Magnetized Beam Simulations (LDRD)
Fay Hanon
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OVERVIEW
Goals

• Produce a magnetized beam from a 350kV DC gun
• Measure magnetization
• Measure emittance
• Demonstrate a round to flat transform
# Beam Evolution

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cathode Bz</td>
<td>0.2T</td>
</tr>
<tr>
<td>XY_rms, top-hat</td>
<td>1.5mm</td>
</tr>
<tr>
<td>t rms, Gaussian</td>
<td>23ps</td>
</tr>
<tr>
<td>Charge</td>
<td>0 – 420pC</td>
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<tr>
<td>Gun voltage</td>
<td>350kV</td>
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</tbody>
</table>
Transverse rms beam size

Location of solenoid

Big beam!

20pC, 100pC, 210pC, 420pC

TRANSPORT THE SAME: DOMINATED by canonical angular momentum!
Transverse normalize trace-space emittance

Angular momentum included in calculation of emittance
Bunch length rms

Longitudinally we see space charge as usual.
MEASUREMENTS
- EMITTANCE
Double slit emittance measurement
Double slit virtual experiment

- At the diagnostic, break the beam up into beamlets transversely to simulate the beam scanning over the slit
- Let the beamlet particles drift to the second slit location (removing any that intercept the diagnostic)
- Break the beamlet up into more beamlets
- Count particles in each sub beamlet
- Produce phase space
Virtual result

Directly from simulation

Reconstructed via 2 slit method

Can change slit size and spacing to get best design
MEASUREMENTS
- MAGNETIZATION
Magnetization/Angular momentum

• Insert a slit into the beamline to select an emittance-dominated beamlet.
• Let the beamlet drift to a screen and image it.
• \[ < L > = \frac{2p_z\sigma_1\sigma_2 \sin \theta}{D} = B_z e a_0^2 \]
  - \( \sigma_1 \): beam rms at diagnostic cross 1
  - \( \sigma_2 \): beam rms at diagnostic cross 1
  - \( D \): drift between diagnostics, \( \theta \): angular rotation, \( p_z \): longitudinal momentum
Fermilab experiment
Example beam
Movie
Magnetization virtual experiment

Blue – beam at the slit (500k, 20um slit)
Red – particles selected by slit
Green – particles tracked to screen 0.26m away

Not linear!
Assumes a solenoid at cathode with 0.2T peak
0.07% particles through slit

420pC
Magnetization virtual experiment

The curve is still evident at 20pC.

This isn’t charge related.

The curve is still evident at 20pC.
Phase space plots

This is what the slit cuts out in phase space
Why is there an ‘S’?

This is the solenoid field I used...

Could it be because the field isn’t uniform transversely over the emitting spot?
Why is there an ‘S’?

- This is what simulation assumes off axis
- Slight variation
Why is there an ‘S’?

Make fake field map.

Make fake Helmholz pair field

Cathode here!
Compare

Both 420pC

Fake Helmholtz coil

Standard solenoid
4 real field maps, scaled to give ~0.2T

Options Combined

- Bmod_lousy
- Bz_helmholtz
- Bmod_coil_puck
- Bmod_coil
- Normal sol

Bz_mod vs z (cm)
Transverse beam size, emittance
Magnetization virtual experiment

Can’t see ‘S’ – all seem linear… why is this…

At 1m
Normal solenoid
Normal solenoid

Ldrd.014
Is the trick to keep beam small in beamline solenoids?

- Trying not to have different B.dl over transverse direction.
Let beam get big and then focus

So even with good Helmholtz field it can become distorted!
MEASUREMENTS
- ROUND TO FLAT TRANSFORM
Emittance splits into a large and small component
Beam evolution
Beam evolution
CONCLUSIONS
• Simulations show we should be able to demonstrate measurement of angular momentum dominate beams
• Space charge does not effect transverse transport much
• Should try to keep transverse size small
• Round to flat possible with low energy beam
Increase gun voltage

CAM dominated
So what does the emittance look like

Remove the contribution from angular momentum. Calculate the angular momentum from a correlation in the $x$, $px$ phase space and subtract prior to the emittance calculation.
Field calculation

• In astra – off axis fields calculated from the on-axis field profile derivatives polynomial expansion

• $B_z(r) = B_z,0 - \left(\frac{r^2}{4}B_z''\right) + \left(\frac{r^4}{64}B_z'''ight) \ldots \text{etc}$

• $B_r(r) = -\frac{r}{2}B_z' + \left(\frac{r^3}{16}B_z''\right) \ldots \text{etc}$

• Flatter the profile, less variation in $B_z$ off axis.