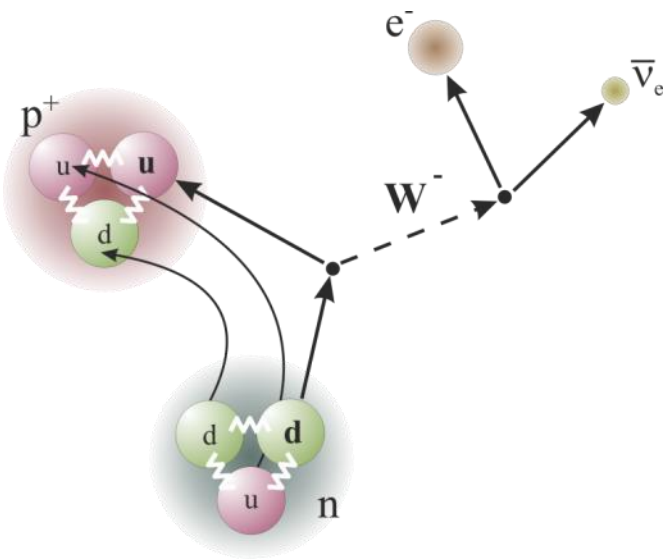
ÖAW AUSTRIAN ACADEMY OF SCIENCES

SMI – STEFAN MEYER INSTITUTE FOR SUBATOMIC PHYSICS

Momentum Spectroscopy of Neutron Beta Decay Products with NoMoS

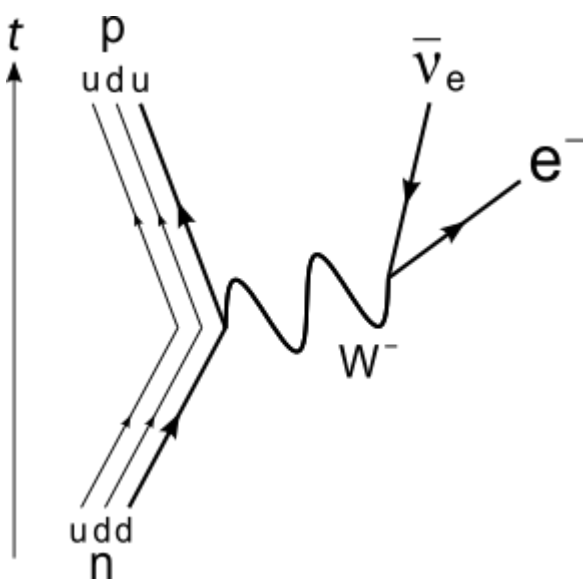
Neutron decay pr**O**ducts **MO**mentum **S**pectrometer

Waleed Khalid for the NoMoS Collaboration
ÖPG & SPS Joint Annual Meeting 2019
August 27, 2019



Thanks for contributions from R. Jiglau, G. Konrad, D. Moser, & M. Valentan

Neutron Decay in the Standard Model



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$$T_{e,max} = 781.6 \text{ keV}$$

$$\tau_n \propto \frac{1}{|V_{ud}|^2} \frac{1}{(1+3|\lambda|^2)} \quad ; \quad \tau_n = 879.4(0.6)\text{s}$$

PDG 2019

quark mixing

$\lambda = g_A/g_V$

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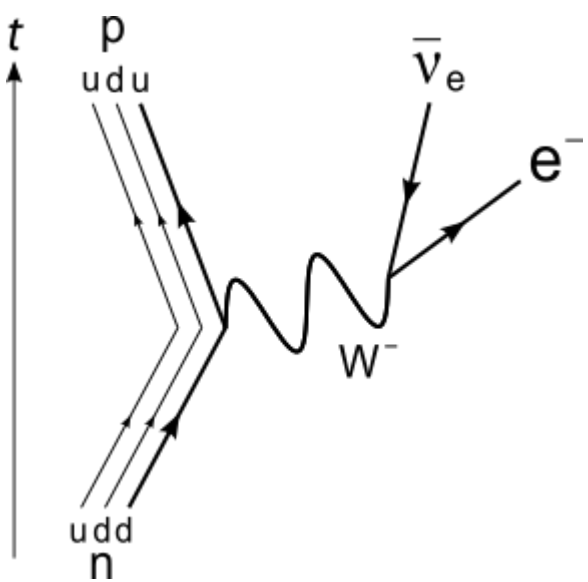

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PDG 2019

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Electron-Neutrino Correlation Coefficient

$$a = \frac{1-|\lambda|^2}{1+3|\lambda|^2} = -0.1059(28)$$

PDG 2019

Fierz Interference Term

$$b = 2\frac{\mathrm{Re}(g_S + 3\lambda g_T)}{1+3|\lambda|^2} = 0.067(90)$$

PR C 96, 042501, 2017

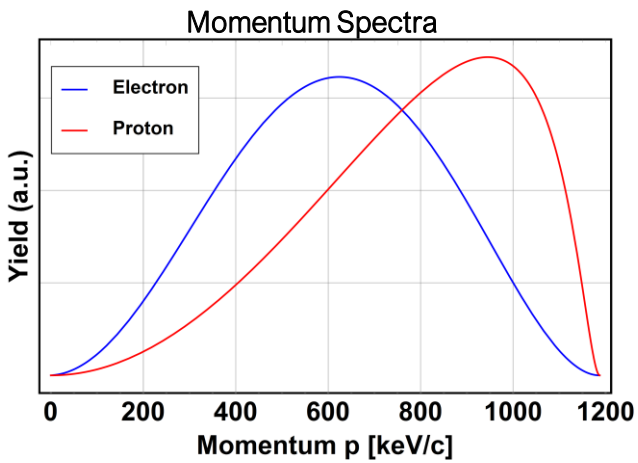
Measurement Principles

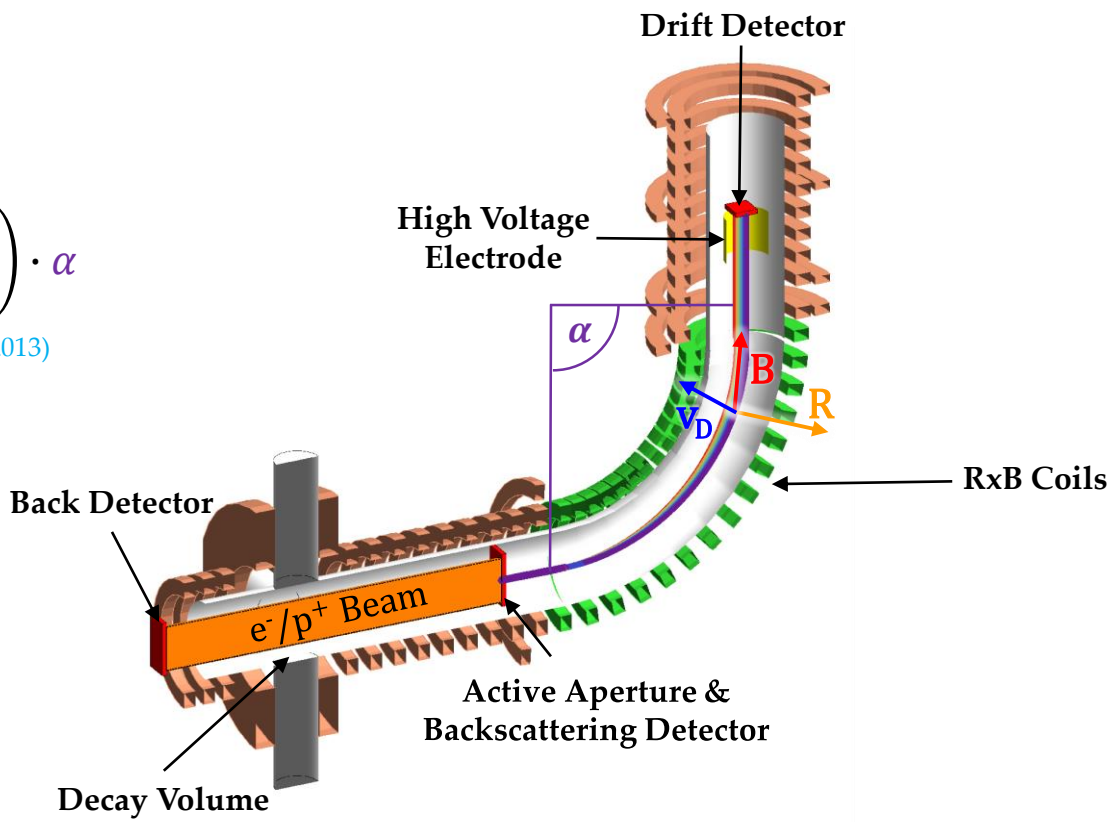
$$\vec{v}_D \propto \frac{1}{q}\frac{\vec{R}\times\vec{B}}{R^2B^2}$$

$$D(p,\theta) = \int_T v_D \,\mathrm{d}t$$

$$= \frac{p}{qB}\cdot\frac{1}{2}\left(\cos\theta + \frac{1}{\cos\theta}\right)\cdot\alpha$$

X. Wang et al., NIM A **701**, 254 (2013)





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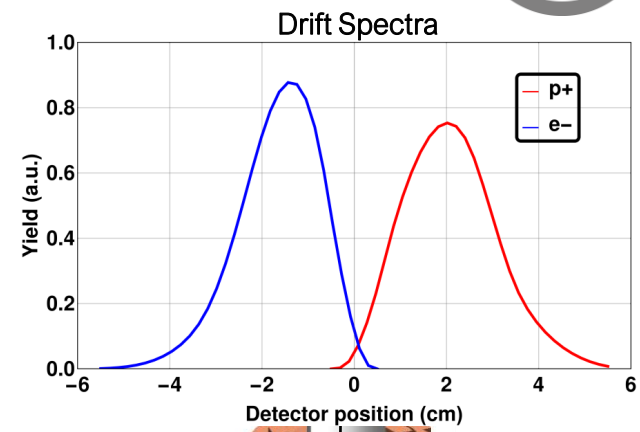
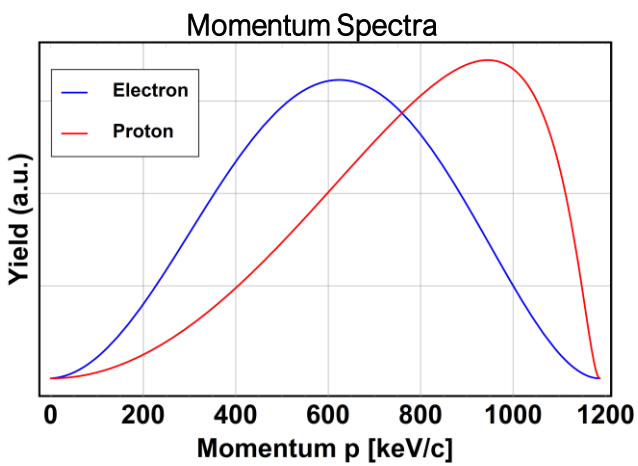
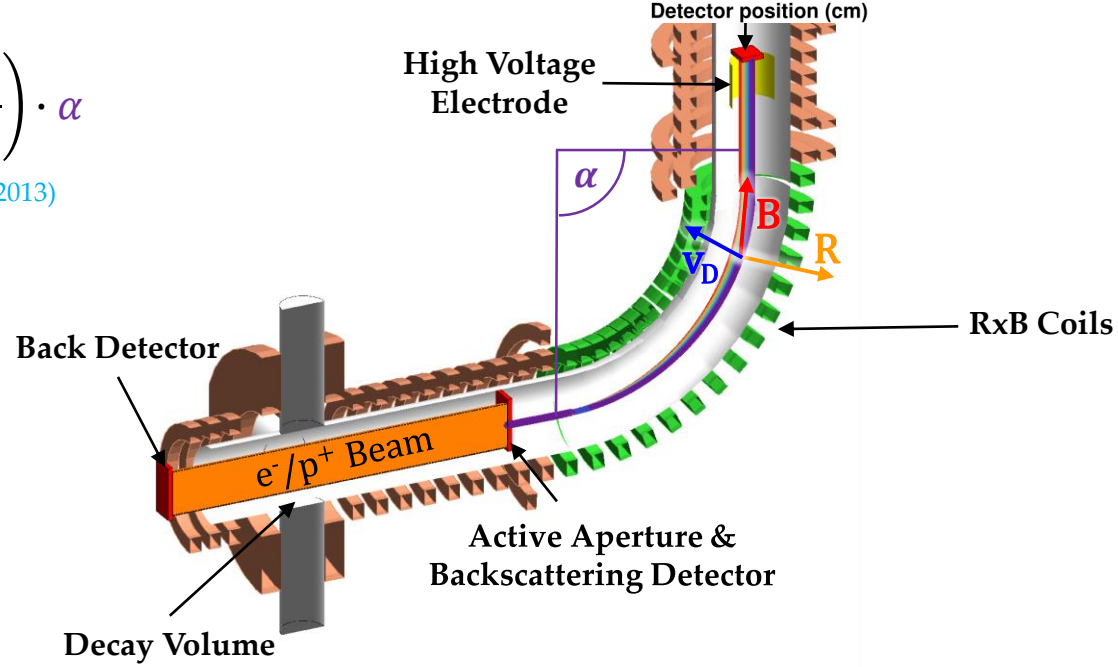
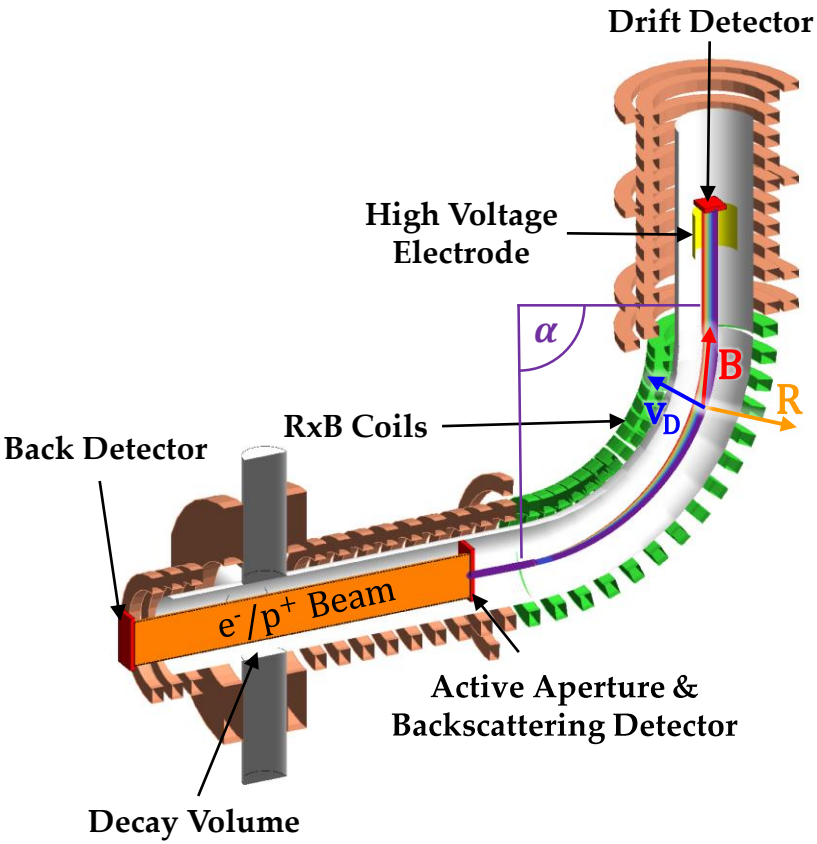






Systematic Effects

D. Moser et al., PPNS2018 Proc. arXiv:1906.04511



$$D(p,\theta) = \frac{p}{qB} \cdot \frac{1}{2}\left(\cos\theta + \frac{1}{\cos\theta}\right) \cdot \alpha$$

- **Beam definition**
  - Neutron beam: shape of profile, residual polarization
  - B Field: homogeneities
  - Aperture: edge effect & backscattering
- **R×B drift**
  - B Field: absolute height, homogeneity, radial gradient
  - Opening angle α
- **Drift distance measurement**
  - Detector alignment & Edge effects
  - Backscattering & **Detector Efficiency**
- **Background**: Residual gas, neutron-induced radiation
- ***Proton measurements***
  - Electrostatic potentials: E×Bs, filter, offset, trapping
  - Doppler effect: neutron velocity

Proton Detector Considerations

- $T_{p,max} = 751$ eV
  - Post Acceleration (≈-15 kV)
- Large Detection Area (10x7 cm^2)
- Low Backscattering
- High spatial resolution (<1 mm)
- Linear Gain
- High Efficiency
- High S/N ratio

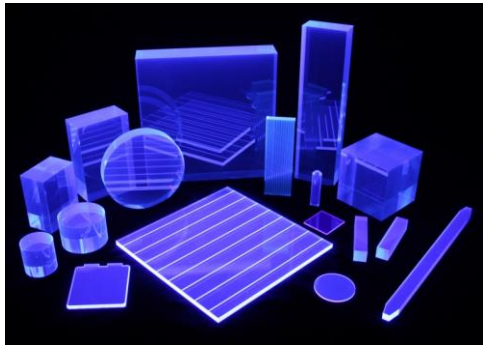


Image Credit: Eljen Technology

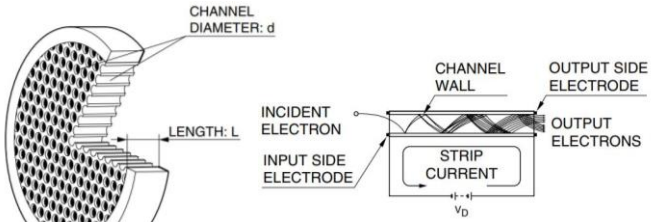


Image Credit: Hamamatsu

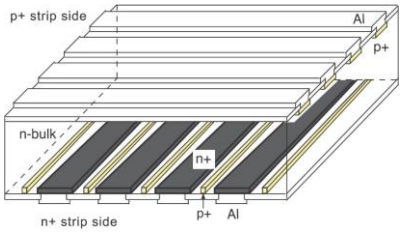


Image Credit: Takeda S. DOI: 1117/2.1200802.0889

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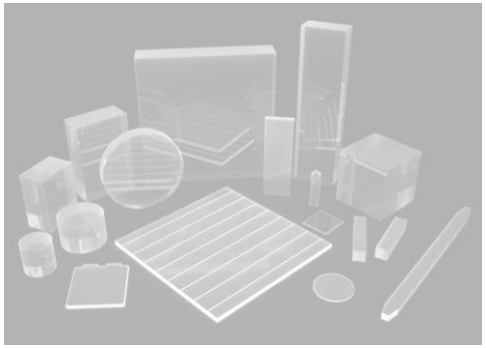

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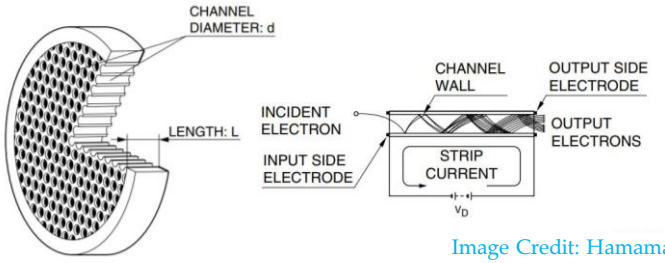

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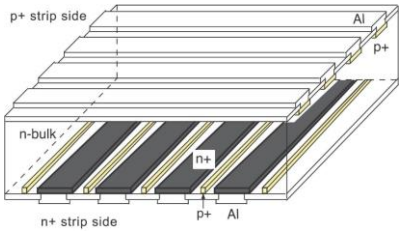

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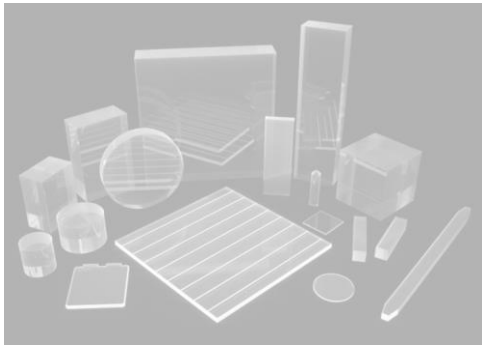

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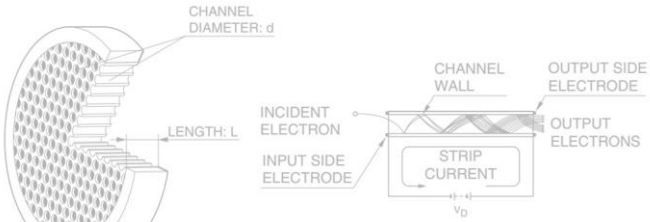

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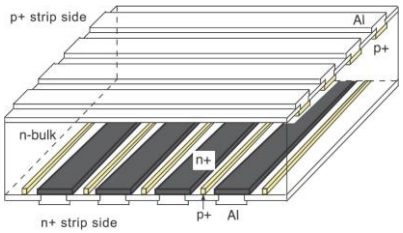

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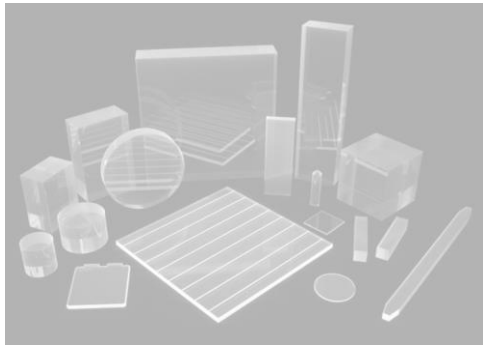

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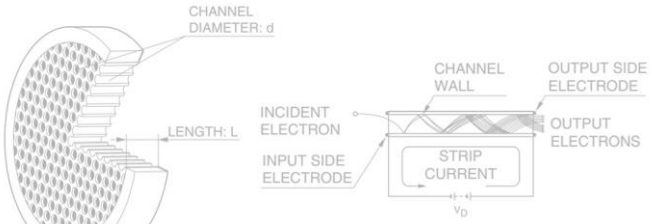

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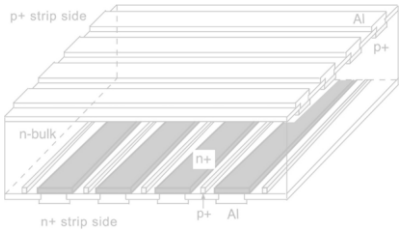

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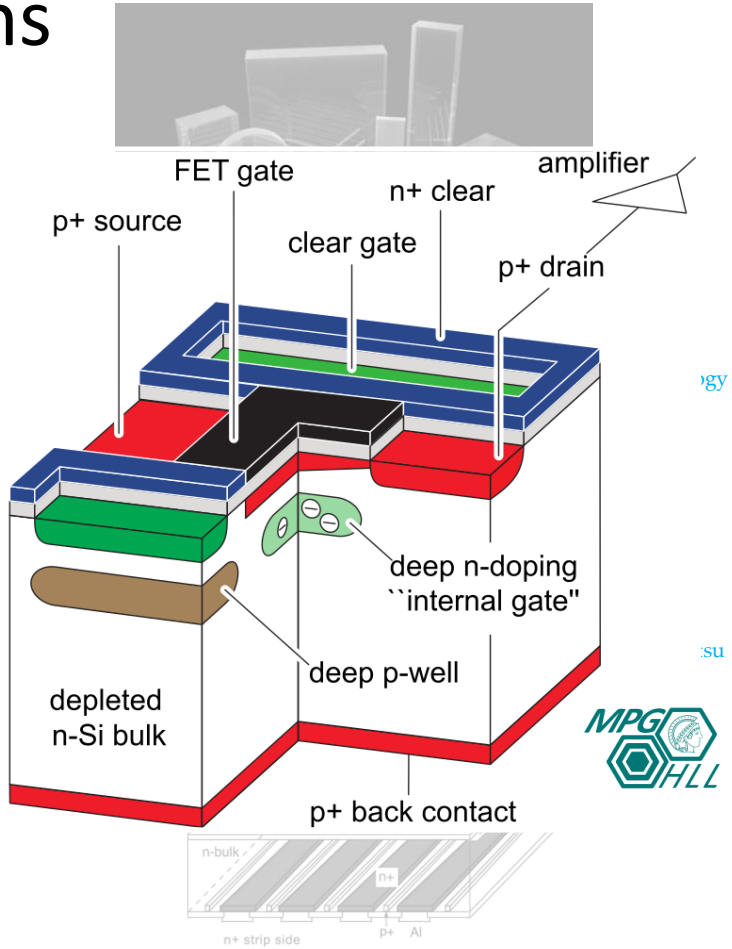
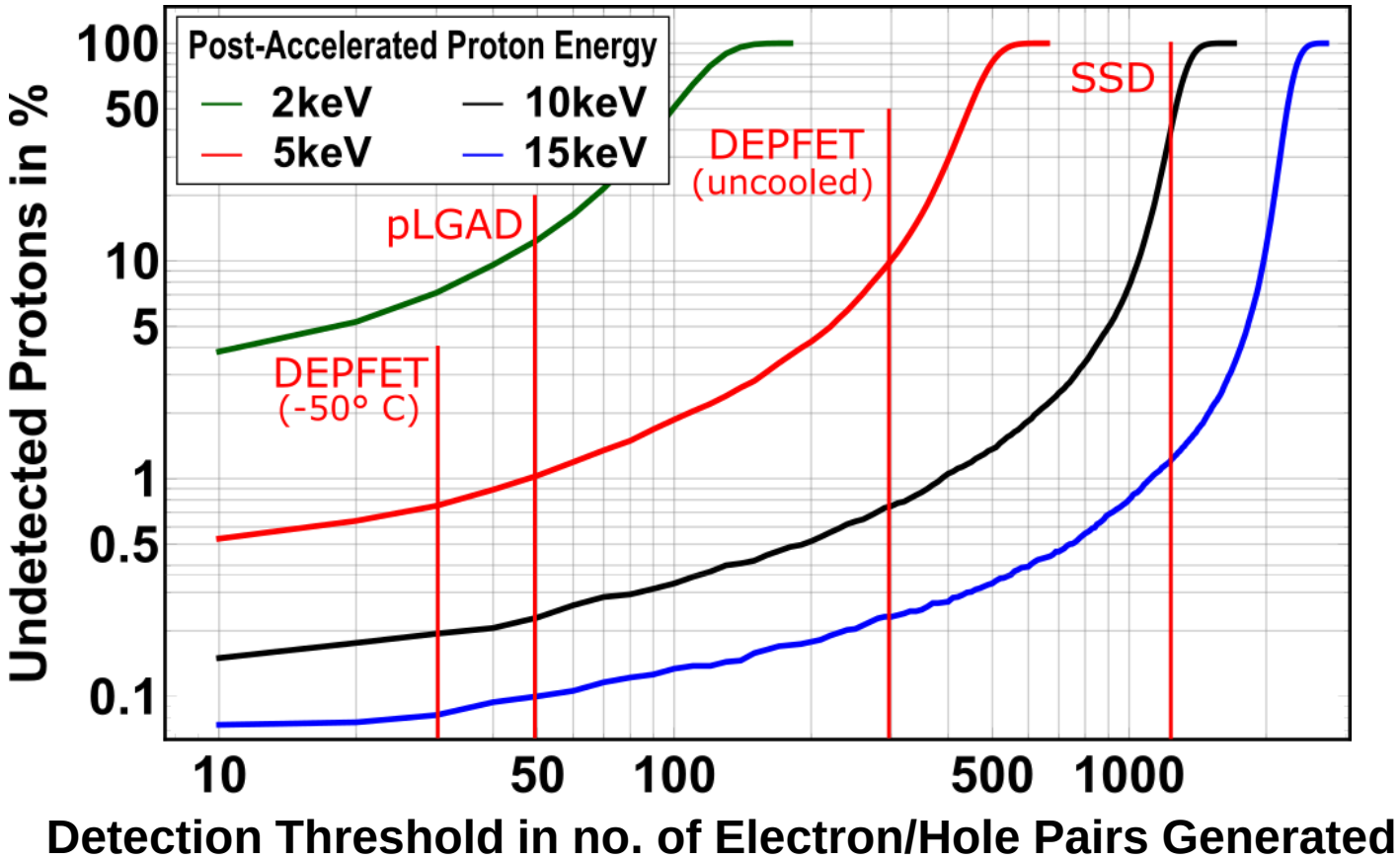


Proton Detector Efficiency



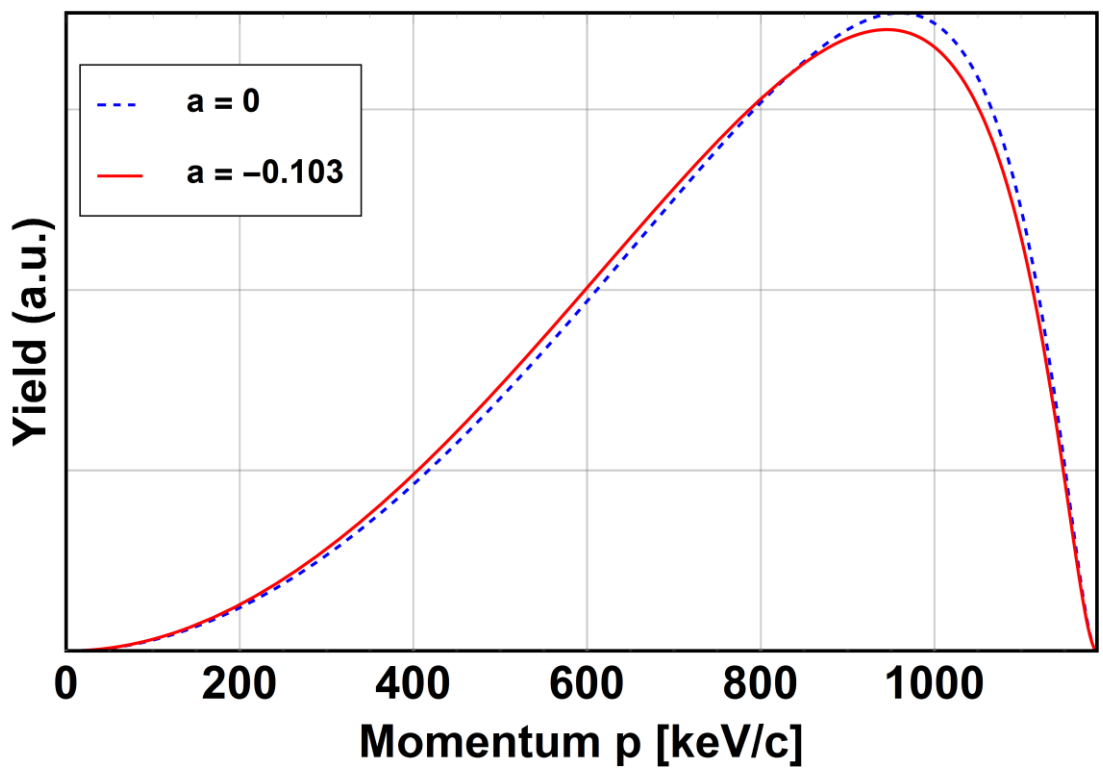
*Preliminary Result

Summary and Outlook

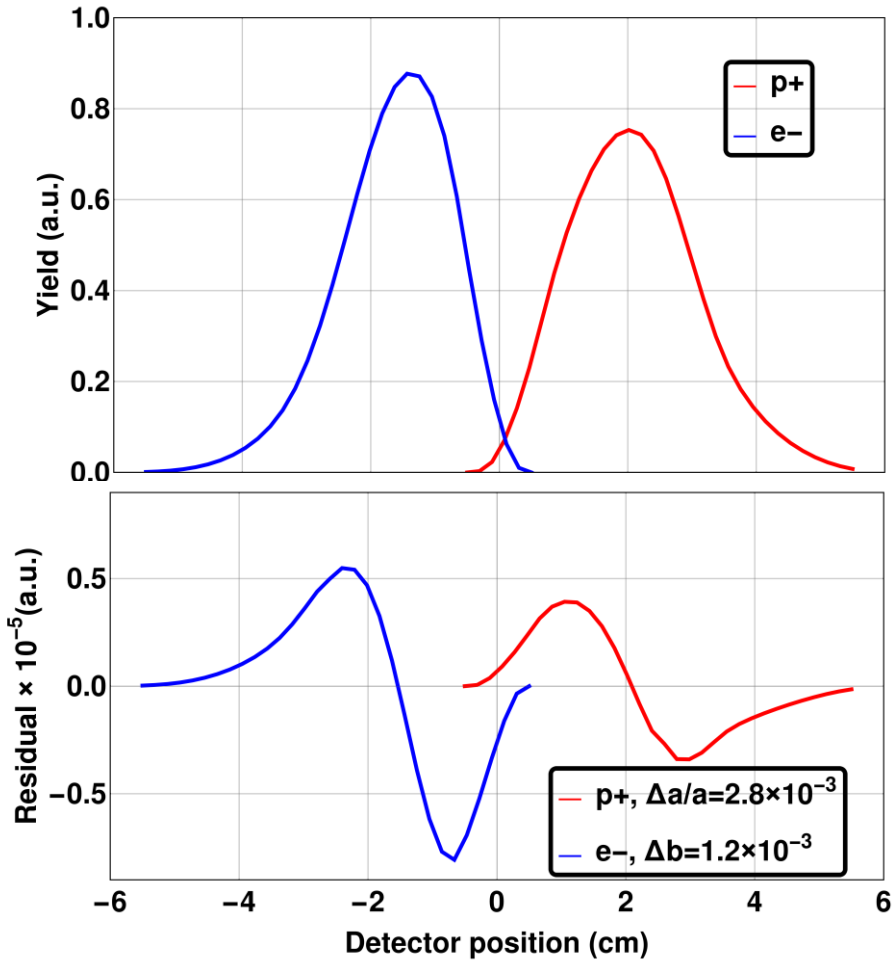
- Precision measurements of neutron decay
  - Independent value for V_{ud} needed to shed light on top row CKM unitarity
  - Search for Physics beyond the Standard Model
- NoMoS Magnet system
  - Final optimizations in progress
- Systematic effects
  - Most systematic effects incorporated into fit function
  - Further investigations incl. MC simulations under way (using Geant)
- Detection System
  - Comparison of different detection techniques for secondary detectors in progress
  - Electrode design being developed (TASK Poster ID: 386)
  - Pursuit of pLGADs as the proton drift detector looks promising

BACKUP SLIDES

Influence of Electron-Neutrino Coefficient on Spectra



Residual Spectra



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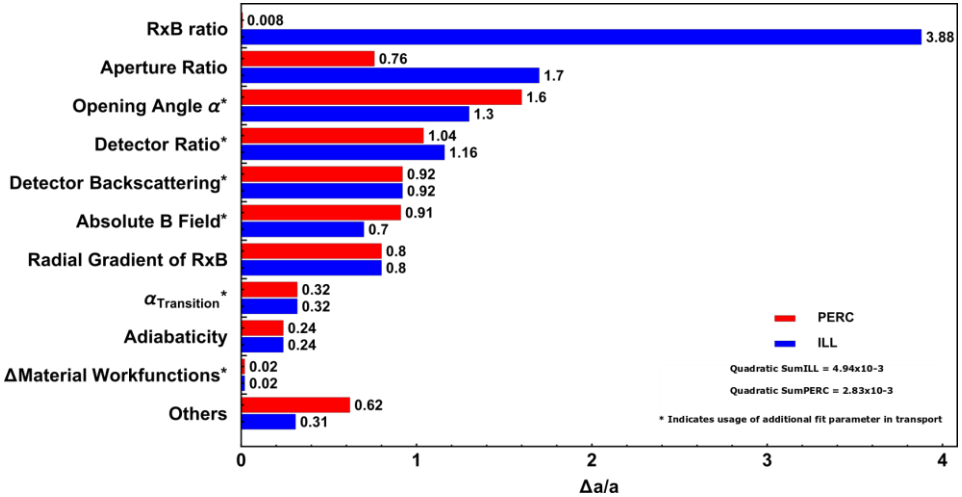
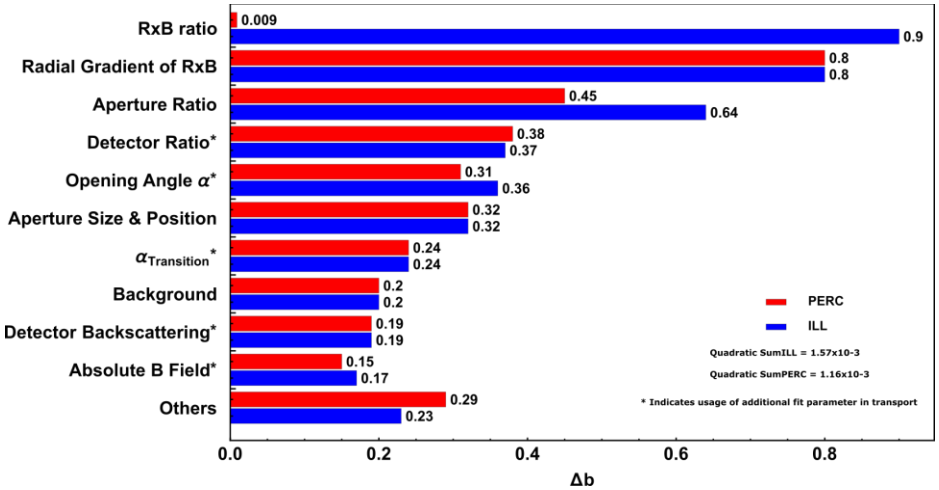




*Preliminary Results

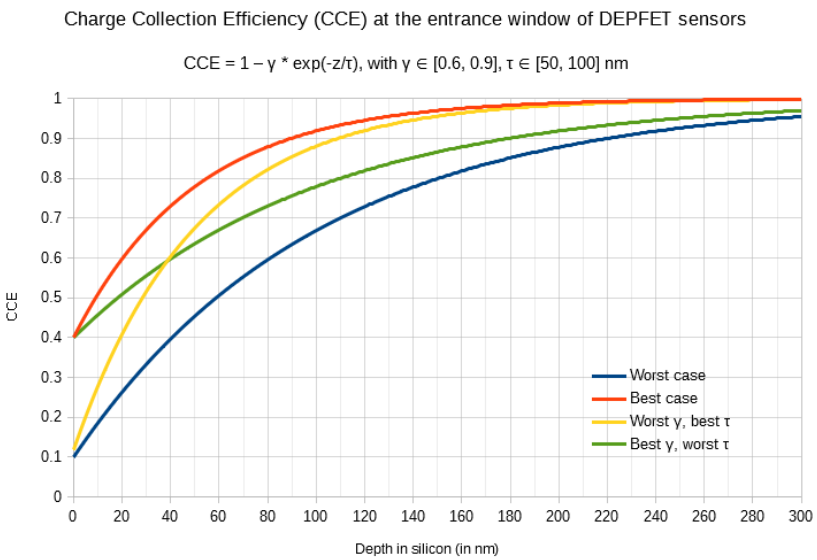
Surface Effects (Charge Collection Efficiency)

M. Popp et al., Nucl. Instr. Meth. A, 439, 567 (2000)

- For Protons CCE is an important effect to consider
- CCE is not uniform due to
  - Surface defects
  - Recombination of holes and electrons

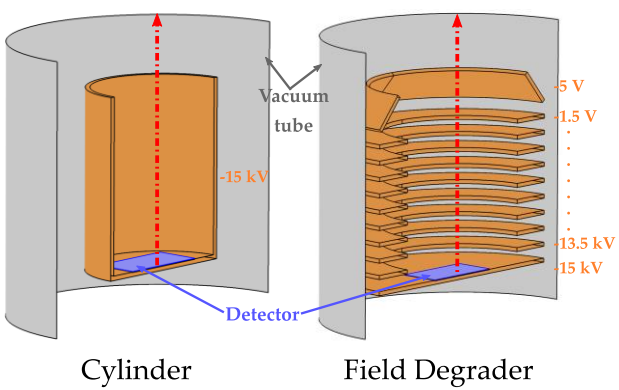
$$f_{cce}(z) = 1 - \gamma e^{-\frac{z}{\tau}}$$

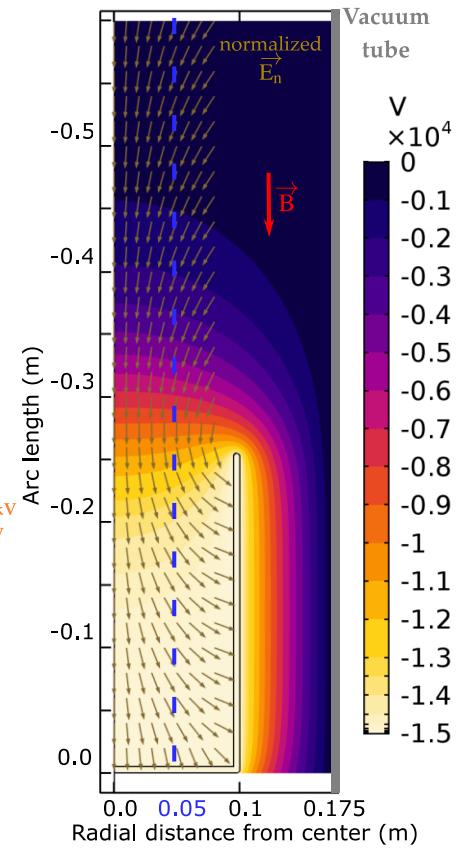
$\gamma \epsilon [0.6,0.9]$ & $\tau = [50,100]$nm



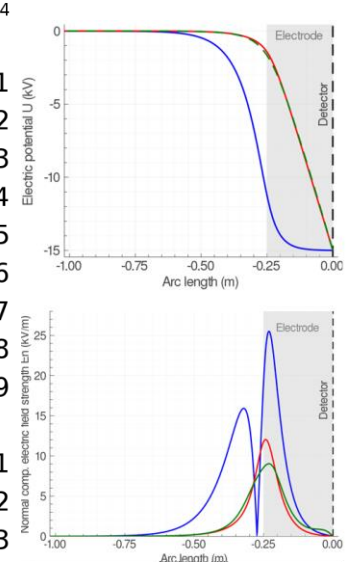
Post-Acceleration Electrode

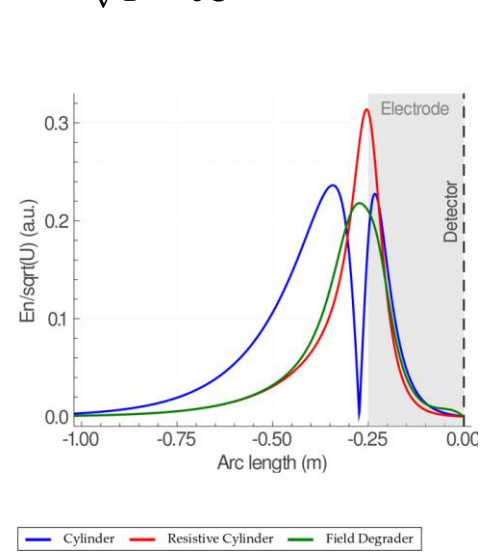
Different Geometries





$$D_{E\times B} \propto \frac{E_n}{\sqrt{T - eU}}$$

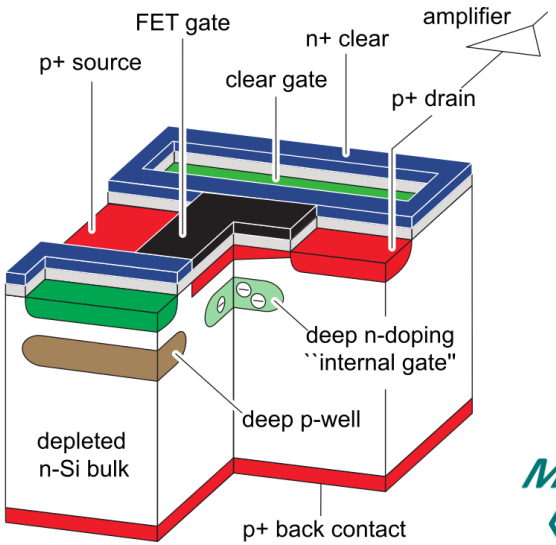




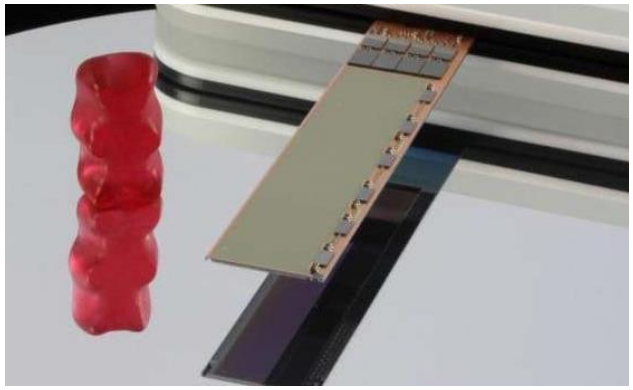
*Work in Progress

Best sensor: DEPFET

- Depleted P-channel Field Effect Transistor
- Fully depleted pixel sensor,
  pixels of any size possible
- Stores signal charge,
  can be read repeatedly
  - Very low noise
  - Best suited to our needs

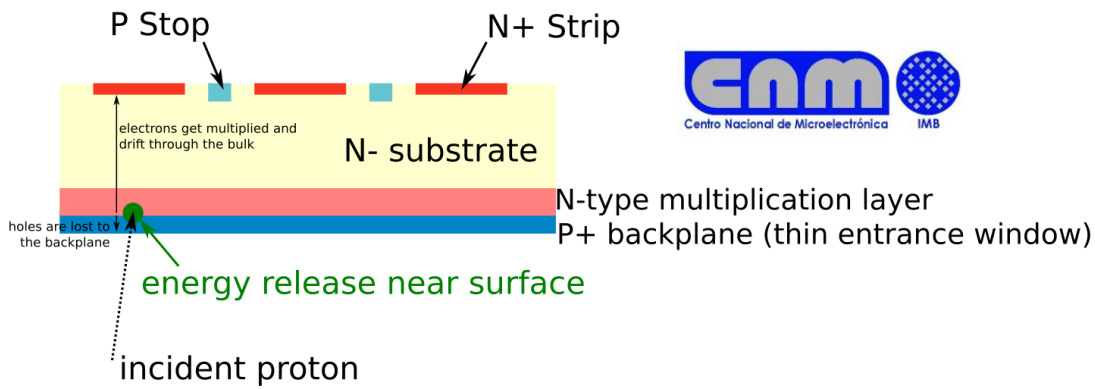


- But long lead time (2 years),
  very expensive (5 sensors, 300 k€) and it requires additional cooling
  → not feasible at the moment



Current focus: pLGAD

- Combination of two existing concepts:
  - Low Gain Avalanche Diode for internal signal amplification
  - Pixel readout structure for 2D information and low noise rate



- Compared to a cooled DEPFET sensor, this sensor type
  - Has higher noise and thus lower efficiency
  - Has a much simpler readout
  - It is a lot cheaper
  - Would be a new, custom development (2 years)