# A MW Class Target System for Muon Beam Production

## AAC 2014

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BROOKHAVEN NATIONAL LABORATORY

Harold G. Kirk
Brookhaven National Laboratory

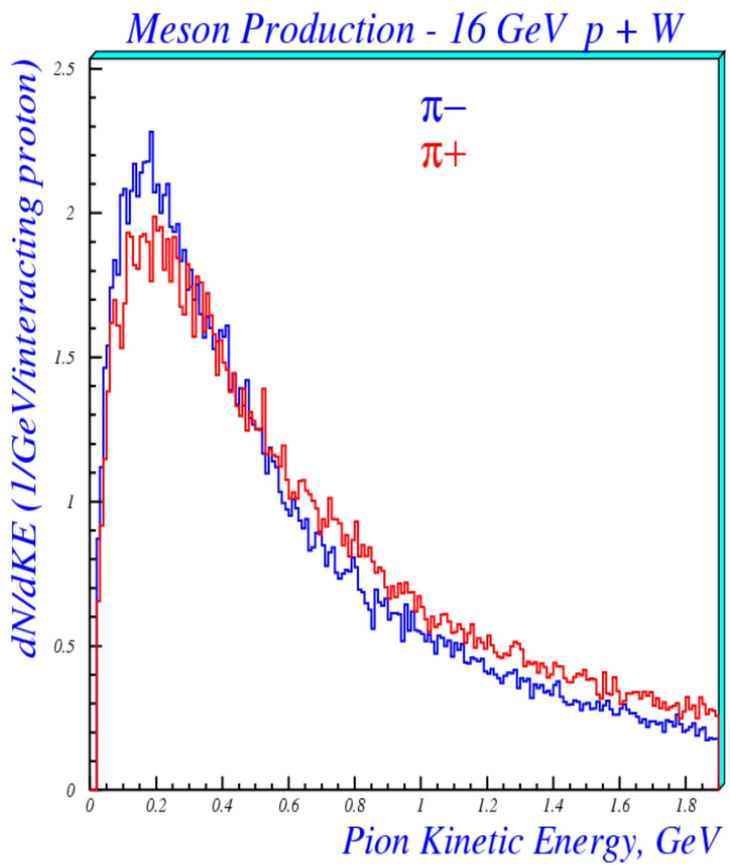
# High-power Targetry Challenges

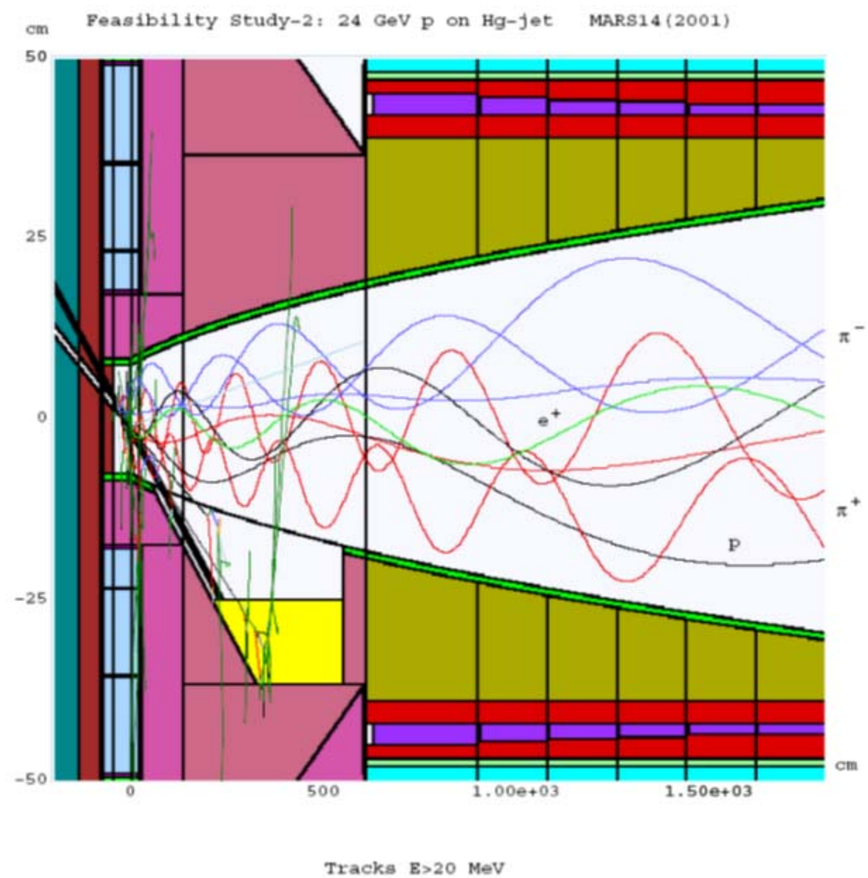
## High-average power and high-peak power issues

- Thermal management
  - Target melting
  - Target vaporization
- Radiation
  - Radiation protection
  - Radioactivity inventory
  - Remote handling
- Thermal shock
  - Beam-induced pressure waves
- Material properties

# PRODUCTION OF INTENSE MUON BEAMS

**Muon beams produced as tertiary beams: p → π → μ**



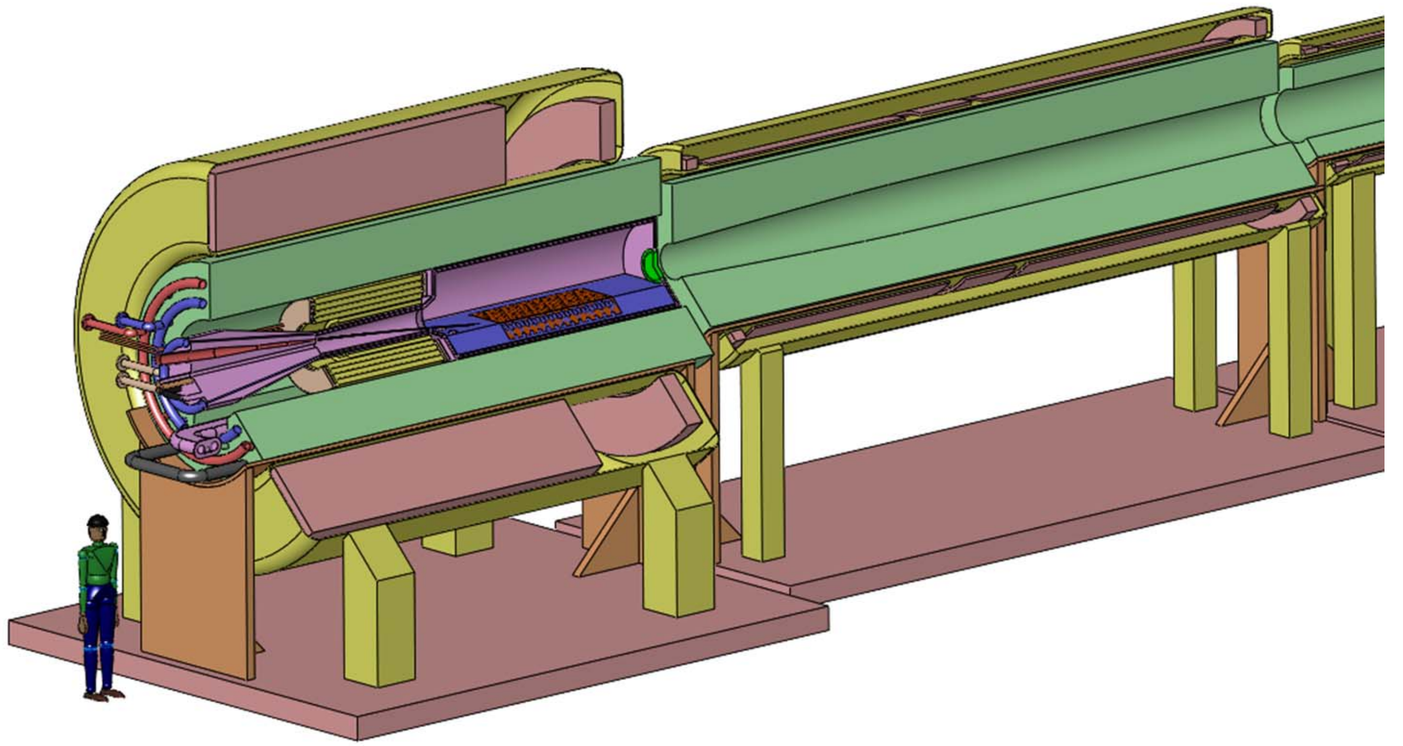



# The Capture Solenoid

A Neutrino Factory and/or Muon Collider Facility requires challenging magnet design in several areas:

- Target Capture SC Solenoid (15T with large aperture)
- Stored Energy ~ 3 GJ
- 10MW, 5T resistive coil in high radiation environment

Possible application for High Temperature Superconducting magnet technology



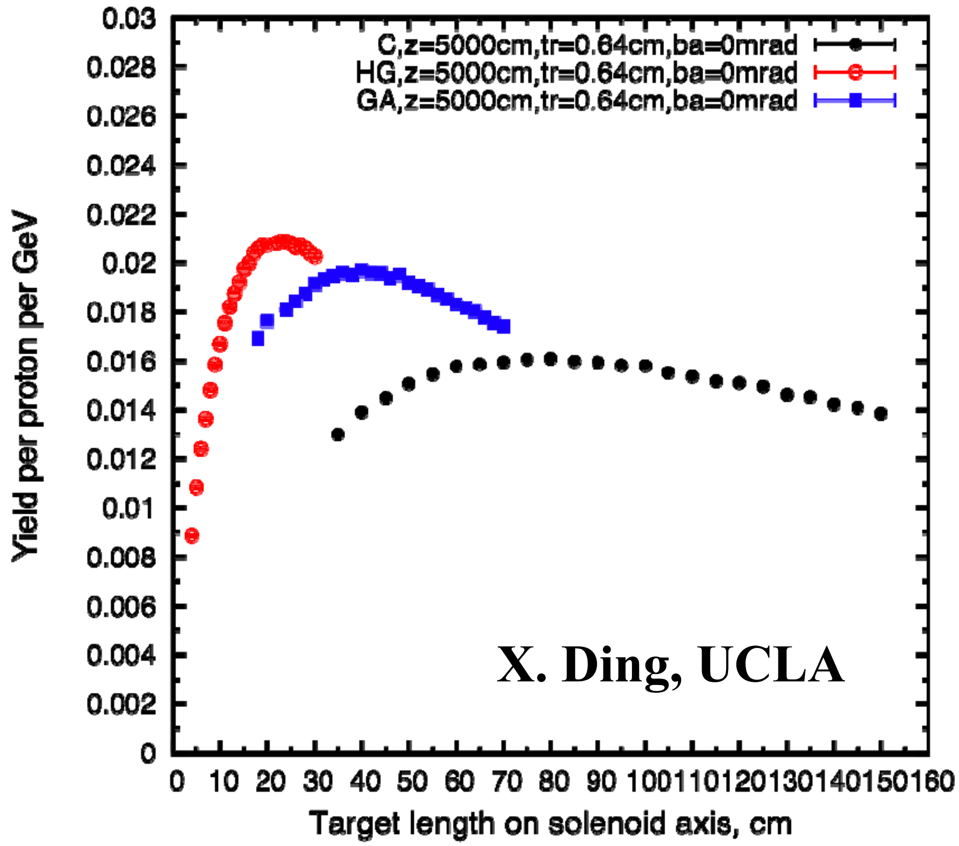
# Choice of Target Materials

**We consider proton beam powers of 1- ,2- and 4-MW**

**Solid and liquid targets considered:**

- **High-Z, eg. W, Hg, PbBi**
- **Mid-Z, eg. Ga, Cu, Ni**
- **Low-Z, eg.  Be,C**

# Choice of Target Materials II




- **High Z (e.g. Hg)**
- **Mid Z (e.g. Ga)**
- **Low Z (e.g. Carbon)**

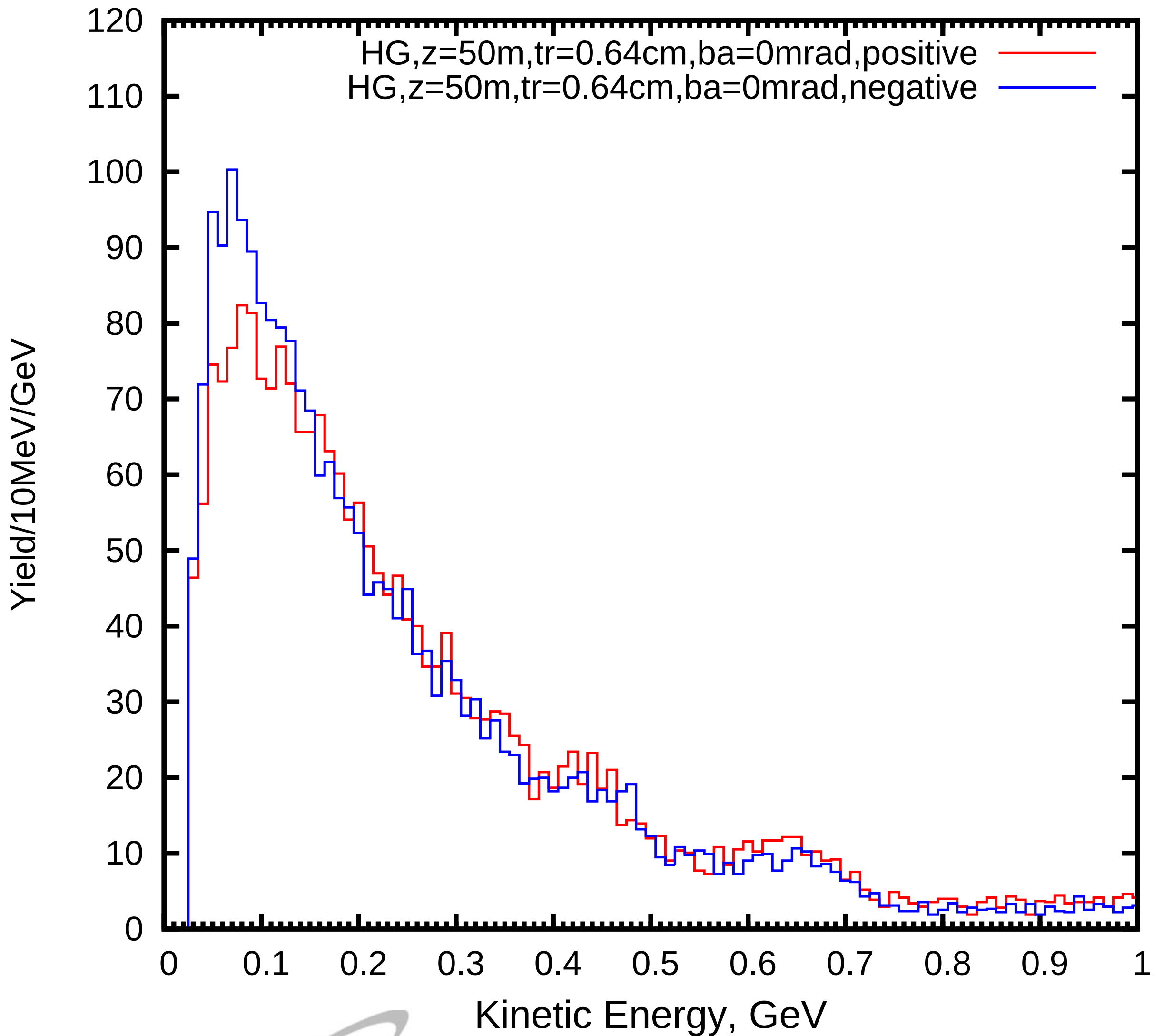
**A 25% advantage of using high-Z Hg compared to low-Z Carbon**

**Low-z Carbon is attractive due to it's simplicity and robustness**

**Proton Beam: KE = 6.75 GeV**

**Normalization: For Hg $\Sigma(\mu^+ + \mu^-)$/proton ≈ 30%**

# Captured Muon Spectra



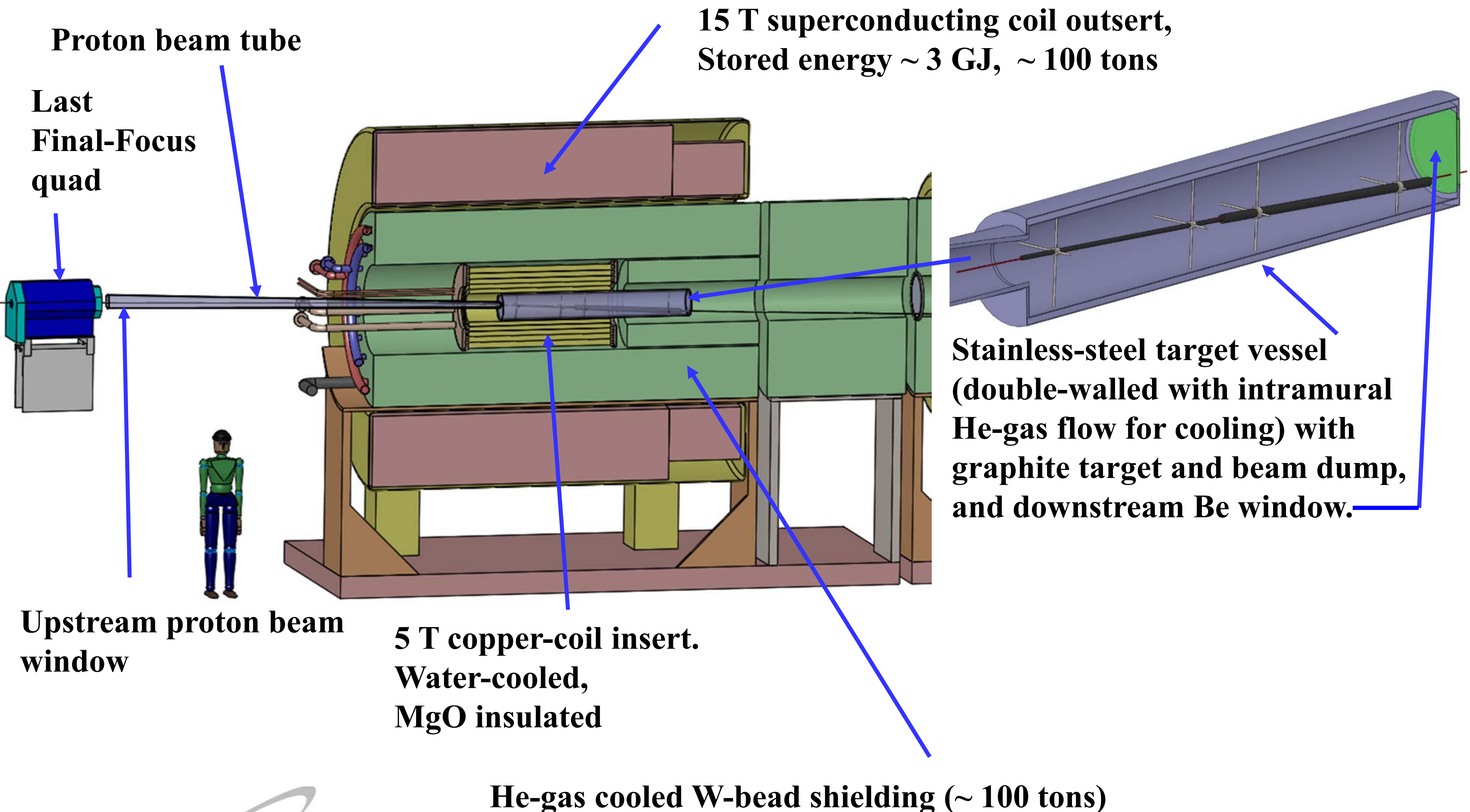

**For p + Hg**
**Total Captured Muons per incoming protons**

**$\mu^+/p = 14.6\%$**

**$\mu^-/p = 14.8\%$**

**For 6.75GeV protons**
**1MW ➔ $10^{15}$ protons**

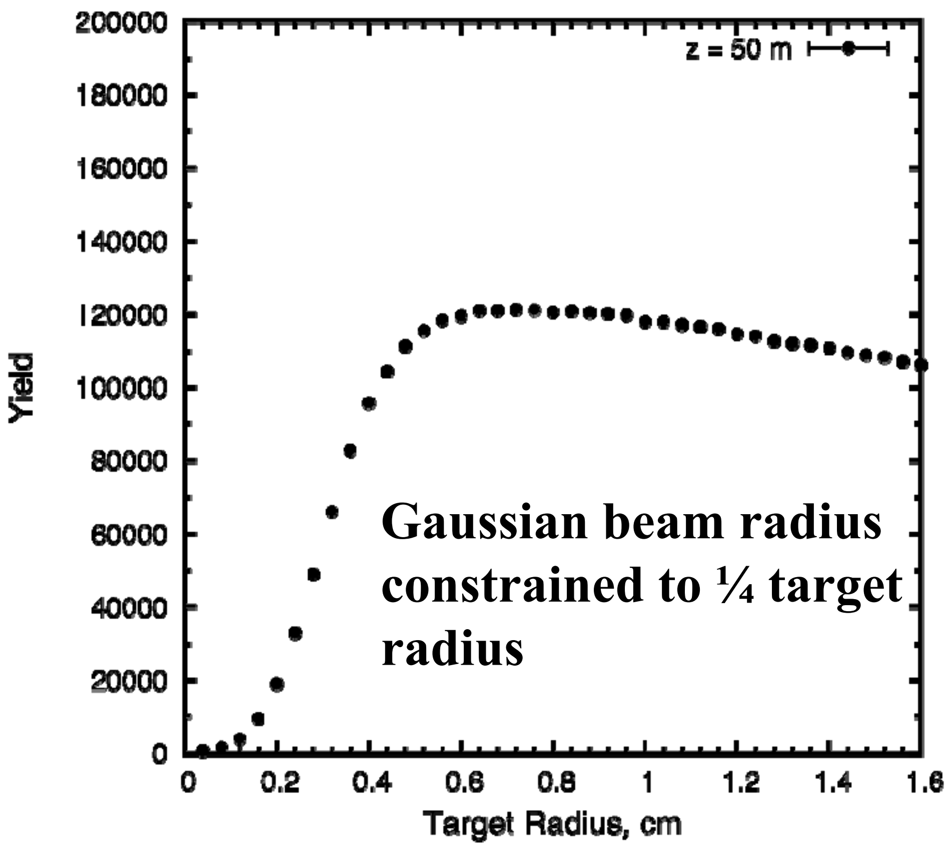
# A Graphite Target Core



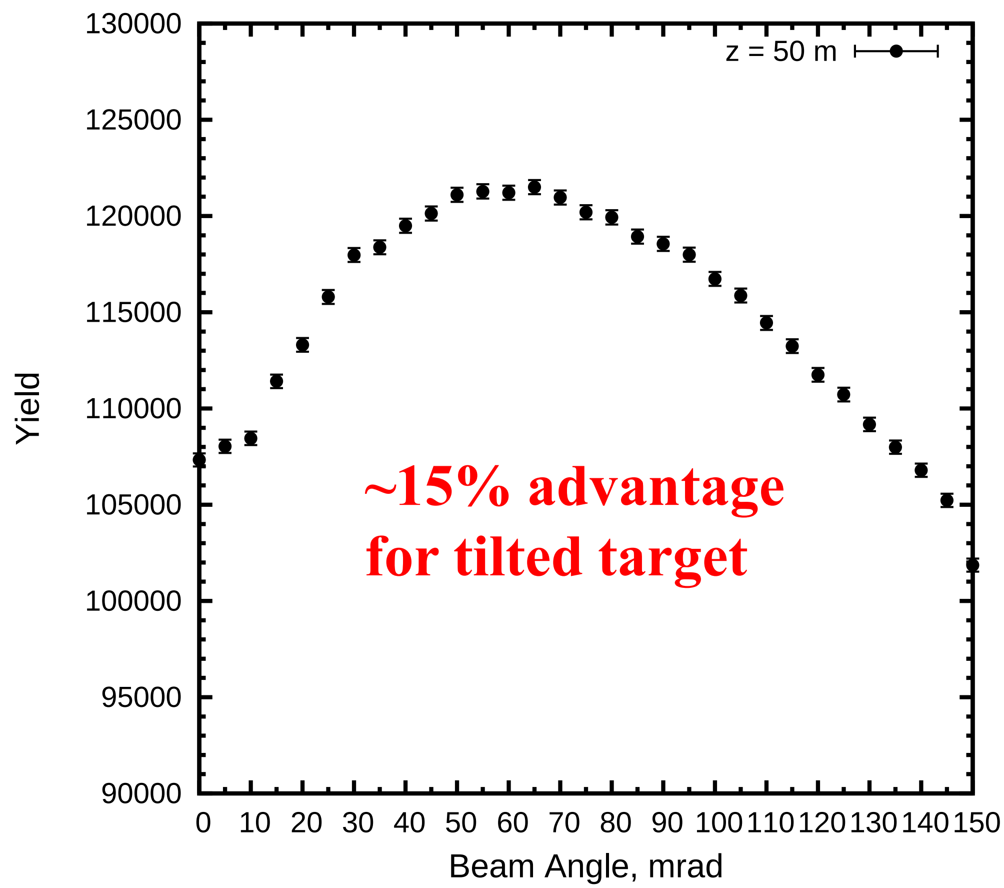
# Optimization of Carbon Target Dimensions

**X. Ding, UCLA**

**Target Radius**
**6cm < R < 12cm**



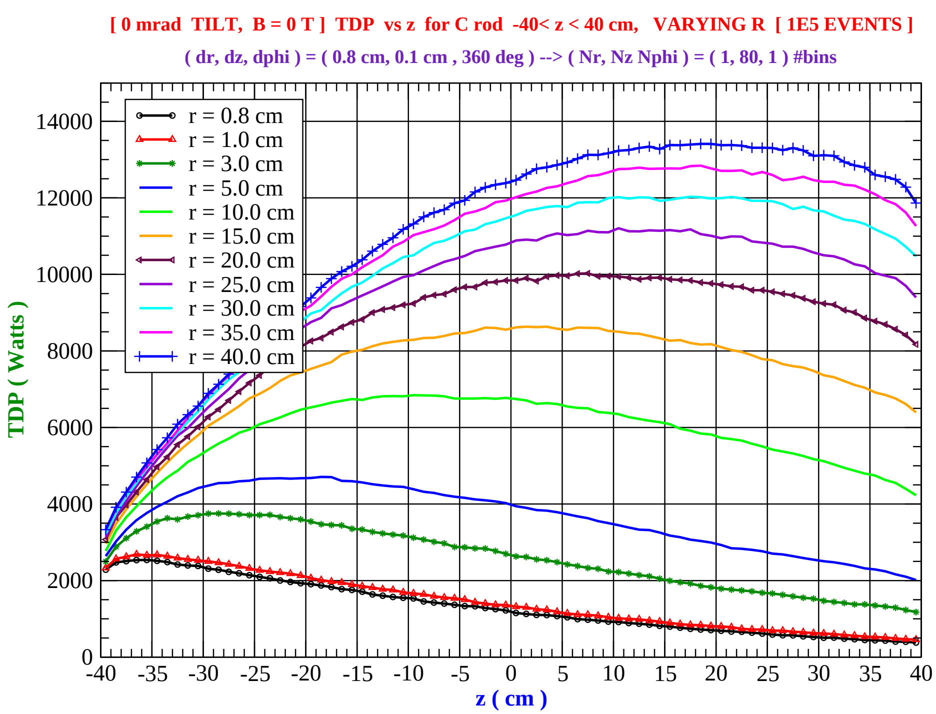

**Target/Solenoid Axis Angle**
**50 mrad < θ < 80 mrad**



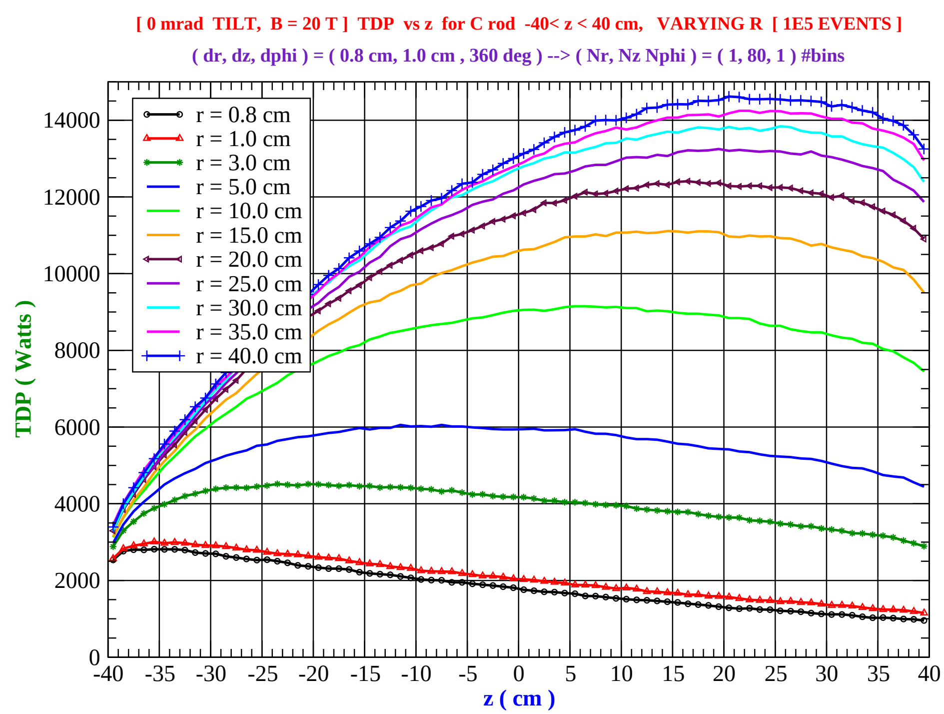
# Energy Deposition in a Graphite Targets

**Graphite targets of various radii (0.8 to 40cm). Proton beam has an rms radius of 2mm at the center of the target and β* = 80 cm.** . **N.Souchlas, PBL**

**B = 0 T**



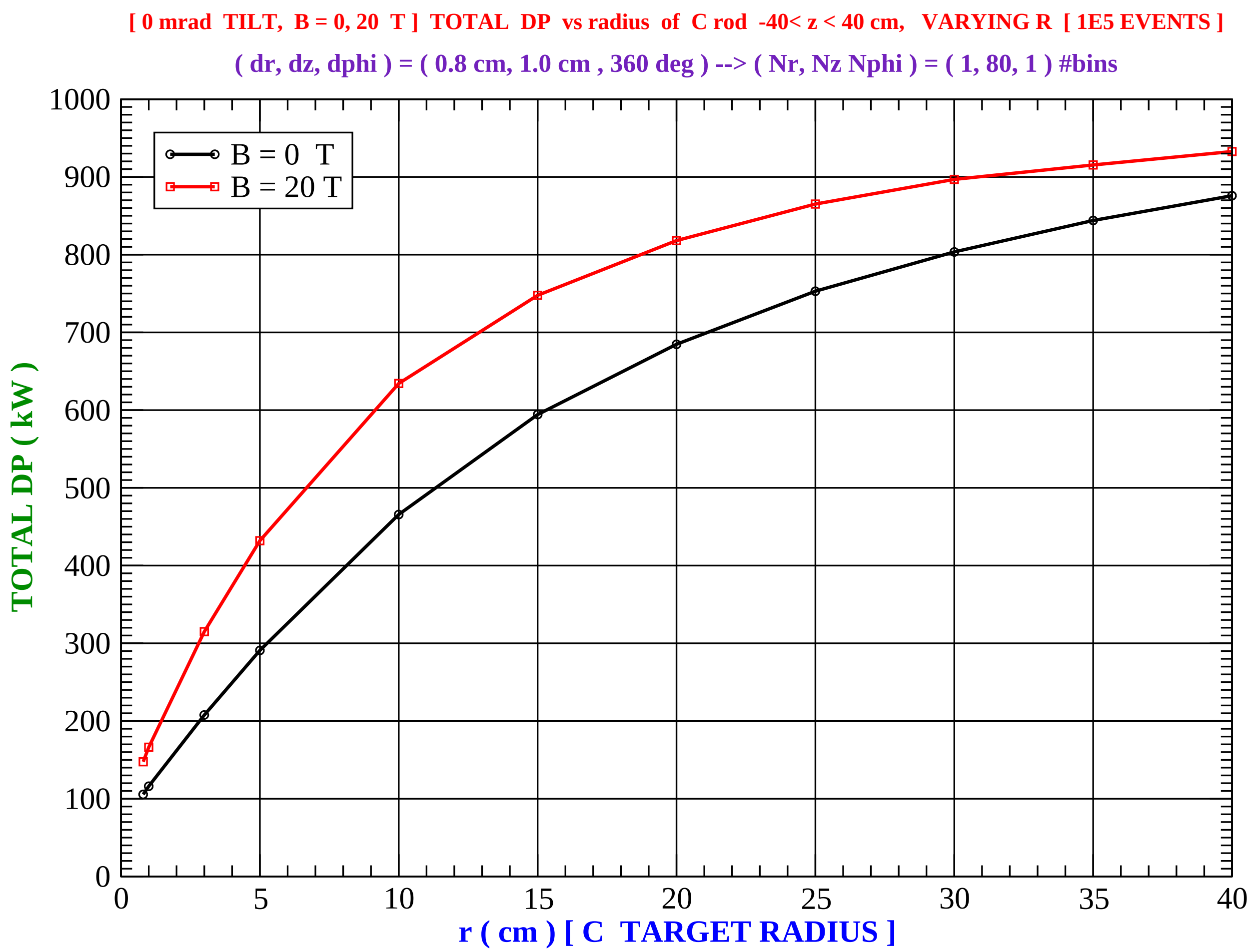

**B = 20 T**




**Largest power deposition for R=8mm case is 4 cm into target, but at ~60cm in targets with large radii...**

# Total power absorbed in the target

## The steady state power increases with magnetic field

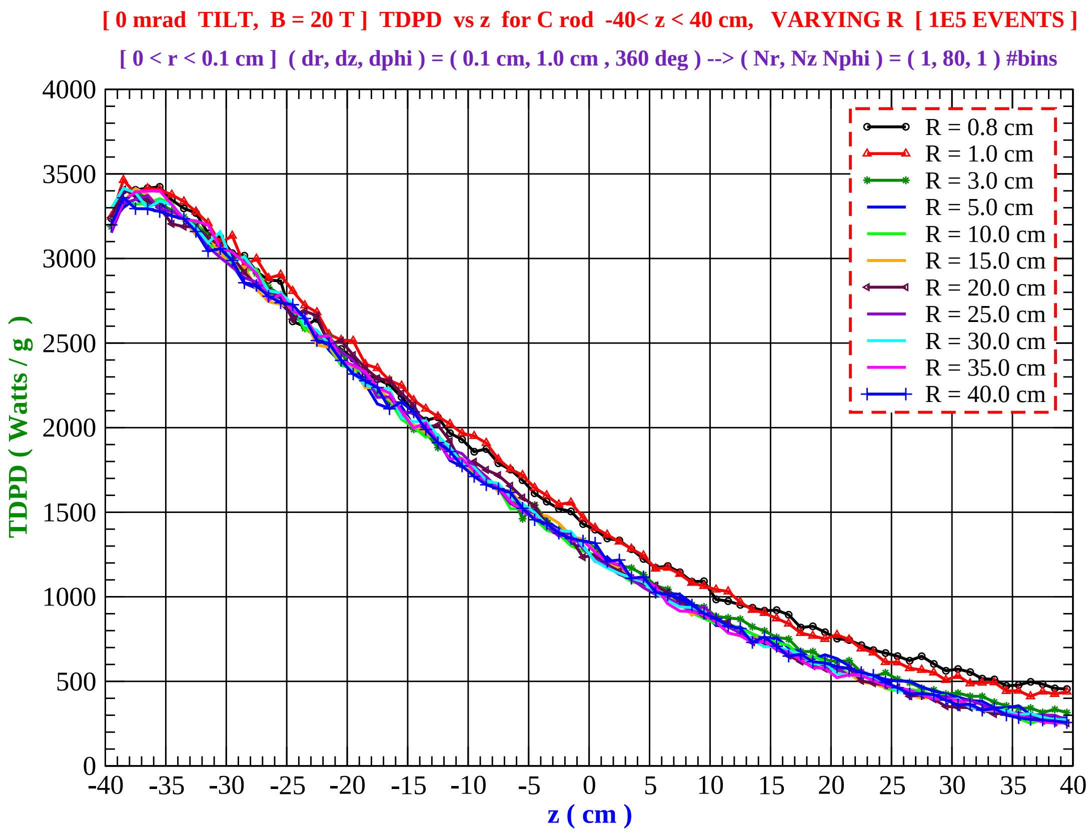



**For R=8mm total power is <u>150kW for 4MW</u> protn beam**

# Peak Energy Deposition

N. Souchlas, PBL

**80cm graphite target with various radii**




**Simulations for a 1.8g/cm$^3$ graphite rget**

**eak energy deposition occurs 3 to cm into the target.**

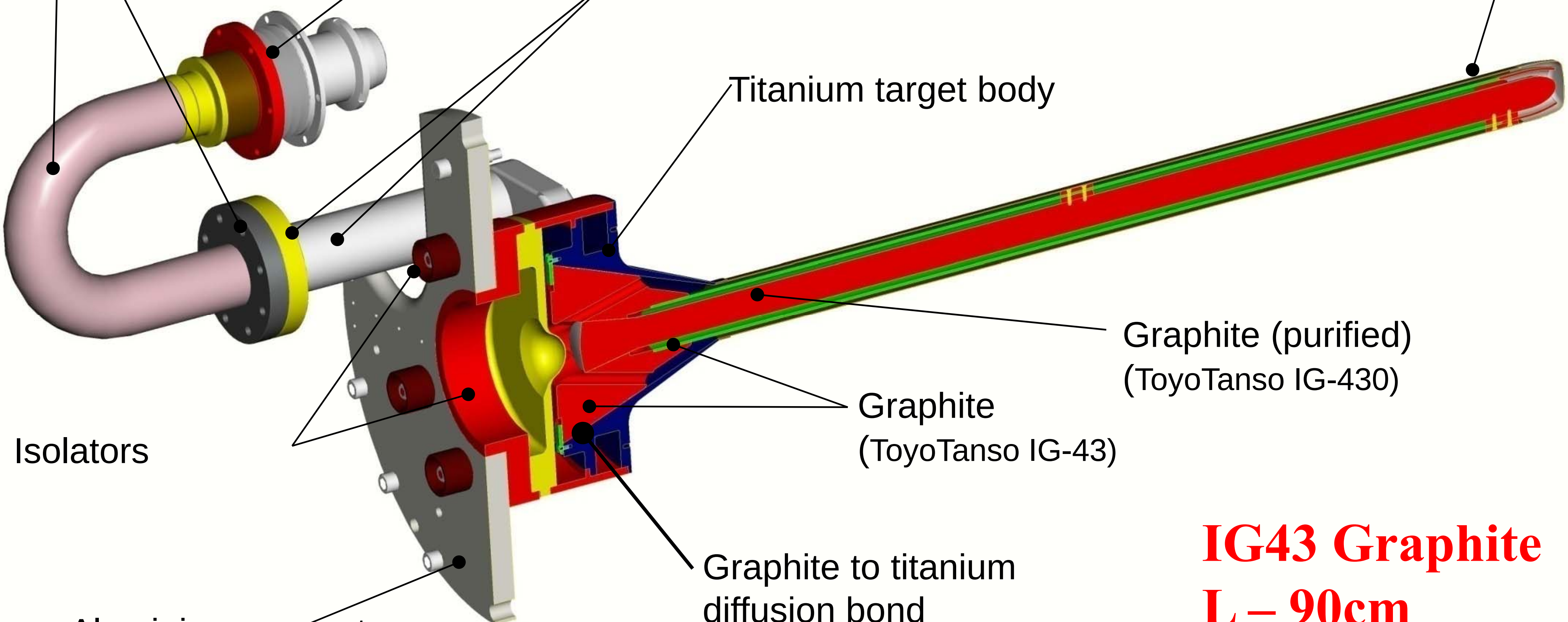
**eak energy deposition is 3600J/g r a 4-MW, 6.75 GeV proton beam**

# Energy Deposition on Carbon Target

| Beam Power | Rep Rate | Peak ED | Steady State ED |
|---|---|---|---|
| MW | Hz | J/g | kWatts |
| 1 | 60 | 15 | 38 |
| | 15 | 60 | 38 |
| | | | |
| 2 | 60 | 30 | 75 |
| | 15 | 120 | 75 |
| | | | |
| 4 | 60 | 60 | 150 |
| | 15 | 240 | 150 |

**Figure of Merit: T2K Graphite Target Peak ED Design Limit is 200 J/g**

# The T2K Target Design




**IG43 Graphite**
**L – 90cm**
**R=13mm**

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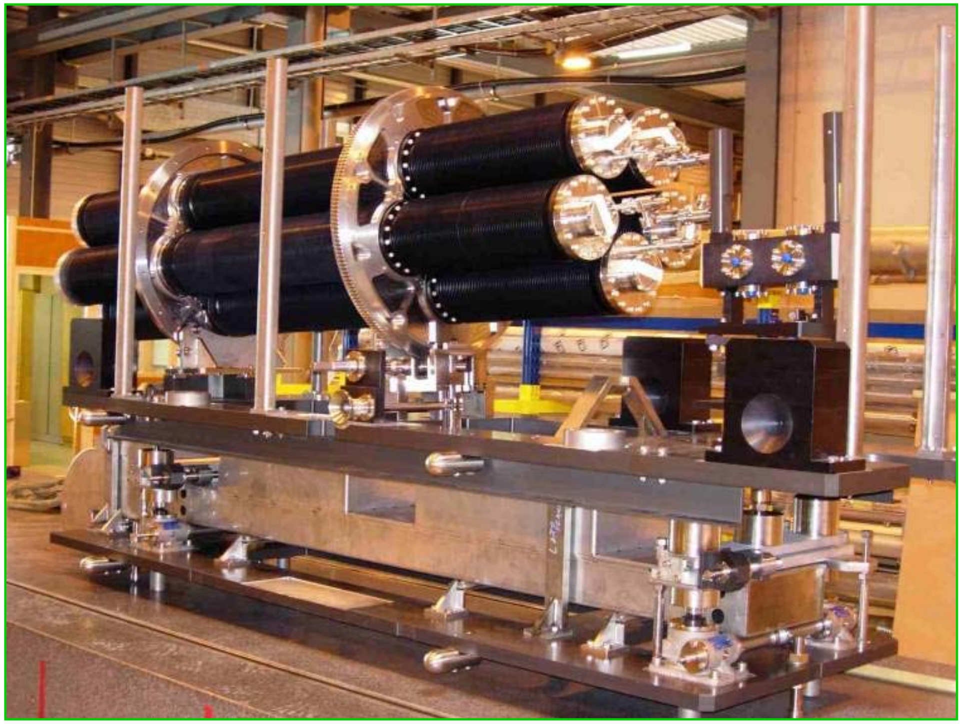
# The CERN CNGS Target



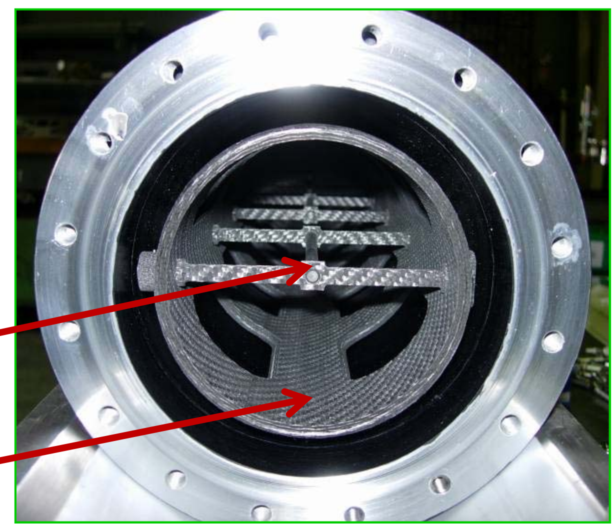
13 graphite rods, each 10cm long,

Ø = 5mm and/or 4mm

2.7 interaction lengths

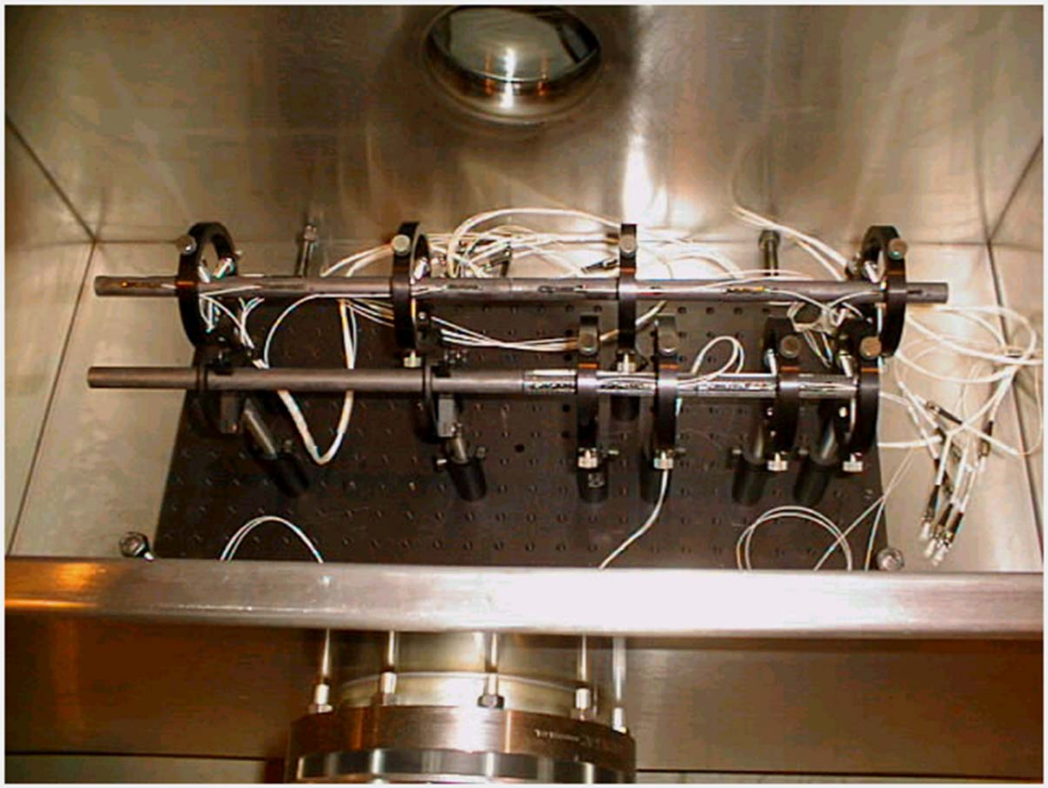
Target magazine holds 1 target plus

4 spares

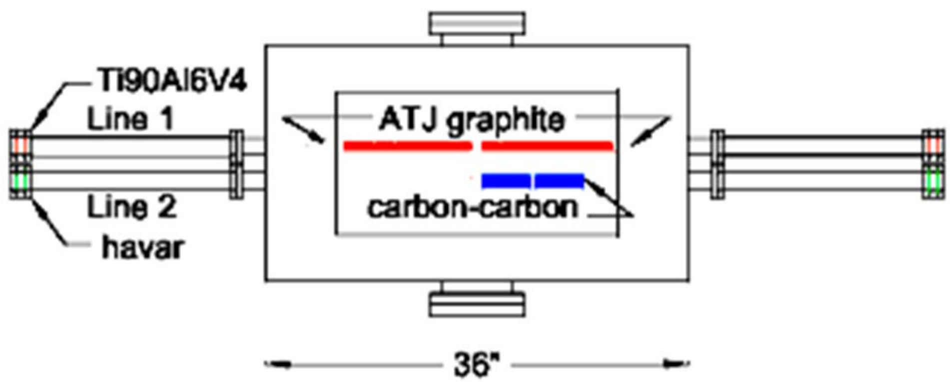
Graphite Core
Carbon-Carbon Support

# AGS E951: Graphite & Carbon-Carbon Targets



Key Material Properties

| | ATJ | CC X/U |
|---|---|---|
| Y, GPa | 10 | 54/5.3 |
| $\alpha_T$ , $10^{-6}/^0K$ | 2.5 | ~0 |
| Tensile Strength, MPa | 15 | 182/44 |

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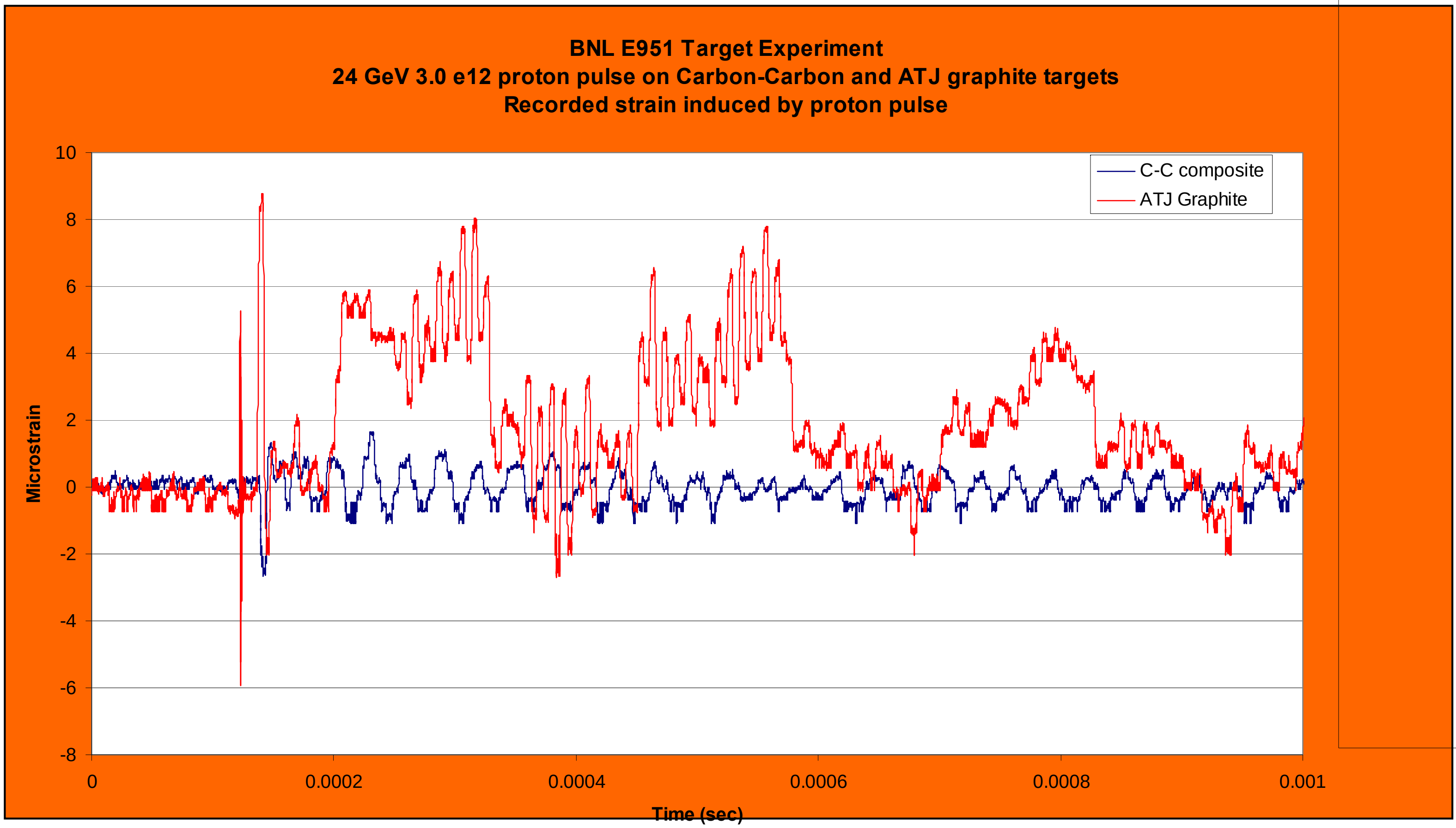
# AGS E951: Strain Gauge Measurements

## 24 GeV, 3 x $10^{12}$ protons/pulse



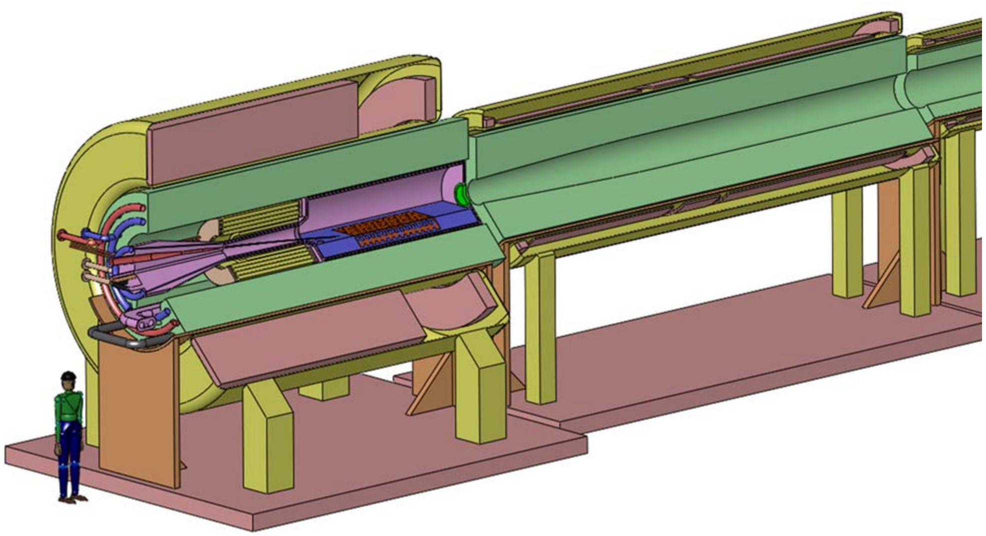
# Consider High-Z Targets

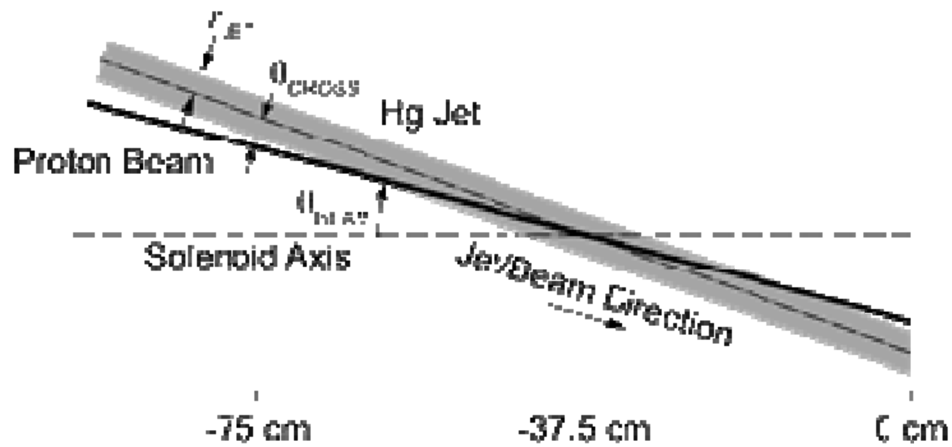
**Advantages:**

- 30% enhanced π/μ production
- If liquid then free jet mitigates shock damage

**Disadvantages:**

- Enhanced energy deposition ➔ liquid targets
- Enhanced radionuclide inventory

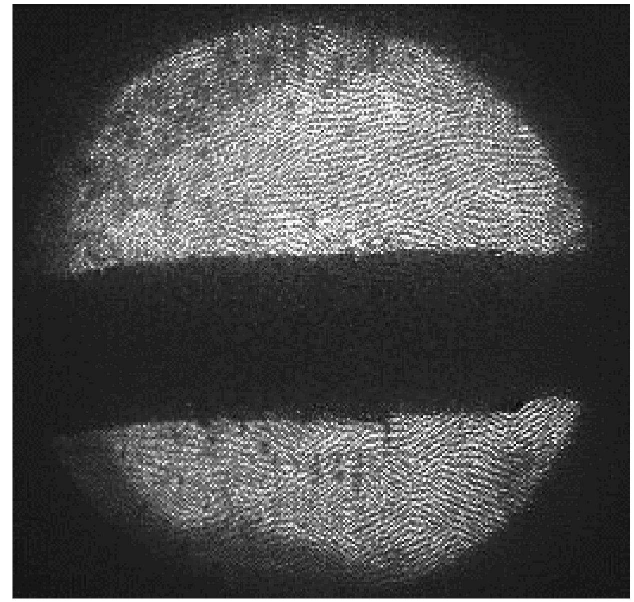


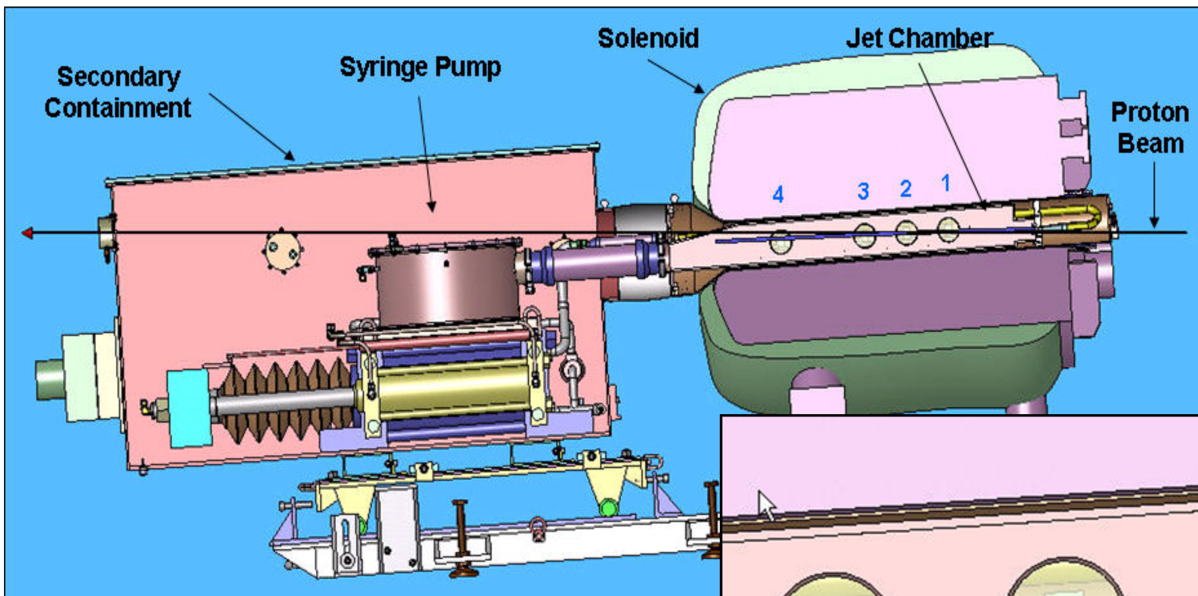


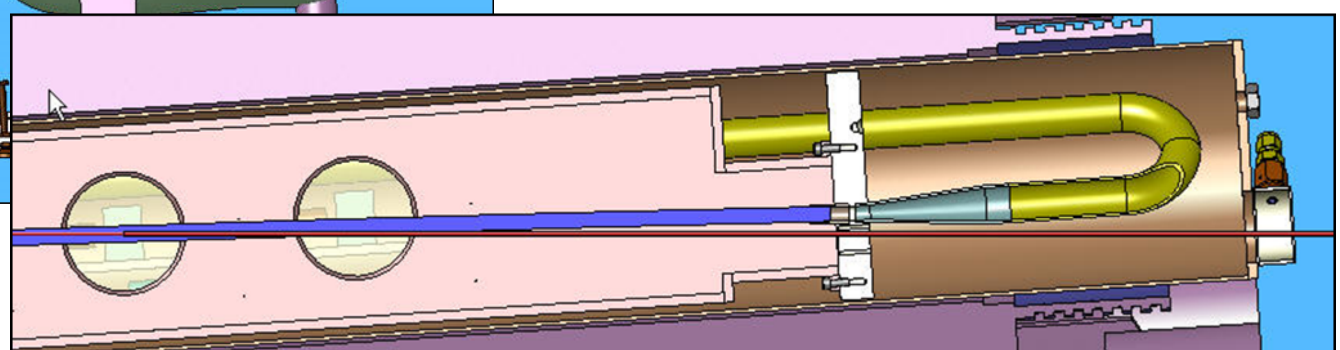
# The MERIT Experiment

## The MERIT Experiment at the CERN PS

- Proof-of-principle demonstration of a liquid Hg jet target in high-field solenoid
- Demonstrated a 20m/s liquid Hg jet injected into a 15 T solenoid a with a 115 KJ/pulse beam!

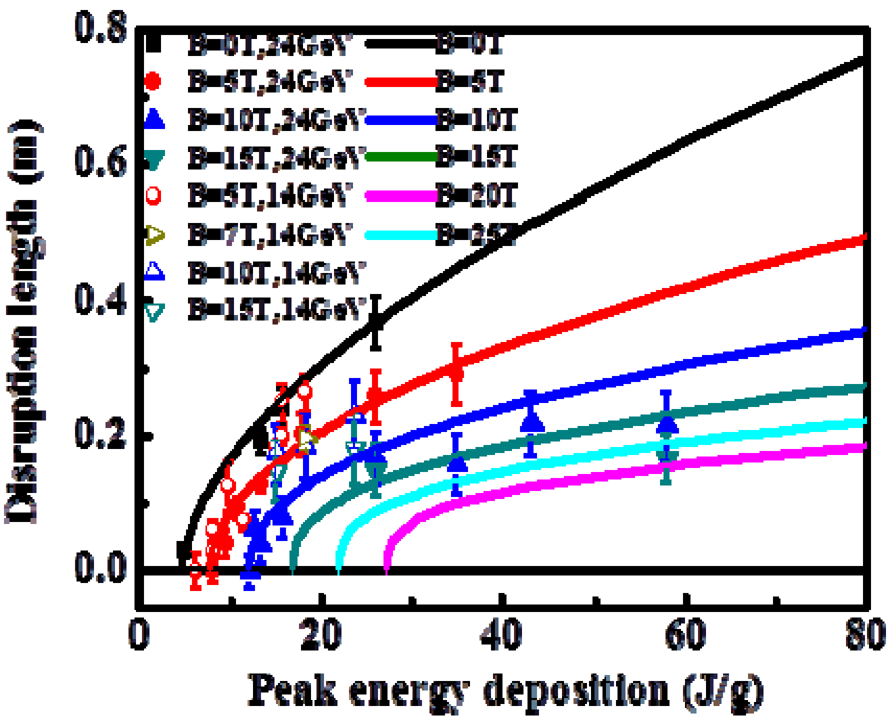




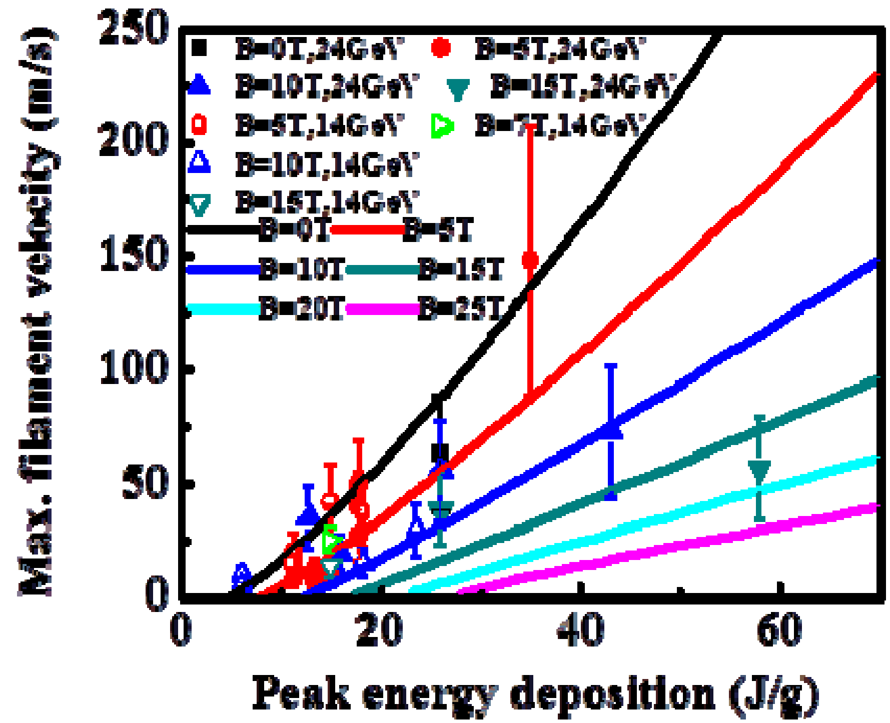



# Key MERIT Results

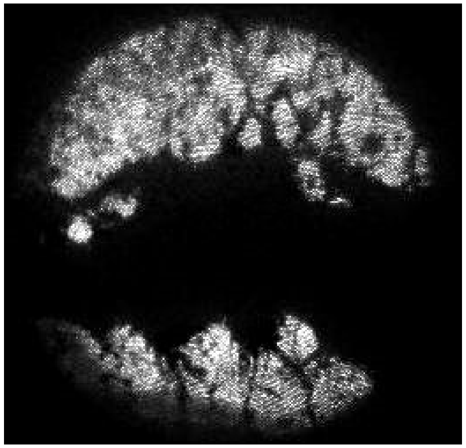
**Jet Disruption Length**



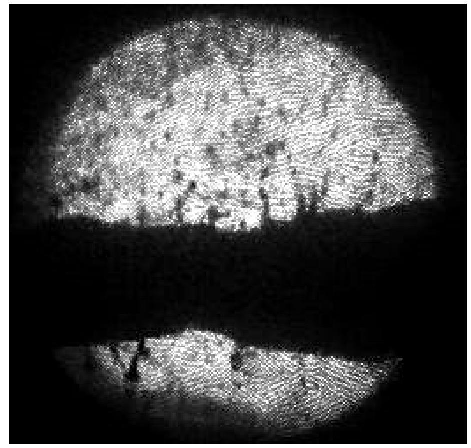

**Filament Ejection Velocity**



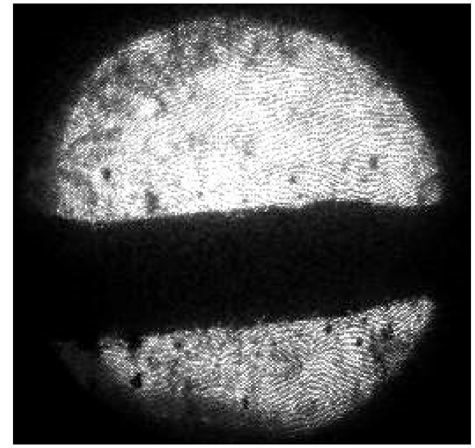
# Study with 4 T$p$ + 4 T$p$ at 14 GeV, 10 T



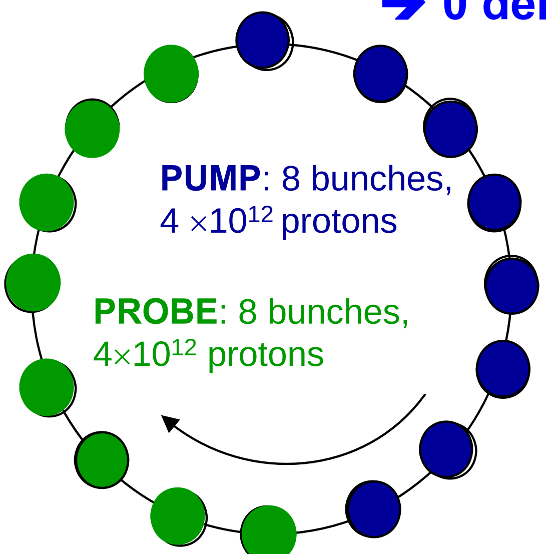
**Single-turn extraction**
**➔ 0 delay, 8 T$p$**



**4-T$p$ probe extracted on subsequent turn**
**➔ 3.2 μs delay**



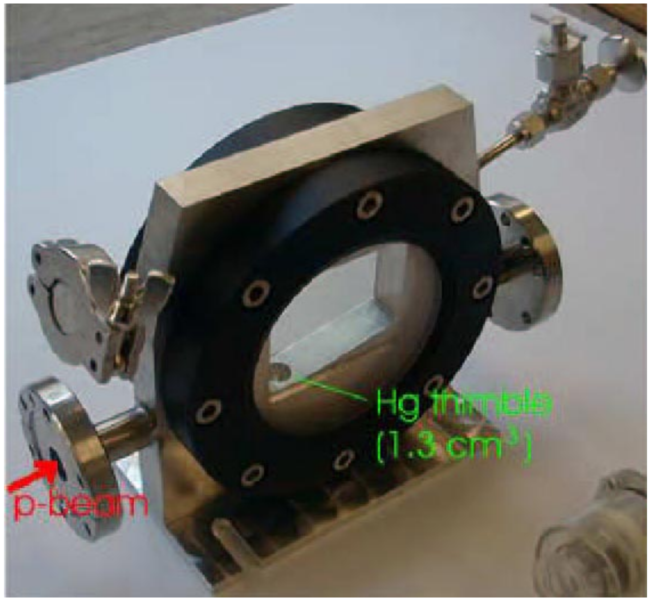
**4-T$p$ probe extracted after 2nd full turn**
**➔ 5.8 μs Delay**



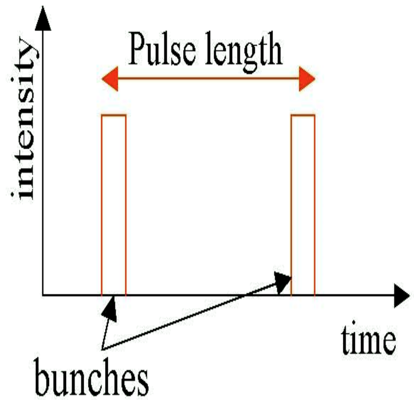

**Threshold of disruption is > 4 T$p$ at 14 Gev, 10 T.**

**⇒Target supports a 14-GeV, 4-T$p$ beam at 172 kHz rep rate without disruption.**

# CERN ISOLDE Hg Target Tests

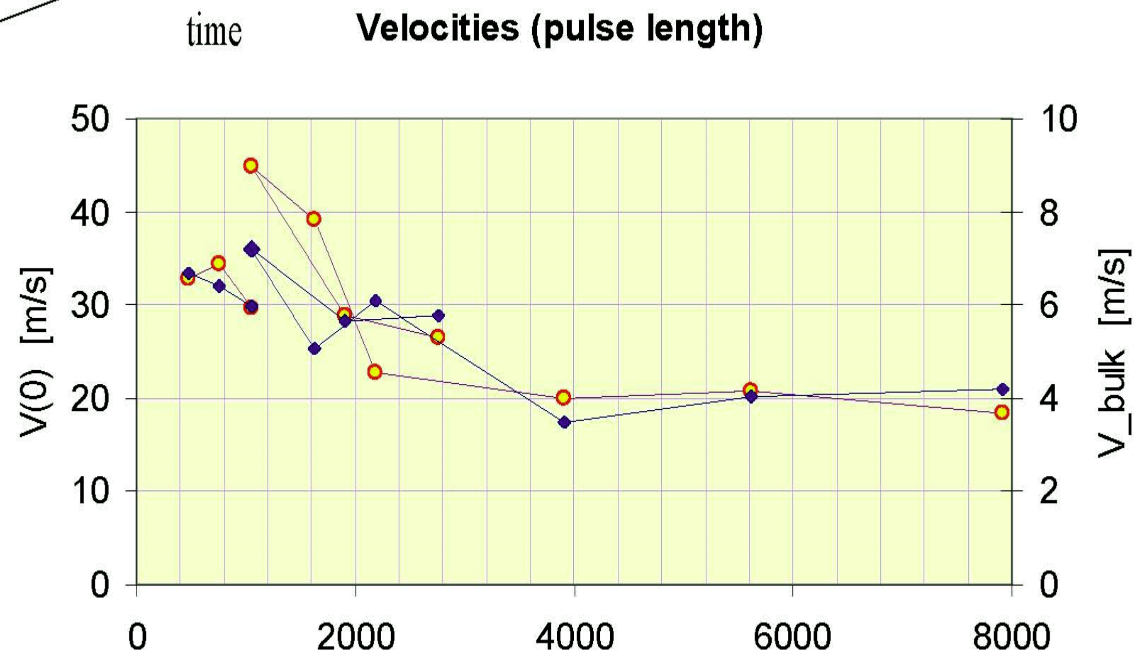



A. Fabich, J. Lettry, CERN




## Pulse length

Proton beam 5.5 TP per Bunch.

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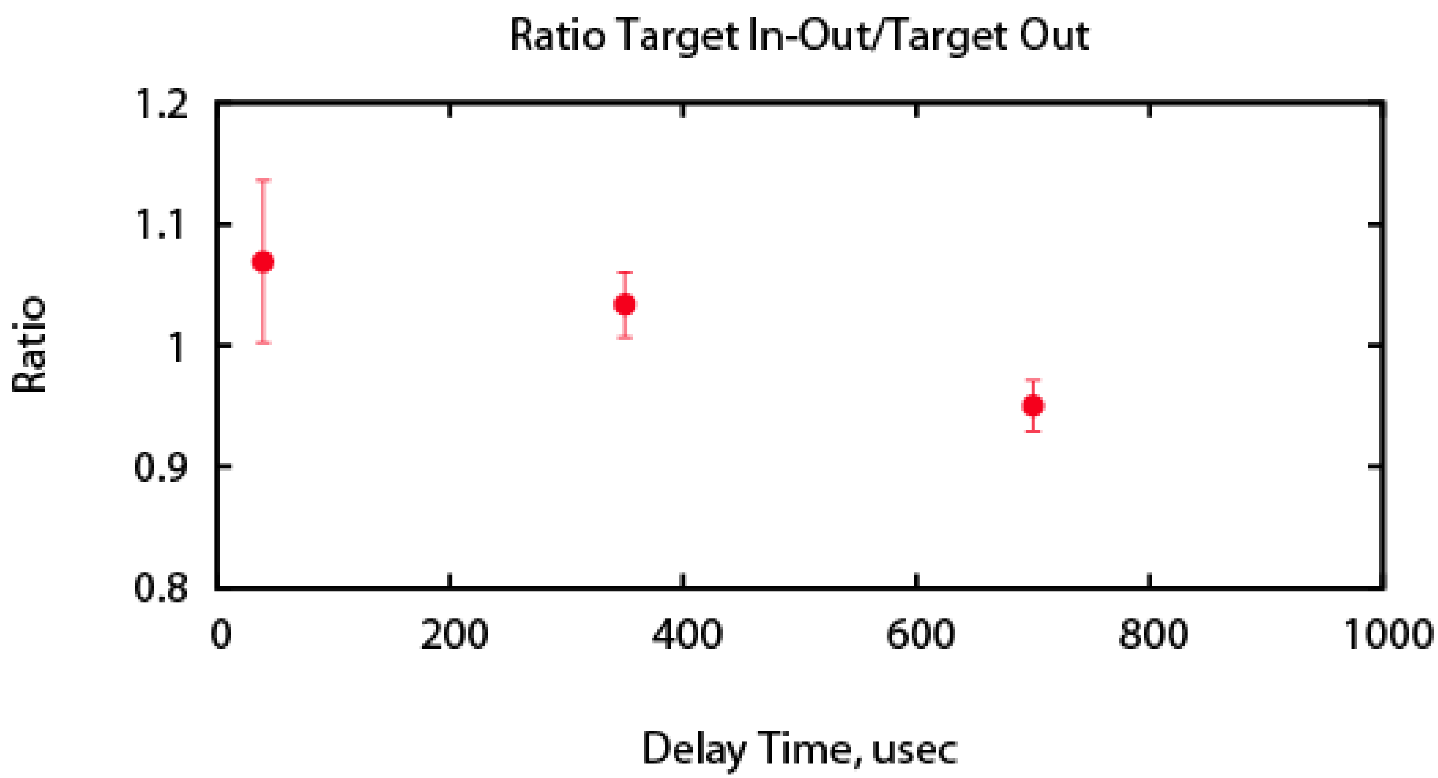
# Pump-Probe Test

**Production Efficiency:** **Normalized Probe / Normalized Pump**




**No loss of pion production for bunch delays of 40 and 350 μs,**

**A 5% loss (2.5-σ effect) of pion production for bunches delayed by 700 μs.**

# Key MERIT Results

- Jet surface instabilities reduced by high-magnetic fields
- Hg jet disruption mitigated by magnetic field
  - 20 m/s operations allows for up to 70Hz operations
- 115kJ pulse containment demonstrated

  → 8 MW capability demonstrated
- Hg ejection velocities reduced by magnetic field
- Pion production remains stable up to 350μs after previous beam impact
- 170kHz operations possible for sub-disruption threshold beam intensities

# SUMMARY

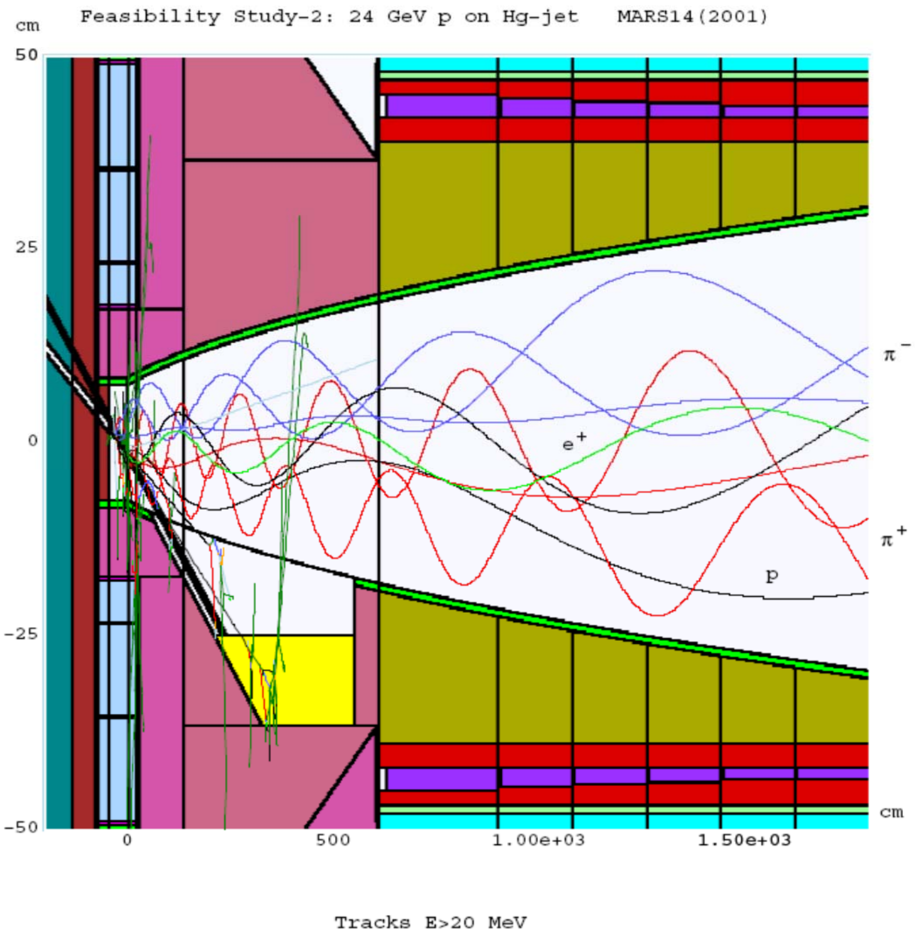
- A solenoid capture system could be a source for intense muon beams
- A solid graphite based target looks promising for 1-MW and 2-MW drive beam applications and may be possible at 4-MW for high-rep rates (50-60 Hz)
- Liquid high-Z targets are more efficient in the production of π/μ beams and are suitable for low rep-rate, 4-MW class drive beams

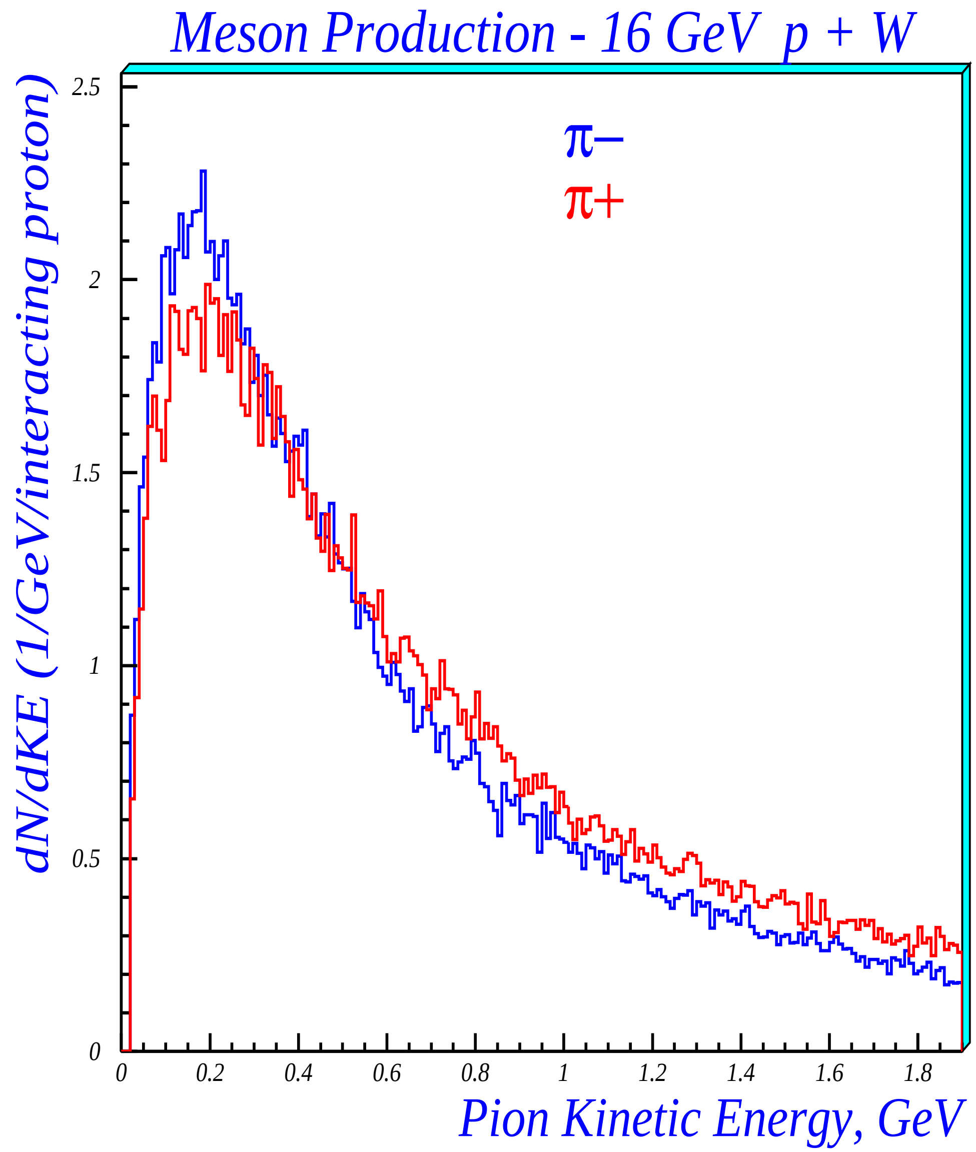
# Backup Slides

# The Neutrino Factory Target Concept

**Maximize Pion/Muon Production**

- **Soft-pion Production**
- **High-Z materials**
- **High-Magnetic Field**




**Palmer, PAC97**

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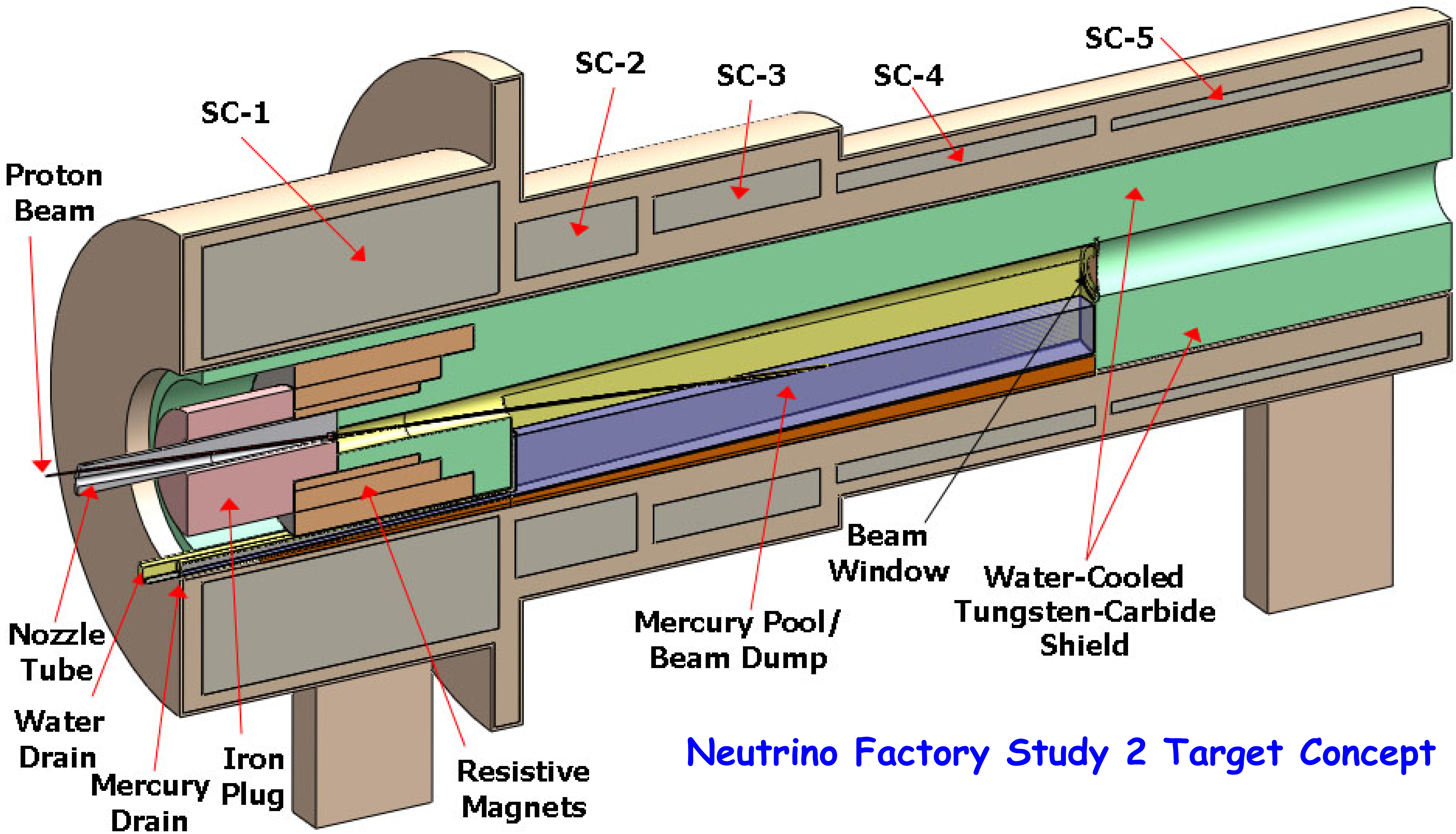
# The NF Study 2 Target System




Neutrino Factory Study 2 Target Concept