Targetry at 1MW in a Solenoid

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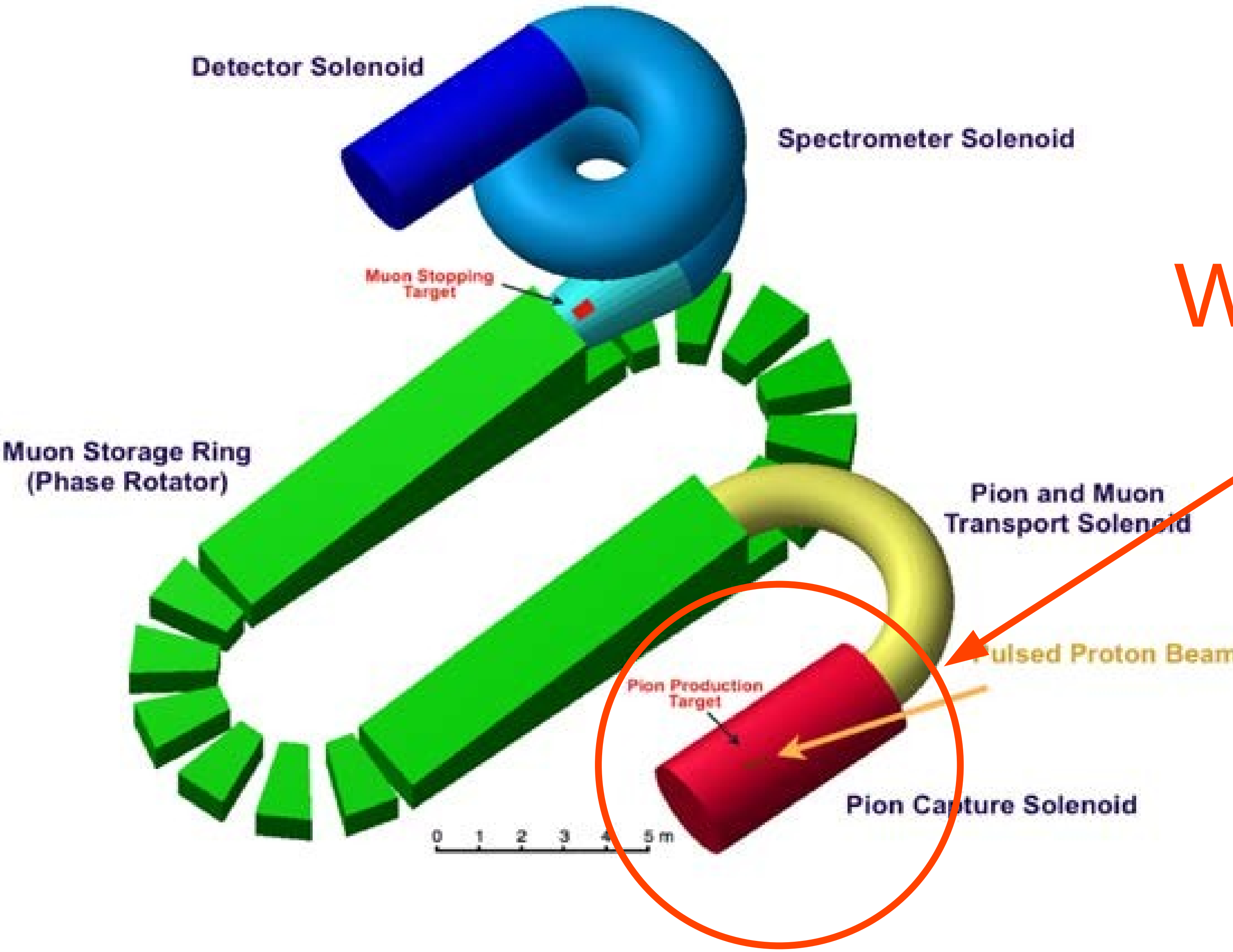
Overview

We are here!



We have conflicting goals for our production targets

- High particle yields
- Low production of backgrounds
- Long, problem-free operational lifetimes

Production targets face a host of severe issues

- Tight alignment tolerances
- High radiation-damage tolerance
    - Active materials research area!
- High temperature tolerance
    - Heat removal systems
- Tolerance to large thermal and stress fluctuations
- Exotic chemistry
- Remote inspection and servicing
- Severe radiological safety issues
- Difficult disposal problems

Things can go very bad, very fast

CERN-HiRadMat – thermal shock

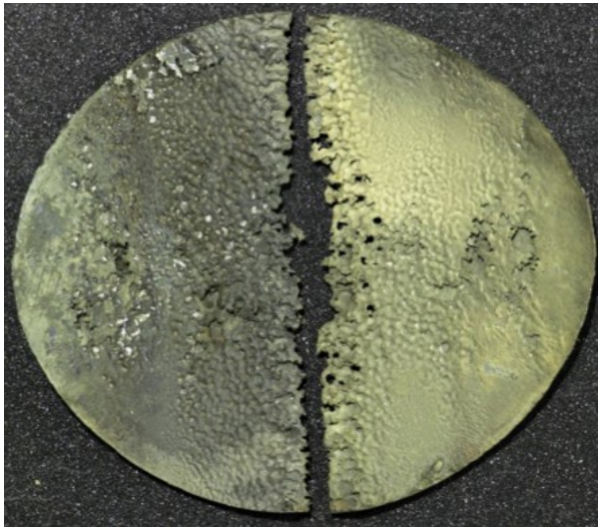
Swelling – JNM 159 (1988) p.114

This can go very bad, very fast

- Void formation and Embrittlement
- Creep
- Swelling
- Conductivity loss
- Changing moduli
- Fatigue

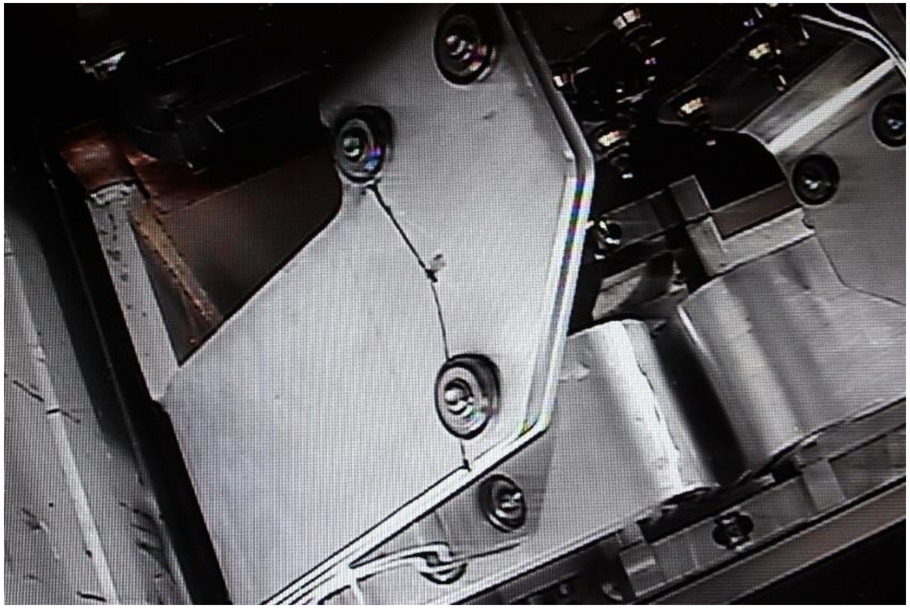
Effects depend not only on total irradiation, but also rates, temperatures, stresses, irradiating species, etc.

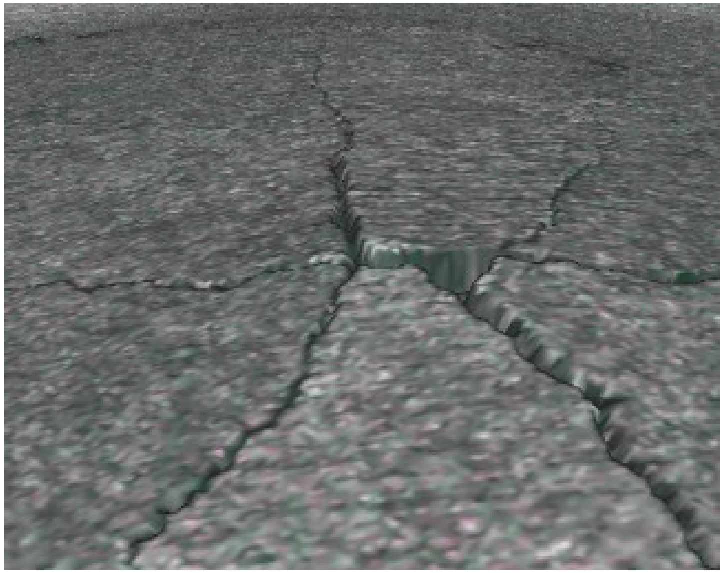
It’s not just the targets themselves that are vulnerable, but their enclosures



Target containment vessel cavitation (ORNL - SNS)

Horn stripline fatigue failure (FNAL)





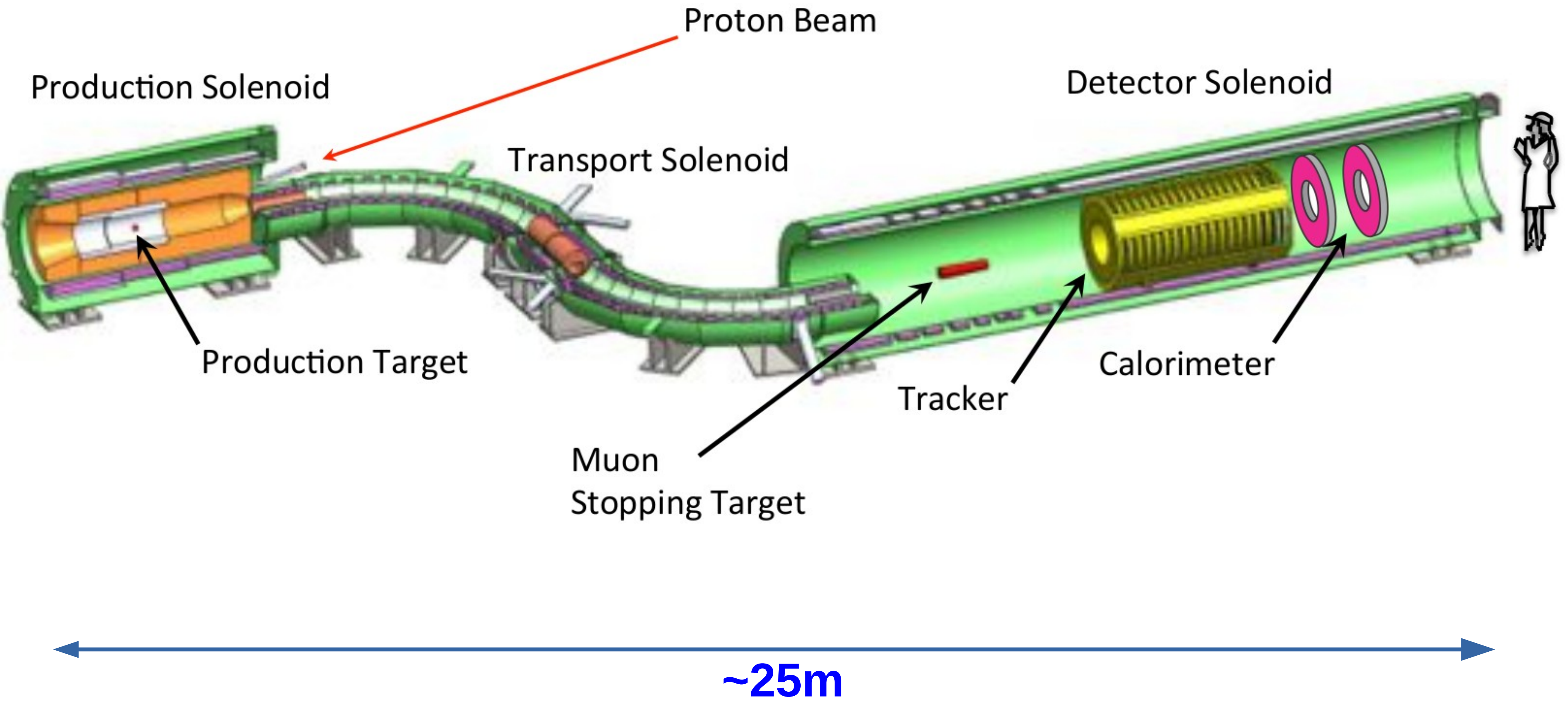
Be window embrittlement (FNAL)

Let's take a look at some of the issues specific to a CLFV production target

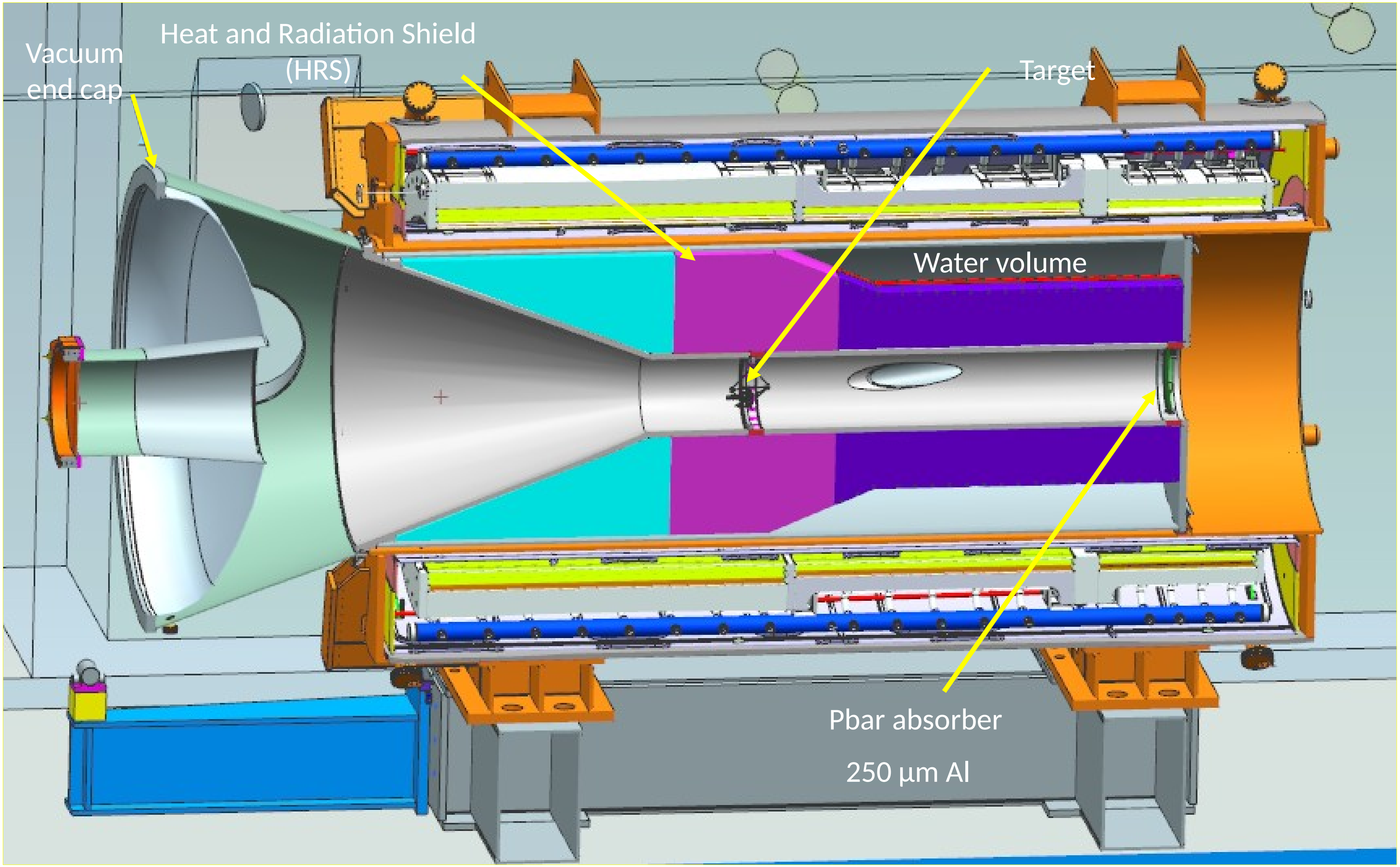
- Coherent, neutrinoless muon to electron conversion in the field of a nucleus

- Mu2e (COMET)
    - Under construction
- Mu2e-II
    - Early R&D
- A 1MW ENIGMA program
    - Snowmass discussions

Mu2e: Targetry at 8kW



Let's zoom into the PS



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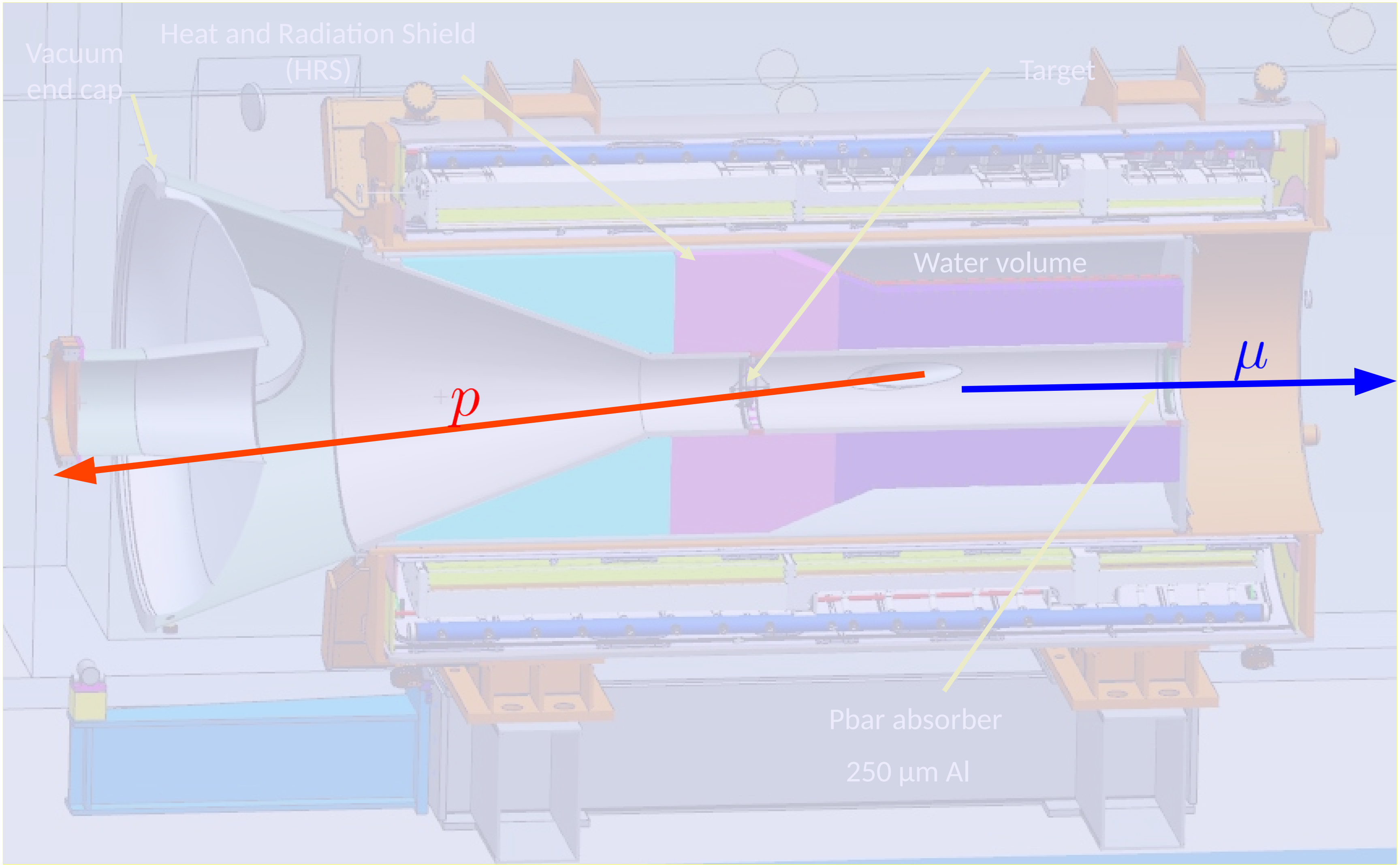


Backward Beam

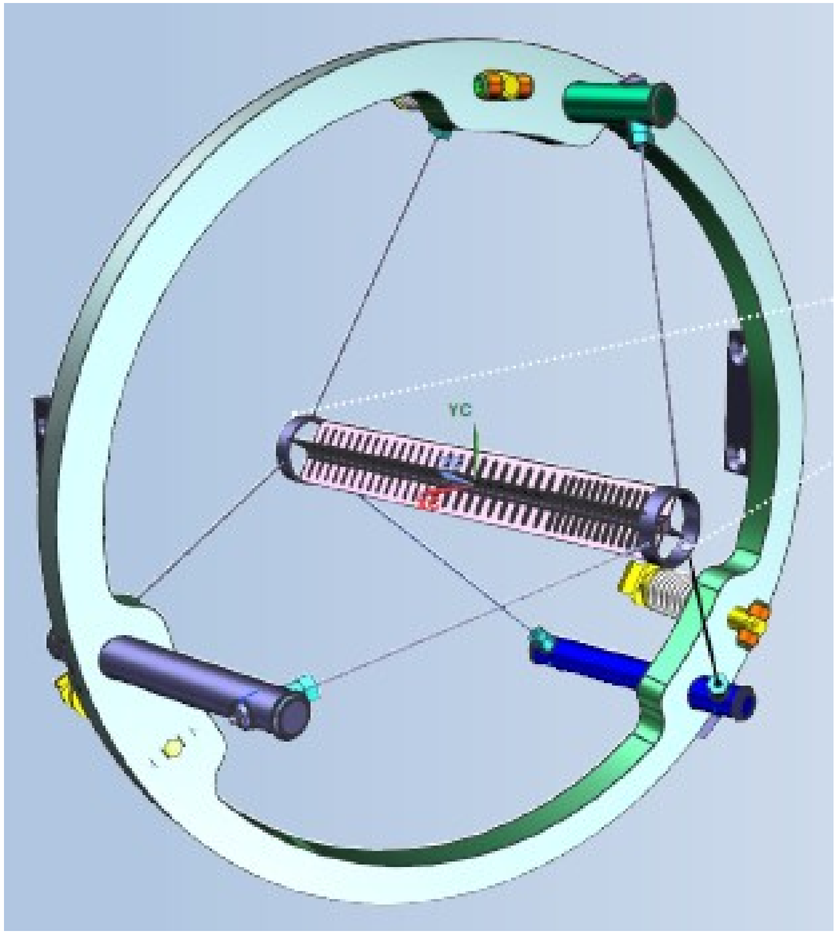
For cost reasons, Mu2e will use a radiation cooled target

- Tight alignment tolerances:
  - 0.25 mm placement
  - 0.25 mm stability
- Maximize muon yield
- High thermal conductivity
- High melting point
- High mechanical integrity
- *Operational lifetime of at least 1yr*
- Remote replacement

- Low-momentum muons

Tens of person-years were required to converge on a solution meeting these requirements

- Bicycle wheel support
- Refractory metal: Tungsten
- Longitudinally segmented cylinder (stress management):
  - 3.15 mm radius
  - 160+60 mm length
- Longitudinal fins (structure and thermal management)
- 1mm tungsten spokes
- ~ 700 W power absorption
- ~ 1500 K temperature



Mu2e-II: Targetry at 100kW

- Mu2e-II will largely reuse the Mu2e concept
  - Upgraded detectors
  - Increased beam power from PIP-II
  - New production target system
    - 8MeV/8kW → 800MeV/100kW
    - ***Same volume target***
- Heat extraction and radiation damage are now truly significant challenges!
  - Must be actively cooled
  - Monolithic target probably not feasible due to radiation damage and lifetime concerns

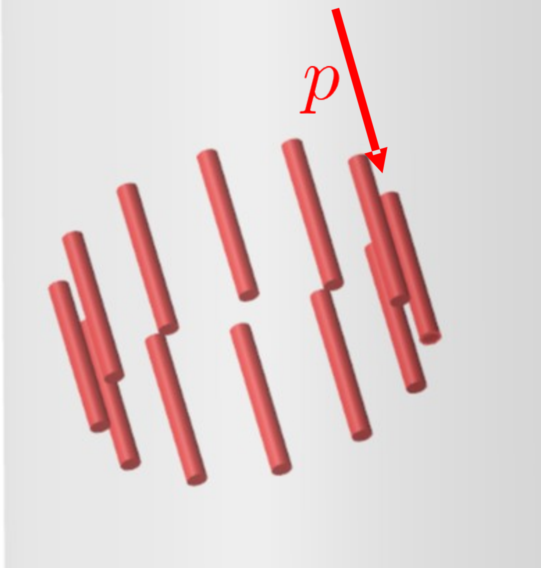
Conceptual target design LDRD

- We need an actively cooled target
  - H_20, He are typical cooling fluids
  - May need a phase change to extract enough heat (NH_3?)
- We need to replace target material regularly (not annually!) to keep ahead of radiation damage
  - Mu2e: < 1 DPA/yr
  - Mu2e-II: > 300 DPA/yr

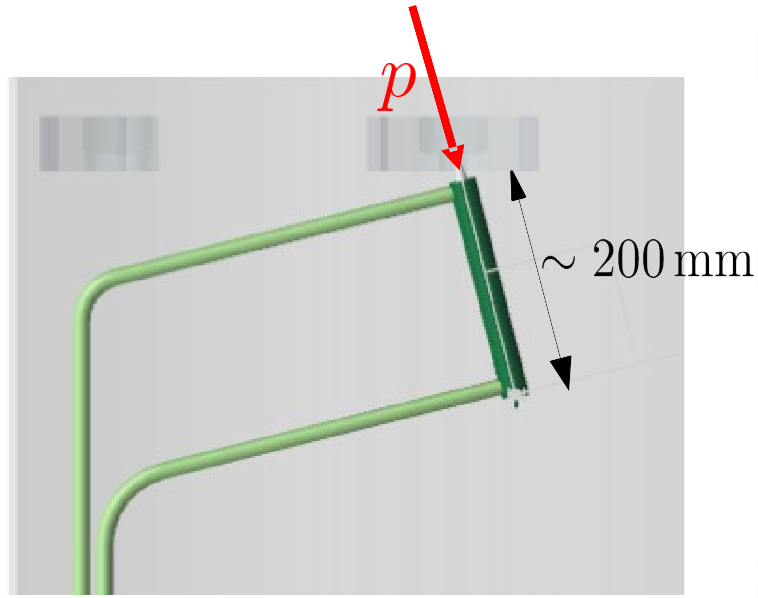
DPA: Displacements per Atom

Conceptual target design LDRD

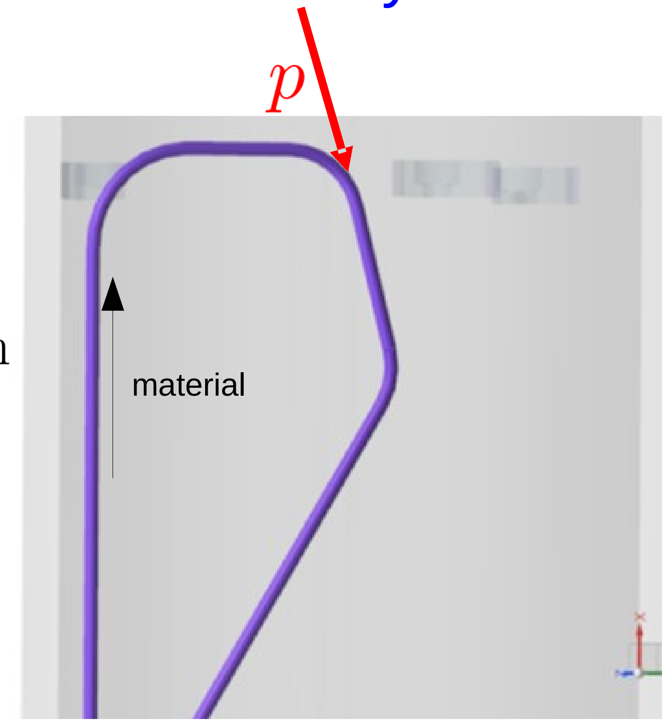
Rotating cassette



Fixed granular



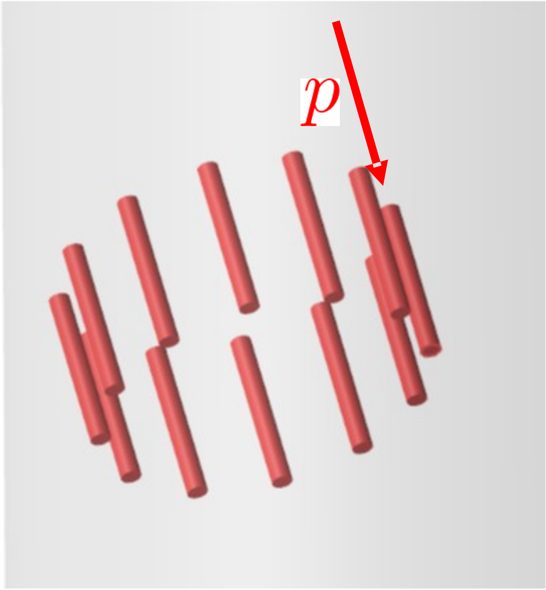
Conveyor



There are, of course, other potential options of significantly increased complexity that we'll come back to later…

Rotating cassette

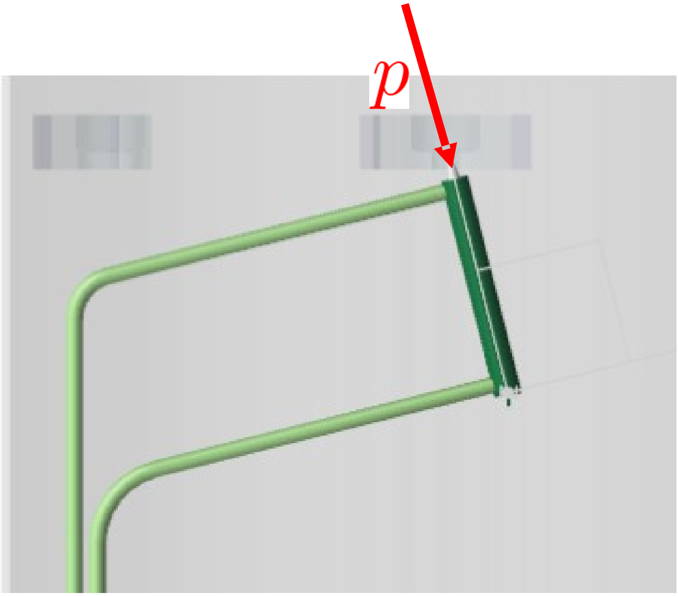
- Pros:
  - Radiation damage can be distributed over many rods that are rotated into the beam over time
- Cons:
  - Cooling is difficult
  - Rotation hardware and unused rods consume significant space in the bore
  - Radiation damage is still an issue over 1 year of operation



Alternatively, rotating wheel (great experience at PSI)

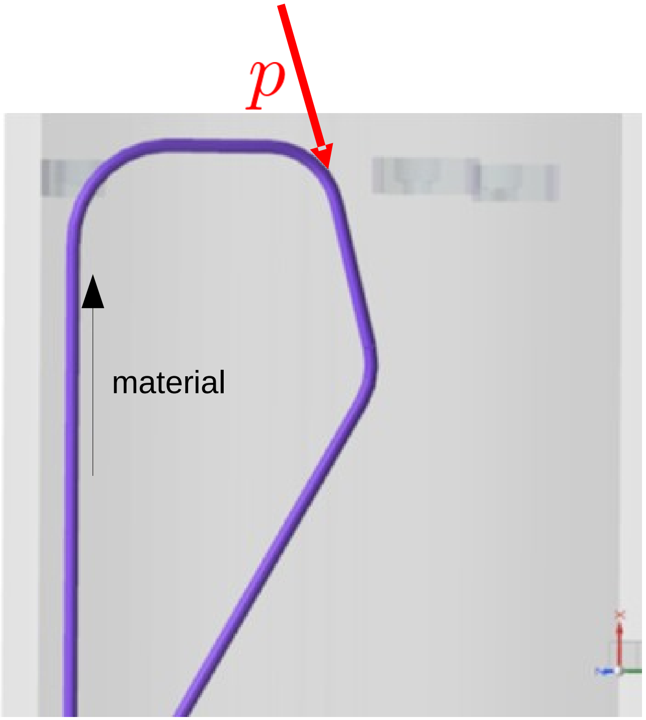
Fixed granular

- Pros:
  - Small space requirement
- Cons:
  - Radiation damage extremely high (peak DPA similar to fixed solid target)
  - Gas cooling efficiency is probably poor



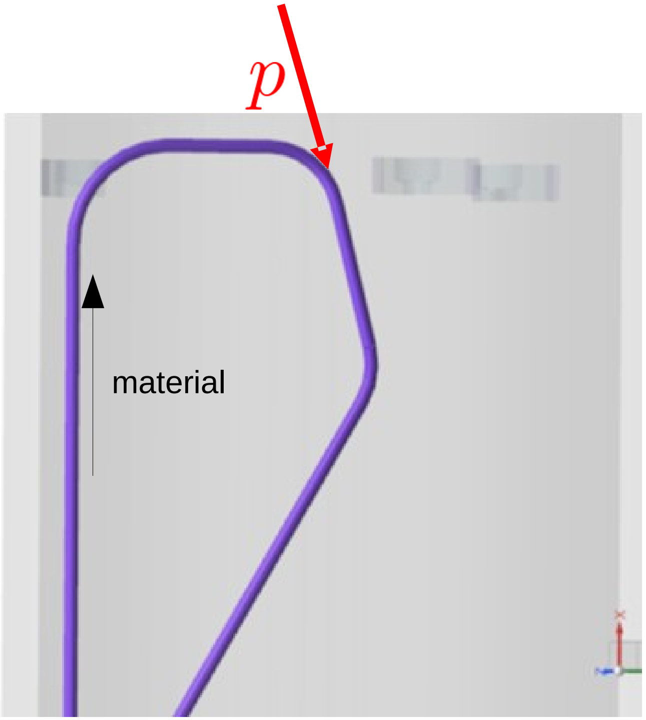
Conveyor for spherical target balls

- Pros:
  - Small space requirement
  - Cooling fluid can assist in moving target balls
  - Balls can be swapped during operation to minimize radiation damage
- Cons:
  - Technical complexity!
    - Drive train
    - Drive/cooling marriage
    - Phase change cooling may be required
    - Windows!



Conveyor for spherical target balls

- Various materials are good candidates:
  - W
  - WC
  - SiC
  - MoGRCF
  - Graphite
- This is our current leading candidate design, and mechanical prototyping is underway.



ENIGMA: Targetry at 1MW

- Initial consideration for 1MW of beam at 800MeV from PIP-II, delivered from proton compressor ring
- Has much in common with Muon Collider target designs
    - Solenoidal capture channel
    - High power, pulsed proton beam
    - Significant power deposition in solenoid shielding
    - Significant power deposition in proton beam stop

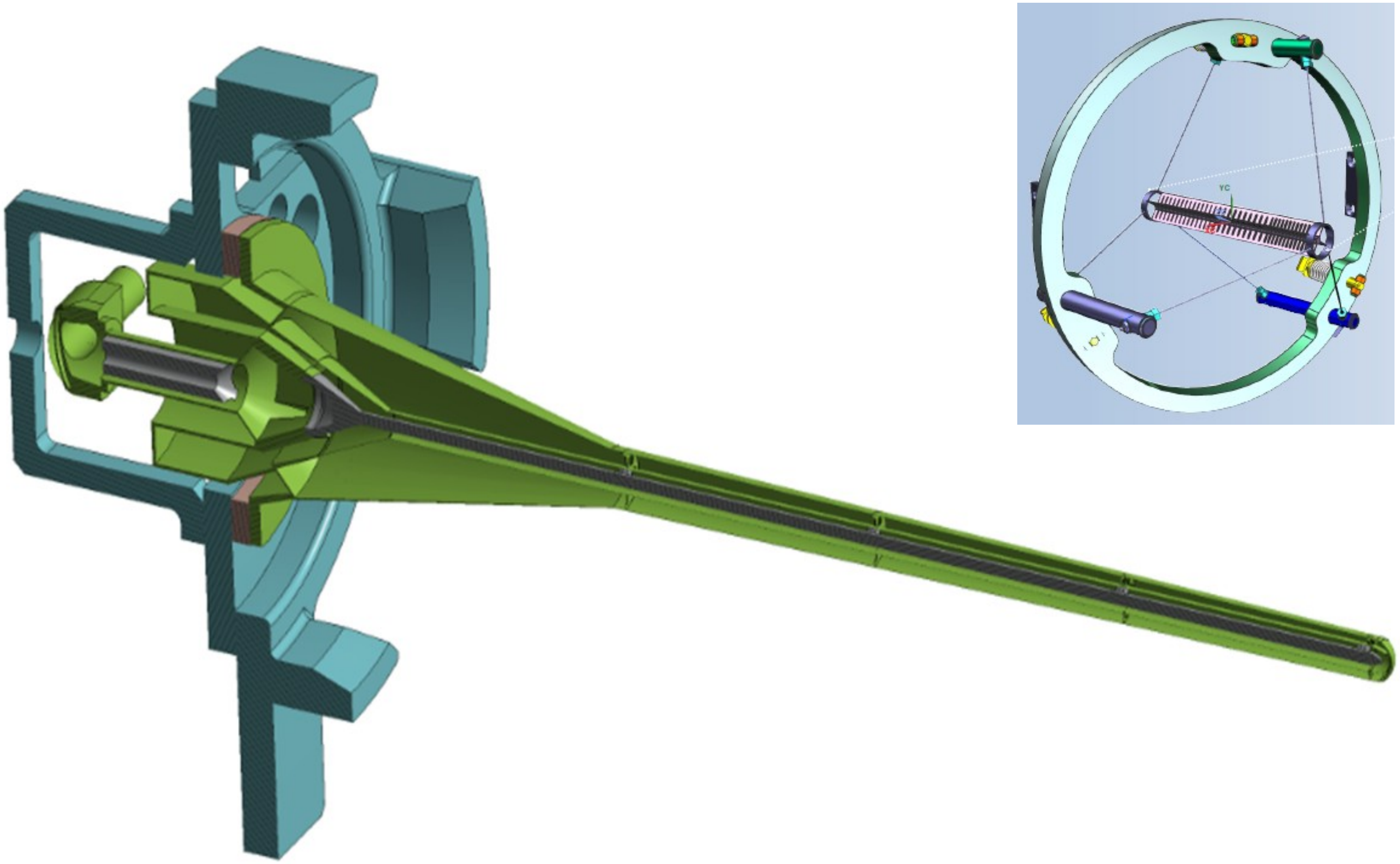
ENIGMA: Targetry at 1MW

- We already “know” how to do targets at MW scale
  - Nova (~700kW)
  - SNS (~1.4MW)
  - LBNF (~1.2-2.4 MW)
- But these are not compact targets in a solenoid!
  - LBNF: segmented graphite core 16mm x 1.5-1.8 m
- Low duty cycle beams:
  - LBNF: 10μs every 0.7-1.2 s, 120GeV
  - SNS: 695ns at 60Hz, 1GeV

ENIGMA: a rough idea of scale

LBNF Target core
16mm x 1.5m x 25kW

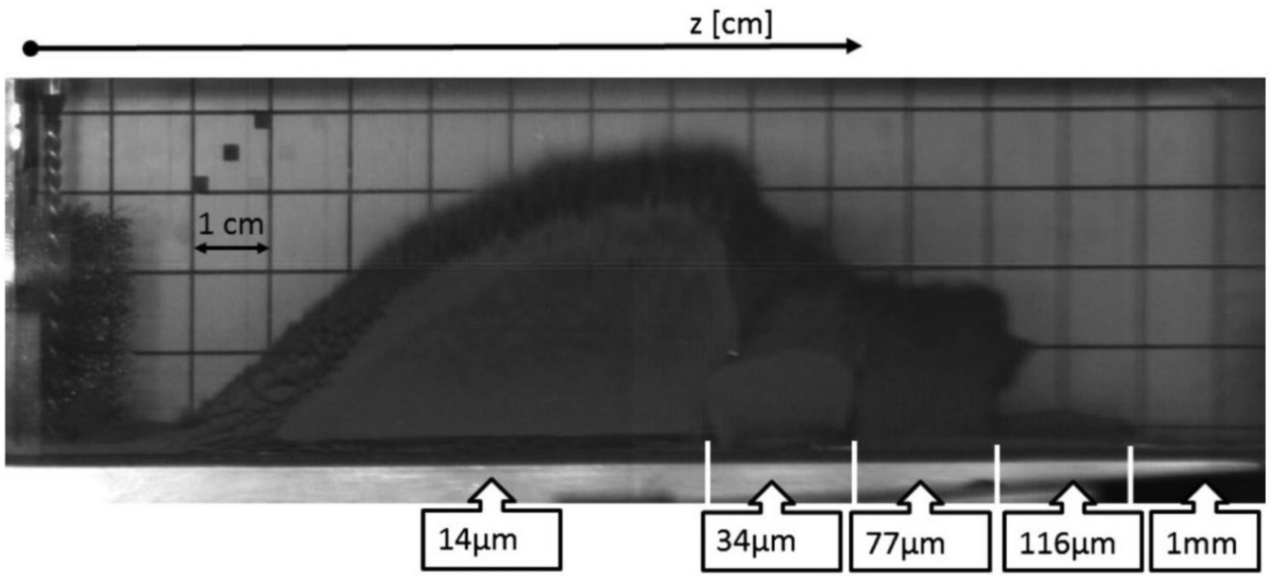
Mu2e Target Core
6.3mm x 220mm x 250kW



ENIGMA: Targetry at 1MW

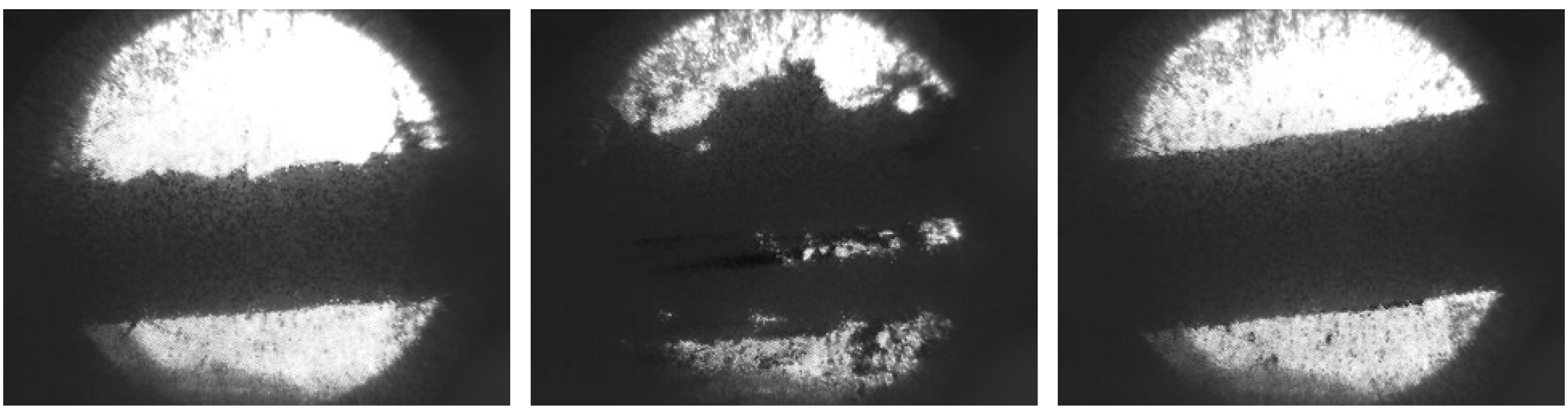
- How compact does the target really need to be?
  - Long target could use graphite (or similar) technology we know how to build
  - Shorter target might need radical ideas
    - Liquid metal (Hg? Pb/Ta?)
      - Muon collider R&D on liquid jets
      - Liquid target are difficult to build and operate
      - Liquid jets have been rate limited
    - Granular material
      - Tungsten powder jet prototypes have been tested
    - Rep rates are a problem
- Whatever we do, significant R&D (materials!) will likely be necessary

ENIGMA: liquid target challenges



Response of various size spherical tungsten particles to 2E11 protons

- Top: eruption of fluidized tungsten powder
- Bottom: disruption of liquid metal jet



Other considerations

- Solenoid design
  - Muon Collider designs utilize 10-20T solenoids with forward production
  - Normal or superconducting?
  - Heat and radiation shielding
    - Lifetime?
- Target handling and replacement
- Beam transport
  - Windows!
- Beam stop design
  - Accident conditions!
- Radiological issues
  - Personnel and environmental protection
  - Waste storage and disposal

Conclusions

- We think we know how to build a 100kW low momentum muon source
- Target and solenoid design for a 1MW muon facility will go hand in hand and present significant challenges across many fronts
- There is potentially significant synergies with the muon collider community

- Thanks for your interest and attention!