Electromagnetic Dipole Moments

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2023.11.29

Disclaimer: There are many exciting efforts in this field but only part of them will be covered here. Apologize for omitting any of your experiments.

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Many thanks to inputs from P. Schmidt-Wellenburg, G. Venanzoni, P. Winter, X. Fan, B. Lauss, J. Martin, F. Piegsa, S.Y. Hoh!

Complementarity between frontiers

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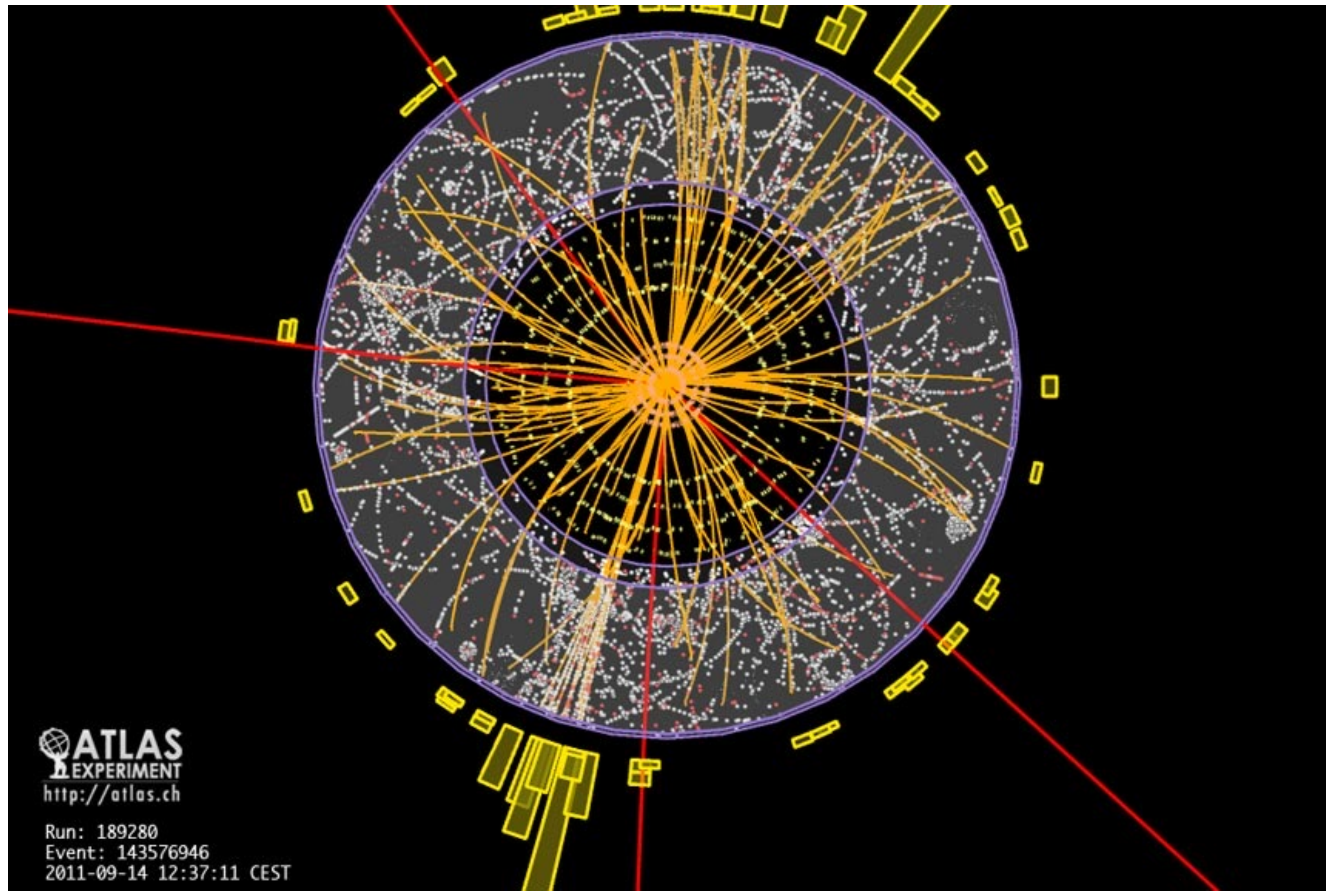
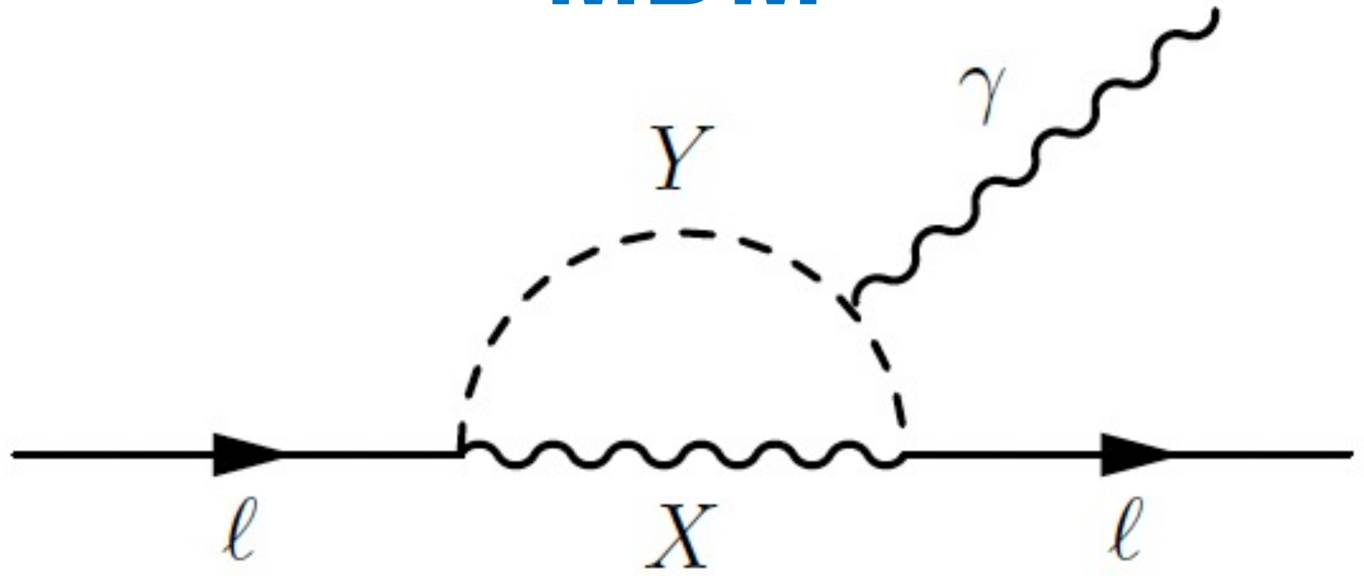
Energy Frontier



New physics through observations of new particles

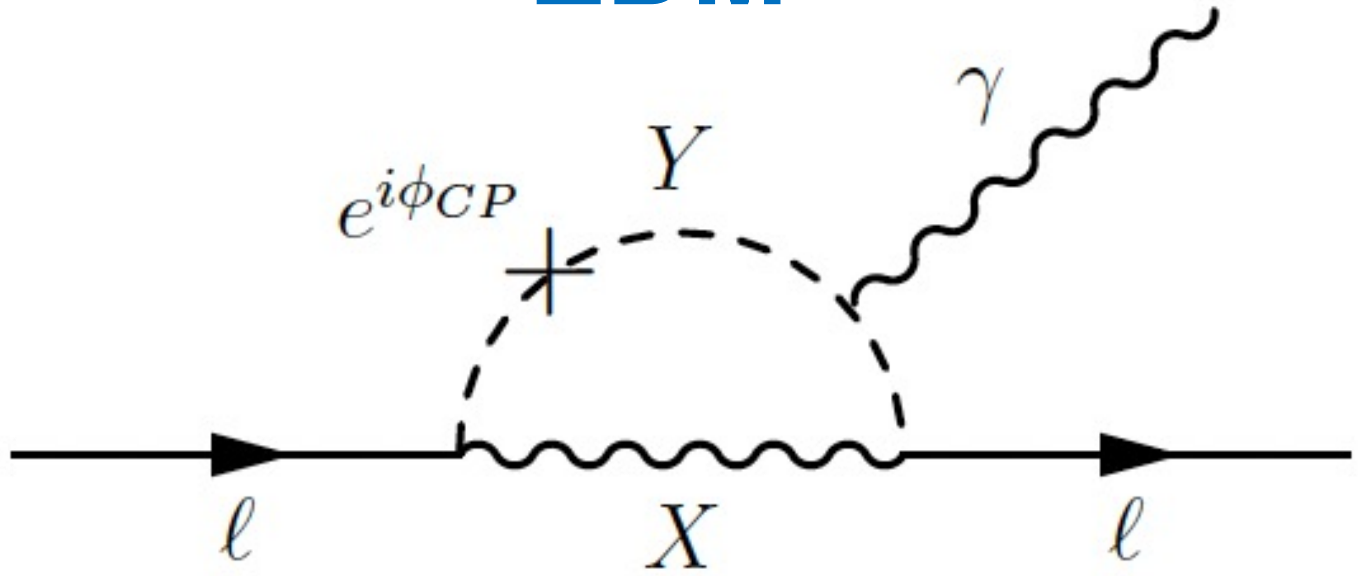
Precision/Intensity Frontier

MDM



$$\mu_\ell^{\mathrm{NP}} \sim e \left(\frac{k_\mu^2}{4\pi}\right)^n \frac{m_\ell}{\Lambda_\mu^2}$$

EDM



$$d_\ell^{\mathrm{NP}} \sim e \left(\frac{k_d^2}{4\pi}\right)^n \frac{m_\ell}{\Lambda_d^2} \sin\phi_{CP}$$

New physics through observations of effects of virtual particles

Complementary approaches, allow us to discriminate between various BSM models!

Adapted from Adam West

Overview of EDM experiments

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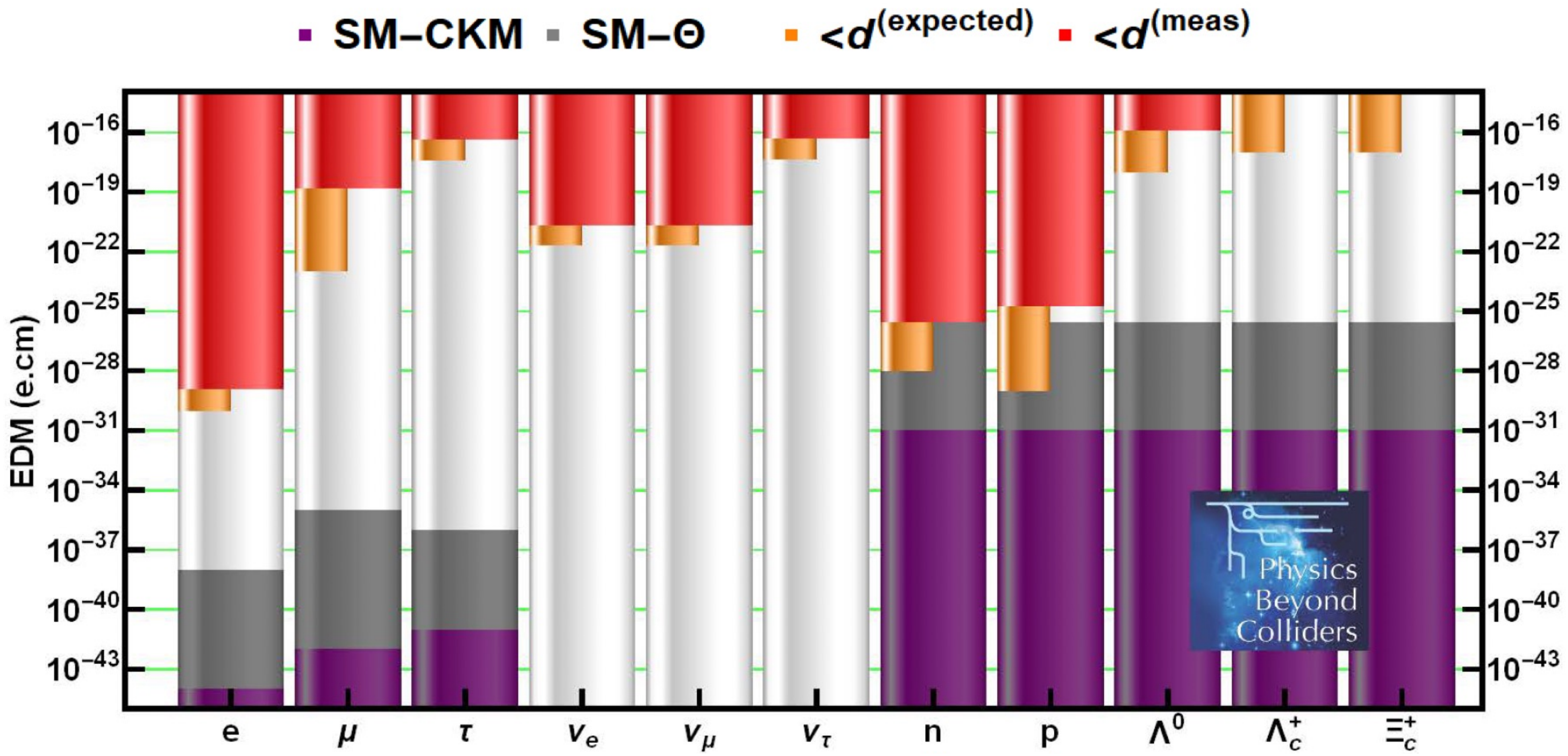
- **Category 1: Neutron EDM experiments**
  - Traditional, UCN and beam approaches
- **Category 2: Paramagnetic atoms/molecules (unpaired electron)**
  - Powerful systems for searching electron EDM (ThO, YbF, HfF^+, …)
- **Category 3: Diamagnetic atoms/molecules (no unpaired electrons)**
  - Powerful systems for searching hadronic EDMs (Hg, Xe, Ra, …)
- **Category 4: Storage ring experiments**
  - Huge potential but challenging (μ, p, ^{2}H, e)



Complementarity between EDMs

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The EDM Community (~700)

Neutrons: (~ 200 ppl.)
- Beam EDM @ Bern
- LANL nEDM @ LANL
- nEDM @ PSI
- nEDM @ SNS
- PanEDM @ ILL
- PNPI/FTI/ILL @ ILL
- TUCAN @ TRIUMF

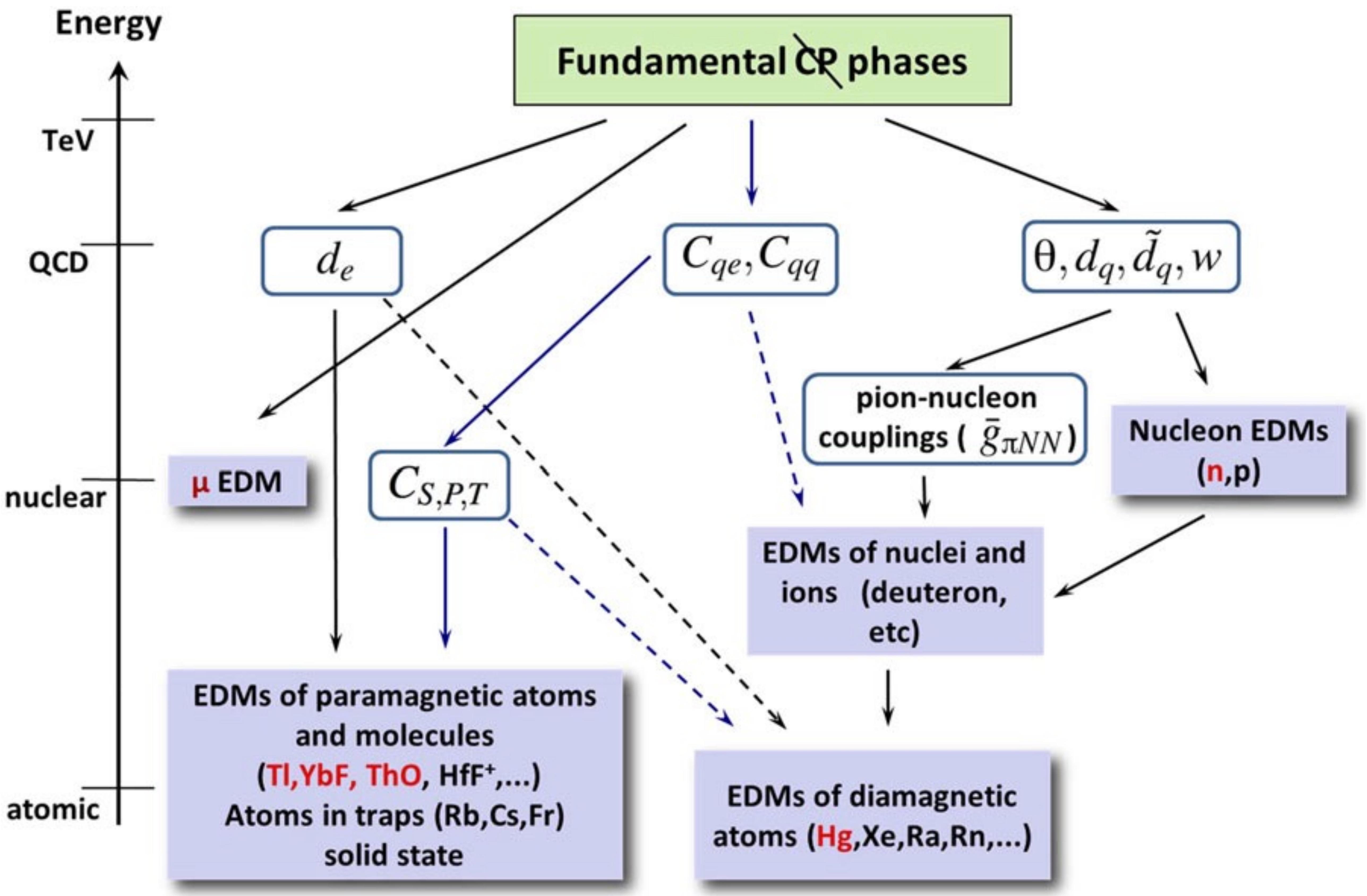
Storage rings: (~ 400 ppl.)
- CPEDM/JEDI
- muEDM @ PSI
- g-2 @ FNAL
- g-2 @ JPARC

Atoms: (~ 60 ppl.)
- Cs @ Penn State
- Fr @ Riken
- Hg @ Bonn
- Hg @ Seattle
- Ra @ Argonne
- Xe @ Heidelberg
- Xe @ PTB
- Xe @ Riken

Molecules: (~ 55 ppl.)
- BaF (EDM[3]) @ Toronto
- BaF (NLeEDM) @ Groningen/Nikhef
- HfF+ @ JILA
- ThO (ACME) @ Yale
- YBF @ Imperial

Full list: https://www.psi.ch/en/nedm/edms-world-wide

PSI nEDM webpage



The association of observable EDMs to their possible fundamental CPV sources, which might be chromo-, quark-, lepton-, and semi-leptonic EDMs, or the QCD "theta" parameter. (A. Ritz, D. Hertzog)

EDM measurements in a nutshell

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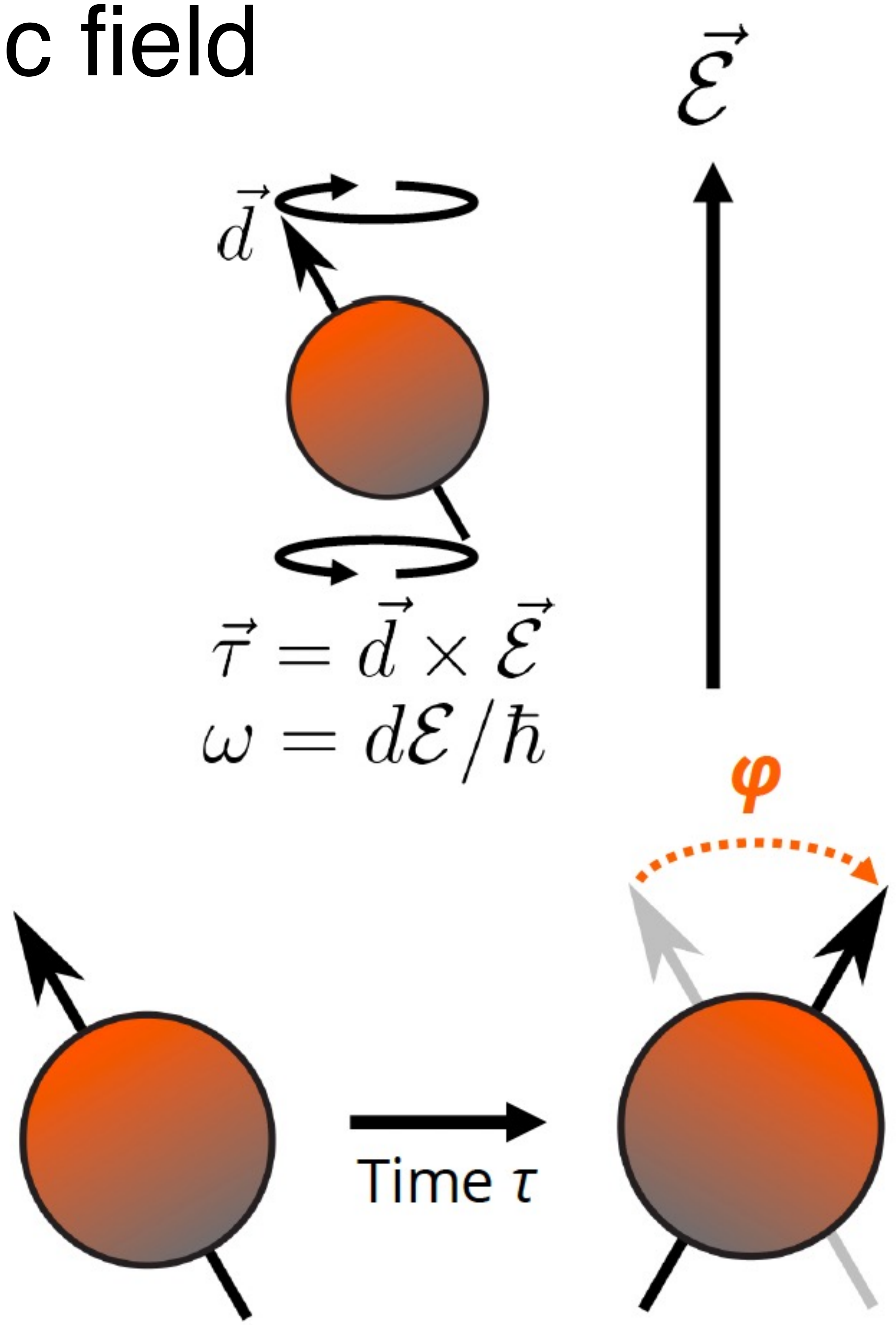
- An EDM experiences a torque in an electric field
- Experiment:
  - Initialize, precess, measure, repeat…

$$\varphi = d\mathcal{E}\tau/\hbar$$

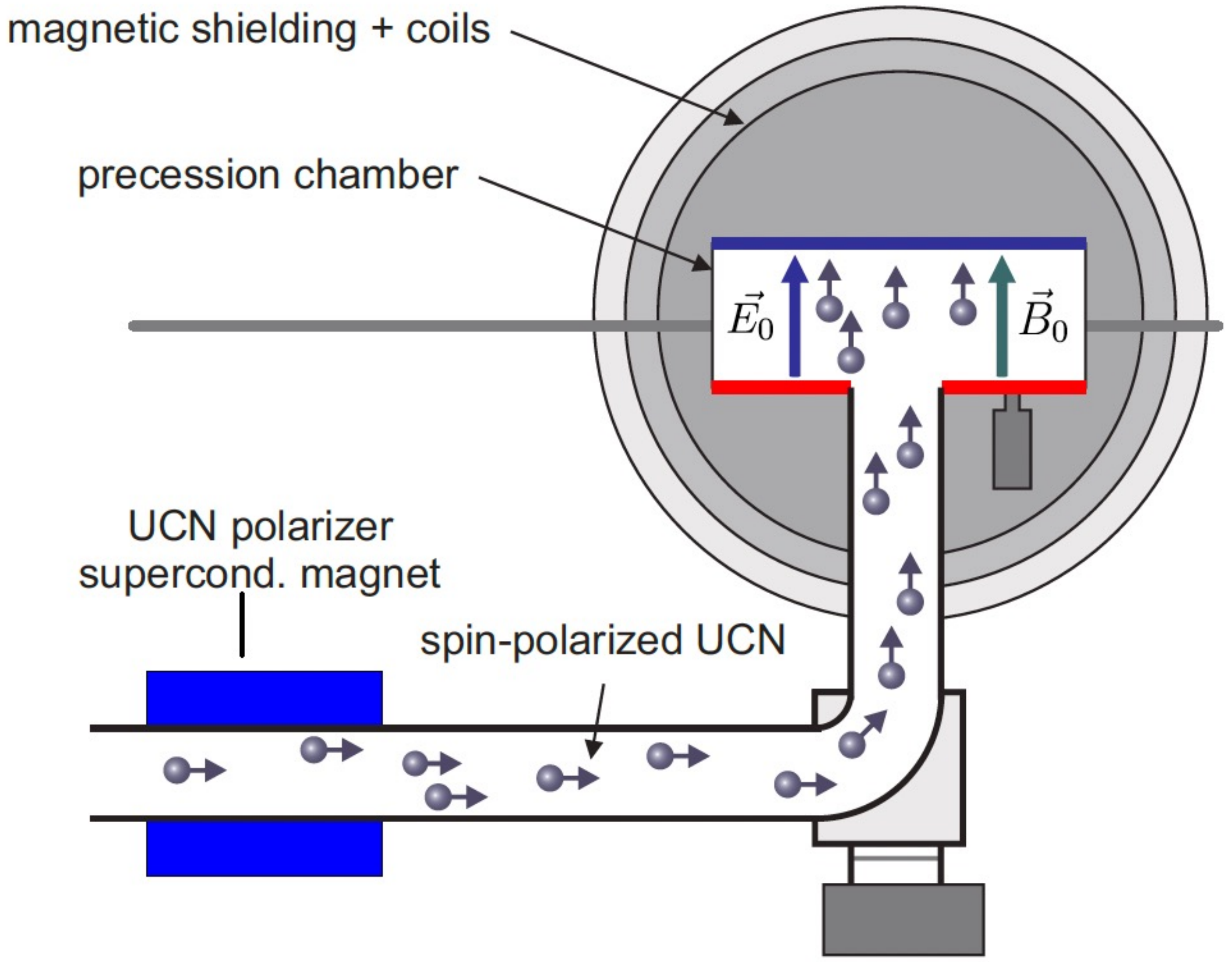
Want large electric field

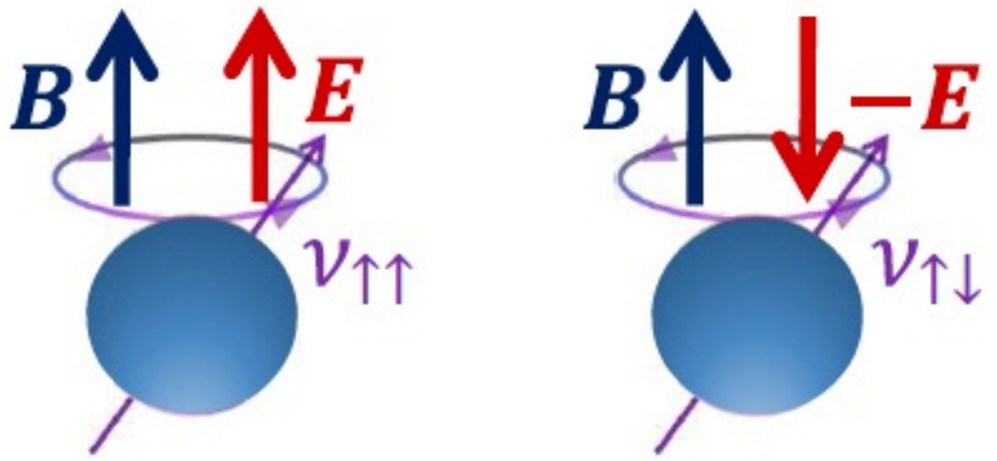
Want long interaction time



Courtesy: Nick Hutzler (Caltech)

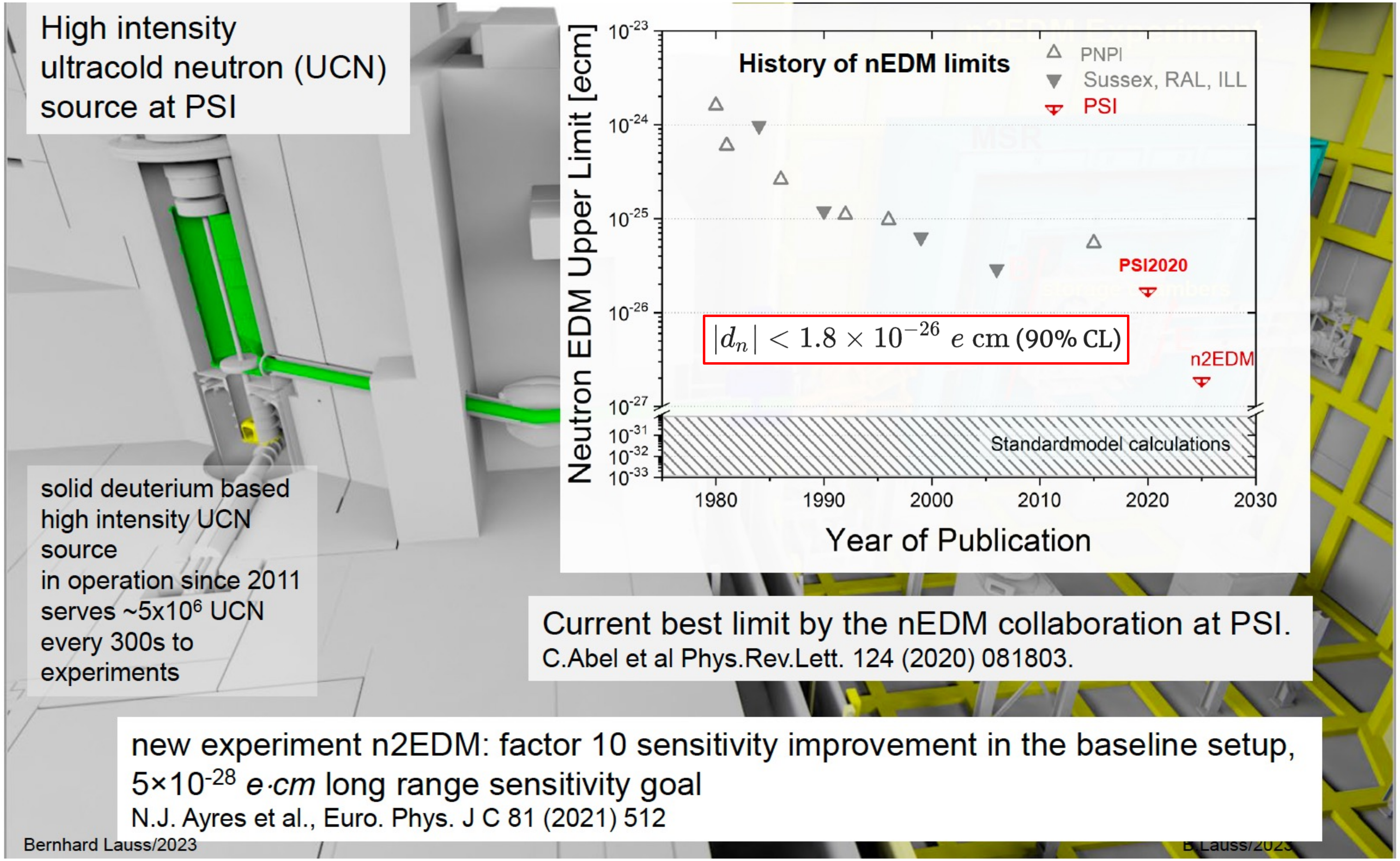
Neutron EDM: nEDM@PSI





$$\nu_{\uparrow\uparrow} = \frac{2\mu B + 2dE}{h} \qquad \nu_{\uparrow\downarrow} = \frac{2\mu B - 2dE}{h}$$

$$\Delta\nu = \nu_{\uparrow\uparrow} - \nu_{\uparrow\downarrow} = \frac{4dE}{h}$$



High intensity ultracold neutron (UCN) source at PSI

solid deuterium based high intensity UCN source
in operation since 2011
serves ~5×10^6 UCN every 300s to experiments

Current best limit by the nEDM collaboration at PSI.
C.Abel et al Phys.Rev.Lett. 124 (2020) 081803.

new experiment n2EDM: factor 10 sensitivity improvement in the baseline setup,
5×10^{-28} *e·cm* long range sensitivity goal
N.J. Ayres et al., Euro. Phys. J C 81 (2021) 512

Bernhard Lauss/2023

Courtesy Bernhard Lauss

Neutron EDM: n2EDM@PSI

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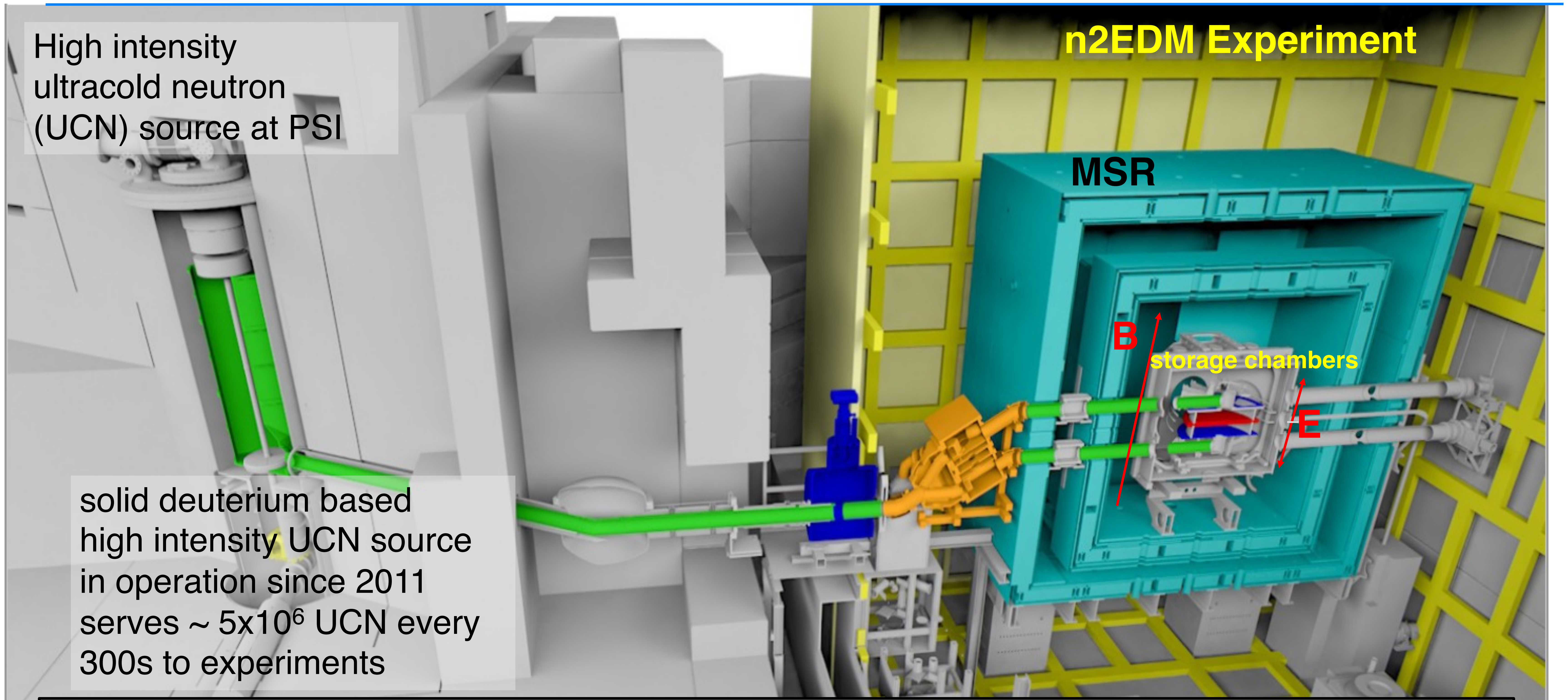
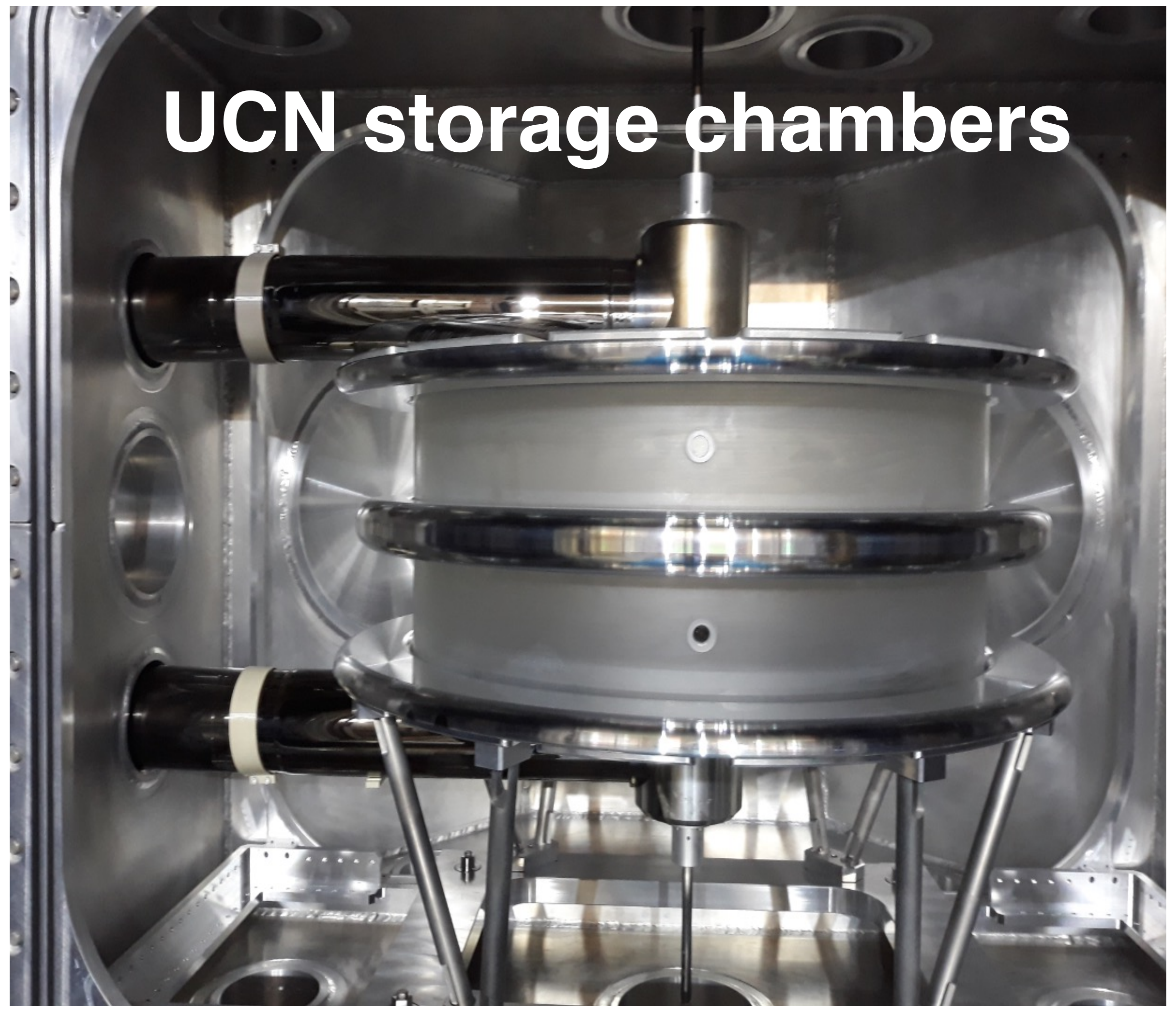




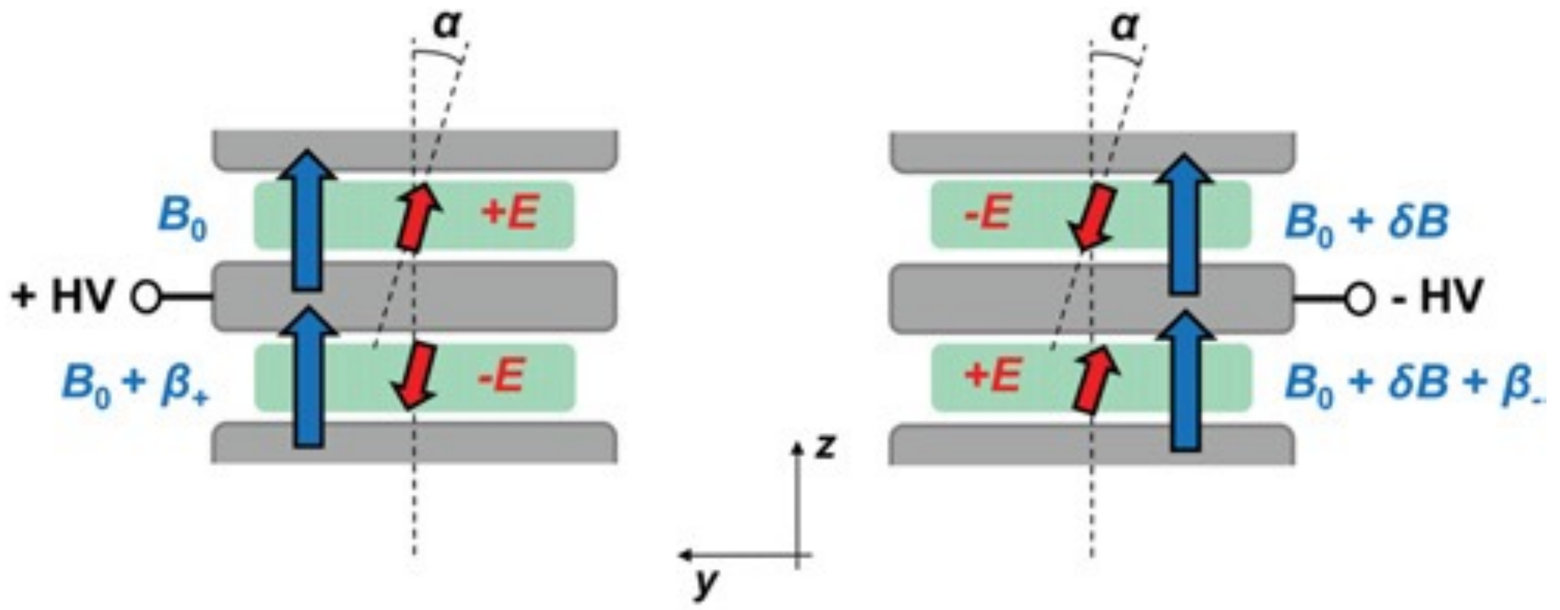
Status:

- record magnetically shielded room (MSR) - shielding factor 10^5 at 0.01Hz in $25m^3$ - **operating**
- 55 km coils for active magnetic shield (AMS) - **operating**
- internal magnetic field system at 1 mT and 60 ppm homogeneity - **operating**
- UCN chambers and beamline - **commissioning**
- **start measurement in 2024 - 500 days for 1.2×10^{-27} e·cm sensitivity goal in baseline**
- planned 'MAGIC field' phase with further significant improvement

Bernhard Lauss

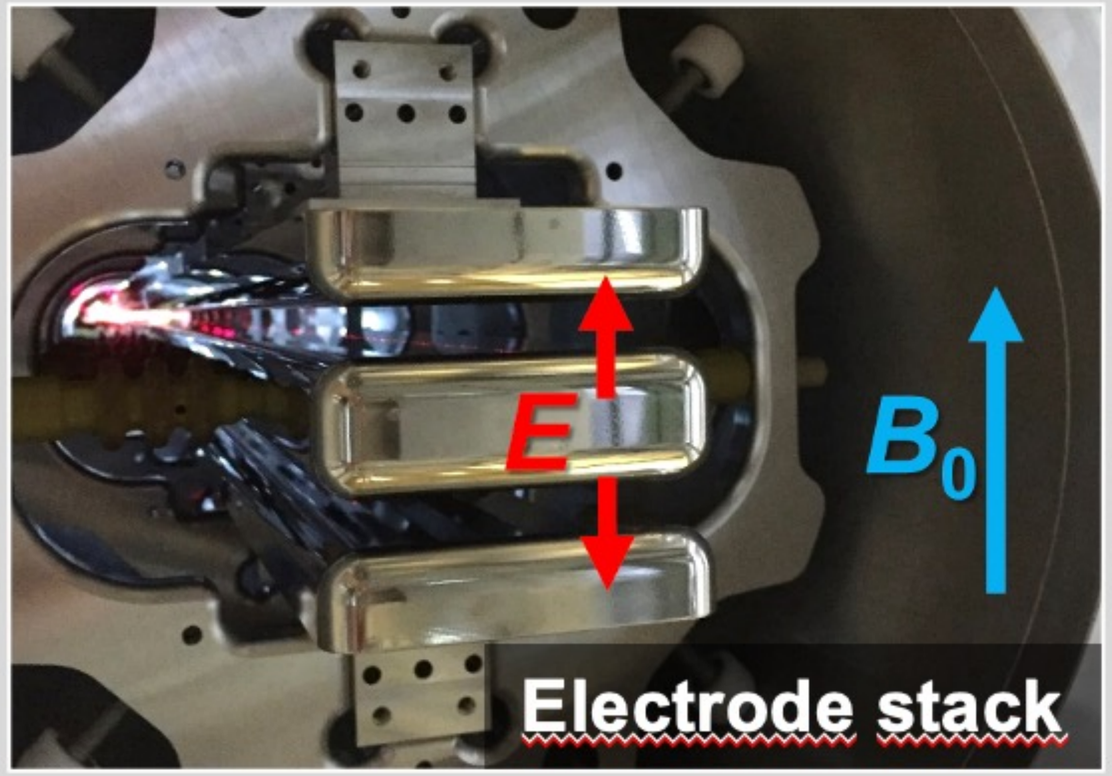
nEDM is part of the European Strategy for Partice Physics and the NUPPEC Lond Range Plan.

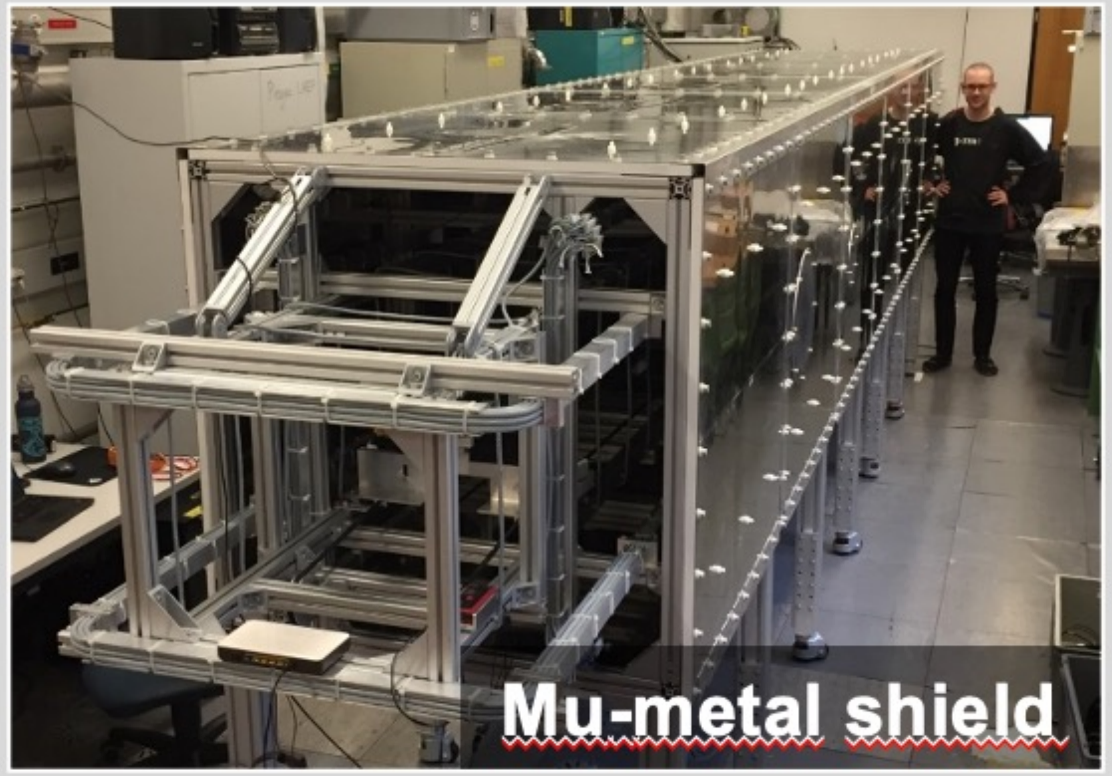
Neutron EDM: Beam EDM

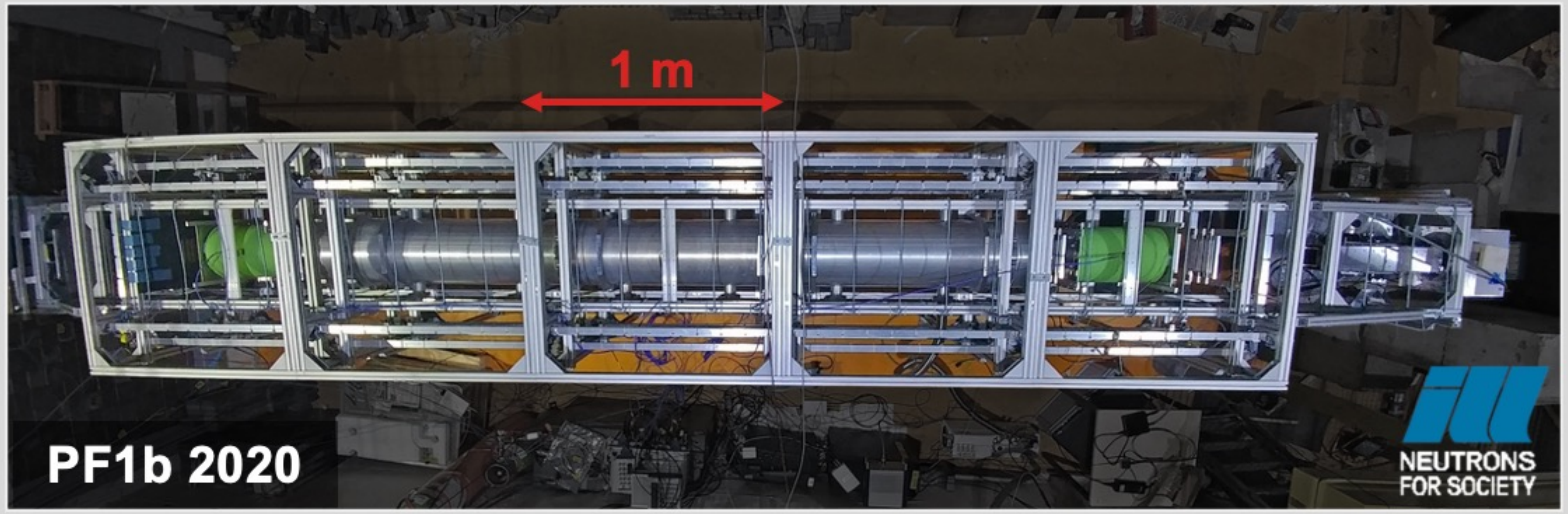


Statistical sensitivity:

$$\boxed{\sigma_{\mathrm{Beam}}(d_{\mathrm{n}}) \approx \frac{2\hbar}{\eta\tau E\sqrt{N}}}$$







$\sigma(d_{\mathrm{n}}) \approx 5 \times 10^{-26}$ **e cm / day**

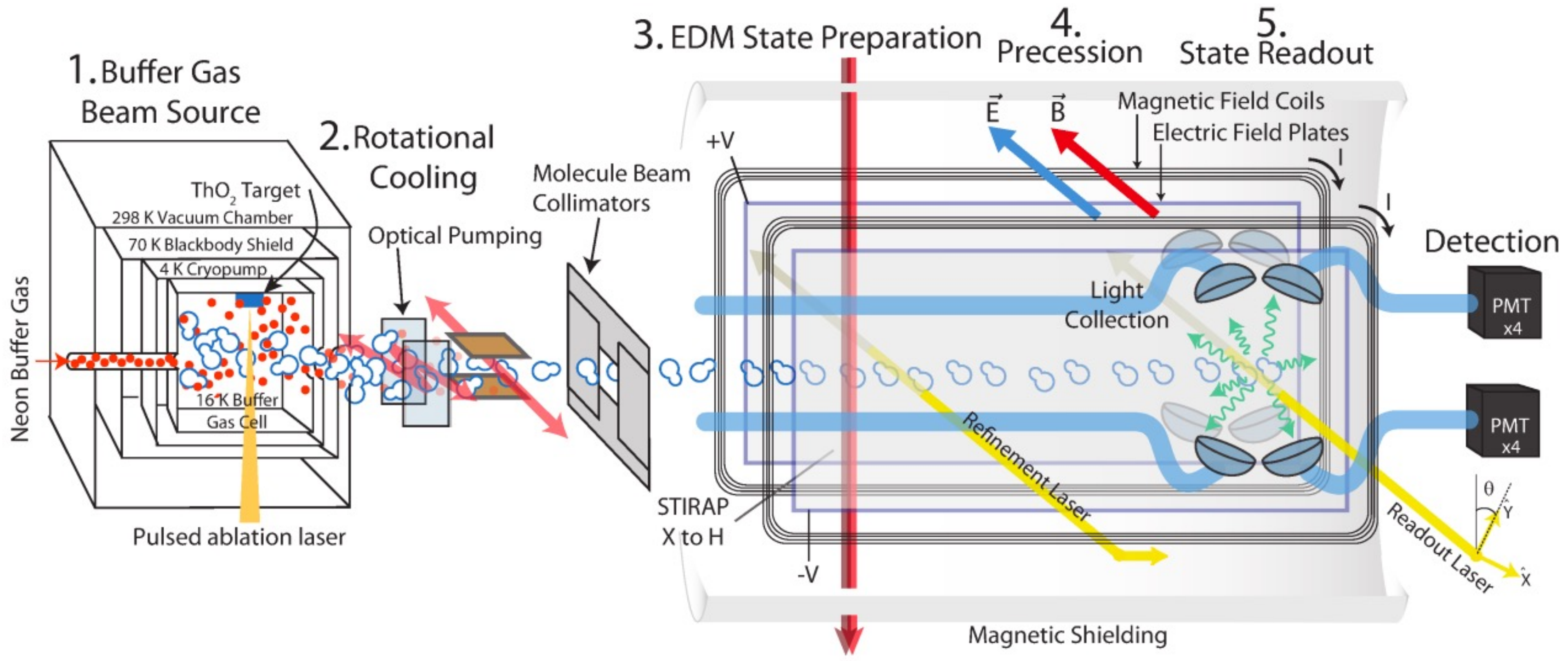
- **New complimentary neutron EDM search using a pulsed beam**
- **Project based in Bern with proof-of-principle experiments at PSI and ILL**
- **Full-scale experiment intended for ESS, competitive to UCN experiments**

Piegsa, *PRC* 88, 045502 (2013)
Chanel et al., *EPJ Conf.* 219, 02004 (2019)
Schulthess et al., *PRL* 129, 191801 (2022)

Courtesy Florian Piegsa

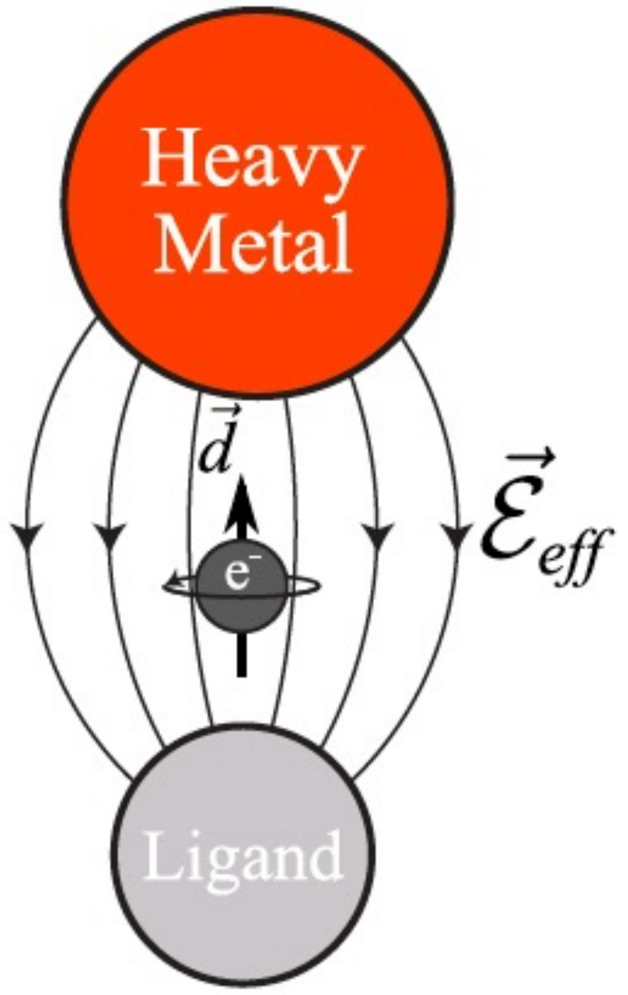
Electron EDM: Paramagnetic systems

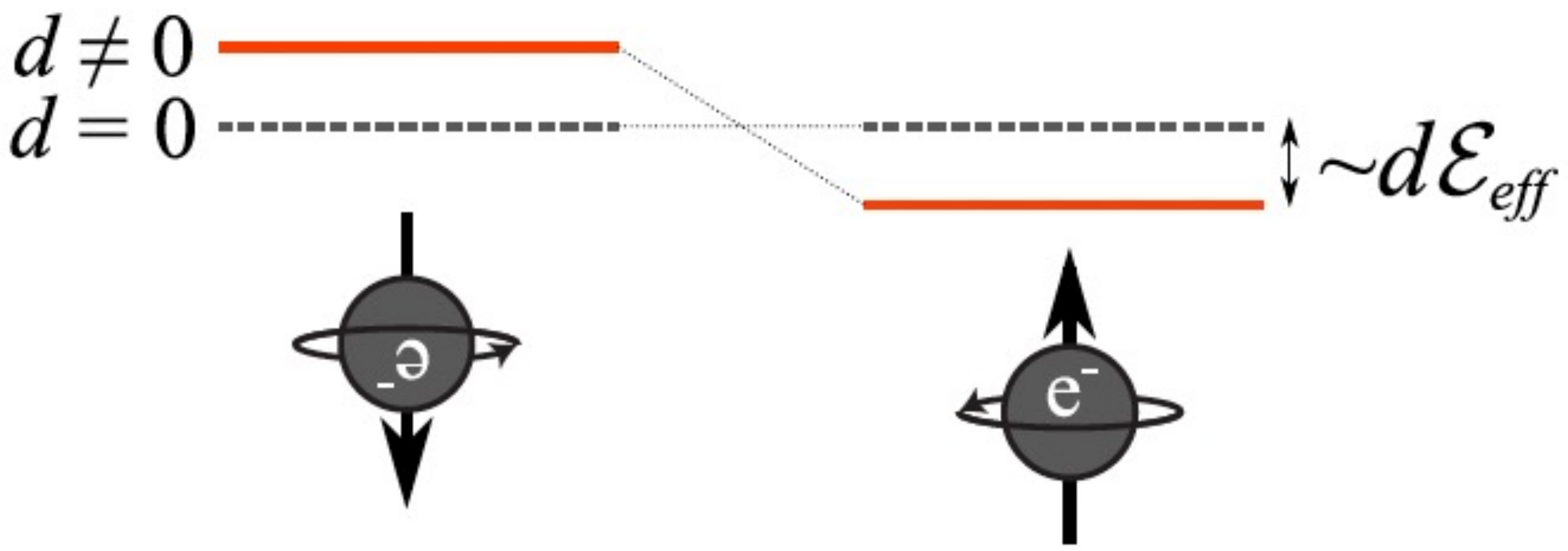
- Atoms/molecules have extremely large fields
  - ~100 GV/cm for heavy species
  - Maximum lab field ~100 kV/cm
  - eEDM of valence e interacts with the internal field
    → symmetry-violating energy shifts



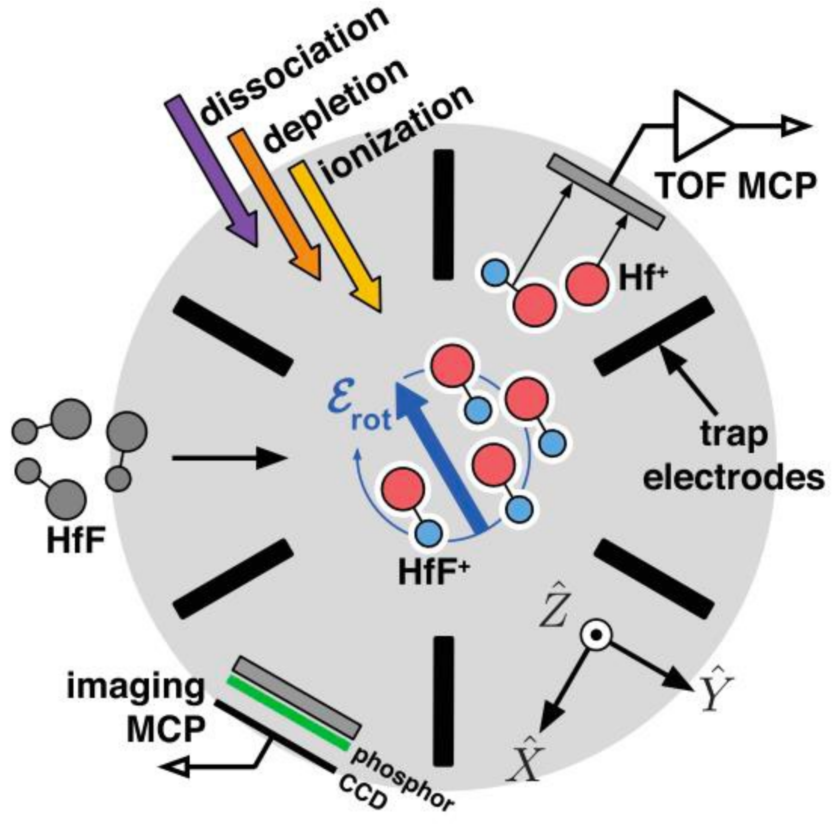
ACME, ThO, Harvard/Yale/Northwestern

- Spin precession in cryogenic beam
- $|d_e| < 8.7 \cdot 10^{-29}$ e cm (2014)
- $|d_e| < 1.1 \cdot 10^{-29}$ e cm (2018)





Quantum Sci. Technol. 5 044011



HfF+, JILA/Boulder

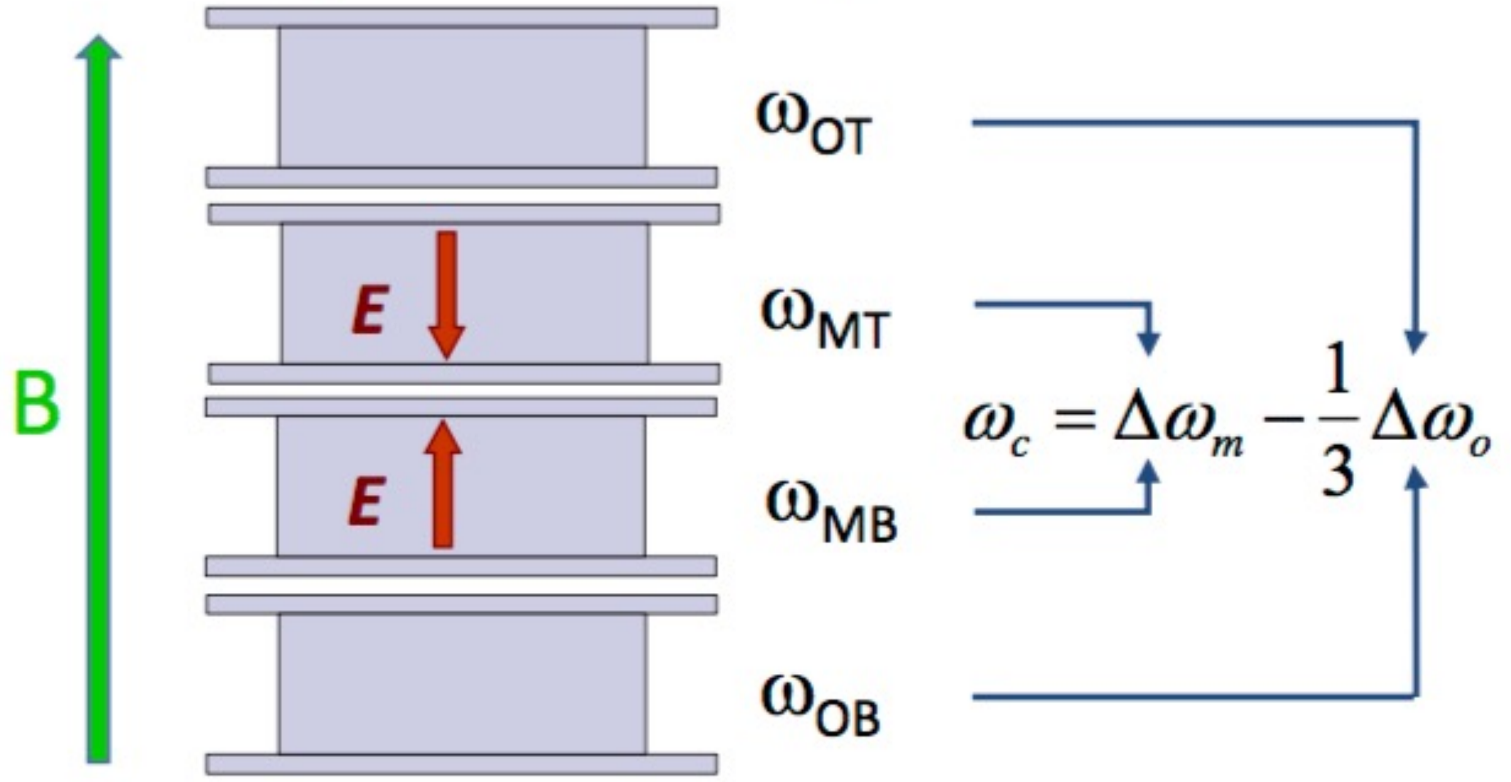
- Spin precession in ion trap
- Long coherence time from trapping
- Current most sensitive limits
- $|d_e| < 4.1 \cdot 10^{-30}$ e cm Science 381 665 (2023)

Improvements are expected in the coming years

Hadronic EDM: Diamagnetics Atoms

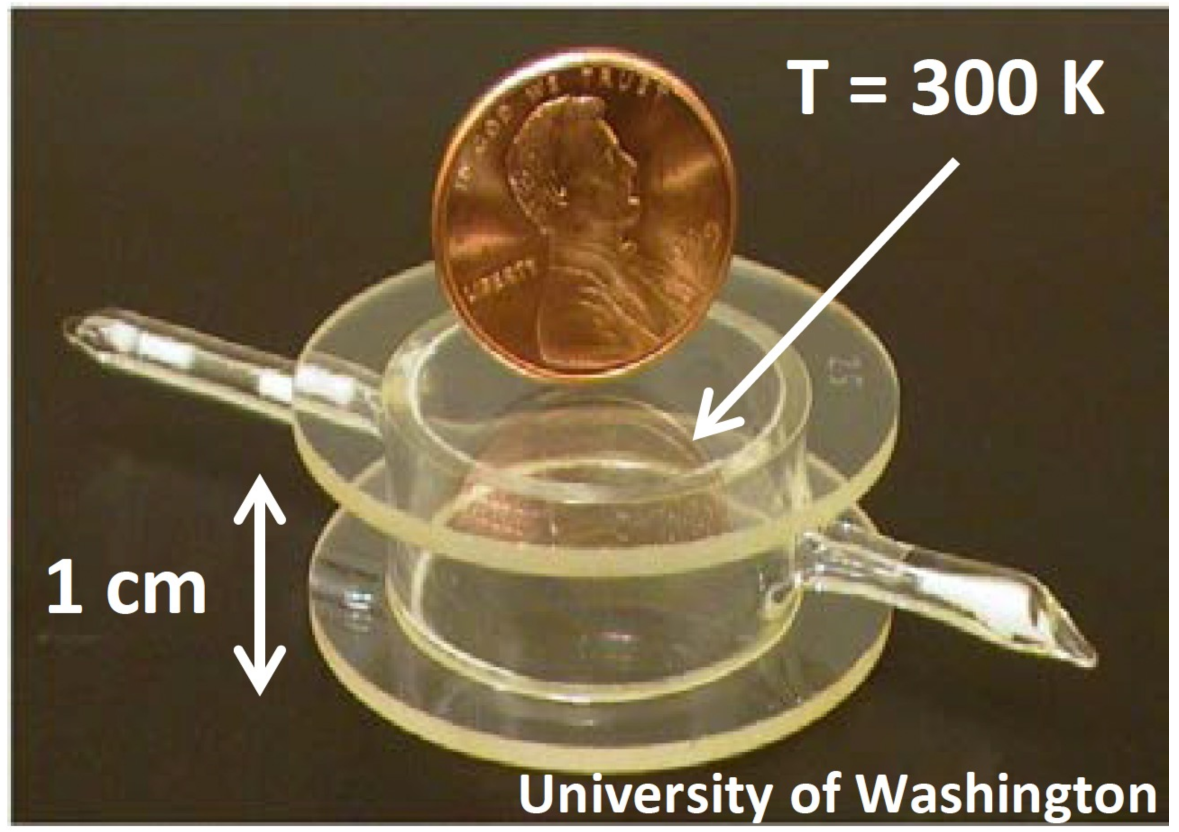
^{199}Hg, Univ. Washington, Seattle

$$H = -(\vec{\mu}\cdot\vec{B} + \vec{d}\cdot\vec{E})$$

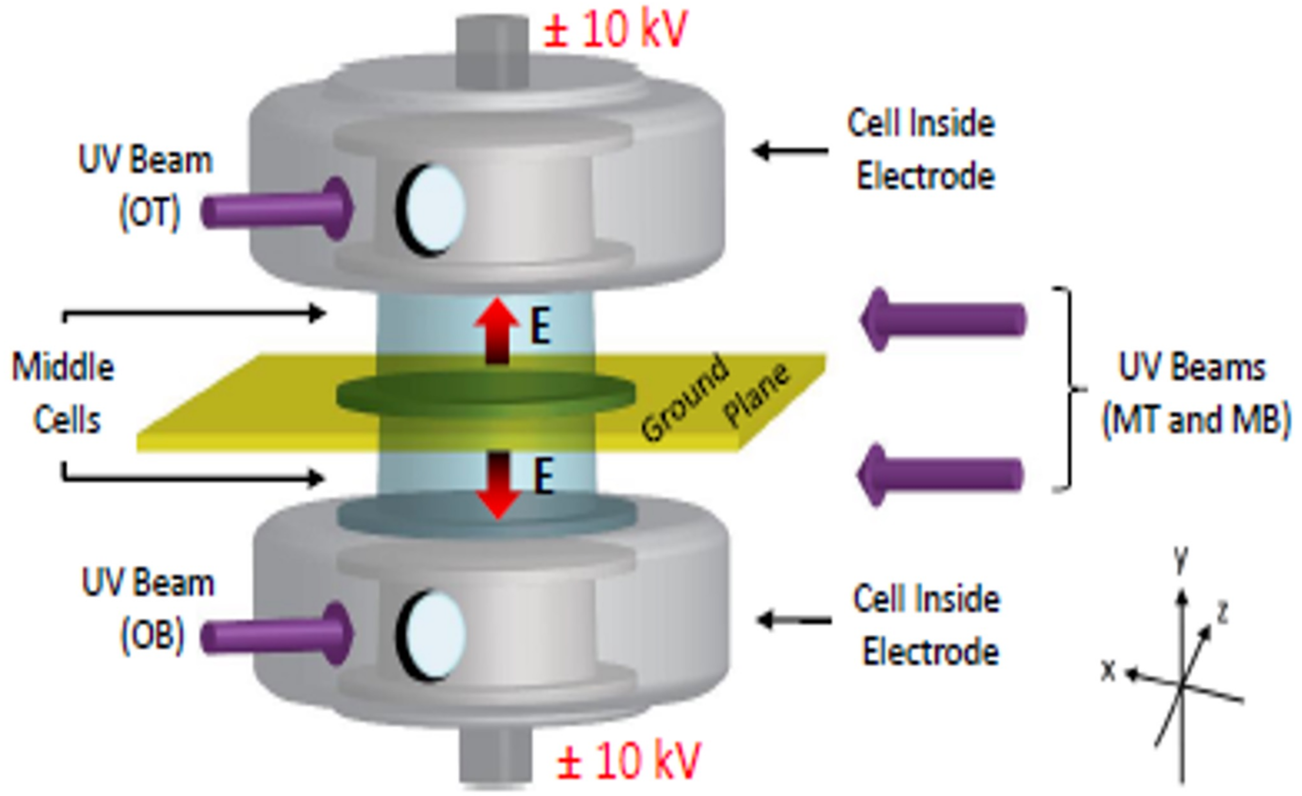


$$\omega_c = \frac{\mu}{\hbar}\left(-\frac{8}{3}\frac{\partial^3 B}{\partial z^3}\Delta z^3\right) + \frac{4dE}{\hbar}$$

Cancels up to 2nd order gradient noise
Same EDM sensitivity as Middle Difference



T_2 Spin Relaxation: 300 - 600 sec



CENPA
Center for Experimental Nuclear Physics and Astrophysics

2016 Seattle Hg-199 EDM experiment:

$|d_{Hg}| < 7.4 \times 10^{-30}$ *e* cm

Courtesy Brent Garner

"Large Collaboration"

The Team

Graduate Students
Jennie Chen
Brent Graner*

Scientific Glassblower
Eric Lindahl

Faculty
B. R. Heckel

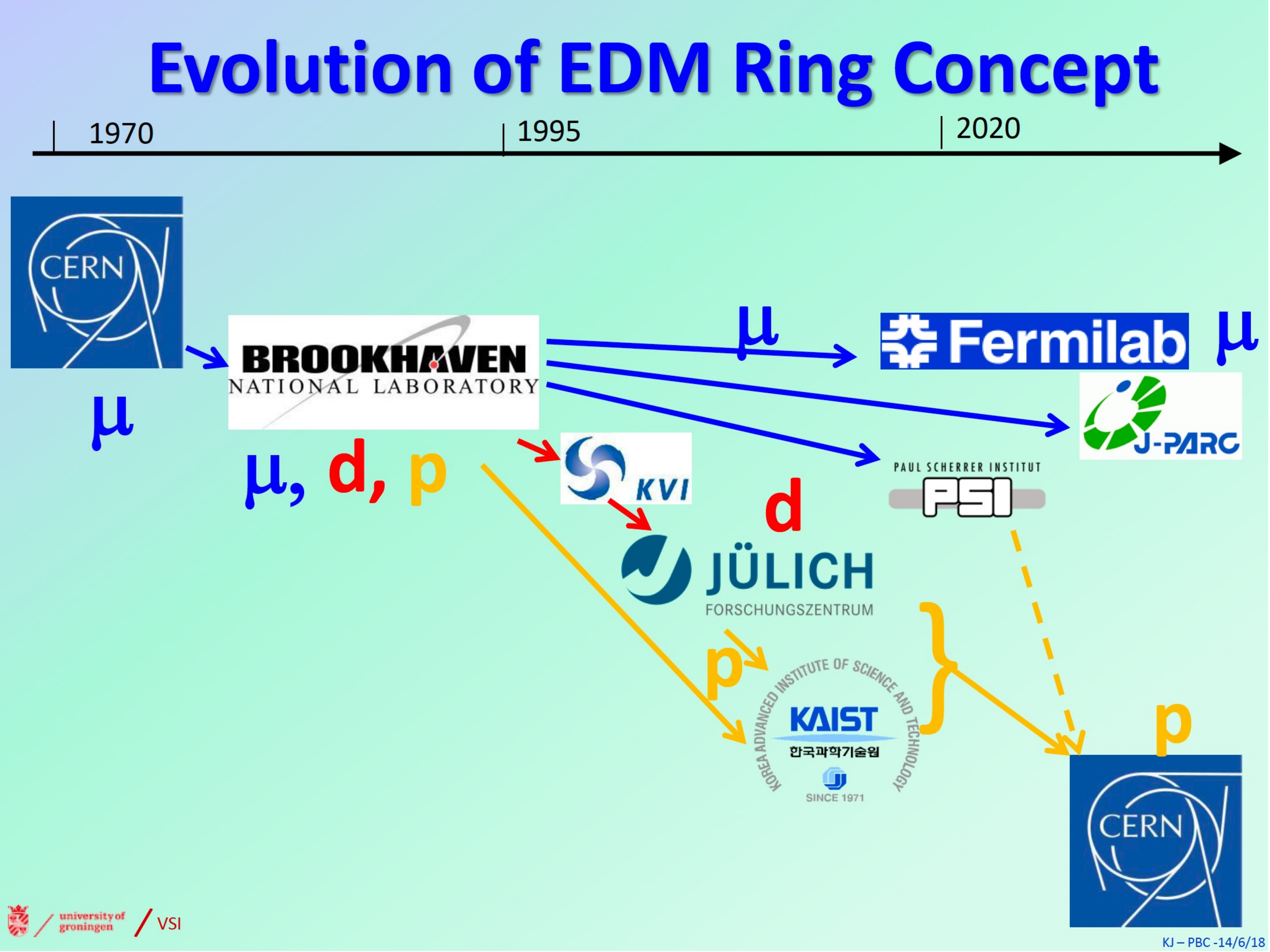
Primary support from NSF
* Supported by DOE Office of Nuclear Science

PRL 116.161601 (2016)

Quantity	Expression	Limit	Ref.
$\mathbf{d}_n$	$\mathbf{S}_{\mathrm{Hg}}/(1.9\ \mathrm{fm}^2)$	$1.6\times10^{-26}\ e\,\mathrm{cm}$	[21]
$\mathbf{d}_p$	$1.3\times\mathbf{S}_{\mathrm{Hg}}/(0.2\ \mathrm{fm}^2)$	$2.0\times10^{-25}\ e\,\mathrm{cm}$	[21]
$\bar{g}_0$	$\mathbf{S}_{\mathrm{Hg}}/(0.135\ e\,\mathrm{fm}^3)$	2.3×10^{-12}	[5]
$\bar{g}_1$	$\mathbf{S}_{\mathrm{Hg}}/(0.27\ e\,\mathrm{fm}^3)$	1.1×10^{-12}	[5]
$\bar{g}_2$	$\mathbf{S}_{\mathrm{Hg}}/(0.27\ e\,\mathrm{fm}^3)$	1.1×10^{-12}	[5]
$\bar{\theta}_{QCD}$	$\bar{g}_0/0.0155$	1.5×10^{-10}	[22,23]
$(\tilde{d}_u-\tilde{d}_d)$	$\bar{g}_1/(2\times10^{14}\ \mathrm{cm}^{-1})$	$5.7\times10^{-27}\ \mathrm{cm}$	[25]
C_S	$\mathbf{d}_{\mathrm{Hg}}/(5.9\times10^{-22}\ e\,\mathrm{cm})$	1.3×10^{-8}	[15]
C_P	$\mathbf{d}_{\mathrm{Hg}}/(6.0\times10^{-23}\ e\,\mathrm{cm})$	1.2×10^{-7}	[15]
C_T	$\mathbf{d}_{\mathrm{Hg}}/(4.89\times10^{-20}\ e\,\mathrm{cm})$	1.5×10^{-10}	see text

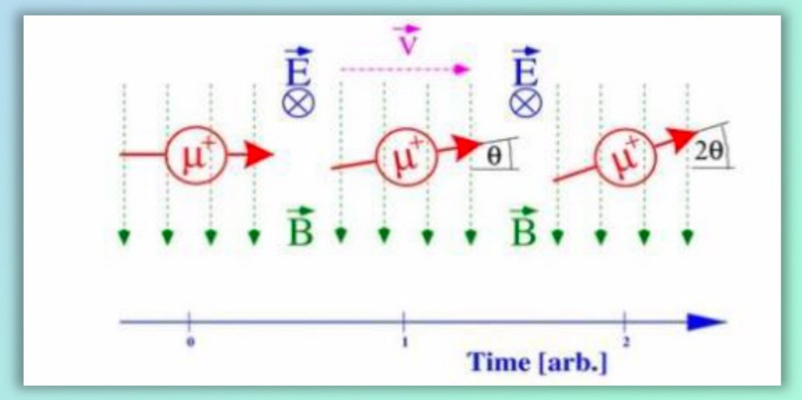
Limits on CP-violating observables from the 199Hg EDM limit (assuming it is the sole contribution to the atomic EDM)

Storage ring for EDM searches



EDM – Experiments on Particles in Storage Rings

Basics:



- exploit motional electric/magnetic fields
- stop g-2 precession
- observe spin rotation angle Θ(t)

Muon:

- parasitically with muon g-2
  - since 1960ies @ CERN & BNL
  - now Fermilab & J-PARC
- dedicated ring in preparartion (PSI)
- interesting from d < 10^{-22} ecm

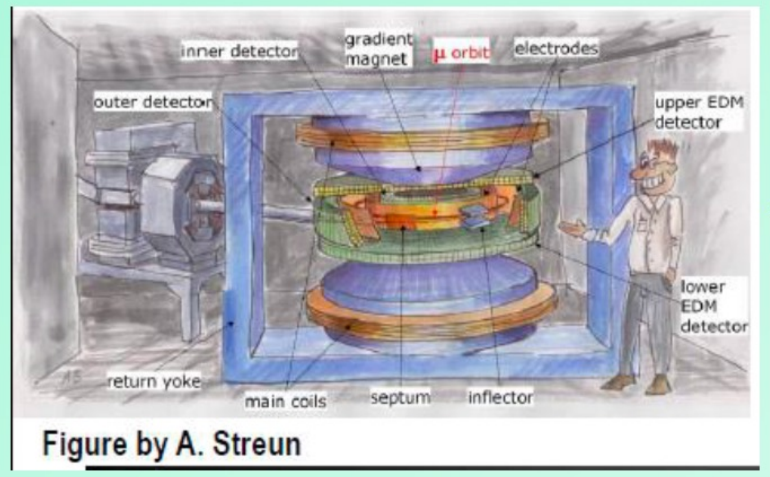


Figure by A. Streun

PSI, Antognini, Kirch et al.

Deuteron:

- dedicated ring (BNL → COSY → CERN ?)
- magnetic device
- intermediate stage @ some 10^{-24} ecm
- lots of preparatory work conducted

Proton:

- dedicated ring (CERN ?)
- electrostatic device
- lots of preparatory work conducted
- Sensitivity to environmental fields (B < nT level)

university of groningen / VSI

CPEDM Collaboration (sr EDM + JEDI + CERN)

KJ – PBC -14/6/18

Courtesy Klaus Jungmann

Muon EDM: muEDM@PSI

The frozen-spin approach

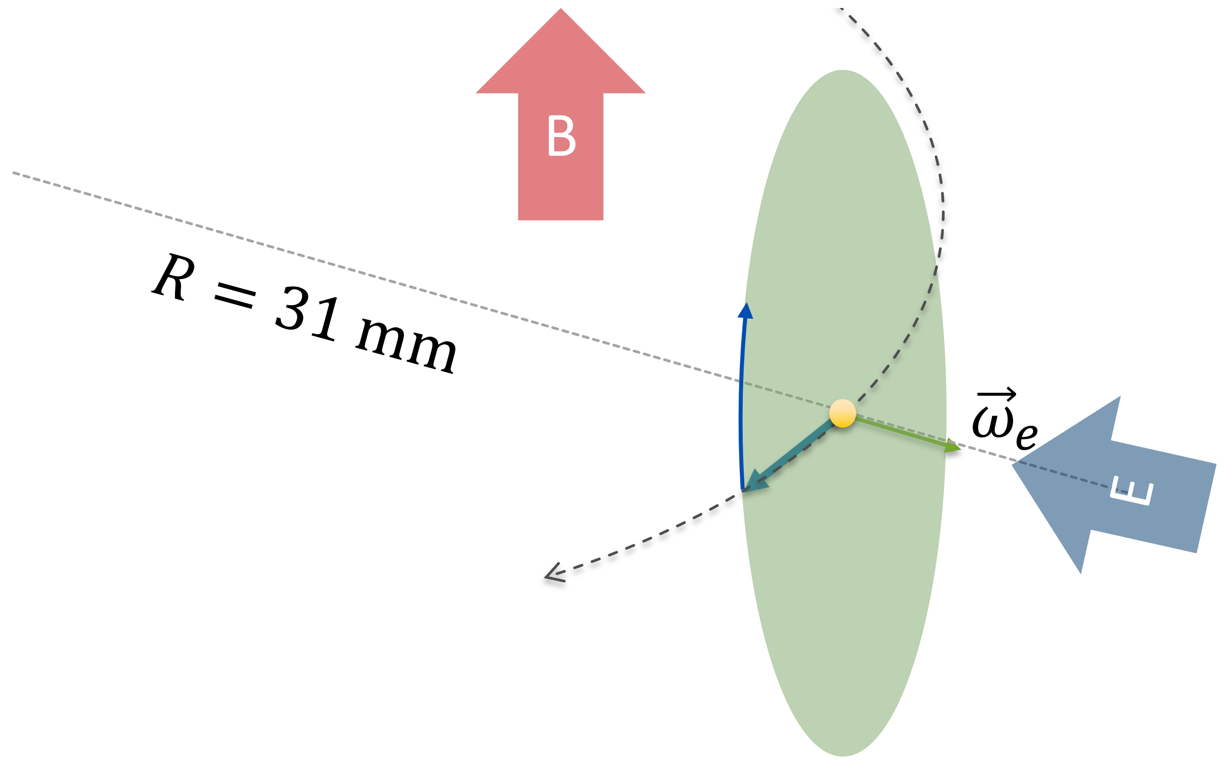
$$\vec{\omega}_s - \vec{\omega}_c = -\frac{e}{m}\left\{\underbrace{\cancel{a\vec{B} + \left(\frac{1}{\gamma^2-1} - a\right)\frac{\vec{\beta}\times\vec{E}}{c}}}_{\omega_a\,:\,\text{g-2}} + \underbrace{\boxed{\frac{\eta}{2}\left(\frac{\vec{E}}{c} + \vec{\beta}\times\vec{B}\right)}}_{\omega_\eta\,:\,\text{EDM}}\right\}$$

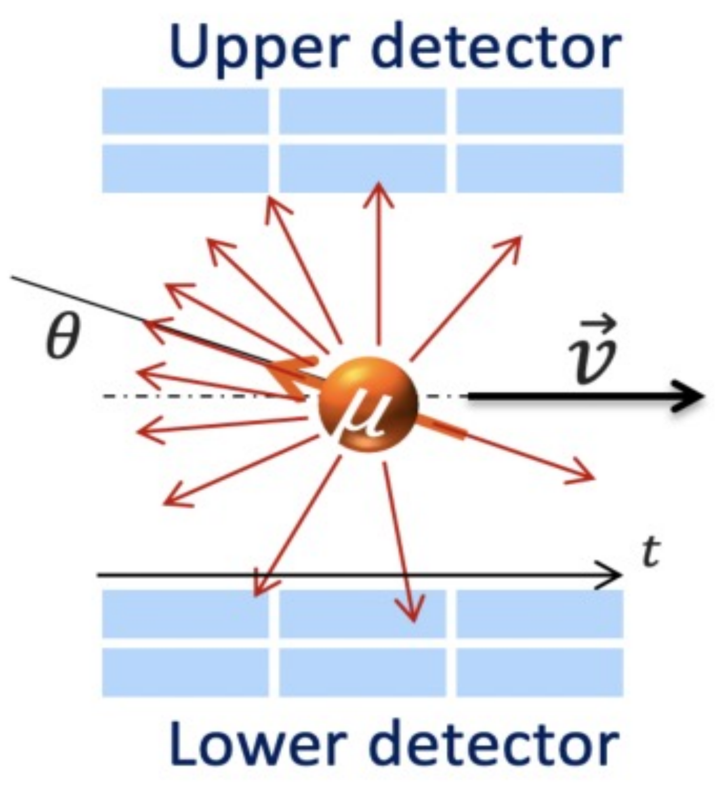
Muon EDM Sensitivities

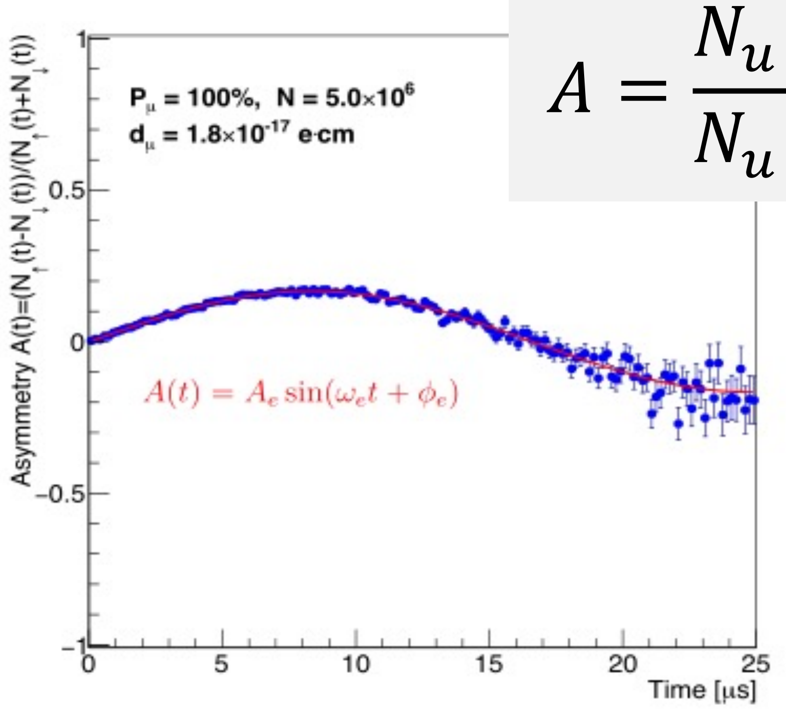
BNL g-2 limit: $d_\mu < 1.8\times10^{-19}$ e cm

Phase I: $d_\mu < 3\times10^{-21}$ e cm

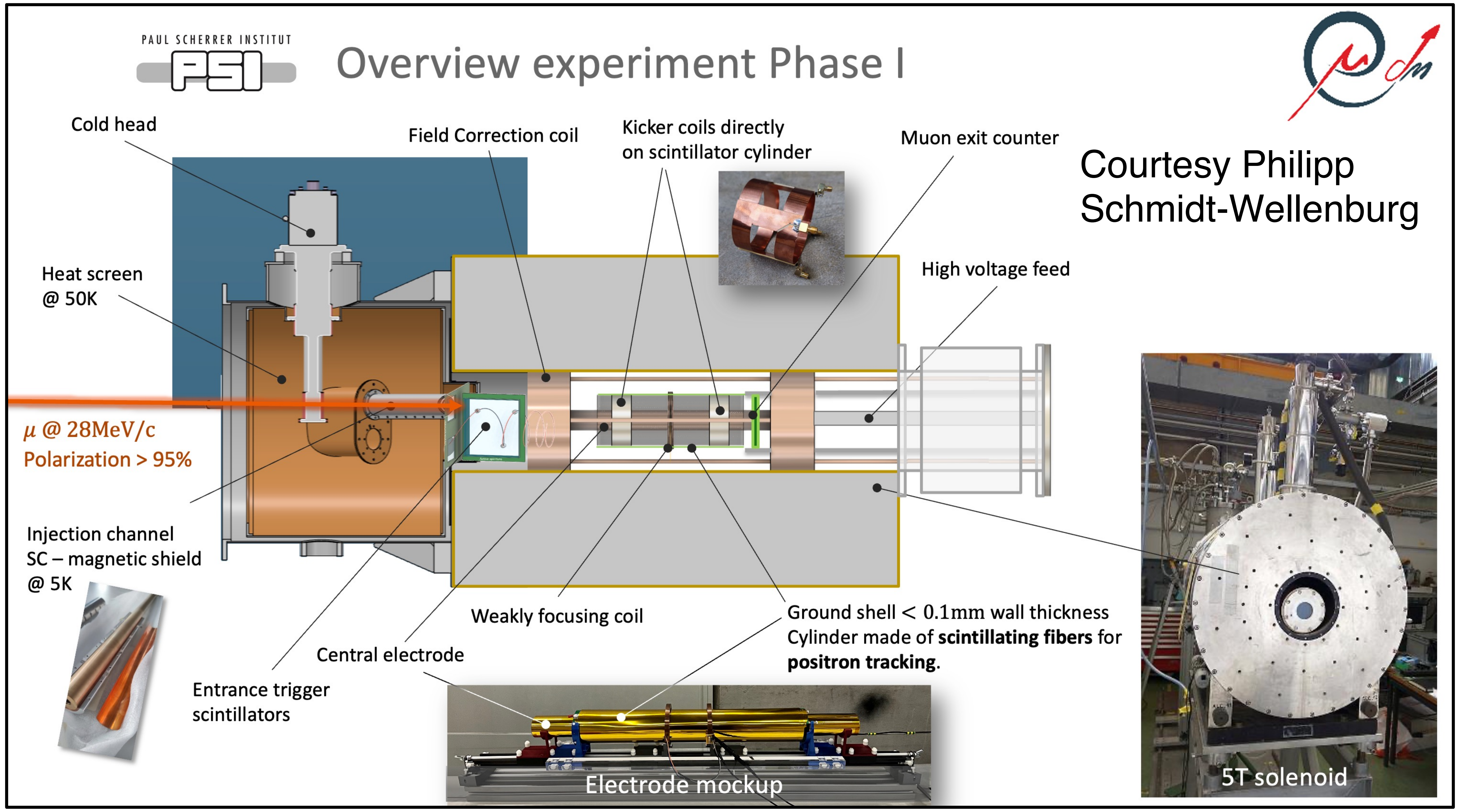
Phase II: $d_\mu < 6\times10^{-23}$ e cm







$$A = \frac{N_u - N_d}{N_u + N_d}$$



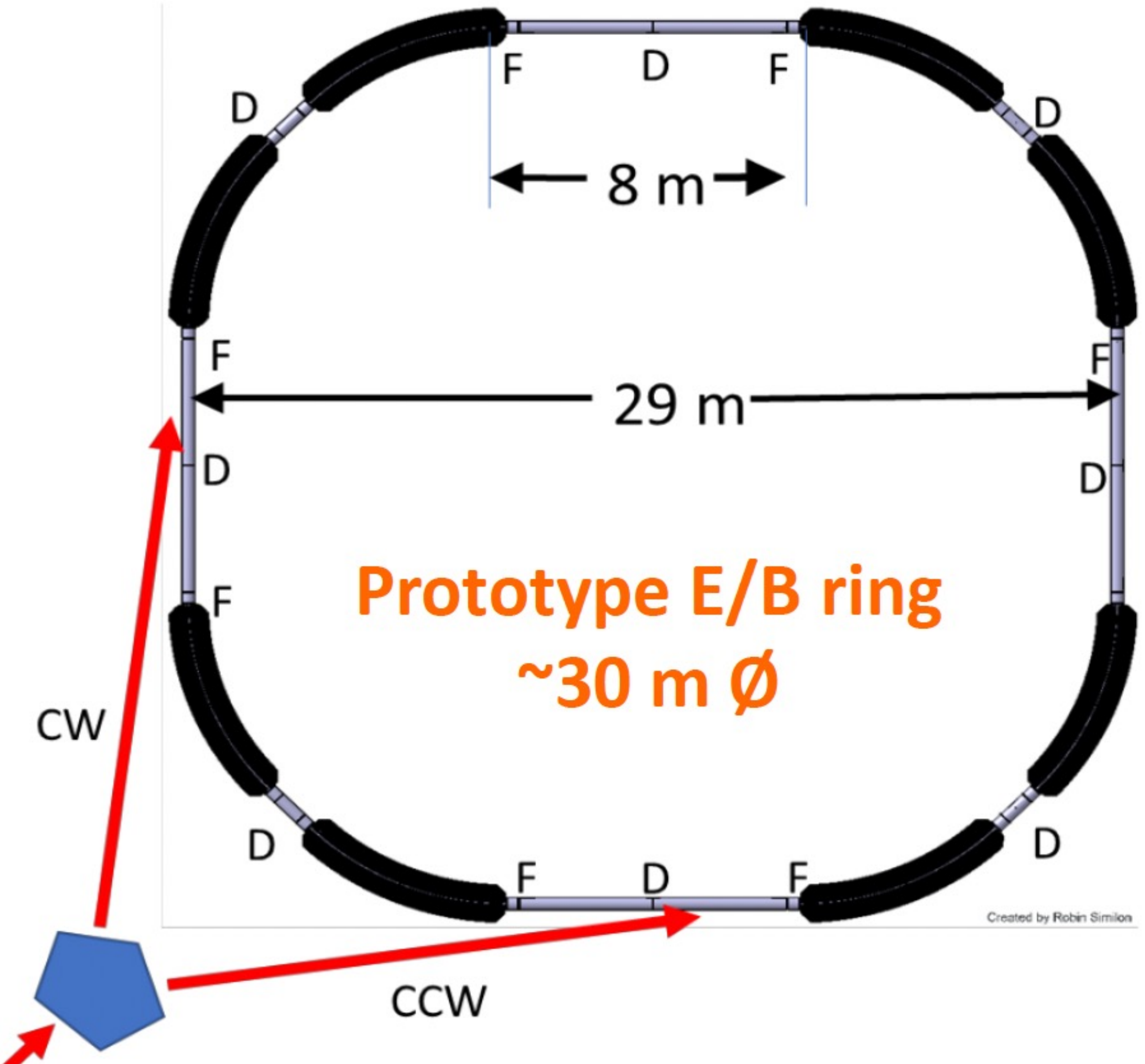
Proton EDM: CPEDM

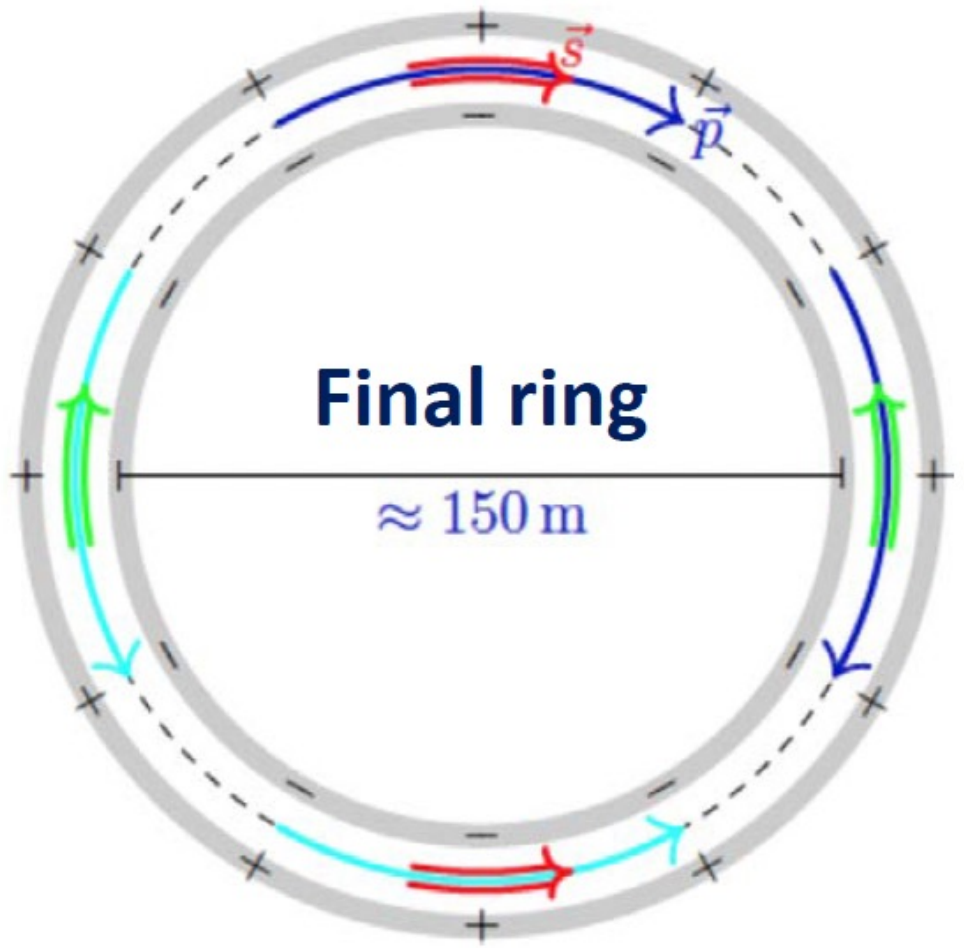
Courtesy Claude Vallée

PROTON EDM RING

COSY at Jülich supported by EPPSU as possible site for developing the project

Ongoing precursor experiment at Jülich (magnetic ring)





Design sensitivity: 4. 10^{-29} e.cm

TDR for prototype ring in preparation by CPEDM Collaboration (incl. CERN)

Many systematics issues to be solved: lattice, deflectors, RF cavities, B-shield, BPMs…

Electron EDM: Storage ring

PLB 843 (2023) 138058

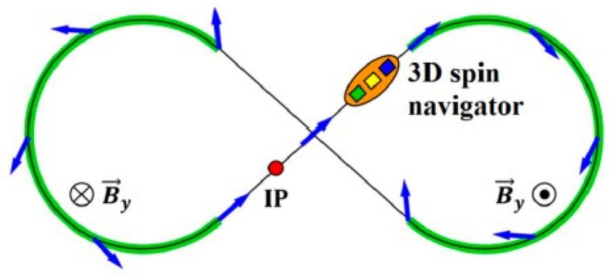
- No SR eEDM proposal in the past due to no viable polarimetry at “magic” momentum (the momentum where the electron spin is not affected by the v x E term, ~15 MeV)

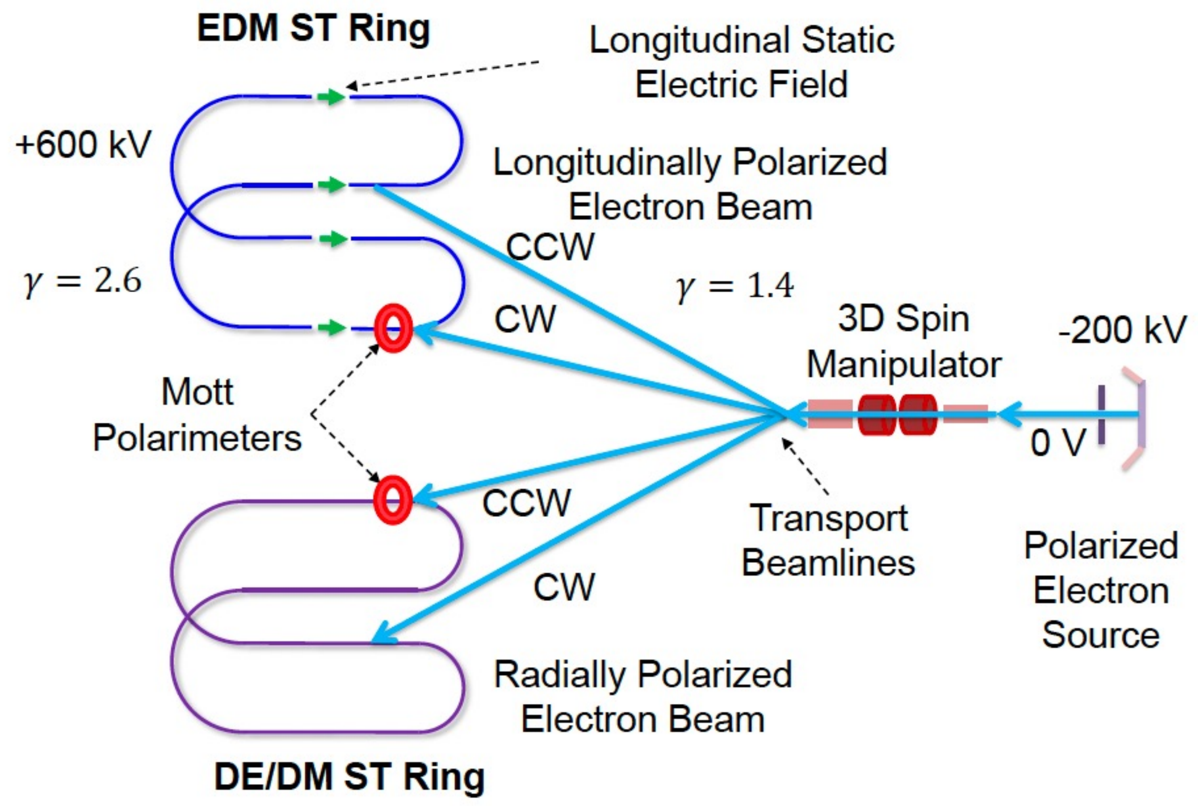
Electron Spin-Transparent Storage Ring

- In ST mode, any spin direction repeats after a particle turn along periodic orbit in storage ring – an ideal definition; but it can be approached with a high precision
- Best example is a figure-8 magnetic or electric ring; here global spin tune is zero independent of particle energy
- Remaining challenge is to compensate for misalignments and spin decoherency due to beam emittances

https://doi.org/10.1103/PhysRevLett.124.194801

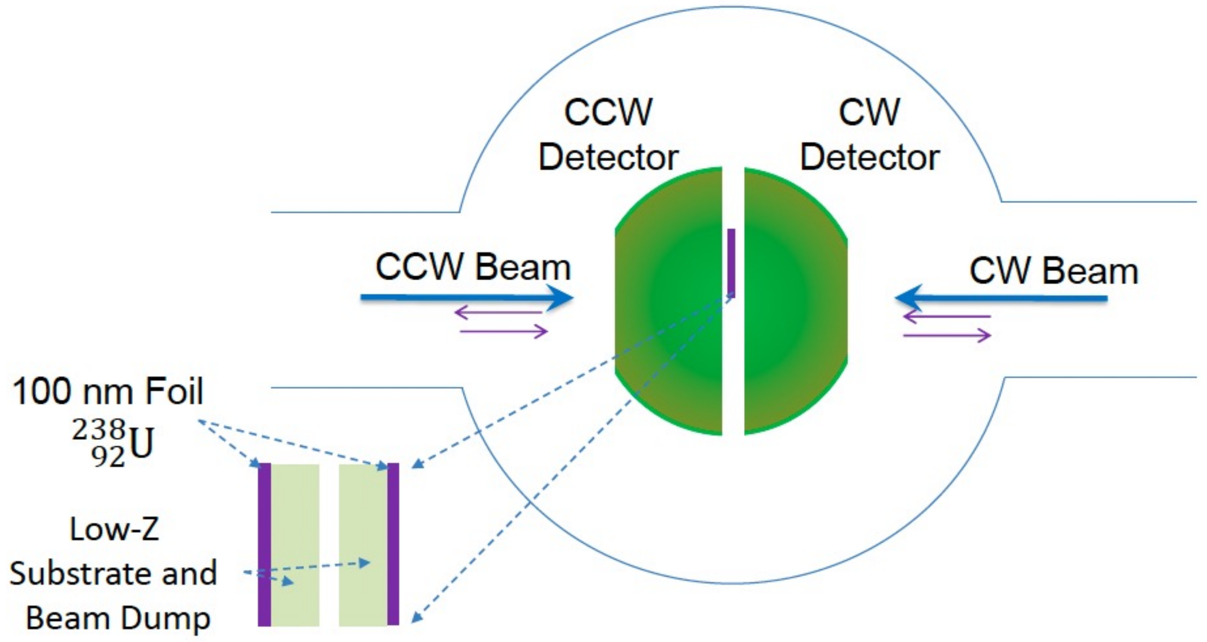
https://doi.org/10.3390/sym13030398





Mott Polarimeter & Statistical Uncertainties

Detector Coverage:
- $\varphi: 0 \rightarrow 2\pi$
- $\theta: 90° \rightarrow 160°$



- Statistical uncertainty per fill with continuous Mott measurements:

$$\sigma_{EDM} = \sqrt{24}\frac{d_e}{\sqrt{N_e}\,\epsilon\, Ay\, P\, \Omega_{EDM}\, SCT}$$

$$\sigma_{EDM} = 4.7 \cdot 10^{-27}\ e \cdot cm$$

- In one year:

$$\sigma_{EDM} = 8.4 \cdot 10^{-29}\ e \cdot cm$$

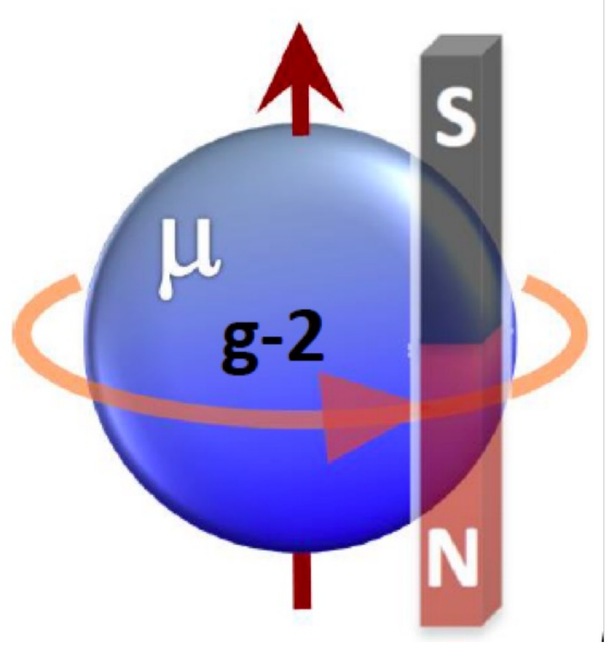
- Current limit from ThO molecule: $d_e < 1.1 \times 10^{-29}\ e \cdot cm$ (90% C.L.)

Electrons per Fill	N_e	$1.2 \cdot 10^{10}$ $6 \cdot 10^{9}$ **CW,** $6 \cdot 10^{9}$ **CCW**
Polarimeter Efficiency	ϵ	0.0024
Analyzing Power	A_y	0.45
Beam Polarization	P	0.9
Precession Frequency	Ω_{EDM}	0.48 nrad/s (calculated assuming $1 \cdot 10^{-29}$ e·cm)
Spin Coherence Time	SCT	10000 s

- **Further optimization and improvements will lower this limit to less than $1.0 \times 10^{-29}\ e \cdot cm$**

Overview of MDM experiments

- **Category 1: Storage ring/solenoid experiments**
  - Traditional, magic momentum approach, pure B-field approach
- **Category 2: Penning Traps**
  - High precision Penning traps, suitable for stable particle (p,e)
- **Category 3: e^+e^- & Pb-Pb Colliders**
  - Less precise, suitable for short-lived particles (tau, Baryon)
- High precision comparison of theory-experiment provides a stringent test of SM



$$\vec{\mu} = g\frac{e}{2m}\vec{s}$$

Particle	g-factor	Relative uncertainty
Electron	2.002 319 304 361 18(26)	1.3×10^{-13}
Muon	2.002 331 841 10(47)	2.3×10^{-11}
Proton	5.585 694 689 3(16)	2.9×10^{-10}
Antiproton	5.585 694 690 6(60)	1.5×10^{-9}

FNAL Muon g-2

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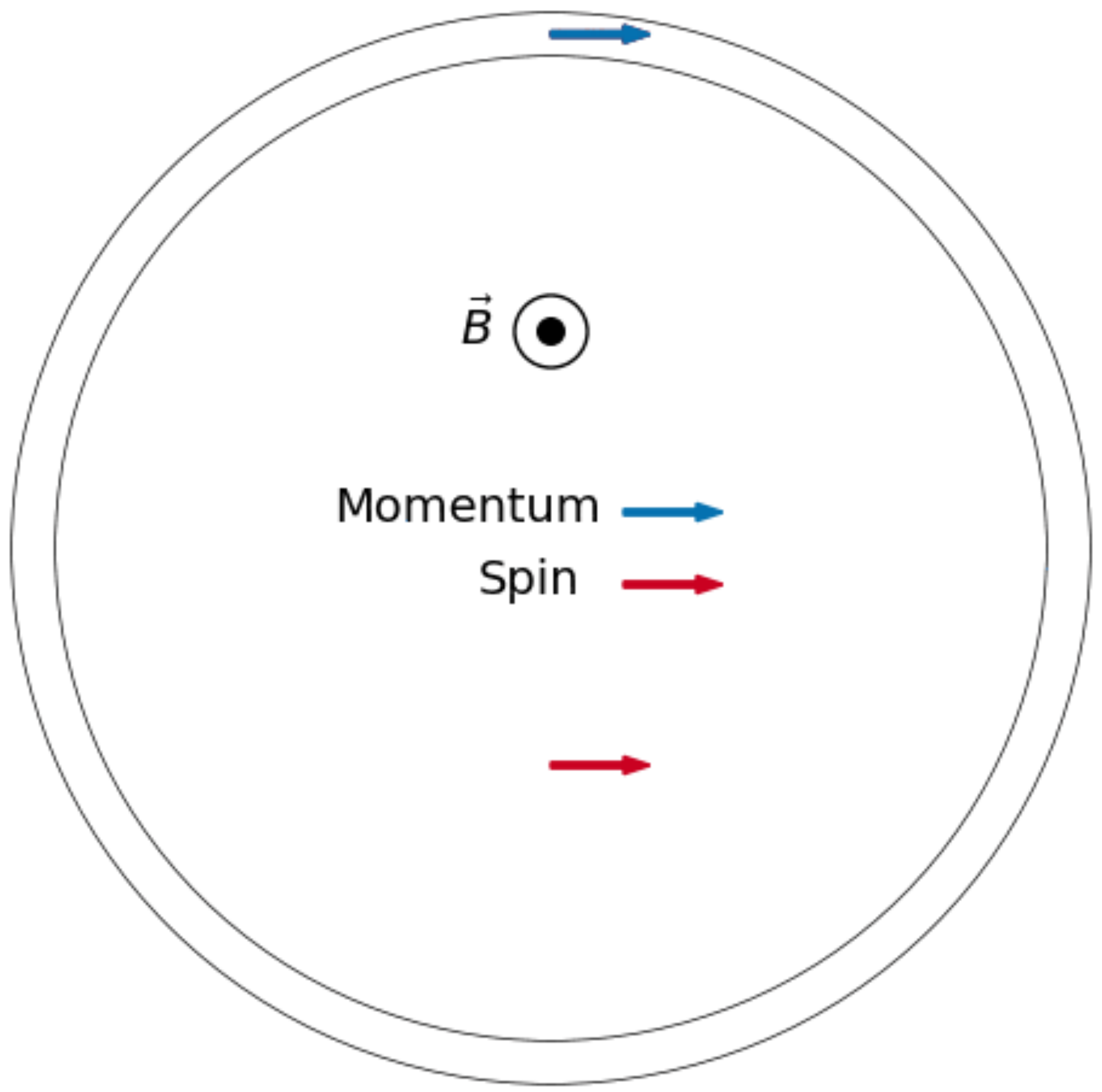
Courtesy Graziano Venanzoni and Peter Winter



Larmor **Thomas** **Cyclotron**

$$\boxed{\omega_s = \frac{geB}{2m} + (1-\gamma)\frac{eB}{\gamma m}} \quad \boxed{\omega_c = \frac{eB}{\gamma m}}$$

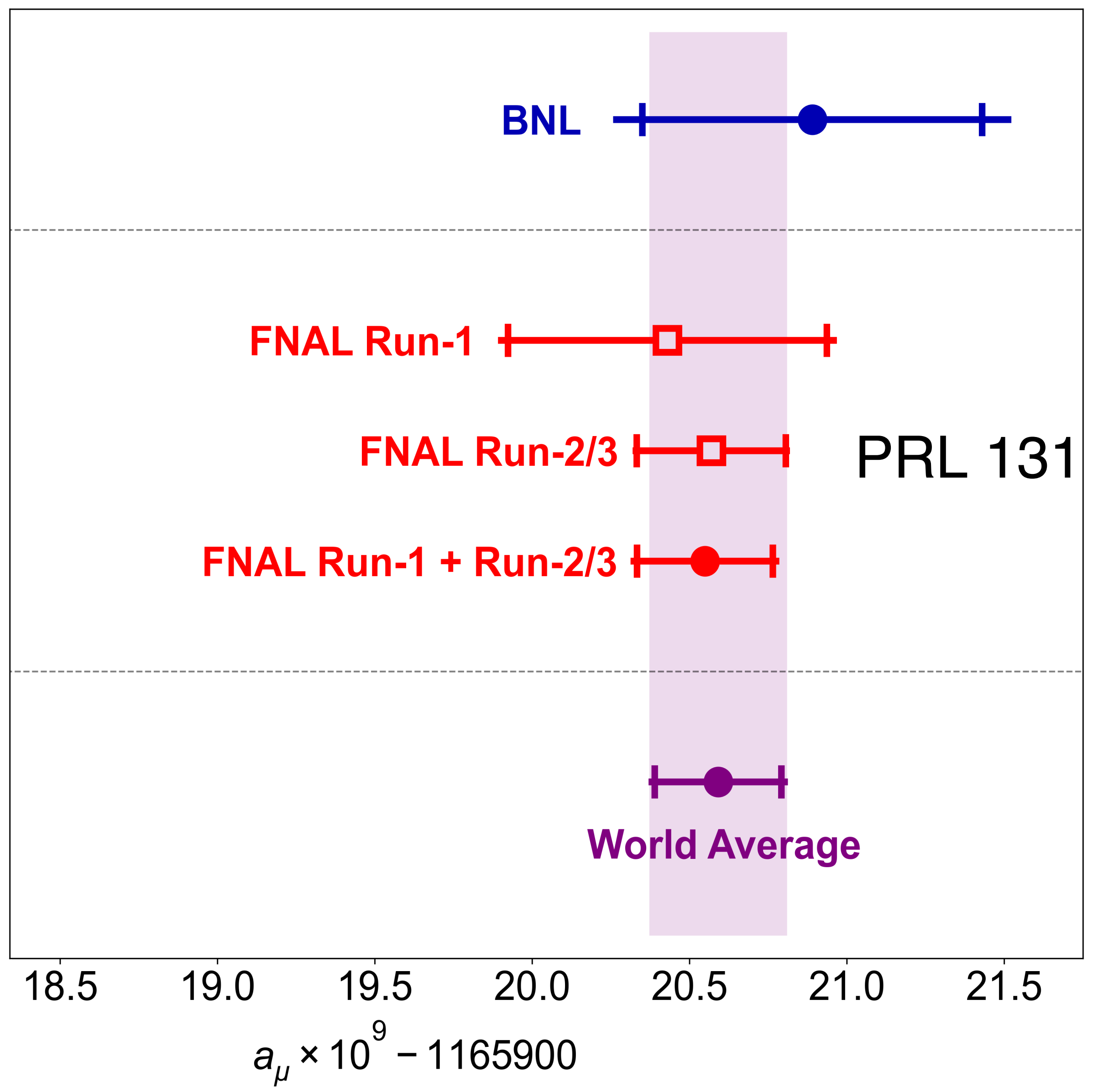
Anomalous precession frequency

$$\boxed{\omega_a = \omega_s - \omega_c = \left(\frac{g-2}{2}\right)\frac{eB}{m}}$$

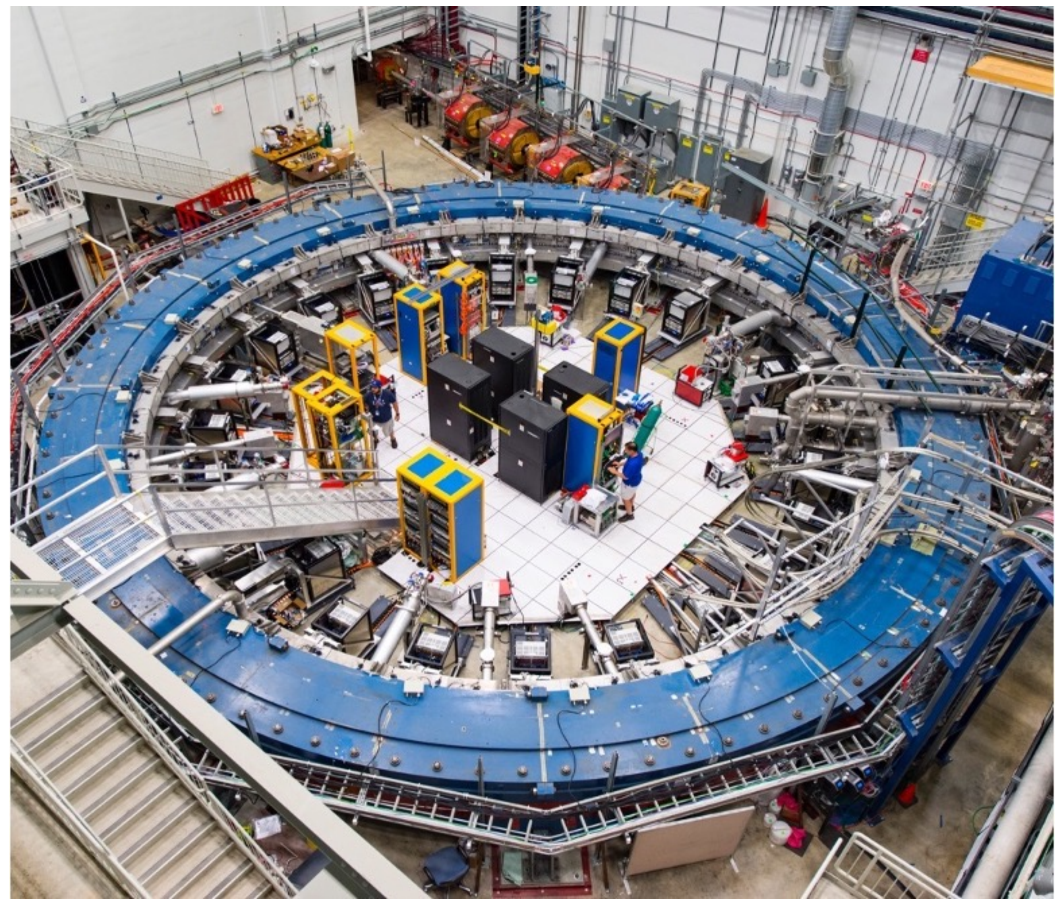
measure difference in frequency precisely

$$\boxed{\omega_a = a_\mu \frac{eB}{m}}$$

homogenous field and precise field measurement



PRL 131 161802 (2023)



Excellent agreement

- Second result agrees well with FNAL Run-1 and BNL

Precision milestone

- Systematic uncertainty of **70 ppb** already surpasses goal

World average

- New average has **190 ppb** precision, dominated by **FNAL**

Statistical uncertainty goal

- With >21x BNL final statistics, on track to reach **100 ppb** statistical goal

FNAL Muon g-2: current situation

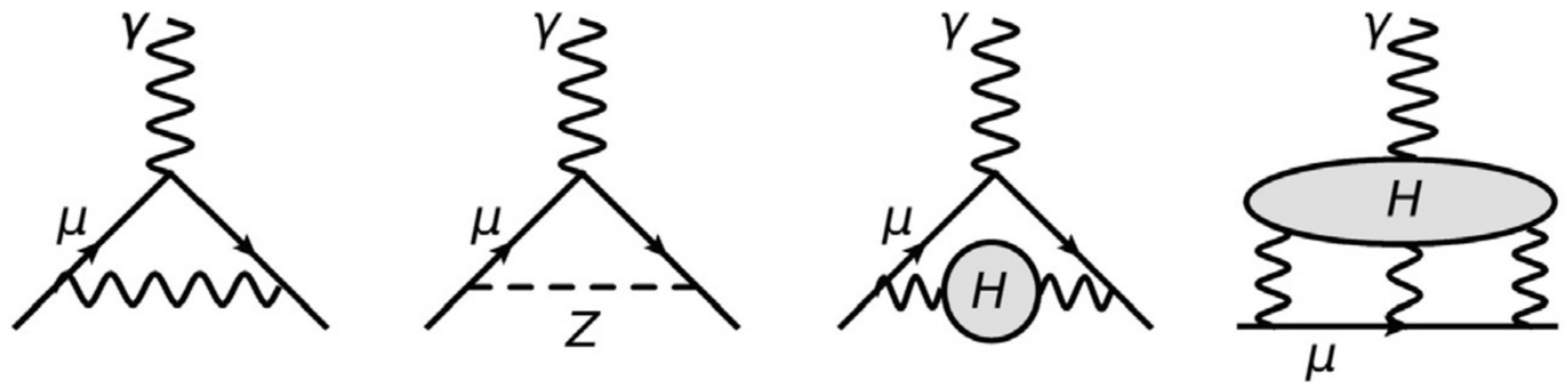
T. Aoyama et al. Phys. Rept. **887** (2020)

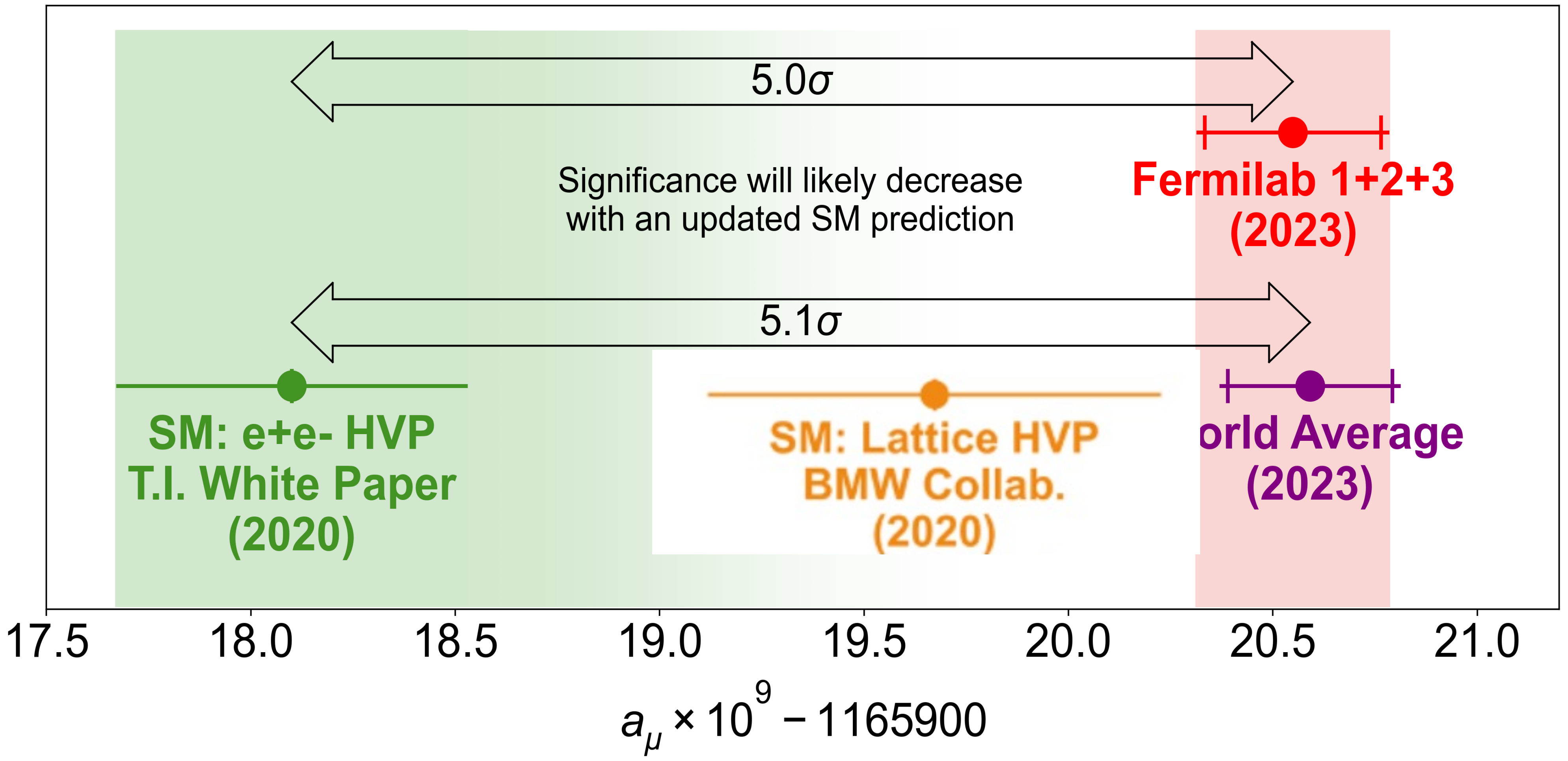
Experimental outlook

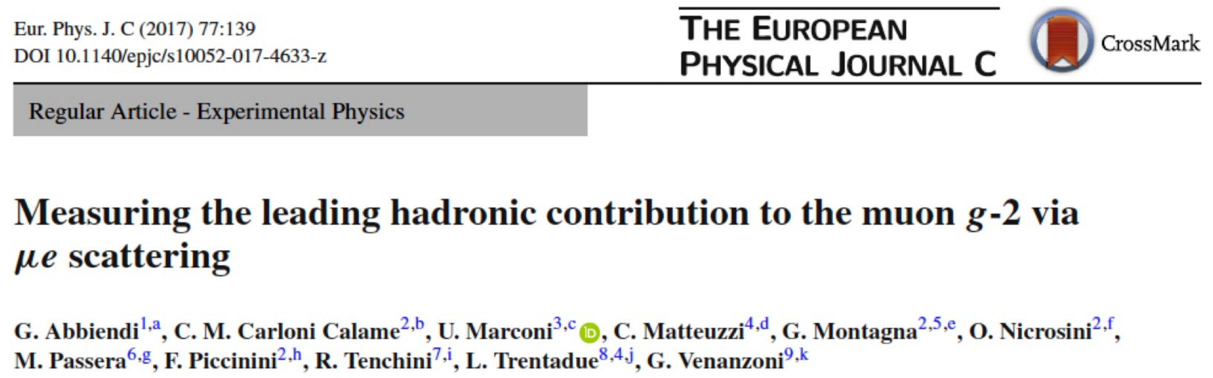
- Plan to **publish full dataset in 2025** with 2x precision
- Will reach or slightly surpass precision goal of **140 ppb**

Comparison with theory

- Large discrepancy between experiment & theory, **FNAL alone** gets to **5.0σ**
- Recent calculation from lattice and e^+e^- data from CMD-3 show tensions with 2020 theory prediction (being closer to the experimental value)
- Updated prediction expected in 2025 using all available data will **likely yield a smaller and less significant discrepancy**
- Theory community working hard to:
  - Understand discrepancy between dispersive calculation and Lattice QCD
  - Scrutinize both new CMD-3 result and former e^+e^- data






Eur. Phys. J. C (2017) 77:139
DOI 10.1140/epjc/s10052-017-4633-z

THE EUROPEAN PHYSICAL JOURNAL C

CrossMark

Regular Article - Experimental Physics

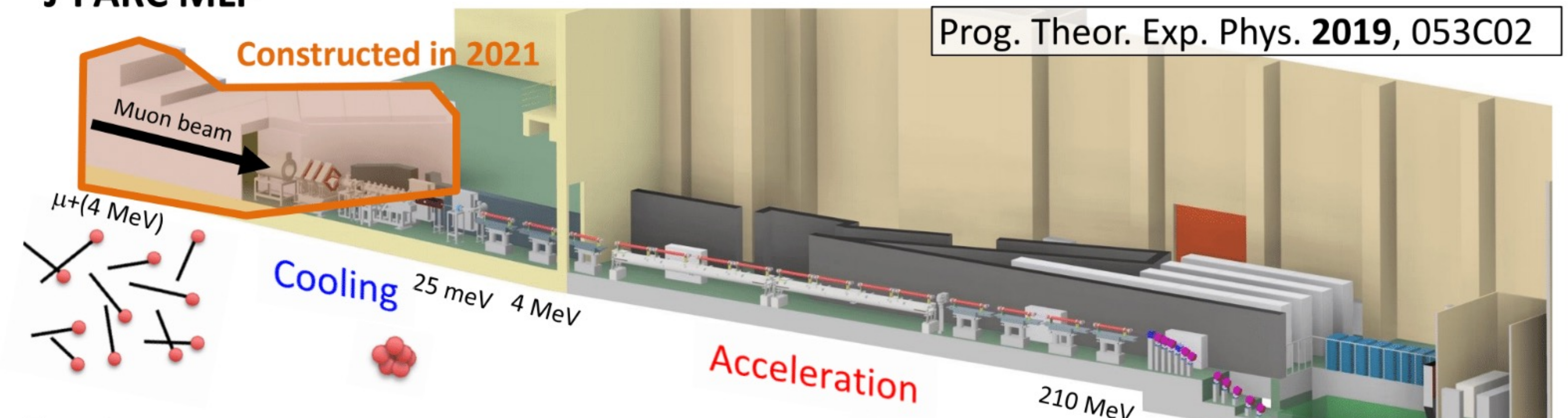
Measuring the leading hadronic contribution to the muon g-2 via μe scattering

G. Abbiendi[1,a], C. M. Carloni Calame[2,b], U. Marconi[3,c], C. Matteuzzi[4,d], G. Montagna[2,5,e], O. Nicrosini[2,f], M. Passera[6,g], F. Piccinini[2,h], R. Tenchini[7,i], L. Trentadue[8,4,j], G. Venanzoni[9,k]

Courtesy Graziano Venanzoni and Peter Winter

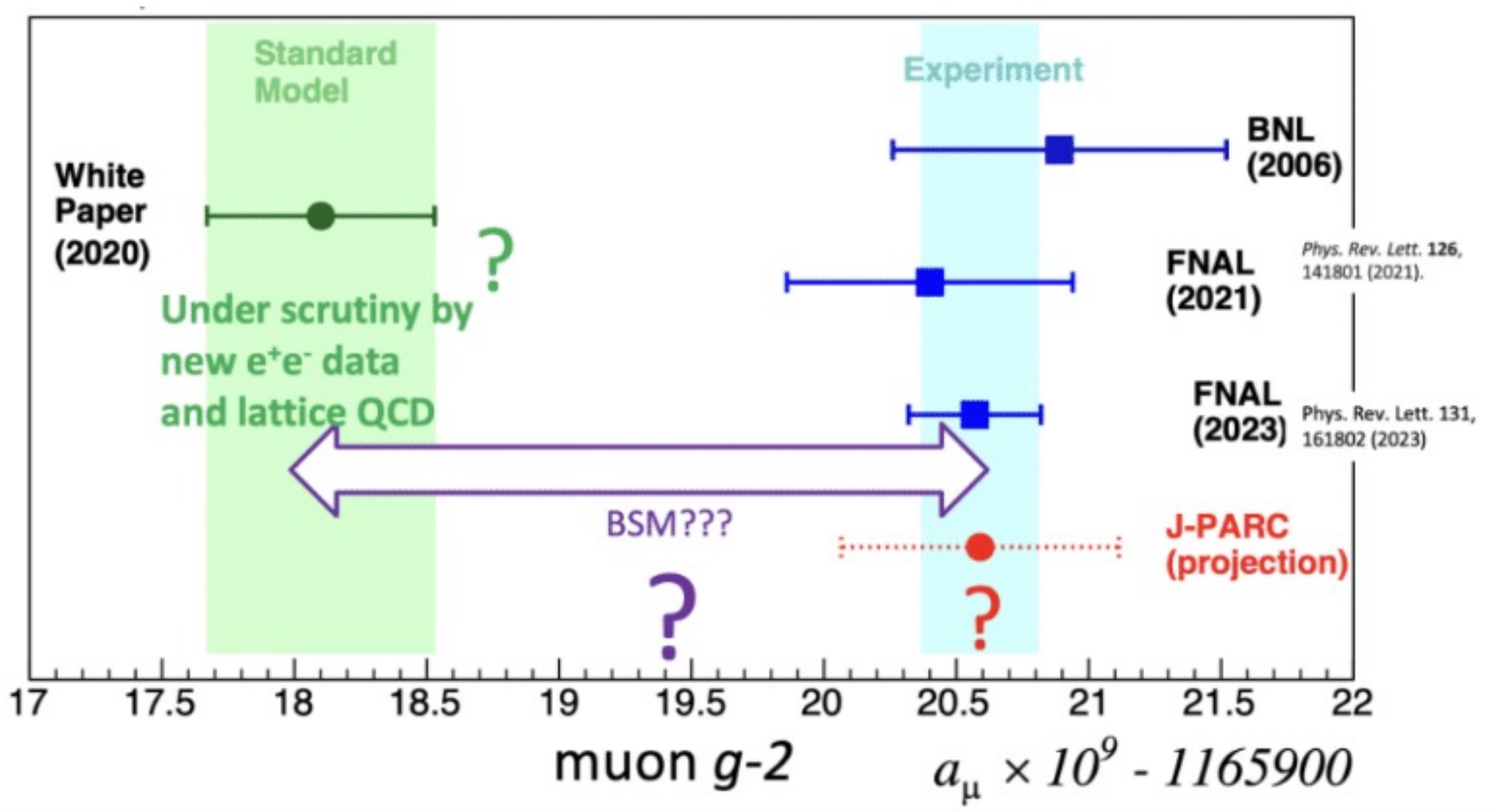
J-PARC Muon g-2/EDM

J-PARC MLF



Features:

- Low emittance muon beam (1/1000)
- No strong focusing (1/1000) & good injection eff. (x10)
- Compact storage ring (1/20)



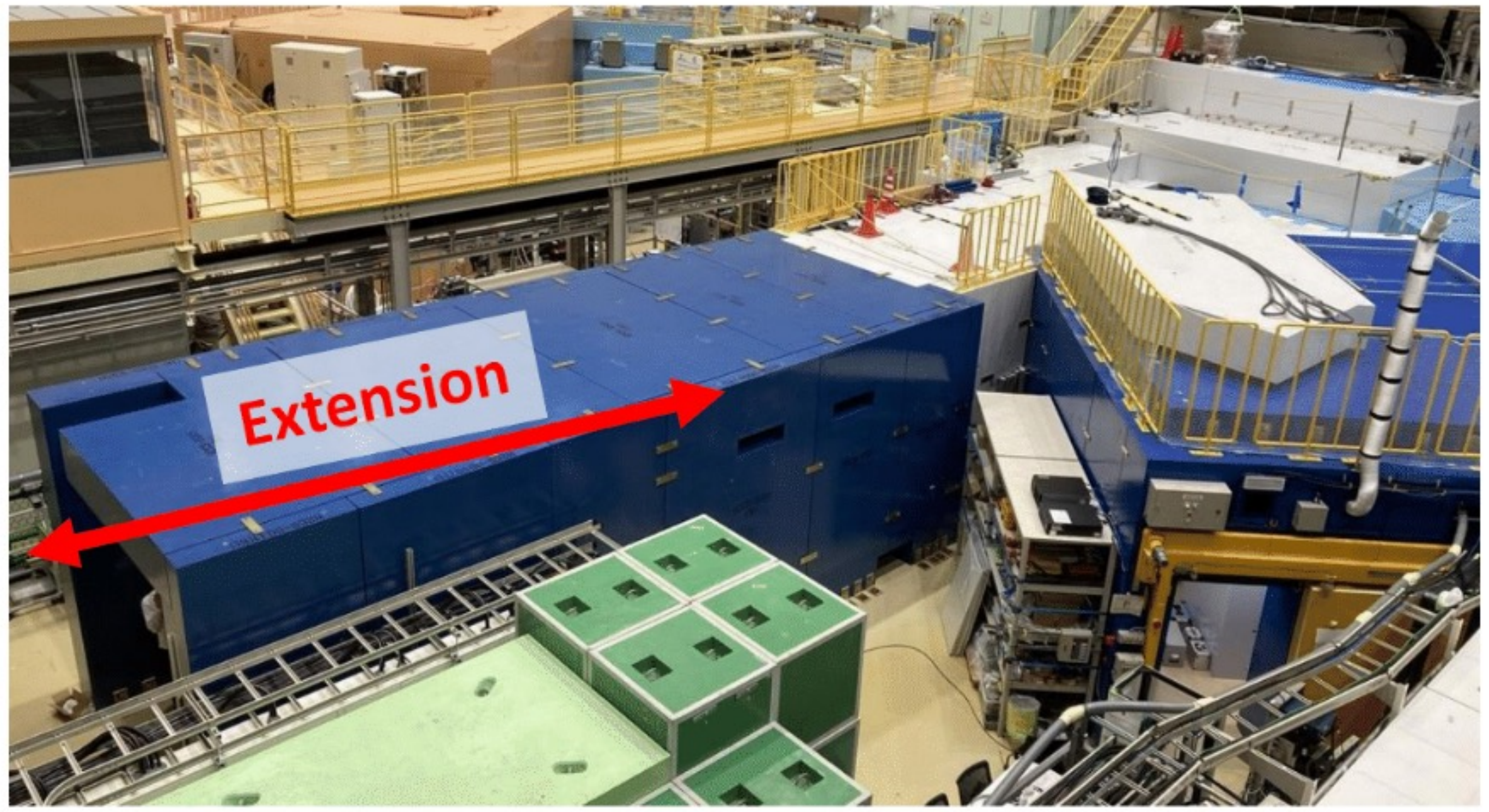
J-PARC is **the only experiment** to check FNAL/BNL results.

g-2 : 450 ppb

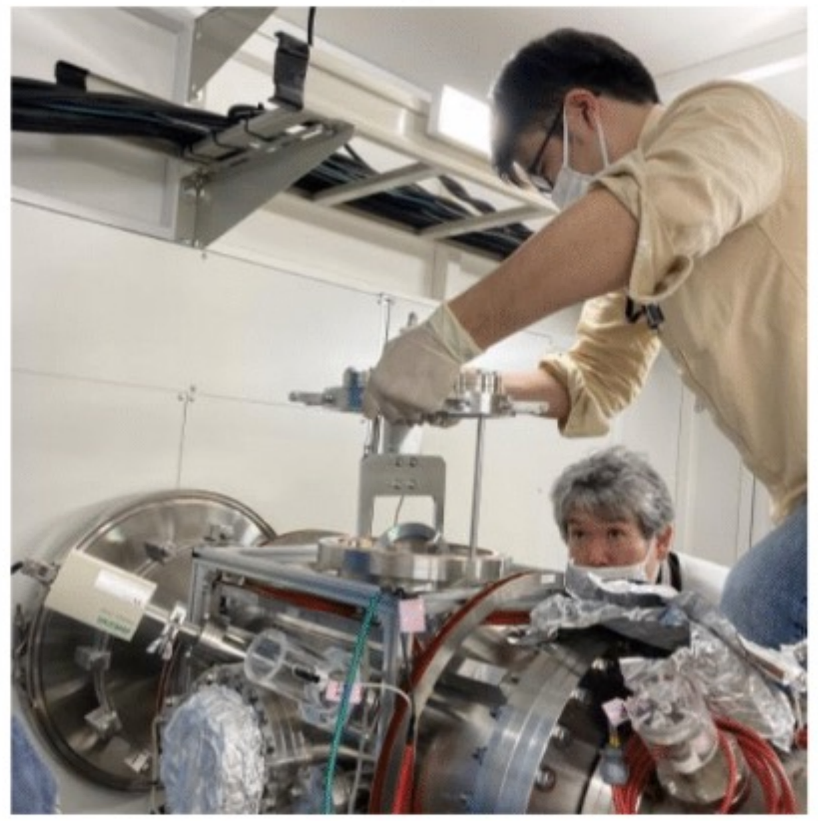
EDM : 1.5 E-19 ecm

Aiming for data taking from 2028

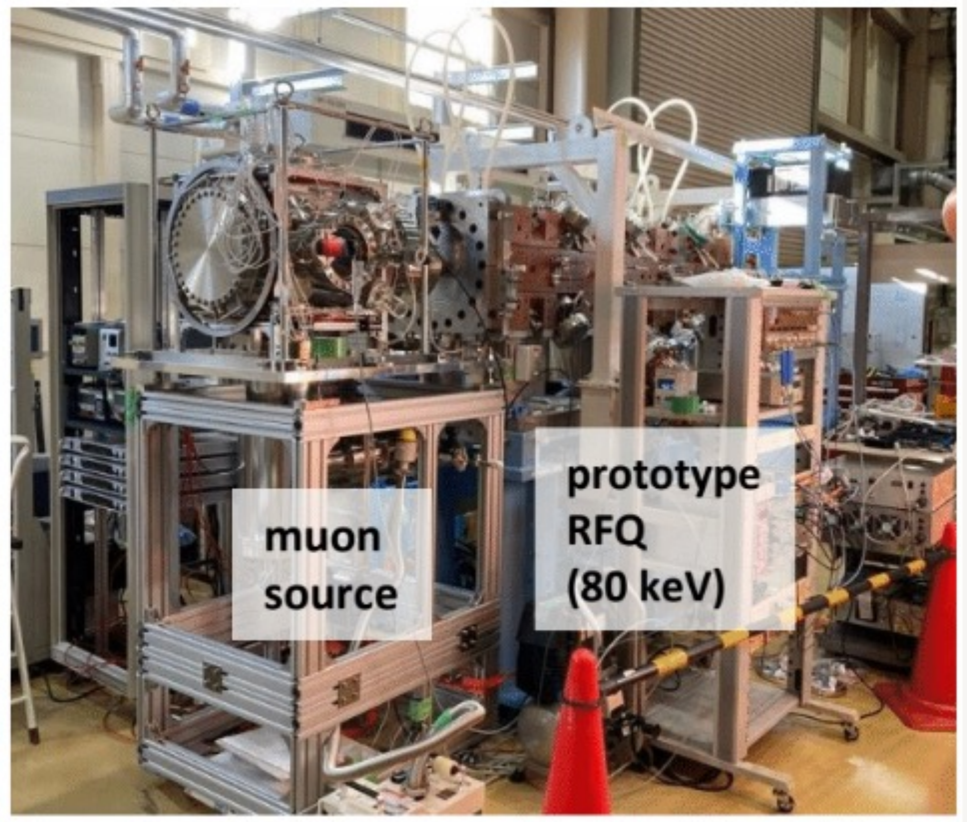
Assembled radiation shields for extension (Oct 15, 2022)



Muon cooling test (2022-)



Cooling + acceleration test (2024-)



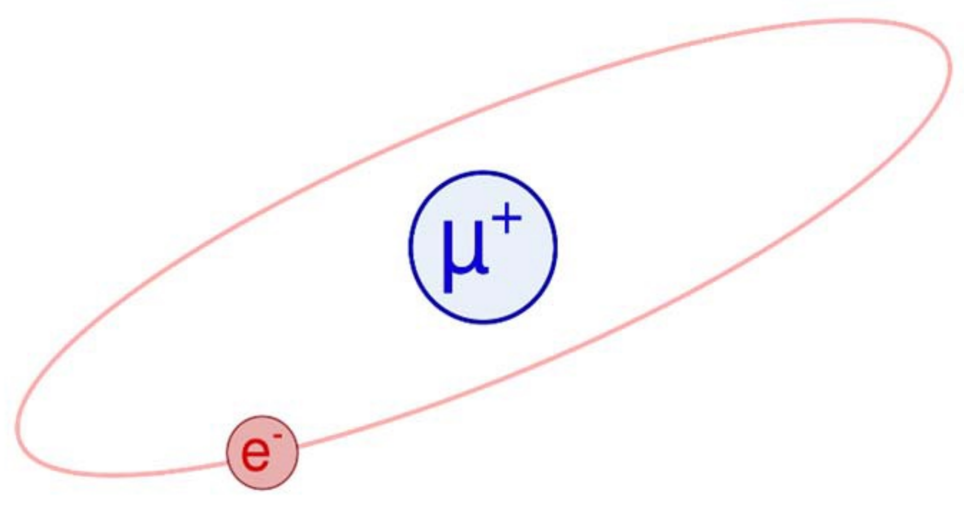
Courtesy Mibe Tsutomu

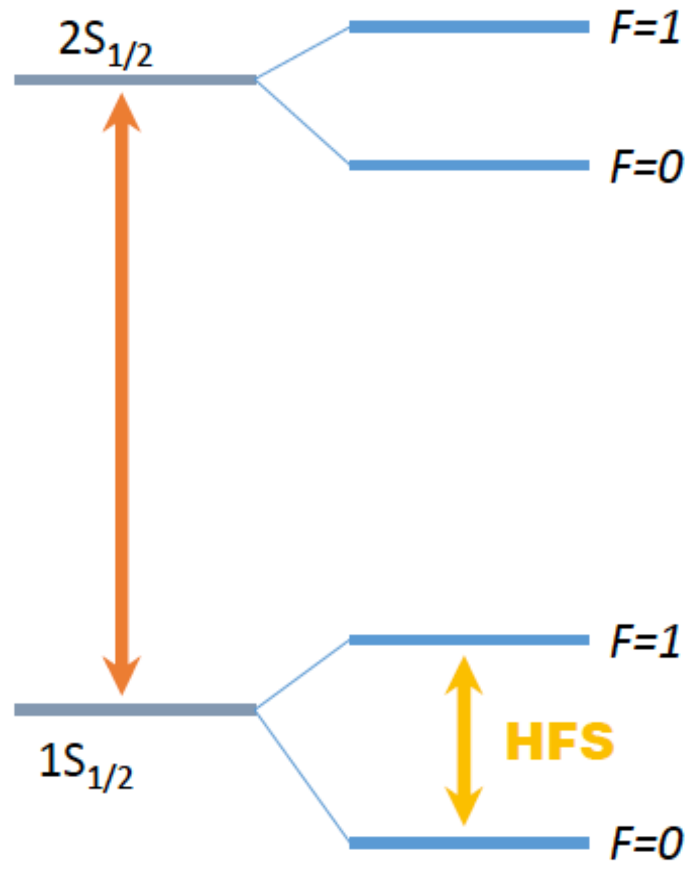
Muon g-2 from Muonium Spectroscopy

TSUNG-DAO LEE INSTITUTE

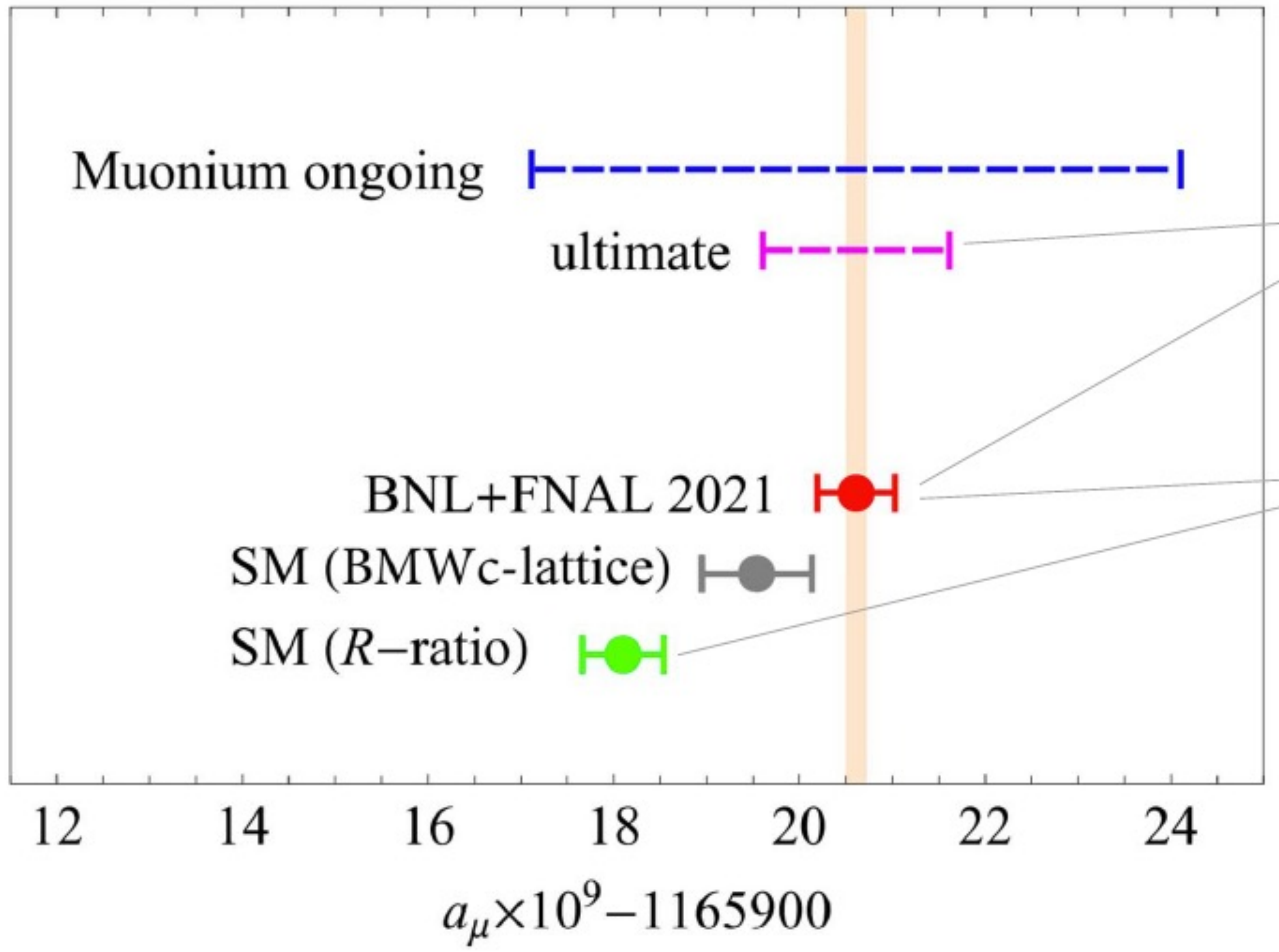
Phys. Rev. Lett. 127 (2021) 25, 251801

Muonium = QED bound-state of positive muon + electron





Courtesy Cédric Delaunay



A value of $a_\mu^{\rm Mu}$ at $\mathcal{O}(1\rm ppm)$ is not competitive to current spin-precession measurements

However, it may help to understand the origin of the $\sim 2\rm ppm$ difference between (R-ratio) SM and experiment

Ground-state HFS theory

$$\nu_{\rm HFS} = \frac{16}{3}(1+a_\mu)\frac{m_e}{m_\mu}\frac{R_\infty c\alpha^2}{(1+m_e/m_\mu)^3}[1+\delta_{\rm HFS}]$$

- **Rydberg constant** $R_\infty \equiv \alpha^2 m_e c/(2h)$
- **fine-structure constant**
- nonrelativistic **Fermi energy** from $H_{\rm HFS}$
- **electron-muon mass ratio**
- $\mathcal{O}(\alpha)$ correction [CODATA 2018 + refs therein]

$$\delta_{\rm HFS} = \delta_{\rm Dirac} + \delta_{\rm rad} + \delta_{\rm rec} + \delta_{\rm rad-rec} + \delta_{\rm weak} + \delta_{\rm had}$$

- relativistic (exact); antimuon charge $Z=1$
- radiative known up to $\mathcal{O}(Z\alpha^4)$ including a_e
- recoil known up to $\mathcal{O}[(m_e/m_\mu)(Z\alpha)^3]$ $\sim 60\,\rm Hz$ uncertainty
- radiative-recoil known up to $\mathcal{O}[(m_e/m_\mu)\alpha^3]$ $\sim 10\,\rm Hz$ uncertainty
- Z-exchange $-65\,\rm Hz$
- hadronic vacuum pol. $= 237.7(1.5)\,\rm Hz$

Total TH uncertainty $\sim 70\,\rm Hz\,(16ppb)$ dominanted by (yet) uncalculated QED corrections at three-loop order

[Eides-Shelyuto IJMPA 2016]

1S-2S theory

$$\nu_{\rm 1S-2S} = \frac{3}{4}\frac{R_\infty c}{(1+m_e/m_\mu)}[1+\delta_{\rm 1S-2S}]$$

- nonrelativistic energy (including recoil)
- $\mathcal{O}(\alpha^2)$ correction [CODATA 2018 + refs therein] rescaling hydrogen formulae with the muon mass and removing nuclear finite size and pol. effects

$$\delta_{\rm 1S-2S} = \delta_{\rm Dirac} + \delta_{\rm rel-rec} + \delta_{e\rm SE} + \delta_{\rm VP} + \delta_{2\gamma} + \delta_{3\gamma} + \delta_{\rm rad-rec} + \delta_{\mu\rm SE}$$

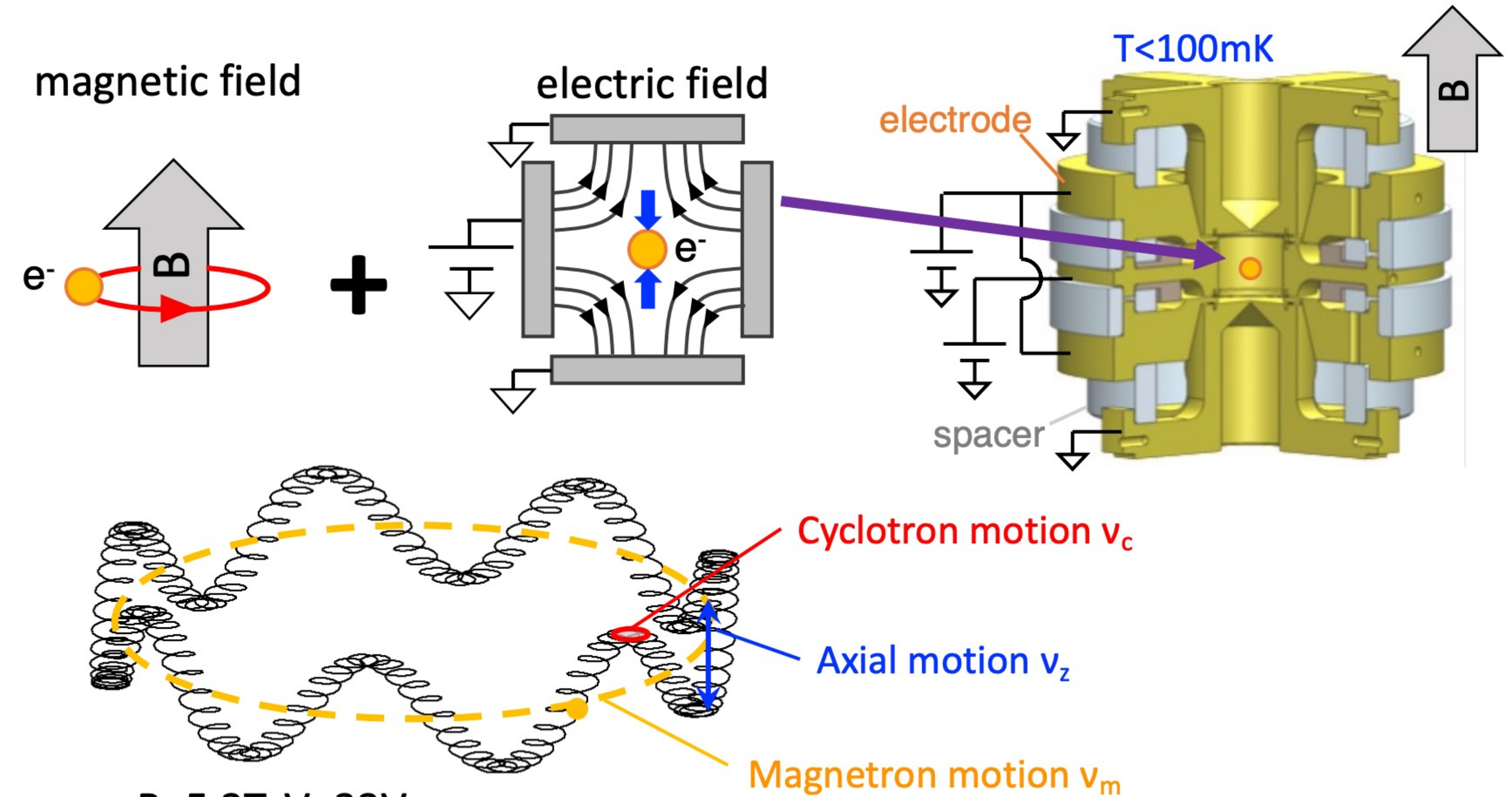
- relativistic (exact)
- relativistic-recoil known up to $\mathcal{O}[(m_e/m_\mu)(Z\alpha)^4]$
- electron self-E $\mathcal{O}[\alpha(Z\alpha)^4]$ known
- vacuum pol. known up to $\mathcal{O}[\alpha(Z\alpha)^4]$
- 2+3 photon exchange known up to $\mathcal{O}[\alpha^3(Z\alpha)^4]$
- radiative-recoil known up to $\mathcal{O}[(m_e/m_\mu)\alpha(Z\alpha)^3]$
- muon self-E

Total TH uncertainty $\sim 20\,\rm kHz\,(8ppt)$ from (yet) uncalculated QED (rad-rec) corrections at three-loop order

[Karshenboim et al. PLB 2019]

Electron g-factor

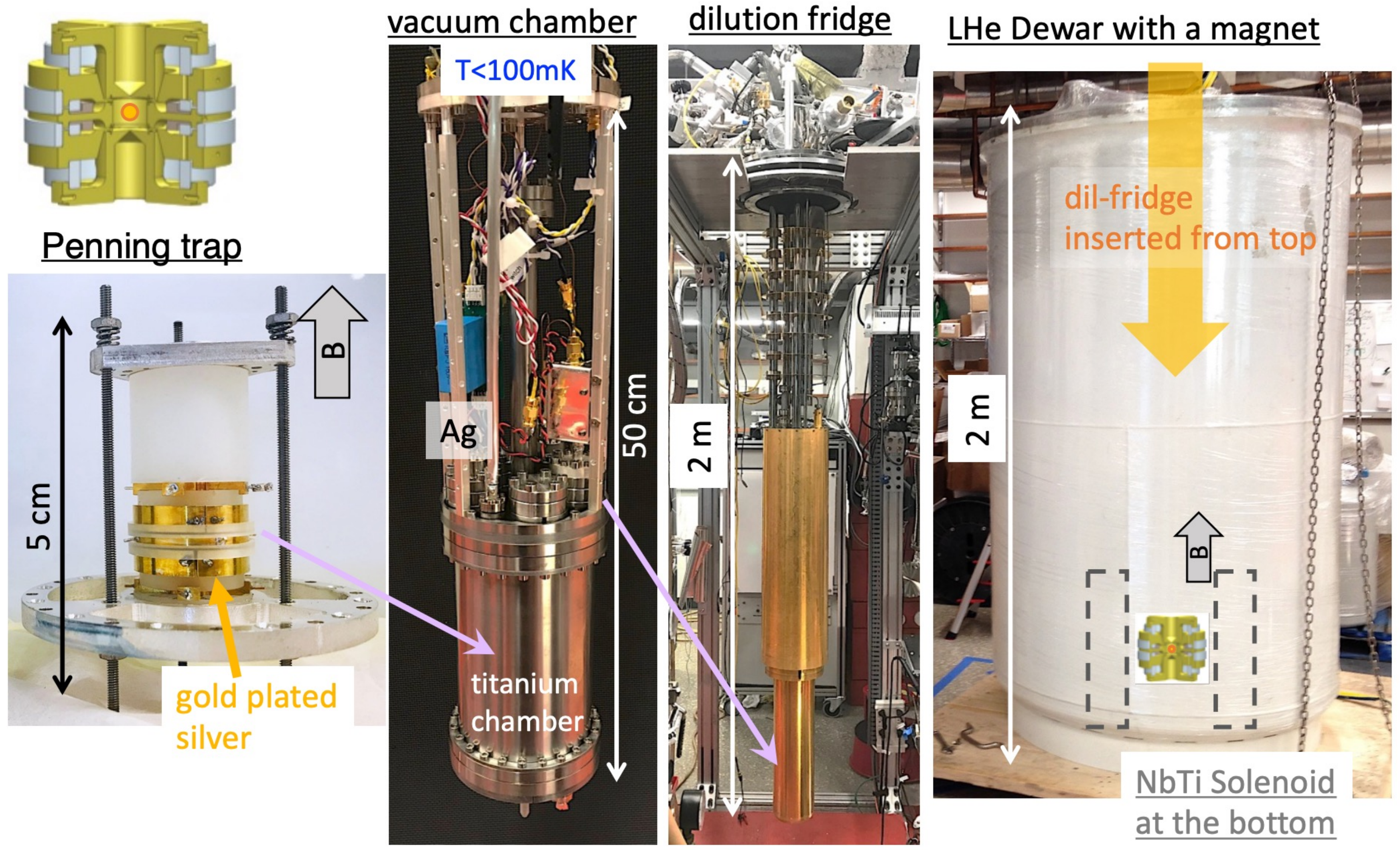
Courtesy Xing Fan



e.g. B=5.3T, V=33V

ν_c~150GHz >> ν_z~100MHz >> ν_m~50kHz

$\nu_s = \nu_c \times g/2$ ~150.17 GHz



$$\frac{g}{2} = \frac{\nu_s}{\nu_c} = 1 + \frac{\nu_a}{\nu_c}$$

$\nu_a = \nu_s - \nu_c$

~1.001

measuring this with 10^{-13} precision

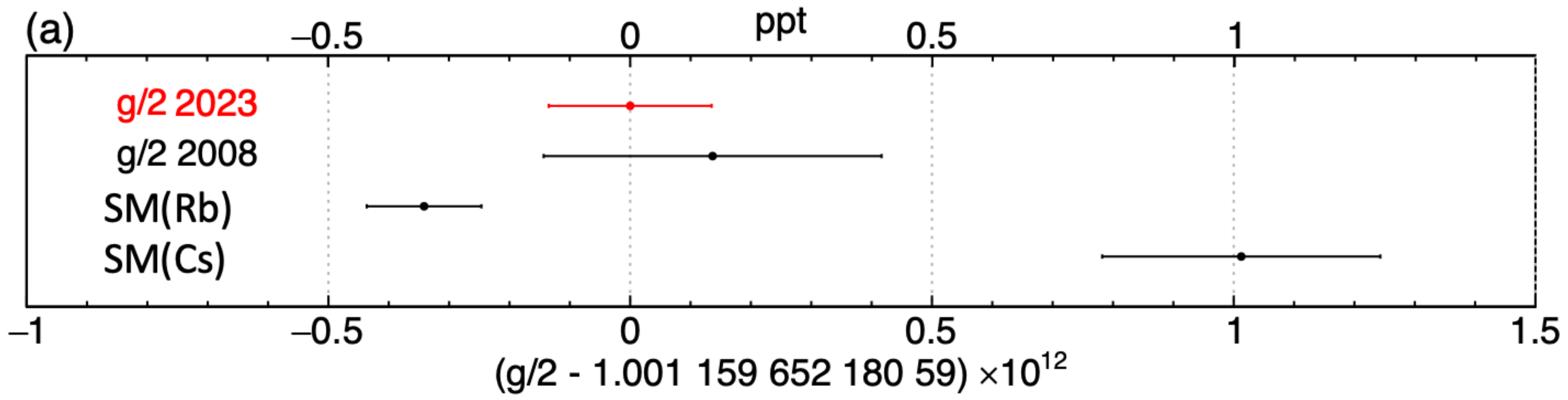
measuring this with 10^{-10} precision

$$\frac{g}{2} = 1.001\ 159\ 652\ 180\ 59\ (13)$$

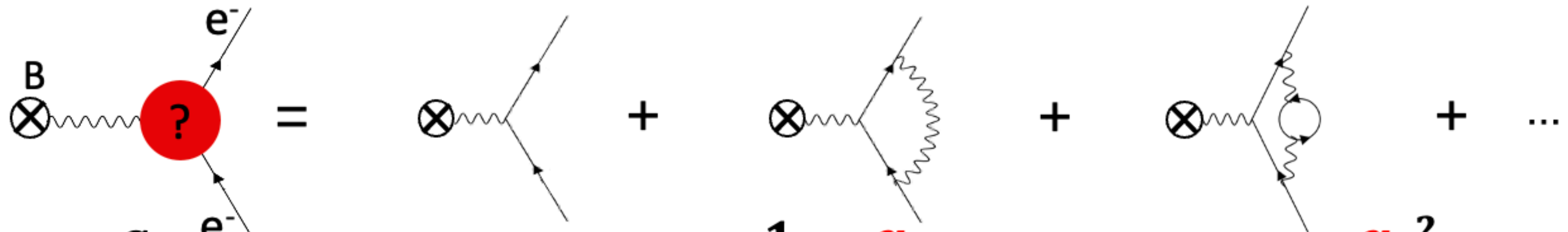
$$\alpha^{-1} = 137.035\ 999\ 166\ (15)$$

PRL 130, 071801 (2023)

- Most precise test of the Standard Model



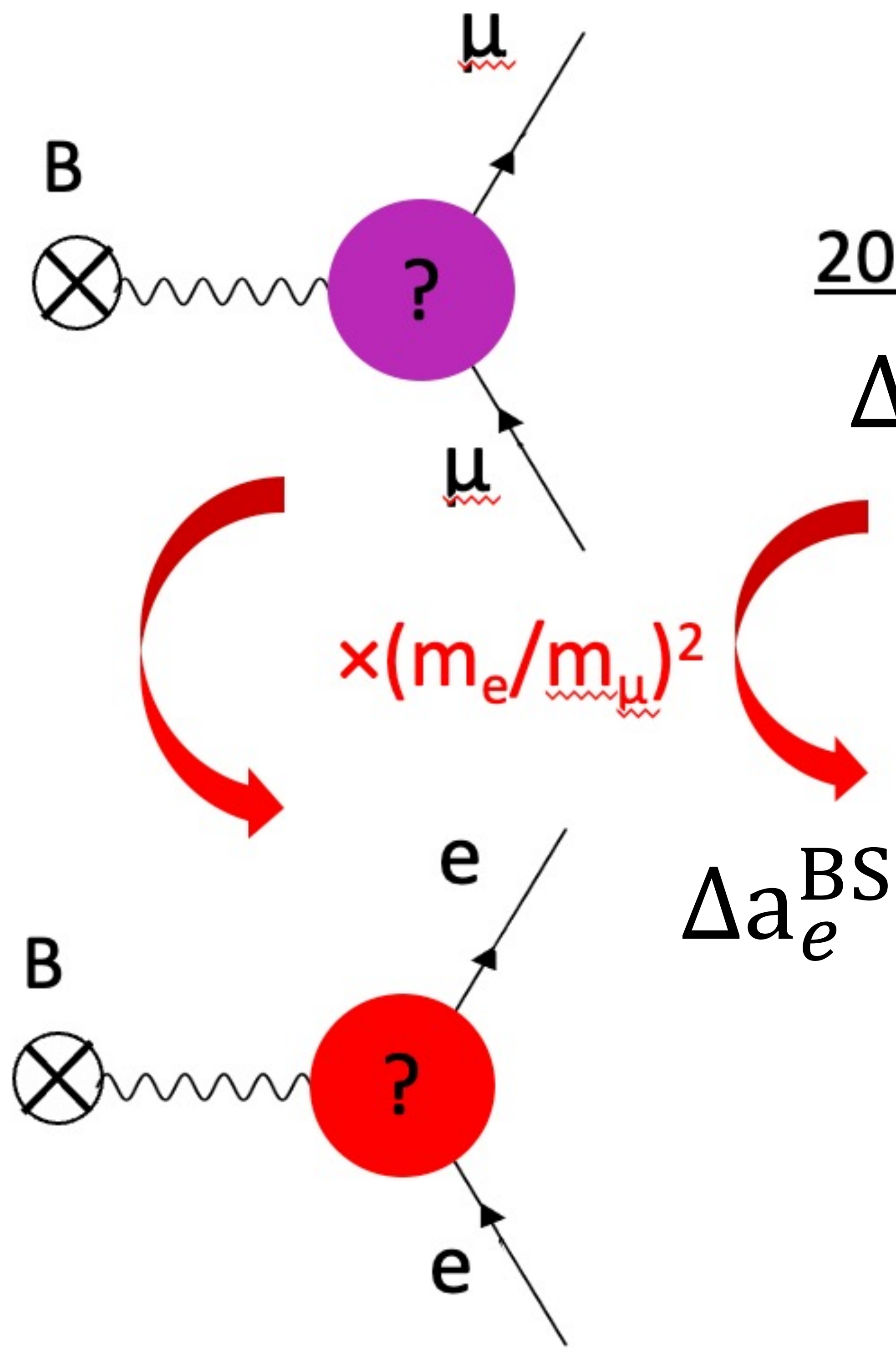
SM calculation: 5th order QED, ~13,000 diagrams + QCD + W/Z bosons



$$\frac{g}{2} = 1 + \frac{1}{2}\times\left(\frac{\alpha}{\pi}\right) + -0.328\ldots\times\left(\frac{\alpha}{\pi}\right)^2 + \cdots$$

fine structure constant: independently measured using Rb or Cs atom

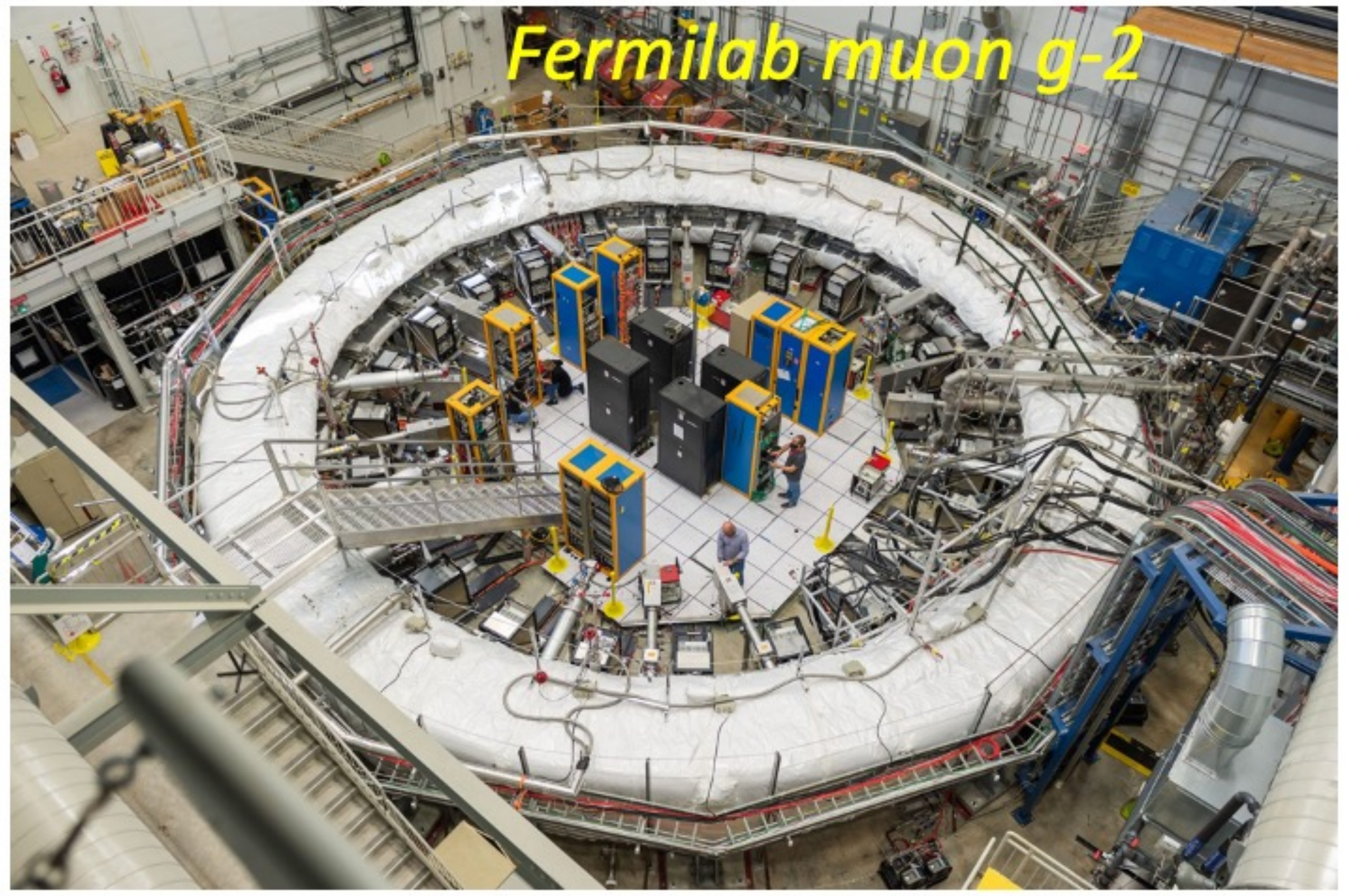
BSM contribution to Electron?



2023 experiment and 2020 Muon g-2 theory

$$\Delta a_\mu^{\mathrm{BSM}} = a_\mu^{\mathrm{exp}} - a_\mu^{\mathrm{theo}} = 2.49(48)\times 10^{-9}$$

$$\Delta a_e^{\mathrm{BSM}} \sim \Delta a_\mu^{\mathrm{BSM}} \times \left(m_e/m_\mu\right)^2 \sim 5.83(11)\times 10^{-14}$$



Phys. Rev. Lett. **131**, 161802 (2023)
Physics reports **887**, 1 (2020)

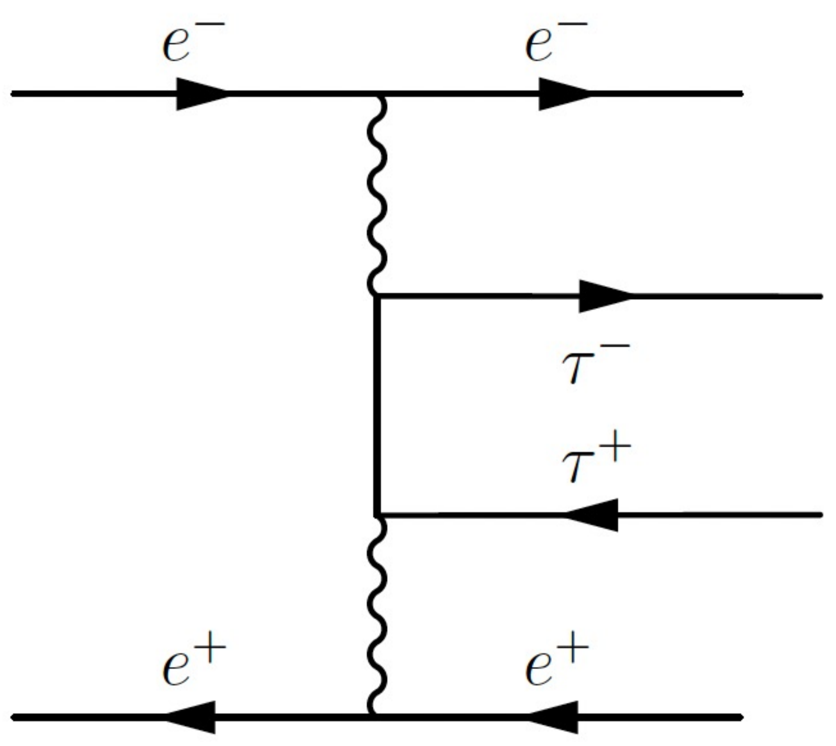
Only a factor of 2 away from the
2023 electron g-2 measurement uncertainty (13×10^{-14})
& a consistent α determination

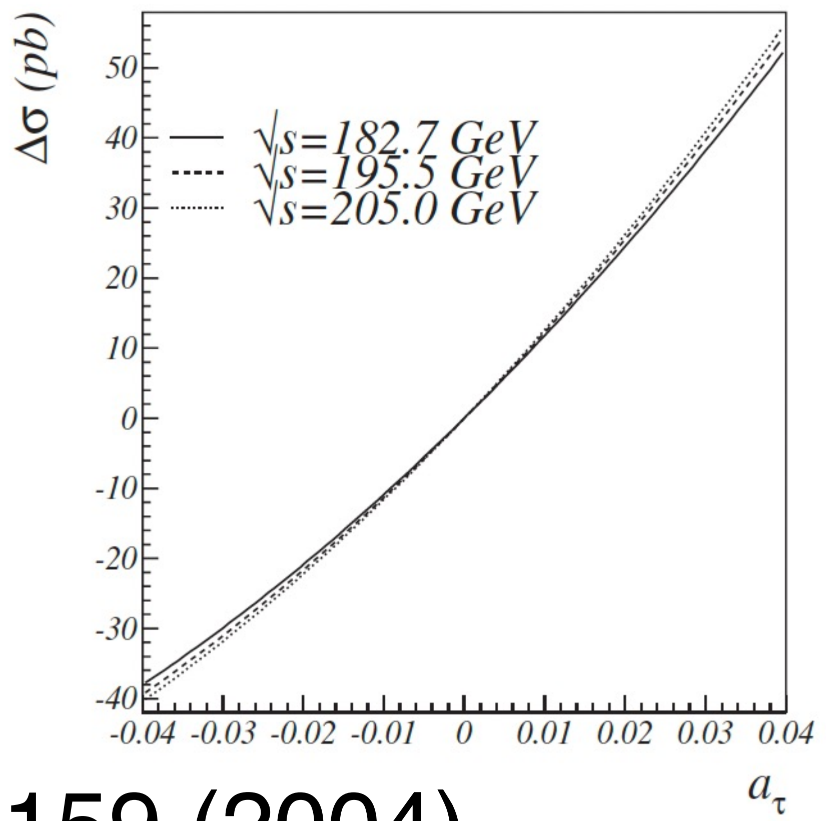
Courtesy Xing Fan

Tau g-2 in colliders

Short lifetime: not possible through spin precession approach

e^+e^- collider: DELPHI

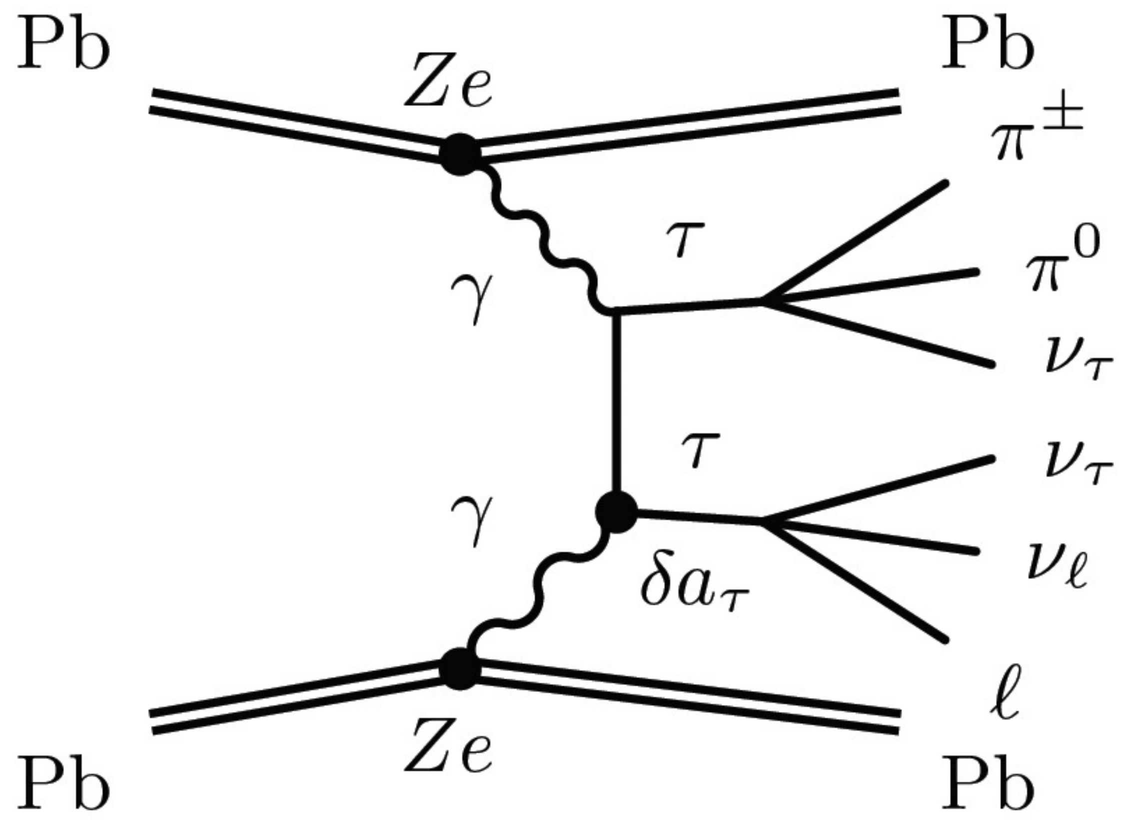




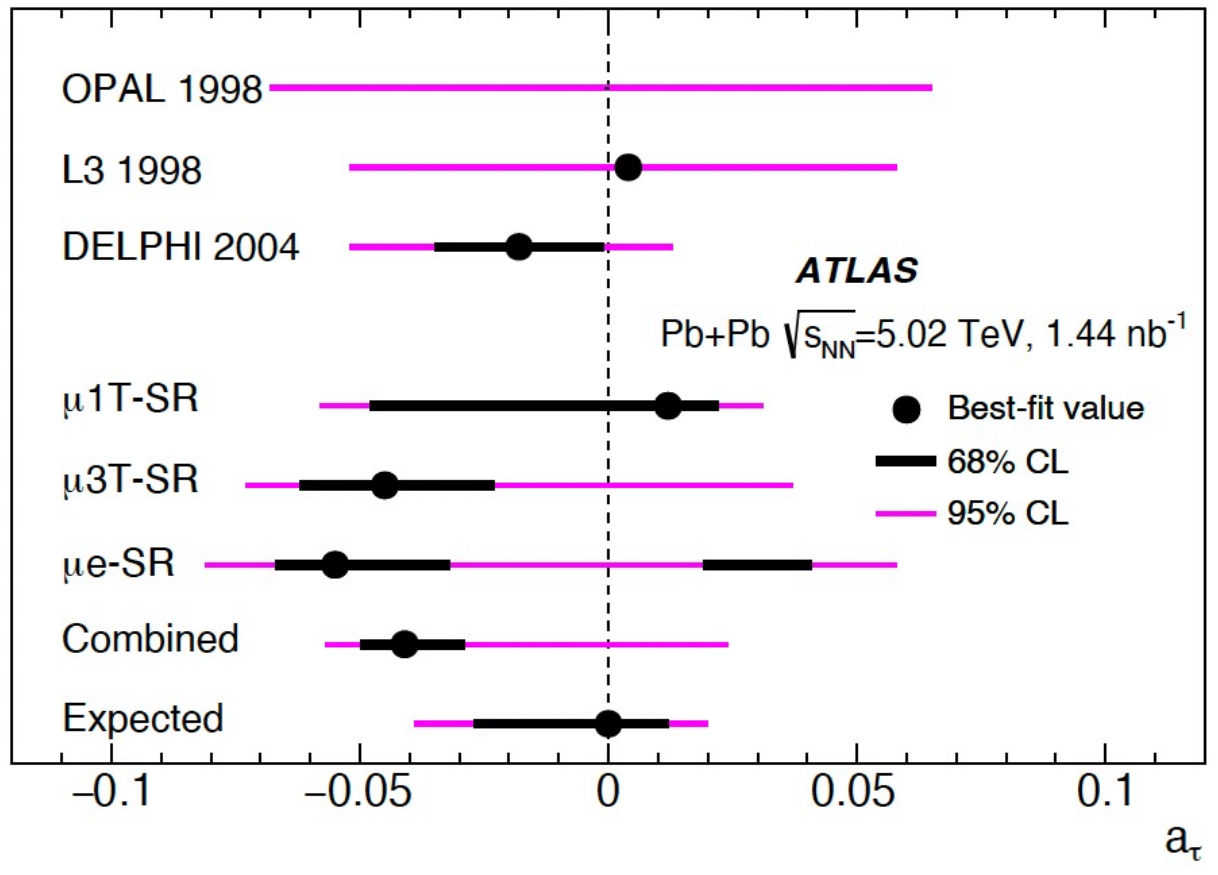
EPJC 35, 159 (2004)

$$-0.052 < a_\tau < 0.013 \ (95\% \ \mathrm{C.L.}).$$

PbPb collider: ATLAS



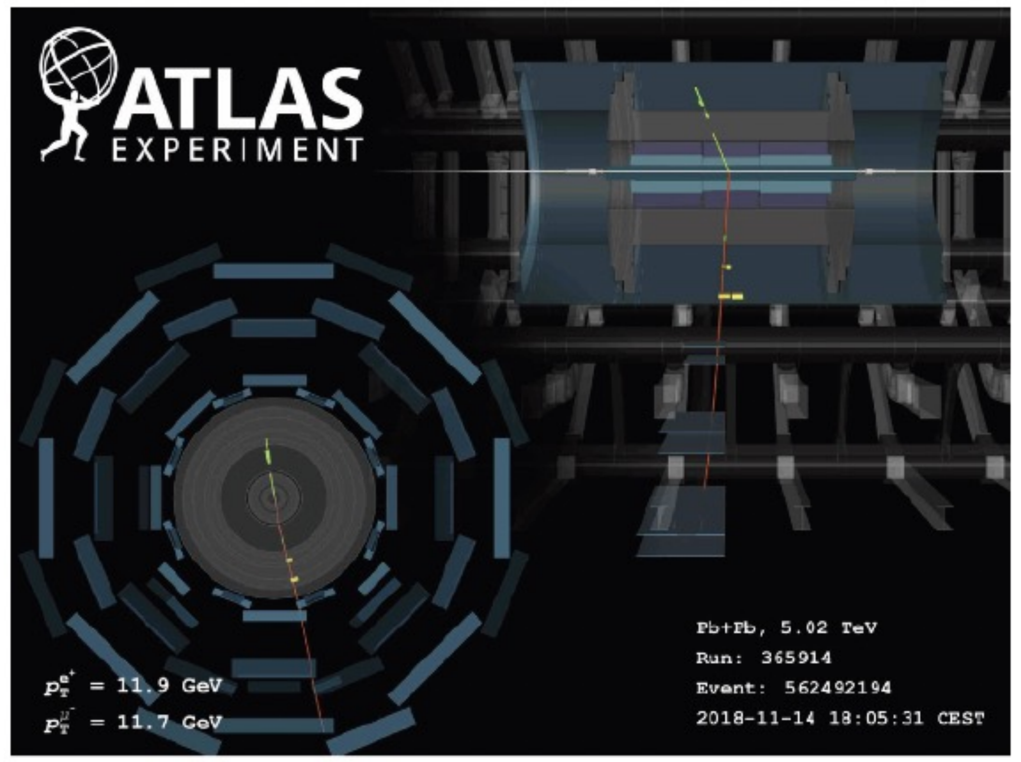
PRL 131, 151802 (2023)



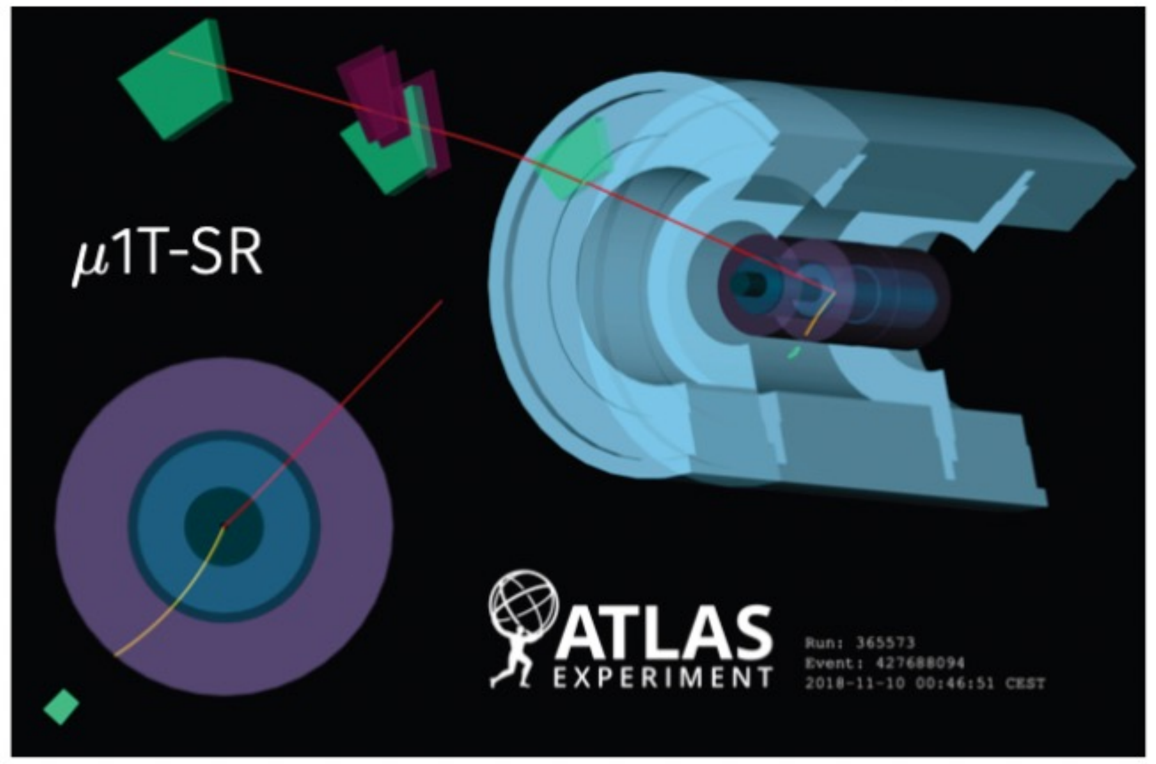
$a_\tau \in (-0.057, 0.024)$

Expecting substantial improvements from Run 3 & 4 data!

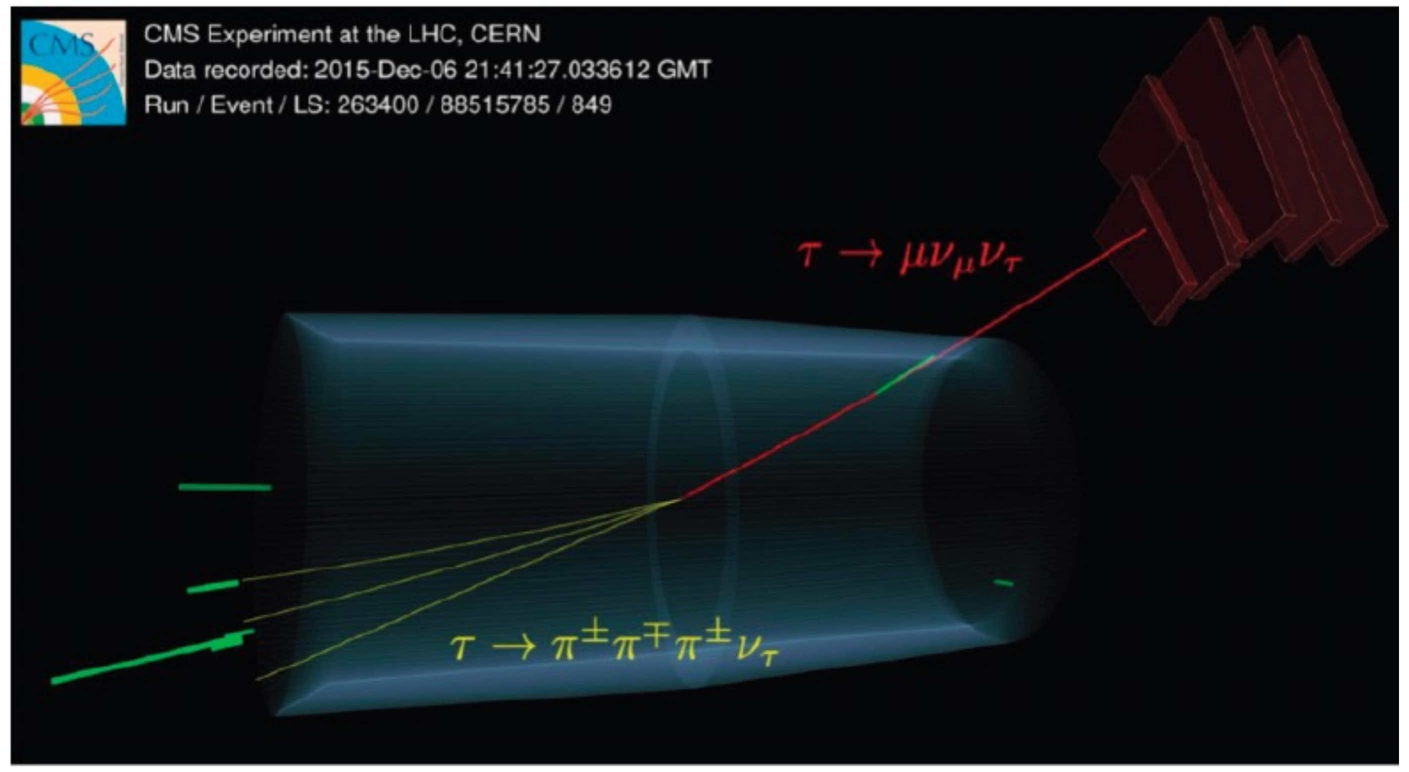
μe



μ+1 track



μ+3 track



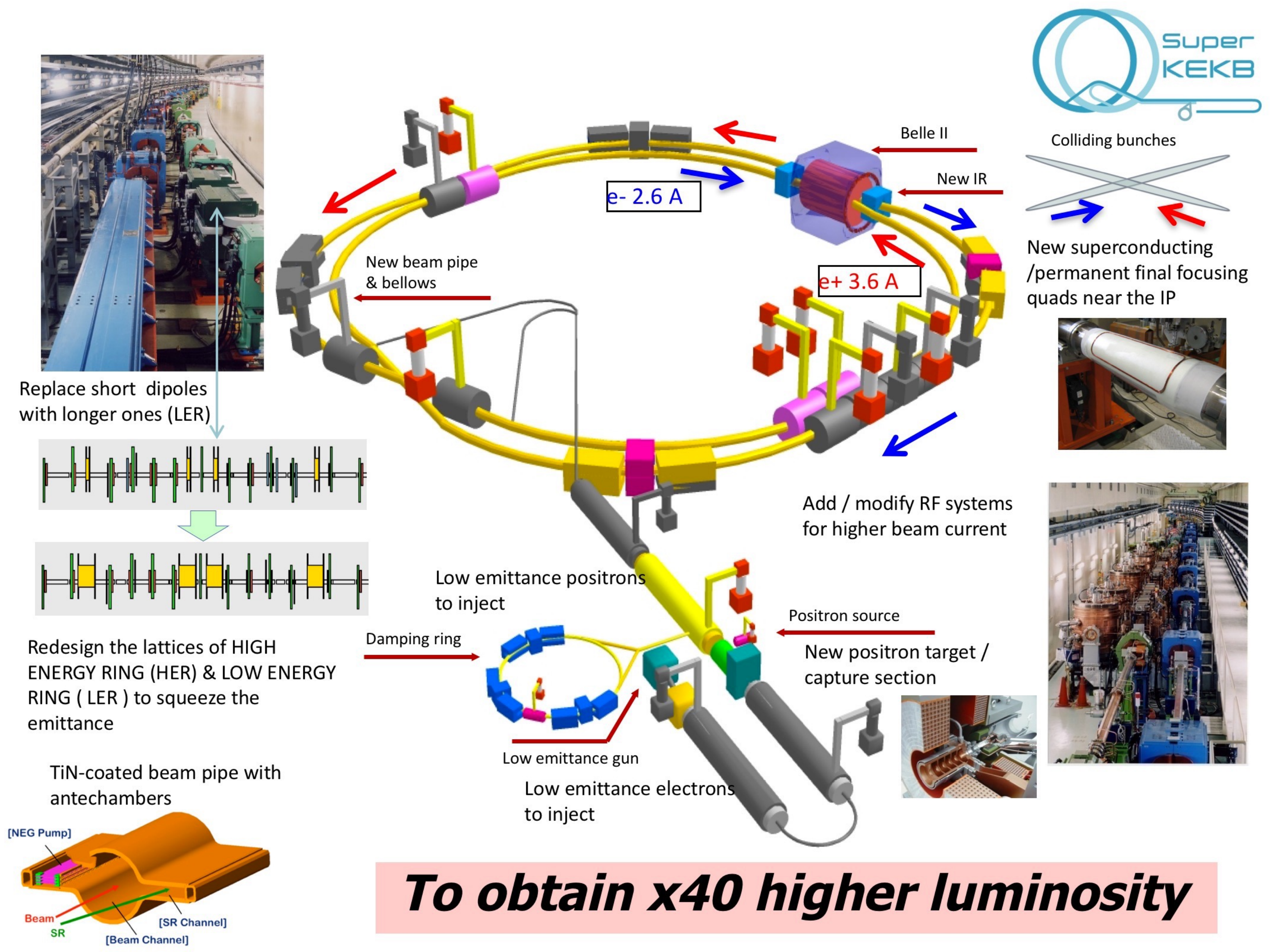
Slides from
Peter Steinberg
@ QM 2023

BSM contribution to Tau?

$$a_\tau^{\mathrm{BSM}} \sim a_\mu^{\mathrm{BSM}} \left(\frac{m_\tau}{m_\mu}\right)^2 \sim 10^{-6}$$

Various methods to measure at have been proposed:
- radiative tau decays
- channeling in a bent crystal
- γp and heavy-ion reactions at the LHC

but these do not reach that level of precision



Control Systematic Uncertainties using e⁻ Beam polarization asymmetries

$$\mathrm{Re}(F_2^{\mathrm{eff}}) = \mp \frac{8(3-\beta^2)}{3\pi\gamma\beta^2\alpha_\pm}\left(A_T^\pm - \frac{\pi}{2\gamma}A_L^\pm\right)$$

With 40 ab^{-1} of polarized beam data, and 60% efficiency for selecting semileptonic tau decays, the statistical uncertainty would be ~1 x 10^{-5}

1000 x more precise than current limits

So to get to 1 x 10^{-6} would require more statistics as well as higher precisions on M(Υ(1S)) and m_τ

We would also run on the Υ(4S), so we will need two-loop calculations of Re F^{eff}_2 (100GeV²)

Towards Testing the Magnetic Moment of the tau at 1 ppm 23

Slides from J. Michael Roney @ SPIN 2023

Summary

李政道研究所
TSUNG-DAO LEE INSTITUTE

- High sensitivity EDM searches and high precision MDM measurements are powerful tools to search for BSM physics
  - Complementary to Energy Frontiers
  - Very high mass scale beyond LHC reach can be explored (under some assumptions)
- EDMs are connected to CPV sources beyond SM
  - Measurements on various species are needed to discriminate between BSM theories
- MDMs provide stringent tests of SM calculations and the CPT symmetry
  - Ongoing puzzles in the muon and electron sector provide a window into deeper understanding of SM and BSM

Many more experiments will go online starting from next year!
The moment has arrived for the dipole moments!