Particle Production of a Carbon/Mercury Target System for the Intensity Frontier

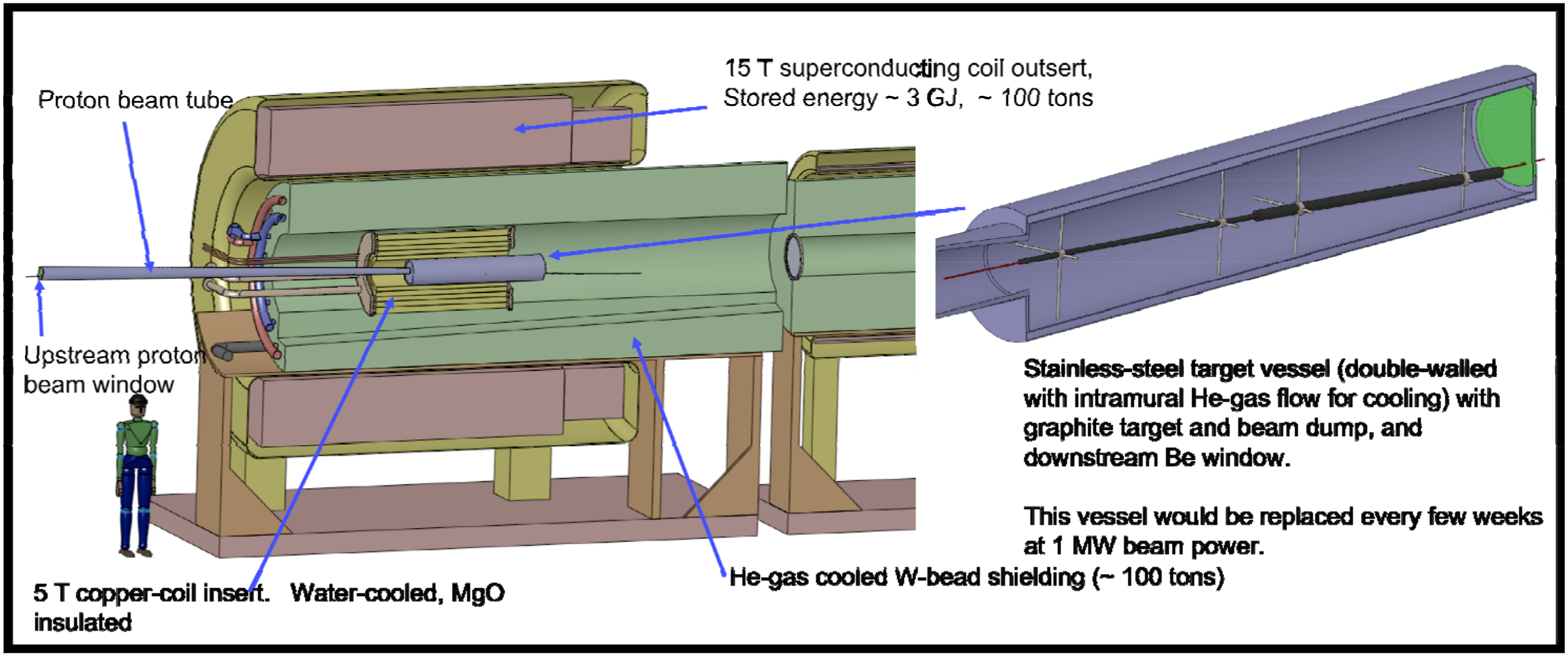
X. Ding, UCLA
H.G. Kirk, BNL
K.T. McDonald, Princeton Univ.

2015 MAP Spring Collaboration Meeting
18-22 May, 2015
FNAL

OUTLINE

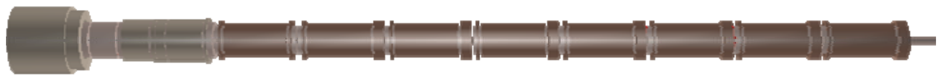
- Carbon target concept, ROOT-based geometry setting and fieldmap
- Carbon target optimization in a peak field of 20 T
- Beam dumps of carbon target
- Mercury target configuration and optimization in a peak field of 15 T
- Yield comparison between carbon target and mercury target
- Summary

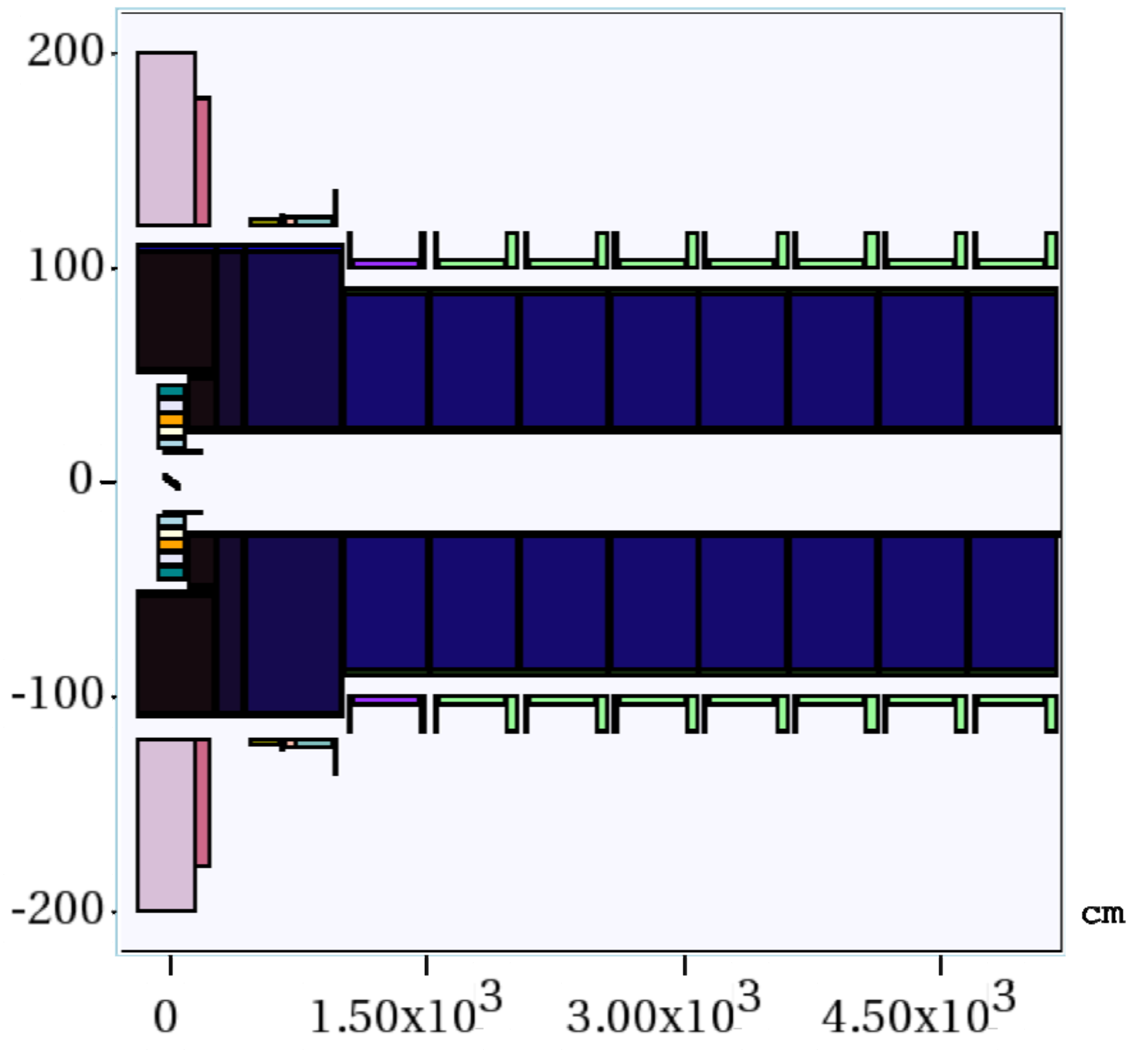
Carbon Target Concept



http://physics.princeton.edu/mumu/target/hptw5_poster.pdf

ROOT-based Carbon Target Setting
(20to2T5m120cm configuration)





Target Containment Vessel

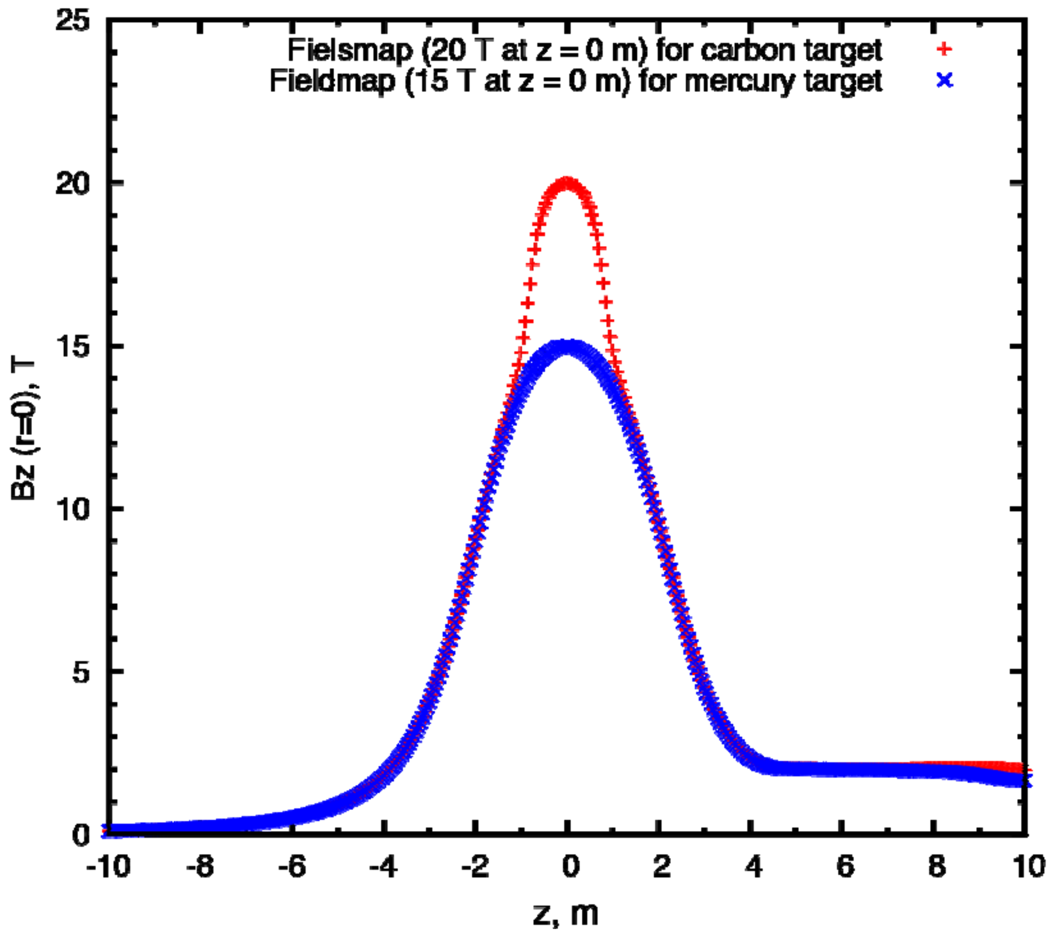
- The containment vessel is cooled by He-gas flow between its double walls. The outer cylinder extends over $-46 < z < 170$ cm, with outer radius $r = 15$ cm. The inner cylinder extends over $-45 < z < 169$ cm, with inner radius $r = 14$ cm.
- The downstream faces of the vessels are Be windows, ≈ 1 mm thick.

Magnet Modules
(front end for 5 < z < 50 m)

- The Front End for 5 < z < 50 m consists of nine 5-m-long superconducting magnet modules, each with internal tungsten shielding around the 23-cm-radius beam pipe. The latter has thin Be windows, ≈ 0.05 mm thick, at each end of a magnet module, and is filled with He gas at 1 atmosphere.
- This model does not include a chicane.

Fieldmap along SC axis

(Capture magnet 20to2T5m120cm for carbon target and 15to2T5m120cm for mercury target)



http://physics.princeton.edu/mumu/target/weggel/15to2T~5m5x5cm.txt
http://physics.princeton.edu/mumu/target/weggel/20to2T5m120cm4pDL.txt

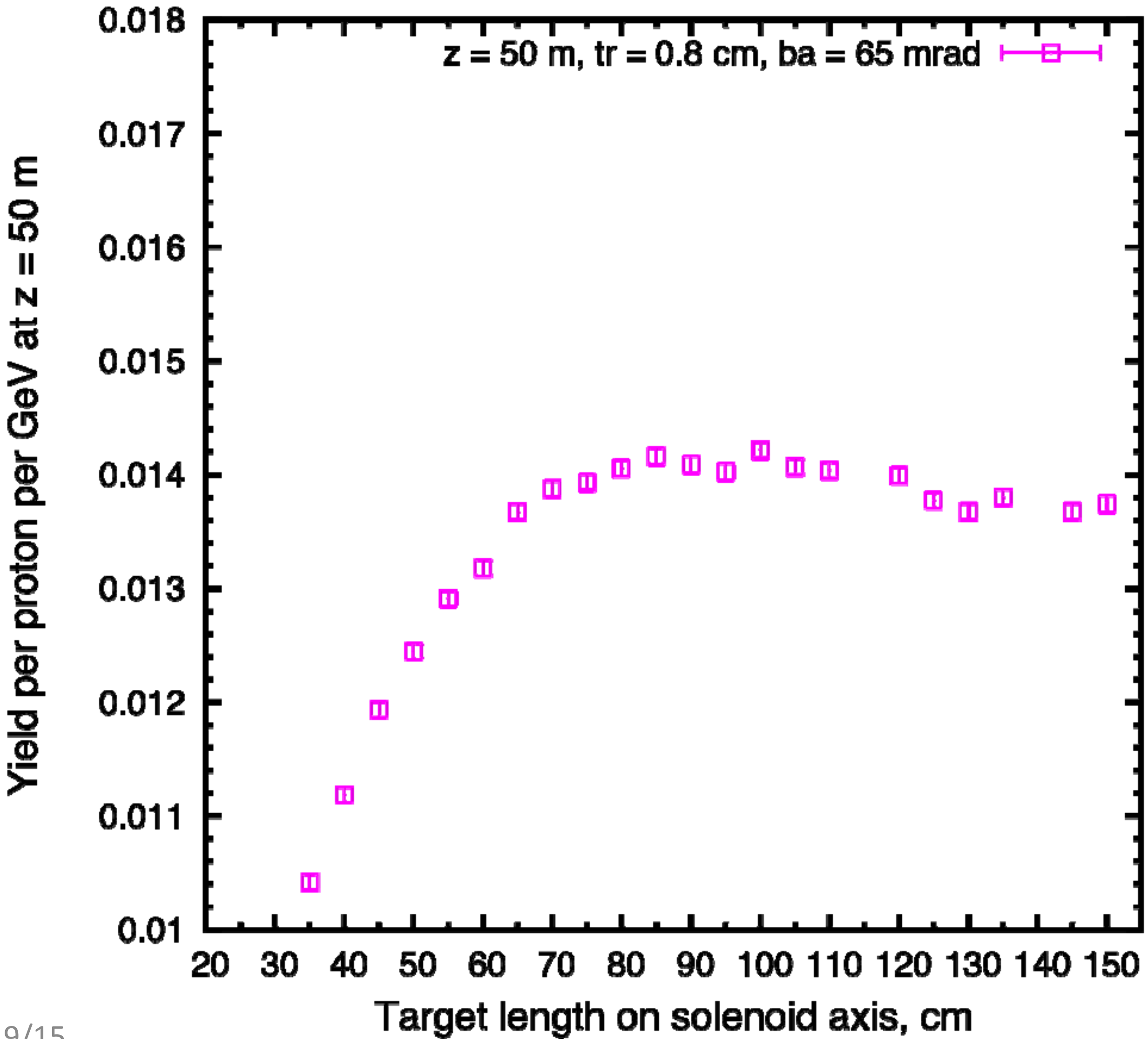
Carbon Target Optimization

- *Simulation code:* MARS15(2014) with ICEM 4 = 1 (default) and ENRG 1 = 6.75, 2 = 0.02, 3 = 0.3, 4 = 0.01, 5 = 0.05, 6 = 0.01, 7 = 0.01 ;
- *Carbon target configuration:* Fieldmap (20 T $\rightarrow$ 2 T) with taper length of 5 m, Graphite density = 1.8 g/cm^3;
- *Beam pipe radius:* 14 cm (initial) and 23 cm (final);
- *Proton beam:* 6.75 GeV (KE), 1 MW, ¼ of target radius, waist and 5-50 μm geometric emittance at z = 0 m (intersection point), launched at z = -100 cm;
- *Production collection:* z = 50 m, 40 MeV < KE < 180 MeV.

Launched Proton Beam at z = -100 cm

- Generate an antiproton beam having a specified rms transverse emittance, beam angle and waist at the center of the target (z = 0);
- Propagate all antiprotons in the beam back from z = 0 to z = -100 cm without a target;
- Generating a positive proton beam by changing the signs of charge and p_x, p_y and p_z of the antiproton beam above. This will be the launched beam at z = -100 cm for subsequent propagation in the positive z direction.

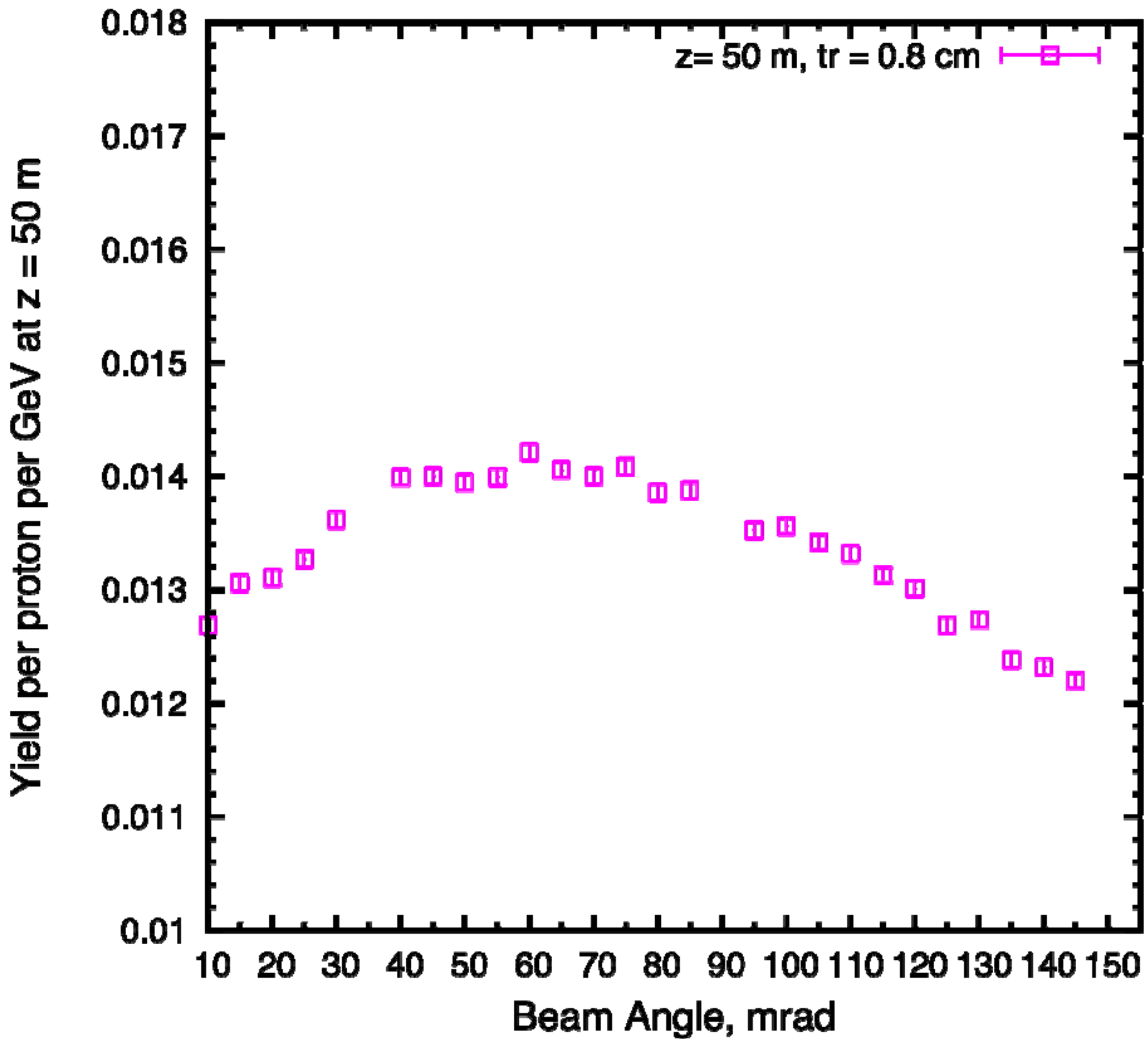
Target Length Optimization
(5 µm transvers beam emittance, no beam dump)



The optimized target length is set at 80 cm.

Beam Angle Optimization

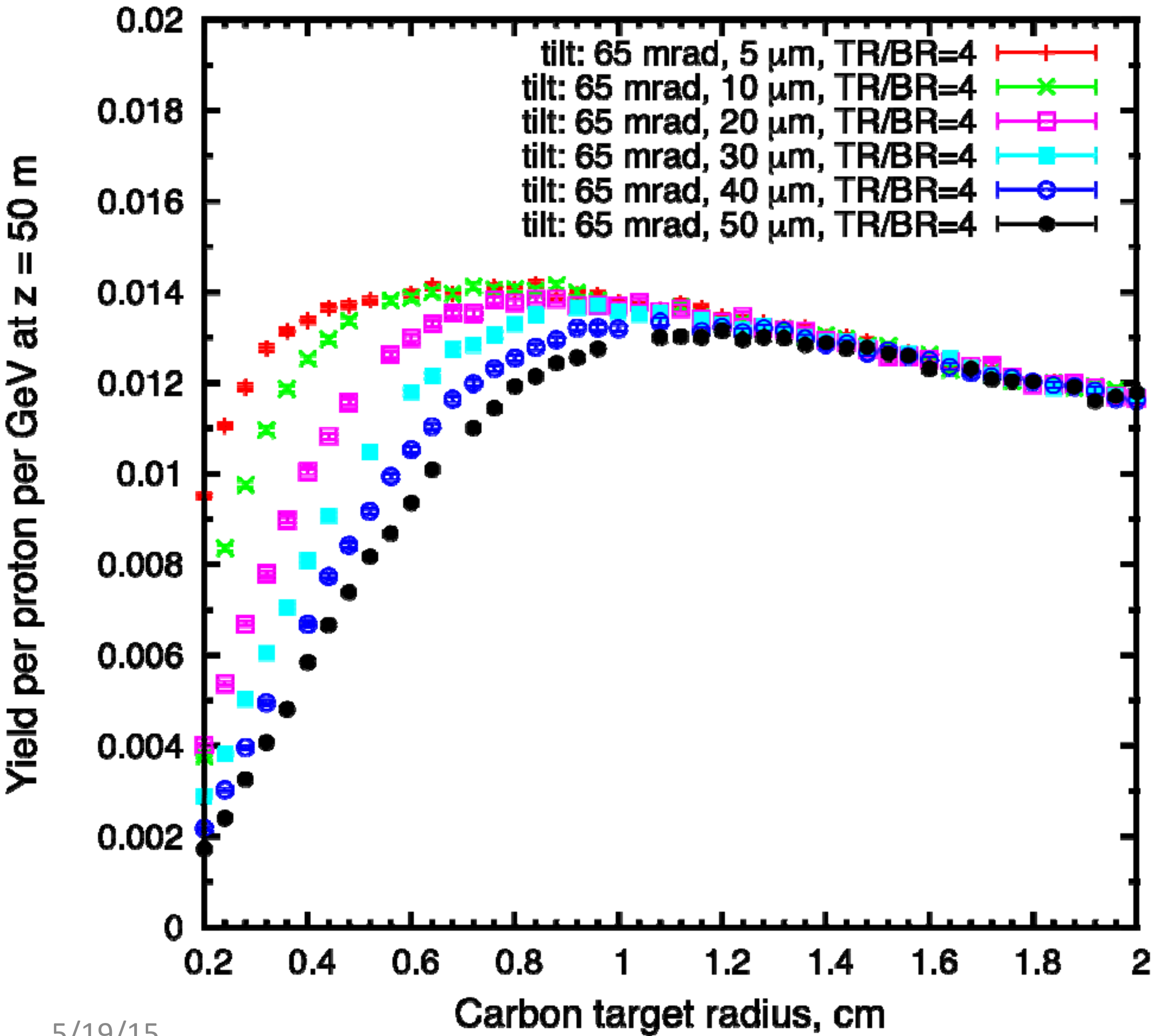
(5 µm transverse beam emittance, no beam dump)



Collinear target and beam

The optimized beam angle is set at 65 mrad to the magnetic axis.

Target Radius Optimization
(varied beam emittance from 5 to 50 μm)



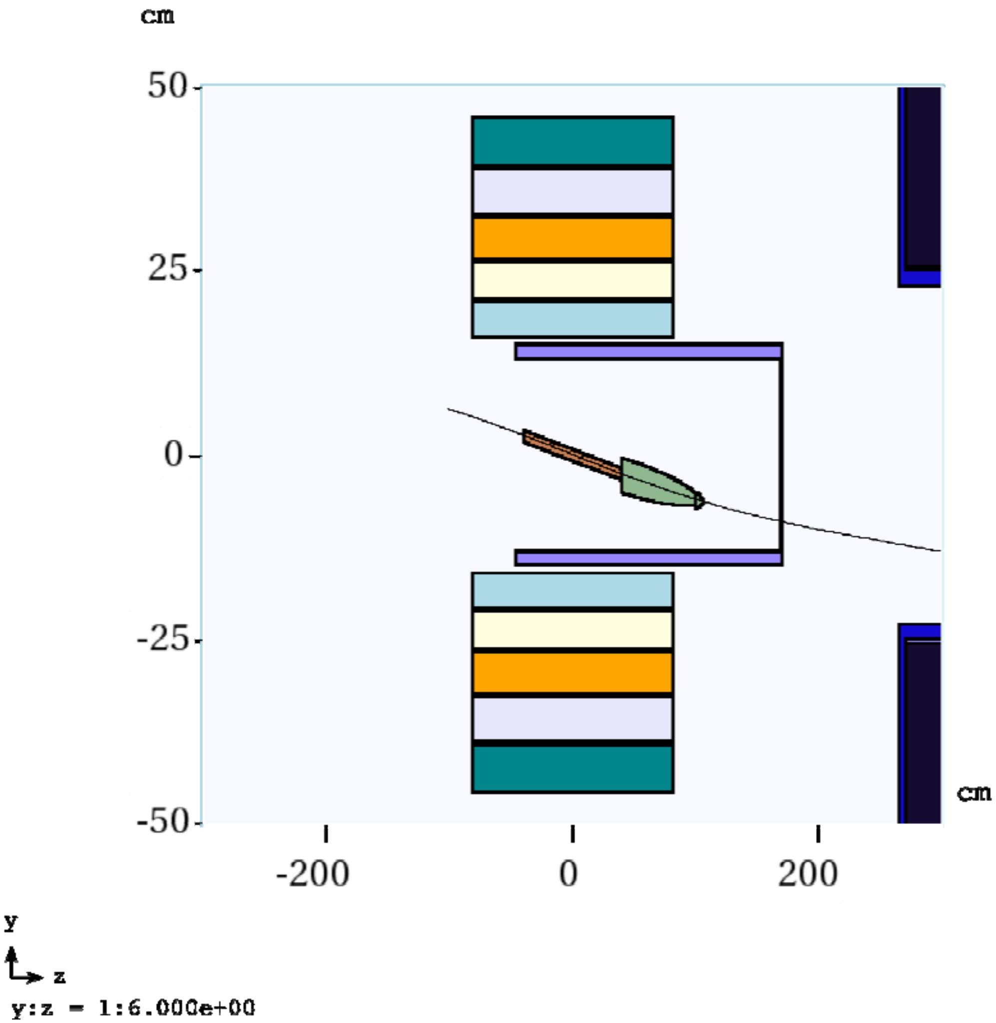
The optimized target radius is set at 0.8 cm for any emittance ≤ 20 μm;

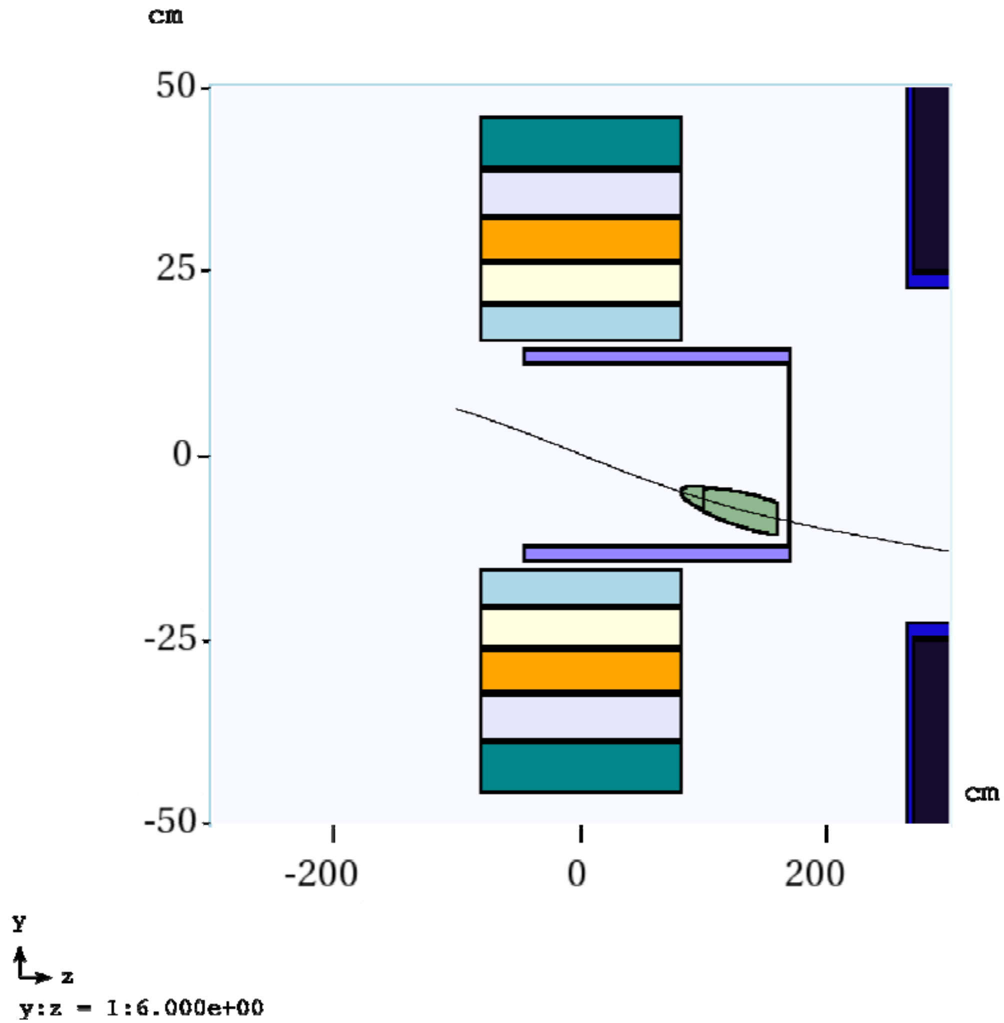
Particle production decreases only slowly with increasing emittance.

Yield for 50 μm emittance and target radius of 1.2 cm is only 10% less than that for the nominal case of 5 μm emittance and 0.8 cm target radius;

Setup of Beam Dump in ROOT

(based on central ray trajectory)



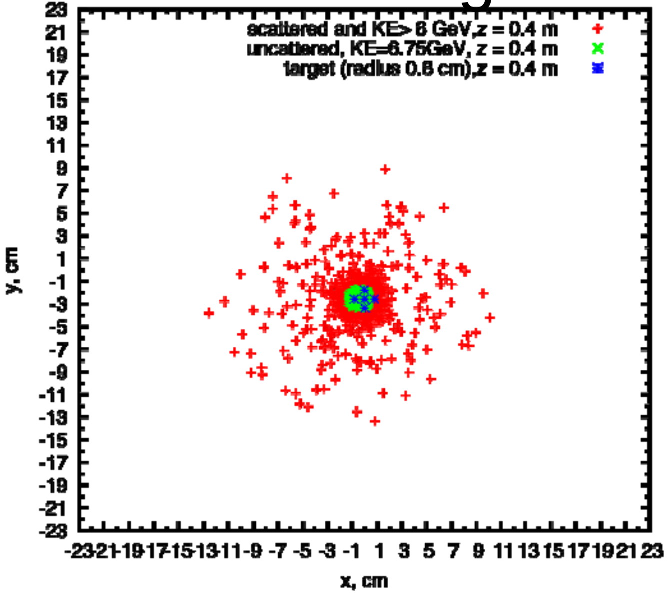


x = 0 cm

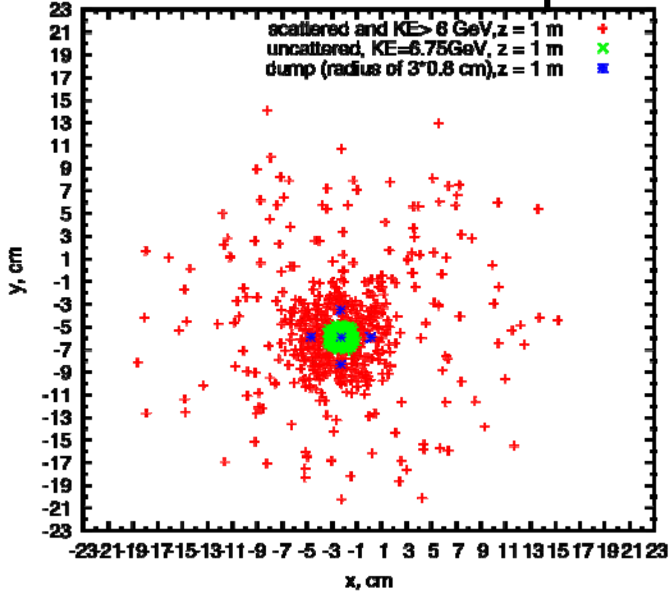
x = -4 cm

Setup of Beam Dumps in ROOT

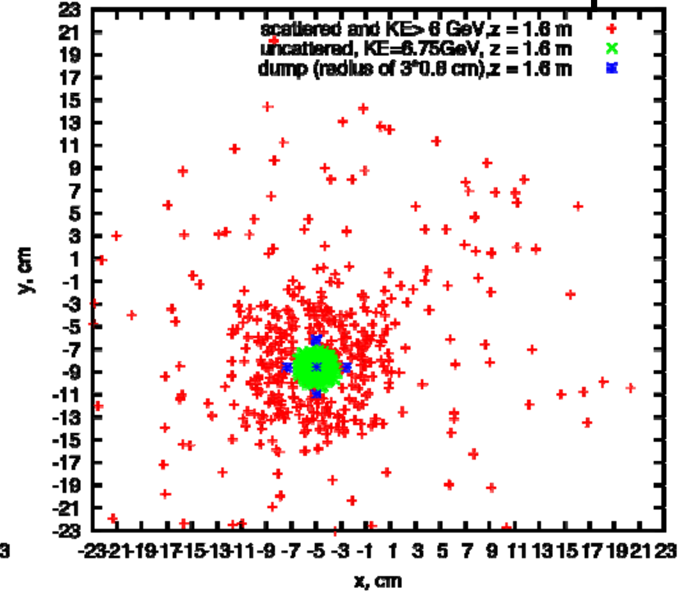
End of target



End of 1st dump



End of 2nd dump



Target: length = 80 cm (-40 < z < 40 cm), radius = 0.80 cm,
beam angle of 65 mrad in the *y-z* plane, center of end of target (0,-2.6,40) cm

1st beam dump rod: radius 3 $\times$ target radius, length = 60 cm
(40 < z < 100 cm), centers of end faces: (0,-2.6,40), (-2.3,-5.9,100) cm

2nd beam dump rod: radius 3 $\times$ target radius, length = 60 cm
(100 < *z* < 160 cm), centers of end faces: (-2.3,-5.9,100), (-5.0,-8.6,160) cm

Particles at z = 5 m from Carbon Target

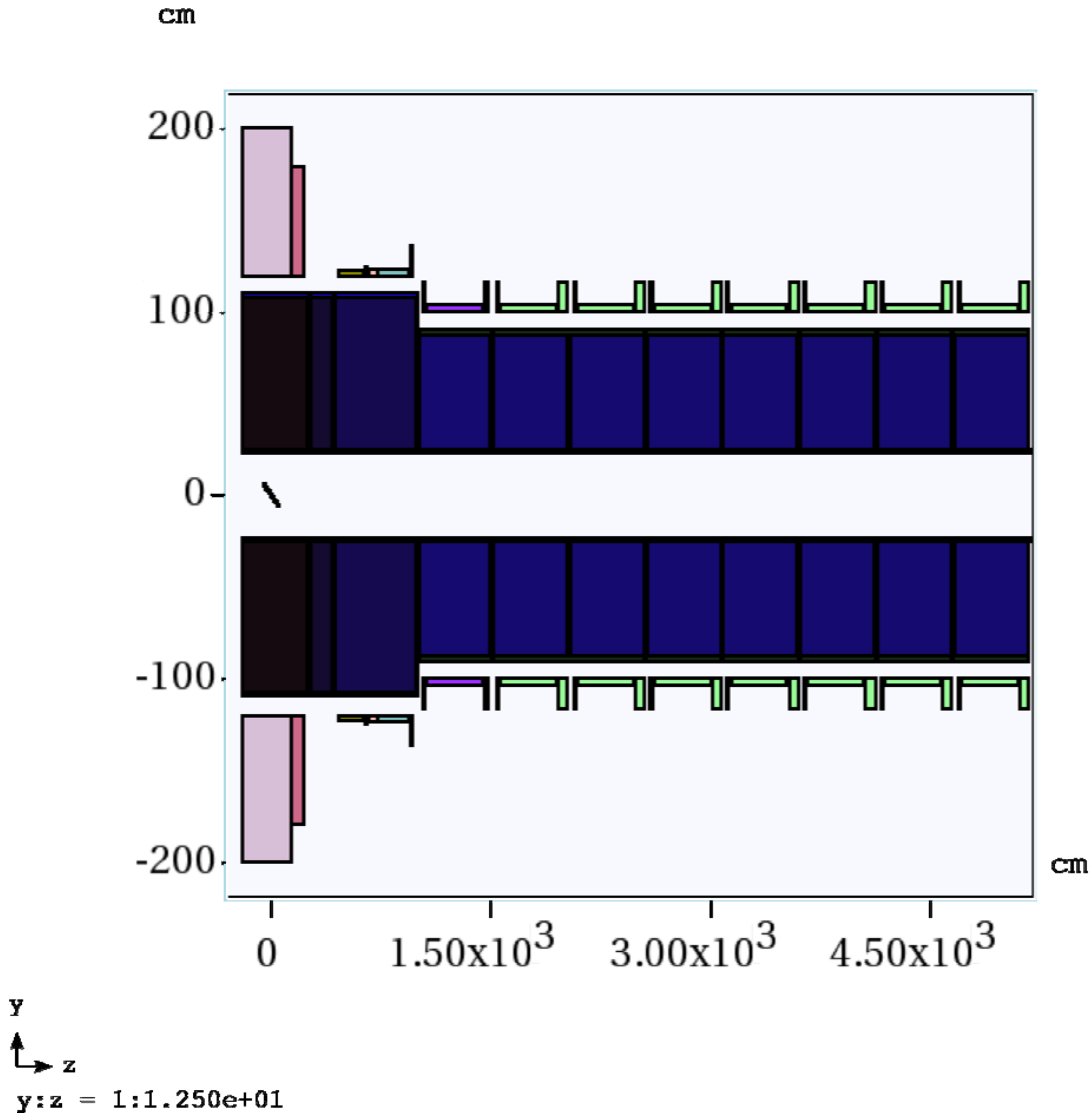
1 MW beam **(9.26 × 10^{14} protons with KE of 6.75 GeV)**
beam angle = 65 mrad, target radius = 0.8 cm

L_{dump} (cm)	R_{dump}/R_{target}	Total KE (protons) (r <23 cm) [MW]	Total KE (non-protons) [MW]	Protons KE > 6 GeV	Yield at z = 50 m
0	0	0.086793	0.103681	262 × **9.26 × 10 10**	939 × **9.26 × 10 10**
120	3	0.067306	0.088229	121 × **9.26 × 10 10**	835 × **9.26 × 10 10**

The beam dump would intercept about ~54% of the (diverging) unscattered proton beam with kinetic energy above 6 GeV while causing only 11% decrease in the yield.

Mercury Target Configuration

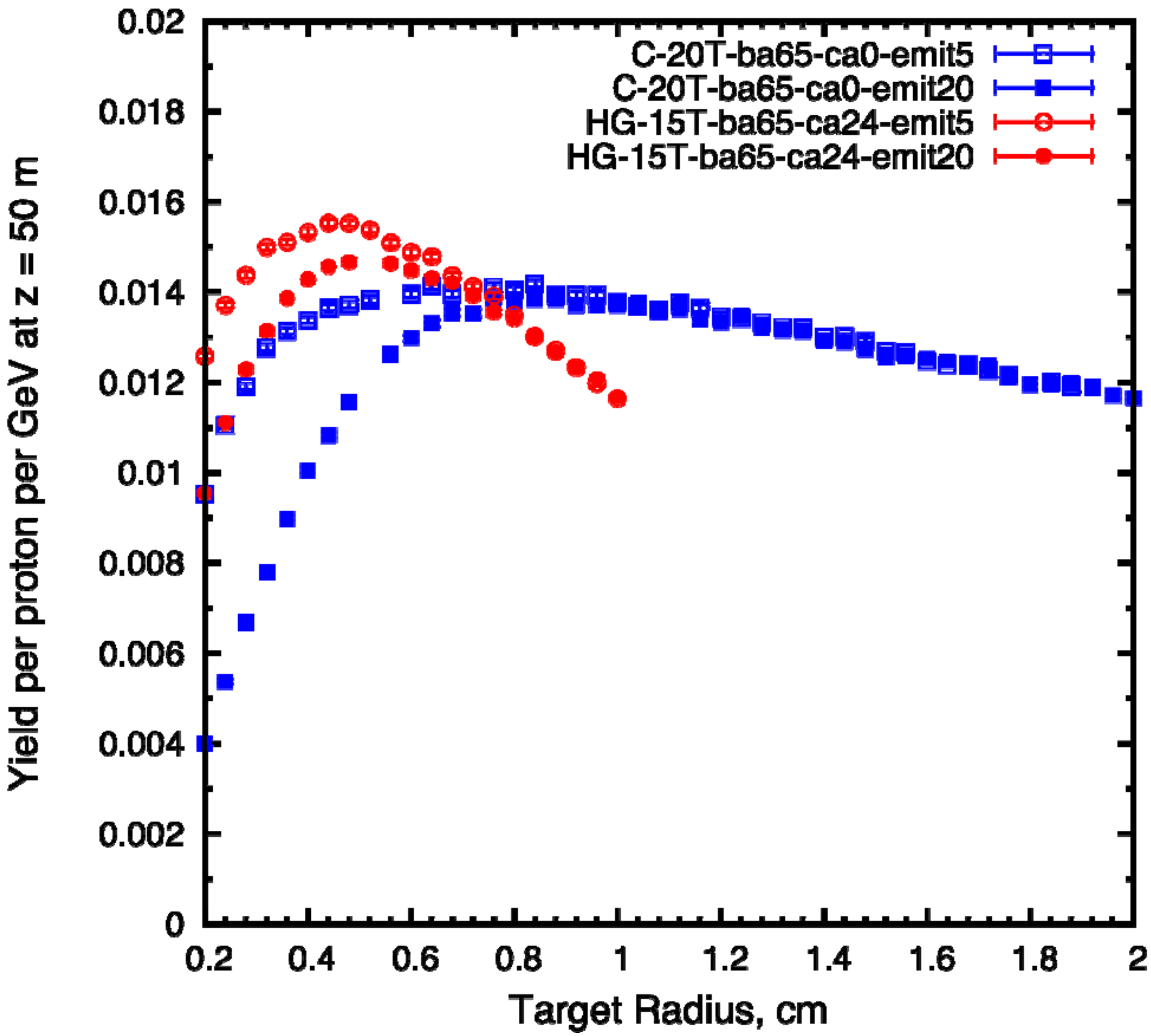
(Mercury Pool not shown)



Mercury Target Optimization

- *Simulation code:* MARS15(2014) with ICEM 4 = 1 (default) and ENRG 1 = 6.75, 2 = 0.02, 3 = 0.3, 4 = 0.01, 5 = 0.05, 6 = 0.01, 7 = 0.01 ;
- *Mercury target configuration:* Fieldmap (15 T $\rightarrow$ 2 T) with taper length of 5 m;
- *Mercury jet length:* assumed to be 100 cm along SC axis;
- *Beam pipe radius:* 23 cm;
- *Proton beam:* 6.75 GeV (KE), 4 MW, 30% of target radius, waist and 5-20 µm geometric emittance at z = 0 m (intersection point), launched at z = -100 cm;
- *Production collection:* z = 50 m, 40 MeV < KE < 180 MeV.

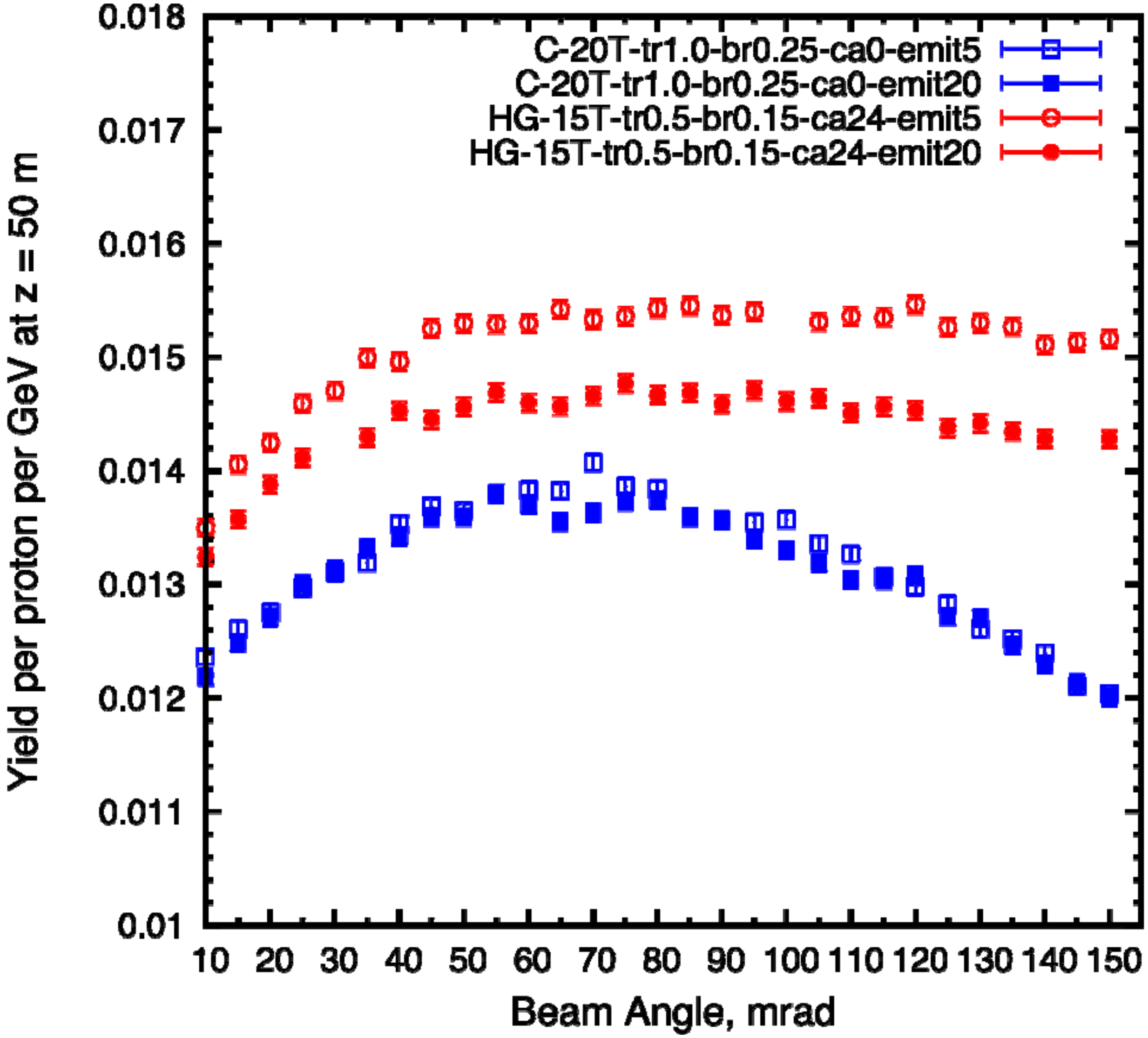
Target Radius Optimization



The optimized target radius is set at 0.5 cm for HG target.

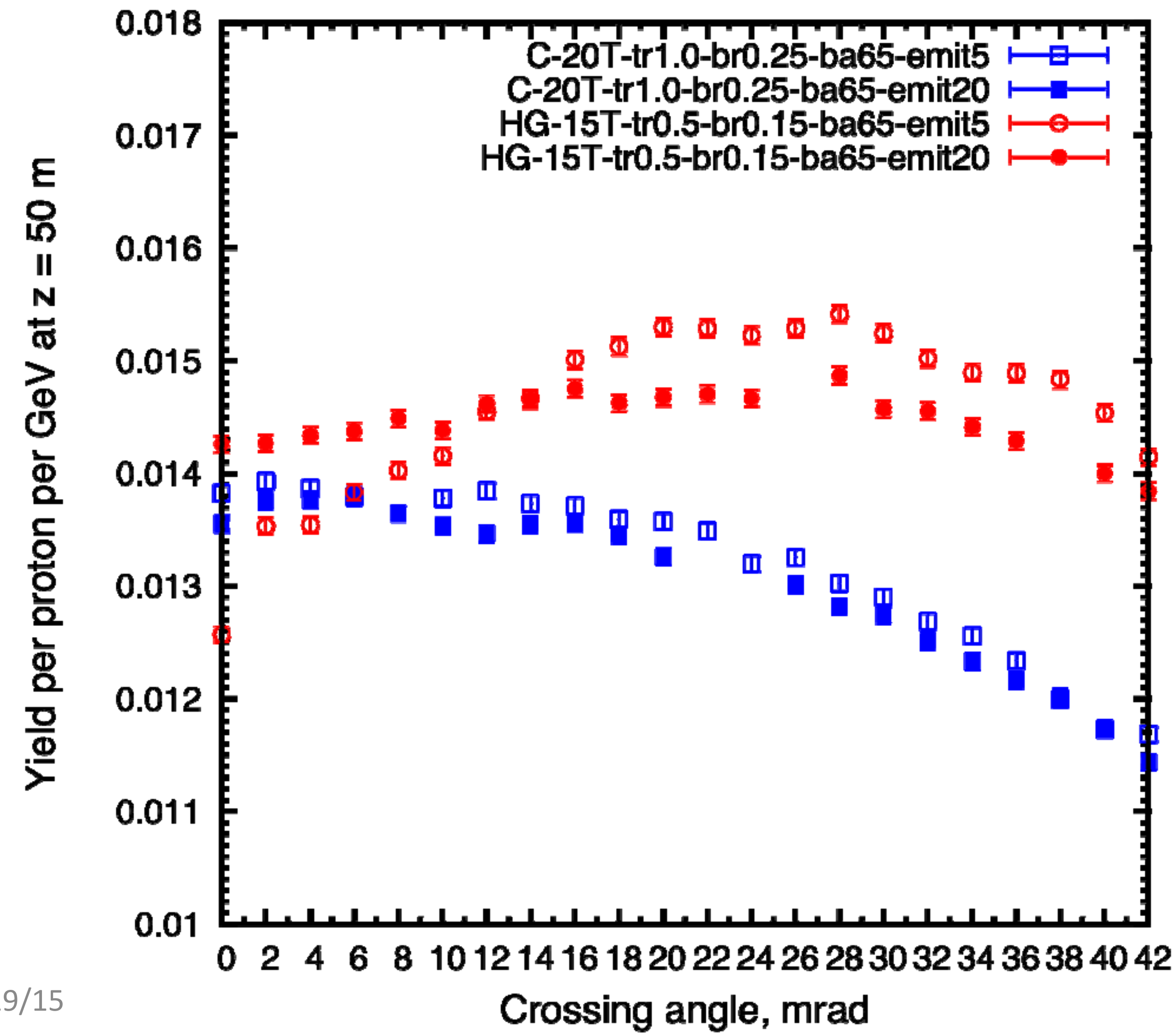
The mercury target at a peak field of 15 T gives about 10% more yield than the carbon target at a peak field of 20 T.

Beam Angle Optimization



The optimized beam angle is set at 65 mrad for HG target.

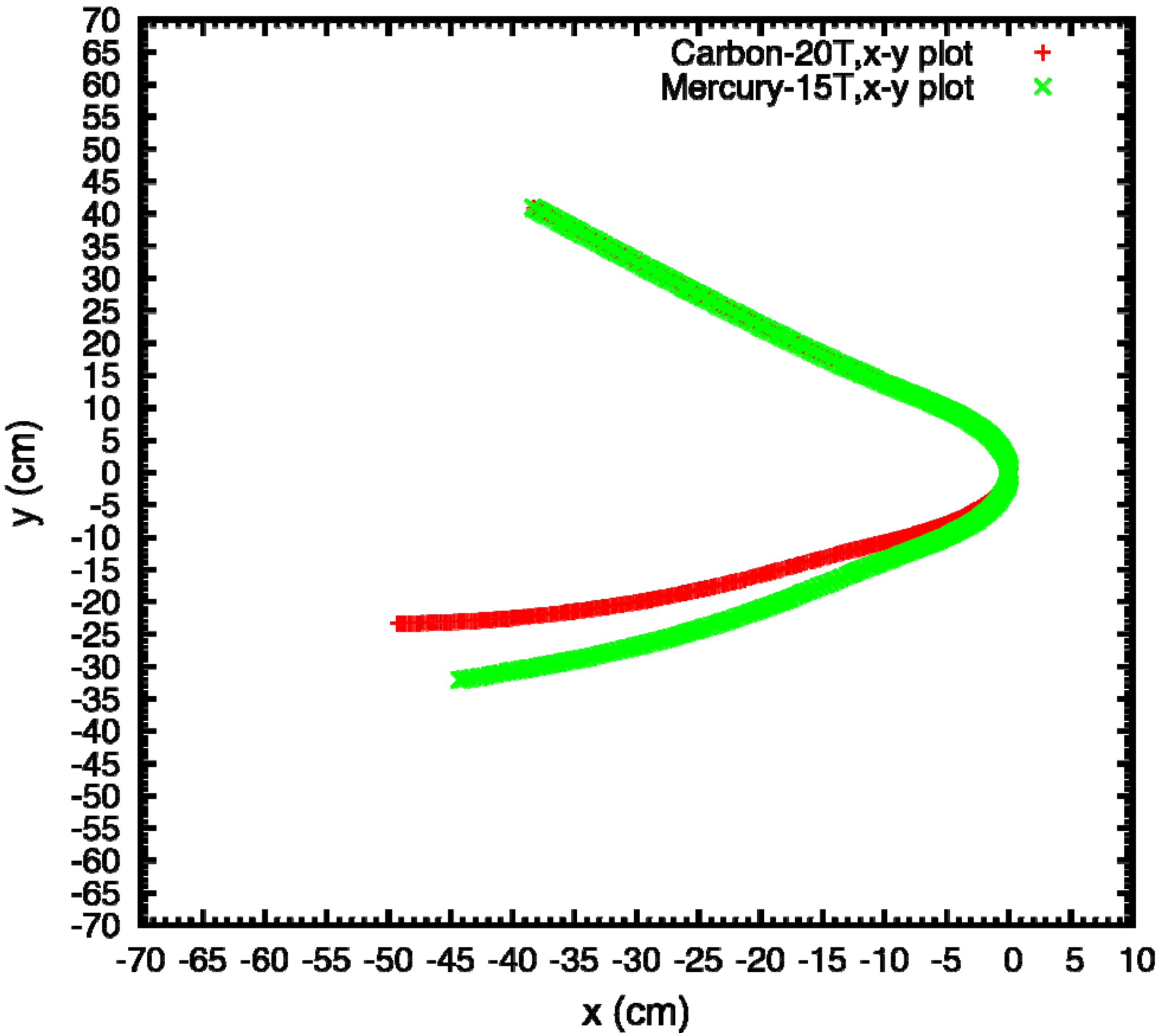
Beam/Target Crossing Angle Optimization



The optimized beam/target crossing angle is set at 24 mrad for HG target.

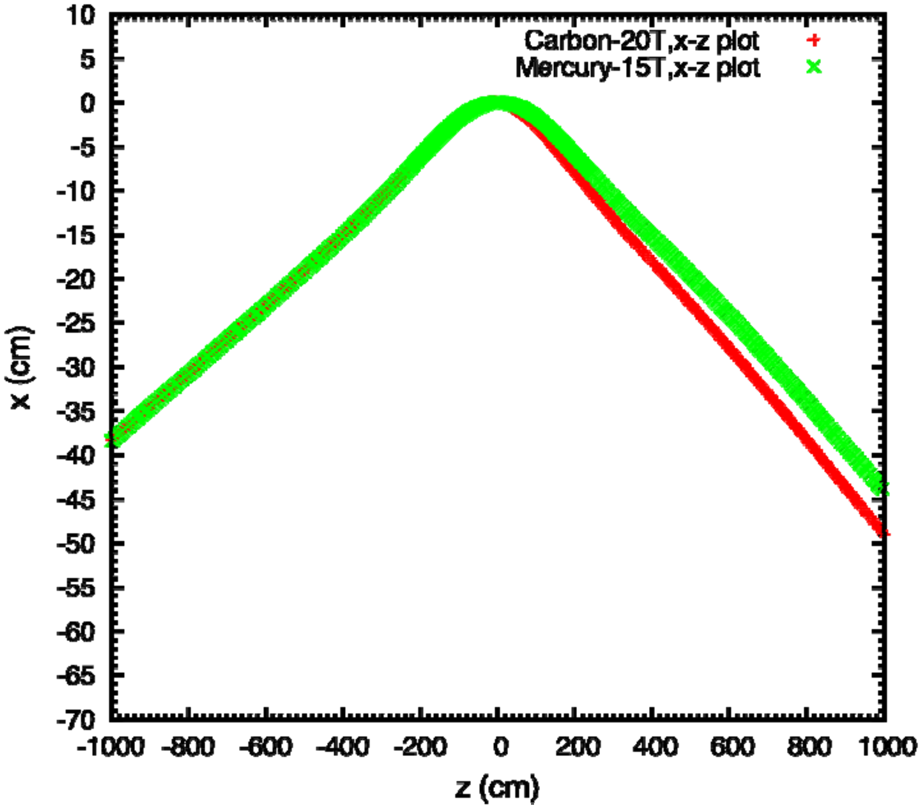
Central Ray Tracking

(Vary *z* from -1000 to +1000 cm)

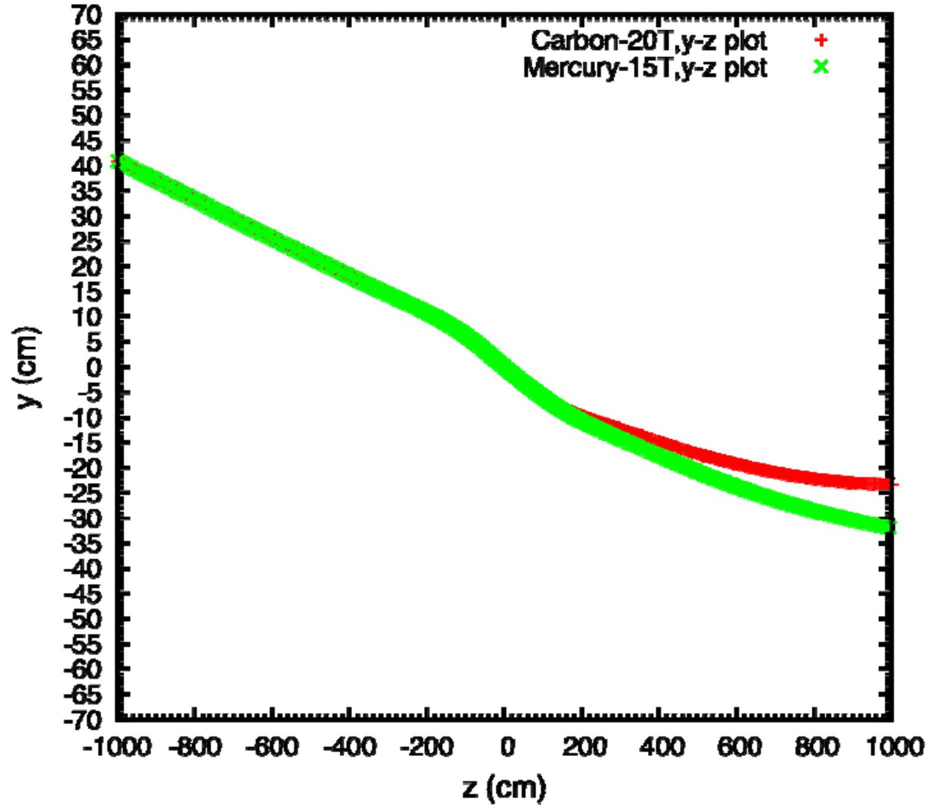


Central Ray Tracking

(Vary z from -1000 to +1000 cm)



x-*z* plot



y-*z* plot

Summary

- Carbon Target System: 1 MW, 6.75 GeV (KE) proton beam, the 20 T field on target drops to the ~2 T field over ~5 m and graphite target.
- Successfully designing the target system and complicated beam dumps with ROOT-based geometry.
- Optima for graphite target (tilt beam):

  length = 80 cm, radius = 8 mm (with 2 mm rms beam radius), tilt angle = 65 mrad.

Summary (Cont'd)

- Higher beam emittance and higher target radius are favored:
  - Improved the radiation cooling of the target,
  - Lower peak power deposition,
  - Only slight decrease in the particle yield,
  - Easier for Proton Driver to deliver higher emittance.
- Graphite proton beam dump now setup via ROOT:
  - 120 cm long, 24 mm radius, 2 segments,
  - Intercepts most of the (diverging) unscattered proton beam.

Summary (Cont'd)

- Mercury Target System: 4 MW, 6.75 GeV (KE) proton beam, the 15 T field on target drops to the ~2 T field over ~ 5 m and mercury target.
- Optima for mercury target (tilt beam):

  radius = 5 mm (with 1.5 mm rms beam radius), tilt angle = 65 mrad, beam/target crossing angle = 24 mrad.
- Yield is about 10% higher for Hg target at 15 T than for Carbon Target at 20 T.

Backup

Setup of Beam Dumps in ROOT

- Rotation defined by GRANT3 angles:

```
TGeoRotation *r1 = new TGeoRotation();
r1->SetAngles(th1,phi1, th2,phi2, th3,phi3)
```

This is a rotation defined in GEANT3 style. Theta and phi are the spherical angles of each axis of the rotated coordinate system with respect to the initial one.

Setup of Beam Dumps in ROOT

- Rotated cylinder can be described as having axes 1, 2 and 3, where 3 is the symmetry axis and goes from the origin to the specified point (x,y,z). Axis 1 is defined to lie in the x-z plane

phi1 = 0

th1 = acos(x / sqrt(x^2 + z^2))

phi2 = atan2[(x^2 + z^2)/x , $-y$]

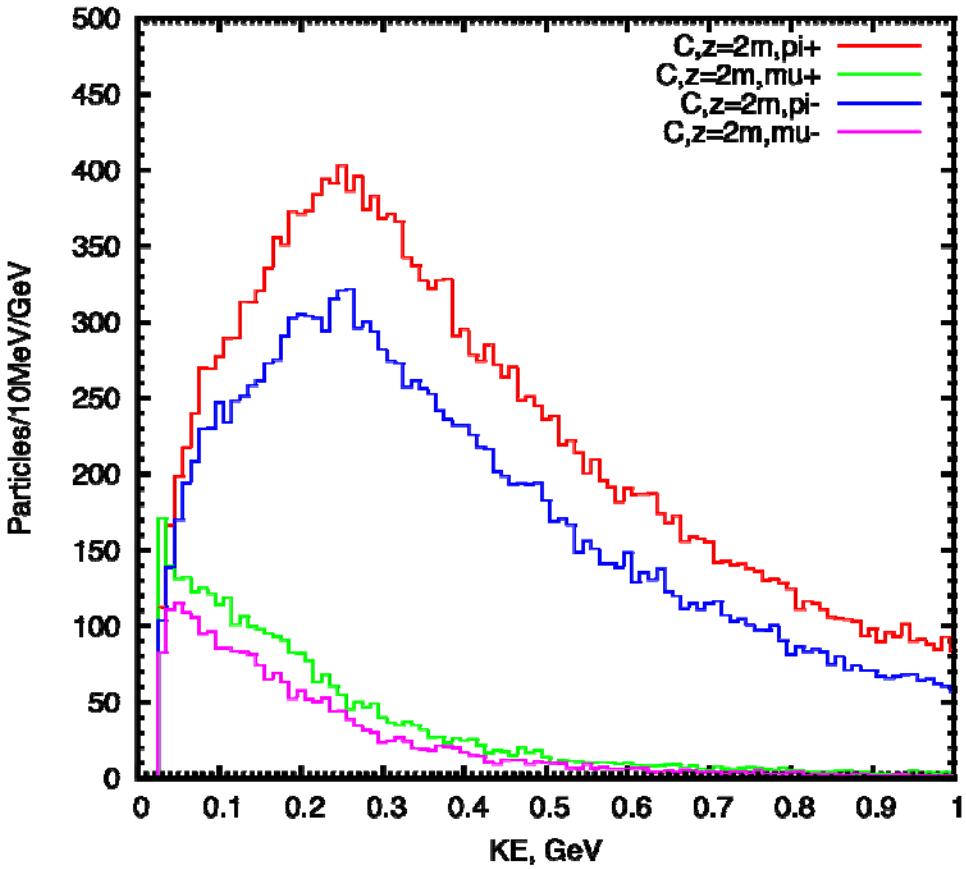
th2 = acos[- y z /sqrt(L^2 (x^2 + z^2)]

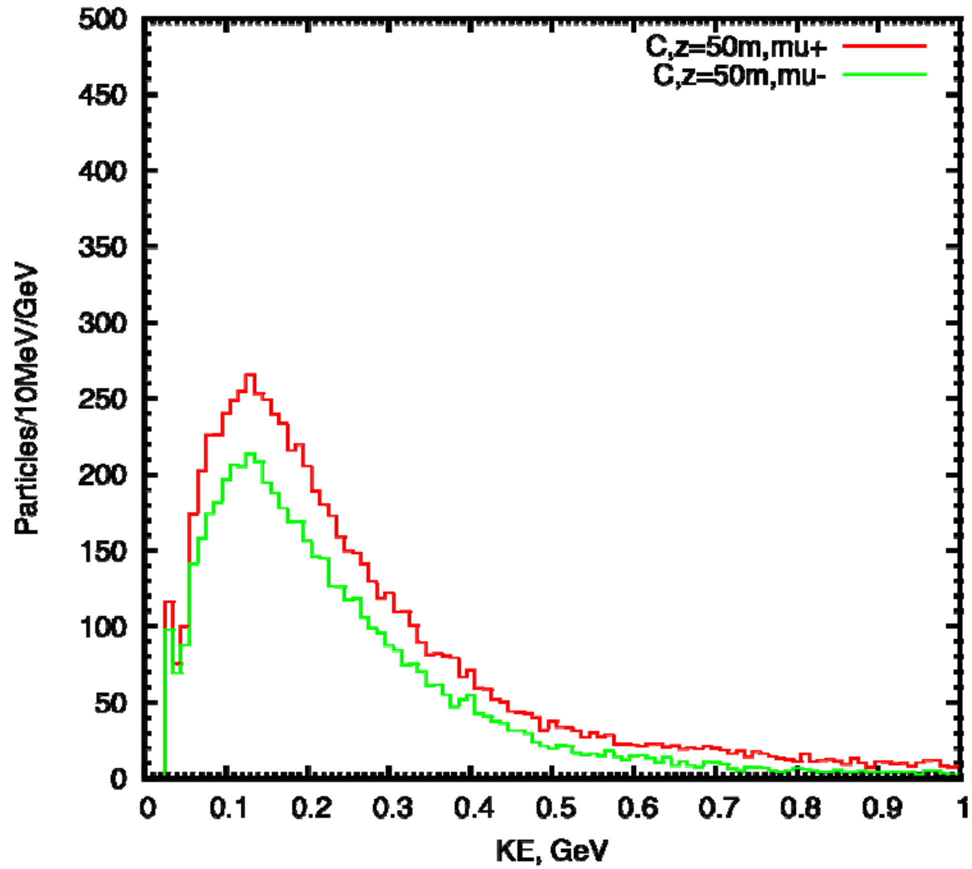
th3 = acos(z/L)

phi3 = atan2(y,x)

Energy Spectra for Carbon Target

(400,000 events)





Energy Spectra for Mercury Target

(400,000 events)