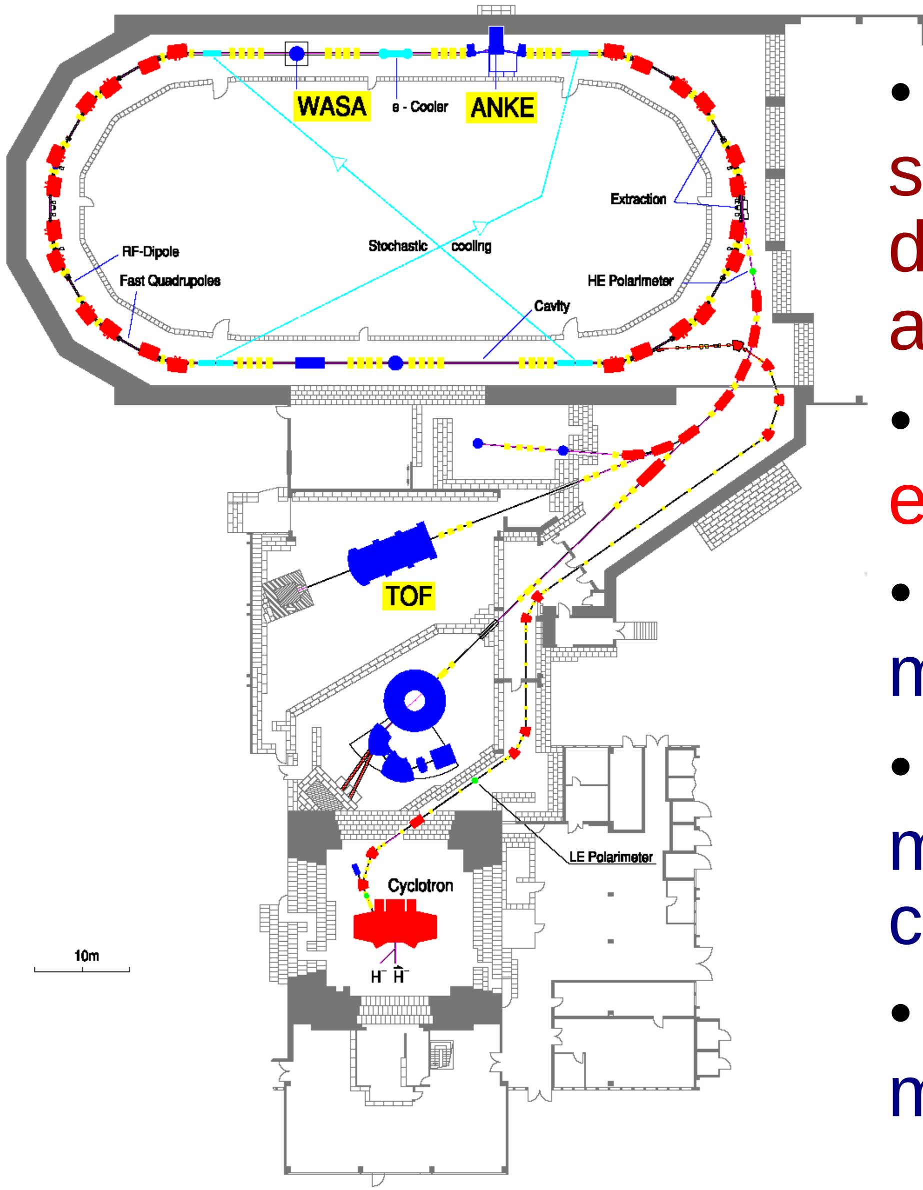
Polarized beams and spin manipulation at COSY

13.March 2017, Bernd Lorentz
IKP4-Forschungszentrum Jülich
EDM kick-off meeting

Outline

- COSY
- Spin resonances
- Polarimetry
- Spin Manipulation

Cooler Synchrotron (COSY)



- **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 (100 kV)
- new e cooler: upto max. momentum (2 MV, under commissioning)
- Stochastic cooling at high momenta (β>0.8)

Spin Motion

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

Spin Resonances in Cosy

JÜLICH FORSCHUNGSZENTRUM

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+

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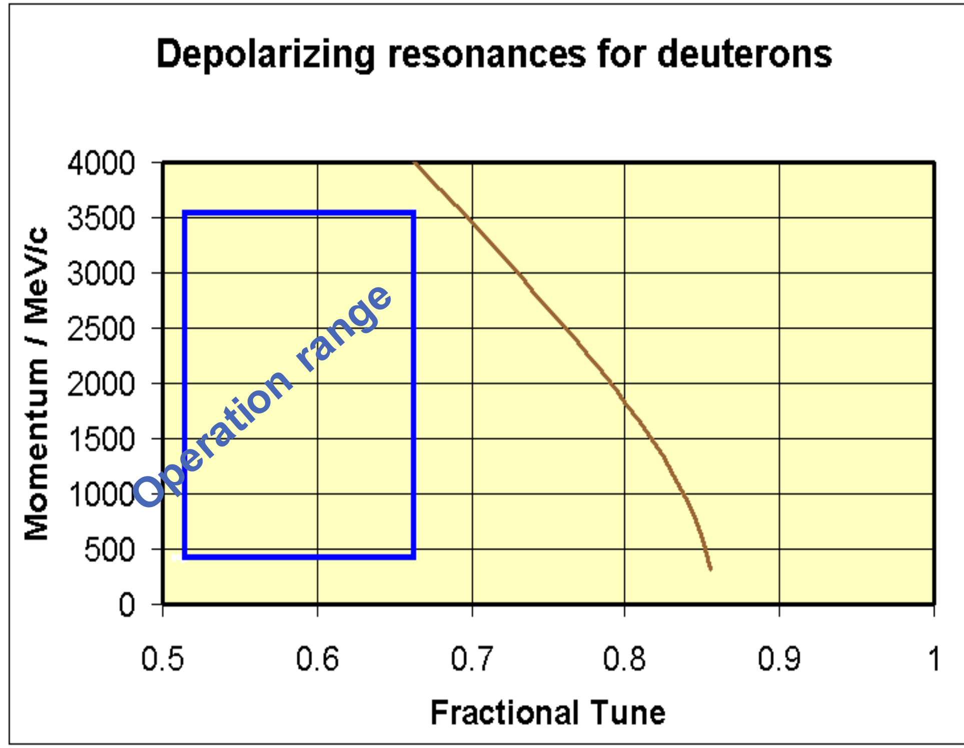
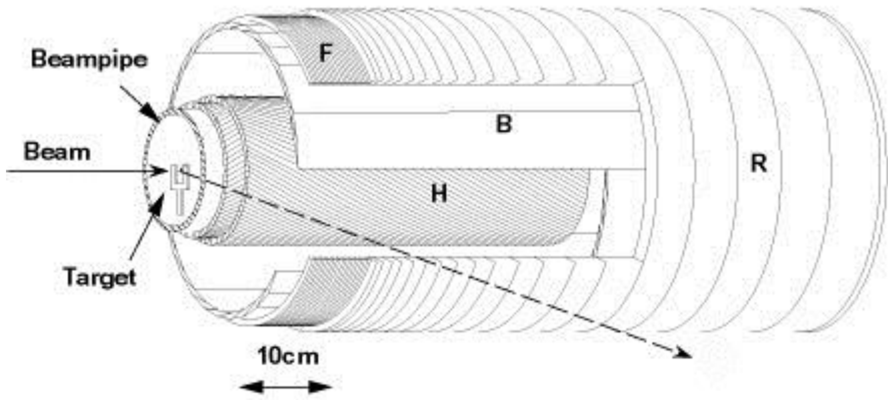
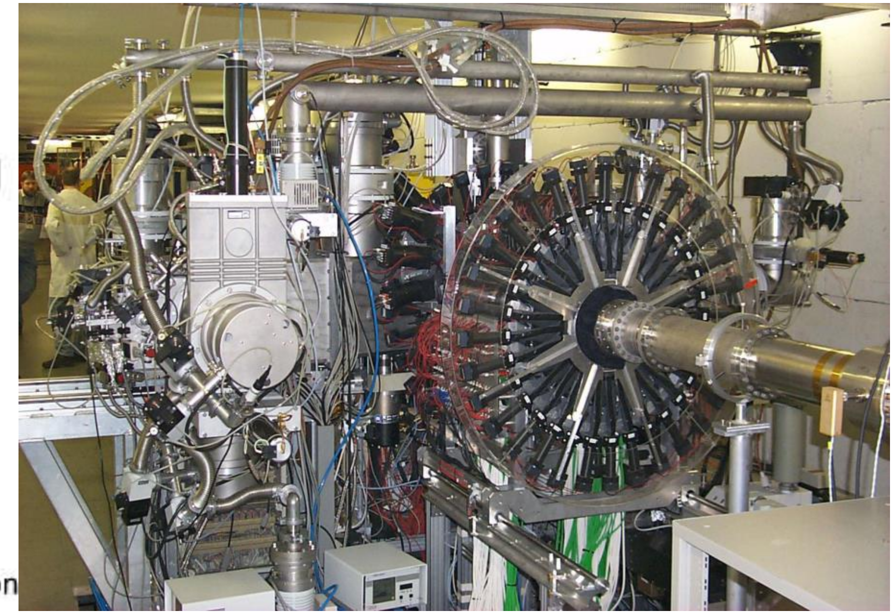
Deuterons



EDDA Polarimeter





- two-layered cylindrical scintillator structure
  - Outer Layer (→ trigger!)

    D: 32 overlapping slabs of triangular cross-section ($\Delta\phi = 11.25^o$)

    F,R: 2x29 semirings ($\Delta\theta_{\rm lab} = 2.5^o$)

    left semirings $\phi \in [-90^o, 90^o]$

    right semirings $\phi \in [90^o, 270^o]$
  - Inner Layer (H): 640 scintillating fibers

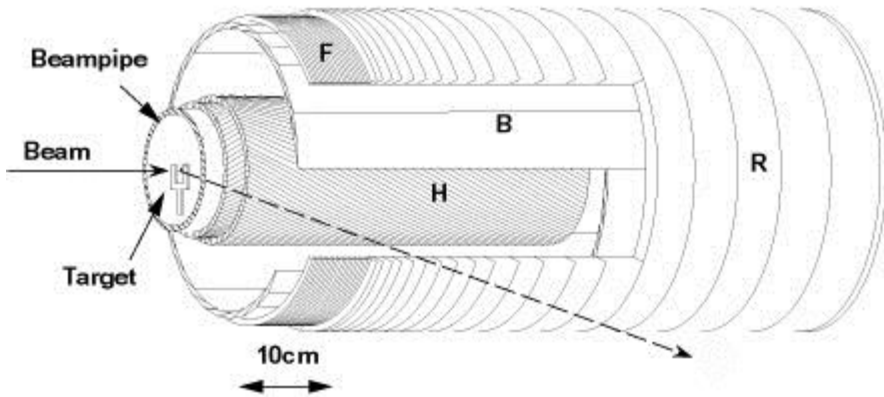
    → vertex reconstruction ($\sigma \approx 1$mm)
- Acceptance: $\theta_{\rm lab} \in [10^o, 72^o]$
- Targets: CH_2 and C fiber targets, polarized H and D atomic beam target.

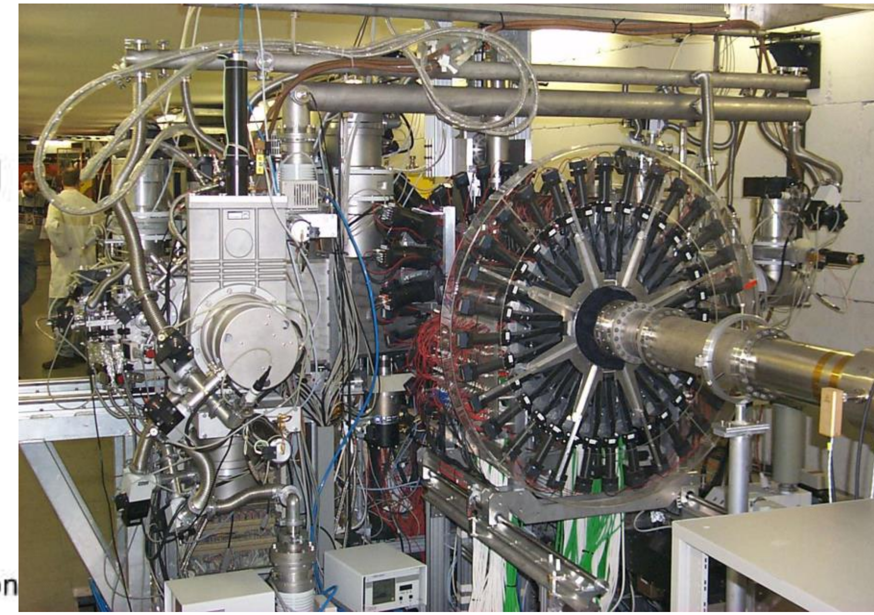
Designed for left right coincidences, best suited for proton polarimetry over the full COSY energy range

(The EDDA experiment measured p-p elastic scattering cross sections and spin correlation parameters)

fast polarimetry (during acceleration)

EDDA Polarimeter





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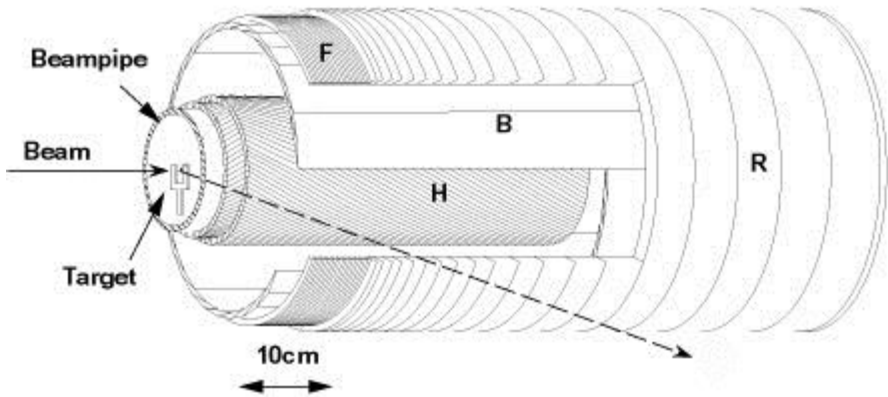
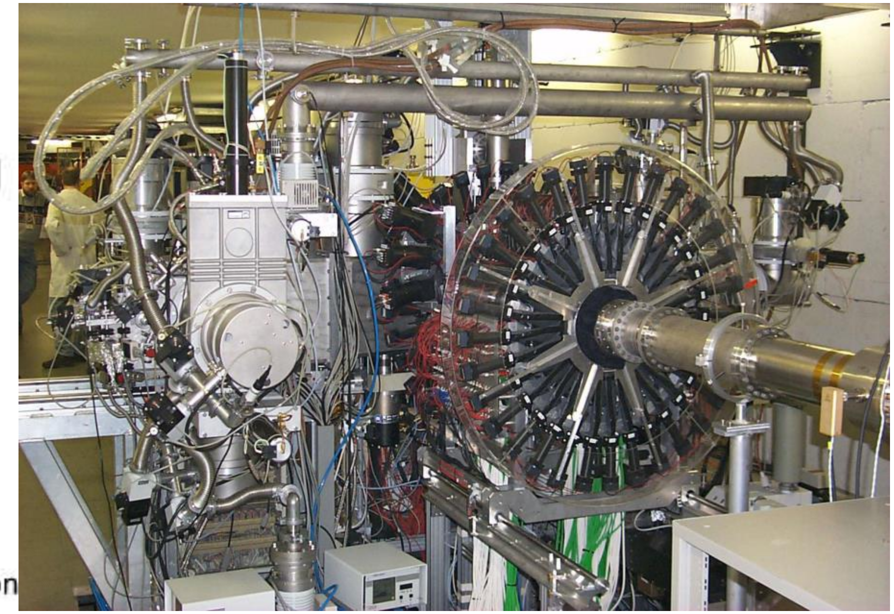
fast polarimetry (during acceleration)

extension of polarimetry to lower p momenta

EDDA Polarimeter





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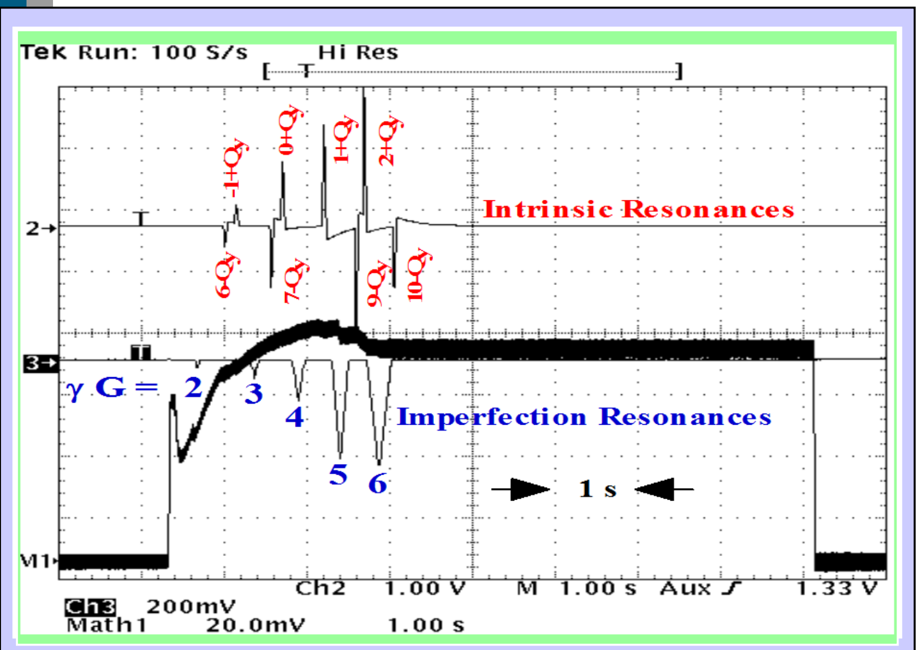
Designed for left right coincidences,
best suited for proton polarimetry over the full COSY energy range
(The EDDA experiment measured p-p elastic scattering cross sections and spin correlation parameters)
fast polarimetry (during acceleration)

also usable for deuteron and horizontal polarization measurement (upto now used by JEDI)

Polarized Proton Beam

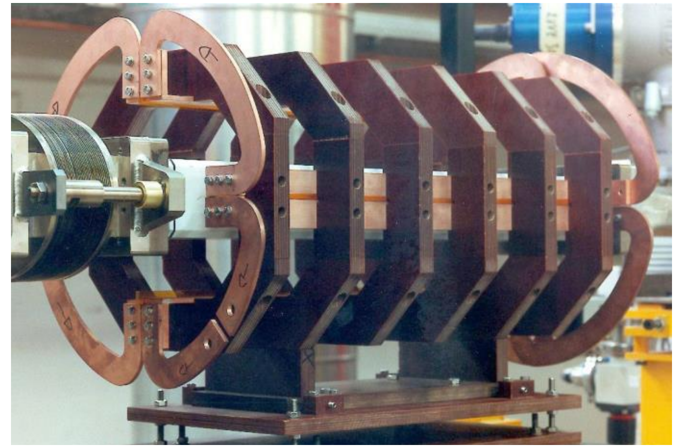
Methods to preserve polarization



→ tune jumps

→ vertical orbit excitation

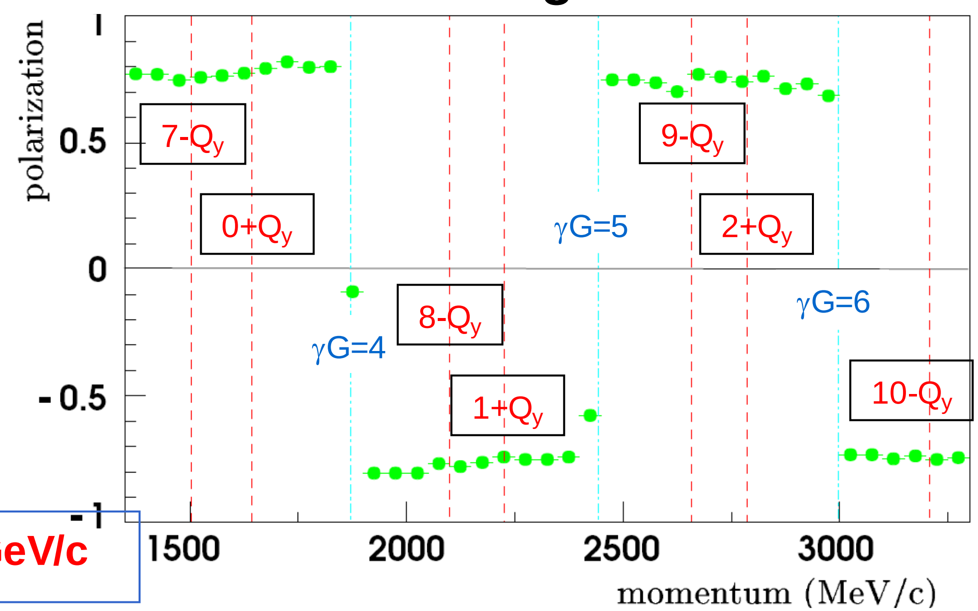
Achieved: 10^{10} protons with P > 75% at 3.3 GeV/c



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



Spin Flipping

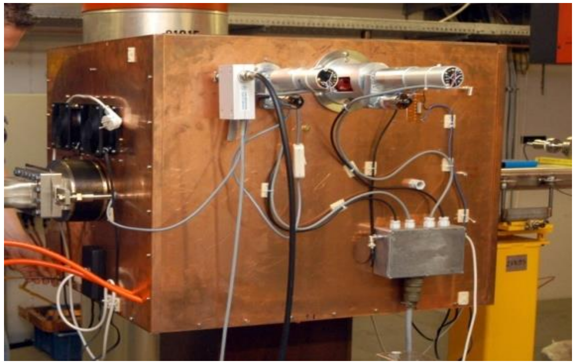
Reversal of the polarization of the stored beam by crossing an artificial depolarizing resonance created by transverse RF-fields (dipole or solenoid).

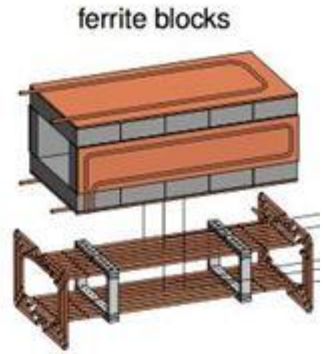
$$f_{res} = (k+\gamma G)\, f_0$$

Extensive studies carried out by Spin@Cosy collaboration (papers can be found in Physical Review Special Topics - Accelerators and Beams)

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

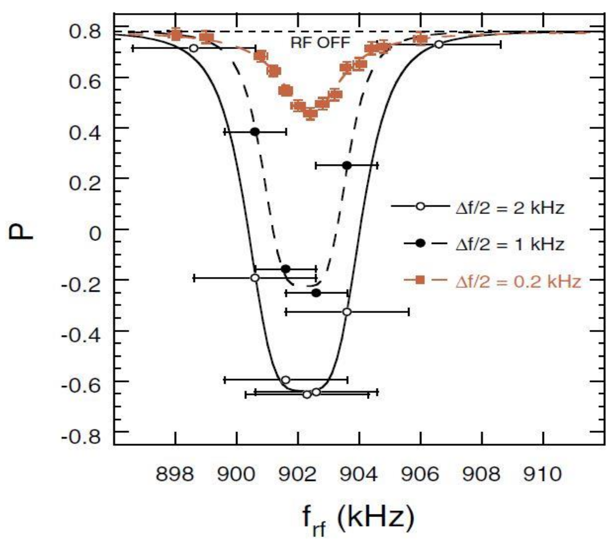
RF-B Dipole





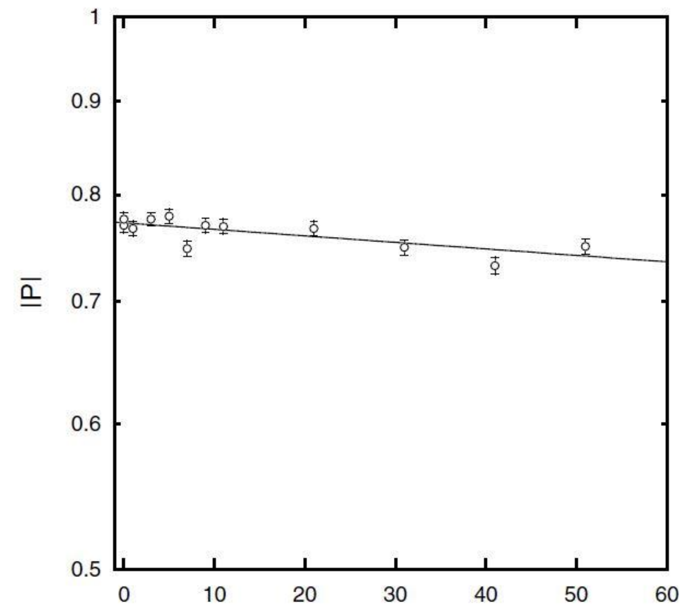
8 turn watercooled copper tubes in LC resonant circuit
2.4 kV rms @ 902.6 kHz
0.46 T mm

dipole frequency sweeps across resonance (Froissart-Stora) -> polarization reversal



Hor. Bars indicate sweep

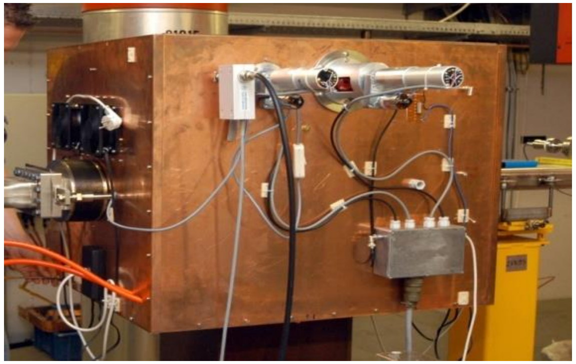
Multiple crossing of resonance



number of sweeps

Achieving 99.9% Proton Spin-Flip Efficiency for 2.1 GeV/c protons , M. A. Leonova, PRL 93, 224801 (2004)

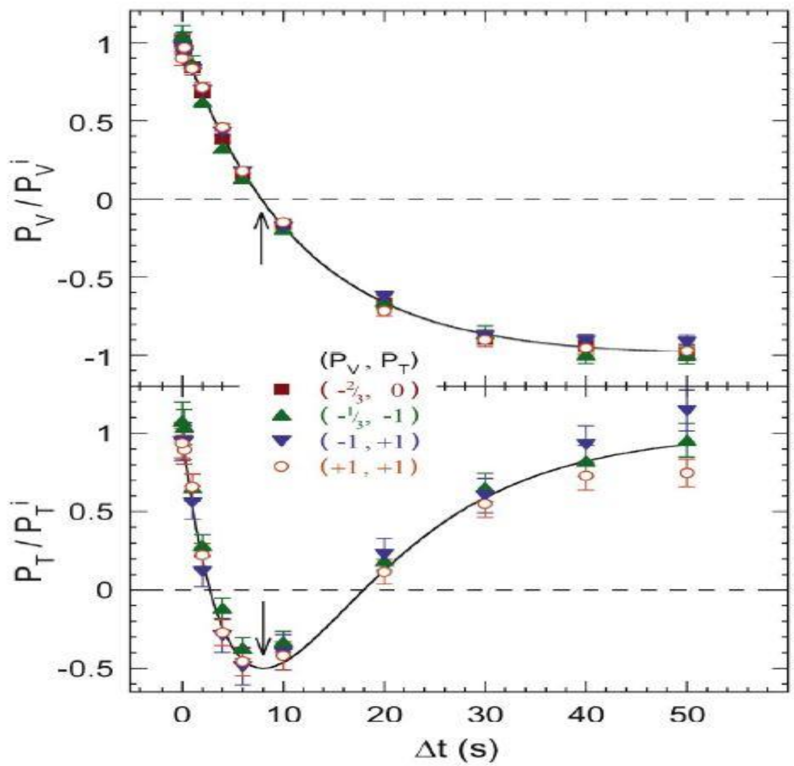
RF Solenoid



28 turn coil, watercooled
copper tubes
5.7 kV rms
0.5-1.5 MHz
0.67 Tmm

some example, 1.85 GeV/c deuterons,
measurement with EDDA,
97 % flipping efficiency

Froissart Stora Sweep, sweep time varried



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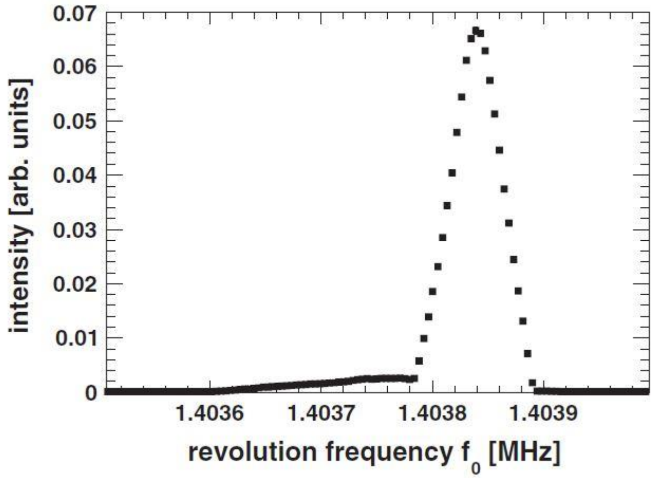
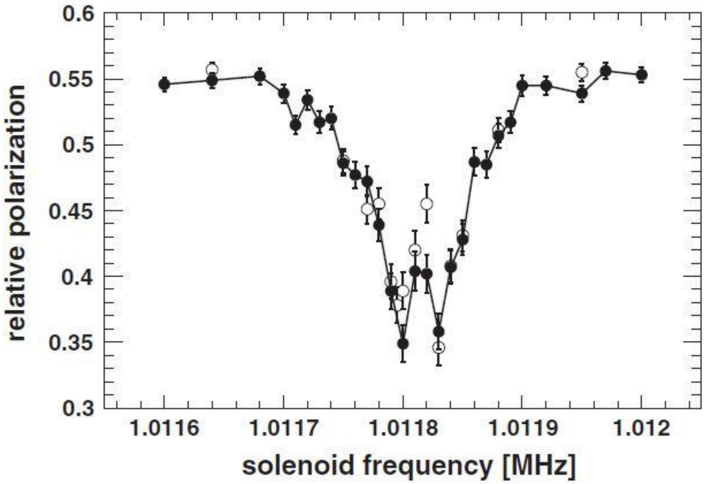
Other applikations

ANKE: η-mass determination in d p -> $^3He\ \eta$ at Anke
Use depolarizing resonance for accurate determination of beam momentum

revolution frequency from schottky spectra -> f_0



depolarzing resonance from solenoid -> f_{res}



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

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

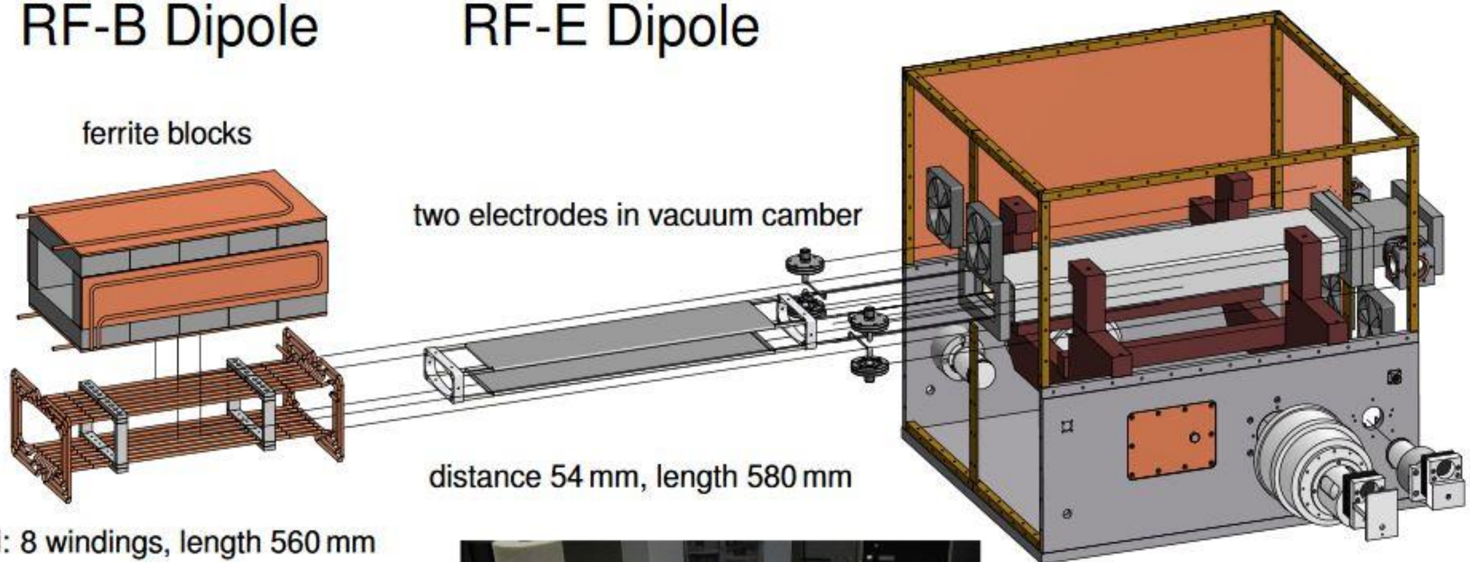
P.Goslawski et al., Physical Review Special Topics - Accelerators and Beams (Vol.13, No.2, 2010)

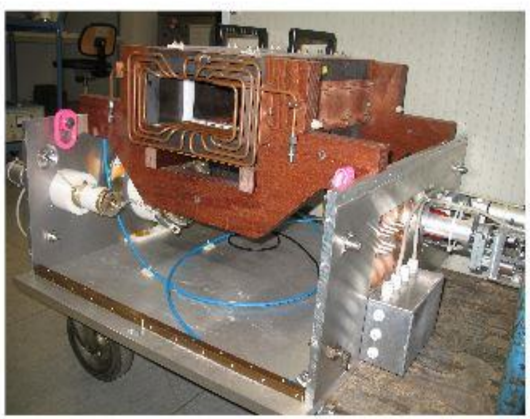
use for JEDI: preparing polarization in the horizontal plane from intitial vertical polarization (90 degree rotation)

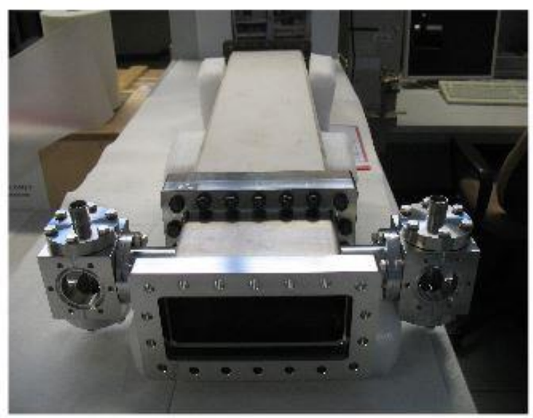
shielding Box

RF-B Dipole

RF-E Dipole







ceramic beam chamber
two separate resonance circuits

Field Compensation

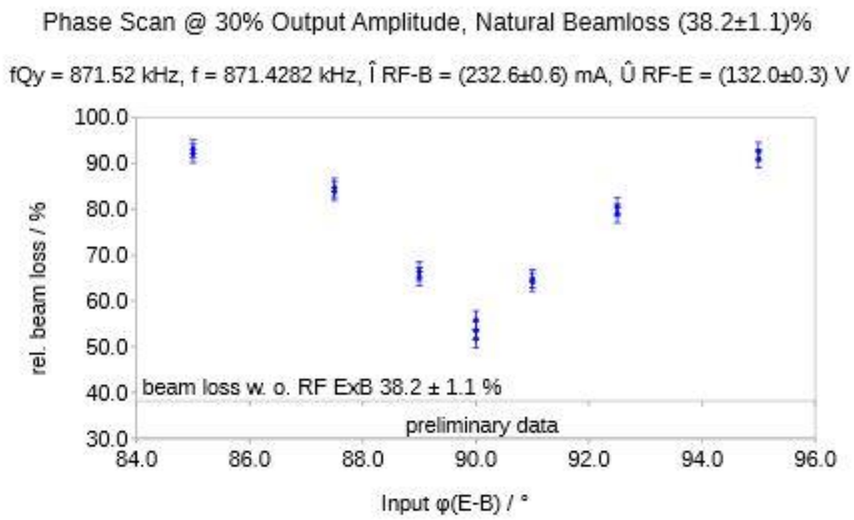
- measurement on betatron frequency for max. sensitivity
- polarimeter target directly above beam-pipe-center limits acceptance

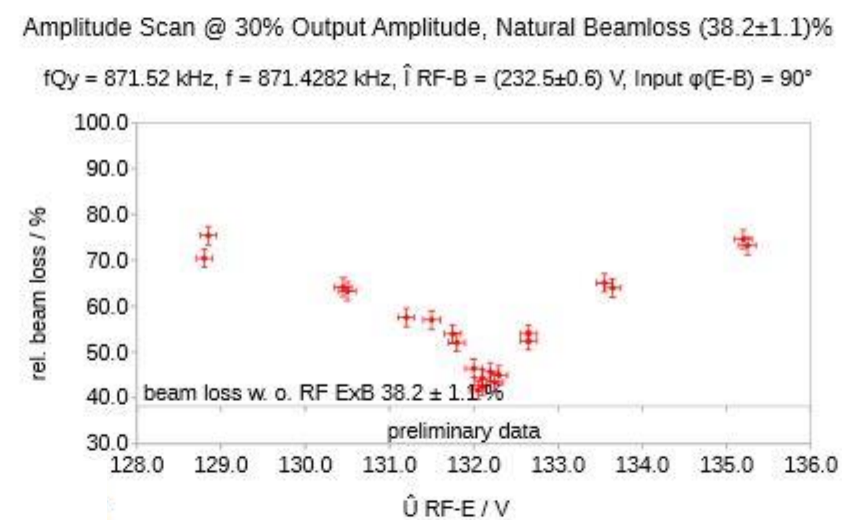
⇒ exited part of beam is removed

⇒ diagnosis with COSY beam current transformer

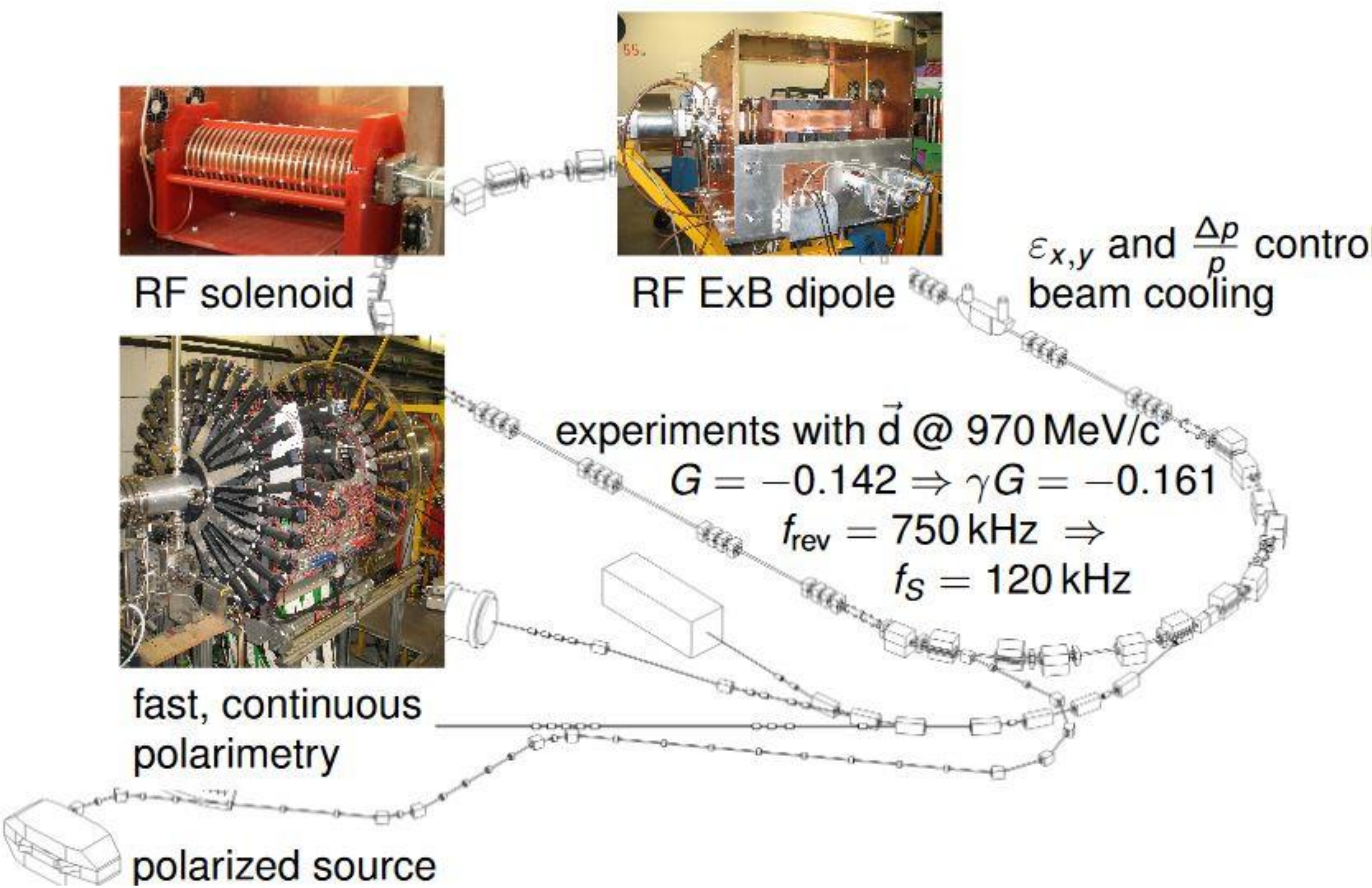
- determination of amplitudes and phase for Lorentz force compensation down to per mille!

from S.Mey

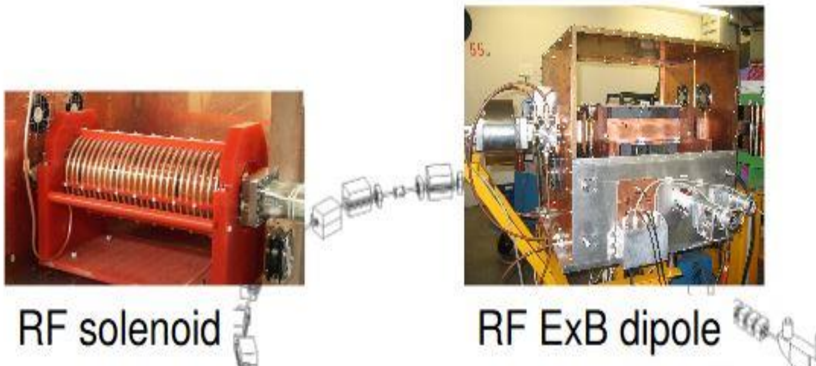


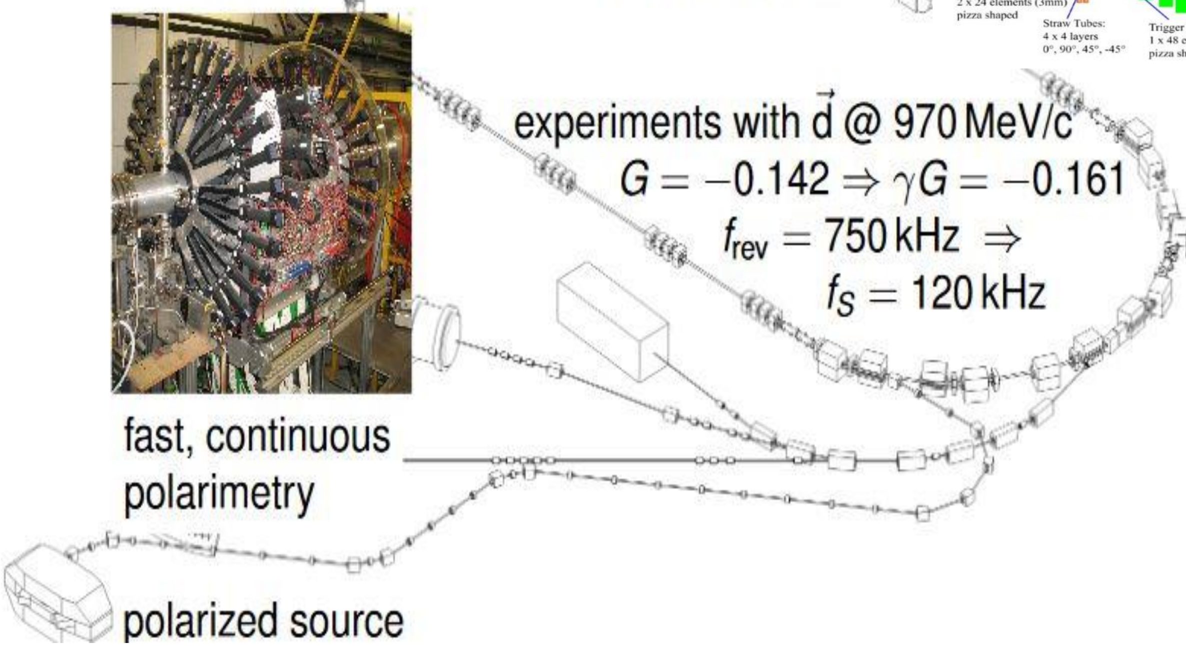


COSY as Spin Physics R&D facility



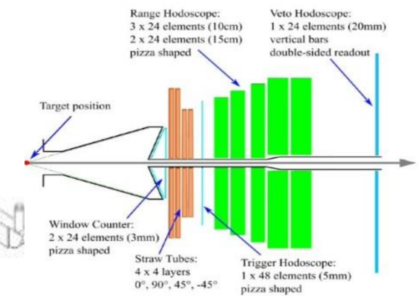
COSY as EDM test facility



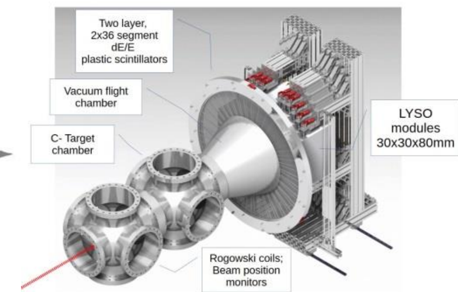


highly efficient
deuteron polarimeter

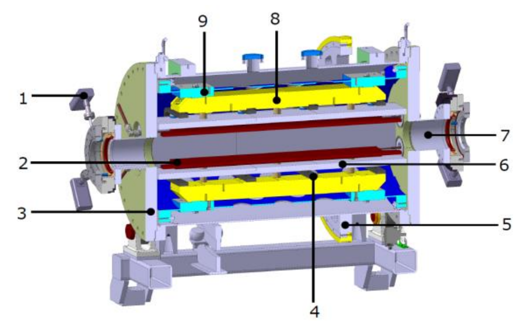
WASA



JEDI-> I.Keshelashvili



precision RF Wien Filter
->F.Rathmann



The team:
no names here, the list would be too long

everybody in IKP-4 is needed
to make these things work

Thank you for your attention

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