The HERMES H/D Polarized Gas Target

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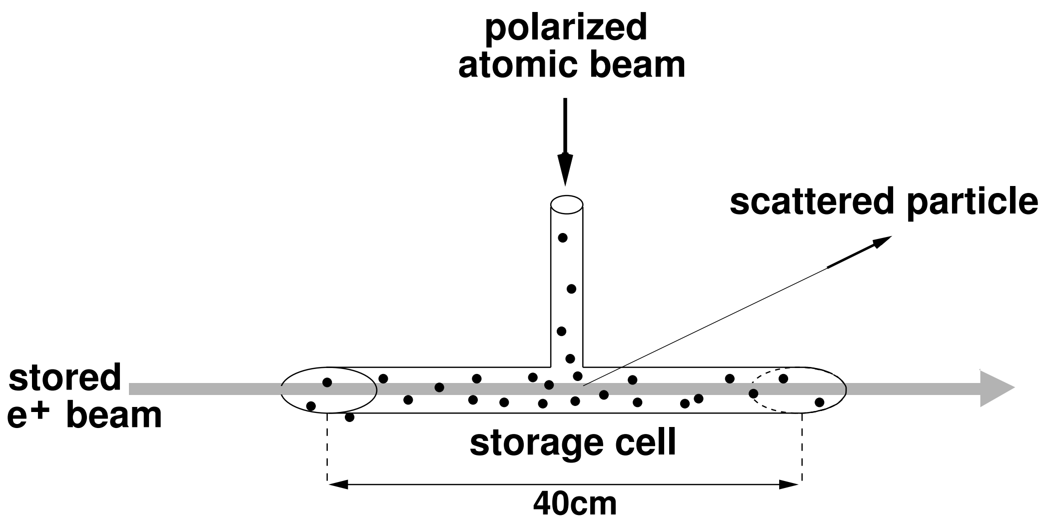
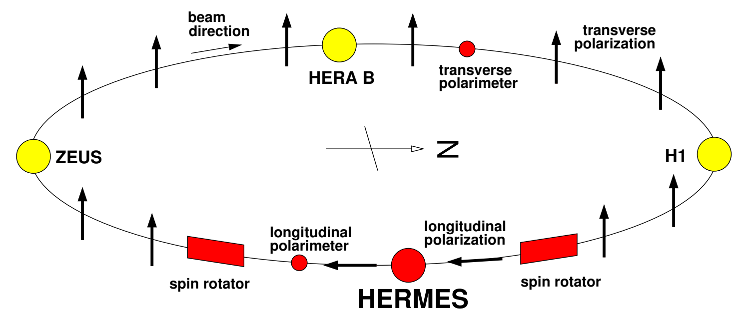
- Introduction
- Hardware Description
- The Design of the Tranverse Magnet
- Beam Induced Depolarization Measurements
- Target Polarization
- Overview on Target Perfomance
- Conclusion

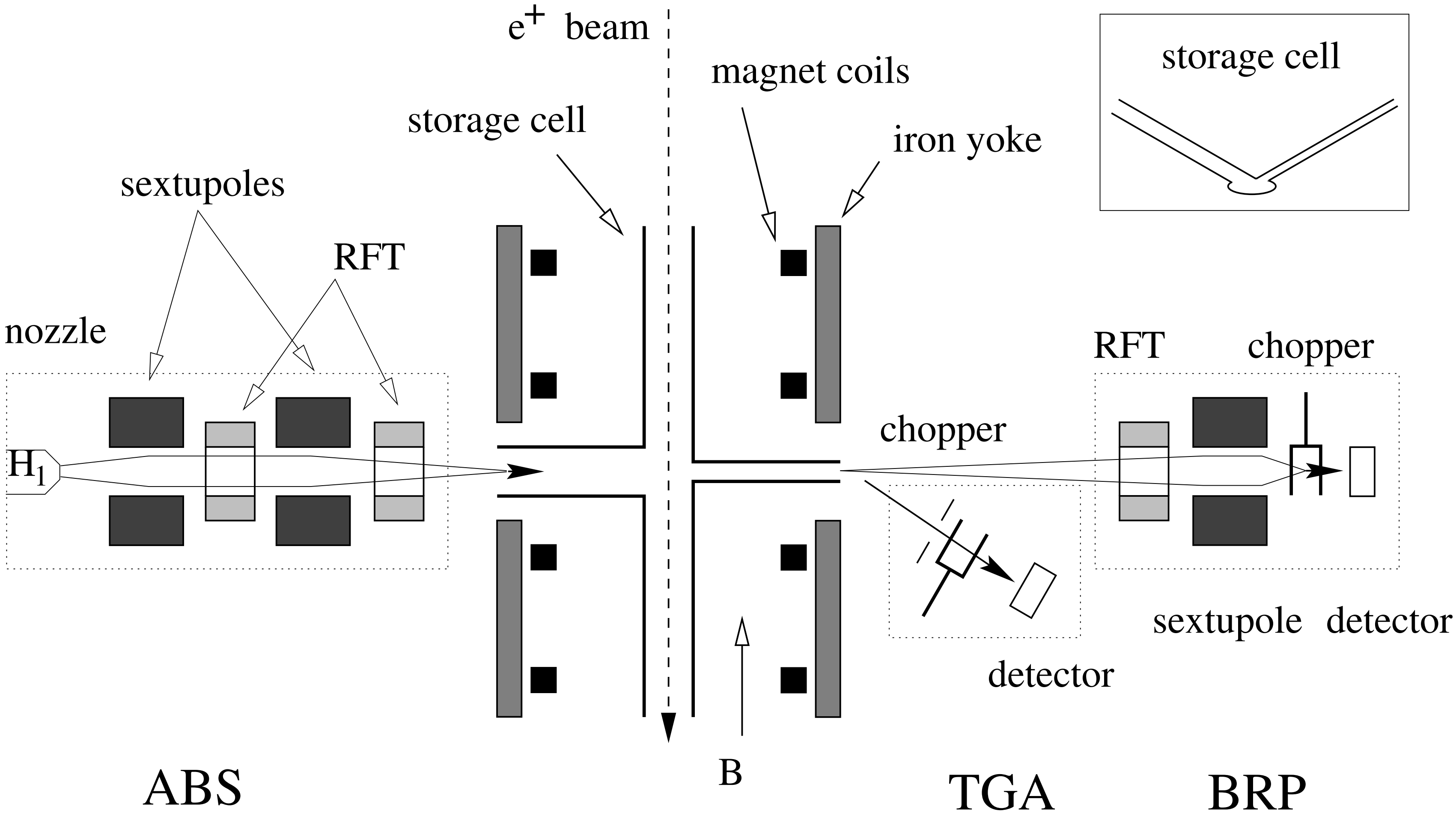
Benefits of Polarized Gas Targets





- High degree of polarization ($P^T > 0.8$)
- No dilution ($f \approx 1$)
- Fast spin reversal ($<$ 1 s)

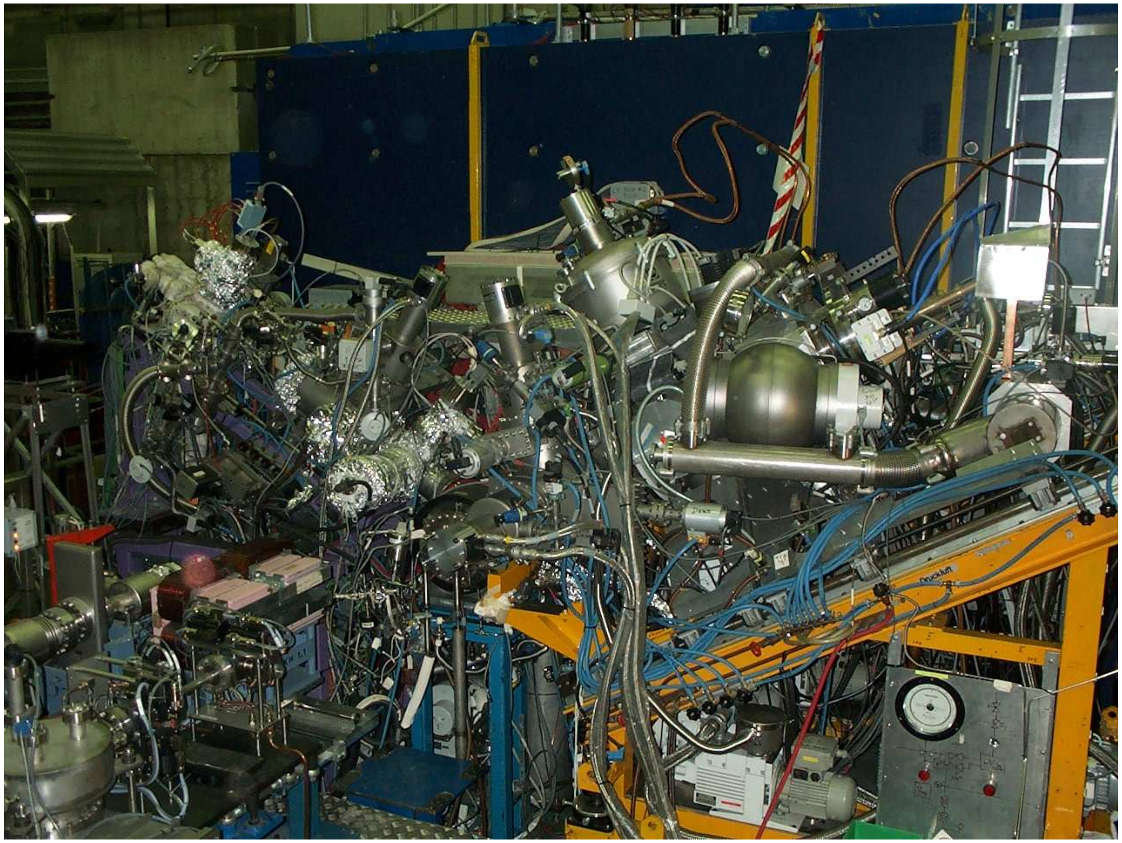
Polarized Target Setup



HERMES Physics Program

Longitudinal Polarization

- 1996 - 1997: Hydrogen
- 1999 - 2000: Deuterium



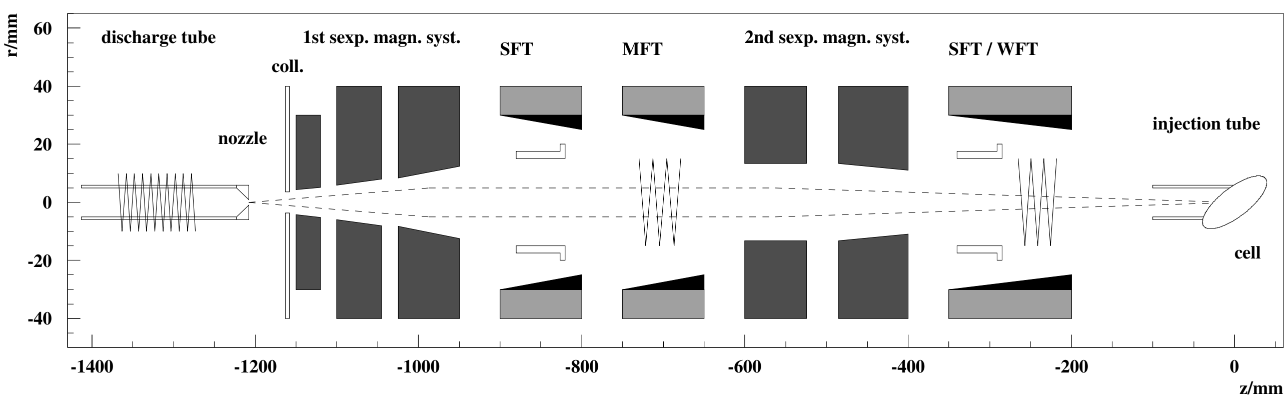
Transverse Polarization

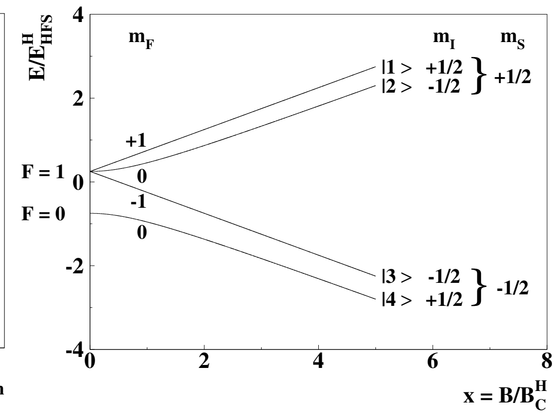
- 2002 - 2005: Hydrogen

Unpolarized Program

- 2006 - 2007

The Atomic Beam Source (ABS)



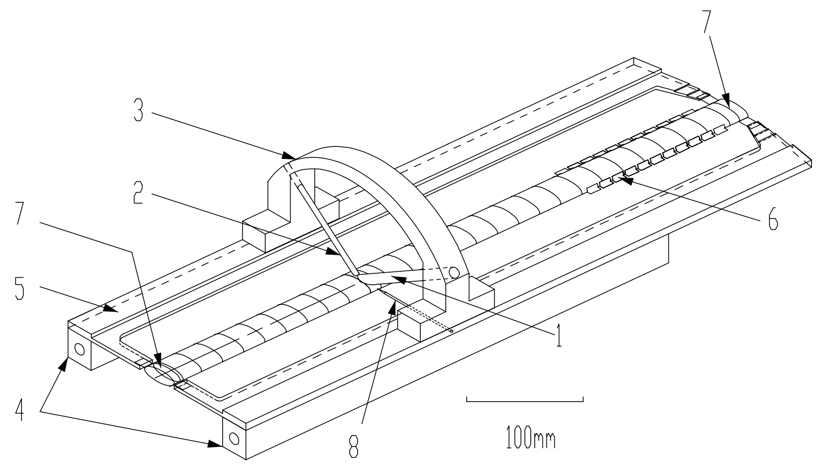


- Dissociator: from molecules to atoms
  - Air-cooled RF dissociator with $\approx 85\%$ degree of dissociation at 1.3 mbar·l/s
  - Small amount of O_2 improves discharge properties
- Sextupole Sytem: focus atoms with $m_s = +\frac{1}{2}$
  - 5 (tapered) magnets in a 3 magnet and a 2 magnet subsytem
- RF Transitions: HF states occupation exchange

Two injected hyp. states during data taking

The Storage Cell

- Technical Specifications
  - Material: Drifilm coated Alluminum
  - Length: 400 mm
  - Elliptical Cross Section:
    - 29x9.8 mm (1996-'99)
    - 21x8.9 mm (since 2000)
  - Temperature: $30\,\mathrm{K} \leq T_{cell} \leq 300\,\mathrm{K}$



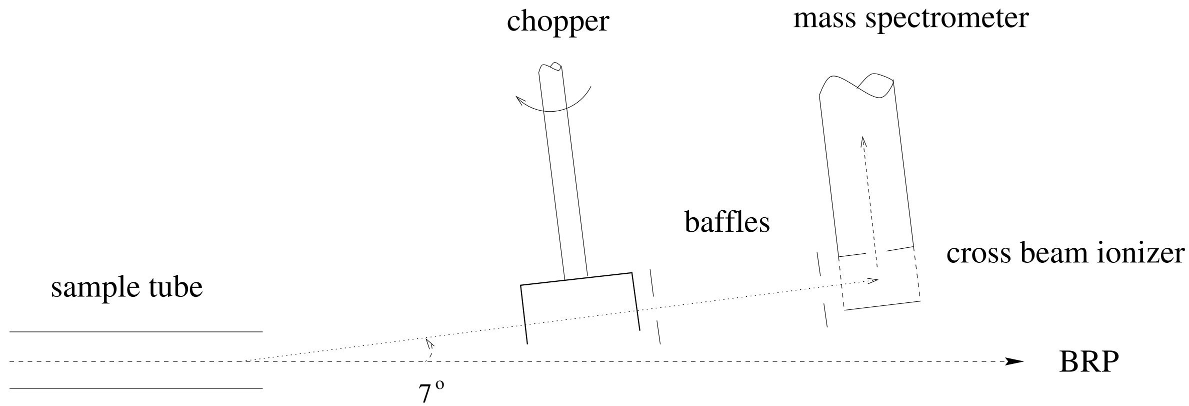
- Advantages
  - Increased Target Thickness:
    - Jet Target $\approx 10^{12}$ Nucleons/cm^2
    - Storage Cell $\approx 10^{14}$ Nucleons/cm^2

- Possible Drawbacks
  - Atomic Recombination: wall collisions
  - Nuclear Depolarization: wall and spin-exchange collisions

The Longitudinal Magnet

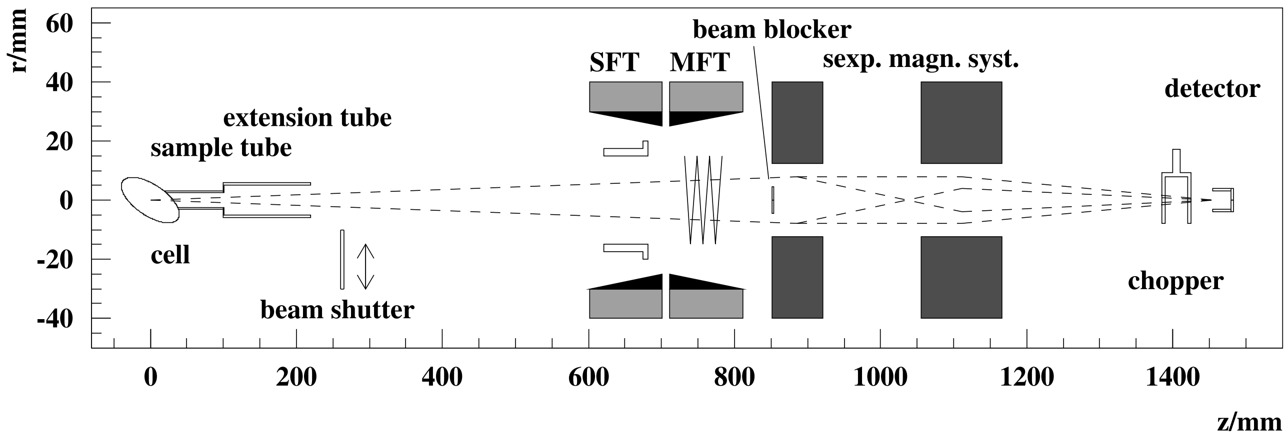
- Superconducting Solenoid
- Intensity: $B_T = 350\,$mT @ 45 A
- Homogeneity $\approx 1\,\%$

The Target–Gas Analyzer (TGA)



- Task
  - Measure the atomic fraction of sample beam
- Measurement
  - Use of chopper to subtract background
  - Signals related to nucleon fluxes: $S_i \propto \Phi_i$
    * Measurement of atomic signal S_{atom}
    * Measurement of molecular signal S_{mol}
  - Degree of dissociation: $$\alpha^{\text{TGA}} = \frac{S_{\text{atom}}}{S_{\text{atom}} + \sqrt{2}\kappa S_{\text{mol}}}$$

The Breit–Rabi Polarimeter (BRP)



- Task
  - Measure the hyperfine population of sample beam
- Measurement
  - Use of chopper for background subtraction
  - Measurements with different HFT modes: $\Rightarrow$ linear system, solution for N_i
- Performance
  - Mininum time for polarization measurement $\approx 30\ s$
  - Statistical uncertainty < 0.005,   Systematic uncertainty ≤ 0.01

Transverse Target: the Basic Idea

2002 - 2005 $\rightarrow$ Transversely Polarized Target (H)

New Target Holding Field

Drawbacks and Solutions:

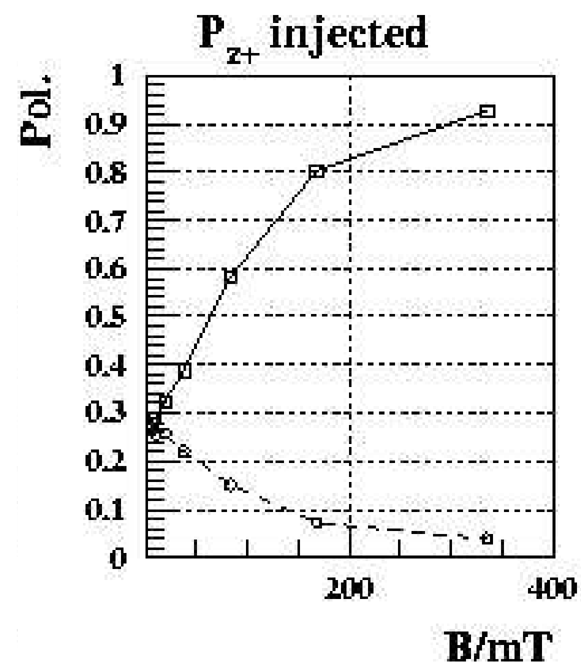
- Bending of the electron beam:
  Orbit compensation
- Synchrotron radiation emission:
  Avoid the spectrometer acceptance
- Possible beam induced nuclear depolarization:
  Conceive a holding field which minimizes this effect

The Magnet Design

- Conventional static vertical dipole

- $B_T > 280$ mT to inhibit spin relaxation

- $B_T < 400$ mT to minimize synchrotron radiaton

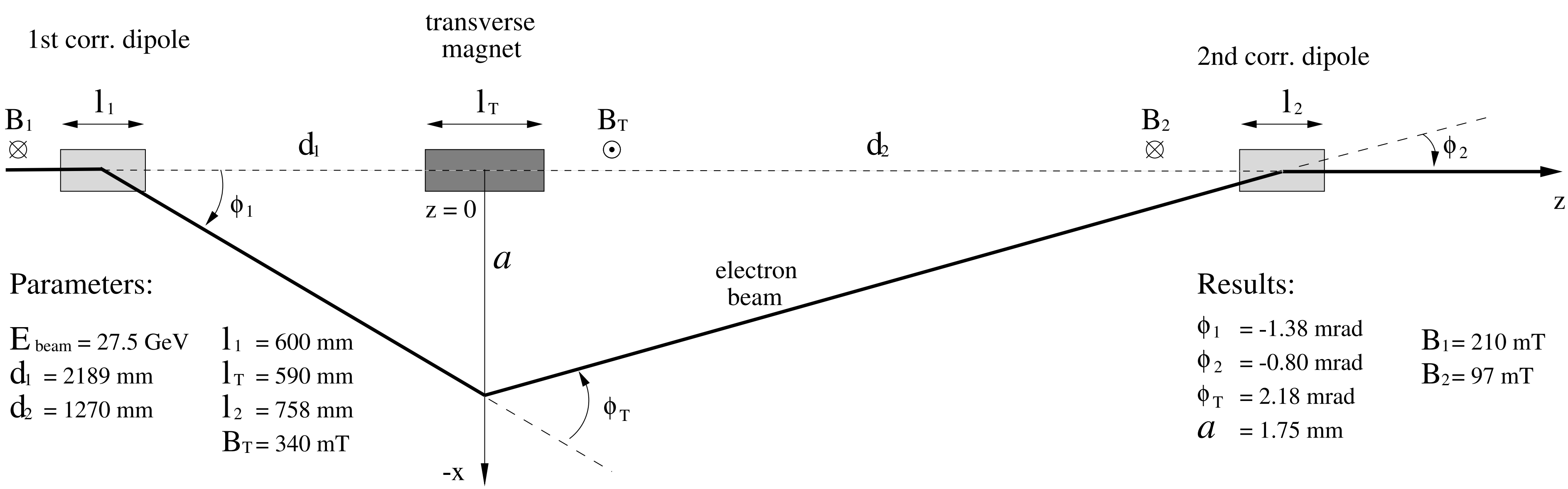


- $\Delta B < 0.15$ mT inside the cell $(400 * 20 * 10\text{mm}^3)$, to avoid beam induced depolarization

- Dimensional constraints: pole length < 650 mm, pole width < 200 mm

The Effects on the HERA e-Beam (I)

Bending ($B_T = 340$ mT):



Parameters:

$E_{beam} = 27.5$ GeV
$d_1 = 2189$ mm
$d_2 = 1270$ mm
$l_1 = 600$ mm
$l_T = 590$ mm
$l_2 = 758$ mm
$B_T = 340$ mT

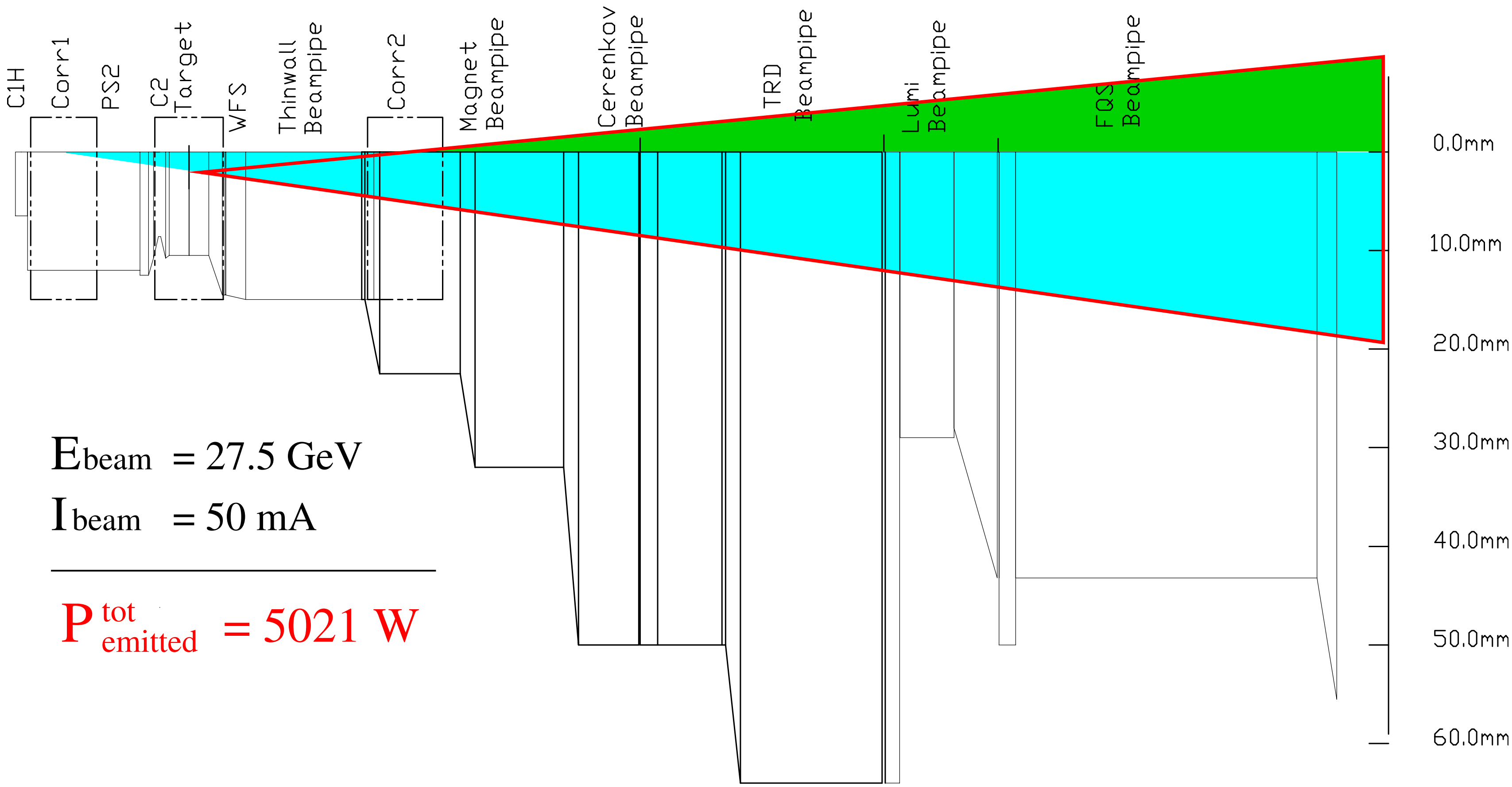
Results:

$\phi_1 = -1.38$ mrad
$\phi_2 = -0.80$ mrad
$\phi_T = 2.18$ mrad
$a = 1.75$ mm

$B_1 = 210$ mT
$B_2 = 97$ mT

The Effects on the HERA e-Beam (II)

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



$E_{\mathrm{beam}} = 27.5\ \mathrm{GeV}$

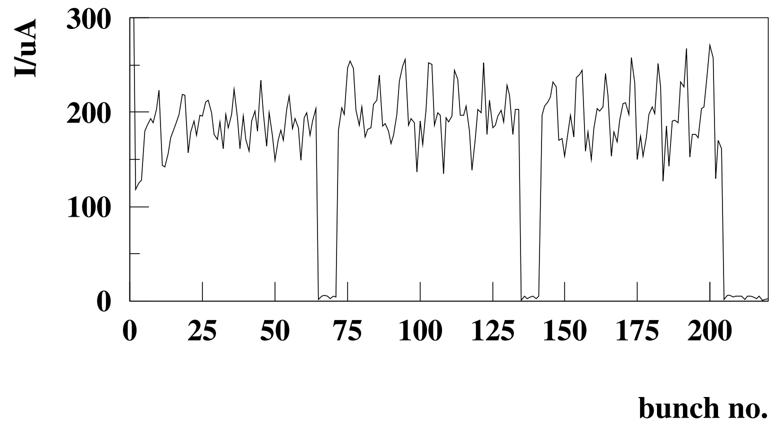
$I_{\mathrm{beam}} = 50\ \mathrm{mA}$

$P^{\mathrm{tot}}_{\mathrm{emitted}} = 5021\ \mathrm{W}$

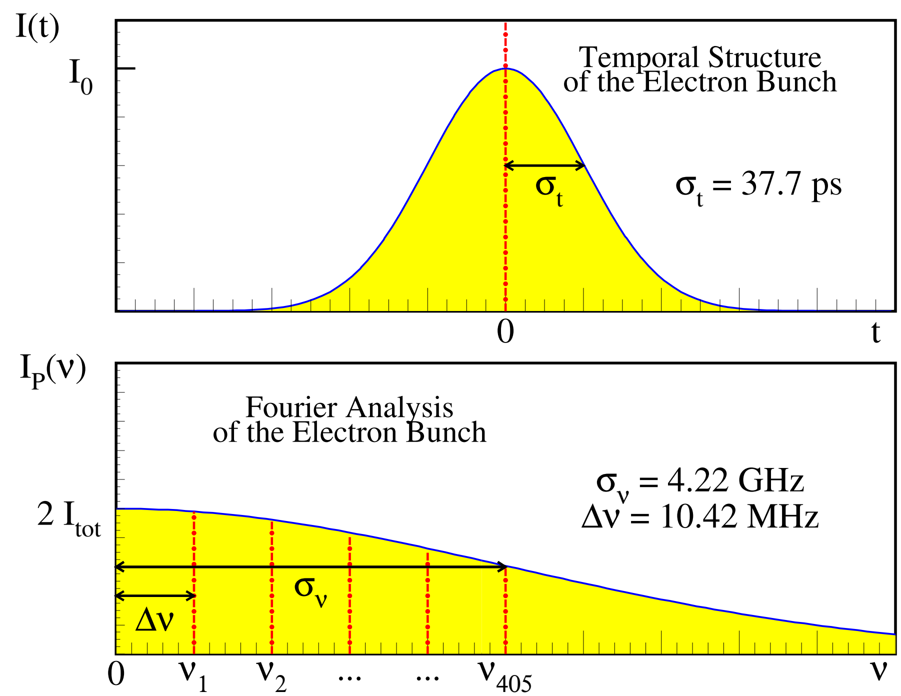
Depolarization by Beam Interaction

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:

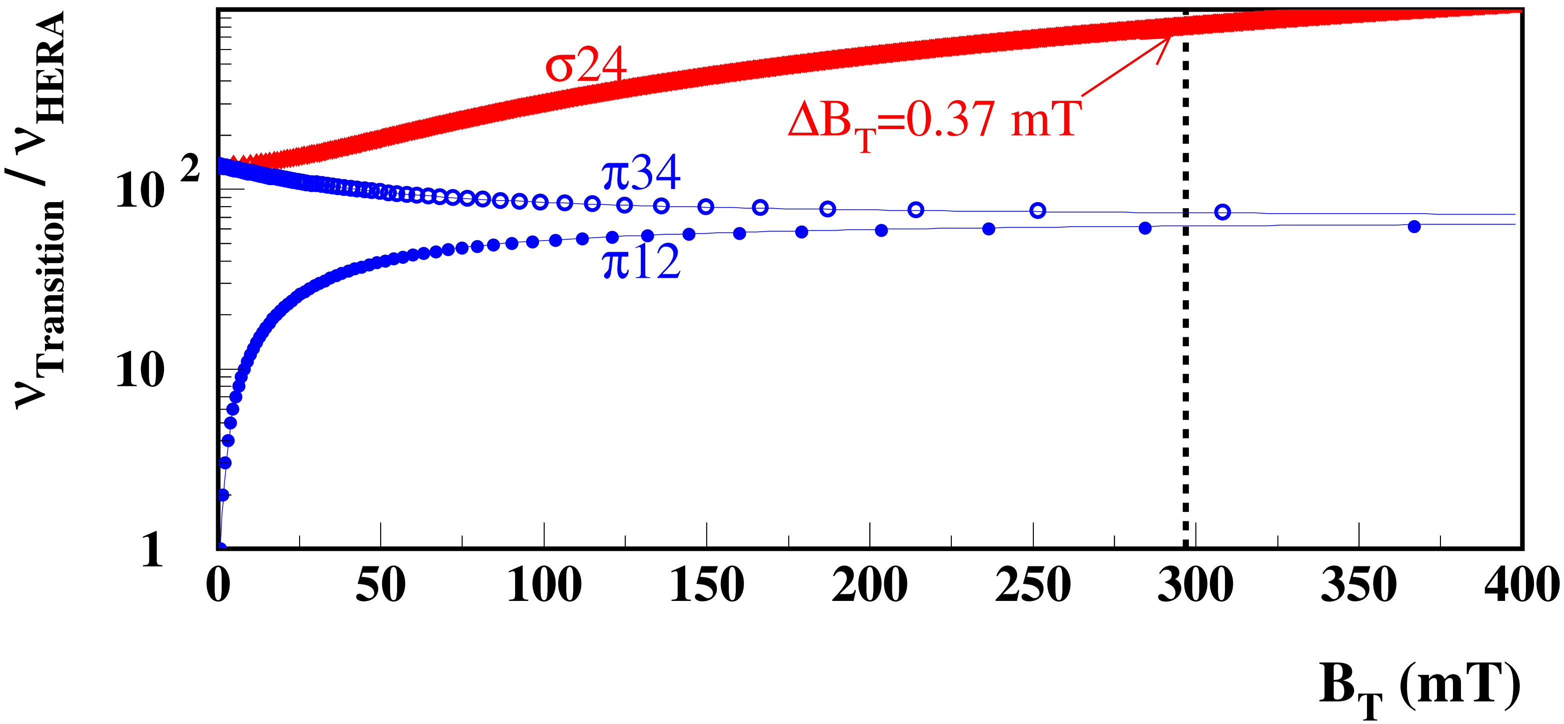
$$\frac{|E_i - E_f|}{h} = \nu_n \qquad n = 1, 2, \ldots$$

$\Rightarrow$ Depolarization!

Resonance Conditions (Nucl. Trans.)

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

But... ΔE_{if} depends on B_T!

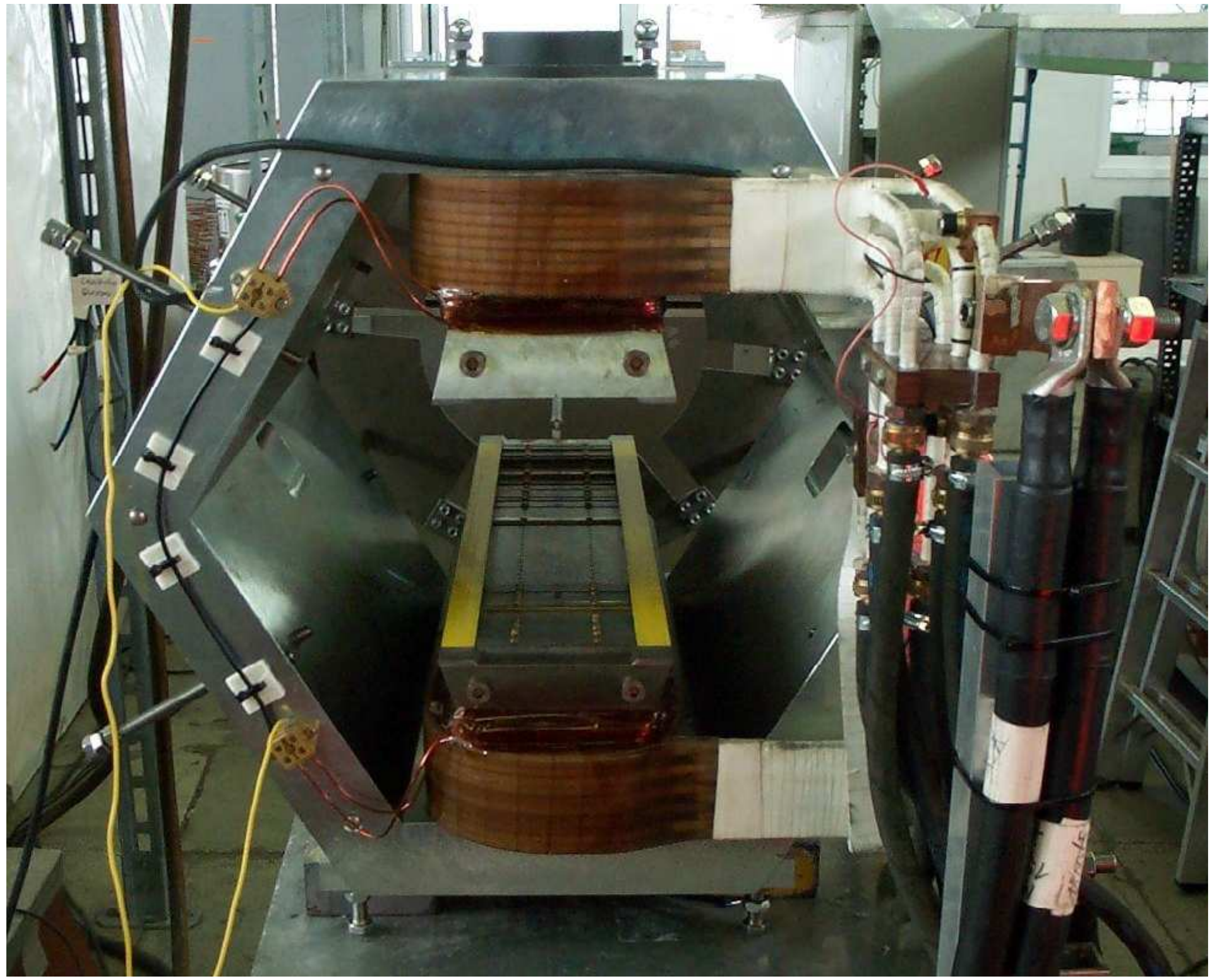


- π-transitions ($B_{ST} \perp B_{RF}$) $\Rightarrow$ Long. & Trans. Target
- σ-transitions ($B_{ST} \parallel B_{RF}$) $\Rightarrow$ Trans. Target Only!

The Transverse Magnet

- Intensity: $B_T = 297\,\mathrm{mT}$ @ 545 A
- Uniformity:
  - ΔB along z: $0.05\,\mathrm{mT}$
  - ΔB along y: $0.18\,\mathrm{mT}$
  - ΔB along x: $0.7\,\mathrm{mT}$

Correction coils needed!



Cell-Embodied Correction Coils

- Aim

  Improve x uniformity from 0.7 mT to 0.2 mT

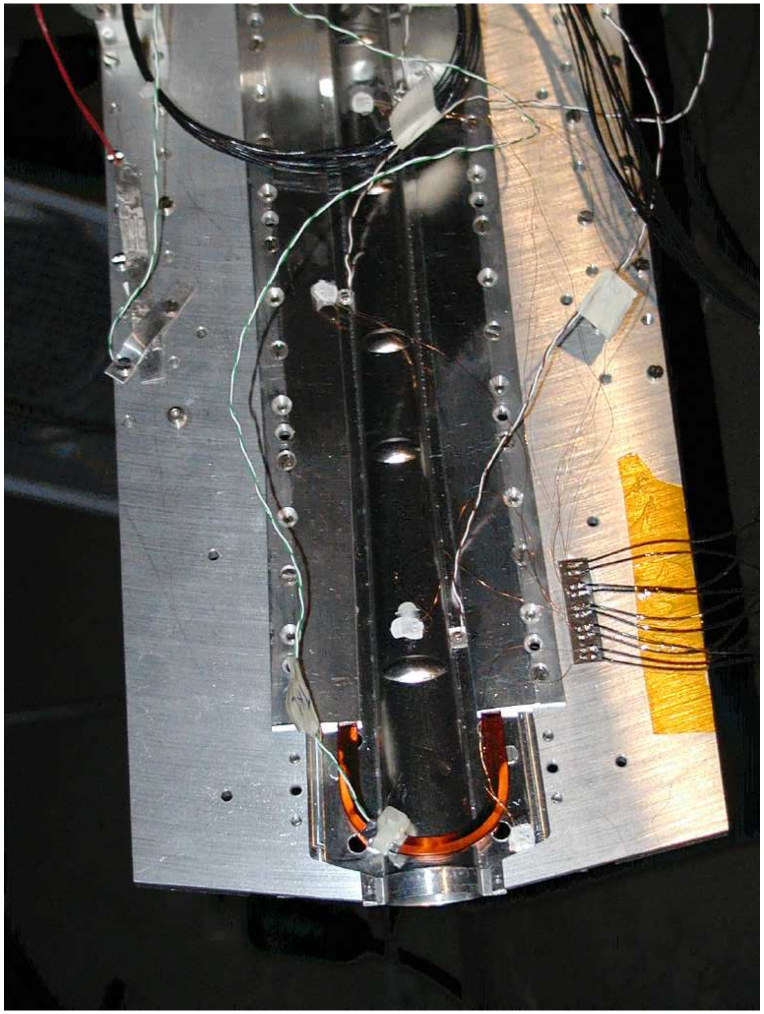
- Technique

  Coils built in the Cell Support Structure

- Field Strength $\approx 0.4\,mT$ along the cell axis

- Current $\approx 60\ A$

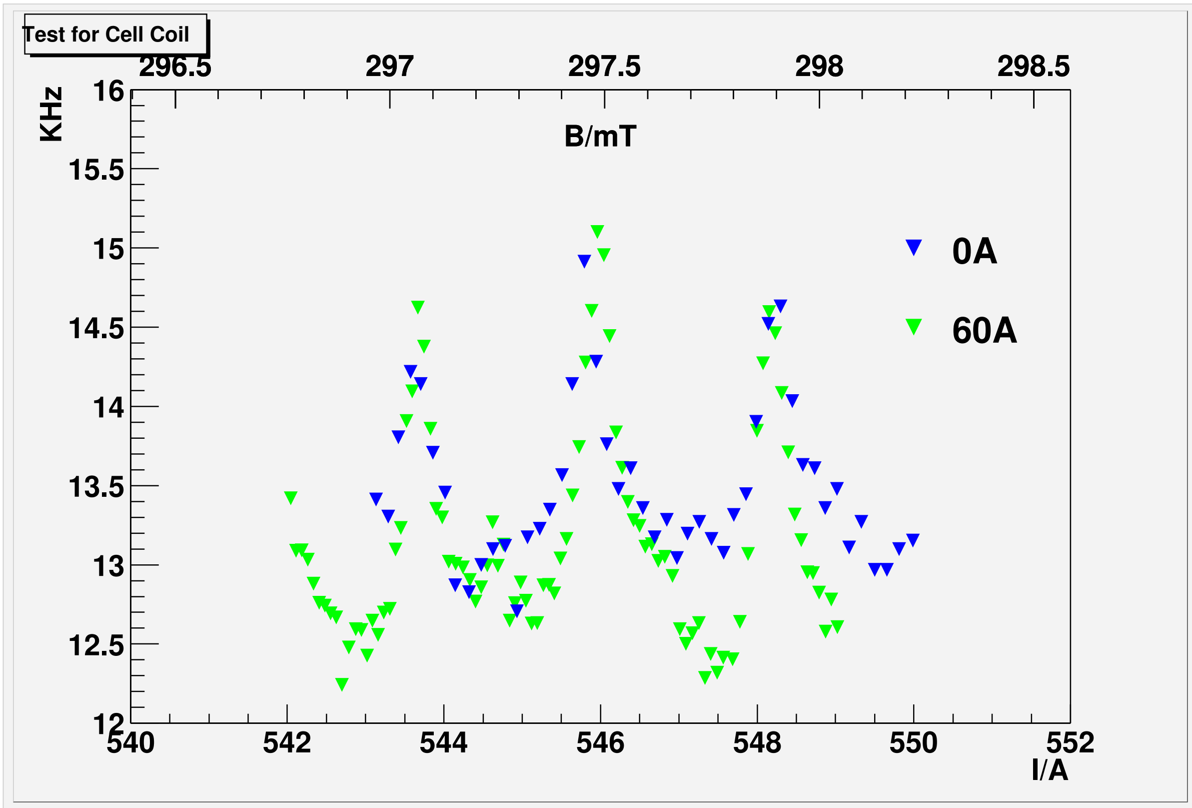
- Cooling from cell's helium cryo system



σ Resonances Measurements

Spin-Flip Measurement with and without Correction Coils

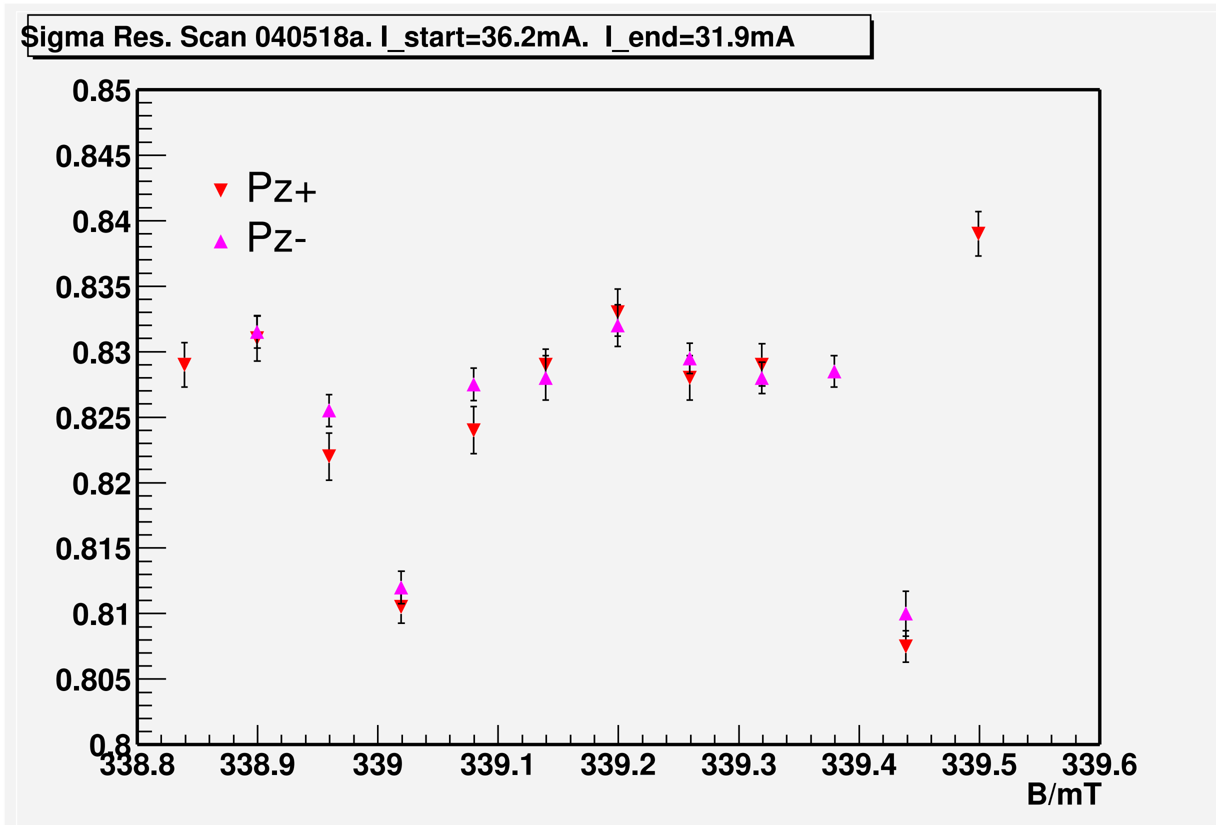
- Beam Current $\approx$ 30 mA
- State $|\,4\,\rangle$ injeted (ABS)
- Target Field scanned around the working point
- Fast detection of states $|\,1\,\rangle$ and $|\,2\,\rangle$ (BRP)
- Correction Coils change Shape of Resonance



Polarization Measurement

Polarization Measurement with Correction Coils

- Beam Current ≈ 30 mA
- Target Field scanned around the working point
- $\Delta P \approx 2.5\,\%$



Target Polarization Formula

N_a Polarized H/D Atoms

N_r Polarized H/D Molecules (Recombination on the Cell Wall)

N_m Total Number of H/D Molecules (Recombination + Residual Gas + ABS Ballistic)

$$P^T = \alpha_0[\alpha_r + (1-\alpha_r)\beta]P_a$$

$\alpha_0 = \frac{N_a+2N_r}{N_a+2N_m}$ Dilution Factor

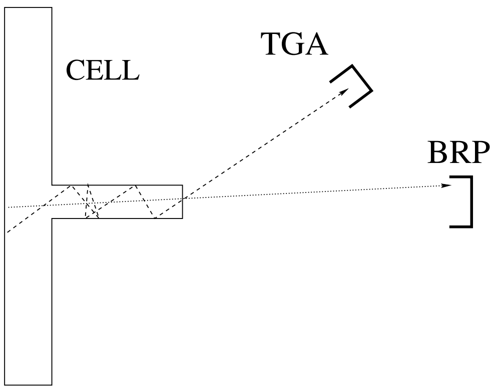
$\alpha_r = \frac{N_a}{N_a+2N_r}$ Recombination

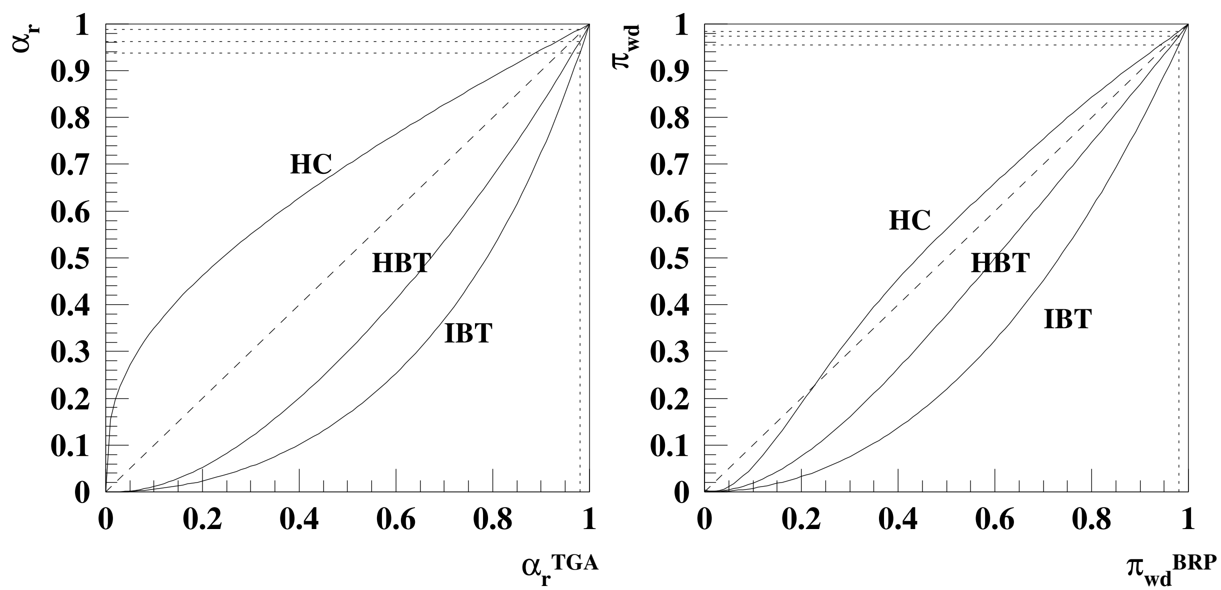
P_a Atomic Polarization (possible depol. via wall and spin-exchange collisions)

$\beta = P_m/P_a$ Relative Polarization of Recombined Molecules

Sampling Corrections

From TGA/BRP Measurements to Cell-Averaged Values

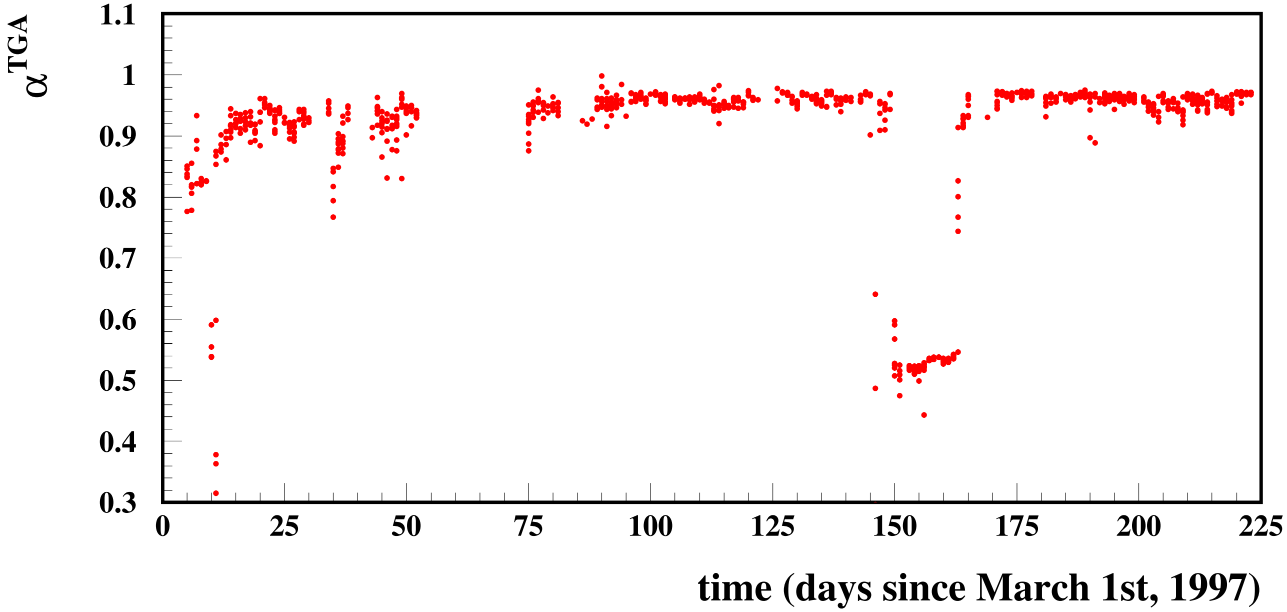




$$\alpha_r = c_\alpha \cdot \alpha_r^{TGA} \qquad P_a = c_P \cdot P_a^{BRP}$$

hermes

Measurement of β (Hydrogen 1997)



	$T = 100$K	$T = 260$K
α_0	0.959 ± 0.029	0.969 ± 0.030
α_r	0.932 ± 0.044	0.260 ± 0.040
P_{a+}	0.908 ± 0.007	0.938 ± 0.016
P_{a-}	0.912 ± 0.007	0.940 ± 0.014

- $T_{cell} = 100$ K: Nominal Temp.
- $T_{cell} = 260$ K: Measurement of β

β: Measurement Technique

- Longitudinal DIS Asymmetry:

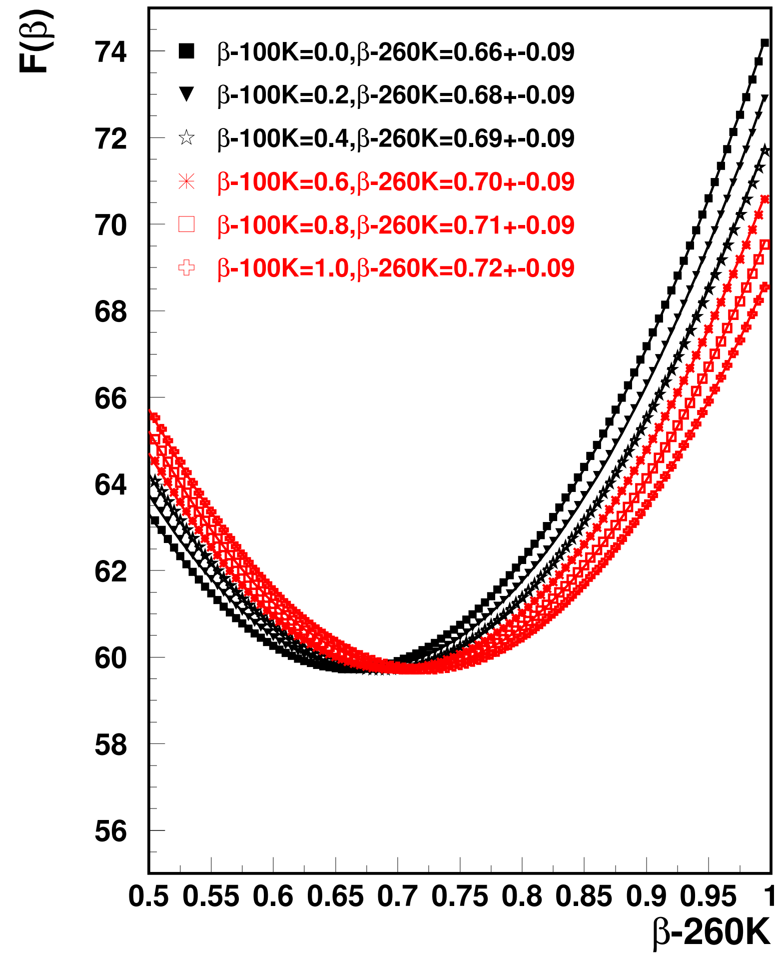
$$A_{||}^{meas} = \frac{\sigma^{\overset{\rightarrow}{\Leftarrow}} - \sigma^{\overset{\rightarrow}{\Rightarrow}}}{\sigma^{\overset{\rightarrow}{\Leftarrow}} + \sigma^{\overset{\rightarrow}{\Rightarrow}}} = \frac{1}{P_b P_T} \frac{(N/L)^{\overset{\rightarrow}{\Leftarrow}} - (N/L)^{\overset{\rightarrow}{\Rightarrow}}}{(N/L)^{\overset{\rightarrow}{\Leftarrow}} + (N/L)^{\overset{\rightarrow}{\Rightarrow}}}$$

- β: Measurement Strategy
  - T_{cell}=260 K to increase Recombination
  - $A_{||}^{100K}$ = $A_{||}^{260K}$ $\longrightarrow \frac{C_{||}^{100K}}{P_T^{100K}} = \frac{C_{||}^{260K}}{P_T^{260K}}$
    * $P_T^{100K} = \alpha_0^{100K}[\alpha_r^{100K} + (1-\alpha_r^{100K})\beta^{100K}]P_a^{100K}$
    * $P_T^{260K} = \alpha_0^{260K}[\alpha_r^{260K} + (1-\alpha_r^{260K})\beta^{260K}]P_a^{260K}$

β^{260K}: Analysis and Result

- Fixing β^{100K} and minimizing

$$F(\beta) = \sum_{i=1}^{bins} \left[\frac{\frac{C_{||}^{260K}}{P_T^{260K}(\beta 260K)} - \frac{C_{||}^{100K}}{P_T^{100K}(\beta 100K)}}{\left((\sigma_{C||}^{260K})^2 + (\sigma_{C||}^{100K})^2\right)^{1/2}} \right]^2$$



$$\beta^{260K} = 0.68 \pm 0.09_{stat} \pm 0.06_{syst}$$

From β^{260K} to β^{100K}

Recomb. Mechanism: atom from the volume inpinging onto an atom on the surface

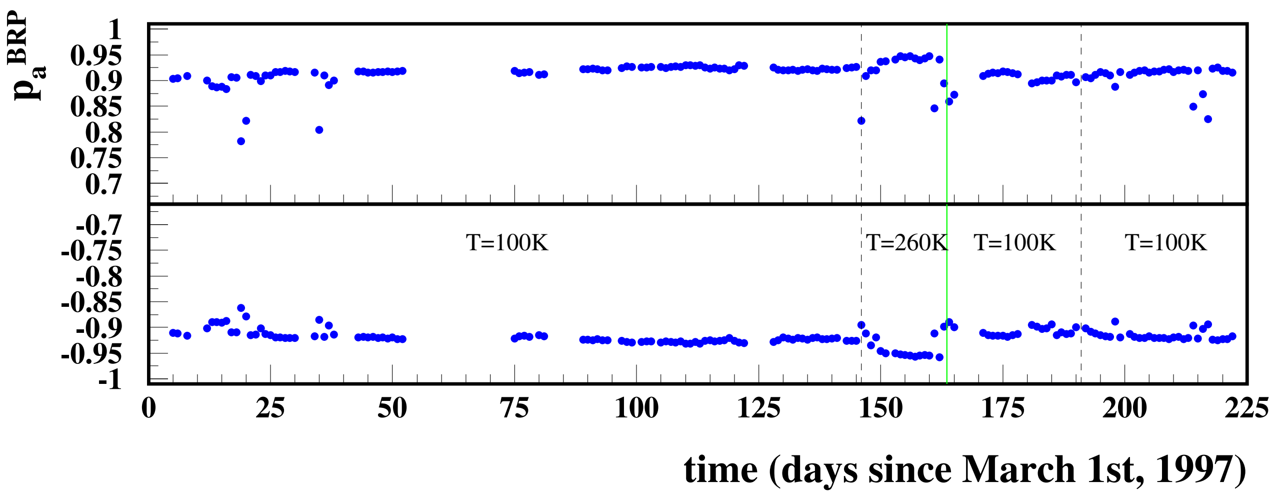
$$\beta = \frac{P_m}{P_a} \qquad P_m = \frac{P_a + P_s}{2} e^{-n(B_c/B)^2}$$

(T. Wise et al. Phys. Rev. Lett. 87 (2001), 42701)

At HERMES $\quad e^{-n(B_c/B)^2} = 0.9 \qquad P_a^{100K} = 0.9$

- $P_s = 0 \Rightarrow \beta_{min}^{100K} = 0.45$
- $\beta^{260K} = \beta_{max}^{100K} = 0.68 + 0.15 = 0.83$
  ($260K \Rightarrow$ larger recomb. probability = lower depolarization on the surface)
- $\beta^{100K} = 0.64 \pm 0.19$

Target Performance in 1997 (H Long.)

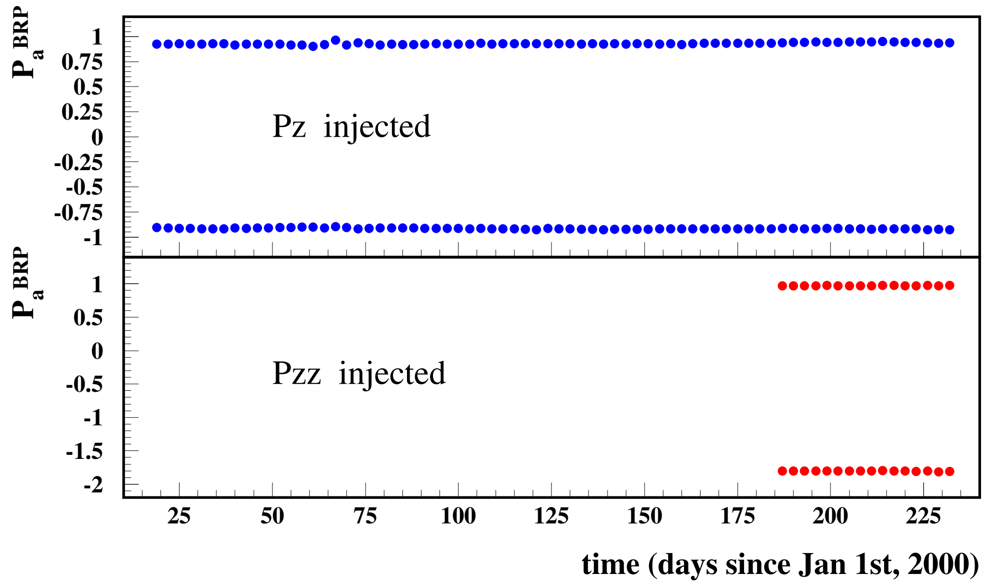


- Fairly stable running conditions
- Injected Polarization: $P_{inj} \approx 97\%$
- Depolarization: $\Delta P \approx 7\%$
- Recombination: $1 - \alpha_r \approx 7\%$

Average Polarization $(T = 100\,K)$ $\quad P^T = 0.852 \pm 0.033 \quad \dfrac{\Delta P^T}{P^T} = 3.9\,\%$

Target Performance in 2000 (D Long.)

- Outstanding Performance
- $T_{cell} = 60\ K$
- Tensor Polarization Injected
- Injected Polarization: $P_{inj} \approx 92\%$
- Depolarization: absent!
- Recombination: absent!



$$P_z^T+ \quad = \quad +0.851 \pm 0.029 \qquad (3.4\,\%)$$

10.2 Million DIS Events!

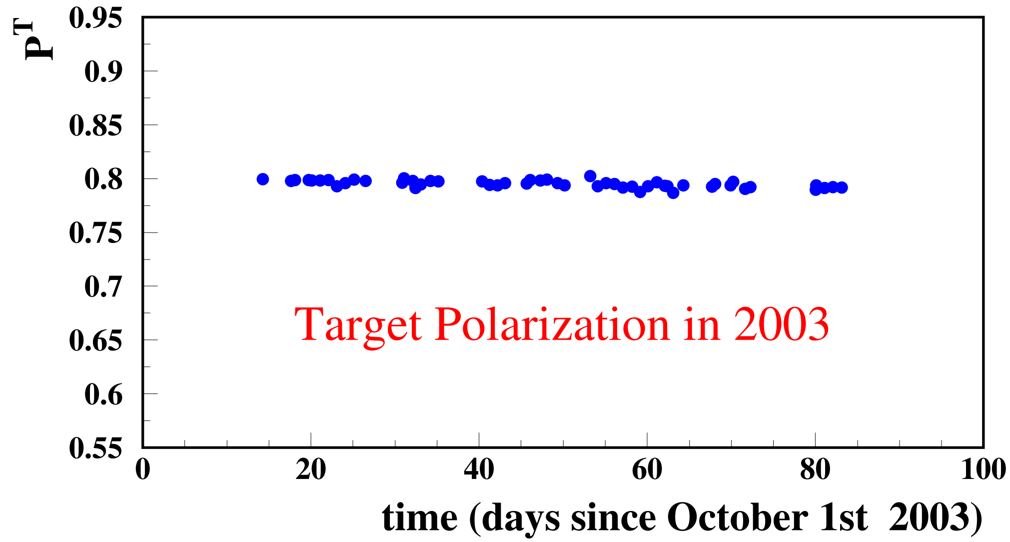
$$P_z^T- \quad = \quad -0.840 \pm 0.026 \qquad (3.0\,\%)$$

$$P_{zz}^T+ \quad = \quad +0.891 \pm 0.027 \qquad (3.0\,\%)$$

$$P_{zz}^T- \quad = \quad -1.656 \pm 0.049 \qquad (2.9\,\%)$$

Target Performance in 2002/03 (H Trans.)

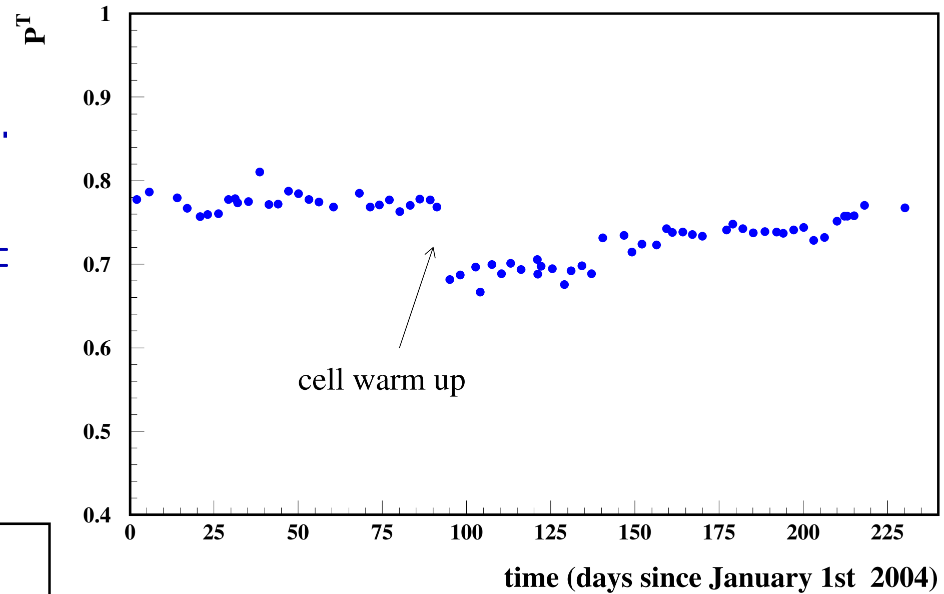
- Very Stable Performance
- $T_{cell} = 100\,K$
- Injected Polarization: $P_{inj} \approx 97\%$
- Depolarization: $\Delta P \approx 10\%$
- Recombination: absent!

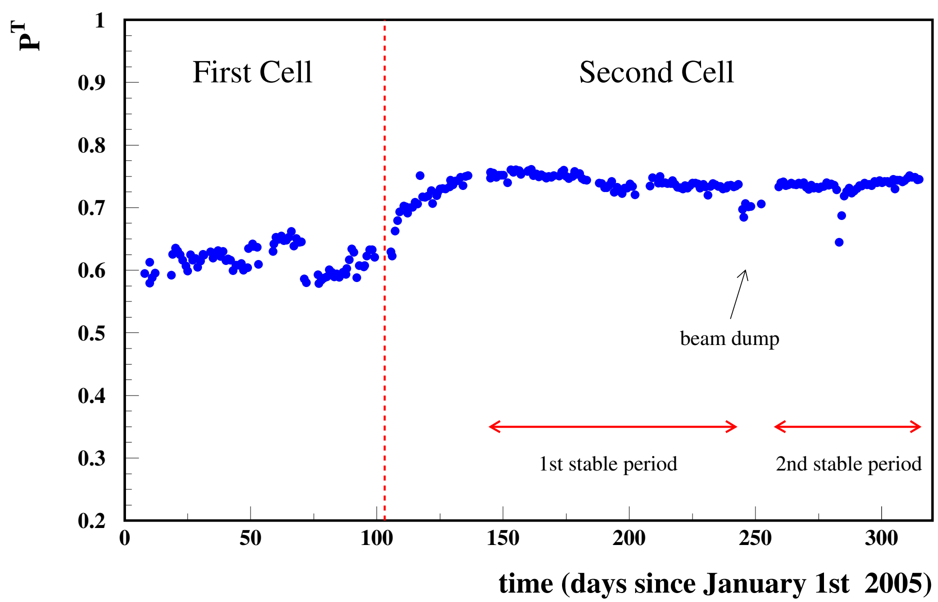


Average Polarization $P^T = 0.795 \pm 0.033$ $\dfrac{\Delta P^T}{P^T} = 4.2\,\%$

Target Performance in 2004 and 2005 (H Trans.)

- April 2004:
  cell warmed up to room temp. (detector problems)
- $P^T = 0.777 \pm 0.039 \rightarrow P^T = 0.648 \pm 0.090$
- Polarization recovered over monthes





- 2005: two cells employed
- First Cell: Poor Performance
- Second Cell: better, but not outstanding

Summary

- The HERMES Polarized Gas Target worked reliably over 10 years
- Longitudinal Polarization $P^T \approx 0.85 \quad \Delta P_T/P_T \approx 3\%$
- Transverse Polarization $P^T \approx 0.80 \quad \Delta P_T/P_T \approx 4\%$
- Target Thickness $\approx 10^{14}$ Nucleons/cm^2

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