Muon Collider Solenoids

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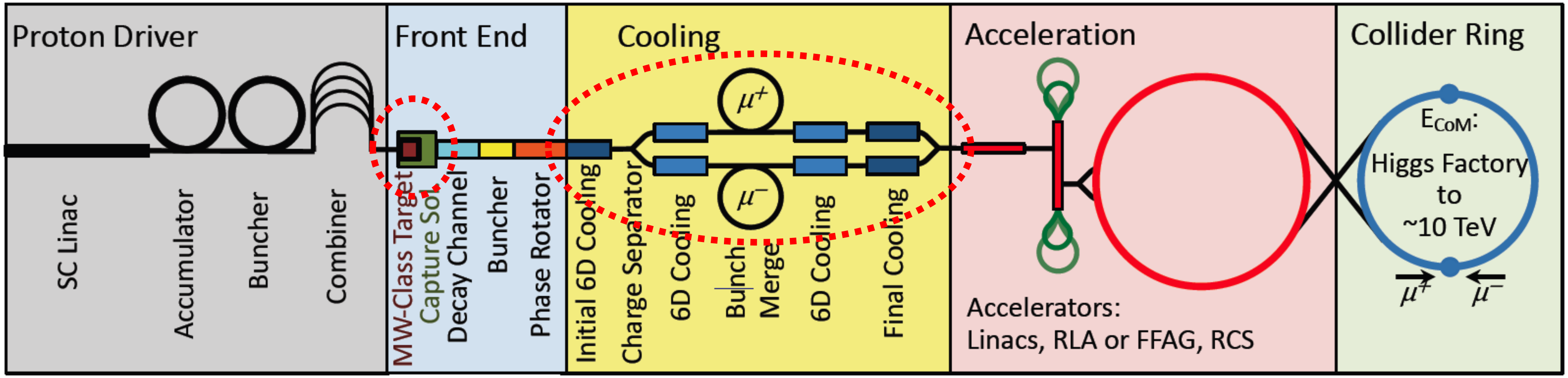
13 October 2022

The solenoids



Scope

- address feasibility and technology limits
- Assess R&D activities

Partecipating institutes

CERN-EP, LNCMI, PSI, University of Geneva, INFN LASA, University of Southampton, University of Twente

CEA

Final cooling solenoid

Aim at **higher field** (up to factor 2), and **compact winding** (500 A/mm^2)

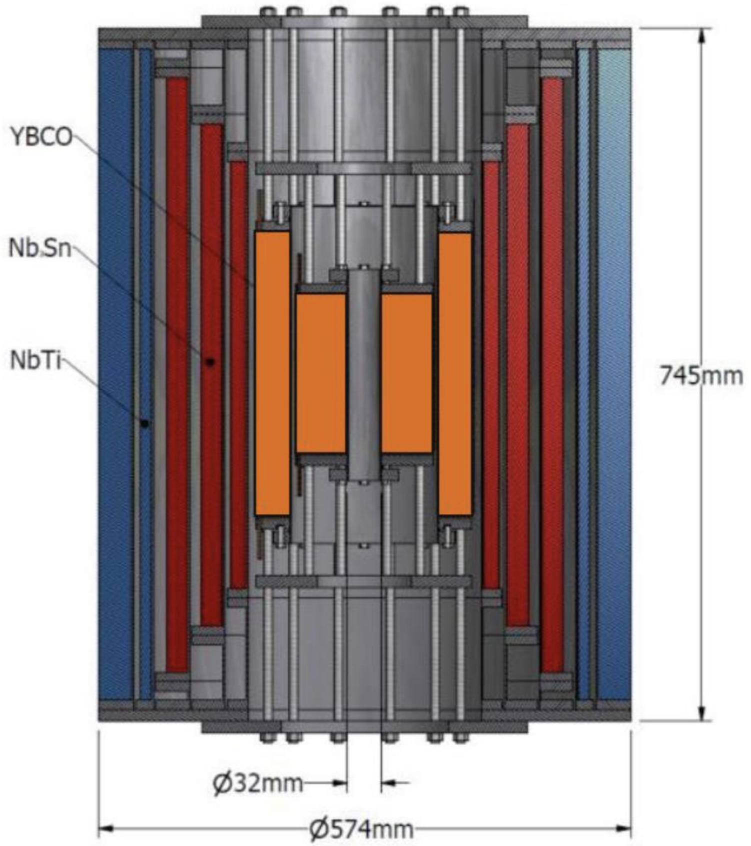
- Tentative specs
  - On-axis peak field: 40 T minimum, 60 T target (study will determine maximum that can be achieved)
  - Bore(1): 60 mm diameter
  - Magnetic length at peak field: 0.5 m (tentative)
  - Homogeneity: 1 % (tentative)
  - HTS NI (and variants) conductor technology to achieve $J_E \approx 500$ A/mm^2 (compact windings are necessary to maintain forces and cost low(2))
  - Operating temperature range(1): 10…20 K (gain factor 2…5 on COP)

(1) Absorber integration may modify bore and operating temperature

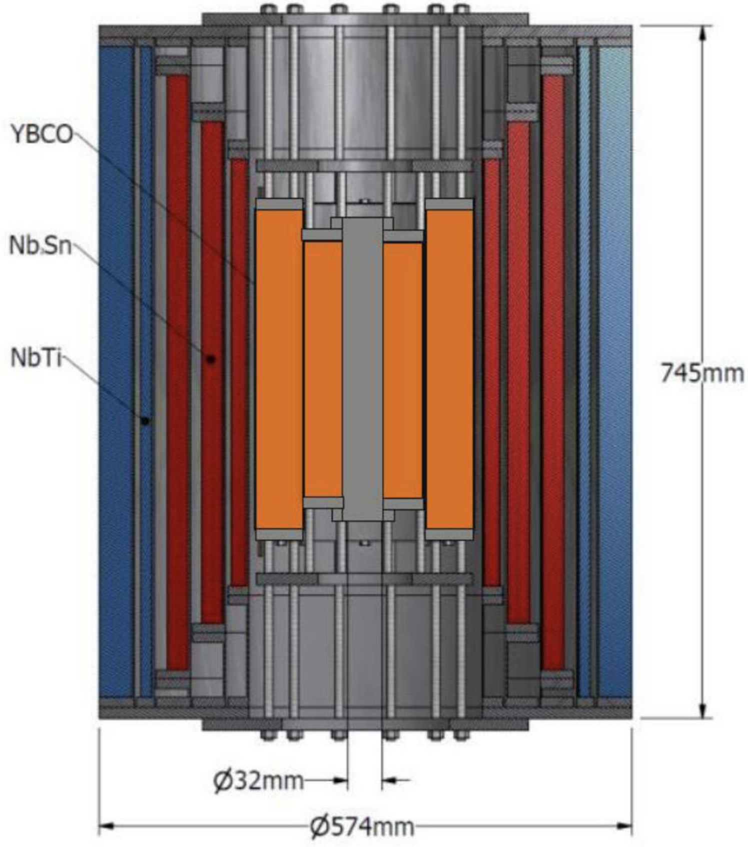
(2) The solenoids of the 6D cooling cells will require compact windings for cost optimization reasons. Work on HTS NI will also profit these magnets

Some highlights – UHF solenoids

Cross section of 32 T, 32 mm user facility solenoid (existing)



Cartoon design of 40 T, 32 mm user facility solenoid (planned)



R&D test achieved 25.4 T

I. Dixon, NHMFL

NATIONAL HIGH MAGNETIC FIELD LABORATORY

Some highlights – UHF solenoids

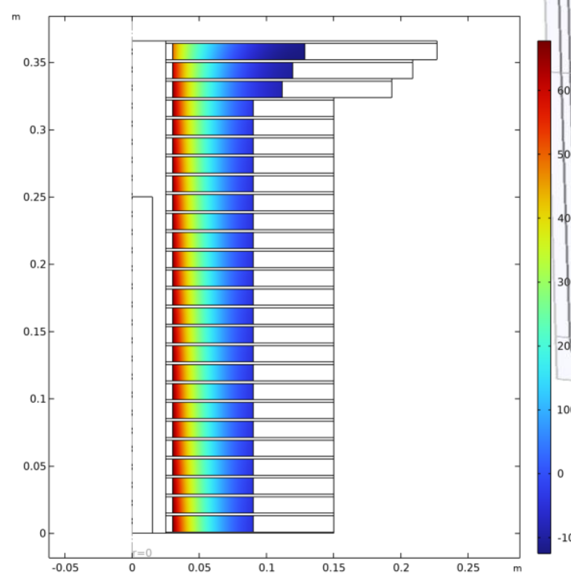
R&D NI insert achieved
32.5 T at LNCMI

J.-B. Song, LNCMI

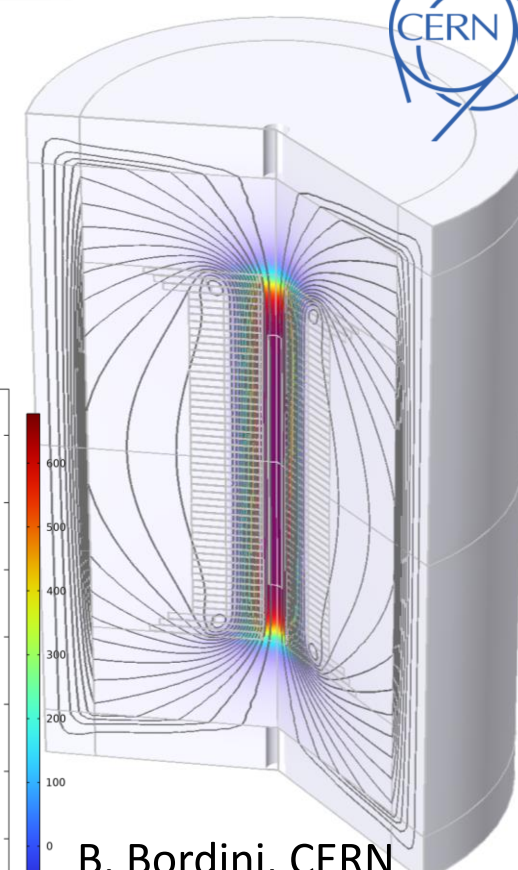
Swiss Accelerator
Research and
Technology

R&D NI coil achieved
18 T at PSI

J. Kosse, PSI



NI solenoid design
for 40 T



B. Bordini, CERN

European Magnetic Field Laboratory

Discussion on performance limits – 1

For smallest possible solenoid with no bore (R_{in}=0) maximum field is

$$B_{max} = 2 \cdot \sqrt{\sigma_{max} \cdot \mu_0}$$

$B_{bore} = \mu_0 \cdot J \cdot (R_{out} - R_{in}) = \mu_0 \cdot J \cdot R_{out}$

$J_{max} = 2/R_{out} \cdot \sqrt{\sigma_{max}/\mu_0}$

Assuming that stress level of 600 Mpa is not degrading HTS

$$B_{max} \approx 55\ \mathrm{T}$$

But is such stress level achievable in the **real** coil package ??????

A. Dudarev, CERN

Discussion on performance limits – 2

- A 40 T HTS magnet seems to be within technology reach, though it requires a very substantial R&D. This is the objective of other programs, specifically for high field science, though with other requirements and specifications

- The mechanical limit of a HTS solenoid is expected to be in the range of 55 to 60 T (simple analytic estimate)

- Critical question: is there a hard request for a factor 2 increase in final cooling solenoid field w/r to US-MAP ?

Target solenoid and capture channel

Aim at **smaller SC bore** than US-MAP (factor 2) and running at 10...20 K to **reduce helium and consumption** (factor 2)

- Tentative specs
  - On-axis peak field: 20 T (same as US-MAP)
  - Bore(1): 1.2 m diameter (reduction by factor 2 w/r to US-MAP)
  - Magnetic length at peak field: 0.5 m (tentative)
  - Homogeneity: 1% (tentative)
  - HTS conductor technology, two options:
    - Large CICC cable ($J_E \approx 50$ A/mm^2) (e.g. EU-DEMO conductors)
    - NI stacks in supporting structure ($J_E \approx 500$ A/mm^2) (e.g. MIT/CFS R&D)
  - Operating temperature range(1): 10…20 K (gain factor 2…5 on COP)

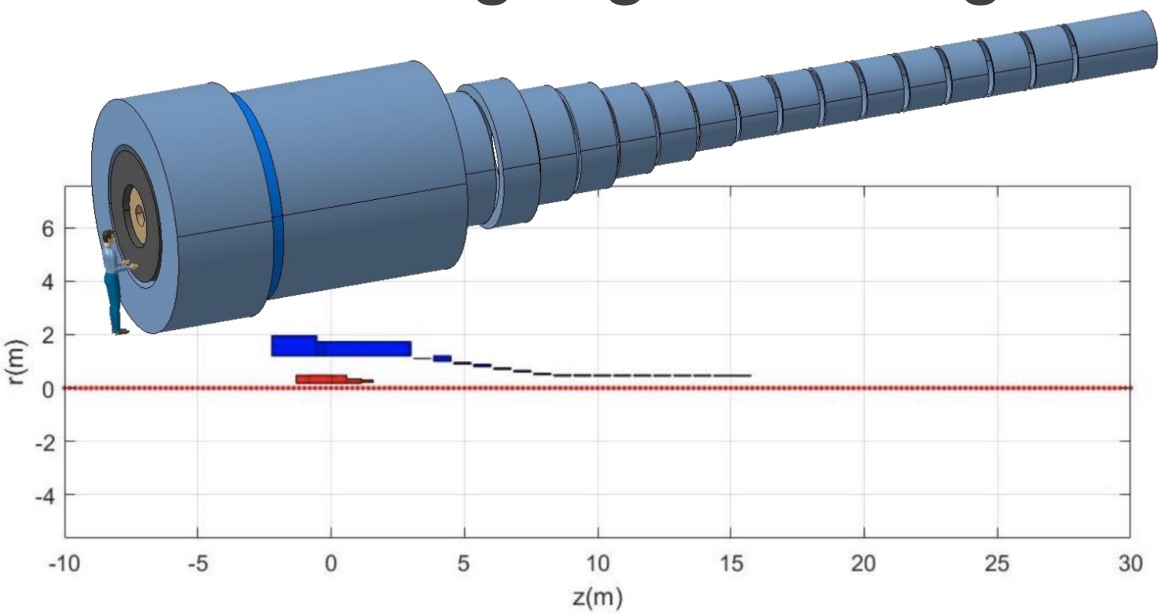
- On-axis field along capture channel(2)

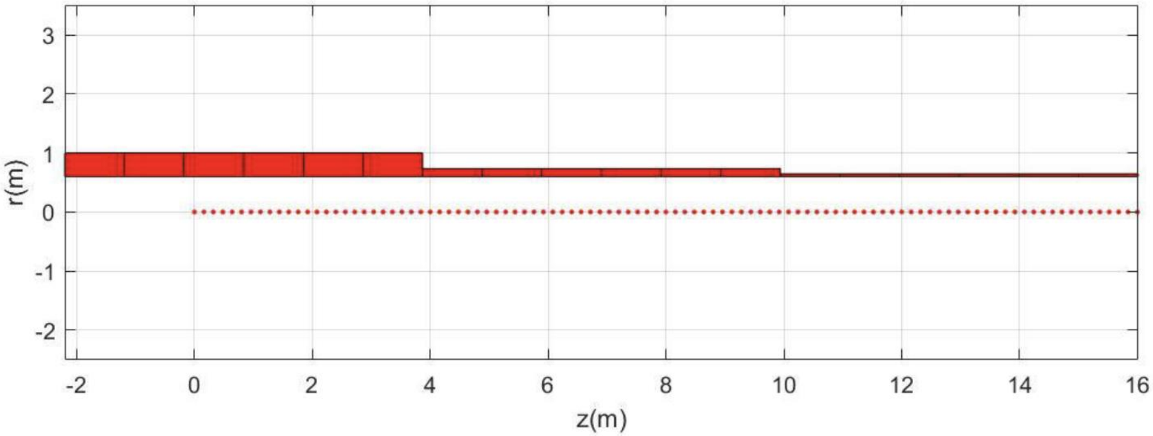
$$\frac{B_i B_f L_t^3}{B_i z^2 (3L_t - 2z) + B_f (L_t - z)^2 (2z + L_t)}$$

(1) Target and shield integration will modify the bore and operating temperature

(2) Hisham Kamal Sayed, J. Scott Berg, "Optimized capture section for a muon accelerator front end", PRSTAB 17, 070102 (2014)

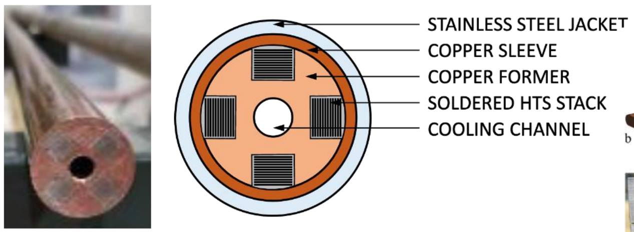
Some highlights – target solenoid



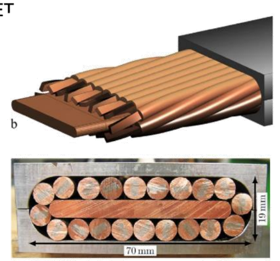


E_M = 2.9 GJ
T_{op} = 4.2 K
M_{coils} = 200 tons

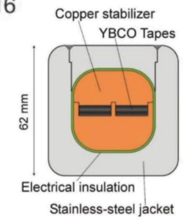
E_M = 1 GJ
T_{op} = 10…20 K
M_{coils} = 110 tons



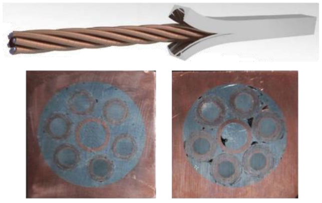
M. Takayasu et al., IEEE TAS, 21 (2011) 2340
Zachary S Hartwig et al 2020 Supercond. Sci. Technol. 33 11LT01



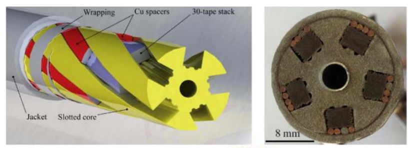
D. Uglietti et al 2015 Supercond. Sci. Technol. 28 124005



Y. Nagato et al., Nucl. Fus., 55 (2015) 053021



T. Mulder et al., IEEE TAS, 26 (2016), 4803605



G. Celentano et al., IEEE TAS, 24 (2014), 4601805

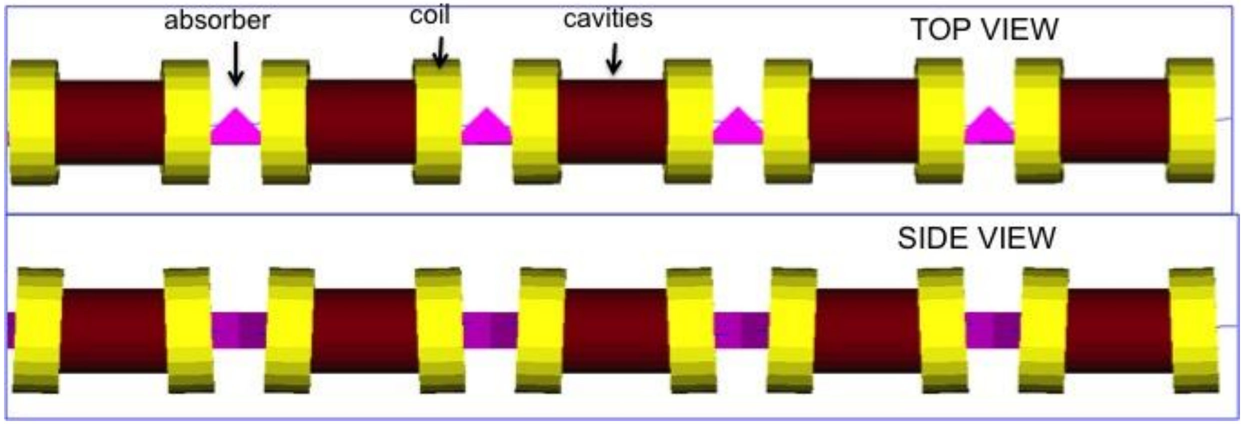
A. Portone, F4E

Discussion

- It may be possible to reduce substantially the mass and stored energy of the target and capture channel solenoids, profiting from HTS.
- This looks interesting enough to follow-up. The suitability of this variant needs to be studied further, integrating beam, target, shielding, cryogenic and vacuum requirements

6-D cooling solenoid

- Tentative specs span a wide range of field and aperture
- The main issue will most likely be **configuration and integration** (defined as a separate topic in the design study WP8)
  - Several coils housed in the cooling module to produce the field profile, coils may be tilted, e.m. forces among coils, will require elaborate support
  - *Cold* magnets to integrate with *warm* RF cavities and *cold* absorbers
- Sustainability, operating temperature

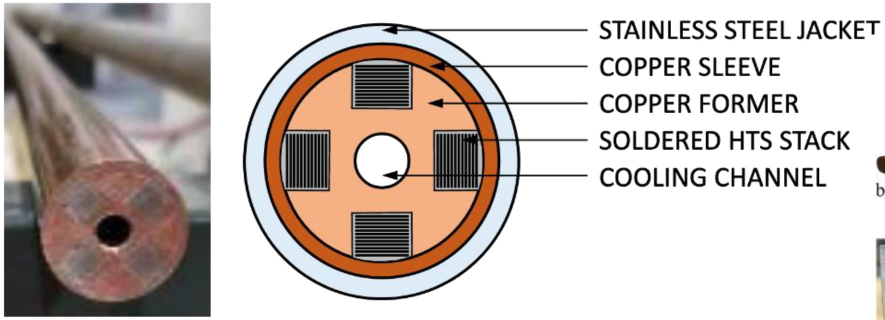


Conductor

Identify wire configurations
HTS, support, stress, strain
Fatigue….

HTS measurements
- Tape and/or cable

Where?
PSI – UniGe – LASA –
Uni Southampton – Uni Twe



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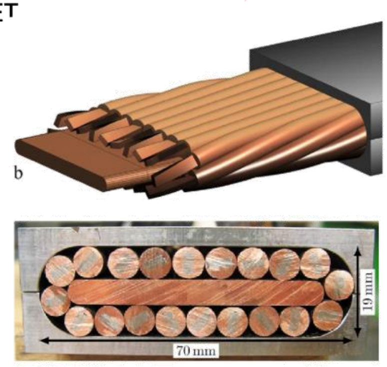
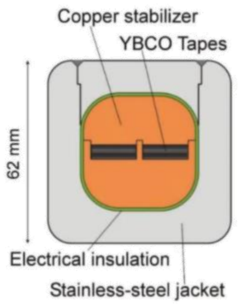


D. Uglietti et al 2015 Supercond. Sci. Technol. 28 124005



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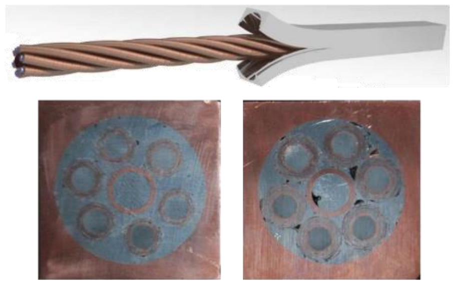
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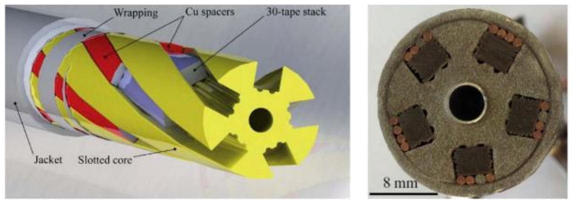


G. Celentano et al., IEEE TAS, 24 (2014), 4601805

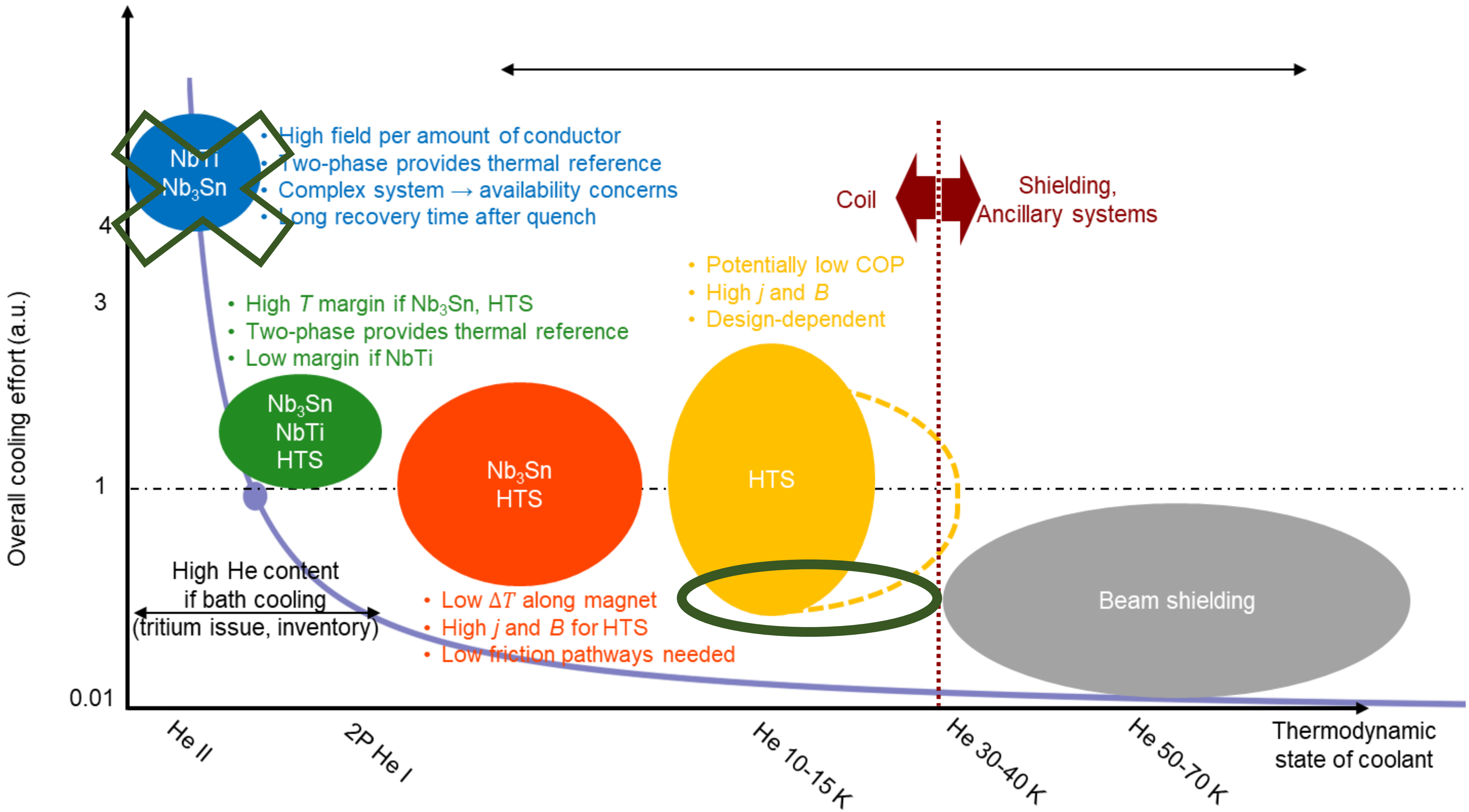
A. Portone, F4E

What?
TBD, however…
- We need a minimal set of properties necessary for design and result analysis (every tape is, unlikely, still different)
- We need to find a smart configuration to probe identified limits

We design for > 40 T! Where can we test at very high field?
- LNCMI Grenoble?
- MagLab Tallahssee?

Cryogenics and sustainability

Keywords: performance (field and field quality), cost, sustainability



P. Borges de Sousa

Conclusion

- Scope Address feasibility and technology limits
  - Assess R&D activities
- Main challenges have been highlighted
  - Performance (magnetic field – mechanics and protection !) and feasibility
  - Cost optimization
  - Sustainibility
- Task 2 output
  - Preliminary design of the solenoids representing the main challenges. Final cooling, and, if resources allow, target and capture channel
  - R&D plan for the design of MuColl solenoids
  - Conceptual design of all solenoid families

THANKS

International
MUON Collider
Collaboration