Steve Sidhu
PhD Candidate

Improving the sensitivity of the neutron electric dipole moment experiment at TRIUMF

Overview

In this talk I will briefly explain

- The figure of merit used to analyze simulations and how it was improved
- How varying operational timing affects the energy distribution of UCN
- How the timings are optimized to increase sensitivity

Sensitivity formula

For this method, statistical sensitivity is given by:

$$\sigma(d_n) \approx \frac{\hbar}{2\alpha T_{\mathrm{Ramsey}} E \sqrt{N_{\mathrm{det}}}}$$

- where α is the visibility of the central fringe, T_{Ramsey} is the free precession time, E is the strength of electric field, and N_{det} is the number of UCN detected

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- where α is the visibility of the central fringe, T_{Ramsey} is the free precession time, E is the strength of electric field, and N_{det} is the number of UCN detected
- To improve the precision of the experiment is we must either increase the number of neutrons detected, increase their polarization (α), increase their storage time, or increase the strength of the electric field

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- This will help us remain competitive with other experiments around the world
- Systematic studies will add additional days/years to obtain a final result

Days-to-reach metric

The sensitivity formula was adopted to analyze simulations by minimizing the total measurement time for the experiment: the figure of merit used was the days-to-reach metric. The steps to calculate are:

- First, calculate $\sigma(d_n)$ for an individual Ramsey cycle,

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- Third, calculate the total N_{cycles}/day, (avg of 16.14 hr/day)
- Finally, divide the total number of cycles required by the cycles per day

$$\text{days} = \frac{N_{\text{cycles}}}{N_{\text{cycles}}/\text{day}}$$

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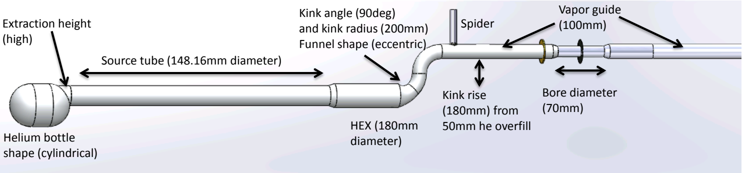
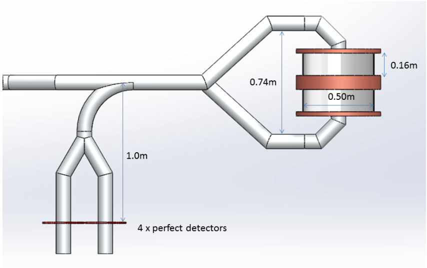
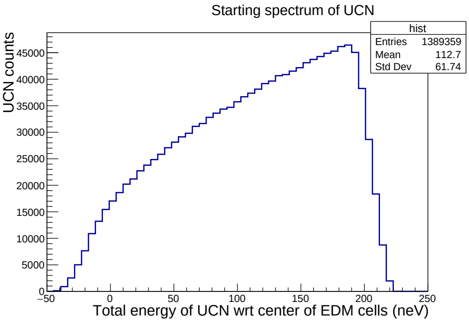
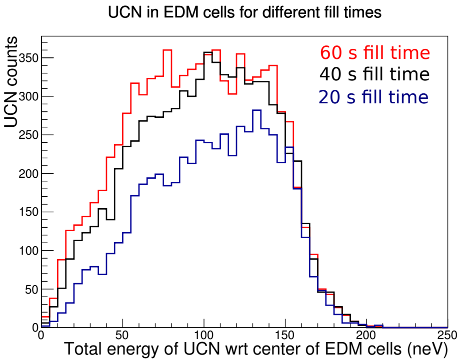
Simulation model







Simulation results and analysis



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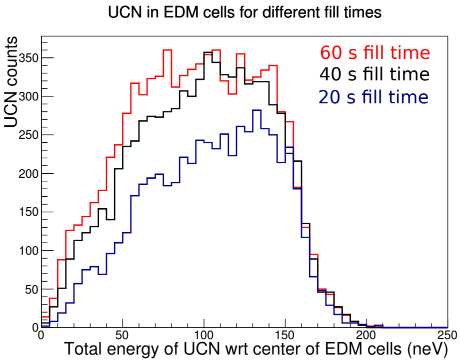

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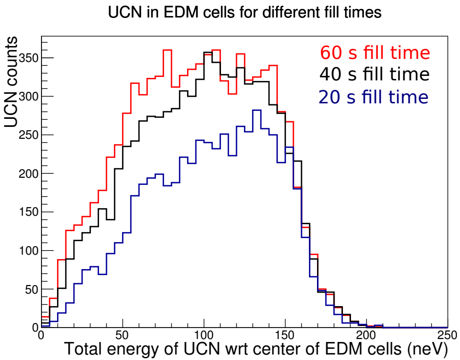

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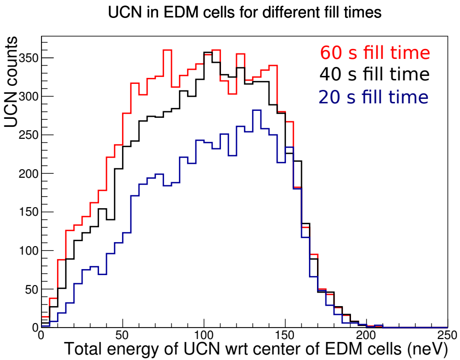

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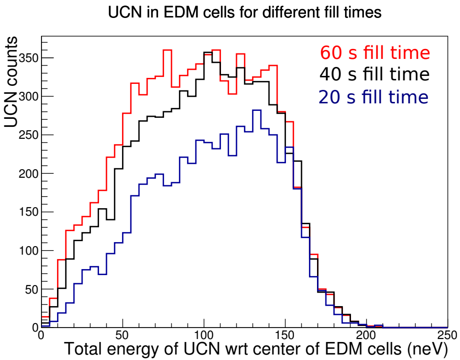

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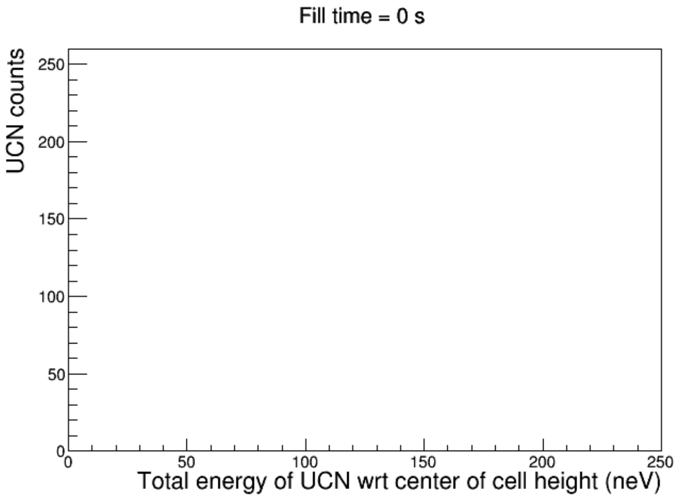
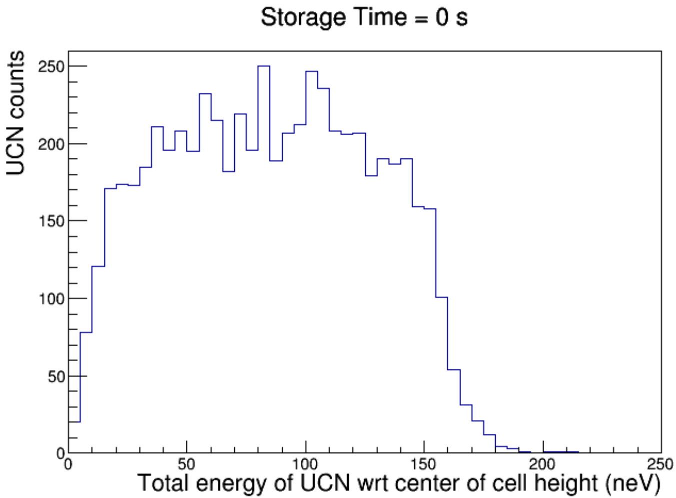
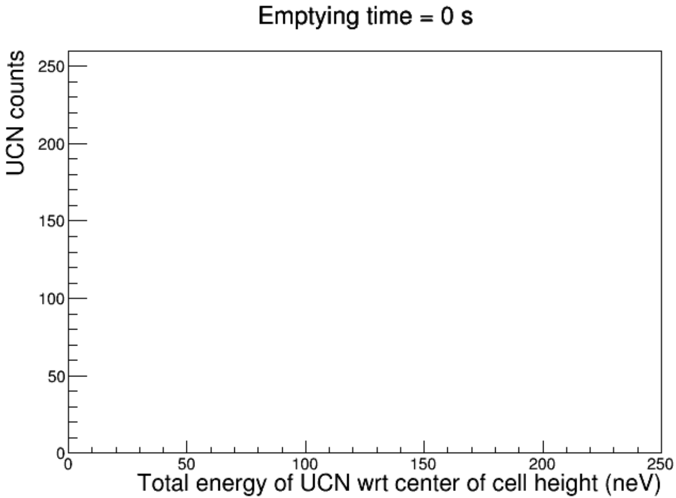
- This was a new idea for us, which I originally implemented to understand the error bars better, and it helped us understand the affect of the energy spectrum on the days-to-reach
- Main result: the energy spectrum of UCN of the entire experiment and operational timings must be optimized as a whole
- t_{fill} and t_{empty} almost doubled from before, t_{storage} also got longer, this is because of the storage lifetime of UCN


Fill time = 0 s
UCN counts
0
50
100
150
200
250
0
50
100
150
200
250
Total energy of UCN wrt center of cell height (neV)

Storage in EDM cells



Emptying to detectors



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- We used the algorithm provided by SciPy library

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- With this new method we were able to reduce the expected days-to-reach from 800 days to $<$ 400 days

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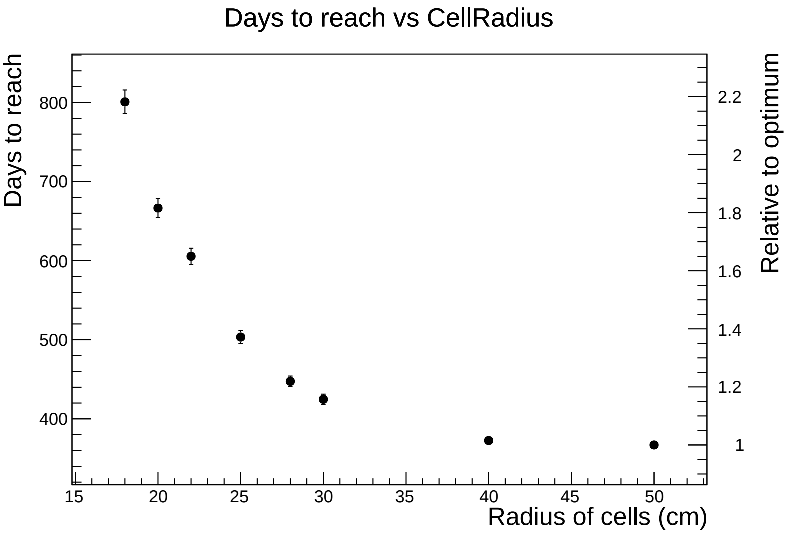
- Lower-energy UCN are favored for their longer storage lifetimes and thus longer T_{Ramsey}
- Lower-energy UCN take a longer time to transport
- It is important to optimize for timing parameters
- With this new method we were able to reduce the expected days-to-reach from 800 days to $<$ 400 days
- Thank you!

Results from source simulations

Parameter Studied	Values	Optimum	Spread from optimum (%)	Remarks	Concept Design
He bottle shape	Cyl (r=170 + 150), sph (r=180 + 38)	Sphereical	~5%	~3% better	Cylinder
He bottle material	Al6061,Al2219,AlBeMet	AlBeMet	~25%	~17-20% better	Al6061
Bottle extraction	Low, mid, high	high	~13%	dbl kink ~ 5% better than high	High extraction
Source tube diameter (mm)	100,125,150,180	150	~7%	150 ~ 4% better than 125	150
21.7KG HEX diameter (mm)	125,150,180,200	180	~60%	(KG = 21.7) 180 ~ 50% better than 150, 200	148
35KG HEX Diameter (mm)	125,148,180,200	148	~6%	148 and 125 are roughly the same	148
Funnel shape	Symmetric, asymmetric, eccentric	eccentric	~7%	eccentric ~ 4% better than Asymmetric	eccentric
Kink rise (cm)	18,23,28,33,38,43	18	~ 8%	18 ~ 2% better than next best	18
Kink radius (cm)	15,22,29,36,43,50,57	no clear optimum	~ 0	no significant difference	17.5
Kink angle (deg)	45,50,55,60,65,70,75,80,85,90	no clear optimum	~ 0	no significant difference	90
UCN guide diameter (mm)	86, 95,100,125	125	~10 %	95 ~ 7% better than 86, ~ 2% worse than 125	100
Bore guide diameter (mm)	60,65,70,75,85,100,	70	~10 %	5% better than 85mm	70
Spider location	On 45 deg kink, on and out side 90 deg kink	no clear optimum	~1 %	no significant difference	out side of 90deg kink
Cell radius (cm)	18,20,22,25,28,30,40,50	50	~100 %	30cm ~ 20% better than 25cm	25

Figure: Summary of study results and parameters in the current conceptual design model

Cell radius


Days to reach vs CellRadius
Days to reach
800
700
600
500
400
Relative to optimum
2.2
2
1.8
1.6
1.4
1.2
1
15
20
25
30
35
40
45
50
Radius of cells (cm)

Model assumptions

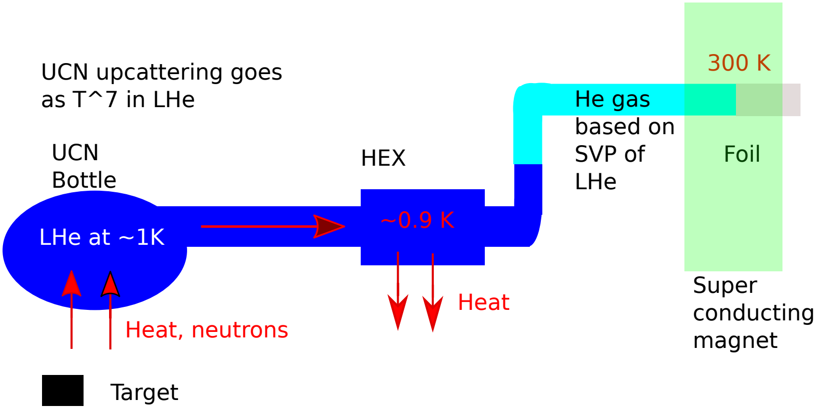


Figure: Simplified picture of simulation model

Why search for nEDM?

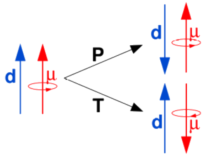


Figure: non-zero nEDM violates T and CP symmetries.

- The existence of a neutron EDM violates CP-symmetry, would imply CP violation in the quark sector

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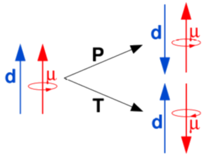

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- CP violation is one of Sakarov's requirements for Baryon Asymmetry.

Sensitivity

$$\sigma(d) = \frac{\hbar}{2\alpha E\, T_{Ramsey}\sqrt{N_{det}}}, \tag{1}$$

where

$$\alpha = \alpha_0 * e^{-t_{EDM}/T_2-(t_{wait}+2*t_{\pi/2})/T_1)} * \epsilon_{depol} * P_{analyzer}$$

with an initial visibility of $\alpha_0 = 0.95$, depolarization (5 $\%$, $\epsilon_{depol} = 0.95$), efficiency of the spin analyzers ($P_{analyzer} = 0.90$). For the simulations:

$$N_{\rm det} = N_{\rm coll} * \epsilon_{\rm det} * 0.5 * P_{real}/P_{sim} * e^{-t_{storage}/\tau_{Xe}},$$

where $\epsilon_{\rm det} = 0.90$ detector efficiency, and $N_{\rm coll}$ includes

$$N_{\rm surv} = \sum_E N_{\rm det}(E) * e^{-t_{storage}/\tau(E)}$$

Days-to-reach

The cycles to reach a sensitivity of $1 \times 10^{-27}\ e \cdot cm$ is given by

$$CTR = \left(\frac{\sigma_d}{8 * \ 1 \times 10^{-27}} \right)^2 \quad (2)$$

The cycles per day are thus given by:

$$CPD = \frac{t_{stable}}{8 * (t_{irrad} + t_{fill} + t_{EDM} + t_{empty}) + 2 * t_{flipPol} + t_{degauss}/10} \quad (3)$$

$$days = \frac{CTR}{CPD}.$$