Magnetized Beam LDRD

FAY HANNON

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Measurements

- **Phase 1**
  - Thermal emittance (solenoid scan)

- **Phase 2: With space charge**
  - Emittance
  - Magnetization (If we can source a magnet)

- **Phase 3:**
  - Magnetization
  - Round to Flat transform
Phased approach

1. ... 2. ... 3. ...
Emittance
What emittance do we measure

- Transverse normalized rms phase space emittance. Output from ASTRA – based on canonical variables
  \[ \frac{1}{\langle m_e \rangle} \sqrt{\langle x^2 \rangle \langle p_x^2 \rangle - \langle x \cdot p_x \rangle^2} \]
- Geometric emittance
  \[ \frac{1}{\langle E \rangle} \sqrt{\langle x^2 \rangle \langle p_x^2 \rangle - \langle x \cdot p_x \rangle^2} \]
- Transverse normalized rms trace space emittance based on geometrical parameters. Typically measured in machines as \( x' \) is observed rather than \( p_x \). Only differs from canonical emittance when large energy spread or divergence.
  \[ \frac{\langle E \rangle}{m_e} \sqrt{\langle x^2 \rangle \langle x'^2 \rangle - \langle x \cdot x' \rangle^2} \]
Emittance

- Can’t do solenoid scan as SC/CAM dominated.
  - Exception is thermal emittance
- Vary solenoid, change emittance, SC non-linear, so can’t make a fit.

Location of diagnostic
Non-magnetized beam example
Emittance

- **Multi slit**
  - If beam is very divergent, beamlets will overlap. Difficult to fit, then interpolate to give phase space.

- **Double slit**
  - Use correctors to scan one slit, then the other and collect particles with Fcup. 3 diagnostic crosses.

- **Single slit**
  - Use correctors to scan one slit, image on viewer and process to get phase space. 2 diagnostic crosses
Emittance

- For a good measurement need
  - Laminar beam ish
  - Reasonable size at slit
  - Narrow, thin slit
- With solenoid at present location beam is big – gets lost on beam pipe
Emittance

- Redesign beamline to locate the slits closer to the solenoid
- Carefully choose slit dimensions and separation between slits.
Double slit virtual experiment
Double slit virtual experiment

- **1mm thickness, 20um width**
- **3mm thickness, 20um width**

Green, particles that make it through the slit

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Double slit virtual experiment

- Simulate 500k particles from cathode to location of the diagnostic

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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<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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</table>
Transverse rms beam size

20pC, 100pC, 210pC, 420pC

TRANSPORT THE SAME: DOMINATED by canonical angular momentum!
Transverse normalize trace-space emittance
Longitudinally we see space charge as usual.
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

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Virtual result

Directly from simulation

Reconstructed via 2 slit method

Can change slit size and spacing to get best design

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Magnetization
This is a real experiment we would like to do to measure magnetization.

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
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

This isn’t charge related.

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Magnetization virtual experiment

The curve is still evident at 20pC.

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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?

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Why is there an ‘S’?

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

Make fake field map.

Cathode here!

Make fake Helmholz pair field
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

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Transverse beam size, emittance
Magnetization virtual experiment

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

At 1m
Normal solenoid
Is this space charge in EC sol?

opC
Is the trick to keep beam small in beamline solenoids?

- Trying not to have different B.dl over transverse direction.
Could this explain difference between helmholtz and normal sol

Normal

Helmholtz

Focusing solenoid here
Let beam get big and then focus

So even with good Helmholtz field it can become distorted!
Increase gun voltage

CAM dominated

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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.
Reverse polarity of EC solenoid

- No space charge case
Conclusions

- Beam is CAM dominated
- Good cathode field uniformity not as important as keeping beam from blowing up
- In essence, try to approximate transport in a continuous solenoid with discrete magnets