

Pion-production target LDRD: status update

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Fermilab

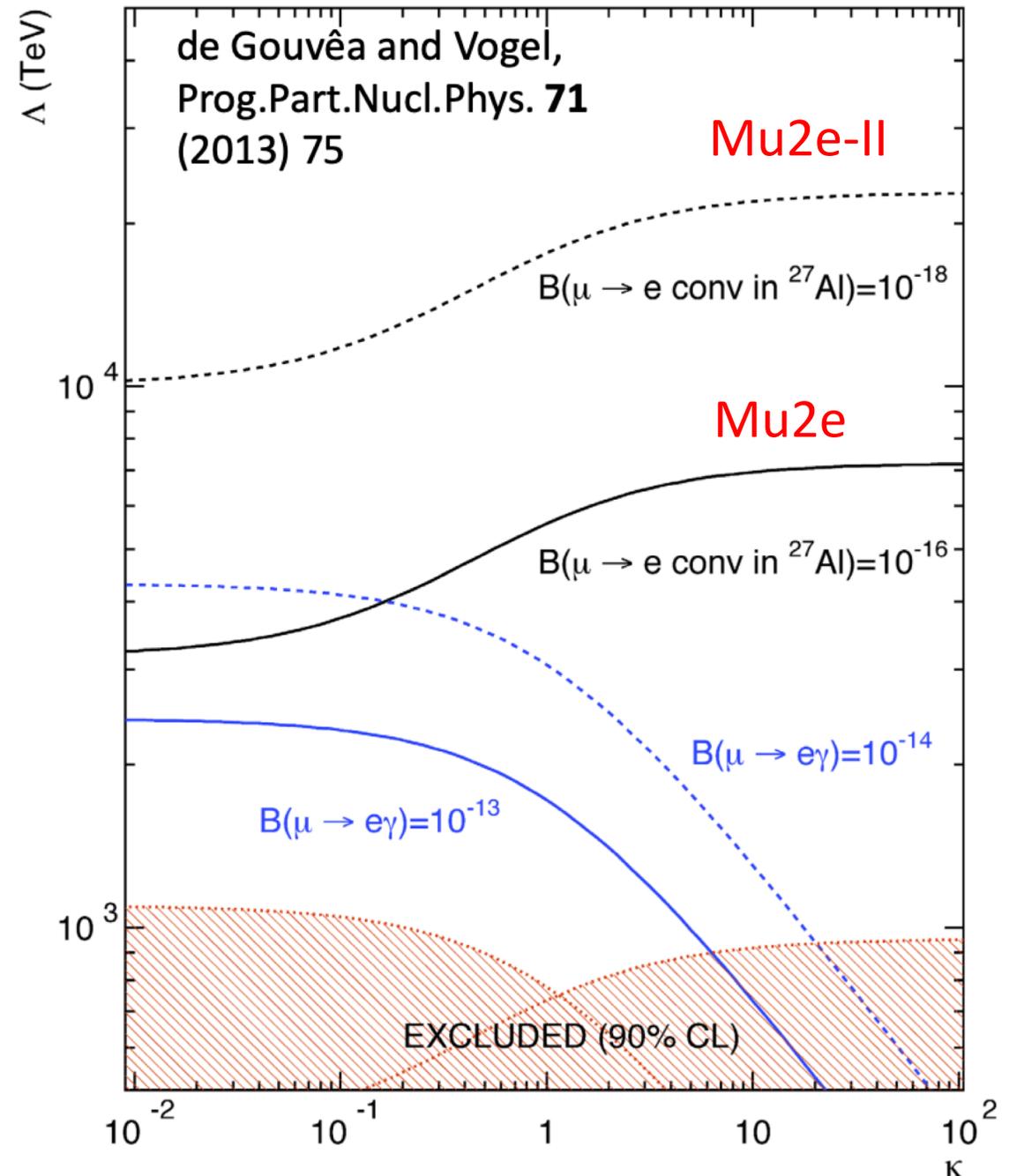
On behalf of the LDRD team: I.Fang, K.Lynch, D.Neuffer, J.Popp, D.Pushka

TSD Meeting

02/18/21

The Mu2e experiment

- The Mu2e experiment at Fermilab will search for evidence of charged lepton flavor violation by observing the conversion of a negative muon into an electron in the Coulomb field of a nucleus without emission of neutrinos. It will probe effective new-physics mass scales in the 10^3 - 10^4 TeV range.
- The Mu2e-II improved sensitivity would be enabled by the PIP-II accelerator upgrade project, which is a 250-meter-long linac capable of accelerating a 2 mA proton beam to a kinetic energy of 800 MeV corresponding to 1.6 MW of power (Mu2e-II is planning to use 100 kW).

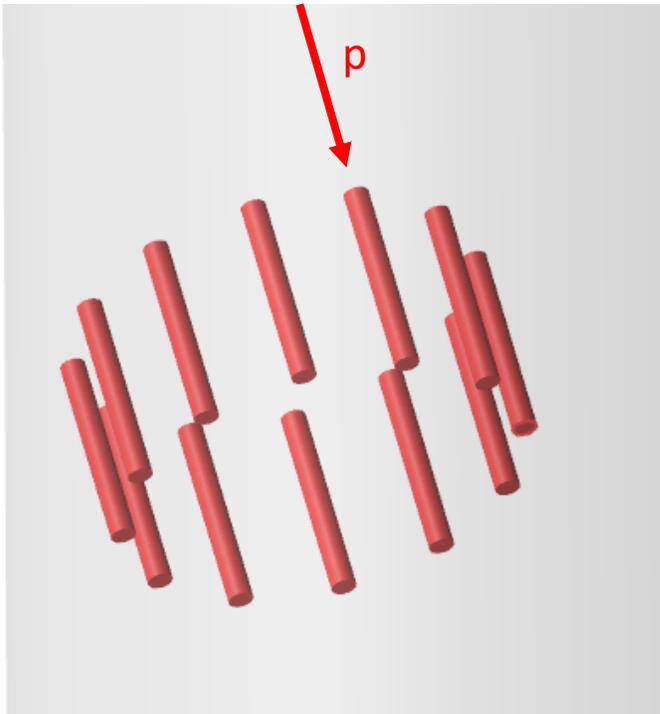


Scope of LDRD

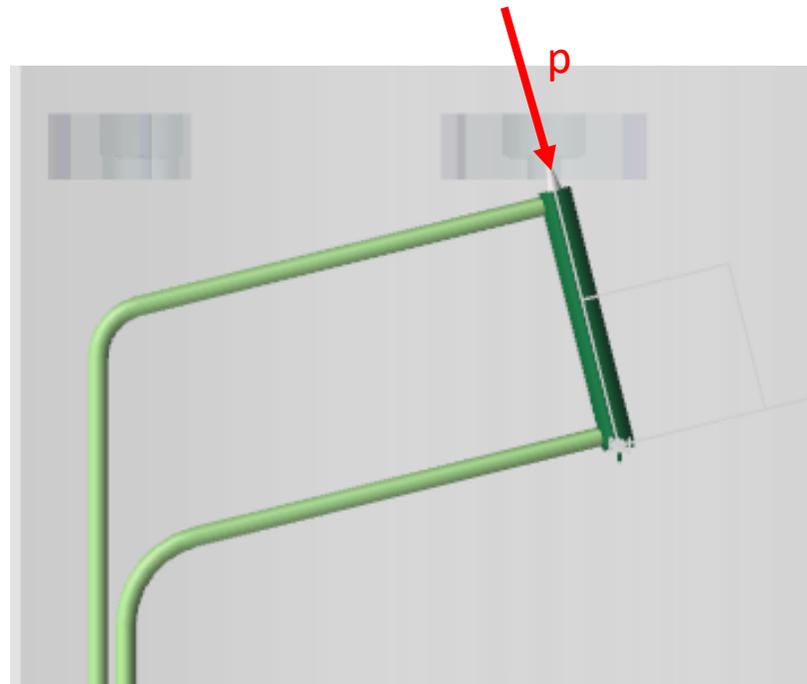
- Project for the **PIP-II era**: proton current on the Mu2e target could be higher by as much as a factor of 100 compared to the baseline Mu2e (**~x10 improvement** in the single event sensitivity).
- There is no Mu2e upgrade target concept close to satisfying the new requirements (for a **100-kW 800-MeV** proton beam). (We are aware of a 50-W target prototype designed for MECO and PRISM at Irvine CA: “MECO Production Target Development”, J.L.Popp, AIP V.721, p.321, 2003.)
- We are developing **a conceptual design using the MARS15 and G4beamline Monte-Carlo codes, Mathematica** and utilize the most favorable aspects of the **granular, “conveyor”, and rotating cylindrical targets**. We are simulating the **overall target pion production performance and durability at beam induced pulsed energy deposition spikes**, thermal stress, radiation damage, muon stopping rates, residual activation and radiation loads.
- The project is aimed at the **design of the prototype** of the Mu2e-II pion-production target for the **100-kW 800-MeV** proton beam and its mechanical tests.
- **Deliverables. First year**: the **plausible design** for the Mu2e-II target.
- **Second year**: **prototypes** designed, printed, and tested. Conclusions regarding **feasibility** drawn.

Plans for 2020

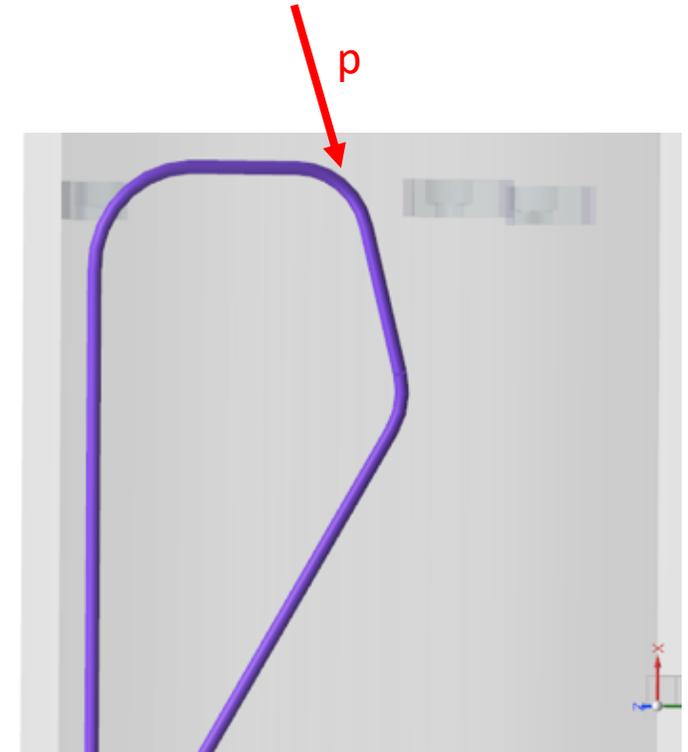
Plan for 2020: To simulate the overall target pion production performance and durability at beam induced pulsed energy deposition spikes, thermal stress, radiation damage, muon stopping rates, residual activation and radiation loads



Rotating Elements



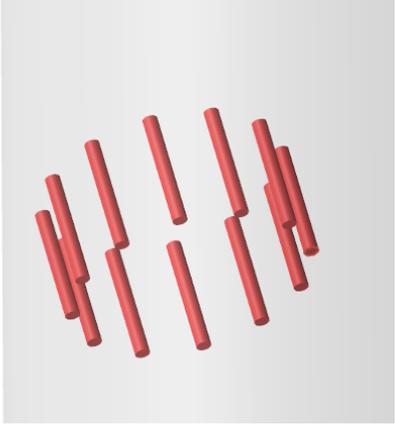
Fixed Granular with Gas Cooling



Conveyor

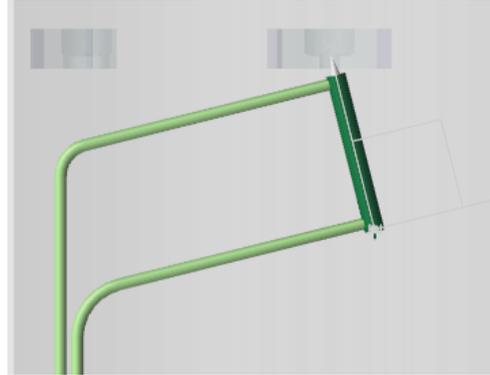
Prioritizing designs

- Constraint: compatibility with the current HRS design (inner bore=20 (25) cm)



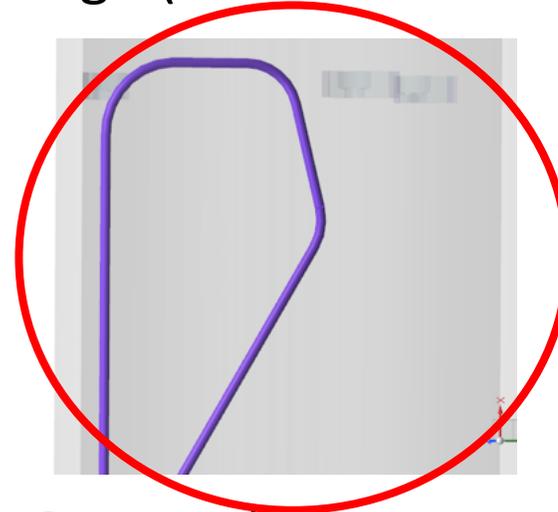
Pros: radiation damage can be distributed over many rods

Cons: its hardware would require a significant space inside the bore (complicates cooling and muon flow)



Pros: small space required

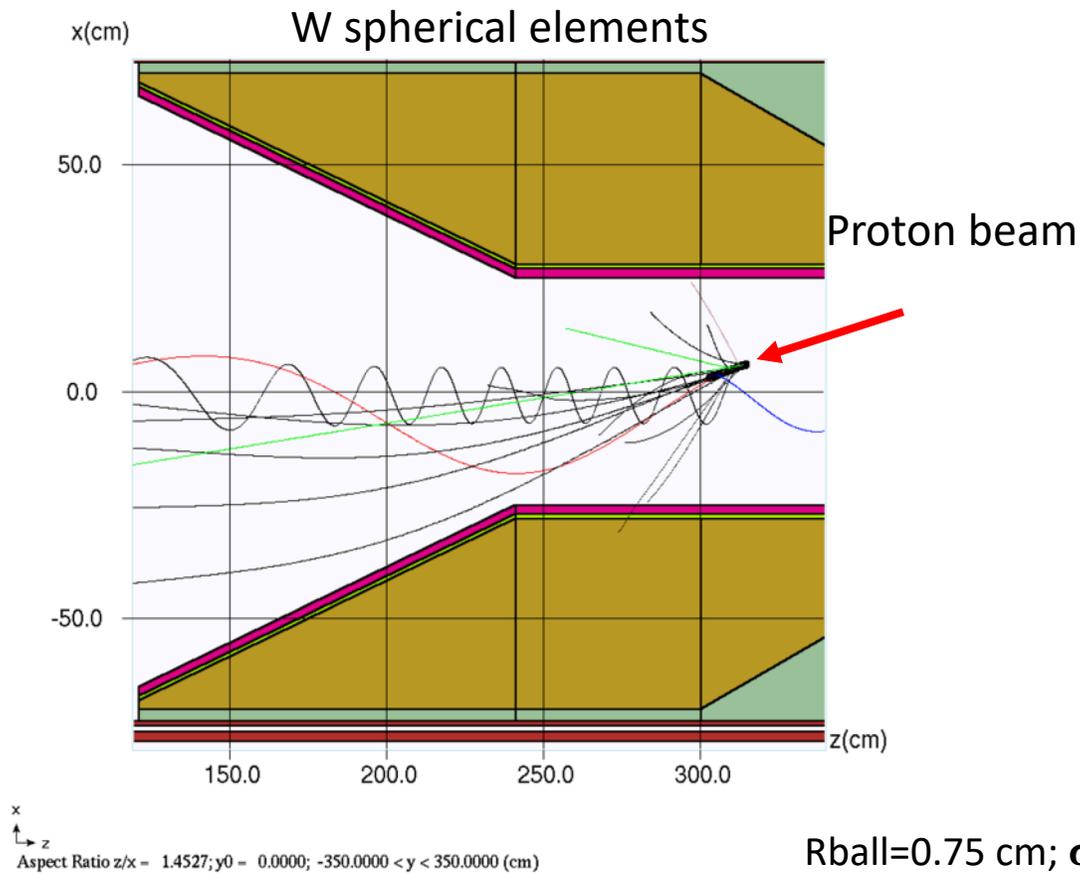
Cons: peak DPA (MARS15) >300/yr; gas cooling cannot be performed effectively



Pros: small space required; He gas could be used for both cooling and moving elements inside conveyor; radiation damage can be distributed; **Cons:** technical complexity (prototyping needed)

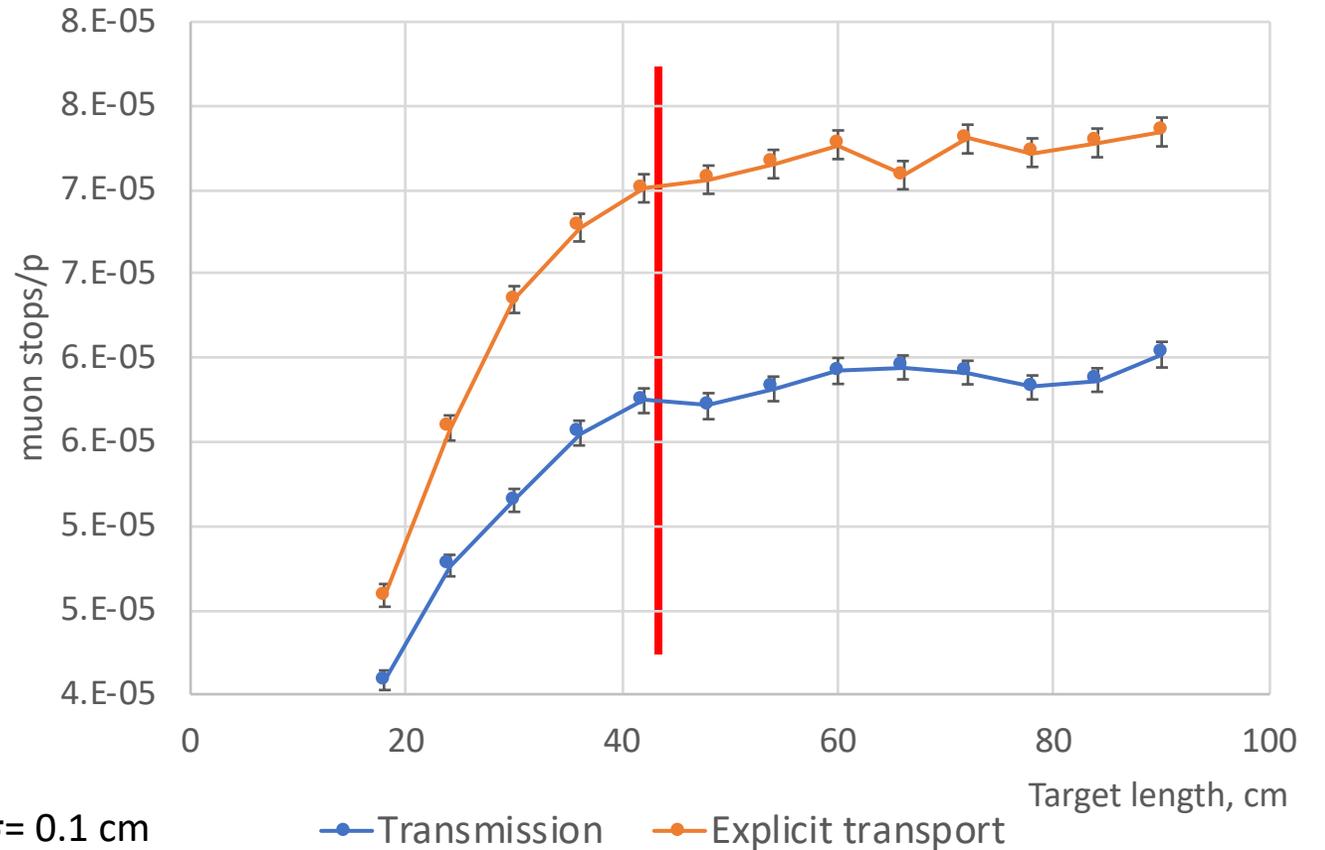


Conveyor target length optimization



Rball=0.75 cm; σ = 0.1 cm

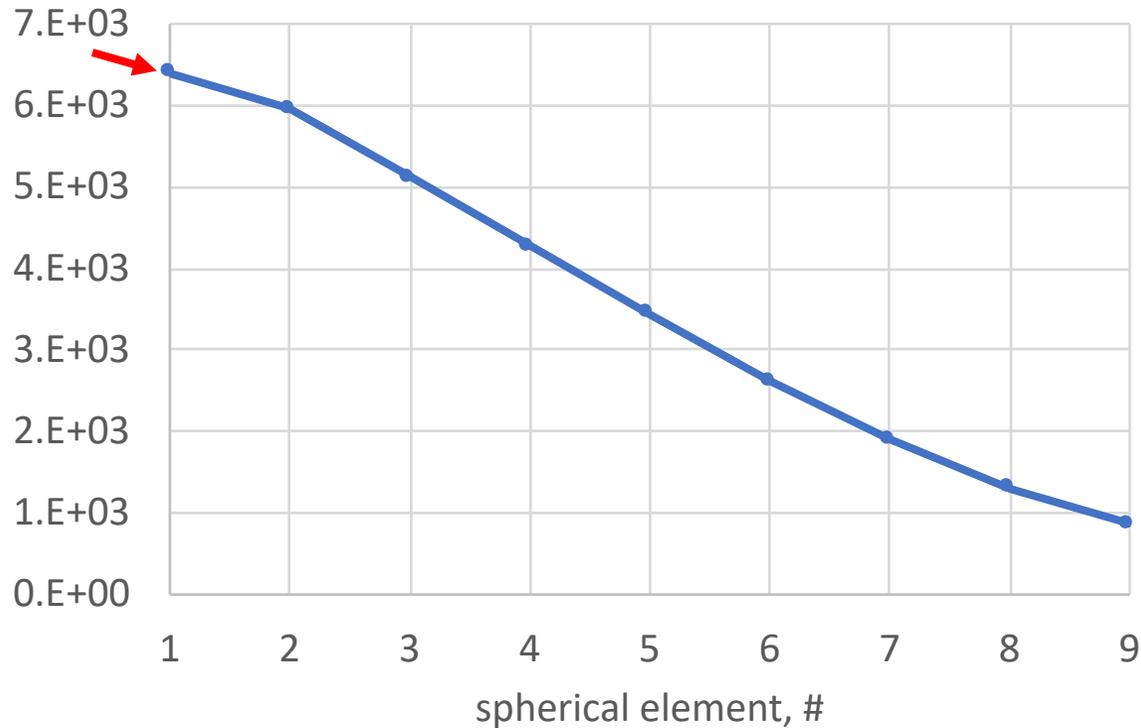
Carbon target length optimization by muon stops



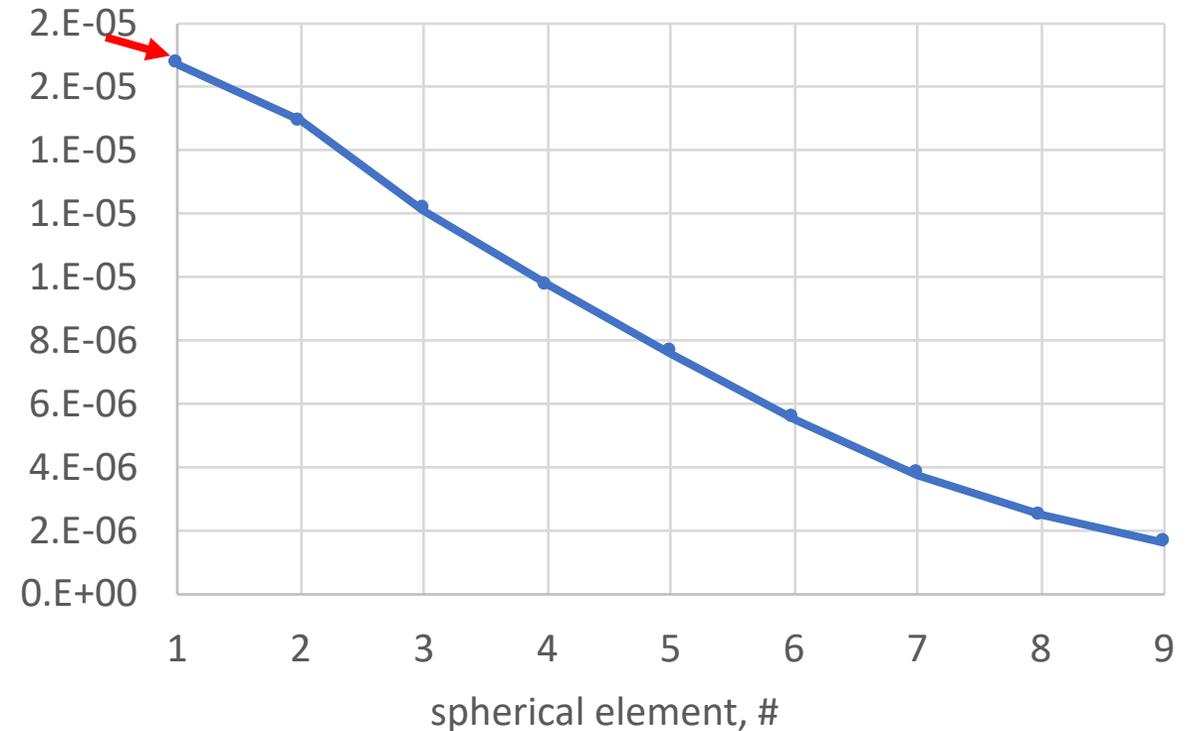
Based on muon stopping rate studies with MARS15 and G4beamline optimal target lengths were determined to be: 28 balls (C target), 9 balls (W and WC targets), 19 balls (SiC); MoGRCF was studied. Agreement between transmission and explicit allows saving computation time.

Energy deposition and radiation damage analysis

Energy deposition, W



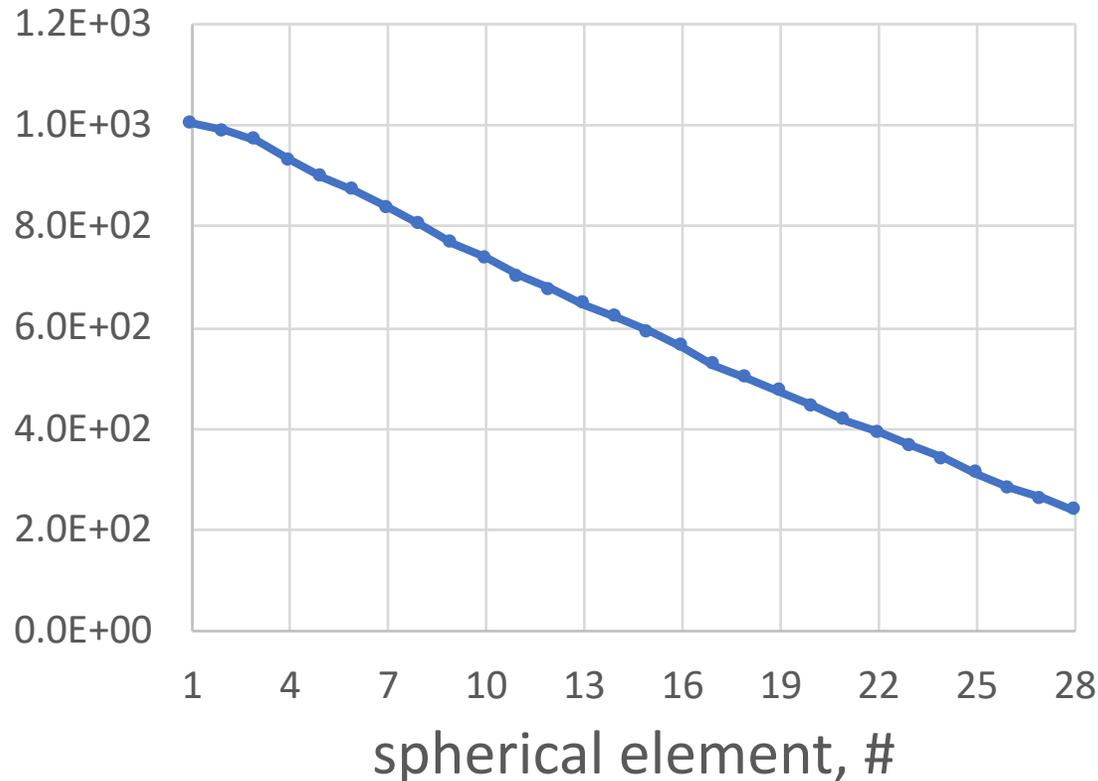
DPA in position/sec



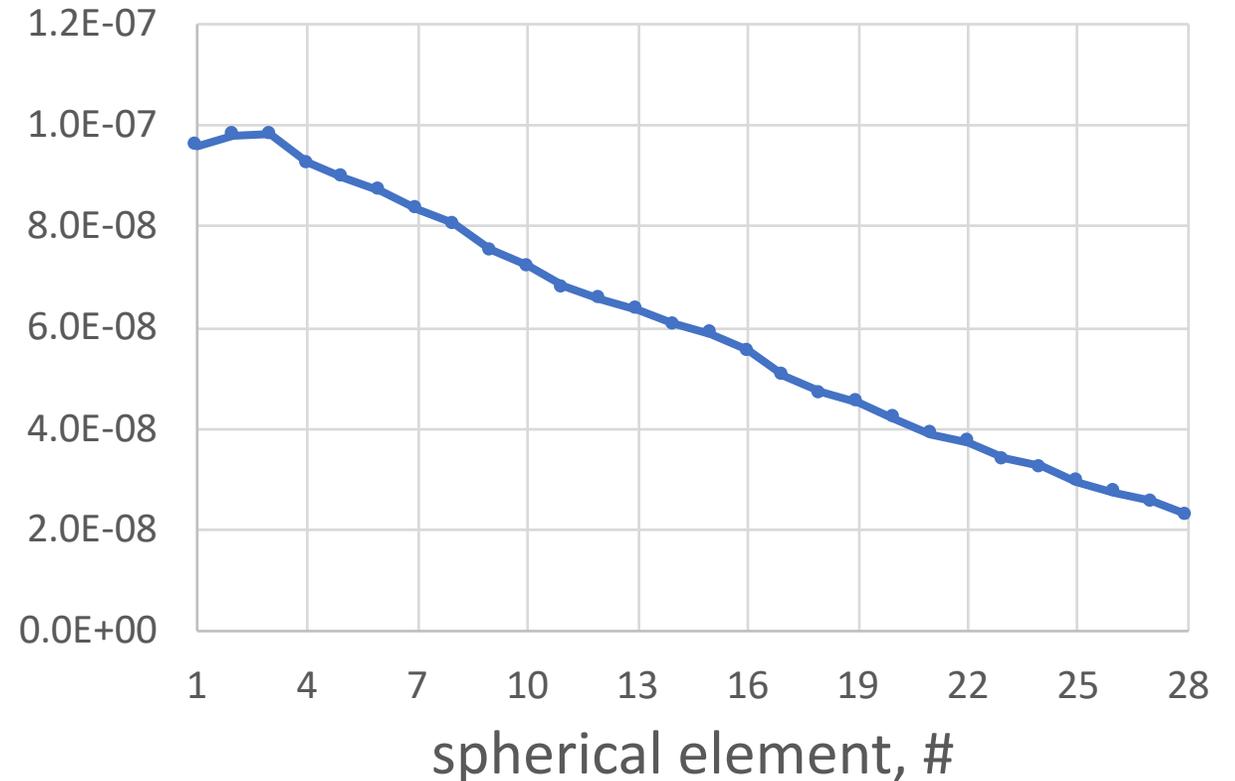
- Total Edep = 31.8 kW; peak DPA (Nordlund) = 330 DPA/yr; min balls required (DPA) = 150/yr
- Motion speed of spherical elements in conveyor is 10 cm/sec
- (1.35 sec for an element to pass the beam). **More balls are required by thermal analysis**

Edep and radiation damage in the C target

Energy deposition, W

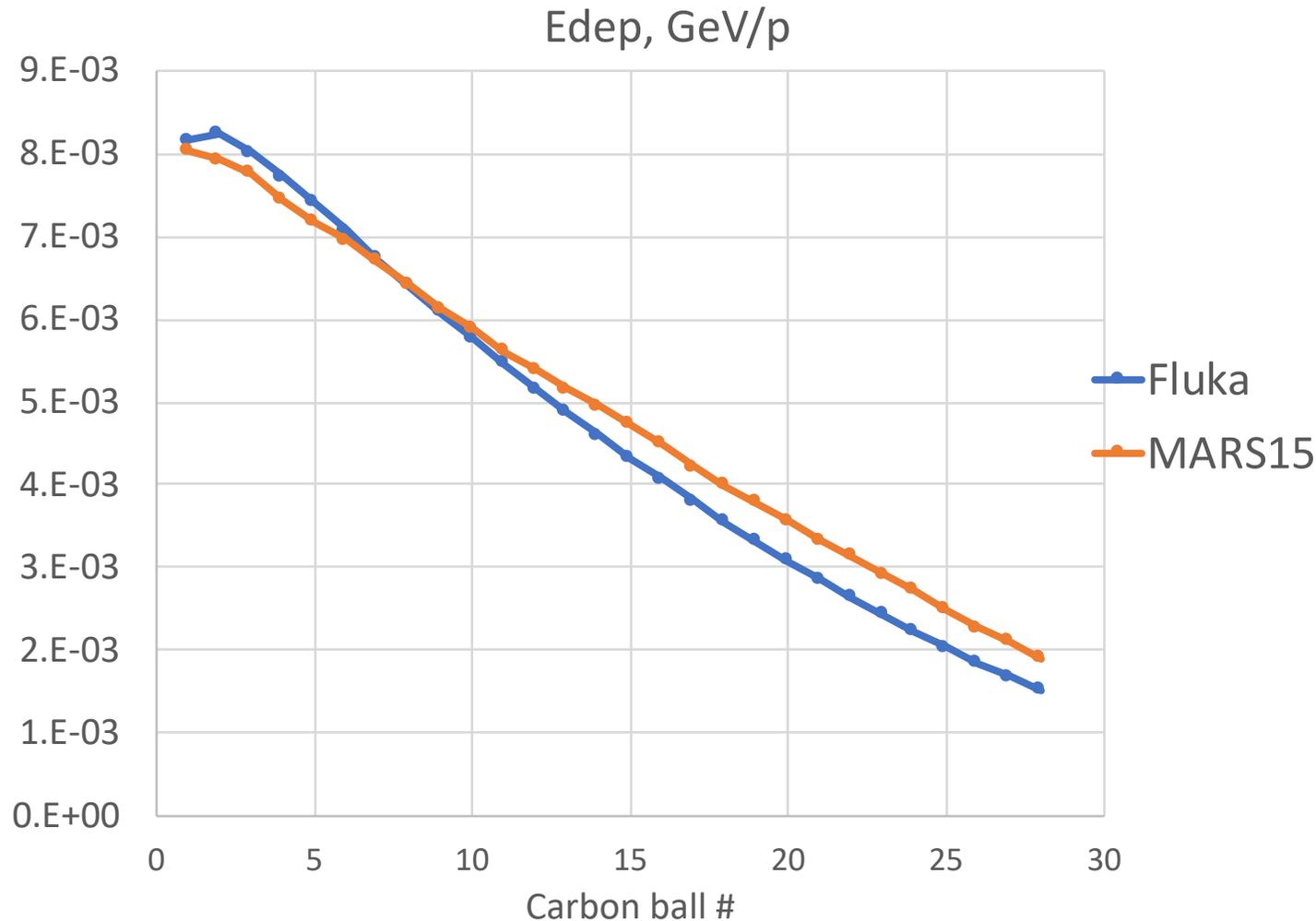


DPA in position, sec



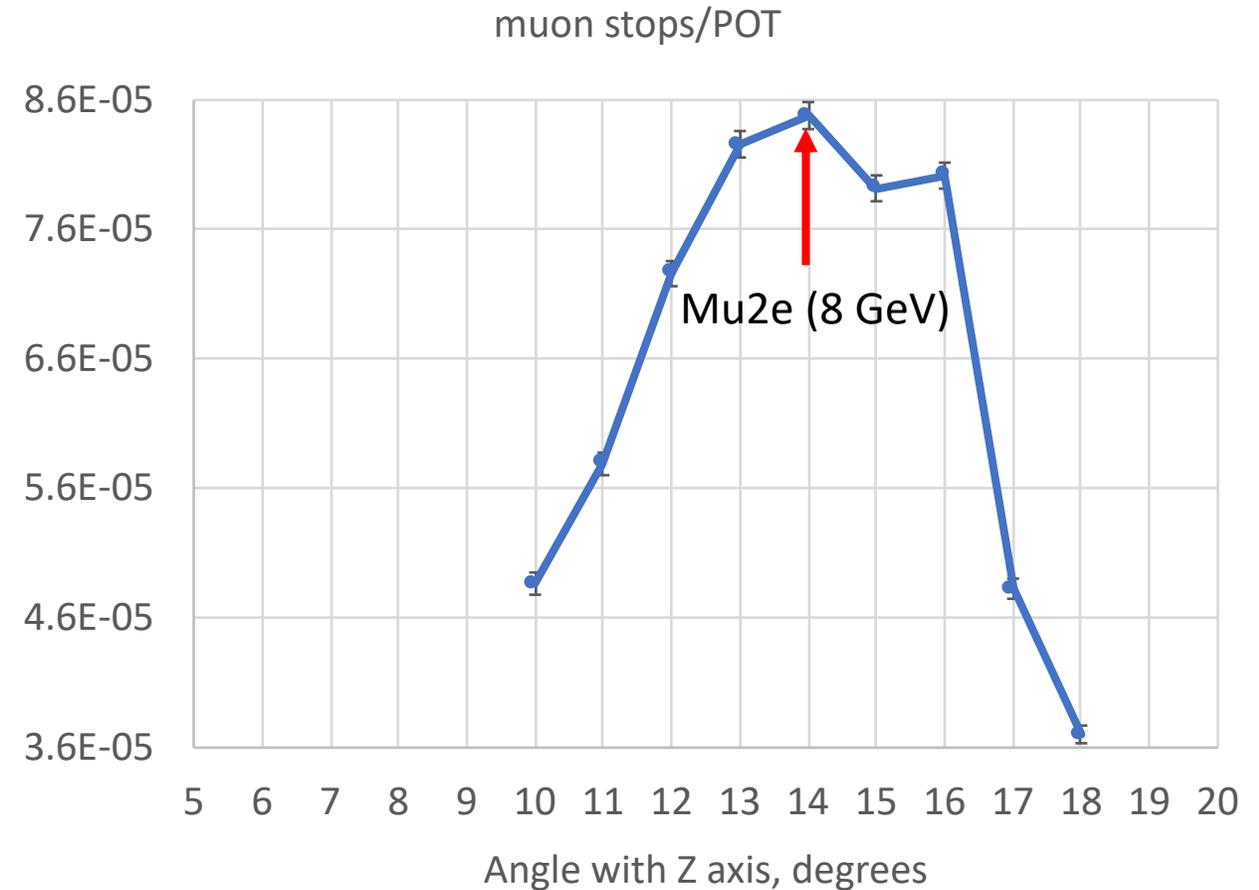
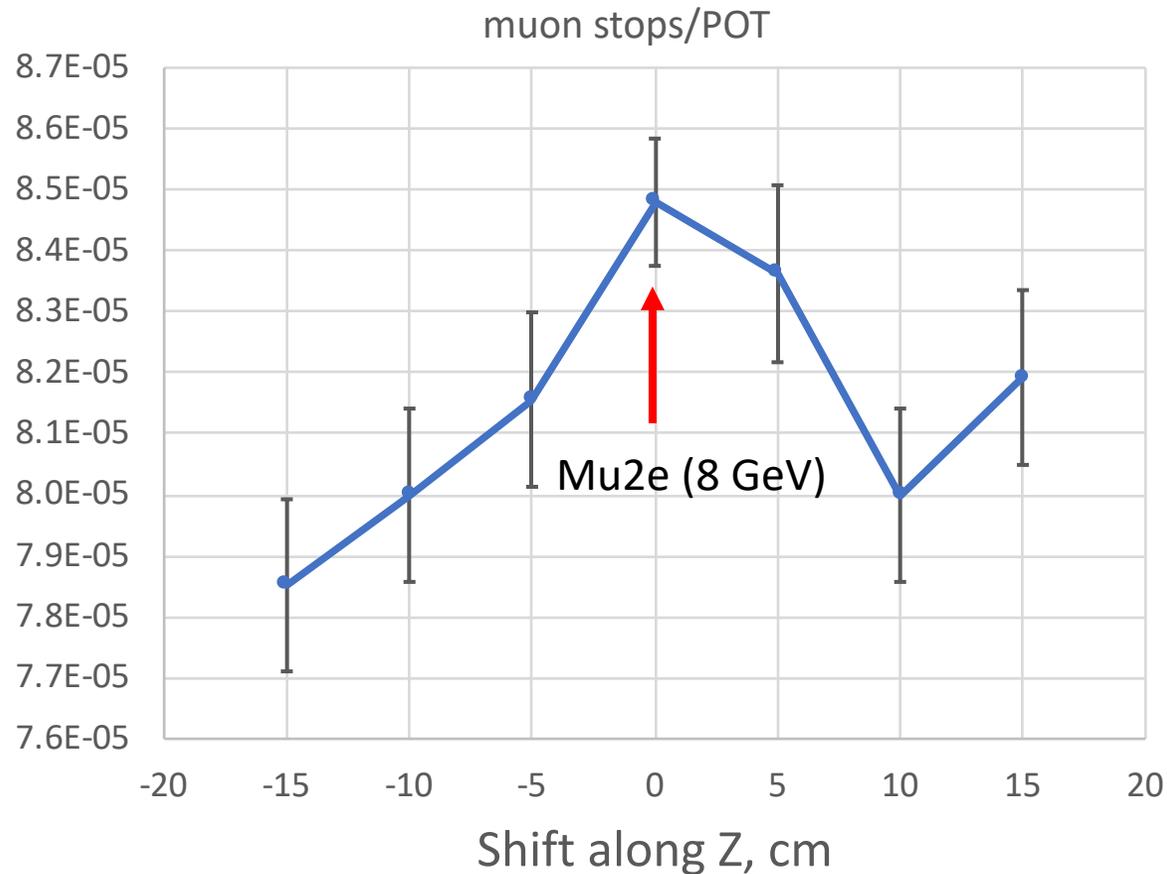
- Total Edep = 17.1 kW; peak DPA (Nordlund) = 2 DPA/yr; min balls required (DPA) = 34/yr
- Motion speed of spherical elements in conveyor is 10 cm/sec
- (4.2 sec for an element to pass the beam). **More balls are required by thermal analysis**

MARS15/Fluka comparison is ongoing



- Disagreement is a few % near the beam entrance but reaches ~20-25% downstream.
- Maybe satisfactory for thermal analysis
- G4bl will be added
- Fluka 2020 (S.Mueller) is looking into kaon production and transport peculiarities to understand Edep underestimation

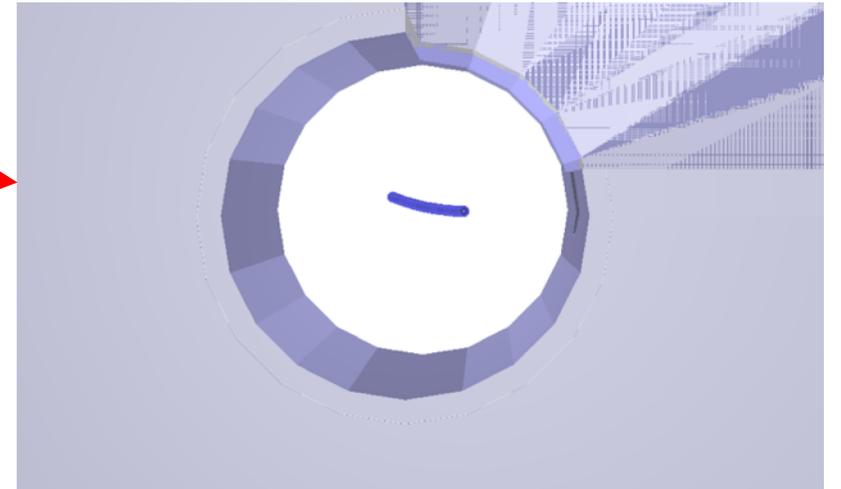
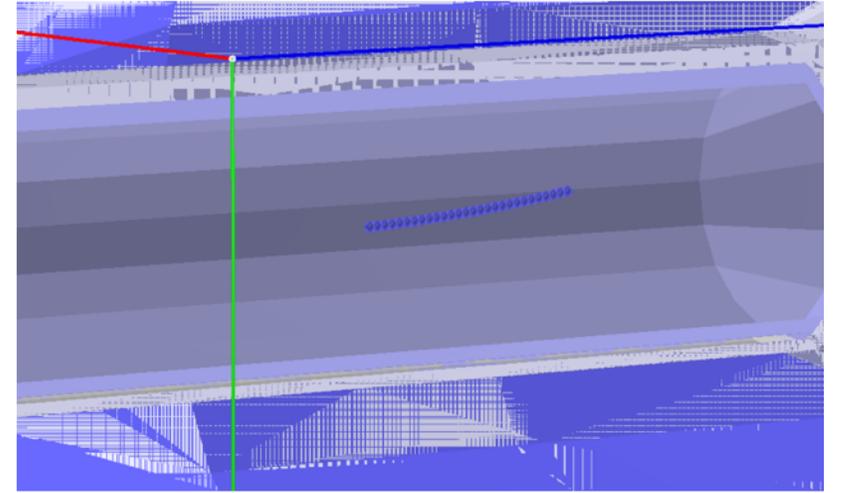
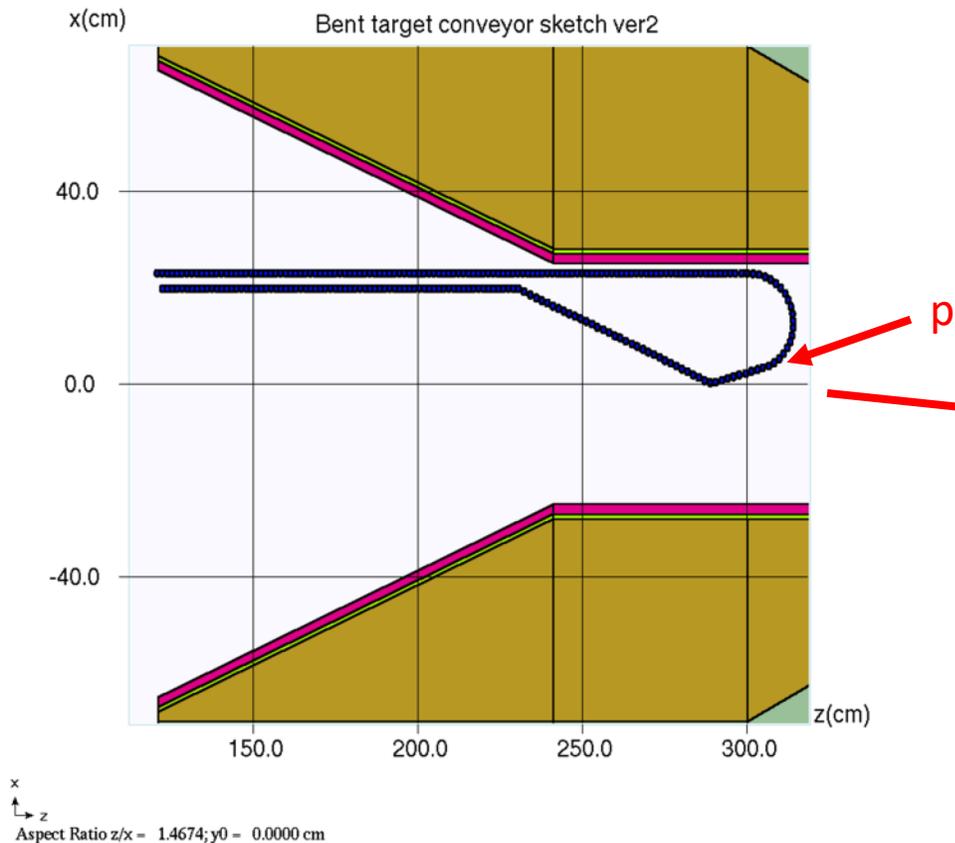
Position and angle of the target (rod)



Mu2e (8 GeV) position and angle of the target within HRS bore seems to be optimal also for the Mu2e-II energy (assuming the PS magnetic field is the same as Mu2e baseline). Re-optimization may be necessary for spherical elements.

Ongoing activities

- Target hardware (full conveyor) modeling is ongoing to estimate its effects on muon stopping rates for implementation in framework



Plot of the C target in framework by M.MacKenzie

Summary and future work

- The conveyor bent target (C or W) is the primary candidate for prototyping
- Lengths, shapes, angles, positions for the target elements have been optimized assuming Mu2e baseline parameters
- We found that energy deposition imposes more constraints on number of target elements in the system (requires more elements) than radiation damage (DPA)
- Target version models are being adopted for framework sensitivity analyses, simulations are ongoing
- Cross-comparisons of MARS15 with Fluka and G4bl are being carried out (angular distributions are the next step)
- Considering both He and convective cooling

	Tungsten/WC	Lower-density bent (Carbon)
Rotated	Requires a large hardware in HRS	Too large to fit HRS
Fixed granular	DPA is too high	DPA is high; lower pion production
Conveyor	Thermal analysis is ongoing	Lower pion production; thermal analysis is ongoing