Seminar@JLab 3/29/04

Developing tools for high enegy spin physics experiments

Spin flipper rf dipole magnet

And

Ultra-cold polarized Hydrogen gas jet target

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What tools I was developing?

- **Spin flipper rf dipole magnet**
  - Manipulate spin direction
- **Ultra-cold polarized Hydrogen gas jet target**
  - Use for very high intensity beam
  - Use for polarimeter
    - p-p asymmetry by Coulomb Nuclear Interference

SpinPhysicsCenter

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Ultra-cold polarize Hydrogen Gas Jet Target*

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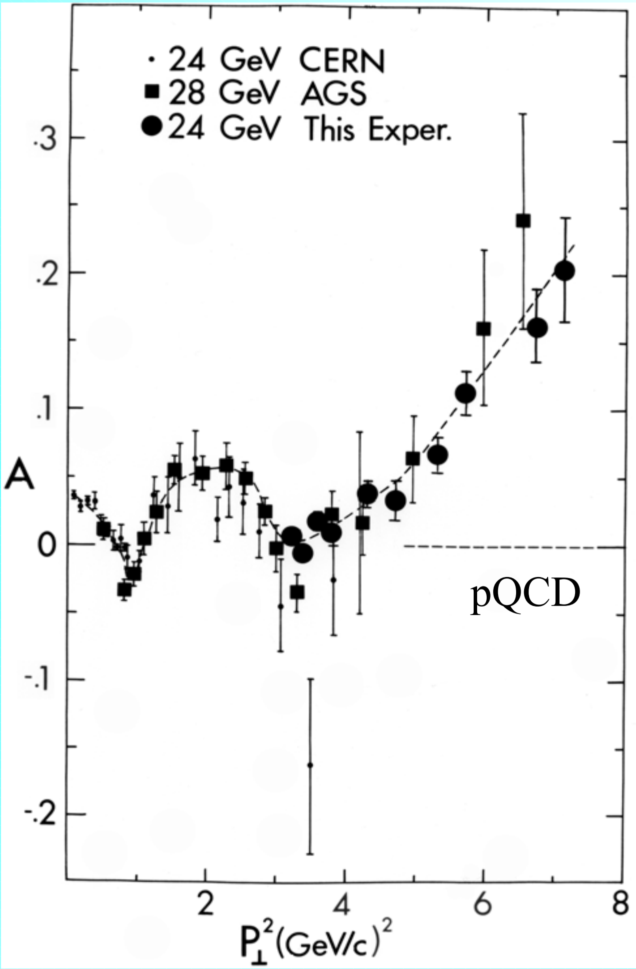
* Research supported by a Research Grant from the U.S. Department of Energy

Polarization in *p-p* elastic scattering

- Leading order pQCD cannot explain this phenomenon.
  - pQCD can only predict the interaction mechanism at $|t|$ & $|s| >> m^2$
- It is necessary to test pQCD theory by polarized p-p elastic scattering.

Need highly polarized proton target at high $P_\perp^2$ region

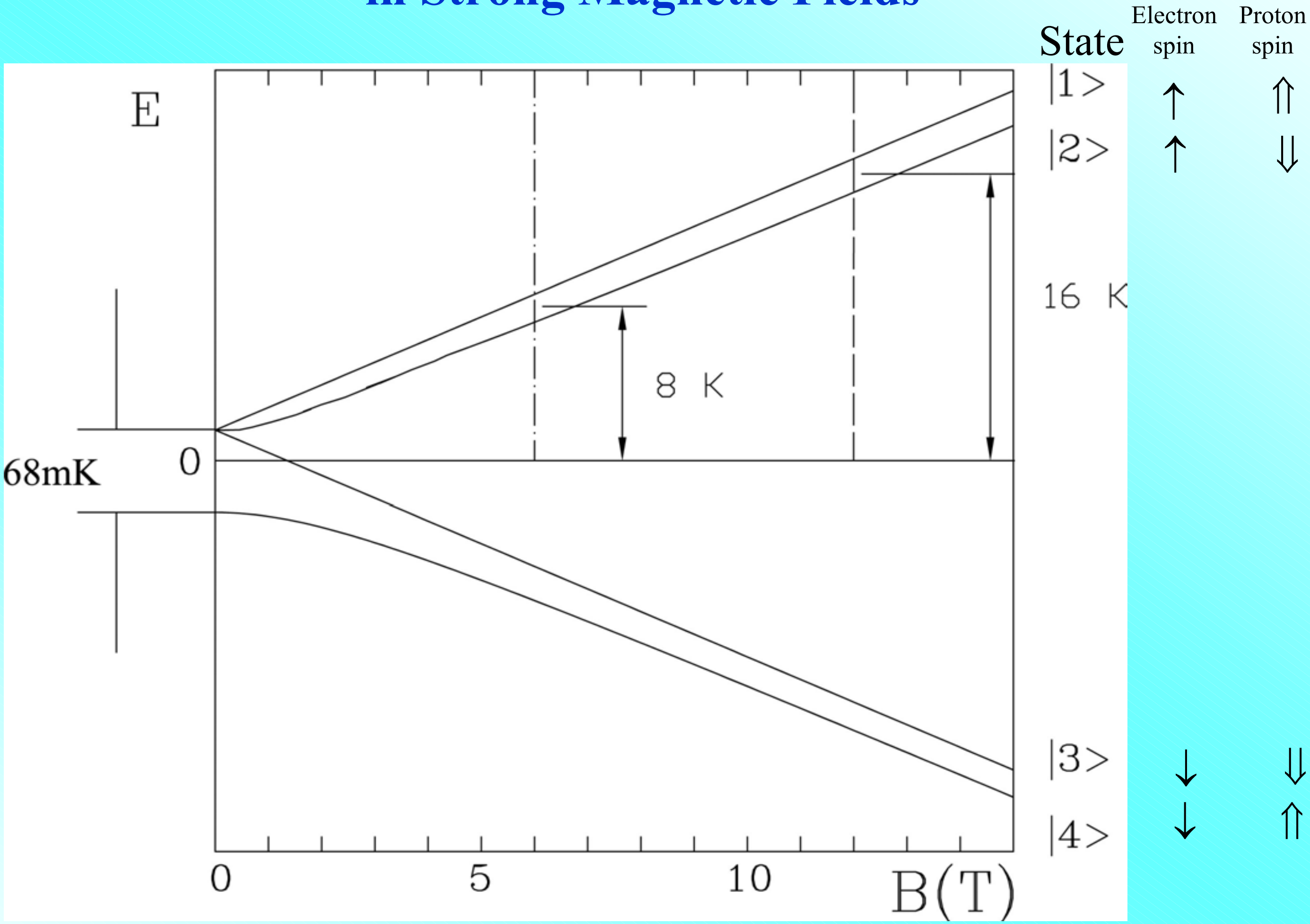


(D.G. Crabb et al. PRL **65,** 3241 (1990))

Advantages of Ultra-cold Polarized Atomic Hydrogen Gas Jet Target

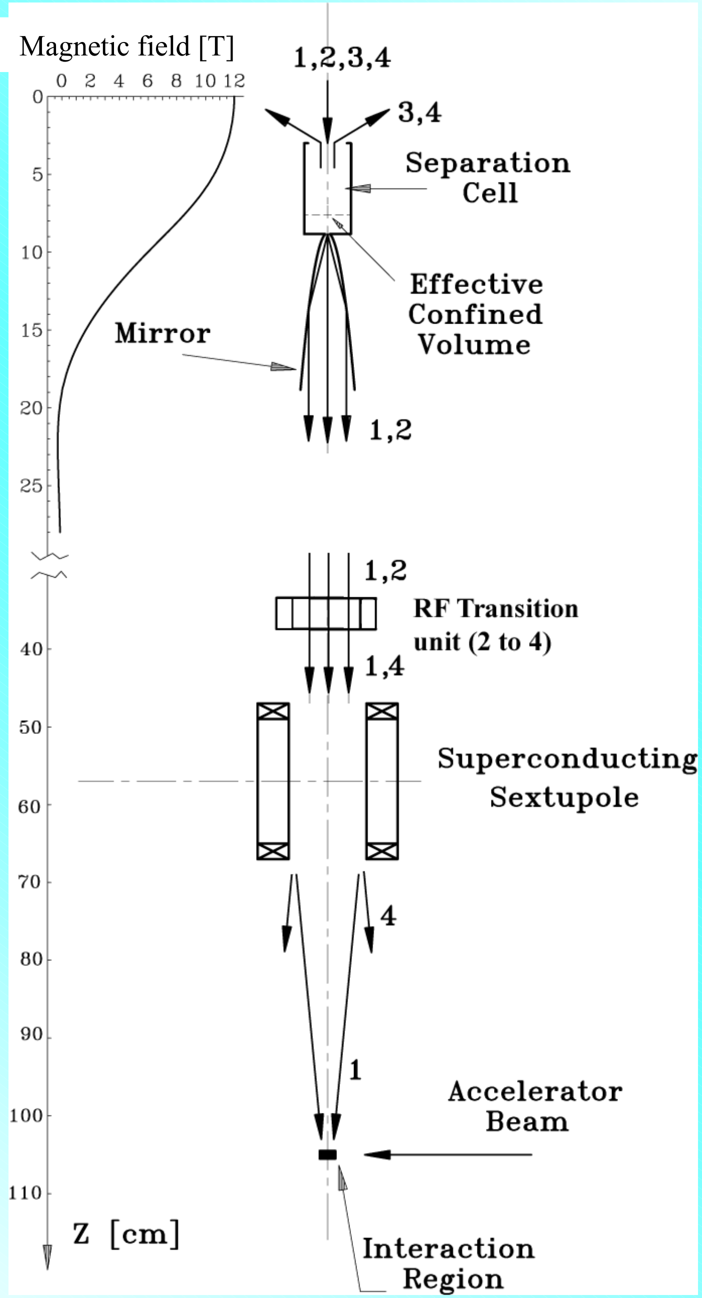
- Highly polarized proton/electron
- Pure atomic hydrogen
  - No background in scattering experiments
- No radiation damage
- Very monochromatic beam
  - Very small spot size
  - High density compared to other gas jet target

Energy diagram of atomic hydrogen in Strong Magnetic Fields



Schematic Breit-Rabi diagram for atomic hydrogen

Beam Formation



Acceleration by solenoid magnet

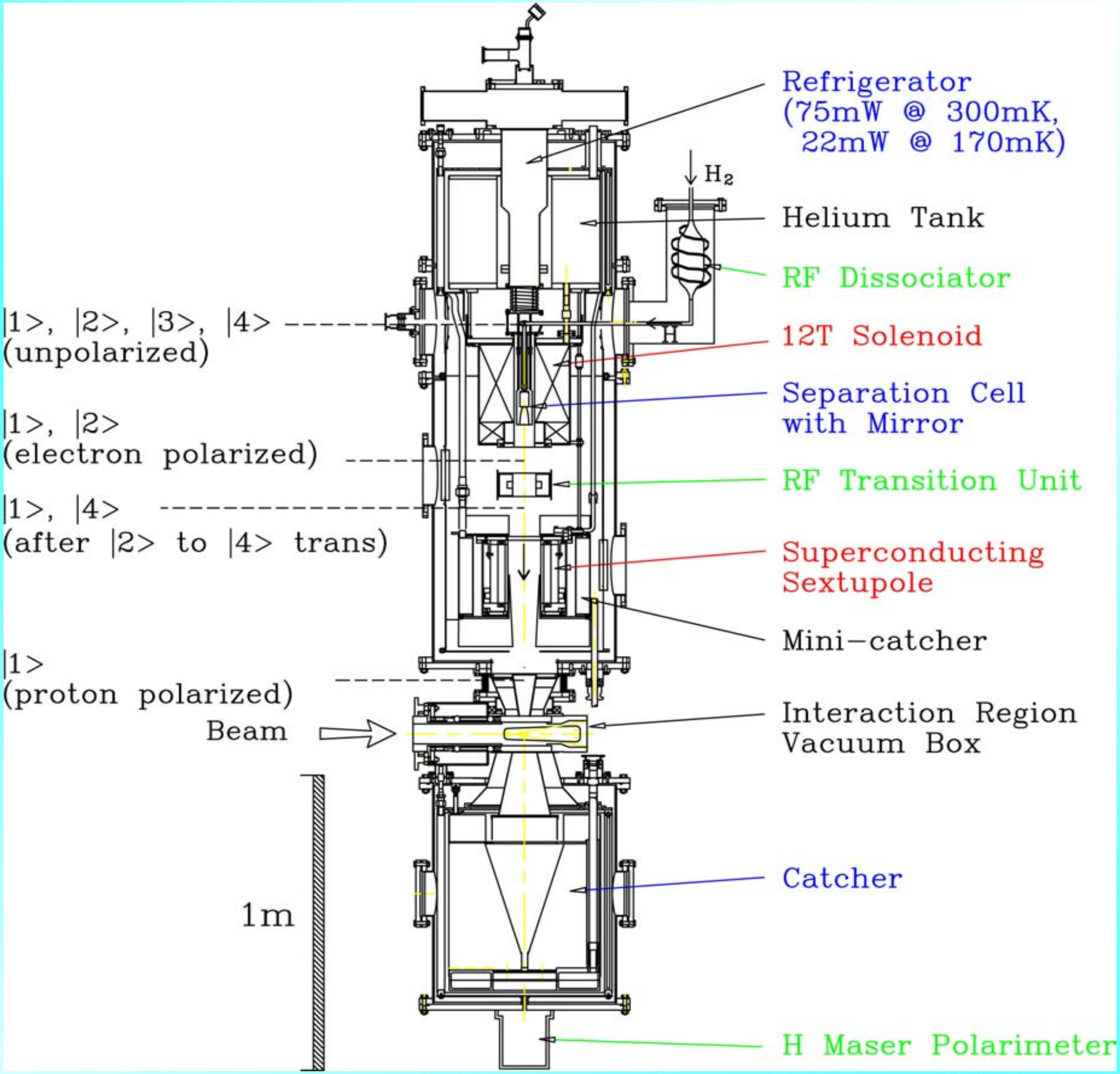
$F \sim -\mu_e\, \partial B_z/\partial z$

Focusing by sextupole magnet

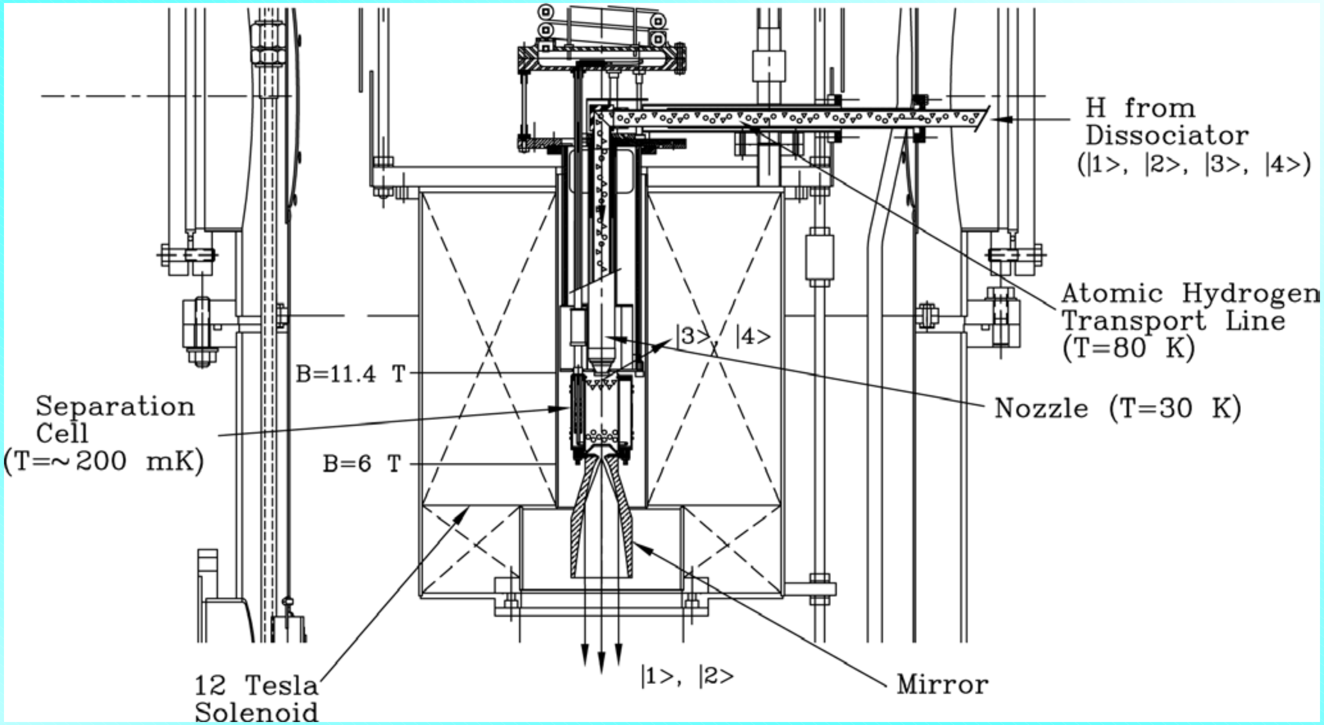
$F \sim -\mu_e\, \partial B/\partial r$

Proposed Michigan Ultra-Cold Jet

- **RF dissociator**:
  Produces unpolarized atomic-hydrogen
- **12T Solenoid**:
  Separates electron-polarized states
- **Separation cell**:
  Cools down atomic-hydrogen
- **Mirror**:
  Makes beam parallel
- **RF transition unit**:
  |2> to |4>transition
- **Sextupole magnet**:
  Focuses |1>
  Defocuses |4>
- **Catcher**:
  Cryocondensation pump
  1.2×10^7 l/sec
- **H Maser Polarimeter**:



Separation region



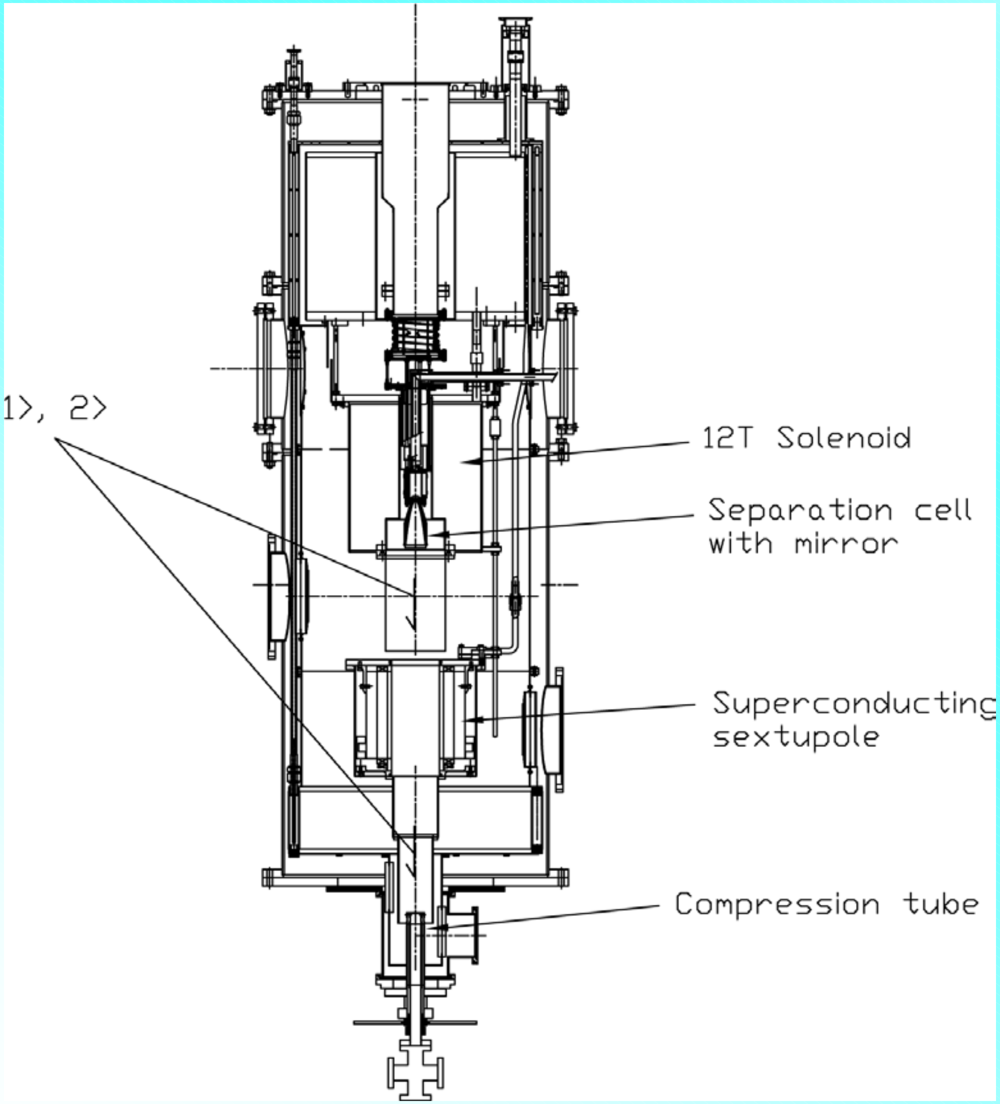
Parabolic mirror makes hydrogen beam parallel:

- ***Coated with superfluid ^{4}He film to suppress depolarization and recombination of hydrogen atoms***
- ***80 % mirror reflection of cold hydrogen from a helium-film-covered surface***

  (J.J. Berkhout et al. PRL ***63****, 1689 (1989))*
- ***Beam intensity increases by a factor of 3.***

Present Test Assembly

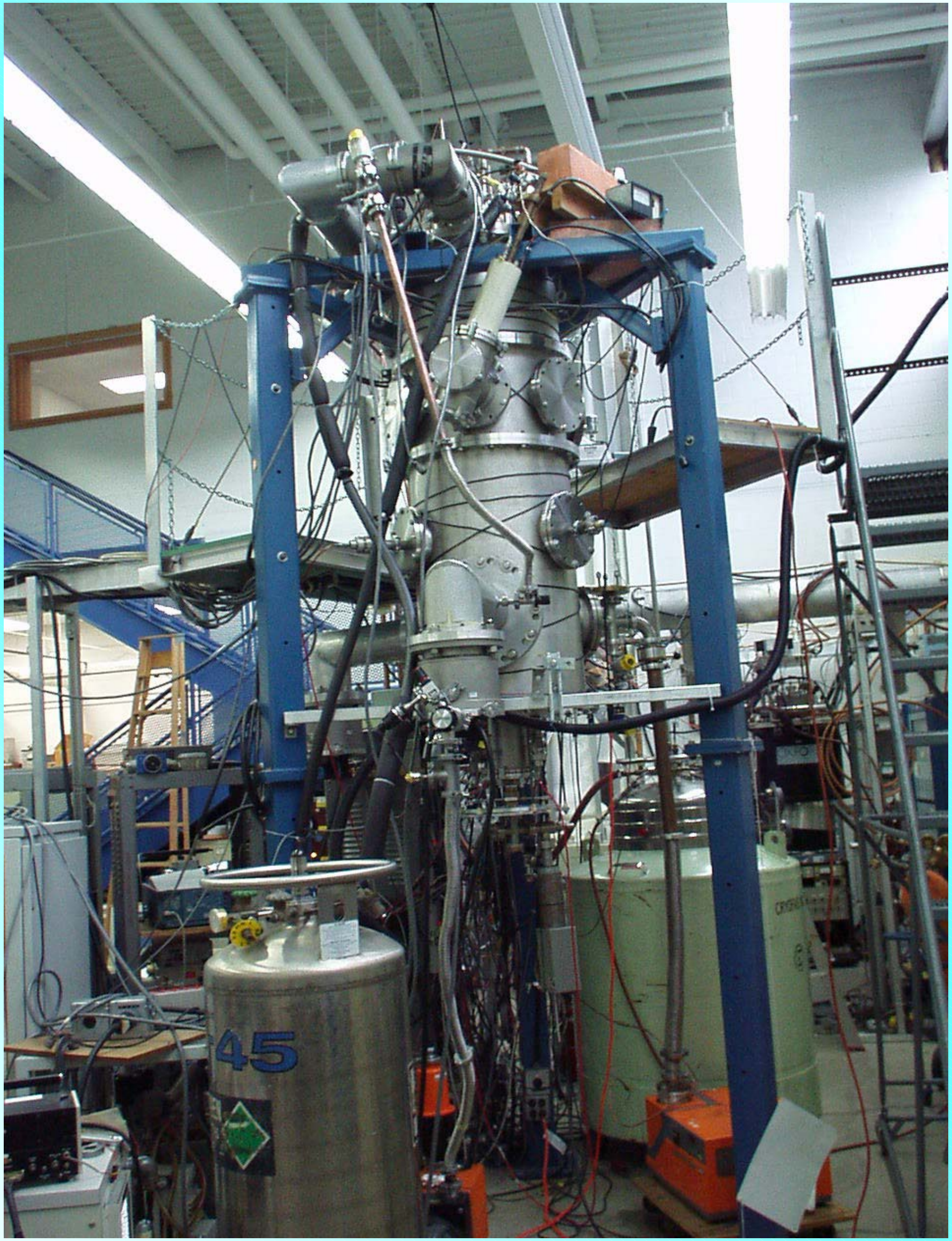
Now being constructed and tested



RF transition unit
Maser polarimeter

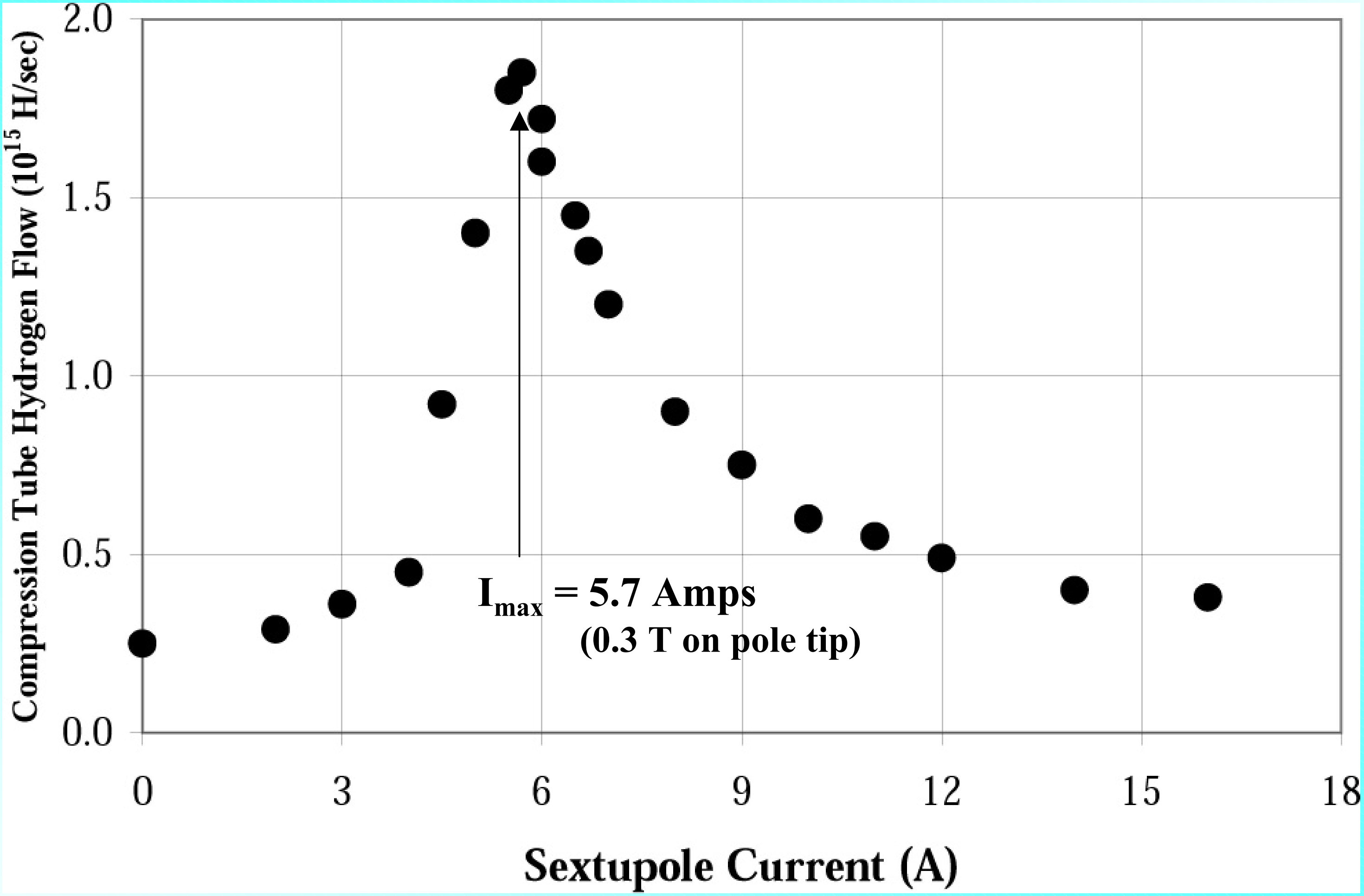
(R.S. Raymond, PST Proceedings, *Erlangen, Germany* (1999))

Electron polarized Hydrogen gas jet target is available


45

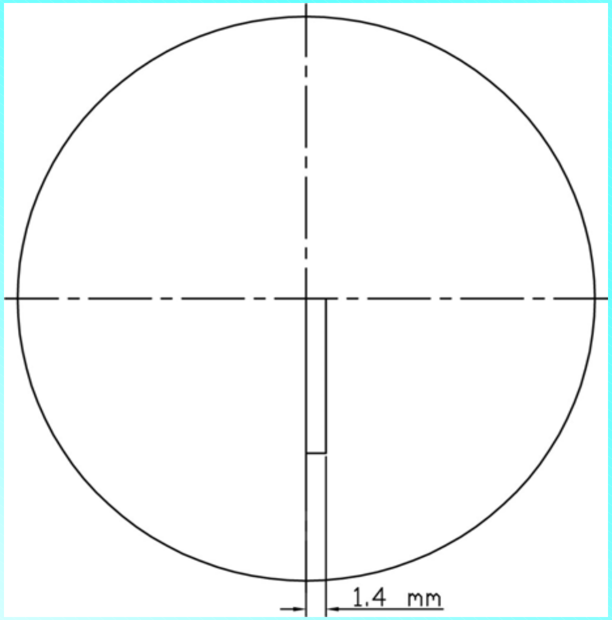
Hydrogen Flow Rate vs Sextupole Magnet Current

(February 2000)

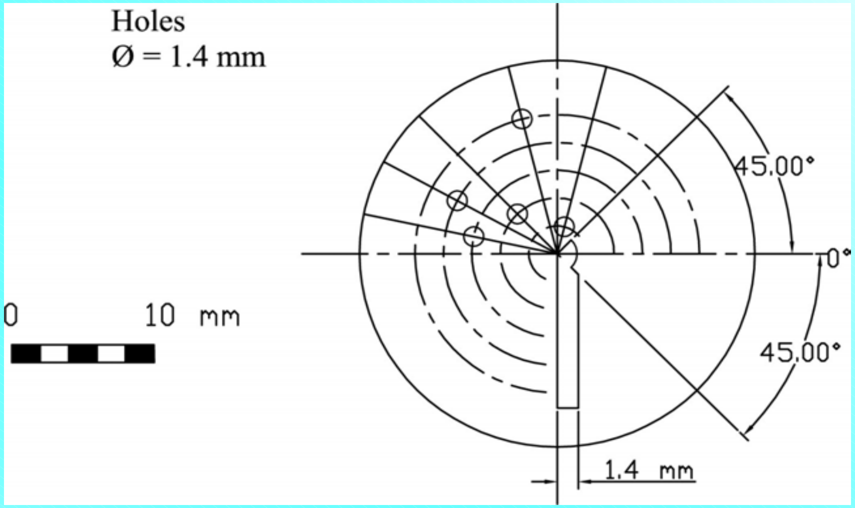


Compression Tube Covers

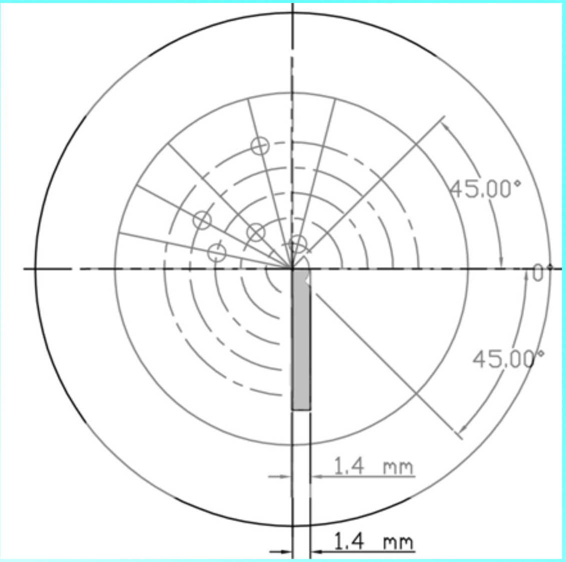
Top Cover



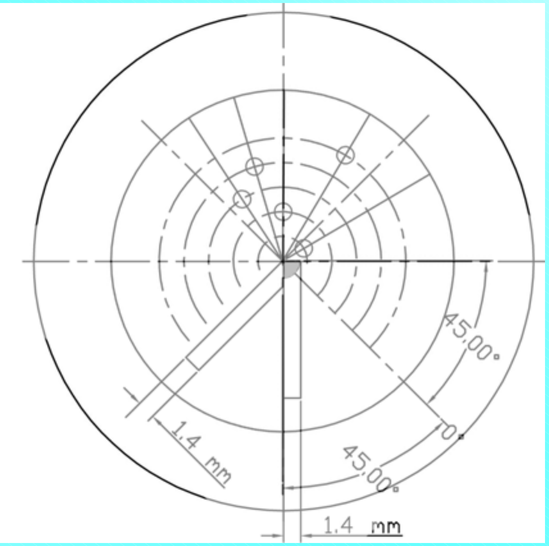
Bottom Cover



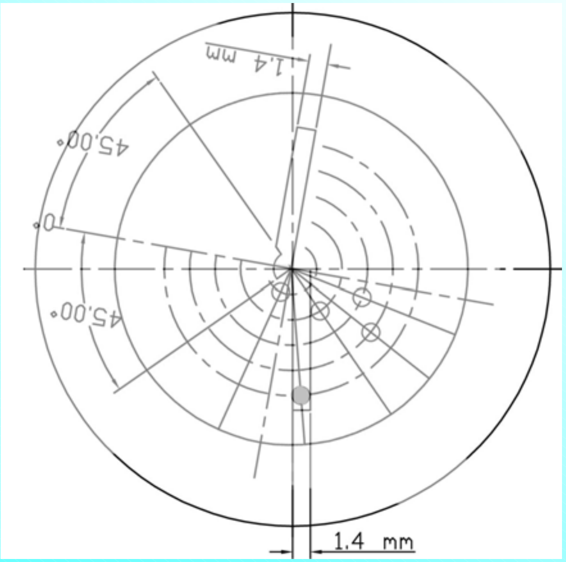
Rotation bottom cover



Long slot



0 mm hole
(center hole)

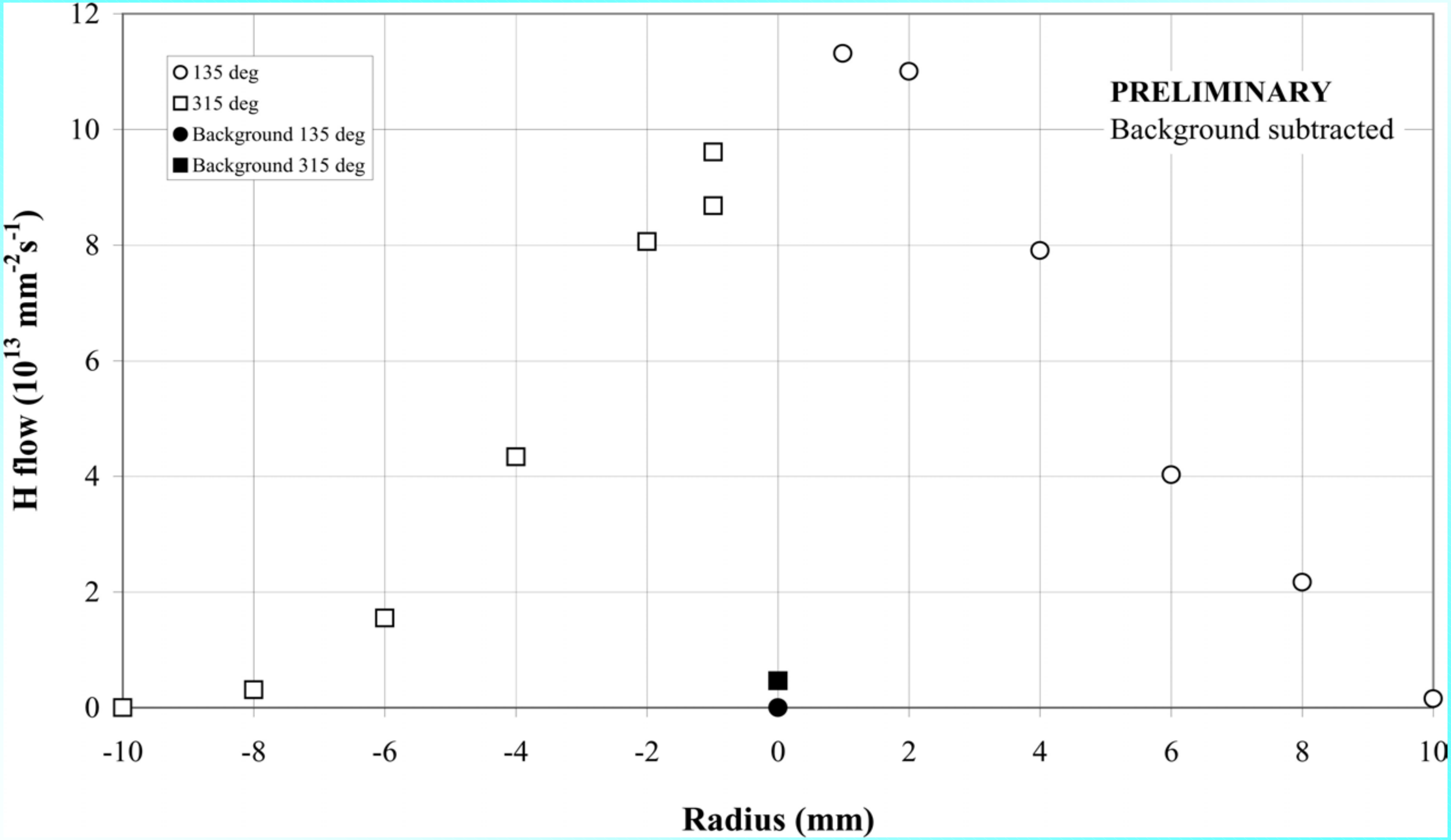


10 mm hole

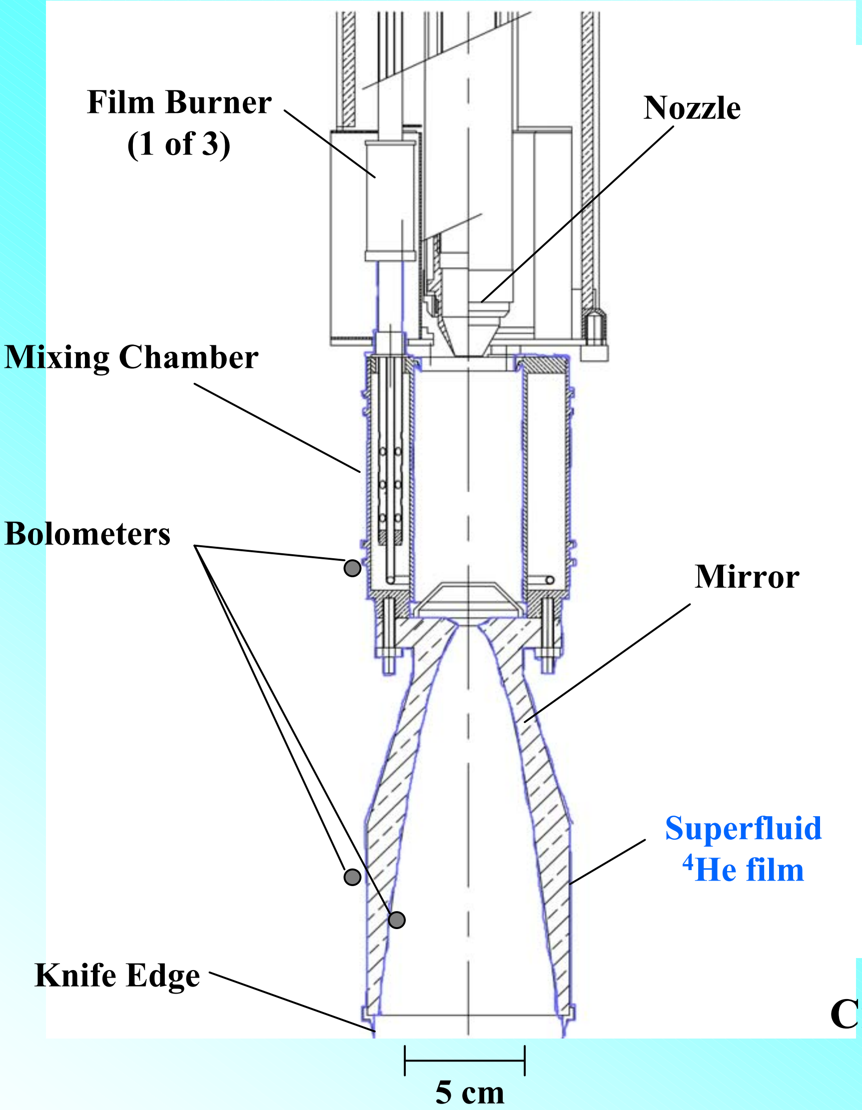
Radial Beam Distribution

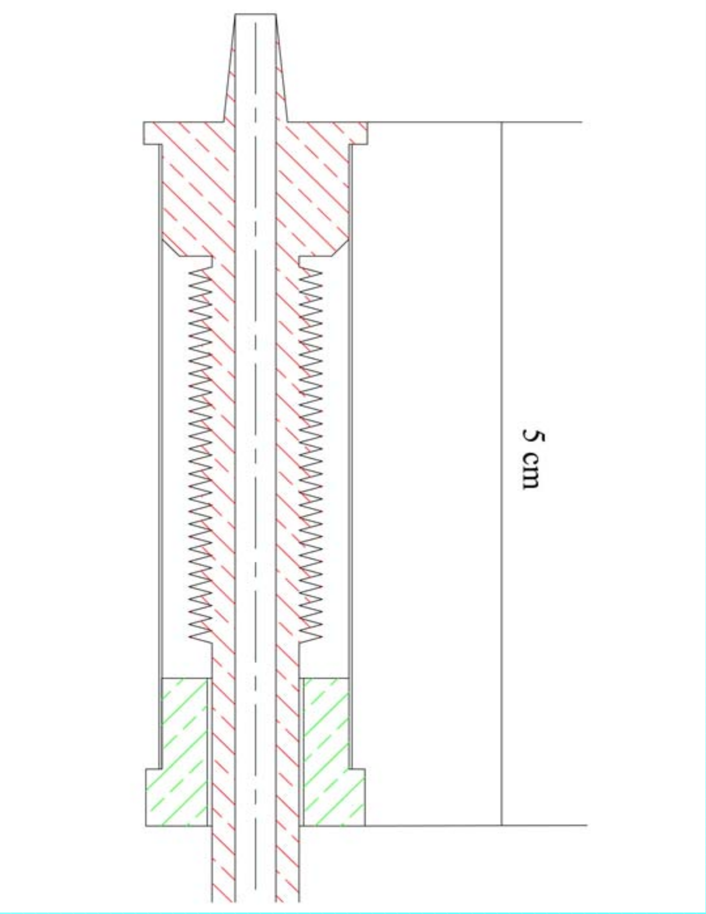
T_{nozzle} = 30 K; H_2 flow = 0.52 sccm; CT angle =135 deg

(August 2002)



Film Burner assembly

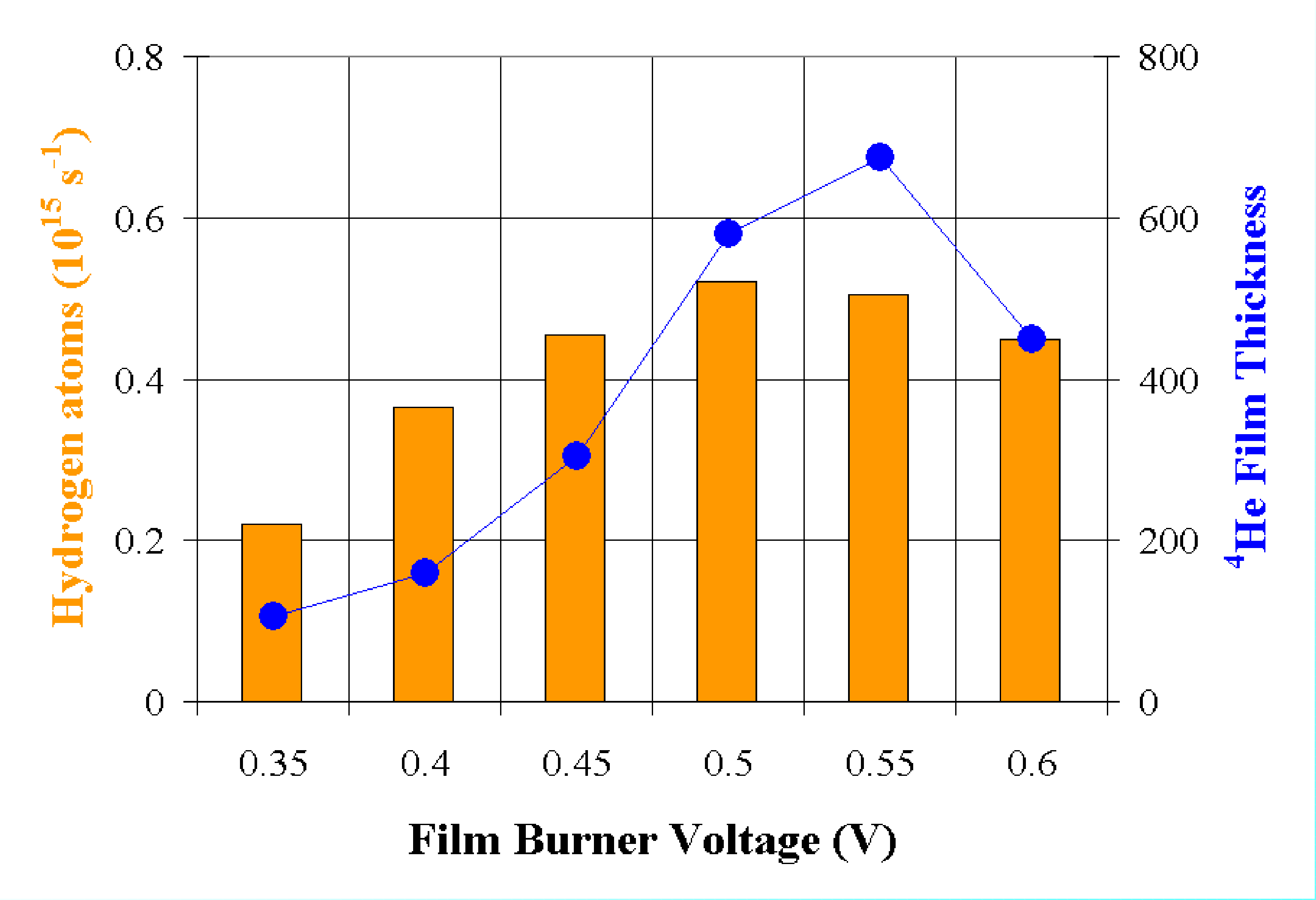




Cross-sectional view of Film Burner

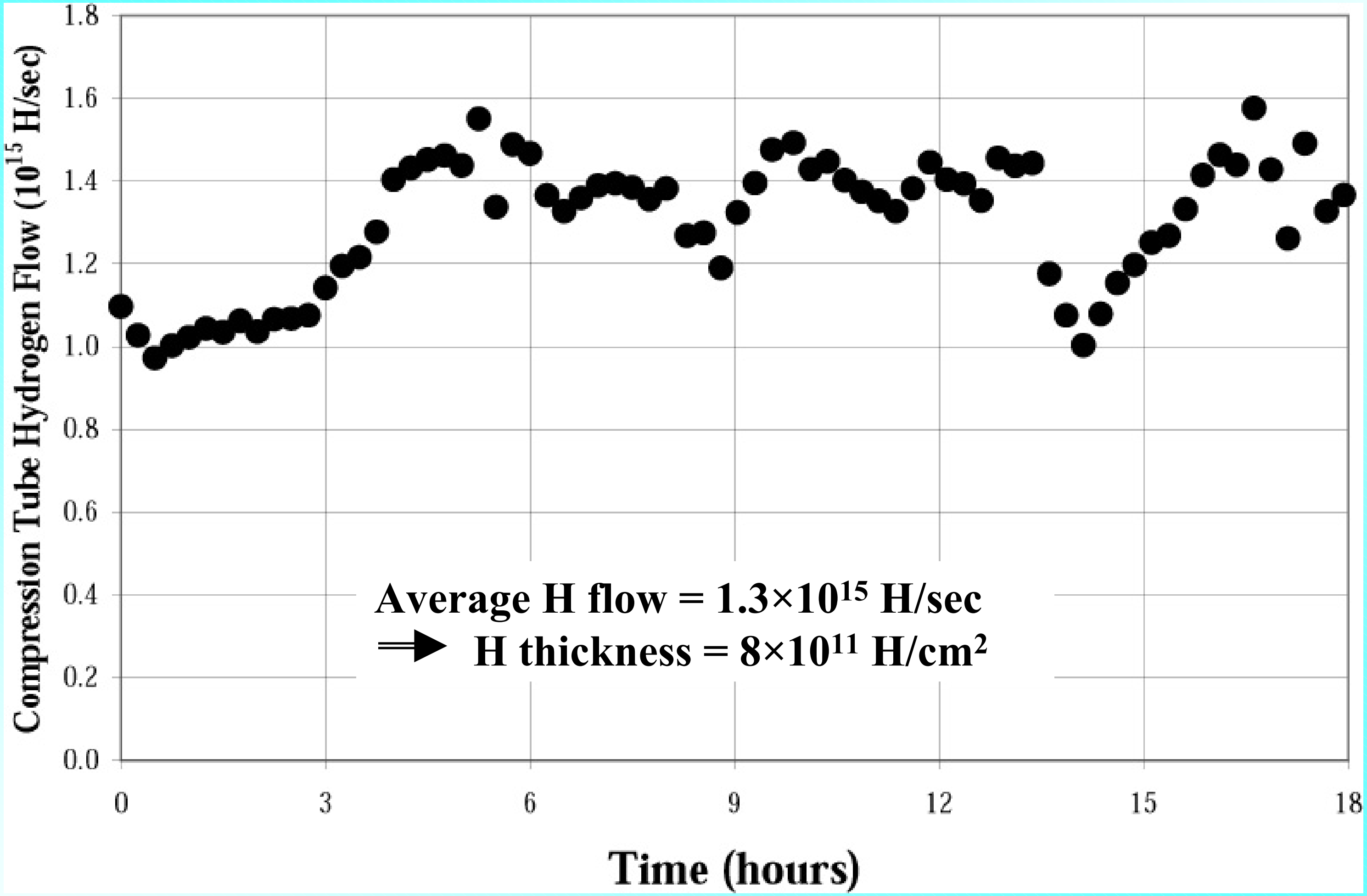
CT signal vs Film Burner Voltage

(August 2003)



Long Term Hydrogen Flow Stability

(August 2002)



Present status of Michigan Jet

- Basic parameters
  - *Velocity of atomic hydrogen at CT (interaction region)* **~ 280 m/sec**
  - *Electron polarization* **~ 100 % (in high field)**
  - *Proton polarization* **~ 50 % (in low field)**

- Summary of long term flow stability
  - *Average hydrogen flow* **1.3×10^{15} H/sec**
  - *Average hydrogen jet thickness* **8×10^{11} H/cm^2**
  - *Longest running time* **18 hours**

- Maximum hydrogen jet thickness **1.1×10^{12} H/cm^2**

Spin-Flipping Polarized Deuterons at COSY*

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*Research supported by a Research Grant from the U.S. Department of Energy

Motivation for the Research

In scattering asymmetry experiments with polarized beams in storage rings, the systematic error may be greatly reduced by frequently reversing the stored beam's polarization direction.

Artificial rf-induced spin resonances can be used to cause such reversals, or spin-flips, in a well-controlled way.

Spin motion in an accelerator ring

- Unperturbed spin motion can be seen as precession of the spin-polarization vector around vertical fields of the ring's dipoles.

- The number of precessions during one turn around the ring is the spin tune:

$$\nu_{sp} = G\gamma,$$

  - G is a gyromagnetic anomaly
  - γ is the Lorentz energy factor.

- Horizontal rf magnetic fields can cause a spin resonance whenever the rf field's frequency f_{rf} is correlated with the spin precession frequency as:

$$f_{rf} = f_c(k \pm \nu_{sp}),$$

  - f_c is a circulation frequency
  - k is an integer.

The Idea of Spin-Flipping

The final vector polarization of the beam P_f, after an adiabatic linear crossing of an isolated spin resonance, is given by the Froissart-Stora formula:

$$P_f = P_i\left(2e^{-\frac{\pi|\varepsilon|^2}{2\alpha}} - 1\right)$$

where P_i is the initial vector polarization, ε is the resonance strength, and α is the resonance crossing rate:

$$\alpha = \frac{1}{2\pi f_c^{\,2}}\frac{df_{rf}}{dt}$$

In the extreme case of a strong resonance and a low crossing rate, one has:

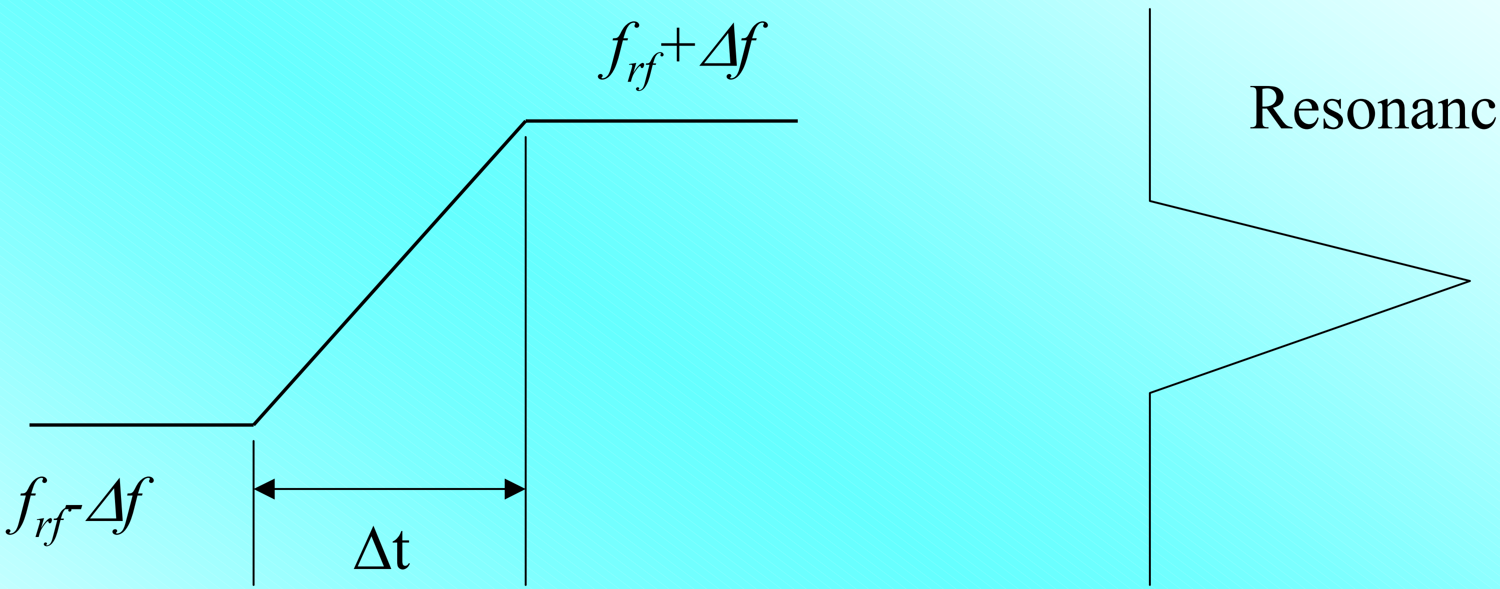
$$\frac{\pi|\varepsilon|^2}{2\alpha} >> 1 .$$

Then $P_f \approx - P_i$; thus the polarization is flipped by 180^0 with almost no depolarization.

The spin-flip efficiency is defined as:

$$\eta = \frac{-P_f}{P_i}$$

Concept sweeping frequency



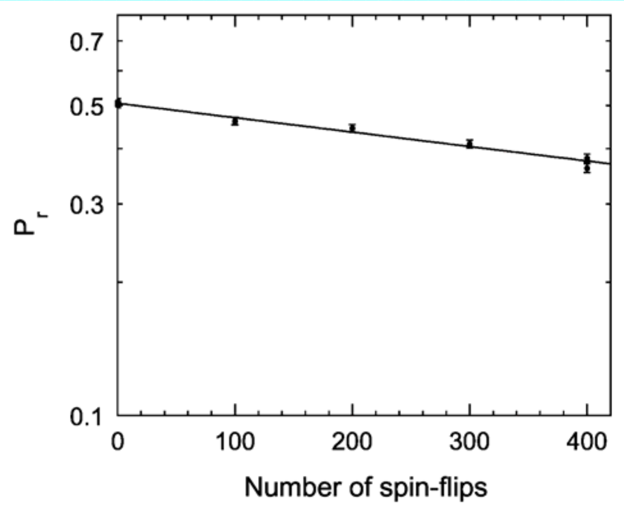
Single spin flipping

Properties of particles

Electron	$G=1.1597\times10^{-3}$ $\mu=1.0011597\mu_B$ $\mu_B=5.79\times10^{-11}$ MeV/T
Proton	$G=1.7928$ $\mu=2.7928\mu_N$ $\mu_N=3.15\times10^{-11}$ MeV/T
Deuteron	$G=-0.14299$ $\mu=0.8574\mu_N$ $\mu_B=3.15\times10^{-11}$ MeV/T
Muon	$G=1.1659\times10^{-3}$ $\mu=1.0011659\mu_B$ $\mu_B=2.80\times10^{-13}$ MeV/T

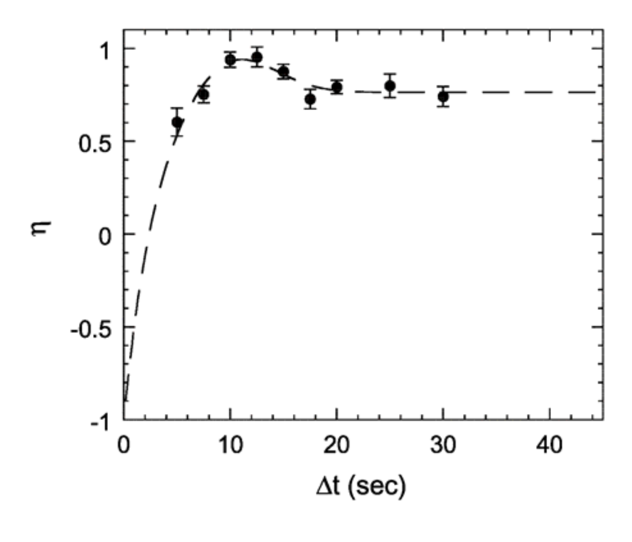
Results of polarized proton and electron beams

Polarized Proton beam run @IUCF



The measured radial proton polarization at 120 MeV is plotted against the number of spin flips. The measured spin-flip efficiency is 99.93 ± 0.02%. [1,2]

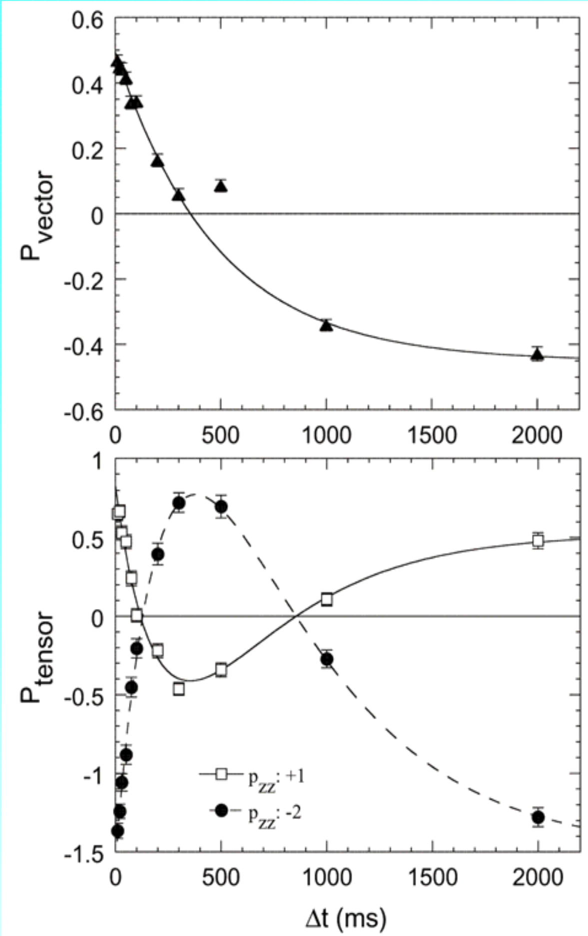
Polarized Electron beam run @MIT



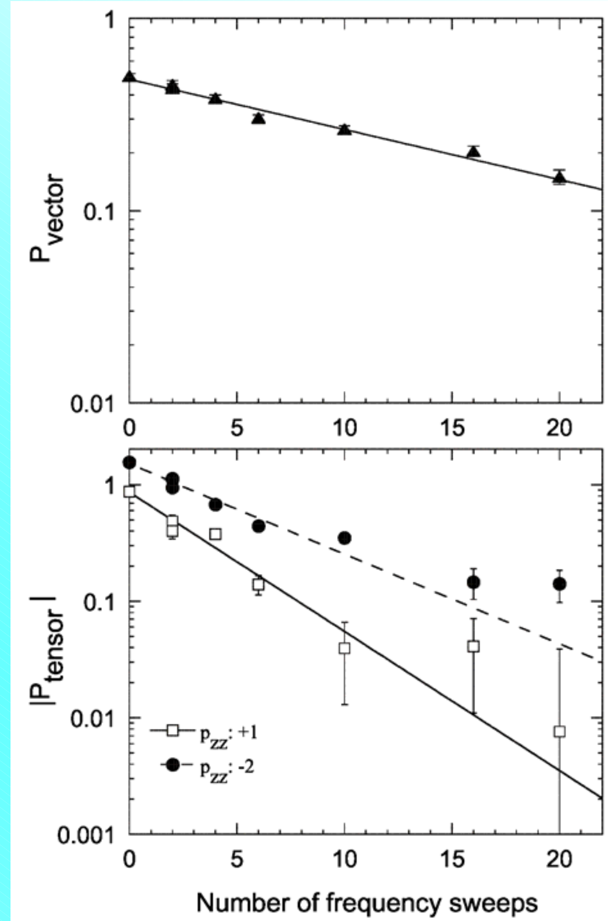
The efficiency of spin-flipping the electron beam at 669.2 MeV is plotted against the rf dipole's ramp time Δt. The measured spin-flip efficiency is 94.5 ± 2.5%. [3]

[1] B. B. Blinov *et al.*, Phys. Rev. Lett. **88**, 014801 (2002).
[2] "Snake charming induces spin-flip", CERN Courier, **42**, No. 3, News p. 6 (April 2002).
[3] V.S. Morozov *et al.*, Phys. Rev. ST-AB **4**, 104002 (2001).

Polarized Deuteron run @ IUCF



Spin-flipping the vector and the tensor polarization of 270 MeV deuterons. The vector and tensor polarization are each measured, and are then plotted against the rf solenoid's ramp time Δt. Note that both are flipped, but at different Δt values. [4]



The measured vector and tensor deuteron polarizations at 270 MeV are plotted against the number of frequency sweeps. The measured vector polarization spin-flip efficiency is 94 ± 1%. [4]

[4] "Spin flipping and polarization lifetimes of a 270 MeV deuteron beam", V.S. Morozov *et al.*, *Proc. SPIN 2002: 15th International Spin Physics Symposium*, Brookhaven, Sept 2002

What’s happen for higher γ Deuteron beam?

Polarization of a Beam of Spin-1 Deuterons

- A spin-1 particle has three possible spin states $|p_z\rangle$ along the vertical axis: $|+1\rangle, |0\rangle, |-1\rangle$.
- The degree of vector polarization is given by

$$p_Z = \frac{N_+ - N_-}{N_+ + N_0 + N_-} \ .$$

- The degree of tensor polarization is given by

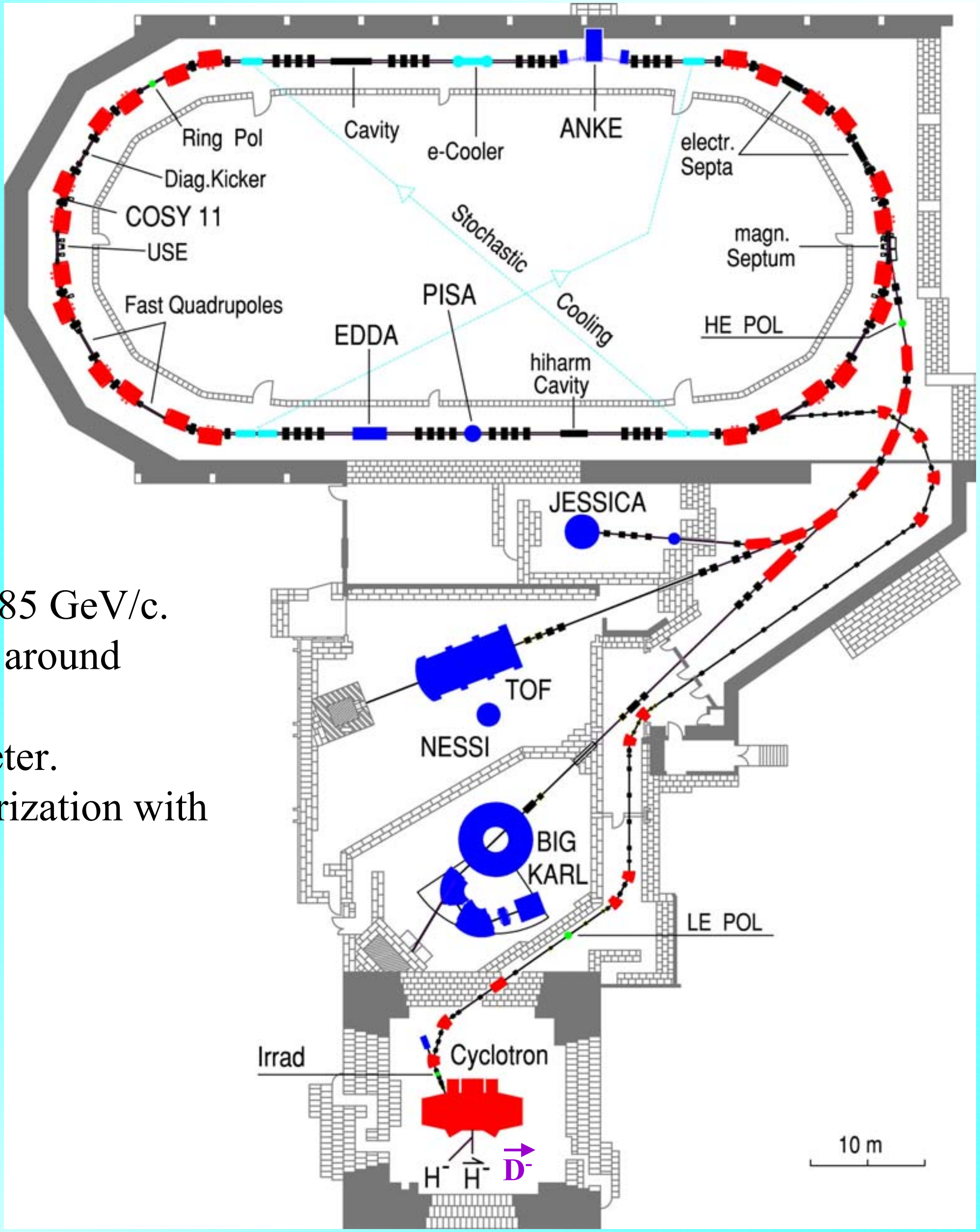
$$p_{ZZ} = 1 - \frac{3N_0}{N_+ + N_0 + N_-} \ ,$$

where N_+, N_0 and N_- are the number of particles in the $|+1\rangle, |0\rangle, \text{and} |-1\rangle$ states.

- To reduce the systematic error we normally cycled COSY's deuteron source through the four vertical polarization states:

$$|p_z \, p_{zz}\rangle \ \text{of} \ |1\,1\rangle, |-1\,1\rangle, \left|-\tfrac{1}{3}\ -1\right\rangle, \ \text{and} \ \left|-\tfrac{2}{3}\ 0\right\rangle .$$

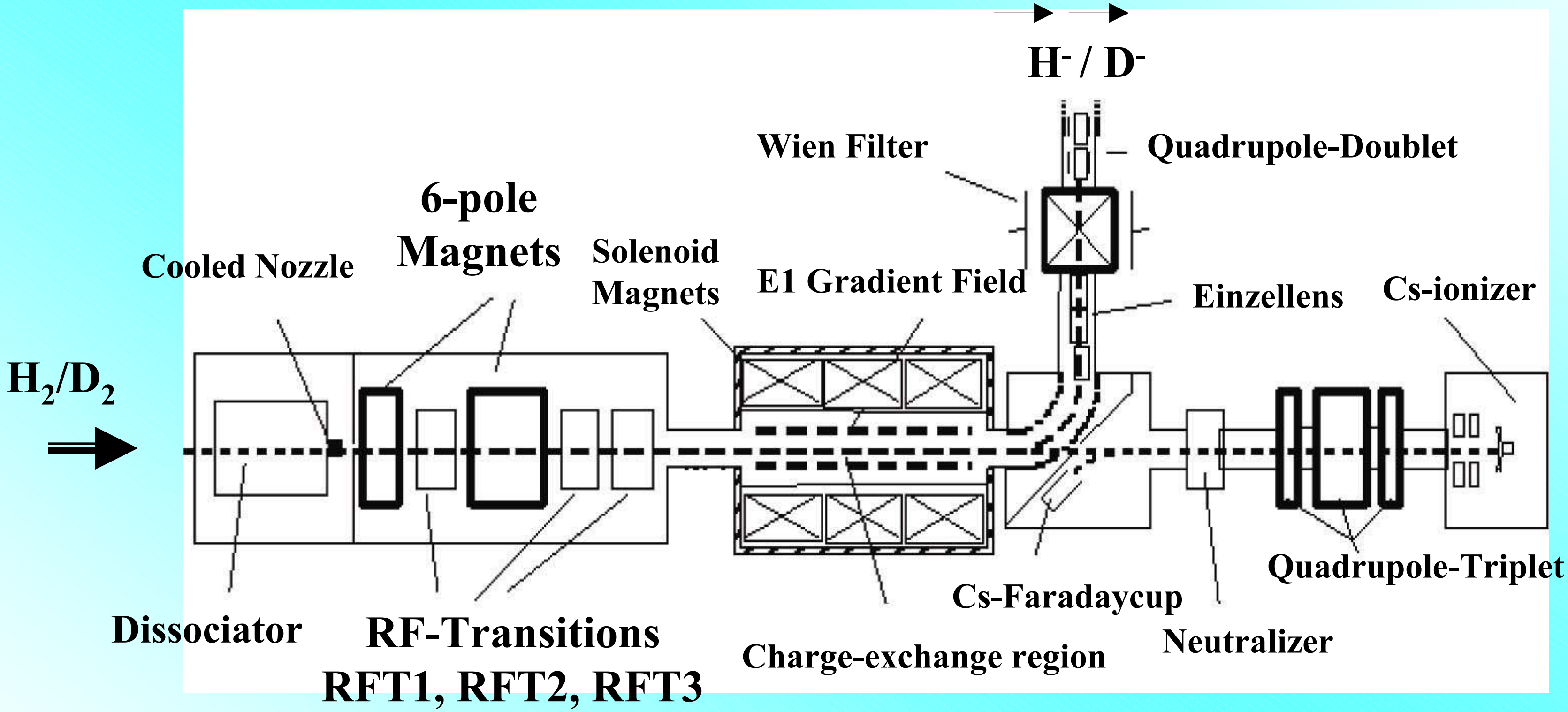
COSY layout



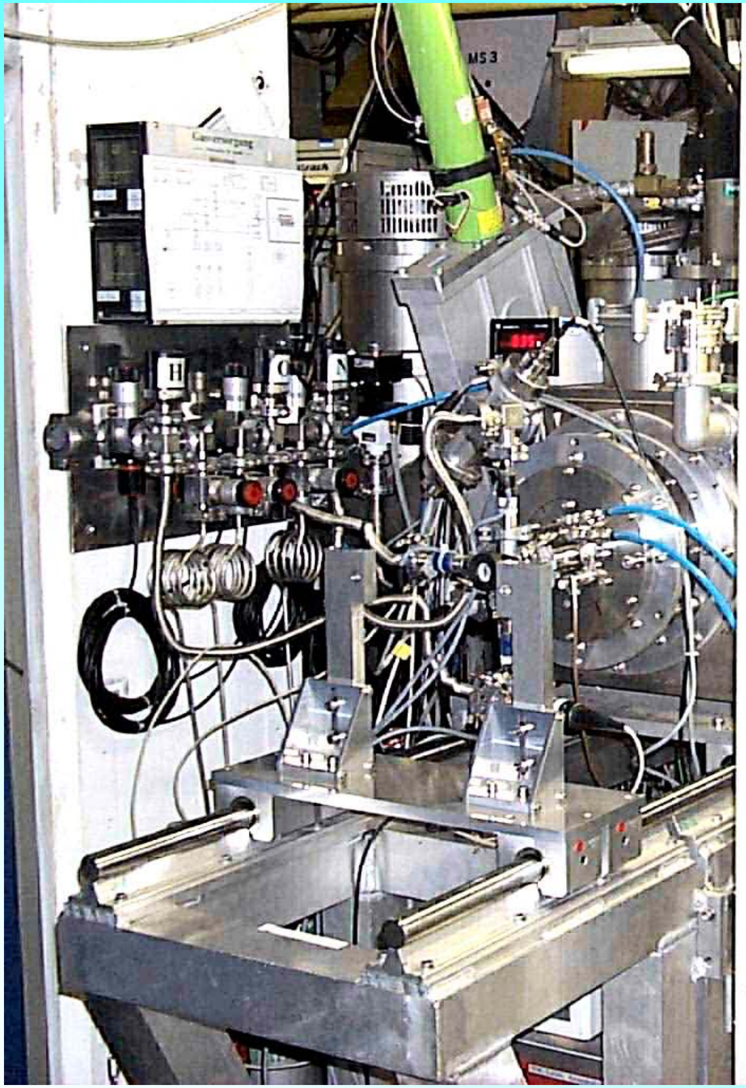
- Momentum of deuterons was 1.85 GeV/c.
- RF dipole magnet was installed around the Fast Quadrupole magnet.
- We used EDDA as the polarimeter.
- We monitored the injected polarization with the Low Energy Polarimeter.

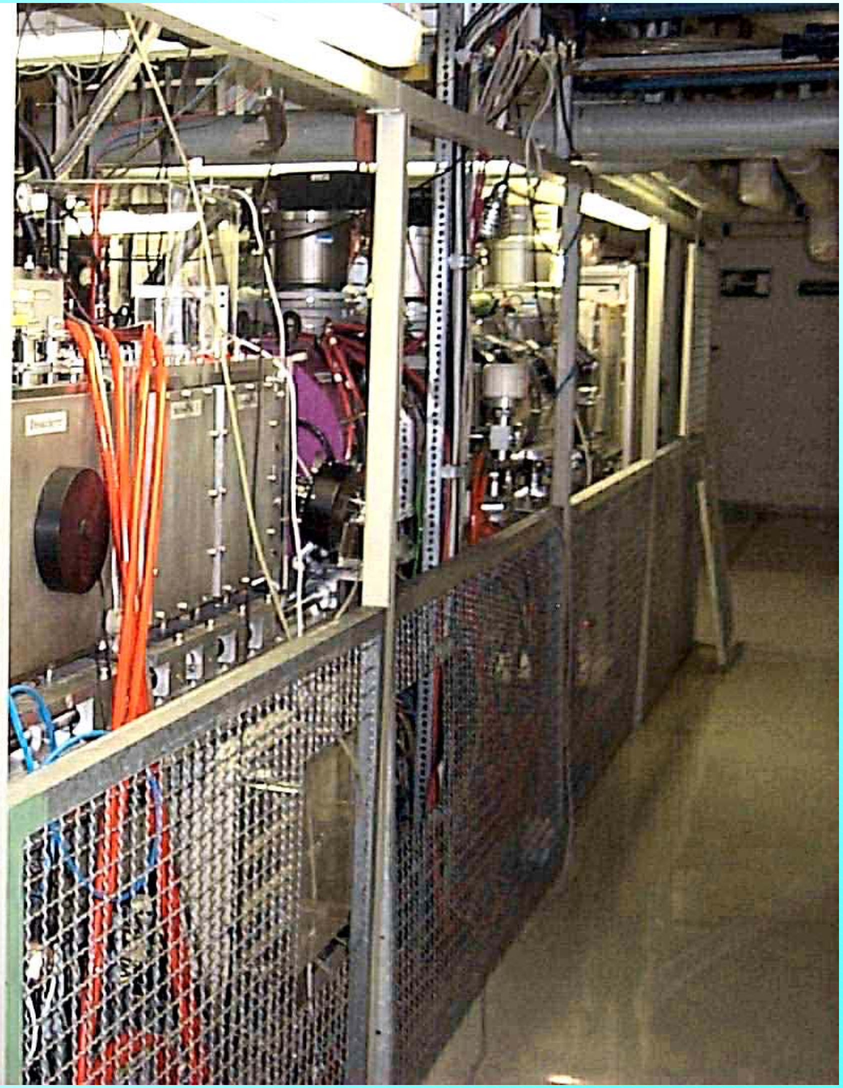
COoler-SYnchrotron COSY

COSY ABS polarized H⁻/D⁻ ion source

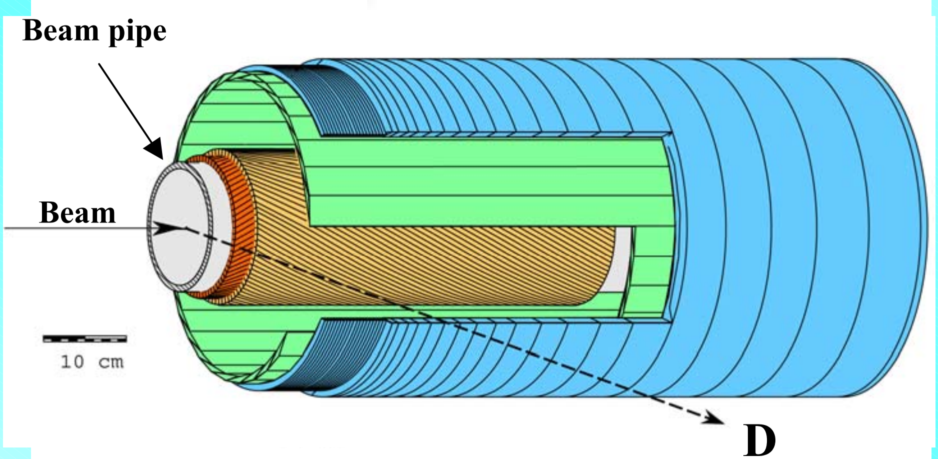


COSY ABS polarized H^-/D^- ion source

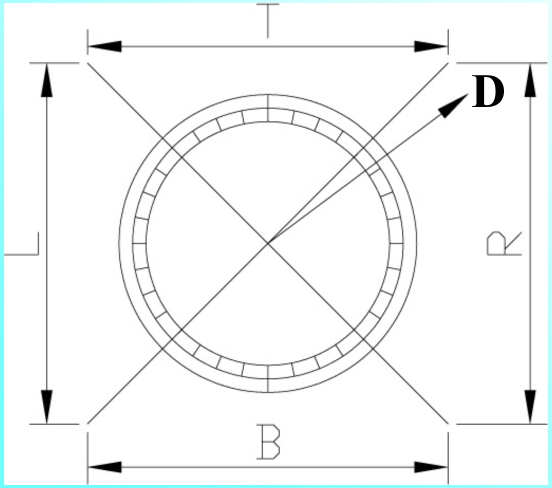




EDDA polarimeter

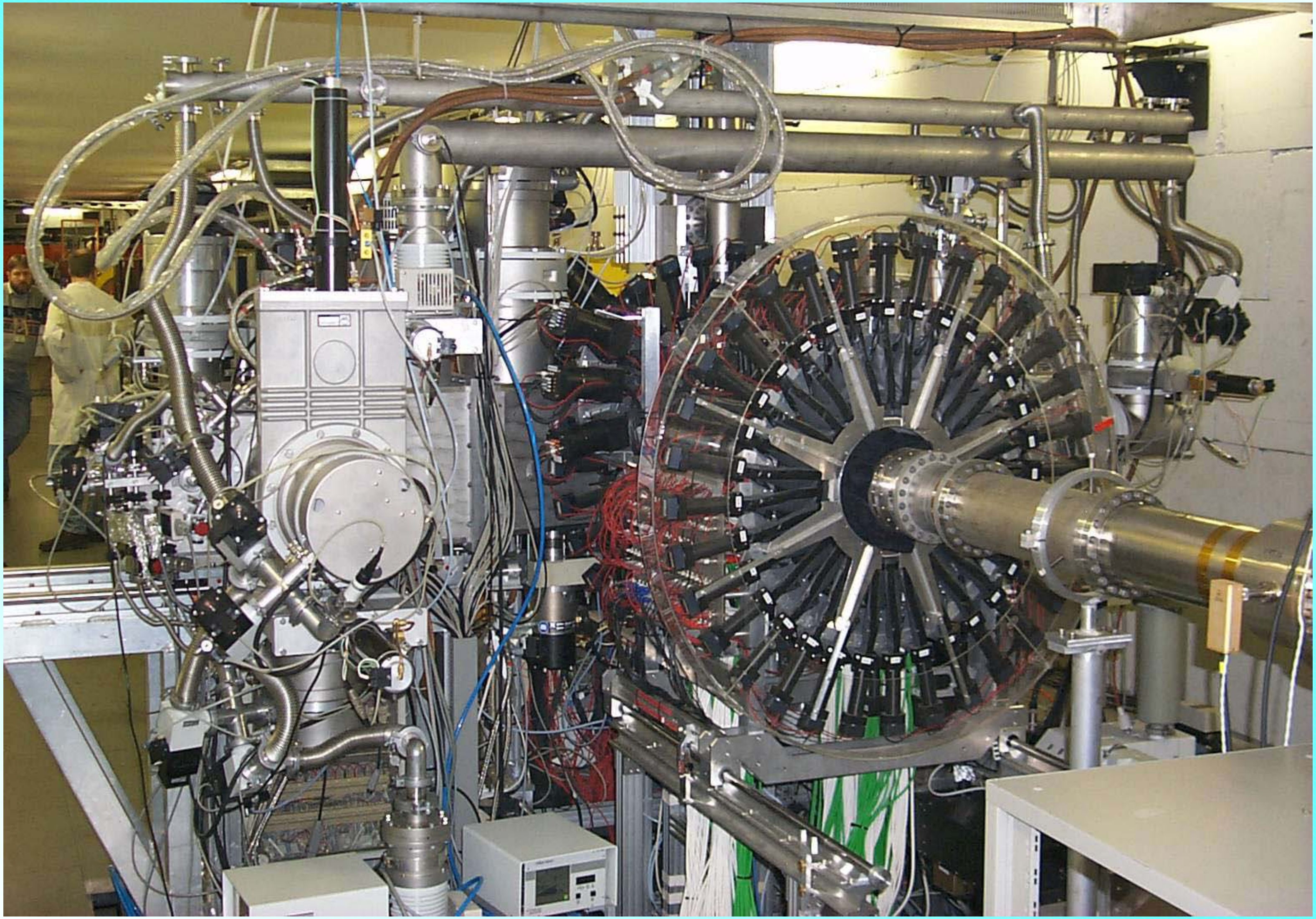


- two-layered cylindrical scintillator structure
  - Outer Layer (→ trigger!)
    D: 32 overlapping slabs of triangular cross-section ($\Delta\phi = 11.25^o$)
    F,R: 2x29 semirings ($\Delta\theta_{\mathrm{lab}} = 2.5^o$)
    left semirings $\phi \in [-90^o, 90^o]$
    right semirings $\phi \in [90^o,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

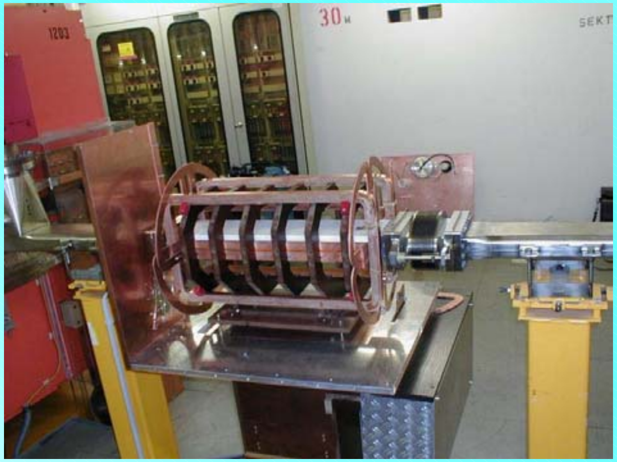


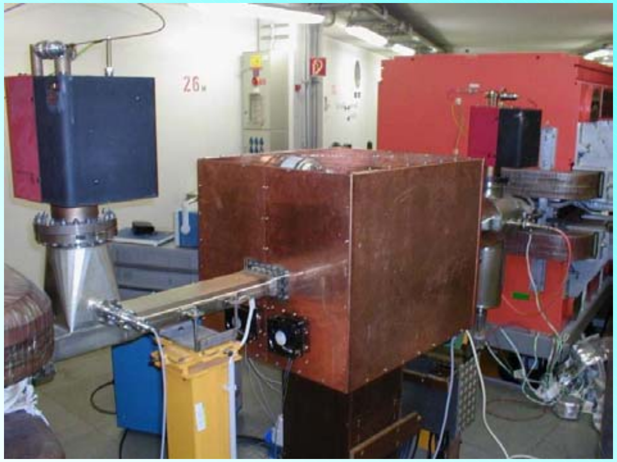
Cross-sectional view of Outer Layer

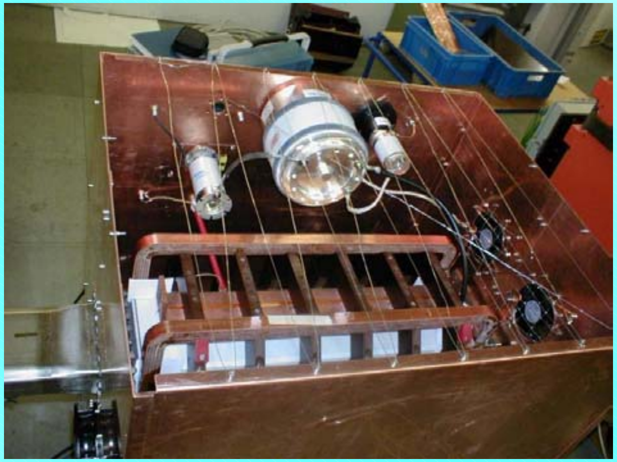
EDDA Polarimeter



COSY RF Dipole Magnet

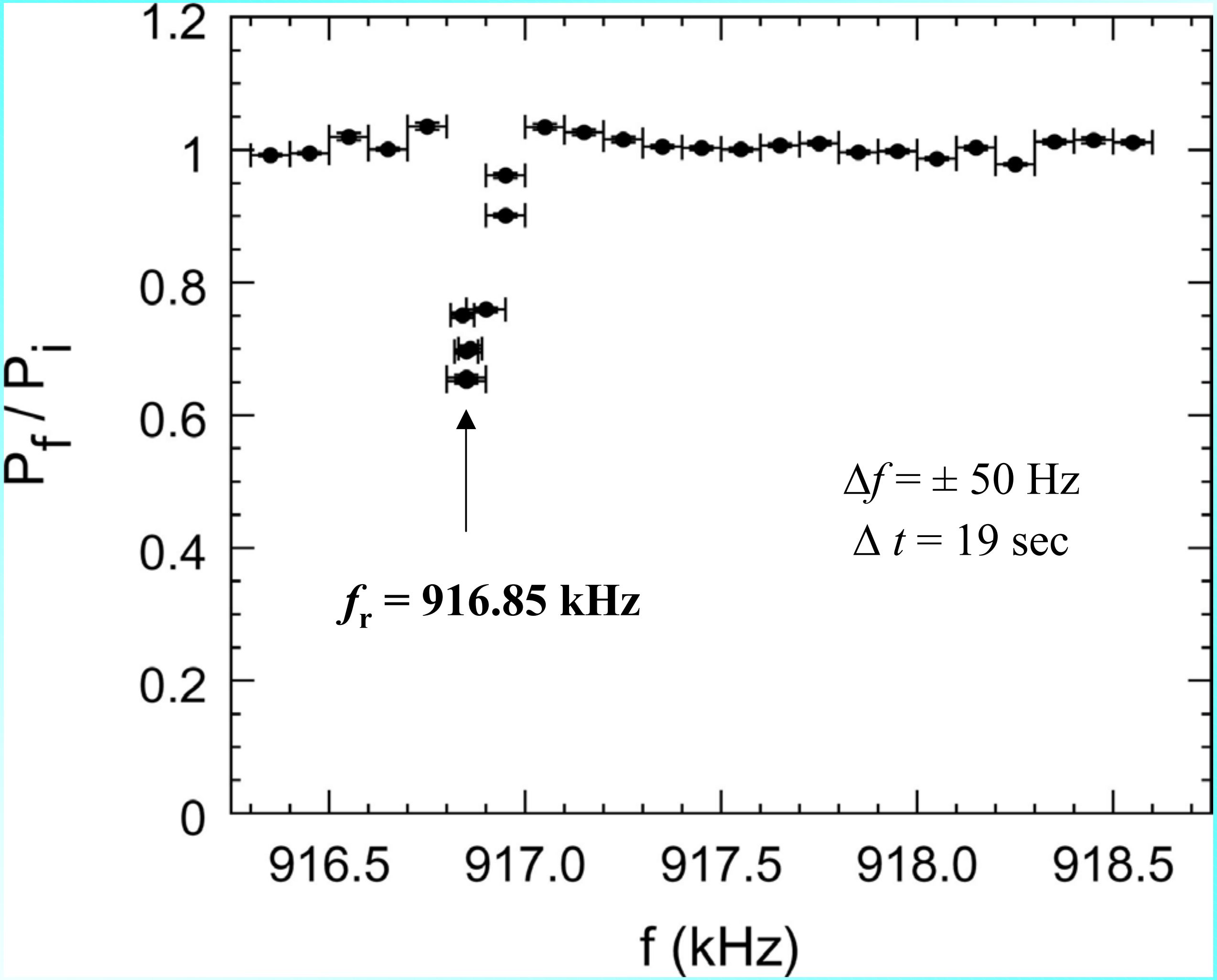




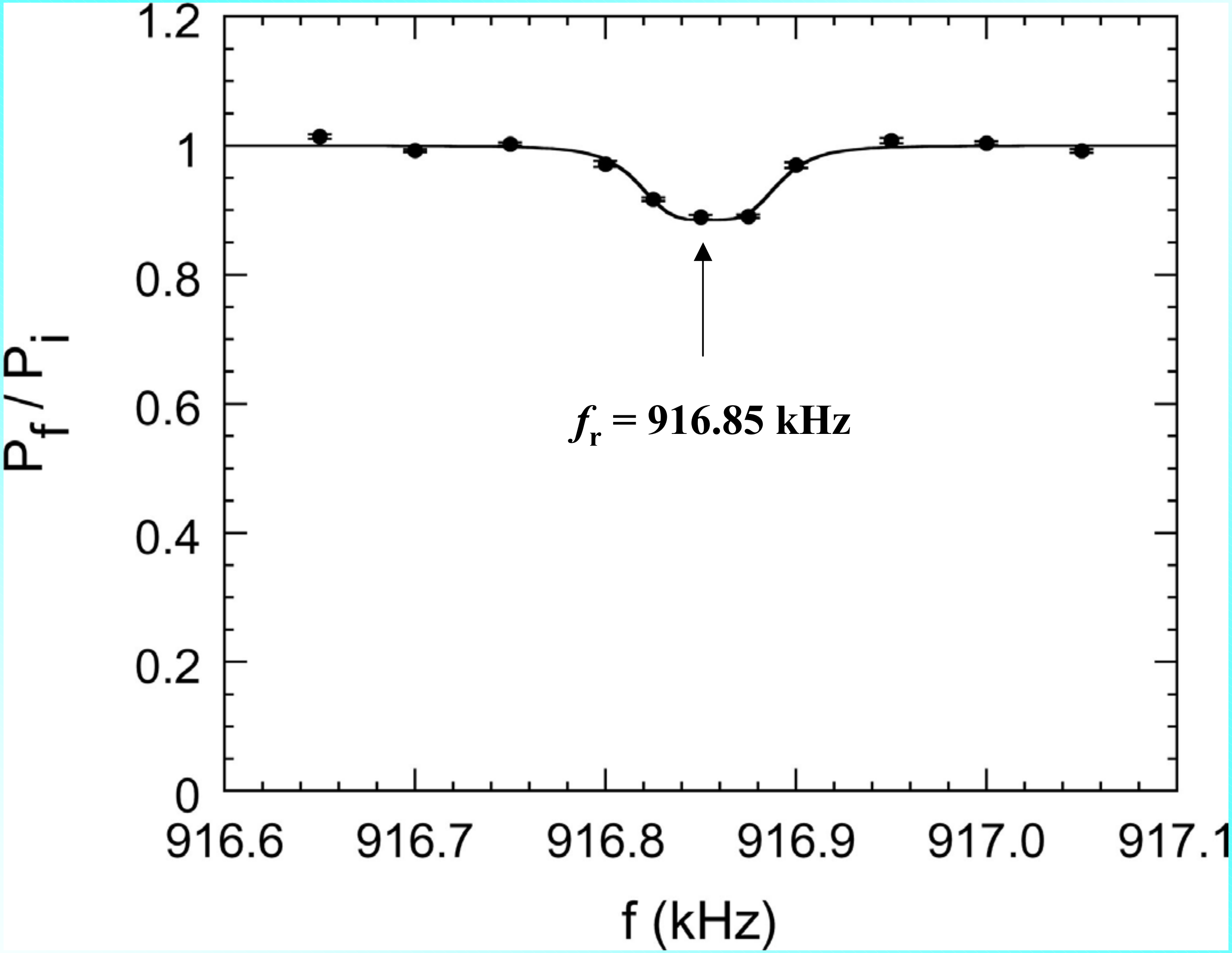


- $\int B \cdot dl \;\; = 0.2$ T·mm
- Air-core type
- Ceramic vacuum tube

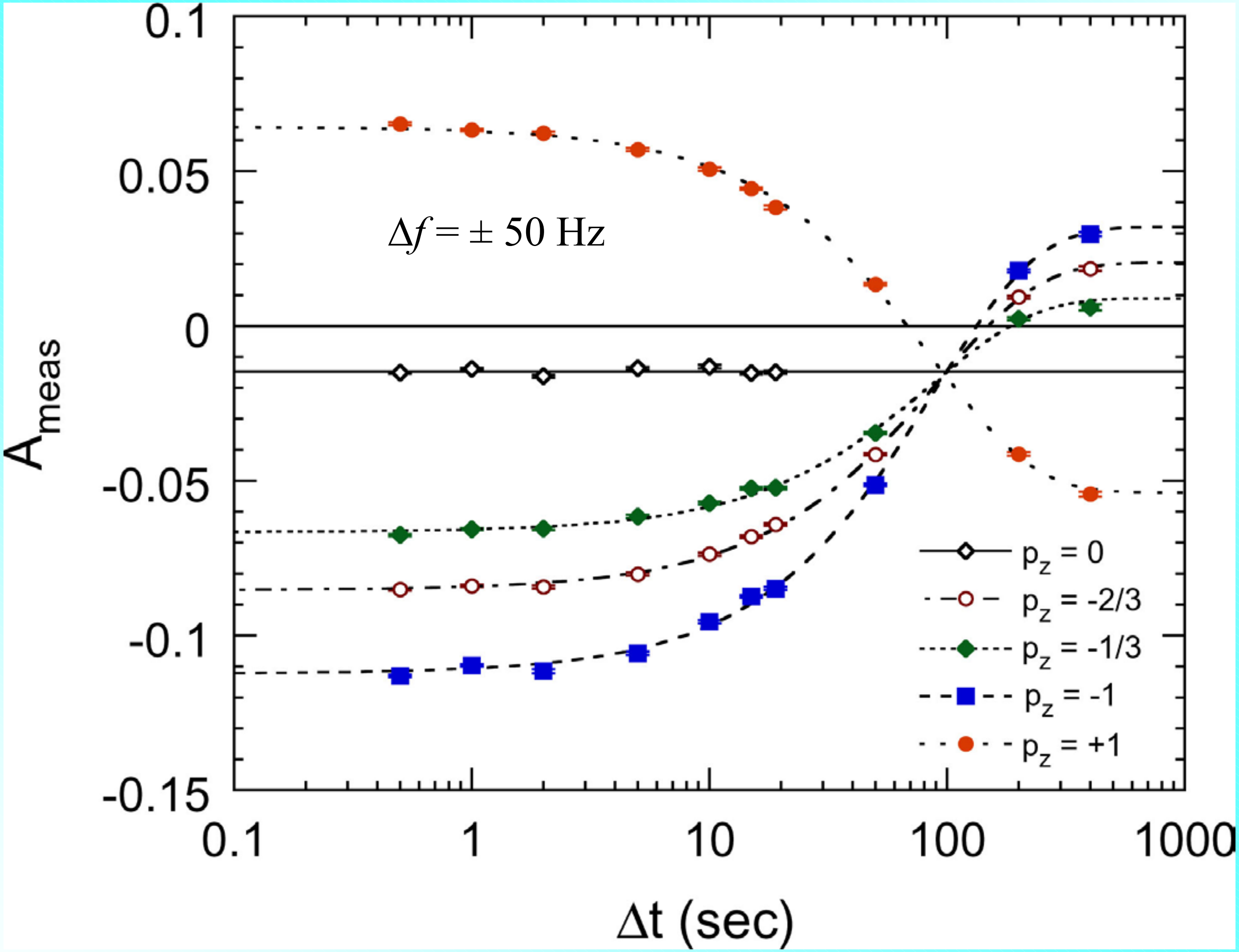
Resonance frequency search



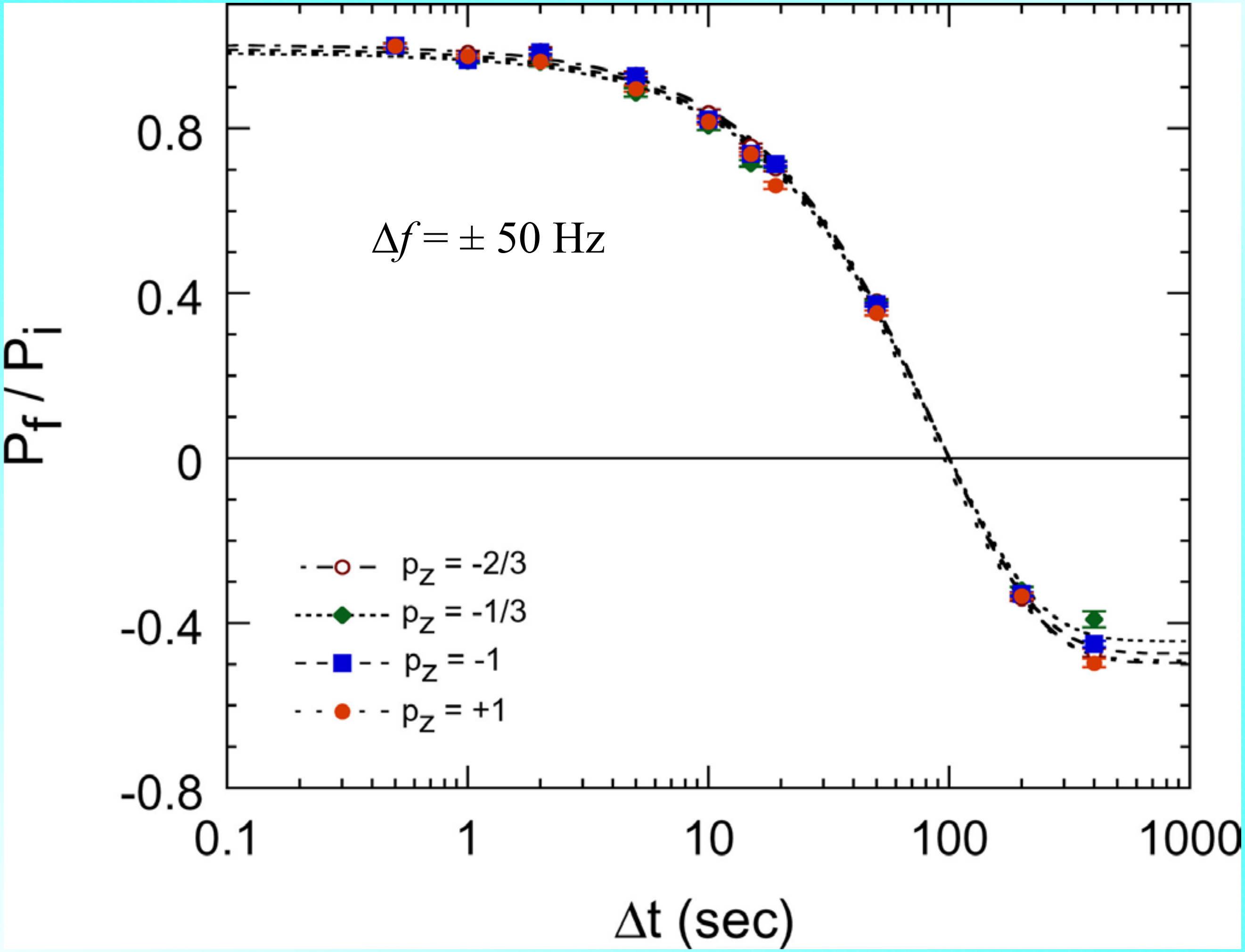
Resonance mapping with fixed frequency



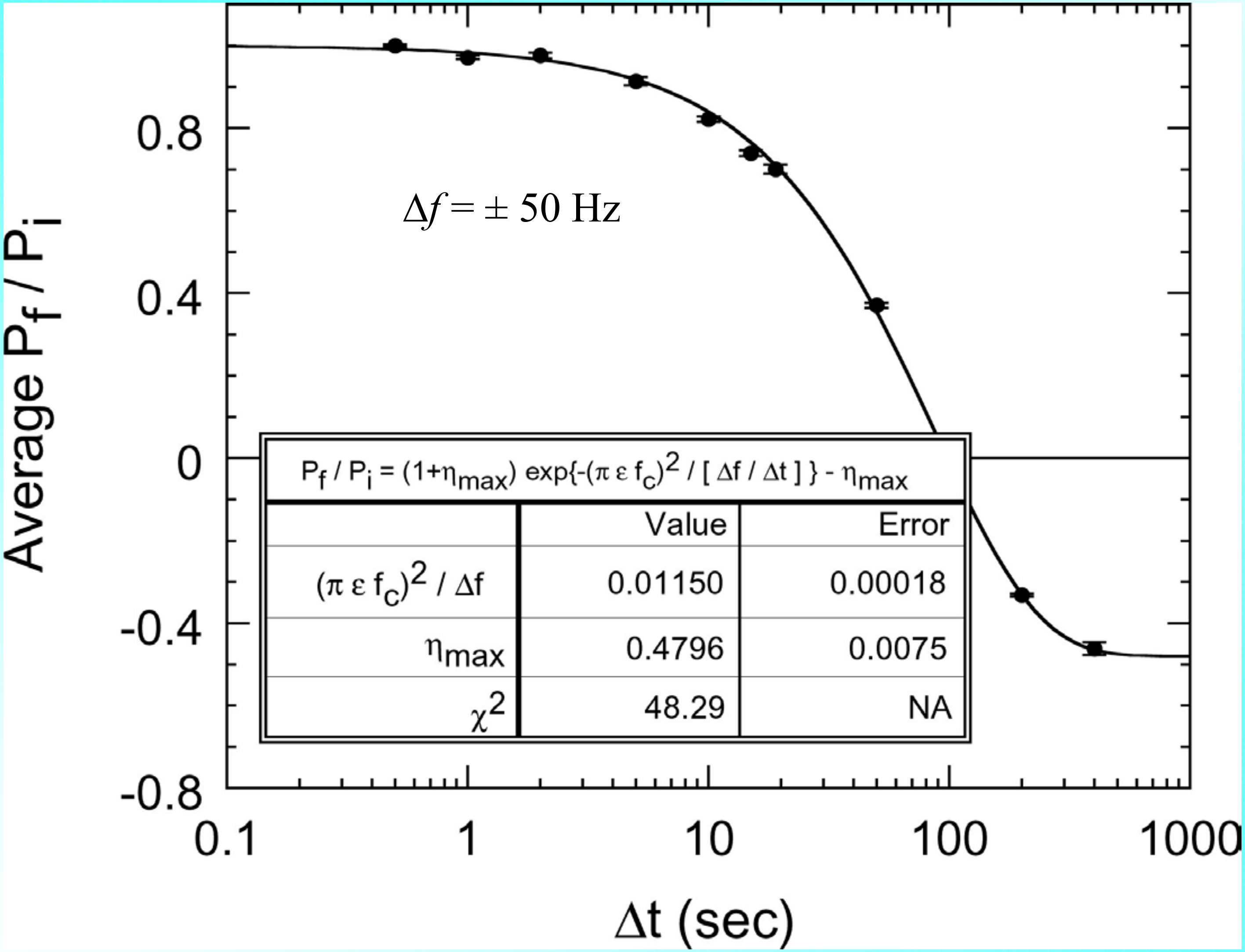
Measured Asymmetry vs Δ t



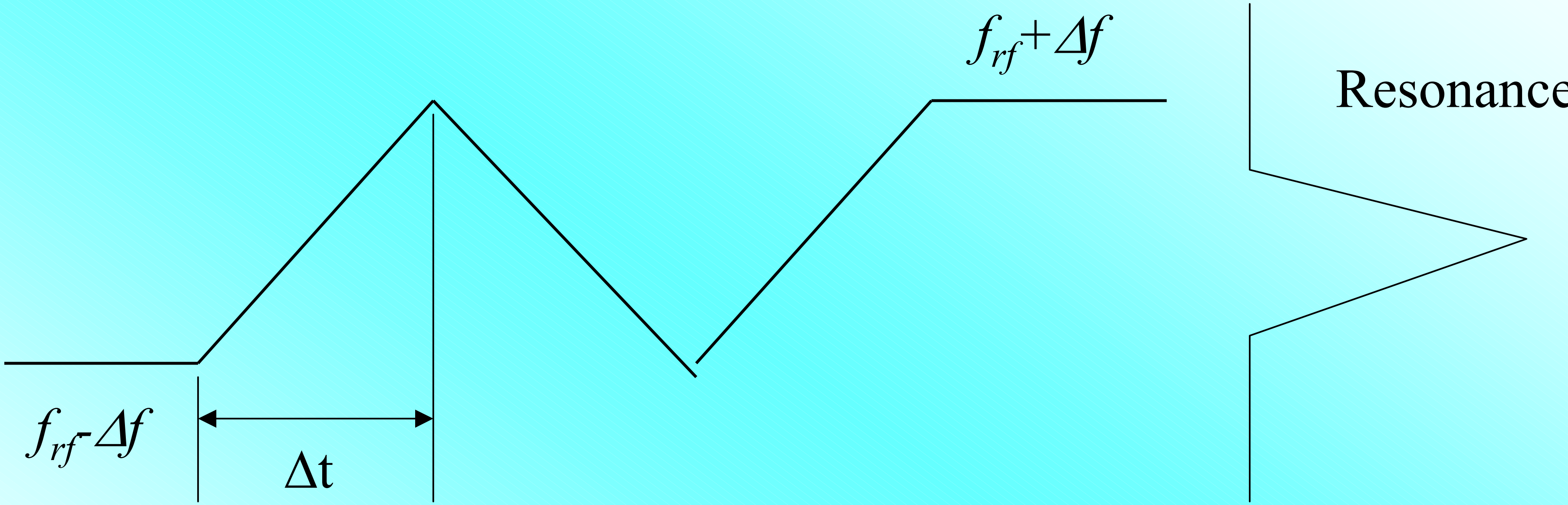
P_f / P_i vs Δ t



Average P_f/P_i vs Δ t

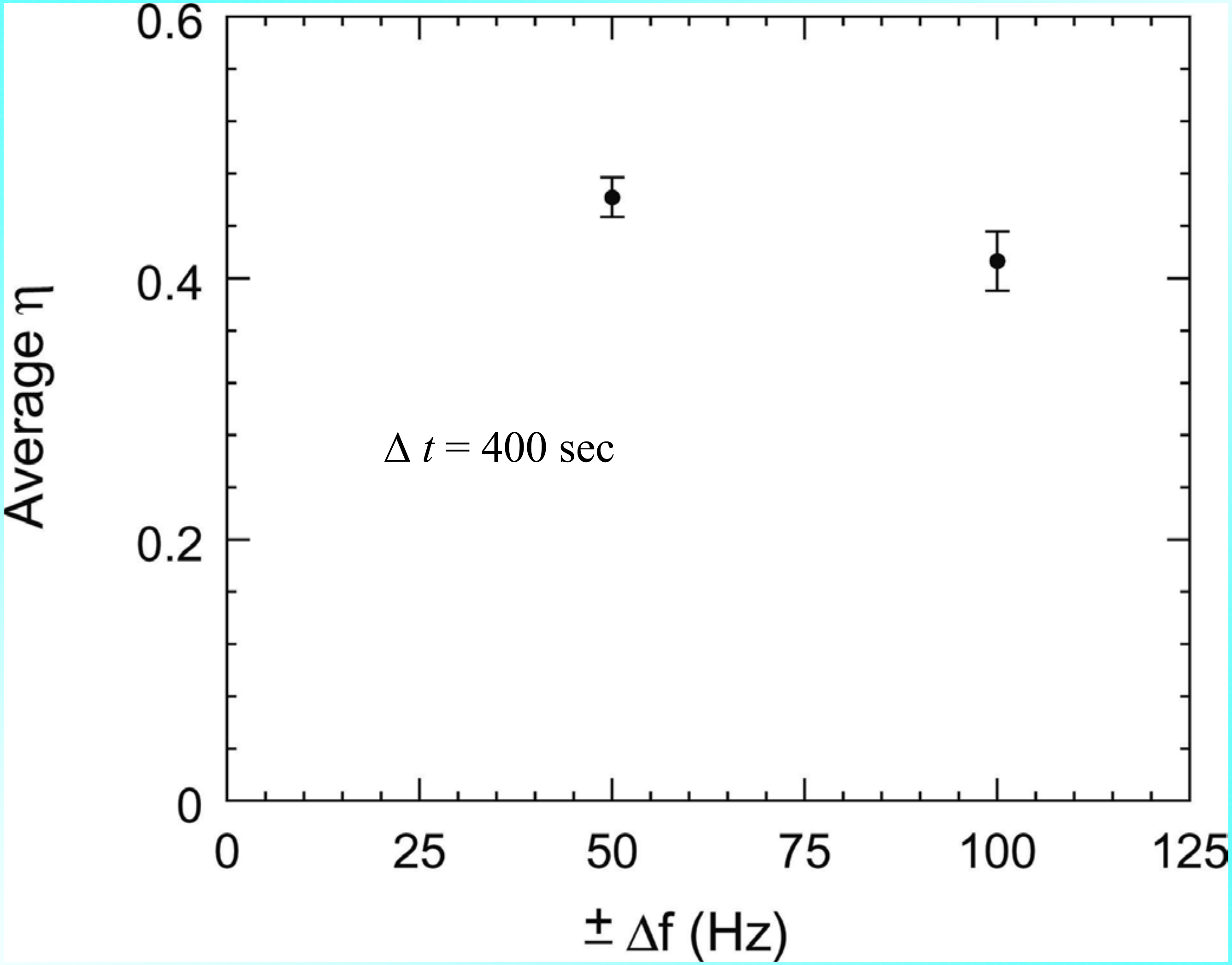


Concept sweeping frequency



Multiple spin flipping

Spin-flip efficiency vs Frequency range



Conclusion

- Deuteron spin-flip efficiency at maximum RF power was about 48 ± 2 %.

- We plan to add a ferrite box to the RF magnet
  - should increase the RF magnetic field by almost 50 %.

- We plan to increase the maximum RF power by using cooling water in the coils
  - should allow further increase of the RF magnet field.