

Physics studies for the Muon Collider target system

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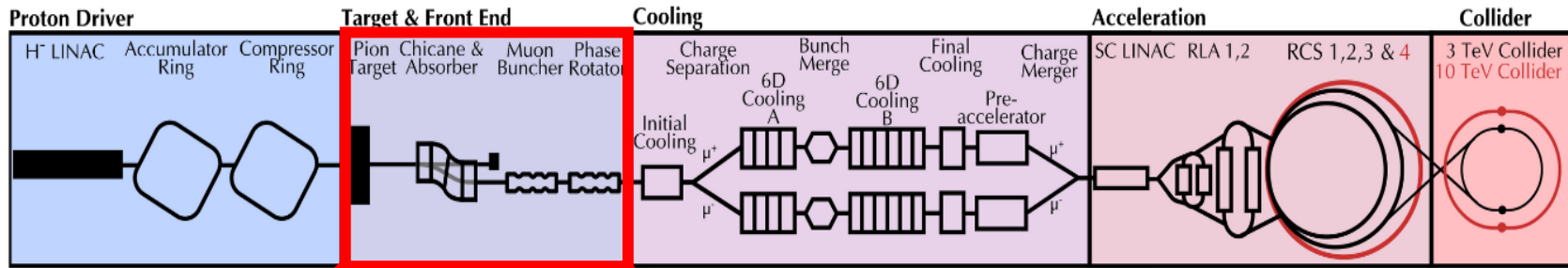


Figure from R. Taylor

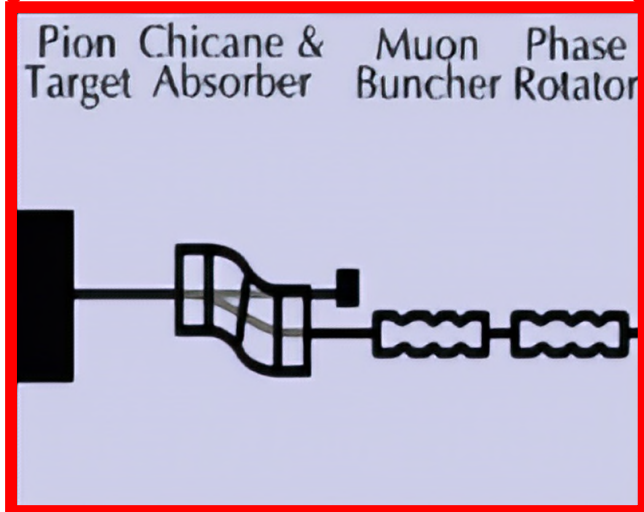
R. Taylor v1.5 (2025)

What is the Muon Collider?

- A multi-TeV lepton Collider based on $\mu^+\mu^-$ collisions
- Novel technologies are required across the collider, in this case, the target

Why the Muon Collider?

- High precision measurements
- Muons have high mass and low Bremsstrahlung, enabling high energy reach
- Precision Higgs and electroweak measurements



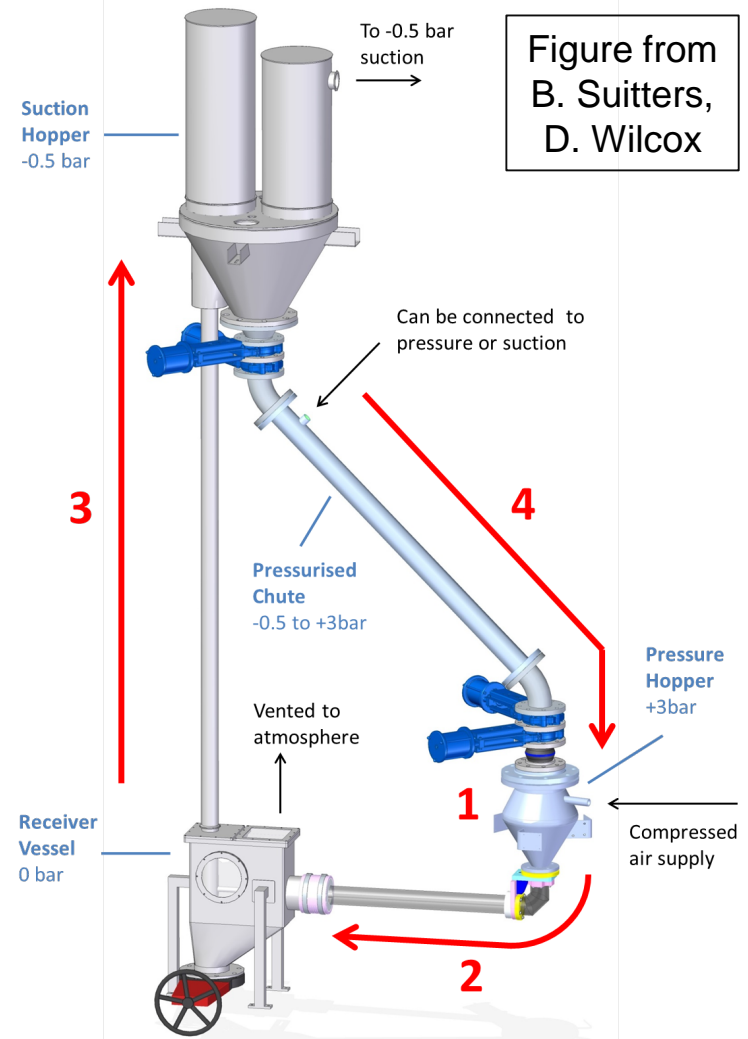
Tungsten powder (WJet) background

Why Tungsten?

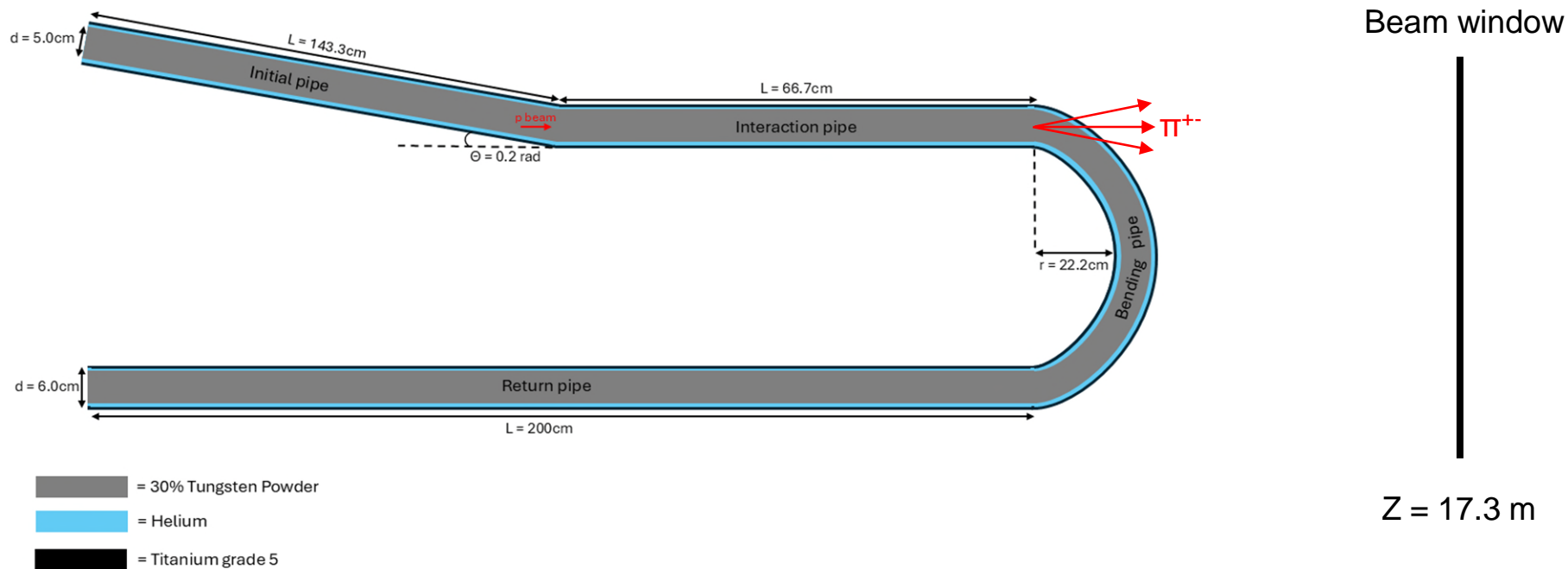
- High density (19.25 g/cm³) – **Increased yields**
- High melting point (3695 K) – 4 MW beam produces high energy deposition; W has more tolerance
- Resistive to radiation – Prolonged exposure is less of an issue

Why use a powder over a solid or liquid?

- Better thermal dissipation – More surface area caused by increased particles
- Self replenishing – As the powder flows around the loop, it cools down
- Cavitation is impossible – Solid nature means pressure drops cannot form vapour bubbles

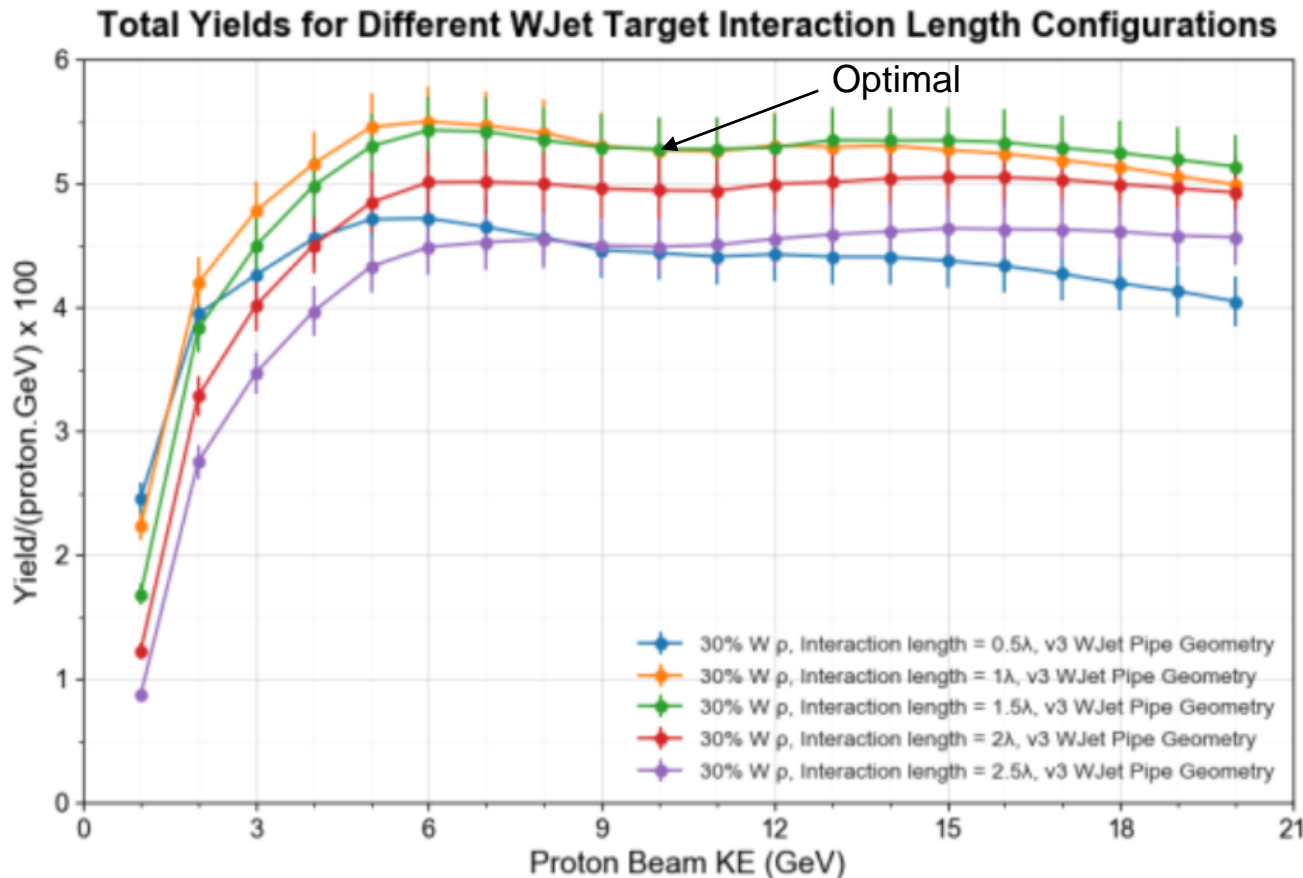


Initial Tungsten powder jet target geometry



- Testing various geometries (Interaction pipe length, interaction pipe radius, pipe thickness, pipe tilt, return pipe bending radius)
- Each parameter is modular, can be varied to match criteria
- 30% density is the estimated engineering limit although 50% may be feasible
- Rough implementation within FLUKA, which all the data was simulated from

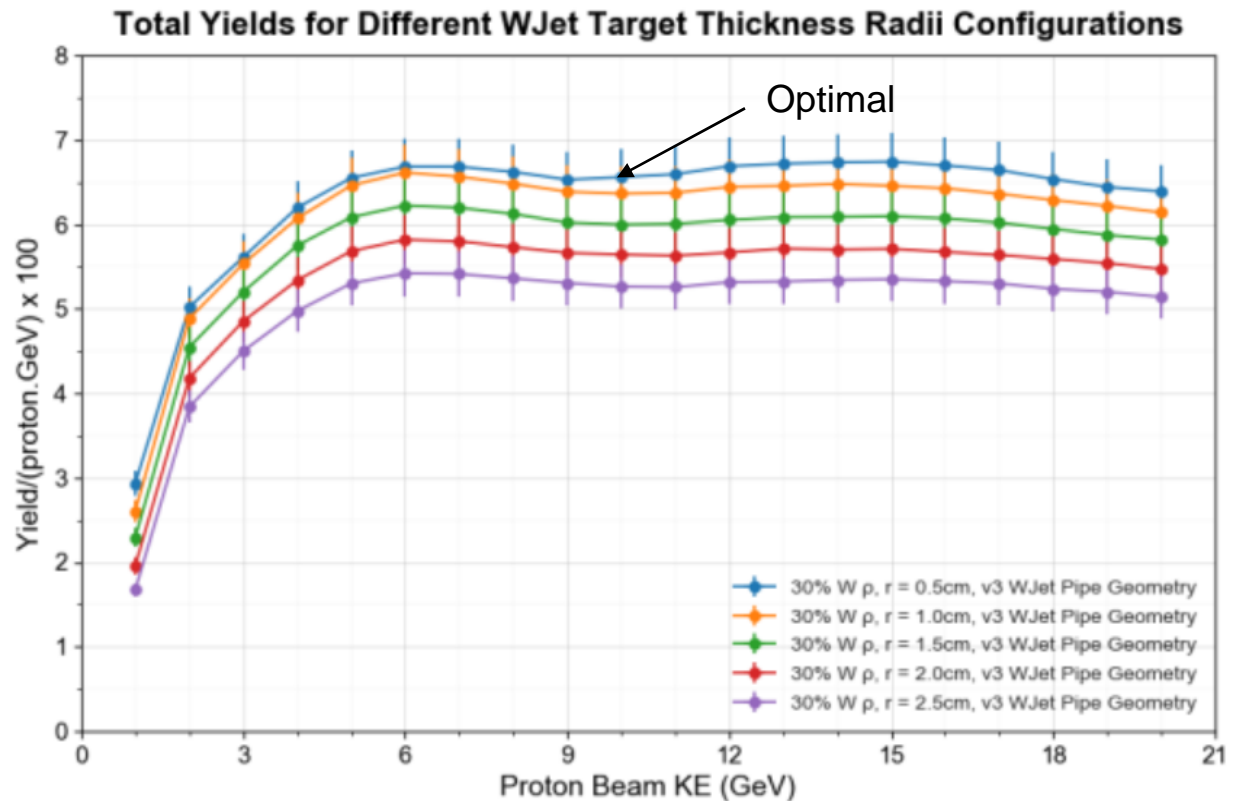
Interaction length pion & muon yield plots



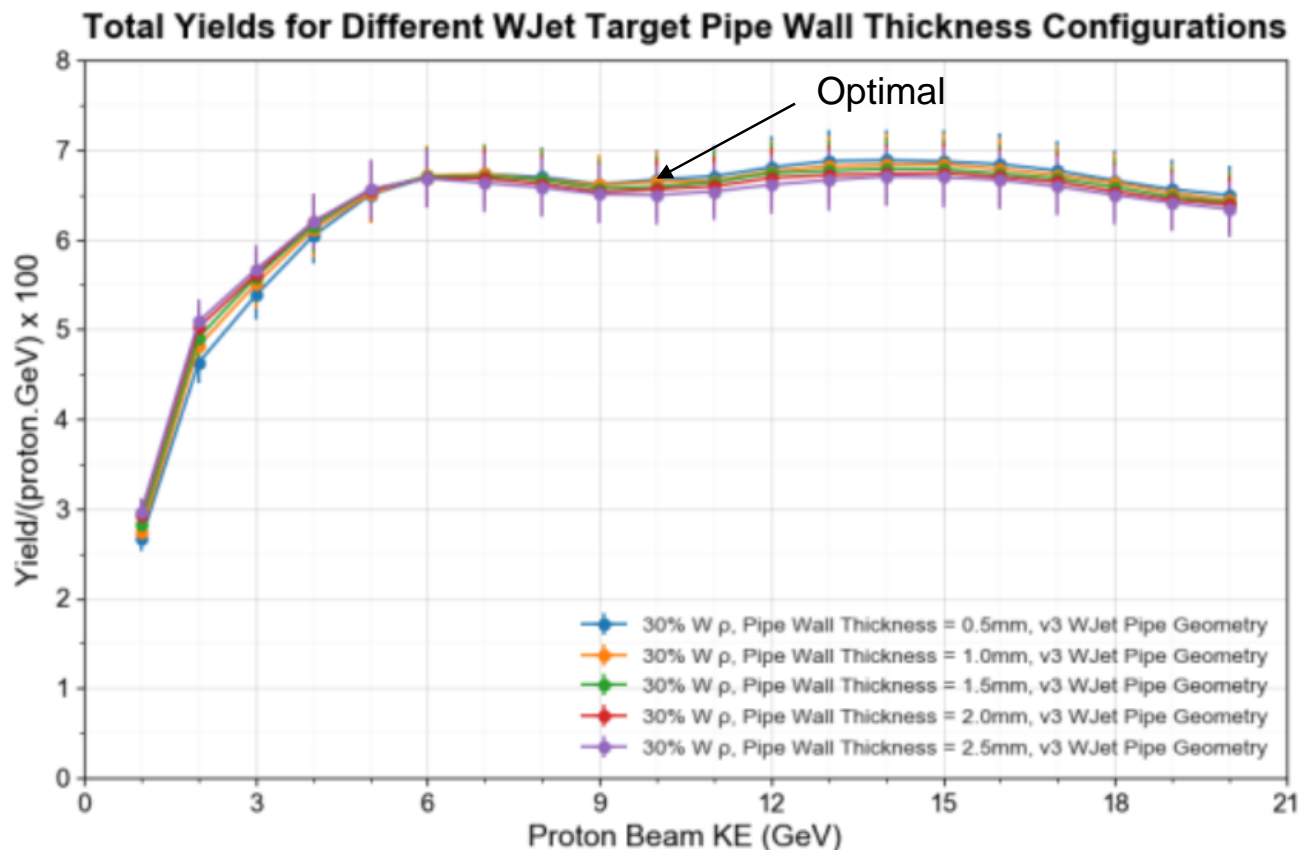
- 1 Million events for all GeV, KE acceptance range: 10 to 500 MeV
- Data taken at a 17.3 m beam window, muon yields dominate with reduced pion yields due to decay distance
- 1.5λ produces ~10% more particles than the previously used 2λ
- 1.5λ and 1λ are competitive at 10 GeV but 1.5λ had less load on the Superconducting (SC) magnets

WJet, $L \approx 33.3\text{cm}$, 1λ  WJet, $L \approx 66.7\text{cm}$, 2λ 

- Each yield plot is iterative; it uses the previous optimal configuration within the new geometry
- Radius varied, beam sigma was kept consistent as $r/3$, 99.3% of the gaussian beam hits the circular end of the WJet
- Up to 25% higher yields at $r = 0.5$ cm than the initial $r = 2.5$ cm configuration

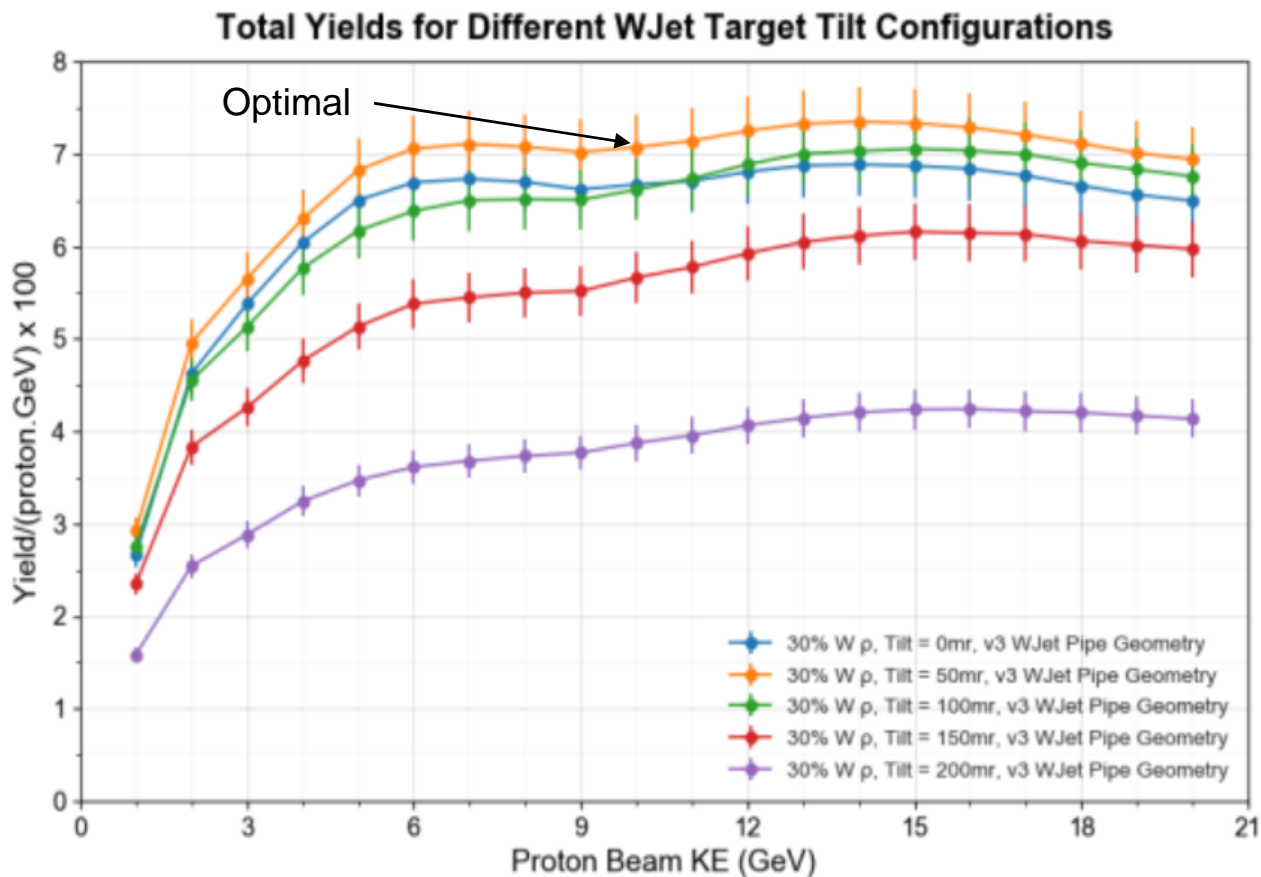


Wall thickness pion & muon yield plots

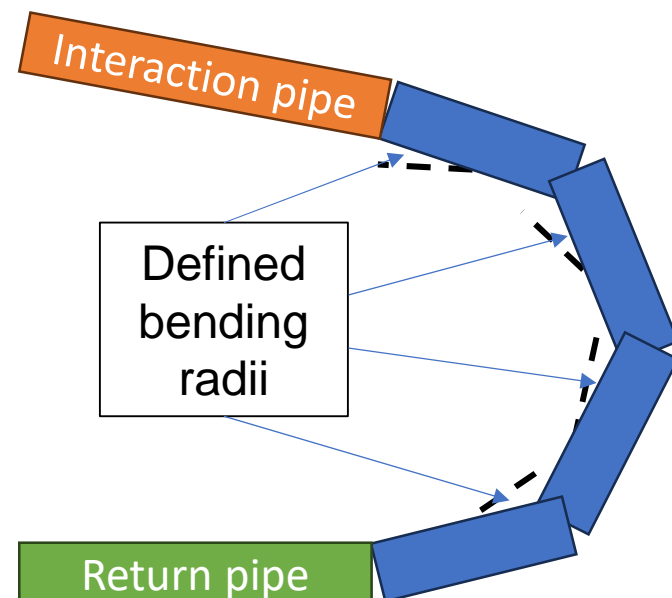
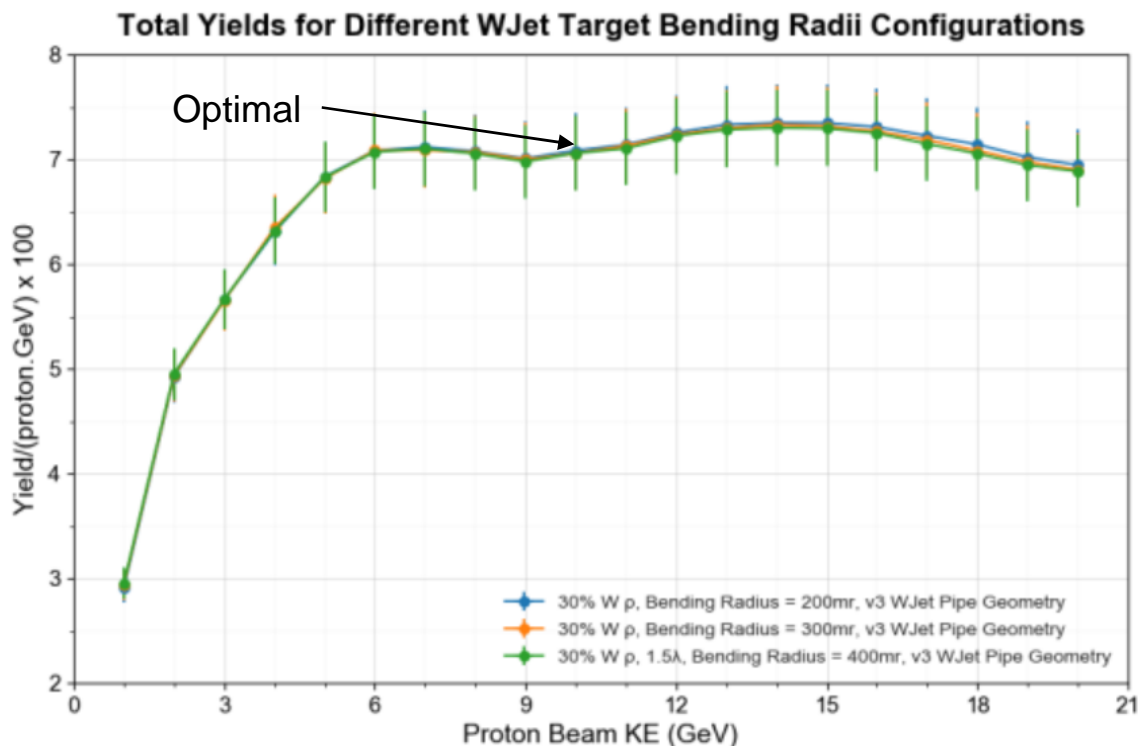


- Wall thickness is not substantial on the muon yields, only ~5% difference between each data set

- **Addition of the tilt:**
 - Reduces pions being re-absorbed by the target/pipes
 - Reduces magnetic focusing relative to the z-axis
- 50 mr has a ~10% yield increase compared to no tilt
- Increasing the tilt past 100 mr has diminishing returns



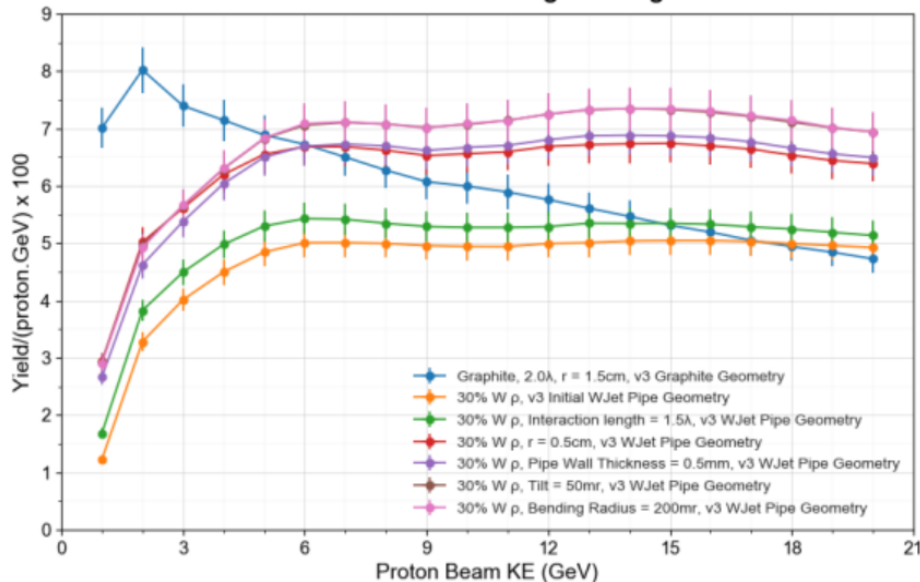
Bending Radii pion & muon yield plots



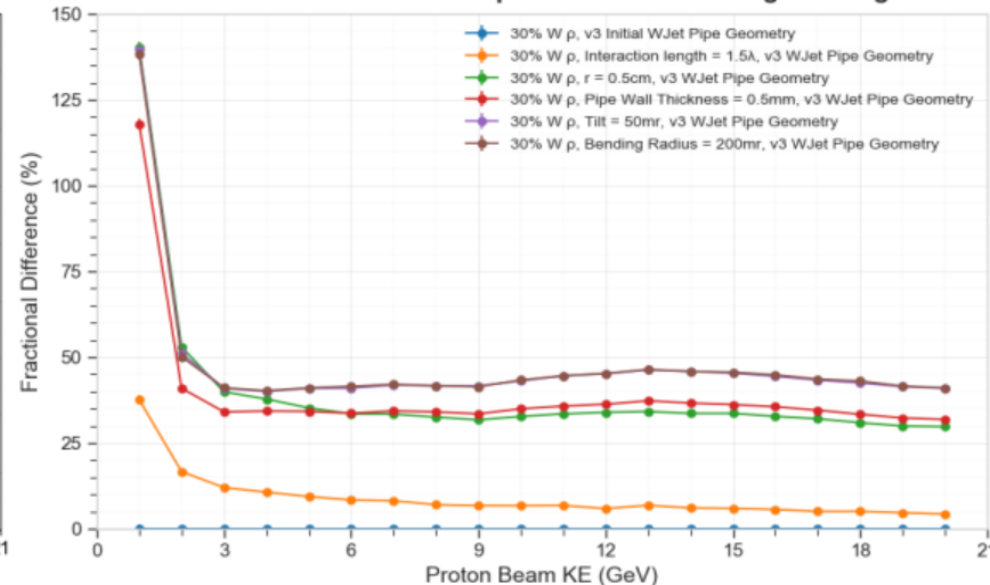
- Bending radius limited by pipe engineering specs defining it within the shielding, helps heat dissipation and performance
- The data is roughly comparable across all energies ($\pm 1\%$), considering statistical variations

Yield comparison plots of implemented optimisations

Total Yields for Different Target Configurations



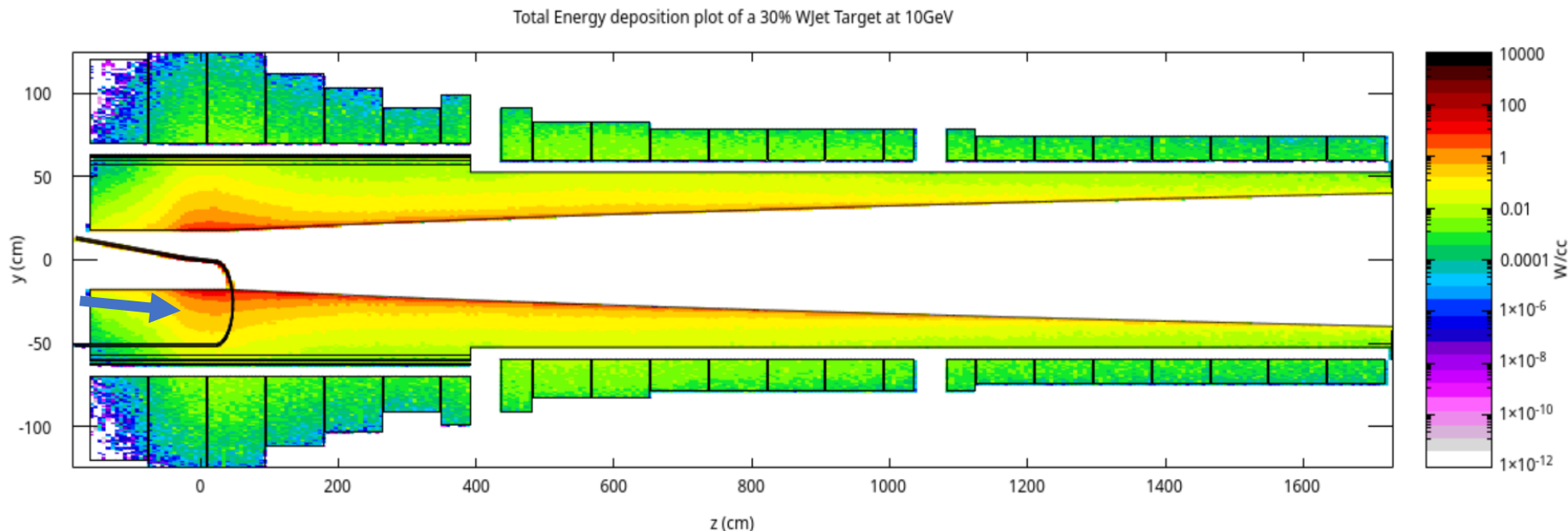
Yield Fractional Difference Compared to the Initial Target Configuration



After optimisations:

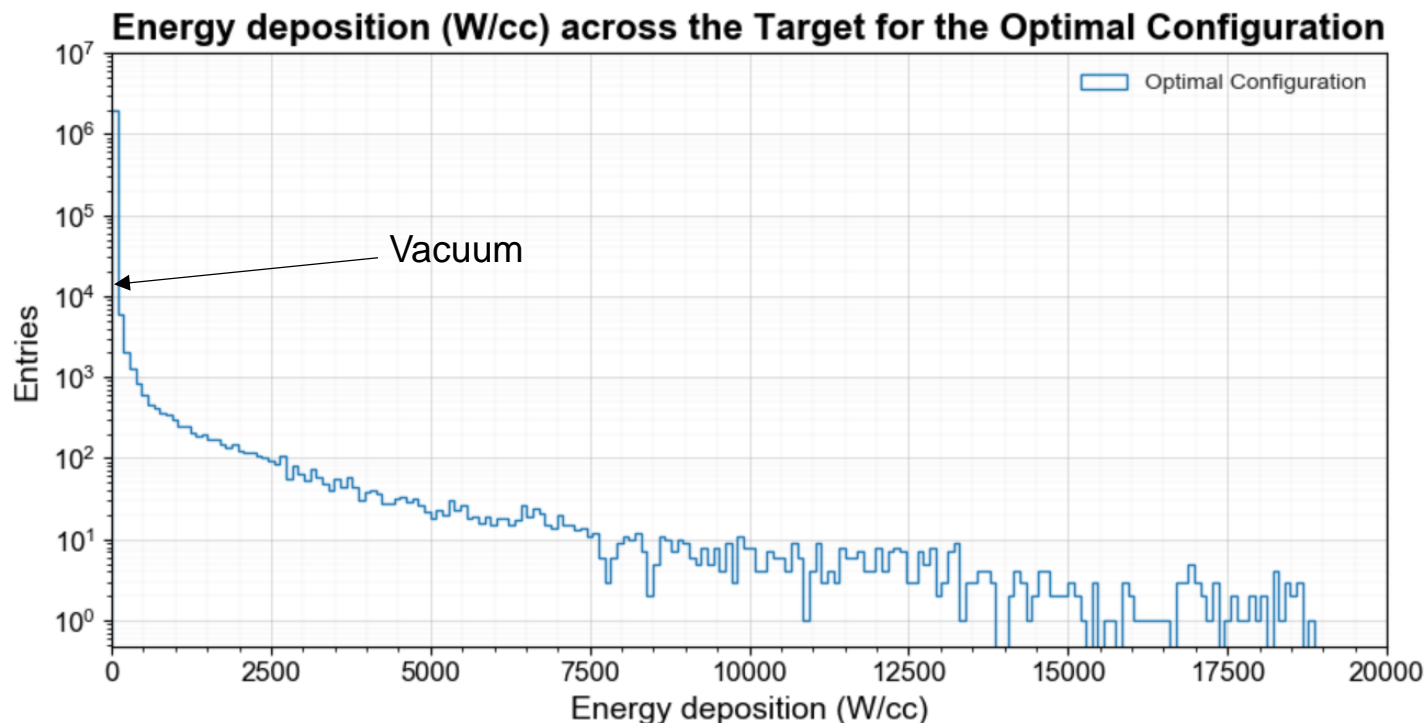
- ~45% increase in yields from the Initial configuration and ~15% increase compared to graphite
- The interaction length and target radii have major impacts on muon yields
- 10 GeV was the focal point but the peak WJet yield is around 14 GeV across most data sets
- Potentially comparable to other materials depending on engineering constraints

WJet target (10 GeV beam) FLUKA energy deposition (E_{dep})



- Edep plots chosen using the peak yield target configuration at 10 GeV
- Peak power deposition is seen within the target with lower intensities throughout the rest of the system
- Superconducting magnets require more shielding, SC1 has 0.080 mW/g and SC23 has 0.24 mW/g, with the latter having more deposition than the quenching limit of 0.1 mW/g
- Taper shape keeps the Energy deposition load on the SC magnets consistent

Target Edep Breakdown plot



- Peak target deposition of ~ 18.9 kW/cc
- Concern that it is too large for the target to handle this deposition, causing breakdown
- Optimal configuration is not ideal and will need engineering constraints to account for the large deposition

Summary

- Tungsten powder jet target is a promising target for the Muon Collider
- WJet optimal configuration for peak yields are:
 - Interaction length = 1.5λ
 - Target radii = 0.5 cm
 - Wall thickness radii = 0.5 mm
 - Tilt = 50 mr
 - Bending radii = 200 mr
- Optimisations have a broader energy range in which the yield is larger than graphite or the initially proposed configuration
- 2 MW, 5 GeV beam is competitive between the two materials but for 4 MW at 10 GeV, WJet has better overall performance ~15% more yield
- Energy deposition plots show the W jet target displays potential downstream SC quenching and target breakdown
- More shielding needs to be added within the system to counter this

Thank you



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