ST2: Hadron Accelerators
- Progress and Plans -

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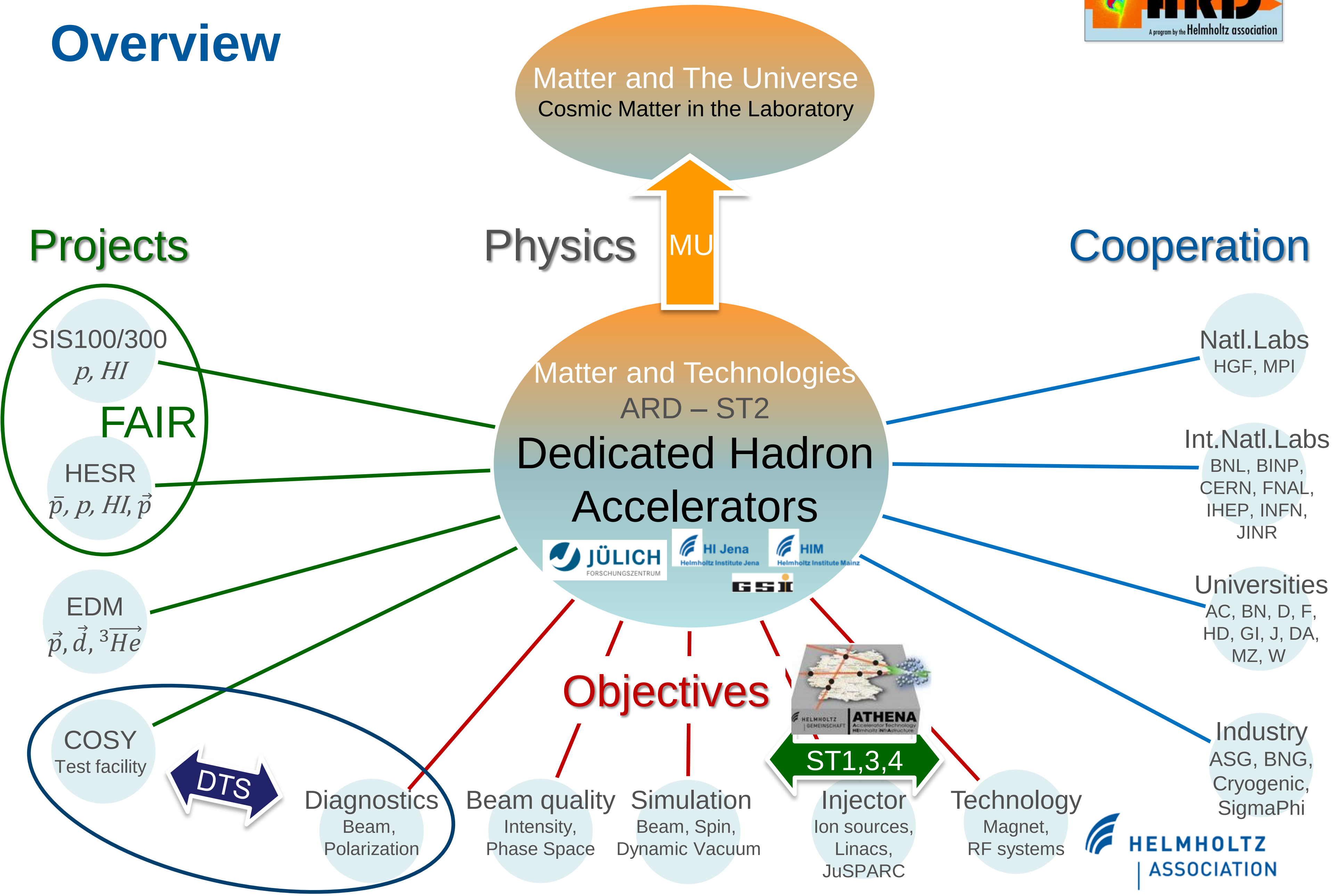
ST2 coordinator

Overview


Matter and The Universe
Cosmic Matter in the Laboratory
MU
Physics
Projects
Cooperation
SIS100/300
p, HI
FAIR
HESR
$\bar{p}, p, HI, \vec{p}$
EDM
$\vec{p}, \vec{d}, \overrightarrow{{}^3He}$
COSY
Test facility
DTS
Matter and Technologies
ARD – ST2
Dedicated Hadron Accelerators
JÜLICH
FORSCHUNGSZENTRUM
HI Jena
Helmholtz Institute Jena
HIM
Helmholtz Institute Mainz
GSI
Natl.Labs
HGF, MPI
Int.Natl.Labs
BNL, BINP, CERN, FNAL, IHEP, INFN, JINR
Universities
AC, BN, D, F, HD, GI, J, DA, MZ, W
Industry
ASG, BNG, Cryogenic, SigmaPhi
Objectives
HELMHOLTZ GEMEINSCHAFT
ATHENA
ST1,3,4
Diagnostics
Beam, Polarization
Beam quality
Intensity, Phase Space
Simulation
Beam, Spin, Dynamic Vacuum
Injector
Ion sources, Linacs, JuSPARC
Technology
Magnet, RF systems

Outline

Overview & Introduction

Highlights

- High-Precision Spin Manipulation
- Ion Sources
- High-Energy Beam Cooling

Summary

- Progress and Plans

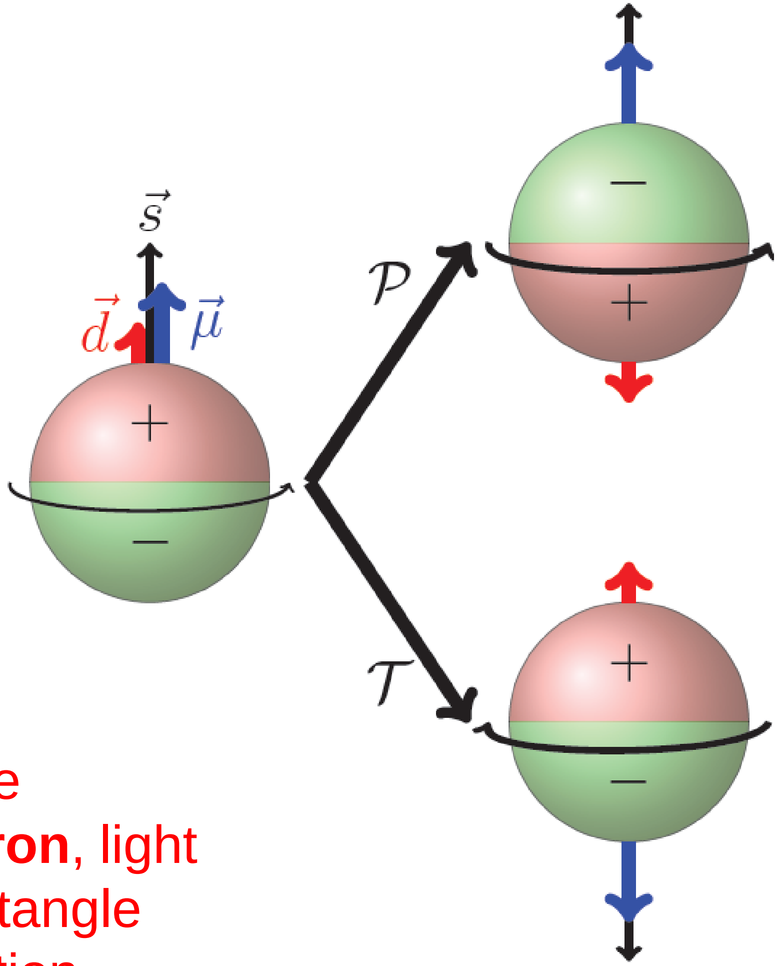
Electric Dipole Moments

$\vec{d}$: EDM
$\vec{\mu}$: magnetic moment
both || to spin

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

$$\mathcal{T}: \quad H = -\mu\vec{\sigma}\cdot\vec{B} + d\vec{\sigma}\cdot\vec{E}$$

$$\mathcal{P}: \quad H = -\mu\vec{\sigma}\cdot\vec{B} + d\vec{\sigma}\cdot\vec{E}$$



It is important to measure neutron **and proton and deuteron**, light nuclei EDMs in order to disentangle various sources of CP violation.

EDMs are candidates to solve mystery of matter-antimatter asymmetry

Spin Precession with EDM

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:

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

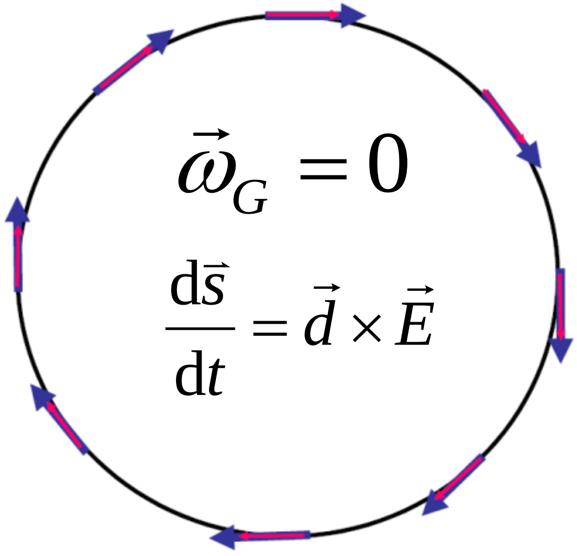
$$\vec{\Omega}=\frac{q}{m}\left\{G\vec{B}+\left(G-\frac{1}{\gamma^2-1}\right)\left(\vec{v}\times\vec{E}\right)+\frac{\eta}{2}\left(\vec{E}+\vec{v}\times\vec{B}\right)\right\}.$$

Magnetic Moment — Electric Dipole Moment

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

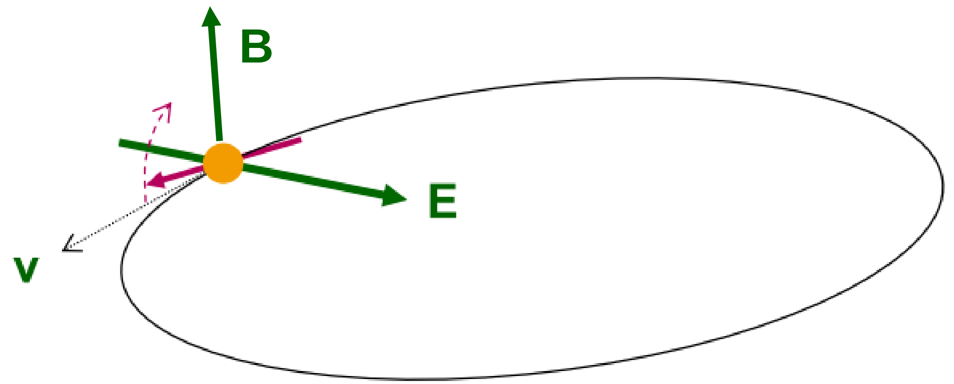
Search for Electric Dipole Moments

Approach: EDM search in time development of spin in a storage ring:



$$\vec{\omega}_G = 0$$

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



"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

Storage Ring EDM Project

Accelerator Research and Development ARD – A program by the Helmholtz association

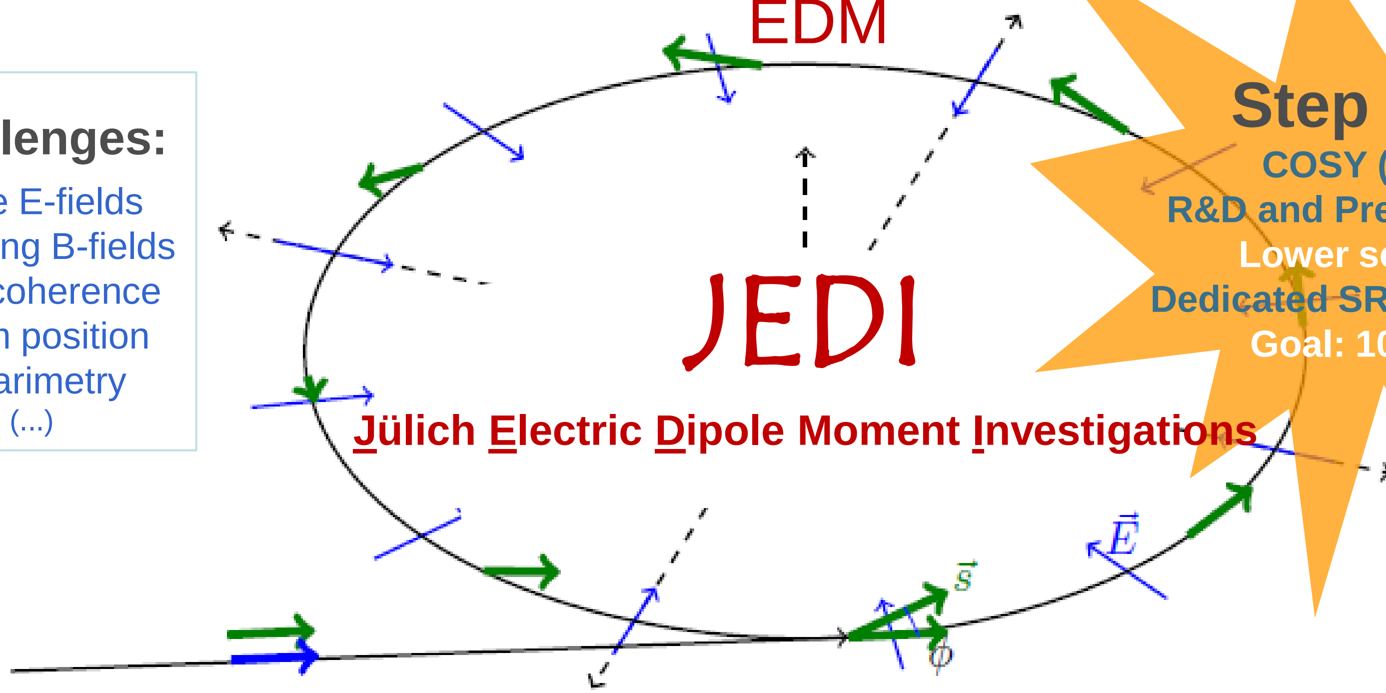
… measure for development of vertical polarization

⇔

EDM

Challenges:

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



JEDI

Jülich **E**lectric **D**ipole Moment **I**nvestigations

Step wise:

COSY (PoF-III)
R&D and Precursor Expt.
Lower sensitivity
Dedicated SR (after PoF III)
Goal: 10^{-29} e·cm

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

JARA Jülich Aachen Research Alliance

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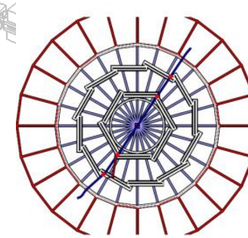
EDM: Prototyping and Spin Physics

Accelerator Research and Development ARD A program by the Helmholtz association

MT / ARD

RF ExB Wien Filter

MU

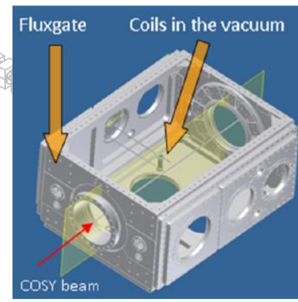


Prototype Polarimeter

MT / ARD

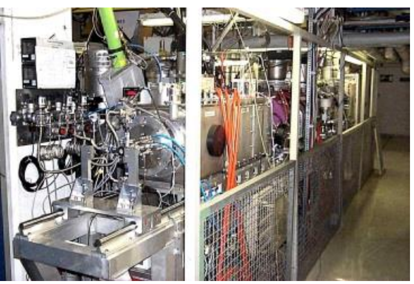
Electrostatic Deflector

MU



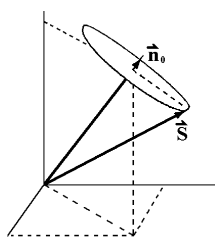
SQUID BPMs

MT / ARD

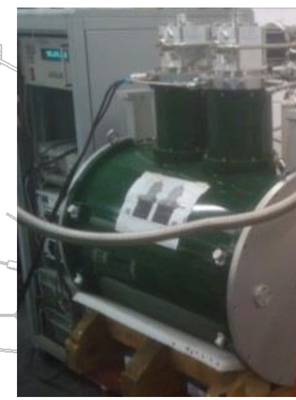


Polarized Ion source

MT / ARD



Beam and Spin Dynamics



Siberian Snake

EDM accelerator and detector component tests

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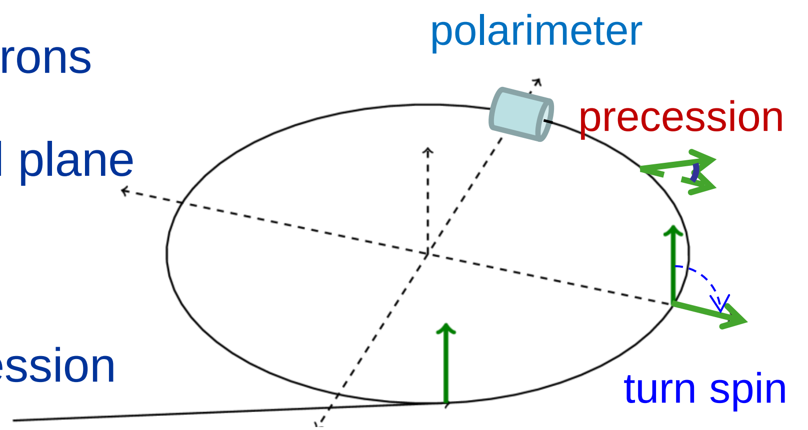
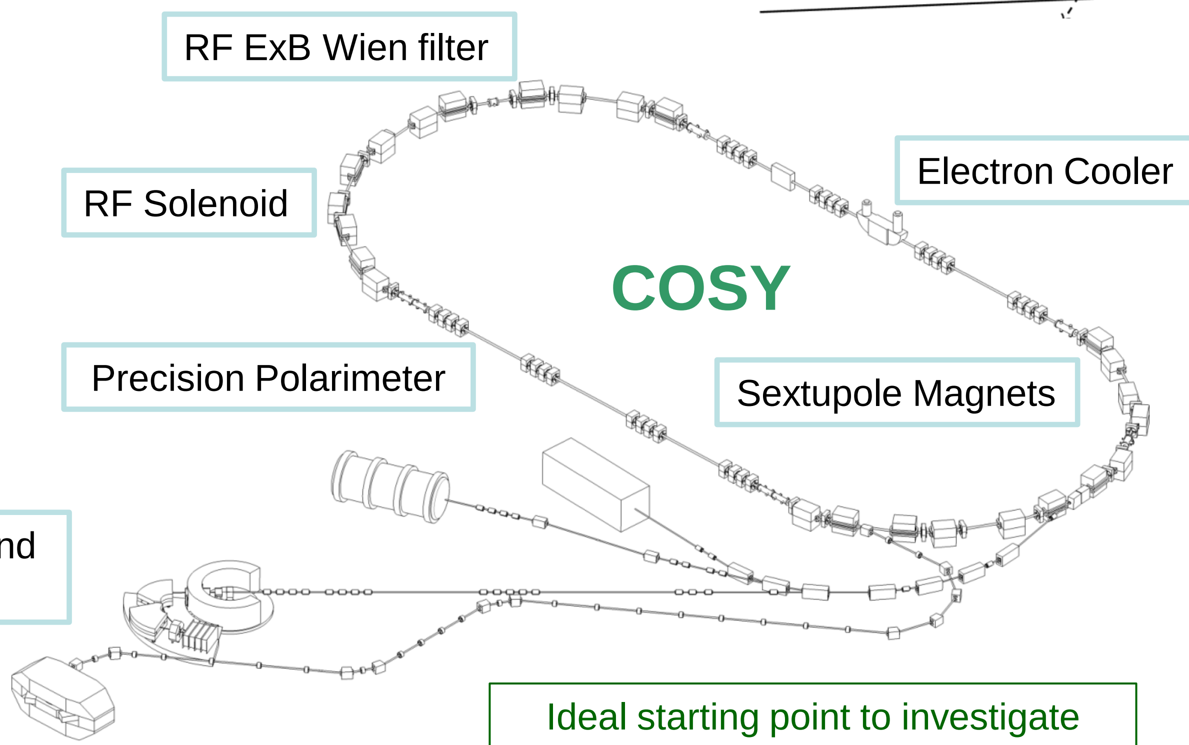
Experimental Setup for R&D

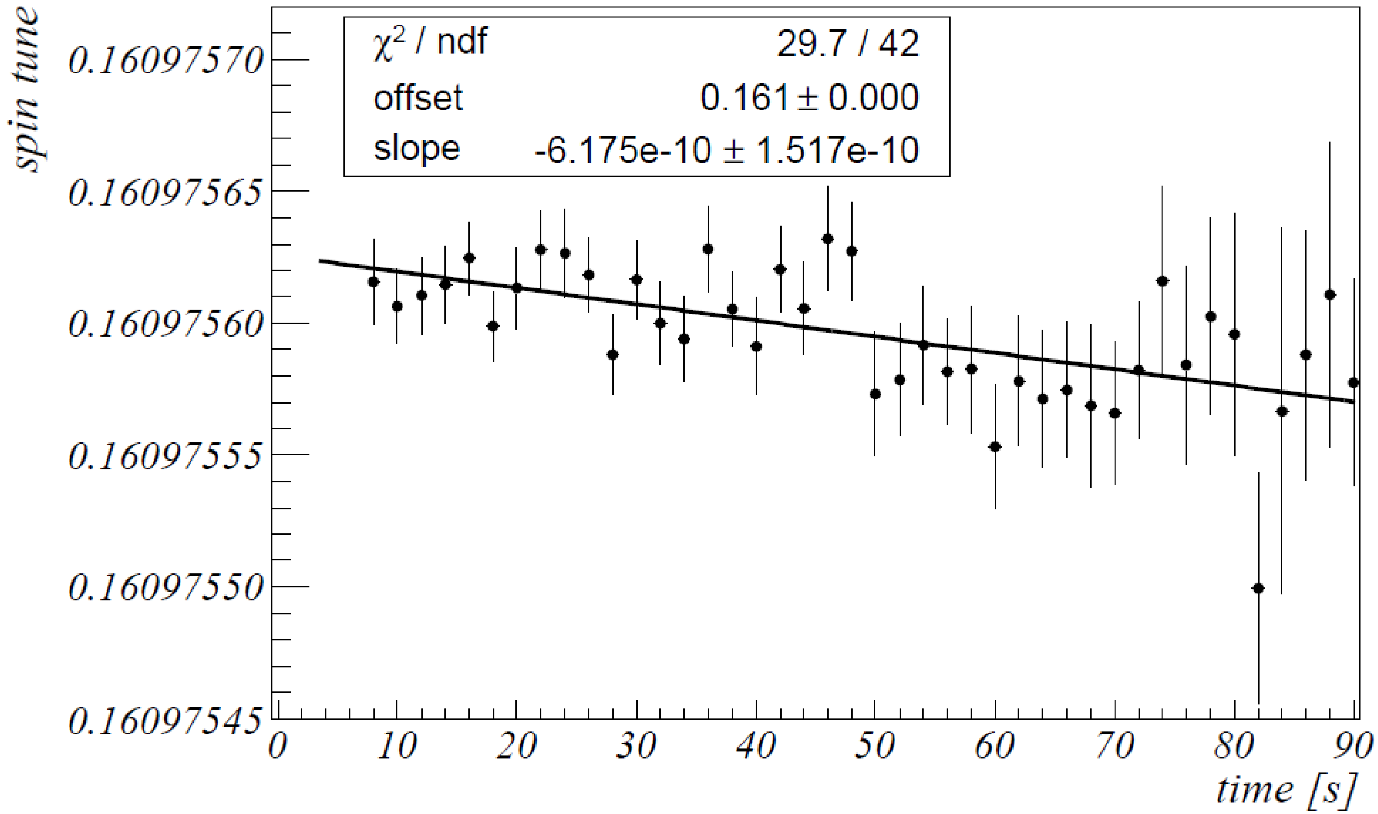
- Inject and accelerate vertically polarized deuterons
- Flip spin with help of a RF fields into horizontal plane
- Extract beam slowly (in 100 s) on target
- Measure asymmetry and determine spin precession





Ideal starting point to investigate EDM measurements in storage rings

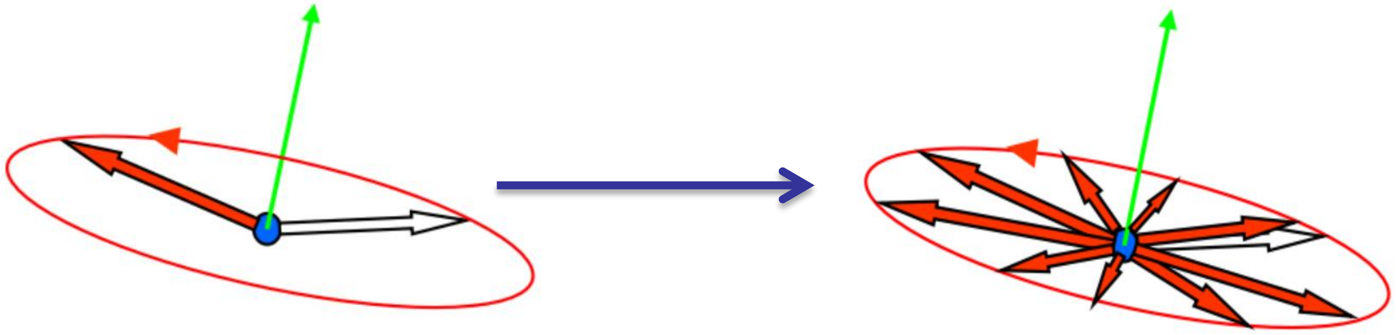
Spin Tune Measurement



- Spin tune ν_s can be determined to 10^{-8} in 2 s
- Average ν_s in cycle (100 s) determined to 10^{-10}
- $\nu_s \approx \gamma G$ varies within one cycle and from cycle to cycle by 10^{-8}

Spin Coherence Time (SCT)

- Statistical sensitivity of EDM proportional to SCT
- Spin precession with $f_s = \gamma G\, f_{ref} \approx 125\ \mathrm{kHz}$
- Momentum spread leads to different precession frequencies



Horizontal Polarization Vanishes !

- Loss of horizontal polarization ↔ spin decoherence

Spin coherence time of more then 400s reached in COSY

Simulation Program Development

COSY Infinity (MSU) and MODE (StPSU):

- 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
- an MPI version of COSY Infinity is running on the Jülich supercomputer
- bench marking with “analog computer” Cooler Synchrotron COSY and other simulation codes

Spin Simulations

Accelerator Research and Development ARD A program by the Helmholtz association

COSY Toolbox

COSY Lattice

JÜLICH FORSCHUNGSZENTRUM

COSY INFINITY

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

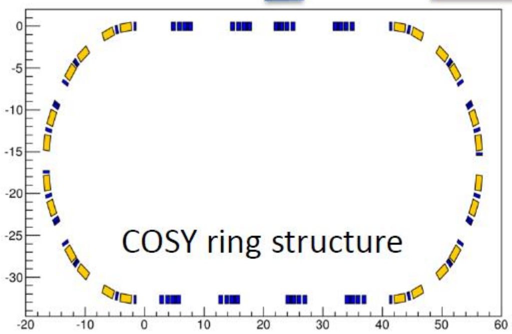
COSY Toolbox

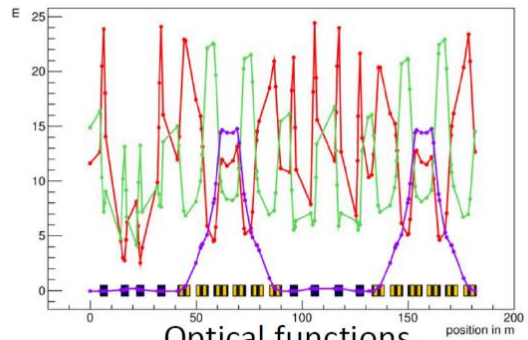
Armadillo

- linear algebra operations
- SVD, pseudo-inverse

ROOT

- plotting
- storage (ROOT files/trees)





Optical functions

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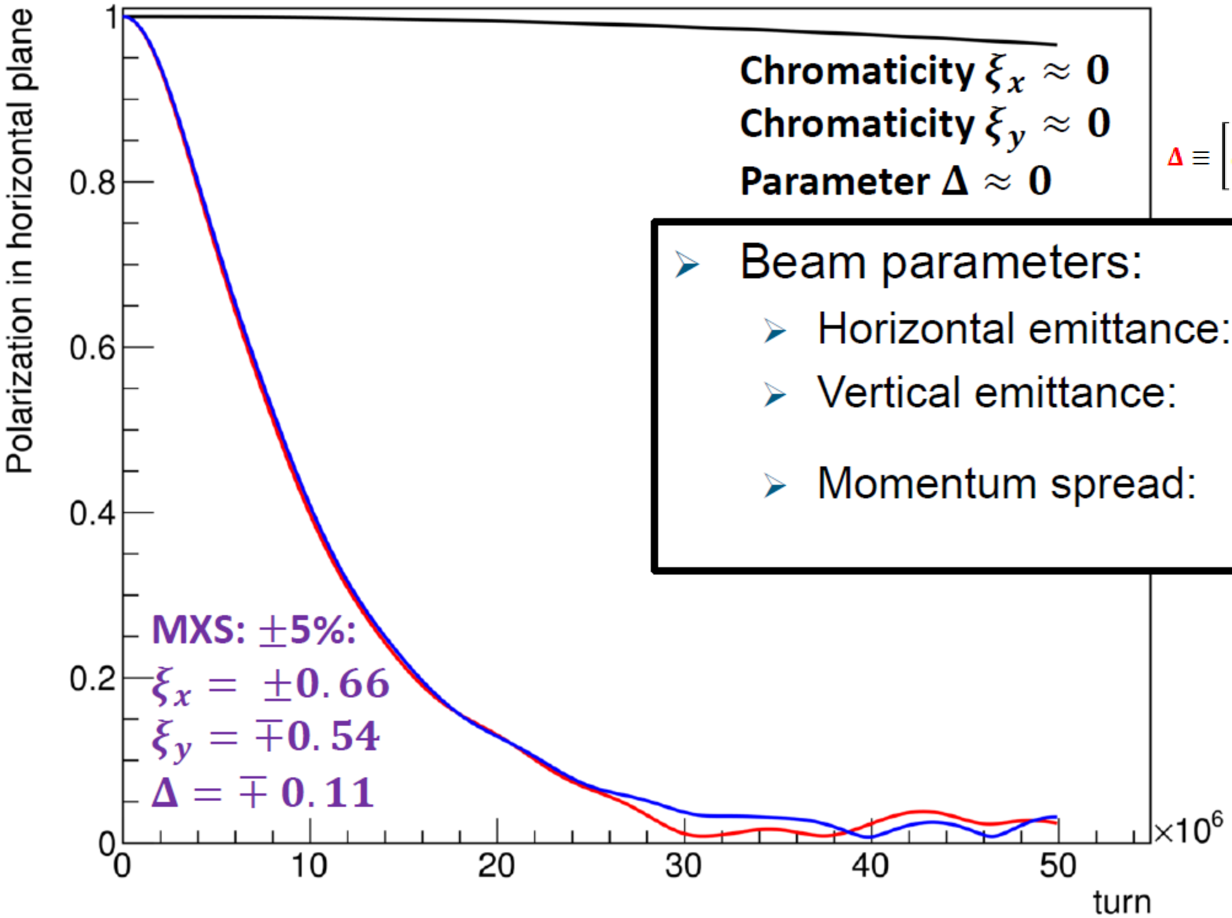
Simulations of SCT

- Deuterons, $p = 970\ MeV/c$, initially radial polarized (→ precession around vertical axis)



$$\Delta \equiv \left[\alpha_1 + \frac{3}{2\gamma_0^2}\left(\beta_0^2 - \left(\alpha_0 - \frac{1}{\gamma_0^2}\right)\right)\right] = 0$$

- Beam parameters:
  - Horizontal emittance: $\epsilon_x = 5\ \mathrm{mm\ mrad}$
  - Vertical emittance: $\epsilon_y = 5\ \mathrm{mm\ mrad}$
  - Momentum spread: $\left(\frac{\Delta p}{p}\right)_{rms} = 5 \cdot 10^{-4}$

→ **More tracking results presented by M. Rosenthal in the student retreat**

Simulation Program Development

Aim:

- Robust and advanced numerical tracking codes for exploring various systematic effects.
- Sophisticated lattice design tools for storage rings in the energy range of 0.7-1.5GeV/c with all electrostatic elements as well as combined magnetic and electric elements.

Capabilities:

- Accurate description of all ring elements including fringe fields.
- Allowing various error inputs for systematics investigation.
- Accurate implementation of RF spin manipulation elements.
- Calculation of both orbital and spin motion with a high accuracy for over 10^9 orbital revolutions.
- Allowing multipole particle tracking for exploring IBS as well as beam-beam effects.
- User friendly graphic interfaces for extracting physical information from tracking data.
  (e.g., orbit, betatron tune, and spin tune from tracking data)

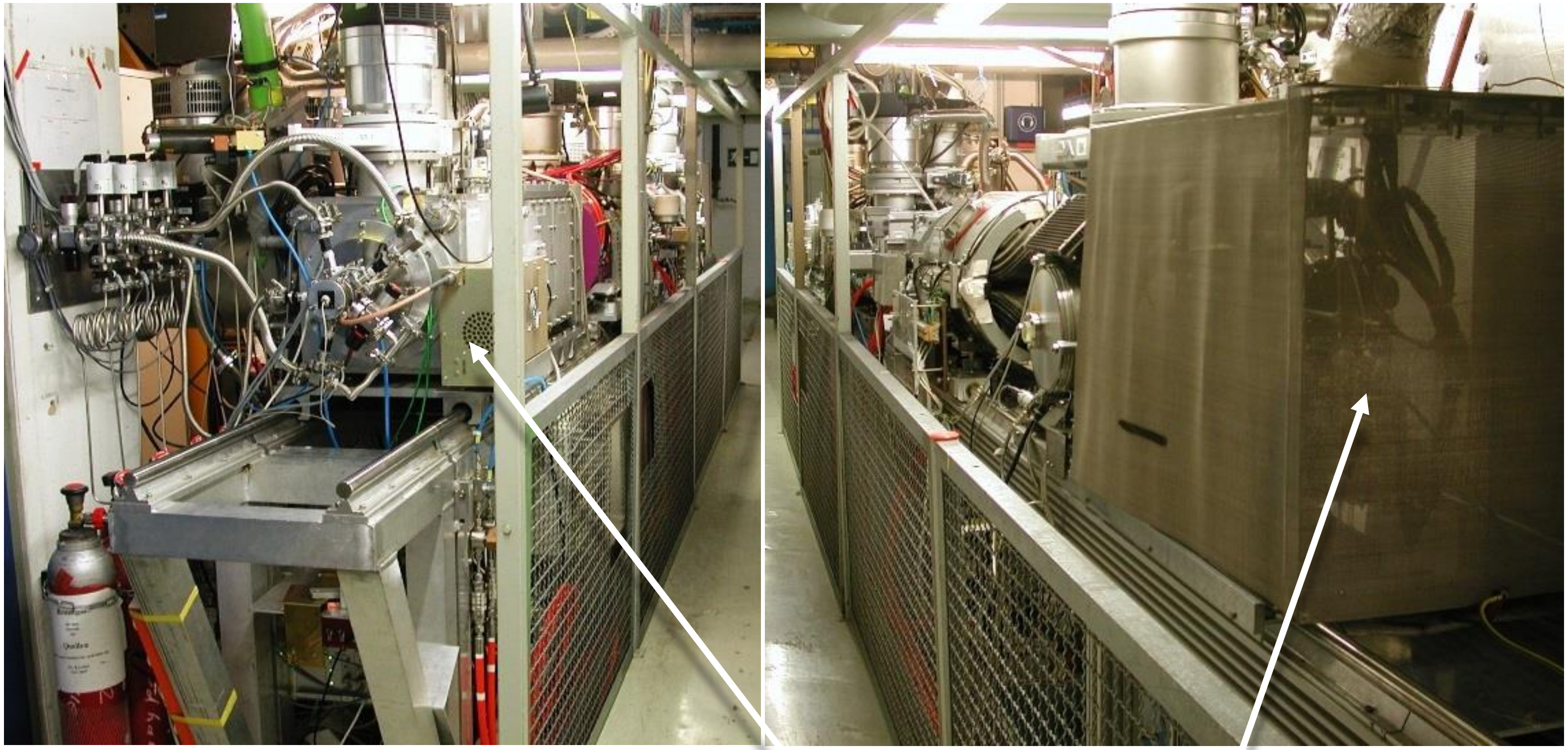
IPAC15 satellite meeting
on Spin Tracking for Precision Measurements
https://indico.cern.ch/event/368912/program

Ion Source Development

Polarized ion source at COSY

Intensity of polarized deuterons increased by 30%

Pulsed nuclear polarized atomic beams   Pulsed Cs ionizer for charge exchange



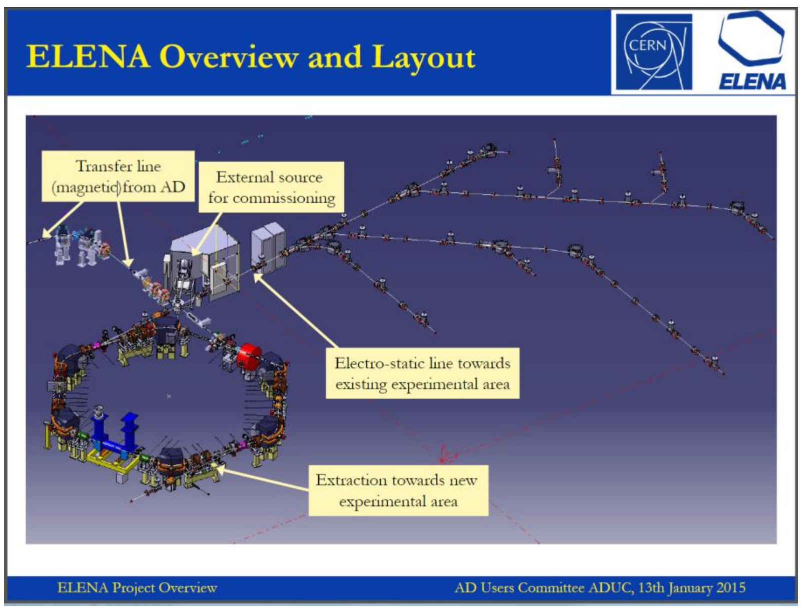
About 6 m from the pulsed ABS to the Cs ionizer

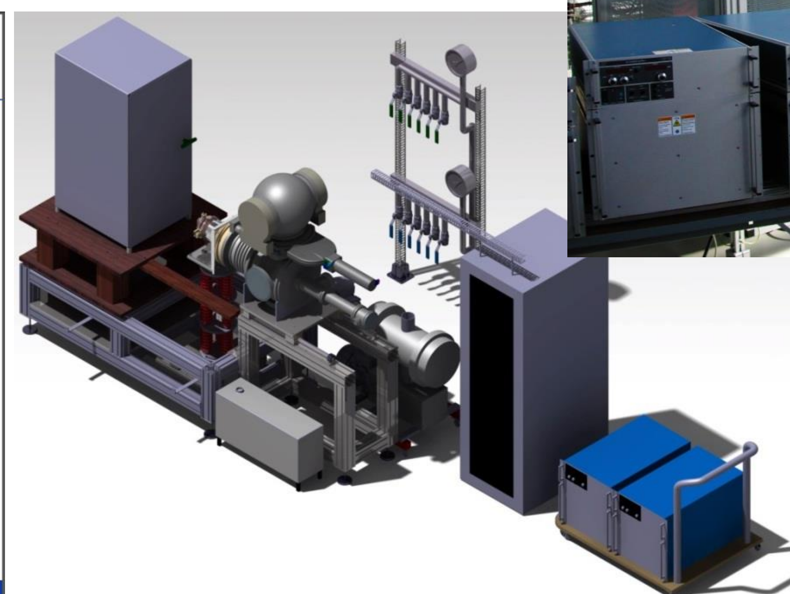
Ion Source Development

Ion source for ELENA at CERN

Commissioning and first measurements with 100 keV H- and p beams

- FZJ provides ion source for H-/protons
- Commissioning of antiproton synchrotron
- antiproton low energy electron cooling, precision
- Time line: 2016 commissioning with beam





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COSY Facility: Developments for HESR

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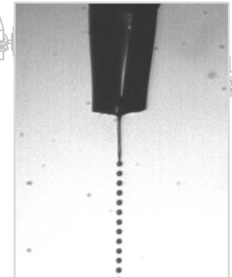
Barrier Bucket Cavity
mean energy loss compensation



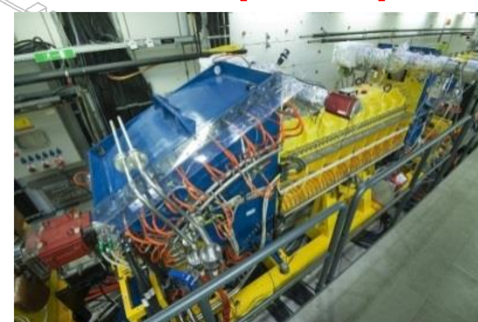
Pellet Target
beam-target interaction

Low-Energy Electron Cooler
100 kV

COSY: 0.3 -3.7 GeV/c
Pol. protons and deuterons
HESR: 1.5 – 15 GeV/c
Antiprotons and HI

High-Bandwidth Stochastic Cooling

ARD (PoF 2)



High-Energy Electron Cooler
2 MV

Residual Gas Profile Monitor

DTS

Test bench for HESR components and FAIR detectors

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Summary

Progress:

- Precision Spin Manipulation (talk by S. Mey)

  Spin tune measurement with precision of 10^{-10}
  Spin coherence time of more then 400s
  Spin tracking codes developed and partly benchmarked
  RF Wien filter build and applied

- Ion Sources

  Increase of polarized source performance
  First measurements with ELENA/CERN source

- High-Energy Beam Cooling (talk by V. Kamerdzhiev)

  Commissioning of 2 MV Electron Cooler
  Construction and test with beam of high-bandwidth stochastic pickups

Plans:

- Bench marking experiments for spin tracking in electric fields
- Development of static E/B deflectors
- Investigation of combined Electron and Stochastic Cooling