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JÜLICH FORSCHUNGSZENTRUM

How to polarize antiprotons and what to use them for?

May 4, 2010

Frank Rathmann

4th Georgian – German School and Workshop in Basic Science
Tbilisi, Georgia

Polarized Antiproton EXperiments

PAX Collaboration

180 Physicists

35 Institutions (15 EU, 20 Non-EU)

Spokespersons:

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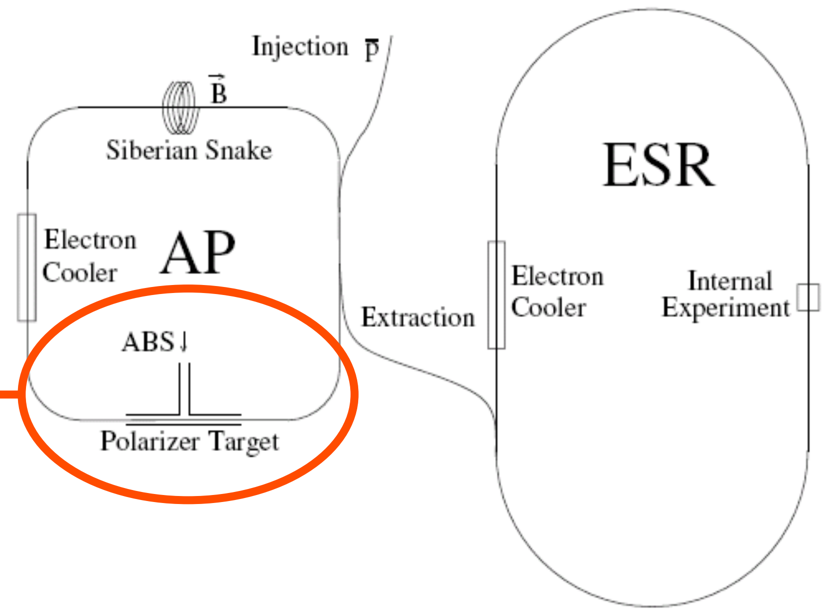
Introduction

PRL **94,** 014801 (2005) PHYSICAL REVIEW LETTERS week ending 14 JANUARY 2005

A Method to Polarize Stored Antiprotons to a High Degree

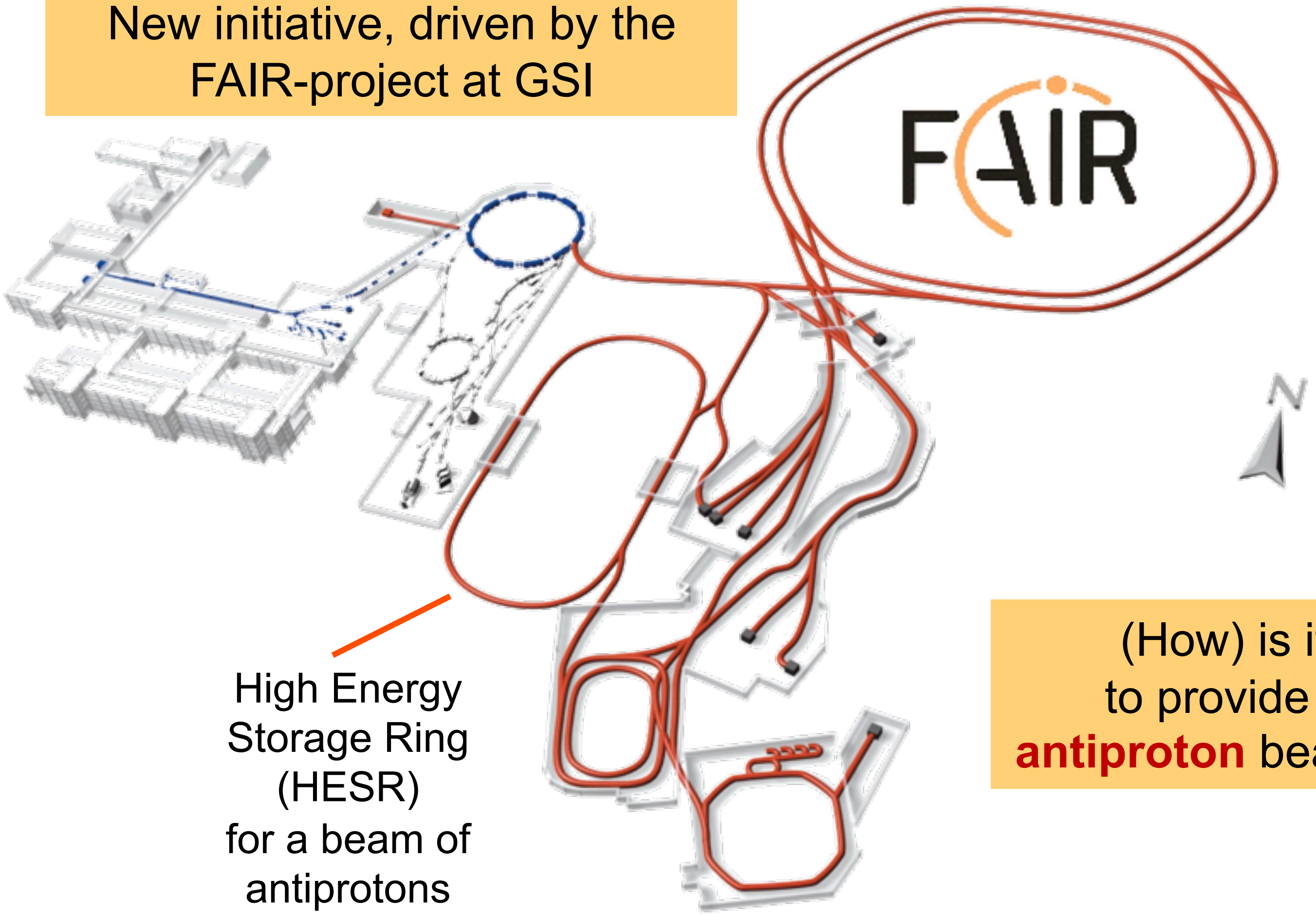
F. Rathmann,[1,*] P. Lenisa,[2] E. Steffens,[3] M. Contalbrigo,[2] P. F. Dalpiaz,[2] A. Kacharava,[3] A. Lehrach,[1] B. Lorentz,[1] R. Maier,[1] D. Prasuhn,[1] and H. Ströher[1]

We have proposed a method to polarize antiprotons by „spin-filtering"



Introduction

New initiative, driven by the FAIR-project at GSI

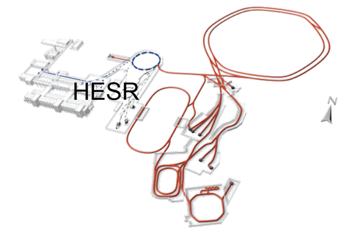


High Energy Storage Ring (HESR) for a beam of antiprotons

(How) is it possible to provide **polarized antiproton** beams in HESR?

QCD Physics at FAIR uses unpolarized Antiprotons

PAX → Polarized Antiprotons

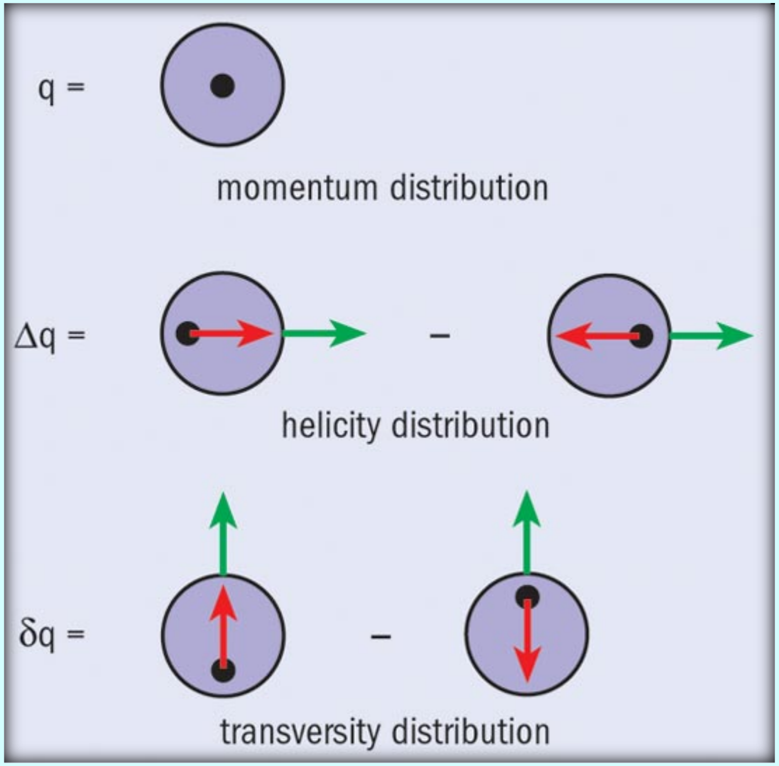


Physics Case:

Transversity distribution of the nucleon in Drell-Yan:

- Last leading-twist missing piece of the QCD description of the partonic structure of the nucleon
- **Direct measurement of $h_1^q(x,Q^2)$ of the proton for valence quarks** (A_{TT} in Drell-Yan >0.2)
    - **transversely polarized proton beam or target (✓)**
    - **transversely polarized antiproton beam (✗)**
- **+ other polarization observables in $\vec{\bar{p}}\vec{p}$**

Proton spin structure



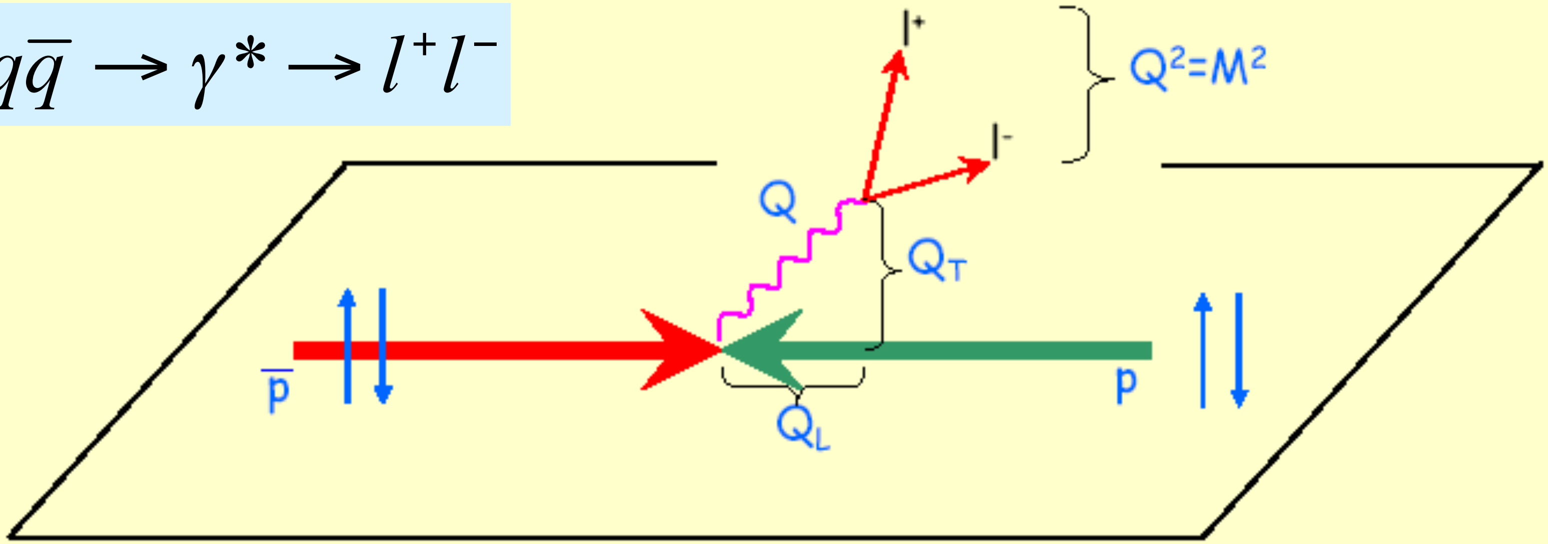
Very well known

Well known

unknown

Quark Transversity Distribution in Drell-Yan

$$q\bar{q} \to \gamma^* \to l^+ l^-$$



Double transverse spin asymmetry:

$$A_{TT} \equiv \frac{d\sigma^{\uparrow\uparrow} - d\sigma^{\uparrow\downarrow}}{d\sigma^{\uparrow\uparrow} + d\sigma^{\uparrow\downarrow}} = \hat{a}_{TT} \frac{\sum_q e_q^2 h_1^q(x_1, M^2) h_1^{\overline{q}}(x_2, M^2)}{\sum_q e_q^2 q(x_1, M^2) \overline{q}(x_2, M^2)}$$

First direct measurement: No competitive processes

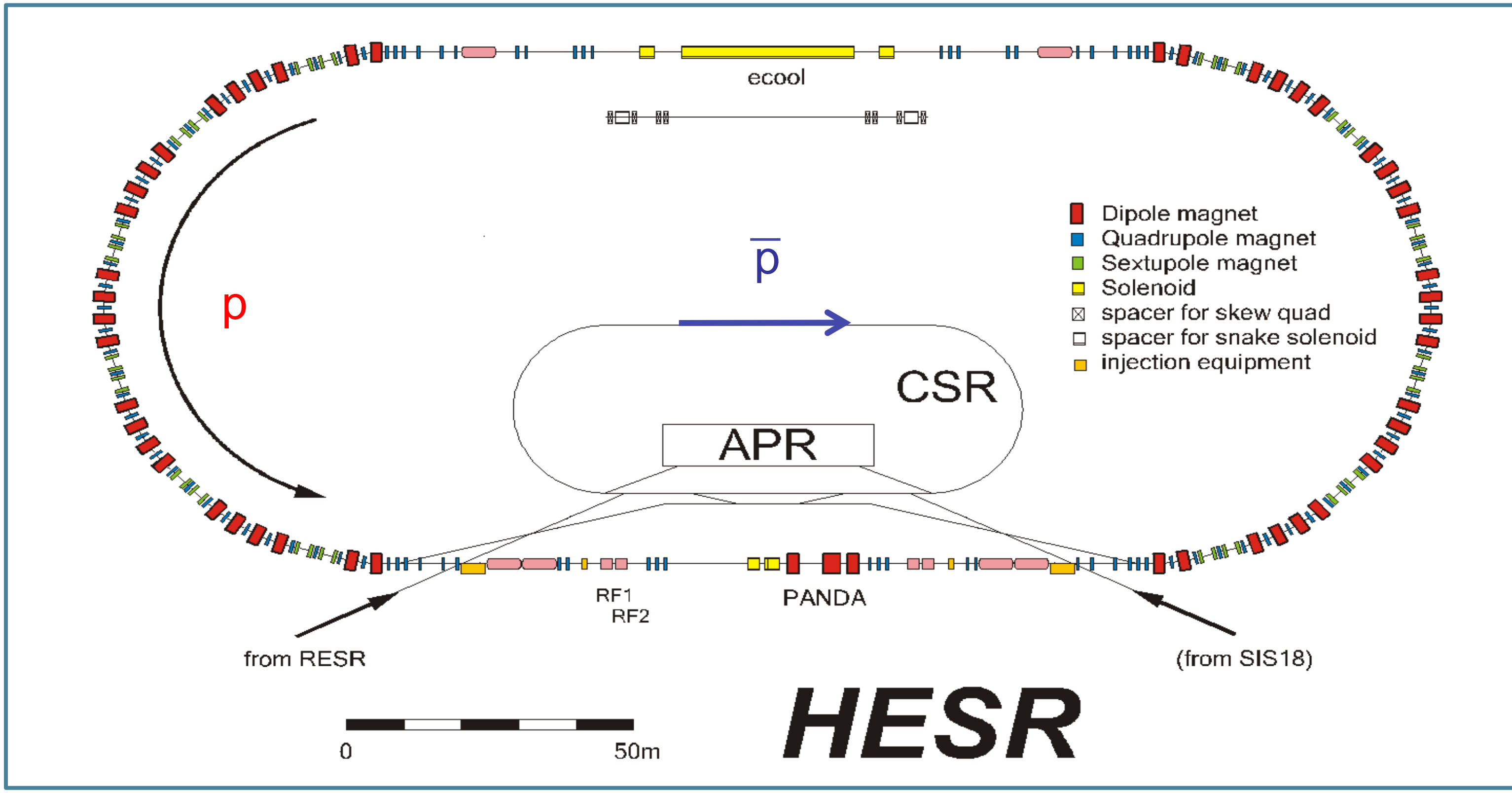
Routes to Transversity

	non-TMD	TMD
self-sufficient	$\bar{p}^{\uparrow}\, p^{\uparrow} \to \ell\,\bar{\ell}\, X$	$p\,\bar{p}^{\uparrow} \to \ell\,\bar{\ell}\, X$
	$p^{\uparrow}\, p^{\uparrow} \to (\text{high-}p_T \text{ jet})\, X$	$\bar{p}\,p^{\uparrow} \to \ell\,\bar{\ell}\, X$
using external input	$e\,p^{\uparrow} \to e'\,\Lambda^{\uparrow}\, X$	$e\,p^{\uparrow} \to e'\,\pi\, X$
	$p\,p^{\uparrow} \to \Lambda^{\uparrow}\, X$	$\pi\,p^{\uparrow} \to \ell\,\bar{\ell}\, X$
	$e\,p^{\uparrow} \to e'\,(\pi^{+}\,\pi^{-})\, X$	
	$p\,p^{\uparrow} \to (\pi^{+}\,\pi^{-})\, X$	

(from Daniel Boer http://arxiv.org/abs/0808.2886v1, *2008)*

Only double polarized Drell-Yan is self-sufficient to determine transversity

Hadron Physics „Dream Machine“ for FAIR



… an asymmetric (double-polarized)
proton (15 GeV/c) – antiproton (3.5 GeV/c) collider
using HESR, CSR and APR

Plan of talk

- Polarizing antiprotons …
  - Proposals, ideas, calculations, …
  - Experiments

    FILTEX (TSR)

    $e\vec{p}$ spin flip cross section measurement at COSY

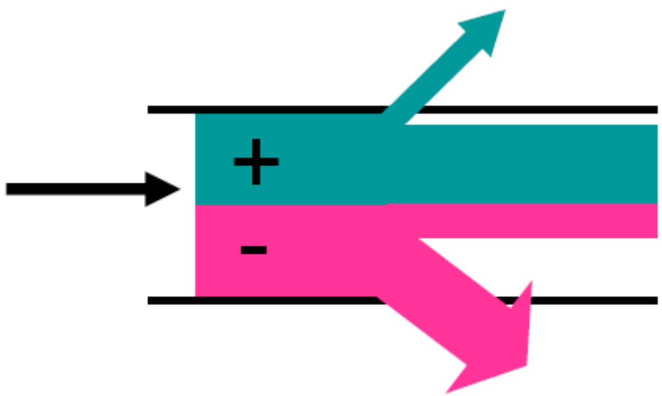
    Spin-filtering at AD/CERN

    Spin-filtering at COSY
  - Conclusion

Production of polarization in a stored beam

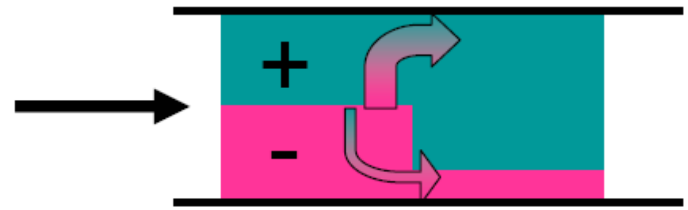
Two Methods: Loss versus spin flip

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)

Proposed methods: Spin flip

Eur. Phys. J. A **34**, 447–461 (2007)
DOI 10.1140/epja/i2007-10462-x

THE EUROPEAN PHYSICAL JOURNAL A

Special Article – Tools for Experiment and Theory

A surprising method for polarising antiprotons

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Communicated by E. De Sanctis

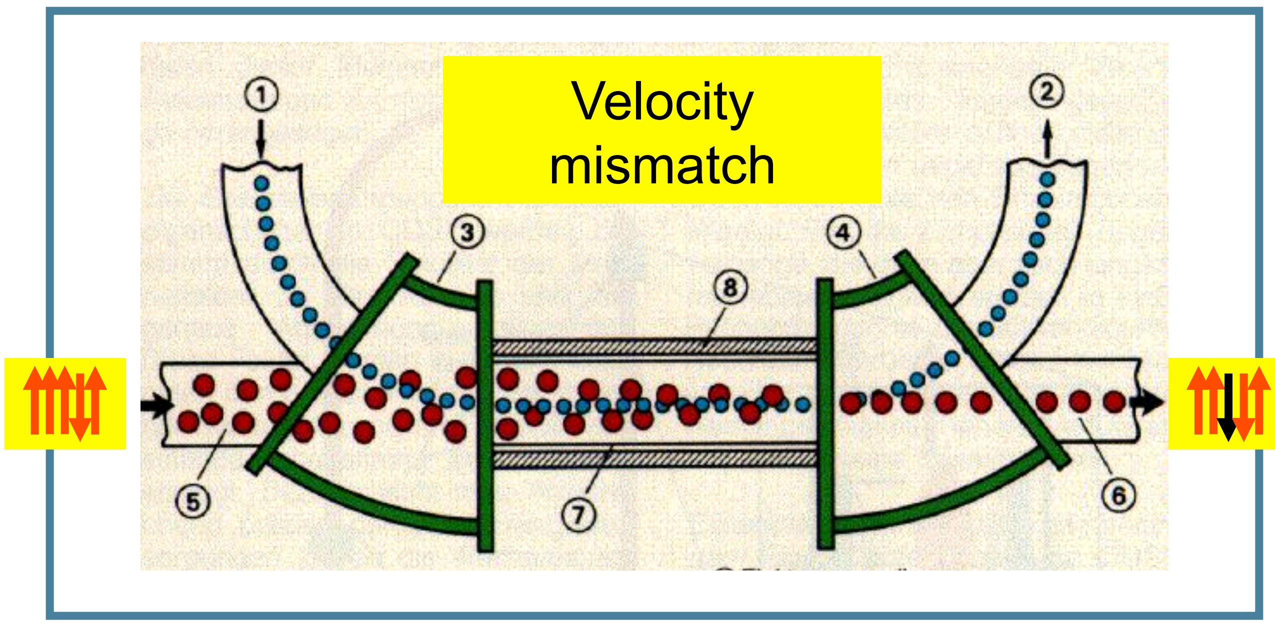
Abstract. We propose a method for polarising antiprotons in a storage ring by means of a polarised positron beam moving parallel to the antiprotons. If the relative velocity is adjusted to $v/c \approx 0.002$ the cross-section for spin-flip is as large as about $2 \cdot 10^{13}$ barn as shown by new QED calculations of the triple spin cross-

→ Need for an experimental test of this idea!

Depolarization Studies at COSY: Idea

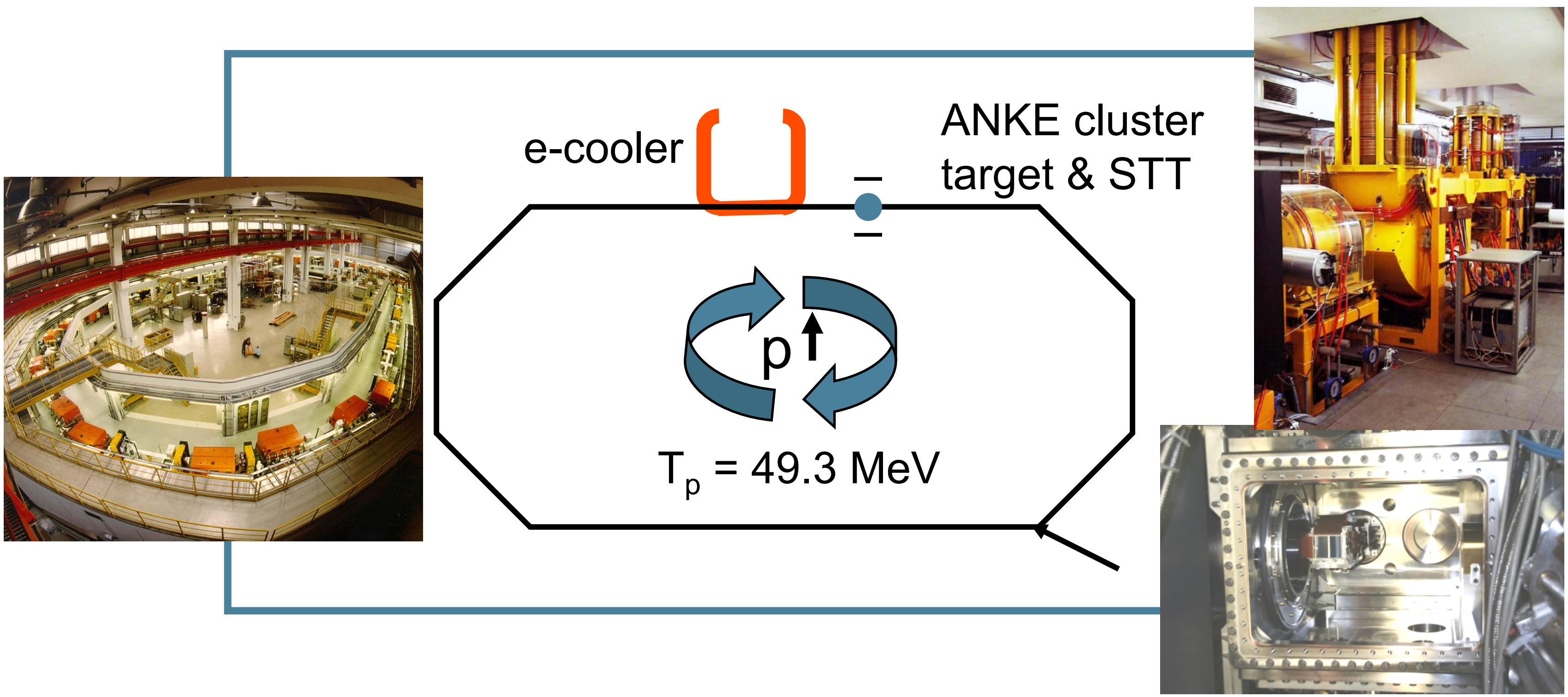
- Use proton beam and co-moving electrons
- Turn experiment around: p $\vec{e}$ → $\vec{p}$ into $\vec{p}$ e → p

  i.e. observe depolarization of a polarized proton beam



ep spin flip studies at COSY: Principle

- Use **(transversely) polarized** proton beam circulating in COSY
- Switch on **(detuned) electron cooler** to depolarize proton beam
- Analyze **proton polarization** with internal D_2-cluster target of ANKE



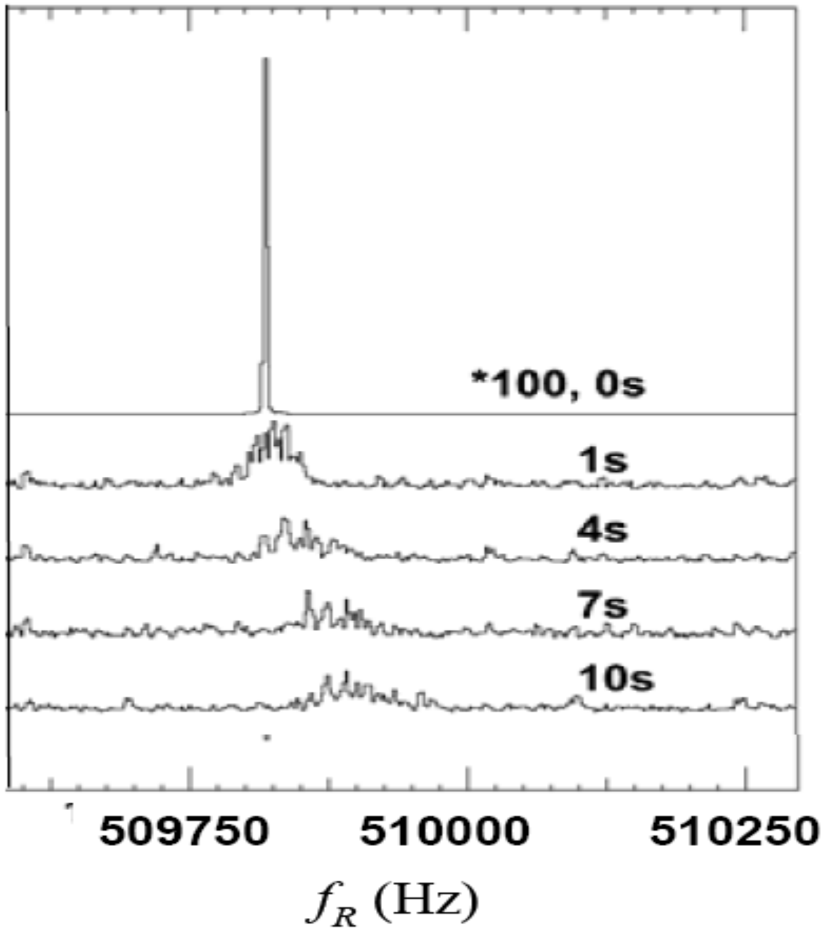
ep spin flip studies at COSY: Feasibility

After detuning, proton energy slowly follows electron energy:

$\Delta U = 245\text{ V} \rightarrow \Delta v_e = 1.5 \cdot 10^{-3}\text{ c}$
$\Delta f_R = 40\text{ Hz in 5 s}$:

$$\Delta v_p = \frac{v_p \cdot \Delta f_R}{\eta \cdot f_R}$$
$$= \Delta f_R \cdot 8.7 \cdot 10^{-7}$$
$$= 4 \cdot 10^{-5} \cdot c$$

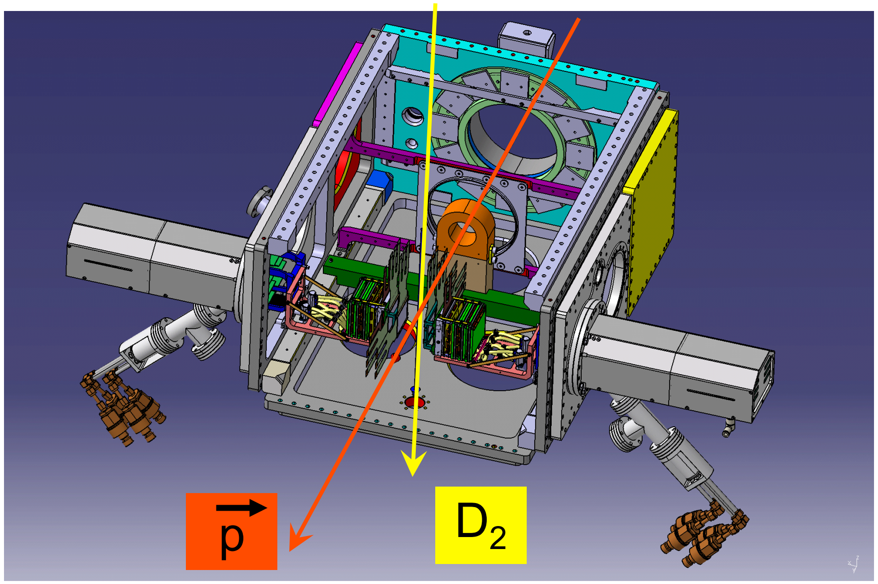
$\Delta v_p / \Delta v_e \sim 0.03$



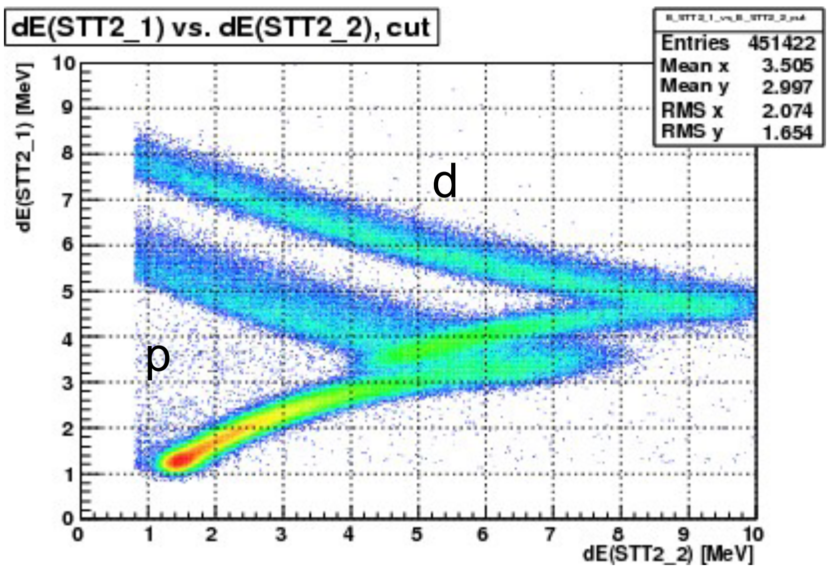
Detuning e-cooler for 5 s only ensures that proton momentum stays fixed.

Polarimetry

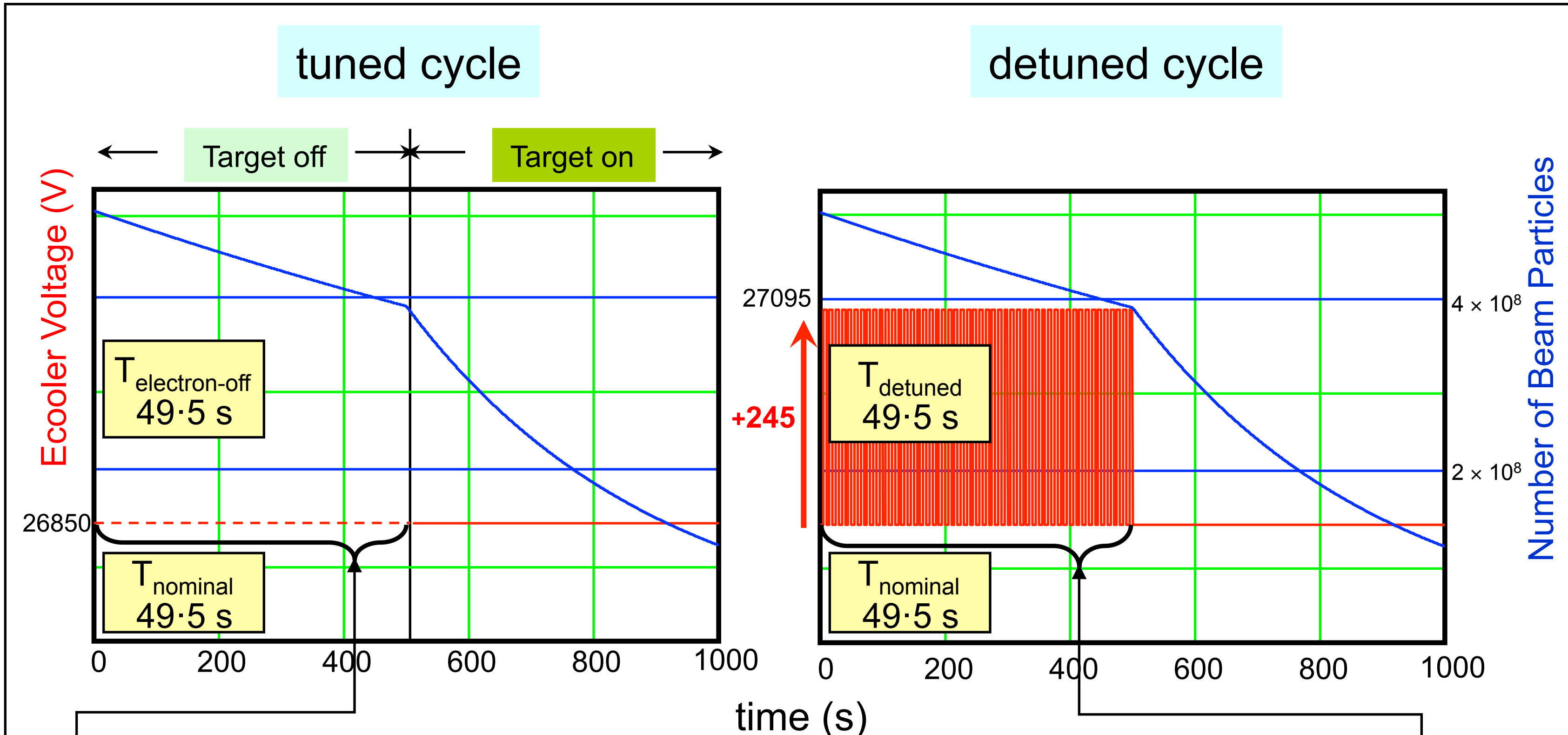
pd elastic scattering:
detection in two (L-R) symmetric Silicon Tracking Telescopes



Deuteron identification

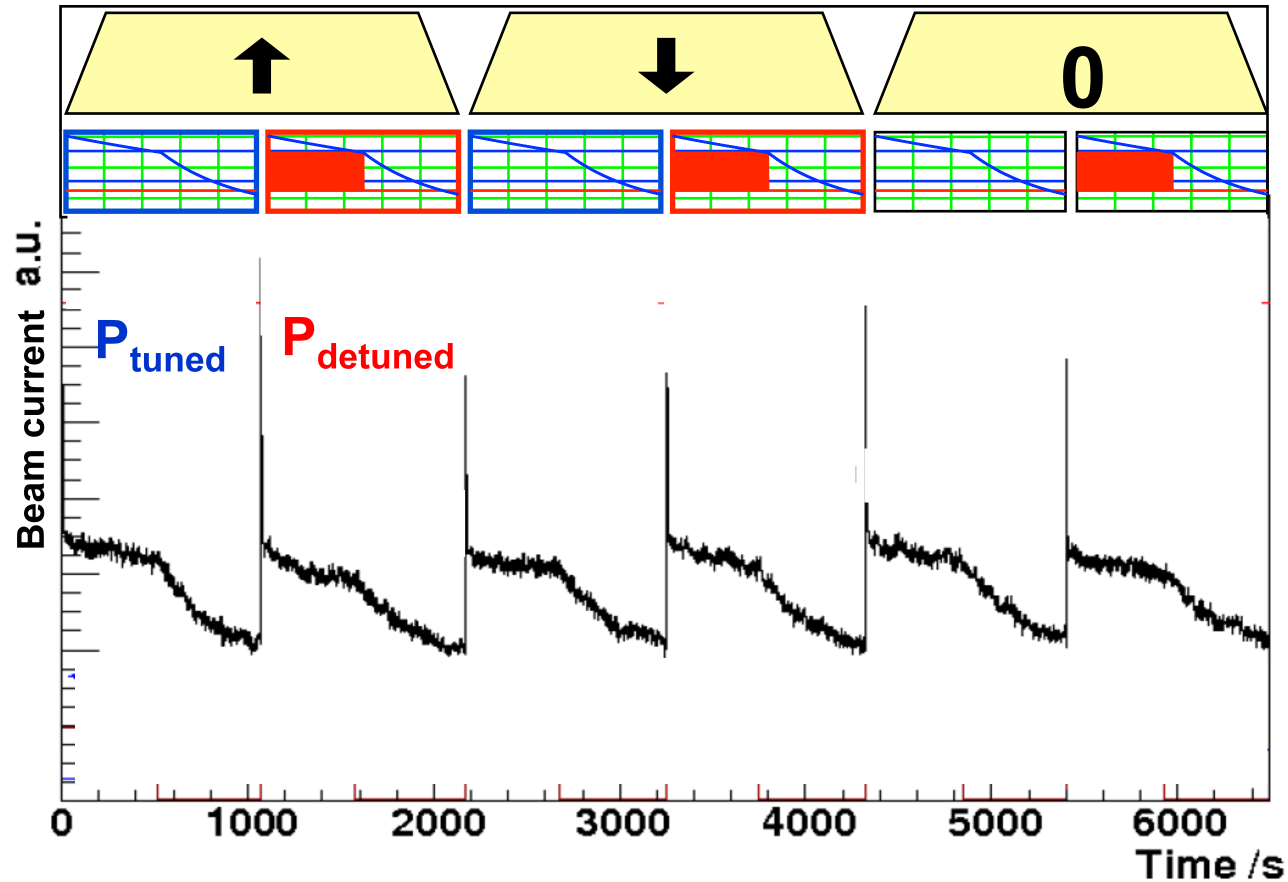


$e\vec{p}$ spin flip studies at COSY: Cycle setup



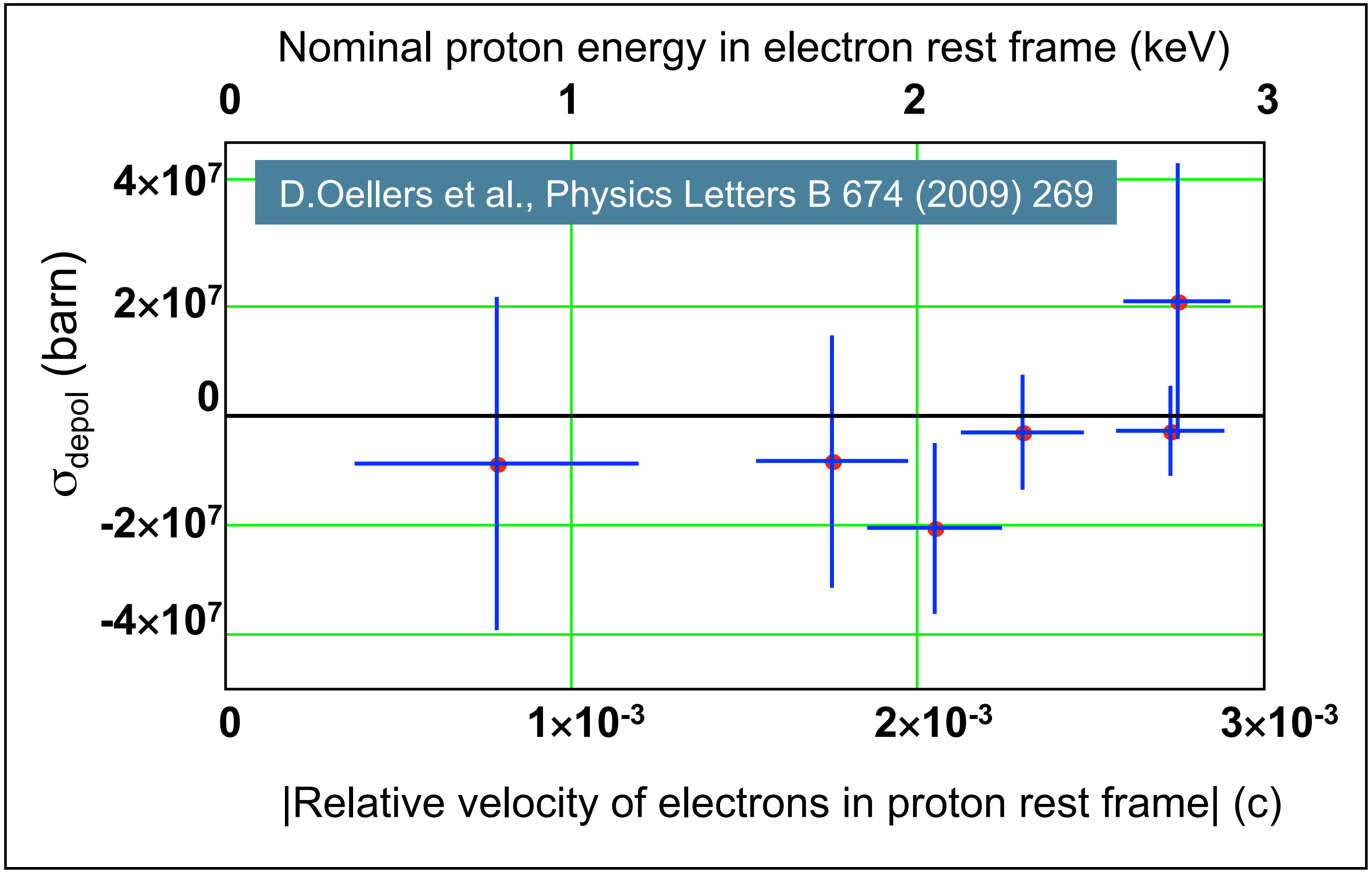
Compare cycle-by-cycle: **No electrons** to **detuned electrons**

Setup of the Super Cycle



Determine P_{tuned} and $P_{detuned}$ from *identical* cycles, except for detuned cooler

$e\vec{p}$ spin flip cross section at COSY



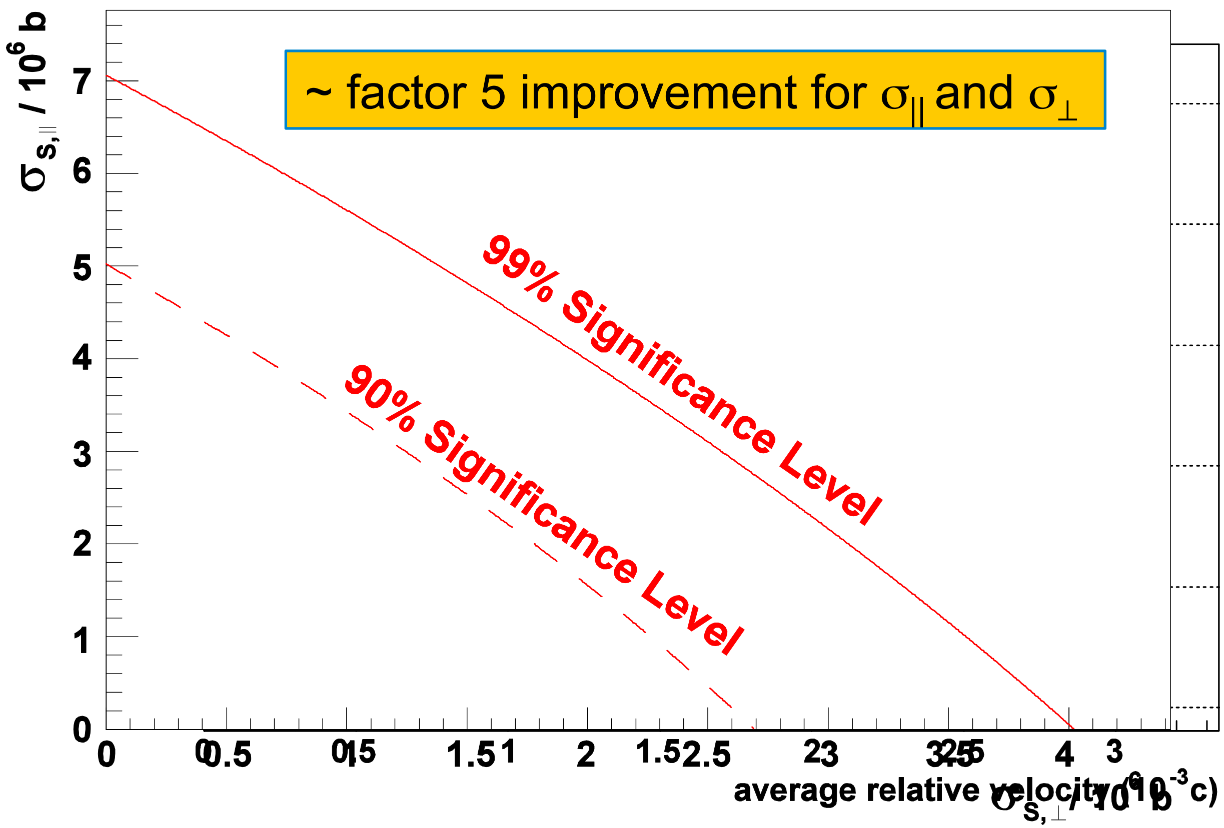
No effect observed: measured cross sections at least 6 orders-of-magnitude smaller than predicted 10^{13} b.

Meanwhile, Mainz group discovered numerical problems in the calculation → two errata.

More statistics from ep spin flip cross sections

Two disjunct samples with high statistics
1. Minimum bias cut for deuterons
2. All additional single track events

$P_E / P_0 = (\varepsilon_E * A_y) / (\varepsilon_0 * A_y) = \varepsilon_E / \varepsilon_0$



ep spin flip studies at COSY: New calc´s

Available online at www.sciencedirect.com

ScienceDirect

Nuclear Instruments and Methods in Physics Research B 266 (2008) 3453–3457

NIM B Beam Interactions with Materials & Atoms

www.elsevier.com/locate/nimb

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Polarization effects in non-relativistic *ep* scattering

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Available online 30 April 2008

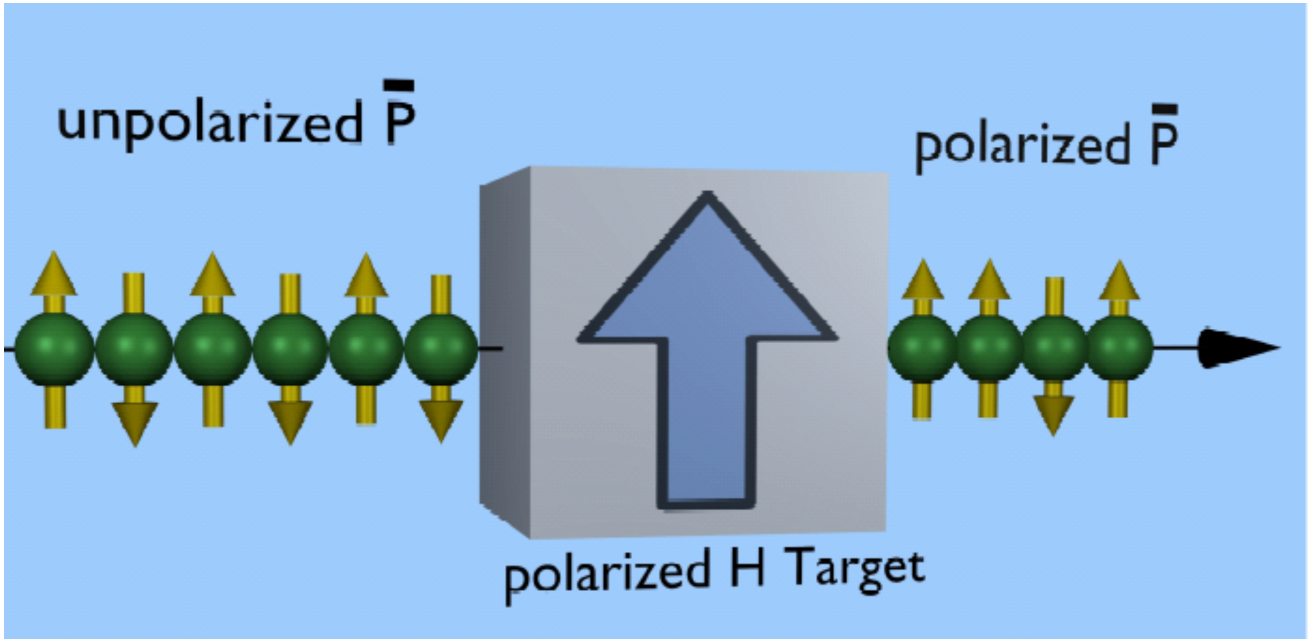
Abstract

The cross section which addresses the spin–flip transitions of a proton (antiproton) interacting with a polarized non-relativistic electron or positron is calculated analytically. In the case of attraction, this cross section is greatly enhanced for sufficiently small relative velocities as compared to the result obtained in the Born approximation. However, it is still very small, so that the beam polarization time turns out to be enormously large for the parameters of $e^{\pm}$ beams available now. This practically rules out a use of such beams to polarize stored antiprotons or protons.

~ 1 mb → **No effect expected!**

Spin-filtering

Polarization build-up of an initially unpolarized particle beam by repeated passage through a polarized hydrogen target in a storage ring:



ep spin-flip experiment settled a long-standing controversy:
Only nucleon-nucleon interaction contributes to polarization build-up

Polarization Buildup

$$\sigma_{tot} = \sigma_0 + \sigma_1 \cdot \vec{P} \cdot \vec{Q} + \sigma_2 \cdot (\vec{P} \cdot \vec{k})(\vec{Q} \cdot \vec{k})$$

P beam polarization
Q target polarization
k || beam direction

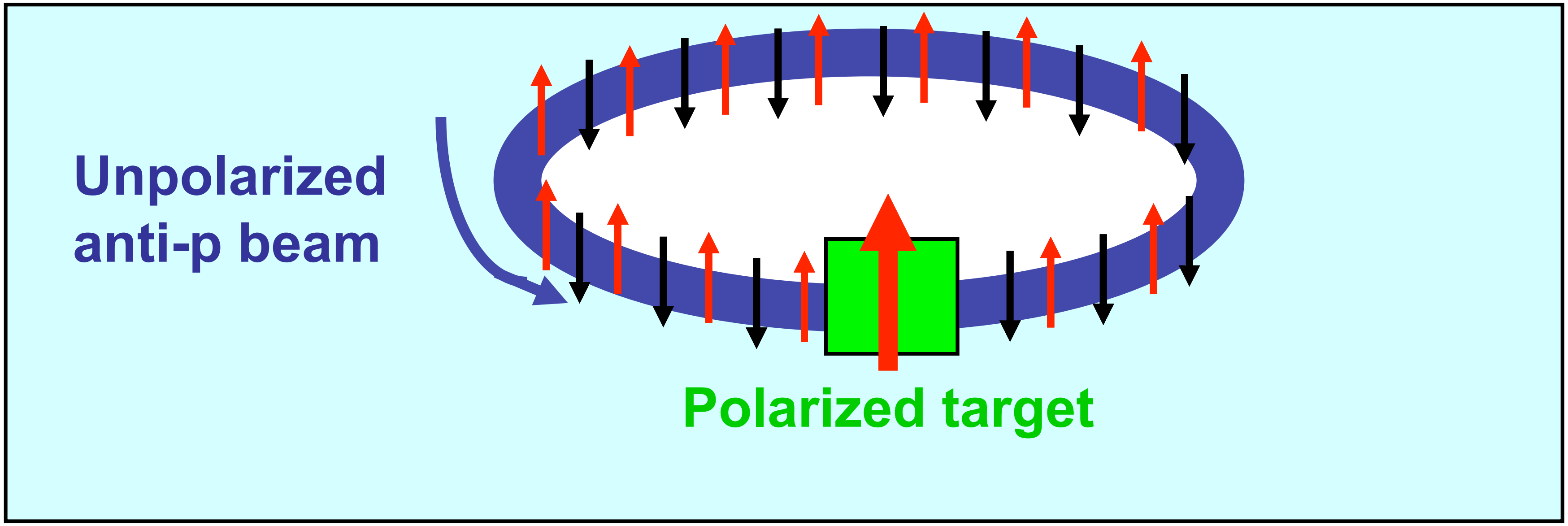
For initially equally populated spin states: ↑ (m=+½) and ↓ (m=-½)

transverse case:

$$\sigma_{tot\pm} = \sigma_0 \pm \sigma_1 \cdot Q$$

longitudinal case:

$$\sigma_{tot\pm} = \sigma_0 \pm (\sigma_1 + \sigma_2) \cdot Q$$



Polarization Buildup

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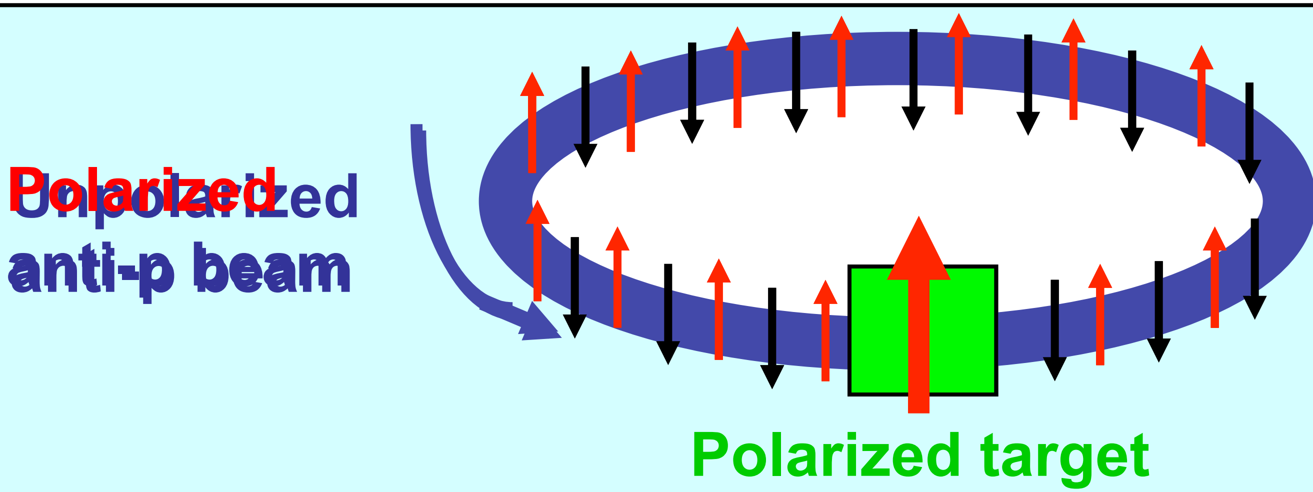

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$$\sigma_{tot\pm} = \sigma_0 \pm \sigma_1 \cdot Q$$

longitudinal case:

$$\sigma_{tot\pm} = \sigma_0 \pm (\sigma_1 + \sigma_2) \cdot Q$$

$$\tau_{beam} = \frac{1}{(\sigma_0 + \Delta\sigma_c) \cdot d_t \cdot f_{rev}}$$

$$\tau_{pol} = \frac{1}{\sigma_{pol} \cdot Q \cdot d_t \cdot f_{rev}}$$

$$I_+(t) = \frac{I_0}{2} \cdot e^{-\frac{t}{\tau_{beam}}} \cdot e^{-\frac{t}{\tau_{pol}}}$$

$$I_-(t) = \frac{I_0}{2} \cdot e^{-\frac{t}{\tau_{beam}}} \cdot e^{+\frac{t}{\tau_{pol}}}$$

Time dependence of P, I, and FOM

$$P(t) = \frac{I_+ - I_-}{I_+ + I_-} = -\tanh\left(\frac{t}{\tau_{pol}}\right)$$

$$I(t) = I_+ + I_- = I_0 \cdot e^{-\frac{t}{\tau_{beam}}} \cdot \cosh\left(\frac{t}{\tau_{pol}}\right)$$

$$FOM(t) = P(t)^2 \cdot I(t)$$

Polarization Buildup: Figure of Merit

statistical error of a double polarization observable (A_{TT})

$$\delta_{A_{TT}} = \frac{1}{P \cdot Q \cdot \sqrt{N}}$$

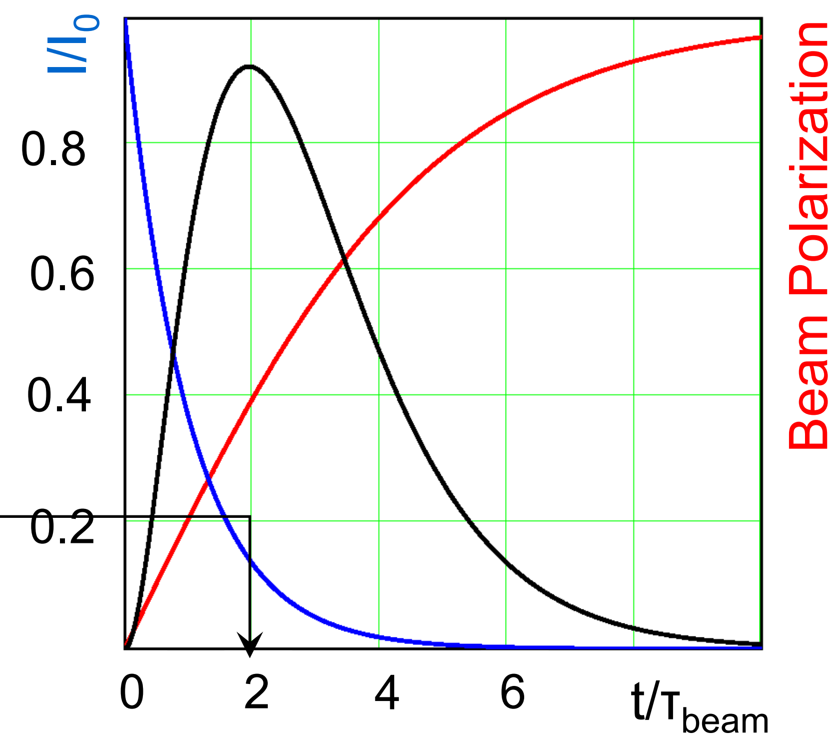
(N ~ I)

Measuring time t to achieve a certain error δ_{ATT}

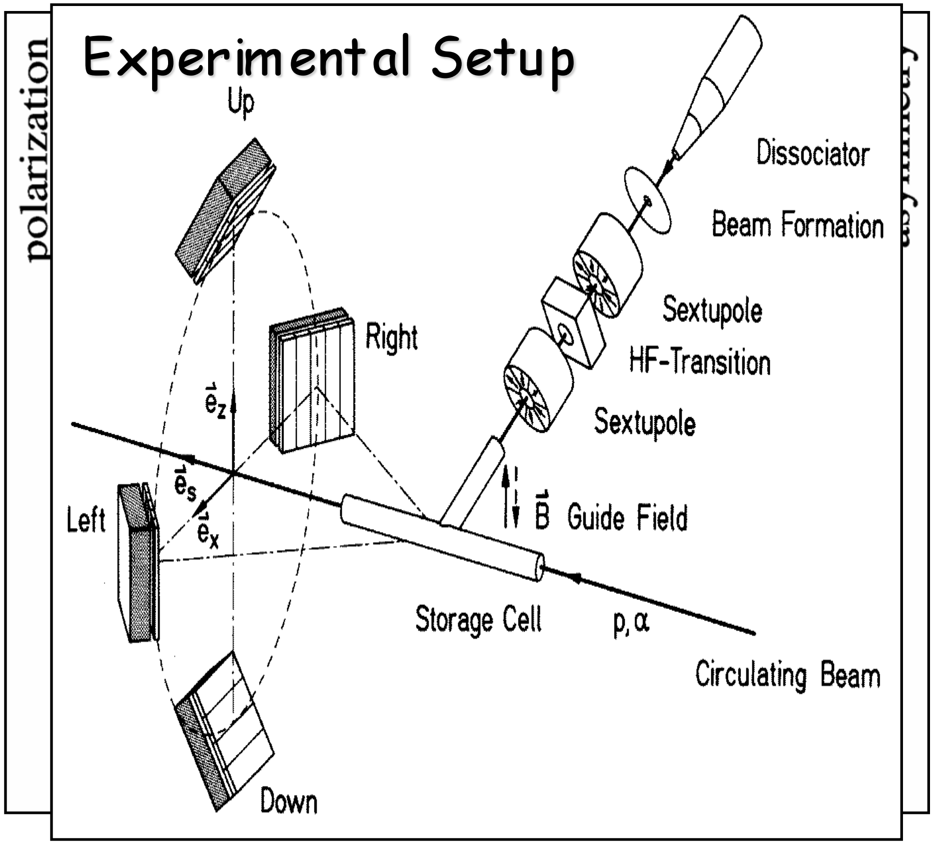
$t \sim FOM = P^2 \cdot I$

Optimimum time for Polarization Buildup given by maximum of FOM(t)

$t_{filter} = 2 \cdot \tau_{beam}$



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



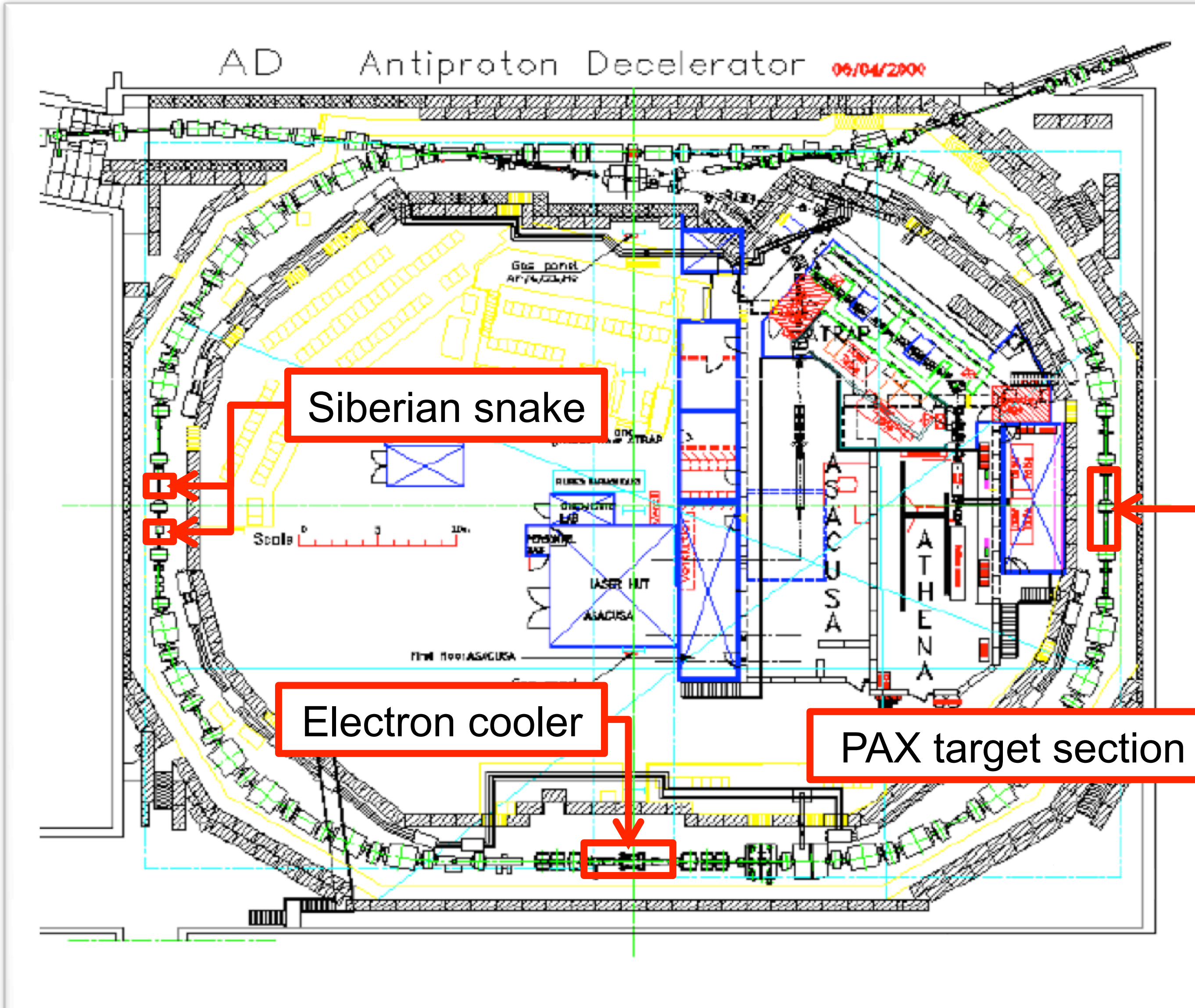
Spin filtering works
for protons

PAX submitted new proposal to find out **how well does spin filtering work for antiprotons:**

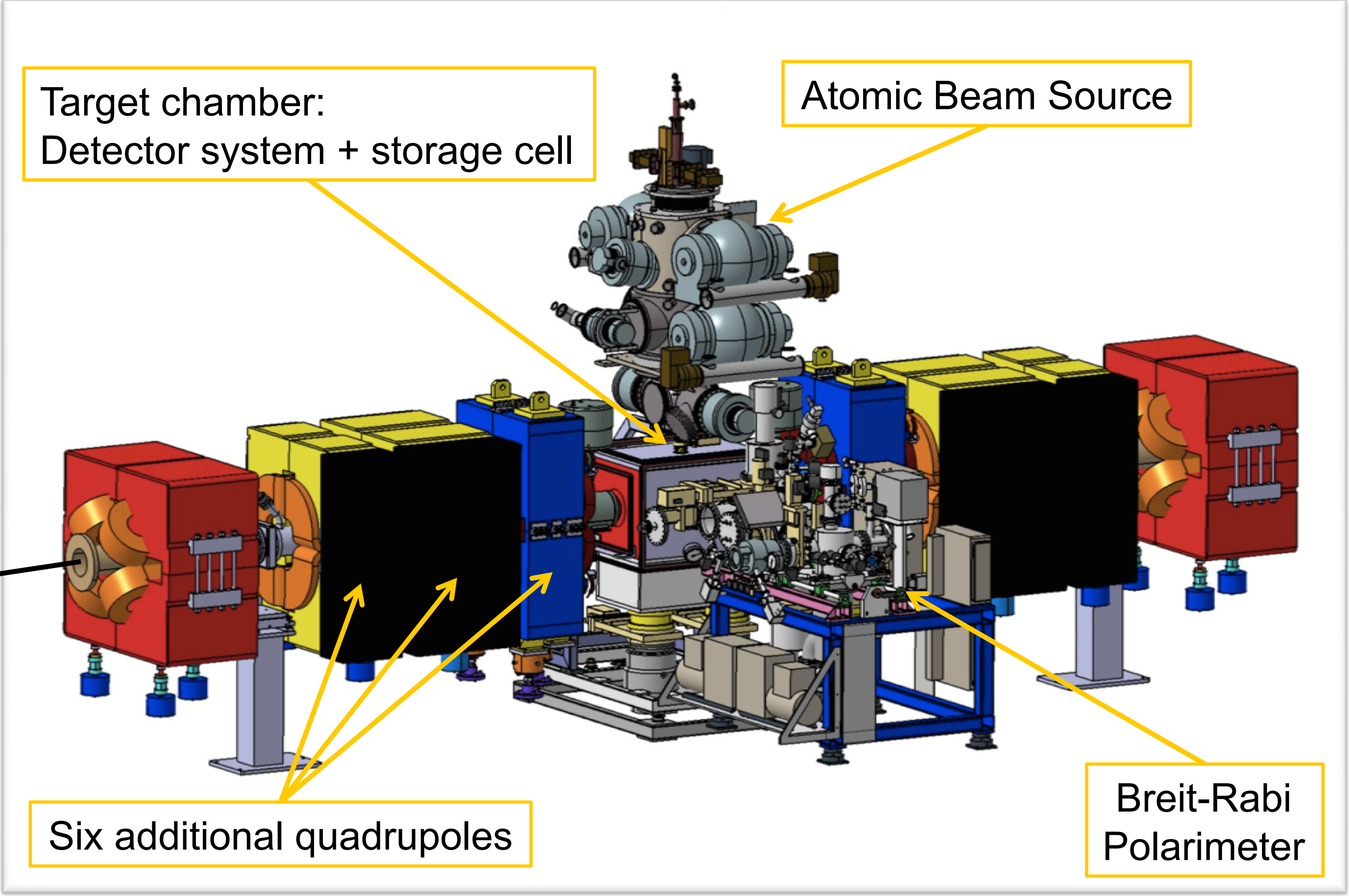
Measurement of the Spin-Dependence of the $\bar{p}p$ Interaction at the **AD** Ring

(CERN-SPSC-2009-012 / SPSC-P-337)

PAX at the AD (the only place worldwide)

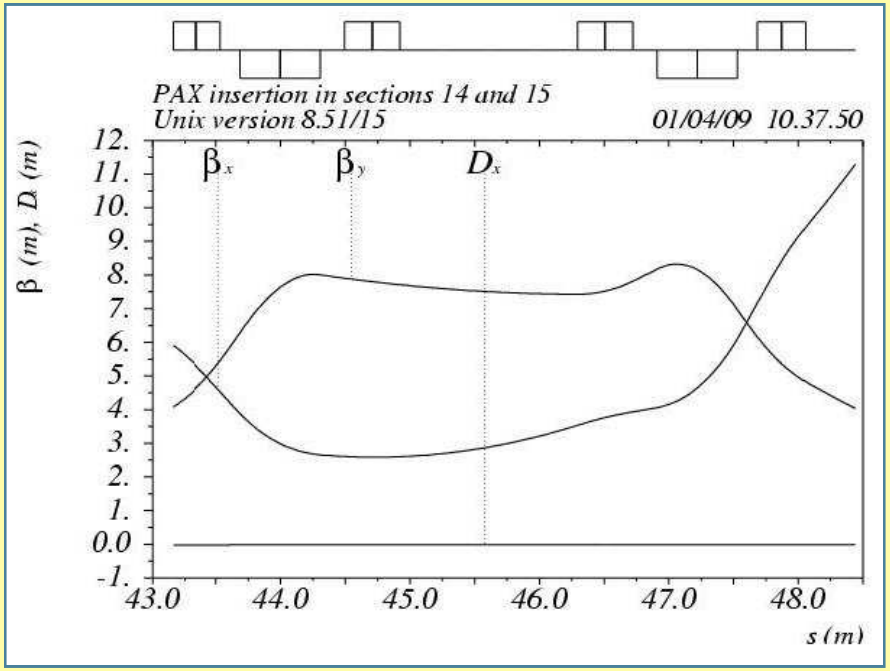


Experimental Setup

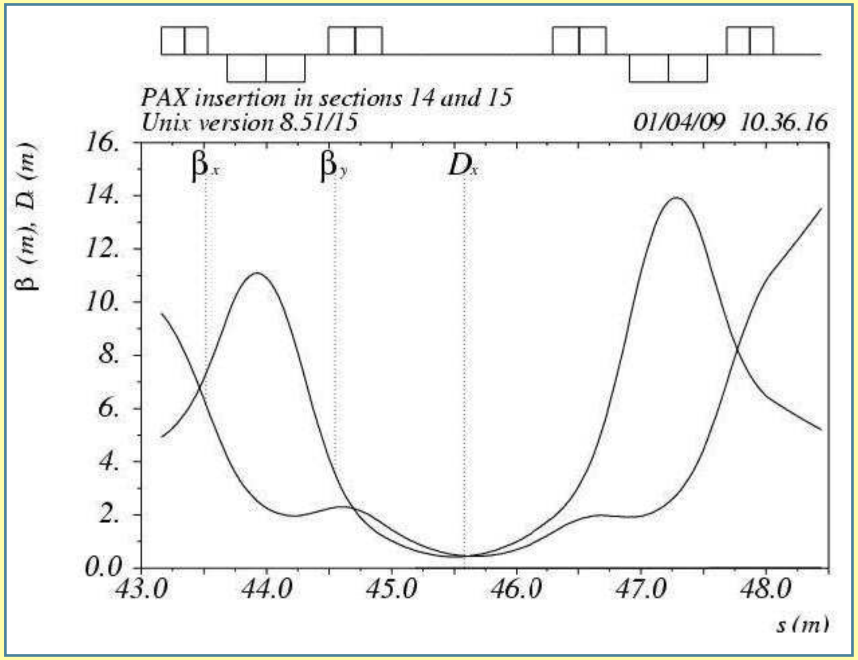


AD optics for spin-filtering studies

At injection
(3.5 GeV)

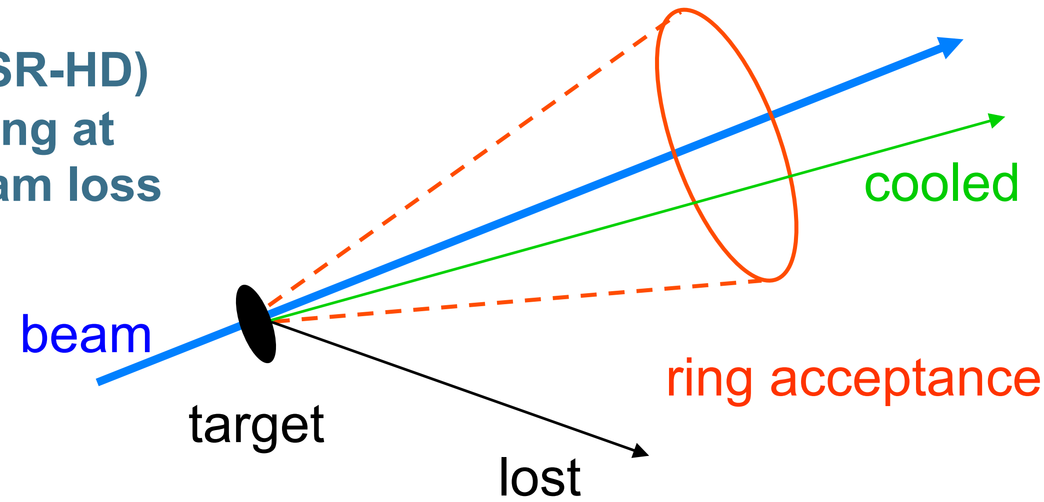


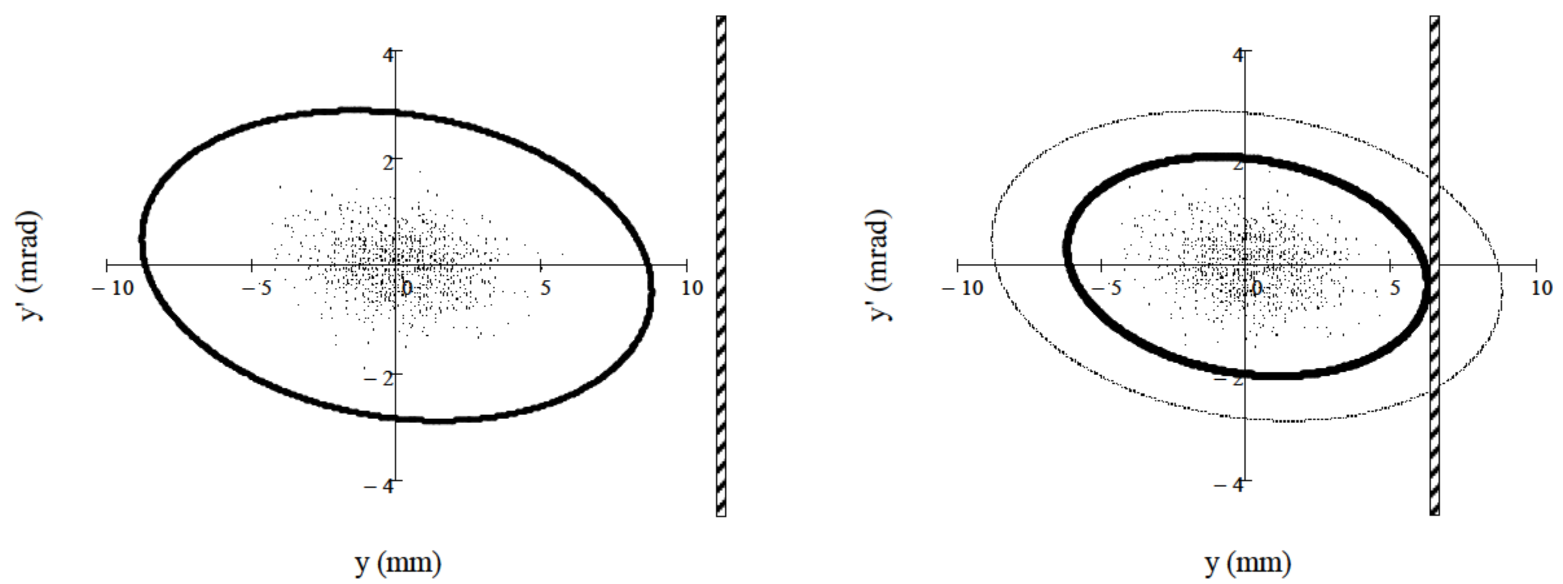
Squeezed β-functions
(at experiment energies 50 – 500 MeV)



Machine acceptance

In an ideal machine (like TSR-HD)
→ Single-Coulomb scattering at the target dominates beam loss

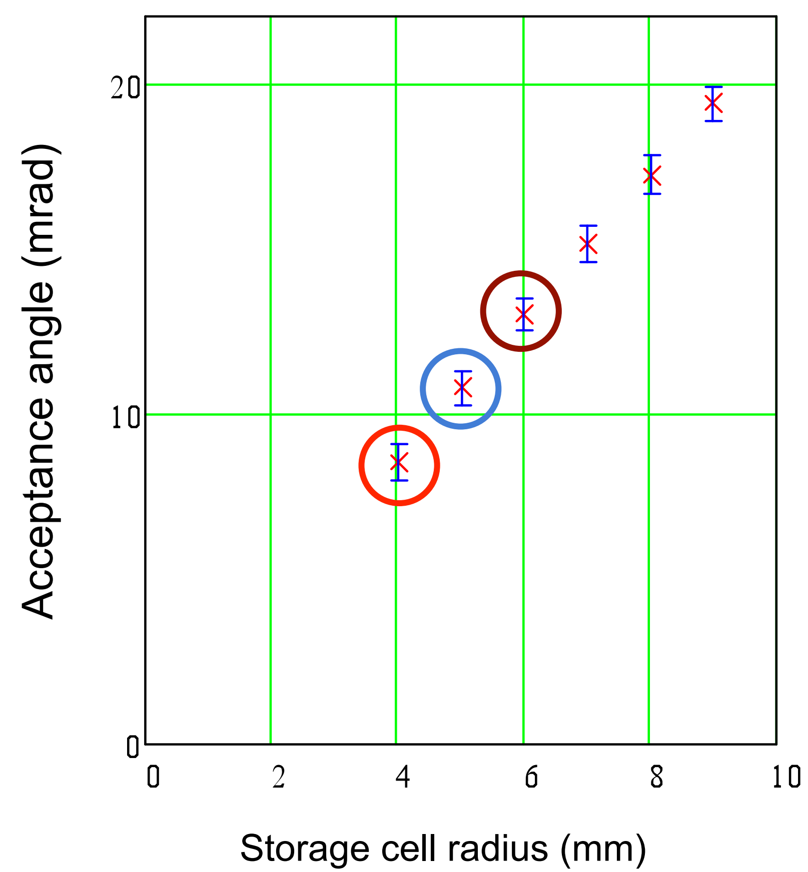




K. Grigoriev et al., NIMA 599,130 (2009)

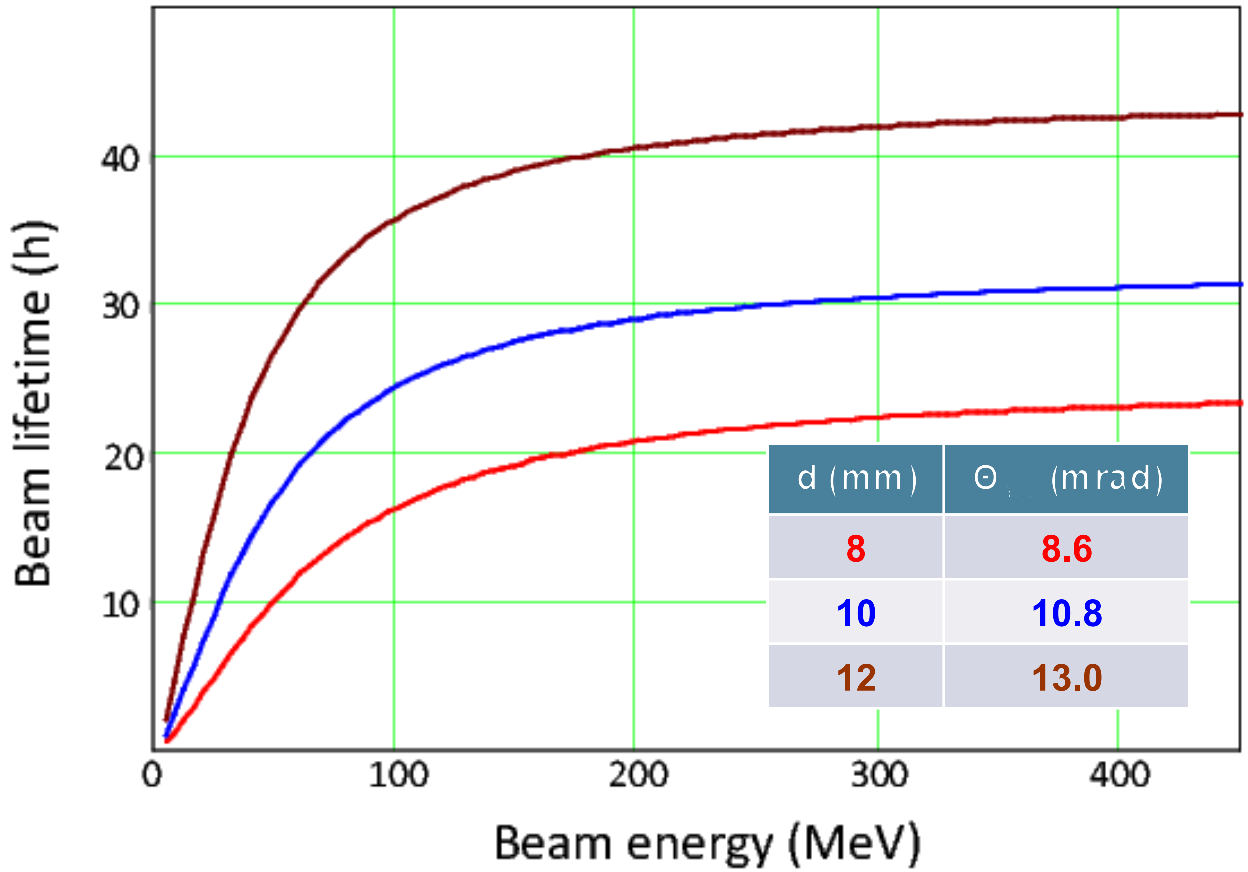
Expected antiproton beam polarization
(in an ideal machine)

- AD machine acceptance:
  - A_x=180 μm
  - A_y=200 μm
- Cooled 2σ beam emittance = 1 μm
- Realistic calculation of θ_{acc}(mrad) using
  - AD lattice functions
  - triangular density distribution in cell
- **Model A:** T. Hippchen et al., Phys. Rev. C 44, 1323 (1991)
- **Model D:** V. Mull, K. Holinde, Phys. Rev. C 51, 2360 (1995)



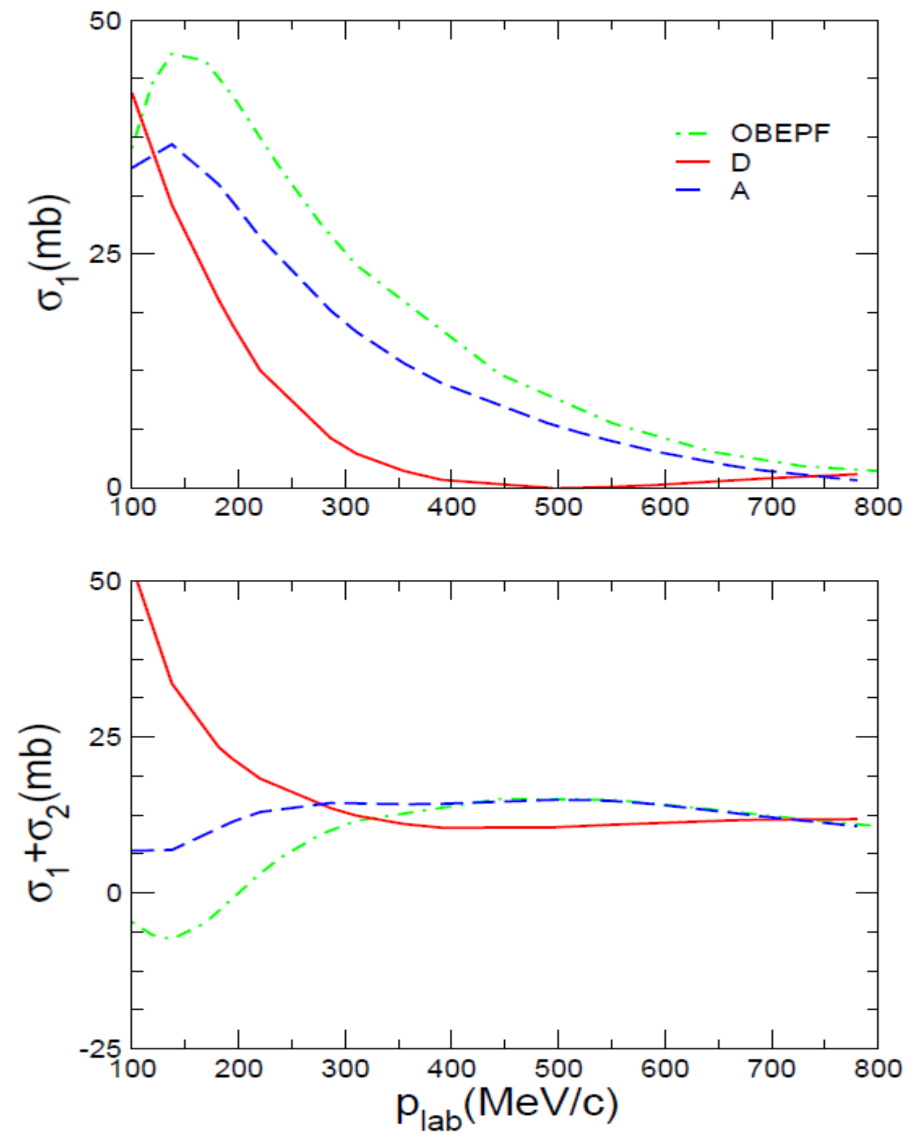
Beam lifetime

Ideal ring → Single-Coulomb scattering at the target dominates beam loss



d (mm)	Θ (mrad)
8	8.6
10	10.8
12	13.0

Predictions for the spin-dependent cross sections



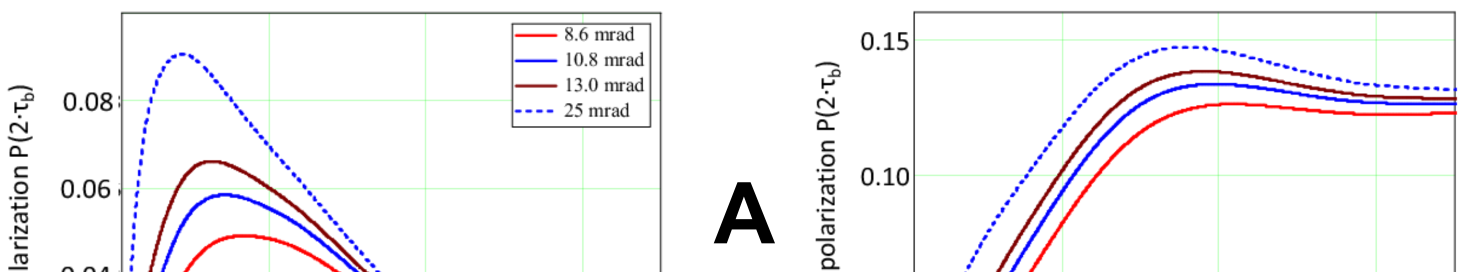
Model A: T. Hippchen et al., Phys. Rev. C 44, 1323 (1991).

Model OBEPF: J. Haidenbauer, K. Holinde, A.W. Thomas, Phys. Rev. C 45, 952 (1992).

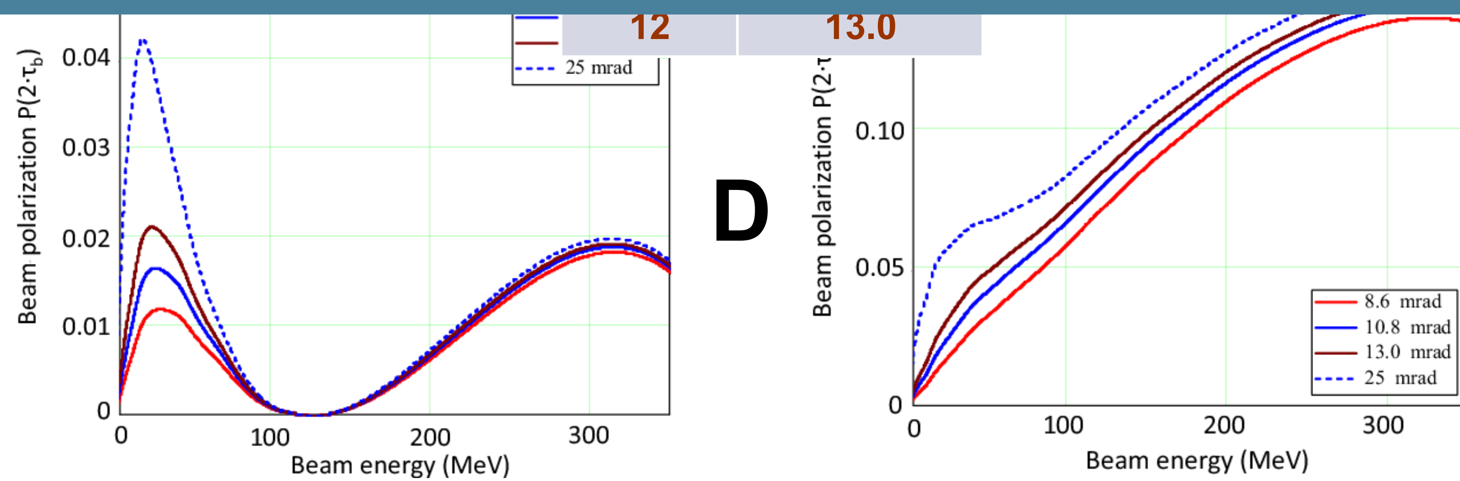
Model D: V. Mull, K. Holinde, Phys. Rev. C 51, 2360 (1995).

Expected polarizations after filtering for two lifetimes

transverse | longitudinal



- Measurement of the buildup equivalent to the determination of σ_1 and σ_2
- Once a polarized antiproton beam is available, differential double-spin observables can be measured (50-500 MeV) → $\bar{p}p$ potential.
- Protonium gave already first information about $\bar{p}p$ potential at rest.

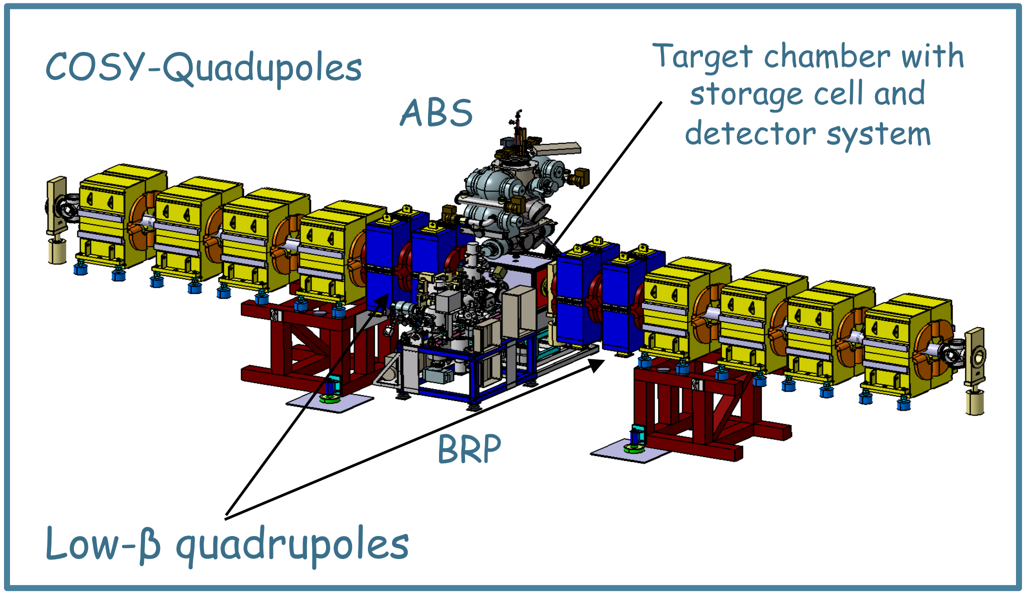


Spin-filtering studies at COSY

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

Phases of COSY installation:

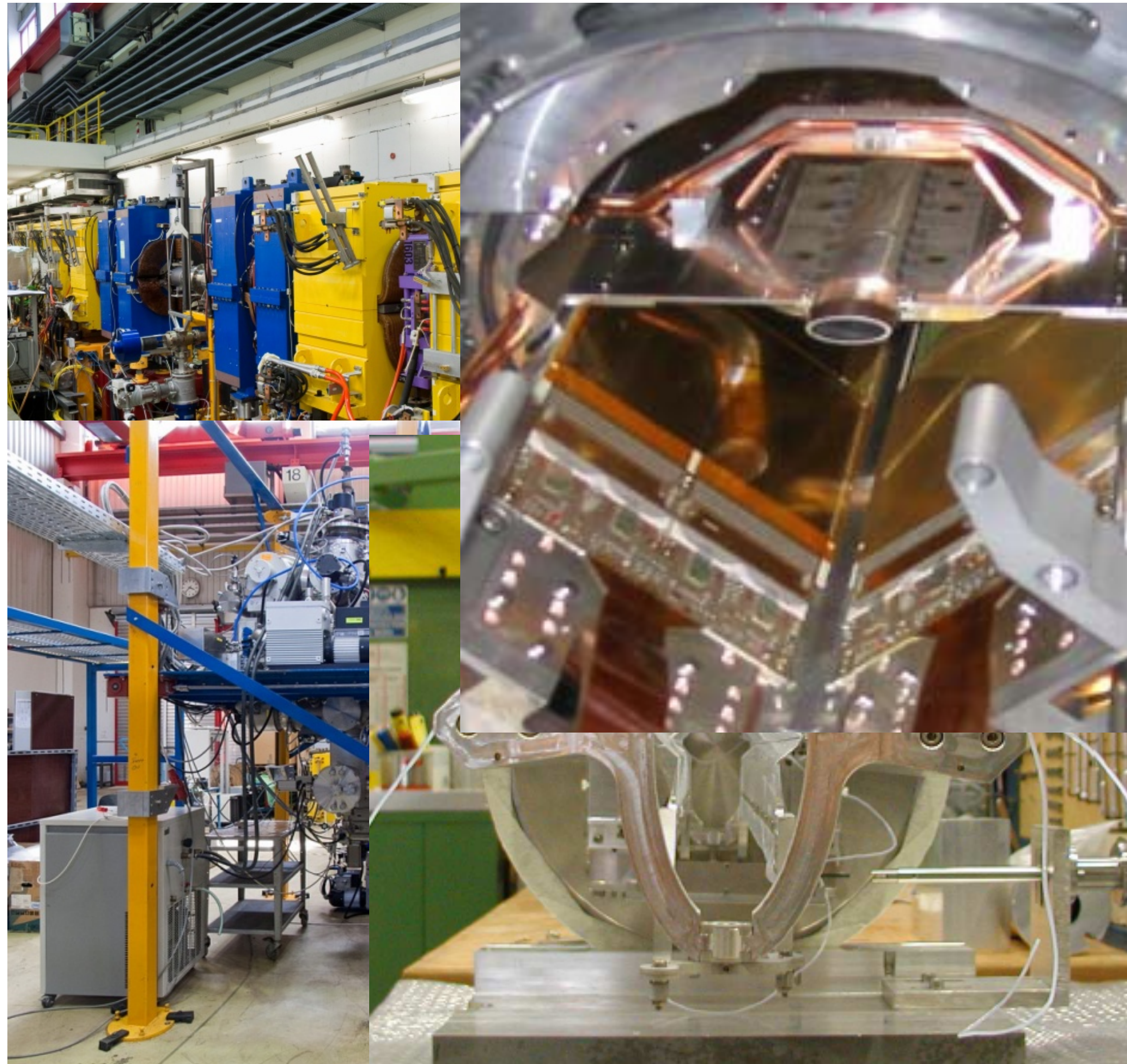
1. July 2009: Installation of quadrupole magnets (✓)
2. July 2010: Installation of rest of equipment
3. After July 2010: Spin-filtering studies with protons



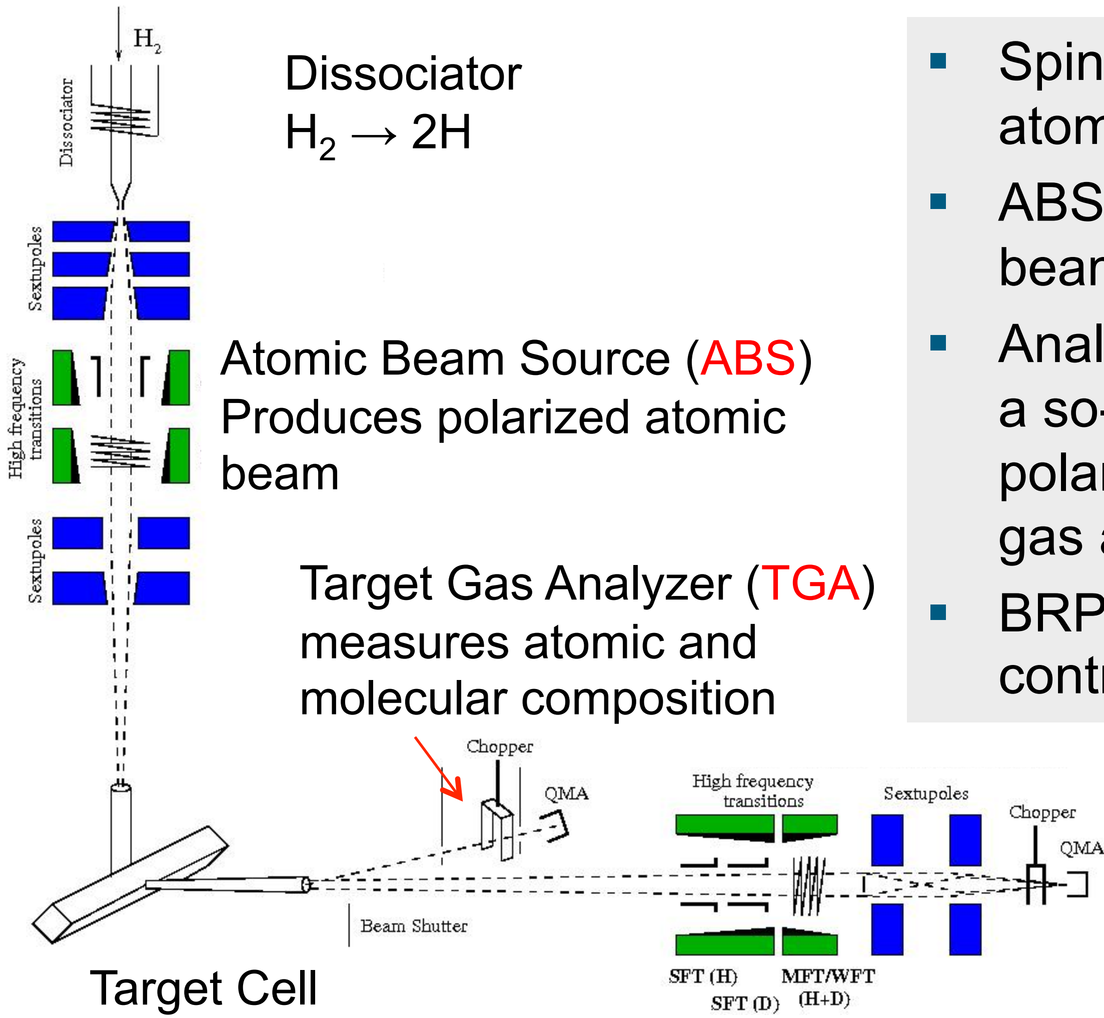
Spin-filtering studies at COSY

Experimental setup:

- low-ß section
- Atomic Beam Source
- Breit-Rabi polarimeter
- Openable storage cell
- Si tracking telescopes



Setup of the Polarized Target



Dissociator
$H_2 \rightarrow 2H$

Atomic Beam Source (ABS)
Produces polarized atomic beam

Target Gas Analyzer (TGA) measures atomic and molecular composition

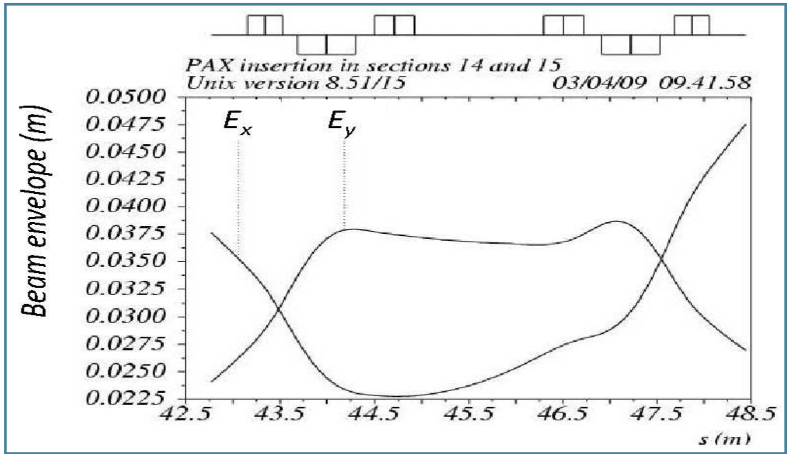
Target Cell

Breit-Rabi Polarimeter (BRP) measures nuclear polarization

- Spin filtering requires $>10^{13}$ atoms/cm^2 $\rightarrow$ storage cell
- ABS produces polarized atomic beam
- Analysis of target polarization by a so-called Breit-Rabi polarimeter (BRP) and a target gas analyzer (TGA)
- BRP measures polarization for control and analysis

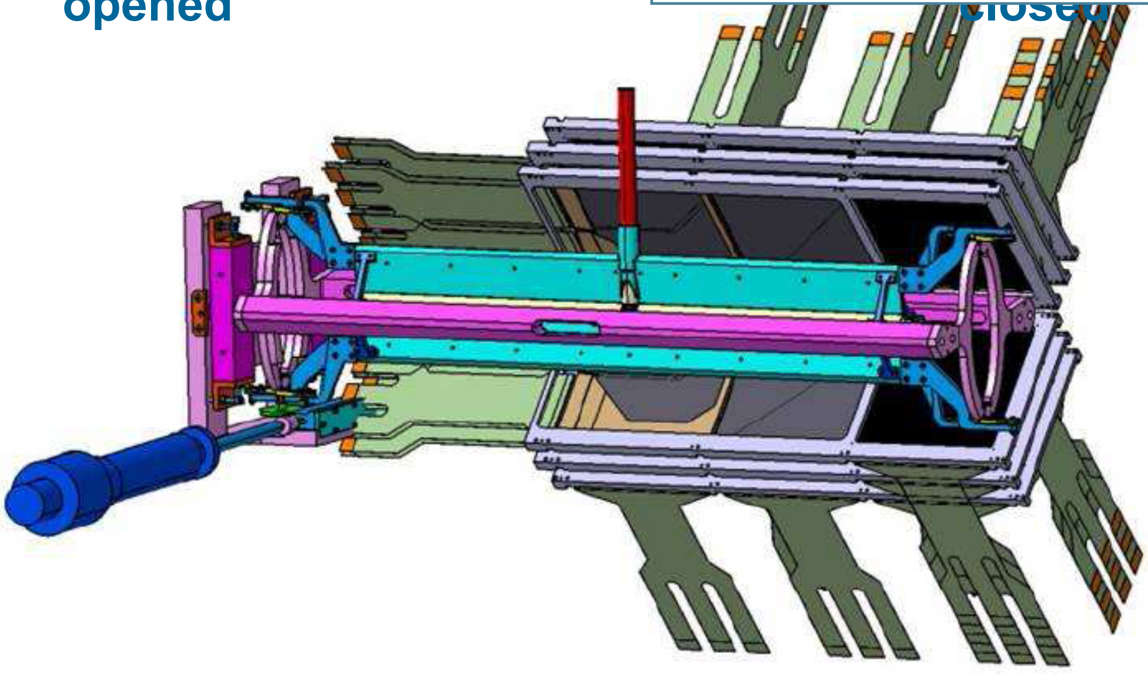
Openable storage cell

AD beam envelope at injection requires openable storage cell: (developed by Ferrara group)

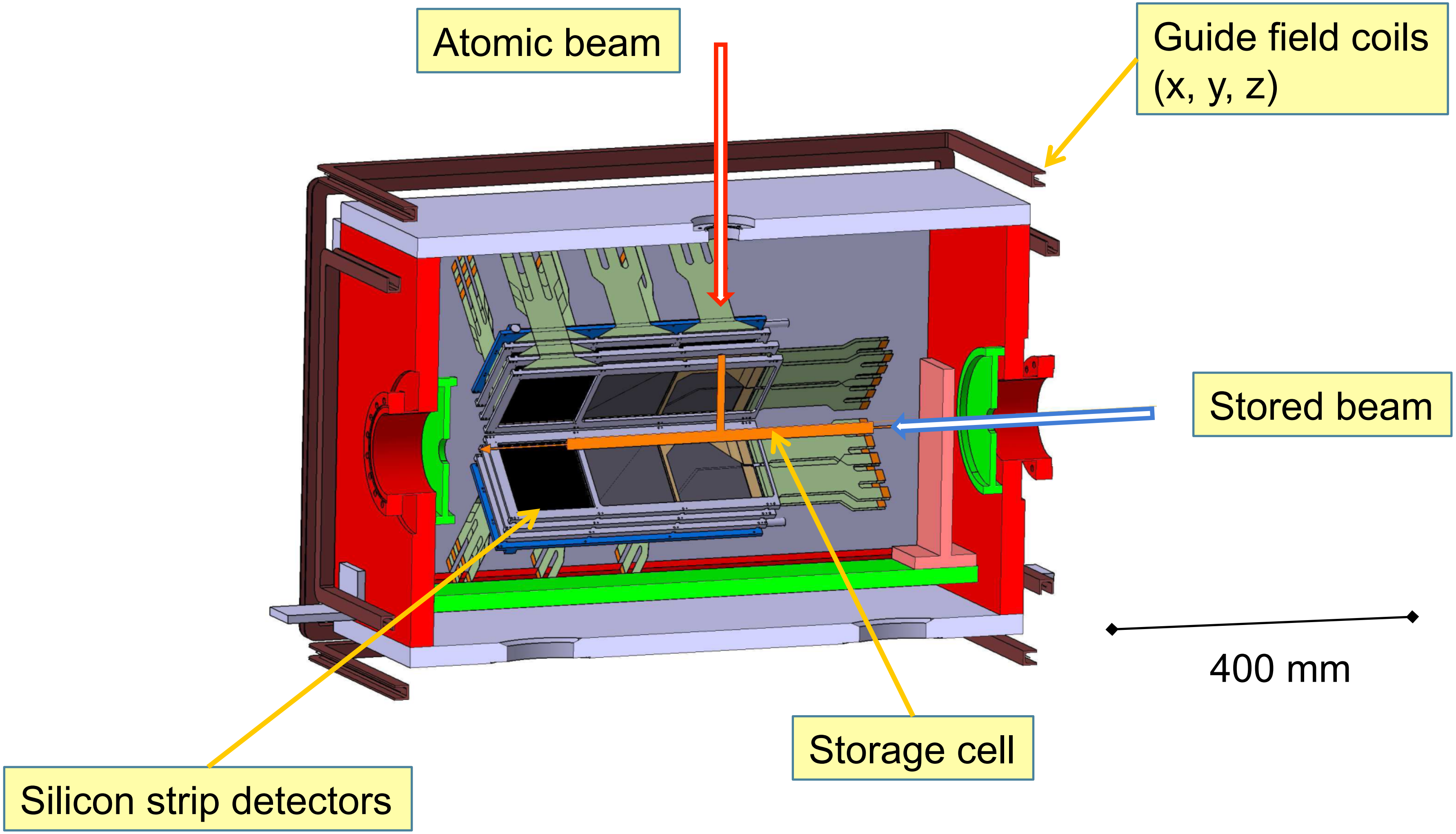


opened

closed



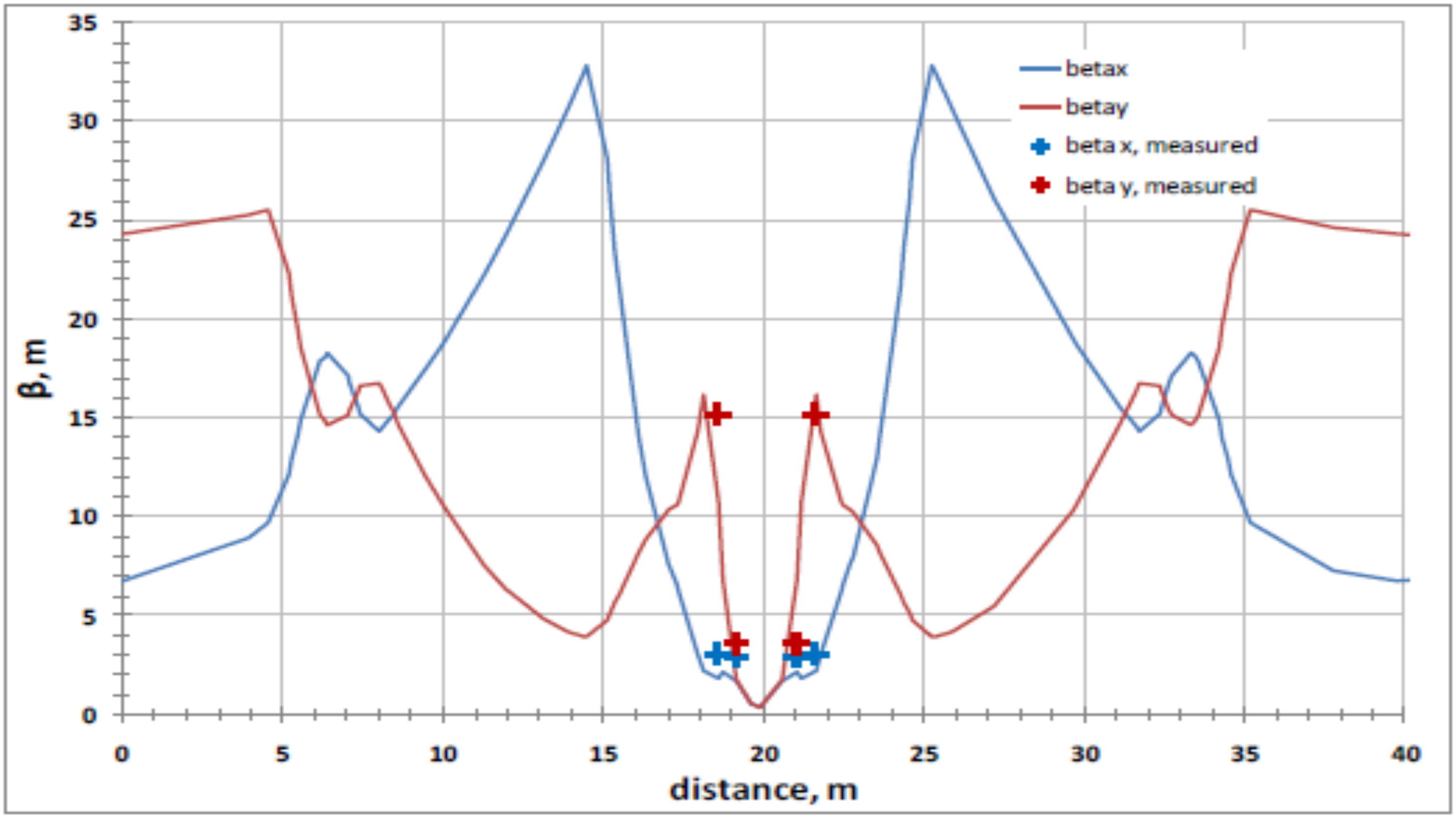
Target chamber, cell and detector system



Installation and commissioning of PAX low-β section

2009 Installation of quadrupoles with additional steerers
Fast shutters, NEG tubes, BPMs

2010 COSY quadrupole commissioning (✓)
~ 0.3 m beta functions at target place (✓)
no adverse impact on beam lifetime (4500s - 8000s) (still too short)



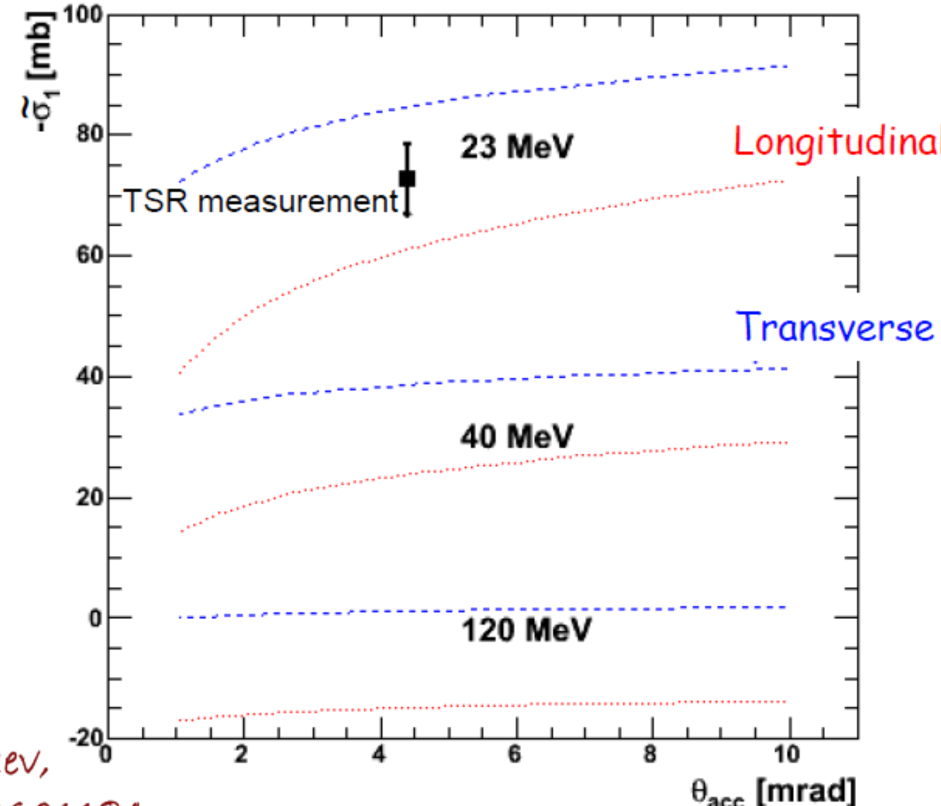
Polarisation buildup cross sections

$$\sigma_{tot} = \sigma_0 + \sigma_1 \cdot \vec{P} \cdot \vec{Q} + \sigma_2 \cdot (\vec{P} \cdot \vec{k})(\vec{Q} \cdot \vec{k})$$

P beam polarisation
Q target polarisation
k || beam direction

$$\sigma_1 = 2\pi \int_{0}^{\vartheta_{max}} \frac{d\sigma}{d\Omega}(A_{xx} + A_{yy})\, d\vartheta$$

$$\tilde{\sigma}_1 = 2\pi \int_{\vartheta_{acc}}^{\vartheta_{max}} \frac{d\sigma}{d\Omega}(A_{xx} + A_{yy})\, d\vartheta$$



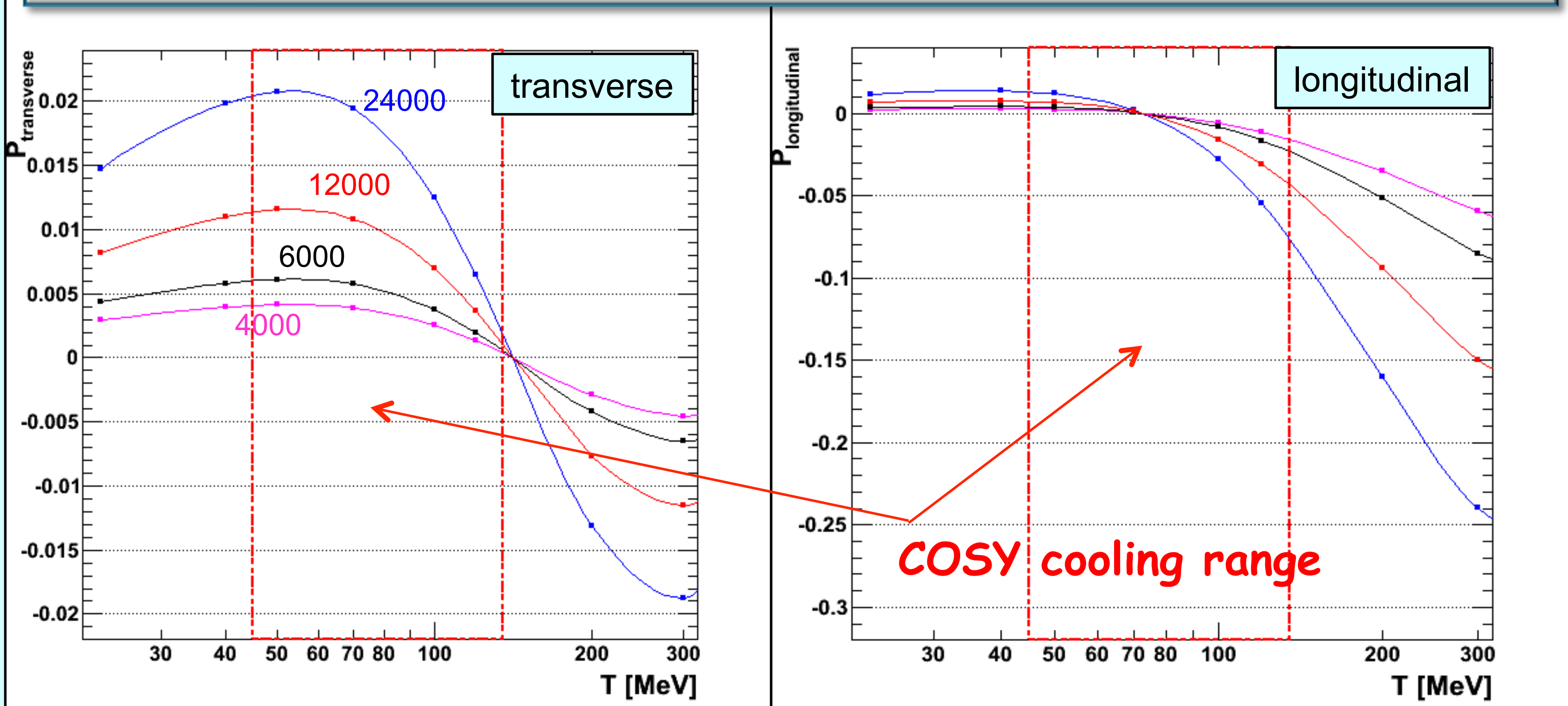
N.Nikolaev, arXiv:hep-ph/0601184

Polarizations expected at COSY

Still not fuly understood beam lifetimes in COSY:

- this was much simpler at TSR
- Test of the contribution from Touschek-effect

calculated beam polarization after 2 beam lifetimes (T_P = 49.3 MeV; Q = 0.8; $d_t = 5\cdot10^{13}\,cm^{-2}$)



Conclusion or **Where are we now?**

- **Clear task**
  - *Only nucleon-nucleon scattering contributes to polarization buildup*
- **Technically feasible**
  - *equipment being prepared for expertimental setups at COSY and AD*
  - *need to convince CERN-SPS committee*
- **Expertise and commitment** by PAX-collaboration
- **High discovery potential**

Now and here or never!

σ_2 : AD longitudinal spin-filtering requires Siberian snake
$\rightarrow$ **needs funding**
σ_1 : AD transverse spin-filtering at T > 70 MeV requires ecooler upgrade
$\rightarrow$ **needs funding**

Polarized Antiprotons receive ERC Grant

European Research Council
Executive Agency

a nice Xmas present

Brussels, 21/12/2009
ERC.C1 D(2009) / 602641

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Programme "Ideas" - Call identifier: ERC-2009-AdG
Proposal No 246980 - POLPBAR

1584 ERC AdvG Proposals submitted

- 236 selected (15% success rate)
  - Life Science (89)
  - Social Sciences & Humanities (42)
  - Physical science & Engineering (105)
    - PE2-Fundamental constitutents of Matter (11)

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Georg Christoph Lichtenberg (1742-1799)

Es ist unmöglich mit der Fackel der Wahrheit durch eine Menge zu gehen, ohne jemandem dabei den Bart zu versengen.

It is impossible to walk with the torch of truth through a crowd, without burning someone's beard.