Muon Collider WP7-Task 4
Collider Complex

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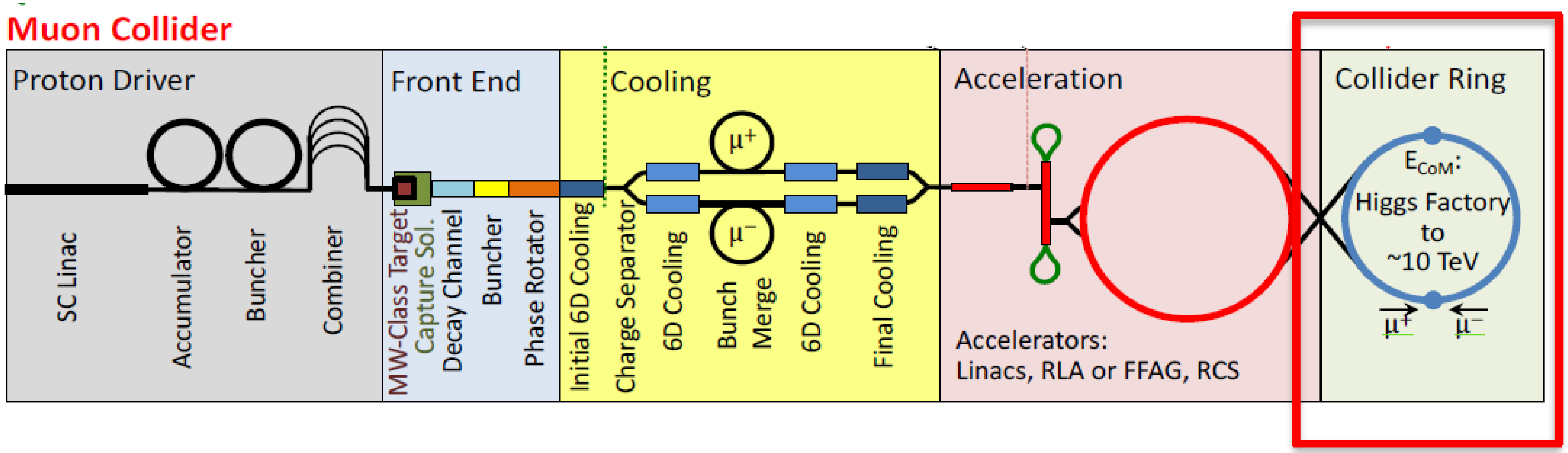
IMCC Collaboration Meeting, CERN, 12-10-2022

Task 7.4



Scope:

- assessing realistic performance targets for the collider magnets, in close collaboration with beam physics, machine-detector interface, and energy deposition studies
- produce Design Study Credible and Affordable

(contain cost, energy efficient, sustainable operation)

Partecipants:

- INFN Milano

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- INFN Genova

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- UNIMI

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- CERN

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Tentative proposal

3 TeV machine

- Provide a design study for the 3 TeV machine collider arc magnets
  - ➢ *if this is an interesting option for a staged strategy*

NbTi is compatible with required magnetic field

- ➢ Are combined function magnets requested also for this options?
- ➢ Nb_3Sn can also be considered, if working at 1.9 K is not an option

N.B. This technology is not scalable, magnets for 3 TeV machine or 10 TeV machine are completely different beasts, the studies will be completely different

10 TeV machine

- Provide a design study for the 10 TeV machine collider arc magnets
  - ➢ Most likely, the magnetic field required will not be compatible with Nb_3Sn **HTS is more suitable**
  - ➢ Working temperature will also constrain this choice: if we want to work @10K to reduce energy consumption, again **HTS is the way**

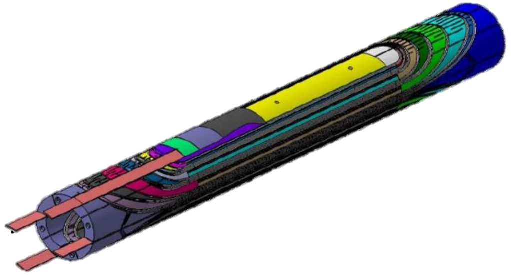
Global Effort on HTS Studies

- ReBCO tape and BSSCO are at the moment the most promising conductors option.

We are NOT YET able to build a reliable configuration up to 16 T in LTS or HTS

CERN
- Eucard2 Experience
  Roebel Cable
- NI Coils for Solenoids

CEA
- Cos-theta like magnet



USA
- CCT Magnet development program
  CORC conductor (CCT-C3 5T demonstrator)

Fusion:

MIT Plasma Science & Fusion Center
- SPARC experience

significant R&D effort is needed!!!

USA 20T+ Magnet development Program
- Hybrid Solutions
- Different Configurations

(cos-theta, block coils, cct, common-coil ecc.)

INFN Milano-Genova

Dipolar Test station

Magnetic Field: 8-10 T

Aperture: 80x50 mm

12 mm wide ReBCO tape

Operating Temperature: 10 K

Magnet requirements

- Define requirements for the combined function collider arc magnets:
  - dipolar magnetic field
  - gradient
  - magnet aperture
  - length

Milestone T_0 + 6 months
Arc Dipole Parameter specifications

This task requires an iterative interaction with beam dynamics teams, loss and radiation teams, vacuum and cryogenics and will lead to the choice of the technology to use (Nb_3Sn, HTS)

Current status of beam dynamics requirements

10 TeV machine

	Dipolar field [T]	Quadrupolar field [T/m]	Aperture (diameter) 2*(5σ+2cm) [mm]	Minimum Coil Bore Aperture [mm]
AQF1	12.3	87.2	82.3	132.3
AQD1	12.3	-120.3	59.7	109.7
AQF2	8	266.9	57.1	107.1
AQD2	6.5	-366.9	51.5	101.5

Beam Screen +50 mm (diameter) →

- Beam screen still to be defined

Reasonable coil aperture $\emptyset_{bore}$=150 mm

- Magnetic field on the conductor can be higher than 20 T -> Nb_3Sn is no more an option
- Parameters must be revised considering the magnet feasibility
  - The Stress on the coil is a critical aspect
  - Combined Function design is not "trivial" (see also later)

Magnet requirements

- Tentative specs for first feasibility evaluation (to be revised)

On-axis peak field(1)	10 T
On-axis peak gradient(1)	300 T/m
Bore(2)	150 mm
Magnetic length	15 m
Field Quality	10 units
Technology	LTS/HTS
Temperature range(2)	1.9/4.2 K (LTS) or 10 to 20 K (HTS)

Not Possible
At the same Time

(1) Field and gradient are evolving with optics

(2) Muon decay shield integration may modify bore and operating temperature

(3) Some of the technology choices are limited by the values of peak field and temperature

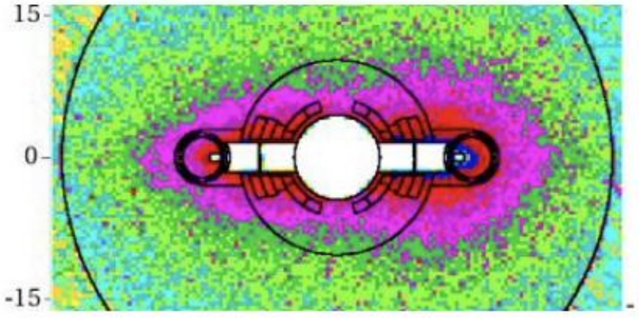
Magnet requirements

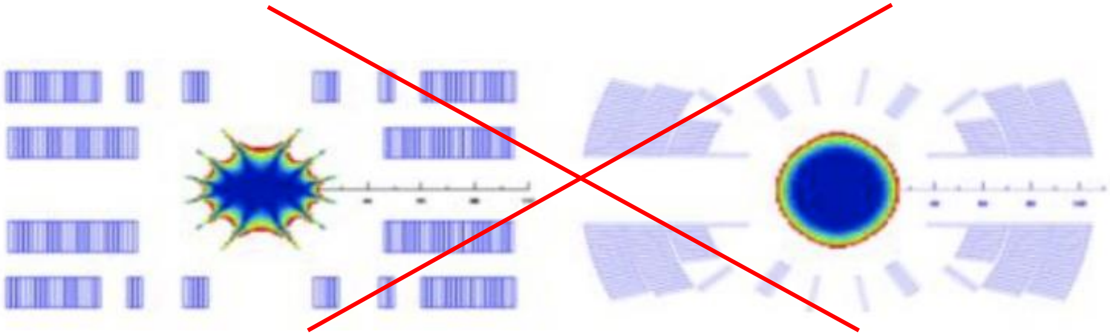
- Radiation map and dose estimate to design the beam screen
- Cryogenic system design
  - ➢ Which cooling rate should be considered affordable?
  - ➢ Working temperature? 1.9 K? 10 K?

CERN in charge for these tasks

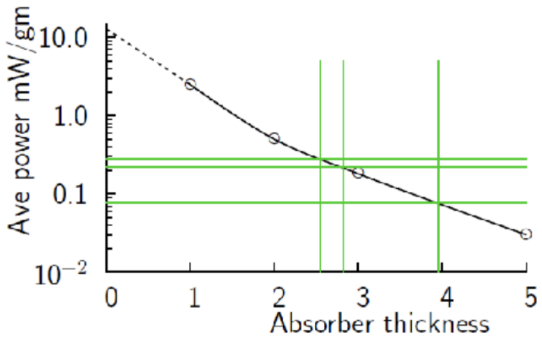
Also in this case iterative interactions between radiation team and magnet design team will lead to the best compromise in terms of magnet requirements

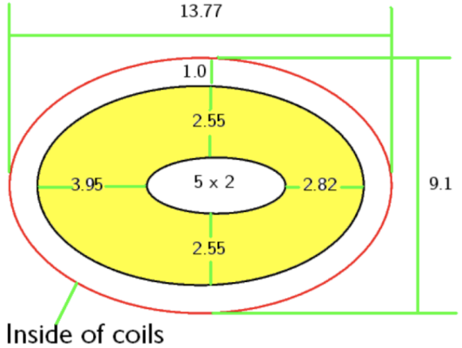
Due to the muon decays, the dose induced by the neutrino beams will be huge in the midplane region

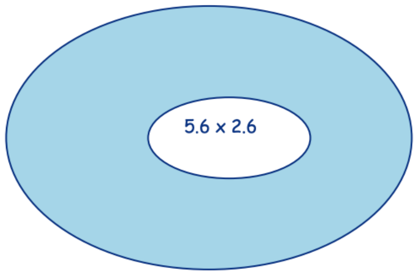




B. Palmer, MCSR Magnet workshop, 2011

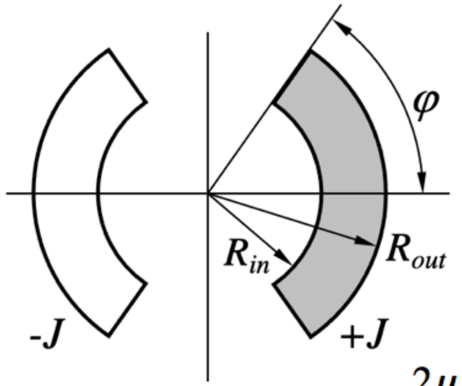




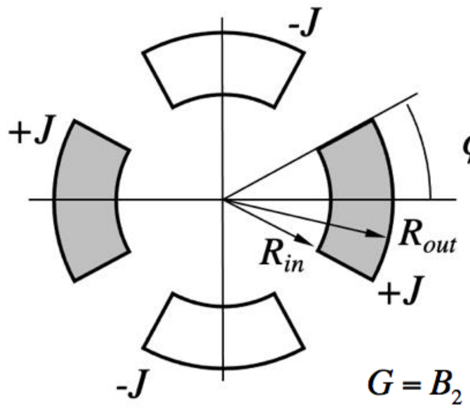


Fast evaluation of magnet parameters

In order to provide fast feedback on the magnet requirements provided by beam optics, MDI, radiation and cryogenics teams, a set of analytic expressions will be setup at least for the main parameters (Main Component, Peak Field, Field Errors, Forces).



$$B_1 = \frac{2\mu_0}{\pi} J \left(R_{out} - R_{in}\right) \sin(\varphi)$$



$$G = B_2 = \frac{2\mu_0}{\pi} J \ln\left(\frac{R_{out}}{R_{in}}\right) \sin(2\varphi)$$

Analytical expressions for NbTi and Nb3Sn type dipoles and quadrupoles already exists: field, error, forces and energy

- Scalable laws can be extensively used for simplified cos(nθ) configurations

Points to be addressed

- Equivalent expressions for block coil design?
- Peak Field to be evaluated numerically

HTS magnet are different from LTS configurations

- Limiting parameters and optimal configuration of the design can be different

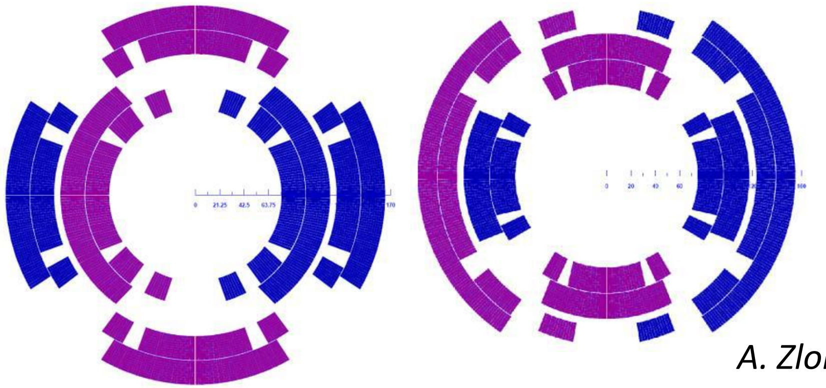
Milestone T_0 + 12/14 months
Analytical Magnet Cross-section

Combined function magnets

The straight path generates sharp cones of neutrino beams from muon decays

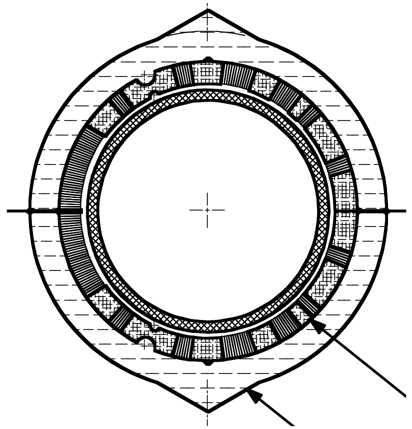
COMBINED FUNCTION MAGNETS

Nested



A. Zlobin

Asymmetric



T. Ogitsu

- **Pros**: Separate Powering Dipole/Quadrupole
- Inherit experience on Nb3Sn magnets for HiLumi and LARP-US development program

- **Cons**: Stress on Coil is critical (large forces where currents are opposite)
- Difficult alignment between the two coils
- Two types of different coil to be produced (Higher Costs)

- **Pros**: Single type of coil
- Optimized margin and field quality

- **Cons**: Fixed Dipole/Quadrupole ratio
- Stress on the supporting structure is not balanced
- Magnet protection more difficult

Margin and Protection Calculation

This task will be performed in collaboration with Tiina Salmi and Tampere University

(to be confirmed)

Study of Material Properties extremely important for accurate modelling of the magnet performances

Critical parameters have to be set for the magnet safety (Maximum Voltage to ground, Maximum Temperature, Time Delay, Stored Energy)

Protection Scheme: Quench Heaters, CLIQ, Dump R?

HTS behaviour for stability and quench propagation is a complete different beast

- Slow rise of temperature
- Hysteretic Losses
- Eddy Currents in the substrate
- NI Coils (maybe not suitable for the field quality)

Schedule

Preliminary timeline

- T_0+ 6 months Consolidate magnet requirements
- T_0 + 12/14 months Analytical expressions for Magnet Cross-Section
- T_0 + 33 months D 7.1 Intermediate Report
- T_0 + 42 months M 7.3 Workshop on HFM for collider
- T_0 + 45 months D 7.2 Consolidated report

- INFN is in charge of all the aspects of the magnet design (except for protection), not R&D studies but realistic optimization of modern technology
- Finding possible synergy with other magnet groups (Berkeley, FNAL, CEA) will make it possible to explore different solutions in parallel and make the design study more credible and affordable

Conclusions

- Aim of the Task 4 is to produce a preliminary design of a combined function arc dipole, of required **field/gradient/aperture** (TBD), **dose tolerance** (TBD) and **minimum energy consumption** (TBD)

- The point of the study is to produce a credible and affordable accelerator complex design (contain cost, energy efficient, sustainable operation), technology is a mean, not the end.

Thank you
for your attention