Beam Induced Depolarization in the HERMES Transversely Polarized Hydrogen Target

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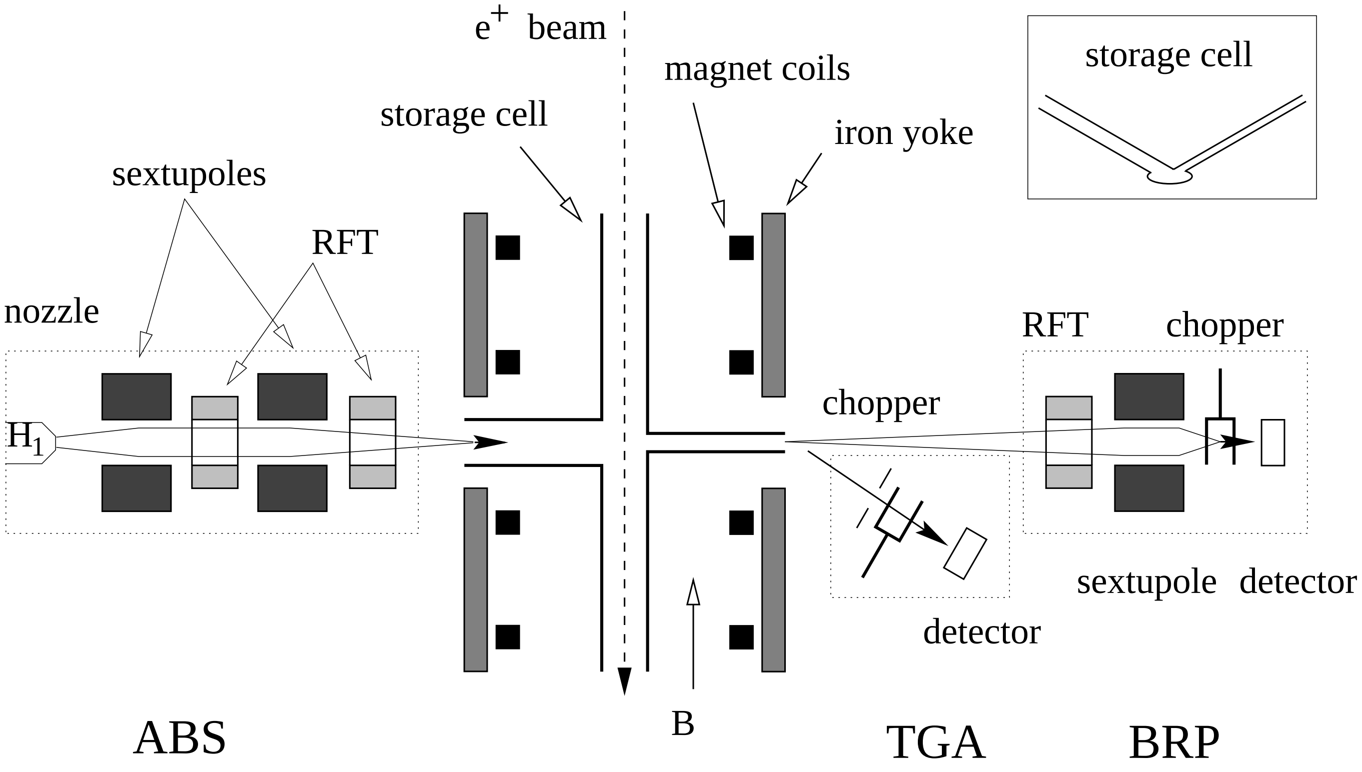
Outline:

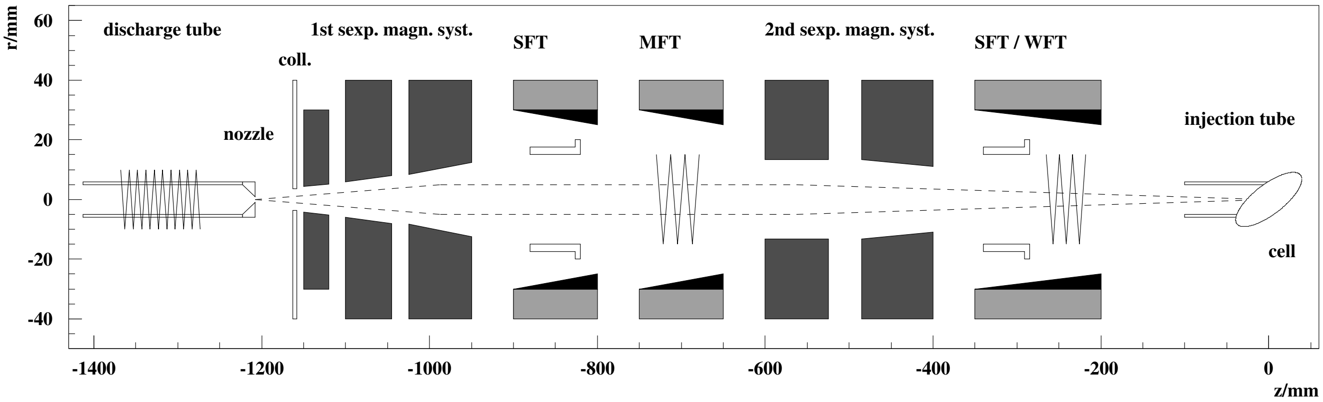
- The HERMES Target
- The Transverse Magnet Design
- Beam Induced Depolarization Measurements
- Summary

The HERMES Polarized Target



- 1996 - 2000: Longitudinal Polarization (Hydrogen/Deuterium)
- Since 2002: Transverse Polarization (Hydrogen)

The Atomic Beam Source (ABS)



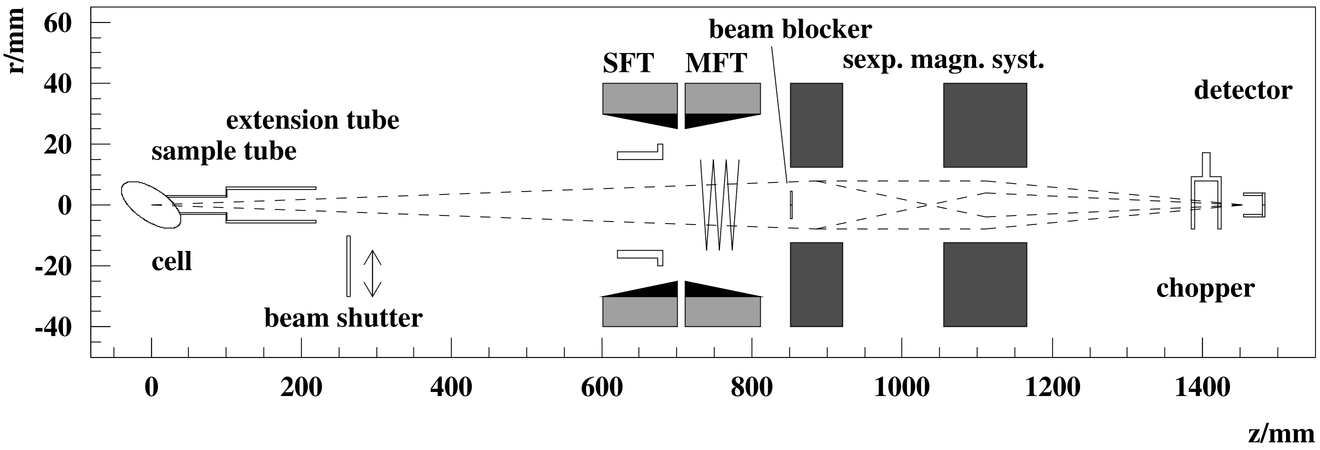
- Dissociator: from molecules to atoms
  - Air-cooled RF dissociator with $\approx$ 85% degree of dissociation at 90 sccm
  - Small amount of O_2 (0.15 sccm) improves discharge properties
- Sextupole Sytem: focus atoms with $m_s = +\frac{1}{2}$
  - 5 (tapered) magnets in a 3 magnet and a 2 magnet subsytem
- RF Transitions: HF states occupation exchange

Two injected hyperfine states during data taking

Example: Hydrogen Nuclear Polarization P_z+

$$\begin{pmatrix} n_1 \\ n_2 \\ n_3 \\ n_4 \end{pmatrix} \xrightarrow[6pole]{} \begin{pmatrix} n_1 \\ n_2 \\ 0 \\ 0 \end{pmatrix} \xrightarrow[SFT\,2-4]{} \begin{pmatrix} n_1 \\ 0 \\ 0 \\ n_2 \end{pmatrix}$$

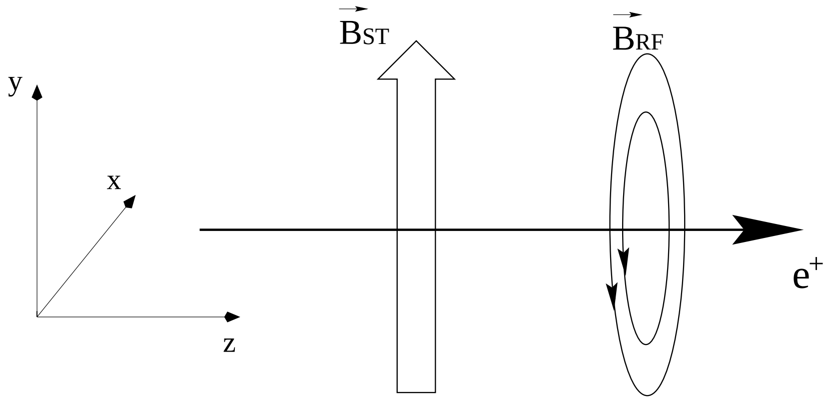
The Breit–Rabi Polarimeter (BRP)



- Task
  - Measure the polarization of sample beam
- Measurement
  - Use of chopper to subtract background
  - Measurements with different HFT modes:
    $\Rightarrow$ linear equations system, solution for N_i
- Calibration
  - $N_{\text{sig}} > N_{\text{hfs}}$ $\Rightarrow$ system overdetermined
    $\Rightarrow$ RFT efficiencies can be measured
- Performance
  - Mininum time for polarization measurement $\approx 30\ s$
  - Statistical uncertainty < 0.005
  - Systematic uncertainty ≤ 0.01

Transverse Target: the Basic Idea

From July 2001 $\rightarrow$ Transverse Polarized Target (H)



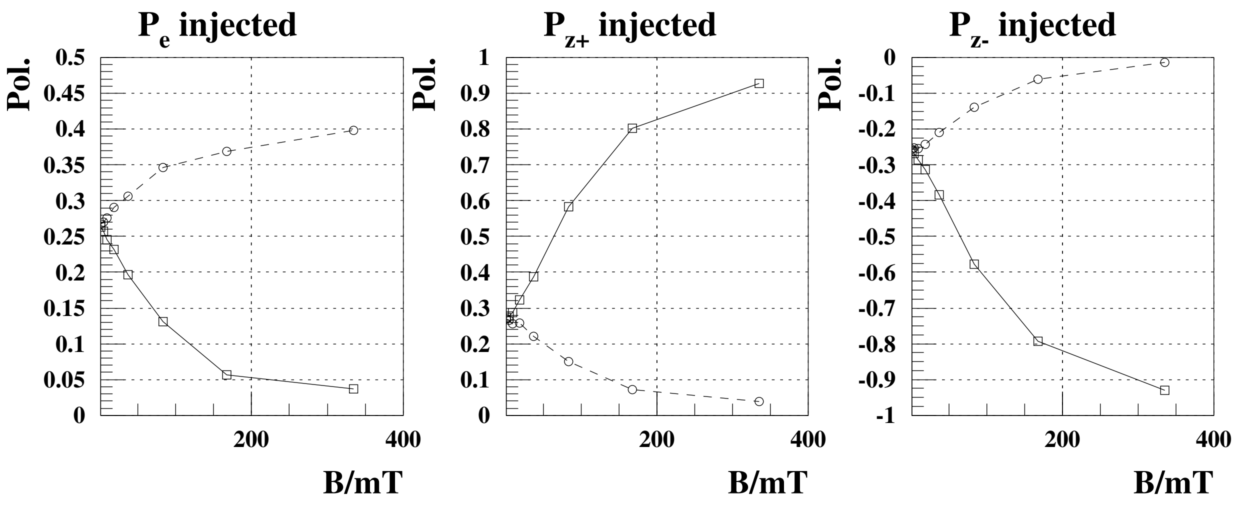
New Target Holding Field

Drawbacks and Solutions:

- Bending of the electron beam:
  Orbit compensation
- Synchrotron radiation emission:
  Avoid the spectrometer acceptance
- Possible beam induced nuclear depolarization:
  Conceive a holding field which minimizes this effect

The Magnet Design

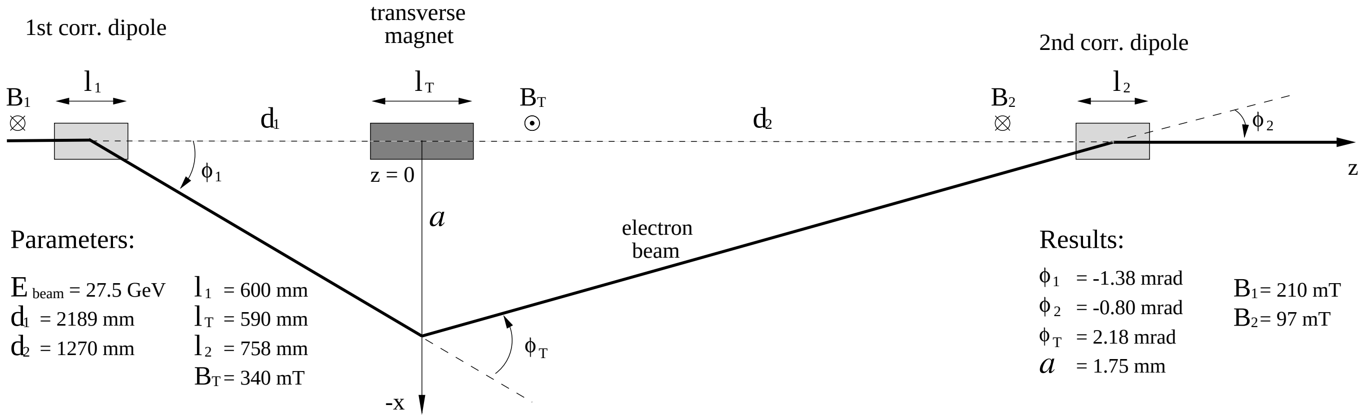
- Conventional static vertical dipole
- $B_T > 280$ mT to inhibit spin relaxation



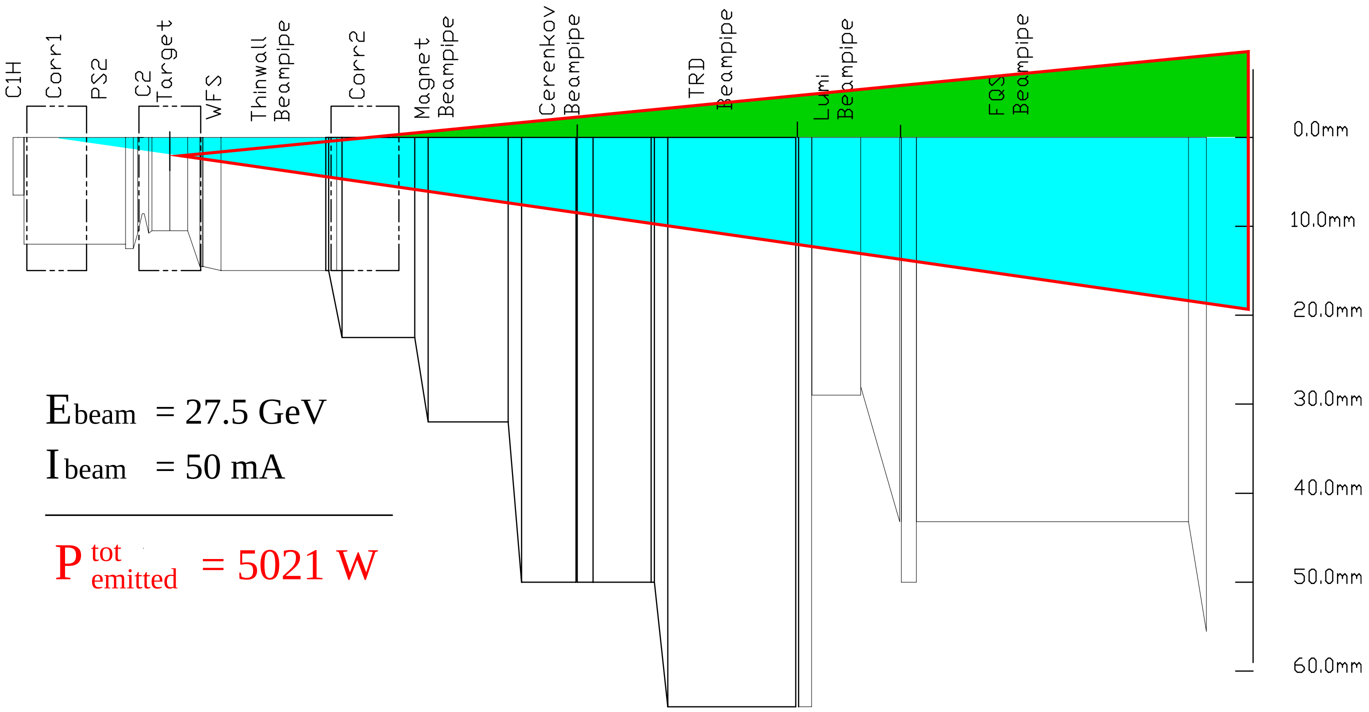
- $B_T < 400$ mT to minimize synchrotron radiaton
- $\Delta B < 0.15$ mT overall the cell region ($400 * 20 * 10$ mm), to avoid beam induced depolarization
- Dimensional constraints:
  pole length < 650 mm
  pole width < 200 mm

The Effects on the HERA Beam

Bending ($B_T = 340\,\mathrm{mT}$):



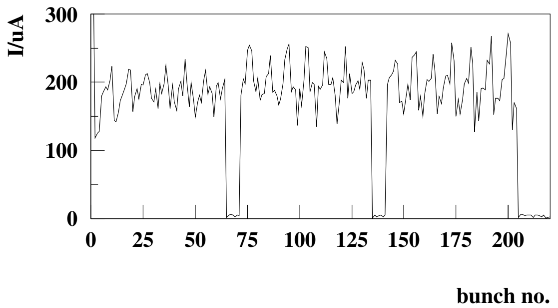
Synchrotron radiation ($B_T = 340\,\mathrm{mT}$):



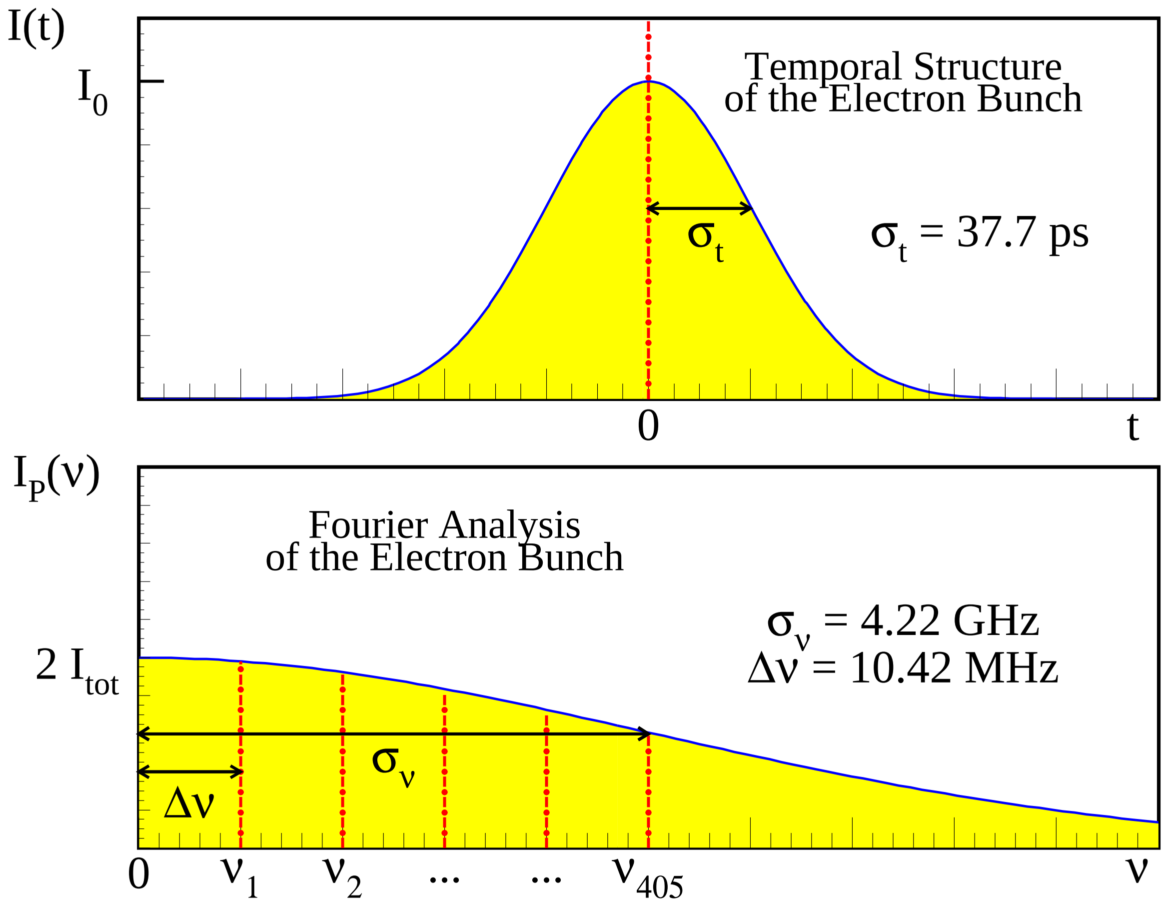
Depolarization by Beam Interaction

HERA e-beam structure:

- 220 Bunches
- Spacing: $\Delta t = 96\,ns$
- Bunch width: $\sigma_t = 37.7\,ps$



Fourier Analysis of the electron bunch:



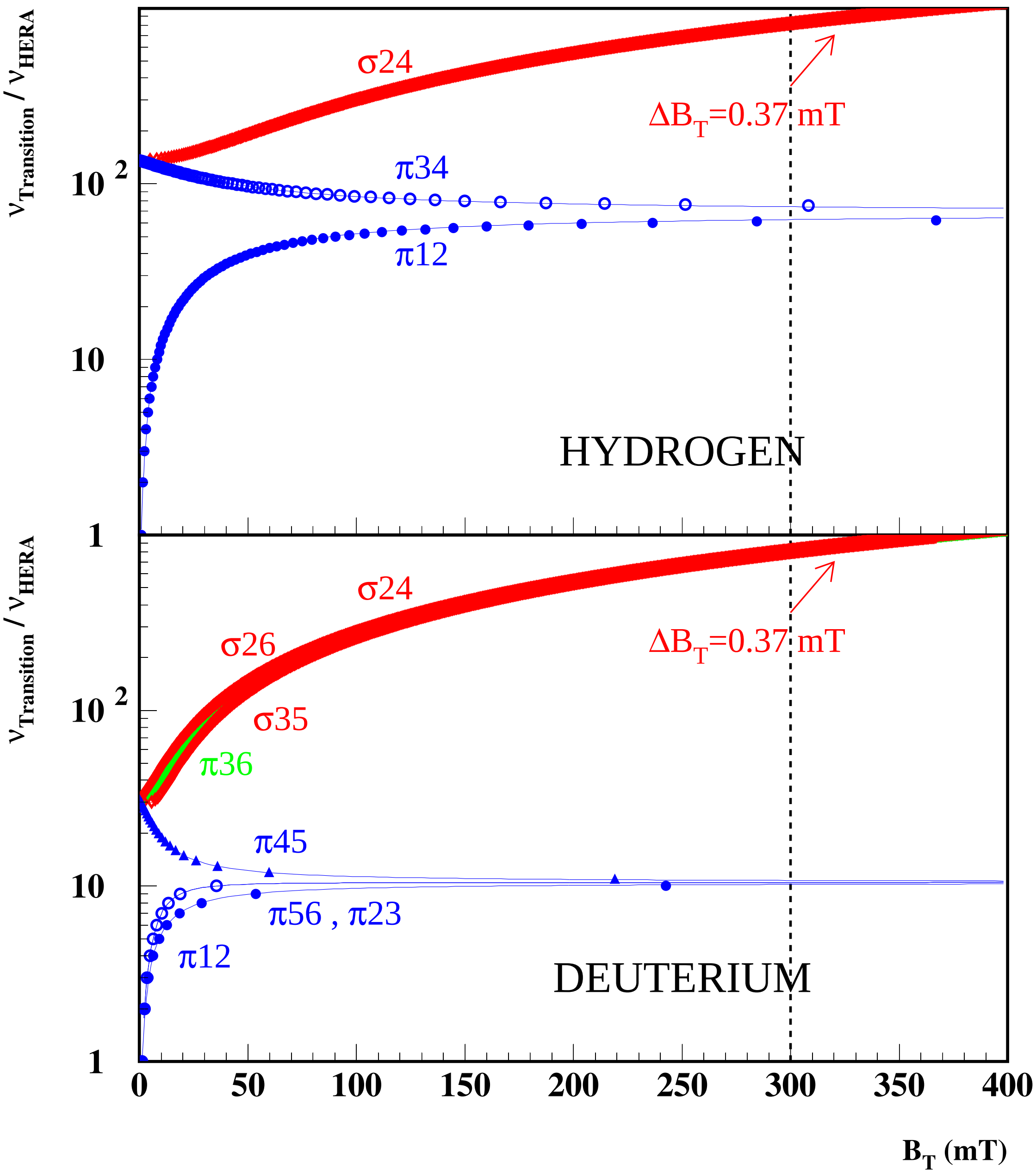
Resonance Conditions: $\frac{|E_i - E_f|}{h} = \nu_n \qquad n = 1, 2, \ldots$

$\Rightarrow$ Depolarization!

Resonance Conditions (Nucl. Trans.)

$$|E_i - E_f|/h = \nu_n \qquad n = 1, 2, \ldots$$

But... ΔE_{if} depends on B_{ST}!



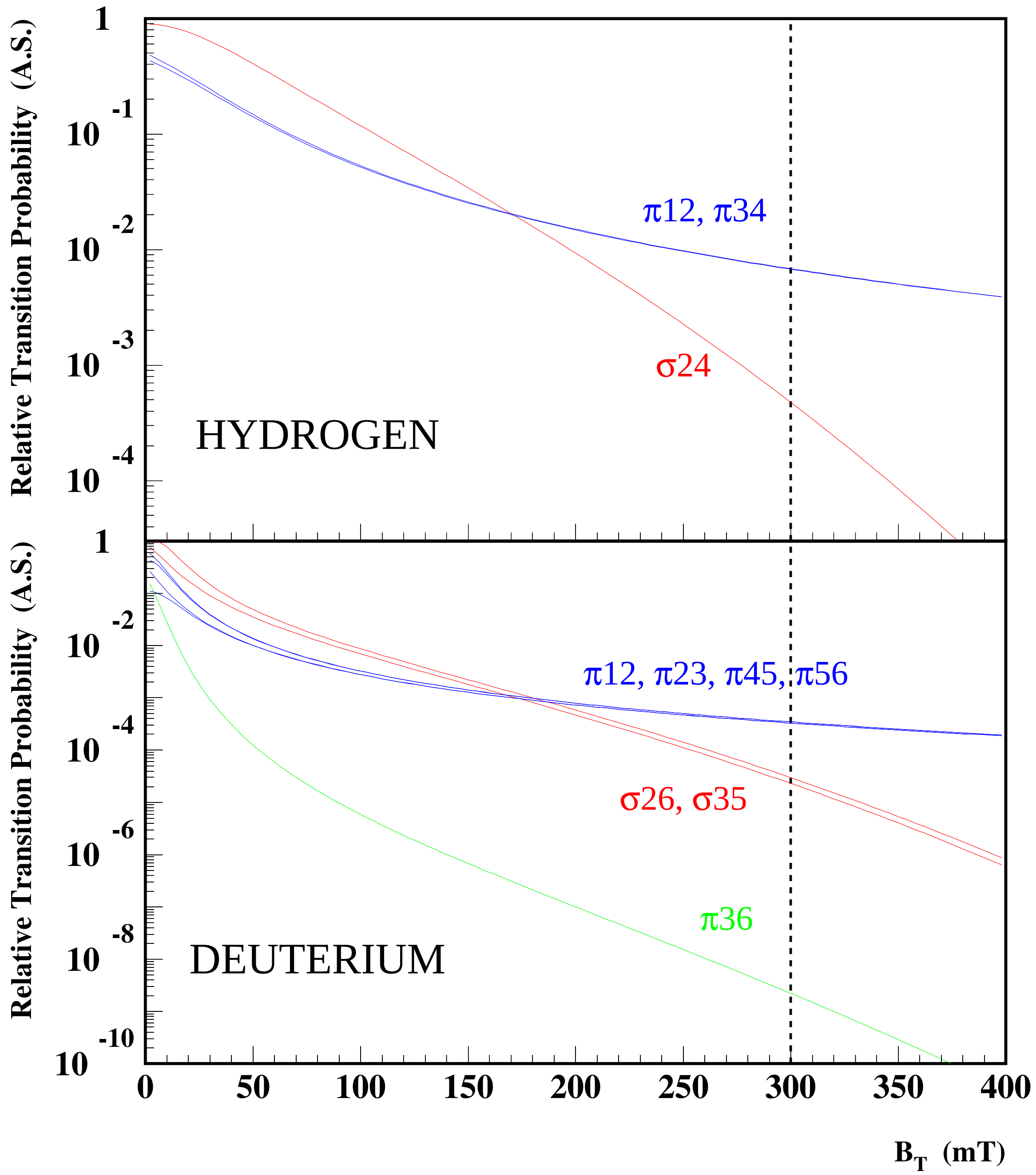
- π-transitions ($B_{ST} \perp B_{RF}$) $\Rightarrow$ Long. & Trans. Target
- σ-transitions ($B_{ST} \parallel B_{RF}$) $\Rightarrow$ Trans. Target Only!

Relative Transition Probabilities

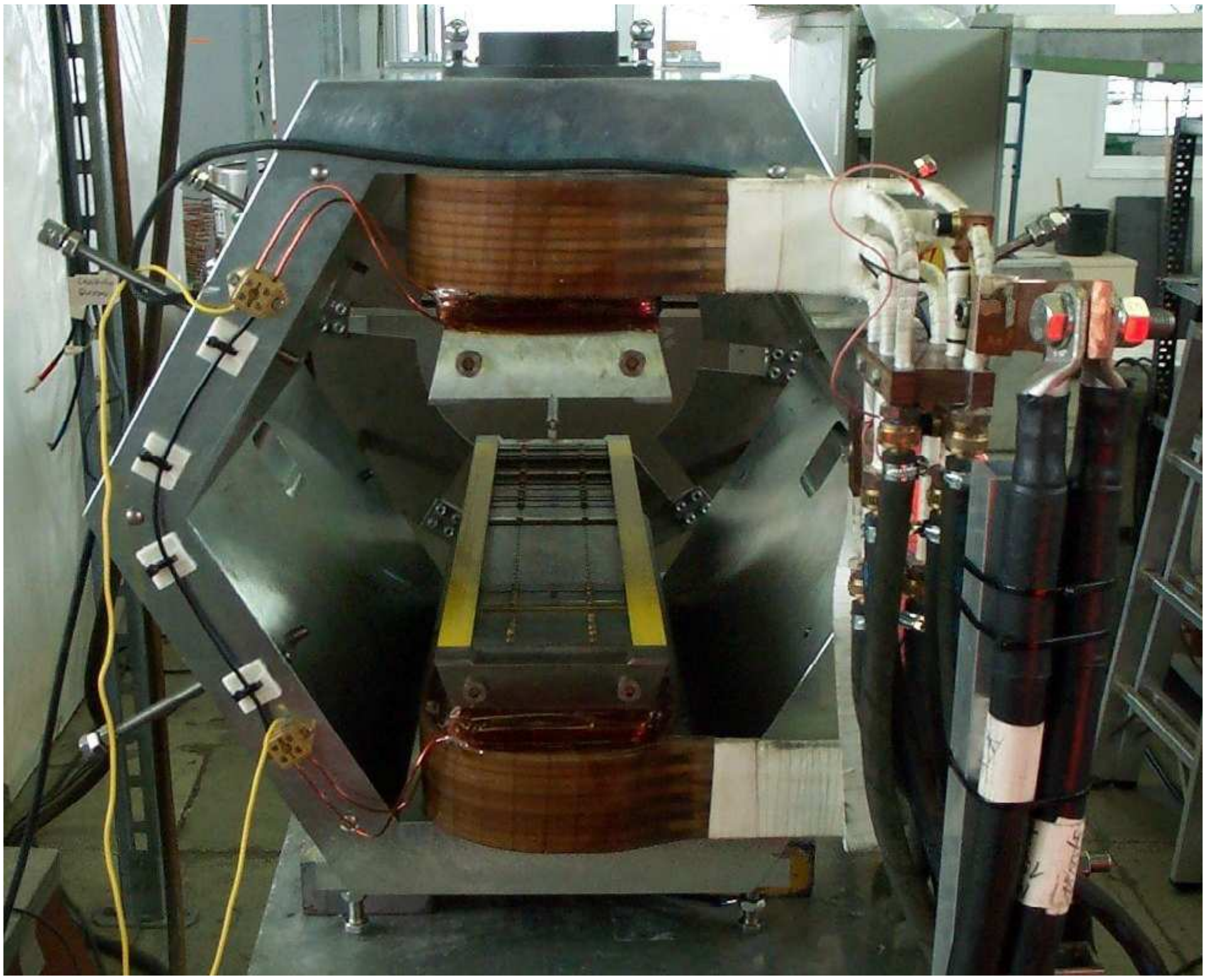
$$W_{if} \propto B_{RF}^2 \cdot |V_{if}|^2 \cdot \tau^2$$

- B_{RF} depends on the harmonic number
- The harmonic number depends on B_{ST}

Fixing τ and evaluating $|V_{if}|^2 \quad \Rightarrow \quad W_{if}$ vs B_{ST}:



The Transverse Magnet



- Field intensity: $B_T = 297\,$mT @ 545 A

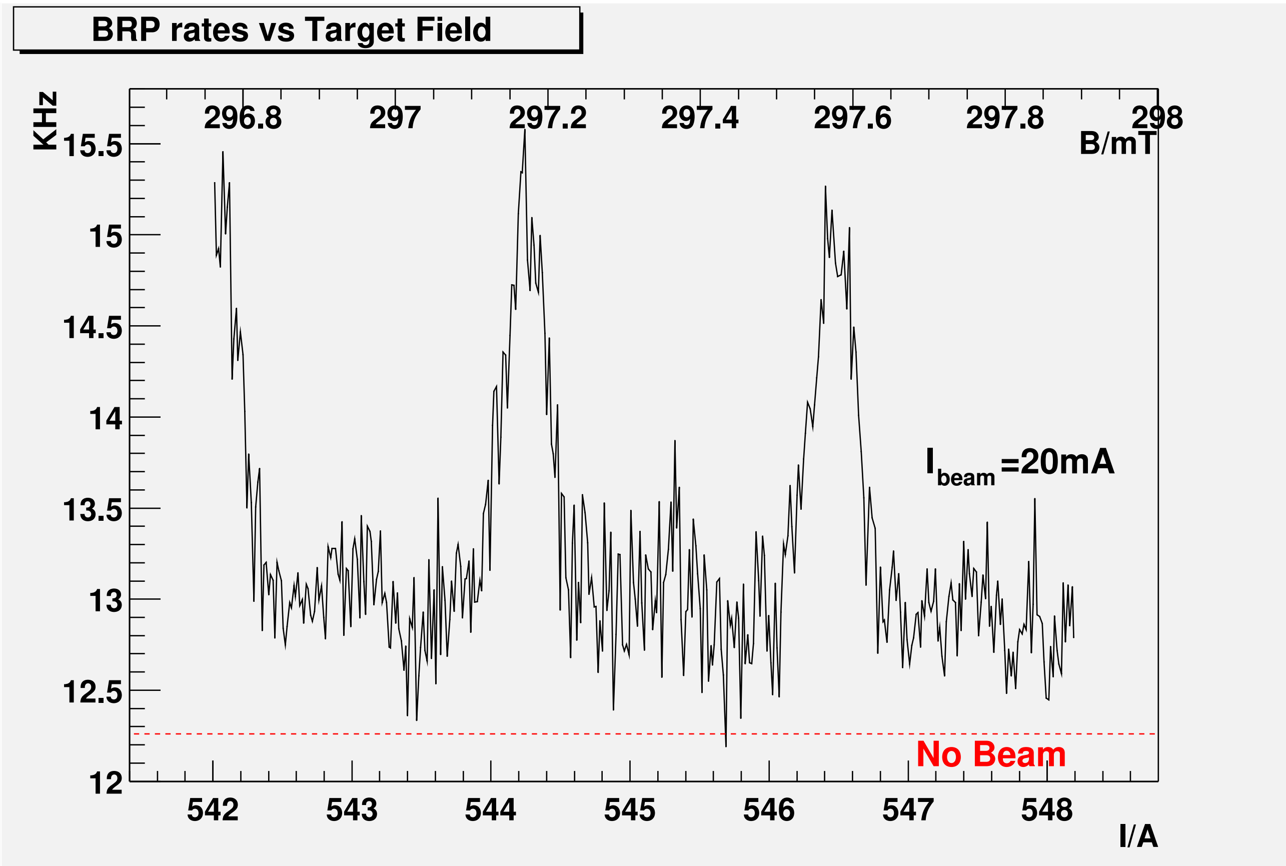
- Field uniformity:

  - ΔB along z: $0.05\,$mT
  - ΔB along y: $0.18\,$mT
  - ΔB along x: $0.7\,$mT

$\Rightarrow$ additional correction coils needed!!!

σ Reson. Measurements

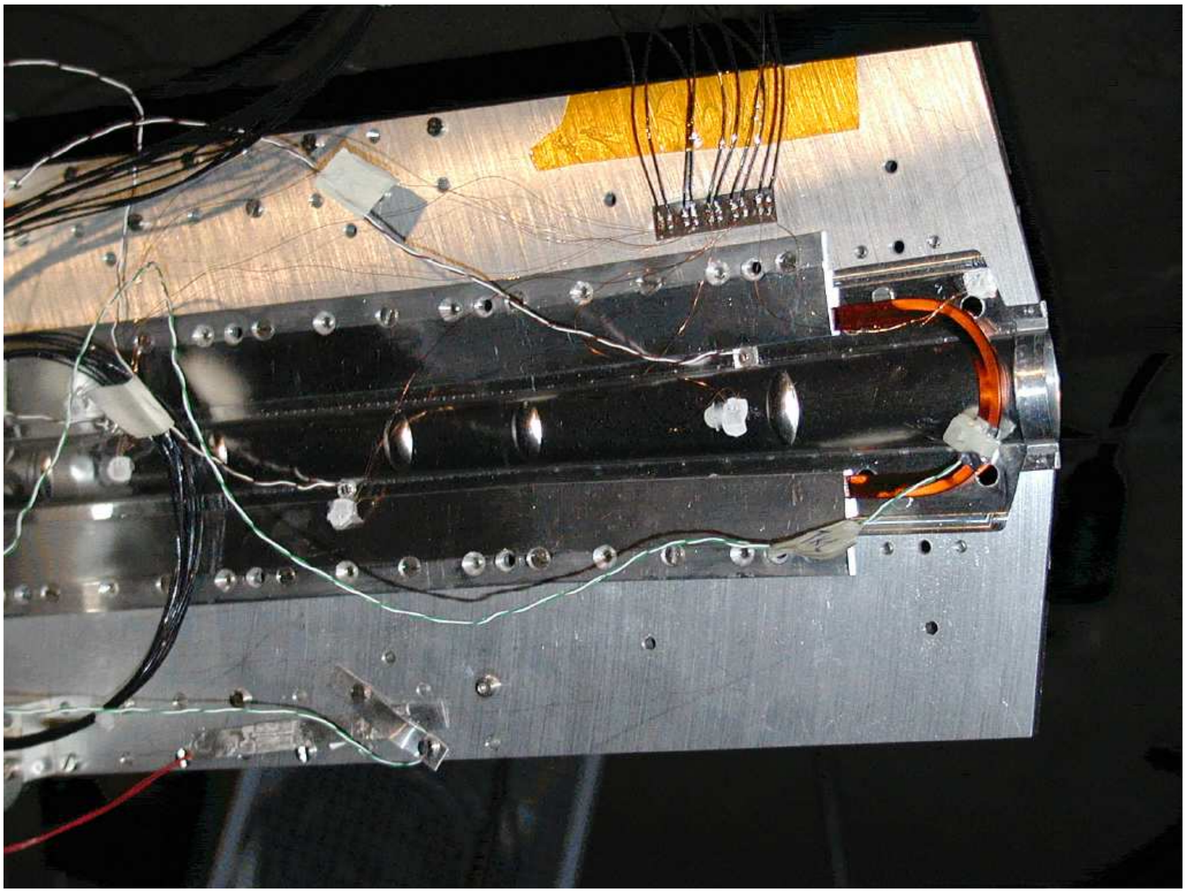
- Spin-Flip Measurement
  - Beam Current = 20 mA
  - State $|\,4\,\rangle$ injeted (ABS)
  - Target Field scanned around the working point (297 mT)
  - Fast detection of states $|\,1\,\rangle$ and $|\,2\,\rangle$ (BRP)
  - Possible Beam-Induced Resonances:
    - $\sigma\ |\,2\,\rangle \leftrightarrow |\,4\,\rangle$ (elec. and nuclear, 0.37 mT)
    - $\pi\ |\,1\,\rangle \leftrightarrow |\,4\,\rangle$ (electron, 0.37 mT)



Cell-Embody Correction Coils

Since March 2004

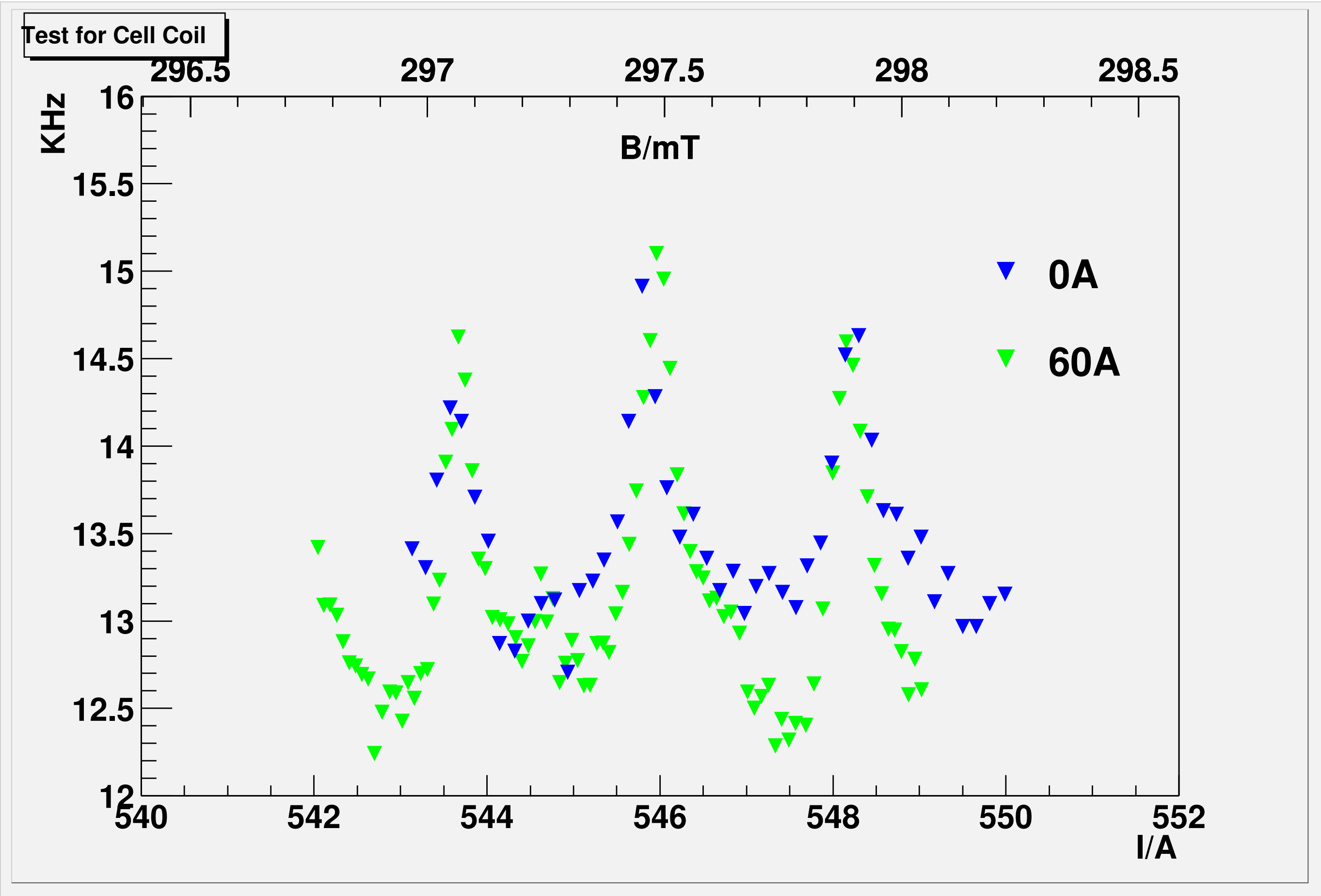
- Aim
  Improve x non-uniformity from 0.7 mT to 0.2 mT
- Technique
  Correction Coils built in the Cell Support Structure



- Fiel Strength $\approx 0.4\, mT$ along the cell axis
- Current $\approx 60\ A$
- Cooling from cell's helium cryo system

σ Reson. Measurements with Correction Coils

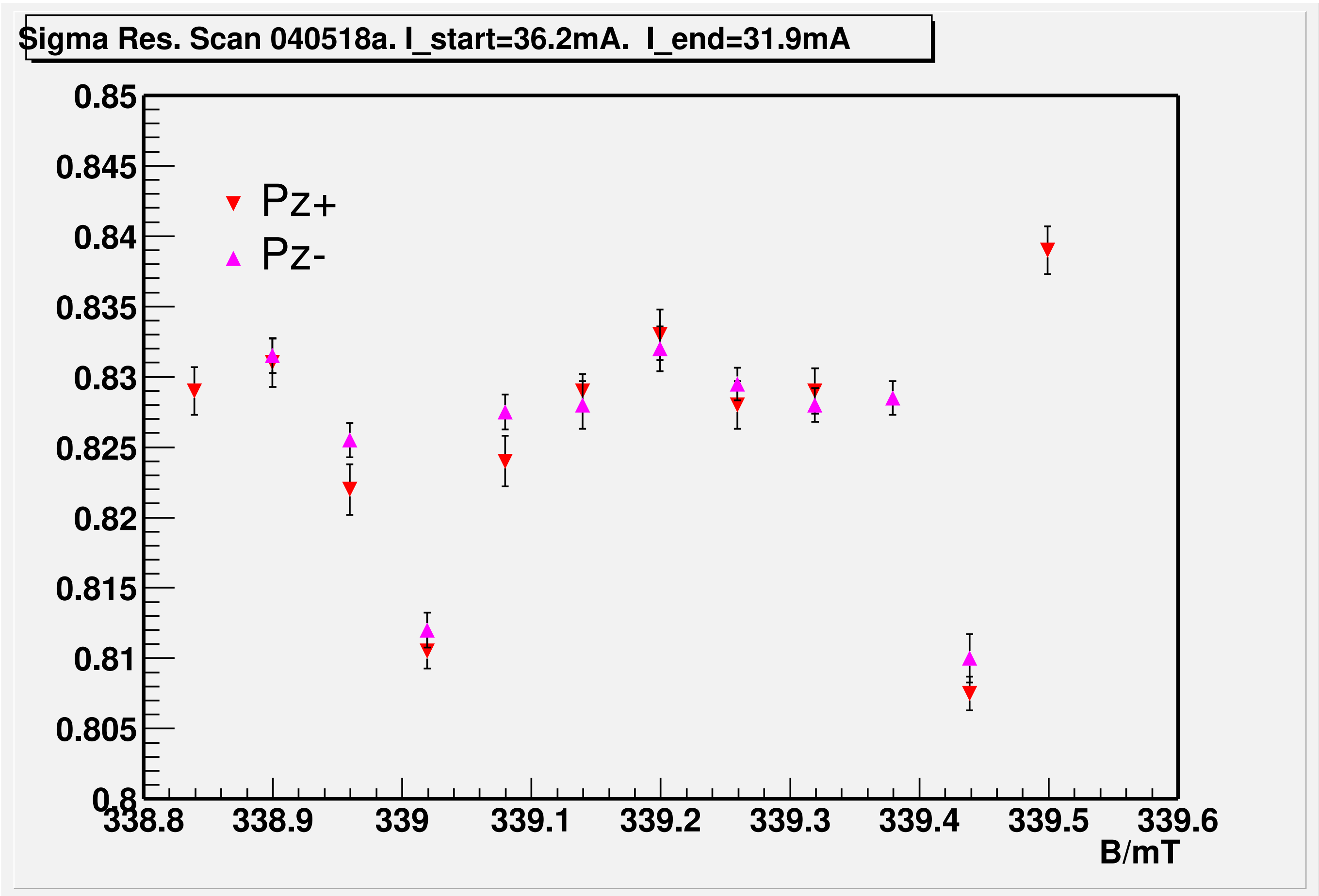
- Spin-Flip Meas. with and without Correction Coils
  - Beam Current $\approx$ 30 mA
  - State $|\,4\,\rangle$ injeted (ABS)
  - Target Field scanned around the working point (297 mT)
  - Fast detection of states $|\,1\,\rangle$ and $|\,2\,\rangle$ (BRP)
  - Correction Coils change Shape of Resonance



Correction Coils improve the Target Performance!

Polarization Measurement

- Polarization Measurement with Correction Coils
  - Beam Current ≈ 30 mA
  - Target Field scanned around the working point (297 mT)
  - $\Delta P \approx 2.5\,\%$



Working Field Tuning

Summary

- Hydrogen Transversely Polarized Gas Target running at HERMES
- Average Polarization in 2002/03:
  $P^T = 0.795 \pm 0.033$
- Beam Induced Depolarization @ $I_{beam} \leq 28$ mA:
  $\Delta P^T \leq 1.5\,\%$
- Beam-induced Densely Spaced (0.37 mT) Depolarizing Resonances measured with the Breit-Rabi Polarimeter
- Since 2004:
  Improved Target Field Quality thanks to
  Cell built-in Correction Coils