Center for Axion and Precision Physics Research

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PBC teleconference

Systematic errors, Lattice work

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Proton, and deuteron

- Storage ring p,d EDMs @ $<10^{-29}$e-cm level
- What we know for far, what needs to be done more
- "known" and "unknown" systematic errors, how to deal with unknown ones!

Purpose of Systematic error work-packages

- To convince the non-experts and harshest critics that the systematic errors are under control by
  - Ensure simple case proofs
  - Provide material for the experts that the work has been done adequately and the method is feasible

Systematic errors

- Generated by E & B field directions of elements
  - Element placement
  - Value of field away from ideal
  - Fringe fields
- External, unwanted fields
- Beam itself
- Polarimeter related

Storage Ring Electric Dipole Moments

Fields	Example	EDM term	Comments
Dipole magnetic field **(B)**	Muon g-2	Tilt of the spin precession plane. (Limited sensitivity due to spin precession)	Eventually limited by geometrical alignment. Requires CW and CCW injection to eliminate systematic errors
Combination of electric and magnetic fields **(E, B)**	Deuteron, ^{3}He, proton, etc.	Mainly: $\frac{d\vec{s}}{dt} = \vec{d} \times \left(\vec{v} \times \vec{B}\right)$	Most powerful. Small ring. Need to build combined B and E-field system. Reduce vertical E-field.
Radial Electric field **(E)**	Proton, etc.	$\frac{d\vec{s}}{dt} = \vec{d} \times \vec{E}$	Large ring, CW & CCW storage. Simplest to achieve. Reduce radial B-field.

TABLE III. Main systematic errors of the experiment and their remediation.

Effect	Remediation
Radial B-field	SQUID BPMs with 1 fT/$\sqrt{\text{Hz}}$ sensitivity eliminate it.
Geometric phase	Plate alignment to better than 100 μm, plus CW and CCW storage. Reducing B-field everywhere to below 10-100 nT. BPM to 100 μm to control the effect.
Non-radial E-field	CW and CCW beams cancel the effect.
Vert. quad misalignment	BPM measurement sensitive to vertical beam oscillation common to CW and CCW beams.
Polarimetry	Using positive and negative helicity protons in both the CW and CCW directions cancels the errors.
Image charges	Using vertical metallic plates except in the quad region. Quad plates' aspect ratio reduces the effect.
RF cavity misalignment	Limiting longitudinal impedance to 10 kΩ to control the effect of a vertical angular misalignment. CW and CCW beams cancel the effect of a vertically misplaced cavity.

Proton case

- Fields:

1. Radial B-field Constant part of it around the ring. QUID-based BPMs feasibility looks good
2. Radial B-field changing sign as a function of azimuth. By itself +- averages to zero. Combined with B-fields in another direction it can create a problem. It's also called geometrical phase. It cancels CW and CCW.
3. Gravity and common vertical E-fields: cancel CW and CCW.

Proton case (Cont'd)

4. Excessive radial or longitudinal or vertical E-fields. By themselves they average to zero. No effect on spin. Special combinations can give rise to geometrical phase errors.

5. Spin rotations in two dimensions (e.g. horizontal axis and longitudinal axis) can give rise to rotation wrt the third axis (for this example the radial axis). In general their effect is proportional to the product of each amplitude divided by the number of cycles around the ring.

6. Manageable for protons.

Proton vs. Deuteron on field errors

- Protons. (near "magic" momentum, field errors have a small effect)

$$\vec{\omega}_a = \frac{q}{m}\left\{\left[a - \left(\frac{mc}{p}\right)^2\right]\frac{\vec{\beta}\times\vec{E}}{c}\right\}$$

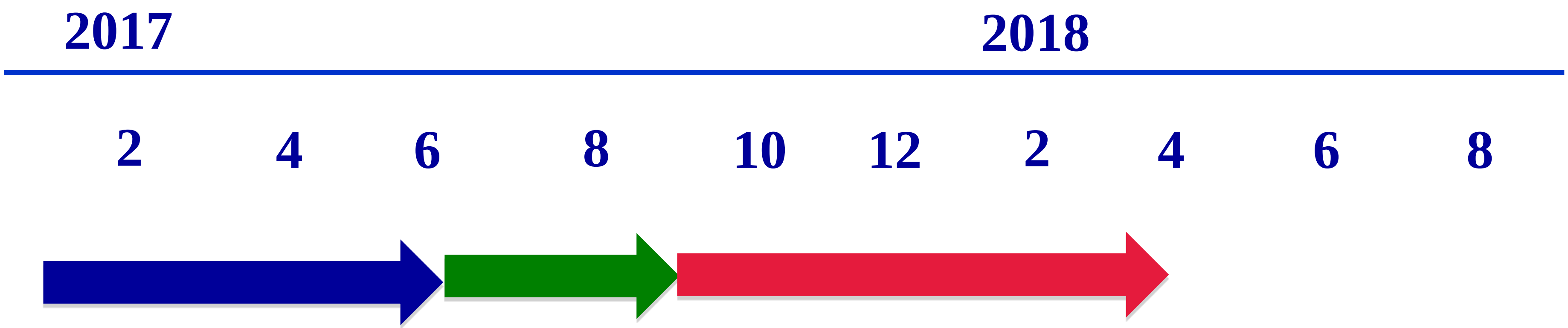
- Deuterons (balancing off large coefficients)

$$\vec{\omega}_a = -\frac{q}{m}\left\{a\vec{B} - \left[a - \left(\frac{mc}{p}\right)^2\right]\frac{\vec{\beta}\times\vec{E}}{c}\right\}$$

Proton and Deuteron systematic errors plan

- Collect all that is available already for each particle. Provide first draft. Call for input.
- Call a meeting for discussions (one day meeting on all the systematic errors)
- Point out work that still needs to be done.
- Finish the write-up with recommendations on future work. Follow up on syst. error work.

Technically driven pEDM timeline



- Collect all available systematic error studies. First draft.

- Prepare for the one day meeting on systematic errors. At the meeting point out to work that still needs to be done.

- Regular teleconference meetings until work is finalized

Work on the proton and deuteron lattices

Functionality of Proton and Deuteron lattices

- Aim for statistical sensitivity of order 10^{-29}*e*-cm at a reasonable number of years (1-4).
- Allow for CW and CCW

- Minimize systematic errors by
  - applying local spin cancellation rules allowed by presently available technology
  - Applying strict symmetry rules for CW vs. CCW

- Minimize development cost in both time and $$

Proton and Deuteron lattices plan

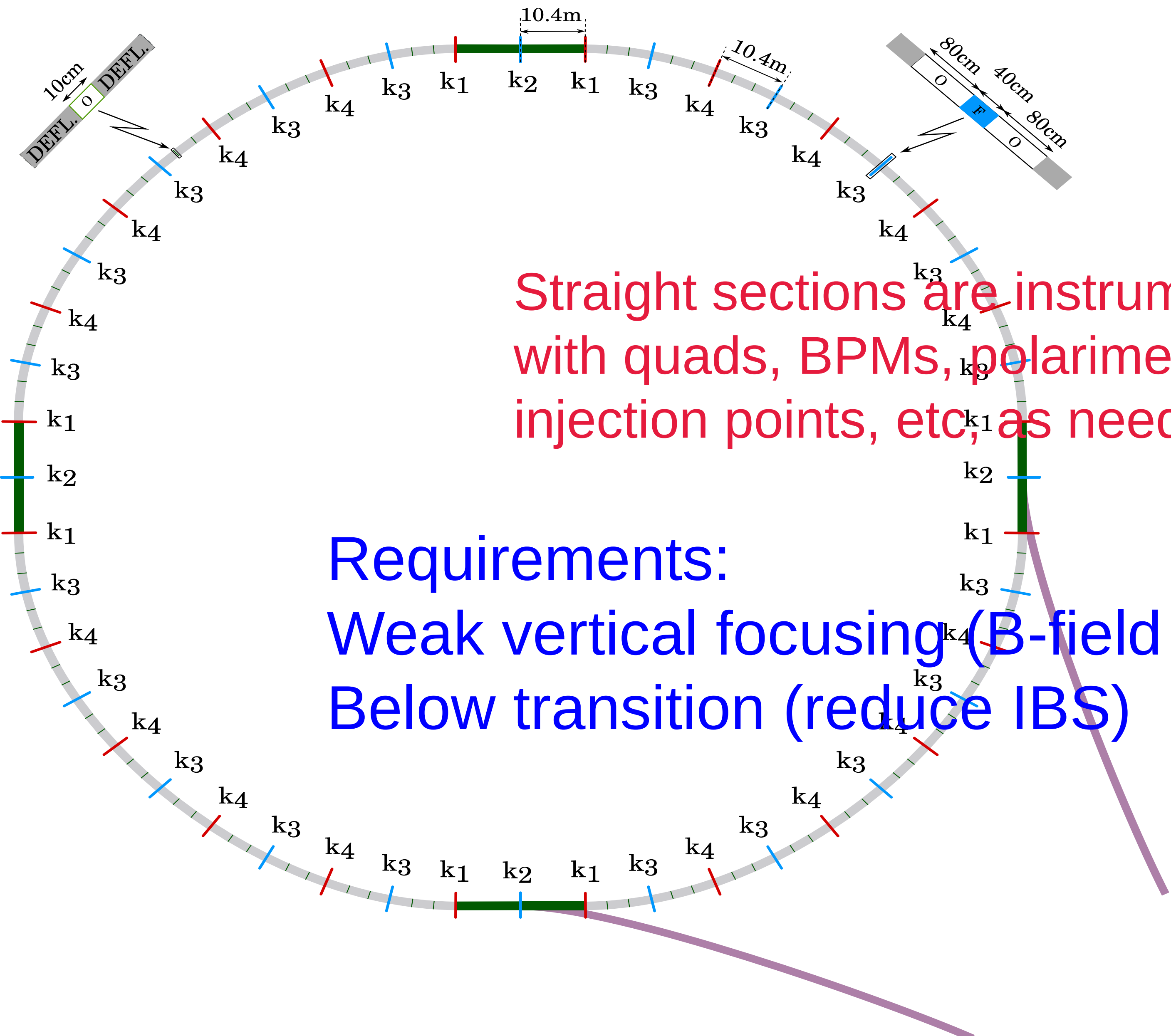
- Collect all that is available already for each particle. Call for input. Provide first draft.
- Call a meeting for discussions: one day meeting on the present lattices. Pickup winning strategies in designing the lattices.
- Point out work that still needs to be done.
- Finish the write-up with recommendations on future work. Follow up on syst. error work.

Summary

- Aim for ultimate sensitivity for p,dEDM < 10^{-29} e-cm
- Collect together currently available amount of work. Call for input. Prepare for a one day on systematic errors, ½ day(?) for lattices meeting in the fall 2017. Point to additional needed work.
- Follow up the work with monthly teleconferences on both subjects.

Extra slides

The proton EDM ring (alternate gradient)



Straight sections are instrumented with quads, BPMs, polarimeters, injection points, etc, as needed.

Requirements:

Weak vertical focusing (B-field sensitivity)

Below transition (reduce IBS)

srEDM Collaboration

REVIEW OF SCIENTIFIC INSTRUMENTS **87**, 115116 (2016)

A storage ring experiment to detect a proton electric dipole moment

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