ÖAW AUSTRIAN ACADEMY OF SCIENCES

SMI – STEFAN MEYER INSTITUTE FOR SUBATOMIC PHYSICS

The Veto System for Kaonic Deuterium X-Ray Measurements at DAΦNE

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STRANEX ECT*
Trento
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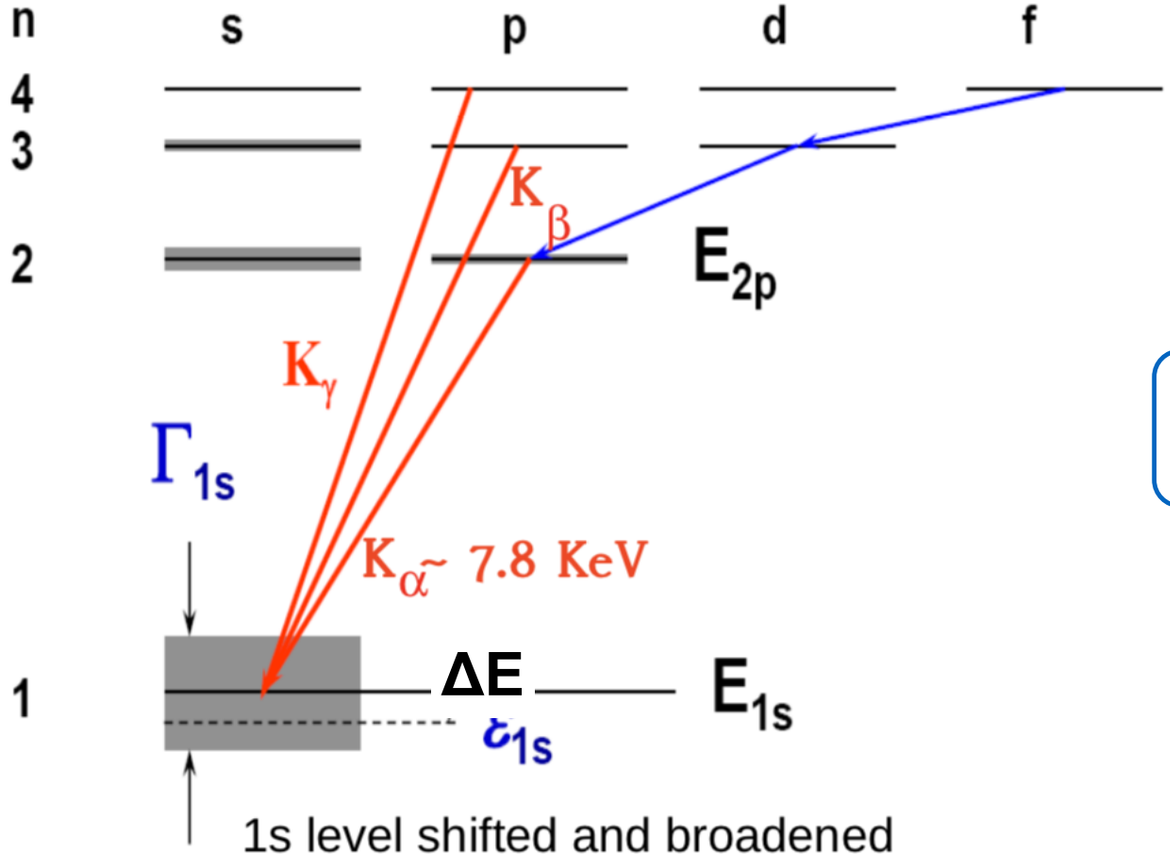
OUTLINE

- For the last time – Introduction
- The SIDDHARTA-2 Apparatus
  - Experimental Challenges
- The Veto System
  - The Veto-1 System
  - The Veto-2 System
- Conclusion and Outlook

Introduction: 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



$$\Delta E = E_{measured} - E_{em}$$

MOTIVATION: KAONIC ATOMS

- Direct study of low-energy QCD with strangeness
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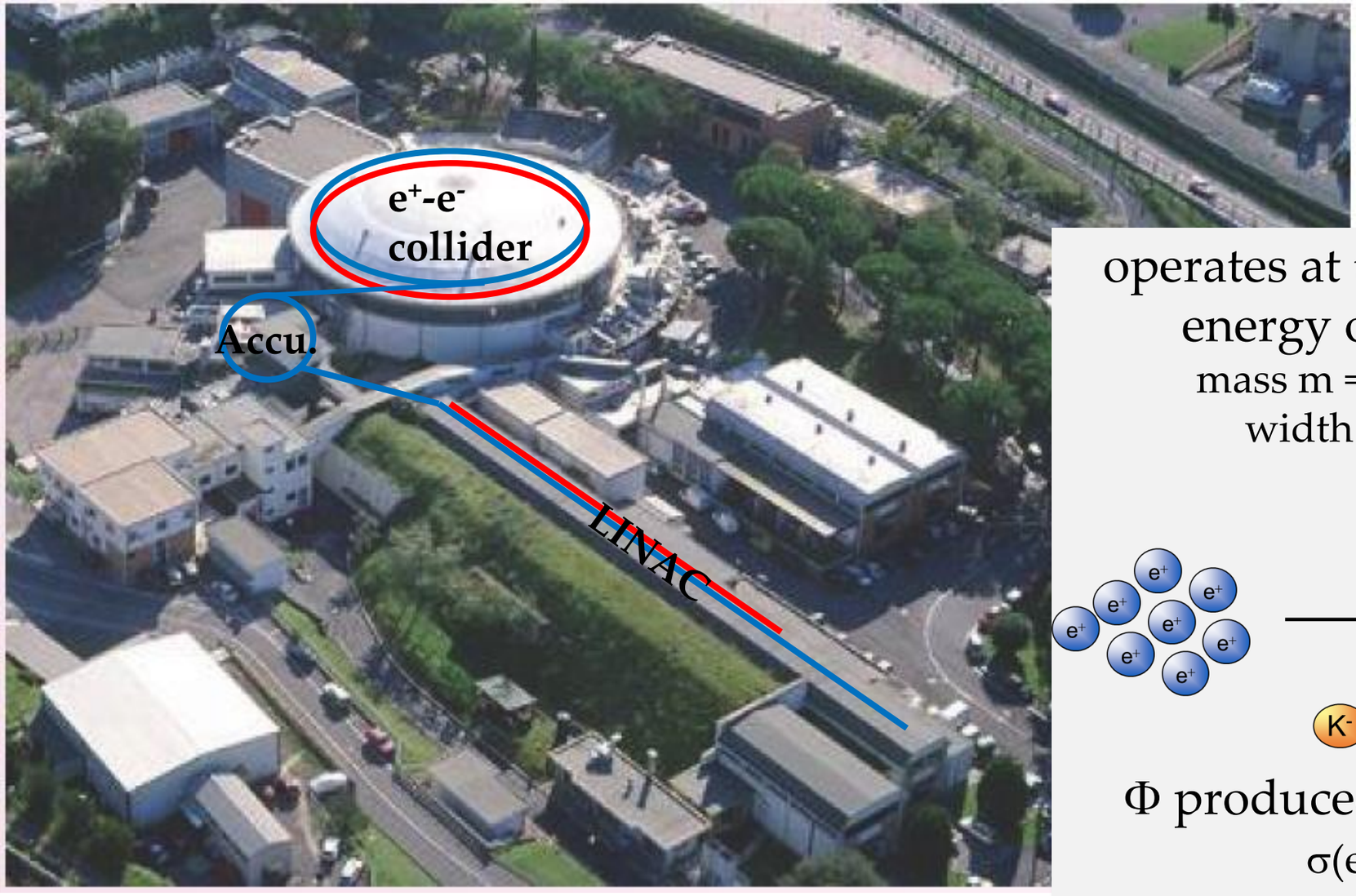
- **SIDDHARTA:**
  - Precise experimental data for kaonic hydrogen
- **SIDDHARTA-2:**
  - Kaonic deuterium measurement needed to extract isospin-dependent $\bar{K}N$ scattering lengths a_0, a_1

The SIDDHARTA-2 Apparatus

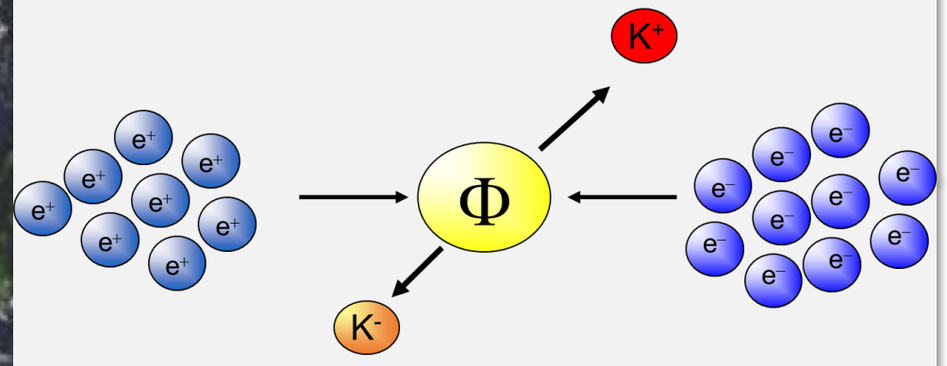
DAΦNE COLLIDER AT LNF



operates at the centre-of-mass energy of the Φ meson

mass m = 1019.413 ± 0.008 MeV

width Γ = 4.43 ± 0.06 MeV



Φ produced via e^+e^- collision

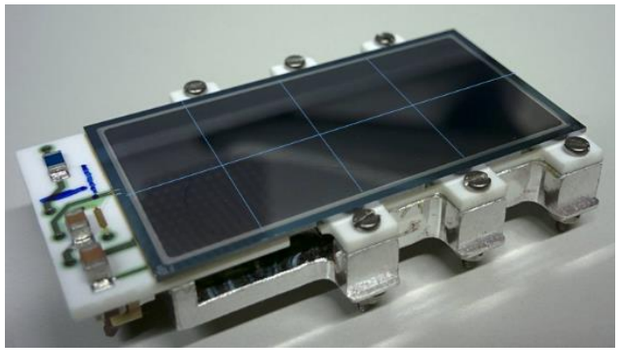
$\sigma(e^+e^- \rightarrow \Phi) \sim 5\ \mu b$

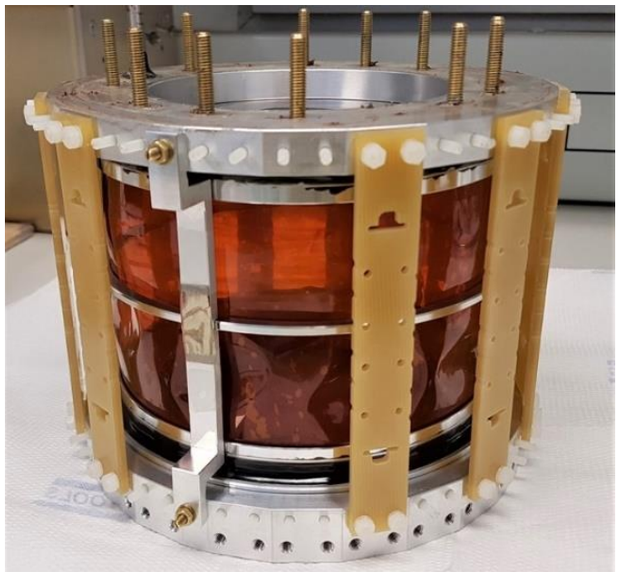
→ monochromatic kaon beam (127 MeV/c)

EXPERIMENTAL CHALLENGES

Kaonic deuterium:

- **X-ray yield lower than K^-p yield**
- **Width approx. 2× K^-p width**
- **High background environment**





→ Large area X-ray detectors

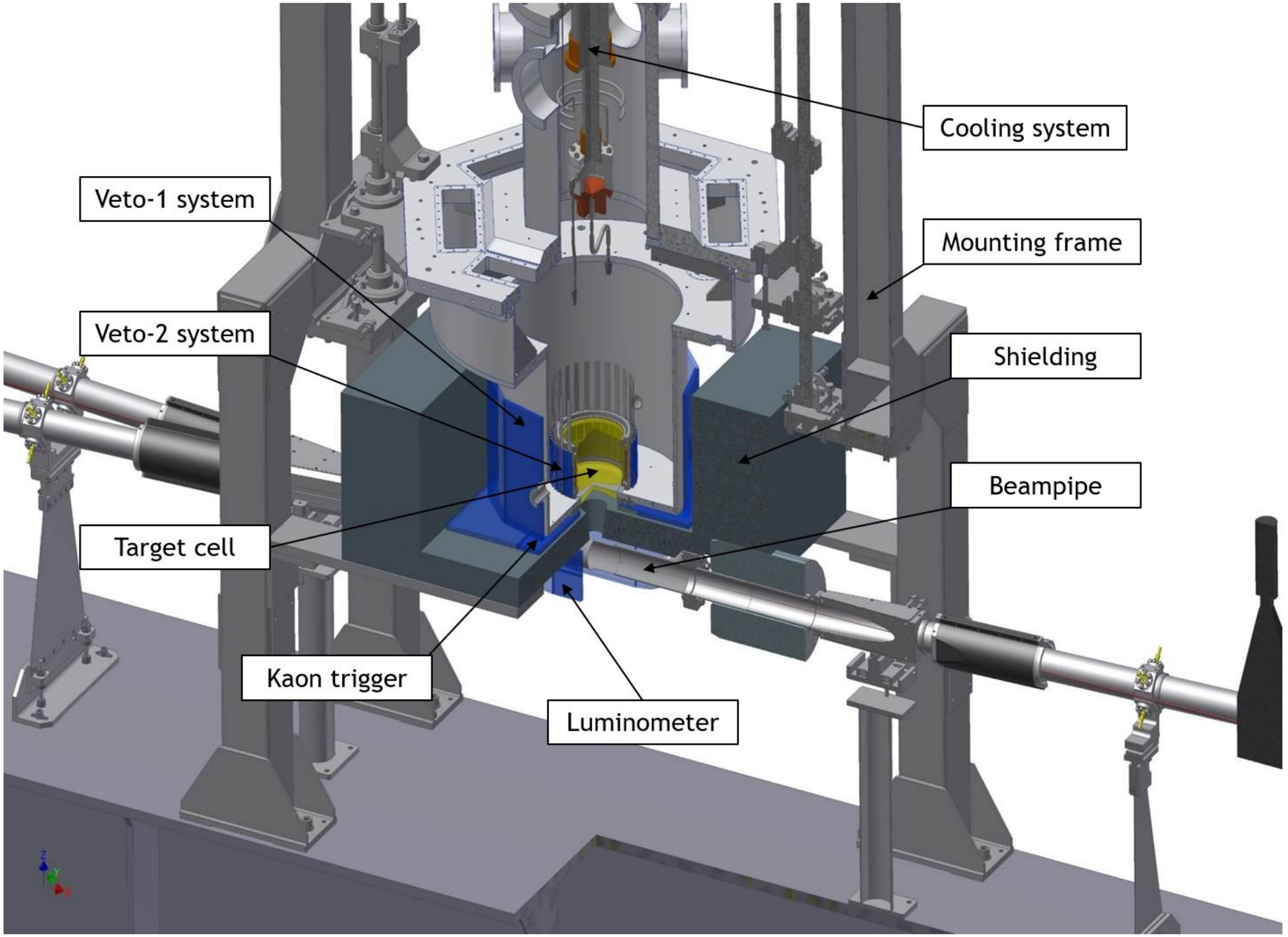
→ Lightweight cryogenic gaseous target

→ **Veto system:**

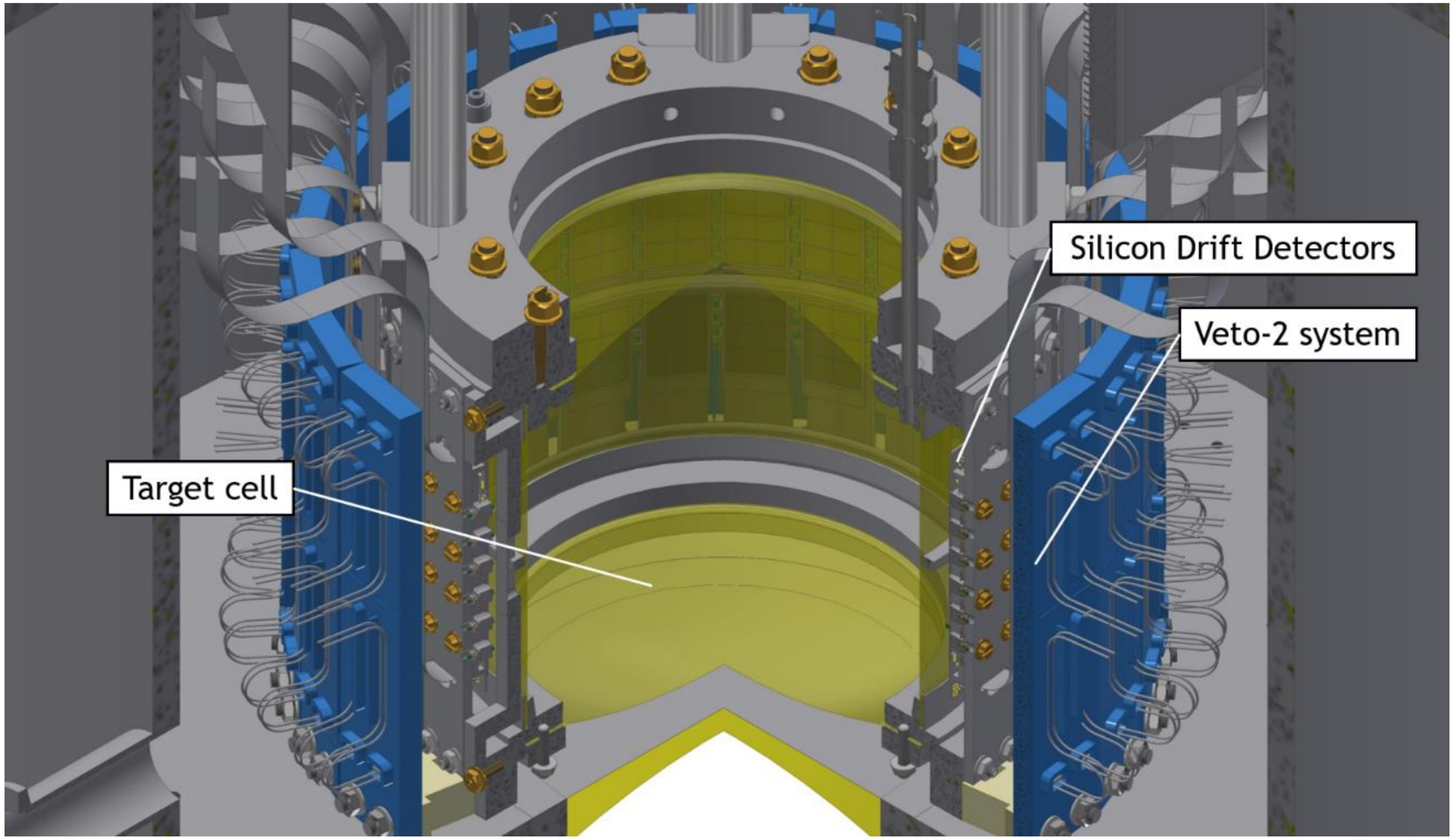
Veto-1: Suppression of kaon stops in material

Veto-2: Suppression of MIP background from kaon absorption

DETECTOR SYSTEM SIDDHARTA-2



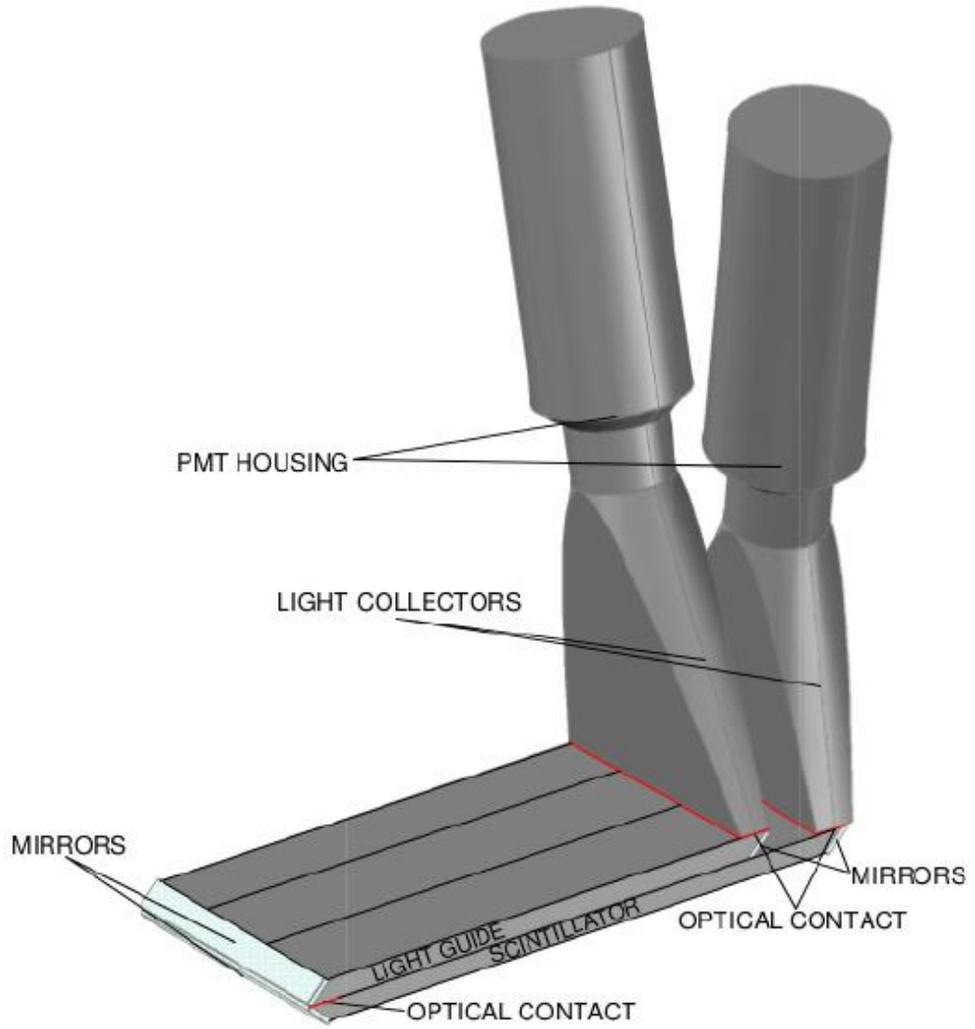
DETECTOR SYSTEM SIDDHARTA-2



The Veto System

THE VETO-1 SYSTEM

- **Timing information:** distinction between kaon stops in gas and material
- Scintillators with PMT read-out on both ends
- 12 detector units outside vacuum chamber



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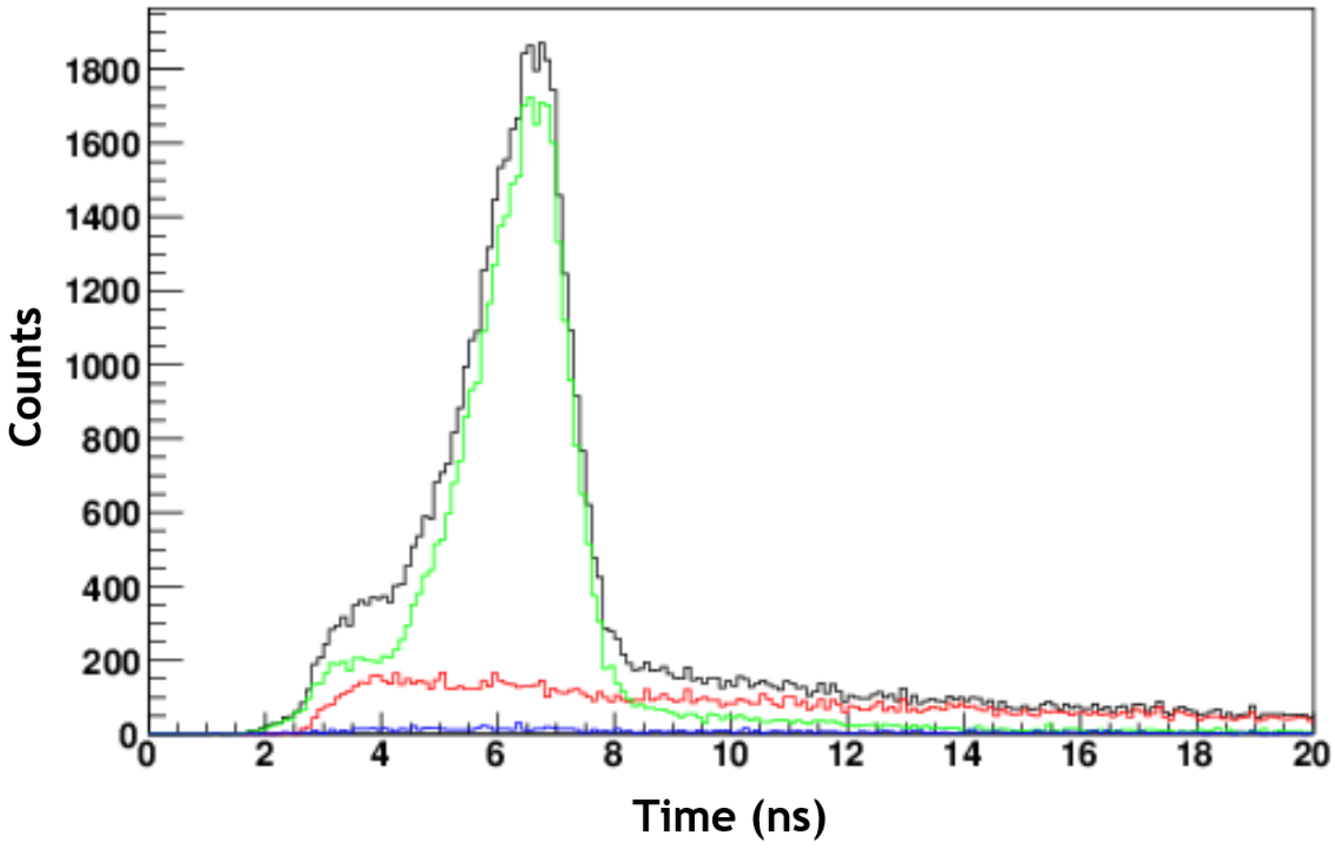
THE VETO-1 SYSTEM

- MC simulation of response of scintillator mounted outside of vacuum chamber
- Time resolution of < 1 ns needed

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



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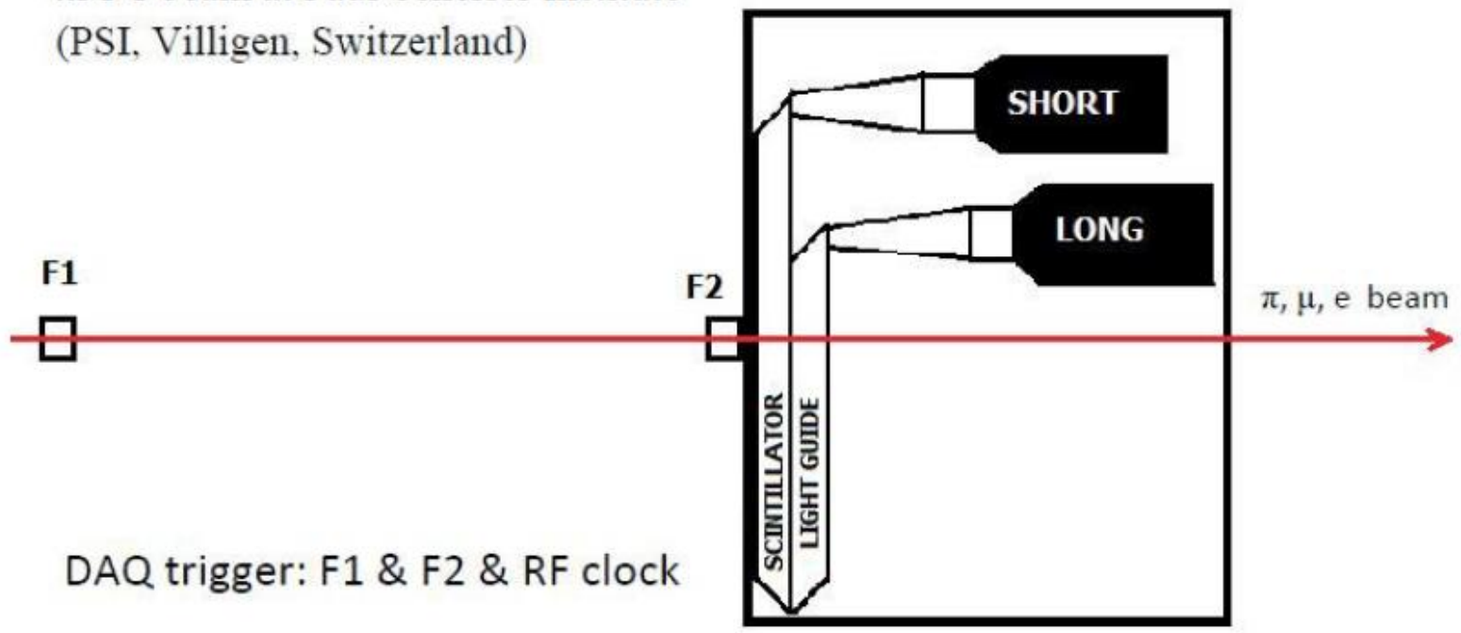
THE VETO-1 SYSTEM

- **Time Resolution and Efficiency**

πM-1 beam at Paul Scherrer Institute
(PSI, Villigen, Switzerland)



- Mean **time resolution** for 170 MeV/c pions: **(746 ± 53) ps** (FWHM)
- Overall **efficiency** for 170 MeV/c pions: **(96 ± 2)%**

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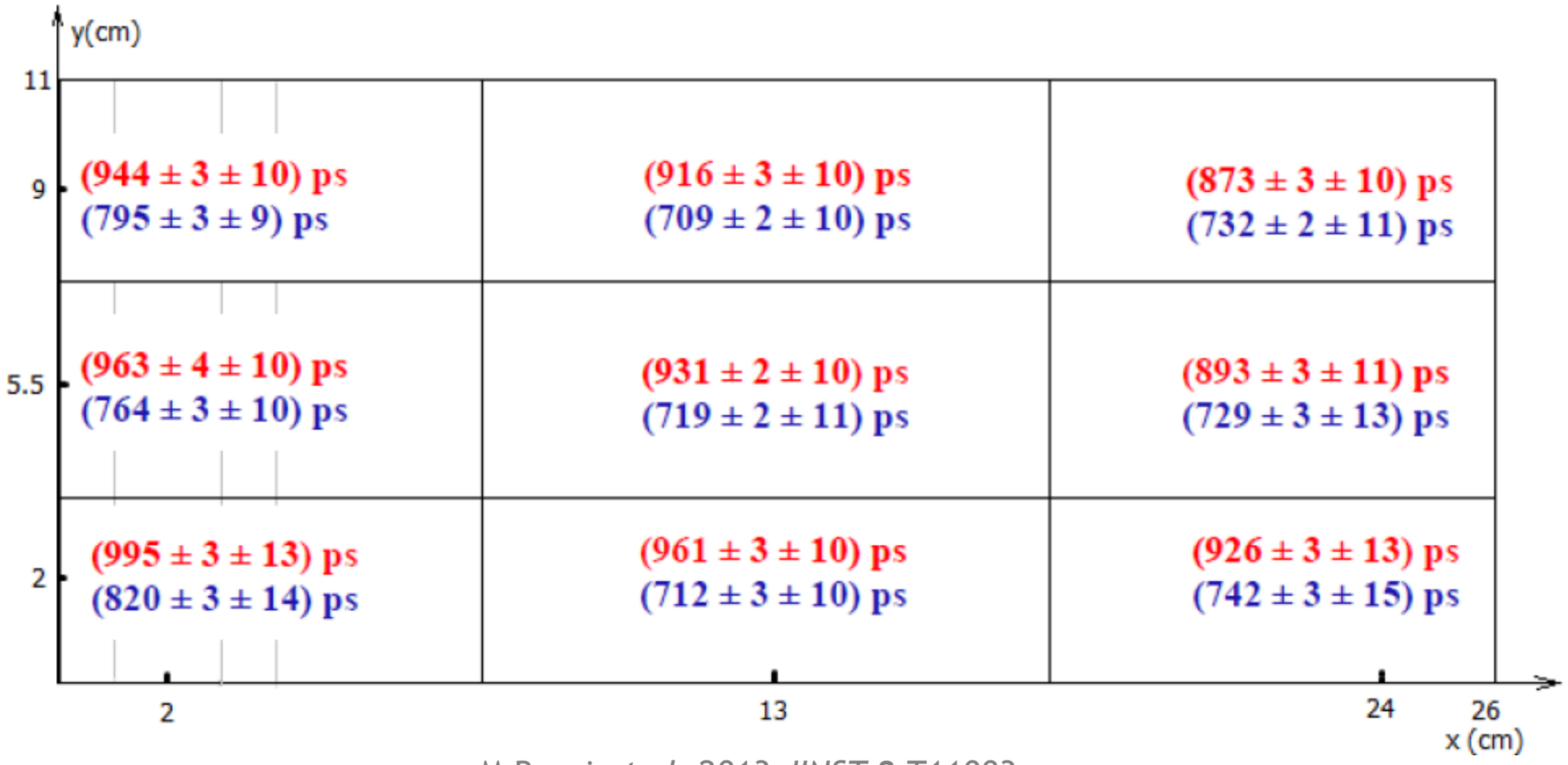
THE VETO-1 SYSTEM

- **Time Resolution for 170 MeV/c Pions:**
  - Red: LONG, Blue: SHORT



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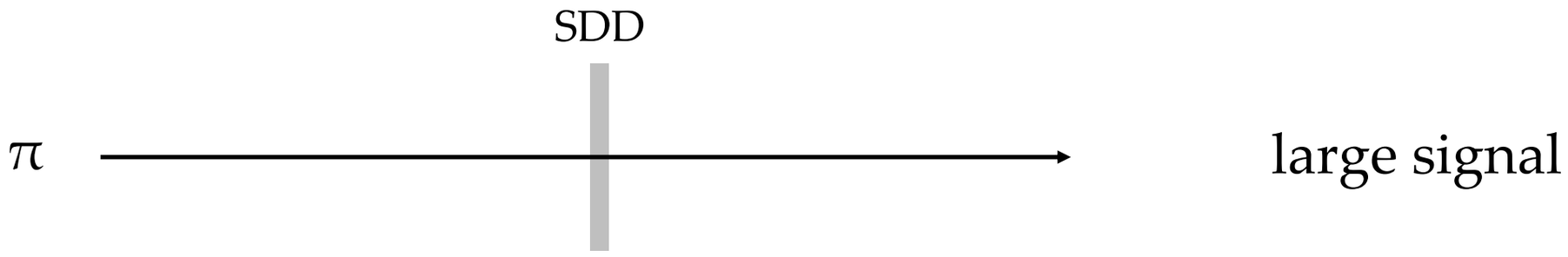
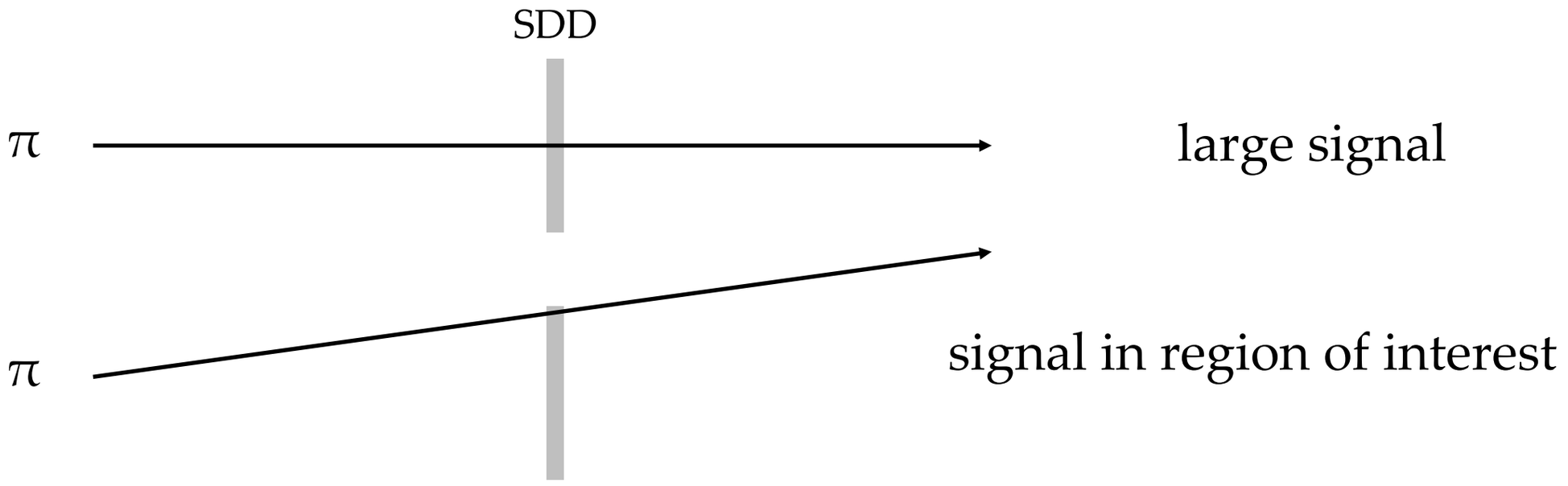
THE VETO-2 SYSTEM



THE VETO-2 SYSTEM



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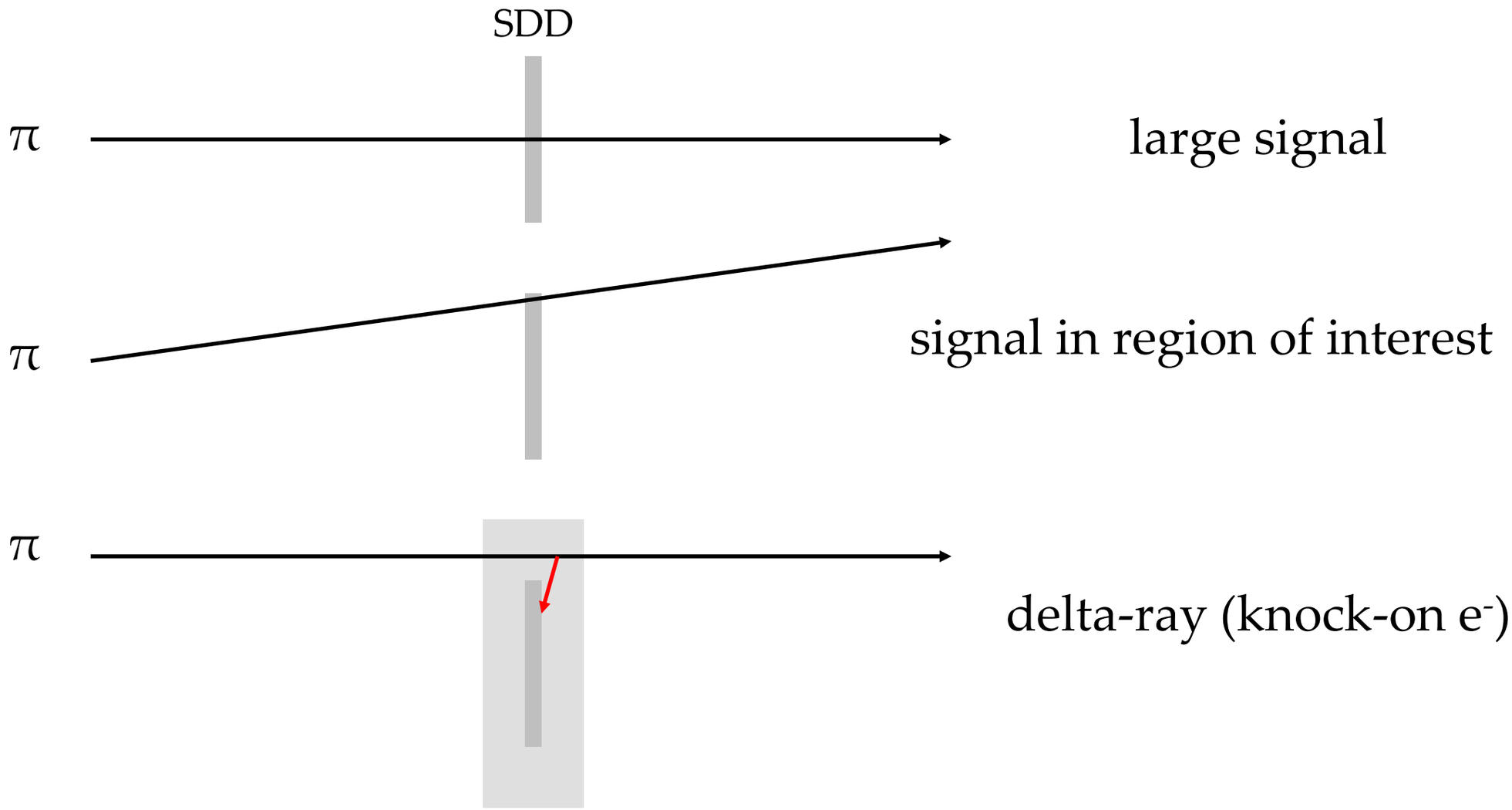

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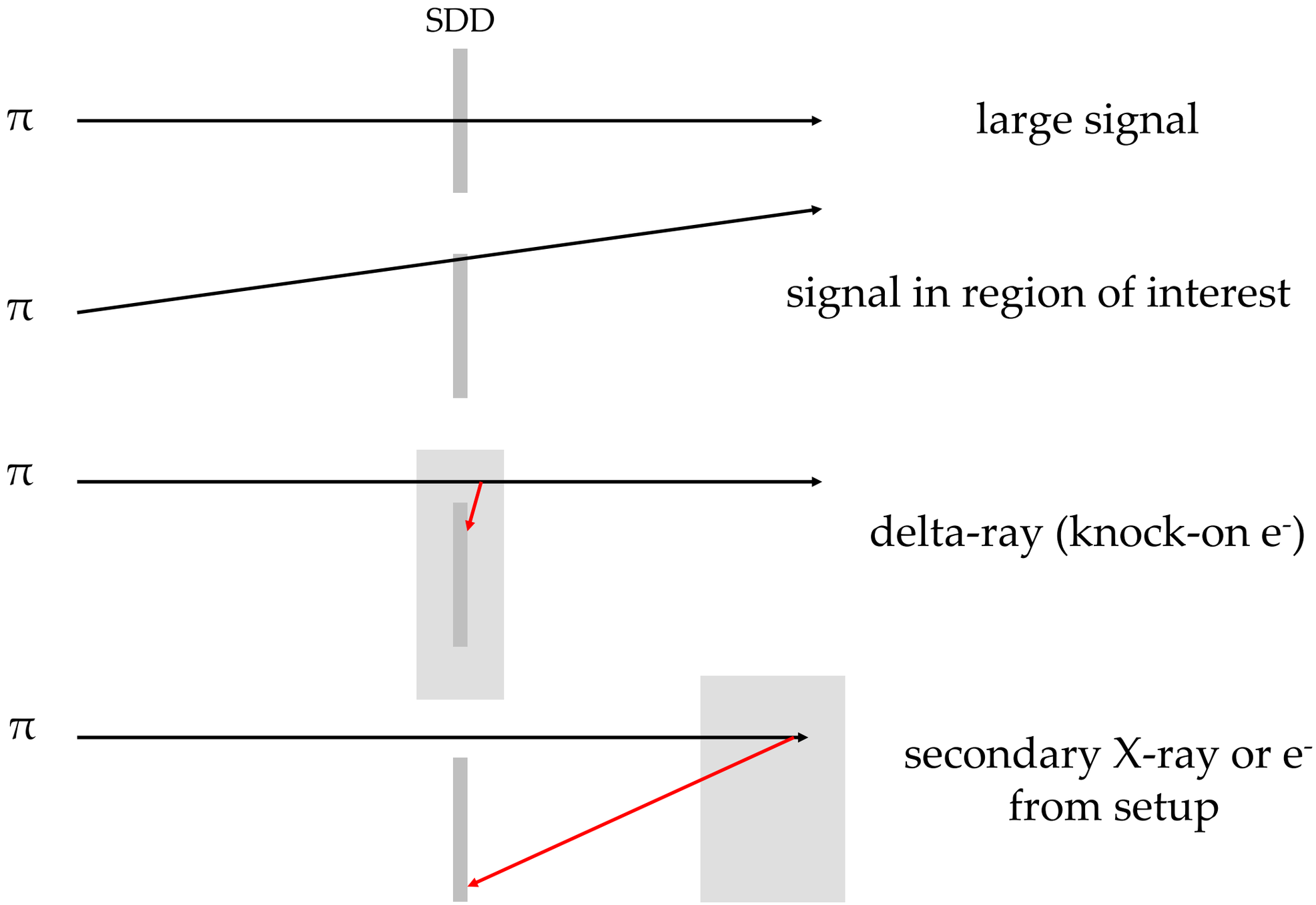


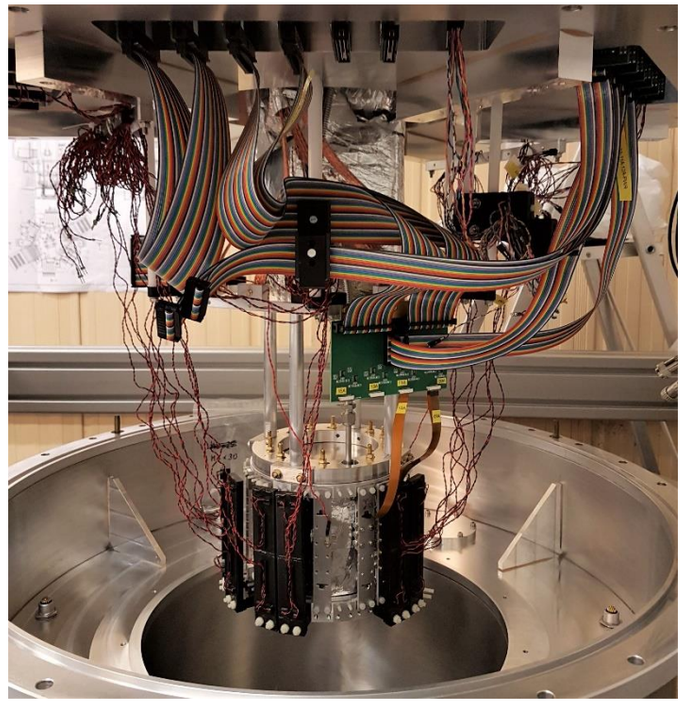
THE VETO-2 SYSTEM

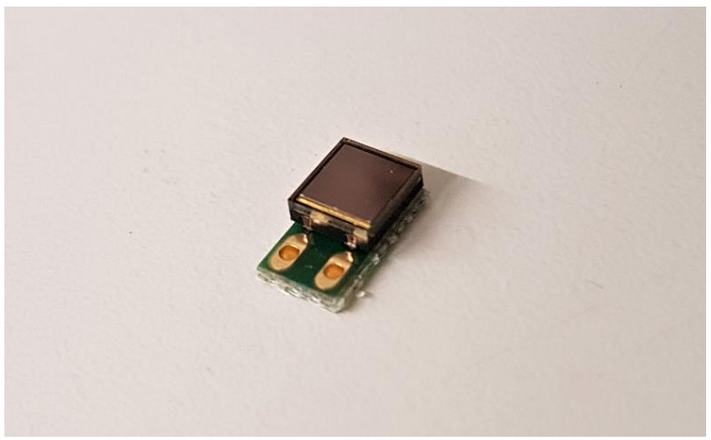
- 96 detector units:

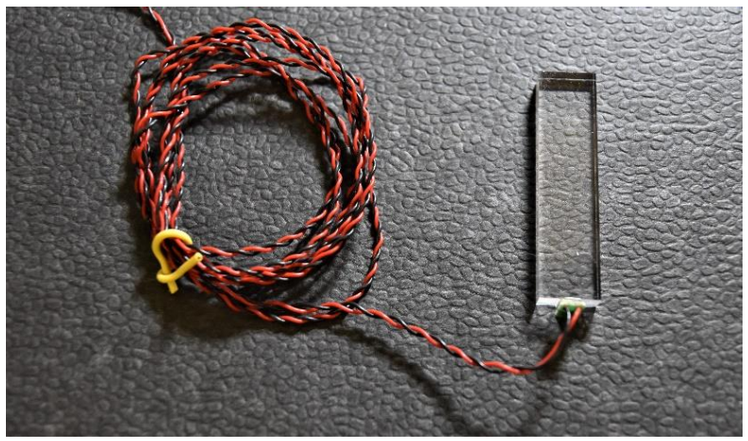
  Plastic scintillators with SiPM read-out

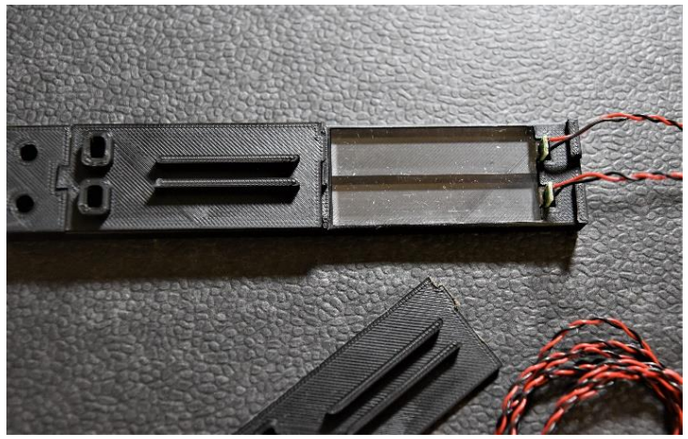
  Twisted pair cables

- Mounted directly behind SDDs



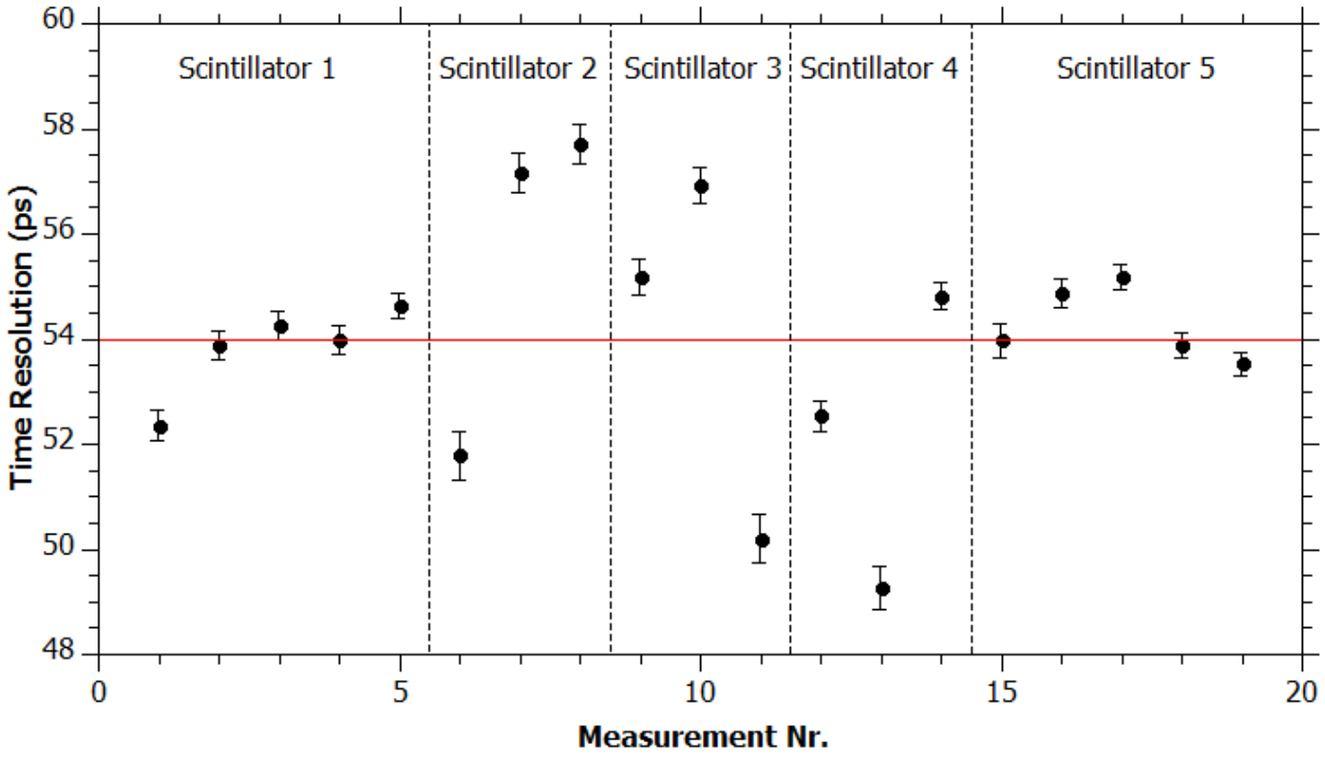


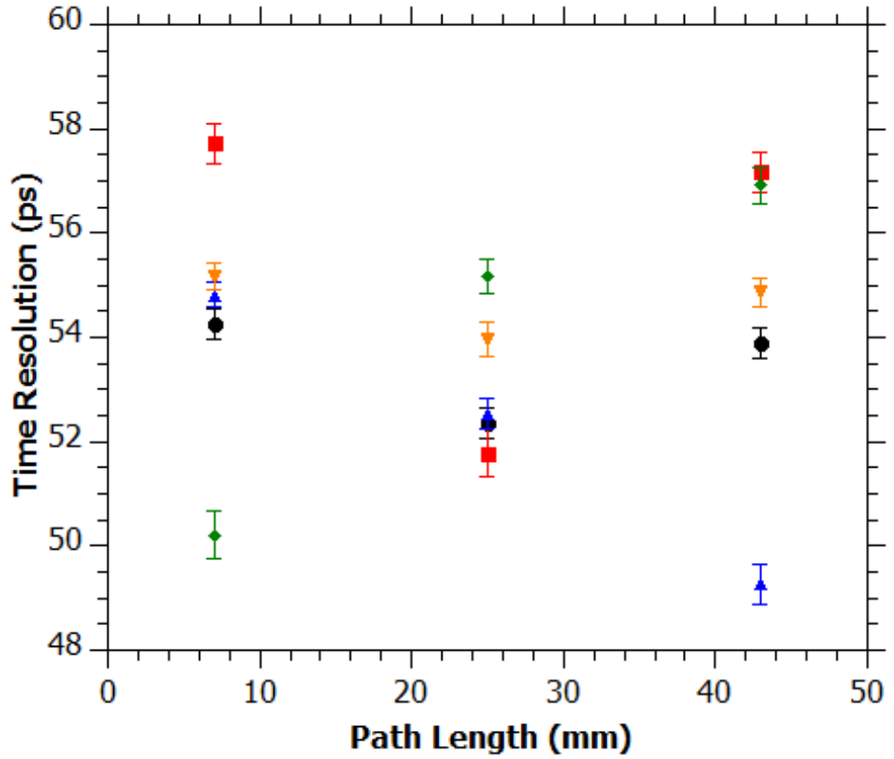




THE VETO-2 SYSTEM

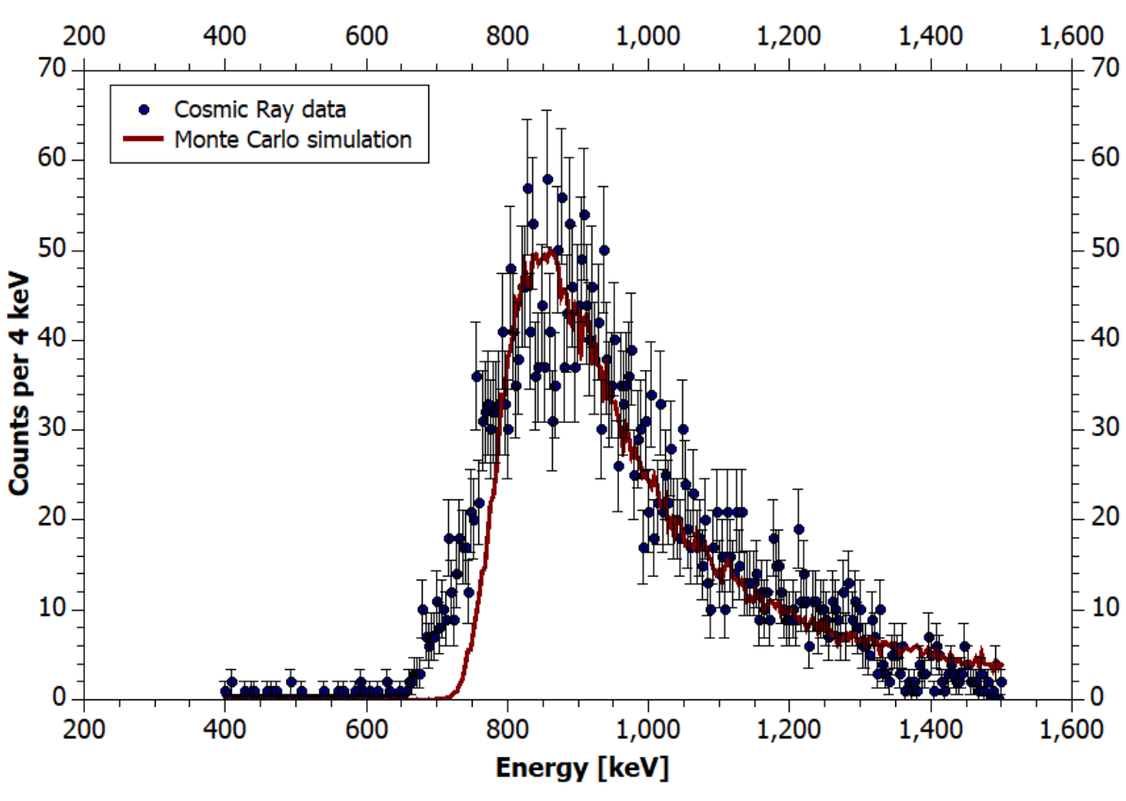
- **Time Resolution**
  - No systematic trend in position dependency
  - Average local time resolution (FWHM): **(54 ± 2) ps**
  - Average time resolution of Veto-2 system (FWHM): **(293 ± 45) ps**



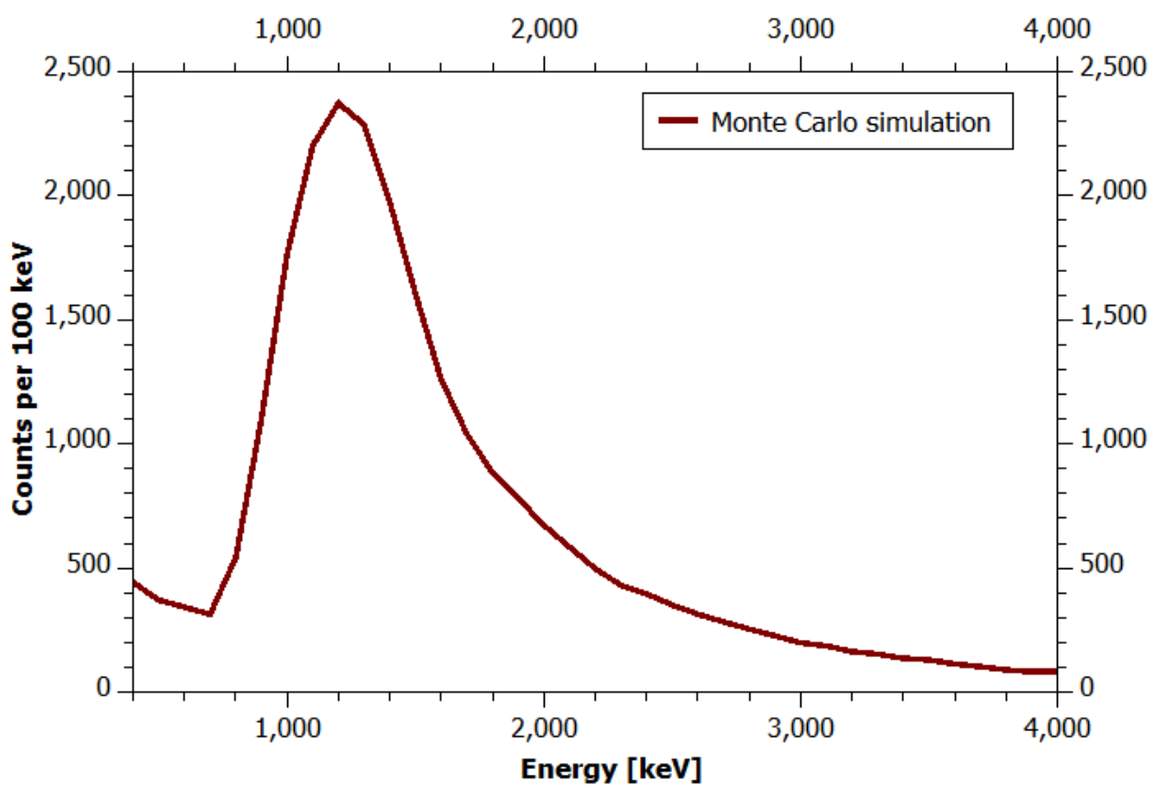


THE VETO-2 SYSTEM

- **Detection Efficiency**
  - Detection efficiency of **(99.1 ± 0.2)%**



Cosmic data + MC simulation



MC simulation: K^-N decay products

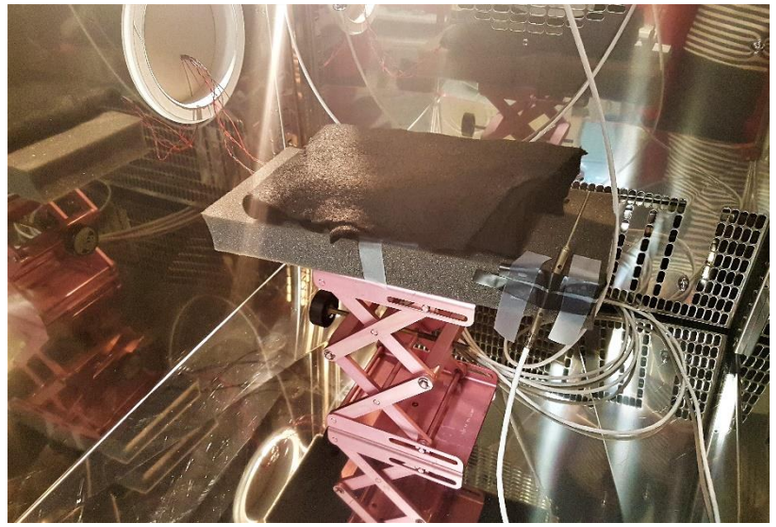
THE VETO-2 SYSTEM

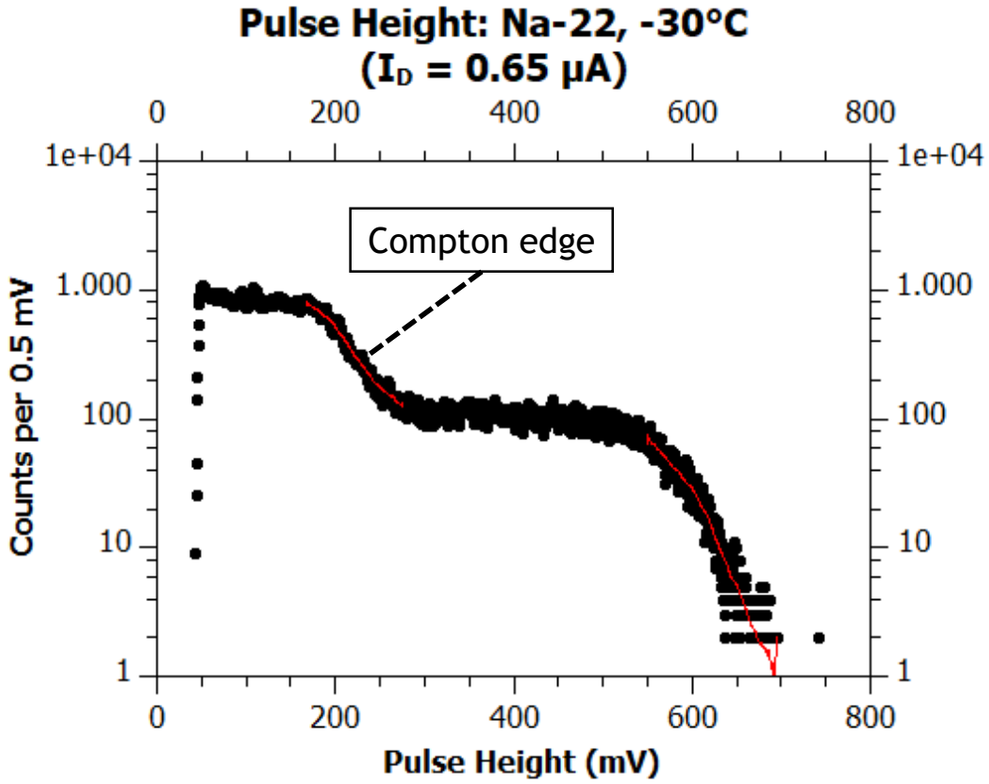
- **Temperature studies of Detectors**

  - SiPMs in climate chamber with Na-22 source

  - Amplification board outside at constant temperature

  - Pulse height spectra from T = -40°C to +40°C





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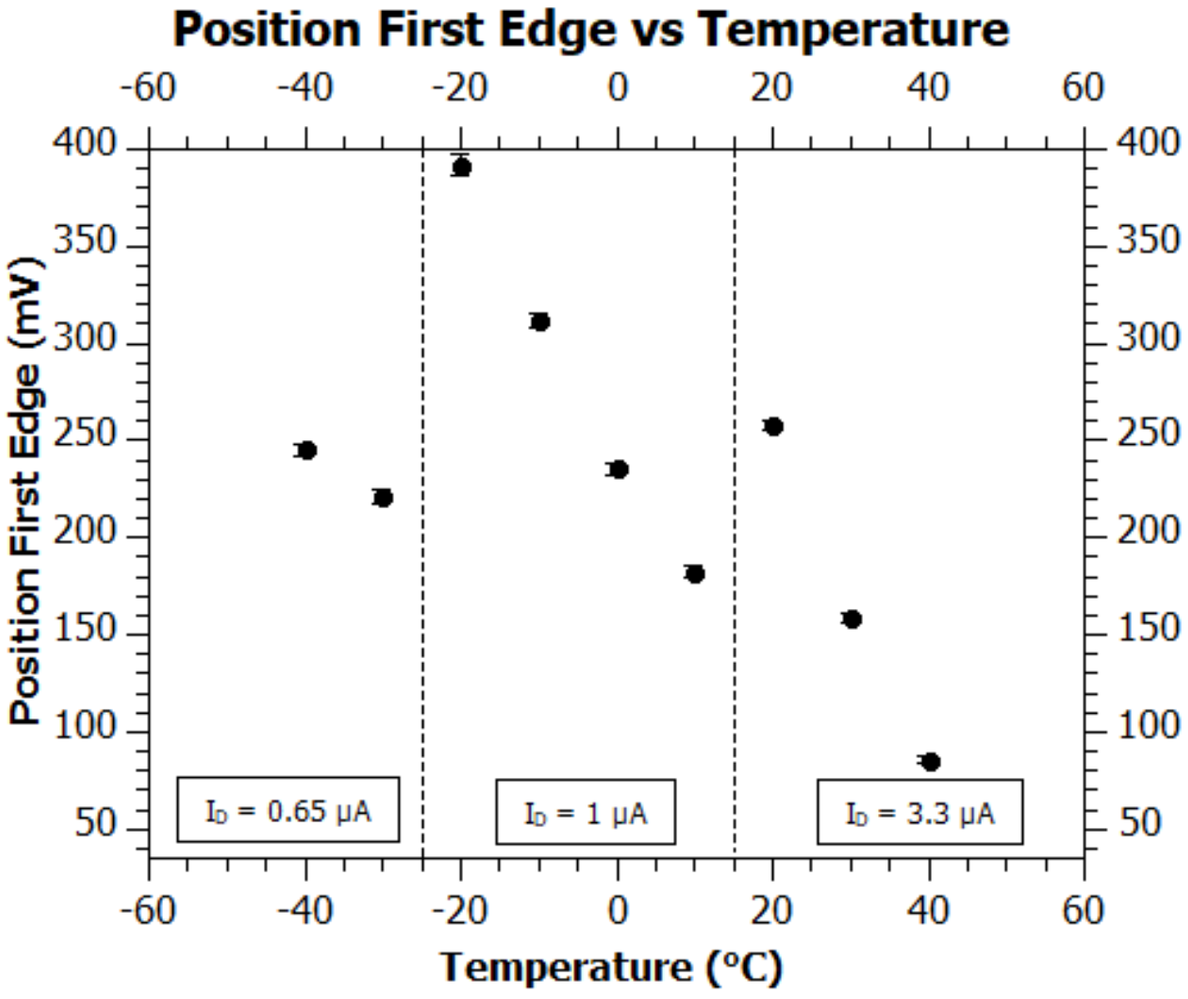
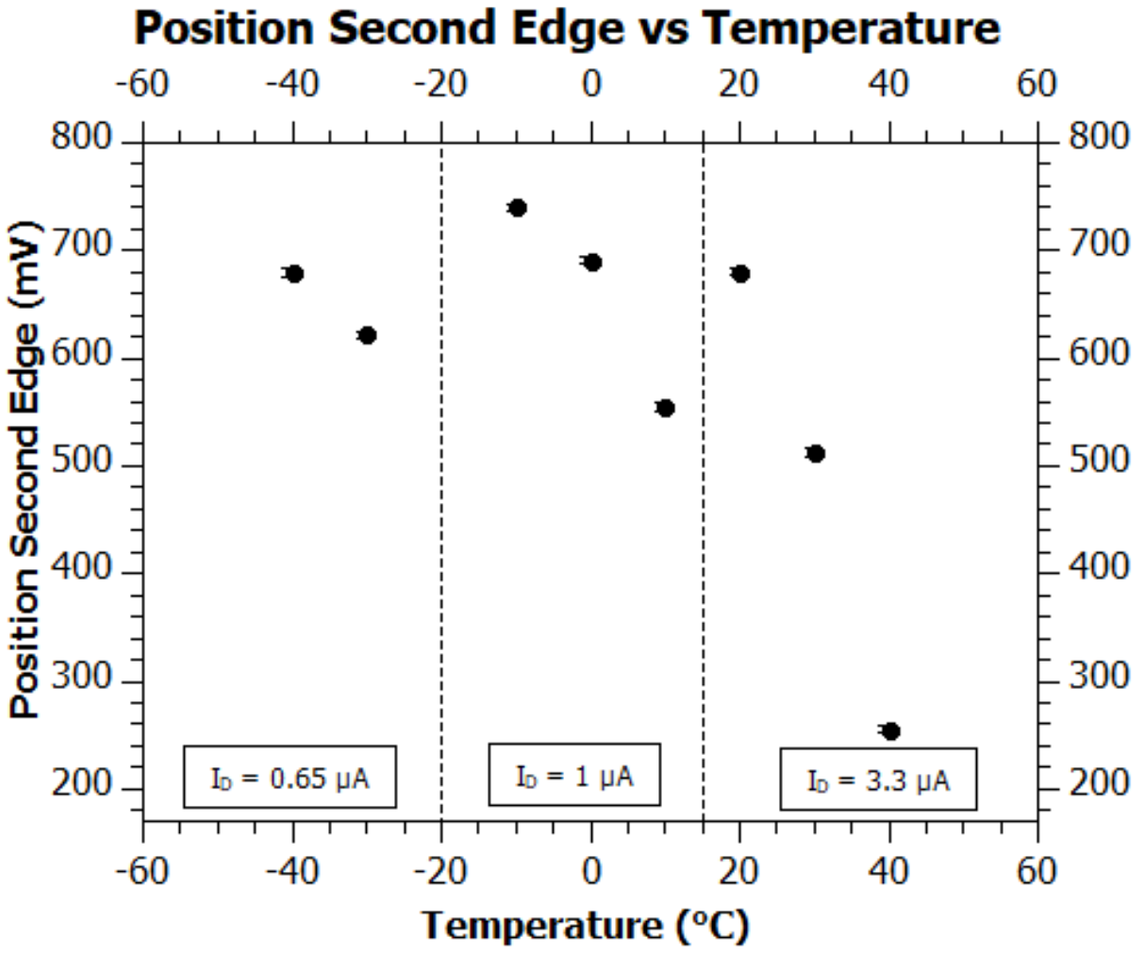
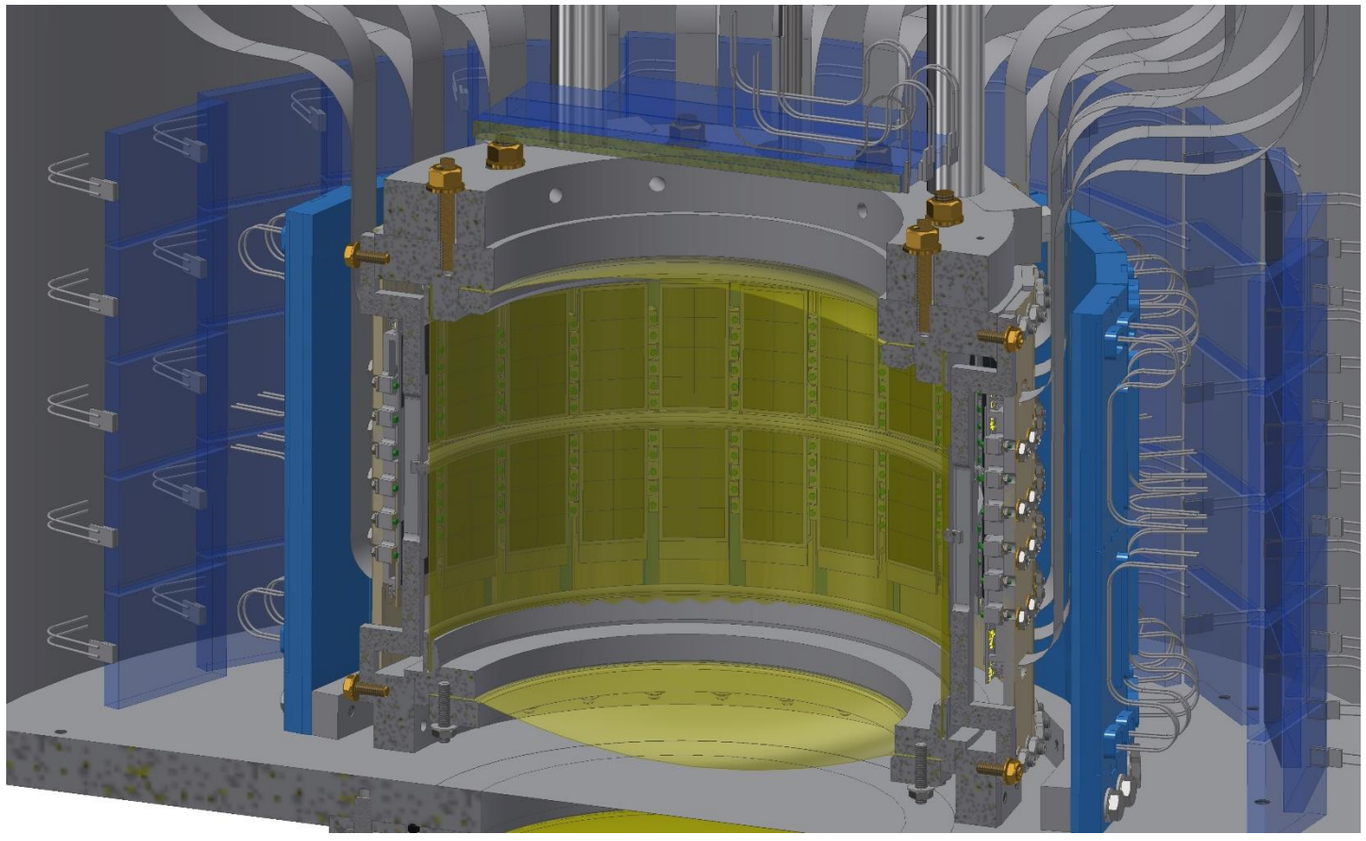


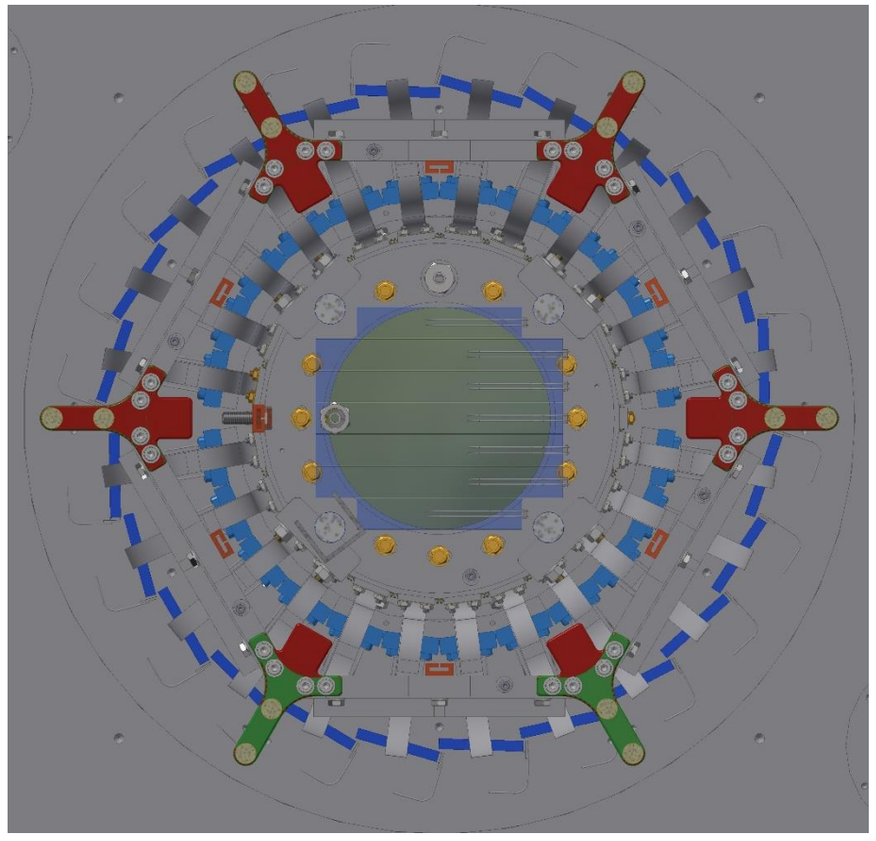


CONCLUSION & OUTLOOK

- **Conclusion:**
  - **Veto-1 system:**
    - Time resolution of (746 ± 53) ps
    - Detection efficiency of (96 ± 2)%
  - **Veto-2 system:**
    - Time resolution of (293 ± 45) ps
    - Detection efficiency of > 99%
- **Outlook:**
  - Update of Veto-2 system
  - SIDDHARTINO
  - Kaonic deuterium: 2020

CONCLUSION & OUTLOOK





- **Outlook:**
  - **Update of Veto-2 system**
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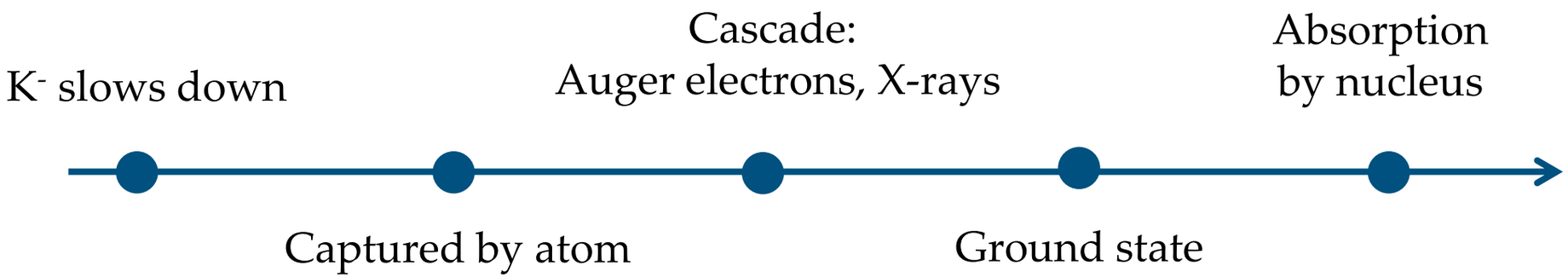
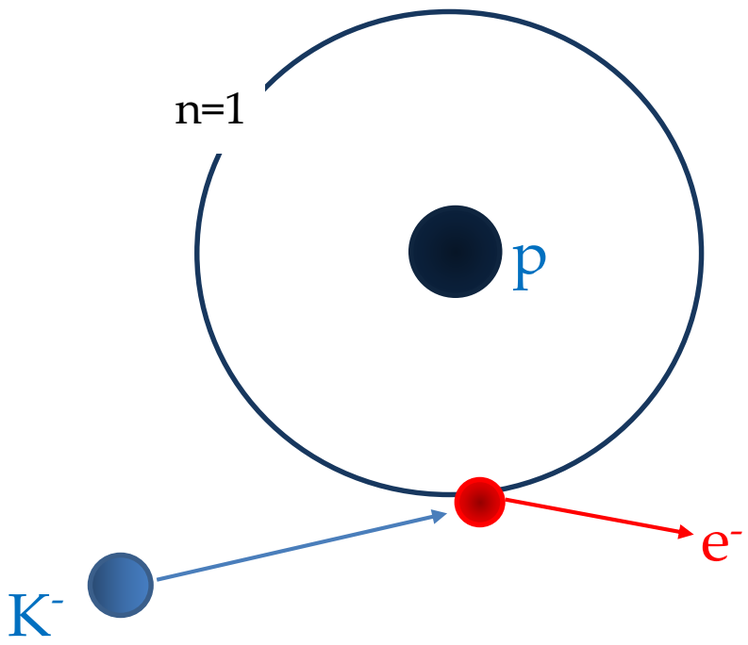
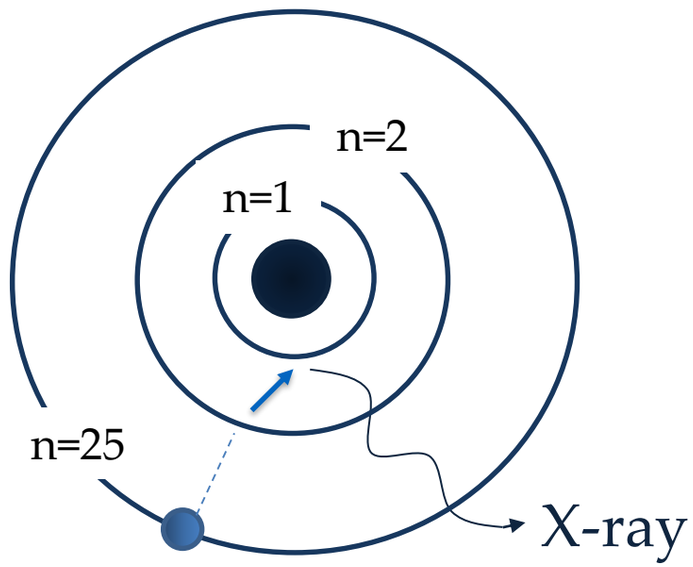
Attachment

FORMATION OF KAONIC ATOMS







SCATTERING LENGTHS

- **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 KN scattering lengths a_0, a_1:**

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

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

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

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

FORMATION OF KAONIC ATOMS

- **Properties:**
  - m_{K^-} : 493.677 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: $n_X \propto n_e\sqrt{\frac{m_X}{m_e}}$

SCATTERING LENGTHS

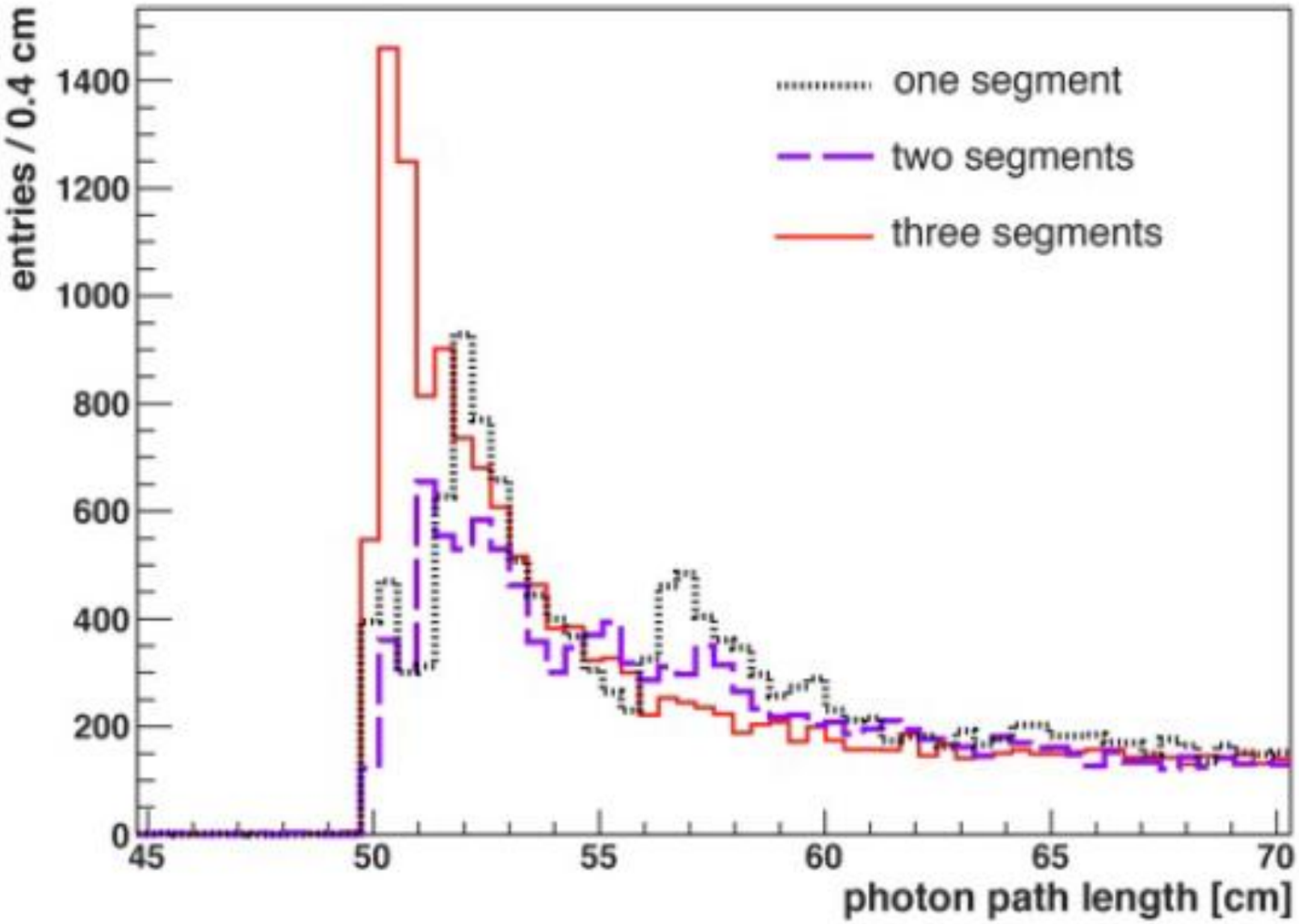
• Theoretical Predictions:

- 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)

THE VETO-1 SYSTEM

- **Detector Segmentation:**



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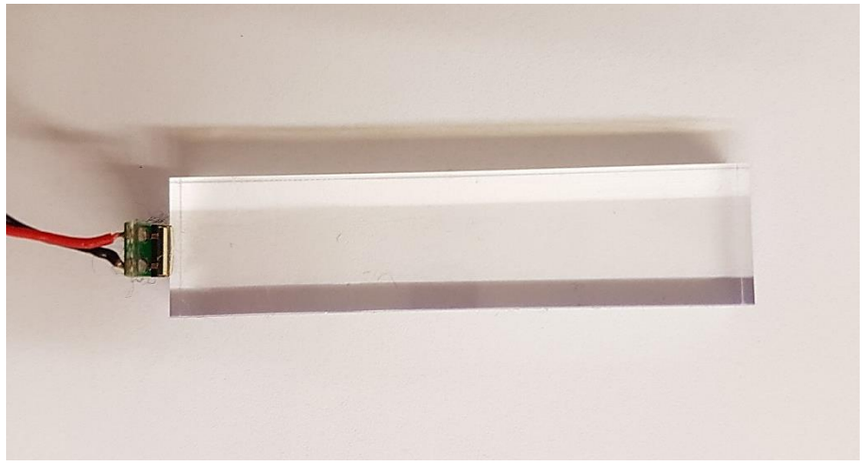
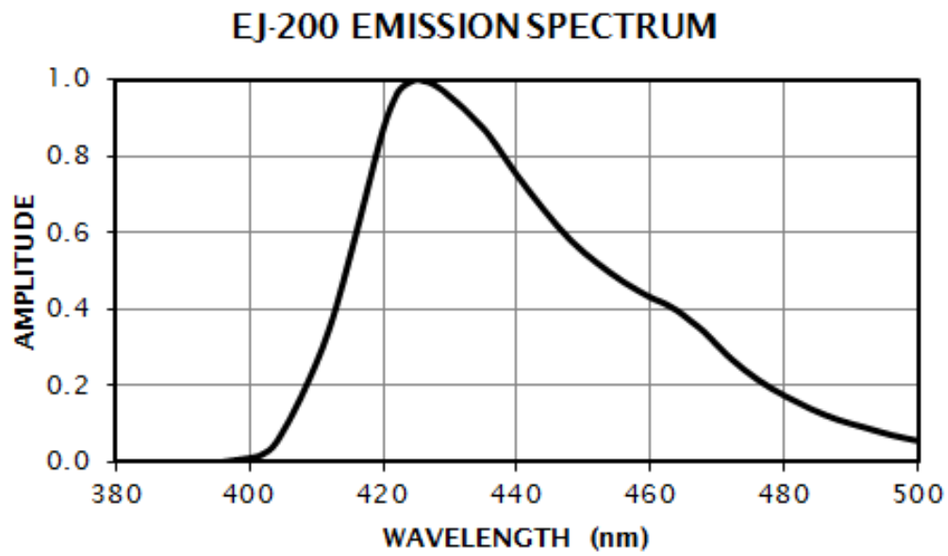
THE VETO-2 SYSTEM

- **SiPMs**
  - FBK-AdvanSiD (Trento)
  - Near-UV operation (420 nm)
  - Active area 4 x 4 mm^2
- **Scintillators**
  - EJ-200 plastic scintillators
  - 50 x 12 x 4 mm^3
  - Wavelength of maximum emission 425 nm



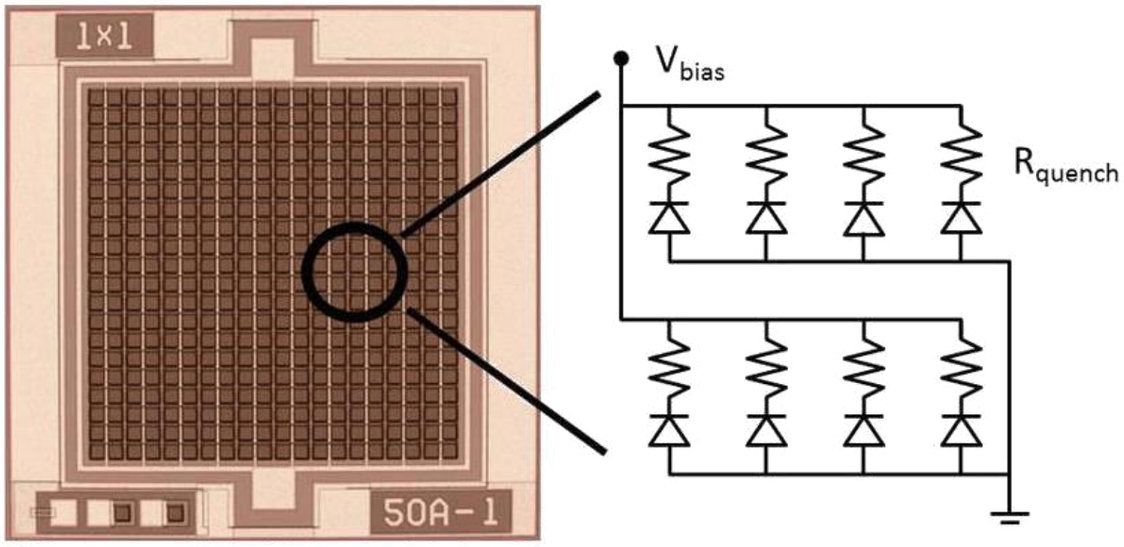


DETECTOR SETUP - SiPMs

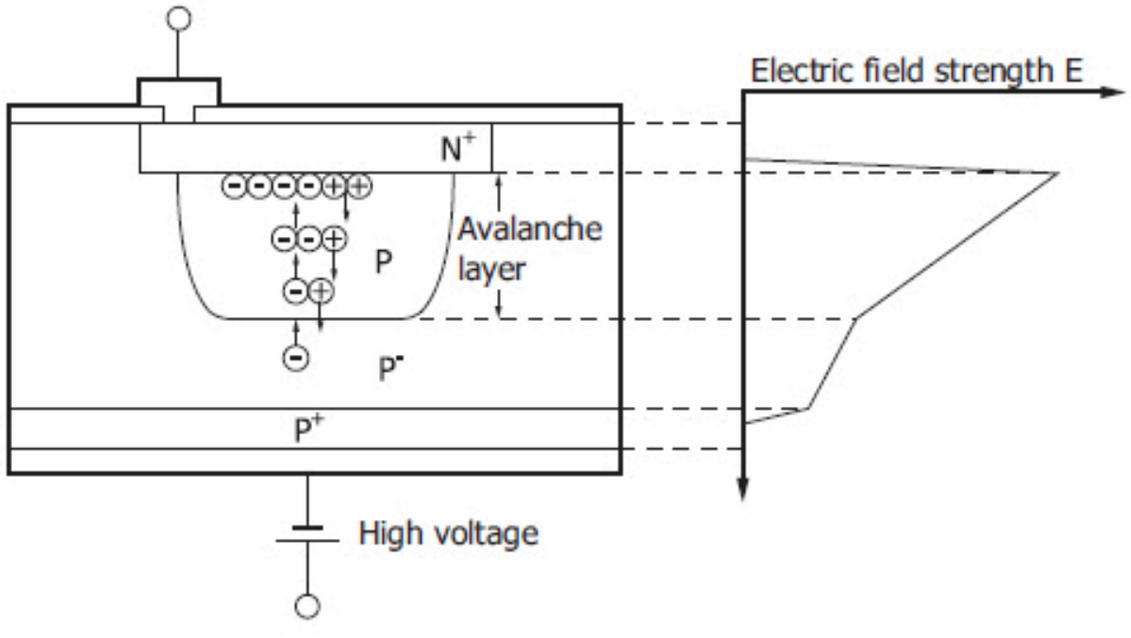
- **SiPM vs PMT:**

	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

DETECTOR SETUP - SiPMs



- Array of Geiger-mode avalanche photodiodes (G-APDs)
- Geiger-mode: high S/N-ratio
- Active quenching resistors

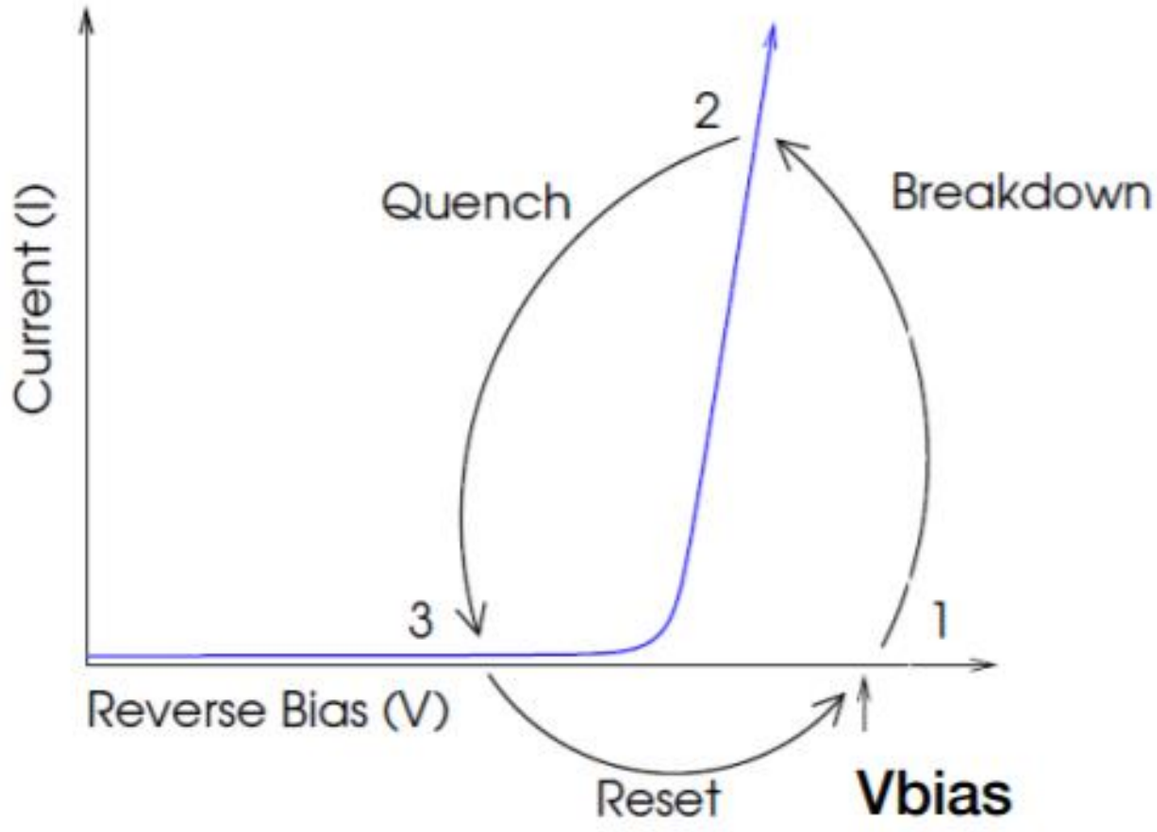


Hamamatsu microcell structure

https://www.ketek.net/sipm/technology/

https://www.ketek.net/sipm/technology/microcell-construction/

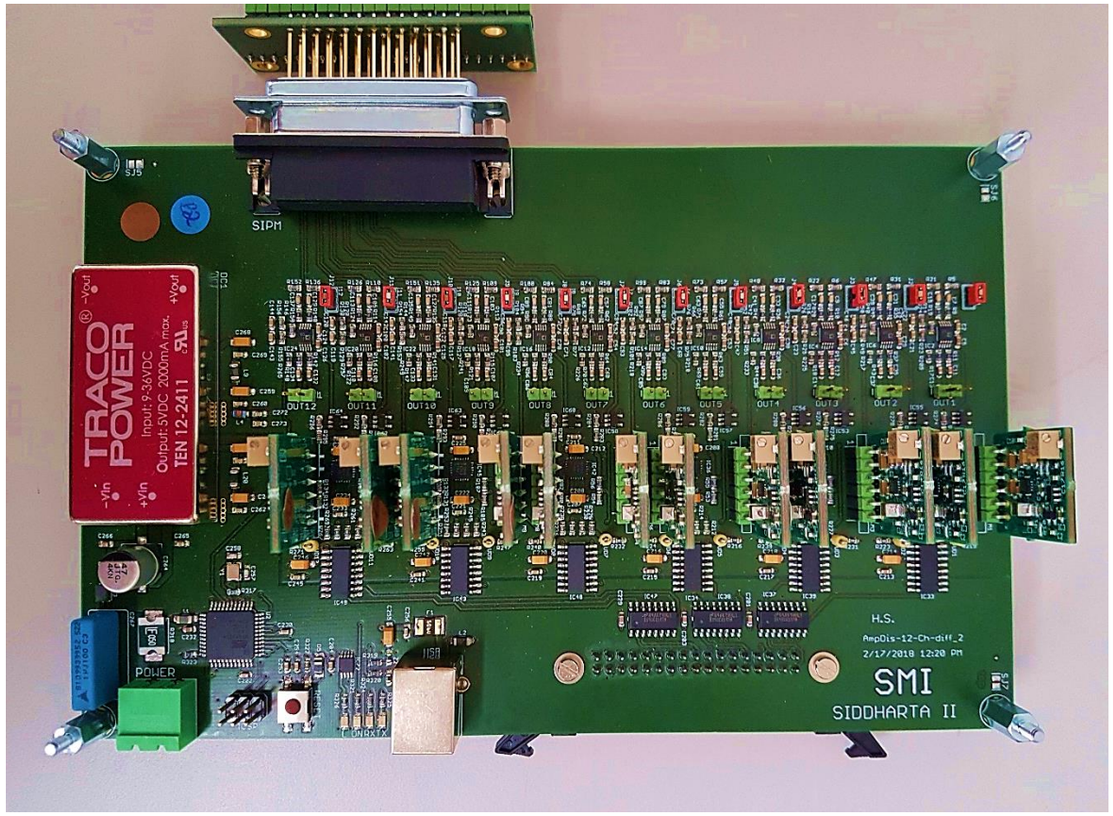
DETECTOR SETUP - SiPMs



https://www.sensl.com/downloads/ds/TN%20-%20Intro%20to%20SPM%20Tech.pdf

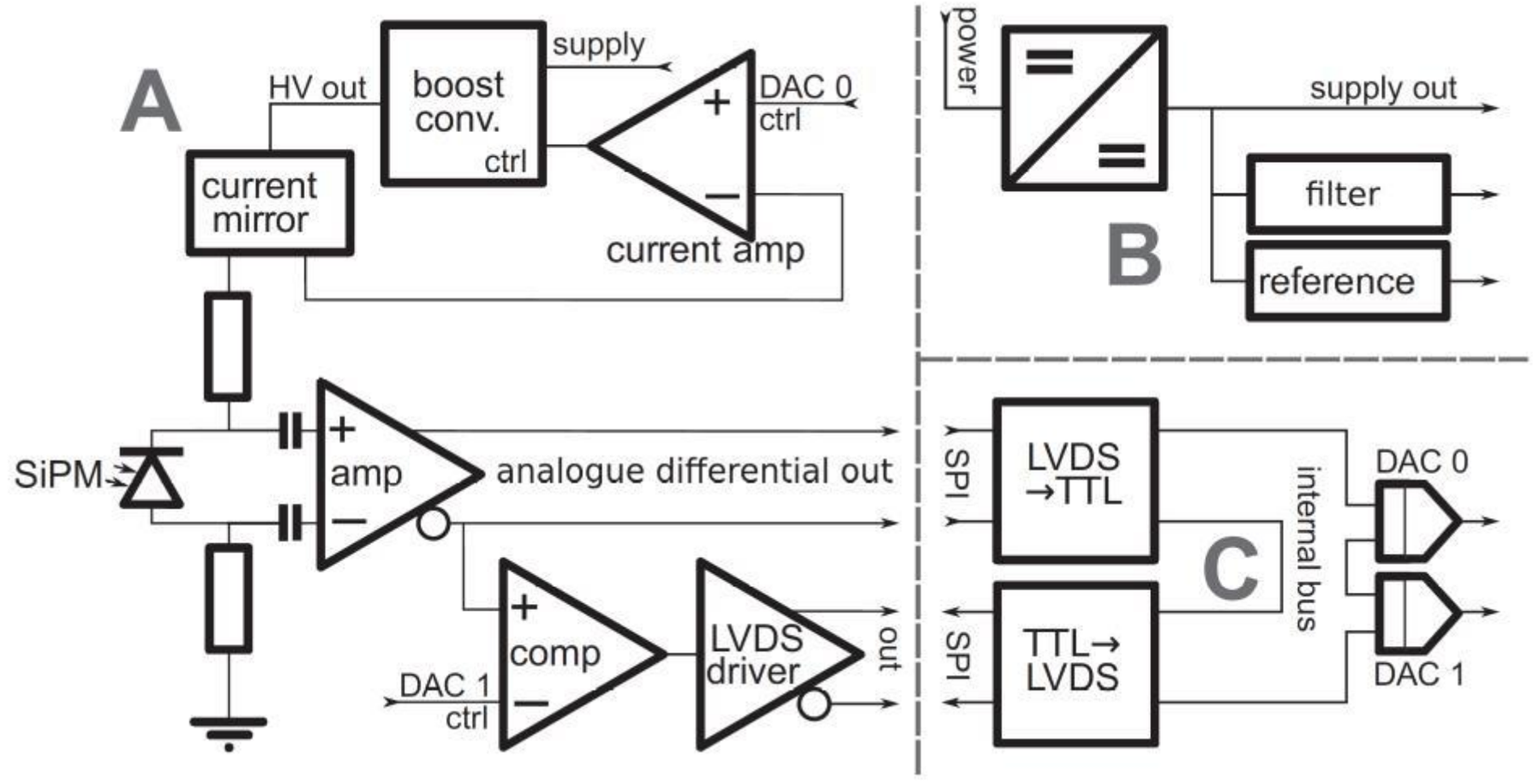
THE VETO-2 SYSTEM

• Amplification Boards



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

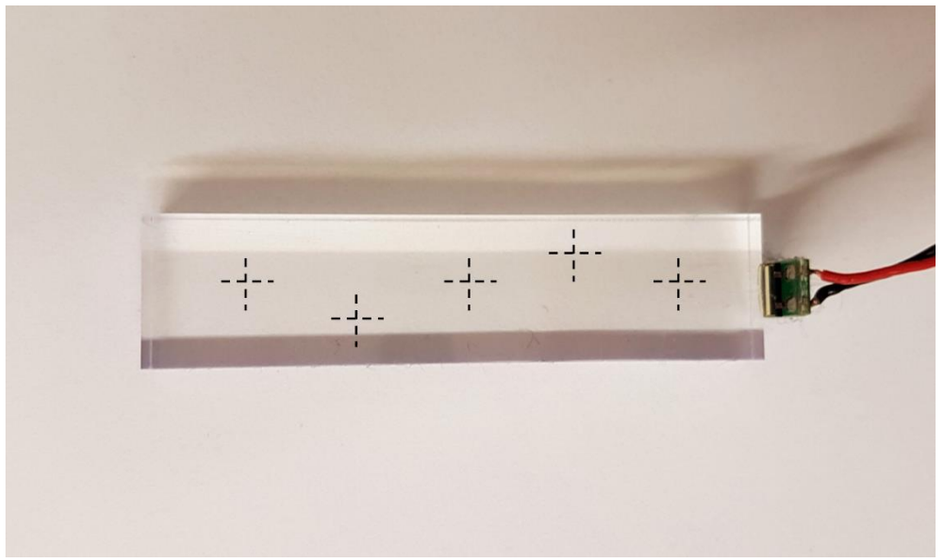
THE VETO-2 SYSTEM

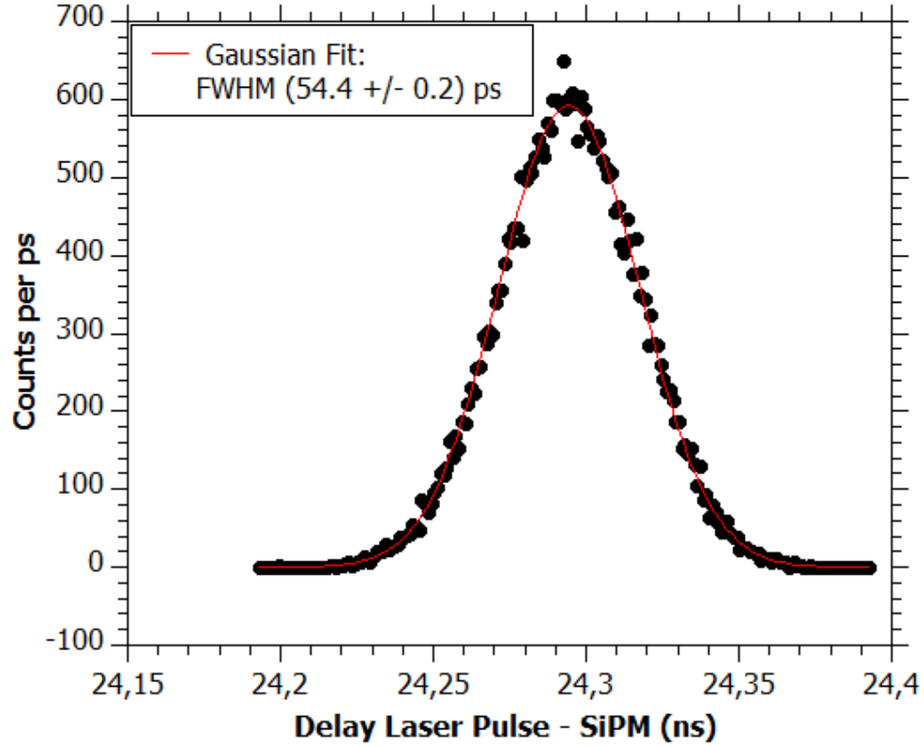


Sauerzopf C. et al. (2016) Nucl. Instrum. Meth. Phys. Res. A 819 163–166

THE VETO-2 SYSTEM

- **Time Resolution**
  - Diode laser (450 nm) on three or five positions
  - Time delay between laser pulse – SiPM signal

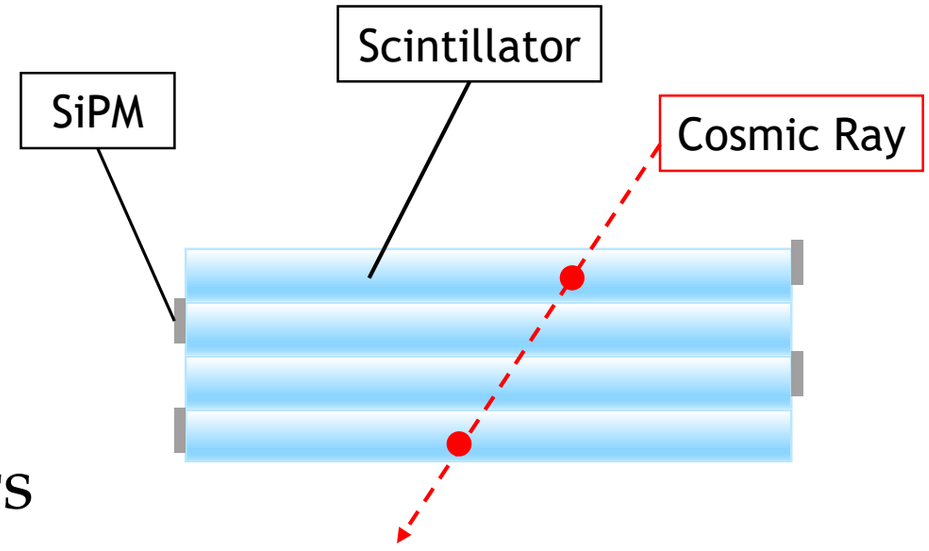




THE VETO-2 SYSTEM

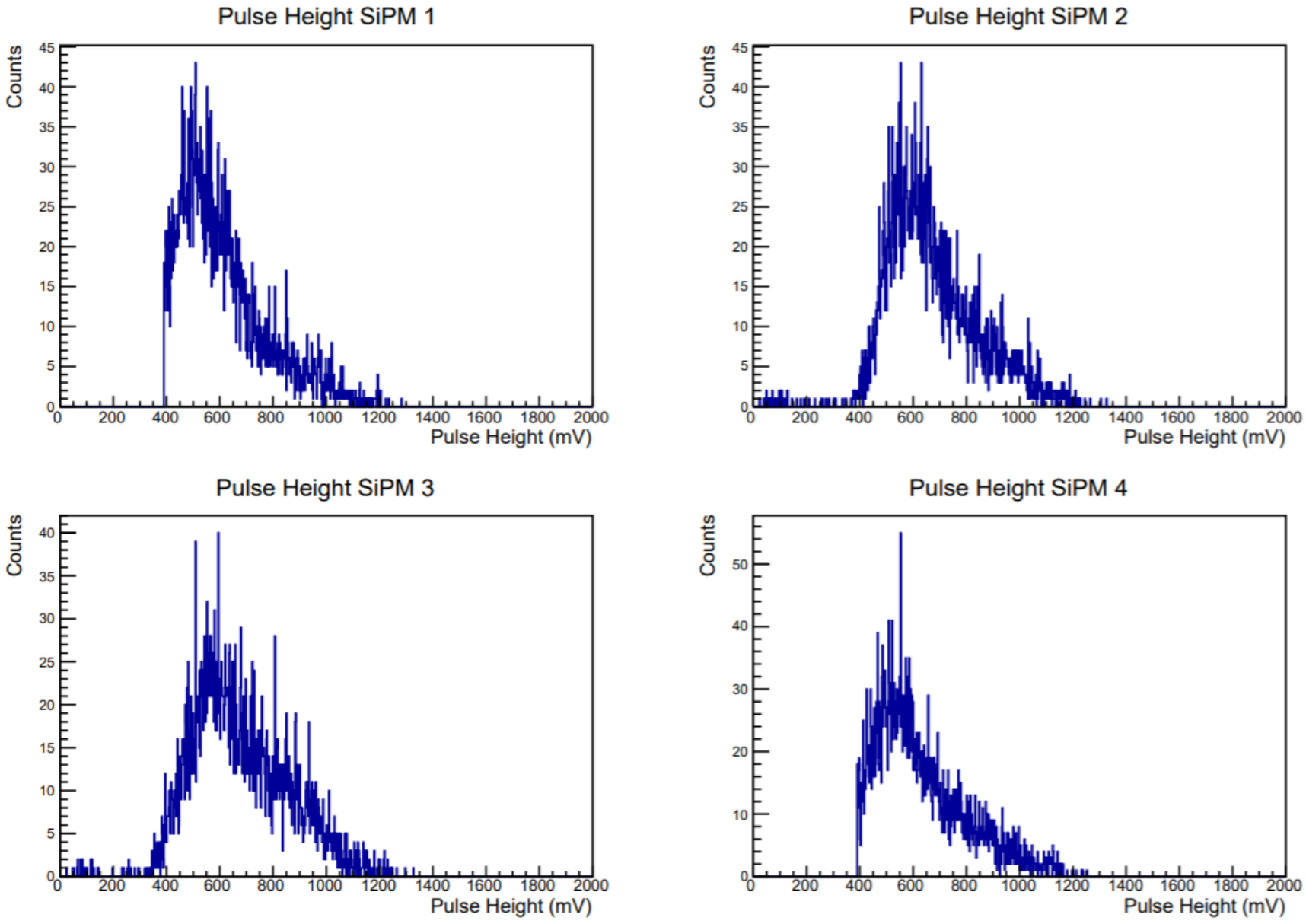
- **Detection Efficiency**

  - Cosmic rays
  - Stack of four scintillator-SiPM tiles
  - Pulse height spectra
  - Coincidence between outer detectors



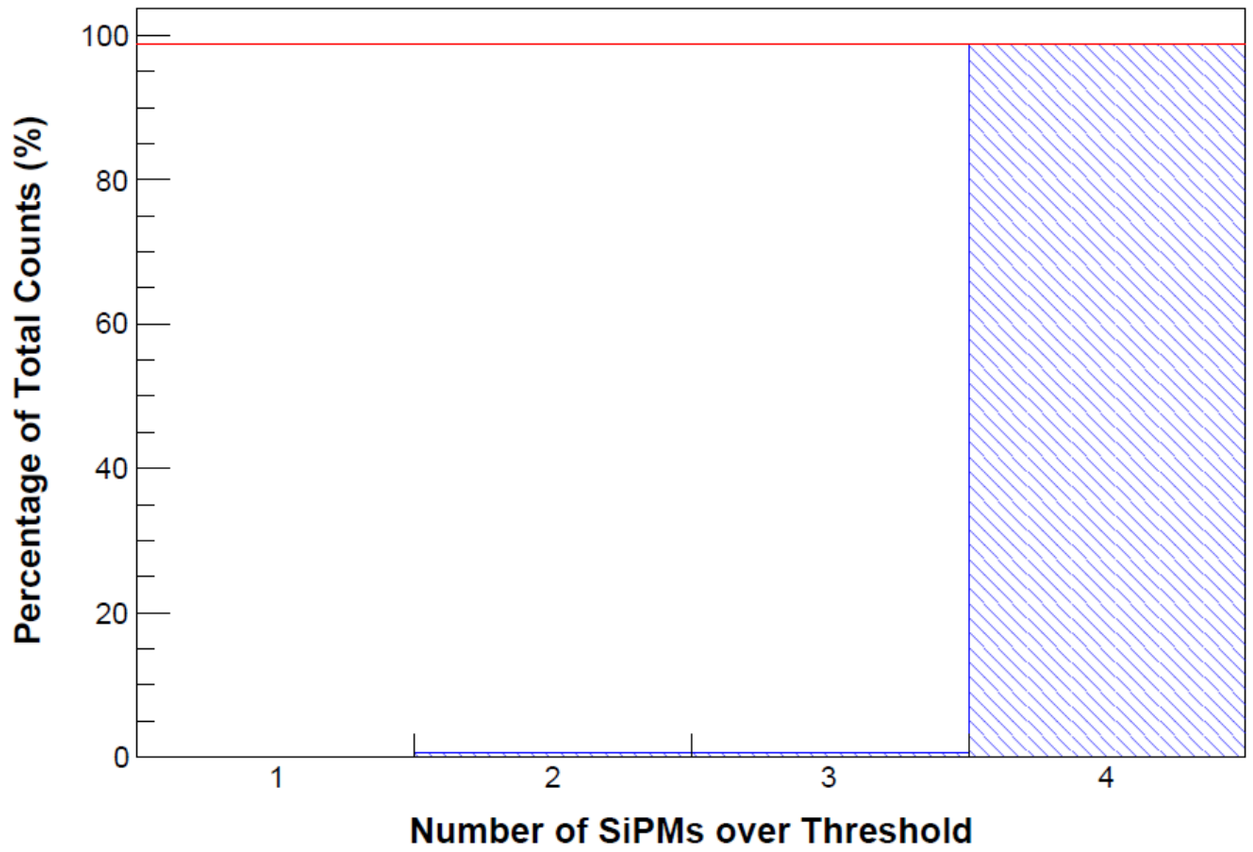
THE VETO-2 SYSTEM

- **Detection Efficiency**



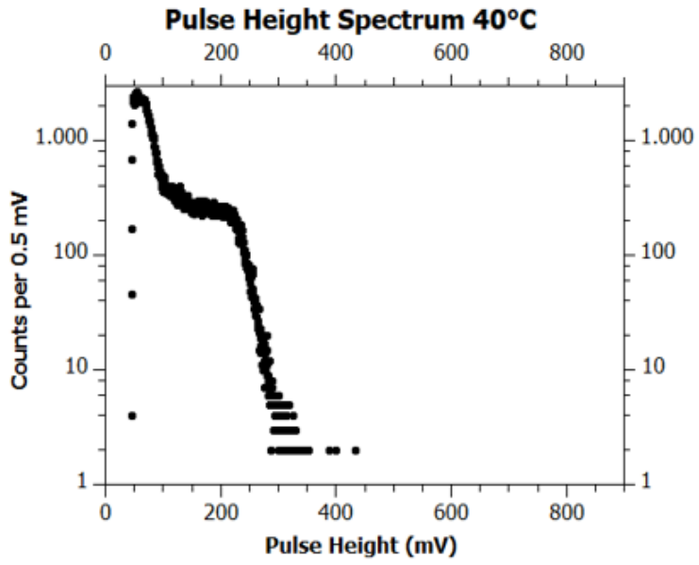
THE VETO-2 SYSTEM

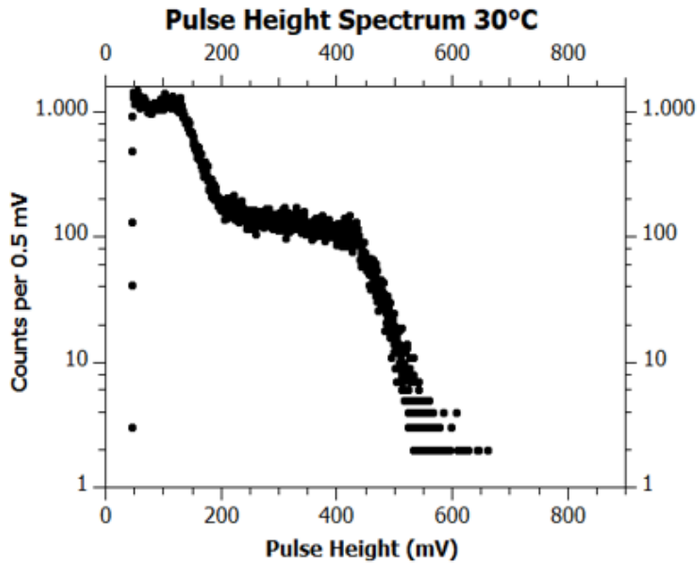
- **Detection Efficiency**
  - Multiplicity: (98.8 ± 0.2)% for four detectors

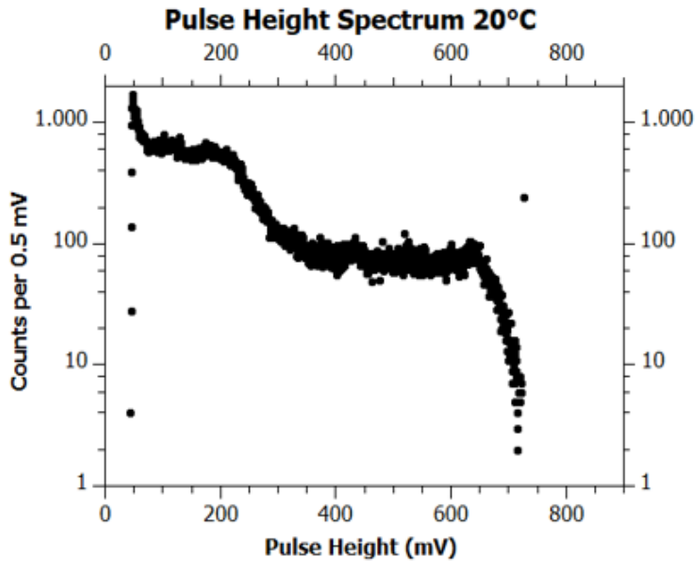


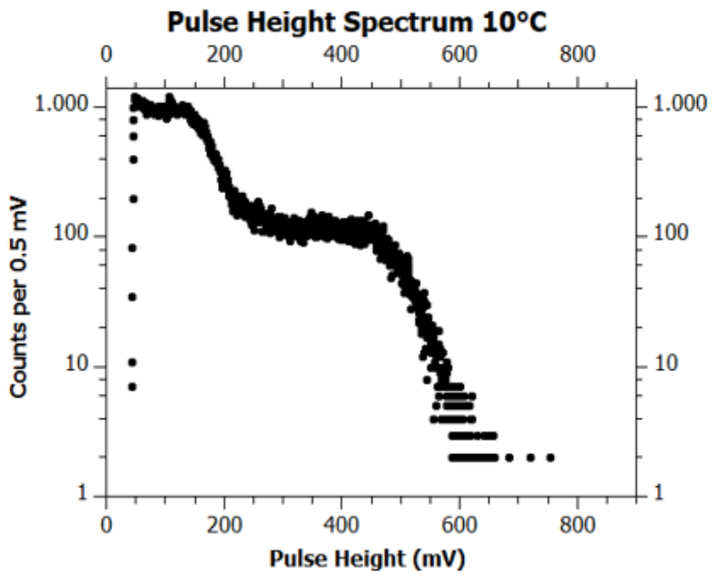
THE VETO-2 SYSTEM

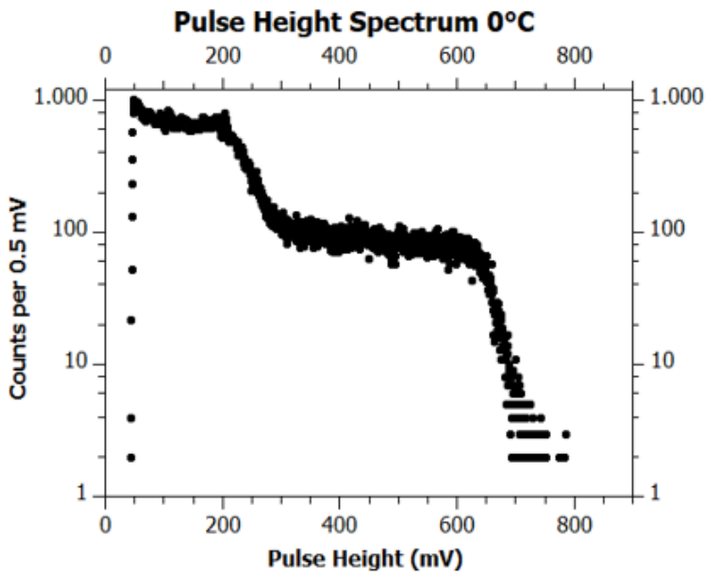
- **Temperature studies of Detectors**





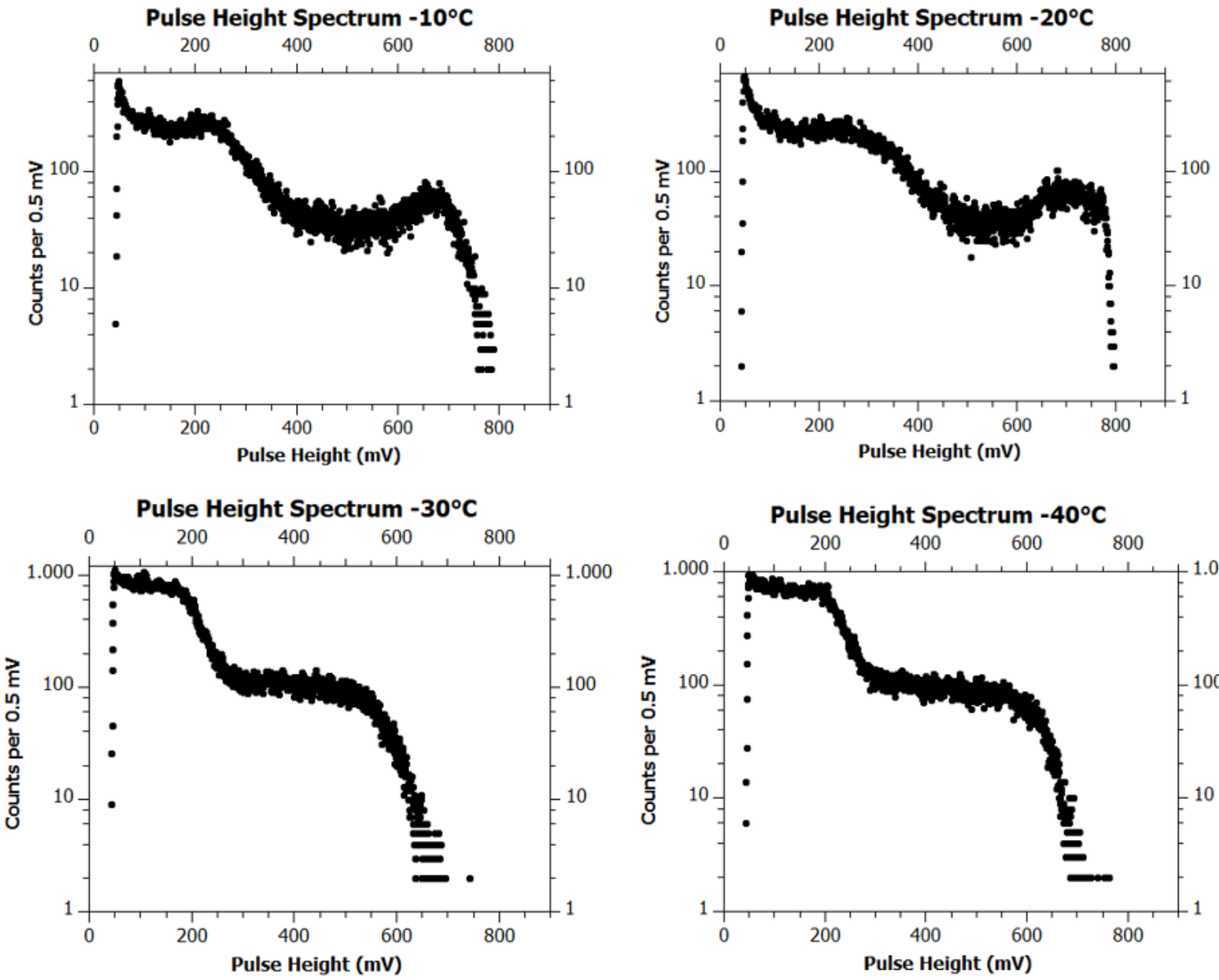






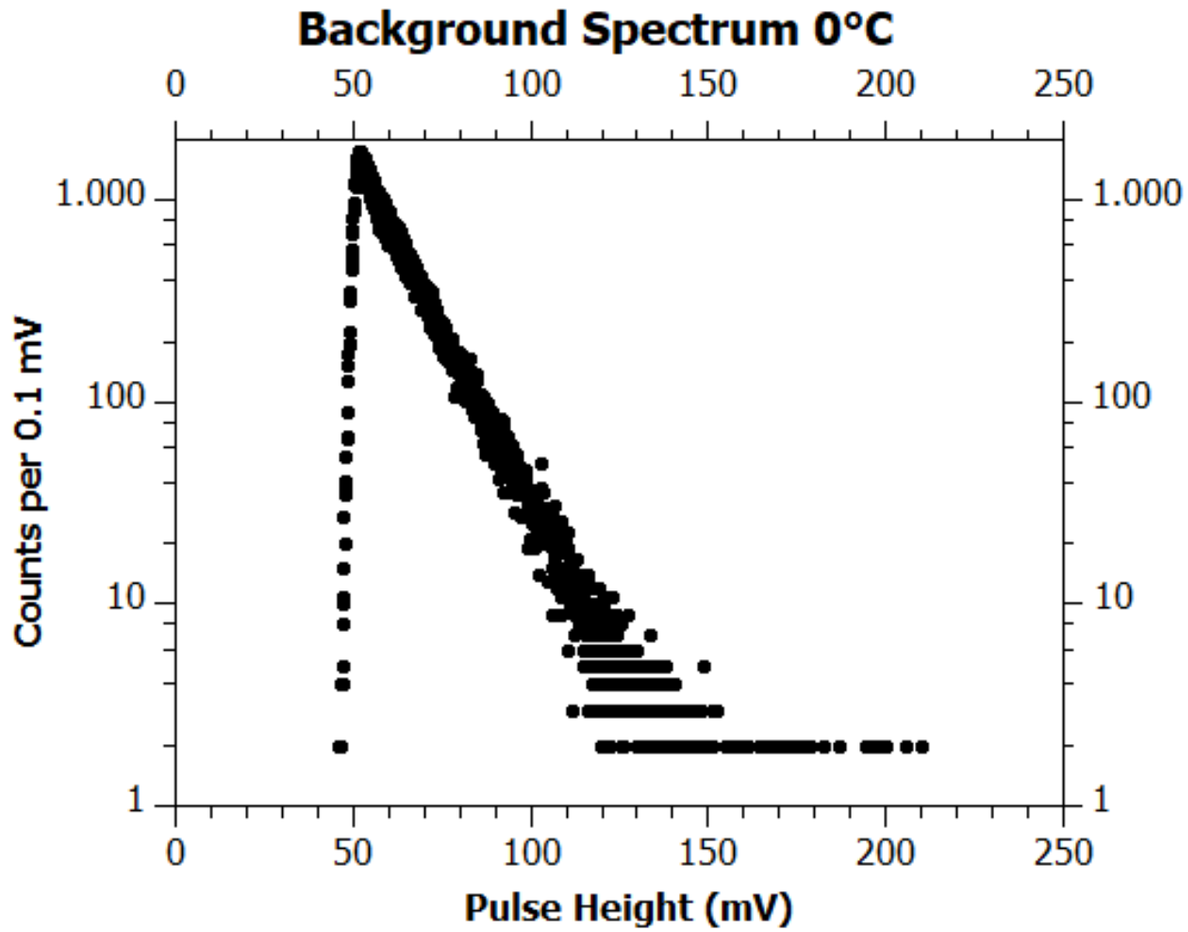
THE VETO-2 SYSTEM

- **Temperature studies of Detectors**



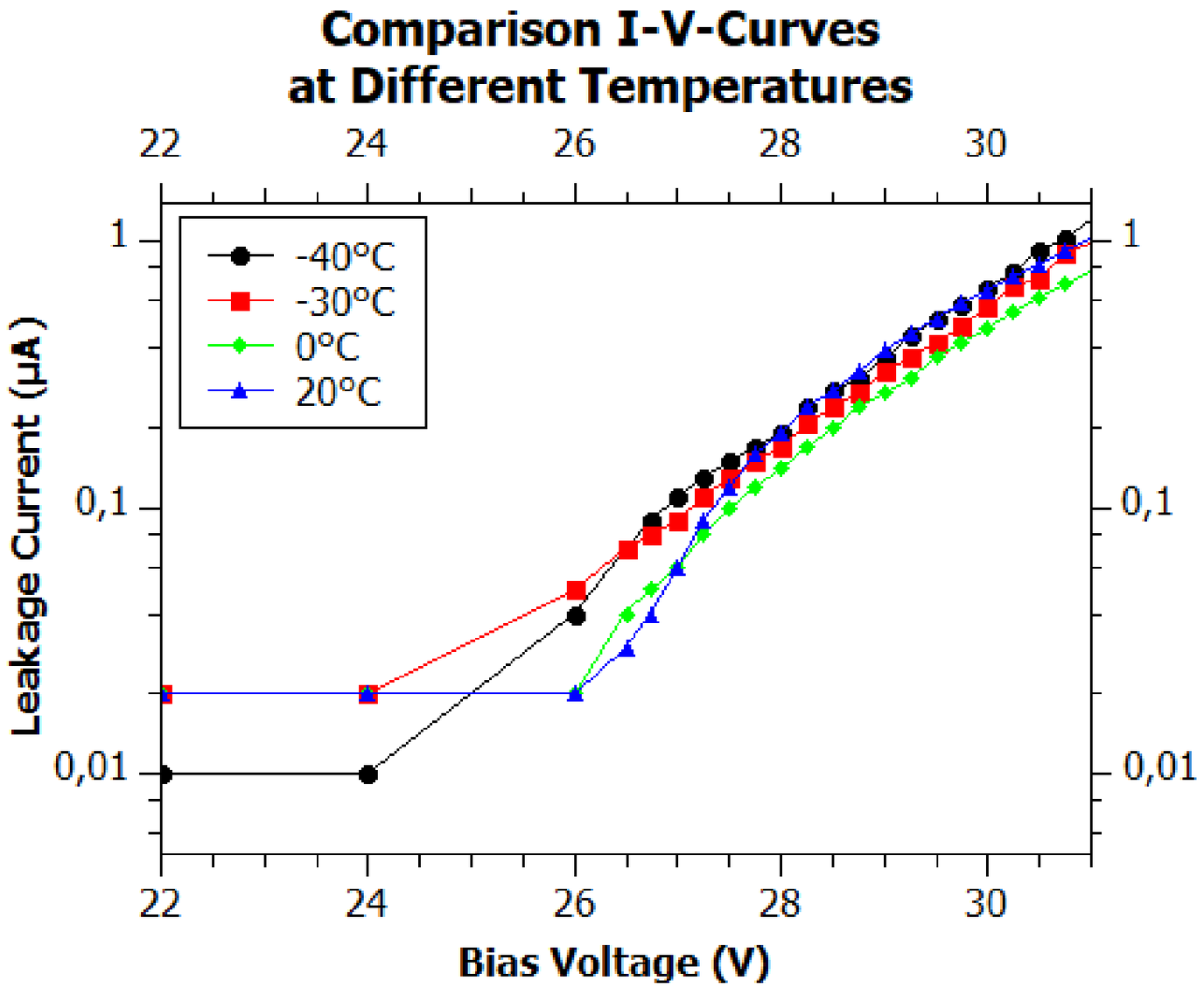
THE VETO-2 SYSTEM

- **Temperature studies of Detectors**



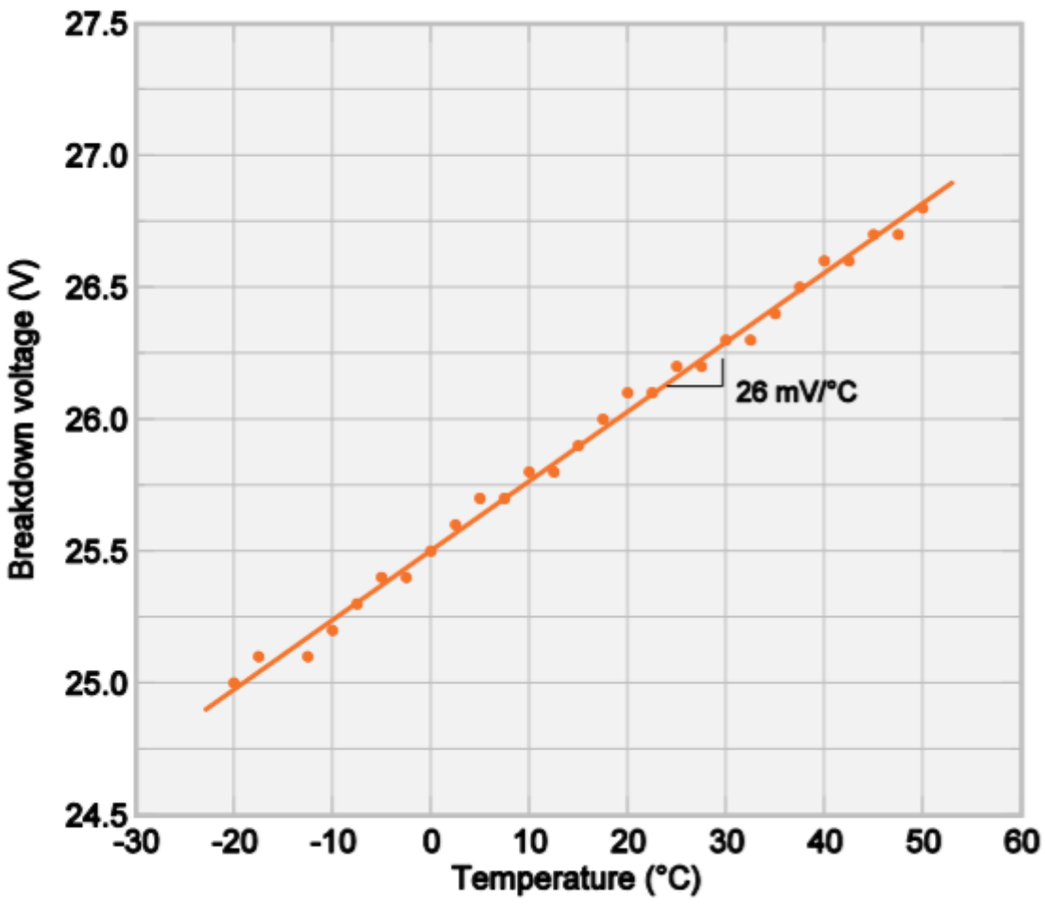
THE VETO-2 SYSTEM

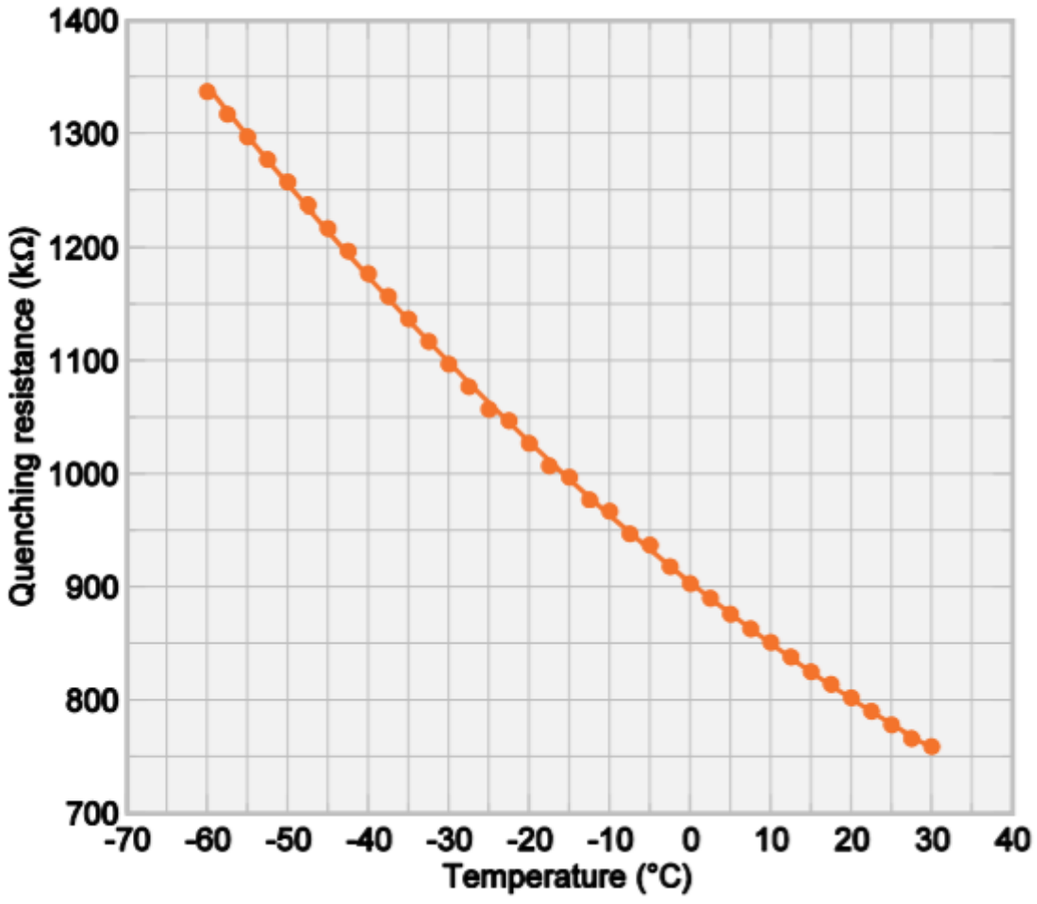
- **Temperature studies of Detectors**



THE VETO-2 SYSTEM

- **Temperature studies of Detectors**

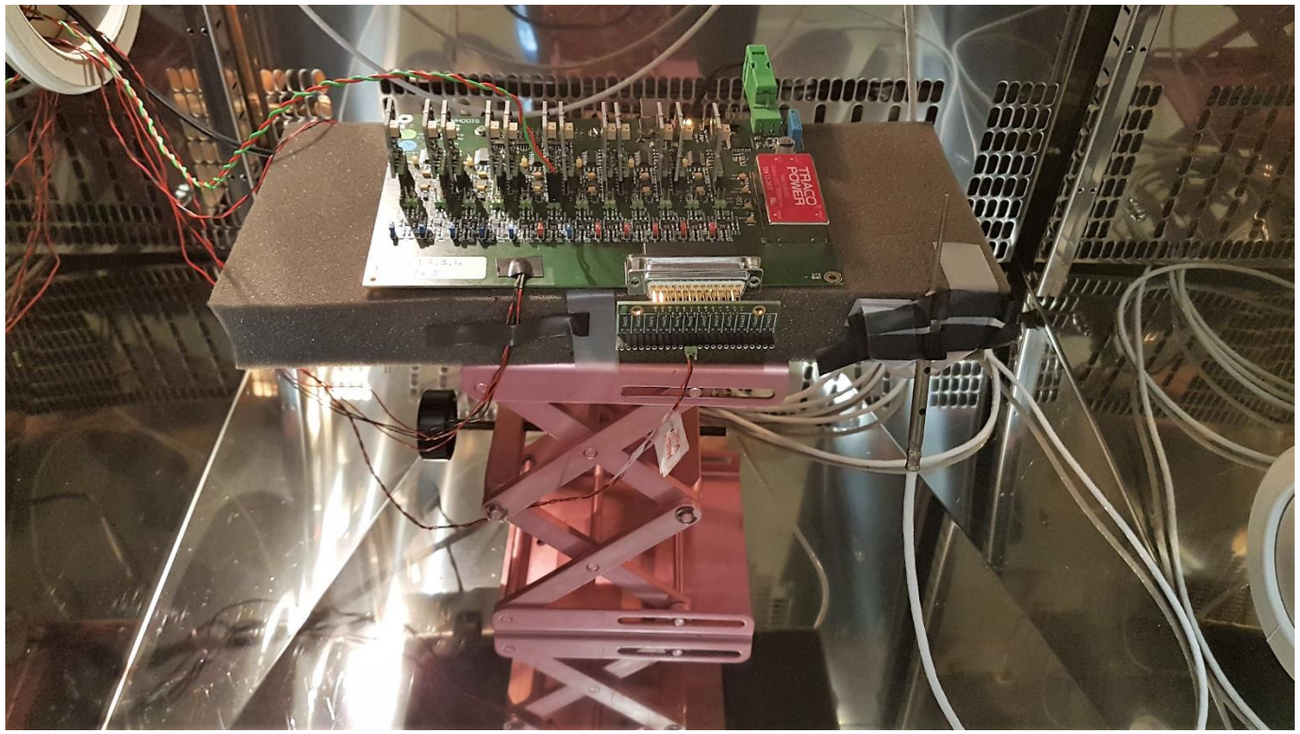




AdvanSiD. NUV SiPMs Datasheet (Rev.9). www.advansid.com/products/product-detail/asd-rgb-nuv-4s-p (Accessed 12.03.2019)

THE VETO-2 SYSTEM

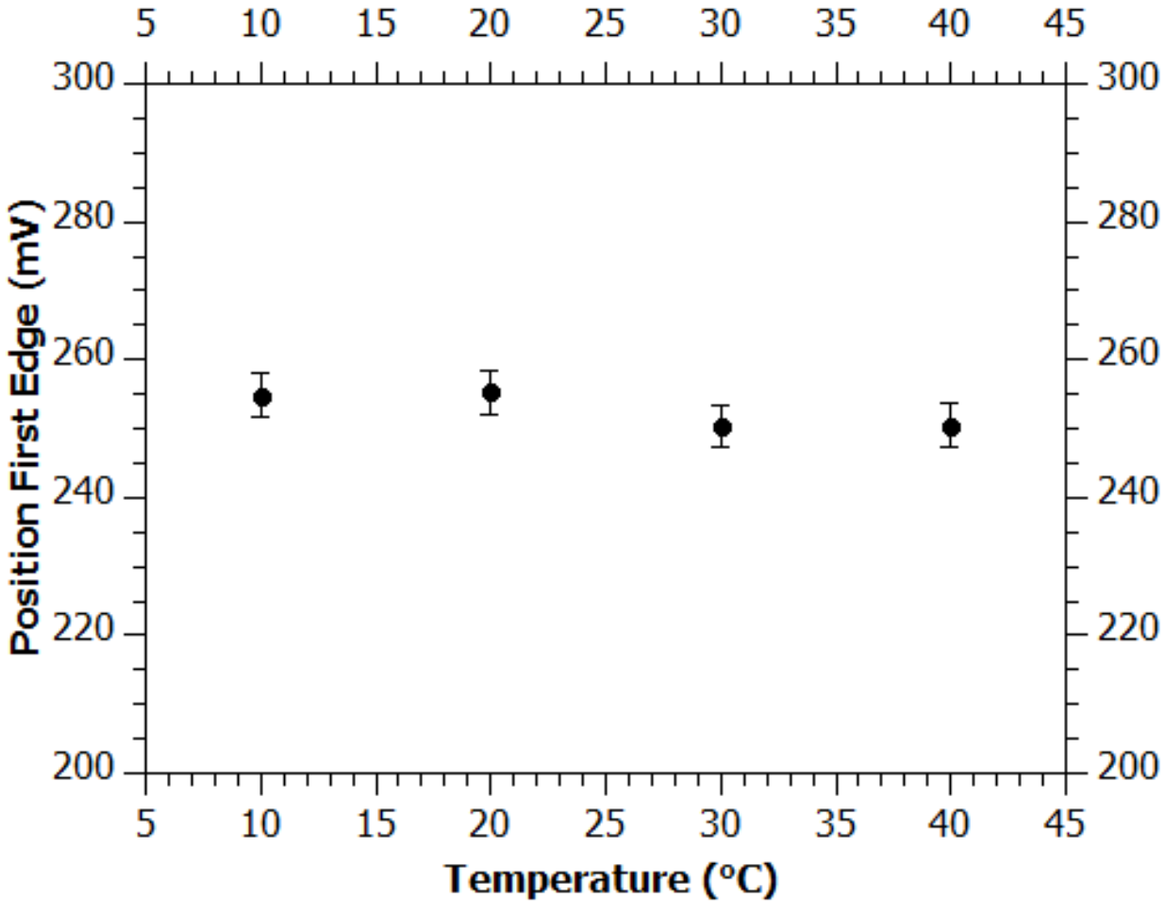
- **Temperature studies of Amplification Boards**
  - Amplification board in climate chamber
  - SiPM with Na-22 source outside at constant temperature
  - Pulse height spectra at T = (10, 20, 30, 40)°C



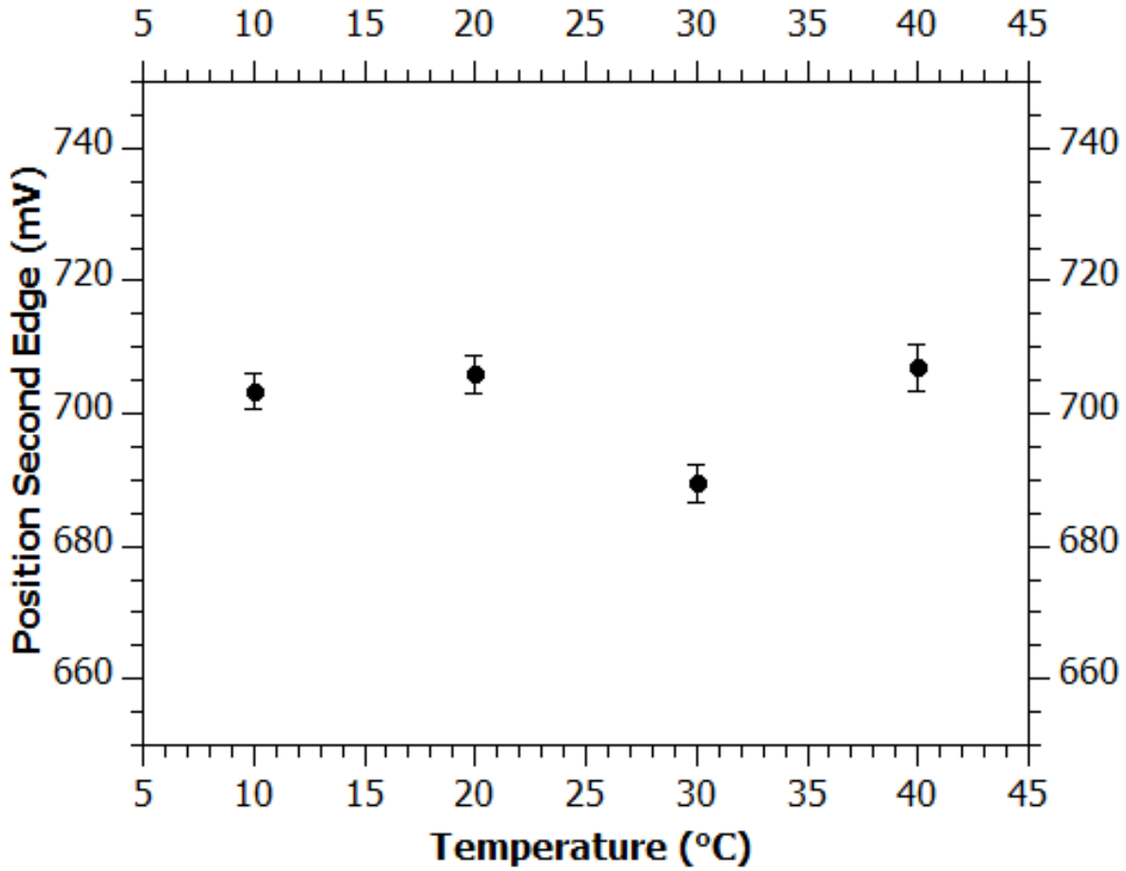
THE VETO-2 SYSTEM

- **Temperature studies of Amplification Boards**

Comparison Position of First Compton Edge



Comparison Position of Second Compton Edge



THE VETO-2 SYSTEM

- **Correlation of ToT and Amplitude**