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NuFACT22

Design and Prototype for a Pion-production Target for Mu2e-II

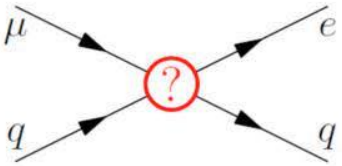
Outline

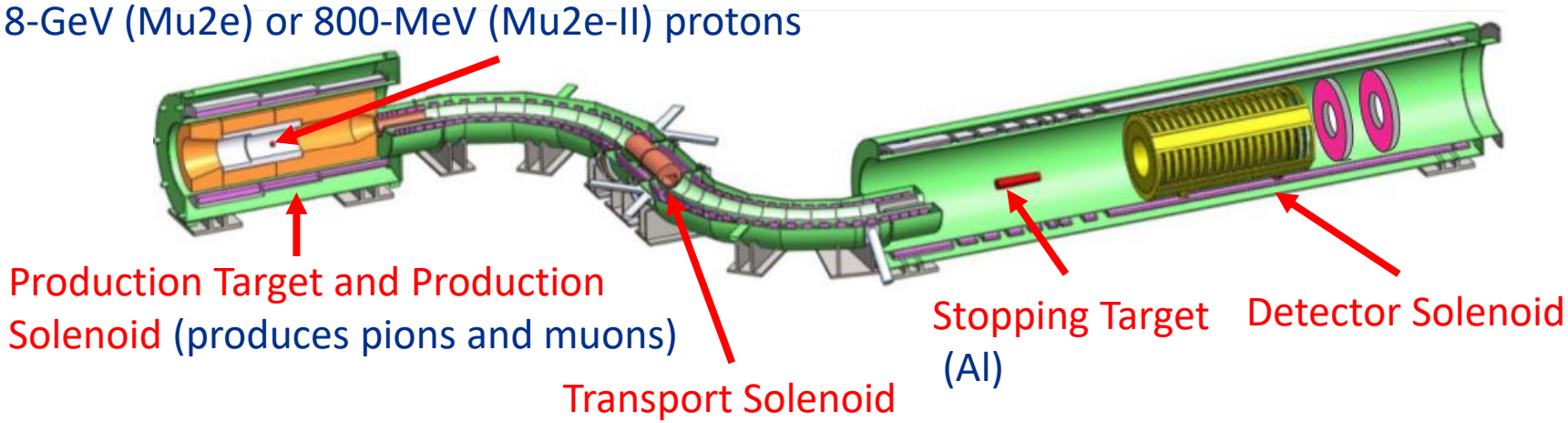
- Introduction
  - **Mu2e → Mu2e-II**
  - Mu2e target features
  - Mu2e-II required modifications
- Laboratory Directed Research and Development (**LDRD)** project
  - Tested approaches
    - Simulations, etc.
  - Summary results
- Prototype with Euclid Techlabs
  - Description
  - Test results
  - Next changes
- Summary and conclusions

The Mu2e experiment and its upgrade Mu2e-II

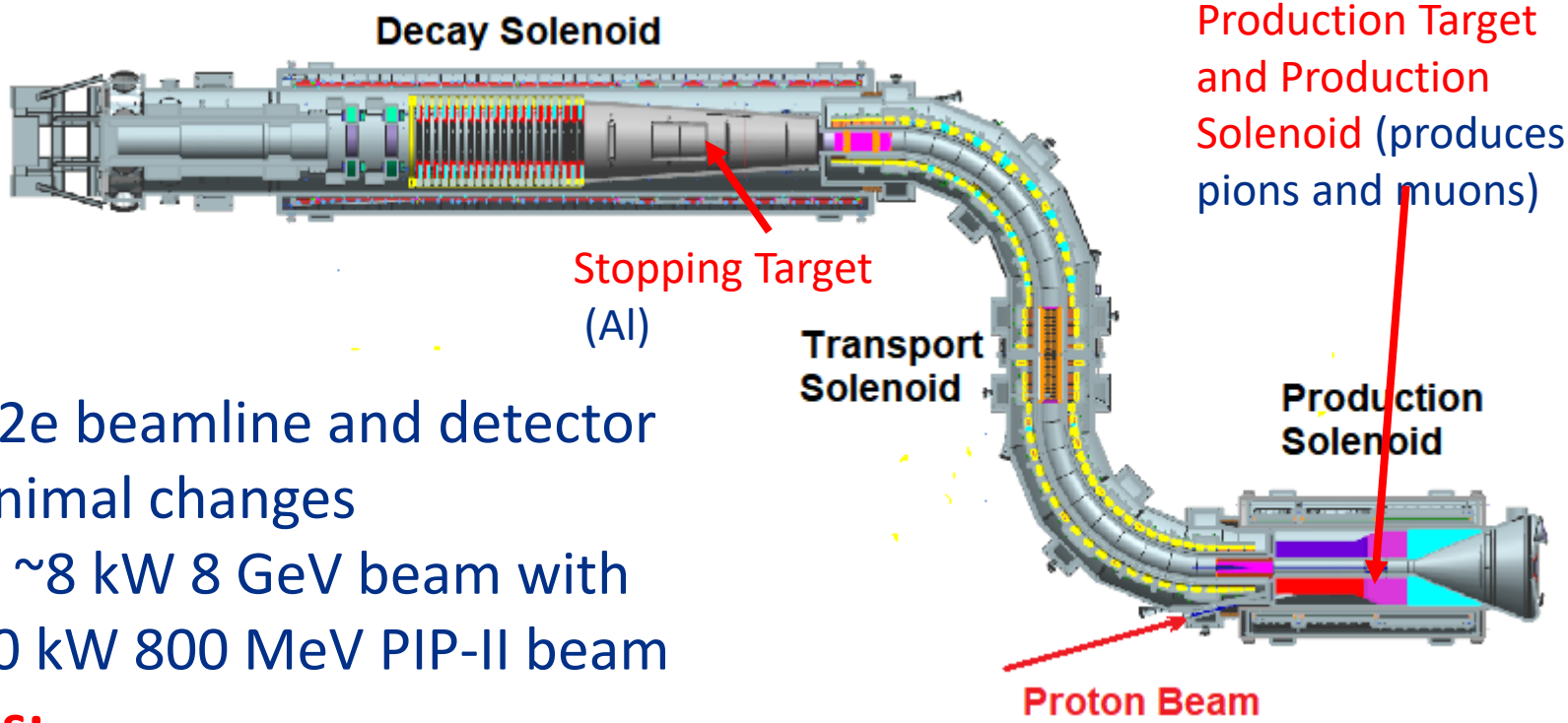
- Mu2e searches for lepton number violation by observing the conversion of a muon into an electron in a nucleus.
  - Create π/μ from p on target
  - μ^- captured in target
  - Wait for 105 MeV e^- from decay
    - Background : $\mu^- \rightarrow e^- \nu\tilde{\nu}$

$$\mu^- + Al \quad e^- + Al$$





The Mu2e experiment and its upgrade Mu2e-II



8-GeV (Mu2e) or 800-MeV (Mu2e-II) protons

Use Mu2e beamline and detector with minimal changes

Replace ~8 kW 8 GeV beam with

>100 kW 800 MeV PIP-II beam

Requires:

cw 800 MeV PIP-II beam

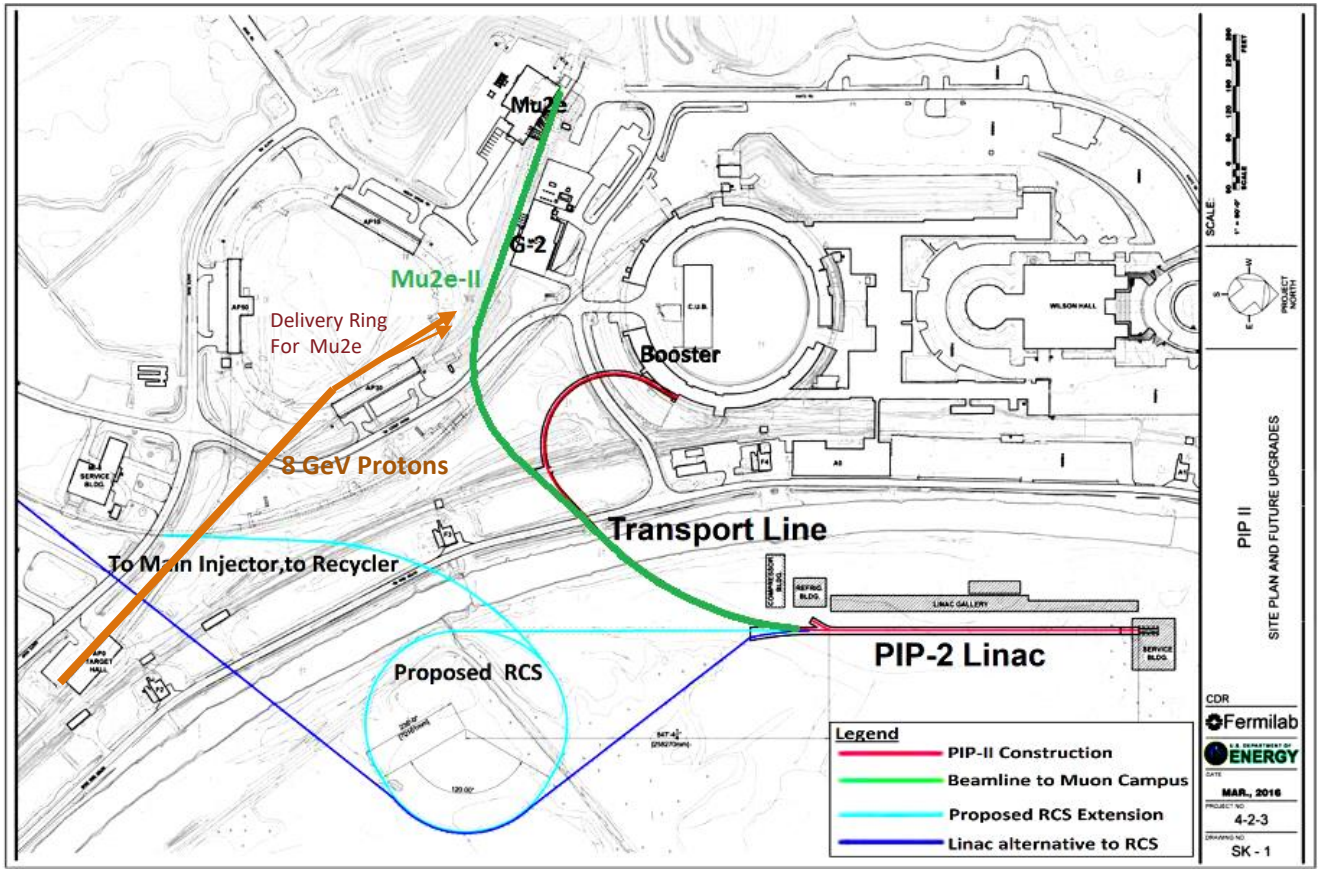
Transport to Mu2e

Optics match to 800 MeV

Target within solenoid for ~100 kW

Tevatron target was 79 kW

Accelerator beamline geography

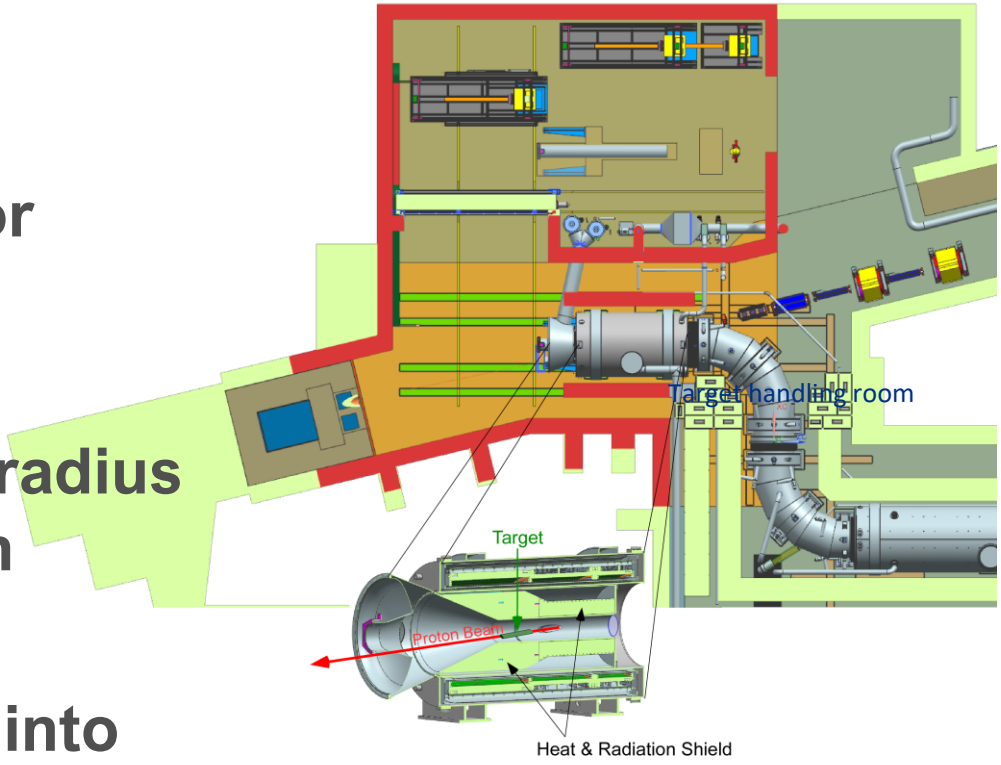


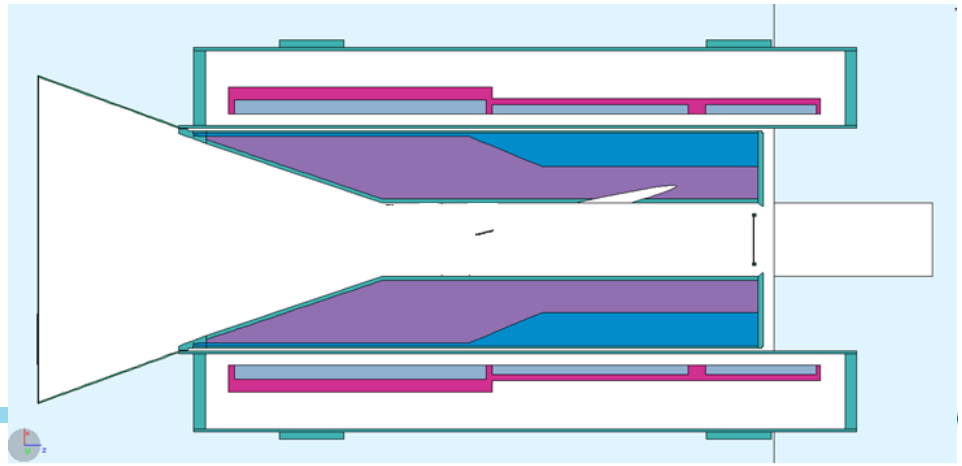
Mu2e_II vs Mu2e parameter comparison

Parameter	Mu2e	Mu2e-II	Comment
Proton Source	DR- slow extraction	PIP-II Linac	
P kinetic energy	8 GeV	0.8	
Beam power	8 kW	100 kW	Mu2e-II can be increased
Proton/s	6.25×10^{12}	7.8×10^{14}	
Pulse cycle	1.693 µs	1.693 µs	Variable for Mu2e-II
Proton rms emittance	2.7	0.25	mm-mrad, normalized
Proton geom. emitt.	0.29	0.16	mm-mrad, unnormalized
Proton energy spread	20 MeV	0.275 MeV	
Δp/p	2.25×10^{-3}	2.2×10^{-4}	
Stopped µ per proton	1.59×10^{-3}	9.1×10^{-5}	
Stopped µ per cycle	~6×10^{4}	1.2×10^{5}	PIP-II is cw; DR not
Stopped µ per year	10^{17}	10^{18}	

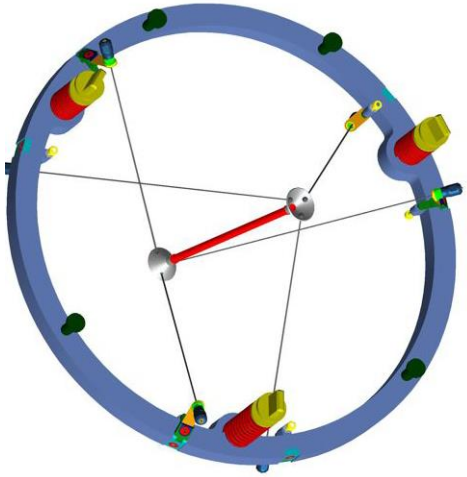
Target station detail

- Mu2e targets design for robotic insertion and replacement
- Must fit within ~20 cm radius of HRS shielding within solenoid
- Mu2e-II target must fit into similar hole and remote handling

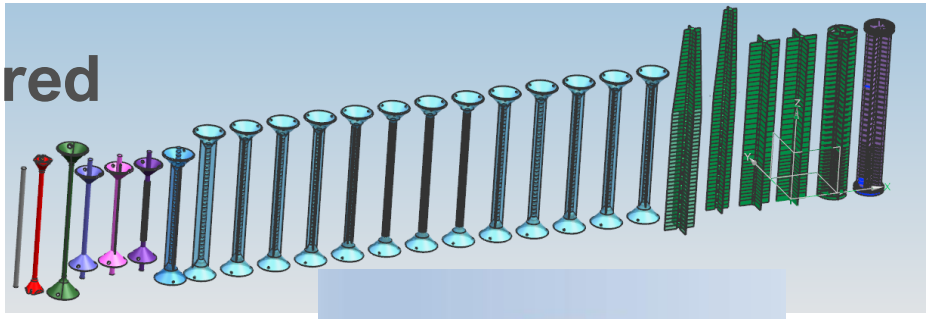


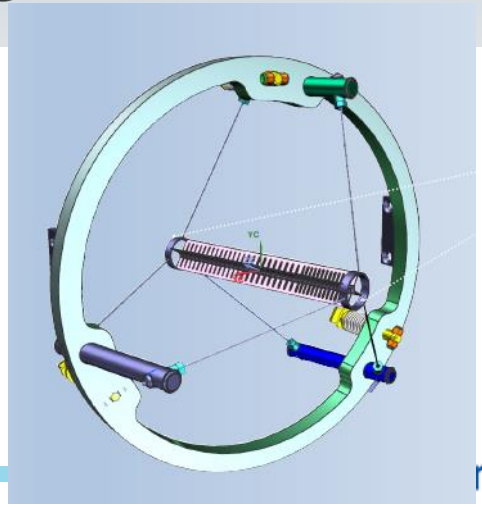


Mu2e target development



- Mu2e target – 8kW, 8GeV beam
  - Radiatively cooled W target
  - Supported within frame for robotic remote handling
    - Easy insertion, replacement
- Initial design hotter than desired
  - T > ~1500° C
    - Crystallization of material
  - Added fins, segmentation
    - spreads out heating, increases radiation
  - T < 1130° C





Mu2e-II target design → LDRD project

- Project Title: Design of a Mu2e upgrade Target Station with the optimal physics performance for the PIP II era

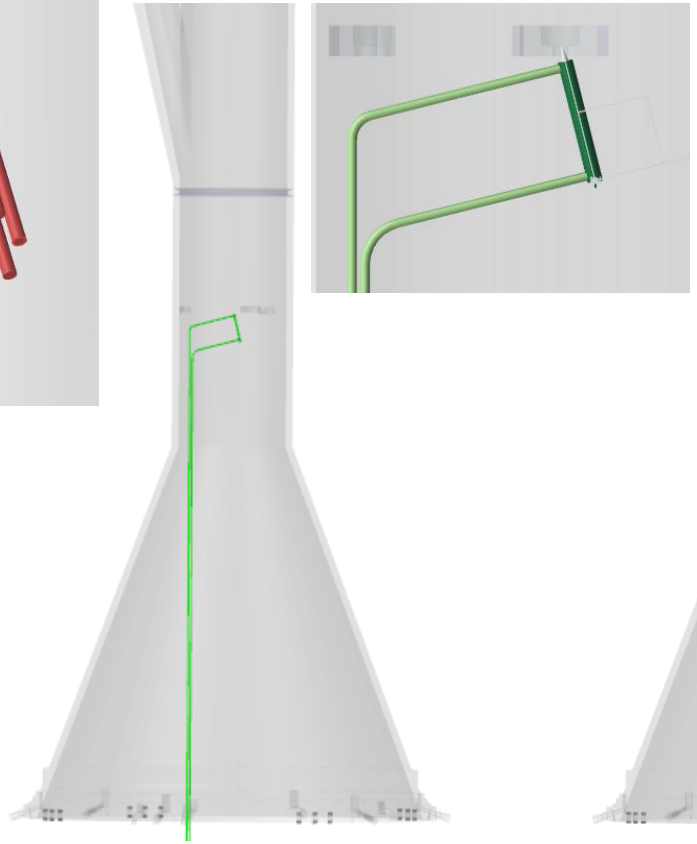
  Principal Investigator: Vitaly Pronskikh
- Co-Investigators (w/institutions): Jim Popp (CUNY), Kevin Lynch (CUNY), David Neuffer (Fermilab), Dave Pushka (Fermilab), Ingrid Fang (Fermilab).

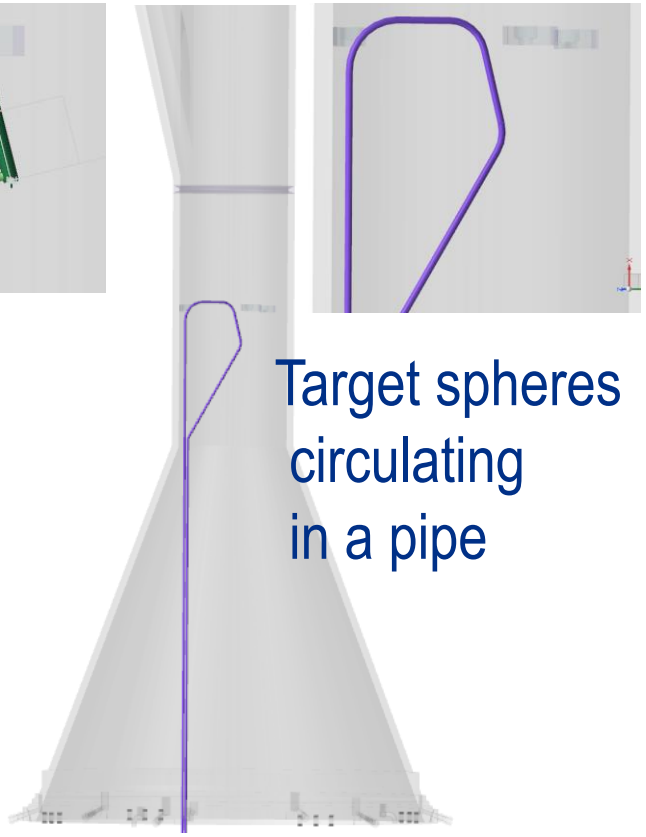
Deliverables:

- **Mid-2020 – Mid-2021: plausible design(s) for the Mu2e-II target.**
- **Mid-2021 – Mid-2022: prototype designed, built, and tested. Conclusions regarding feasibility and future development**
-

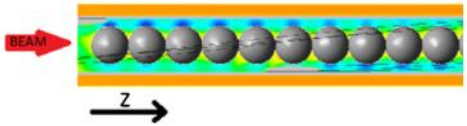
Designs Under Investigation

Rotating Elements **Fixed Granular with Gas Cooling** **“Conveyor”**



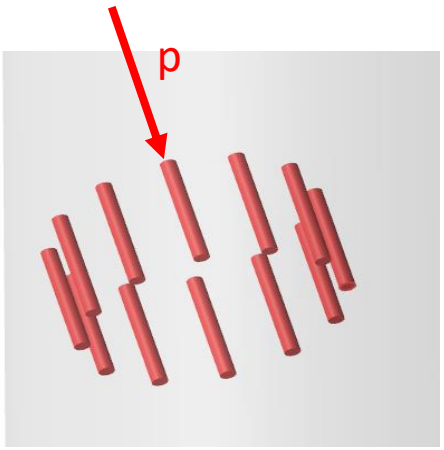


Target spheres circulating in a pipe

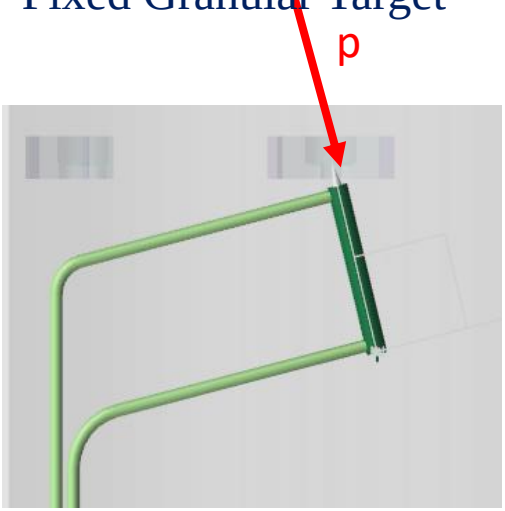


Prioritizing the designs under consideration for prototyping

Rotating Elements



Fixed Granular Target



Pros: heating and radiation damage can be distributed over many rods

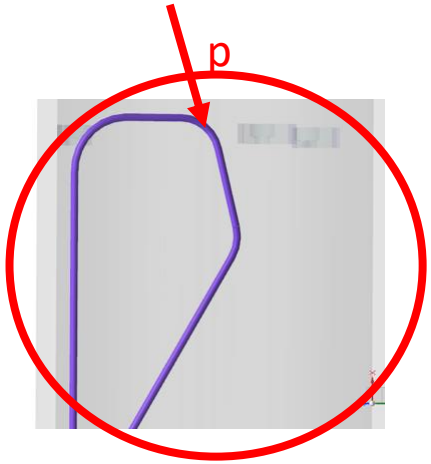
Cons: hardware (Targets plus supports plus rotation mechanism) would occupy a large space inside the bore (complicates cooling and π/μ transmission)
Radiation cooling is inefficient

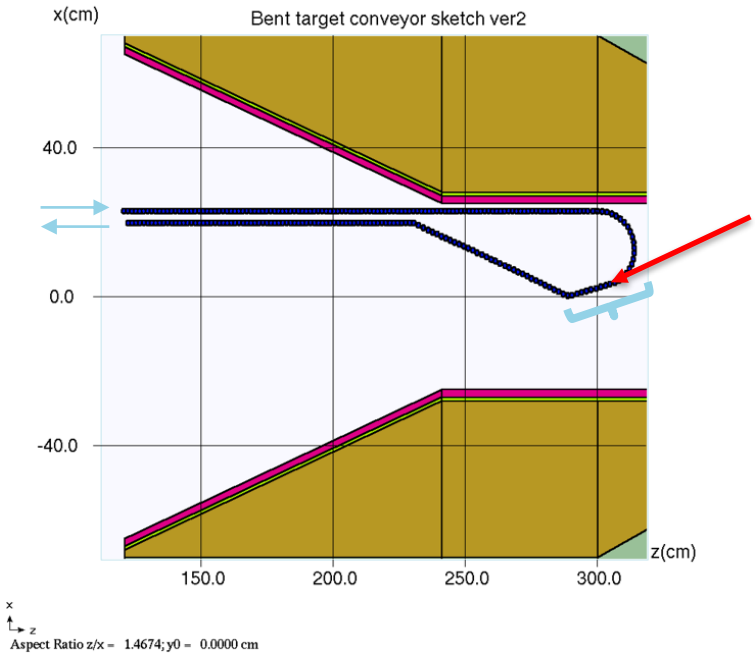
Pros: small space required

Cons: peak DPA (MARS15) >300/yr; gas cooling system difficult,
Cannot be performed efficiently

Prioritizing the designs under consideration for prototyping

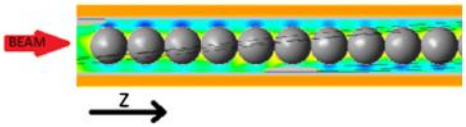
Conveyor

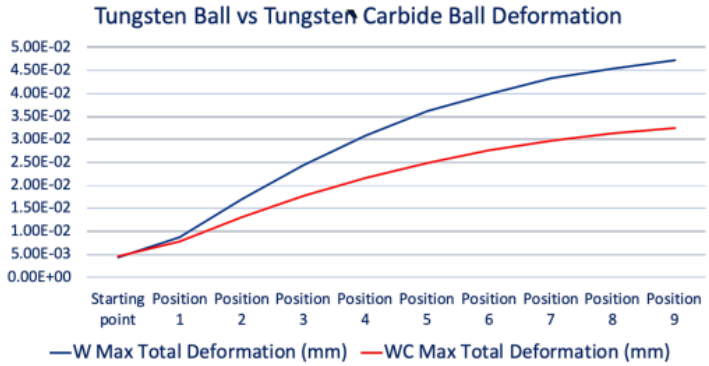




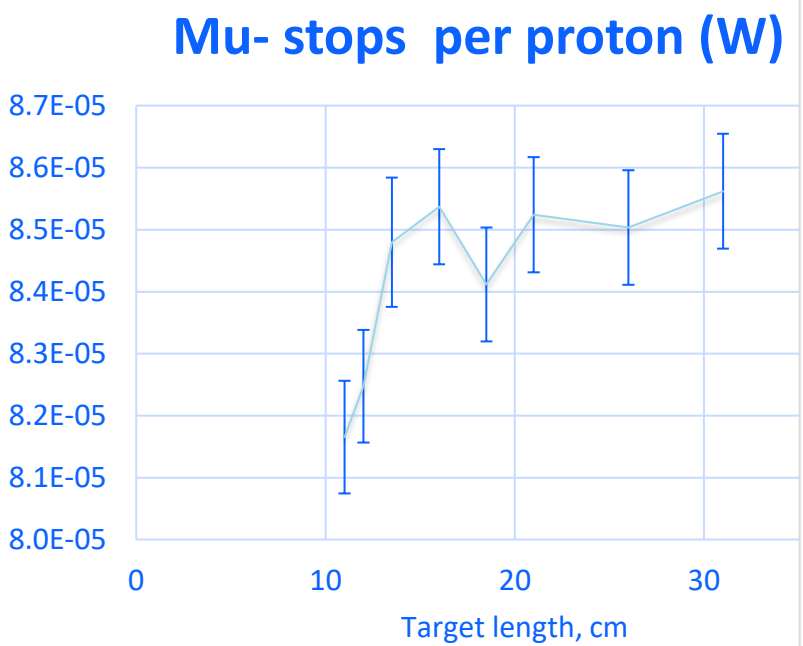
Pros: small space required;
two-phase ammonia could be used for both cooling and moving elements inside conveyor;
radiation damage can be distributed;

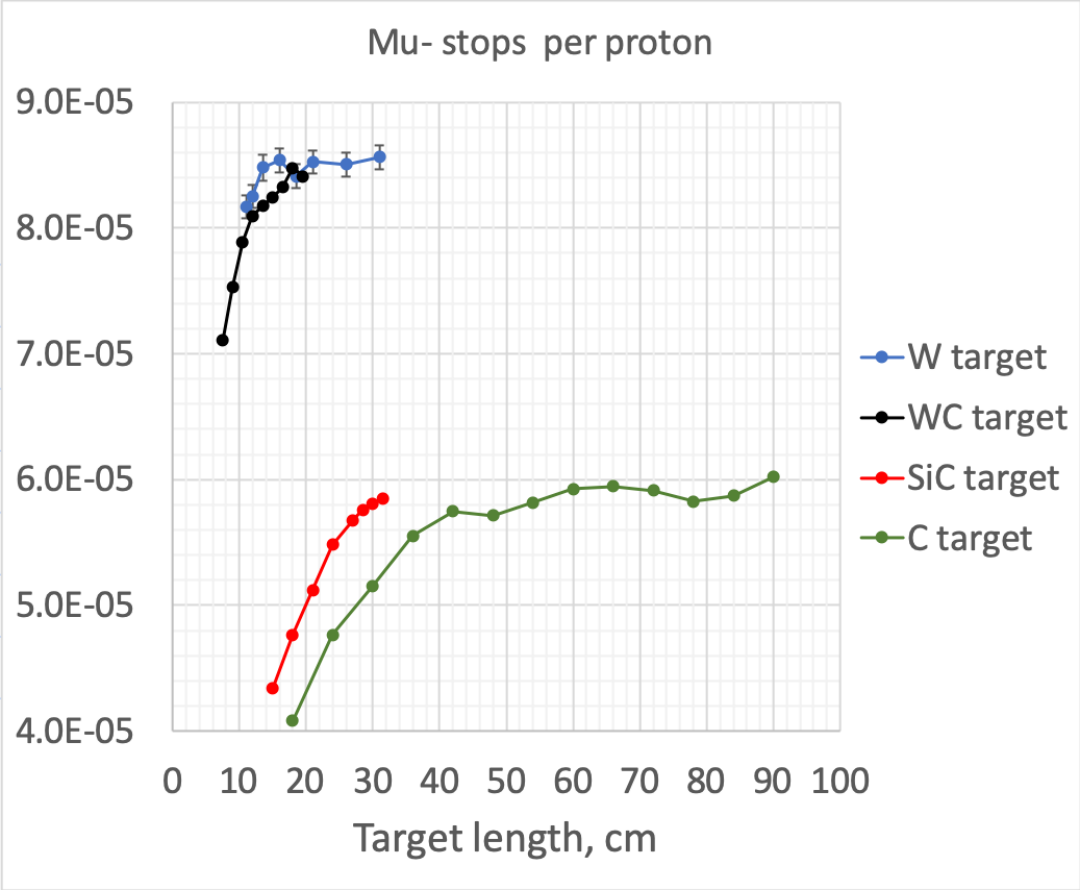
Cons: technical complexity (prototyping needed)





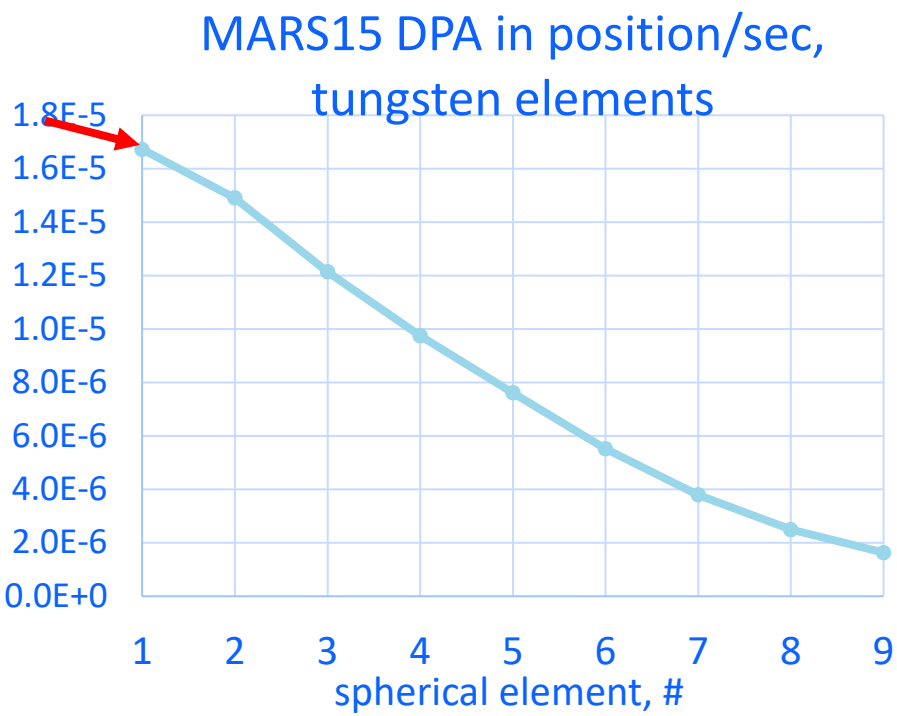
Target optimization

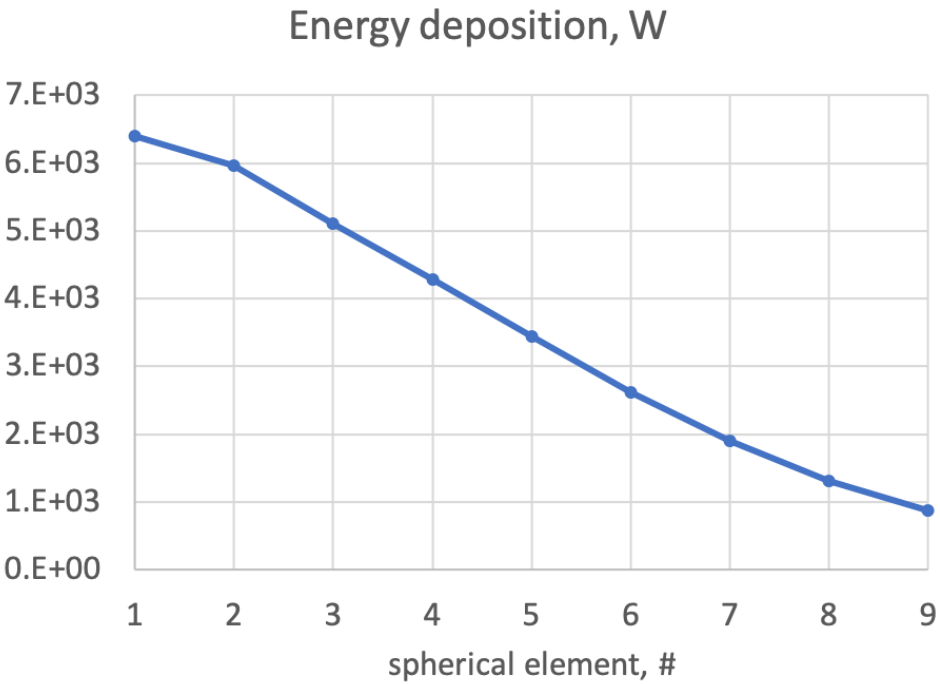




Based on muon stopping rate studies with MARS15 and G4beamline the optimal target lengths were determined to be: 28 balls (C target), 9 balls (W and WC targets), 19 balls (SiC); MoGRCF was studied, too. Spheres were 0.75 cm radius; tried also 0.5, 0.63 cm.

Interaction length and DPA



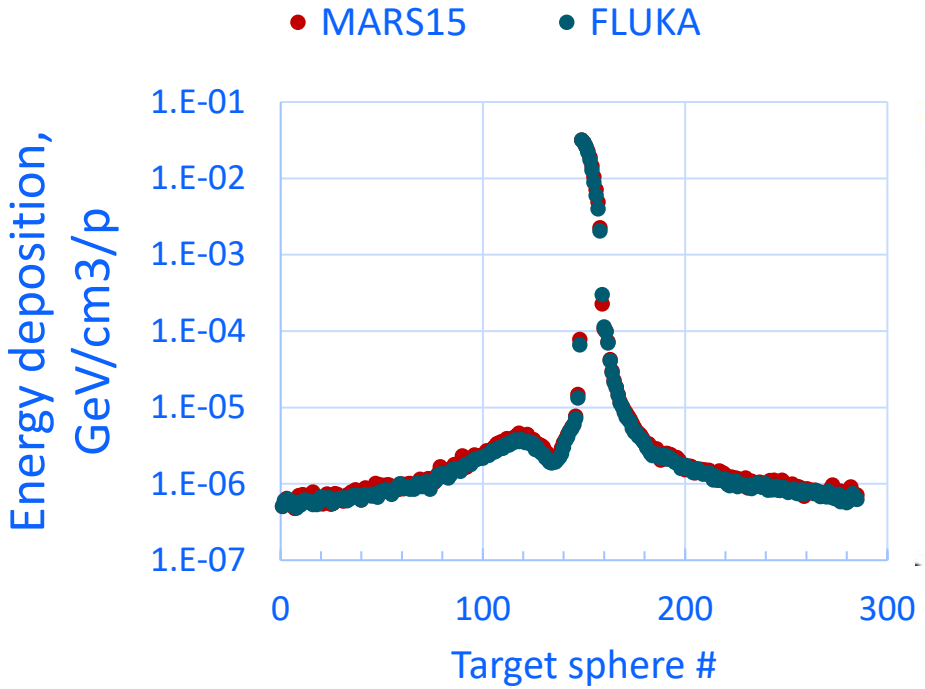


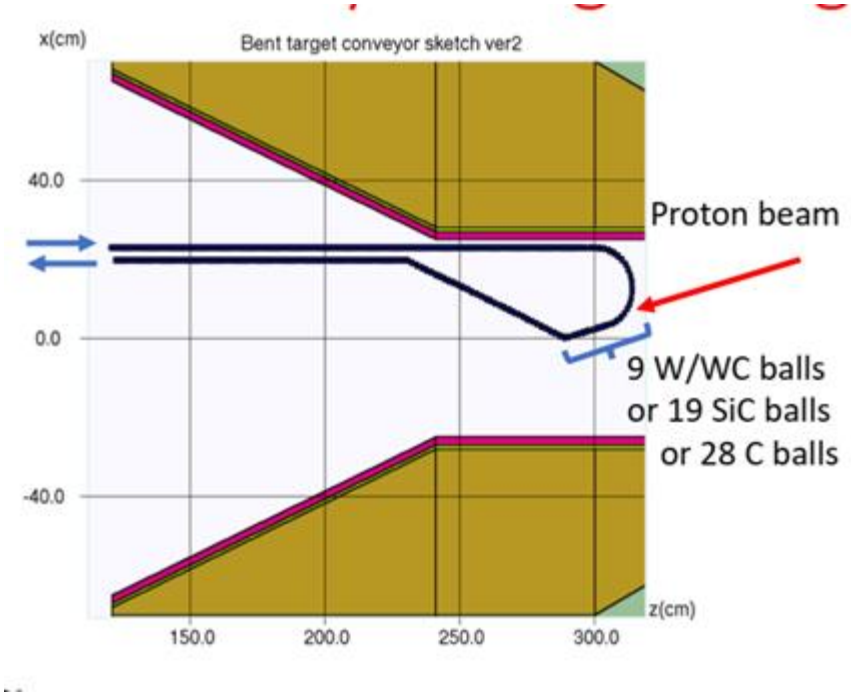
min balls required (DPA) = 150/yr

Radiation is reduced by increasing number of circulating spheres need at least 150 to reduce below limit. (Expect ~300 in complete recirculating target.)

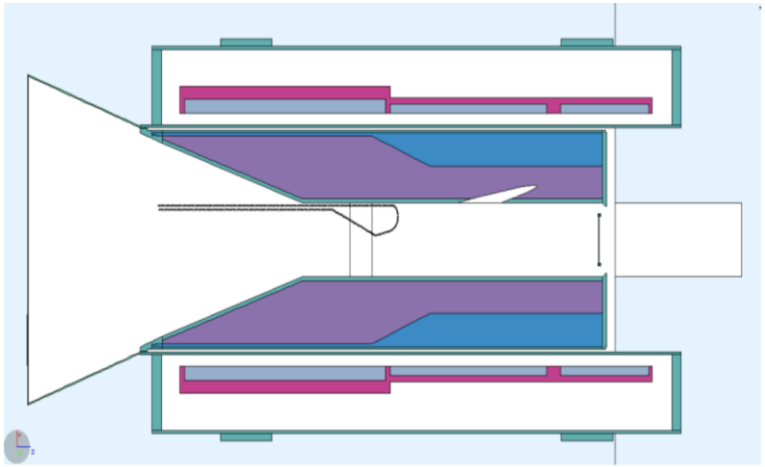
Work is underway to reconcile the results of MARS15 and FLUKA DPA calculations

Energy deposition for a W target



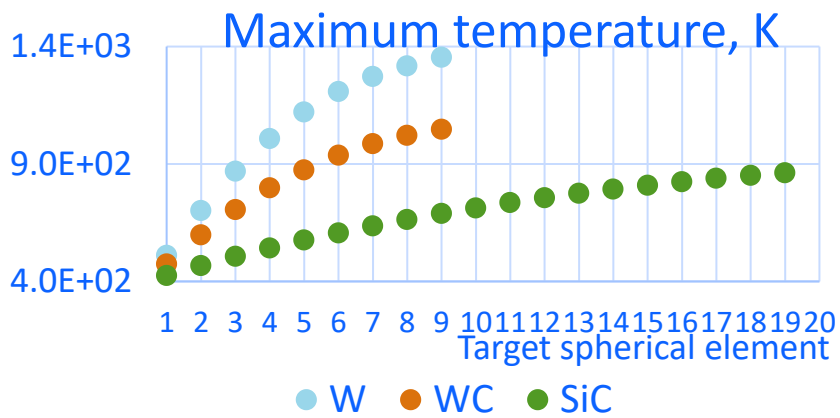


FLUKA model

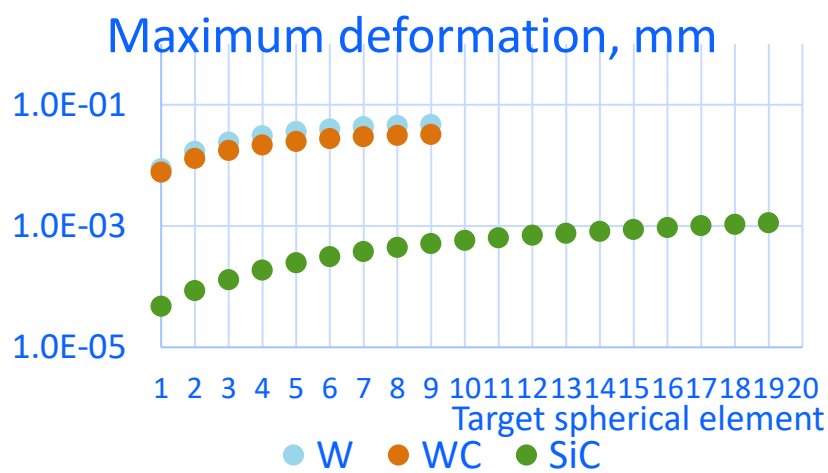


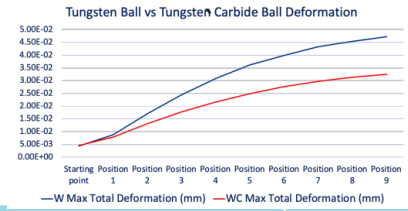
- MARS15/FLUKA data agreement is better than 20% for energy deposition.
- Total E_{dep} = 31.8 kW; peak DPA (Nordlund) = 330 DPA/yr (assuming fixed balls in beam, no tubing);
- Motion speed of spherical elements in conveyor is 10 cm/sec, DPA limit assumed <= 10
- (1.35 sec for an element to pass through the beam).

Thermal and mechanical ANSYS analyses: conveyor



Melting points:
3422 C for W; 2870 C for WC; 2730 C for SiC

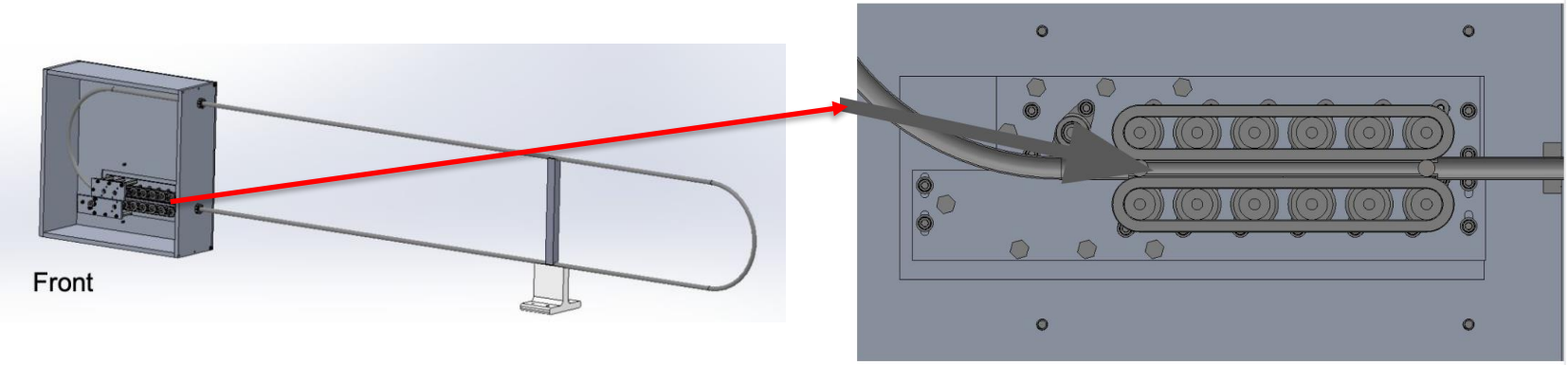




	Tungsten/WC	Lower-density bent (Carbon or SiC)
Rotated	Requires large hardware device inside HRS	Too large to fit in HRS
Fixed granular	DPA is too high	DPA is high; lower pion production
Conveyor	Thermal and mechanical analyses are ongoing; currently looks feasible	Lower pion production; thermal analysis is ongoing; currently looks feasible

Maximum deformation must be compared to the deformation of tubing

Initial prototype design (Euclid Techlabs)

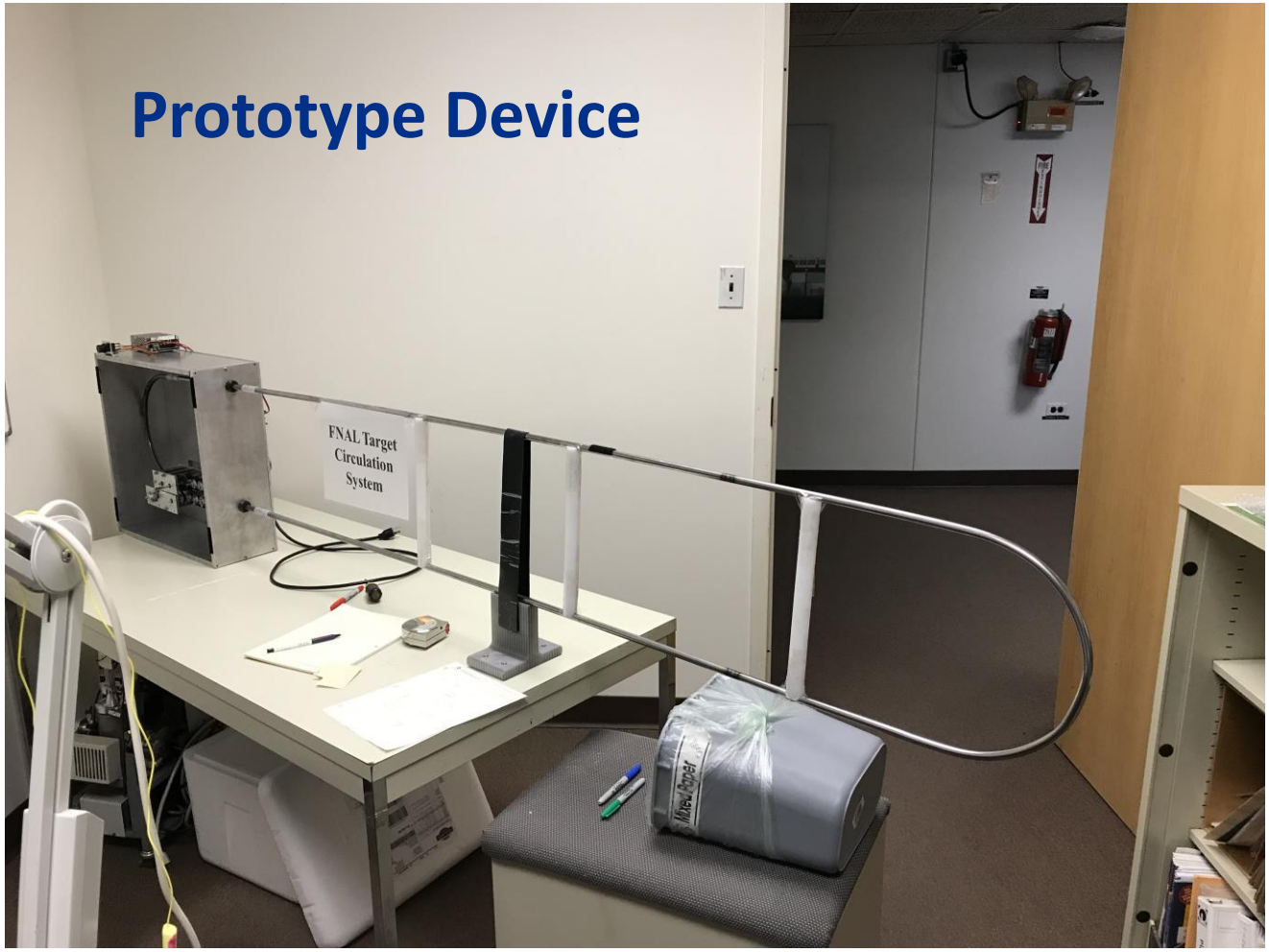


Euclid engineering team:
A.Liu, E.Gomes, M.Camarena

Prototype design:

- circulates Steel balls R=1 cm
- U-turn R=15 cm; L = 245 cm.
- Racetrack shape (no beam straight section)
- Tubing slightly larger than the balls (tolerance)
- Variable velocity
- Sealable design (for future vacuum to avoid oxidation in air)
- Track actuated from two sides in gearbox
- Track is gripped in drivetrain

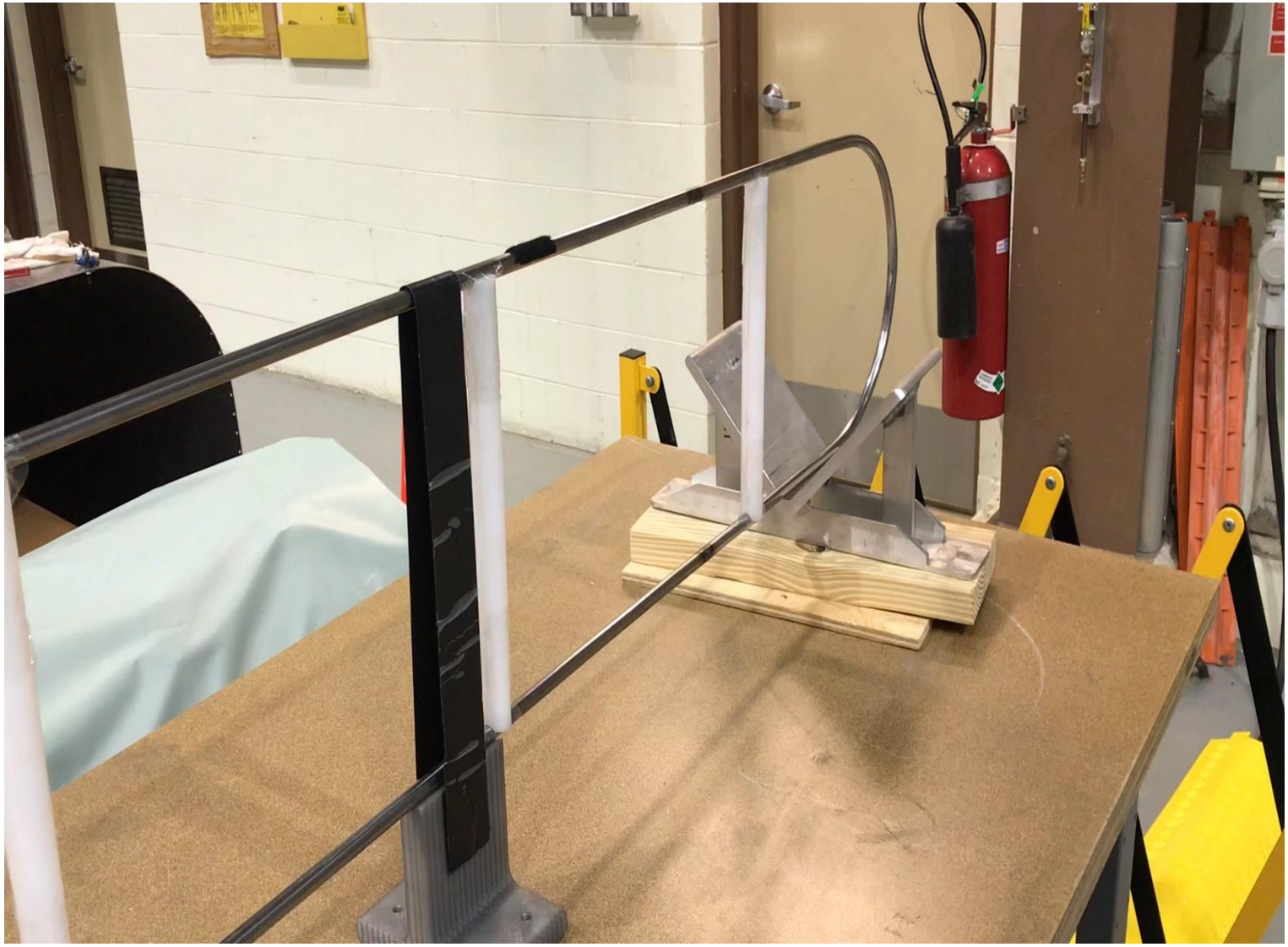
Prototype Device



In MI-8 Mezzanine: test at 10--16 cm/s

Not all rollers were engaged

Mechanical tests at Fermilab



In Fermilab's MI-8 Mezzanine: test at 12.3 cm/s

Mechanical tests: observations and conclusions

The prototype, despite many simplifications, does the job

- Demonstrated stable operation at 8 cm/s, 12 cm/s, and 16 cm/s for at least half-hour without interruptions (10 cm/s initial design required 10 cm/s)
- After ~1 hour of integrated operation we saw that the traveling belt crumbles (not high-T, or rad resistant)

Some rollers slip and do not turn

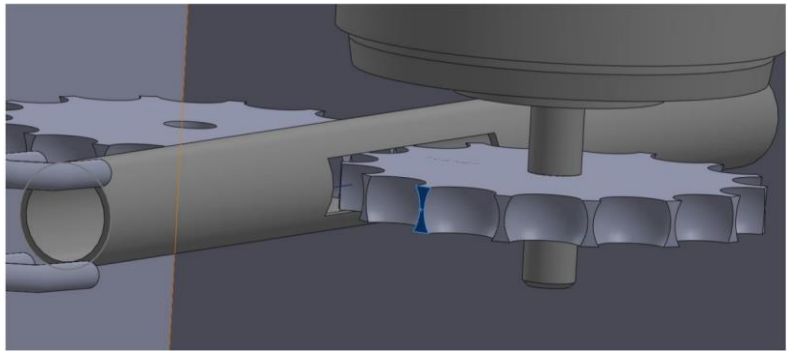
- In general, long-term uniform movement of the balls in the tube can be ensured. The design is generally feasible.
- Several further studies are necessary

Crumbs

Further studies needed and future plans

Future improvements of the prototype:

- Changing the racetrack shape to a more complex one with a straight beam interaction section (fitted to PS slot)
- Replacing the traveling belt system with a sprocket system
  - Motion stability and
- Adding gas flow for gas cooling and gas-facilitated motion

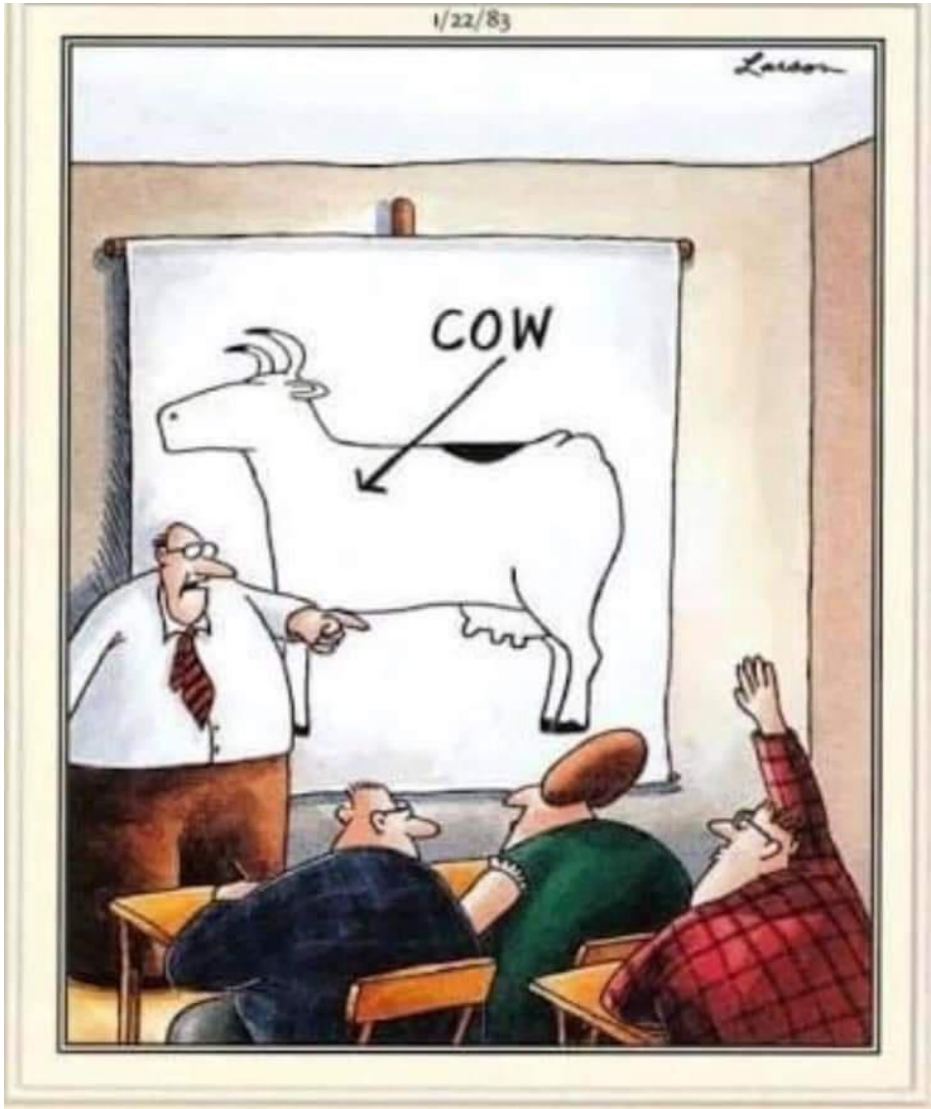


- Simulation studies needed in the support of the design:

Energy deposition in tubing must be studied to determine the thermal and radiation tolerances

- MARS15/FLUKA agreement in DPA is needed to determine the target circulation requirements during the Mu2e-II run

Comments, questions, suggestions



"Yes ... I believe there's a question there in the back."