Possible
Coil Developments

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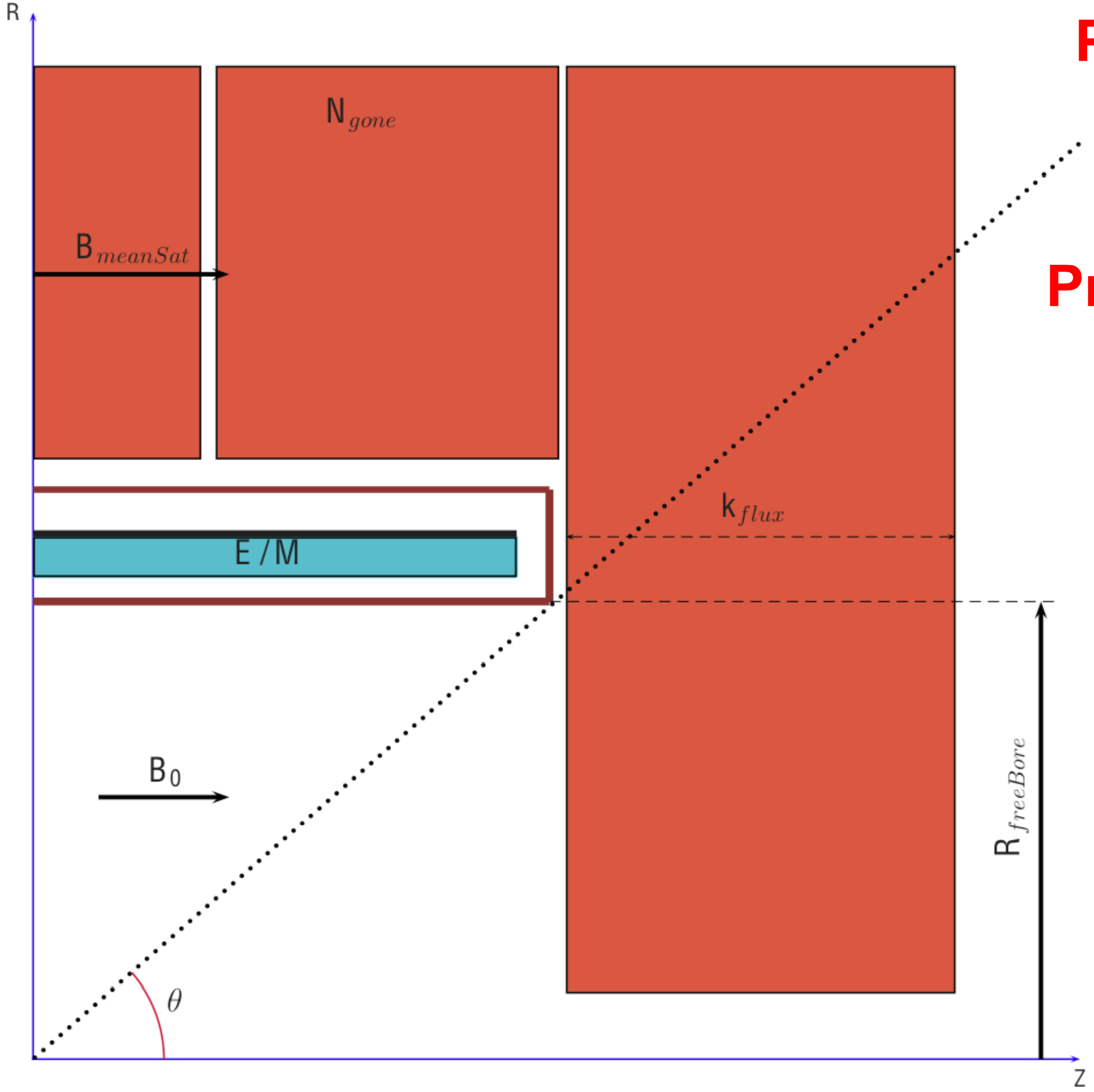
Common General Design For



Past: 1.5 T

DELPHI

ALEPH

Present: 4 T

CMS

Future
3.5 to 5 T

ILD

SiD

and
CLIC!

It is time to think!

- Since the success of the CMS magnet, the international design team (CERN, INFN-Genova & Saclay) has critically reviewed the choices taken.

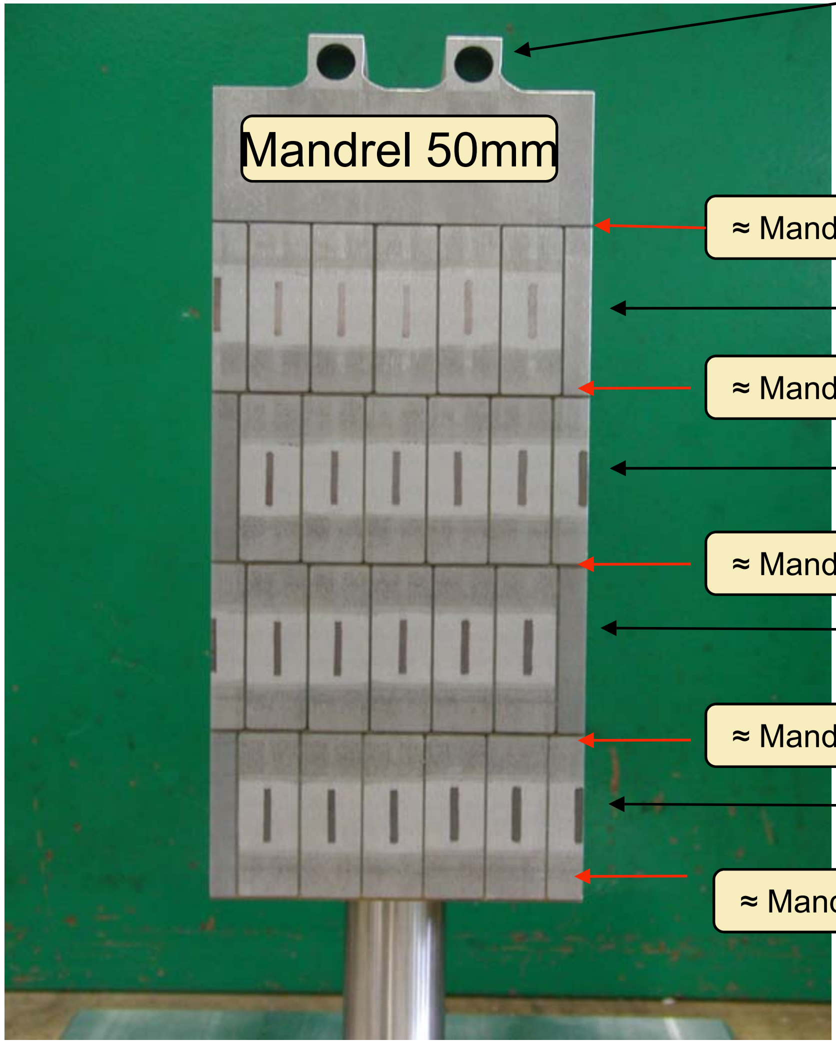
- Could better technical choices be made today?

- In particular for the coil can:

- the thickness be reduced?
- the cost decreased?
- the risks lowered?

- This is particularly relevant for future projects of thin large coils for detector magnets with field > 3.5 T, like ILD.

I will concentrate on the conductor



Thermosiphon cooling

Mandrel 50mm

≈ Mandrel 4

≈ Mandrel 3

≈ Mandrel 2

≈ Mandrel 1

≈ Mandrel 0

Coil Axis

Due to the glued construction all materials must be thermally compatible with Glass/Epoxy and *today* only families of aluminum and aluminum alloys are usable!

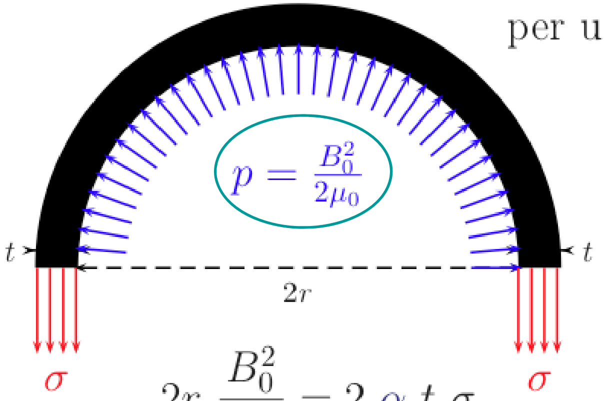
(waiting for new developments)

The conductor must

1. Incorporate enough section of NbTi to create the field and support the maximum field on conductor with a good temperature margin (> 1K).
2. Have enough pure aluminium (or equivalent low elec. conductivity alloy) to have a sufficient stability against local disturbances.
3. Have enough structural material (Al alloy or equivalent) to limit the equiv. strain to 0.15%.
4. Represent enough mass (including mandrel), that is have a sufficient Enthalpy, to limit the temperature after of fast dump to less than 80 K.

Specific Stored Energy Vs. Strain
A Coil is a Thin Tube!

Force consideration



per unit ler

t

$$2r\,\frac{B_0^2}{2\mu_0} = 2\,\alpha\,t\,\sigma$$

α : ratio of structural material

with hoop strain $\epsilon = \frac{\sigma}{Y}$ then

Y : Young's modulus of aluminum

Specific Stored Energy Vs. Strain
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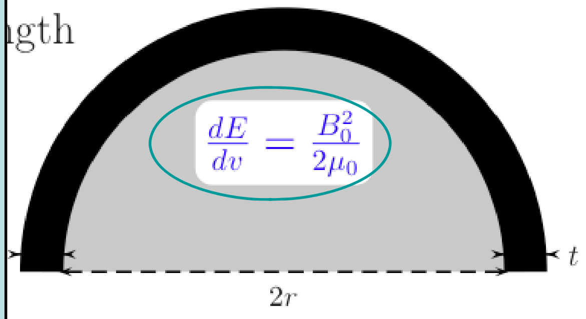
Energy consideration

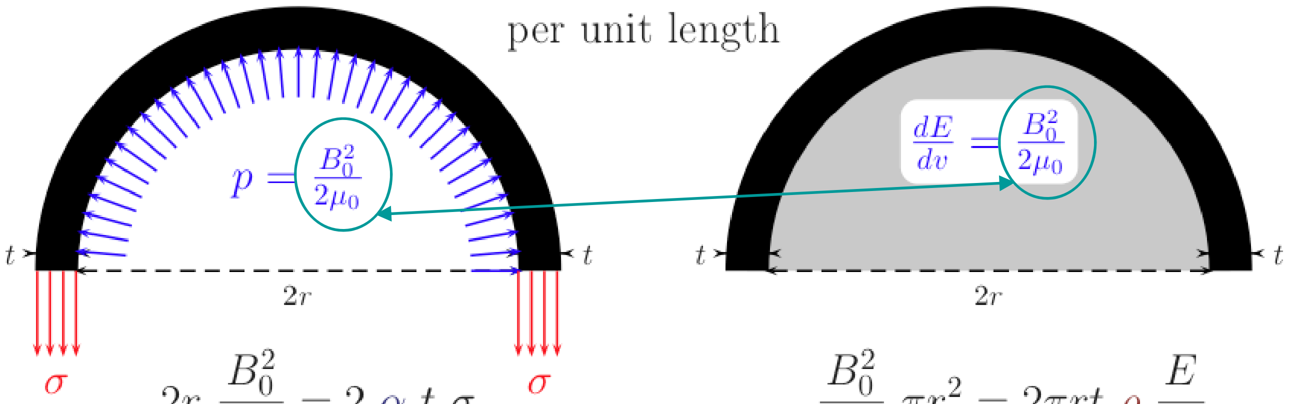


$$\frac{B_0^2}{2\mu_0}\pi r^2 = 2\pi r t\,\rho\boxed{\frac{E}{M}}$$

ρ : density of aluminum

Specific Stored Energy Vs. Strain
A Coil is a Thin Tube!

Force consideration   Energy consideration



$$2r\,\frac{B_0^2}{2\mu_0} = 2\,\alpha\,t\,\sigma \qquad \frac{B_0^2}{2\mu_0}\,\pi r^2 = 2\pi r t\,\rho\,\frac{E}{M}$$

α : ratio of structural material

ρ : density of aluminum

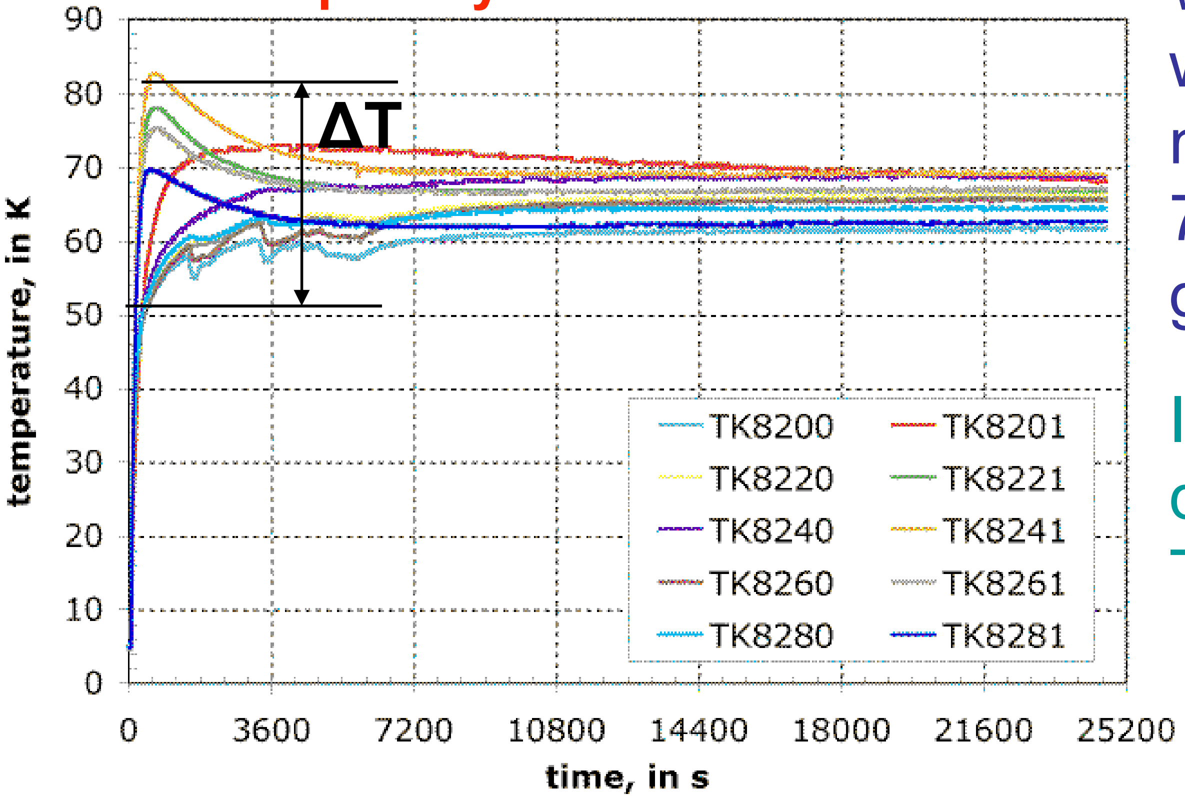
with hoop strain $\epsilon = \frac{\sigma}{Y}$ then : $\boxed{\frac{E}{M} = \alpha\,\frac{Y}{2\rho}\,\epsilon}$

Y : Young's modulus of aluminum

This is the limiting factor!

Actual temperature distribution in CMS coil during a fast dump with 50% energy extraction and E/M=12kJ/kg

Fast dump analysis in CMS



With E/M=12kJ/kg, when all is OK, the mean Temp. reaches 70K with a thermal gradient of 30K.

If all the energy is dumped in the coil the Temp. reaches 130K

This is a ‘safety limit’!

Signification of the Formula

Taking into account Enthalpy of aluminum, this is representative of the temperature of cold mass after a fast dump. 12 kJ/kg, that is 130 K, seems a safe limit for the *full energy* in the cold mass (70 K for 50% extraction)

$$\frac{E}{M} = \alpha \frac{Y}{2\rho} \epsilon$$

Hoop strain of 0.15% seems a good limit

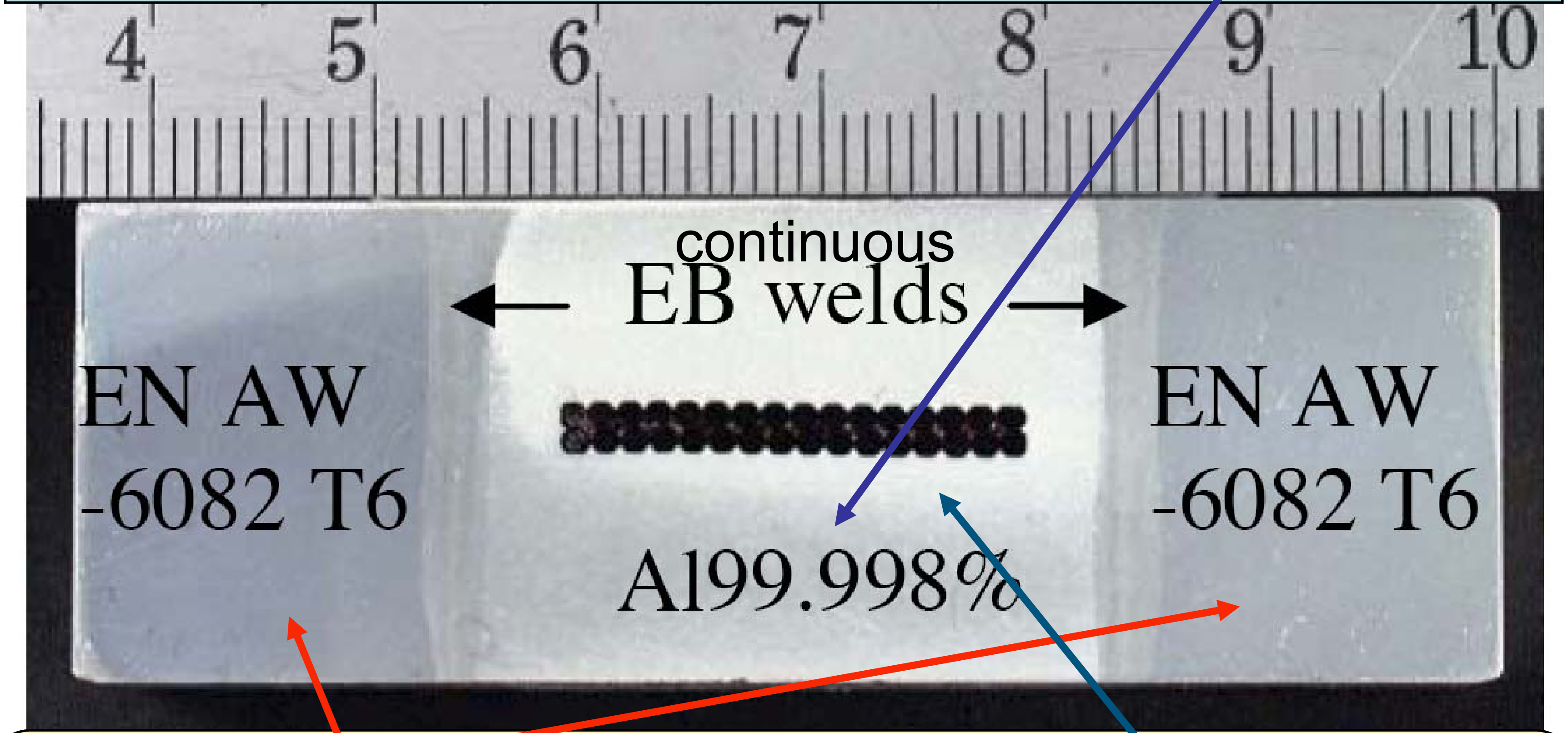
Ratio of structural material : 0.6 for CMS neglecting pure aluminum, could go up to ≈ 1 for stabilizer stronger mechanically than pure aluminum

This is a constant for aluminum construction :

$Y = 7.5\ 10^{10}\ \mathrm{N/m^2}$

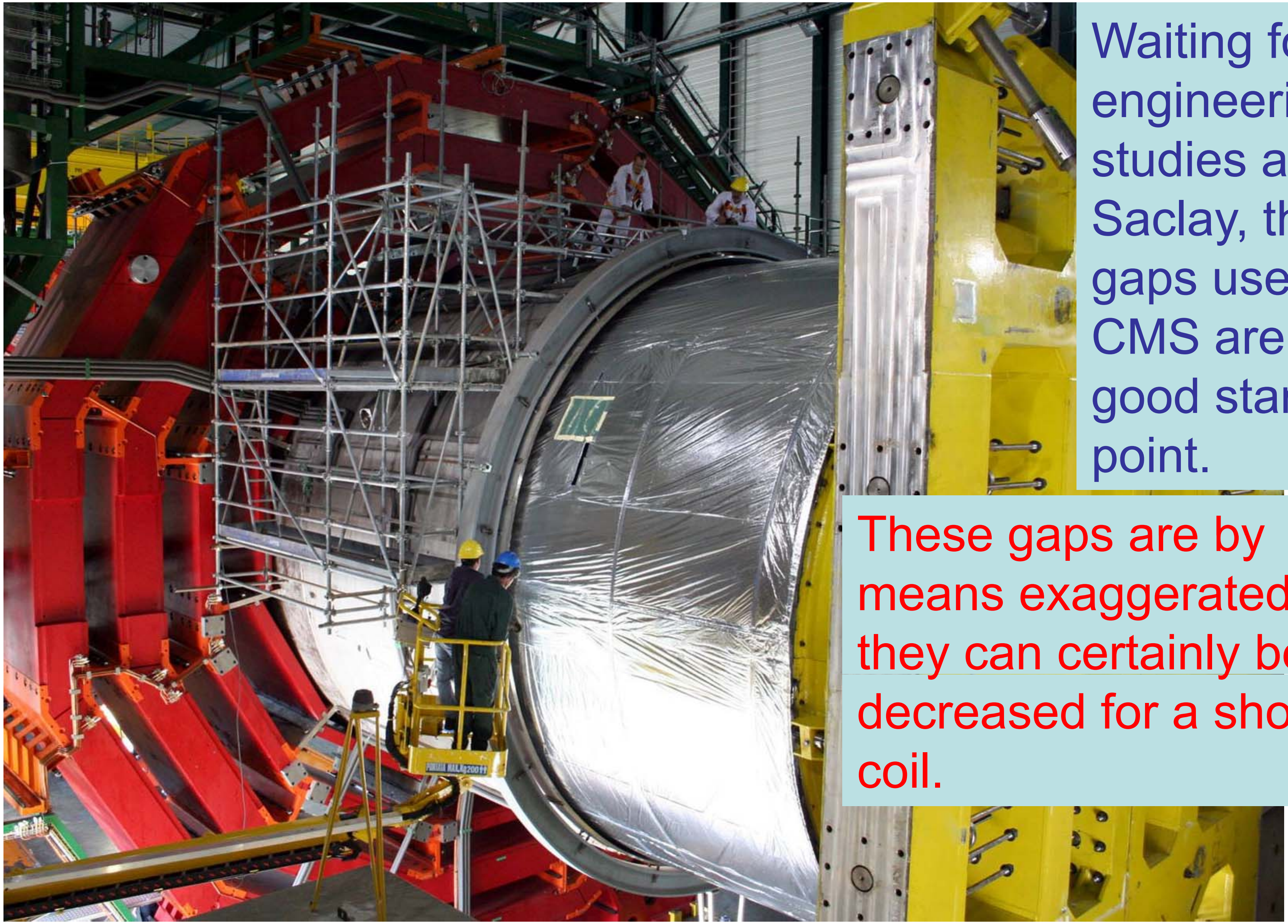
$\rho = 2\,700\ \mathrm{kg/m^3}$

The only possible change is to replace the pure aluminium by a structural material like Yamamoto's alloy



aluminum alloy sections added to "standard" conductor

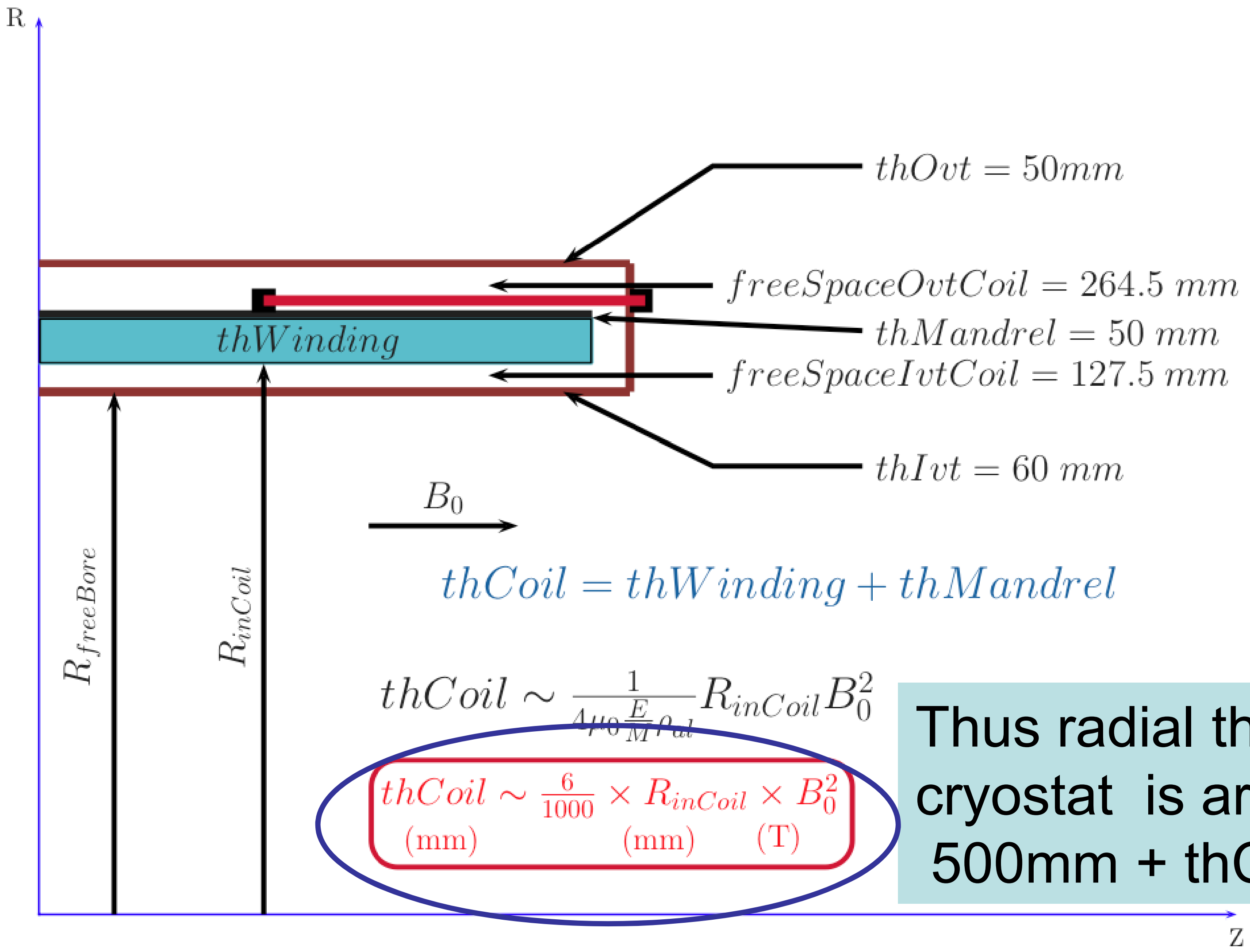
Radial gaps in Coil System



Waiting for new engineering studies at Saclay, the gaps used for CMS are a good starting point.

These gaps are by no means exaggerated, but they can certainly be decreased for a shorter coil.

Radial gaps in Coil System



$thOvt = 50mm$

$freeSpaceOutCoil = 264.5\ mm$

$thMandrel = 50\ mm$

$freeSpaceIvtCoil = 127.5\ mm$

$thIvt = 60\ mm$

$$thCoil = thWinding + thMandrel$$

$$thCoil \sim \frac{1}{4\mu_0 \frac{E}{M}\rho_{al}} R_{inCoil} B_0^2$$

$$\underset{(mm)}{thCoil} \sim \frac{6}{1000} \times \underset{(mm)}{R_{inCoil}} \times \underset{(T)}{B_0^2}$$

Thus radial thickness of cryostat is around 500mm + thCoil

Conclusions-I

- The cold mass thickness governs the post-dump temperature.
- The maximum gain in thickness would be ≈ 30% if ALL material is structural, *however increasing the post-dump temperature to a dangerous zone* (especially if, as ultimate scenario, all the energy is dumped in the cold mass).
- This potential gain of 100 mm has to be compared to the total thickness of the cryostat of 900 mm, and added risk!
- An increase in mechanical properties is anyway required for the end modules carrying the compensation currents!
- Thus the proposal from Saclay seems very reasonable, keeping an overall mean value of 12kJ/kg but increasing the mechanical properties at least in the end modules

Conclusions-II

There is a starting R&D effort at CERN for the conductor:

- To review and optimize the conductor geometry.
- To replace pure aluminum by a Ni doped alloy, as used in the ATLAS central solenoid (Yamamoto et al.), and produce a demonstration length.
- To replace the electron beam welding by a less expensive process.

It would thus be judicious for ILD
to join this R&D effort.