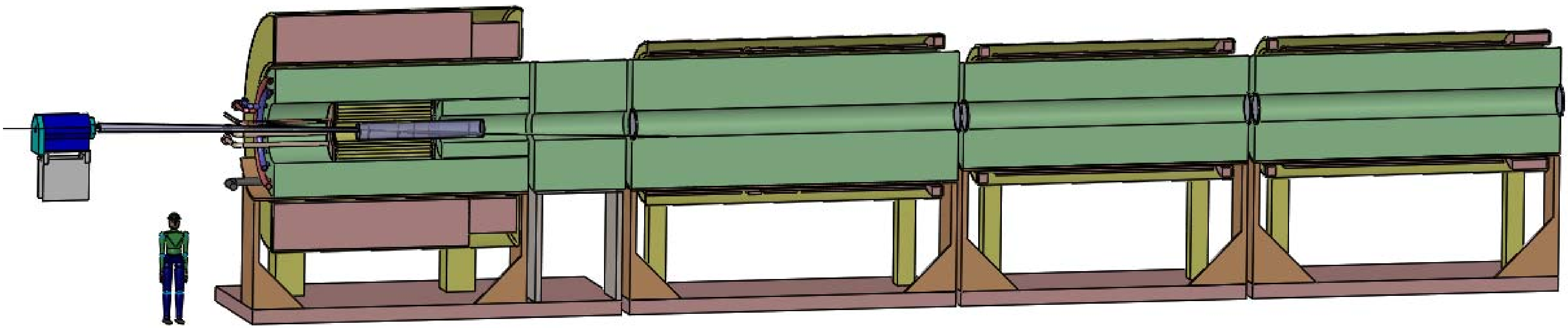
Target System Concept for a Muon Collider/Neutrino Factory



K.T. McDonald

Princeton University

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Specifications from the Muon Accelerator Staging Scenario

- 6.75 GeV (kinetic energy) proton beam with 3 ns (rms) pulse.

- 1 MW initial beam power, upgradable to 2 MW (perhaps even to 4 MW).

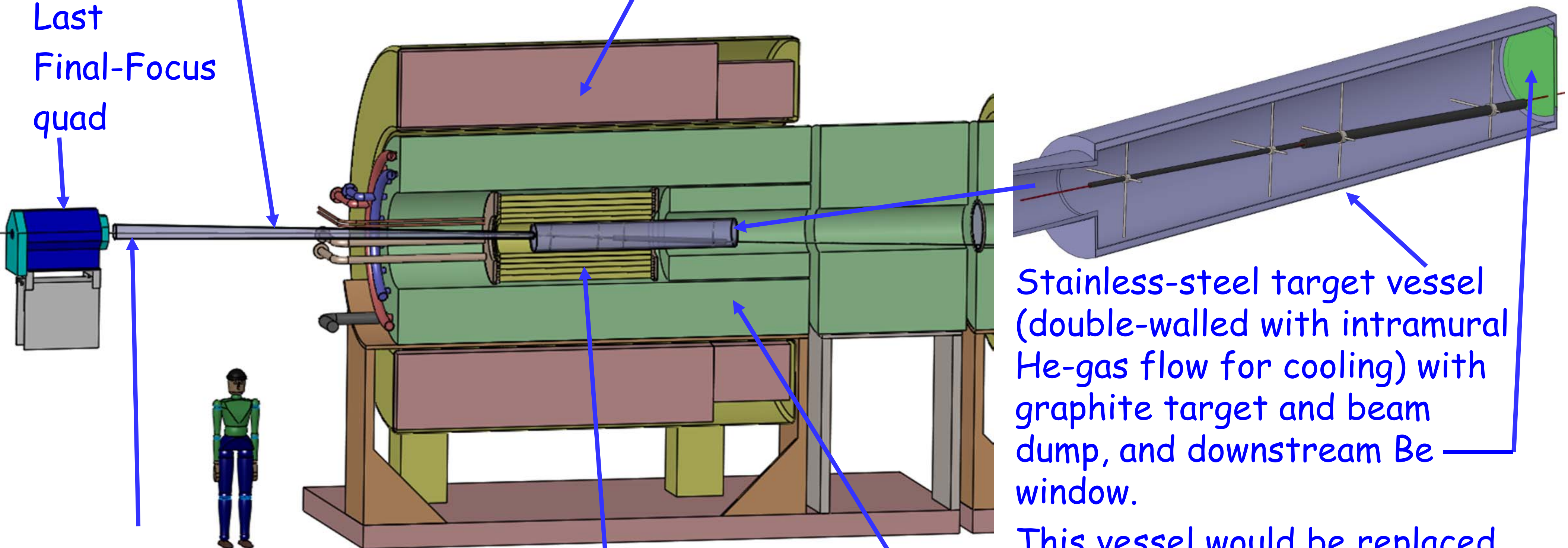
- 60 Hz initial rep rate for Neutrino Factory;
  15 Hz rep rate for later Muon Collider.

- The goal is to deliver a maximum number of soft muons,
  ~ 40 < KE < ~ 180 MeV.

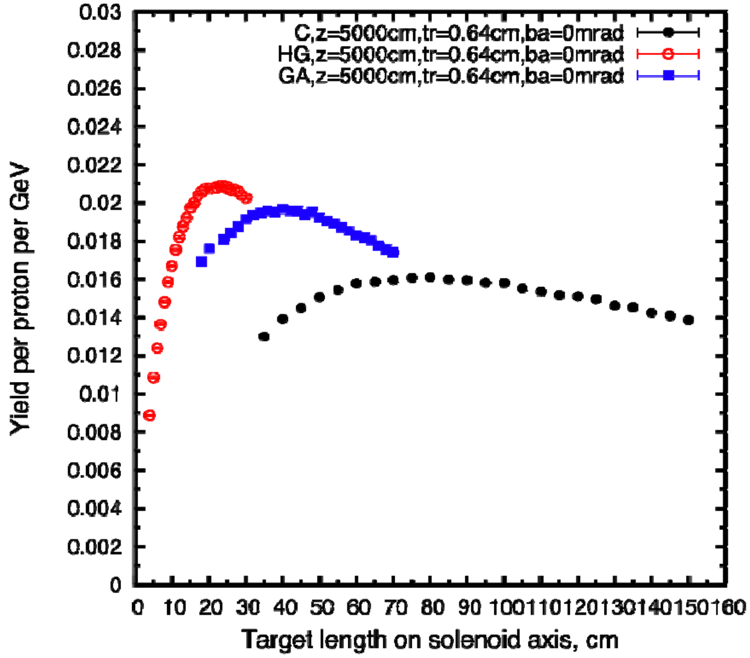
Target System Concept

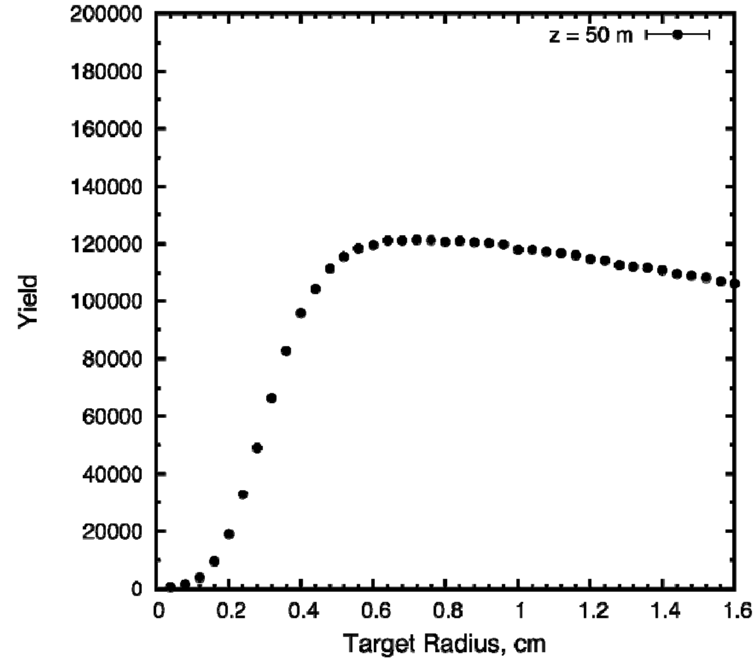
- Graphite target ($\rho \sim 1.8$ g/cm^3), radiation cooled (with option for convection cooling); liquid metal jet as option for 2-4 MW beam power.
- Target inside high-field solenoid magnet (20 T) that collects both $\mu^{\pm}$.
- Target and proton beam tilted with respect to magnetic axis.
- Superconducting magnet coils shielded by He-gas-cooled W beads.
- Proton beam dump via a graphite rod just downstream of the target.
- Some of the proton and π/μ transport near the target is in air.

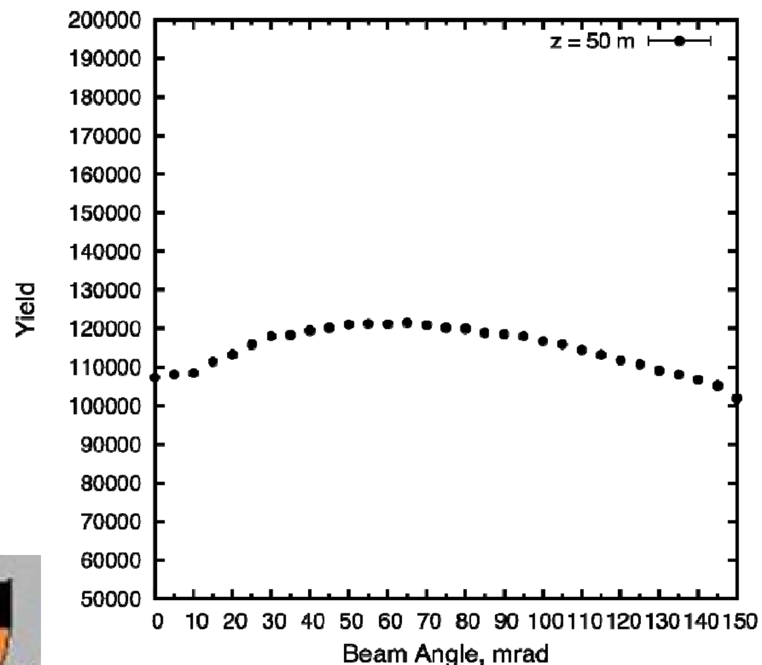
Target System Concept

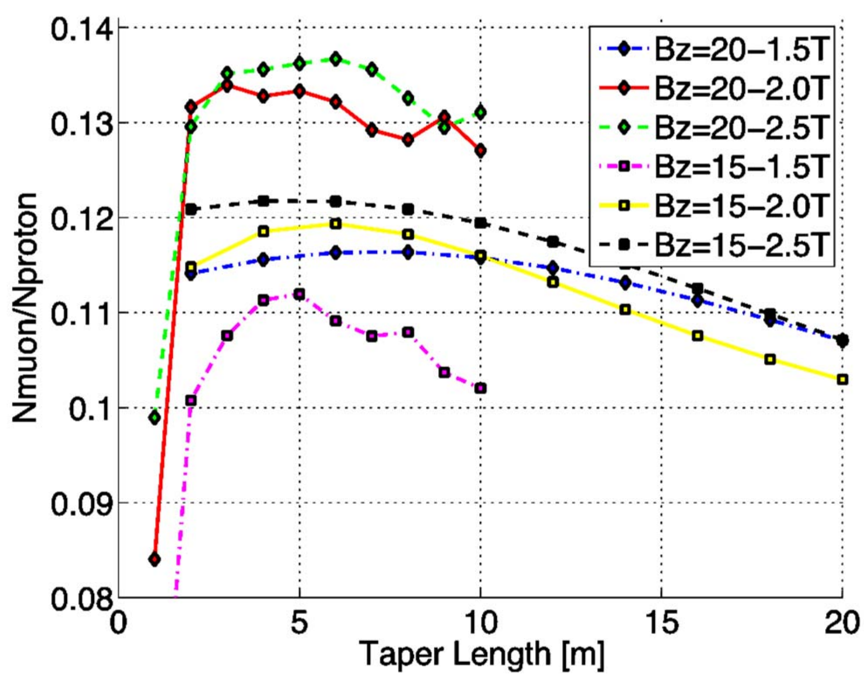


Target System Optimization









Target System Optimizations

- High-Z favored.

- Optima for graphite target: length = 80 cm,
  radius ~ 8 mm (with σ_r = 2 mm (rms) beam radius),
  tilt angle = 65 mrad,
  nominal geometric rms emittance $\varepsilon_\perp = 5\ \mu$m.
  $\beta^* = \sigma_r^2 / \varepsilon_\perp = 0.8$ m.

- Graphite proton beam dump, 120 cm long, 24 mm radius to intercept most of the (diverging) unscattered proton beam.

- The 20 T field on target should drop to the ~ 2 T field in the rest of the Front End over ~ 5 m.

Issues for Further Study

- Thermal "shock" of the short proton pulse
  Probably OK for 2 MW and 60 Hz operation;
  15-Hz option needs study.

- Cooling of target, and the W beads.

- Lifetime of target against radiation damage.

- Beam windows.

- β^* and beam emittance at the target.

- To preserve liquid-metal-jet upgrade option, need related infrastructure installed at $t = 0$.

Thermal Issues for Solid Targets

When beam pulse length t is less than target radius r divided by speed of sound v_{sound}, beam-induced pressure waves (thermal shock) are a major issue.

Simple model: if U = beam energy deposition in, say, Joules/g, then the instantaneous temperature rise ΔT is given by $\Delta T = U / C$, where C = heat\ capacity in Joules/g/K.

The temperature rise leads to a strain $\Delta r / r$ given by $\Delta r/r = \alpha\, \Delta T = \alpha\, U / C$,
where α = thermal expansion coefficient.

The strain leads to a stress P (= force/area) given by $P = E\, \Delta r/r = E\, \alpha\, U / C$,
where E = modulus of elasticity.

In many metals, the tensile strength obeys $P \approx 0.002\, E$, $\alpha \approx 10^{-5}$, and $C \approx 0.3$ J/g/K,
in which case $U_{max} \approx P\, C / E\, \alpha \approx 0.002 \cdot 0.3 / 10^{-5} \approx 60$ J/g.

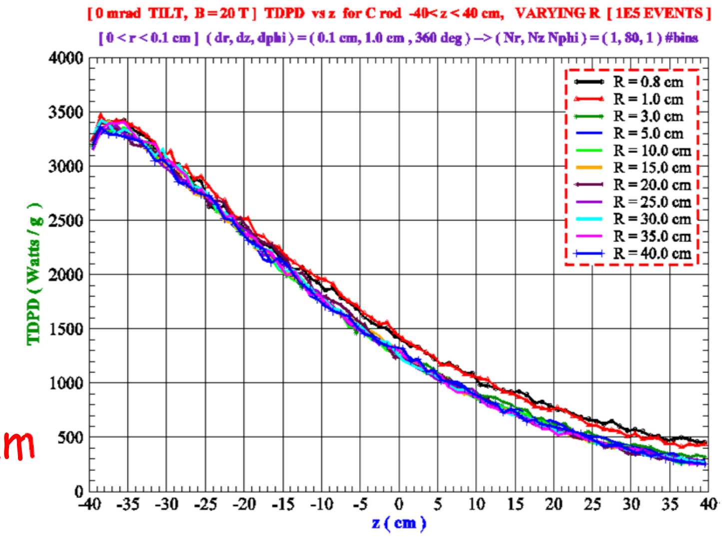
Graphite @ 1400° C: P = 42.4 Mpa, E = 7.2 Gpa, $\alpha = 4.8 \times 10^{-5}$, C = 1.4 J/g, $U_{max} \approx 1700$ J/g.
($\alpha \approx 1 \times 10^{-5}$ for carbon-carbon composite)

[A nickel target at FNAL has operated with $U_{max} \approx 1500$ J/g.]

These arguments are from *A Short Course on Targetry*, KTM, NuFact03 Summer Institute

How Much Beam Power Can a Solid Target Stand?

What is the maximum beam power this material can withstand without cracking, for a 6.75-GeV beam at 15 Hz with area 0.1 cm^2?



Ans: MARS15 indicates that the peak energy deposition in a "pencil" target is essentially just that of dE/dx,
$\Rightarrow$ 1.5 MeV/(g/cm^2) for graphite.

Now, 1.5 MeV = $2.4 \cdot 10^{-13}$ J, so 1500 J/g requires a proton beam intensity of (1500 J/g)/($2.4 \cdot 10^{-13}$ J·cm^2/g) $\approx 6 \cdot 10^{15}/cm^2$.

$\Rightarrow P_{max} \approx 15\ \text{Hz} \cdot 6.75 \cdot 10^9\ \text{eV} \cdot (1.6 \cdot 10^{-19}\ \text{J/eV}) \cdot (6 \cdot 10^{15}\ /\text{cm}^2) \cdot 0.1\ \text{cm}^2 \approx 1 \cdot 10^7\ \text{J/s} = 10\ \text{MW}.$

If graphite cracks under singles pulses of > 1500 J/g, then safe up to 10 MW beam power @ 15 Hz.