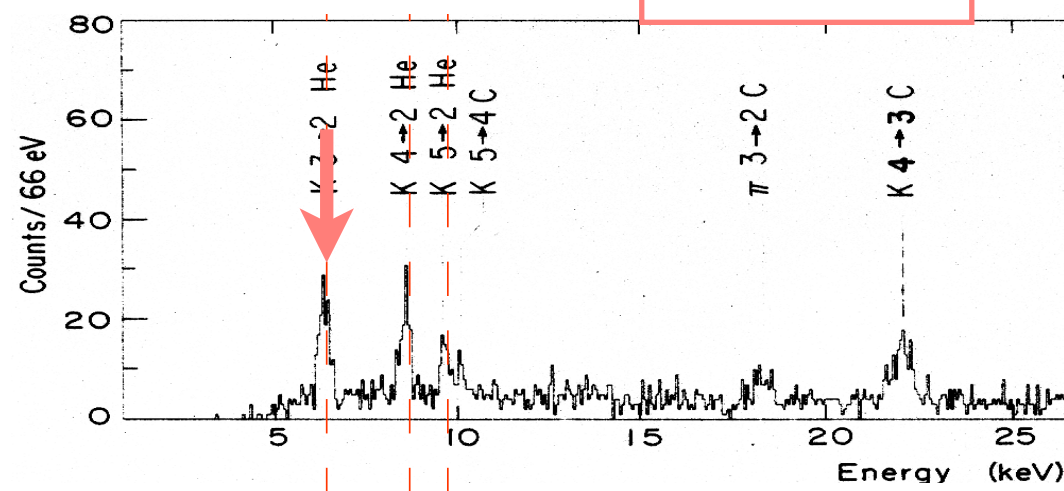
謎

Long-standing
kaonic-helium puzzle

3 past experiments



1971



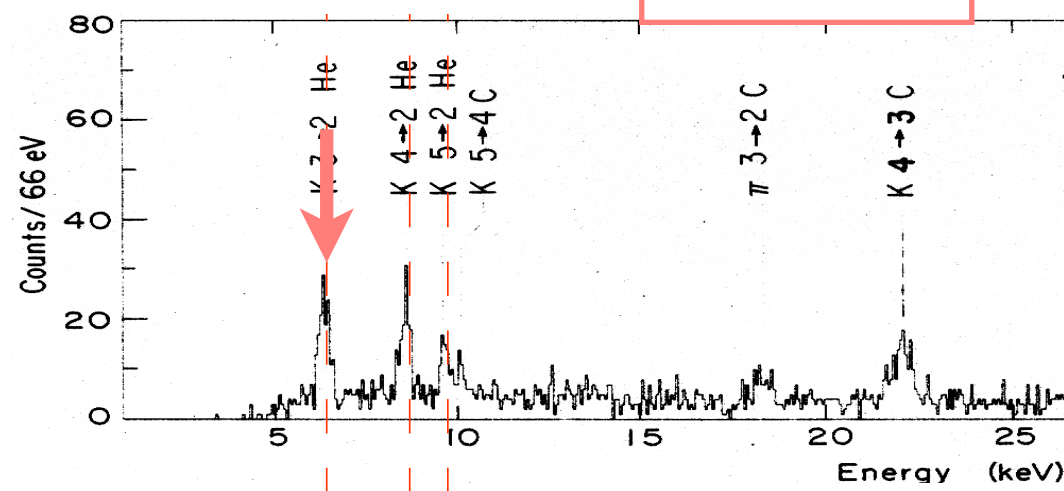
C. Wiegand and R. Pehl,
Phys. Rev. Lett. 27, 1410 (1971)

3 past experiments

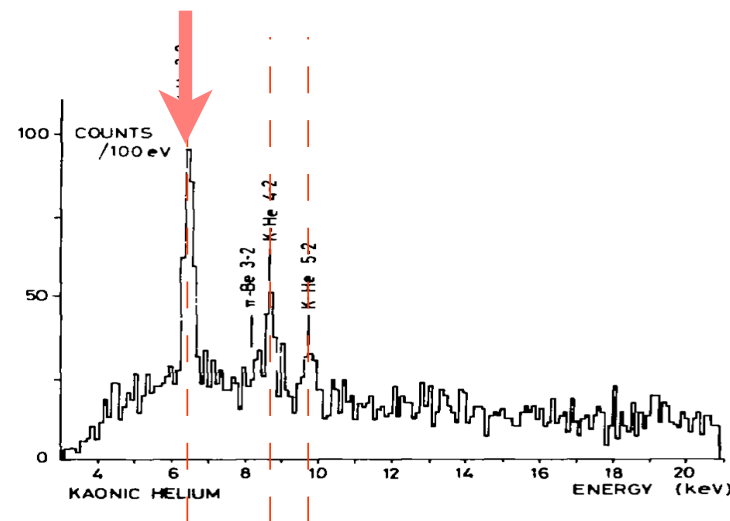


1979

1971



C. Wiegand and R. Pehl,
Phys. Rev. Lett. 27, 1410 (1971)



C. Batty et al.,
Nucl. Phys. A326, 455 (1979)

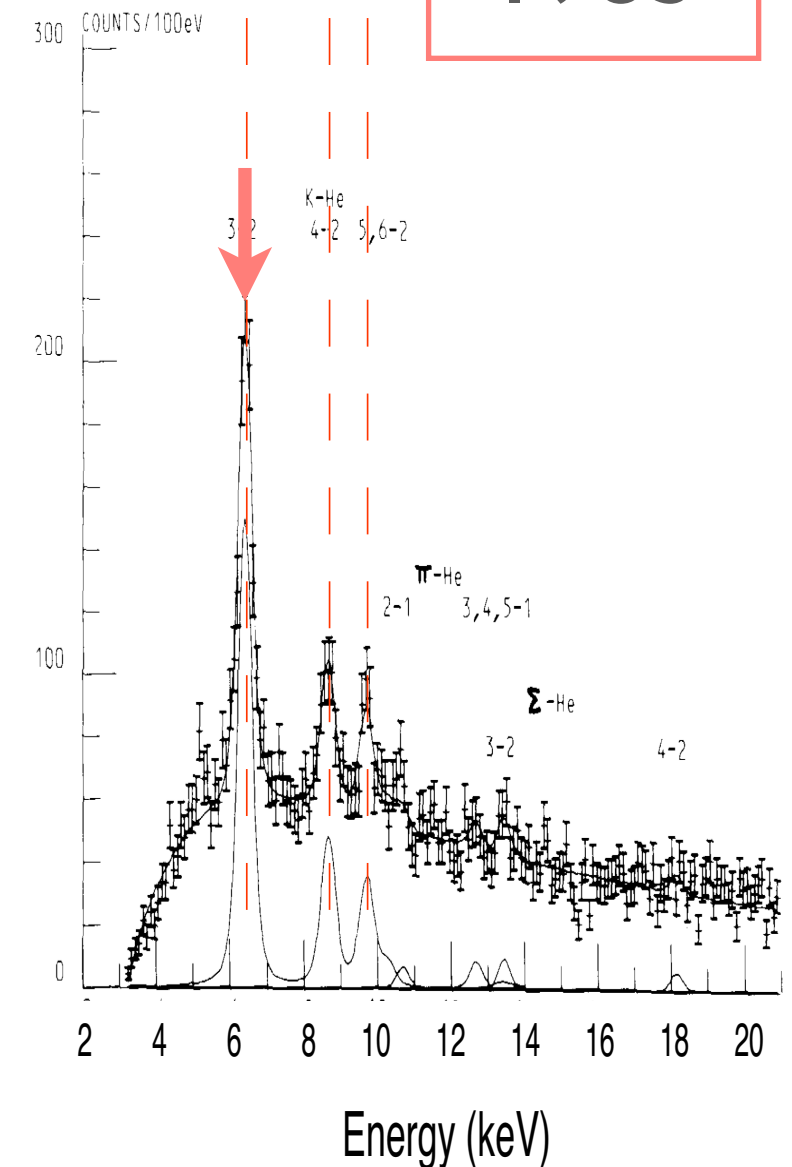
3 past experiments



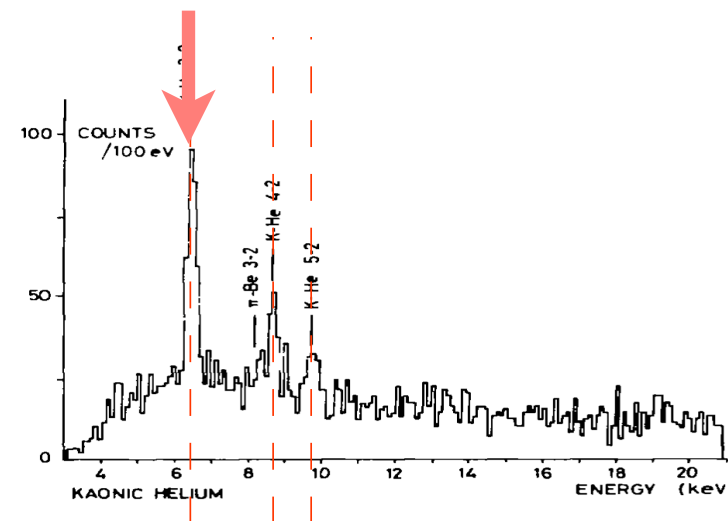
1983

1979

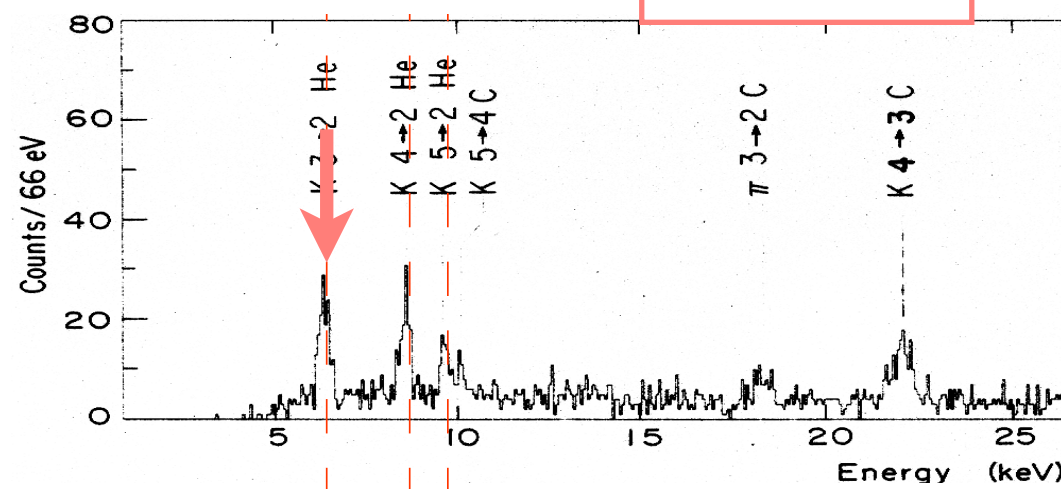
1971



S. Baird et al.,
Nucl. Phys. A392, 297 (1983)

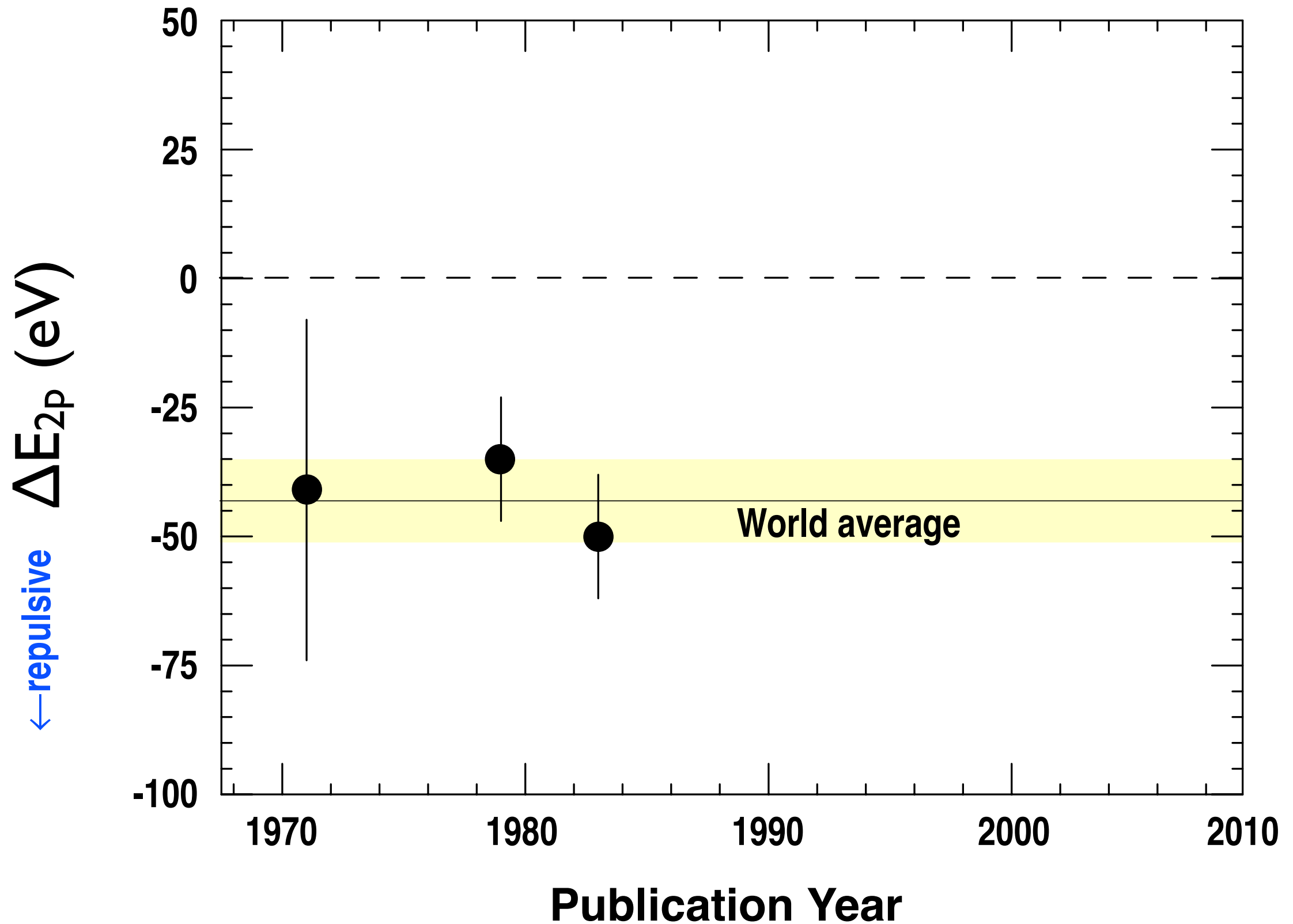


C. Batty et al.,
Nucl. Phys. A326, 455 (1979)

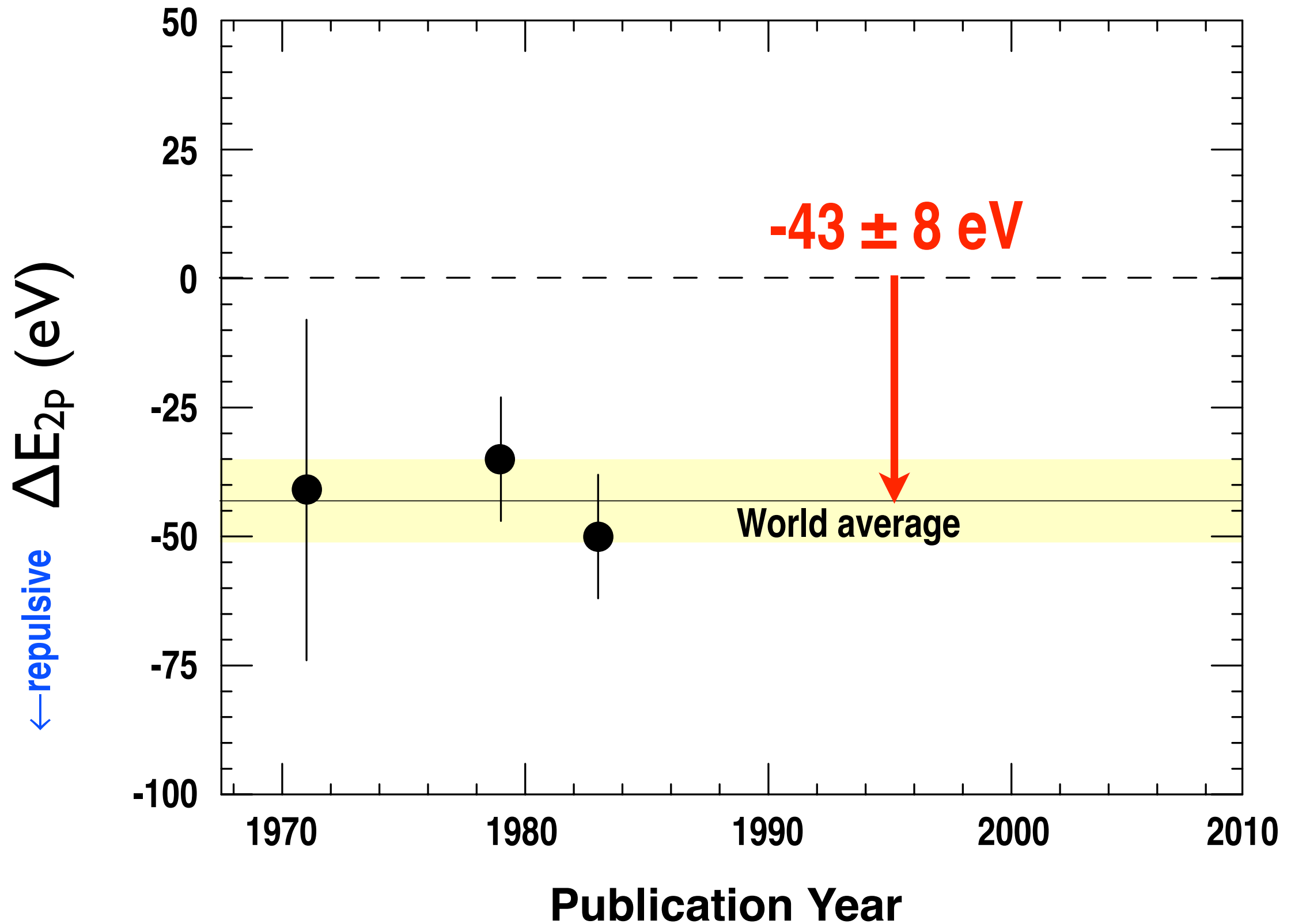


C. Wiegand and R. Pehl,
Phys. Rev. Lett. 27, 1410 (1971)

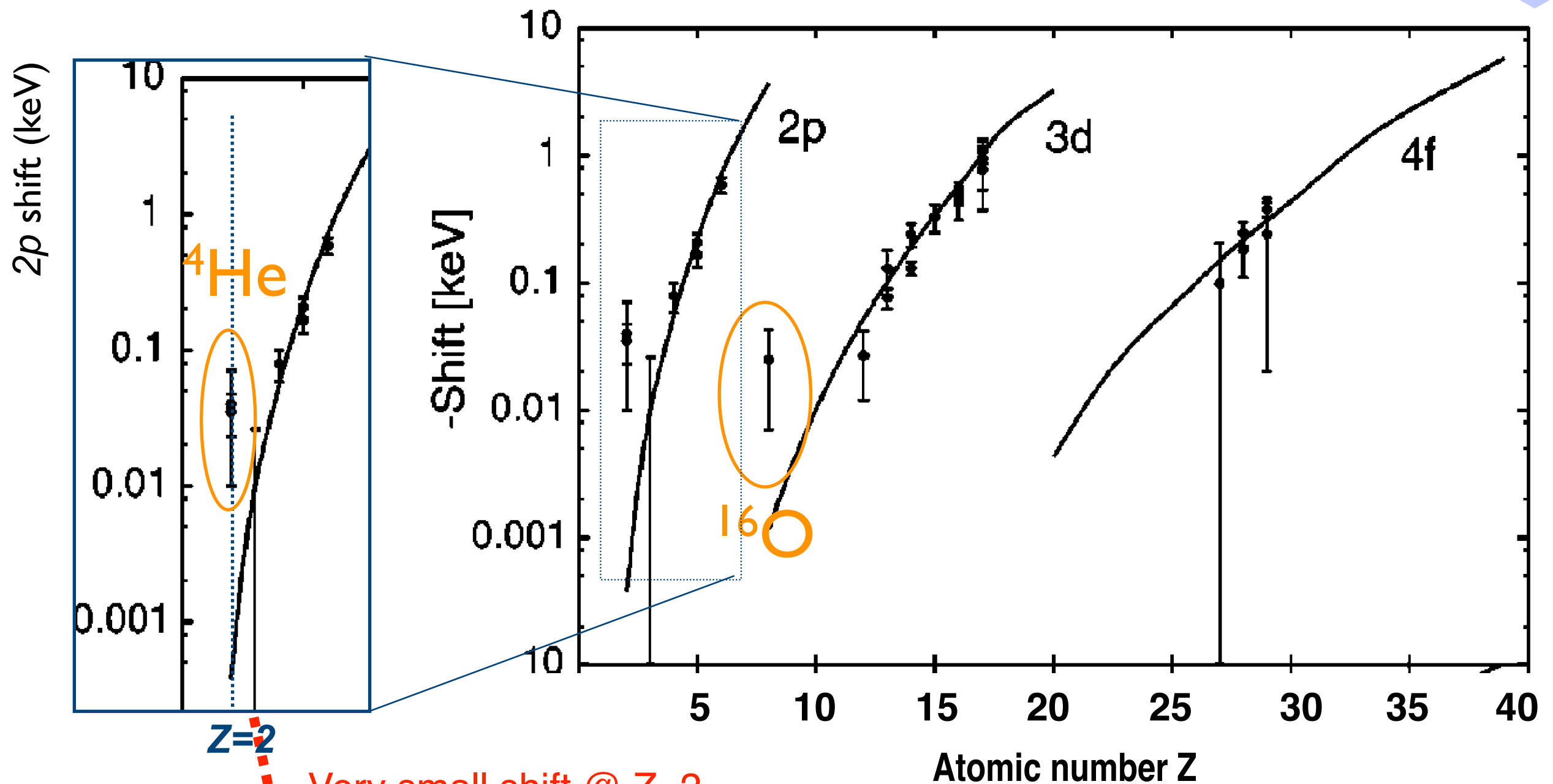
Kaonic Helium X-ray Spectroscopy



Kaonic Helium X-ray Spectroscopy



but theory...

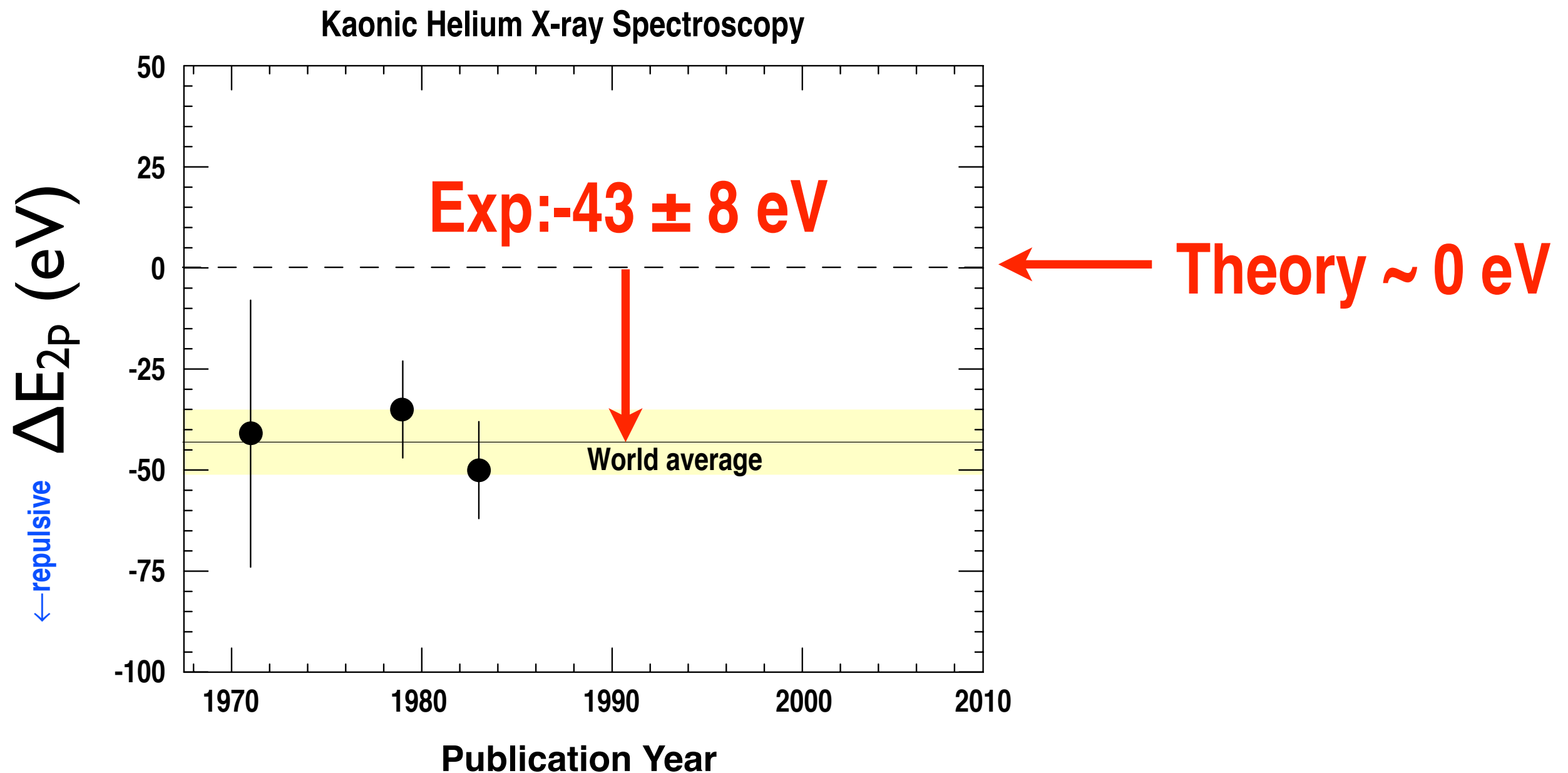


(chiral unitary+ optical model):

$\sim 0.2\text{eV}$

Batty (1990),
Hirenzaki et al (2000),
Friedman (2007)

Puzzle: 5σ discrepancy





Available online at www.sciencedirect.com



Physics Letters B 653 (2007) 387–391



PHYSICS LETTERS B

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Precision measurement of the $3d \rightarrow 2p$ x-ray energy in kaonic ^4He

S. Okada^{a,*}, G. Beer^b, H. Bhang^c, M. Cargnelli^d, J. Chiba^e, Seonho Choi^c, C. Curcio^f,
Y. Fukuda^g, T. Hanaki^e, R.S. Hayano^h, M. Iio^a, T. Ishikawa^h, S. Ishimotoⁱ, T. Itoh^j,
K. Itahashi^a, M. Iwaiⁱ, M. Iwasaki^{a,g}, B. Juhász^d, P. Kienle^{d,j}, J. Marti^k,
H. Ohnishi^a, H. Ota^a, M. Sato^{g,l}, P. Schmid^d, S. Suzukiⁱ, T. Suzuki^m, Y. Tomono^a,
E. Widmann^d, T. Yamazaki^{a,h}, H. Yimⁿ

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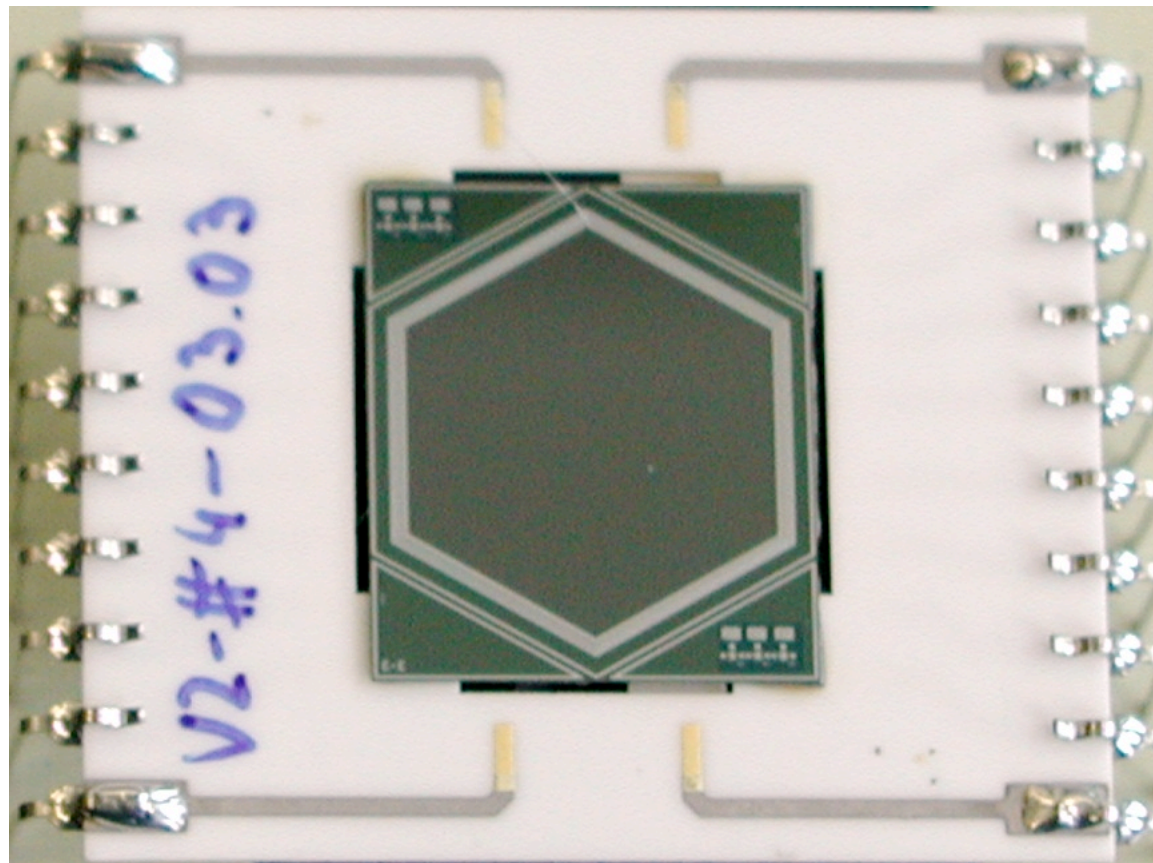
^j Physik Department, Technische Universität München, D-85748 Garching, Germany

Received 30 June 2007; accepted 13 August 2007

solved the long-standing kaonic helium puzzle

① x2 better resolution

SDD (silicon drift detector)



Produced by KETEK GmbH

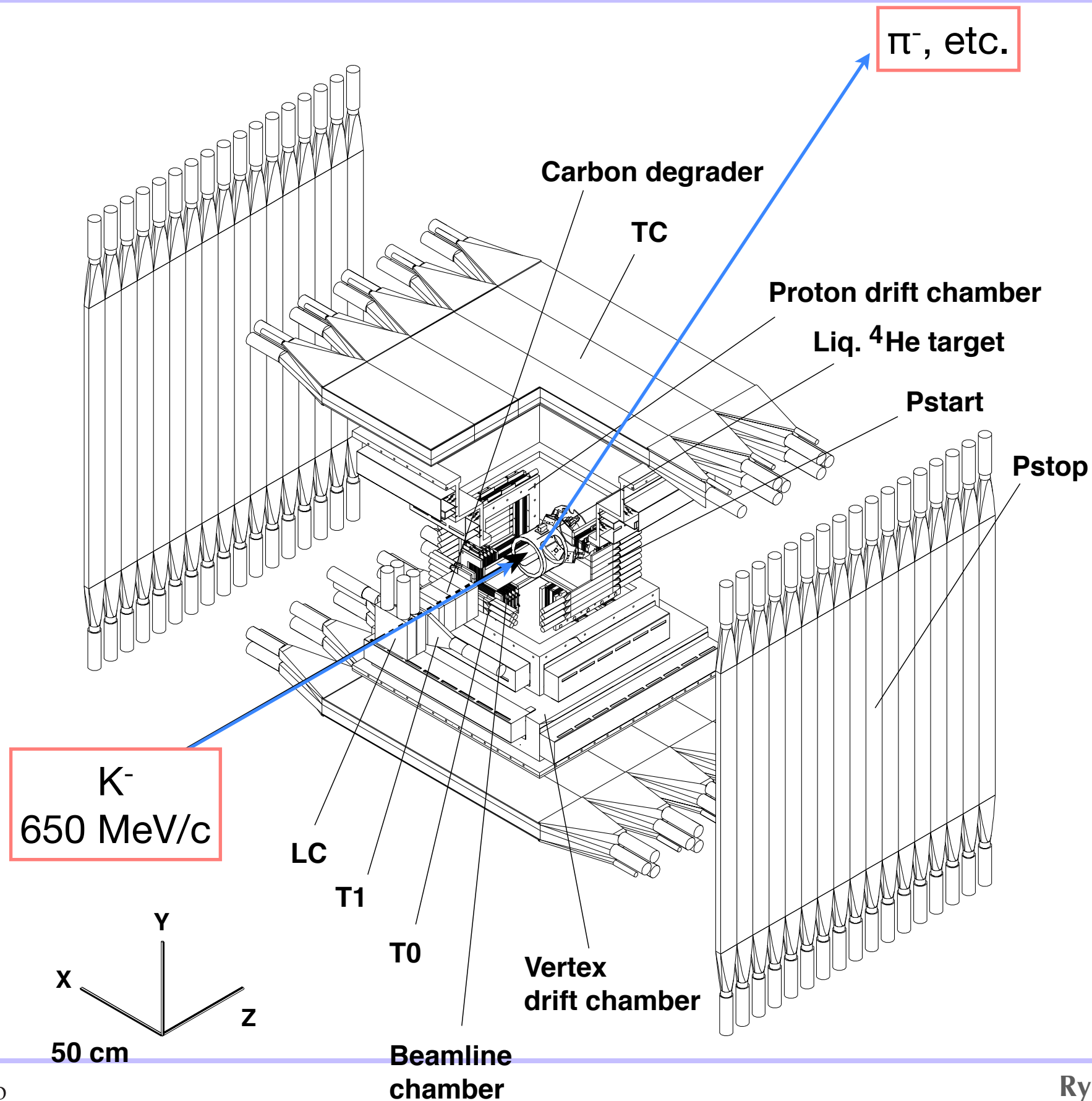
electrons drift to a small anode (small capacitance)

high resolution
(185 eV FWHM @ 6.4 keV),
despite large area (100 mm²)

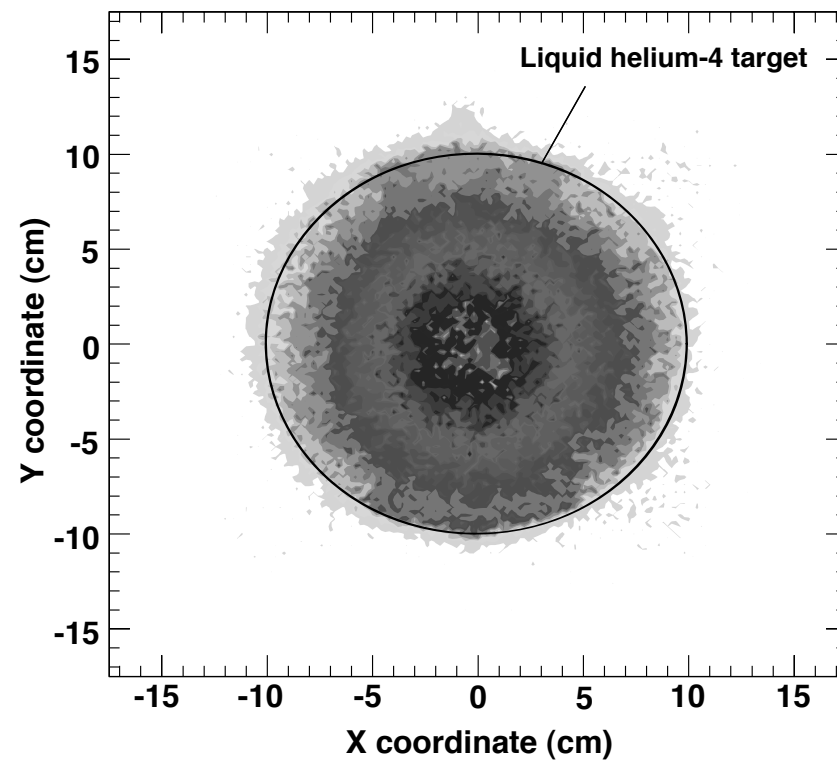
8 such SDDs used in E570

② x6 better S/N

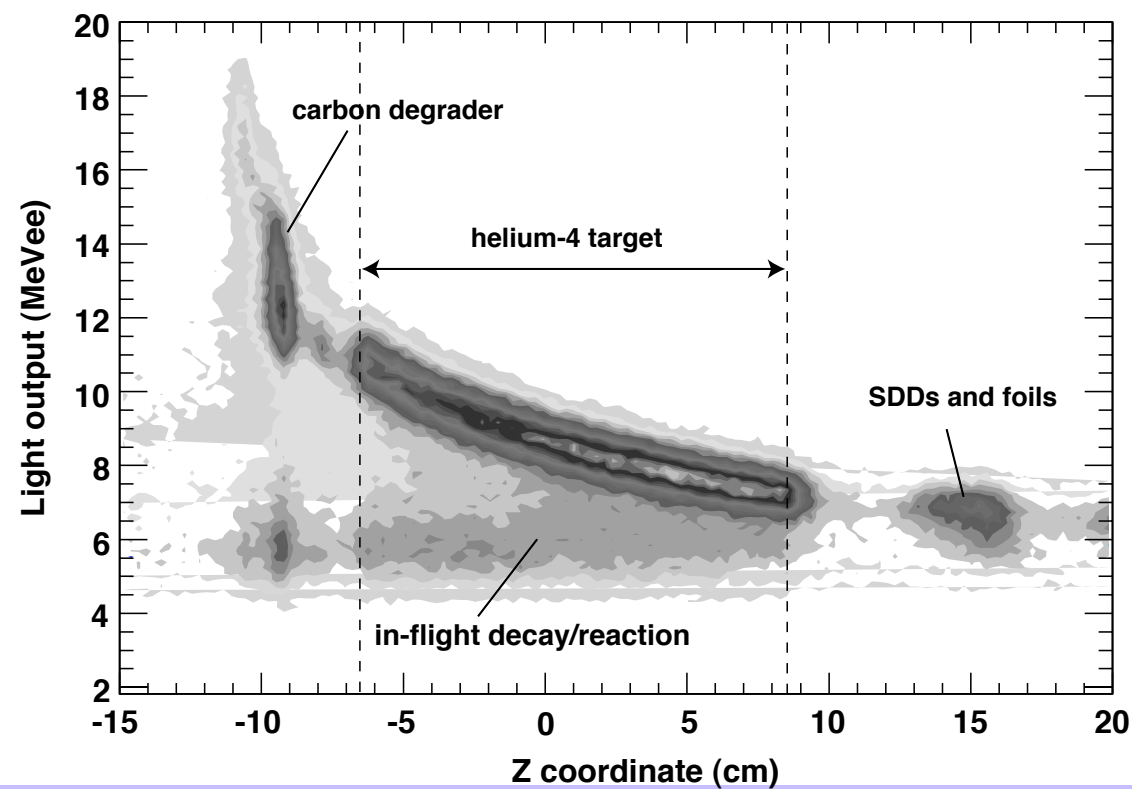
K^- stop vertex



Fiducial selection

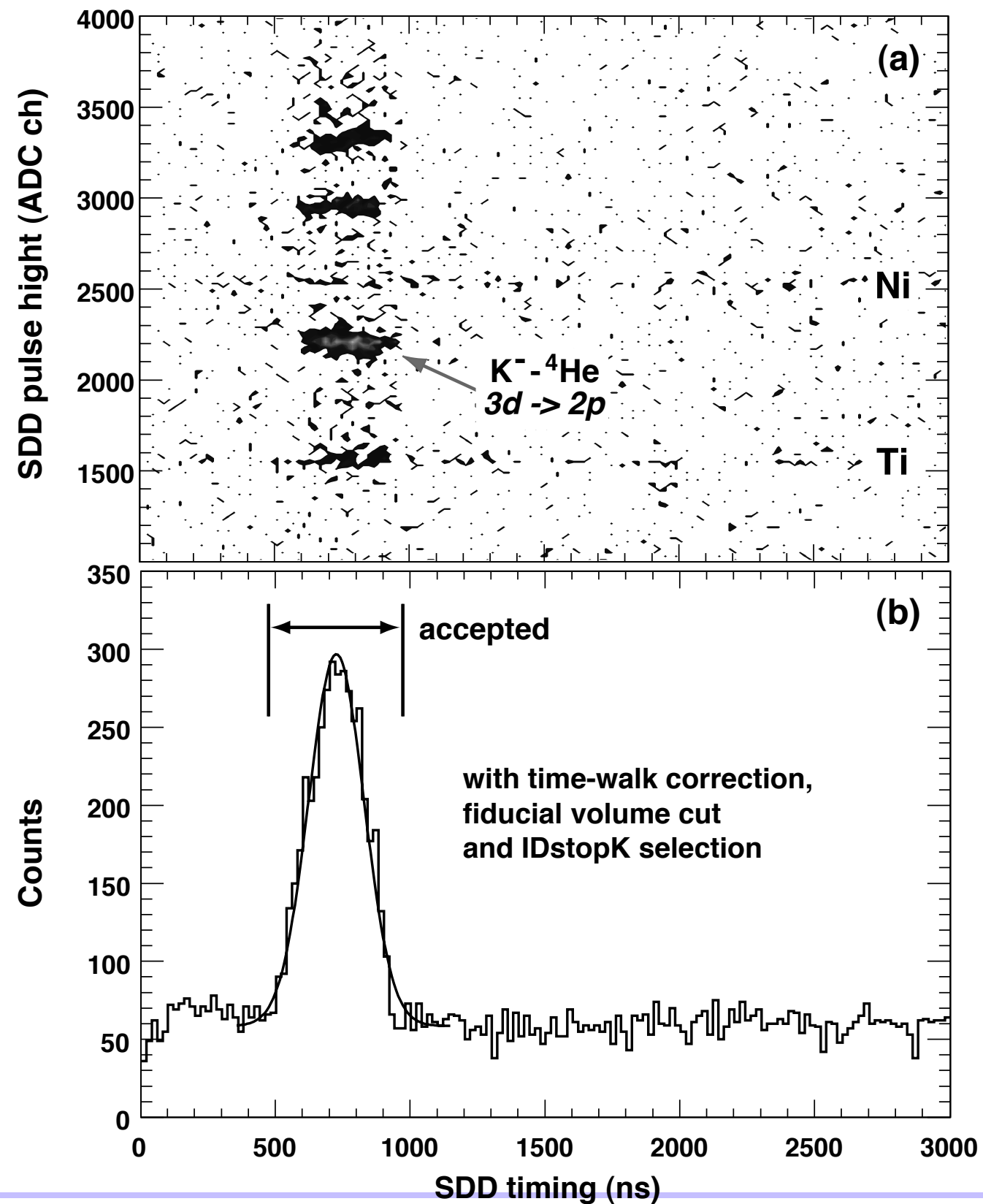


front view



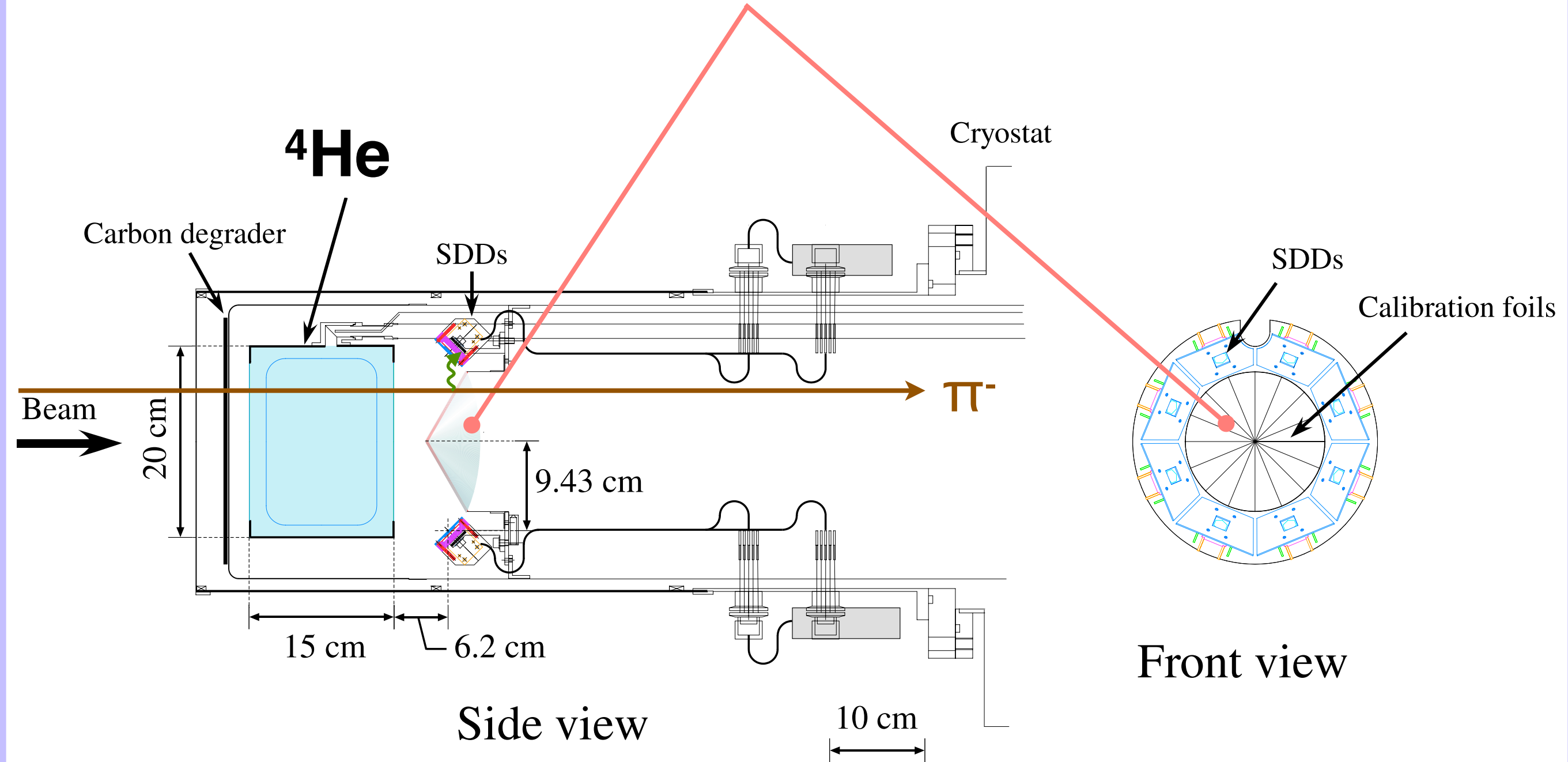
side view

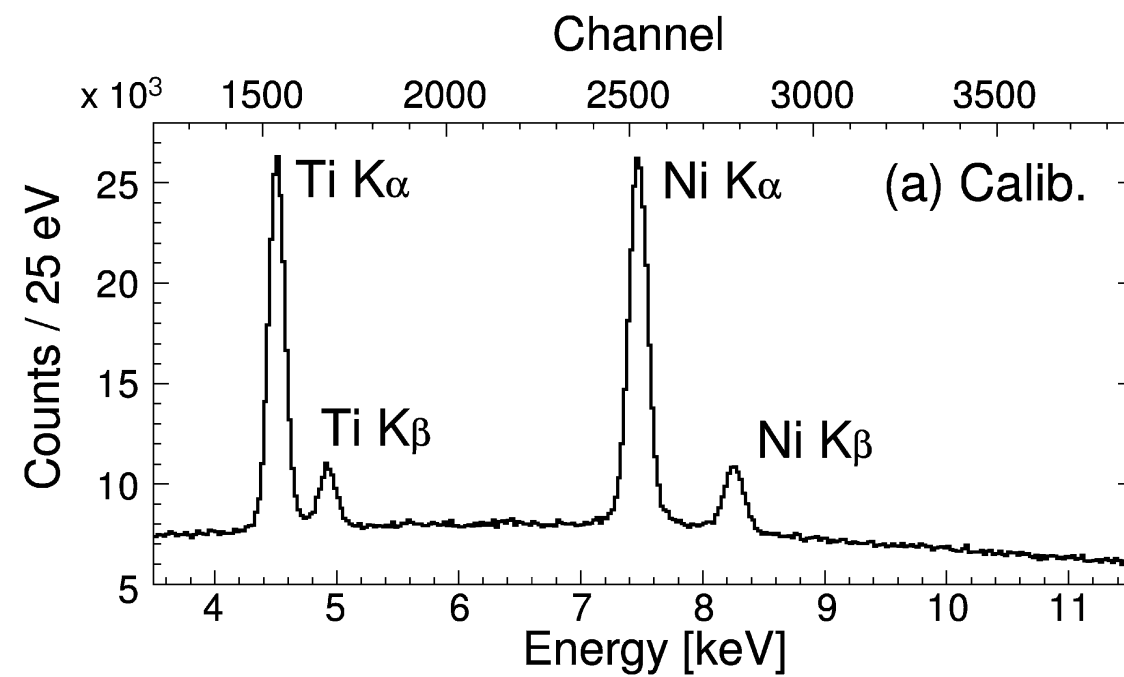
Timing selection



③ in-situ calibration

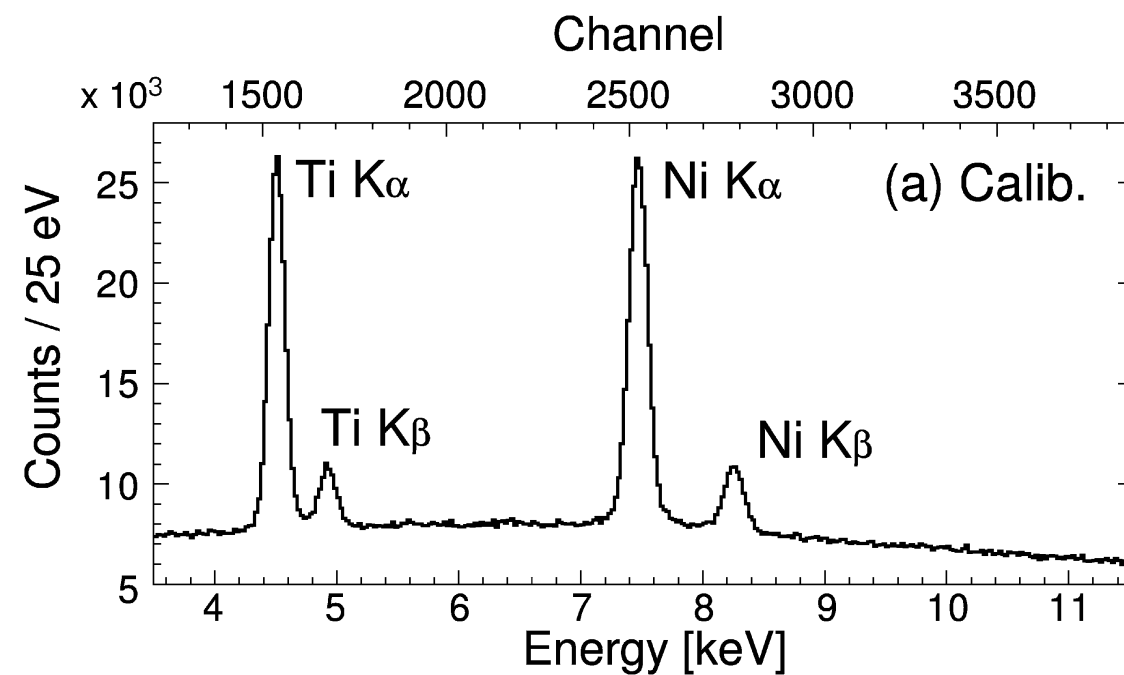
Ti & Ni foils



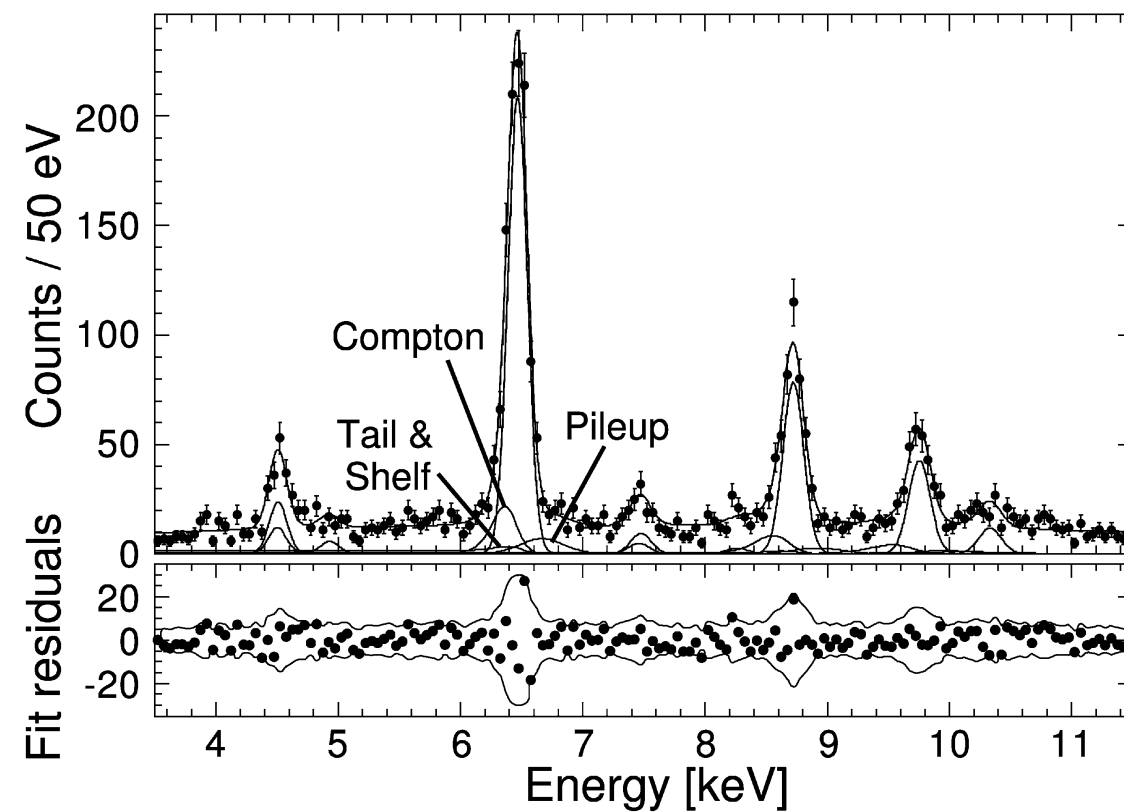


SDD Self trigger

Okada et al., PLB 653 (2007) 387



SDD Self trigger

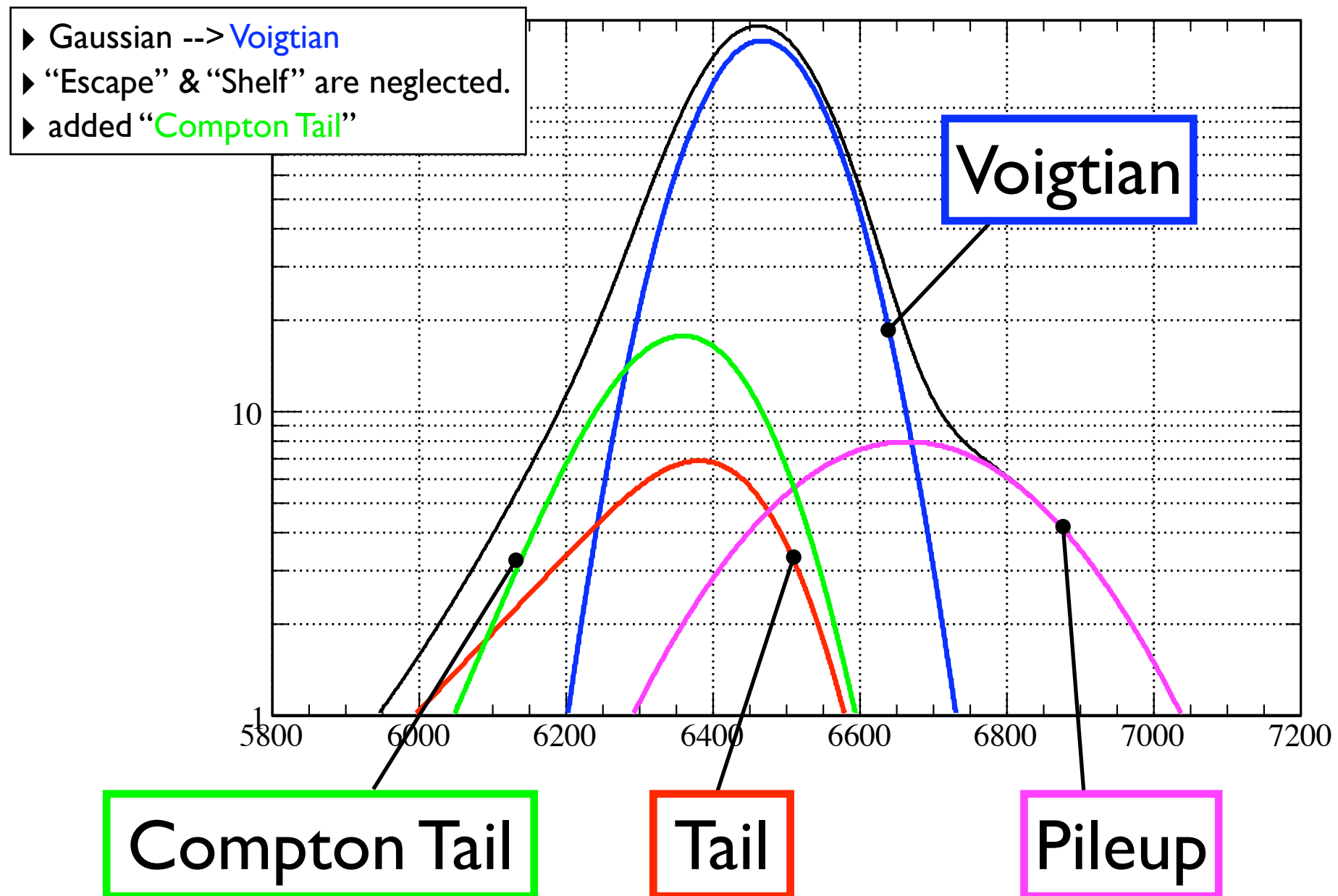


Kaon trigger,
fiducial & timing cut

Okada et al., PLB 653 (2007) 387

④ line shape

the fit



Okada et al., PLB 653 (2007) 387

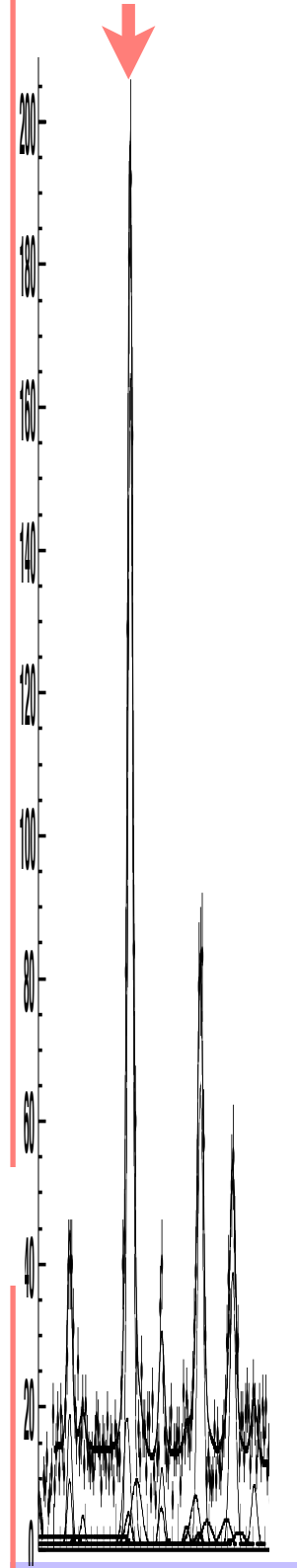
結果

Results

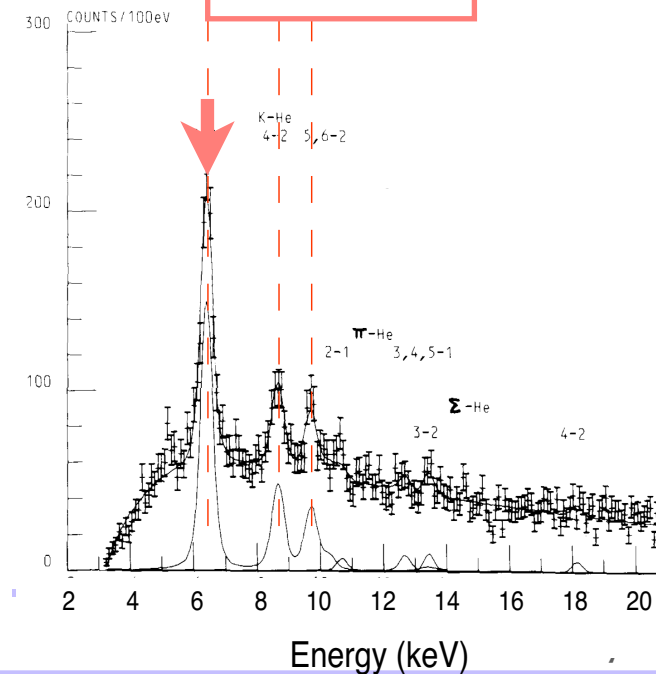
Same-scale comparison



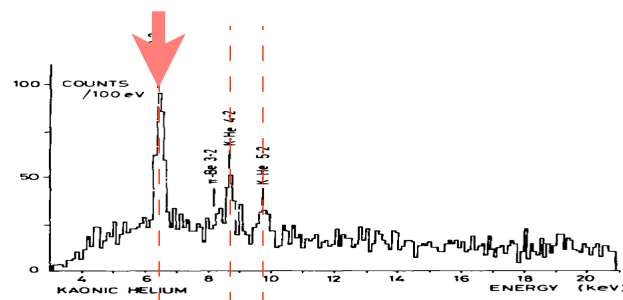
2007



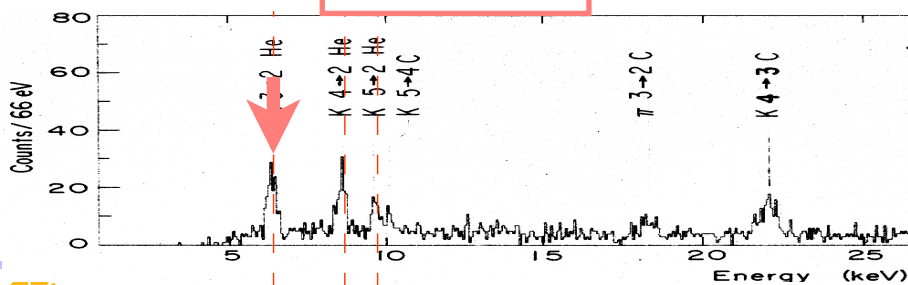
1983



1979



1971

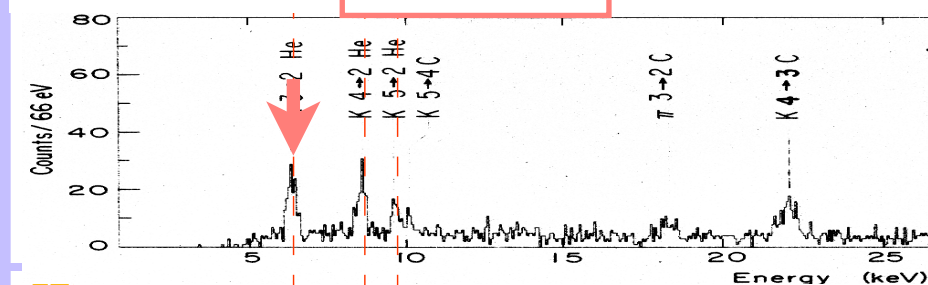


Same-scale comparison

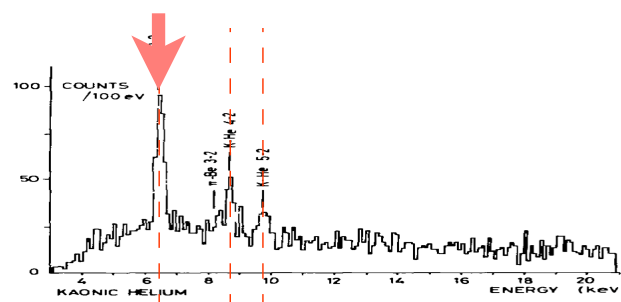


statistics	x3
S/N ratio	x6
resolution	x2

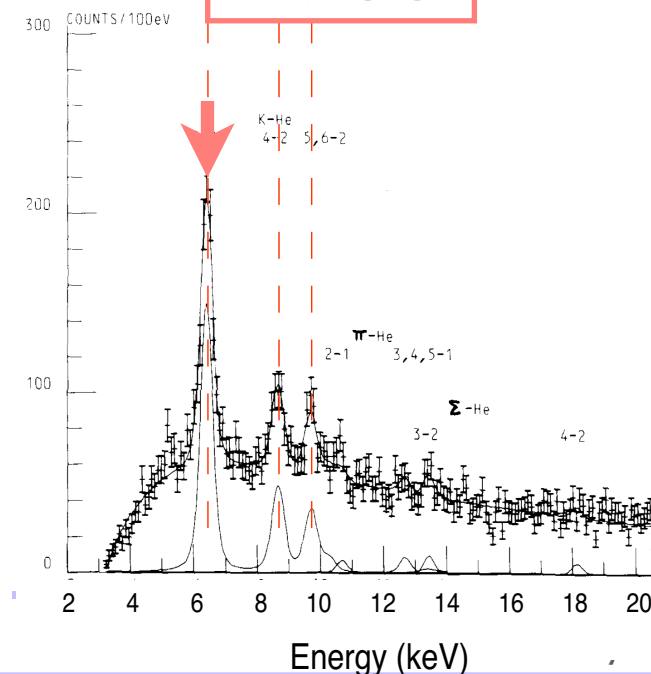
1971



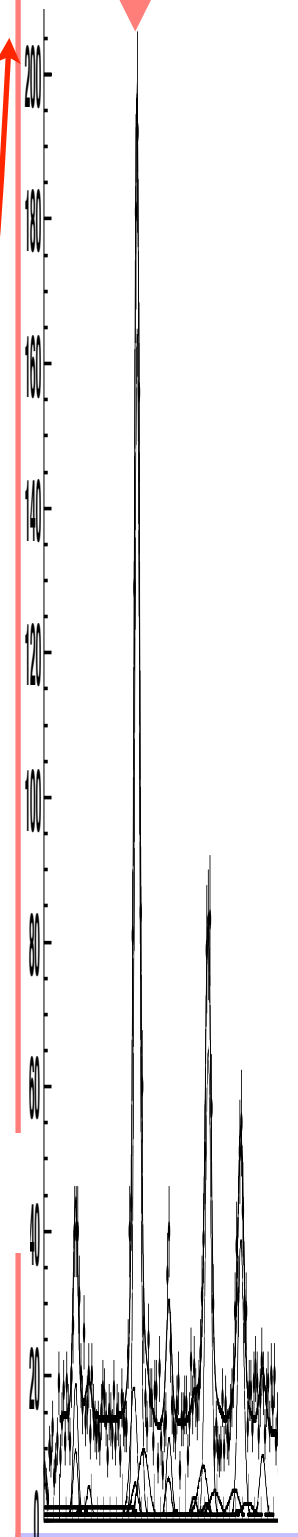
1979



1983



2007

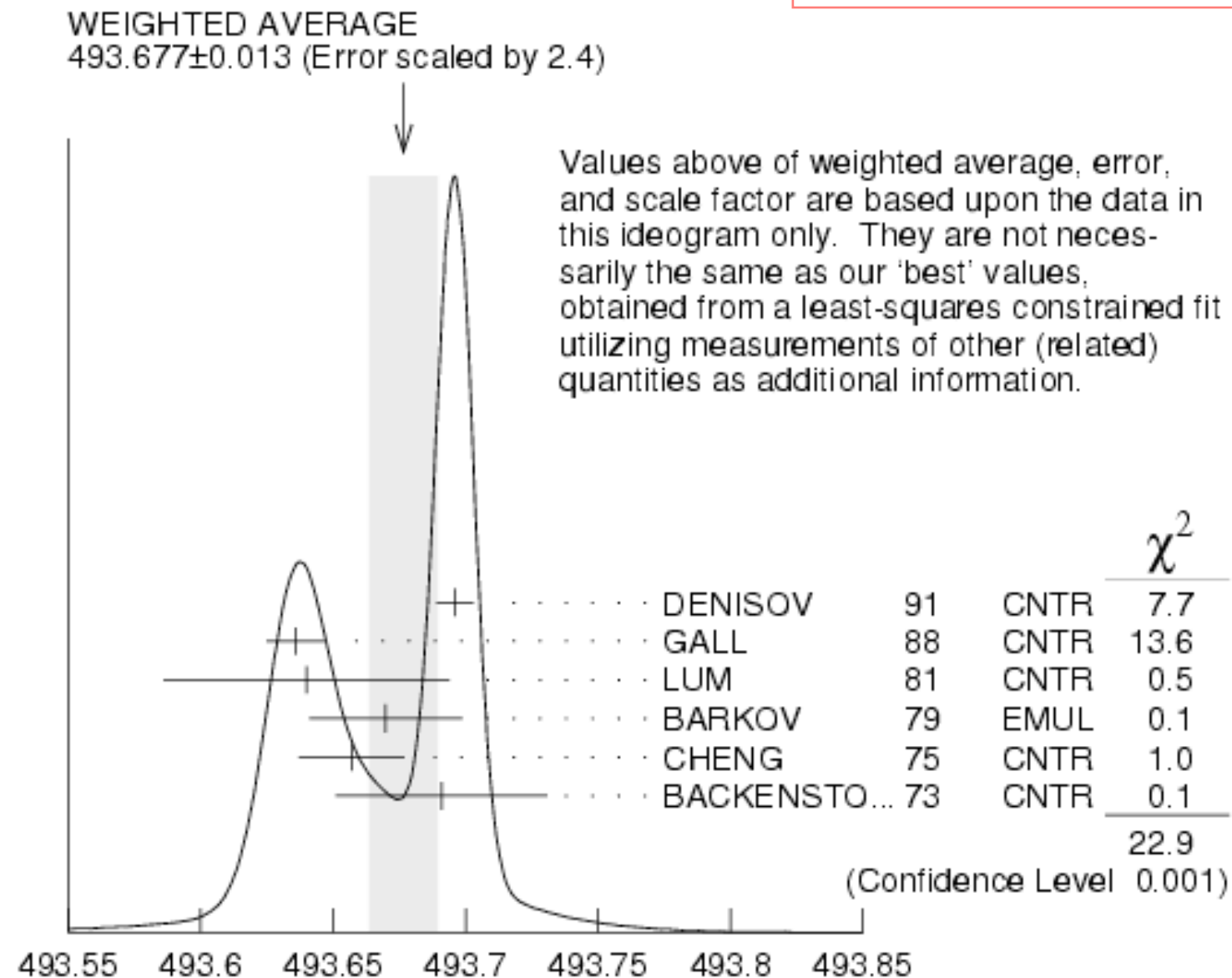


ayano, MENU2010

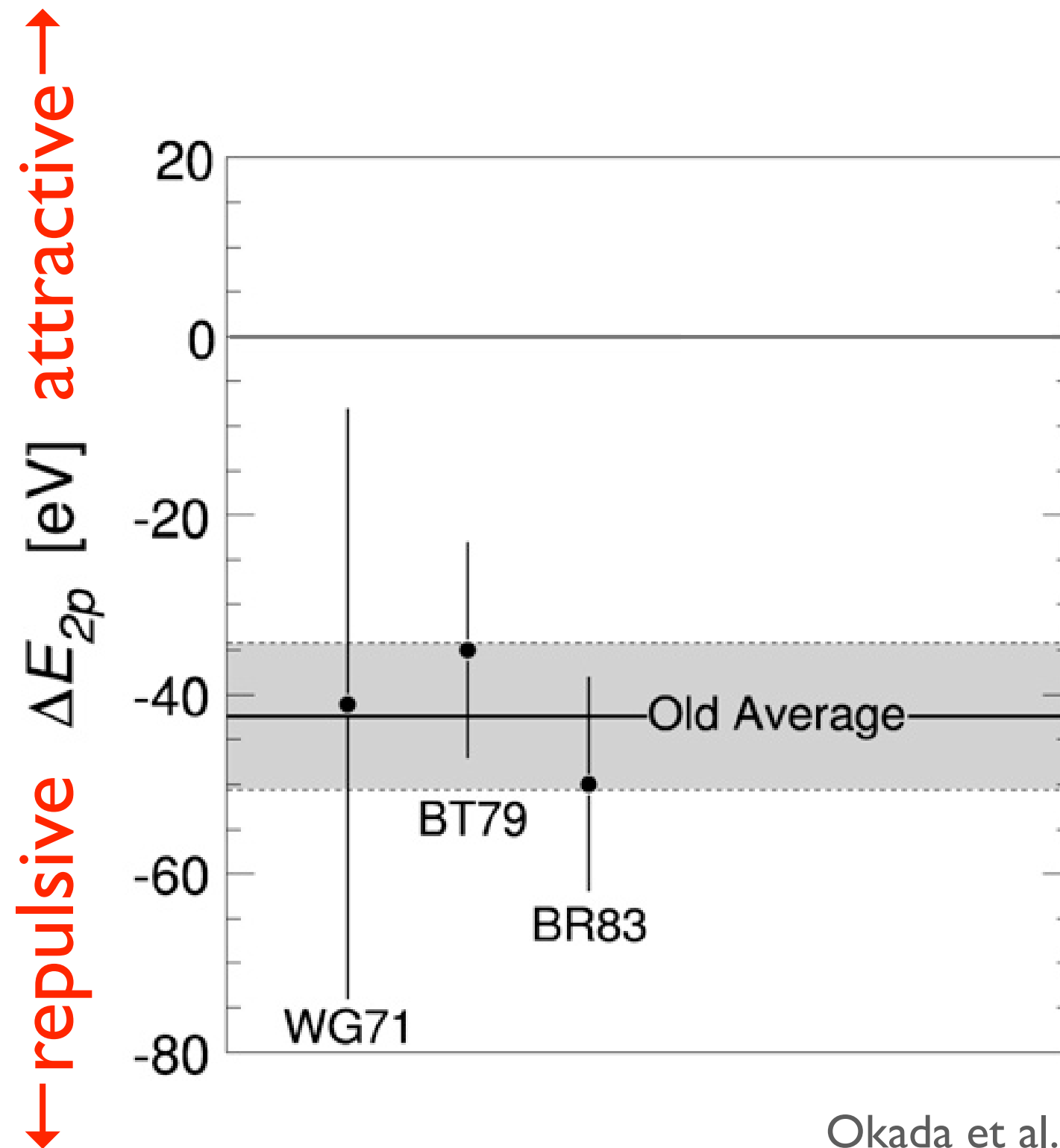
$$\text{shift} = E^{\text{exp}} - E^{\text{EM}}$$

$E_{\text{EM}}(\text{eV})$ 6463.46 ± 0.15 (Koike)

due to the K mass error

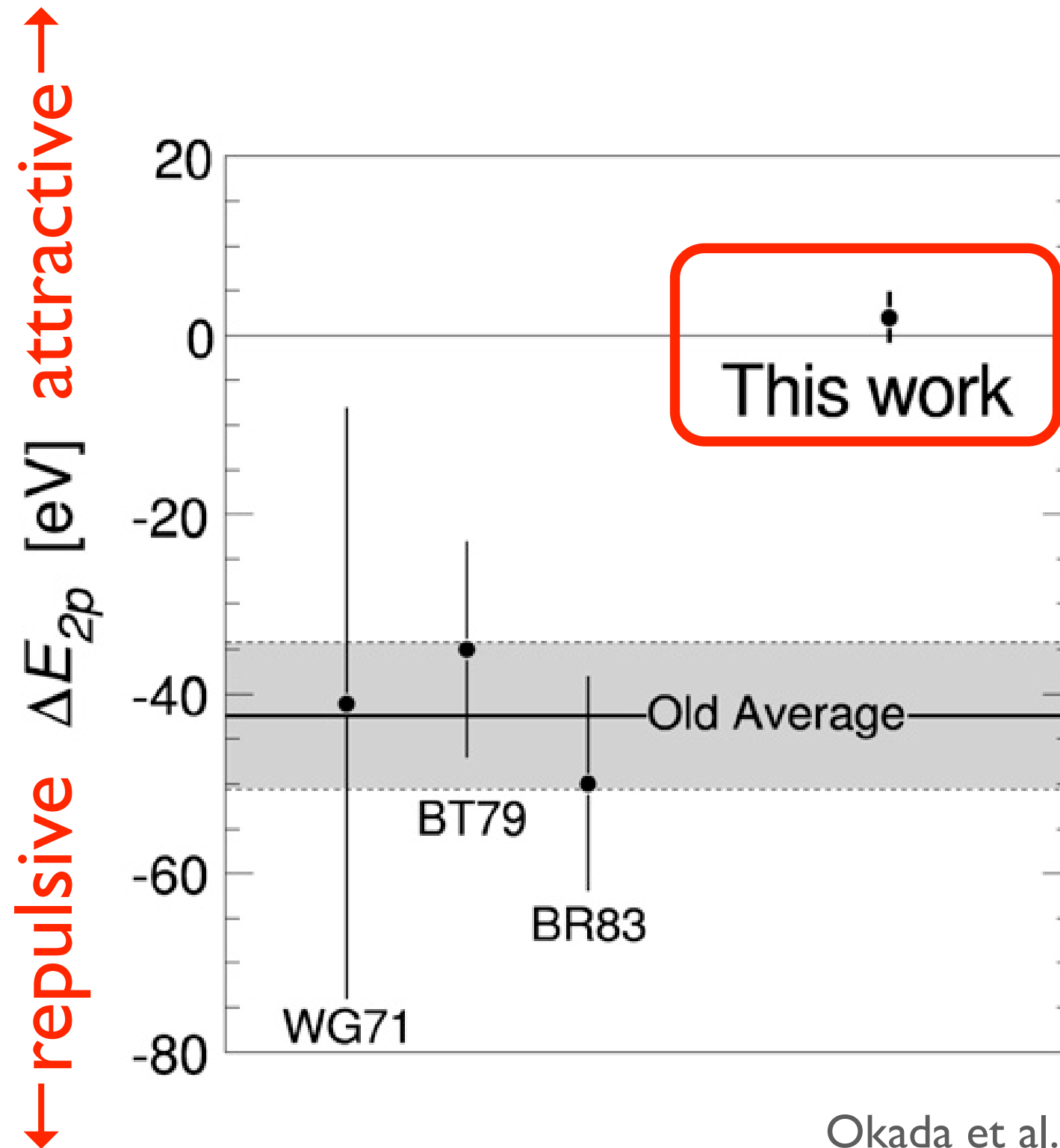


corresponds to ± 1 eV in X-ray energy



Okada et al., PLB 653 (2007) 387

$$\Delta E_{2p=2} = 2 \pm 2(\text{stat}) \pm 2(\text{sys}) \text{ eV}$$

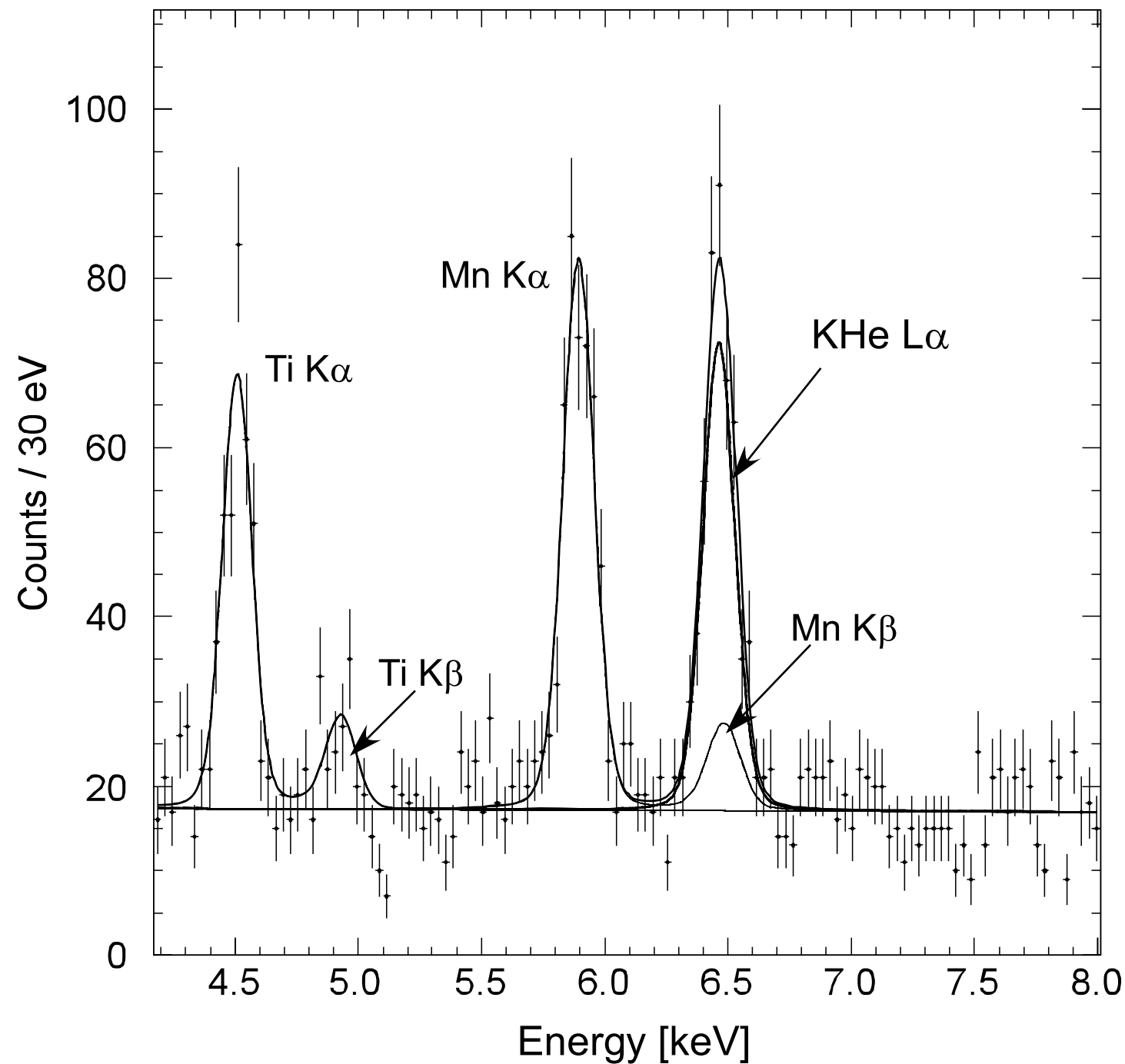


Okada et al., PLB 653 (2007) 387

SIDDHARTA $K^{-}{}^4\text{He}$



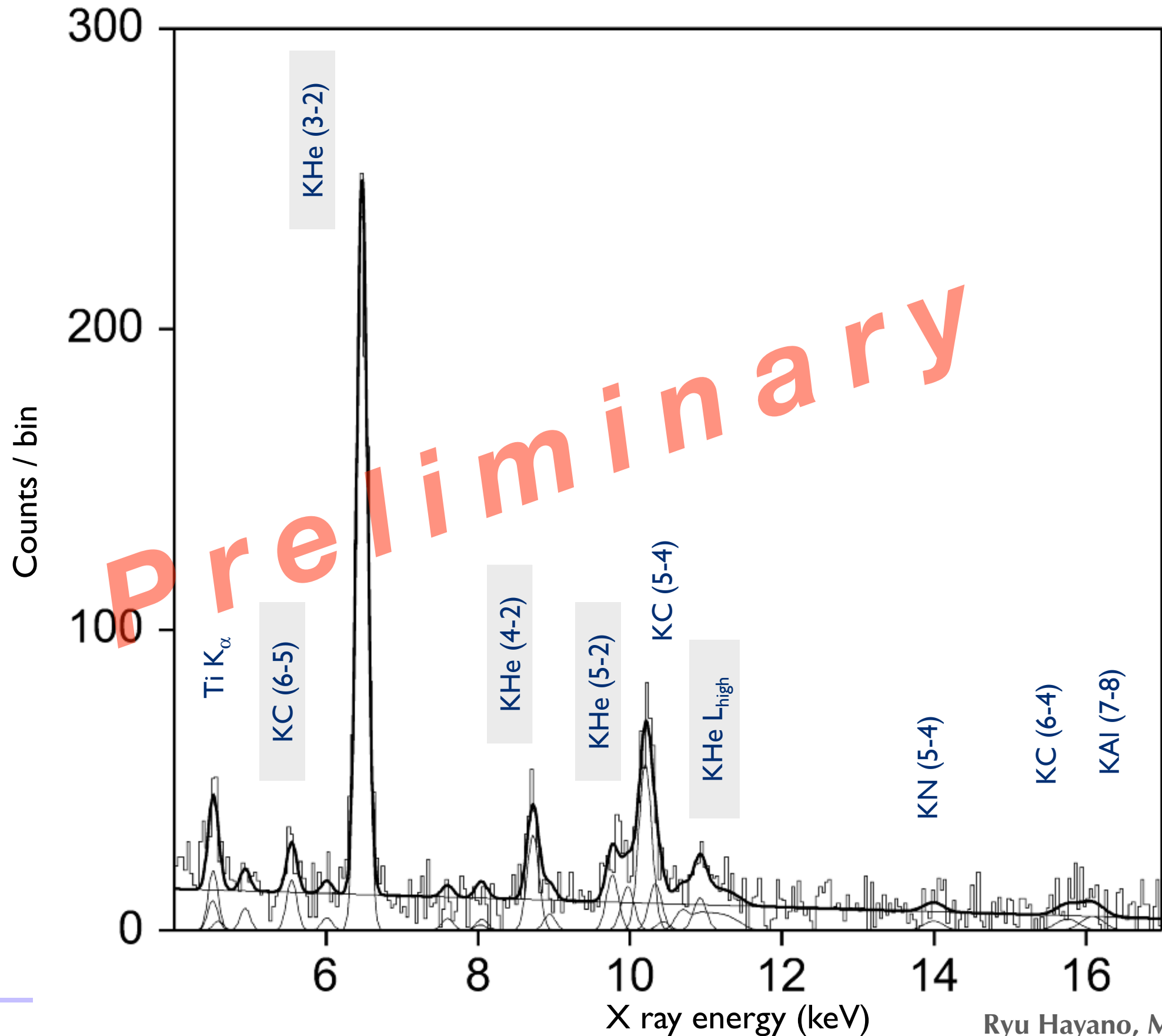
Gaseous ${}^4\text{He}$ target



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

M. Bazzi et al., Phys. Lett. B 681, (2009) 310

Siddharta K-⁴He





E17: the “day-1” experiment @ J-PARC

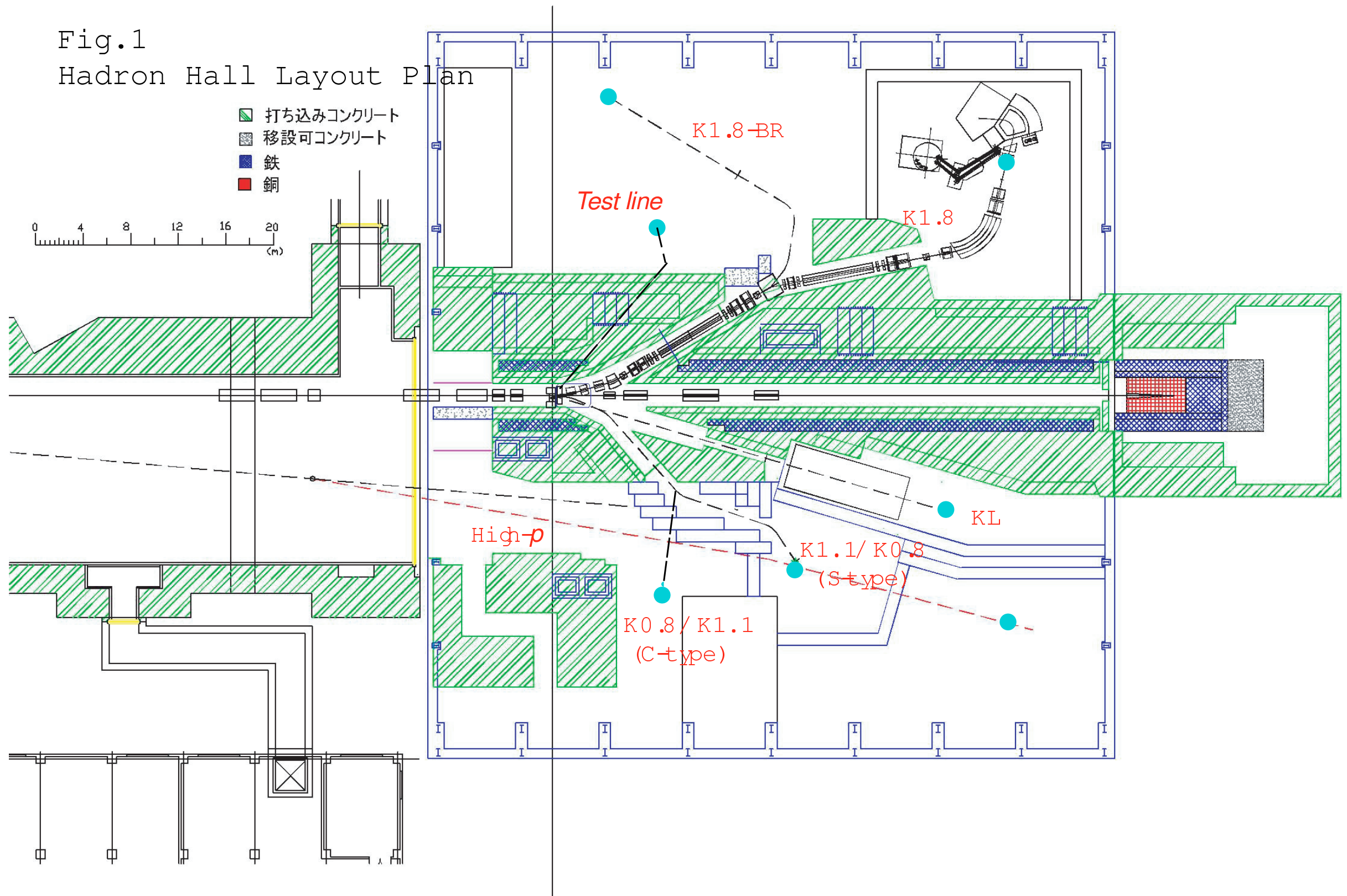




Hadron hall

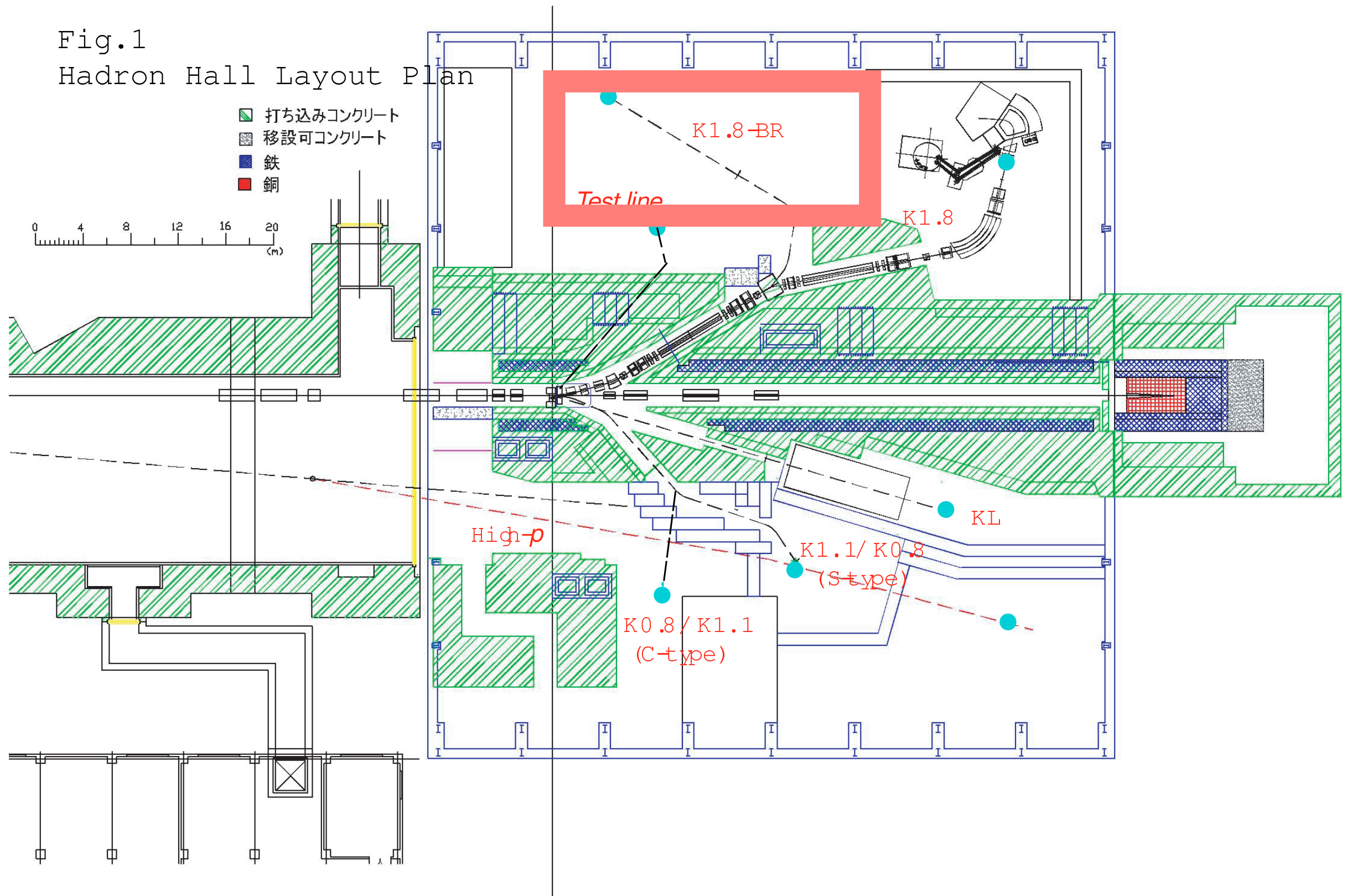
Hadron hall

Fig.1
Hadron Hall Layout Plan



Hadron hall

Fig.1
Hadron Hall Layout Plan

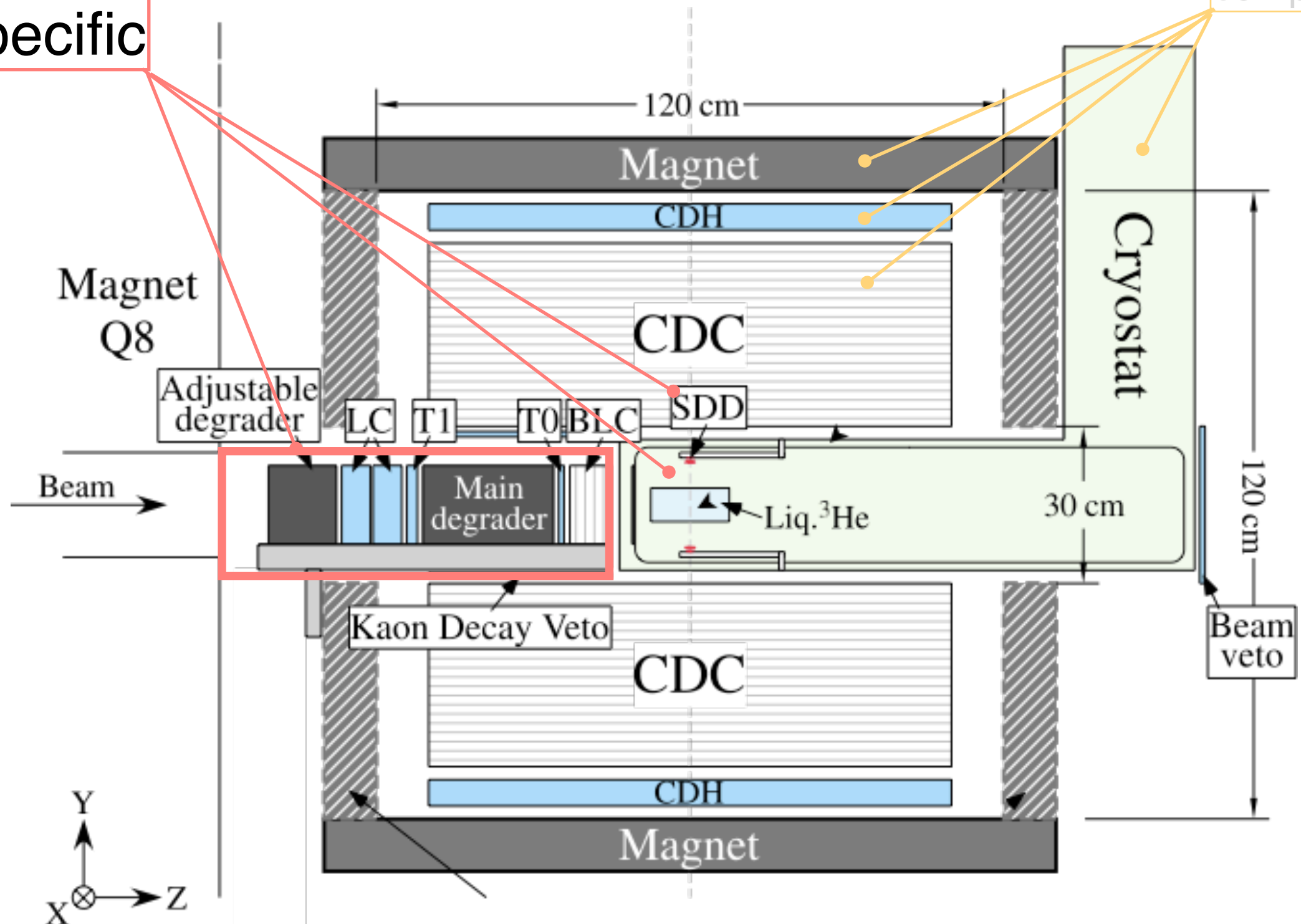


E17(I5) setup

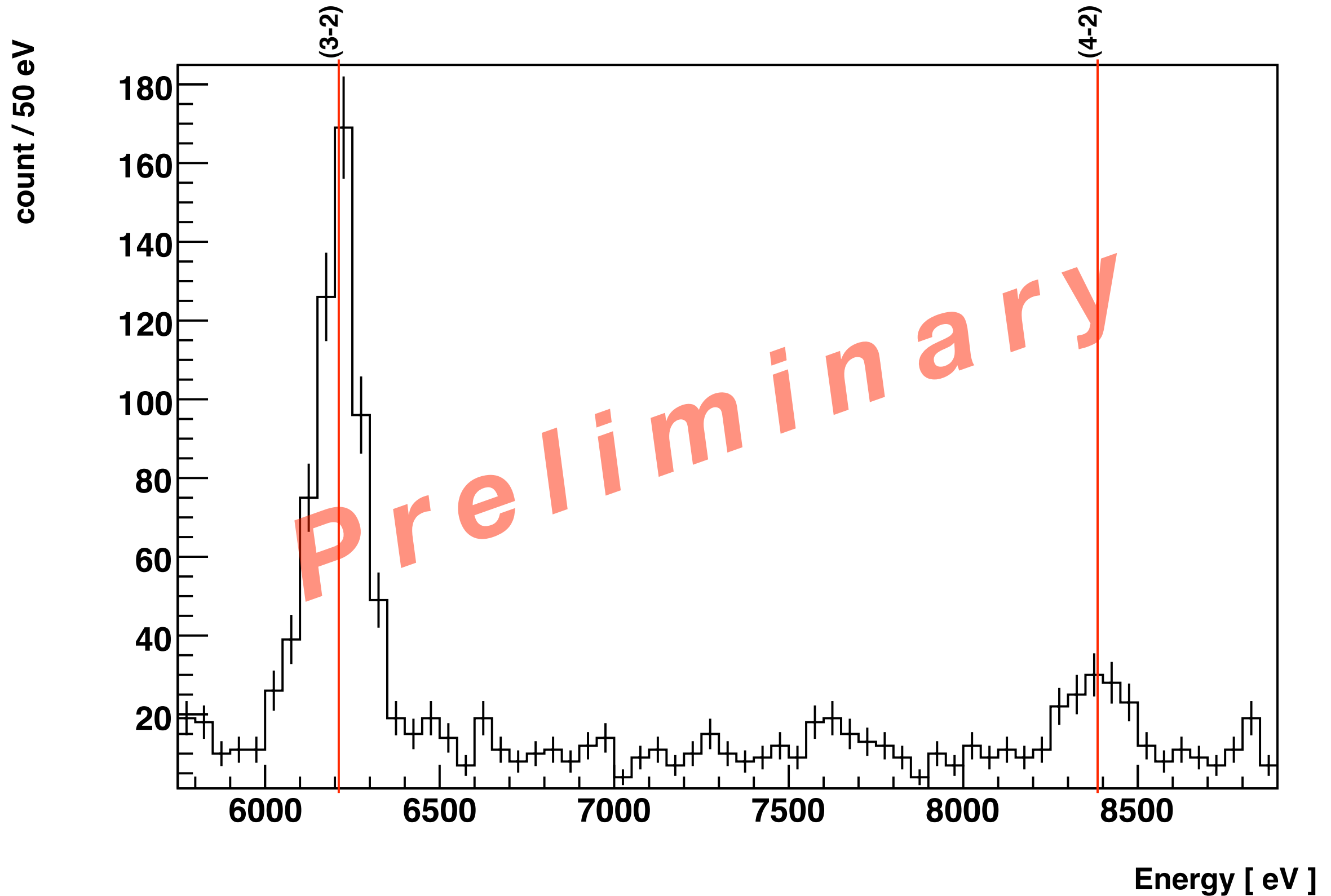


E17
specific

E15
components



SIDDHARTA $K^{-3}\text{He}$



結論

Summary

- ✓ Kaonic X-rays: scattering lengths at threshold
- ✓ K^-p : KpX - DEAR - SIDDHARTA
- ✓ $K^-^4\text{He}$: KEK E570 (no more Kaonic Helium puzzle); confirmed by SIDDHARTA
- ✓ $K^-^3\text{He}$: J-PARC E17 (& SIDDHARTA)