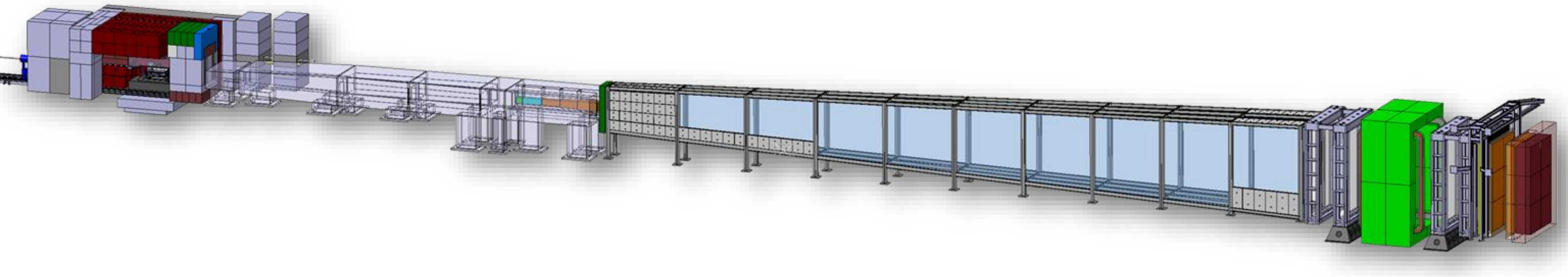


Engineering challenges

Pablo Santos Diaz on behalf of the SHiP collaboration

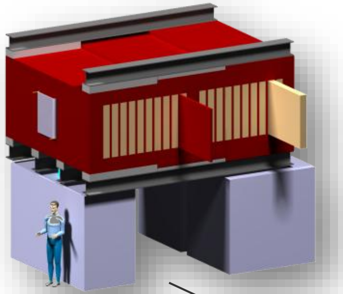
Spain@SHIP opportunities / 5-05-2026
Instituto de Física Corpuscular (IFIC), Valencia (Spain)

SHiP
Search for Hidden Particles

Engineering challenges for construction

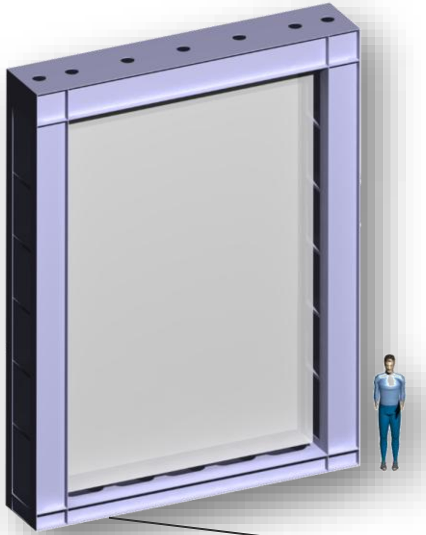
Muon shield generic magnets

Magnetic and thermo-mechanical design.



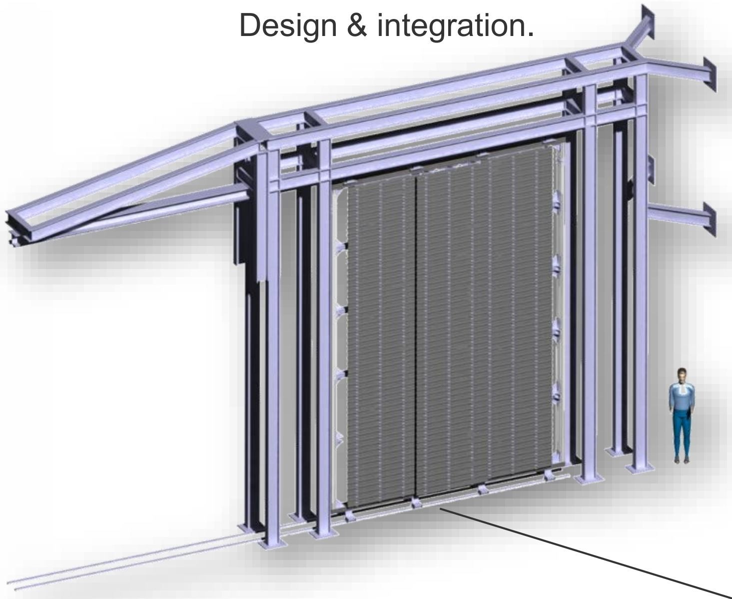
Straw tracker frame

Design & integration.



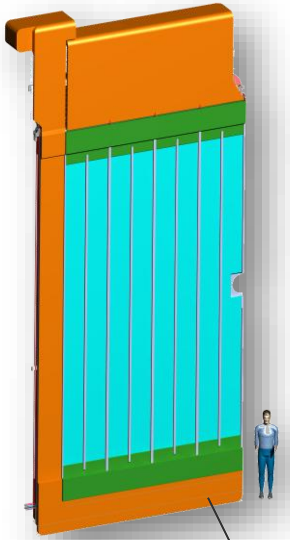
Timing detector mechanics

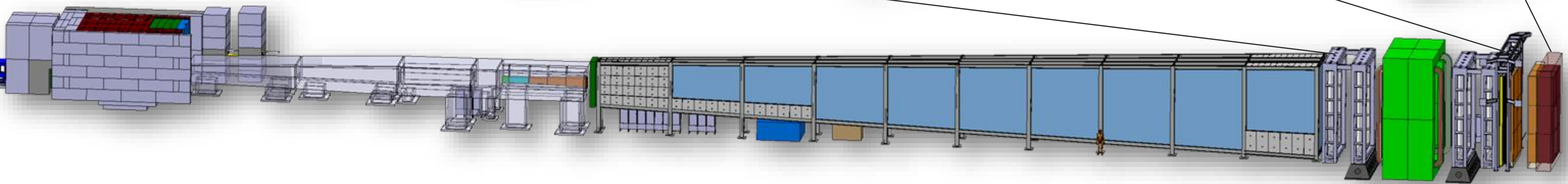
Design & integration.



Particle Identification Detector mechanics

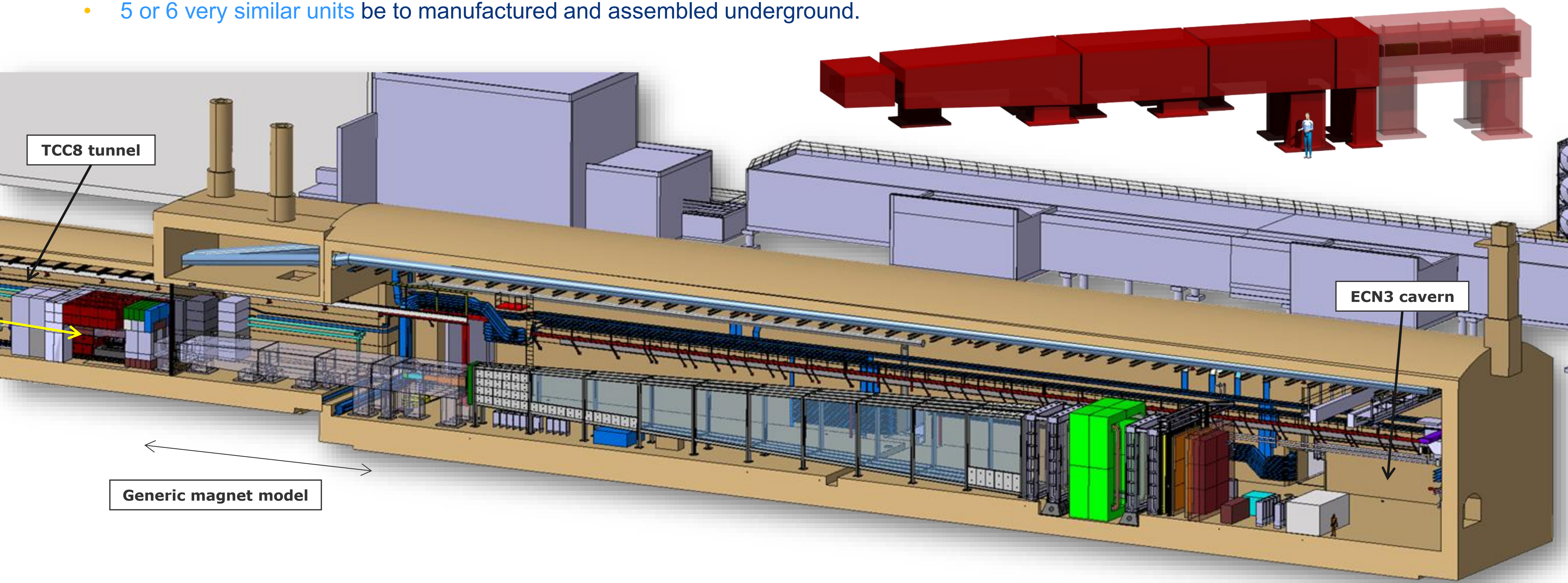
Design & integration.





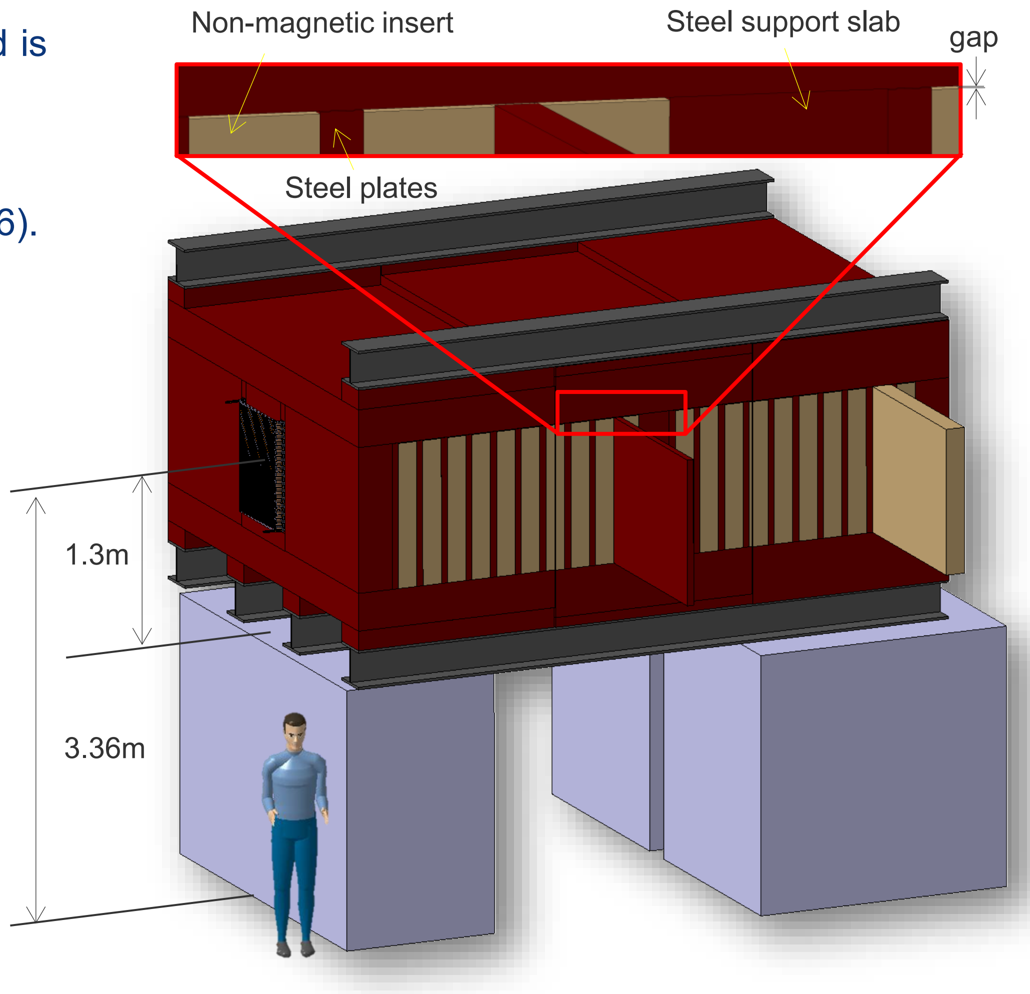
Muon shield template magnet

- A 4.8m long generic concept has been developed for the standardized tapered-shaped muon shield magnets.
- 5 or 6 very similar units be to manufactured and assembled underground.

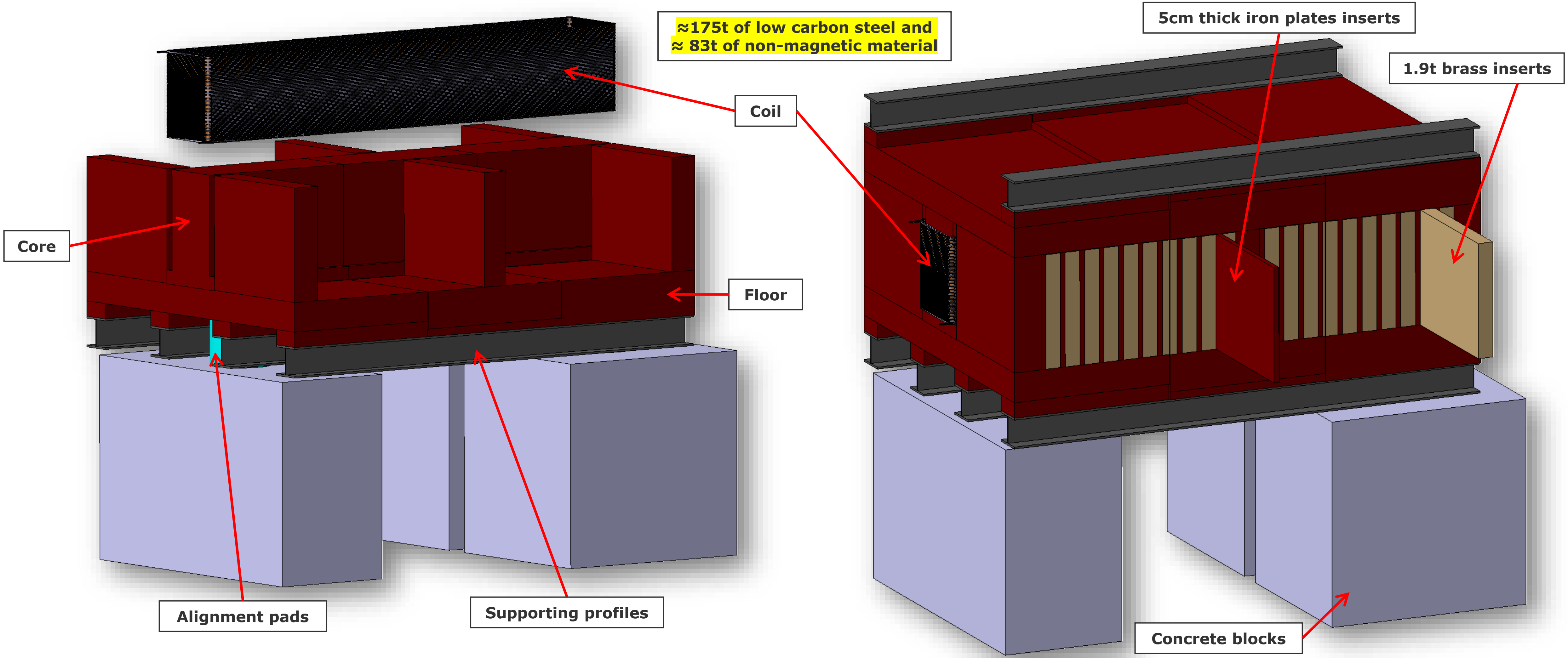


A generic muon shield magnet, the K7 concept

- To be assembled inside the ECN3 cavern and the TCC8 tunnel.
  - Overhead crane capacity is 30t where weight plus remanent field as total load is to be considered.
- Yoke:
  - Hot-rolled thick plates of High Purity Ultra Low Carbon Magnet Steel (AISI 1006).
    - Maximum part thickness 780mm.
  - 1.9T in the good field (core) region.
- Coil:
  - Demineralised water-cooled copper conductor.
    - Up to 80kW to be extracted. 4 cooling circuits to be integrated.
  - 500A maximum current & a magnetomotive force (NI) ≈22000.
  - Vacuum Pressure Impregnation (VPI) for large coils might apply.
- A few tons non-magnetic lateral inserts and iron plates position should be rearrangeable.
  - Handling system to be developed if extracted from the side.
- Alignment system for the 235t magnet might apply.
- The design is open to ease operation and manufacturability, therefore, to optimise cost.

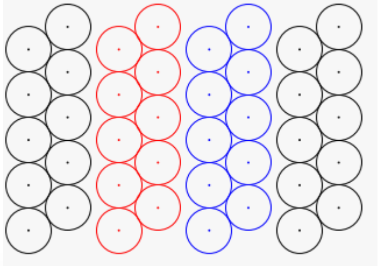


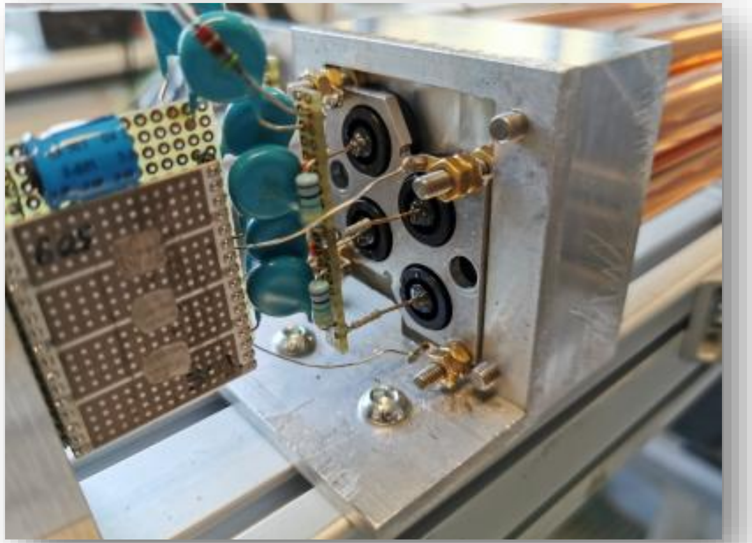
Conceptual assembly of the magnet

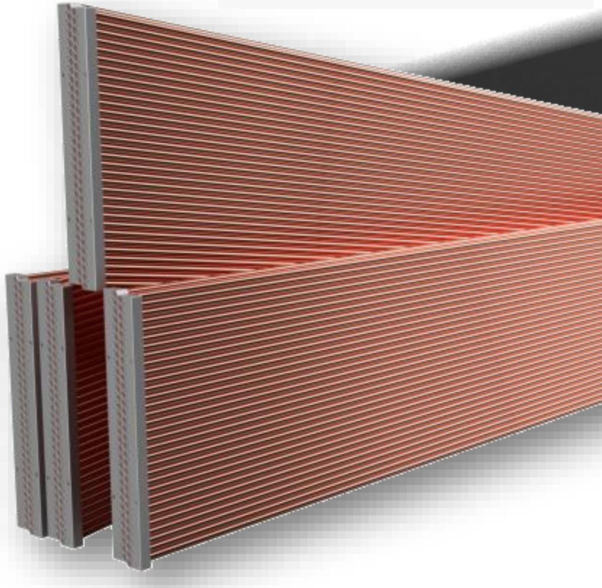


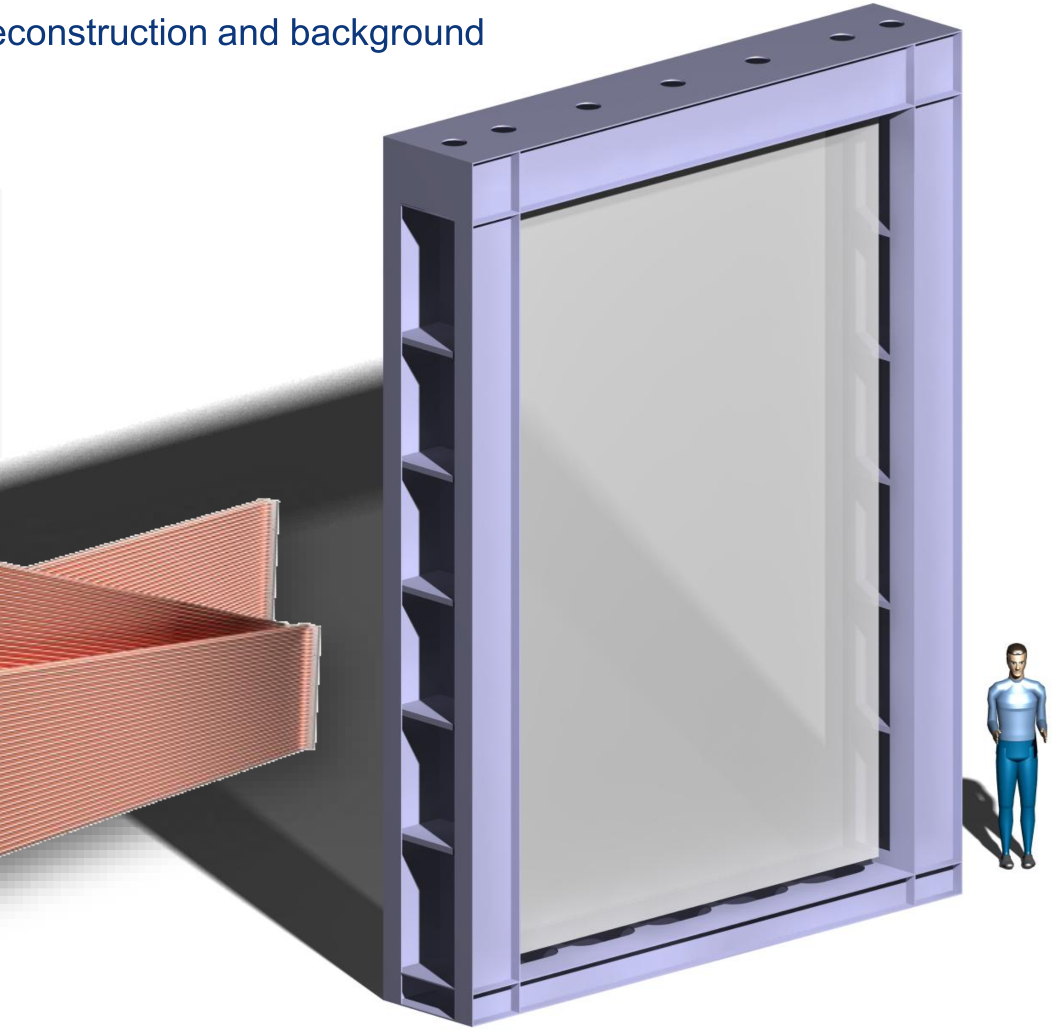
The Main straw tracker – supporting frame

- A spatial resolution better than 120µm is foreseen to guarantee a precise vertex reconstruction and background rejection
- The horizontal 2400 per station straw tubes are 2cm diameter and 4m length.
- The straws will be operated with a gas mixture of Ar/CO_2.
  - Front end electronics and gas manifolds to be integrated with the frame.



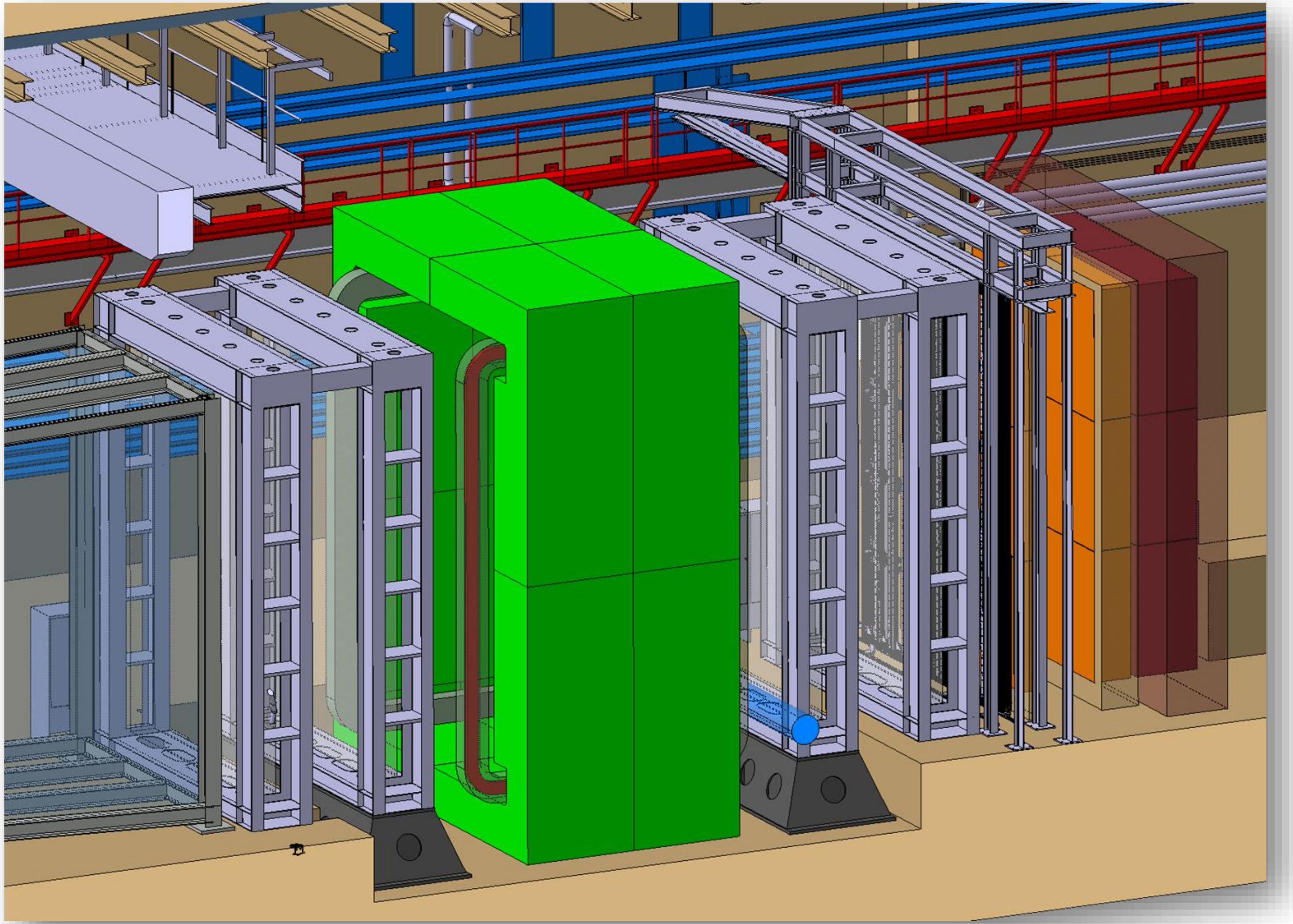






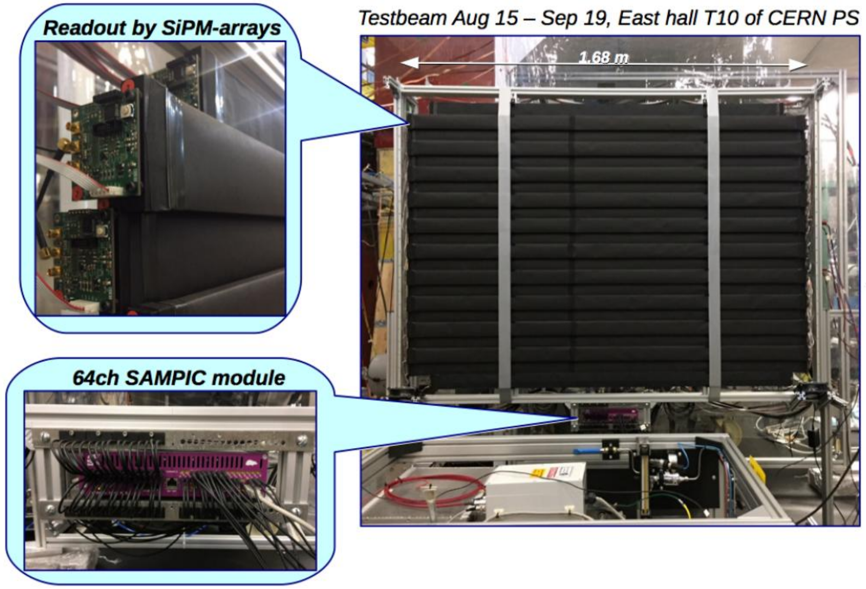
Challenge integration!

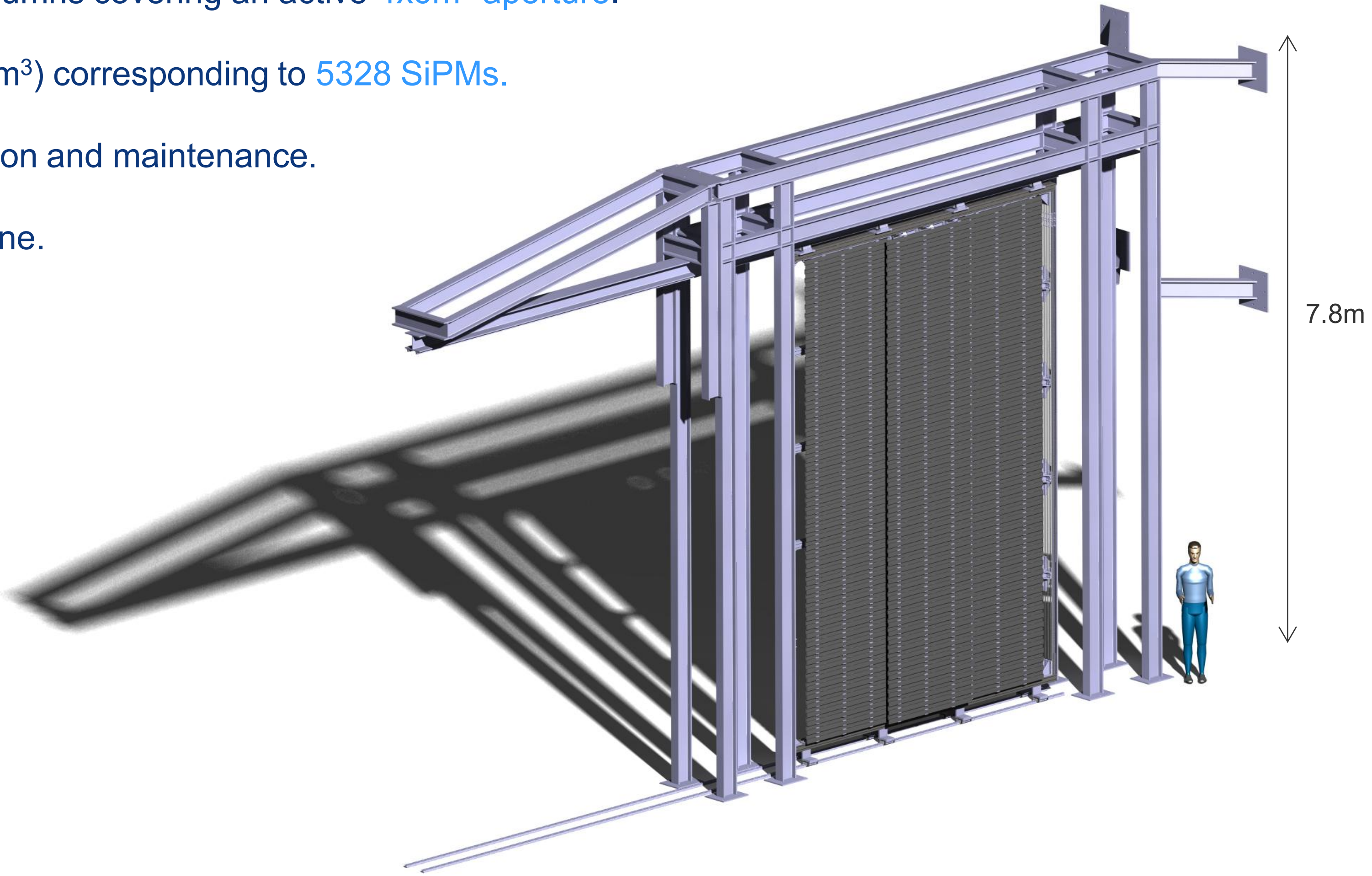
- Baseline is to weld the frame in the cavern.
- Then, to insert the 32cm high modules from the top with the crane accessing exclusively laterally and from one side of the frame.
- 4 identical straw stations (two of them with additional supports as they fall on the trench).
- 4m x 6m physics aperture.
- Material, the lighter the better!
    - Steel, aluminium and carbon fibre considered.
- Supporting frame design (including material trade-off study) together with its construction.



The timing detector - integration and mechanical design

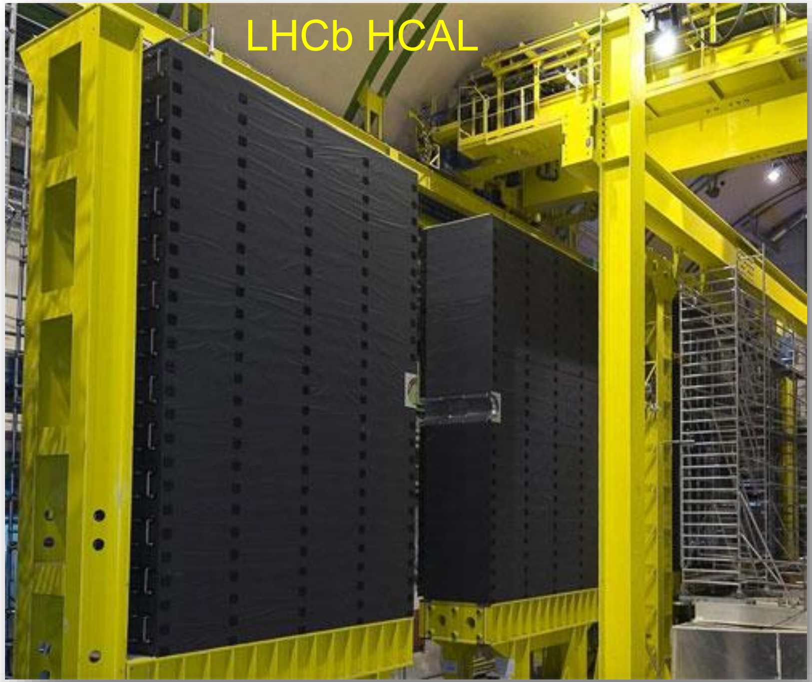
- Detectors will be made from EJ200 scintillating material with light read out by silicon photomultipliers (SiPM).
  - Staggered 1.4m long bars in three different columns covering an active 4x6m^2 aperture.
- In the present design there are 333 bars (140×6×1cm^3) corresponding to 5328 SiPMs.
- Active area should slide to the side during construction and maintenance.
- Detailed integration and mechanical design to be done.

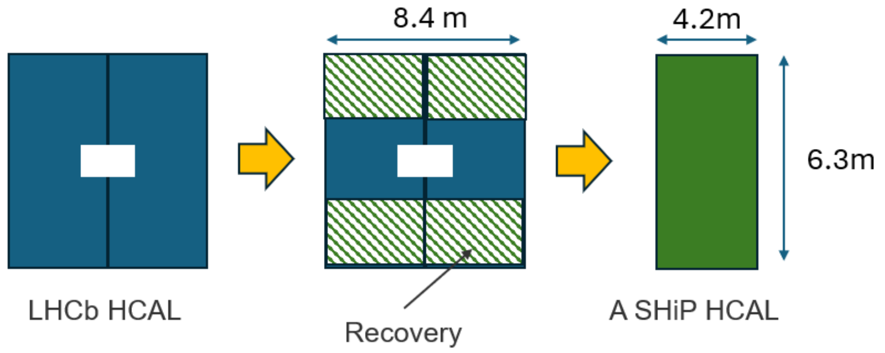




PID – LHCb HCAL re-configuration

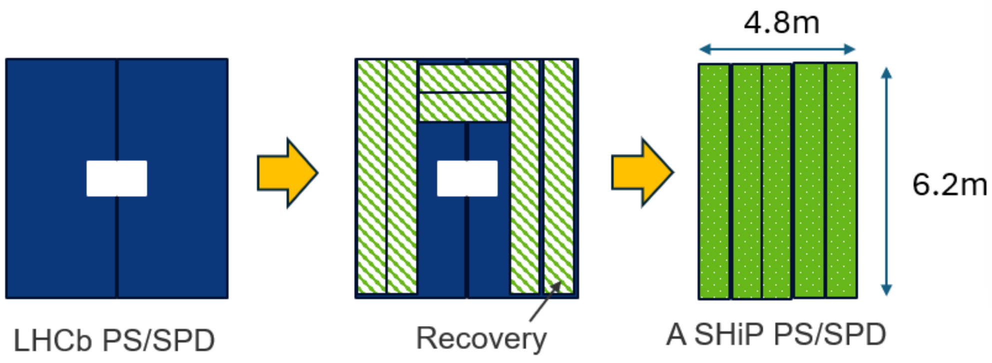
- HCAL modules from LHCb expected to be recovered for Run4 SHiP PID configuration.
  - Readout subdivided into two zones, inner and outer, with square cells of size 13×13cm^2 in the inner zone and 26×26cm^2 in the outer zone.
  - One module weights about 9.5 t.
  - Calibration and monitoring are built around embedded 137Cs source scans and LED monitoring also expected to be recovered.
  - To be dismantled from LHCb in Q2-2027.
- Full detector integration to be done for Run4 SHiP PID configuration considering ECN3 handling constraints and SHiP detector integration.
- Supporting structure to be designed for 24modules with a total weights of ≈228t.
- Required services to be addressed and if required, redesign them where applicable.





PID – LHCb SPD and PS re-configuration

- SPD and PS super modules from LHCb expected to be recovered for Run4 SHiP PID configuration.
  - LHCb sensitive area about 7.6m wide and 6.2m high, with 11'904 pad channels.
    - The active readout uses WLS fibres, clear fibres and compact 64-channel. MaPMTs that might be recovered.
  - Already dismantled during LS2.
- Full detector integration to be done for Run4 SHiP PID configuration considering ECN3 handling constraints and SHiP detector integration.
- Supporting structure to be designed.
- Required services to be addressed and if required, redesign them where applicable.



Conclusions

- Muon shield resistive magnet conceptual design.
  - Very attractive challenge to go thought its detailed engineering design, construction, up to its final installation in ECN3.

- Straw tracker frame as unique opportunity to contribute the next largest particle physics gas detector.

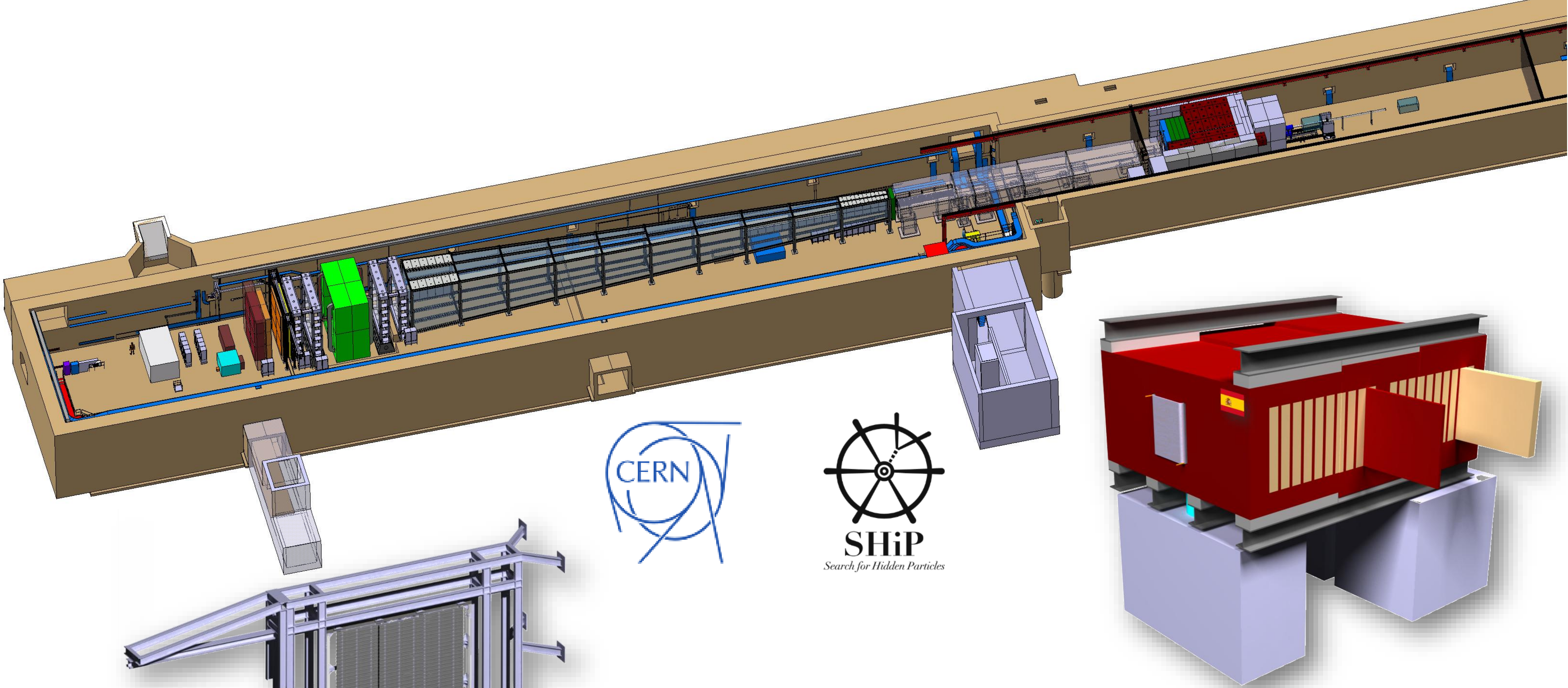
- Timing detector integration and full-scale mechanical design to cover with scintillating bars a $6x4m^2$ active area extremely interesting for a specialised group in scintillating technology.

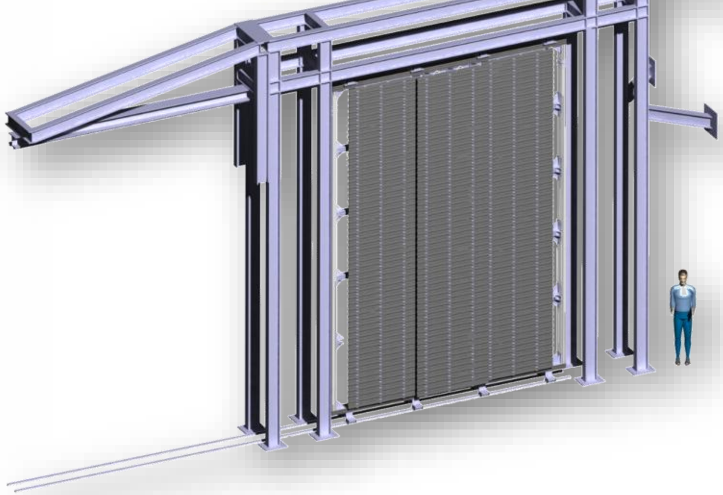
- Mechanics and infrastructure design of the PID configuration for Run4 based on the HCAL, SPD and PS LHCb recovery as potential very interesting activity for a calorimetry group.

- Spanish industry is fully capable of constructing each of the subsystems' items presented.

- SHiP engineering activities ramped up last year.
  - **An excellent time to join the effort** as there are many open engineering challenges!

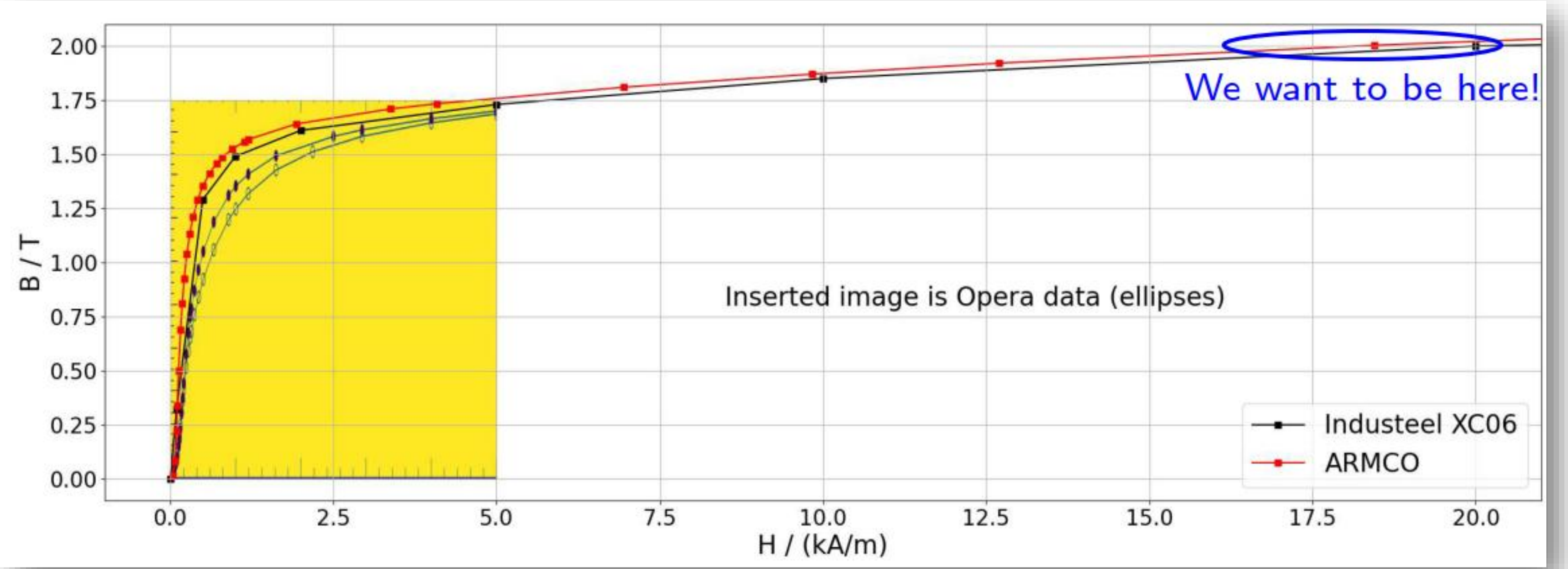
- Many other engineering defies to come!





Thank you for your attention!

Muon shield yoke magnetic material (≈925t)

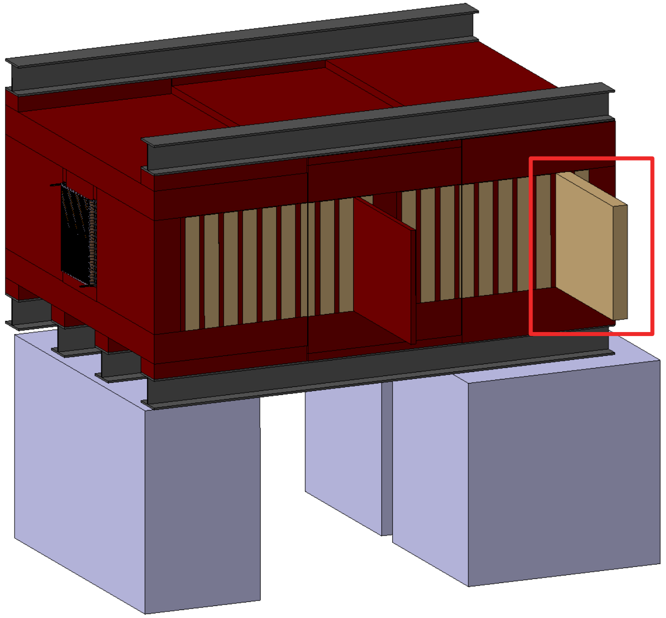


Courtesy of M. Ferro-Luzzi

Non-magnetic inserts (≈450t)

- Non-magnetic material specifications
  - Having the XC06 as the magnetic material, the relative permeability shall be 1000 of magnitude less. Then, if it is 1 or 2, even 5 is acceptable.
  - Feasibility of extracting these blocks from the slot when the magnet is powered off.
  - Non-magnetic properties are stable during the 15years of operation.
  - These 1.9t slabs are not used for structural purposes in the magnet but just as filling material. They are only used for "ranging out the muons" (that means "making the muons lose energy") and that is why we need a large density (larger or equal than iron).
  - Density shall not be less than 0.05% of the nominal value.
    - Value is not justified by any study but just to say that there shall not be big porous or void volumes inside.
  - The cheapest possible.

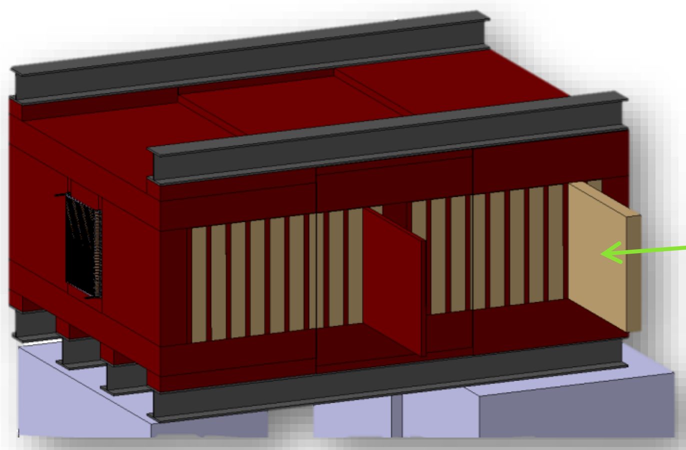
- Options investigated (thanks to S. Sgobba and K. Buchanan for their advice):
  - Brass: definitely too expensive.
  - Lead: safety aspects to be considered but definitely an option when space is to be shared with a detector in the slot.
  - Stainless steel :
    - Nickel based: 304LN can be a cheapest one commonly used in Europe.
    - Manganese based [2]: UNS21904 could be even cheaper than 304LN but are rarely produced in Europe. Commonly available India or Japan but transport is a cost.
      - For the required quantities, a European foundry could be interested.

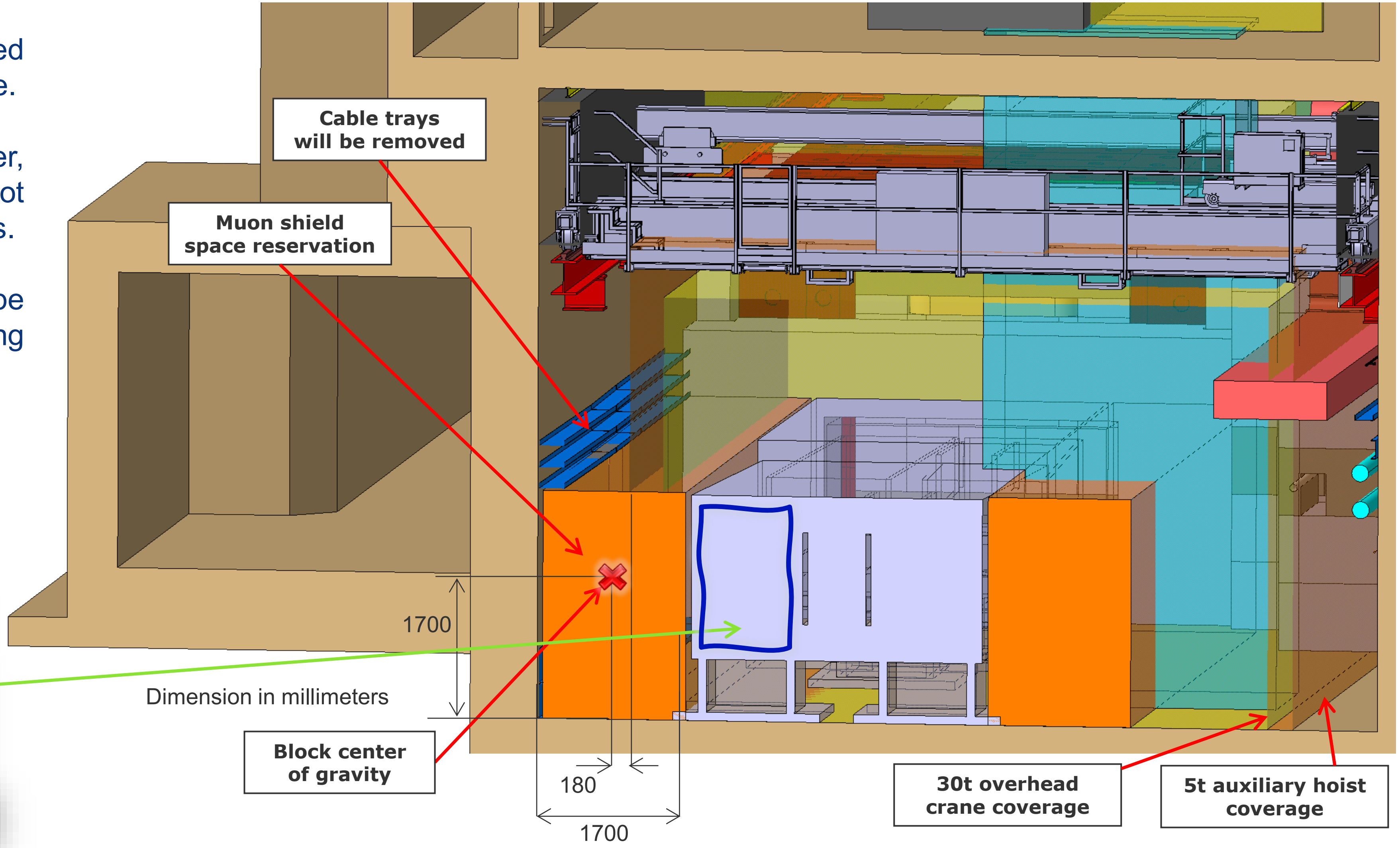


- Lead and stainless-steel options under investigation with European manufacturers.

Muon shield overhead crane coverage

- Auxiliary hoist coverage very limited for side insertion on the Salève side.
- 5m height crane coverage, however, 5t auxiliary hoist coverage does not falls on the CoG of the insert blocks.
- Therefore, a handling tool is to be developed. Solutions are being investigated in the industry.





Overall engineering analytical computations

- Parameters for a 500A “exceptional” operation to exploit POLARIS 2P potential and for safety reasons.
  - Maximum power 100kW.

Parameters	Magnets					
	1	2	3	4	5	6
Length, l_{iron} [m]	4.95	4.95	5.61	4.65	1.70	4.68
Required magnetomotive force [NI]	77500	77500	75000	70000	70000	77500
No. of turn, N	155	155	150	140	140	155
Core width, c [m]	0.73					
Average turn length, l_{turn} [m]	11.36	11.36	12.68	10.76	4.86	10.82
Current, I [A]	500					
Conductor width, w_{width} [mm]	13					
Conductor height, w_{height} [mm]	13					
Conductor hollow diameter, d [mm]	9					
Conductor cross section, A_{cond} [mm^2]	105.38					
Current density, j [A/mm^2]	4.74					

Parameters	Magnets					
	1	2	3	4	5	6
Resistance total, R [Ω]	0.287	0.287	0.310	0.246	0.111	0.274
Inductance, L [H]	34.97	34.97	37.11	26.80	9.80	33.06
Heat dissipation, P [kW]	71.847	71.847	77.609	61.467	27.763	68.432
Cooling ΔT	30					
Number of hydraulic circuits in parallel, N_{hydr}	7			6	3	6
Cooling flow total, Q_{tot} [l/min]	34.25	34.25	36.99	29.30	13.23	32.62
Water velocity, v [m/s]	1.28	1.28	1.38	1.28	1.16	1.42
Reynolds number	16150	16150	17445	16119	14561	17946
Length of each hydraulic circuit in parallel, L_{hydr} [m]	251.54	251.54	271.71	251.07	226.80	279.52
Circuit drop pressure, Δp [bar]	7.12	7.12	8.81	7.09	5.36	9.52

Alignment jacks' ideas

- Looking around CERN to avoid reinventing the wheel.

- ATLAS.
  - Airpads.
    - Designed for much heavy loads and also to displace “”long distance” the loads.
  - Hydraulic jacks with 3 axis adjustment.
    - Appropriate for the 235t magnet load but horizontal plane oil/o-ring sealing while adjusting might leak.
    - 4 supporting points instead of three might apply due to stability reasons. Not so good for alignment.
    - Mechanical blocking once aligned. Ball joint to be included.
    - Certainly, very interesting if robustness is validated.
  - As potential use for any application in reducing the friction coefficient, the permaglide material.

- CMS: greasing pads.

- LHCb magnet (weight 1500t) alignment pads.

- 30t FAIR jacks that can be scalable as candidate for the muon shield magnets.