RD_MUCOL @ CSN1

work done and further steps

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

MoU almost final to be signed

Mainly @ CSN1 since 2021 RD_MUCOL: 17.3 FTE/90 phys/eng 13 sections
2016-2020 RD_FA (WP8) and CSN5-grant 2019-2020

Nadia Pastrone

INFN TORINO

Meeting December 11, 2020

BUDGET 250 keu (di cui 115 Missioni)

rd_mucol-all@lists.infn.it

SEDE	# pers	FTE	RL	The	Phy/Lum	Detec	MDI	Targ	Mac	Lem
BA	9	1	A. Colaleo							
BO	4	1	F. Maltoni							
FE	4	0.5	A. Mazzolari							
LNF	10	2.9	M. Boscolo							
LNL	5	0.4	S. Corradetti							
MI	2	0.3	A. Bacci							
MIB	3	0.4	M. Bonesini							
PD	15	4.4	D. Lucchesi							
PV	6	1.2	C. Riccardi							
RM1	7	2.1	F. Anulli							
RM3	5	0.4	A. Passeri							
TO	16	2.1	N. Amapane							
TS	2	0.4	S. Levorato							

rd_mucol-rl-ra@lists.infn.it

Proposta

- Almeno una riunione mensile di aggiornamento – 1-2 h max
- …..

News: Current Constraints

Daniel Schulte

- Definition of European **Accelerator R&D Roadmap** by LDG
  - Define scope of muon collider study until September 2021
  - Organization not yet known
  - Some overlap with our planned organization (**IRAP**, Interim R&D Advisory Panel) delays the latter

- **Snowmass/P5** process in the US
  - Input until June 2021, decisions in 2022
    - will have to prepare white papers
  - Submitted several Letters Of Interest from the collaboration
    - In addition, others refer to the muon collider, e.g. technologies, physics, …
  - High priority for us
  - Might change situation dramatically after P5 concluded in 2022

May be delayed by one year

Way Forward

Daniel Schulte

Are in gradual transition from community effort to organized effort

Foresee **IRAP (Interim R&D Advisory Panel)**

- group to propose **initial target parameters, tentative functional specifications** and **prioritised R&D list** by middle of next year
- to be coordinated with the European Roadmap committee, hence a bit slow …

Prepare one comprehensive but compact **report** to describe muon collider

- Design choices (e.g. technologies for components)
- Parameters (e.g. beam parameters along facility)
- Initial target functional specifications (e.g. targets for magnetic fields)
- Identify critical R&D challenges
- Identify R&D priorities
- Input to Snowmass and European Roadmap, can extract executive summaries

Will start in January

Will have to see how to efficiently combine Roadmap and Snowmass

Synergies in EU,USA…. more to find

- Many LoI submitted to SnowMass 2021
  ➔ now under discussion towards Contributed Papers due by July 2021

- **Roadmap R&D Accelerators** coordinated by CERN Lab Directors Group
- **Roadmap R&D Detectors** coordinated by ECFA
  (tracking, calorimetry, electronics, on detector processing, new ideas)

- **Medium term plan** at CERN 2021-2025 - dedicated budget line -
  per year 5 FTE staff, 6 fellows, 4 students, 1 associate, 5 x 2 MCHF

- **New approved EU INFRA-INNOV project: I.FAST** on accelerator R&D
  - **MUST** – MUon colliders STrategy network *(INFN, CERN, CEA, CNRS, KIT, PSI, UKRI)*
- **New approved EU RISE project: aMUSE** (with activities @ FNAL Muon Campus)
  - Donatella Lucchesi (Univ. PD) for Muon Collider with US Laboratories FNAL, BNL
- **New approved EU INFRA-INNOV project: AIDAinnova** on detector R&D

Conclusion

D. Schulte @ PECFA Nov 2020

Started meetings on design and specialised topics

- Accelerator design
- Physics and detectors

Topical meetings

- Physics potential
- Detector simulations
- Muon cooling

Will have project meeting with everyone

- Every few months, half day long

Attività internazionale

- **International Muon Design Study Collaboration**
  - Waiting to sign MoU + Addenda CERN
  - e-groups: MUONCOLLIDER-DETECTOR-PHYSICS MUONCOLLIDER-FACILITY
  - indico: https://indico.cern.ch/category/11818/
  - Website: https://muoncollider.web.cern.ch/
  - Not all activities properly started

- **SnowMass Process**
  - many LoI submitted ➔ contributed papers
  - workshops/dedicated meeting
  - multi-frontier forum on muon collider discussions (*)

(*) The intent of this Forum is to create a venue where people participating in Snowmass who are also interested in the muon collider can freely share ideas and studies across frontiers, learn from each other, in harmony with the wider muon collider community. **slack: "muon-collider-forum"**

Physics

https://indico.cern.ch/category/11839/

- Generators
- Physics potential
- Full simulation
- MC samples

- Higgs physics
- BSM
- Neutrinos
- LLP
- ….

Huge INFN contribution

Theoretical predictions for a muon collider

Challenges and opportunities

Fabio Maltoni
Università di Bologna
Université catholique de Louvain

Donatella Lucchesi et al.

PACC Workshop: Muon collider physics

020, 16:00 → 2 Dec 2020, 22:30 Europe/Rome

of Pittsburgh

Muon collider detector performance: from full simulation to R&D

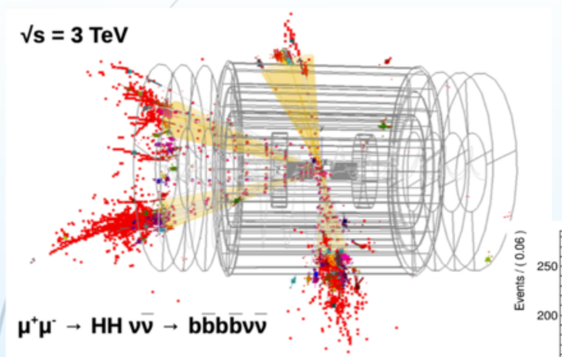
Donatella Lucchesi[a] and Sergo Jindariani[b]
[a]University of Padova and INFN, [b]Fermi National Laboratory
for
C. Aimè, P. Andreetto, N. Bartosik, L. Buonincontri, M. Casarsa, L. Lee, R. Lipton, A. Gianelle, S. Pagan Griso, K. Krizka, C. Riccardi, L. Sestini, M. Swiatlowski, H. Weber, M. Valente, D. Zuliani

Università degli Studi di Padova — Fermilab — INFN

2

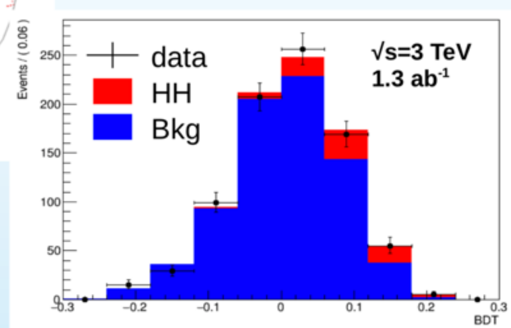
Exciting Physics measurements in the full simulated detector

The process $\mu^+\mu^- \to HH\nu\bar{\nu} \to b\bar{b}b\bar{b}\nu\bar{\nu}$ at $\sqrt{s} = 3$TeV is under study by using the full detector simulation



Assumptions

- $\mathcal{L}_{int} = 1.3\ ab^{-1}$
- Running time = $4 \cdot 10^7$ s
- one detector



With a simple fit to the BDT output $\frac{\Delta\sigma}{\sigma} = 0.33$

CLIC has 10% with 5 ab^{-1} and very refined analysis

2/12/2020

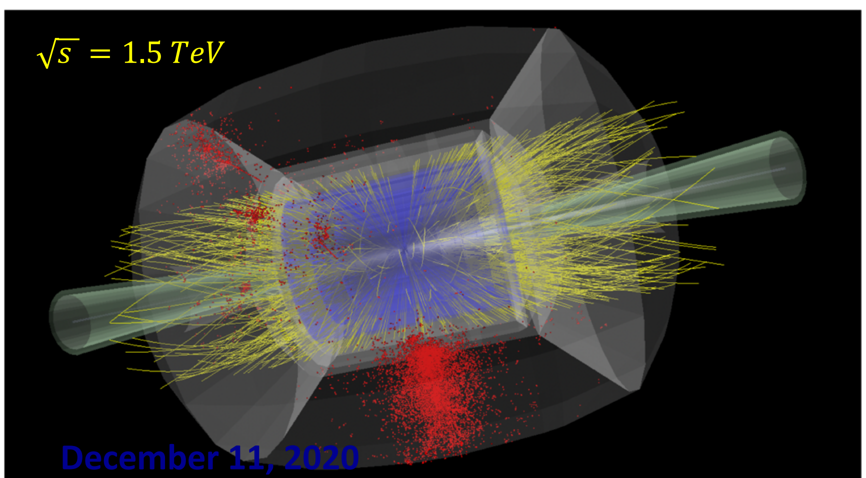
Mauro Chiesa, Fabio Maltoni, Barbara Mele, Fulvio Piccinini, Andrea Wulzer and many others

December 11, 2020

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



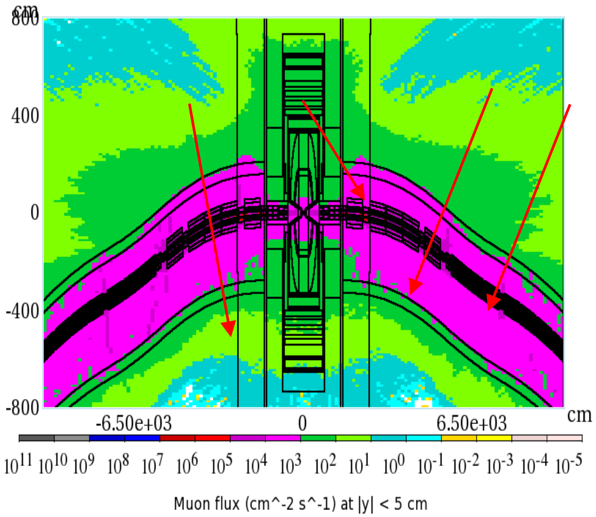
Detector must be designed for robustness

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

Detailed design of machine is required

Machine Detector Interface

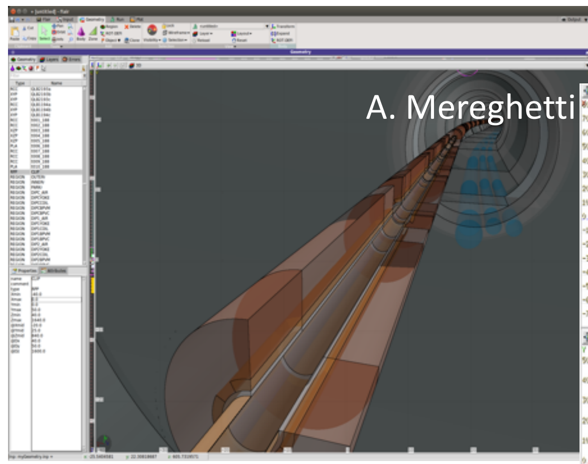
Donatella Lucchesi et al.



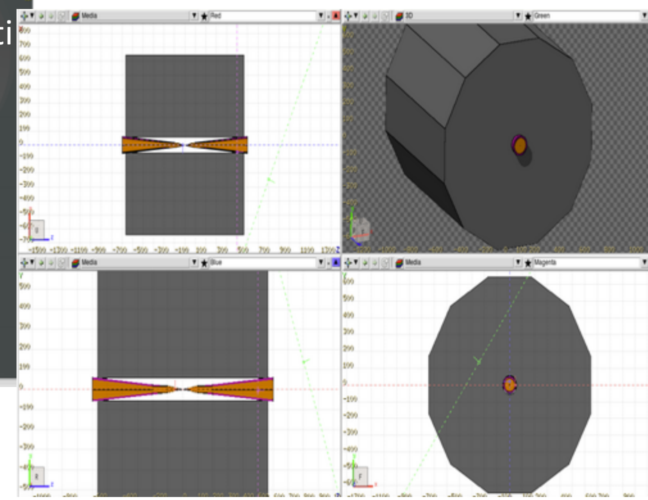
BIB available for =1.5 TeV and =125 GeV

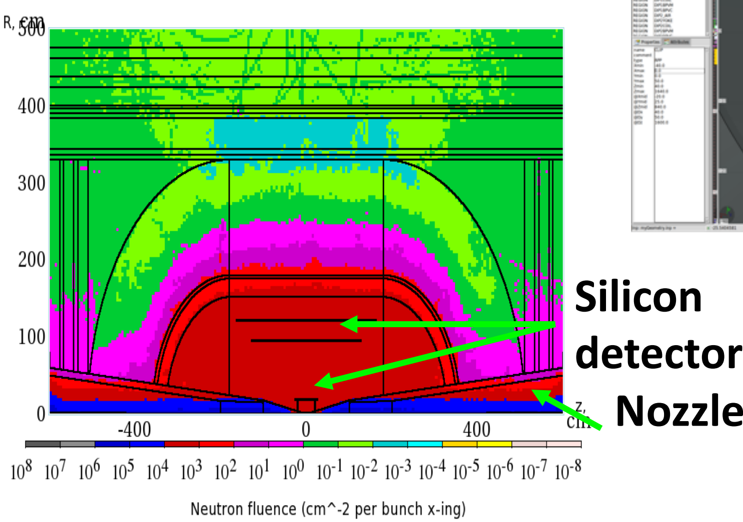
Prepare a new tool based on Fluka to generate new BIB:

- at different
- Modifying the detector and the interaction region

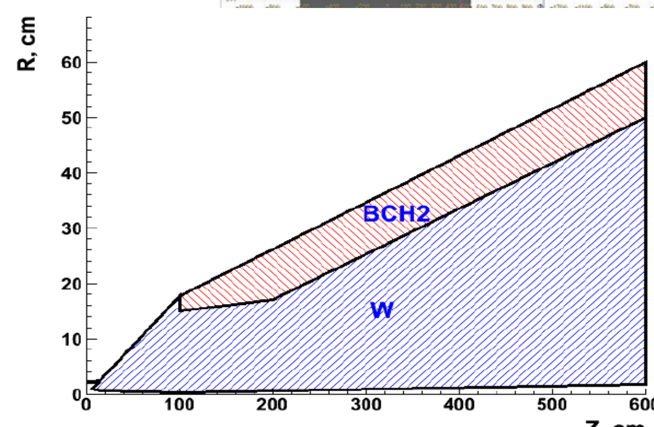


F. Collamati, C. Curatolo

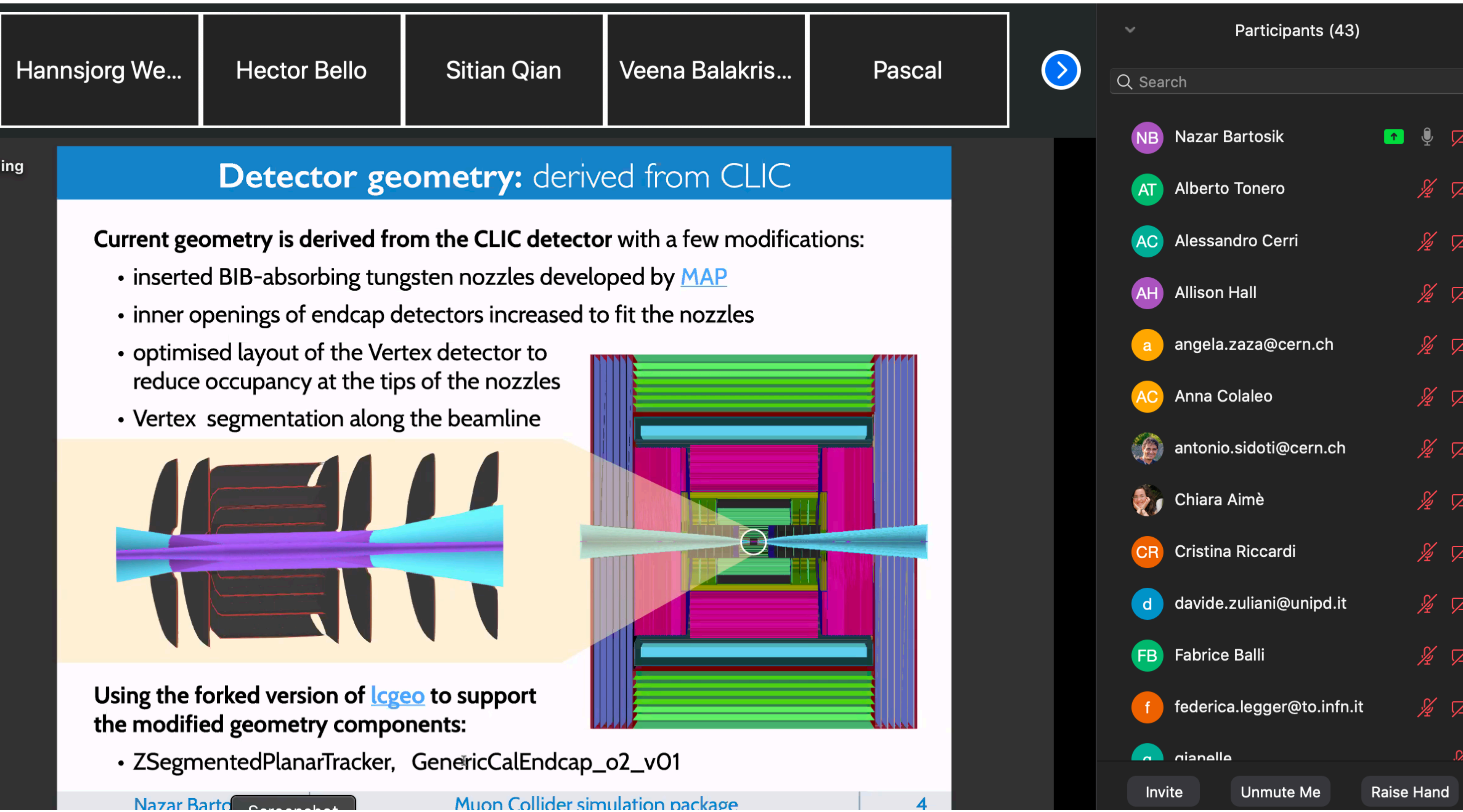




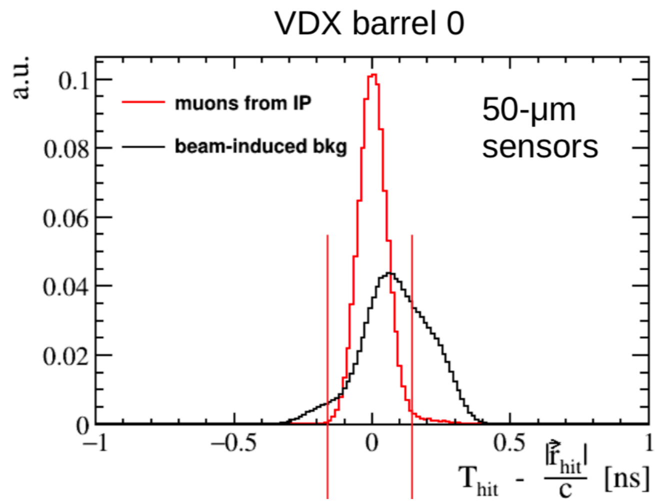
N. Mokhov et al. Fermilab-Conf-11-094-APC-TD

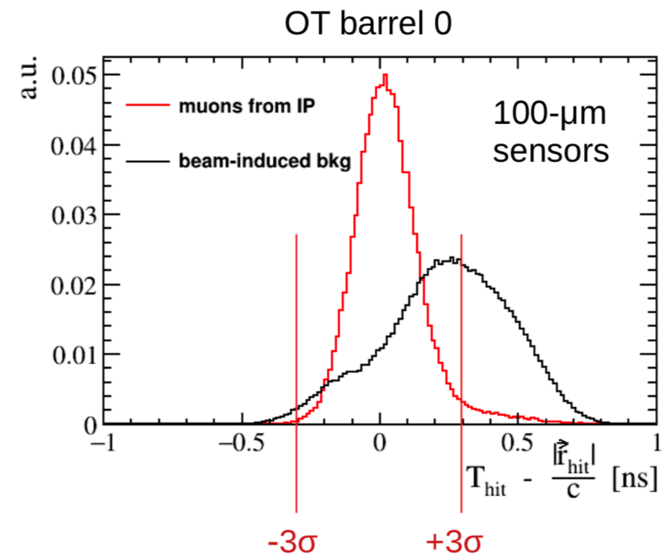


Experiment design to be improved



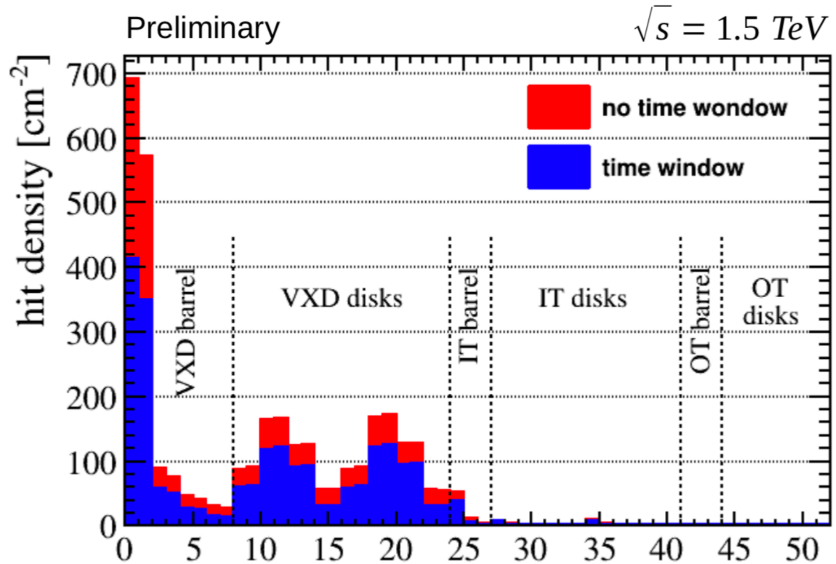
Tracking requirements ➔ R&D needs





- ±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

4D-tracking with RSD

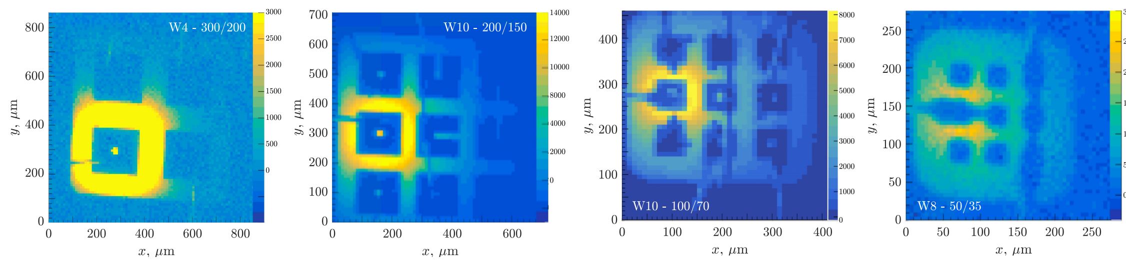
Resistive AC-Coupled Silicon Detectors (RSD)

Marco Mandurrino et al.

FBK able to reproduce the **optimal physical-technological parameters** we found at INFN through **numerical modeling** with high precision, reproducibility and homogeneity.

We also demonstrated to reach the challenging goal of producing (working) **100% fill-factor** Silicon detectors with **internal gain** and **high-segmentation level**:

50 keu requested for
1 FBK submission ~ 25 keu
Read-out electronics ~ 25 keu



Measurements, confirmed by a **testbeam analysis**, show that both space and time resolution are gain- and geometry-dependent.

Laser measurements

RSD1	Gain 12		Gain 17		Gain 24	
	σ_x [μm]	σ_t [ps]	σ_x [μm]	σ_t [ps]	σ_x [μm]	σ_t [ps]
100/70	3.2	17.6	2.8	15.3	2.5	13.9
200/100	8.6	31.1	6.2	22.3	-	-
200/190	17.9	58.7	14.3	62.6	8.8	59.9
500/200	27.3	45.7	20.6	34.6	20.6	32.6

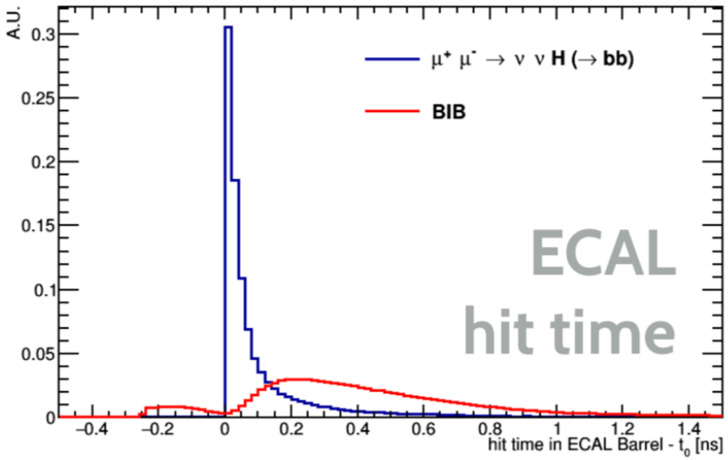
FNAL testbeam

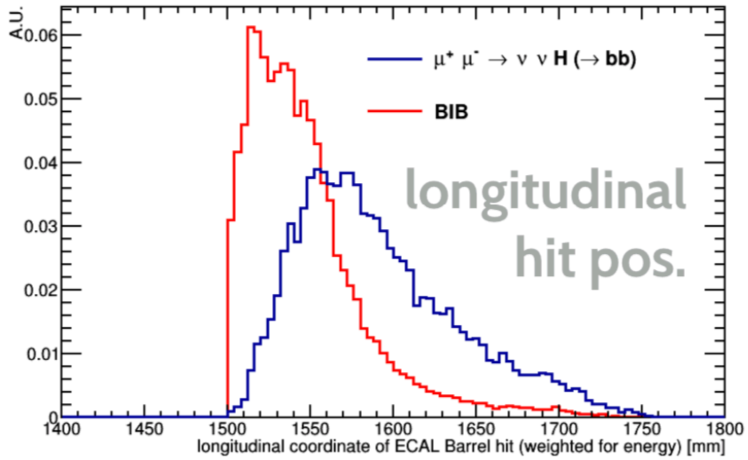
⇨ $\sigma_x = \sim 5\ \mu m$ and $\sigma_t = \sim 40$ ps
(rate capability: 50-100 MHz)

all the main signal properties are conserved in large-area RSD detectors

Calorimeter optimization

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





Various BIB mitigation approaches for ECAL can be studied

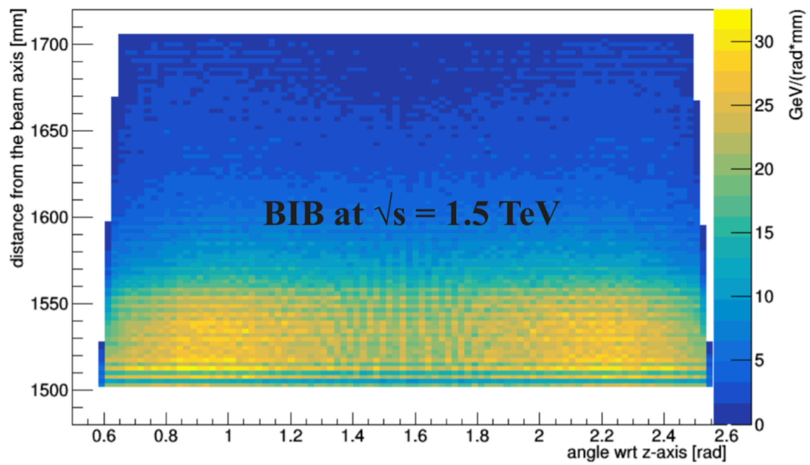
- possibly adding a preshower for absorbing the initial part of BIB in ECAL
- subtraction of BIB depositions using the hit time+depth information

Hadronic showers have longer development time → timing not critical

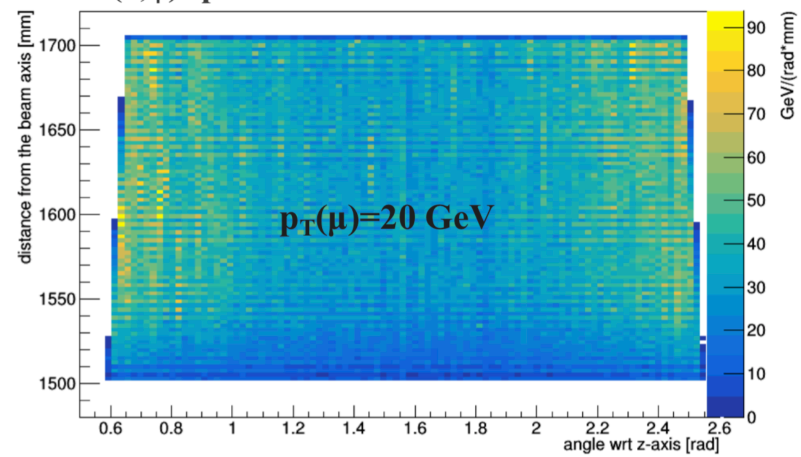
- the most straightforward approach: evaluate the average BIB energy deposition and consider only energy deposits above the BIB level

Calorimeter R&D

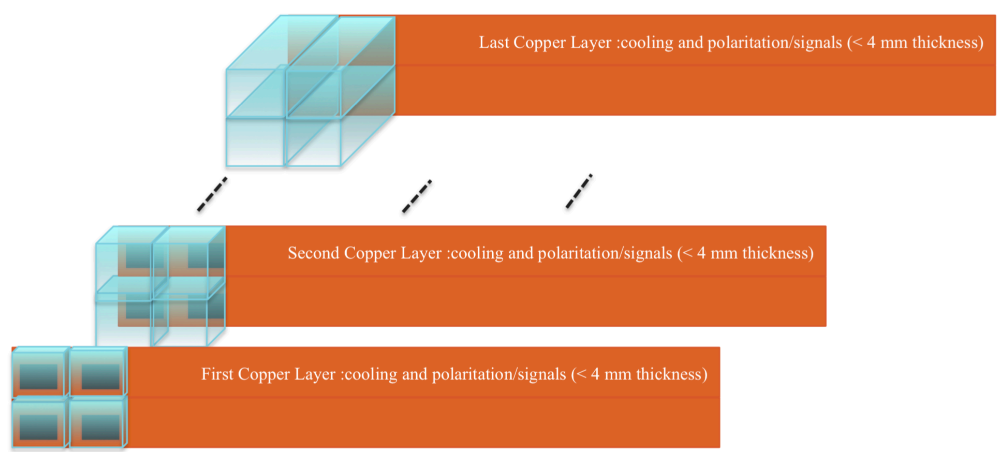
Energy released in ECAL barrel by one BIB bunch crossing



Energy released in ECAL barrel by uniformly distri buted prompt muons in the (θ,φ) space



- Calorimeter Layout: **the calorimeter can be segmented longitudinally** as a function of the energy of the particles and the background level.



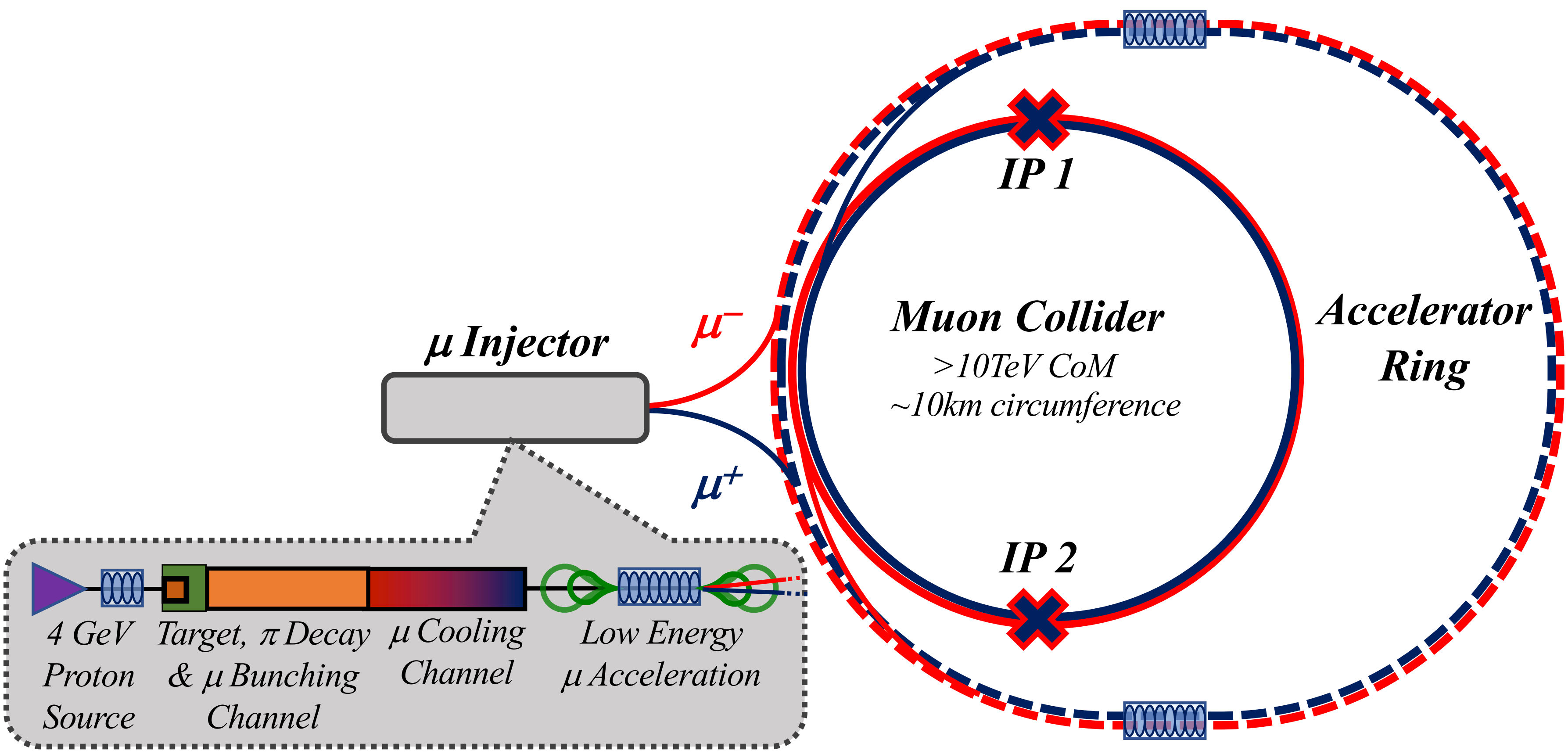
- A reduced first layer used as active pre-shower for timing → PbF2 or LYSO (5÷10 mm).

30 keu @ LNF - PD – TO
LNF ready to study a new faster and cheaper solution: ~ 17 keu

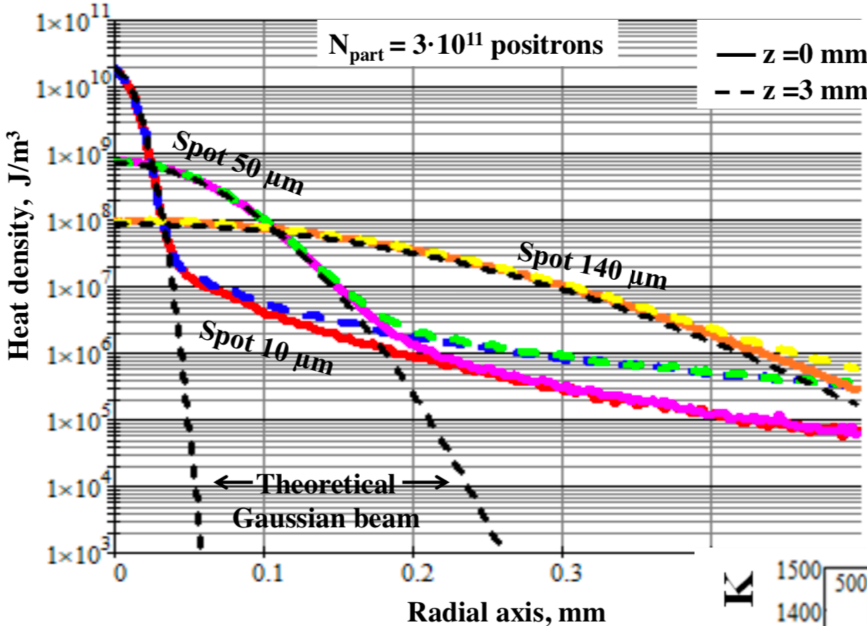
Later to be complemented by new material studies
Synergy with LHCb upgrade and AIDAinnova

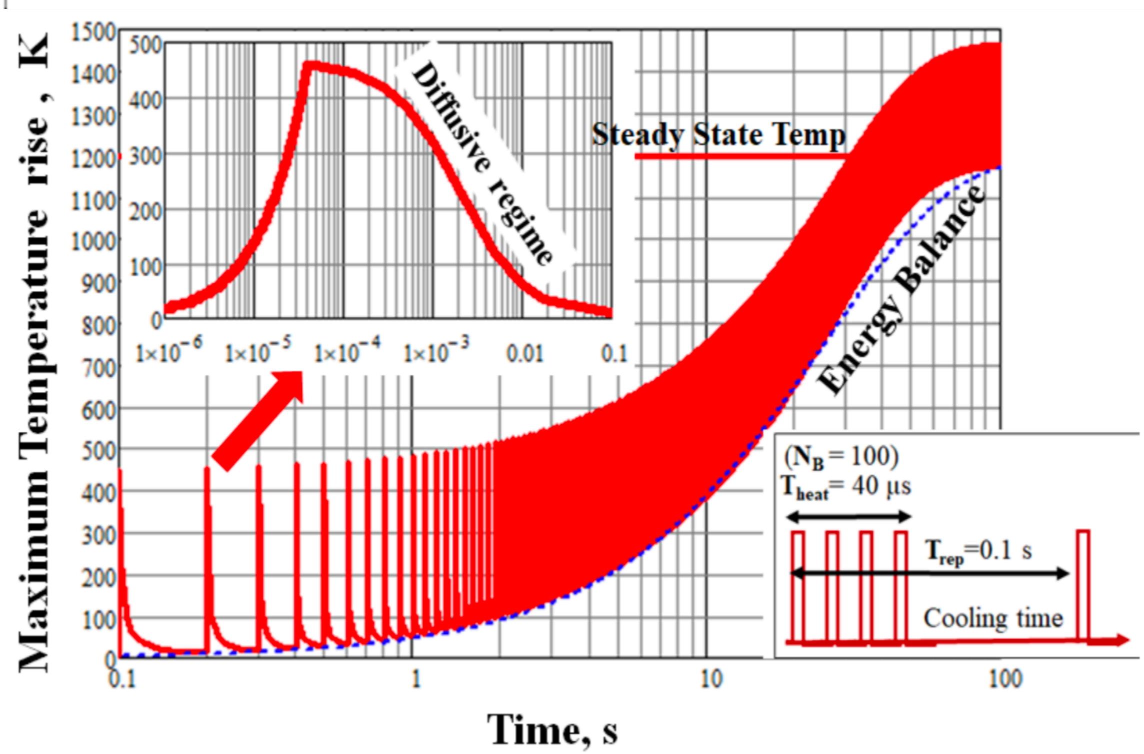
December 11, 2020

Sketch of the facility



Targets and material studies - simulation



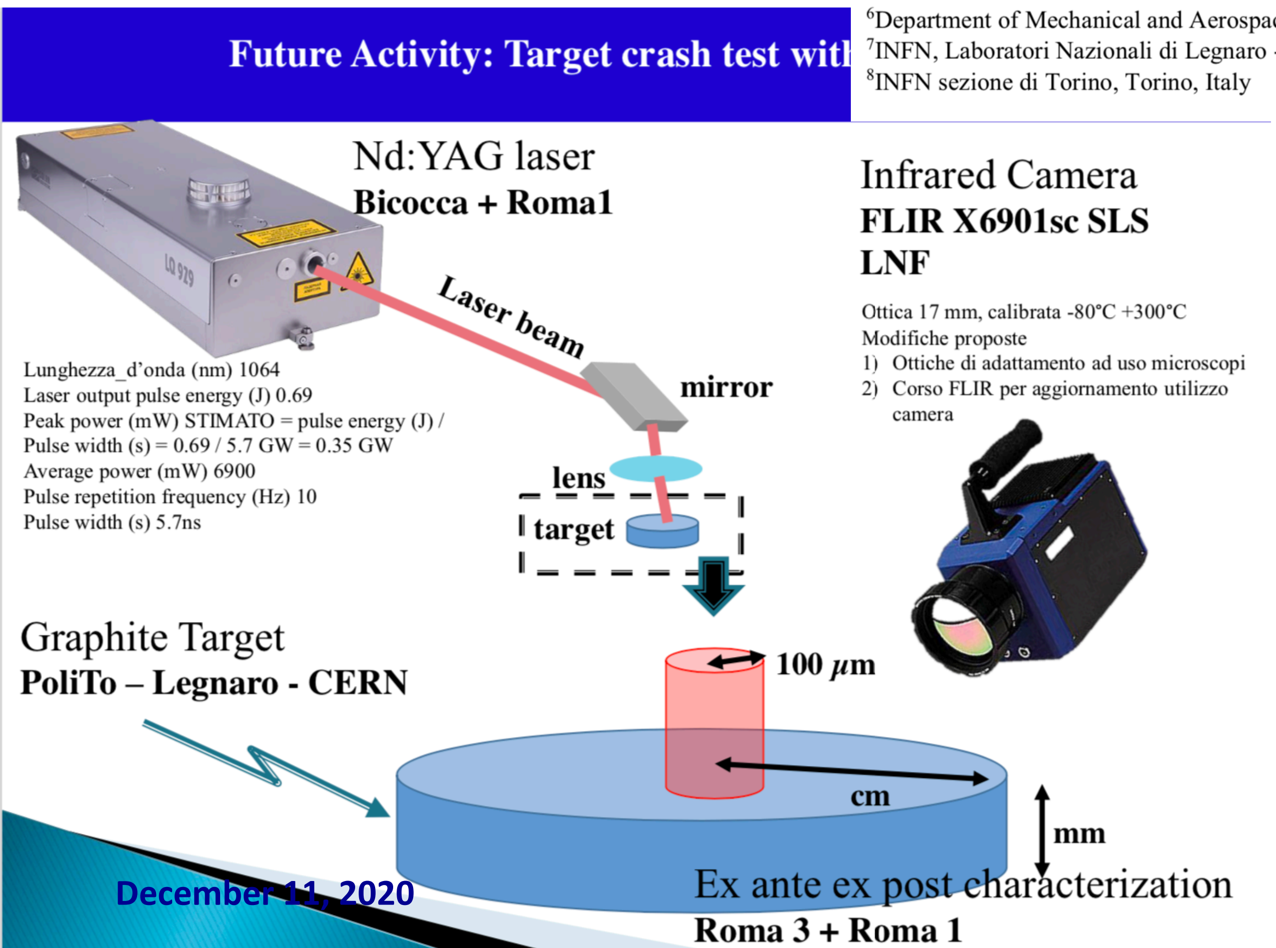


Targets and material studies - plans

Studies of target materials and layout for a low emittance muon source (LEMMA)

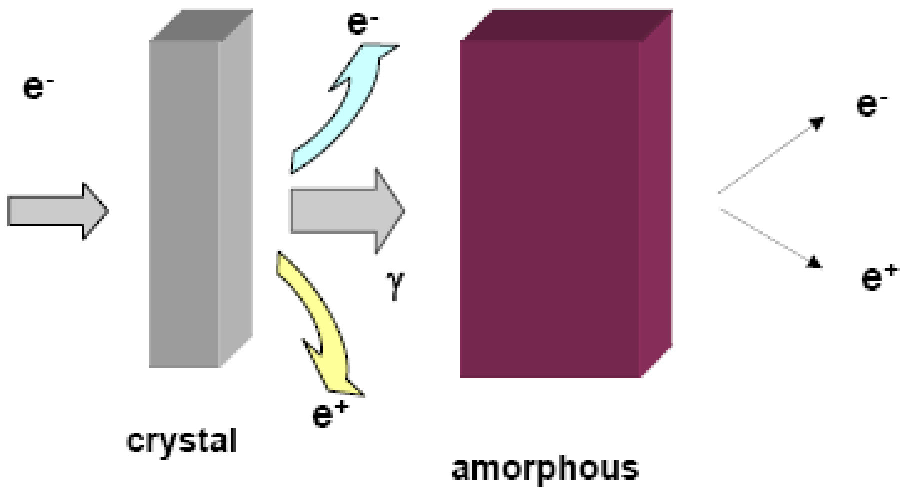
R. Li Voti[1,*], G. Cesarini[1], F. Anulli[1], M. Bauce[1], G. Cavoto[1], F. Collamati[1], S. Rosati[1], M. Antonelli[2], M.E. Biagini[2], M. Boscolo[2], P. Branchini[3], R. Di Nardo[3], A. Passeri[3], L. Tortora[3], V. Berandi[4], G. Catanesi[4], R. Spina[4], M. Bonesini[5], R. Benocci[5], L. Peroni[6], M. Scapin[6], L. Centofante[7], S. Corradetti[7], M. Manzolaro[7], A. Monetti[7], D. Scarpa[7], and N. Pastrone[8]

[1]INFN, Sezione di Roma e Università degli Studi di Roma "*Sapienza*"; *roberto.livoti@uniroma1.it
[2]INFN, Frascati National Laboratories, Frascati, Italy
[3]INFN Roma Tre e Università Roma Tre, Rome, Italy
[4]INFN Sezione di Bari e Università e Politecnico di Bari, Bari, Italy
[5]INFN Sezione di Milano Bicocca e Università di Milano Bicocca, Milano, Italy
[6]Department of Mechanical and Aerospace Engineering, Politecnico di Torino, Torino, Italy
[7]INFN, Laboratori Nazionali di Legnaro - Legnaro (PD), Italy
[8]INFN sezione di Torino, Torino, Italy



Crystals manifacturing and studies

Positron source using a crystal



Idea of R. Chehab, V. Strakhovenko and A. Variola

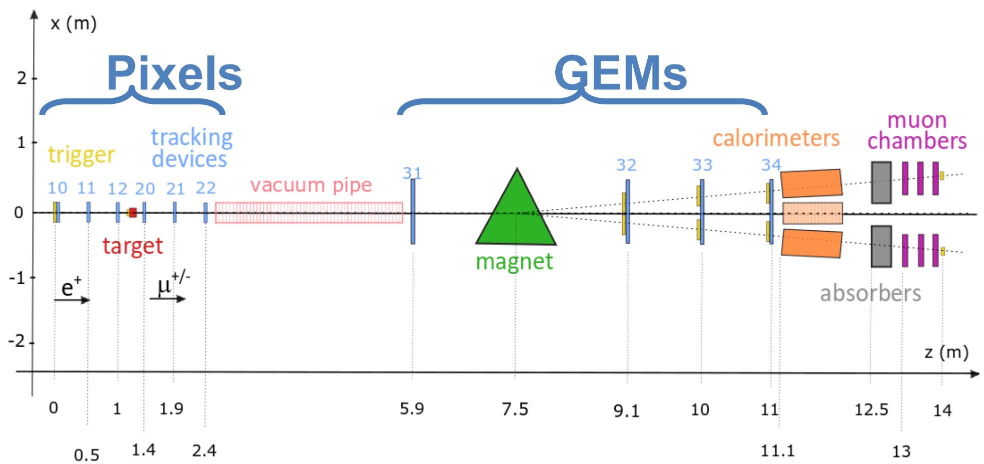
I.Chaikovska and R.Chehab, responsible for FCC-ee positron source are already involved in the Muon Collider group and recently iniziated a formal collaboration with the our team (Coord. L. Bandiera) in Monte Carlo simulation and crystal tests on beam.

Possible usage of bent crystal collimators in the muon collider facility

First attempt to start an investigation in collaboration with the CERN Muon Collider group

Test Beam @ CERN

- Experimentally measure the key parameters of the LEMMA approach
  - **Emittance** of emerging μ beam
  - $\mu^+\mu^-$ production **cross-section at threshold**
  - properties of **spent e^+ beam** (transverse emittance and energy spectrum)
  - Effect of the **target material/thickness**
- Although these are theoretically known and can be obtained from simulations**, precise measurements do not exist at the $\mu^+\mu^-$ production threshold**
  - GEANT does not include e.g. near-threshold Coulomb enhancements, and has not been experimentally tested in this regime



Request for 3-weeks beam time in H4 submitted to SPSC
http://cds.cern.ch/record/2712394

December 11, 2020

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]

Strong interest on Muon Collider!

RD_MUCOL (CSN1) at present a group of about 90 physicists/engineers

Ongoing activities:

- Physics and detector simulations
- Detector R&Ds
- MDI studies
- Neutrino hazard studies
- Targets simulations and R&Ds and crystals for targets and beam manipulation
- LEMMA studies and other machine technologies to be further discussed and agreed
- New interests: Magnets, RF, beam dynamics, collective effects

  ➔ to be further discussed beyond this meeting
- AOB

PRIN

https://prin.miur.it/

- Macrosettore PE - *Mathematics, physical sciences, information and communication,*
- *engineering, universe and earth sciences*: Euro 62.630.292,32, pari al 35% dello stanziamento complessivo disponibile (di cui Euro 6.263.029,00 riservati a progetti presentati da PI di età inferiore a 40 anni alla data del presente bando);

Expected CONSOLIDATOR ERC GRANT Call Opening: 21-01-2021
(subject to adoption of Horizon Europe and ERC WP 2021)

Ongoing activities @ INFN (1)

- **Physics Potential** **10+ TeV is a completely new regime to explore!**

  Direct/indirect discovery reach – VBF and VBS – precise Higgs measurements
  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
  Machine Detector Interface: beam induced background shaped by machine optics design at different energies sets constraints on nozzles and experiment design and performances

- **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 ➔ synergies
  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

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

Ongoing activities @ INFN (2)

- **Machine Detector Interface**

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

- **Neutrino Radiation Hazard Studies**

  Preliminary full FLUKA simulation: μ decays (ring/straight sections), ν interactions.
  Next: simulations with realistic ring geometries and new orbits design.

  Strong collaboration with machine design.

- **Material studies for targets**
- **Crystals manufacturing for targets and collimation**

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

➔ **MuST** – MUon colliders Strategy network (*INFN, CERN, CEA, CNRS, KIT, PSI, UKRI)*

Two Meeting with INFN-Accelerators October/December

Discussion on Magnets/RF and other contributions

Possible synergies on exploiting neutrino beams at facilities

Proposta - Milestones 2021

31-08-2021 Sottomissione White Papers SnowMass 2021 – contributi originali

31-10-2021 Messa a punto codice simulazione Machine Detector Interface (MDI) - test con ottica MAP @ 3 TeV per produzione fondi di macchina

30-11-2021 Studi preliminari su prototipi sensori RSD per tracciatore dedicato

15-12-2021 Prime misure prototipo calorimetro a cristalli e ricerca di nuovi materiali

15-12-2021 Messa punto test in laboratorio e misure su diverse tipologie di bersagli

15-12-2021 Completamento costruzione componenti per test beam LEMMA

15-12-2021 Produzione di bersagli cristallini e cristalli per manipolazione bunch muoni

15-12-2021 Articolo sottomesso su studi HH->bbbb @ 3 TeV con full simulation *extras*

Memorandum of Understanding

D. Schulte @ PECFA

Basically ready, waiting for final approval of DG

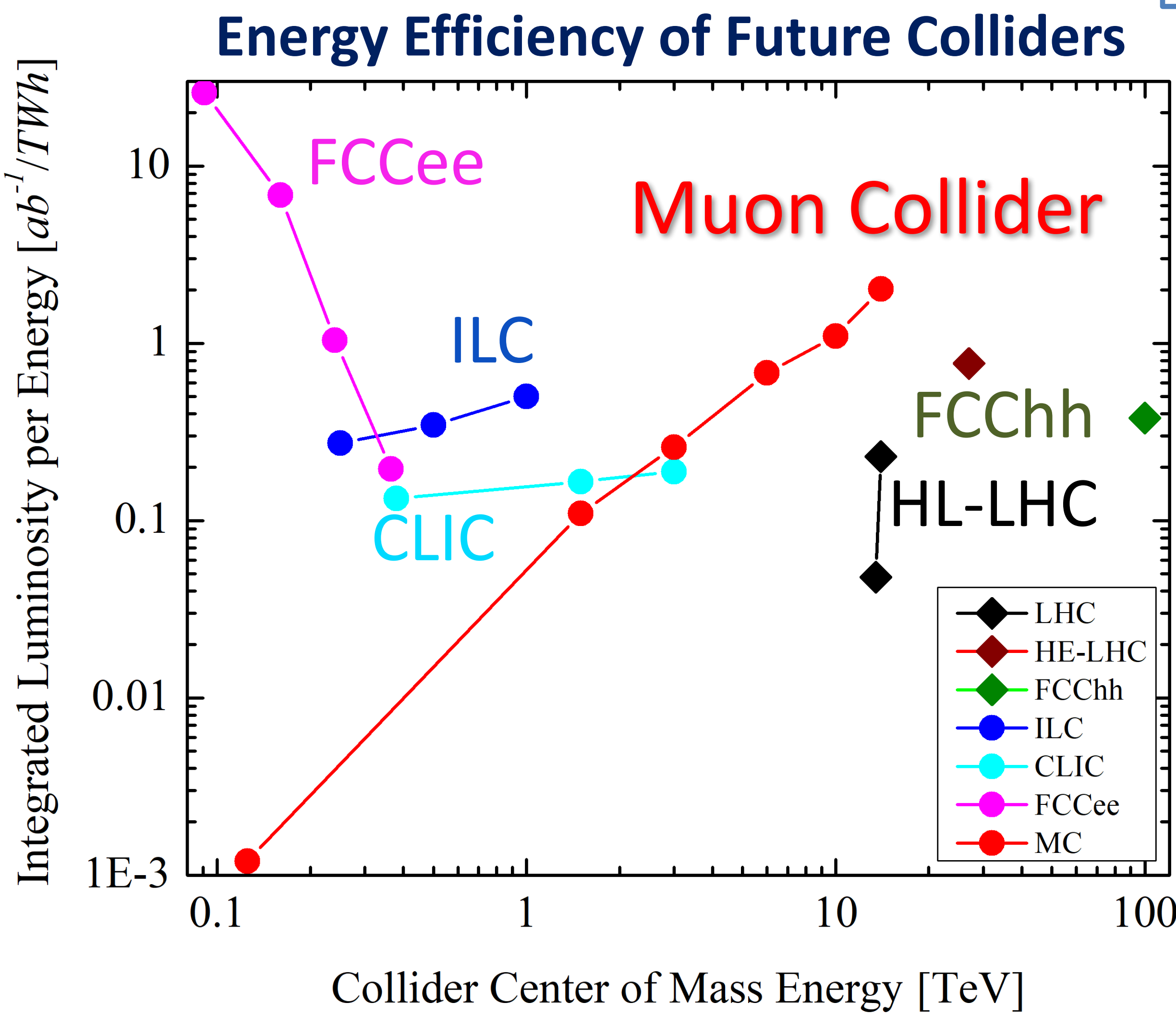
CERN is initially hosting the study

- International collaboration board (ICB) representing all partners
  - elect chair and study leader
  - can invite other partners to discuss but not vote (to include institutes that cannot sign yet)
- Study leader
- Advisory committee reporting to ICB

Addenda to describe actual contribution of partners

Figure of merit

arXiv:2007.15684 [physics.acc-ph]



Overwhelming physics potential:

- **Precision measures**
- **Discovery searches**

Challenging Machine Design:

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

First Thought on Content

Daniel Schulte

Accelerator Design
- Parameters
- Proton complex
- Front-end
- Muon cooling (maybe needs to be split)
- Initial muon acceleration
- RCS
- FFA
- Collider ring
- Beam dynamics

Technologies
- Magnet systems (including power converters)
- RF systems
- Beam intercepting devices
- Other technologies and integration

Site, safety and environment
- Some site considerations
- List of cost and power drivers
- Radiation considerations

Typically a couple of authors/editors per chapter

More people to do the actual work

Snowmass Submissions

International Muon Collider Collaboration (corresponding author: D. Schulte)
Muon Collider Facility (c.a.: D. Schulte)
Proton complex design
A Proton-Based Muon Source for a Collider at CERN (c.a.: Ch. Rogers)
A Flowing Granular Tungsten Pion Production Target for a Muon Collider at CERN (Ch. Densham et al.)
Issues and Mitigations for Advanced Muon Ionization Cooling (c.a.: Ch. Rogers)
Muon Acceleration for a $\sqrt{s}$ = 10 TeV $\mu+\mu-$ Collider (A. Bogacz et al.)
Applications of Vertical Excursion FFAs (vFFA) and Novel Optics (c.a.: S. Machida)
Pulsed synchrotron ring
Collider ring
Solving Critical Problems of the Muon Collider Higgs Factory: Optics, Magnets and their Protection, and Detector Backgrounds (Y.I. Alexahin et al.)
Machine Detector Interface Studies at a Muon Collider (c.a.: D. Lucchesi)
Magnet Systems
RF Systems
Beam-intercepting devices (in part in target)
Other technologies
Radiation issues, safety
LEMMA: a positron-driven muon source for a muon collider (c.a.: M.E. Biagini)

Snowmass Submissions

International Muon Collider Collaboration (corresponding author: D. Schulte)
Muon Collider Facility (c.a.: D. Schulte)
Proton complex design

More strategic US papers:

Future Energy Frontier Collider Options for the United States (P. C. Bhat et al.)
The Need for Research into Early Conceptual Integration and Optimization, and Maturity Evaluation of Future Accelerators (Sergei Nagaitsev et al.)

Pulsed synchrotron ring
Collider ring
Solving Critical Problems of the Muon Collider Higgs Factory: Optics, Magnets and their Protection, and Detector Backgrounds (Y.I. Alexahin et al.)
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Other technologies
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LEMMA: a positron-driven muon source for a muon collider (c.a.: M.E. Biagini)

Snowmass Submissions

Physics potential:

Muon Collider Physics Potential (c.a.: A. Wulzer, for the collaboration)
Muon Collider: Study of Higgs couplings and self-couplings precision (C. Aimè et al.)
EW effects in very high-energy phenomena (C. Arina et al.)
Beyond the standard model with high-energy lepton colliders (H. Al Ali et al.)
Muon Collider: A Window to New Physics (D. Berry et al.)
Electroweak Multiplets at the muon collider (R. Capdevilla et al.)
Higgs and Electroweak Physics at the Muon Collider (A. Apyan et al.)

Detector:

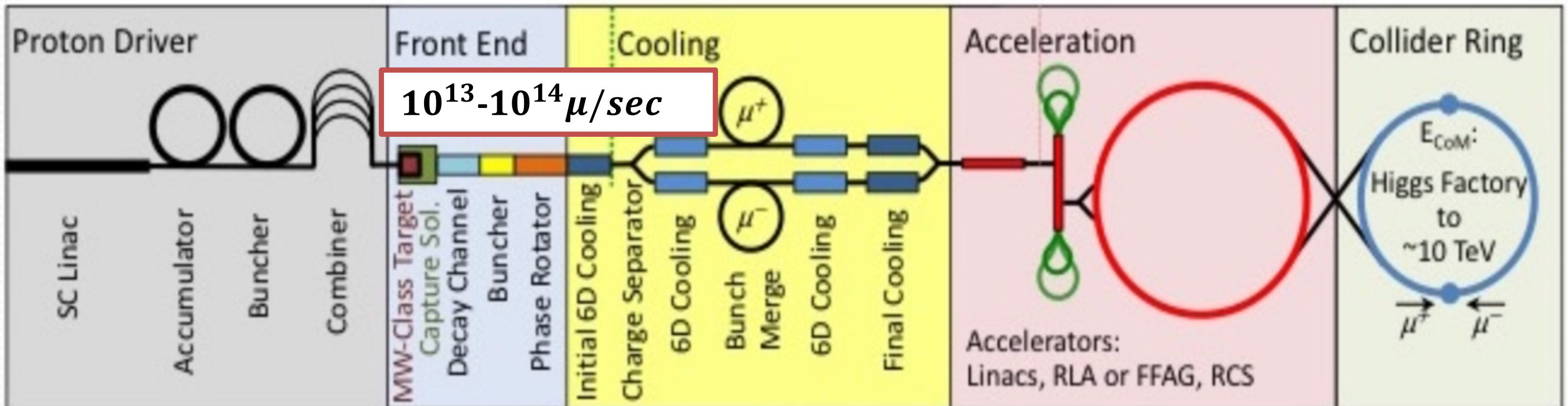
Muon Collider experiment: requirements for new detector R&D and reconstruction tools (c.a.: N. Pastrone)
Machine Detector Interface Studies at a Muon Collider (c.a.: D. Lucchesi)

Exploratory Phase – Key Topics

- Physics potential evaluation
  - requires to define energy, luminosity and detector performance goals
- Impact on the environment
  - The neutrino radiation and its impact on the site. This is known to require mitigation strategies for the highest energies.
  - Power consumption (accelerating RF, magnet systems, cooling)
- The impact of machine induced background on the detector, as it might limit the physics reach.
- High-energy systems that might limit energy reach or performance
  - Acceleration systems, beam quality preservation, final focus, cost, power consumption
- High-quality beam production, preservation and use

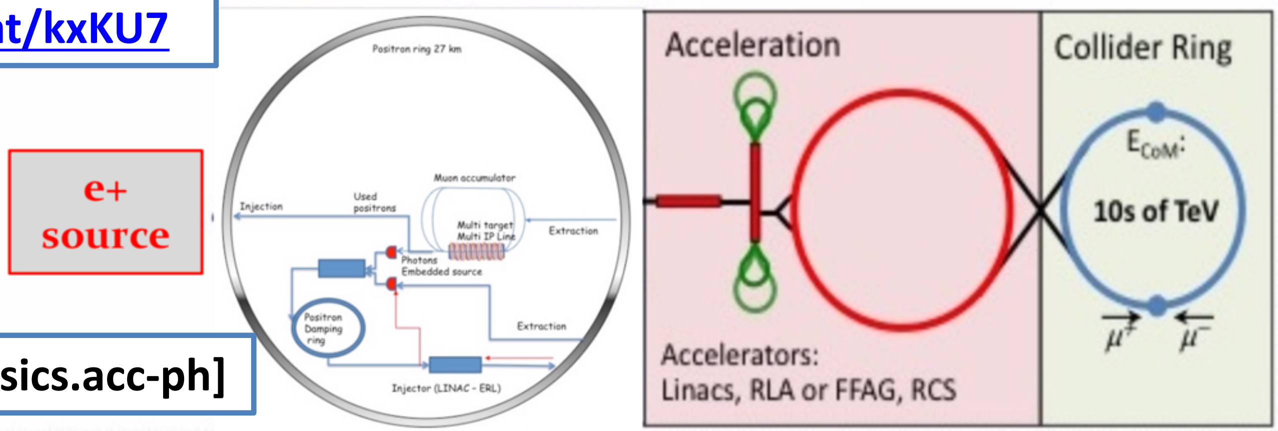
proton (MAP) vs positron (LEMMA) driven Muon Source

MAP



MUON JINST, shorturl.at/kxKU7

LEMMA



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

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

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

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

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

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

Critical Issues to be studied

- **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

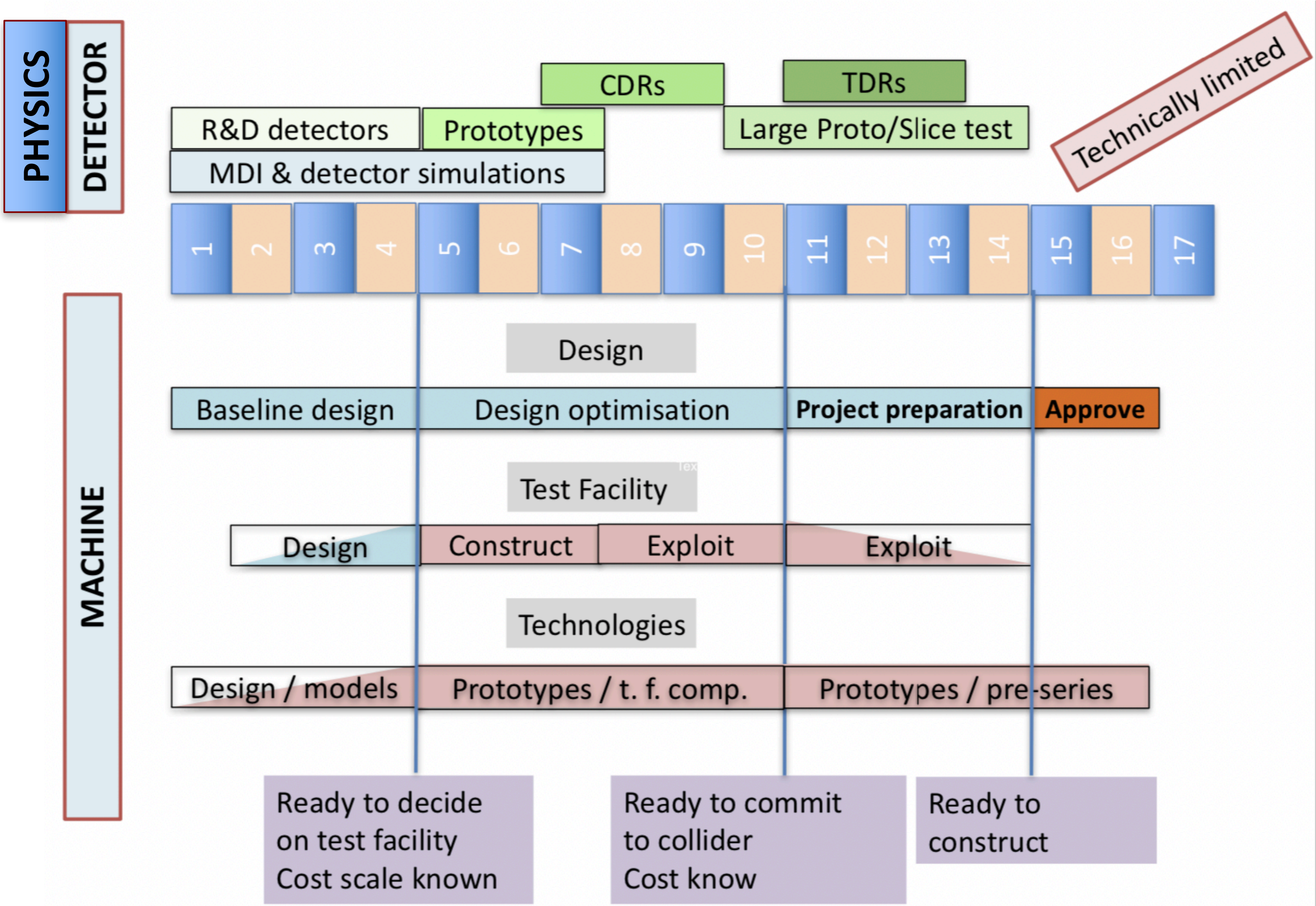
- **MDI**
- **High-energy complex**
- **Muon cooling**
- **Target area**
- **Proton complex**
- **LEMMA specific activities**
  - generally integrate with other working groups (e.g. targets)
  - LEMMA is an alterative

- **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**

Technically Limited Potential Timeline

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



Muon Collider Collaboration: Objective and Scope

Objective:

In time for the next European Strategy for Particle Physics Update, the study 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.

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

CONTEXT: two main strategic processes are ongoing

- Definition of European Accelerator R&D Roadmap by LDG
  - Define scope of muon collider study until September 2021
- Snowmass/P5 process in the US
  - Input until June 2021, decisions in 2022
    - will have to prepare white papers
  - Submitted several Letters Of Interest (> 20 ++)

Exploratory Phase – Key Topics

Daniel Schulte @ PECFA Nov 2020

- Physics potential evaluation

- Impact on the environment
  - The neutrino radiation and its impact on the site. This is known to require mitigation strategies for the highest energies.
  - Power consumption (accelerating RF, magnet systems, cooling)

- The impact of machine induced background on the detector, as it might limit the physics reach.

- High-energy systems that might limit energy reach or performance
  - Acceleration systems, beam quality preservation, final focus

- High-quality beam production, preservation and use
  - Target and target area
  - Cooling, in particular final cooling stage that does not yet reach goal
  - Proton complex

Key Initial Steps

D. Schulte @ PECFA

Define tentative collider energy and luminosity goals

Define tentative detector performance specifications to be able to launch physics potential studies

Start verification of detector performance

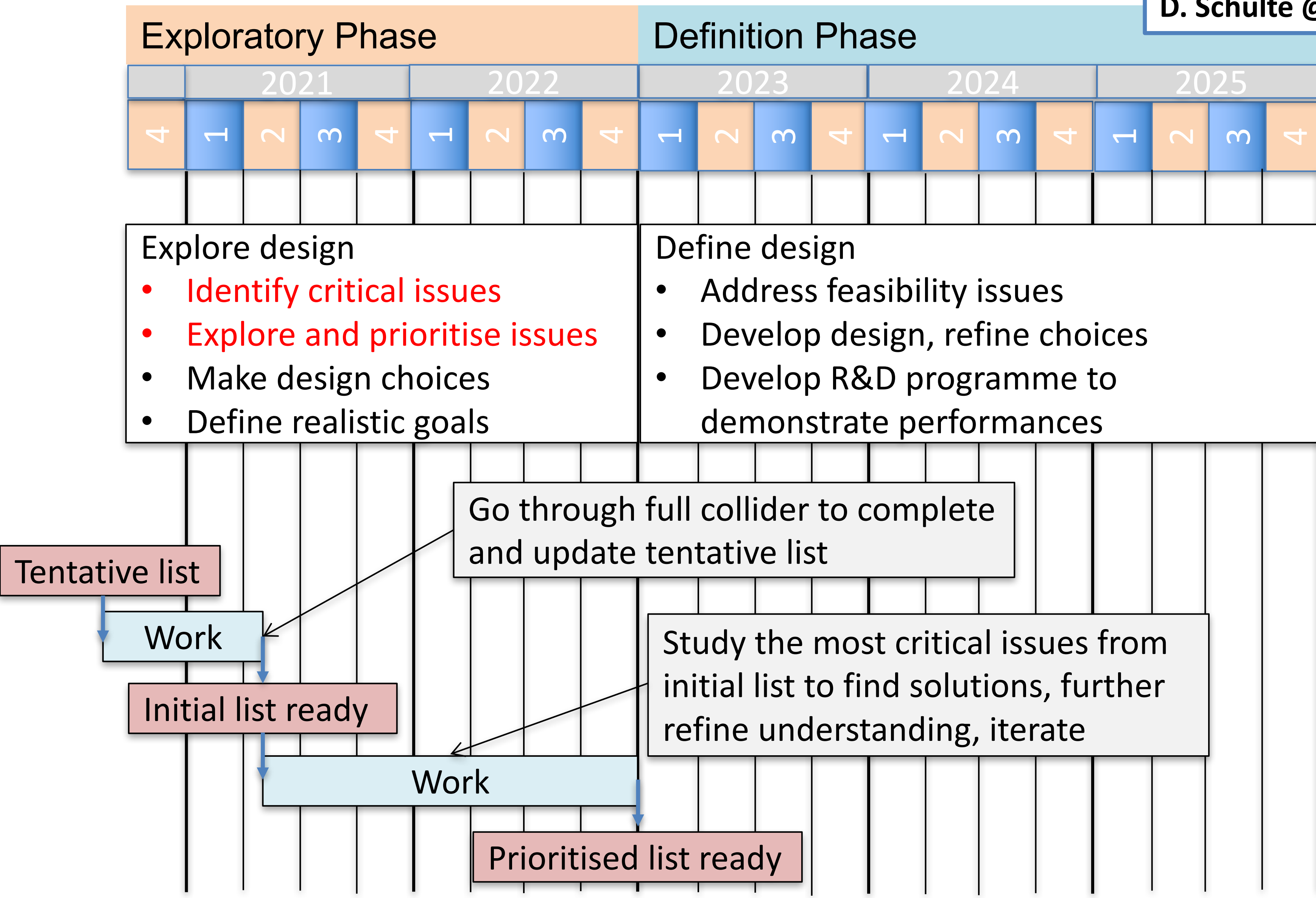
- beam-induced background conditions
- technologies

Start verification of accelerator performance, affordability and siting

- also estimate (and mitigate if possible) beam-induced background

Tentative Roadmap

D. Schulte @ PECFA



CERN – Mid Term Plan

Medium Term Plan at CERN 2021-2025 - dedicated budget line -
per year 5 FTE staff, 6 fellows, 4 students, 1 associate, 5 x 2 MCHF

"The muon collider study is aimed to evaluate the feasibility of a muon collider. Such a facility could allow reaching lepton collision energies beyond the range of linear colldiers and hence define the lepton energy frontier."

24c. Muon colliders

Goal	The muon collider study is aimed to evaluate the feasibility of a muon collider. Such a facility could allow reaching lepton collision energies beyond the range achieved in linear colliders and hence define the lepton energy frontier. Workshops and meetings were organized since 2018; Raising interest was demonstrated by the physics community. The feasibility study shall build on this interest and aim at forming an international collaboration.
Approval	Presented to Council 2020.
Start date	To be defined.
Costs	The feasibility study foresees resources at the level of 6 fellows, 4 PhD students and one 1 associate. In addition, the CERN personnel needs to be secured. External contributions to the study are expected in the framework of the collaboration that has to be set up. Minor expenses for travel and consulting are foreseen.
Competitiveness	The muon collider study provides input on the feasibility of a muon collider, as requested for the next EPPSU. If its feasibility can be established, Muon colliders open another option to maintain CERN's world-leading role in particle physics and push the high-energy lepton frontier.
Risks	In the long term, the failure to support the study might put at risk CERN's potential leading role in Muon colliders, which is an option to be assessed by CERN, as world-leading high-energy frontier laboratory, in particular in view of potential developments in other regions.
2021 targets	The EPPSU results will be presented in 2020. It is anticipated that it identifies the muon collider as an important subject for the accelerator R&D. The main goal for 2021 is the definition of a programme of work and the initiation of an international collaboration.
Future prospects & longer term	The study will address fundamental feasibility issues and limitations for the energy reach. It will develop a baseline concept and prepare an R&D programme that can lead to a CDR. In the first half of the period toward the next EPPSU the specific high energy limitations will be explored. In the second half of this period a wider effort will address all critical technical systems.

MAP Budget/Effort Overview

Mark Palmer

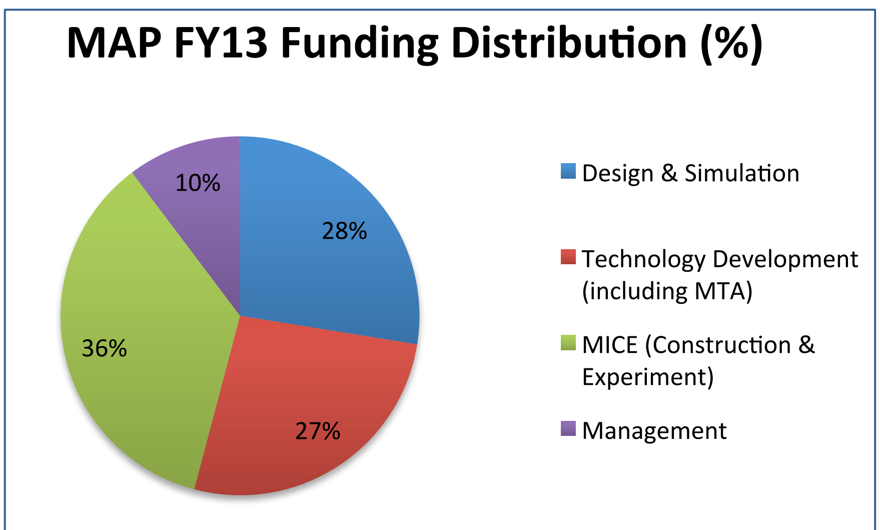
- Overview of FY12-FY17
  - Full program in FY12-14 (funding includes fully burdened labor)
  - Ramp-down with focus on MICE completion during FY15-17

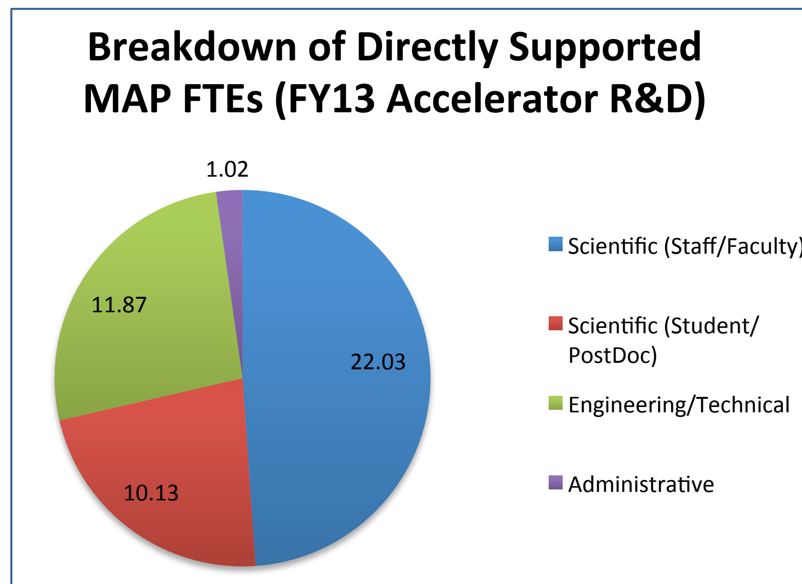
	FY12	FY13	FY14	FY15	FY16	FY17
US Funding (M$)	12.0	11.8	12.7	9.0	6.0	1.0

Reduced scope of effort

Snapshot of Effort Distribution During "full" program operation in FY13

- 23 Institutions Participating
- ~45 FTEs





Ongoing Accelerator Work

D. Schulte @ PECFA

Muon collider is new in Europe

- Have to get up to speed

Together with US colleges are starting to take (shared) ownership of design

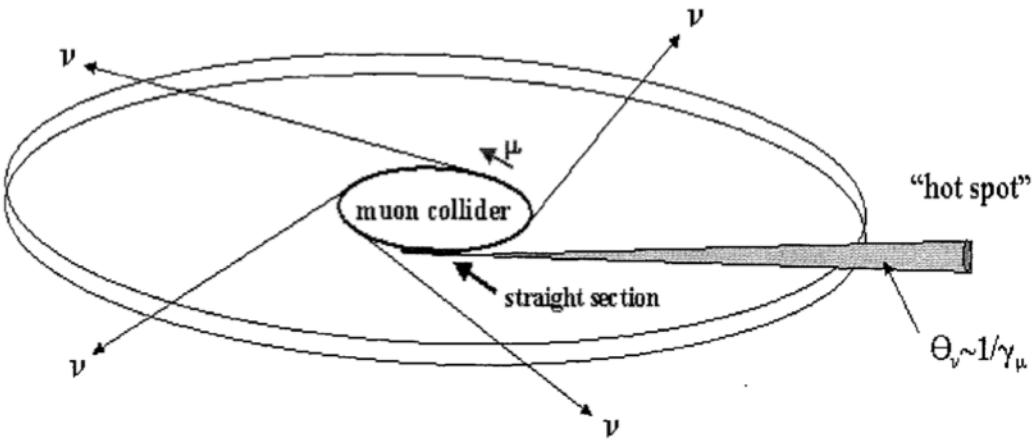
- Detailed presentations and discussions in serious of Design Meetings
- Transfer of lattice decks
- As new partners are forming own opinions
- Identifying issues that have been neglected
- Already part of generating the critical issues list
- Understanding the challenges and the resource needs

An important phase, excellent time to identified overlooked issues because of fresh view

Also have to find consensus on sometimes diverging opinions or define way to arrive at agreement

Challenge: Neutrino Radiation Hazard

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



Potential mitigation by

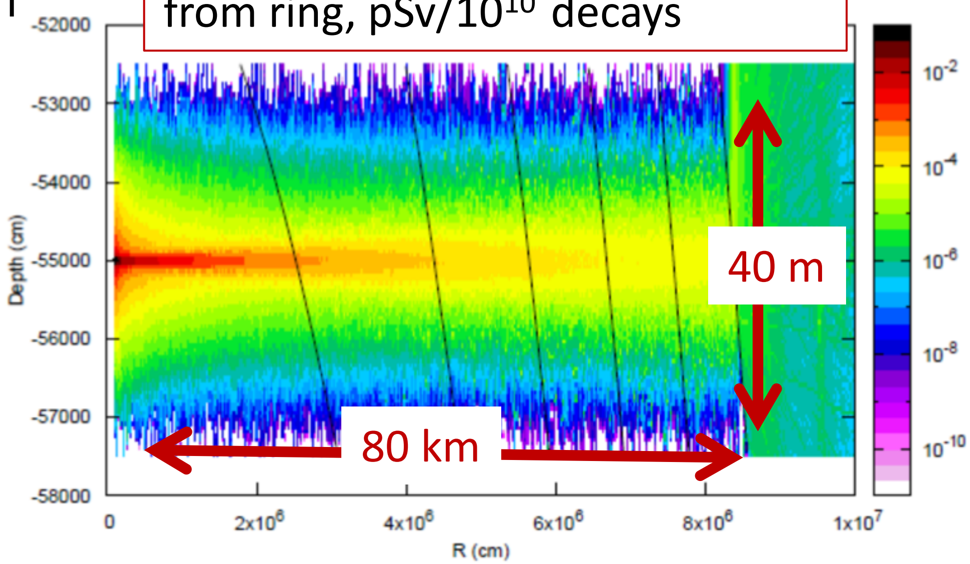
- Site choice
- Having a dynamic beam orbit so it points in different directions at each turn in the arcs
  - Or at least paint the beam in the the straights to dilute radiation

More important at higher energies (scaling E^3)

US study concluded: 6 TeV parameters are OK

Reasonable goal 0.1 mSv/ year, to be verified

Dose from 1 TeV $\mu^{\pm}$ vs distance from ring, pSv/10^{10} decays

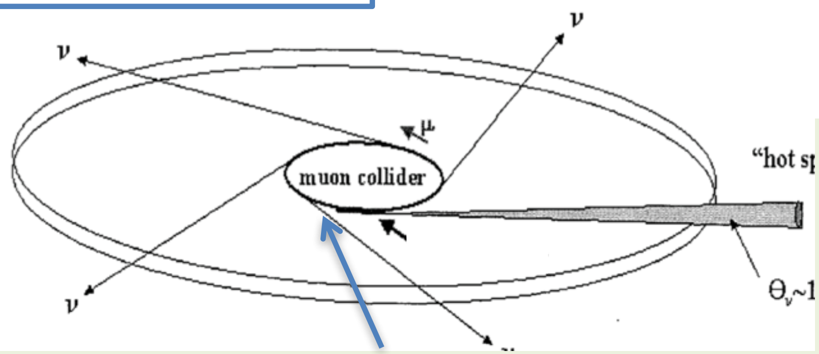


On-going simulations and studies for mitigation with existing/future tunnels

Example Neutrino Radiation Mitigation

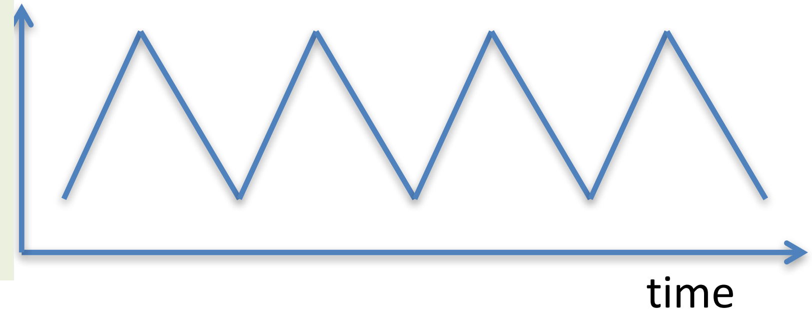
D. Schulte @ PECFA

Mitigation by varying beam orbit in collider is limited and costly (more space in magnets needed)

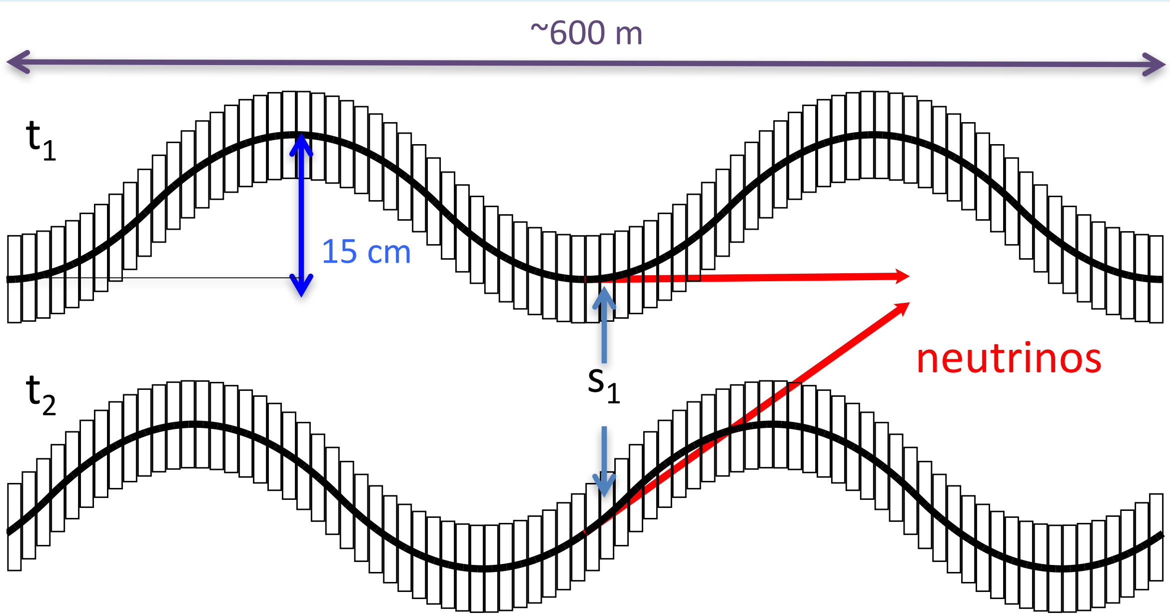


Relevant length of arc at s_1 is O(10 cm)

Vary vertical beam angle at s_1 in time



Move collider ring components, e.g. vertical bending with 1% of main field



Opening angle $\pm$ 1 mradian

O(100) larger than decay cone
$\Rightarrow$ gain O(100) in radiation

In straights, additional improvement in horizontal

Need to study impact on beam and operation, e.g. dispersion control

Demonstrator and Neutrinos

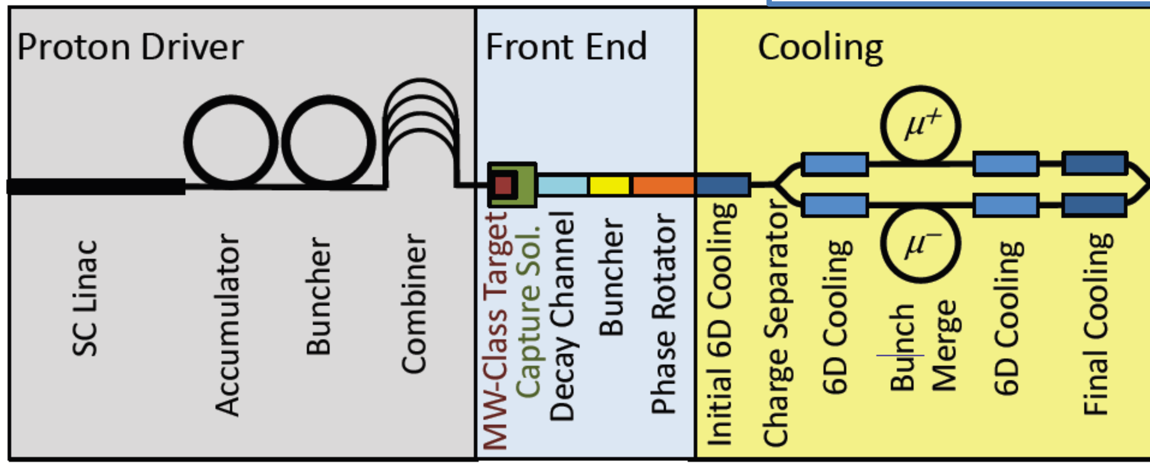
D. Schulte @ PECFA

Need to develop R&D programme for implementation after next ESU

Key will be demonstrator facility to produce useful muon beam

Risk not being that cheap

Can this be combined with a neutrino facility such as NuSTORM?



Will explore synergies

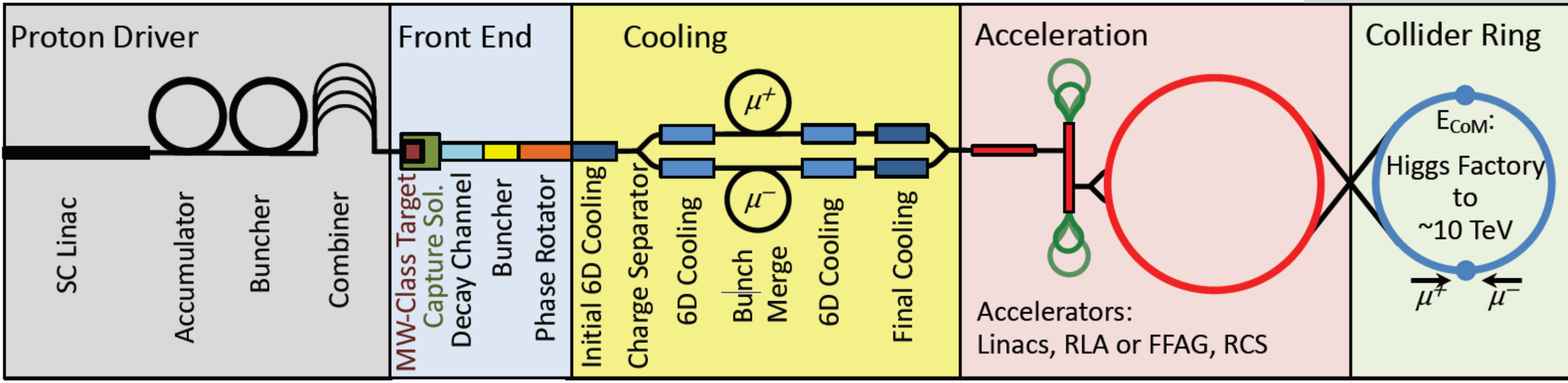
Also explore if the neutrinos from the straights of the collider could be used for physics
First suggestion (A. De Roeck, E. Tsesmelis)
Deep-sea installations in Mediterranean (KM3NeT-Fr, KM3NeT-It, KM3NeT-Gr)
But could be too deep, maybe interesting for test facility

Ideas are very welcome

Muon Collider Baseline Concept

D. Schulte @ PECFA

MAP collaboration



Proton Driver and Front End, Cooling and First part of Acceleration have same challenge level as in MAP designs

Final cooling misses transverse emittance target by factor 2

Still a **challenging design** with **challenging components**

Started to review to complete R&D item list and prepare priority

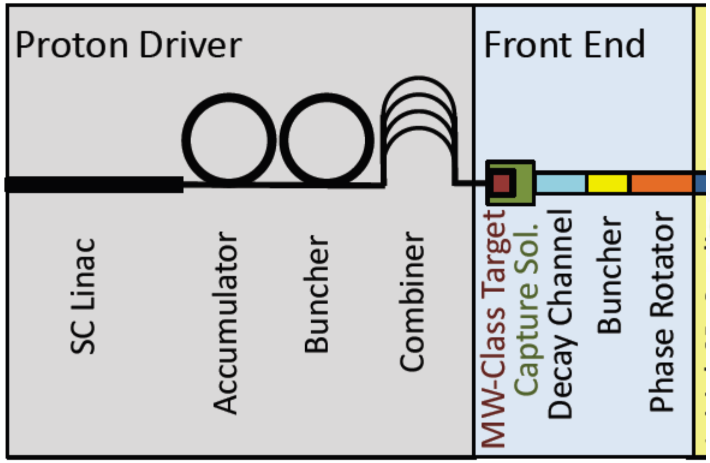
Accelerator ring, collider ring, interaction region, MDI, neutrino radiation become **more challenging with energy**
Also will drive cost and power

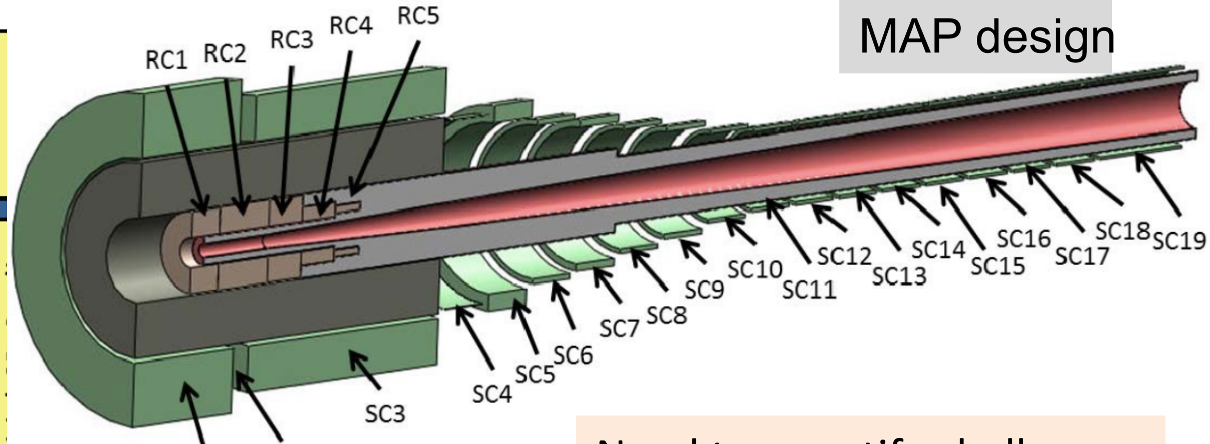
They will **limit energy reach**

Challenging design with **challenging components**

Proton Complex and Front-end

D. Schulte @ PECFA





Need to quantify challenges

Will launch activity soon

Intense proton beam is challenging

Need to make choices for the **target**

Ambitious **high-field solenoid**

Radiation in magnet

Downstream radiation from MW proton beam
Need to cool

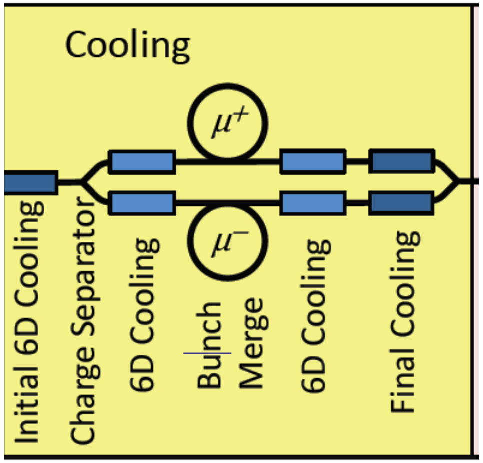
Target has to withstand **strong shock**

- liquid mercury target tested at CERN (MERIT)
- but solid target better for safety
- or beads
- or …

What could be made available at CERN (or elsewhere) as a proton driver for a potential test facility?

Muon Cooling

D. Schulte @ PECFA



Presentations:
Chr. Rogers, D. Neuffer, D. Bowring, P. Jurj, D. Summers

6D cooling can probably be better than foreseen
- Review integration aspects (cryogenic magnet coils next to normal conducting magnets)
- Optimise the design

Final cooling misses target transverse emittance by factor 2
- Higher field solenoids should help (>> 30 T), KTI proposal to BMFT (T. Arndt)
- Equilibrium emittance proportional to 1/B

Chopping and recombining bunch as alternative to final cooling suggested (D. Summers)
- To be reviewed

Experimentally proven RF gradients are higher than in design
- More muons will survive
- Can have more cooling
- Maybe can reuse some CLIC drive beam hardware for tests of RF

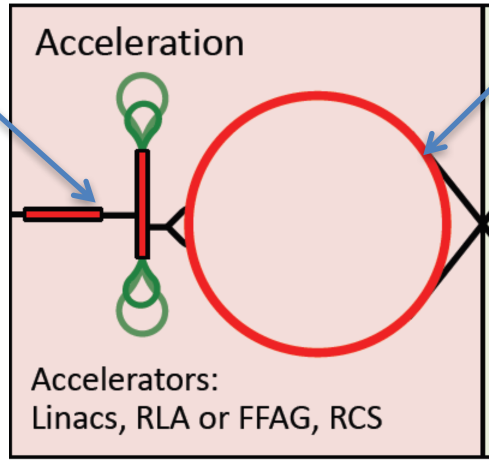
Muon Acceleration

D. Schulte @ PECFA

Design of initial acceleration (A. Bogacz) looks very solid

Does not change with collider energy

Main question is if we can further optimise



Accelerator ring is cost driver

Changes with collider energy

- potential energy limit

Two options are considered (presented by S. Berg, S. Machida, D. Summers)

- RCS (Rapid Cycling Synchrotron) with fast-ramping magnets
- FFAG with static magnets and special optics

Optics design (Interest: RCS: A. Chance, CEA, FFAG: S. Machida, Rutherford Lab)

Fast-pulsing magnets (normal-conducting or HTS (Interest: L. Rossi, INFN))

Efficient energy recovery of fast pulsing magnets (Interest: CERN)

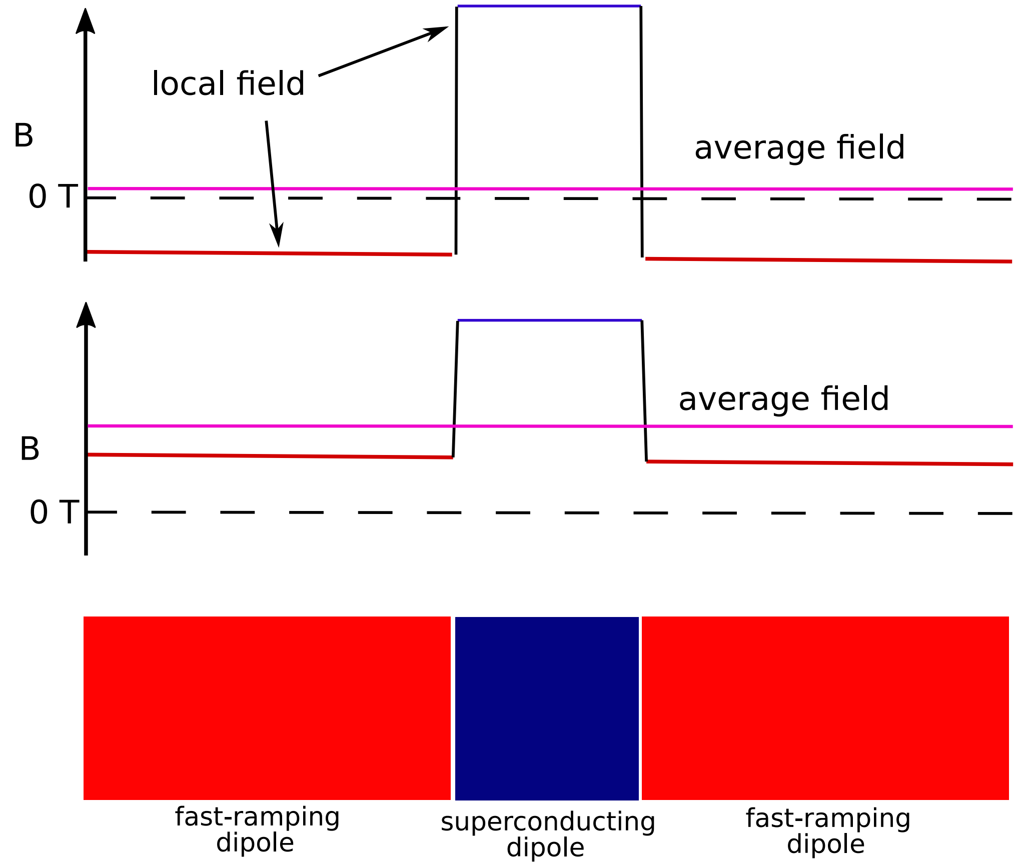
Efficient superconducting RF for short, intense bunches (Interest: U. van Rienen, Rostock, A. Grudiev, CERN)

High-energy Acceleration

D. Schulte @ PECFA

Rapid cycling synchrotron (RCS)

- Inject beam at low energy and ramp magnets to follow beam energy
- Could use combination of static superconducting and ramping normal-conducting magnets



Fast-pulsing magnets (O(ms) ramps))
Field defines size of accelerator ring

- normal-conducting
- HTS is interesting

Important energy in fast pulsing magnets

- O(200 MJ) @ 14 TeV
- need **very efficient energy recovery**

FFAG
Challenging lattice design for large bandwidth and limited cost
High field magnets

RF challenge:
High efficiency for power consumption
High-charge, single-bunch beam (10 x HL-LHC)
Maintain small longitudinal emittance

RF Challenge

D. Schulte @ PECFA

Acceleration and collider ring RF

14 TeV: 1 mm long bunch with 0.1 % energy spread in collider ring

Almost same longitudinal emittance as after muon cooling

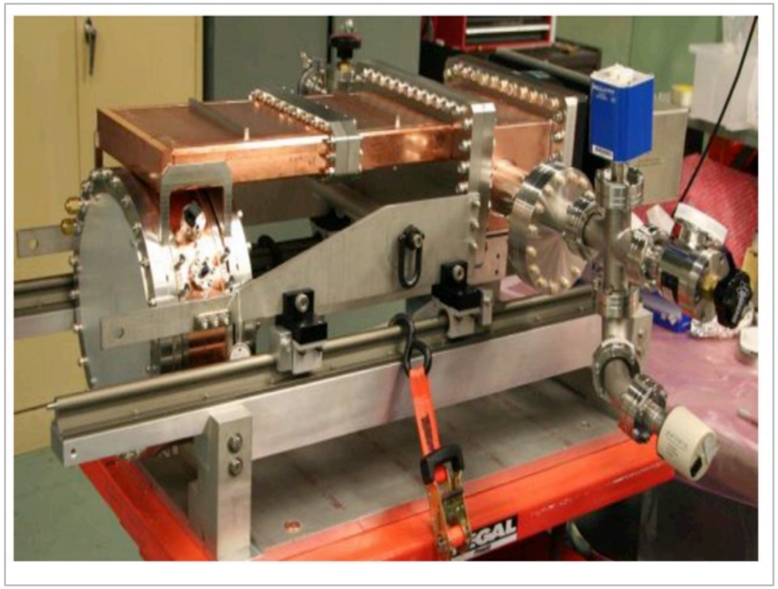
High bunch charge of 2×10^{12} muons

Start with long bunch that is subsequently compressed

Need concept of longitudinal dynamics all along the accelerator

Challenging to maintain emittance

MuCool: >50 MV/m in 5 T field



Muon cooling RF

Proof of principle in US (gas-filled copper and vacuum beryllium cavities)

Other RF

e.g. proton complex RF

making contact, may need more effort later

Collider Ring

D. Schulte @ PECFA

Challenging optics (short bunch, long ring, minimal RF)
Important **collective effects** (beam-beam etc.)

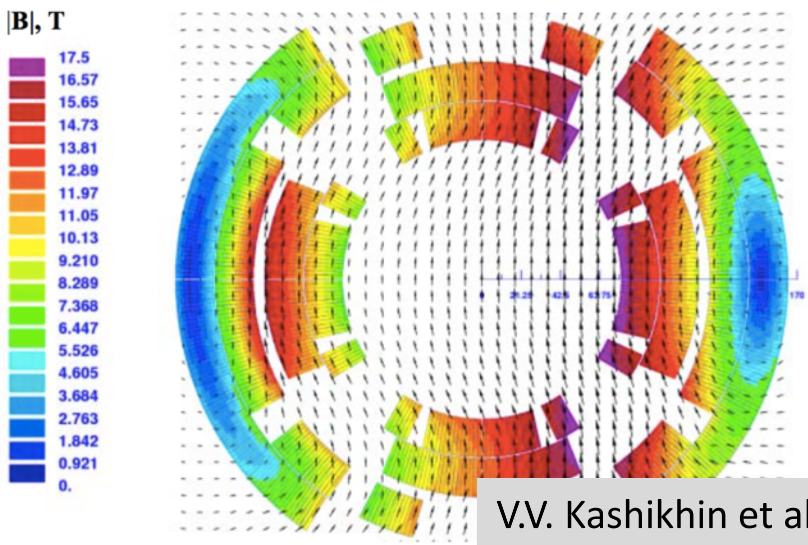
High-field, large aperture dipoles to minimise collider ring size and maximise luminosity

Combined function magnets replace quadrupoles to avoid straights

O(400 W/m) **beam loss**

- 5 MW total at 10 TeV
- Need to shield magnets
  - MAP at 3 TeV: 30-50 mm shielding
- Large apertures
  - MAP at 3 TeV: 150 mm

Combined function magnet design



V.V. Kashikhin et al.

Will consider different technology options at different energies (NbTi, Nb_3Sn, HTS)
Balance performance, cost and timescale

Final Focus

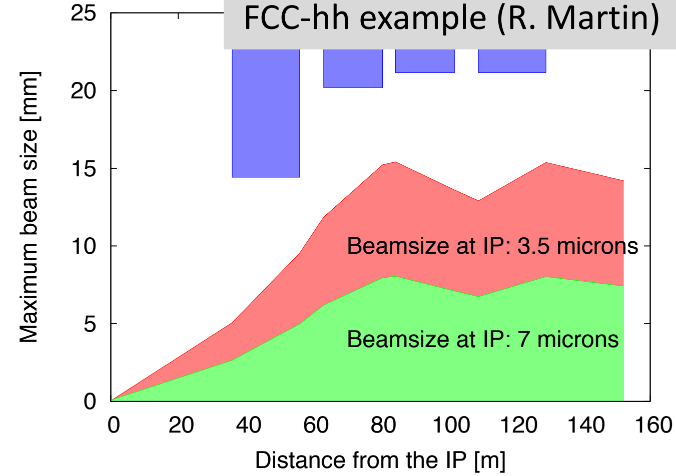
D. Schulte @ PECFA

Need smaller betafunctions at higher energy
Or smaller longitudinal emittance / larger energy acceptance

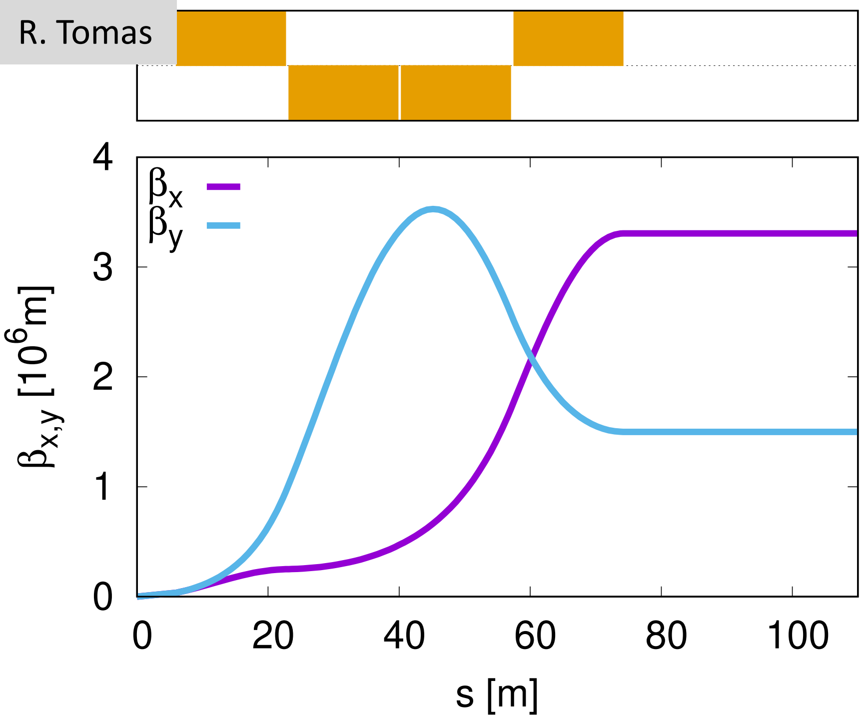
$$\beta^* \propto \frac{1}{E}$$

And focusing of higher energy beam is more difficult

FCC-hh example (R. Martin)



R. Tomas



$\beta^*_{x,y}$ = 1 mm
B_{peak} = 18 T
N_σ = 10 σ
E = 7 TeV
Aper. = 0.7 m

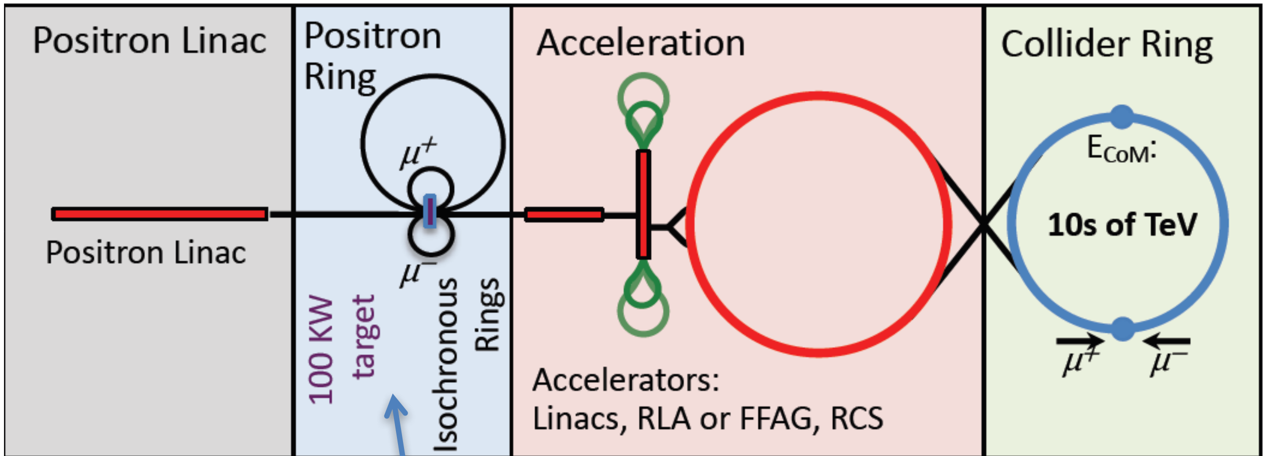
0.7 m for 10 σ
0.3 m for 6 σ

First look from Rogelio Tomas on final triplet at 14 TeV (L* = 6 m):

Challenging system
Need to add shielding

Alternative: the LEMMA Scheme

D. Schulte @ PECFA

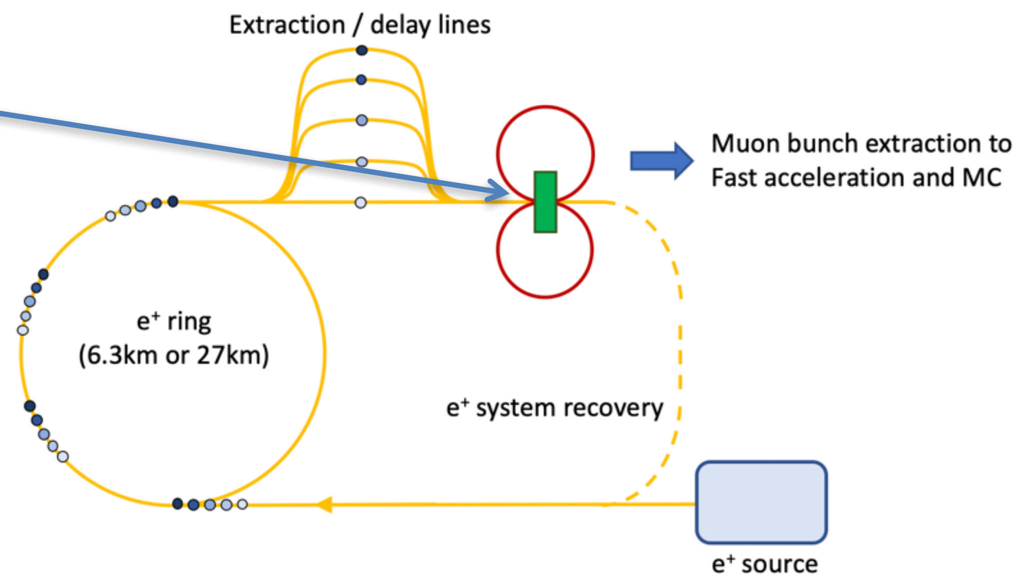


M. Antonelli, M. Boscolo et al

Less mature than proton scheme (less resources)

Progress in design but no parameter set for

45 GeV positrons to produce muon
Accumulate muons from several passages



Goal: produce low emittance muon beam, no cooling required

Challenge to get enough charge into the bunch

Will try to put together **target parameter list** based on fundamental limitations (e.g. target and collider ring) to identify potential and R&D issues

LEMMA Source Activities @ INFN

- **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. LNF, RM1 + RM3 + LNL + MIB + PoliTO

  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

LEMMA R&D - LoI - AF4 Multi-TeV colliders

Marica Biagini et al.

1. **TARGETS** → common to e^+ and $\mu^\pm$ source. Material studies and experimental tests done and several options to be explored for the μ source. Prototype of rotational target (single thick target or ensemble of close thin targets) with an amorphous and a granular amorphous material. Hydrogen target (pellet) studies. Crystal targets studies for muons recombination and post-production cooling. **Synergy with AF7**, **separate LoI presented by R. Li Voti**
2. **VERY HIGH PRODUCTION RATE e^+ SOURCE** → **synergy with AF7**, **separate LoI presented by I. Chaikovska**
3. **BEAM PHYSICS** → design e^+ and $\mu^\pm$ rings with very high energy acceptance, design of Interaction Region and Separation Region for 3 beams (e^+, μ^+, μ^-). **Synergy with AF1**
4. **HIGH FIELD MAGNETS** → need to focus 45 GeV e^+ and 22.5 GeV $\mu^\pm$ together in a short low β-function IR → high gradient, large aperture and compact quadrupoles. Design of the multi-targets $\mu^\pm$ production line requires efficient 3-beams separation design, aiming at minimising particle losses, with high field, large aperture dipoles. **Synergy with AF1, AF7**
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IDEAS

6. **MUON COOLING** → longer $\mu^\pm$ lifetime at production allows for introducing moderate cooling mechanism to further reduce production emittance. Different evaluations were done in the past for the cooling efficiency given by stochastic cooling, optical stochastic cooling, crystal cooling. A full revaluation of these mechanisms associated to high energy, low emittance and bunch current needs to be done. **Synergy with AF1, AF7**
7. **MUON RECOMBINATION** → testing muon bunches recombination techniques, that can increase the number of particle per bunch without been drastically affected by the consequent emittance increase. New hypothesis: possible recombination of different muon bunches by injection in a curved crystal. Combining the channeling angle with the volume reflection it should be possible to merge two different bunches with a relative emittance increase, mainly in the distribution tail. The efficiency of this process should be optimized. **Synergy with AF1, AF7**

LEMMA Accelerator studies @ 2020

- Design for the Damping Ring, 45 GeV e+ ring, and compressor Linac were studied last year

- This year the work has been focused on:
  - **Positron source and embedded sources**
    (I. Chaikovska et al., IJCLab, A. Bacci Milano, LNF, Roma I)
  - **Injection of spent beam**
    (M. Biagini et al., LNF, I. Debrot Milano, Roma I)
  - **Accumulator design and targets line** (M. Boscolo et al., LNF)
  - **Target studies** (R. Li Voti et al., Roma I)

Critical key issues

- **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 are 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**

Synergies

- Important synergies exist for the key muon collider technologies
  - Magnet development for hadron colliders
    - e.g. link to high-temperature superconducting magnet development
  - Superconducting RF cavities for hadron colliders and ILC
  - Normal-conducting structures for CLIC
  - Cooling for hadron colliders
  - Material, target, shielding, …
  - Instrumentation, vacuum, ...
- Synergies for physics and experiment will also be exploited
  - Physics studies
  - Simulation tools
  - …

Ongoing activities and interests @ INFN

- **LEMMA ➔** how to proceed??
- **Machine Detector Interface** *F.Collamati, et al. + A.Mereghetti CERN*

  Optics design required as part of the collider parameters studies. Fix constraints on nozzles design. Simulation tools. Strong collaboration with CERN
- **Material studies for targets** *Roberto Li Voti, RM1, RM3, LNL, MIB, PoliTO*
- **Crystals manufacturing targets/collimation** *L. Bandiera, A. Mazzolari et al.*
- **Neutrino Radiation Hazard Studies** *Alfredo Ferrari, Anna Ferrari, P. Sala et al.*

  Preliminary full FLUKA simulation: μ decays (ring/straight sections), ν interactions.
  Next: simulations with realistic ring geometries/orbits design. **Input from machine design.**

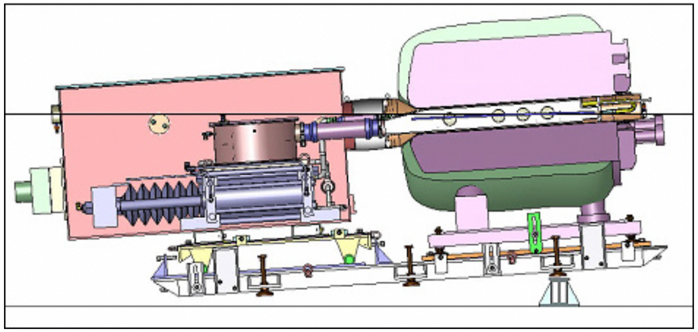
Strong synergy within the **new**:

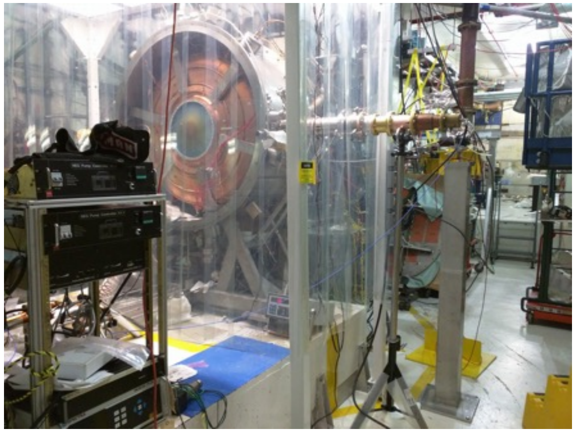
- **approved EU RISE project: aMUSE** (with activities @ FNAL Muon Campus)

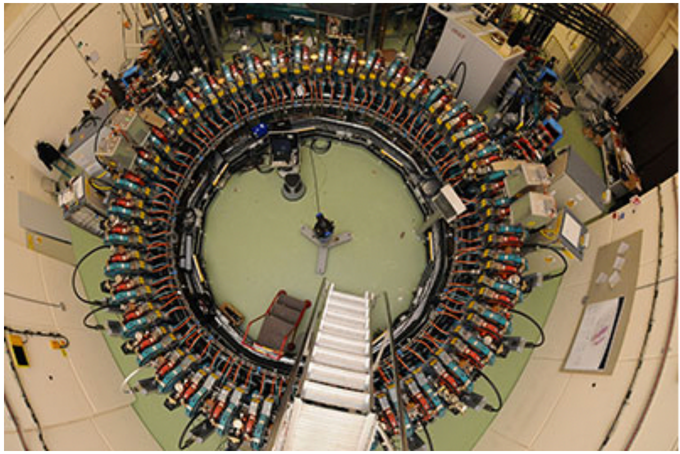
  Donatella Lucchesi (Univ. PD) for Muon Collider with US Laboratories FNAL, BNL
- **approved EU project I.FAST**

➔ **MUST** – MUon colliders Strategy network (*INFN, CERN, CEA, CNRS, KIT, PSI, UKRI)*

International R&D program







MERIT - CERN

Demonstrated principle of liquid Mercury jet target

MuCool Test Area - FNAL

Demonstrated operation of RF cavities in strong B fields

EMMA - STFC Daresbury Laboratory

Showed rapid acceleration in non-scaling FFA

MICE - RAL

Demonstrate ionization cooling principle
Increase inherent beam brightness
→ number of particles in the beam core
"Amplitude"

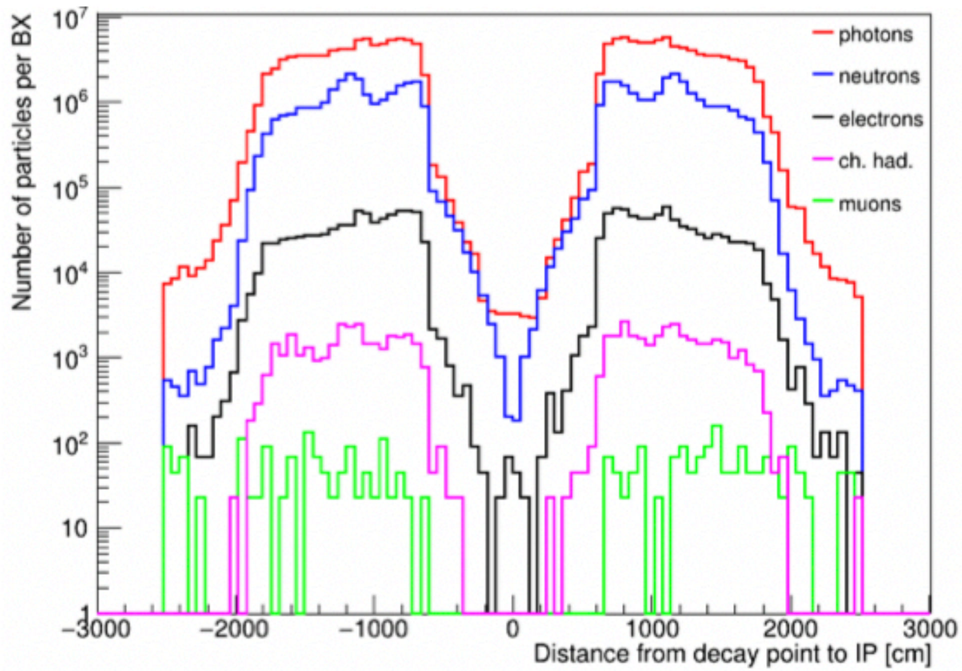
Beam Induced background @ 1.5 TeV

Nikolai Mokhov et al. - MARS15

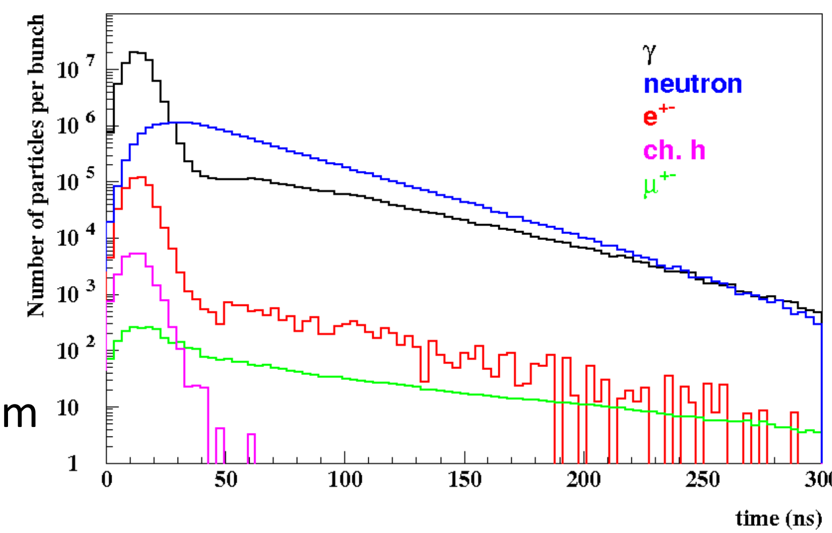
***JINST* 15 (2020) 05, P05001**

Beam muons decay products interact with machine elements and cause a continuous flux of secondary and tertiary particles (mainly γ, n, $e^{\pm}$, $h^{\pm}$) 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

Studies of target materials and layout for a low emittance muon source (LEMMA)

R. Li Voti[1,*], G. Cesarini[1], F. Anulli[1], M. Bauce[1], G. Cavoto[1], F. Collamati[1], S. Rosati[1], M. Antonelli[2], M.E. Biagini[2], M. Boscolo[2], P. Branchini[3], R. Di Nardo[3], A. Passeri[3], L. Tortora[3], V. Berandi[4], G. Catanesi[4], R. Spina[4], M. Bonesini[5], R. Benocci[5], L. Peroni[6], M. Scapin[6], L. Centofante[7], S. Corradetti[7], M. Manzolaro[7], A. Monetti[7], D. Scarpa[7], and N. Pastrone[8]

[1]INFN, Sezione di Roma e Università degli Studi di Roma "*Sapienza*"; *roberto.livoti@uniroma1.it
[2]INFN, Frascati National Laboratories, Frascati, Italy
[3]INFN Roma Tre e Università Roma Tre, Rome, Italy
[4]INFN Sezione di Bari e Università e Politecnico di Bari, Bari, Italy
[5]INFN Sezione di Milano Bicocca e Università di Milano Bicocca, Milano, Italy
[6]Department of Mechanical and Aerospace Engineering, Politecnico di Torino, Torino, Italy
[7]INFN, Laboratori Nazionali di Legnaro - Legnaro (PD), Italy
[8]INFN sezione di Torino, Torino, Italy

Physics and technology challenges in generating high intensity positron beams

I. Chaikovska[1], R. Chehab[1], A. Variola[2], F. Zimmermann[3], J. Grames[4], F. Lin[4], L. Bandiera[5], V. Guidi[5], A. Mazzolari[5], U. Wienands[6], Y. Enomoto[7], P. Martyshkin[8]
[1] Université Paris-Saclay, CNRS/IN2P3, IJCLab, 91405 Orsay, France. [2] INFN Sezione di Roma1, 00185 Roma, Italy. [3] CERN. [4] JLab. [5] INFN Ferrara Unit, 44122 Ferrara, Italy. [6] ANL. [7] KEK. [8] BINP

Physics potential

Fisica al Muon Collider

INFN Roma Barbara Mele

Quartic Higgs self-coupling: arXiv:2003.13628 [hep-ph]
Vector Boson Fusion: arXiv:2005.10289 [hep-ph]

a few final comments

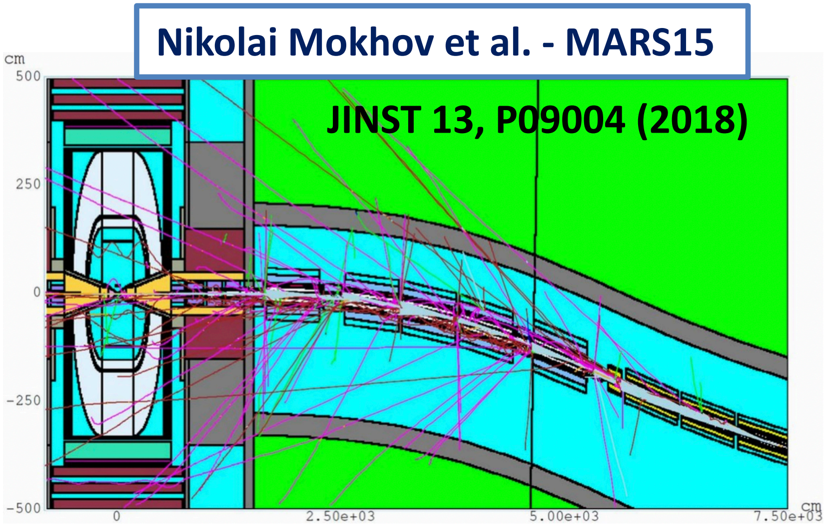
- such a high energy at pointlike level opens up hugely new perspectives !
- μ colliders @10+TeV can be considered WW colliders !
- qualitatively new Higgs physics
- physics bckgds expected mild also for hadronic final states but simulations are quite hard (many particles in phase-space)
- explore goodness of Equivalent Vector-Boson Approx.
- many many possible new directions for exploring BSM [VBF-production role to be extensively considered…]
- amazing boost for precision physics @10+TeV muon colliders !

https://agenda.infn.it/event/23693/

* thanks to M.Chiesa, F.Maltoni, F.Piccinini for discussions !

December 11, 2020

Beam Induced background @ 1.5 TeV



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

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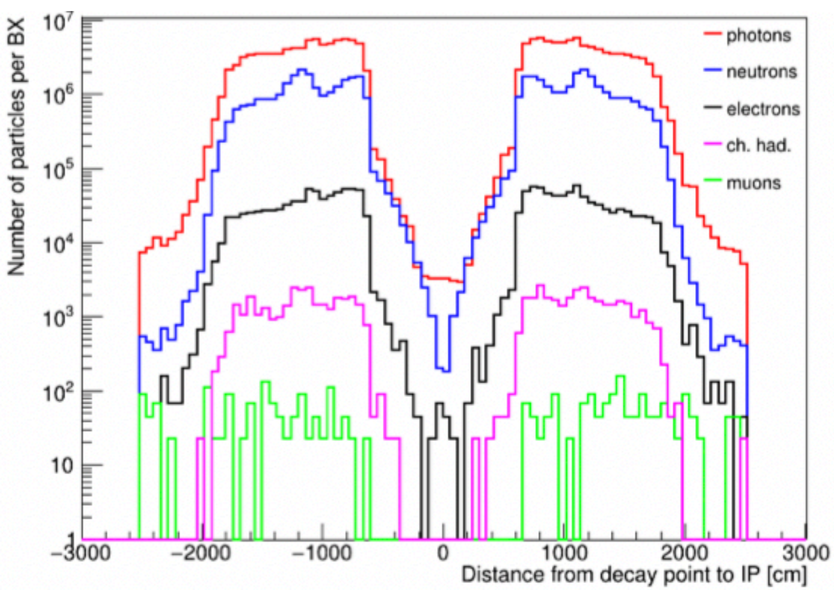

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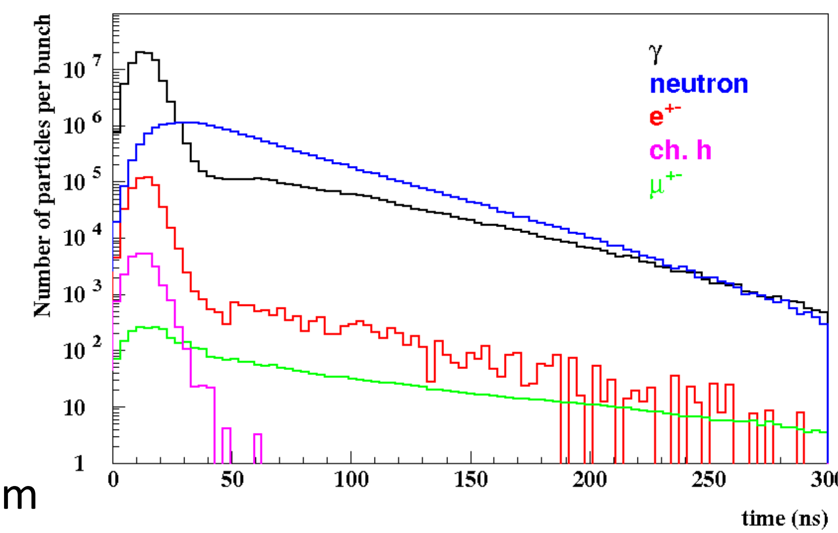
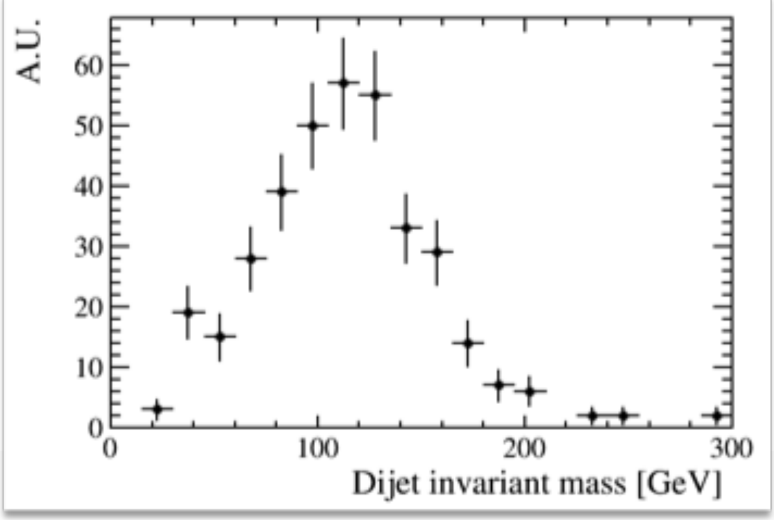


Secondary and tertiary particles have low momentum and different arrival time in the Interaction Point

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.

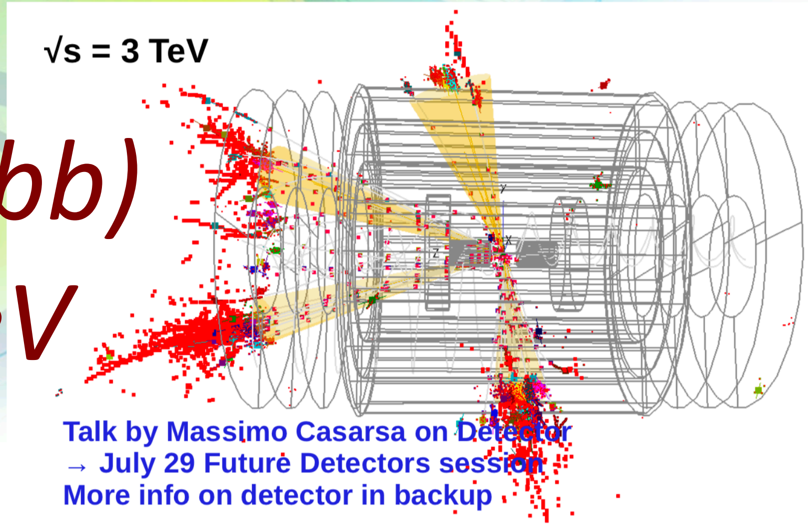
$\sqrt{s}$ [TeV]	A [%]	ϵ [%]	$\mathcal{L}$ [cm^{-2}s^{-1}]	$\mathcal{L}_{int}$ [ab^{-1}]	σ [fb]	N	B	$\frac{\Delta\sigma}{\sigma}$ [%]	$\frac{\Delta g_{Hbb}}{g_{Hbb}}$ [%]
1.5	35	15	$1.25 \cdot 10^{34}$	0.5	203	5500	6700	2.0	1.9
3.0	37	15	$4.4 \cdot 10^{34}$	1.3	324	33000	7700	0.60	1.0
10	39	16	$2 \cdot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

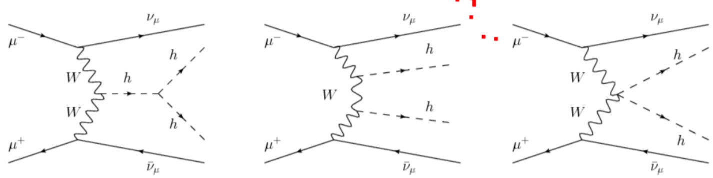
CLIC numbers are obtained with a model-independent multi-parameter fit performed in three stages, taking into account data obtained at the three different energies.

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

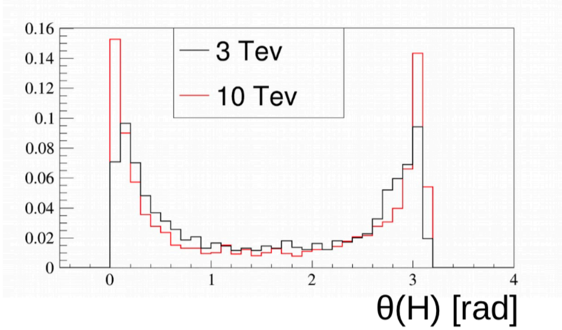
H(bb)H(bb) @ 3 TeV



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



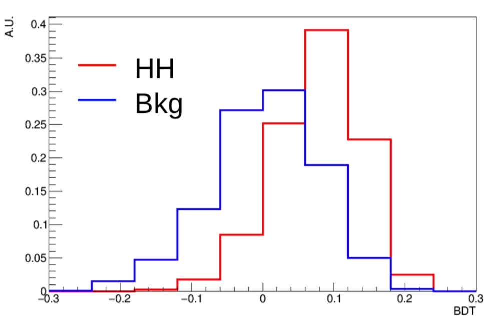
- Next step: **study of the HH production.**
- We are now using a **modified version of the CLIC detector**, with nozzles and a different vertex detector, using the ILCSoft framework for the full simulation and reconstruction.
- Signal and backgrounds are generated with WHIZARD.
- Higgs is likely to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

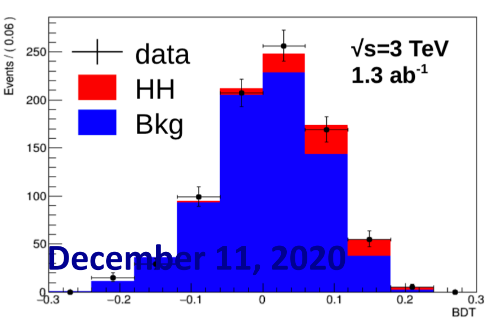


11

HH

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**.

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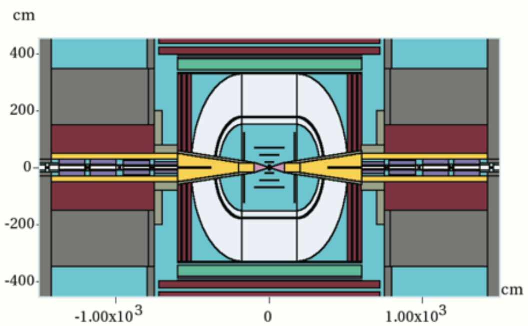
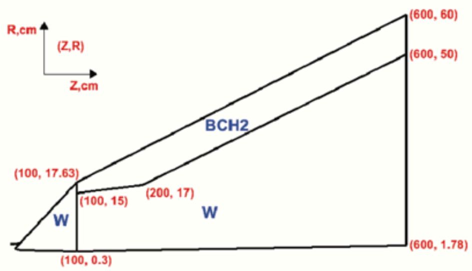
Lorenzo Sestini @ ICHEP 2020

Machine Detector Interface



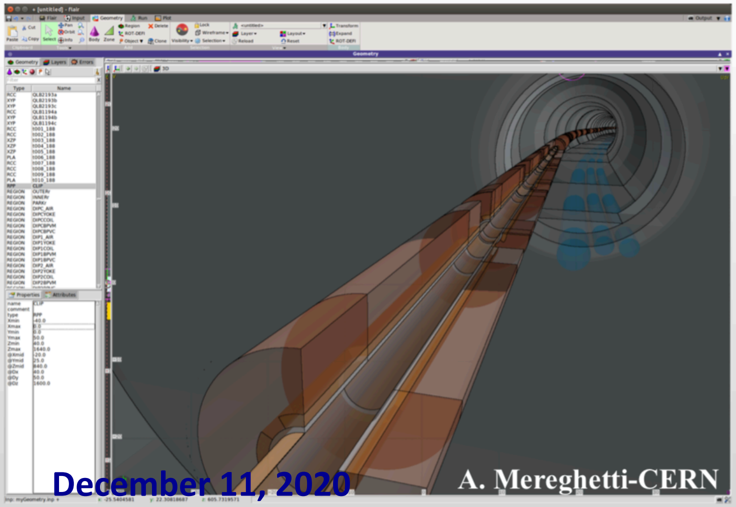


Need for a flexible tool from machine optics to simulation

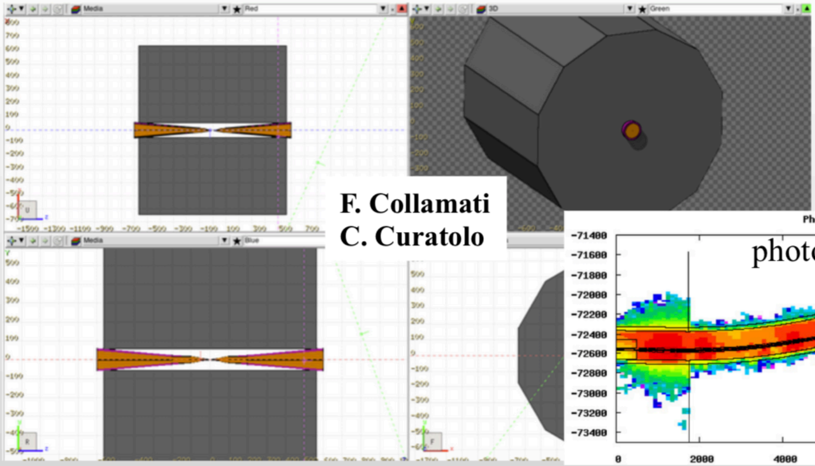
See F. Collamati talk at ICHEP2020

Input data
Output data
Software program

machine lattice & optics → LineBuilder
Fluka Element DB → LineBuilder
LineBuilder → machine geometry
detector nozzle description → Flair + new code → detector nozzle position
machine geometry, detector nozzle position → Fluka simulation muon decay & interaction with material → Background on detector envelope

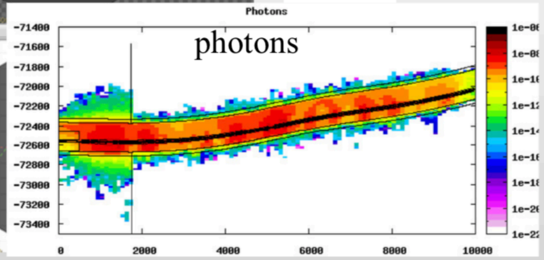


A. Mereghetti-CERN



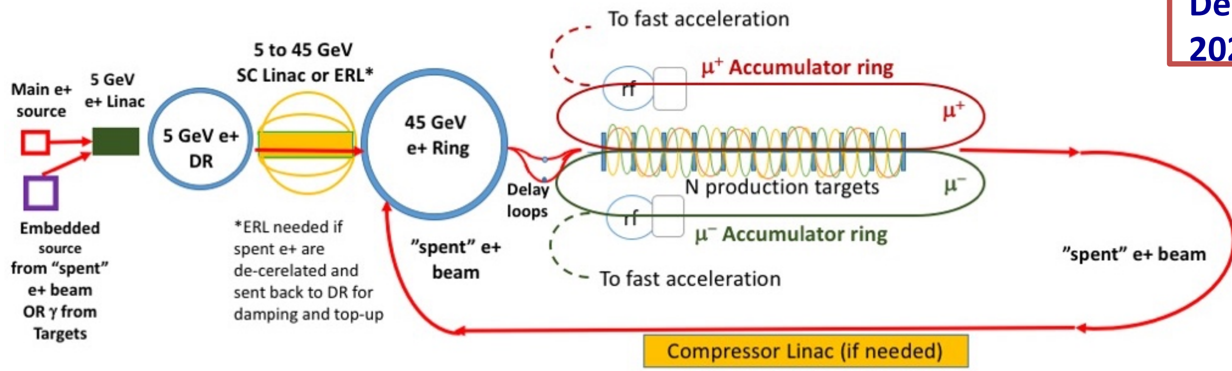
F. Collamati
C. Curatolo

P. Sala



LEMMA R&D - LoI Snowmass'21 - AF4 Multi-TeV colliders

December 11, 2020



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