GADGET: a novel ultra-cold neutron gaseous detector for the n2EDM project

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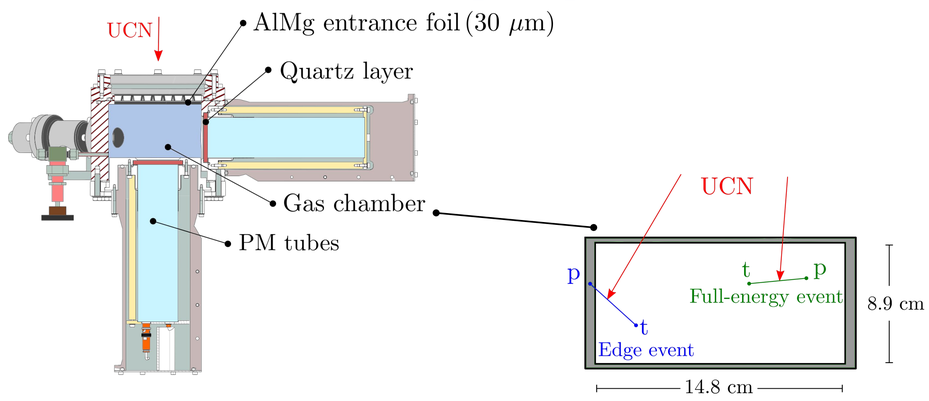
Motivation

Measuring the electric dipole moment of neutron as proposed in the n2EDM project requires a high-efficient UCN detection system.

Objective

Test, characterize and analyze the performance of a novel gaseous detector: the GADGET prototype.

Detection principle

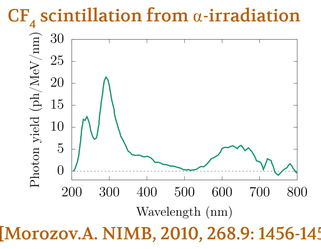


Indirect detection with $^3He + CF_4$ gas mixture

1. UCN absorption by ^3He: **$n + {}^3He \rightarrow p + t + 764$ keV.**
2. CF_4 scintillation ($\tau \approx 6$ ns) due to ionization and excitation produced by proton and tritium.

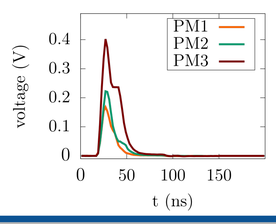
   Assuming p and t produce same scintillation as α particles around 2050 photons per UCN are expected.

   CF_4 scintillation from α-irradiation

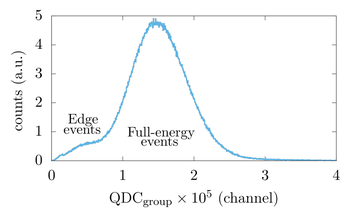


[Morozov.A. NIMB, 2010, 268.9: 1456-1459]

3. Light **collection** by 3 PM-tubes operating in coincidences (to reduce background events).



$$QDC = \sum_{t=\text{gate start}}^{t=\text{gate end}} V(t).$$



Efficiency study

Comparison of absolute counting rates of GADGET and a cascade (Boron based) detectors.

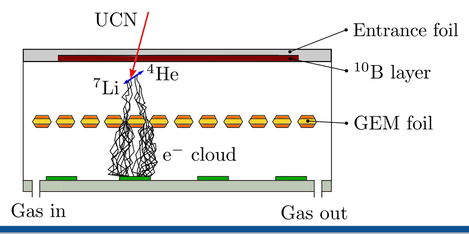
P_{CF_4} (mbar)	$\frac{r_{cascade}}{r_{gadget}} \times 100$ (%)
400	54(2)
1000	53(2)
1400	56(2)

GADGET is double more efficient than the cascade detector.

Origin of the losses: entrance foil material, lost in boron layer, entrance foil thickness

$$\approx 25\% + 15\% + 10\% = 50\%$$

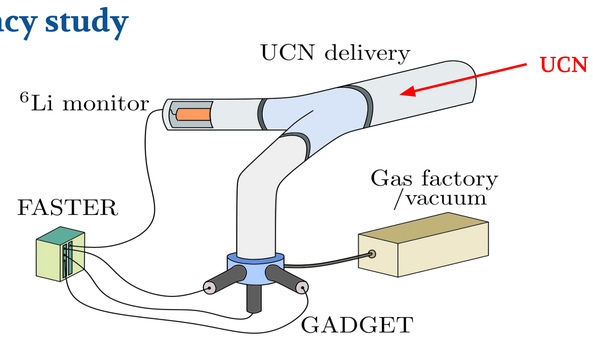
Cascade detector sketch [Klein, M., & Schmidt, C. J. ,2011]



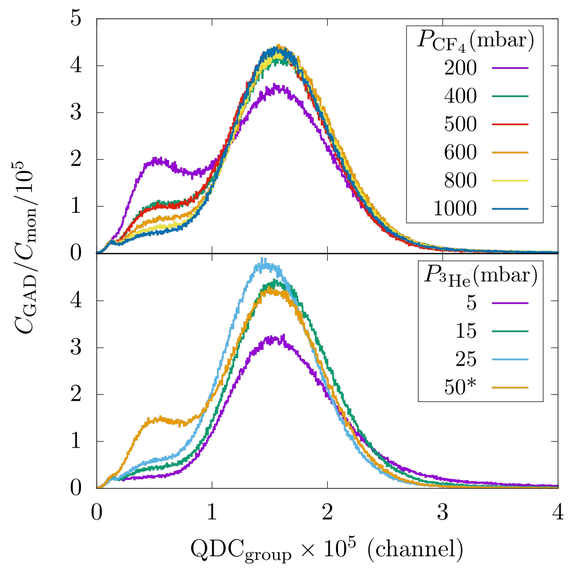
Pressure dependency study

Setup at PSI's west 2 beam-line:

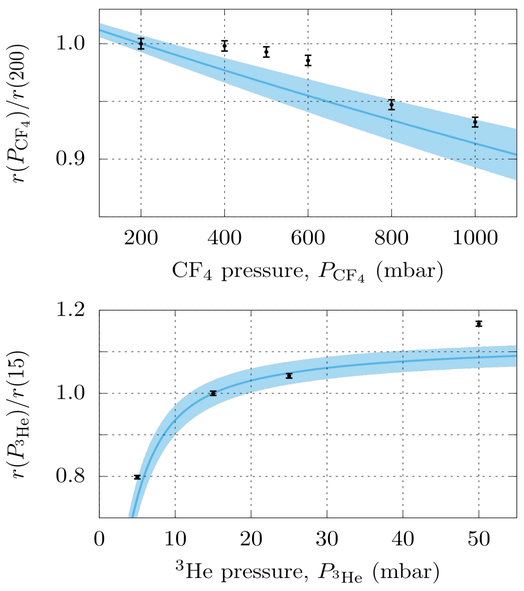
- ^6Li detector to monitor UCN flux.
- Vacuum and gas feeding controlled from *Gas factory*.
- Readout to digital acquisition system *FASTER**.



Integrated charge spectra (QDC) for different gas pressures



Total counting rate (r) as function of gas pressures



Pressure	counting rate	edge events
CF_4 ↗	↘	↘
CF_4 ↘	↗	↗
^3He ↗	↗	↗
^3He ↘	↘	↘

↗ : increase ↘ : decrease

A simplified analytical model for the total absorption probability as function of gases pressures:

$$\mathcal{P}_{ab}^{tot}(P_{^3He}, P_{CF_4}) = \frac{P_{^3He}\sigma_{ab}}{P_{CF_4}\sigma_{up} + P_{^3He}\sigma_{ab}}\left[1 - \exp\left(-L/\lambda\right)\right]$$

Suggested operation conditions: ^3He @ 25 mbar and CF_4 @ 400 mbar → High absorption and low upscattering *(avoiding edge events as much as possible)*

Pulse shape analysis (PSA)

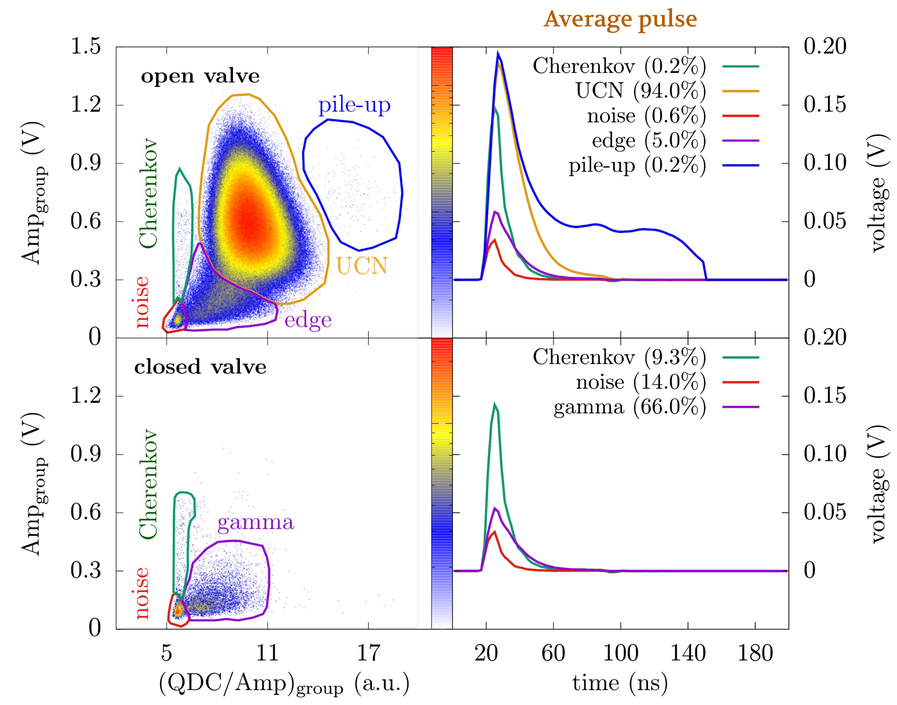
PM pulses describe different shapes depending on the interaction process (good for background identification)

PSA based on amplitude (Amp) and QDC parameters shows:

- "Pile-up", "noise" and "Cherenkov" events are straightforwardly identified.
- Non UCN events account for **less than 3%.**
- Since "edge" and "gamma" regions overlap, GADGET should be lead-shielded.

Region	decay time (ns) open valve	decay time (ns) closed valve
UCN	11.8(1)	-
noise	6.1(2)	6.0(1)
edge	12.1(3)	-
Cherenkov	7.7(2)	7.7(1)
gamma	-	12.3(3)

Average pulse



Further developments

1. Use PMTs with better light collection efficiency.

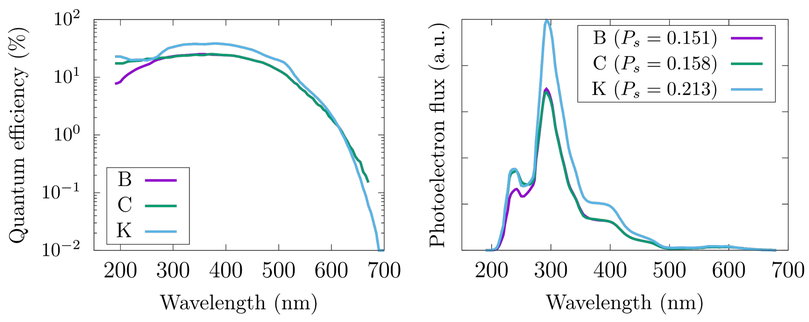
Candidate PMTs

Type	Photocathode	Window	Diameter (in)
B	Bialkali	UV glass	3
C	Bialkali	Quartz	2
K	Super Bialkali	Quartz	2

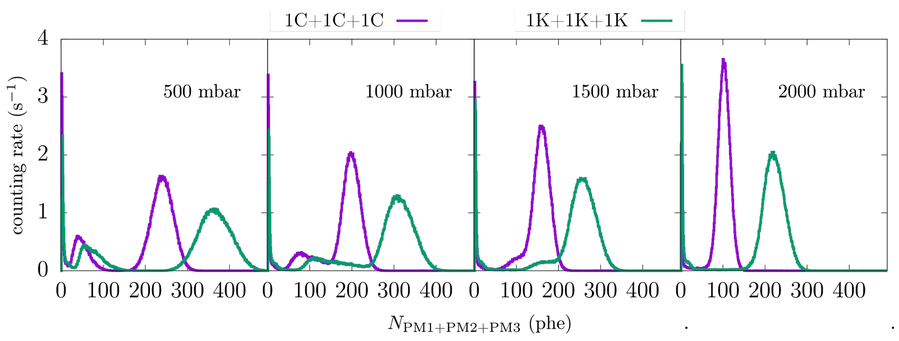
Light collection efficiency given by:

$$P_s = \int_{200\text{ nm}}^{700\text{ nm}} I_{spectrum} \cdot T_{window} \cdot QE_{PMT}\, d\lambda$$

- $I_{spectrum}$: light scintillation spectrum.
- T_{window}: quartz window (GE124, 6 mm) transmittance ≈95%.
- QE_{PMT}: spectral response.



Photoelectron distribution from α-irradiation of CF_4



- K-type PMTs manifest larger collection efficiency than C-type.
- Low CF_4 pressures increase the number of photoelectrons and therefore the resolution.

(One promising configuration: **2 K-type + 1 B-type PMTs**. Light collection efficiency would raise by a 68%).

2. A thinner entrance foil is expected to enhance the detection efficiency (stress tests already performed with 15 μm foils).

3. We will evaluate thinner quartz windows, different scintillating gases and magnetic fields effects on GADGET functioning.

Conclusions

- Gadget is one of the most suitable UCN detectors for the n2EDM project. Its detection principle gives place to a high counting efficiency and clear background identification.
- Its versatility in terms of operation conditions allowed the evaluation of optimal parameters: 400 mbar for CF_4 and 25 mbar for ^3He gases, they represent high UCN absorption, low upscattering and edge events.
- New PMT models have proved to be more efficient in collecting CF_4 scintillation light. Other models in different configurations will also be studied.

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