


# Polarized Hydrogen Jet Target for Measurement of RHIC Proton Beam Polarization

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Brief history of jet design and testing.

- January 2000 workshop at BNL  
Polarized Hydrogen Jet was best option for an absolute calibration of RHIC proton beam
  - June 2000  
We agree to design the source
  - April 2002  
ABS trajectory calculation completed (with H. Kolster, P. Quin), Magnets ordered
  - January 2002  
Wisconsin-BNL design details
  - **JANUARY 2003**  
Chambers for Jet ordered
  - **8<sup>TH</sup> OCTOBER, 2003**  
WORKING JET IN RING (test installation)
- 

MANY PEOPLE HELPED WITH THIS VERY RAPID ASSEMBLY SEQUENCE

TODAY I WILL TALK ABOUT

- SELECTED DESIGN DETAILS •
- PERFORMANCE OF THE JET IN THE RHIC RING •

# PRINCIPLE OF OPERATION

SOURCE HAS CONVENTIONAL DESIGN EXCEPT FOR THESE NOTED ITEMS

RF dissociator has **VARIABLE FREQUENCY** for impedance matching and improved coupling (MIT).

PRE-COOLING OF DISSOCIATED GAS BEFORE NOZZLE  
Design discussed in A. Zelenski talk.

Tapered 6-pole magnets have larger bore than previously used .

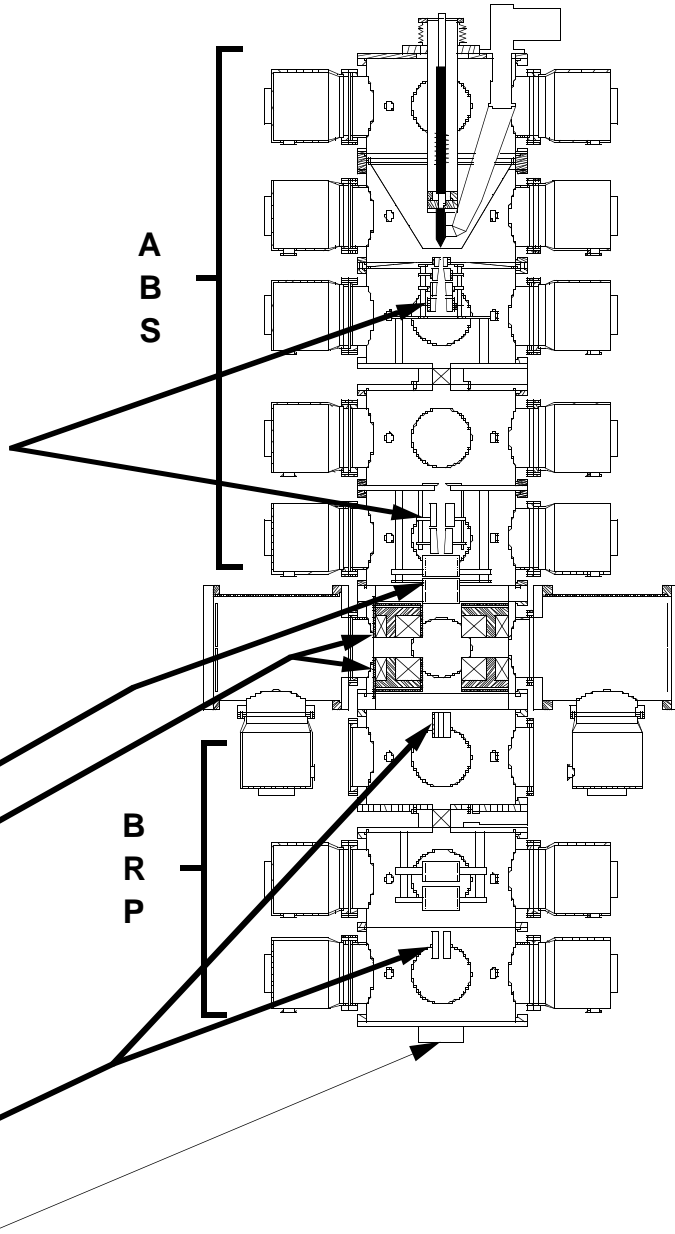
Unusually long **650mm** drift length between two magnet groups

NINE stages of pumping  
5 FOR ABS 3 FOR BRP + TARGET

RF transitions have **highly uniform field gradients**

**Nested, opposing Helmholtz** target magnet. (W. Meng design)

**Breit Rabi In-line atom polarimeter :**  
**TWO rf transitions**  
**TWO 6-pole magnets**  
**TWO beam blockers**  
**ION GAGE BEAM DETECTOR**



## DESIGN CONSTRAINTS SPECIFIC TO RHIC INSTALLATION

- **VERTICAL** TARGET POLARIZATION  $\Rightarrow$  **VERTICAL** GUIDE FIELD
- **LEFT-RIGHT** RECOIL DETECTORS AT  $90^\circ \Rightarrow$  **VERTICAL** ATOMIC BEAM
- LOW RECOIL ENERGY OF 1-10 MeV  $\Rightarrow$  ONLY MINIMAL DEFLECTION BY GUIDE FIELD CAN BE TOLERATED
- HIGH INTENSITY  $\Rightarrow$  TWO HYPERFINE STATES  $\Rightarrow$  STRONG GUIDE FIELD (0.12 TESLA  $\chi=2.3$ )
- RHIC BEAM IS BUNCHED  $\Rightarrow$  GUIDE FIELD **UNIFORMITY** OF  $\Delta B/B = 5 \times 10^{-3}$  TO AVOID BUNCH INDUCED DEPOLARIZING RESONANCES
- **60mm** CLEAR BORE FOR RHIC PROTON BEAMS
- RF TRANSITIONS MUST BE SHIELDED FROM VERTICAL GUIDE FIELD
- ATOMS EXPERIENCE A **ROTATING** GUIDE FIELD

**FOR 80K H ATOMS:  
THE ADIABATIC CONDITION WILL BE SATISFIED IF**

$$d\theta/dz < 0.03(\text{rad/cm}) \times B(z)$$

**SATISFYING ALL OF THE ABOVE  
SIMULTANEOUSLY WAS CHALLENGING**

## FURTHER DESIGN CHARACTERISTICS

- SMALL BEAM SPOT -- 9MM COLLIMATING APERTURE
- CLEAN OIL FREE RING VACUUM

$$\text{BASE} < 5 \times 10^{-9}$$

$$\Delta P < 2 \times 10^{-8}$$

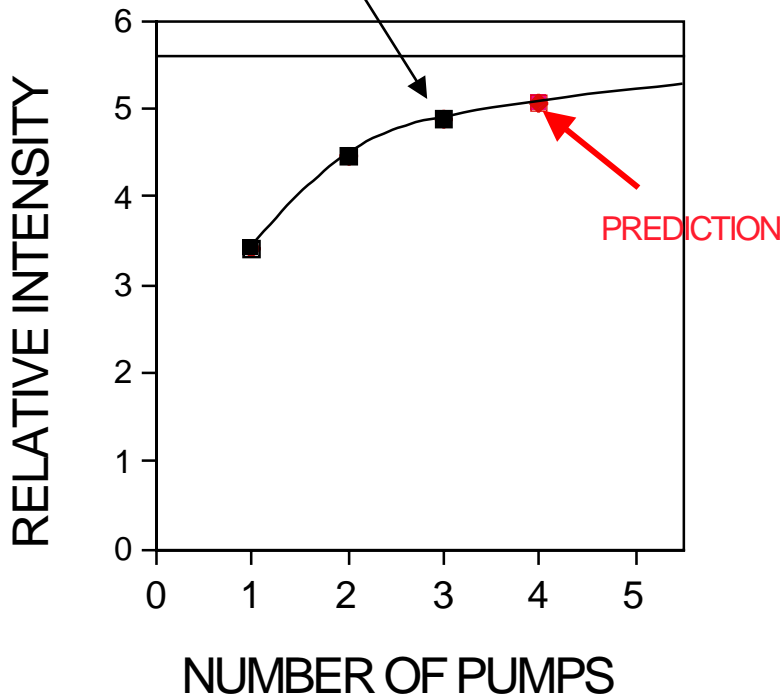
- RF TRANSITION FLIP PROBABILITY AS HIGH AS POSSIBLE
- REVERSE JET POLARIZATION FREQUENTLY WITHOUT MODULATING TARGET THICKNESS
- CONTINUOUSLY MONITOR JET POLARIZATION
- CONSTANT IMPEDANCE FOR BEAM BUNCH IMAGE CURRENTS THROUGH JET CHAMBER
- 3 DAY INSERTION AND REMOVAL FROM RHIC TUNNEL

# PUMPING SYSTEM

1000 Liter/s ceramic bearing turbo-pumps (Varian 1000HT)  
Backed by dry piston pumps (Leybold Drytel)

TWO pumps per stage and FIVE STAGES **except**

THREE pumps in first stage



Pressures in and adjacent to target chamber with JET ON:

(CC-GAGE READINGS)

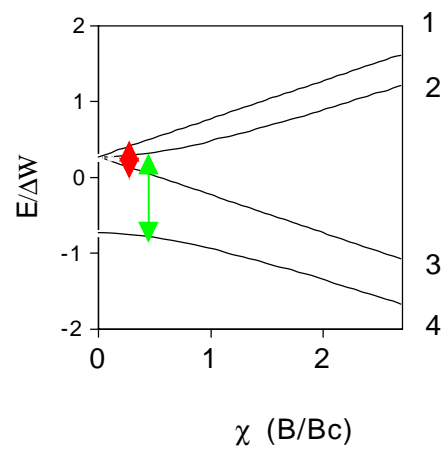
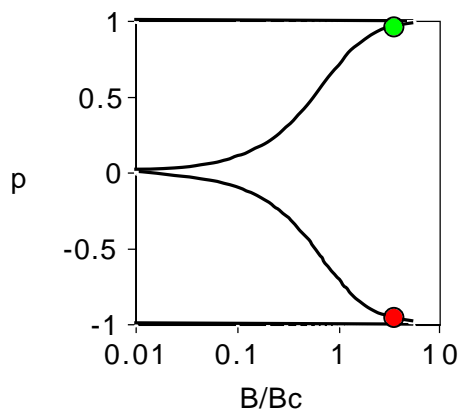
Chamber FIVE  $1.7 \times 10^{-7}$

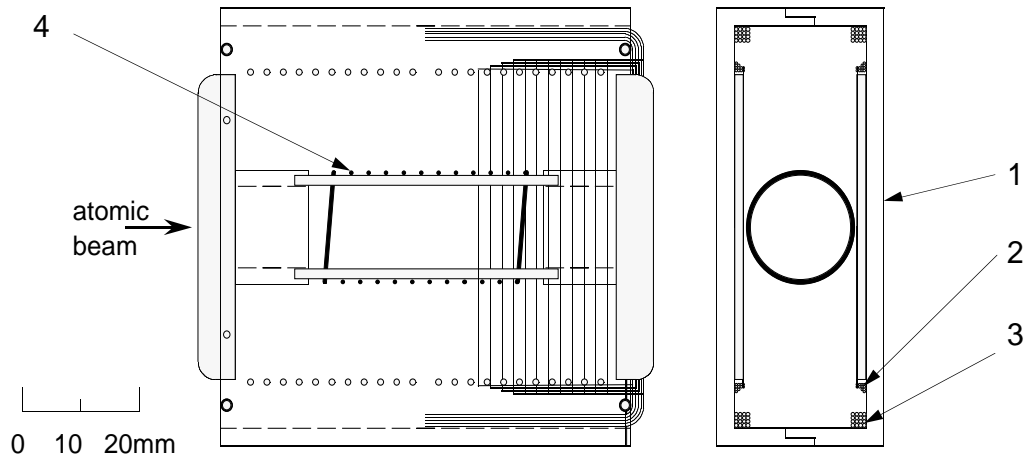
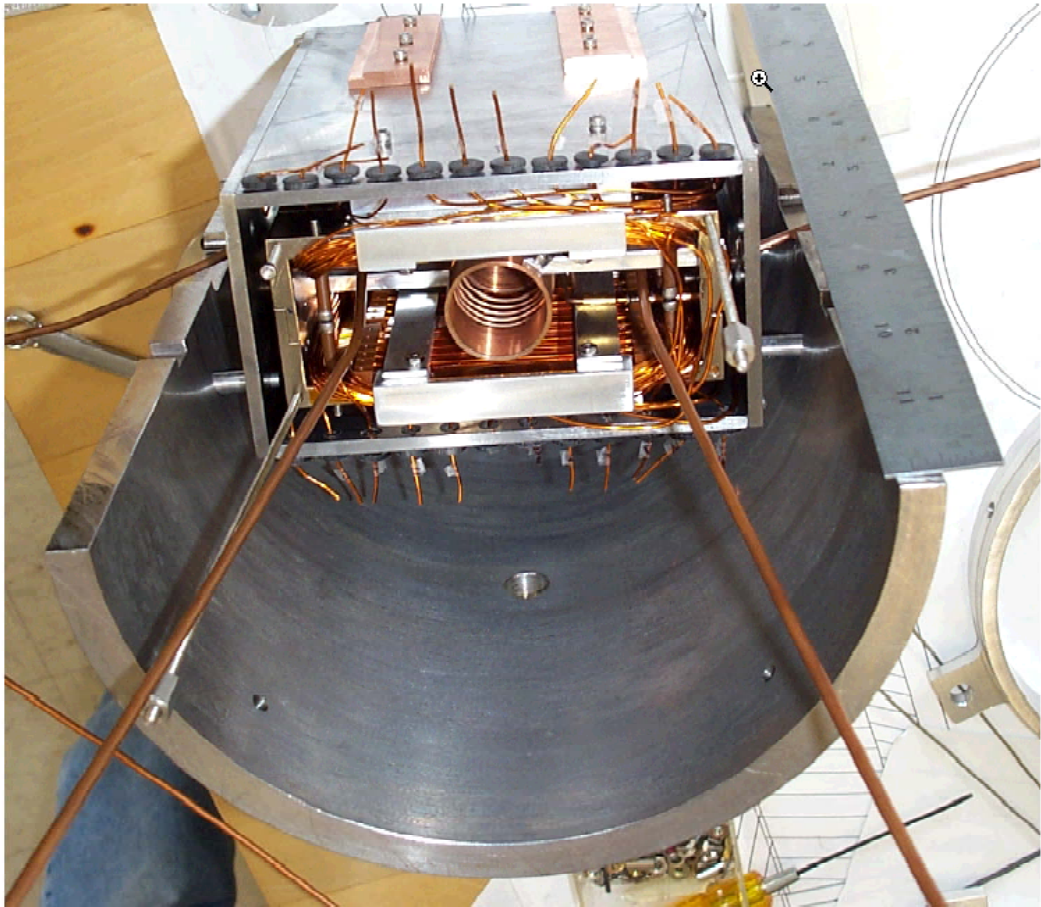
**TARGET chamber**  $1.4 \times 10^{-8}$  (base jet OFF =  $4 \times 10^{-9}$ )

Chamber SEVEN  $1.3 \times 10^{-7}$

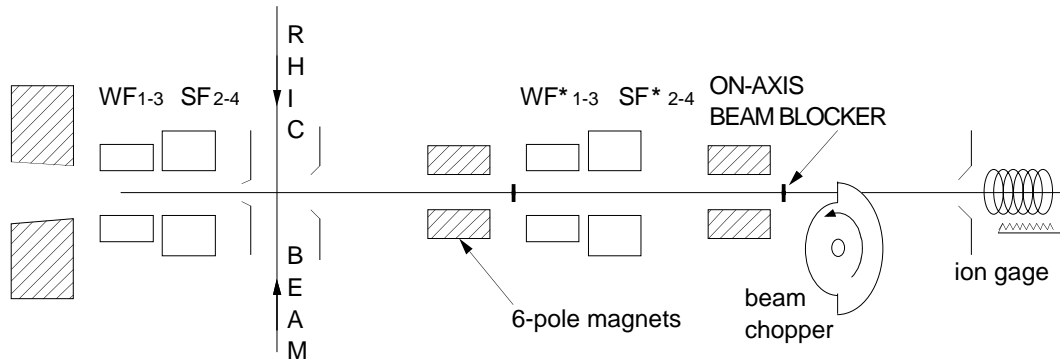
## RF TRANSITIONS

- WIDE AND LONG DESIGN HAS HIGHLY UNIFORM GRADIENT FIELDS  
(we traded field uniformity for a few percent intensity loss)
- NO COUPLING BETWEEN ADJACENT WF(1-3) AND SF(2-4)
- LOCATED AFTER LAST 6-POLE
- NO INTENSITY MODULATION WITH REVERSAL OF POLARIZATION
- **EFFICIENCIES APPROACH 100%** •





# BREIT-RABI POLARIMETER



-USUAL BRP CONCEPT(simplified):

- comparison gives EFFICIENCY and POLARIZATION**
- ABS 1-3 ON  
state 3 atoms rejected  
The remaining state 1 atoms are detected
  - NEXT STEP:**
  - BRP 1-3 is turned ON---  
the remaining state 1 atoms are rejected

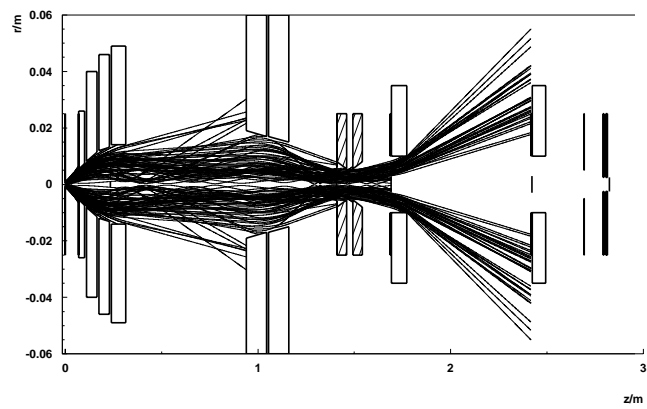
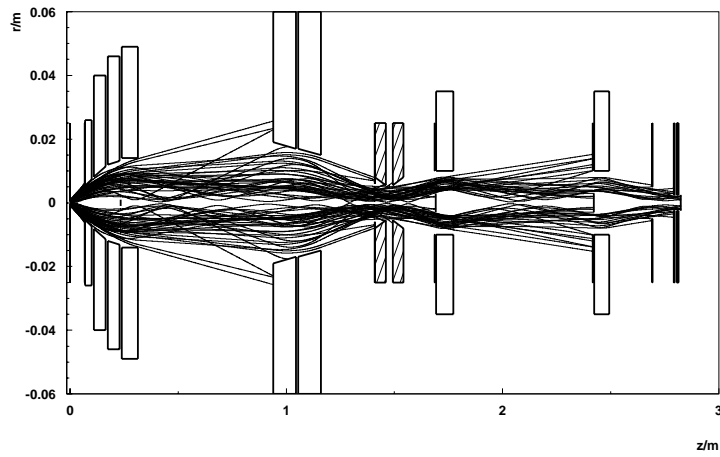
WHAT WE DO INSTEAD:

The efficiency of ABS rf transitions is so high there are **almost no state 1 atoms to begin with.**

We turn on SF 2-4 and WF 1-3 simultaneously and minimize detected beam (close to zero atoms detected when tuned)

Measurements are very fast (described by A.Nass this session)

Ray tracing plot below to show rejection of atoms by BRP

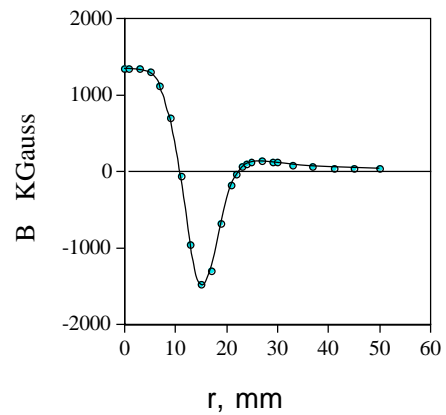
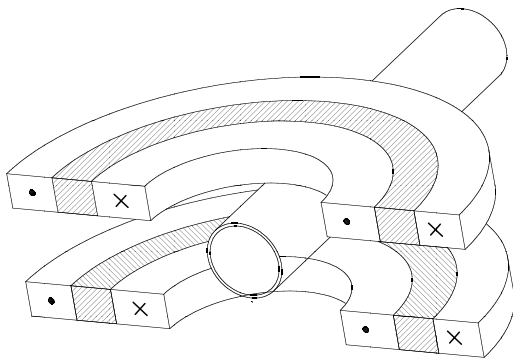


# MAGNETIC FIELDS

STRONG GUIDE FIELD and LOW ENERGY RECOILS CONFLICT

Solution:

## NESTED OPPOSING HELMHOLTZ-TYPE COILS (designed by W. Meng)



**GIVES DESIRED UNIFORMITY AT 1.2 KG FIELD**

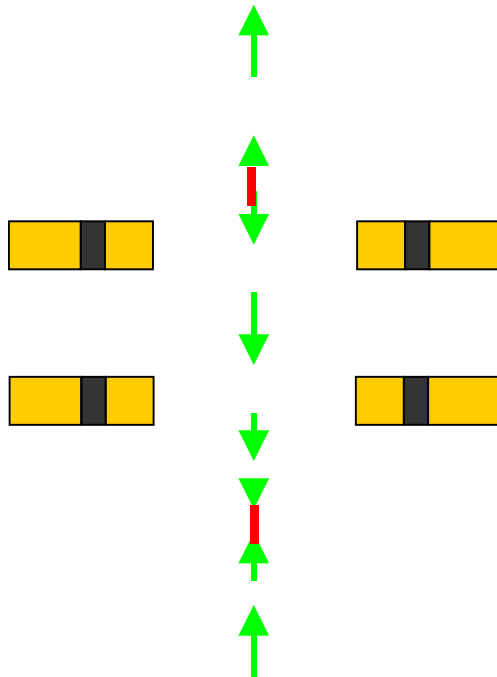
**AND SMALL DISPLACEMENT OF RECOILS  
IN HORIZONTAL PLANE**

Every solution generates a problem

Field direction **REVERSES DIRECTION** twice along atomic beam.

Non-adiabatic field rotation will occur resulting in

POLARIZATION LOSS



Problem is even more complicated

Rf transitions are located in region of strong axial magnetic field

Shielding required

Field **rotates 90 degrees** going into and out of transitions where field is weak

and **also violates adiabatic rotation.**

### Our Requirement:

- In the **atom rest frame** the **B** field rotates **1000X more slowly than the Larmor precession** frequency

$$(\omega_{\text{beam}} < 10^{-3} \omega_{\text{larmor}})$$

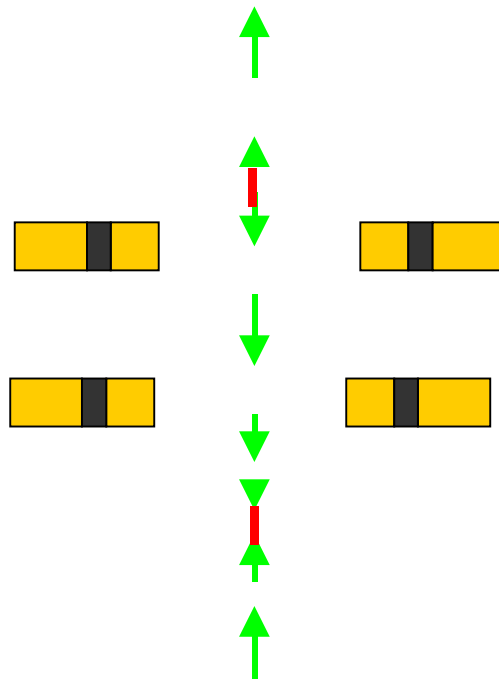
For atoms at 2000 meter/s we required that

$$d\theta/dz < 0.03B(z) \text{ rad/cm}$$

(B in Gauss)

With the Wisconsin ABS at IUCF we observed moderate depolarization

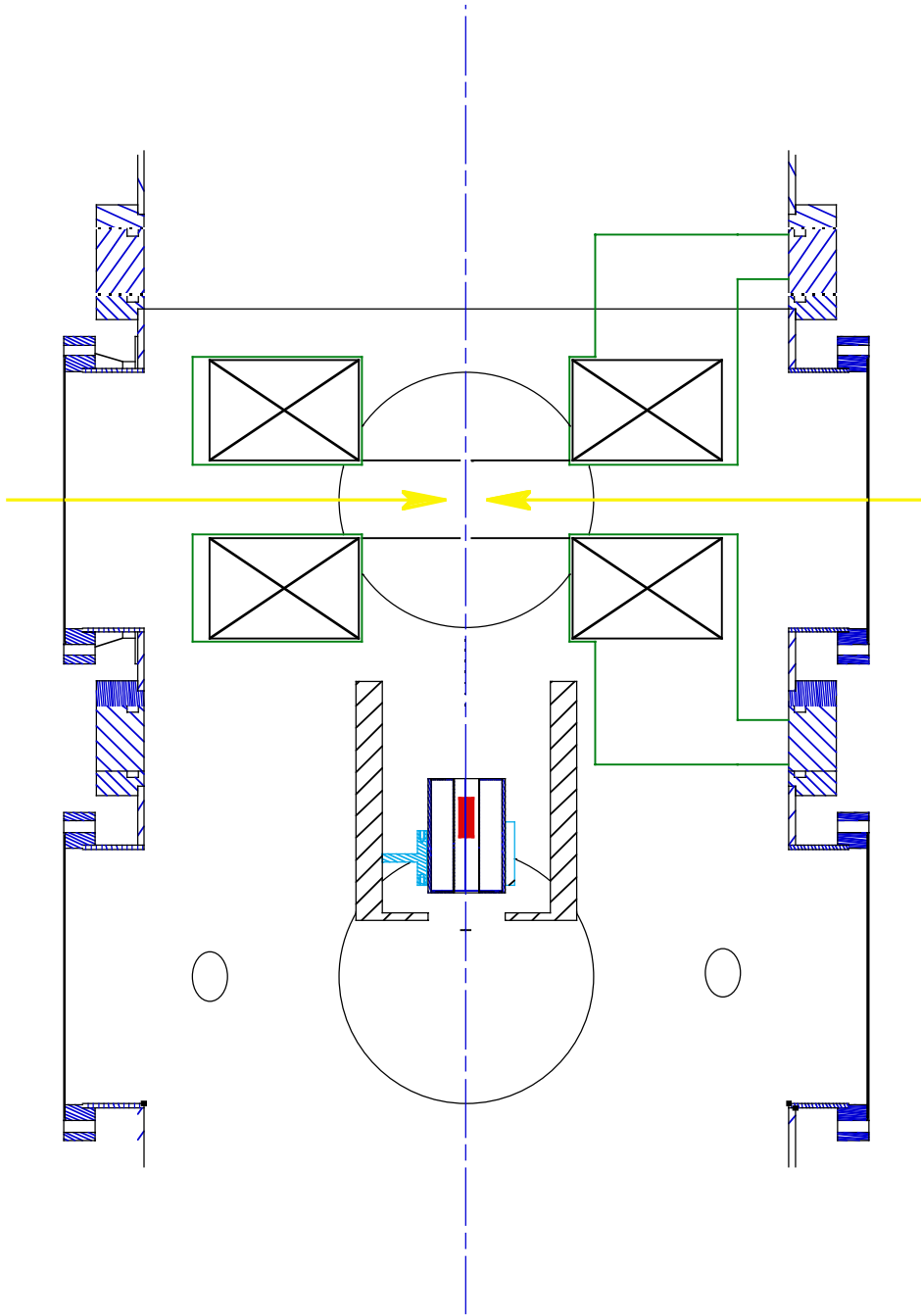
$$\text{when } \omega_{\text{beam}} \sim 10^{-2} \omega_{\text{larmor}}$$



Eventually solved by 3-D modeling of complete system

Using a **lot of IRON** we

- Moved upper violation region into rf transition boxes •
  - Moved lower violation region into BRP six-pole •



SCHEMATIC OF JET BELOW INTERACTION REGION  
RED SHOWS NON-ADIABATIC REGION AFTER MOVING IT INTO 6-POLE  
MAGNET

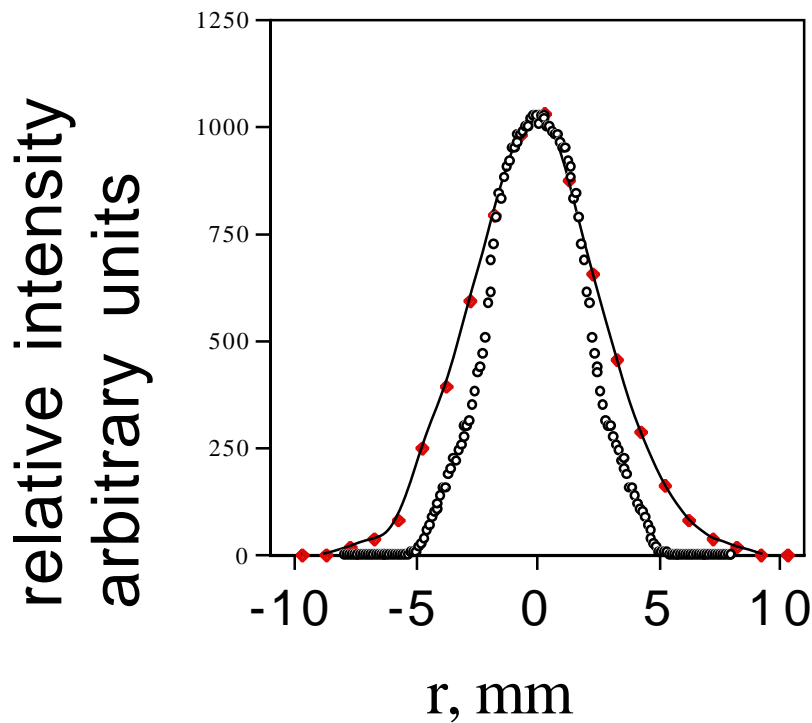
# PERFORMANCE OF SOURCE AS A JET TARGET

VACUUM ACCEPTABLE AT I.P.

BASE  $5 \times 10^{-9}$  (VALVE CLOSED)

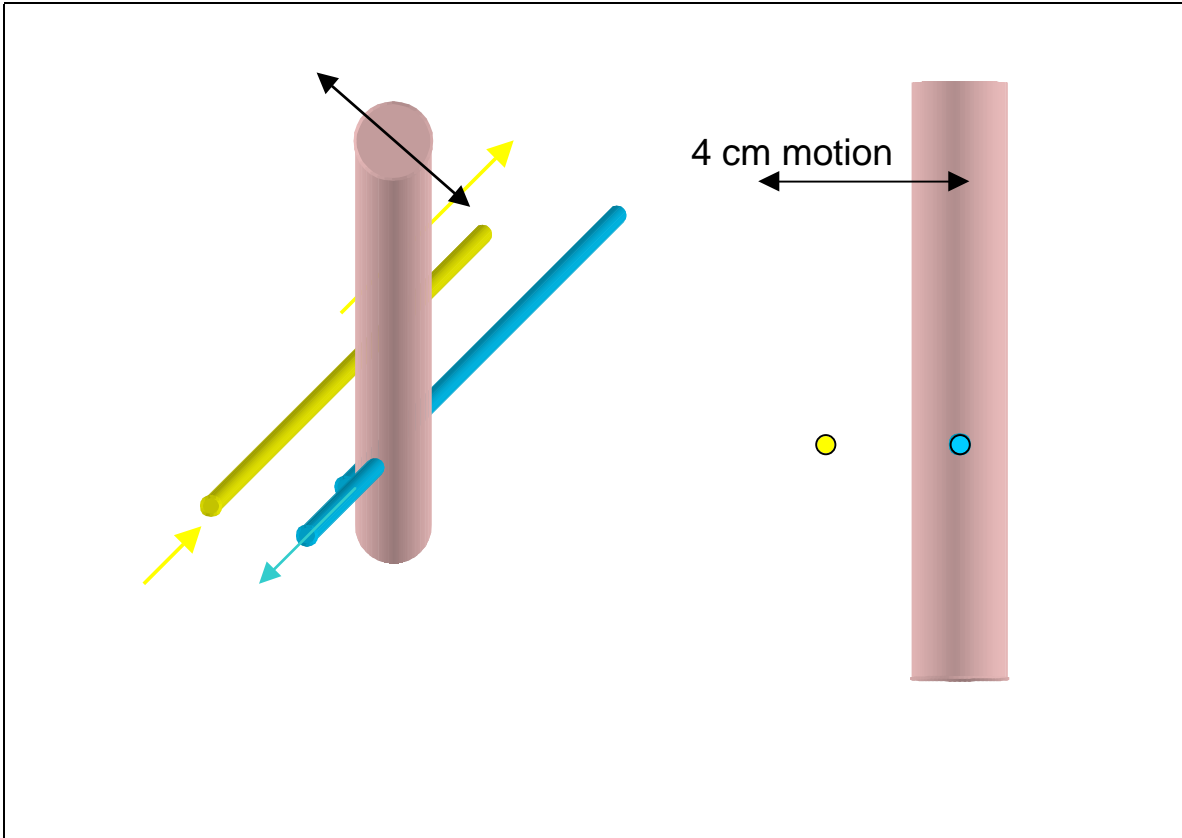
JET ON:  $1.4 \times 10^{-8}$

CALCULATED AND MEASURED BEAM PROFILE



CALCULATED PROFILE NARROWER THAN MEASURED  
Central intensity was normalized.

Profile is small enough to individually select **Blue** and **Yellow**  
(clockwise and c-clockwise) RHIC beams



BEAMLINE HAS BELLOWS TO ALLOW ENTIRE JET ASSEMBLY  
**INCLUDING DETECTORS** TO MOVE LEFT-RIGHT 4 cm

## ATOMIC BEAM INTENSITY

**$(1.24 \pm 0.2) \times 10^{17}$**

$9 \times 10^{16}$  predicted

(by Wisconsin simulation code)

Measured three ways and all agree:

Calibrated compression tube at I. P.

Compared to a calibrated flow into large vacuum chamber

Calculated using turbo pump speed and pressure rise

## TARGET THICKNESS

ALSO DEPENDS ON ATOM VELOCITY AND ATOMIC BEAM  
PROFILE

A LINE INTEGRAL along RHIC BEAM  
DUPLICATES SENSITIVITY  
OF RHIC BEAM TO THE TARGET GAS

(MORE DETAILS WILL BE GIVEN BY A. NASS)

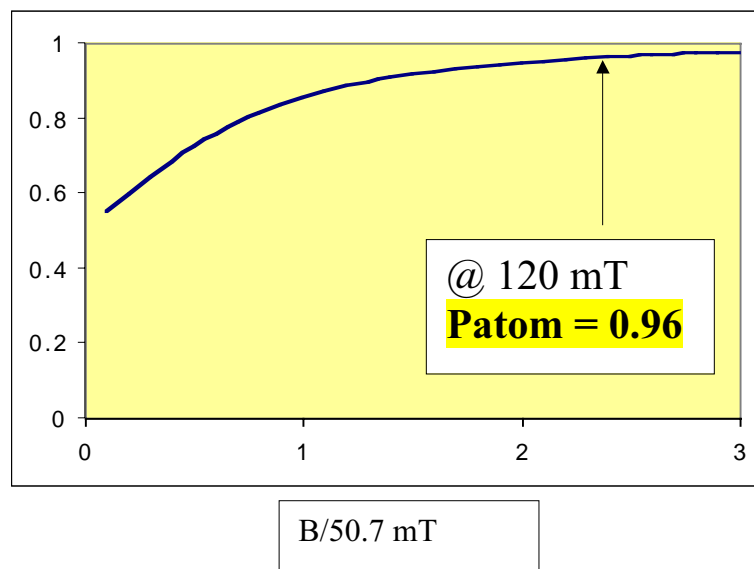
Average velocity generated by calculations was **1860 meter/s**  
Velocity **recently measured** is **1560 meters/s**

Calculated (predicted) thickness was  $9.6 \times 10^{11} / \text{cm}^2$   
Measured thickness is  **$(1.3 \pm 0.2) \times 10^{12} / \text{cm}^2$**

**FIVE FACTORS** AFFECTING JET POLARIZATION

- 1)** WE HAVE TWO HYPERFINE STATES  
SO POLARIZATION DEPENDS ON GUIDE FIELD STRENGTH

TWO-STATE  
ATOM  
POLARIZATION



**2) RF TRANSITION EFFICIENCY**

**VERY NEARLY 100% ! ( $\geq 99.7\%$  )**

**MAKES BREIT-RABI POLARIMETRY ALMOST TRIVIAL**

**3) CHAMBER "REST" GAS DILUTION**

**ABOUT 0.5%**

**4) H<sub>2</sub> AND H<sub>2</sub>O CONTAMINATION IN THE BEAM**

**THIS IS BY FAR THE LARGEST CONTRIBUTION TO  
UNCERTAINTY IN TARGET POLARIZATION**

**WE HAVE A VERY PRELIMINARY ESTIMATE  
OF 3% NUCLEONS AS H<sub>2</sub>**

**5) BUNCH FIELD DEPolarIZATION**

**WE CAN DETECT BUNCH FIELD DEPolarIZATION  
PROBABILITY AS SMALL AS 0.2% WITH "FLIP IN" BRP  
MEASUREMENT.**

**NONE WAS DETECTED FOR 60 BUNCH OPERATION OF RHIC  
PROTON BEAMS**

PRESENT BEST ESTIMATE OF JET POLARIZATION

$$P^+ = 0.923 \pm 2\%$$

$$P^- = 0.925 \pm 2\%$$

WE WILL SIGNIFICANTLY REDUCE THIS ERROR BY DIRECTLY  
MEASURING H<sub>2</sub> CONTAMINATION.

FUTURE WORK

# ACCURATELY MEASURE H2 CONTAMINATION

## METHOD

### CROSS BEAM ELECTRON IMPACT IONIZER WITH EXTRACTION AND MOMENTUM ANALYSIS OF POSITIVE IONS

