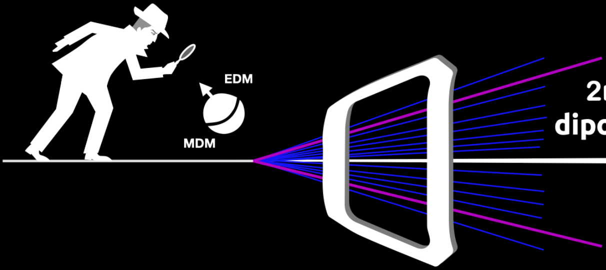


2nd Workshop on electromagnetic dipole moments of unstable particles

25-28 September 2022
Gargnano del Garda, Italy

Muon and tau $g-2$ and EDM results and perspectives

Alberto Lusiani
Scuola Normale Superiore and INFN, sezione di Pisa

Introduction

- magnetic and electric dipole moment of fundamental particles (MDM and EDM) are perhaps the simplest and most fundamental predictions of the Standard Model
- SM leading order prediction for mu and tau MDM is $\mu_\ell^{\text{LO}} == g_\ell^{\text{LO}} \frac{e}{2m_\ell} \frac{\hbar}{2}$, with $g_\ell^{\text{LO}} = 2$
  - MDM is often indicated with $g-2$ or $a = \frac{g-2}{2}$ (magnetic anomaly)
- EDM cal also be described with a-dimentional parameter like a_ℓ:

$$H_M = -\vec{\mu}_x \vec{B} = -g_x \left(\frac{q_x \hbar}{2m_x c}\right) \left(\frac{\vec{S}}{\hbar}\right) \vec{B}, \qquad H_E = -\vec{d}_x \vec{E} = -f_x \left(\frac{q_x \hbar}{2m_x c}\right) \left(\frac{\vec{S}}{\hbar}\right) \vec{E}$$

- in the following $a_x \leftrightarrow \text{MDM}(\text{particle } x)$ $d_x,\ f_x \leftrightarrow \text{EDM}(\text{particle } x)$

SM predictions

- MDM SM predictions are precise: a_μ predicted to 0.37 ppm, a_τ predicted to 42 ppm
- EDM SM predictions are small: $f_\mu \sim 4.4 \cdot 10^{-29}$ $f_\tau \sim 1.3 \cdot 10^{-26}$

Status of SM predictions and experimental measurements

μ	a_μ	d_μ [e cm]
experiment	$116\,592\,061(41)\cdot10^{-11}$ [0.35 ppm] [1]	$0.0(9)\cdot10^{-19}$ [2]
theory prediction	$116\,591\,810(43)\cdot10^{-11}$ [0.37 ppm] [3]	$\sim2.0\cdot10^{-42}$ [4]

τ	a_τ	d_τ [e cm]
experiment	$-0.018(17)$ [5a], $-0.0015(35)$ [5b]	$[-0.62(63) + -0.40(32)i]\cdot10^{-17}$ [6]
theory prediction	$117721(5)\cdot10^{-8}$ [42 ppm] [7]	$\sim3.5\cdot10^{-41}$ [8]

[1] BNL 2006 + FNAL 2021

[2] BNL 2006

[3] Muon $g-2$ theory initiative, Dec 2020

[4] M.Pospelov & A.Ritz, PRD 89 (2014) 056006

[5a] Delphi 2004 $\sigma(e^+e^- \to e^+e^-\tau^+\tau^-)$ $(\gamma\gamma)$

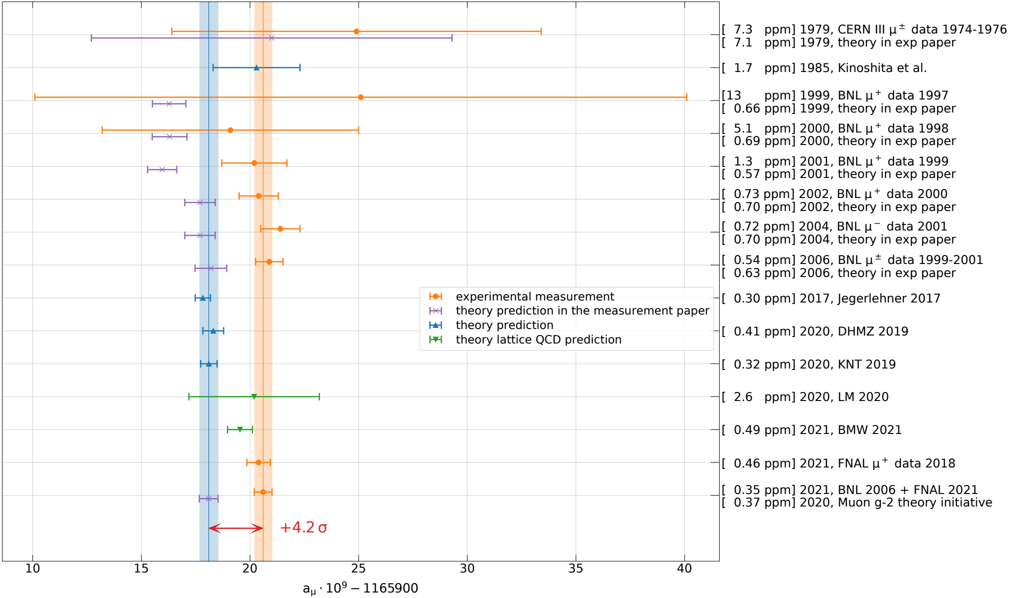
[5b] review, Nucl.Phys.B 582 (2000) 3

[6] Belle 2002 tau EDM search
[d_τ complex form factor measured on $e^+e^- \to \tau^+\tau^-$, hence at $q^2 \sim m_\tau^2$]

[7] Mod.Phys.Lett.A 22 (2007)159

[8] M.Pospelov & A.Ritz, PRD 89 (2014) 056006

a_μ measurements and SM predictions



a_μ measurement: muon momentum and spin in in uniform magnetic field

muon spin precession relative to momentum observed in lab frame

$$\omega_s \quad - \quad \omega_c \quad = \quad \omega_a$$

$$\boxed{-g_\mu \frac{eB}{2m_\mu} - (1-\gamma)\frac{eB}{m_\mu \gamma}} - \boxed{-\frac{eB}{m_\mu \gamma}} = \boxed{-a_\mu \frac{eB}{m_\mu}}$$

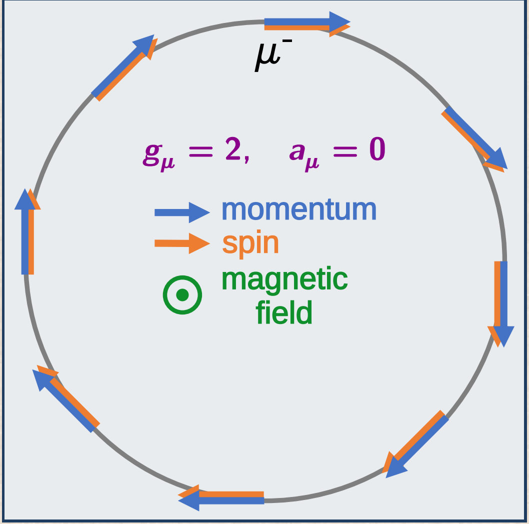
Larmor + Thomas precessions

cyclotron frequency

no γ!

- frequency measurements best for precision
- magnetic field NMR measurement also frequency
- angle between momentum and spin $\theta(t) = \omega_a t$

polarized muons in magnetic storage ring



a_μ measurement: muon momentum and spin in in uniform magnetic field

muon spin precession relative to momentum observed in lab frame

$$\underset{\text{Larmor + Thomas precessions}}{\overset{\omega_s}{\boxed{-g_\mu \frac{eB}{2m_\mu} - (1-\gamma)\frac{eB}{m_\mu\gamma}}}} - \underset{\text{cyclotron frequency}}{\overset{\omega_c}{\boxed{-\frac{eB}{m_\mu\gamma}}}} = \underset{\text{no }\gamma!}{\overset{\omega_a}{\boxed{-a_\mu \frac{eB}{m_\mu}}}}$$

- frequency measurements best for precision
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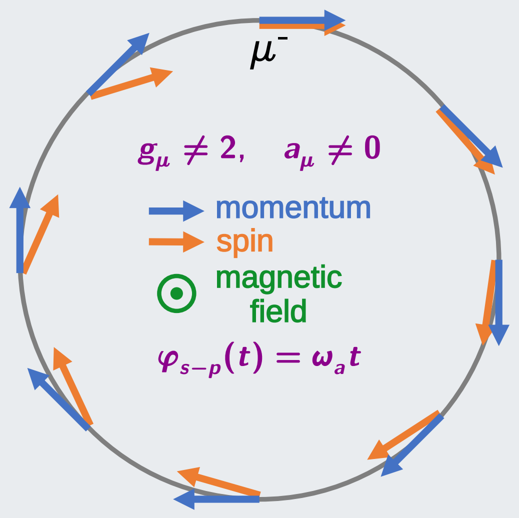
- angle between momentum and spin $\theta(t) = \omega_a t$

polarized muons in magnetic storage ring



a_μ measurement: focusing electric field and magic energy

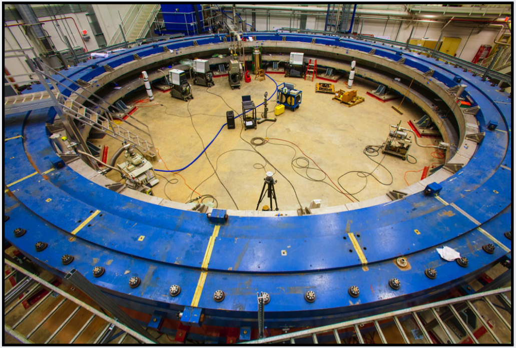
in presence of (focusing) electric field and motion not perfectly transverse to magnetic field

$$\vec{\omega}_a = -\frac{e}{m_\mu}\left[a_\mu \vec{B} - \left(a_\mu - \frac{1}{\gamma^2 - 1}\right)(\vec{\beta} \times \vec{E}) - a_\mu \frac{\gamma}{\gamma + 1}\left(\vec{\beta} \cdot \vec{B}\right)\vec{\beta}\right]$$

CERN 1975-, BNL, FNAL

$$p_\mu^{\text{magic}} = 3.094\,\text{GeV} \quad \Rightarrow \quad \gamma = 29.3$$

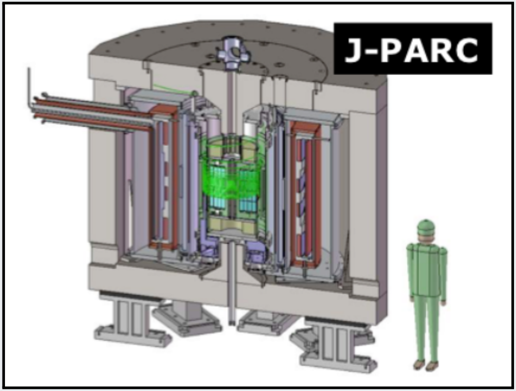
$$\Rightarrow \quad \left(a_\mu - \frac{1}{\gamma^2 - 1}\right) \simeq 0$$



J-PARC E34

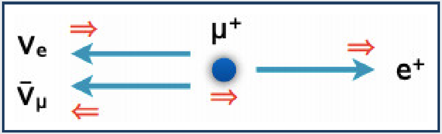
ultra-cold muons

$$E = 0 \quad \Rightarrow \quad \vec{\beta} \times \vec{E} = 0$$

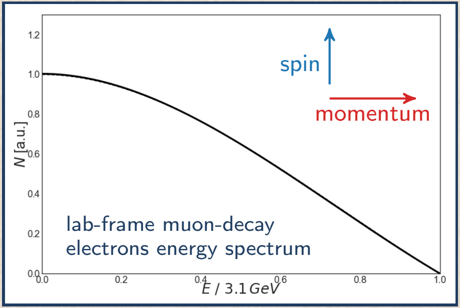


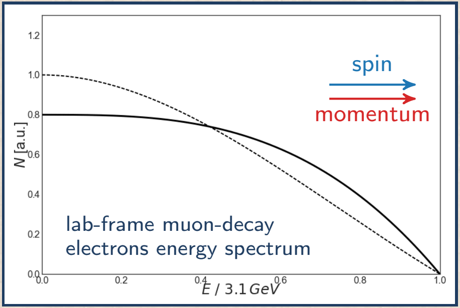
a_μ measurement: rate of high-energy muon-decay electrons $\propto \cos\omega_a t$

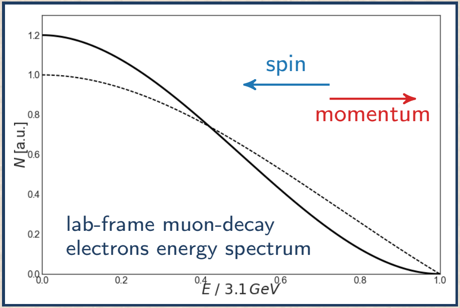
- because of parity violation in muon decay, decay electrons peak along muon spin



- electrons decaying along muon momentum have highest energy in laboratory frame
- $\boxed{N_e(E_e > E_t) = N_{e0}\, e^{-t/\tau_\mu}(1 + A\cos\omega_a t)}$

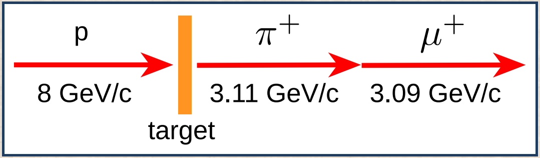


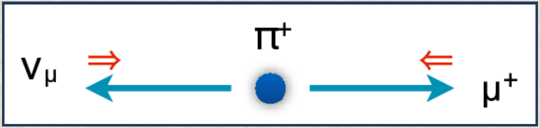




a_μ measurement: production of polarized muons

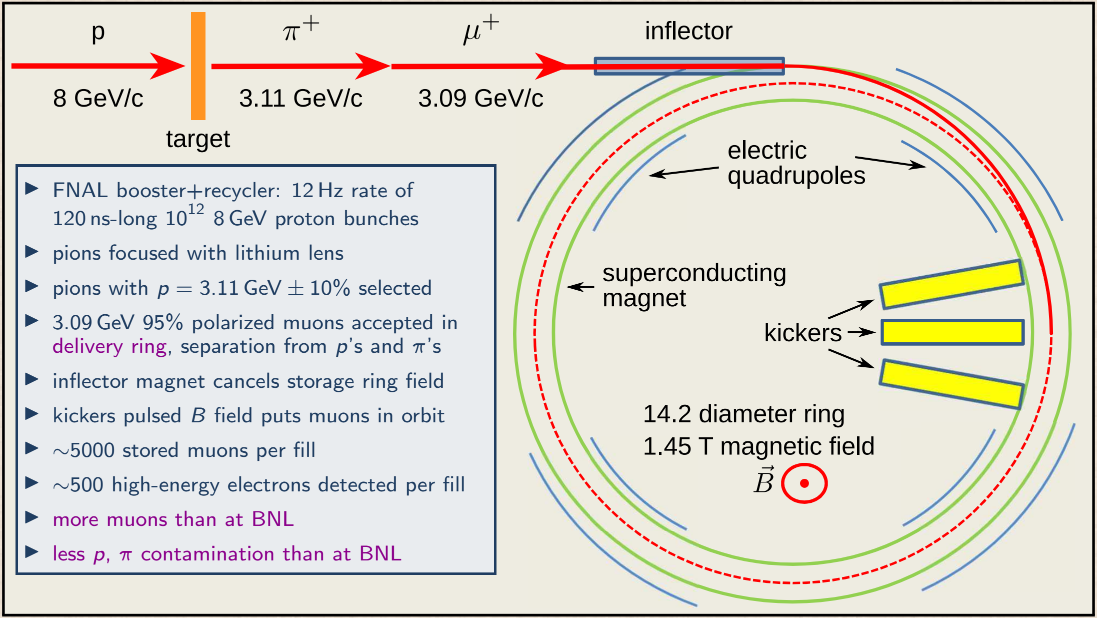
- dump 8 GeV protons on target to produce pions
- select pions with momemtum $p \simeq 3.11$ GeV
- let them decay into muons
- in pion rest frame, because of parity violation in pion decay, μ^- spin is aligned with momentum (μ^+ spin is anti-aligned with momentum)
- in laboratory frame, highest energy muons are >90% polarized





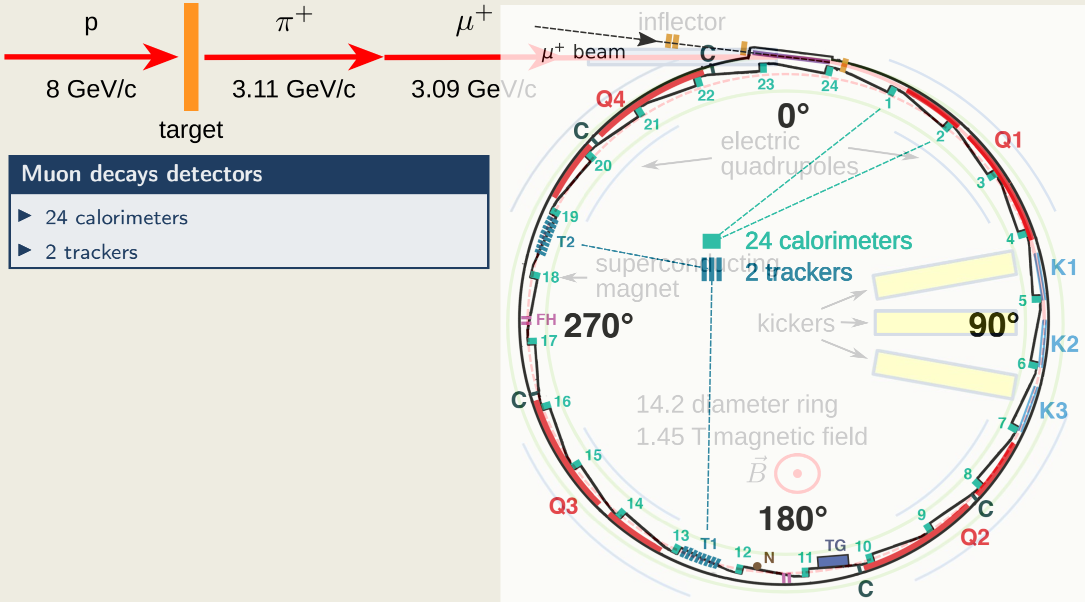
- with 8 GeV protons on target, μ^+ are produced ~4× more frequently than μ^-

a_μ measurement: muon production, storage and decay at FNAL



- FNAL booster+recycler: 12 Hz rate of 120 ns-long 10^{12} 8 GeV proton bunches
- pions focused with lithium lens
- pions with $p = 3.11$ GeV $\pm$ 10% selected
- 3.09 GeV 95% polarized muons accepted in delivery ring, separation from p's and π's
- inflector magnet cancels storage ring field
- kickers pulsed B field puts muons in orbit
- $\sim$5000 stored muons per fill
- $\sim$500 high-energy electrons detected per fill
- more muons than at BNL
- less p, π contamination than at BNL

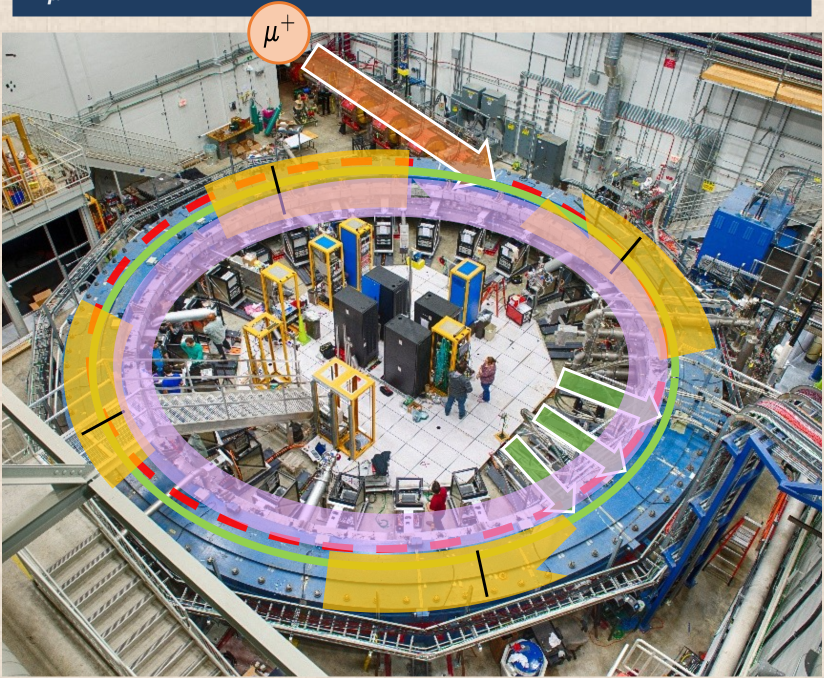
a_μ measurement: muon production, storage, decay and detection at FNAL



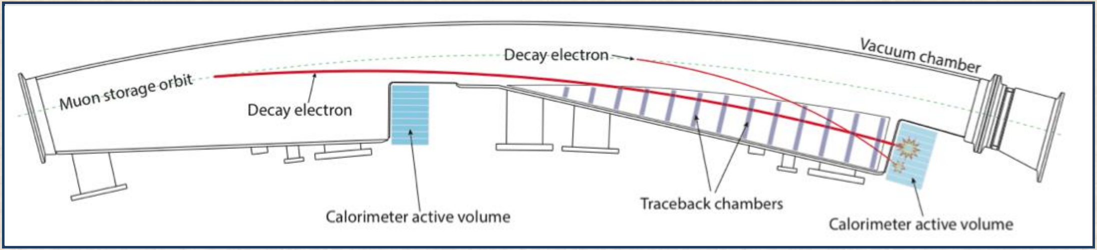
Muon decays detectors

- 24 calorimeters
- 2 trackers

a_μ measurement: FNAL-E989 storage ring and detectors



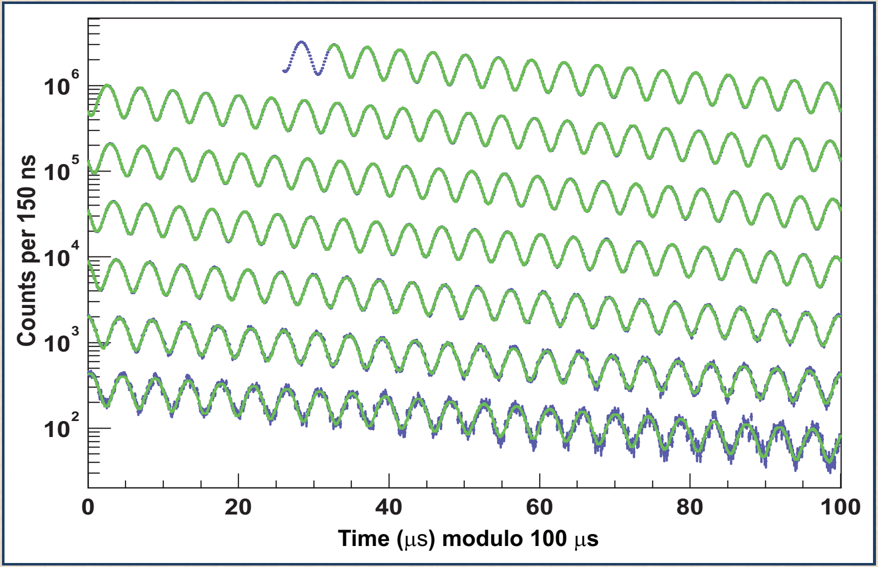
Muon decays detectors



- 24 calorimeter modules of 6×9 PbF_2 crystals with 800 MHz-sampling SiPM readout
  - measure muon-decay electrons energy detecting Cherenkov light
  - accurate gain monitoring with laser calibration system
- 2 straw chamber trackers with total of about 1000 channels
  - reconstruct beam distribution inside storage ring from muon decay electrons

a_μ measurement: fill wiggle plot, whose fit returns ω_a

- fill wiggle plot counting decay positrons exceeding threshold energy in time bins



a_μ measurement: obtain $a_\mu = f(\omega_a/\omega_p)$

measurement of magnetic field: ω_p

- proton spin precession frequency measures magnetic field (NMR): $\hbar\omega_p = 2\mu_p B$

measurements

- $\omega_a = a_\mu \dfrac{eB}{m_\mu}, \quad \hbar\omega_p = 2\mu_p B$

spin 1/2 particle x = proton, muon

- $S_x = \dfrac{\hbar}{2}, \quad \mu_x = g_x \dfrac{e}{m_x} S, \quad a_x = \dfrac{g_x - 2}{2}$

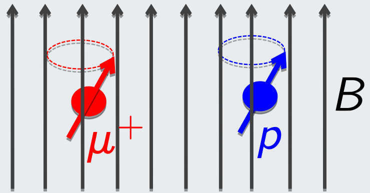
$$a_\mu = \frac{\omega_a/\omega_p}{\mu_\mu/\mu_p - \omega_a/\omega_p}$$

muonium & hydrogen hyperfine transitions

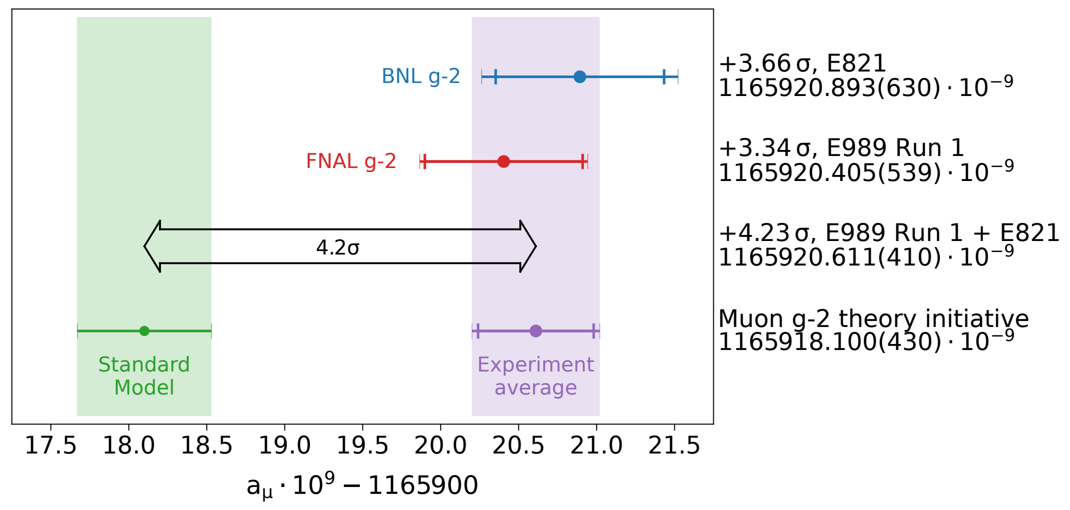
mainly LAMPF 1999 experiment
precision on CODATA 2018 fit: 22 ppb

actually, best a_μ obtained by adding ω_a/ω_p measurement to Fundamental Physical Constants CODATA fit

ω_a & ω_p in same magnetic field



a_μ measurement: FNAL April 2021 result



- a_μ(BNL) recomputed from R_μ(BNL) like a_μ(FNAL)
- included correlation due to external measurements, assumed no other correlation between BNL and FNAL

a_μ measurement: FNAL April 2021 result biases and systematics

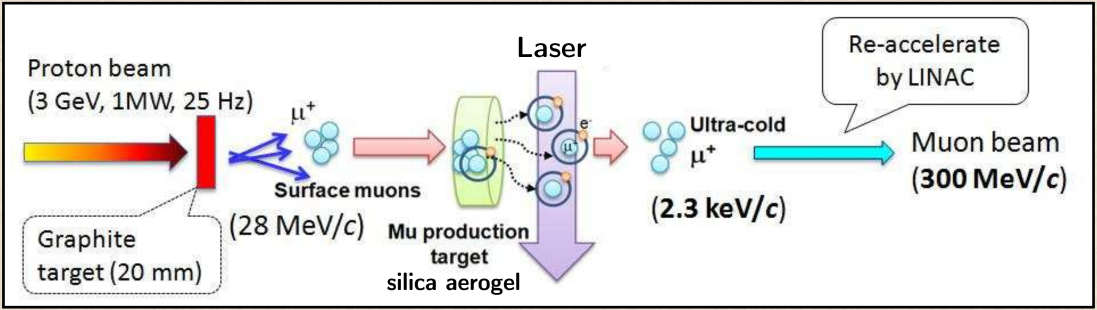
	Correction	Uncertainty	Design goal
ω_a^m (statistical)	–	434	100
ω_a^m (systematic)	–	56	
base clock	–	2	
C_e	489	53	
C_p	180	13	
C_{ml}	-11	5	
C_{pa}	-158	75	
ω_a beam dynamics corrections $(C_e + C_p + C_{ml} + C_{pa})$	499	93	
ω_a total systematic	499	109	70
$\omega'_p(T)(x, y, \varphi)$	–	54	
$M(x, y, \varphi)$	–	17	
$\langle\omega'_p(T)(x, y, \varphi) \times M(x, y, \varphi)\rangle$	–	56	
B_q	-17	92	
B_k	-27	37	
$\tilde{\omega}'_p(T)$ transient fields corrections $(B_q + B_k)$	-44	99	
$\tilde{\omega}'_p(T)$ total [note: correction sign now for $\omega_a/\tilde{\omega}'_p(T)$]	44	114	70
$\omega_a/\tilde{\omega}'_p(T)$ total systematic	544	157	100
external measurements	–	25	
total [correction is for $\omega_a/\tilde{\omega}'_p(T)$]	544	462	140

a_μ measurement: experimental precision at BNL and FNAL projects

FNAL-E989 design precision, compared to BNL-E821 final report (2006)

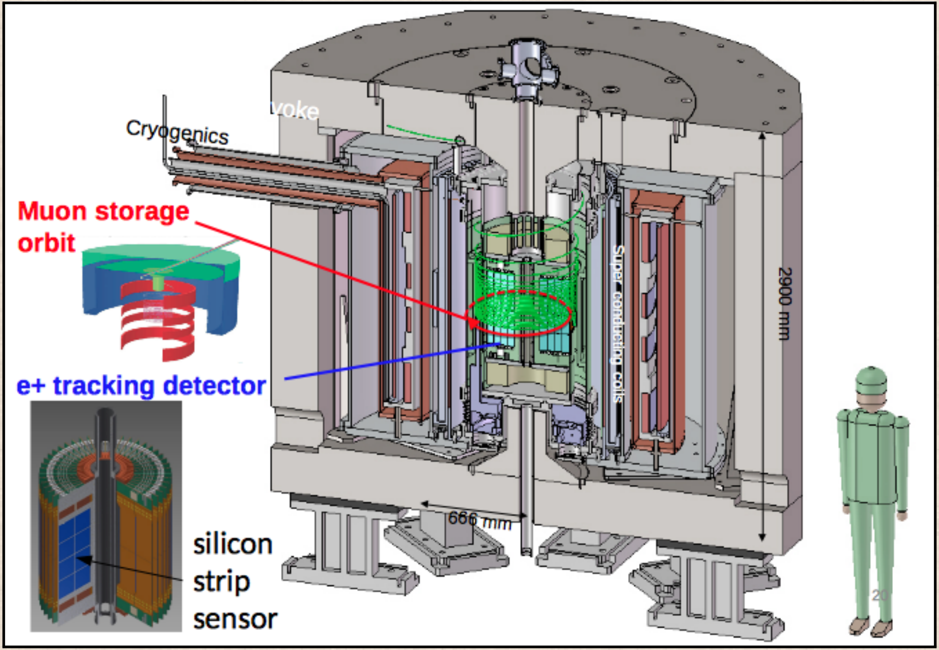
	BNL E821	FNAL E989	
ω_a statistical	460 ppb	100 ppb	×21 detected muon decays ($1.6 \cdot 10^{11}$)
ω_a systematic	210 ppb	70 ppb	faster calorimeter with laser calibration, tracker
ω_p systematic	170 ppb	70 ppb	more uniform B, improve NMR measurement
external measurements	negligible		
total	540 ppb	140 ppb	

a_μ measurement: J-PARC E34 experiment, muon production and storage



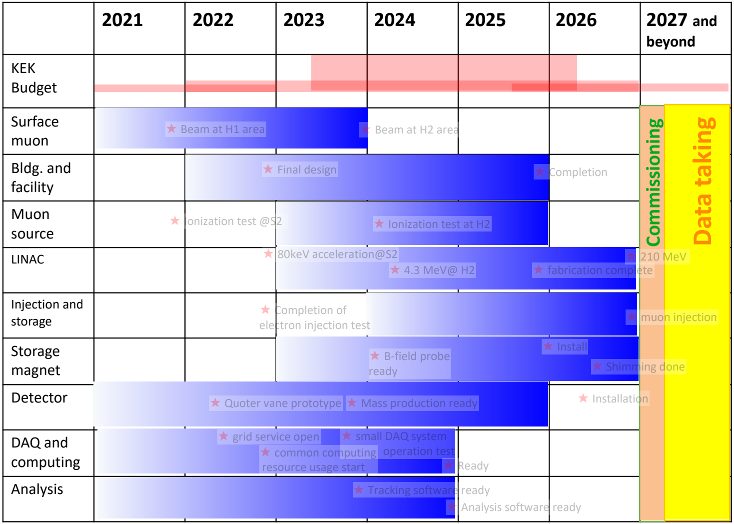
- pions from proton-target collisions stop in target and decay to muons
- surface muons stop in silica aerogel target and form muonium ($e^-\mu^+$)
- 300 K° muons have 2.3 keV average momentum (ultra-cold)
- resonant laser ionization splits muonium, producing 50% polarized muons
- muons are accelerated to $p_L = 300\,\text{MeV}$, while $p_T \sim 2.3\,\text{keV}$ $\Rightarrow$ $p_T/p_L \simeq 4{\cdot}10^{-4}$
  - thermalized muons beam emittance 1π mm·mrad, vs. typical 1000π mm·mrad
- muons stored in 33 cm-radius MRI 3 T magnet
- very weak magnetic focusing, no electric field

a_μ measurement: J-PARC E34 experiment, storage ring and detector



a_μ measurement: J-PARC E34 experiment, expected precision and schedule

schedule, T.Mibe, 2022



expected precision

450 ppb stat.

$<$ 70 ppb syst.

a_μ measurement: other proposals

HIAF, Huizhou, China

- Heavy Ion Accelerator Facility, $\sim 30\times$ higher muon intensity than Fermilab
- a_μ measurement "potentially improved to the precision of 70 ppb"
- doi:10.1360/SSPMA-2020-0287

muEDM collaboration at PSI

- PSI high-intensity muon beamline (HiMB), $10^{10}\,\mu^+$/s at 28 MeV/c
- expect precision of 100 ppb in one year of data-taking
- more details in the following of this presentation, on muon EDM measurements
- https://indico.psi.ch/event/10547/contributions/28105/

a_μ measurement: other proposals

Farley 2003

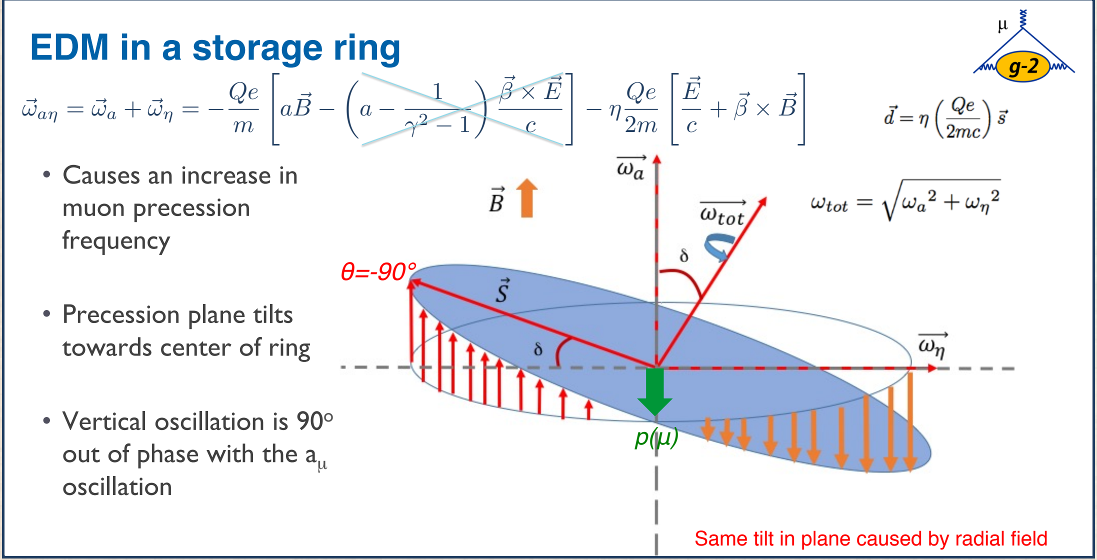
- 15 GeV muons
- non-continuous magnets with edge focusing
- magnetic field measured with polarized proton beam
- could potentially reach 30 ppb
- F.J.M.Farley, A new ring structure for muon $g-2$ measurements, NIM A 523 (2004) 251

Silenko 2010

- similar to [Farley 2003]
- CERN PS East Area
- A.J. Silenko, Potential for a new muon $g-2$ experiment, PLB 695 (2011) 55

Muon EDM measurement

from J.Price, 2020



EDM in a storage ring

$$\vec{\omega}_{a\eta} = \vec{\omega}_a + \vec{\omega}_\eta = -\frac{Qe}{m}\left[a\vec{B} - \cancel{\left(a - \frac{1}{\gamma^2-1}\right)\frac{\vec{\beta}\times\vec{E}}{c}}\right] - \eta\frac{Qe}{2m}\left[\frac{\vec{E}}{c} + \vec{\beta}\times\vec{B}\right]$$

$$\vec{d} = \eta\left(\frac{Qe}{2mc}\right)\vec{s}$$

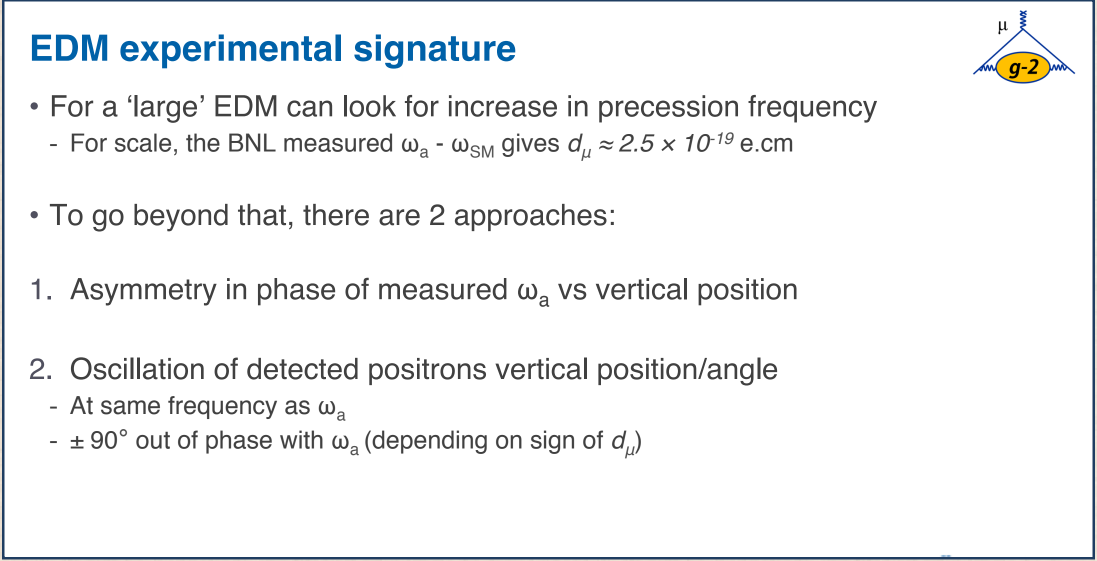
- Causes an increase in muon precession frequency
- Precession plane tilts towards center of ring
- Vertical oscillation is 90° out of phase with the a_μ oscillation

$$\omega_{tot} = \sqrt{{\omega_a}^2 + {\omega_\eta}^2}$$

Same tilt in plane caused by radial field

Muon EDM measurement

from J.Price, 2020



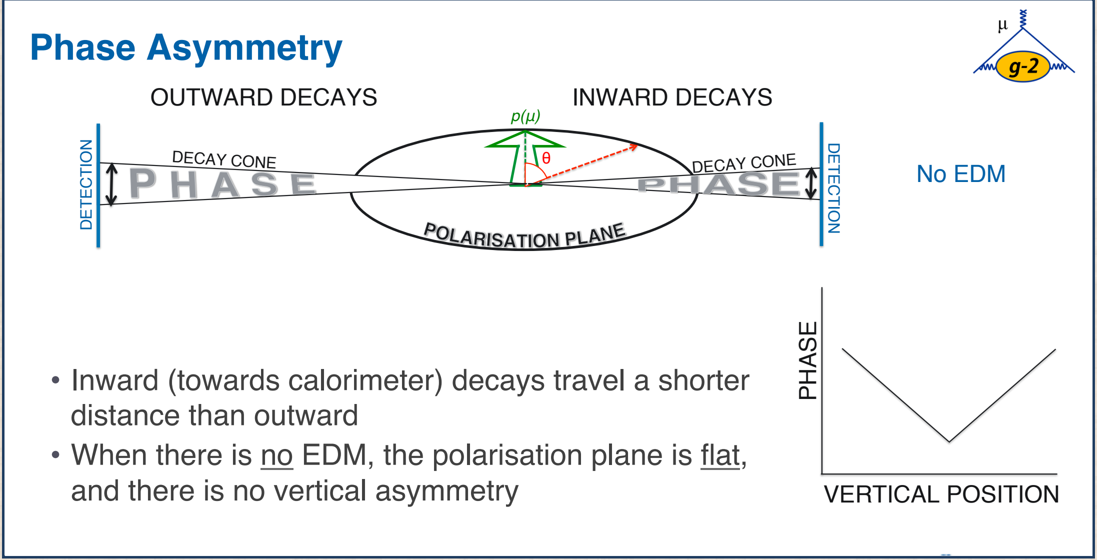
EDM experimental signature

- For a ‘large’ EDM can look for increase in precession frequency
  - For scale, the BNL measured ω_a - ω_{SM} gives $d_\mu \approx 2.5 \times 10^{-19}$ e.cm
- To go beyond that, there are 2 approaches:

1. Asymmetry in phase of measured ω_a vs vertical position
2. Oscillation of detected positrons vertical position/angle
   - At same frequency as ω_a
   - ± 90° out of phase with ω_a (depending on sign of d_μ)

Muon EDM measurement

from J.Price, 2020

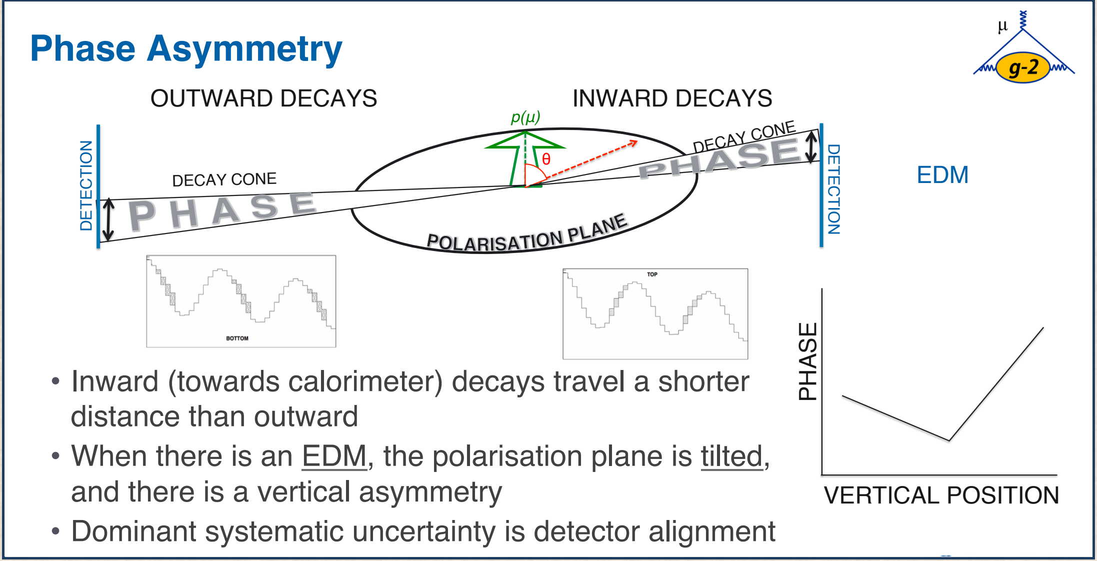


Phase Asymmetry

- Inward (towards calorimeter) decays travel a shorter distance than outward
- When there is no EDM, the polarisation plane is flat, and there is no vertical asymmetry

Muon EDM measurement

from J.Price, 2020

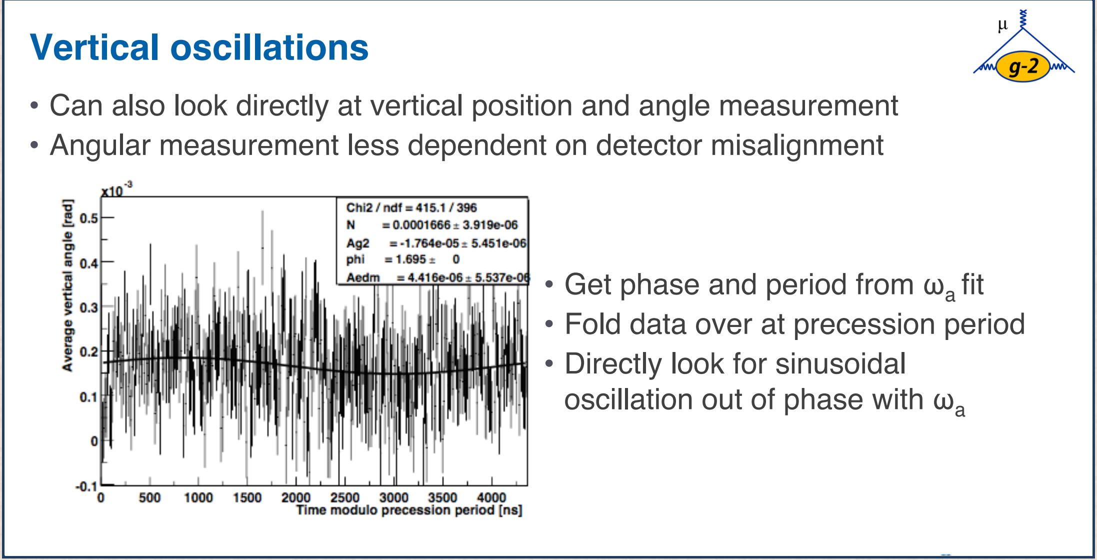


Phase Asymmetry

- Inward (towards calorimeter) decays travel a shorter distance than outward
- When there is an EDM, the polarisation plane is tilted, and there is a vertical asymmetry
- Dominant systematic uncertainty is detector alignment

Muon EDM measurement

from J.Price, 2020



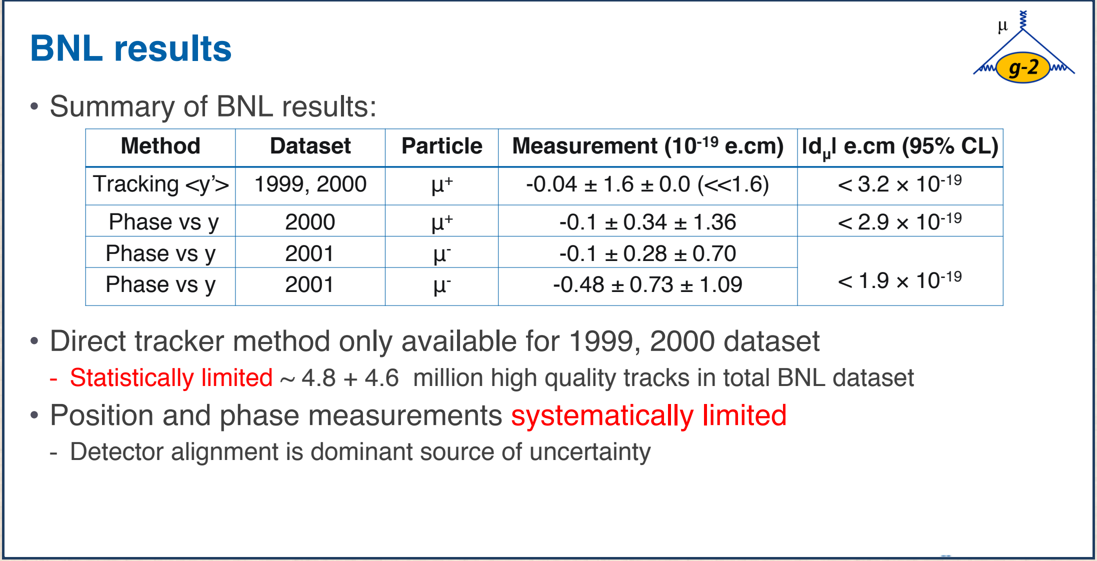
Vertical oscillations

- Can also look directly at vertical position and angle measurement
- Angular measurement less dependent on detector misalignment

- Get phase and period from ω_a fit
- Fold data over at precession period
- Directly look for sinusoidal oscillation out of phase with ω_a

Muon EDM measurement: BNL results

from J.Price, 2020



BNL results

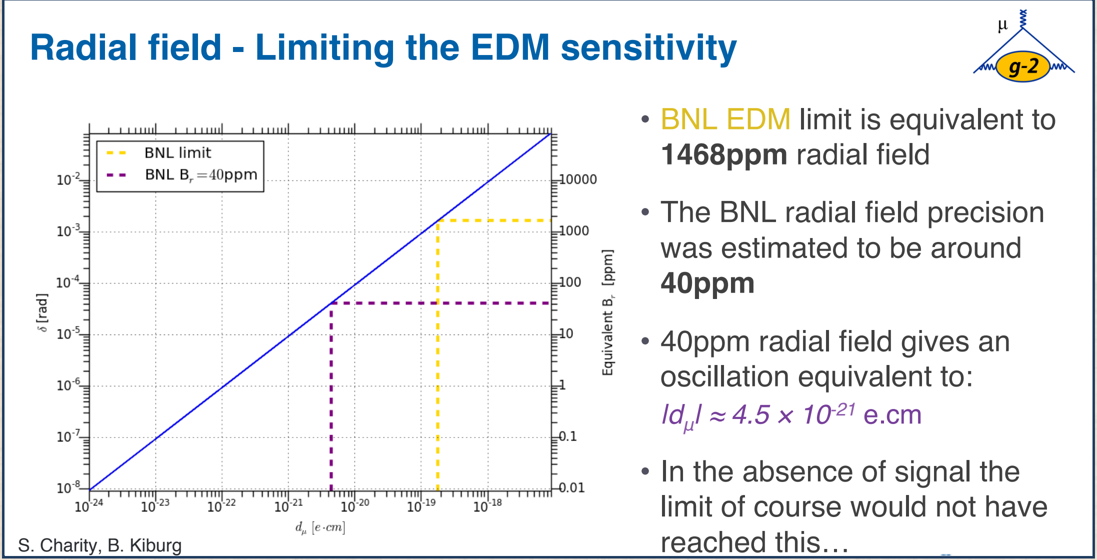
- Summary of BNL results:

Method	Dataset	Particle	Measurement (10^{-19} e.cm)	$\lvert d_\mu \rvert$ e.cm (95% CL)
Tracking <y'>	1999, 2000	μ^+	-0.04 ± 1.6 ± 0.0 (<<1.6)	$< 3.2 \times 10^{-19}$
Phase vs y	2000	μ^+	-0.1 ± 0.34 ± 1.36	$< 2.9 \times 10^{-19}$
Phase vs y	2001	μ^-	-0.1 ± 0.28 ± 0.70	$< 1.9 \times 10^{-19}$
Phase vs y	2001	μ^-	-0.48 ± 0.73 ± 1.09	

- Direct tracker method only available for 1999, 2000 dataset
  - Statistically limited ~ 4.8 + 4.6 million high quality tracks in total BNL dataset
- Position and phase measurements systematically limited
  - Detector alignment is dominant source of uncertainty

Muon EDM measurement: BNL systematic limit

from J.Price, 2020



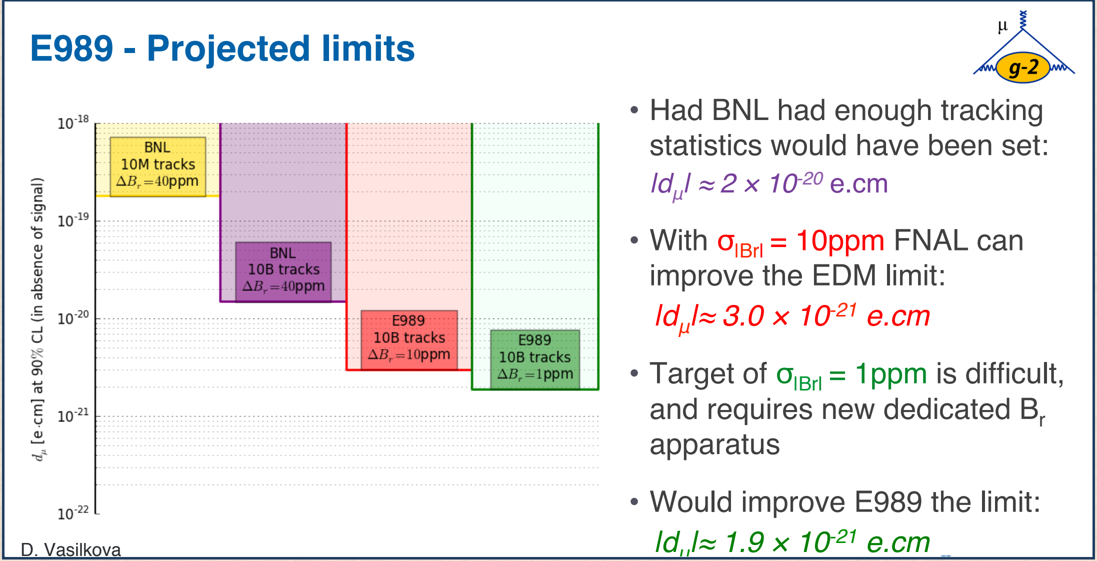
Radial field - Limiting the EDM sensitivity

- BNL EDM limit is equivalent to **1468ppm** radial field
- The BNL radial field precision was estimated to be around **40ppm**
- 40ppm radial field gives an oscillation equivalent to: $|d_\mu| \approx 4.5 \times 10^{-21}$ e.cm
- In the absence of signal the limit of course would not have reached this…

S. Charity, B. Kiburg

Muon EDM measurement: FNAL prospects

from J.Price, 2020

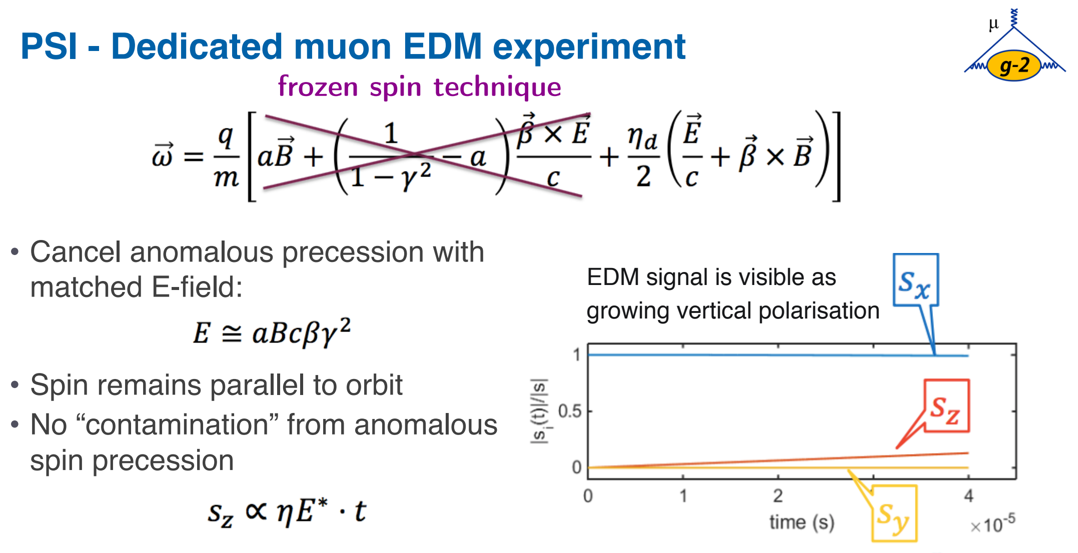


E989 - Projected limits

- Had BNL had enough tracking statistics would have been set: $|d_\mu| \approx 2 \times 10^{-20}$ e.cm
- With $\sigma_{|Br|} = 10$ppm FNAL can improve the EDM limit: $|d_\mu| \approx 3.0 \times 10^{-21}$ e.cm
- Target of $\sigma_{|Br|} = 1$ppm is difficult, and requires new dedicated B_r apparatus
- Would improve E989 the limit: $|d_\mu| \approx 1.9 \times 10^{-21}$ e.cm

Muon EDM measurement: PSI MuEDM

from J.Price, 2020



PSI - Dedicated muon EDM experiment

frozen spin technique

$$\vec{\omega} = \frac{q}{m}\left[\xcancel{a\vec{B} + \left(\frac{1}{1-\gamma^2} - a\right)\frac{\vec{\beta}\times\vec{E}}{c}} + \frac{\eta_d}{2}\left(\frac{\vec{E}}{c} + \vec{\beta}\times\vec{B}\right)\right]$$

- Cancel anomalous precession with matched E-field:

$$E \cong aBc\beta\gamma^2$$

- Spin remains parallel to orbit
- No “contamination” from anomalous spin precession

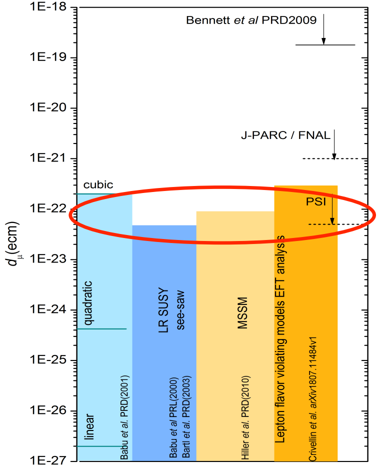
$$s_z \propto \eta E^* \cdot t$$

EDM signal is visible as growing vertical polarisation

Muon EDM measurement: PSI MuEDM

from J.Price, 2020

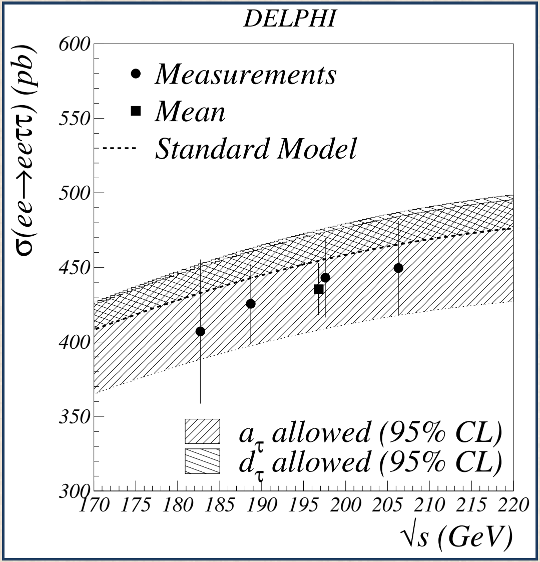
Prospects for compact μ-EDM at PSI



- Apply frozen spin technique
  - PSI μE1: *2×10^8 μ^+/s*, ***γ=1.57***
  - Polarisation from pion decay: ***P=0.9***
  - Mean asymmetry of muon decay: ***a=0.3***
  - Compact conventional magnet:
    - ***B = 1.5 T ➡ R=0.28m, E = 10 MV/m***
  - Detection rate 200kHz
  - Run time 2×10^7 *s* ➡ N = 4×10^{12} *e^+ per year*
- PSI Sensitivity (1 year):

  $\sigma(d_\mu) < 5 \times 10^{-23}$ e.cm

Tau dipole moments measurements: DELPHI 2004



- compares measured $\sigma(e^+e^- \rightarrow e^+e^-\tau^+\tau^-)$ with SM prediction and obtains limits on extra contributions
- $a_\tau = 0.018(17)$
- $d_\tau = 0.0(2.0)\cdot 10^{-16}$ e cm
- Eur.Phys.J.C 35 (2004) 159

Tau EDM measurement with global fit of LEP and SLD measurements

- $a_\tau = -0.0015(35)$
- G.A.Gonzalez-Sprinberg, A.Santamaria and J.Vidal, "Model independent bounds on the tau lepton electromagnetic and weak magnetic moments", Nucl.Phys.B 582 (2000) 3

Tau EDM measurement by Belle 2022

from Diptaparna Biswas, Phipsi 2022

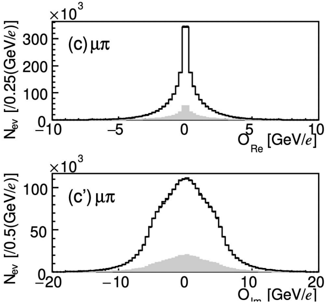
Search for tau EDM

833 fb^{-1} of Belle data

- A non-zero electric dipole moment of τ can provide signatures of new physics.
  - ➢ CP/T violating parameter in γττ vertex.
  - ➢ SM prediction of τ EDM, $d_\tau \sim O(10^{-37})$ e cm
- Method of optimal observable is used to perform this measurement.
  - ➢ Introduced in this paper: PRD 45 (1992) 2405
  - ➢ The optimal observables used in this analysis are:

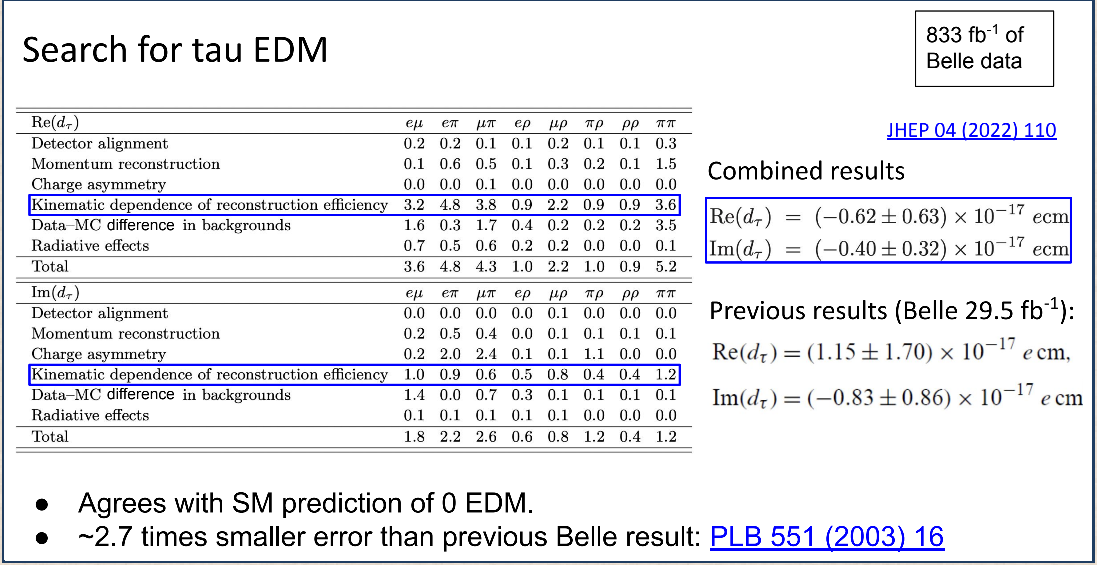
$$\mathcal{O}_{\mathrm{Re}} = \frac{\chi_{\mathrm{Re}}}{\chi_{\mathrm{SM}}}, \quad \mathcal{O}_{\mathrm{Im}} = \frac{\chi_{\mathrm{Im}}}{\chi_{\mathrm{SM}}}$$

  - ➢ The squared spin density matrix (χ_{prod}) for the $\tau^+\tau^-$ production vertex is $\chi_{\mathrm{prod}} = \chi_{\mathrm{SM}} + \mathrm{Re}(d_\tau)\chi_{\mathrm{Re}} + \mathrm{Im}(d_\tau)\chi_{\mathrm{Im}} + |d_\tau|^2\chi_{d^2}$
  - ➢ χ_{SM} is the SM term. χ_{Re} and χ_{Im} are the interference terms between the SM and the real and imaginary parts of d_τ.
  - ➢ χ_{Re} and χ_{Im} are measured from the asymmetry in azimuthal and polar angles of τ daughter tracks momenta, respectively.



Tau EDM measurement by Belle 2022

from Diptaparna Biswas, Phipsi 2022



Search for tau EDM

833 fb^{-1} of
Belle data

Re(d_τ)	$e\mu$	$e\pi$	$\mu\pi$	$e\rho$	$\mu\rho$	$\pi\rho$	$\rho\rho$	$\pi\pi$
Detector alignment	0.2	0.2	0.1	0.1	0.2	0.1	0.1	0.3
Momentum reconstruction	0.1	0.6	0.5	0.1	0.3	0.2	0.1	1.5
Charge asymmetry	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0
Kinematic dependence of reconstruction efficiency	3.2	4.8	3.8	0.9	2.2	0.9	0.9	3.6
Data–MC difference in backgrounds	1.6	0.3	1.7	0.4	0.2	0.2	0.2	3.5
Radiative effects	0.7	0.5	0.6	0.2	0.2	0.0	0.0	0.1
Total	3.6	4.8	4.3	1.0	2.2	1.0	0.9	5.2

Im(d_τ)	$e\mu$	$e\pi$	$\mu\pi$	$e\rho$	$\mu\rho$	$\pi\rho$	$\rho\rho$	$\pi\pi$
Detector alignment	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0
Momentum reconstruction	0.2	0.5	0.4	0.0	0.1	0.1	0.1	0.1
Charge asymmetry	0.2	2.0	2.4	0.1	0.1	1.1	0.0	0.0
Kinematic dependence of reconstruction efficiency	1.0	0.9	0.6	0.5	0.8	0.4	0.4	1.2
Data–MC difference in backgrounds	1.4	0.0	0.7	0.3	0.1	0.1	0.1	0.1
Radiative effects	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.0
Total	1.8	2.2	2.6	0.6	0.8	1.2	0.4	1.2

JHEP 04 (2022) 110

Combined results

$$\begin{aligned}\mathrm{Re}(d_\tau) &= (-0.62 \pm 0.63) \times 10^{-17}\ e\mathrm{cm}\\ \mathrm{Im}(d_\tau) &= (-0.40 \pm 0.32) \times 10^{-17}\ e\mathrm{cm}\end{aligned}$$

Previous results (Belle 29.5 fb^{-1}):

$$\mathrm{Re}(d_\tau) = (1.15 \pm 1.70) \times 10^{-17}\ e\,\mathrm{cm},$$

$$\mathrm{Im}(d_\tau) = (-0.83 \pm 0.86) \times 10^{-17}\ e\,\mathrm{cm}$$

- Agrees with SM prediction of 0 EDM.
- ~2.7 times smaller error than previous Belle result: PLB 551 (2003) 16

Tau dipoles measurement on $e^+e^- \to \tau^+\tau^-$ theory

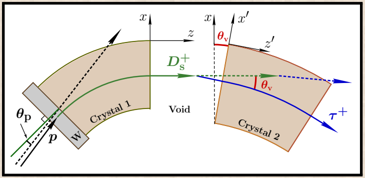
- J.Bernabeu, G.A.Gonzalez-Sprinberg and J.Vidal, CP violation and electric-dipole-moment at low energy tau production with polarized electrons, Nucl.Phys.B 763 (2007) 283
- J.Bernabeu, G.A.Gonzalez-Sprinberg, J.Papavassiliou and J.Vidal, Tau anomalous magnetic moment form-factor at super B/flavor factories, Nucl.Phys.B 790 (2008) 160

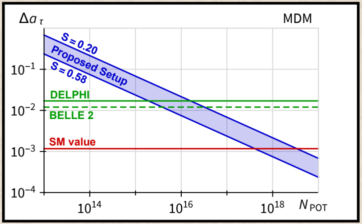
Tau dipoles measurement on $e^+e^- \to \tau^+\tau^-$ sensitivity estimates

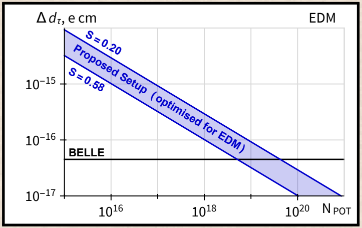
- Xin Chen, Yongcheng Wu, Search for the Electric Dipole Moment and anomalous magnetic moment of the tau lepton at tau factories, JHEP 10 (2019) 089
  Belle II 50 ab^{-1}: $\delta d_\tau = 2.04{\cdot}10^{-19}$ e cm, $\delta a_\tau^{\text{NP}} = 1.75{\cdot}10^{-5}$ (1.5% of SM prediction),
  when systematics are not considered
- A.Crivellin, M.Hoferichter, J.M.Roney, Towards testing the magnetic moment of the tau at one part per million, arXiv:2111.10378 [hep-ph]
  higher order SM calculations needed to reach 1 ppm resolution
- Werner Bernreuther, Long Chen, and Otto Nachtmann, Electric dipole moment of the tau lepton revisited, Phys. Rev. D 103, 096011
  Belle II 50 ab^{-1}: $\delta\,\text{Re}\, d_\tau = 5.8{\cdot}10^{-20}$ e cm, $\delta \text{Im} d_\tau = 3.2{\cdot}10^{-20}$ e cm
- Werner Bernreuther, Long Chen, Otto Nachtmann, Probing the tau electric dipole moment at the BEPC-II collider, Phys.Rev.D 104 (2021) 11, 115002
  $\delta d_\tau = 2.2 - 5.3{\cdot}10^{-18}$ e cm
- Hieu Minh Tran, Yoshimasa Kurihara, Tau $g-2$ at e^-s^+ colliders with momentum dependent form factor, Eur.Phys.J.C 81 (2021) 2, 108
  a_τ prospects at ILC, CLIC, CEPC, FCCee:
  4-5 times better than LEP thanks to beam polarization and high luminosities

Tau dipoles measurements prospects with bent crystals

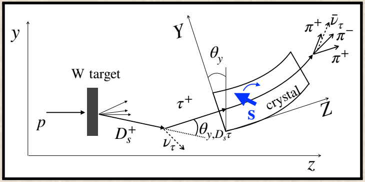
Fomin, Korchin, Stocchi, Barsuk, Robbe 2018

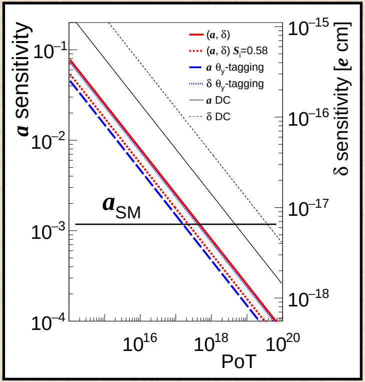






Fu, Giorgi, Henry, Marangotto, Martínez Vidal, Merli, Neri, Ruiz Vidal 2019





Tau dipoles measurements with hadronic ultra-peripheral collisions

measurements

- CMS, Observation of tau lepton pair production in ultraperipheral lead-lead collisions at $\sqrt{s_{NN}} = 5.02\,\text{TeV}$, arXiv:2206.05192 [nucl-ex]
  measured $\sigma(\gamma\gamma \to \tau^+\tau^-)$, compared to SM prediction,
  model-dependent $a_\tau = 0.001^{+0.055}_{-0.089}$

feasibility studies

- Paul Bühler, Nazar Burmasov, Roman Lavicka, Evgeny Kryshen, Feasibility study of tau-lepton anomalous magnetic moment measurements with ultra-peripheral collisions at the LHC, EPJ Web Conf. 262 (2022) 01021
  We discuss the feasibility of the a_τ measurement in ultraperipheral collisions with the ALICE experiment
- Nazar Burmasov, Evgeny Kryshen, Paul Buehler, Roman Lavicka, Feasibility of tau g-2 measurements in ultra-peripheral collisions of heavy ions arXiv:2203.00990 [hep-ph] (conf.proc.)
  We review recent proposals to study ditau production via semi-leptonic tau decays in Pb-Pb UPC with the available ATLAS and CMS data

Conclusions

- widespread activity to improve experimental resolution on muon and tau dipole moments
- for tau moments, Belle and Belle II measuremets are most precise, and test $q^2 \sim m_\tau^2$
- to measure the moments at $q^2 \sim 0$ bent crystals appear to be the only investigated option

Thanks for your attention!