POLARIZED JET
DESIGN ISSUES AND OPTIMIZATION

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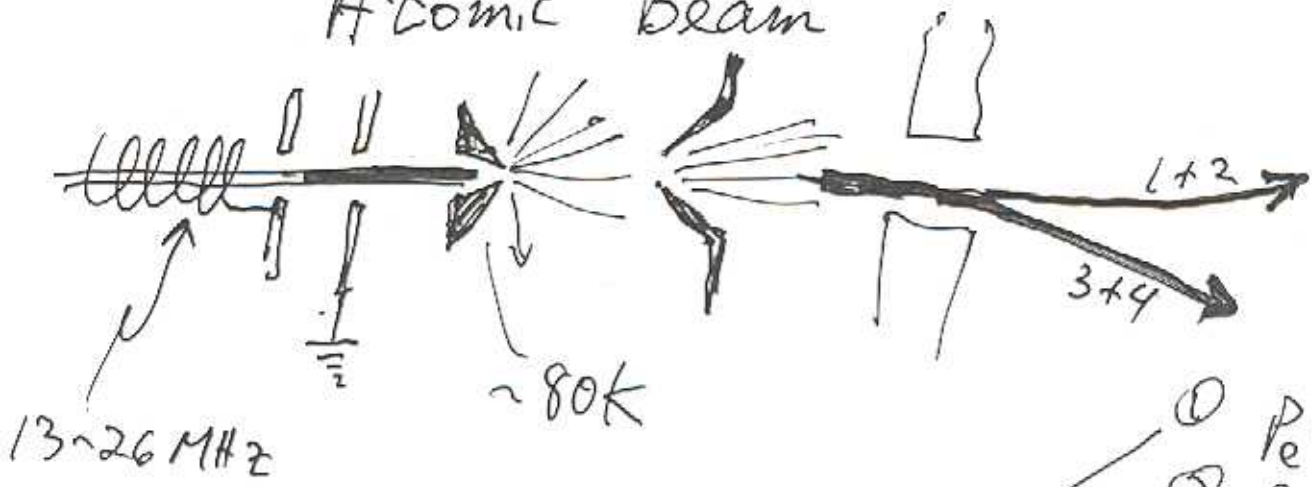
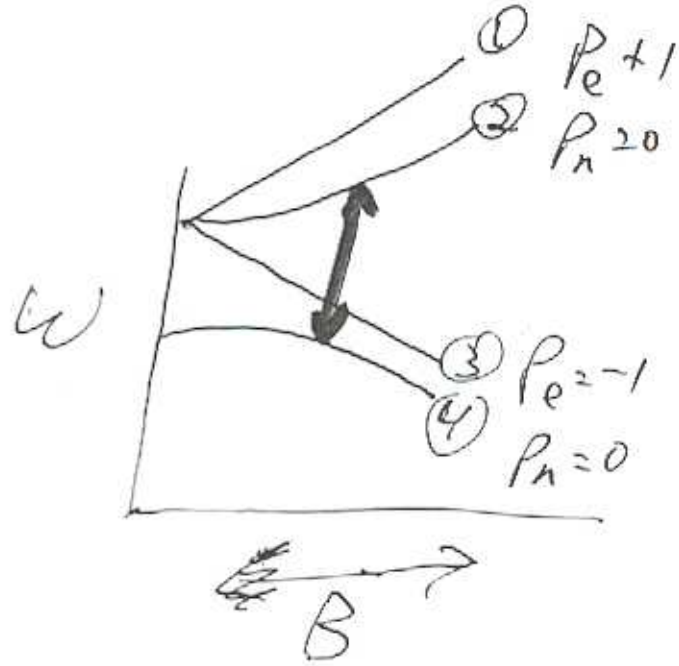
MIT: H. Kolster

Atomic Beam





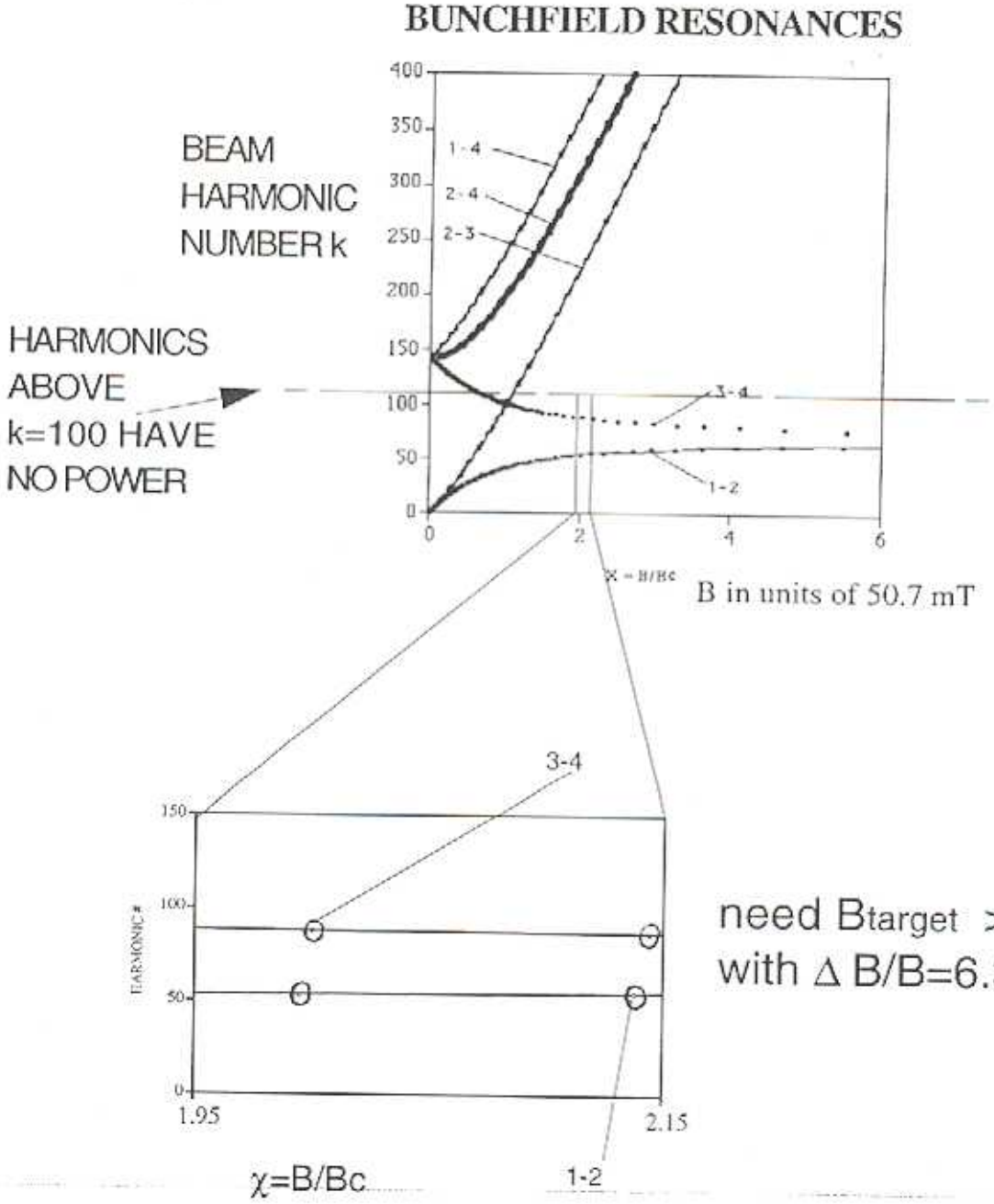
Rf transition required

for use as Calibration

Need more than High intensity

we
- Need to know occupation #'s for the 4 substates.

TARGET REGION CONSTRAINTS



need Btarget > 1kG
with Δ B/B=6.3X10^-3

- ~32mm POLETIP GAP FOR CIRCULATING BEAM
- MINIMIZE MAGNETIC FIELD FOR LOW ENERGY RECOIL PROTONS
- VERTICAL ABS MUST ACCOMODATE 69" (1765mm) TO FLOOR

6-pole

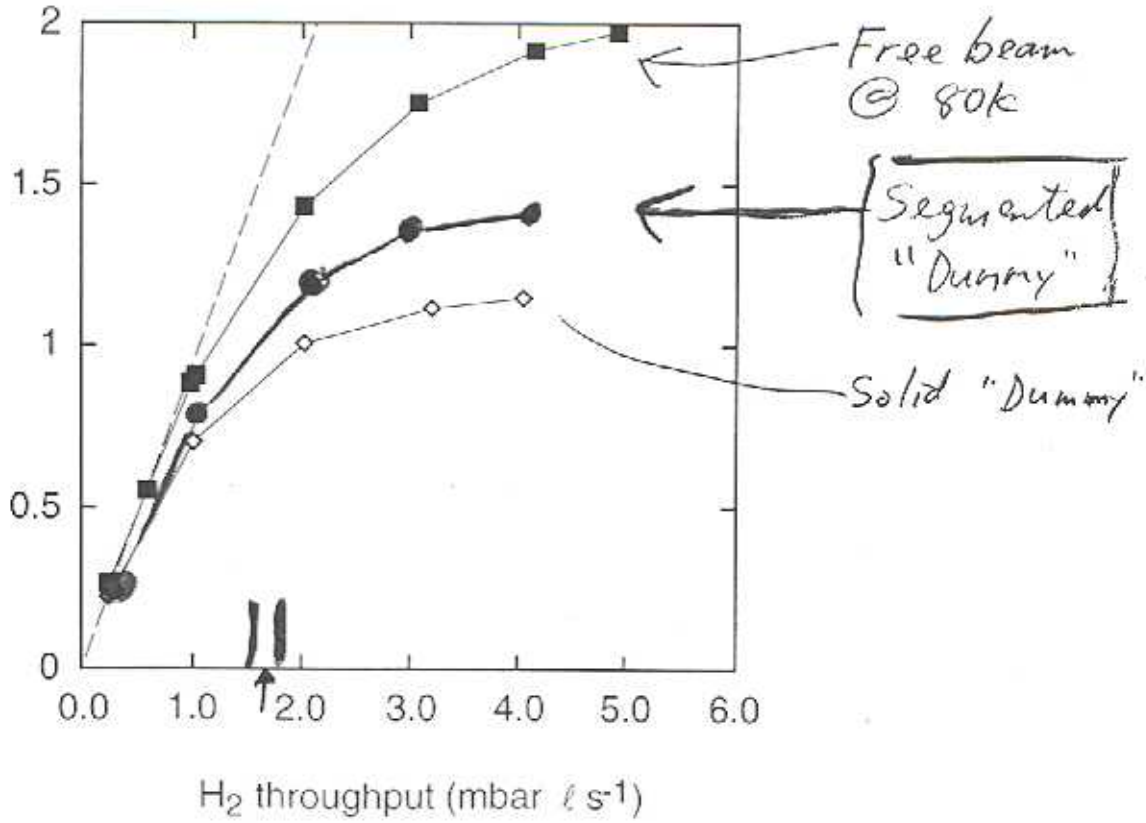
MAGNET DESIGN

- Two codes used
- Both had errors
- Now they agree (two weeks ago)

One version picks random geometries and fills a 10 parameter space.

The other starts somewhere and performs a gradient search.

We added some factors to the output:
a) BEAM ATTENUATION -- gas scattering. (wisconsin 1992)

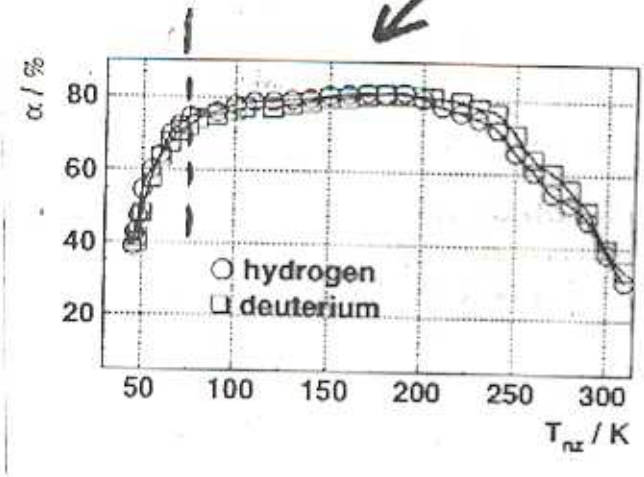


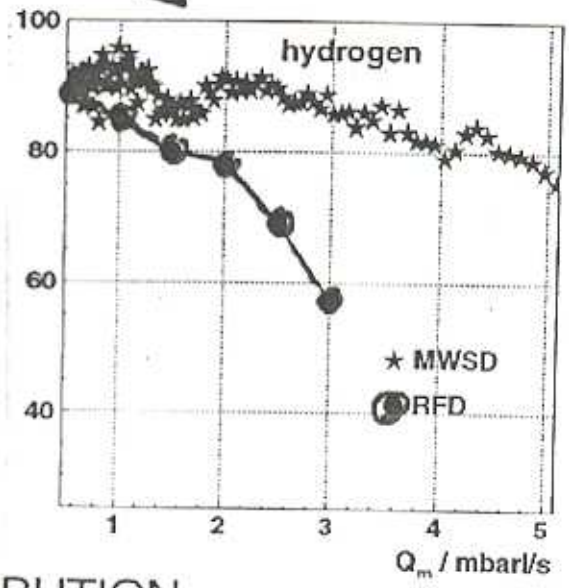
(b) DEGREE OF DISSOCIATION $\alpha = \#H/(\#H + 2*\#H_2)$

Wisconsin 1992 and N. Koch thesis HERMES--1999

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

Assume Q, T dependence is separable





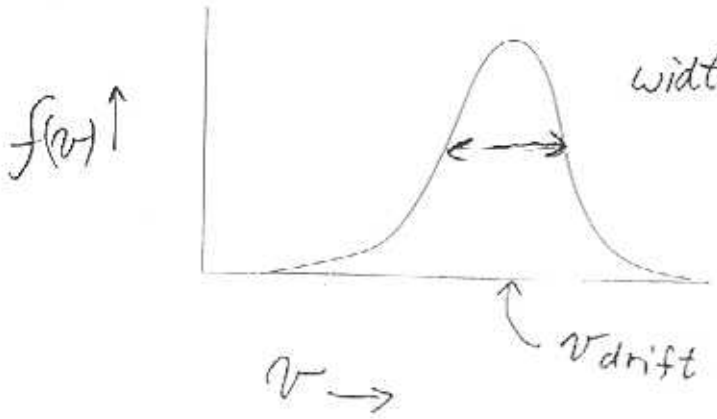
(c) START-VELOCITY DISTRIBUTION

B. LORENTZ DIPLOMARBEIT, HEIDELBERG 1993

based on measurements with rf dissociated atomic beam

$$f(v) = 4\pi v^2 \left(\frac{m}{2\pi kT_{beam}}\right)^{\frac{3}{2}} \exp\left\{-\left(\frac{m}{2kT_{beam}}\right)(v - V_{drift})^2\right\}$$

Vdrift depends on Tnozzle and Q (mbar liter/s)
Tbeam depends onTnozzle and Q (mbar liter/s)



Vdrift ≈ 1900 Meter/s

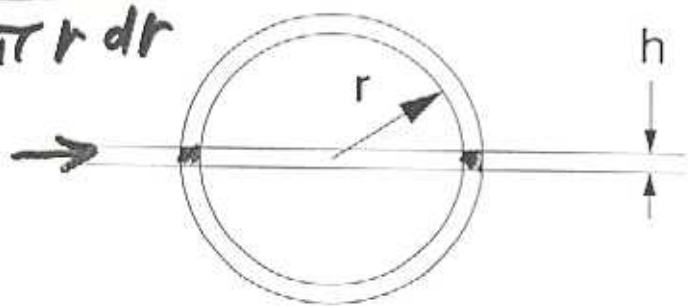
T beam ≈ 20K

(d) WE HAVE JET, NOT STORAGE CELL:
We give increased weighting to lower velocity atoms to account for their longer time in beam path.

$$\sum_{1/v}$$

(e) RHIC BEAM IS LINE CHARGE: improve statistics of ray trace code by summing 1/r.

$$\frac{2h\,dr}{2\pi r\,dr}$$



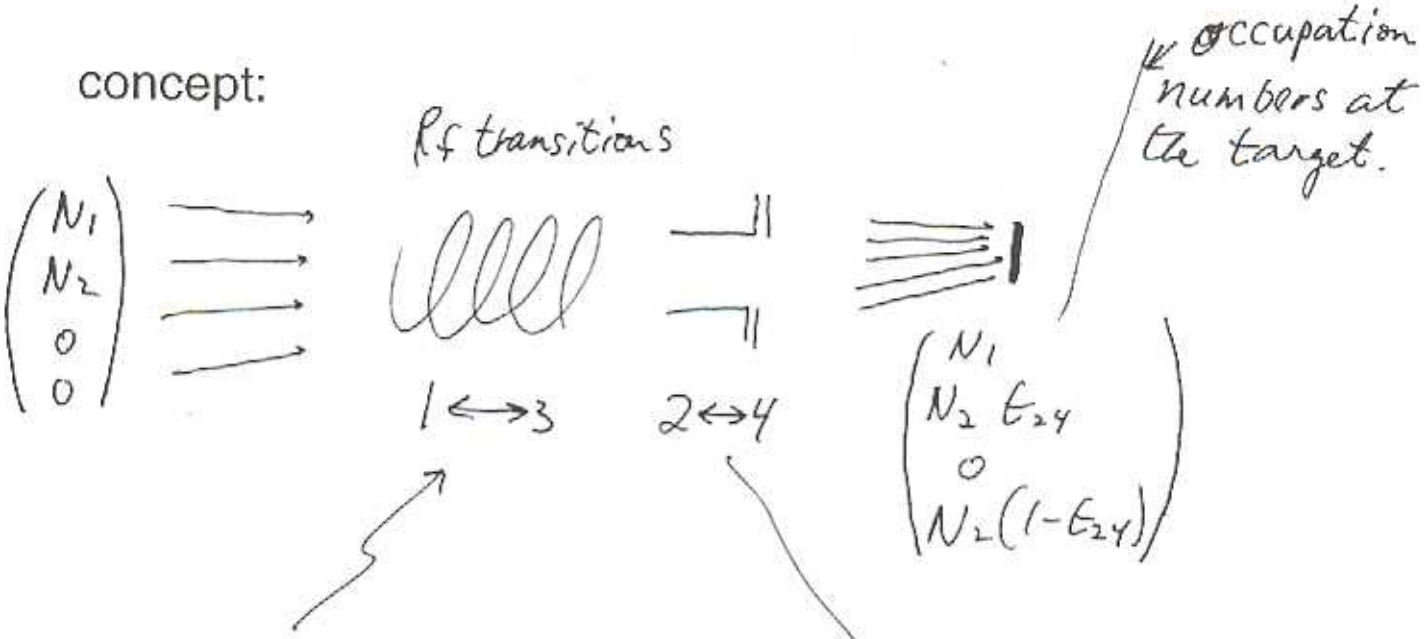
fraction of calculated trajectories at radius r that are seen by RHIC = h/r.
RHIC density prop. to 1/h.

COMBINING ALL OF ABOVE we optimize the function:

$$\tau(Q,T) = Q * \alpha(Q) * \alpha(T) * \{1 - A(Q,T)\} * \frac{\Omega}{N} * \sum_N \frac{1}{vr}$$

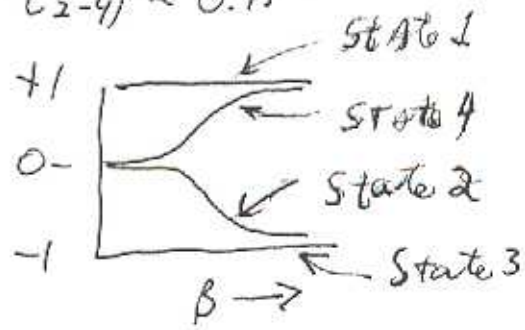
WHAT IS THE JET POLARIZATION?

concept:



efficiency $= (1-\epsilon_{1-3}) \simeq 0.95$ $\qquad (1-\epsilon_{2-4}) \simeq 0.95$

Example above 1-3 is <u>off</u>
2-4 is <u>on</u>.



State 1 polarization $Q_1 = 1$

State 2 " $\quad -a \equiv Q_2 = \dfrac{-\chi}{\sqrt{1+\chi^2}} \simeq -0.9 \text{ @ } \chi \simeq 2$

$$Q_3 = -1$$

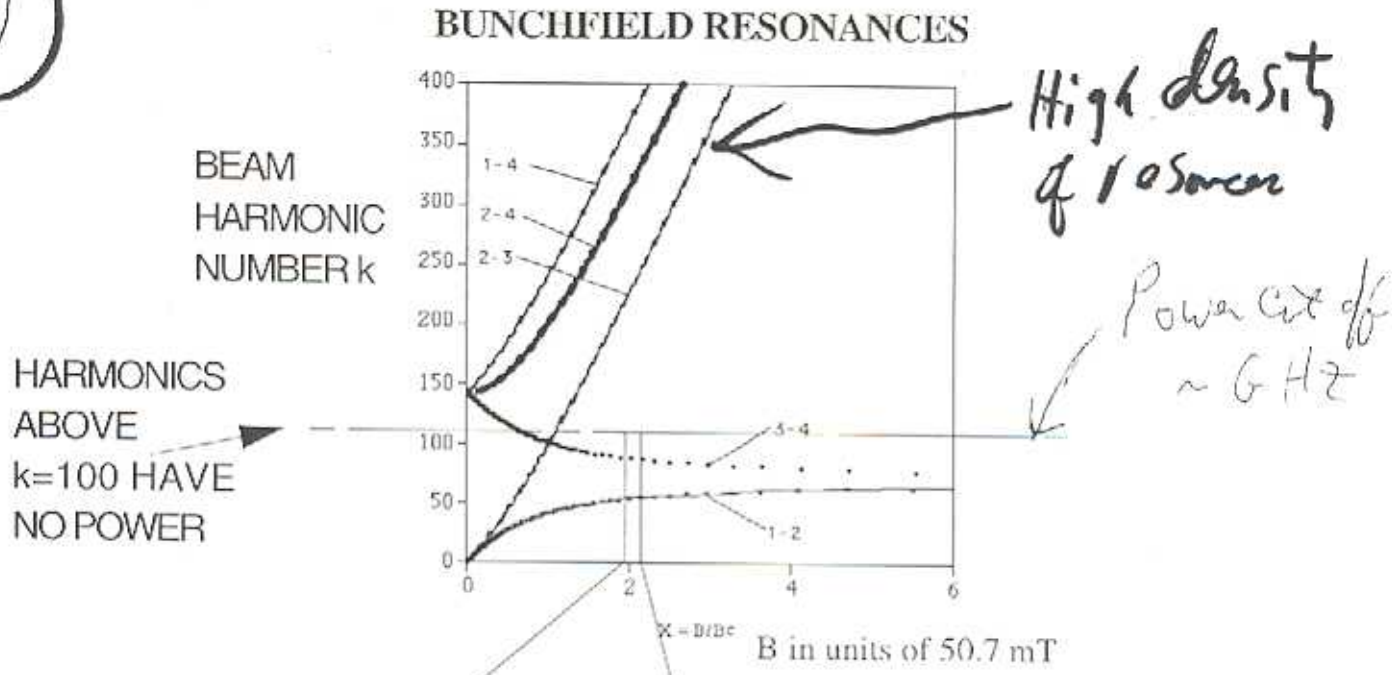
$$+a \equiv Q_4 = \frac{+\chi}{\sqrt{1+\chi^2}} \simeq 0.9 \text{ @ } \chi \simeq 2$$

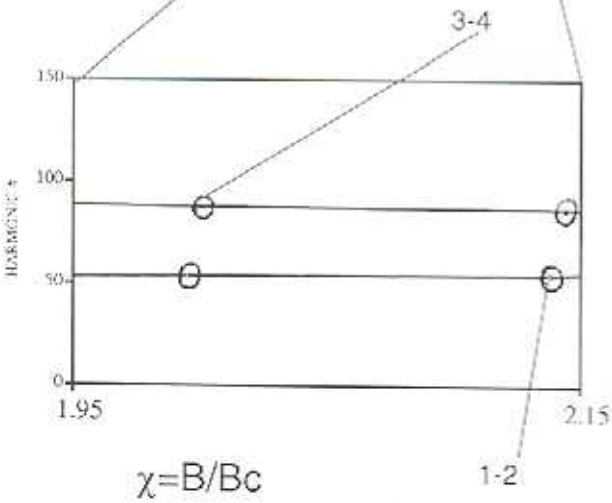
$$Q_{24} = \frac{N_1 - a\,\epsilon_{2-4} N_2 - 0 + a(1-\epsilon_{24}) N_2}{N_1 + N_2}$$

$$Q_{13} = \frac{\epsilon_{13} N_1 - a N_2 - (1-\epsilon_{13}) N_1 + 0}{N_1 + N_2}$$

TARGET REGION CONSTRAINTS

1





need Btarget > 1kG
with Δ B/B=6.3X10^-3

low field
=> tighter
uniformity

2

3

4

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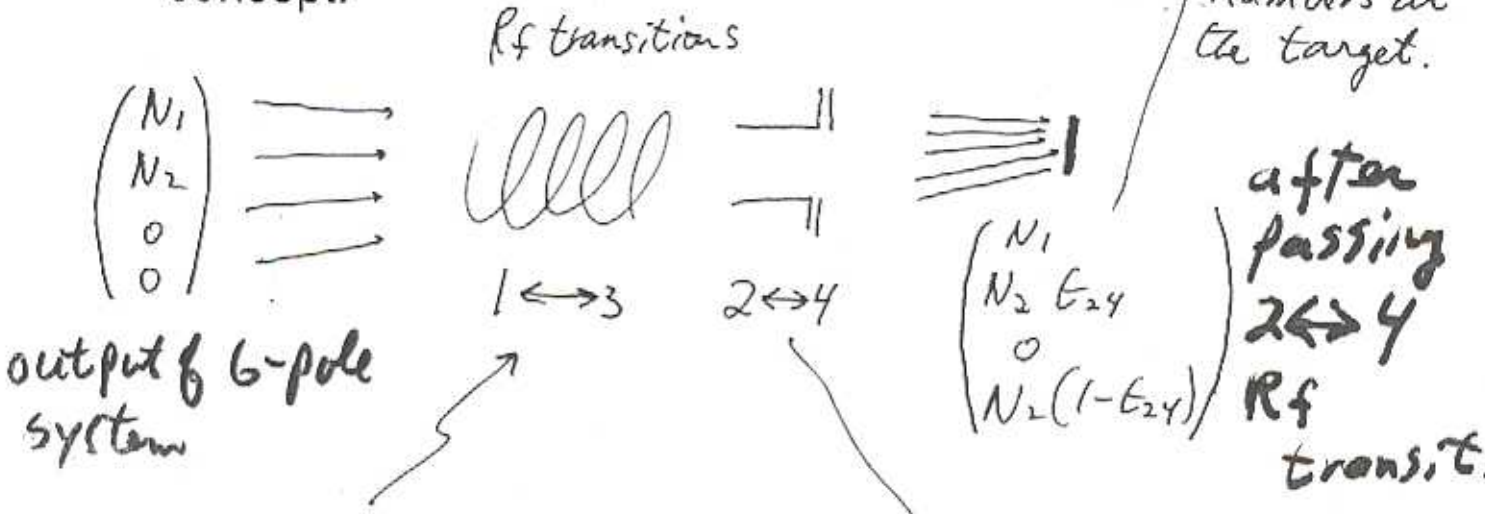
- MINIMIZE MAGNETIC FIELD FOR LOW ENERGY RECOIL PROTONS
- VERTICAL ABS MUST ACCOMODATE 69" (1765mm) TO FLOOR

WHAT IS THE JET POLARIZATION?

concept:

occupation numbers at the target.



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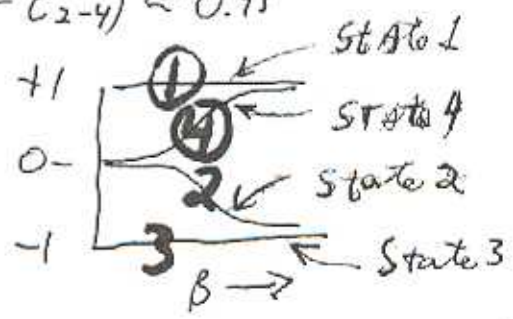


State 1 polarization $\quad Q_1 = 1$

State 2 " $\quad \boxed{-a} \equiv Q_2 = \dfrac{-\chi}{\sqrt{1+\chi^2}} \simeq -0.9 \;@\; \chi \simeq 2$

state 3 " $\quad Q_3 = -1$

State 4 " $\quad \boxed{+a} \equiv Q_4 = \dfrac{+\chi}{\sqrt{1+\chi^2}} \simeq +0.9 \;@\; \chi \simeq 2$

$$Q_{24} = \frac{N_1 - a\,\epsilon_{2-4} N_2 - 0 + a(1-\epsilon_{24}) N_2}{N_1 + N_2} \simeq 1$$

$$Q_{13} = \frac{\epsilon_{13} N_1 - a N_2 - (1-\epsilon_{13}) N_1 + 0}{N_1 + N_2} \simeq -1$$

NEED TO KNOW N_1/N_2, ε_{1-3} AND ε_{2-4}.
(not easily done)

Our solution:
1) Add two additional rf transitions and separation magnets.
2) Completely remove rejected states (3,4) at each stage by use of on-axis beam blockers.
3) Run multiple combinations of Rf transitions to generate 10 intensity measurements and solve for five unknowns.

N_1/N_2, ε_{1-3}, ε_{2-4}, ε'_{1-3}, ε'_{2-4}, σ_1/σ_2

ABS transitions

BRP transitions

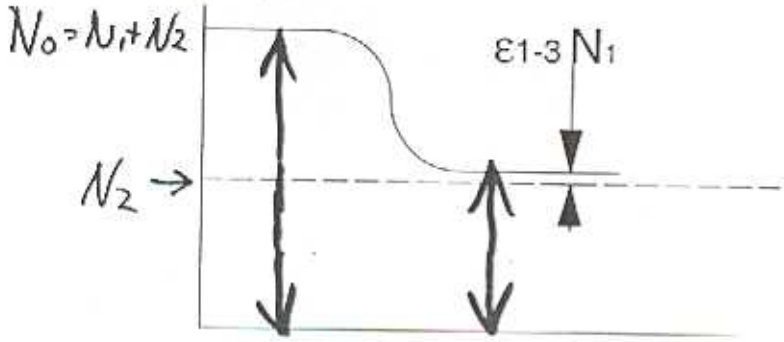
state1/state2 transmission ratio for BRP

present BRP solution

Also Very Long.
Same scale as ABS Solution

USEFUL WAY TO LOOK AT THE PROBLEM

BEAM INTENSITY AS RF1-3 IS TURNED ON. — as Seen by QMS. (Abs Polarimeter)



$$R_{13} = \frac{\varepsilon_{13} N_1 + N_2}{N_0}$$

$$R_{24} = \frac{N_1 + \varepsilon_{24} N_2}{N_0}$$

AFTER SOME ALGEBRA WE FIND CHANGE IN POLARIZATION:

$\Delta Q = Q_{1-3} - |Q_{2-4}|$:

$$\Delta Q = 2(1 + a - R_{1-3} - aR_{2-4})$$

N_1/N_2 does not effect ΔQ

<Q> does depend on N_1/N_2

Helpful Notation

$$\frac{N_1}{N_0} = \frac{1}{2}\left(1 \underline{\underline{+}} X_{abs}\right) \qquad \frac{N_2}{N_0} = \frac{1}{2}\left(1 \underline{\underline{-}} X_{abs}\right)$$

$$\frac{N_1}{N_2} = \frac{(1 + X_{abs})}{(1 - X_{abs})}$$

After Some Algebra:

$$\langle P \rangle = \frac{P_{13} + P_{24}}{2} = \frac{-a\, t_{24} + t_{13} - X\left(a\, t_{24} + t_{13}\right)}{2}$$

Error by ignoring $X_{abs} \neq 0$ is $\frac{-X\,(a\, t_{24} + t_{13})}{2}$

for $X = .03$ $\left(\frac{N_1}{N_2} = 1.06\right)$

$t_{13} \simeq t_{24} = 0.05$ Error in $\langle P \rangle = 0.0015$

Not the entire story

BRP also has unequal State 1, State 2 transmission.

i.e. $\frac{\sigma_1}{\sigma_2} \neq 1$

Error from ignoring $\sigma_1/\sigma_2 \neq 1$:

BRP Detector sees $\dfrac{N_1\sigma_1}{N_2\sigma_2} = \dfrac{1+x}{1-x} \simeq$

$$\simeq \frac{1 + X_{abs} + X_{brp}}{1 - X_{abs} - X_{brp}}$$

After some algebra, X_{abs} cancels

$$\boxed{\text{Error } \Delta P} = X_{brp}(t_{13} - a\,t_{24} + \underbrace{a - 1}_{\text{dominates.}})$$

$$\boxed{\Delta P \simeq -0.1\, X_{brp}}$$

$$\boxed{\text{Error } \langle P \rangle} = -\frac{X_{brp}(a\,t_{24} + t_{13})}{2}$$

for $X_{brp} = 0.05$ $\left(\dfrac{\sigma_1}{\sigma_2} \simeq 1.1\right)$

$t_{13} \simeq t_{24} = 0.04$

$a = 0.9$

Error $\Delta P \simeq -.005$

Error $\langle P \rangle = -.002$

Design conclusions:

1) although not critical we aim for
$N_1/N_2 = 1$

2) BRP must transmit close to
$\sigma_1/\sigma_2 = 1$ to avoid errors in target polarization measurement.

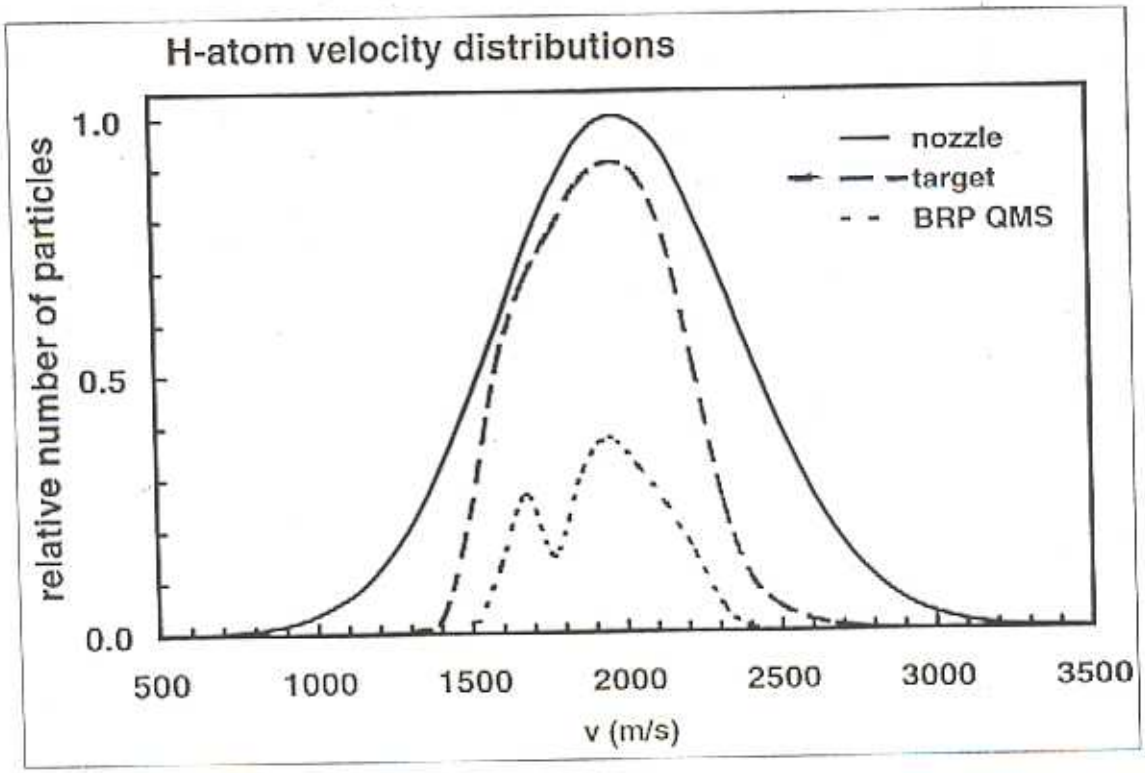
Ray tracing results

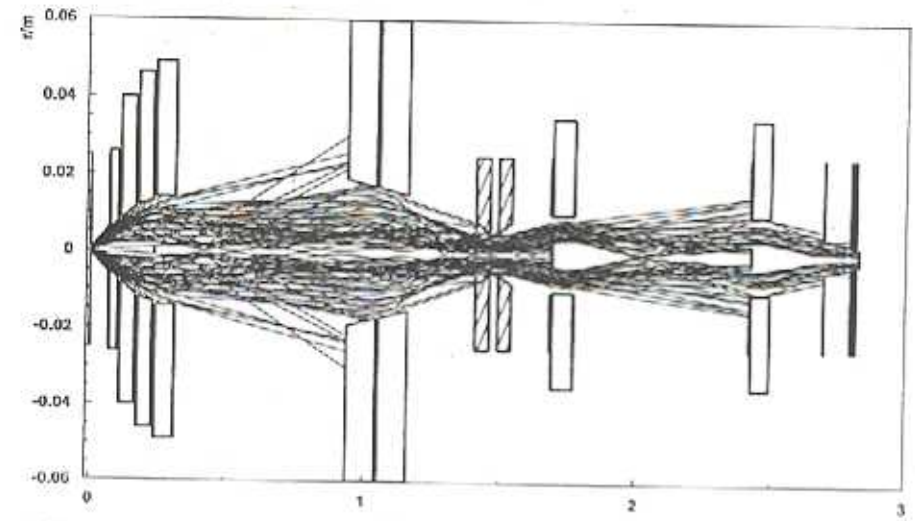
$$\frac{N_1}{N_2}\left(\Sigma \frac{1}{r v}\right) = 0.987 \Rightarrow X_{abs} = -0.007$$

$$\frac{N_1 \sigma_1}{N_2 \sigma_2}\left(\Sigma \frac{1}{r v}\right) = .976 \Rightarrow X_{BRP} = -0.006$$

velocity dependent attenuation not accounted for yet.

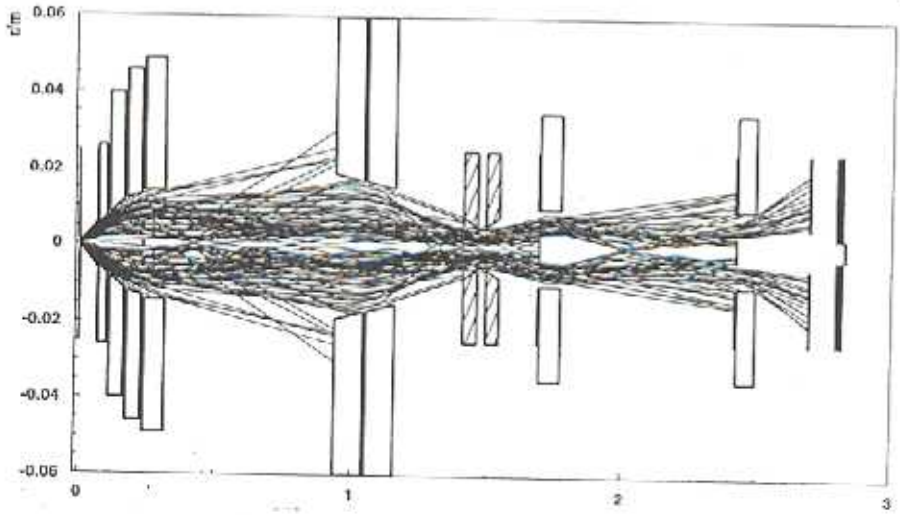
Rejection of states 3, 4 better than 10^{-3}


H-atom velocity distributions
relative number of particles
1.0
0.5
0.0
500
1000
1500
2000
2500
3000
3500
v (m/s)
nozzle
target
BRP QMS

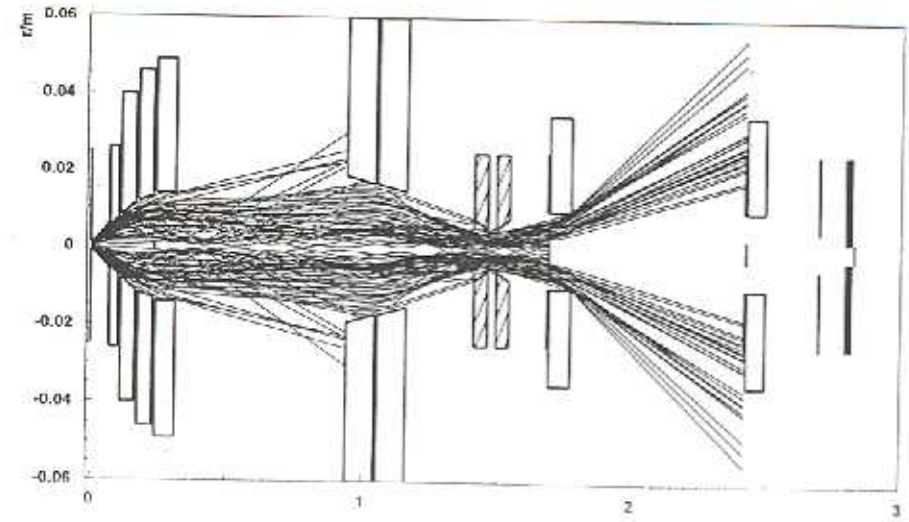


100 RAYS
each RAY is
~1% effect.

1, 1, 1
No Rf on



1, 1, 3 BRP
Rf 1↔3
ON

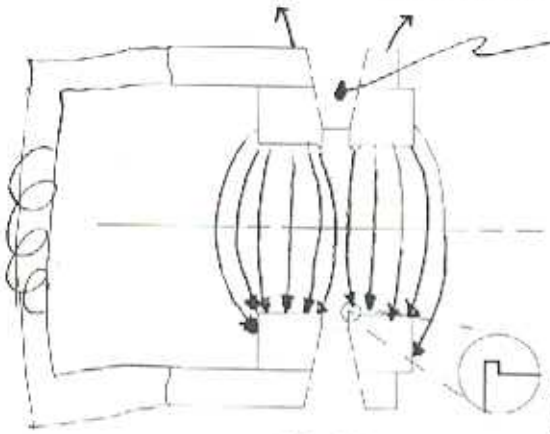


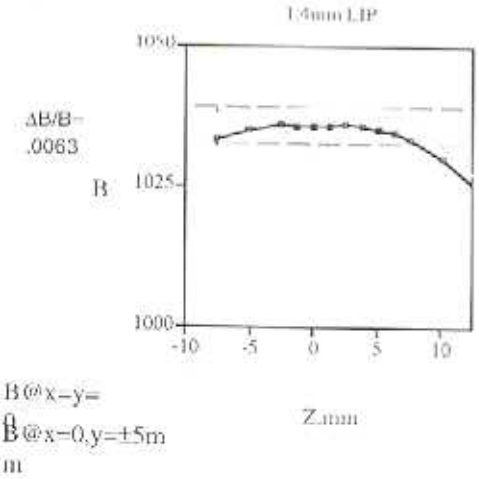
1, 3, 1
Both ABS+BRP
Rf 1↔3 ON

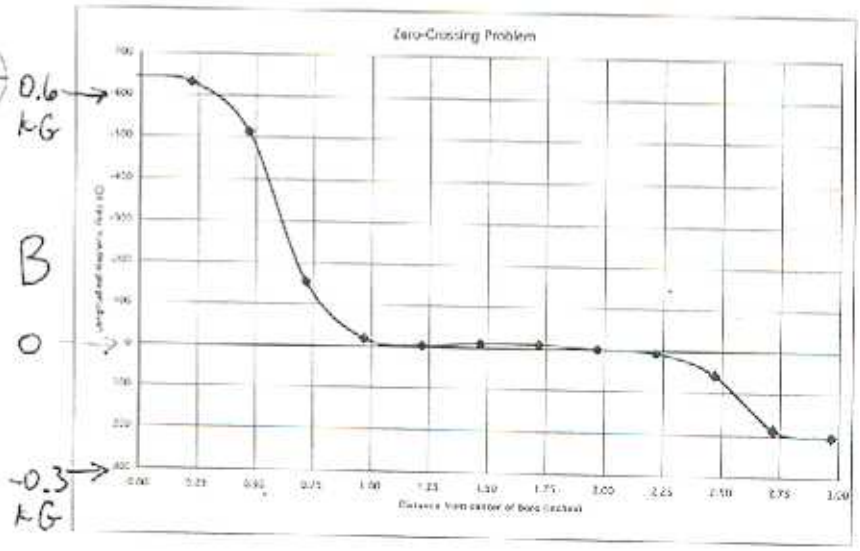
TARGET REGION MAGNET.

uniformity issue already solved

We have new problem--ZERO CROSSING







we added ceramic magnet pellets to make transverse field.--only partially sucessful.

Computer modeling required.