Mitglied der Helmholtz-Gemeinschaft

Spin Tracking & Final Ring

September 1, 2016 | Andreas Lehrach

RWTH Aachen University & Forschungszentrum Jülich

on behalf of the JEDI collaboration

(Jülich Electric Dipole Moment Investigations)

Computational Needs

- Many particle revolutions: $>>10^6$ turns (~ 1 seconds)

  → efficient simulation program

- Large number of particle to study systematic effects

  → MPI version on a supercomputer

- Precision:

  COSY precursor: 10^{-10}–10^{-9} radians per turn

  Dedicated ring: EDM rotation with by of 10^{-15} radians per turn → roughly 10^{-18} radians per element

  → double precision (64 Bit) provides16 significant decimal digits precision

- EDM spin kick
- Static and RF ExB element including fringe fields

Utilized Simulation Programs

COSY Infinity by M. Berz and K. Makino (MSU)

- based on map generation using differential algebra and the subsequent calculation of the spin-orbital motion for an arbitrary particle, including higher-order nonlinearities, normal form analysis, and symplectic tracking

PTC (Polymorphic Tracking Code) by E. Forest (KEK)

- TPSA maps (truncated power series algebra by Taylor expansion)

Bmad by D. Sagan (Cornell)

- PTC tracking and Runge-Kutta integration

Bench marking with “analog computer” Cooler Synchrotron COSY and other simulation codes

Simulation Setup for COSY Infinity

COSY Toolbox

COSY Lattice → **COSY Toolbox**

COSY INFINITY ↔ **COSY Toolbox**

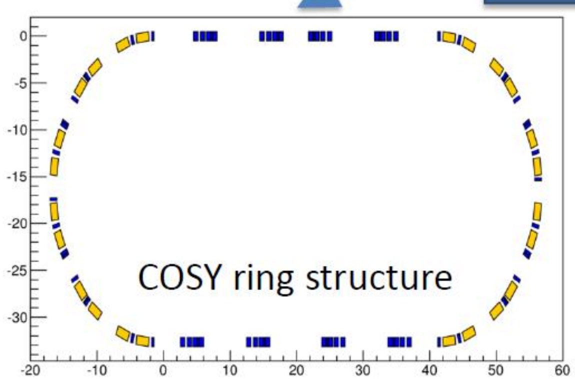
- Calculator:
  - Optical functions
  - Closed orbit
  - Spin tune …
- Tracker:
  - Static maps
  - RF maps (*)

Armadillo ↔ **COSY Toolbox**

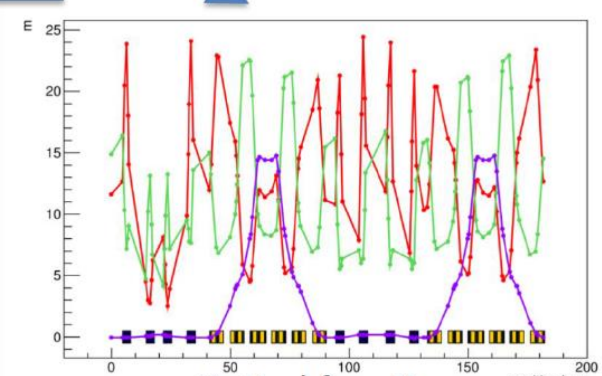
- linear algebra operations
- SVD, pseudo-inverse

COSY Toolbox → **ROOT**

- plotting
- storage (ROOT files/trees)



COSY ring structure



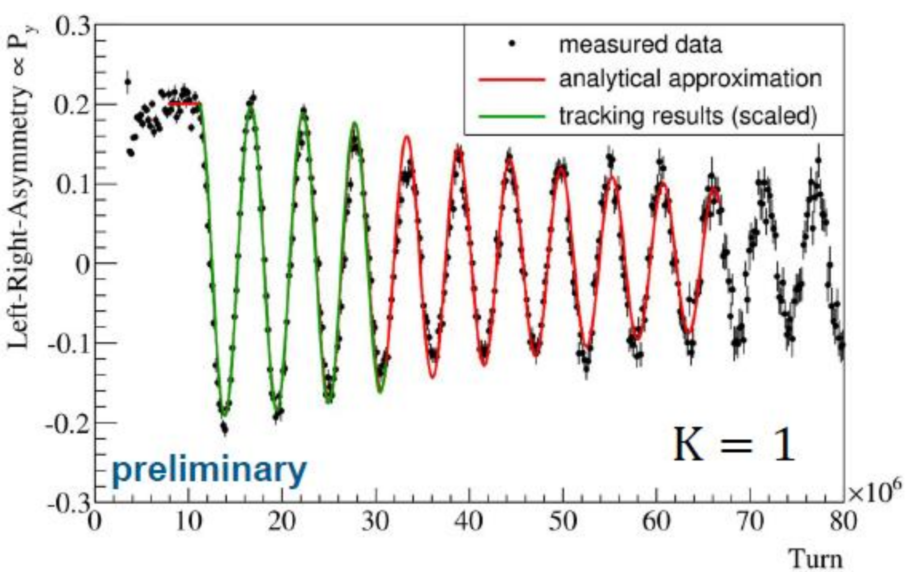
Optical functions

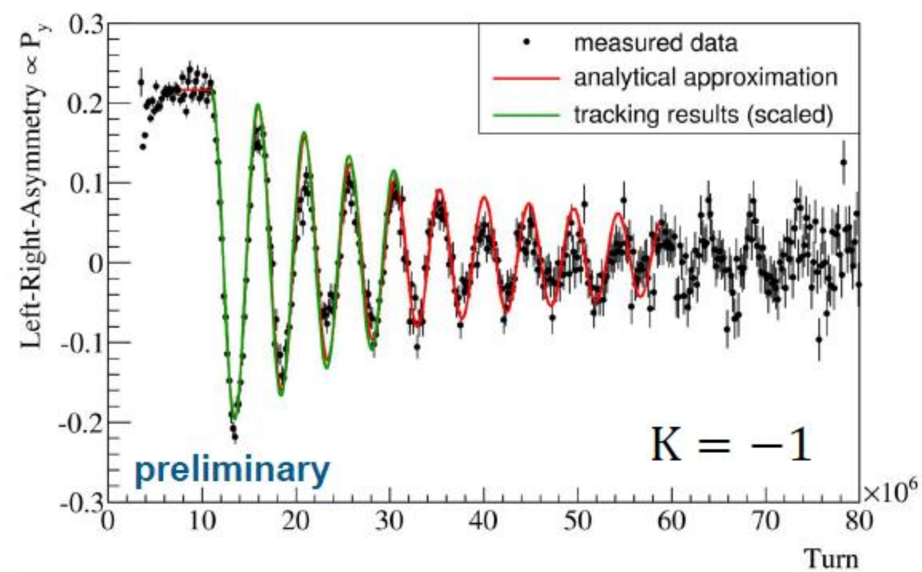
Courtesy: Marcel *Rosenthal* (FZJ)

Benchmarking (COSY INFINITY)

RF spin manipulation elements implemented.
Benchmarking experiment at COSY using driven oscillations induced by the RF solenoid

RF field: $B_{sol} = B_0 \cdot \cos(2\pi \cdot \nu_{sol} \cdot n + \Phi_{sol})$, *resonance condition* $\nu_{sol} = \gamma G \pm k$





Marcel Rosenthal, Andreas Lehrach (FZJ; RWTH Aachen): Proceedings at IPAC 2015: THPF032
Spin Tracking Simulations towards Electric Dipole Moment Measurements at COSY

Deuteron EDM Storage Rings at COSY

„all-in-one“ storage ring

Protons: p_p = 0.701 GeV/c
E_R = 16.8 MV/m, B_V = 0 T

Deuterons: p_d = 1.0 GeV/c
E_R = -4.0 MV/m, B_V = 0.16 T

Helium-3: $p_{3_{He}}$ = 1.285 GeV/c
E_R = 17.0 MV/m, B_V = -0.05 T

„all-in-one“ storage ring

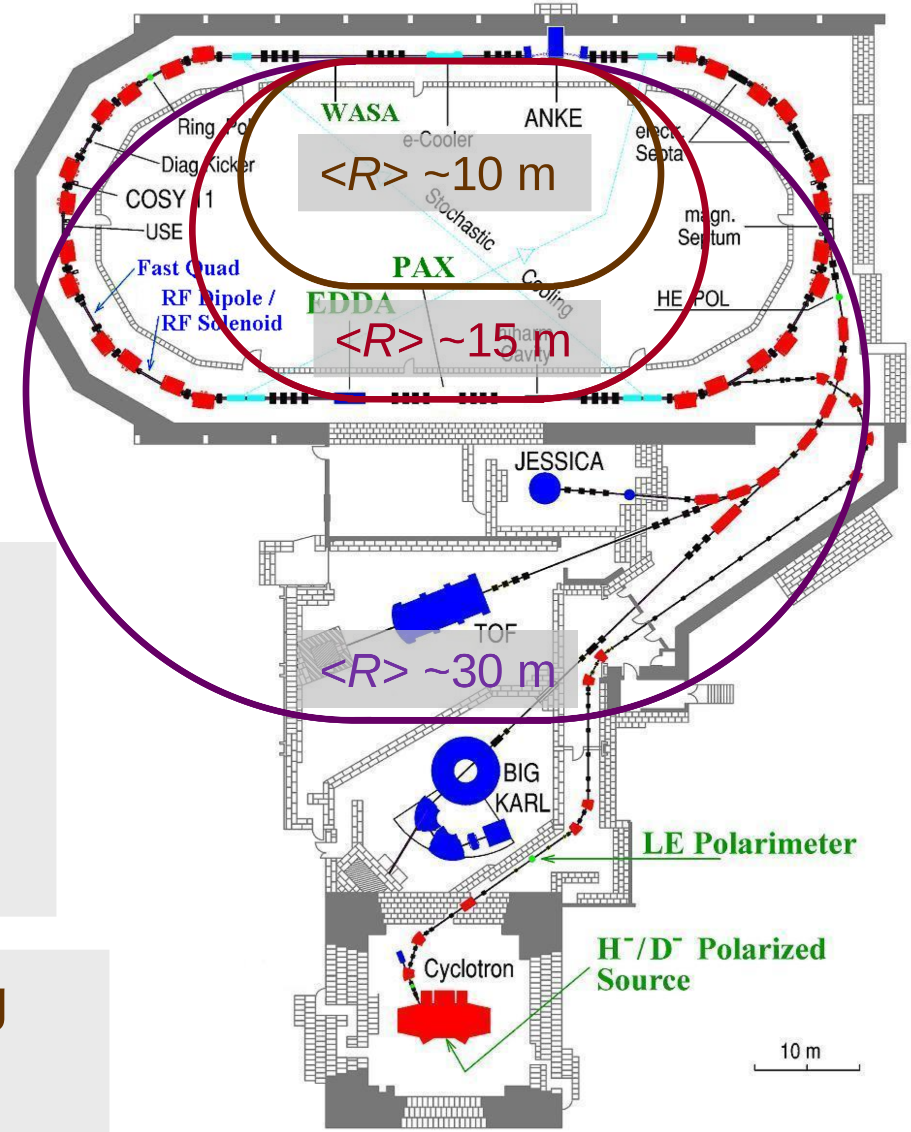
Protons: p_d = 0.527 GeV/c
E_R = 16.8 MV/m, B_V = 0.02 T

Deuterons: p_d = 1.0 GeV/c

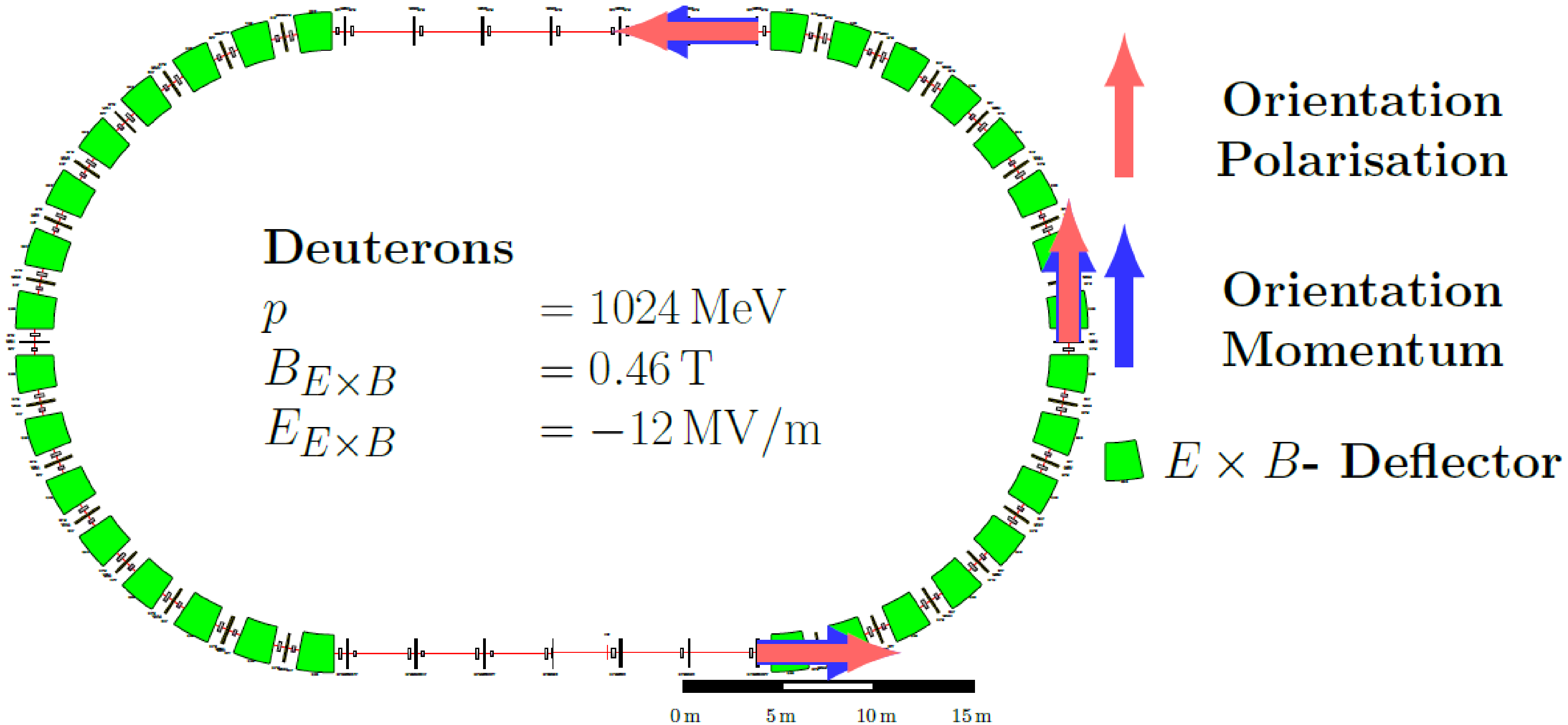
Helium-3: $p_{3_{He}}$ = 0.946 GeV/c

Dedicated deuteron storage ring

Deuterons: p_d = 1.0 GeV/c
E_R = -12.0 MV/m, B_V = 0.48 T

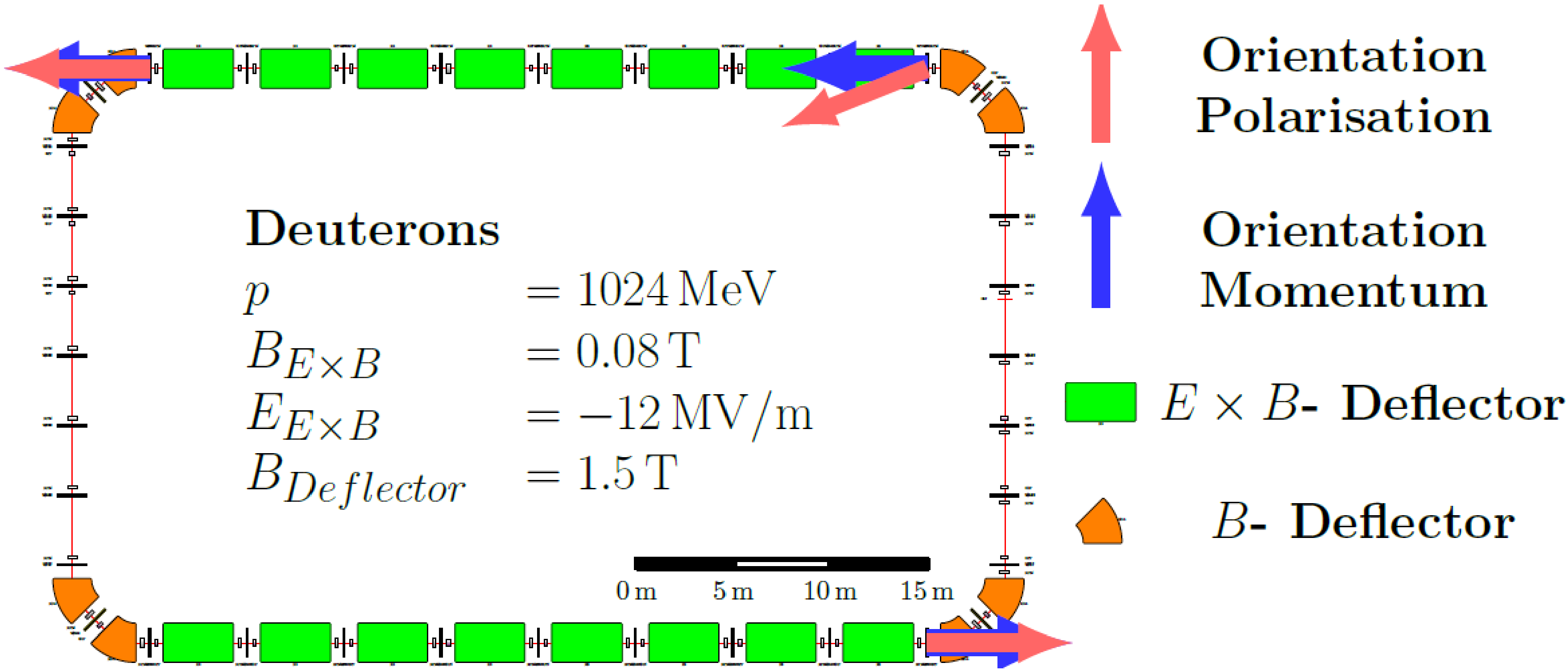


Frozen Spin Ring



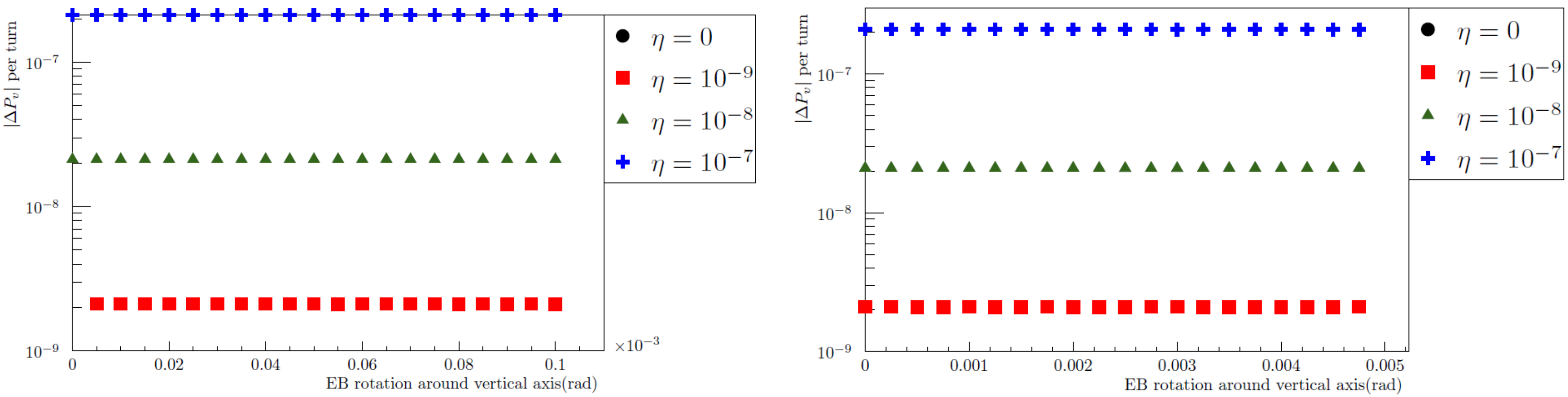
Courtesy: Yu.Senichev (FZJ)

Quasi-Frozen Spin Ring



Courtesy: Yu. Senichev (FZJ)

Simulation Results (preliminary)

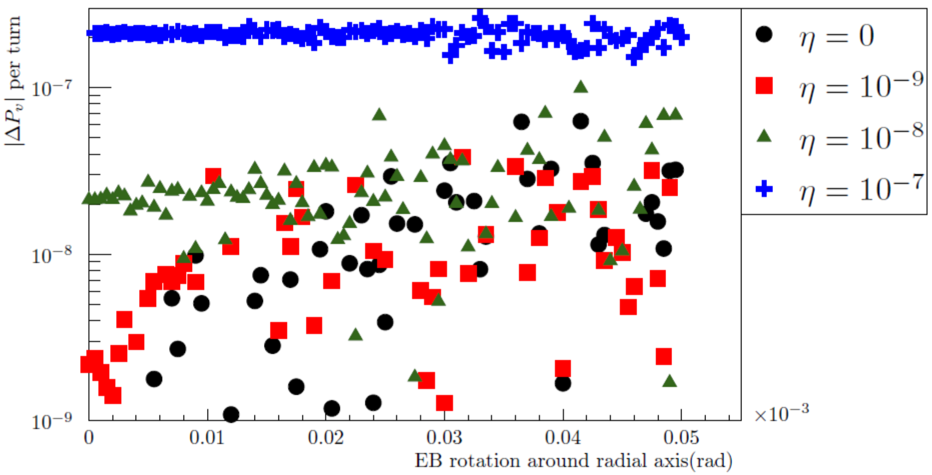


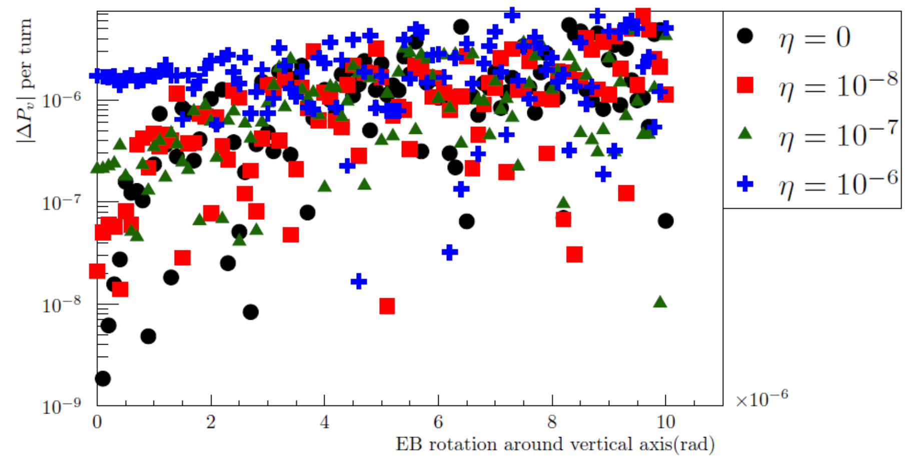
Frozen Spin (left) – Quasi-Frozen Spin (right)

Vertical spin build up for different magnitudes of EDM and RMS of rotation misalignments of the ExB deflectors around the vertical axis.
Each simulation has new randomly generated misalignments.

Courtesy: A. Skawran (FZJ)

Simulation Results (preliminary)



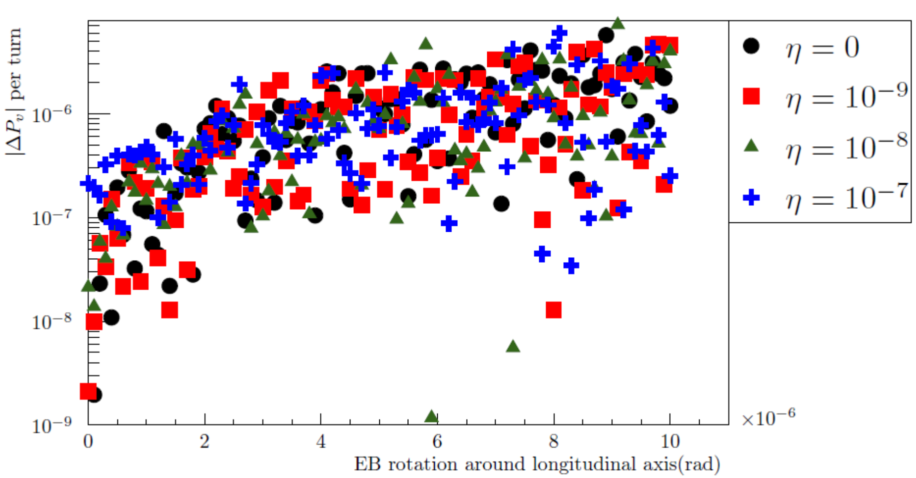


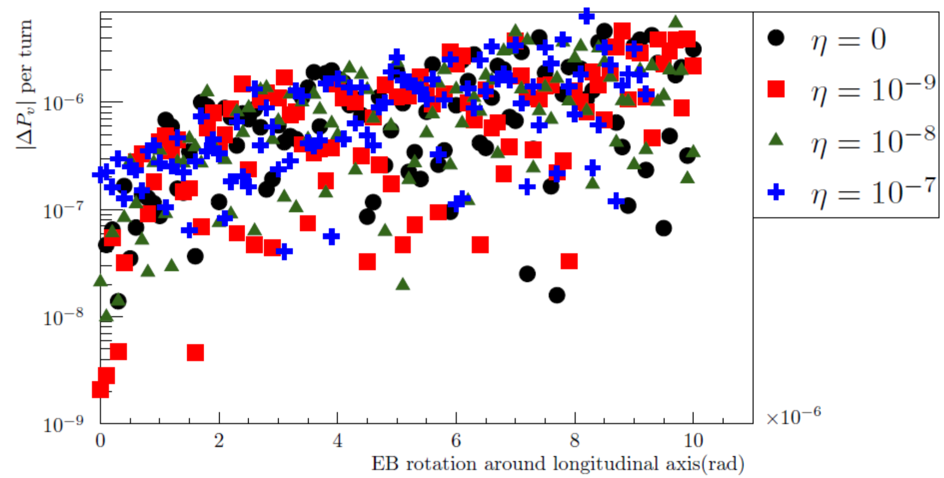
Frozen Spin (left) – Quasi-Frozen Spin (right)

Vertical spin build up for different magnitudes of EDM and RMS of rotation misalignments of the EB deflectors around the radial axis.
Each simulation has new randomly generated misalignments.

Courtesy: A. Skawran (FZJ)

Simulation Results (preliminary)



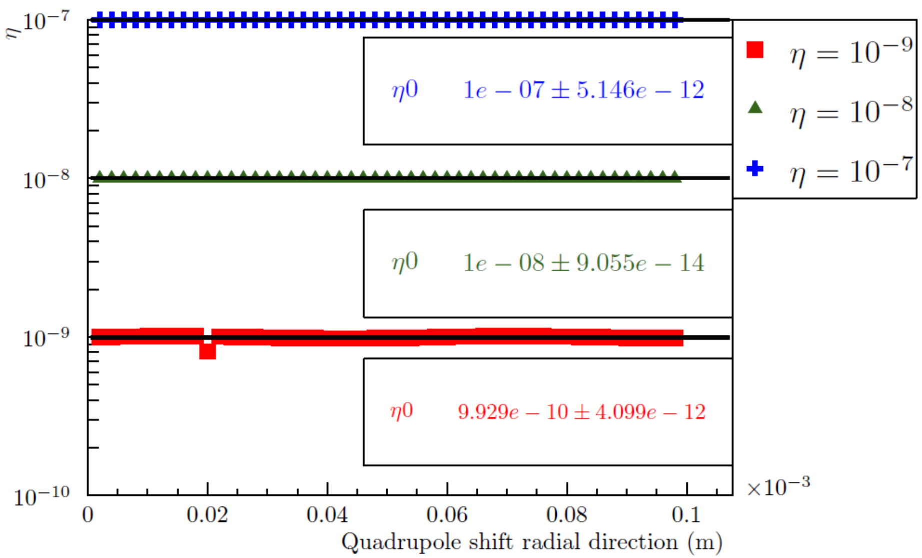


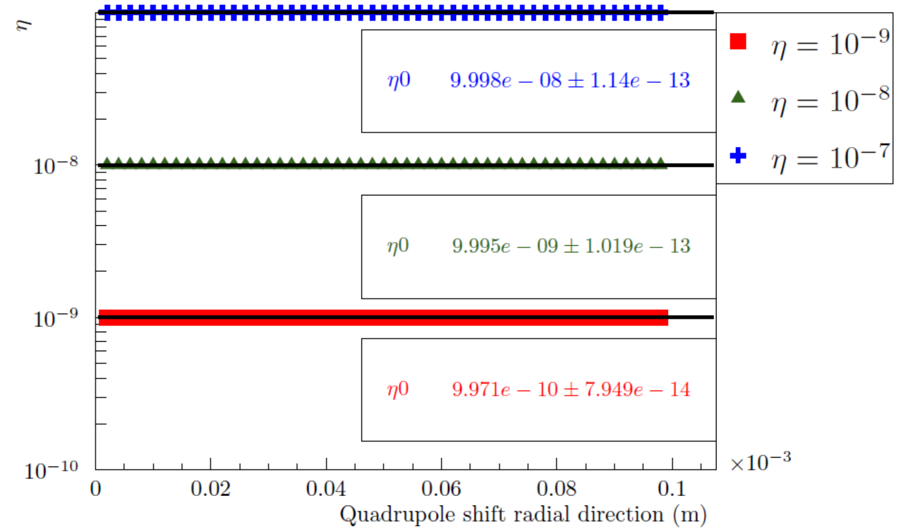
Frozen Spin (left) – Quasi-Frozen Spin (right)

Vertical spin build up for different magnitudes of EDM and RMS of rotation misalignments of the EB deflectors around the longitudinal axis.
Each simulation has new randomly generated misalignments.

Courtesy: A. Skawran (FZJ)

Simulation Results (preliminary)





Frozen Spin (left) – Quasi-Frozen Spin (right)

Difference of the vertical spin build up for different magnitudes of EDM and RMS of shift misalignments of the quadrupoles in radial direction divided by 2.

Courtesy: A. Skawran (FZJ)

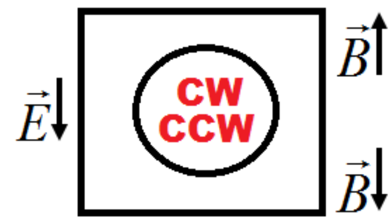
Deuteron EDM Proposal (srEDM)

Deuteron momentum: p = 1 GeV/c,

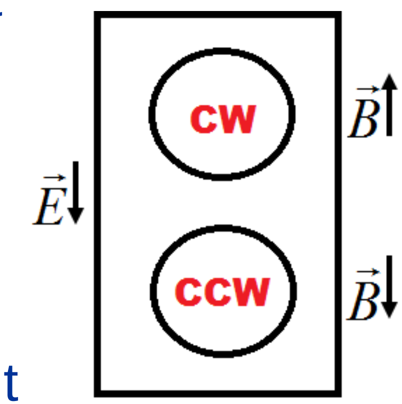
Ring parameter: R_B = 8.4 m, $<R>$ ~ 10 m, C = 85m

Deflectors: E_R = -12 MV/m (radial), B_V = 0.48 T (vertical)

- 2004 BNL proposal: single ring
  CW and CCW consecutive beam injections
  Limiting error: time-dependent part of the
  average vertical electric field over the entire ring
  → sensitivity $\sim 10^{-27}\, e \cdot cm$ for one year measurement



- 2008 BNL proposal: double ring
  CW and CCW simultaneously
  2-in-1 magnet design with common E-field plates
  → sensitivity $\sim 10^{-29}\, e \cdot cm$ for one year measurement



See http://www.bnl.gov/edm


Thank you!