UCN-Detection System for the PanEDM Experiment

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on behalf of the PanEDM Collaboration

The PanEDM Experiment

What?

- Measurement of the **n**eutron **E**lectric **D**ipole **M**oment (d_n)
- Aiming to reach a sensitivity better than $\sigma_{d_n} < 7.9 \times 10^{-28}\,\mathrm{ecm}$

best current limit:
$d_n < 1.8 \times 10^{-26}\,\mathrm{ecm}$[1]

Why?

- nEDM is violating the CP-symmetry and could help explain the Baryon asymmetry[2]
- SM prediction for the nEDM through CKM-physics is of the order of $10^{-32}\,\mathrm{ecm}$; many theories beyond the SM predict a bigger nEDM [2]

For more information have a look at Florian Kuchler's talk.

[1]DOI: 10.1103/PhysRevLett.124.081803
[2]DOI: 10.1103/RevModPhys.91.015001

How?

Ramsey spectroscopy of polarized **U**ltra **C**old **N**eutrons (UCN)

Measured quantity is the polarisation $P = \frac{N_\uparrow - N_\downarrow}{N_\uparrow + N_\downarrow}$,

its statistical uncertainty can be approximated by $\sigma_P \approx \frac{1}{\sqrt{N_\uparrow + N_\downarrow}}$ close to $P = \frac{1}{2}$.

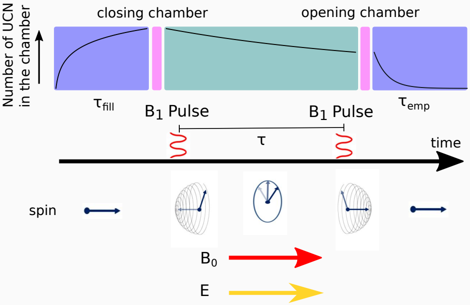


Figure 1: Schematic overview of one measurement sequence.

The PanEDM, Detection System, Key Features

Simultaneous spin detection with four sets of spin flippers, polarizers and detectors.

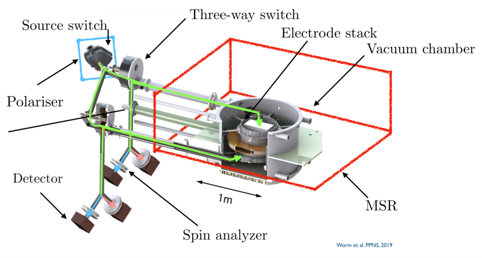


Figure 2: Measurement Setup.

To be discussed, the for PanEDM necessary background limit (intrinsic/external), rate capability and detection efficiency

Additional important features: Stable over many measurement sequences,

Maintainable on site

False EDM due to Systematic Detector Contribution

- For ith measurement sequence, an additive constant (e.g background effects) $\Delta N_\uparrow$ in one detector changes P to: $P^i_{\Delta N_\uparrow} = \frac{N_\uparrow + \Delta N_\uparrow - N_\downarrow}{N_\uparrow + \Delta N_\uparrow + N_\downarrow}$.
- Expressing this as deviation from P: $\Delta P^i_{\Delta N_\uparrow} = P^i_{\Delta N_\uparrow} - P^i = \frac{2\Delta N_\uparrow N_\downarrow}{(N_\uparrow + \Delta N_\uparrow + N_\downarrow)(N_\uparrow + N_\downarrow)}$.
- With the relation for the nEDM: $d_n = \frac{\delta P \hbar}{2|E|P_0\tau}$

  the false EDM is: $\Delta d^i_{n,\Delta N_\uparrow} = \frac{\Delta P^i_{\Delta N_\uparrow} \hbar}{2|E|P_0\tau}$.

Background Limits

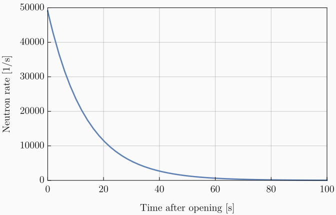
Differentiate two kinds of background:

- Correlated with measurements sequences (worst case):
  The background limit is 1.3 mcps so that $\Delta d_{n,\Delta N_{\uparrow}} < 3.8 \times 10^{-27}$ ecm (statistical sensitivity goal for Phase I[3])
- Non-correlated:
  The background limit is 1 cps. For $\Delta P^{i}_{\Delta N_{\uparrow}} < \sigma_P$

[3] DOI: 10.1051/epjconf/201921902006

Detection Bandwidth

- Emptying of a storage chamber can be calculated with[4]: $R(t) = \frac{N_0}{\tau_{emp}(v)} \mathrm{Exp}(-\frac{t}{\tau_{emp}(v)})$
- for the PanEDM setup and expected parameters[3] we can estimate: $\tau_{emp}(v) \approx 14\,\mathrm{s}$
- this leads to maximum expected rate of 5 kcps for phase I of SuperSUN and 50 kcps for phase II



[3]DOI: 10.1051/epjconf/201921902006
[4]ISBN 10 : UCAL:B4128983

Detection Efficiency

Goal for the statistical limit after 100 days of measurement is 3.8×10^{-27} ecm [3].

For a maximum of eight additional measurement days (still possible to finish in two reactor cycles) a relative efficiency of at least 92.5% is required, compared to a ^{3}He detector (PF2 Dunia).

[3] DOI: 10.1051/epjconf/201921902006

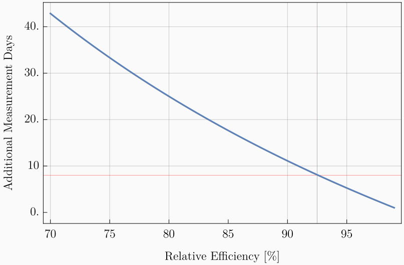


Figure 3: Additional Measurement Days.

Working Principle of a Cascade Detector

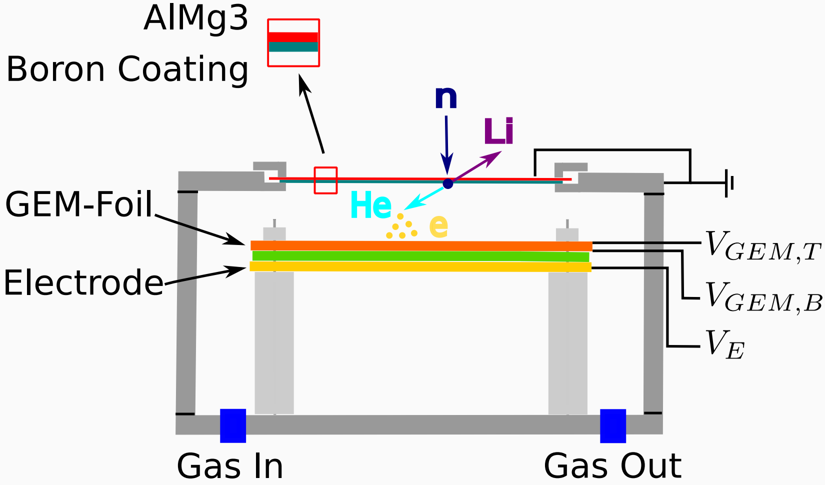
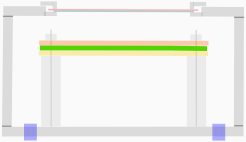


Figure 4: Schematic overview of a Cascade-U 1D-100 Detector. Built by CDT GmbH, Heidelberg, www.n-CDT.com

Hardware Improvements, Spacer between GEM Foil and Electrode:



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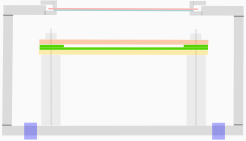


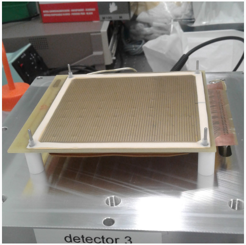


Figure 5: Teflon spacer.

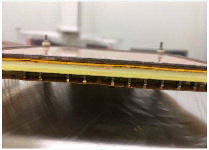
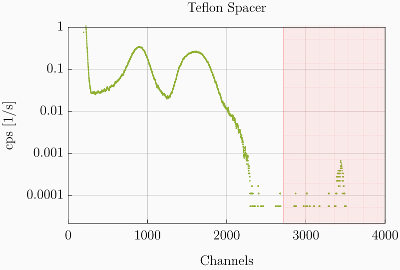


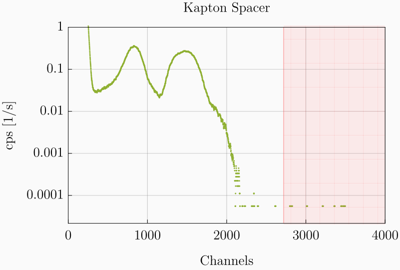
Figure 6: Wrinkles.

Figure 7: Kapton spacer.

Hardware Improvements, Spacer between GEM Foil and Electrode:

Effects on Pulse Height Spectrum (PHS):





The rate beyond the ROI decreases by nearly 90%,

$\mathrm{rate}_{\mathrm{Teflon}} = (39 \pm 5)\,\mathrm{mcps} \quad \mathrm{rate}_{\mathrm{Kapton}} = (4.4 \pm 1.6)\,\mathrm{mcps}$

Hardware Improvements, Spacer between GEM Foil and Electrode:

Time constant for stable operation:

If the interior of the detector is exposed to air, PHS shifts over time.

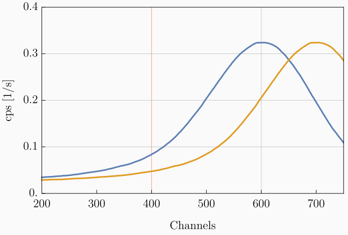


Figure 8: Artificial shift of 100 channels for demonstration. Shown is the Lithium peak.

Increase of the rate of 1.4% inside the neutron ROI.

Shift of Lithium peak:

Teflon spacer

day 2 to day 9 $\rightarrow$ 98.3 ± 1.4 ch. or 11.7 ± 0.7 %

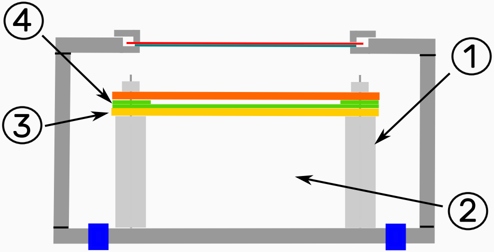
day 9 to day 16 $\rightarrow$ 33.0 ± 1.5 ch. or 3.4 ± 0.1 %

Kapton spacer

day 3 to day 4 $\rightarrow$ 34 ± 7 ch. or 2.1 ± 0.4 %

day 4 to day 6 $\rightarrow$ 1 ± 5 ch. or 0.006 ± 0.030 %

Further Implemented Hardware Improvements



Improvements:

1. Ceramic spacer
2. Ar/CO_2 gas mixture 85/15 $\rightarrow$ 90/10
3. Single PCB electrode
4. Kapton spacer (frame)

Support Structure:

- Gas handling with mass-flow controller
- New 8-ch. Analog Digital Converter
- Modular RF-shielding

Key Figures of the Improved System

Detection Bandwidth

Detection bandwidth ≈ 50 kcps with 2% dead time.

→ Good enough for phase II

Detection Efficiency

Estimated:

$\frac{\mathrm{E}_{\mathrm{Cas}}}{\mathrm{E}_{\mathrm{Dun}}} \approx 91\%$

Equivalent to additional 12 measurement days for the "100 days" limit.

Background (Shielding)

Intrinsic / non-correlated background 10 mcps

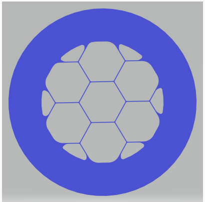
Effect of correlated background from on site neutron background, assuming perfect correlation with measurement sequence is Δd_n=$(1.63 \pm 0.75) \times 10^{-27}$ ecm. For comparison, a background of 1.3 mcps gives an upper limit of $\Delta d_n = 7.58 \times 10^{-28}$ ecm

Outlook, Detection Efficiency

Main neutron loss factor is the entrance foil consisting of 100 µm AlMg3 (13%)

$\rightarrow$

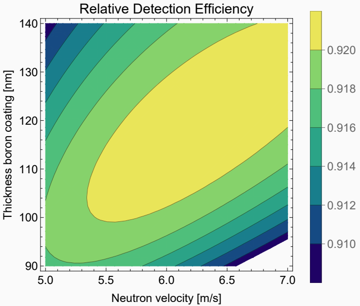
50 µm aluminium foil with support structure (Simulated by Louis Roix). Covers less than 4% of the active area.



Optimize the boron coating thickness.

$\rightarrow$

$\approx$ 117 nm



From 91.6% to 96.2% relative efficiency @ 6.3 $\mathrm{m\,s^{-1}}$.

The End!

Thank you for your attention!