III. Physikalisches Institut B | RWTH AACHEN UNIVERSITY

JEDI

JÜLICH FORSCHUNGSZENTRUM

Search for Electric Dipole Moments at COSY in Jülich – Closed-Orbit influencing Effects

March 22th, 2017 | Vera Schmidt on behalf of the JEDI collaboration
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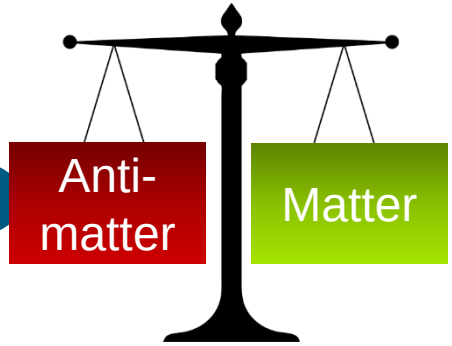
Baryogenesis

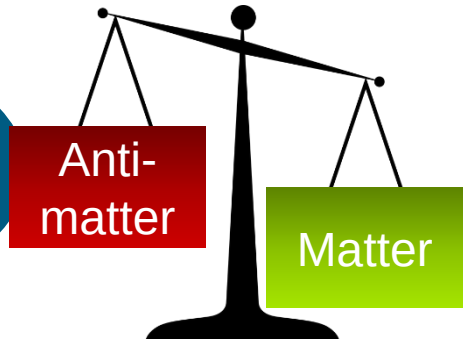
Big Bang
Matter-Antimatter Symmetry



Early Universe

Sakharov conditions:

1. Baryon number violation
2. Non thermal equilibrium
3. **Violation of $\mathcal{C}$ and $\mathcal{CP}$ symmetry**



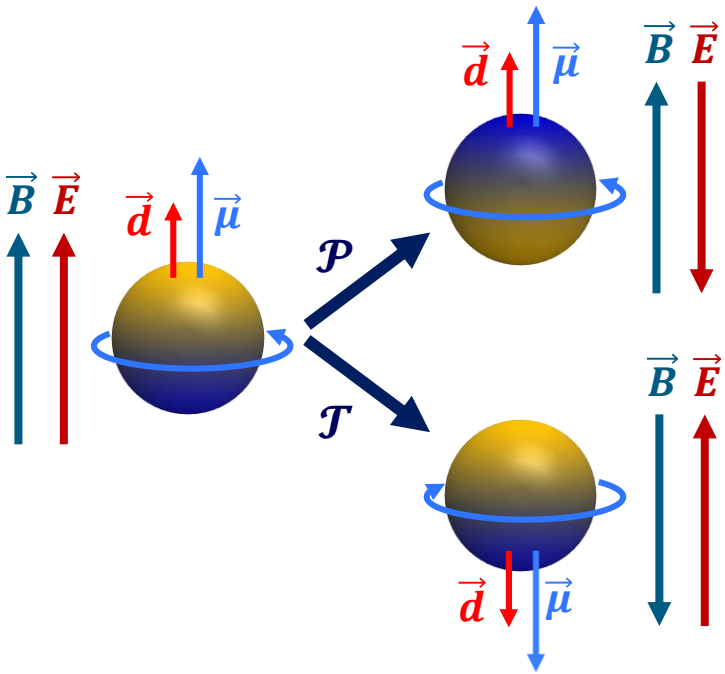
Annihilation

Today
Only matter observed

Baryon-to-photon density ratio	
Measured	$(6.14 \pm 0.25) \cdot 10^{-10}$
Theory	10^{-18}

Matter

Electric Dipole Moments (EDMs)



$$\mathcal{H} = -\vec{\mu} \cdot \vec{B} - \vec{d} \cdot \vec{E}$$
$$\mathcal{P}\colon \mathcal{H} = -\vec{\mu} \cdot \vec{B} + \vec{d} \cdot \vec{E}$$
$$\mathcal{T}\colon \mathcal{H} = -\vec{\mu} \cdot \vec{B} + \vec{d} \cdot \vec{E}$$

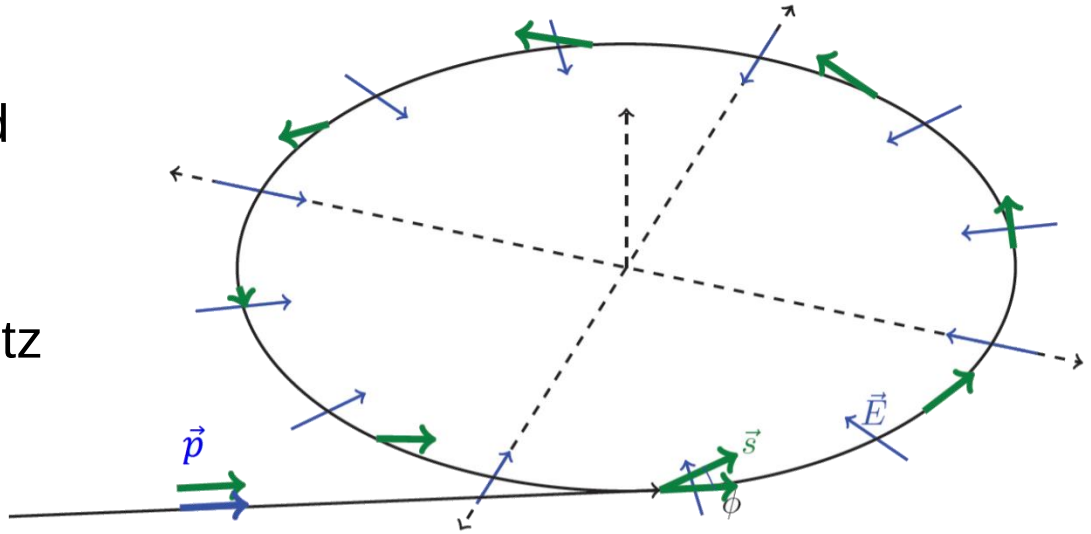
- Permanent EDMs of light hadrons are $\mathcal{T}$- and $\mathcal{P}$-violating
  ➡ $\mathcal{CPT}$ theorem ⇒ $\mathcal{CP}$ violation
- Measuring EDMs of charged particles in storage rings

EDM		
Classical	$\vec{d} = \sum_i q_i \cdot \vec{r}_i$	Water molecule $d \approx 3.7 \cdot 10^{-8}\ e \cdot cm$
QM	$\vec{\mu} = g \cdot \frac{q}{2m}\vec{S}$ and $\vec{d} = \eta \cdot \frac{q}{2mc}\vec{S}$	Neutron $d < 3 \cdot 10^{-26}\ e \cdot cm$

EDM measurements in storage rings

All EDM experiments:

- Interaction of EDM $\vec{d}$ and electric field $\vec{E}$
  ⇒ spin rotation
- Charged particles: Lorentz force
- Storage ring as particle trap

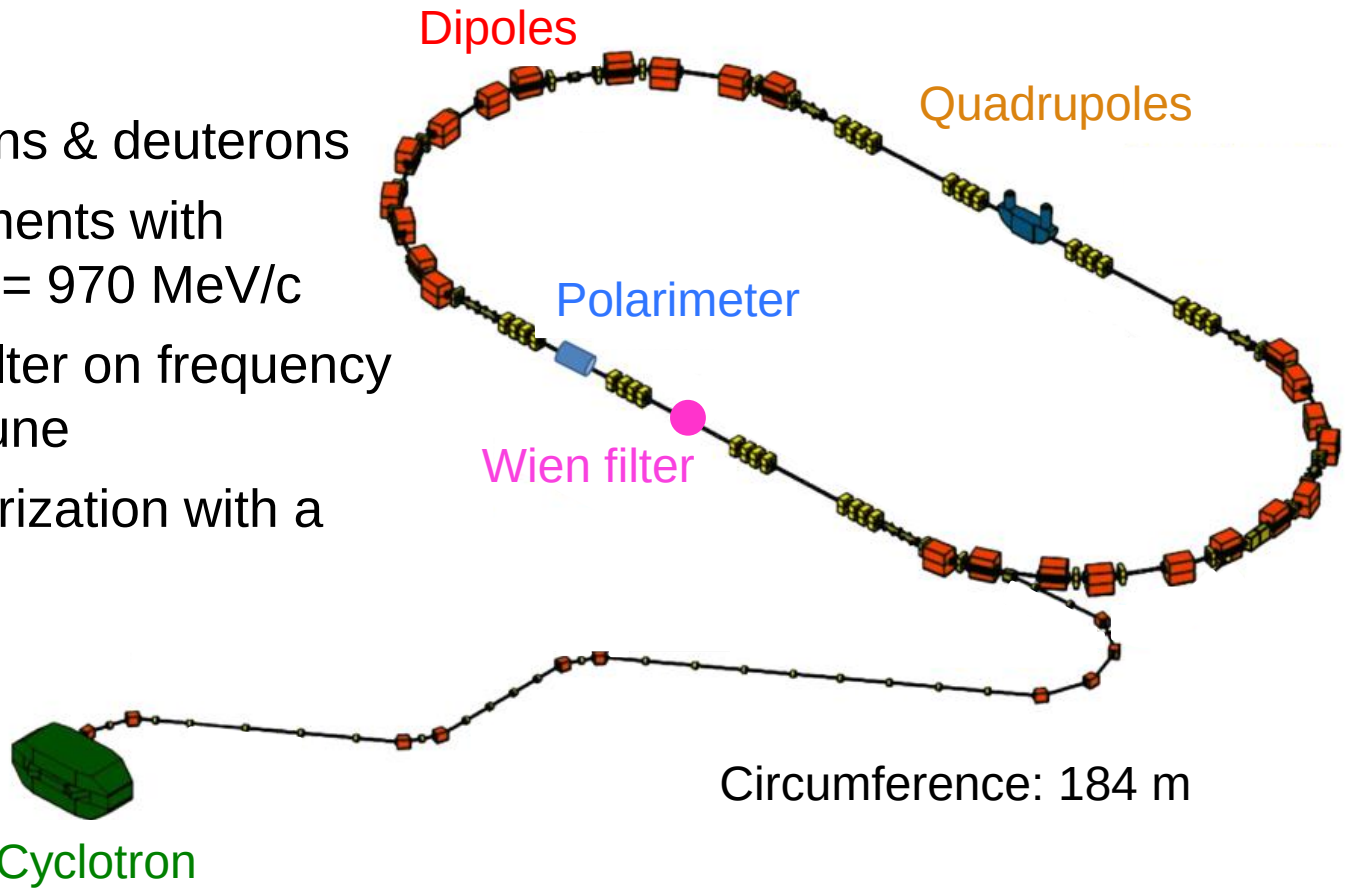


Basic idea:

- Inject particles with $\vec{p} \parallel \vec{S}$
- Apply radial electric field
- For $\vec{d} \neq 0$: spin rotates out of horizontal plane
- Measure: build-up of vertical polarization ($\phi \propto < |\vec{d}|$)

Cooler synchrotron COSY in Jülich

- Polarized protons & deuterons
- Current experiments with deuterons at p = 970 MeV/c
- Run RF Wien filter on frequency tuned to spin tune
- Measuring polarization with a polarimeter

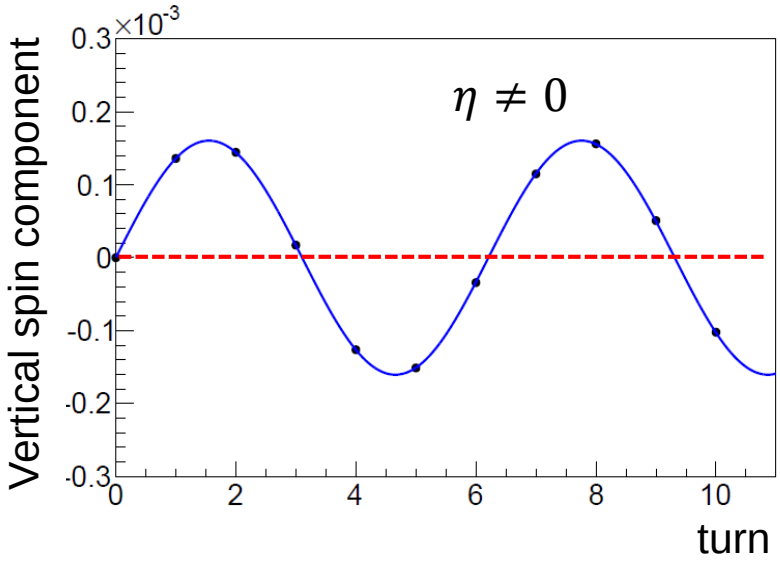


Resonant Wien filter method

$$\frac{d\vec{S}}{dt} = \left(\vec{\Omega}_{MDM} + \vec{\Omega}_{EDM}\right) \times \vec{S} \approx \left(\frac{q}{m} G\vec{B} + \frac{q\eta}{2m}\vec{\beta} \times \vec{B}\right) \times \vec{S}$$

Magnetic ring:

- Vertical fields
- $\vec{S} \parallel \vec{p}$
- Spin rotates in horizontal plane
- $\vec{d} \neq 0$: vertical spin build-up
- Amplitude $\approx \left|\frac{\eta\beta}{2G}\right|$



→ No net EDM effect

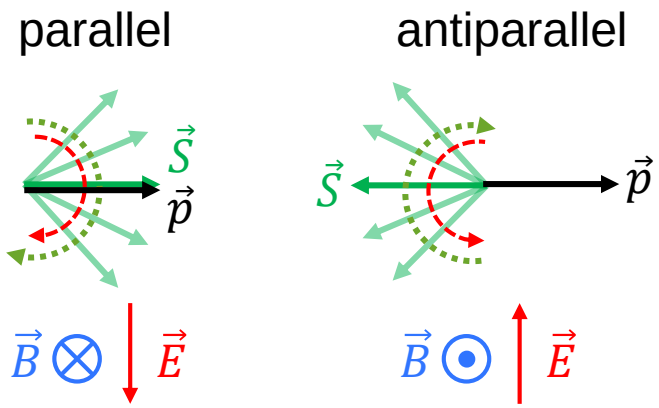
Resonant Wien filter method

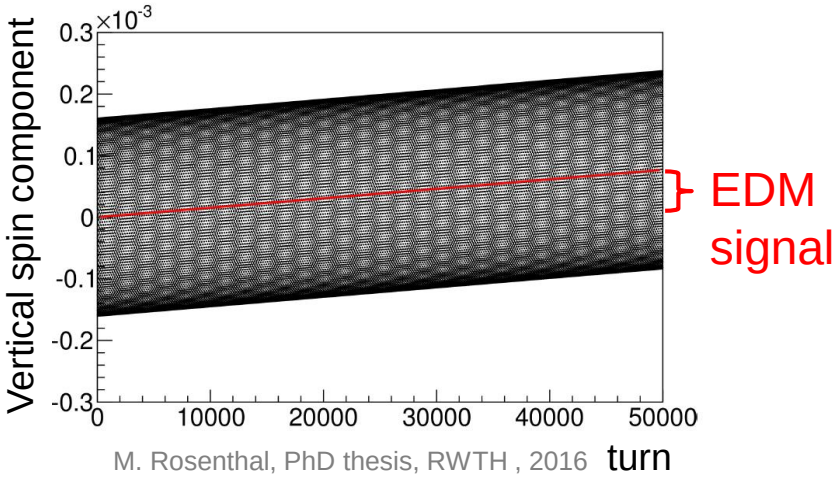
- RF device used to accumulate the EDM signal:

  Radial electric field: $E_x \sim \cos(\omega t + \varphi)$
  Vertical magnetic field: $B_y \sim \cos(\omega t + \varphi)$

- Wien filter: Lorentz force vanishes → no beam perturbation
- RF frequency tuned to horizontal spin precession

Horizontal precession

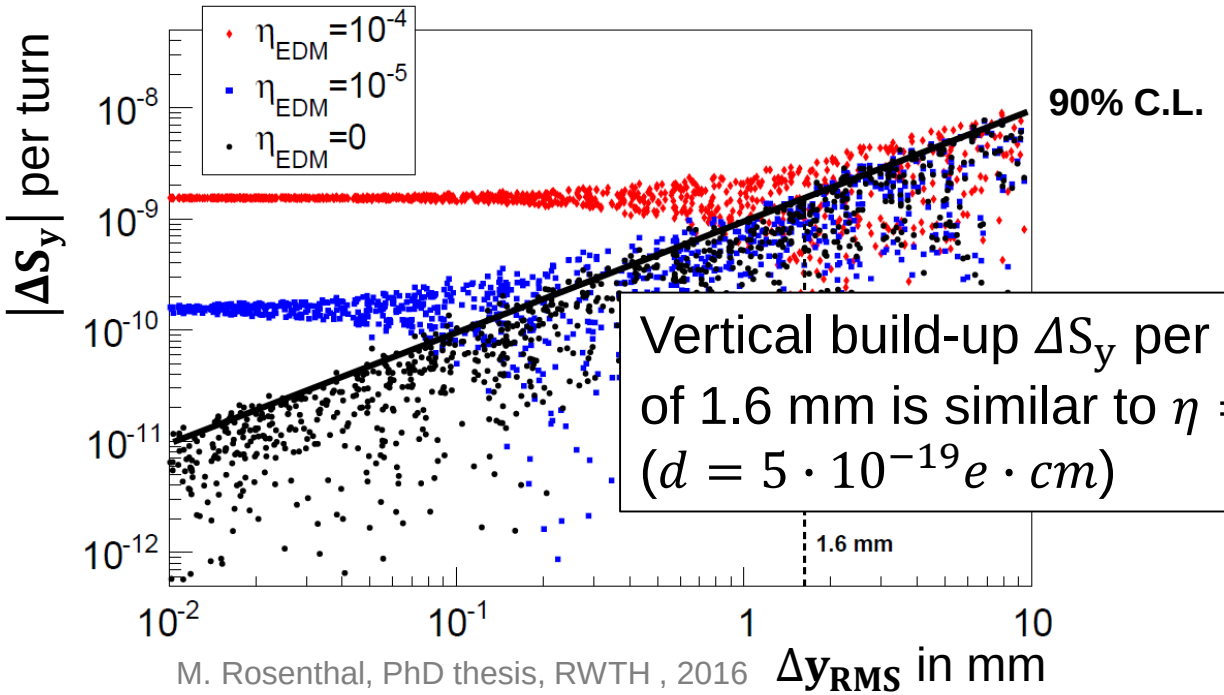




→ Net EDM effect

Systematic effects

- Gaussian distributed quadrupole shifts
- Vertical spin buildup due to magnet misalignments
- Vertical spin buildup due to non-vanishing EDM



Vertical build-up ΔS_y per turn for RMS of 1.6 mm is similar to $\eta = 10^{-4}$ $(d = 5 \cdot 10^{-19} e \cdot cm)$

M. Rosenthal, PhD thesis, RWTH , 2016

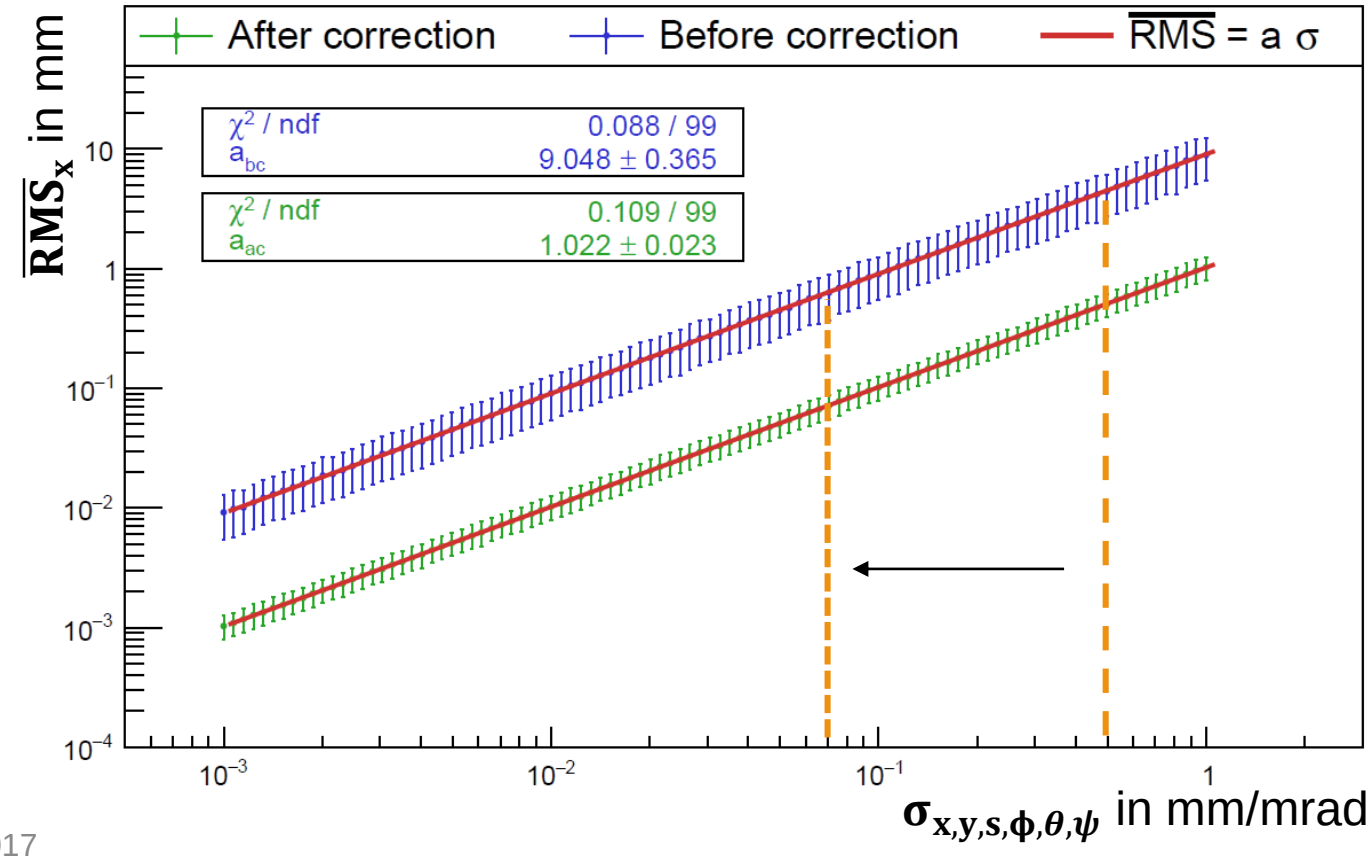
Reduction of closed orbit RMS is required!

Closed-orbit influencing effects

1) Magnet misalignments

$$\Delta(x, y, s, \phi, \theta, \psi) = \mathbf{Gauss}\left(0, \sigma_{x,y,s,\phi,\theta,\psi}\right)$$

$$1\ \mu m < \sigma_x = \sigma_y = \sigma_s < 1\ \mathrm{mm} \qquad 1\ \mu\mathrm{rad} < \sigma_\phi = \sigma_\theta = \sigma_\psi < 1\ \mathrm{mrad}$$

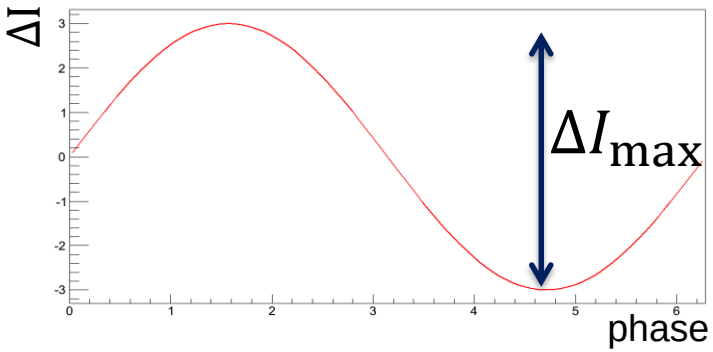


Closed-orbit influencing effects

2) Power supply oscillations

- Residual power supply oscillation

  $\Longrightarrow$ field variations
- Gaussian distributed amplitudes
- Simulate closed-orbit changes due to field changes



	Δx (per ppm of I_0)	Δy (per ppm of I_0)	Rel. error
Dipole	(1.38 $\pm$ 0.01) µm	(0.45 $\pm$ 0.01) nm	20 ppm
Quadrupole	(55.56 $\pm$ 0.51) nm	(35.70 $\pm$ 0.50) nm	20 ppm
Corrector	(0.34 $\pm$ 0.03) µm	(0.28 $\pm$ 0.02) µm	100 ppm
Sextupole	(0.10 $\pm$ 0.01) nm	(0.11 $\pm$ 0.01) nm	500 ppm

Summary & Outlook

- EDMs as candidate for physics beyond the Standard Model
- Measure EDM at COSY with RF Wien filter method
- Transverse closed-orbit reduction required
- Magnet misalignments are the major source for closed-orbit pertubations
- Magnets at COSY are realigned
- First measurements in 2018

Thank you