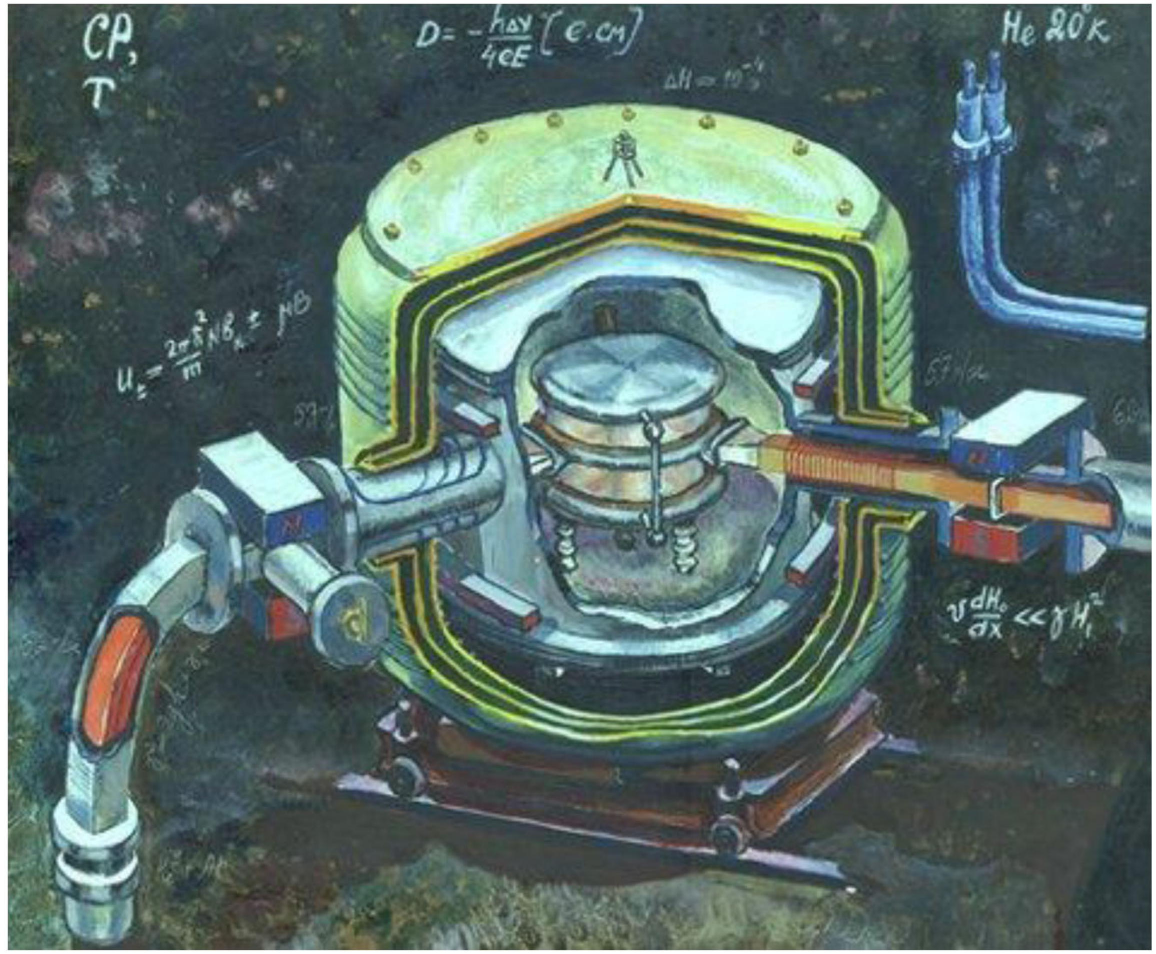
Highlights of nEDM2021 workshop – my personal perspectives

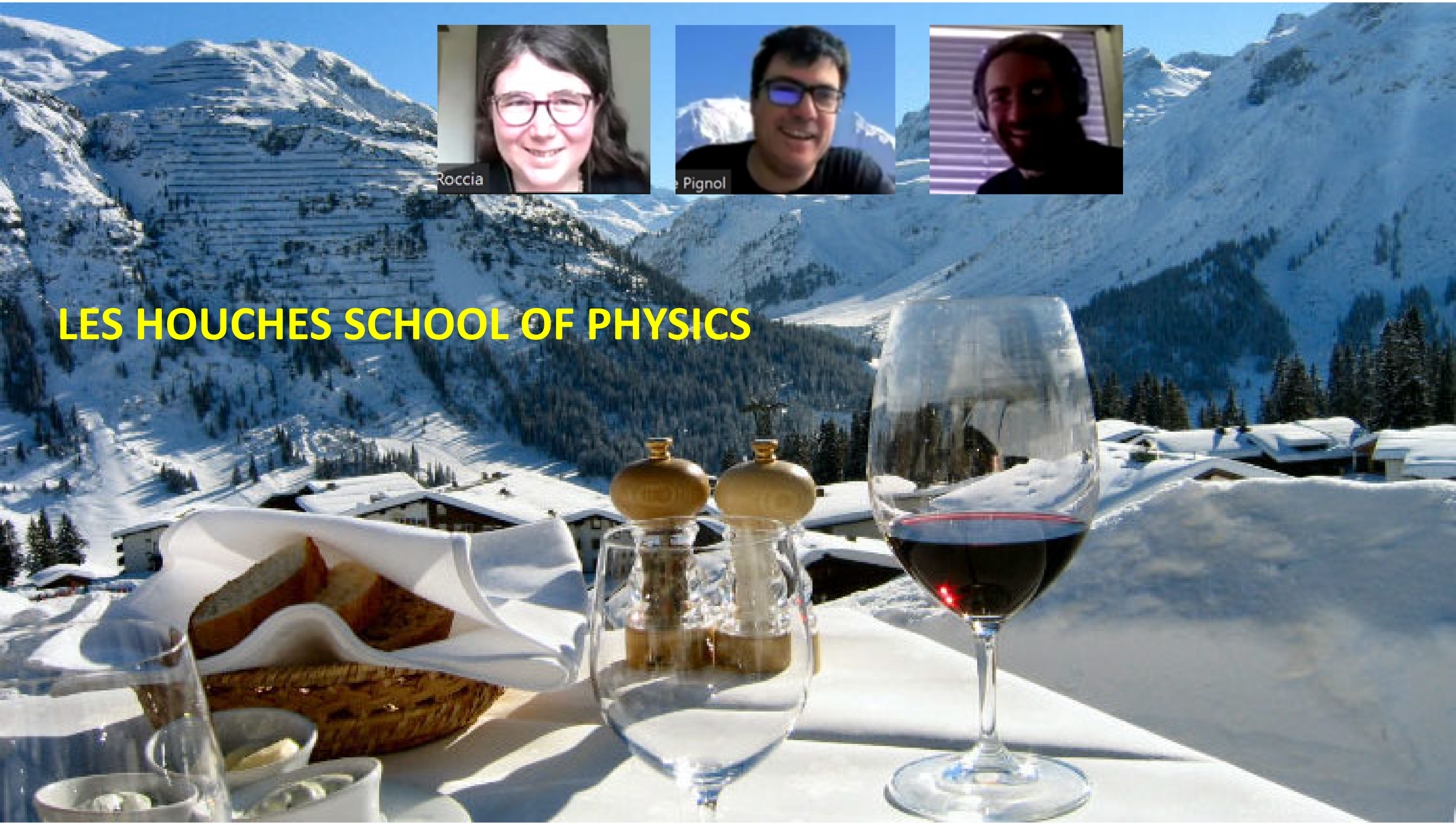
Chen-Yu Liu
Indiana University
2/19/2021

INTERNATIONAL WORKSHOP ON SEARCHES FOR A NEUTRON ELECTRIC DIPOLE MOMENT

LES HOUCHES SCHOOL OF PHYSICS



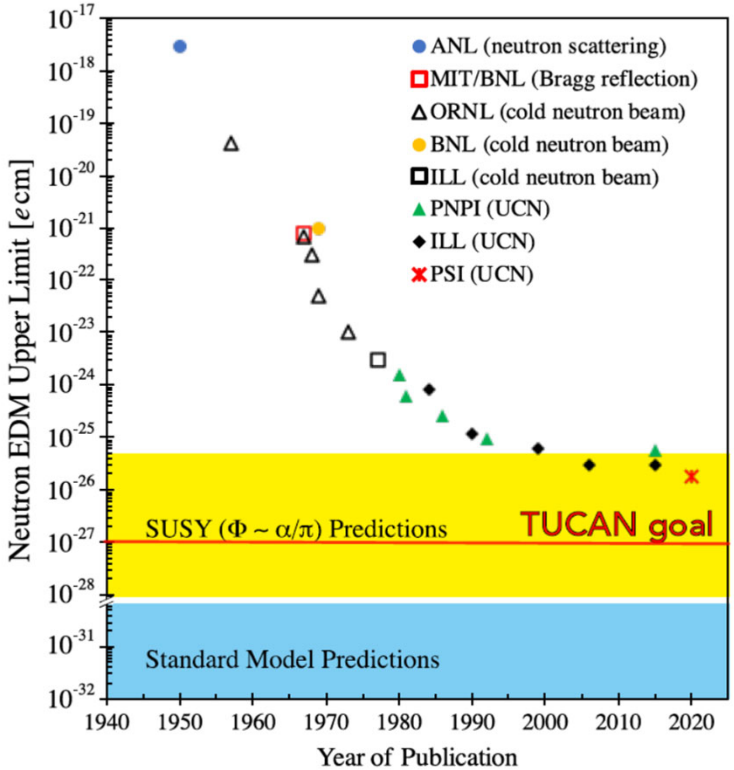
Slide credit: all presenters in this workshop


Roccia
Pignol
LES HOUCHES SCHOOL OF PHYSICS

“International Workshop on Searches for a Neutron Electric Dipole Moment”,

or in plain English,

A Workshop on *Ongoing Efforts to measure* d_n*=0.000000000000000000000000000 … e-cm?*



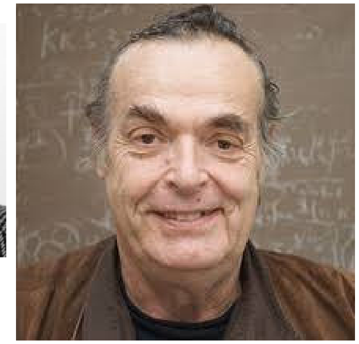
An Odyssey….

Fyodor L. Shapiro
(1915—1973)

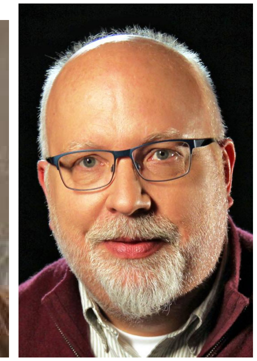
Yakov B. Zeldovich
(1914—1987)

Norman Ramsey
(1915—2011)

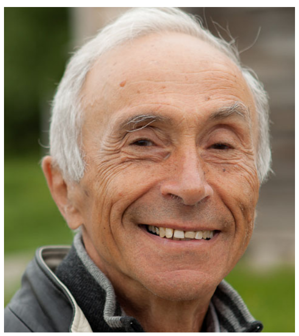
Michael Pendlebury
(1936—2015)



Bob Golub



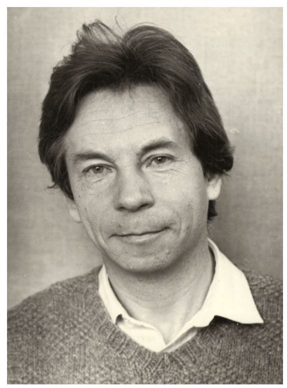
Steve Lamoreaux



Iosif Khriplovich

Yuri Pokotilovski

Vladimir Ignatovish
(1937—2020)

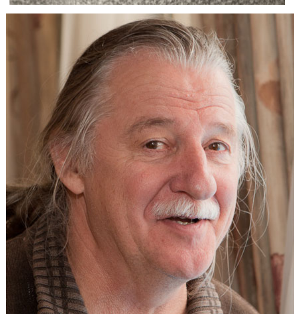


Albert Steyerl
(1938—2020)

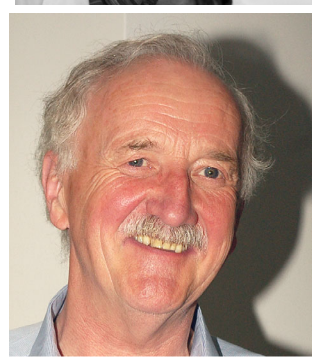
Tom Bowles

V.A. Lobashov

Anatoly Serebrov



Peter Geltenbort



Werner Heil

Manfred Daum

Beatrice (she/her) TRIUMF
Chen-Yu Liu
Clark Griffith
Duarte Pais
Georg Bison
Bernhard Lauss
Dieter Ries
Stephanie Roccia
Philipp Schmidt-Wellenburg
Guillaume Pignol
Marie Blatnik
Jacob Thorne
Felicity Blue Hills
Pierre Delahaye
bob
Mark Broering
Eric Miller
John Ramsey (ORNL)
chenjianqi
Klaus Kirch
Ruediger Picker
Chanel, Estelle Ghislaine ...
Tim Chupp
Alexey Fomin
Wolfgang Schreyer

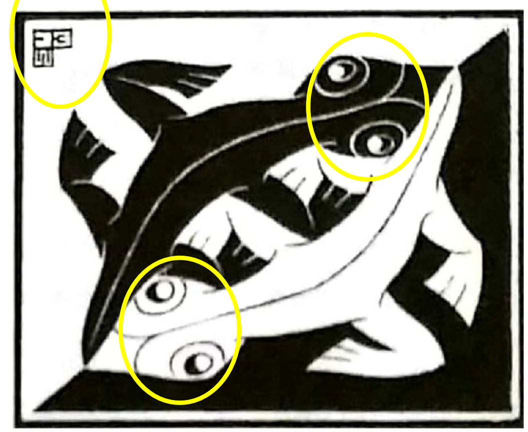
d_n =0.0000000000000000000000000000…1

Evidence # 1: Escher's print

Mirror (left→right)

Challenge: Can you find the differences between the final and the original picture?

Mirror (up → down)



P

Black←→white

CP

"Plane-filling motif with reptiles" by M.C. Escher

"Signatures of the Artist," by Steve Vigdor, Oxford University Press (2018)

d_n =0.0000000000000000000000000000...1

Evidence # 2: Bach's music

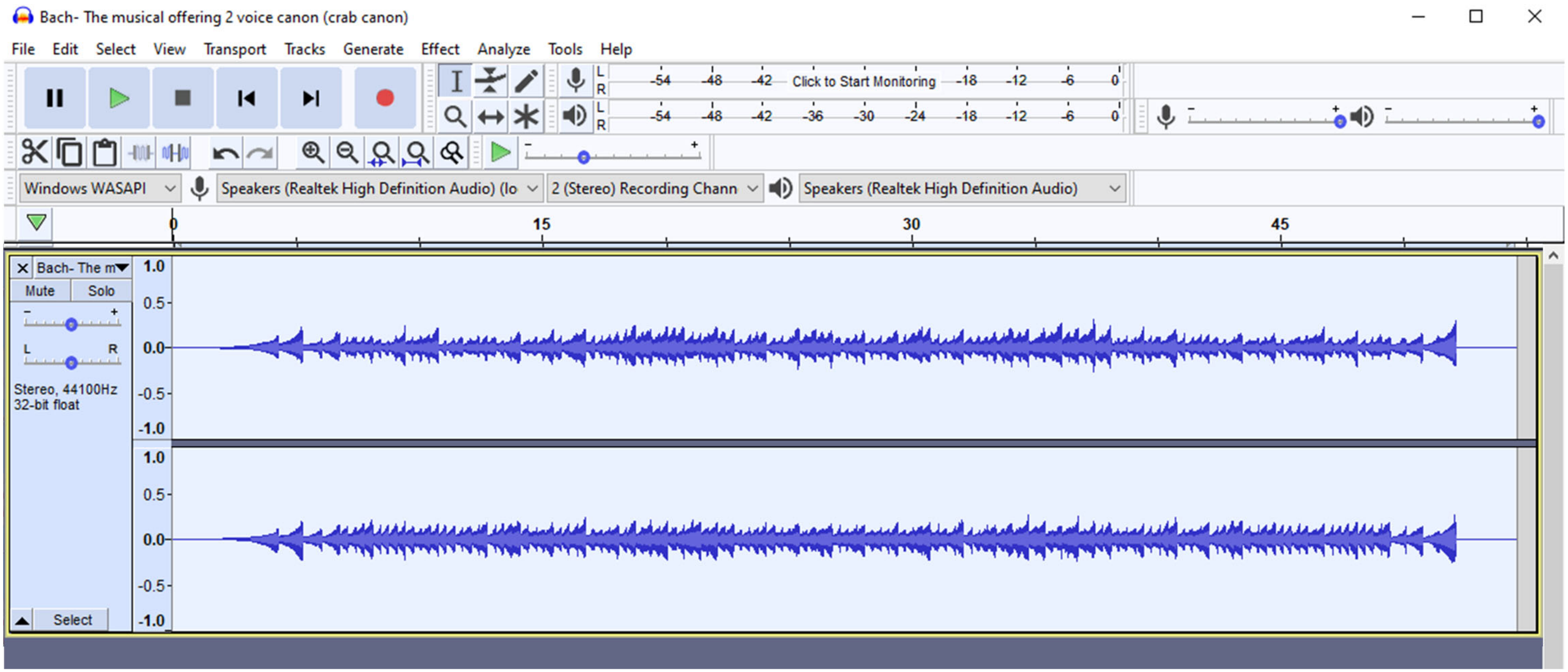
Crab Canon

Musikalisches Opfer (1747) by *Johann Sebastian Bach*

Playing forward

Playing backward

Audacity Music Program: reverse track



$$d_n = 0.0000000000000000000000000\ldots1$$

Evidence # 3: Corned Beef Sandwiches

National Public Radio (NPR)
Joe Palca
May 25, 2019 8:20 AM ET

https://www.npr.org/2019/05/25/723215836/why-corned-beef-sandwiches-and-the-rest-of-the-universe-exist

Why Corned Beef Sandwiches — And The Rest Of The Universe — Exist

May 25, 2019 · 8:20 AM ET
Heard on Weekend Edition Saturday

JOE PALCA

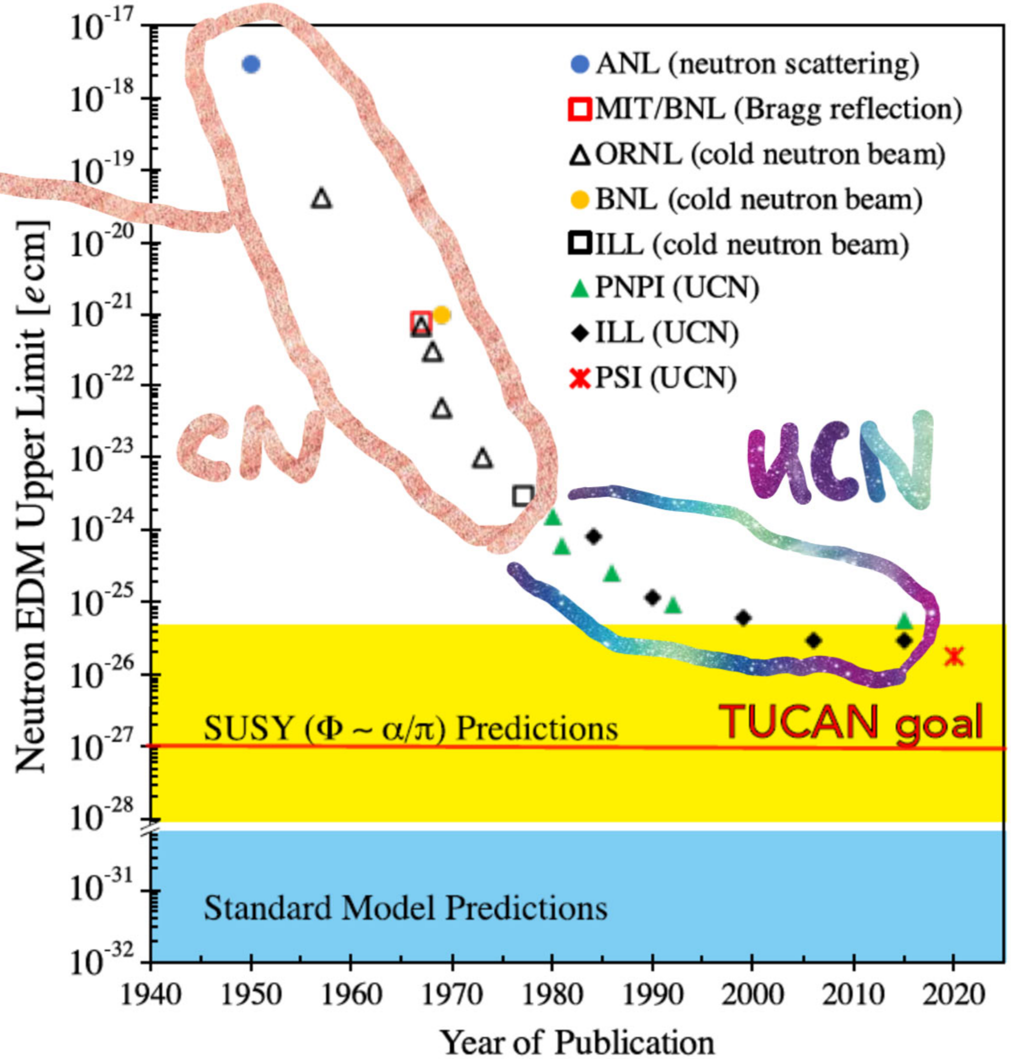
4-Minute Listen + PLAYLIST

An imbalance between matter and antimatter in the universe produced all the things in existence, including corned beef sandwiches.

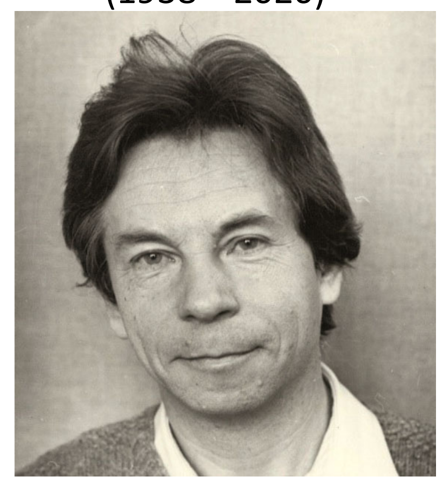
Erik Rank/Getty Images

Norman Ramsey
(1915—2011)

Michael Pendlebury
(1936—2015)

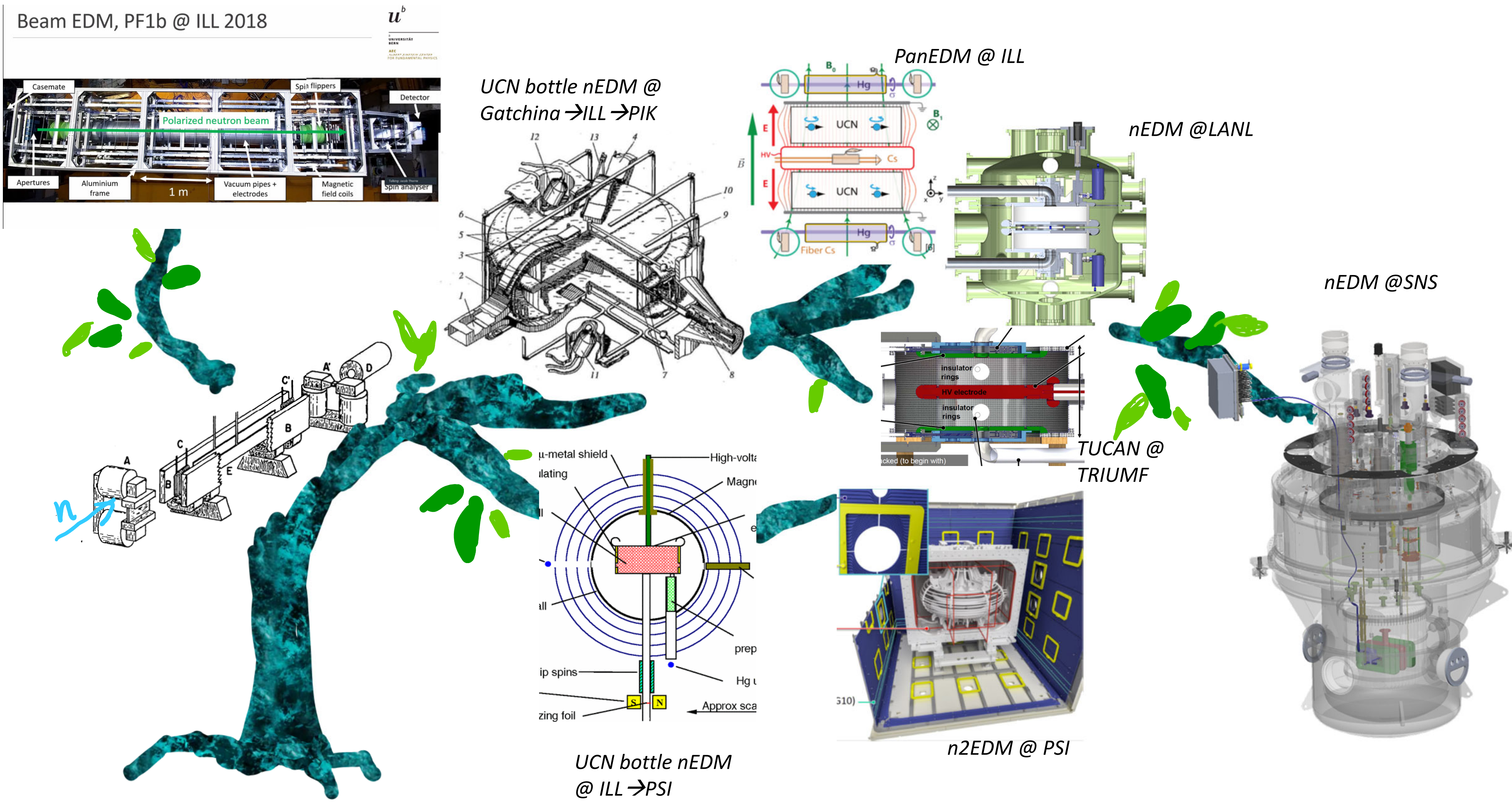


Albert Steyerl
(1938—2020)



Vladimir Ignatovish
(1937—2020)

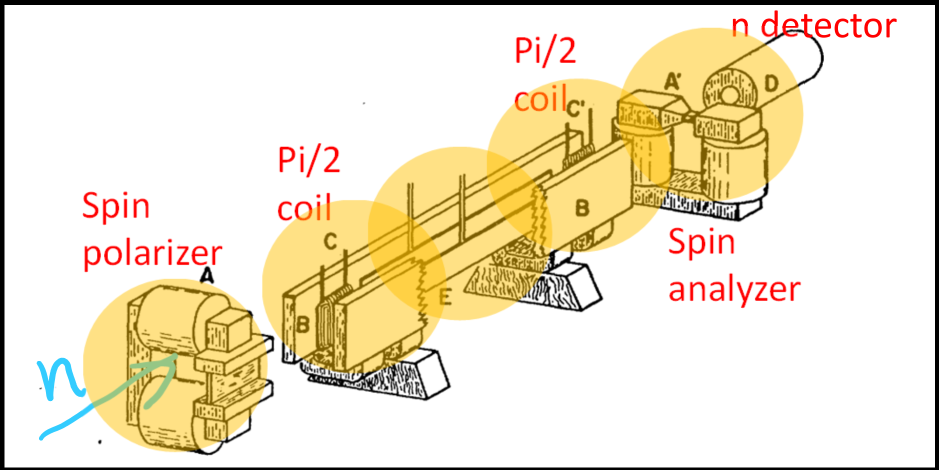
Family Tree of nEDM Experiments

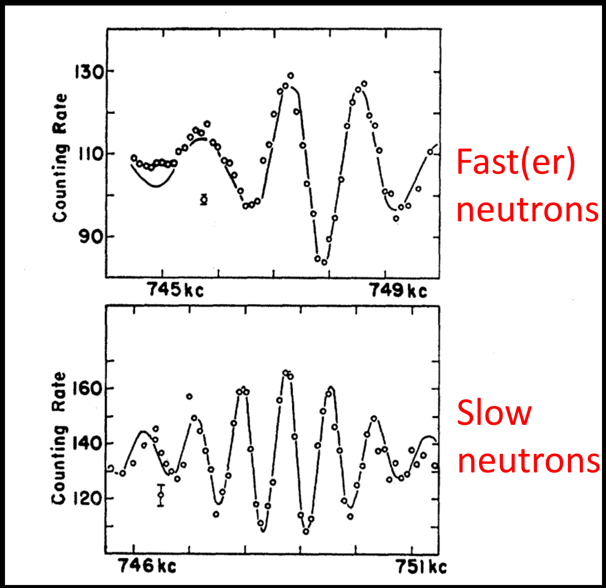


A particular arrangement that is more advantageous in many cases is one in which the oscillating field is confined to a small region at the beginning of the space in which the energy levels are being studies and to another small region at the end, there being no oscillating field in between.

-- N. Ramsey (1950)

Smith, Purcell, Ramsey, Phys. Rev. 108, 120 (1957)





Features of the separated oscillatory fields:

1. Narrow fringes
2. Not sensitive to the field uniformity.

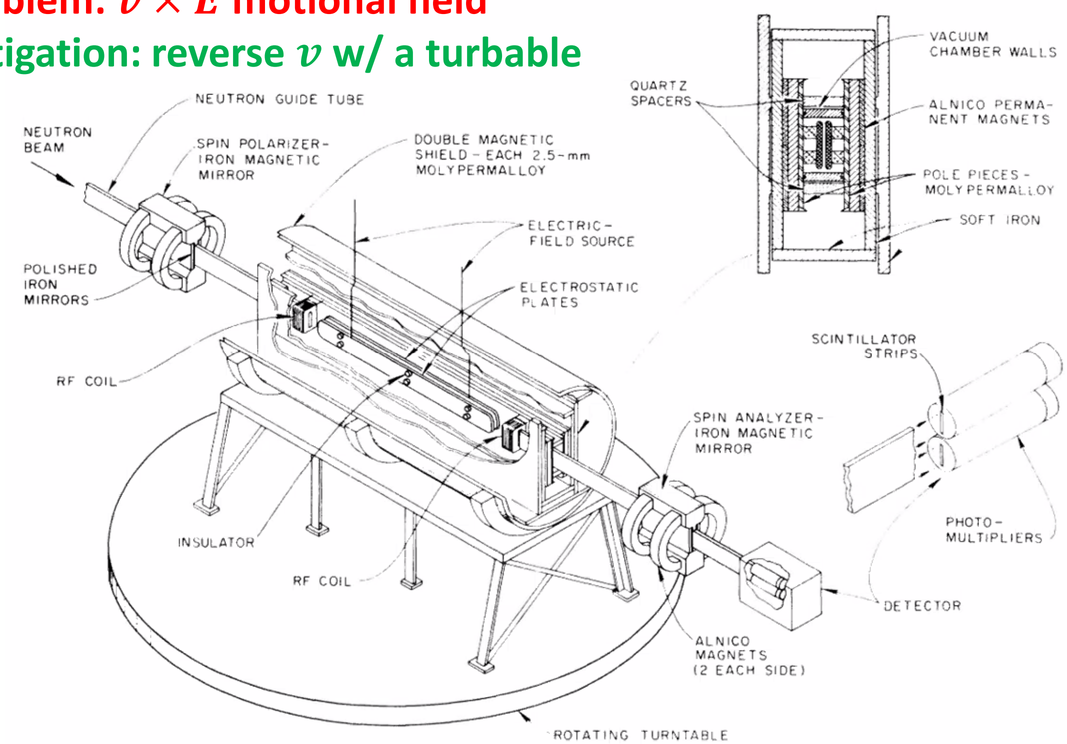
BeamEDM experiments

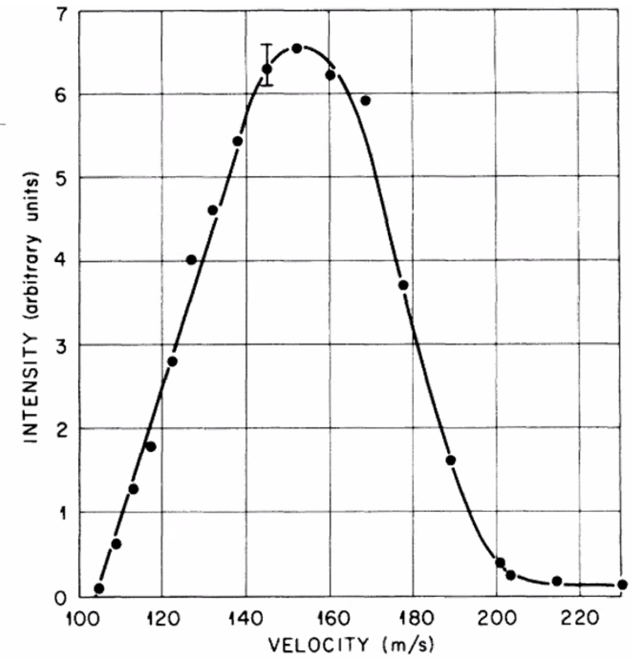
Jacob Thorne

Last beam type experiment (1977)

Problem: $v \times E$ motional field

Mitigation: reverse v w/ a turbable





Performed at ILL

Talking: Jacob Thorne

Systematic can occur due to relativistic $\vec{v} \times \vec{E}$ effect

$|d_n| < 3 \times 10^{-24}$e·cm (90% C.L.)[3]

[3] Dress, W. B. et al. Physical Review D 15.9 (1977)

Beam EDM, PF1b @ ILL 2018

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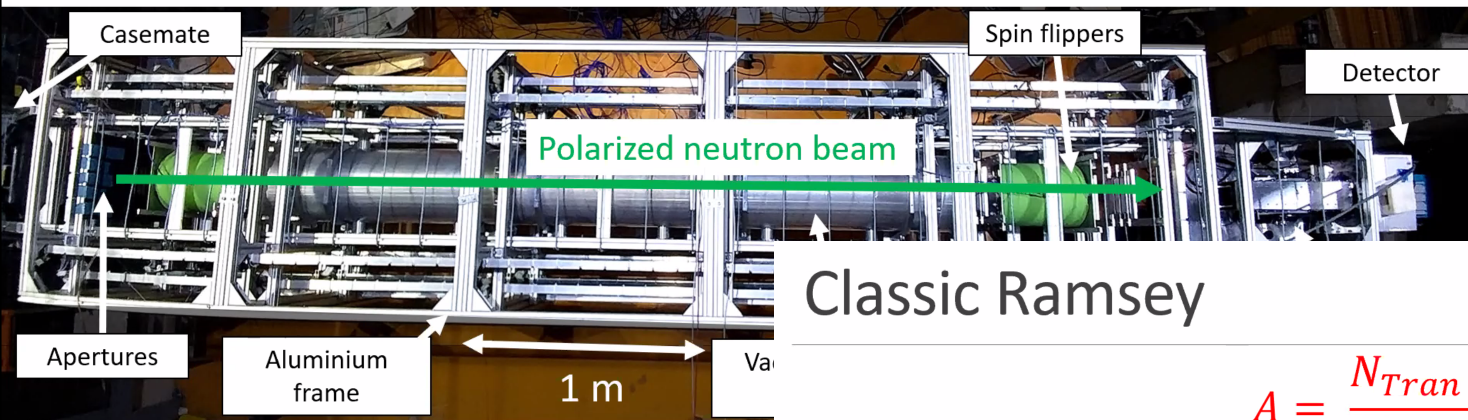

Jacob Thorne

Classic Ramsey

UNIVERSITÄT BERN
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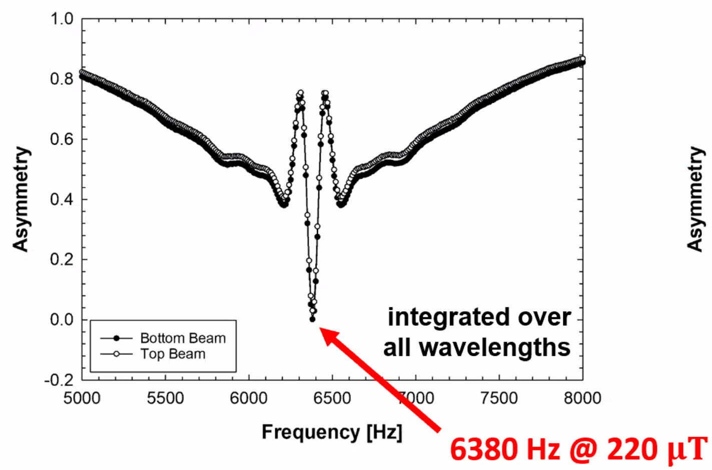
$$A = \frac{N_{Tran} - N_{Refl}}{N_{Tran} + N_{Refl}}$$



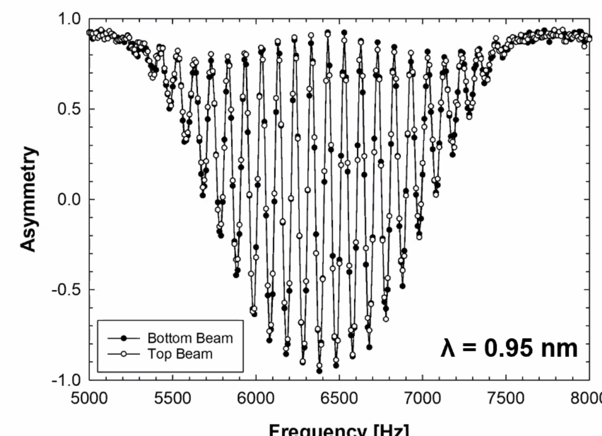
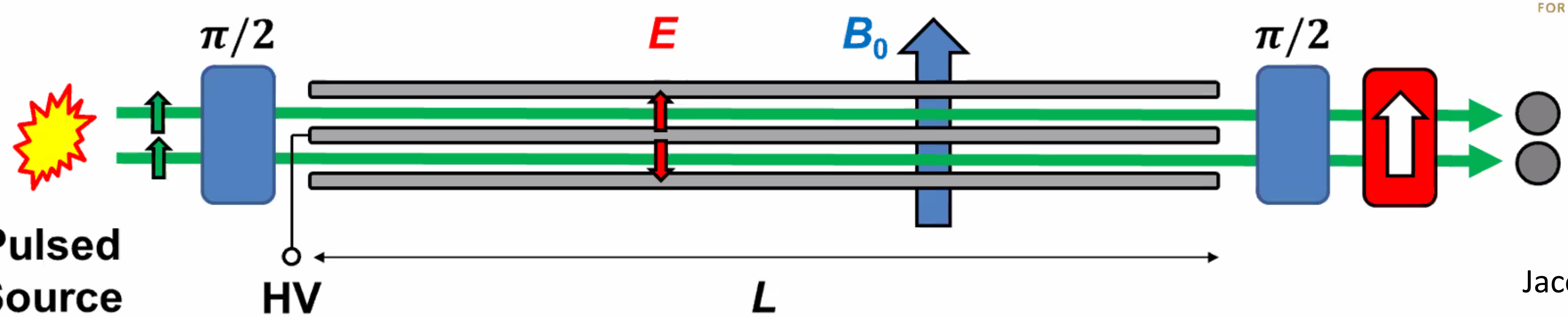
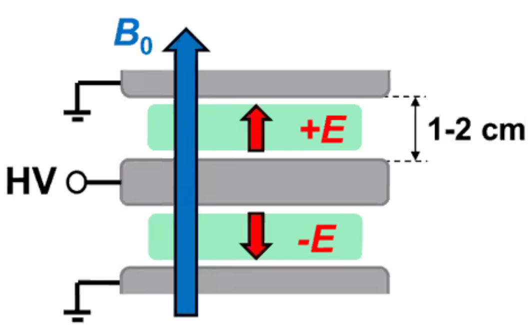
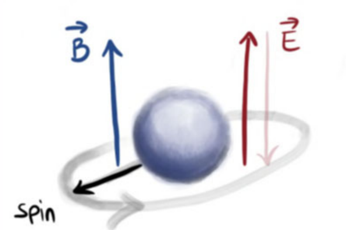


Diagram of the experiment (ILL 2020)



Jacob Thorne





2 neutron beams

$E \approx 40\ \mathrm{kV/cm}$

$B_0 \approx 220\ \mu\mathrm{T}$

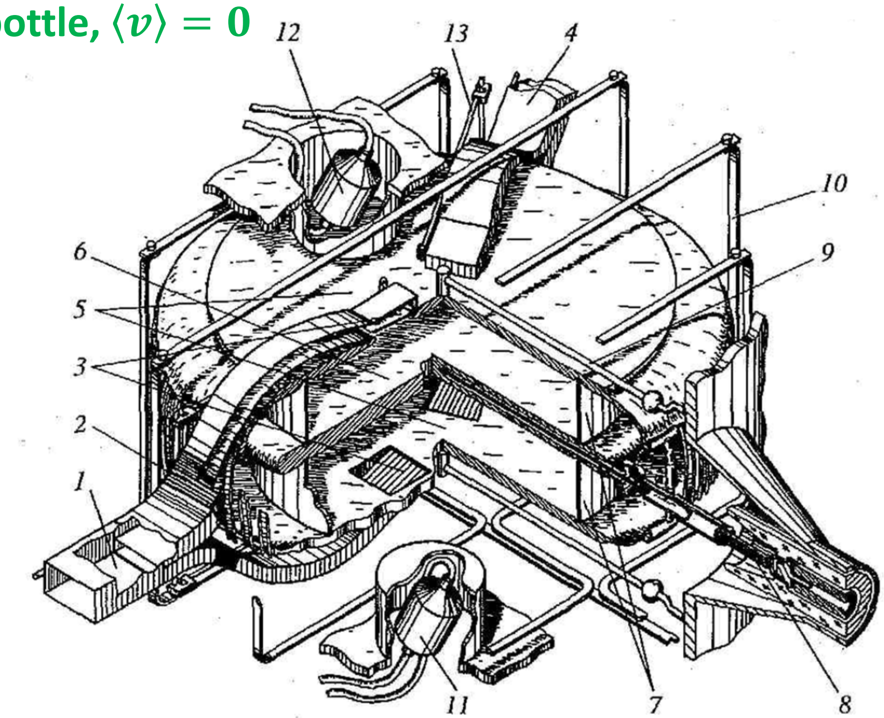
$L = 3\ \mathrm{m}$

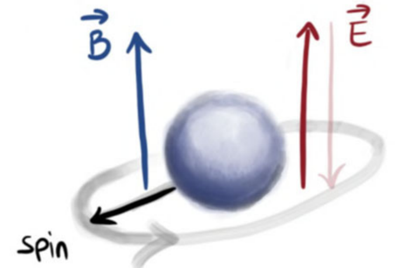
ESS proposal:
L = 50 m
Use a pulsed neutron source and time-of-flight to account for the velocity dependent effects.

EPJ Web of Conferences **219**, 02004 (2019)

UCN Bottle nEDM experiments

Problem: $v \times E$ motional field
Mitigation: UCN in a bottle, $\langle v \rangle = 0$





$$2\pi f = \frac{2\mu}{\hbar} B \pm \frac{2d}{\hbar} E$$

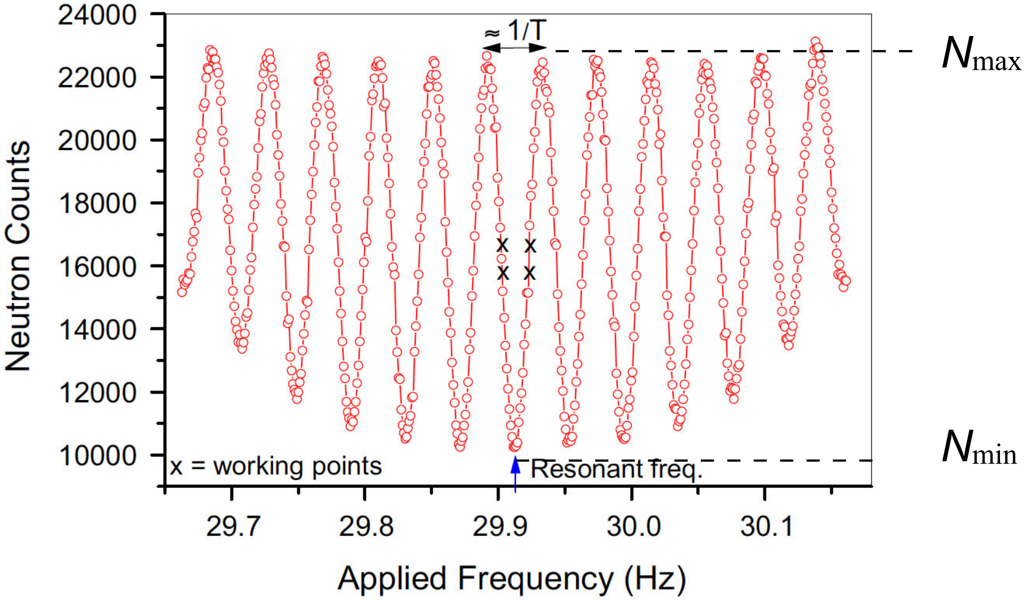
$$f(\uparrow\uparrow) - f(\uparrow\downarrow) = \frac{4}{2\pi\hbar} dE$$

Double-cell configuration:

In one load, the EDM is extracted by the frequency difference between the two cells.
→ Less sensitive to *temporal drifts* of the background B fields.

nEDM sensitivity:

The principle is to measure frequency of spin precession, but in practice we are still counting neutrons.



$$\sigma(d_n) \geq \frac{\hbar}{2\alpha E T\sqrt{N}\sqrt{M}}$$

α: fringe visibility

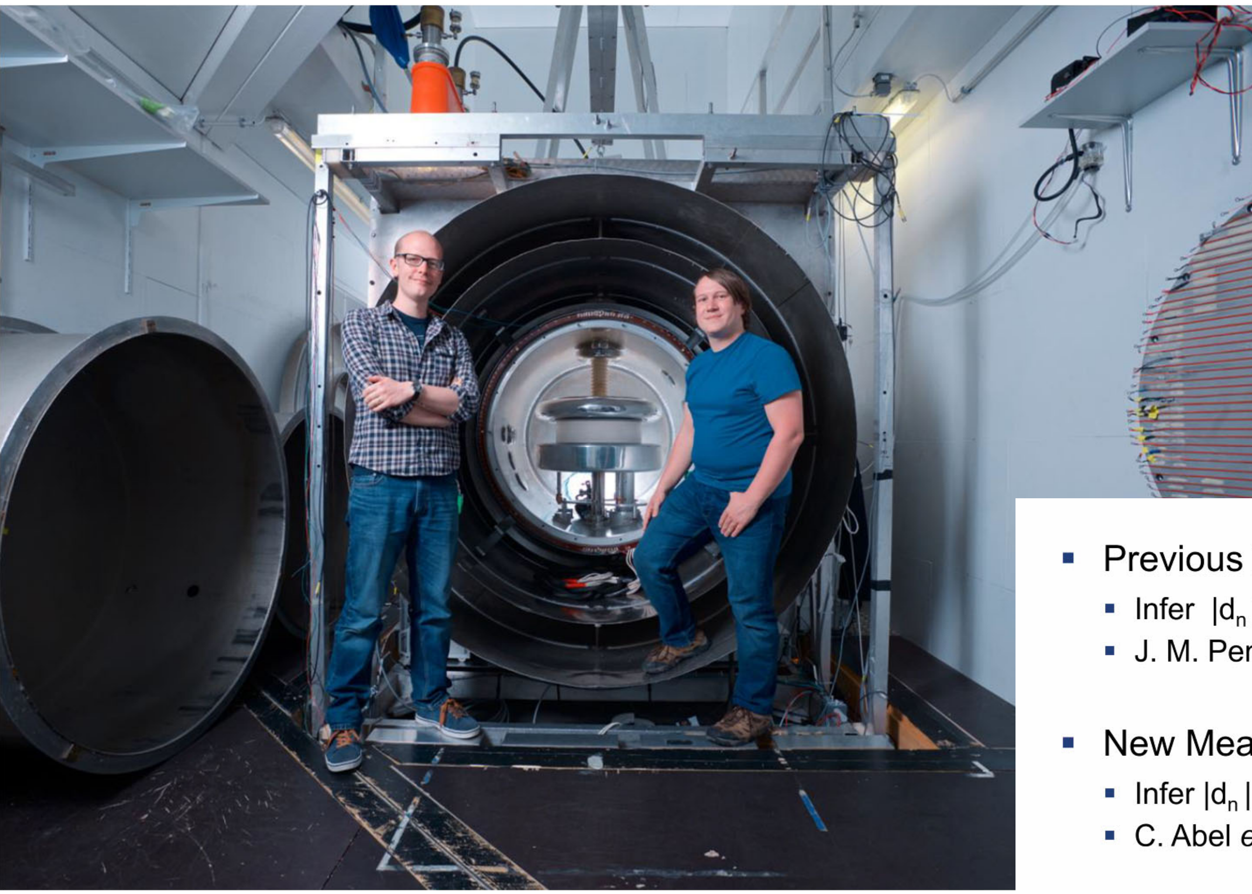
E: Electric field

T: Free precession time

N: number of neutrons counted

M: number of repeats

Highlight #1: PSI published a new nEDM limit (2020)



$$\sigma(d_n) \geq \frac{\hbar}{2\alpha E T \sqrt{N}\sqrt{M}}$$

$\alpha = 0.76$
$E = 11$ kV/cm
$T = 180$ s
$N = 11{,}400$

$M = 288$ cycles/day

2005-2015: improving OILL apparatus @ PSI
2015-2016: physics data taking
2017: field mapping

- Previous Measurement: $(-0.2 \pm 1.5_{\text{stat}} \pm 1.0_{\text{sys}}) \times 10^{-26}$ e cm
  - Infer $|d_n| < 3 \times 10^{-26}$ e cm (90% CL)
  - J. M. Pendlebury *et al.* Phys. Rev. D **92**, 092003 (2015)
- New Measurement: $(0.0 \pm 1.1_{\text{stat}} \pm 0.2_{\text{sys}}) \times 10^{-26}$ e cm
  - Infer $|d_n| < 1.8 \times 10^{-26}$ e cm (90% CL)
  - C. Abel *et al.* PRL **124**, 081803 (2020)

ETHzürich

Additional Systematics

Effect	Shift (x10^{-28} e cm)	Error (x10^{-28} e cm)
Error on $\langle z \rangle$	...	7
Higher-order gradients $\hat{G}$	69	10
Transverse field correction $\langle B_T^2 \rangle$	0	5
Hg EDM [8]	−0.1	0.1
Local dipole fields	...	4
$v \times E$ UCN net motion	...	2
Quadratic $v \times E$	...	0.1
Uncompensated G drift	...	7.5
Mercury light shift	...	0.4
Inc. scattering ^{199}Hg	...	7
TOTAL	69	18

Included in Crossing Lines Fit (Error on $\langle z \rangle$, Higher-order gradients, Transverse field correction)

Dedicated mapping measurements (Higher-order gradients, Transverse field correction)

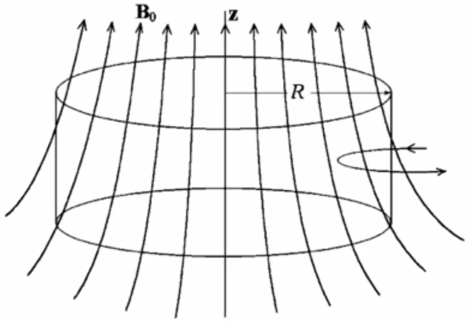
Constrained with measurement at PTB Berlin (Local dipole fields)

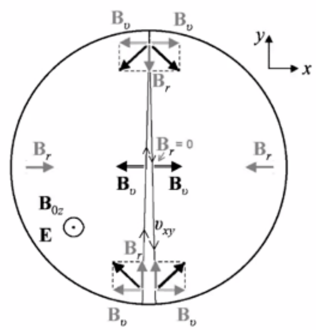
Cs Magnetometers (Uncompensated G drift)

Not anticipated at design, bear in mind for next time (Inc. scattering ^{199}Hg)

Total systematic error **0.18 x 10^{-26} e cm**
Factor 5 improvement on previous measurement
Only 20% of statistical error

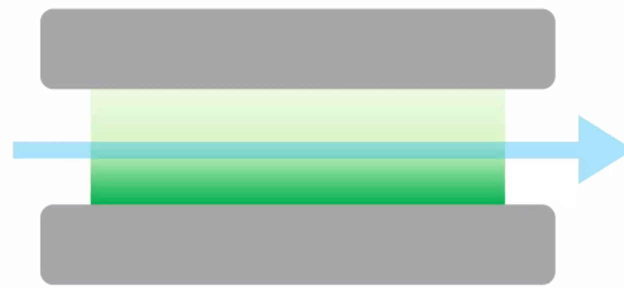
Leading Systematic: False EDMs and Gravitational Shift





Conspiracy between vertical gradient and motional magnetic field from Lorentz transform of *E* into Hg atom frame causes *E*-correlated frequency shift

$$d_{\mathrm{n}\leftarrow\mathrm{Hg}}^{\mathrm{false}} = \frac{G_{1,0}}{1\ \mathrm{pT/cm}} * 4.4 * 10^{-27}\mathrm{e\ cm}$$



Slow UCN hang at the bottom of the chamber
Shifts $\mathcal{R}$ shift proportional to vertical gradient

$$\mathcal{R} = \mathcal{R}_0\left(1 + G_{1,0}\frac{\Delta h}{B_0}\right) \qquad \Delta h \approx 0.35\ \mathrm{cm}$$

To first order these are proportional, but more complicated fields can cause a “phantom” effect

PRA **99**, 042112 (2019)

Beyond 1e-26 e-cm…

$$\sigma(d_n) \geq \frac{\hbar}{2\alpha E T\sqrt{N}\sqrt{M}}$$

Experiment	Facility	α	E (kV/cm)	T (s)	N	neutron density (1/c.c.)	Chamber D (cm) or volume	Coating	σ(d) per day (e-cm)	σ(d) (e-cm)
OILL	PSI-sD2	0.76	11	180	11,400	2	47	DLC + dPS	11e-26	1.5e-26
n2EDM	PSI-sD2	0.8	15	180	121,000	2	80	DLC + dPS	2.6e-26	
LANL	LANL-sD2	0.8	12	180	80,000	15	47	dPS	4 e-26	3.4e-27 (1y)
TUCAN	TRIUMF-lHe				600,000-2,000,000	200-400	30,000 c.c.	dPS		1e-27 (400d)
PanEDM	ILL—lHe					3.9 40		dPE	3.8e-26 (I) 7.9e-27 (II)	3.8e-27 (100d) 7.9e-28 (100d)
PNPI	PIK—lHe		12→ 27			200			1.5e-26	1e-27 (1y)
SNS	SNS—lHe		75	500	380,000	120	3,000 c.c.	dTPB-dPS		3e-28 (3y)
BeamEDM	ILL/ESS		40	4e-2			FP=50m		5e-26	

$$\sigma(d_n) \geq \frac{\hbar}{2\alpha ET\sqrt{N}\sqrt{M}}$$

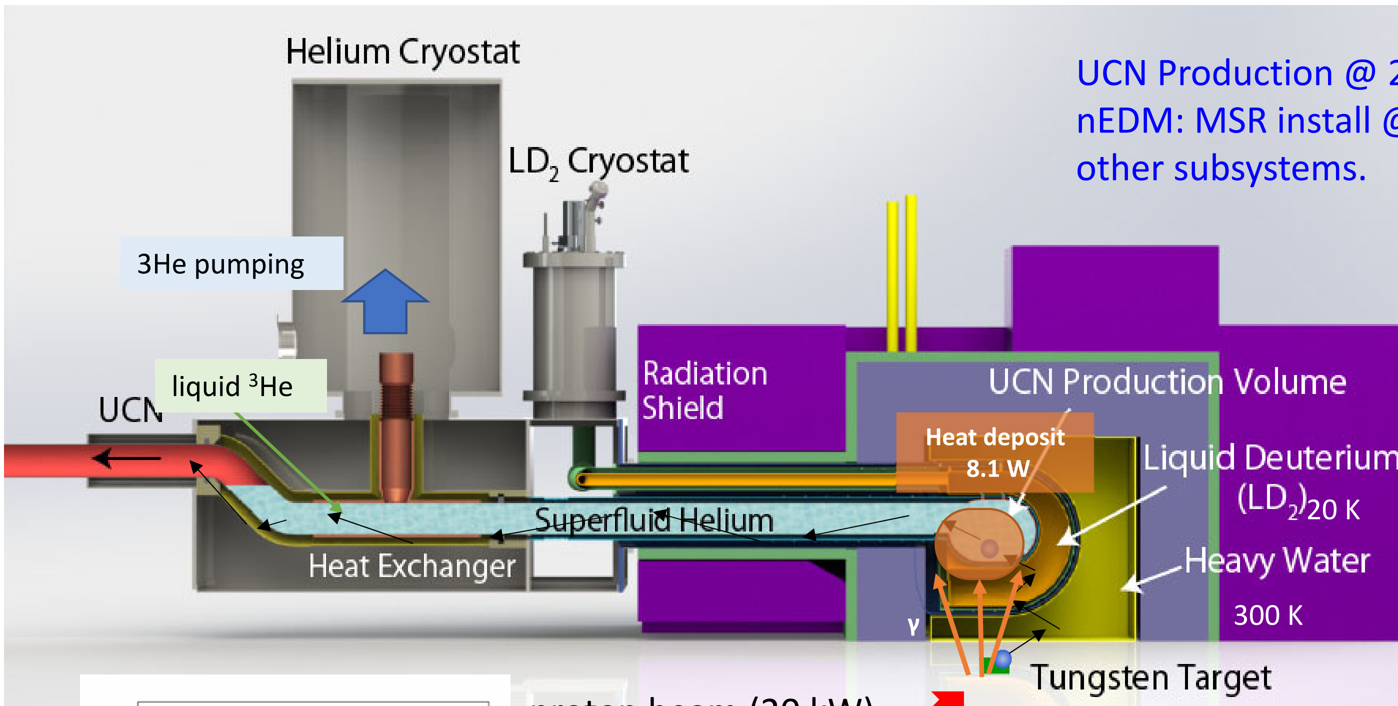
nEDM sensitivity is still limited by the UCN counting statistics → continuing efforts to make more intense UCN sources

Facility		Current	Power	UCN converter	Production volume (L)	UCN rate (1/s)	Storage (s)	Temper ature (K)	Heat load in target (W)	Neutron density (1/c.c.)
PSI	590 MeV p	2.4 mA (1%)	1.4 MW	sD2	30			5		2
LANL	800 MeV p	9 μA	7.2 kW	sD2	2		40	5		15
TRIUMF	480 MeV p	40 μA	20 kW	lHe	27	1.4-1.6e+7	30	1.1	8.1+1.5	200-400
ILL	9A n flux			lHe	12			0.6		200
PNPI—PIK reactor	9A n flux	5e+8 (/cm^2-s-A)		lHe				1.15	3.85	350
SNS				lHe	3	0.31/c.c.		0.5		

Highlight #2: UCN sources are getting better. Construction of the liquid He UCN sourcess are ramping up!

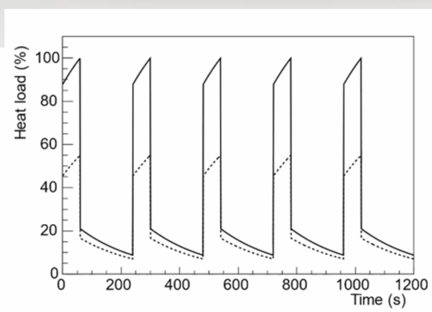
TRIUMF UCN source

UCN Production @ 2022!
nEDM: MSR install @ 2022, followed by other subsystems.



proton beam (20 kW)

Shinsuke Kawasaki



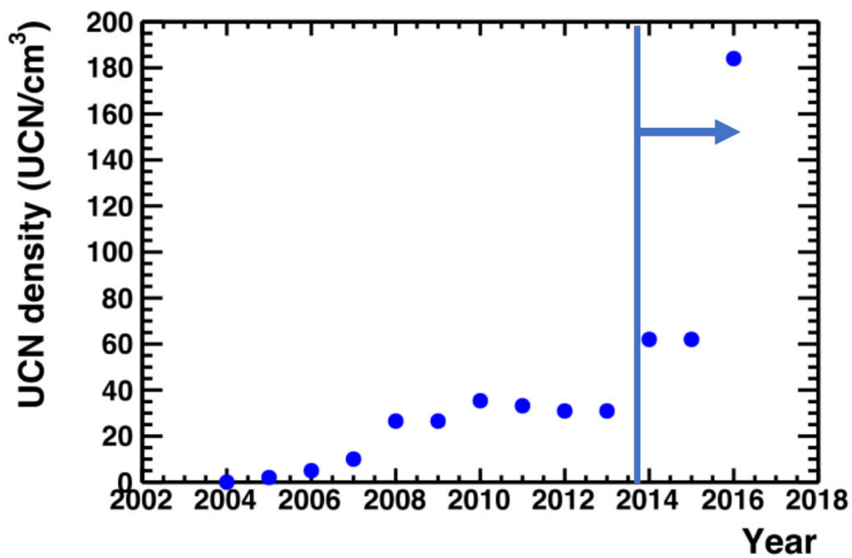
Temperature of the Superfluid helium converter kept around 1.0 K.

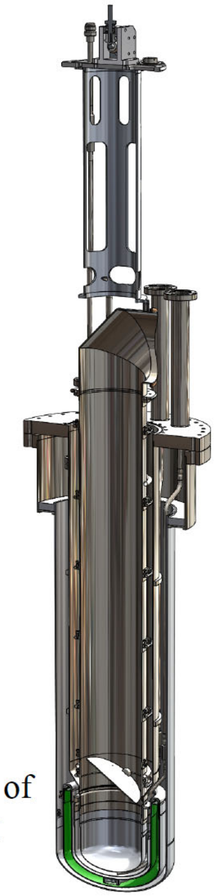
$\tau_{up\text{-}scat}$ = 35 sec @ 1.2 K
125 sec @ 1.0 K

LANL UCN source upgrade

Tim Chupp

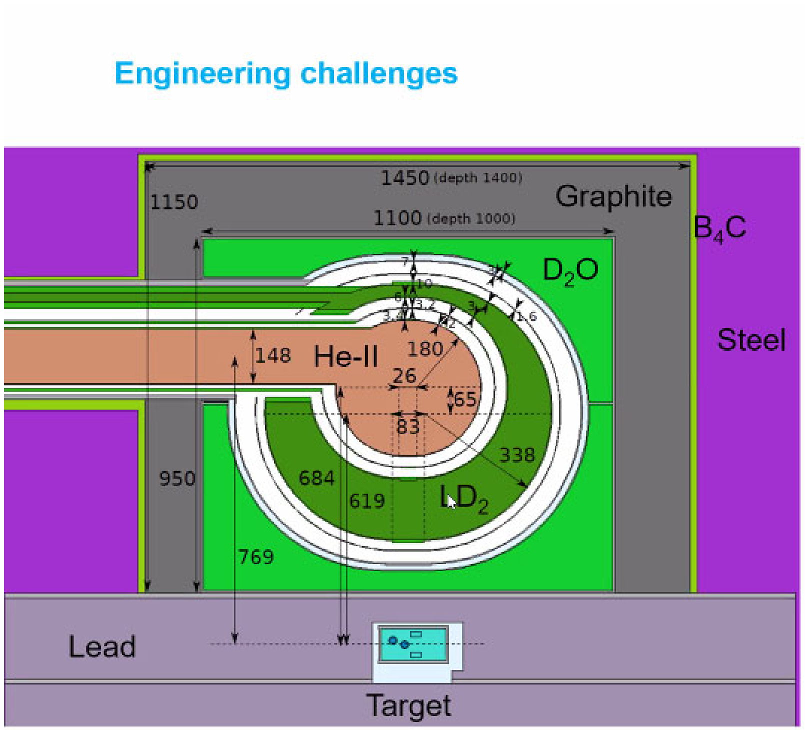
- Simulation based optimization of cryostat and moderator geometry
- Replaceable moderator: New flapper valve design: Modify UCN tee

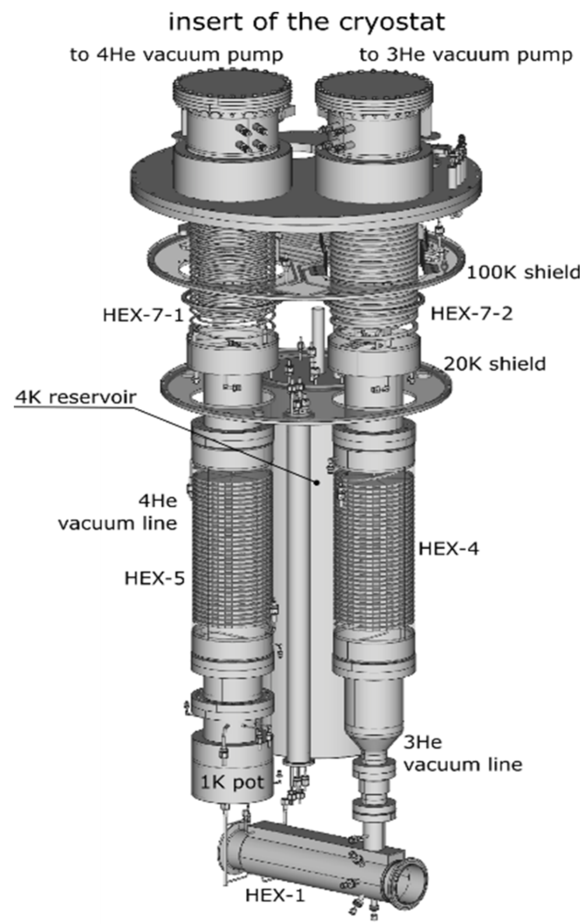




The source is shown to perform as modeled. The UCN density measured at the exit of the biological shield was **184(32) UCN/cm³**, a fourfold increase from the highest previously reported

Full-scale TRIUMF UCN source





- **Helium cryostat cooling power:** 0.4 W → 10 W

Enables operation at 40 µA beam current (x40 UCN yield)

- **Cold-neutron moderator :** sD2O → LD2 (x3)
- **Larger production volume:** 8 L → 27 L (x3)

Expected UCN yield: **1.4–1.6×10^7 UCN/s**

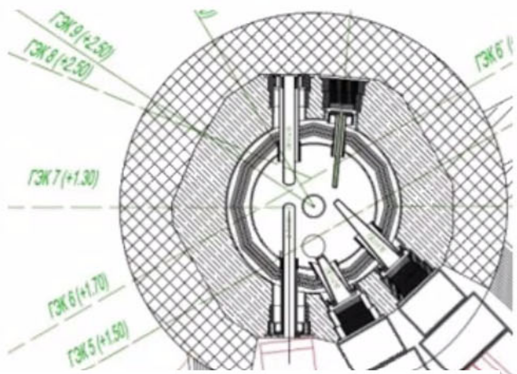
Wolfgang Schreyer
Russel Mammei
Shinsuke Kawasaki

UCN source at the PIK reactor

Anatoly Serebrov

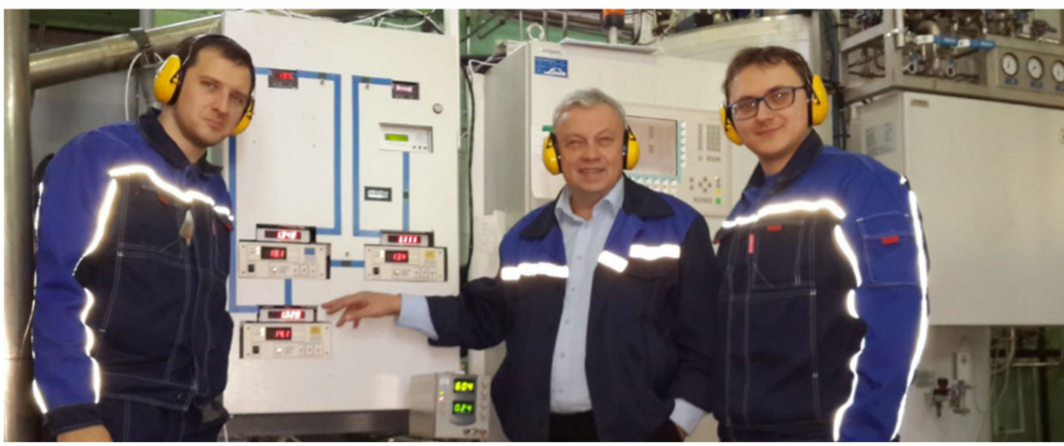
ULTRACOLD NEUTRON SOURCE

Cryogenics + UCN source ready, just waiting for the reactor to turn on.



The temperature of superfluid helium is obtained 1.08 K in the cryostat bath

The temperature of superfluid helium is obtained 1.3 K in the UCN source at a load of 15 W



- The UCN density in the EDM spectrometer for new UCN sources will be at least 35 times higher than for the currently operating UCN sources

PIK UCN source parameters:

Parameter	Value
UCN converter temperature, K	1,15
Thermal neutron flux, $cm^{-2}s^{-1}$	$2{,}8 \cdot 10^{10}$
9Å flux density, $cm^{-2}s^{-1}Å^{-1}$	$5 \cdot 10^{8}$
UCN density in UCN source, cm^{-3}	$1{,}3 \cdot 10^{3}$
UCN density in the EDM trap, cm^{-3}	$3{,}5 \cdot 10^{2}$
Energy release in the helium chamber, W	3,85
Energy release in the pre-moderator chamber, W	10,7
Energy release in the lead shield, W	267

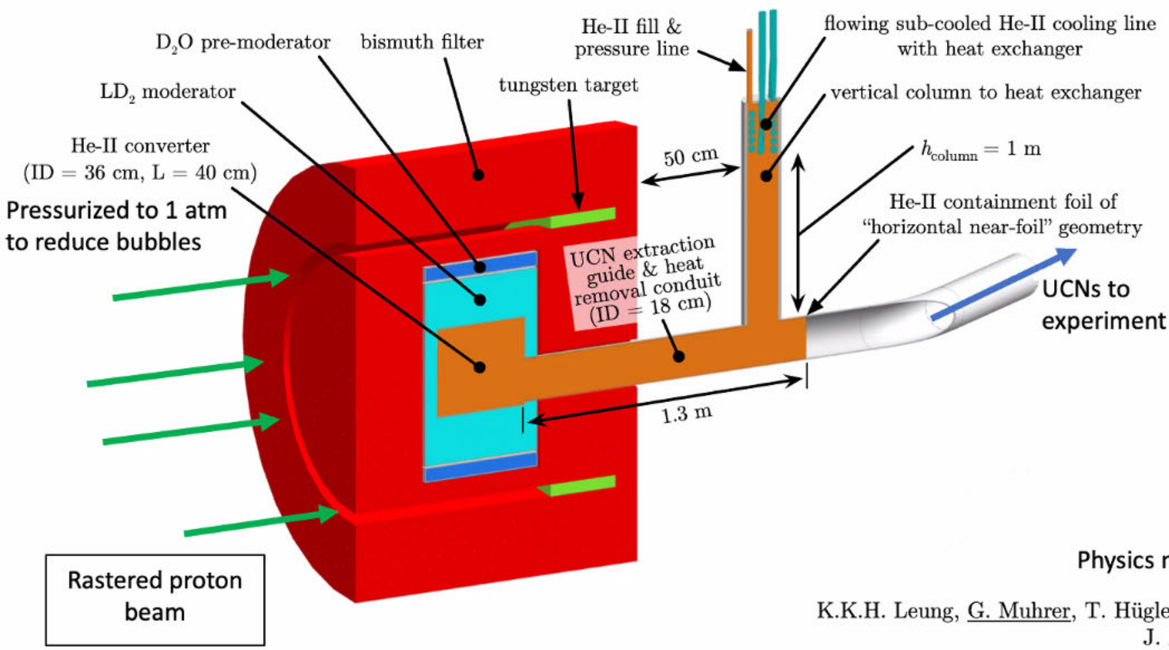
Kent Leung

High UCN-current, "inverse spallation target geometry", sf-^{4}He source (small digression)

Talking: Kent Leung

- Take **1 MW proton beam** @ 800 MeV energy (available SNS/LANL/Fermilab)
- 40 L sf-^{4}He bath with **100 W @ 1.6 K using sub-cooled helium technology** (e.g. common at LHC, JLab, SNS, Fermilab, ESS)
- At 1.6 K, up-scattering $\tau_{up} \approx 3$ s, **optimize for a maximum current UCN source** (**pessimistically assume single passage transport only**)
- **Raster proton beam** on "ring" shaped tungsten spallation target allows **edge water cooling**
- Total UCN production rate in sf-^{4}He is **1.8 x 10^9 UCN/s**.
- UCN delivery, **5 m away in 18 cm diameter guide**, from UCN simulations is **5 x 10^8 UCN/s** (1-passage efficiency 28%. Foil ~ 68% transmission.)

*^{58}Ni cut-off potential & unpolarized



Delivered equilibrium UCN density to external bottle with 18 cm hole:

V_{bottle} (l)	5	50	500	5×10^3	5×10^4
ρ_{bottle} ($\times 10^4$ UCN cm^{-3})	1.12	1.11	1.05	0.80	0.31
τ_{bottle} (s) (Filling time)	0.11	1.1	10	80	315

(pessimistically assume if UCN leaves volume then it is lost)

- Density doesn't drop until extremely large volumes
- If filling restricted by a small hole (e.g. 1 cm Ø => 200 s fill time) then need 1 **MW beam needed at ~ 10% duty**

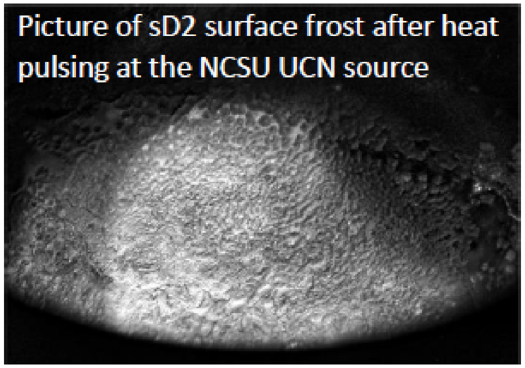
Physics model (w/ minor engineering considerations) published in:

K.K.H. Leung, G. Muhrer, T. Hügle, T.M. Ito, E.M. Lutz, M. Makela, C.L. Morris, R.W. Pattie, A. Saunders, A.R. Young
J. Appl. Phys. 126, 224901 (2019). doi:10.1063/1.5109879

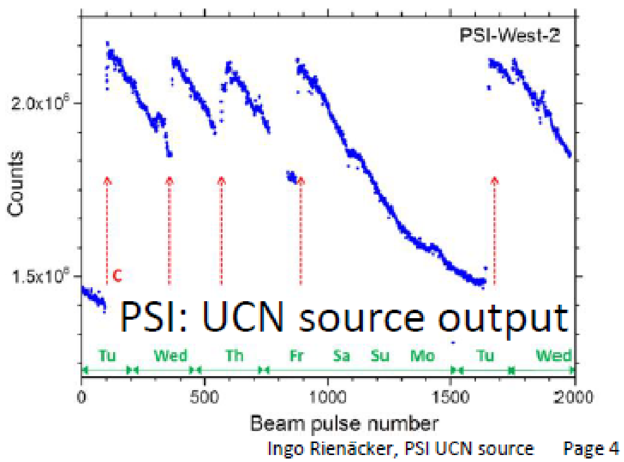
Understanding Limitation of UCN output from the sD_2 source

Ingo Rienacker

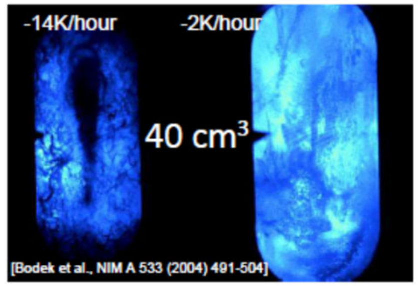
Surface effects

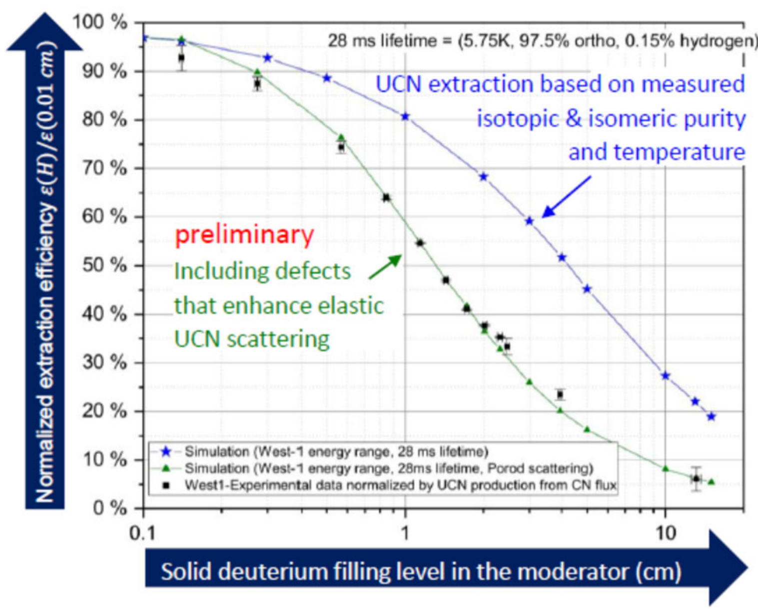


A. Anghel et. al, Solid deuterium surface degradation at ultracold neutron sources, Eur. Phys. J. A (2018) 54: 148

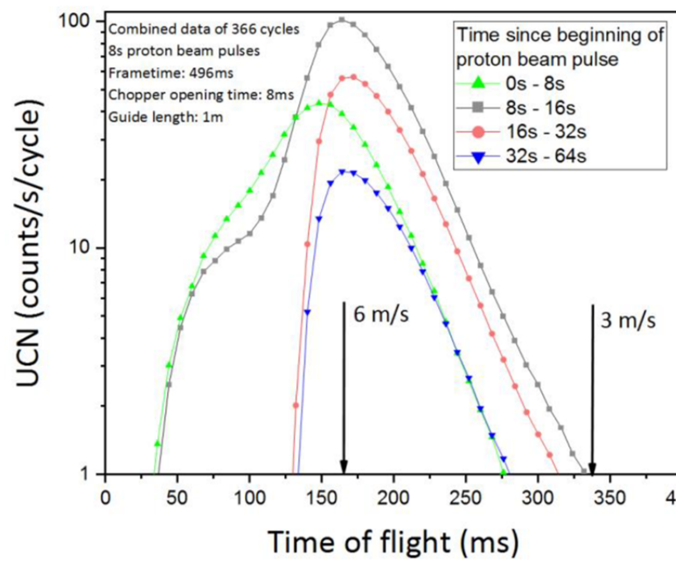


Bulk effects





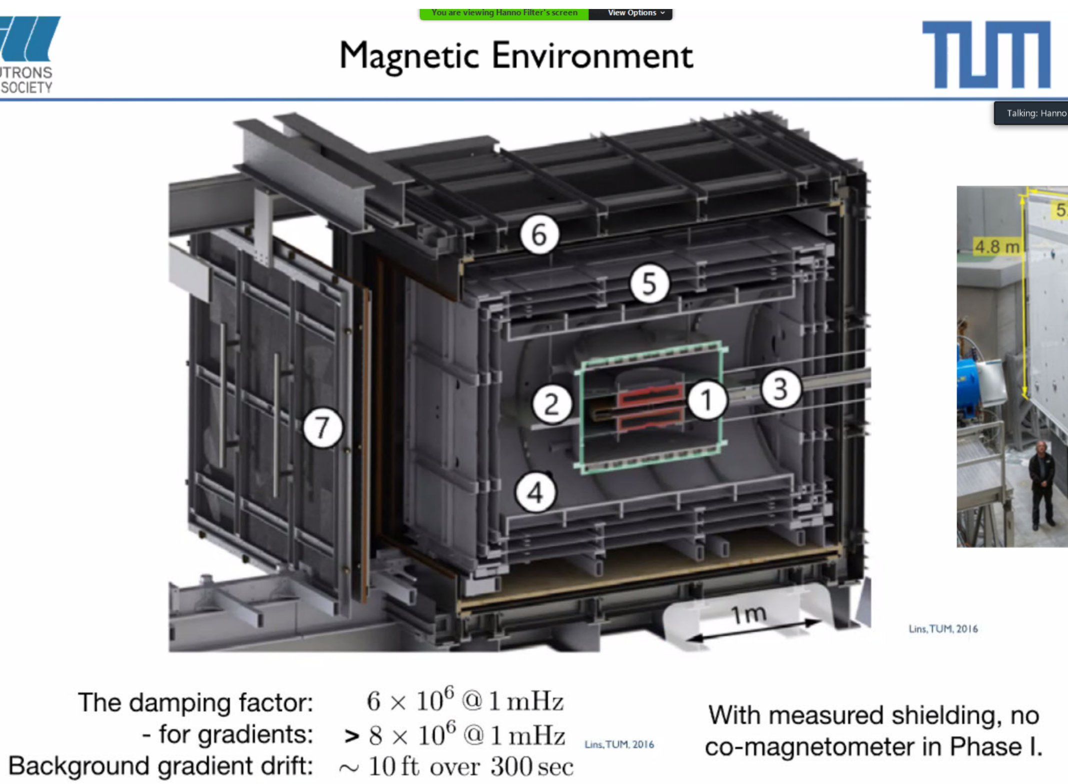
Slow crystal growth (over 15 days) gives 10-20% gain in UCN output.

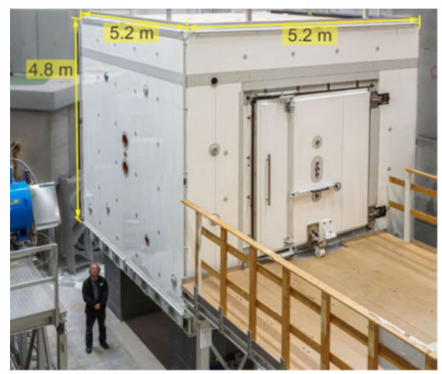


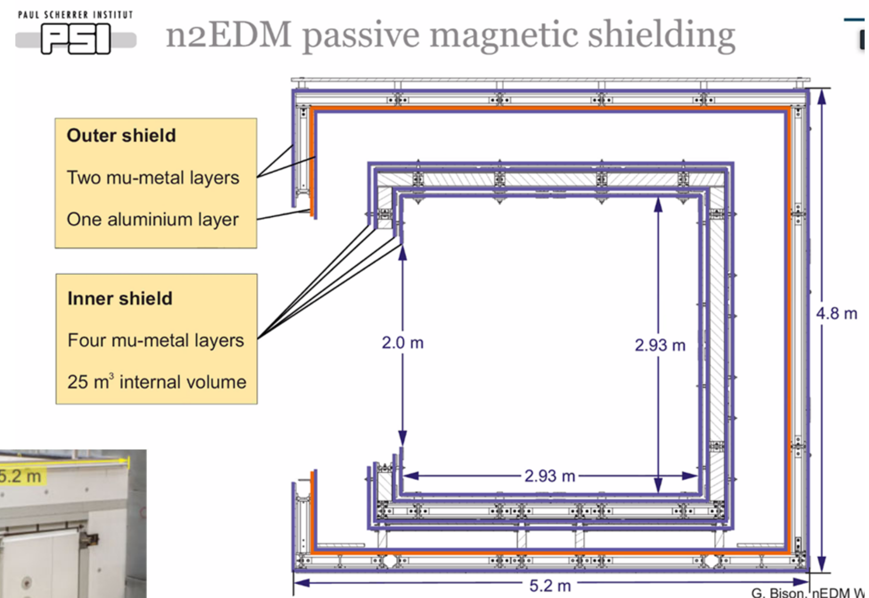
Highlight # 3: Significant field damping in large magnetically shielded rooms.

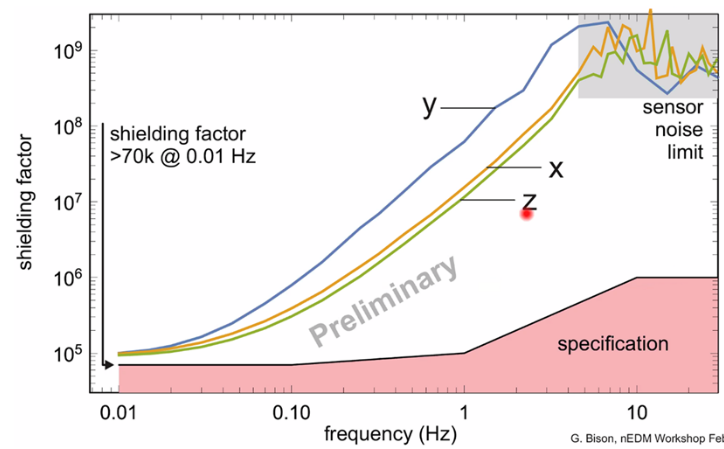
Georg Bison

Hanno Filter





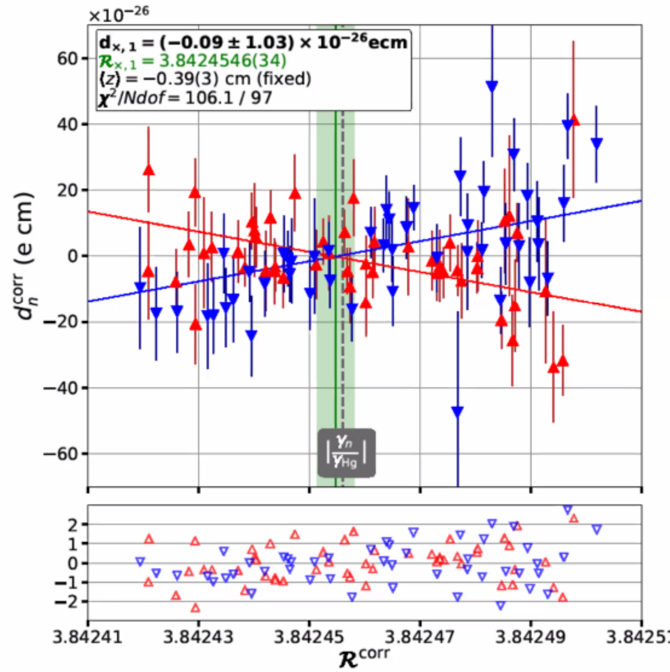




False EDMs and Crossing Lines Analysis

- Cesium magnetometer absolute accuracy too poor to use as sole measure of vertical gradient
- Use the gravitational shift to measure the vertical gradient
- Similar concept to that used on previous generation Sussex-RAL-ILL experiment

?



B Up B Down

Highlight #4: External magnetometer array and off-line field mapping for systematic corrections.

1. Tackling the systematic $d_{\mathrm{Hg}\to n}^{false}$

A convenient representation of $\vec{B}$ in spherical harmonics [Abel, C. et al. Phys.Rev.A 99, 4 (2019)] allows the representation of $d_{\mathrm{Hg}\to n}^{false}$ in terms of the gradients $G_{l,0}$ (k_l are simple coefficients)

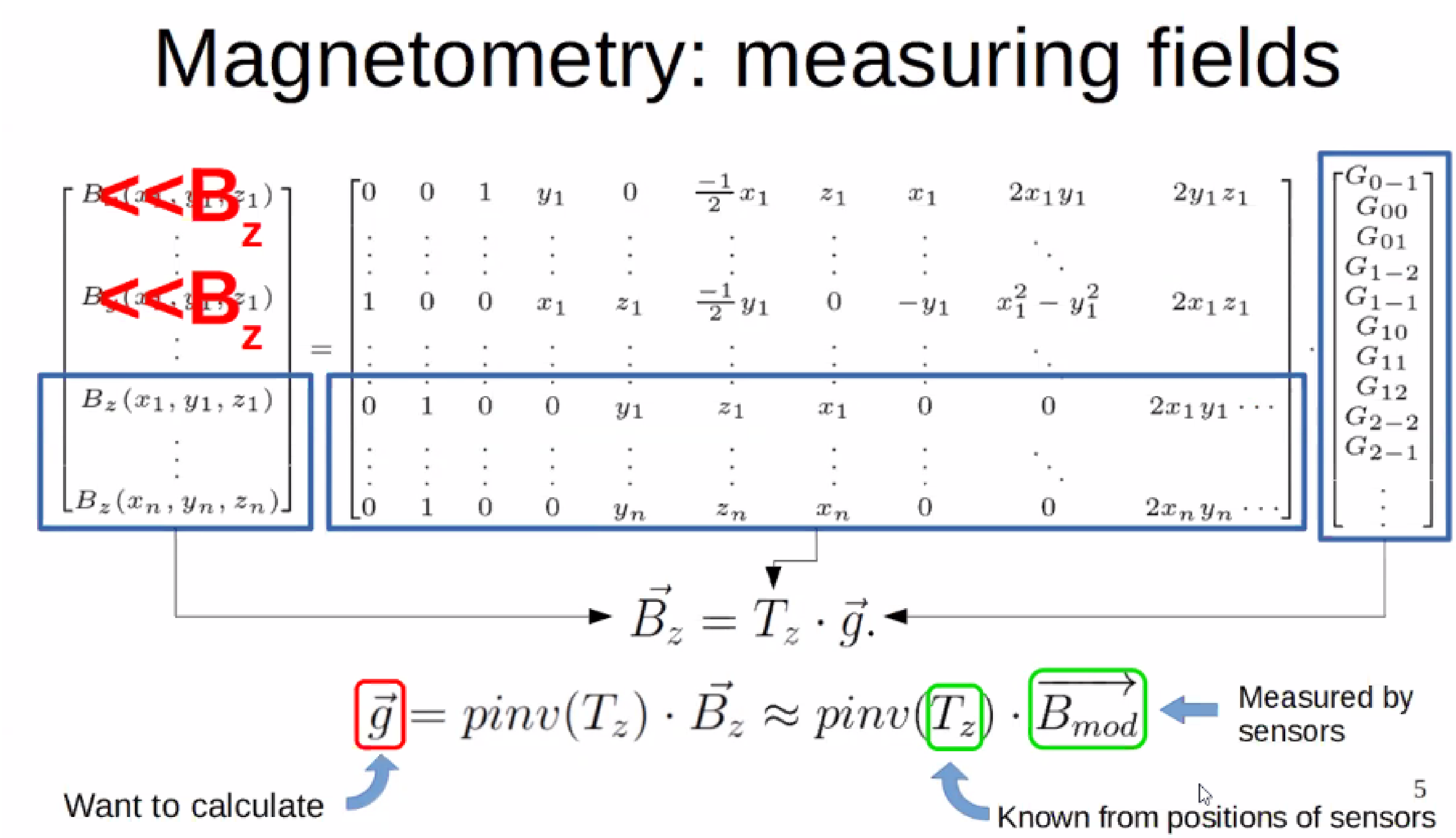
$$d_{\mathrm{Hg}\to n}^{false} = -\frac{\hbar\left|\gamma_{\mathrm{n}}\gamma_{\mathrm{Hg}}\right|}{2c^2}\sum_{l,m} \mathbf{G}_{\mathbf{l,m}} \left\langle \rho\Pi_{\rho,l,m}\right\rangle = k_1 G_{TB} + k_3 G_{3,0} + k_5 G_{5,0} + \cdots$$

$\mathbf{G}_{\mathbf{l,m}}$ are the magnetic field gradients

HgM
(online)
see Selim Touati's talk

Field mapper
(offline) see Kseniia Svirina's talk

Caesium magnetometer array
(online)

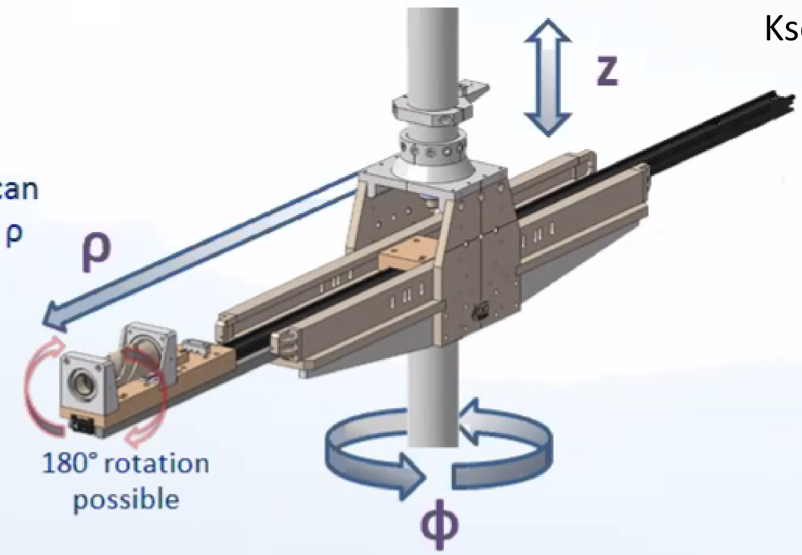

Magnetometry: measuring fields
<<Bz
<<Bz
Measured by sensors
Want to calculate
Known from positions of sensors
5

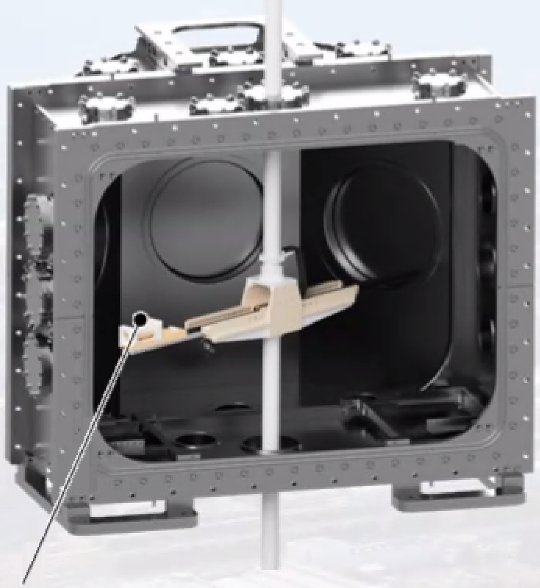
Ksenila Svirina

The general idea.
Description of the mapper.

Its characteristics:

- a cart with a precise magnetic sensor (**fluxgate**) can move along the **ρ**, **ϕ** and **z** axes, + a 180° flip along ρ
- fully made of non-magnetic materials (e.g. PEEK, POM, ceramics, aluminum)
- 3 sharp stepper-motors coupled to encoders. Resolution: 100 μm (ρ), 2 mrad (ϕ), 5 μm (z).
- an inclinometer sensor on the cart





Fluxgate sensor

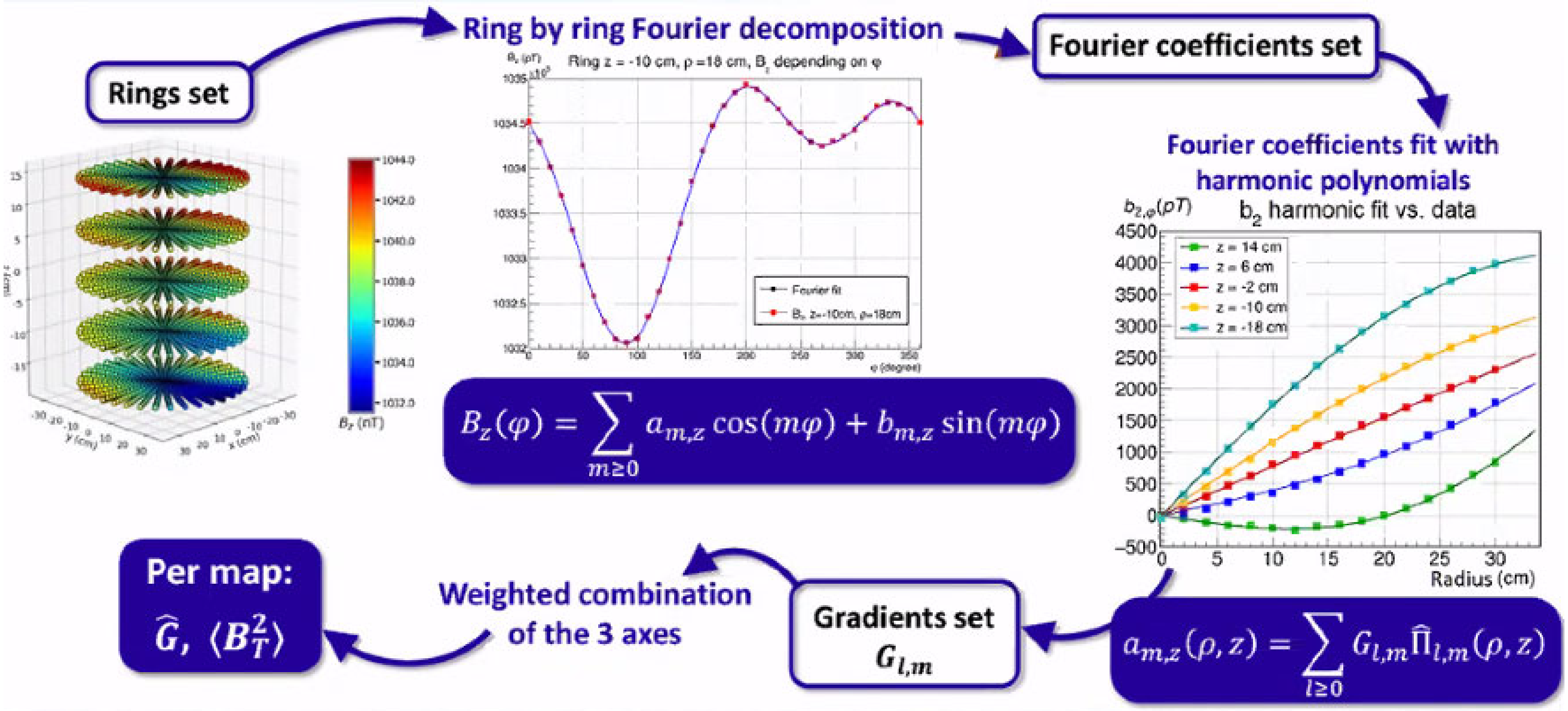
The mechanical precision is well within the requirements for extracting the **fifth-order phantom mode**

(the error on the correction for the fifth-order phantom mode must be lower than 3×10^{-28} e cm) <=> the accuracy:

$$\delta \acute{G}_5 < 20\,\mathrm{fT/cm}$$

Ksenila Svirina

The analysis strategy of a single map (nEDM):



1. Introduction
i. What is the false EDM?

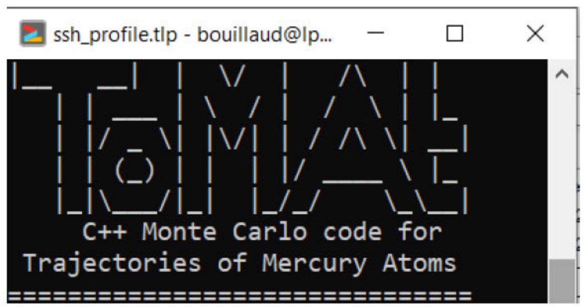
Thomas Bouillaud

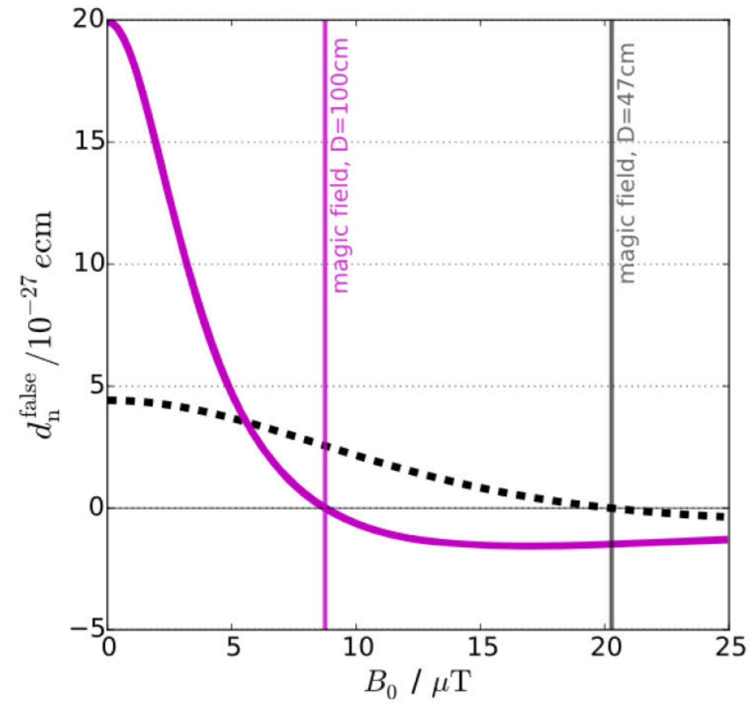
G. Pignol, Phys. Lett. B 793 440 (2019)

To sum up, the false EDM is produced by the correlation between the motional and the non-uniform transverse fluctuating fields :

$$d_{n\leftarrow \mathrm{Hg}}^{\mathrm{false}} = \frac{\hbar\left|\gamma_n \gamma_{\mathrm{Hg}}\right|}{2c^2}\int_0^\infty d\tau \cos(\omega\tau)\frac{d}{d\tau}\overbrace{\langle x(\tau)B_x(0) + y(\tau)B_y(0)\rangle}^{C(\tau)}$$

- Can be numerically calculated (TOMAt monte-carlo simulation)





False EDM produced by a linear gradient G_1 as a function of holding field B_0

1. $d_{n\leftarrow \mathrm{Hg}}^{\mathrm{false}}(B_0)$ increases with chamber size → concerning for n2EDM
2. $d_{n\leftarrow \mathrm{Hg}}^{\mathrm{false}}(B_0)$ has a zero crossing ! We call this the magic value B_{0m}

Thomas Bouillaud

Phantom Fields can also be suppressed near the magic field!

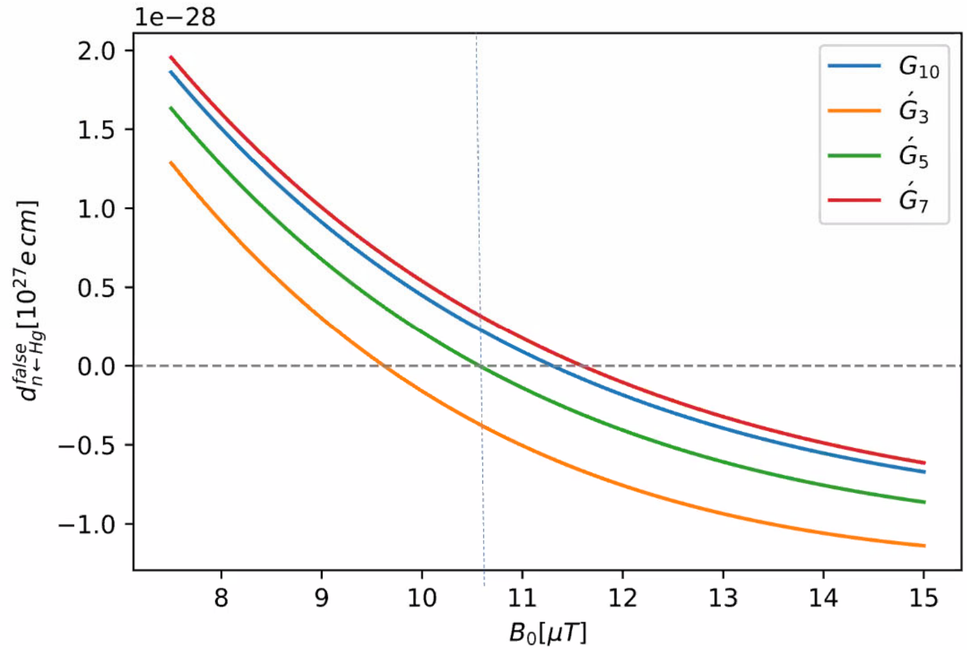
2. The magic field option
iv. Results

Talking: Thomas Bouillaud

Best magic value for a combination of those phantom modes ?

One possibility is to set it to $B_{0m,5}$

- Cancels 5th order mode
- Suppresses 3rd order mode by a factor 30
- Suppresses the 7th order mode by a factor 40

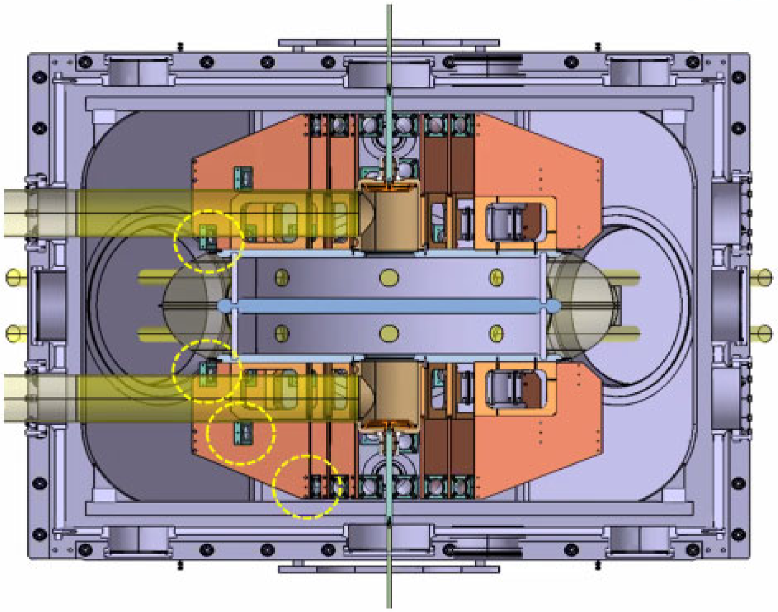


$B_{0m,3} = 9.6\mu\mathrm{T}$ $B_{0m,5} = 10.5\mu\mathrm{T}$ $B_{0m,1} = 11.3\mu\mathrm{T}$ $B_{0m,7} = 11.6\mu\mathrm{T}$

Duarte Pais

2. The caesium magnetometer array subsystem

Characterisation Goal:
$$\Delta(k_3 G_{3,0}) \leq 3 \times 10^{-28}\ e.\mathrm{cm}$$



This is possible with an **array of caesium magnetometers (CsM).**

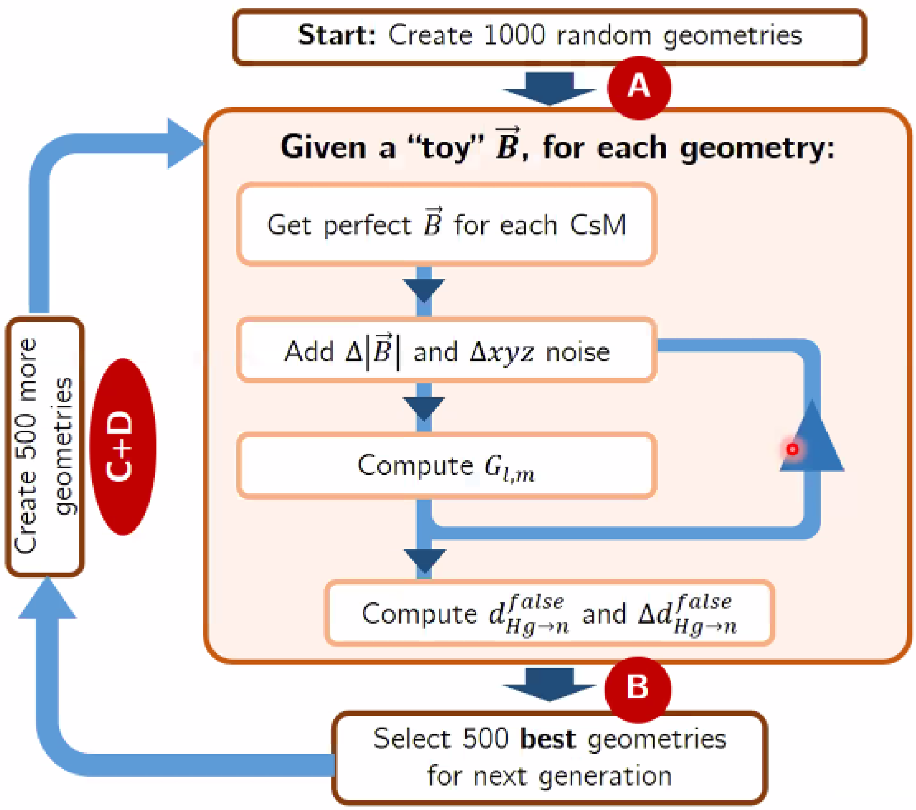
$|\vec{B}|$ at CsM xyz → $G_{l,m}$ are calculated → $\boldsymbol{d}^{\mathbf{false}}_{\mathbf{Hg \rightarrow UCN}}$ is characterised

To ensure this performance, the geometry of the array has been optimised with a genetic algorithm.

Duarte Pais

Evolution & Natural Selection:

2. The CsM array: genetic algorithm



A Gene pool

The genes of one individual are the (x_i, y_i, z_i) coordinates of its sensors

B Selection

Fittest individuals survive

C Crossover

The genes of the fittest individuals are mixed to generate new ones

D Mutation

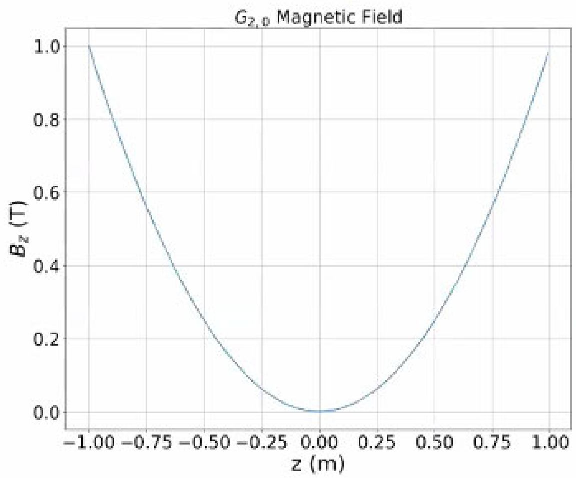
The genes of random individuals are changed.

Innovative magnetic coil designs:

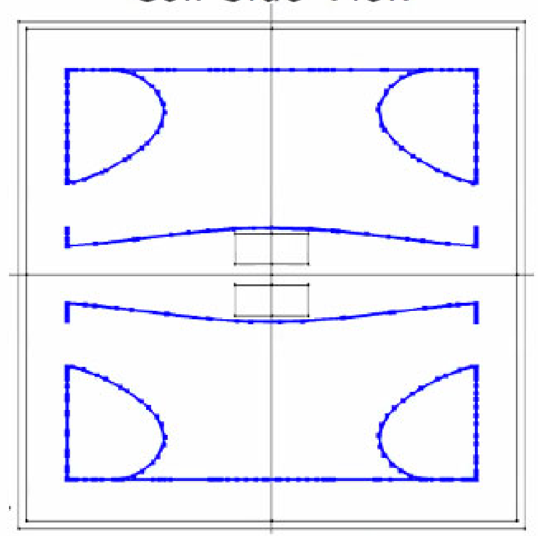
Mark McCrea

$G_{\ell,m}$ Coil Shapes

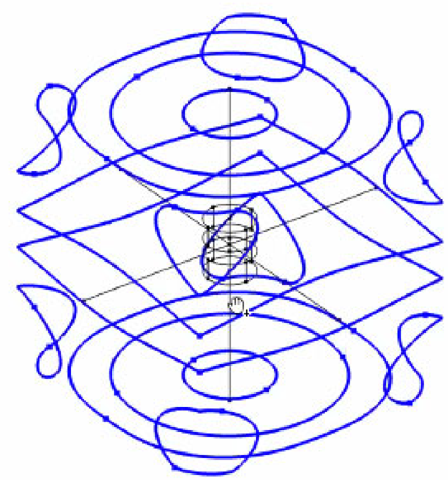
Field Shape



Coil Side View

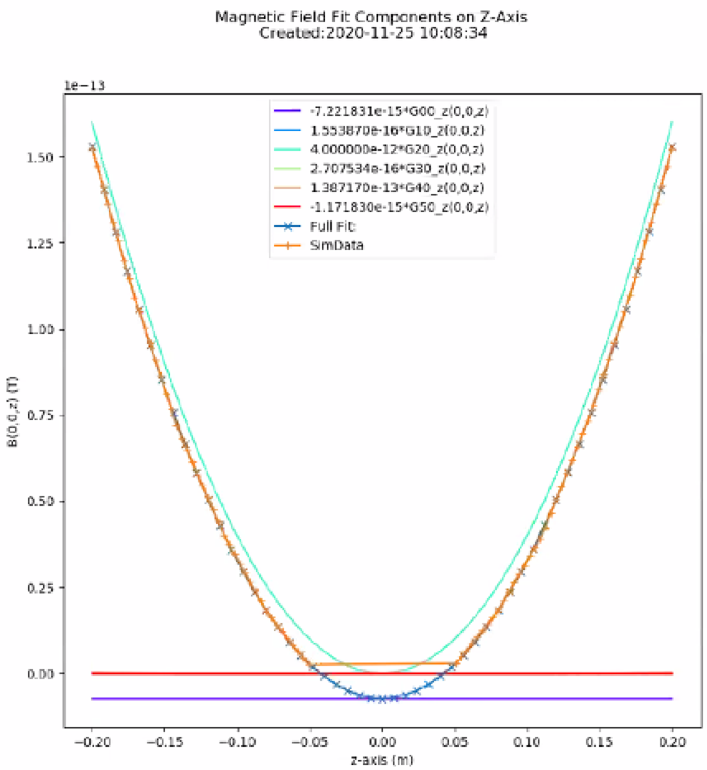


Coil Isometric View



Mark McCrea

Example $G_{\ell,m}$ Evaluation

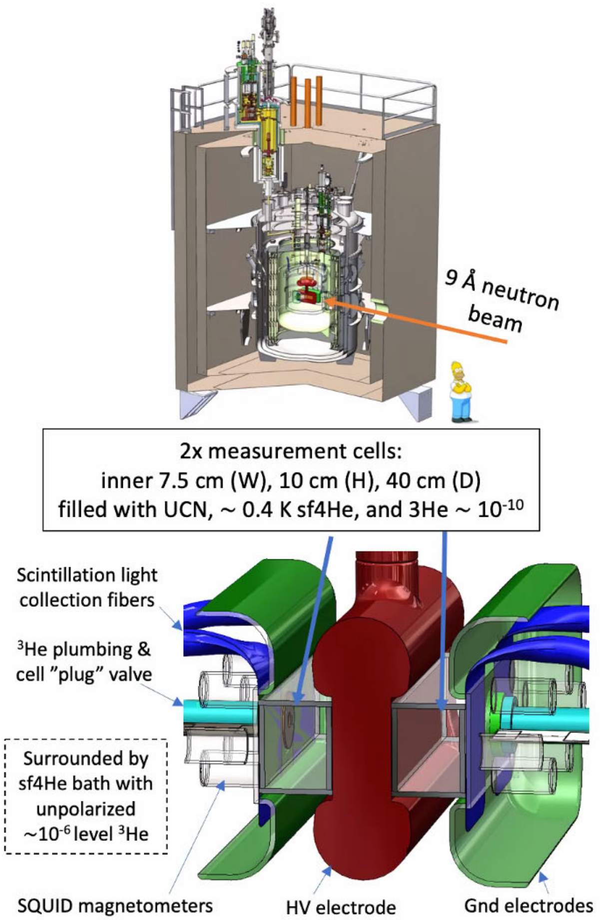


Relative $G_{\ell,0}$	
$G_{\ell,0}$	$G_{\ell,0}/G_{2,0}$
$G_{0,0}$	0.002
$G_{1,0}$	0.00004
$G_{2,0}$	1.0
$G_{3,0}$	0.00007
$G_{4,0}$	0.03
$G_{5,0}$	0.0003

Comparision to Ideal			
$B_z(T)$	Simulated	Ideal	Difference
mean	3.03e-14	3.79e-14	0.76e-14
$\sigma(B_z)$	4.87e-14	4.78e-14	0.09e-14
ΔB_z	21.69e-14	15e-14	6e-14
$\langle xB_x + yB_y \rangle$	-8.30e-15	-8.16e-15	0.14e-15

$d_{Hg}^{false} \propto \langle xB_x + yB_y \rangle$

Highlight #5: Steady progress in preparing for the big cryogenic nEDM experiment



The nEDM@SNS experiment

Talking: Kent Leung

Golub & Lamoreaux's technique: polarized **UCN** + polarized ^{3}**He** atoms + superfluid ^{4}**He**

Statistical "shot noise" limit: $$\sigma(d_n) \sim \frac{\hbar}{2\alpha E T\sqrt{N}}$$

$E =$ electric field (75 kV/cm thanks to sf-^{4}He. See Ito, Riley, Blatnik, Korsch talks.)

$\alpha =$ polarization contrast (UCN polarization ~ 98%)

$T =$ precession time (goal to use 1000 sec if wall loss times low enough)

$N =$ no. detected neutrons (high density from in-situ super-thermal production & accumulation. Density increases with $\tau_{storage}$. No need to transport. But "filling" time is ~ 1000 sec)

Polarized ^{3}He (~ 98%) serves as in-situ & live UCN spin analyzer (new type of signal!)

Low temperature (~ 0.4 K): SQUIDs and superconducting magnetic shielding

^{3}He + SQUIDs as co-magnetometer. Small changes of sf^{4}He temperature causes large changes (~ $T^{7.5}$) of ^{3}He mean-free-path as dominated by ^{3}He-phonon scattering. Great for co-magnetometer systematic checks .

Spin Dressing Intro:

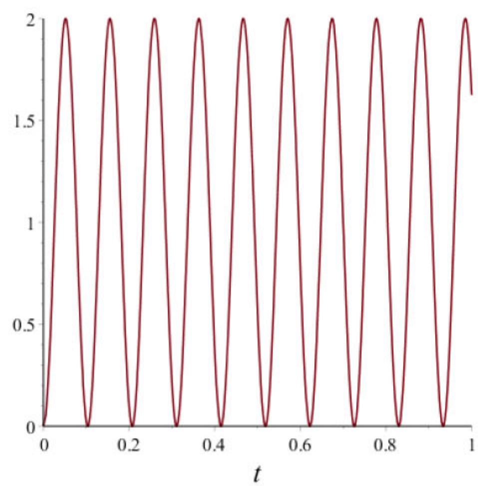
Two species free precession (FID)

- Uniform B field
  - Signal oscillates at beat frequency.

nEDM Signal E=±75kV/cm, $d_n=10^{-28}$

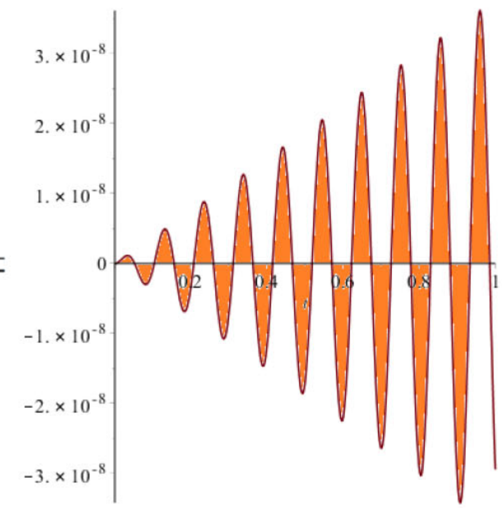
$$S(t) = \frac{\rho_{UCN} V}{\tau_{^3\mathrm{He}}} (1 - P_n P_{^3\mathrm{He}} \cos\theta_{n3}(t))$$

$S(t)$



$$N_\pm = \int S_\pm(t)dt$$

$S_\pm - S_\mp$



Sensitivity is a Function of the Phase Difference

Chris Swank

$$A = \frac{N_+ - N_-}{N_+ + N_-} \qquad N_\pm = \int S_\pm(t)dt \qquad \sigma_A = \sqrt{N_+ + N_-}$$

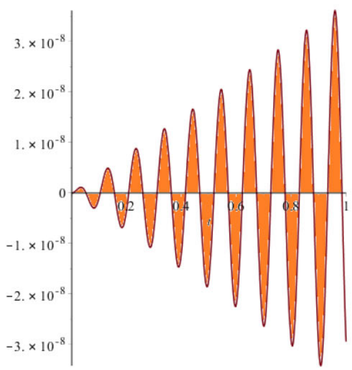
- We can maximize sensitivity if we can take away Zeeman splitting

$$\sigma_d = \frac{\pi\hbar}{4ET\sqrt{N}} \xrightarrow{\text{Spin Dressing}} \frac{\hbar}{2ET\sqrt{N}}$$

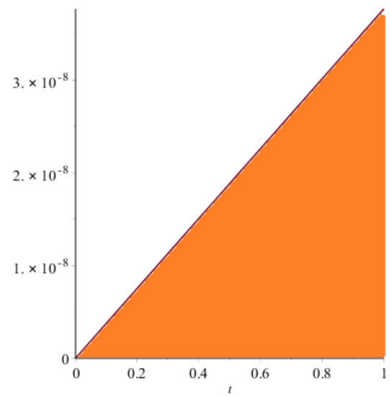
Free precession

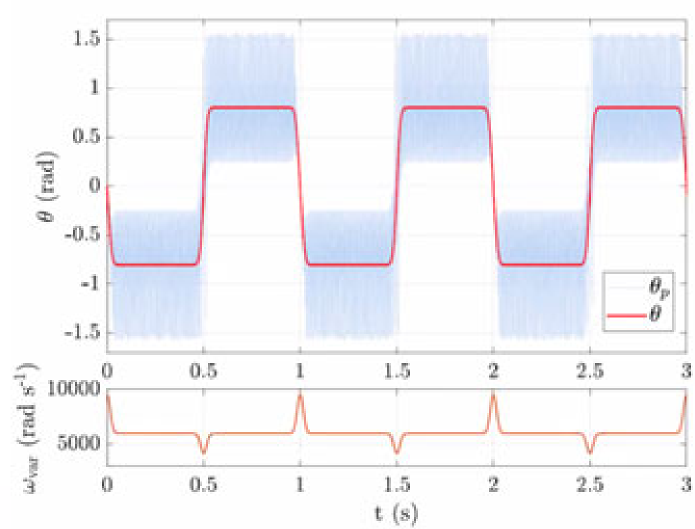
Improvement by factor pi/2

$S_\pm - S_\mp$



$S_\pm - S_\mp$





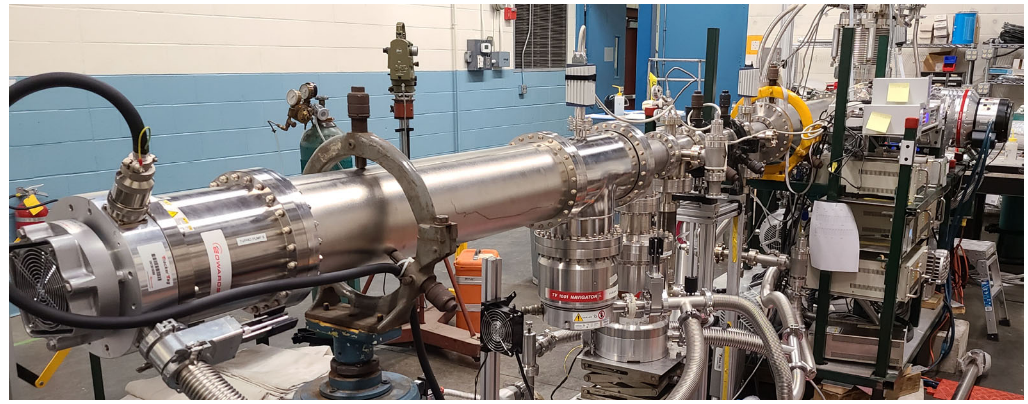
Modulated Critical Dressing

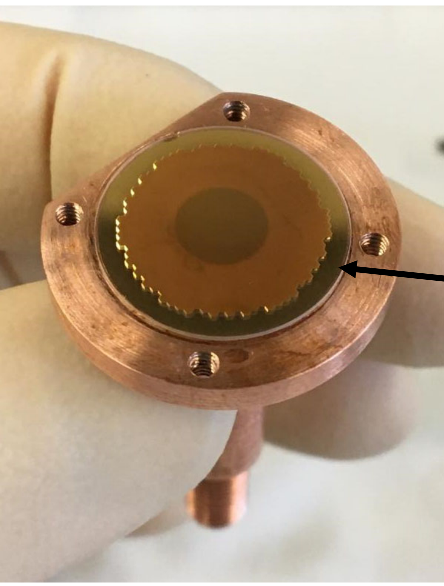
- B_0 drifts, and ^{3}He-n pseudomagnetic field can be mitigated by modulation
  - Maintain maximum sensitivity by modulating to maximum sensitivity phase.
  - Dressing parameters must be evaluated in SOS PULSTAR to find optimum

Talking: Christopher M. Swank

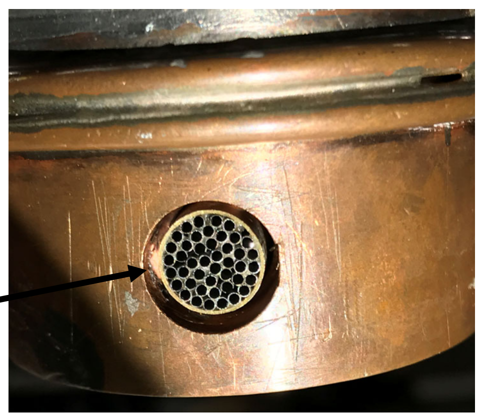
Polarized Atomic He3 Beam Source: Microchannel Plate Nozzle

Mark Broering





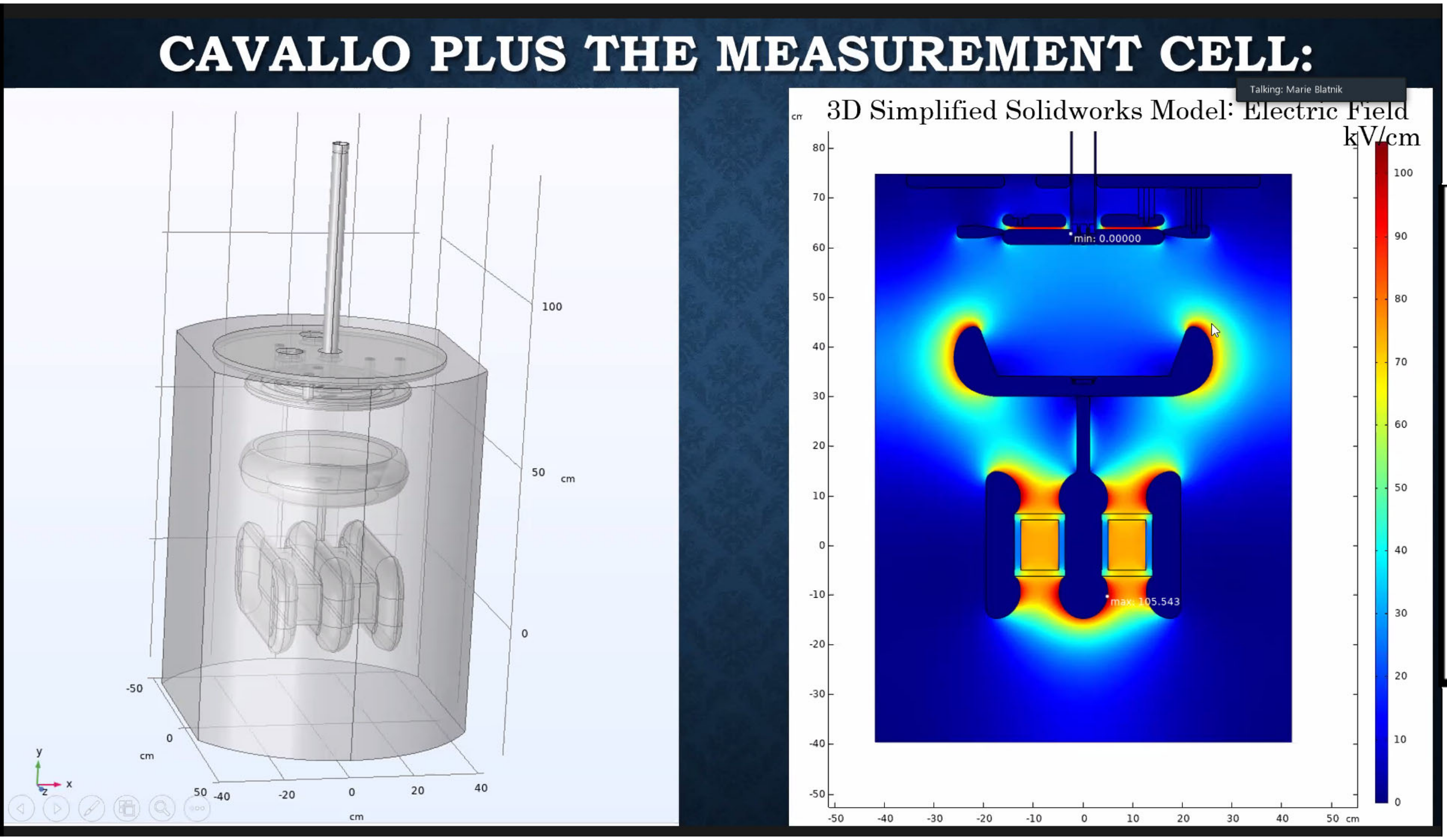
MC Plate



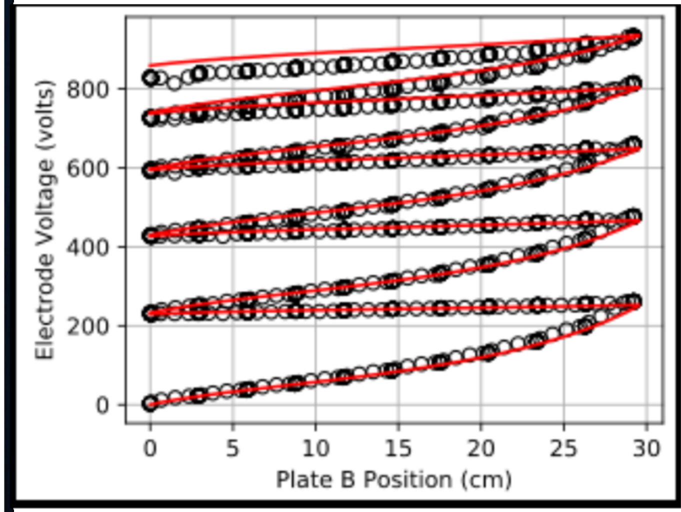
Needle Nozzle

- More pointed distribution improves system in two ways:
  - Reduces necessary minimum operating pressure
  - Reduces fraction of gas available to be converted into background
- MC plate nozzle
  - Simulated Transmission: 0.25%
  - Simulated Polarization: >99.9%

Multiply HV from 35kV to 800 kV in-situ!



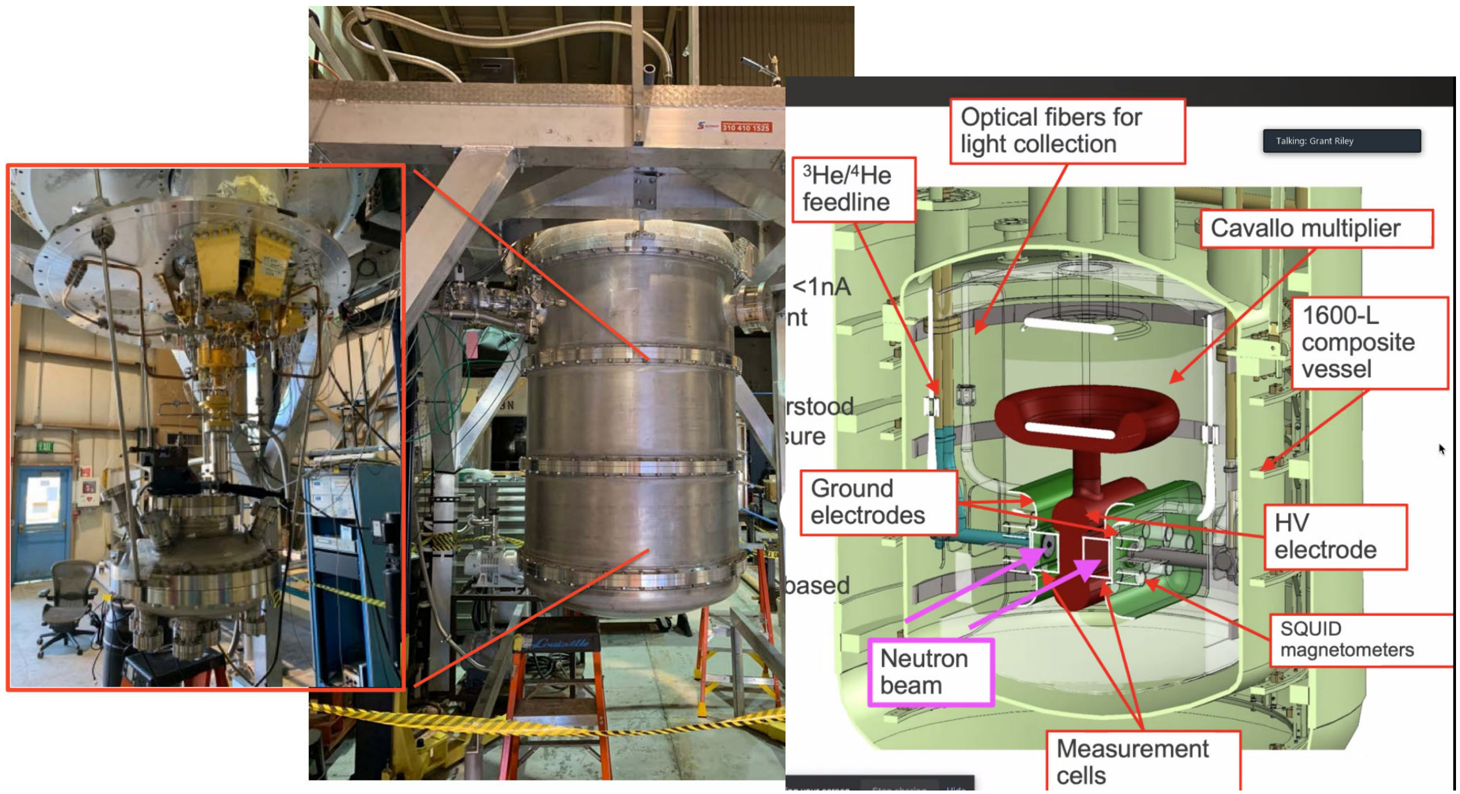
Marie Blatnik



Grant Riley

Half Scale High Voltage System

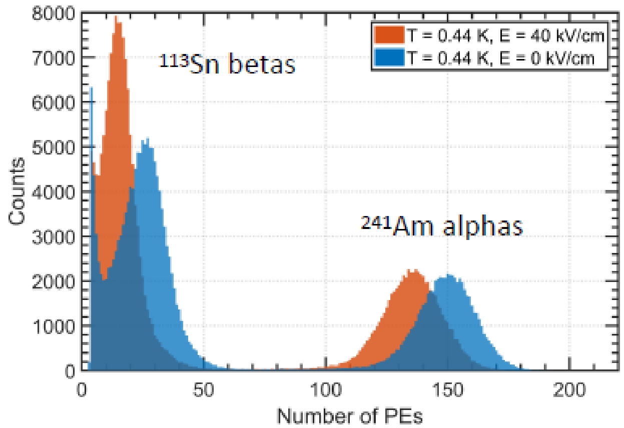
- R&D system designed to study high voltage breakdown in superfluid liquid helium
- Study stainless steel electrodes
- Study coated PMMA electrodes
- PMMA electrodes shaped similarly to the nEDM@SNS experiment electrodes
- Study electrical breakdown probability for nEDM@SNS conditions at half scale
- Study effect of breakdowns on electrode material, surface finish, performance



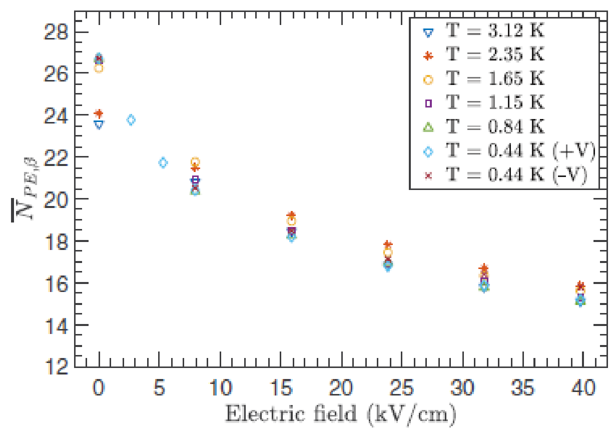
n-He3 capture scintillation detection

Takeyasu Ito

Results for prompt signal (first 100 ns)

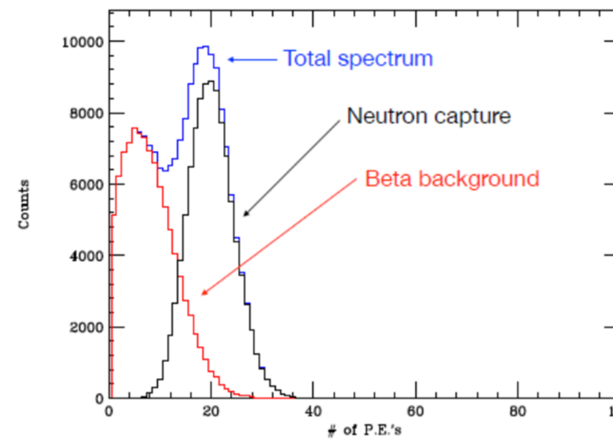


Electrons

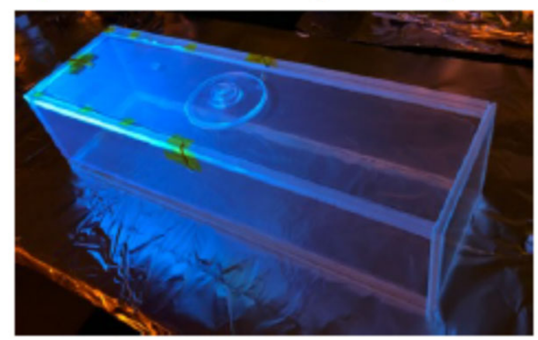


- The results for alphas are consistent with our previous results.
- For electrons, the electric field dependence for low temperature data are consistent with what is expected from the ionization current measurement.
- The low field data points for higher temperature data for electrons appear to be at odds with other data points.

Simulated spectrum of n-He3 capture @ E=75kV/cm



Full-sized test measurement cell (illuminated by 360 nm UV lamp)
Temperature sensors embedded from outside for tests.



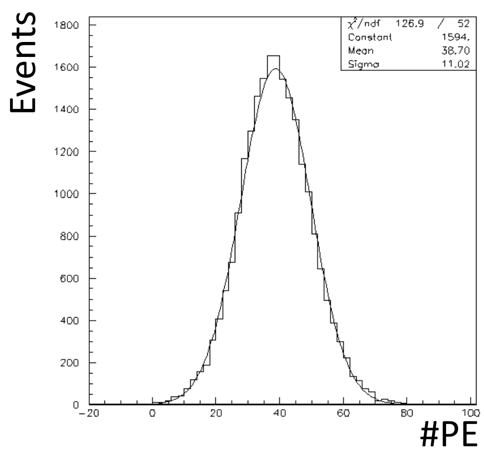
Kent Leung

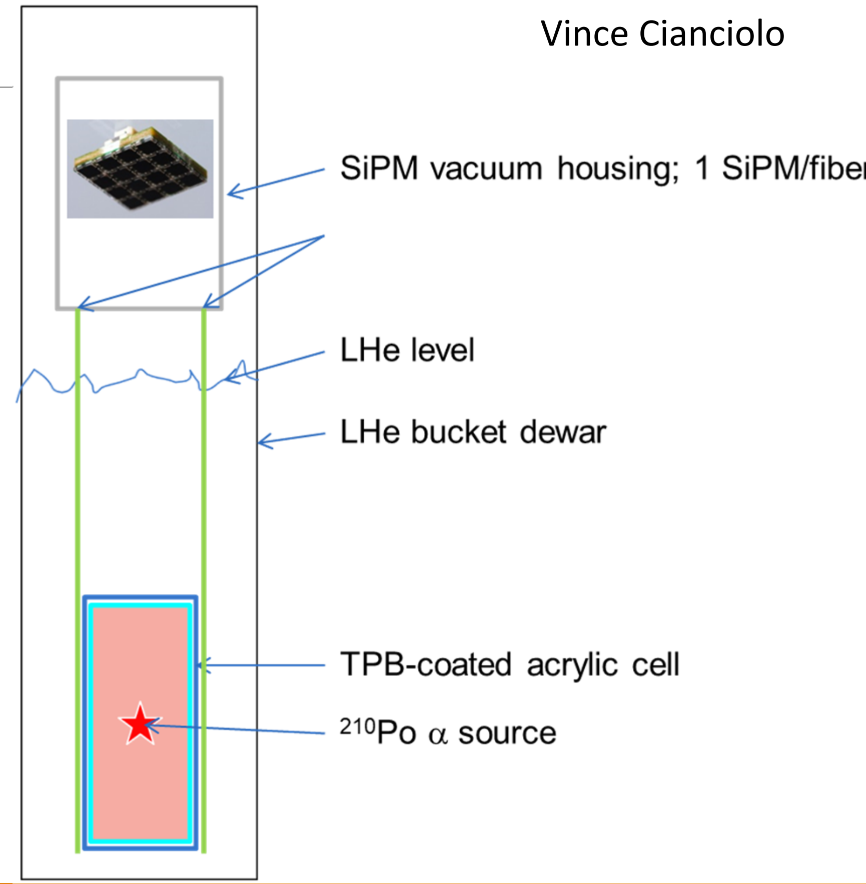
Prototype Results

Vince Cianciolo

Small-scale prototype using a 5 MeV α source observed 39 photoelectrons

Simple scaling factors (TPB coverage, SiPM photon detection efficiency, n/α photon yield) suggests final system will see ~19 PE; detailed simulations find ~16 PE (next talk, D. Loomis)





The reality of a cryogenic experiment:

Grant Riley

Talking: Grant Riley

Half scale previous activity

- Previous cooldowns in February 2019, June 2020
- February cooldown: Could not cool CV below 70 K
- June cooldown: Automatic refill capability lost, cooldown aborted
- Between cooldowns
  - Capillary lines re-plumbed inside HSHV
  - Pre-cool dewar outfitted with new lid
  - Internal leak check of all components
  - Helium recovery system constructed and tested
- Goals of November Cooldown
  - Cool Helium bath, inner shield and CV to 4K
  - Cool CV to below 2.1K by pumping on it
  - Determine if 1K pot can cool itself and the central volume (CV) below the superfluid transition with CV sealed
  - Determine if capillary sizes for 1K pot are appropriate to maintain cooling

  - Test helium recovery system
  - Test helium bath heat exchanger
  - Test roots blower integration

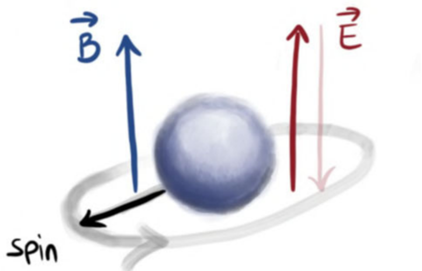
Training for the nEDM measurements:

Look at me!
Look at me!
Look at me NOW!
It is fun to have fun
but you have to know how.

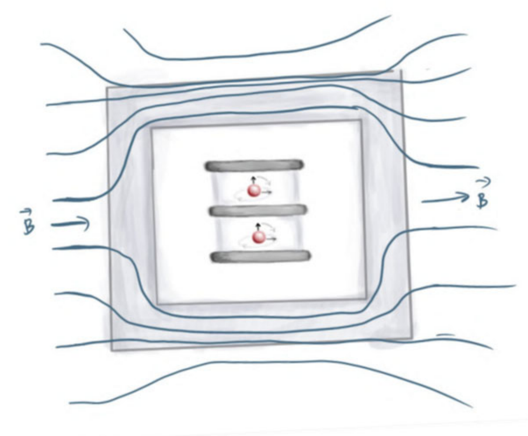
I can hold up the cup
and the milk and the cake!
I can hold up these books!
and the fish on a rake!
I can hold the toy ship
and a little toy man!
And look! With my tail
I can hold a red fan!
I can fan with the fan
As I hop on the ball!
but that is not all.
Oh, no
That is not all…

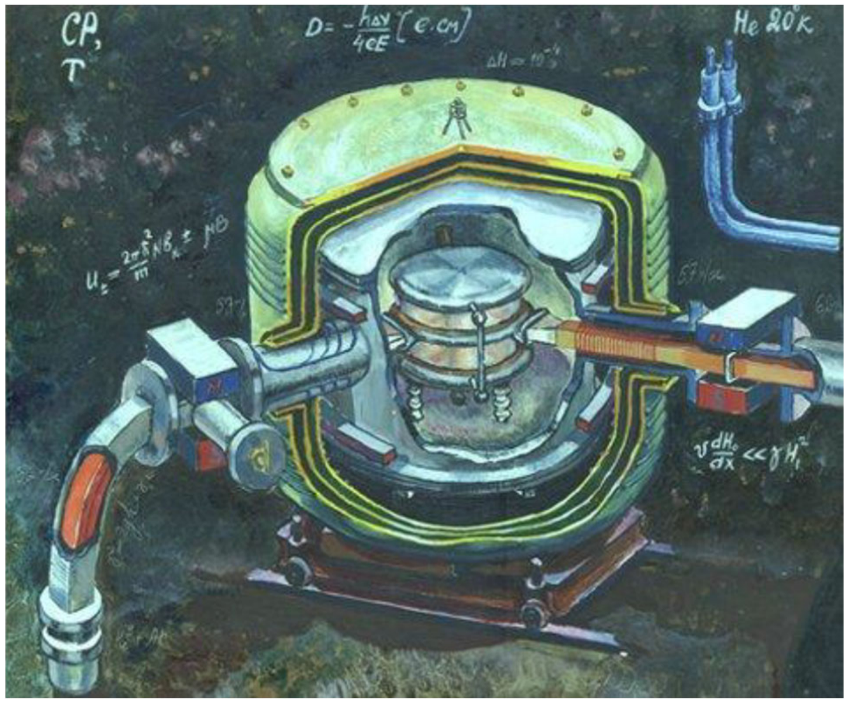
-- Dr. Suess in Cat in the Hat

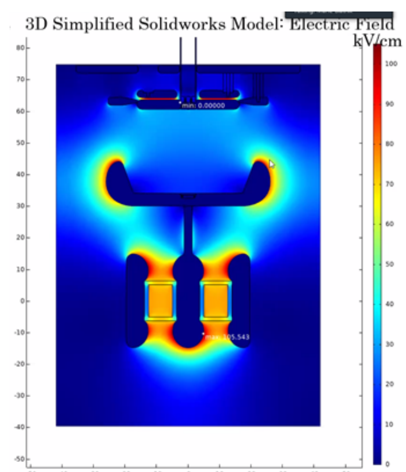
nEDM Arts



Ivana Belosevic

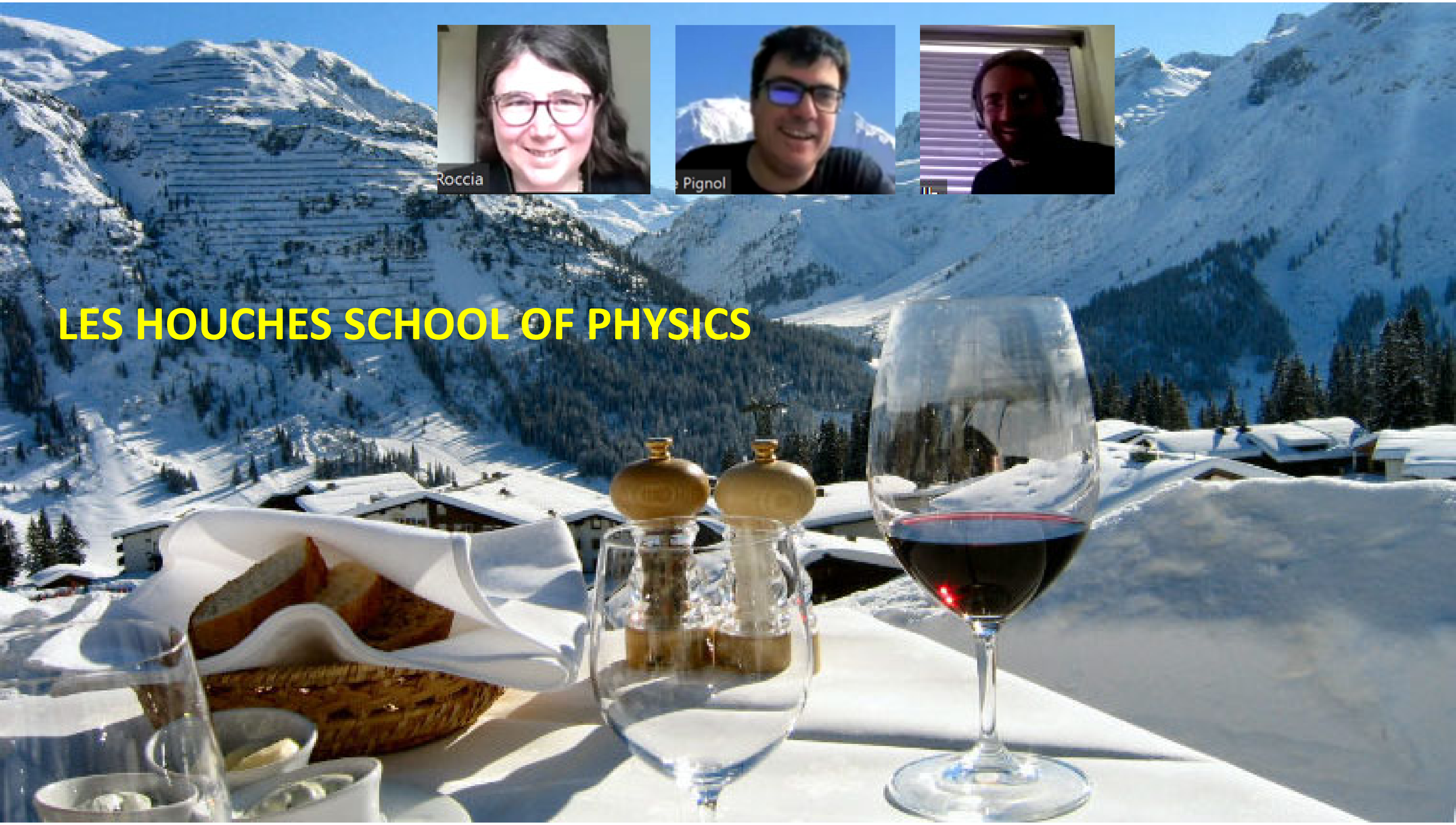






nEDM2023

- Los Alamos will host nEDM2023.
- We will hopefully meet in person.
- There will be lots to talk about.
- Until then. Take care.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