Electric Dipole Moments of Charged Particles

— Activities at COSY/Forschungszentrum Jülich - Plans for a new Storage Ring at CERN

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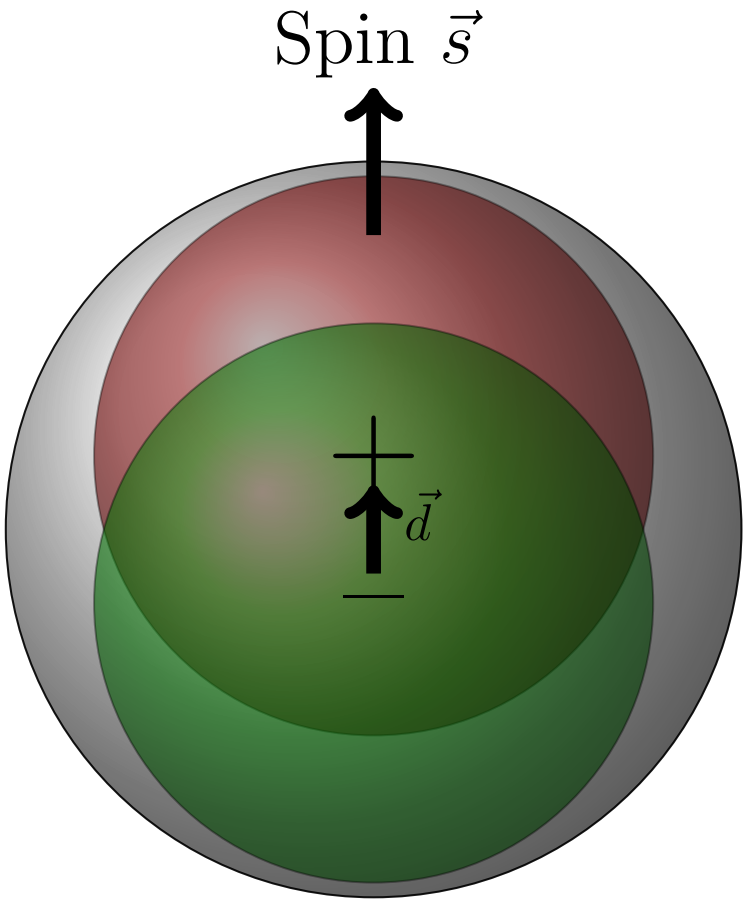
Outline

- Electric Dipole Moment (EDM) requires dedicated new storage ring ($\rightarrow$ long term project)
- this talk:
  - intermediate steps using existing storage ring COSY at Forschungszentrum Jülich, Germany
  - design of a new storage ring (at CERN)

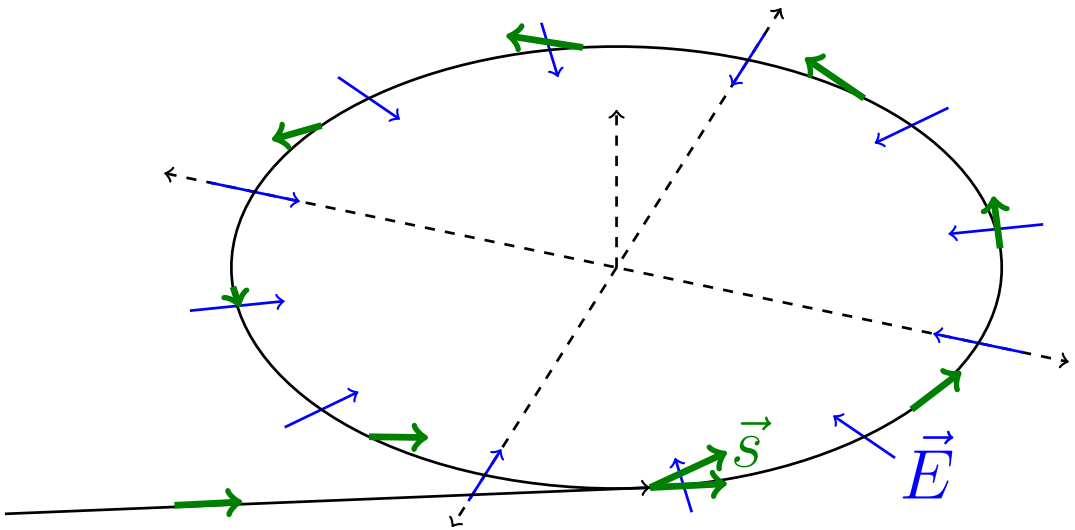
Electric **D**ipole **M**oments (EDM)



- permanent separation of positive and negative charge
- fundamental property of particles
  (like magnetic moment, mass, charge)
- existence of EDM only possible via violation of time reversal $\mathcal{T}$ ($\overset{\mathcal{CPT}}{=}\ \mathcal{CP}$) and parity $\mathcal{P}$ symmetry
- close relation to origin of matter-antimatter asymmetry in in the universe

Experimental Method: Generic Idea

For **all** EDM experiments (neutron, proton, atoms, . . .):
Interaction of $\vec{d}$ with electric field $\vec{E}$
For charged particles: apply electric/magnetic field in a storage ring:



$$\frac{\mathrm{d}\vec{s}}{\mathrm{d}t} \propto d\vec{E} \times \vec{s}$$

In general:

$$\frac{\mathrm{d}\vec{s}}{\mathrm{d}t} = \vec{\Omega} \times \vec{s}$$

build-up of vertical polarization $s_\perp \propto |d|$

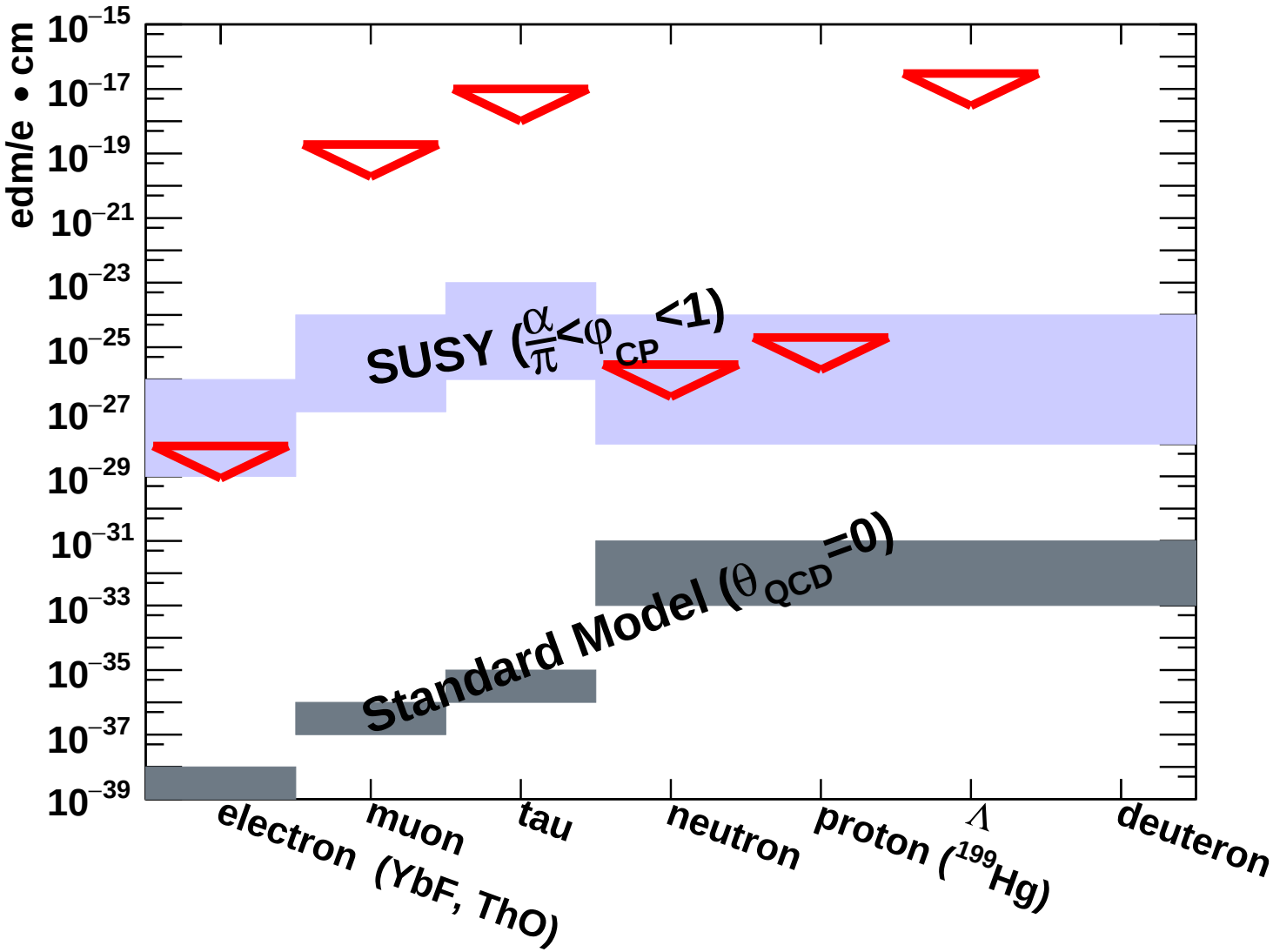
Requirements

- storage ring for protons and/or deuterons ($p \approx 1\text{GeV}/c$)
- polarized hadron beams ($P = 0.8$)
- high intensity beams ($N = 4 \cdot 10^{10}$ per fill)
- long spin coherence time ($\tau = 1000\,\text{s}$),
- large electric fields ($E = 10\,\text{MV/m}$)
- polarimetry (analyzing power $A = 0.6$, acc. $f = 0.005$)

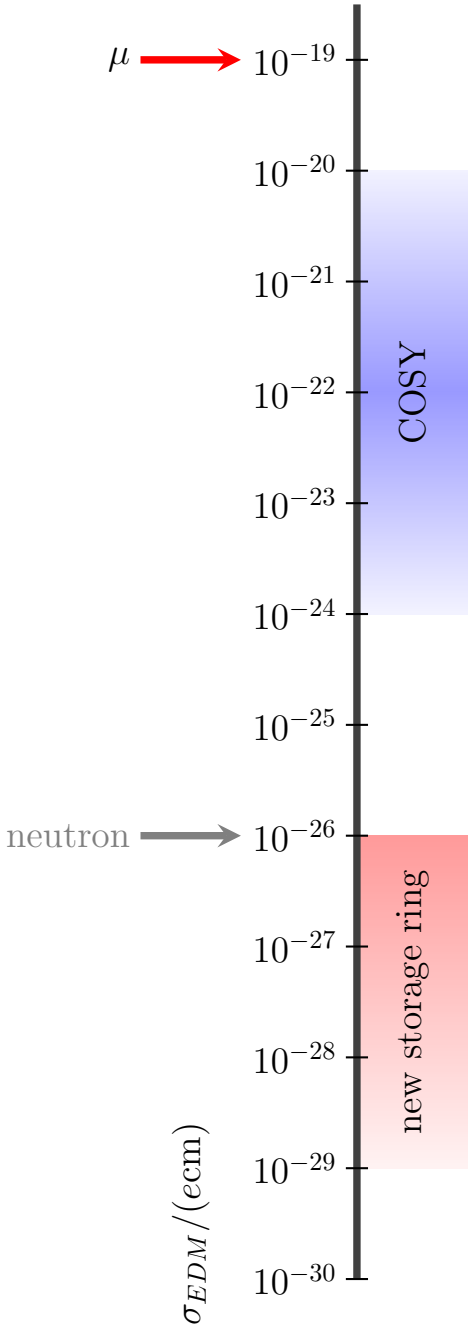
$$\sigma_{\text{stat}} \approx \frac{\hbar}{\sqrt{Nf}\tau PAE} \quad \Rightarrow \sigma_{\text{stat}}(1\text{year}) = 10^{-29}\, e\cdot\text{cm}$$

challenge: get σ_{sys} to the same level

EDM Limits


edm/e • cm
10^{-15}
10^{-17}
10^{-19}
10^{-21}
10^{-23}
10^{-25}
10^{-27}
10^{-29}
10^{-31}
10^{-33}
10^{-35}
10^{-37}
10^{-39}
SUSY ($\frac{\alpha}{\pi}<\varphi_{CP}<1$)
Standard Model ($\theta_{QCD}=0$)
electron (YbF, ThO)
muon
tau
neutron
proton (^{199}Hg)
Λ
deuteron

Storage Ring EDM



- Only storage ring measurement: muon (parasitic measurement to muon $g-2$)
- COSY at Forschungszentrum Jülich, Germany:
  magnetic storage ring,
  pol. proton and **deuteron** beams up to 3 GeV/c
  $\rightarrow$ ideal starting point

Cooler Synchrotron COSY

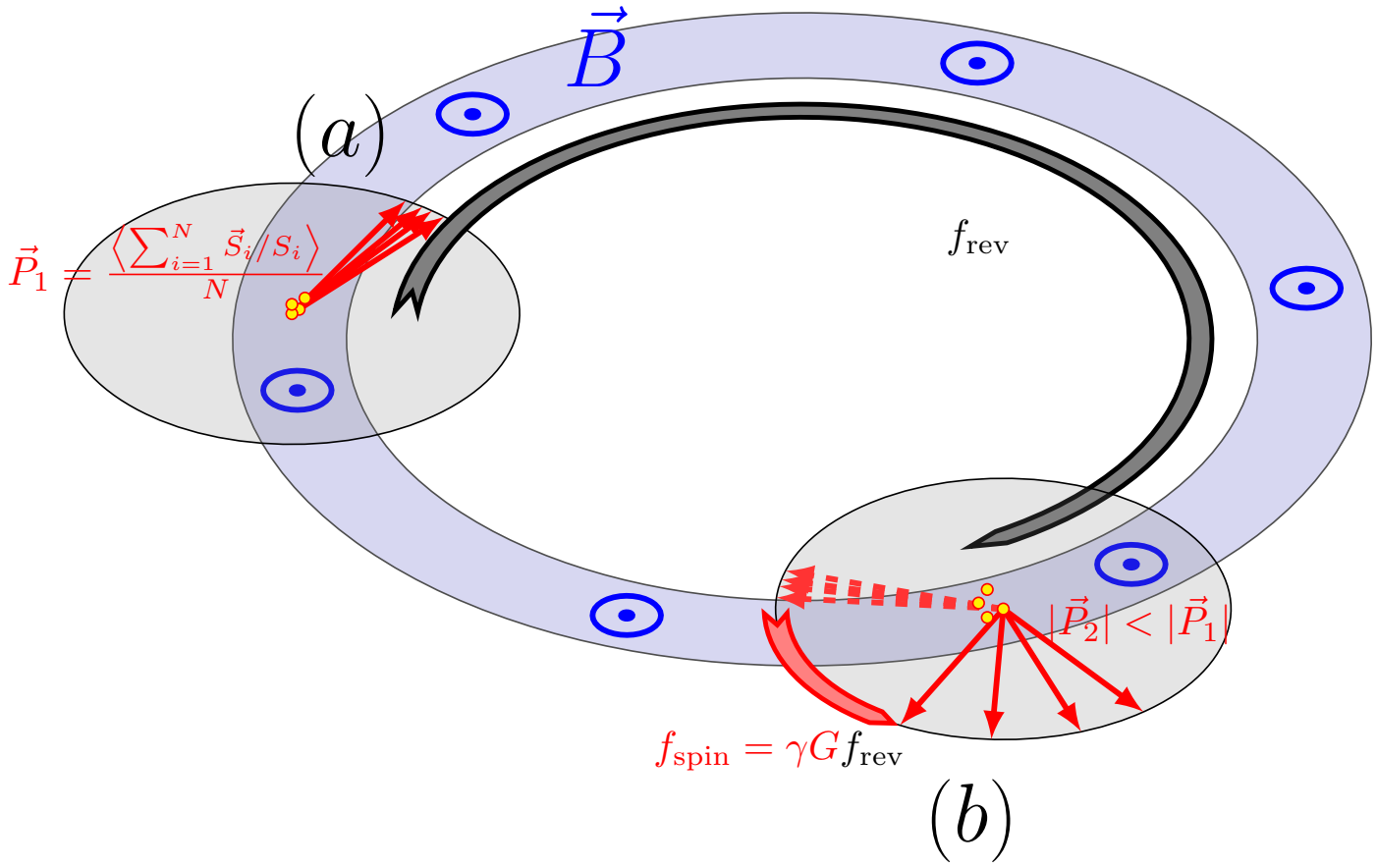
Recent achievements and activities

1. **Spin coherence time:** $\tau > 1000$ s
   (PRL 117, 054801 (2016))
2. **Spin tune:** $\overline{\nu_s} = -0.16097\cdots \pm 10^{-10}$ in 100 s
   (PRL 115, 094801 (2015))

- Spin feedback: polarisation vector kept within 12 degrees
  (PRL 119 014801 (2017))
- Polarimetry
- Deflector development
- beam instrumentation
- Spin Tracking (benchmarking of codes)

based on this: first measurement of deuteron EDM in 2018
(proof of principle)

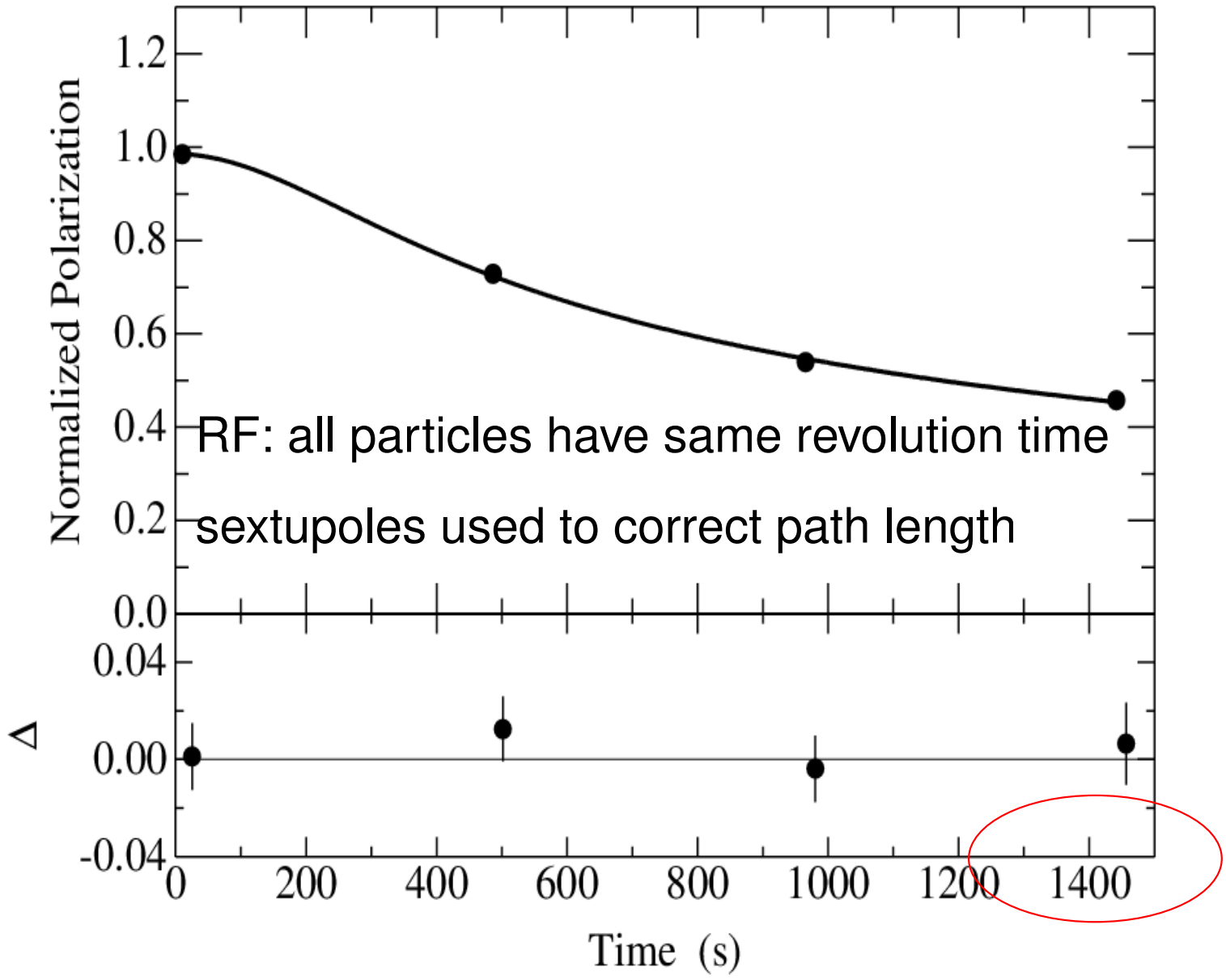
Spin Precession



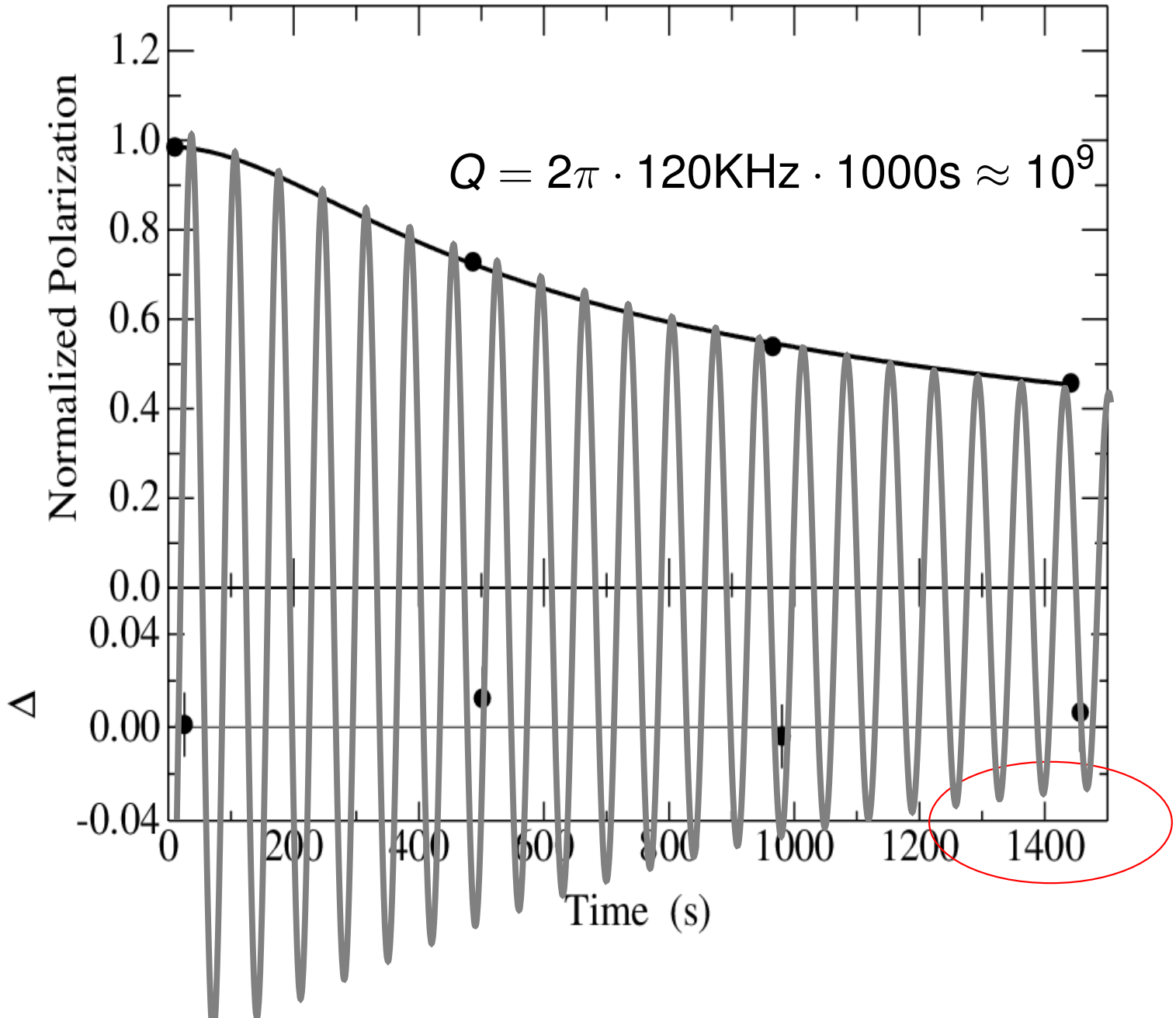
Spin precession frequency: $f_{spin} = \gamma G f_{rev} \approx 120$ KHz
with $\Delta\gamma \approx 10^{-6} \rightarrow$ decoherence after 10^6 turns $\widehat{=}1$ s

gyromagnetic anomaly $G(\mathrm{deuteron}) = -0.142561789$

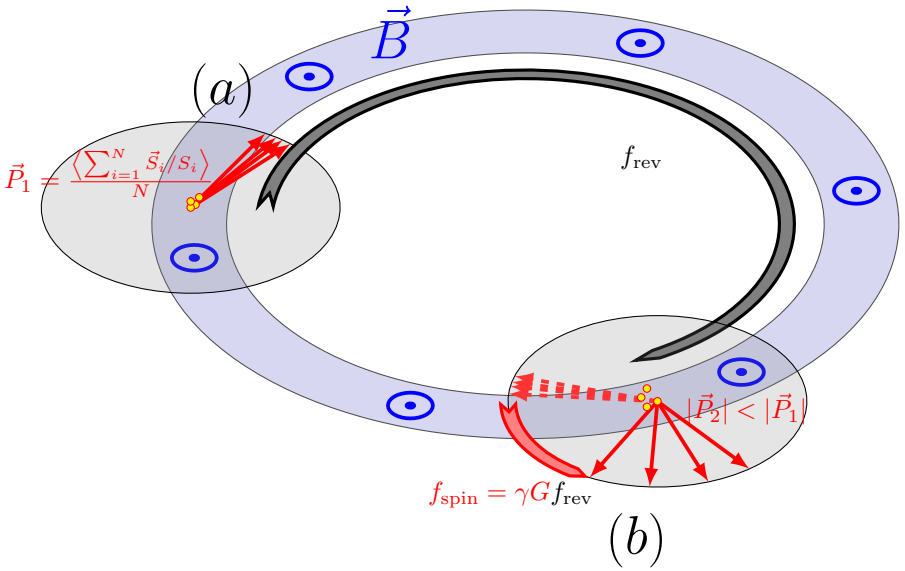
1.) Spin Coherence Time (SCT)

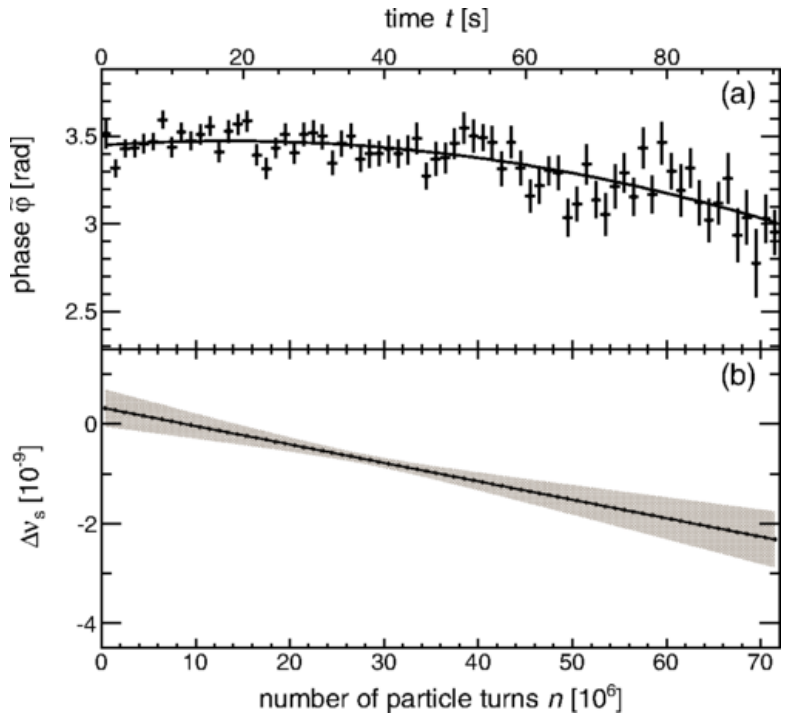


1.) Spin Coherence Time (SCT)



2.) Spin Tune ν_s

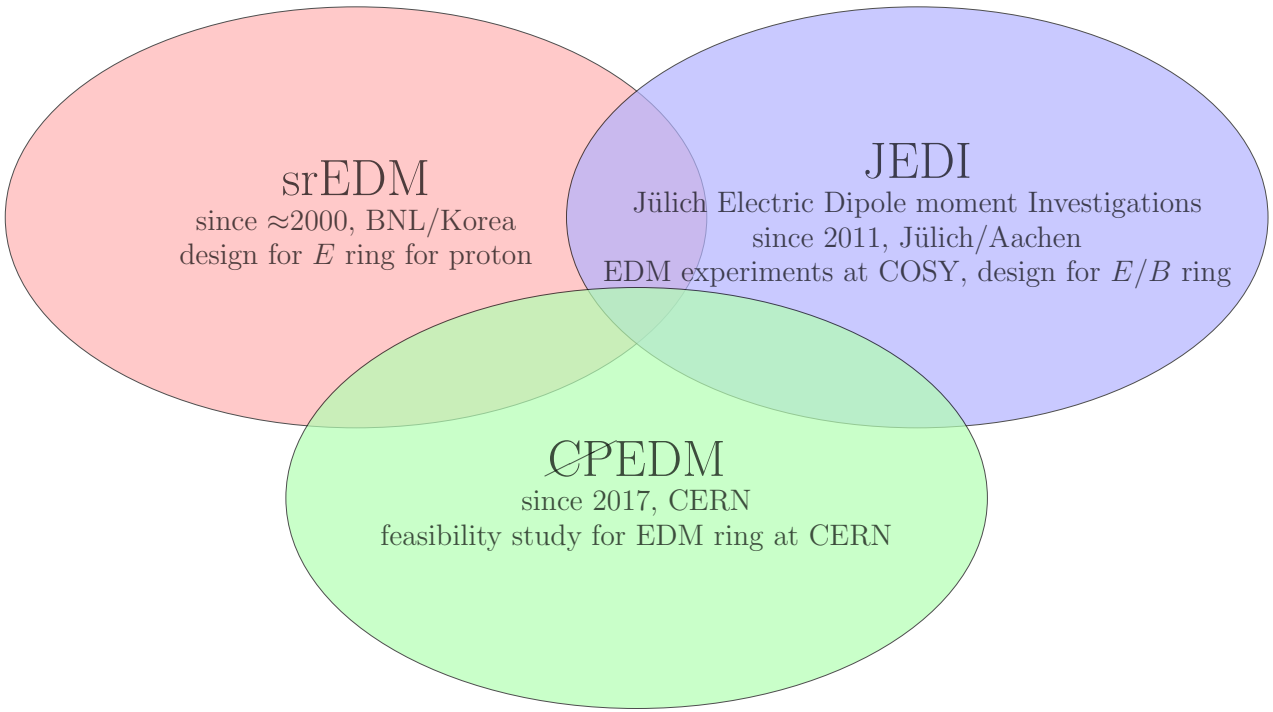




$\sigma(\nu_s = \gamma G) \approx 10^{-10}$ in 100 s

Note: $\gamma G = \dfrac{f_{spin}^{MDM}}{f_{rev}}$, $\qquad \dfrac{f_{spin}^{EDM}}{f_{rev}} \approx 10^{-10}$ for EDM $d = 10^{-24}\, e\,\mathrm{cm}$

- CPEDM (charged particle EDM) collaboration established



Kick-off meeting 1-2 March 2017

Work packages

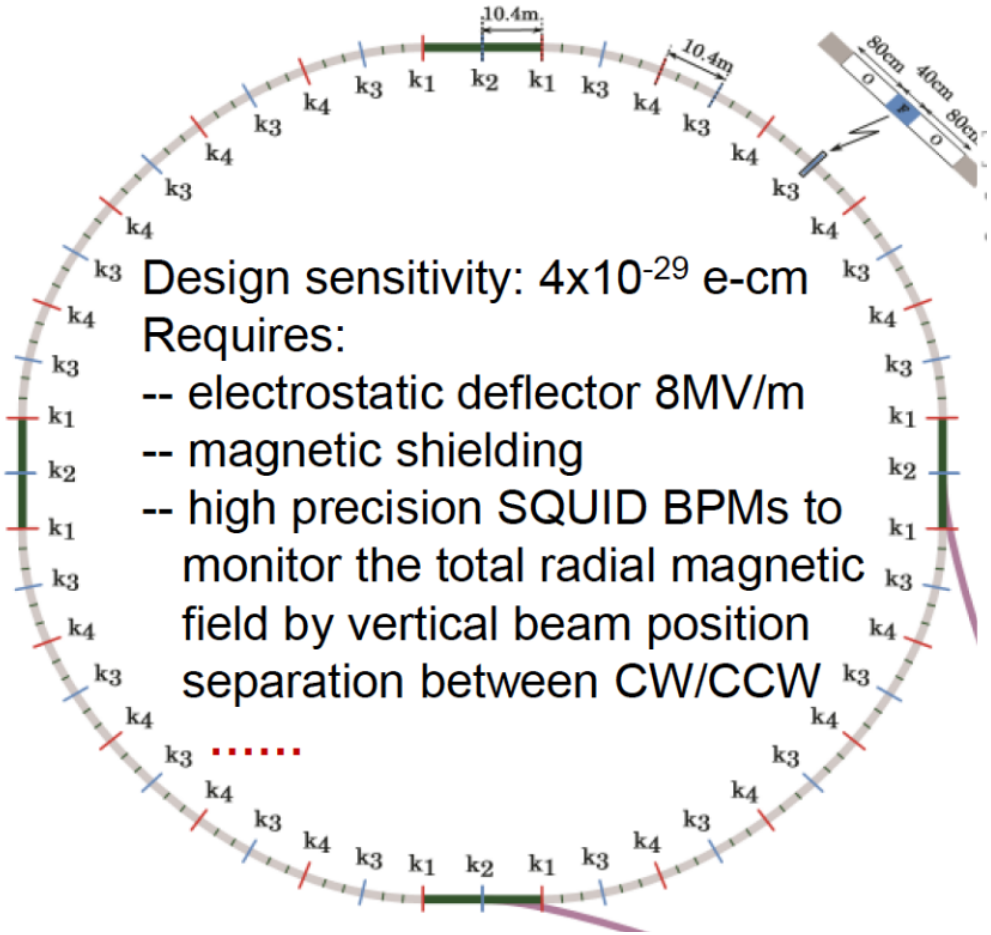
WP	Institute	Comment
Science case	KAIST/FZJ/CERN	
Ring design	KAIST/FZJ/CERN	different options
Beam control	FZJ	cooling, feedbacks
Beam delivery	CERN/FZJ	Source, acceleration, injection
Ring components I	CERN	RF, vacuum, Beam Instr.
Ring components II	KAIST/FZJ/CERN	Shielding, deflectors
Polarimetry	FZJ	p,d, targets, systematics
Siting at CERN	CERN	Site,CE,cost
Systematics	KAIST/FZJ/CERN	alignment, B_r, orbit
		phase space CW/CCW, . . .

KAIST: Korea Advanced Institute of Science & Technology
FZJ: Forschungszentrum Jülich

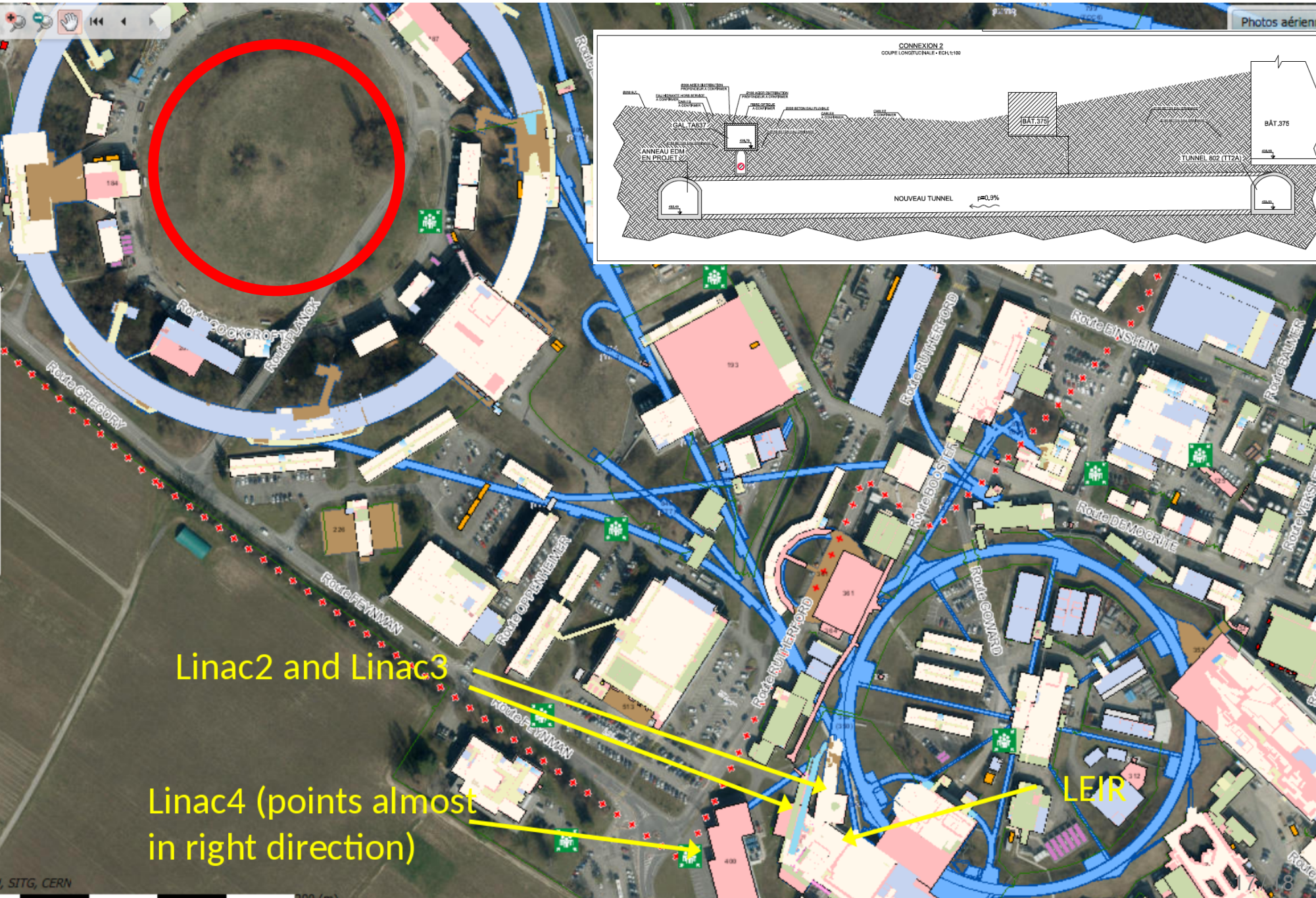
Goal: Feasibility study for proton/deuteron storage ring

Options for an EDM ring

	☺	☹
pure electric ring	no $\vec{B}$ field needed, CW/CCW beams simultaneously	works only for particles with $G > 0$ with (e.g. p with 0.7007 GeV/c)
combined ring	works for p, d, ^{3}He, . . .	both $\vec{E}$ and $\vec{B}$ required field reversal needed to run CW/CCW



Possible Site at CERN



Summary

- EDMs are unique probe to search for new CP-violating interactions
- **charged** particle EDM searches require new high precision storage rings
- Activities are underway at magnetic storage ring COSY at Forschungszentrum Jülich
- Collaboration (CPEDM) established to investigate possibility for the construction of new storage ring
  Goal: Feasibility study end of 2018