

Main Features of the SIDDHARTA-2 Apparatus For Kaonic Deuterium X- Ray Measurements

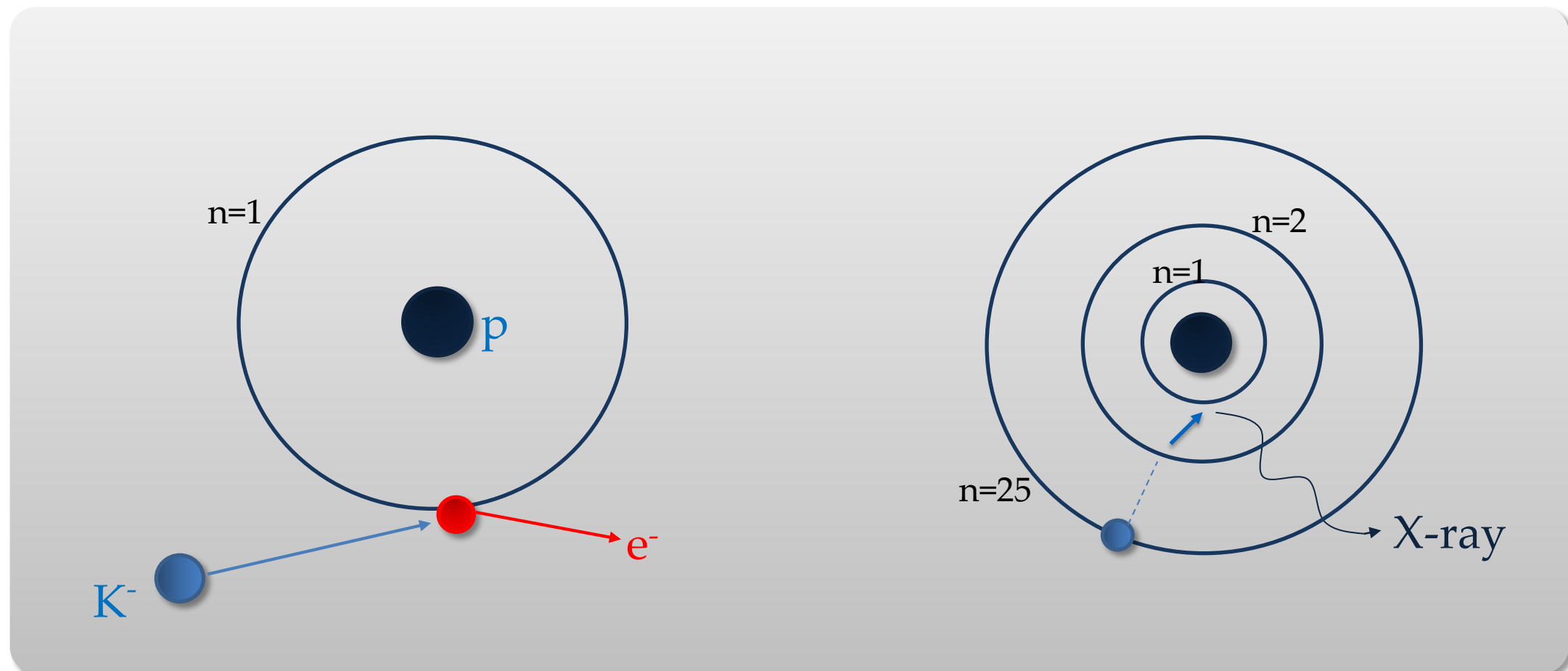
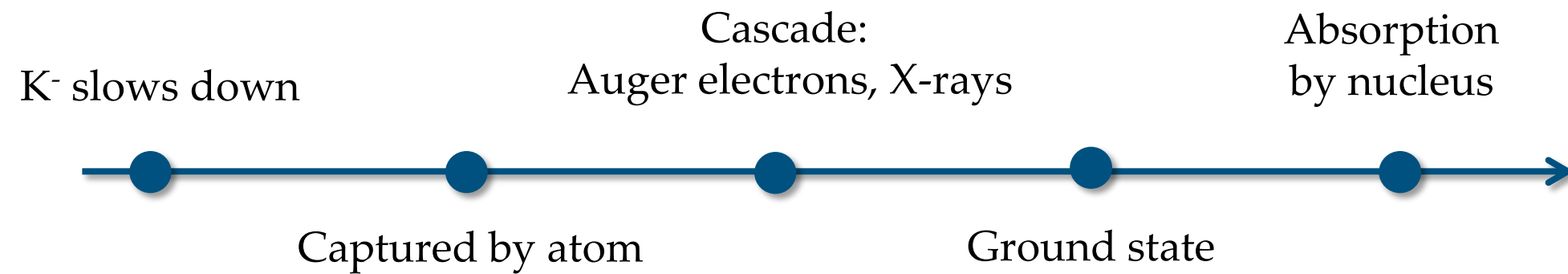
Marlene Tüchler

Poster Session

EXA 2021

Motivation

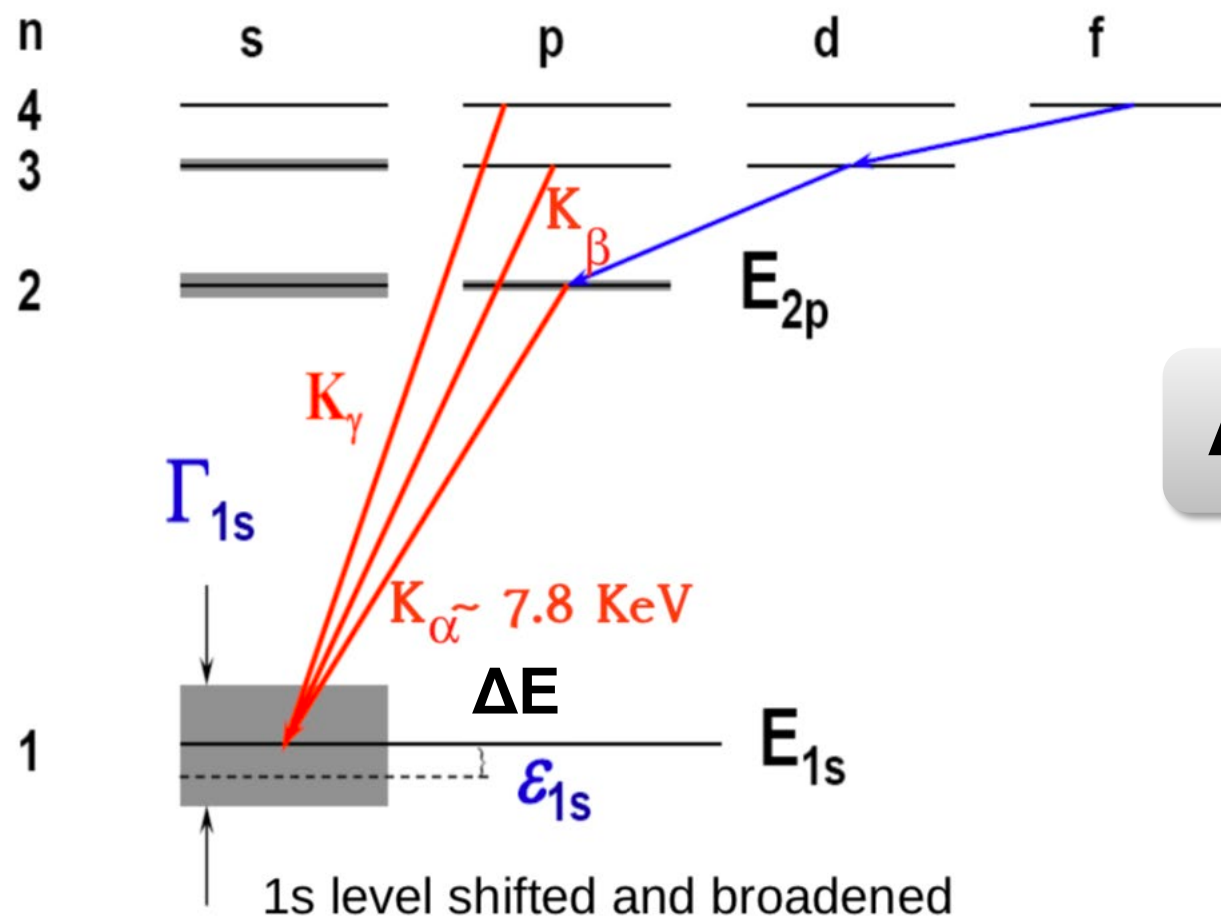
FORMATION OF KAONIC ATOMS



MOTIVATION: KAONIC ATOMS



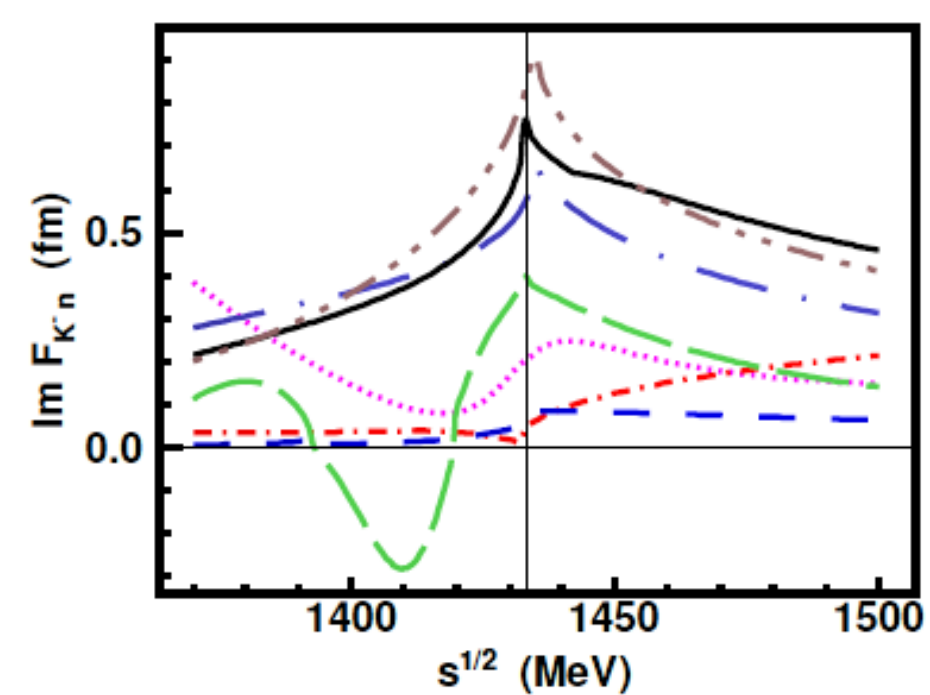
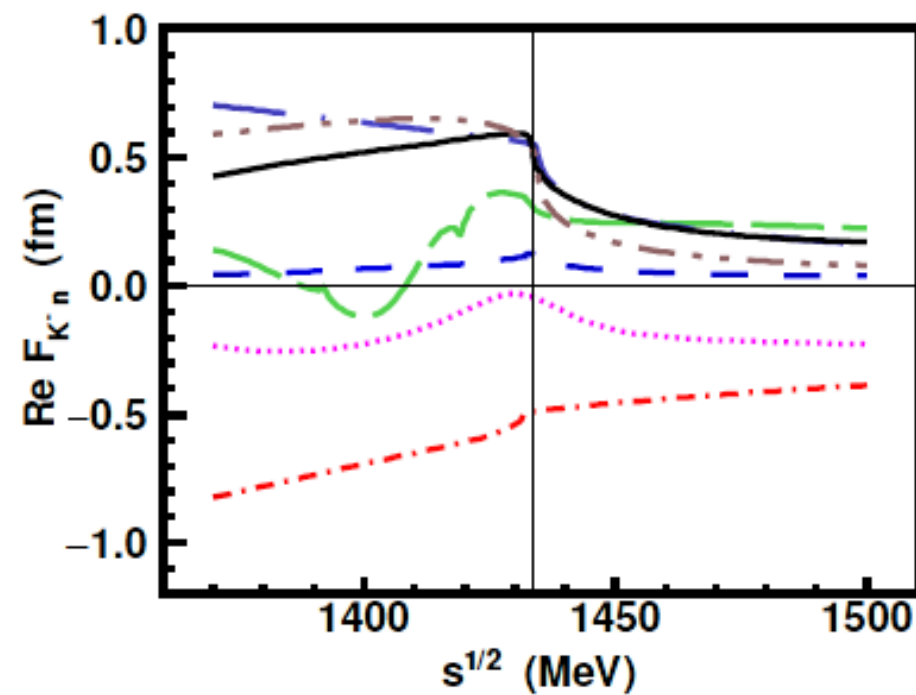
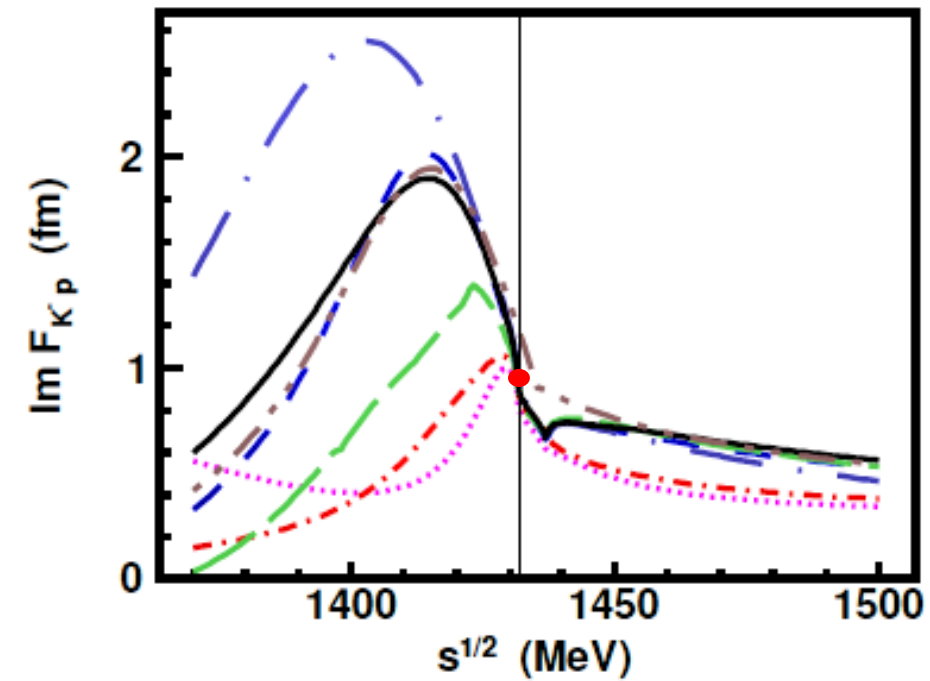
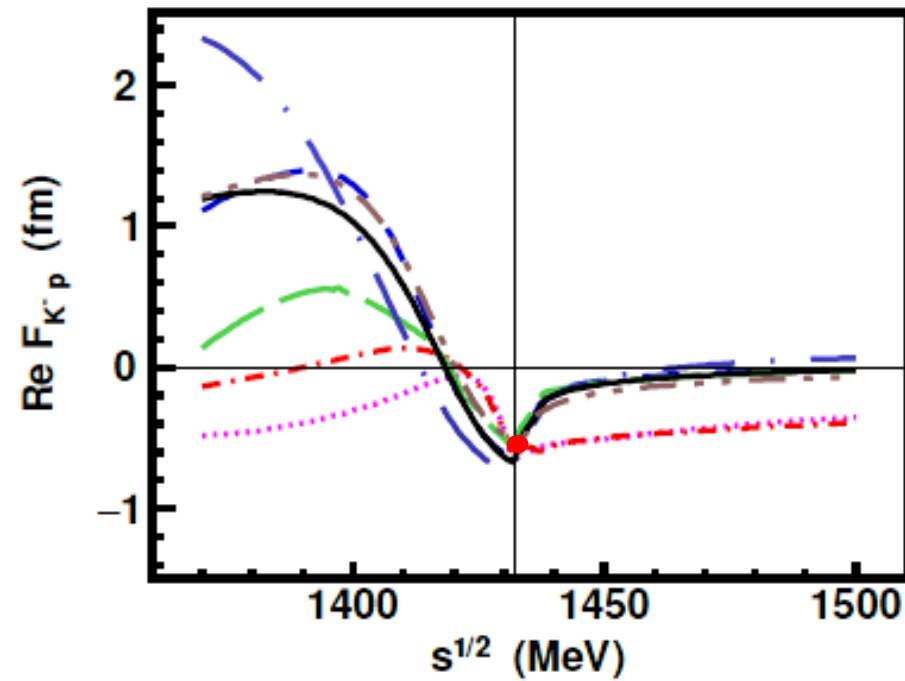
- Direct study of low-energy QCD with strangeness
- **Strong interaction:** energy shift ε_{1s} and width Γ_{1s} of ground state - directly observable



$$\Delta E = \varepsilon_{1s} = E_{\text{measured}} - E_{\text{em}}$$

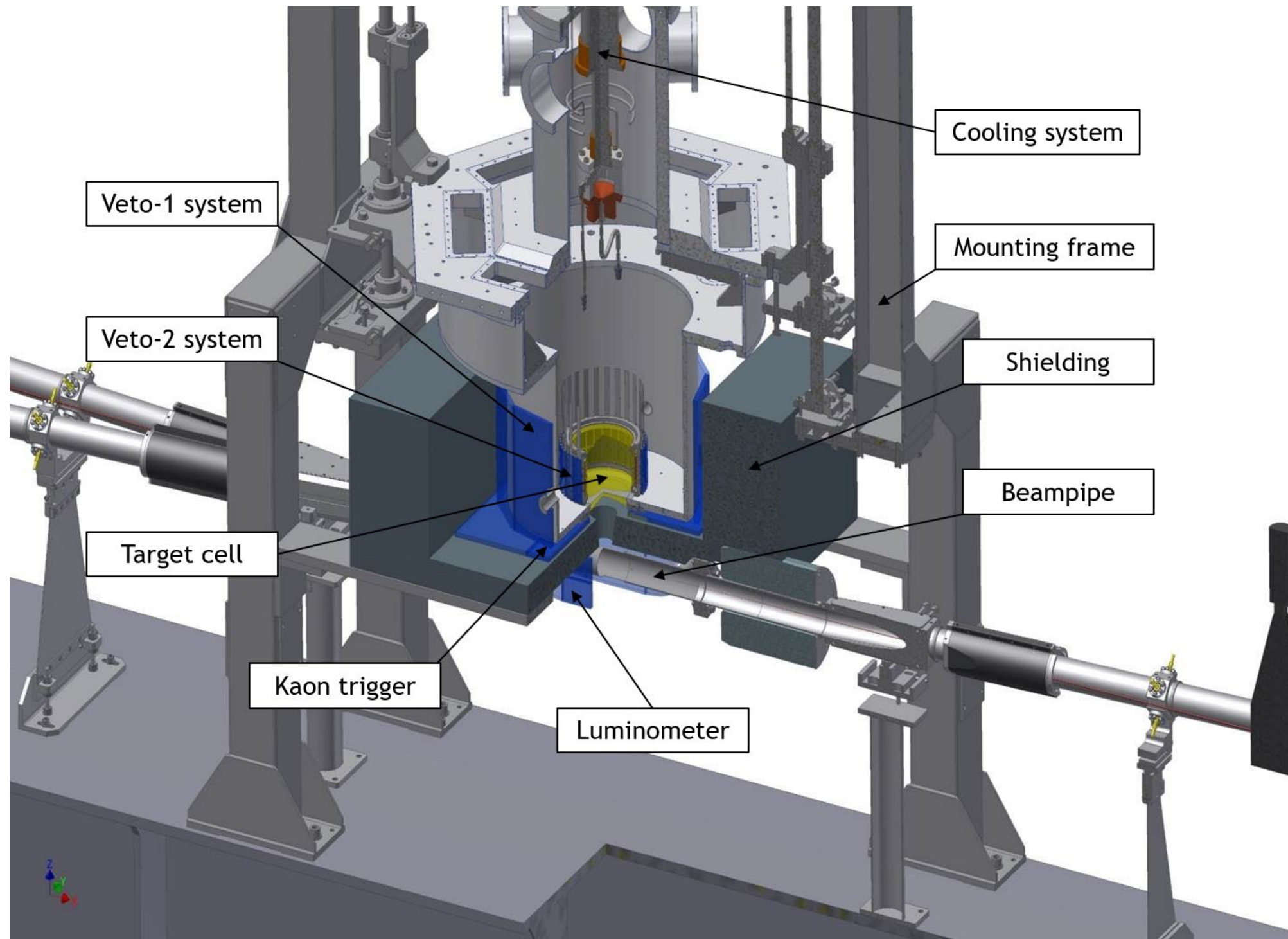
MOTIVATION: KAONIC ATOMS

$$\int dk \Pi$$



The SIDDHARTA-2 Apparatus

THE SIDDHARTA-2 APPARATUS



THE EXPERIMENTAL CHALLENGE



Kaonic deuterium:

- Yield lower than K^-p yield
- Width approx. $2\times$ K^-p width

- Lightweight cryogenic gaseous target
- Large area X-ray detectors with good energy resolution
- Veto system:

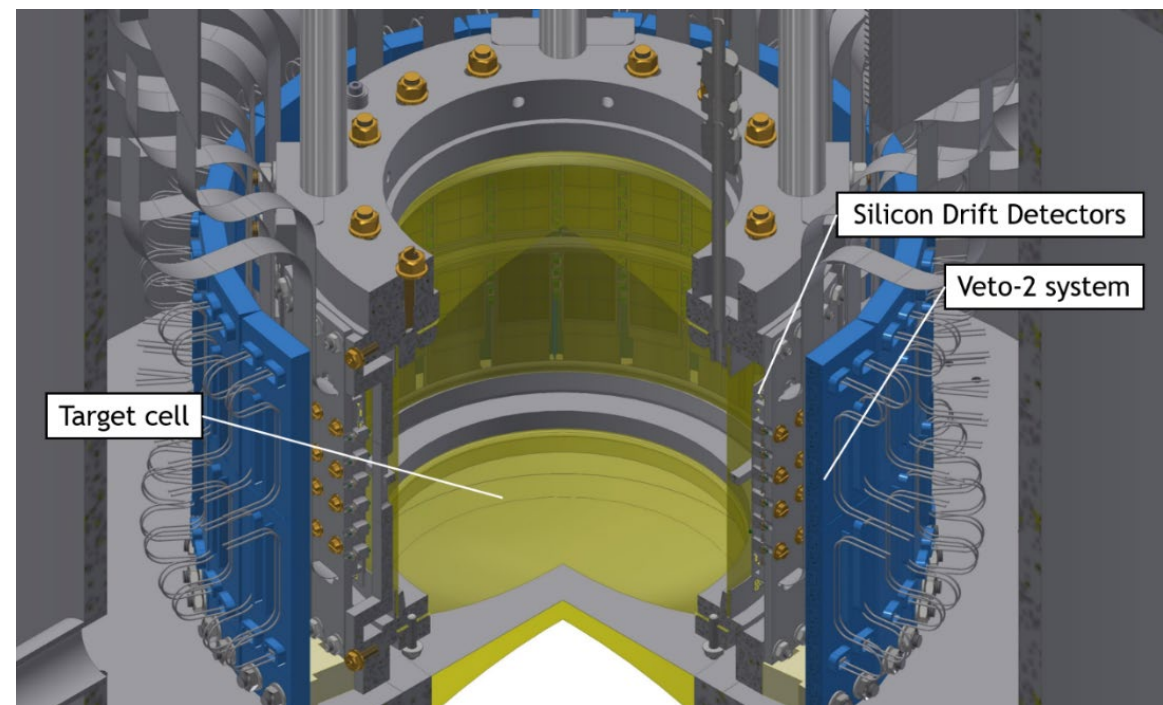
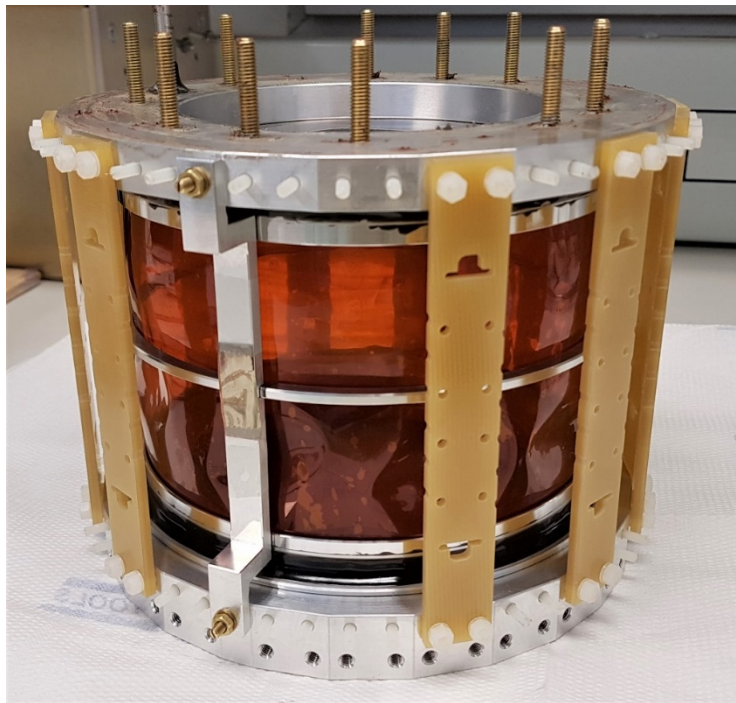
Outer Layer: Veto-1

Inner Layer: Veto-2

THE TARGET CELL

- Operated at cryogenic temperatures
- Side walls of two layers of Kapton
- Total thickness $\sim 150 \mu\text{m}$ for optimal X-ray transmission to the SDDs

Working Parametres	
Temperature	30 K
Working Pressure	0.3 MPa
Density	1.5 % LDD

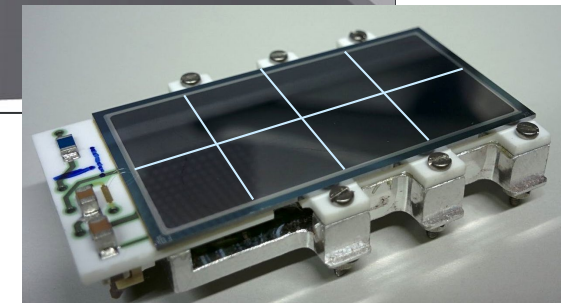
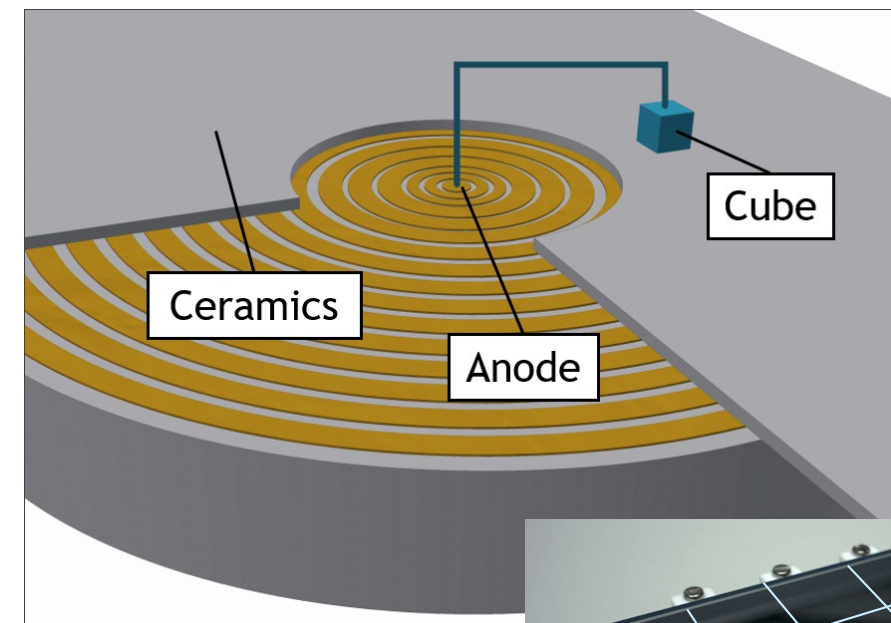
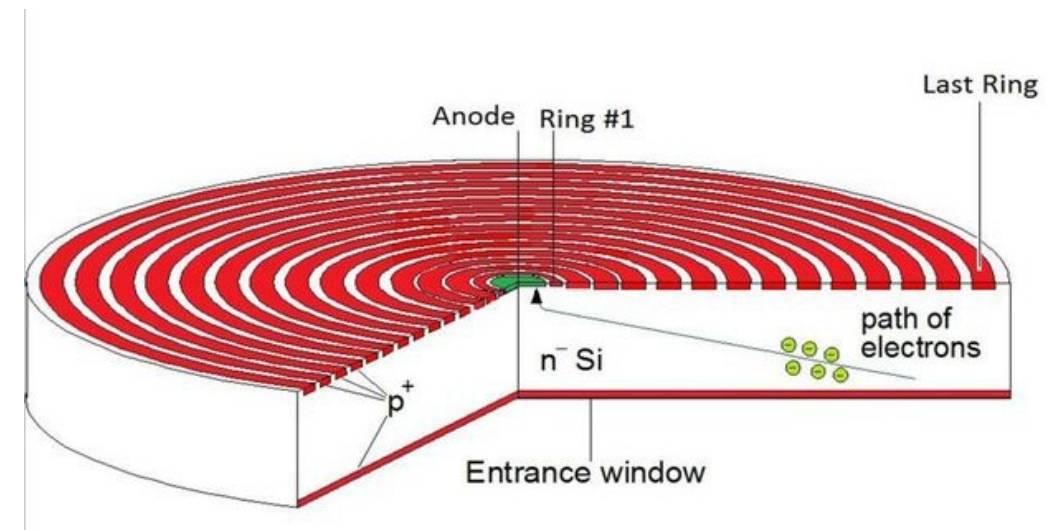
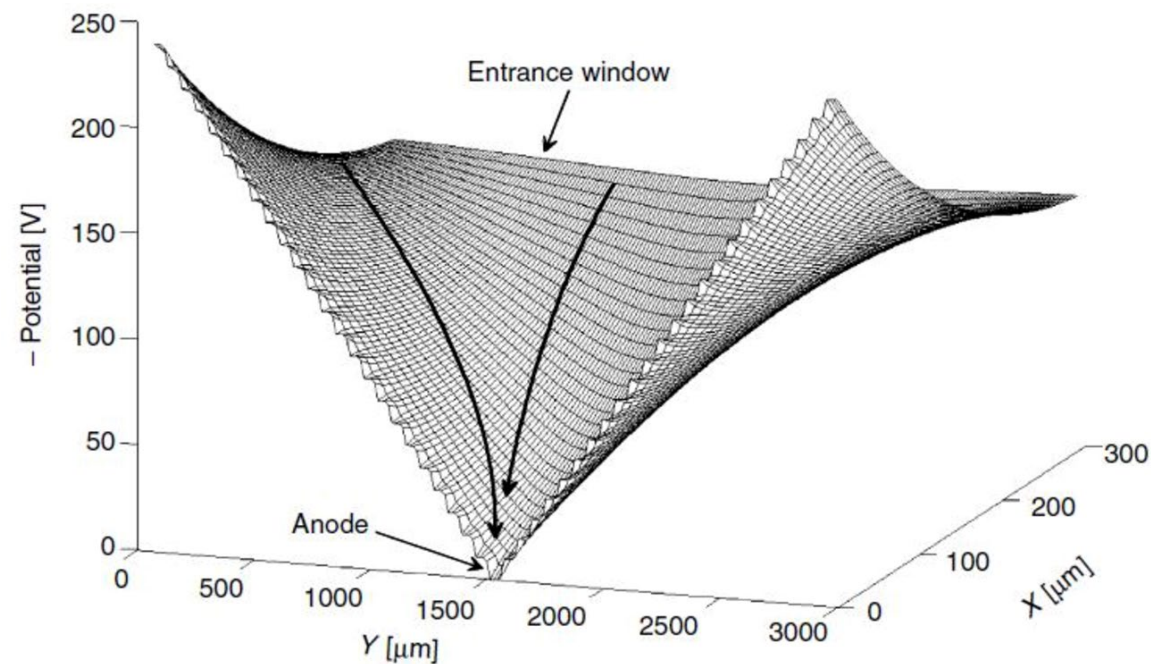


THE X-RAY DETECTION SYSTEM

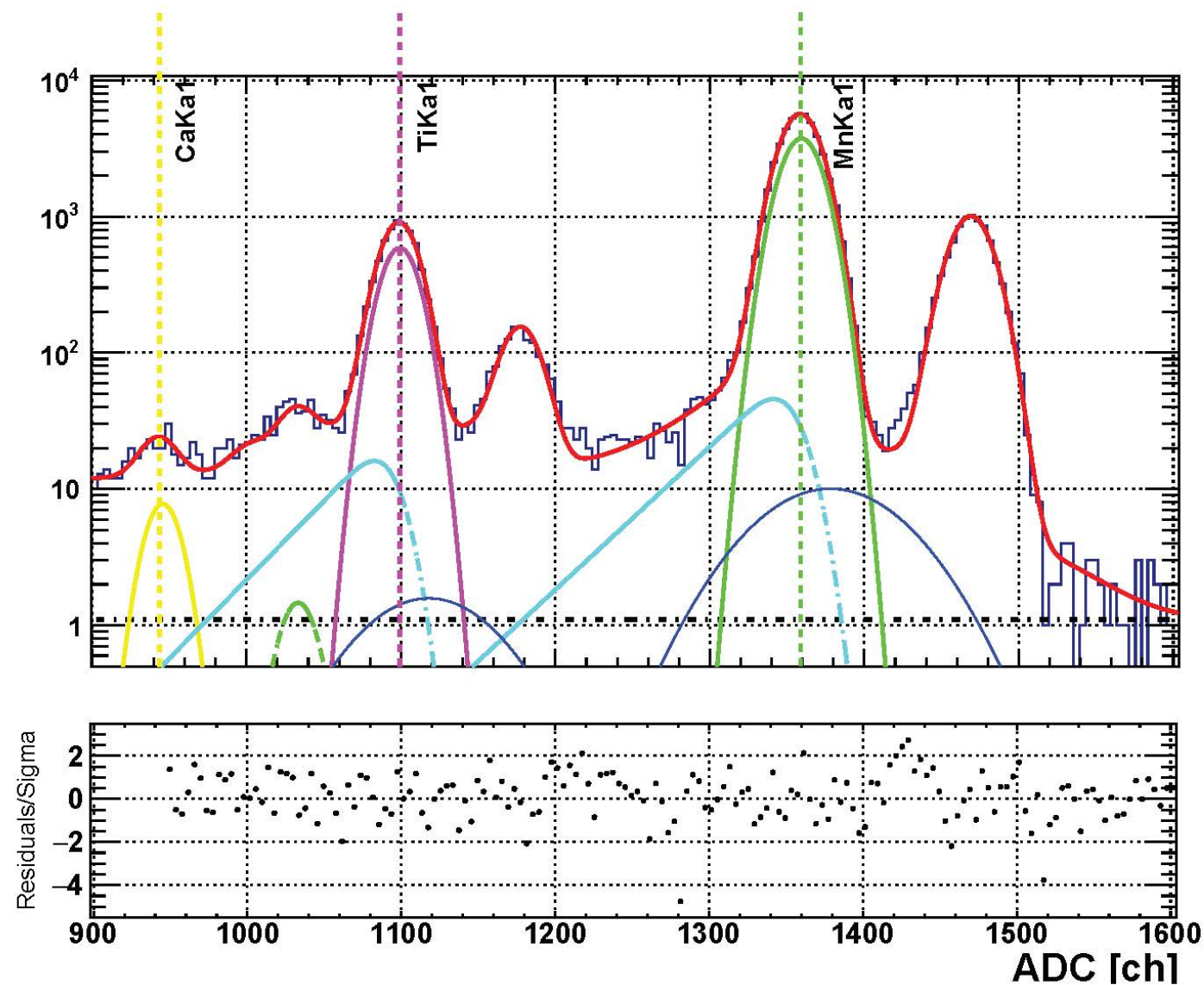


• Silicon Drift Detectors

- Updated design for SIDDHARTA-2
- CUBE preamplifier (MOSFET)
- 48 arrays with 246 cm² active area



• Silicon Drift Detectors

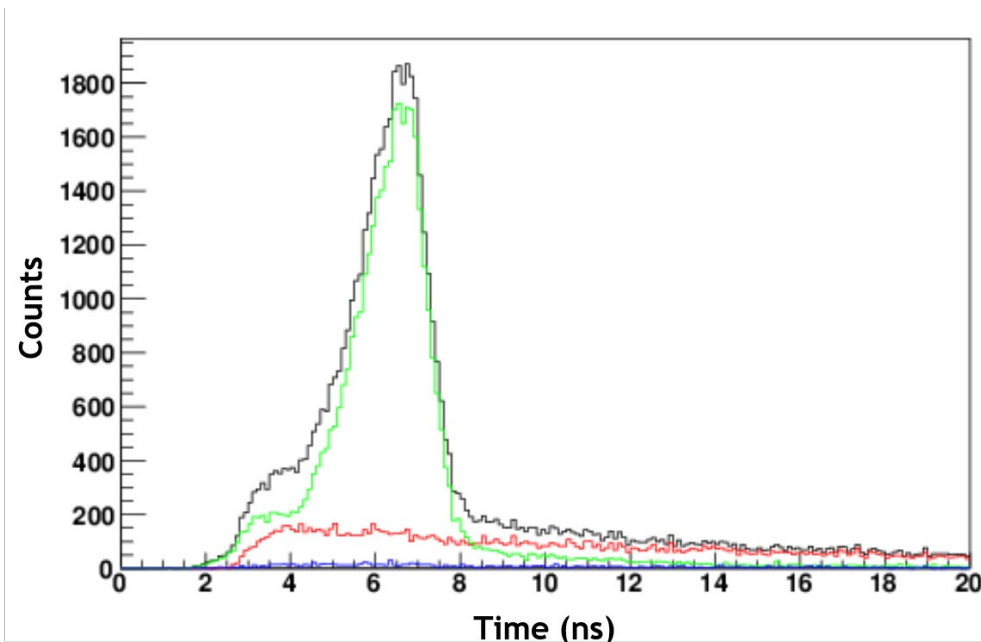
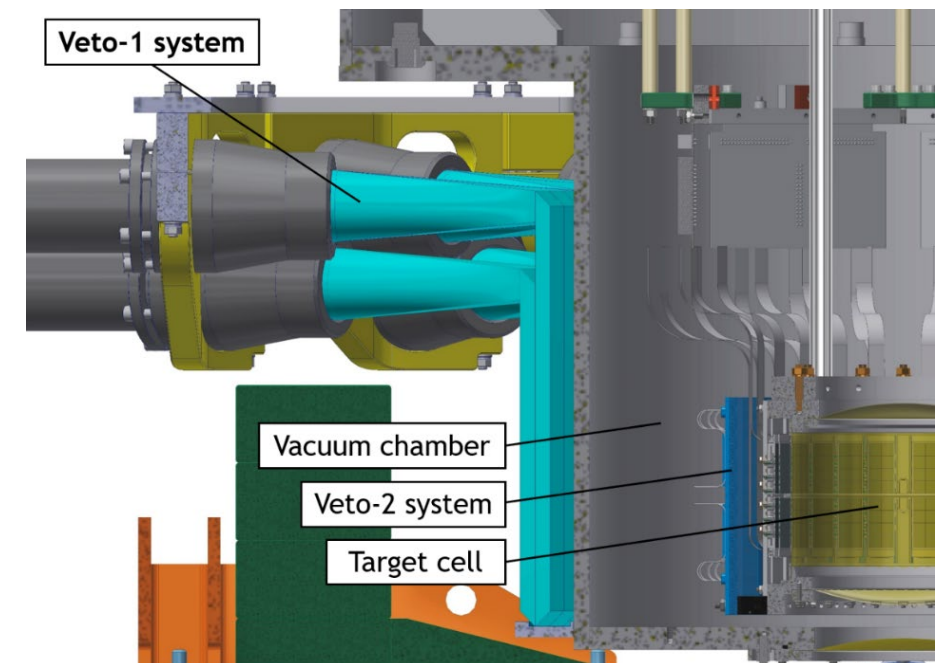


- Calibration measurement in lab with Fe-55 source and Ti foil
- During run: calibration with X-ray source
- Energy resolution at 6 keV and ~120 K of 145 eV (FWHM)

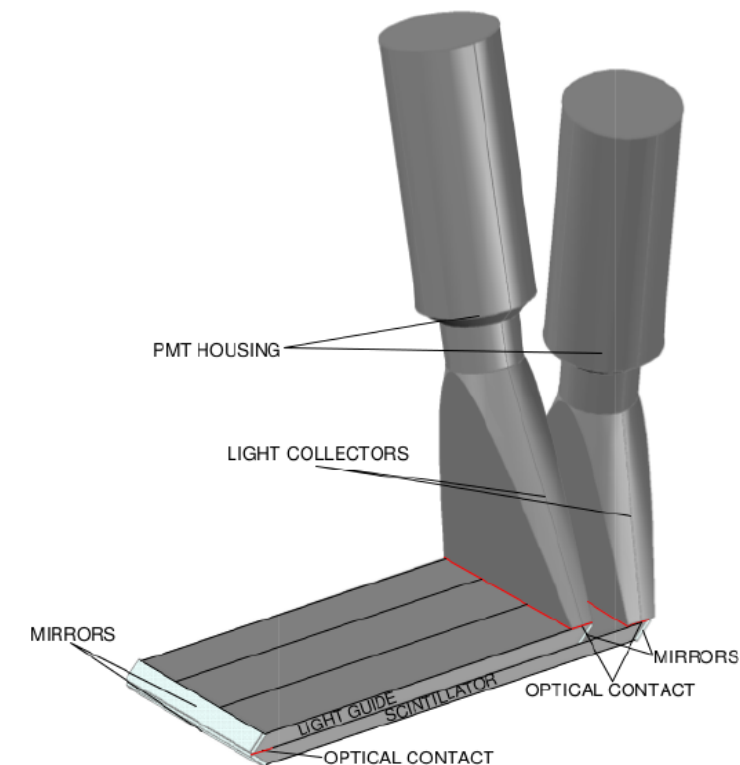
THE VETO-1 SYSTEM



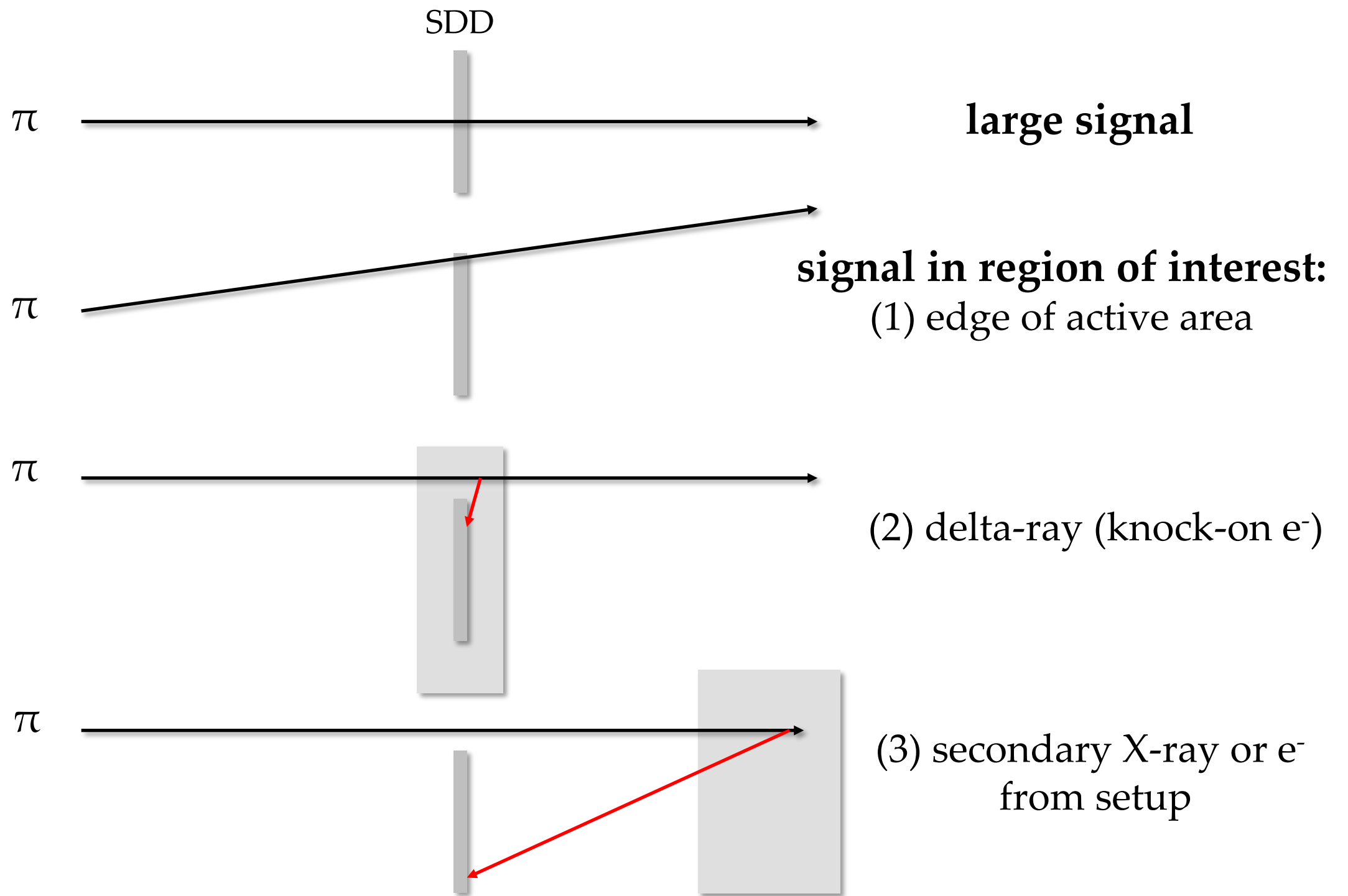
- Outer layer of veto system
- Distinction between kaon stops in gas and in surrounding material using **timing information**
- Time resolution of **< 1 ns** required
- **Setup:**
 - Plastic scintillators - read out on both ends by photomultipliers (PMTs) using light guides



- **K⁺ in bottom scintillator of kaon monitor**
- **K⁻ in bottom scintillator of kaon monitor**
- **Neither K⁺ nor K⁻ detected**
- **Sum of all distributions**



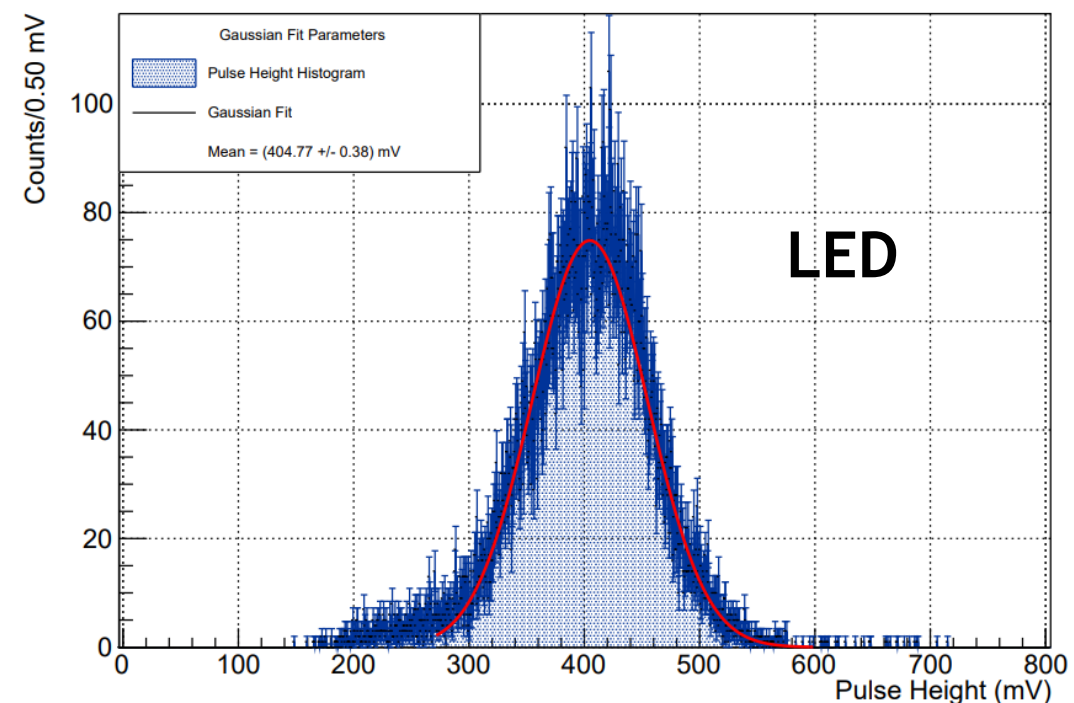
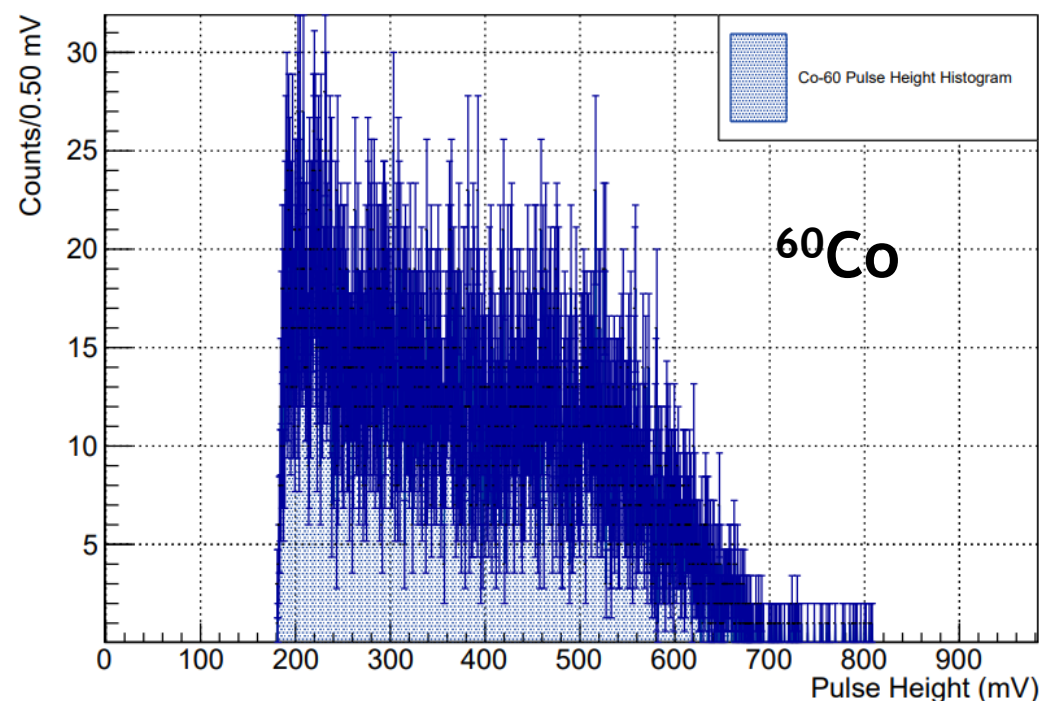
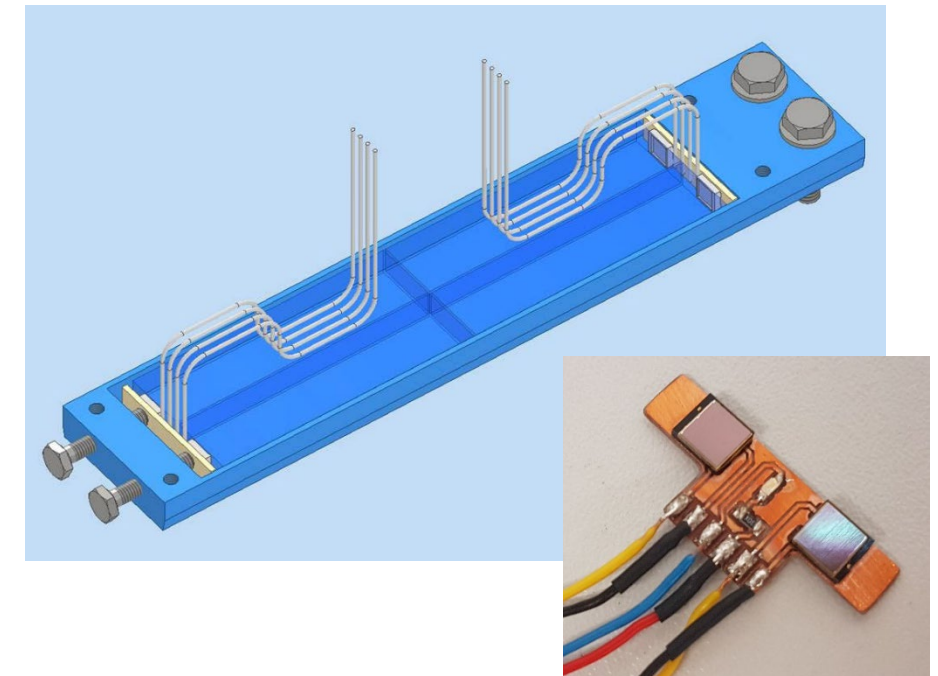
THE VETO-2 SYSTEM



THE VETO-2 SYSTEM



- Inner layer of veto system
- Supression of MIP signals in region of interest using **spatial correlation**
- Detection efficiency of $(99.1 \pm 0.2)\%$
- **Setup:**
 - 96 plastic scintillators read out by
 - 96 exchangeable SiPMs
 - 48 pulsed LEDs for in-situ calibration



Attachment

- **Properties:**

- $m_K^- : 493.677 \text{ MeV}$
- Bohr energy levels and Bohr orbit:

$$E_n = -\frac{\mu c^2}{2} \left(\frac{Z\alpha}{n}\right)^2$$
$$r_n = \frac{\hbar^2}{\mu e^2} \frac{n^2}{Z}$$

α ... fine structure constant
 μ ... reduced mass of moving particle
 n ... principal quantum number

- Particle captured in highly excited state:

$$n_X \propto n_e \sqrt{\frac{m_X}{m_e}}$$

- Improved Deser-Trueman:

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

α ... fine structure constant

μ_c ... reduced mass of K^-p system

- Isospin-dependent $\bar{K}N$ scattering lengths a_0, a_1 :

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

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

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

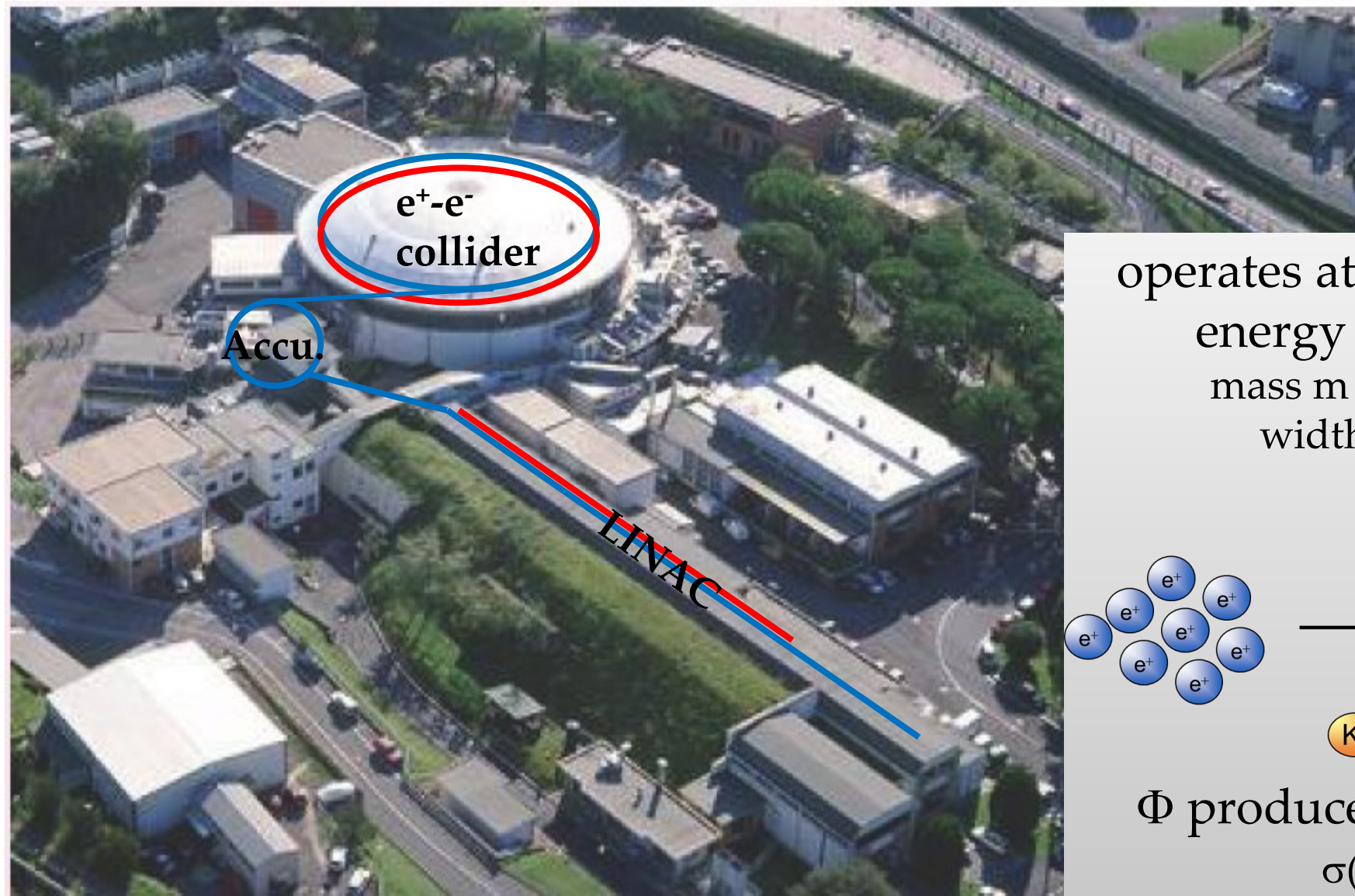
$$k = \frac{4[m_n + m_K]}{[2m_n + m_K]}$$

- **Theoretical Predictions:**

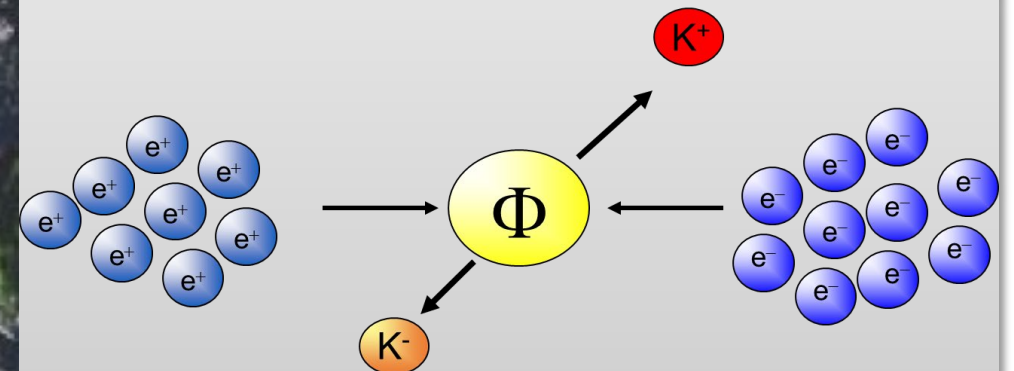
- Expected values for kaonic deuterium

ε_{1s} (eV)	Γ_{1s} (eV)	a_{K^-d} (fm)	Reference
−670	1016	$-1.42 + i\ 1.60$	Weise et al. (2017)
−887	757	$-1.58 + i\ 1.37$	Mizutani et al. (2013)
−787	1011	$-1.48 + i\ 1.22$	Shevchenko (2012)
−779	650	$-1.46 + i\ 1.08$	Meißner et al. (2011)
−769	674	$-1.42 + i\ 1.09$	Gal (2007)

DAΦNE COLLIDER AT LNF



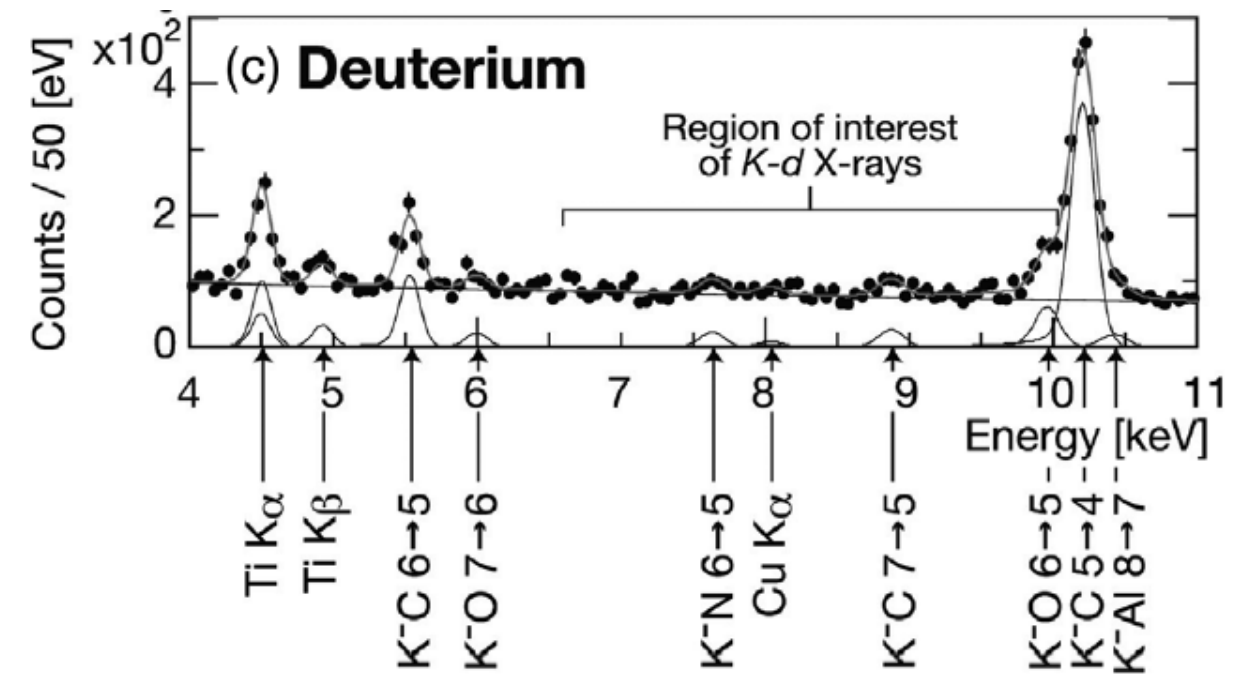
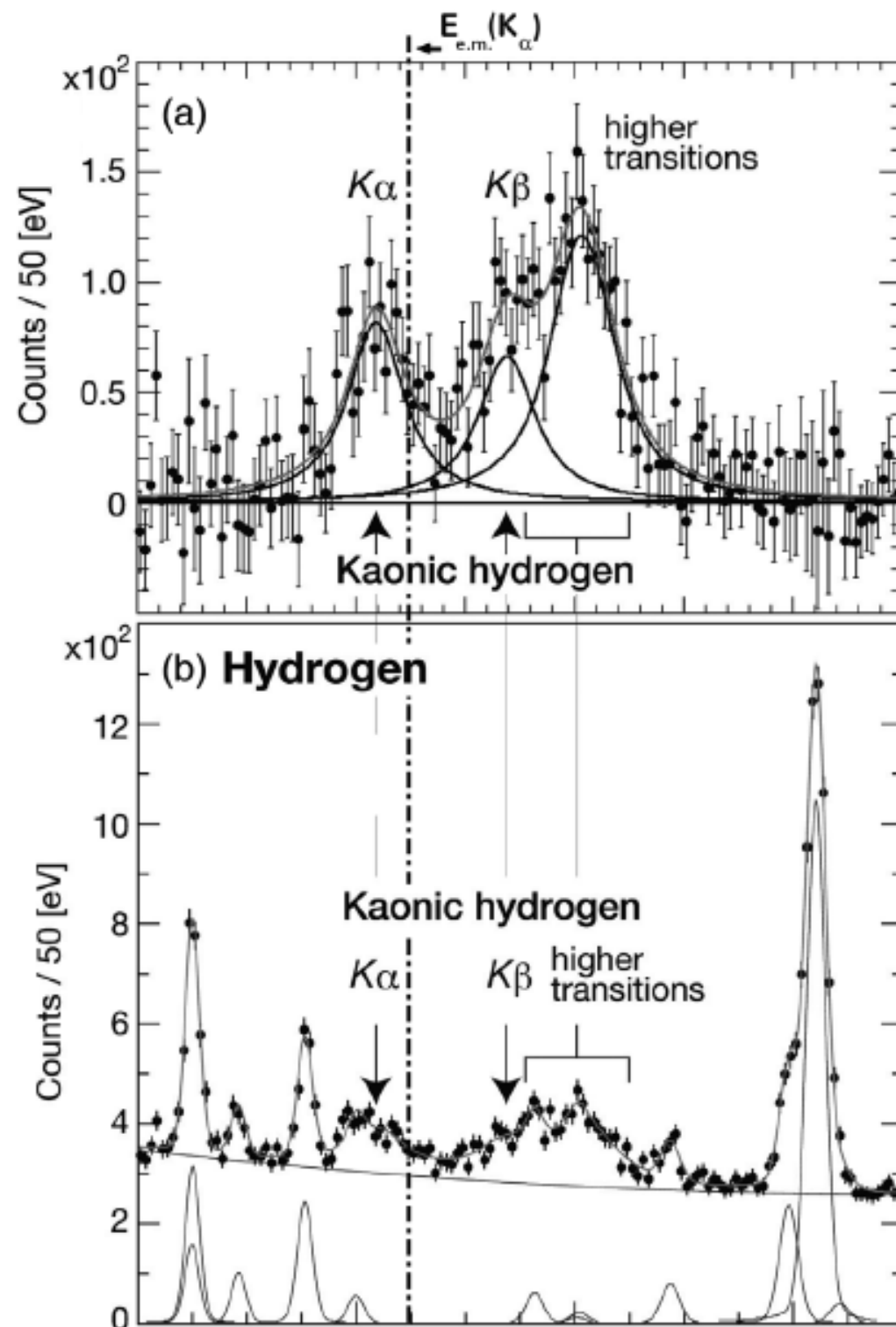
operates at the centre-of-mass
energy of the Φ meson
mass $m = 1019.413 \pm 0.008$ MeV
width $\Gamma = 4.43 \pm 0.06$ MeV



Φ produced via e^+e^- collision
 $\sigma(e^+e^- \rightarrow \Phi) \sim 5 \mu\text{b}$

→ **monochromatic kaon beam**
(127 MeV/c)

SIDDHARTA EXPERIMENT



Bazzi et al., 2011a, Phys. Lett. B 704, 113.

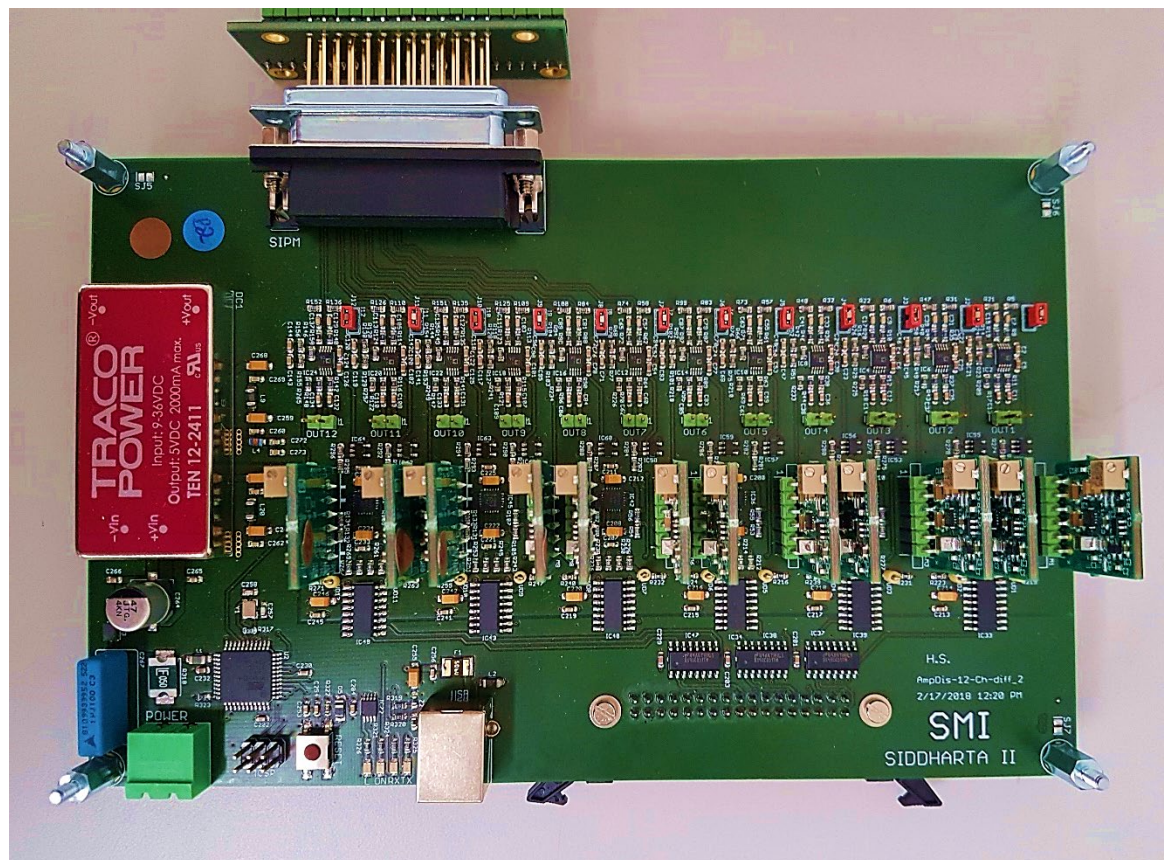
$$\varepsilon_{1s} = (-283 \pm 36(\text{stat}) \pm 6(\text{syst}))\text{eV}$$

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

- **SiPM vs PMT:**

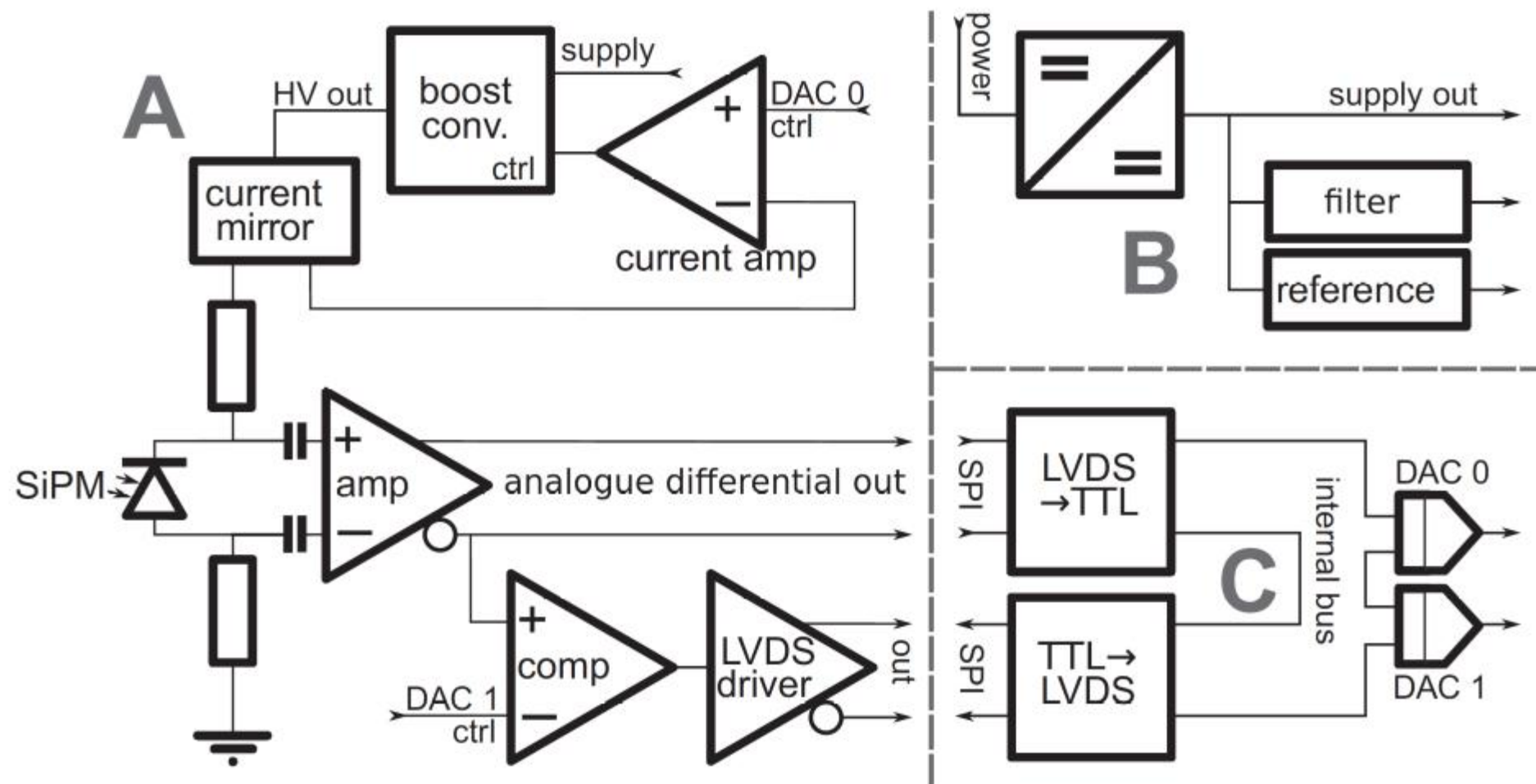
	SiPM	PMT
Supply Voltage	20 – 100 V	1000 - 3000 V
Gain	$10^5 - 10^7$	$10^4 - 10^9$
Quantum Efficiency	max. 80%	25% - 40%
Rise Time	< 1 ns	0.5 – 3.5 ns
Sensitive to B-fields	no	yes

- Amplification Boards



- 12 channels with analogue (DS) and digital output (LVDS)
- Digital: Time over Threshold
- Gain and threshold: remotely adjustable

AMPLIFIER BOARDS



Sauerzopf C. et al. (2016) Nucl. Instrum. Meth. Phys. Res. A 819 163-166

- CUBE Preamplifier on Ceramics

