International
MUON Collider
Collaboration

MuCol

Muon Collider

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On behalf of the International Muon Collider Collaboration

KET Meeting, DESY, November, 2024

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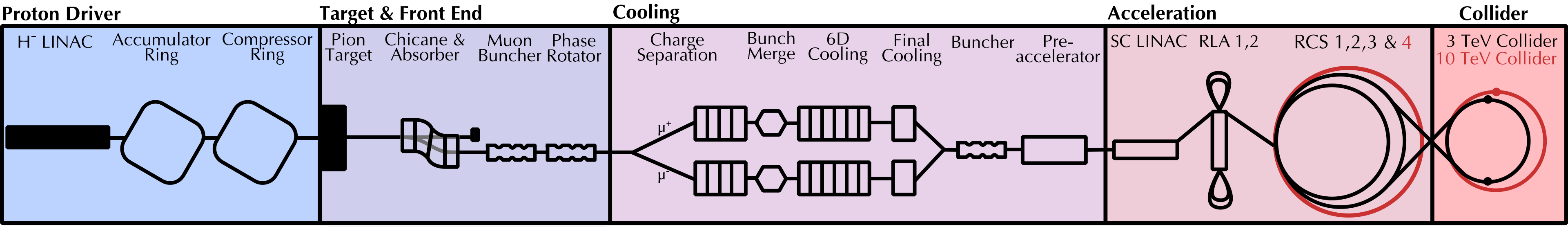
Muon Collider Overview

Would be easy if the muons did not decay
Lifetime is $\tau = \gamma \times 2.2\ \mu s$ (e.g. 3100 turns in collider ring)



Short, intense proton bunch

Protons produce pions which decay into muons which are captured

Ionisation cooling of muon in matter

Acceleration to collision energy

Collision

IMCC

International Muon Collider Collaboration

Develop high-energy muon collider as option for particle physics:

- Muon collider promises **sustainable** approach to the **energy frontier**
    - limited power consumption, cost and land use
- **Technology** and **design advances** in past years
- Reviews in Europe and US found **no unsurmountable obstacle**

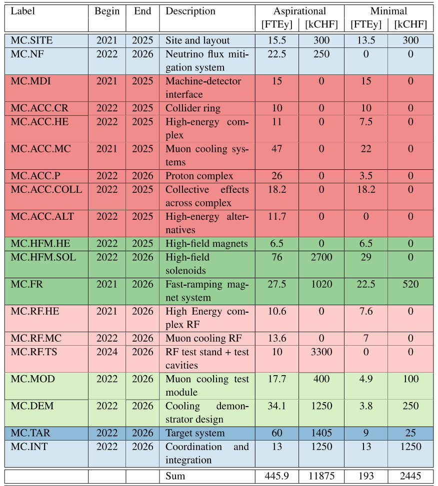
Initial workplan in **LDG Accelerator R&D Roadmap**

Focus on **10 TeV feasibility**

- **Initial stage by 2050**, maybe around 3 TeV or 10 TeV with lower luminosity
- Could later consider other energies (above 10 TeV, 125 GeV, …)

Goals for ESPPU is to provide document with

- **Assessment of muon collider** concept, technologies and work progress
- An **R&D plan** for the next 5 and 10 years
- **Implementation considerations** (including site, timeline, …)



Label	Begin	End	Description	Aspirational		Minimal	
				[FTEy]	[kCHF]	[FTEy]	[kCHF]
MC.SITE	2021	2025	Site and layout	15.5	300	13.5	300
MC.NF	2022	2026	Neutrino flux mitigation system	22.5	250	0	0
MC.MDI	2021	2025	Machine-detector interface	15	0	15	0
MC.ACC.CR	2022	2025	Collider ring	10	0	10	0
MC.ACC.HE	2022	2025	High-energy complex	11	0	7.5	0
MC.ACC.MC	2021	2025	Muon cooling systems	47	0	22	0
MC.ACC.P	2022	2026	Proton complex	26	0	3.5	0
MC.ACC.COLL	2022	2025	Collective effects across complex	18.2	0	18.2	0
MC.ACC.ALT	2022	2025	High-energy alternatives	11.7	0	0	0
MC.HFM.HE	2022	2025	High-field magnets	6.5	0	6.5	0
MC.HFM.SOL	2022	2026	High-field solenoids	76	2700	29	0
MC.FR	2021	2026	Fast-ramping magnet system	27.5	1020	22.5	520
MC.RF.HE	2021	2026	High Energy complex RF	10.6	0	7.6	0
MC.RF.MC	2022	2026	Muon cooling RF	13.6	0	7	0
MC.RF.TS	2024	2026	RF test stand + test cavities	10	3300	0	0
MC.MOD	2022	2026	Muon cooling test module	17.7	400	4.9	100
MC.DEM	2022	2026	Cooling demonstrator design	34.1	1250	3.8	250
MC.TAR	2022	2026	Target system	60	1405	9	25
MC.INT	2022	2026	Coordination and integration	13	1250	13	1250
			Sum	445.9	11875	193	2445

Table 5.5: The resource requirements for the two scenarios. The personnel estimate is given in full-time equivalent years and the material in kCHF. It should be noted that the personnel contains a significant number of PhD students. Material budgets do not include budget for travel, personal IT equipment and similar costs. Colours are included for comparison with the resource profile Fig. 5.7.

http://arxiv.org/abs/2201.07895

The Collaboration

Collaboration currently **hosted by CERN**
New partners still joining (**58 signed**, more in the process)
- From different regions

EU co-funded design study MuCol started 2023

Strong recommendation from **P5 «This is our muon shot»**
- Interest in hosting at FNAL

US partners are joining/plan to join
- **Strong interest** at US Muon Collider Inauguration Meeting in August at FNAL (about 300 participants)
- Addendum to **CERN-DoE agreement** in preparation

Strong US contribution to **IMCC R&D plan**

IMCC will carry out the R&D together and develop options to host the collider at CERN or at FNAL and potentially also other sites

MuCol

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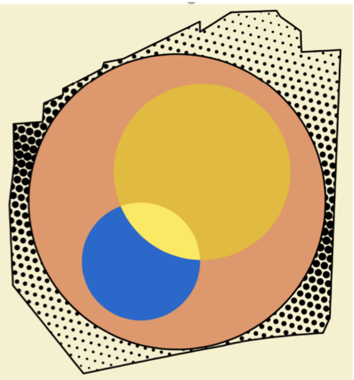
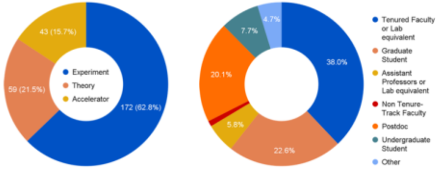


- In early August, held an open meeting of the US community
    - ○ 274 (+25 virtual) participants



IMCC Partners

IEIO	**CERN**
FR	**CEA-IRFU**
	CNRS-LNCMI
	Mines St-Etienne
DE	DESY
	Technical University of Darmstadt
	University of Rostock
	KIT
UK	**RAL**
	UK Research and Innovation
	University of Lancaster
	University of Southampton
	University of Strathclyde
	University of Sussex
	Imperial College London
	Royal Holloway
	University of Huddersfield
	University of Oxford
	University of Warwick
	University of Durham
	University of Birmingham
	University of Cambridge

IT	**INFN**
	INFN, Univ., Polit. Torino
	INFN, LASA, Univ. Milano
	INFN, Univ. Padova
	INFN, Univ. Pavia
	INFN, Univ. Bologna
	INFN Trieste
	INFN, Univ. Bari
	INFN, Univ. Roma 1
	ENEA
	INFN Frascati
	INFN, Univ. Ferrara
	INFN, Univ. Roma 3
	INFN Legnaro
	INFN, Univ. Milano Bicocca
	INFN Genova
	INFN Laboratori del Sud
	INFN Napoli
Mal	**Univ. of Malta**
EST	**Tartu University**
PT	**LIP**
NL	**University of Twente**

SE	**ESS**
	University of Uppsala
FI	**Tampere University**
LAT	**Riga Technical University**
CH	**PSI**
	University of Geneva
	EPFL
	HEIA-FR
BE	**Univ. Louvain**
AU	**HEPHY**
	TU Wien
ES	**I3M**
	CIEMAT
	ICMAB
China	***Sun Yat-sen University***
	IHEP
	Peking University
	Inst. Of Mod. Physics, CAS
KO	**Kyungpook National University**
	Yonsei University
	Seoul National University
India	***CHEP***

CA	Université Laval
US	**Iowa State University**
	University of Iowa
	Wisconsin-Madison
	University of Pittsburgh
	Old Dominion
	Chicago University
	Florida State University
	RICE University
	Tennessee University
	MIT Plasma science center
	Pittsburgh PAC
	Yale
	Princeton
	Stony Brook
	Stanford/SLAC
	…
DoE labs	FNAL
	LBNL
	JLAB
	BNL
Brazil	***CNPEM***

Signed MoC (58), ***requested MoC***, contributor

Key Challenges

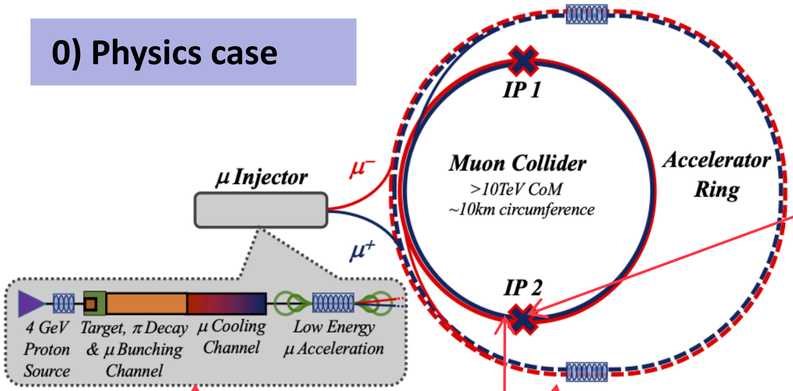
Environmental impact
- Neutrino flux mitigation
- Power, cost, CO_2, …

Key technologies for timeline
- Magnet technology
- Muon cooling technology
- Detector

Other technologies are instrumental for performance, cost, power consumption and risk mitigation
- Accelerator physics, cryogenics, superconducting cavities, ….

Other important timeline considerations are
- Civil engineering
- Decision making

0) Physics case



2) Beam-induced background

4) Muon production and cooling drives the **beam quality**
MAP put much effort in design
optimise as much as possible

1) Dense neutrino flux mitigated by mover system and **site selection**

3) Cost and **power** consumption limit energy reach
e.g. 35 km accelerator for 10 TeV, 10 km collider ring
Also impacts **beam quality**

Environmental Impact

Limited study on CO_2 etc at this moment

Inherent muon collider benefits

- Compact size limits material use/CO_2 footprint
- Limited power consumption
- Limited land use, in particular if existing tunnels are reused

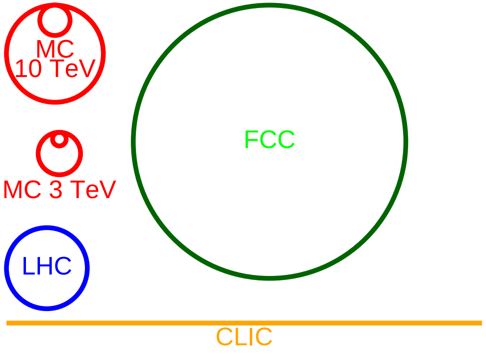
Aim at minimising neutrino flux

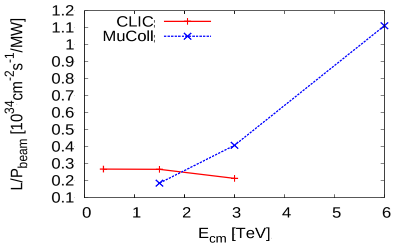
- Focus on collider ring for now
    - Need to expand later
- Working with **RP**
- Improved **geoprofiling tool** to place collider ring
- Mechanical system to avoid localized neutrino flux

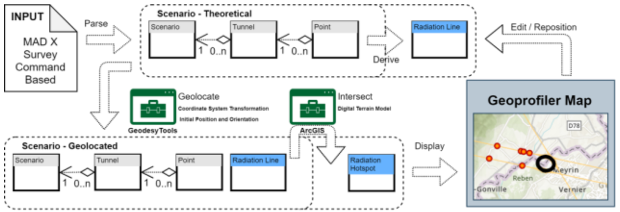
First **promising site and orientation** identified

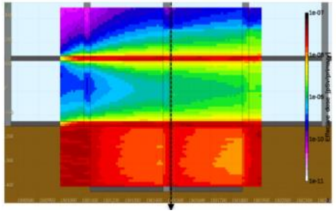
- Mitigates flux from experiments
- Arc flux likely negligible for 3 TeV
    - Approvable/negligible for 10 TeV

Further site optimization, detailed study, development of technical systems and beam study needed



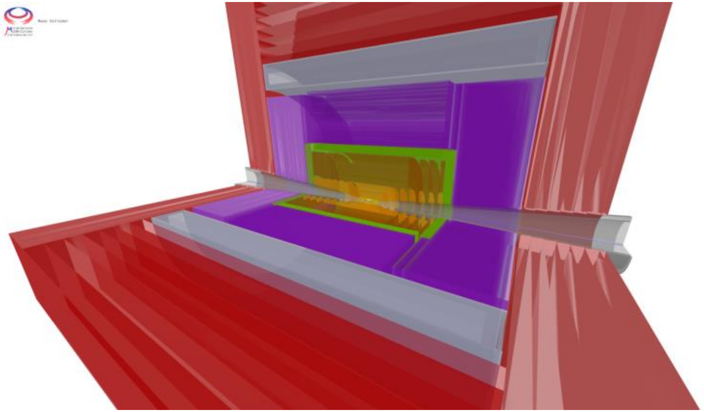




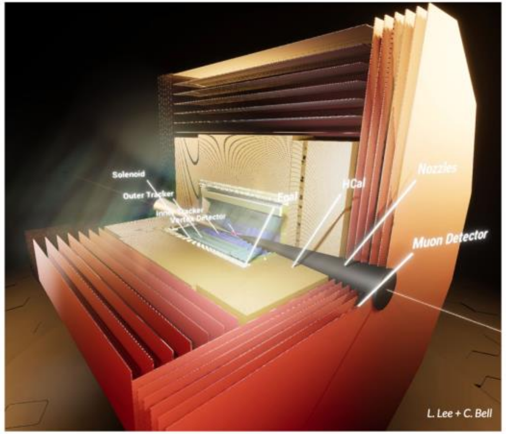


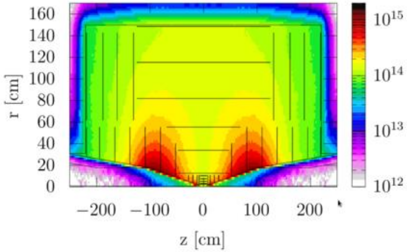
Physics and Detector Concepts

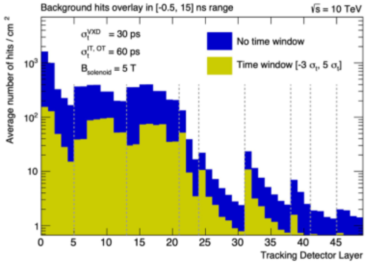
MUSIC
(MUon System for Interesting Collisions)

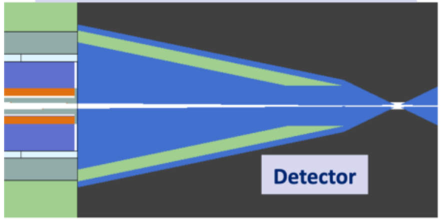


MAIA
(Muon Accelerator Instrumented Aperatus)









Two detector concepts are being developed

- Required resolutions
- MDI and background suppression
- …

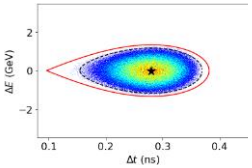
Can do the important physics with near-term technology also thanks to HL-LHC developments

Increasing effort to use available time for further improvements and exploiting **AI, ML** and **new technologies**

Closer **integration with ECFA detector R&D** highly welcome

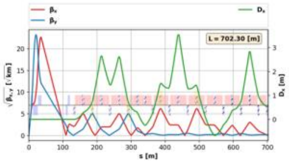
Facility Design

Good progress in the different system designs
- Proton complex, muon production and cooling, acceleration and collider ring, collective effects, …



Preliminary design of **cooling chain** advanced
- 24 to 30 um transverse emittance
- Goal 22.5 um, MAP achieved 55 um

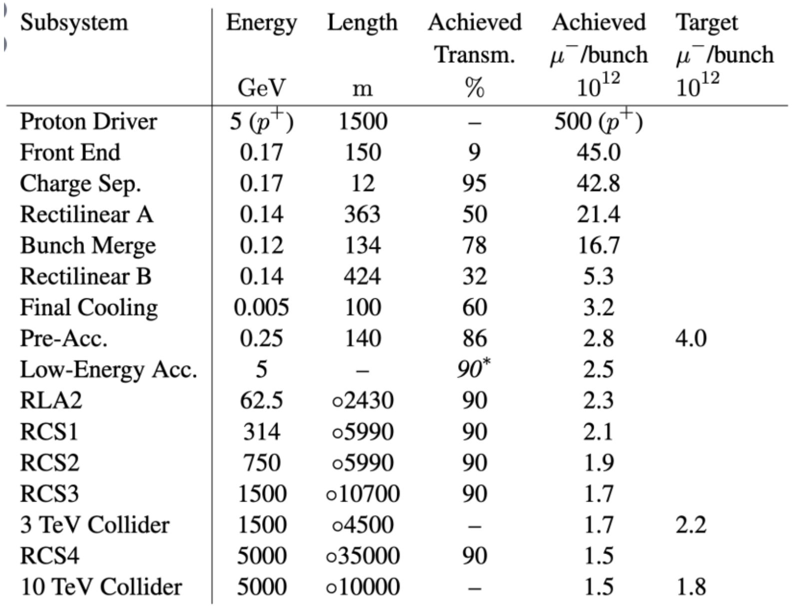
Collider ring lattice design
- Achieve beta-function
- Need to improve energy acceptance (2-3 x)



Preliminary **muon transmission** estimate
- 1.5 x 10^{12} muons at IP (goal 1.8 x 10^{12})
- Cooling transmission below target
- High-energy complex is above (would like to reduce for cost)

Need resources to improve system design

Will study higher power target (graphite or liquid metal)



Subsystem	Energy GeV	Length m	Achieved Transm. %	Achieved μ^-/bunch 10^{12}	Target μ^-/bunch 10^{12}
Proton Driver	5 (p^+)	1500	–	500 (p^+)	
Front End	0.17	150	9	45.0	
Charge Sep.	0.17	12	95	42.8	
Rectilinear A	0.14	363	50	21.4	
Bunch Merge	0.12	134	78	16.7	
Rectilinear B	0.14	424	32	5.3	
Final Cooling	0.005	100	60	3.2	
Pre-Acc.	0.25	140	86	2.8	4.0
Low-Energy Acc.	5	–	90^*	2.5	
RLA2	62.5	$\circ$2430	90	2.3	
RCS1	314	$\circ$5990	90	2.1	
RCS2	750	$\circ$5990	90	1.9	
RCS3	1500	$\circ$10700	90	1.7	
3 TeV Collider	1500	$\circ$4500	–	1.7	2.2
RCS4	5000	$\circ$35000	90	1.5	
10 TeV Collider	5000	$\circ$10000	–	1.5	1.8

Time to **increase design effort** to cover and integrate all systems (“**start-to-end simulation**”), improve codes, performances and consider alternatives

Magnets

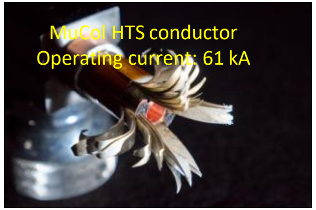
Systematic **dipole performance prediction** for **LTS** and **HTS**

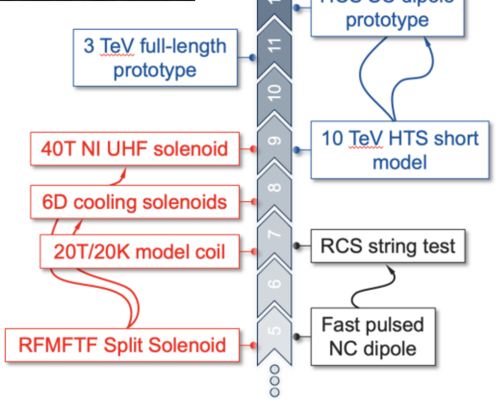
- Aperture, field, cost, stress, loadline, protection, …

HTS solenoid designs (6D cooling, final cooling, target)

Normal-conducting **fast-pulsed dipoles** (HTS as alternative)

Technical timeline


MuCol HTS conductor
Operating current: 61 kA



10 TeV full-length prototype

HCS SC dipole prototype

3 TeV full-length prototype

10 TeV HTS short model

40T NI UHF solenoid

6D cooling solenoids

20T/20K model coil

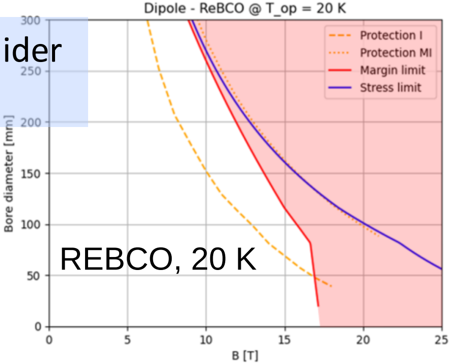
RCS string test

Fast pulsed NC dipole

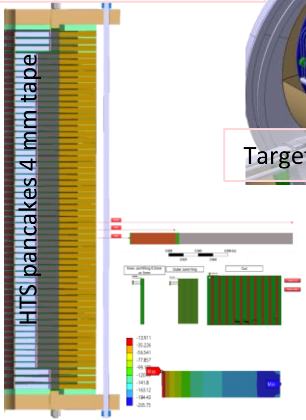
RFMFTF Split Solenoid

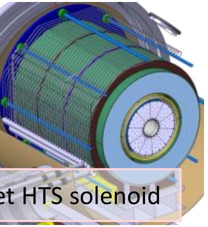

First **HTS winding tests**

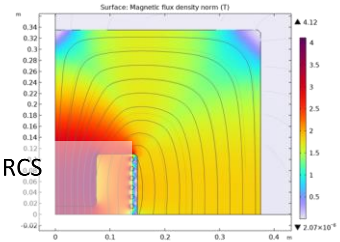
Will slightly adjust collider ring field for cost



HTS final cooling solenoid mechanical design




Target HTS solenoid



Normal-conducting RCS **pulsed magnets**

Opportunity to **ramp up** effort

- Engineering designs
- Tests of cables, building models, …

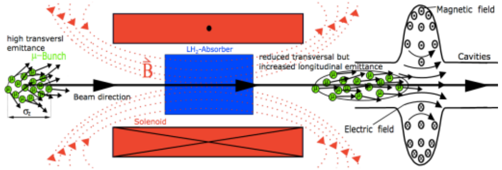
With sufficient resources **HTS solenoids** and **Nb$_3$Sn dipoles** could be **ready for decision in 10-15 years**

HTS dipoles likely take longer

Muon Production and Cooling

Muon cooling technology and **demonstrator**

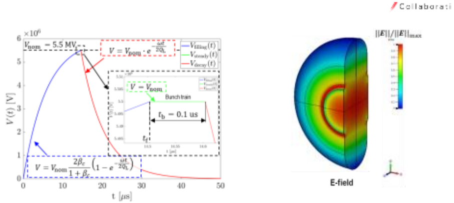
- Most integrated technology
- Operational demonstrator in O(10 years), with enough resources
- Allows to perform final optimization of cooling technology



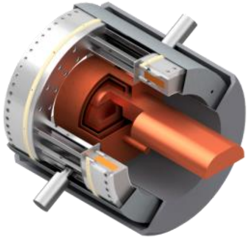
Very bright muon beam challenges **absorbers** and **windows**

- First tests of absorber windows performed

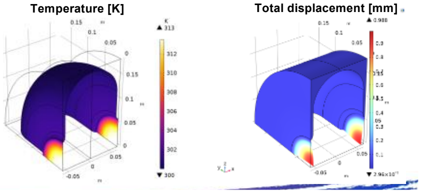
Strong theoretical and experimental programme required

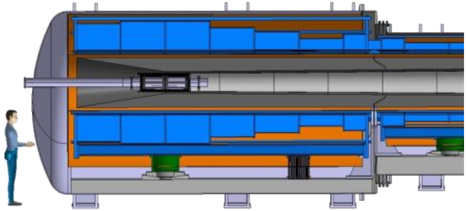


Engineering **module design** started
Including solenoid



RF design ongoing





2 MW graphite target looks very promising

- Some work on windows remains

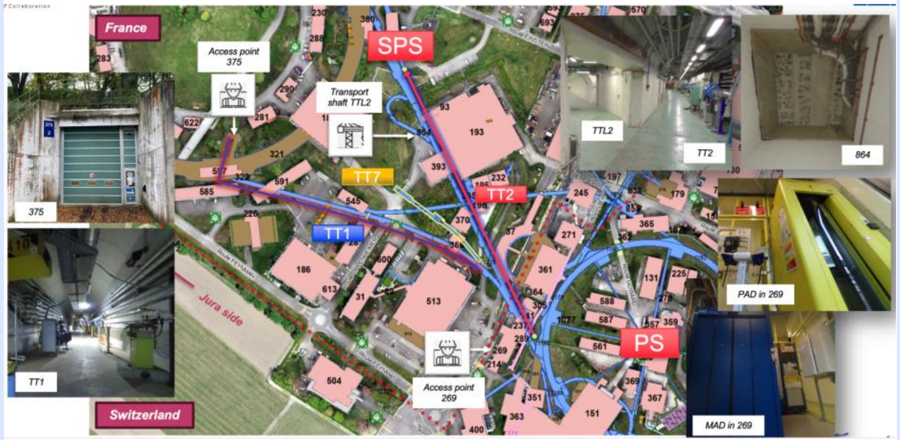
Will study alterative higher power (4 MW) target

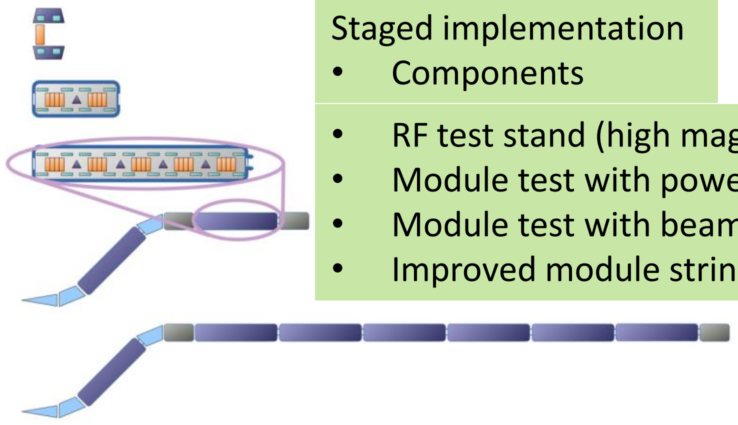
- Graphite, liquid metal, fluidized tungsten

Ready to **widen effort**, in particular beamdynamics, prototyping and experimental work

Demonstrator

Ultimate **6D cooling technology integration**
- Components: Magnets, RF systems, absorbers, vacuum, instrumentation, cryogenics, …
- Integration, operation, performance with beam
- Gradual upgrades as cell design evolves, confidence grows
- Will be important part of commissioning preparation after the decision to build the muon collider





Staged implementation
- Components
- RF test stand (high magnetic field)
- Module test with power
- Module test with beam
- Improved module string

Detailed studies of site at CERN ongoing, considering TT7 tunnel
US plan to start detailed study at FNAL

Effort **ramp-up** in several stages
Modular plan will allow quickly moving forward
- adjust to developments in Europe and the US

Other R&D Programme

R&D on other technologies also needed
Power converter, high-field superconducting cavities, efficient RF power sources, cryogenics (e.g. **liquid hydrogen**), instrumentation, …

Most important is training of **young people**

- Most important resource
- Strong interest by early career experts
  - e.g. https://indico.cern.ch/event/1422393/
- Motivating challenges

Exploit synergies with other fields (technology and physics)

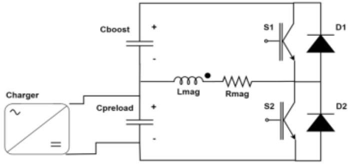
- Strong **synergy** with **LDG HFM** and **RF**

HTS solenoids have important potential

- Fusion
- Power generators for windmills and motors
- Life sciences
- Important step toward FCC-hh HTS dipoles
- …

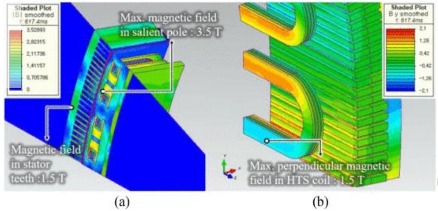
Detector technology development

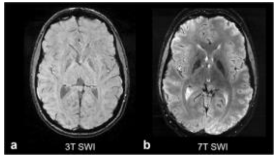
- AI, ML, …

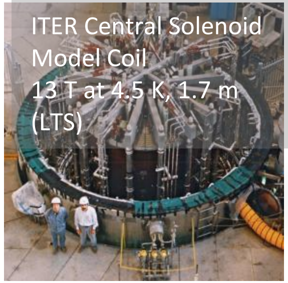


RCS power converter
Synergy with MMC
For high-power transfer
e.g. off-shore windmills

Design of 10 MW
HTS wind generator







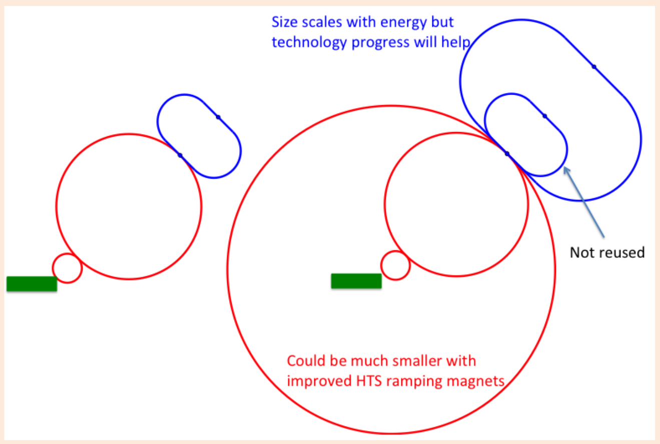
ITER Central Solenoid Model Coil
13 T at 4.5 K, 1.7 m (LTS)

28.2 T LTS+HTS, 54 mm

Opportunities to profit from synergies
Attract young generation
R&D programme can be distributed world-wide

Staging

Expect to be ready for implementation in 15 years
- **Detector**
- **Muon cooling technology**
- **HTS solenoid technology**
- **Nb_3Sn dipoles (11T)** for collider ring
- High-field HTS dipoles for second stage are likely later



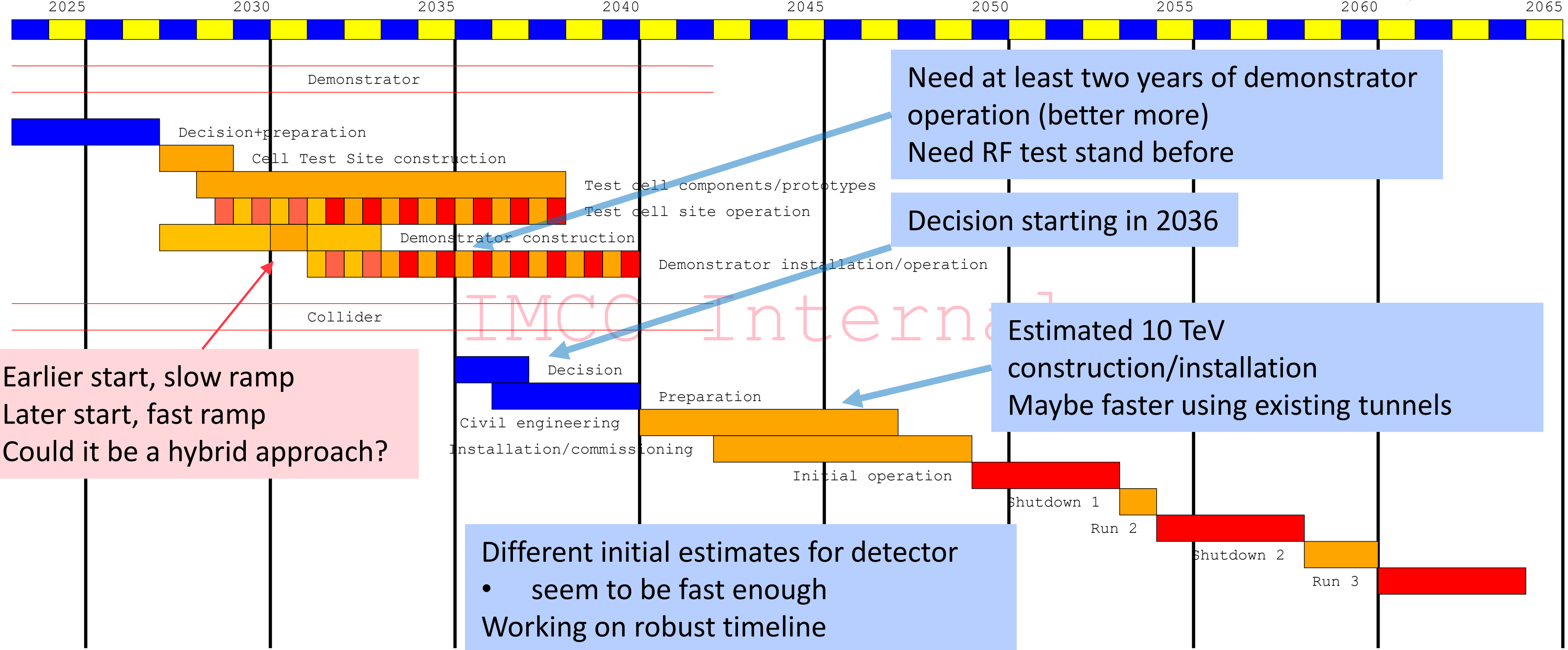
Energy staging
- 3 TeV design takes lower dipole performance into account
  - HL-LHC type performances
- Cost split over two stages, little increase in integrated cost

Luminosity staging
- Longer collider ring arcs and less performant interaction region lead to less luminosity in first stage
- Can later upgrade interaction region (as in HL-LHC), remain at 2/3 of luminosity because of arcs
- Full cost at first stage

Parameter	Unit	3 TeV	10 TeV	10 TeV	10 TeV
L	10^{34} $cm^{-2}s^{-1}$	1.8	20	tbd	13
N	10^{12}	2.2	1.8	1.8	1.8
f_r	Hz	5	5	5	5
P_{beam}	MW	5.3	14.4	14.4	14.4
C	km	4.5	10	15	15
<B>	T	7	10.5	7	7

Potential Timeline (Fast-track 10 TeV)

Only a basis to start the discussion, being reviewed



Need at least two years of demonstrator operation (better more)
Need RF test stand before

Decision starting in 2036

Estimated 10 TeV construction/installation
Maybe faster using existing tunnels

Earlier start, slow ramp
Later start, fast ramp
Could it be a hybrid approach?

Different initial estimates for detector

- seem to be fast enough

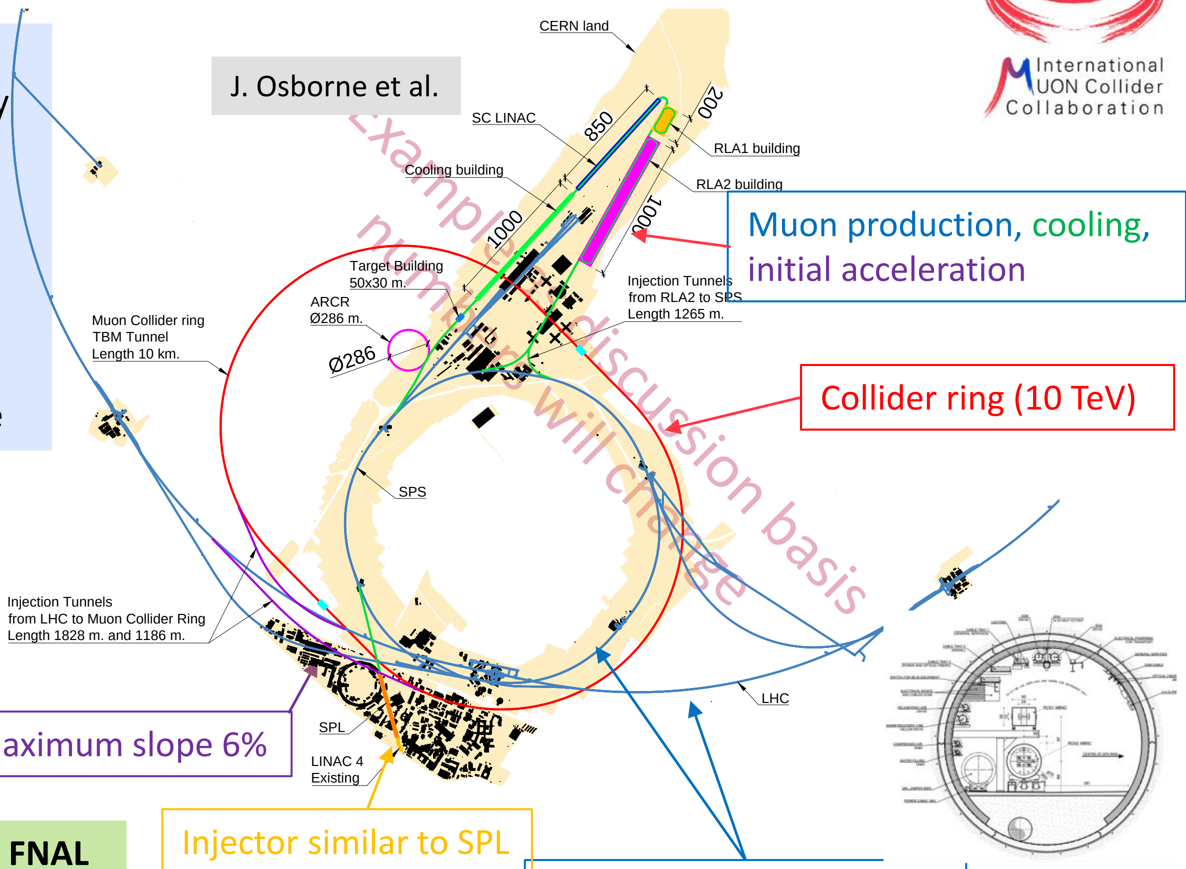
Working on robust timeline

Exploratory Site Studies

At **CERN**, first look is promising:

- First collider ring site identified that largely **mitigates neutrino flux from experiments**
    - Some more work required
- SPS and LHC tunnels reused
- All construction on CERN land (maybe one experiment not)
- Energy stages maybe 2.5-3 and 8 TeV (tbc)
- More studies will be required in the future

J. Osborne et al.



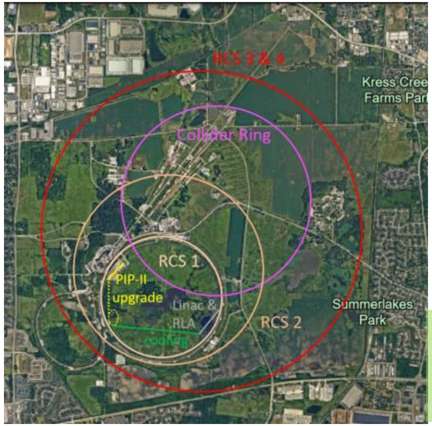
Muon production, cooling, initial acceleration

Collider ring (10 TeV)

Transferline maximum slope 6%

Injector similar to SPL

SPS and LHC used for RCSs



Initial concepts at **FNAL** are being considered

Maturity, Cost, Power, Land Use

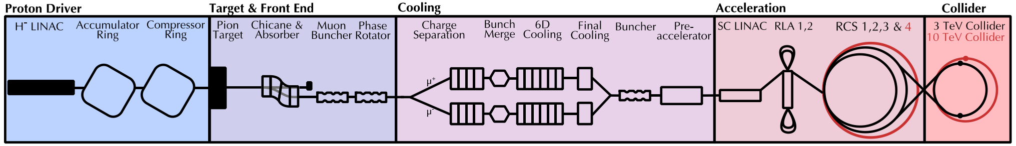
Maturity

The moment to commit depends on many factors

- Important for society
- Willingness to take risk
- …

Feel that we need a decade more R&D

- Further and optimize overall design
- Address challenges

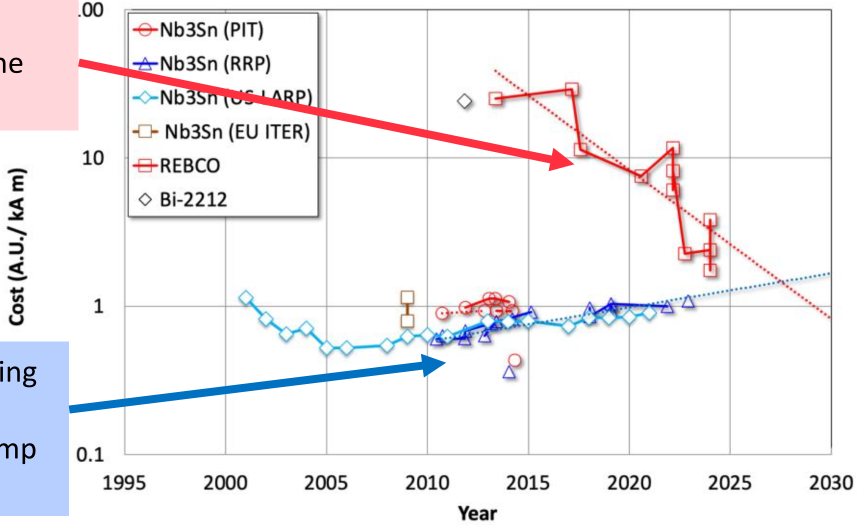


Cost and Power

Are collecting cost and power information (Carlo Rossi is also leading the CLIC costing), at this moment

- Remaining uncertainties exist
- Important magnet cost uncertainty
- Are asked to adjust to FCC-hh costing methodology

HTS cost is coming down
How much depends on the overall use of HTS



Nb3Sn cost slowly increasing
We may be the only users
Industry would have to ramp up just for us

Land Use looks promising

German Considerations

Muon collider is high-energy **Particle Physics** option

- Important option as **next flagship after HL-LHC** in Europe, if higgs factory were not in Europe
- Important **option for the US** as high-energy frontier particle physics project
- Important option as **flagship after a higgs factory** in Europe, no matter what the geometry
- There can be facilities on the way
  - Proton linac, neutrino facilities, …

Muon collider provides **exciting R&D opportunities**, can exploit synergies and German strengths:

- Physics and detector expertise (DESY)
  - Technologies, AI, ML
- RF expertise (Rostock)
- Particle-matter interaction
- Magnet expertise (Darmstadt, KIT)
- Exciting accelerator physics
- Environmental impact

Obviously, current involvement level should be increased

Very motivating for the **young generation**, can bring new people to the field

- Strong synergy with **societal applications**
  - E.g. very active magnet R&D (wind generators, fusion, …)
  - Links to liquid hydrogen, power converter, …

Conclusion

The status

Interest in Muon collider is rising and collaboration is growing

- EU co-funding, contributions from increasing number of partners
- Very strong interest in the US

Made important progress addressing identified challenges but still on our way

- Identified some additional challenges
- Moved much closer to our target

First exploration of CERN site motivates more detailed studies

- FNAL is also exploring their site

The future

Timeline with focus on fast scenario with physics starting around 2050

Will provide an R&D plan to ESPPU

- Identifying priorities for the next five and ten years

Excellent opportunity for Europe to maintain muon collider as option

- Magnets, cooling technology, detector, accelerator physics, …
- Profit from synergies and contribute to society
- Engage young generation

Many thanks to the collaboration for all the work

To join contact muon.collider.secretariat@cern.ch

Reserve

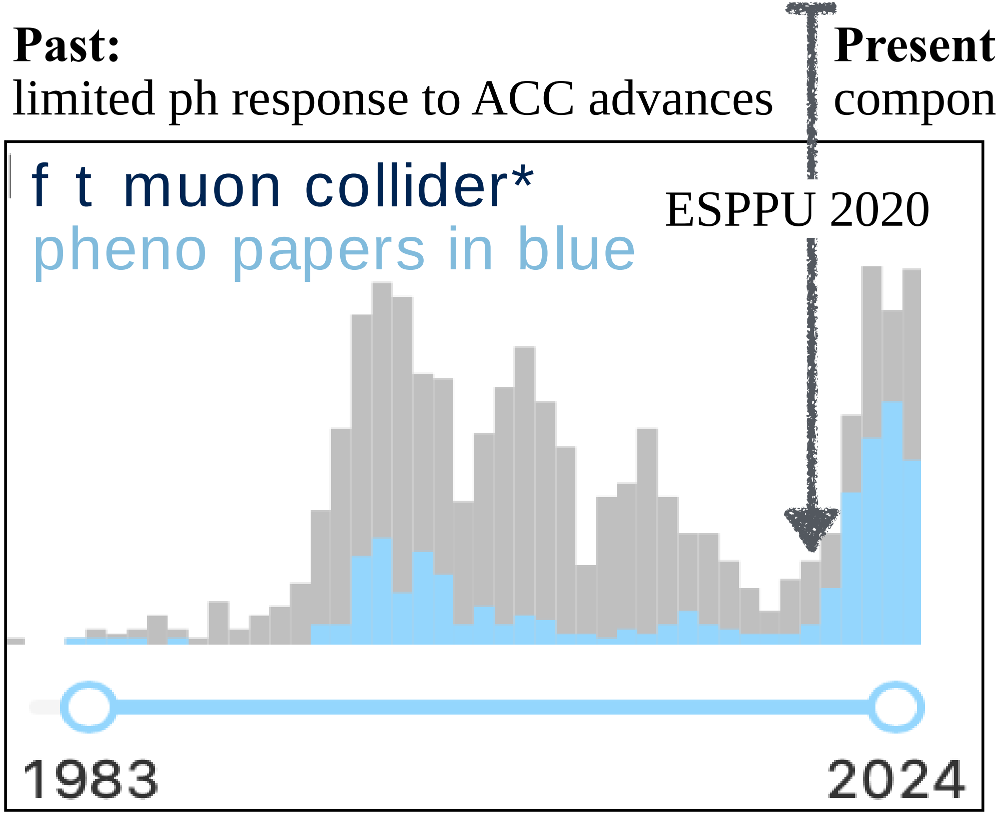
Muon Collider Physics Case

A. Wulzer

A Physics-Driven Collider

Past:
limited ph response to ACC advances

Present: hep-ph is dominant component of MuC papers



A. Wulzer
Muon Collider
Physics
Potential

Why this enthusiasm?

1. **Higgs-Electroweak** interplay at very high energy (AKA, the SM) is new frontier, as well as the origin or the solution to SM/BSM mysteries.
   → Need **high-energy leptonic** collisions
2. **Physicists need** the truly **novel** challenges/opportunities offered by a radically new type of particle collider

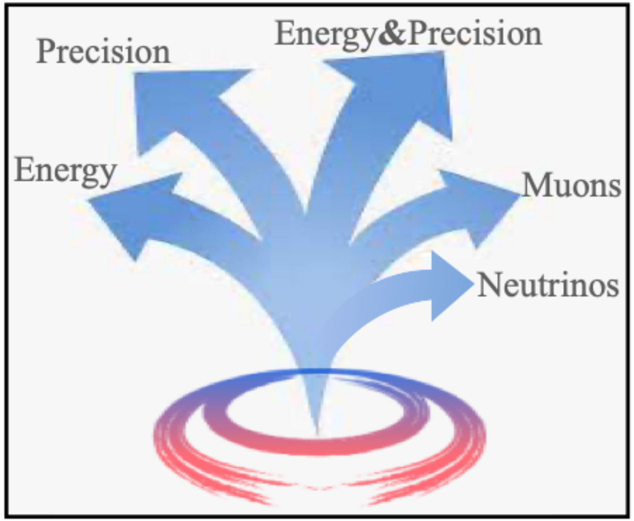
Physics case in short:

—***discover new particles*** *with presently inaccessible mass, including WIMP dark matter candidate*

—*discover cracks in the SM by the* ***precise study of the Higgs boson****, including the precise direct measurement of triple Higgs coupling.*

—***uniquely*** *pursue the quantum imprint of new phenomena in novel observables by* ***combining precision with energy****.*

—***unique access*** *to* ***new physics coupled to muons*** *and delivers* ***beams of neutrinos with unprecedented properties*** *from muons decay.*



Even shorter

—***unique probe of EW+Higgs in novel high-energy regime.***

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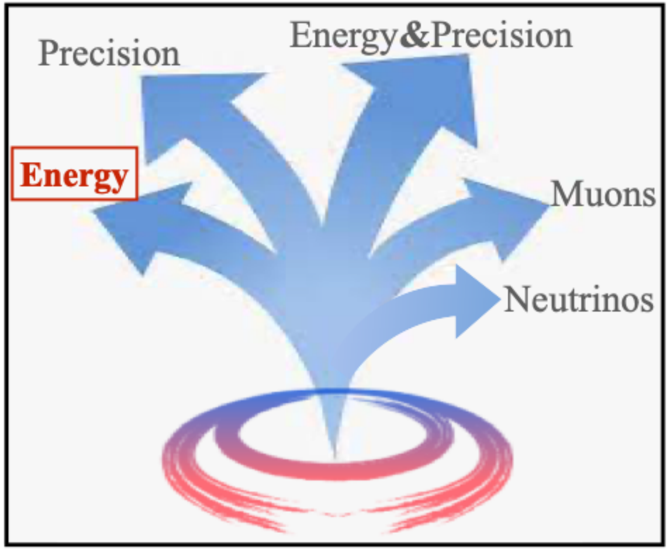
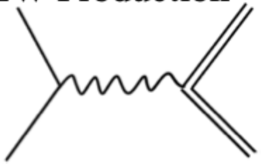
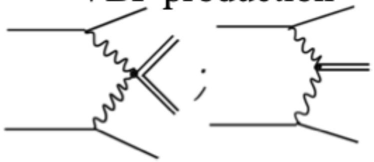
Physics
Potential

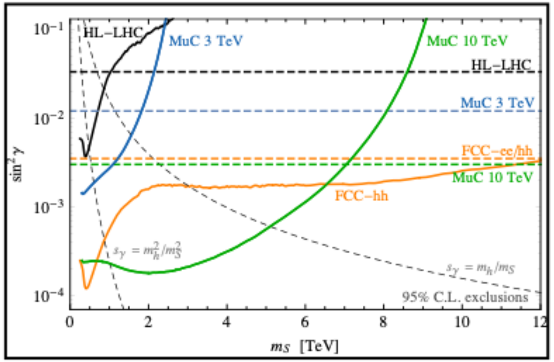


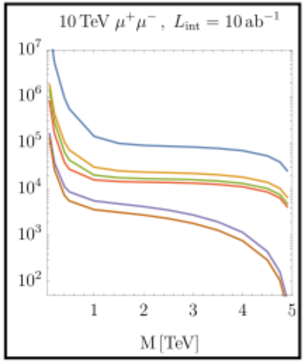
EW Production

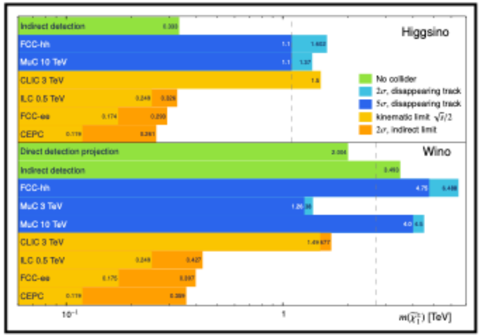


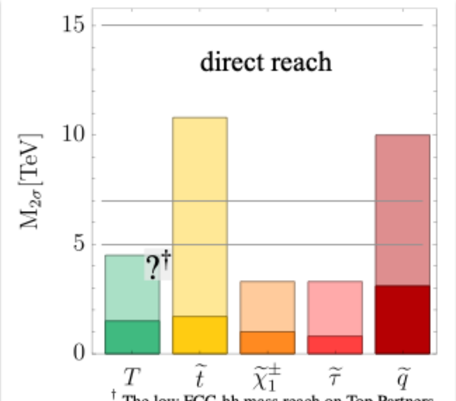
VBF production











† The low FCC-hh mass reach on Top Partners could be due to a non-optimal analysis

Discover new heavy particles …

… such as long-sought WIMP dark matter candidates

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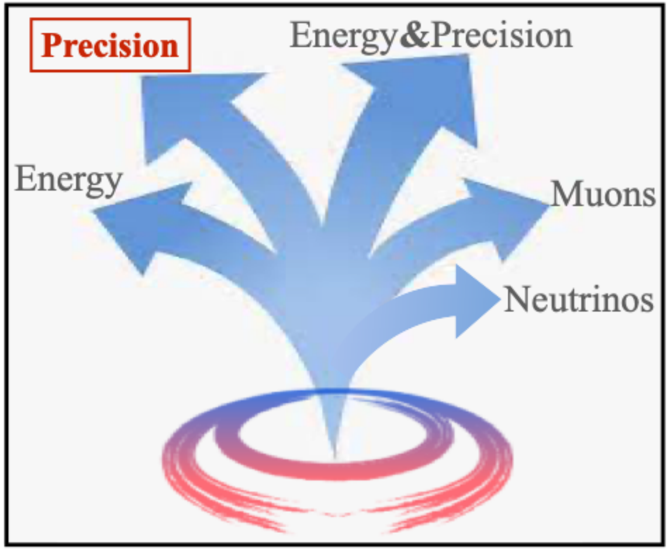
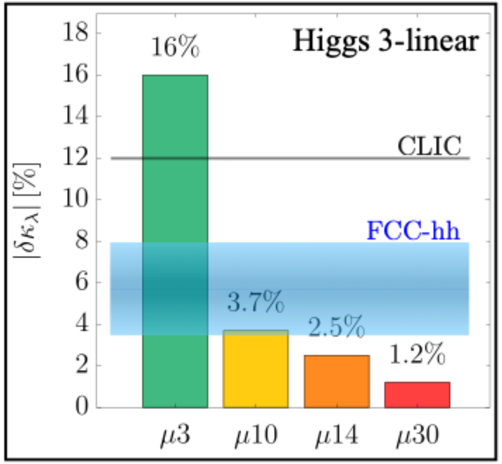
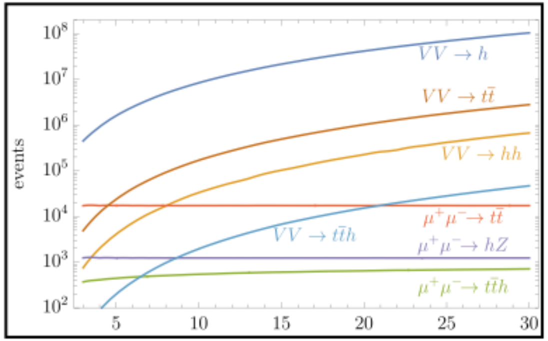
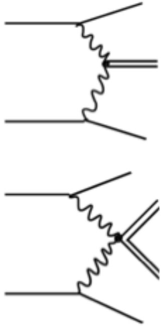
Physics
Potential





κ[%]	HL-LHC	HL-LHC +10 TeV	HL-LHC +10 TeV + ee
κ_W	1.7	0.1	0.1
κ_Z	1.5	0.4	0.1
κ_g	2.3	0.7	0.6
κ_γ	1.9	0.8	0.8
$\kappa_{Z\gamma}$	10	7.2	7.1
κ_c	-	2.3	1.1
κ_b	3.6	0.4	0.4
κ_μ	4.6	3.4	3.2
κ_τ	1.9	0.6	0.4
κ_t^*	3.3	3.1	3.1





10 M Higgs bosons produced → Permille-level precision on Higgs couplings

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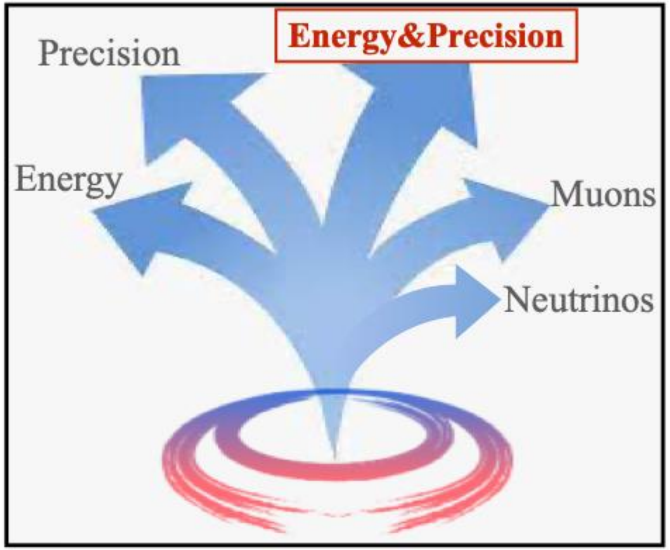
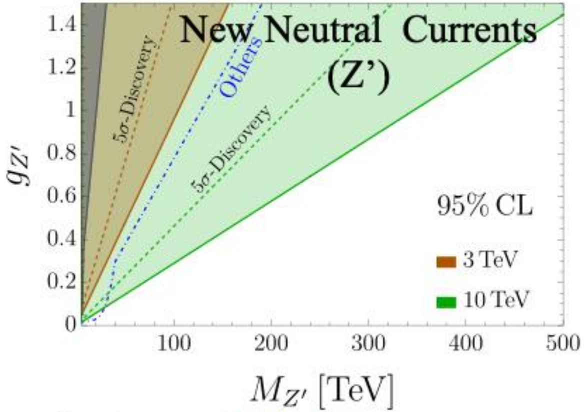
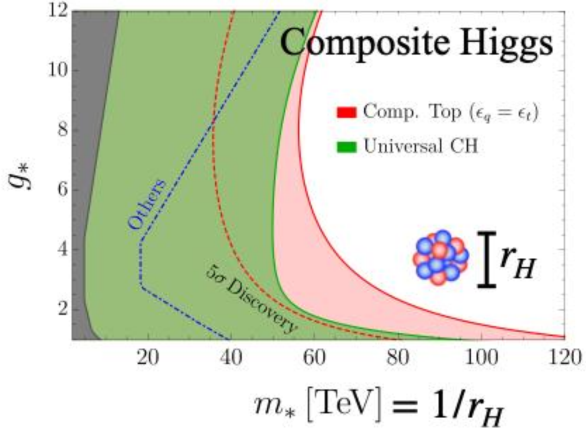
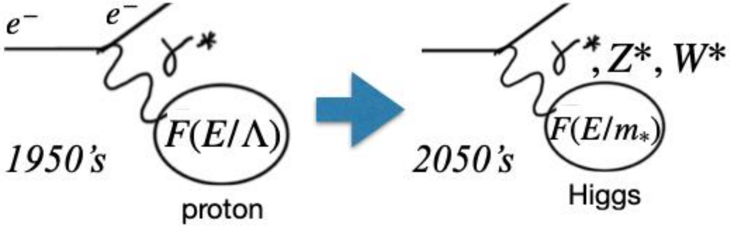
Muon Collider
Physics
Potential









Higher-energy observables are more sensitive to heavy physics:

$$\frac{\Delta\sigma(E)}{\sigma_{\rm SM}(E)} \propto \frac{E^2}{\Lambda^2_{\rm BSM}} \overset{[\text{say, } \Lambda_{\rm BSM} = 100\,\text{TeV}]}{=}$$

10^{-6} at EW [FCC-ee] energies

10^{-2} at muon collider energies

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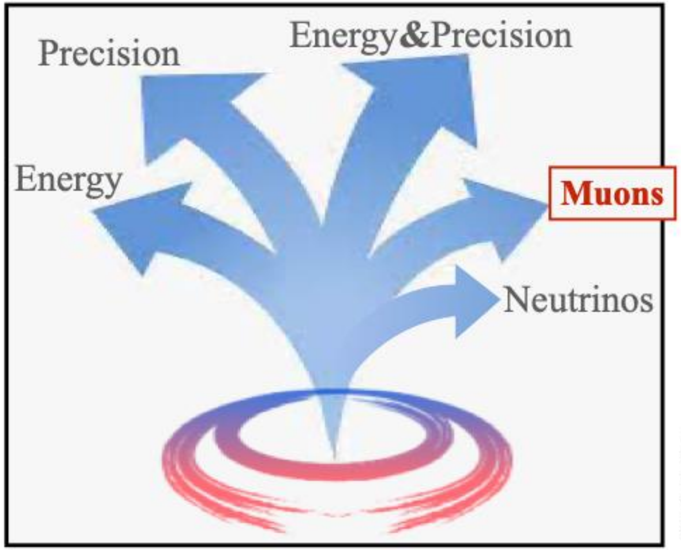
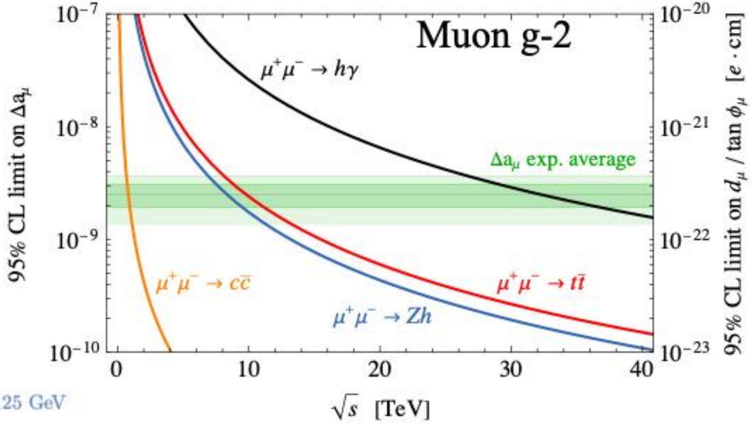
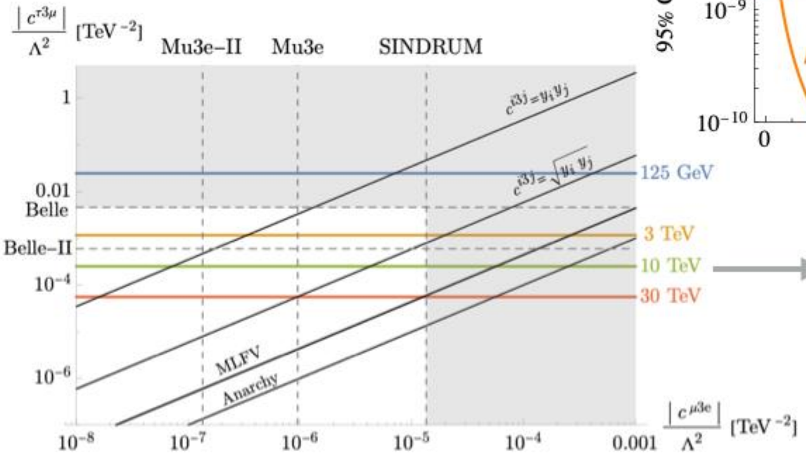
Physics
Potential



NP might couple primarily to muons because:

1. The Higgs does
   (so maybe NP in EWSB as well)
2. Possible connection with flavour
3. And because we haven't checked!





Complementarity with low-energy Lepton Flavour Violation probes

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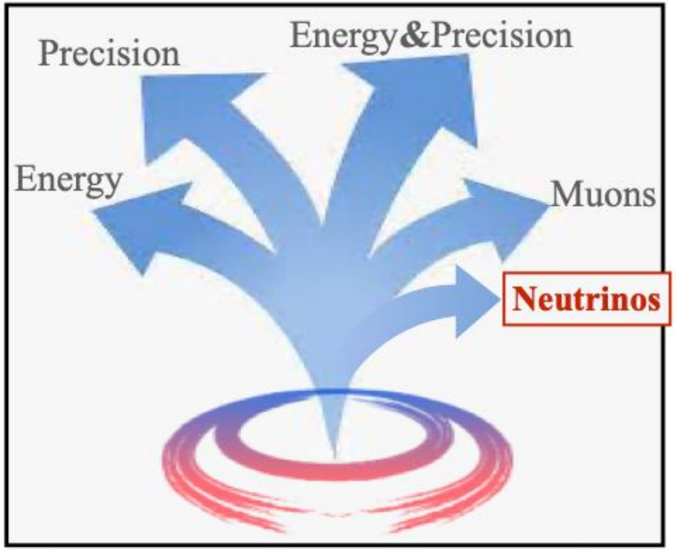
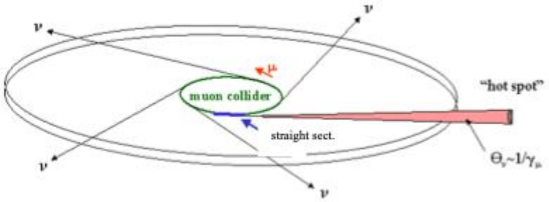
Physics
Potential



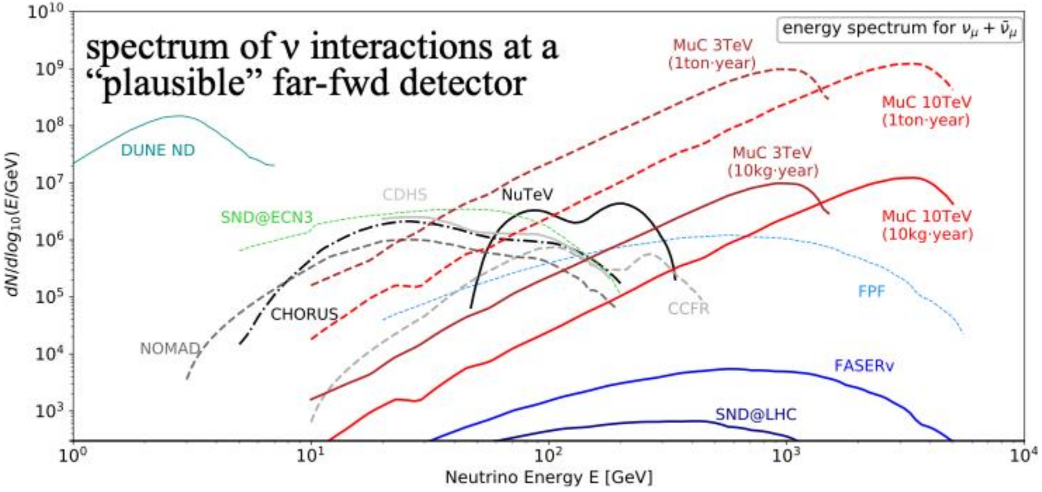


Muons decay to neutrinos:

Collimated, perfectly known, TeV-energy neutrino beams

First flux estimate with IMCC MuC beam appears in Interim Report

Still unexplored physics opportunities



Muon Collider Experiment Status

D. Lucchesi, F. Meloni

Reminder of target parameters

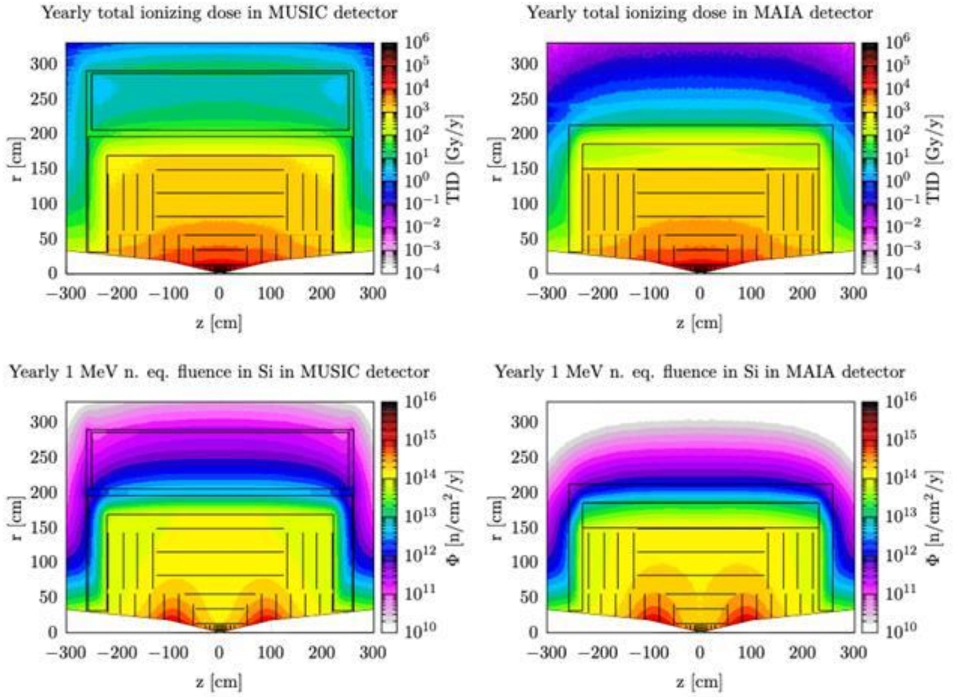
From interim report

Requirement	Baseline $\sqrt{s} = 3$ TeV	Baseline $\sqrt{s} = 10$ TeV	Aspirational
Angular acceptance ($\eta = -\log(\tan(\theta/2))$)	$\lvert\eta\rvert < 2.5$	$\lvert\eta\rvert < 2.5$	$\lvert\eta\rvert < 4$
Minimum tracking distance [cm]	~ 3	~ 3	< 3
Forward muons ($\eta > 5$)	–	tag	$\sigma_p/p \sim 10\%$
Track σ_{p_T}/p_T^2 [GeV^{-1}]	4×10^{-5}	4×10^{-5}	1×10^{-5}
Photon energy resolution	$0.2/\sqrt{E}$	$0.2/\sqrt{E}$	$0.1/\sqrt{E}$
Neutral hadron energy resolution	$0.5/\sqrt{E}$	$0.4/\sqrt{E}$	$0.2/\sqrt{E}$
Timing resolution (tracker) [ps]	$\sim 30 - 60$	$\sim 30 - 60$	$\sim 10 - 30$
Timing resolution (calorimeters) [ps]	100	100	10
Timing resolution (muon system) [ps]	~ 50 for $\lvert\eta\rvert > 2.5$	~ 50 for $\lvert\eta\rvert > 2.5$	< 50 for $\lvert\eta\rvert > 2.5$
Flavour tagging	b vs c	b vs c	b vs c, s-tagging
Boosted hadronic resonance ID	h vs W/Z	h vs W/Z	W vs Z

Status: radiation environment

BIB sets the requirements for radiation hardness of detector technologies.

- Expected in line with HL-LHC



Yearly total ionizing dose in MUSIC detector

Yearly total ionizing dose in MAIA detector

Yearly 1 MeV n. eq. fluence in Si in MUSIC detector

Yearly 1 MeV n. eq. fluence in Si in MAIA detector

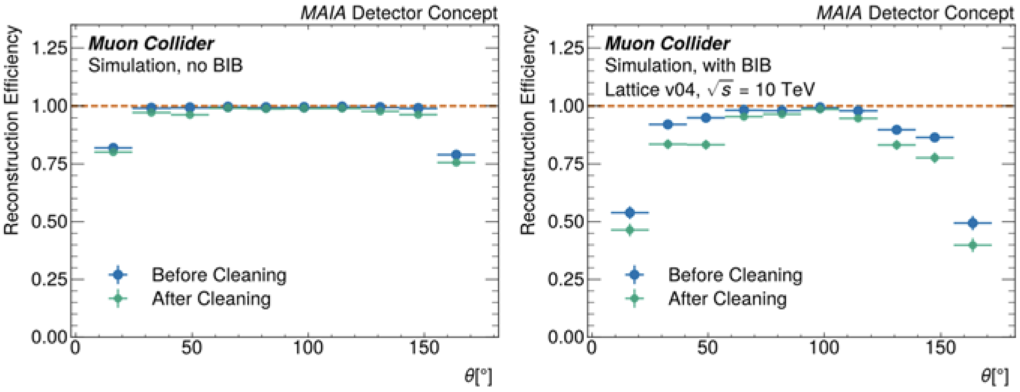
Status: tracking 1/2

BIB and incoherent pairs affect reconstruction performance via hit multiplicity.

Tracking performance well under control (using LHC CKF reconstruction)

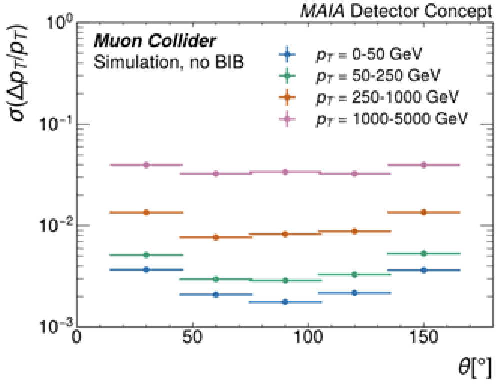
The main bottleneck in algorithmic execution time

- The O(5%) inefficiencies present in the current reconstruction are caused by the need of keeping the CPU time within O(minutes) per event.
  Track parameter resolutions (pT, d0, z0) are unaffected by BIB.
- Expected to improve with future computing hardware and seeding strategies

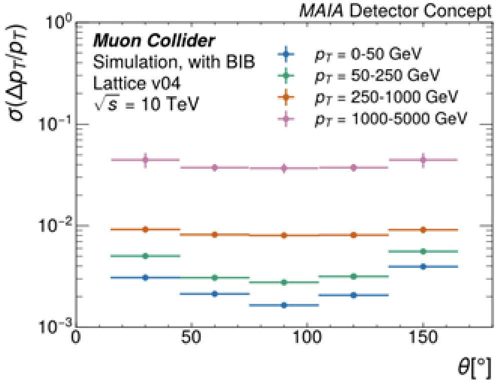


(a) No BIB (b) BIB

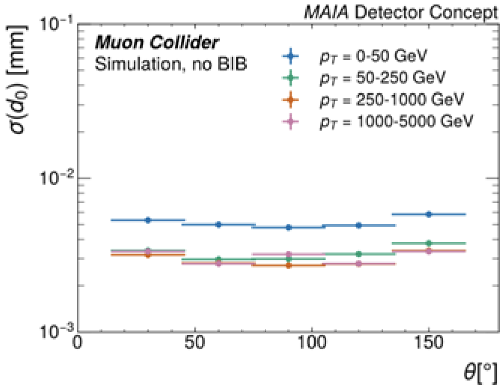
Status: tracking 2/2



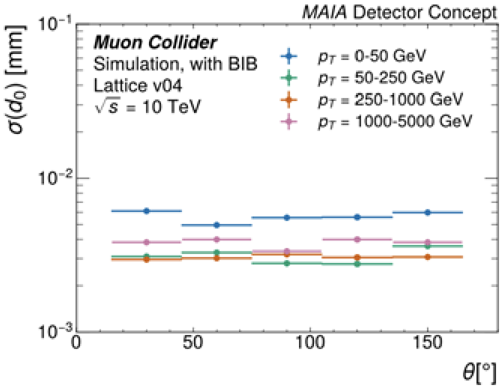
(a) No BIB



(b) BIB



(a) No BIB



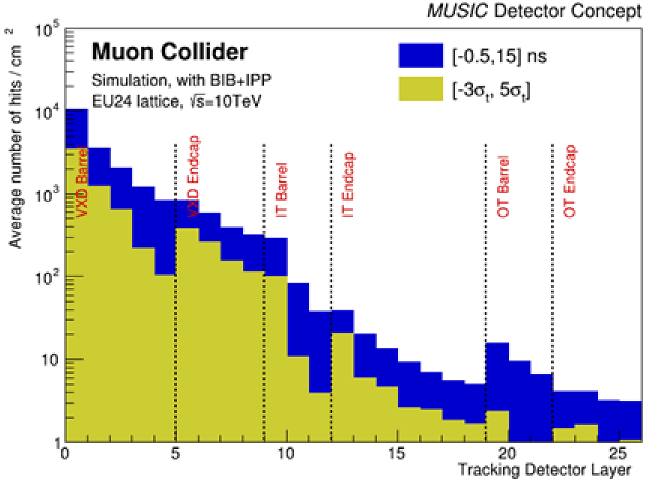
(b) BIB

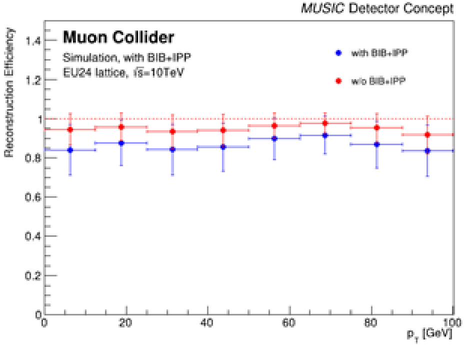
Status: MUSIC tracking efficiency

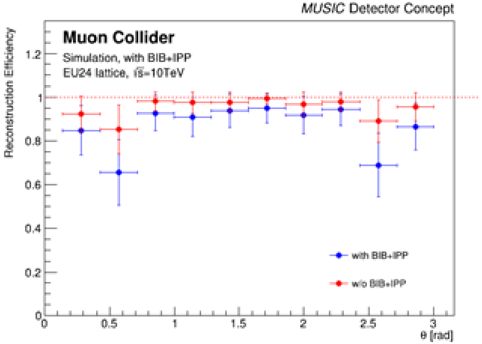
Tracking system optimized for a better coverage up to the nozzle angle.

Performance evaluated with **BIB** and **incoherent pair production (IPP) events** produced with Interaction Region version EU24 frozen for ESPPU.

Despite the high occupancy, track reconstruction optimized (not fully) to reach high performance.

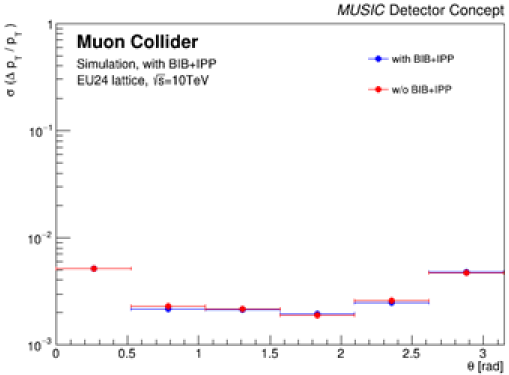






Status: MUSIC tracking performance

The resolution on track parameters are not impacted by the BIB presence.

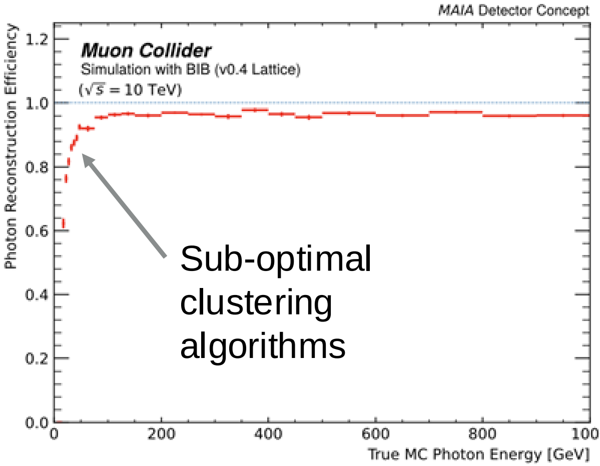


Status: Calorimetry 1/3

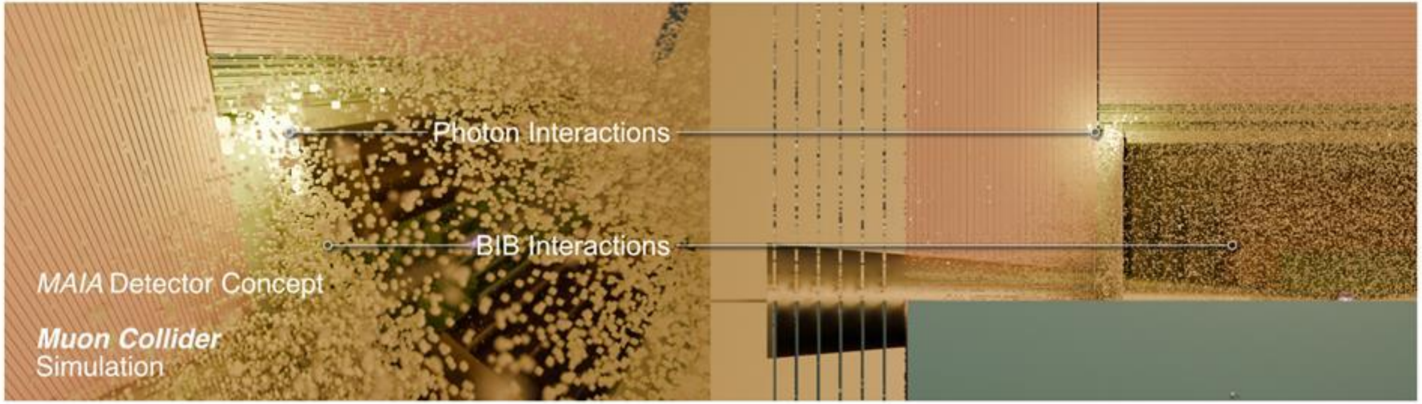
BIB impact on calorimetry more different across 10 TeV detector concepts

- Solenoid placement
- Technological choices - semi-homogeneous (MUSIS) vs sampling (MAIA)

Performance close to minimal targets, limited by reconstruction algorithms (most notably clustering and background subtraction)



Sub-optimal clustering algorithms



Status: Calorimetry 2/3

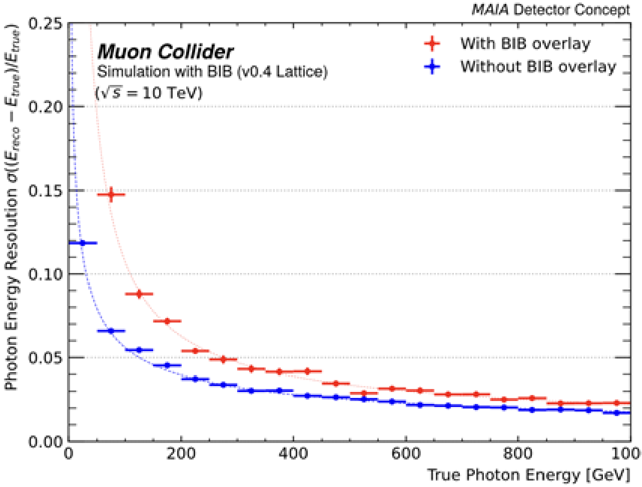
Lack of BIB subtraction (a-la-PUPPI) affect energy resolution.

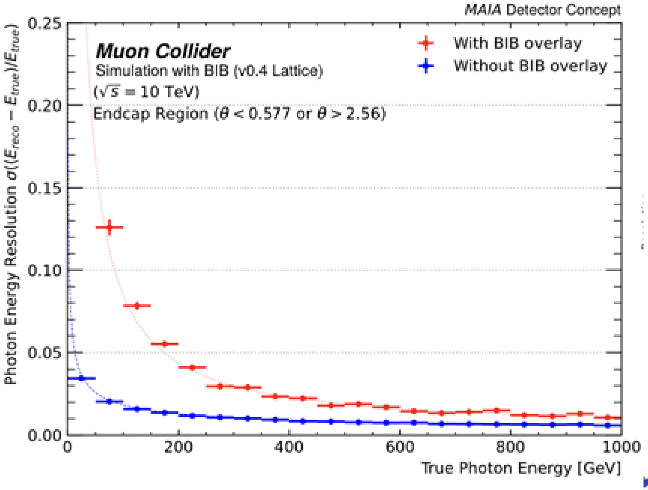
- Cell thresholds raised to counterbalance BIB effects, de facto decreasing the sampling fraction

Achieved performance close to baseline goals

- Expect to improve once advanced algorithms are implemented

Fit Params	Stochastic	Noise	Constant
No BIB	0.184	0.0	0.0
BIB	0.213	8.219	0.0





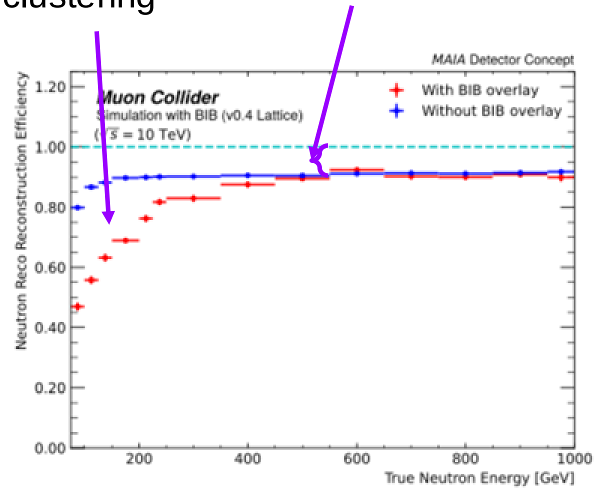
Status: Calorimetry 3/3

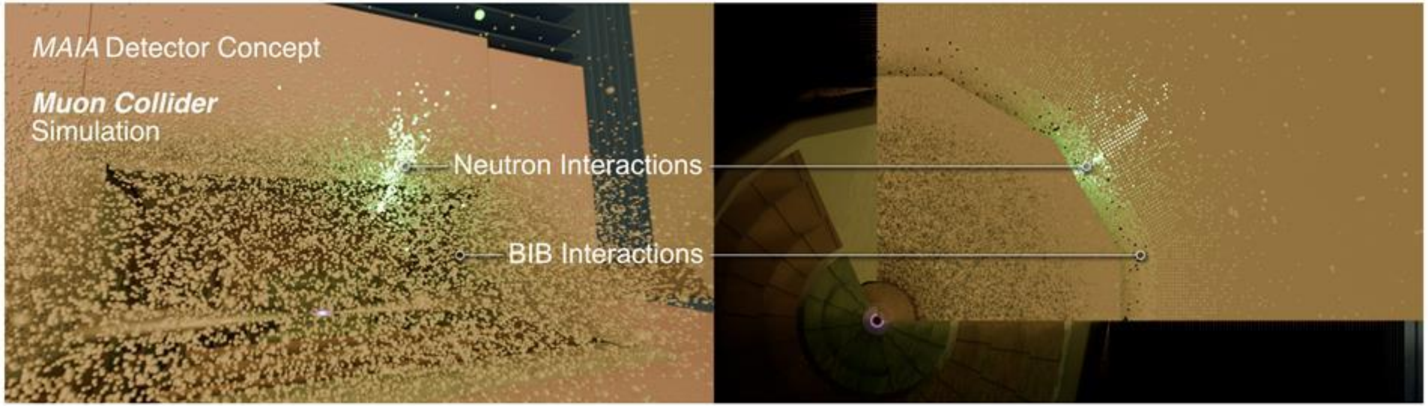
Neutral PFO reconstruction affected by same algorithmic limitations

- Forward region particularly challenging

Sub-optimal clustering

Acceptance at large theta



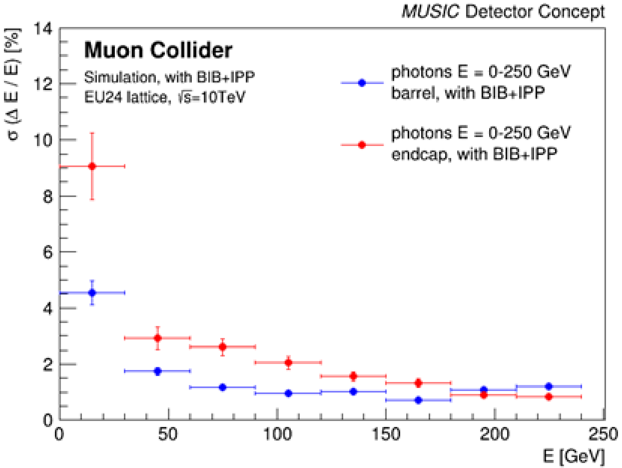


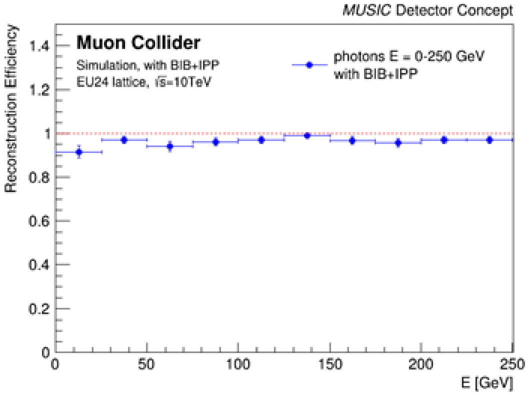
Status: MUSIC Calorimeter

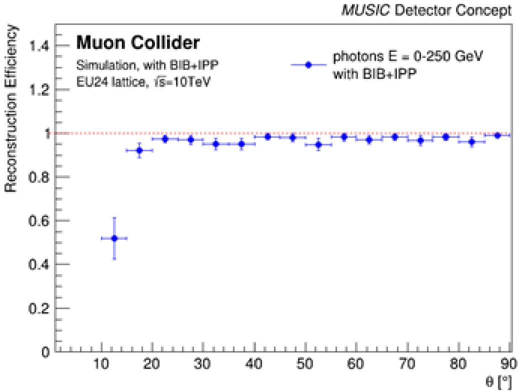
MUSIC calorimeter system:

- ECAL: CRILIN, *CRystal calorImeter with Longitudinal INformation* designed for MuC
- HCAL: Iron-scintillator sampling calorimeter common to other detectors

So far reconstructed: photons and electrons, jets in progress.



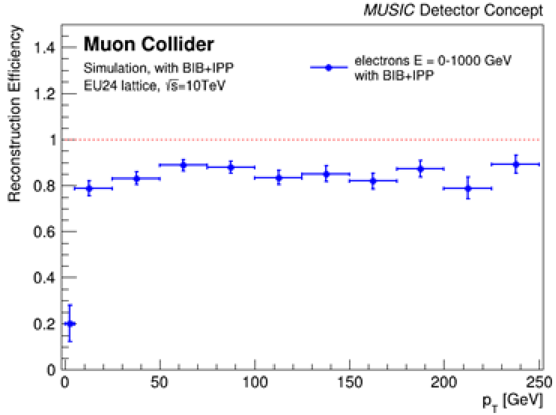


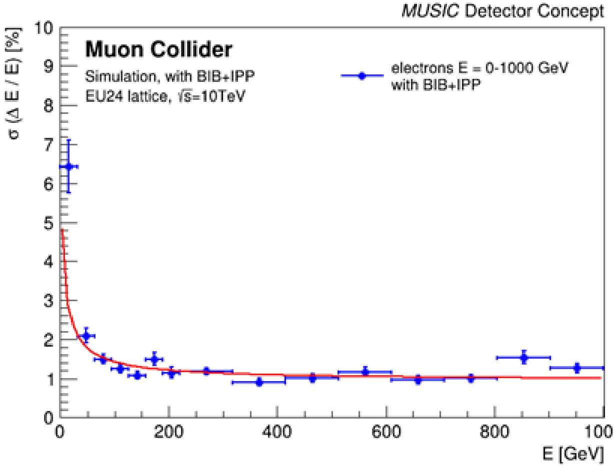


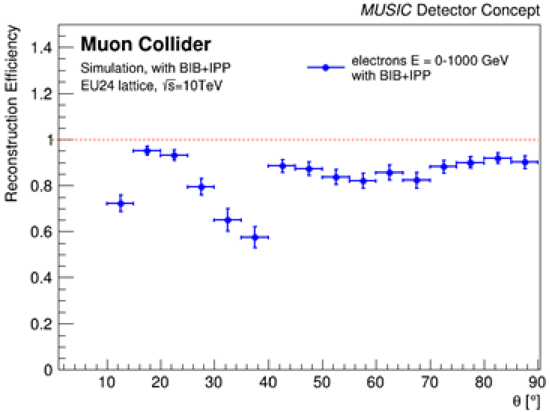
Status: MUSIC Calorimeter

The electron are reconstructed for the first time in muon collisions at 10 TeV CoM

Tracks reconstructed with ACTS are matched to a ECAL cluster by using PandoraPFA. The results show that even if not optimized (there is no Bremsstrahlung recovery yet) the MUSIC detector performs very well also for electrons







Status: muons and forward

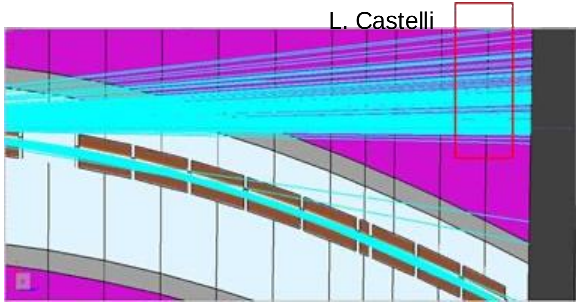
Muon systems are almost free from BIB contributions

- Performance at 10 TeV not yet studied in detail, as it is not expected to be a challenging task

Both concepts don't foresee a dedicated muon spectrometer but rather rely on inner detector tracks with a PID match from a barebones muon system placed beyond the HCAL

- Choice motivated by track resolution being dominated by inner tracker measurement across pT spectrum

Forward (~10 deg) and very forward (5 deg) regions require dedicated studies and development of detector concepts for which only initial studies have been performed.


L. Castelli

Plans

Ongoing work to update to latest collider lattice for ESPPU.

❿ BIB expected to have a harder energy spectrum, but final performance comparable (at the cost of a larger stress on computing resources)

Over the next several years, migrate reconstruction algorithms to fully exploit LHC know-how.

For example:

❿ CMS HGCAL clustering (CLUE)
❿ Local pile-up substraction -> BIB subtraction
❿ Multivariate/AI approaches to flavour tagging (for which we demonstrated only basic inputs)