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Snowmass, Accel.
UC Davis

The proton Electric Dipole Moment method with the Hybrid-ring

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- The hybrid storage ring (E-field for bending, with alternate magnetic focusing) is a major advance in battling systematic errors

- It eliminates the first order systematic errors

Hadronic EDMs

- Sensitive to New Physics. SUSY-like NP sensitivity at 10^3 TeV
- Sensitive to theta_QCD<10^{-10} related to axion and perhaps dark matter. Storage ring pEDM will improve sensitivity by three to four orders of magnitude!
- Recent work shows sensitivity to Dark Matter/Dark Energy
- Alternative systems also needed to pinpoint CP-violation source

Bill Marciano

Generic Physics Reach of $d_p \sim 10^{-29}$ e-cm

$$d_p \sim 0.01 (m_p/\Lambda_{NP})^2 \tan\phi^{NP} e/2m_p$$

$$\sim \mathbf{10^{-22} (1TeV/\Lambda_{NP})^2 \tan\phi^{NP} e\text{-cm}}$$

If ϕ^{NP} is of O(1), Λ_{NP}~3000TeV Probed!

If Λ_{NP}~O(1TeV), $\phi_{NP} \sim 10^{-7}$ Probed!

Unique Capabilities!

Bill Marciano

Heavy Leptons…

EDMs may soon be discovered: $d_e, d_n, d_p \ldots d_D$

Or significantly constrain "New Physics"

Eg CP violation in ***H→γγ*** ***(Contemporary topic)***

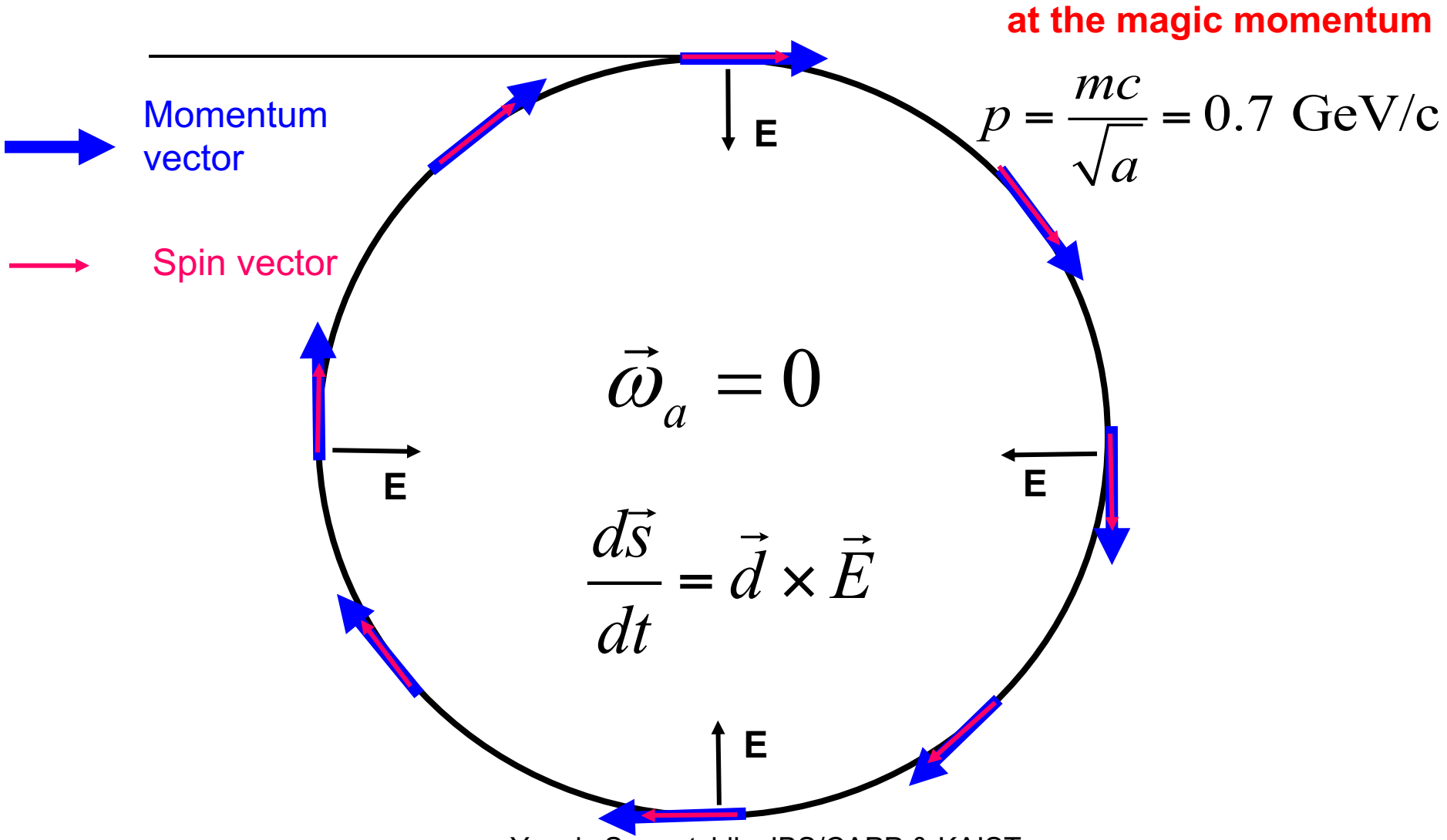
CP violation better explored by 2 loop edms

than all diboson (*γγ, ZZ, WW…)* modes at the LHC!

Atomic, Molecular. Neutron, ***Storage Ring*** (All Complementary)

45

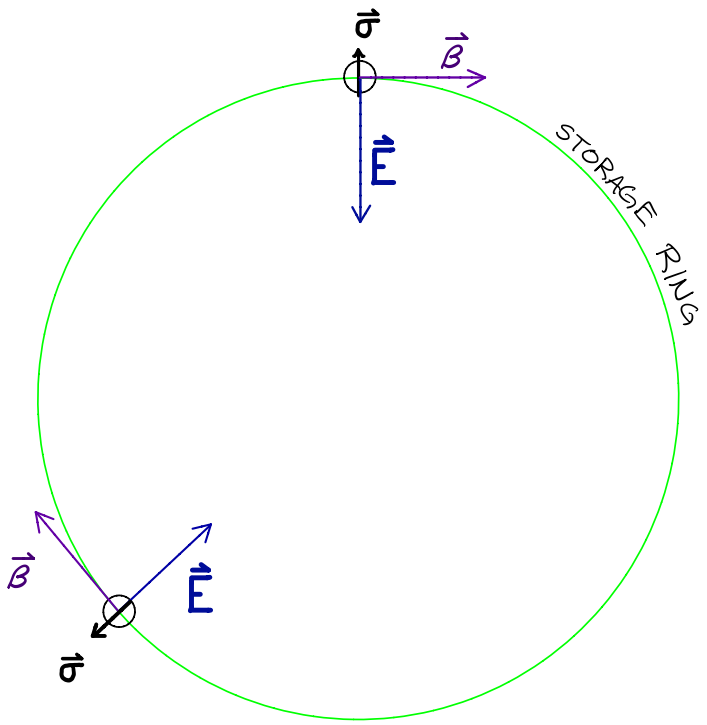
EDM: Frozen spin method in electric ring. Proton spin is aligned with the momentum vector

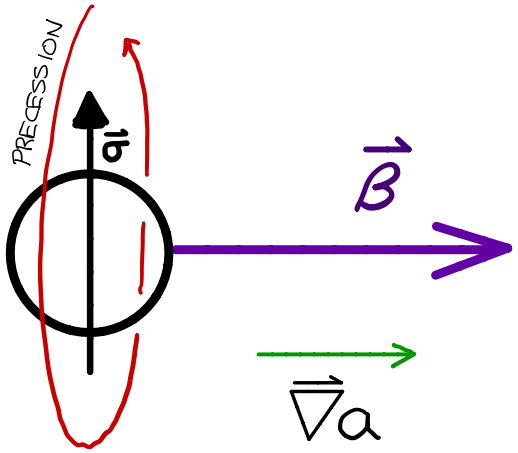


Dark Matter/Dark Energy: frozen spin method in electric ring, spin is kept in the radial direction

arXiv:2005.11867v1 [hep-ph] 25 May 2020

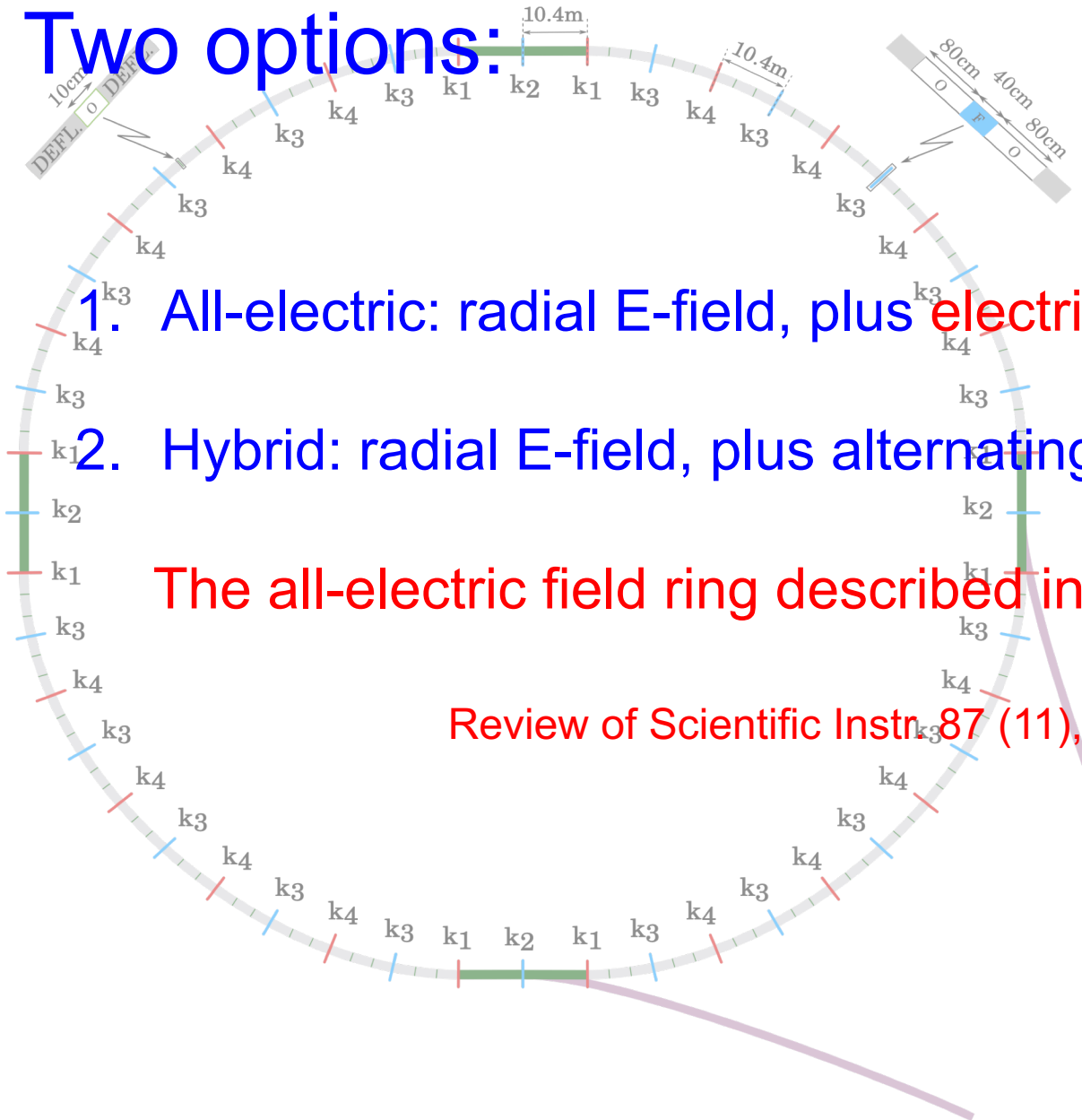
$$\Delta\theta_{prec} \simeq \frac{g_{\mathrm{aNN}}\beta\sqrt{2\rho_{\mathrm{DM}}}}{m_a}\sin(m_a T))$$





The proton EDM electric ring, 500m circ.

Two options:



1. All-electric: radial E-field, plus electric focusing
2. Hybrid: radial E-field, plus alternating magnetic focusing

The all-electric field ring described in

Review of Scientific Instr. 87 (11), 115116

Hybrid storage ring: electric bending, alternate magnetic focusing

- It allows simultaneous clock-wise (CW) and counter-clock-wise (CCW) storage

- It eliminates the main syst. error sources: ext. B-fields and vertical electric fields

PHYSICAL REVIEW ACCELERATORS AND BEAMS **22,** 034001 (2019)

Hybrid ring design in the storage-ring proton electric dipole moment experiment

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(Received 25 October 2018; published 5 March 2019)

A new, hybrid design is proposed to eliminate the main systematic errors in the frozen spin, storage ring measurement of the proton electric dipole moment. In this design, electric bending plates steer the particles, and magnetic focusing replaces electric. The magnetic focusing should permit simultaneous clockwise and counterclockwise storage to cancel systematic errors related to the out-of-plane dipole electric field. Errors related to the quadrupole electric fields can be eliminated by successive runs of magnetic focusing with different strengths.

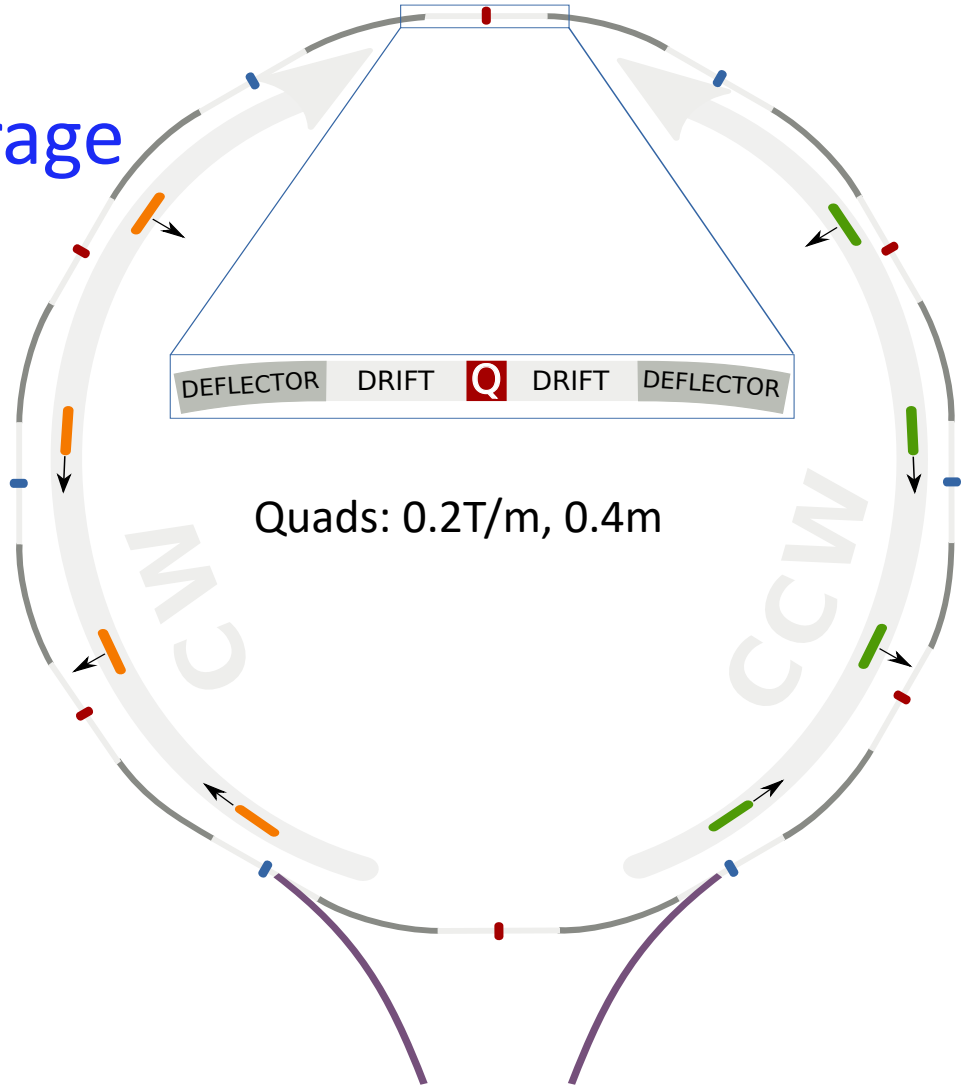
DOI: 10.1103/PhysRevAccelBeams.22.034001

Hybrid storage ring lattice

- Use E-field for particle bending, alternate magnetic focusing allows CW and CCW storage

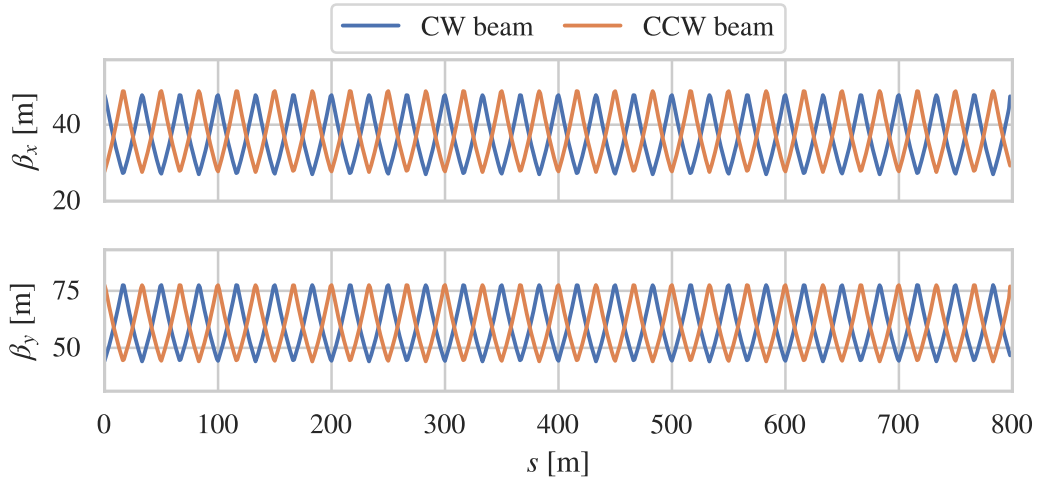
Table 1: The lattice parameters for the storage-ring proton EDM experiment.

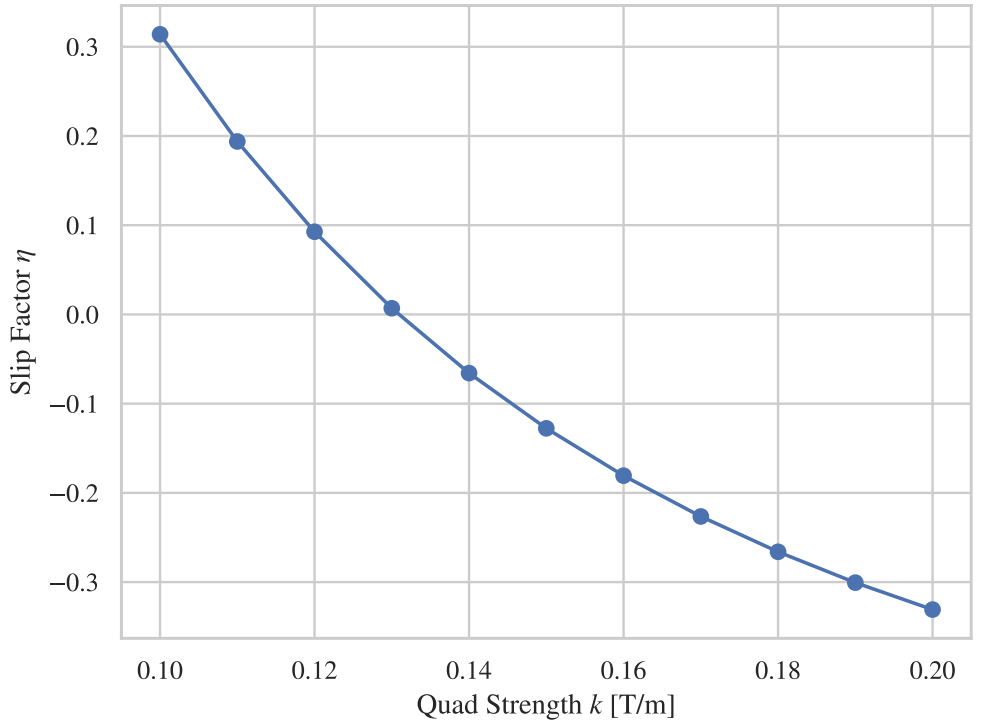
Parameter	Magnitude	Description
p_0	0.71 GeV/c^2	Magic momentum
β	0.59	$= v/c$, the particle speed
R_0	95.5 m	Deflector radius
C	800 m	Ring circumference
f_c	0.22 MHz	Cyclotron frequency
f_x	0.51 MHz	Horizontal betatron frequency
Q_x	2.3	Horizontal betatron tune
f_y	0.49 MHz	Vertical betatron frequency
Q_y	2.2	Vertical betatron tune
E_0	4.4 MV/m	Deflector electric field
k	0.2 T/m	Quadrupole strength
L_{quad}	40 cm	Quadrupole length
L_{str}	4.6 m	Straight section length (incl. quad.)
N	48	Number of cells



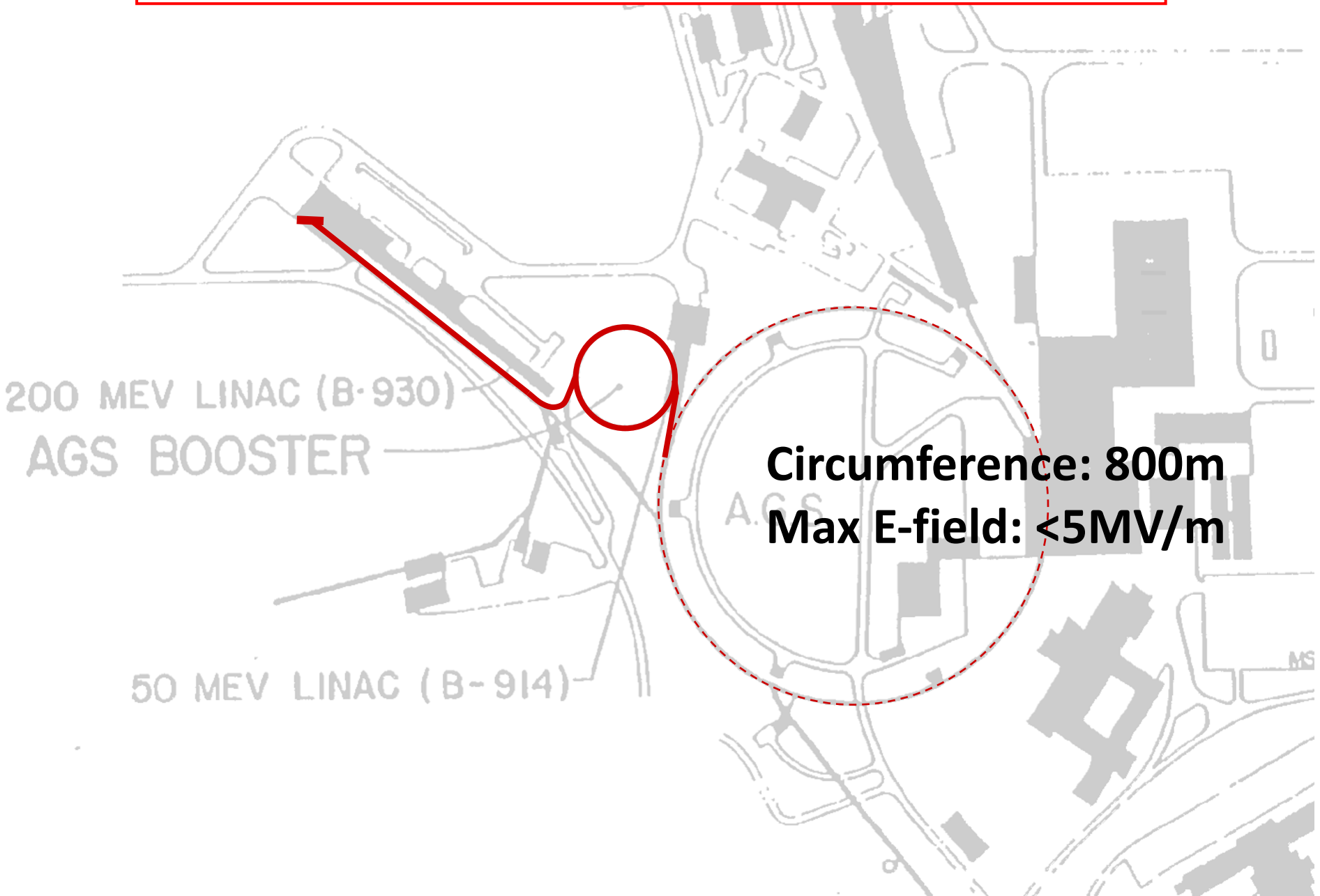
Hybrid storage ring lattice

- Highly symmetric ring lattice
- Reduced Intra-Beam-Scattering issues





The proton EDM in the AGS tunnel at BNL

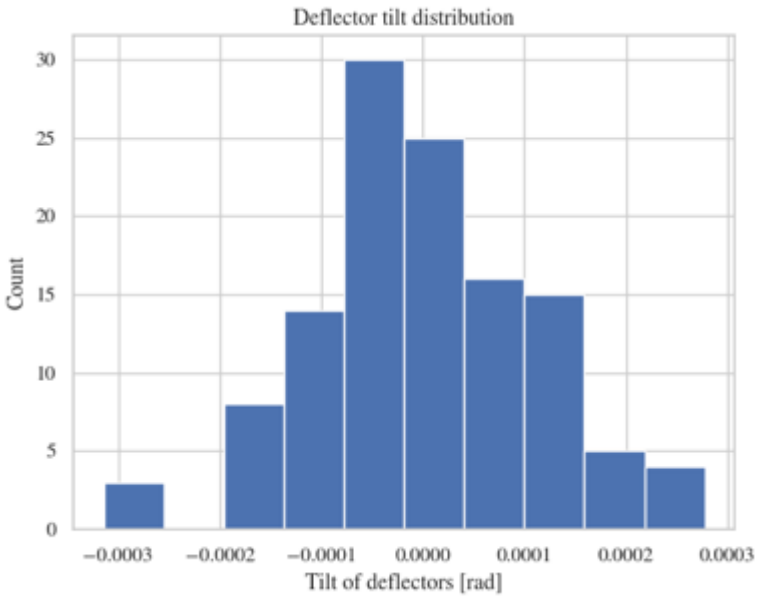


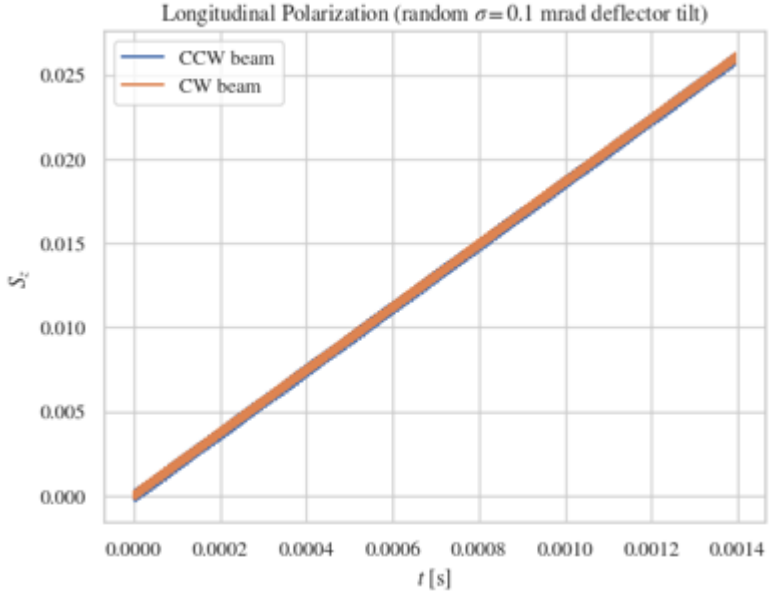
Circumference: 800m
Max E-field: <5MV/m

What happens with misaligned elements?

Running the EDM experiment

Potential systematic error: tilted E-field plates



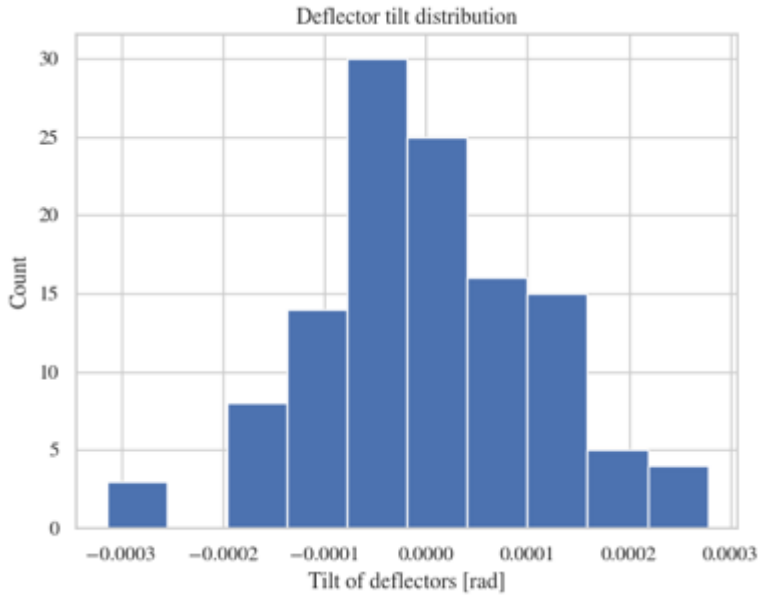


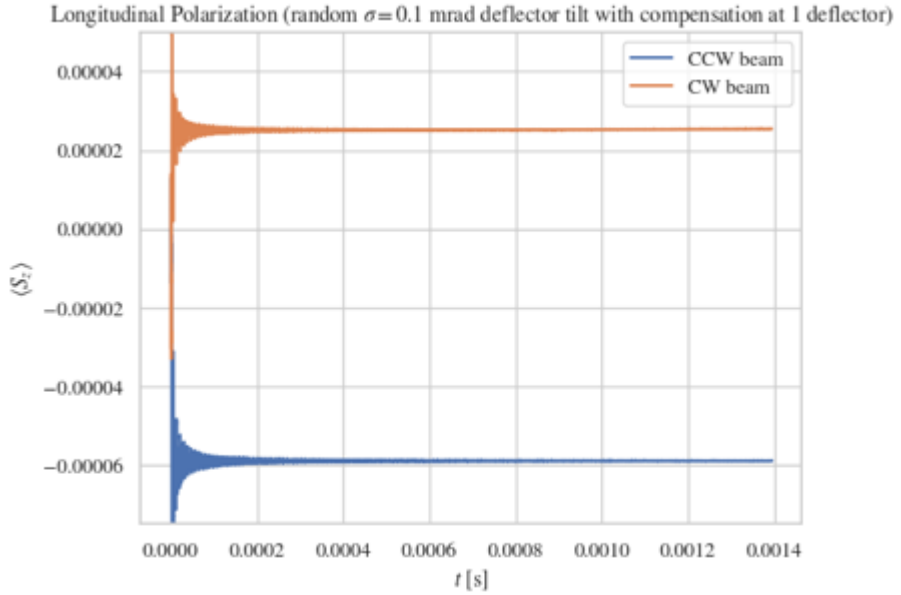
Clock-wise and counter-clock-wise vertical spin precessions are equal and cancel.

Zhanibek Omarov's simulation

Running the EDM experiment

Potential systematic error: tilted E-field plates



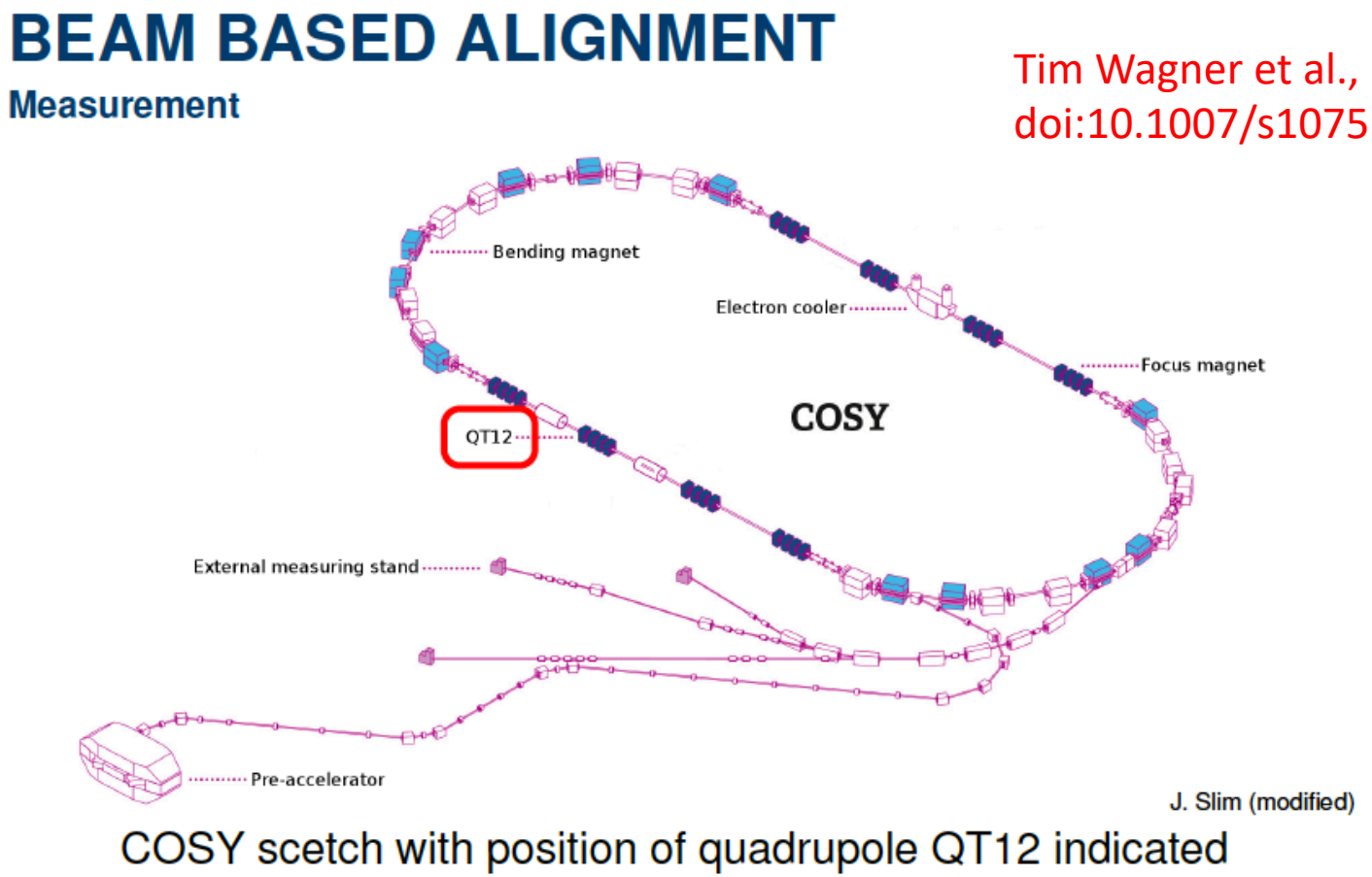


Clock-wise and counter-clock-wise vertical spin precessions are equal, shown here with 1 compensating element.

Zhanibek Omarov's simulation

Beam-based alignment: What is possible?

Beam-based alignment at COSY



COSY scetch with position of quadrupole QT12 indicated

Tim Wagner et al., Hyperfine Interact (2018) 239: 61
doi:10.1007/s10751-018-1539-6

Slide by Tim Wagner, COSY/Juelich, March 2018

Beam-based alignment at COSY

BEAM BASED ALIGNMENT

Derivation of formula for orbit change

$$\Delta x(s) = \left(\frac{\Delta k \cdot x(\bar{s}) l}{B\rho}\right)\left(\frac{1}{1 - k\frac{l\beta(\bar{s})}{2B\rho \tan \pi\nu}}\right)\frac{\sqrt{\beta(s)}\sqrt{\beta(\bar{s})}}{2 \sin \pi\nu}\cos(\phi(s) - \phi(\bar{s}) - \pi\nu)$$

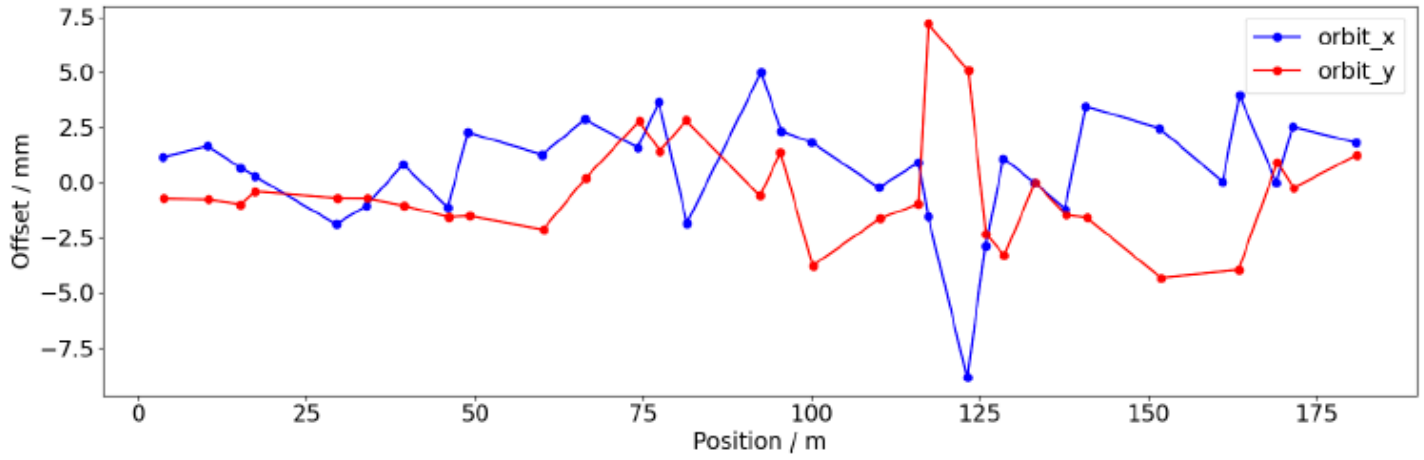
- Δx = orbit change
- s = measurement position
- $\bar{s}$ = position of quadrupole
- Δk = change of quadrupole strength
- $x(\bar{s})$ = position of beam inside the quadrupole
- β = beta function
- ν = tune
- ϕ = betatron phase
- k = quadrupole strength
- l = length of quadrupole
- $B\rho$ = magnetic rigidity of the beam

Slide by Tim Wagner, COSY/Juelich, March 2018

Beam-based alignment at COSY

BEAM BASED ALIGNMENT

Measurement



Slide by Tim Wagner, COSY/Juelich, March 2018

Beam-based alignment at COSY

BEAM BASED ALIGNMENT

Results

	Optimal Position	in mm
Horizontal	-0.255 ± 0.028	-1.98 ± 0.01
Vertical	2.329 ± 0.011	1.15 ± 0.01

- Optimal position given in script setting
- The values in mm are the BPM 6 readings nearby

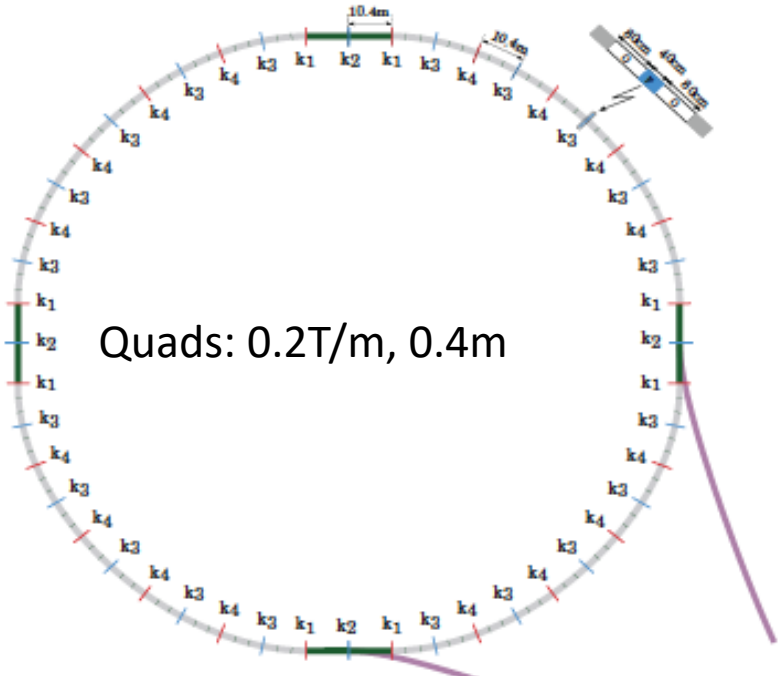
Slide by Tim Wagner, COSY/Juelich, March 2018

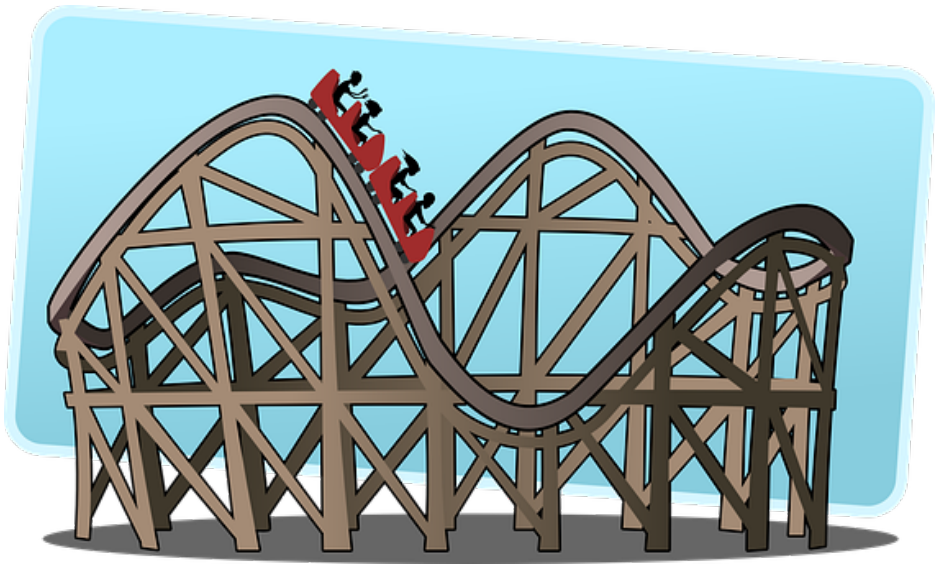
Beam-based alignment

- Quadrupole alignment resolution achieved at COSY: 10 microns
- Limited by the detector resolution (Rogowski coils)
- SQUID-based BPMs have much higher resolution: 10nm/$\sqrt{\mathrm{Hz}}$

What happens with lattice corrugation?

Relevant effect: keep CW and CCW beams at same place to 1-10 microns





What's needed

- Beam-based alignment ~1-10μm of quads (to eliminate geometrical phase issues)
- Clock-wise and counter-clock-wise stored beams need to be same within a SD of ~1-10μm
- Need to hold high voltage for large surface area plates 5 – 8 MV/m for 3cm plates separation (determines ring size)
- Build one section, a 1/48 of the ring lattice to check compatibility & reliability.

Summary

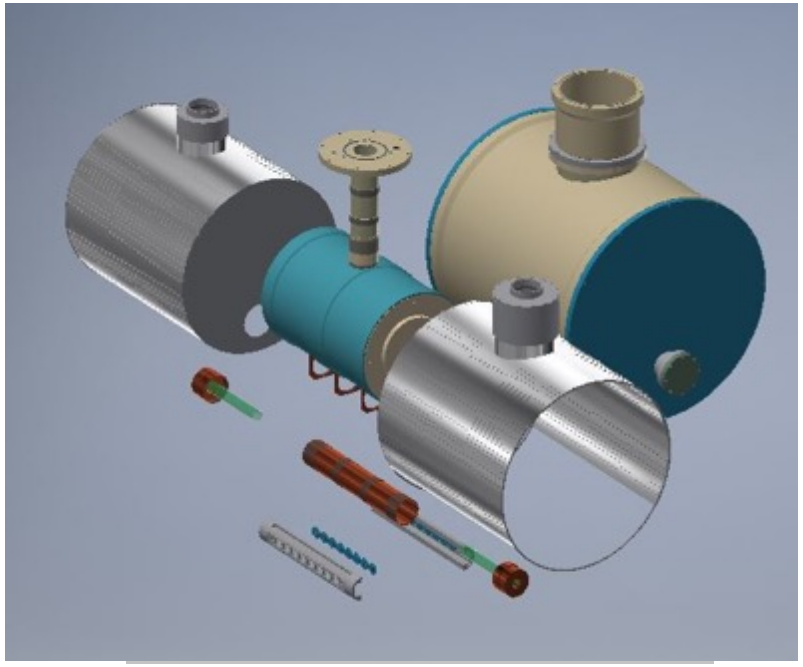
- Great physics reach:
  - Matter-antimatter asymmetry of the universe, CPV
  - Largest sensitivity to New Physics, theta_QCD, DM/DE physics

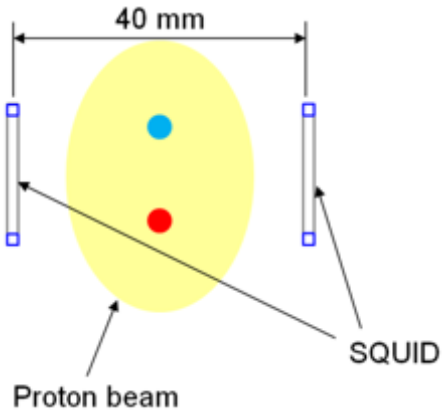
- Hybrid ring design, eliminates main systematic error sources
- S-BPMs and high-precision simulation offer powerful tools in combating systematic errors. Beam-based alignment at micron level

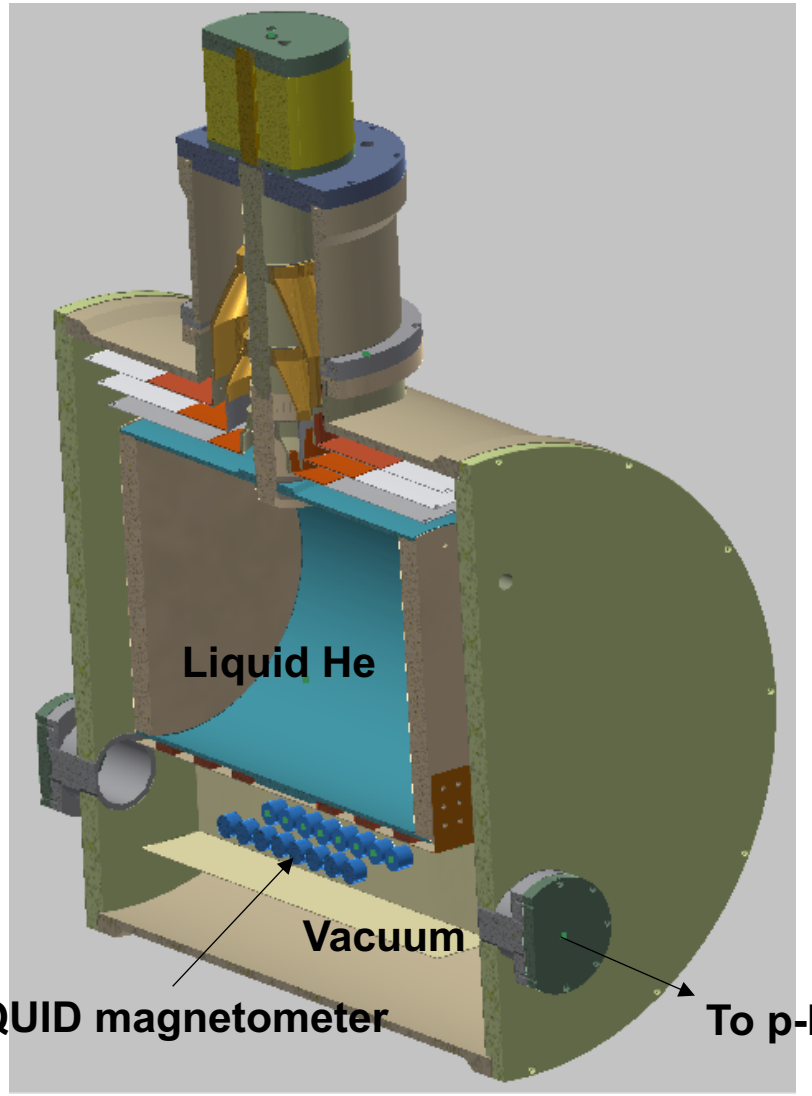
- The proton EDM ring: 500m-800m.

Extra slides

Beam position monitor: SQUID array

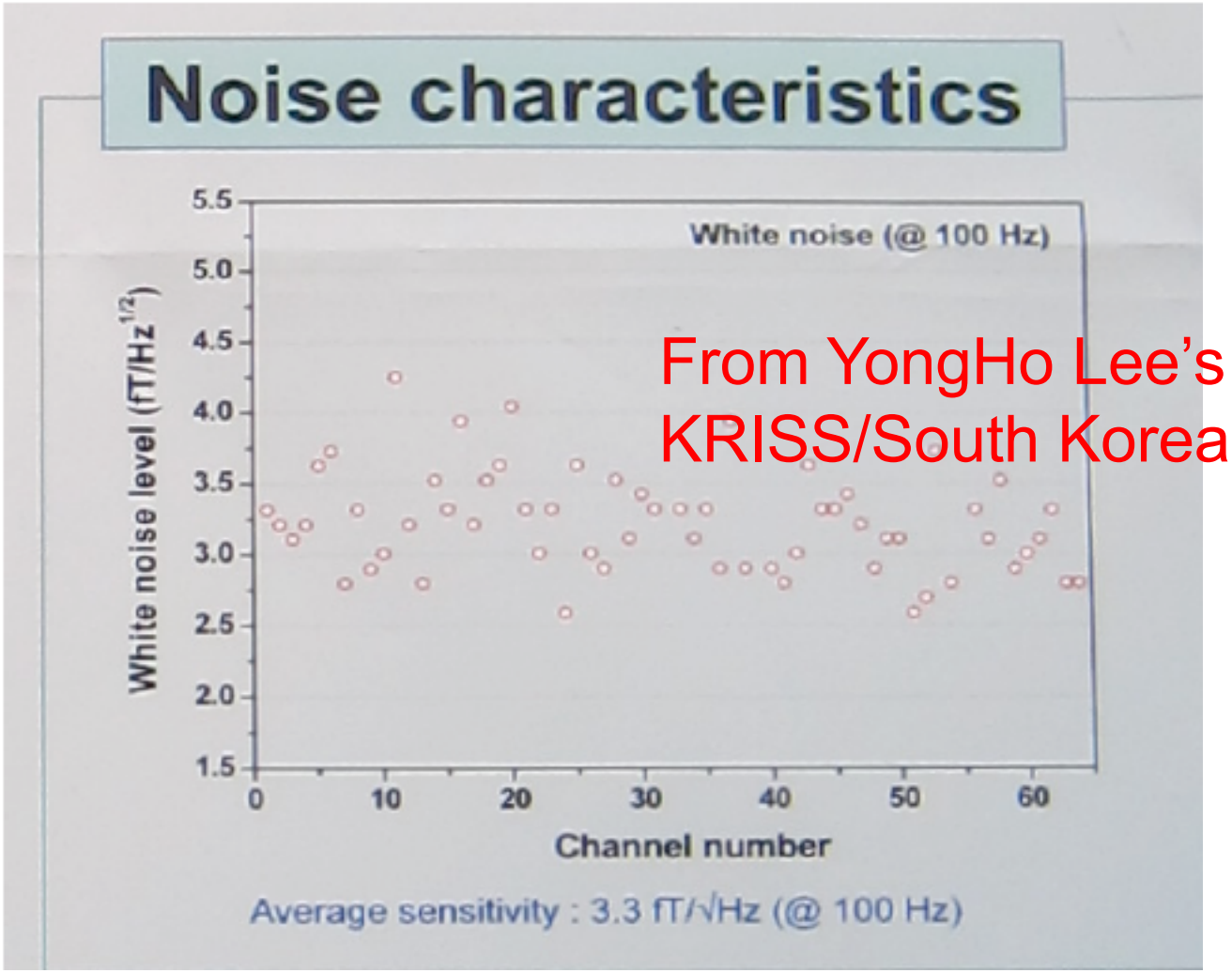






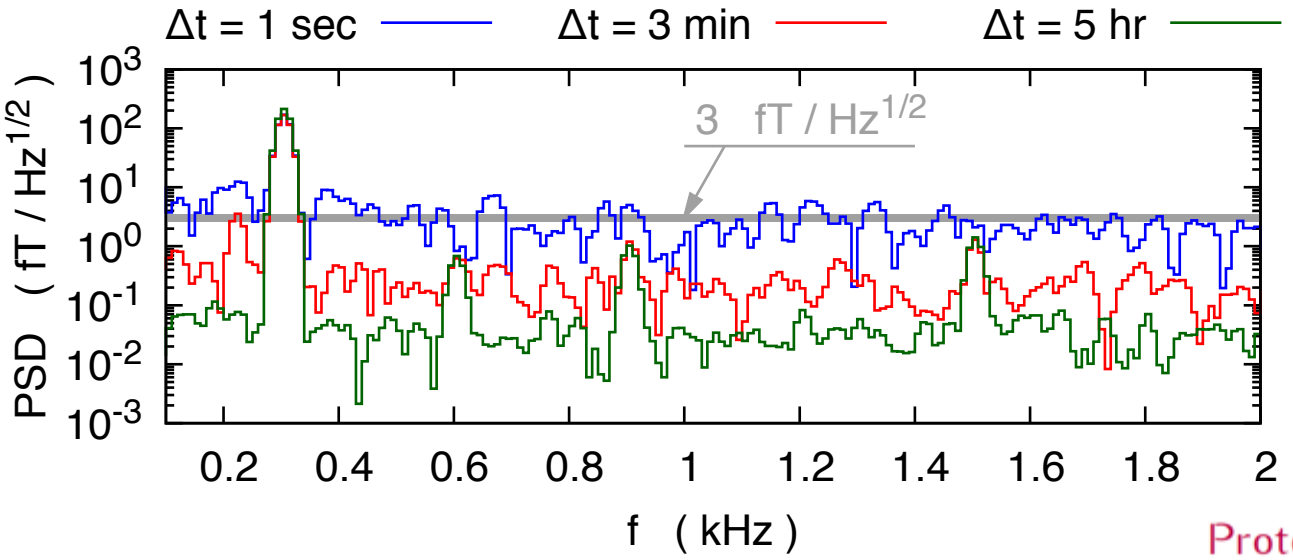
Cylindrical Dewar: under fabrication

Total noise of (65) commercially available SQUID gradiometers at KRISS



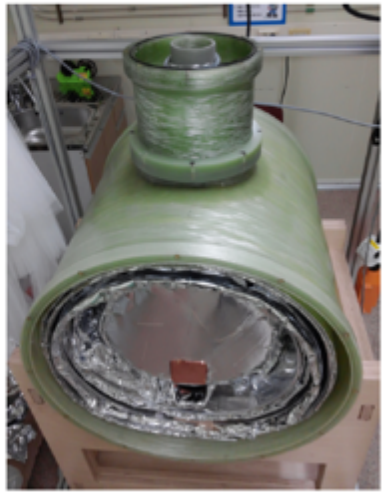
From YongHo Lee's group
KRISS/South Korea

SQUID-based BPMs, Korea



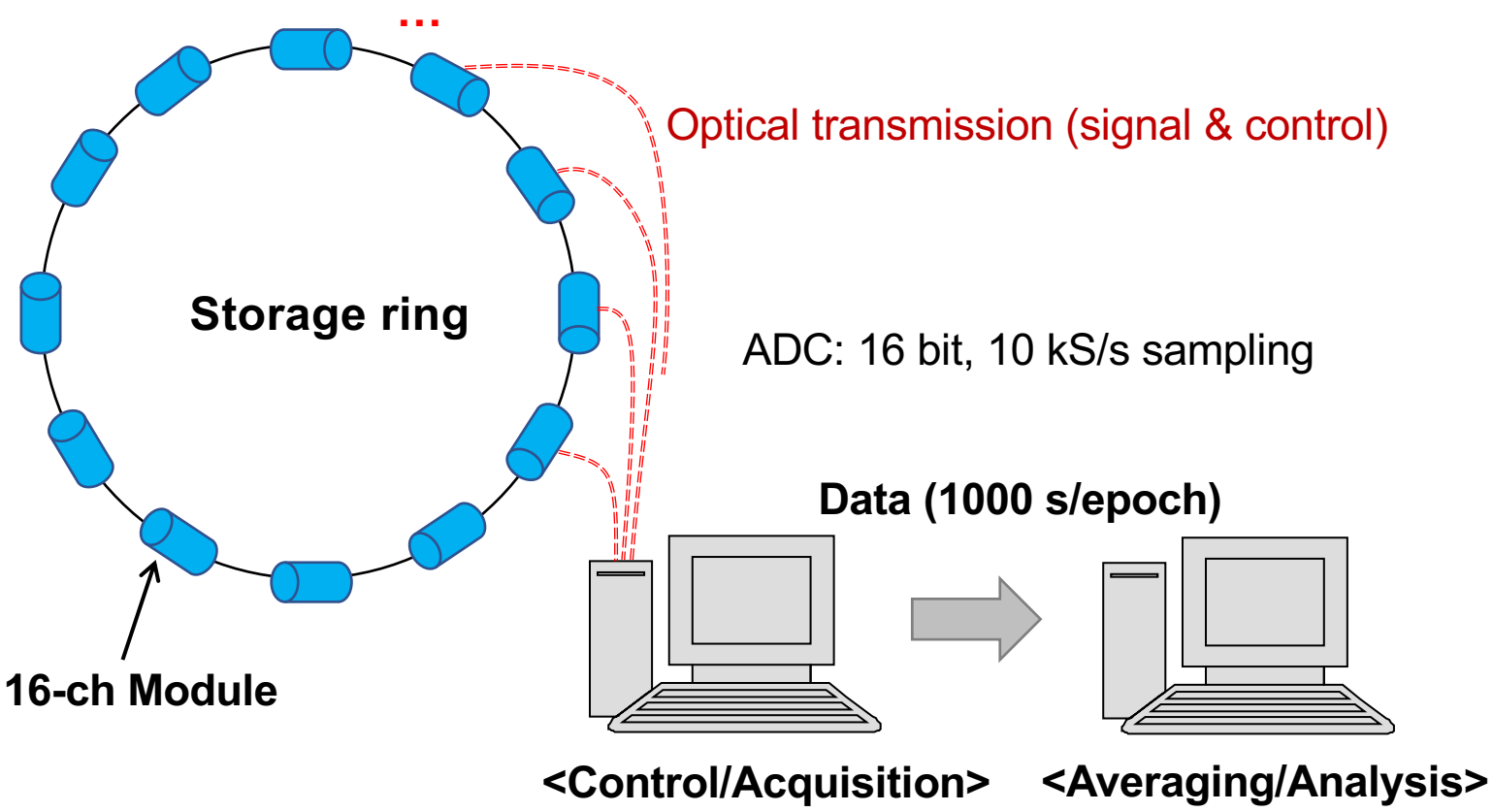
Prototype

- The new design is to be delivered by summer
- Will be 2fT$\sqrt{Hz}$
- We will make wire tests in Korea
- Would be good to test here at COSY



Selcuk Haciomeroglu, IBS/CAPP

BMP Systems in the Storage Ring



Interference-free control

Noise-free acquisition

No time-delay bet. modules

YongHo Lee, KRISS