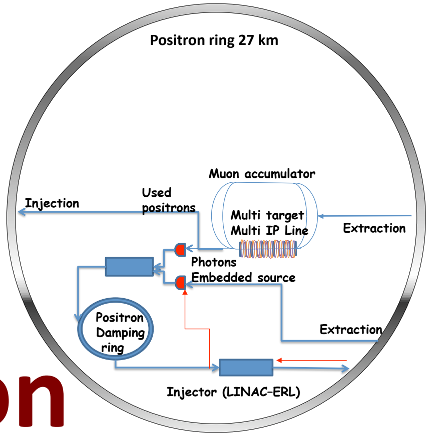
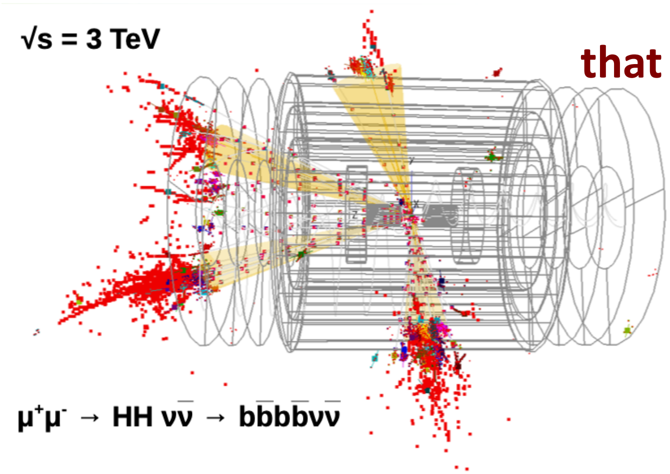
Giornate sulla European Strategy, 21-22 Settembre 2020, Roma



Muon Collider: International collaboration

Italian contributions and further steps under planning



to develop an integrated muon collider design concept that encompasses the physics, the detectors, and the accelerator

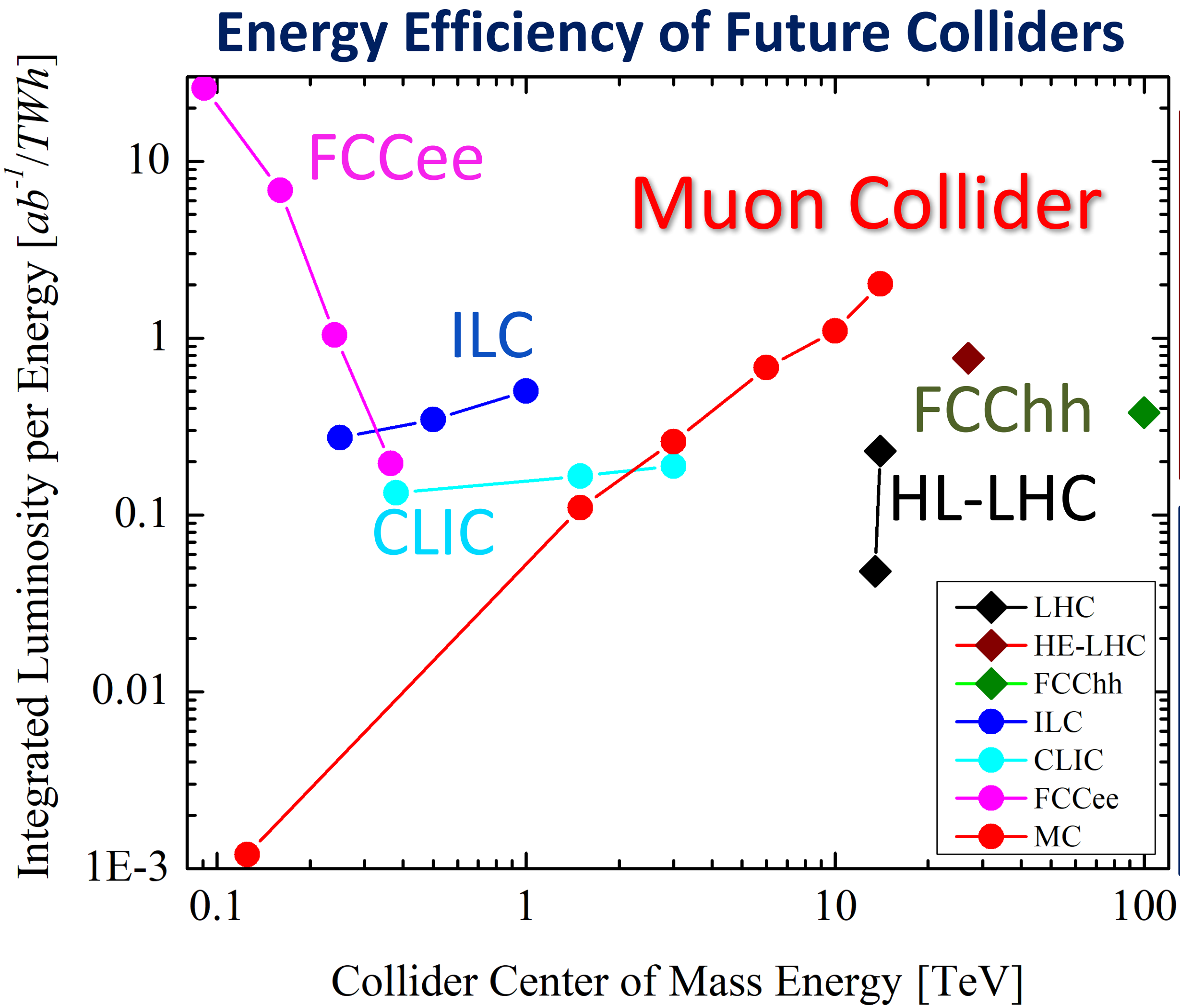
Nadia Pastrone

INFN TORINO

Dipartimento di Fisica – Roma Sapienza September 22, 2020

Why a multi-TeV Muon Collider?

arXiv:2007.15684 [physics.acc-ph]



Overwhelming physics potential:

- Precision measures
- Discovery searches

[Barbara Mele]

Challenging Machine Design:

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

[Alessandro Variola]

A long story… up to now and here!

- The **muon collider idea** was first introduced in **early 1980's** *[A. N. Skrinsky, D. Neuffer et al.,]*
- Idea further developed by a **series of world-wide collaborations**
- **US Muon Accelerator Program – MAP,** created in **2011,** was terminated in **2014**
  *MAP developed a **proton driver scheme** and addressed the feasibility of novel technologies required for Muon Colliders and Neutrino Factories* ***"Muon Accelerator for Particle Physics," JINST,*** *https://iopscience.iop.org/journal/1748-0221/page/extraproc46*
- **LEMMA (Low EMittance Muon Accelerator)** proposed in **2013** *[M. Antonelli e P. Raimondi]*
  *a new end-to-end design of a **positron driven scheme** presently under study by INFN-LNF et al. to overcome technical issues of initial concept* ➔ arXiv:1905.05747
- **CSN1 – RD_FA** new activity on Future Colliders ➔ 2015-2020
- **CERN-WG on Muon Colliders** since September 2017
- MAC discussion ➔ report
- Padova Aries2 Workshop on Muon Colliders – July 2018
- **Input document** submitted to ESPPU: "Muon Colliders" arXiv:1901.06150 December 2018 (*)
- LEMMA project presented to INFN Management by A. Variola in October 2019
- Various workshop/meeting to prepare for Granada (2019) and during ESPPU

FINDINGS and RECCOMENDATIONS (*):
Set-up an international collaboration to promote muon colliders
And **organize the effort on the development of both accelerators and detectors** and to define the road-map towards a CDR by the next Strategy update….
Carry out the R&D program toward the muon collider

EU Strategy → International Design Study

European Strategy Update – June 19, 2020:

3 High-priority future initiatives

High-priority future initiatives [..]In addition to the high field magnets the **accelerator R&D roadmap** could contain:
[..] an **international design study** for a **muon collider**, as it represents a unique opportunity to achieve a *multi-TeV energy domain beyond the reach of e^+e^-colliders*, and potentially within a *more compact circular tunnel* than for a hadron collider. The biggest challenge remains to produce an intense beam of cooled muons, but *novel ideas are being explored*;

European Large National Laboratories Directors Group (LDG) – July 2

LDG chaired by Lenny Rivkin

Agree to start building the collaboration for international muon collider design study

Accept the proposal of organisation

Accept the goals for the first phase

Daniel Schulte ad interim project leader

Strengthening cooperation and ensuring effective use complementary capabilities

Core team: N. Pastrone, L. Rivkin, D.Schulte

International Muon Collider Collaboration kick-off virtual meeting - July 3

(>250 participants) https://indico.cern.ch/event/930508/

Muon Collider collaboration: Objective and Scope

Objective:

In time for the next European Strategy for Particle Physics Update, the study aims to establish whether 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.

Deliverable:

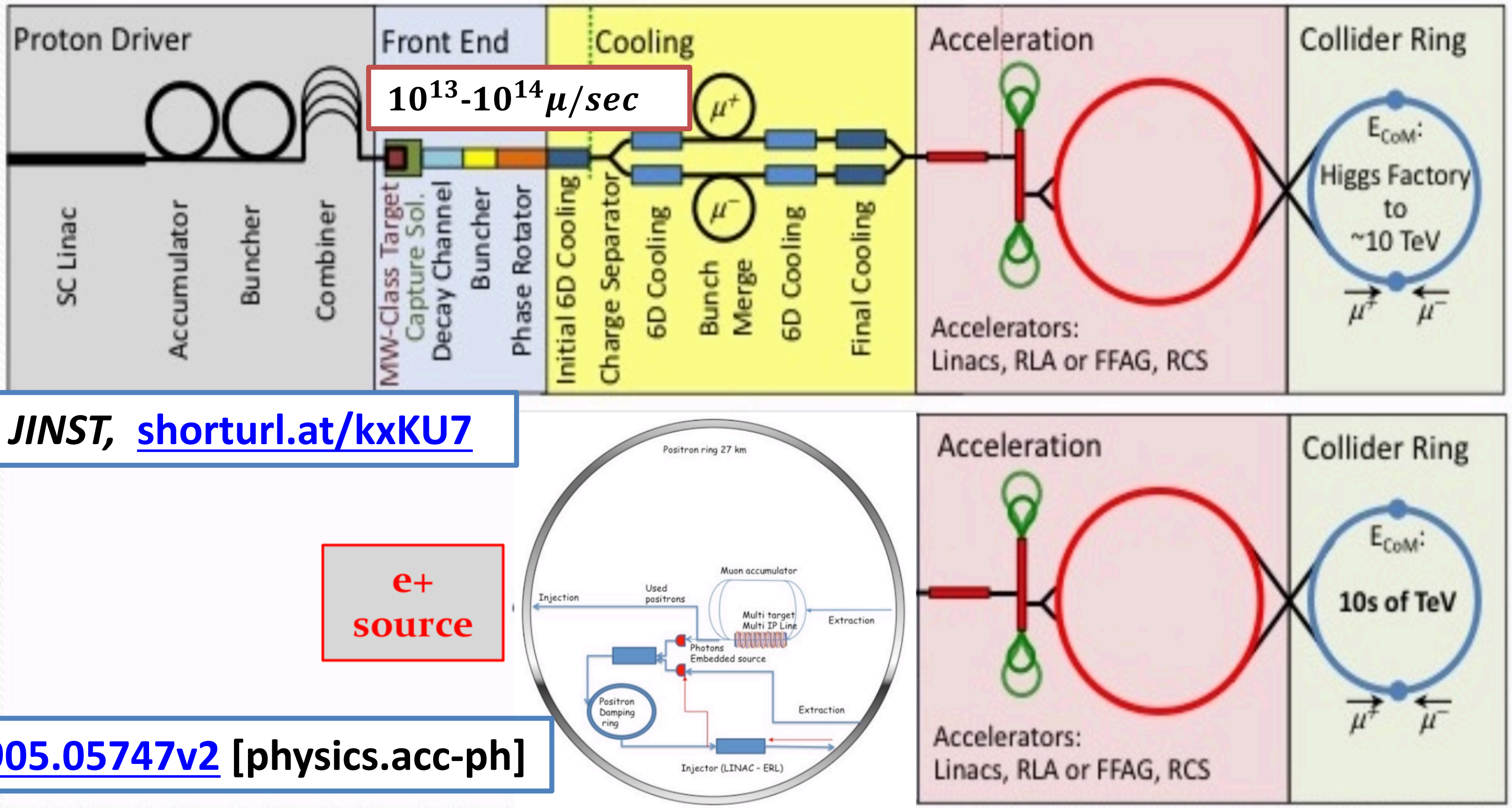
Report assessing muon collider potential and describing R&D path to CDR

Scope:

- Focus on two energy ranges:
  - 3 TeV, if possible with technology ready for construction in 10-20 years
  - 10+ TeV, with more advanced technology
- Explore synergy with other options (neutrino/Higgs factory)
- Define R&D path

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

MAP



MUON JINST, shorturl.at/kxKU7

LEMMA

e+ source

arXiv:1905.05747v2 [physics.acc-ph]

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

Tentative Target Parameters

Based on extrapolation of MAP parameters

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

Note:
The study should verify that these parameters can be met

Develop emittance budgets

$$\mathcal{L} = (E_{CM}/10\text{TeV})^2 \times 10\ \text{ab}^{-1}$$

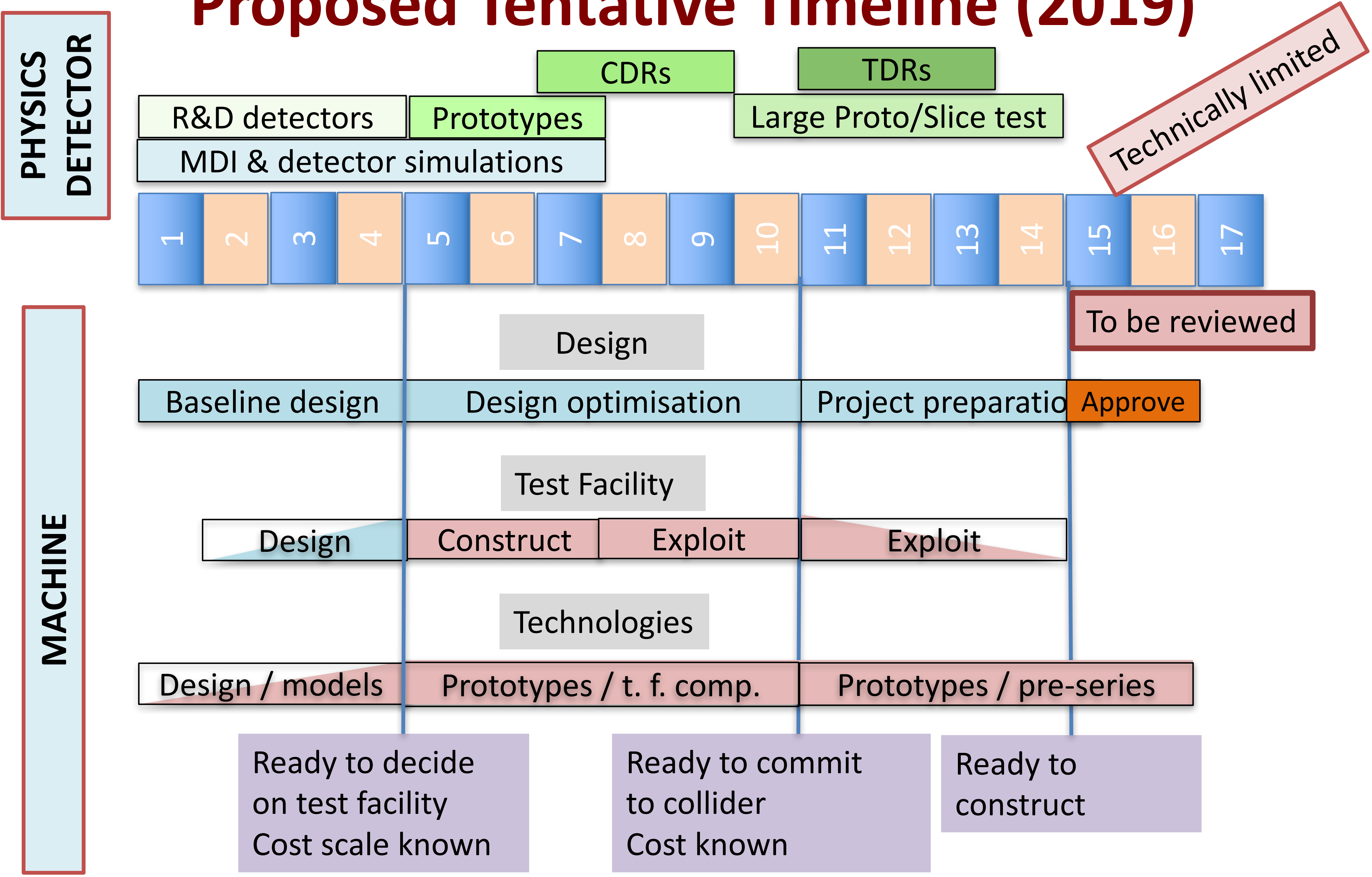
↓

@ 3 TeV ~ 1 ab^{-1} 5 years

@ 10 TeV ~ 10 ab^{-1} 5 years

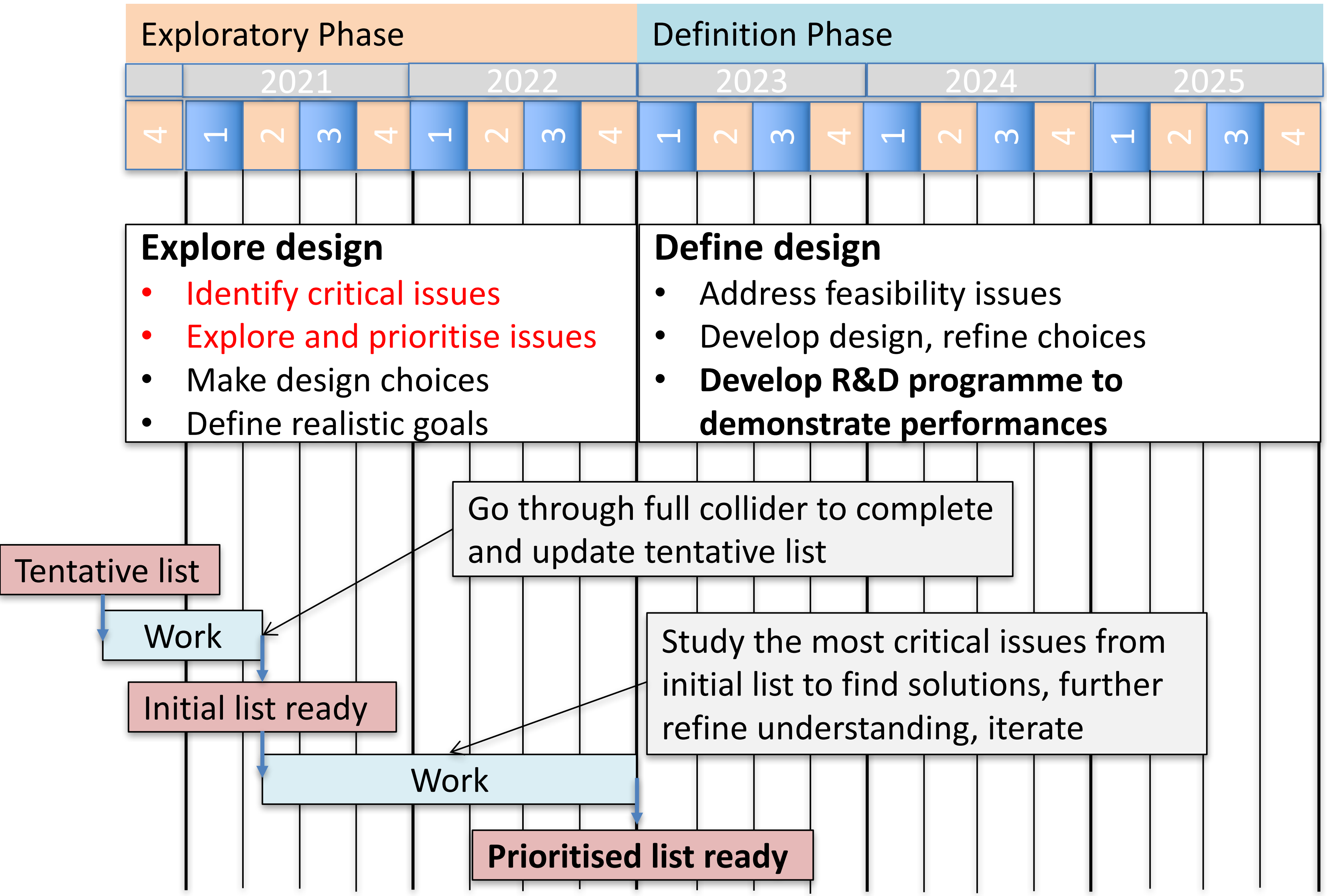
@ 14 TeV ~ 20 ab^{-1} 5 years

Proposed Tentative Timeline (2019)



Physics Briefing Book arXiv:1910.11775v2 [hep-ex]

Tentative Timeline - September 2020



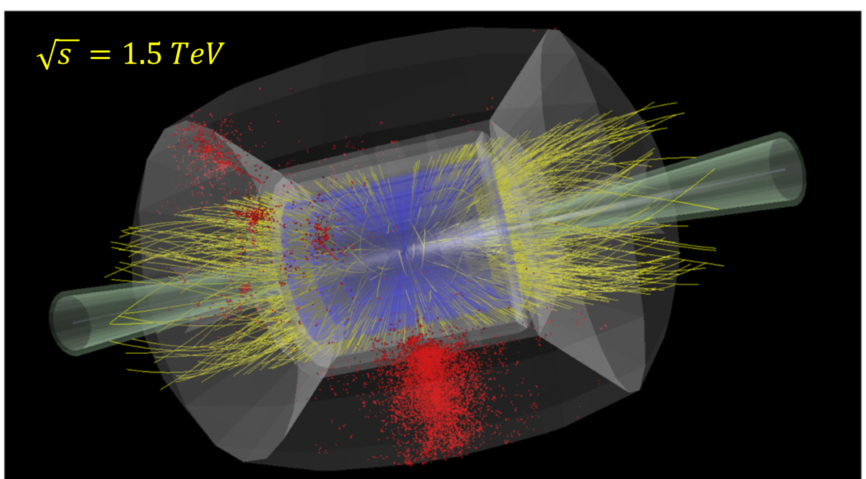
Exploratory Phase – Key Topics

- **Physics potential**
  - physics and detector study mandatory to assess the physics reach
- **Impact on the environment**
  - Neutrino radiation and its impact on the site
    ➔ require mitigation strategies for the highest energies
  - Power consumption (accelerating RF, magnet systems, cooling)
- **Impact of machine induced background** on the detector,
  ➔ might limit the physics reach – work in progress…
- **High-energy systems** that might limit energy reach or performance
  - Acceleration systems, beam quality preservation, final focus
- **High-quality beam production**
  - Target and target area
  - Cooling, in particular final cooling stage does not yet reach goal

Physics and Detector

Physics at 10+ TeV is in uncharted territor ➔ need important effort

- Physics case and potential under study, also in comparison to other options
- Need to include realistic assumptions about the detector performance:
  - use synergies with technologies that will be developed for other detectors
  - identify additional needs for muon collider ➔ R&D
- Main detector challenge in machine detector interface (MDI)
  - @ 14 TeV: 40,000 muons decay per m and bunch crossing
  - @ 3 TeV: 200,000 muons per m and bunch crossing



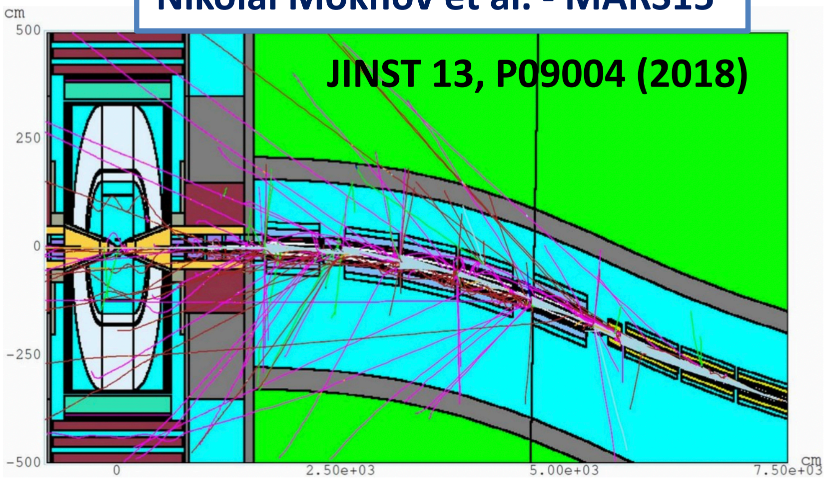
Detector must be designed for robustness

- effective masking
- high granularity
- fast timing
- clever algorithms

Detailed design of machine is required

Beam Induced background @ 1.5 TeV

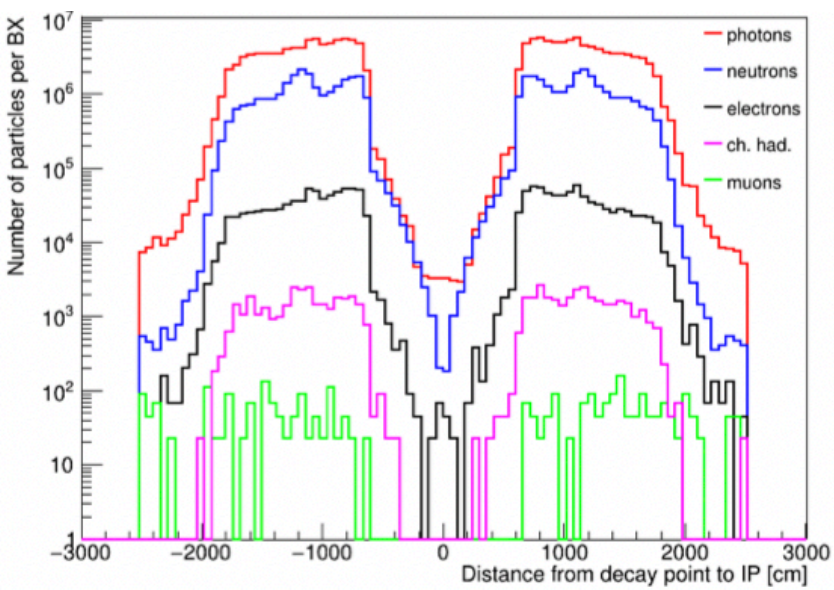
Nikolai Mokhov et al. - MARS15



JINST **15 (2020) 05, P05001**

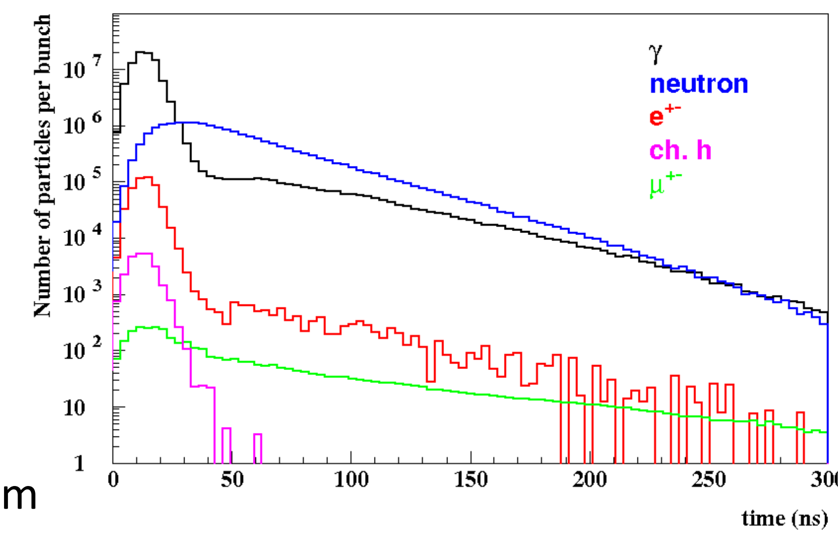
Beam muons decay products interact with machine elements and cause a continuous flux of secondary and tertiary particles (mainly γ, n, e±, h±) that eventually reach the detector

The amount and characteristics of the beam-induced background (BIB) depend on the collider energy and the machine optics and lattice elements



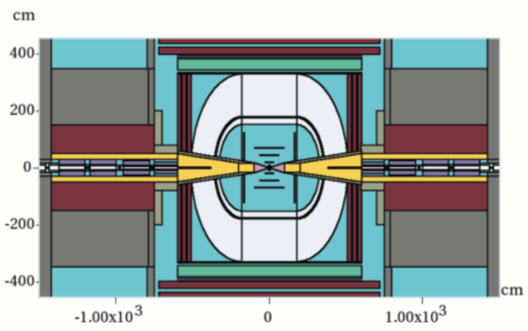
muon beams of **0.75 TeV** with **2×10^{12}muons/bunch**

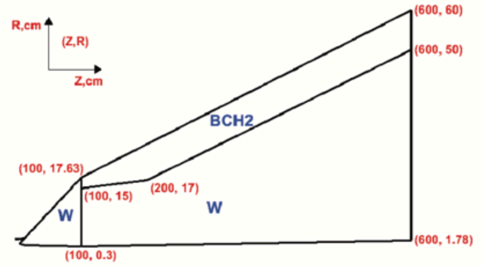
➔ **4×10^{5} muon decays/m** in single bunch crossing



Secondary and tertiary particles have low momentum and different arrival time in the Interaction Point

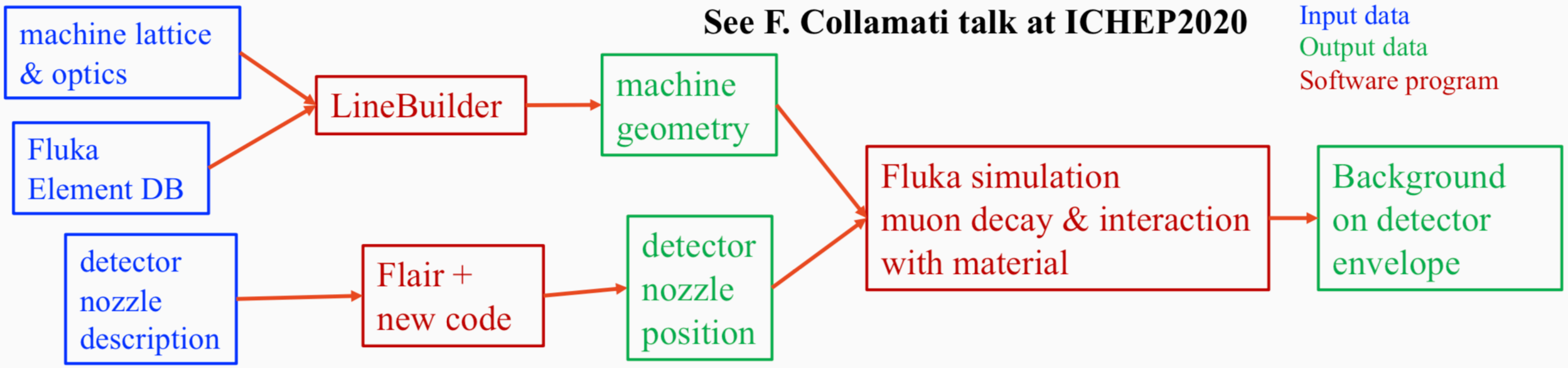
Machine Detector Interface

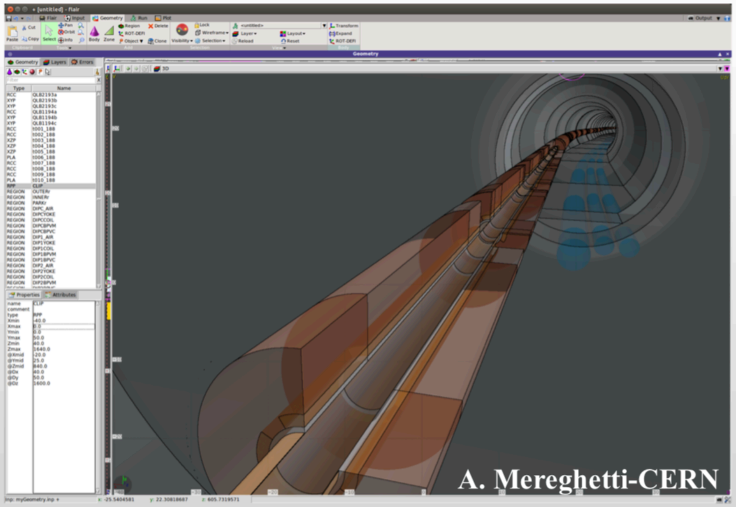


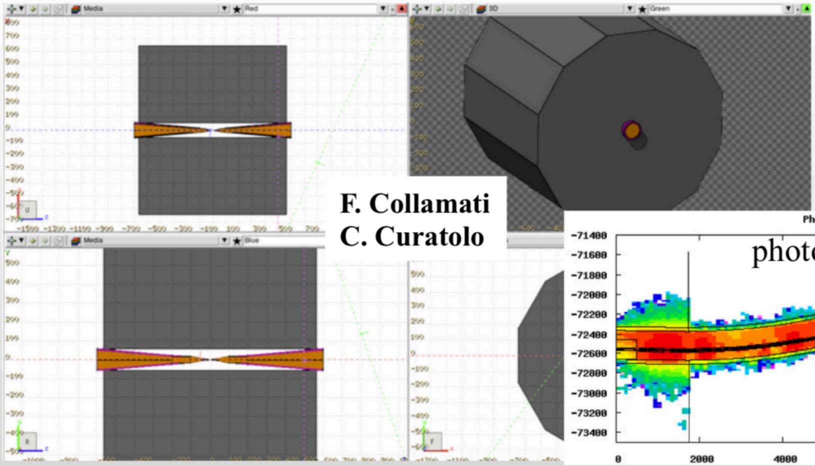


Need for a flexible tool from machine optics to simulation

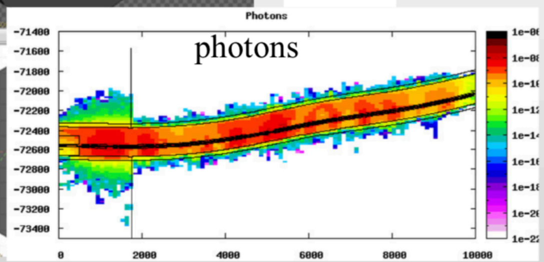
See F. Collamati talk at ICHEP2020







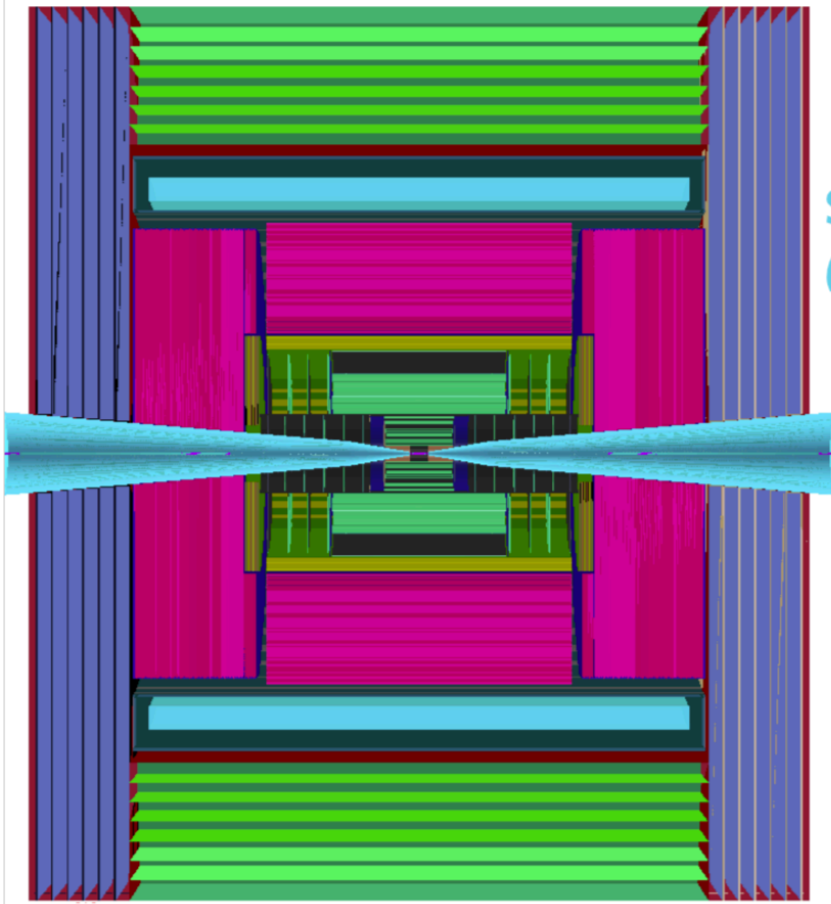
P. Sala

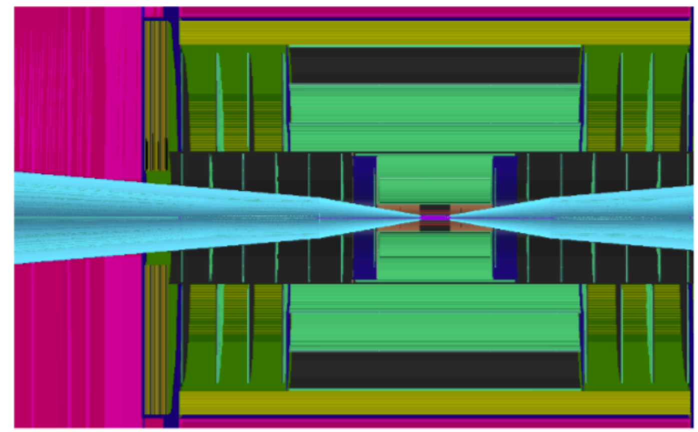


Experiment Design

Detector geometry derived from the CLIC design with a few optimisations:

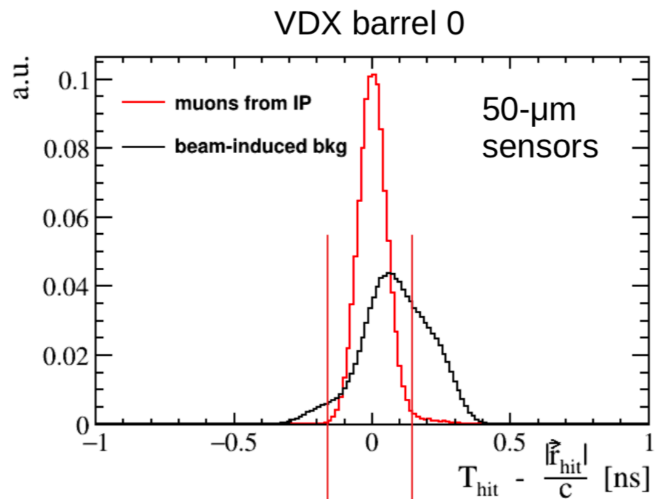
Vertex Tracker,	Inner Tracker,	Outer Tracker,	ECAL,	HCAL,	Muon Detector
(4 + 4×2) × 2	3 + 6×2	3 + 4×2	40	60	7 + 6×2

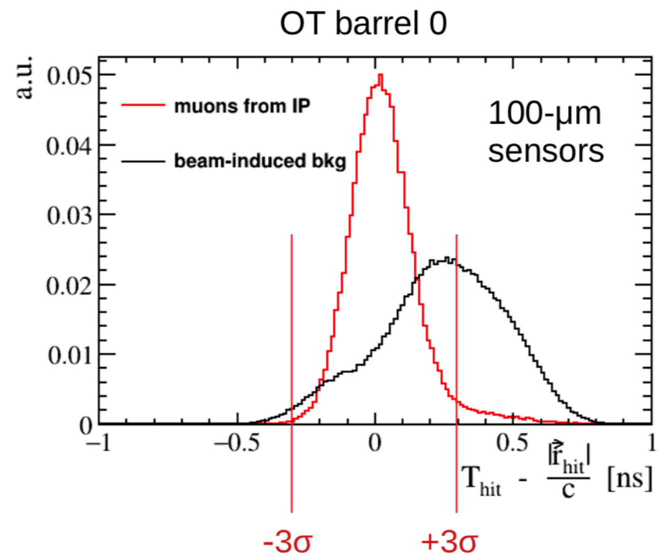




- inserted BIB-absorbing tungsten nozzles developed by MAP
- inner openings of endcap detectors increased to fit the nozzles
- optimised layout of the Vertex detector to reduce occupancy

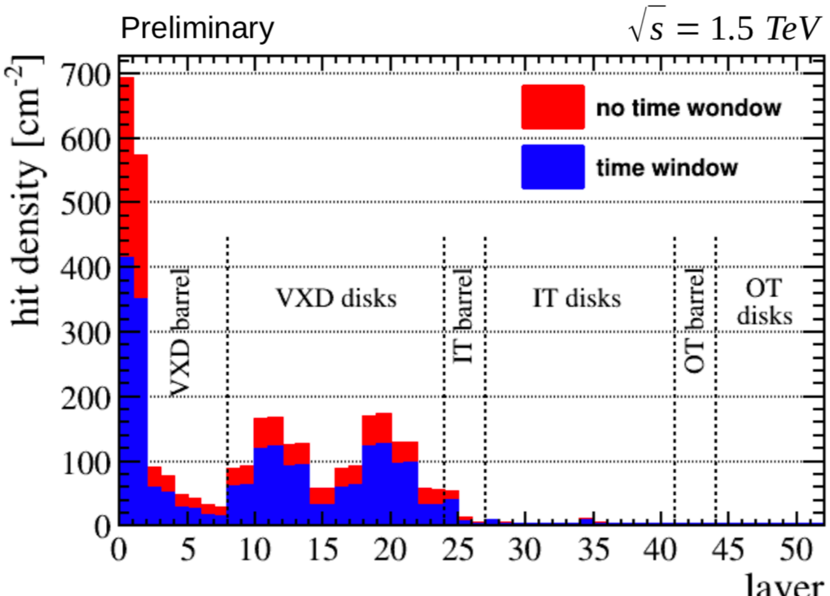
Tracking requirements





- ±150ps window at 50ps time resolution in the Vertex detector allows to strongly reduce the occupancy (by ~30%)

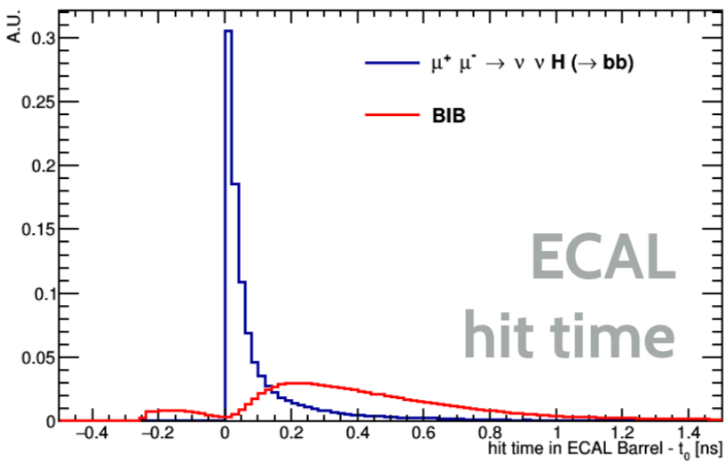
- Handles to reject spurious hits from BIB:
  - applying a time window to readout only hits compatible with particles originating from interaction region;
  - exploiting energy deposited in the tracker sensors (under development);
  - correlating hits on double-layer sensors (under development).

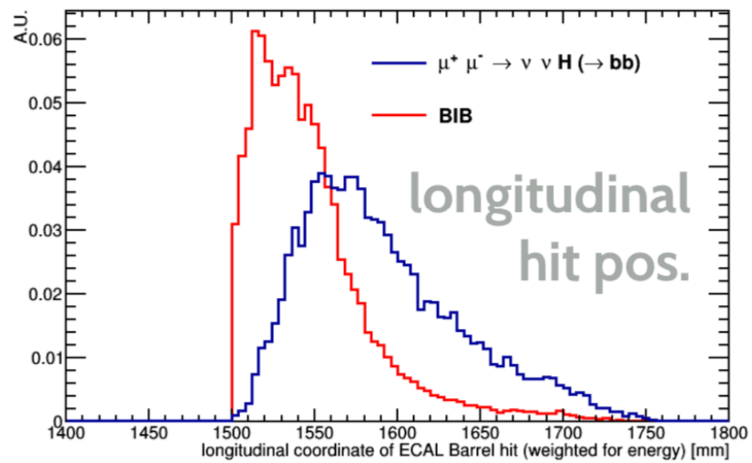


State of the art fast tracking sensors can push this even further: σ_t~10ps

Calorimeter optimization

Timing and longitudinal shower distribution provide a handle on BIB in ECAL





Various BIB mitigation approaches for ECAL can be studied

- possibly adding a preshower for absorbing the initial part of BIB in ECAL
- subtraction of BIB depositions using the hit time+depth information

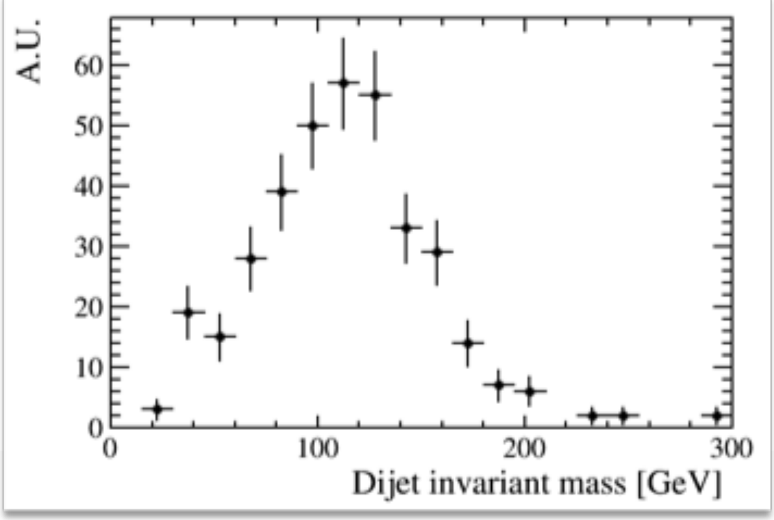
Hadronic showers have longer development time → timing not critical

- the most straightforward approach: evaluate the average BIB energy deposition and consider only energy deposits above the BIB level

Hbb @ 1.5 TeV

D. Lucchesi et al.

$\mu^+\mu^- \rightarrow H\nu\bar{\nu} \rightarrow b\bar{b}\nu\bar{\nu}$ + beam-induced background fully simulated



Higgs $b\bar{b}$ Couplings Results

- The instantaneous luminosity, $\mathcal{L}$, at different √s is taken from MAP.
- The acceptance, A, the number of signal events, N, and background, B, are determined with simulation.

$\sqrt{s}$ [TeV]	A [%]	ϵ [%]	$\mathcal{L}$ [cm^{-2}s^{-1}]	$\mathcal{L}_{int}$ [ab^{-1}]	σ [fb]	N	B	$\frac{\Delta\sigma}{\sigma}$ [%]	$\frac{\Delta g_{Hbb}}{g_{Hbb}}$ [%]
1.5	35	15	$1.25 \cdot 10^{34}$	0.5	203	5500	6700	2.0	1.9
3.0	37	15	$4.4 \cdot 10^{34}$	1.3	324	33000	7700	0.60	1.0
10	39	16	$2 \cdot 10^{35}$	8.0	549	270000	4400	0.20	0.91

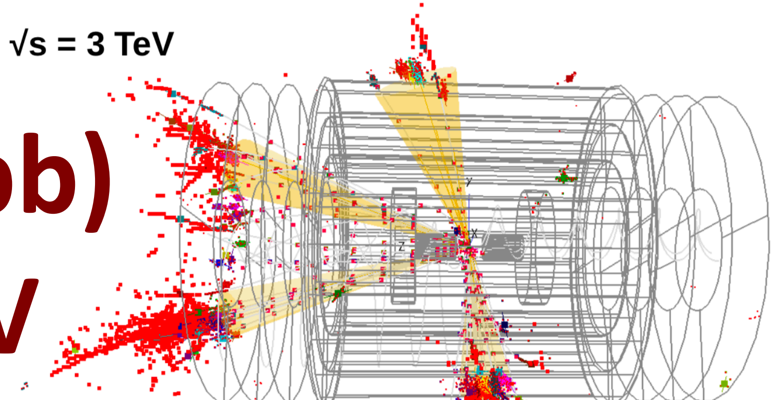
	$\sqrt{s}$ [TeV]	$\mathcal{L}_{int}$ [ab^{-1}]	$\frac{\Delta g_{Hbb}}{g_{Hbb}}$ [%]
Muon Collider	1.5	0.5	1.9
	3.0	1.3	1.0
	10	8.0	0.91
CLIC	0.35	0.5	3.0
	1.4	+1.5	1.0
	3.0	+2.0	0.9

CLIC numbers are obtained with a model-independent multi-parameter fit performed in three stages, taking into account data obtained at the three different energies.

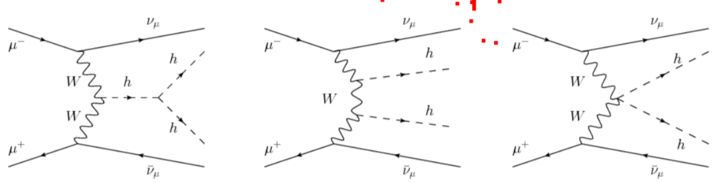
Results published on JINTST as Detector and Physics Performance at a Muon Collider

H(bb)H(bb) @ 3 TeV

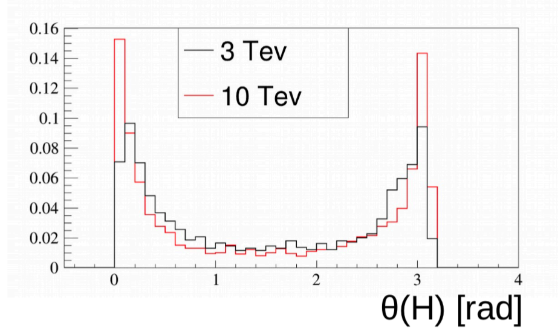
$\sqrt{s}$ = 3 TeV



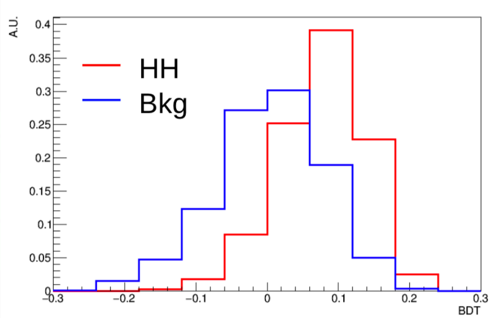
Talk by Massimo Casarsa on Detector → July 29 Future Detectors session
More info on detector in backup

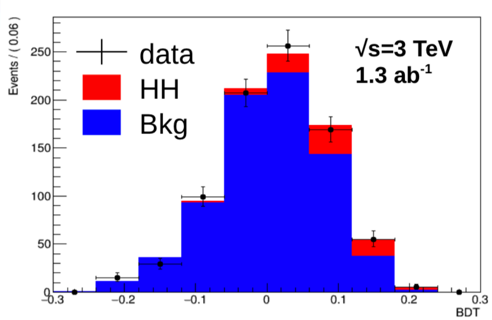


- Next step: **study of the HH production.**
- We are now using a **modified version of the CLIC detector**, with nozzles and a different vertex detector, using the ILCSoft framework for the full simulation and reconstruction.
- Signal and backgrounds are generated with WHIZARD.
- Higgs is likely to be emitted in the forward region.



PRELIMINARY





- As a first attempt to estimate the HH cross section uncertainty at 3 TeV, we applied the tagging efficiencies obtained in the 1.5 TeV case → **Again this is very conservative!**
- A 5-observable Boosted Decision Tree has been trained to separate signal from background.
- **With 1.3 ab^{-1} (4 years of data taking) at 3 TeV we expect to select 67 HH events and 745 background events.**
- With a simple fit to the BDT → **An uncertainty of 33% on the cross section** has been **obtained**.

Lorenzo Sestini @ ICHEP

Synergies in Italy, EU, USA….

- Meeting with the new group INFN-Acceleratori October 9
- Sygergy with **UFSD/LGAD R&D, TimeSPOT**
- **New approved EU RISE project: AMUSE** (with activities @ FNAL Muon Campus)
  - Donatella Lucchesi (Univ. PD) for Muon Collider with US Laboratories FNAL, BNL, SLAC
- To be evaluated: **AIDAinnova** on detector R&D
- To be evaluated: **I.FAST: MUST** – MUon colliders STrategy network
  (INFN, CERN, CEA, CNRS, KIT, PSI, UKRI)
- **Roadmap R&D Accelerators** coordinated by LDG
- **Roadmap R&D Detectors** coordinated by ECFA
- Many LoI submitted to SnowMass 2021:
  - Marica Biagini: LEMMA contact
  - Software tutorial SnowMass Muon Collider → **September 30 at 5pm CET**
    https://indico.fnal.gov/event/45187/ Software Contact: Donatella Lucchesi
  - **Planning Meeting SnowMass 5-8 ottobre** https://indico.fnal.gov/event/44870/

All invited to join!

- **International Collaboration:** MoU in preparation Plan presented to LDG
- Machine meeting started: September 14 Kick-off
- Soon planned to set-up an ad interim R&D Advisory Panel to work during the initial phase of the study as representing the activities and the communities
- Plan first project meeting in November
  - ✓ IMPORTANT e-group CERN
  - ✓ MUONCOLLIDER-DETECTOR-PHYSICS
  - ✓ MUONCOLLIDER-FACILITY
  - ✓ Indico: https://indico.cern.ch/category/11818/
  - ✓ Website: https://muoncollider.web.cern.ch/

Please register for the mailing lists
- Go to http://e-groups.cern.ch/
- Sign in with your institute

(find a list at the bottom of the sign-in page)
- Then search for “muoncollider”

RD_MUCOL is a group of about 90 physicists/engineers

Activities:

- LEMMA studies and other machine technologies to be further discussed and agreed
- Physics and detector simulations
- Detector R&Ds
- Targets simulations and R&Ds and crystals for targets and beam manipulation
- MDI studies

extras

extras

Ongoing activities: Physics-Experiment

International Muon Collider Design Study, CERN, July 3, 2020

- **Physics Motivation**

Direct/indirect discovery reach – VBF and VBS – precise Higgs measurements

A.Costantini, M.Chiesa, R.Franceschini, F.Maltoni, B.Mele, F.Piccinini, A.Wulzer et al. ++

Quartic Higgs self-coupling: arXiv:2003.13628 [hep-ph]

Vector Boson Fusion: arXiv:2005.10289 [hep-ph]

Benchmarks at different energies steer machine parameters and experiment design

- **Experiment and Physics Validation**

Flexible framework - background simulation, detector simulation and event reconstruction in use to study detector requirements/performances at different center of mass energies

First full-simulation study $\mu\mu \to H\nu\overline{\nu} \to b\overline{b}\nu\overline{\nu}$ @ $\sqrt{s} = 1.5\ TeV$ J. Inst. 15 P05001, 2020

D.Lucchesi et al. + US-MAP + CLICdp *the core team is growing + SnowMass21 interest*

➔ **Machine Detector Interface:** beam induced background shaped by machine optics design at different energies sets constraints on nozzles and experiment design and performances

10+ TeV is a completely new regime to explore!

Ongoing activities: Experiment-Detectors

- **Experiment Design and Detector R&D**

  Flexible framework to study detector requirements/performances at physics benchmarks
  R&D to exploit state of the art "5D" detectors and beyond are mandatory
  but in synergy with the on-going upgrade of existing experiments and new
  on-going developments with national and international grants

  INFN experts and infrastructures cover many crucial area of interest to be explored:

  – Sensors and read-out for trackers + timing (DMAPS, LGAD…)
  – Calorimeter developments
  – Exploit new ideas for muon detection
  – Common software tools for simulation and reconstruction also ML techniques

P. Andreetto, N. Bartosik, A. Bertolin, L. Buonincontri, M. Casarsa, F. Collamati,
C. Curatolo, A. Gianelle, D. Lucchesi, N. Pastrone, C. Riccardi, P. Sala, L. Sestini, I. Vai
++ al. joining

Strong synergy within the **new submitted EU project AIDAinnova**

Ongoing activities: MDI - Machine

- **Machine Detector Interface**

  Optics design required as part of the collider parameters studies. Fix constraints on nozzles design. Simulation tools. Strong collaboration with CERN.

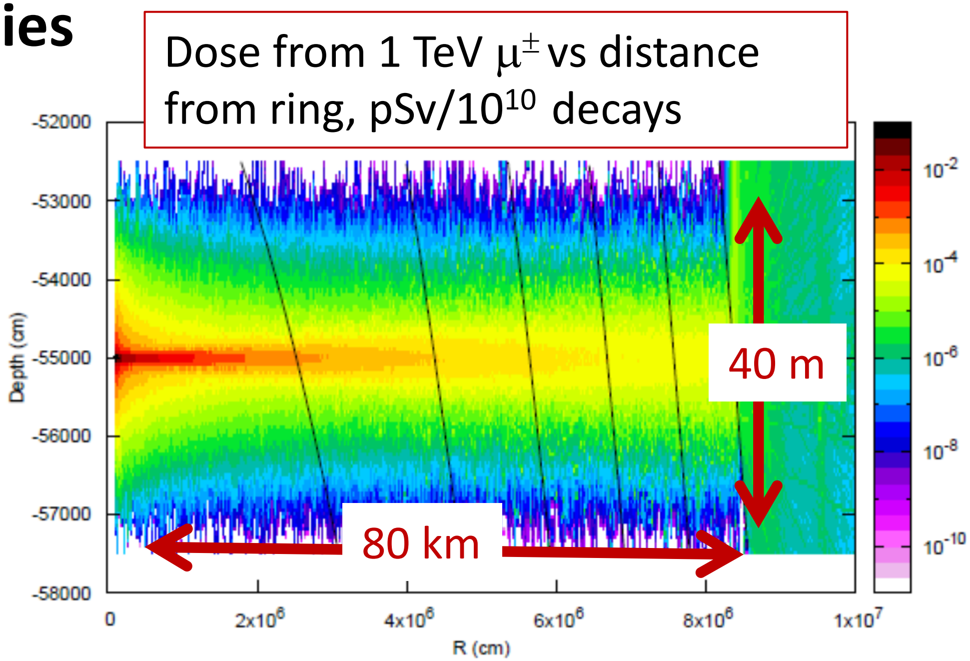
  F.Collamati, et al. + A.Mereghetti CERN

-

- **Neutrino Radiation Hazard Studies**

  Preliminary full FLUKA simulation:
  μ decay (ring/straight sections),
  ν interactions. Checked scaling law.
  Next: simulations with realistic ring geome
  and new orbits design.
  Strong collaboration with machine design.

  Alfredo Ferrari, Anna Ferrari, P. Sala et al.



Ongoing activities: LEMMA Source

- **Positron-based Muon Source – LEMMA**

Positron production and acceleration, muon targets, muon accumulation

M.Antonelli, M.E.Biagini, M.Boscolo, S.Guiducci, P.Raimondi, A.Variola et al.
arXiv:1905.05747v2 [physics.acc-ph] ➔ paper in preparation

- Positron source studies – collaboration with IJCL *+ A.Bacci, I.Drebot et al.*

  also on crystal applications: *L.Bandiera, A.Mazzolari et al.*

- Material simulations and studies for positron and muon production targets

  M.Antonelli, R.Li Voti, G.M. Cesarini et al. + PoliTO + other interested

  measurements and R&D planned using beam at LNF and CERN

- Muon accumulator optics and multi-target new layout *+ O.Blanco, A. Ciarma*:

  FFAG – with UK multibend-achromat – with ESRF Phys. Rev. Accel. Beams 23, 051001

- CERN test beam to evaluate targets and emittance *J. Inst.* **15** P01036, 20

  ➔ new proposal to run at CERN in 2022 with improved set-up

  + N.Amapane, F. Anulli, A.Bertolin, M.Zanetti et al.

Resource plan towards a pre-CDR submitted by Alessandro Variola (10/19)

need consolidation to prove feasibility

to overcome technical limitations and reach higher muon intensities

Interests: Machine

- **Fast-ramping SC magnet systems for accelerator ring**
  L.Rossi, P.Fabbricatore, S.Farinon, R.Musenich, M.Sorbi, M.Statera et al.

- **Material studies for targets**

- **Crystals manufacturing for targets and collimation**

Strong synergy within the **new submitted EU project I.FAST**

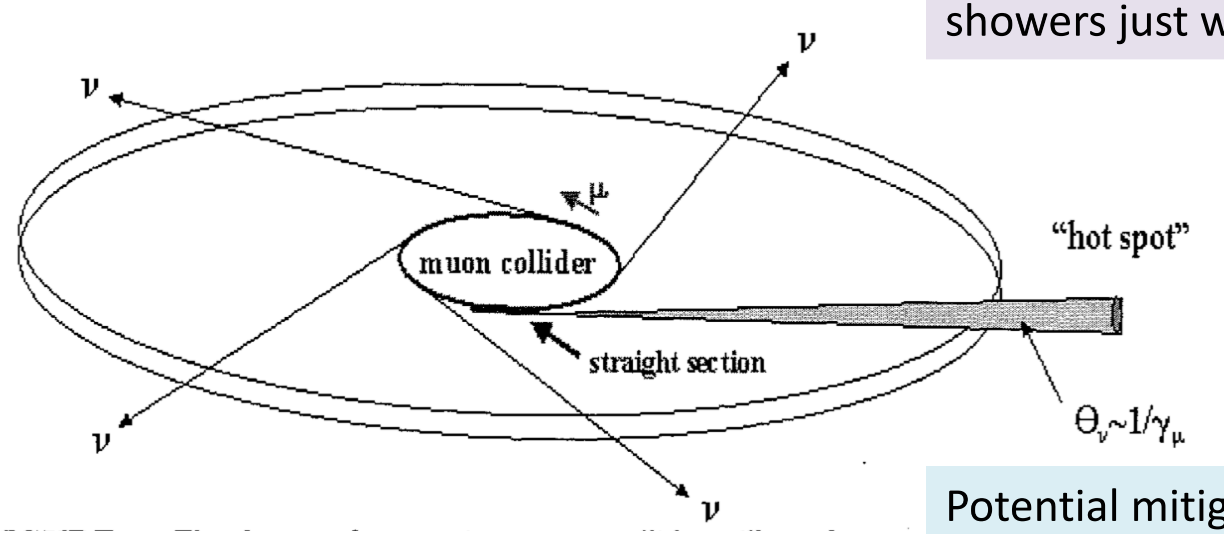
➔ **MuST** – MUon colliders Strategy network

INFN, CERN, CEA, CNRS, KIT, PSI, UKRI

Delivery: International collaboration plans towards a multi-TeV muon collider

- **Synergies on exploiting neutrino beams at facilities**
  M.Bonesini, G.Catanesi, D.Orestano, L.Tortora et al.

Challenge: Neutrino Radiation Hazard



Neutrinos from decaying muons can produce showers just when they exit the earth

Particularly bad in direction of straights
But also an issue in the arcs

Potential mitigation by

- Site choice
- Owning the land in direction of experimental insertion

- Having a dynamic beam orbit so it points in different directions at each turn in the arcs
    - Or at least paint the beam in the the straights to dilute radiation

Becomes more important at higher energies (scaling E^3)

US study concluded that 6 TeV parameters are OK

Reasonable goal is 0.1 mSv/ year, but to be verified

On-going simulations and studies for mitigation even with existing/future tunnels

Initial Workplan

Exploratory phase (first two years)

- forming collaboration
- exploration of options
- making choices
- work on already identified key issues
- completion of key issues list
- definition of scope of demonstrator
- definition of prioritised work programme for definition phase

Definition phase

- implementation of work programme
- conceptual design of demonstrator
- conceptual design of key high-energy components, where possible
- hardware tests
- increase in resources required and redirection of work as needed

Note: will exploit synergies, e.g. with magnet development for hadron colliders

Critical Machine Issues Include:

- **Advanced detector concepts and technologies**, requiring excellent timing, granularity and resolution, able to reject the background induced by the muon beams.
- **Advanced accelerator design** and beam dynamics for high luminosity and power efficiency.
- **Robust targets and shielding** for muon production and cooling as well as collider and detector component shielding and possibly beam collimation.
- **High field, robust and cost-effective superconducting magnets** for the muon production, cooling, acceleration and collision. High-temperature super-conductors would be an ideal option.
- **High-gradient and robust normal-conducting RF** to minimise muon losses during cooling.
- High rate **positron production** source and high current positron ring (LEMMA).
- **Fast ramping normal-conducting, superferric or superconducting magnets** that can be used in a rapid cycling synchrotron to accelerate the muons and efficient power converters.
- **Efficient, high-gradient superconducting RF** to minimise power consumption and muon losses during acceleration.
- **Efficient cryogenics systems** to minimise the power consumption of the superconducting components and minimise the impact of beam losses.
- Other accelerator technologies including high-performance, compact **vacuum systems** to minimise magnet aperture and cost as well as fast, robust, **high-resolution instrumentation**.

Accelerator Themes/Working Groups

- **MDI**
- **High-energy complex**
- **Muon cooling**
- **Target area**
- **Proton complex**
- **LEMMA specific activities**
  - generally integrate with other working groups (e.g. targets)
  - LEMMA is an alterative

- **Magnets (and power converters)**
- **RF (normal and superconducting)**
- **Targets, shielding, collimation, vacuum, cooling, …**
- **Technologies: Exploratory technology review: Instrumentation, beam transfer, …**

- **Beamdynamics, simulation codes, …**
- **Layout, environment, infrastructure**

Some Collaboration Discussions (Machine)

France

- CEA: RCS accelerator ring, RF, high-field solenoid
- CNRS: GUINEA-PIG, maybe wandering snake with Annecy

UK

- Cooling, FFAGA, (final focus), could do some source work

Germany

- KIT, Darmstadt, magnets, cooling
- Rostock: high-energy acceleration, MPI: muon cooling
- DESY waiting for discussion

Italy

- INFN: MDI, collective effects, magnets, targets, LEMMA

Switzerland

- beam-beam (EPFL), some more interest to be discussed

Spain

- some interest in the physics, need to follow up on machine

Sweden, Norway

- Uppsala some interest (proton complex), ESS would require add. funding, Oslo

Austria

- some interest in physics, student on machine

US

- SLAC, JLAB, providing old design files

Sorry to have started mainly in Europe
CERN is going to be reorganised …
Need to discuss with other regions

Initial Organisation: IRAP

"Interim R&D Advisory Panel"

The IRAP will work during the initial phase of the study, mostly in two subgroups: one on detector and physics, one on the accelerator complex. Its mandate is to:

- propose initial detector performance specifications
- establish a list of critical issues for the detector
- suggest initial priorities for the identified critical issues
- propose the scope of the work on the most critical issues
- propose initial accelerator complex performance specifications
- establish a list of critical issues for the accelerator complex
- suggest initial priorities for the identified critical issues
- propose the scope of the work on the most critical issues

Members representing large laboratories and communities as well as critical technical expertise

- include all regions

Fields of interest

- **Physics Motivation.** Physics potential of the collider, physics benchmark points, requirements for energy and luminosity.
- **Experiment and Physics Simulation.** Performance of collider and detector, event reconstruction, simulation tools, performance benchmark points, detector performance goals.
- **Detector Design and R&D.** Detector development, prototypes, detector performance goals, ...
- **Machine Detector Interface.** Background, ...
- **High-energy Collider Design.** Experimental insertion, collider ring, accelerator ring, linacs, ...
- **Proton-based Muon Source.** Proton complex, muon production, muon cooling, bunch merging
- **Positron-based Muon Source.** Positron production, positron acceleration, muon target, muon accumulation
- **Magnets.** High-field superconducting magnets, final focus quadrupoles, collider ring dipoles/combined function magnets, cooling solenoids, fast ramping magnet systems in accelerator, ...
- **Radio Frequency Technology.** Superconducting RF for high energy acceleration and and normal-conducting high-gradient RF for the cooling, proton and positron RF, ...
- **Radiation, Shielding, Losses, Targets, Collimation, Materials.** Detector/magnet shielding, high-power production target, neutrino radiation, beam losses, background, ...
- **Other Technologies.** Including efficient cooling, good vacuum, robust instrumentation, ...
- **Civil engineering and Infrastructure.**
- **Synergies.** Includes application of muon collider technology for other purposes, such as a neutrino factory.

attività INFN

- **Simulazioni di fisica**

(collaborazione con CSN4)
➔ **reach di fisica vincolato dal disegno dell'esperimento**

- **Disegno dell'esperimento**

(simulazioni e R&D in sinergia)

- **Machine Detector Interface**
- **Studi di radiazione da neutrino**
- **Sorgente LEMMA - disegno:**

fascio di positroni - bersagli – accumulatore

- **Test Beam @ CERN per 2022**

NEW

- **R&D tecnologia per magneti ++ dedicati al muon collider**