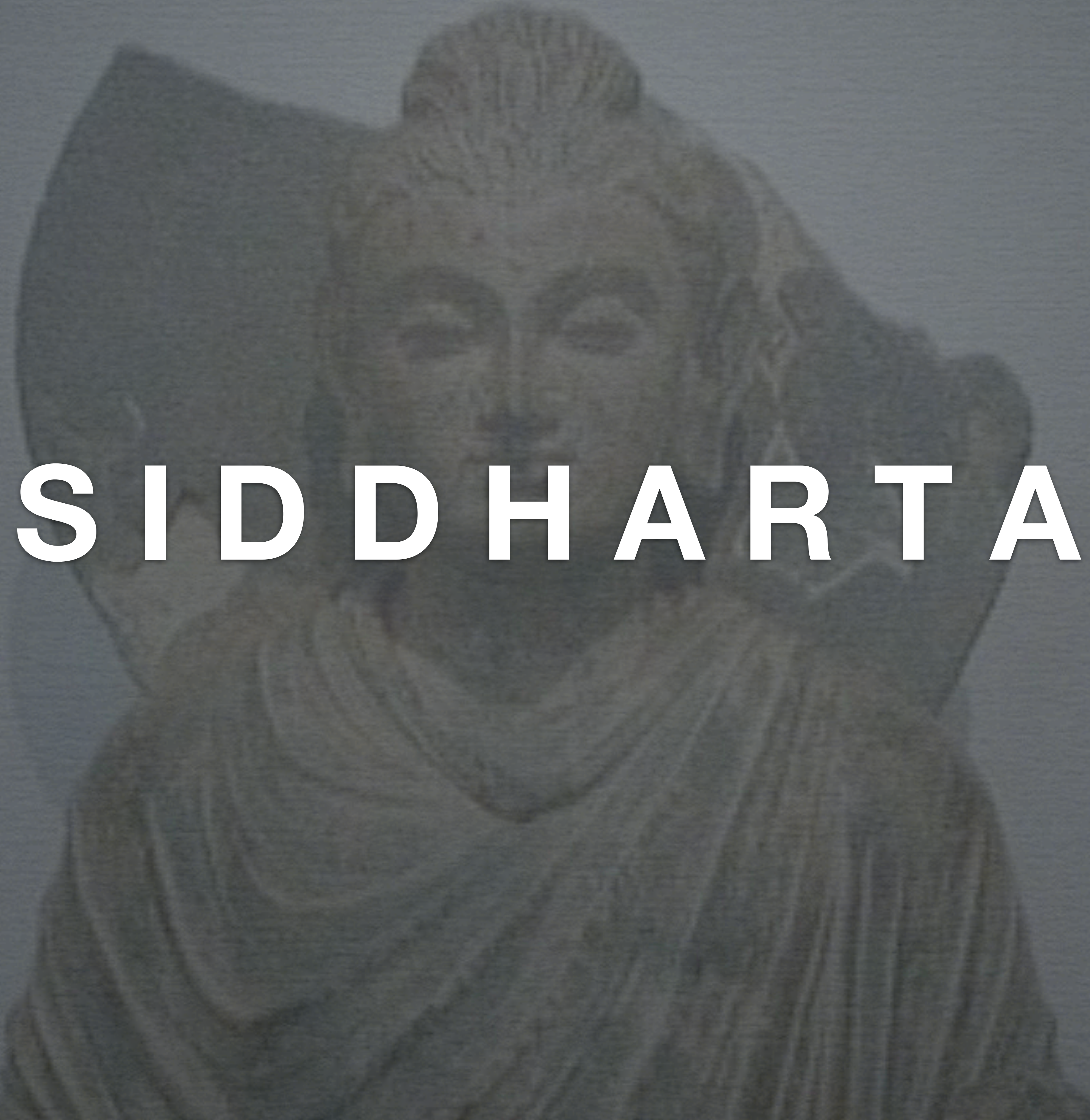
14 May 2009, XIV Frascati Spring School -YRW

Kaonic atoms at DAFNE

INFN-LNF Shinji Okada
on behalf of SIDDHARTA collaboration

SIlicon Drift Detector for Hadronic Atom Research by Timing Application

SIDDHARTA



SIDDHARTA Collaboration

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

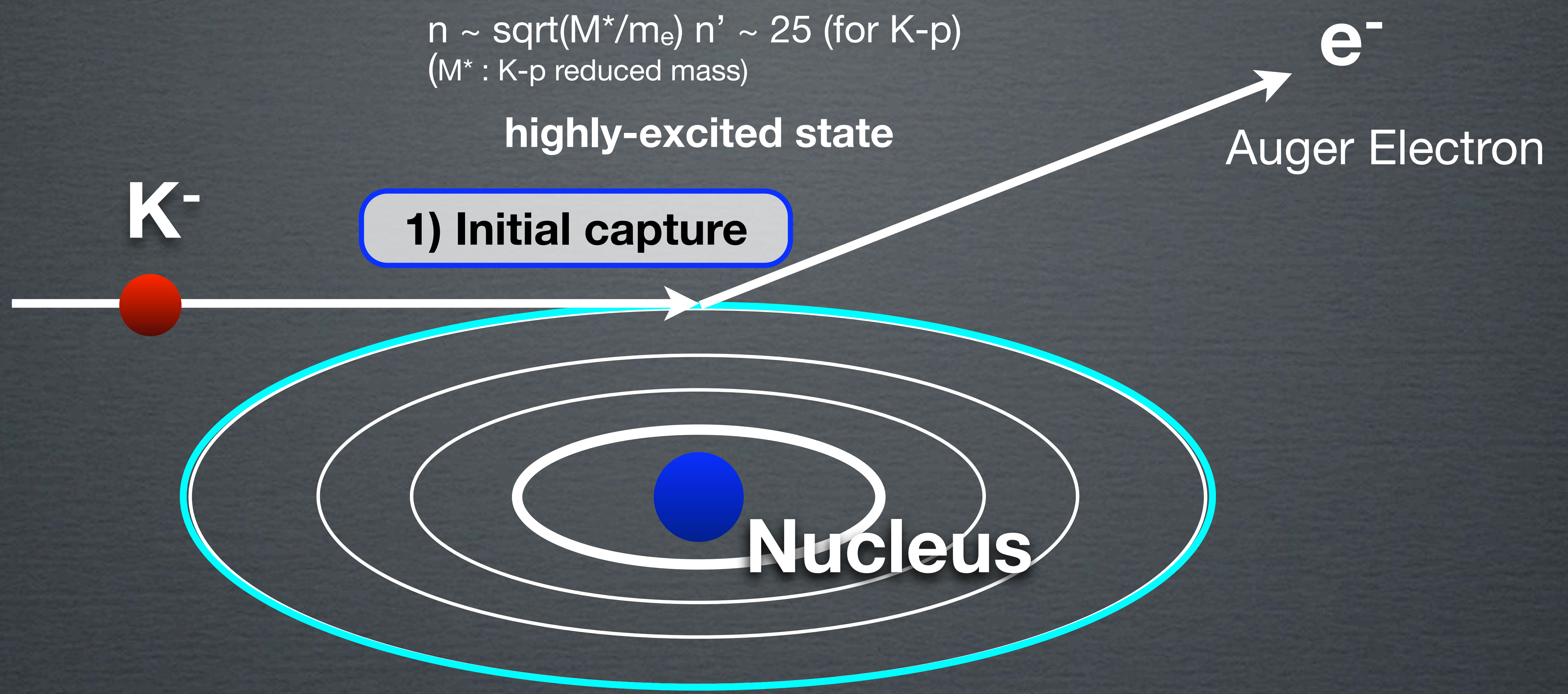
Introduction

Spectroscopy of Kaonic atom x-ray

Fundamental study of **strong interaction**
between anti-K & nucleus at low energy limit

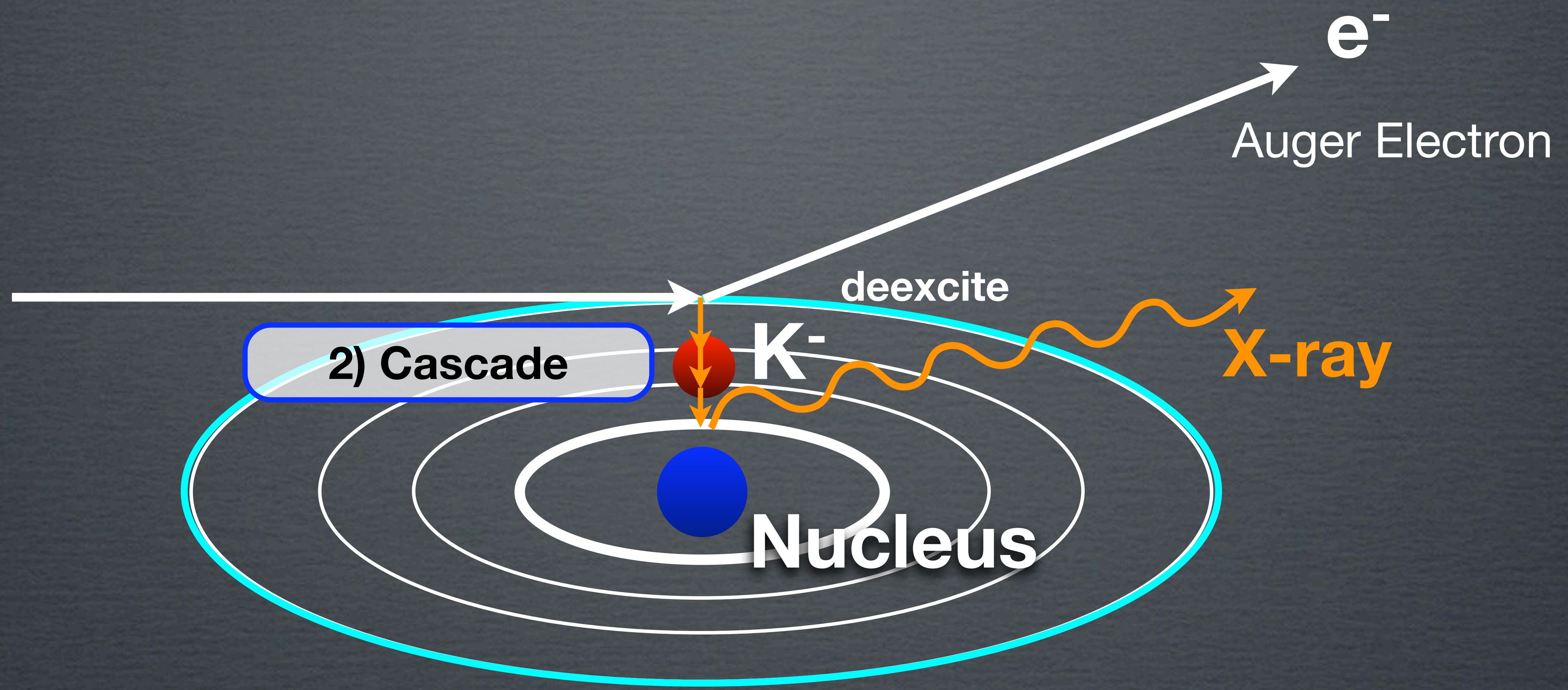
What is
Kaonic atom ?

Kaonic atom formation

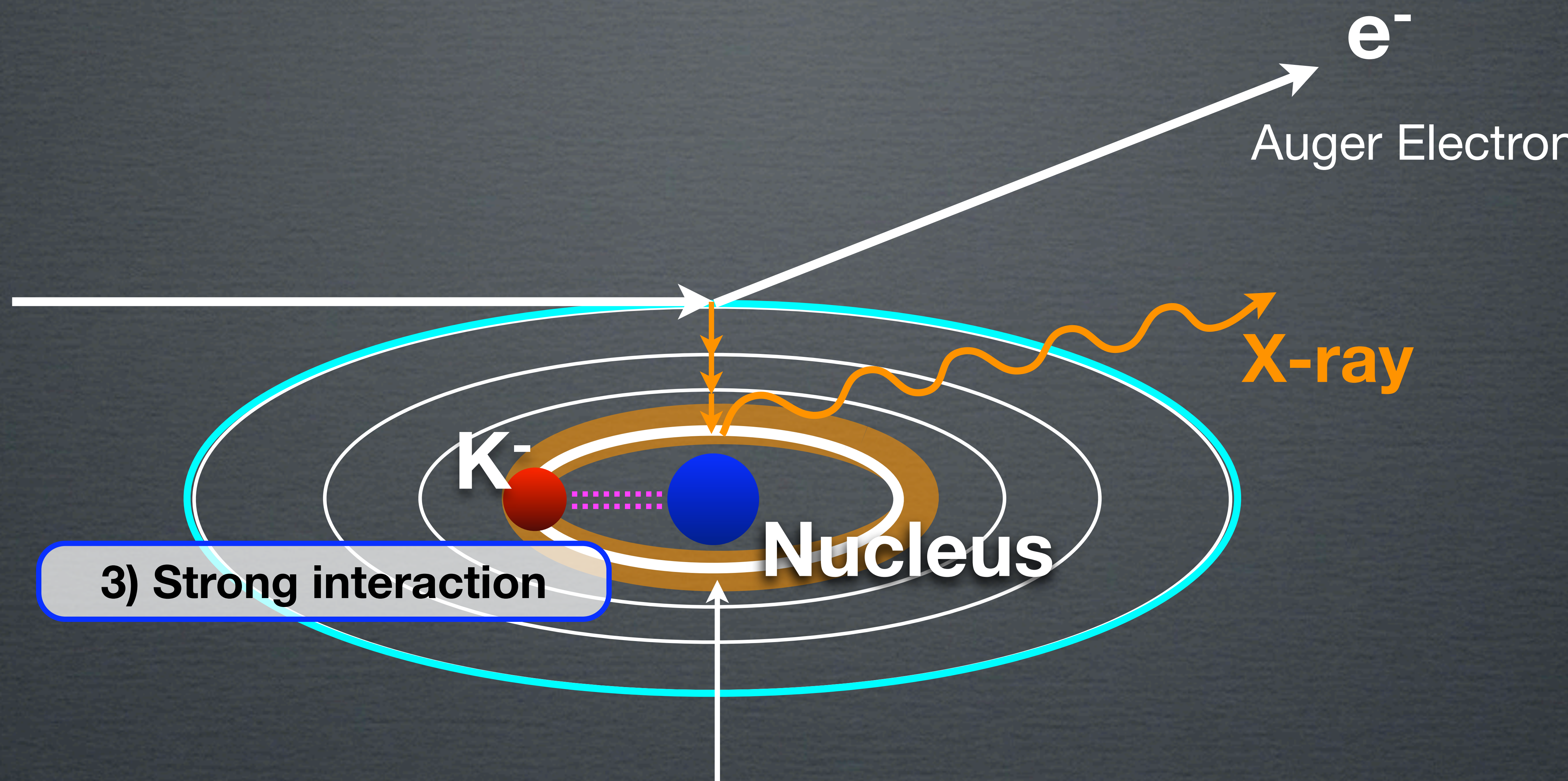


stopped in a target medium

Kaonic atom formation

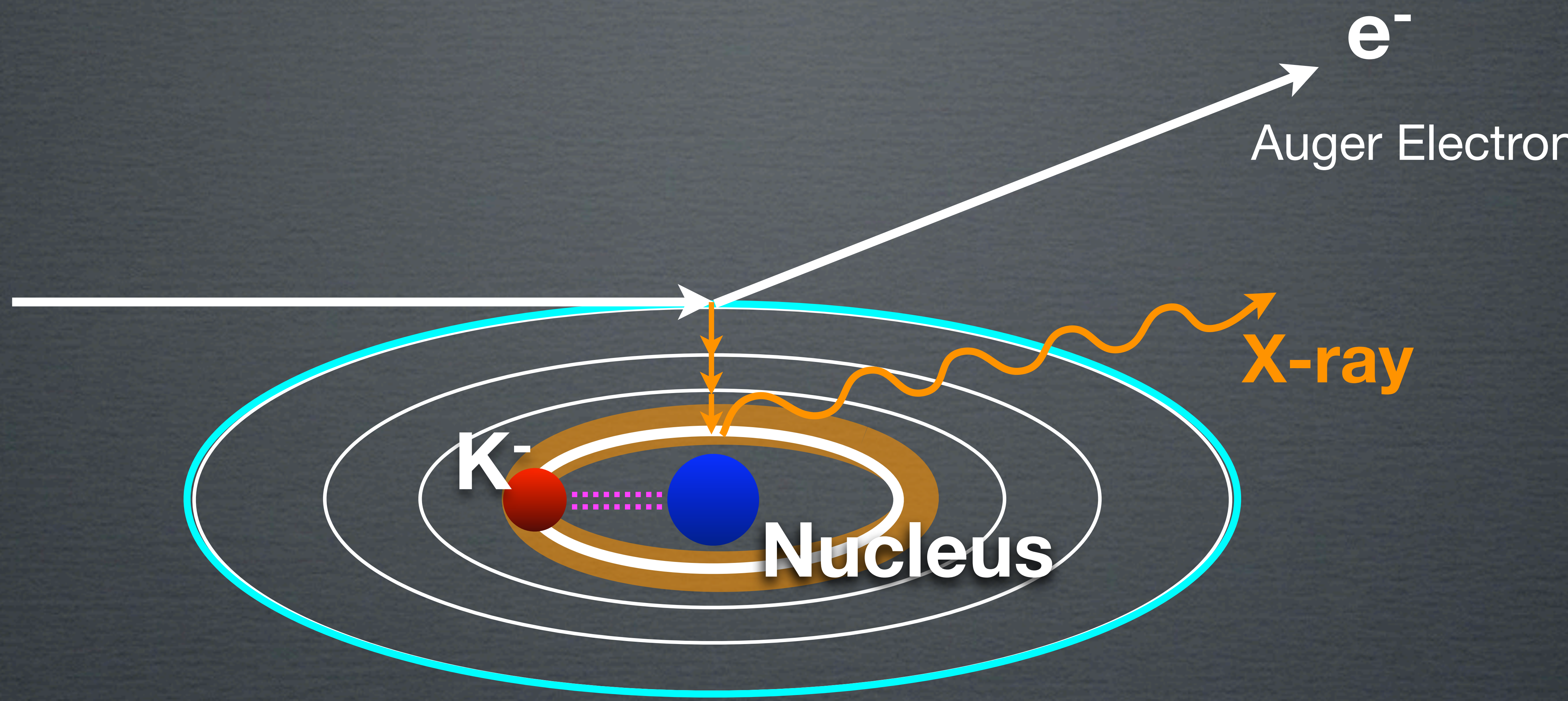


Kaonic atom formation



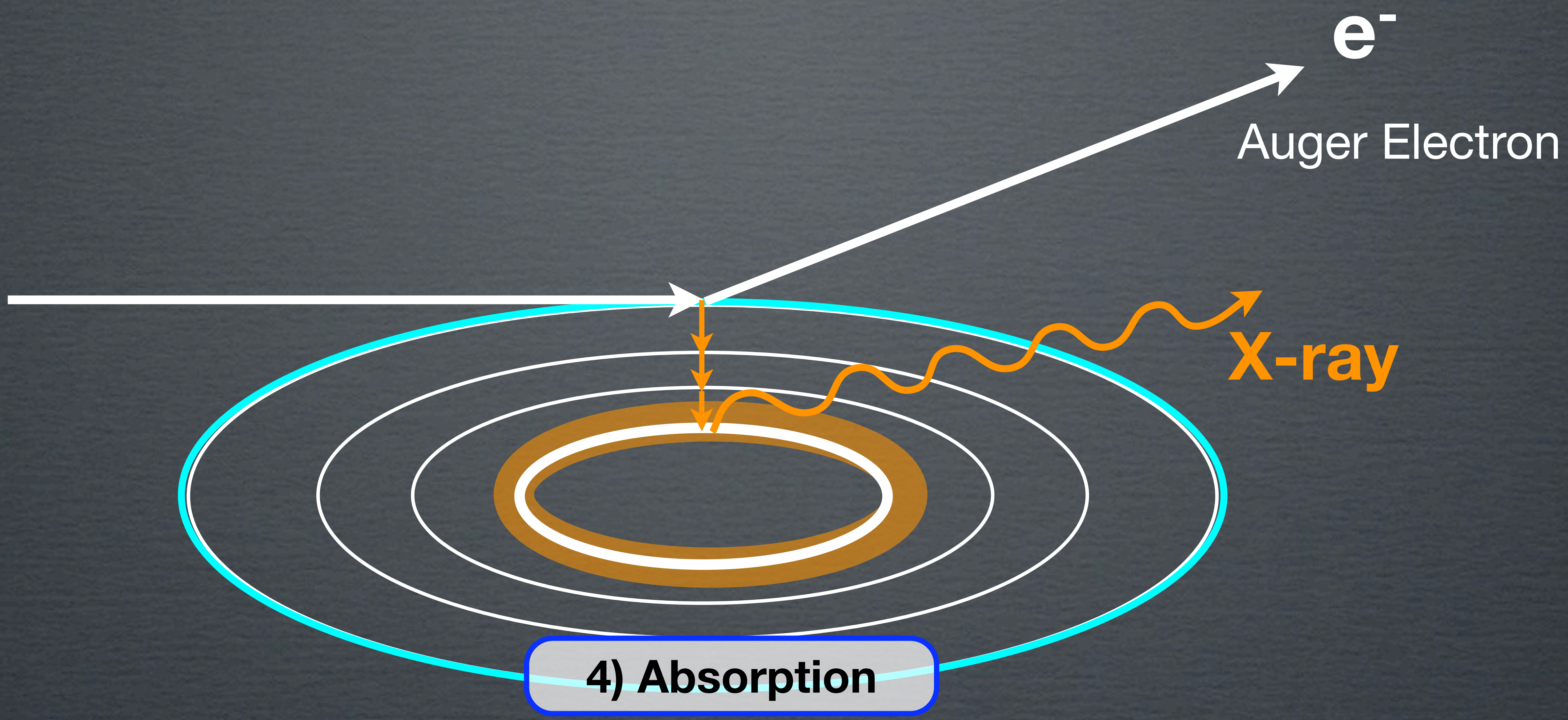
e.g. · **1s** for K-p, K-d
· **2p** for K-He

Kaonic atom formation



The strong int. width > Radiative trans. width

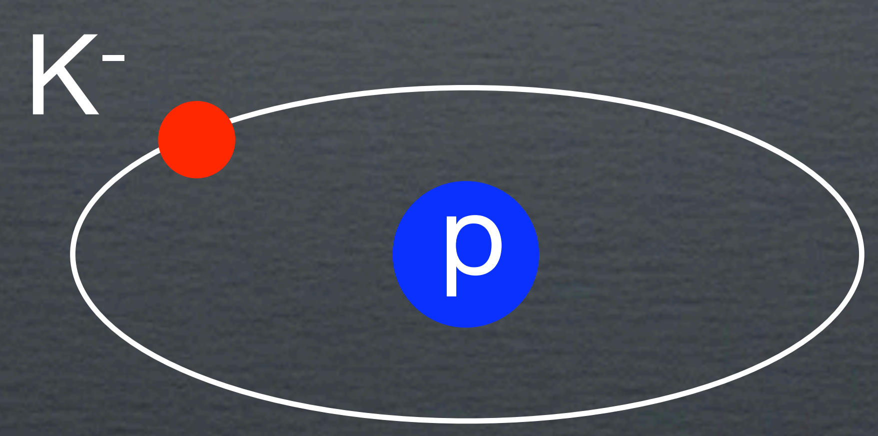
Kaonic atom formation



The strong int. width > Radiative trans. width

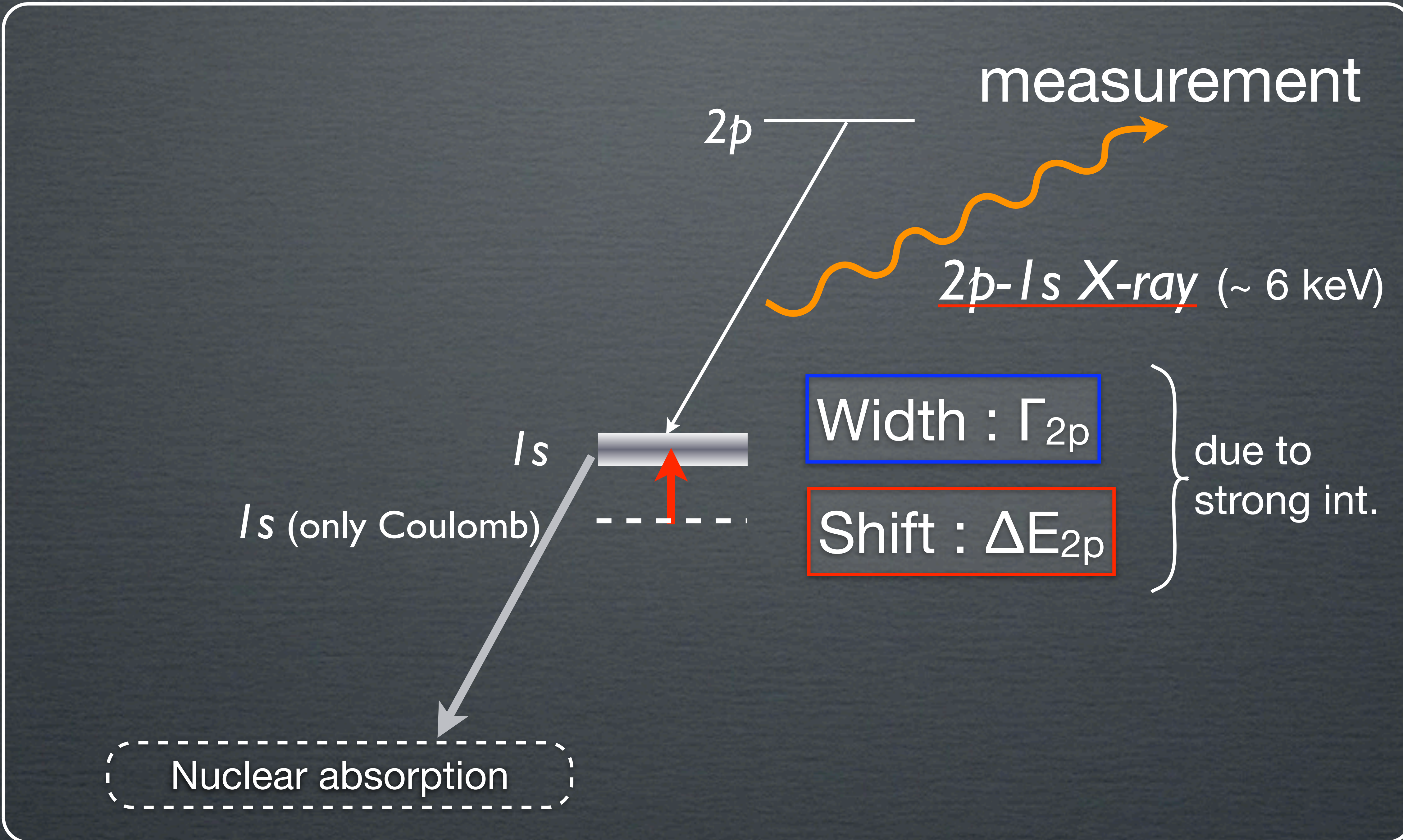
The simplest Kaonic atom

Kaonic Hydrogen



Last orbit = 1s

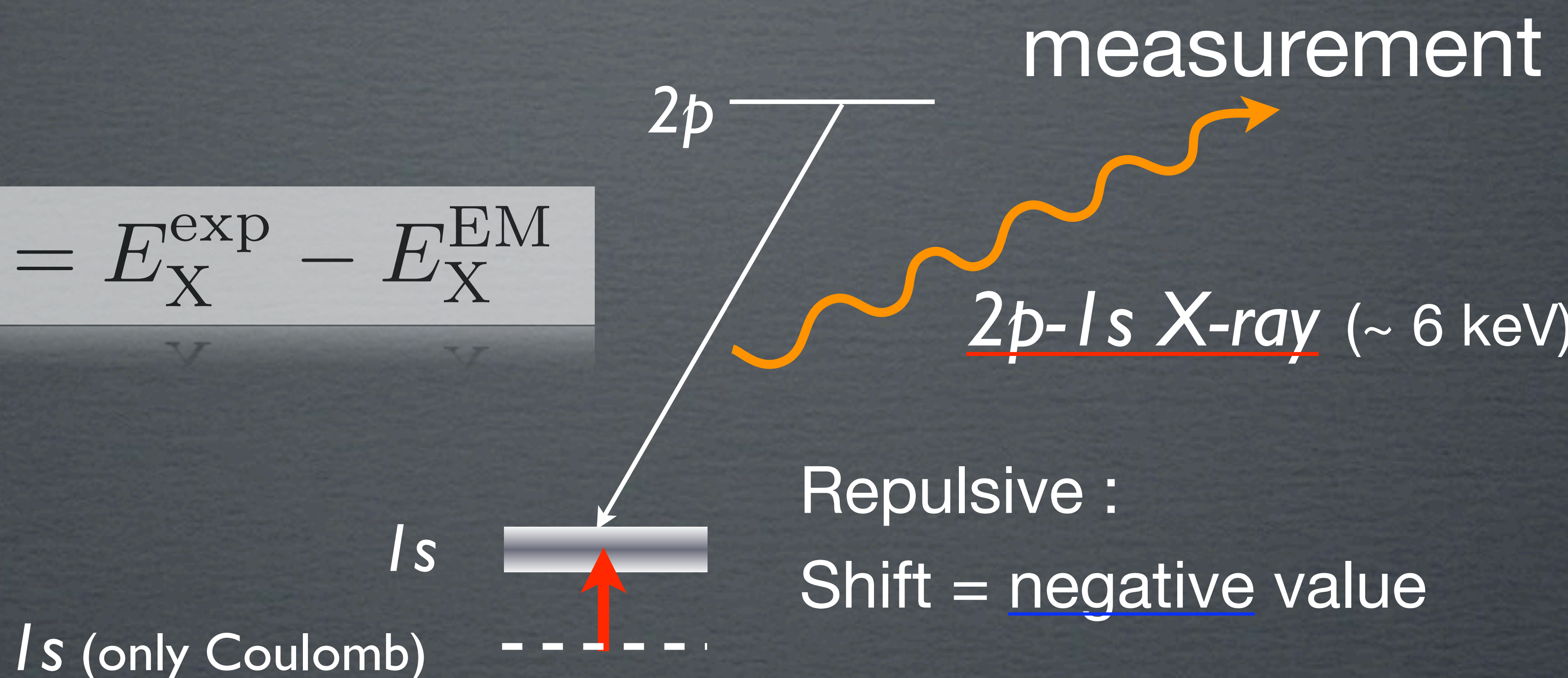
~ Kaonic hydrogen ~



Last orbit = 1s

~ Kaonic hydrogen ~

$$\Delta E_{2p} = E_{\mathrm{X}}^{\mathrm{exp}} - E_{\mathrm{X}}^{\mathrm{EM}}$$



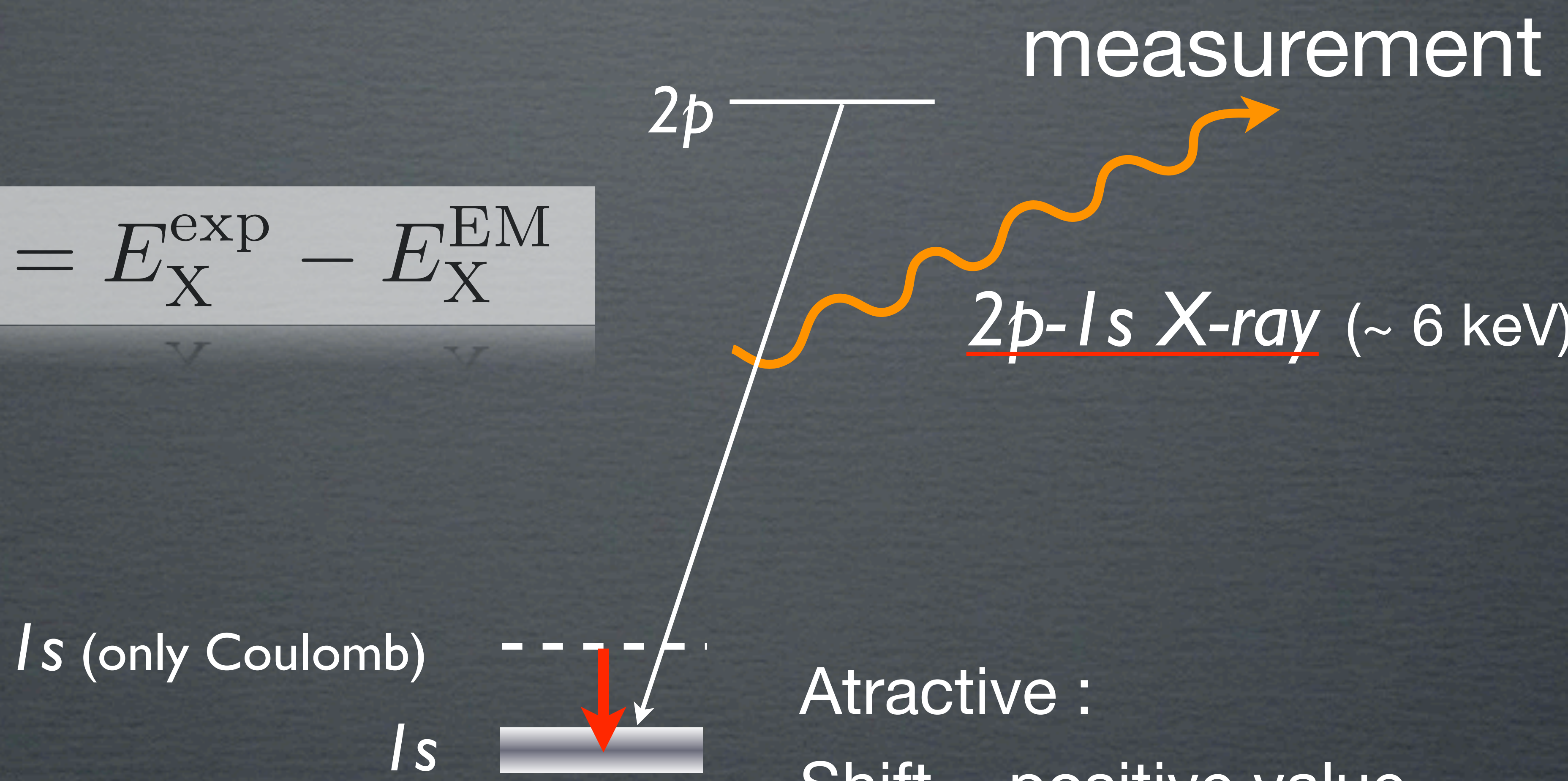
Repulsive :

Shift = negative value

Last orbit = 1s

~ Kaonic hydrogen ~

$$\Delta E_{2p} = E_{\mathrm{X}}^{\mathrm{exp}} - E_{\mathrm{X}}^{\mathrm{EM}}$$



Atractive :

Shift = positive value

Deser Formula

$$-\varepsilon_{1s} + i\frac{\Gamma_{1s}}{2} = 2\alpha^3\mu^2 a_{K^-p}$$

Shift **Width**

Kaonic hydrogen

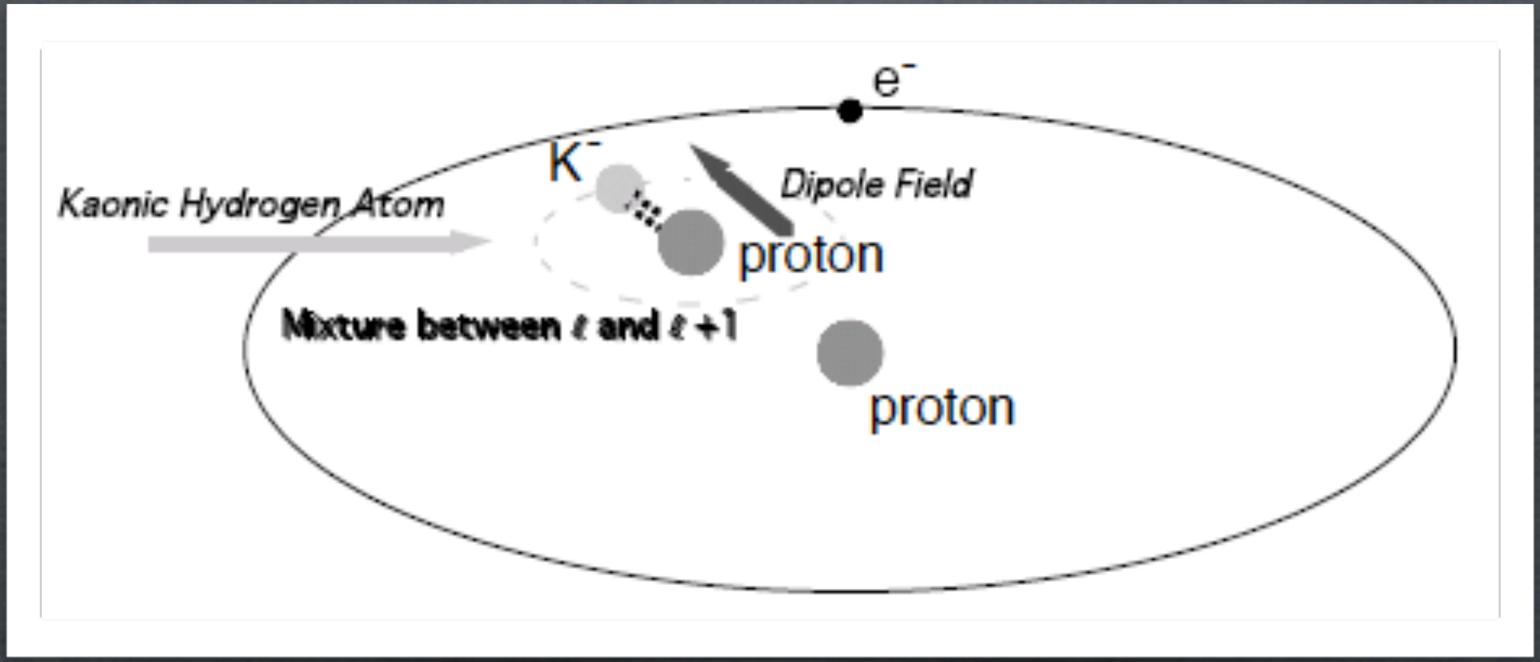
S-wave scattering length "a $_{K\text{-}p}$"
expressed with isospin dependent scattering lengths a_0 (I=0), a_1 (I=1)

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

One of the most important observable
on the physics of the KN interaction
~ together with the values of K-d (for "a $_{K\text{-}n}$") ~

Difficulty of KH Kα X-ray

Density-dependent yield due to **Stark mixing**

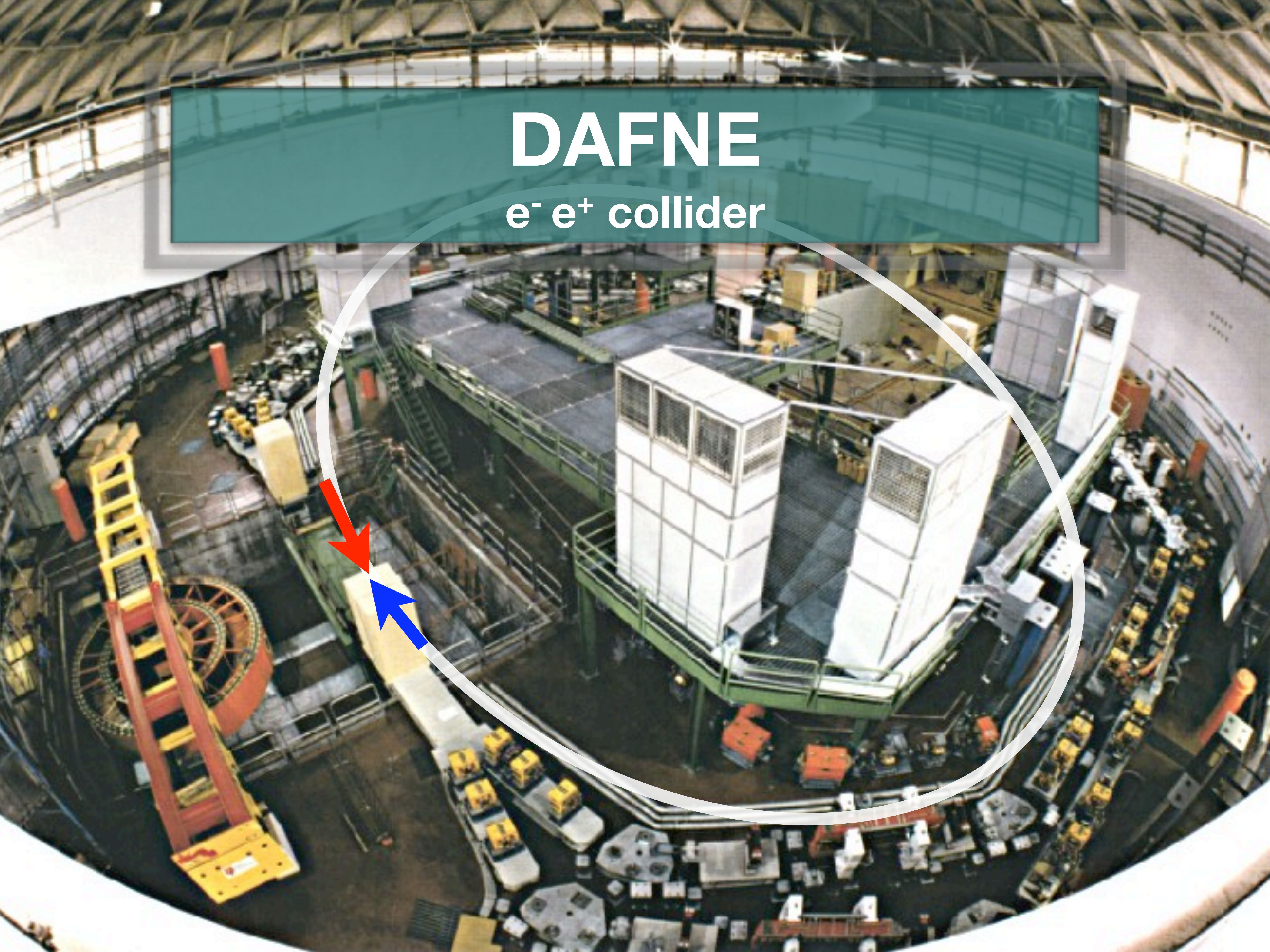


→ Low density gaseous hydrogen target

→ Low energy Kaon with small energy spread

DAFNE

$e^- e^+$ collider



DAFNE

$e^- e^+$ collider

- **$\Phi \rightarrow K^- K^+$** (49.1%)
- **Monochromatic low-energy K^-** (~127MeV/c)
- **No (beam) hadronic background**

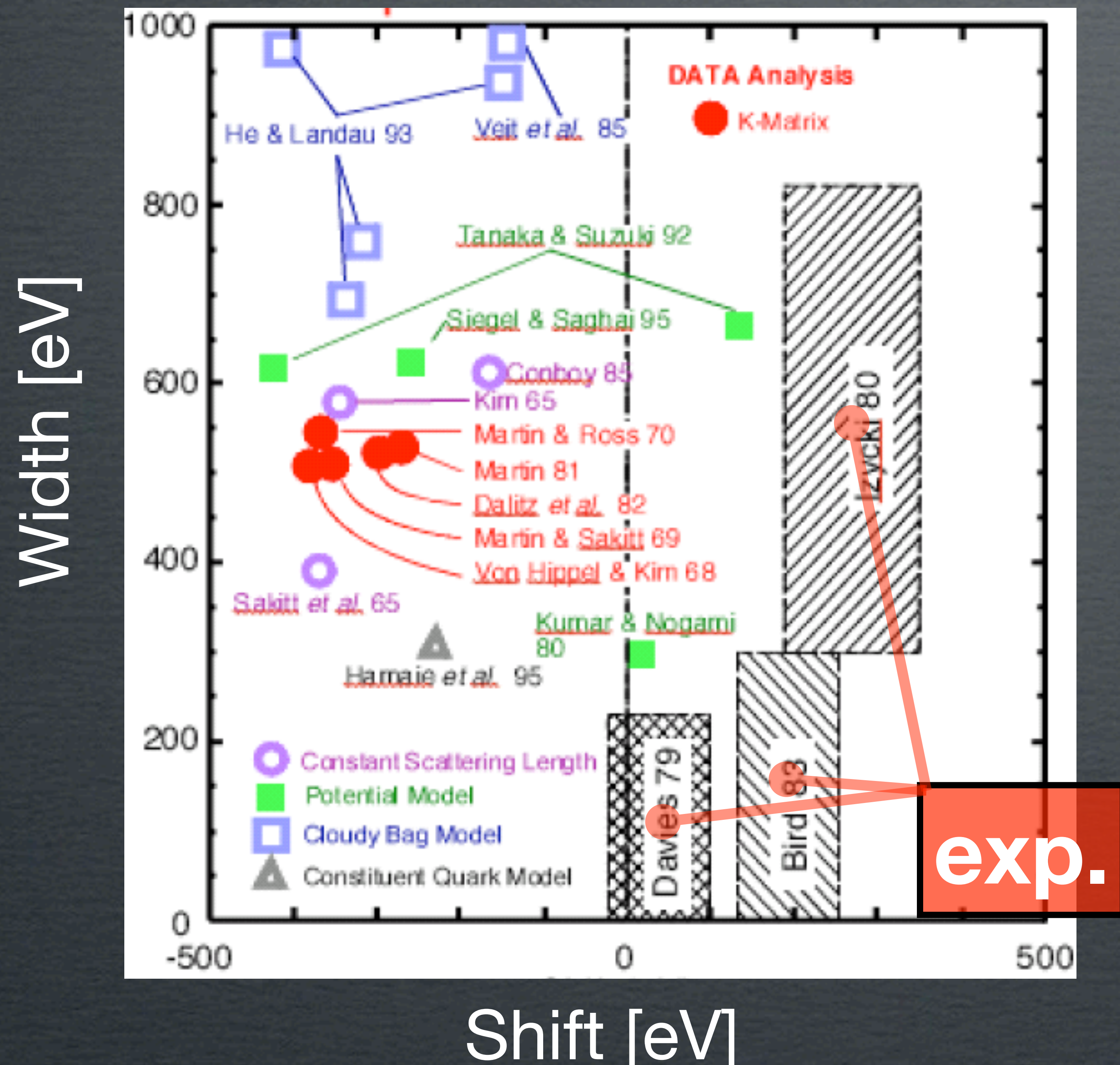
(compare to hadron beam line : e.g. KEK)

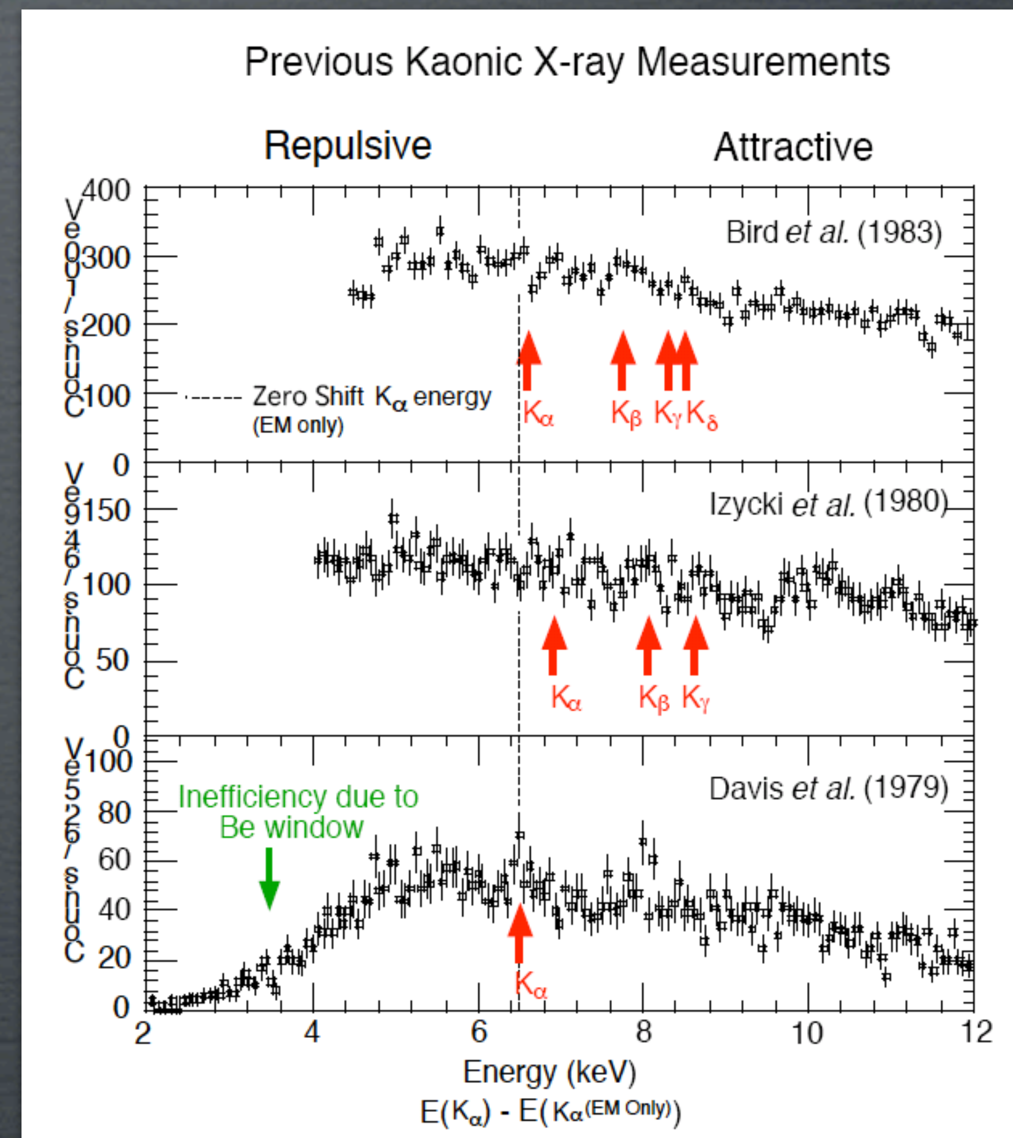
Suitable for Kaonic atom exp.

History of Kaonic hydrogen measurement

70-80's : Kaonic hydrogen puzzle

Repulsive **Attractive** **past 3 exp.**

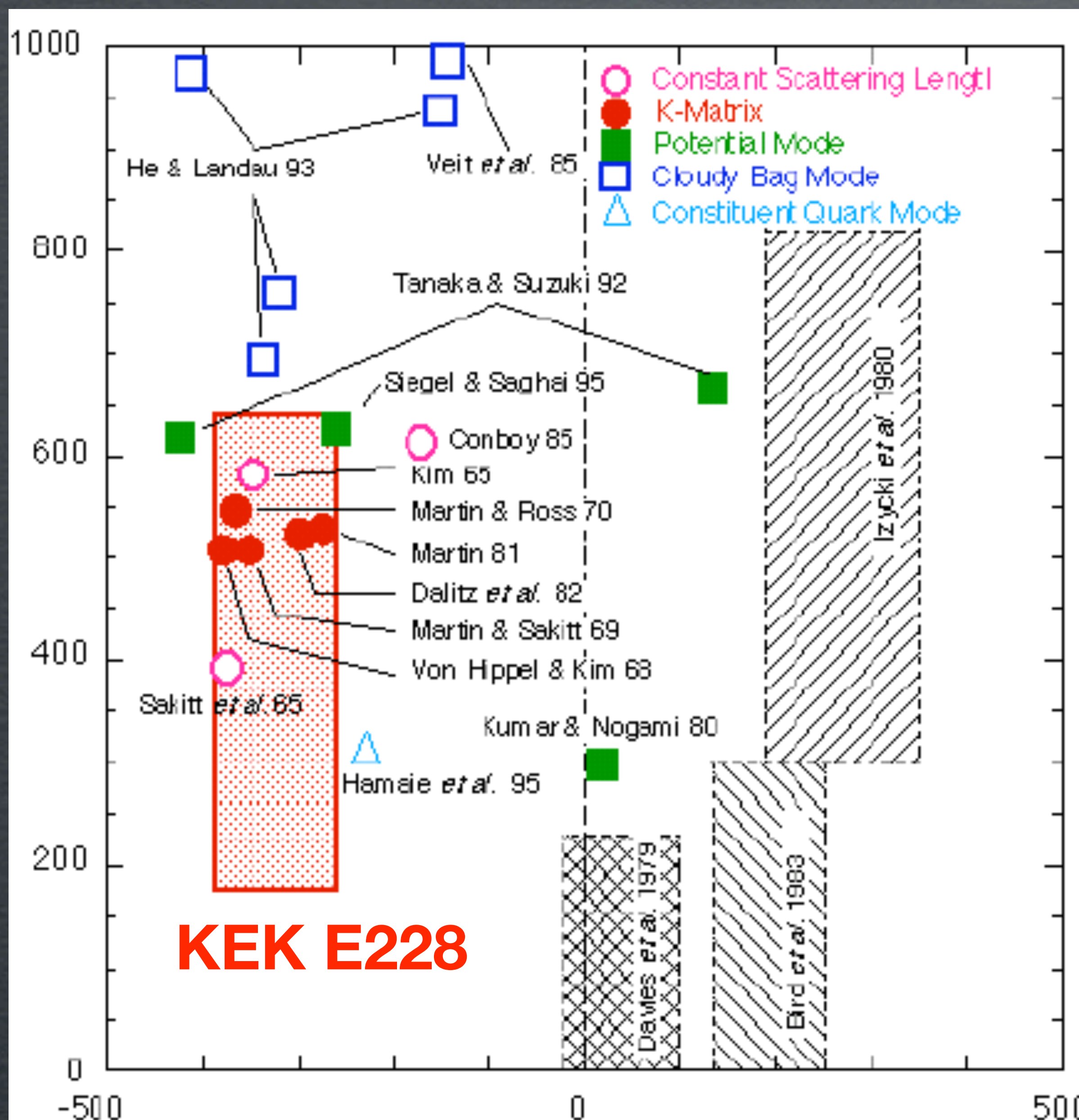




98' : solving K-p puzzle

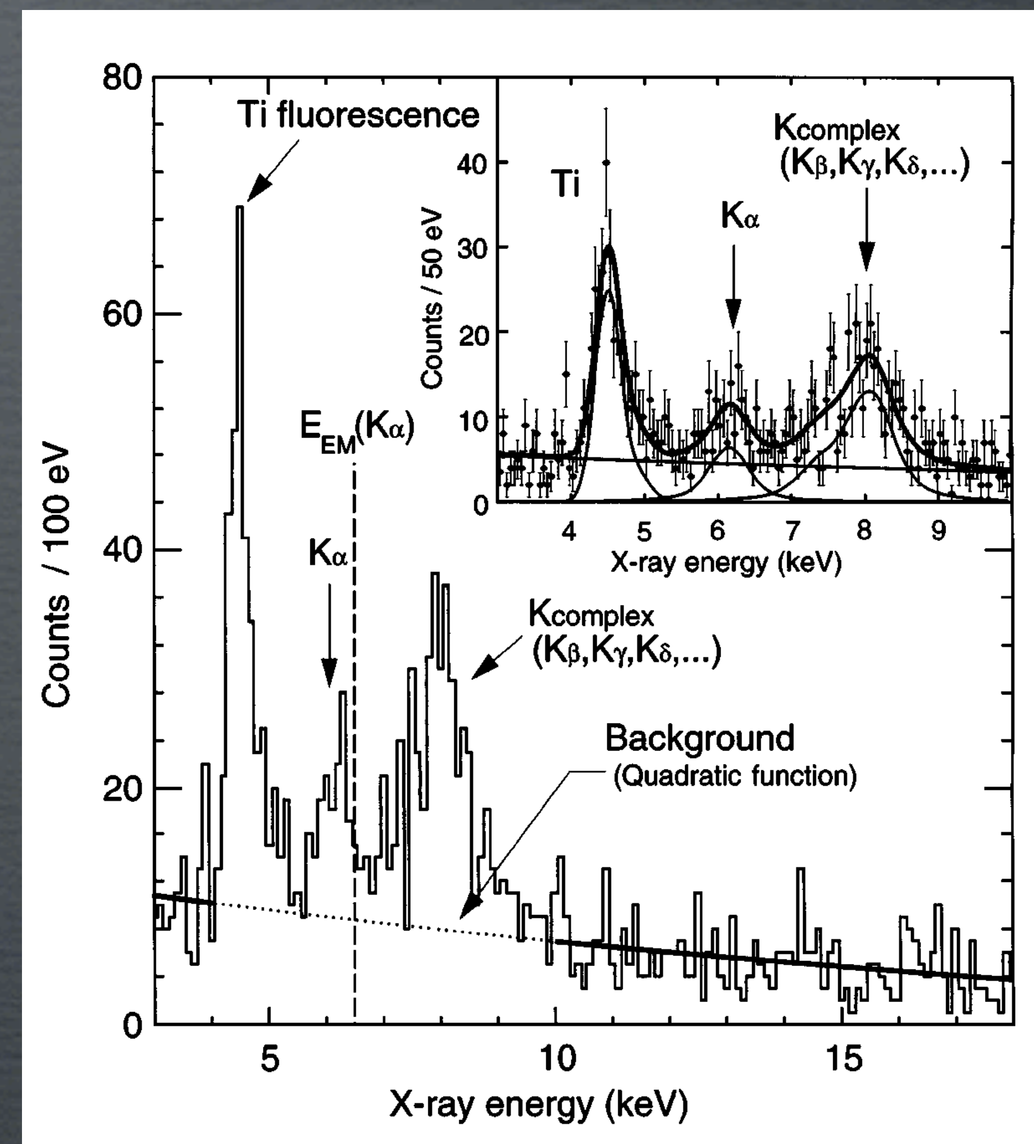
Repulsive **Attractive**

Width [eV]



Shift [eV]

KEK-E228 exp.



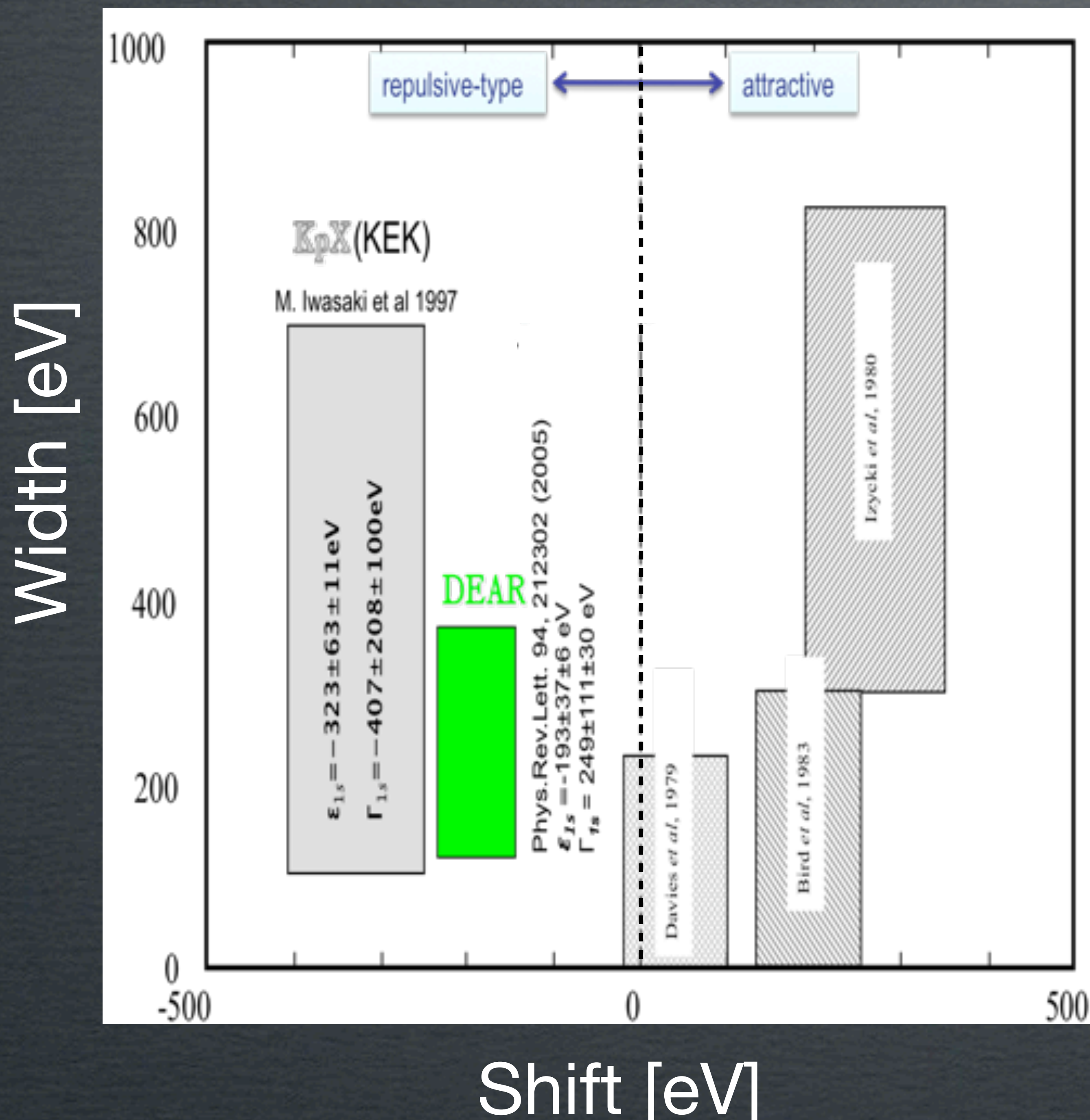
*Gas target
*Si(Li) as x-ray detector
*Hadron beamline

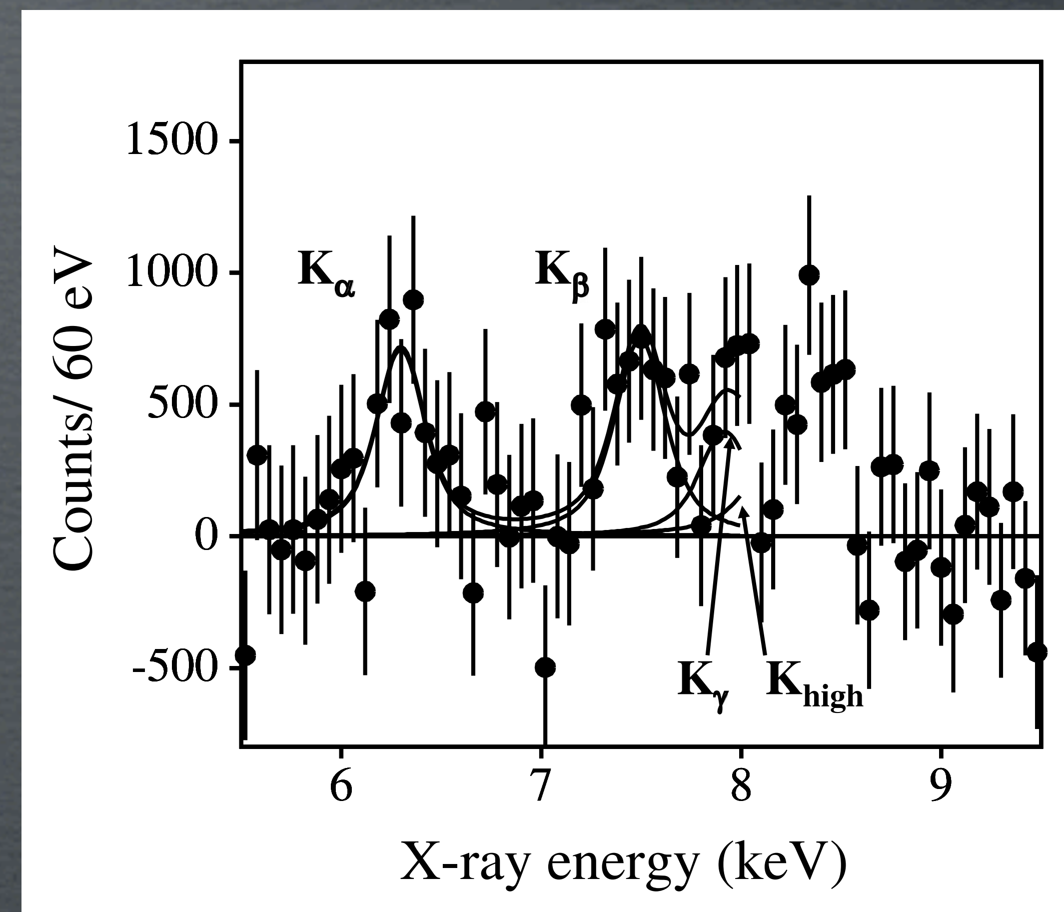
M.Iwasaki, PRL78(1997)3067

05' : confirming repulsive shift

Repulsive **Attractive**

DEAR @ DAFNE



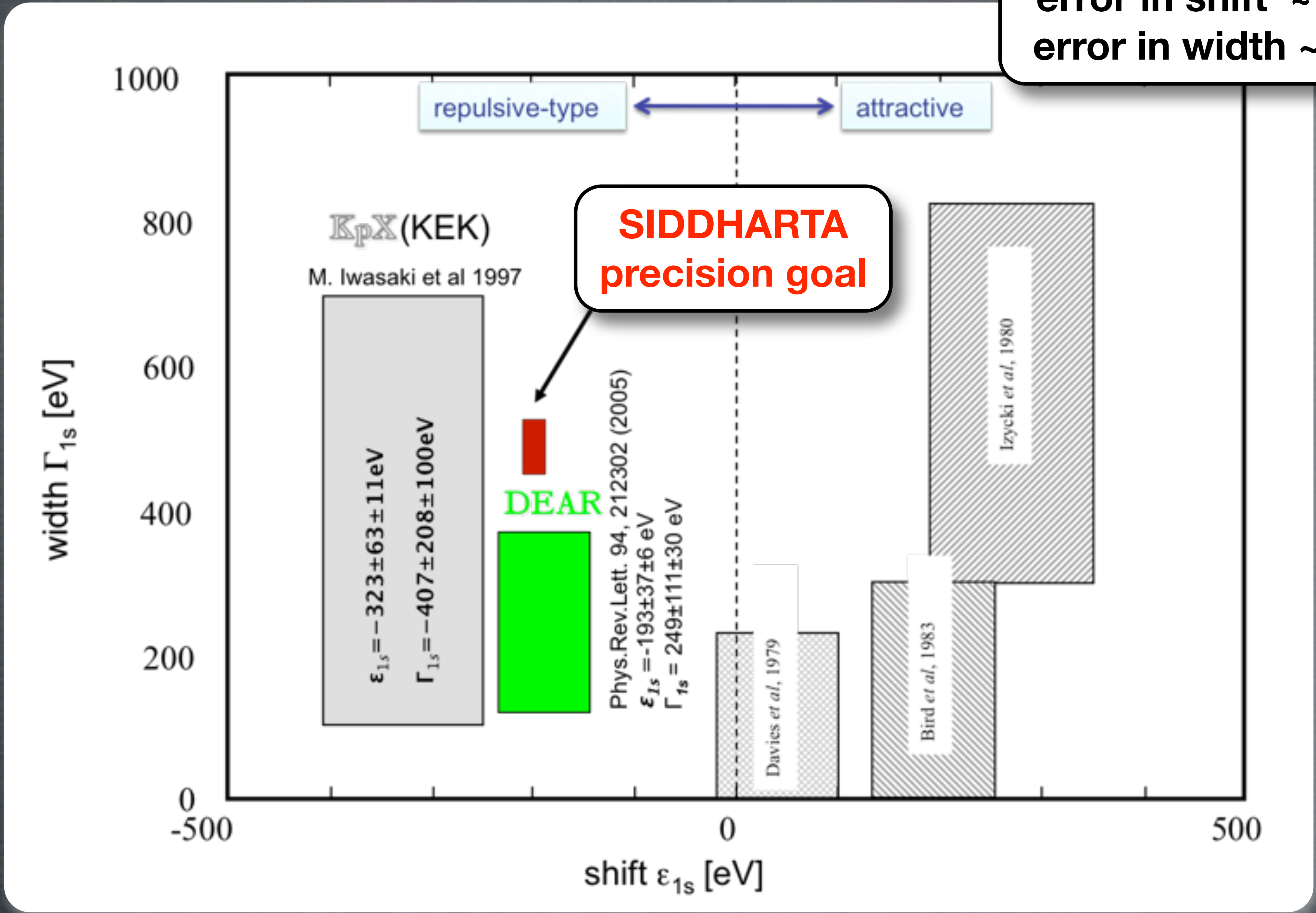


*Gas target
*CCD as x-ray detector

G. Beer et.al., PRL94(2005)212302

09' : Present experiment

error in shift ~ ± 10 eV
error in width ~ ± 35 eV



SIDDHARTA experiment

- **Kaonic Hydrogen :** 2p->1s (~6.4 keV)

  --- simplest kaonic atom -> K-p scattering length ---

  Significant improvement over previous measurements

- Kaonic Deuterium : 2p->1s (~7.8 keV)

  --- extract K-n scat. length (three body int. of K-d) ---

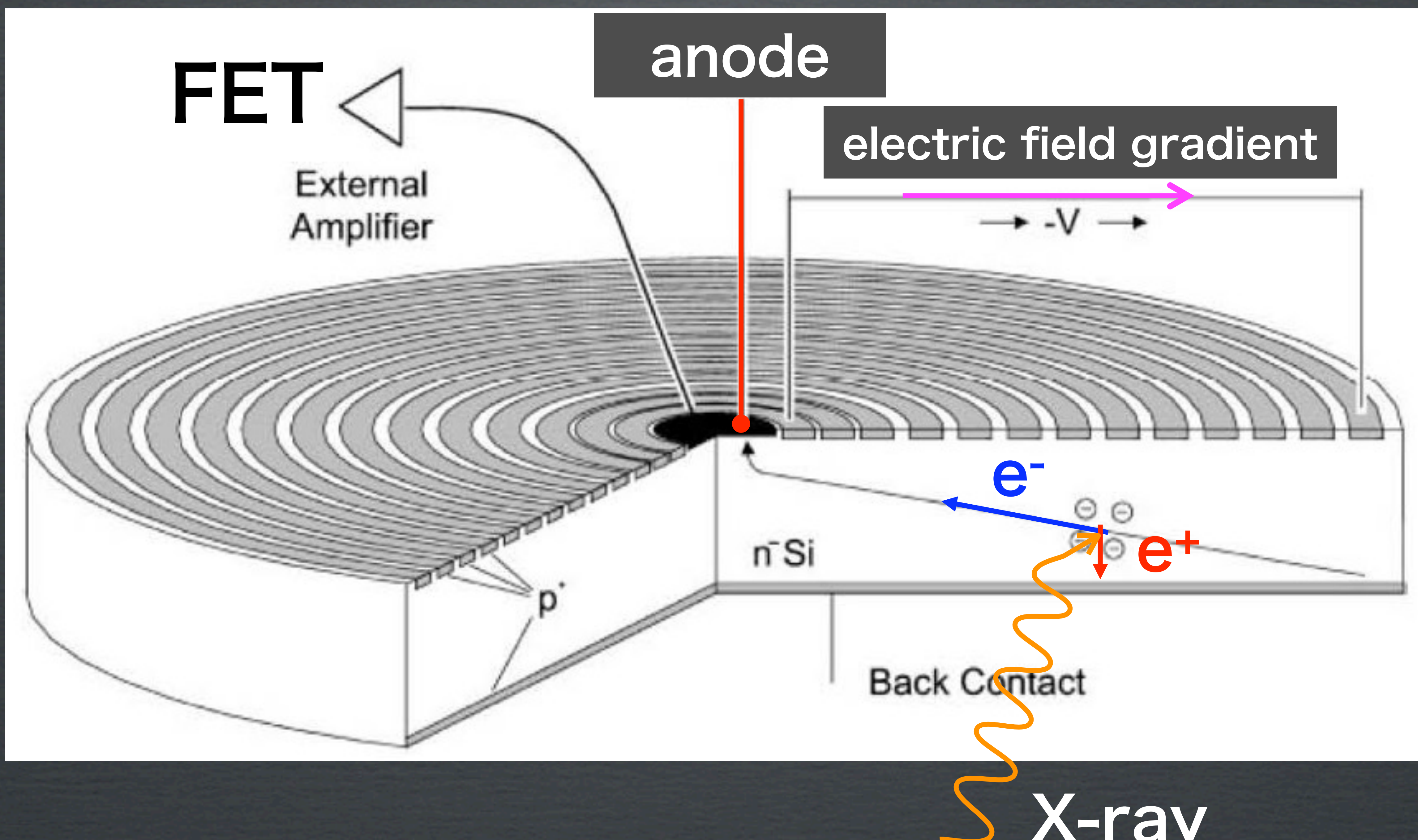
  First measurement !

- Kaonic Helium : 3d->2p (~6.4 keV)

  First measurement with gaseous helium target

Experiment

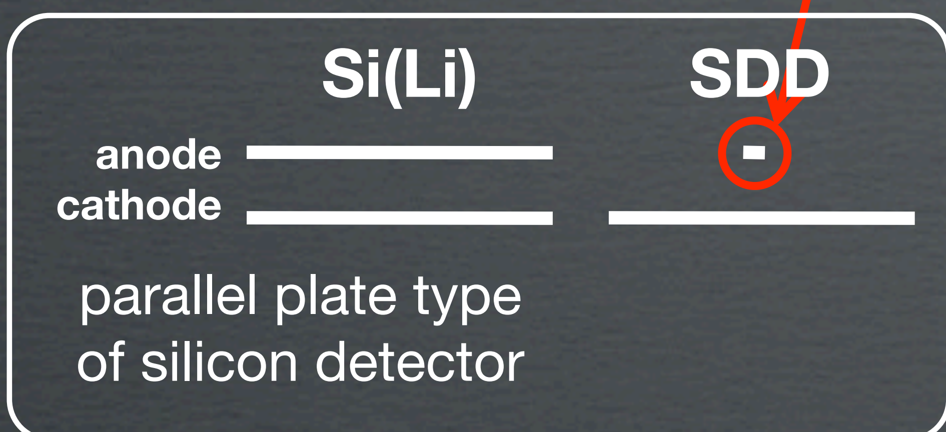
Silicon Drift Detector - SDD



Silicon Drift Detector - SDD

$(C = \varepsilon_0 S / d)$

electrode



small anode

small capacitance

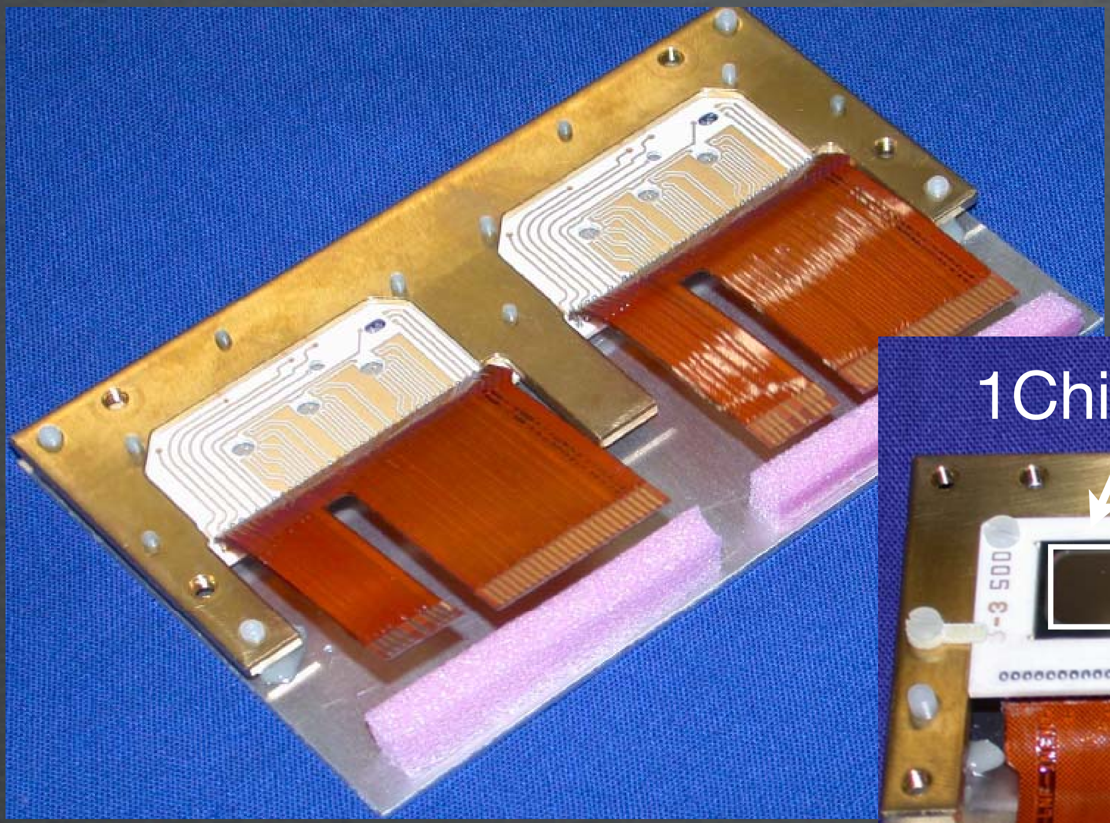
High resolution
with thin depletion layer

<u>Suppress a background</u>
due to Compton scattering
inside the detector

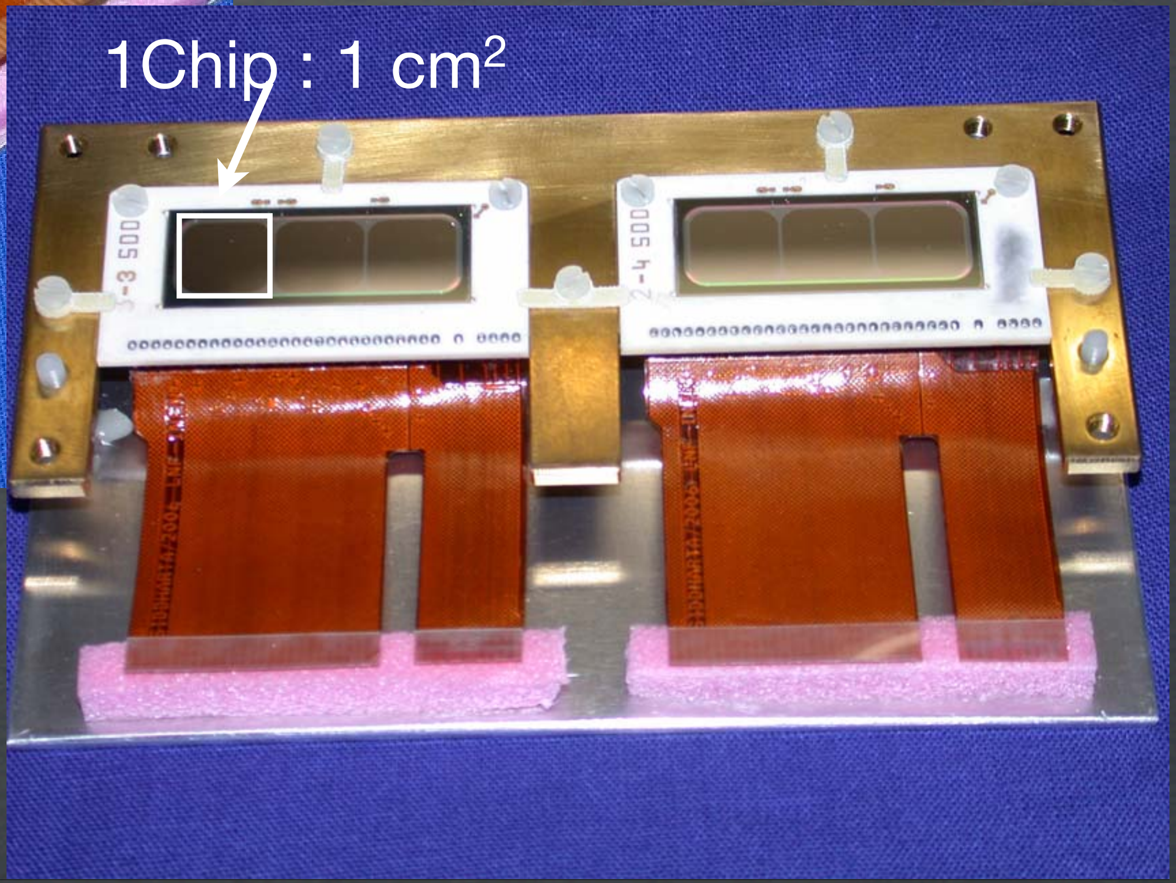
Silicon Drift Detector - SDD

	KEK, 1998	DEAR, 2005	SIDDHARTA	
Detector	Si(Li)	CCD	SDD	
Energy Resolution	360 eV	180 eV	180 eV	
Thickness	sub 10 mm	sub mm	sub mm	
Effective area	120 cm^2	116 cm^2	114 cm^2	Same order
Time resolution	sub μsec	~ 30 sec	sub μsec	

Silicon Drift Detector - SDD

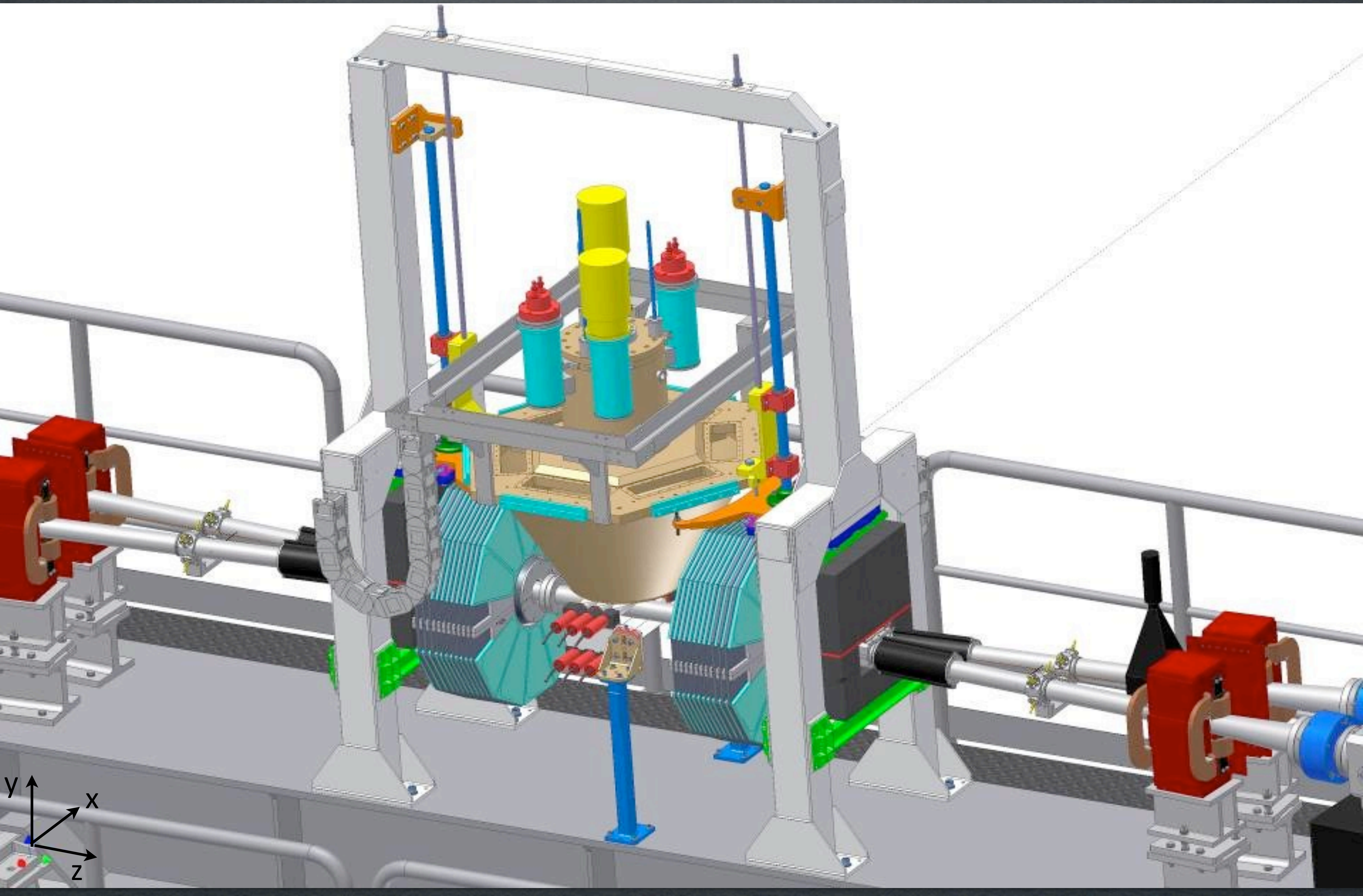


Gluing and bonding at Fraunhofer Institut - Berlin

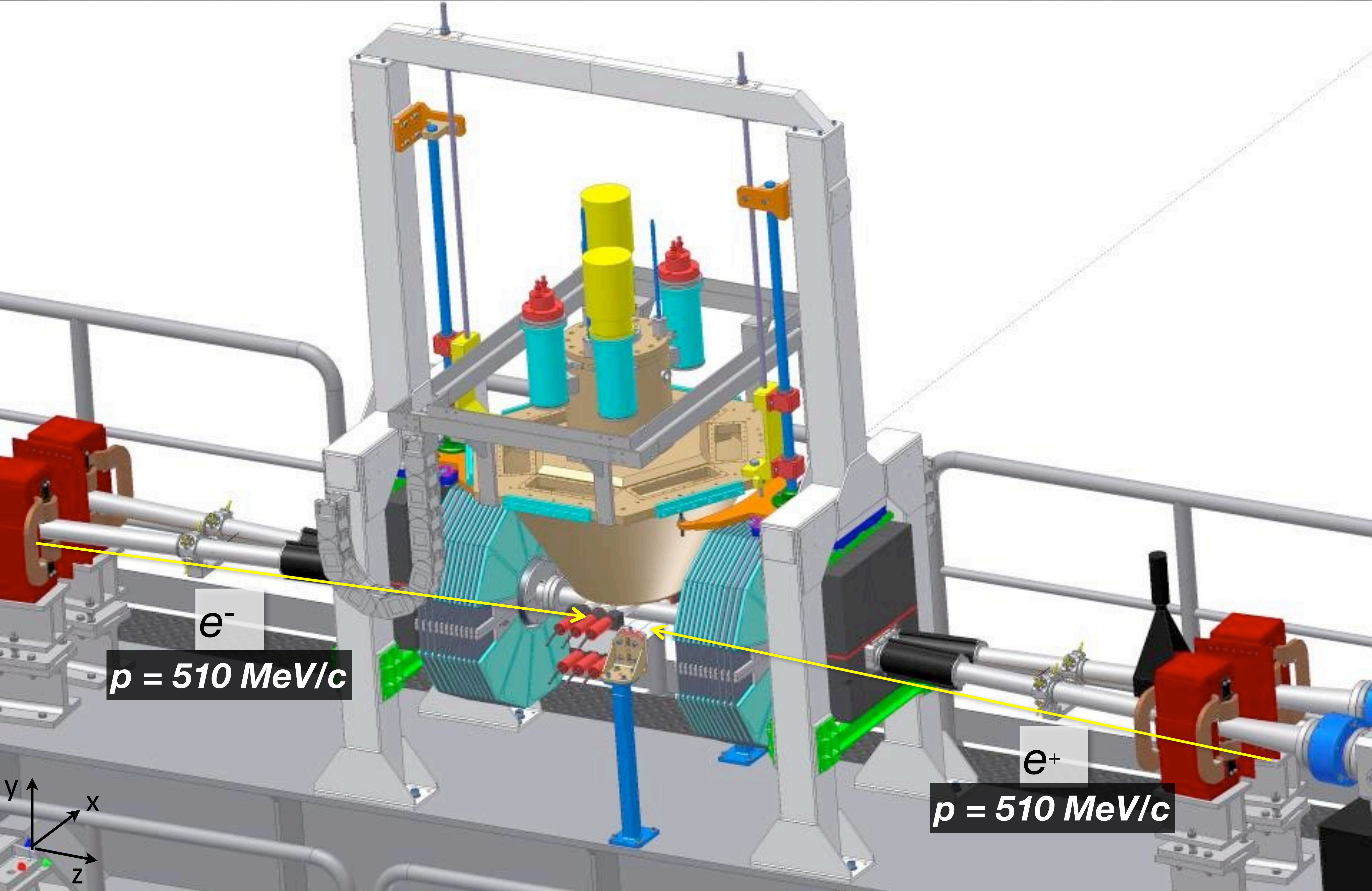


Final testing and assembling at SMI

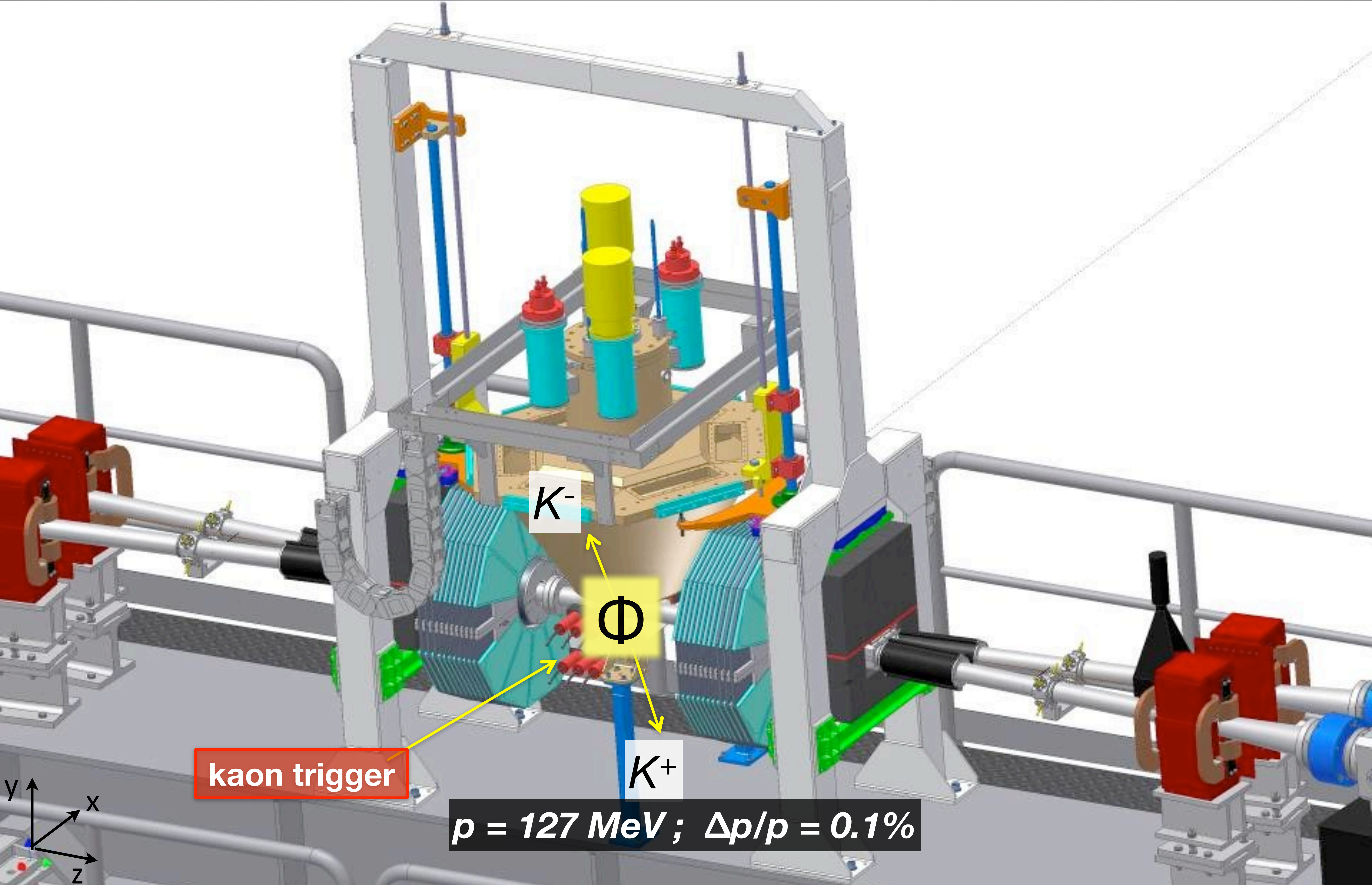
SIDDHARTA overview



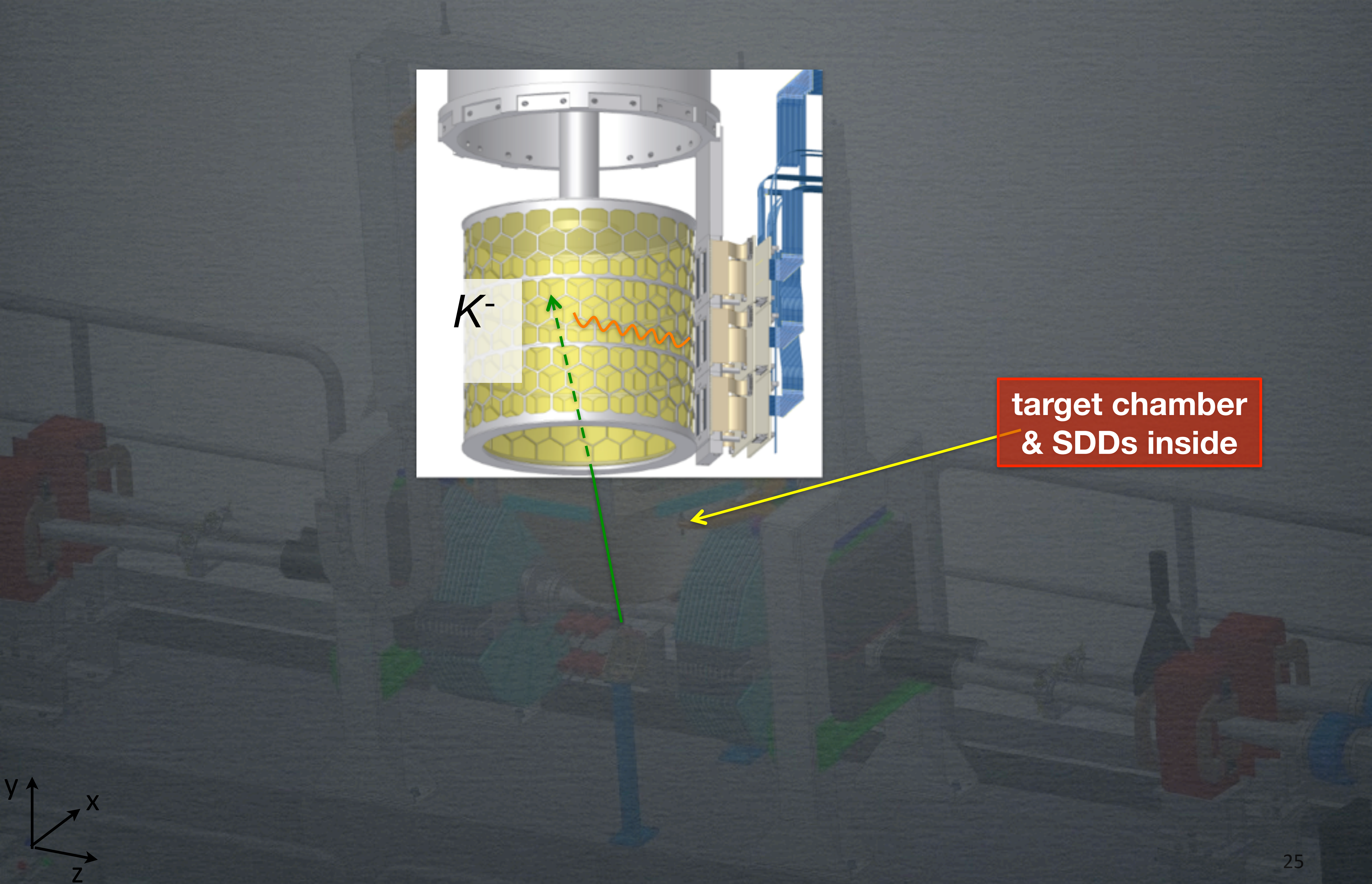
SIDDHARTA overview



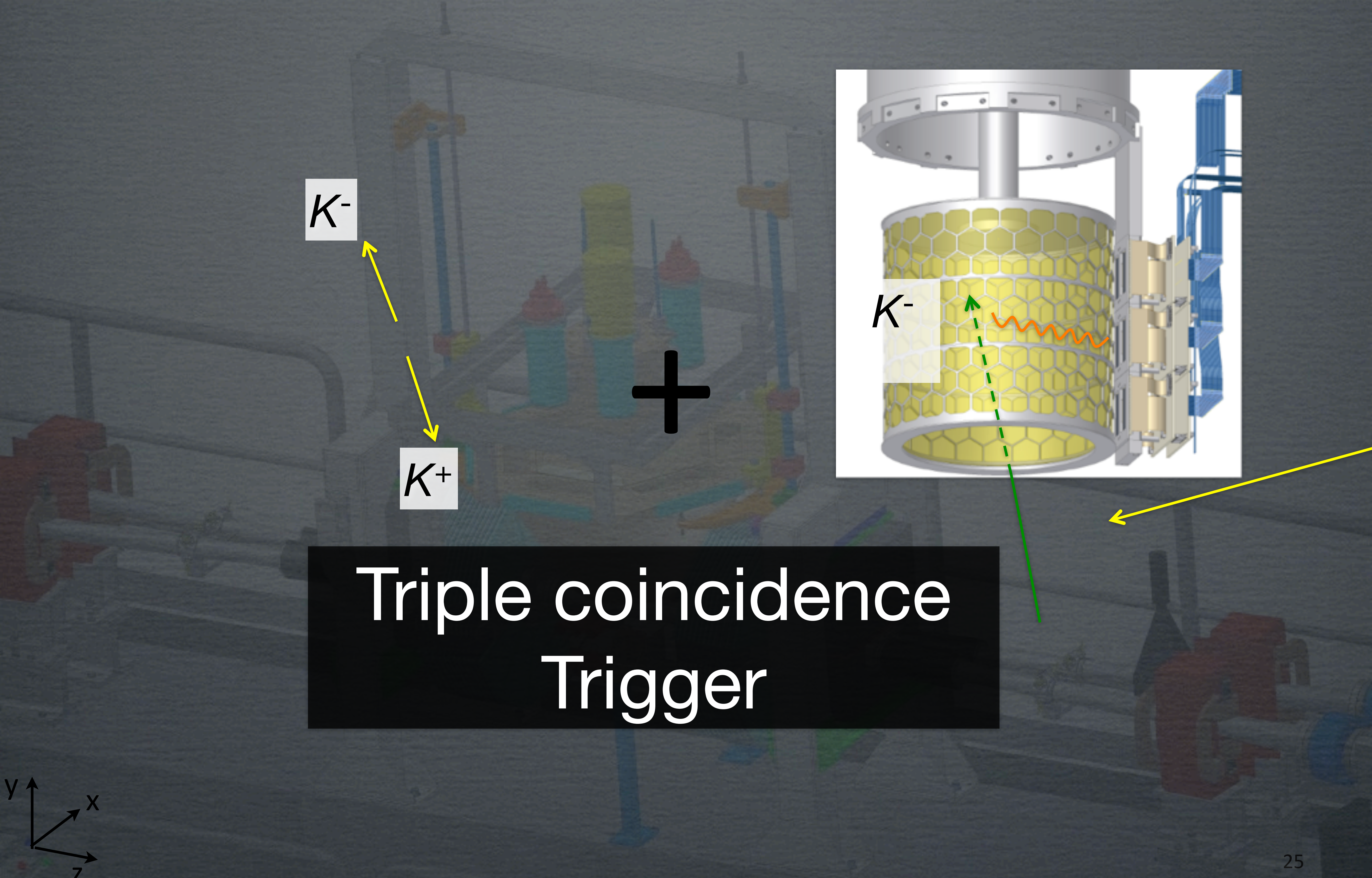
SIDDHARTA overview



SIDDHARTA overview

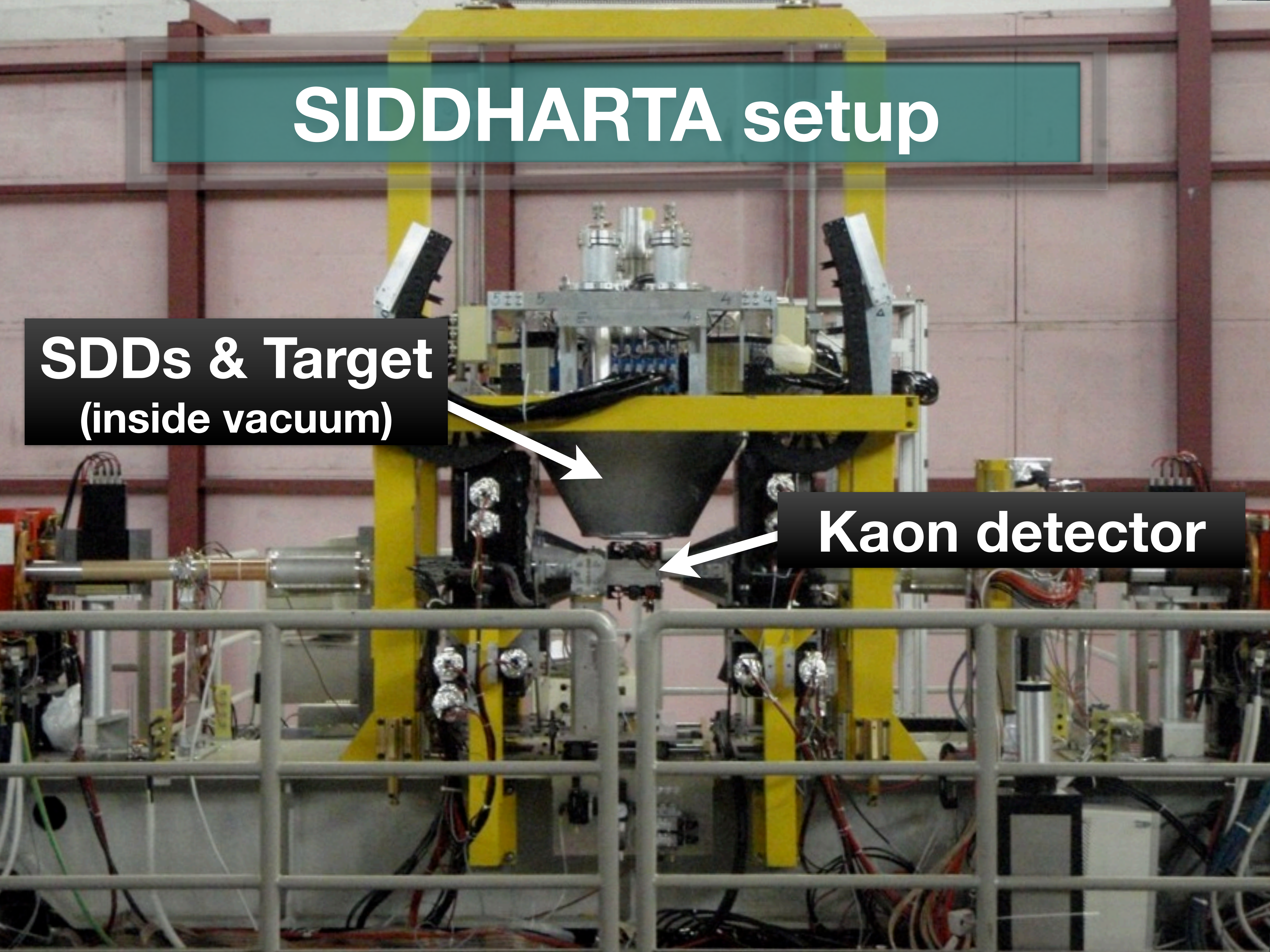


SIDDHARTA overview

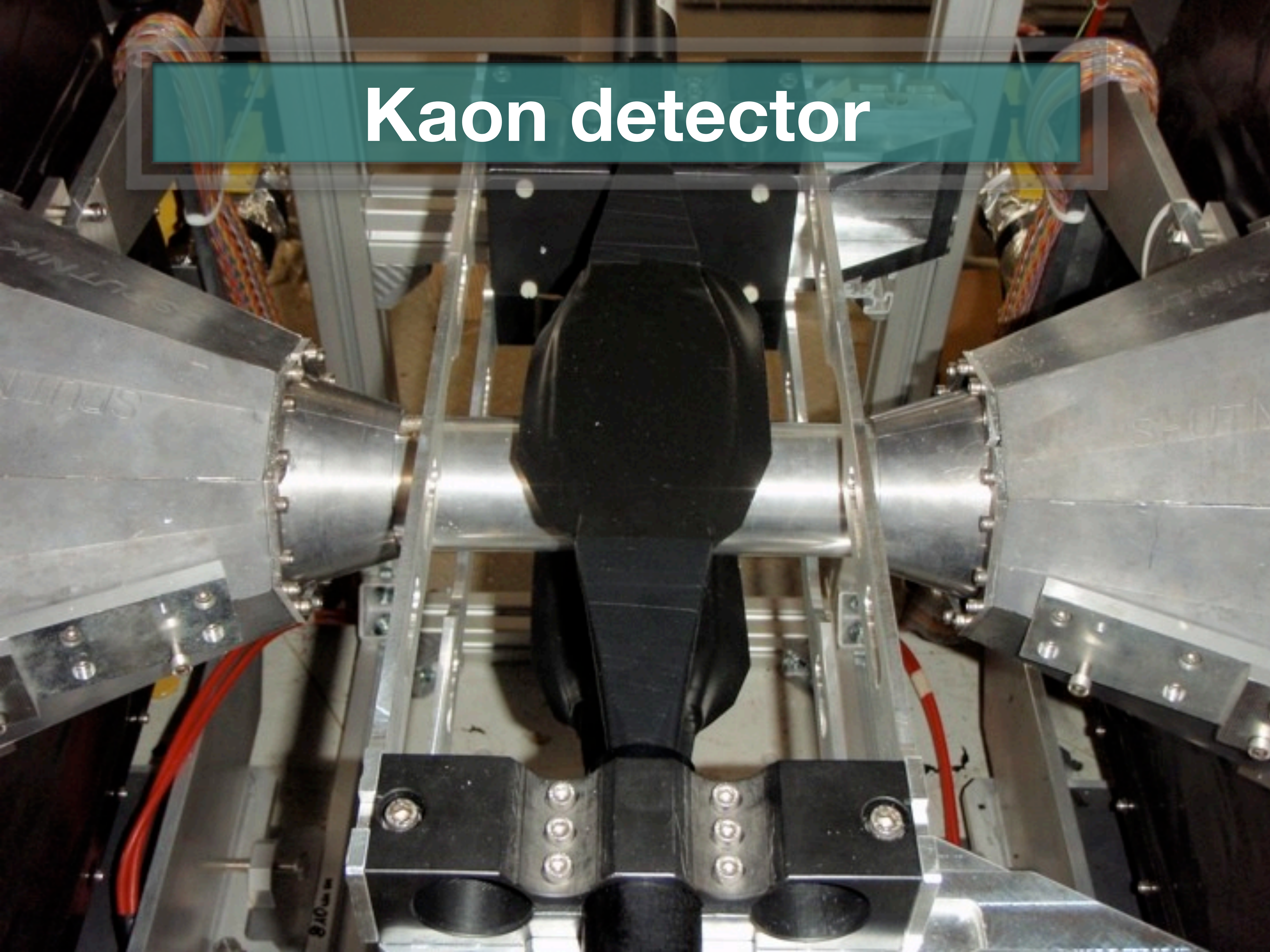


Triple coincidence
Trigger

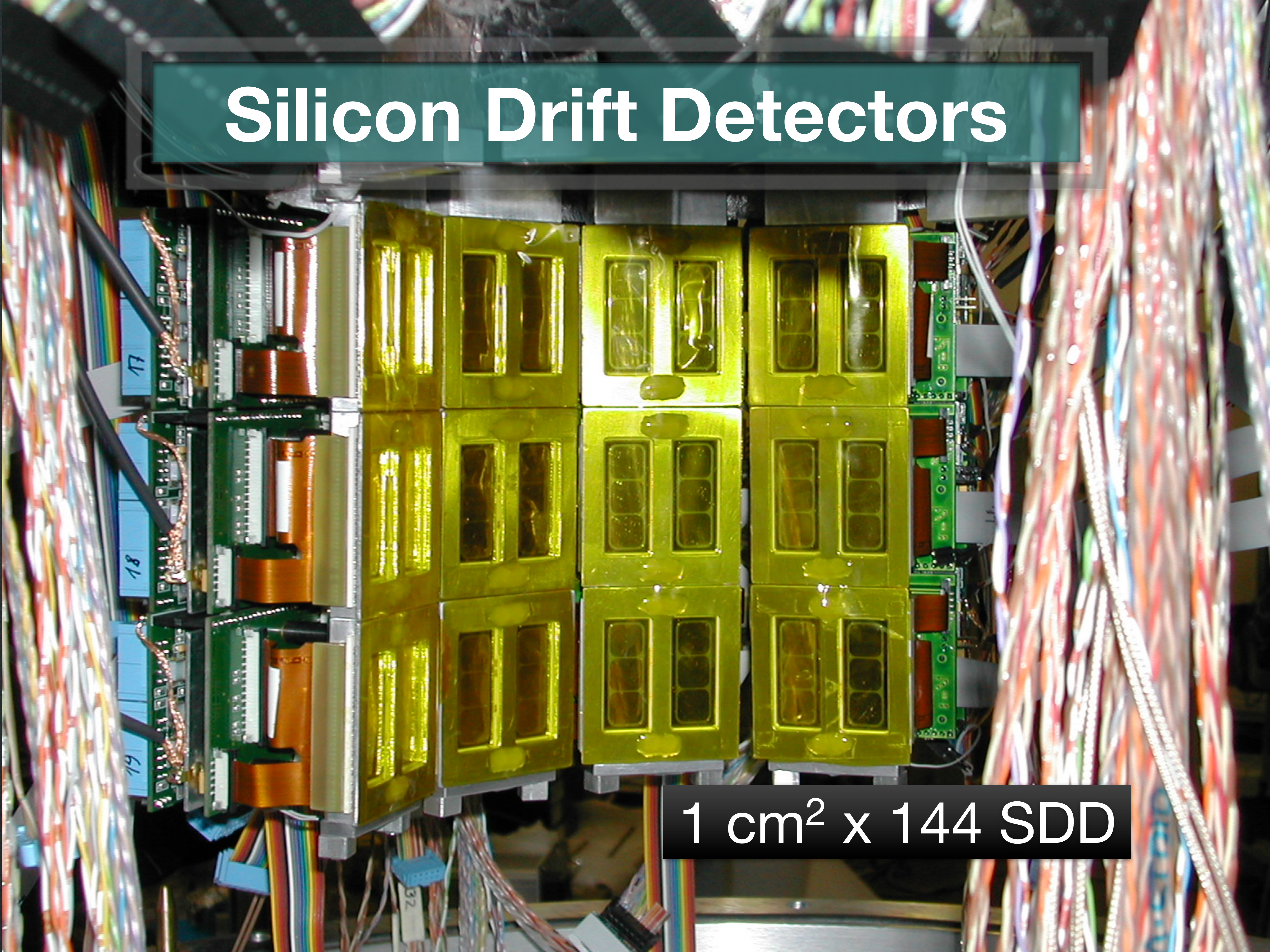
SIDDHARTA setup



Kaon detector

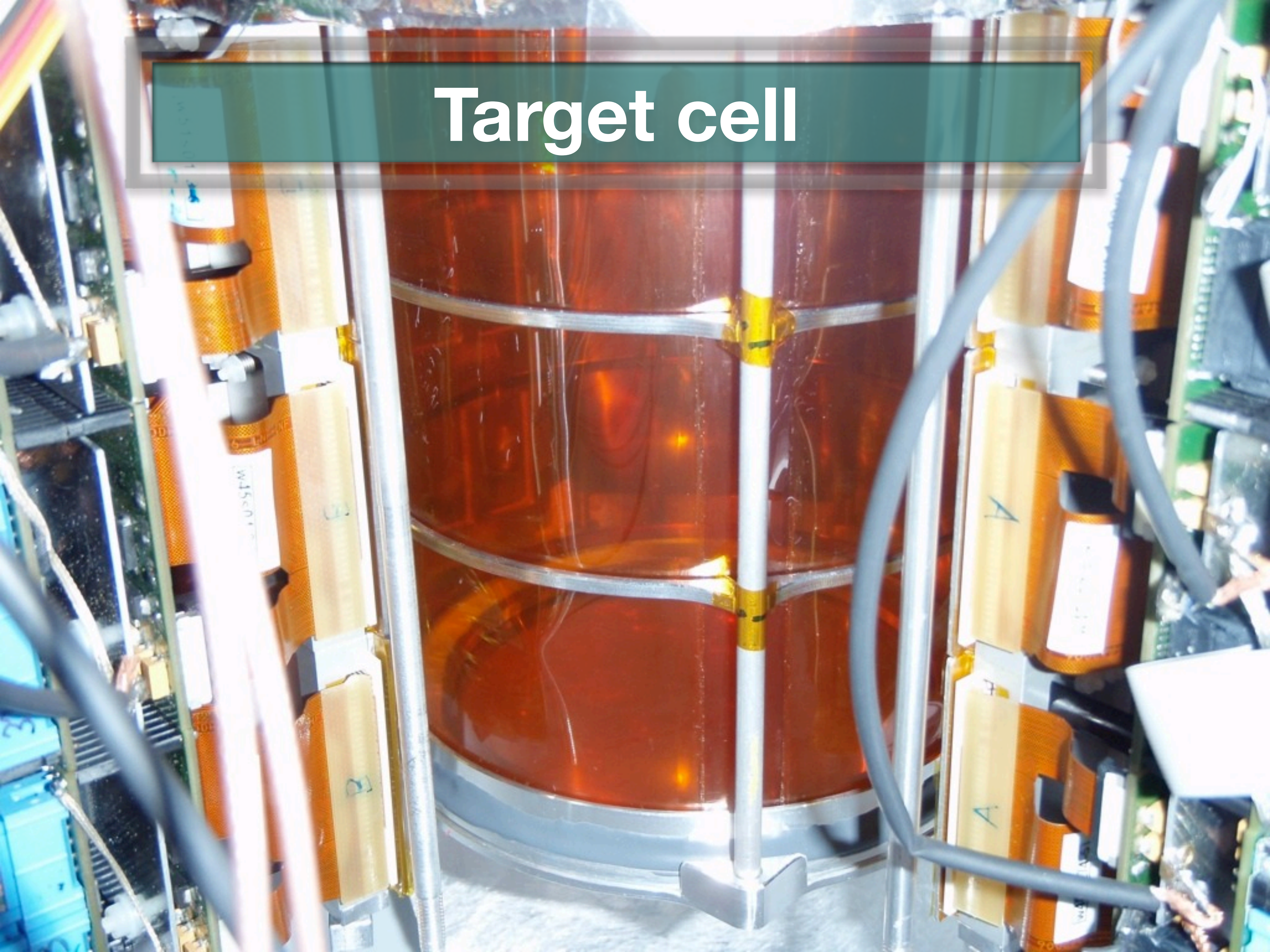


Silicon Drift Detectors



1 cm^2 x 144 SDD

Target cell



Kaonic helium Result

~ Estimation of statistical accuracy of KH shift value ~

Good for the test of KH Kα measurement

	Energy (EM)	Yield rate* (per stopK)
K^4He Lα	6.4 keV	~10^{-1}
KH Kα	6.5 keV	~10^{-2}

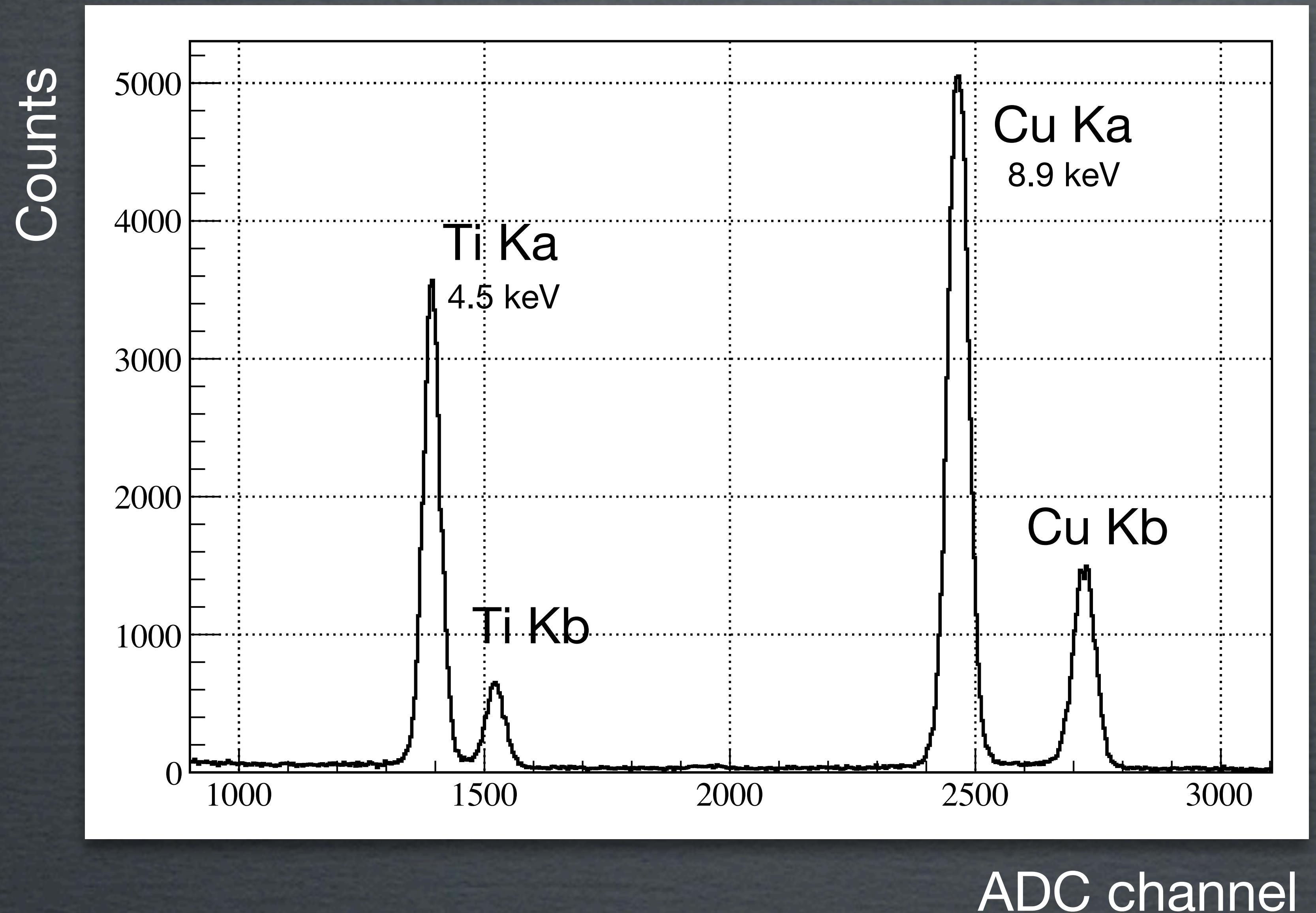
✓ **similar value** of each transition energies

✓ **~10 times faster** than the KH Kα yield rate

* At ~ 10 ρ_{STP} of helium gas, x ray event per stopped kaon

Calibration with X ray tube

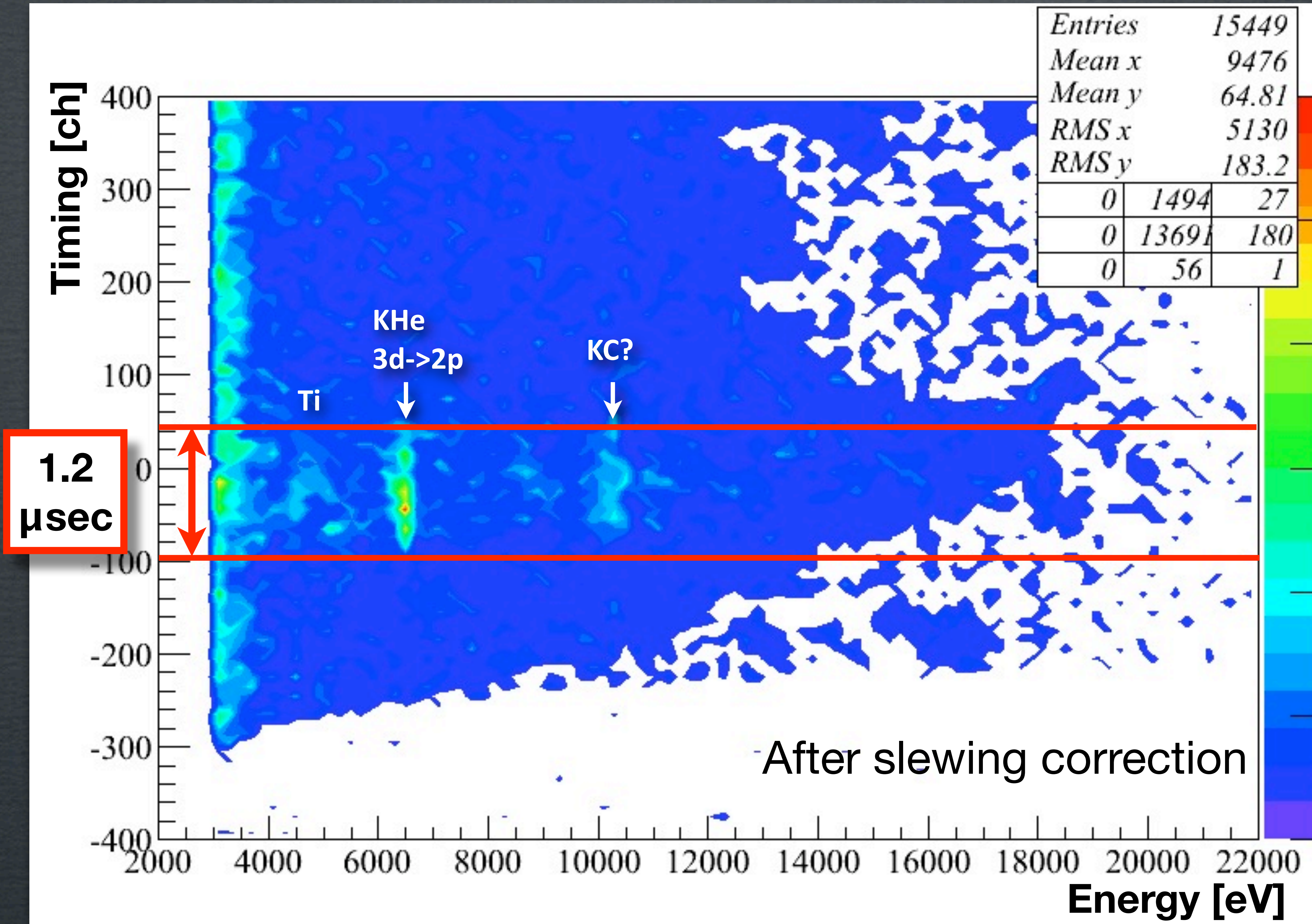
Typical calibration spectrum for one SDD



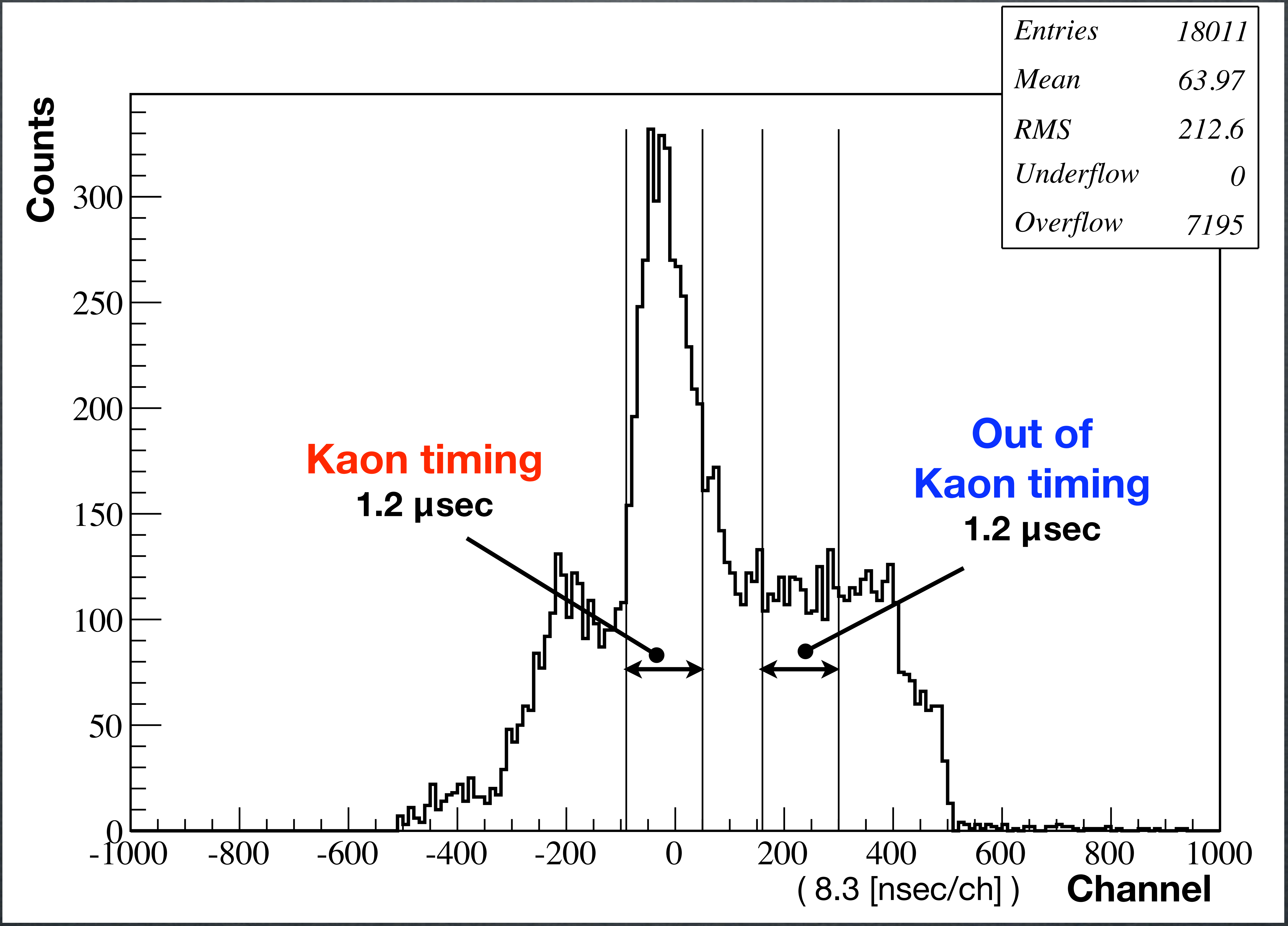
- ✓ In-beam
- ✓ X ray tube
- ✓ Ti, Cu foils

Energy resolution : **FWHM (@6.4keV) ~ 170 eV**

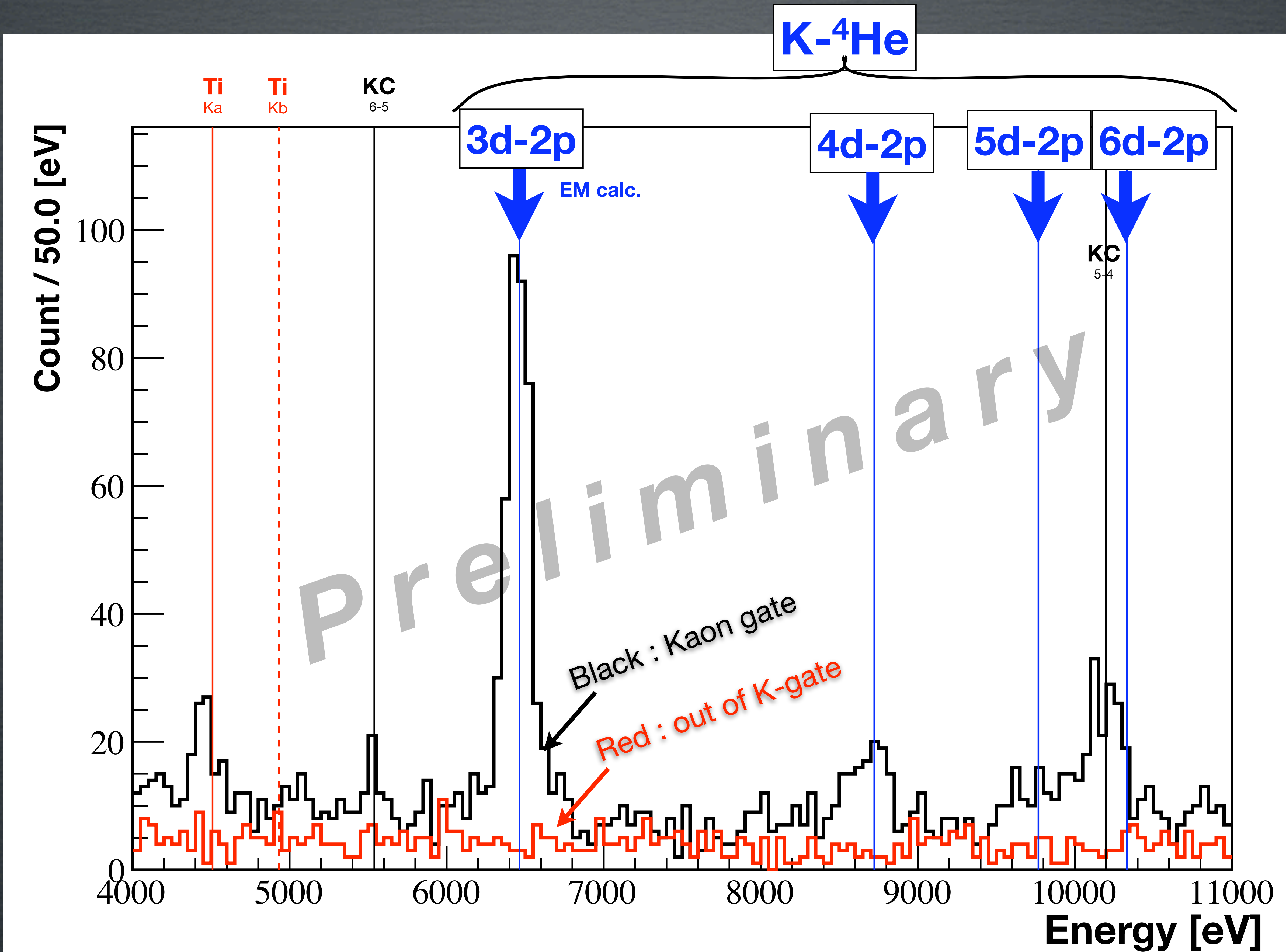
Kaon correlated event timing



Timing spectrum



Energy spectrum of KHe



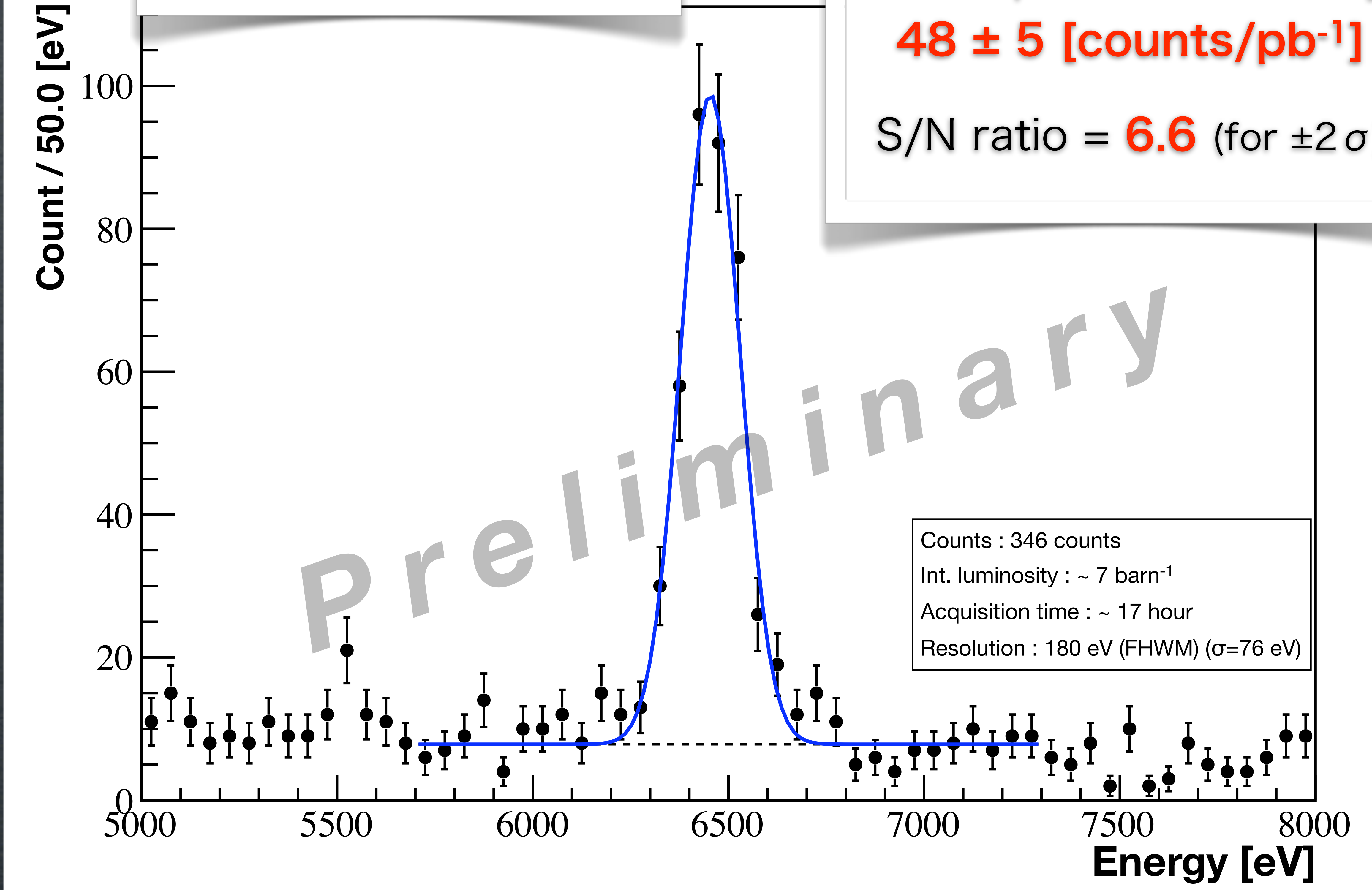
K-^{4}He 3d->2p : Gaussian fit

The mean value (shift) is consistent with previous value

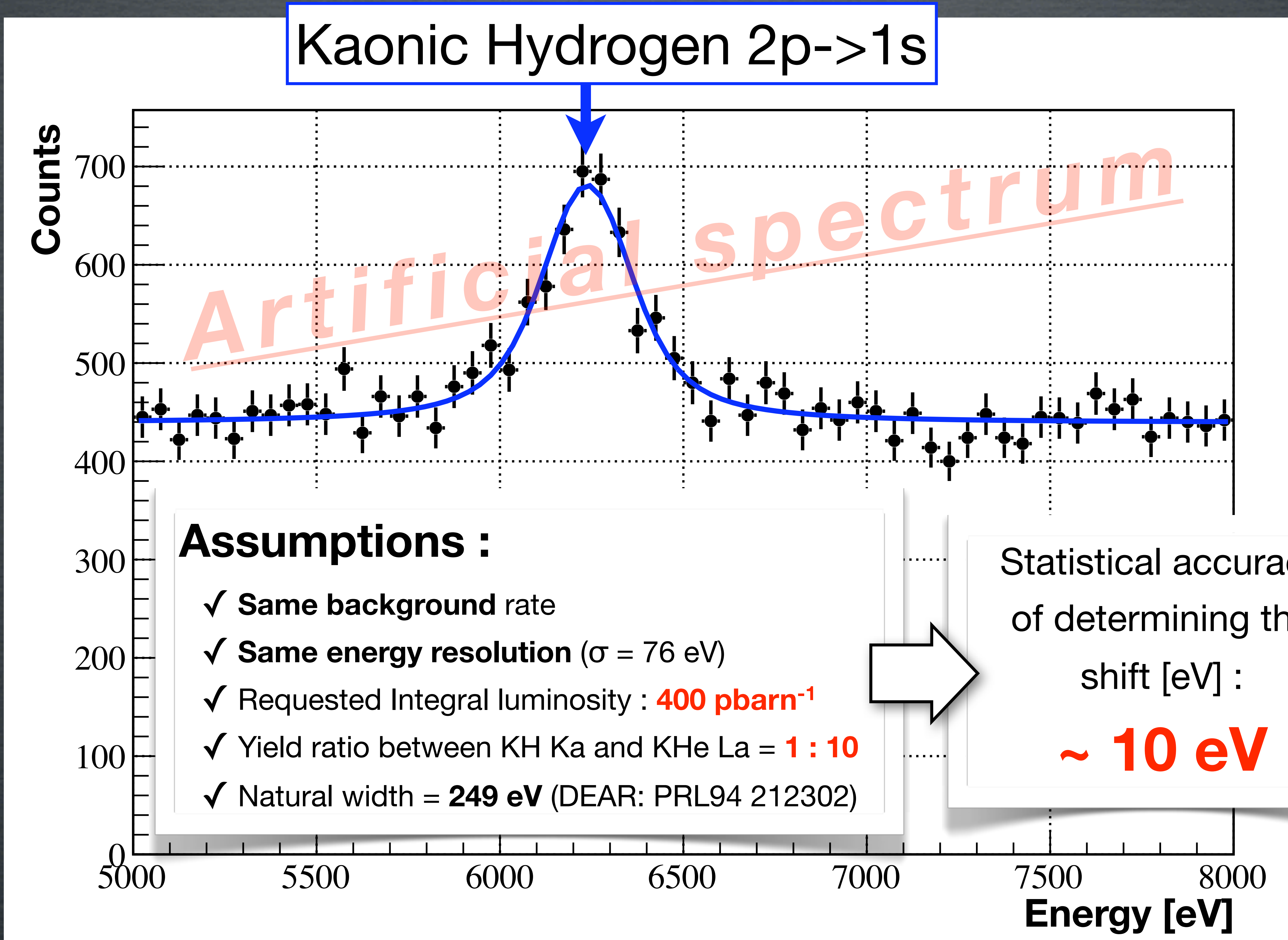
Yields per int. luminosity

48 ± 5 [counts/pb^{-1}]

S/N ratio = **6.6** (for ±2σ)



Estimated precision of KH Kα



Assumptions :

✓ **Same background** rate

✓ **Same energy resolution** (σ = 76 eV)

✓ Requested Integral luminosity : **400 pbarn^{-1}**

✓ Yield ratio between KH Ka and KHe La = **1 : 10**

✓ Natural width = **249 eV** (DEAR: PRL94 212302)

Statistical accuracy of determining the shift [eV] :

~ 10 eV

Summary

Summary

✓ SIDDHARTA setup with 144 SDDs in operation

✓ KHe L_α line mean value consistent with previous value

✓ KH K_α precision ~ 10 eV for 400 $pbarn^{-1}$

➡ Further tuning for hydrogen target run in progress.