Liverpool HEP 2026

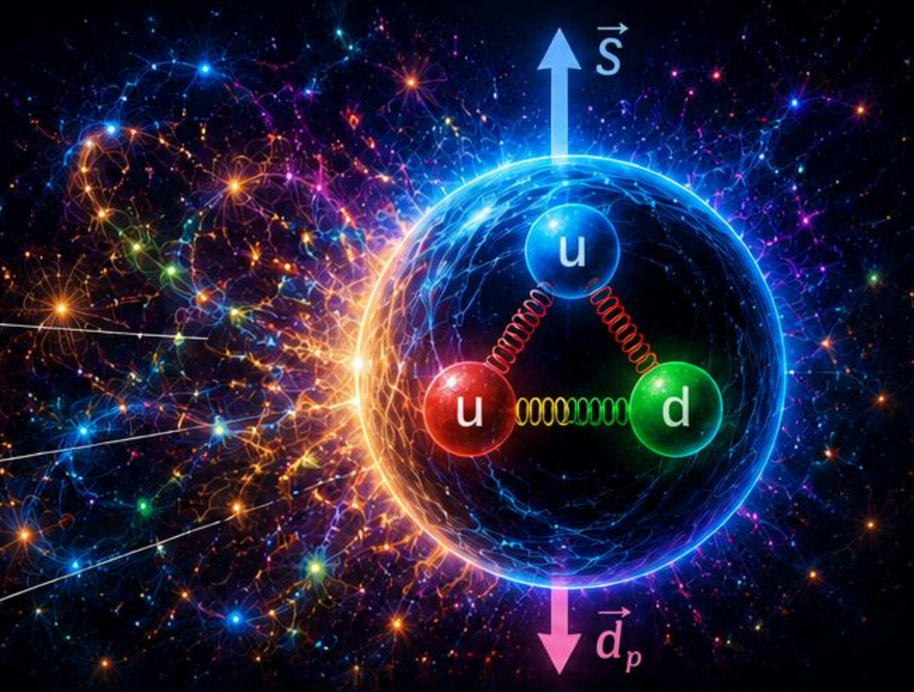
T. Bowcock

PROTON ELECTRIC DIPOLE MOMENT

A WINDOW TO NEW PHYSICS, THE QCD VACUUM AND THE ORIGIN OF MATTER

THE QCD VACUUM

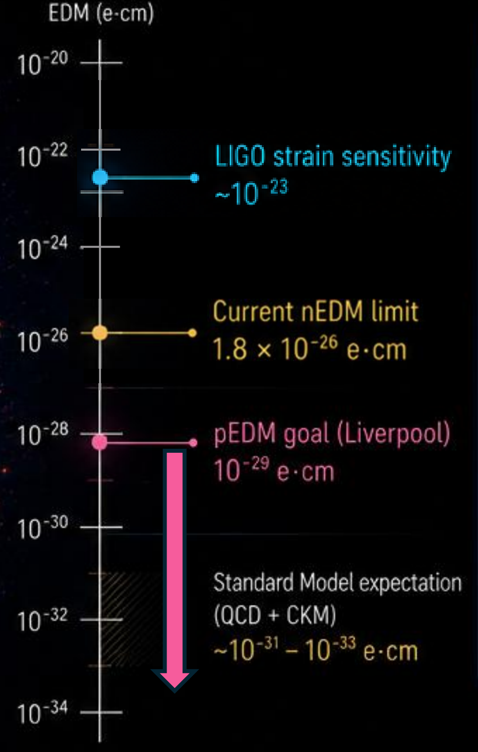
A seething, dynamic medium of quark–gluon fluctuations, instantons and topology. CP-violating effects here can generate a proton EDM.



A NON-ZERO pEDM SIGNALS NEW SOURCES OF CP VIOLATION BEYOND THE STANDARD MODEL

BEYOND LIGO PRECISION

Probing effects at incredible energy scales



WHY pEDM?

- CP — Tests CP symmetry and the matter–antimatter asymmetry of the Universe
- Sensitive to ultra-high energy new physics far beyond colliders
- Complementary to neutron, electron and atomic EDM searches
- Probes the QCD vacuum and the strong CP problem

THE EXPERIMENT

- Polarized protons storage ring.
- Counter clockwise beams for systematics.
- Unprecedented control of systematics.
- Sensitivity to a dipole 10^{10} times smaller than current limits.

THE AGS: A UNIQUE ENVIRONMENT

UNIVERSITY OF LIVERPOOL

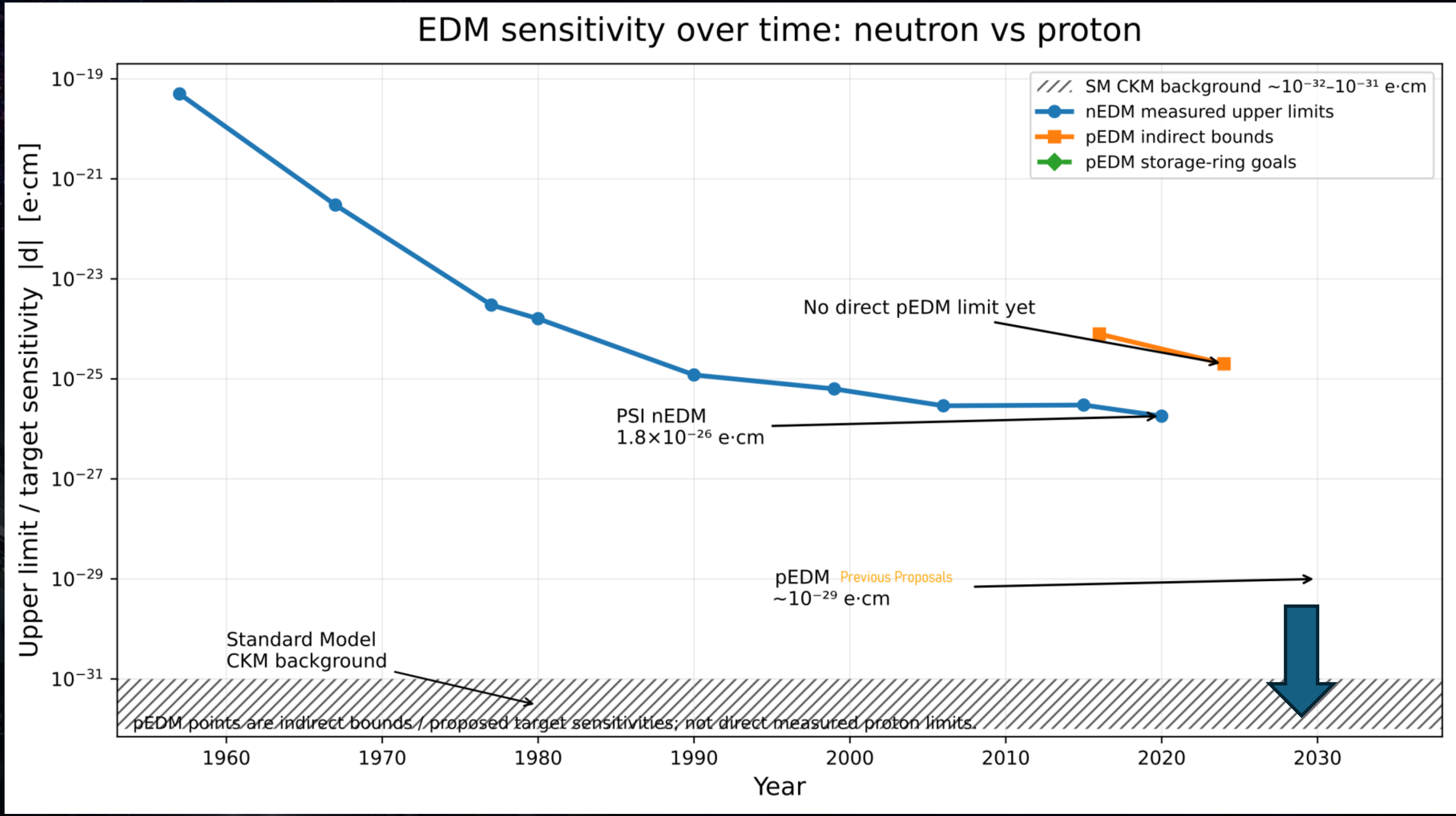
Building the world's most sensitive pEDM experiment.

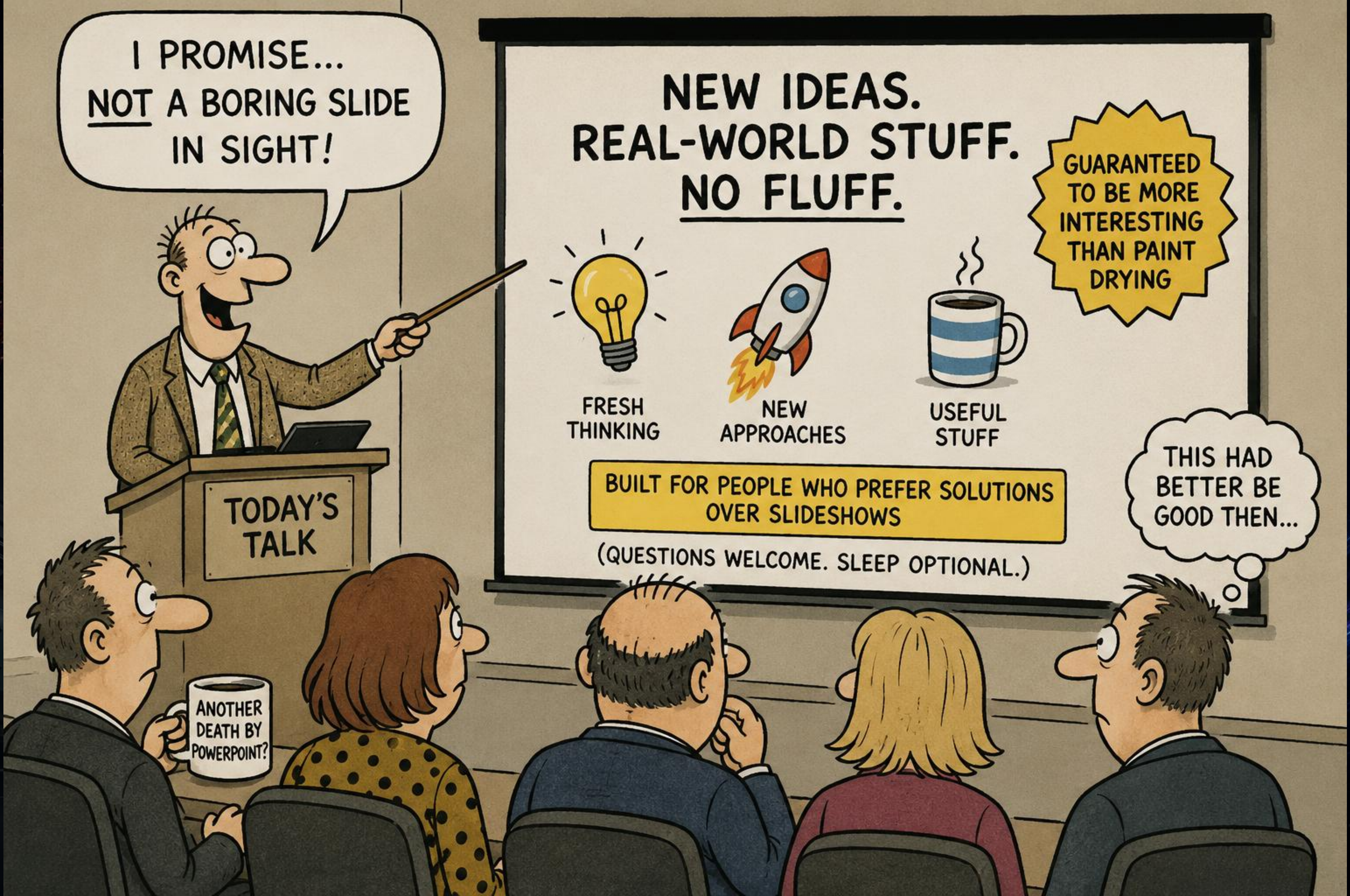
FROM THE QCD VACUUM TO THE COSMOS – MEASURING WHAT MATTERS

What is it? Why do we care?

- Proton EDM ≠ 0 ⇒ new CP violation beyond the Standard Model;
- Tests fundamental T/CP symmetries with sensitivity to physics far beyond direct collider reach.
- Probes ultra-small QCD CP-violating effects
    - ; strong CP problem
- Axion theories dynamically suppress EDMs and simultaneously provide a leading dark matter candidate.
- Complements neutron, leptonic, and atomic EDM searches in constraining new CP-violating physics.
- pEDM and HVP both test nonperturbative QCD vacuum dynamics and precision hadronic structure calculation – an experimental challenge!

Previously...


EDM sensitivity over time: neutron vs proton
SM CKM background ~10⁻³²–10⁻³¹ e·cm
nEDM measured upper limits
pEDM indirect bounds
pEDM storage-ring goals
No direct pEDM limit yet
PSI nEDM
1.8×10⁻²⁶ e·cm
pEDM Previous Proposals
~10⁻²⁹ e·cm
Standard Model
CKM background
pEDM points are indirect bounds / proposed target sensitivities; not direct measured proton limits.
Upper limit / target sensitivity |d| [e·cm]
Year
1960
1970
1980
1990
2000
2010
2020
2030
10⁻¹⁹
10⁻²¹
10⁻²³
10⁻²⁵
10⁻²⁷
10⁻²⁹
10⁻³¹


I PROMISE... NOT A BORING SLIDE IN SIGHT!
NEW IDEAS. REAL-WORLD STUFF. NO FLUFF.
GUARANTEED TO BE MORE INTERESTING THAN PAINT DRYING
FRESH THINKING
NEW APPROACHES
USEFUL STUFF
BUILT FOR PEOPLE WHO PREFER SOLUTIONS OVER SLIDESHOWS
(QUESTIONS WELCOME. SLEEP OPTIONAL.)
THIS HAD BETTER BE GOOD THEN...
TODAY'S TALK
ANOTHER DEATH BY POWERPOINT?

#1

Revised pEDM experiment aims to make a measurement well into the SM predicted level… << 10^{-32} e·cm. *THREE Orders of magnitude better than that presented to P5 and 10 orders better than existing indirect limits*

#2

- Unique engineering capability and prototypes built at Liverpool (see talk by Mark)
- The experiment requires very precisely manufactured electrostatic deflectors

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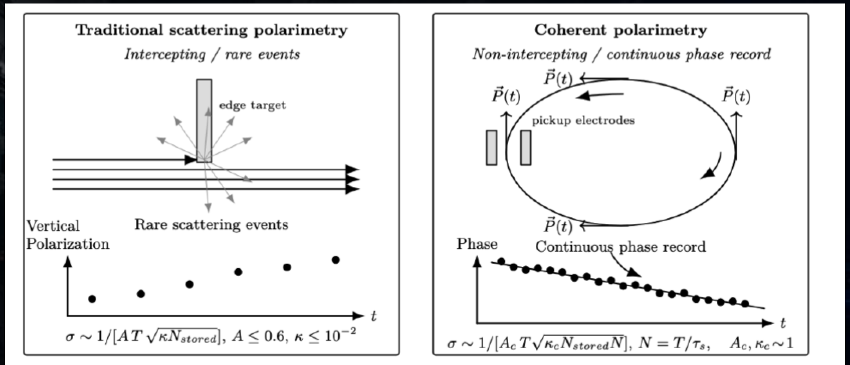
#3

NEW POLARIMETER CONCEPT APPLICABLE TO ALL MACHINES

This is on the ARXIV from this morning USA time. Liverpool Authors

Continuous coherent spin-frequency metrology in storage rings via resonant beam-driven detection

Younggeun Kim,[1,2,3] Themis Bowcock,[4] Dmitry Budker,[1,2,3,5] Giovanni Cantatore,[6] Hooman Davoudiasl,[7] Dmitry Denisov,[7] Abhay Deshbande,[7] Wolfram Fischer,[7] Selcuk Haciomeroglu,[8] Haixin Huang,[7] David Kawall,[9] Alexander Keshavarzi,[10] On Kim,[11] Ivan Koop,[12] Valeri Lebedev,[13] Jonathan Lee,[7] William M. Morse,[7] Cenap Ozben,[14] Vincent Schoefer,[7] Yannis K. Semertzidis,[15,*] Edward Stephenson,[16] Vladimir Tishchenko,[7] Nicholaos Tsoupas,[7] Graziano Venanzoni,[4,17] Joost Vossebeld,[4] and Peter Winter[18]



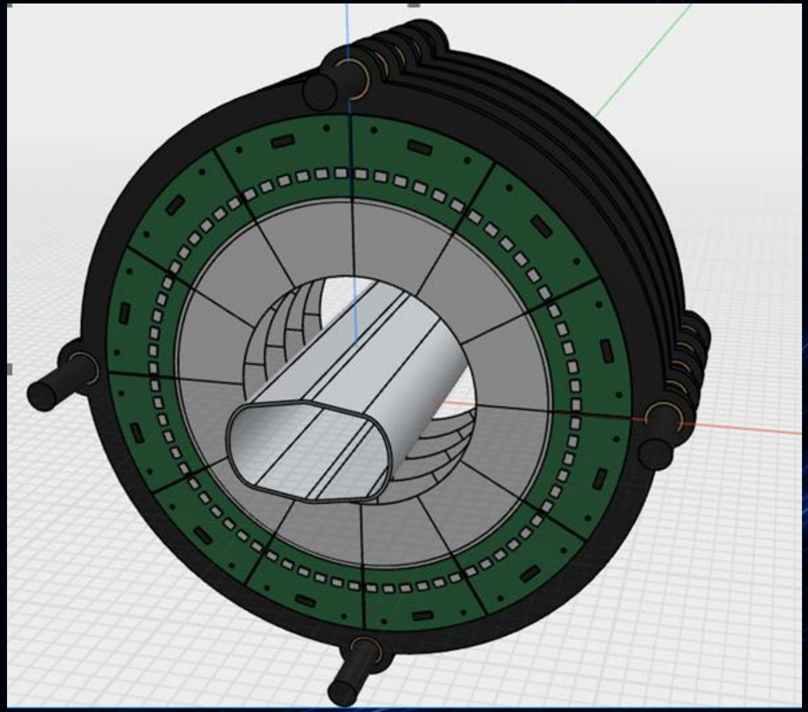
Traditional v New Polarimetry

- Standard polarimetry measures *individual protons* on the extremes of the beam orbit (or samples the beam)
- The new technique senses the WHOLE beam
  - Looks for specific frequencies in pickup electrodes and is able to isolate and amplify them enhancing S:N by ~10^{14} or more.
  - Heterodyne technique (adding reference frequencies) similar to LIGO. A direct extension of that used in axion searches
- Win huge factors in statistics (sqrt(N))
- Makes pEDM proposal more sensitive than previously proposed.
- *MEASURE in SM REGIME*

#4 Applications: e.g. a new g-2 experiment

- New proposed experiment on g-2
- Using the AGS 38 GeV we "win" over traditional measurement
  - Accelerate protons in EIC, create pions.capture muons in transfer line to AGS
  - Store muons in AGS
  - By higher momentum (sensitivity goes γ^2)
  - Better measurement of precession
  - Mu+ and Mu- possible
- We use pEDM techniques (spin alignment) to make a precision map of the B-field using protons and deuterons
- New/different systematics
- The experiment can be done and achieve 10ppb with a TRADITIONAL detector (for example see a Liverpool design for Brookhaven)
- *This new experiment (CDR 2026?) will have the potential to get g-2 sensitivity of FNAL in days rather than years. Aim ~ 1ppb using the COHERENT RESONANCE technique*
  - *See the ARXIV*

Brookhaven-Liverpool Polarimeter (new design)

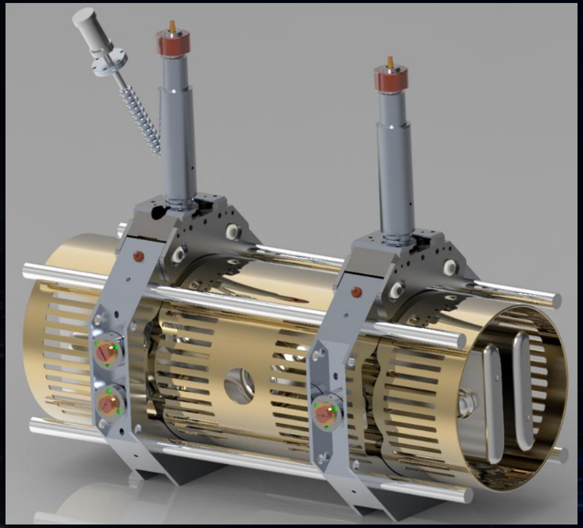


Pictures

- Design
- Control position in space and separation to microns
- Roll to sub arc-second precision

Anchor
(Delivered)

Yoke & Bellows
(Delivered)



Cradle

Electrode pain through which the beam travels

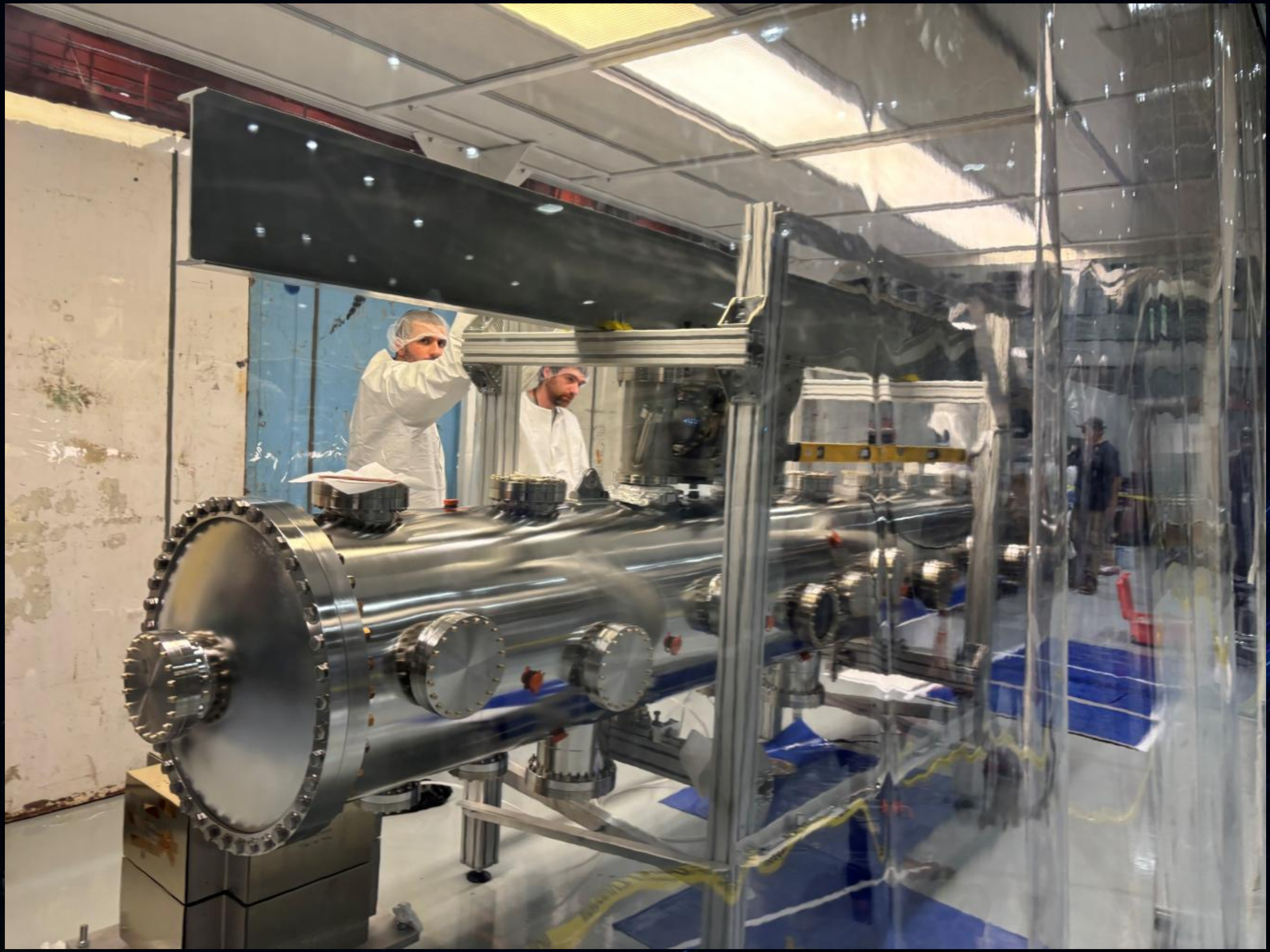
Electrodes

- Flat to microns over 1m
- Perfect Surface finish
- With more prototyping
  - Remove any “spring”/stress effects
  - Confident can build them curved
- We have a cost and time estimate

Team at BNL

Installation at BNL

- Next delivery in weeks



Team

- Workshop (Mark W.) every single member who contributed to manufacture
- Dan H. – Electrode/Coupon manufacture, +…
- Kevin M. – design concepts. Precision roll/pitch/yaw
- Luke – Ground Shield
- George S. – manufacturing drawings (60+) stored in official BNL archive
- John C – main model
- Kieran B – installation, logistics

Summary

1. New frontiers enabling us to measure pEDM at and beyond SM expected level. Technology suggest >10^9 improvement
2. Prototype (BNL funded) demonstrates unique capabilities of Liverpool and constrains cost and defines manufacturing method
3. New polarimetry technique
4. New experiment the most precise ever performed including LIGO
5. Application and possibility of new g-2 measurement “in a day”

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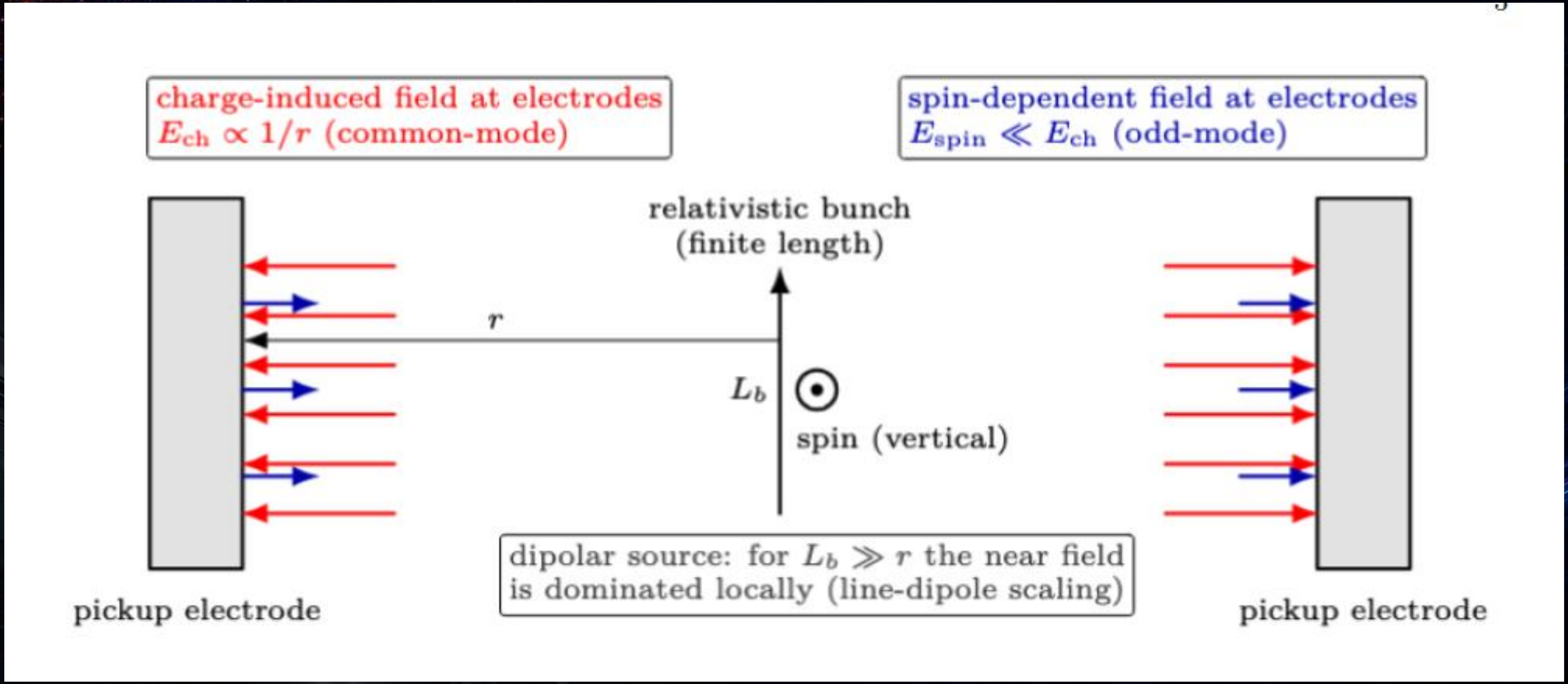
Backup

Polarimeter BC




RHIC
G-2
BOOSTER
LINAC
AGS
TANDEMS

TABLE II. Characteristic time and frequency scales in the coherent polarimeter concept.

Quantity	Symbol	Representative value / comment
LC-resonator carrier frequency (bunch harmonic)	f_0	18.18 MHz
Loaded resonator quality factor	Q_L	10^5
Resonator bandwidth	Δf	$\Delta f \simeq f_0/Q_L \sim 180$ Hz
Resonator response time (memory)	τ	$\tau \simeq Q_L/(\pi f_0) \sim 1.8$ ms
Spin-wheel reference frequency	$f_{\rm sw}$	$\pm(0.1 - 10)$ Hz
Time between CW and CCW bunch crossings	T_b	27.5 ns
Helicity alternation period (same direction)	T_h	~ 2.2 μs
Spin coherence time	SCT	10^3–10^5 s
Independent sample spacing	τ_s	$\tau_s \gtrsim \tau$ (baseline $\sim$ ms)

TABLE III. Baseline beam parameters and symmetry-tagged channel construction.

Item	Symbol	Meaning / role
Protons per bunch	N_p	$\sim 1.2 \times 10^8$
Number of stored bunches per direction	N_b	~ 80
Stored polarization	P	~ 0.8
Beam speed	β	~ 0.6
Beam–electrode distance	r	~ 2 cm
Electrode gap	d	~ 4 cm
Ring circumference	L	~ 800 m
Left–right differencing	$V_\Delta = V_L - V_R$	suppresses common-mode charge pickup
Helicity subtraction	$\phi_+ - \phi_-$	rejects helicity-even pickup/drifts
CW–CCW subtraction	$\phi^{\rm CW} - \phi^{\rm CCW}$	rejects direction-even systematics
Spin-wheel synchronous detection	$\cos(\Omega_{\rm sw} t)$	projects onto the controlled reference tone
Slope estimator scaling	σ_b	$\sigma_b \propto T^{-3/2}$ (under CR conditions)