# Carbon Target Design and Optimization for an Intense Muon Source

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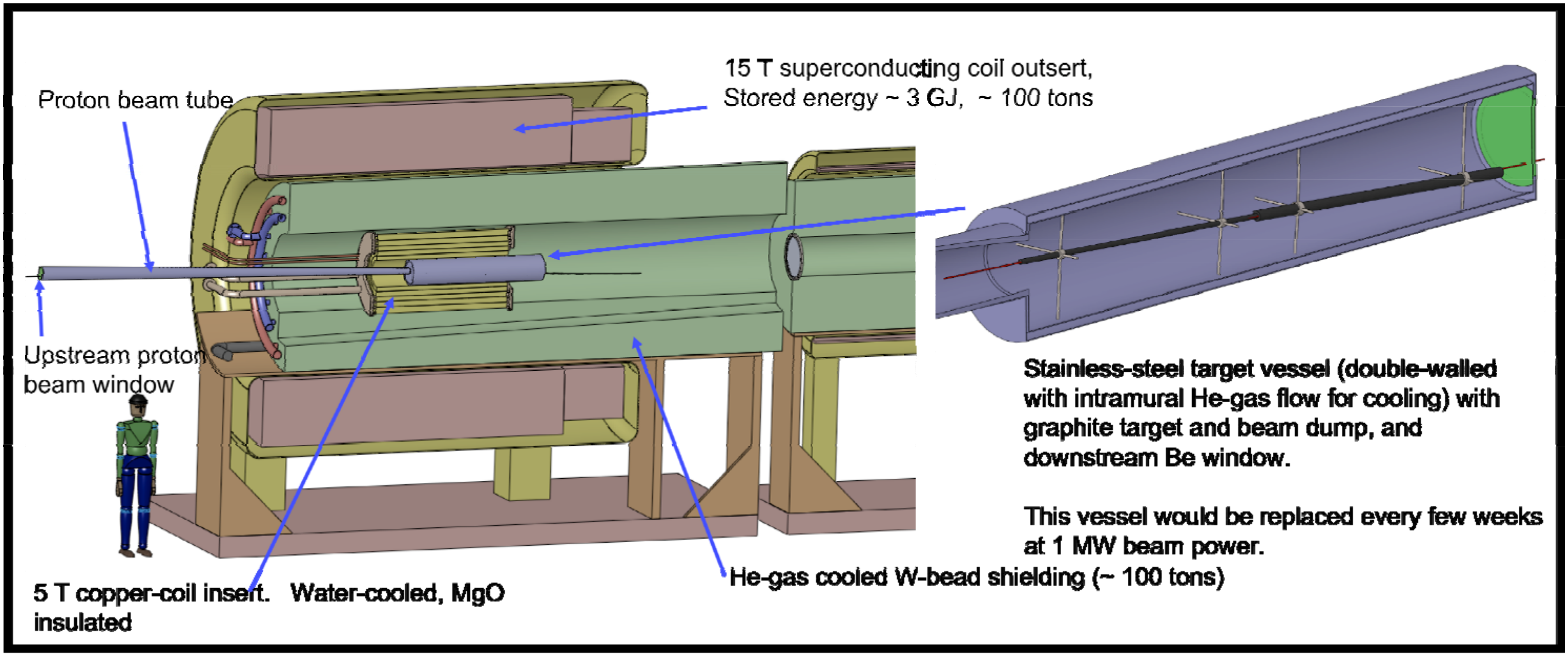
# OUTLINE

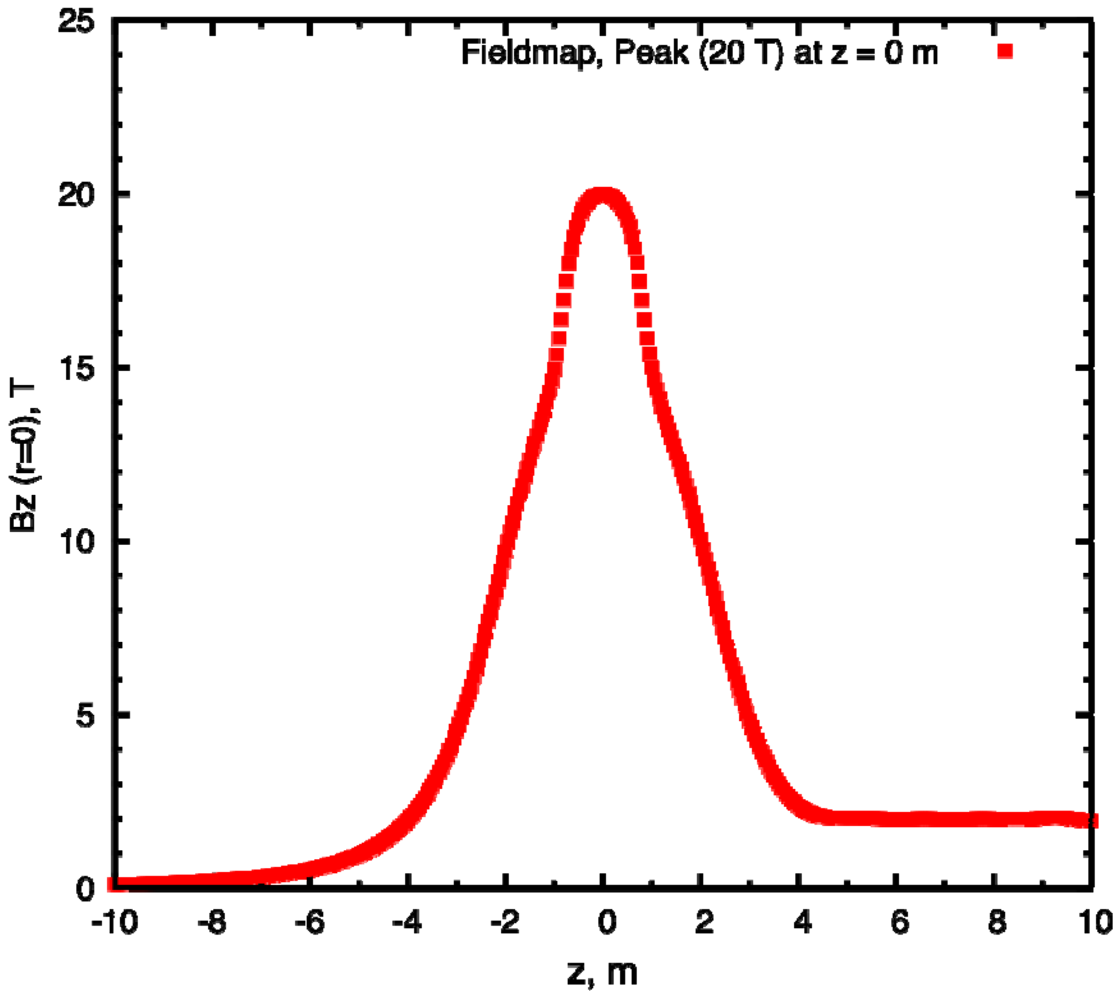
- Carbon target concept and fieldmap
- ROOT-based geometry setting for target station
- Carbon target optimization and yield comparison (no beam dumps)
- Design of beam dumps
- Summary

# Carbon Target Concept

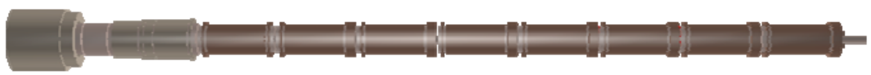


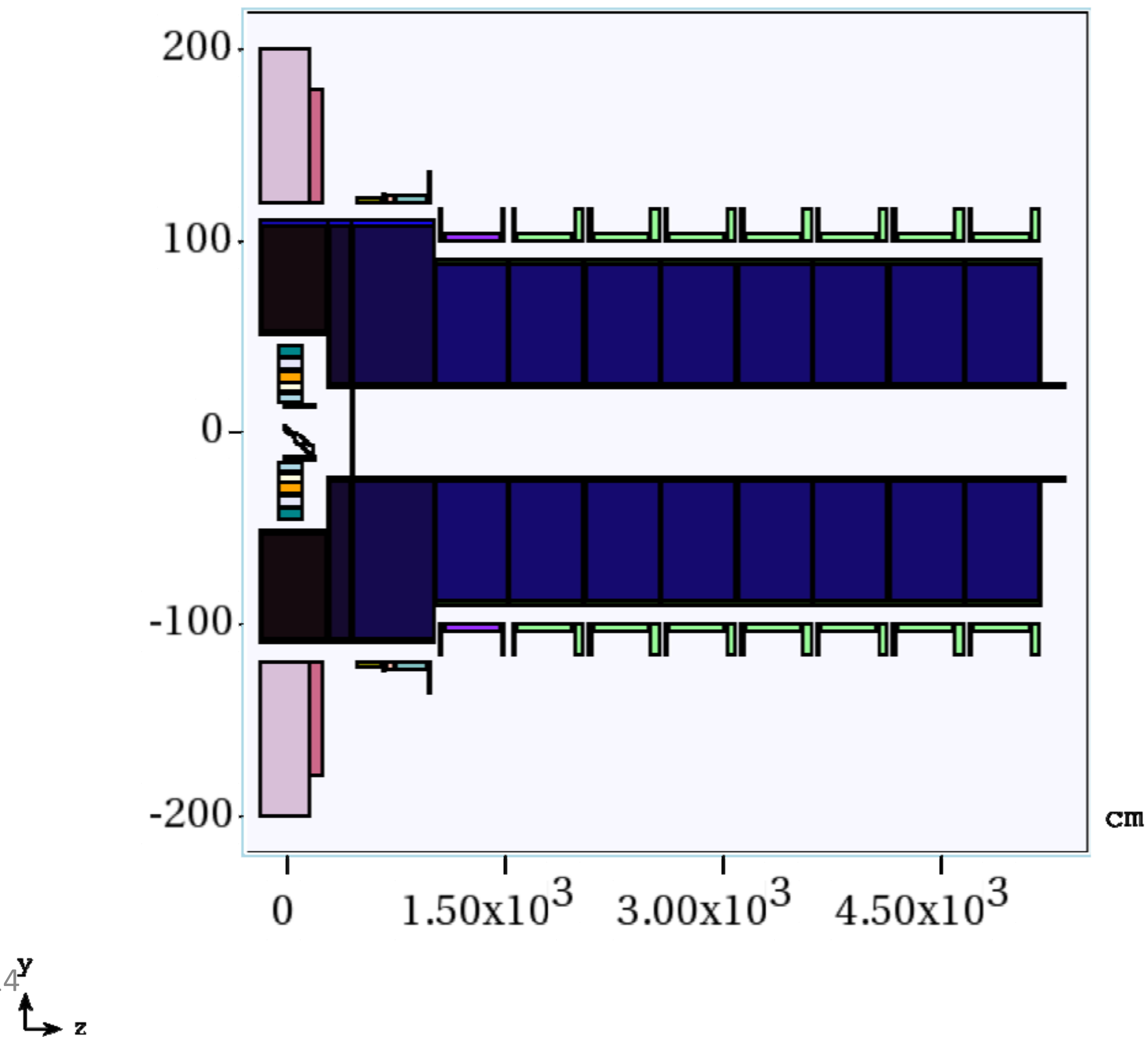

http://physics.princeton.edu/mumu/target/hptw5_poster.pdf

# Fieldmap along SC axis
## (Capture Magnet 20to2T5m120cm)



# ROOT-based Target Setting






New target setting (ROOT-based geometry).

Previous target setting (non-standard and standard geometry in MARS15)

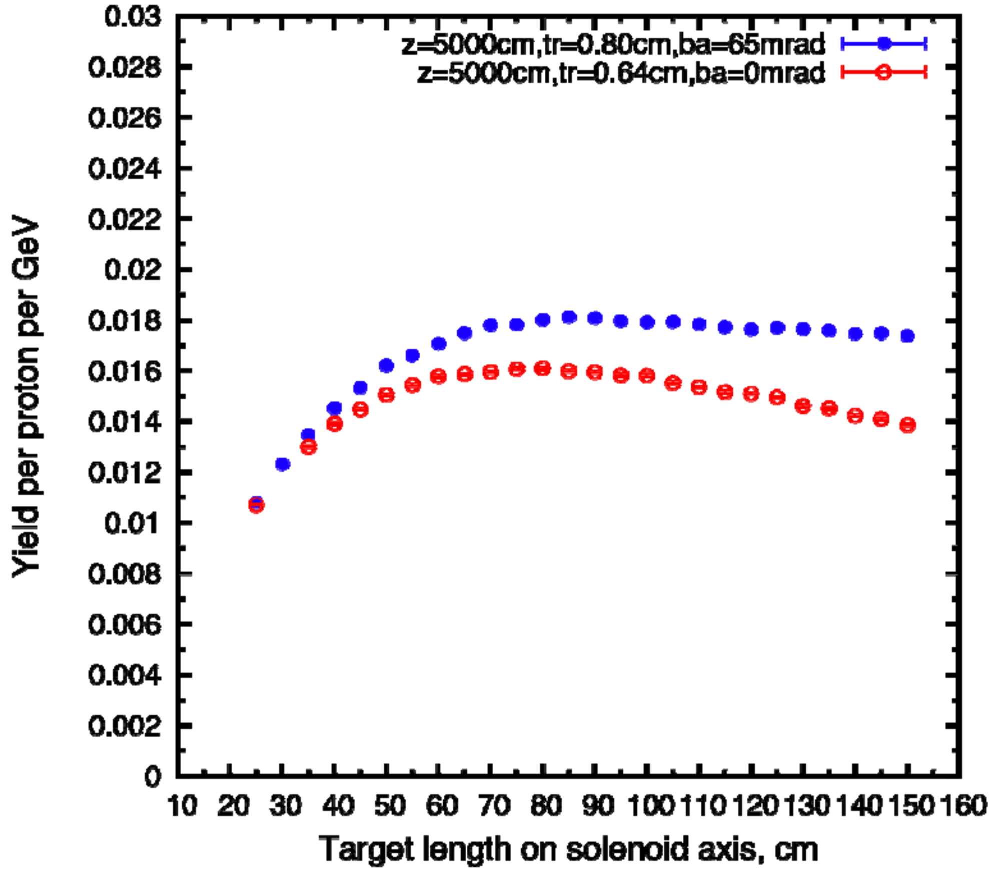
# Carbon Target Optimization

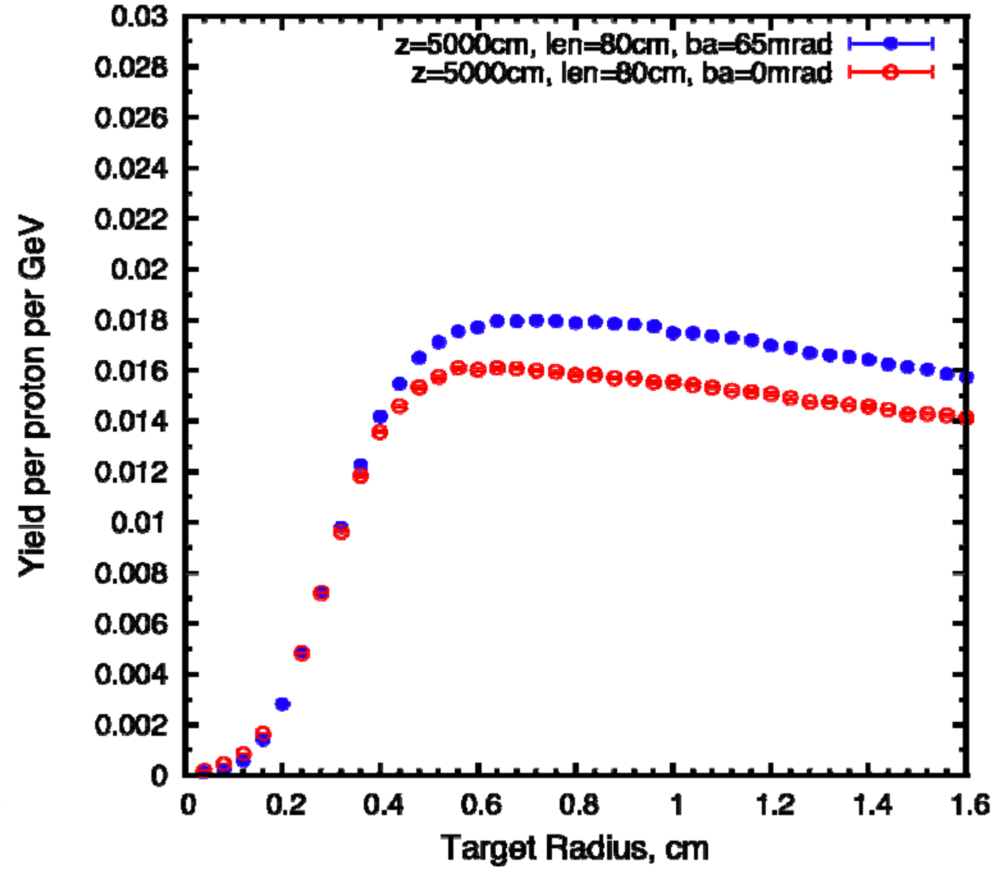
- *Simulation code:* MARS15(2014) with ICEM 4 = 1 (default) and ENRG 1 = 6.75, 2 = 0.02, 3 = 0.3, 4 = 0.01, 5 = 0.05, 6 = 0.01, 7 = 0.01 ;
- *Carbon target configuration:* Fieldmap (20T→2T) with taper length of 5 m, Graphite density = 1.8 g/cm$^3$;
- *Beam pipe radius:* 13 cm (initial) and 23 cm (final);
- *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;
- Particle distribution for front end: created at z = 2 m.

# New Procedure for Generating the Launched Beam at z = -100 cm

- Generate a negative proton beam having desired 2D emittance and waist at z = 0;
- Track back all negative protons in the beam from z = 0 to the left side and collect them at z = -100 cm;
- Generating a  positive proton beam by changing the signs of charge and px, py and pz of negative proton beam above. This will be the launched beam to the right side  at z = -100 cm.

# Yield Comparison (5 μm emittance)
## (no-tilt *vs*. tilt proton beam, no beam dump)

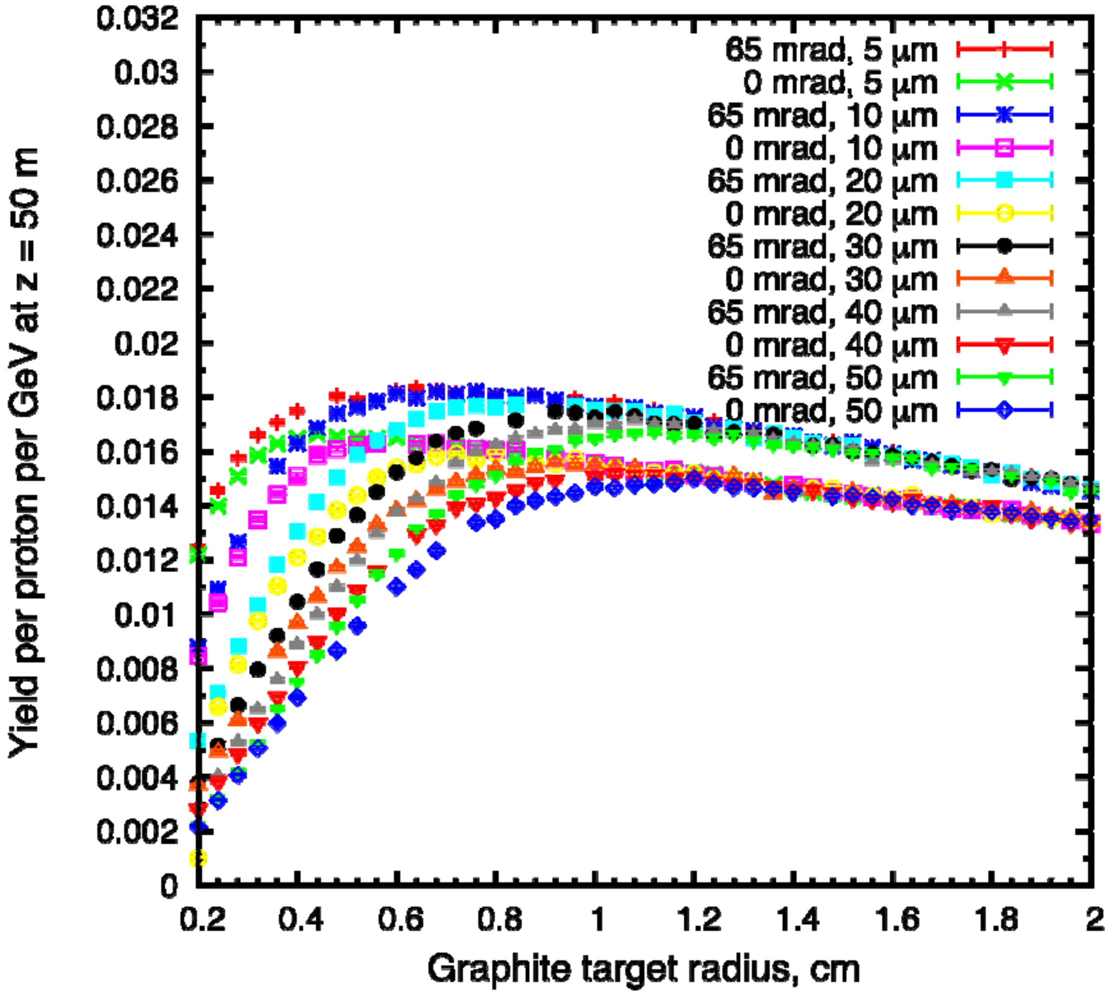



Optimized target length is 80 cm and target radius is 0.8 cm for tilt or 0.64 cm for no-tilt beam. Optimized tilt beam angle is 65 mrad. Collinear target and beam. TR/BR (target radius/beam radius) = 4.

~ 13% advantage to tilting the beam/target

# Yield Comparison (varied emittance)
## (no-tilt *vs*. tilt proton beam, no beam dump)




~ 13% advantage to tilting the beam/target;

For $r_{target}$ = 8 mm, same yield for any emittance ≤ 20 μm;

Little loss of muon yield for 20 μm 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;

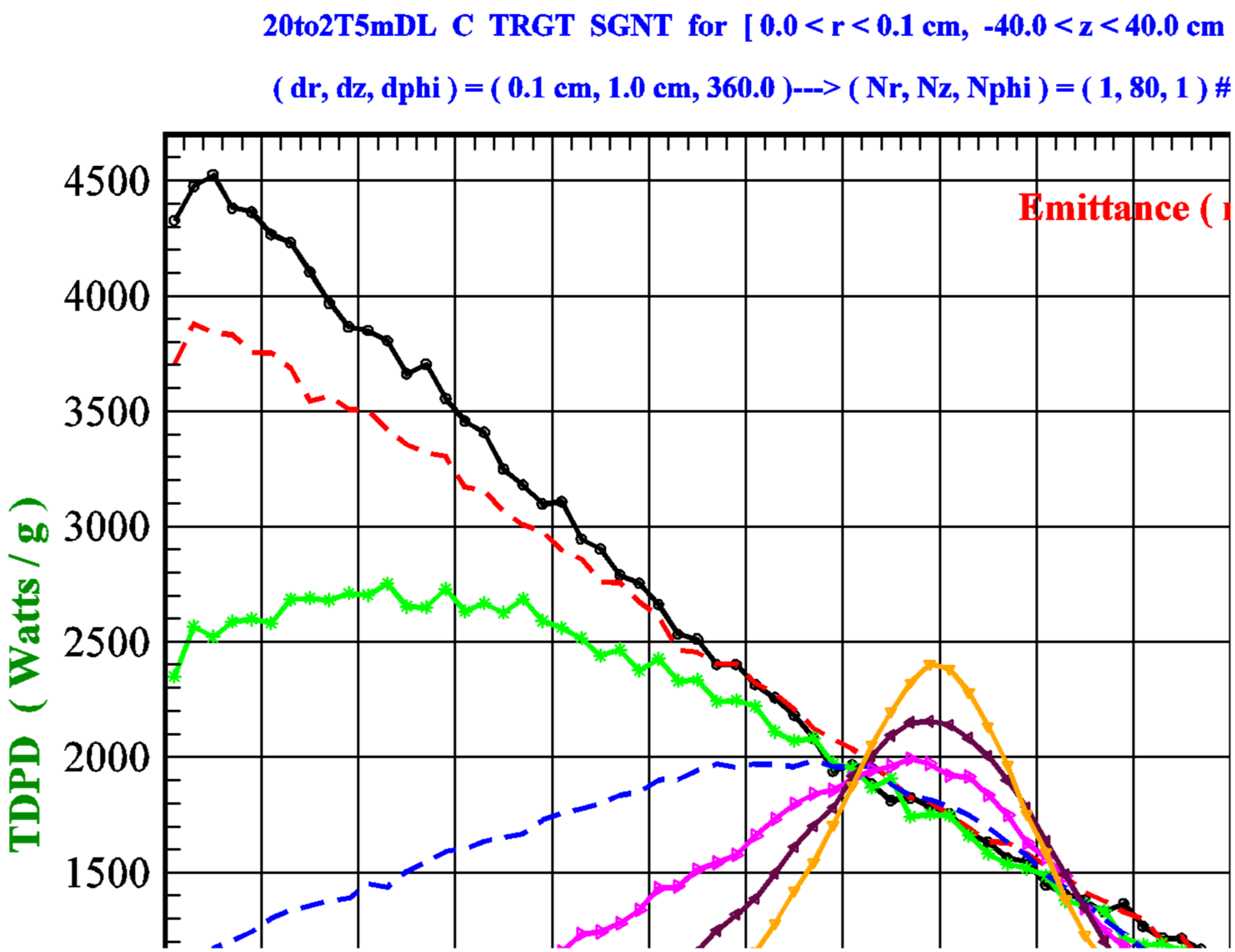
We prefer target radius ≥ 8 mm (beam radius ≥ 2 mm) for viable radiation cooling of the target.

http://physics.princeton.edu/mumu/target/targettrans106.pdf

# Advantage of Higher Emittance Beams

For a fixed target radius (8 mm on this page), higher beam emittance ⇒ higher beam divergence, more diffuse beam at upstream end of target, ⇒ lower peak power deposition.

For emittance ≥ 20 μm the peak power deposition is only ≈ 1/2 that for 5 μm, ⇒ additional advantage to use of higher emittance beams.




Simulation with MARS15 by N. Souchlas

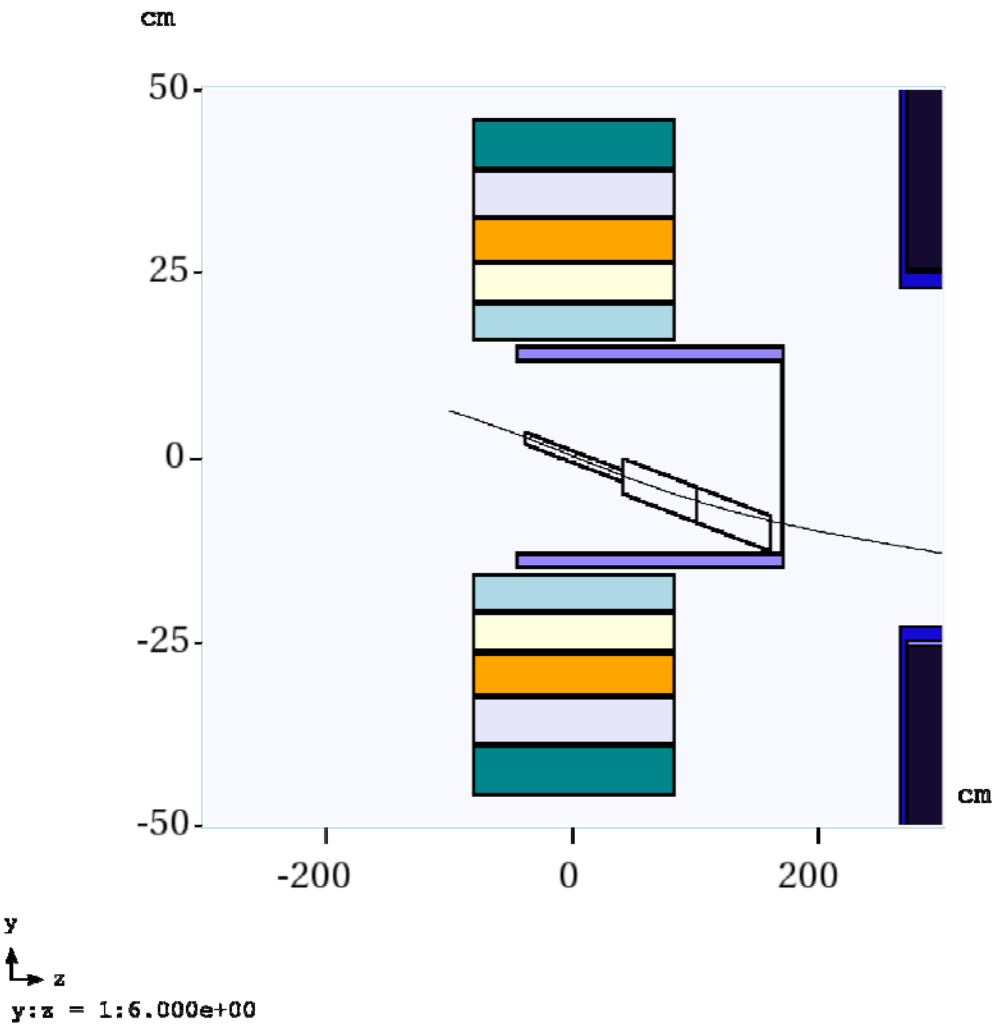
Result confirmed by J. Back with FLUKA



http://physics.princeton.edu/mumu/target/Ding/ding_140807.pdf

# Simple Setup of Beam Dumps in ROOT

## (same tilt angle as the target )




Target: length of 80 cm
(z = -40 cm to z = 40 cm),
radius of 0.80 cm,
beam angle of 65 mrad,
co-linear target and beam,
TR/BR = 4

1st beam dump rod:
length of 60 cm
(z = 40 cm to z = 100 cm),
Radius 3 x target radius,
beam angle of 65 mrad

2nd beam dump rod:
length of 60 cm
(z = 100 cm to z = 160 cm),
Radius 3 x target radius,
beam angle of 65 mrad

# Advanced 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.

# Advanced 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))

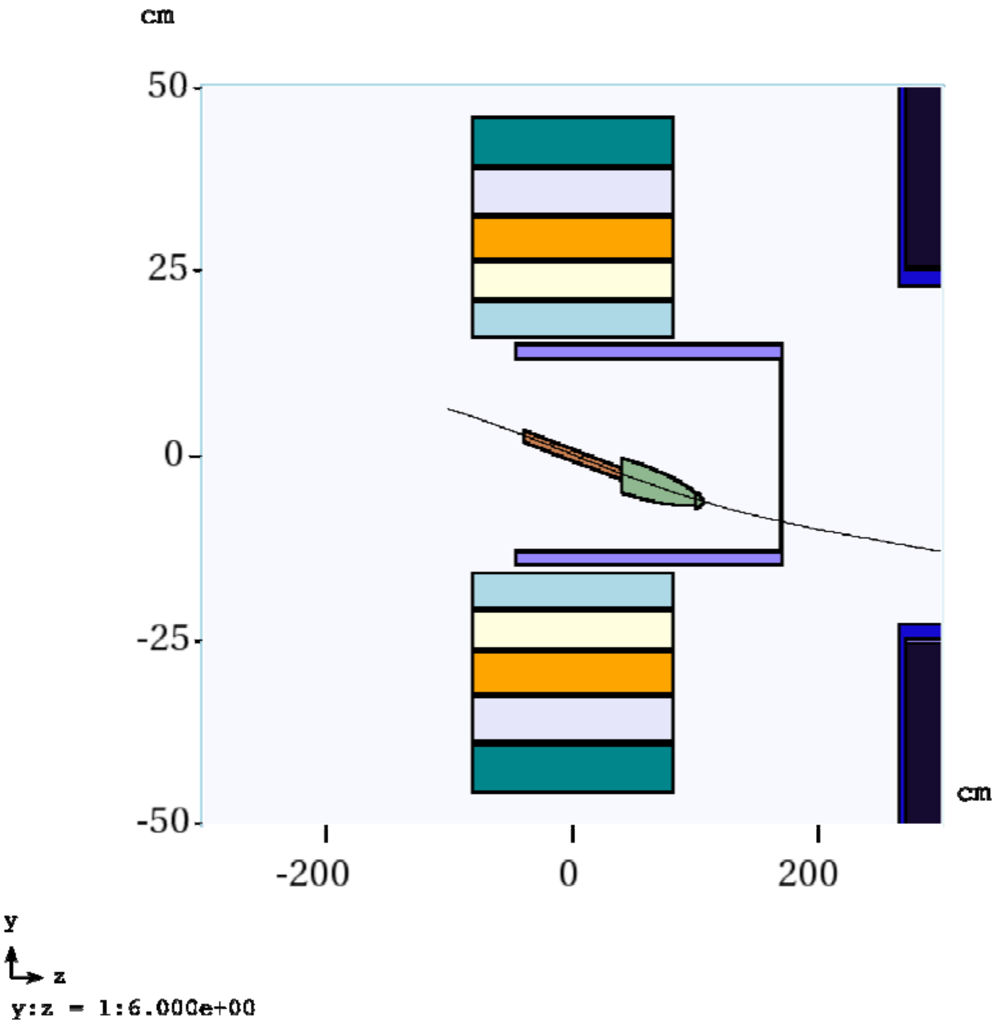
phi2 = atan2[(x^2 + z^2)/x , –y]

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

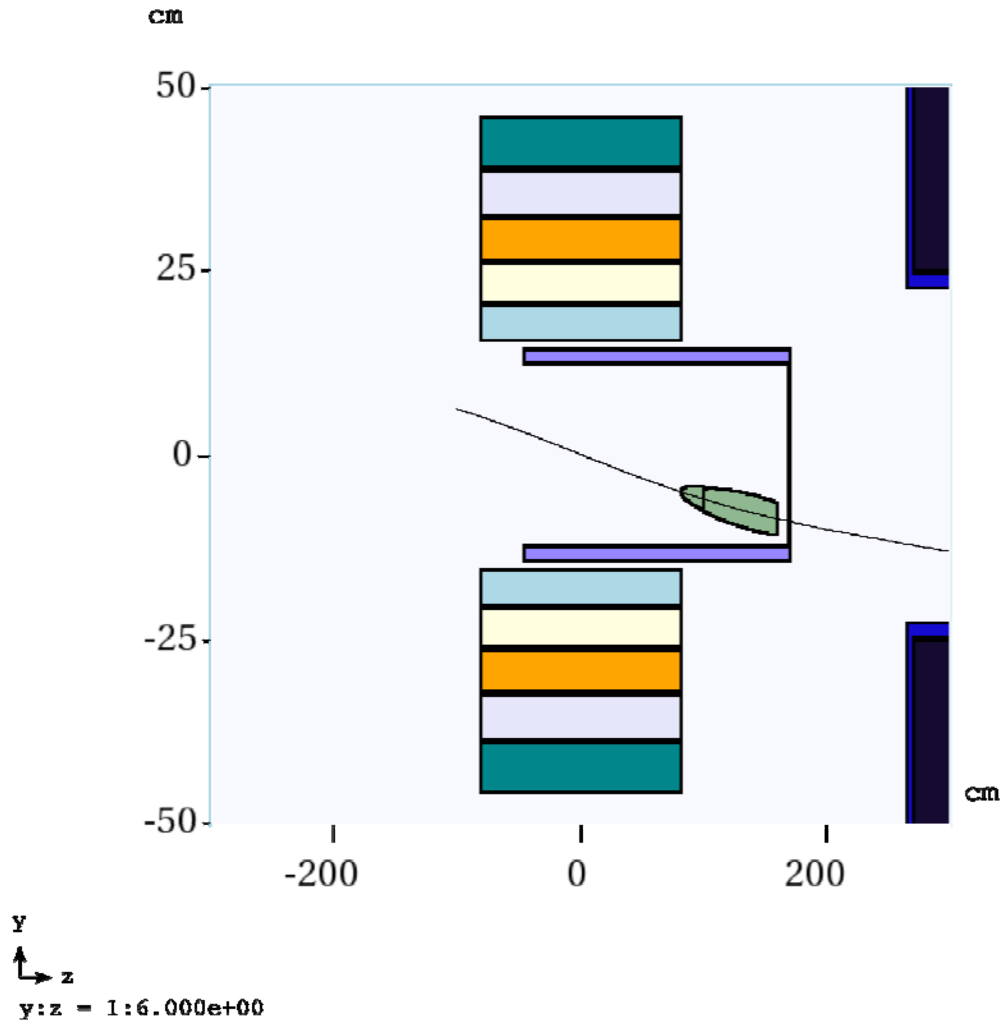
th3 = acos(z/L)

phi3 = atan2(y,x)

# Advanced Setup of Beam Dumps in ROOT



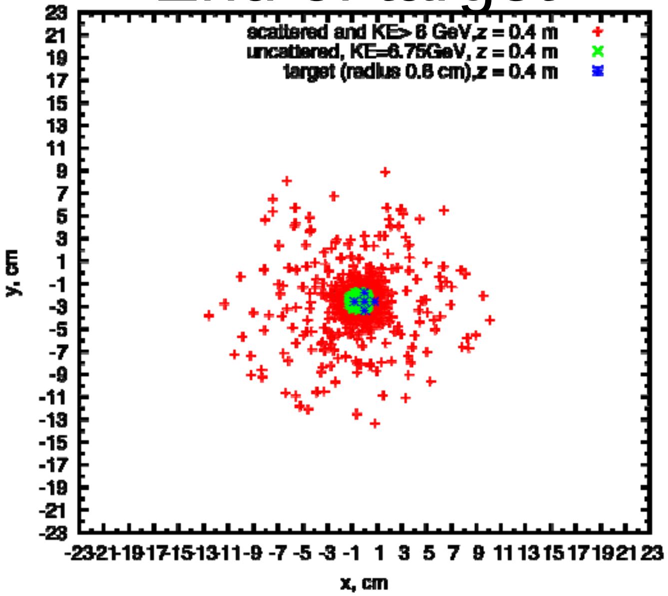

X = 0 cm



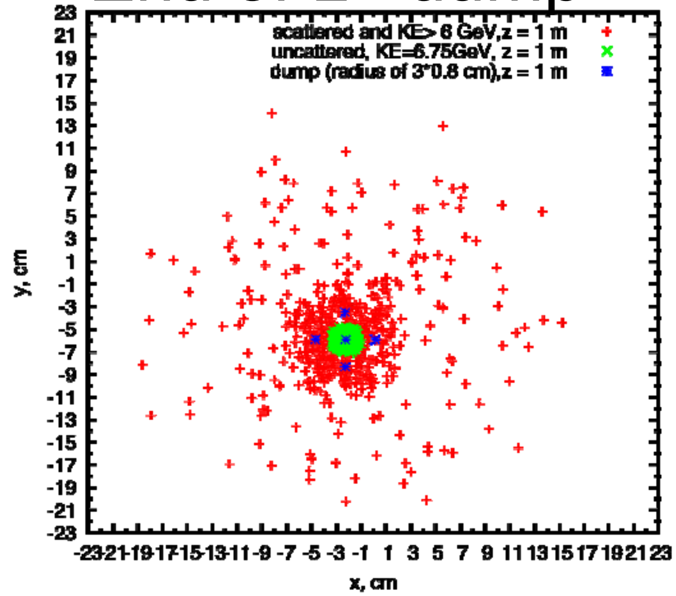

X = -4 cm

# Advanced Setup of Beam Dumps in ROOT

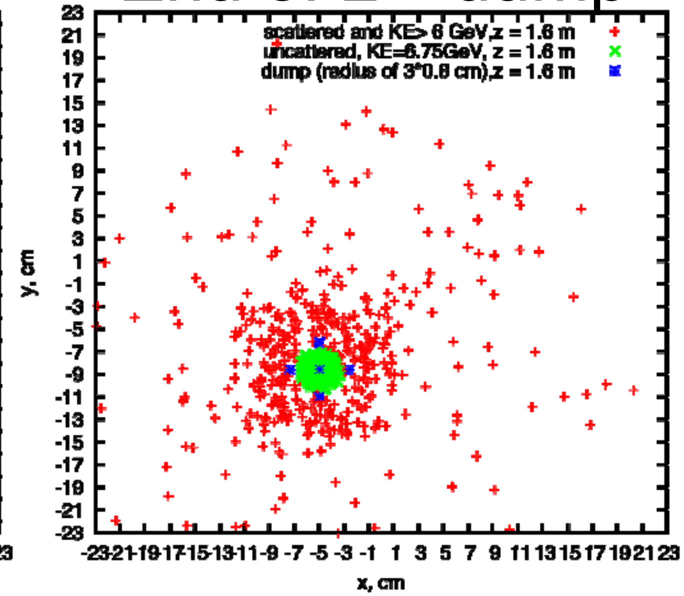
End of target




End of 1st dump




End of 2nd dump




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

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

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

# 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) [Watts] | Total KE (non-protons) [Watts] | Protons KE > 6 GeV ( × 9.26 × $10^{10}$) | Yield at z = 50 m ( × 9.26 × $10^{10}$) |
|---|---|---|---|---|---|
| Geometry Setting of Beam Dumps in MARS | | | | | |
| 0 | 0 | 88359 | 105454 | 301 | 1240.7 |
| 120 | 3 | 66430 | 94936 | 130 | 1134.6 |
| Advanced ROOT-based Geometry Setting for Beam Dumps | | | | | |
| 0 | 0 | 84479 | 98313 | 283 | 1211 |
| 120 | 3 | 64199 | 84966 | 116 | 1061 |
| Simple ROOT-based Target Geometry Setting for Beam Dumps (same tilt as the target) | | | | | |
| 120 | 3 | 63415 | 85514 | 136 | 1096 |

# Summary

- Target System: 1 MW, 6.75 GeV (KE) proton beam,
  the 20 T field on target drops to the ~2 T field in the rest of the Front End over ~ 5 m) and graphite target.
- Optima for graphite target (tilt beam):
  length = 80 cm, radius = 8 mm (with 2 mm rms beam radius), tilt angle = 65 mrad.
- Successfully designing the target system and complicated beam dumps with ROOT-based geometry.
- For 6.75 GeV (KE) beam, about 13% higher production by tilting the carbon target/proton beam.

# 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.
- Particle distributions were generated at z = 2m for Front End studies.