# ELECTROSTATIC DEFLECTOR DEVELOPMENT

## for an EDM storage ring

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# Outline

What are EDM?

- Why are they interesting?
- How can they be measured?

Stages of EDM measurements

- Cooler Synchrotron COSY
- Prototype ring
- Dedicated EDM ring

Development of an $\vec{E} \times \vec{B}$ deflector

- Test setup for small electrodes
- New setup for larger electrodes
- Simulation of the fields

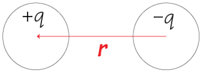
Conclusion

# EDM and CP violation


The universe is dominated by matter.

- There is much more matter than antimatter in the universe.
- Andrei Sakharov, 1967:
  - Baryon number *B* violation
  - C- and CP-symmetry violation
  - Interactions out of thermal equilibrium
- Time and parity symmetry are both violated by EDM.
- Assuming CPT symmetry holds, CP symmetry is also violated.
- A permanent EDM could explain the baryon/antibaryon asymmetry in the universe.

# Electric Dipole Moment



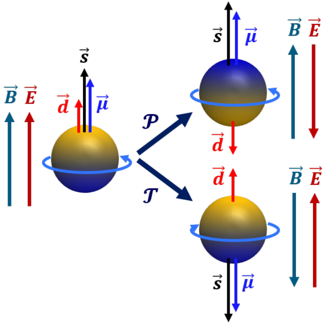

$$\vec{d} = q\vec{r}$$

- EDM is the separation of positive and negative charge.
- Permanent EDM violates P and T symmetry.
- $\vec{d} \parallel \vec{S}$
- The Hamiltonian is:

$$\mathcal{H} = -\vec{\mu}\vec{B} - \vec{d}\vec{E}$$

$$P(\mathcal{H}) = -\vec{\mu}\vec{B} + \vec{d}\vec{E}$$

$$T(\mathcal{H}) = -\vec{\mu}\vec{B} + \vec{d}\vec{E}$$




A permanent EDM violates P and T symmetry.

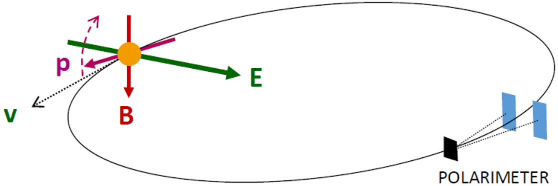
# EDM in an electric ring

- The motion of particle spin is described by the Thomas-BMT equation:

$$\frac{d\vec{S}}{dt} = \left(\vec{\Omega}_{MDM} + \vec{\Omega}_{EDM}\right) \times \vec{S}$$

$$= -\frac{q}{m}\left(\left[G\vec{B} - \left(G - \frac{1}{\gamma^2 - 1}\right)\frac{\vec{\beta} \times \vec{E}}{c}\right] + \frac{\eta}{2c}\left[\vec{E} + c\vec{\beta} \times \vec{B}\right]\right) \times \vec{S}$$

- Initially spin polarization is parallel to the velocity.
- One working principle:
  - ’Freeze’ MDM
  - EDM will cause a vertical polarization.
  - Conclusions about EDM based on time behaviour.



# Cooler Synchrotron COSY in Jülich

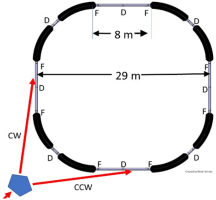
- Synchrotron with a circumference of 184 m
- Used for polarized deuterons and protons.
  - At the moment polarized deuterons with $p = 970$ MeV/c.
- Stochastic cooling and 2 electron coolers installed.
- EDM precursor experiment running.
- Polarimeter used to measure polarization.
- R&D work, precursor experiment, future injector.

# Stages of EDM measurement

Stage 1: Cosy (current stage)

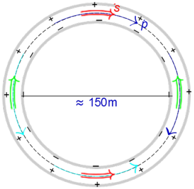
- Precursor experiment
- Magnetic ring
- 970 MeV/c

Stage 2: Prototype ring (future plan)




- Electromagnetic
- Either CW/CCW use or EDM measurement
- 30 MeV or 45 MeV

Stage 3: EDM ring (far future plan)

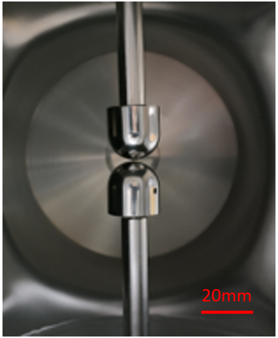



- All electric
- 701 MeV/c
- CW/CCW beam and measurement at same time.

⇒ Gaining more precision and fewer systematic errors with each stage.

# Up to now: Small electrodes

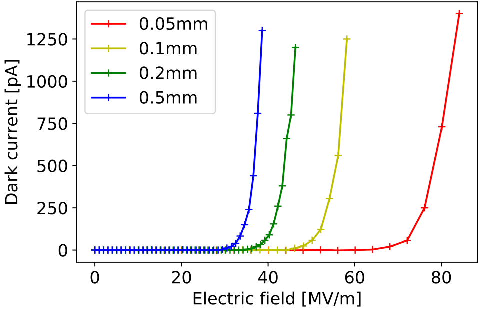
- Diameter of 20 mm.
- Vacuum of $p \approx 10^{-10}$ mbar.
- Different surface treatment and coatings:
  - Cleaning
  - Polishing
  - TiN coating
- Different materials:
  - Stainless steel
  - Aluminium
- Testing for different distances.
- Field strengths reach up to 90 $\frac{\mathrm{MV}}{\mathrm{m}}$ before breakdown.

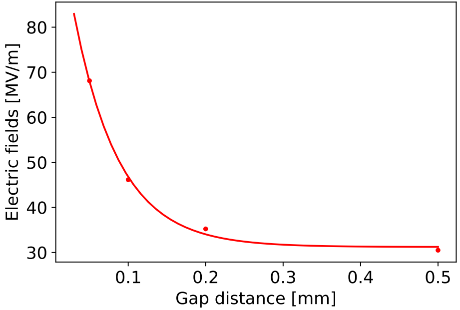



Stainless steel electrodes.

# Results for small electrodes

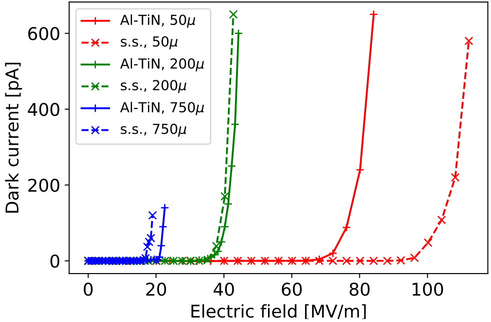
- Electrode diameter of 20 mm.
- Electrode material aluminium.
- Coated with TiN.

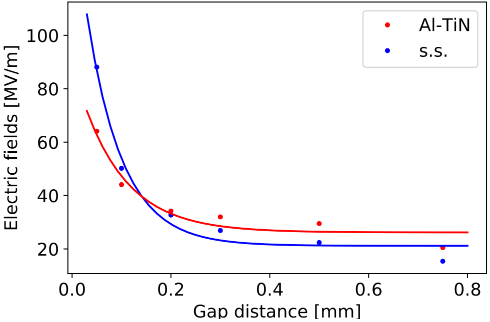


# Results for small electrodes contd.

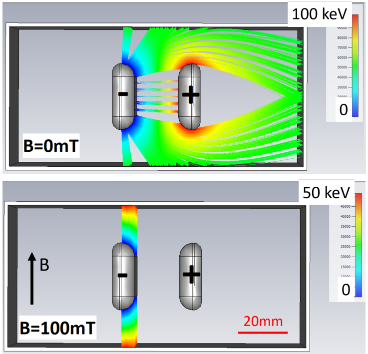
## Comparison for different electrodes:



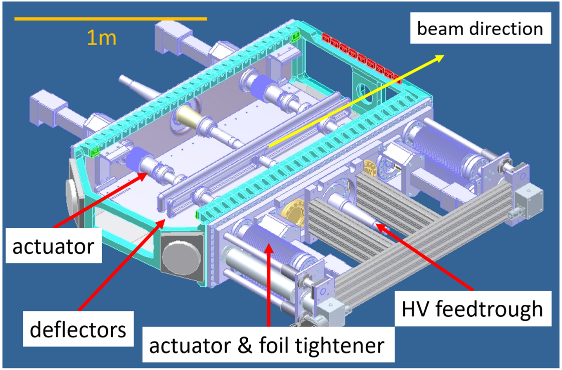
# Simulation of larger electrodes

- Simulation done with CST Studio.
- Electrodes have the same shape as new large ones.
- Different parameters can be changed:
  - Distance between electrodes.
  - Electric potentials.
  - Overlaid magnetic field.
- Trajectories of the electrons are calculated.
- Result: Electrons hit and possibly damage other electrode.
- Solved by overlaid magnetic field.




Electron trajectories with and without B-field.

# Layout of ExB deflector

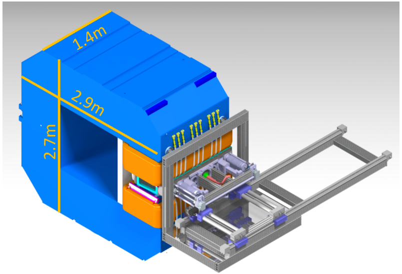


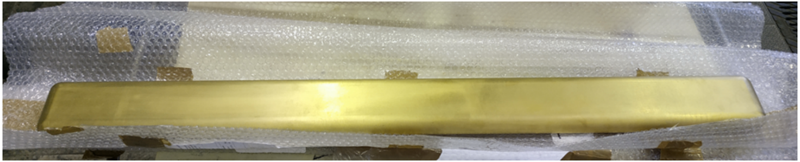

- Electrodes:
  - Aluminium coated with TiN.
  - Size in mm: 1020 × 90 × 30.
  - Edges are bended with a 18 mm and 10 mm radius at the front and at the back respectively.
- Form shaped in a way to insert whole set-up in magnet to protect electrodes.
- Foil at top and bottom to protect vacuum chamber in case of spark.

Setup to test large electrodes inside a magnetic field.

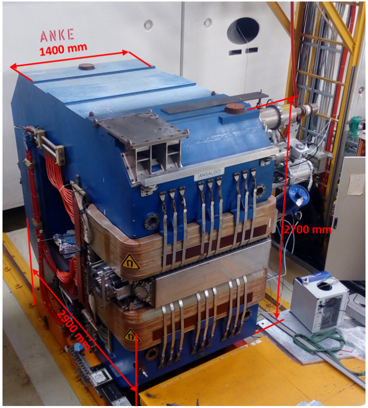
# The future: Larger electrodes

- Target field of $E = 8\,\frac{\mathrm{MV}}{\mathrm{m}}$.
- Electrode distance between 20 and 120 mm.
- Voltage up to $\pm 200$ kV.
- Currently being assembled.



# Conclusion and outlook




The magnet where the set-up will be installed.

- Achievements:
  - Different electrodes tested.
  - Preparations for the new set-up more or less finished.
  - Simulation shows first results.
- Future plans:
  - Do further measurements with the small electrodes (new material, coating,…).
  - Finish assembling for the large electrodes.
  - Perform measurements with the large electrodes.
  - Test for the influence of the magnetic field on the behaviour.
  - Simulate the deflector to cross check and get information for further development.

Thank you!

# Backup Slides

# EDM measurement in a magnetic ring

- In a magnetic ring, the spin motion is: $\dot{\vec{S}} \propto \left(\vec{\beta} \times \vec{B}\right) \times \vec{S}$.
- Due to spin rotation, the vertical component is oscillating without a net signal.
- RF Wien filter manipulates the field to produce a net signal.