ÖAW AUSTRIAN ACADEMY OF SCIENCES

SMI – STEFAN MEYER INSTITUTE FOR SUBATOMIC PHYSICS

Silicon Detectors for Kaonic Atom X-Ray Measurements at DAΦNE

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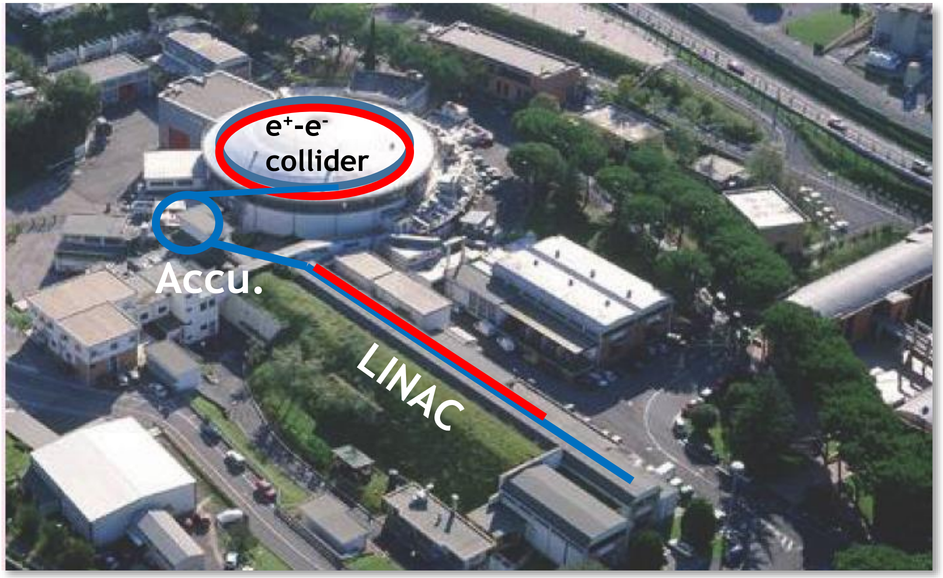
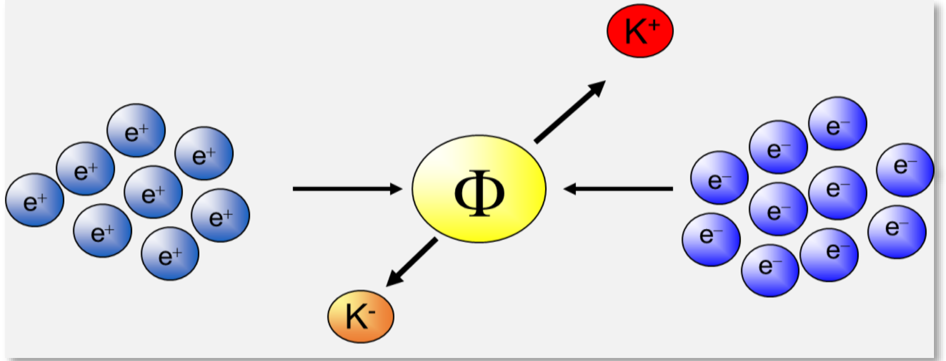
Vienna Conference on Instrumentation 2022

The DAΦNE collider at LNF



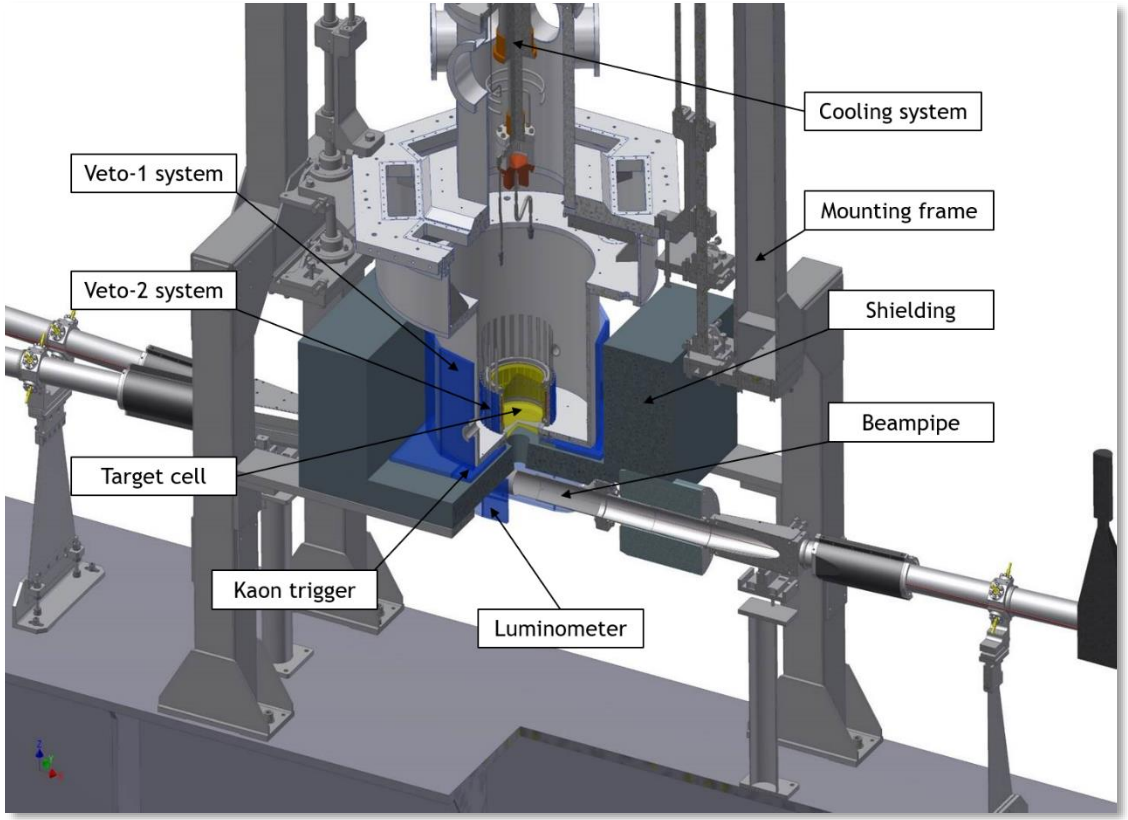


- Located at Laboratori Nazionali di Frascati (LNF)
- electron-positron collider operating at centre-of-mass energy of Φ meson (1.019 GeV)
- Φ meson produced in e^+e^- collision

  $$\sigma(e^+e^- \rightarrow \Phi) \sim 5\ \mu b$$

- Low-momentum, monochromatic kaons (127 MeV/c) emitted back-to-back

The SIDDHARTA-2 Experiment at DAΦNE

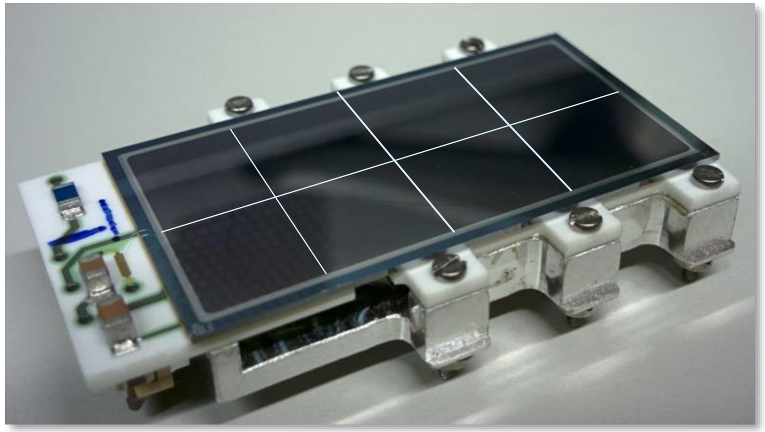


- Kaonic hydrogen & deuterium X-ray spectroscopy to study low-energy QCD
- $K^{-}d$: experimentally challenging due to low X-ray yield – increase of S/B ratio compared to kaonic hydrogen necessary

- Two novel Silicon detectors:
  - Silicon Drift Detectors (SDDs) for X-ray detection
  - Silicon Photomultipliers (SiPMs) for background minimisation

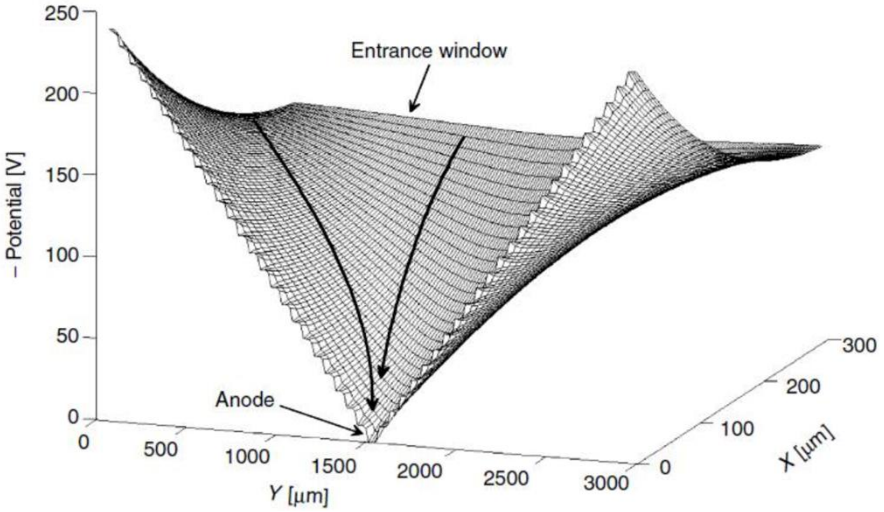
Silicon Drift Detector X-Ray Detection System

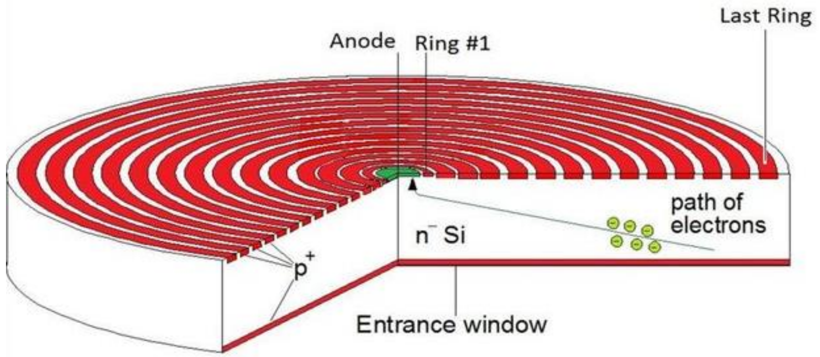
- Newly developed monolithic SDD arrays (INFN-LNF, FBK, Politechnico di Milano and SMI Vienna)
- 48 arrays of 8 read-out channels
- 246 cm^2 total active area, 450 μm thickness
- Geometry of ceramic carrier allows for compact packing around target cell
- Front-end analog processing ASIC developed by Politechnico di Milano: SFERA
  - Programmable fast and slow shapers
  - Amplitude and timing information

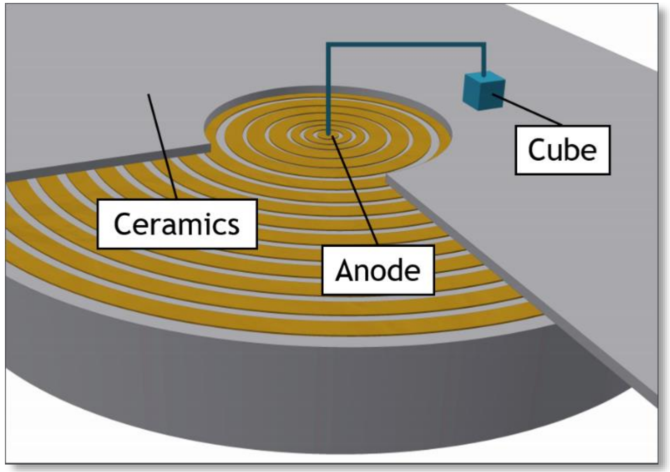


Silicon Drift Detector X-Ray Detection System

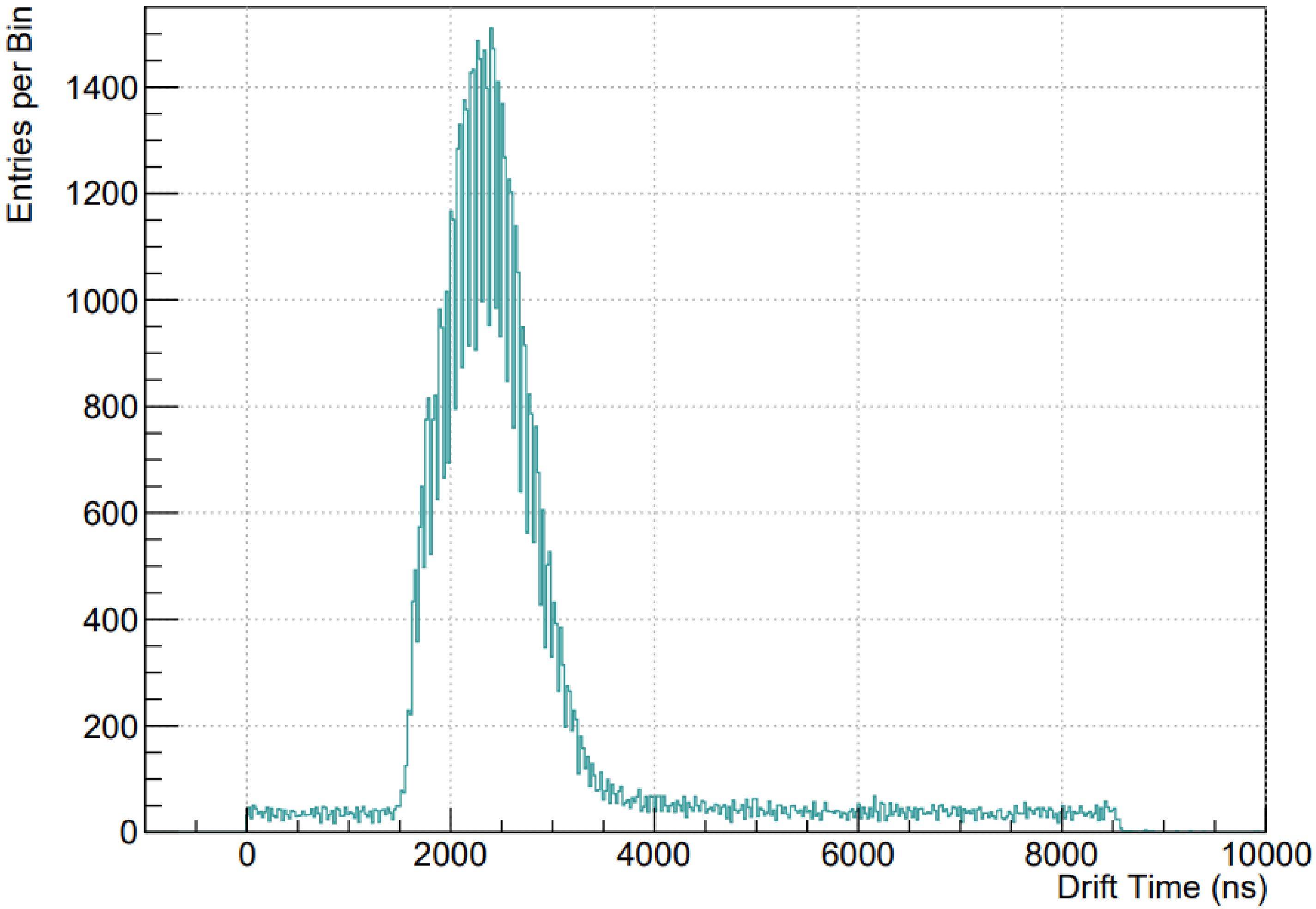
- Updated design:
  - Previously: JFET implemented directly on anode (middle figure)
  - Now: CUBE preamplifier (CMOS) implemented on ceramic carrier close to anode (right figure)





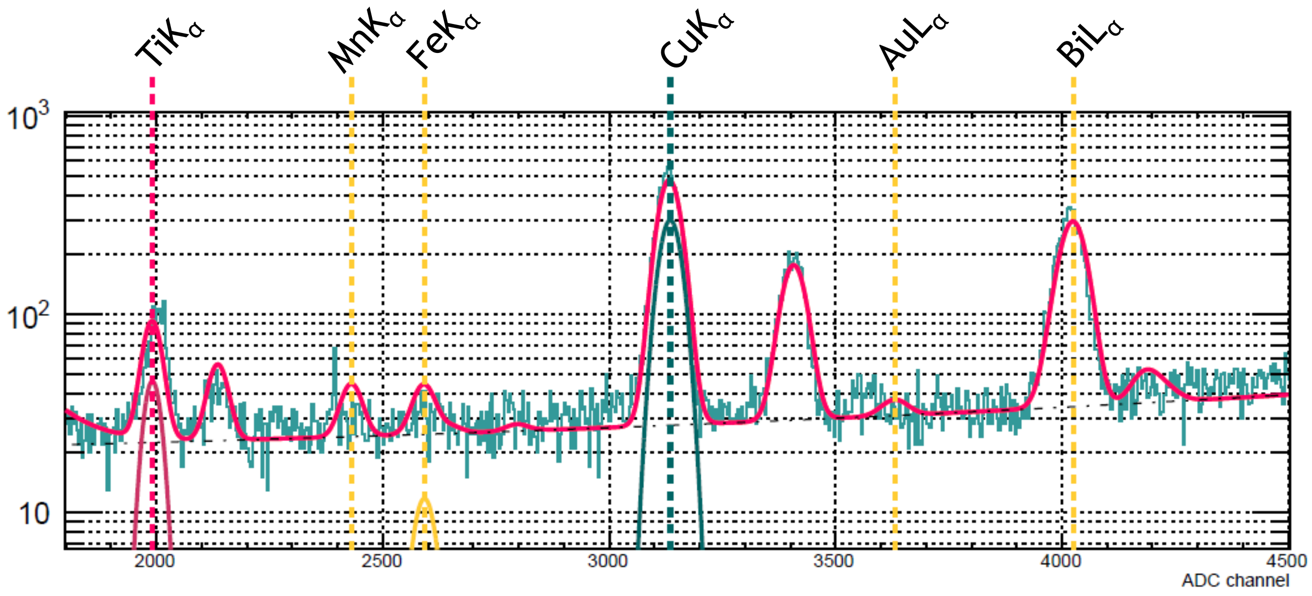


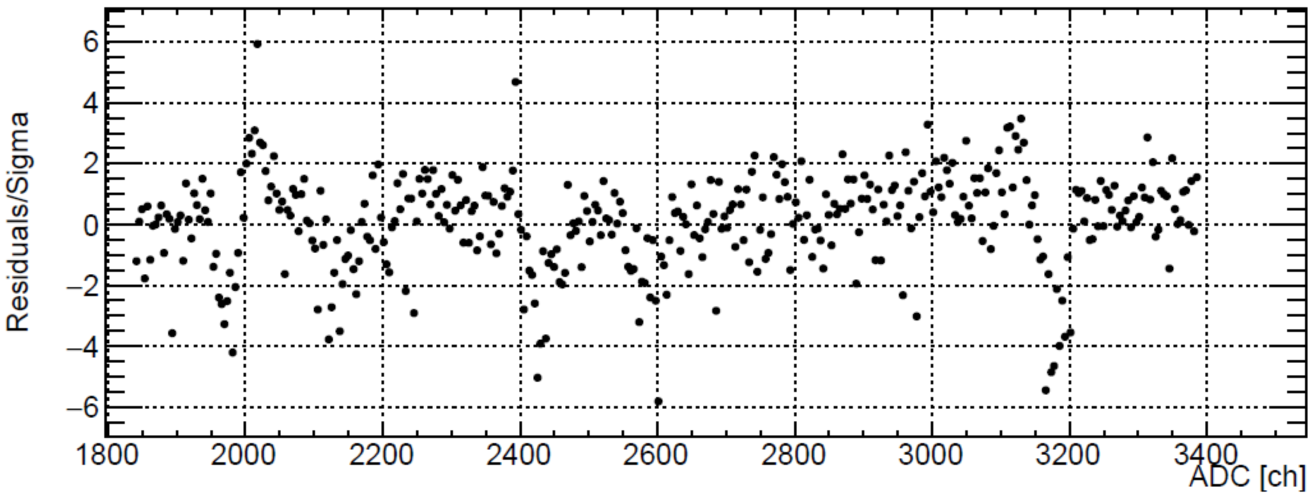
The SDDs' Timing Performance



- CUBE preamplifier allows to cool down SDDs to 120 K
- Lower temperature improves drift time to < 1 µs (FWHM)

Spectroscopic Response and Calibration of the SDDs

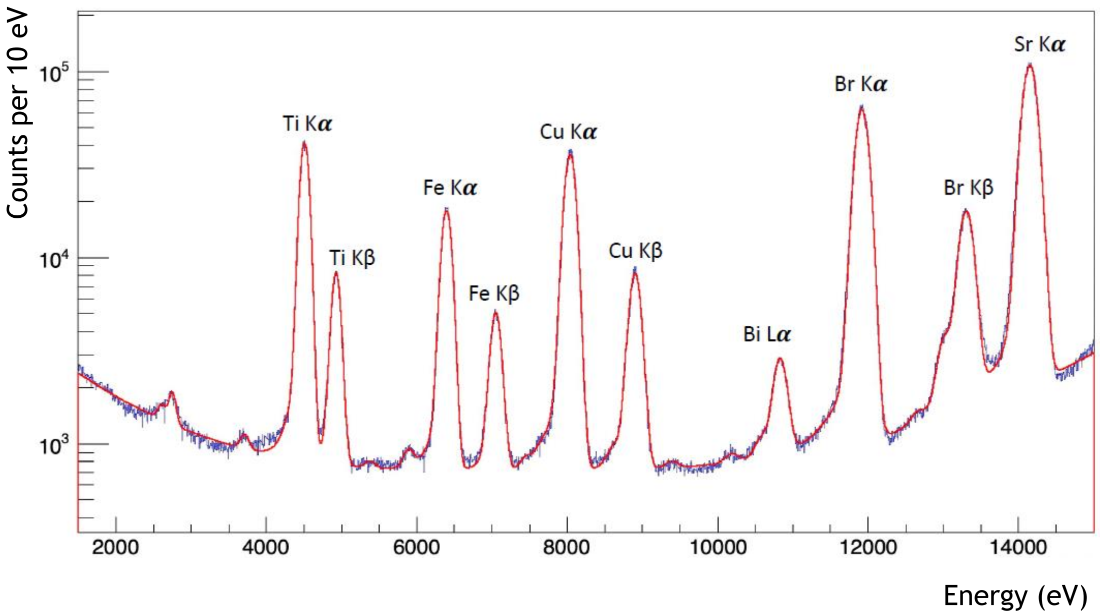


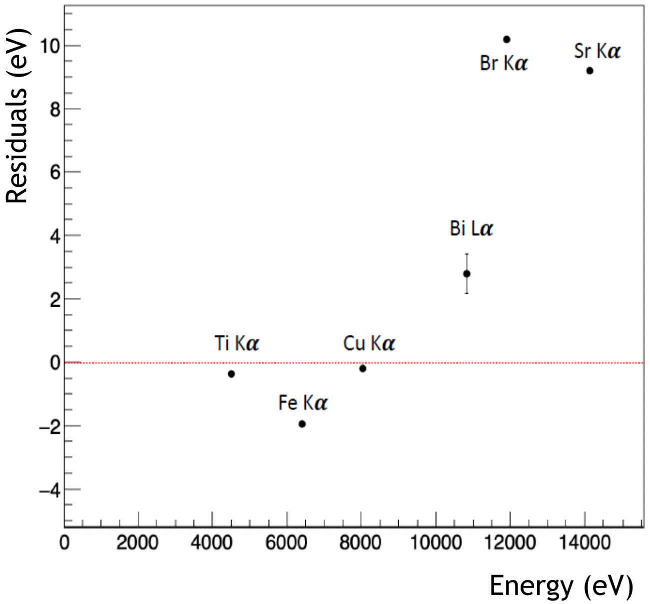


- Calibration spectrum obtained with X-ray tube activating Ti and Cu foils during KHe run
- Energy resolution at 6 keV:

  ~ 160 keV (FWHM)
- Calibration based on Ti and Cu K_α peaks at 4.5 keV and 8 keV

Linearity of the SDDs



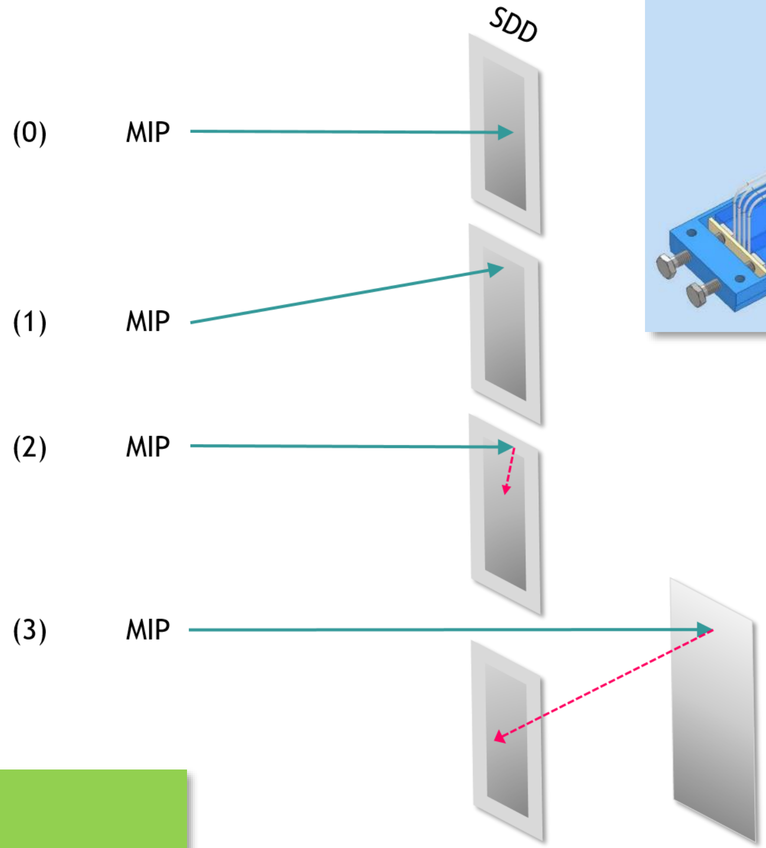


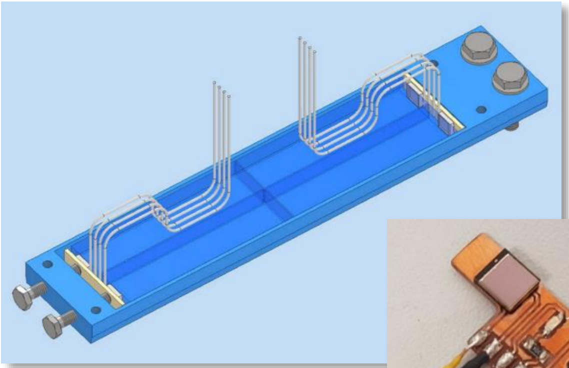
- Spectrum obtained with X-ray tube shining on multi-element target (Ti, Fe, Cu, Br, Sr)
- Residual at Fe K_α (6.4 keV) from (Ti, Cu)-calibration of **(-1.93 ± 0.09) eV**

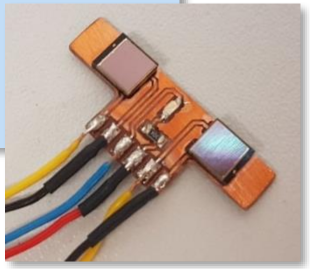
SIDDHARTA-2 and SiPMs – The Veto-2 System

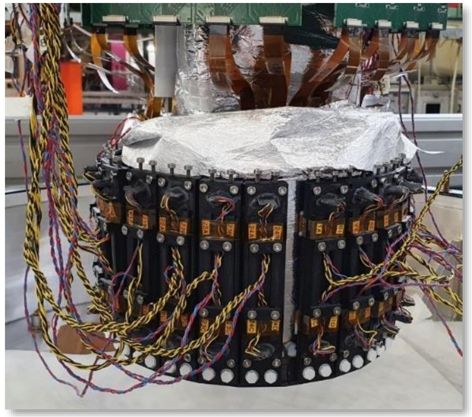
- Suppression of background from edge hits of the SDDs by Minimum Ionizing Particles (MIPs (cases (1) – (3))
- Barrel of 96 plastic scintillators read out by SiPMs
- SiPMs by AdvanSiD, 4x4 mm^2 active area, near-UV operation
- One unit consists of four scintillators and SiPMs, with two LEDs for calibration

Detection Efficiency	> 99%
Time Resolution	(293 ± 45) ps



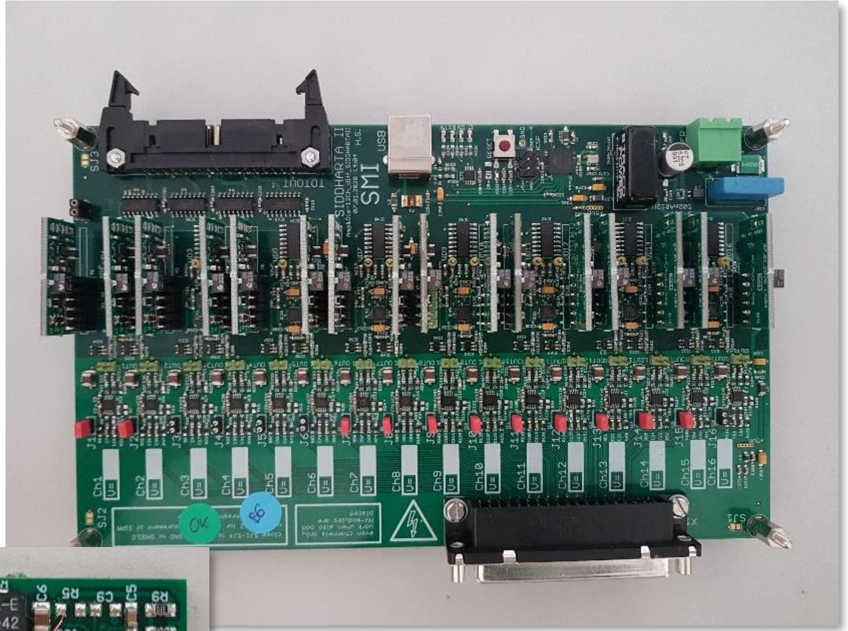
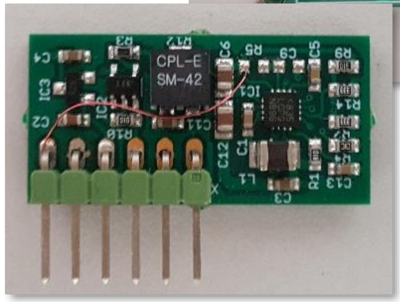






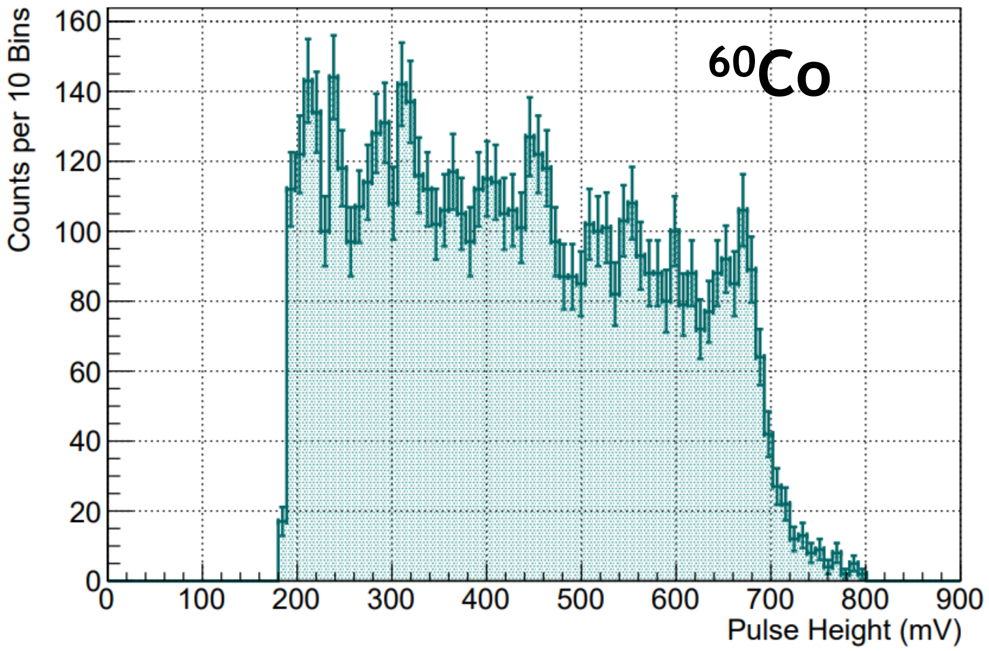
SiPM Amplification Boards

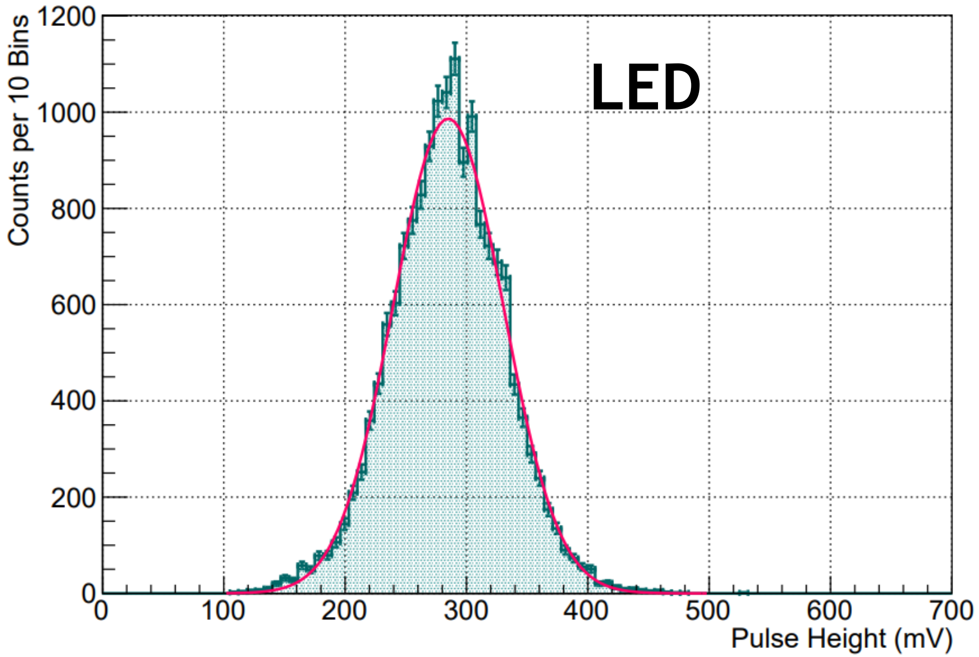
- 16-Channel amplification boards:
  - Bias voltage supply of SiPMs
  - Amplification of analog SiPM signal (differential signal)
  - Digital Time-over-Threshold (ToT) signal (LVDS)
  - SiPM gain and ToT threshold remotely programmable
- Bias supply:
  - High Voltage modules
  - Voltage stabilizing to enable SiPM operation despite radiation damage

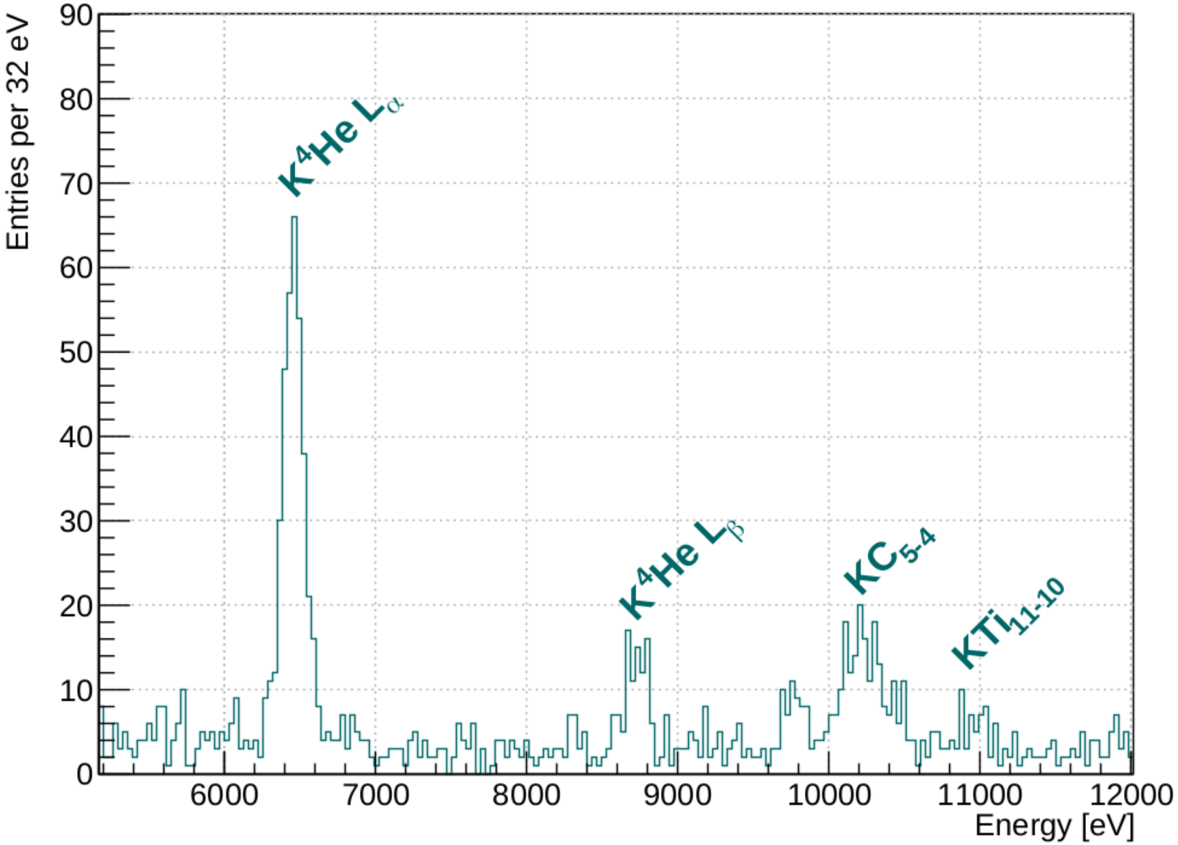
The Veto-2 Calibration

- Pulsed LEDs to monitor the amplitude of the SiPMs' signals
- Enables in-situ calibration at DAΦNE
- Pre-calibration performed at SMI with ^{60}Co and LEDs





SIDDHARTINO – KHe Measurement



- Kaonic ^{4}He measurement to finalise beam commissioning phase for total integrated luminosity of 30.9 pb^{-1}
- Preliminary spectrum for integrated luminosity of 9.3 pb^{-1}
- KHe L_α peak clearly visible at 6.4 keV
- Other peaks due to interaction of kaons with setup materials

Summary and Outlook

Silicon Drift Detectors for kaonic atom X-ray detection

- CUBE preamplifier
- Improved drift time of < 1 μs
- Energy resolution of ~ 166 keV at 6 keV
- Non-linearity < 2 eV at 6.4 keV

Silicon Photomultipliers for background suppression

- Amplifiers to operate in high-radiation environment
- LEDs for in-situ calibration
- Detection efficiency > 99%
- Time resolution ~ 300 ps

Outlook

- All detectors installed in the SIDDHARTA-2 apparatus at LNF
- First successful preparatory run with kaonic helium in summer 2021
- Kaonic deuterium data taking campaign in 2022

Further Reading

- M. Miliucci *et al.*, "Silicon Drift Detectors' Spectroscopic Response during the SIDDHARTA-2 Kaonic Helium Run at the DAΦNE Collider", Condens. Matter **6(4)**, p. 47, 2021.
- M. Miliucci *et al.*, "Silicon drift detectors technology for high precision light Kaonic atoms spectroscopic measurements at the DAΦNE collider", AIP Conference Proceedings **2416(1)**, p. 020009, 2021.
- M. Miliucci *et al.*, "Silicon Drift Detectors system for high precision light kaonic atoms spectroscopy", Measurement Science and Technology **32(9)**, p. 095501, 2021.
- C. Curceanu *et al.*, "The modern era of light kaonic atom experiments", Rev. Mod. Phys. **91**, p. 025006, 2019.
- M. Tüchler, .J Zmeskal *et al.*, "Probing low-energy QCD with kaonic atoms at DAΦNE", J. Phys.: Conf. Ser. **1643**, p. 012182, 2020.
- M. Tüchler *et al.*, "A charged particle veto detector for kaonic deuterium measurements at DAFNE", J. Phys.: Conf. Ser. **1138**, p. 012012, 2018.