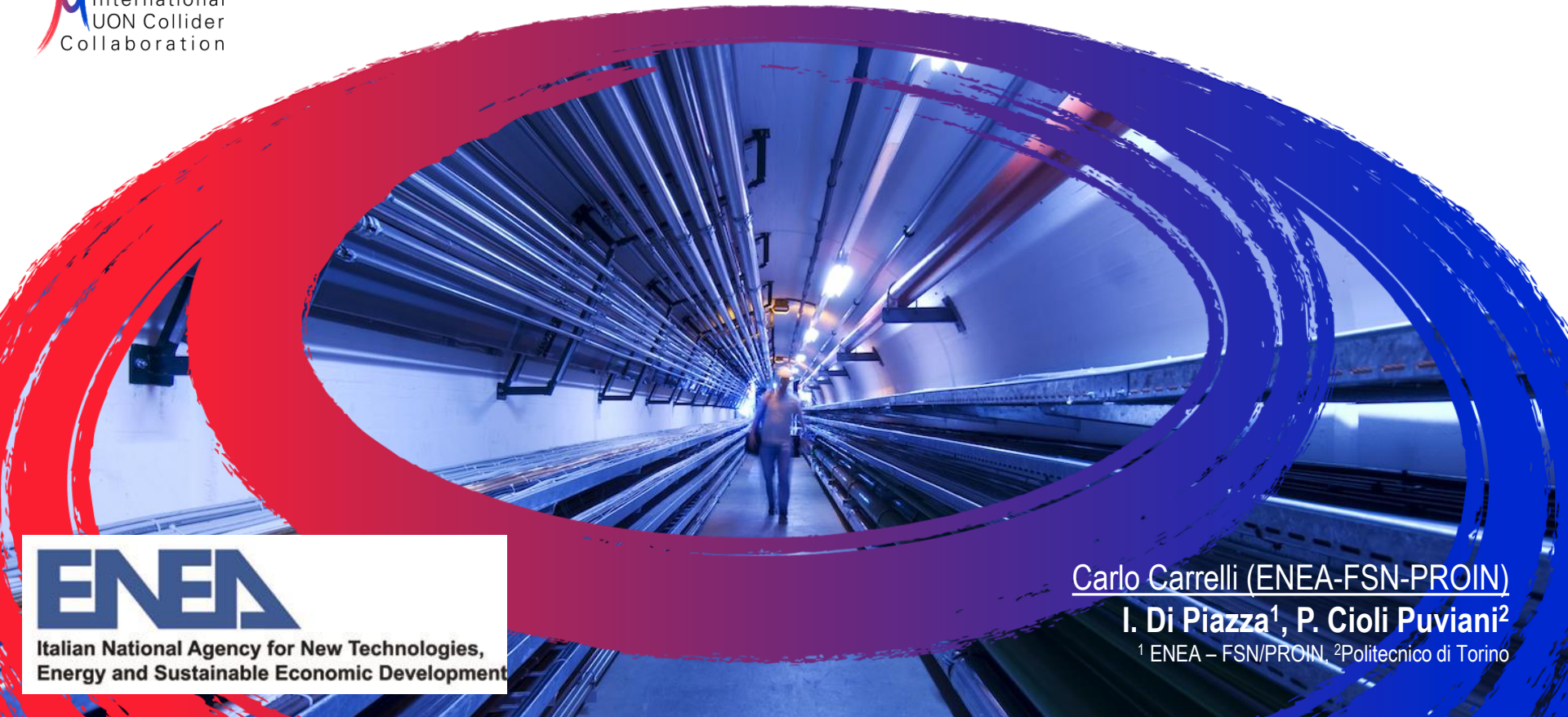
IMCC Annual Meeting 2023 - Orsay

21/06/2023

Heavy liquid metal target concept and challenges for the Muon Collider



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Italian National Agency for New Technologies, Energy and Sustainable Economic Development

Outline

- Intro
- Liquid lead: overview
- Liquid target options
  - 1 – Pipe
  - 2 – Curtain
  - 3 – Jet
- Outcome

Intro

- WP 4.2 – Target system development

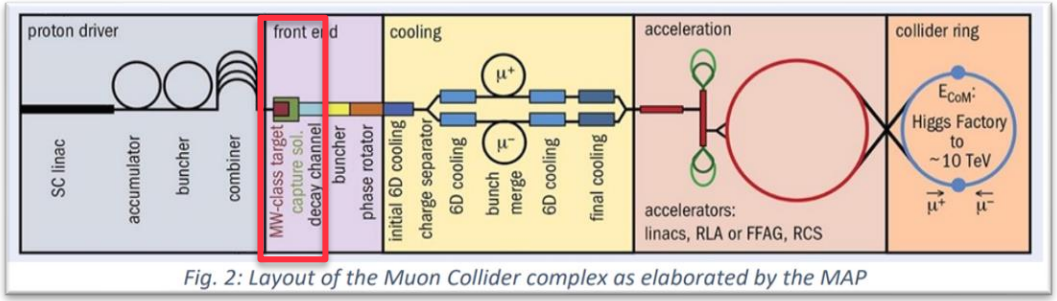
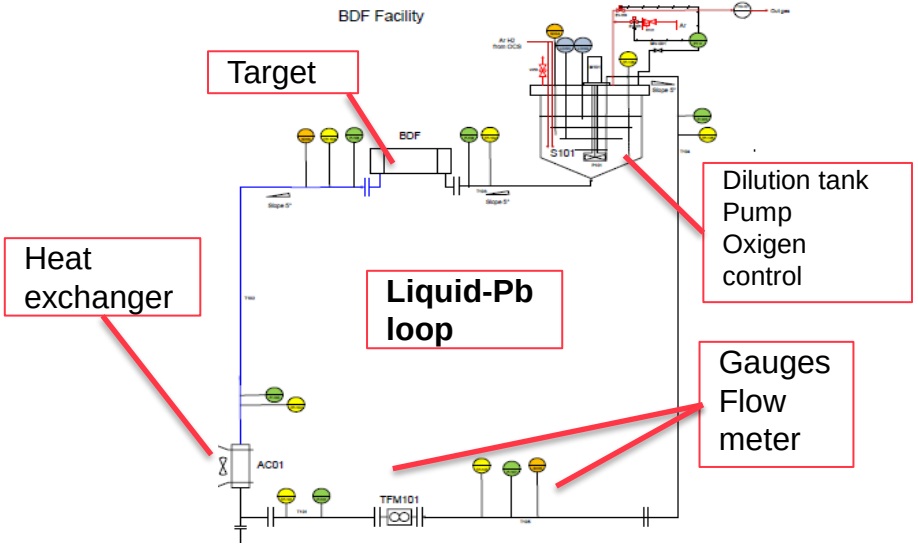


Fig. 2: Layout of the Muon Collider complex as elaborated by the MAP

- Exploring solutions for 2-4 MW class target
  - p^+ beam: 2 ns, 5 Hz, 2 MW_{AVE}
  - Available space: R < 170mm
  - 20 T magnetic field
- Extensive experience with heavy liquid metals in Gen IV fast reactors

Liquid Lead - Overview

- Density: 10660~9000 kg m^{-3}
- Melts: 600 K
- Boils: ~2020 K



Technological aspects:

- Steel corrosion at T > 450°C (slow process, 10^3 hrs)
- Stagnation areas in loop to be avoided (O_2 accumulation, local freezing)
- Ambient pressure operation

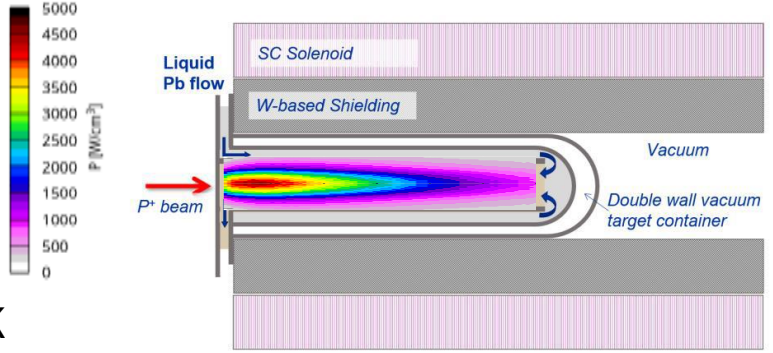
Radiological aspects (nuclear fission technology):

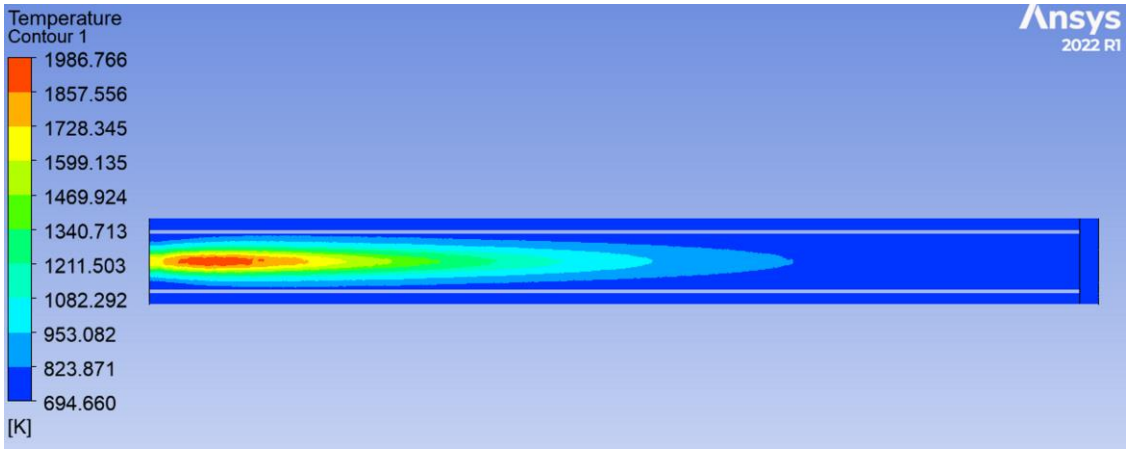
- Pb is neutron multiplier: n – 2n
- ^{210}Po production under neutron irradiation in pure lead is ~10^4 less than in LBE[1]
- Studies are being conducted for MHYRRA ADS reactor to verify Polonium production under proton irradiation[2]

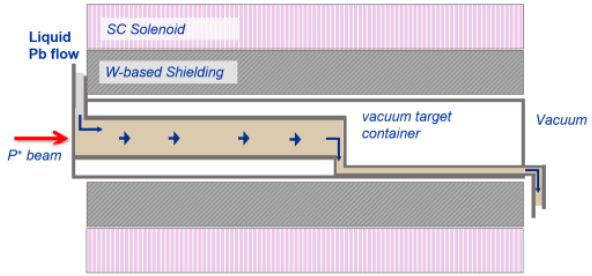
[1]Toshinsky et al, 2020
[2]Choudhury et al, 2018

Liquid target options – 1 (pipe)

- Inlet temperature: 400°C
- Target volume: D30 x L509 mm
- Lead flowing in cylindrical vessel
- Lead temperatures locally close to boiling point
- Average lead volume temperature increase is about 190 K

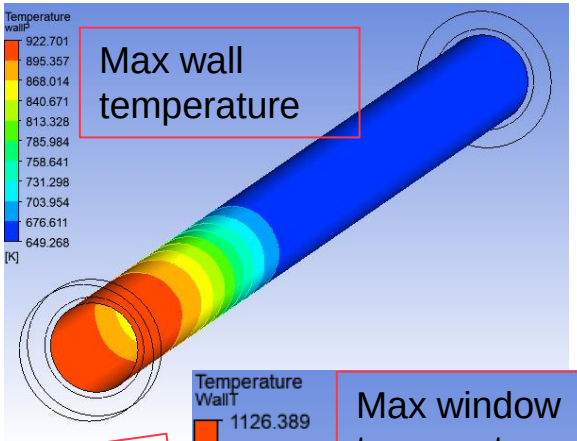




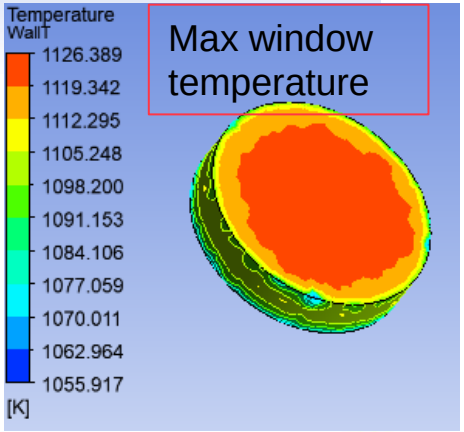


Liquid target options – 1 (pipe)

- Shockwaves and cavitation expected
- Significant MHD losses
- Vessel wall temperatures OK..ish
- Back window temperature not OK



on hold

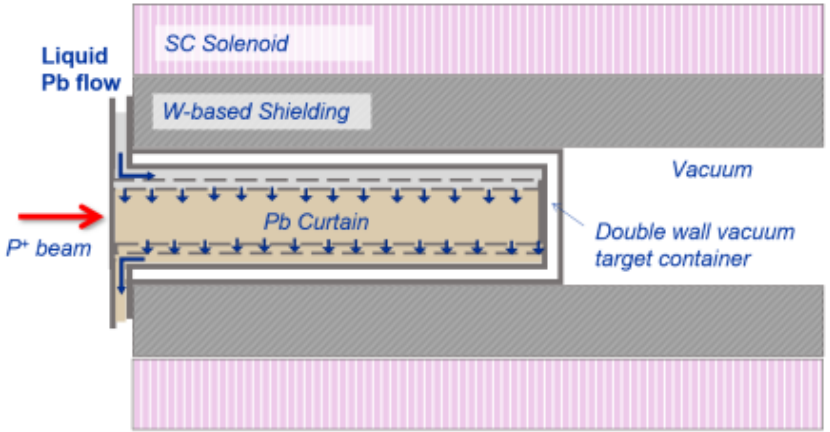


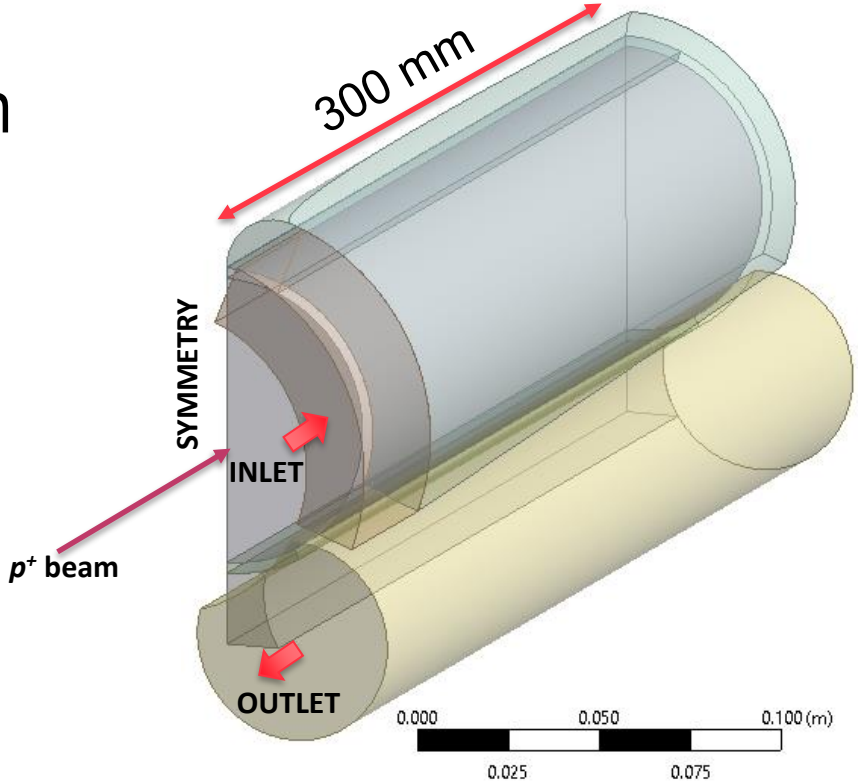
- Challenging to simulate high-speed, multi-phase flow dynamics
- Previous experience on liquid Hg targets show severe cavitation-induced erosion[3] on metallic containments when operating with MW-class beams

[3]Winder et al, 2021

Liquid target options – 2 (curtain)

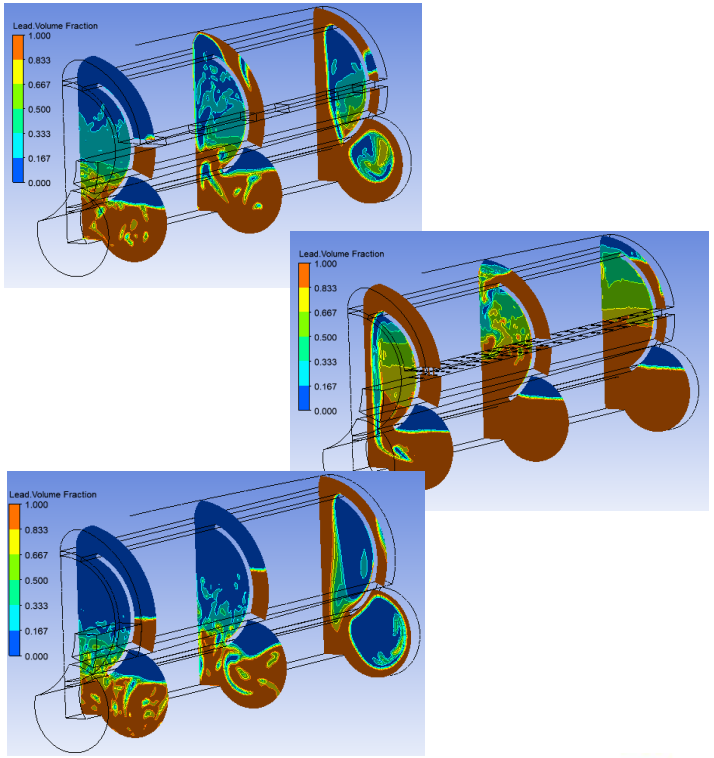
- Currently under investigation
  - Lead curtain in Ar cover gas





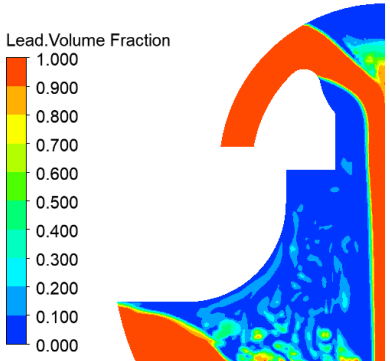
Liquid target options – 2 (curtain)

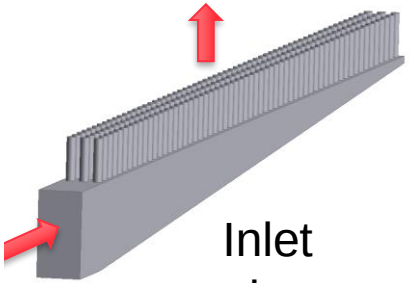
- Pros
  - Decouple liquid Pb from walls and windows
  - Transverse cross-section can be optimized to reduce overall mass flow rate and maximize pion/muon yield
  - Target segmentation possible
- Cons
  - Two-phase increase simulation complexity
  - Curtain stability after each pulse
  - Space constraints



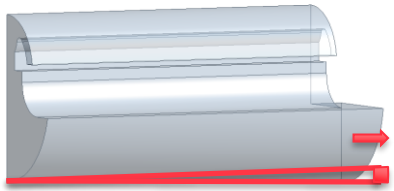
Liquid target options – 2 (curtain)

- Under investigation:
  - Inlet geometry → plenum for axial-to-radial flow transition
  - Outlet geometry → sloped sump to help drainage / outlet suction
  - Lead velocity and $\dot{m}$ → curtain vertical velocity > 1.5 ms^{-1}
- Next steps:
  - High-speed dynamics simulation (SIMMER III, LS-DYNA)
  - Vessel material (coated metal, ceramics)
  - MHD losses evaluation





Inlet plenum

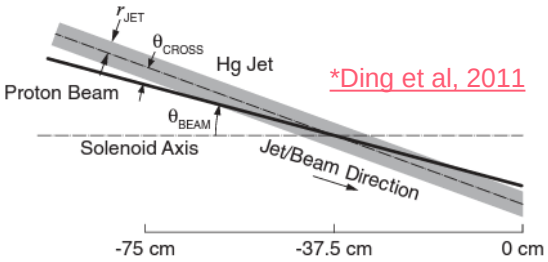


α

Outlet slope

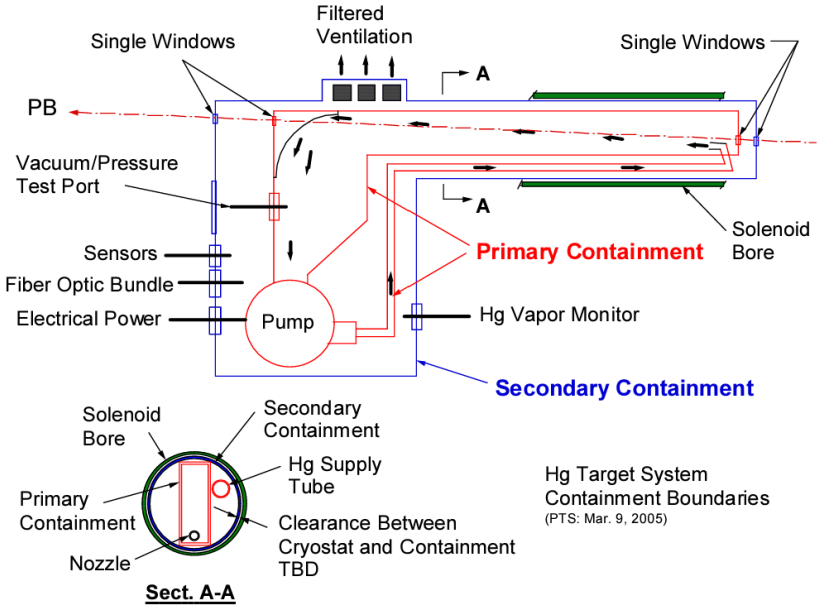
Liquid target options – 3 (jet)

- High-velocity liquid jet:
  - Explored with Hg (SNS, Mucol)
  - Stabilizing MHD effect
  - No segmentation
  - Issue with windows
  - To be investigated…



*Ding et al, 2011

FIG. 3. The mercury jet target geometry. The proton beam and mercury jet cross at $z = -37.5$ cm.

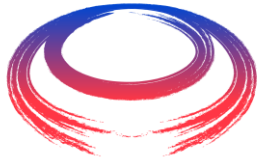


*Spampinato et al, 2005

Figure 2: Schematic diagram of the target system.

Outcome

- Opportunities:
  - Known liquid-Pb / LBE thermo-hydraulics
  - Cooling outside vacuum chamber
  - Species mostly retained
  - No degradation of target material
- Challenges:
  - Liquid-Pb containment vessel and windows (material, temperatures, DPA)
  - MHD interaction
  - Temperature management



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Thank you