Reports of the working groups: Magnets

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Muon Collider Collaboration Meeting

CERN, 11-14 October 2022

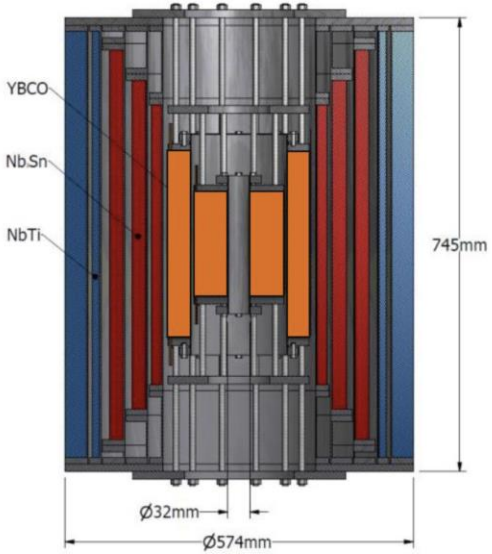
MAGNET WG: who are we ?

- **Institutional participants to EU MuCol:**
  - CERN, INFN, CEA, LNCMI, PSI, SOTON, UNIBO, UNIGE and TWENTE
- Additional participation from:
  - NHMFL, US-MDP, KEK, IHEP, F4E, MIT, ATI, TUT
- A very intense session. **A total of 23 talks on recent advances and plans,** with discussion and debate. VERY enticing and motivating !
- More than 30 on-site participants in the spectacular setting of the TE-MSC **Large Magnet Facility** (grateful thanks for hosting !), and about 20 participants on-line over 17 time zones

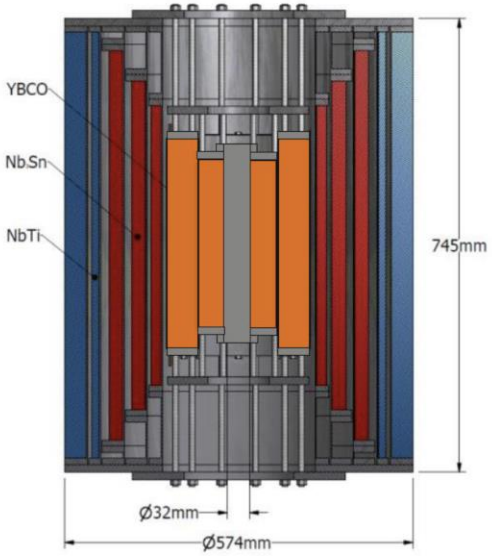
International
MUON Collider
Collaboration

Highlights – Solenoids – 1

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



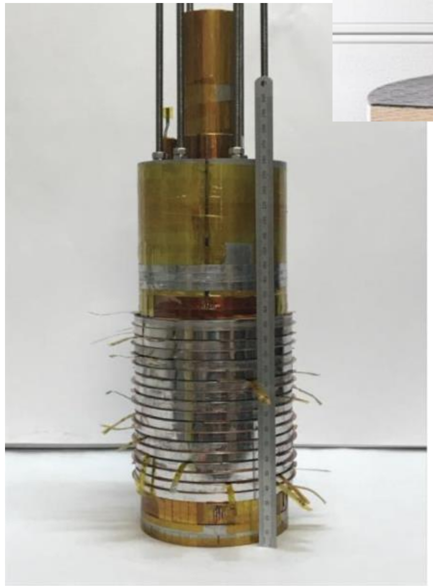
Cartoon design of 40 T, 32 mm user facility solenoid (planned)



I. Dixon, NHMFL

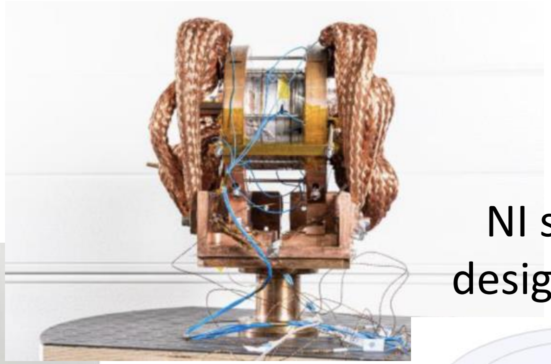
R&D test achieved 25.4 T

R&D NI insert achieved 32.5 T at LNCMI



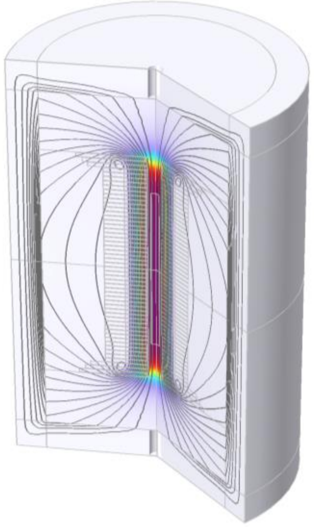
J.-B. Song, LNCMI

R&D NI coil achieved 18 T at PSI



J. Kosse, PSI

NI solenoid design for 40 T



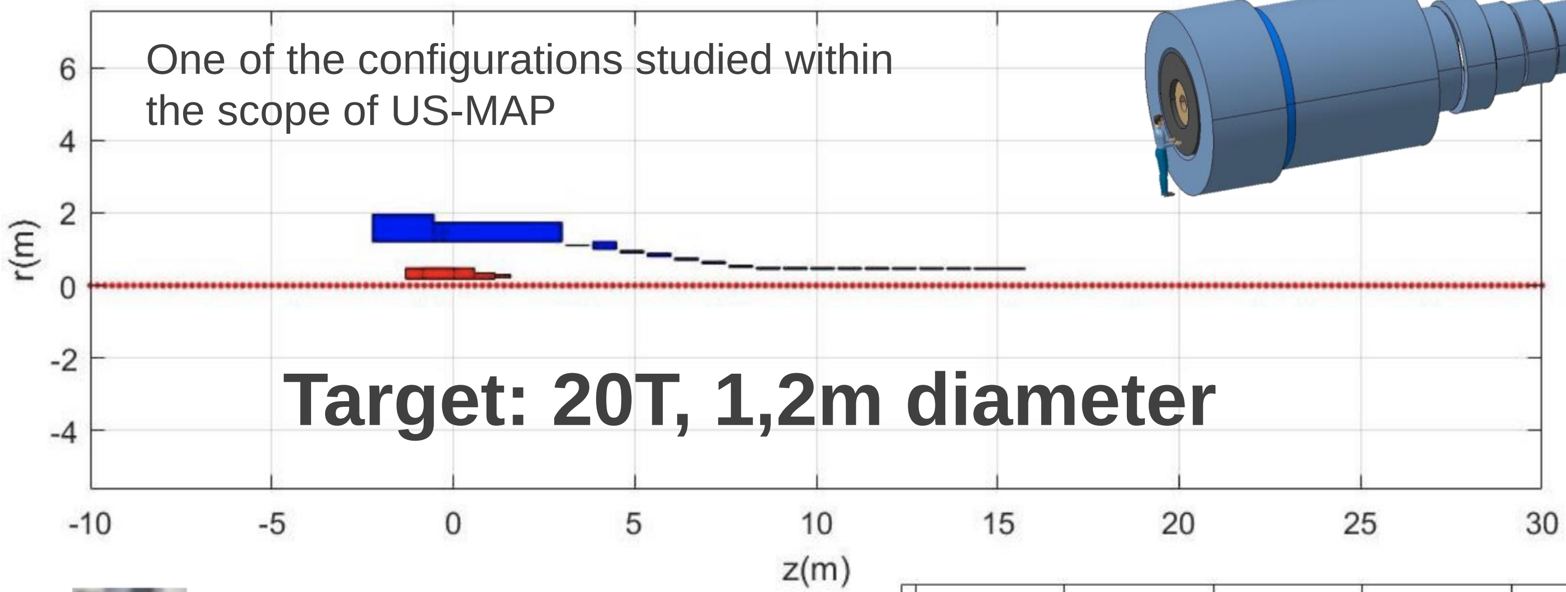
B. Bordini, CERN

There is a technology path towards compact 40 T solenoids
Higher fields may be possible (**upper limit around 55 T ?**), but the magnets will be:

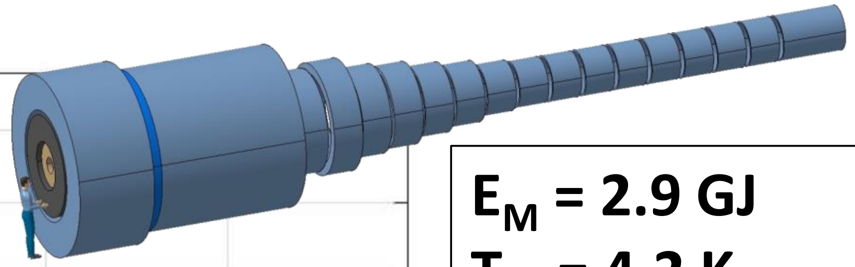
- More complex
- Larger
- **More expensive ?!?**

Highlights – Solenoids – 2

One of the configurations studied within the scope of US-MAP

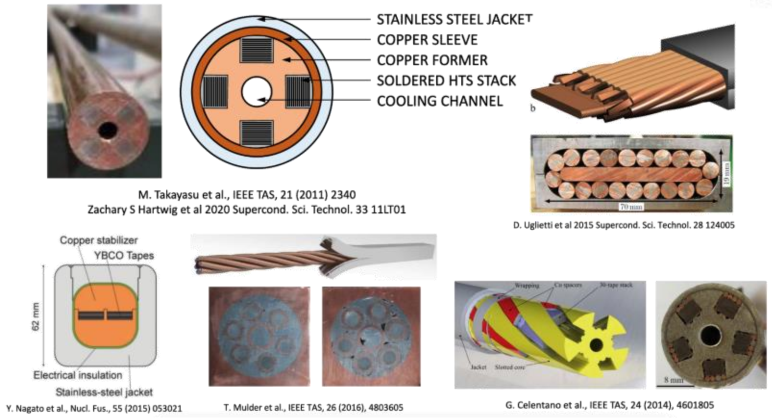


Target: 20T, 1,2m diameter



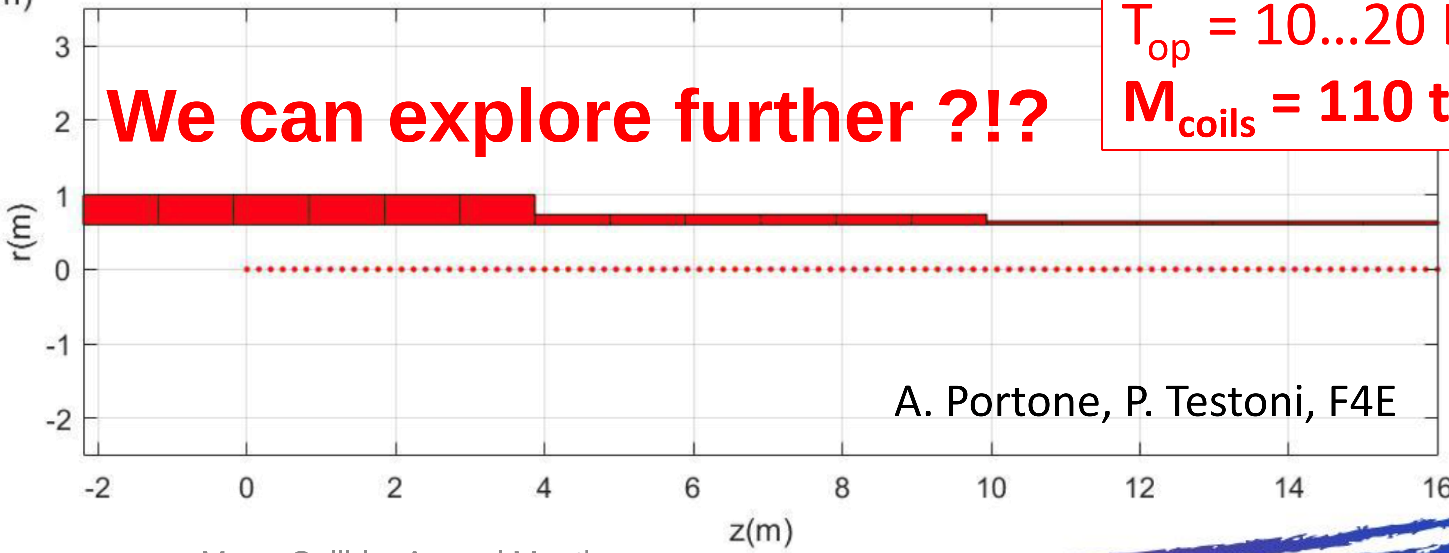
E_M = 2.9 GJ
T_{op} = 4.2 K
M_{coils} = 200 tons
M_{shield} = 300 tons
P = 12 MW

Potential for **significant gain** in mass, cost and consumption



HTS technology from fusion R&D

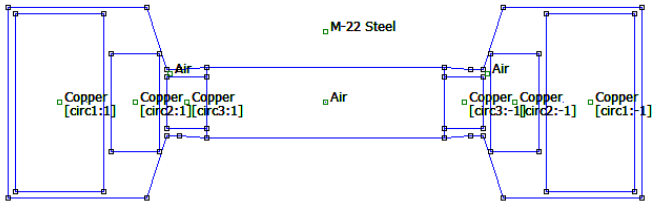
We can explore further ?!?

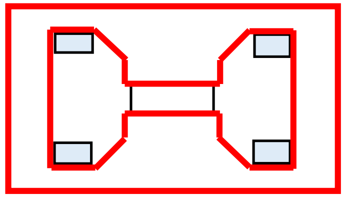


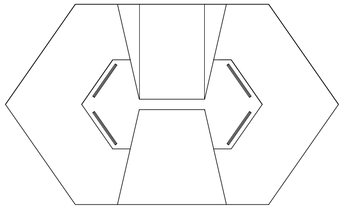
E_M = 1 GJ
T_{op} = 10…20 K
M_{coils} = 110 tons

A. Portone, P. Testoni, F4E

Highlights – Fast accelerators







M. Breschi,
P. Ribani,
R. Micelli,
UniBo

	Active power [kW/m]	Reactive power [MVar/m]	Gap energy [J/m]	Energy in air (no gap) [J/m]	Energy in coils [J/m]	Losses in iron [kW/m]
Windowframe magnet	1236	14.0	3697	668	1485	18
H magnet - 3 coils	356	16.3	3814	1305	552	26
H magnet - 2 coils	182	19.9	3875	3140	142	111
Hourglass magnet	149	15.7	3821	1165	7	122

F. Boattini, CERN

Components testing may help reducing the large safety factor (about 10 !!!) for the stored energy in a capacitor in case of bi-polar voltage swings

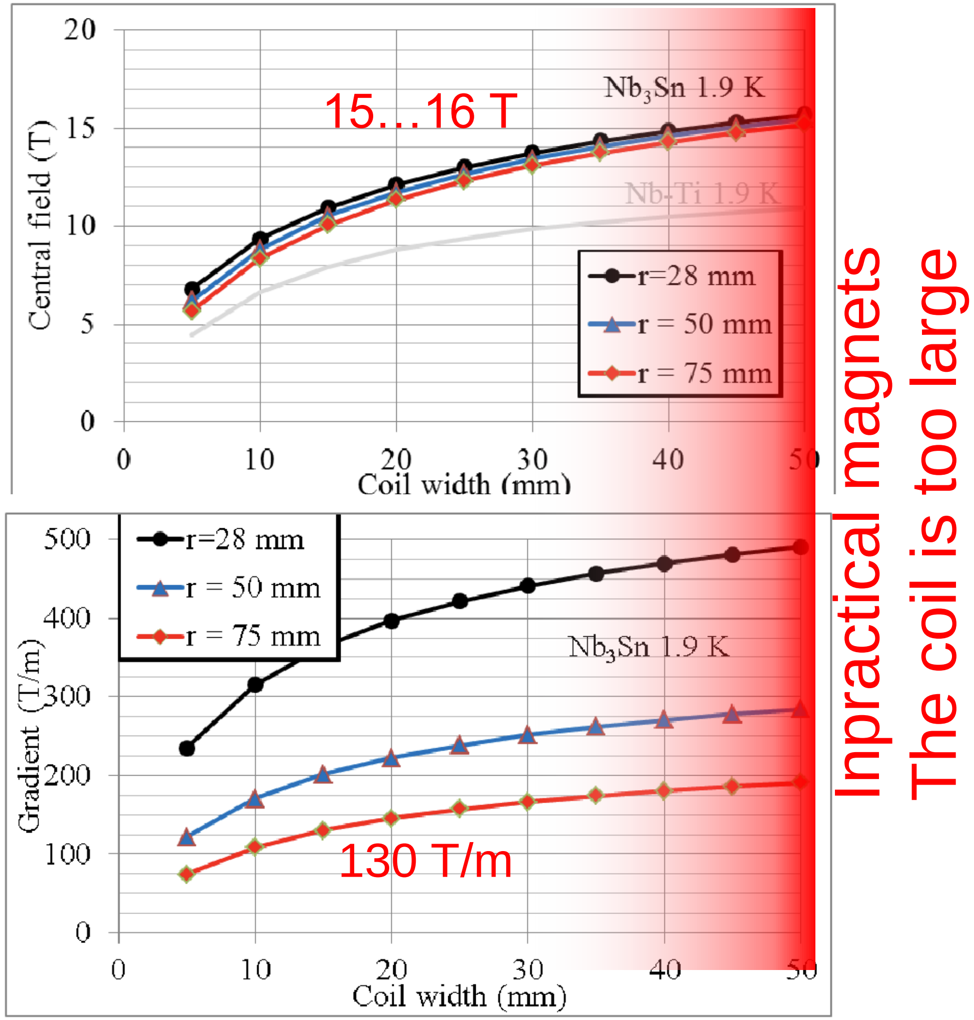
POPS capacitor container.
12mx2.5mx2.5m; 26tons; 3.3MJ; 0.5MCHF;

Muon Accelerator capacitor container.
12mx2.5mx2.5m; 26tons; 0.22MJ; 0.5MCHF

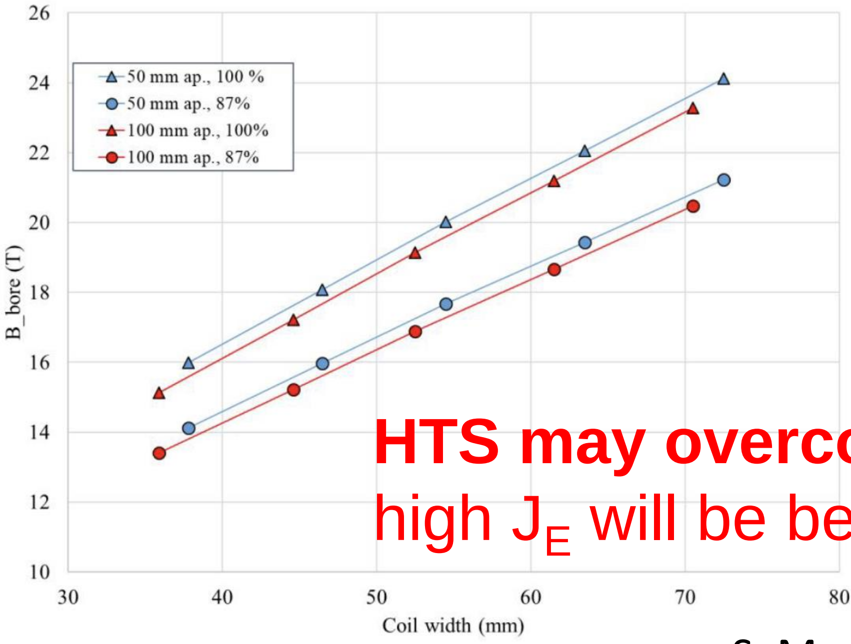
Design of resistive accelerator magnets has started, revealing interesting features:

- US-MAP design is highly optimized !
- **There may be configurations with lower reactive power** (easier for energy storage and ramp management) and **acceptable active power loss**
- **The design and analysis tools (this is just the start !) will tell us more**

Highlights – Collider



P. Ferracin (LBNL), E. Rochepault (CEA), from E. Todesco and L. Rossi



HTS may overcome the limits,
high J_E will be beneficial

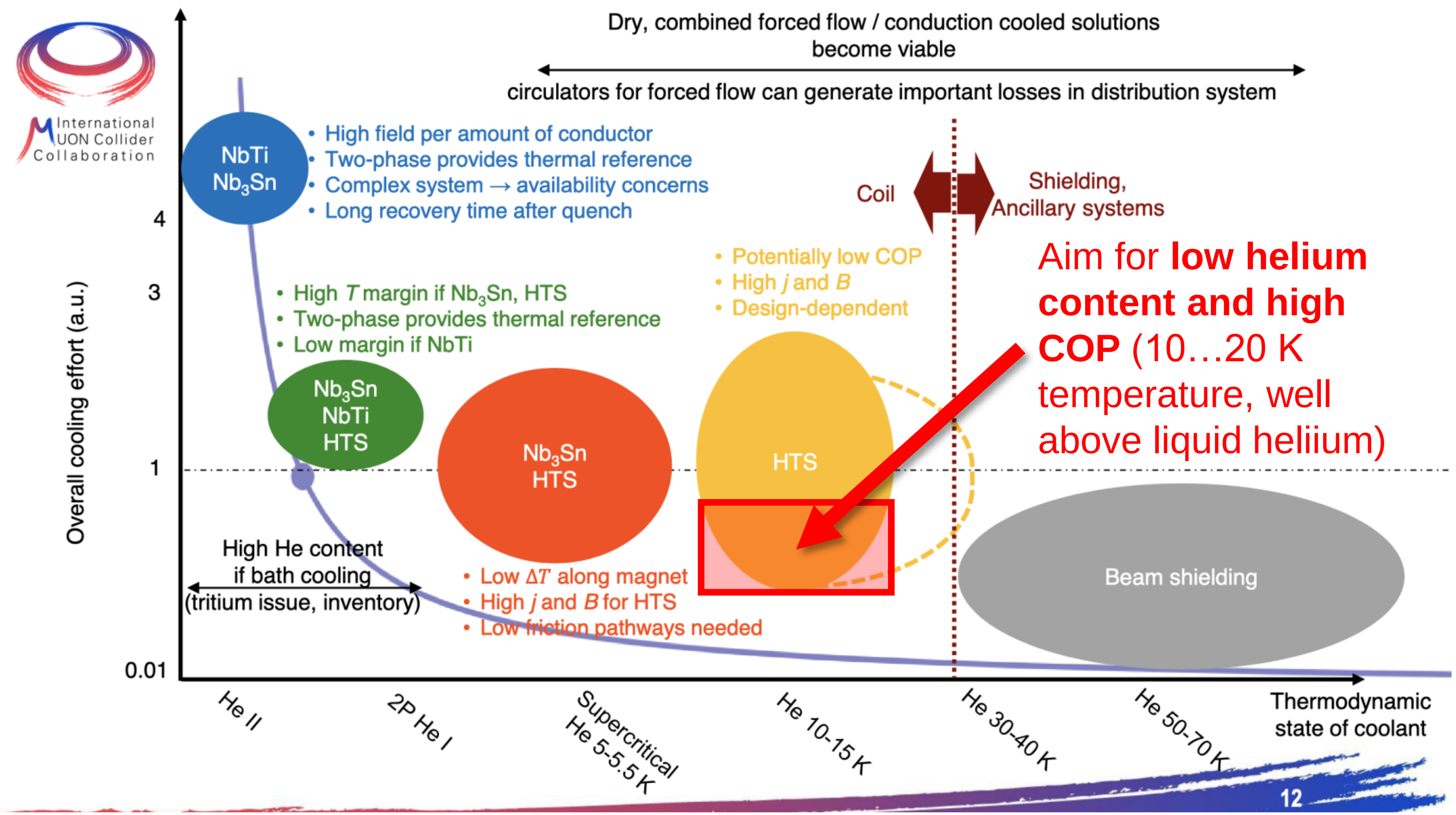
S. Mariotto, B. Caiffi (INFN)

On-axis peak field(1)	10 T
On-axis peak gradient(1)	300 T/m
Bore(2)	150 mm
Magnetic length	15 m

Not possible at the same time

We need rapidly an iteration on the beam demands

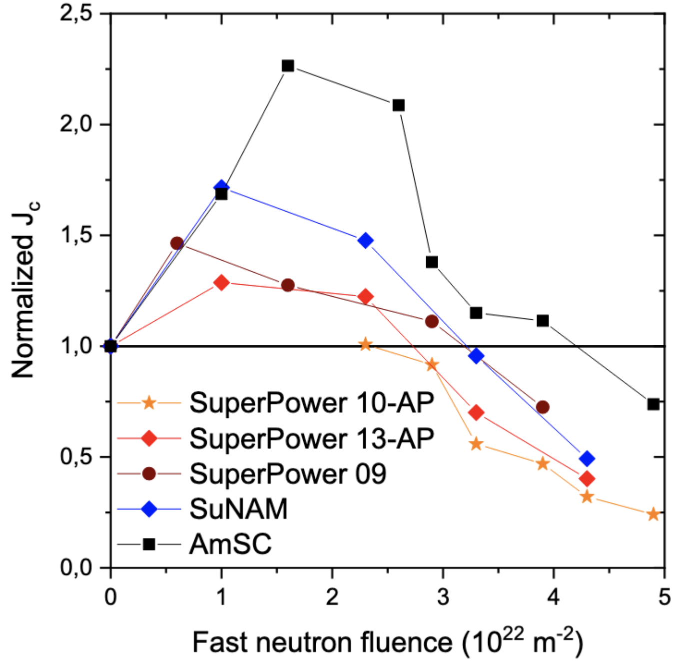
Highlights – Technologies



Aim for **low helium content and high COP** (10…20 K temperature, well above liquid heliium)

P. Borges de Sousa, R. van Weelderen (CERN)

M. Eisterer (ATI)



Understanding radiation effects, developing radiation hardness and mitigation is a crucia (and work-intense) topic for the muon collider (see also A. Lechner)

We will actively pursue collaboration (e.g. ATI, KEK, MIT)

Some preliminary conclusions Magnets vs. Physics

- We have some crucial questions to be resolved rapidly, so that magnet work can be focused towards producing a **credible and affordable accelerator complex design** (contain cost, energy efficient, sustainable operation)
  - Aperture, energy deposition and dose in the proton target area
  - Absorber dimension in the cooling cells
  - Need and level of UHF in the final cooling cells
  - Aperture needs in the rapid cycling synchrotrons
  - Dipole, quadrupole and aperture in the collider arc and IR's
- **Initiate discussions to reach convergence** on challenging but reasonable values, on the time scale of 2…4 weeks

Some preliminary conclusions Magnet Technology – 1/3

- Conductor is THE key topic:
  - Nb_3Sn has a known potential (intermediate field solenoids, accelerator magnets for the collider, outsert of hybrid magnets) and will be developed within the scope of HFM, as well as other programs (e.g. US-MDP)
  - BUT…
  - **A strong R&D effort on HTS is needed** for several magnets that cannot be built otherwise (cooling solenoid, target solenoid, possibly some of the fast ramped magnets)
  - We need to understand J_C, but (and especially) mechanical properties (e.g. stresses, fatigue, ...), whether and **how to make cables**, and **how to make cost-efficient magnets** out of **existing and future HTS conductors and cables**

Some preliminary conclusions
Magnet Technology – 2/3

- **The field of HTS Magnet design is wide:**
  - Conductor design (tapes, flat cables, CORC, CICC, ...)
  - High potential of controlled insulation (MI-PI-RI and similar)
  - Innovative mechanical designs are needed for the exceptional force levels
  - Quench and protection is a specialty by itself
  - Select optimized operating temperature and cooling methods
  - New manufacturing techniques need to be devised
- **We need to establish and exploit synergies** with other programs/labs
  - EU-HFM
  - KIT (e.g. KIT-CERN KC4)
  - US-MDP
  - Other worldwide programs such as Japanese and Chinese HFM R&D
  - High-field magnet labs (EMFL, NHMFL)

Some preliminary conclusions Magnet Technology – 3/3

- Why HTS ? Considerations of **energy efficiency and sustainability** seem to favor this direction
- **The demands on HTS conductor and solenoids are not far from what can be done already**
- We need to **involve cognizable industrial partners** from the start
  - Make them aware of our needs
  - Develop our knowledge and a good understanding of their limitations and perspective (this is a relatively novel industry, compared to LTS)
  - Profit from the developments that take place in other fields

Thank you !

- This was an excellent technical and personal exchange. Our thanks to the organizers for having provided a perfect setting

- We wish to have more similar occasions, more often than the annual meeting. Define a dedicated setting for plenary magnet technology meetings ? Ideas:
  - I-FAST HTS workshop
  - Other occasion to be organized (e.g. in 6 months ?)

THANKS

Planning

		Year 1												Year 2												Year 3												Year 4											
Tasks	**Description**	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48
WP1: Coordination and Communication			M	M		D	M						D			M			M						D			M			M						D			M									D
1.1	Study Coordination																																																
1.2	Technical Coordination																																																
1,3	Quality Management																																																
1,4	Communication and Dissemination																																																
1,5	Implementation Scenarios																																																
WP2: Physics and Detector Requirements							M							M					M							M					D						D												M
2.1	Design of detector configurations at √s=3 TeV and																																																
2.2	Design and implementation of event reconstruction																																																
2.3	Evaluate detector performance at different																																																
WP3: Proton Complex																																														D			
3,1	High Power Lincas																																																
3,1	Compressor rings design																																																
WP4: Muon Production and Cooling																									D									D														D			
4,1	Cooling System development																																																
4,2	Target system development																																																
4,3	Code development																																																
WP5: High Energy Complex																M			M	M						M	M																		D	D			
5,1	Collider Design																																																
5,2	Pulsed synchrotron and FFA design																																																
5,3	Beam dynamics																																																
5,4	MDI design and background to the experiment																																																
WP6: RadioFrequency Systems																																											D			D			
6,1	Baseline Concept of the RF system for the																																																
6,2	Baseline concept of the RF system for the Muon																																																
6,3	Breakdown mitigation studies for cavities of the																																																
6,4	Baseline concept of the high efficiency and high-																																																
WP7: Magnet Systems																															M			D									M			D			
7,1	Technical Coordination and Integration																																																
7,2	Target, Capture and Cooling Magnets																																																
7,3	Fast Cycled Accelerators																																																
7,4	Collider Ring Magnets																																																
WP8: Cooling Cell Integration																D																		M									D						
3.1	Absorbers and windows																																																
3.2	Solenoids																																																
3.3	RadioFrequency																																																
3.4	Cooling cell performance																																																
3.5	Integration																																																

M Milestone
D Deliverable