

Fringe E-Fields of Deflectors in the Storage Ring pEDM Experiment

ERIC METODIEV

CAPP/IBS, HARVARD COLLEGE

HAWAII, JOINT APS/PSJ NP MEETING

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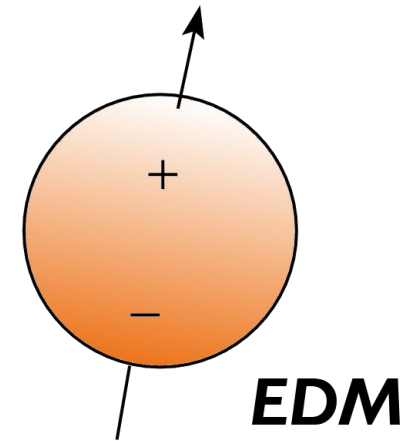


The Storage Ring pEDM Experiment

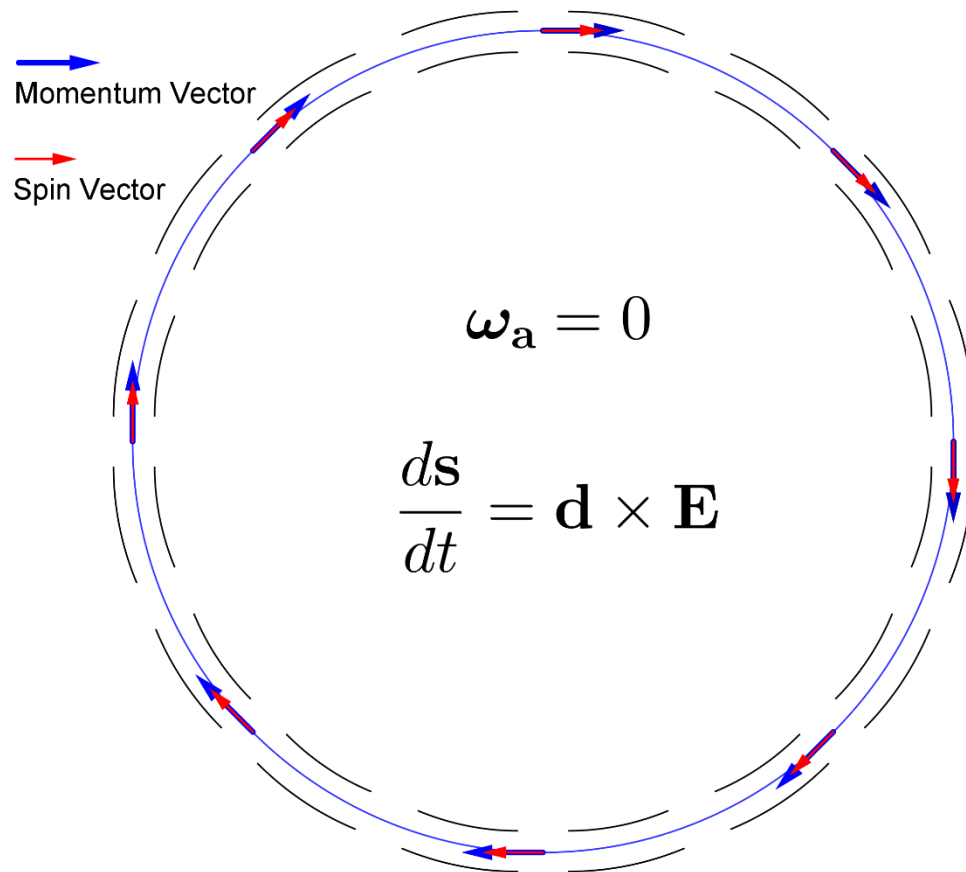
Target sensitivity of $10^{-29} e \cdot \text{cm}$ to $10^{-30} e \cdot \text{cm}$.

Spin precession physics similar to those in the Muon (g-2).

The systematics of the Storage Ring pEDM are very different from the Muon (g-2) experiment and from other EDM experiments.



The basic idea



Protons circulate in ring at their magic momentum, with their spin vectors frozen along their momentum of 0.7 GeV/c.

Spin precession out of the plane indicates an EDM.

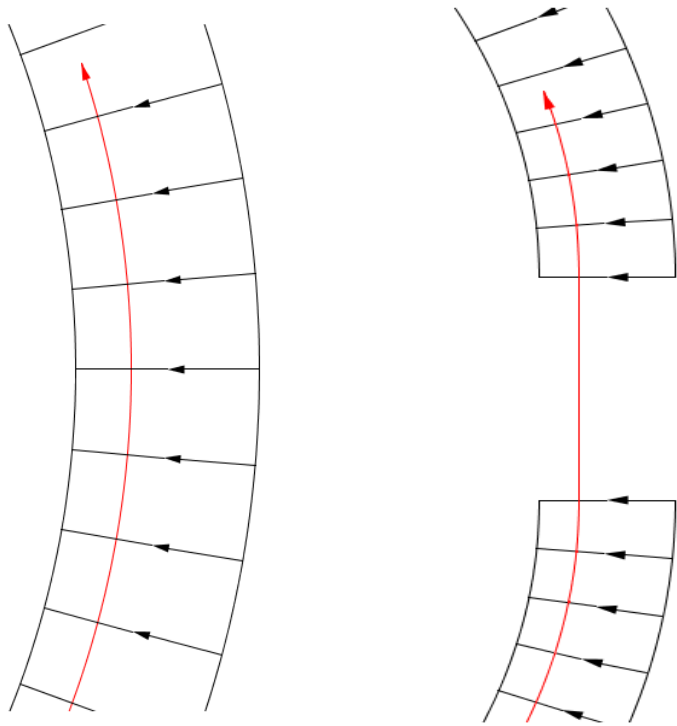
This assumes:

- The electric fields are always radial
- There is no electric field outside of the deflectors

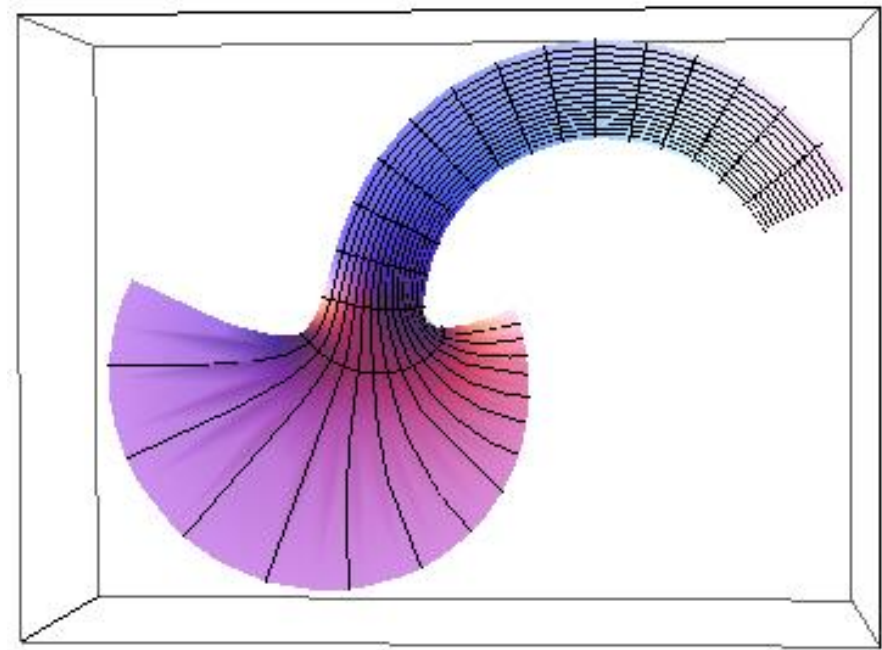
This is not quite true! We want to use precision tracking to see what the realistic effects are.

Treatments of fringe fields

As a first approximation: Hard Edge



Numerical simulations



Treatments of fringe fields

As a first approximation: Hard Edge

- Easy to deal with analytically and to implement in simulations.
- The hard edge approximation is not a solution to Maxwell's equations.
- Is an intuitive approximation, but may not be very accurate.

Numerical simulations

- Must recalculate the potential if the plate spacing or radius of the ring changes.
 - During R&D, several ring geometries and sizes are considered, and all must be simulated.
- Can be relatively difficult to implement in tracking simulations.

Questions to answer

Are the particles stable when we consider fringe fields?

Do the fringe fields affect the spin dynamics to our sensitivity?

Are there ways to cancel the fringe effects and deflections?

Analytical Solution consistent with Maxwell

For a semi-infinite cylindrical plates, we can find an analytic solution. In terms of implicitly defined coordinates u, v :

$$\rho = \sqrt{R_1 R_2} \exp \left[\frac{1}{2\pi} \ln \frac{R_2}{R_1} (e^u \sin v + v) \right]$$

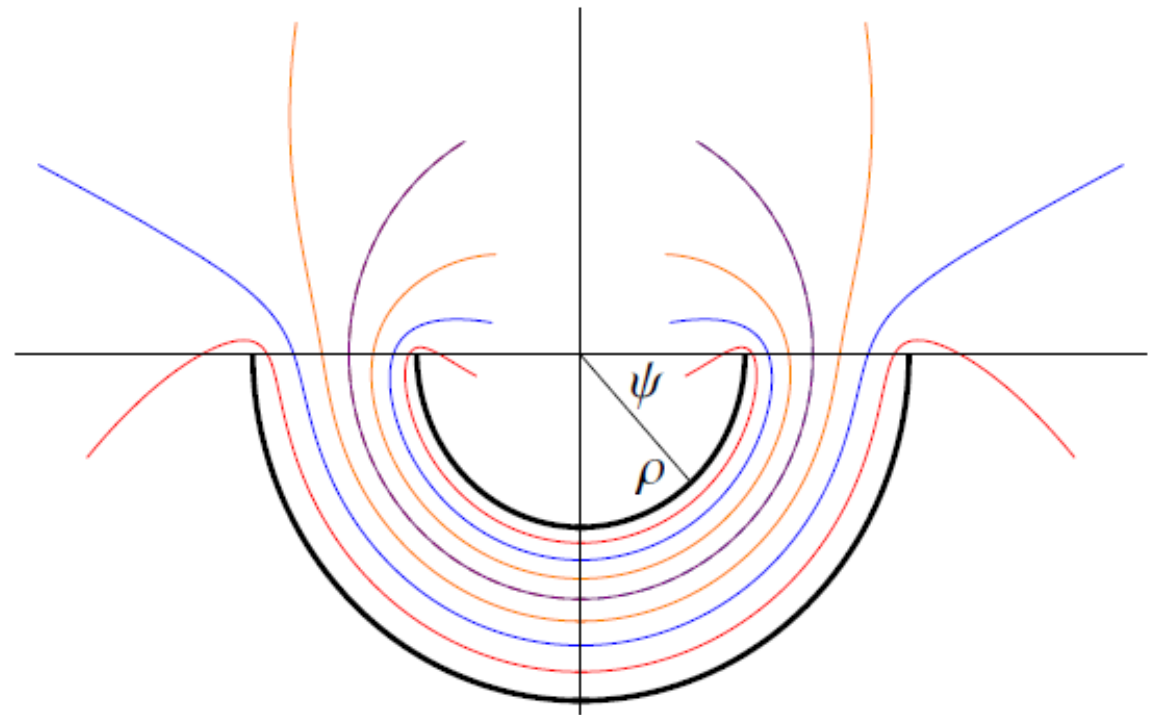
$$\psi = \frac{1}{2\pi} \ln \frac{R_2}{R_1} (1 + e^u \cos v + u)$$

The potential is then $V = V_0 v/\pi$.

After some work, this can be inverted to:

$$v = \Im \left[-1 + \frac{2\pi z}{\ln(\frac{R_2}{R_1})} - W \left(\exp \left(-1 + \frac{2\pi z}{\ln(\frac{R_2}{R_1})} \right) \right) \right]$$

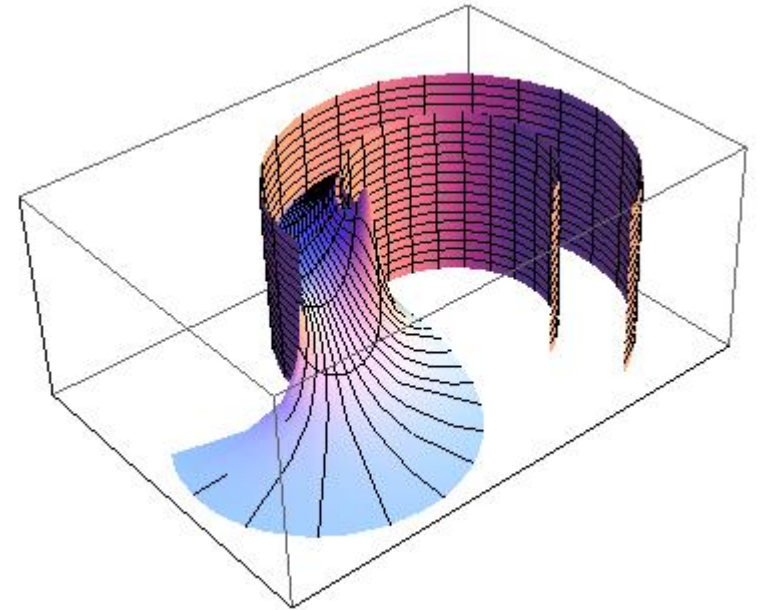
where $z = \psi + i \ln(\rho/\sqrt{R_1 R_2})$



Our implementation

The approximation: we take the deflector sections to be far enough apart, so we added together the analytical solutions for each section.

- This is still a solution to Maxwell, just for a slightly different geometry.
- We found that this was a good approximation to our sensitivity.
- Much better approximation than hard edge.
- Will conserve energy in precision tracking.

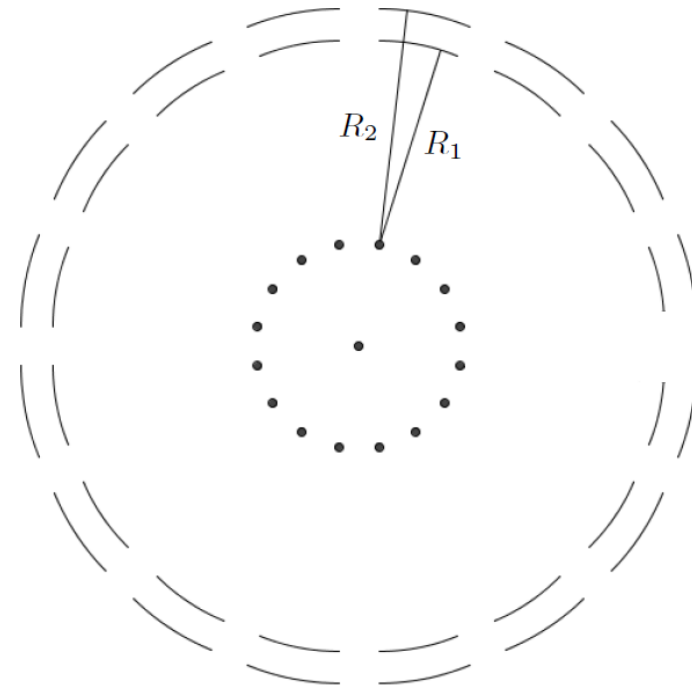


Tracking

As a proof of concept, we used a fourth order Runge-Kutta integrator with a step size of 1ps.

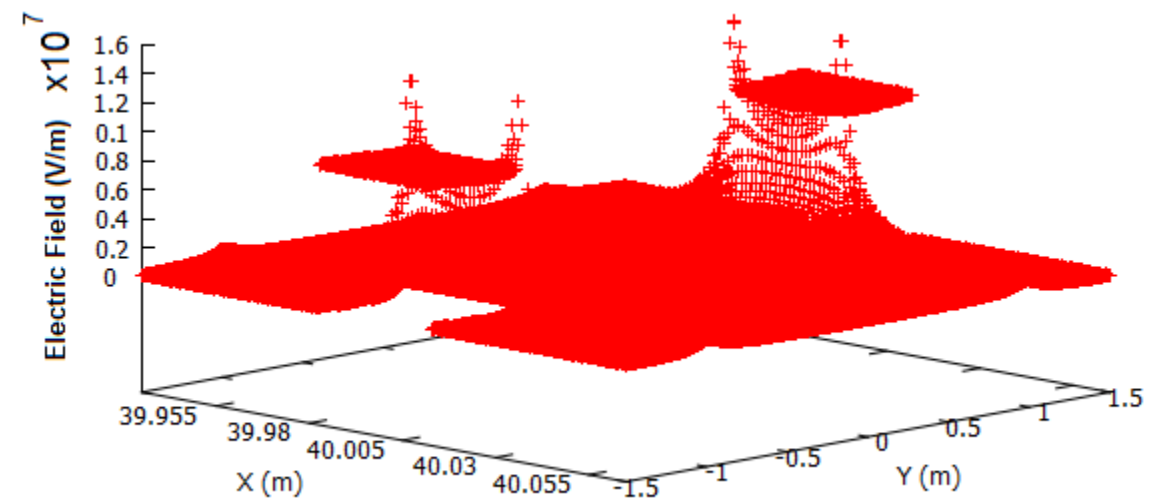
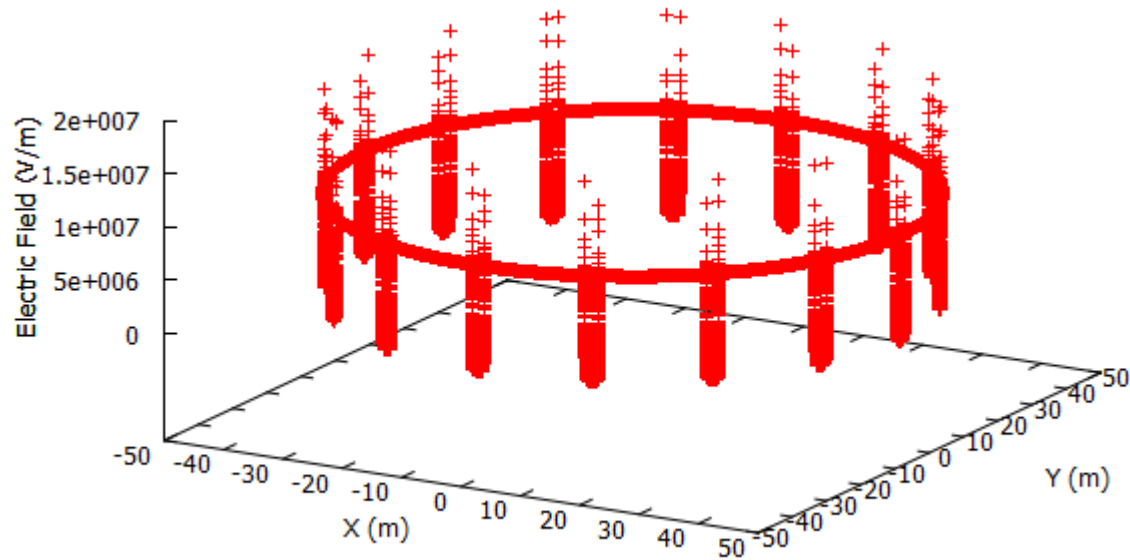
$$\frac{d\vec{\beta}}{dt} = \frac{e}{m\gamma c} [\vec{E} - \vec{\beta}(\vec{\beta} \cdot \vec{E})]$$

$$\frac{d\vec{s}}{dt} = \frac{e}{m} \vec{s} \times \left[- \left(a + \frac{1}{\gamma + 1} \right) \frac{\vec{\beta} \times \vec{E}}{c} \right]$$



Tracking

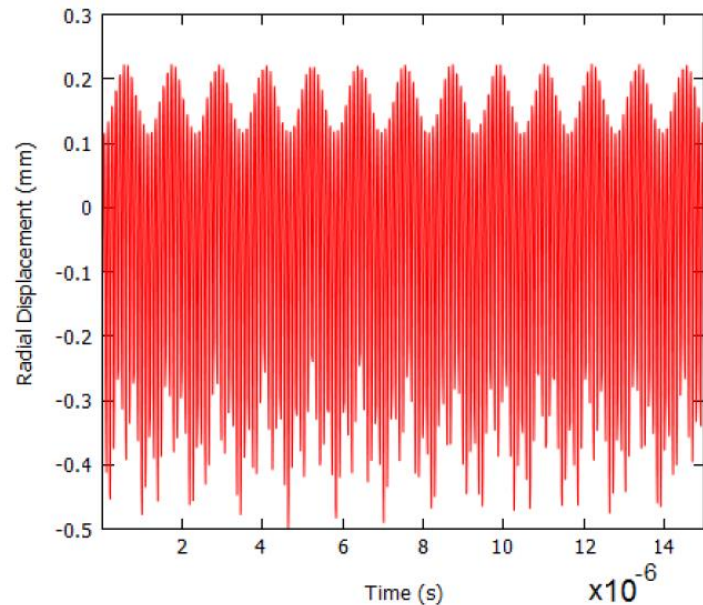
We implemented a model of the pEDM ring, using realistic fringe fields:



Results

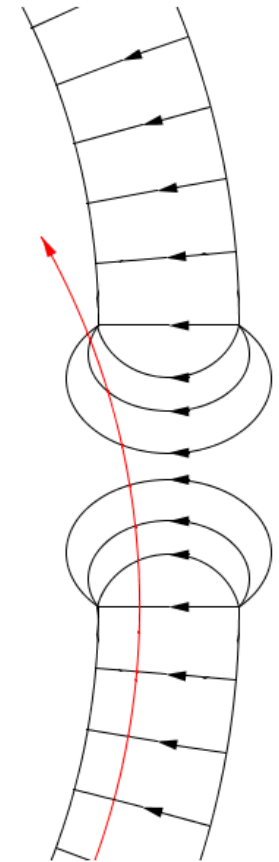
Particles are stable with a suitable change of geometry!

Their paths deviate from the hard-edge orbits by less than millimeters.



The spin dynamics of the particles were not distinguishable to our sensitivity from the same particles in a hard edge approximation.

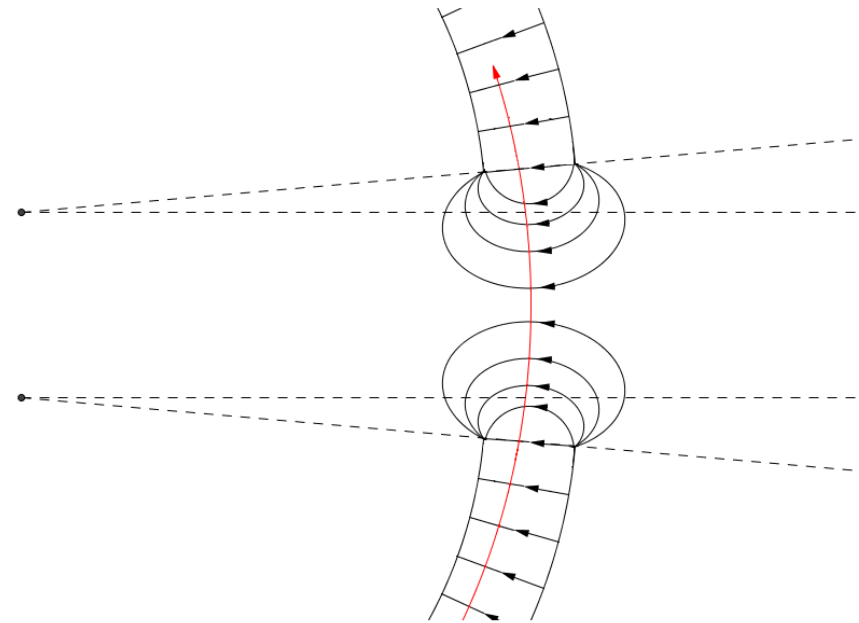
The aperture of the ring is very slightly affected. There is a slight radial deflection due to the fringes



Possible Changes to the Experiment

There are two possible changes to the experimental geometry to correct for the deflection due to the fringes:

- Shorten the deflectors by several millimeters.
- Change the radius of curvature of the deflectors.

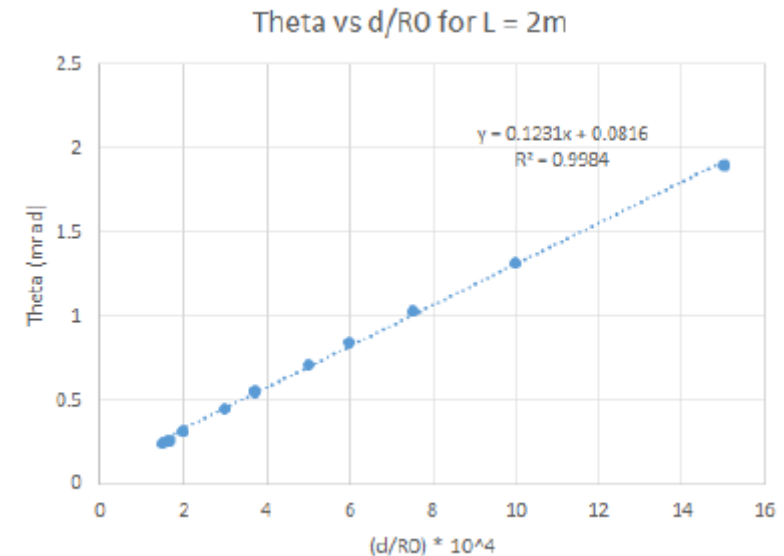


Possible Changes to the Experiment

The possible alterations to the geometry have been studied. The deflection can be compensated by appropriately shortened electrodes.

- These have been studied for a variety of possible bending radii and plate spacings

Without the slight change in the geometry, the particles were actually found to not be stable in the ring!



Some specifics

We developed a set of tools to deal with fringe fields and allow them to naturally be incorporated in precision tracking programs.

- The vertical dimension was neglected in treating the problem. There are fringe fields in this direction as well, but they do not treat the directions asymmetrically, as the horizontal fringe fields do.
- Other horizontal and vertical focusing (such as due to quads) was left out of the analysis. We investigated whether the lattice was stable in the ideal case, and we found that slight modifications were necessary.

Bottom line

With realistic analytical estimates of the fringe electric fields in the pEDM deflectors, using precision tracking we have shown:

- The particles are stable inside the ring, accounting for fringe fields
- The spin dynamics are not significantly altered
- Very small changes to the deflector geometry can further cancel the effects

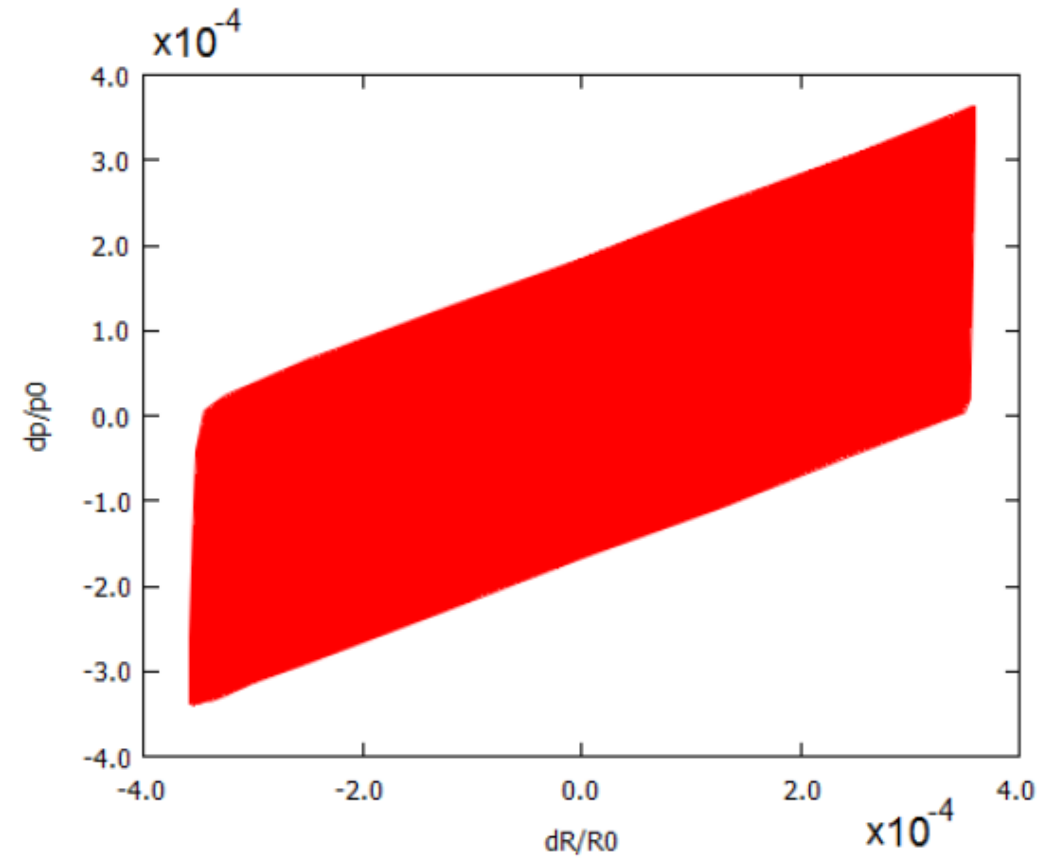
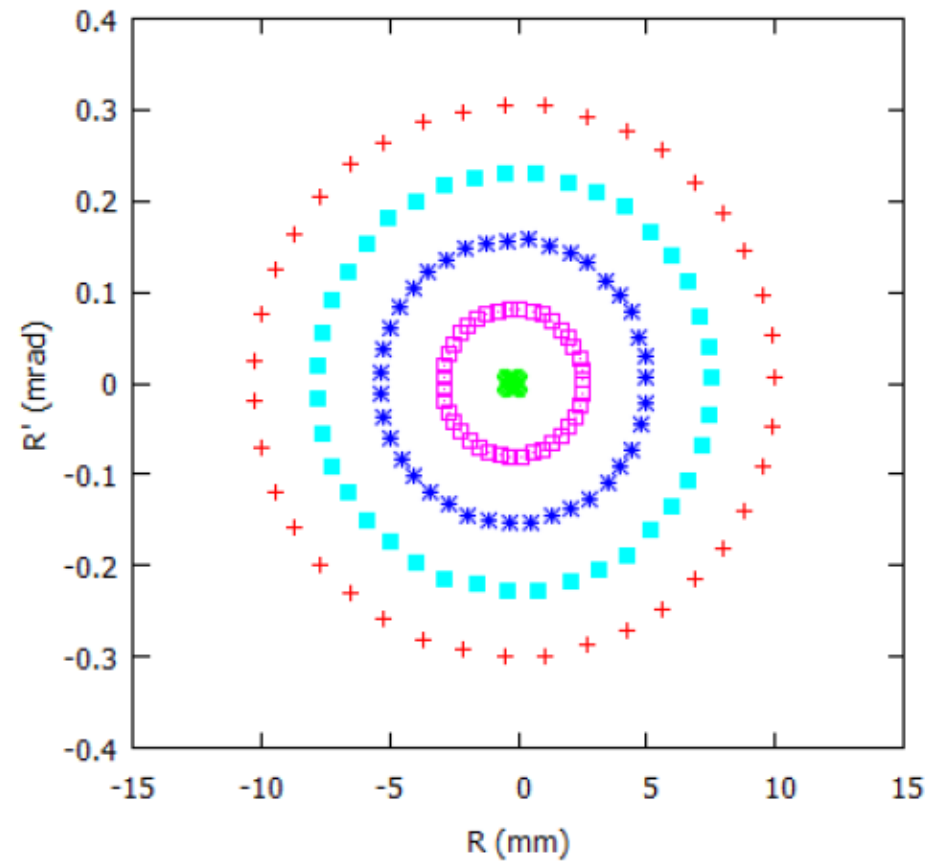
The End

Thank you!

Questions?

For more detail see Metodiev, et al. PRSTAB, 2014.

Additional Slides



Additional Slides

