Magnets for HEP experiments

Andrea Bersani

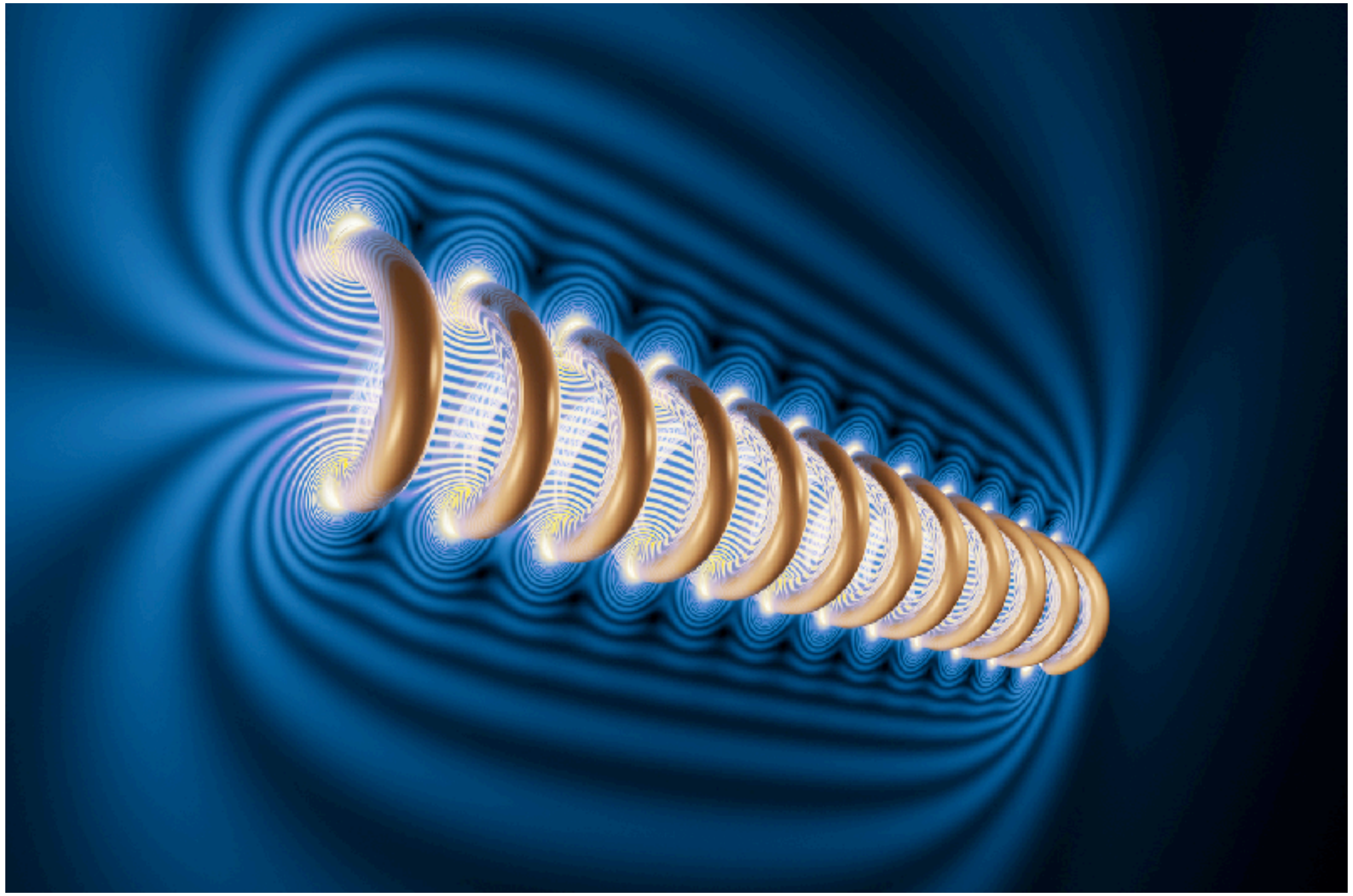
INFN Sezione di Genova
Istituto Nazionale di Fisica Nucleare

Rationale

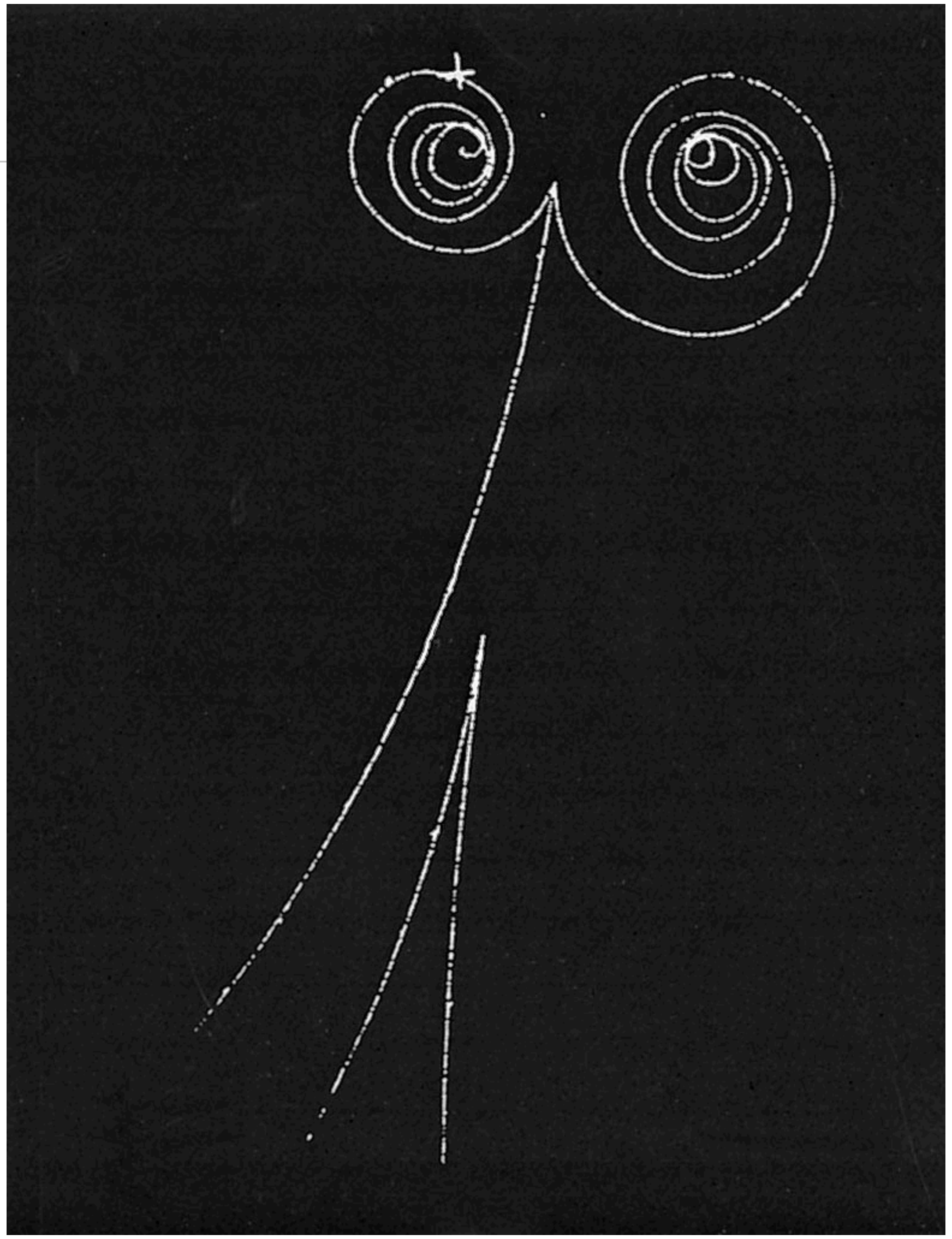
- Just a starting point for discussion and possible implementations

- No "better" design is in my mind

- Every constraint forces technical choices
  - magnetic field, value and orientation
  - magnet transparency to particles
  - overall mass
  - detector integration
  - size and shape
  - ramp-up time
  - power consumption
  - . . .



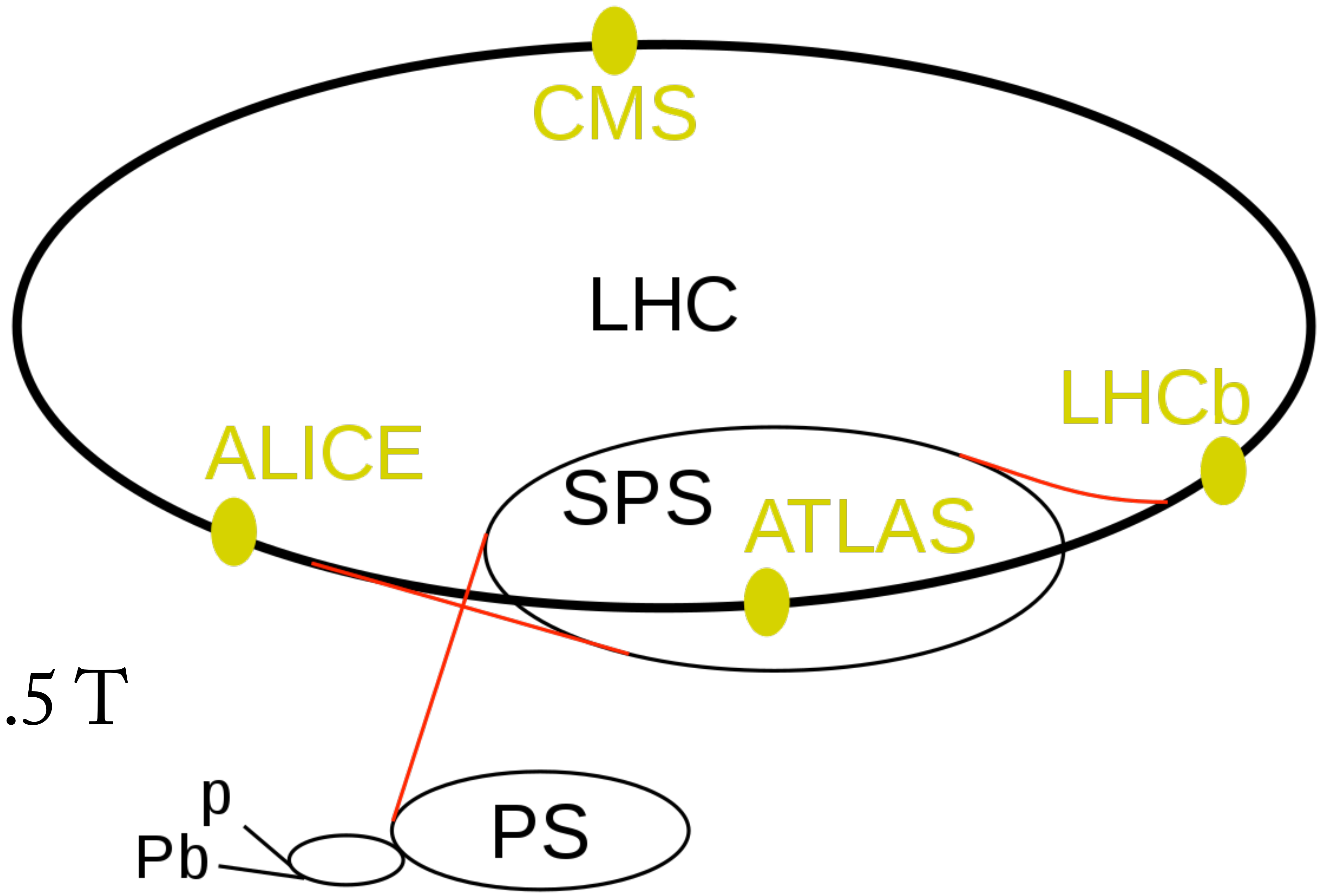
What we need



- Momentum resolution improves as $B \cdot r^2$
  - the stronger and the larger is the better
- Particles of interest must "get out" to outer detectors
- What particles are "of interest" in a muon collider at 1, 3 or 10 TeV?
  - which momentum do we expect for these?
  - which acceptance in rapidity do we need?
  - do we need to change magnetic field often - quickly?
- Recent and proposed magnets for HEP are somehow similar
  - 2 to 5 T central field
  - mostly based on low temperature superconductors, namely niobium titanium in a copper matrix, stabilised in aluminium
  - few to several metres in diameter and lenght

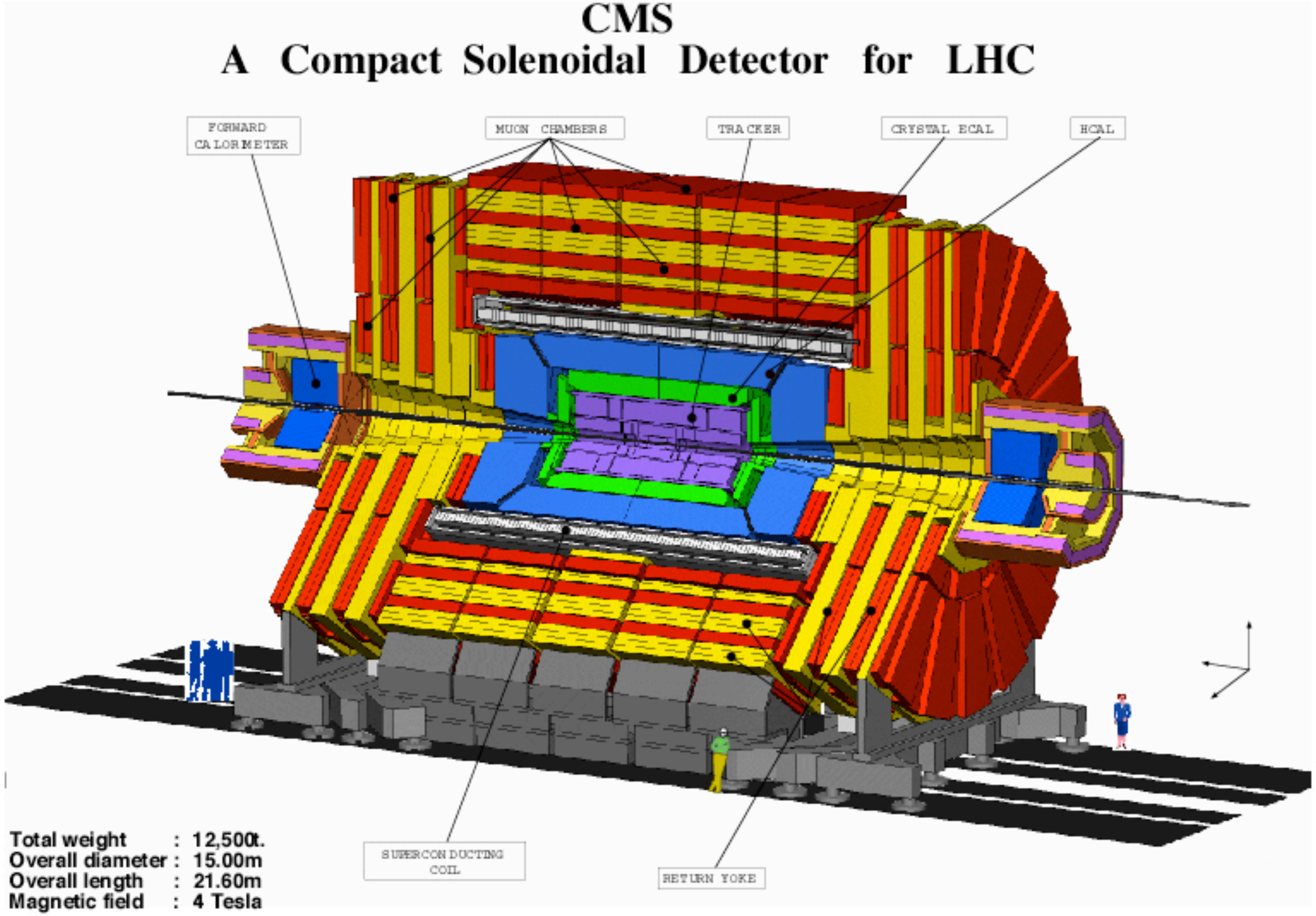
LHC experiments

- CMS: "not so thin", very large solenoid, 4 T
- Atlas: thin solenoid + toroids, 2 T
- LHCb: normal conducting dipole, 1 T
- Alice: normal conducting solenoid (ex L3) and dipole, ~ 0.5 T
- SND: plans for a small clever solenoid
  - just for muons tracking, iron inside
  - normal conducting is fine
  - hard to scale (?)



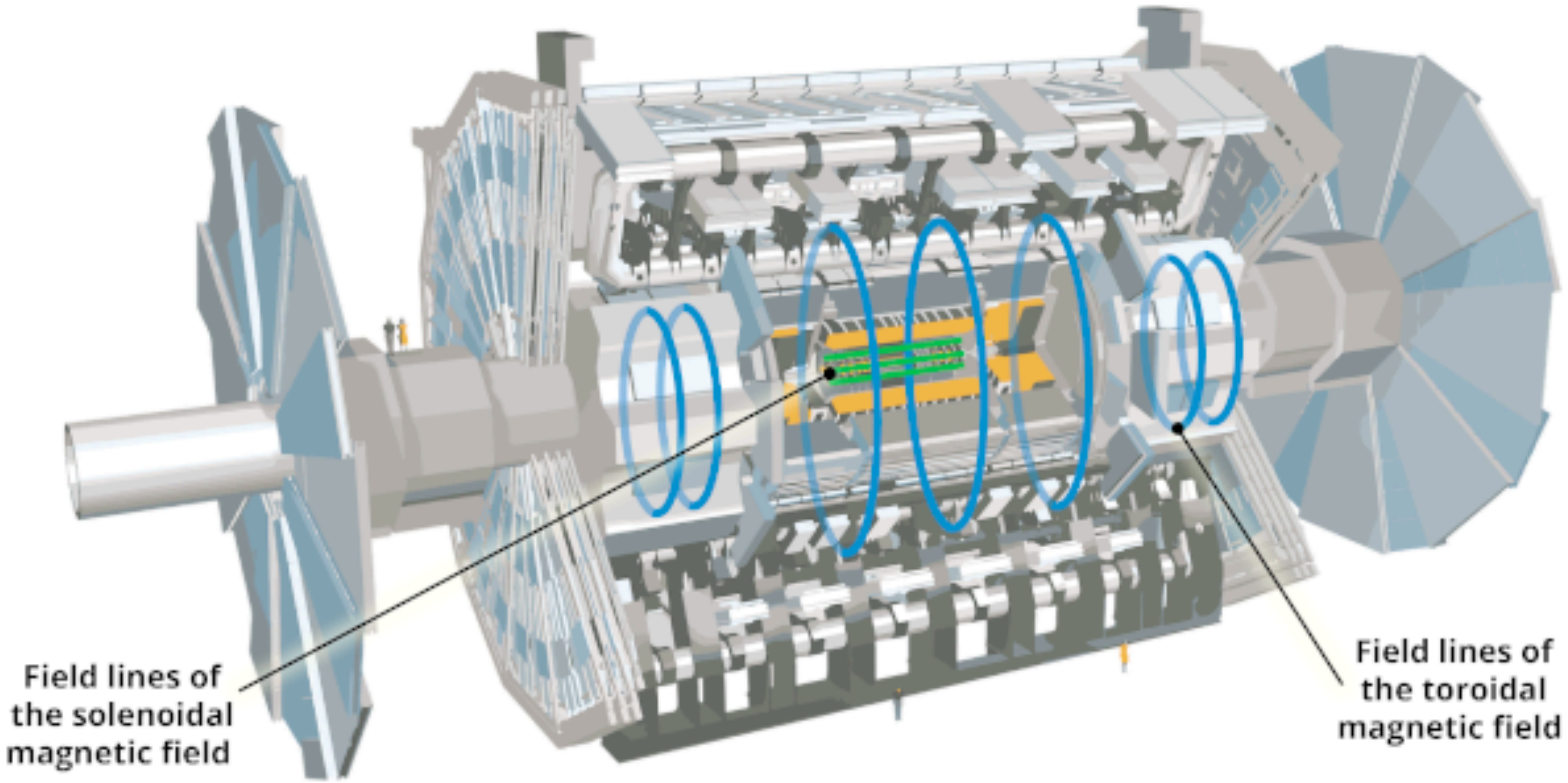
CMS superconducting solenoid

- Bore radius: ~ 3 m
- Centre field: 4 T
- Coil length: 12.5 m
- Coil layers: 4
- Thickness: ~ 0.35 m
- Current: 20 kA
- Stored energy: 2.6 GJ
- Cold mass: 220 t
- E/m: 12.3 kJ/kg
- "Everything" inside
- Big return iron yoke
  - used for muons tracking



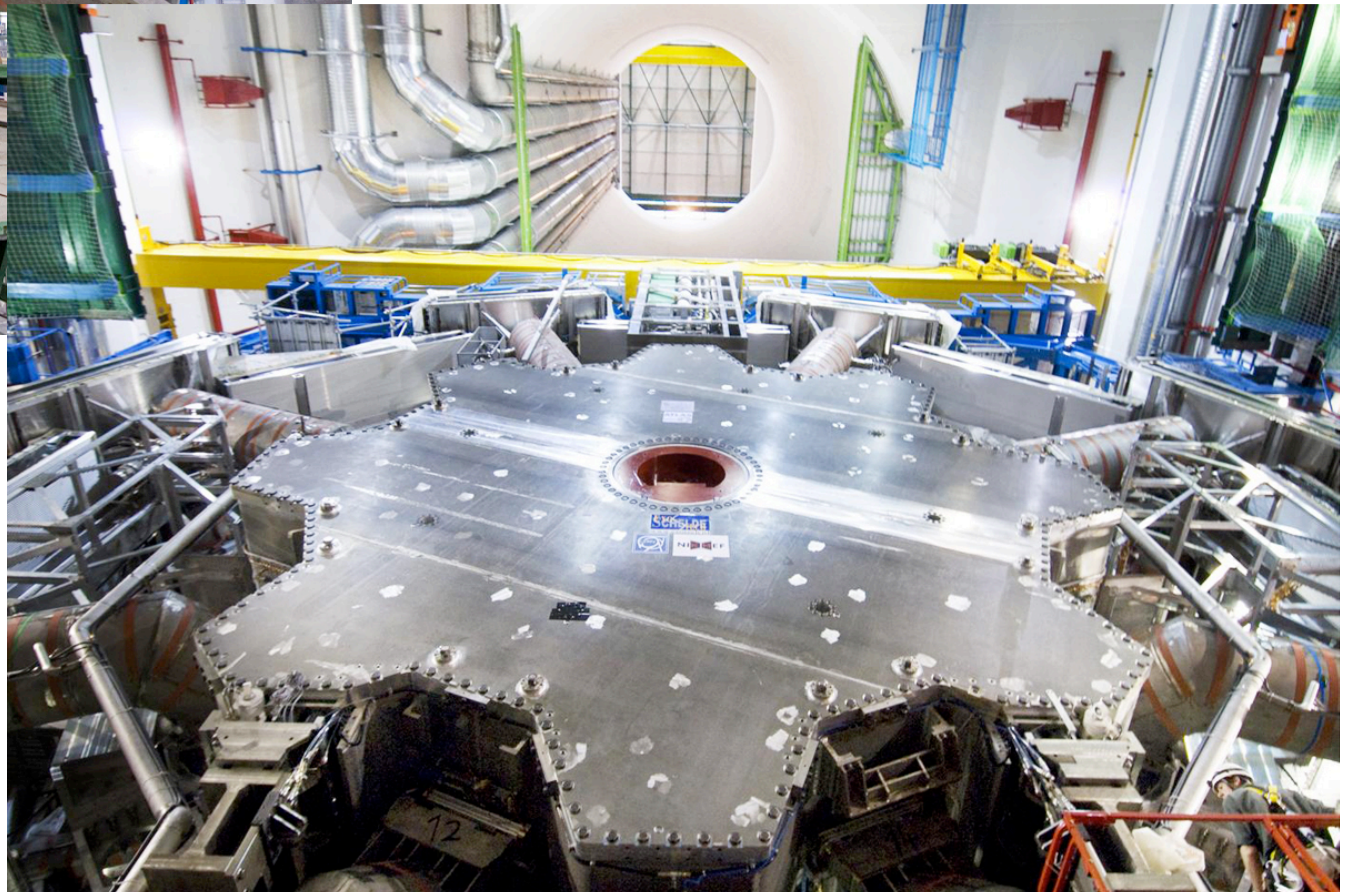
Atlas superconducting solenoid

- Bore radius: ~ 1.2 m
- Centre field: 2 T
- Coil length: 5.4 m
- Coil layers: 1
- Thickness: ~ 0.05 m
- Current: 7.7 kA
- Stored energy: 40 MJ
- Cold mass: 5.7 t
- E/m: 7 kJ/kg
- Tracker and PID inside
- Calorimeter outside
- No return iron yoke
  - iron in calo makes the job



Atlas superconducting toroids

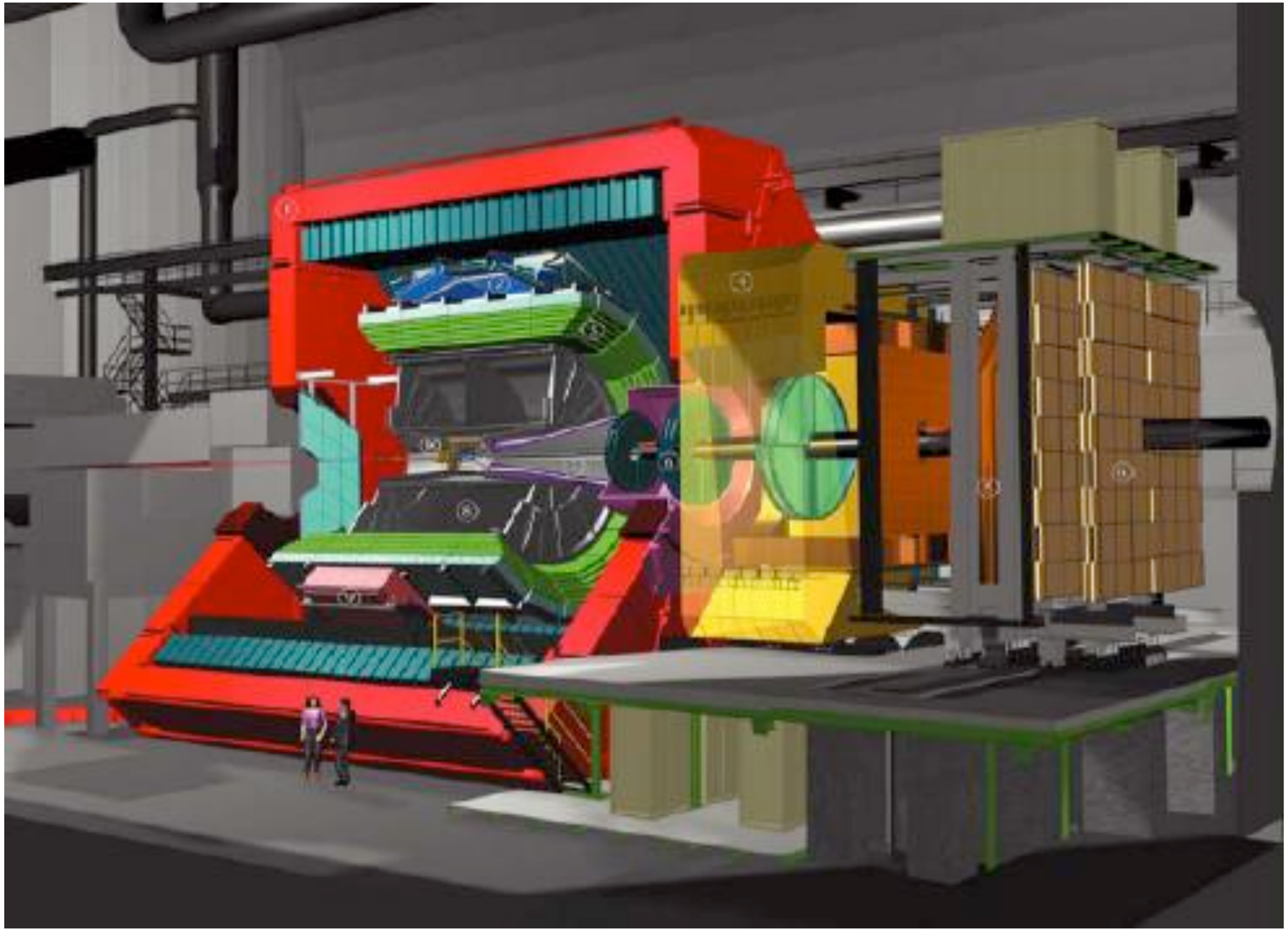
- Barrel toroid:
  - 8 racetrack coils
  - 25.3 m long
  - 20 m outer diameter
  - 370 t cold mass
  - 20.5 kA current
- End cap toroids
  - 8 coils each
  - 5 m long
  - 10.7 m outer diameter
  - 320 t total cold mass
  - 20.5 kA current



Alice

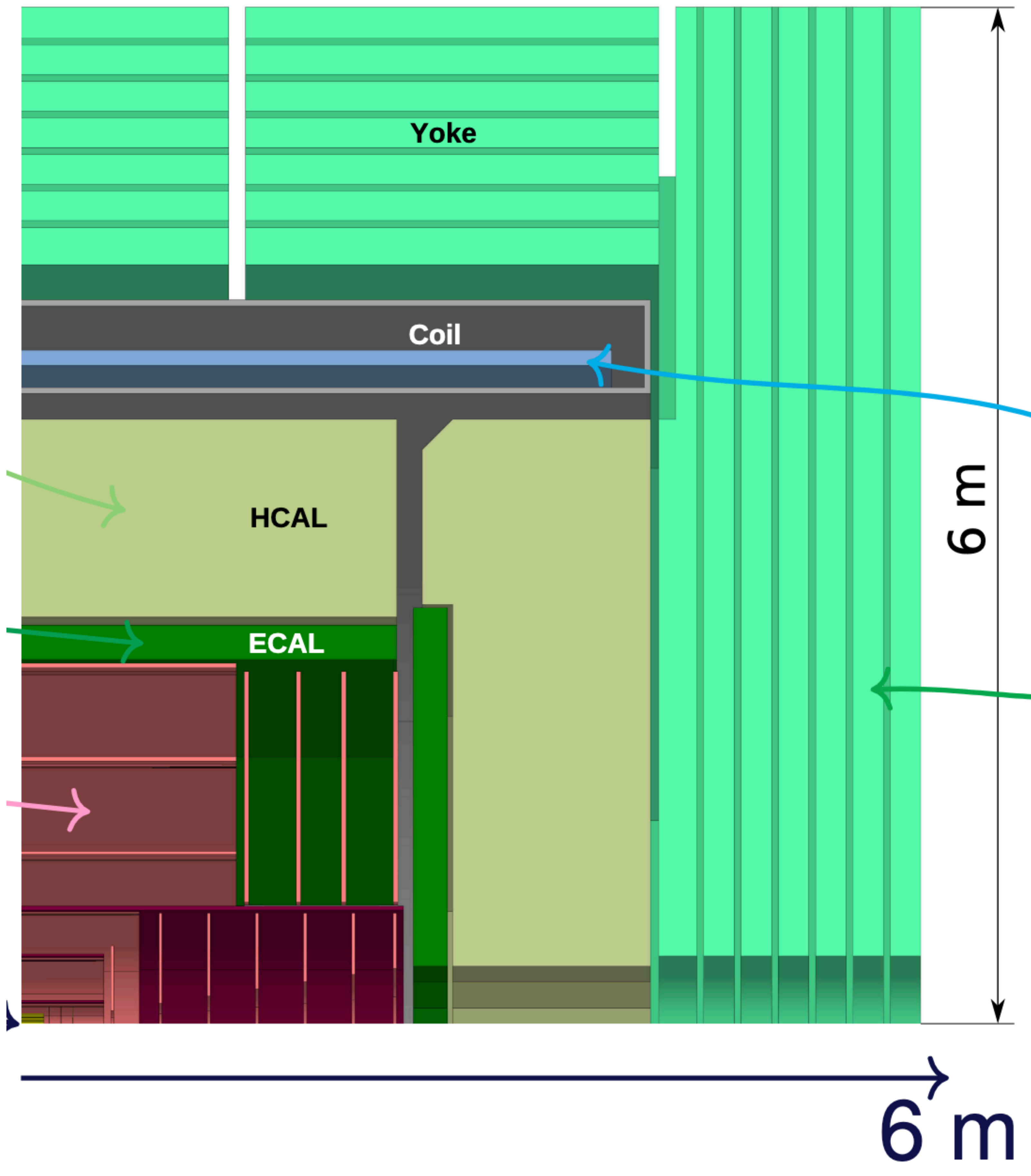
- Solenoid:
  - 168 turns
  - 89 cm thick
  - up to 30 kA
  - $0.5\ A/mm^2$
- Dipole:
  - 168 turns
  - < 6 kA
  - 3.5 MW power consumption

- Plans to go superconducting

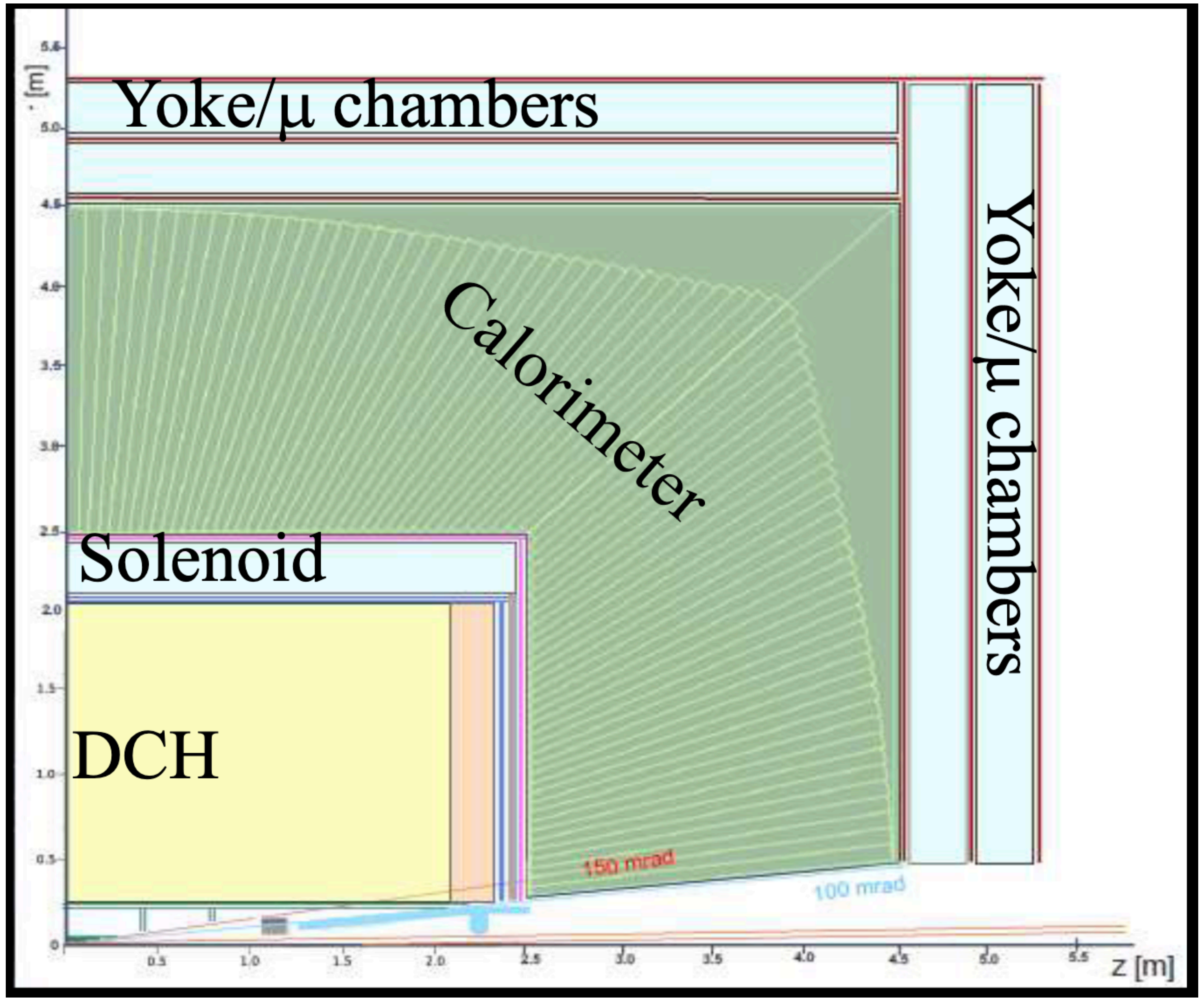


FCC-ee (hundreds of GeV)

- CLD vs. IDEA

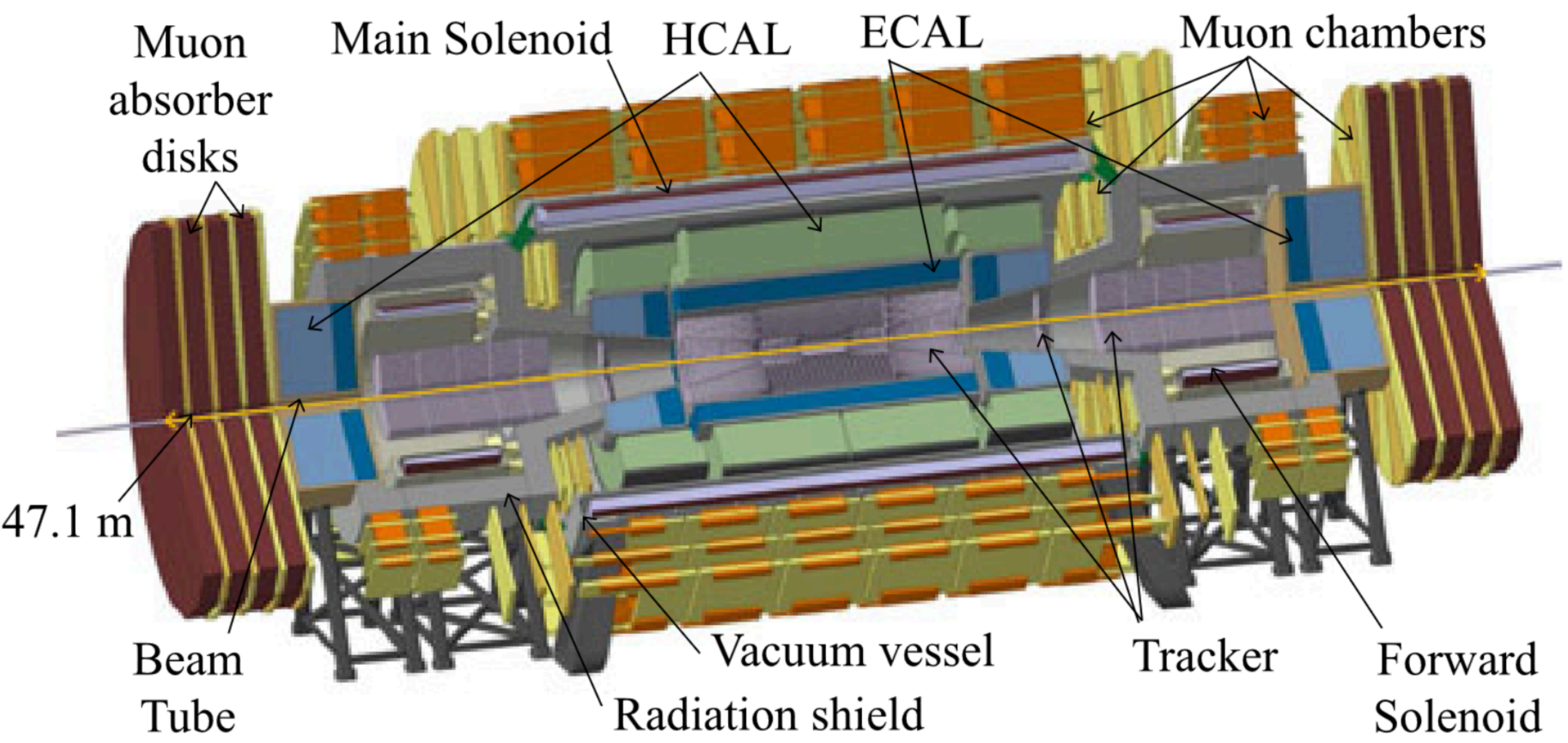


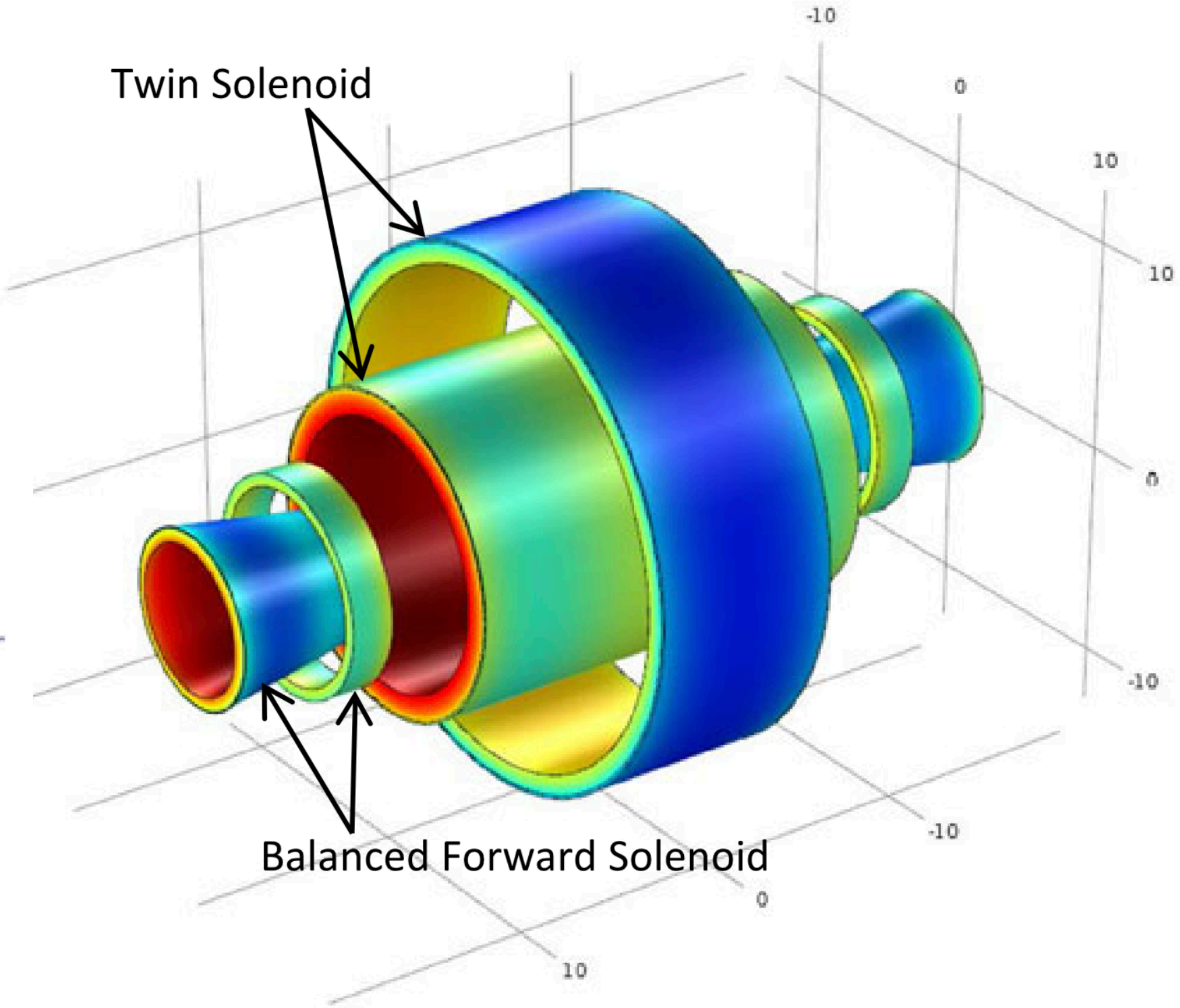
- Superconducting Solenoid of 2 T
- Iron Yoke with RPCs for Muon ID



FCC-hh (TeV)

- 6 T
- 12 m bore diameter
- 20 m length
- "Active" shielding
- Then they went smaller...

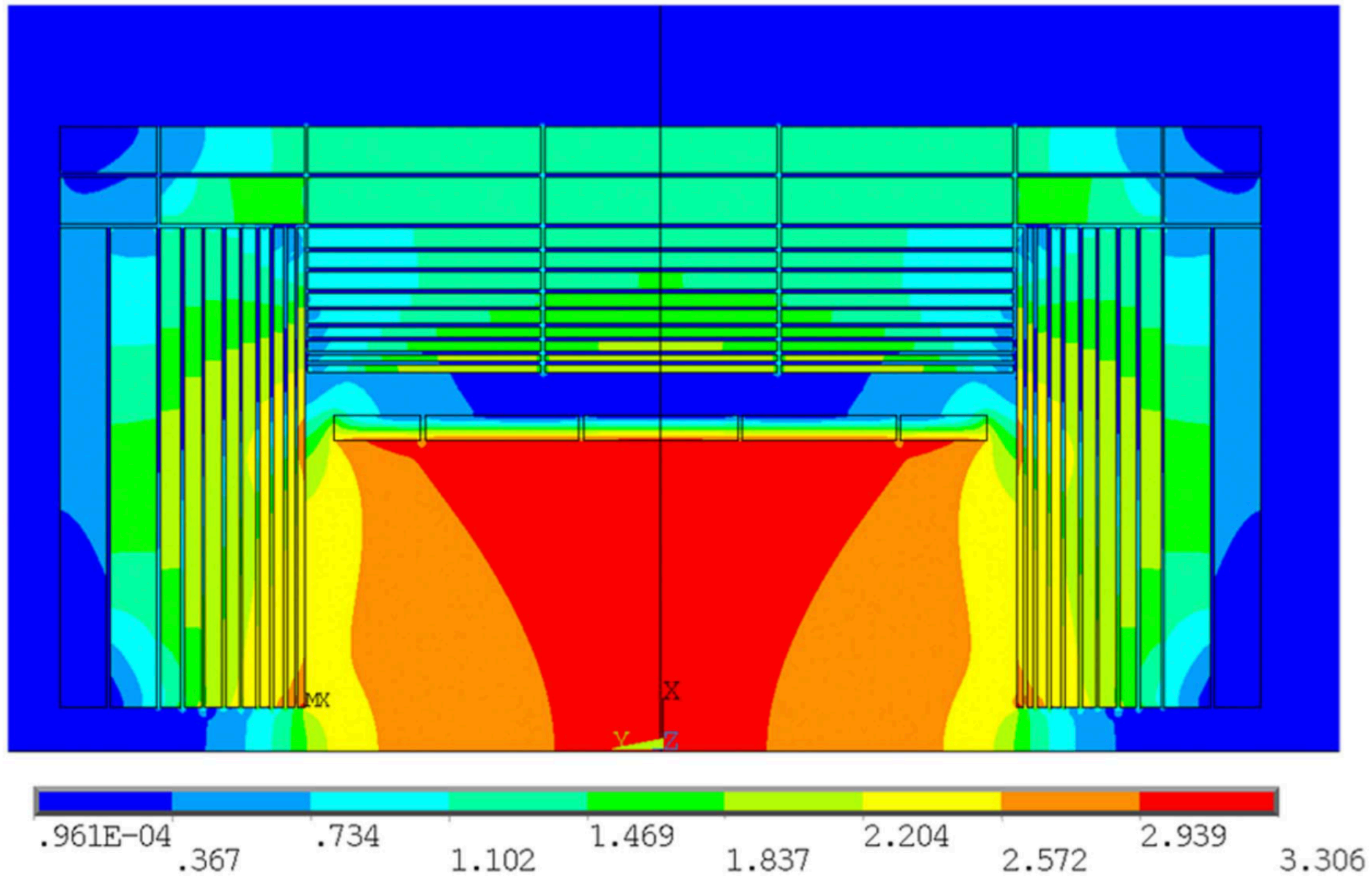


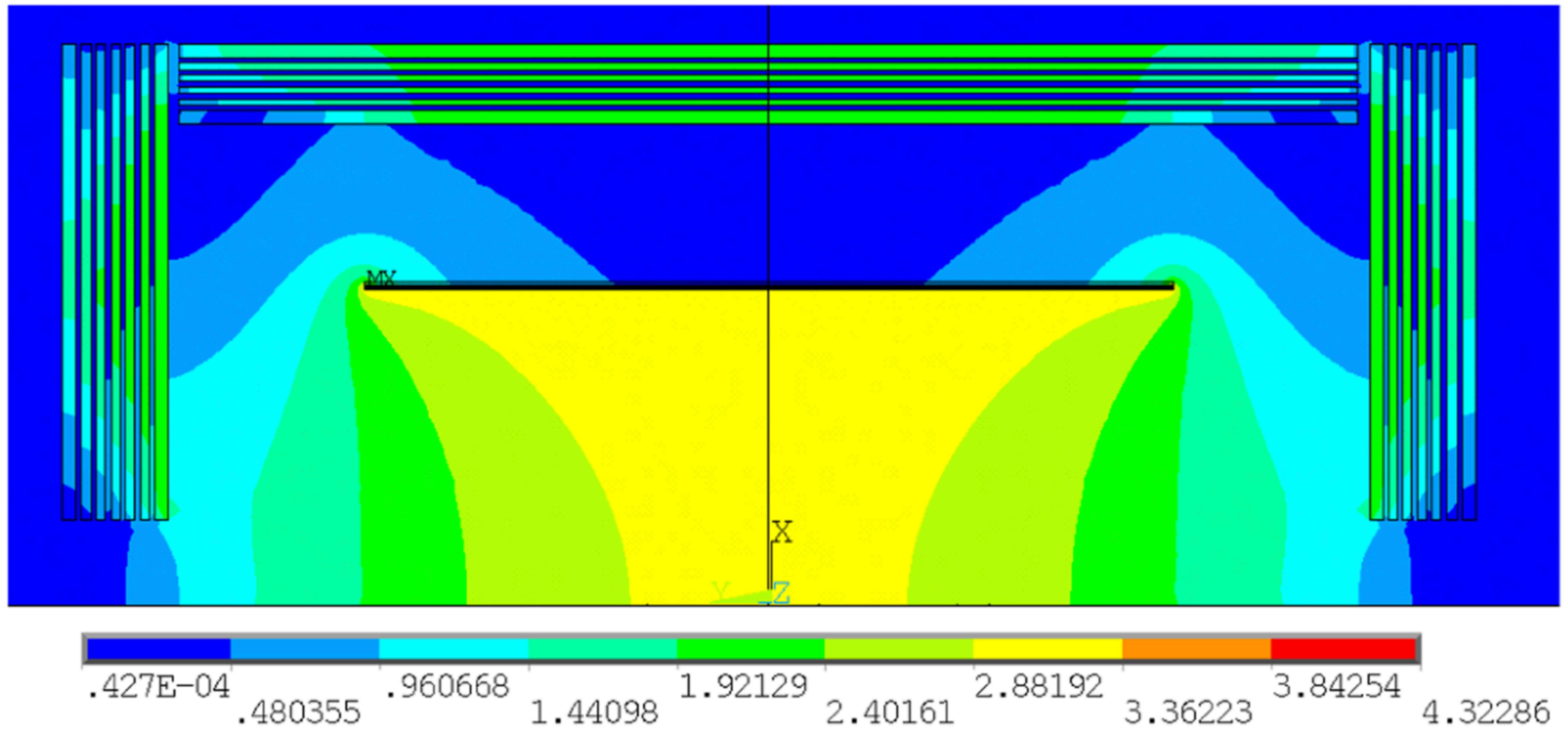


CEPC

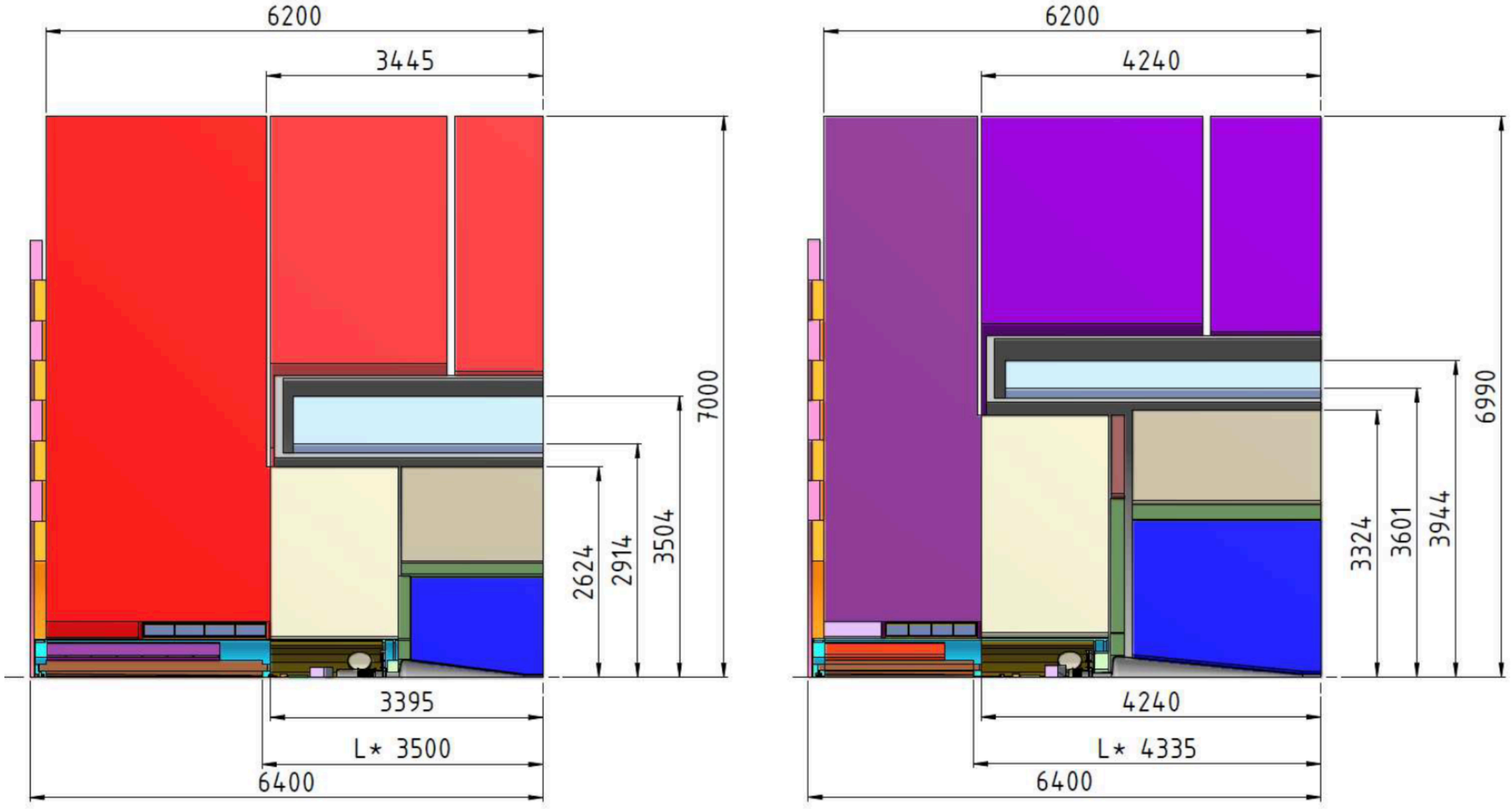
- LTS: calorimeter inside
  - 3 T central field
  - ~7 m diameter, 8 m length
  - 15 kA current
  - 10 H inductance

- HTS: hadronic calorimeter outside
  - 3 T central field
  - 4.7 m diameter
  - 30 kA operating current
  - 1.2 H inductance





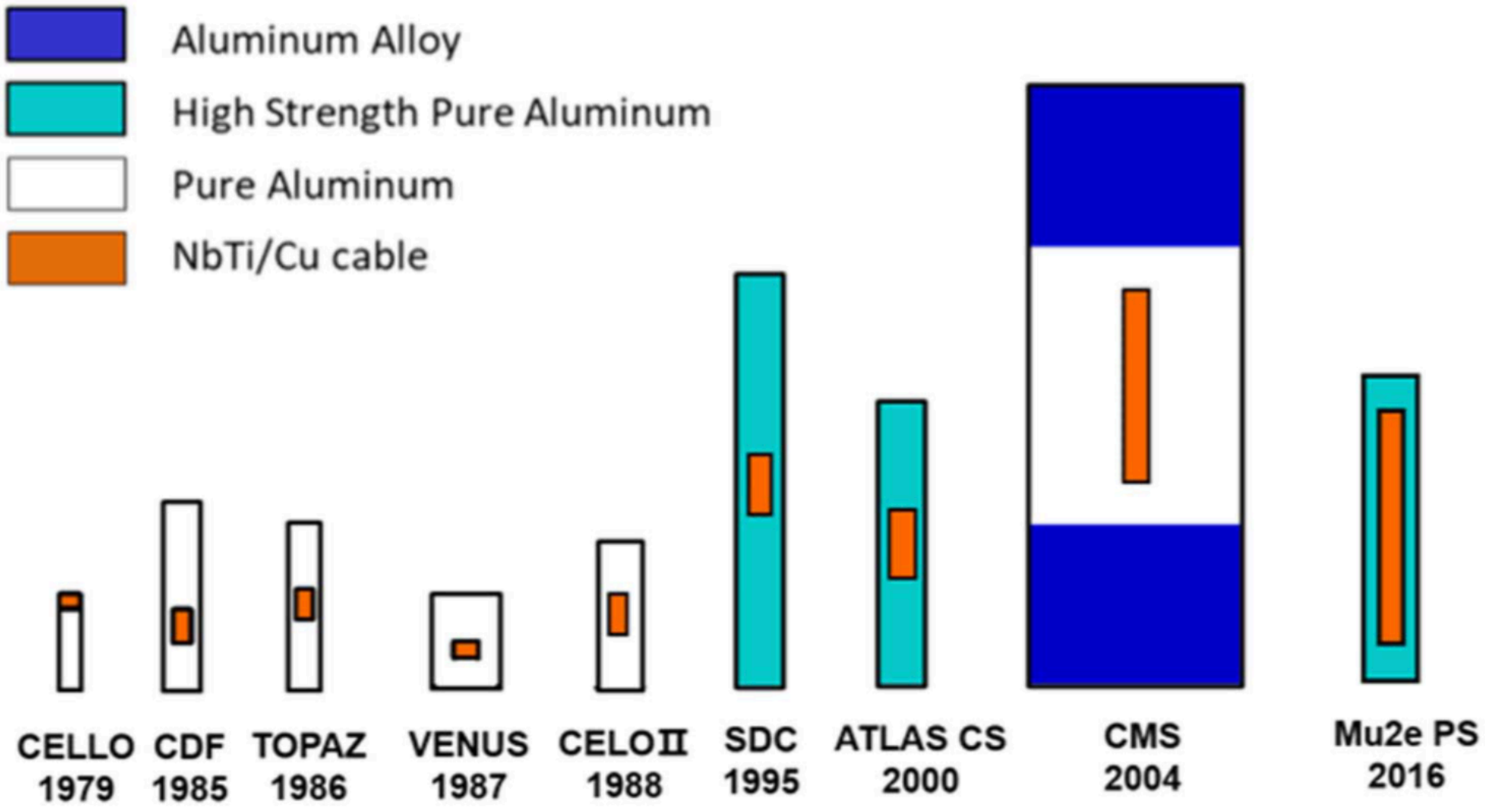
CLIC SiD and ILD



- Large and thick solenoids, 5 and 4 T respectively, with anti-solenoids for focusing quadrupoles

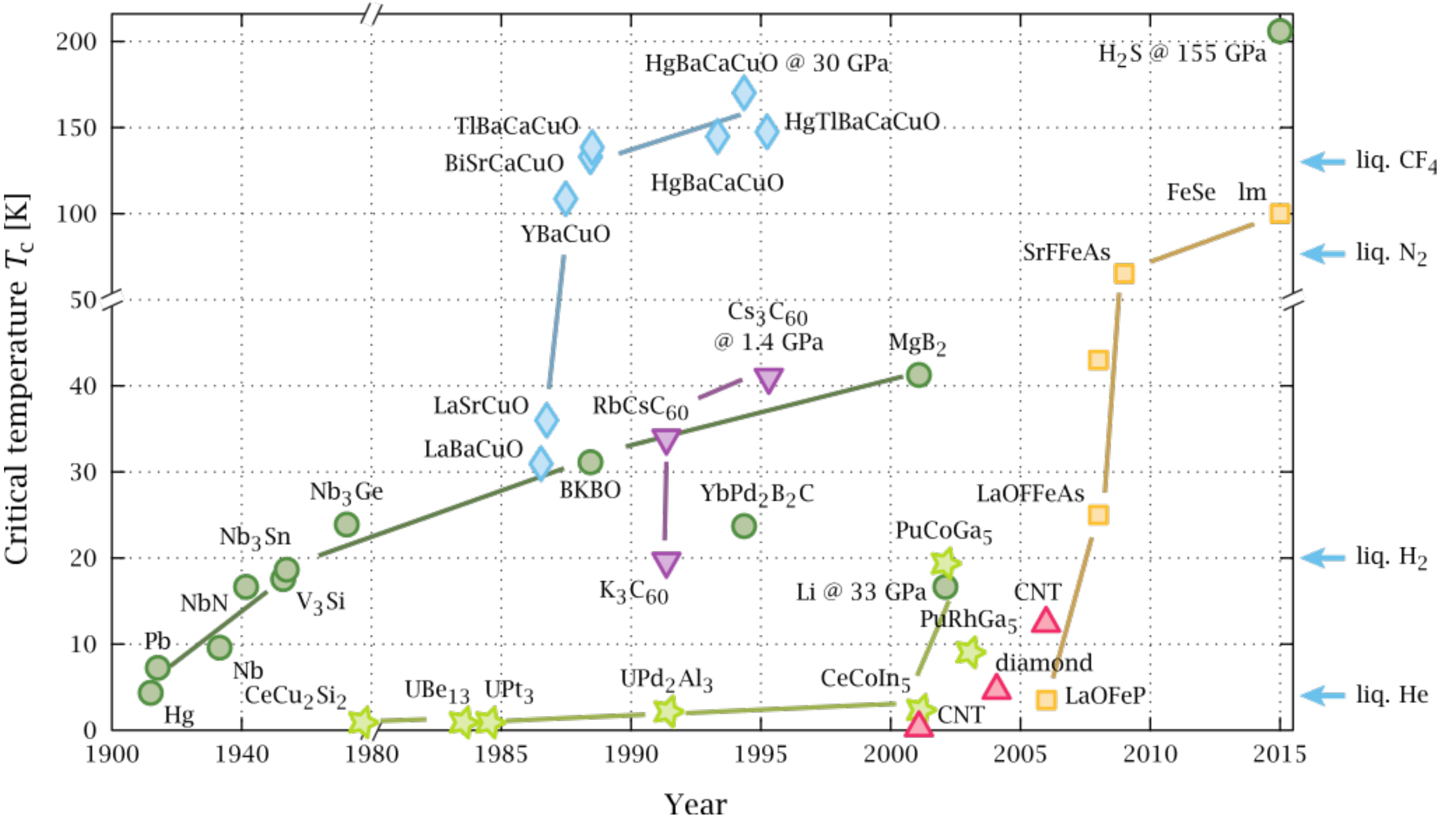
Some considerations on cables

- Everything built is based on the same material
- Technology presently "hardly" available
- What about using other materials?
  - Nb3Sn?
  - REBCO?



Superconducting materials

- Not al are shown
  - hundreds are known
- Actually used: 4
  - pure Nb
  - NbTi
  - Nb_3Sn
  - MgB_2
- Under study
  - BSCCO
  - YBCO
- Others?
  - Nb_3Ge/Al
  - iron based



Exotic designs?

- Double solenoid, sided
  - one is used instead of return yoke, possibly unfeasible
- Double solenoid, nested
  - central field is the sum, not necessarily a good idea
  - possibly also more than two
- Dipoles somewhere
  - complex reconstruction, anisotropic field, but possibly higher
  - ... or embedded in iron yoke
- Toroid in some clever configuration
  - I'm not lever enough to figure out right now

- Something we still don't know