Mu2e Target High-Emittance Coating

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COMET—Mu2e collaboration

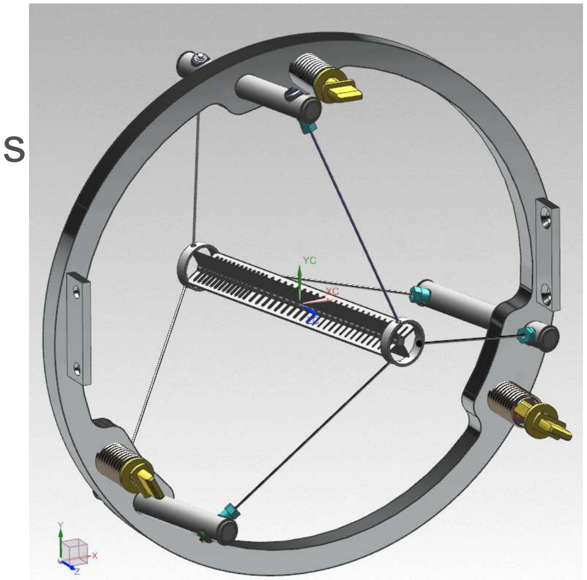
Outline

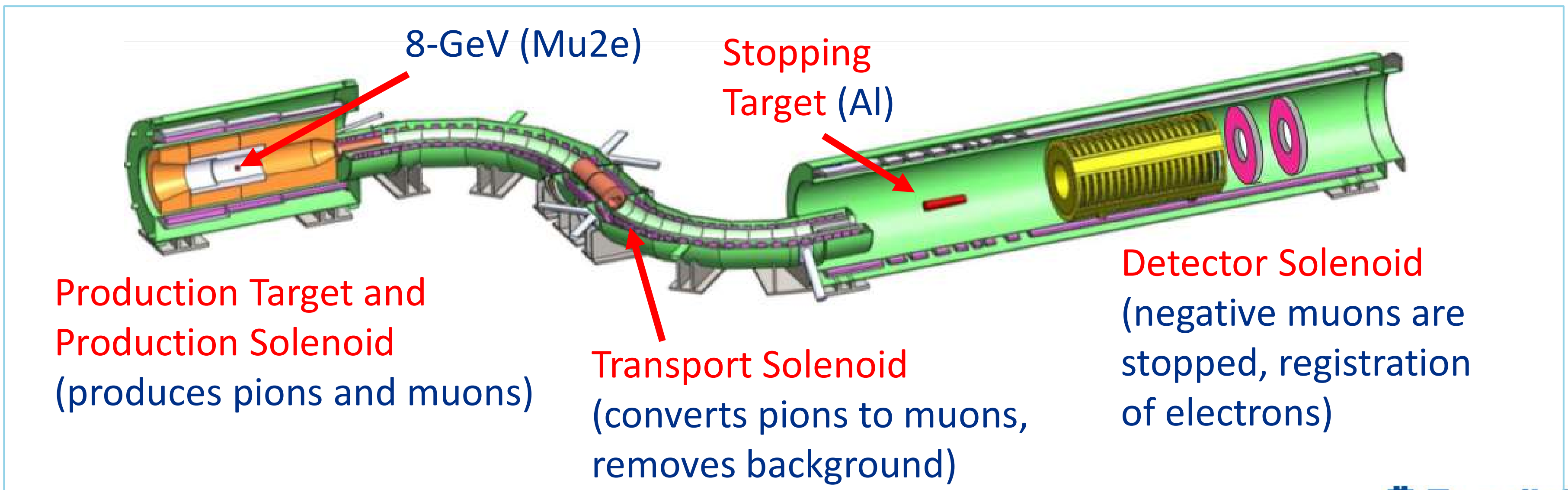
- Status briefing
- Approaches to optimize
- Brief

Mu2e experiment, target & support

Mu2e radiative cooling tungsten target

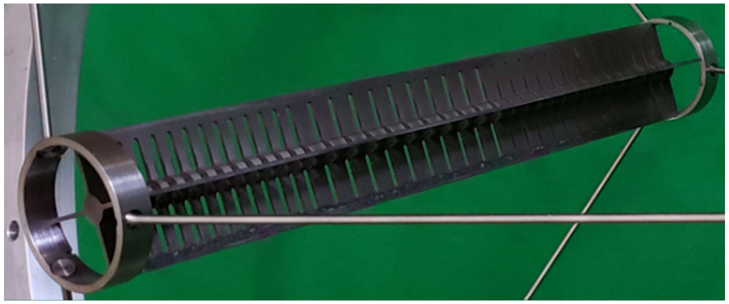
- 8 kW beam power at 8 GeV resonant extracted protons
- 1 year operational lifetime (~ 40 weeks/year)
- Designed for replacement with remote handling equipment
- Optimized for stopped muon production
- Operating in FY 2026





WL10 (W 1% wt. La_2O_3) Target

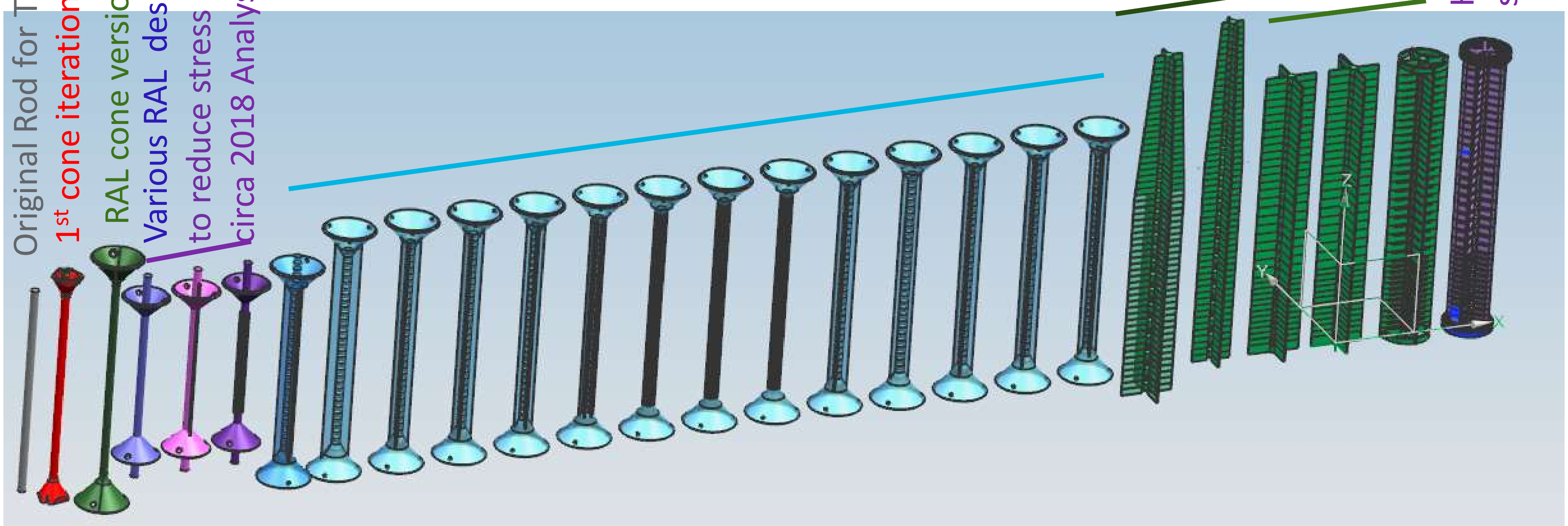
- Core is wire EDMed from single rod
- Longitudinally segmented cylinder:
  - 6.3 mm diameter
  - 160 + 60 mm length
- Longitudinal fins (4)
  - 1 mm thick
  - 13 mm high (each)
- Spokes
  - 1 mm diameter
- Challenge:
  - Muon production rate
  - Geometry complexity
- DPA ~ 100 (NRT, Kavin Ammigan)



Mu2e Target Evolution

Various FNAL/ RAL iterations with fins (n_{fins} = 3 to 18) to augment cooling with increased surface area during 2018. Includes the T1 Milestone target (CRR in April 2018) (rightmost blue target)

Starting in 2018 Analysis included emissivity as a function of temperature, non-uniform time dependent Energy Deposition (Edep) (380 msec of Edep, 1.02 sec of no heating).



Goverging thermal equation

$$P = \sigma \times \varepsilon \times A \times (T^4 - T_b{}^4)$$

- P = Energy Deposition from the Protons in the Target
  - Absorber Power (P) is between 600 and 700 Watts.
- σ = Stefan-Boltzmann **constant** (5.67×10^{-8} W/m2* K)
- ϵ = emissivity (temperature dependent)
- A = surface area of the target
- T = temperature of the target
- T_b = temperature of the surroundings (about 305 K , 90 F)

➔

- Takeaway: only two parameters can be adjusted to change the target temperature with constant power input, ϵ & A.

Approaches for optimization

- Emissivity
  - Coating
  - Material
- Structure
  - Cooling area
  - Thermal stress
  - Creep

Fermilab

High emissivity coating: SiC

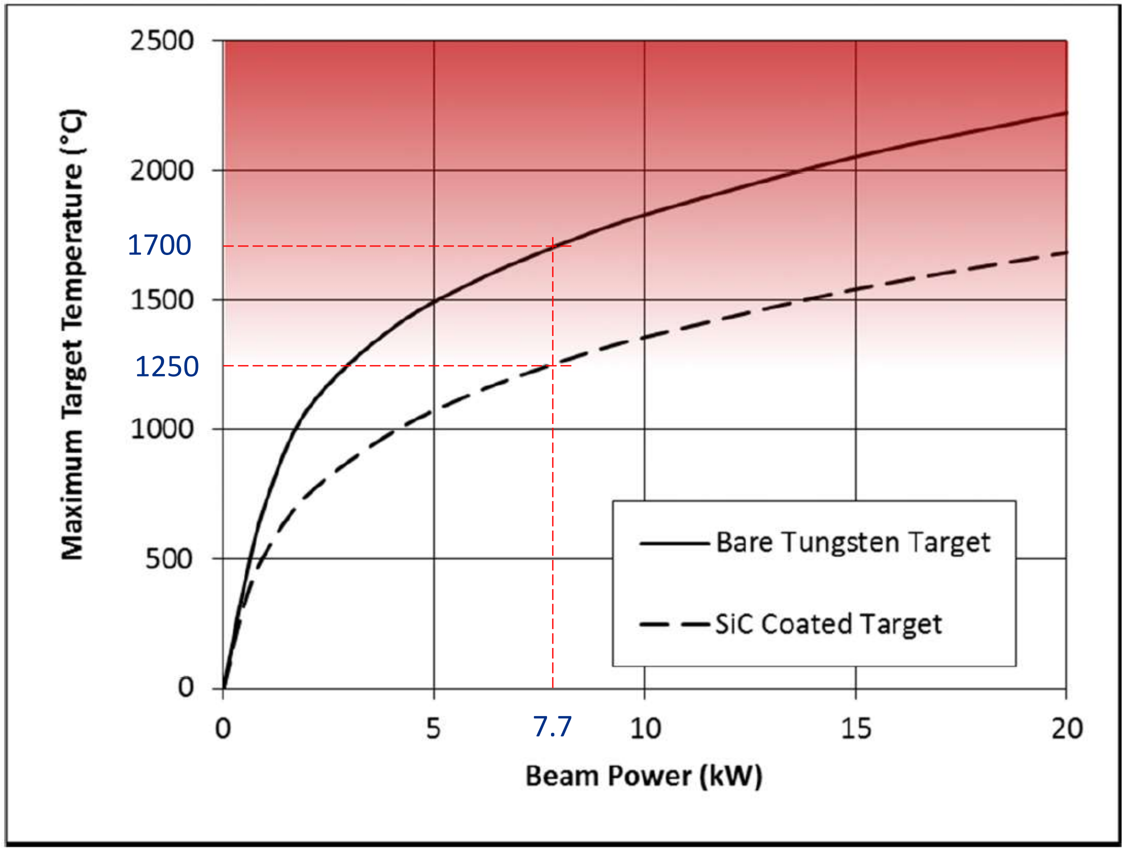
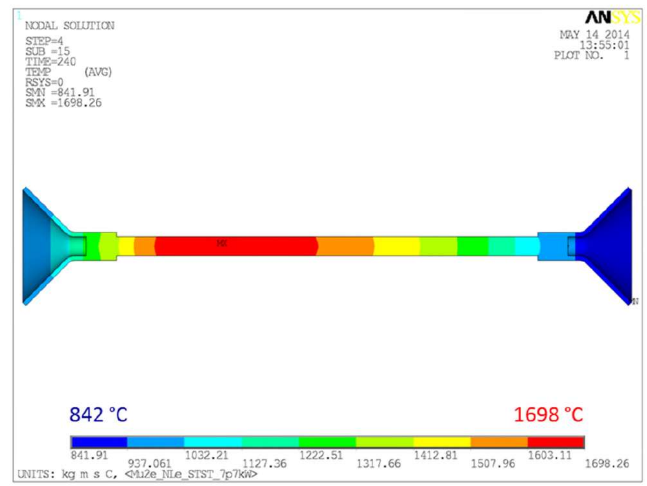


Figure 94, Target equilibrium temperature as a function of beam power

SiC coating:
When heated in a vacuum at 10-4 Torr, an active oxidation prevails.
➔ A volatile oxide is formed leading to recession of the SiC layer



Source: Mu2e-doc-8376, “Final Report on the Design of the Mu2e Pion Production Target”, STFC Rutherford Appleton Laboratory, 2017

SiC3 Cubic Silicon Carbide ceramic coating

- Vendor: Silicon Carbide Coatings | Ceramic Coatings | SiC3 (thermic-edge.com)
- Tungsten has been coated successfully with SiC3 coating.
  - The coating adheres very well and the system has a long-term stability at high temperature.
  - The SiC3 coating can prevent oxidation of the underlying base material in oxidising environments.
- Possible intermediate coating
  - The most promising ceramics to be coated with SiC3 are the silicon based ceramics such as SiC, SiSiC, Si3N4 etc. The reason being that the thermal expansion of those materials fits very well with the SiC3 coating.
- SiC3 coating can be used at high temperature in the following environments:
  - Oxygen (O2)
  - Hydrogen (H)
  - Nitrogen (N2)
  - Carbon-Monoxide (CO) / Carbon-Dioxide (CO2)

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Texture coating

- CVD coating by Ultramet (CA, USA)
- ε ~ 1/T^4:

  Tungsten ~ 1200˚C

  WonW RMS50 ~ 1000 ˚C
- W on W coating strong bond
- Textured rhenium with tungsten overcoat

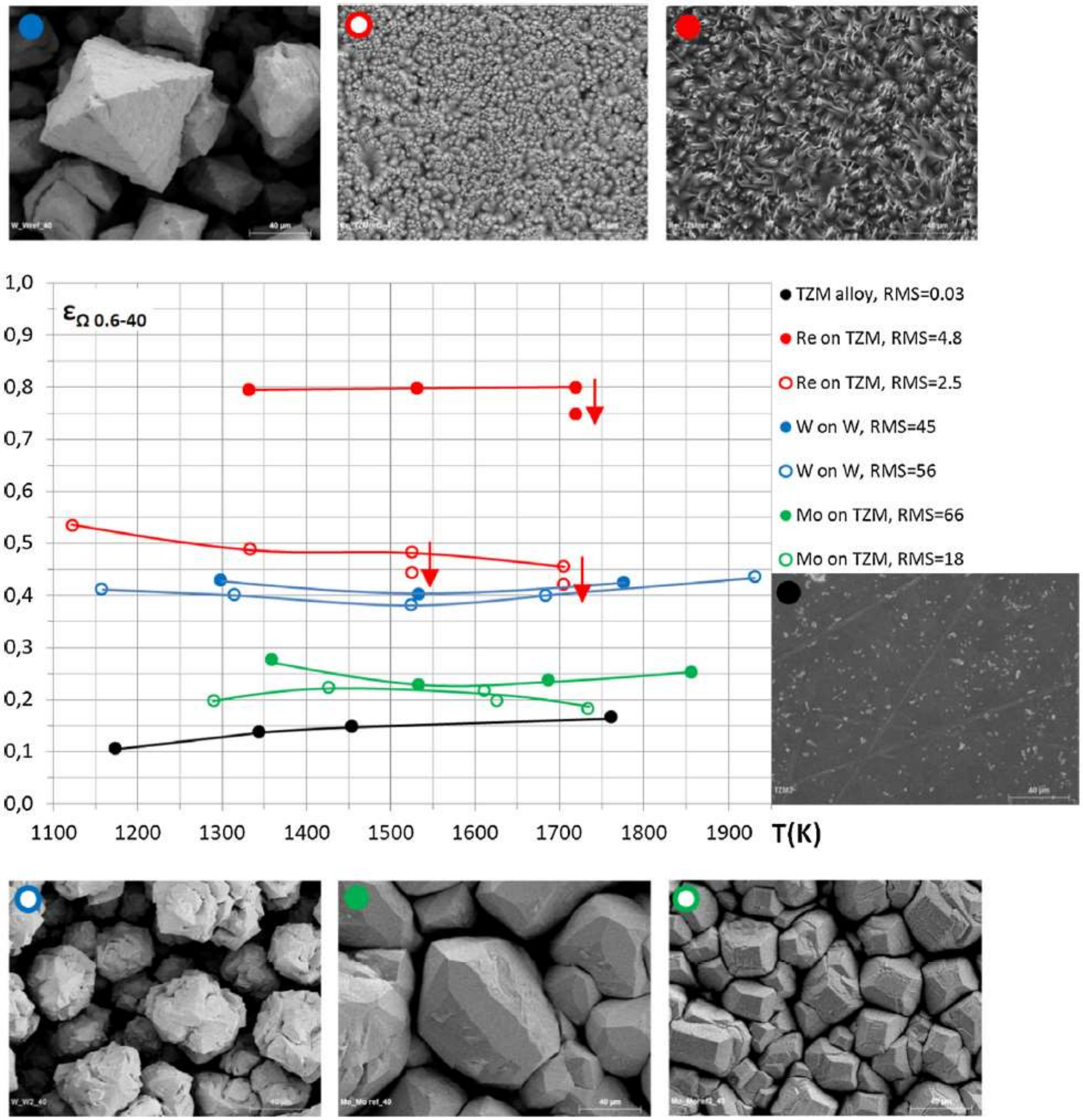

Fig. 17. Comparison of the total hemispherical emissivity of the three coatings, Re on TZM, W on W and Mo on TZM with a polished TZM surface. The red arrows indicate the decrease of emissivity over time measured on the two Re coatings. SEM pictures of the surfaces are provided in order to link each emissivity level to the specific surface structure on which it was measured. The scale bars are all 40 μm. This way one can compare directly the surface structures. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Brief

- Traditional CVD with high emissivity coating material
  - SiC3 coating on tungsten is to be examined
- Textured CVD
  - Textured tungsten on tungsten
  - Textured rhenium with tungsten overcoat
  - Textured iridium on tungsten (procedure not fully developed yet)
- Measurements & tests
  - Hemispherical emissivity
  - Operational service lifetime (thermal fatigue)
  - Pre-heat to crystallization temperature prior to coating to solve creep issue

Thank for your attentions!