Polarized beam experiments with polarized internal storage cell targets at COSY/Jülich

26.September 2016, Bernd Lorentz
IKP4-FZJ and PAX collaboration
SPIN 2016

Outline

- Polarized beams at COSY
- Polarized target
- Low beta insertion
- PAX and TRIC experiment
- Summary and Outlook

Cooler Synchrotron (COSY)

JÜLICH
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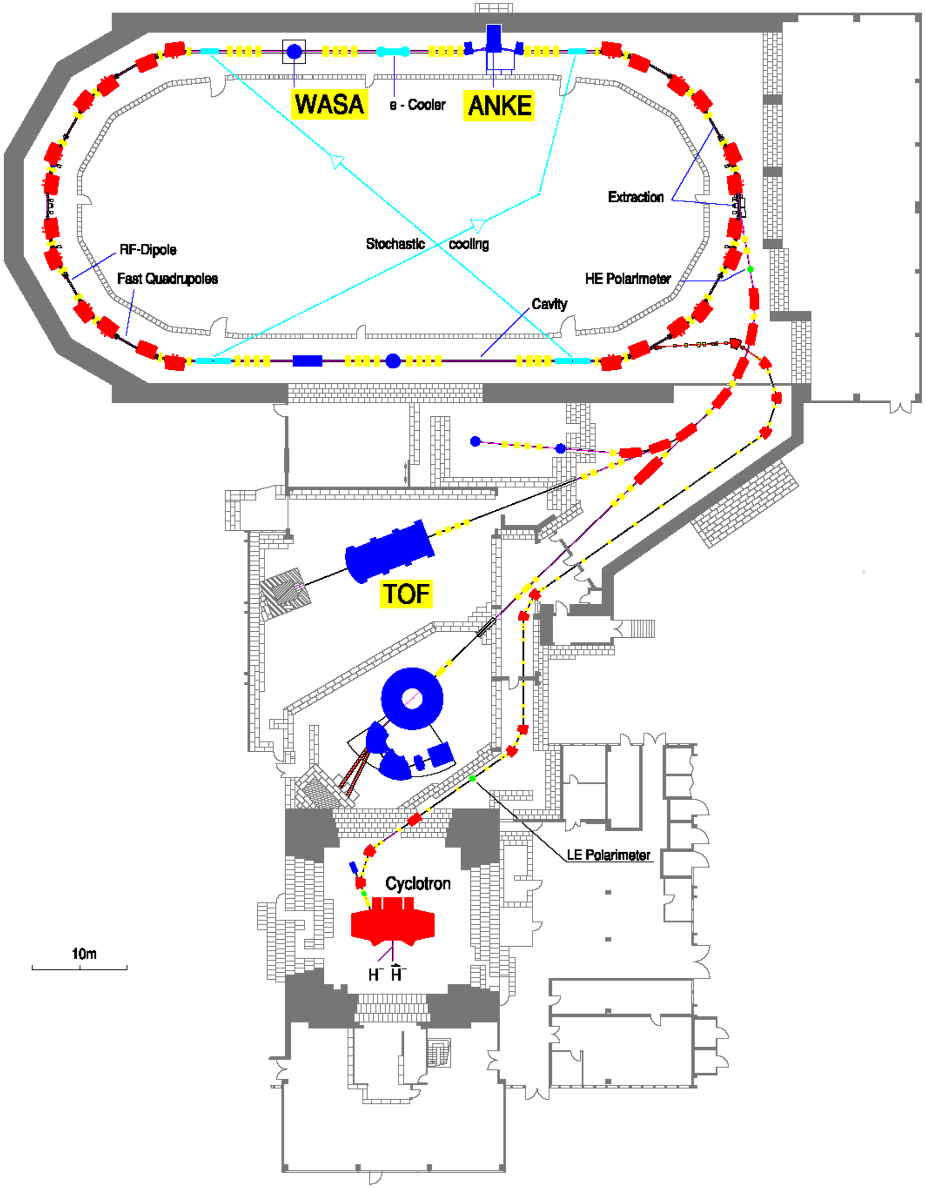
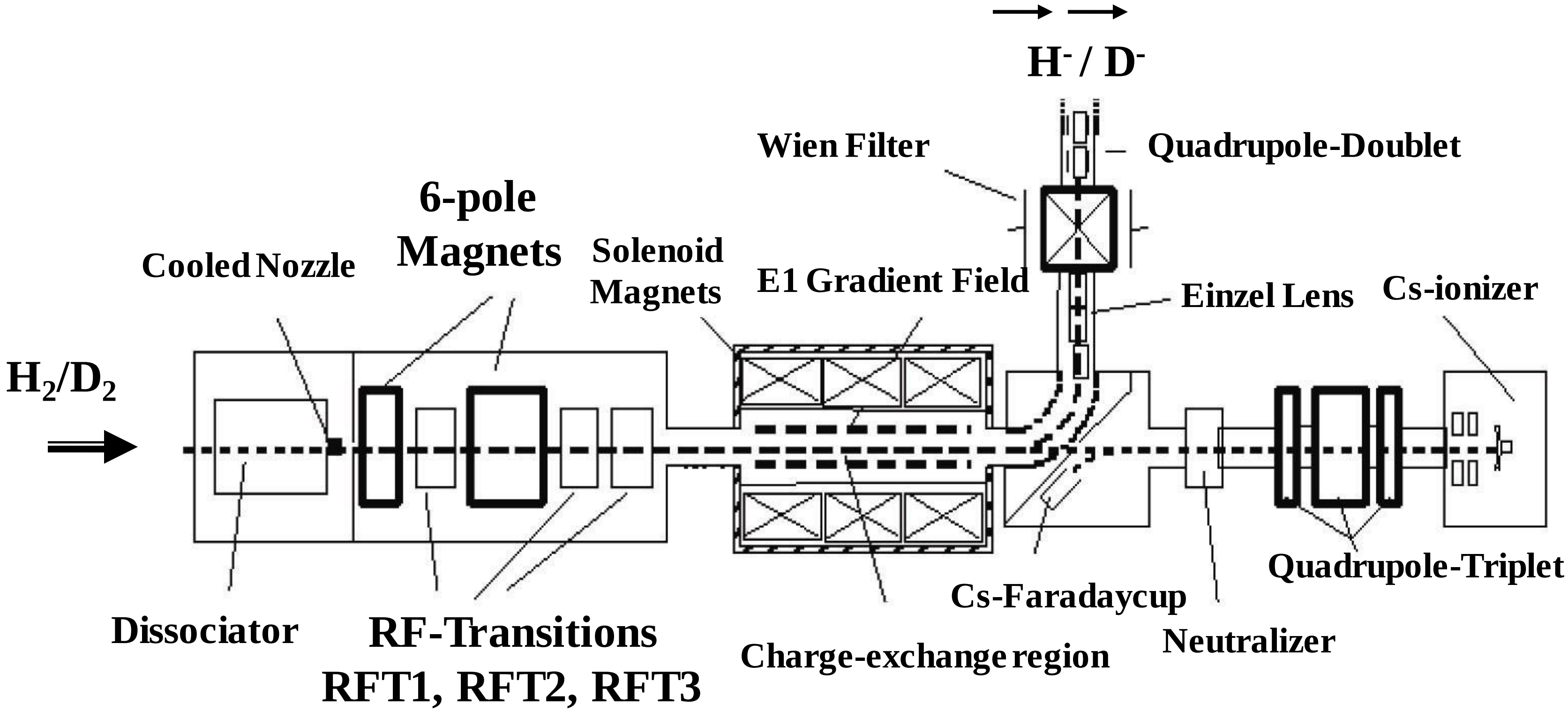


- **COSY** accelerates and stores (polarized) protons / deuterons between 300/600 and 3700 MeV/c

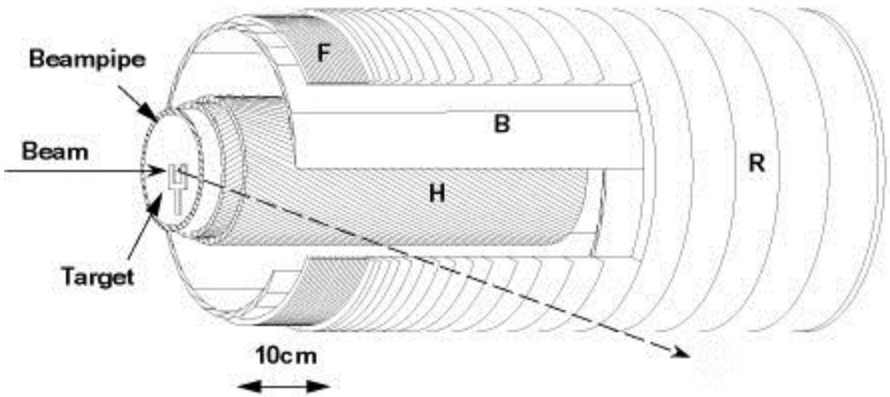
- 4 internal and 3 external experimental areas

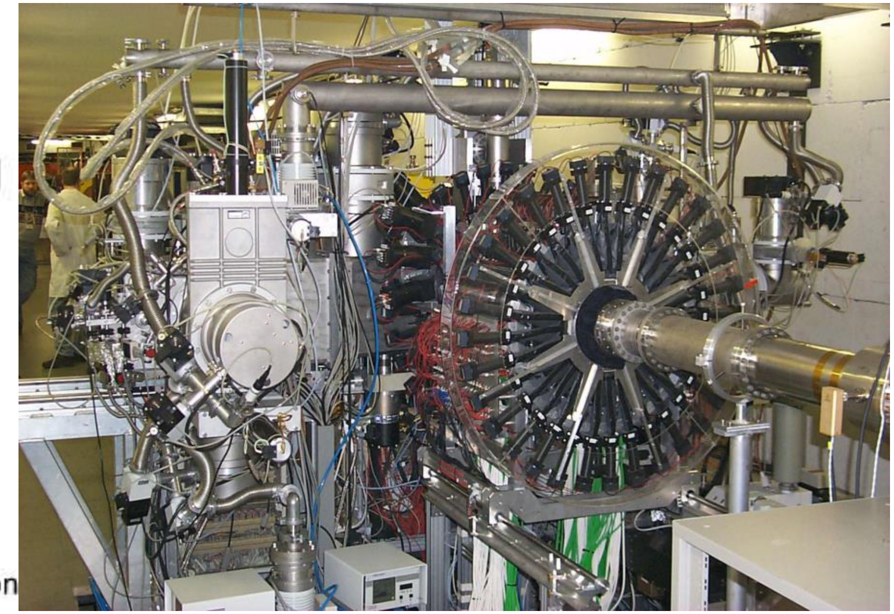
- Electron cooling at low momenta
- Stochastic cooling at high momenta

COSY CBS:
Polarized H^-/D^- Ion Source



EDDA Polarimeter





- two-layered cylindrical scintillator structure
  - Outer Layer ($\rightarrow$ trigger!)
    D: 32 overlapping slabs of triangular cross-section ($\Delta\phi = 11.25^o$)
    F,R: 2x29 semirings ($\Delta\theta_{\mathrm{lab}} = 2.5^o$)
    left semirings $\phi \in [-90^o, 90^o]$
    right semirings $\phi \in [90^o, 270^o]$
  - Inner Layer (H): 640 scintillating fibers
    $\rightarrow$ vertex reconstruction ($\sigma \approx 1\mathrm{mm}$)
- Acceptance: $\theta_{\mathrm{lab}} \in [10^o, 72^o]$
- Targets: CH_2 and C fiber targets, polarized H and D atomic beam target.

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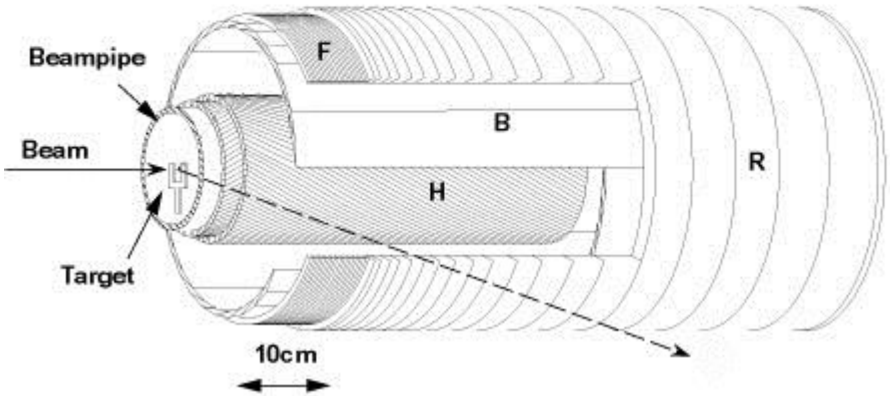

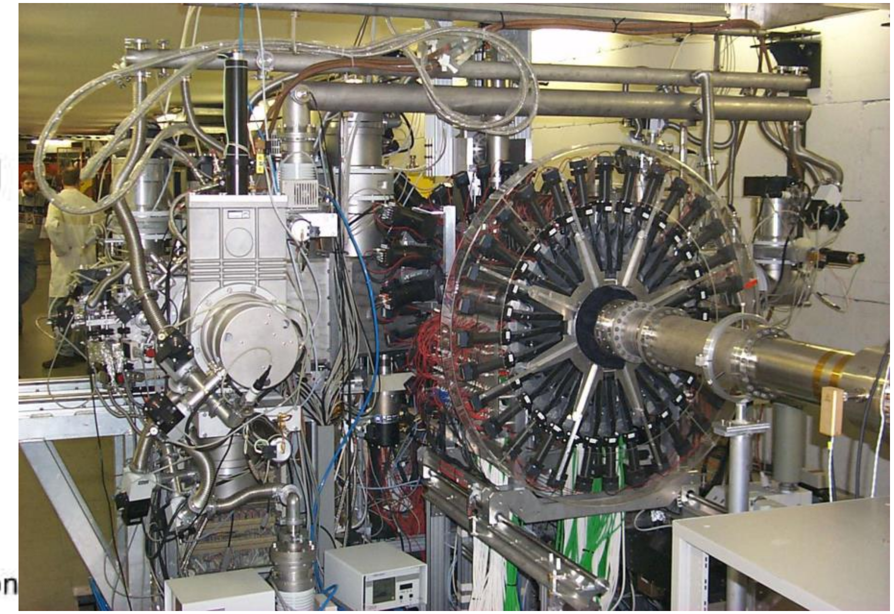

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extension of polarimetry to lower energies

Spin Motion

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Thomas-BMT equation **(Thomas [1927], Bargmann, Michel, Telegdi [1959]):**

$$\frac{d\vec{S}}{dt} = \frac{e}{\gamma m}\vec{S} \; x \; [(1+\gamma G)\vec{B}_{\perp} + (1+G)\vec{B}_{\parallel}]$$

Precession Equation in Laboratory Frame

Number of spin rotation per turn: $\nu_p = \gamma G$

$$G = \frac{g-2}{2}, \; G_p = 1.7928473, \; G_{\bar{p}} = 1.800, \; G_d = -0.142987$$

Imperfection resonance:

$$\gamma G = k$$

***k*: integer**

Field and positioning errors of magnets

Resonance strength ~ y_{rms}

→ adiabatic spin flip (partial snake)
→ vertical orbit correction (reduce strength)
→ increase y_{rms} (increase strength – flip)

Intrinsic resonance:

$$\gamma G = (kP \pm Q_y)$$

***P*: super-periodicity**
***Q_y*: vertical tune**

Vertical focusing fields

Resonance strength ~$\sqrt{\varepsilon_y}$

→ vertical tune jumps
→ vertical coherent betatron oscillations

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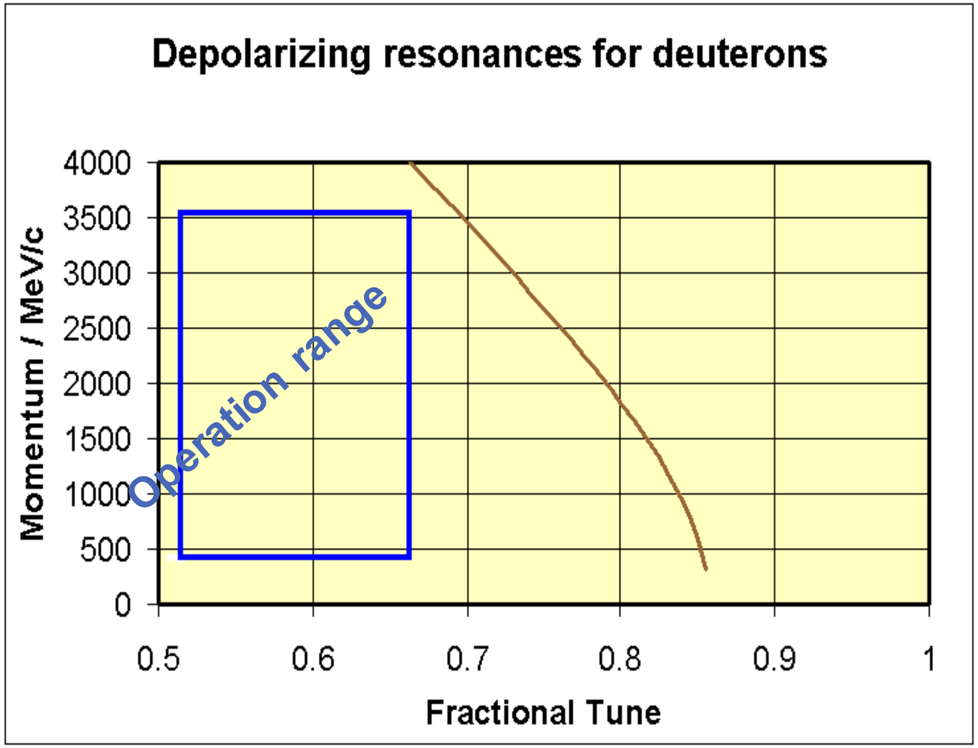
Spin Resonances in Cosy

Protons

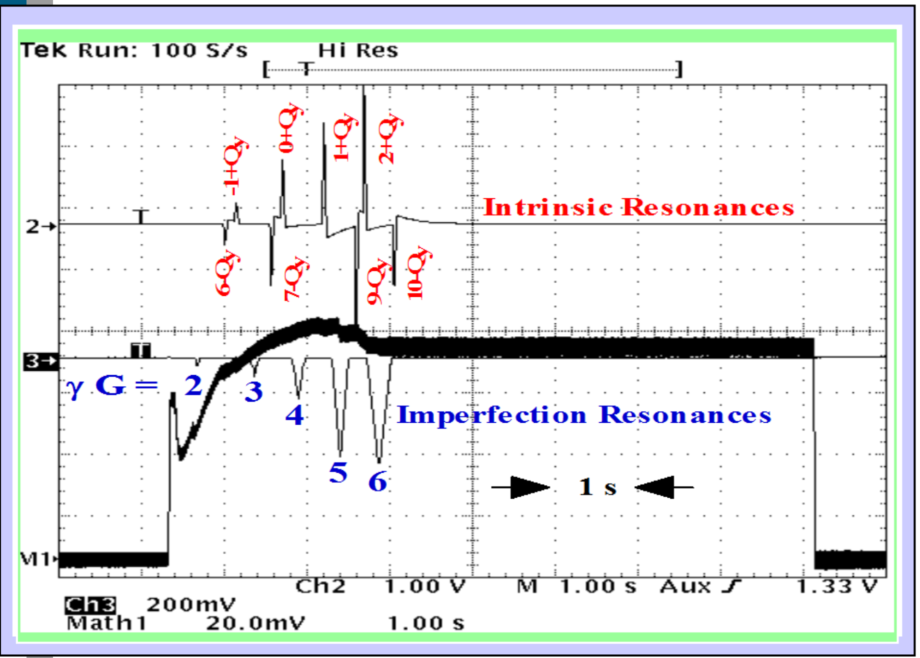
Momentum GeV/c	Kinetic energy GeV	Imperfection resonance $\gamma \cdot G = \ldots$	Intrinsic resonance $\gamma \cdot G = \ldots \pm Q_y$
0.464	**0.108**	**2**	
0.835	**0.318**		**6-**
0.986	**0.422**		**-1+**
1.259	**0.632**	**3**	
1.512	**0.841**		**7-**
1.634	**0.946**		**0+**
1.871	**1.155**	**4**	
2.103	**1.364**		**8-**
2.217	**1.469**		**1+**
2.443	**1.678**	**5**	
2.666	**1.888**		**9-**
2.776	**1.992**		**2+**
2.997	**2.202**	**6**	
3.215	**2.411**		**10-**
3.324	**2.516**		**3+**

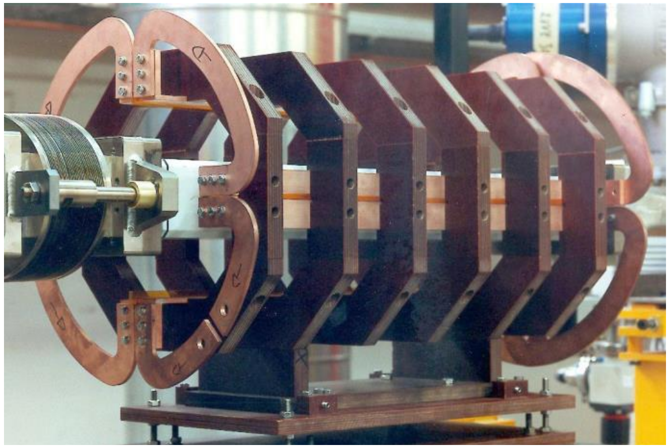
Deuterons



Polarized Proton Beam

Methods to preserve polarization

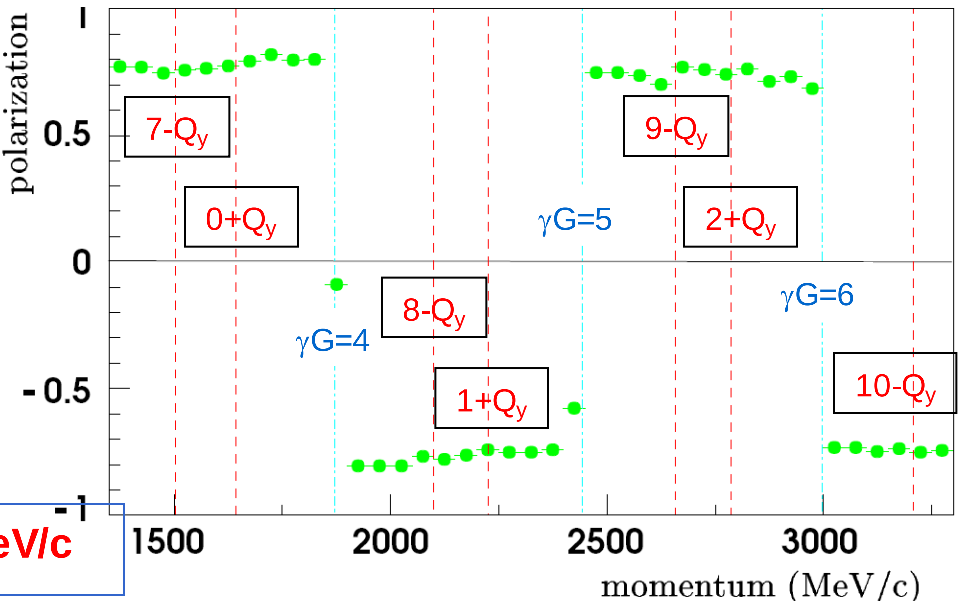




Tune-Jump Quadrupole

- Copper coil air core
- Length 0.6 m
- Max. current ±3100 A
- Max gradient 0.45 T/m
- Rise time 10 μs,
- Fall time 10 to 40 ms

Polarization during acceleration



→ tune jumps

→ vertical orbit excitation

Achieved: 10^{10} protons with P > 75% at 3.3 GeV/c

Spin Flipping

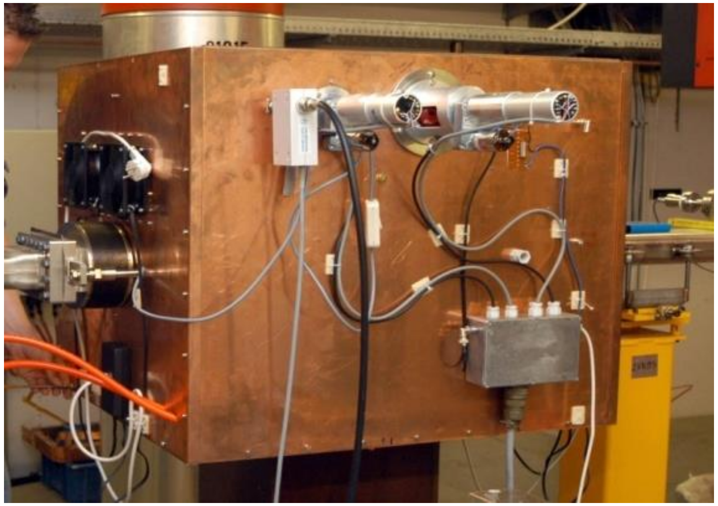
Reversal of the polarization of the stored beam by crossing an artificial depolarizing resonance created by transverse RF-fields.

$$f_{res} = (k+\gamma G)\, f_0$$

Extensive studies carried out by Spin@Cosy collaboration (A.D.Krisch et.al, COSY crew …)

In use today: water cooled air core RF-solenoid (rf-power: ~kW, B-fields: ~mT)

RF-Solenoid



Example of applikation

η-mass determination in d p -> ^{3}He η at Anke

Use depolarizing resonance for accurate determination of beam momentum

$$f_{res} = (1+\gamma G)\, f_0$$

$\Delta p/p < 6\ 10^{-5}$ at 13 momenta between 3100 and 3200 MeV/c

P.Goslawski et al., Physical Review Special Topics - Accelerators and Beams (Vol.13, No.2)

Spin Filtering Experiment
Polarized Antiproton Experiment (PAX)

Principle of Spin Filter Method

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

P beam polarization
Q target polarization
k || beam direction

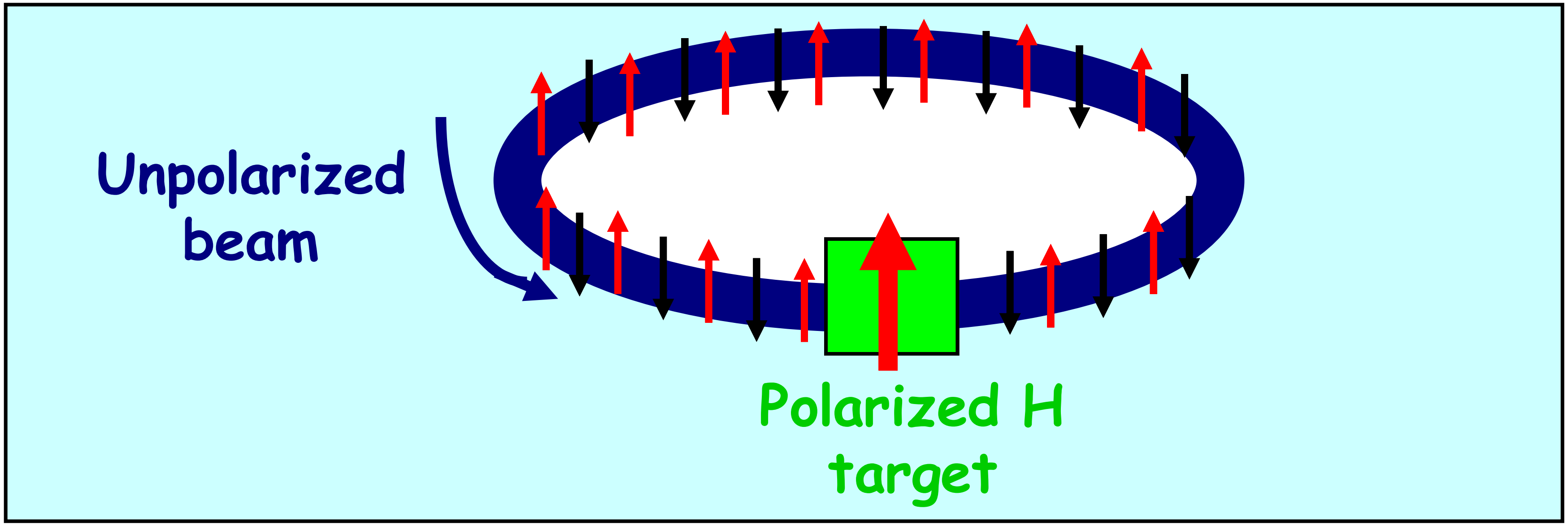
For initially equally populated spin states: ↑ (m=+½) and ↓ (m=-½)

transverse case:

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

longitudinal case:

$$\sigma_{tot\pm} = \sigma_0 \pm (\sigma_\perp + \sigma_\parallel) \cdot Q$$



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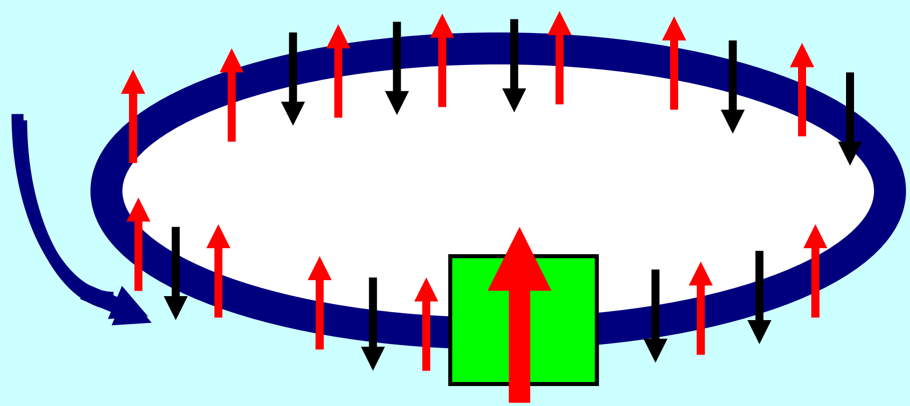

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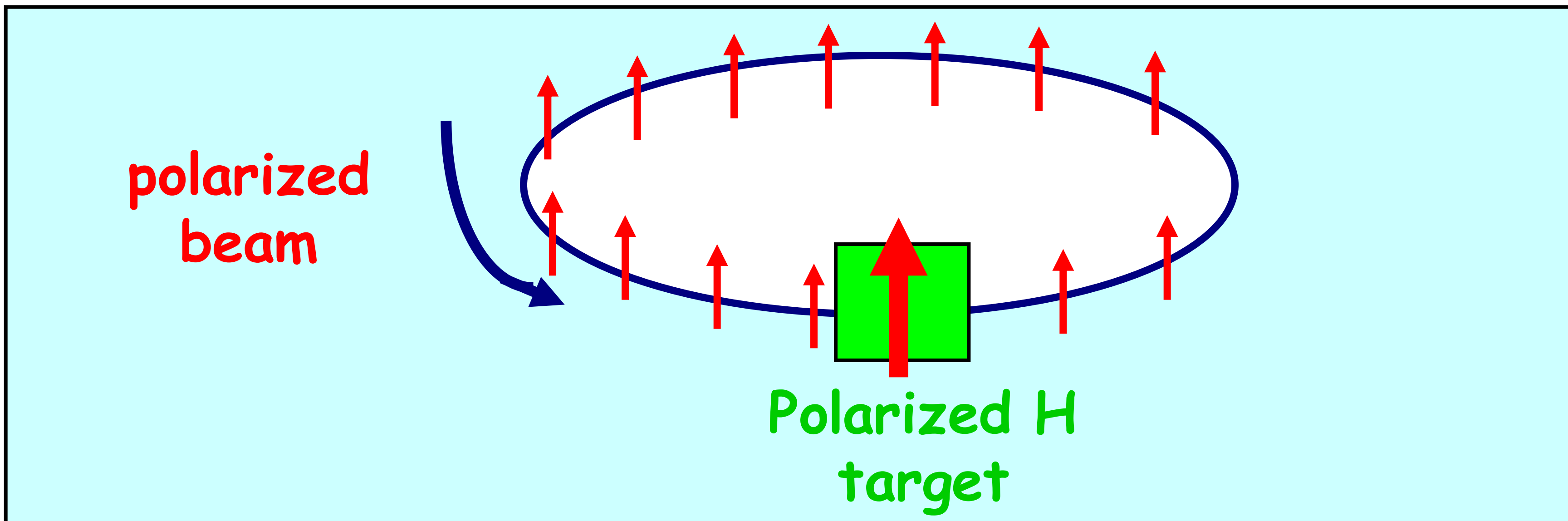
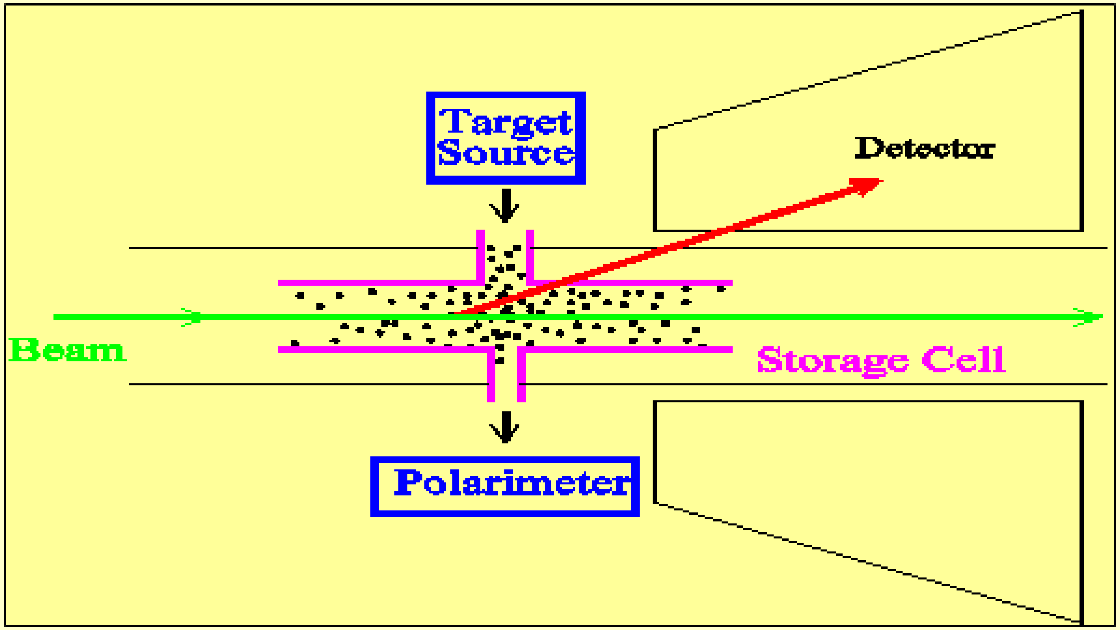


Polarized p (d) target using atomic beam source and storage cell



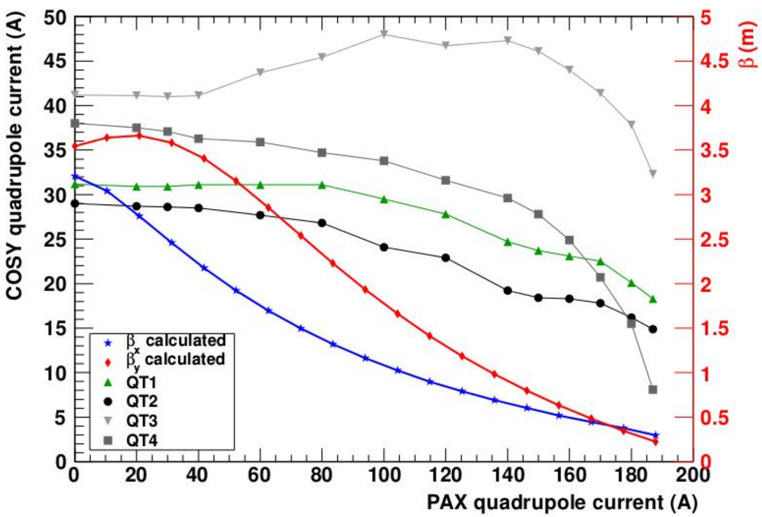
point-like	5-10 mm	free jet	low density	10^{12} cm^{-2}
extended	200-500 mm	storage cell	high density	10^{14} cm^{-2}

More details about target: G. Ciullo: contribution to this conference: 27 Sep 2016, 14:30

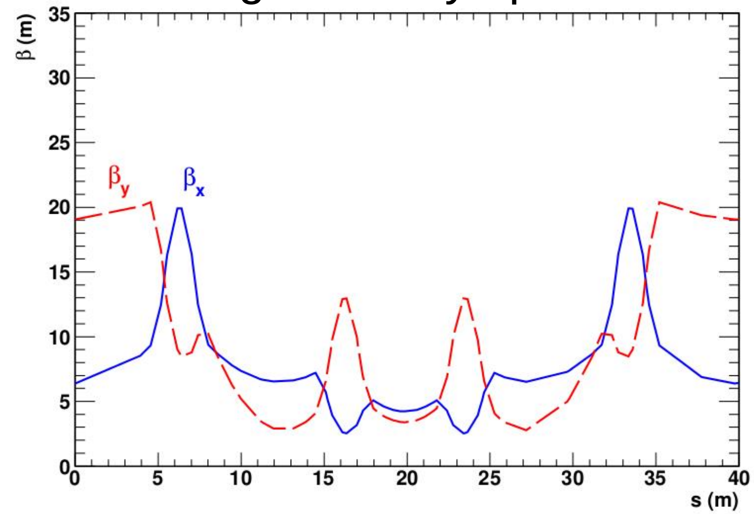
Low-β section

$$t \mu q_{acc}^{2} \mu \frac{1}{b^{2}}$$

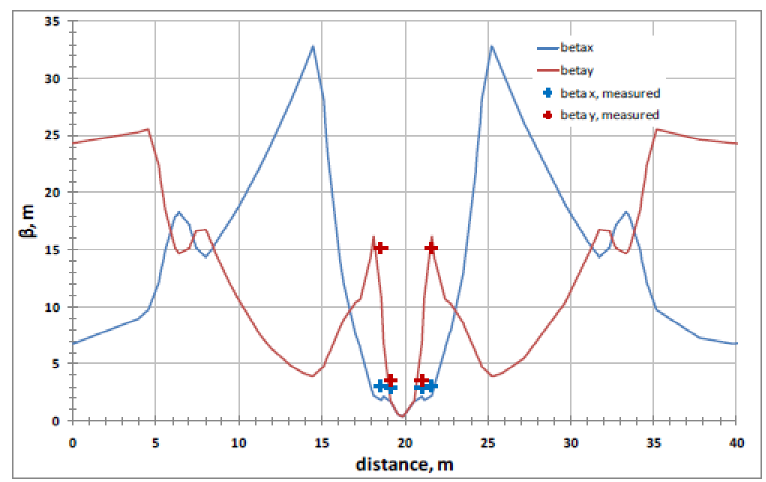
- Significant reduction of the machine acceptance due to storage cell (d = 9.6 mm, l = 400 mm)
- Solution: low-β section



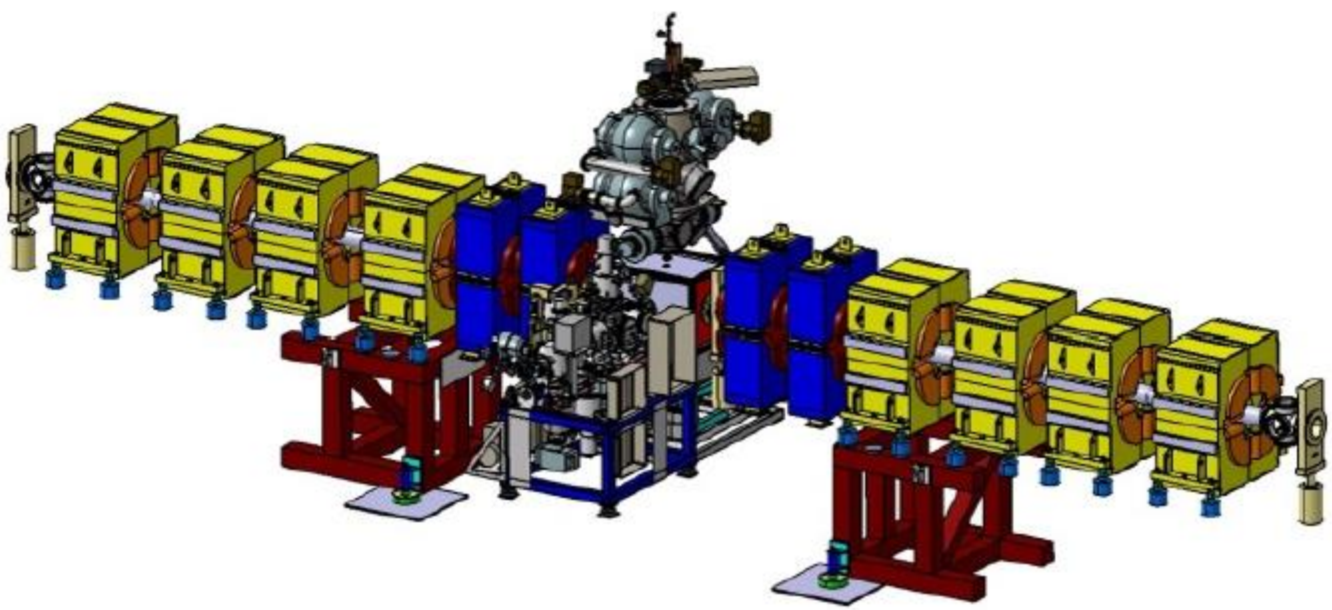
Regular Cosy optics



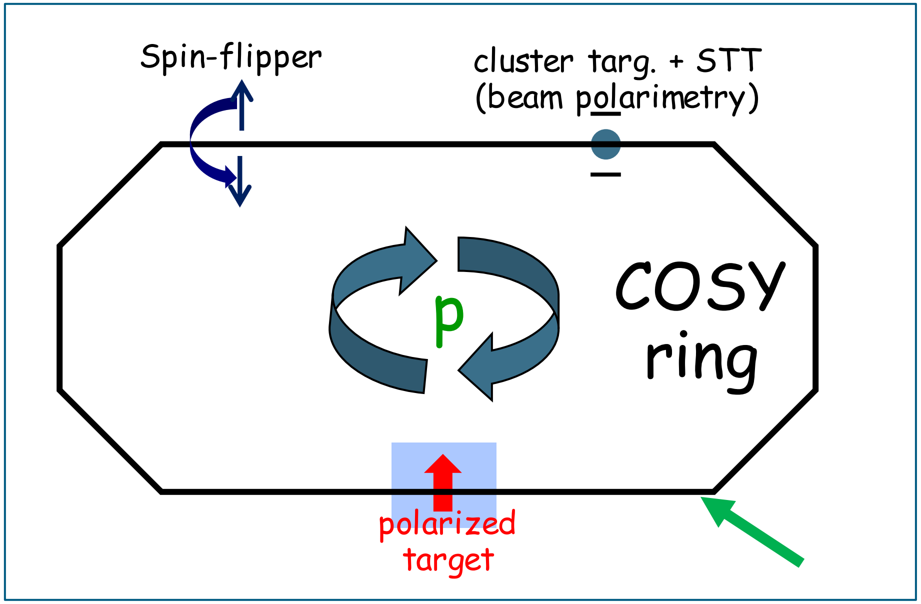
low beta optics

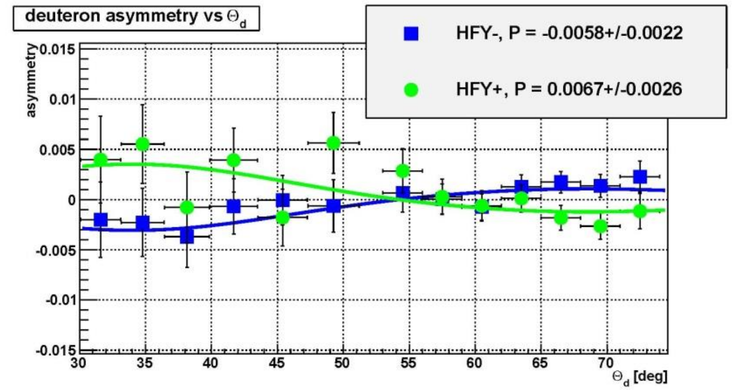


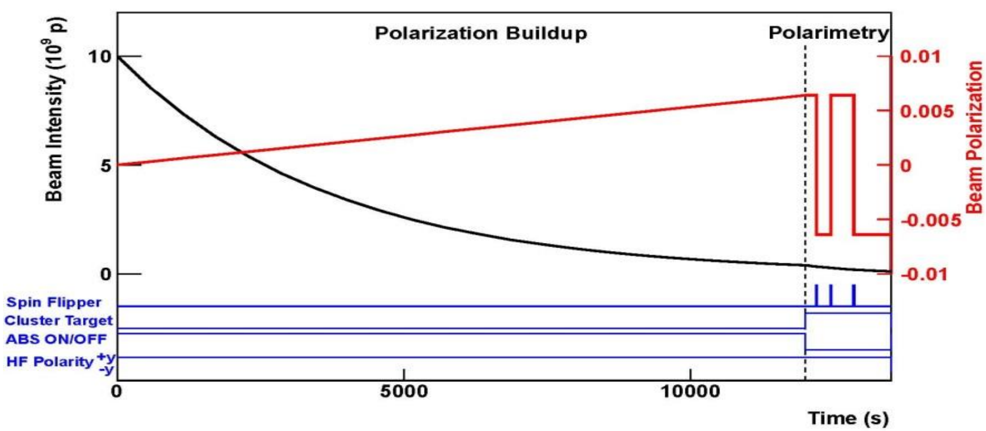
- The low-β section allows one to use a storage cell of small diameter.
- The storage cell and the detector are placed inside the PAX target chamber.
- The magnetic holding field system allows one to control (flip/reorient) the direction of the polarized $\vec{d}$ inside the target.

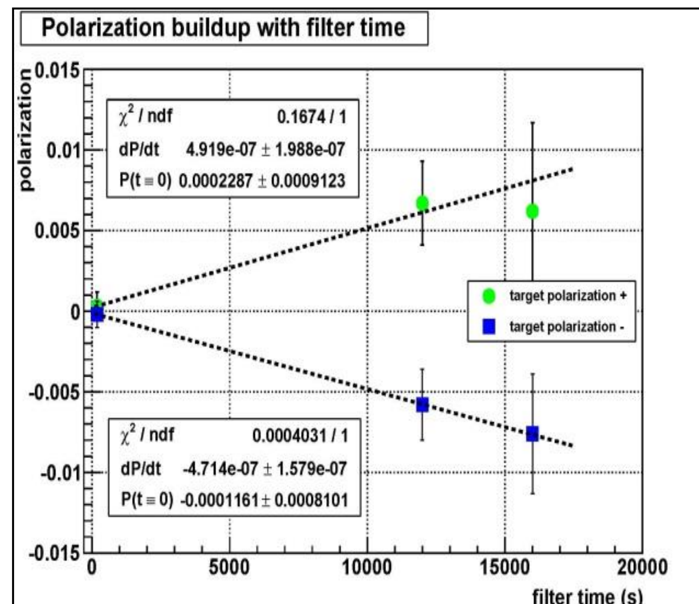


Spin-filtering cycle

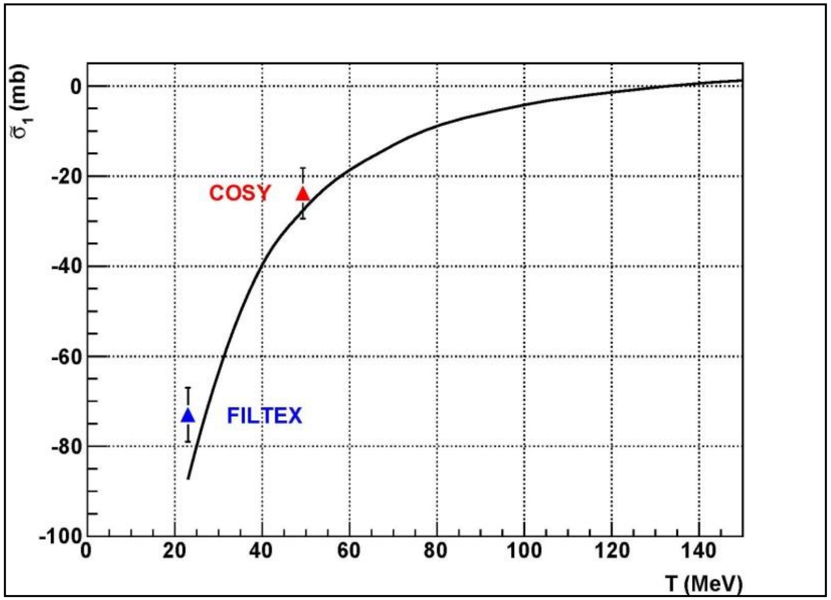








Spin-filtering: result



W. Augustyniak et al., Physi. Lett. B 712 (2012) 64

- Milestone for the field
  - Confirms understanding of spin-filtering as a viable method to polarize a stored beam.
  - Confirms complete control of the systematics of the experiment.

Time Reversal Invariance Experiment at COSY (TRIC)

Polarized proton beam and polarized deuterium storage cell target

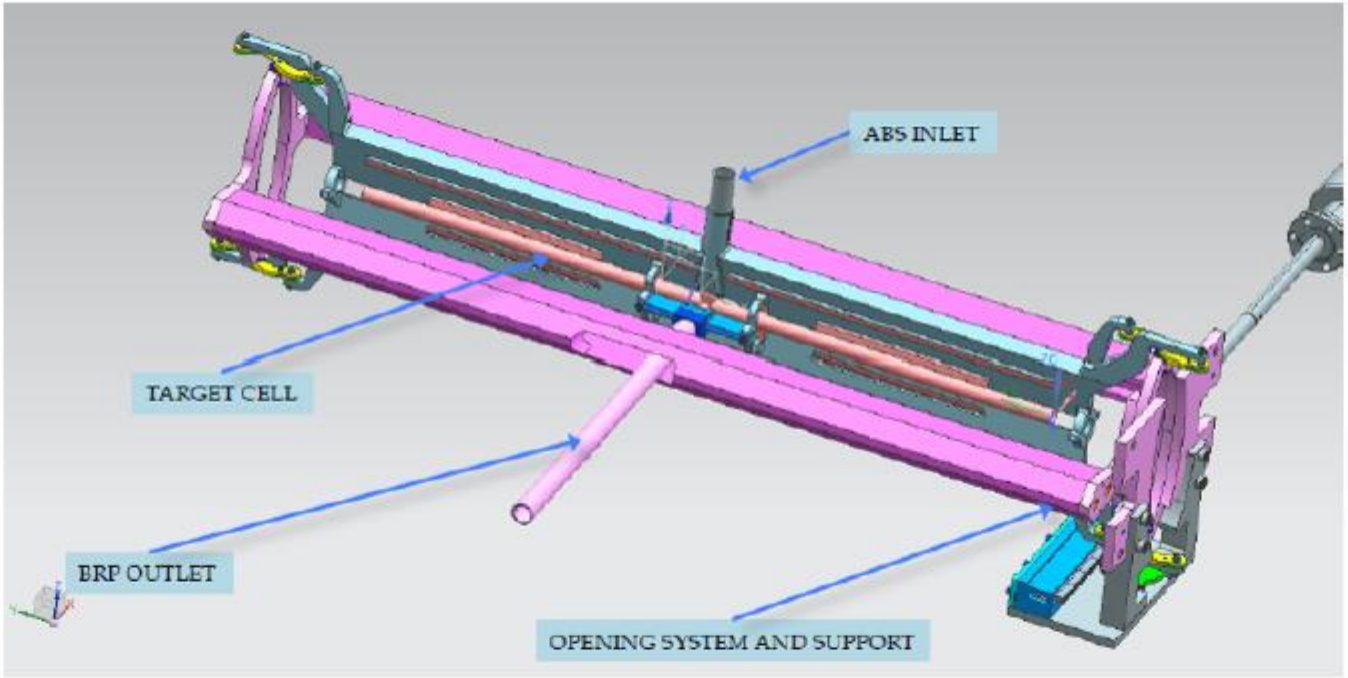
With the Pax installation possible at Cosy

Details tomorrow, 12:45
Yuri Valdau:
Preparation for the Time Reversal Invariance experiment at COSY (TRIC)

Ongoing developments

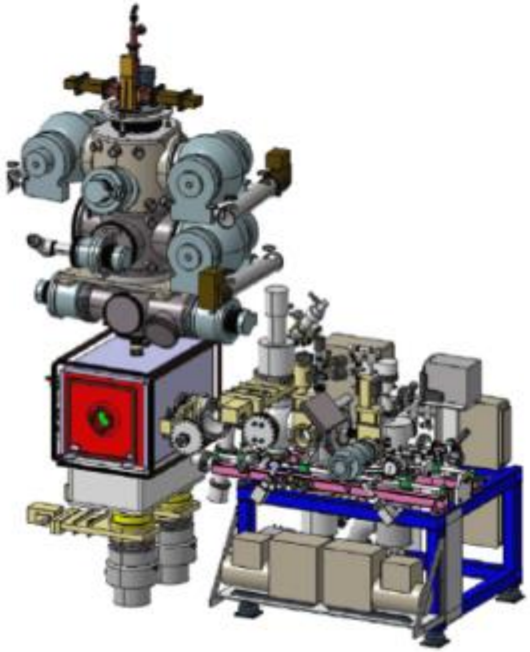
Openable Storage Cell

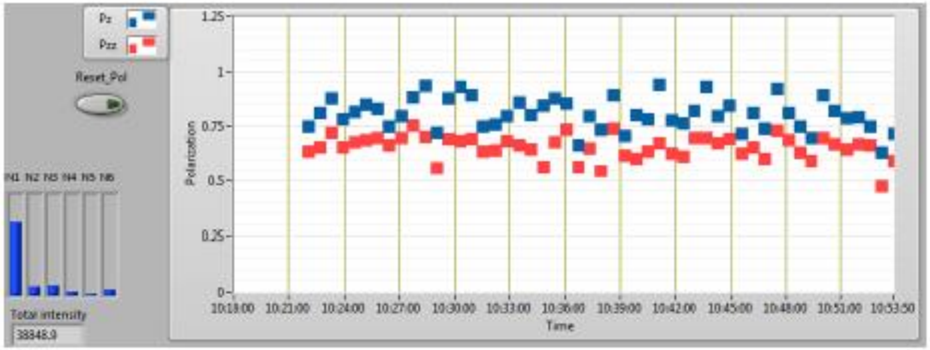
- At the PAX IP one can either install a closed or an openable cell.
- The latter, under preparation by the Ferrara group (2017), offers higher beam current for the TRIC experiment.



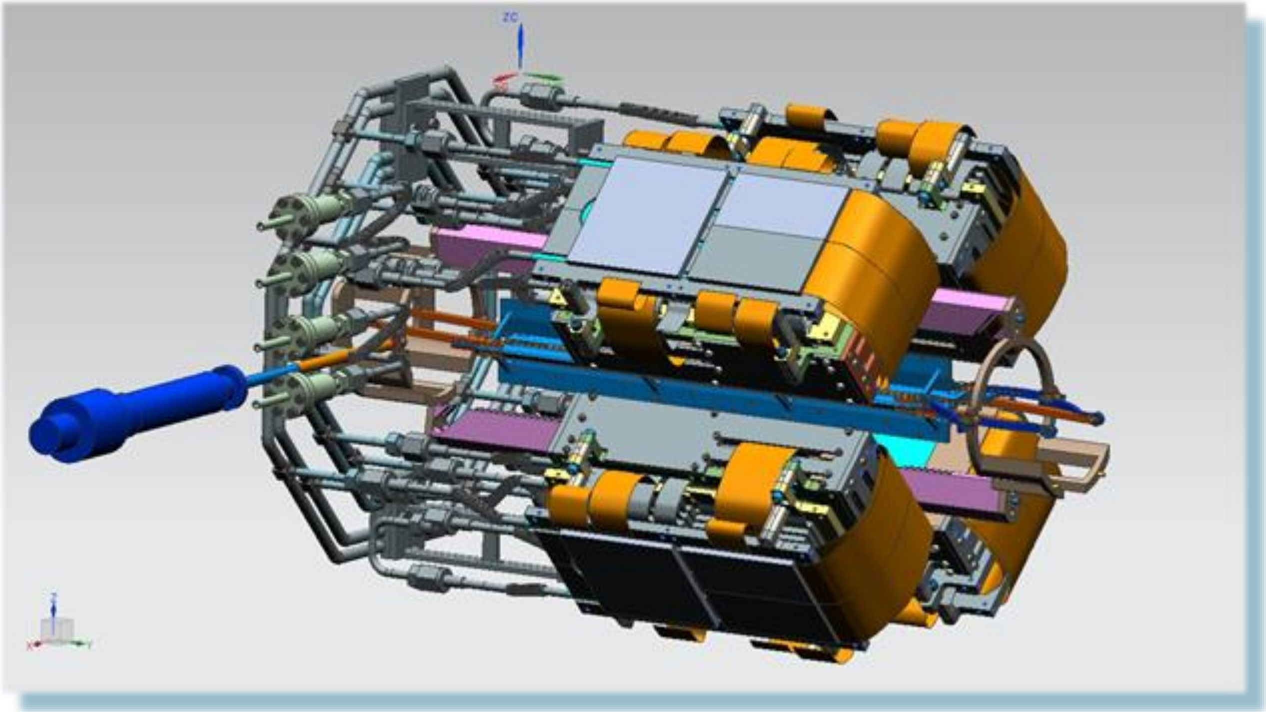
Breit Rabi Polarimeter

- During a test experiment in June 2016, the PAX atomic beam source and the Breit-Rabi polarimeter were commisioned with deuterium gas at COSY.
- Deuterium vector (p_z) and tensor (p_{zz}) polarizations of more than 0.75 were obtained.





PAX Detector



- φ-symmetric detection system
- 24 double-sided silicon strip detectors (300 µm, 300 µm, 1500 µm)
- Strip pitch of 0.7 mm results in a vertex resolution of $\leq$ 1 mm
- All spin observables measurable with φ-dependence ($\cos(\varphi)$, $\cos(2\varphi)$)

Setup and commissioning by COSY-PAX collaboration in 2017

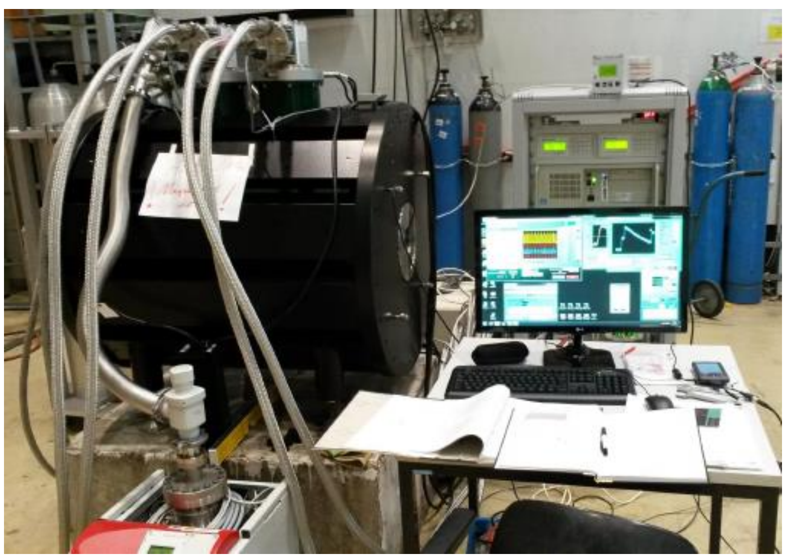
Courtesy: PAX detector group

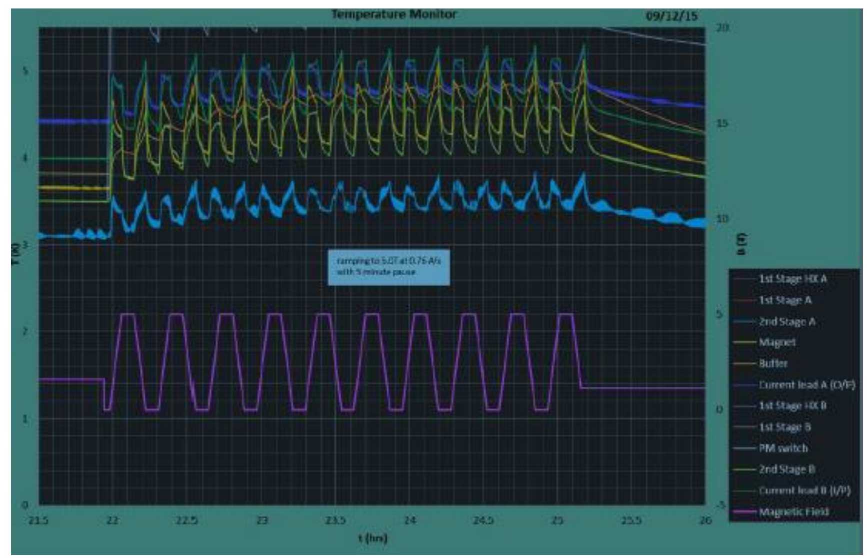
Siberian Snake

For longitudinal beam polarization a siberian snake solenoid was aquired

- 4.7 Tm superconducting solenoid
- on site at Jülich
- lab test ongoing
- preparation for installation in progress
- 2 weeks of commissioning beamtime recomended by Cosy Beam Advisory Committee (CBAC)

Longitudinal spin filtering possible





Conclusion and Outlook

COSY has all tools needed for the proposed polarized beam experiment

- Polarized protons and deuterons from ion source
- Methods for compensating depolarizing resonances during acceleration
- fast beam polarimeter
- Spin manipulation tools (flipper)

PAX installation polarized internal p and d target, already operated for PAX

- Low beta section
- Storage cell
- polarized target and polarimeter

Outlook

Priority of COSY operation shifted to the study of electric dipole moment of deuteron (-> parallel session ‚beam' Tuesday afternoon)

TRIC could be carried through in the near future

PAX longitudinal spin filter tests still on list of things to do