E821 and the Muon Electric Dipole Moment

Ofer Rind
Boston University

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A brief intro to the next talk by Ron McNabb:
- How does one search for an EDM in the g-2 expt.?
- Past, Present and Future

EDM and the Muon Spin Precession

General formula for muon spin precession in the g-2 storage ring, including the effect of a nonzero electric dipole moment:

$$\vec{\omega} = \frac{e}{mc}\left[a\vec{B} - \left(a - \frac{1}{\gamma^2 - 1} \right) \vec{\beta} \times \vec{E} + \frac{1}{2} f \left(\vec{E} + \vec{\beta} \times \vec{B} \right) \right]$$

Eliminated at "magic" gamma of 29.3

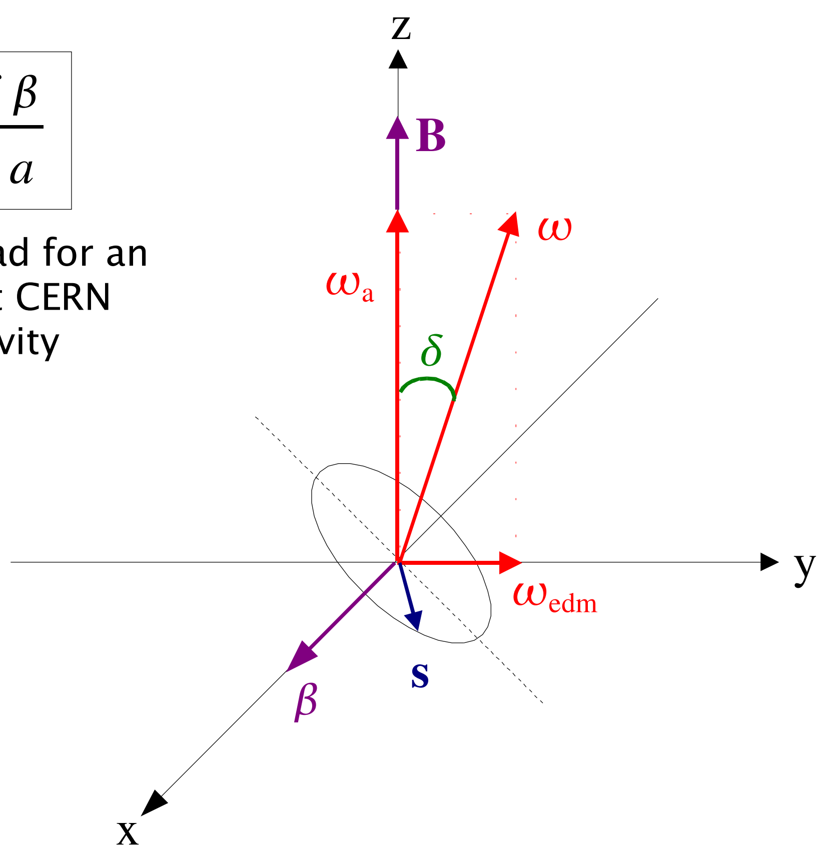
Lab E-field small

where $D \equiv 1/2\, f\, (e\hbar/2mc)$ is the electric dipole moment and the last term comes from the torque acting on the EDM from the apparent electric field in the muon rest frame.

EDM and the Muon Spin Precession

$$\delta = \frac{f\,\beta}{2\,a}$$

~3 mrad for an EDM at CERN sensitivity



An electric dipole moment will tilt the spin precession plane radially ⇒ the muon polarization acquires a vertical component which oscillates with the horizontal precession frequency.

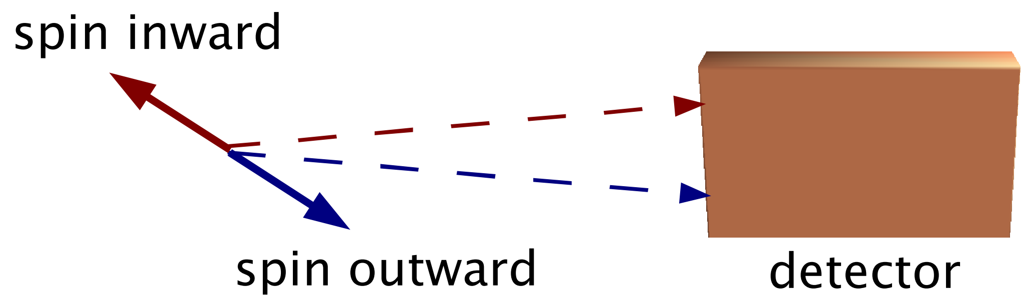
EDM signal:

- Increase in precession frequency (indirect)
- Oscillation of vertical polarization (direct)

$$\vec{\omega} = \vec{\omega}_a + \vec{\omega}_{edm} = \frac{e}{mc}\left[a\,\vec{B} + \frac{1}{2} f\,(\vec{\beta}\times\vec{B})\right], \quad \omega = \omega_a (1+\delta)^{1/2}$$

Direct Search For EDM at CERN III

Tilt in emission angle due to EDM translates to a change in average vertical impact position at detector



CERN method: Two-fold vertical segmentation (5 detectors) $\Rightarrow$ measure phase difference between top and bottom detector halves

$$N_{up} = \frac{1}{2} N e^{-t/\tau} [1 - A_\mu \cos(\omega t + \psi) + A_e \sin(\omega t + \psi)]$$

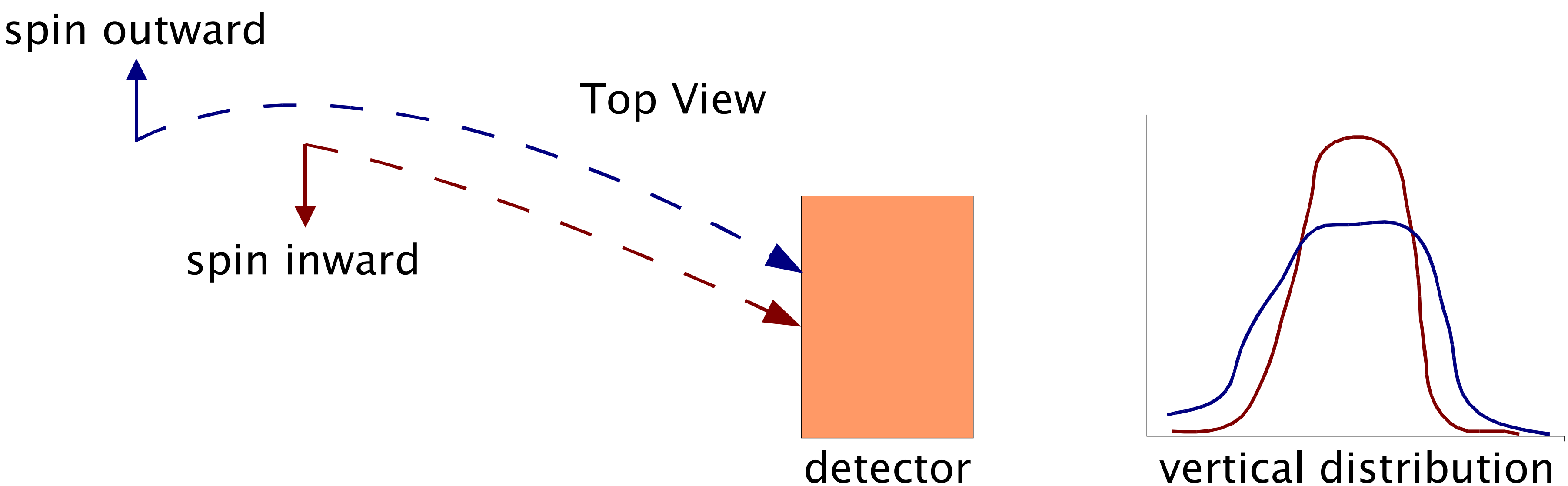
$$N_{down} = \frac{1}{2} N e^{-t/\tau} [1 - A_\mu \cos(\omega t + \psi) - A_e \sin(\omega t + \psi)]$$

where A_e is proportional to EDM and depends on energy threshold (e.g. $A_e = 0.16\delta$ for E>800 MeV and 0.75 dilution).
Top-bottom phase difference: $\Delta\phi \approx 2.2\delta$

Decay Path Length Effect

Outward going positrons follow a longer path to the detector than inward going $\Rightarrow$ larger spread of vertical distribution at detector face.

Distribution changes with g-2 frequency and therefore mimics an EDM signal if systematics are not accounted for (e.g. misalignment or ineffeciency of detector segments)



CERN III Result

Final CERN measurement used a 6-parameter fit to extract the phase in the top and bottom counters separately:

$D_{\mu^+} = (8.6 \pm 4.5) \times 10^{-19}\, e\, cm$ 5.4 Me$^+$

$D_{\mu^-} = (0.8 \pm 4.3) \times 10^{-19}\, e\, cm$ 6.0 Me$^-$

$D_{\mu} = (3.7 \pm 3.4) \times 10^{-19}\, e\, cm$ 11.4 M ($\Delta\Phi = -7.2 \pm 5.2$ mrad)

95% Confidence Level Limits:

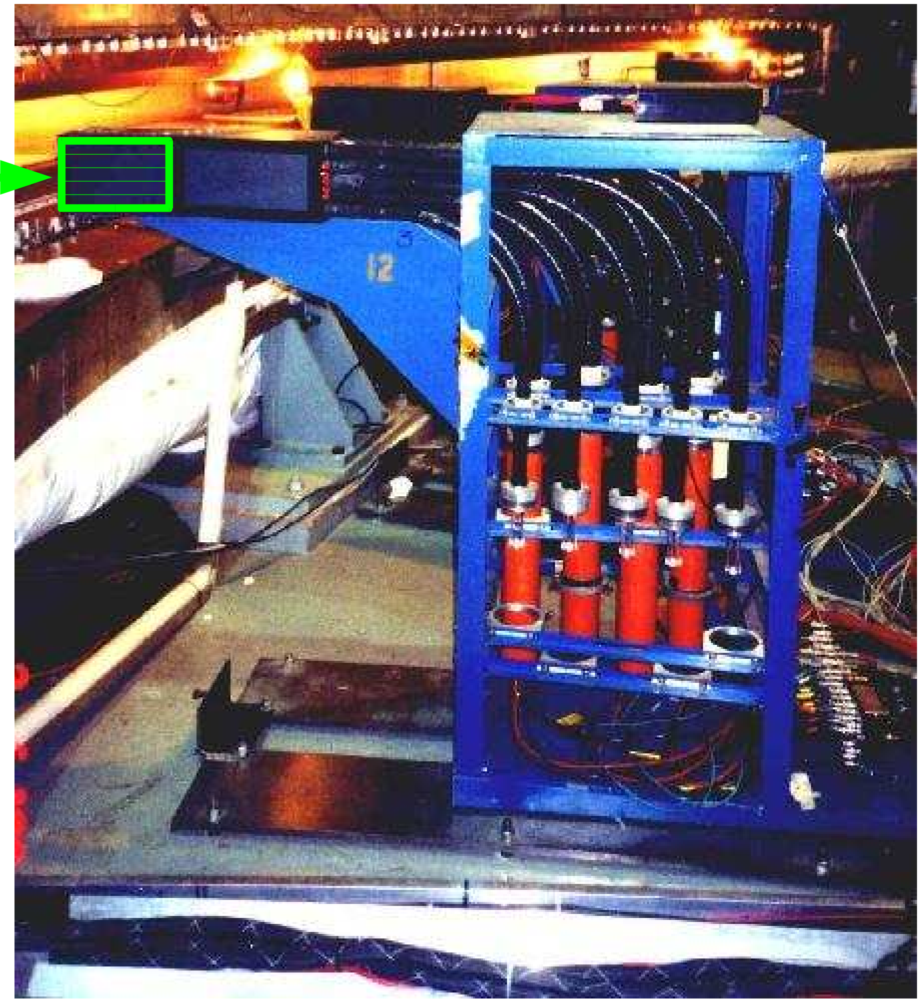
$|D_\mu| \leq 1.05 \times 10^{-18}\, e\, cm$ Direct

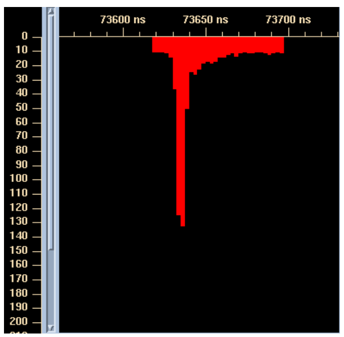
$|D_\mu| \leq 0.74 \times 10^{-18}\, e\, cm$ Indirect

<u>Main systematic</u>: position of horizontal split between up/down counters ($\pm$0.5mm)

E821 Direct Search for EDM

5-fold vertical segmentation with FSD scintillator tiles and/or greater segmentation with PSD hodoscopes

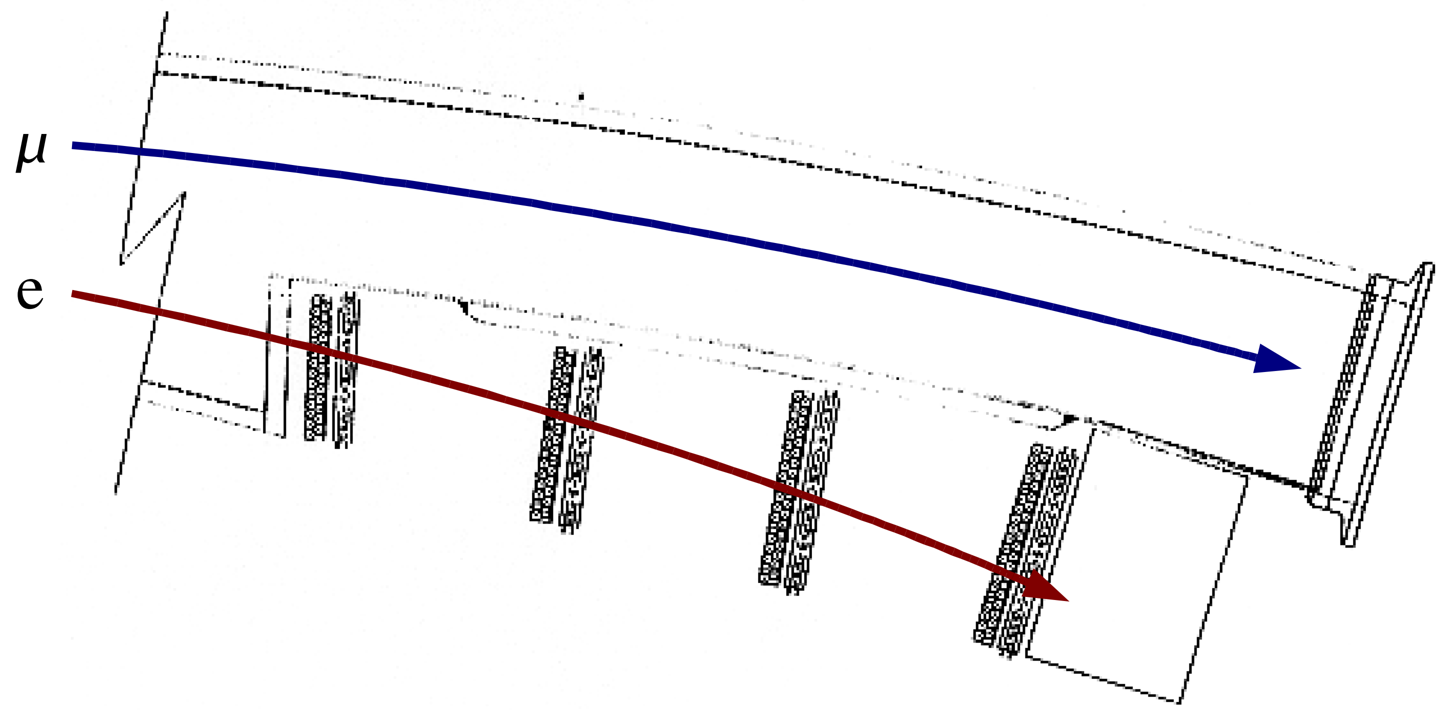




Full pulse sampling allows optimization of energy range

Measurement of vertical beam profile vs. time $\Rightarrow$ better understanding of profile changes due to decay path lengths

E821 Direct Search for EDM



Traceback Chamber:

- Measurement of decay positron trajectory in x and y
  ⇒direct measurement of emission angle
- Limited statistics (one station)
- Different systematics

Summary

- E821 has been designed to improve upon the CERN systematics with improved detector segmentation
- Greater than 100X statistics is already available
- Analysis is still in a nascent stage with myriad systematic effects currently under study...see following talk for the details and expected reach

Indirect limit from '99 result: $D_\mu < 3.9\times10^{-19}$ *e*-cm at 95% CL