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JÜLICH
FORSCHUNGSZENTRUM

From Polarization towards a Storage Ring EDM-Facility at COSY

PSI 2010, October 2010 | Detlev Gotta, Institut für Kernphysik (IKP)

for the EDM@COSY working group

↓

COSY - accelerator

↓

IKP 1- 4

experiment *J. Ritman*
experiment *H. Ströher*
theory *U.-G. Meissner*
accelerator *R. Maier*

Energy range:
0.045 – 2.8 GeV (p)
0.023 – 2.3 GeV (d)

Max. momentum ~ 3.7 GeV/c

Energy variation (ramping mode)

Electron and Stochastic cooling

Internal and external beam

High polarisation (p,d)

Spin manipulation

COSY – Experimental Facilities

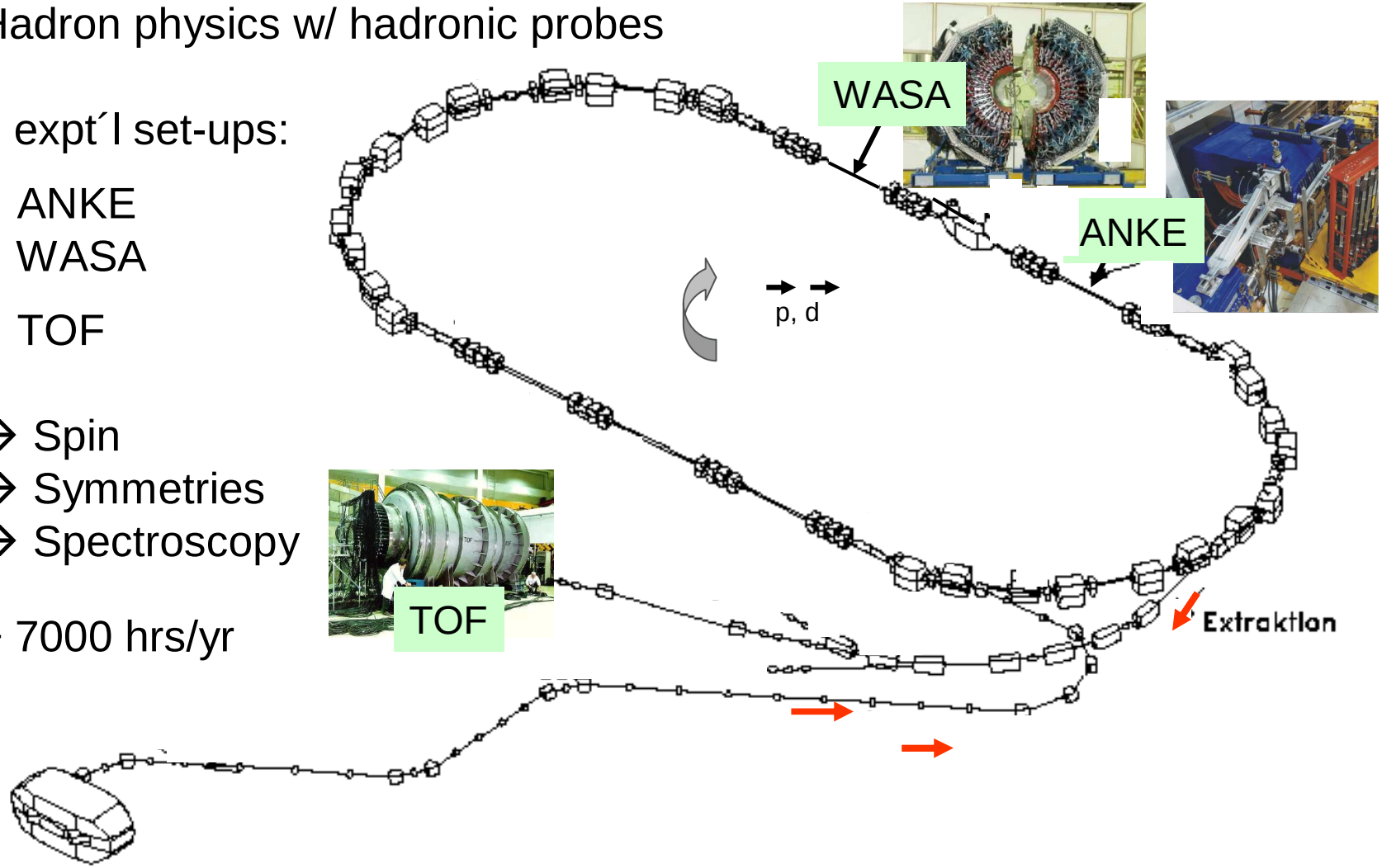
Hadron physics w/ hadronic probes

3 expt´l set-ups:

- ANKE
- WASA
- TOF

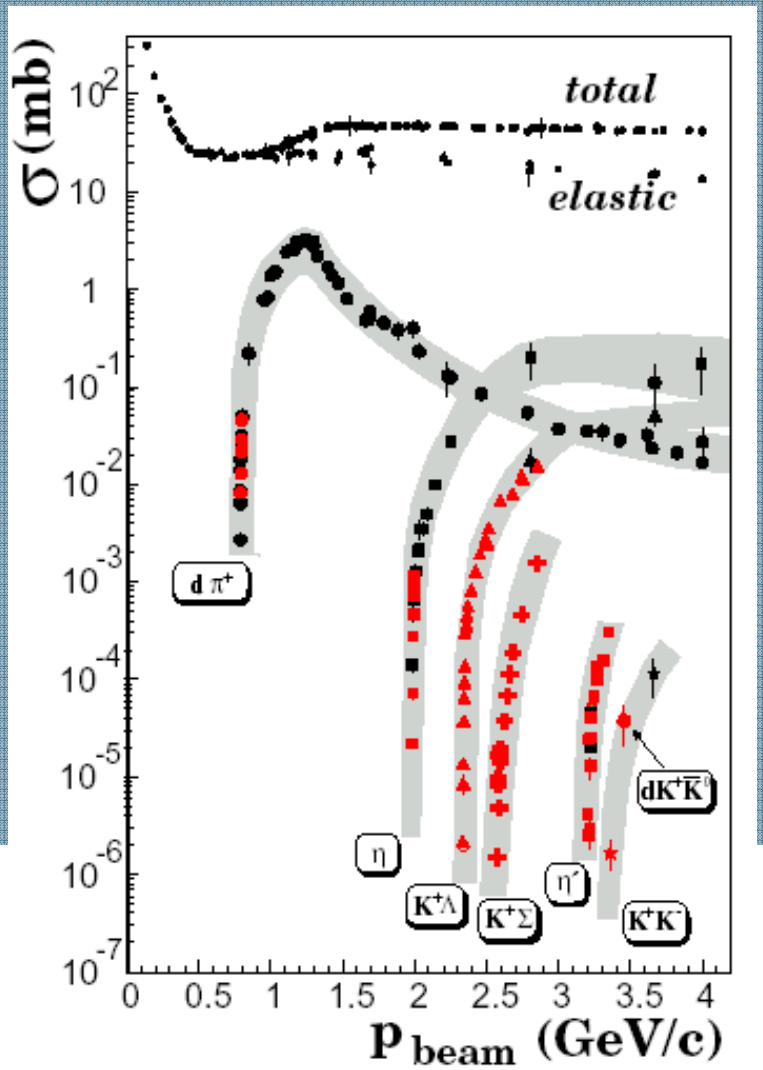
→ Spin
→ Symmetries
→ Spectroscopy

~ 7000 hrs/yr



COSY: Physics – Overview

$p\,\vec{(d)} + p\,\vec{(d,A)} \rightarrow X\,Y\,Z$



NN-, NY- Interaction
(Elastic, Breakup, CEX, Diproton)

Meson Production (N*, Δ*, Y*)
Nm-, Am-Interaction (FSI)

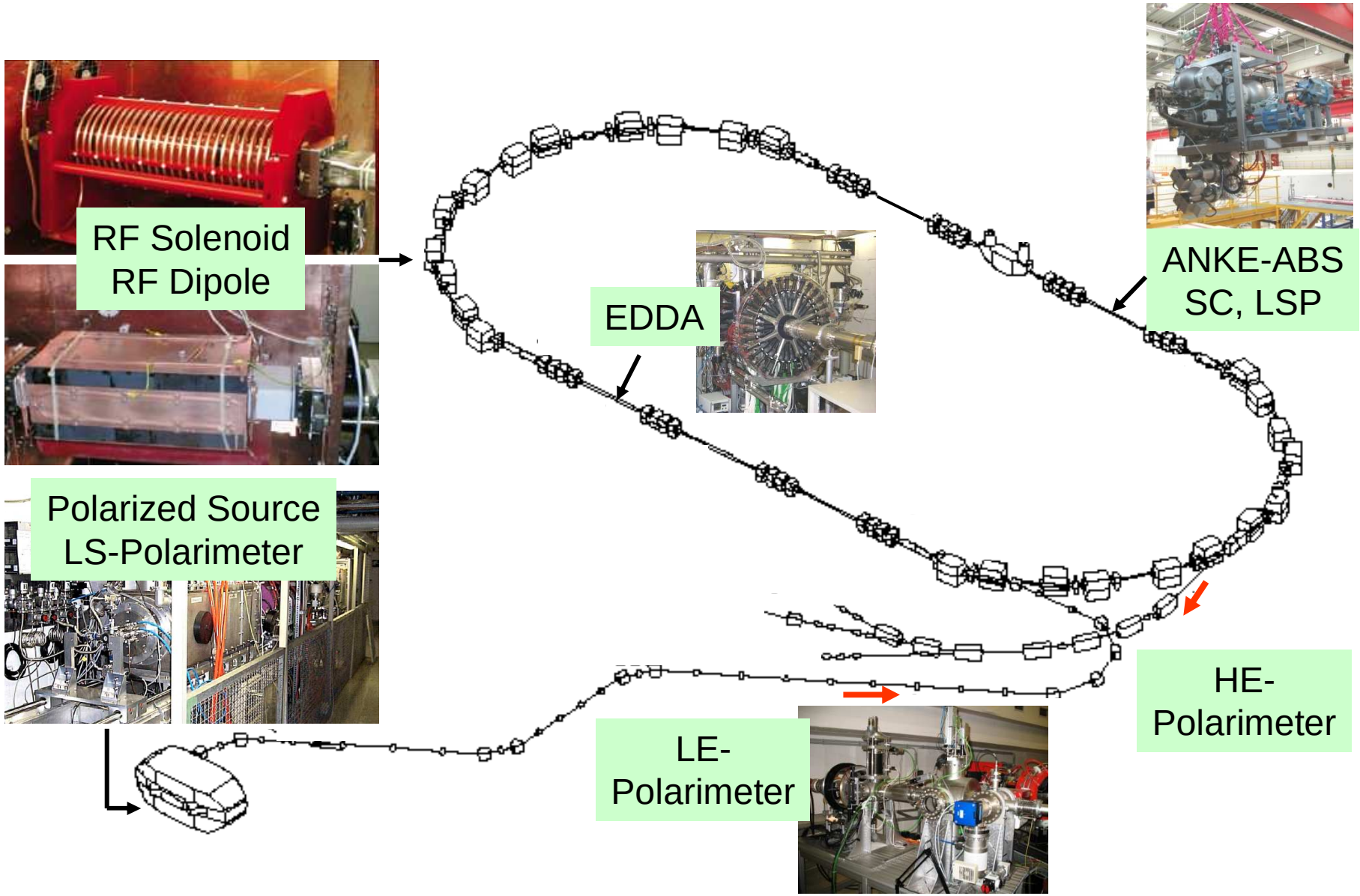
Symmetries, Symmetry Breaking
(Reactions, η- and η´- Decays)

Spin Physics
(*in situ* p-, p̄- Polarization (PAX))

Immediate future - Spin physics

1. Physics using longitudinally polarized beams
2. PAX - towards polarized antiprotons

COSY – Spin Physics



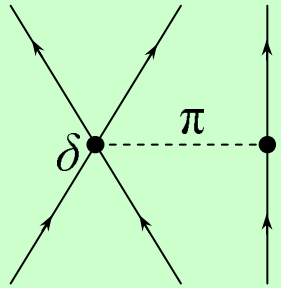
Physics at COSY using longitudinally polarized beams: Pion production

Derive chiral three-body forces from p-wave production

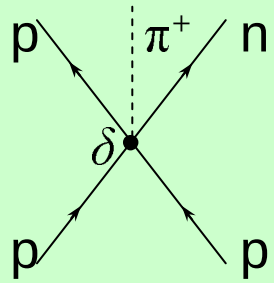
C. Hanhart et al., PRL 85 (2000) 2905

- Very different kinematics, but same δ: **consistency check** of ChPT for NN→NNπ
- Model-independent extraction from ANKE data pn→$\{pp\}_s\pi^-$
- Spin structure of the pn→$\{pp\}_s\pi^-$ (or pp→$\{pp\}_s\pi^0$) defined only by **two** spin **amplitudes** (6 for pp→$d\pi^+$)

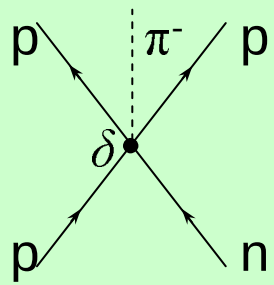
Role of 4Nπ contact term



pd elastic
(RIKEN, KVI, ...)



$^1S_0 \rightarrow {}^3S_1p$
(IUCF)



$(^3S_1 - {}^3D_1) \rightarrow {}^1S_0p$
(unknown)

Physics at COSY using longitudinally polarized beams: Pion production

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$$\left(\frac{d\sigma}{d\Omega}\right)_0 = \frac{1}{4}(|A|^2 + |B|^2),$$

$$A_{xx} = -A_{zz} = \frac{|B|^2 - |A|^2}{|A|^2 + |B|^2}, \quad A_{yy} = 1,$$

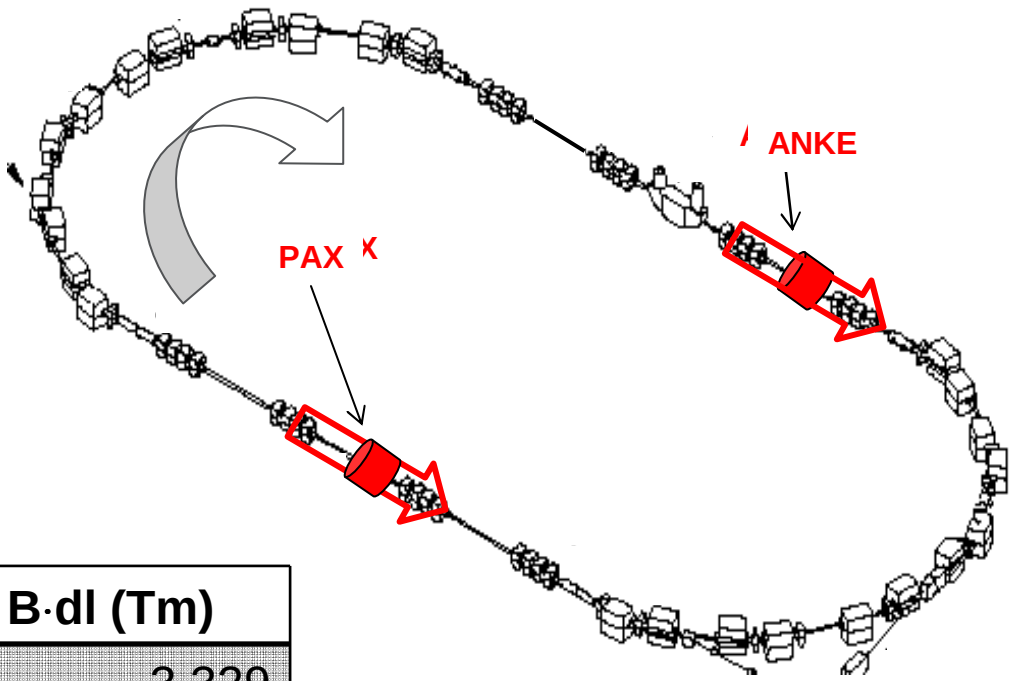
$$A_y^p = A_y^Q = -\frac{2Im(A^*B)}{|A|^2 + |B|^2}$$

$$A_{xz} = A_{zx} = -\frac{2Re(A^*B)}{|A|^2 + |B|^2}$$

Requires Siberian snake

Physics at COSY using longitudinally polarized beams: Snake Concept

- Should allow for flexible use at two locations
- Fast ramping (< 30s)
- Cryogen-free system



	B·dl (Tm)
$pn \rightarrow \{pp\}_s \pi^-$ at 353 MeV	3.329
PAX at COSY 140 MeV	1.994
PAX at AD 500 MeV	4.090
T_{max} at COSY 2.88 GeV	13.887

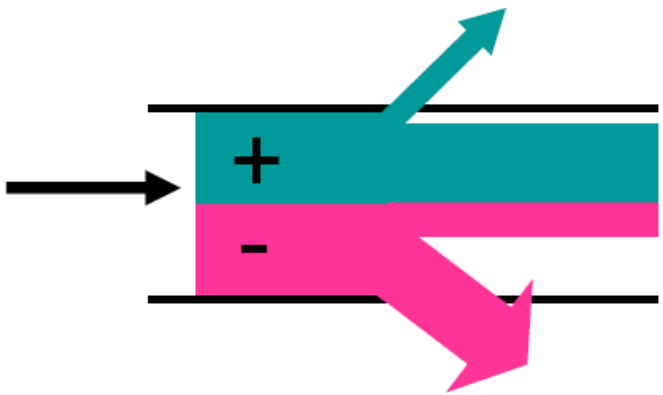
PAX: Towards polarized antiprotons

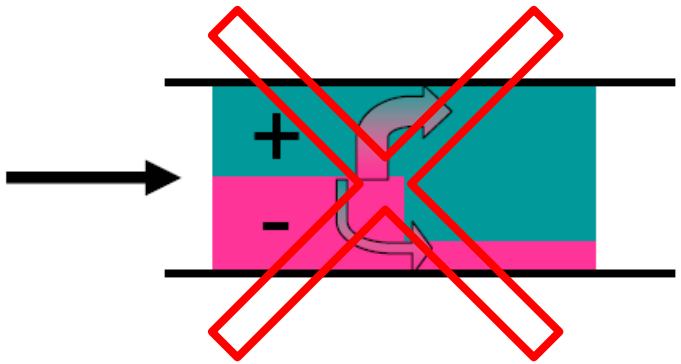
Frank Rathmann (IKP,FZJ), Paolo Lenisa (INFN Ferrara) et al.

Production of polarization in a stored beam

Two Methods: Loss versus spin flip

For an ensemble of spin ½ particles with projections **+** (↑) and **–** (↓)





selective loss

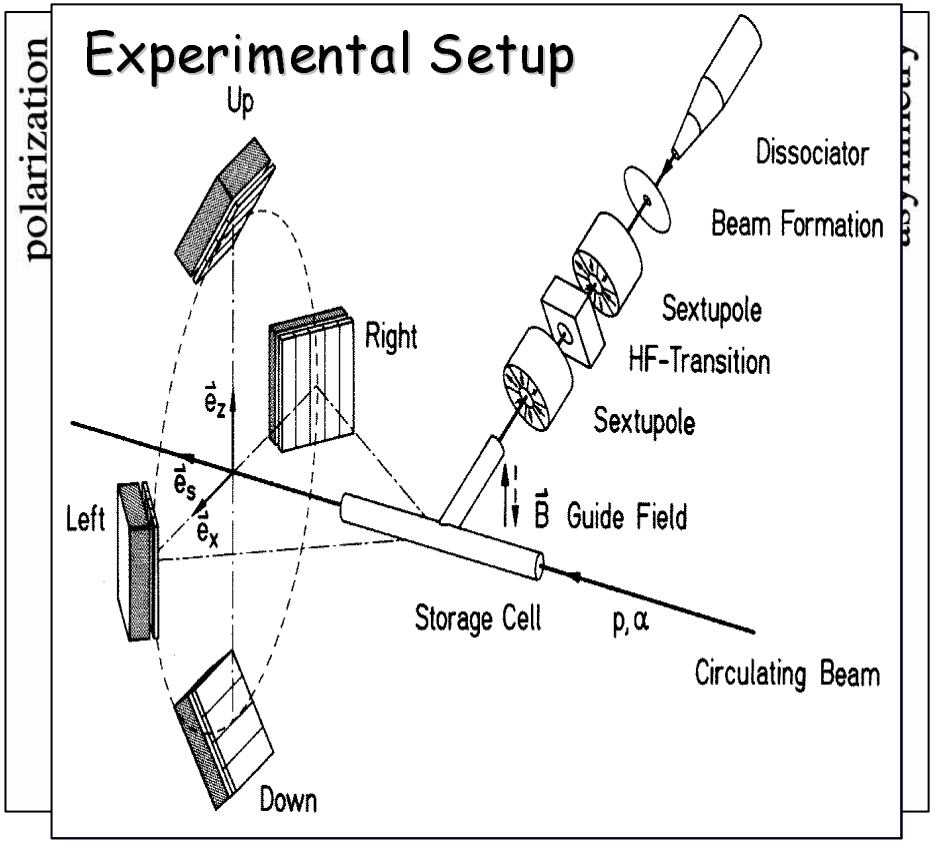
discard (one) substate
(more than the other)

selective flip

reverse (one) substate
(more than the other)

PAX: Towards polarized antiprotons

Spin-filtering at TSR: „FILTEX“ – proof-of-principle



Spin filtering works for protons

PAX submitted new proposal to find out **how well does spin filtering work for antiprotons:**
Measurement of the Spin-Dependence of the p̄p Interaction at the AD Ring
(CERN-SPSC-2009-012 / SPSC-P-337)

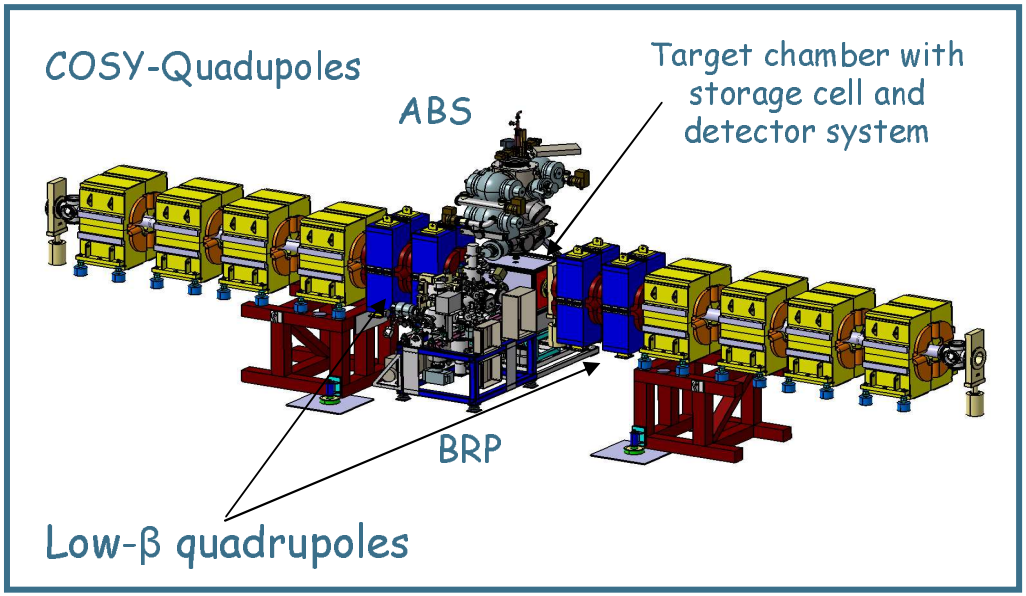
PAX: Towards polarized antiprotons

Spin-filtering studies at COSY → proposed AD

Main purpose:
1. Commissioning of the experimental setup for AD
2. Quantitative understanding of the machine parameters

Phases of COSY installation:

1. July 2009: Installation of quadrupole magnets (✓)
2. July 2010: Installation of rest of equipment (✓)
3. After July 2010: Spin-filtering studies with protons (...)



?

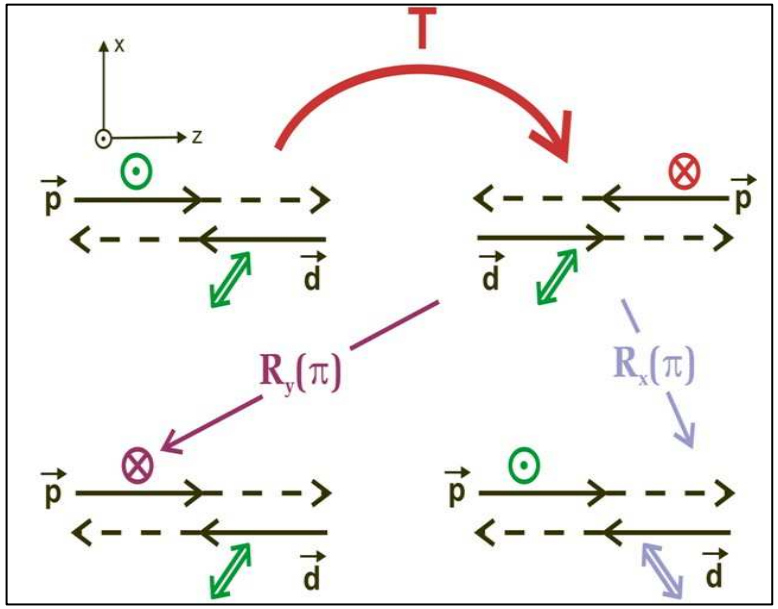
Spin filtering for **antiprotons**

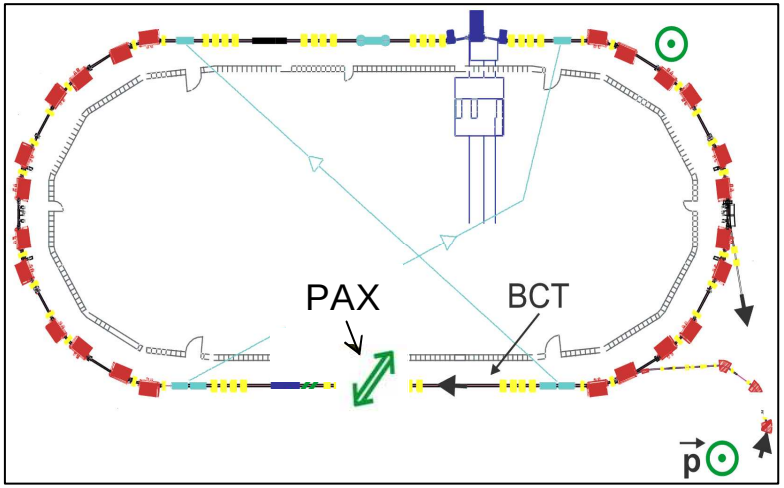
Future

1. *Time Reversal invariance Test*
2. *Search for Electric Dipole Moments*

Future - Time Reversal Invariance Test

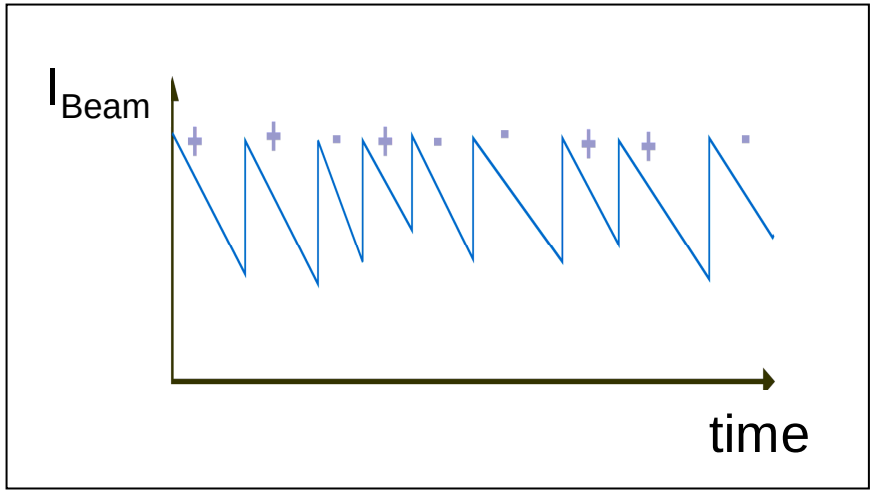
COSY-TRIC: P-even, T-odd





COSY used as accelerator and detector:

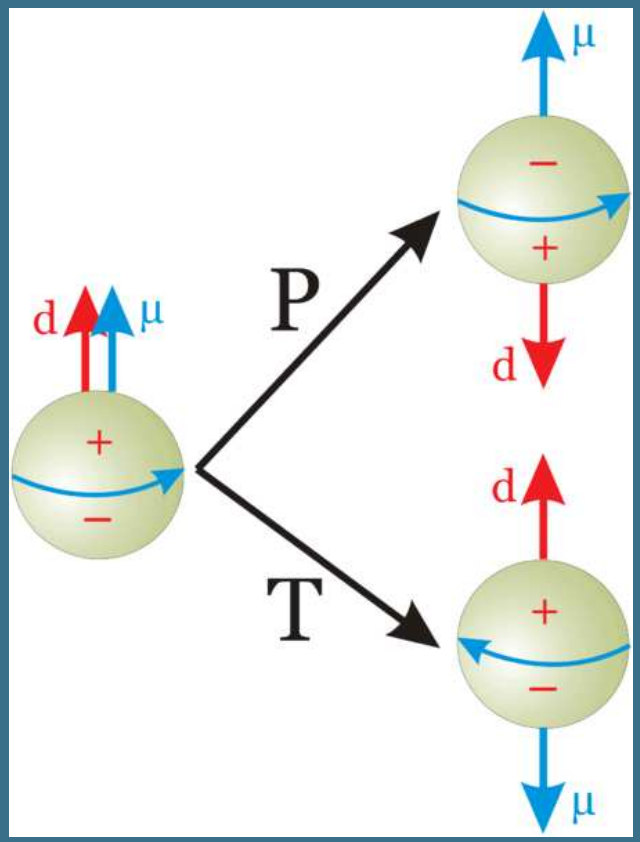
Total polarization correlation coefficient $A_{y,xz}$ leads to relative difference of current slopes



Milestone: Operation of Precision BCT with $\Delta I/I<10^{-4}$

Future - Search for Electric Dipole Moments

Mystery of matter-antimatter asymmetry



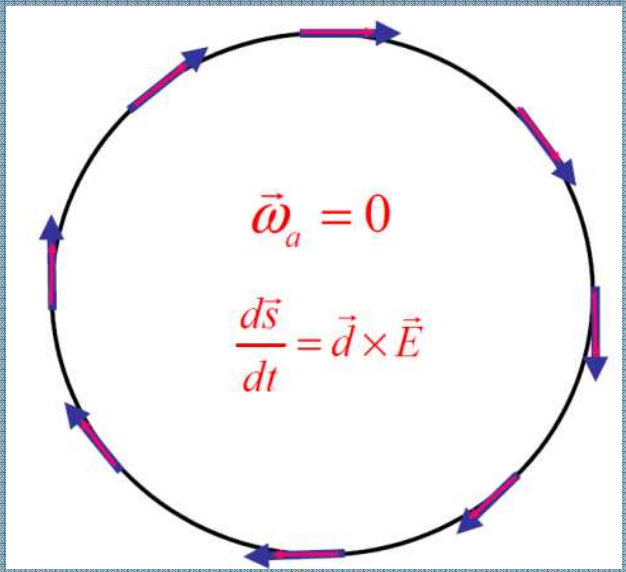
1. proton, deuteron and neutron combined can pin down source if EDM is non-zero

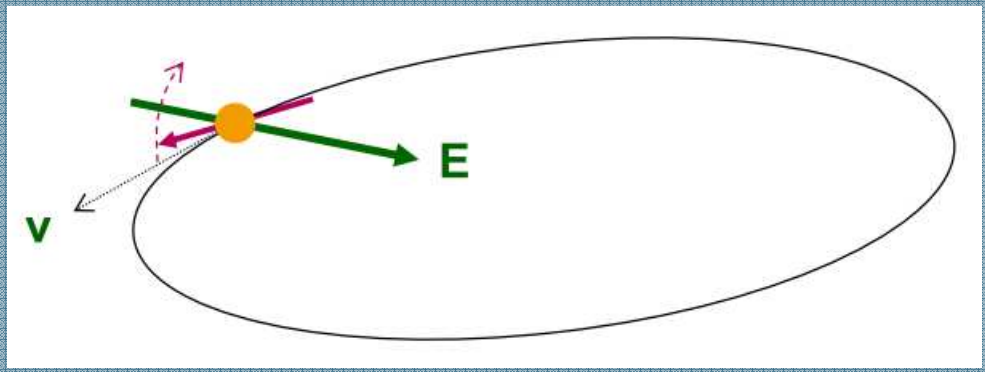
$$d_D = -4.67\,\tilde{d}_d + 5.22\,\tilde{d}_u$$
$$d_n = -0.01\,\tilde{d}_d + 0.49\,\tilde{d}_u$$

2. In particular: differentiate between a QCD-source and physics beyond SM

3. The proton and deuteron provide a path to the next order of sensitivity

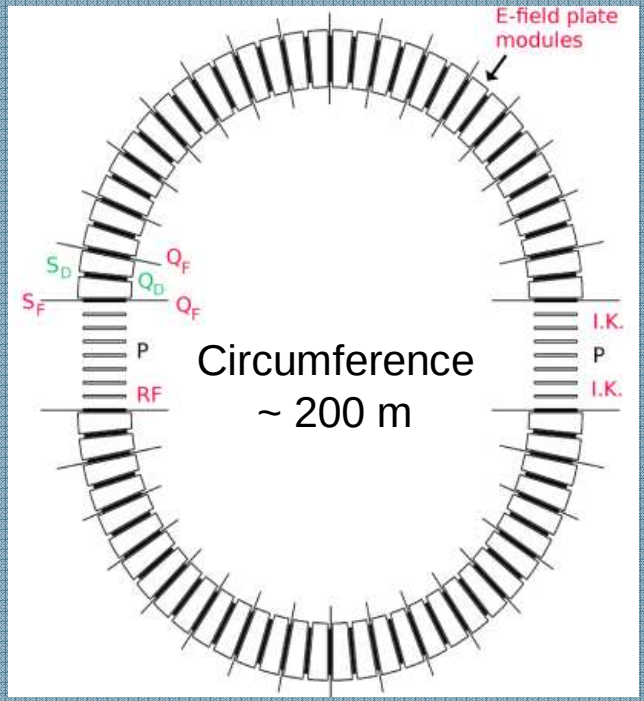
EDM search in time development of spin in a storage ring





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

2 beams simultaneously rotating in a ring (CW, CCW)



Approved BNL-Proposal:
Goal for protons

$$\sigma_{d_p} \approx 2.5 \times 10^{-29}\, \mathrm{e \cdot cm/year}$$

Technological challenges !

- **Spin coherence time (1000 s)**
- **Beam positioning (10 nm)**
- **Continuous polarimetry (< 1ppm)**
- **E - field gradients (~ 17MV/m at 2 cm)**

Carry out proof of principle experiments (demonstrators) at COSY

EDM at COSY – First Steps

JÜLICH FORSCHUNGSZENTRUM

BNL-Review (Dec. 2009):

The Committee recognizes that a great deal of thought and development has already gone into preparations for the experiment, and commends especially the excellent progress made via in-beam tests of polarimetry at COSY.

In order to assess resource needs realistically, and to establish productive cooperative agreements among institutions (e.g., BNL and COSY),

Flesh out measurement plans for a COSY experiment to benchmark simulations of spin coherence time and for possible RHIC tests of BPM performance.

The collaboration is strongly encouraged to move ahead with the plans to develop the new polarimeter and test it in COSY.

EDM at COSY – First Steps

Tests by dEDM-Collaboration at COSY (I):

Proposal 176 : Studies at COSY

Part I : Polarimeter development goals

Measure a change in the vertical polarization with a sensitivity of 10^{-6}
Provide a continuous record with time
Reduce systematic errors to below sensitivity limit

Studies & tests performed

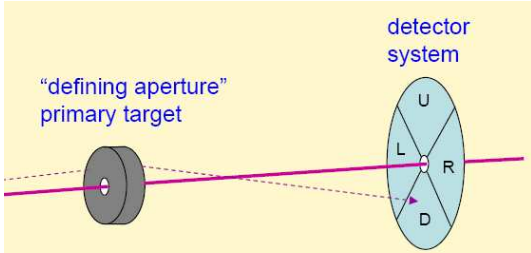
Installed stochastic extraction w/ 15mm carbon target & stripline noise
Installed + tested custom DAQ system
Optimized EDDA efficiency : enhance elastically scattered d's
Generate and measure controlled systematic errors
Tested methods to suppress systematic errors
cross ratios + calibrated model

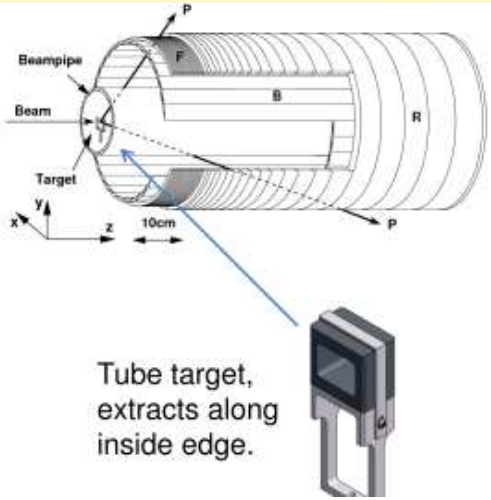
SUCCESS!!!

Accomplishments

Demonstrated high efficiency (7×10^{-4}) with large analyzing power (0.38)
Demonstrated ability to measure slope of $-(4\pm11)\times10^{-6}$/s
Blind test using small solenoid : $\Delta\varphi = +0.87$ mrad ↔ $+(1.4\pm0.4)$ mrad
Scaling to EDM expt. : control slope < 30ppb, **well under requirement**

$\vec{d} + {}^{12}C$





(Transparency by G. Onderwater (KVI, NL))

EDM at COSY – First Steps

Polarimetry for protons:

→ up to now (C-scattering)

→ polarized hydrogen target (FR)
and employ pp elastic scattering (PAX)

EDM at COSY – First Steps

Tests by dEDM-Collaboration at COSY (II):

dEDM
deuteron electric dipole moment

Beam time request 176.4
COSY PAC 38 – 28.6.2010
Gerco Onderwater (KVI)
for the srEDM collaboration

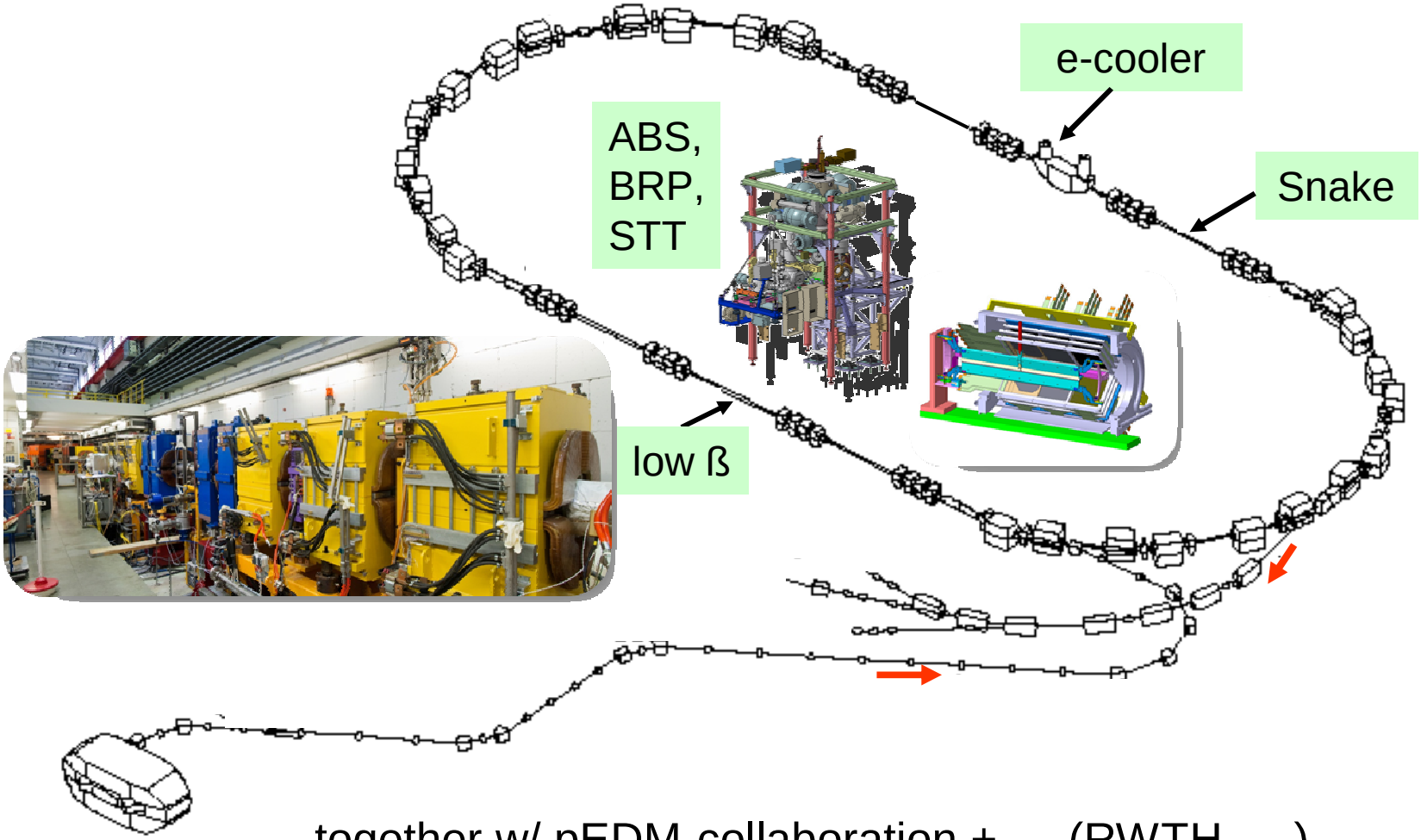
Proposal at recent COSY-PAC (3 weeks)

- spin coherence time (SCT) studies
- horizontal polarization
- SCT optimization

(Transparency after G. Onderwater (KVI, NL))

EDM at COSY – Thoughts

Use COSY „as it is“ for a proof-of-principle measurement !?

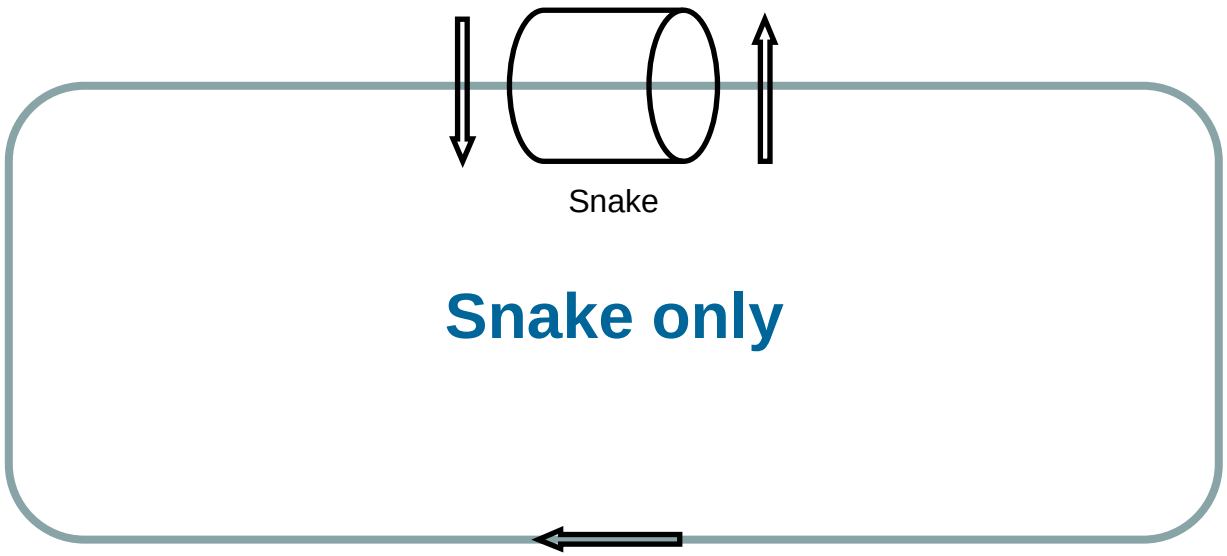


… together w/ pEDM-collaboration + … (RWTH, …)

A pilot experiment at COSY

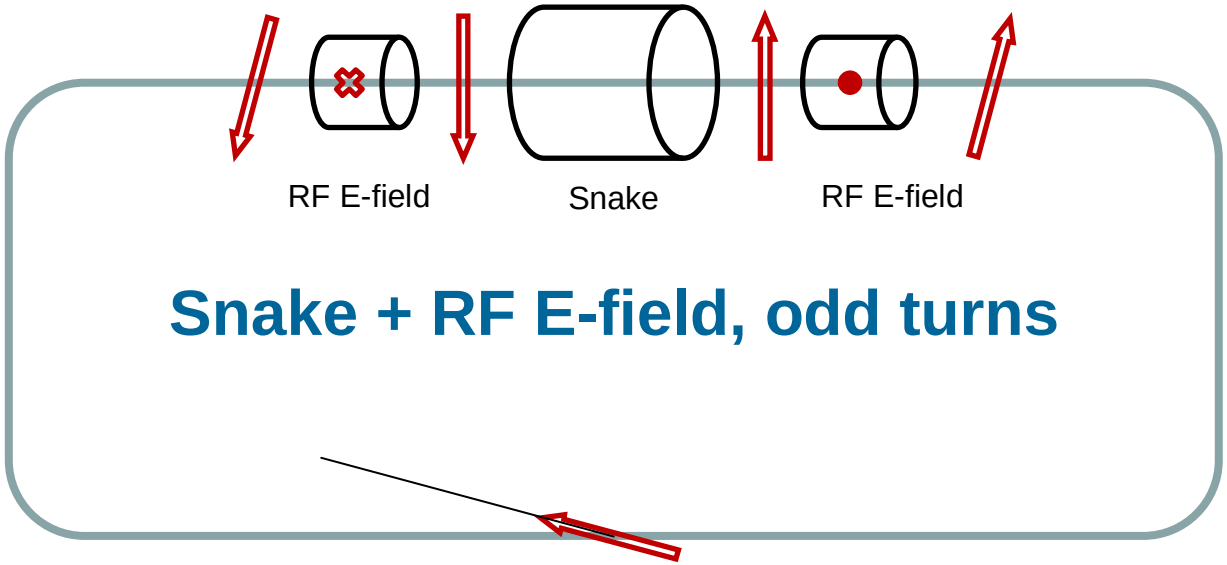
Proof of principle test for EDM searches in storage rings

→ **Combination of a snake and RF fields**

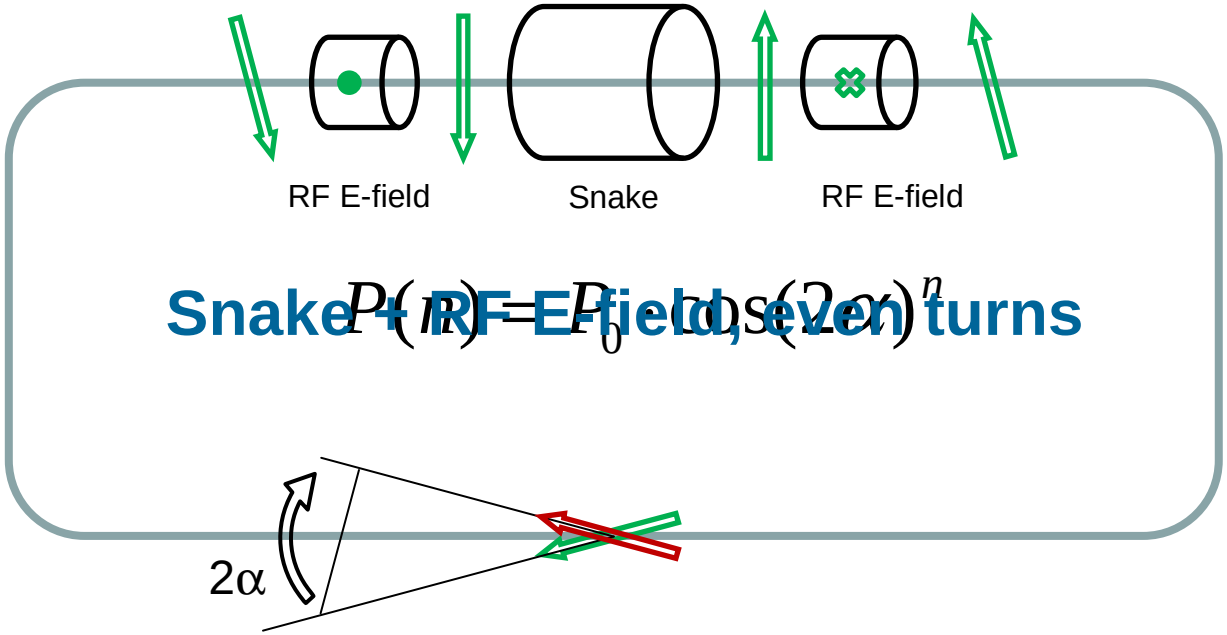


Siberian snake turns closed orbit longitudinal opposite the sake

A pilot experiment at COSY



A pilot experiment at COSY

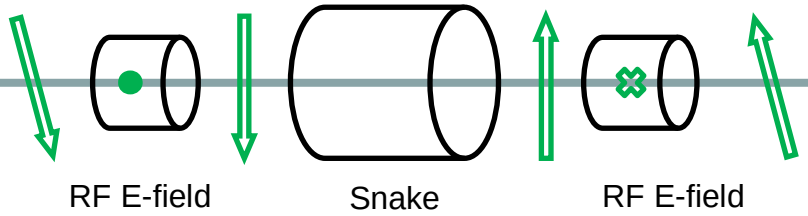


$$P(n) = P_0 \cdot \cos(2\alpha)^n$$

Snake + RF-E-field, even turns

Snake + reversed RF E-fields → depolarization

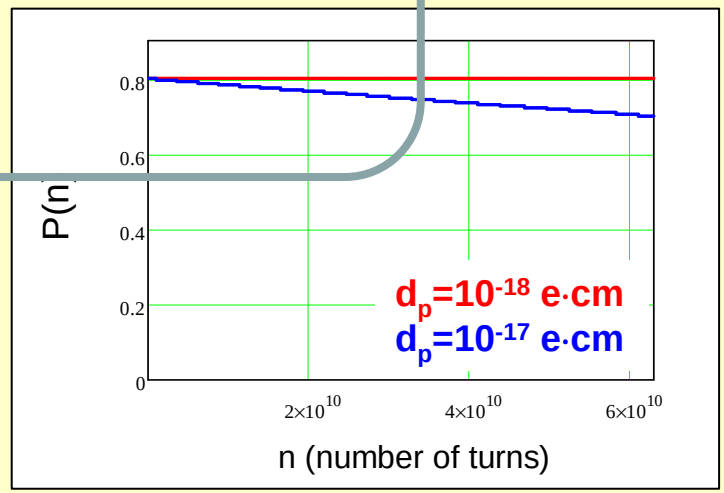
A pilot experiment at COSY



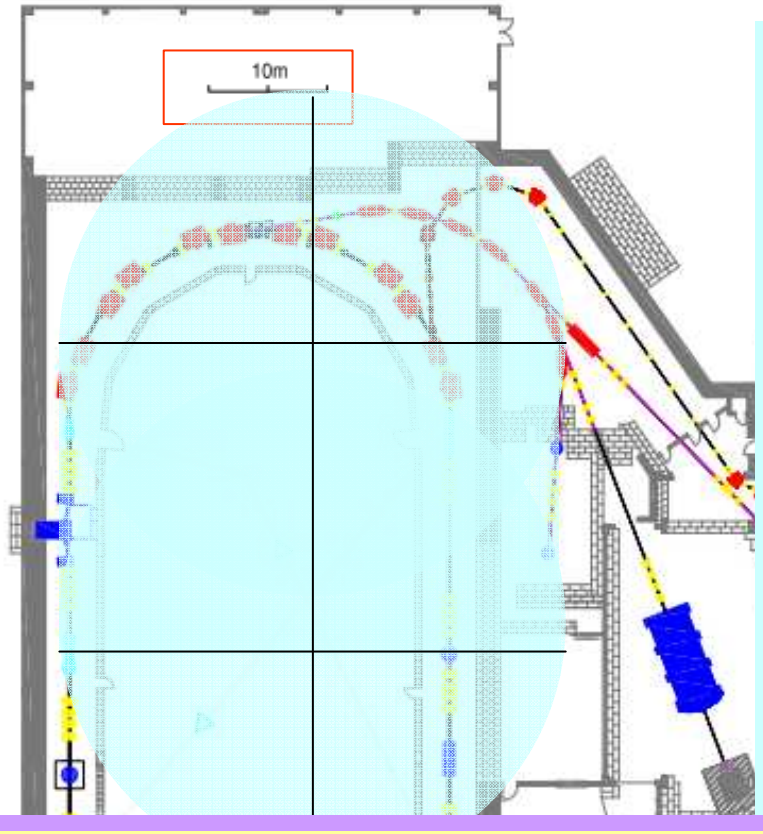
$$P(n) = P_0 \cdot \cos(2\alpha)^n$$

Parameters of a proton EDM measurement:

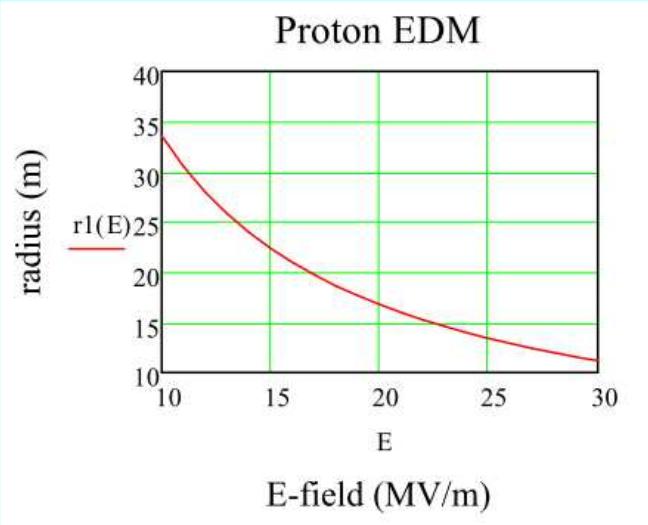
- T_p=140 MeV
- E_{RF}=1 MV/m, L_{cavity}=0.5 m
- Time of store ~24h → 6×10^{10} turns
- α=1 ·10^{-7} rad
- Sensitivity:
  - $d_p=10^{-17}$ e·cm → τ_p=5.9 ·10^5 s
  - $d_p=10^{-18}$ e·cm → τ_p=5.9 ·10^7 s



EDM at COSY – Thoughts



Advantageous if ONE ring for p,d, ^{3}He, and if it would fit into COSY-building:



A *magic* storage ring for protons (electrostatic), deuterons, …

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

EDM searches - only upper limits up to now:

Particle/Atom	Current EDM limit	Future Goal
Neutron	$<1.6\times10^{-26}$	$\sim10^{-28}$
^{199}Hg	$<3.1\times10^{-29}$	$\sim10^{-29}$
^{129}Xe	$<6\times10^{-27}$	$\sim10^{-30}$-10^{-33}
Proton	$<7.9\times10^{-25}$	$\sim10^{-29}$
Deuteron	p + n + (πNN)	$\sim10^{-29}$

Summary

Ongoing

- **Precision experiments with polarization**
- **Build snake for COSY** **essential for future physics**

Proposed

- **Make polarized antiprotons using the AD of CERN**

Planned

- Resume D. Eversheims idea for **time reversal invariance** test

Future

Focus on EDM searches

- carry out proof-of-principle experiment at COSY
- contribute to BNL effort for pEDM ring
- design all-in-one machine for p, d and ^{3}He

EDM at COSY – Formal Steps

Wilhelm und Else Heraeus Seminar

1. **General Information:**

- Title of the WE-Heraeus Seminar:

  Search for Electric Dipole Moments (EDMs) at Storage Rings

- Meeting Place:

  Physikzentrum Bad Honnef

- Date/Duration:

  July 4 – 6, 2011

- Scientific Leader:

  Prof. Dr. Hans Ströher
  Institut für Kernphysik
  Wilhelm-Johnen Straße
  52428 Jülich
  Germany

  PD Dr. Frank Rathmann
  dto.