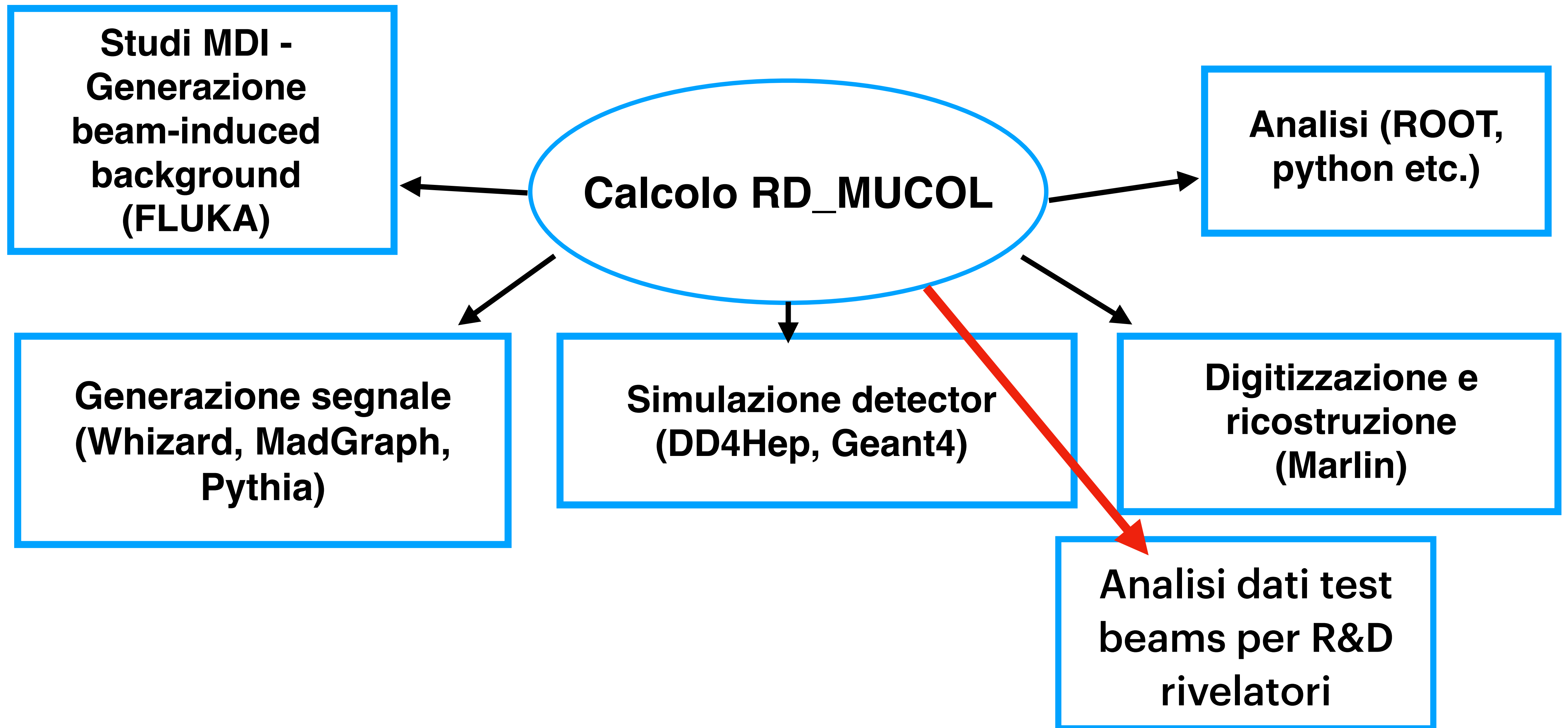




Calcolo RD_MUCOL 2026

Lorenzo Sestini - INFN Firenze

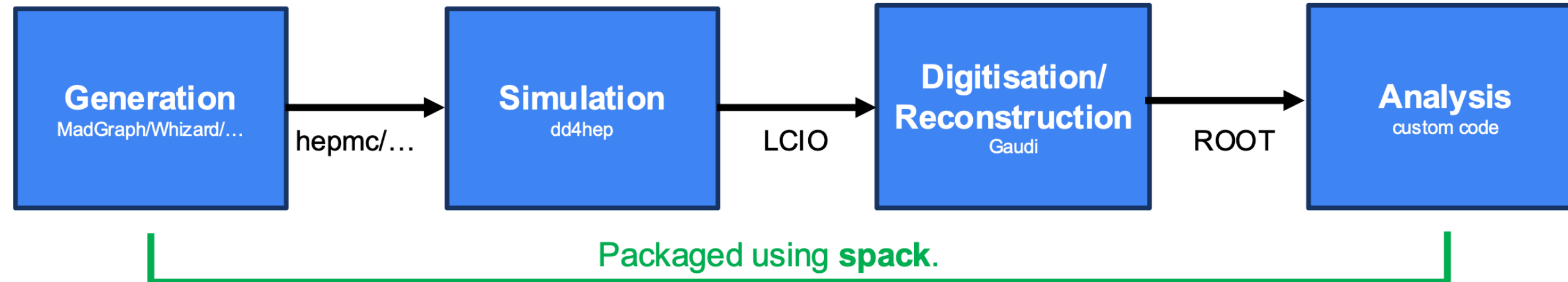
Meeting con i referee di RD_MUCOL - 22/7/2025



Software

Muon Collider Software Stack

Originally based on ILCSoft, being transitioned to [Key4hep](#).



- Gaudi processors are still wrappers around the old Marlin processors.

Tutorials

<https://mcd-wiki.web.cern.ch/software/tutorials>

<https://mcd-wiki.web.cern.ch/software/>

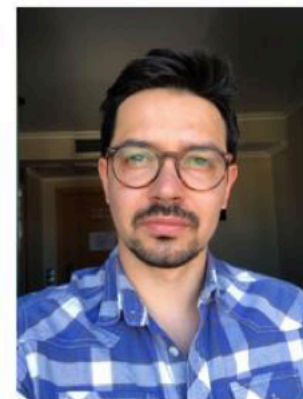
The screenshot shows the 'Software' section of the Muon Collider Physics & Detector Wiki. The page has a teal header with the title 'Muon Collider: Physics & Detector Wiki' and a search bar. Below the header is a navigation menu with links: Home, Detector, Montecarlo Simulated samples, Computing infrastructure, Software, and Resources. The main content area is titled 'Software' and includes a sidebar with links: Software, HowTo, Delphes Card, Software installation, Releases notes, and Tutorials. The main content area has an 'Info' box with the contact email 'muon_collider_software@lists.infn.it'. Below this is a 'Repository' section with links to official ILCSoft packages and the Github repository. The 'Docker distribution' section mentions that Docker images are distributed on several platforms, including CERN GitLab and INFN DockerHub. It also lists unpacked versions of some images hosted on CERN CVMFS, with links to the GitLab registry and DockerHub registry. Finally, it mentions that converted versions suitable for Apptainer (ex. Singularity) are also hosted on CNAF Storage Element.

Software task force

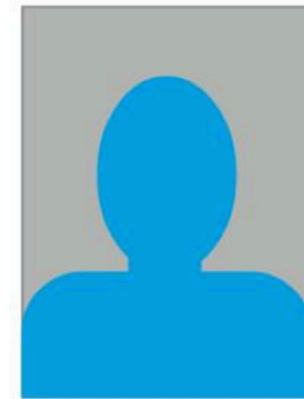
Software Task Force



**Paolo
Andreetto**



**Nazar
Bartosik**



**Alessio
Gianelle**



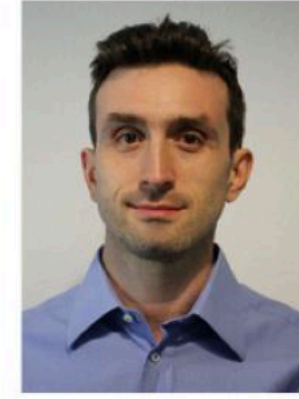
Karol Krizka



**Lawrence
Lee**



**Thomas
Madlener**



**Federico
Meloni
(chair)**

Membri INFN della Task Force

Alessio Gianelle e Paolo Andreetto (INFN-PD)
Nazar Bartosik (INFN-TO)

Roadmap: Short Term

1. Complete the upstreaming of the μ C changes to key4hep packages
 - <https://github.com/MuonColliderSoft/ConformalTracking>
 - <https://github.com/MuonColliderSoft/MarlinTrkProcessors>
 - Set up mucoll-release folders within key4hep-spack
 - Get developer access to manage our own changes
2. Merge bug-fixes from initial ESPPU release (2.9)
 - Adjust ACTS seeding
3. **Include MUSIC and MAIA detector geometries**
4. Build release image and distribute

Roadmap: Medium Term

1. Migration to gaudi/edm4hep-based workflow
 - Migrate digitisers to gaudi
 - Migrate/re-design Overlay processor for gaudi
 - Output edm4hep files by default
2. Configure Issue templates in each repository that is part of the release
3. Organise a systematic review of code to identify any ee assumptions (e.g. occupancy) are baked into the framework
4. Muon PID for 10 TeV detector concepts
5. Setup workflows to build specialized software images (i.e. analysis only)

Roadmap: Long Term

1. Tracking
 - Load tracking geometry from dd4hep plugin - being tackled community-wide, requires changes to ACTS
 - Update again to latest and greatest ACTS (currently v35.2.0)
2. Calo clustering
 - Test/Use of more modern clustering tools, e.g. k4Clue
3. PFO reconstruction
 - Move away from PandoraPFO (worldwide expertise problematic)
 - Switch to simpler / non-monolithic algorithms
 - Break down workflow small configurable algorithms
 - Get rid of hardcoded PFO assumptions
4. Need to monitor wider community and possibly move in synch

Risorse calcolo RD_MUCOL

- **Cloud-Veneto**: 600 VCPU, 2 TB di RAM, ~300 TB di storage
- **CNAF**: batch system basato su HTCondor, 150 TB di storage, 6 CE
- **IBISCO-Bari**: risorse condivise con altri progetti allocate al momento della richiesta
- **CERN**: batch system basato su HTCondor, 600 TB di storage su CERN EOS
- **Risorse locali**: Farm Trieste (modalità opportunistica), Pavia etc.

Cloud-Veneto

Report sull'utilizzo per periodo	2024-07-20	2025-07-21				
ID progetto	1d4bbbed70b794917acaaaa69990873fb					
Istanze attive:	15					
Utilizzo totale VCPU (Ore):	2413786	55				
RAM totale attiva (MB):	704512					
Utilizzo totale memoria (Ore):	9261532503	17				
Dimensione totale disco (GB):	381					
Utilizzo totale disco (Ore):	24213729	59				
Nome Istanza	VCPUs	RAM (MB)	Disco (GB)	Utilizzo (Ore)	Age (Seconds)	Stato
MuonC_32	32	32768	28	8792,45	42307167	Attivo
MuonC_Lorenzo	8	16384	25	8792,45	34445764	Arrestato
Whizard	32	32768	28	8792,45	41729956	Attivo
MuonC_UI	8	8192	25	8792,45	42287956	Attivo
MuonCServer	2	4096	25	1466,19	5278292	Attivo
MuonC_User03	8	32768	25	3502,13	12607661	Arrestato
MuonC_Users01	8	32768	25	8792,45	67124697	Attivo
MuonC_Monster	32	348160	25	8792,45	34111998	Attivo
MuonC_User06	8	32768	25	3164,60	11392560	Arrestato
MuonC_Ubuntu22	8	16384	25	119,49	430167	Attivo
MuonC_01	8	32768	25	7655,78	27560820	Attivo
MuonC_User05	8	32768	25	3501,77	12606360	Arrestato
MuonC_User04	8	32768	25	3501,81	12606499	Arrestato
MDI	8	16384	25	8792,45	42287080	Arrestato
MuonC_User07	8	32768	25	3164,57	11392466	Arrestato

- Risorse in condivisione tra INFN e Università
- **Accesso via INFN IdP, necessita account centralizzato**
- Grazie alla flessibilità della Cloud (ad es. nessun limite ad allocazione RAM o al tempo massimo di esecuzione), riusciamo a girare qualunque tipo di job (generazione, simulazione, ricostruzione etc.)
- **Acquisto di un server da 30k euro completato nel 2025**
- Un anticipo dello storage (circa 80 TB) era stato concesso da Cloud-Veneto alla fine del 2024, permettendo il lavoro sugli input della European Strategy
- Spazio occupato attualmente 117 TB/225 TB (52%), lo giudichiamo sufficiente per le attività del 2026

CNAF

- **Accesso via VOMS**, istruzioni <https://confluence.infn.it/display/muoncollider/Storage+Element>
- **In questo momento usato solo come storage**
- Riscontrati problemi dovuti alla durata dei jobs e alla scadenza del proxy, soprattutto per jobs di ricostruzione
- Attuale occupazione Disco: 117 TB/150 TB
- Stiamo valutando di dismetterlo completamente (anche lo storage), ma ancora non siamo pronti

IBISCO-Bari

- Le risorse di IBISCO-Bari sono state acquisite da RD_MUCOL nel 2022: 7k HS06 e 300 TB
- Destinata alla produzione campioni di b, c e light jets (full simulation + ricostruzione con BIB) per studiare algoritmi di ricostruzione/identificazione basati su machine learning, e a campioni per lo sviluppo di HCAL
- **Le risorse sono attualmente condivise con gli altri progetti, vengono allocate al momento della loro richiesta**
- L'accesso avviene tramite account a Bari, può essere aperto anche da utenti di altre sedi



- **Risorse non finanziate da INFN**
- **Per poter accedere necessario account al CERN**
- Iscrizione su e-groups *muoncollider-readers*, *muoncollider-writers*, *muoncollider-batch*
- 600 TB di spazio disco su EOS
- Attualmente riempito con 562/600 TB (94%)
- Possibilità di sottomettere jobs con HTCondor, potenzialmente abbiamo delle code dedicate

Next steps (2025-2026)

Performance study of the MUSIC detector in $\sqrt{s} = 10$ TeV muon collisions

Contact Persons:

Paolo Andreotto (paolo.andreotto@pd.infn.it), Massimo Casarsa (massimo.casarsa@ts.infn.it), Alessio Gianelle (alessio.gianelle@pd.infn.it), Donatella Lucchesi (donatella.lucchesi@unipd.it), Leonardo Palombini (leonardo.palombini@pd.infn.it), Lorenzo Sestini (lorenzo.sestini@fi.infn.it), Davide Zuliani (davide.zuliani@unipd.it).

for the MUSIC detector study group

Abstract

This study investigates the performance of the MUSIC (MUon System for Interesting Collisions) detector concept in the context of $\sqrt{s} = 10$ TeV muon-antimuon collisions. The detector is designed to mitigate machine-induced background effects while maintaining high efficiency and accuracy in reconstructing physics events, particularly in the Higgs boson sector and searches for new physics. The MUSIC detector features an advanced tracking system, electromagnetic and hadronic calorimeters, and a superconducting solenoid providing a 5T magnetic field. Simulation studies demonstrate promising tracking efficiency, photon and electron reconstruction capabilities, and jet identification performance, confirming the detector's potential for high-energy muon collider experiments.

Sensitivity study on $H \rightarrow b\bar{b}$, $H \rightarrow WW^*$ and $HH \rightarrow b\bar{b}b\bar{b}$ cross sections and trilinear Higgs self-coupling with the MUSIC detector in $\sqrt{s} = 10$ TeV muon collisions

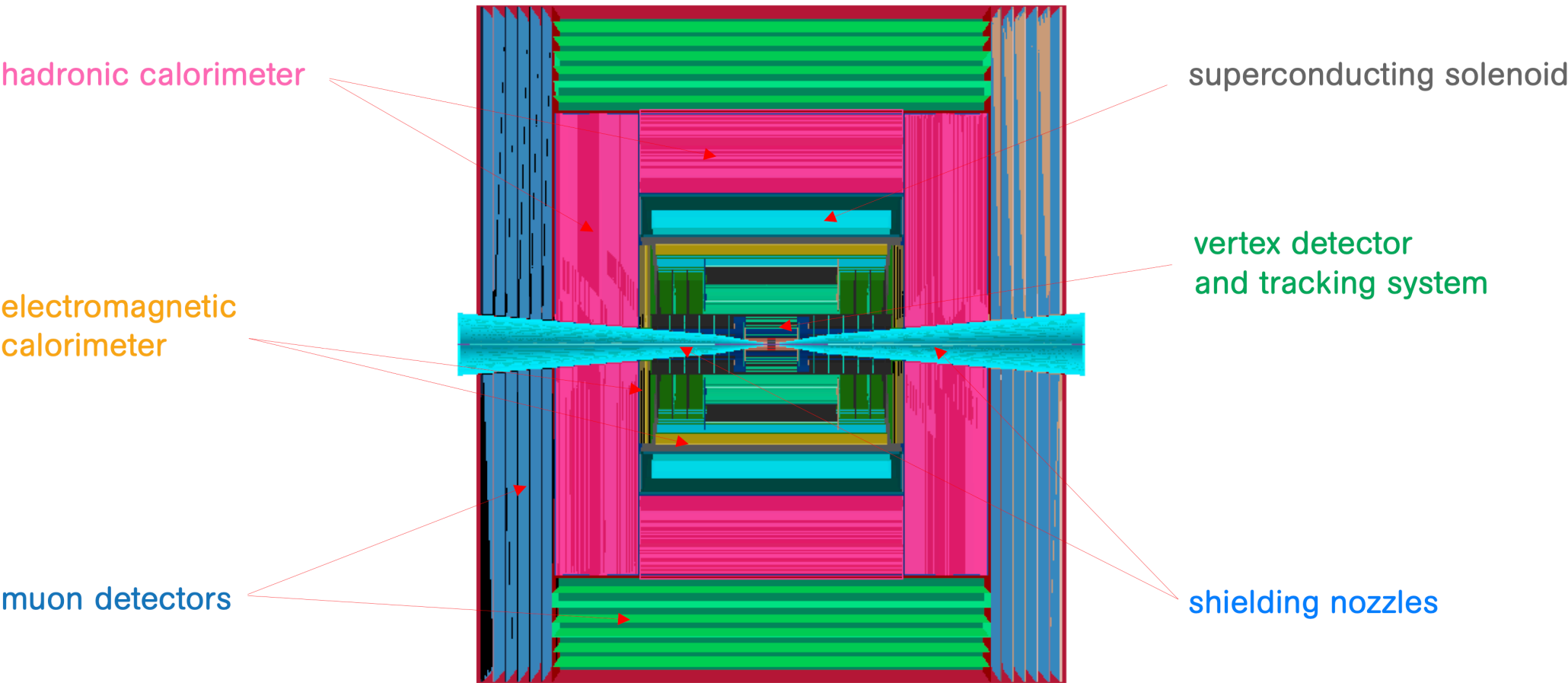
Contact Persons:

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for the Higgs study group with MUSIC detector

Abstract

This study investigates the physics reach in the Higgs sector of muon-antimuon collisions at a center-of-mass energy of 10 TeV. The statistical sensitivity of the production cross sections for $H \rightarrow b\bar{b}$, $H \rightarrow WW^*$, and $HH \rightarrow b\bar{b}b\bar{b}$, as well as the measurement of the Higgs boson trilinear self-coupling, is evaluated using a detailed detector simulation that includes the dominant contributions of the machine-induced background. The studies utilize MUSIC, a detector concept specifically designed and optimized for the muon collision environment at 10 TeV, and assume a dataset of 10 ab^{-1} collected over a five-years period by a single experiment. The results highlight the exceptional potential of a high-energy muon collider for exploring the Higgs sector, in particular for determining the Higgs potential. A multi-TeV muon collider offers a level of precision that cannot be achieved by any other proposed future collider within a comparable time frame.



The MUSIC detector (Muon Smasher for Interesting Collisions).

Studi detector per i 10 TeV:

- Completamento studi presentati alla strategy:
- Determinazione delle performance
- Benchmark di fisica

Documenti
presentati alla
European
Strategy

Next steps (2025-2026)



Tracker R&D

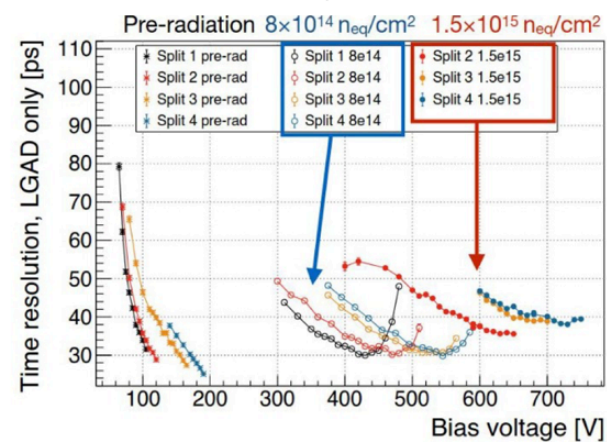
Karol Krizka's talk

Same pathway as for many experiments:
Radiation hardness
Excellent timing resolution (30-60 ps)

Sensor R&D well advanced

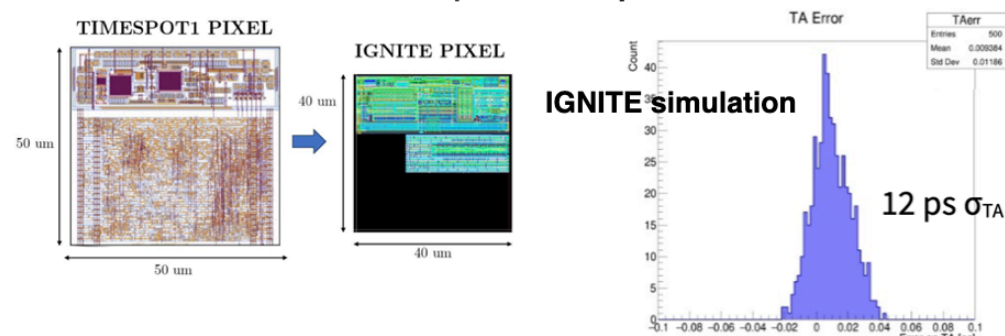
- Low Gain Avalanche Diodes can soon meet our requirements
- R&D for monolithic devices just started, but good option for future

HL-LHC Detector Upgrades, 1.3x1.3 mm² pixels

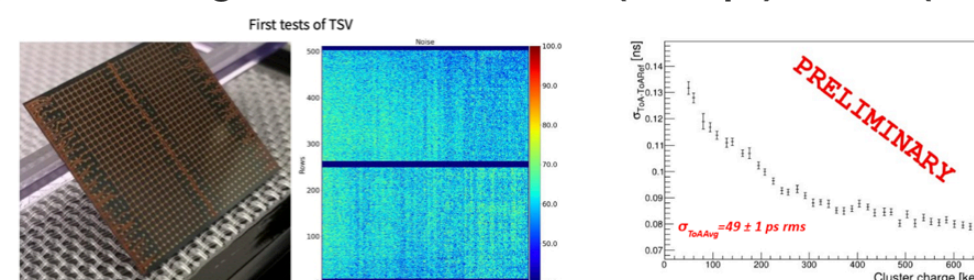


Large challenge for ASIC development

- Demonstrator chips already exists



Large scale timing 65 nm ASIC: TimePix4 ($\sigma_t=30$ ps) PicoPix ($\sigma_t=60$ ps)



Other challenges: readout link, powering, mechanics etc.



Calorimeter R&D

Elisa Di Meco's talk

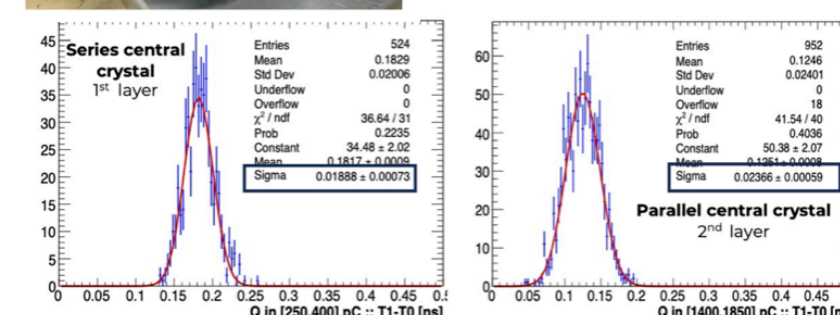
CRILIN: semi-homogeneous PbF₂ calorimeter specifically designed for the muon collider ECAL

- Implemented in DD4HEP
- Matches the ECAL requirements

Proto-1 (3x3 crystals x 2 layers 36 channels)



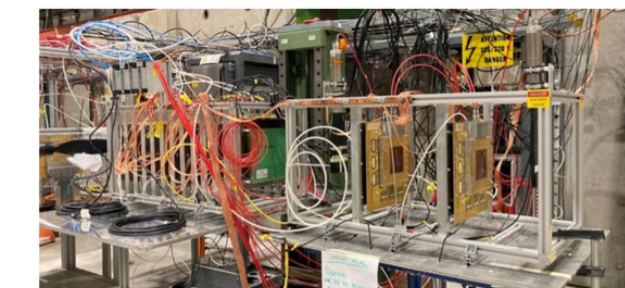
- Testbeams with 450 MeV (LNF-BTF) and 120 GeV (CERN-SPS-H2) electrons
- Time resolution at 120 GeV in the order of 20 ps



Moving upon 9x9 (crystals) x4(layers) prototype thanks to 210kE Italian grant

Micro-pattern Gas Detectors read-out layers for HCAL

- Implemented in DD4HEP
- On-going simulation studies for performance evaluation



Test beam setup at SPS, Size: 20x20 cm², 1x1 cm² pads

RD51 common project:
7 μ -RWELL,
4 MicroMegs,
1 RPWELL

- Testbeam at SPS with high energy muons (MPGD performance)
- Testbeam at PS with low energy pions (calorimeter performance)

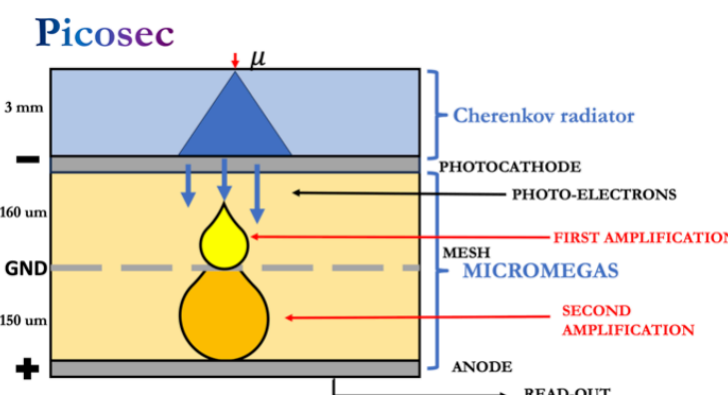
Next steps: two testbeams in 2024, 4 large detectors (50x50 cm²) be built in 2024. Common testbeam with CRILIN in 2025



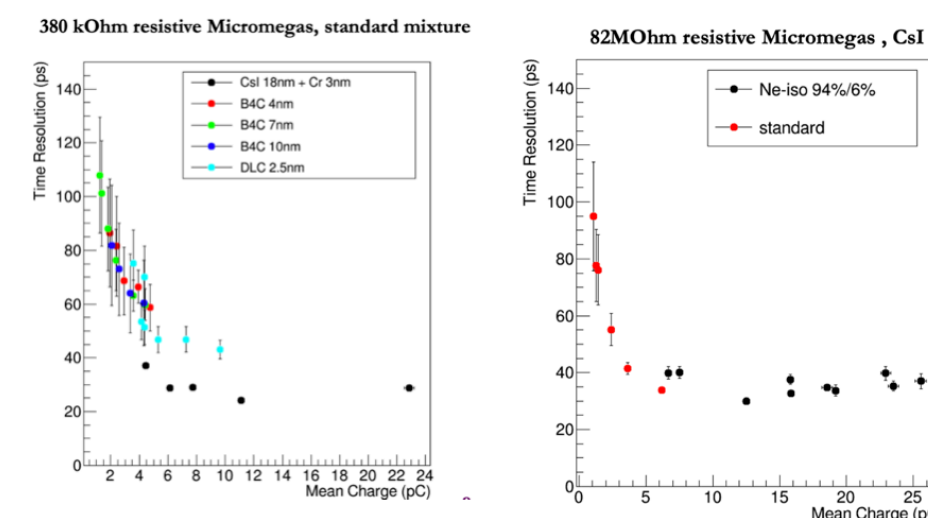
Muon Detector R&D

Matteo Brunoldi's talk

Picosec is an MPGD capable of reaching high performance in terms of **time resolution (order of tens of ps)** and is suitable for future experiments at a Muon Collider facility

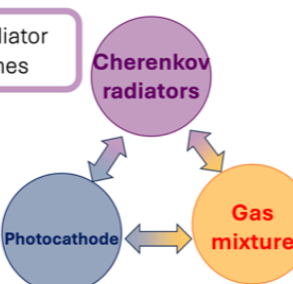


Several configurations tested



MgF₂ is the best radiator among the tested ones

CsI grants higher performances but DLC 2.5nm could be a good alternative



Ne/iC₄H₁₀ 94%/6% Comparable to the standard but:
• wider operating range
• reduced GWP

- **Next steps:** Ongoing study aimed at proving the feasibility of a bigger **Picosec** detector and the scalability of this technology. **New testbeams in 2024**

Intensa attività di sviluppo di detector

Il calcolo è fondamentale per:

- Acquisizione e storage dati dei test beam
- Analisi dei dati

Richieste 2026

- **Non ci sono richieste per Tier1-2/Cloud etc.**
- **Si richiede invece un supporto per i test beams dei calorimetri:**
 - Test beam di CRILIN settembre 2025 -> si utilizzerà un computer acquistato a LNF con performance e spazio disco limitati (non sono disponibili backup)
 - **Test beam ECAL + HCAL a marzo 2026: necessario un server per acquisizione dati/storage analisi/analisi dati**
 - **Thinktower P5 della Lenovo, equipaggiato con SSD PCIe per essere compatibili con le schede di acquisizione della CAEN che abbiamo a disposizione. Poi dovremmo equipaggiarle con schede di rete PCI, per problemi riscontrati con USB-Ethernet**
 - **Prezzo di listino 3.7 keuro, si richiedono 4 keuro in totale per includere accessori**
 - **Per riuscire ad averlo operativo a marzo 2026 potrebbe essere necessario un anticipo nel 2025**