[22nd SY/STI FCC meeting]:

FCC-ee shielding thermal management

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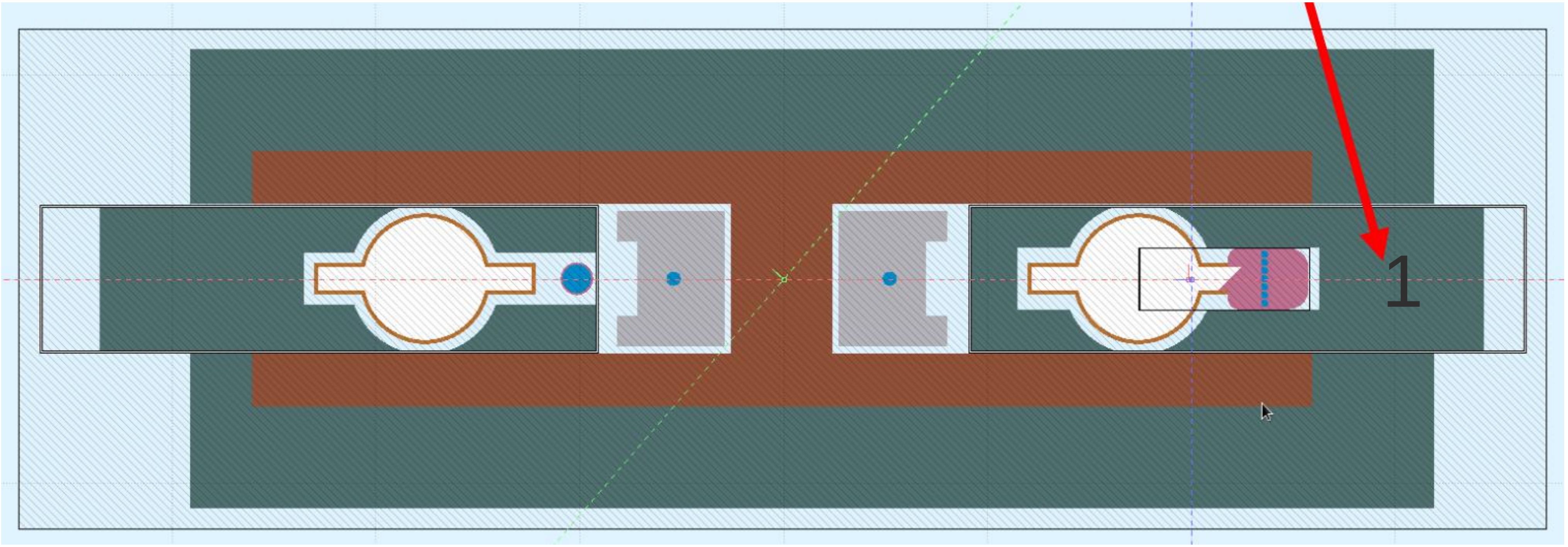
The FCC-ee faces challenges in **managing radiation** from primary synchrotron photons.

Optimization focuses on refining the **shielding's shape, size, and materials**, to improve scalability.

Goals include detailed **cost estimates**, spatial assessments, and a design addressing **thermal management, mechanical integrity**, and structural support, ensuring significant reduction of ionizing dose.

Thermal management external shield element

Energy deposition for this shielding element



The current presentation portrays the first thermomechanical results of the shielding element highlighted above. Soon other elements will be analysed.

Initial thermomechanical approach

Is active cooling needed… to dissipate heat from the tunnel, or also to protect the Pb shield?

Thermal management external shield element

Initial approach

Properties: 64 bunches * 1.48e11 e-/bunch * 3306 Hz
Average thermal power deposited: ~410 W.
Important: power deposited cannot be dissipated into environment.

Relative power deposition with and w/o radiation sheilding

	ZH (120 GeV)		ttbar (182.5 GeV)	
Radiation shielding:	*w/o*	*with*	*w/o*	*with*
Photon stoppers	87.5%	87.3%	77.9%	77.7%
Radiation shielding	N/A	**8.5%**	N/A	**14.1%**
Vacuum chambers	3.2%	3.0%	5.7%	5.6%
Dipoles	7.1%	1.1%	11.7%	2.6%
Quadrupoles	<0.01%	<0.01%	<0.1%	<0.1%
Sextupoles	<0.01%	<0.01%	<0.1%	<0.1%
Environment	**2.2%**	**<0.01%**	**4.6%**	**<0.03%**

By A. Lechner

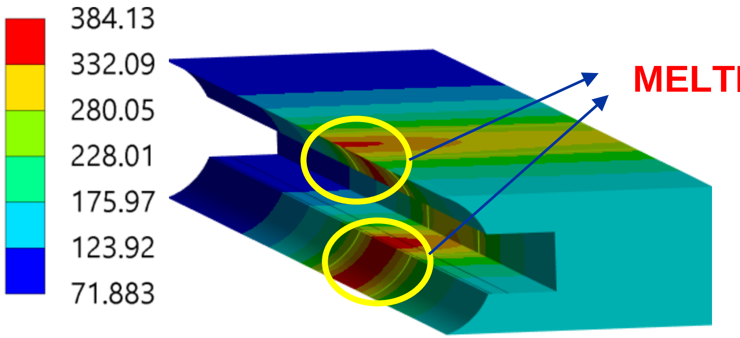
First approach → **No active cooling** → **This will define whether the cooling is only needed to dissipate the power, or also to necessarily cool-down the shielding.**

Second approach → **Active cooling**

Thermal management external shield element

Initial approach

First approach → **No active cooling** →



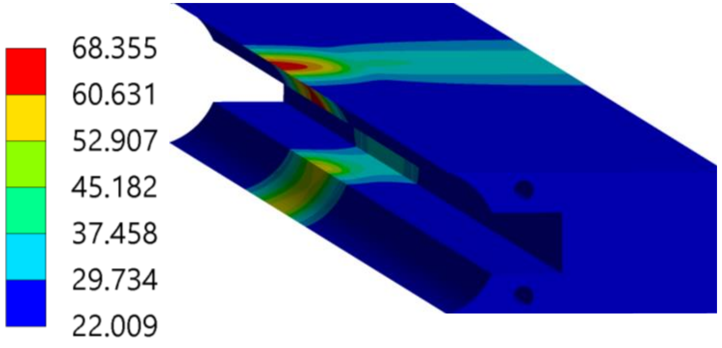
Temperature [C]

MELTING!

Pure Lead

Only natural convection

Second approach → **Active cooling** →



Temperature [C]

Pure Lead
8-mm diameter stainless steel pipes embedded in cast lead.
Forced Convection water (0.75l/min)

98.75% heat dissipated by cooling pipes

1.25% heat dissipated to the environment

Actively cooling is fundamental for the shielding survivability. As observed, no active cooling (only convection to the environment) melts part of the lead.

Beam induced mechanical stresses

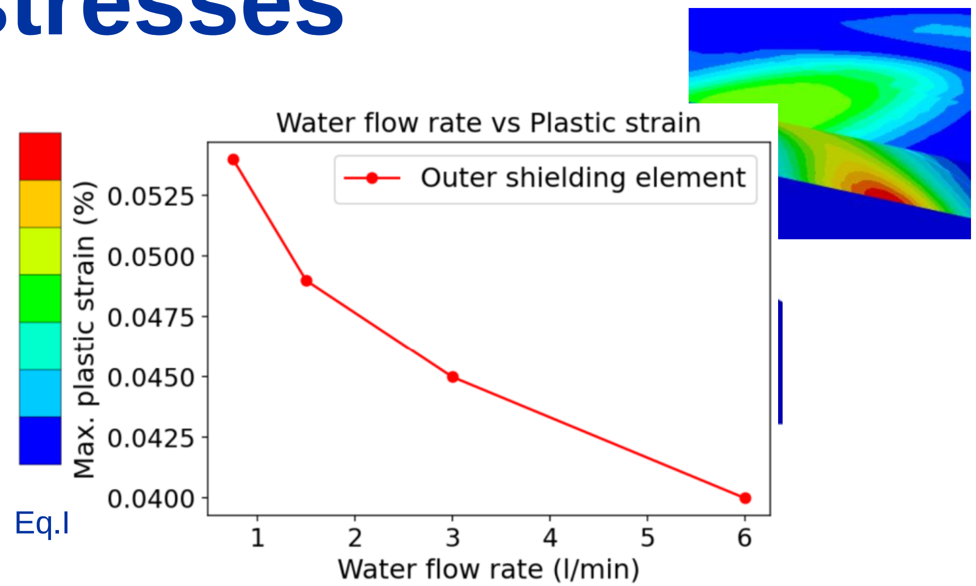
Initial approach

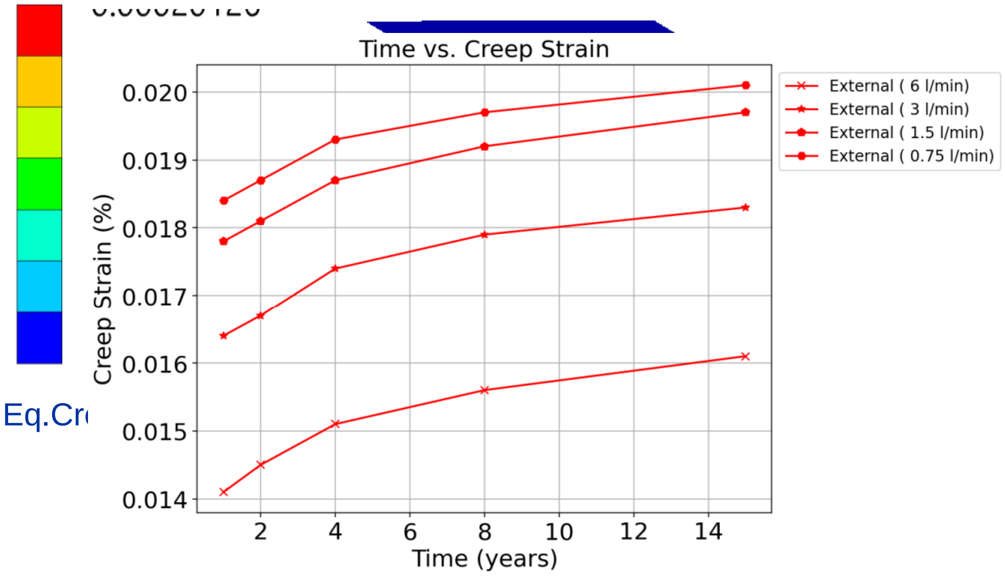
This approach simply considers beam-induced stresses, as mechanical contacts are still not defined.

Second approach → **Active cooling** →

Very small equivalent plastic strain.
Very small equivalent creep strain after 15 years.

Deformations calculated are also small, though contacts are still uncertain.



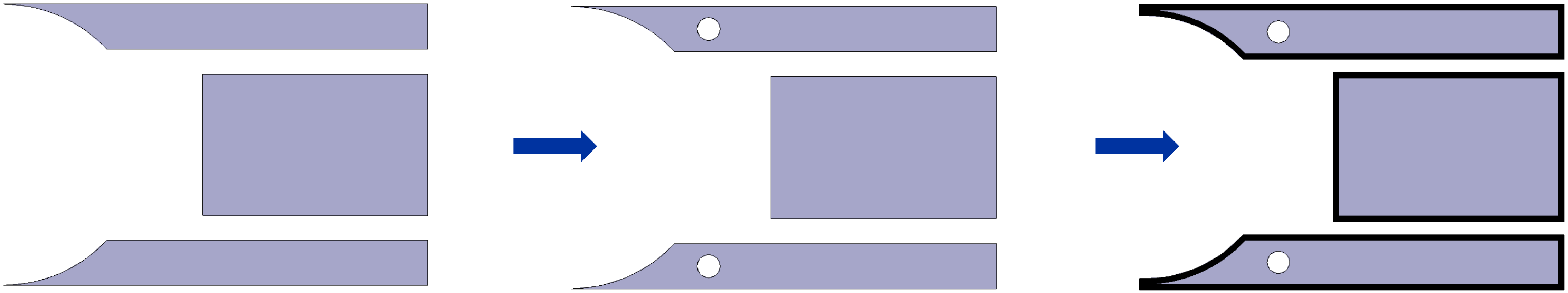


Optimization

Design definition, feasibility, material selection and cooling sensitivity

Optimization

Step by step



- Lead obtained in primitive shapes.
- This will be decided in next stages.
- The material alloy is selected.

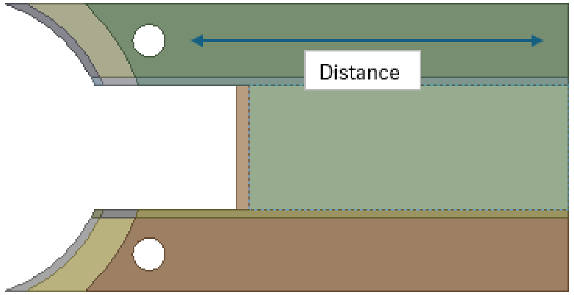
- Stainless steel cooling pipes in cast lead.
- The location of the pipes, as well as the flow-rate required is crucial for feasibility.

The cast lead is shaped in Stainless steel molds.

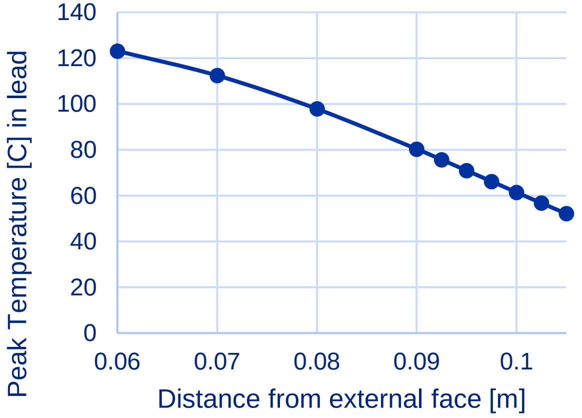
The stainless steel mould:
- Serve as mold for each part.
- Serve as anti-creep structure.
- Avoid direct contact with operators.

Optimization: current fields of investigation

Cooling pipes location



Location of the cooling pipes

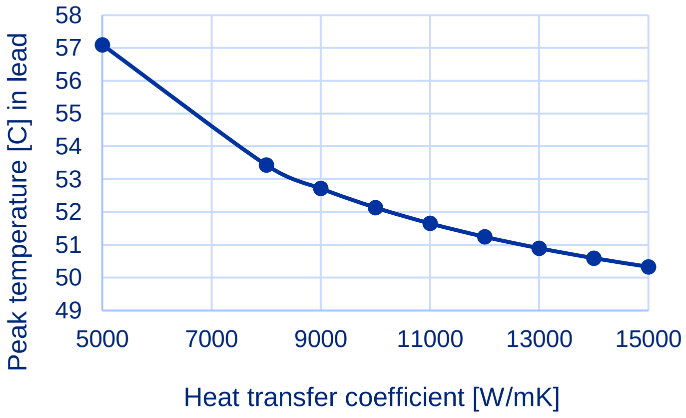


Cooling sensitivity

Where:

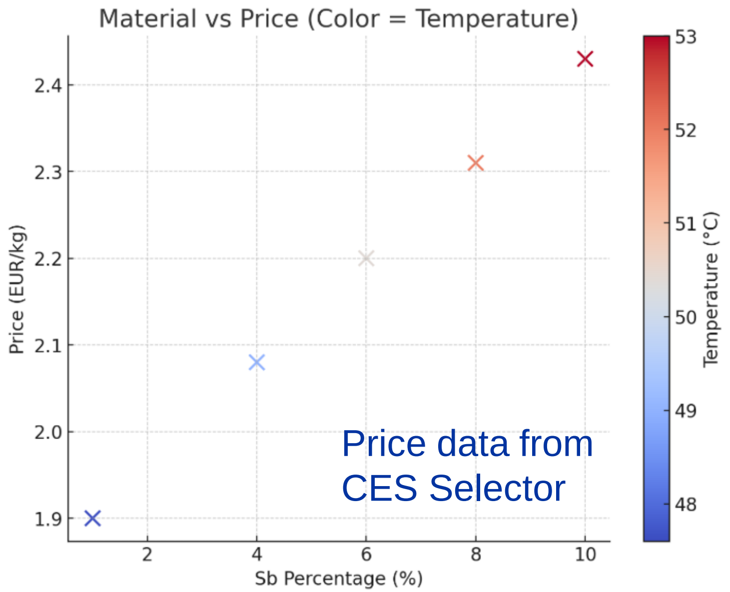
5000 W/mK ~ 3 l/min ~ 1 m/s
10000 W/mK ~ 6 l/min ~ 2 m/s
15000 W/mK ~ 12 l/min ~ 4 m/s

Heat transfer coefficient sensitivity



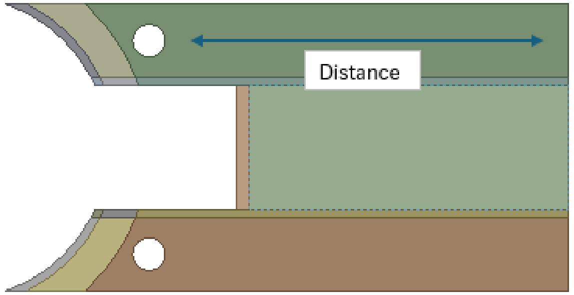
Material

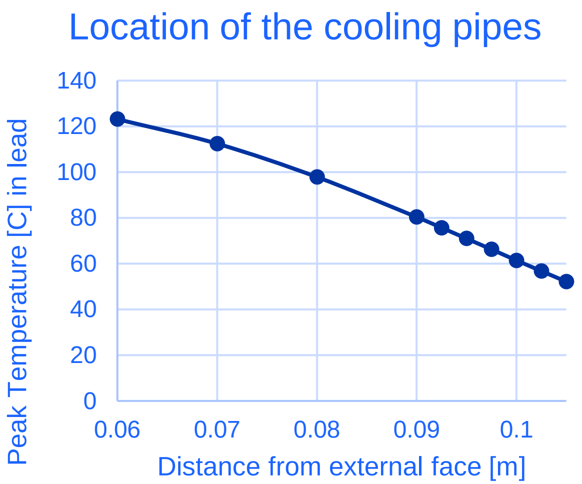
Lead antimony, though the proportion of antimony is to be optimized.



Optimization: current fields of investigation

Cooling pipes location





The location of the cooling pipes is crucial for the shield survivability.

The cooling pipes must be installed "as close as possible" to the internal surfaces of the external shield.

We do not have prior experience using stainless steel pipes in cast lead. To our knowledge, there is also no literature regarding concerning this subject.

Water must never be in contact with lead. Prior experiences, nTOF_1 and nTOF2.

Optimization: current fields of investigation

Cooling sensitivity

Where:

5000 W/mK ~ 3 l/min ~ 1 m/s
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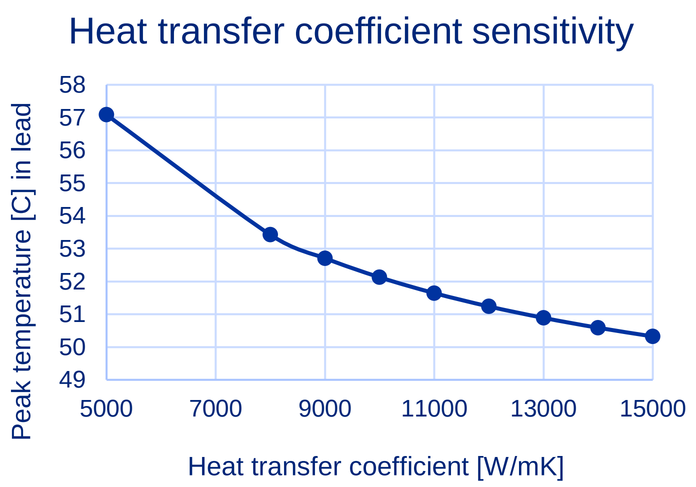


The water flow must be optimized to provide sufficient cooling at a low energy consumption for all the shielding elements.

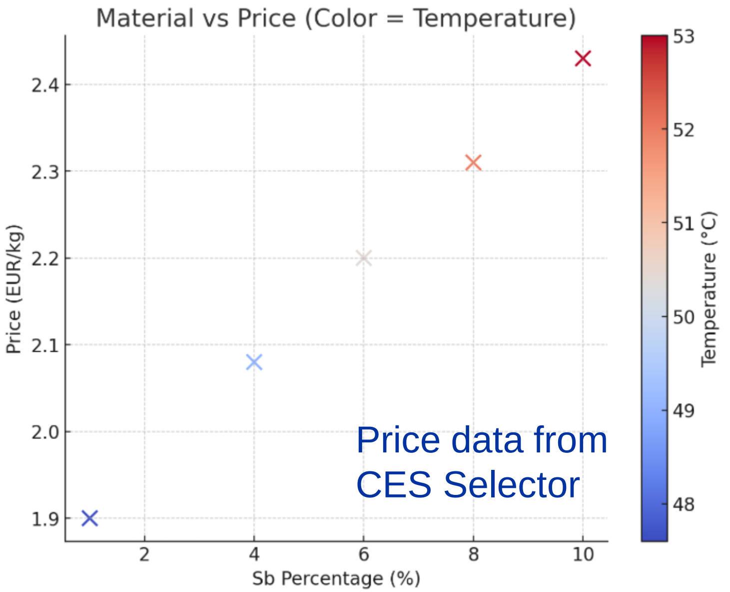
The stainless steel cooling circuit must be designed compliant to a low pressure drop, considering its manifolds and straight sections.

LOCA (loss of cooling accident) compliant. As observed in previous slides, in case where there is no cooling, pure lead would melt (Melting point is 327 degrees). Lead antimony (6%) would melt at 270 degrees).

Optimization: current fields of investigation

Material

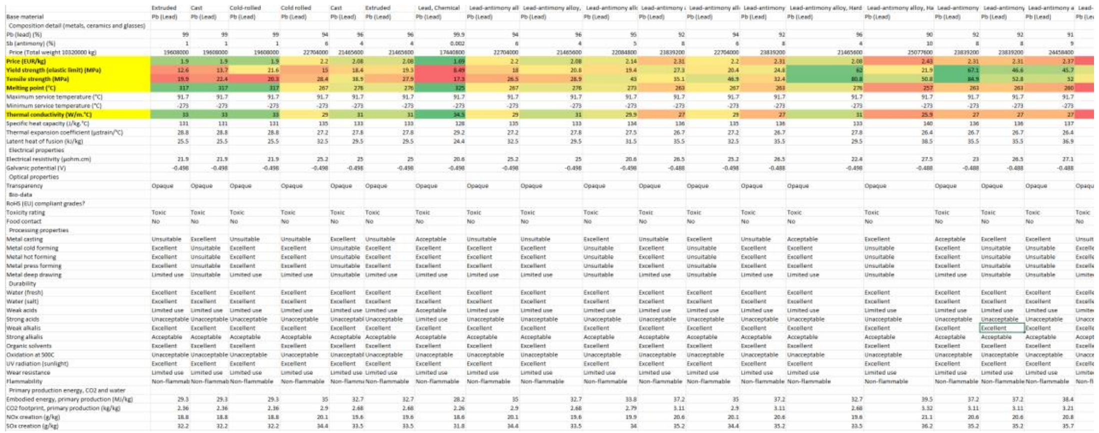
Lead antimony, though the proportion of antimony is to be optimized.



Mechanically stronger

- In the case where energy deposition in the shield increases, PbSb may be a better alternative than pure Pb.
- PbSb enhances the mechanical properties of Pb. However, the price of Pb increases considerably the budget.
- Optimizing the % of Sb is crucial for the economical sustainability of FCC.

CES Selector



	Extruded	Cast	Cold-rolled	Cold rolled	Cast	Extruded	Lead, Chemical
Base material	Pb (Lead)	Pb (Lead)	Pb (Lead)	Pb (Lead)	Pb (Lead)	Pb (Lead)	Pb (Lead)
Composition detail (metals, ceramics and glasses)							
Pb (lead) (%)	99	99	99	94	96	96	99.9
Sb (antimony) (%)	1	1	1	6	4	4	0.002
Price (Total weight 10320000 kg)	19608000	19608000	19608000	22704000	21465600	21465600	17440800
Price (EUR/kg)	1.9	1.9	1.9	2.2	2.08	2.08	1.69
Yield strength (elastic limit) (MPa)	12.6	13.7	21.6	15	18.4	19.3	8.49
Tensile strength (MPa)	19.9	22.4	20.3	28.4	38.5	27.9	17.3
Melting point (°C)	317	317	317	267	276	276	325
Maximum service temperature (°C)	91.7	91.7	91.7	91.7	91.7	91.7	91.7
Minimum service temperature (°C)	-273	-273	-273	-273	-273	-273	-273
Thermal conductivity (W/m.°C)	33	33	33	29	31	31	34.5
Specific heat capacity (J/kg.°C)	131	131	131	135	133	133	128
Thermal expansion coefficient (µstrain/°C)	28.8	28.8	28.8	27.2	27.8	27.8	29.2
Latent heat of fusion (kJ/kg)	25.5	25.5	25.5	32.5	29.5	29.5	24.4
Electrical properties							
Electrical resistivity (µohm.cm)	21.9	21.9	21.9	25.2	25	25	20.6
Galvanic potential (V)	-0.498	-0.498	-0.498	-0.498	-0.498	-0.498	-0.498
Optical properties							
Transparency	Opaque	Opaque	Opaque	Opaque	Opaque	Opaque	Opaque

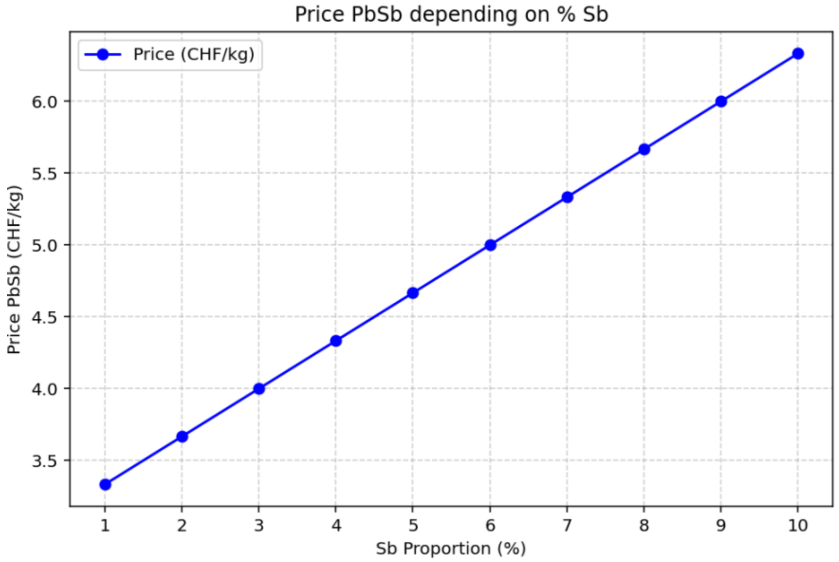
Currently exploring different PbSb alloys

Material characterization campaign for PbSb with different Sb percentage.

Discussion with Swedish ILO

- Recently, we had conversation with the Swedish ILO concerning the lead production.
- For our application, 2 or 3% Sb content should be enough. Pure Pb is not an option due to contamination of tools.
- Sb prices are climbing up. The less Sb we use, the better. Last prices are around 40 kUSD/ton.
- Prices for commercial PbSb are around 5 kUSD/ton, not including machining costs and additional features.

Costs today



Estimating 400kg per shield, we require of 10320 tons of PbSb

PbSb 1% ~ 34.3M CHF

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PbSb 10% ~ 65M CHF

Not including machining, logistics, etc…

Discussion with Swedish ILO

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- As 25800 parts will be needed, it is important to define a strategy to achieve this large amount of lead in a reasonable timeframe.
- From 2029, restrictions regarding exposition of humans to lead will be more stringent.
- It is possible to explore the option of producing Mock-up tests with different Swedish companies to evaluate the viability of the concepts we are currently considering.

Current and future steps

- We need to define the water cooling pipes location, and where they are needed.
- We need to define the contacts and how the shielding will be assembled.
- There is no experience using stainless steel pipes in cast lead, held in an stainless steel mold -> Preparations for designing a prototype.
- Discussions with companies on-going.

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