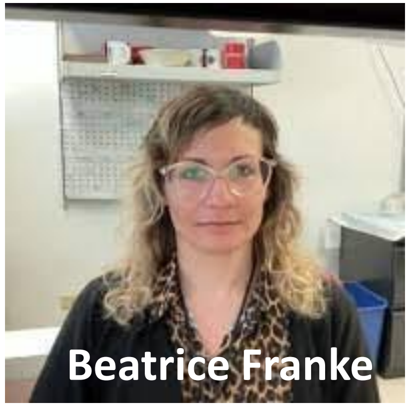
Tests of Electroweak Symmetries



Conveners: Nadia Fomin, Beatrice Franke, Stephanie Roccia, Jordy de Vries

Presented by Russell Mammei

Sessions 1 & 2: EDM Searches & T Reversal Symmetry Violation

1. **Electric Dipole Moments from Lattice QCD** (Andrea Shindler)
2. A Cryogenic Search for the Neutron Electric Dipole Moment at the Spallation Neutron Source (Alina Aleksandrova)
3. **The Los Alamos Neutron EDM experiment** (Alec Tewsley-Booth)
4. The TRIUMF UltraCold Advanced Neutron surce and EDM experiment (Wofgang Schreyer and Russell Mammei)

1. **The search for Permanent Electric Dipole Moments Using Pear-Shaped Nuclei in the FRIB Era** (Jaideep Singh)
2. Beam EDM – A pulsed beam experiment to search for the neutron electric dipole moment (Florian Piegsa)
3. **The search for Electric Dipole Moment (EDM) of 199Hg and its application to the LANL Neutron EDM Experiment** (Jennie Chen)
4. NOPTREX: Searching for Signals of Time-Reversal Violation in Polarized Neutron-Nuclear Resonance Spectroscopy (Danielle Schaper)

Neutron EDM from Lattice QCD

Quark EDM —>
simplest calculation with Lattice QCD. Precision 3%-5%. No Disc.

Theta-term nucleon EDM —> few calculations: 2 σ effect

—> new preliminary results have stronger signal

3 gluon operator —> No Lattice QCD calculation, but now new promising approach

Quark-chromo EDM —>
Only preliminary (bare) lattice QCD calculations
New promising approach based on gradient flow —> first results on renormalization

	Renormalization	Continuum limit	Chiral extrapolation	Finite Volume	Excited States
θ - term	green	green	yellow	yellow	yellow
quark EDM	green	green	green	green	green
quark-chromo	green	red	yellow	red	red
3-gluon	yellow	red	yellow	red	red
4-fermion	red	red	red	red	red

A. Shindler: 08/31

Neutron EDM from Lattice QCD

	Renormalization	Continuum limit	Chiral extrapolation	Finite Volume	Excited States
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3-gluon	yellow	red	yellow	red	red
4-fermion	red	red	red	red	red

Shindler, Luu, de Vries: Phys.Rev.D 92 (2015) 9, 094518

Bhattacharya, Cirigliano, Gupta, Mereghetti, Yoon: Phys.Rev.D 92 (2015) 11, 114026

Bhattacharya, et al.: Phys. Rev. Lett. 115 (2015) 21, 212002

Abramczyk et al.: Phys.Rev.D 96 (2017) 1, 014501

Dragos, Luu, Shindler, de Vries, Yousif: Phys.Rev.C 103 (2021) 1, 015202

Rizik, Monahan, Shindler: Phys.Rev.D 102 (2020) 3, 034509

Bhattacharya, Cirigliano, Gupta, Mereghetti, Yoon: Phys.Rev.D 103 (2021) 11, 114507

Alexandrou, Athenodorou, Hadjiyiannakou, Todaro (ETMC): Phys.Rev.D 103 (2021) 5, 054501

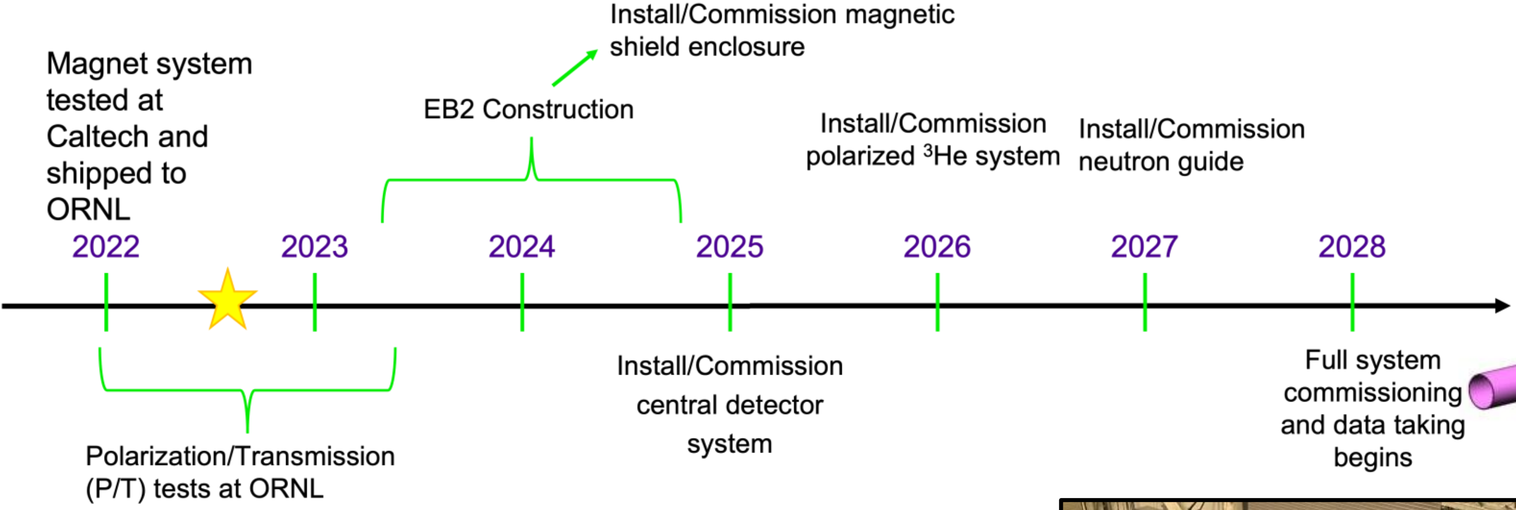
Shindler: Eur.Phys. J.A 57 (2021) 4, 128

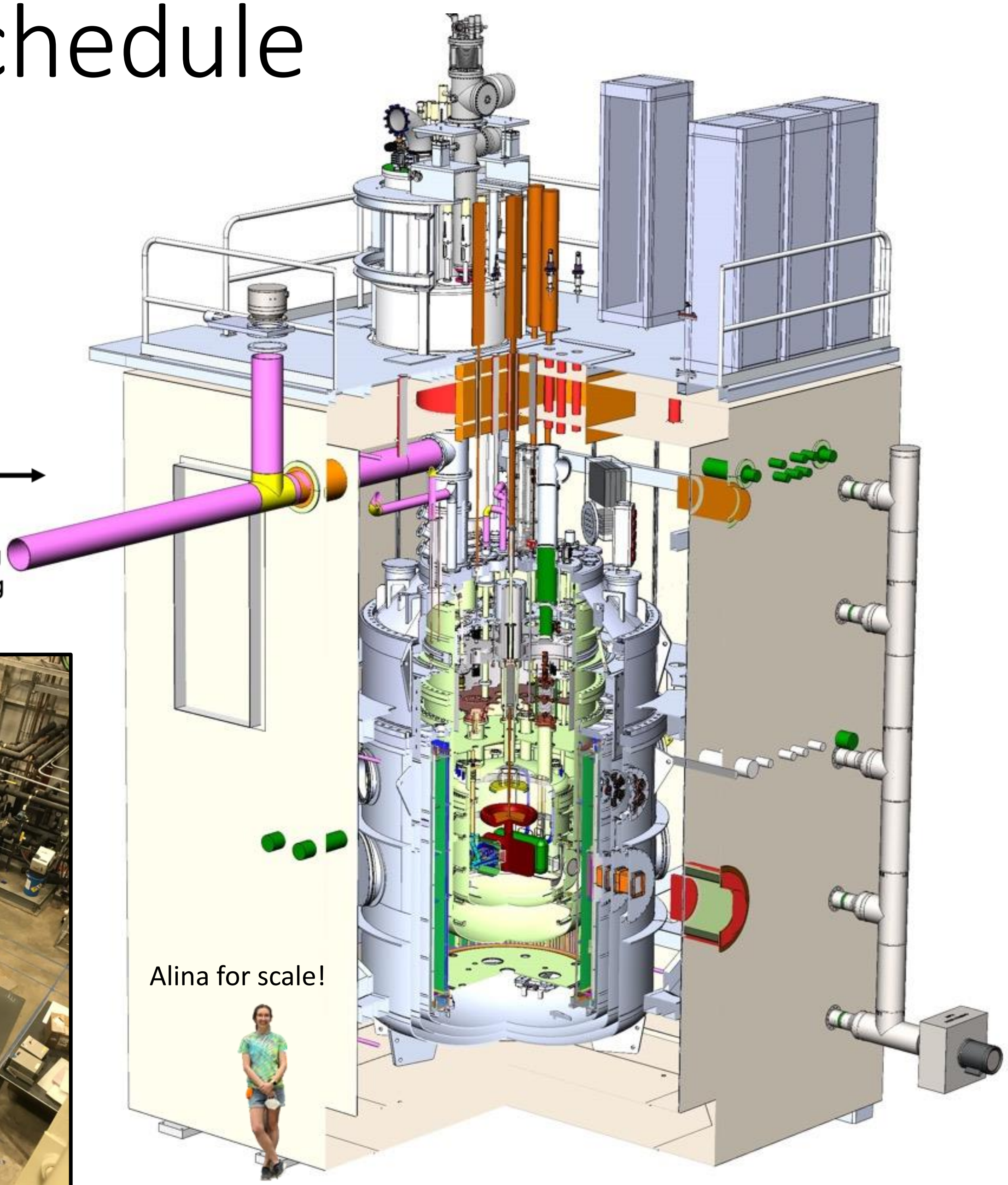
Kim, Luu, Rizik, Shindler: Phys.Rev.D 104 (2021) 7, 074516

Mereghetti, Monahan, Rizik, Shindler, Stoffer: JHEP 04 (2022) 050

Goal: 3×10^{-28} ecm

nEDM@SNS Schedule

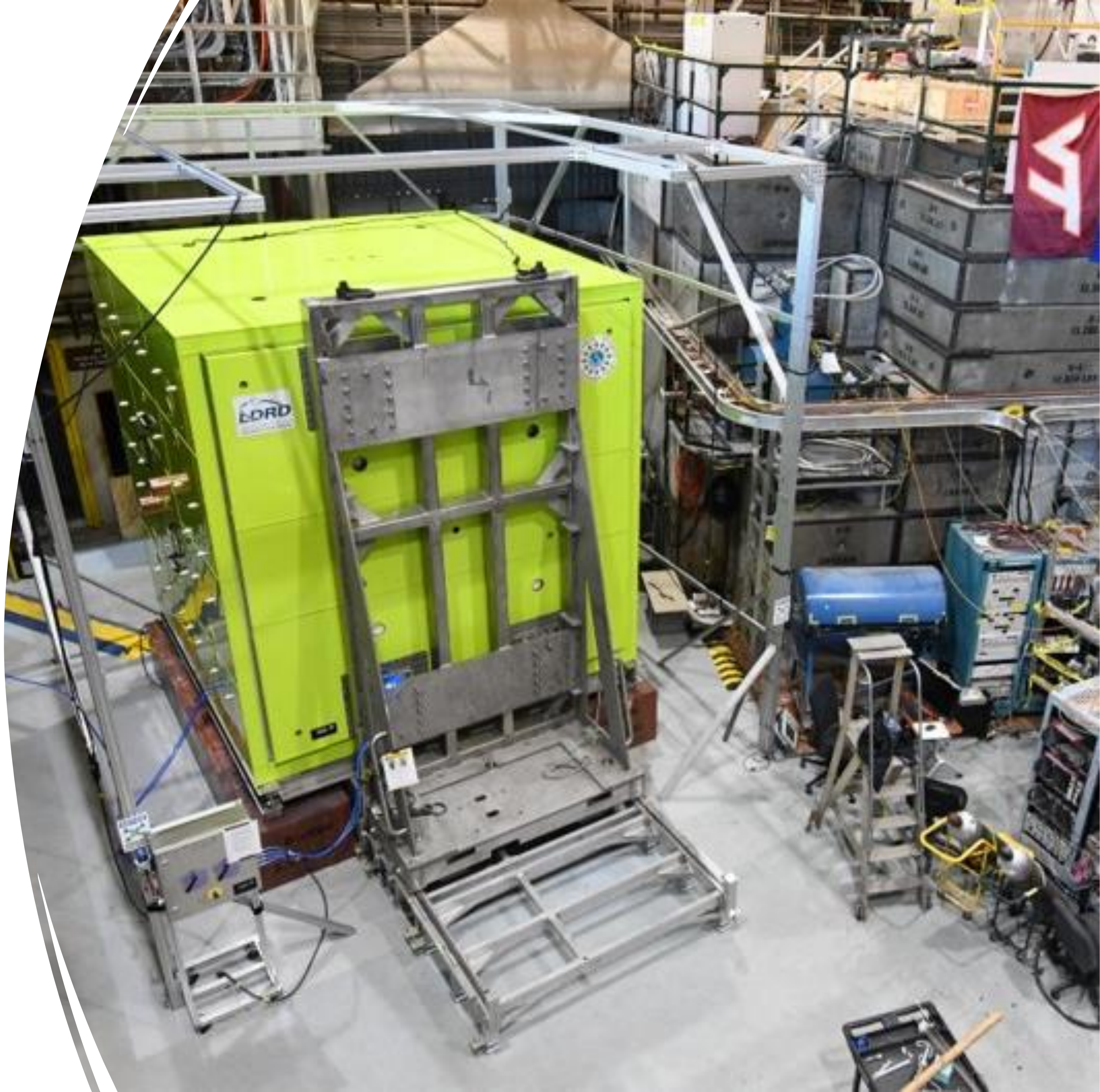




Los Alamos nEDM Update

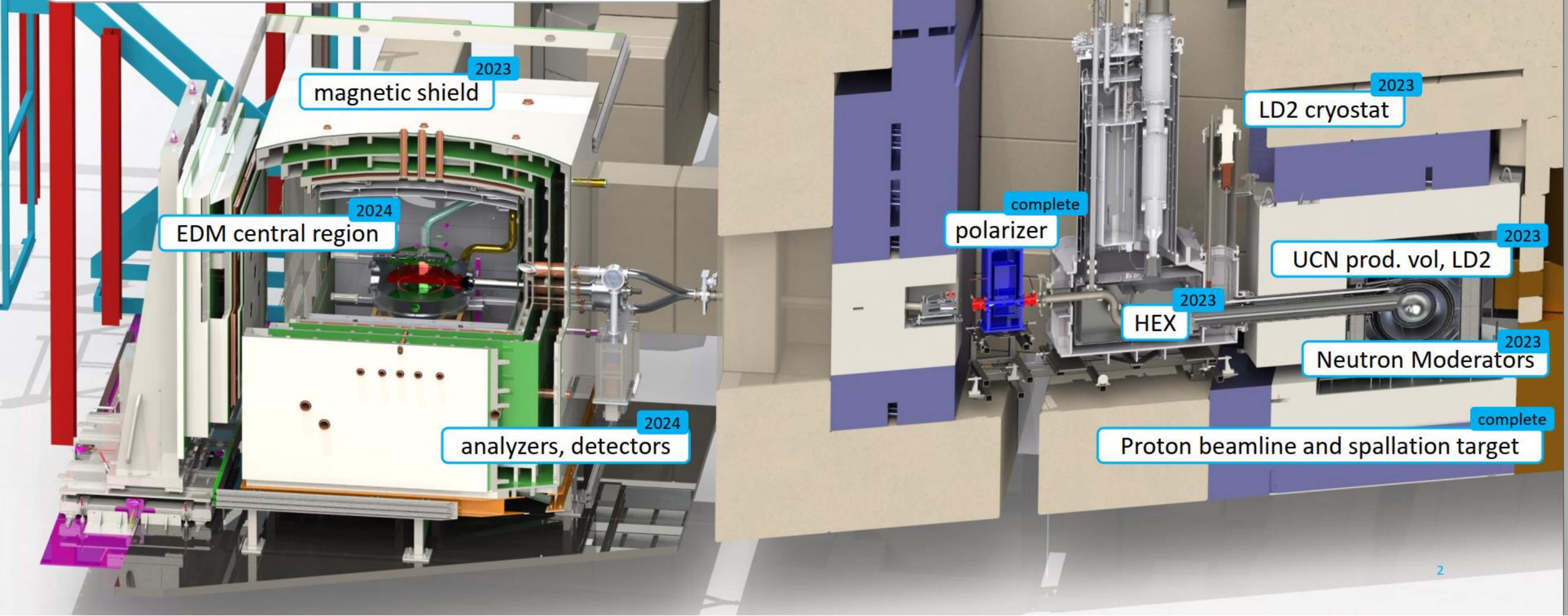
- Magnetically shielded room and B_0 coils installed, characterization under way
- Neutron transport and storage being installed now, hope to demonstrate storage this month
- Magnetometry currently under assessment
- Hg co-magnetometry under development (see ^{199}Hg talk by Jennie Chen)

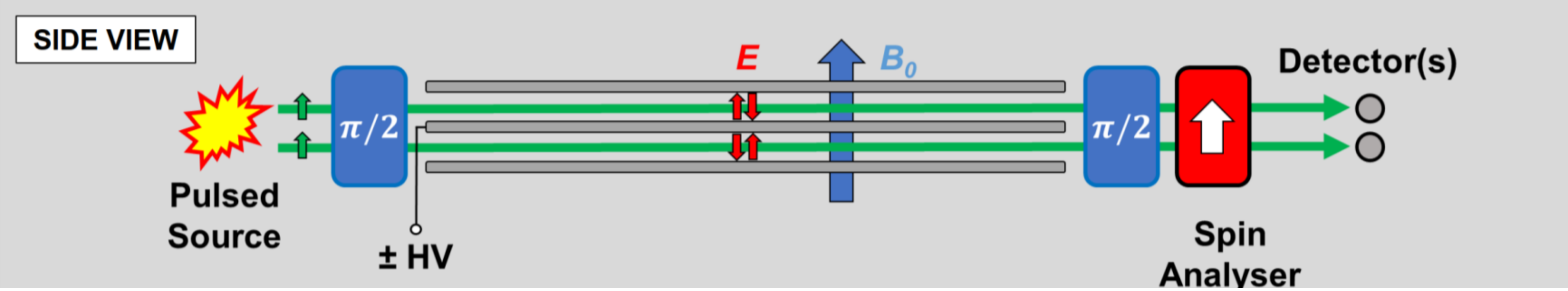
Goal: 2.1×10^{-27} ecm



Main ingredients and status

- Cryogenic commissioning starting this year
- UCN source commissioning with beam starting 2023.
- EDM magnetics commissioning starting 2023.
- EDM beam commissioning starting 2024.





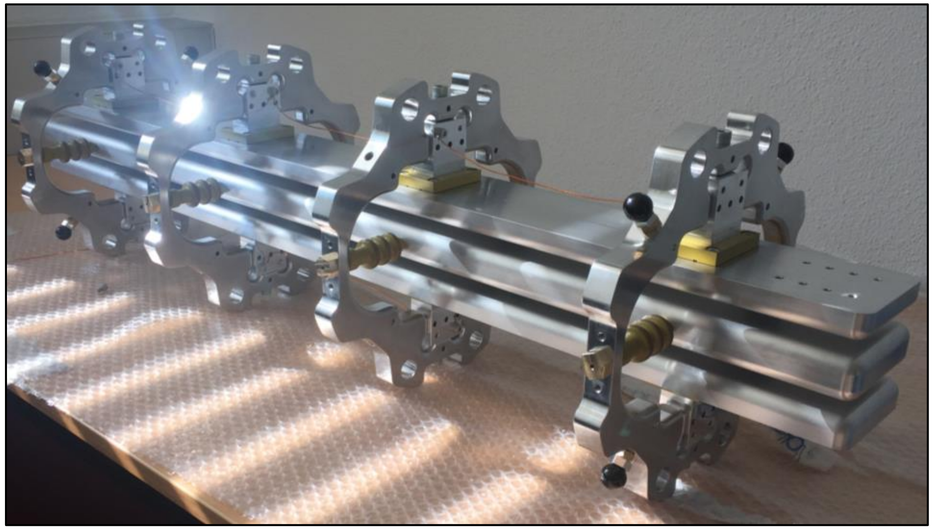
UNIVERSITÄT BERN
AEC ALBERT EINSTEIN CENTER FOR FUNDAMENTAL PHYSICS

Beam EDM represents a new complimentary neutron EDM experiment using a pulsed beam.

Successful proof-of-principle data has been taken at PSI and ILL.

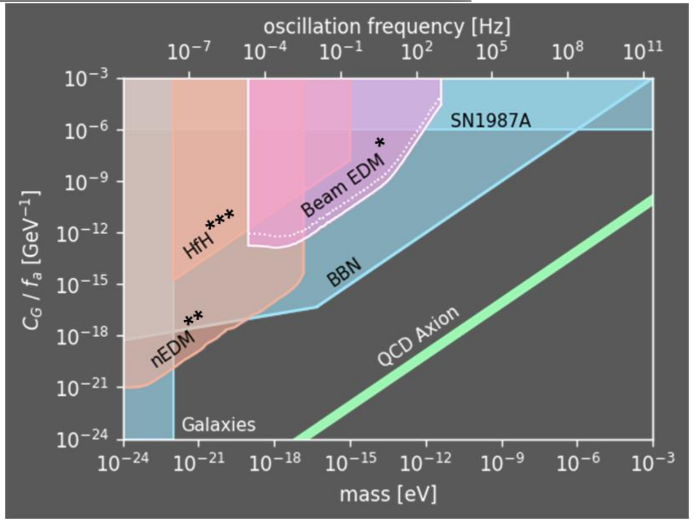
Projected Sensitity on ANNI at ESS:

$$\sigma(d_n) \approx 5 \times 10^{-26} \text{ e cm per day}$$



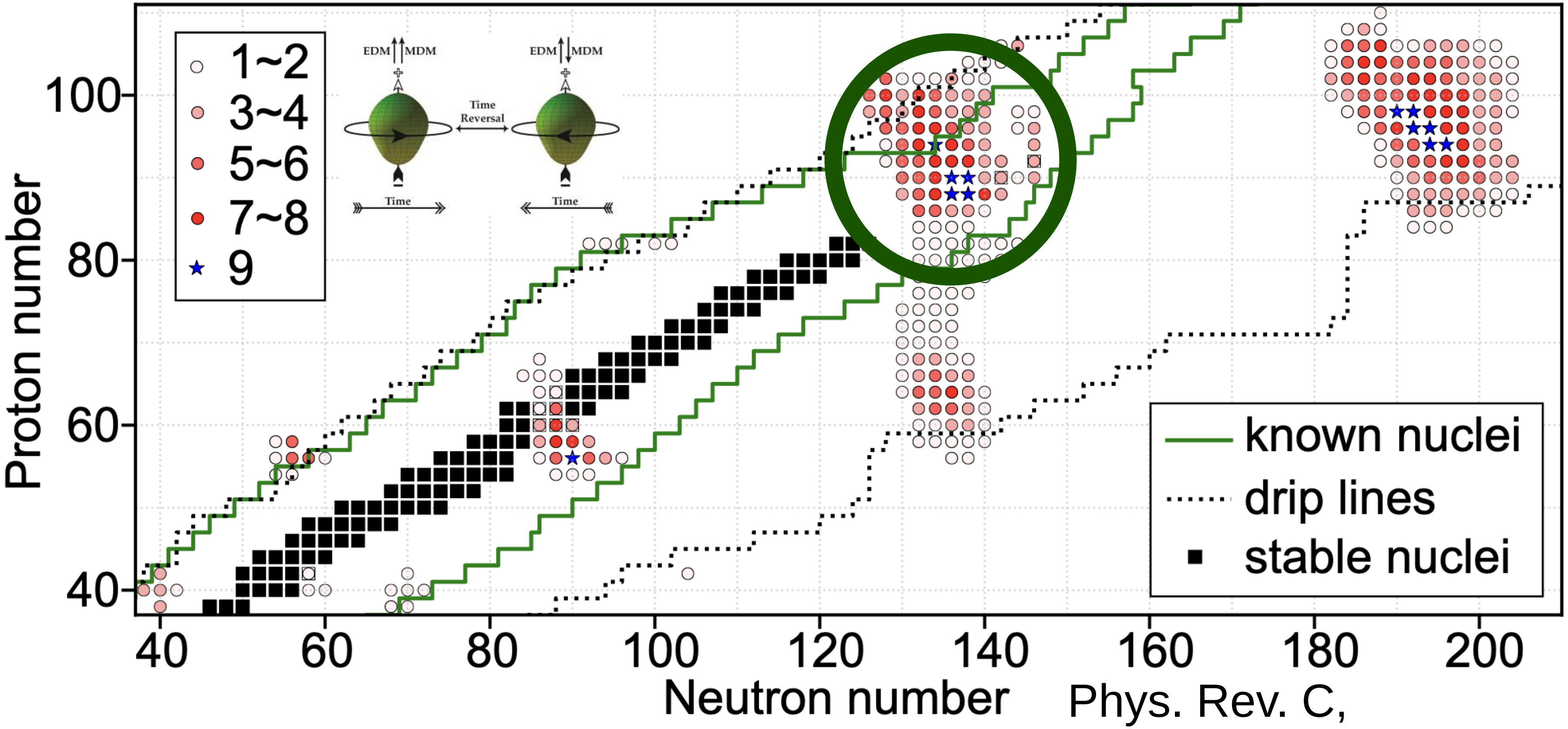
Use Beam EDM apparatus to search for ultralight **axion-like particles** (ALPs) via an oscillating EDM.

***Schulthess et al., arXiv:2204.01454**



Summary Slide – Pear Shaped Nuclei - JTS

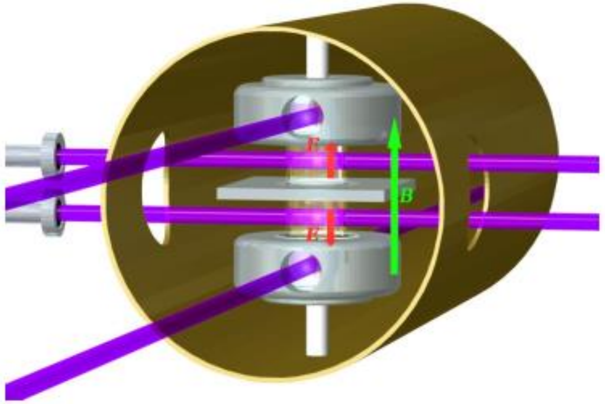
- **Short-lived radioactive molecules with pear-shaped nuclei** potentially have **x10^5 to x10^{10}** more new physics sensitivity than Hg-199 to CP-violation in the hadronic sector on a per atom basis.
- **Isotope harvesting and radiochemistry at FRIB** enables access to these enhancer isotopes in practical quantities for ultrasensitive CP-violation searches.

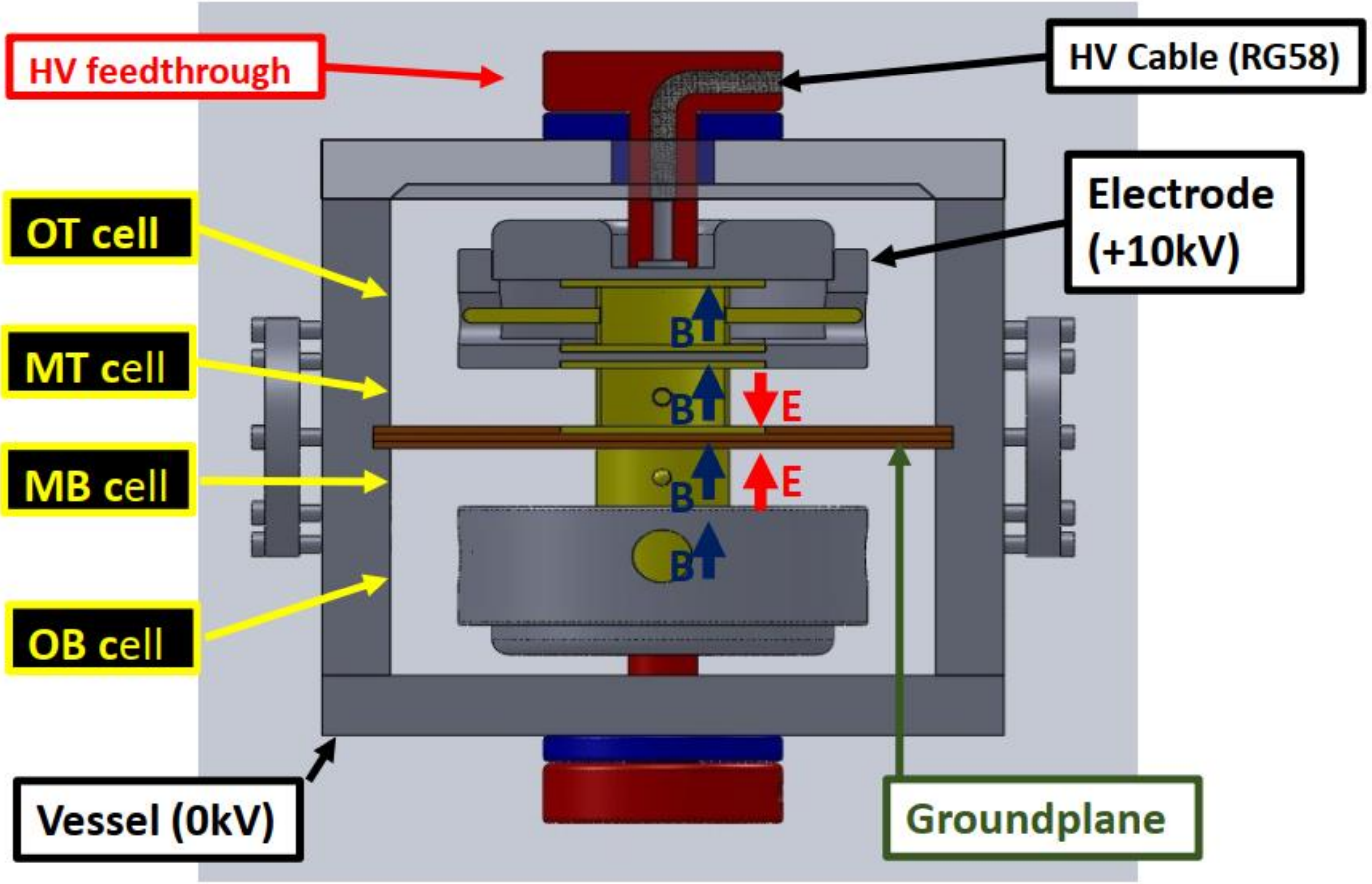


Phys. Rev. C, 102:024311 (2020)

Hg-199 Vapor Cell

Seattle's Hg EDM Experiment

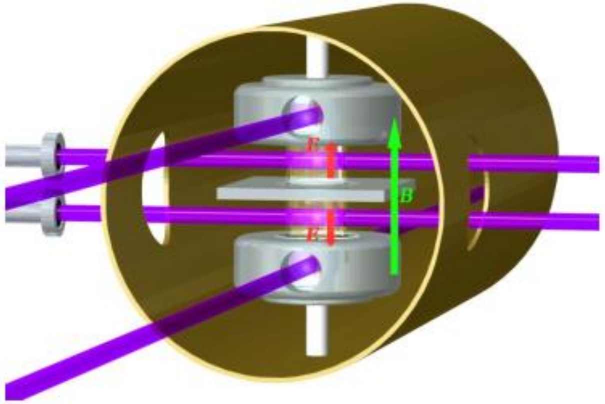


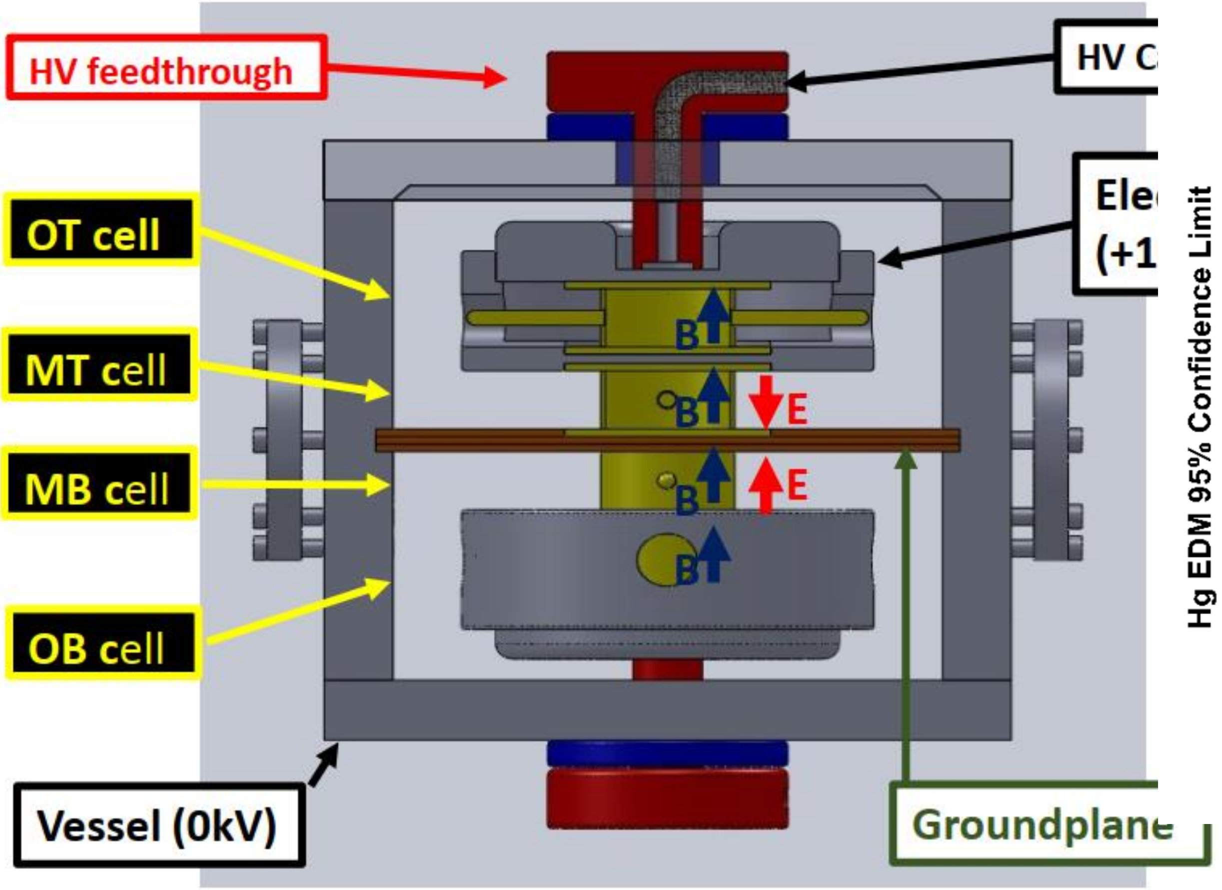


- A stack of four Hg vapor cells
- The fused-silica plate defines the ground
- The outer two cells sit inside of HV electrodes and serve as magnetometers.
- The vessel sits inside the three-layer mu-metal shields.

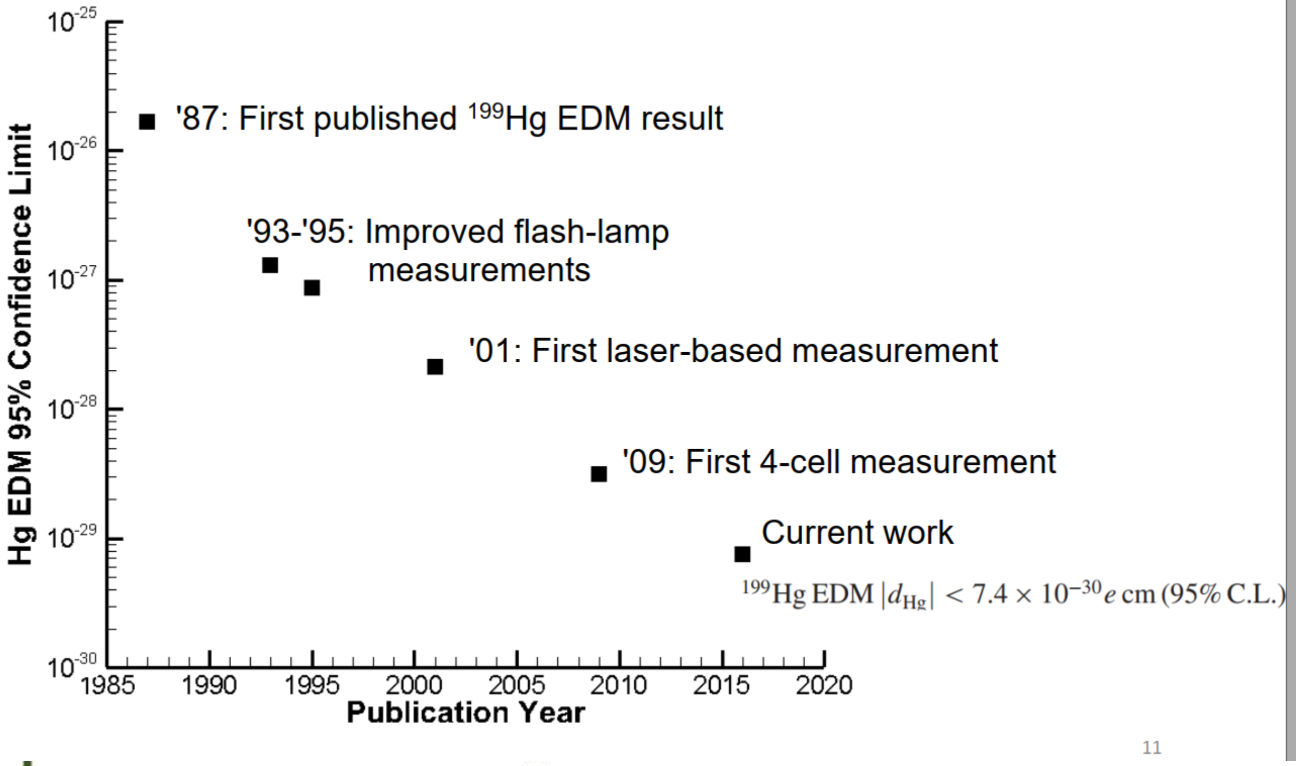
Seattle's Hg EDM Experiment

Hg-199 Vapor Cell





Hg EDM Limits vs. Time



Sessions 3 & 4: Beta Decay

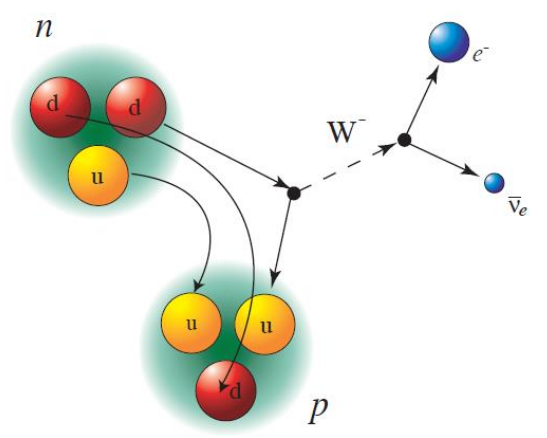
1. **Large Deviations to neutron beta decay radiative corrections (Leendert Hayen)**
2. Ultra-cold Neutron Measurement of Proton branching ratio in neutron Beta decay (UCNProbe) Zhaowen Tang
3. **Searching for Chirality Flipping Interaction via Microwaves (Heather Harrington)**
4. Status Update on the PEN Experiment (Charles Glaser)

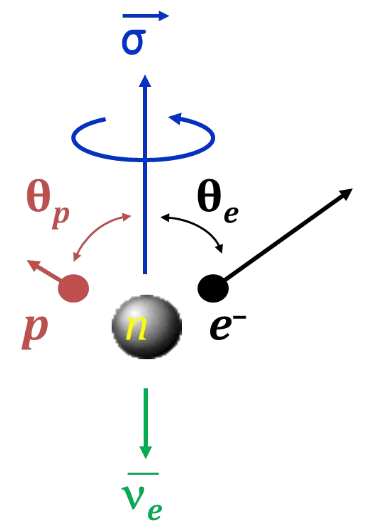
1. **Measuring the Neutron Beta-Neutrino Correlation with the aCORN Experiment (Fred Wietfeldt)**
2. The Nab Experiment at Oak Ridge National Lab and Si detector testing results with the 30 keV proton accelerator at Umanitoba (Russel Mammei)
3. **Decay correlation measurements with PERKEO III and PERC (Bastian Markisch)**
4. Results from the aSPECT Experiment (Stefan Baessler)
5. **Searches for n-n' oscillation: Constraining the direction of a mirror magnetic field bound to the reference frame of the Earth (Prajwal Mohanmurthy)**
6. Experimental Searches for n→ n' Oscillations At the Spallation Neutron Source (Fransisco Gonzalez)

Neutron Beta Decay

$$dw \propto \rho(E_e)\cdot(1+2|\lambda|^2)\cdot\{1+a\frac{\vec{p}_e\cdot\vec{p}_\nu}{E_eE_\nu}+b\frac{m_e}{E_e}+\vec{\sigma}_n\cdot(A\frac{\vec{p}_e}{E_e}+B\frac{\vec{p}_\nu}{E_\nu}+D\frac{\vec{p}_e\times\vec{p}_\nu}{E_eE_\nu})\}$$

Jackson J D, Treiman S B and Wyld H W 1957 Phys. Rev. 106 517



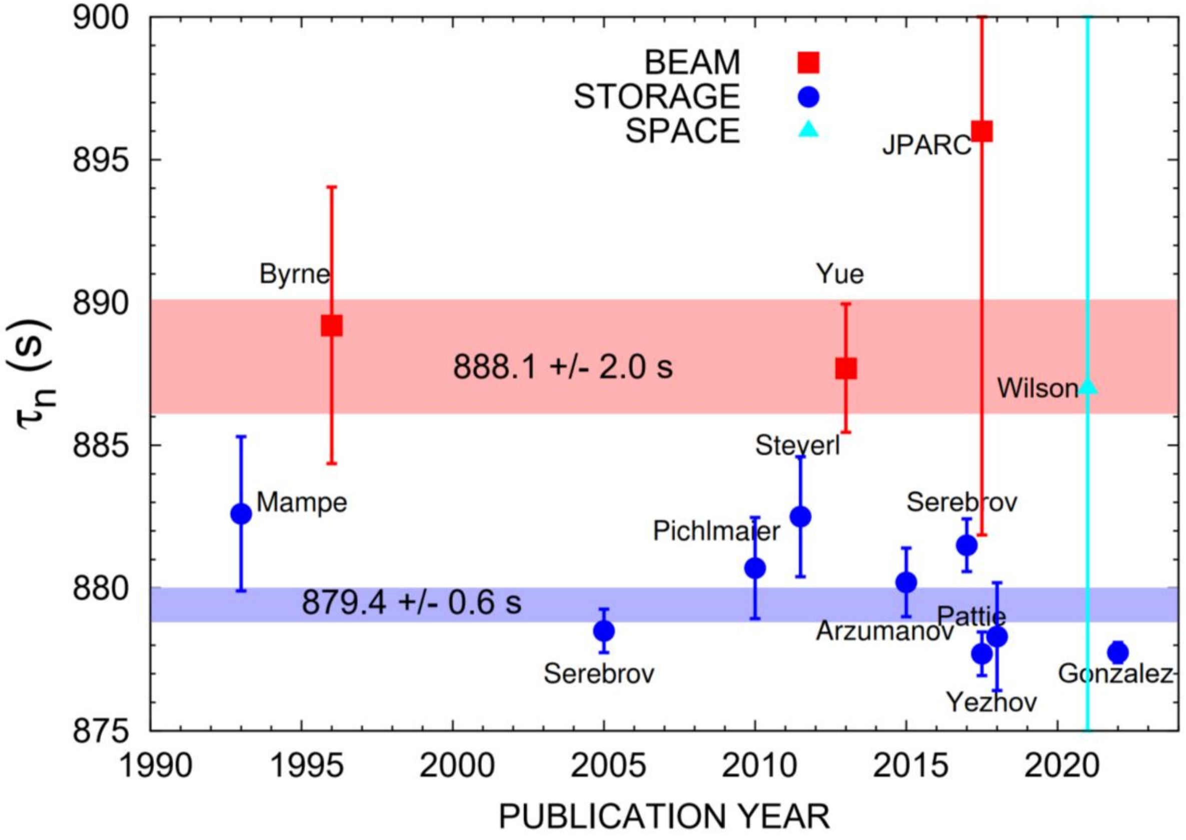


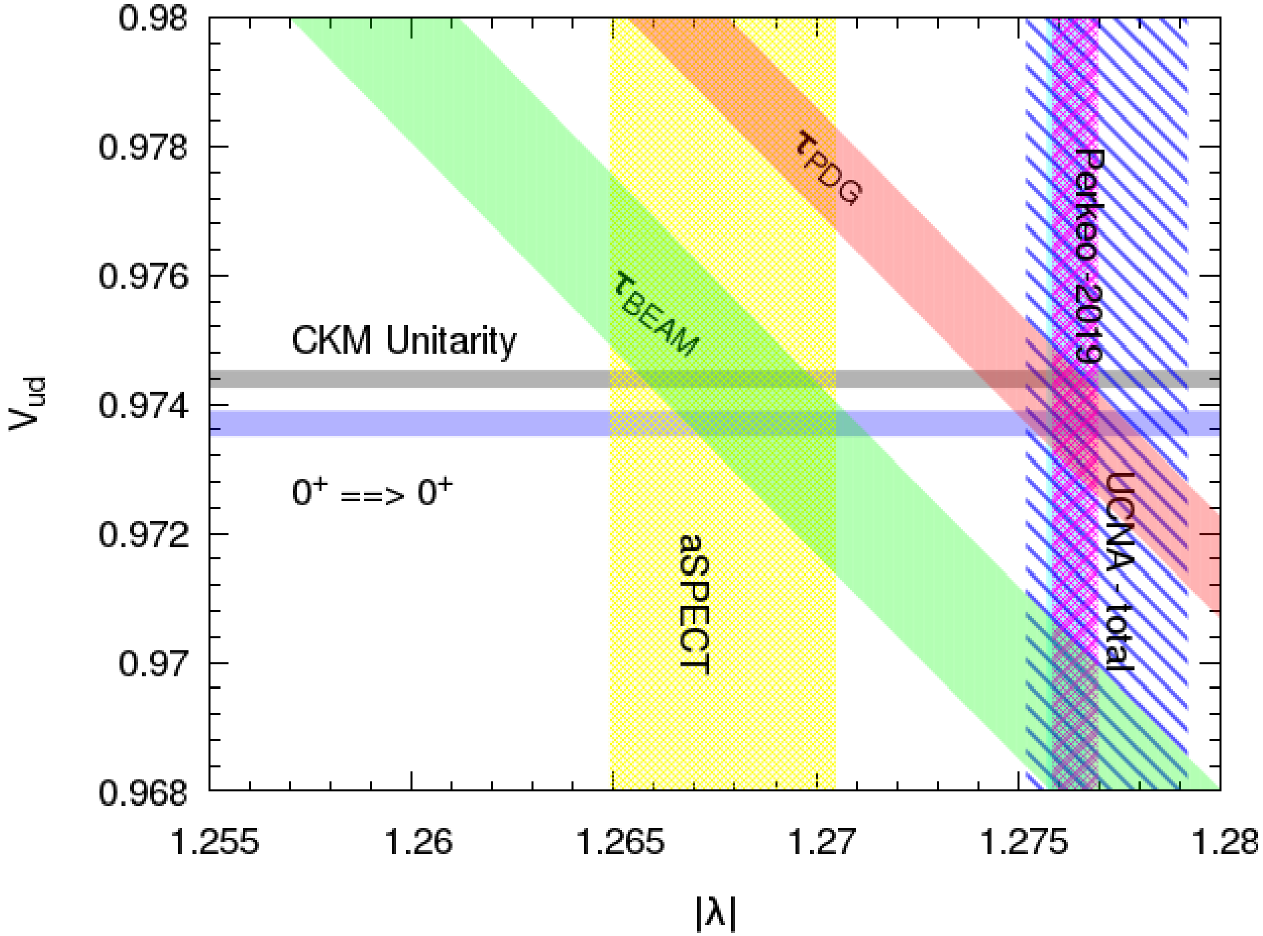
$$V_{ud} = \frac{(4908 \pm 1.9)s}{\tau_N(1+3\lambda^2)}$$

Need lifetime *and* λ for V_{ud}

$$\lambda = \frac{g_A}{g_V} \Leftarrow a = \frac{1-|\lambda|^2}{1+3|\lambda|^2}$$

Experiments must answer for a lot





Large Deviations to neutron beta decay radiative corrections (Leendert Hayen)

Radiative corrections lie at heart of CKM unitarity tests & BSM searches, lots of renewed attention

RC to g_A calculated for first time to $\mathcal{O}(\alpha)$ (but isospin limit for vertex corr.)

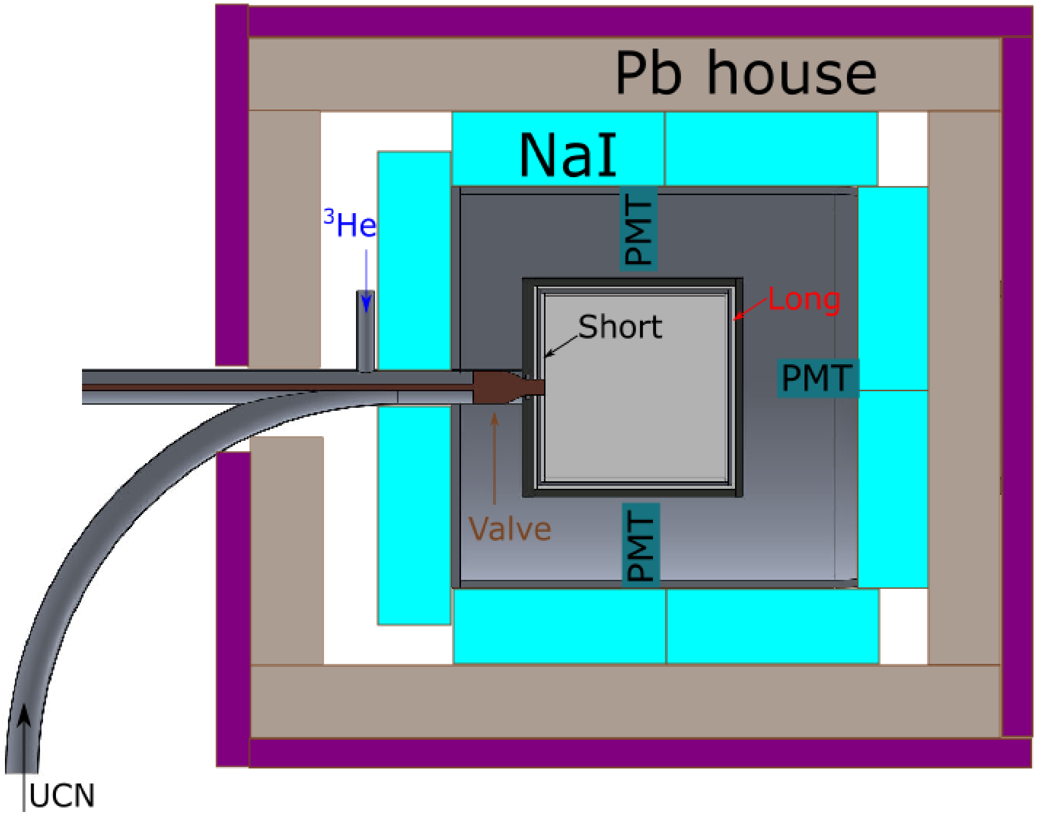
New strong isospin breaking effects in inelastic part of vertex corr. percent-level, much larger than anticipated!

Comparison with LQCD is unique channel for right-handed current searches, but currently **uncertain at few percent** level

Lattice QCD can determine LEC, multi-nucleon incoming

UCNProbe is a new "beam" method experiment using UCN

- **Our goal is to measure τ_β using UCN with a total error of 1-2 seconds with totally different systematic effects compared to pa "beam" experiments.**
- Requires absolute measurements of two quantities to 0.1%
  - Number of neutrons in the trap
  - Number of neutrons that decayed (measurement of charg particles)
- Employs a two-layer deuterated phoswich scintillator box to store UCN and detect beta decay electrons
- ^{3}He will be injected at the end of each measurement cycle to measure the UCN
- The collaboration is completing prototype detector this year
- Plans to start commissioning run with UCN in 2025.



Zhaowen Tang

Does $n \rightarrow n'$ Explain the Neutron Lifetime Discrepancy?

NO!

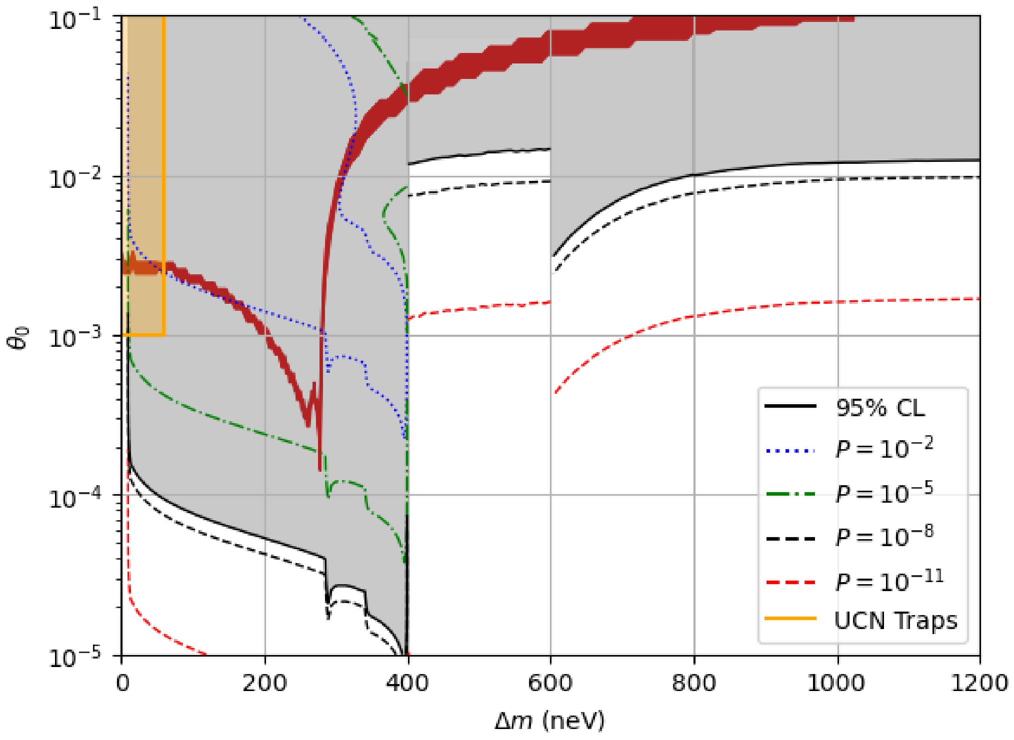
No counts observed above background!

- No transmission $< 2.5 \times 10^{-8}$ (95% CL)
- Excludes gray parameter space

Difference between Beam Lifetime and τ_n (red band)

Mirror neutrons do NOT explain the lifetime shift

- Broussard, L.J. *et al.* Phys. Rev. Lett. 128, 212503 (2022).

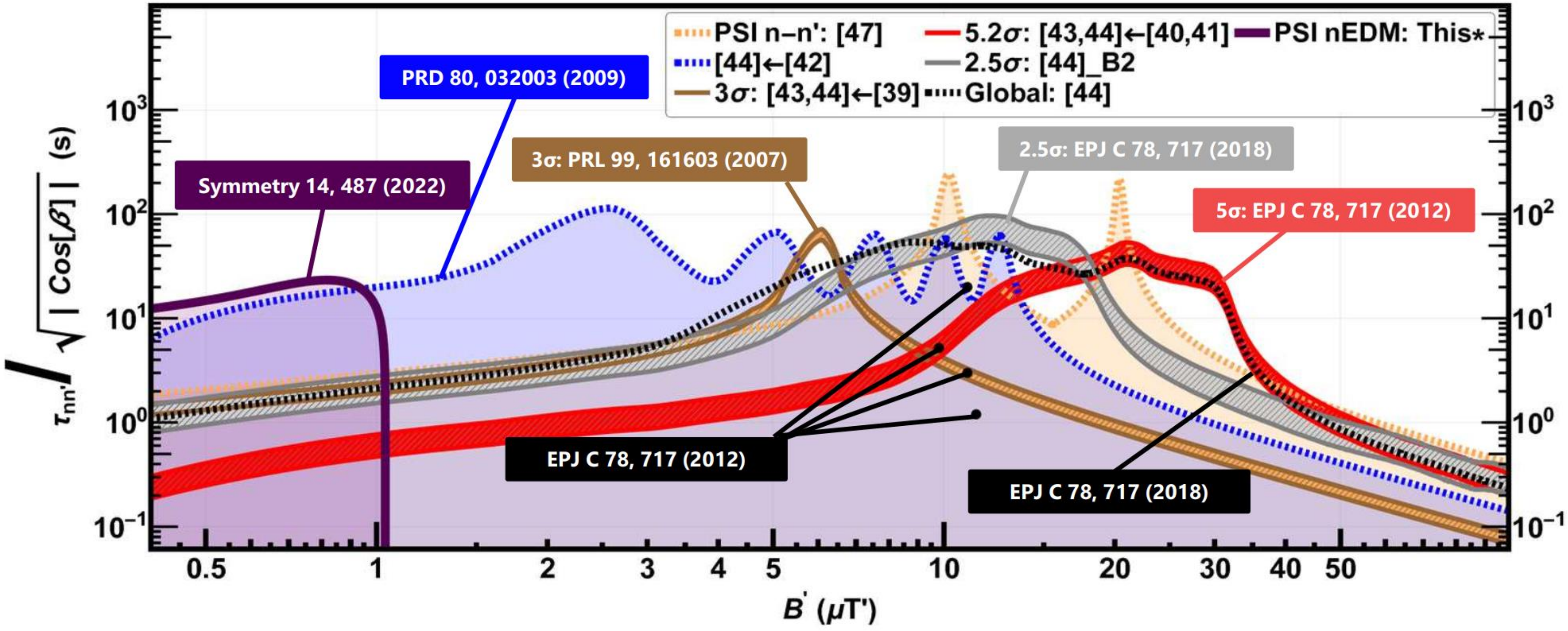


§4 Constraints in Asymmetry Channel

New constraint uses precession frequency of neutrons in {B, -B}

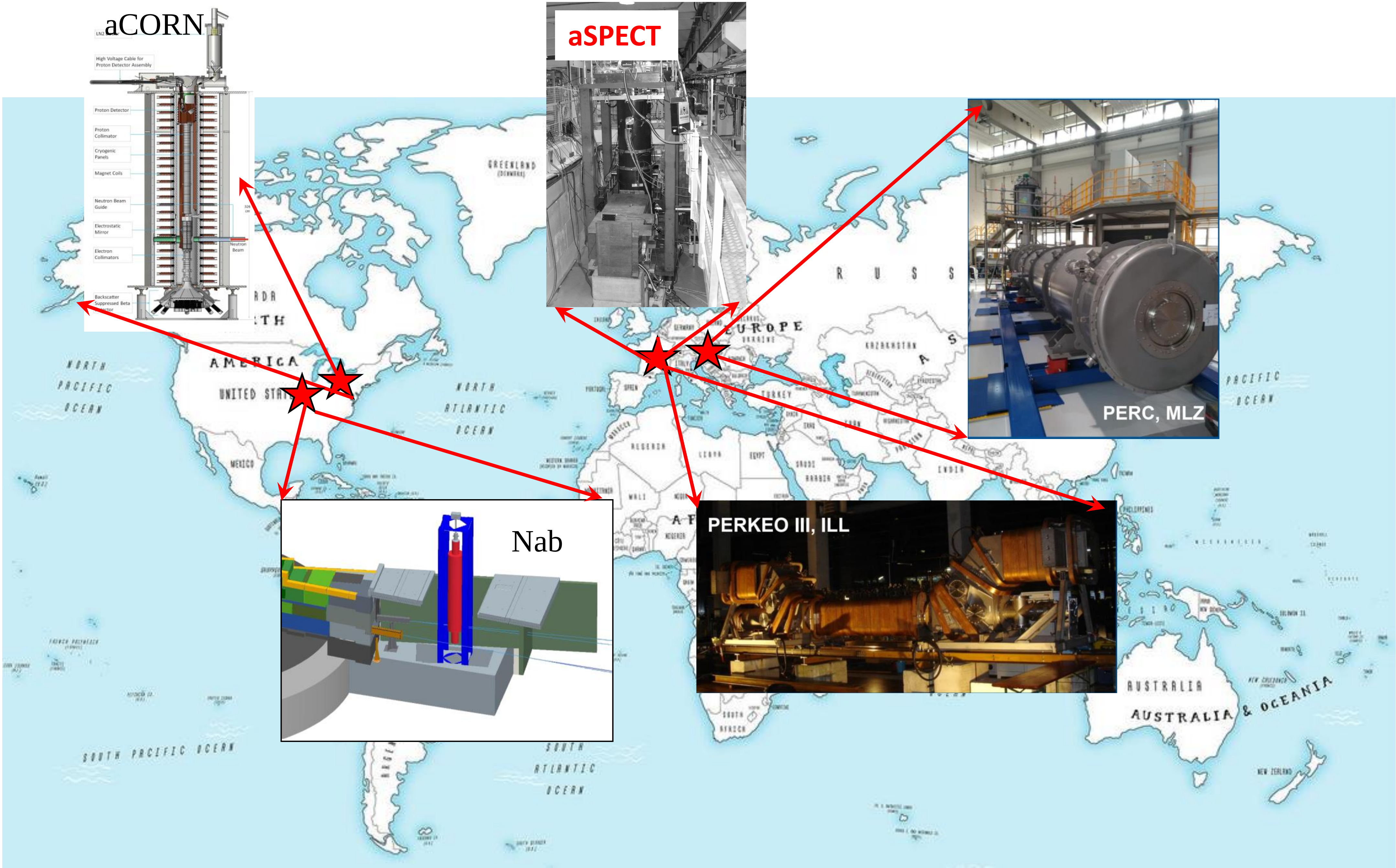
$$\frac{\tau_{nn'}^{B'\neq 0, nEDM}}{\sqrt{\cos\beta}} = \sqrt{\frac{\delta\omega}{\omega}\cdot\underbrace{\frac{1}{\omega'^2\eta(\eta^2-1)}}_{f_d(\eta)}}$$

95% C.L./C.I.



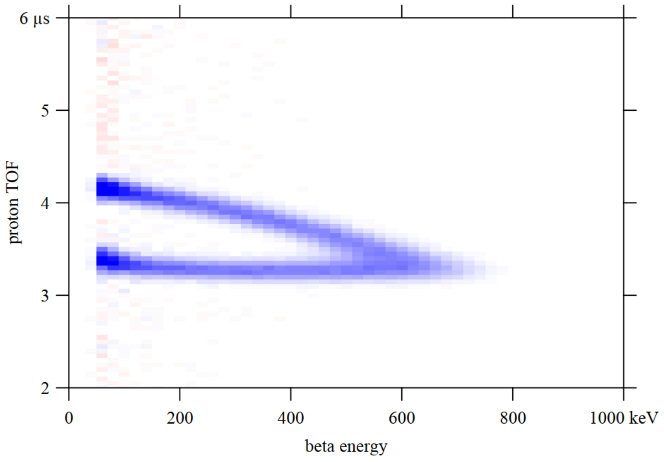
!!!>>> Assuming the angle β is fixed <<<!!!

P. Mohanmurthy et al., *Symmetry* **14**, 487 (2022)

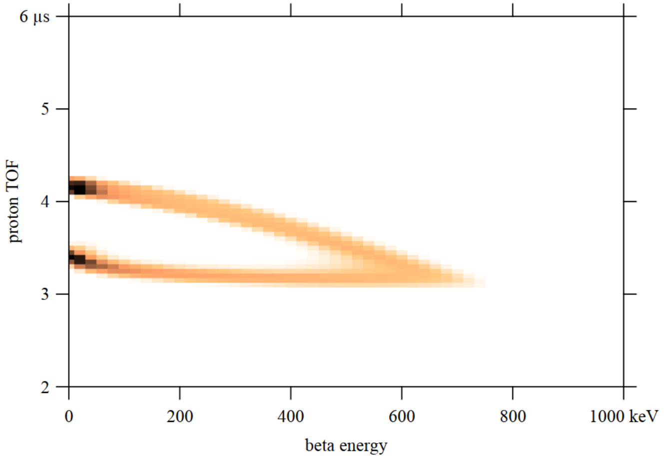


aCORN
High Voltage Cable for Proton Detector Assembly
Proton Detector
Proton Collimator
Cryogenic Panels
Magnet Coils
Neutron Beam Guide
Electrostatic Mirror
Electron Collimators
Neutron Beam
aSPECT
PERC, MLZ
Nab
PERKEO III, ILL
GREENLAND (DENMARK)
EUROPE
NORTH PACIFIC OCEAN
NORTH ATLANTIC OCEAN
SOUTH PACIFIC OCEAN
SOUTH ATLANTIC OCEAN
PACIFIC OCEAN
AUSTRALIA
AUSTRALIA & OCEANIA

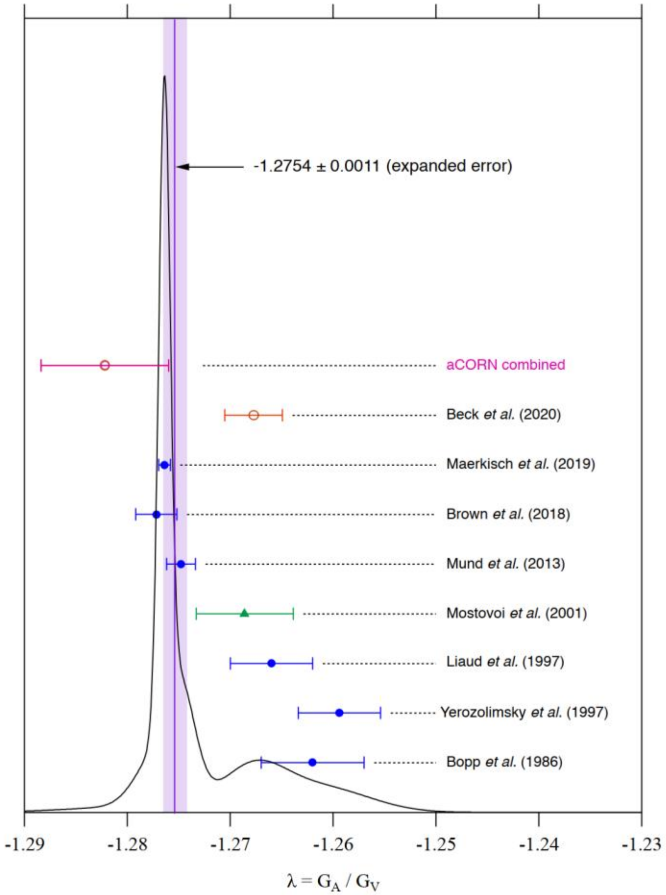
aCORN Experiment (F. Wietfeldt)



Background-Subtracted
Wishbone Data



aCORN Monte Carlo



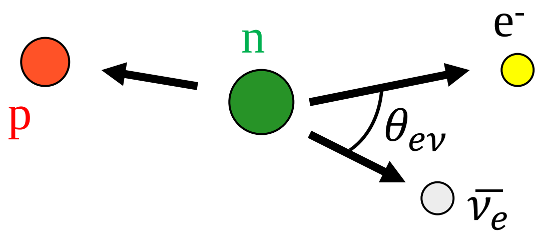
including the
calculated order-α 4-body
radiative correction

F. Glück,
Phys. Rev. D **47**, 47 (1993);
arXiV:2205.05042 (2022)

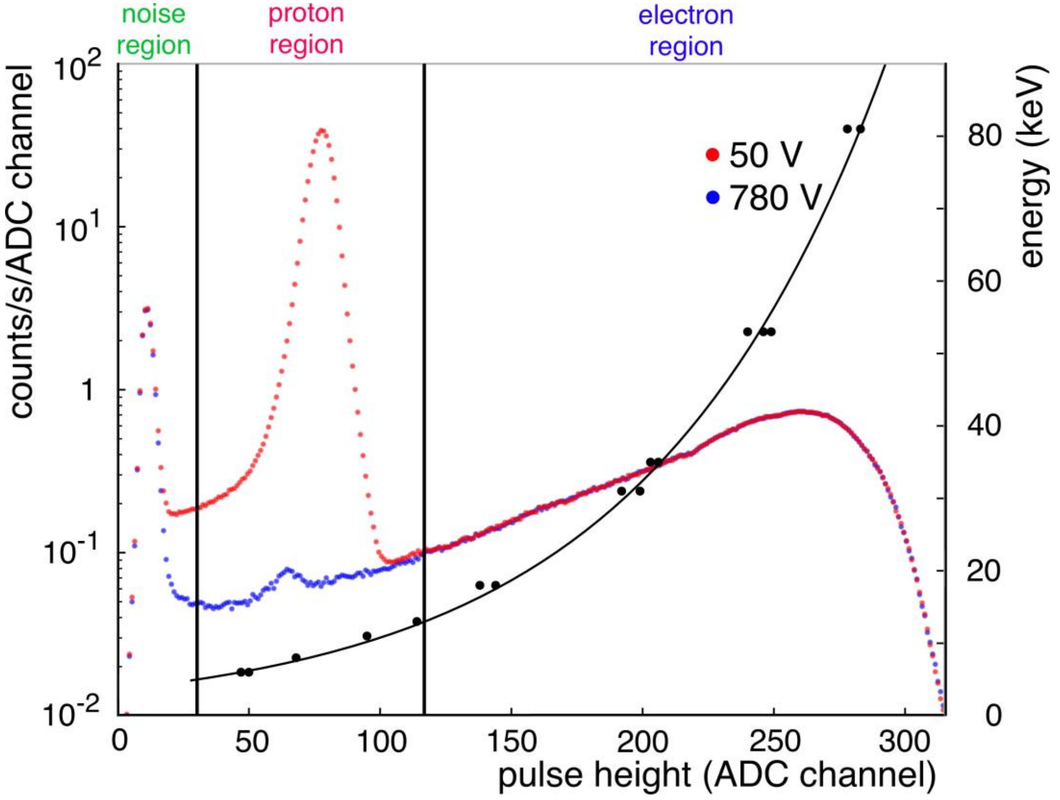
-0.7% shift!
(preliminary)

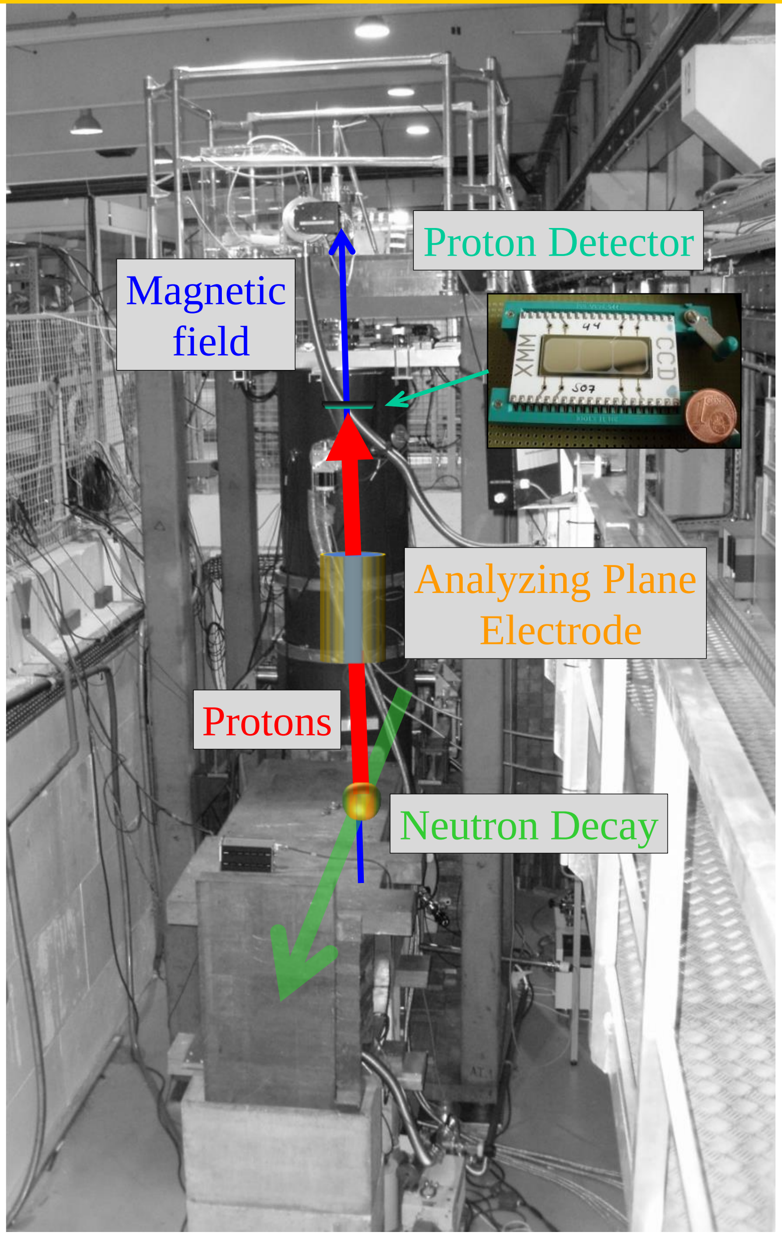
a = -0.1076 ± 0.0014 (stat) ± 0.0015 (sys); 1.9%
Hassan, *et al.* Phys. Rev. C **103**, 045502 (2021)

Results from *a*SPECT (S. Baessler)



$$d\Gamma \propto \rho(E_e)\left(1 + a\frac{\vec{p}_e \cdot \vec{p}_\nu}{E_e E_\nu} + b\frac{m_e}{E_e}\right)$$

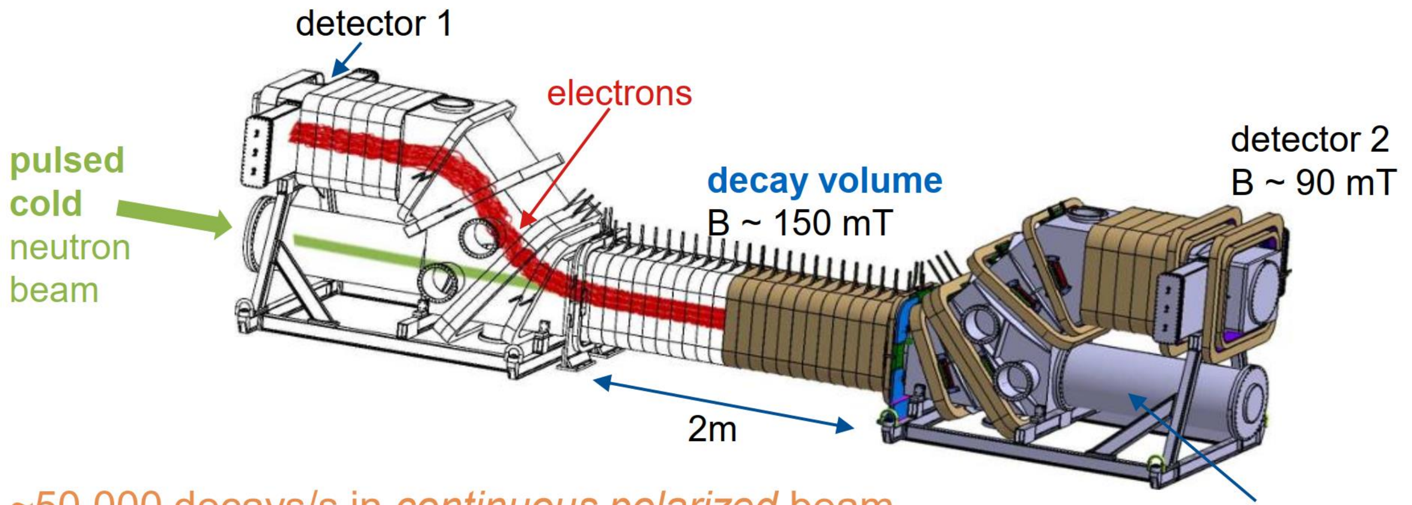




First result (SM Fit): $a = -0.10430(84)$ PRC 101, 055506 (2020)

Small revision, and BSM analysis, in progress.

Perkeo III and PERC (B. Markisch)



~50.000 decays/s in *continuous polarized* beam
time avg. ~200 s^{-1} in **pulsed**, polarized mode
~800 s^{-1} in pulsed, unpolarized mode

PERKEO III (ILL)

$$\frac{\Delta\lambda}{\lambda} = 4.4 \times 10^{-4}$$

BM *et al.*, Phys. Rev. Lett. 122, 222503 (2019)

Goal of PERC (MLZ)

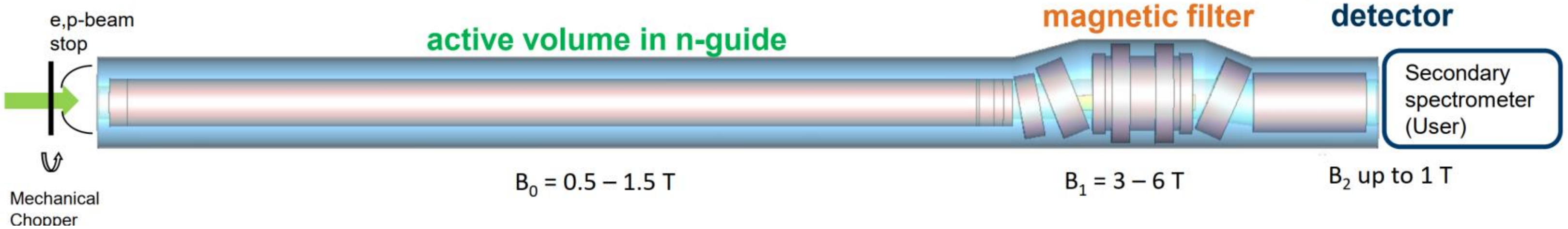
$$\frac{\Delta\lambda}{\lambda} \leq 1 \times 10^{-4}$$

aSpect, aCorn, Nab, BRAND:
this afternoon

PERC Concept and Systematics

PERC's asymmetric layout with magnetic filter improves systematics

Strong field ensures high phase space density, small detectors, excellent S/B and only a single detector!.



- Electron Backscatter Strongly suppressed
- Main Detector shielded from background
- Non-depolarizing neutron guide for PERC

Current Status and Timeline

U of Manitoba undergrad August Mendelsohn

Both mounts installed in Nab spectrometer May 25, 2022

SNS beamtime Summer 2022

- Cool magnet and detectors at the same time
- DAQ sync and time of flight resolution
- Beam polarization measurements
- Electron source calibration system check

SNS beamtime Winter of 2022/23

- Test fixed items and 2nd commissioning

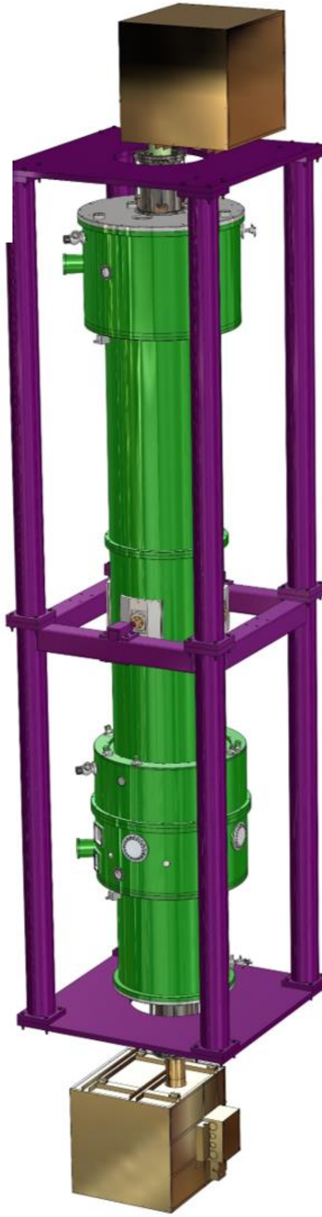
SNS beamtime Summer of 2023

- Physics Data

SNS Shuts down Fall 23/Spring 24

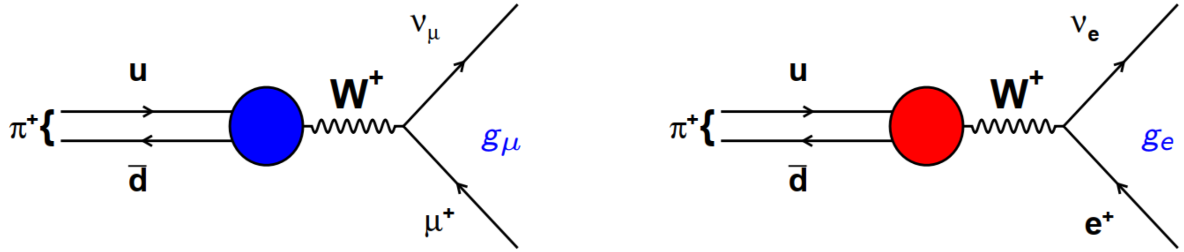
- Upgrade Beam power on spallation target

Hope to get "a" statistics only pape out during this time.



Theory/PEN

Explore the (V−A) interaction through a precision measurement



$$\frac{\Gamma(\pi^+ \to e^+\nu_e(\gamma))}{\Gamma(\pi^+ \to \mu^+\nu_\mu(\gamma) \to e^+\nu_e\bar{\nu}_\mu)} = \left(\frac{g_e}{g_\mu}\right)^2 \left(\frac{m_e}{m_\mu}\right)^2 \frac{\left(1-\left(\frac{m_e}{m_\mu}\right)^2\right)^2}{\left(1-\left(\frac{m_\mu}{m_\pi}\right)^2\right)^2}(1+\delta_R)$$

Theoretical BR: $(1.2352 \pm 0.0001) \times 10^{-4}$ *

Experimental BR: $(1.2327 \pm 0.0023) \times 10^{-4}$

δ_R rad/loop corrections in SM, non V−A extensions

$(\frac{g_e}{g_\mu})^2 = 1.0021 \pm 0.0016$ (experimental)

Goal: relative uncertainty 5×10^{-4} or better

*For Review see: D.Počanić et al J. Physics G **41** 2014 11

^{6}He-CRES Experiment Summary

^{6}He-CRES phases

Phase I: proof of principle

Experiment commissioning

Observe ^{83}Kr lines

Broadband DAQ, networking, and analysis

Understand RF issues and spectra

Measurements of $\beta\pm$ from ^{6}He and ^{19}Ne

Show 5 keV- 5 MeV capability of detection

Done!

Phase II: first measurement ($b < 10^{-3}$)

^{6}He and ^{19}Ne data taking.

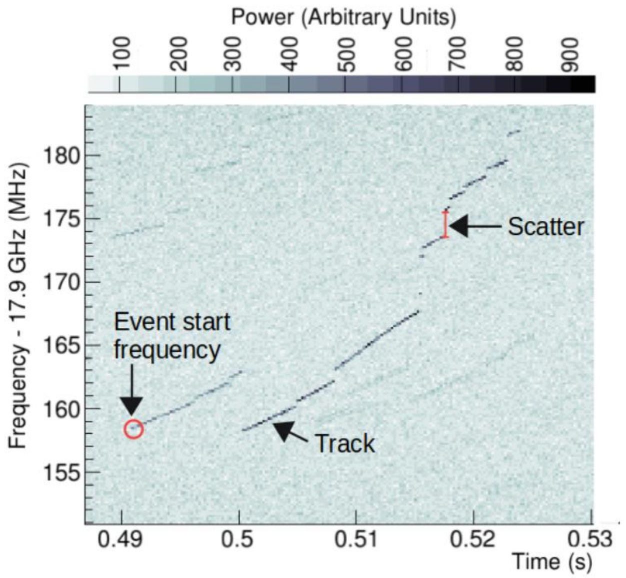
Develop ^{14}O source.

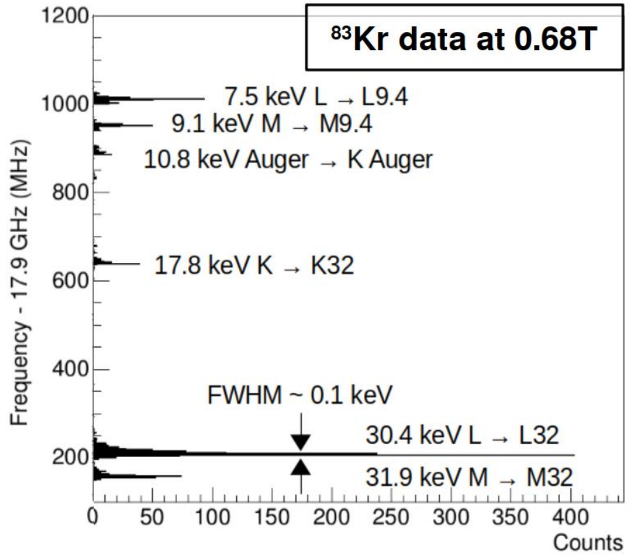
Started

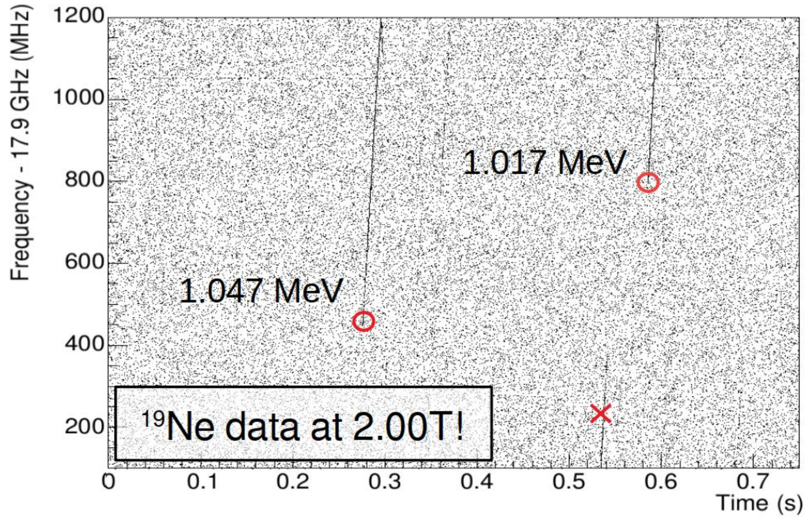
Phase III: ultimate measurement ($b < 10^{-4}$)

^{14}O measurements.

Ion-trap for no limitation from geometric effect.







^{6}He-CRES

Summary

- Significant progress in theory and experiment and exciting developments to look forward to in the next few years!
- We thank Brendan Casey for inviting us to convene the topic of **Tests of Symmetries and Electroweak Interactions**!