DESIGN OF POLARIZED ATOMIC H SOURCE FOR JET TARGET AT RHIC

Two parts: 1) Atomic Beam Optimization
2) Jet Polarimetry

Report on work by:

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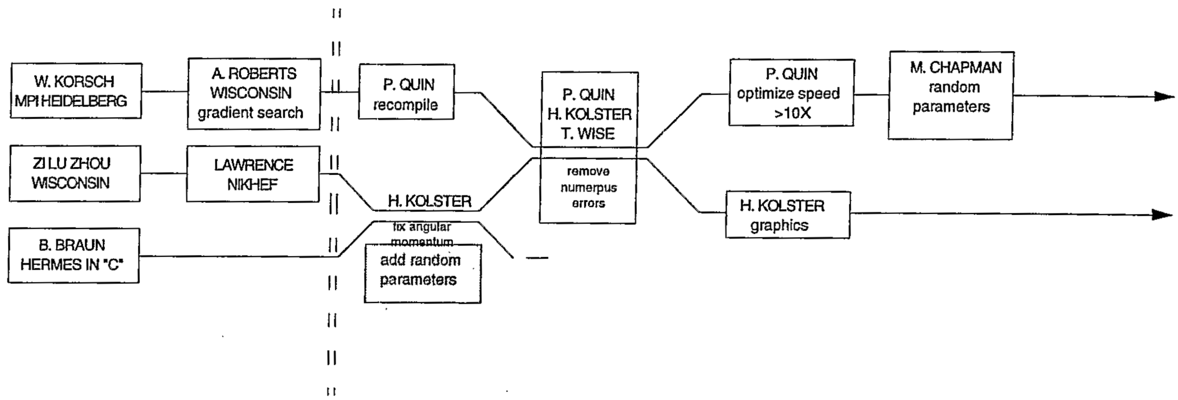
We want to insert a polarized target with polarization **measured to high precision -- at least (2%)**

REQUIREMENTS	DESIGN IMPLICATIONS
• No ring interference	60mm free aperture All UHV construction Gas target
• Large well known polarization • Rapid reversal • Highest target thickness	6-pole ABS with Breit -Rabi style polarimeter Two hyperfine states Strong guide field >1 kG
• Detect low energy elastic recoils	Special magnet design (W.Meng) **No storage cell** possible
• Well defined edge	Collimator near RHIC beam, High pumping speed target chamber
• Avoid Bunch field resonances	High field uniformity - 10^{-3}

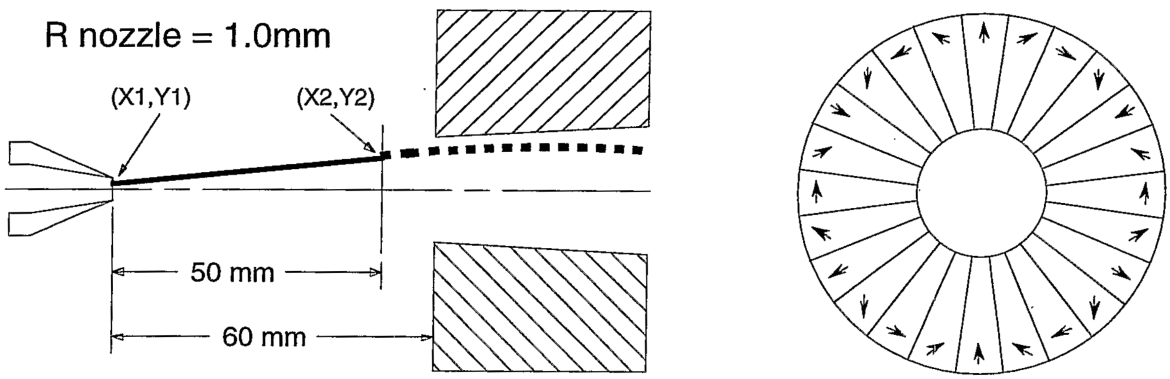
RAY TRACING CODES

CODE "PEDIGREE"



IMPORTANT CODE ASSUMPTIONS

- START GEOMETRY



RANDOM POSITIONS ON NOZZLE AND COLLIMATOR DISCS

- START VELOCITY DISTRIBUTIONS
  from B. Lorentz diplomarbeit [1]

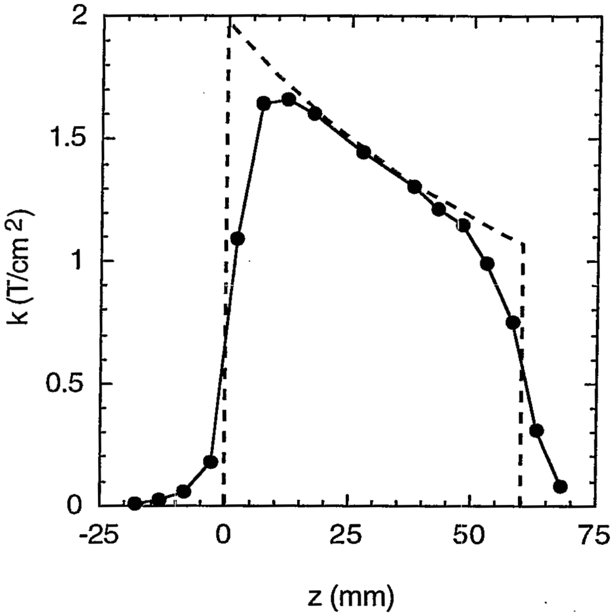
$$f(v) = v^2 e^{\left[\frac{-m}{2k_b T_{beam}}(v - v_{drift})^2\right]}$$

$$T_{beam} = g(Q, T_{nozzle})$$

$$v_{drift} = h(Q, T_{nozzle})$$

- MAGNETIC FIELD
  Halbach formulas [2] for 24 sector 6-poles
  Use Br = 1.29 T (available Ne-Fe-B)

Assume sudden turn on



Ideal and measured field for 6-pole magnet

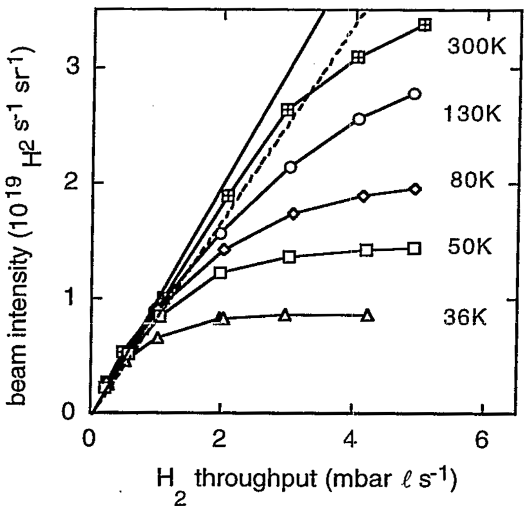
- MAGNET CAN --assume 0.3mm wall

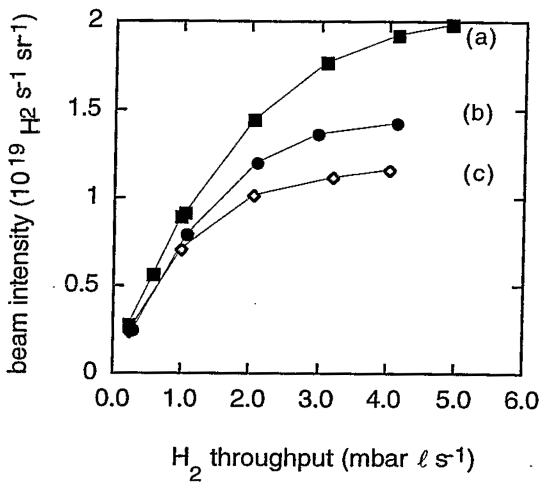
- DEGREE OF DISSOCIATION
  We assumed $\alpha=\alpha(\mathbf{Q})*\alpha(\mathbf{T}_{nozzle})$
  We used N. Koch's $\mathbf{T}_{nozzle}$ dependence [3]
  Wisconsin **Q** dependence [4]

- BEAM ATTENUATION

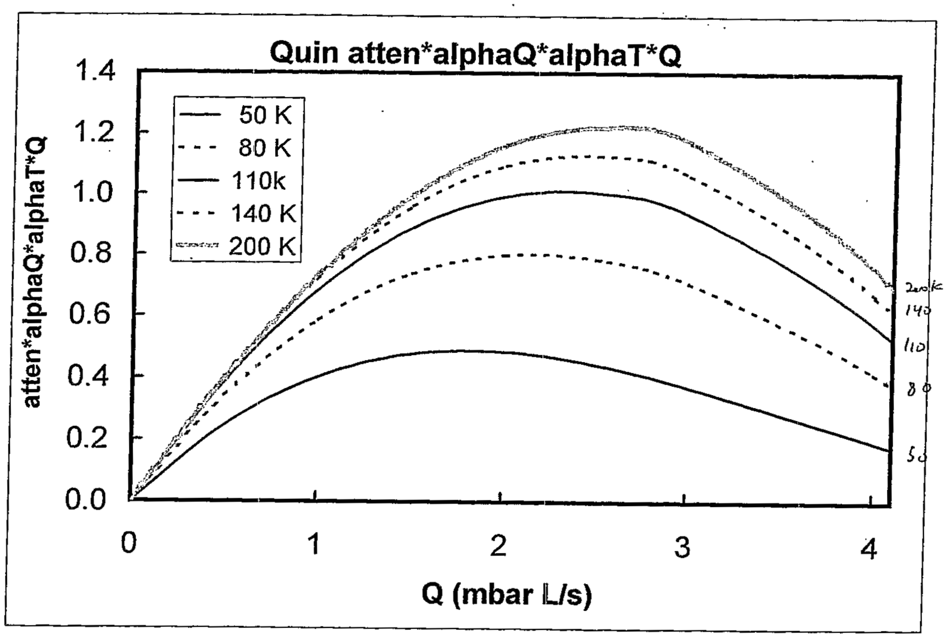
A=A(Q,Tnozzle)

Used Wisconsin data[4] measured on H_2 with aluminum dummy magnets.





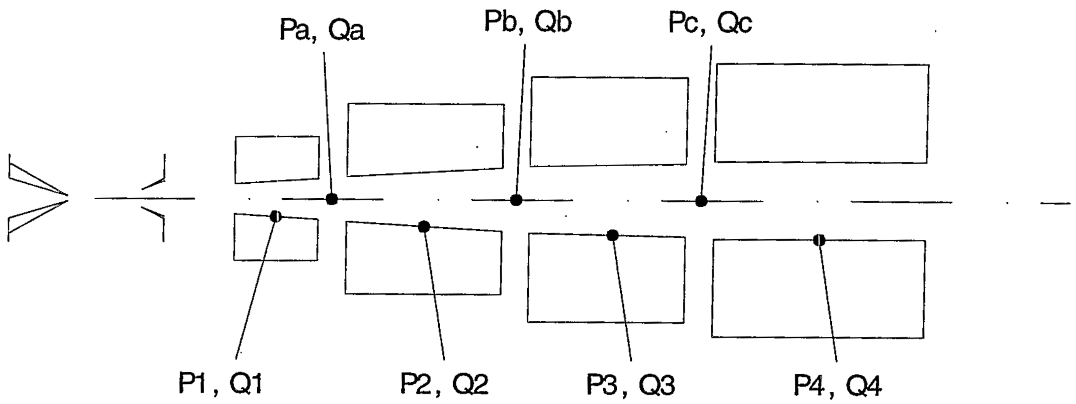
COMBINED FACTOR IS PLOTTED BELOW



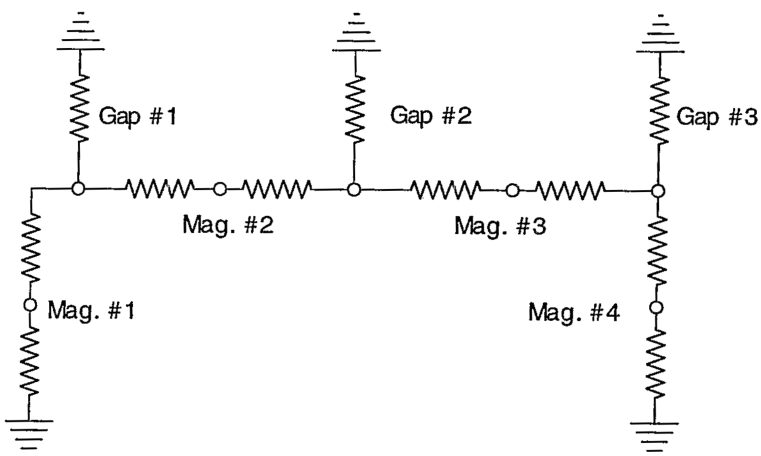
$$A(Q,T) * \alpha(Q) * \alpha(T) * Q$$

GAS SCATTERING CHECK

Is scattering data still valid for new magnet geometry?



Generate Q's from ray tracing code (4 H states + H_2)
Calculate gas conductance of elements from geometry
Combine conductances using analog resistor network
Resistor values proportional to $1/C_{gas}$
Calculate integral of pressure * length



Result:
$\int Pdl(\text{rhic ABS}) = \mathbf{0.9} \int Pdl\ (\text{wisc ABS})$ at same flow **Q**.

PREDICTION OF ABSOLUTE BEAM INTENSITY

ONE STATE INTENSITY:

Q is flow in mbar-liter/s

N_A is Avagadros number

$$I_{atoms/s} = \frac{1}{4} Q \left(\frac{N_A}{22.4 \cdot 1013} \right) \left(\frac{\Omega}{2\pi} \right) \cdot 2 \cdot 2 \cdot A(Q,T) \cdot \alpha(Q,T) \cdot t(Q,T,G)$$

one H hyperfine state

convert units

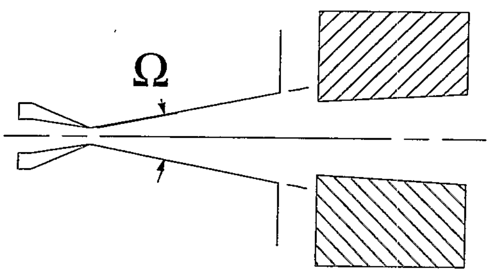
solid angle correction

cos(θ) increase over flat
two atoms/molecule

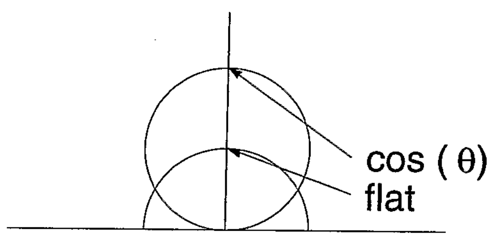
gas attenuation

degree of dissociation

code transmission



SOLID ANGLE OF MAGNET



COS(θ) INCREASE OVER FLAT DISTRIBUTION (polar coordinates)

COMPARING SYSTEMS

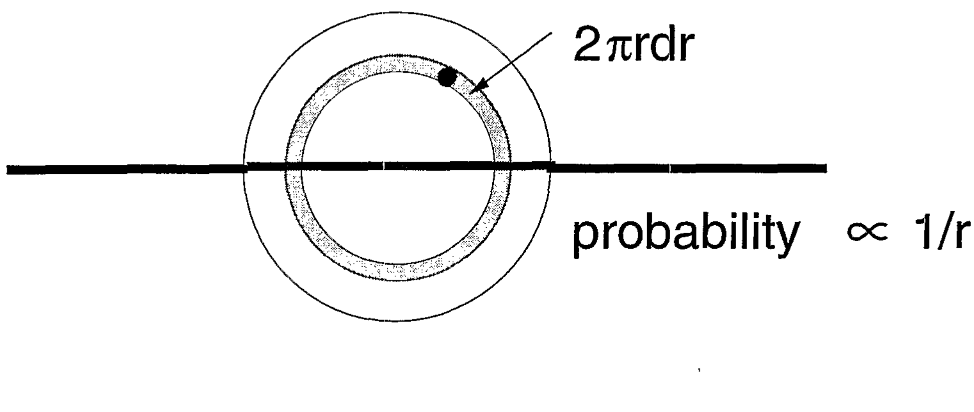
We want to maximize thickness seen by RHIC beam inside 9mm spot size

- Weight each transmitted atom by **1/v**
- Computation trick--weight each atom by **1/r**
    -- allows all transmitted atoms to be included --
- Maximize **target thickness** by **maximizing sum:**

$$\text{THICKNESS} \propto \sum_{\text{atoms}} 1/rv$$

for $0<r<r_{max}$

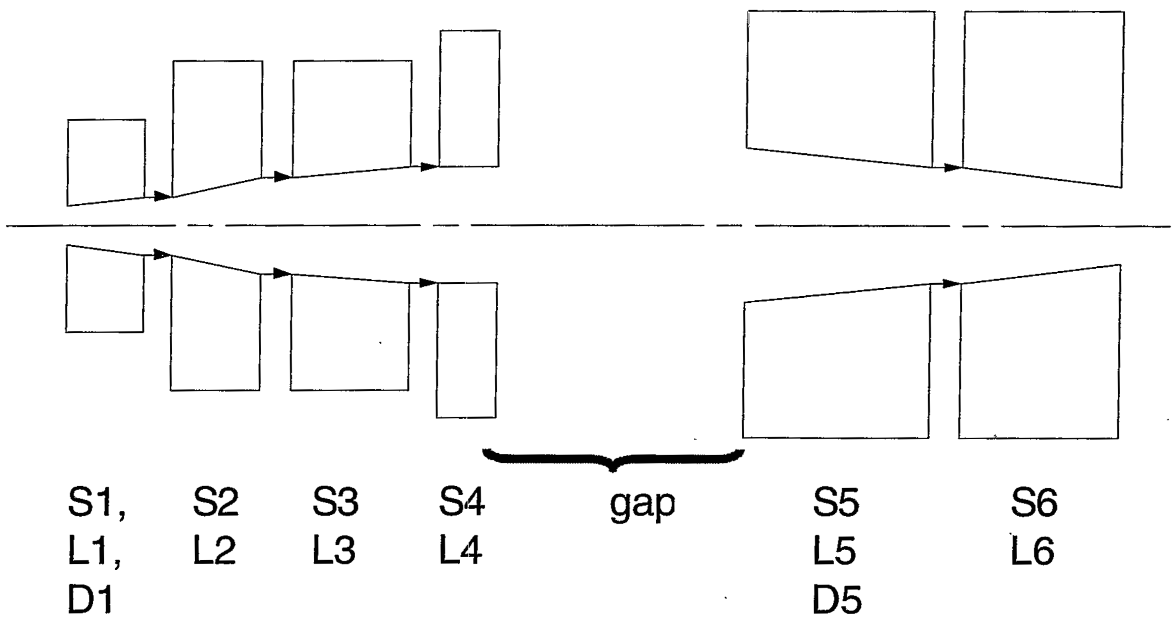
$r_{max} = 4.5\text{mm}$



MAGNET OPTIMIZATION

General problem has **1 6** geometry parameters + **Q** and **T**nozzle

Past experience gives some guidance:
Need pumping gaps , taper and two groups separated by drift



Helpful simplifications:

- small gaps fixed at 10mm
- diverging/converging system
- continuity of magnet bores
- target position and diameter FIXED
  (10mm dia. 316mm after magnets)

But **problem is nearly overwhelming** $5^{17}=7\ x10^{11}$

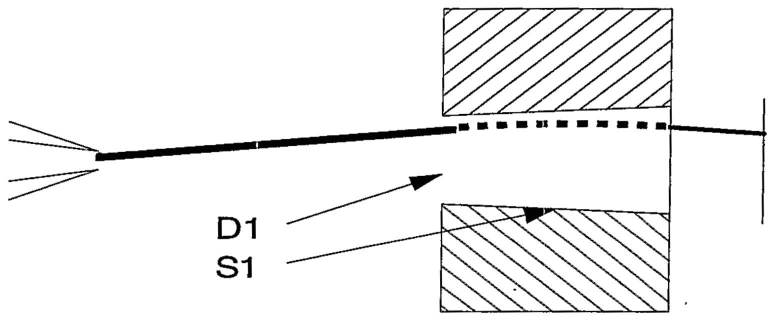
Gradient search not workable. We documented **numerous local maxima**

PROBLEM APPROACHED FROM TWO DIRECTIONS

a) P. Quin idea -- [redacted]

- Use gradient search on one or two parameters of first element
- Move on to next element
- Fine tune total system

Example: search on D1, S1 at constant L1.



RESULT:

→ MAGNETS FOLLOW BEAM ENVELOPE -- slope decreases

→ MAGNETS ARE MASSIVE --difficult to build and expensive

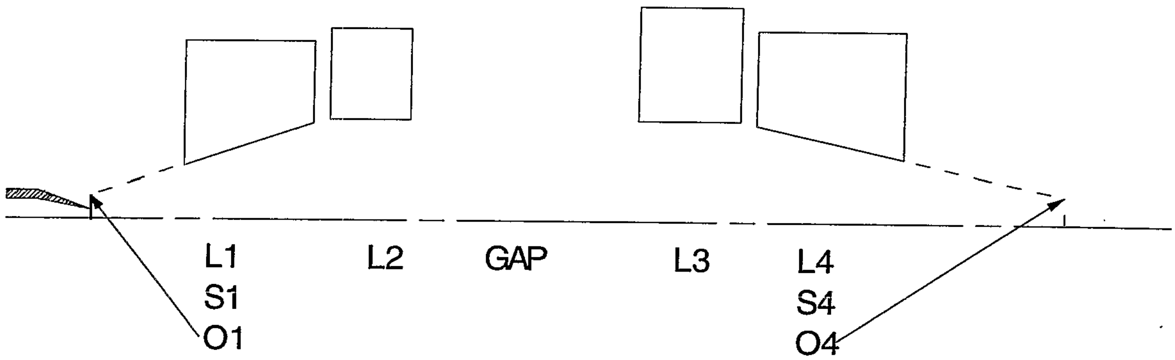
→ LONG GAP BEFORE CONVERGING ELEMENTS (650mm)

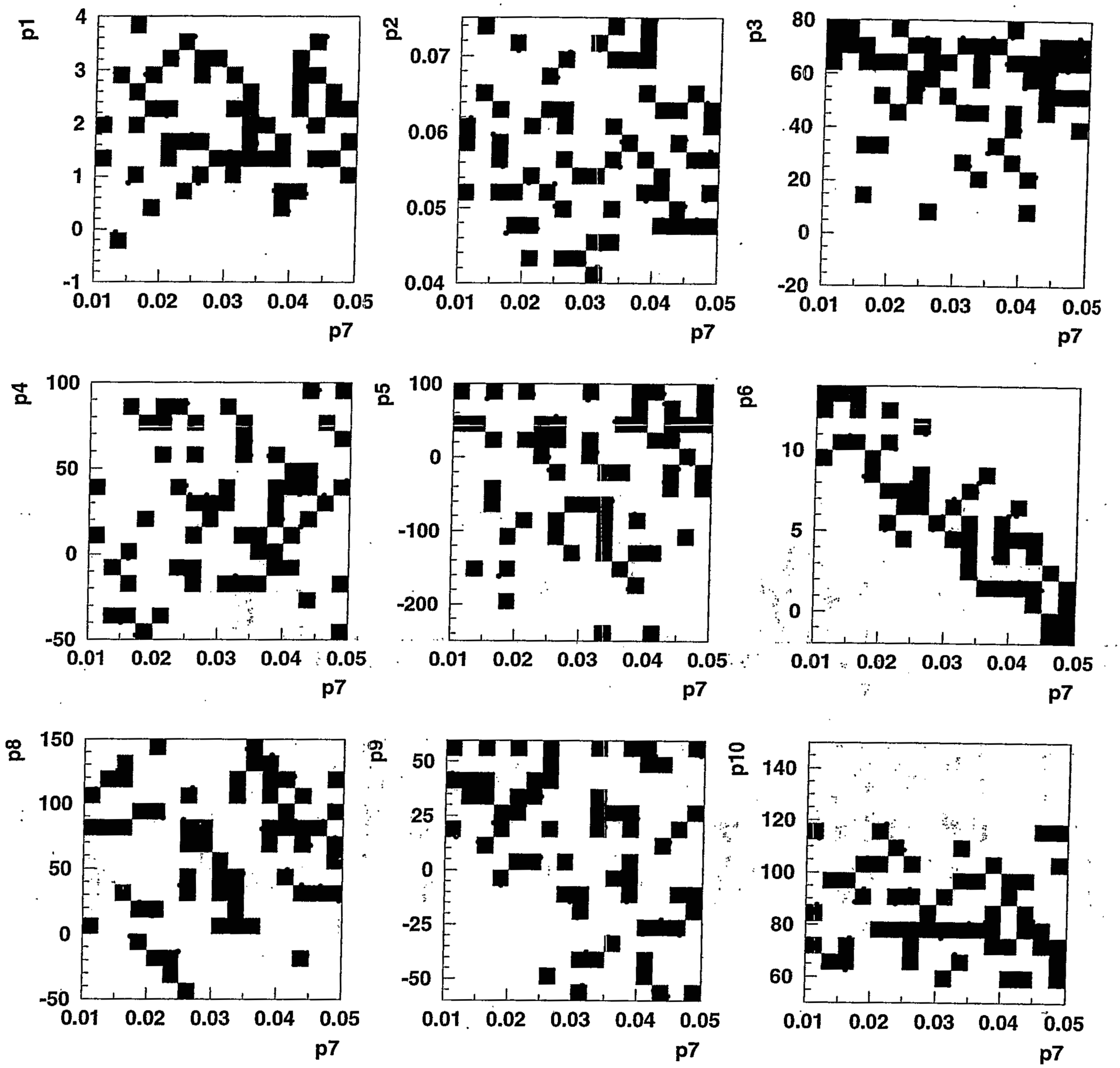
→ HIGH PREDICTED OUTPUT $1X10^{17}$ atoms/s into 9mm disc.

MORE MASS IN LAST ELEMENT THAN ENTIRE WISC ABS

b) H. Kolster method -- simplify design then pick RANDOM parameters.

Problem reduced to 9 geometry, Q and T_{nozzle}





Only systems making thickness cut are shown

Correlations are helpful but not sufficient to optimize a design.

- Ran code for >week and collected 10,000 systems,
- Studied best ones
- Predicted beams exceeded P. Quin/T. Wise design by 5%
- Magnets were **even more massive**.

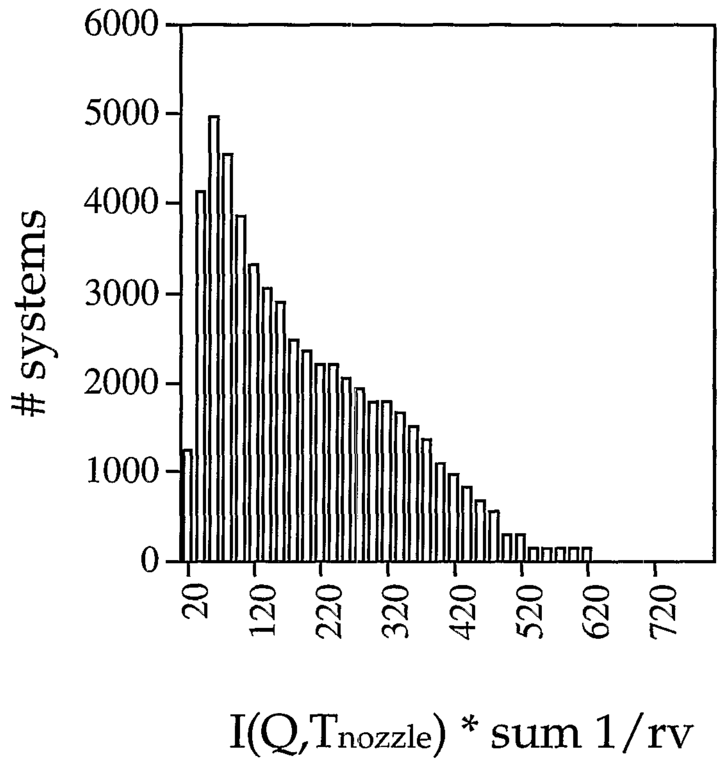
- Streamline code to 20X faster and run >10,000 systems each "trial".
- Examine best systems and further restrict parameter space
- Expand to full problem
- Do not calculate if MAGNET MASS exceeds specific value

example: $R_{entrance}$ started with huge range of 2mm --10mm

Then restricted to 4.5mm< $R_{entrance}$ <6.0mm

Eventually FIXED at 5.2mm while other parameters were still varying.

Similar for T_{nozzle}



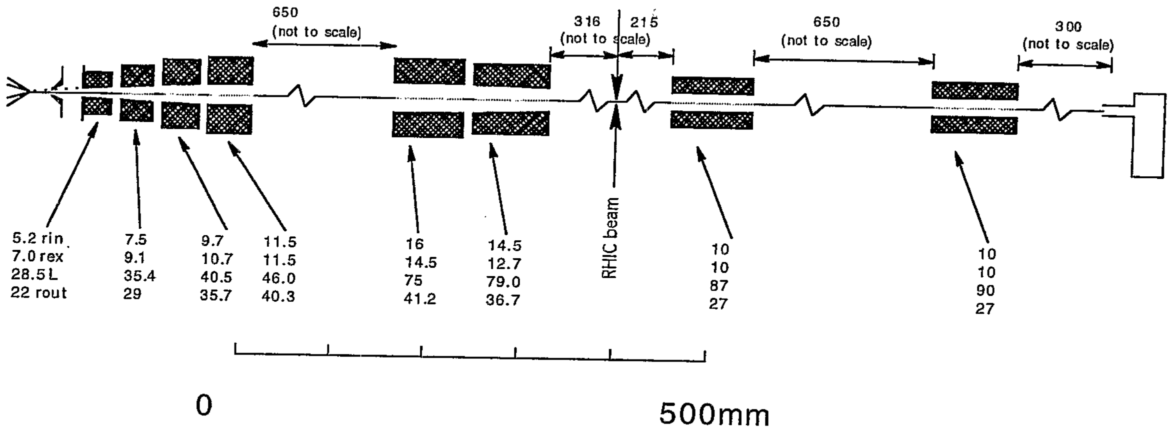
Typical 50,000 system histogram

Hand sorted through top 20

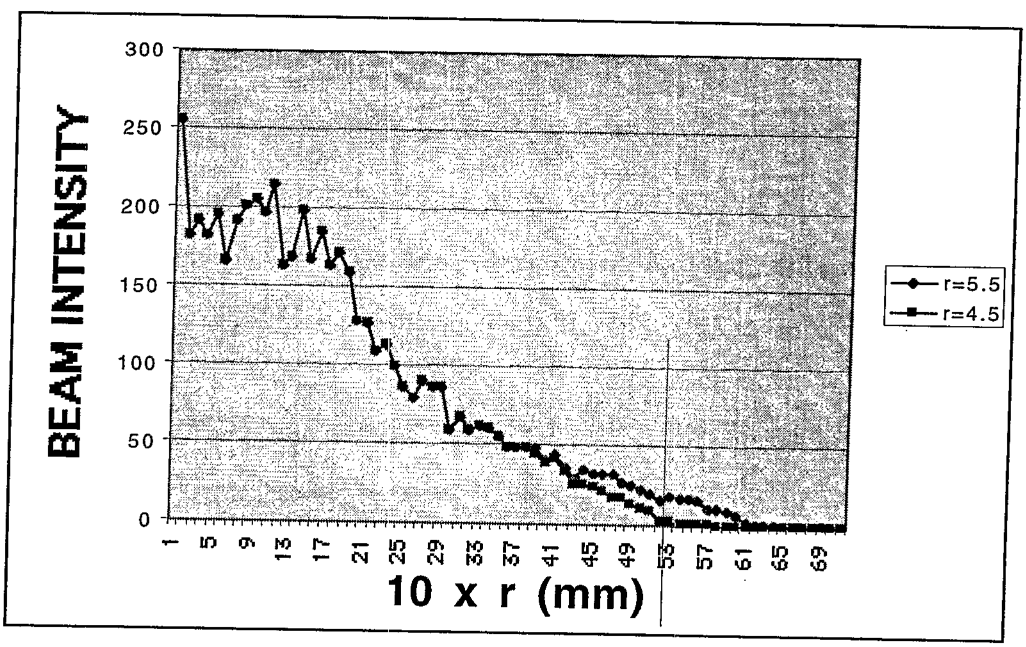
Some of the top 20 systems gave 93% of Quin/Wise "hand grown" design but with 1/2 the mass.

Picked one and further optimized with gradient search feature.

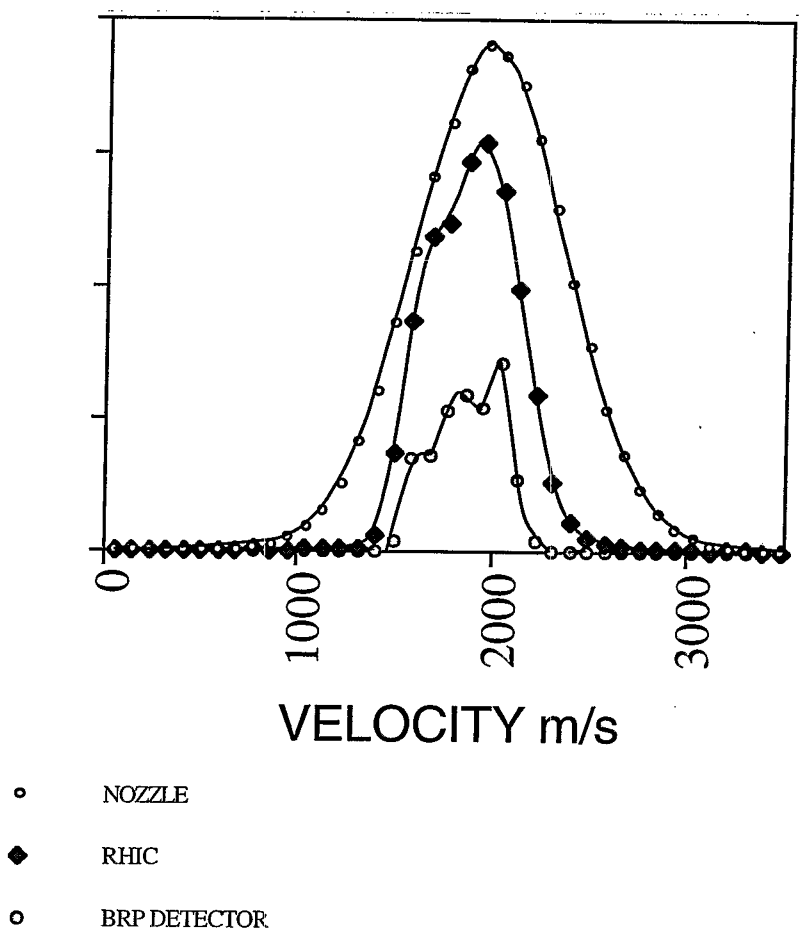
Only gained an additional 1% over random generated system.



final system sent to BNL for purchase
.TO SCALE EXCEPT FOR GAPS



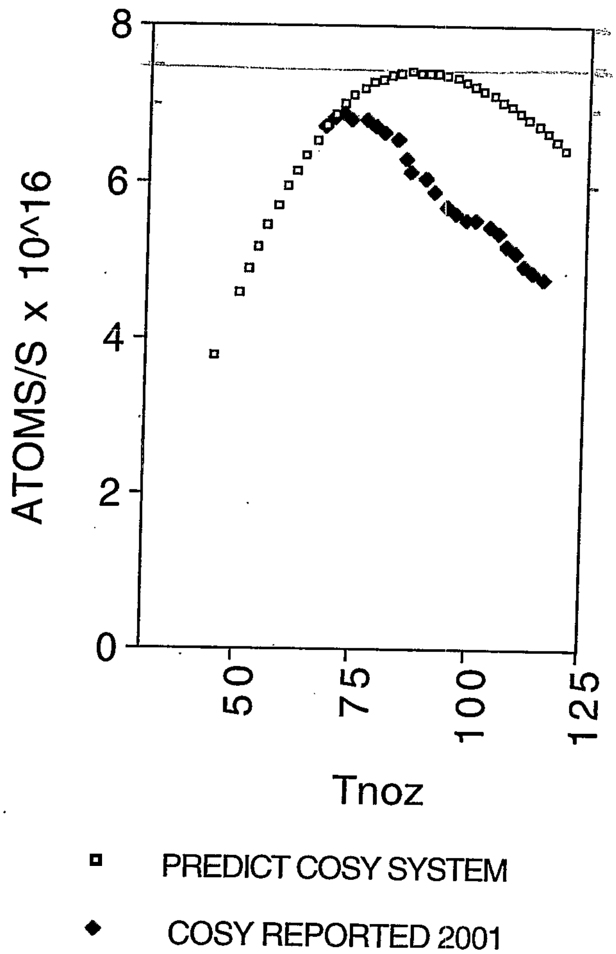
BEAM PROFILE AT RHIC IP
WITH AND WITHOUT 9mm DIAMETER COLLIMATOR

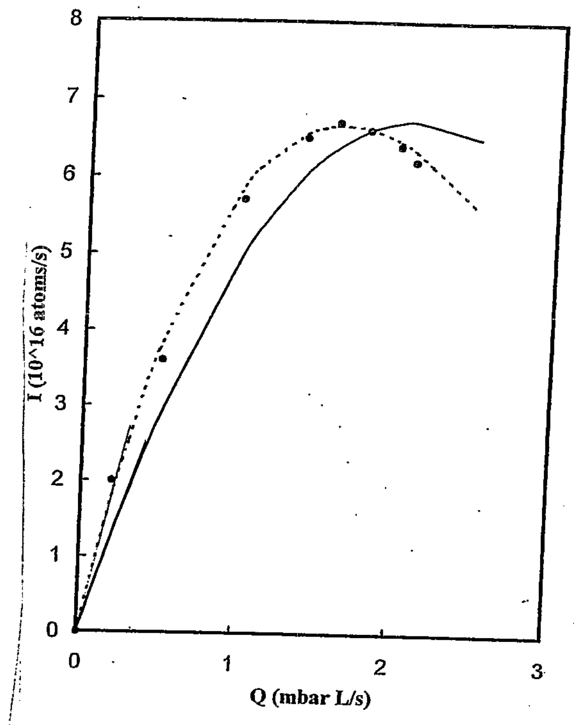


VELOCITY DISTRIBUTION AT NOZZLE, RHIC IP, AND AT BRP DETECTOR

VERIFY CODE ACCURACY

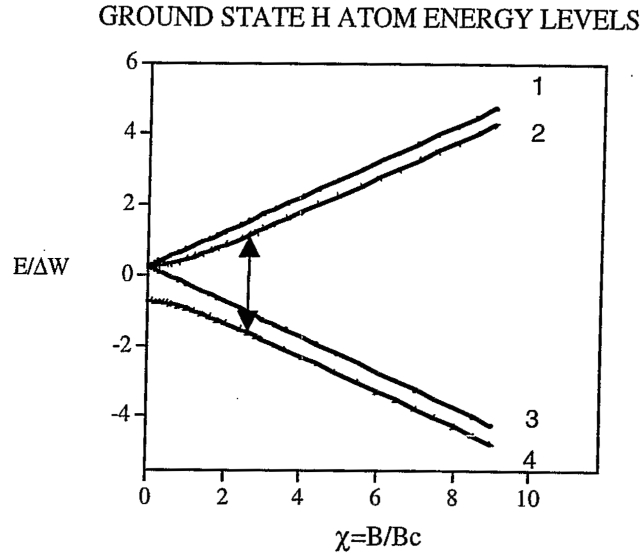
CALCULATED vs MEASURED beam for two existing systems





JET POLARIMETRY

Jet polarization requires 1-3 or 2-4 rf transitions

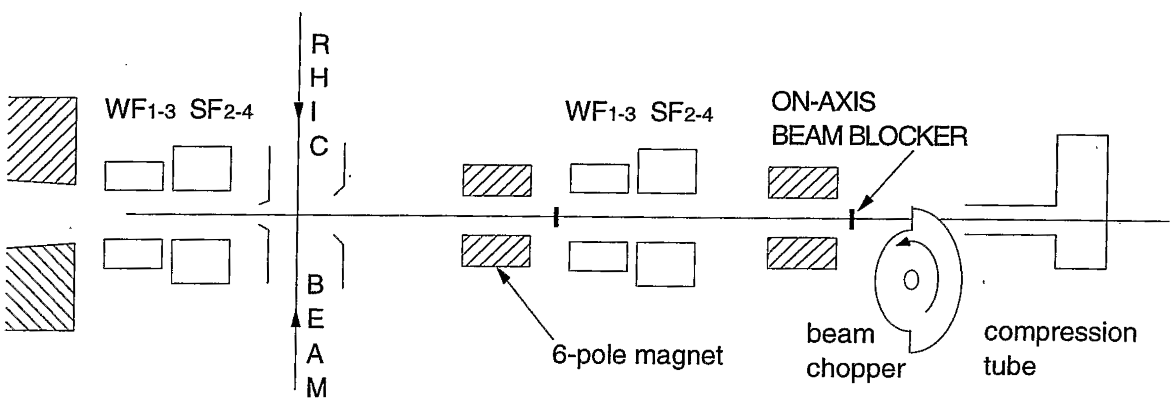


Polarimetry method similar to HERMES–

- Use additional rf transitions and 6-pole magnets.
- Completely reject state 3 &4 atoms.
- Measure beam intensity for various combinations of rf transitions.

- Solve system of simultaneous equations for the unknowns:

  1-3 efficiency, 2-4 efficiency, N_1/N_2



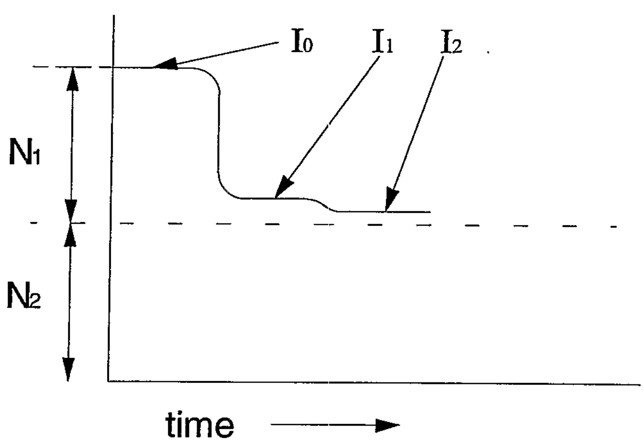
Some examples:

	ABS WF 1-3	ABS SF 2-4	BRP WF' 1-3	BRP SF' 2-4	Polarization
I_0	off	off	off	off	0
I_1	on	off	off	off	-1
I_2	on	**off**	on	**off**	-1
I_3	off	[redacted]	off	off	[redacted]

... etc.

I_{16}

We only need **six** combinations of the 16 possible.



$$\varepsilon_{1-3} = \frac{I_1}{I_0}\left(1 + \frac{N_1}{N_2}\right) - \frac{N_1}{N_2}$$

$$\frac{N_1}{N_2} = \frac{\left(\frac{I_7}{I_2} - \varepsilon_{2-4}\varepsilon'_{2-4}\right)}{\left(1 - \varepsilon_{1-3}\varepsilon'_{1-3}\, {}^{I_7}\!/_{I_2}\right)}$$

Measurement of BRP intensities

$I_0 = 1.5 \times 10^{16}$

Huge compared to HERMES flux

More than **entire output** of old ANAC sources from ~1980

Use chopper and compression tube.

Chop at 2 Hz

Test bench gives I_0 to 2% in 30 seconds

JET DILUTION

- Predicted Jet density is:

  $\rho = \mathbf{7x10^{11}/cm^3} \Leftrightarrow p_{H2} = \mathbf{1.3x10^{-5}\ mbar\ H_2}$ equivalent

- Carefully measure "REST GAS" including large z components.

H_2 and H_2O beams co-linear with JET

a) Nozzle: Ray tracing predicts only 0.3% H_2

b) ABS pumping chambers: not fully understood

Cosy saw [illegible] dilution

c) H_20 beam is small but dilutes with enhanced factor

[illegible] $= 18^{3/2}$

We need to measure Mass 1, 2, &18 densities at IP

Electron gun with crossed beam ionizer is planned

H_2 DILUTION WILL PROBABLY BE THE LARGEST SOURCE OF POLARIZATION ERROR

SYSTEMATIC ERROR FROM N1/N2 $\neq$ 1

RAY TRACING CODE PREDICTS:

AT JET-RHIC I P	AT BRP DETECTOR
N1=1.004	N1=1.020
N2= 1.000	N2= 1.000
N3=1X10-4	N3=0
N4=8X10-4	N4=0

DOES THIS MATTER? No.

Error depends on:

- RF transition efficiency
- Target guide field
- N_1/N_2

For reasonable values of ε_{ij}=.03, x=.01, a=0.9

ERROR IN ΔP = -.001

ERROR IN <P> = $3\text{x}10^{-4}$

$$\text{error}\Delta P = \text{x}\left[\varepsilon_{1-3} - \text{a}\varepsilon_{2-4} + \text{a} - 1\right]$$

$$error < P >= \frac{-\text{x}}{2}\left[\varepsilon_{1-3} + \text{a}\varepsilon_{2-4}\right]$$

$$\text{x} = \frac{N_1 - N_2}{N_1 + N_2}$$

CONCLUSION

JET DESIGNED WITH

- 9×10^{16} ATOMS/S INTO 9mm APERTURE, 316mm FROM LAST FOCUSSING ELEMENT

- JET THICKNESS $6 \times 10^{11}/cm^2$

- CODE AGREEMENT WITH EXISTING SOURCES IS ADEQUATE

- JET POLARIZATION PREDICTED TO BE NEAR 90% AND RAPIDLY REVERSABLE

- WE EXPECT 3-4% ERROR AT FIRST EVENTUALLY DROPPING TO BELOW 2% AFTER A YEAR OF RUNNING