Preliminary technical design for the FCC-ee dipole shielding

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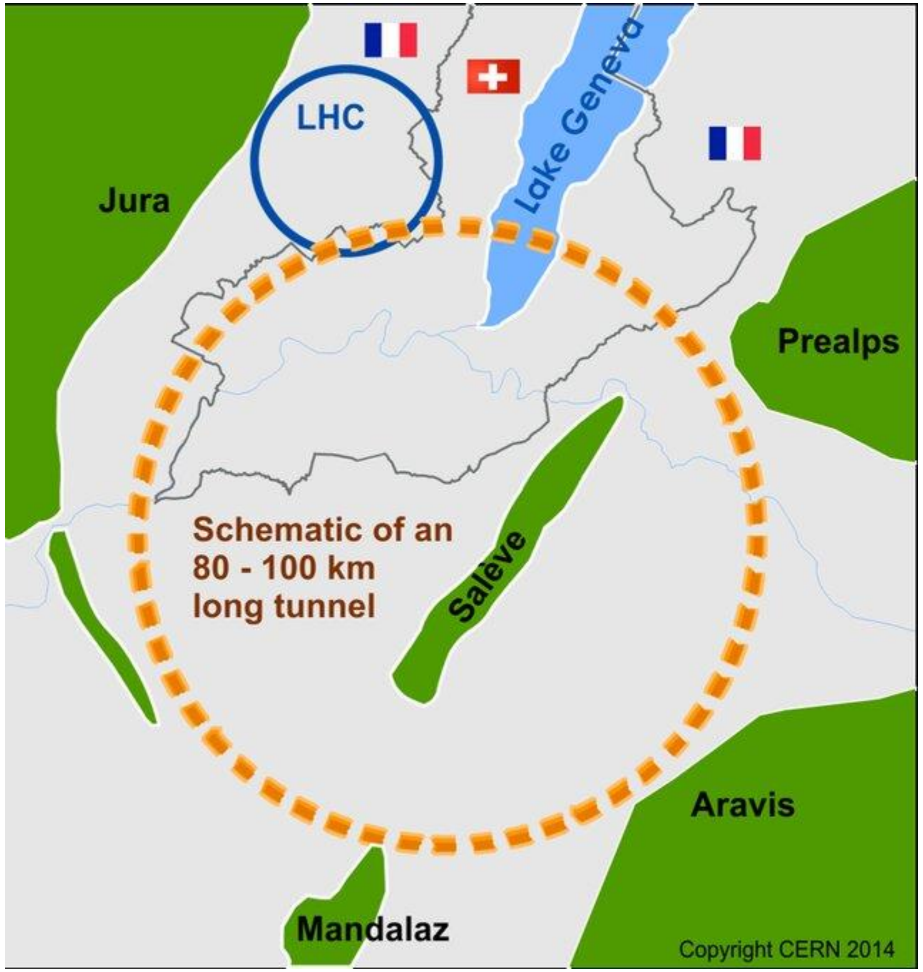
22-05-2025

Outlook

- Background and motivation.
- FCC-ee arc shielding design and development.
  - Feasibility Study Report (FSR) design.
  - Current conceptual design.
- Thermomechanical performance of the shielding.
- Challenges, production and logistics.
- Conclusions.

1. Background and motivation

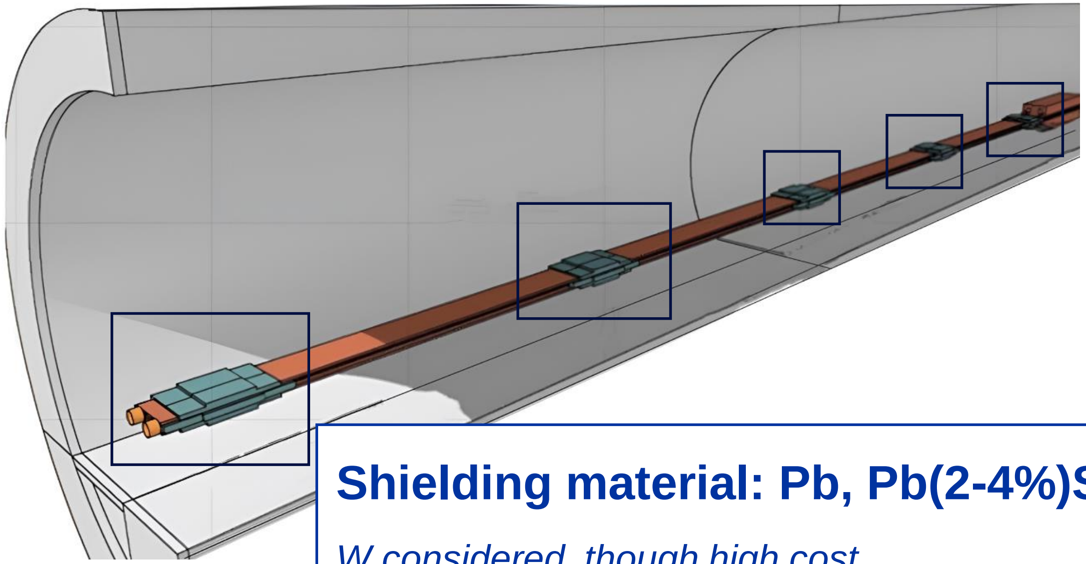


Comprehensive long-term program maximizing physics opportunities.

- **<u>Stage 1 (from 2040, 15 years)</u>: FCC-ee (Z, W, H, ttbar) as Higgs factory, electroweak & top factory at higher luminosities.**
- Stage 2 (from 2070, 25 years): FCC-hh (~100 TeV) as natural continuation at energy frontier, pp & AA collisions; e-h option.

For stage 1, the synchrotron radiation is too high for standard components. **Dedicated shielding is required.**

2. FCC-ee arc shielding design and development



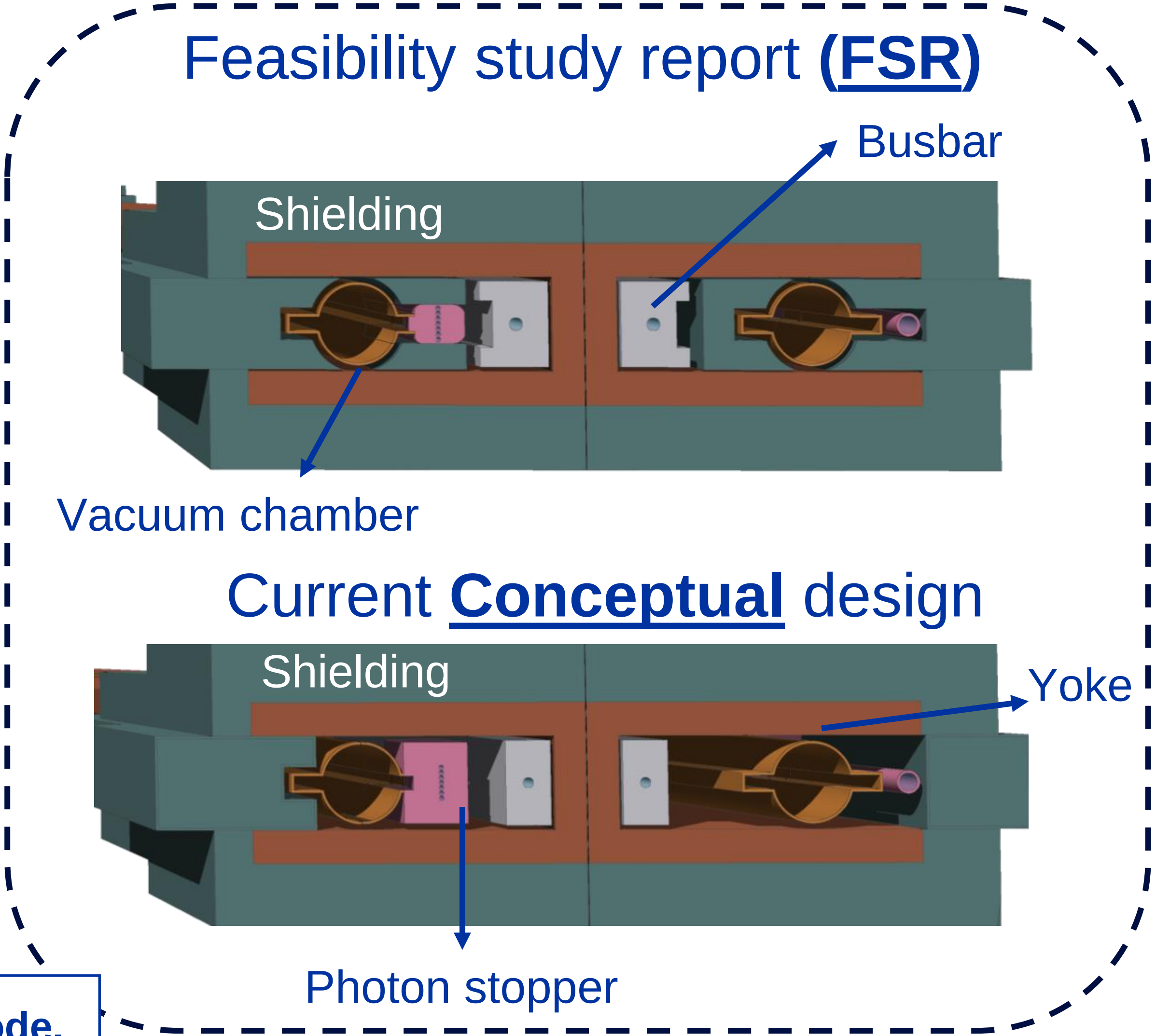
Shielding material: Pb, Pb(2-4%)Sb

W considered, though high cost.

Dipoles: 2840

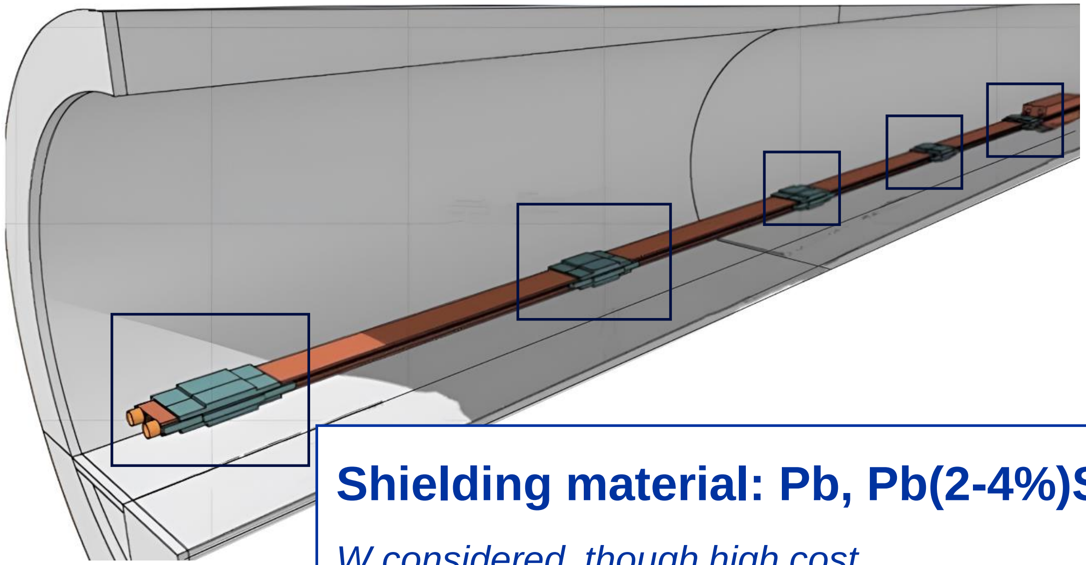
Photon stoppers per dipole: 10

 # Shielding units: 28400



This presentation provides results for ttbar operation mode.

2. FCC-ee arc shielding design and development



Shielding material: Pb, Pb(2-4%)Sb

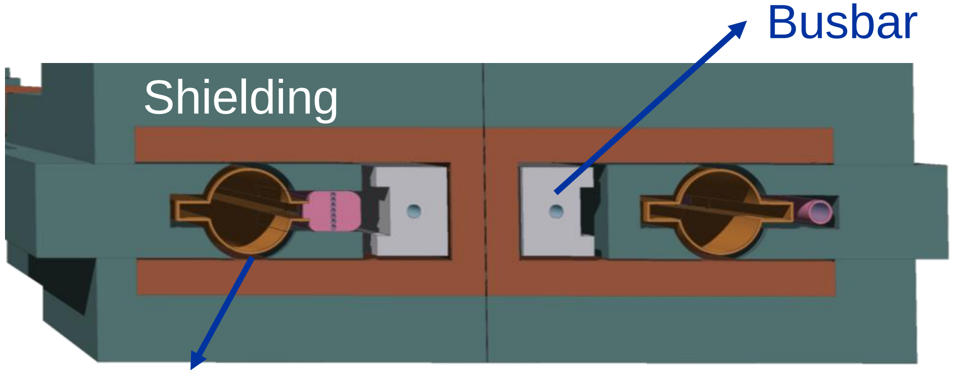
W considered, though high cost.

<u>Pb is not a structural material!</u>

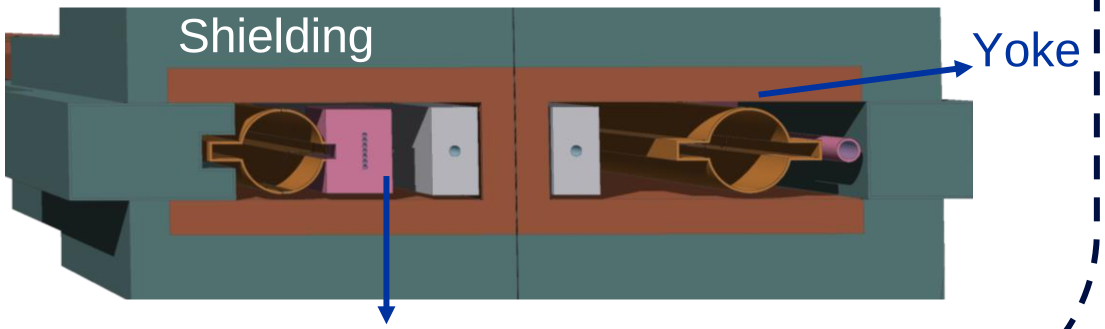
Low melting point (327 ℃), low thermal conductivity (35 W/m℃), highly ductile, yields at ~ 2MPa, creep susceptible…

This presentation provides results for ttbar operation mode.

Feasibility study report **(<u>FSR</u>)**



Current **<u>Conceptual</u>** design



2. FCC-ee arc shielding design and development

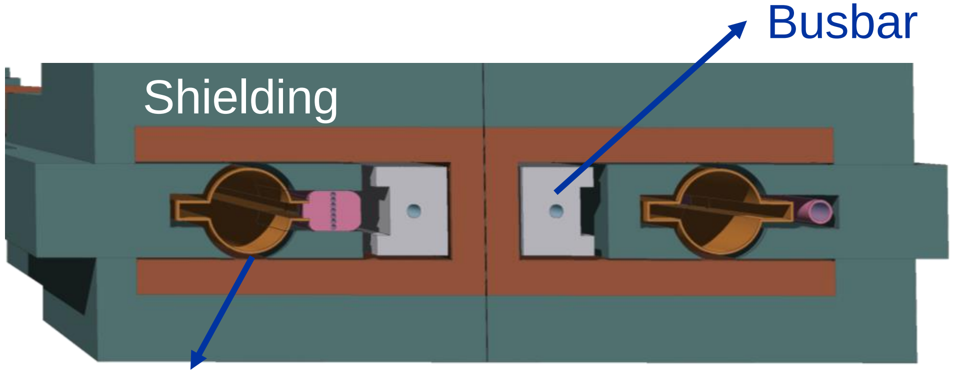
	FSR	Conceptual
Photon stoppers	68.1% (~3.4kW)	80.7% (~4kW)
Radiation shielding	20.4%	3.7%
Vacuum chamber	7.9%	5.2%
Dipoles yokes	3.4%	9.6%
Dipoles busbars	0.1%	0.5%
Environment	<0.03%	<0.05%

Higher energy deposited on shielding units.

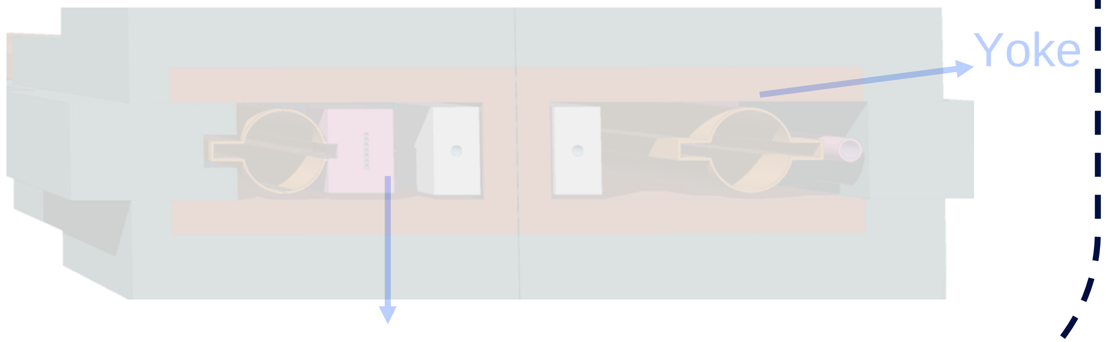
Very complex integration within the dipole.

Higher complexity for series production.

Feasibility study report (**FSR**)



Current **Conceptual** design



2. FCC-ee arc shielding design and development

	FSR	Conceptual
Photon stoppers	68.2% (~3.4kW)	80.7% (~4kW)
Radiation shielding	20.4%	3.7%
Vacuum chamber	7.9%	5.2%
Dipoles yokes	3.4%	9.6%
Dipoles busbars	0.1%	0.5%
Environment	<0.03%	<0.05%

Lower energy deposited on shielding units.

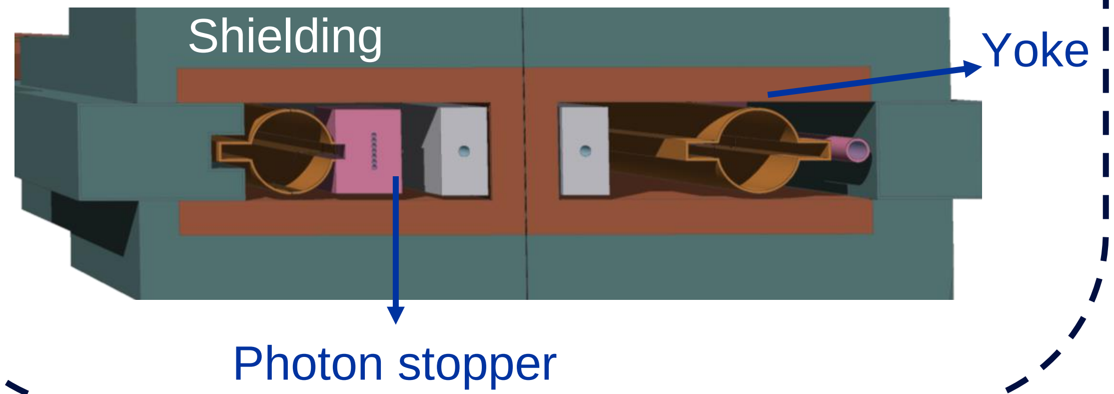
Easier integration within the dipole.

Lower complexity for series production.

HEAT CANNOT BE RELEASED TO THE TUNNEL!

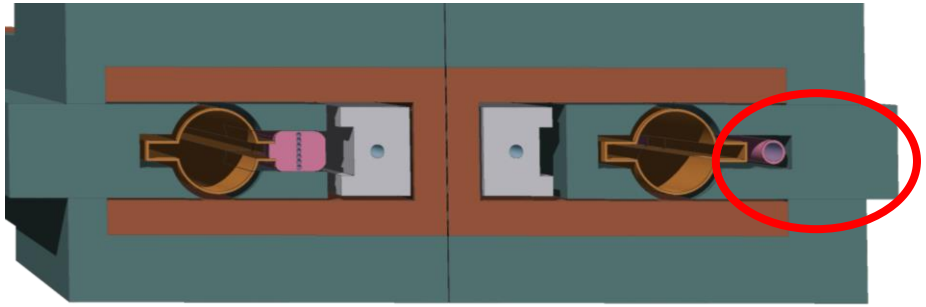
Feasibility study report (**FSR**)

Current **Conceptual** design



2.1 FSR shielding thermal management

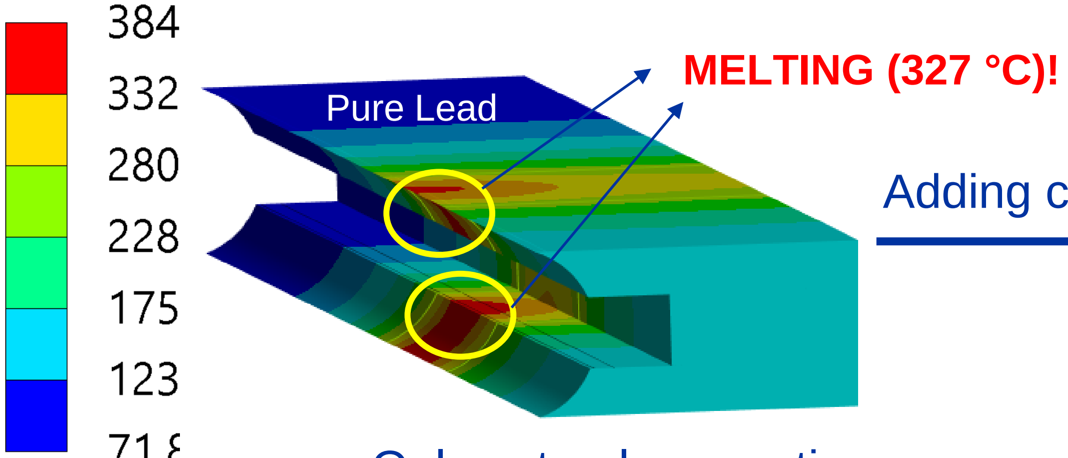
Feasibility study report (FSR) shielding



Shielding block with peak energy deposition ~ 640 W.

Only this block was modelled, as this conceptual approach is impractical to implement.

Calculations in steady state ttbar mode.

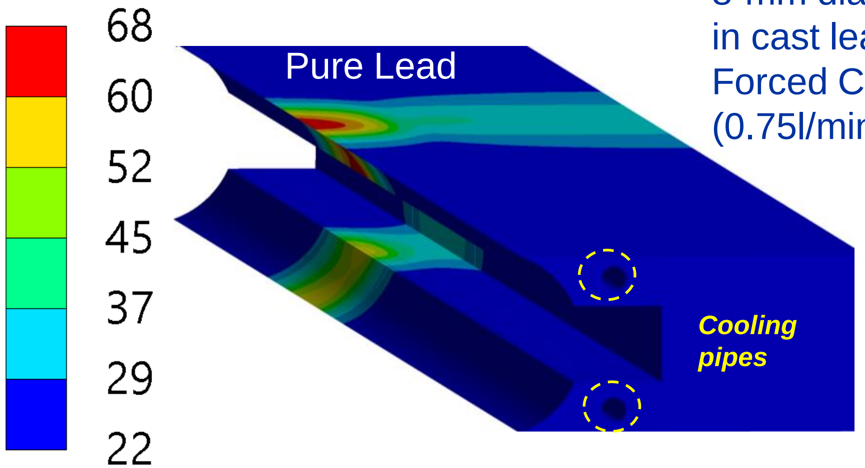


Temperature [°C]

Only natural convection

Adding cooling →

8-mm diameter SS pipes in cast lead.
Forced Convection water (0.75l/min)

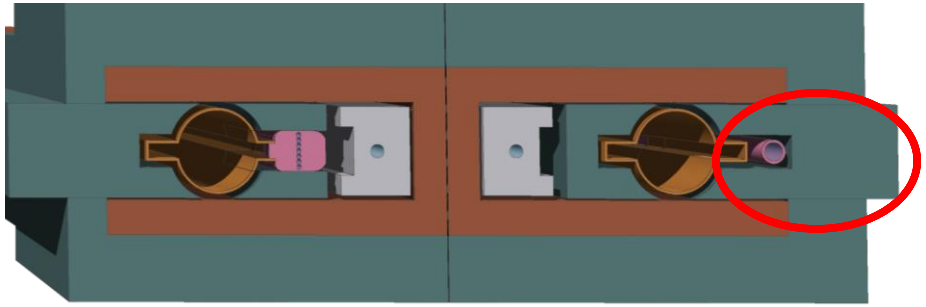


Temperature [°C]

natural convection + water cooling

2.1 FSR shielding structural behavior

Feasibility study report (FSR) shielding



Shielding block with peak energy deposition ~ 640 W.

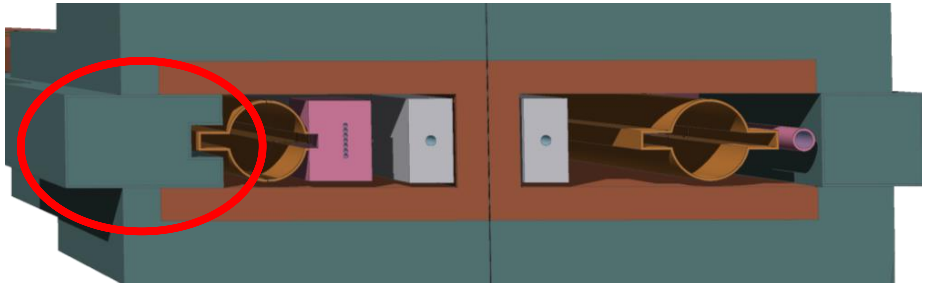
Only this block was modelled, as this conceptual approach is impractical to implement.

Calculations in steady state ttbar mode.

- Beam-induced stresses are minimal, remaining well below 2 MPa (~material's yield)
- Initial plasticity and creep assessments have been conducted; however, these did not include supporting contact conditions.
- **No additional analysis has been pursued**, as the current design has proven to be impractical for implementation.

2.2 Conceptual shielding thermal management

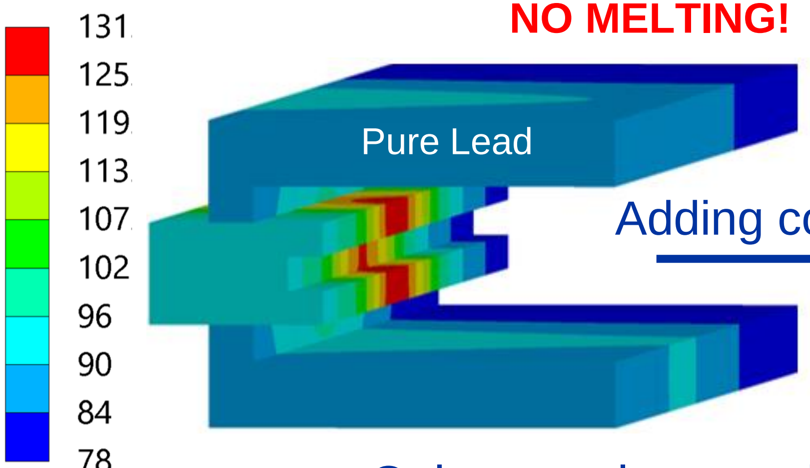
Current conceptual design



Shielding block with peak energy deposition ~ 130 W.

Entire shielding unit modelled.

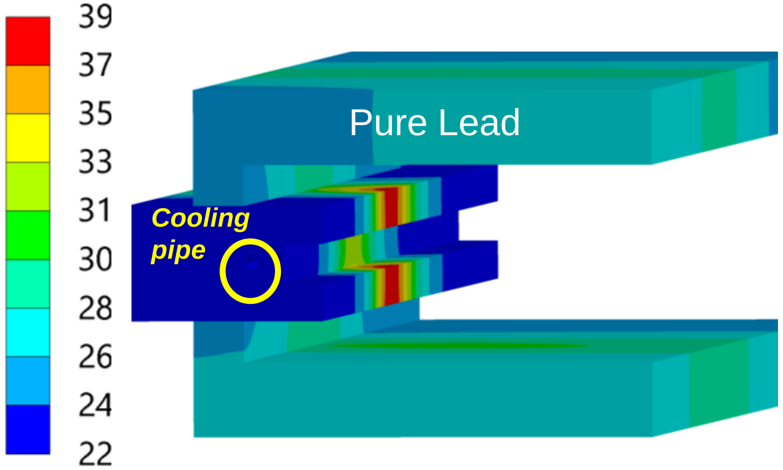
Calculations in steady state ttbar mode.



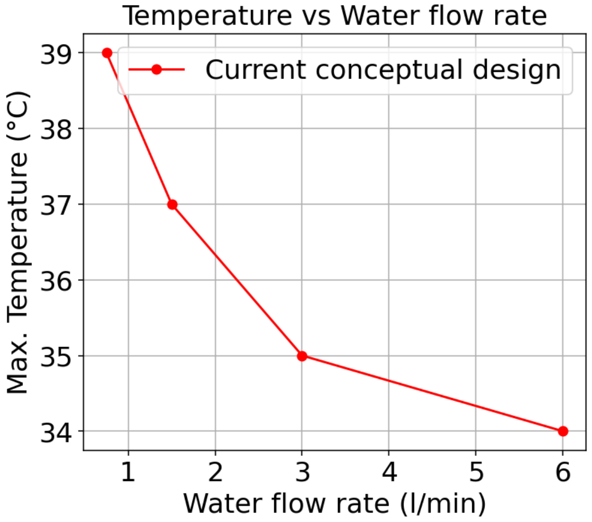
Temperature [°C]

Only natural convection

Adding cooling



Temperature [°C]

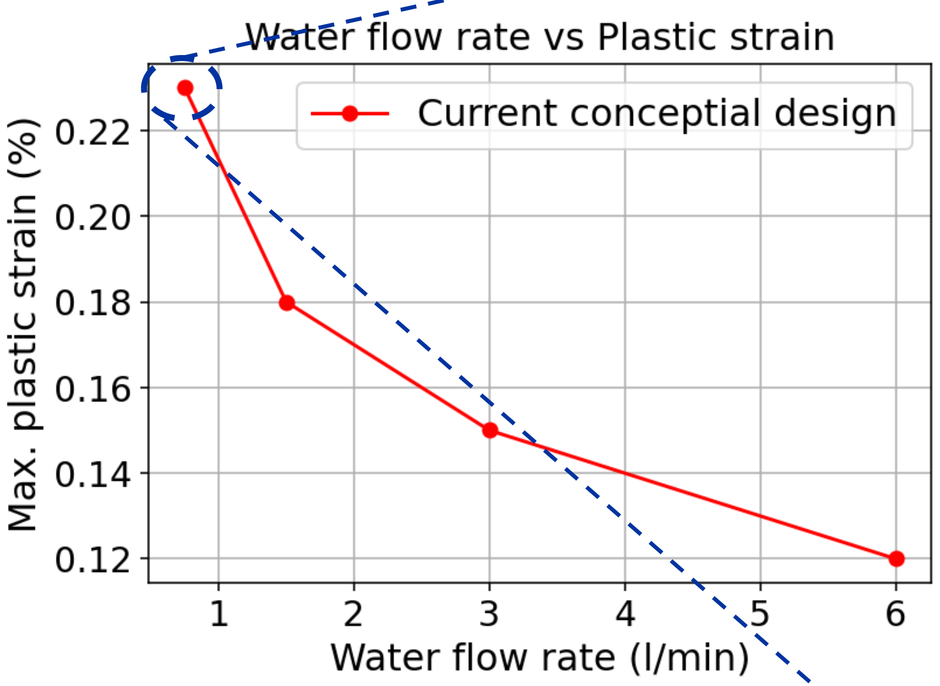


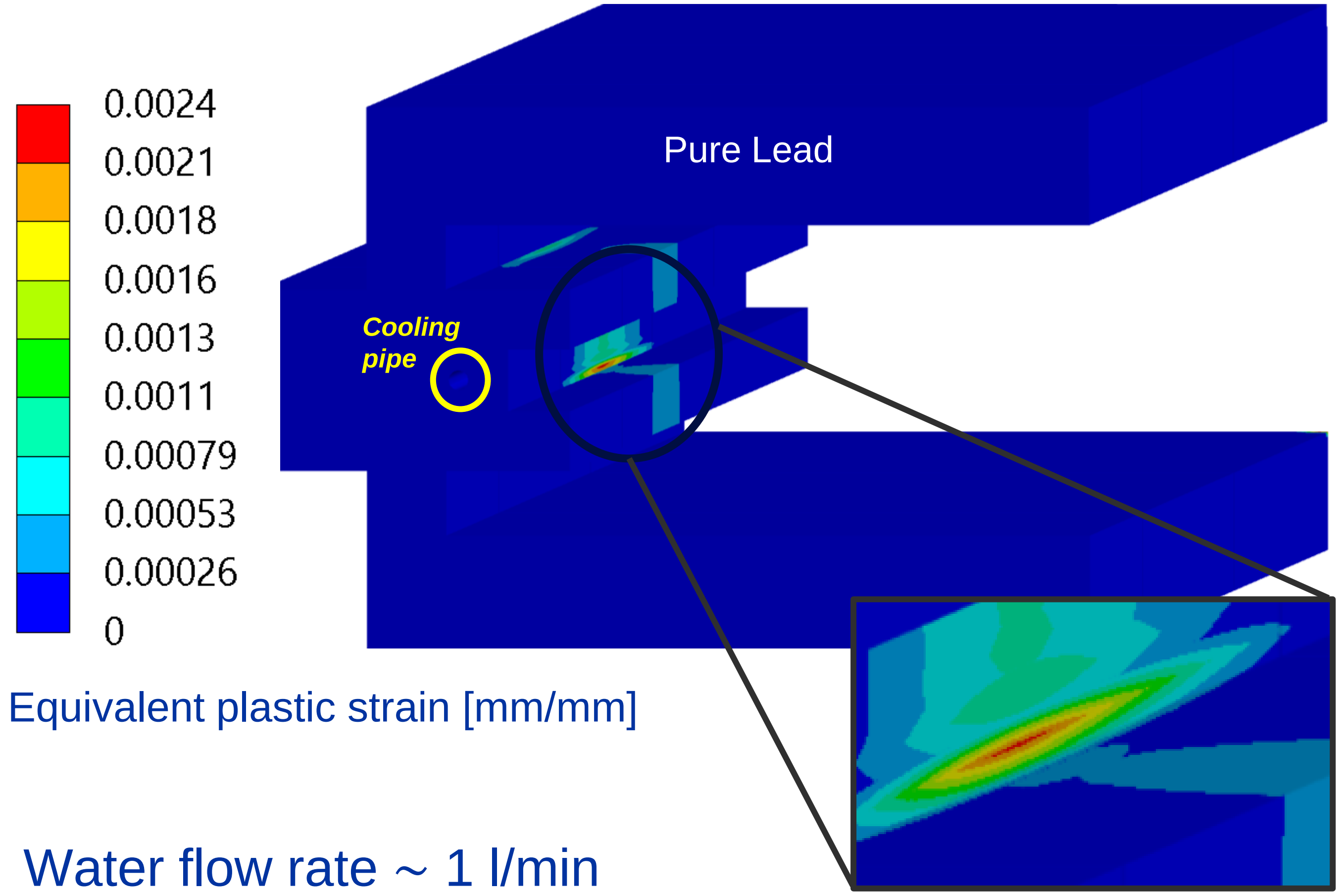
natural convection + water cooling

2.2 Conceptual shielding structural behavior

Beam-induced plastic deformation

Calculations in steady state ttbar mode.



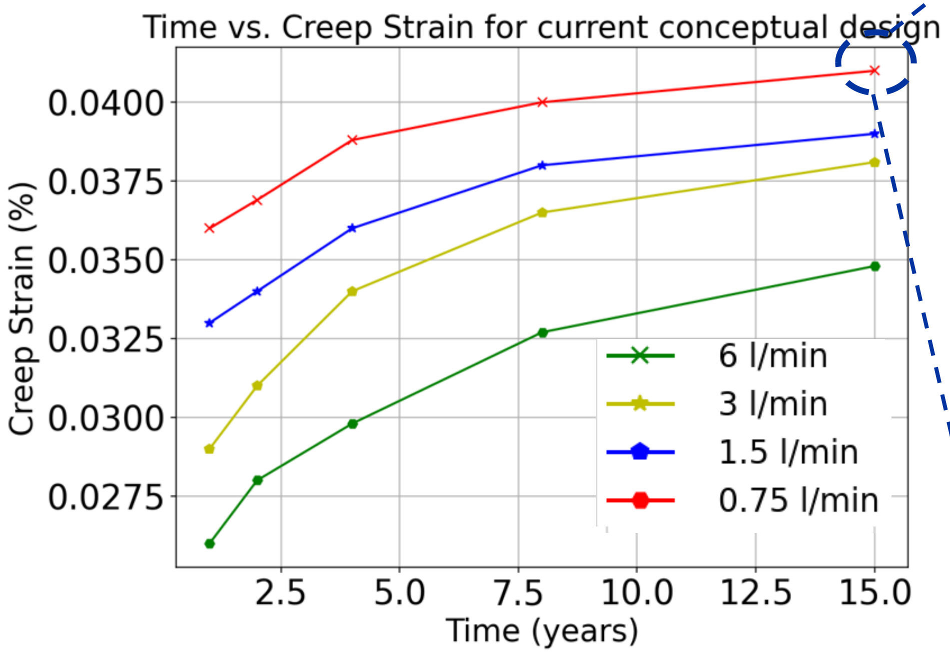


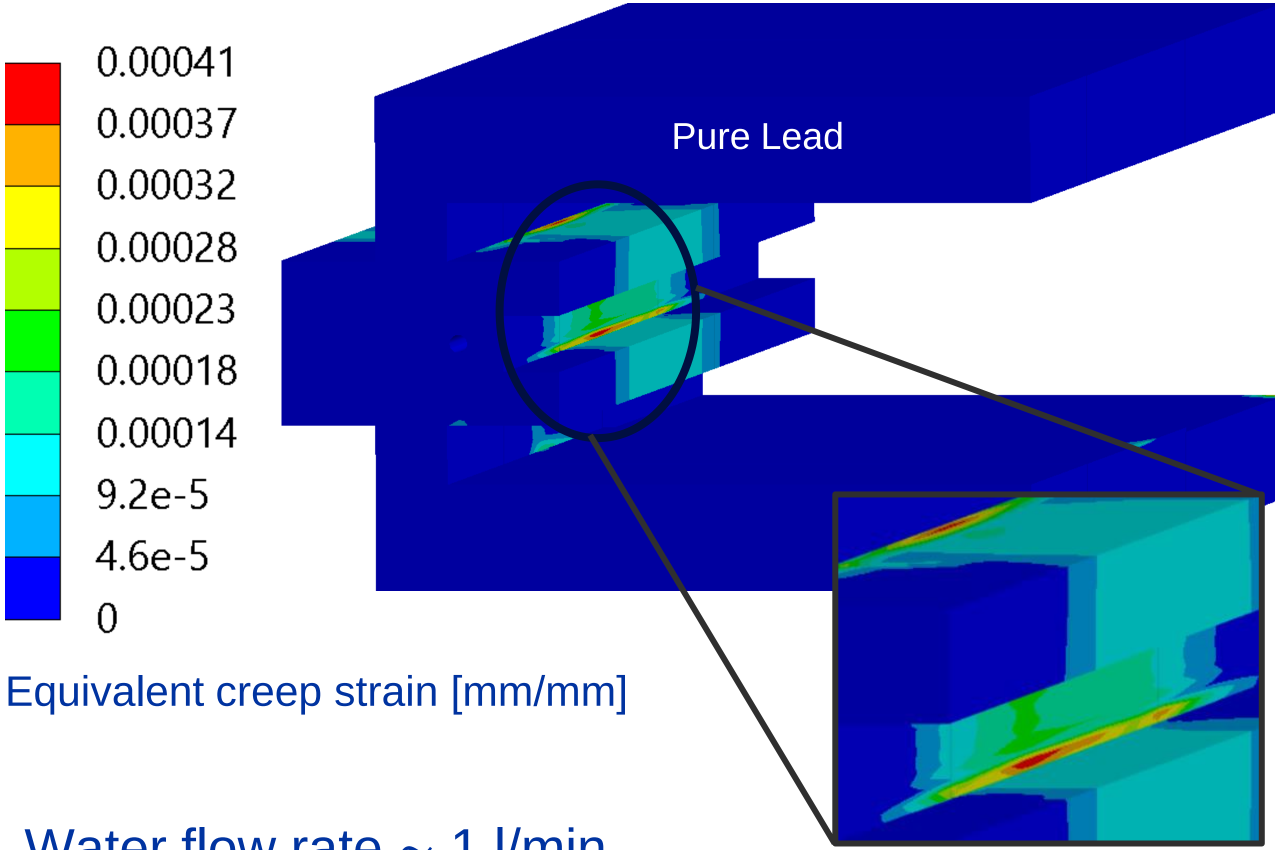
Water flow rate ~ 1 l/min

2.2 Conceptual shielding structural behavior

Beam-induced creep deformation

Calculations in steady state ttbar mode.





Water flow rate ~ 1 l/min
15 years operation

Conclusions

from thermomechanical simulations…

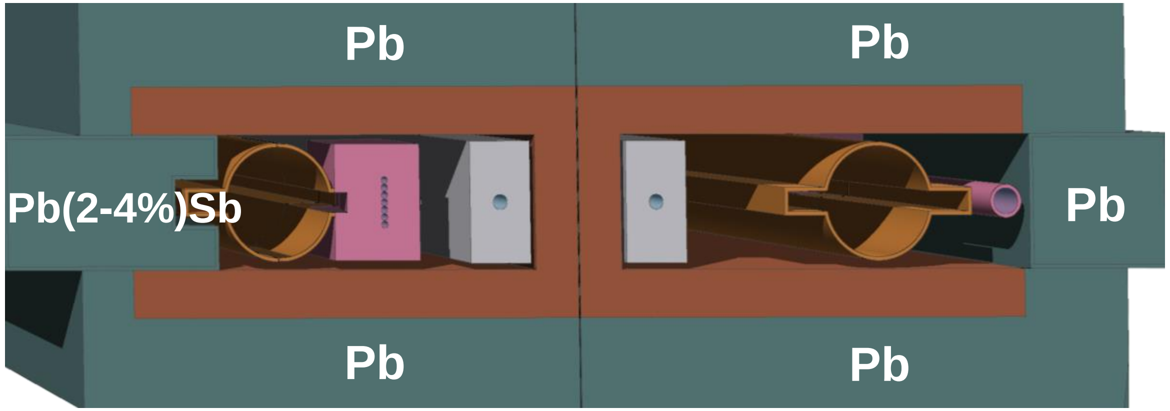
The FSR shielding is impractical for implementation, though temperature and beam-induced stresses are manageable.

The conceptual design results in low beam-induced stresses, which means that after 15 years of steady operation, the structure does not experience significant deformation.

3. Challenges, production and logistics

Design and material selection

- Due to in-series production, what are our design limitations?
- Adding Sb into Pb improves strength, though its high-cost limits use to critical areas.



Example for material selection proposal.

Supports and interfaces

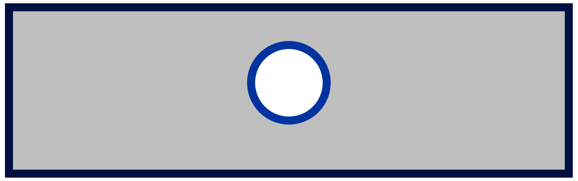
- The Pb shielding wraps around the dipole magnet, fully encasing it. However, it must not support its weight, as this would lead to deformation over time due to creep.

Integration within the dipole

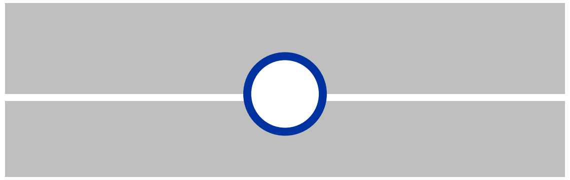
- The shielding fits well around the dipole, but contact points need definition. Top/bottom plate cooling relies on surrounding components to be cooled.

3. Challenges, production and logistics

Actively cooled plates



Embedded stainless steel pipe in cast lead



Stainless steel pipe cladded into two plates

Lowest thermal contact resistance.
Involves casting: **higher** complexity and cost.
Requires of a mould.

Higher thermal contact resistance.
Lower complexity.
Does not require of a mould.

Other options…

Cooling by forced gas convection instead of water (**no stainless-steel pipes needed ***).

Cooling by conduction, attaching a high conductivity body to the shield.

*: Water cannot be in contact with activated lead to avoid erosion-corrosion problems, as maintenance in the cooling loops would be extremely challenging (experience from nTOF#2).

3. Challenges, production and logistics

Transport, storage and installation

- Transport capacity: 10k–15k t of Pb, using dedicated trucks (~25 t per transport).
- With a 3 - 5 year production timeline, Pb must be stored in dedicated facilities.
- Heavy Pb plates can imply significant deformations; straightening capability required before installation.

Safety, dismantle and recycle

- Pb is a toxic material for humans. Radioactive resistance coatings are being studied to avoid direct contact with operators.
- Pb is to be re-used/recycled after FCC-ee.

Next steps

- Prototype construction and potential implementation in the arc cell mock-up.

4. Conclusions

- Ongoing work focuses on optimizing the radiation shielding for the FCC-ee arc. Design implementation in collaboration with MME, VSC and MSC.
- Thermomechanical simulations conducted so far have not revealed any critical issues.
- Active cooling of the shielding is necessary to manage temperature, limit beam-induced stresses, and prevent heat dissipation into the tunnel environment.
- Investigations are underway into methods for integrating stainless steel cooling pipes within the lead shielding.
- The logistical challenges associated with large-scale production are currently being assessed; ongoing studies to optimize cost and design efficiency.

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