RD_MUCOL @ CSN1

International MUON Collider Collaboration

INFN

multi-TeV Muon Collider

Incontro Referee – CSN1 – 14 Settembre 2021

International MUON Collider Collaboration

INFN and the International Community

Since 2021: RD_MUCOL (@ CSN1) ~15-17 FTE / 90-100 phys/eng in 13 sections

Synergies in EU projects: aMUSE, AIDAinnova, I.FAST

CONTEXT:

- **Laboratory Directors' Group (LDG) initiated a muon collider collaboration July 2, 2020**
- CERN Medium Term Plan 2021-2025 - dedicated budget line – 2MCHF/year

mainly to cover machine up to MDI activities: (5 FTE staff, 6 fellows, 4 students, 1 associate)/year

- International Design Study based at CERN ➔ **MoC signed by INFN**

the project encompasses physics, machine, detector and Machine Detector Interface

- European LDG Accelerator R&D Roadmap by fall 2021

dedicated Muon Beams Panel - but also High field magnets, RF and ERL

- European ECFA Detector R&D Roadmap by fall 2021

Muon collider @ 10 TeV is considered as one of the targeted facilities emerging from the EPPSU

- US SnowMass Muon Collider Forum since 2021

share ideas and studies across frontiers

- Snowmass/P5 process in the US by spring 2023 **RESTARTED ➔ Documents by 15 March '22**

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Responsabilità

Third Community Meeting 6-8 Ottobre 2021
https://indico.cern.ch/event/1062146/

Conveners of the 11 working groups:

Radio-Frequency (RF): *Alexej Grudiev (CERN), Jean-Pierre Delahaye (CERN retiree), Derun Li (LBNL), Akira Yamamoto (KEK).*

Magnets: *Lionel Quettier (CEA), Toru Ogitsu (KEK), Soren Prestemon (LBNL), Sasha Zlobin (FNAL), Emanuela Barzi (FNAL).*

High-Energy Complex (HEC): *Antoine Chance (CEA), J. Scott Berg (BNL), Alex Bogacz (JLAB), Christian Carli (CERN), Angeles Faus-Golfe (IJCLab), Eliana Gianfelice-Wendt (FNAL), Shinji Machida (RAL).*

Muon Production and Cooling (MPC): *Chris Rogers (RAL), Marco Calviani (CERN), Chris Densham (RAL), Diktys Stratakis (FNAL), Akira Sato (Osaka University), Katsuya Yonehara (FNAL).*

Proton Complex (PC): *Simone Gilardoni (CERN), Hannes Bartosik (CERN), Frank Gerigk (CERN), Natalia Milas (ESS).*

Beam Dynamics (BD): *Elias Metral (CERN), Tor Raubenheimer (SLAC and Stanford University), Rob Ryne (LBNL)*

Radiation Protection (RP): *Claudia Ahdida (CERN)*

Parameters, Power and Cost (PPC): *Daniel Schulte (CERN), Mark Palmer (BNL), Philippe Lebrun (CERN retiree and ESI), Mike Seidel (PSI), Vladimir Shiltsev (FNAL), Jingyu Tang (IHEP)*

Machine Detector Interface (MDI): *Donatella Lucchesi (University of Padova and INFN), Christian Carli (CERN), Anton Lechner (CERN), Nicolai Mokhov (FNAL), Nadia Pastrone (INFN), Sergo R Jindariani (FNAL)*

Synergy: *Kenneth Long (Imperial College), Roger Ruber (Uppsala University), Koichiro Shimomura (KEK)*

Test Facility (TF): *Roberto Losito (CERN), Alan Bross (FNAL), Tord Ekelof (Uppsala University)*

+++ 3 WG Physics – Detector – Software + R&D

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International Collaboration

Project Leader: *Daniel Schulte*

Objective:
In time for the next European Strategy for Particle Physics Update, the Design Study based at CERN since 2020 aims to **establish whether the investment into a full CDR and a demonstrator is scientifically justified**.
It will **provide a baseline concept**, well-supported performance expectations and assess the associated key risks as well as cost and power consumption drivers.
It will also **identify an R&D path to demonstrate the feasibility of the collider**.

Web page: http://muoncollider.web.cern.ch

Scope:
- Focus on the high-energy frontier and two energy ranges:
– **3 TeV** if possible with technology ready for construction in 10-20 years
– **10+ TeV** with more advanced technology, **the reason to choose muon colliders**
- Explore synergies with other options (neutrino/higgs factory)
- Define **R&D path**

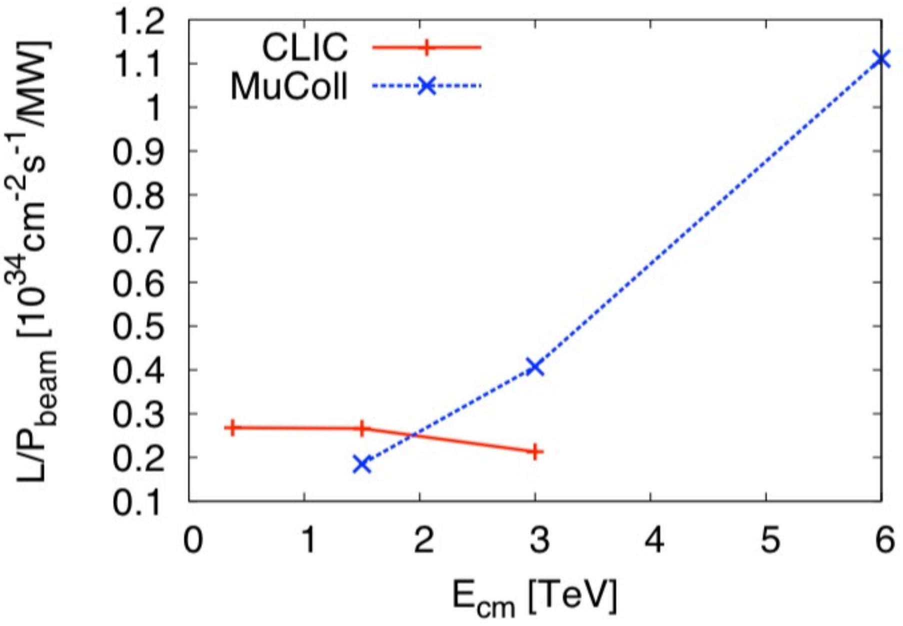
A unique facility

nature physics

Muon colliders to expand frontiers of particle physics

an idea over 50 years old has now the opportunity to become feasible

ESPP Input document: Muon Colliders



Overwhelming physics potential:

- **Precision measurements**
- **Discovery searches**

Challenging Facility Design:

- **Key issues/risks**
- **R&D plan - synergies**

Physics potential

D. Lucchesi, A. Wulzer, F. Maltoni et al

Muon Collider Physics and Detector Workshop

A dream machine to probe unprecedented energy scales and many different directions at once!

Direct searches
Pair production, Resonances, VBF, Dark Matter, …

High-rate measurements
Single Higgs, self coupling, rare and exotic Higgs decays, top quarks, …

High-energy probes
Di-boson, di-fermion, tri-boson, EFT, compositeness, …

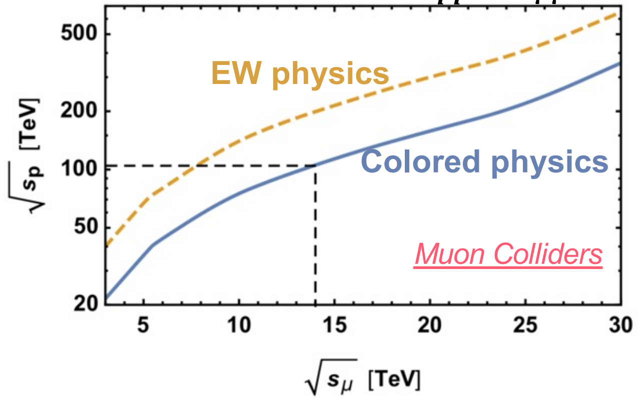
Muon physics
Lepton Flavor Universality, b → sμμ, muon g-2, …

Great and growing interest in the theory community ➔ many papers recently published

Strong and crucial synergies to design the machine and the experiment to reach the physics goals with energy and luminosity allowing % precision measurements

➔ **Physics benchmarks steer machine parameters and experiment design**

Energy at which $\sigma_{pp} = \sigma_{\mu\mu}$



Physics potential

Muon Collider can be the game changer!

D. Buttazzo

- Theory input needed: define energy, luminosity and detector performance goals — physics potential of a multi-TeV muon collider
- Great interest in the theory community:

1807.04743 2005.10289 2008.12204 2012.11555 2102.11292 2104.05720
1901.06150 2006.16277 2009.11287 2101.10334 2103.01617 etc ...
2003.13628 2007.14300 2012.02769 2102.08386 2103.14043

R. Sundrum

CONCLUSIONS

There are BROAD EXCITING PHYSICS THEMES to pursue at future colliders:
Dark Matter, Baryogenesis, SUSY, Compositeness, flavor origins, parallel gauge sectors, long-lived particles, precision Higgs structure

Need a collider at highest energies, clean enough & with sensitive enough detectors, to pursue both high mass &/or weakly coupled BSM at high precision & to excite & challenge next generation of experimentalists.

If new physics (dimly) seen in DM, flavor, EDM, precision, gravitational wave, cosmological expts., we need collider with reach/precision to complement, corroborate, clarify

A Muon Collider is great!

κ-0 fit	HL-LHC	LHeC	HE-LHC S2	HE-LHC S2′	ILC 250	ILC 500	ILC 1000	CLIC 380	CLIC 1500	CLIC 3000	CEPC	FCC-ee 240	FCC-ee 365	FCC-ee/eh/hh	$\mu^+\mu^-$ 10000
κ_W [%]	1.7	0.75	1.4	0.98	1.8	0.29	0.24	0.86	0.16	0.11	1.3	1.3	0.43	0.14	0.06
κ_Z [%]	1.5	1.2	1.3	0.9	0.29	0.23	0.22	0.5	0.26	0.23	0.14	0.20	0.17	0.12	0.23
κ_g [%]	2.3	3.6	1.9	1.2	2.3	0.97	0.66	2.5	1.3	0.9	1.5	1.7	1.0	0.49	0.15
κ_γ [%]	1.9	7.6	1.6	1.2	6.7	3.4	1.9	98⋆	5.0	2.2	3.7	4.7	3.9	0.29	0.64
$\kappa_{Z\gamma}$ [%]	10.	–	5.7	3.8	99⋆	86⋆	85⋆	120⋆	15	6.9	8.2	81⋆	75⋆	0.69	1.0
κ_c [%]	–	4.1	–	–	2.5	1.3	0.9	4.3	1.8	1.4	2.2	1.8	1.3	0.95	0.89
κ_t [%]	3.3	–	2.8	1.7	–	6.9	1.6	–	–	2.7	–	–	–	1.0	6.0
κ_b [%]	3.6	2.1	3.2	2.3	1.8	0.58	0.48	1.9	0.46	0.37	1.2	1.3	0.67	0.43	0.16
κ_μ [%]	4.6	–	2.5	1.7	15	9.4	6.2	320⋆	13	5.8	8.9	10	8.9	0.41	2.0
κ_τ [%]	1.9	3.3	1.5	1.1	1.9	0.70	0.57	3.0	1.3	0.88	1.3	1.4	0.73	0.44	0.31

P. Maede

Di-Higgs too!

Double Higgs production

- Reach on Higgs trilinear coupling: hh → 4b

B, Franceschini, Wulzer 2012.11555
Costantini et al. 2005.10289
Han et al. 2008.12204

E [TeV]	$\mathscr{L}$ [ab⁻¹]	N_{rec}	$\delta\sigma \sim N_{rec}^{-1/2}$	$\delta\kappa_3$
3	5	170	~ 7.5%	~ 10%
10	10	620	~ 4%	~ 5%
14	20	1340	~ 2.7%	~ 3.5%
30	90	6'300	~ 1.2%	~ 1.5%

The Muon Smasher's Guide

Abstract

We lay out a comprehensive physics case for a future high-energy muon collider, exploring a range of collision energies (from 1 to 100 TeV) and luminosities. We highlight the advantages of such a collider over proposed alternatives. We show how one can leverage both the point-like nature of the muons themselves as well as the cloud of electroweak radiation that surrounds the beam to blur the dichotomy between energy and precision in the search for new physics. The physics case is buttressed by

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Luminosity and parameters goals

Target integrated luminosities

$\sqrt{s}$	$\int \mathcal{L}dt$
3 TeV	1 ab^{-1}
10 TeV	10 ab^{-1}
14 TeV	20 ab^{-1}

Note: currently no staging
Would only do 10 or 14 TeV

- Tentative parameters achieve goal in 5 years
- FCC-hh to operate for 25 years
- Might integrate some margins
- Aim to have two detectors

Now study if these parameters lead to realistic design with acceptable cost and power

Tentative target parameters
Scaled from MAP parameters

Comparison:
CLIC at 3 TeV: 28 MW

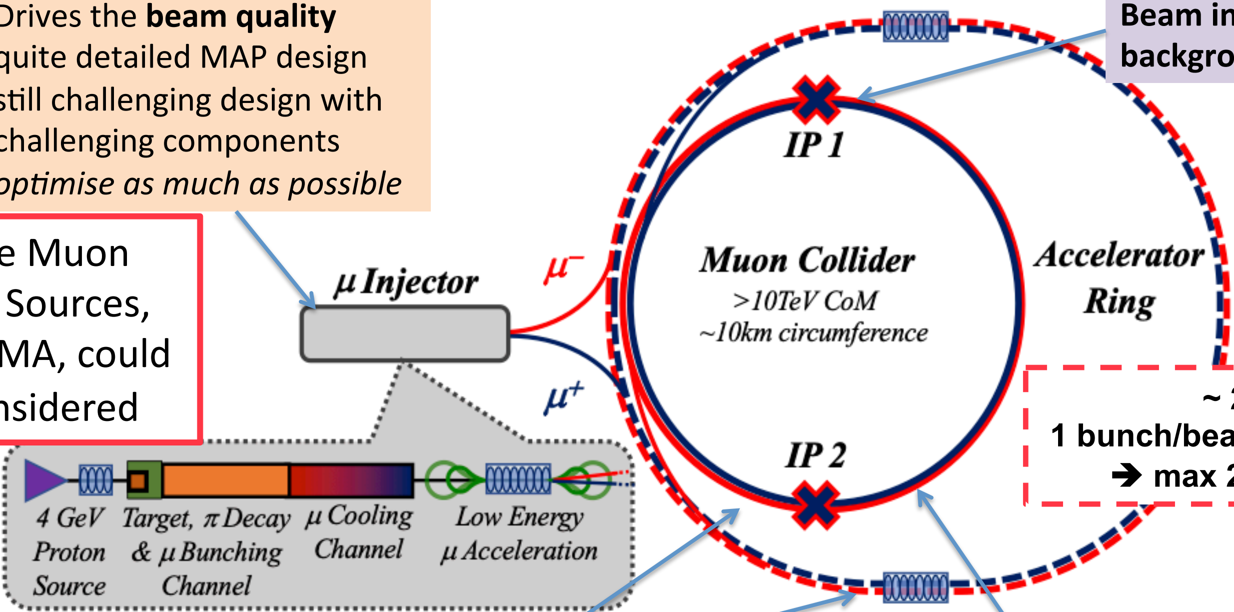
Parameter	Unit	3 TeV	10 TeV	14 TeV
L	10^{34} $cm^{-2}s^{-1}$	1.8	20	40
N	10^{12}	2.2	1.8	1.8
f_r	Hz	5	5	5
P_{beam}	MW	5.3	14.4	20
C	km	4.5	10	14
<B>	T	7	10.5	10.5
ε_L	MeV m	7.5	7.5	7.5
σ_E / E	%	0.1	0.1	0.1
σ_z	mm	5	1.5	1.07
β	mm	5	1.5	1.07
ε	μm	25	25	25
$\sigma_{x,y}$	μm	3.0	0.9	0.63

Sketch of the facility baseline

Drives the **beam quality**
quite detailed MAP design
still challenging design with
challenging components
optimise as much as possible

Alternative Muon production Sources, such as LEMMA, could be also considered

Beam induced background



~ $2\times10^{12}\mu/bunch$
1 bunch/beam colliding each 20-30 μs
➔ max 2 Interaction Points - IP

Dense neutrino flux
mitigated by mover system and site selection

Cost and **power** consumption drivers, limit energy reach
e.g. 30 km accelerator for 10/14 TeV, 10/14 km collider ring
Also impacts **beam quality**

Main considerations

Muon collider can be **cost effective** ➔ need to do a real study to confirm
– cost scaling model predicts it (~ 1.5 x LHC)
– considerations on the facility scale indicate this

Muon collider can be **power efficient** ➔ need a more detailed study to confirm
– the luminosity per beam power increases with collider energy

Muon collider can use a **compact site**
– the 10 TeV collider would have a tunnel length between CLIC 3 TeV and FCC
– could become even more compact with better ramping magnets

Three scenarios require the muon collider to start operation in Europe before 2045
– ILC is being constructed
– CepC is being constructed
– No Higgs factory is being constructed before

➔ **Need to have a muon collider option ready for operation before 2045!**

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Key Performance Drivers

High impact systems
- Neutrino flux mitigation system
- High-field magnets
- Fast ramping magnets and power systems
- Normal conducting cooling RF
- Superconducting RF
- RF power systems
- Target and dump
- Beam loss protection
- Vacuum, instrumentation, cryogenics and others also contribute

Drivers of functional specifications
- Radiation protection
- Machine detector interface
- Beam dynamics

Key Cost Drivers

High cost systems
- High-field magnets
- Fast ramping magnets and power systems
- Superconducting RF
- RF power systems
- Target and dump
- Civil engineering
- Others also contribute

Drivers of cost via specifications
- Beam dynamics
- Beam loss protection
- Radiation protection
- Normal conducting cooling RF

Key Power Drivers

Key power consumers
- High-field magnets
- Fast ramping magnets and power systems
- Superconducting RF
- Normal conducting RF
- RF power systems
- Others also contribute

Drivers of power via specifications
- Beam dynamics

Staged approach and workload

3 TeV collider: physics potential comparable to CLIC at 3 TeV

- option that could be realized much faster than a 10 TeV option:
  - It is cheaper, much more compact with a smaller power consumption
  - It can accept more compromises in technology performance

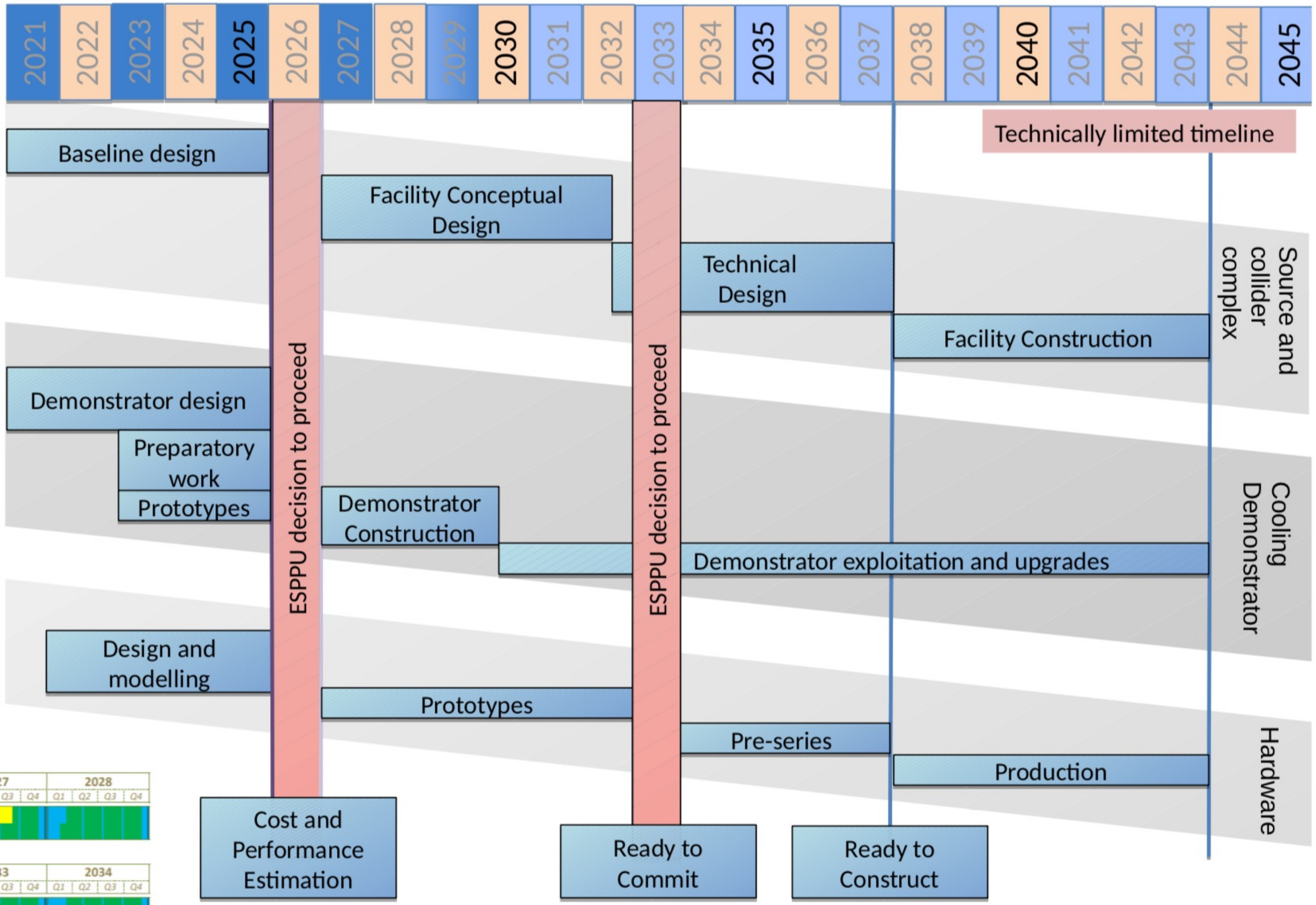
e.g. current ring magnets are comparable in performance to HL-LHC magnets

10 TeV collider

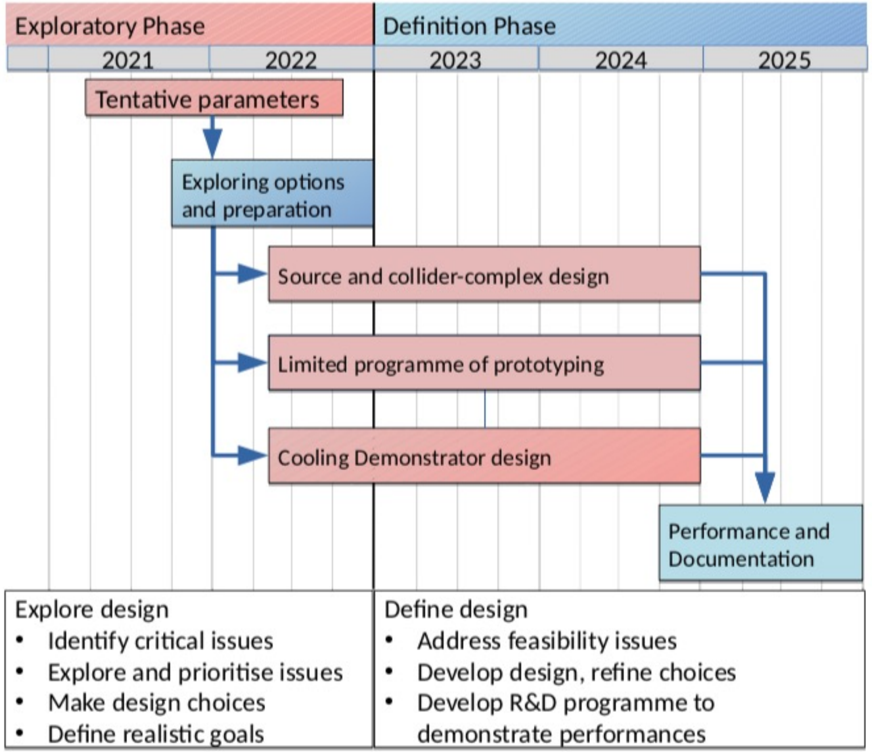
- could then be realized using almost all infrastructure from 3 TeV, but collider ring

- 3 and 10 TeV collider designs share all systems
  - except collider ring and 1.5 to 5 TeV accelerator rings
  - limited lattice design work – more work for MDI
- Some technology challenges are more important at 10 than at 3 TeV
  - higher dipoles fields in collider (O(15 T)) – stronger final focus quadrupoles (O(18-20 T))
  - shorter bunches in cavities of last accelerator ring
  - would like more performance accelerator ring systems to cut length and cost
- **Total additional effort seems acceptable given the importance**

Technically limited timeline



Plan for next 5 years



- **End-to-end design with all systems**
- **Key performance specifications**
- **Evidence to achieve luminosity goal:**

– beam parameters, collective effects, tolerances …

- **Evidence that the design is realistic:**

– performance specification supported by technology
– key hardware performances
– radiation protection, impact and mitigation of losses
– cost and power scale, site considerations

- **A path forward**

– Test facility
– Component development
– Beam tests
– System optimisation

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Test facility needs

- High energy complex requires known components
  → synergies with other future colliders

- **Production and cooling complex is novel and unique to the muon collider**
  - Many components are unconventional
    - ✓ e.g. high-gradient cavities in magnetic field with Be windows or filled with gas
    - ✓ massive use of absorbers in the beam path
  - Novel technologies beyond MAP design can be considered
    - ✓ e.g. very short RF pulse to reduce breakdown probability
  - Compact integration is required to maximise muon survival
    - ✓ complex lattice design optimisation
  - Almost no experience with beam in these components, MICE has been a limited model (no RF, single muons)

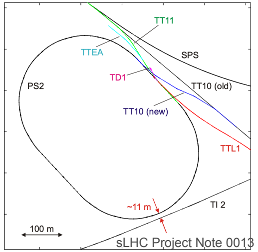
Test Facility is needed where muons are produced and cooled

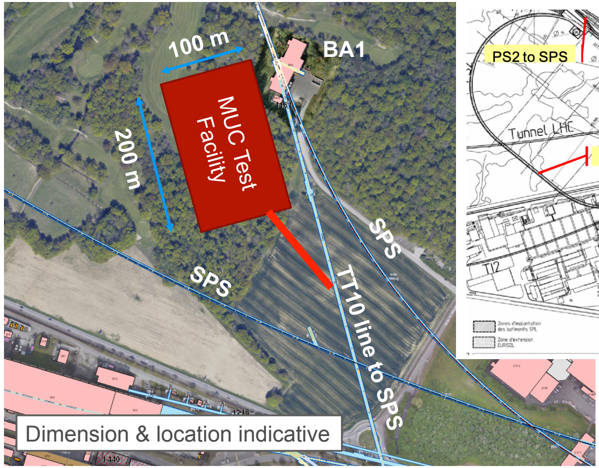
Demonstrator and test facilities

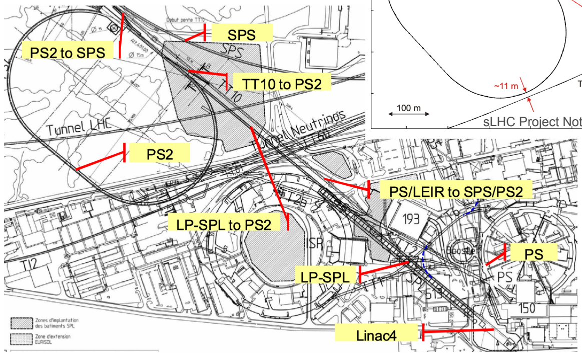
(Muon production) and Cooling Demonstrator @ CERN

Strong synergies with nuSTORM and ENUBET

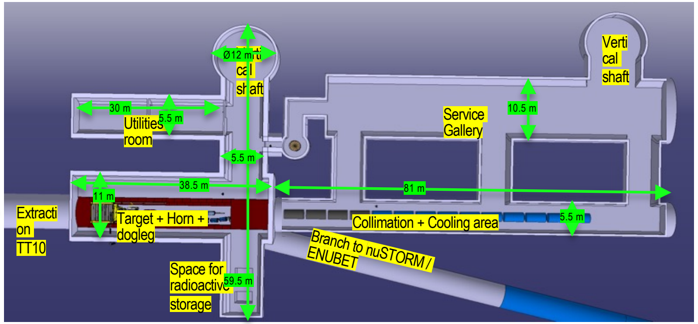
It could be close to TT10, and inject beam from PS
It would be on molasse, no radiation to ground water







M. Benedikt, LHC Performance Workshop, Chamonix 2010
CERN-AB-2007-061

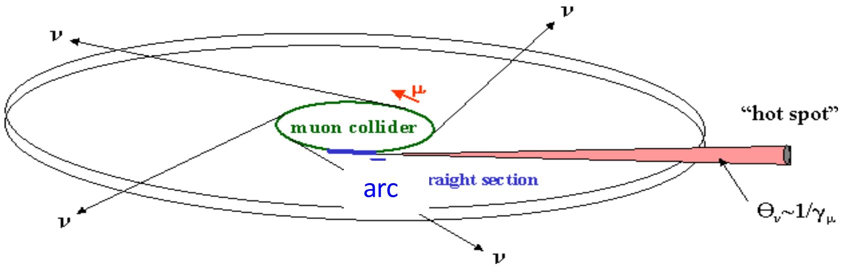


First attempt to design a site
Great opportunity to contribute

Test facilities for enabling tecnologies:
RF, Magnets, Target materials…..

Strong synergies with other future projects

Neutrino Flux Mitigation



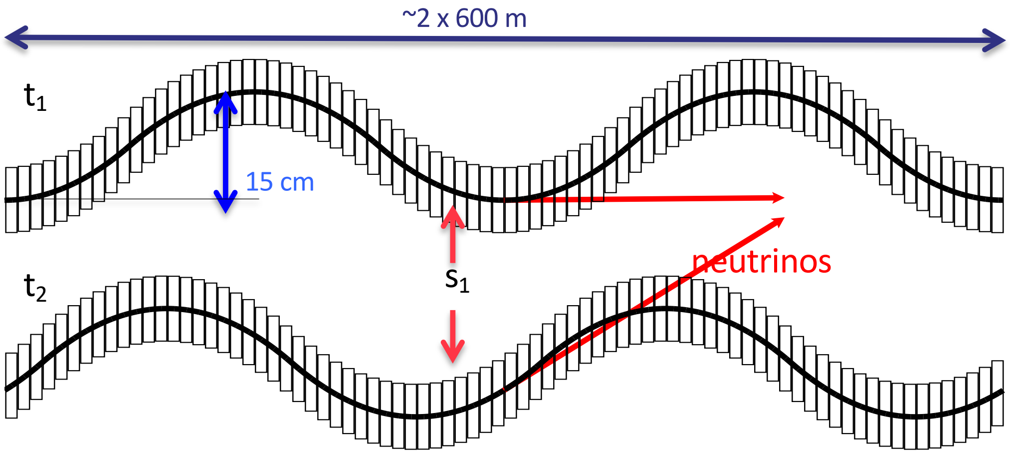
Legal limit 1 mSv/year
MAP goal < 0.1 mSv/year
Our goal: arcs below threshold for legal procedure < 10 μSv/year
LHC achieved < 5 μSv/year

3 TeV, 200 m deep tunnel is about OK

Need mitigation of arcs at 10+ TeV:
idea of Mokhov, Ginneken to move beam in aperture
our approach: move collider ring components, e.g. vertical bending with 1% of main field

Opening angle ± 1 mradian

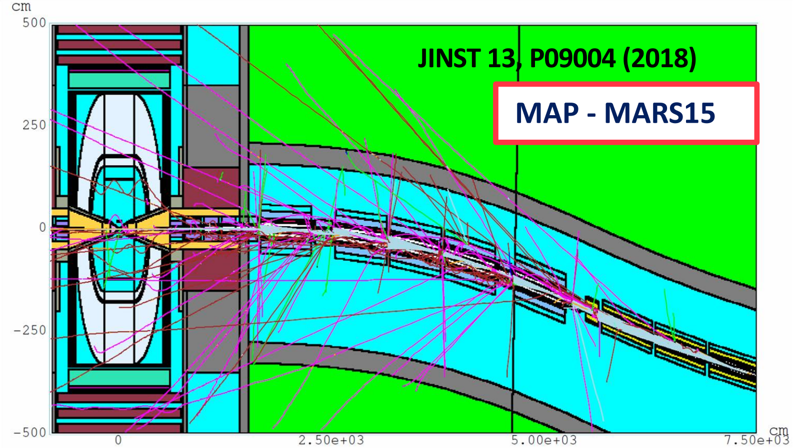
14 TeV, in 200 m deep tunnel comparable to LHC case



Need to study mover system, magnet, connections and impact on beam

Working on different approaches for experimental insertion

Machine-Detector Interface

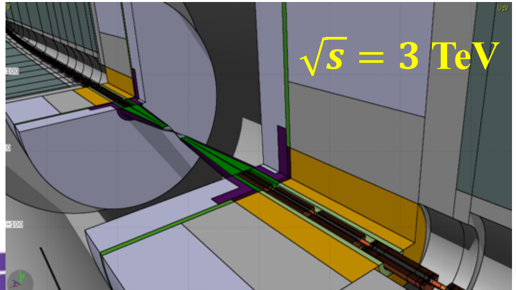


- Study Beam-Induced Background at $\sqrt{s} = 3$ TeV, use MAP IR and the nozzle of $\sqrt{s} = 1.5$ TeV, then
  - Optimize nozzle
  - Optimize IR

- Detector studies are just at the first step, a lot of room for improvements!
- Physics objects performance are very good even if not optimize, room for improvements in particular with ML techniques
- Dedicated studies and optimization is needed for the forward region, covered by the nozzle

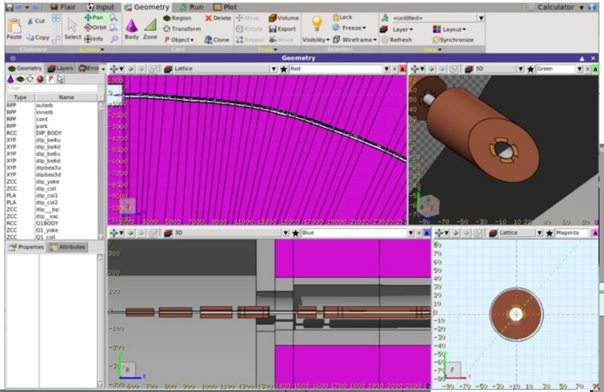
For each collider energy the machine elements, the MDI and interaction region have to be properly designed and optimized

Studies just READY @ 3 TeV to be optimized !!

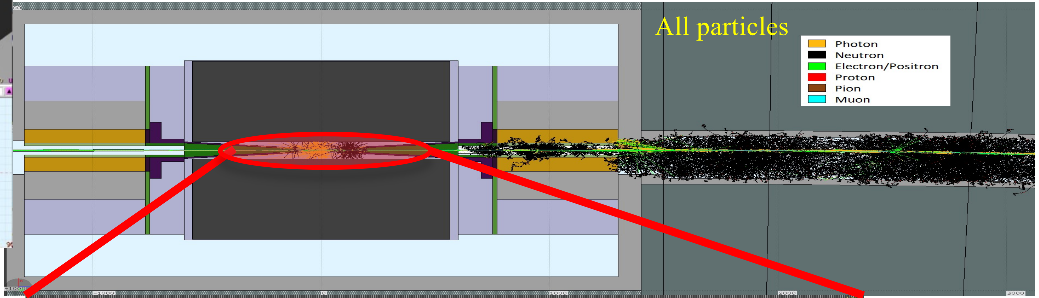


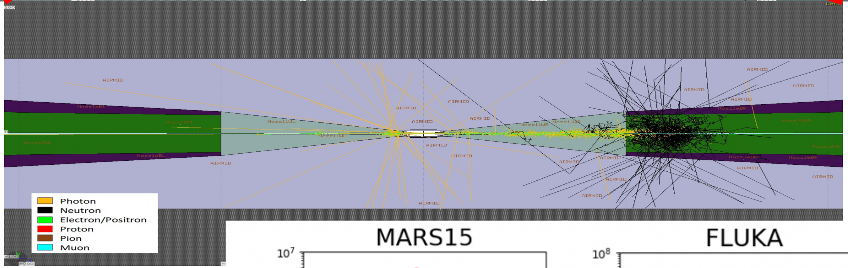
Machine-Detector Interface Studies

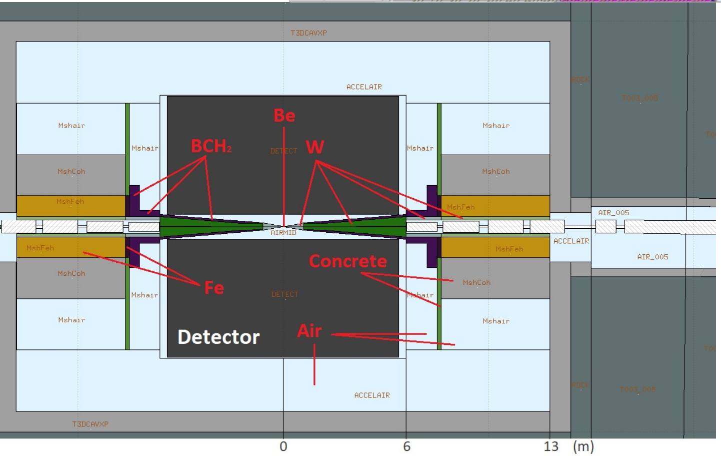
F. Collamati, C. Curatolo, D. Lucchesi, A. Mereghetti, P. Sala

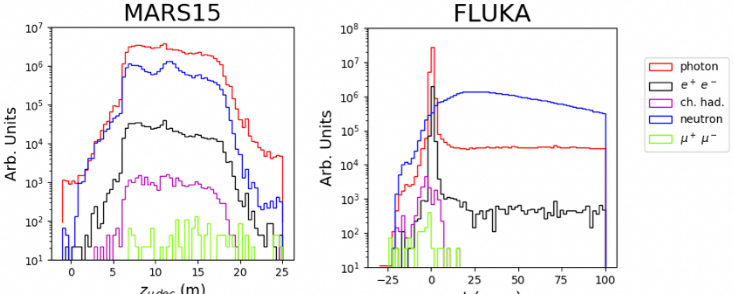


LineBuilder + FLUKA simulation









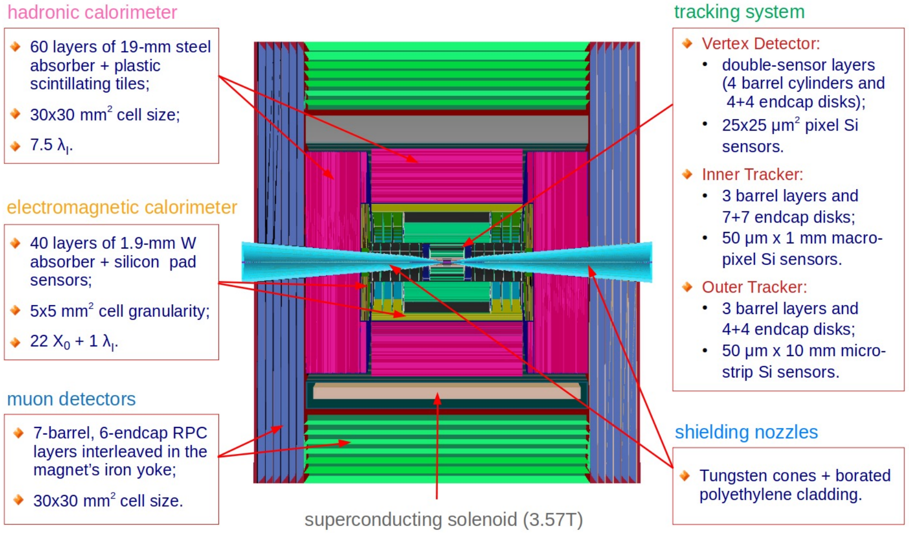
Advanced assessment of Beam Induced Background at a Muon Collider

Experiment design @ $\sqrt{s}$ =1.5 TeV

https://muoncollider.web.cern.ch/design/muon-collider-detector

- CLIC Detector technologies adopted with important modifications to cope with BIB
- Detector design optimization at $\sqrt{s}$=1.5 (3) TeV

TO BE IMPROVED and TUNED at higher $\sqrt{s}$



B = 3.57 T to be studied and tuned

D. Lucchesi, A. Wulzer P&D coordinator
L. Sestini calorimeter & jets reconstruction coordinator
M. Casarsa tracking coordinator
C. Riccardi muon reconstruction coordinator
A. Gianelle and **P. Andreetto** International Collaboration code and framework development and maintenance coordinators

Strong contribution from Germany, US (several institutes)

Software and computing

P. Andreetto, A. Gianelle

MuonCollider Software based on ILCSoftware, heavily modified to meet dedicated requests.

- GRID submission possible, to be finalized
- Code distributed via CVMFS
- SE at CNAF
- Major part of the resources on CloudVeneto, VM can be configured as needed
- Fermilab and LBL mirror sites for Snowmass
- No contribution from CERN for the moment

Information on INFN Software Site

Contacts us: muon_collider_software@lists.infn.it

- Best practices
- Installation
- Releases notes
- Tutorial
    - Docker Setup

Jira issues

Repository

Official ILCSoft packages can be found here

Github repository for MuonCollider packages is here

Docker distribution

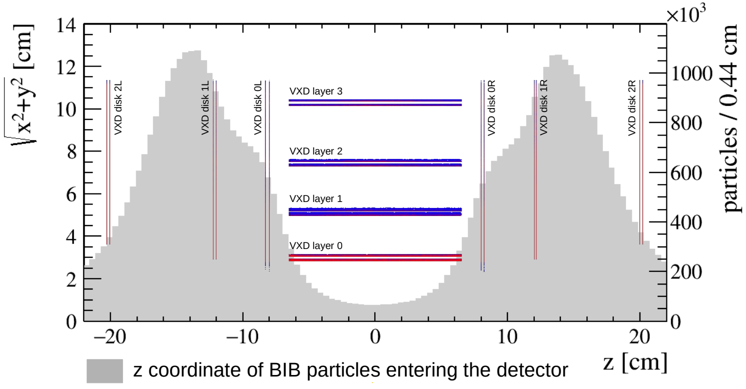
Docker images for the Muon Collider software are available at DockerHub,

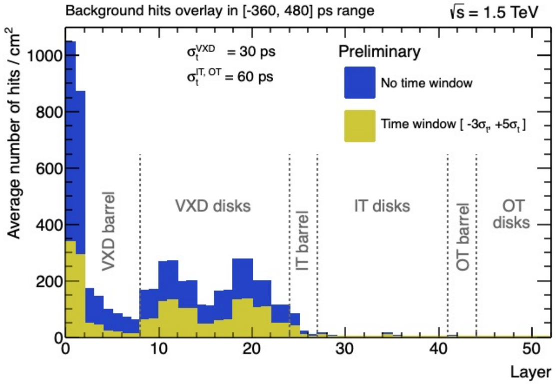
1. **v02-01-pre** → docker pull infnpd/mucoll-ilc-framework:1.0-centos8
2. **v02-02-MC** → docker pull infnpd/mucoll-ilc-framework:1.1-centos8
3. **v02-03-MC** → docker pull infnpd/mucoll-ilc-framework:1.2-centos8
4. **v02-04-MC** → docker pull infnpd/mucoll-ilc-framework:1.3-centos8
5. **v02-05-MC** → idocker pull nfnpd/mucoll-ilc-framework:1.4-centos8
6. **v02-06-MC** → idocker pull nfnpd/mucoll-ilc-framework:1.5-centos8

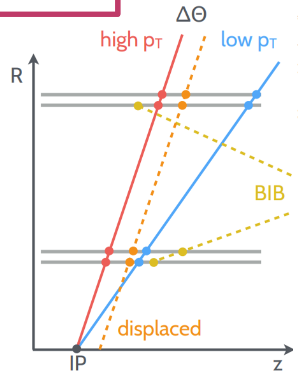
Tracker detector @ 1.5 TeV

N. Bartosik, M. Casarsa

Max radiation tolerance NIEL: 0.5x 1016 neq/cm^2/year
Max radiation tolerance TID: 300 Mrad/year







- Vertex detector properly designed to not overlap with the BIB hottest spots around IR
- Timing window applied to reduce hits from out-of-time BIB
- Granularity optimized to ensure $\lesssim$ 1% occupancy
- Realistic digitization in progress ➔ BIB suppression based on cluster shape
- If primary vertex could be known before ➔ effective angular matching of hit doublets
- To be tuned in presence of secondary vertices or long-lived particles

Calorimeters and Muon detectors

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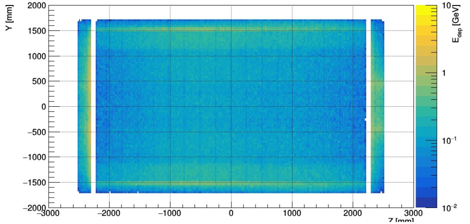
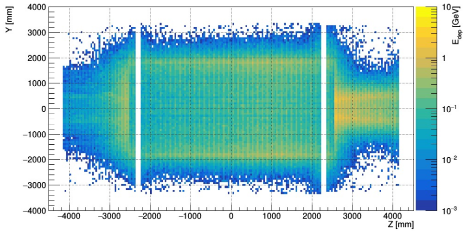
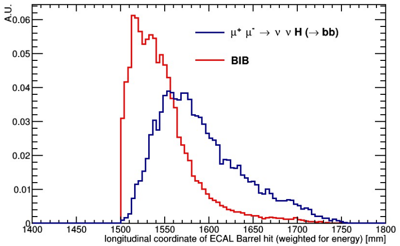
timing and longitudinal measurements play a key role in the BIB suppression

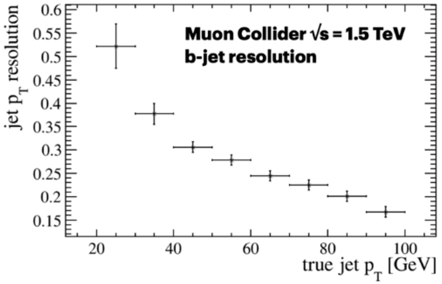
Calorimeters

BIB deposits large amount of energy in both ECAL and HCAL







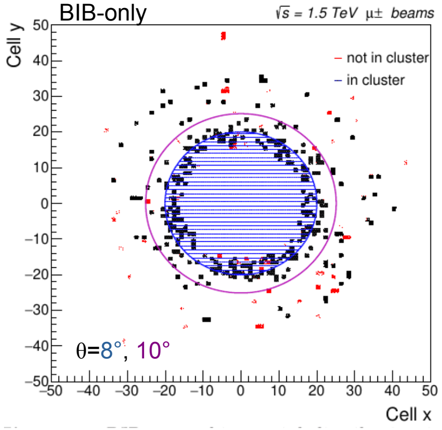


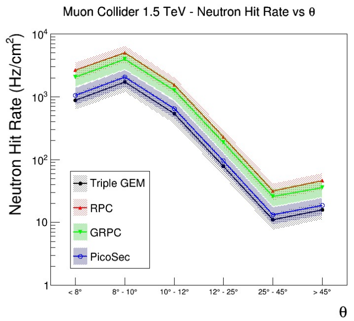
Innovative and computationally efficient event-reconstruction approaches are needed

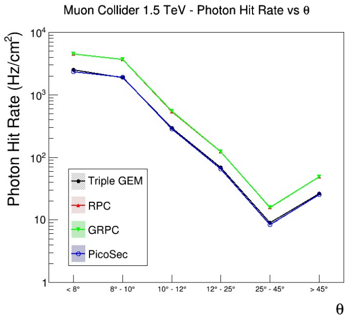
Muon System

Low BIB contribution, concentrated in the low-radius endcap region

C. Aimè, C. Riccardi, P. Salvini, Ilaria Vai, N. Valle



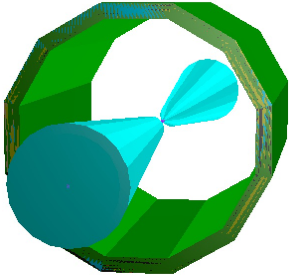




Investigating new technologies for R&D

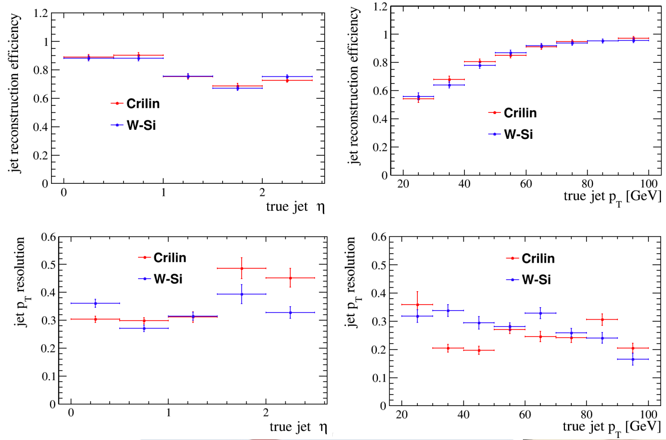
CRILIN: alternative ECAL barrel design

L. Sestini, I. Sarra



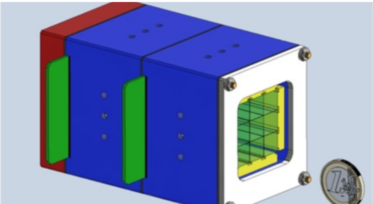
Implemented in Muon Collider simulation framework (DD4HEP)

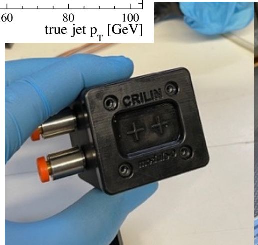
5 layers: 40 mm length, 10X10 mm^2 cell area. Dodecahedra geometry

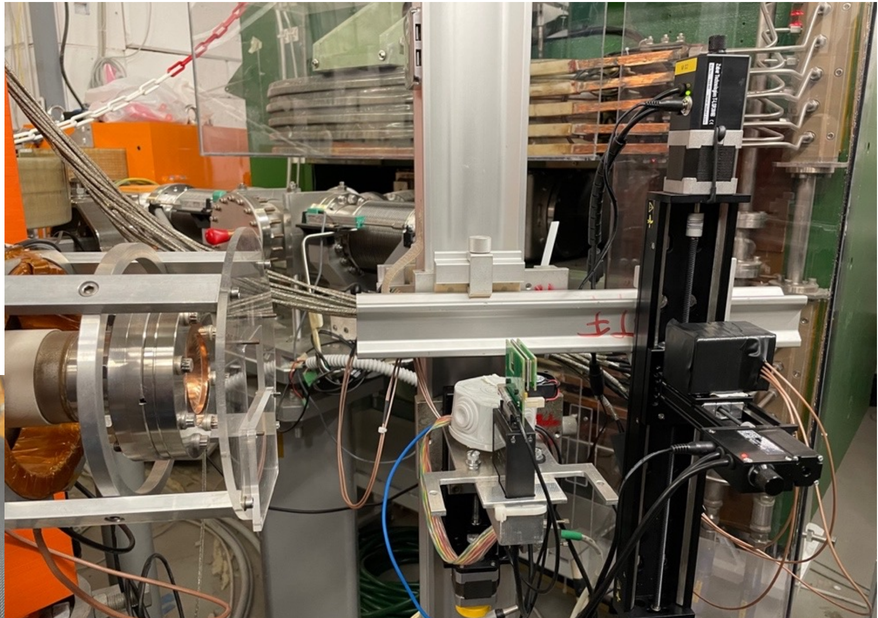


Module0 at BTF

I. Sarra et al.



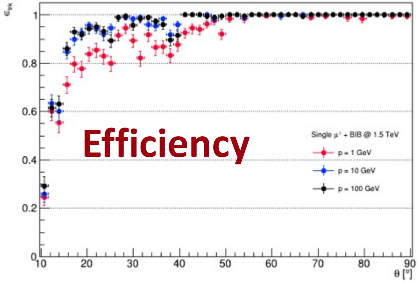


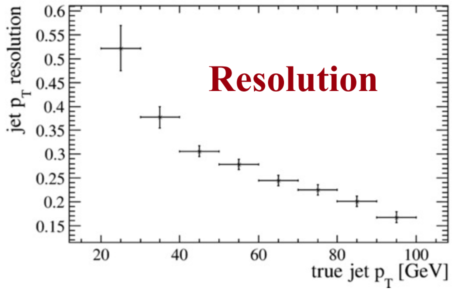


Tracking and Jet Reconstruction Performance

M. Casarsa L. Sestini

Optimized detectors & algorithm needed

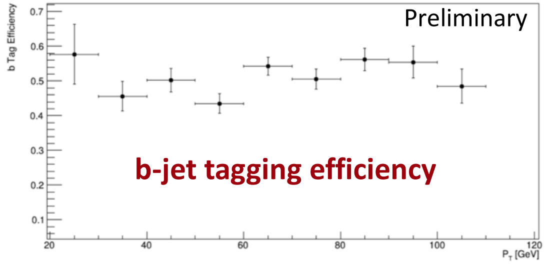


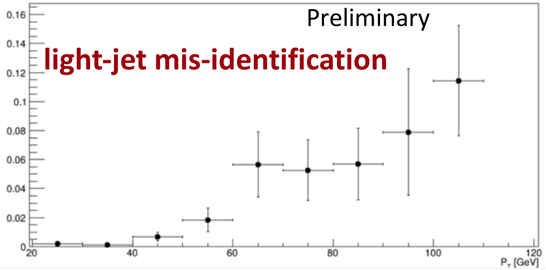


- In the nozzle region:
- Efficiency drops
- Momentum resolution degrades

b-jet secondary vertex Reconstruction

L. Buonincontri, L. Giambastiani, G. Dal Molin,
L. Sestini, R. Venditti, M. Mastrapasqua



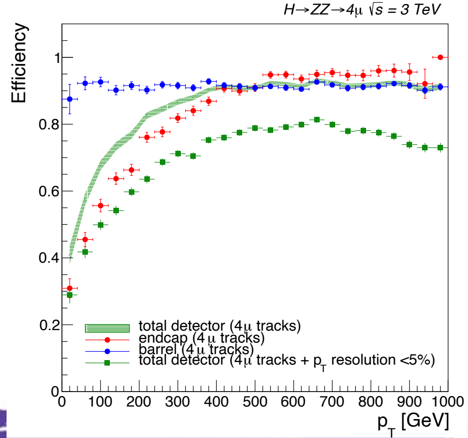


b-jet identification

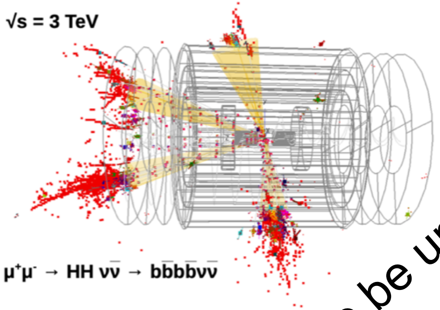
- Tracks selected by the regional tracking
- First step toward a b-jet tagging, under development a ML-based algorithm, in progress

Muon Reconstruction Performance

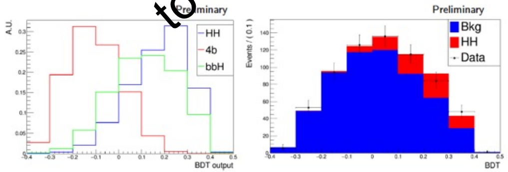
C. Aimè, C. Riccardi, P. Salvini, Ilaria Vai,
N. Valle, A. Zaza, R. Venditti

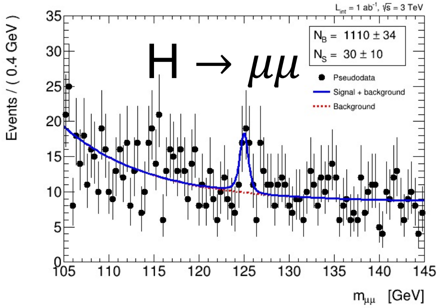


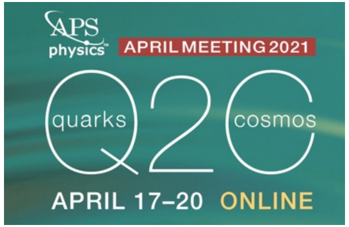
A lot of progress and new studies



to be updated







4 Sessions – 30 talks
Muon Collider Symposium

Ready for EPS2021

EPS2021 Posters and Talks

Tuesday 13 Jul 2021, 09:00 → 19:00 Europe/Zurich

09:00 → 09:20 **Dark-SUSY channels to study muon reconstruction performance at the Muon** — 20m
Speaker: Chiara Aime' (Pavia University and INFN (IT))
Poster_EPS.pdf

09:20 → 09:40 **Design a calorimeter system for the Muon Collider experiment** — 20m
Speaker: Lorenzo Sestini (Universita e INFN, Padova (IT))
poster_mucoll_calo....

09:40 → 10:00 **Prospects for the measurement of σH x BR(H → μμ) at a 3-TeV muon collider** — 20m
Speaker: Alessandro Montella (University of Trieste and INFN-Trieste)
hmumu_mucoll_eps...

10:00 → 10:20 **Study of Beam Induced background at muon collider** — 20m
Speaker: Francesco Collamati (INFN Roma I (IT))

10:20 → 10:40 **Tracking and track reconstruction at a muon collider in the presence of beam-induced background** — 20m
Speaker: Hannsjorg Weber (Humboldt University of Berlin (DE))
haweber_EPS2021....

10:40 → 11:00 **Tracking with ACTS for a Muon Collider detector** — 20m
Speaker: Karol Krizka (Lawrence Berkeley National Lab. (US))
tracking.pdf

11:00 → 11:20 **Using cluster shape for beam-background suppression in a future muon collider experiment** — 20m
Speaker: Elodie Deborah Resseguie (Lawrence Berkeley National Lab. (US))
MuCol_EPS2021_er....

11:20 → 11:40 **Higgs boson couplings at muon collider (talk)** — 20m
Speaker: Laura Buonincontri (Universita e INFN, Padova (IT))

11:40 → 12:00 **Muon reconstruction performance and detector-design considerations for a Muon Collider (Talk)** — 20m
Speaker: Ilaria Vai (Pavia University and INFN (IT))
EPSHEP2021_Ilaria...

Much more to come
Snowmass full steam ahead

LDG Accelerator R&D Roadmap

Preliminary Work-Packages breakdown, to be done in the next 5 years

Two community meetings have been organized to define the project activities:

Workpackages including muon collider specific experiments

- Fast-ramping magnet systems
- Cooling RF test
- Target material tests
- Neutrino mitigation tests

Design studies exploiting technology progress in R&D Roadmap and elsewhere

- Cooling RF design
- Superconducting RF
- Efficient RF power systems
- High-field solenoids
- High-field dipoles / combined function magnets
- Target system
- Neutrino radiation mitigation system

Design studies

- Proton complex
- Muon production and cooling
- High-energy complex
- Collective effects
- Integrated cooling cell design
- Radiation protection
- Accelerator radiation (target, collider ring)
- MDI
- Other technologies

Test facility design

- Application of above workpackages to test facility (should be the same people)
- Studies for test facility implementation: civil engineering, proton complex, …

INFN contribution

Ongoing INFN activities – synergies

- **Physics simulations:** direct/indirect discovery reach – VBF/VBS – precise Higgs measures
  benchmarks at different energies steer machine parameters and experiment design
- **Experiment and Physics Validation** at different center of mass energies:
  - flexible framework: background and detector simulation, event reconstruction
  - detector requirements/performances ➔ **Detector R&D also within AIDAinnova**
- **Machine Detector Interface (MDI)** at different energies sets ➔ FLUKA:
  - beam induced background shaped by machine design/nozzles ➔ **experiment design**
- **LEMMA studies ➔ Alternative option needs review – positron beam studies for FCCee with IJCL**
- **Targets/crystals simulations and R&Ds/test beams**
- **Encouraging interest INFN-Accelerators: Magnets, RF, beam dynamics, collective effects**

APPROVED EU projects

RISE project: aMUSE – INFN, UniPD, HZDR, LIP, PSI, UniRM on Muon Collider - US FNAL, BNL

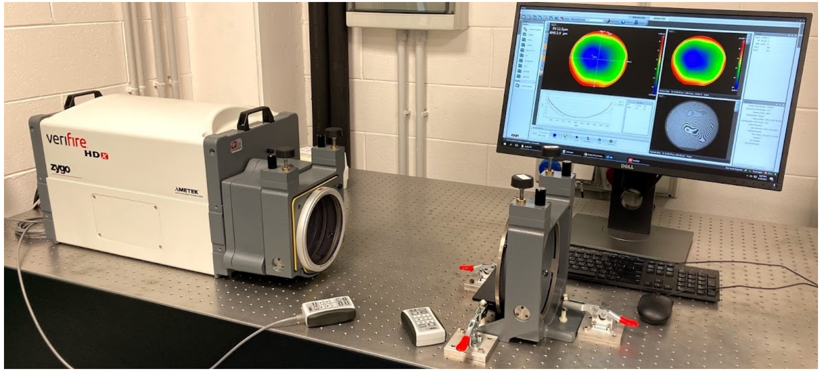
I.FAST – MUST – MUon collider **STrategy** network – (***INFN***, *CERN, CEA, CNRS, KIT, PSI, UKRI)*

AIDAinnova – Detector R&D **4D trackers/fast rad-hard crystals for calo/fast gas detectors/ common software framework for future accelerators**

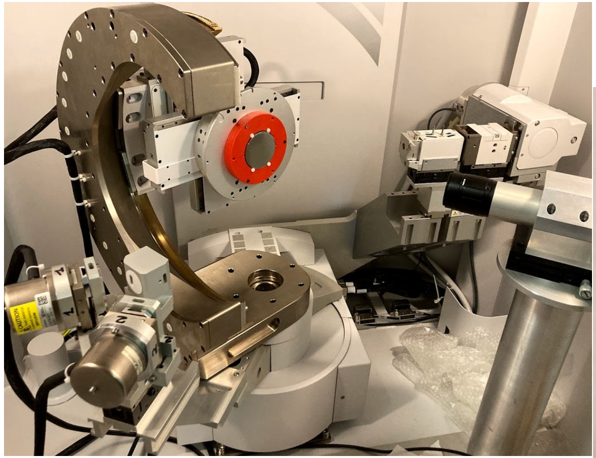
International MUON Collider Collaboration

Cristalli per deflessione di muoni @ 2021

L. Bandiera, V. Guidi, A. Mazzolari, M. Romagnoni, M. Soldani, A. Sytov, M. Tamisari



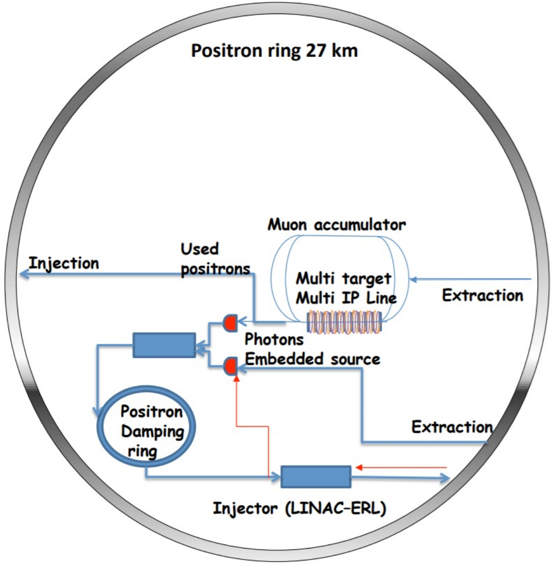
Daniel Schulte ha evidenziato il possibile utilizzo di collimatori a cristalli piegati nel sistema di collimazione del collisore di muoni!



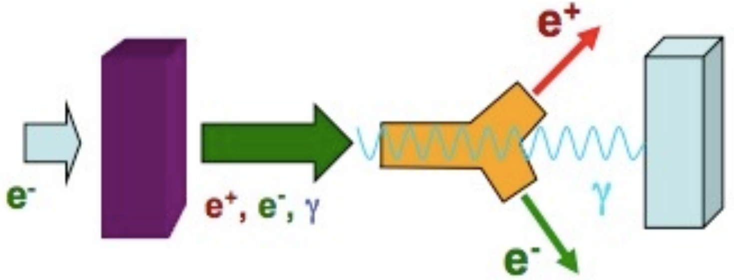
- Avviata la produzione di un cristallo piegato
- Progettato setup per la caratterizzazione a raggi X ed interferometria laser.
- Ci aspettiamo di realizzare e caratterizzare un cristallo piegato entro la fine dell’anno.

Cristalli per sorgenti di positroni @ 2021

PROPOSTA LEMMA per sorgente di muoni a bassa emittanza, basata sull'annichilazione di positroni -> necessità di una sorgente molto intensi di positroni



Sorgente di positroni basata su cristalli orientati



Thin crystal radiator

Thicker amorphus converter target

Il problema principale nelle sorgenti di e+ ad alta intensità non è solo la resa, ma anche la deposizione di energia e la relativa PEDD (Peak Energy Deposition Density)

Principali vantaggi della sorgente a cristalli:

I. Aumento della generazione di fotoni grazie alla channeling radiation -> con aumento della produzione di coppie nel convertitore
II. Alto tasso di fotoni soft -> creazione e+ soft (decine di MeV) facilmente catturati dal Capture System
III. Diminuzione della PEDD nel convertitore di almeno un ordine di grandezza

Cristalli per sorgenti di positroni @ 2021

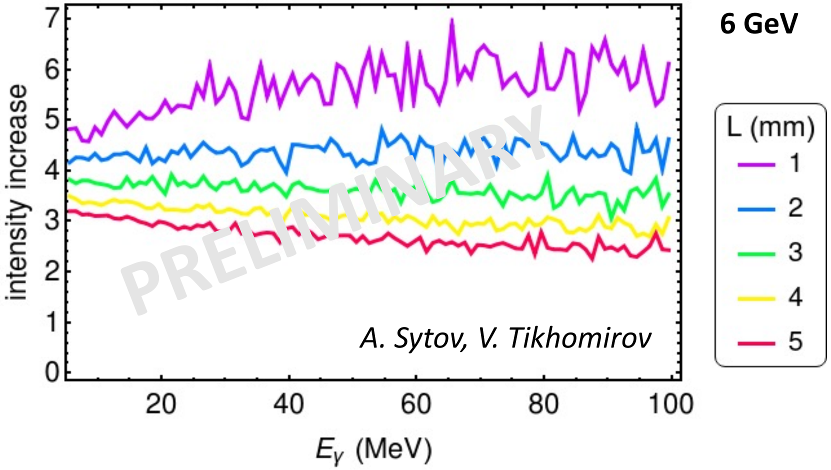
- Caratterizzati cristallograficamente i cristalli di W tramite x-ray diffraction e Rutherford back scattering

- Assegnati due turni di tempo fascio a MAMI (5-8 Novembre; 22-27 Novembre) per l'irraggiamento sia dei radiatori cristallini che dei convertitori amorfi, per valutarne la resistenza. Lavoro in collaborazione con I. Chaikovska (IJCL): forte sinergia con le attività relative alla sorgente di positroni di FCCee

- Lo stato delle attività presentato in un intervento alla conferenza IPAC'21: L. Bandiera et al., "Intense Channeling Radiation as a tool for an hybrid crystal based positron source for future colliders"

- E' in preparazione un articolo scientifico

Sorgente di positroni basata su cristalli orientati



- ✓ Simulazione Monte Carlo per ottimizzare la lunghezza del cristallo di W da utilizzare come radiatore.
- ✓ Tra 1 e 2 mm dovrebbe essere la scelta migliore.

Attività previste @ Ferrara per il 2022

- **Caratterizzazione delle targhette cristalline irraggiate nel 2021**
  Uno degli aspetti cruciali da studiare riguarda la resistenza di questi materiali quando esposti a fasci di particelle di elevata intensità e/o per molto tempo
  - La qualità cristallografica di tale targhette sarà investigata tramite tecniche tipicamente utilizzate per la determinazione del danno indotto da radiazione su materiali cristallini (diffrazione di raggi-x con luce di sincrotrone per caratterizzare il bulk dei cristalli e diffrazione di raggi-x ad alta risoluzione con sorgenti da laboratorio, Rutherford backscattering in modalità channeling presso le strutture INFN di Legnaro)
- **Progettazione di targhette cristalline ottimizzate** mediante Monte Carlo – lavoro in collaborazione con IJCL
- **Caratterizzazione** cristallografica e test di irraggiamento su fascio a MAMI **delle targhette ottimizzate**
- **Caratterizzazione** dei cristalli di PbF2 del **calorimetro CRILIN** e partecipazione al **test beam su fascio** dello stesso

Richieste @ Ferrara

	RICHIESTA	COSTO
MISSIONI	Missioni Italia/CERN per riunioni del gruppo Muon Collider	2.00
	Missioni ad IJCLab per collaborazione progettazione targhette	2.00
	Missioni per test irragiamento su fascio a MAMI (3 persone 1 settimana + giorni di viaggio)	3.50
	Partecipazione e supporto al test beam del calorimetro a PbF2 al CERN (3 persone 1 settimana + giorni di viaggio)	3.50
CONSUMO	Target cristallini e amorfi di interesse per positron source LEMMA, ottimizzati dagli studi del 2021, mediante Monte Carlo e test di irraggiamento a MAMI	8.00
	Holder meccanici per test di irraggiamento a MAMI	1.00
	Caratterizzazione targette cristalline presso sincrotrone ESRF (Francia):topografie a raggi-X	7.00
TRASPORTI	Reperimento materiale da ditte estere	0.50
	Trasporto materiale laboratori esteri	1.00
MANUTENZIONE	Cofinanziamento del 20% Contratto di manutenzione Diffrattometro ad alta risoluzione per caratterizzazione cristalli (offerta allegata ai preventivi)	5.00
TOTALE		33.5

Attività Test Beam LEMMA

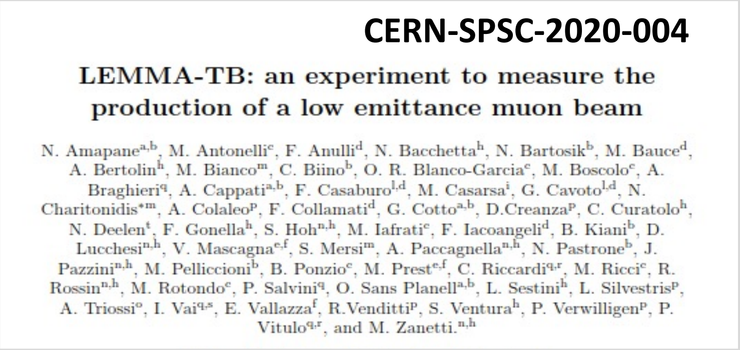
BA, PD, PV, RM1, TO

Reuse from previous LEMMA test beams:

- Muon Chambers (drift tubes) – 4+2 now fully commissioned
- Calorimeters

New for LEMMA '22 test beam:

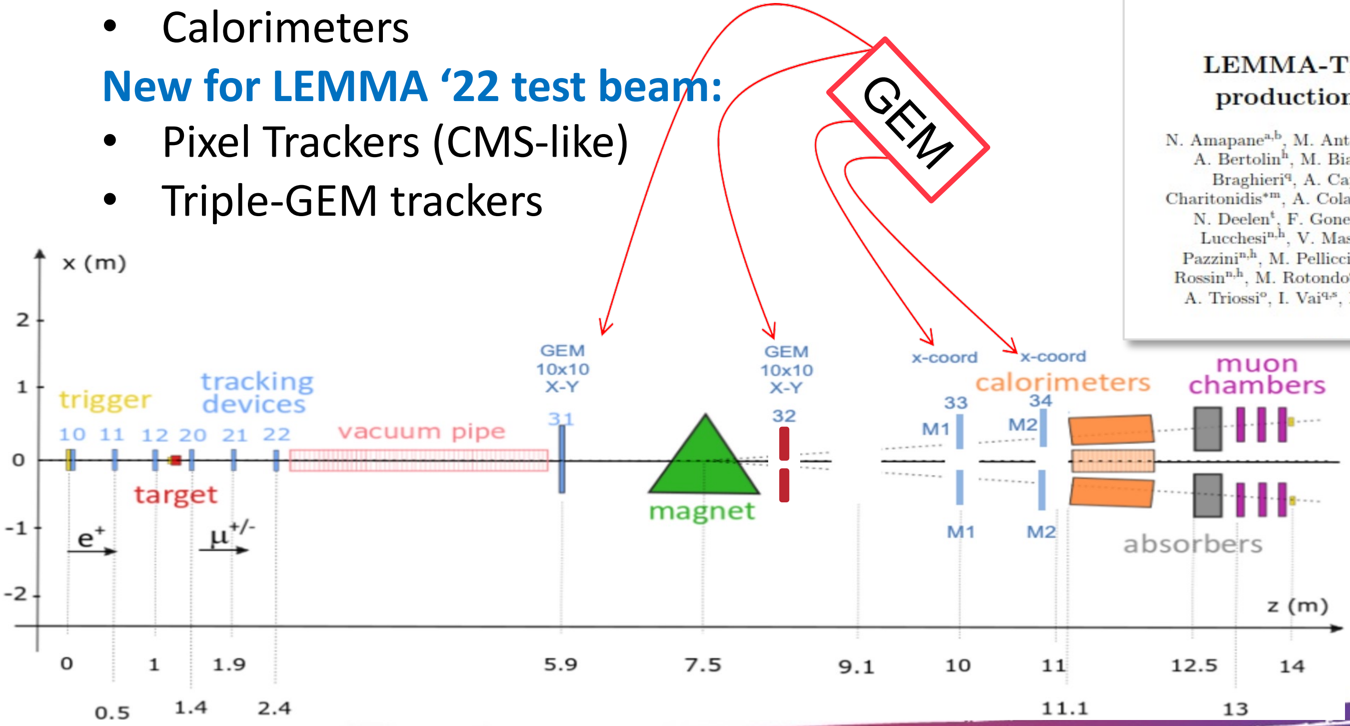
- Pixel Trackers (CMS-like)
- Triple-GEM trackers



CERN-SPSC-2020-004

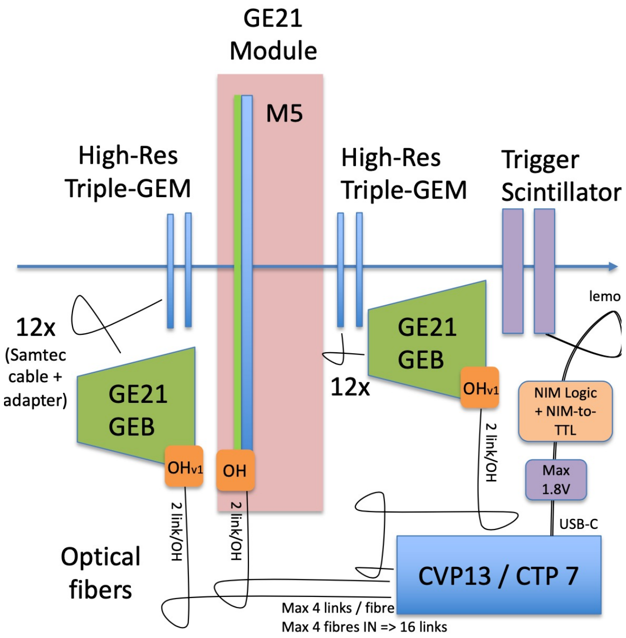
LEMMA-TB: an experiment to measure the production of a low emittance muon beam

N. Amapane[a,b], M. Antonelli[c], F. Anulli[d], N. Bacchetta[h], N. Bartosik[b], M. Bauce[d], A. Bertolin[h], M. Bianco[m], C. Biino[b], O. R. Blanco-Garcia[c], M. Boscolo[c], A. Braghieri[q], A. Cappati[a,b], F. Casaburo[l,d], M. Casarsa[i], G. Cavoto[l,d], N. Charitonidis[*m], A. Colaleo[p], F. Collamati[d], G. Cotto[a,b], D.Creanza[p], C. Curatolo[h], N. Deelen[t], F. Gonella[h], S. Hoh[n,h], M. Iafrati[c], F. Iacoangeli[d], B. Kiani[b], D. Lucchesi[n,h], V. Mascagna[e,f], S. Mersi[m], A. Paccagnella[n,h], N. Pastrone[b], J. Pazzini[n,h], M. Pelliccioni[b], B. Ponzio[c], M. Prest[e,f], C. Riccardi[q,r], M. Ricci[c], R. Rossin[n,h], M. Rotondo[c], P. Salvini[q], O. Sans Planell[a,b], L. Sestini[h], L. Silvestris[p], A. Triossi[o], I. Vai[q,s], E. Vallazza[f], R.Venditti[p], S. Ventura[h], P. Verwilligen[p], P. Vitulo[q,r], and M. Zanetti.[n,h]



Attività Test Beam LEMMA 2021 e 2022

Test beam 2021 GEM



- **RICHIESTA RIASSEGNAZIONE 2022**
  - **20 keu DAQ 40 MHz @ PD**
  - **5 keu trigger scintillatori @ TO**

- **NUOVE RICHIESTE @ RM1 e PD Consumabile**

- **Nuova proposta richiesta fascio 2022**

Situazione 2021 - Avanzi

sezione	missioni				Consumo-Manutenzione			
	assegnato	impegnato	sj	avanzo ass	assegnato	impegnato	sj	avanzo ass
BA_DTZ	1		4		16,5			
BO_DTZ	1			1				
FE_DTZ	4,5		1,5		17,5			
LNF	3,5	2,5	1	1	13			
LNL_DTZ	2,5				3		2	
MI_DTZ	4	1		3				
MIB_DTZ	0,5						7	
PD	8		1,5	6	19	1		19
PV_DTZ	1,5	0,5	1,5	1				
RM1	2,5		1,5	0	52			
RM3_DTZ	2			2	4,5			
TO	61	3	13,5	57,5	5			5
TS_DTZ	0,5			0				
TOT	92,5	62	24,5	71,5	130,5	1	9	24
(yellow)	Eventuali anticipi 2021				96	Avanzo Missioni		
(orange)	da ri-assegnare nel 2022 – testbeam 2022							

Chiediamo di tenere
10 keu indivisi
Dotazioni TO
Meeting ITALIA
Riunioni CERN

DA VERIFICARE
AVANZO FINALE

International MUON Collider Collaboration

Anagrafica

sezione	FTE					SIGLA sinergia
	Persone	FTE DB	FTE/pers	Sinergia	TOTALE	
BA	17	2,3	0,135		2,3	
BO_DTZ	2	0,2	0,1		0,2	
FE_DTZ	4	0,4	0,1		0,4	
LNF_DTZ	5	0,9	0,18	0,2	1,1	I.FAST
LNL_DTZ	5	0,4	0,07		0,4	
MI_DTZ	3	0,4	0,117	0,1	0,5	I.FAST
MIB_DTZ	3	0,3	0,1		0,3	
PD	17	3,6	0,209	0,1	3,7	AIDAinnova
PV	10	2,3	0,23		2,3	
RM1	9	2,1	0,233	0,2	2,3	I.FAST
RM3_DTZ	5	0,4	0,08		0,4	
TO	16	2,2	0,138	0,1	2,3	I.FAST
TS_DTZ	2	0,4	0,2		0,4	
TOT	98	15,9	0,15	0,7	16,6	

Sinergie con sigle/progetti:

INFN-MC @ CSN5 ➔ FLUKA

AIDAinnova ➔ R&D Detector – elettronica – software

I.FAST ➔ Network Muon Collider MUST – collaborazione internazionale

aMUSE ➔ RISE @ USA – inizio 1/1/2022

Outreach – progetto CC3M

International MUON Collider Collaboration

Richieste 2022

Missioni:
Collaborazione @ CERN
SnowMass – documenti finali
Testbeam
Conferenze

Calcolo – Ibisco

In K€

Struttura	A carico dell'I.N.F.N.													A carico di altri enti
	missioni		consumo	altri_cons	seminari	trasporti	licenze-SW	manutenzione	inventario	apparati	spservizi	TOTALI		
BA	24.50		20.00							87.00		131.50		
BO.DTZ	8.00											8.00		
FE.DTZ	11.00		16.00			1.50		5.00				33.50		
LNF	6.00		32.00			1.00						39.00		
LNL.DTZ	7.00		5.00									12.00		
MI.DTZ	5.50											5.50		
MIB.DTZ	4.50		2.00									6.50		
PD	29.50	40.00	6.00									35.50	40.00	
PV	21.00		12.00						8.00			41.00		
RM1	22.00		6.00			2.00						30.00		
RM3.DTZ	8.00		5.00									13.00		
TO	92.00		32.00						20.00			144.00		
TS.DTZ	5.00											5.00		
Totali	**244.00**	*40.00*	**136.00**			**4.50**			**28.00**	**87.00**		***504.50***	***40.00***	

R&D Detector:
CRILIN in corso **LNF**
LGAD resistivi **TO**
mu_picosec **PV**
HCAL-gas **BA**
Cristalli FE
Bersagli LNL-RM1/3

RISE aMUSE – Univ. PD – collaborazione BNL e FNAL

International MUON Collider Collaboration

Financial status – future requests

Physics simulations, Experiment and Physics Validation require computing budget

➔ will benefit by dedicated shared CSN1 ”similfellow grants”

Detector R&D some synergies with AIDAinnova and fully recognized by ECFA Roadmap

crucial to be able to contribute to motivated R&Ds in the next years

➔ will benefit by dedicated shared CSN1 ”similfellow grants”

Machine Detector Interface (MDI) main italian contributions both on FLUKA simulation and lattice studies ➔ **require 2 FTE x 2-3 years**

crucial to understand beam induced background and extrapolate to 10 TeV

Targets/crystals simulation and R&Ds/test beams

INFN-Accelerators: Magnets, RF, beam dynamics, collective effects - Demonstrator

➔ **to be shared with other relevant magnet activities to be finalized**

may require 3 FTE x 2 years

International MUON Collider Collaboration

Conclusions and plans

- Along the Accelerator R&D Roadmap, the Muon Panel and experts are working together with the International Muon Collider Community to revise the project challenges and the needed R&D

  ➔ **updated timeline with Muon collider $\sqrt{s} = 3$ TeV ready to take data in 2045**

  ➔ see EPS LDG and ECFA Roadmap summaries ➔ **to be approved by Council Fall 2021**
- **International Muon Collider Collaboration: MoC ready to be signed**
- Facility work getting well organized in WG, defining work plans for the next 5 years

➔ First Stakeholders meeting on July 14

➔ more by September including **MDI** - strong INFN contribution/interest

➔ strong link to **physics potential and detector design** ➔ new dedicated WG soon

- EU projects in preparation on Design Study discussed also in TIARA

- INFN (D. Lucchesi) is leading the **Physics and Detector** activities to be formalized soon
- INFN should not miss the opportunity to contribute on **accelerator complex study**, development and tests

Grazie!

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CERN DG at FCC week

Remarks on a future collider at CERN

ESPP gives the preferred direction for future collider(s) at CERN: FCC

However, prudently:
- ❑ feasibility study first
- ❑ intensified accelerator R&D for FCC and to prepare alternative scenarios if FCC not pursued

No consensus in European community on which type of Higgs factory (linear or circular)

ILC:
- ❑ Strategy says it's compatible with ESPP if timely (otherwise conflict of resources with next collider at CERN)
- ❑ are ILC and FCC-ee complementary enough in terms of physics? No consensus.

Chinese colliders (CepC, SppC): "direct competition" with FCC

Desired timeline* for a future collider at CERN:
→ recommendation by next ESPP ~ 2026
→ approval by CERN's Council by end of the decade → construction's start early-2030's
→ operation's start mid 2040's.
Such a timeline is realistic for FCC-ee and CLIC, more difficult for FCC-hh (magnet technology, cost)

* A new facility running in the mid-2040's, i.e. within 10 years of end of HL-LHC, is crucial to retain (and expand) CERN's expertise and community → crucial for long-term survival of the field.

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ECFA Detector R&D Roadmap plans

Organisation

May 2020
EPPSU mandate to ECFA to develop a roadmap for detector R&D efforts in Europe

Sep 2020
Structure in place with **Detector R&D Roadmap Panel**

Dec 2020
Task Forces active

Website:
https://indico.cern.ch/e/ECFADetectorRDRoadmap

Expert & Community Consultation

Feb 2021
Collection of requirements of future facilities & projects

Feb/March 2021
Questionnaires of Task Forces to national contacts

Task Forces liaise with experts in
- ECFA countries
- adjacent disciplines
- industry

March-May 2021
Open Symposia

Drafting Roadmap & Feedback

May 2021
Task Forces collate input from symposia

25-28 May 2021 **Drafting sessions**
- opening session with all experts involved
- plenary & parallel sessions with Task Force members
- final session of Roadmap Panel

2 July 2021
Near final draft shared with RECFA*

30 July 2021
Presentation at Joint ECFA-EPS session

Until Sep 2021
Collect final community feedback*

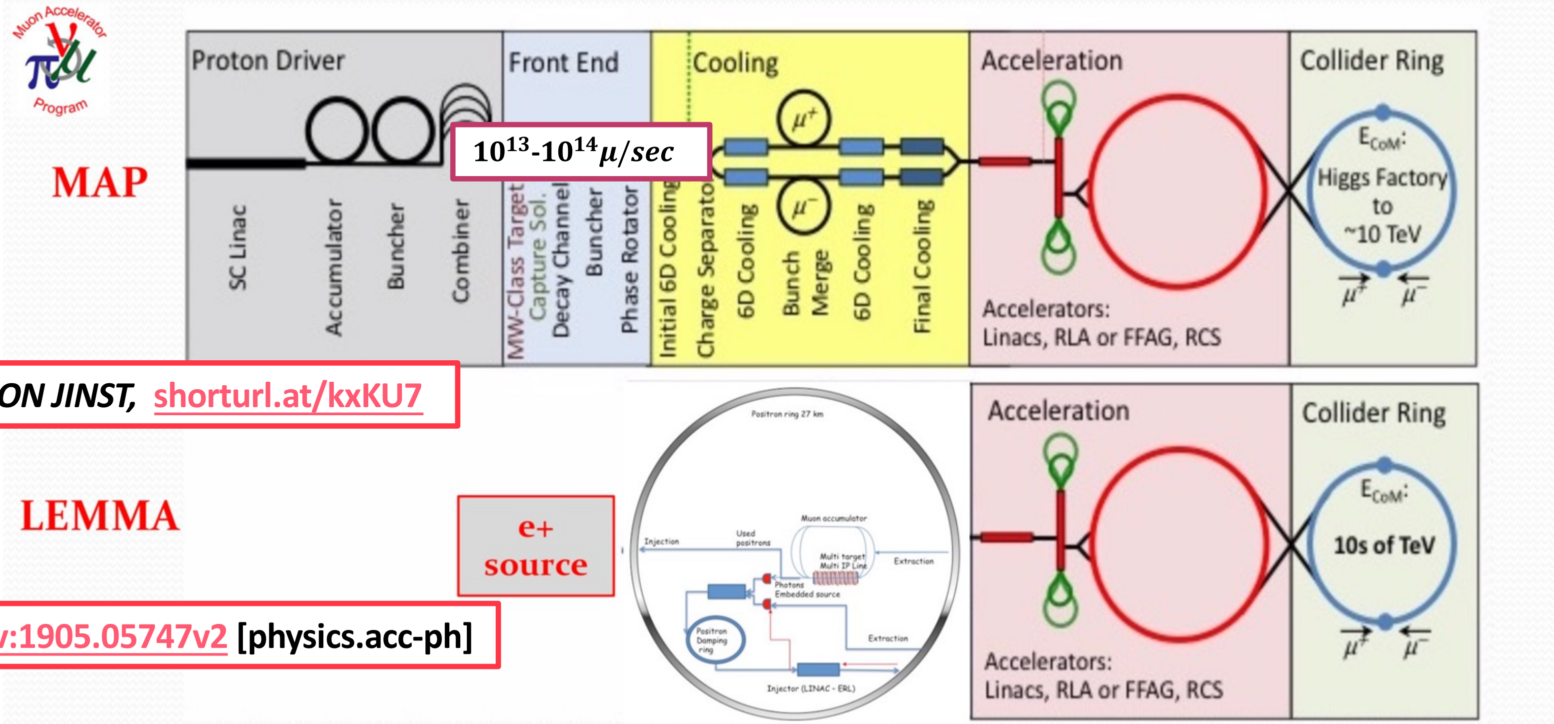
Oct 2021
Detector R&D Roadmap Document submission to RECFA and afterwards to PECFA and Council

*community feedback via RECFA delegates and National Contacts

Detector R&D Roadmap targeted facililies

- Full exploitation of the **HL-LHC** (R&D still needed for LS3 upgrades and for experiment upgrades beyond then)…
- R&D for **long baseline neutrino physics** detectors (including aspects targeting astro-particle physics measurements) and supporting experiments such as at those at the CERN Neutrino Platform
- Technology developments needed for detectors at **e+e- EW-Higgs-Top factories** in all possible accelerator manifestations including instantaneous luminosities at 91.2 GeV of up to 5×10^{36} $cm^{-2}s^{-1}$.
- The long-term R&D programme for detectors at a **future 100 TeV hadron collider** with integrated luminosities targeted up to 30 ab^{-1} and 1000 pile-up for 25 ns BCO
- Specific long-term detector technology R&D requirements of a **muon collider operating at 10 TeV** and with a luminosity of the order of 10^{35} cm^{-2} s^{-1}
- Accelerator-based studies of **rare processes, DM candidates and high precision measurements** (including strong interaction physics) at both storage rings and fixed target facilities, interfacing also with atomic and nuclear physics.
- R&D for optimal exploitation of **dedicated collider experiments** studying the **partonic structure of the proton and nuclei** as well as interface areas with nuclear physics
- Very broad detector R&D areas for **non-accelerator-based experiments**, including dark matter searches (including axion searches), reactor neutrino experiments, rare decay processes, neutrino observatories and other interface areas with astro-particle physics.

proton (MAP) vs positron (LEMMA) driven muon source



MUON JINST, shorturl.at/kxKU7

arXiv:1905.05747v2 [physics.acc-ph]

➔ **need consolidation** to overcome technical limitations to reach higher muon intensities