Storage rings for hadron Electric Dipolar Moments measurements

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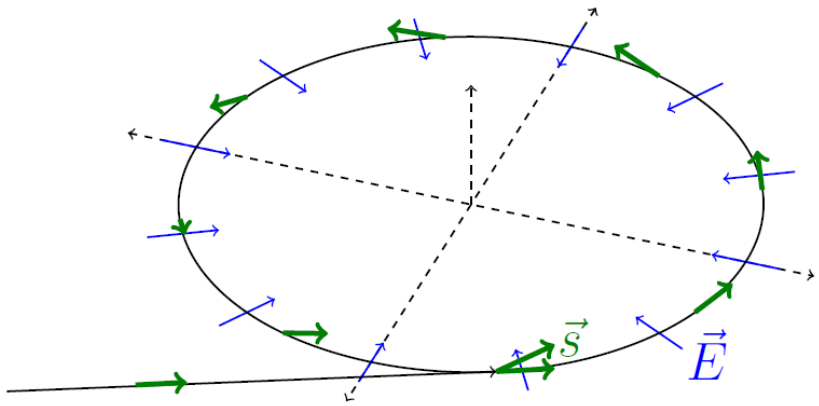
The basic idea: build up of a vertical polarisation

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



$$\frac{d\vec{s}}{dt} \propto d\vec{E} \times \vec{s}$$

In general:

$$\frac{d\vec{s}}{dt} = \vec{\Omega} \times \vec{s}$$

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

In fact, it is much more complicated!: build up must be coherent (resonant devices must be added)

Some numbers

- Very long Spin Coherence Time (SCT: 1000 seconds)
- High precision storage ring (field homogeneity, alignment, imperfections) filled with 4.10^{10} particles
- Small machine (~1 GeV)
- Example: beam position to be measured up to 2 nm is a challenge but remains realistic (20nm achievable)
- Very high electrostatic fields (>10MV/m)
- Polarized beams (80%) and polarimetry
- Systematic errors hunting.

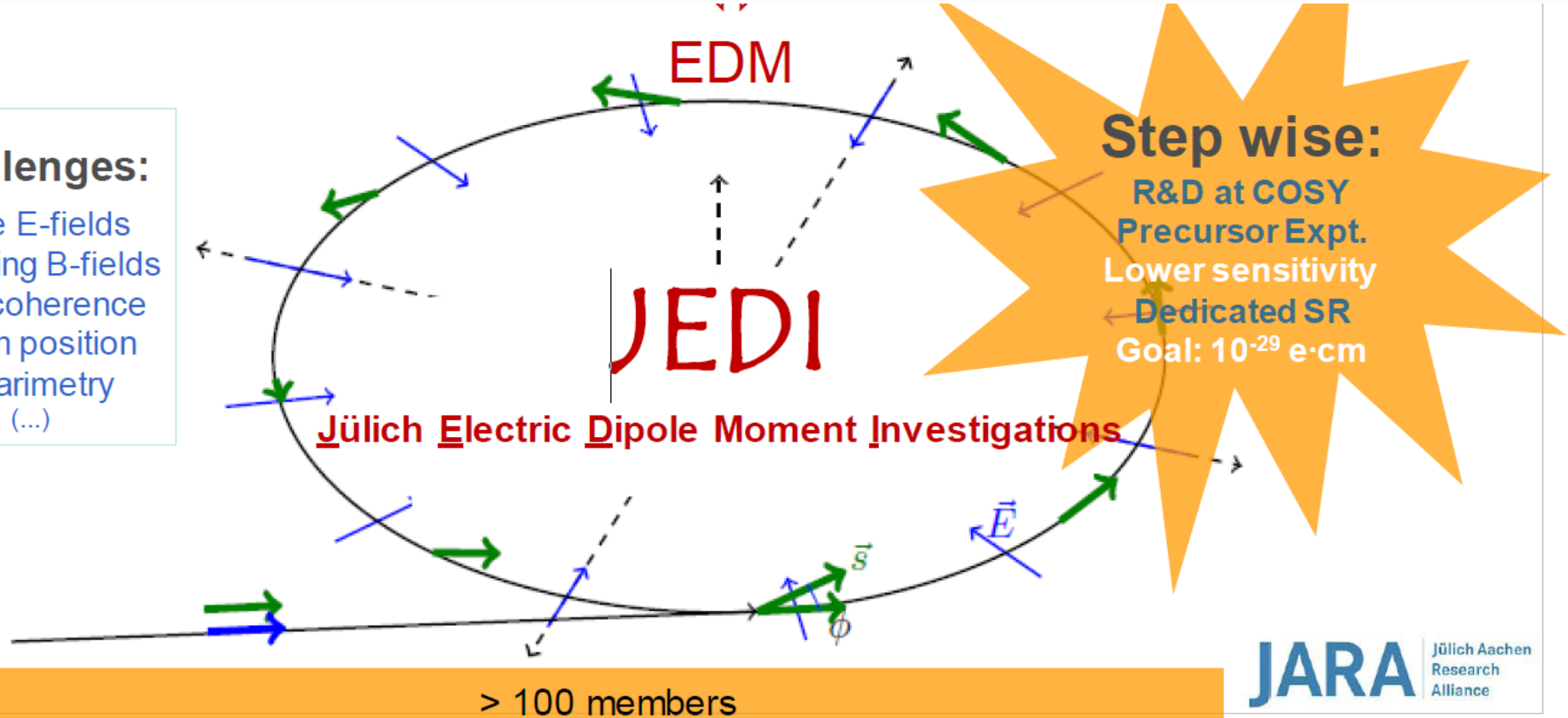
$$\sigma_{\text{stat}} \approx \frac{1}{\sqrt{N f \tau} P A E} \quad \Rightarrow \sigma_{\text{stat}}(1\text{year}) = 10^{-29}\ e{\cdot}\text{cm}$$

challenge: get σ_{sys} to the same level

JEDI

Challenges:

Huge E-fields
Shielding B-fields
Spin coherence
Beam position
Polarimetry
(...)



Step wise:

R&D at COSY
Precursor Expt.
Lower sensitivity
Dedicated SR
Goal: 10^{-29} e·cm

JARA Jülich Aachen Research Alliance

> 100 members
(Aachen, Bonn, Dubna, Ferrara, Cornell, Jülich, Krakow, Michigan, St. Petersburg, Minsk, Novosibirsk, Stockholm, Tbilisi, . . .)
12 PhD students from JARA-FAME (**F**orces and **M**atter **E**xperiments)
http://collaborations.fz-juelich.de/ikp/jedi/

- Fundamental studies of electrostatic or electro/magnetostatic storage rings
- Experimental studies and validation of concepts on COSY machine

Spin precession in a storage ring

Equation for spin motion of relativistic particles in storage rings for $\vec{\beta}\cdot\vec{B}=\vec{\beta}\cdot\vec{E}=0$.

The spin precession relative to the momentum direction is given by:

$$\frac{d\vec{S}}{dt}=\vec{\Omega}\times\vec{S}$$

Zero=*magic* ring

$$\vec{\Omega}=\frac{q}{m}\left\{G\vec{B}+\left(G-\frac{1}{\gamma^2-1}\right)\left(\vec{v}\times\vec{E}\right)+\frac{\eta}{2}\left(\vec{E}+\vec{v}\times\vec{B}\right)\right\}.$$

Magnetic Dipole Moment

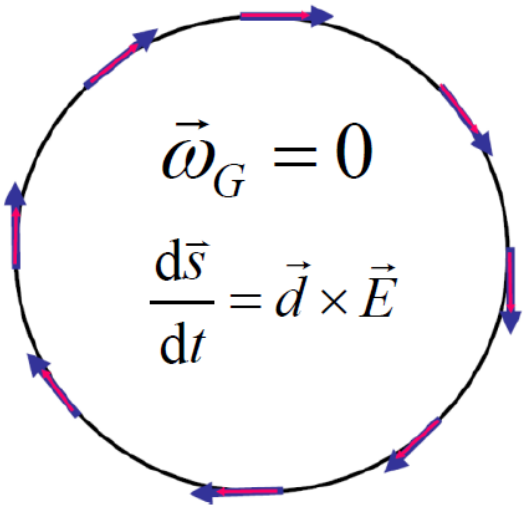
Electric Dipole Moment

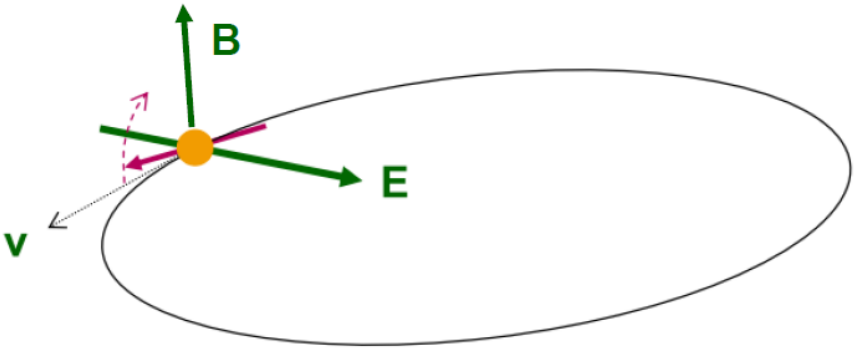
$$G=\frac{g-2}{2},\ \vec{\mu}=2(G+1)\frac{q}{2m}\vec{S},\ \text{and}\ \vec{d}=\eta\frac{q}{2m}\vec{S}.$$

First order spin tune $\nu_s=\gamma G$

Protons: G>0 B=0 and $\gamma_{magic} = \sqrt{\frac{G+1}{G}}$ →circular electrostatic machine

Deuterons: $G < 0$ →B and E fields→dogbone machine





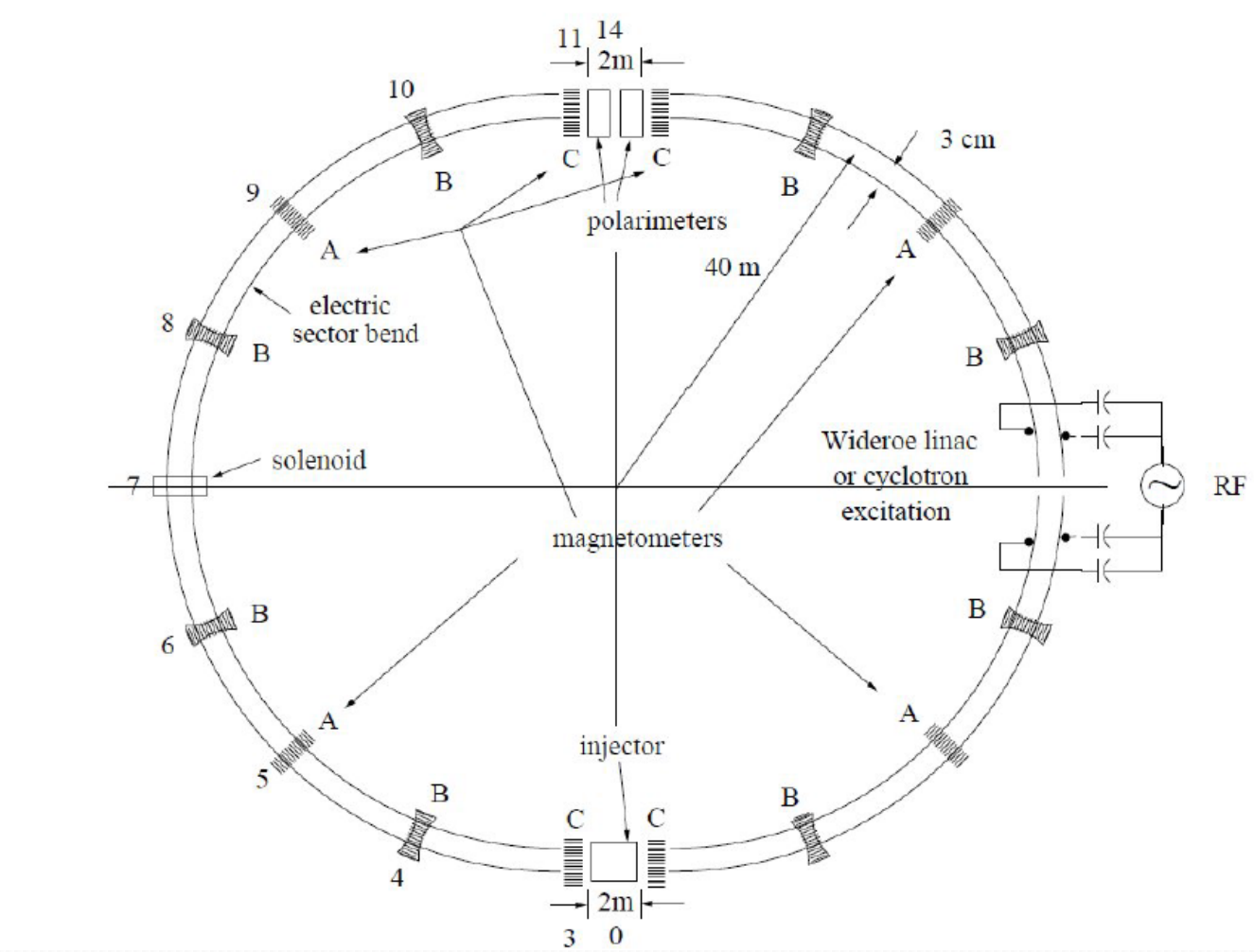
"Freeze" horizontal spin precession; watch for development of a vertical component !

A *magic* storage ring for protons (electrostatic), deuterons, and helium-3

particle	p (GeV/c)	E (MV/m)	B (T)
proton	0.701	16.789	0.000
deuteron	1.000	-3.983	0.160
^{3}He	1.285	17.158	-0.051

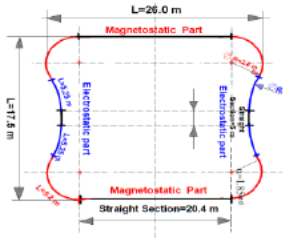
One machine with r ~ 30 m

Brookhaven proposal for protons: two clockwise beams in an electrostatic ring



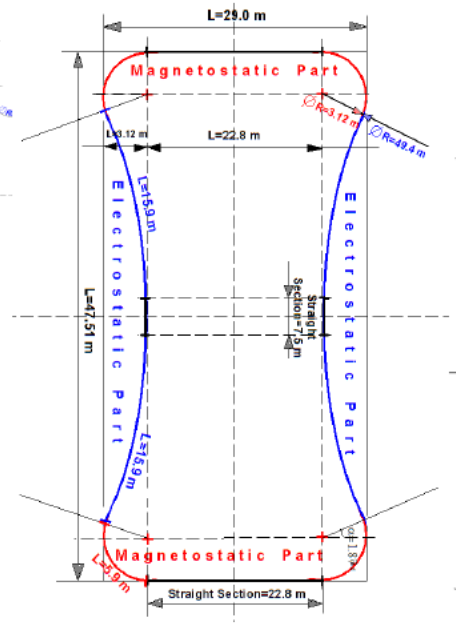
d-EDM ring for different energies

dEDM-75 MeV



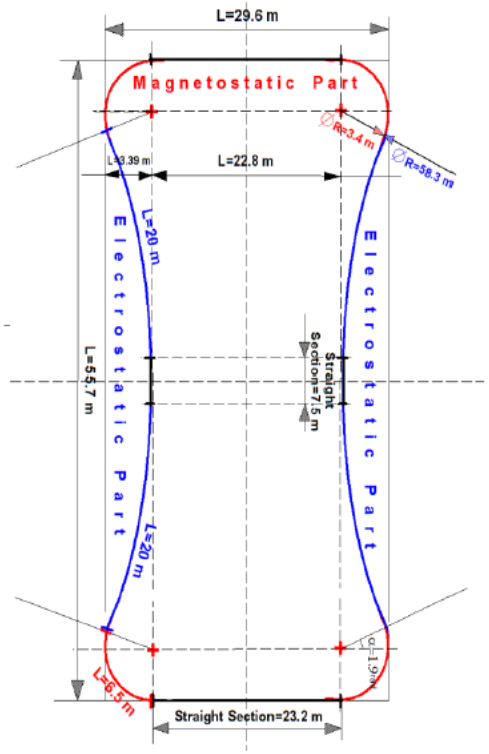
26 m x 17 m

dEDM-200 MeV



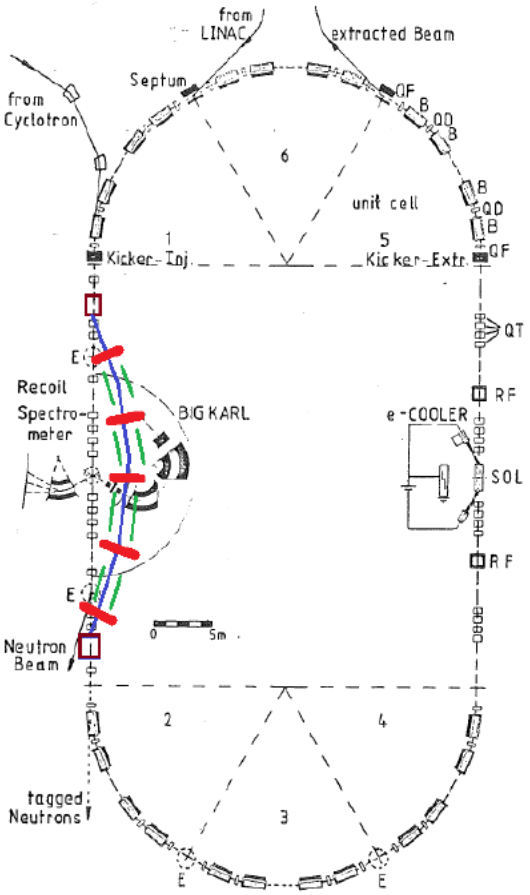
29 m x 47 m

dEDM-270 MeV



29.6 m x 55.7 m

COSY

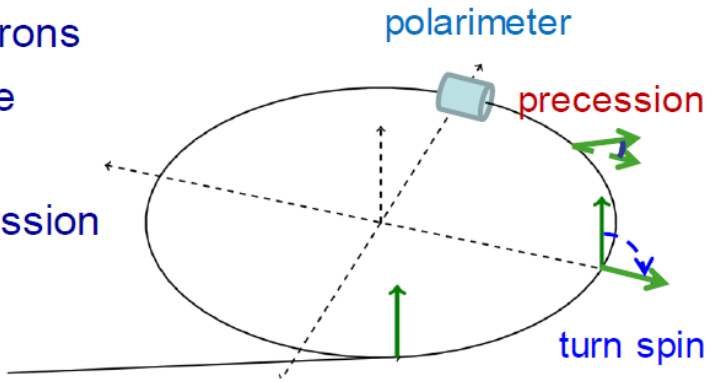


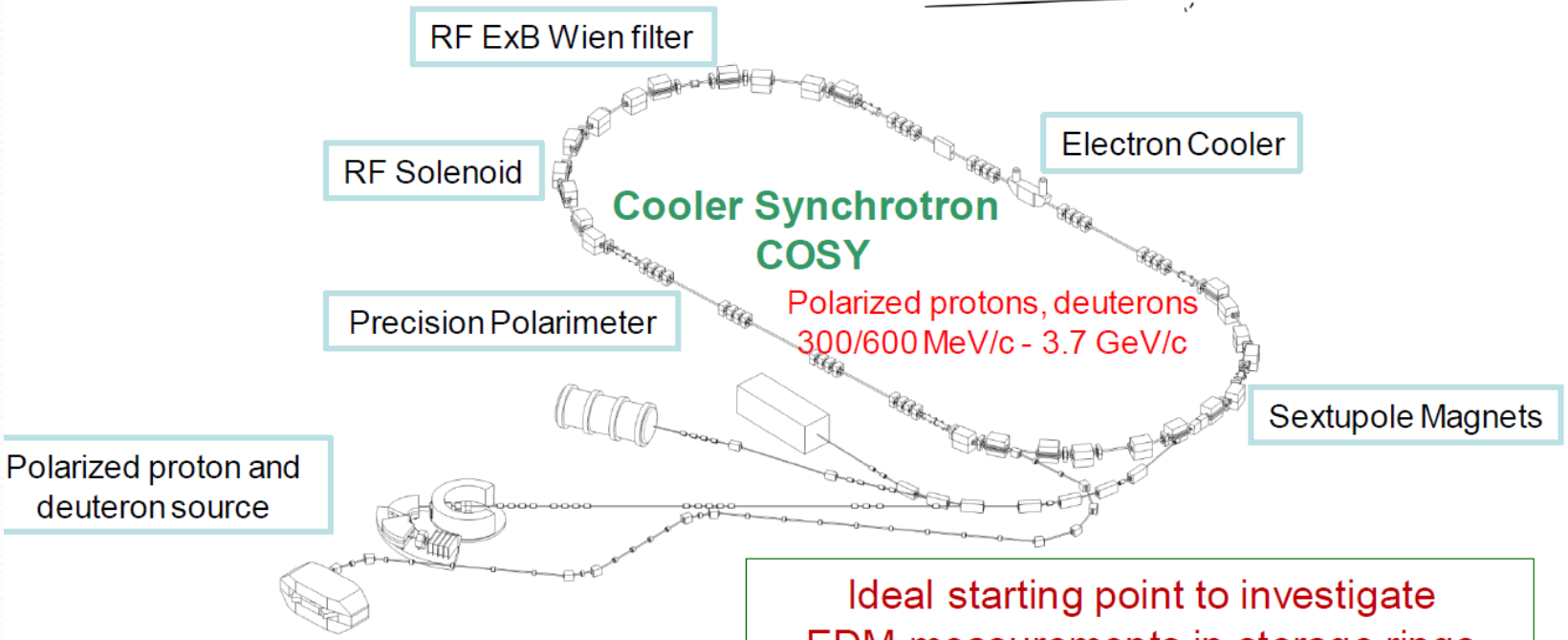
34 m x 71 m

Experimental Setup at COSY

- Inject and accelerate vertically polarized deuterons
- Spin rotated with RF fields into horizontal plane
- Move beam slowly (in 100 s) on internal target
- Measure asymmetry and determine spin precession

At 970 MeV/c deuterons: $\gamma G \cdot f_{rev} \approx 120$ kHz



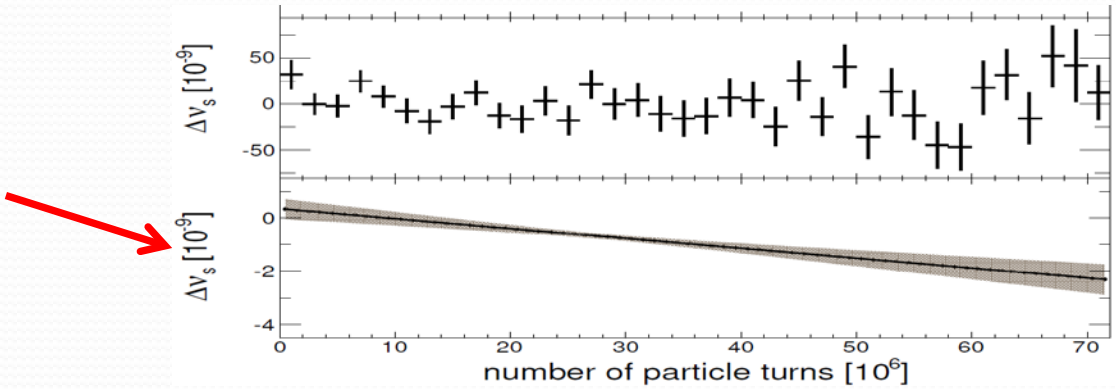


Ideal starting point to investigate
EDM measurements in storage rings

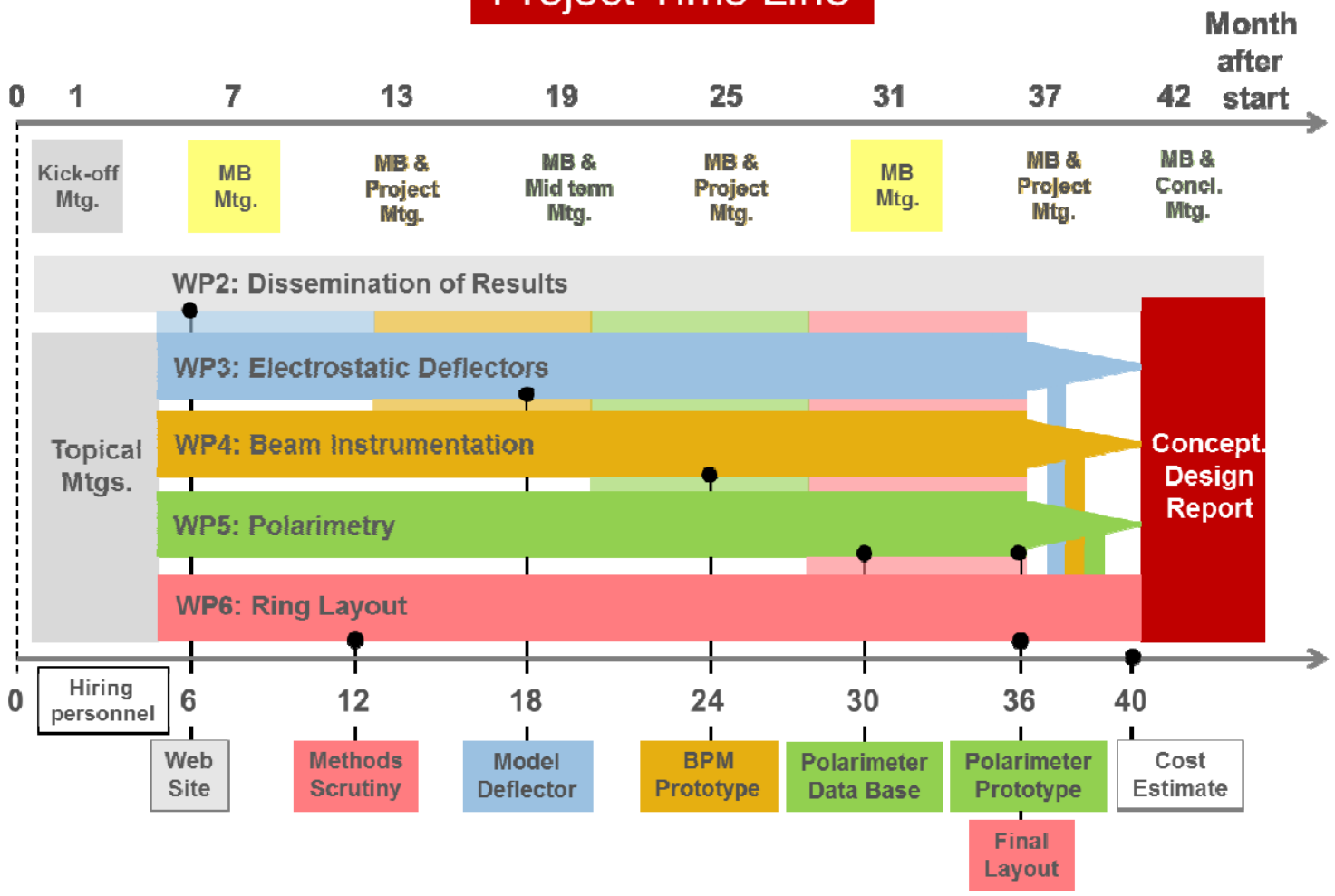
Example: spin coherence time

- SCT ~1000 seconds (10^9 turns)
- The spin tune must be the same for all particles→minimization of aberrations
- $\delta_{vs} = F_{non-lin}\left(x, L_{traj}, \frac{\Delta E}{E_0}, \vec{E} \ldots\right)$ is studied carefully (high accuracy calculations, theoretical models, long term simulations)
- The accurate measurement of the average spin tune is a tool for systematic errors characterization and hunting

10^{-9} !!!



Project Time Line



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