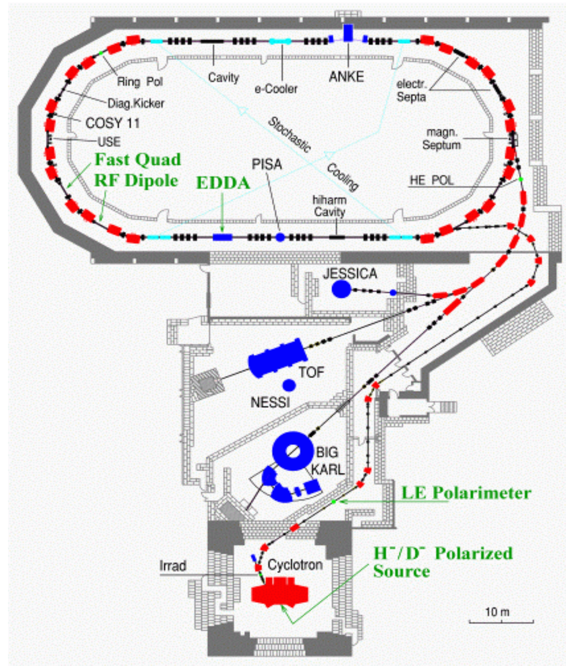
Polarized Beams at COSY

Forschungszentrum Jülich
in der Helmholtz-Gemeinschaft

- Polarized Protons
- Electron Cooling and Polarization
- Polarized Deuterons
- Spin Flipping

COSY Accelerator Facility

Forschungszentrum Jülich
in der Helmholtz-Gemeinschaft



Ions: (pol. & unpol.) p and d

Momentum: **300 to 3650 MeV/c for p**
540 to 3650 MeV/c for d

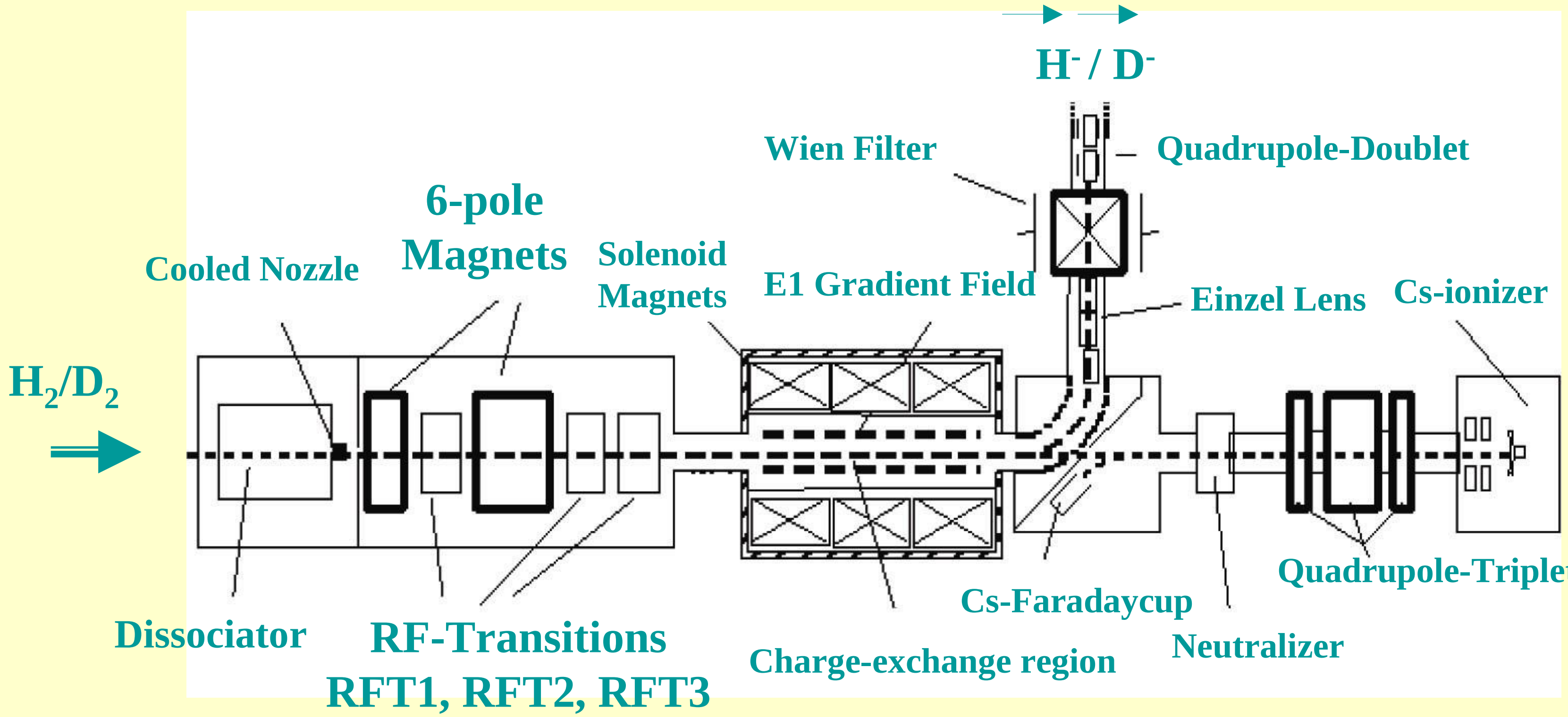
Targets:

- **Internal: solid, cluster, atomic beam**
- **External: solid, liquid**

Beam cooling:

- **Electron cooling at injection for**
  beam accumulation
  high brilliance beams
- **Stochastic cooling above 1.5 GeV/c for**
  luminosity preservation

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



Depolarizing Resonances

Forschungszentrum Jülich
in der Helmholtz-Gemeinschaft

Imperfection resonances: $\gamma G = k$
The spin precession motion is in resonance with the periodic field errors in the lattice of the ring ($\nu_S = \gamma G$: spin tune = number of spin precessions per revolution).
Induced by unavoidable field and positioning errors:

Intrinsic resonances: $\gamma G = k + m\nu_y$
The spin precession motion is in resonance with the betatron oscillation of the stored particles.
Without significant coupling between horizontal and vertical motions, only the vertical betatron oszillation is relevant (vertical polarizations is disturbed by horizontal fields, vertical deviation from reverence orbit lead to higher horizontal field components)

(Higher order resonances: $\gamma G = k + m\nu_y + n\nu_x$)

The Proton Depolarising resonances

Forschungszentrum Jülich
in der Helmholtz-Gemeinschaft

Momentum MeV/c	Kinetic energy MeV	Imperfection resonance $\gamma \cdot G = \ldots$	Intrinsic resonance $\gamma \cdot G = \ldots \pm Q_y$
463.9	108.4	2	
781.2	282.7		6-
1033.3	457.5		-1+
1258.8	631.7	3	
1470.4	806.0		7-
1674.1	980.8		0+
1871.3	1155.1	4	
2064.4	1329.4		8-
2255.0	1504.1		1+
2442.7	1678.4	5	
2628.5	1852.7		9-
2813.4	2027.5		2+
2996.6	2201.8	6	
3178.7	2376.0		10-
3360.6	2550.8		3+

Spin Resonance Crossing

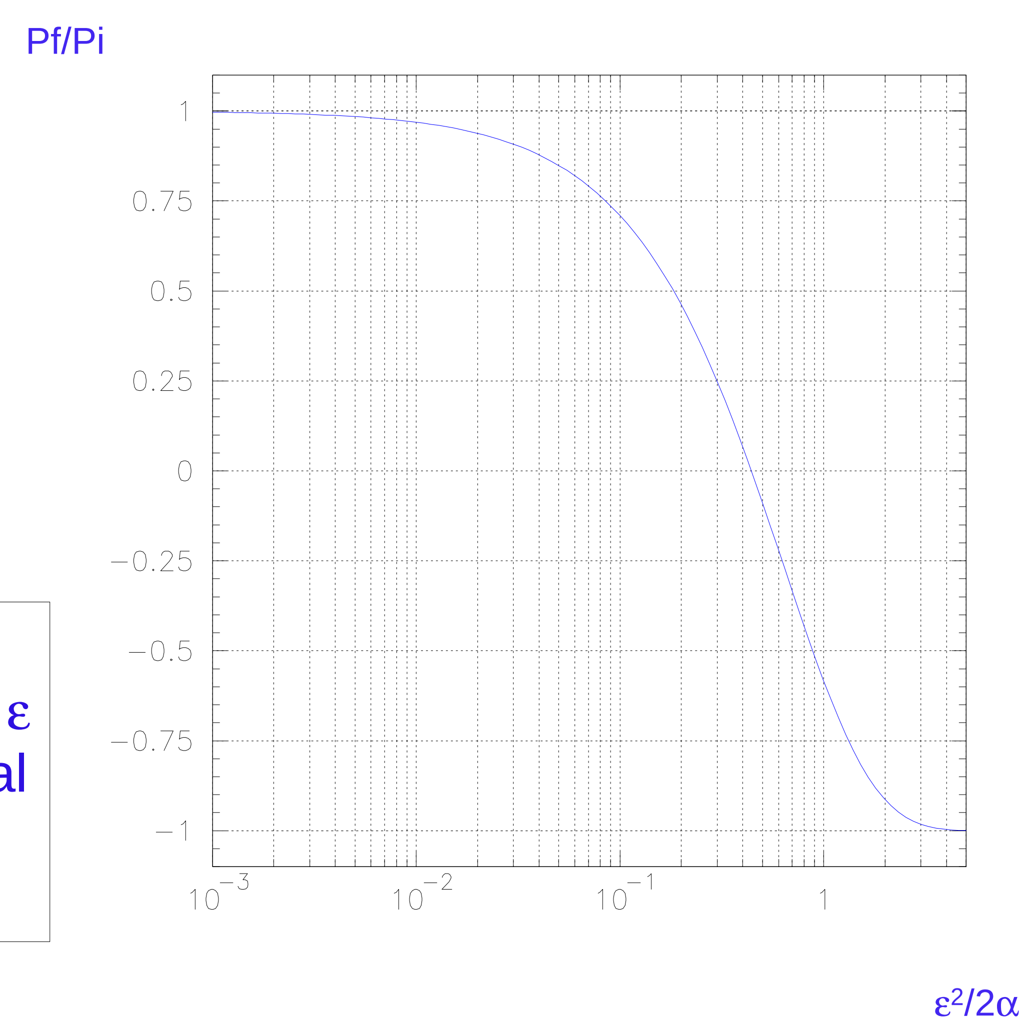
Forschungszentrum Jülich
in der Helmholtz-Gemeinschaft

Crossing of a single resonance is described by Froissart-Stora equation:

$P_f = P_i\,(2\exp(-\pi\varepsilon^2/2\alpha)-1)$

P_f: final polarization
P_i: initial polarization
ε: resonance strength
$\alpha=(\Delta\gamma G + \Delta\nu_y)$: crossing speed

Compensation methods:
- Increase resonance strenghth ε
⇒Complete polarization reversal
- Increase crossing speed α
⇒Polarization preservation



Spin Resonance Crossing

Forschungszentrum Jülich in der Helmholtz-Gemeinschaft

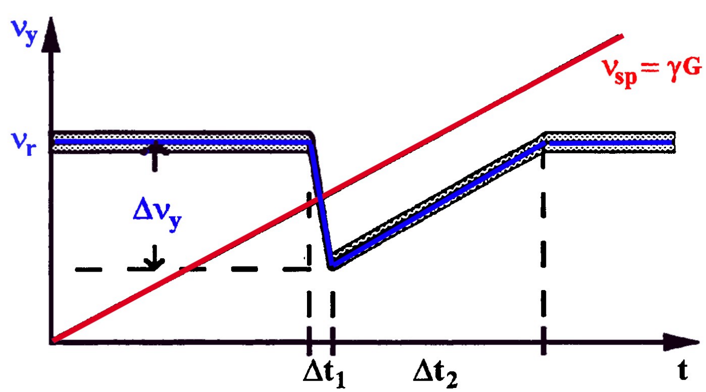
Methods:

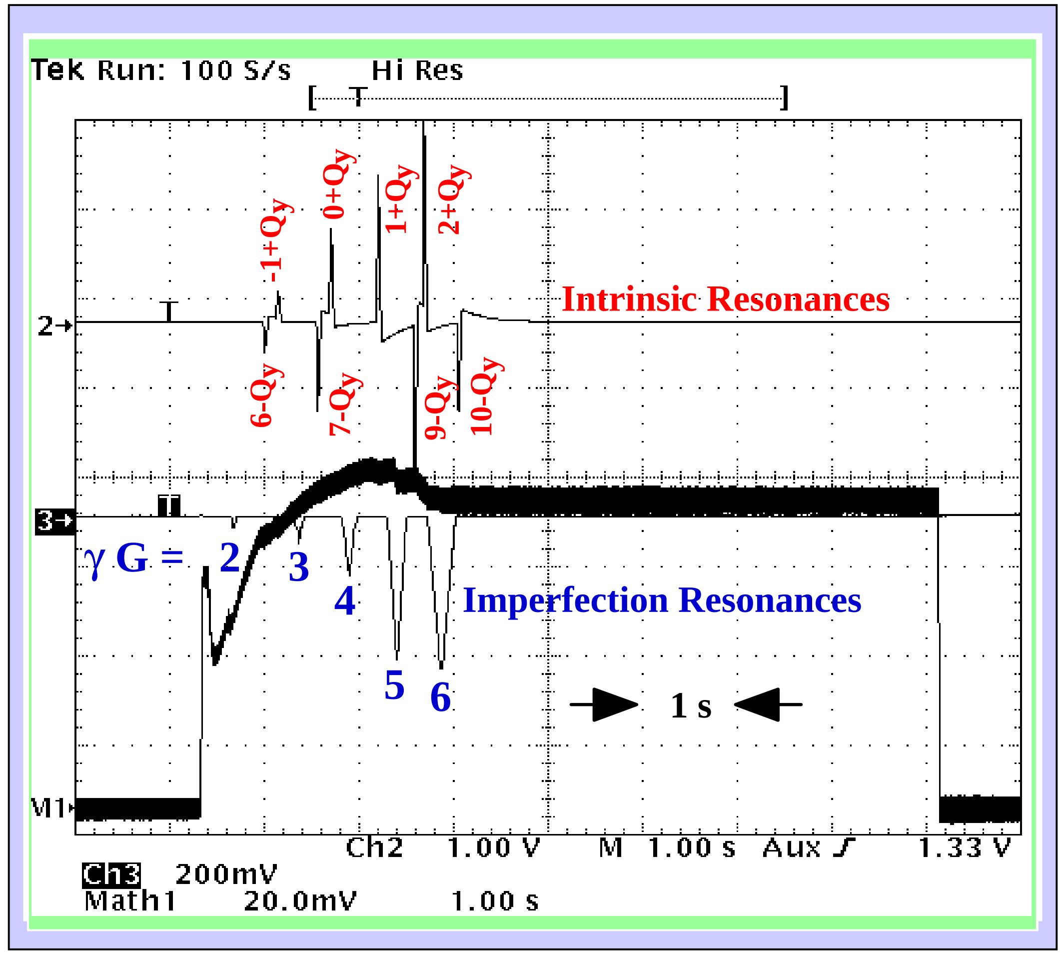
- **vertical orbit distortion**

=> larger horizontal fields and thus increased resonance strength

- **fast tune jump**

=> increased crossing speed





Polarization Measurement

<u>cross section with polarized beam and unpolarized target:</u>

$\sigma = \sigma_0 (1 + P_y A_y \mathrm{Cos}(\phi))$

P_y : beam polarization

A_y : analyzing power

Beam polarization in a planar ring is vertical (without special measures)

=>left right asymmetrie measurements

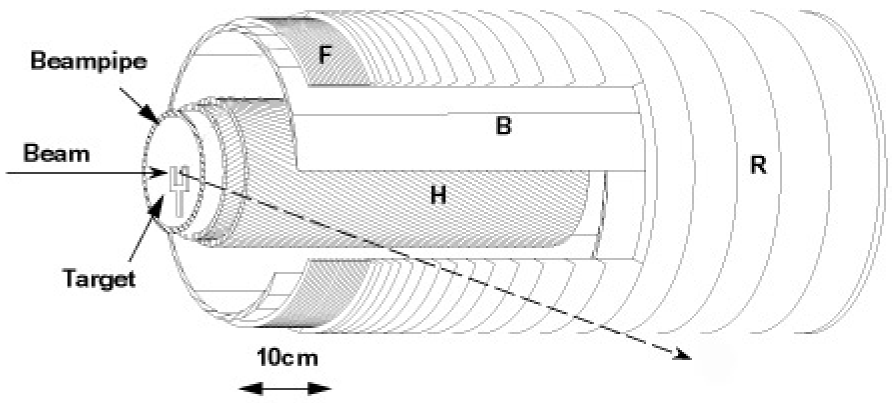
<u>Important for polarization development:</u>

Measurement during the acceleration cycle of COSY (requires good statistics with high time resolution)

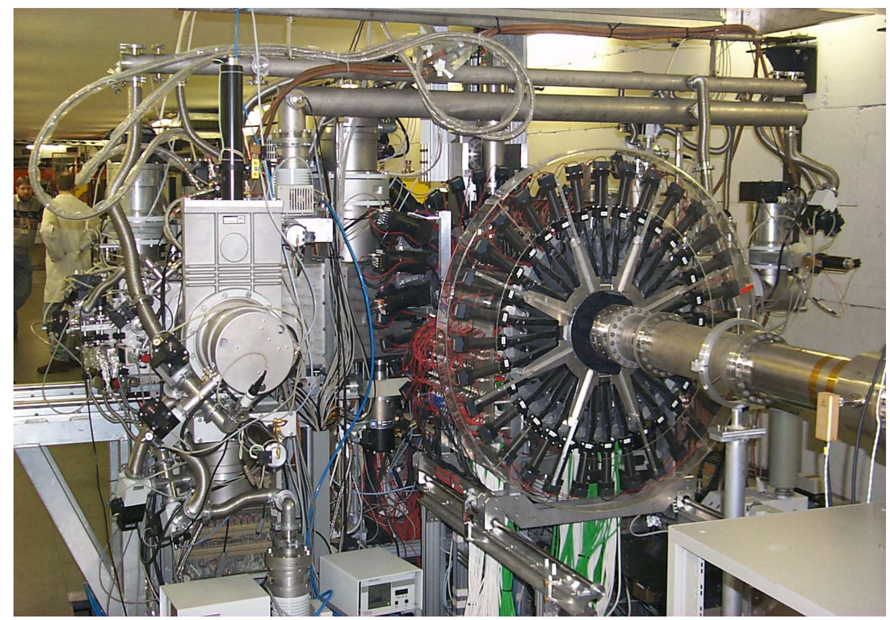
⇒Possible with EDDA experimental setup

EDDA Polarimeter

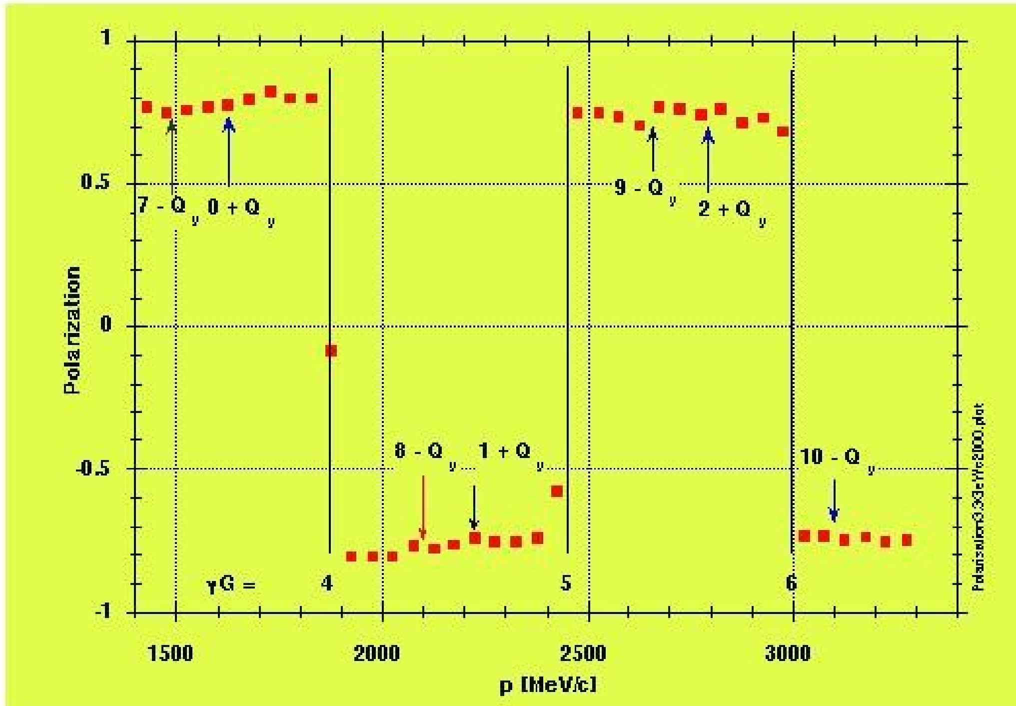
Forschungszentrum Jülich
in der Helmholtz-Gemeinschaft



- 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.



Status of the Polarized Proton Beam



- Internally up to 3.3 GeV/c
  - up to 10^{10} protons
  - > 75% polarization
- Externally at 1.4 GeV/c
  - 10^{8} protons/s
  - 80% polarization

Electron Cooling and Polarization

Forschungszentrum Jülich
in der Helmholtz-Gemeinschaft

- External Experiments: increased phase space density and reduced beamsize => small beamspot, low halo (even after acceleration and extraction).
- Internal experiments: reduced beamsize allows Stacking Injection => increase in beam intensity.

Electron Cooling and Polarization

Forschungszentrum Jülich
in der Helmholtz-Gemeinschaft

The small emittance of the electron-cooled proton beam reduced the influence of the weaker resonances:

Below the momentum of the 8^--resonance we achieved

P > 90%.

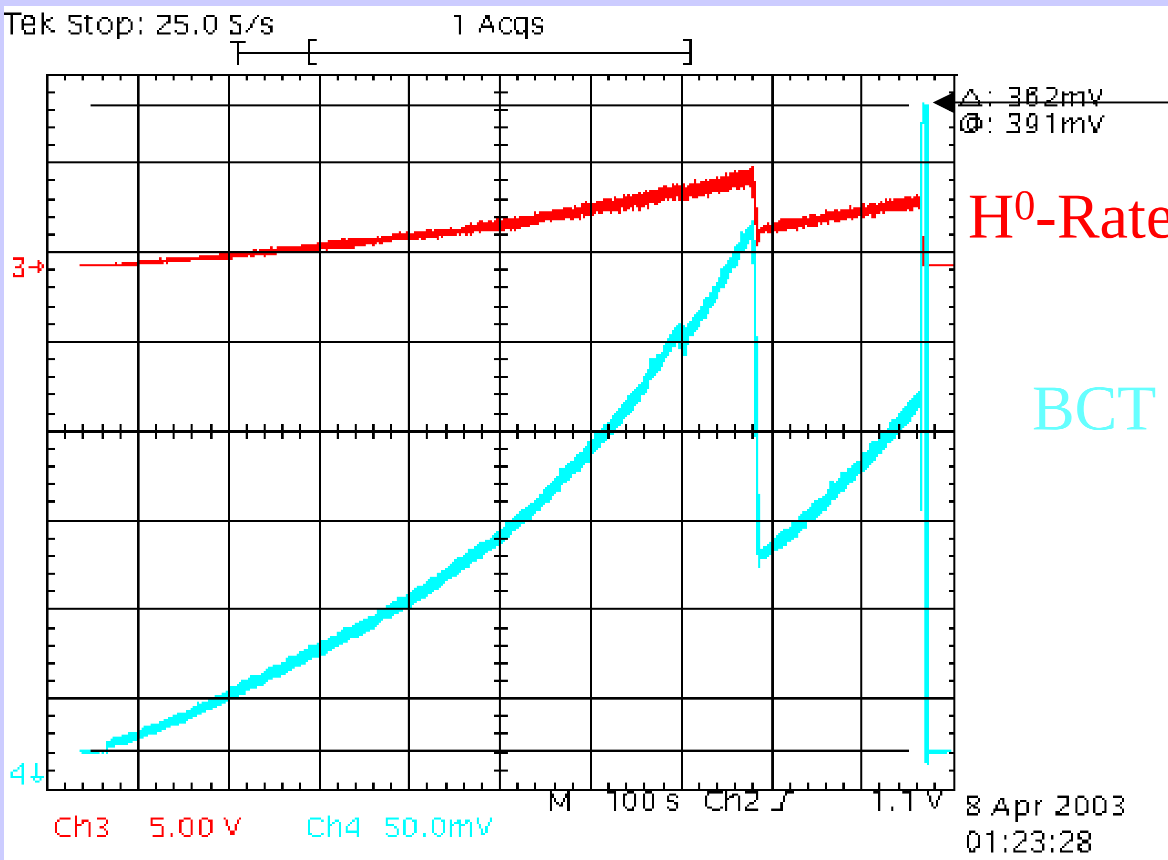
However:

The electron Cooler Solenoids cause coupling of horizontal and vertical phase space. This enhances higher order resonance, and coupling between 8-Qx and 8-Qy:

Above the momentum of the 8^--resonance we achieved only low Polarization ($P < 40$ %).

With enough development time, the Polarization loss at the 8- can be cured by carefull adjustment of tunes.

Stacking of polarised beam (interesting for internal experiments)



$2*10^{10}$ protons

500 Injections every 2 seconds

Protons ←→ Deuterons

Forschungszentrum Jülich
in der Helmholtz-Gemeinschaft

- **Polarization states:** (2S+1) → 3 states for Spin 1
- **Vector polarization:** $P_z = (n_+ - n_-) / (n_+ + n_- + n_0)$ $P_z^{max} = \pm 1$
- **Tensor polarization:** $P_{zz} = (1 - 3n_0) / (n_+ + n_- + n_0)$ $P_{zz}^{max} = 1, -2$
- **Gyro magnetic anomaly:** $G_p / G_d = -12.6$
- **Spin tune:** $\gamma_p G_p / \gamma_d G_d = -25.2$
- **Spin resonances:** 13 (low energies) to 25 (high energies) times weaker
  25 times further apart
- **Isolated resonance crossing:** different for vector and tensor polarization
- **Theoretically:**
  H. Huang, S.Y. Lee, L. Ratner, Transfer matrices of spin tensor polarization with and without snake, Proc. of Part. Acc. Conf. p.432, (1993)
- **Experimentally:**
  V. S. Morozov , Spin Flipping and Polarization Lifetimes of a 270 MeV Deuteron Beam, Contribution SPIN2002

Low Energy Polarimeter Polarizations

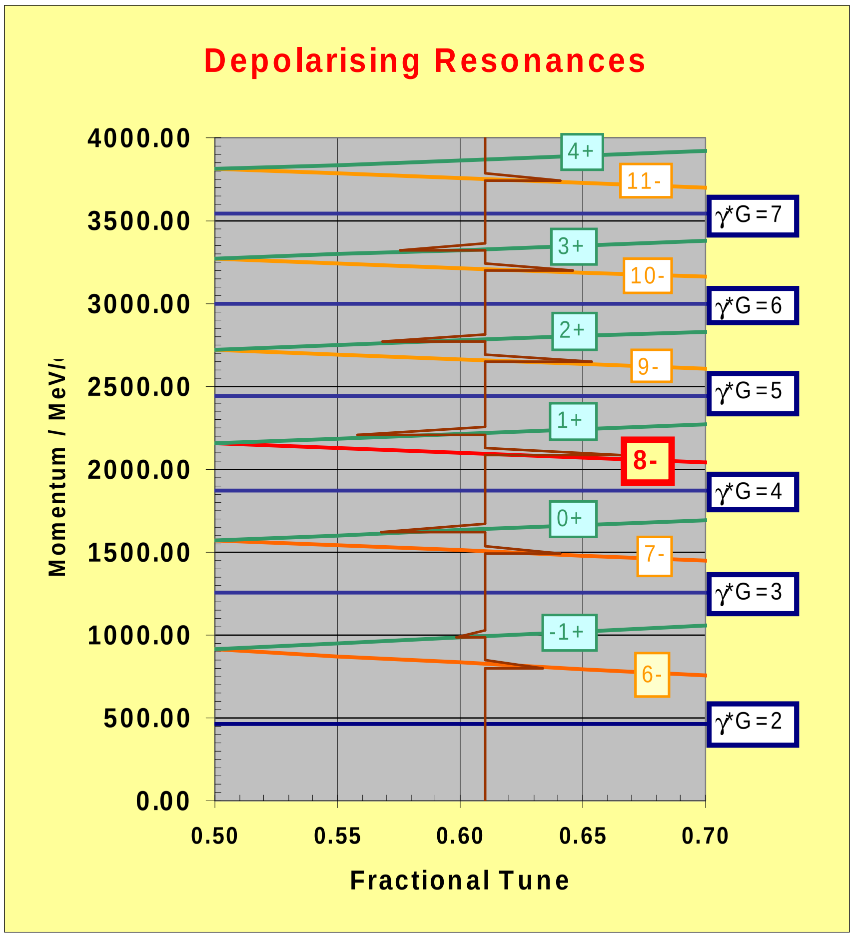
Forschungszentrum Jülich
in der Helmholtz-Gemeinschaft

	Mode	P_z	P_{zz}	RFT1	RFT2	RFT3	P_z Measured ΔP=±0,01±0,05
→	0	0	0	off	off	off	0
→	1	-2/3	0	off	off	5 MHz	-0.46
	2	+1/3	+1	off	415 MHz	off	0.15
→	3	-1/3	-1	off	415 MHz	5MHz	-0.35
	4	+1/2	-1/2	314 MHz	off	off	0.36
→	5	-1	+1	314 MHz	off	5 MHz	-0.70
→	6	+1	+1	314 MHz	415 MHz	off	0.57
	7	-1/2	-1/2	314 MHz	415 MHz	5MHz	-0.52

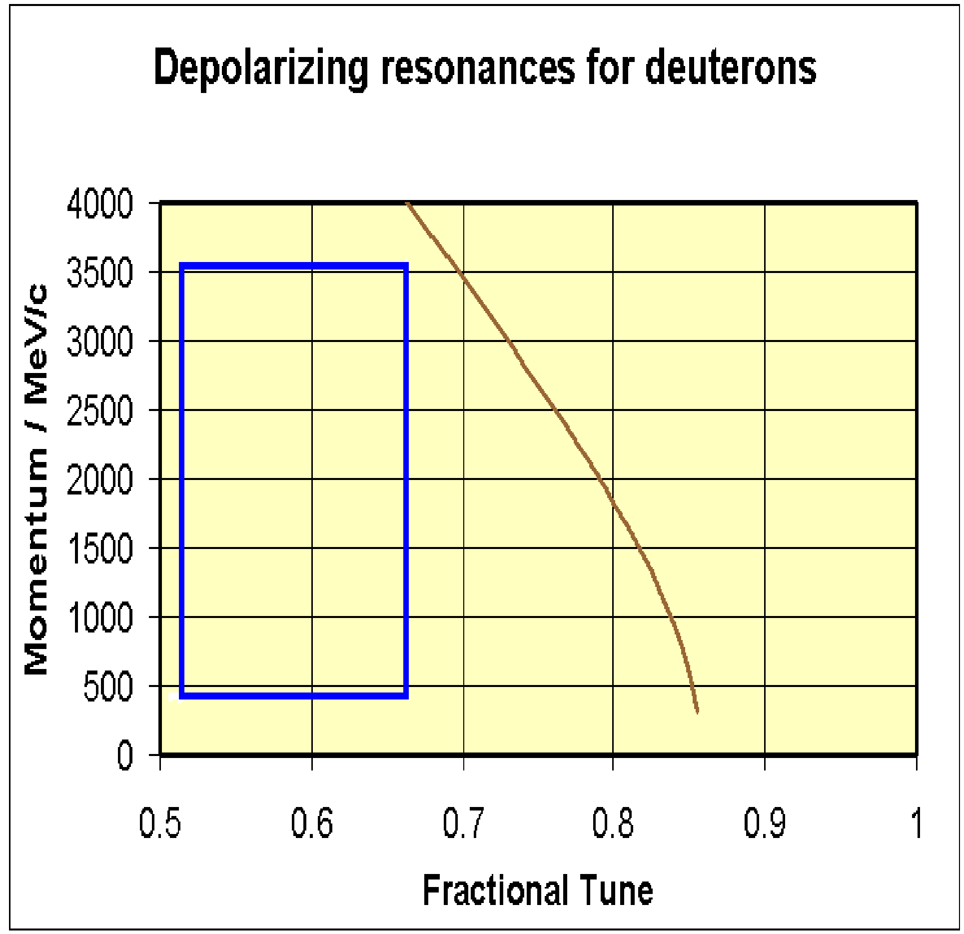
Proton and Deuteron Spin Resonances

Forschungszentrum Jülich
in der Helmholtz-Gemeinschaft

Protons
G=1.792847



Deuterons
G=-0.14265618



Deuteron Polarimetry with EDDA

Forschungszentrum Jülich
in der Helmholtz-Gemeinschaft

- Known Vector and Tensor Analyzing Powers in d+p elastic scattering @ Td = 270 MeV (p=1042 MeV/c) Sekiguchi et al PRC 65, 34003 (2002)
- Measurements with CH2 target with event ID.
- Measurements with C target for background subtraction.

=> check of beampolarization

(Calibration was also exported to two other beam momenta, i.e. 1850 MeV/c and 2400 MeV/c)

Spin@COSY:

Spin-Flipping Polarized Protons and Deuterons at COSY

Forschungszentrum Jülich
in der Helmholtz-Gemeinschaft

A.D. Krisch, V.S. Morozov, R.S. Raymond, V.K. Wong, K. Yonehara

Spin Physics Center, University of Michigan

Ann Arbor, MI 48109-1120, USA

U. Bechstedt, R. Gebel, A. Lehrach, B. Lorentz, R. Maier
D. Prasuhn, A. Schnase, H. Stockhorst

Institut für Kernphysik,Forschungszentrum Jülich

Postfach 1913, 52425 Jülich, Germany

D. Eversheim, F. Hinterberger, H. Rohdjess, K. Ulbrich

Helmholtz Institut für Strahlen- und Kernphysik, Universität Bonn

Nussallee 14-16, 53115 Bonn, Germany

W. Scobel

Institut für Experimentalphysik, Universität Hamburg

Luruper Chaussee 149, 22761 Hamburg, Germany

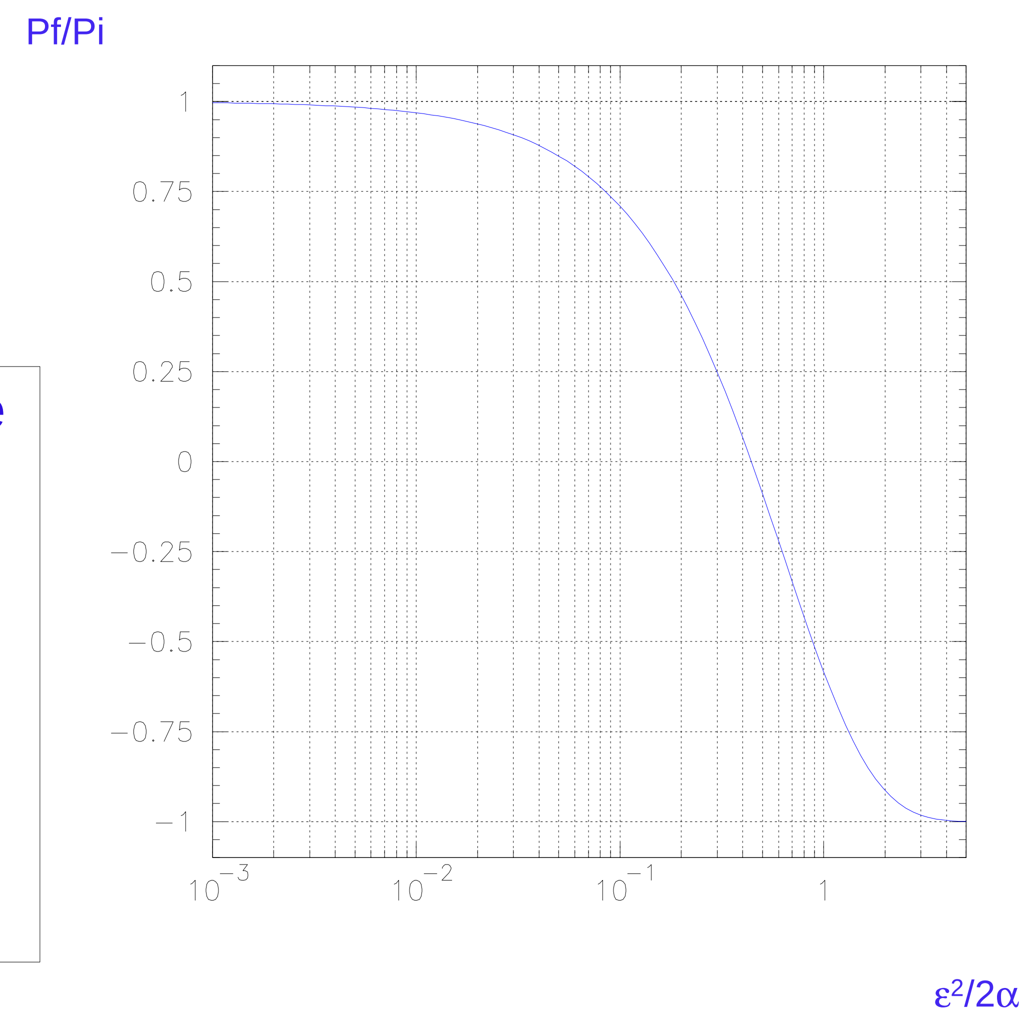
Spin Flipping by Resonance Crossing

Forschungszentrum Jülich
in der Helmholtz-Gemeinschaft

A Spin perturbing horizontal rf-field induces an artificial depolarizing resonance:
$f_{res} = f_0(n +/- \gamma G)$

Crossing of a single resonance is described by Froissart-Stora equation:
$P_f = P_i\,(2 \exp(-\pi\varepsilon^2/2\alpha)-1)$

P_f: final polarization
P_i: initial polarization
ε: resonance strength
α: crossing speed



Spin flipping polarized protons

Forschungszentrum Jülich
in der Helmholtz-Gemeinschaft

Resonance search

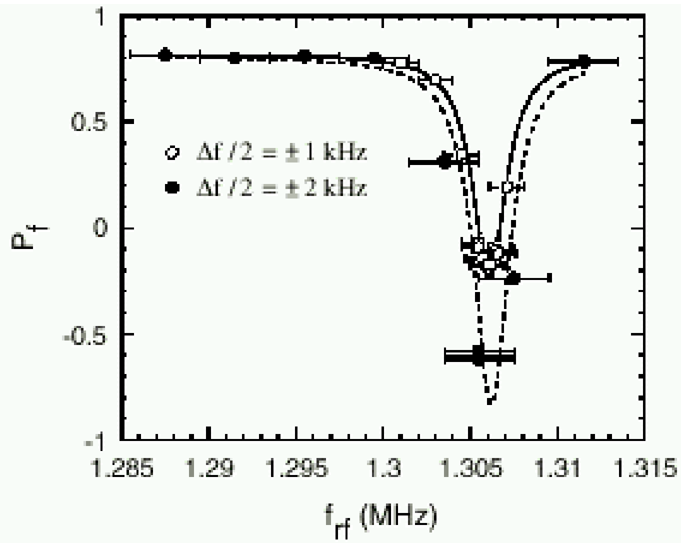


FIG. 2. The measured proton polarization at 1.941 GeV/c is plotted against the central frequency of each ramp; each ramp's Δf range is shown by a horizontal bar. The rf dipole's $\int B_{rms} dl$ was 0.11 T mm; its Δt was 10 s. The curve is a fit using a first-order Lorentzian.

Polarization versus ramptime

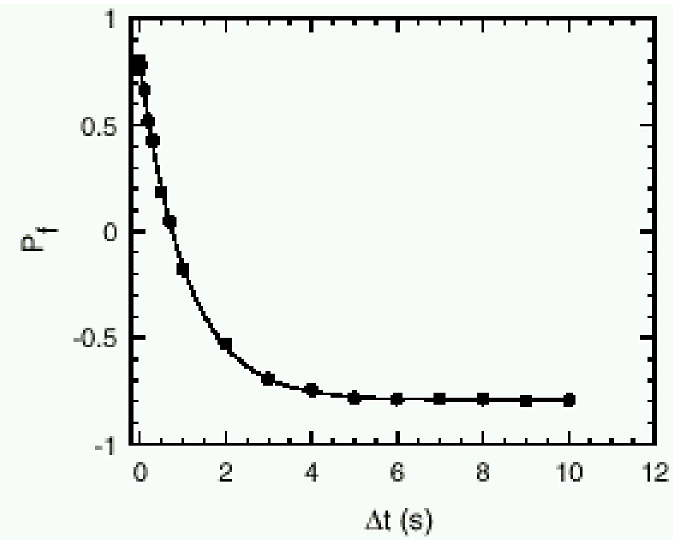


FIG. 3. The measured proton polarization at 1.941 GeV/c is plotted against the rf-dipole ramp time Δt. The rf-dipole's frequency half range $\Delta f/2$ was 5 kHz, and its $\int B_{rms} dl$ was 0.11 T mm. The curve is a fit using Eq. (6).

→ V.S Morozov et al., Phys. Rev. ST Accel. Beams 7, 024002 (2004)

Spin flipping polarized protons

Polarization after 11 flips

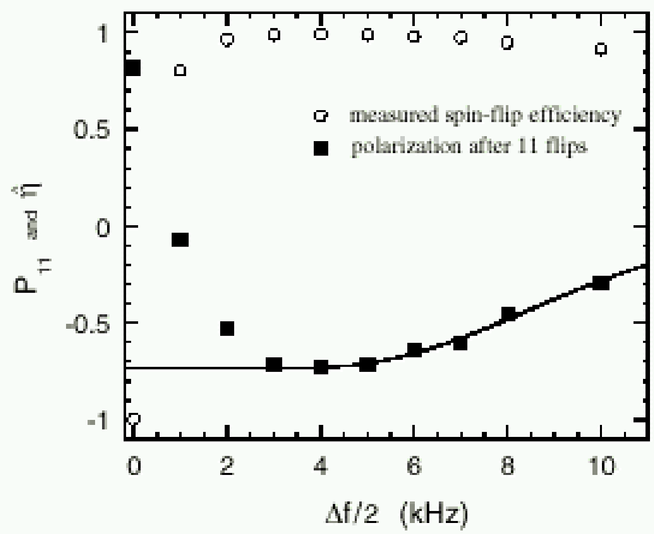


FIG. 4. The measured proton polarization at 1.941 GeV/c after 11 spin flips is plotted against the rf-dipole's frequency half range $\Delta f/2$. The rf-dipole's ramp time Δt was 7.5 s, and its $\int B_{rms} dl$ was 0.11 T mm. The curve is a fit to Eq. (8). Also shown is the measured spin-flip efficiency $\hat{\eta}$ for each Δf obtained using Eq. (7) to take the 11th root of the measured ratio $-P_{11}/P_i$.

Multiple Flipping to determine efficiency

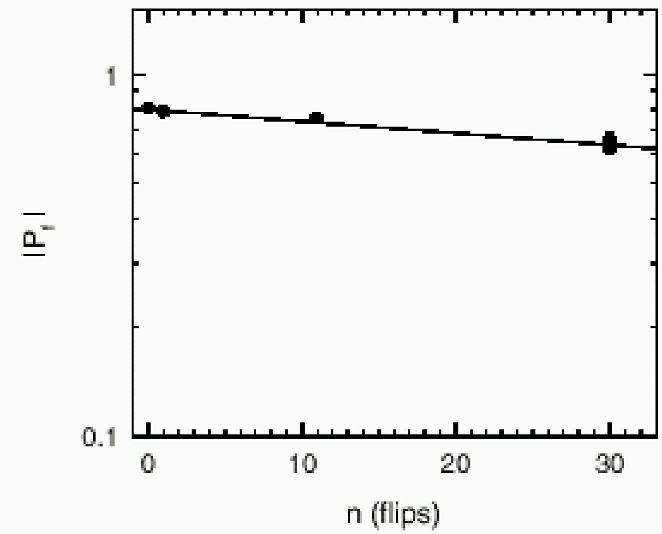


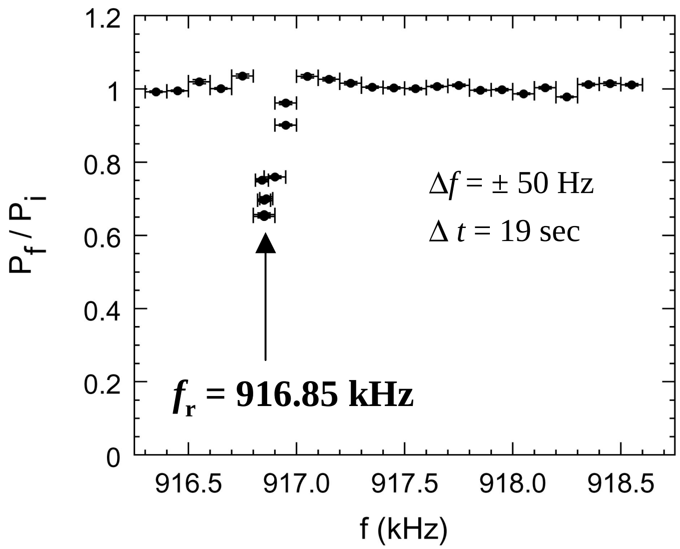
FIG. 5. The measured proton polarization at 1.941 GeV/c is plotted against the number of spin flips. The rf-dipole's frequency ramp time Δt was 10 s; its frequency half range $\Delta f/2$ was 4 kHz, and its $\int B_{rms} dl$ was 0.11 T mm. The line is a fit using Eq. (7).

Flipping Efficiency: 99.3 +/- 0.1 %

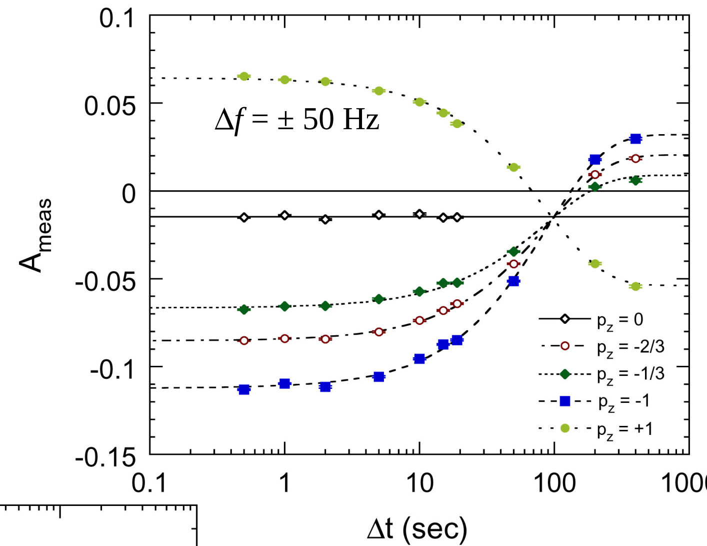
→ V.S Morozov et al., Phys. Rev. ST Accel. Beams 7, 024002 (2004)

Spin-flipping of Polarized Deuteron Beam

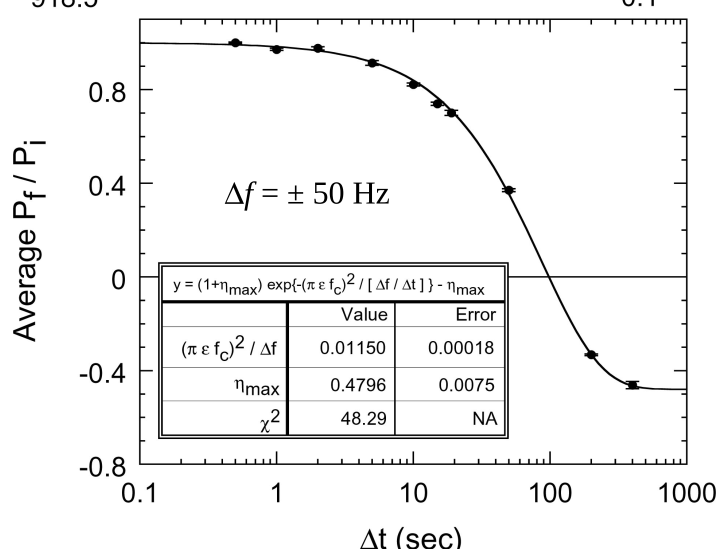
Resonance frequency search



Measured Asymmetry vs Δ t



Average P_f / P_i vs Δ t



1.85 GeV/c

$\int B \cdot dl$ = 0.11 T·mm

→ deuteron spin-flip efficiency 48 ± 2 %

→ K.Yonehara et al, AIP Conf. Proc. 698, 763 (2003)

Summary: Achieved Beam Intensities

Forschungszentrum Jülich
in der Helmholtz-Gemeinschaft

Unpolarized Protons

- Without electron cooling
  $1.4*10^{11}$
- With electron cooling
  $1.5*10^{10}$
- With electron cooling and stacking
  $5.0*10^{10}$

Unpolarized Deuterons

- Without electron cooling
  $1.3*10^{11}$
- With electron cooling
  $4*10^{10}$

Polarized Protons

- Without electron cooling
  $\leq 1.0*10^{10}$
- With electron cooling
  $1.2*10^{9}$
- With electron cooling and stacking
  $1.2*10^{10}$

Polarized Deuterons

- Without electron cooling
  $6*10^{9}$