nEDM Panda Payload Development for OLCF

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Contributions From nEDM@SNS Simulations Team

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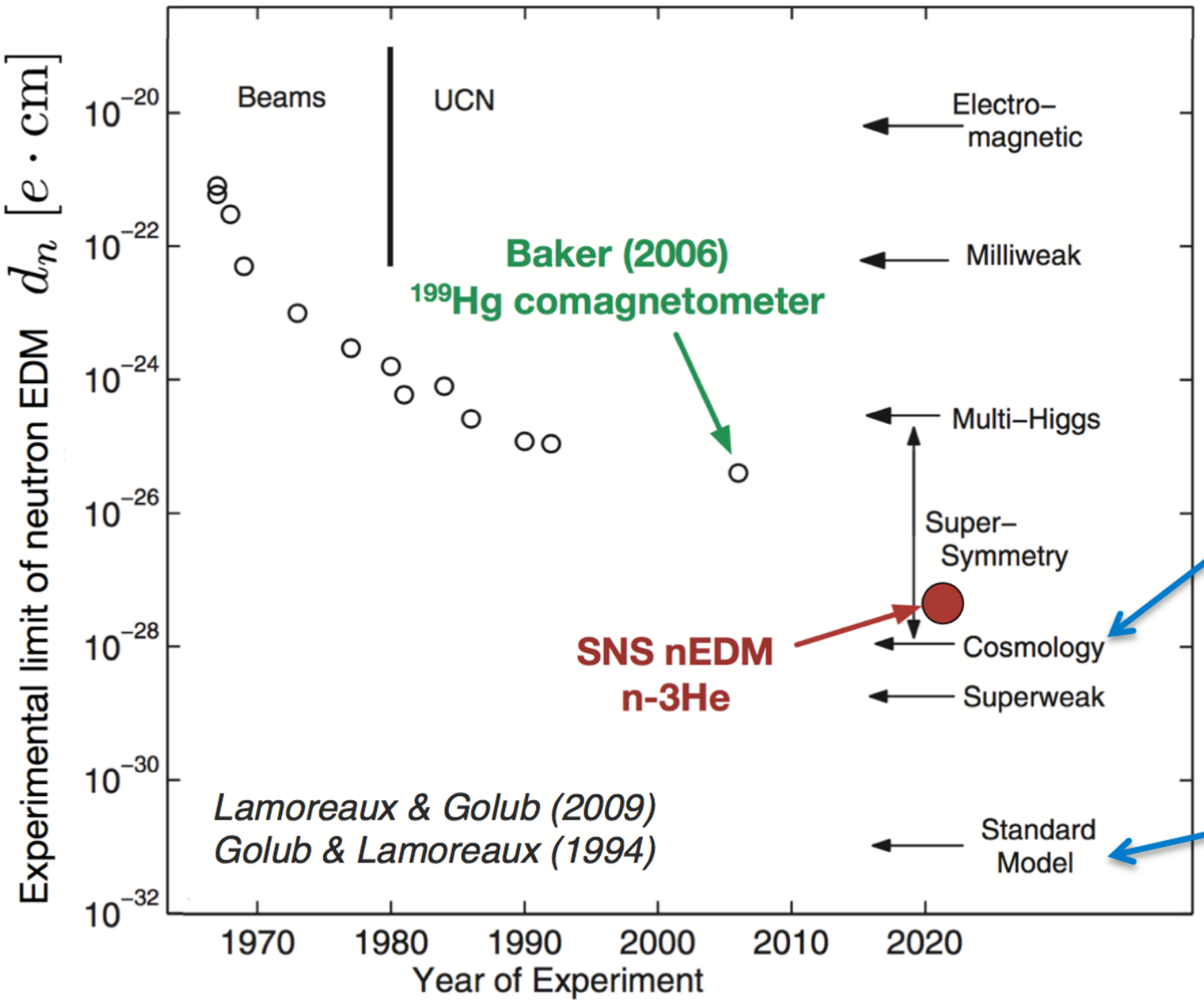
Overview of nEDM Experiment



minimum neutron EDM that produce observed baryon-asymmetry due to known CP-violation along with baryon nonconservation. *Ellis et al. (1981)*

The size of nEDM predicted from known amounts of *CP*-violation in the standard model.

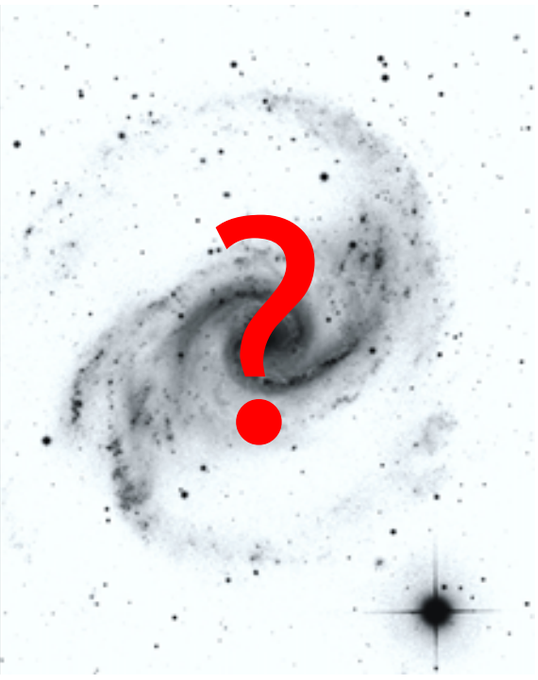
*Slide from Ken Leung.

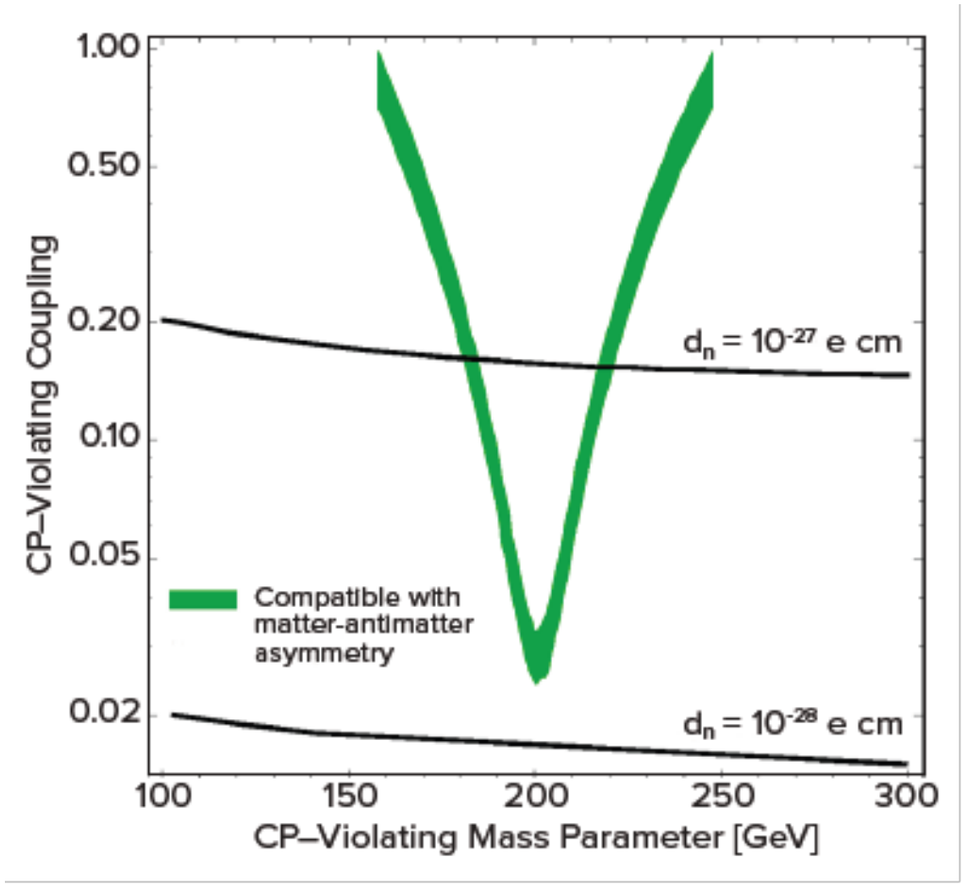
Overview of nEDM Experiment

The Physics Mystery

- Sakharov conditions for cosmic matter-antimatter asymmetry
  - Baryon number violation
  - Charge and **Charge-Parity** violation
  - Outside thermal equilibrium

- Neutron EDM sensitive to undiscovered CP-violating physics

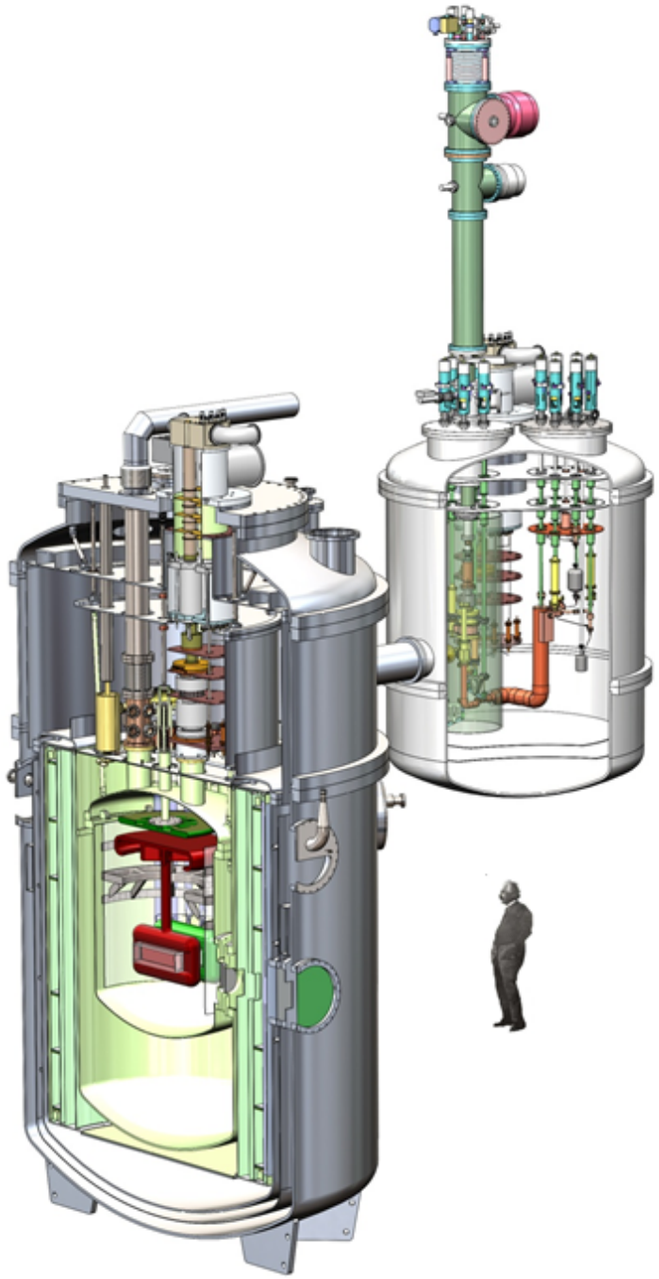




*Slide from Leah Broussard.

Overview of nEDM Experiment

- Major initiative for Physics at ORNL
- Top priority for Fundamental Neutron Physics and prominently featured in 2015 Long Range Plan
- Unprecedented sensitivity to CP violating physics
  - $d_n \sim 10^{-28}$ e-cm



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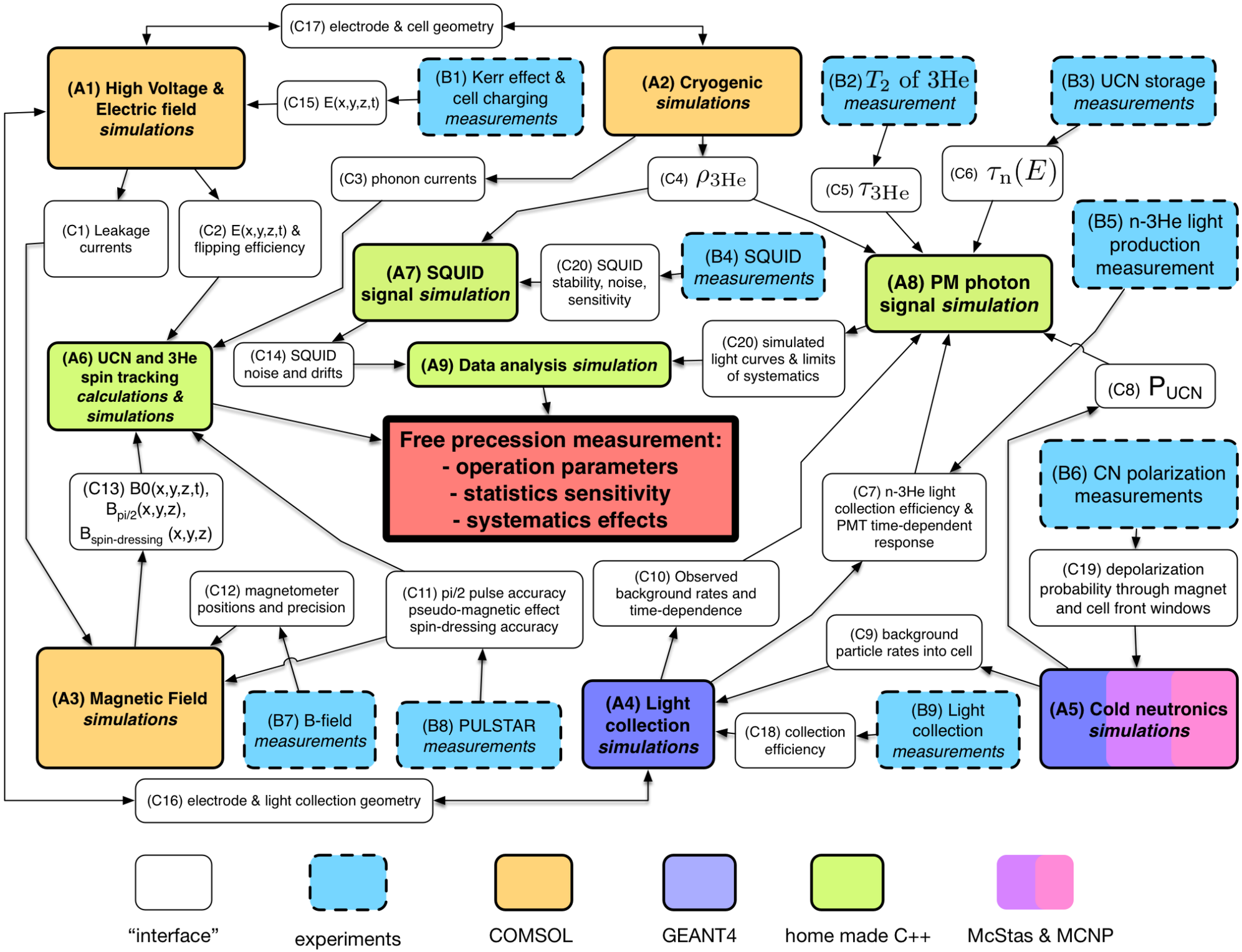
nEDM Simulations Framework



K Leung (NCSU), B Plaster (UKy), L Broussard (ORNL)

Largest Computational Needs

Data Challenge 2.0

- Experiment runs at Spallation Neutron Source 2020+
- We want to have data analysis workflows in place when data collection begins.
- Previous Data Challenge produced 10^9 simulated events with backgrounds.
- Next iteration will produce 10^{11} events: 100k Titan node-hours, or 1.6M core-hours and 20 TB of data.

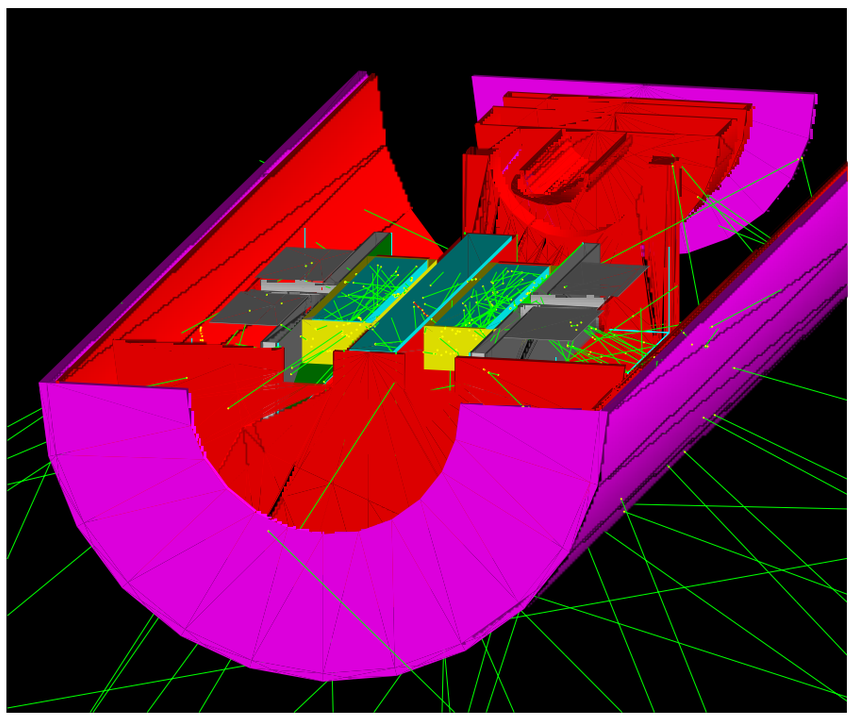
Systematic Studies

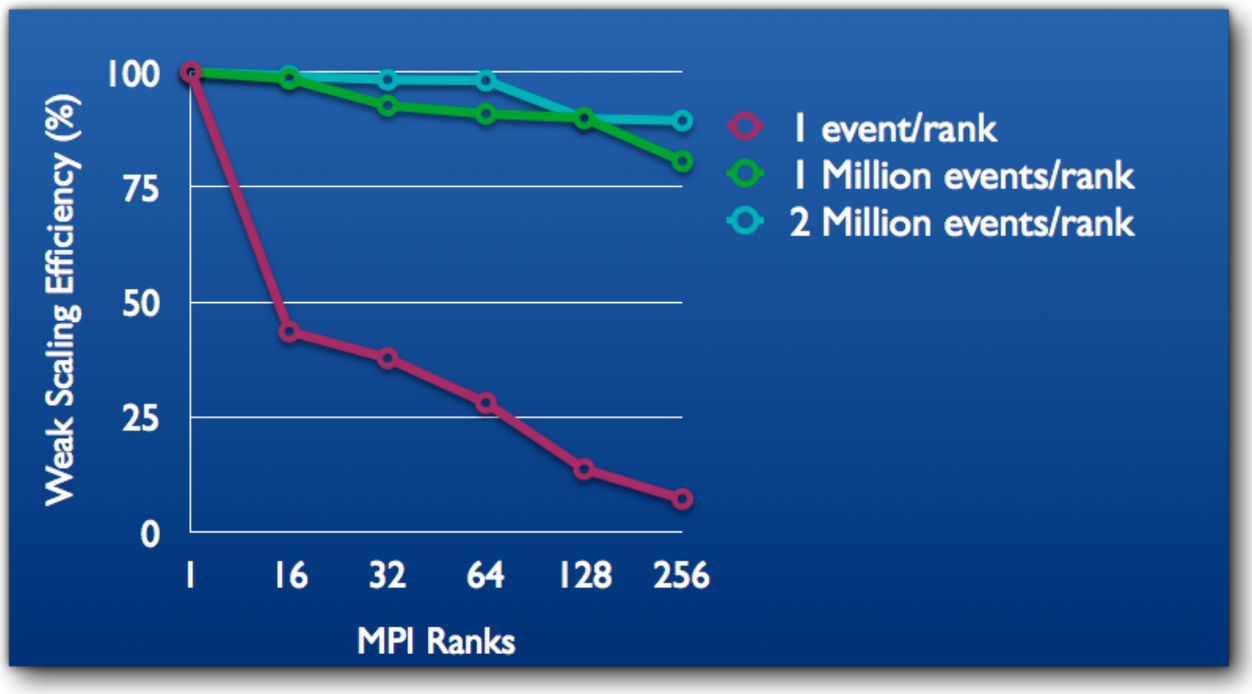
- Detailed tracking of spin propagation in magnetic field is needed to understand systematic uncertainties.
- On the order of 10^8 core-hours and 100 TB required for these studies.
- Stand alone C++ application with ROOT dependency (R. Shmid Dissertation)
- Currently being investigated for GPU vectorization.

Prior Runs on Titan

Activation Background Simulations

- Geant4.9 based simulation with MPI and no multithreading.
- One MPI rank per core.
- Demonstrated efficient weak scaling on up to 100 nodes for tasks longer than a few seconds.
- Implemented a ROOT based analysis workflow on LENS.

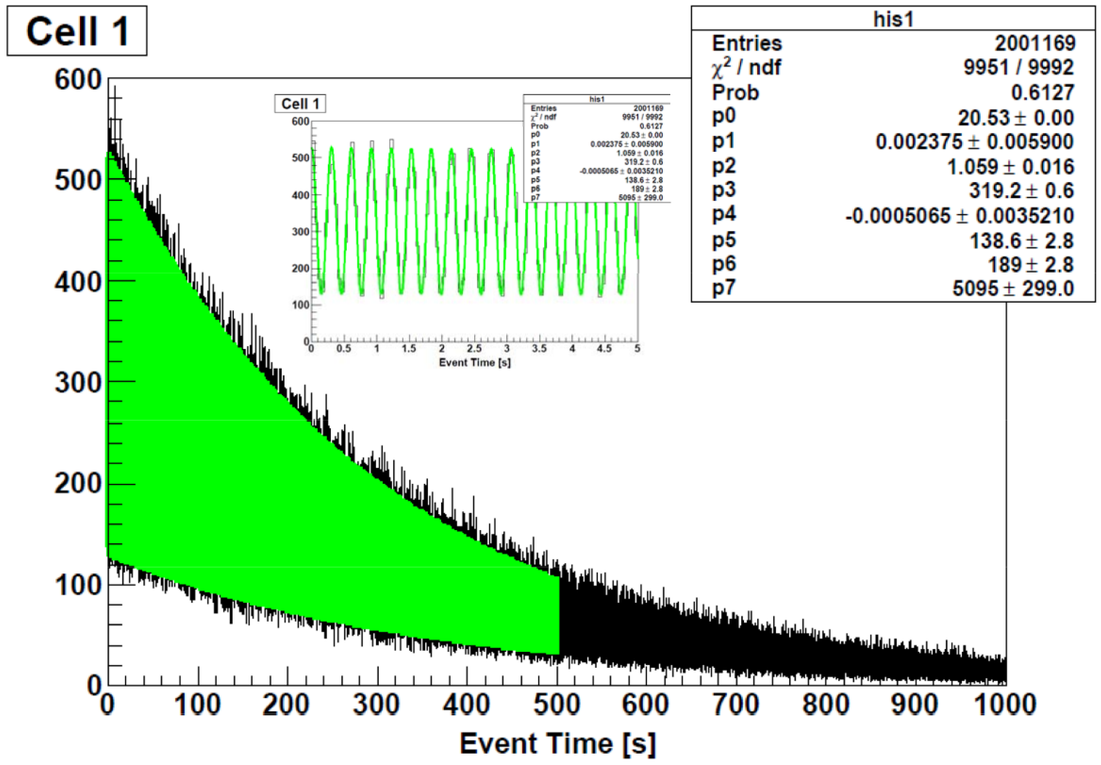




Preparations for Data Challenge

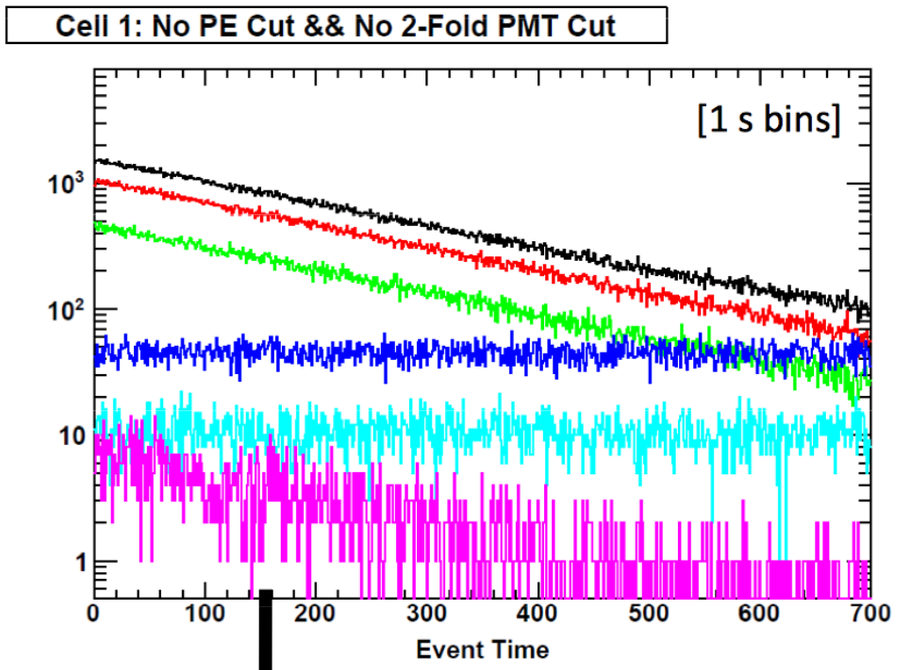
Titan Build Workflow Completed for Central Detector Simulation

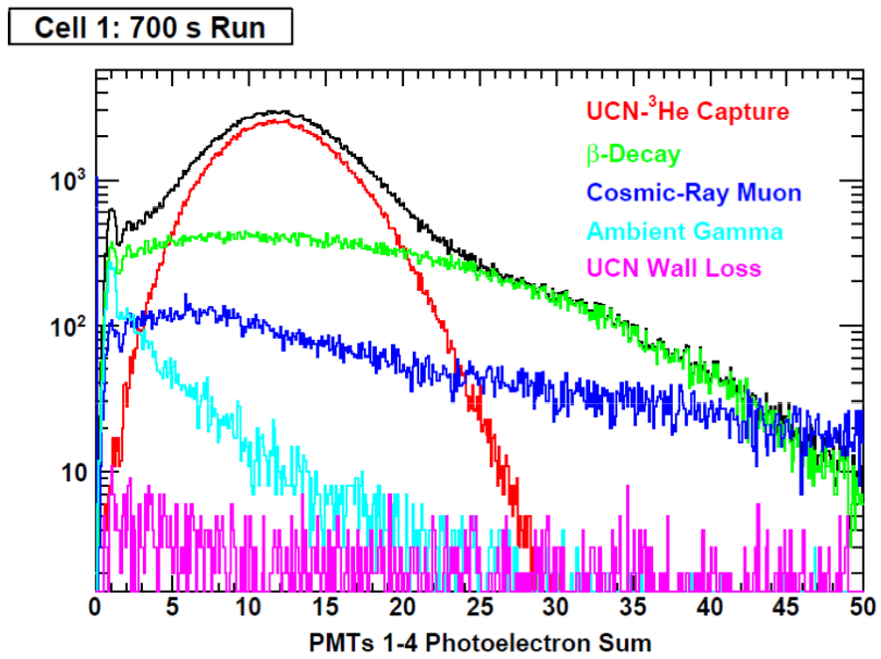
- Geant4.10.03.p01 libraries built for static linking in multithreaded mode.
- Binary built and tested based on previous Central Detector Simulation.
- Timing runs performed to provide estimates of resource needs.
- Expect to be ready to launch production runs within a month.



Expected Science Results

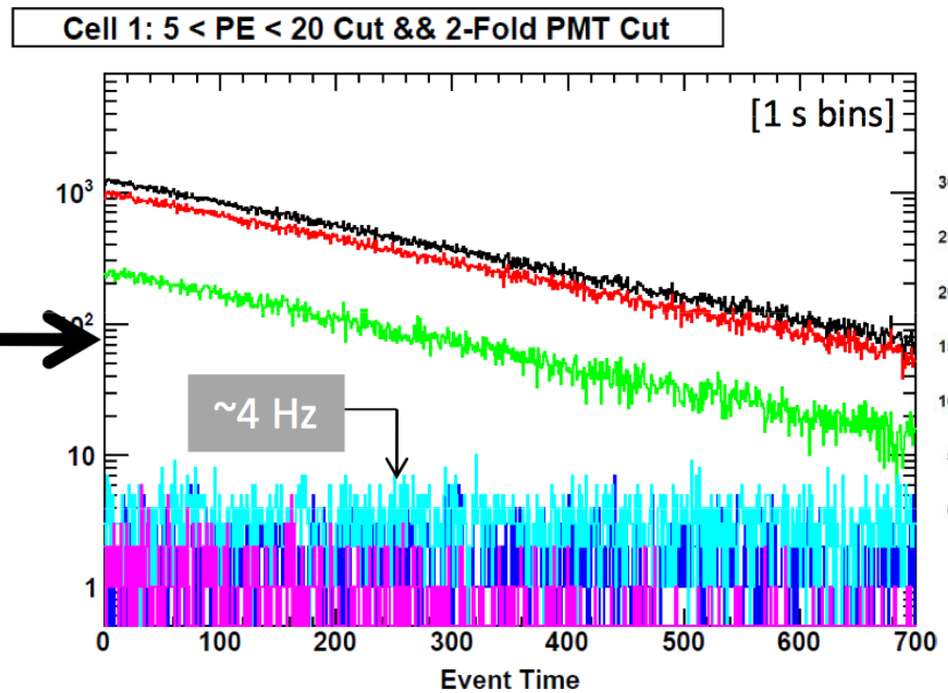
Timing and Photoelectron Spectra

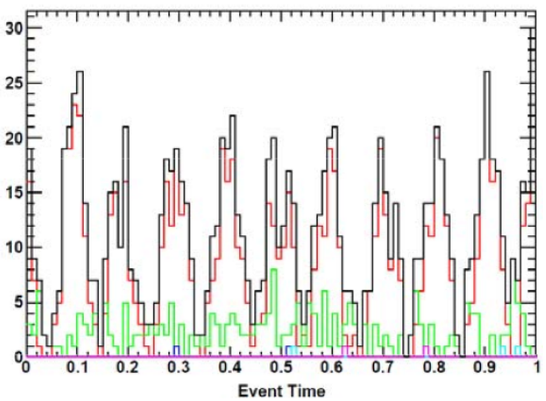




muon MIP peak at ~150

PE Cut
5 < PE < 20
&&
2-Fold PMT
Coincidence Cut





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nEDM Plans for Panda

Minimize extra workforce requirements needed to utilize available computational resources.

- No nEDM collaborators work full time on simulations, but many make intermittent contributions.

Take advantage of fine grained backfill potential.

- nEDM Central Cell Simulation can utilize as little as 36 node-seconds in an efficient manner.
- Results for Data Challenge can be accumulated over time.

nEDM Collaboration

THANK YOU!

Arizona State University

Brown University

Boston University

UC Berkeley

California Institute of Technology

Duke University

Harvard University

Indiana University

University of Illinois Urbana-Champaign

University of Kentucky

Los Alamos National Laboratory

Massachusetts Institute of Technology

Mississippi State University

North Carolina State University

Oak Ridge National Laboratory

Simon Fraser University

University of Tennessee

Valparaiso University

University of Virginia

Yale University

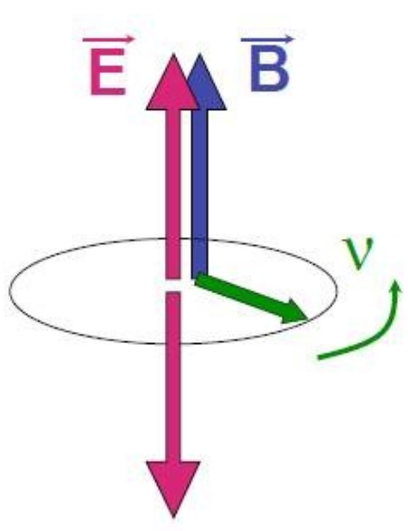
Extra Slides

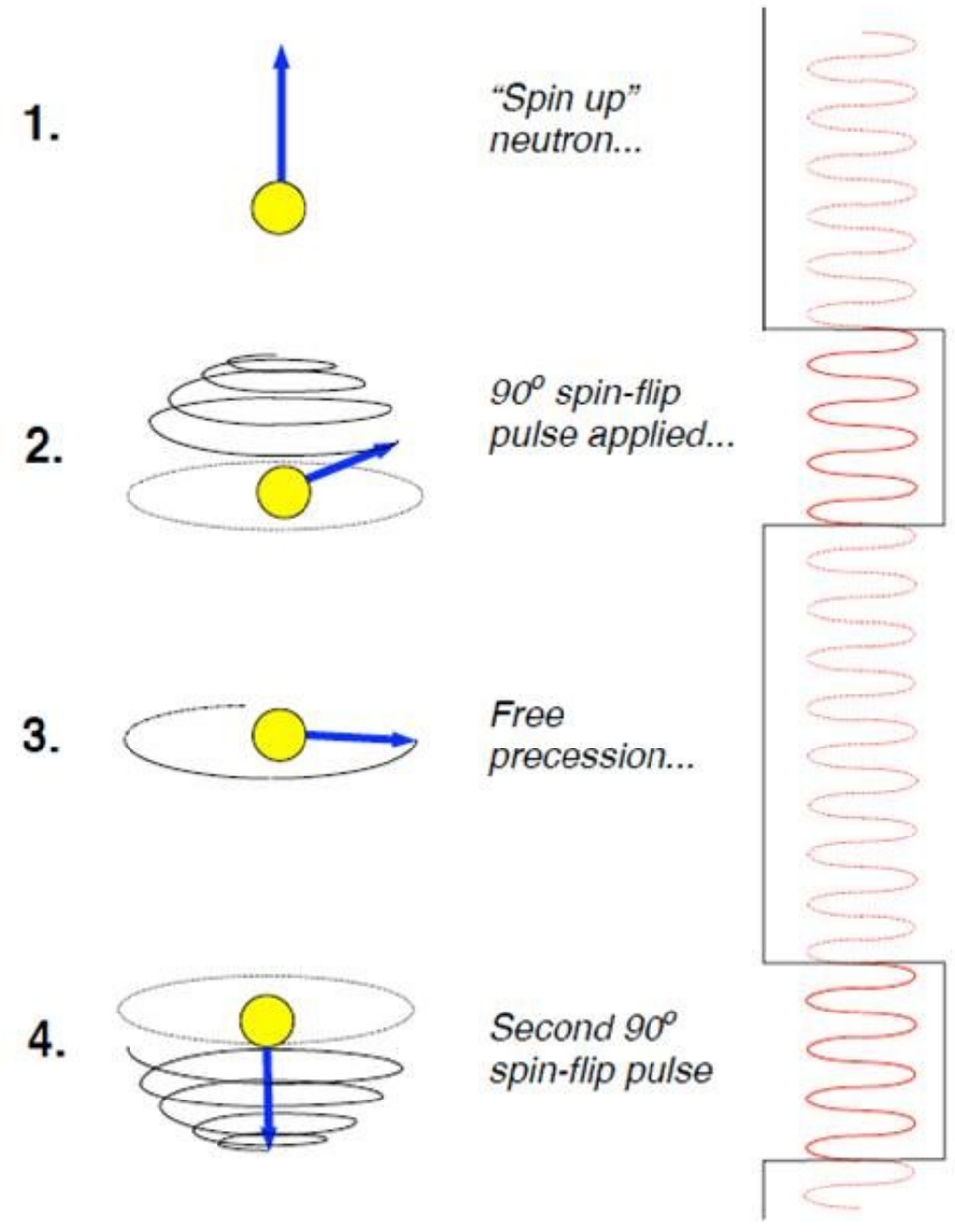
EDM Measurement Technique

- Measure change in precession frequency with parallel vs antiparallel **E**, **B** fields

$$\omega = \frac{2\vec{\mu}\cdot\vec{B} \pm 2\vec{d}\cdot\vec{E}}{\hbar}$$

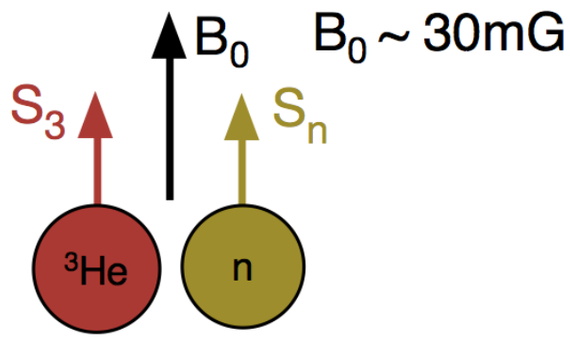
$$\Delta\omega = \frac{4dE}{\hbar}$$

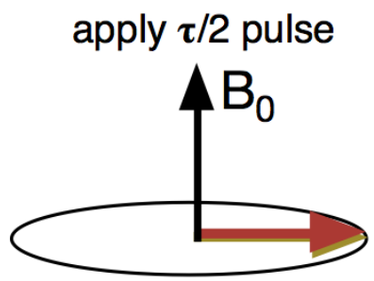


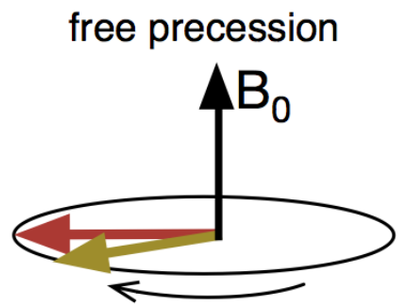


*Slide from Leah Broussard.

EDM Measurement Technique







^{3}He + n → p + ^{3}T (Q=764keV) has **spin-dependent** cross-section (@2200m/s):

Parallel spins: $\sigma_{\uparrow\uparrow} < 10\,\mathrm{b}$ Anti-parallel spins : $\sigma_{\uparrow\downarrow} \approx 11\,\mathrm{kb}$

Scintillation light signal: $1 - P_n\,P_3\,\cos\theta_{\mathrm{n3}}(t)$

← angle between n & ^{3}He spins

Effects of He-3 EDM suppressed by Schiff screening so that:

$$\theta_{\mathrm{n3}} = |\gamma_n - \gamma_3|B_0 t \pm \frac{e d_n |E|}{\hbar} t \qquad \gamma_3 \approx 1.1\,\gamma_{\mathrm{n}} \qquad \gamma_3 B_0/(2\pi) \approx 100\,\mathrm{Hz}$$

Measure ^{3}He precession $\gamma_3 B_0/(2\pi)$ with SQUIDS => sensitivity $\approx 5 \times 10^{-28}\,e.\mathrm{cm}$

Alternative dressed-spin technique: apply strong RF ($B_{\mathrm{rf}} \sim 1\,\mathrm{G}$ $\omega_{\mathrm{rf}}/(2\pi) \sim 3\,\mathrm{kHz}$) and increase sensitivity of exp.

*Slide from Ken Leung.