International MUON Collider Collaboration

INFN CERN Fermilab

Machine-detector interface (MDI) Working Group summary

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3rd Muon Collider Community Meeting

October 6 2021

Objectives of the MDI Work Package

- Study the beam-induced background and identify mitigation strategies
- Develop a (**conceptual**) **interaction region (IR) design** that yields background levels compatible with detector operation, i.e. show that
  - the desired physics performance can be reached
  - the cumulative radiation damage in the detector remains acceptable
- Address **different centre-of-mass energies**, with particular attention to the two distinct energy regimes under consideration:
  - $\sqrt{s}$ = **3 TeV**
  - $\sqrt{s}$ = **10 TeV** (IR design to be scaled up further to $\sqrt{s}$ = **14 TeV** if needed)

Can base the new studies on the valuable experience gained within MAP (N. Mokhov et al.)

Recap of background sources*

- Certainly a **main background source** for all collider options

- **Muon decay** around the ring
  - Major contribution comes from decays in IR
  - Bethe-Heitler muons also from further away
- **Incoherent e^-/e^+ pair production** during bunch crossing in IP
  - e^-/e^+ trajectories influenced by solenoid field
  - can impact on nozzle and detector vacuum chamber
- **Beam-halo losses** at aperture bottlenecks

- Was found not to be an issue at energy of $\sqrt{s}$=2 TeV* (with a solenoid field of a few T)
- **Nevertheless to be studied for the $\sqrt{s}$=10+ TeV collider option**

- Halo losses near detector can yield non-negligible background contribution
- **Acceptable halo loss levels to be defined (halo cleaning)**

*See also talk of **N. Mokhov**
1st Muon Collider community meeting

Deliverables, resources and interested partners

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High-level Deliverables							
1) Optimal detector shielding and study of the beam-induced background at $\sqrt{s}$=3 TeV							
1) Determination of the long-term radiation damage in the detector at $\sqrt{s}$=3 TeV							
1) Conceptual design of the interaction region including detector shielding and characterization of beam-induced background at $\sqrt{s}$=10 TeV							
1) Evaluation of the long-term radiation damage in the detector at $\sqrt{s}$=10 TeV							
Resources	1	2	3		1	2	3
Staff	**5**			Student			
Postdoc	**3.5**+**6.5**			Material			
Interested partners							
CERN, **INFN**: resources partially in place; **FNAL**, **LBL** if supported by Snowmass/P5, DOE and NSF							

Main focus on studies for $\sqrt{s}$=3 TeV

Involvement to be detailed

Main focus on studies for $\sqrt{s}$=10 TeV

Required links with other accelerator WPs

List of topics is not complete (and not all have same priority)

Strong ties needed with:

- High-energy complex
- Magnets
- Beam dynamics
- Radiation protection

MDI WP depends on resource allocation in other WPs to address the different topics

- Iterate on **lattice design**, converge on **L***
- Explore **background mitigation techniques** (e.g. combined-function magnets, chicanes, sweeping magnets)

- Estimate achievable **magnet apertures**
- Integrate shielding/masks (*synergies with heat load/radiation damage studies for magnets*)
- Quantify affordable **minimum beam clearance**

- Model **beam halo**
- Define requirements **for halo cleaning system** for background reduction (in addition to injection scraping)

- Quantify impact of **neutrino hazard mitigation techniques** (e.g. movers) on detector background

Required links with detector community

List of topics is not complete!

Detector experts

- Iteration concerning **detector envelope** (compromise between shielding requirements and detector acceptance)
- Define metric for envelope optimization

- Define (simple) figure-of-merit for first shielding optimization
- Later full detector simulation

The MDI work is mandatory to optimize environment and therefore define the detector specs

- Develop **active background mitigation techniques**, for example:
  - Time gates
  - Smart shielding (instrumented)
  - Directional suppression (e.g. BH muons)

MDI WP tasks ($\sqrt{s}$=3 TeV collider option)

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1	Task description	Resource estimate staff [FTEy]	postdoc [FTEy]	PhD [FTEy]	material [kEuro]
By 2022	Study beam-induced **background characteristics** using the **MAP $\sqrt{s}$=3 TeV** interaction region design	0.2	1		
By 2022	Define a **metric** for the determination of the **shape and dimensions of the shielding** inserted in the detector (nozzle)	0.5	1		
By 2025	Explore **further shielding strategies** (e.g. asymmetric nozzle, optimization of interaction region active elements together with detector modifications)	0.8	1		
Concurrently with other tasks	Provide estimates of the **long-term radiation damage** in the detector	0.5	1		
	Adapt experiment design and propose new detector technologies	0.5	1		

Presently one PostDoc funded for one year in **INFN Milano***

*first year was with University of Padova

Envisaged task timeline (if all resources available)

$\sqrt{s}$=3 TeV collider option – status of MDI studies

- The procedure used to verify the beam-induced background at $\sqrt{s}$ = 1.5 TeV is being used to study background at $\sqrt{s}$ = 3 TeV
- Lattice and optics from Y. Alexahin et al 2018 JINST 13 P11002

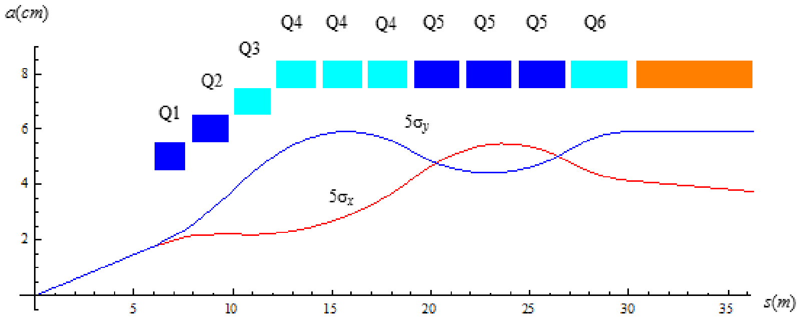


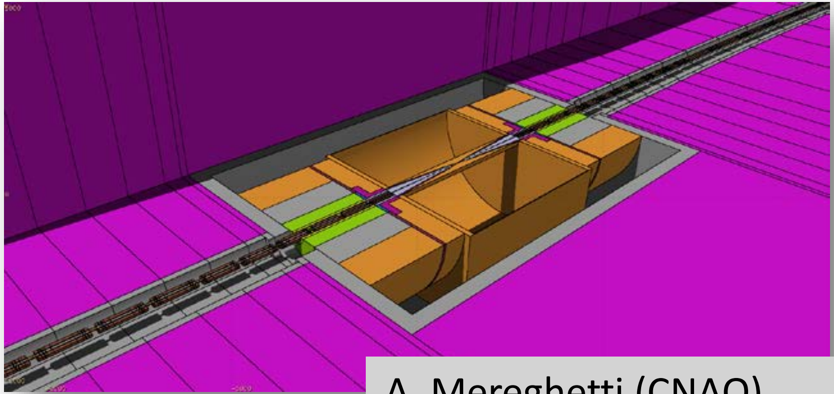
Figure 3. Quadruplet FF quadrupole apertures and 5σ beam envelopes for $E_{c.o.m.}$ = 3 TeV and β^* = 5 mm. Defocusing magnets with 2 T dipole component are shown in cyan. Beam parameters are given in the summary table of section 5.

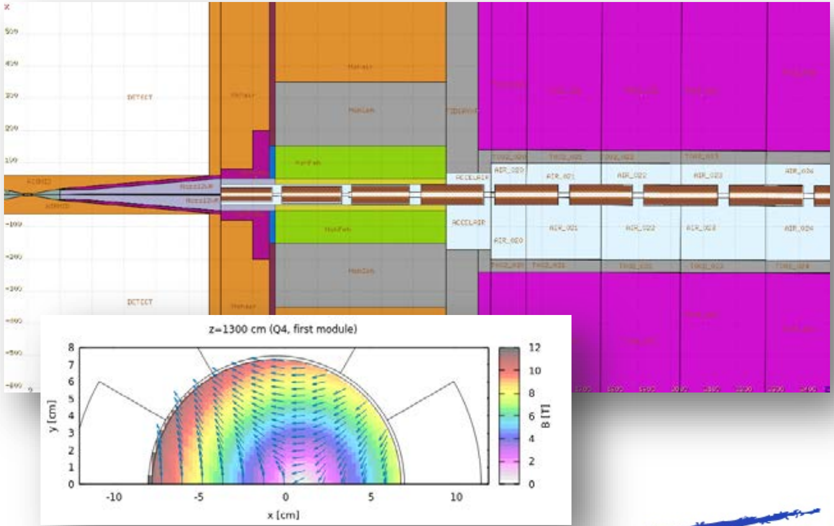
	Q1	Q2	Q3	Q4	Q5	Q6
aperture (mm)	90	110	130	150	150	150
G (T/m)	267	218	-154	-133	129	-128
B (T)	0	0	2	2	2	2
length (m)	1.6	1.85	1.8	1.96	2.3	2.85

The total field at the inner bore of the magnets is limited to 12T

$\sqrt{s}$=3 TeV collider option – status of MDI studies

- Current detector shielding is the same as for $\sqrt{s}$=1.5 TeV → optimization will be done by looking at background levels in the detector
- The beam-induced background production is in progress





A. Mereghetti (CNAO),
C. Curatolo (INFN)

MDI WP tasks ($\sqrt{s}$=10 TeV collider option)

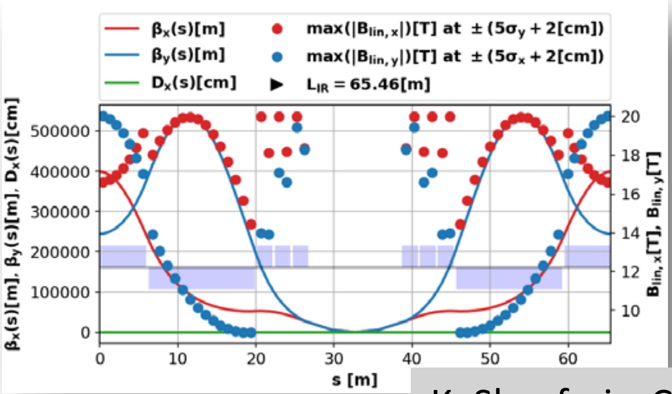
1	Task description	Resource estimate			
		staff [FTEy]	postdoc [FTEy]	PhD [FTEy]	material [kEuro]
By 2022	Develop a **first conceptual interaction region design**, which integrates a detector shielding together with the detector envelope and the final focus system.	0.4	0.35+0.35		
By 2022	Provide a **first estimate of particle fluxes for different source terms** (e.g. muon decay, incoherent electron-positron pair production, halo).	0.4	0.35+0.35		
By 2025	**Optimize the shielding design** with respect to different particle and source term contributions; **explore alternative possible background mitigation techniques** and assess the need of a halo-collimation system for background reduction.	1.0	0.35+ 1.75		
Concurrently with other tasks	Derive estimates of the **long-term radiation damage** in the detector.	0.2	0.15+0.35		
	Adapt experiment design and propose new detector technologies.	0.5	0.3+0.7		

Presently half a Fellow funded for MDI studies in **CERN-SY/STI** group

Envisaged task timeline (if all resources available)

$\sqrt{s}$=10 TeV collider option – status of MDI studies

- First optics for $\sqrt{s}$ = 10 TeV available (with L* = 6m), which is used as a starting point for MDI studies; maximum assumed magnetic field at inner bore is 20 T
- First interaction region model is being implemented in FLUKA → soon ready to start some parametric shielding studies



K. Skoufaris, C. Carli
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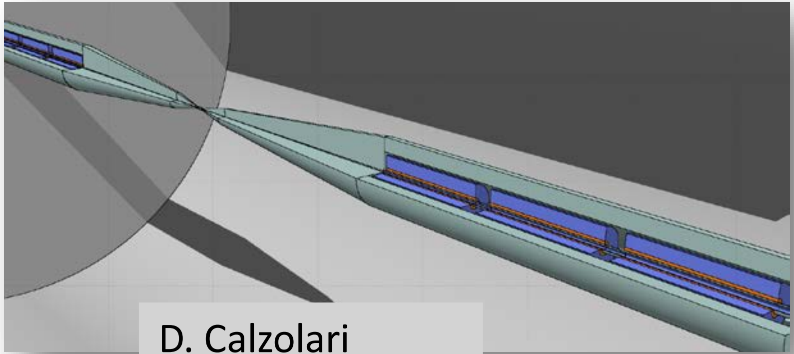
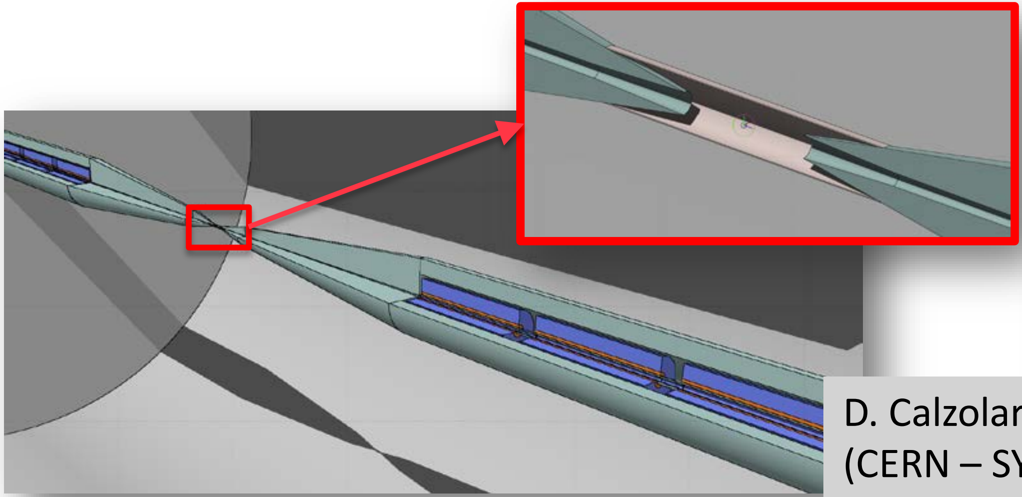
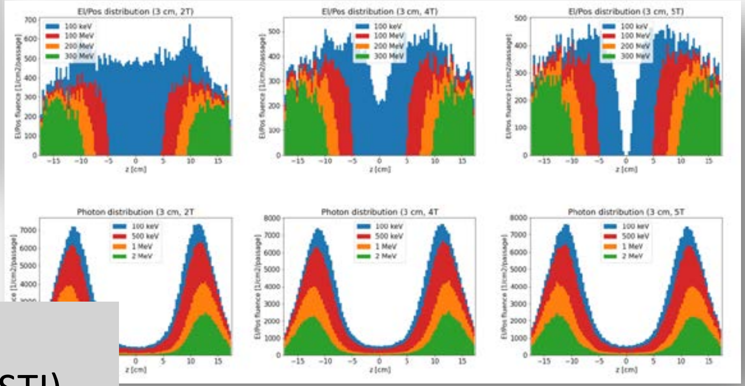


D. Calzolari
(CERN – SY/STI)

$\sqrt{s}$=10 TeV collider option – status of MDI studies

- Started first-order evaluation of background induced by incoherent electron-positron pair production at $\sqrt{s}$=10 TeV
- Source distribution from GUINEA-PIG (distribution provided by D. Schulte)
- Next step: comparison to muon decay background





D. Calzolari
(CERN – SY/STI)

Conclusion

- By end of 2022, aim to have a **first level IR optimization**
  - 3 TeV option: start optimizing the IR design starting from MAP layout
  - 10 TeV option: obtain a first IR design, first quantification of background
- By 2025, aim to have a **mature IR design**
  - Demonstrate the feasibility of reaching the detector performance goals for both collider options
- Meetings (aim for monthly frequency)
  - Common discussions concerning both collider options
  - Will invite contact persons from other WPs (if topic is of common interest)
- Maintain close connection/collaboration with US colleagues involved via the Snowmass process

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Thank you for your attention