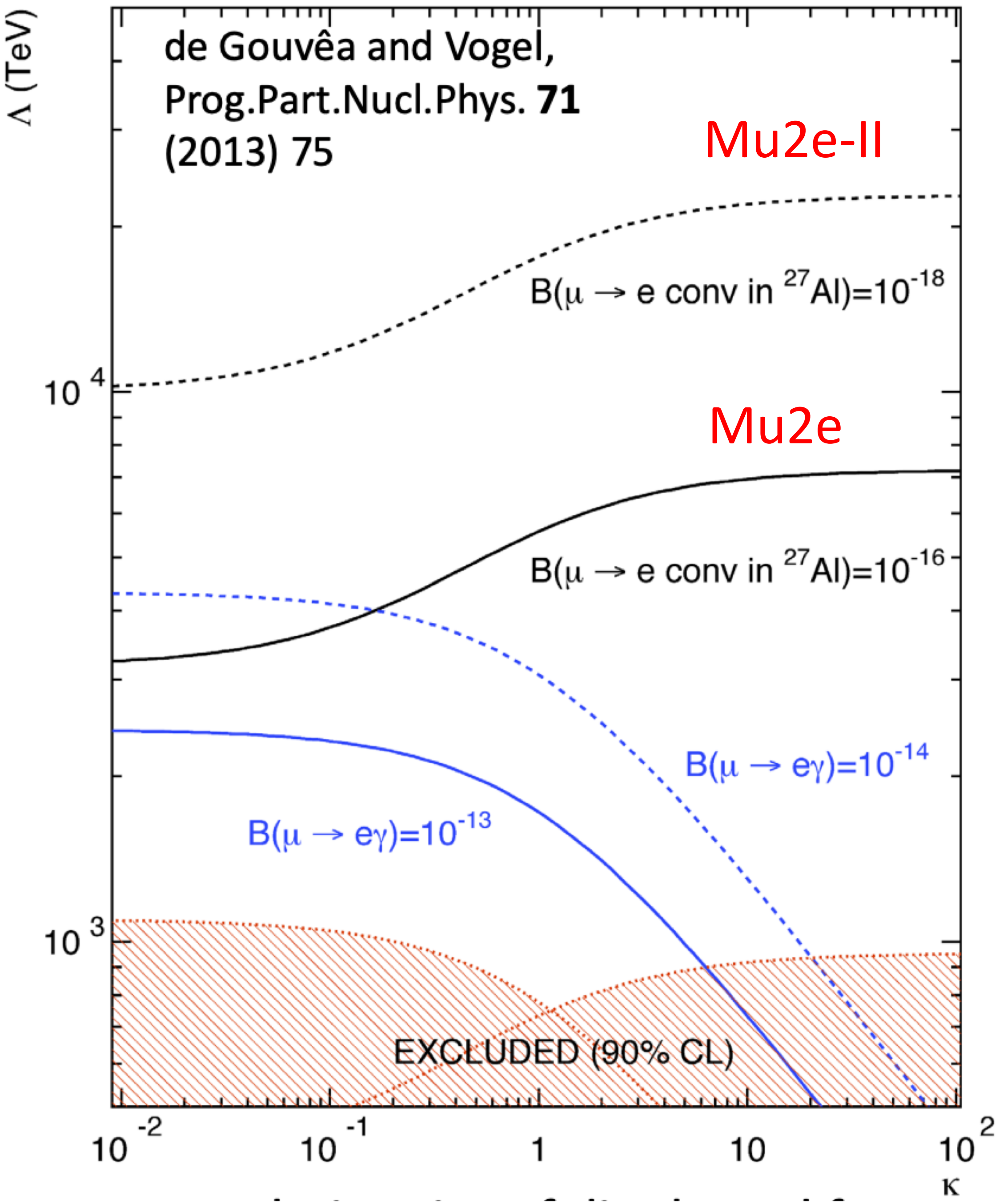
Pion-production target LDRD: status update

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

Mu2e-II Meeting
03/03/21

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).

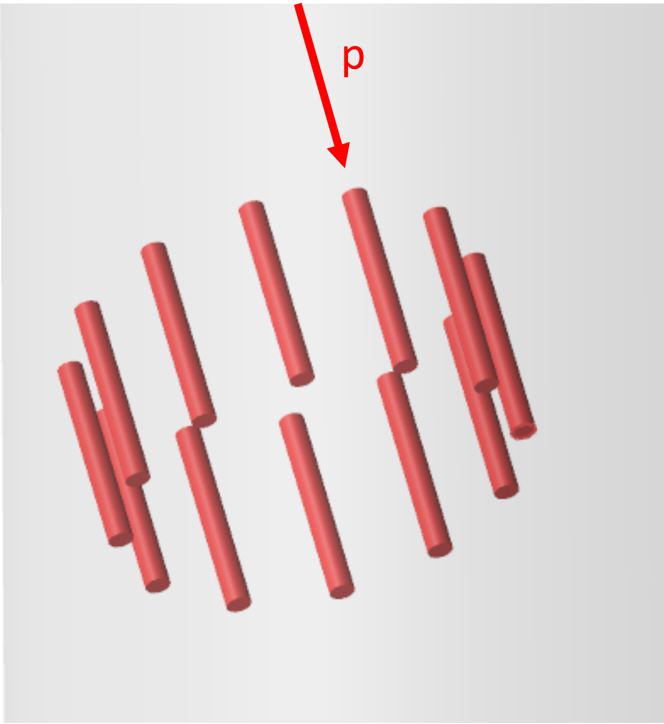


Scope of LDRD

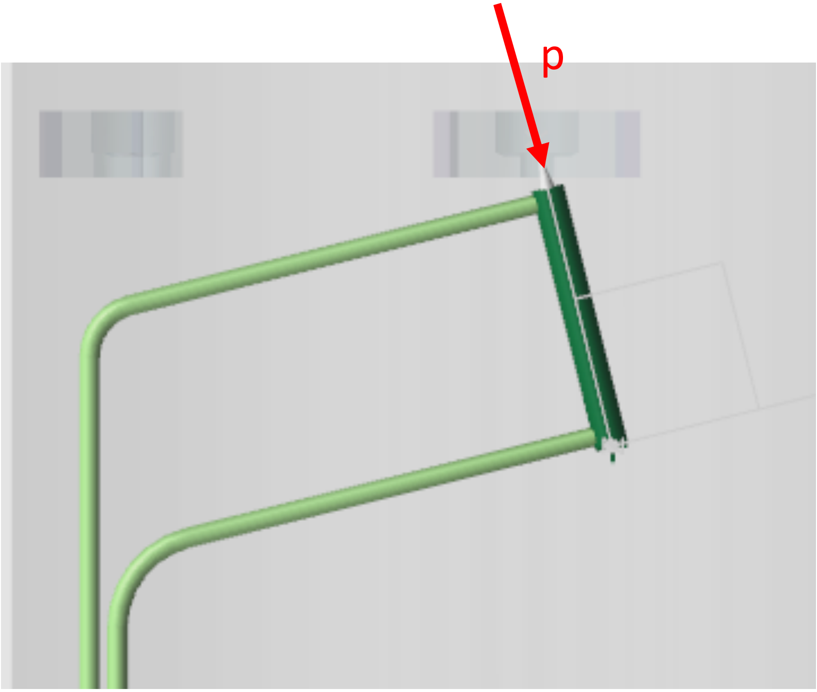
- Project for the PIP-II era: proton current on the Mu2e target could be higher by as much as a factor of 100 compared to the baseline Mu2e (~x10 improvement in the single event sensitivity).
- There is no Mu2e upgrade target concept close to satisfying the new requirements (for a 100-kW 800-MeV proton 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 2020-2021

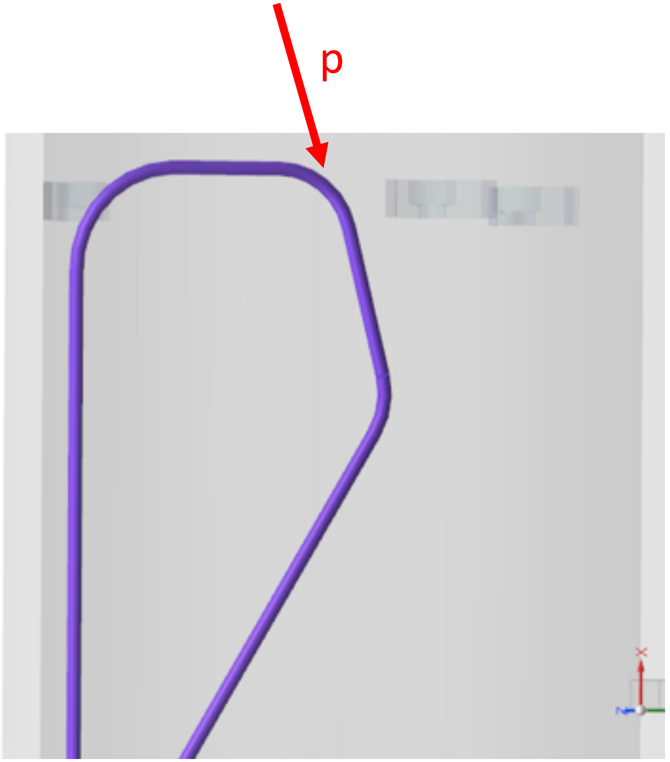
To simulate the overall target pion production performance and durability at beam induced pulsed energy deposition spikes, thermal stress, radiation damage, muon stopping rates, residual activation and radiation loads



Rotating Elements



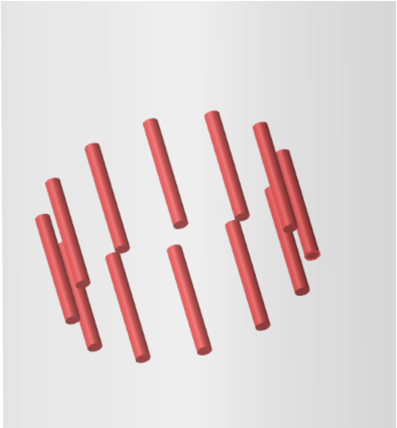
Fixed Granular with Gas Cooling



Conveyor

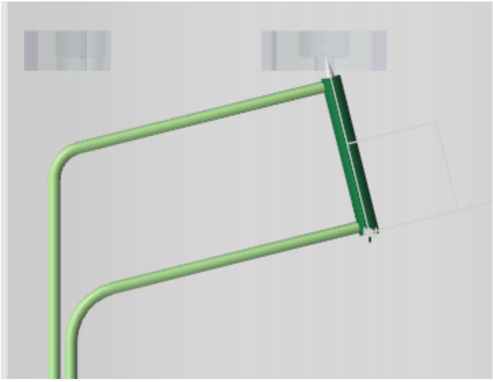
Prioritizing designs

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



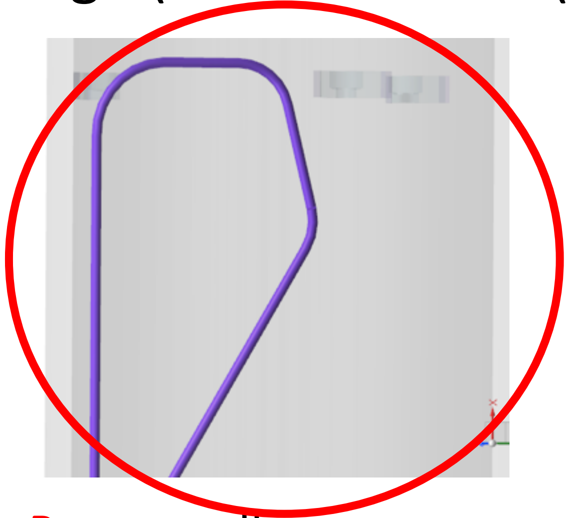
Pros: radiation damage can be distributed over many rods

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



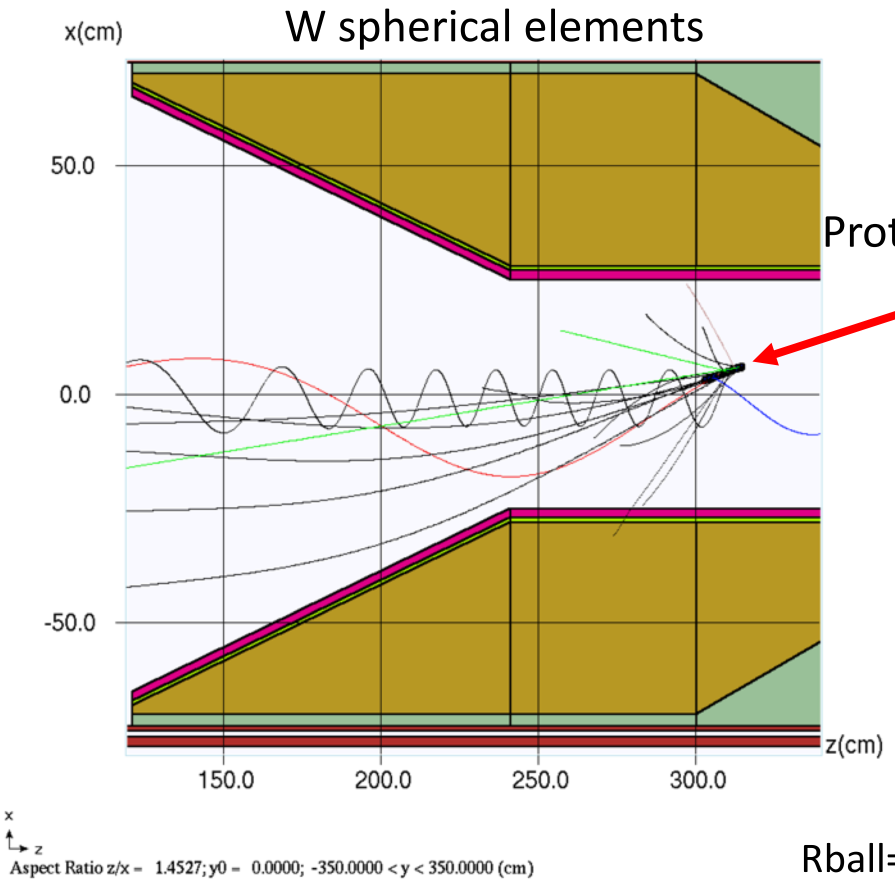
Pros: small space required

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

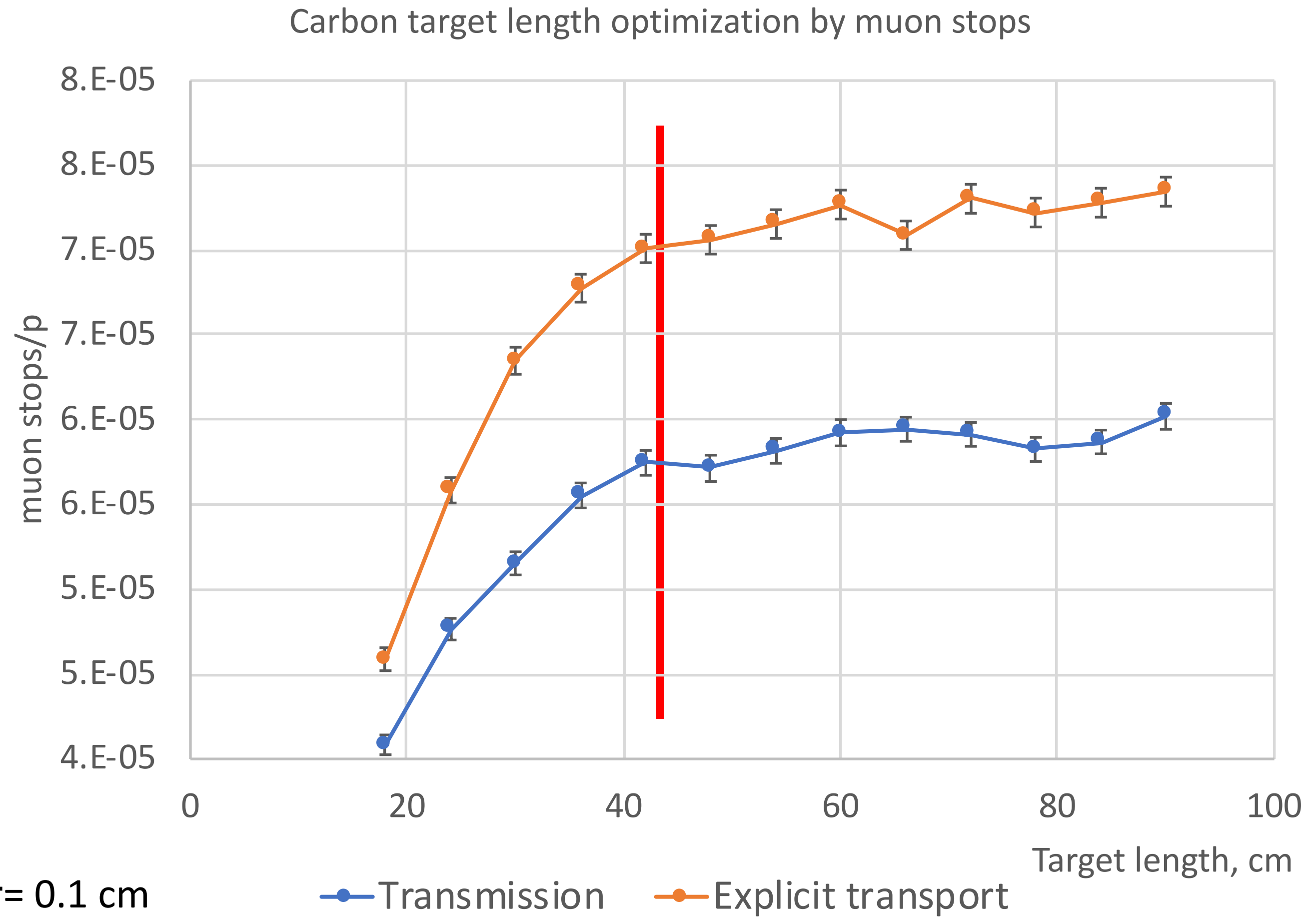


Pros: small space required; He gas could be used for both cooling and moving elements inside conveyor; radiation damage can be distributed; Cons: technical complexity (prototyping needed)

Conveyor target length optimization

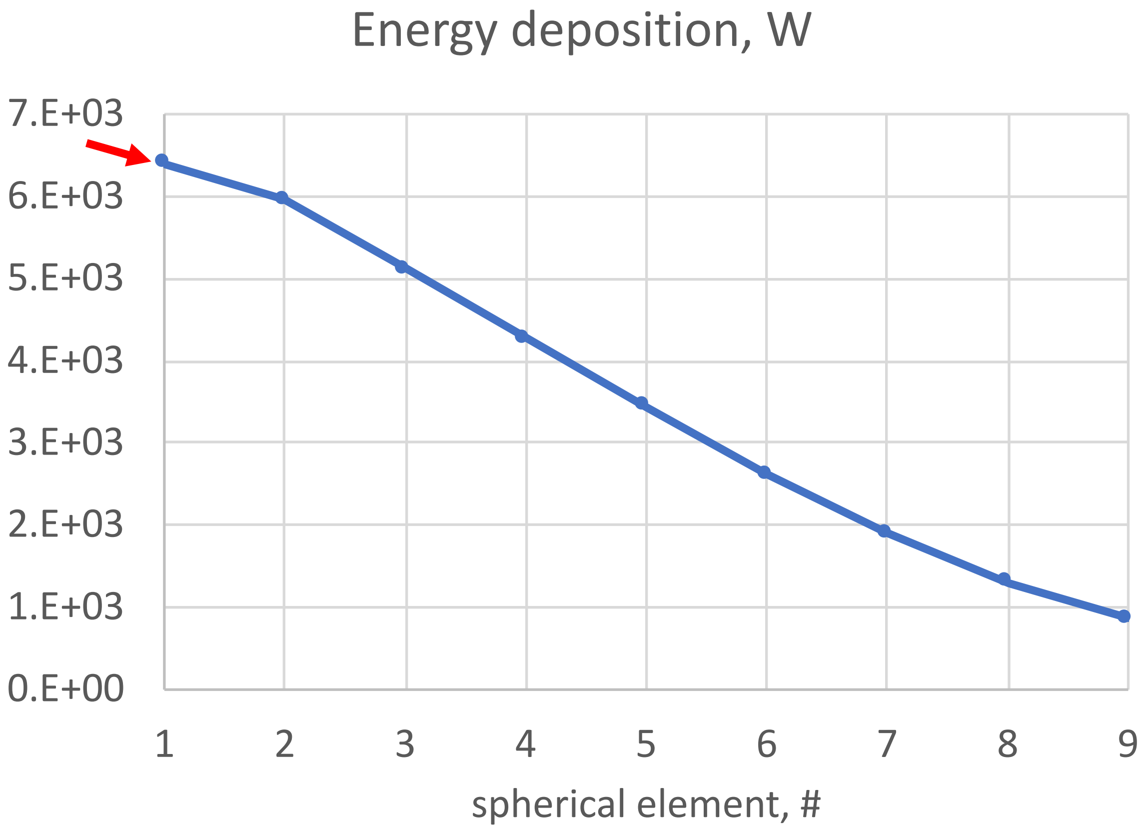


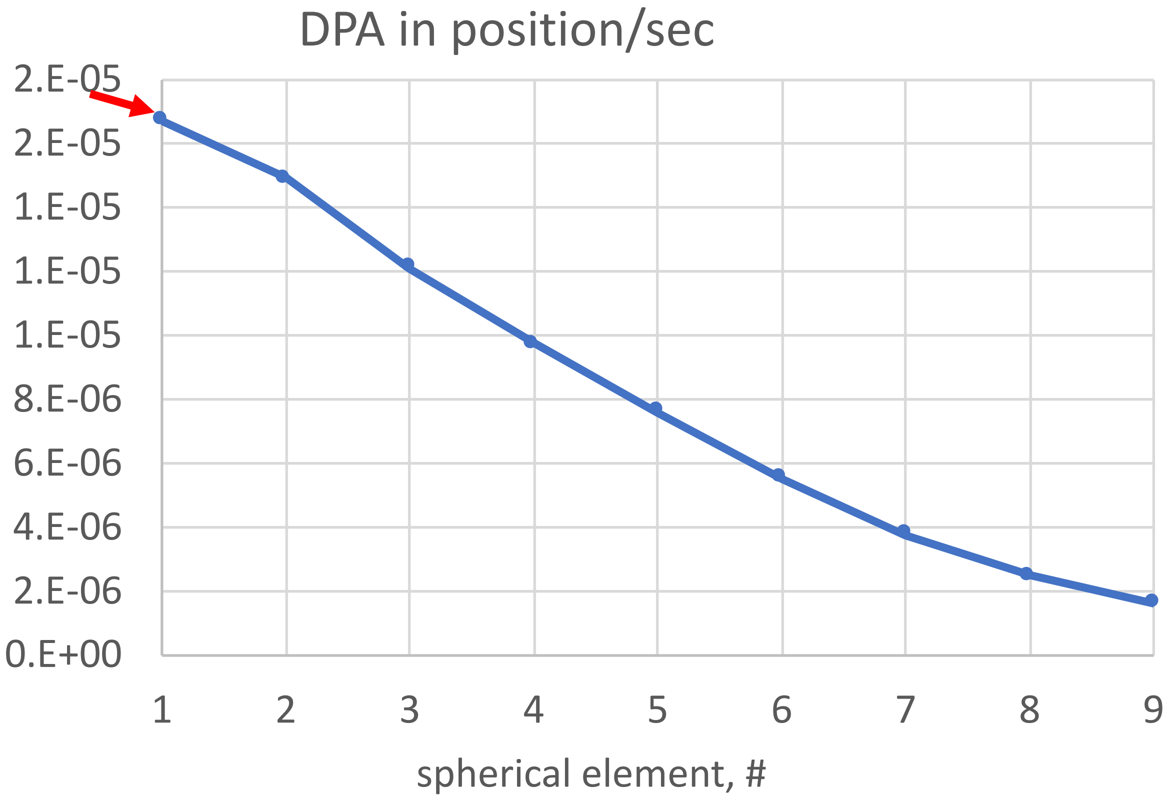
Rball=0.75 cm; σ= 0.1 cm



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.

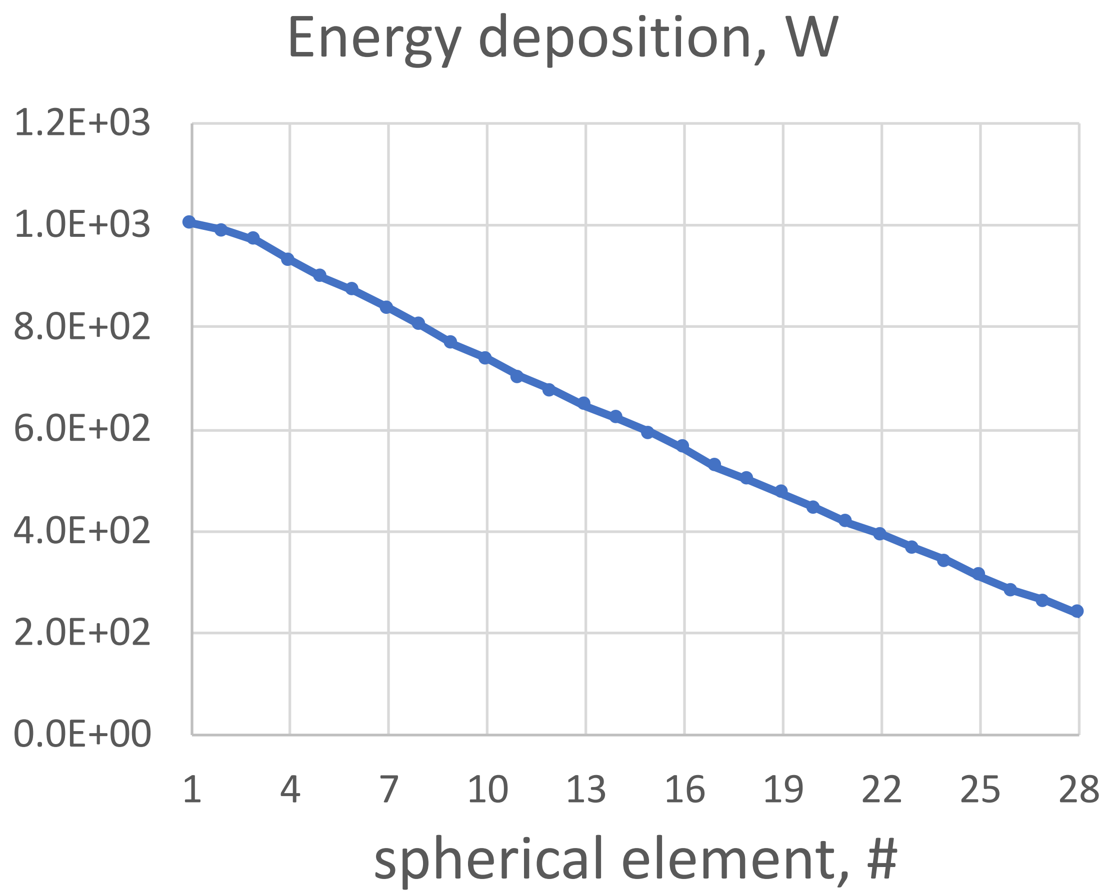
Edep and radiation damage for a W target

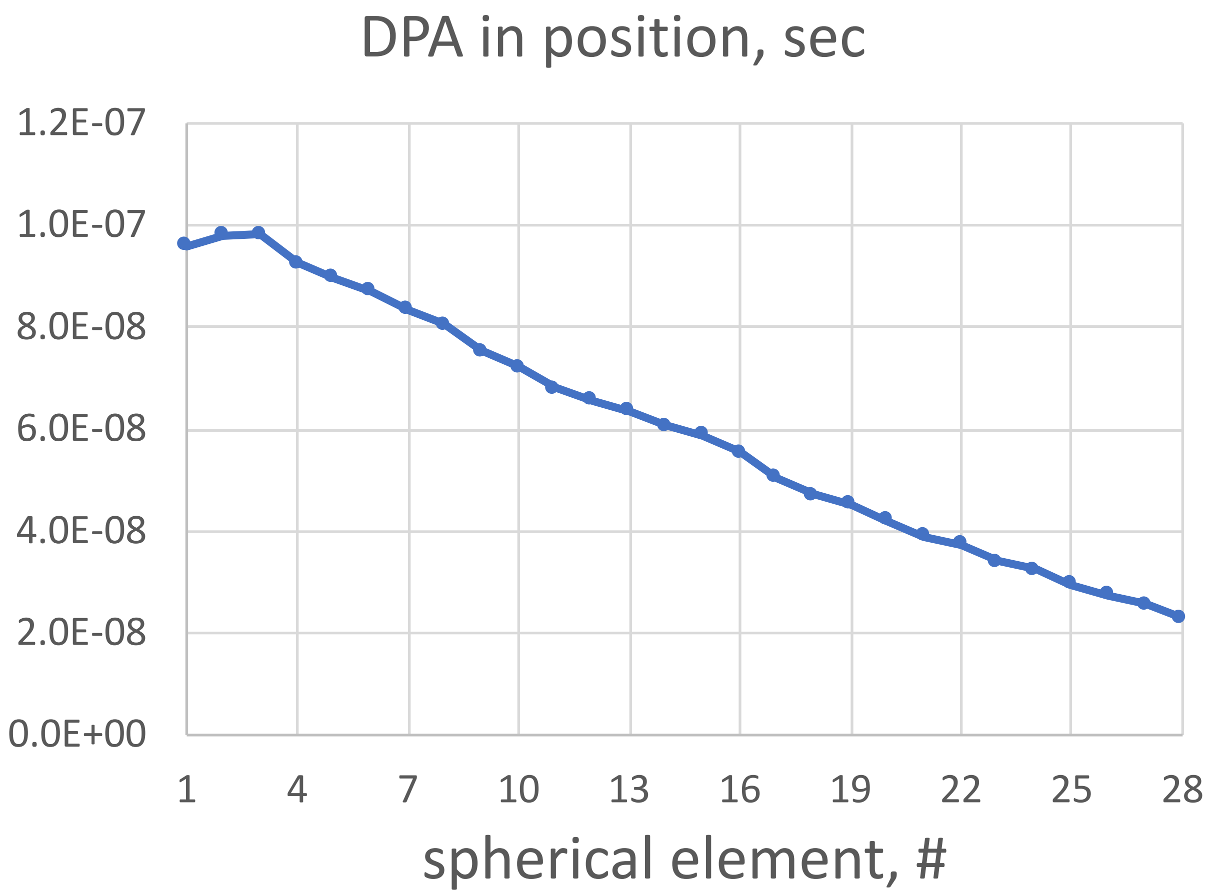




- Total Edep = 31.8 kW; peak DPA (Nordlund) = 330 DPA/yr; min balls required (DPA) = 150/yr
- Motion speed of spherical elements in conveyor is 10 cm/sec
- (1.35 sec for an element to pass the beam). More balls are required by thermal analysis

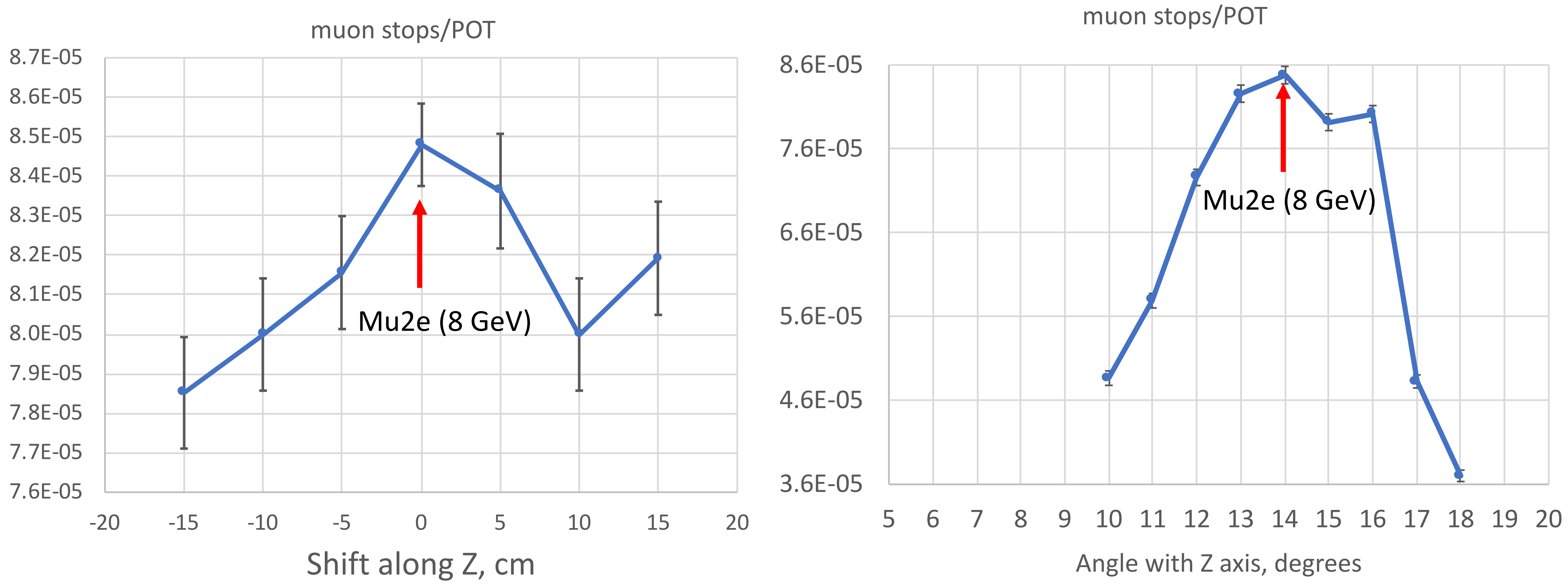
Edep and radiation damage in the C target





- 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 (see S.Mueller's talk for FLUKA)
- (4.2 sec for an element to pass the beam). More balls are required by thermal analysis

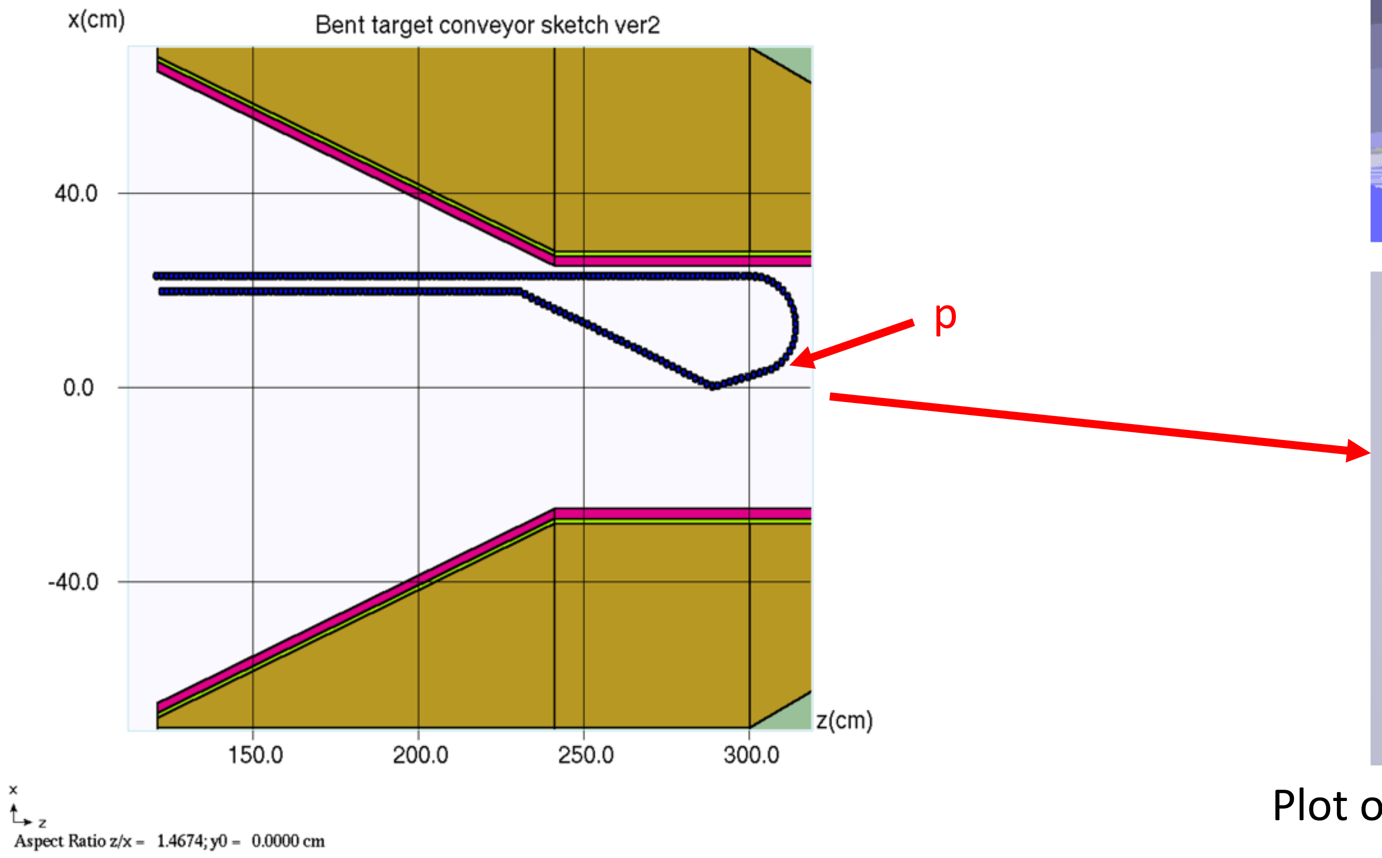
Position and angle of the target (rod)

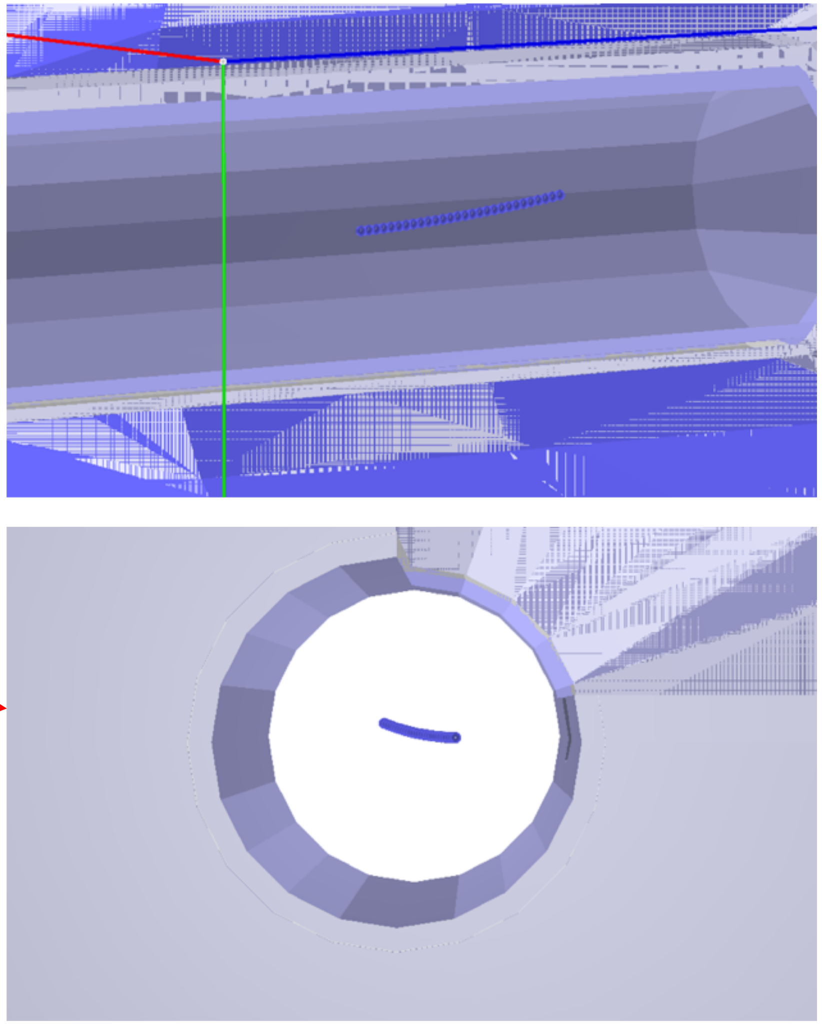


Mu2e (8 GeV) position and angle of the target within HRS bore seems to be optimal also for the Mu2e-II energy (assuming the PS magnetic field is the same as Mu2e baseline). Re-optimization may be necessary for spherical elements.

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

- **Silicon Carbide performed the best in terms of temperature, stress and deformation. However, it takes twice as much time to obtain the energy the Conveyor Target requires.**
- **With nearly half of the travel distance, Tungsten Carbide displayed much better performance in all accounts with respect to Tungsten.**
- **Even though the temperature of the Tungsten ball is the highest, the stress on the ball is still very low.**
- **Please note the highest stress at the support is not real since they are grossly simplified with no real geometry attached.**
- **All in all, the proposed conceptual design is reasonable and sensible.**