Magnetized Beam LDRD

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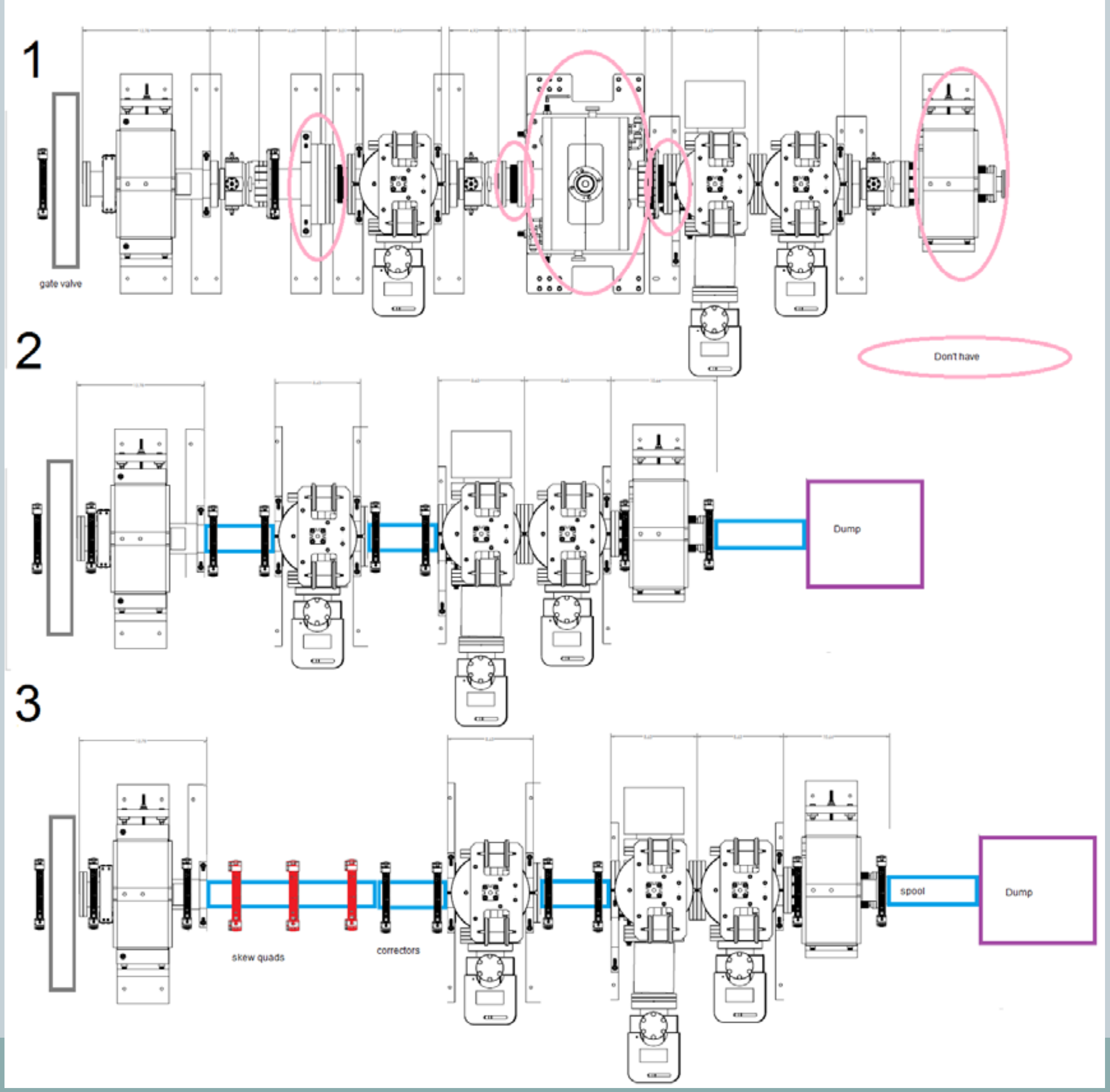
Measurements

- Phase 1
  - Thermal emittance (solenoid scan)
- Phase2: With space charge
  - Emittance
  - Magnetization (If we can source a magnet)
- Phase 3:
  - Magnetization
  - Round to Flat transform

Phased approach



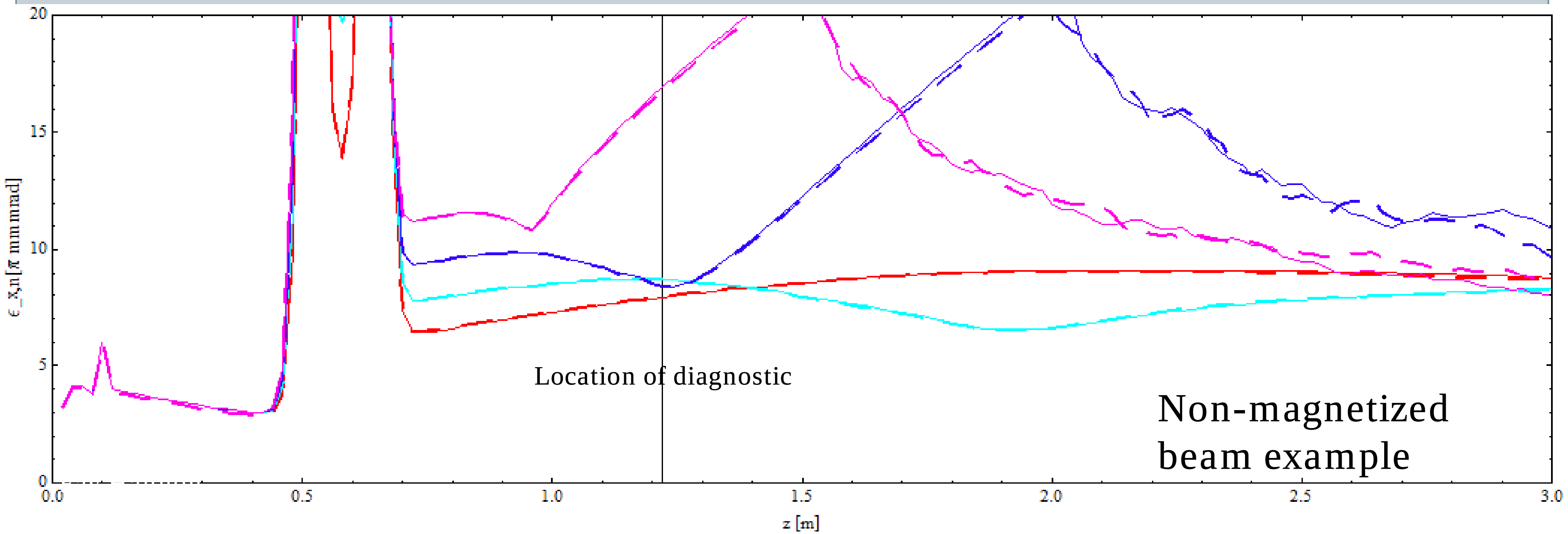
Emittance

What emittance do we measure

- Transverse normalized rms phase space emittance. Output from ASTRA – based on canonical variables
- $\frac{1}{<m_e>}\sqrt{< x^2 >< {p_x}^2 > -< x.p_x >^2}$
- Geometric emittance
- $\frac{1}{<E>}\sqrt{< x^2 >< {p_x}^2 > -< x.p_x >^2}$
- Transverse normalized rms trace space emittance based on geometrical parameters. Typically measured in machines as x' is observed rather than px. Only differs from canonical emittance when larege energy spread or divergence.
- $\frac{<E>}{m_e}\sqrt{< x^2 >< x'^2 > -< x.x' >^2}$

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.

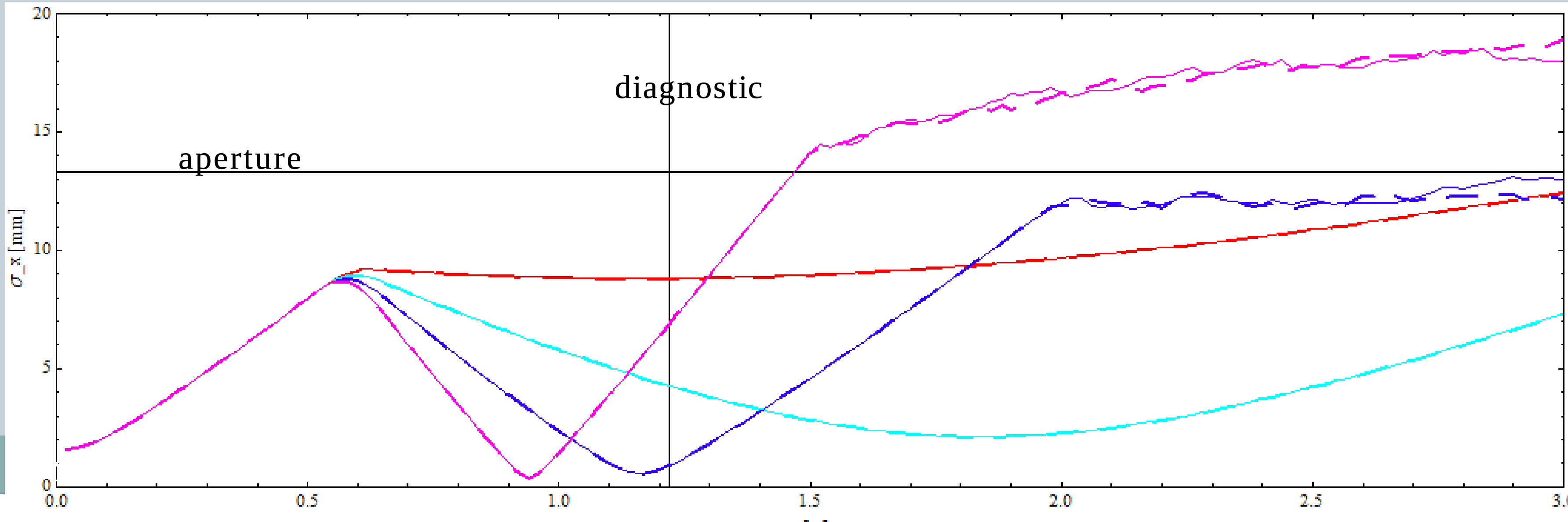


Emittance

- 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

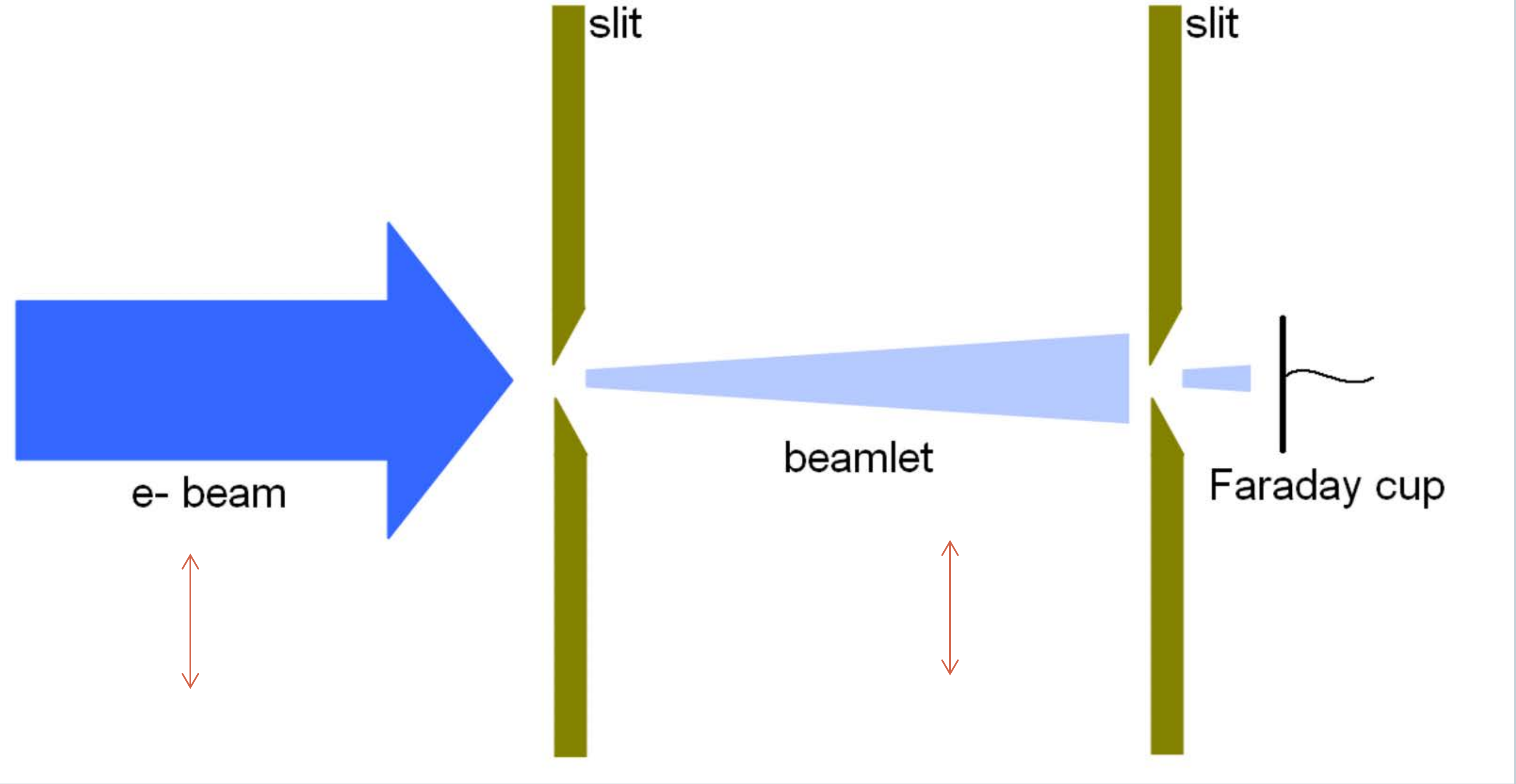
- For a good measurement need
  - Laminar beam ish
  - Reasonable size at slit
  - Narrow, thin slit
- With solenoid at present location beam is big – gets lost on beam pipe



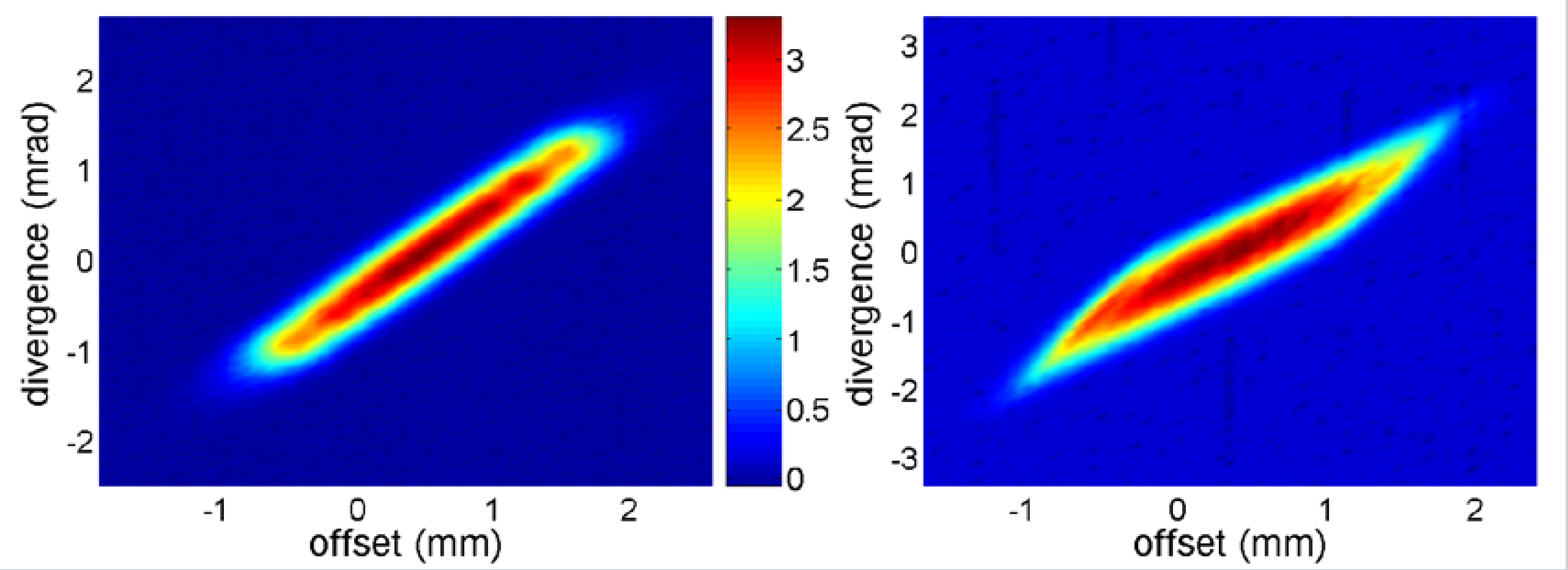
Emittance

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

Double slit virtual experiment

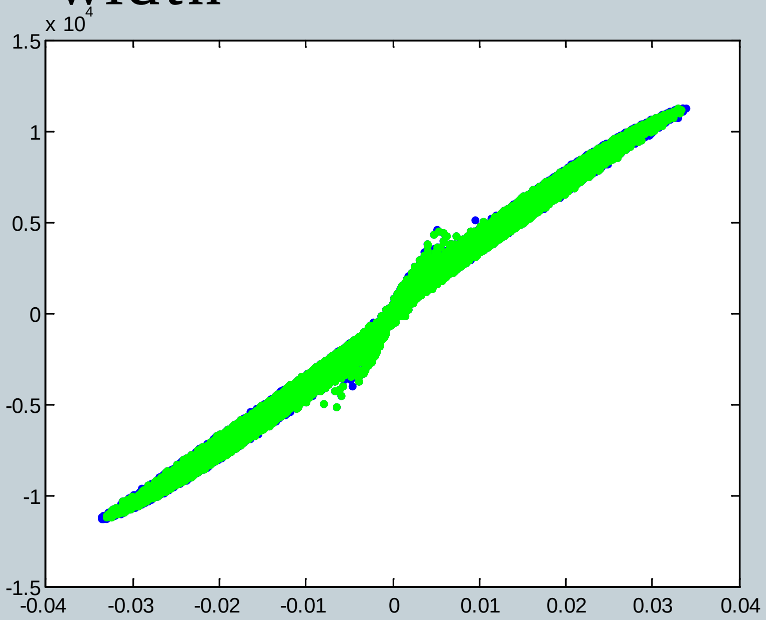


Sample result

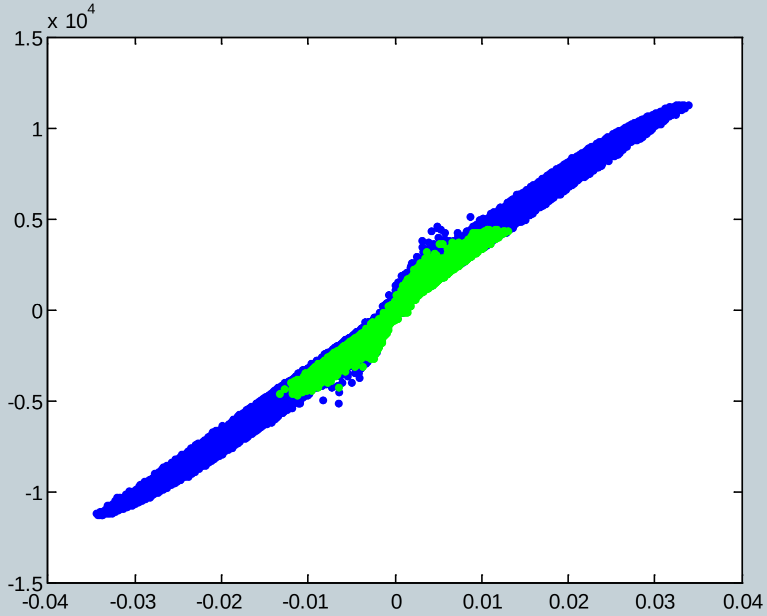


Double slit virtual experiment

- 1mm thickness, 20um width



- 3mm thickness, 20um width



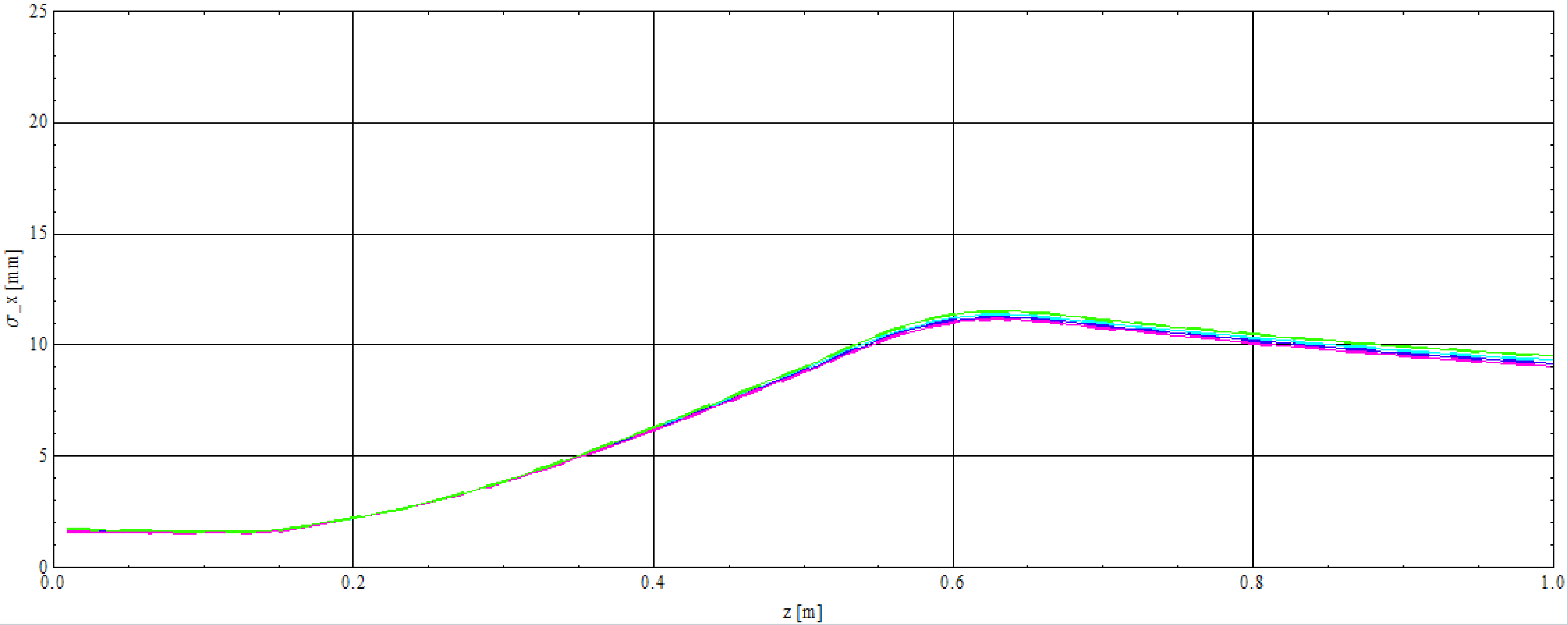
Green, particles that make it through the slit

Double slit virtual experiment

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

Parameter	
Cathode Bz	0.2T
XY_rms, top-hat	1.5mm
t rms, Gaussian	23ps
Charge	0 – 420pC
Gun voltage	350kV

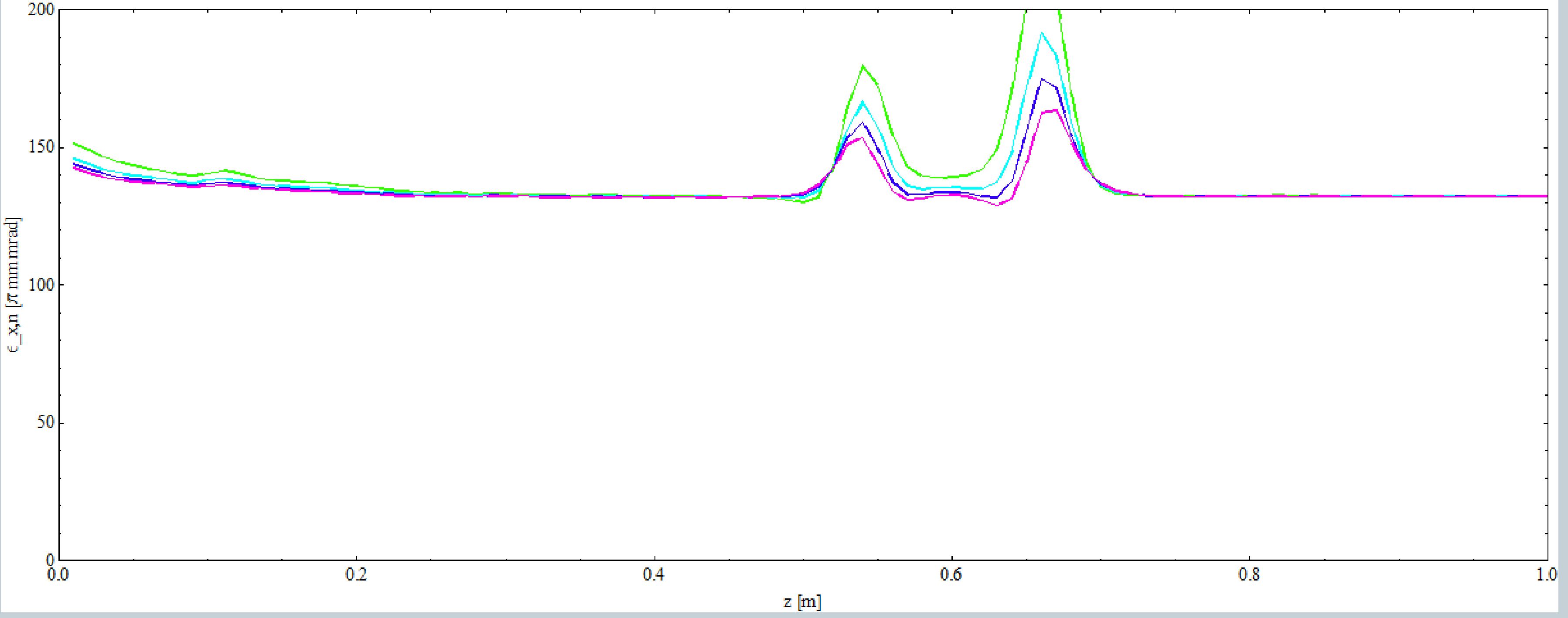
Transverse rms beam size



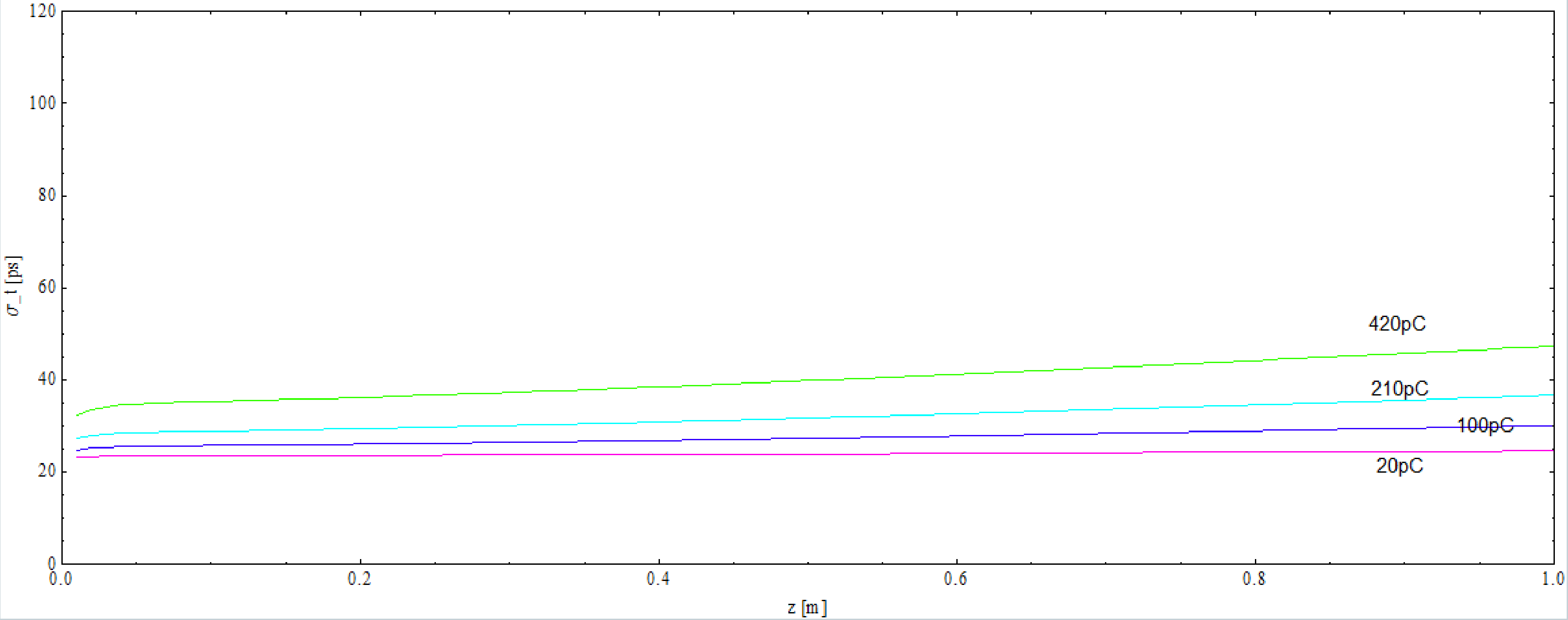
20pC, 100pC, 210pC, 420pC

TRANSPORT THE SAME: DOMINATED by canonical angular momentum!

Transverse normalize trace-space emittance



Bunch length rms



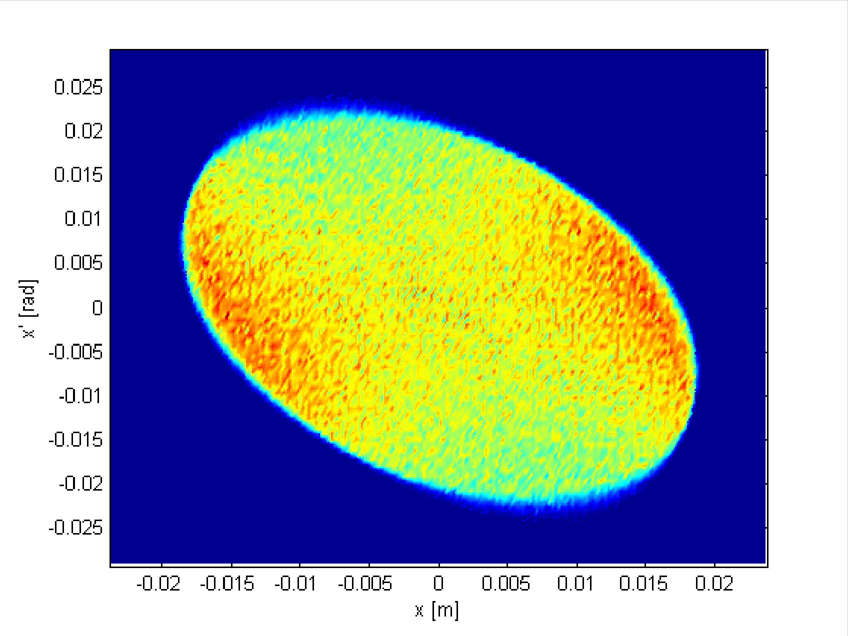
Longitudinally we see space charge as usual.

Double slit virtual experiment

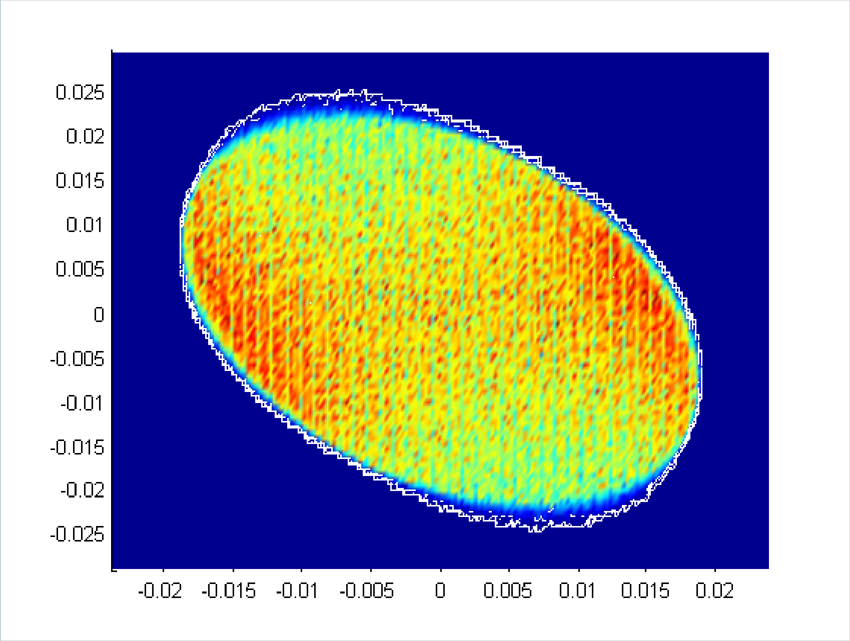
- At the diagnostic, break the beam up into beamlets transversely to simulate the beam scanning over the slit
- Let the beamlet particles drift to the second slit location (removing any that intercept the diagnostic)
- Break the beamlet up into more beamlets
- Count particles in each sub beamlet
- Produce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

Virtual result

Directly from simulation



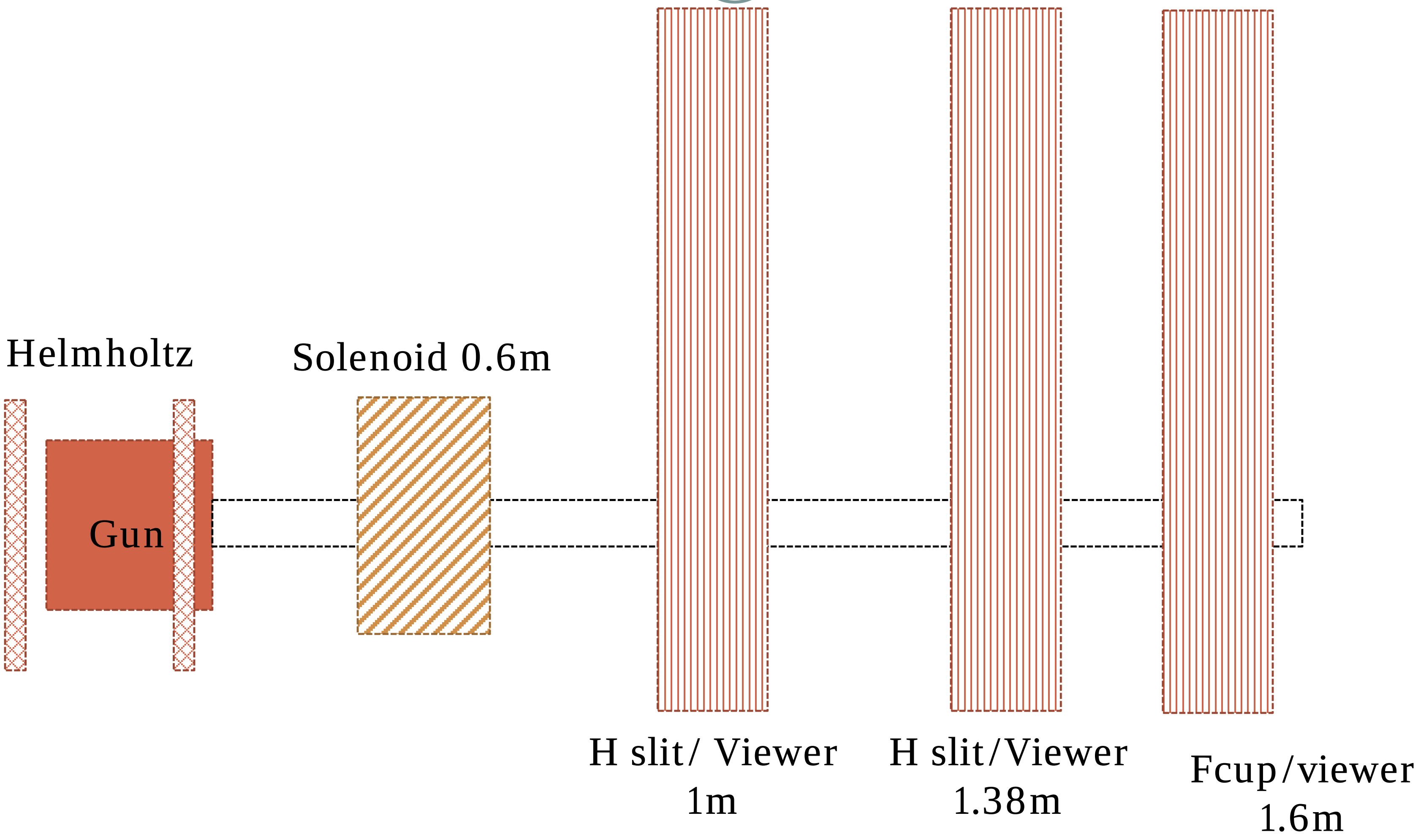
Reconstructed via 2 slit method



Can change slit size and spacing to get best design

Magnetization

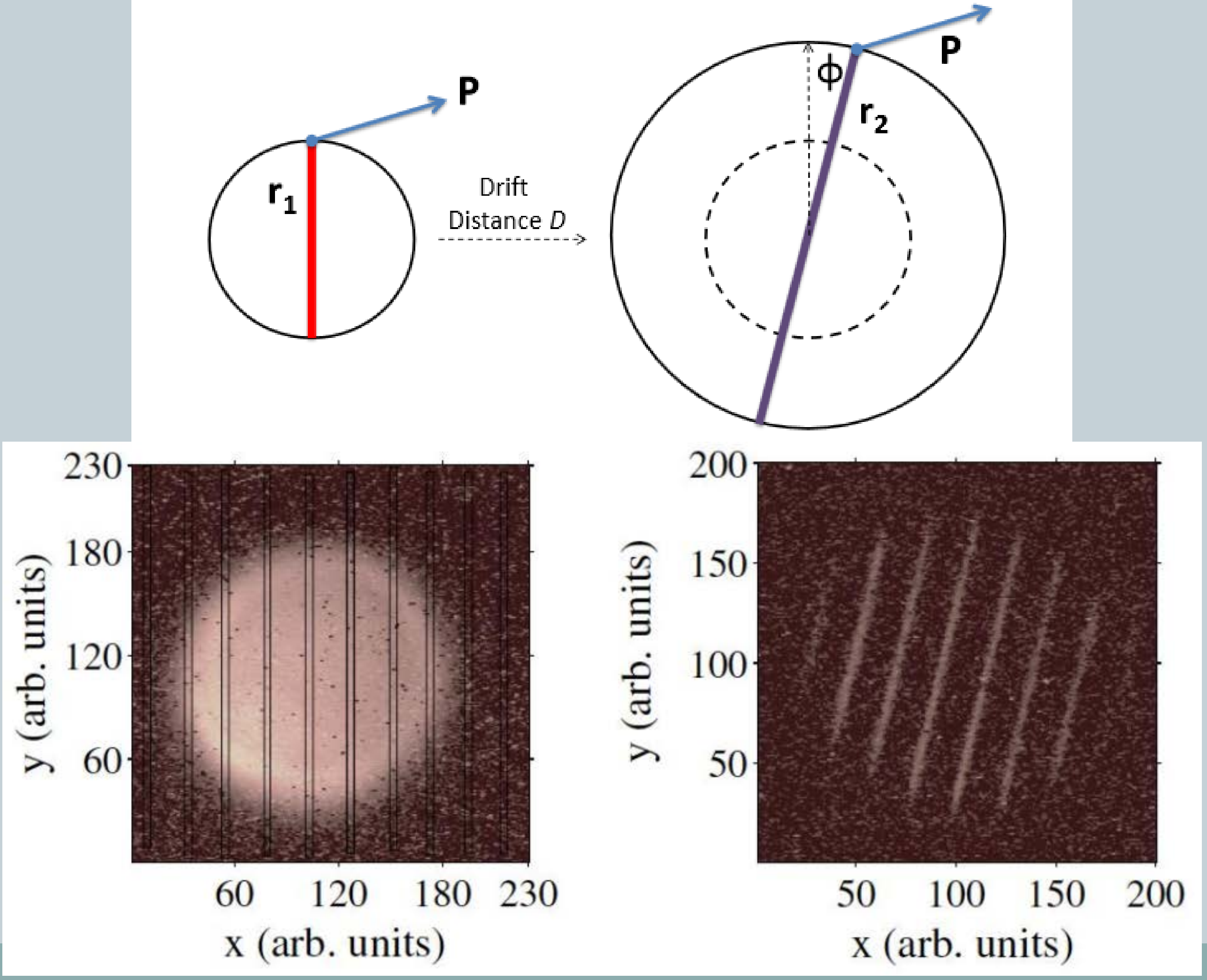
Phase 2 Layout



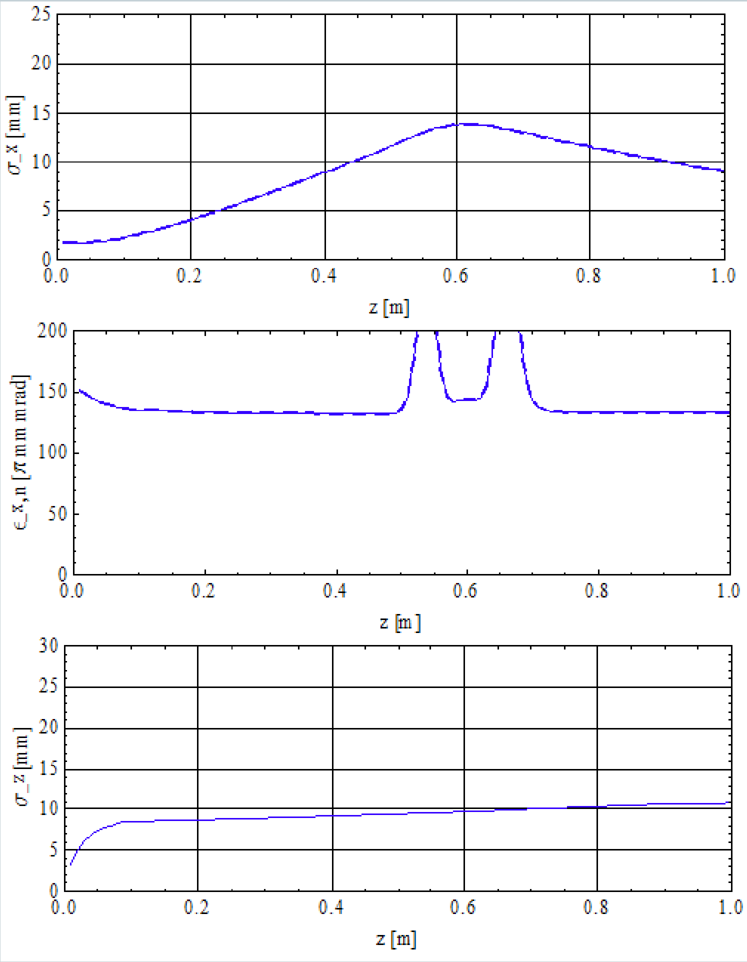
Magnetization

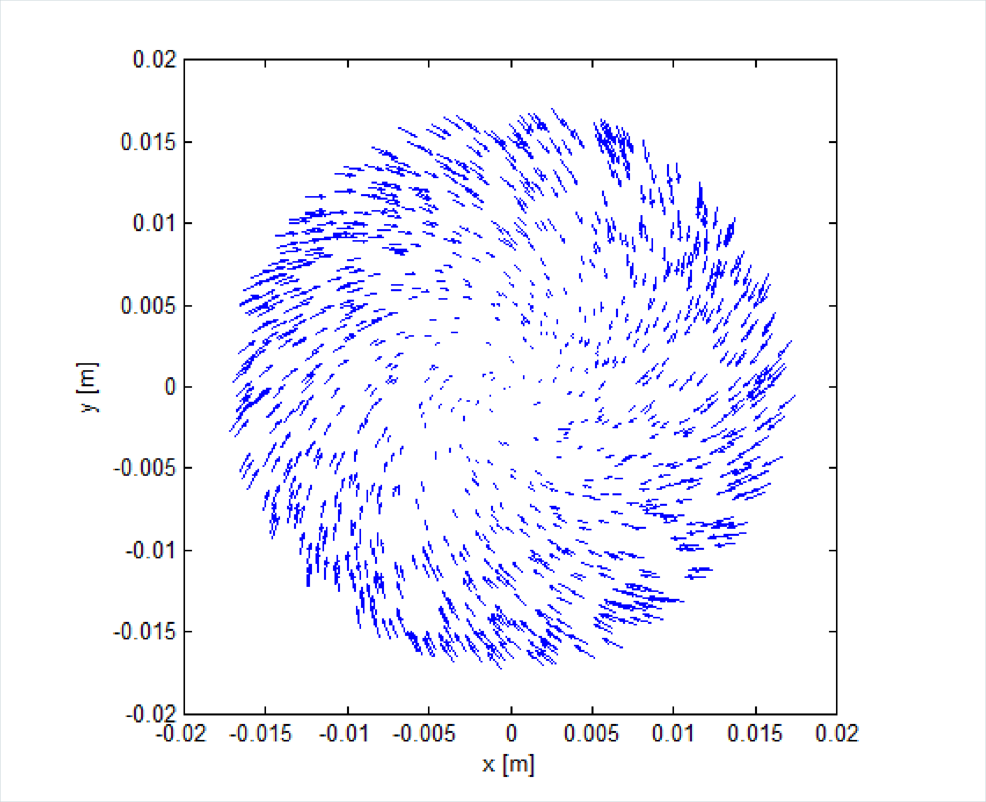
- This is a real experiment we would like to do to measure magnetization.
- Insert a slit into the beamline to select an emittance-dominated beamlet.
- Let the beamlet drift to a screen and image it.
- $< L >= \frac{2p_z\sigma_1\sigma_2 \sin\theta}{D} = B_z e {a_0}^2$
  - σ_1: beam rms at diagnostic cross 1
  - σ_2:beam rms at diagnostic cross 1
  - D: drift between diagnostics, θ: angular rotation, pz : longitudinal momentum

Fermilab experiment



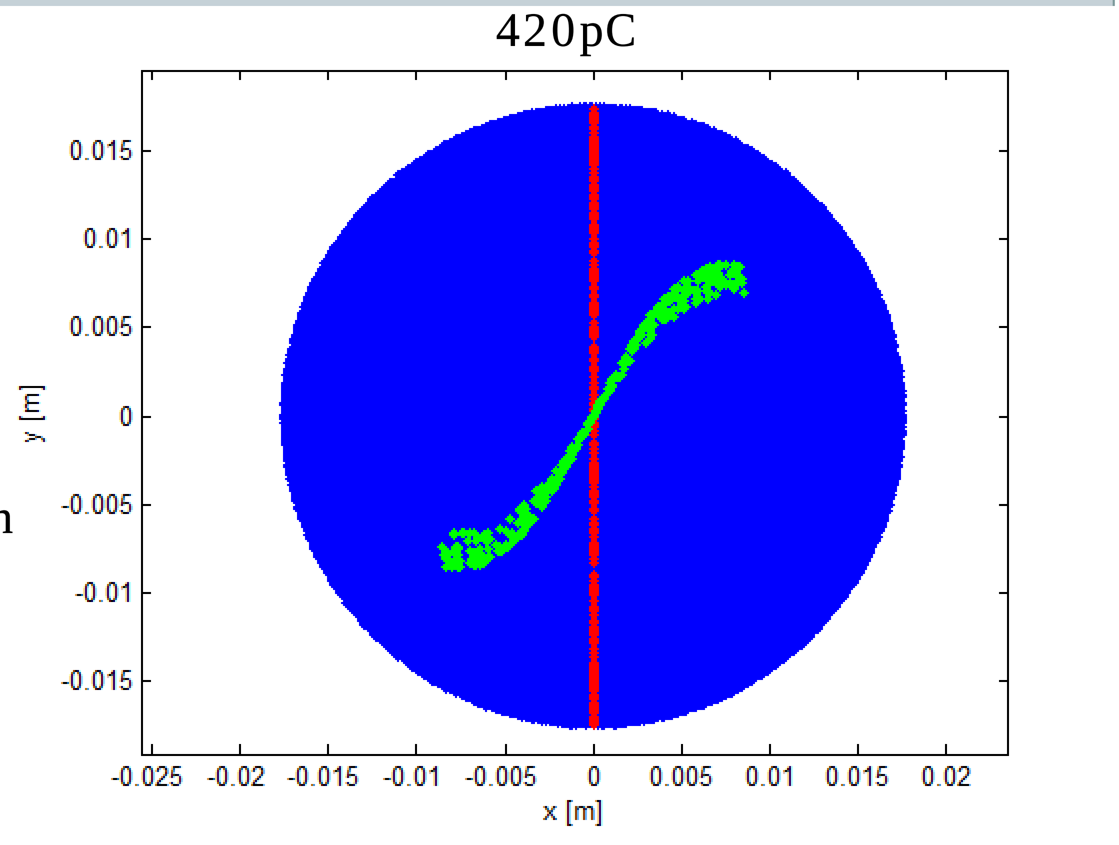
Example beam





Magnetization virtual experiment

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



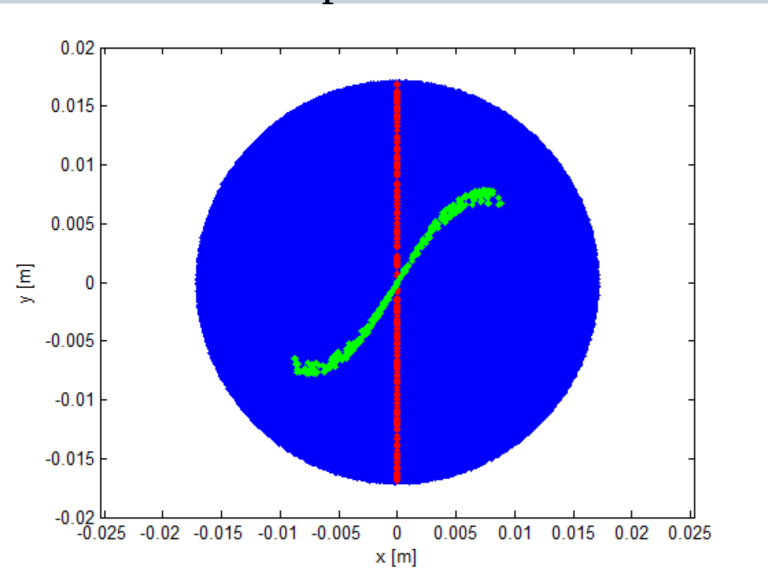
Not linear!
Assumes a solenoid at cathode with 0.2T peak
0.07% particles through slit

This isn't charge related.

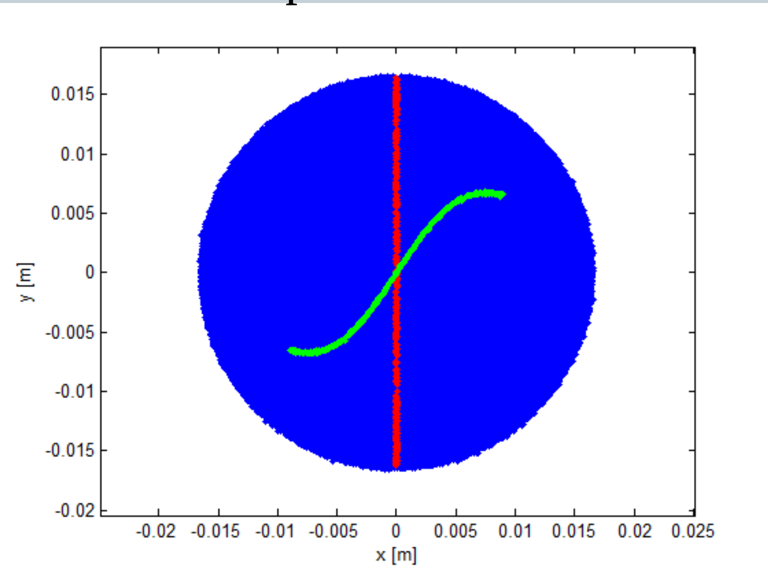
Ldrd.009.0100.001
Nrad=70, Nlong_in=100

Magnetization virtual experiment

210pC



20pC



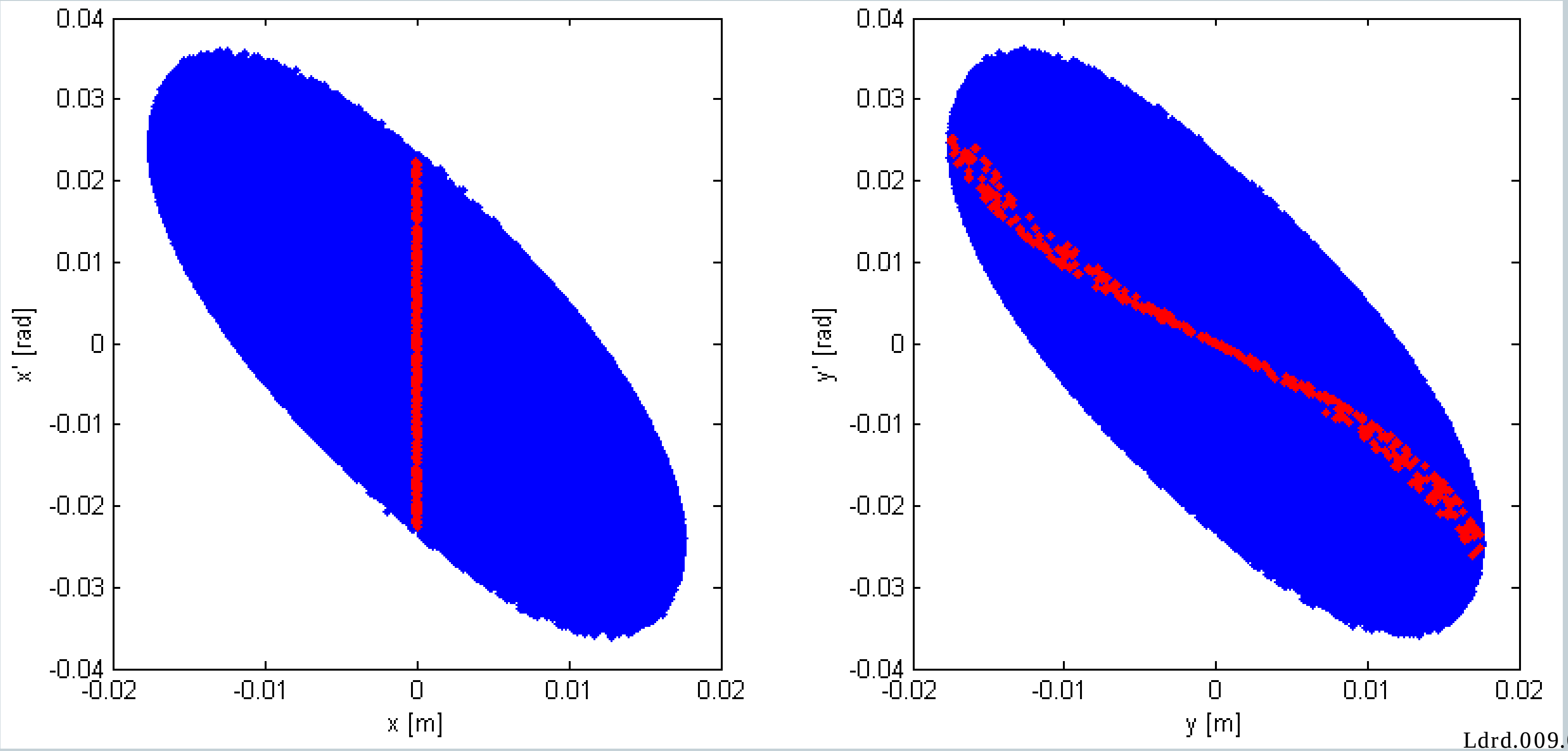
The curve is still evident at 20pC.

Ldrd.009.0100.00
2

Ldrd.009.0100.00
4
Nrad=70,
Nlong_in=100

Phase space plots

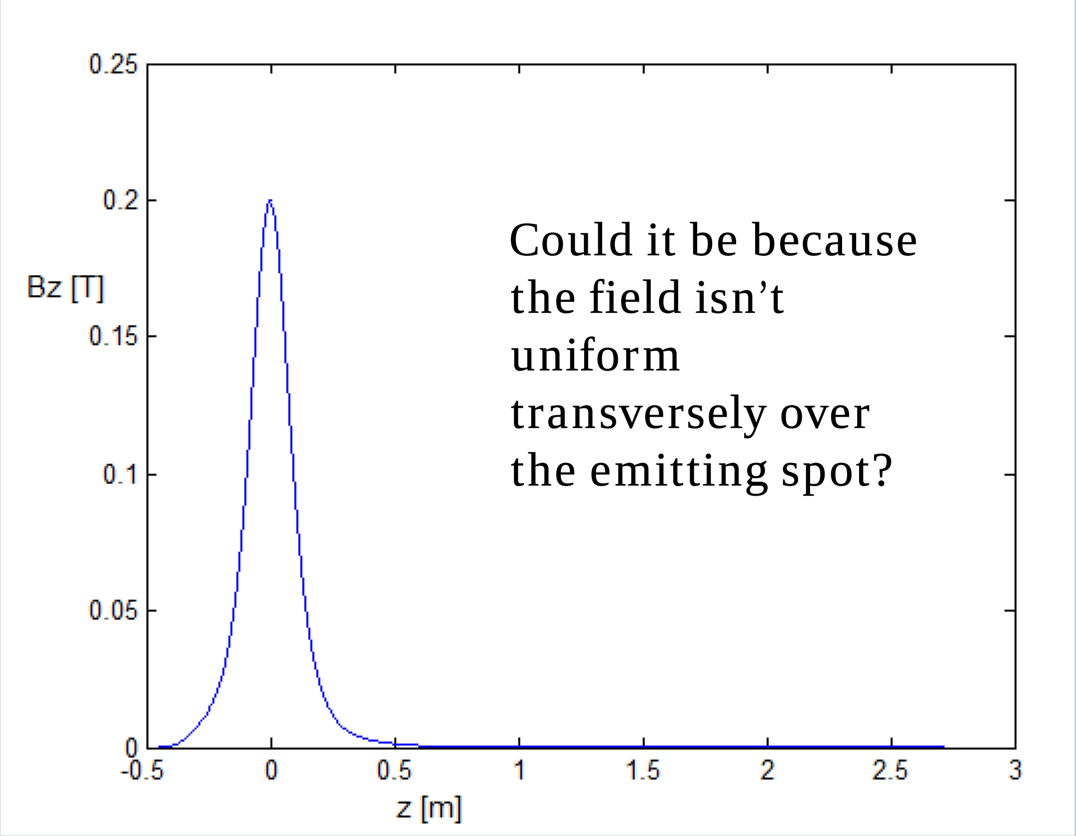
This is what the slit cuts out in phase space



Ldrd.009.0100.001

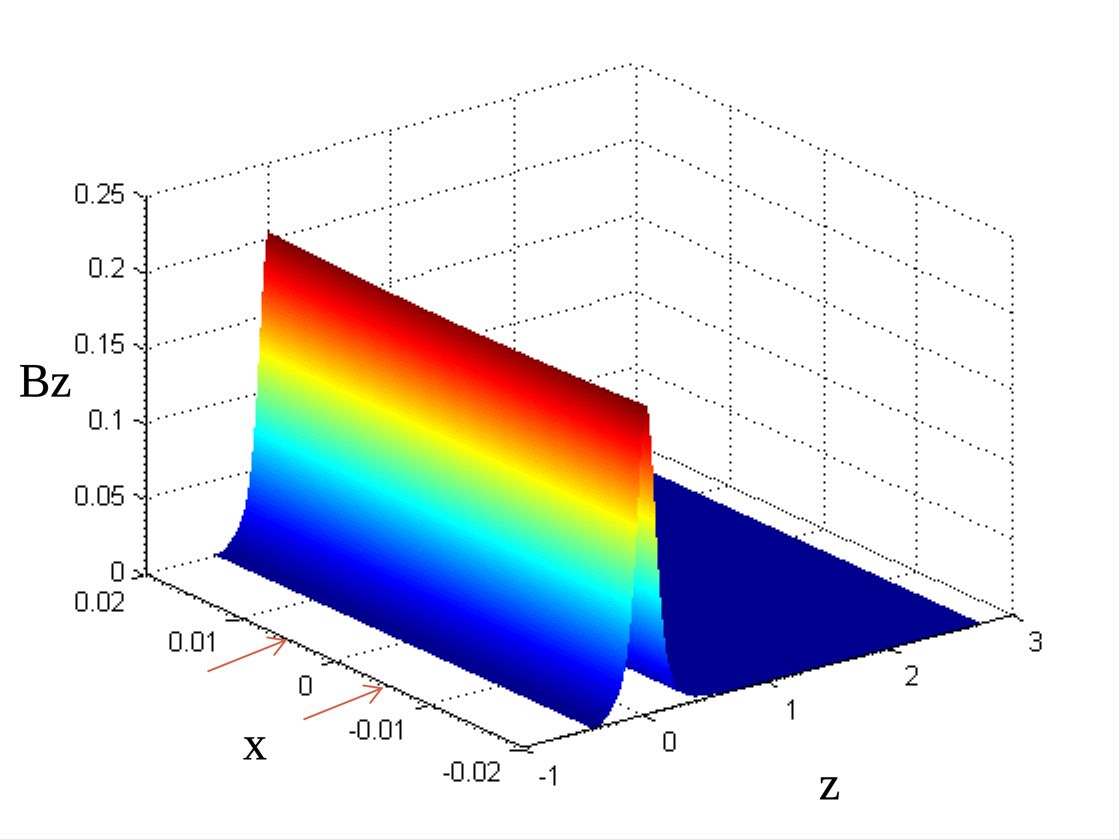
Why is there an 'S'?

This is the solenoid field I used…



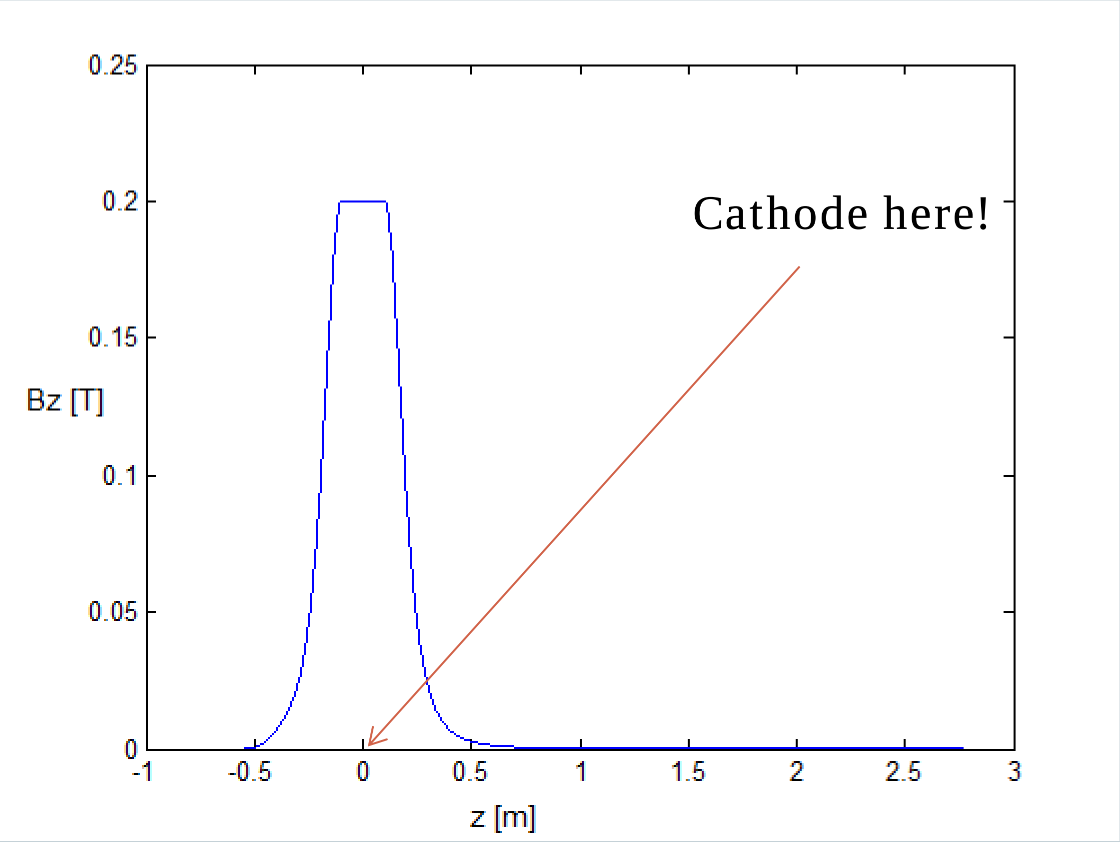
Why is there an 'S'?

- This is what simulation assumes off axis
- Slight variation



Why is there an ‘S’?

Make fake field map.

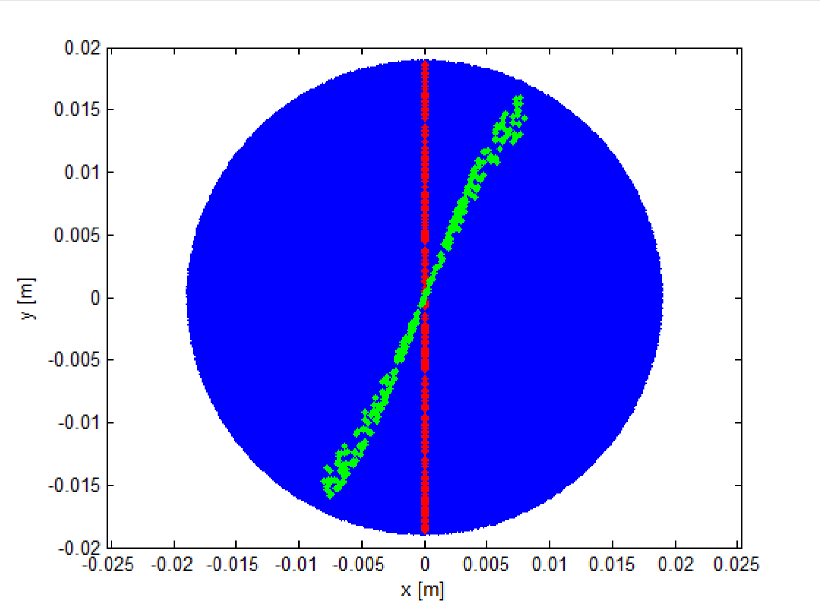


Make fake Helmholz pair field

Compare

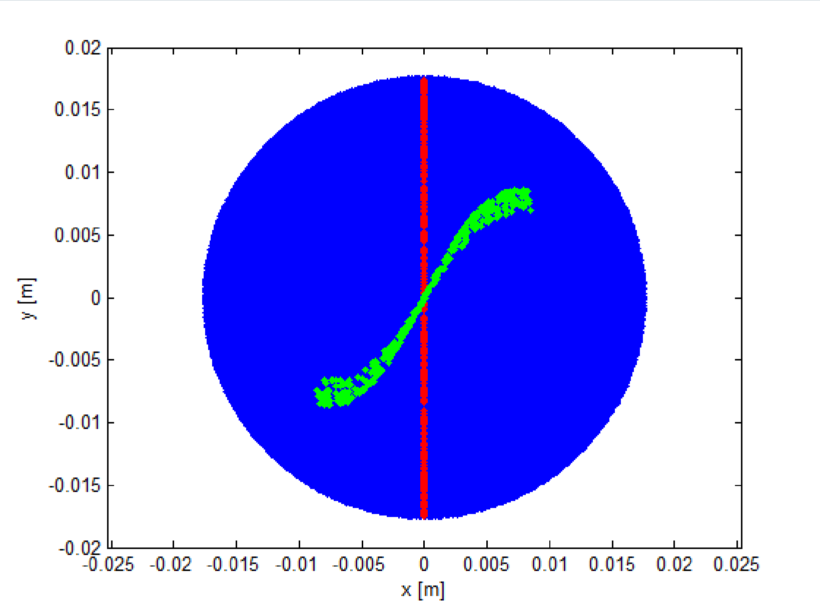
Both 420pC

Fake Helmholtz coil



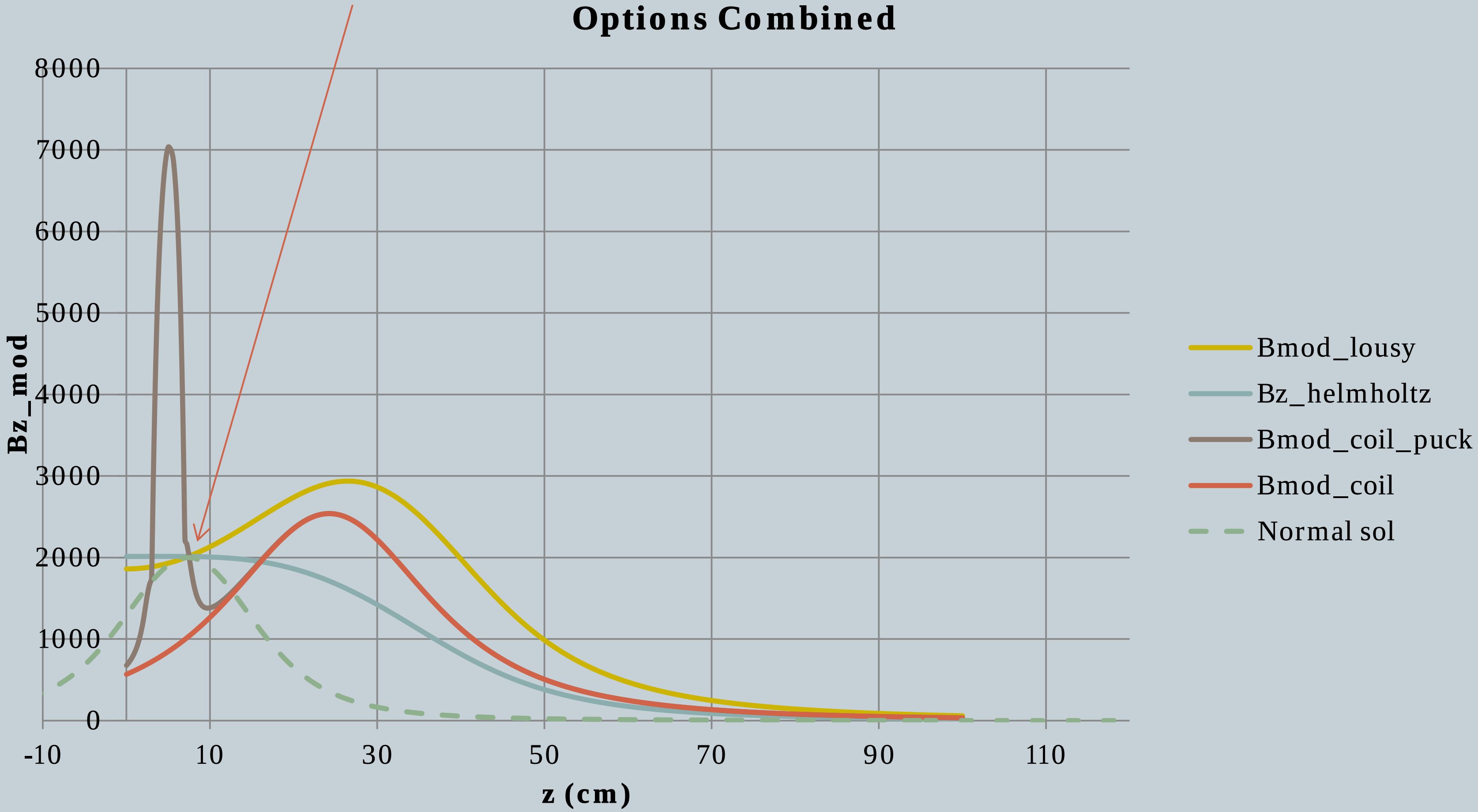
Ldrd.010.001

Standard solenoid

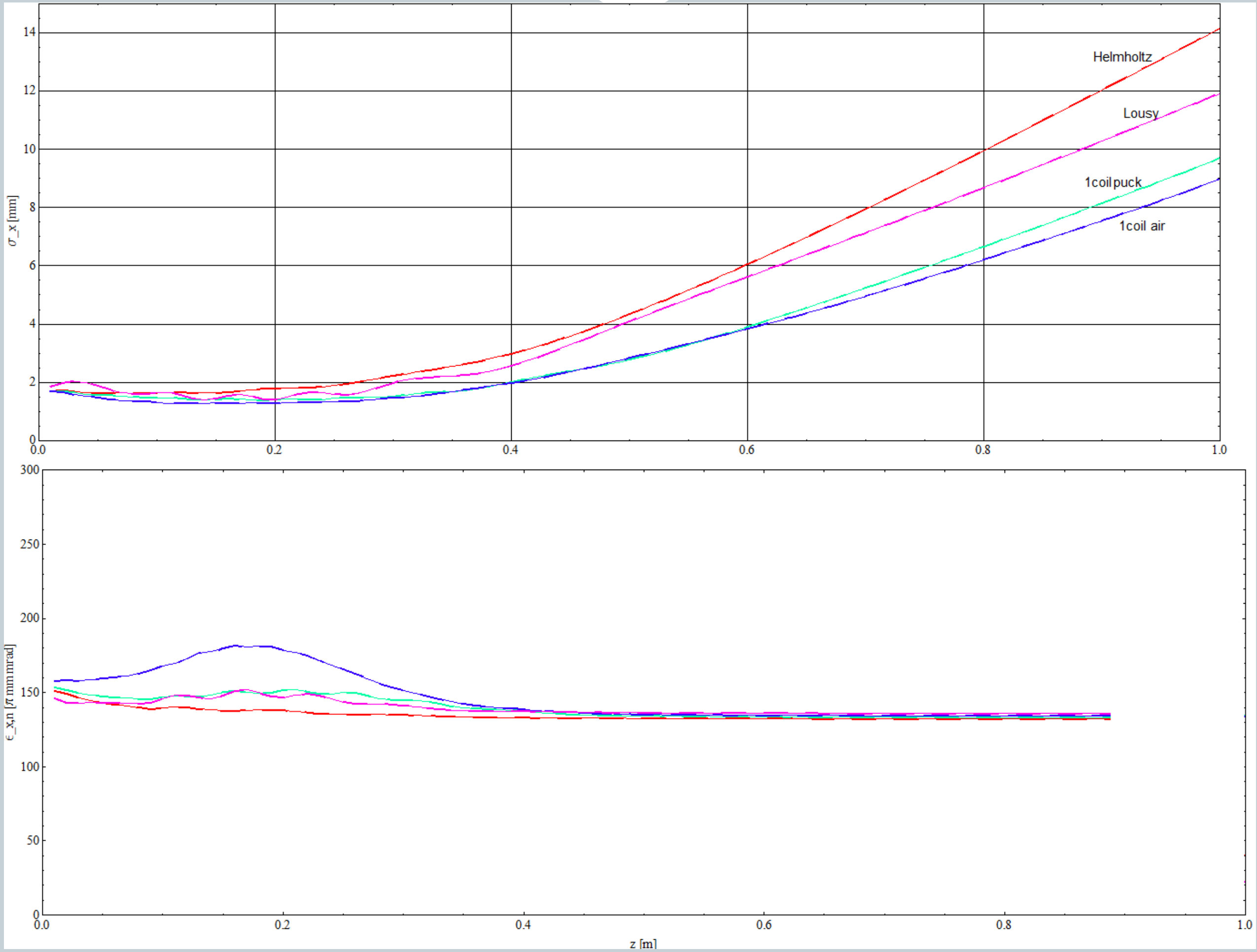


Ldrd.009.001

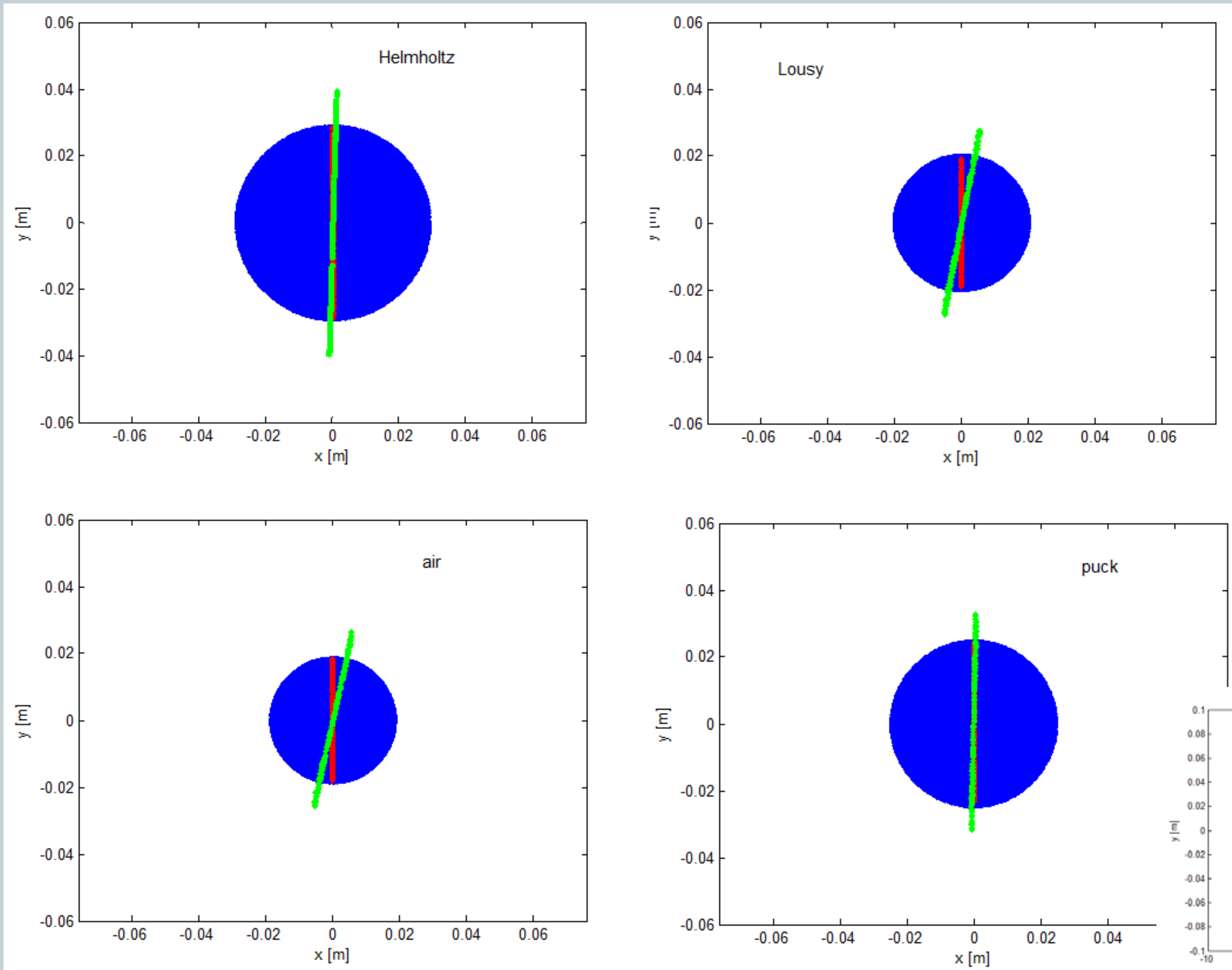
4 real field maps, scaled to give ~0.2T



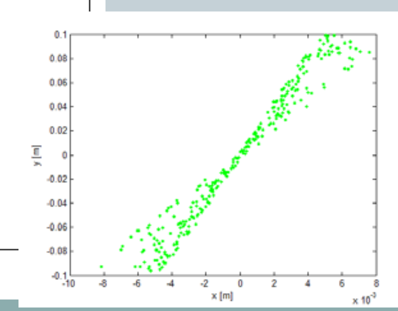
Transverse beam size, emittance



Magnetization virtual experiment

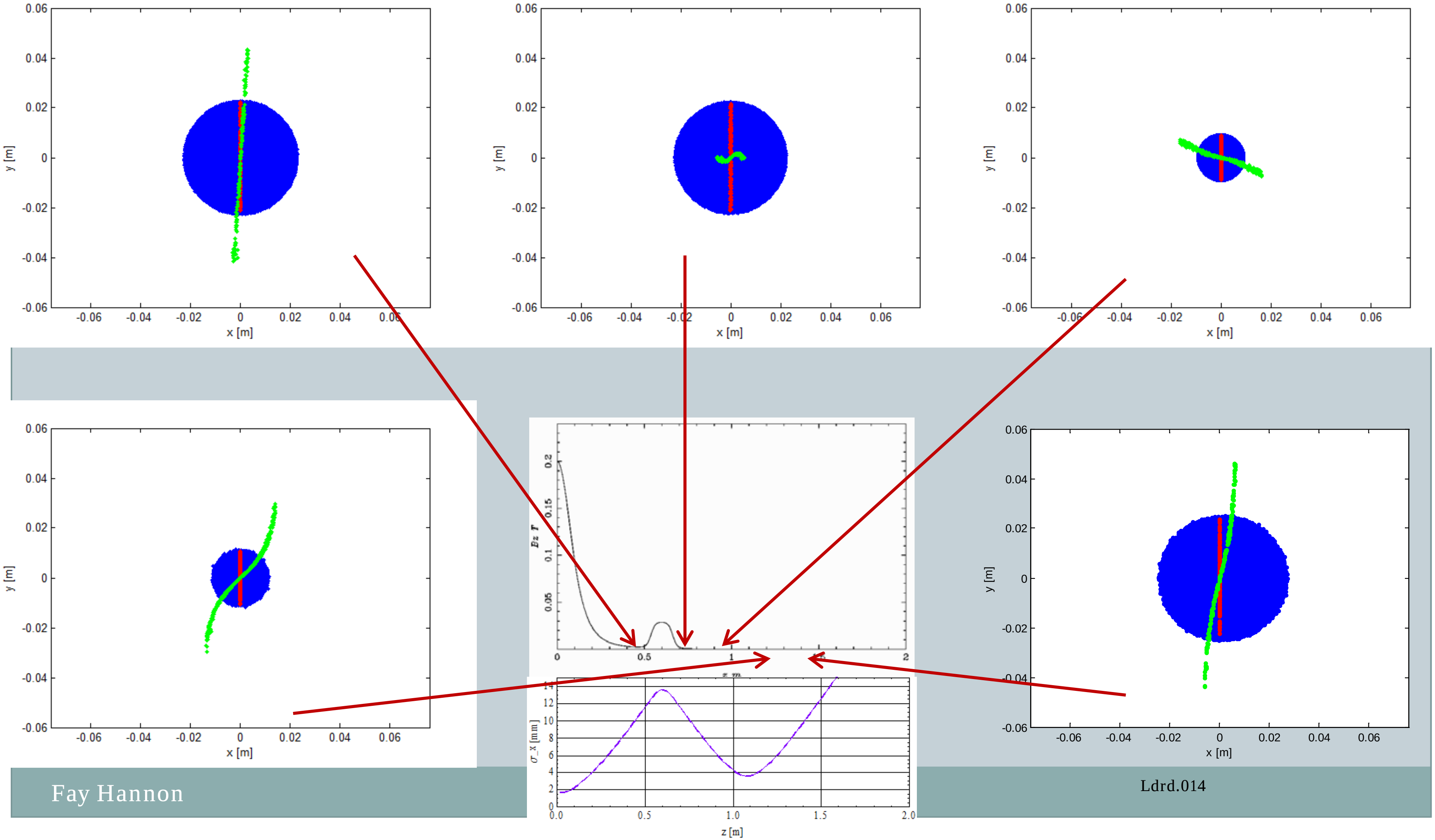


At 1m

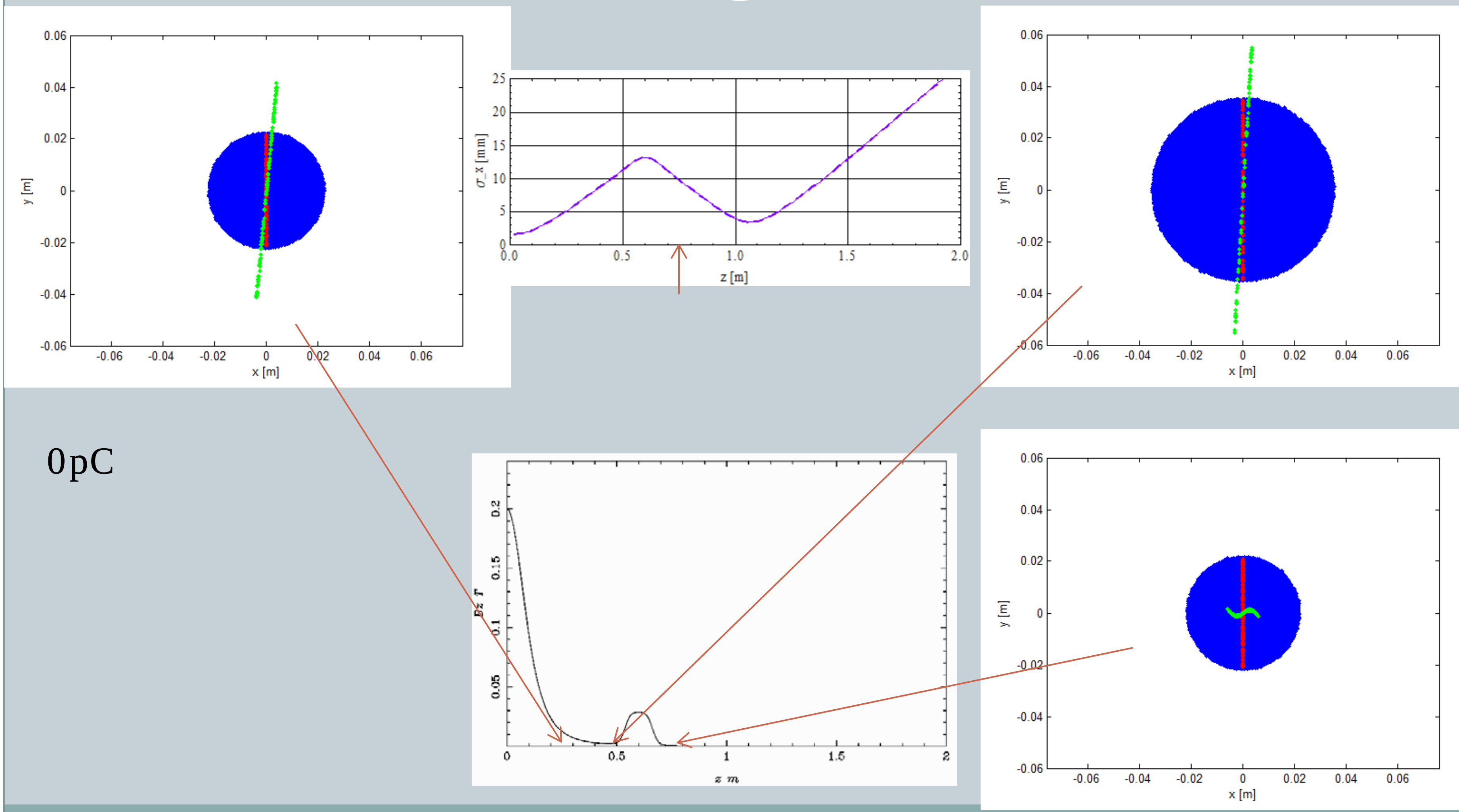


Can't see 'S'
– all seem linear… why is this…

Normal solenoid



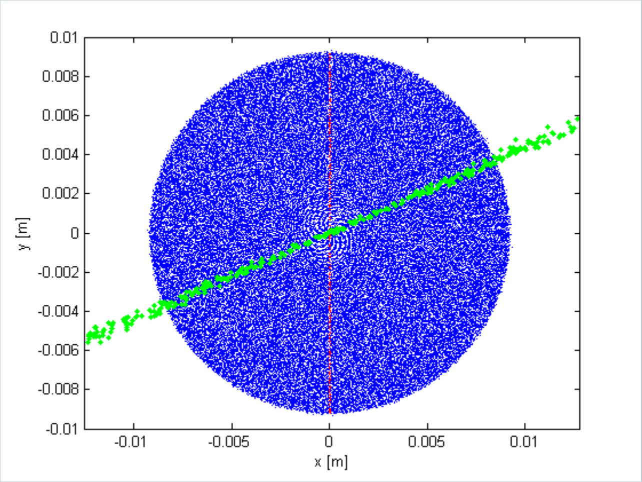
Is this space charge in EC sol?

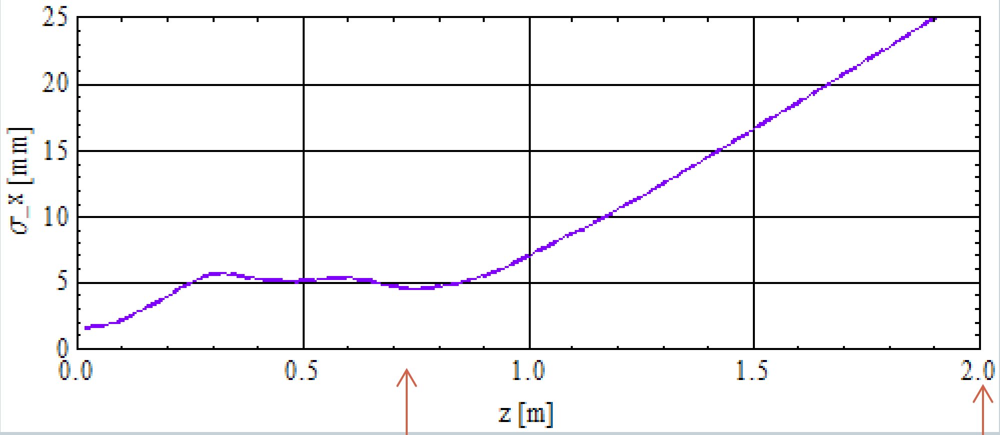


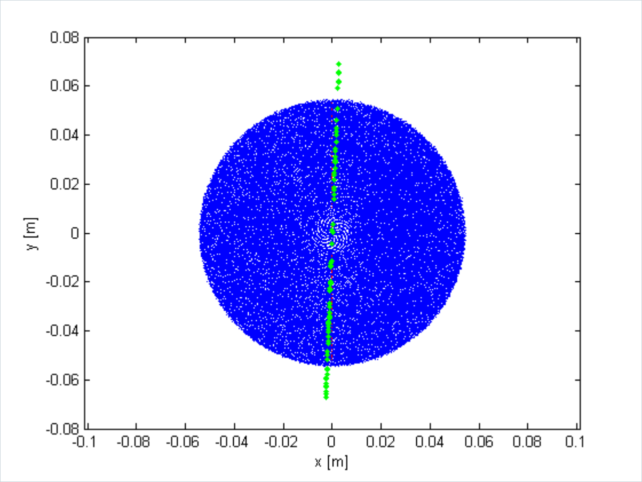
0pC

Is the trick to keep beam small in beamline solenoids?

- Trying not to have different B.dl over transverse direction.

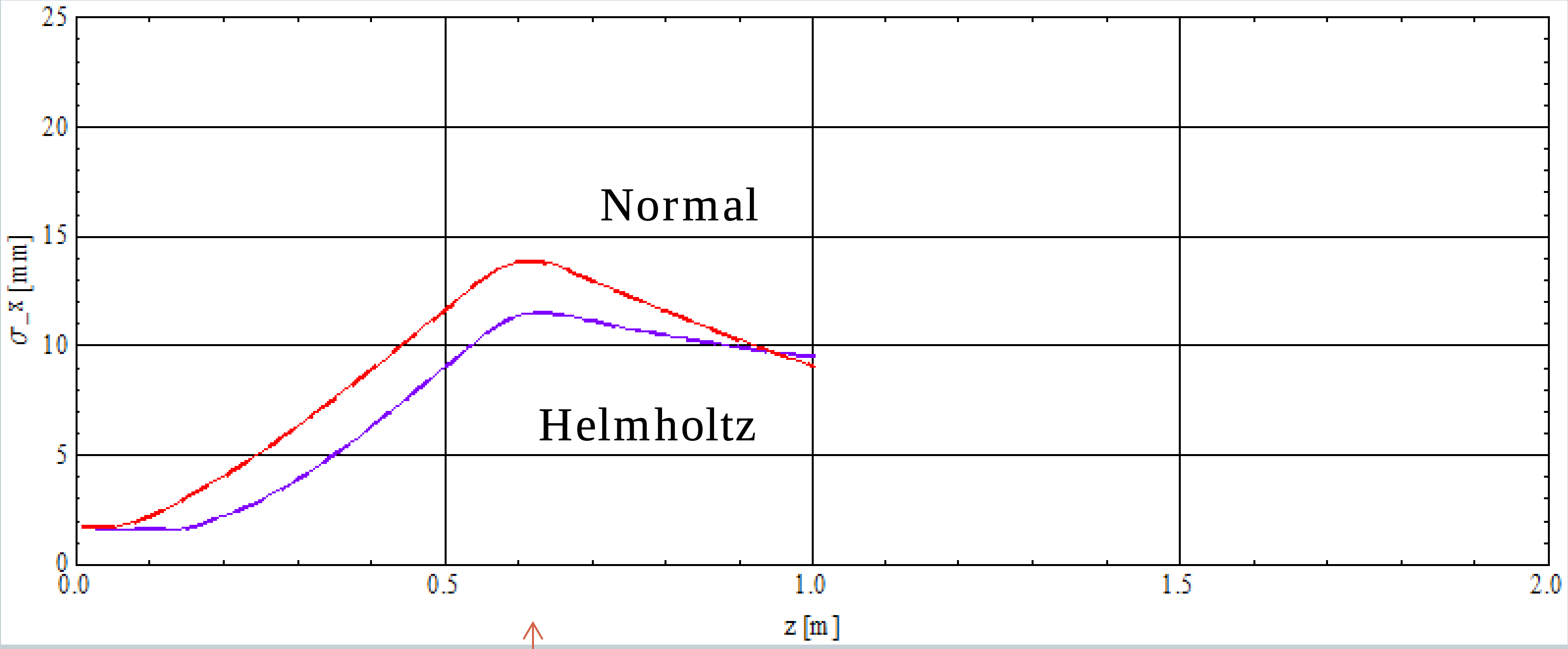






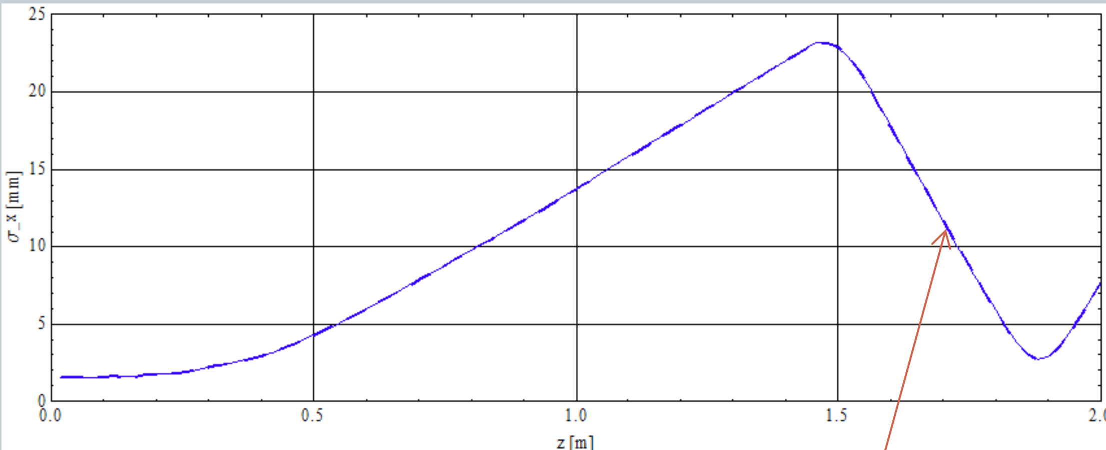
Ldrd.017.0072.004

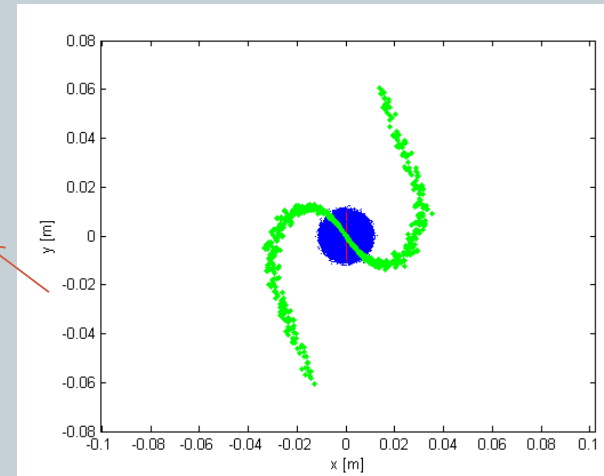
Could this explain difference between helmholtz and normal sol



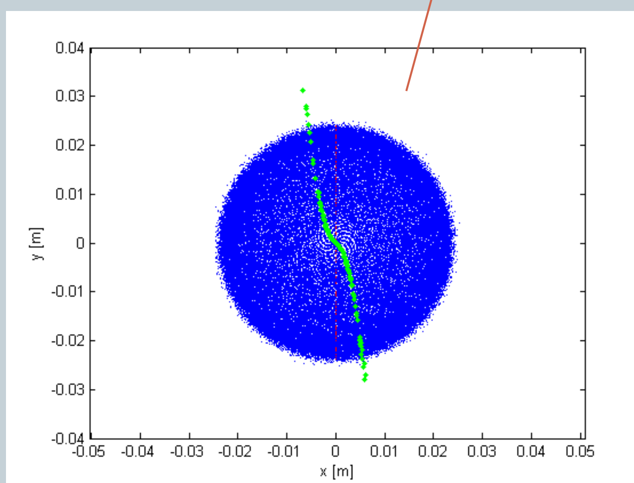
Focusing solenoid here

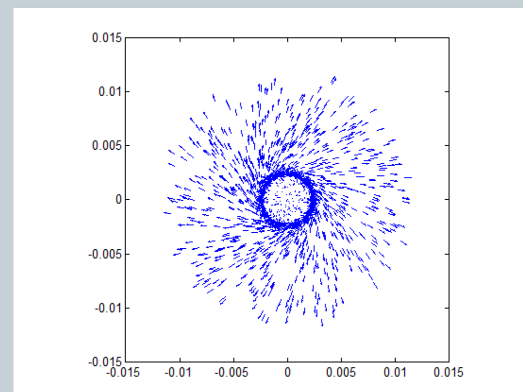
Let beam get big and then focus



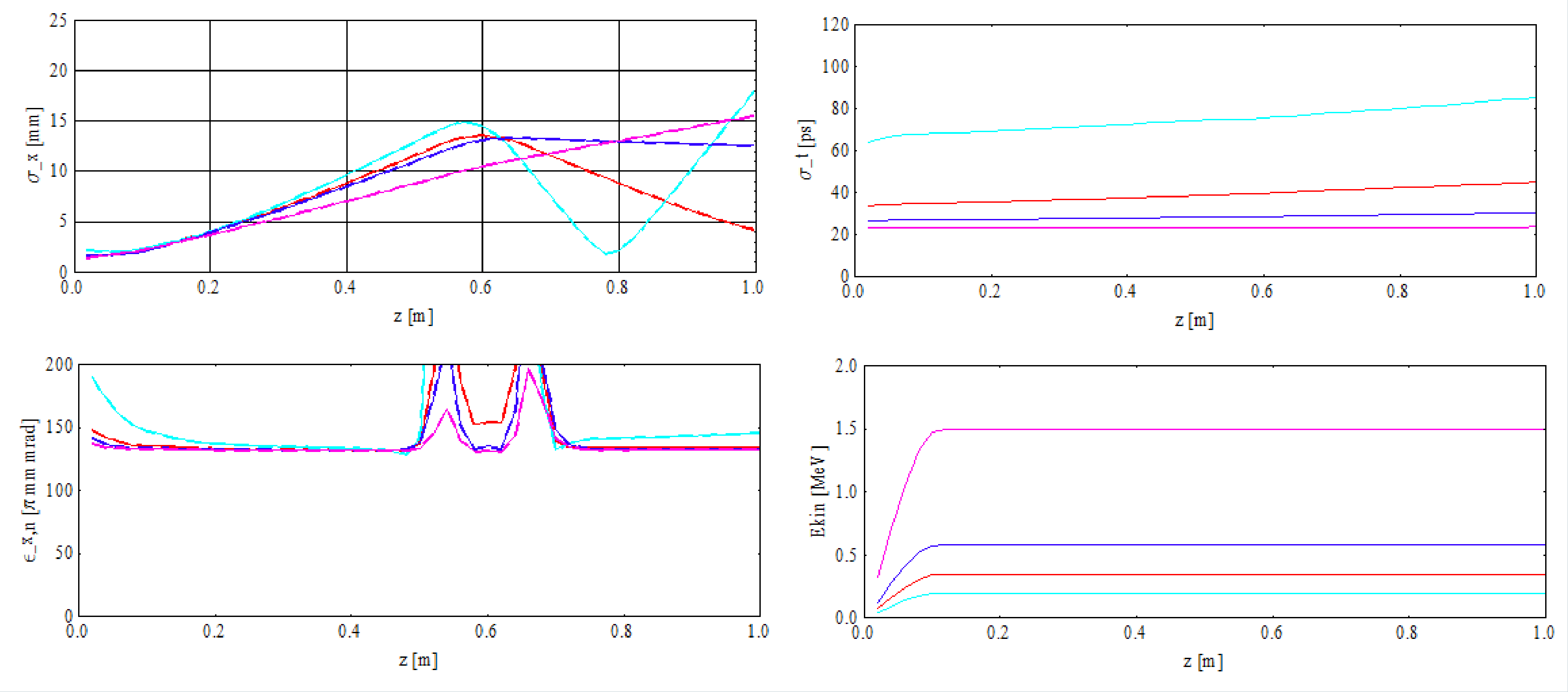


So even with good Helmholtz field it can become distorted!





Increase gun voltage

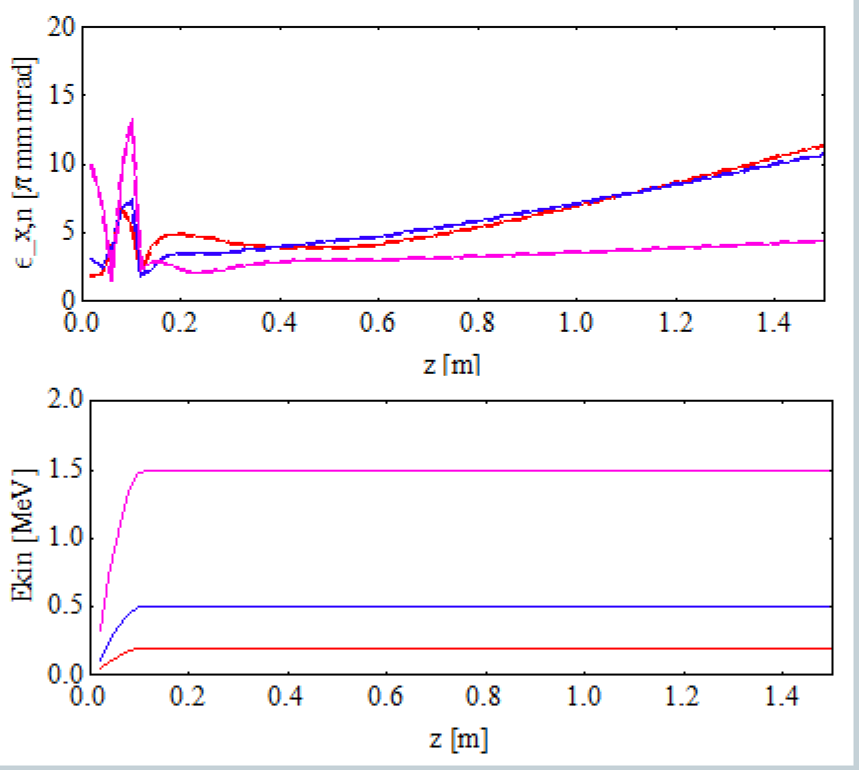


CAM dominated

Ldrd.023

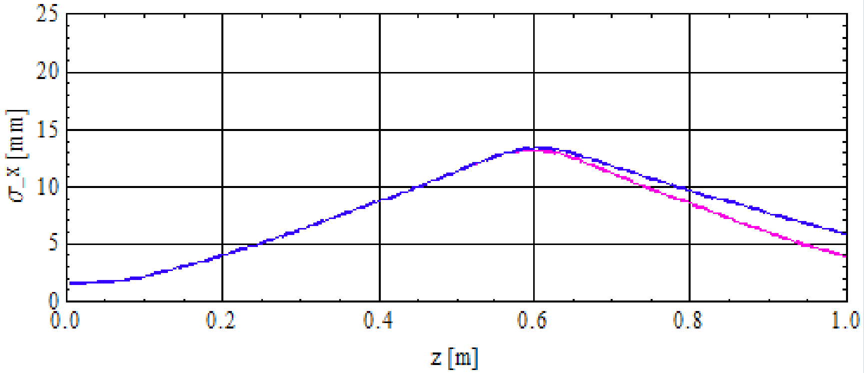
So what does the emittance look like

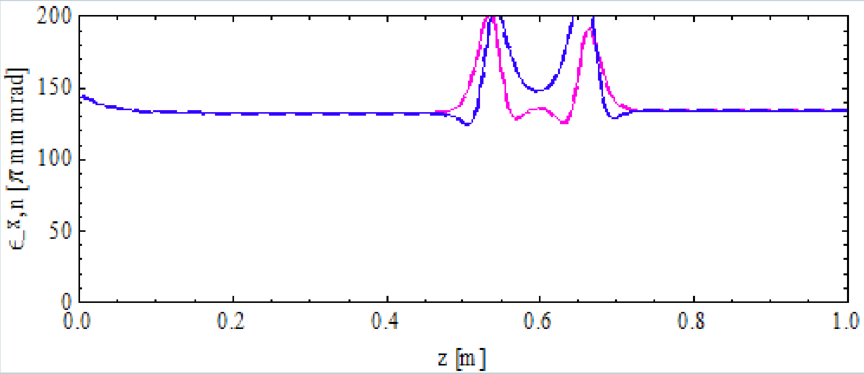
Remove the contribution from angular momentum. Calculate the angular momentum from a correlation in the x, px phase space and subtract prior to the emittance calculation.

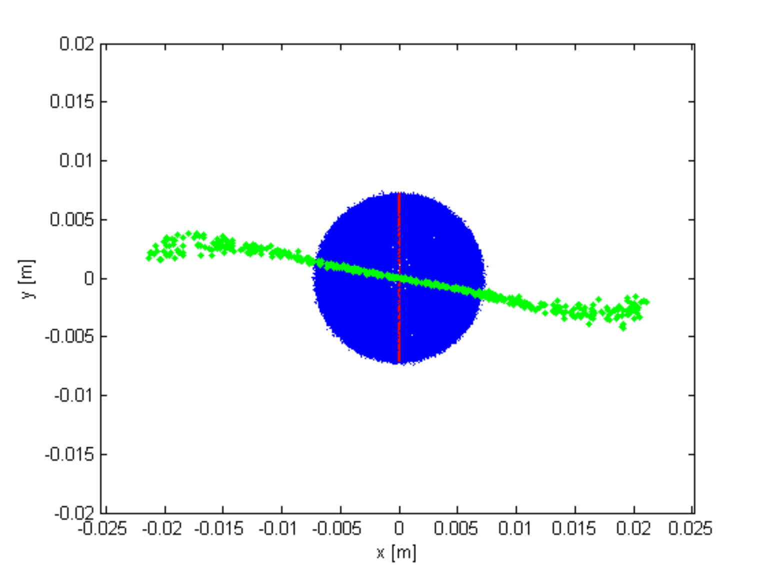


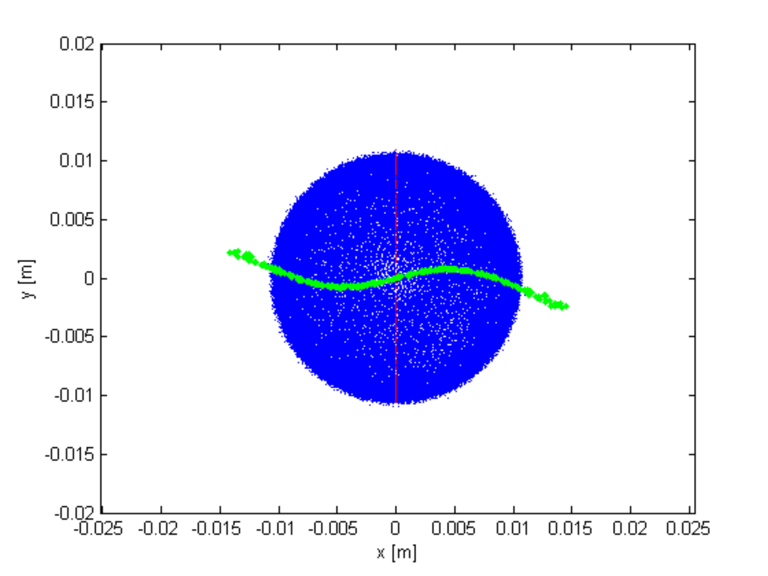
Reverse polarity of EC solenoid

- 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