Space Charge in Target Region

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Space charge effects

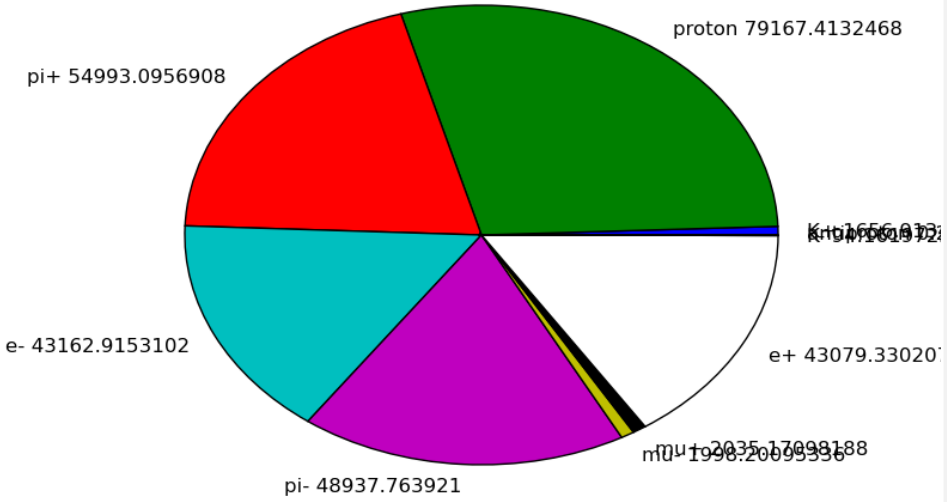
- Consider space charge effect in target region
  - Look at linear space charge effect of pure pi+/- beam
  - Look at transverse kick from proton beam
- I'm no expert in space charge - a learning experience for me!
  - I think I got the physics right
  - ...
- Context is “Checking that we don't have to worry about this stuff”
  - I'm not expecting a problem

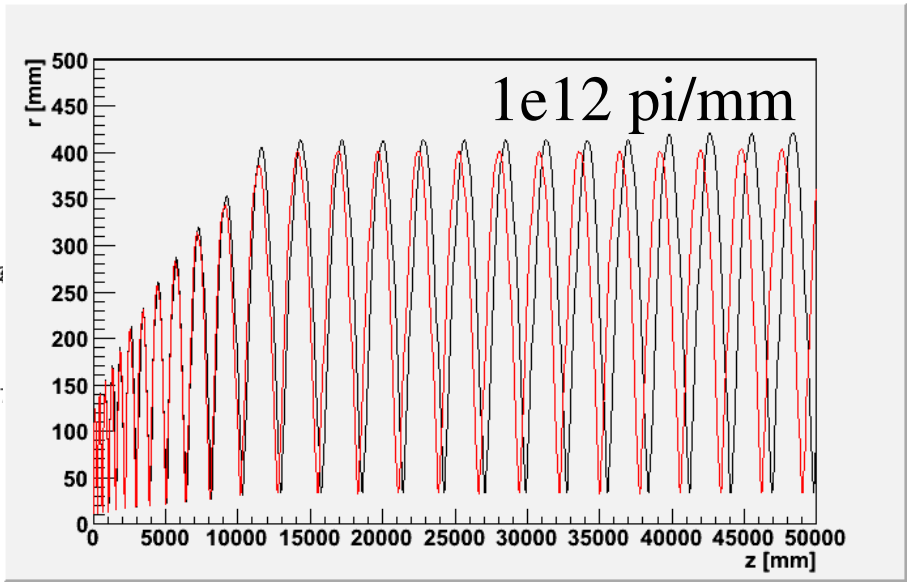
Linear SC in Cooling Section

- Quote 2d envelope evolution equation in the presence of space charge (from S.Y. Lee):
  - $x'' + K_x x - 2 K_{sc}/(x+y) - \varepsilon_x^2/x^3 = 0$
  - $y'' + K_y y - 2 K_{sc}/(x+y) - \varepsilon_y^2/y^3 = 0$
    - x is the width in x of the beam, y is the width in y of the beam
    - Prime denotes differentiation wrt *z*
    - K_x, K_y are transverse lattice focussing strength
    - K_{sc} is a constant ~ number of muons in the beam
- In solenoids, assume cylindrical symmetry
  - $K_x = K_y = B^2/2p$
  - $\varepsilon_x = \varepsilon_y$
  - $x = y$
- Such that we get
  - $x'' + K_x x - K_{sc}/x - \varepsilon_x^2/x^3 = 0$

Linear SC in Target Region

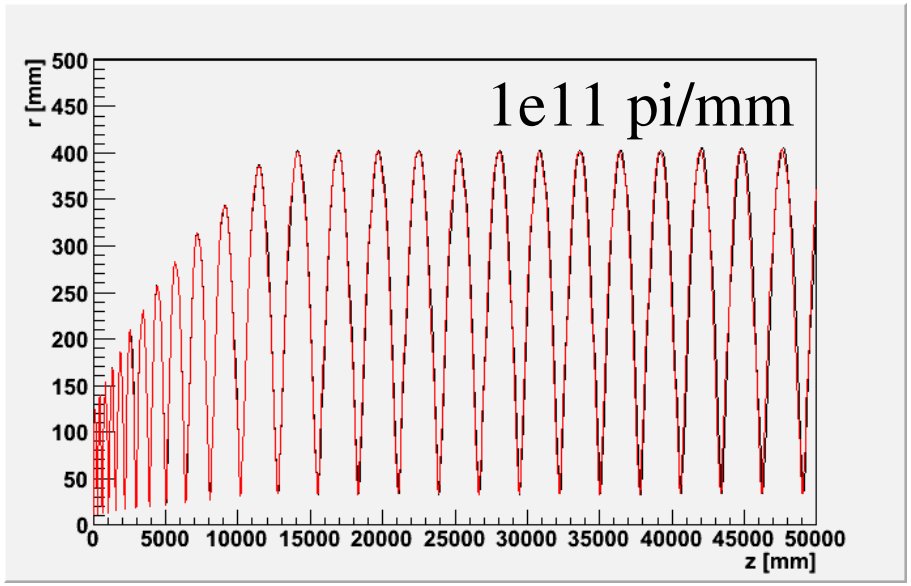
- Evolve linear envelope equation from the target
  - Start with beam envelope radius ~ 1 cm
    - Proton spot size
  - 8 GeV beam @ 50 Hz => 6e13 protons per pulse
  - Scale to 1e5 proton MARS file from Harold
    - 5.5e4 pi+ and 5.0e4 pi-
    - => 3.3e13 pi+ per pulse and 3e13 pi-
  - Assume bunch is 30 cm long => 1e12 pi+/mm





Caveats

- But overlapping pi+ pi- beams which cancel each other's charge
  - 10% more pions => net beam has 1e11 pi+
- But significant scraping after the taper which I have ignored
- Envelope equation should not have such big beta oscillations
- Conclusion: likely no effect, may want to check in a proper space charge code

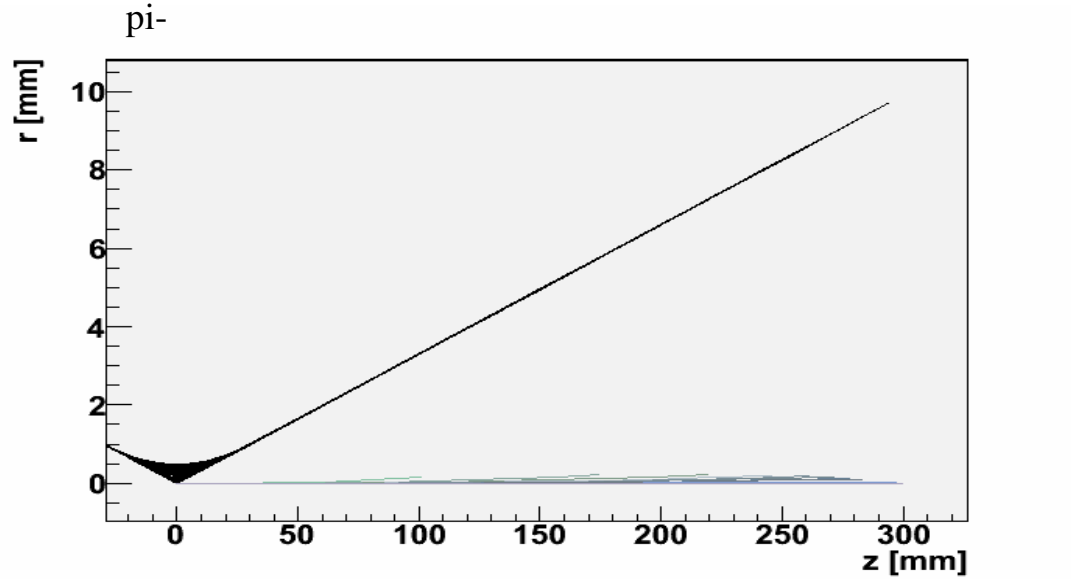


Space Charge in Target Region

- Near to the target we have an intense proton beam moving right next to our pions
  - It is known that space charge does have an effect on the proton beam
  - What is the effect on pions?
- Assume simple, worst case scenario that proton bunch are a spherical charge with radius 1 cm and constant density inside proton bunch
- Then I think electric field goes like (in p rest frame)
  - $V = q / 4 \pi \varepsilon_0 r$ ..... $r > r_{min}$
  - $V = q / 4 \pi \varepsilon_0 r_{min}$ ..... $r < r_{min}$
- In lab frame (A,V) transforms like a 4-vector to calculate the actual field
  - Jargon: retarded potential

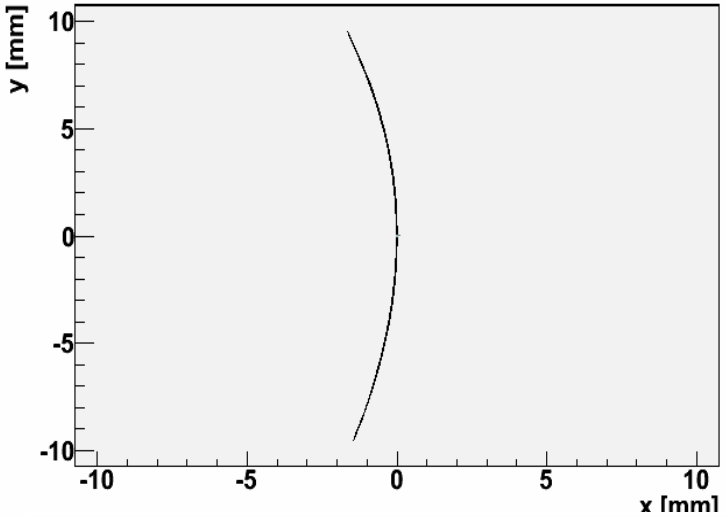
No fields

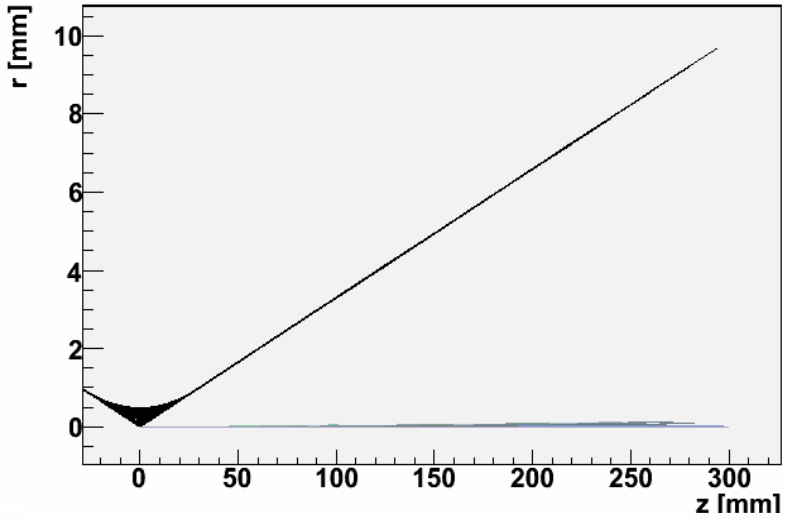
- In the absence of fields, quite a strong effect
  - For 1e14 protons at 5 GeV, 30 cm (1 ns) long bunch, 1 cm spot size
    - Worst case, probably impractical for proton beam
  - Fire pions in momentum range 0.1 - 5 GeV
    - Do not consider pion self-charge for space charge calculation

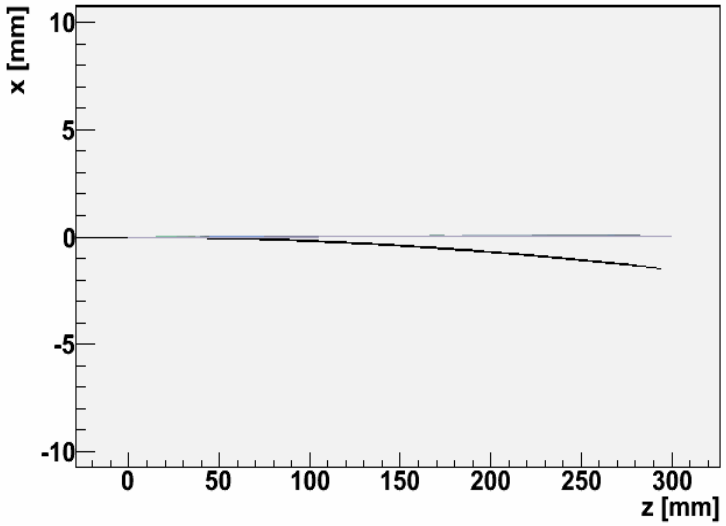


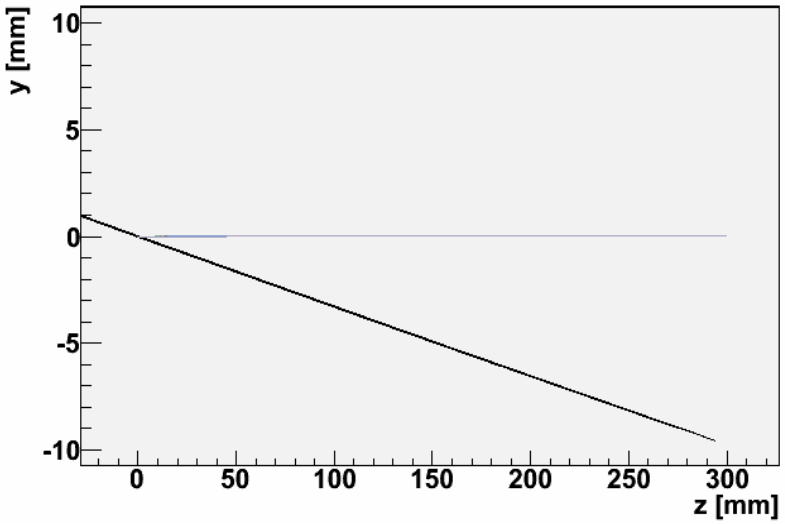
Fields - pi+

- Use the FS2 field taper ... basically no effect









Conclusions

- This is a very basic study
  - *Maybe* see a slight effect on pion beam optics from self-charge but probably not
    - May want to check with proper space charge routines
  - No significant effect from proton beam on pion beam