Design a calorimeter system for a Muon Collider

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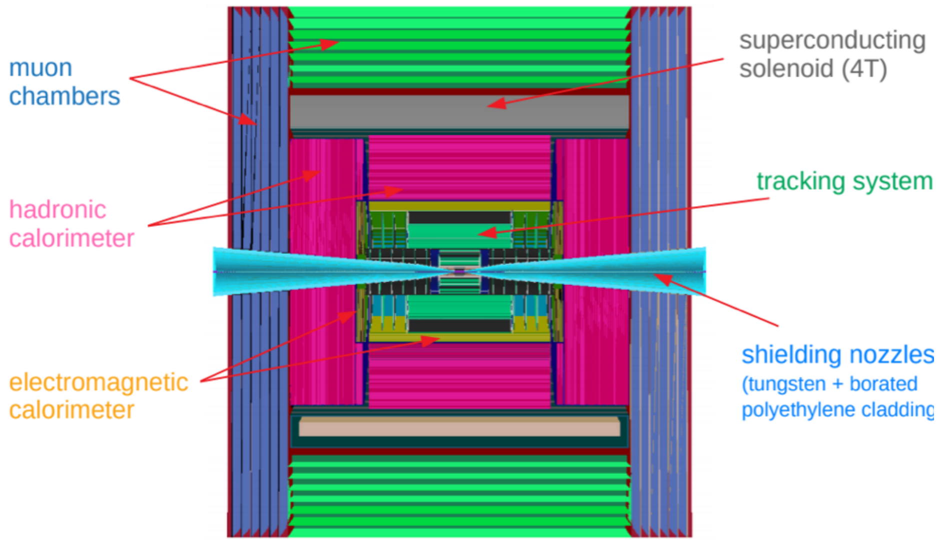
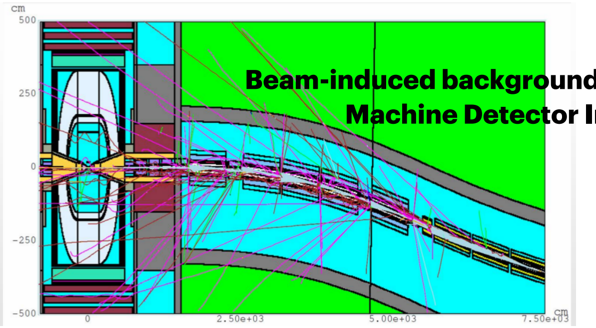
*https://muoncollider.web.cern.ch/node/15

1. Introduction

- The **Muon Collider** is one of the most promising proposals for future accelerators.
- It puts together the advantages of lepton colliders (clean events) and hadron colliders (no bremsstrahlung, energy frontier).
- It features a unique environment due to the **beam-induced background (BIB)** produced by the decay of muons and the subsequent interactions [1].
- Although the BIB can be partially mitigated by shielding nozzles [2], **it poses requirements on the detector development** [3].

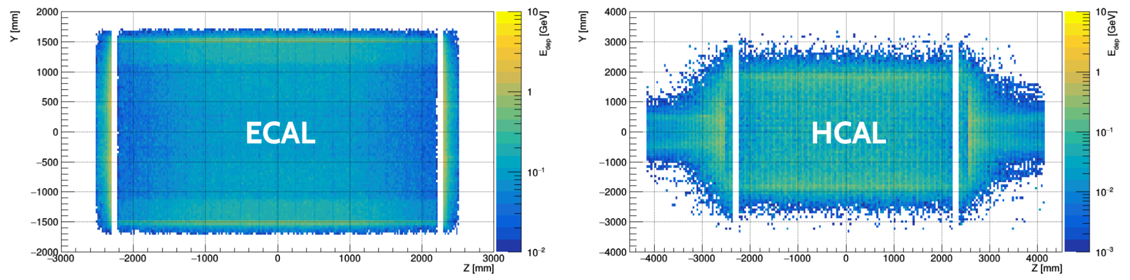




2. Detector Full Simulation

- BIB is simulated at √s = 1.5 TeV by using the MARS15 package [4], while the detector is simulated using a custom branch of ILCSoft [5].
- **Baseline calorimeter system** is that designed by CLIC [6]:

Energy deposition per bunch crossing: at the ECAL barrel surface the flux is 300 particles/cm², most of them are photons with <E>=1.7 MeV.

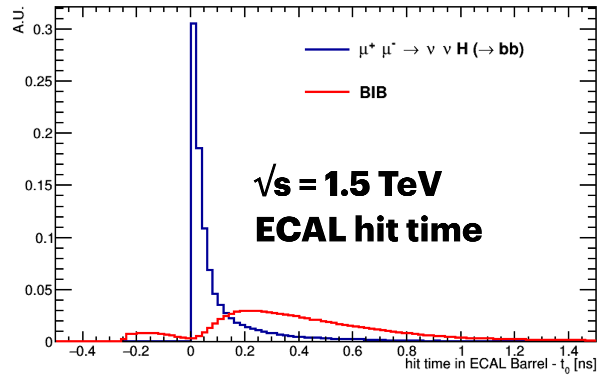


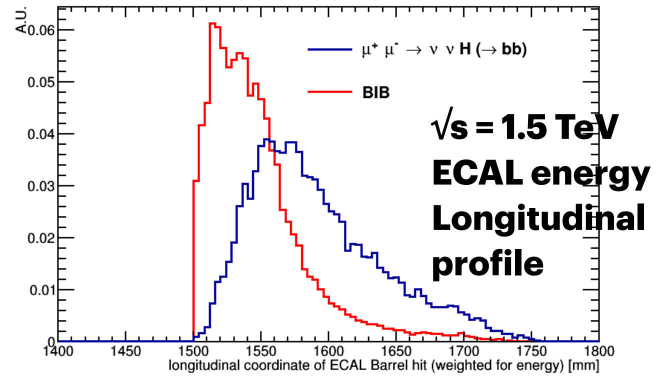
Electromagnetic Calorimeter (ECAL) : 40 layers W absorber and silicon pad sensors, 5x5 mm²

Hadron Calorimeter (HCAL) : 60 layers steel absorber & plastic scintillating tiles, 30x30 mm²

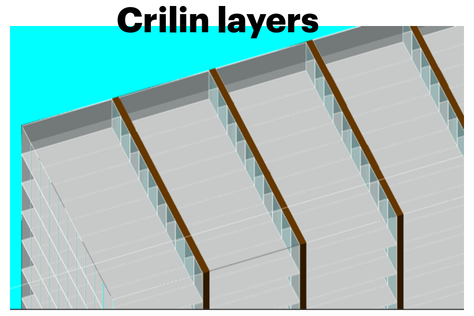
3. ECAL requirements

- BIB simulation in the calorimeter is compared with a reference signal: Higgs boson decaying to two b-quarks.
- BIB is out-of time with respect to bunch-crossing: **time measurement is crucial**.
- An acquisition time window of ±250 ps can get rid of most of the BIB, preserving the signal. **It can be achieved with a time measurement resolution of about 80 ps**.
- The longitudinal profile of the energy released by the BIB is different from the signal: **a longitudinal segmentation of the calorimeter can be useful**.

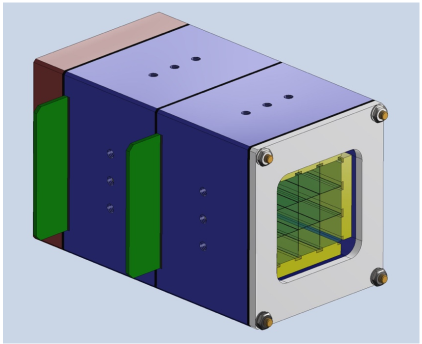




4. New technology: Crilin

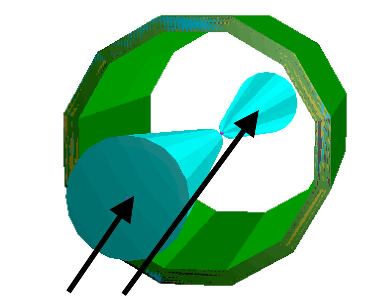


- **Do we have solutions alternative to the W-Si sampling calorimeter for ECAL?**
- **New idea: Crilin** -> a semi-homogeneous crystal calorimeter (PbF_2), where Cherenkov light is read by SiPMs.
- PbF_2 has good light yield (3 pe/MeV), fast signal (300 ps for muons, 50 ps for pions), radiation hard, relatively cheap.
- Five layers (40 mm thick), 10 x 10 mm² of cell area.
- Real cell prototype has been built at the National Laboratory of Frascati (Rome, Italy).



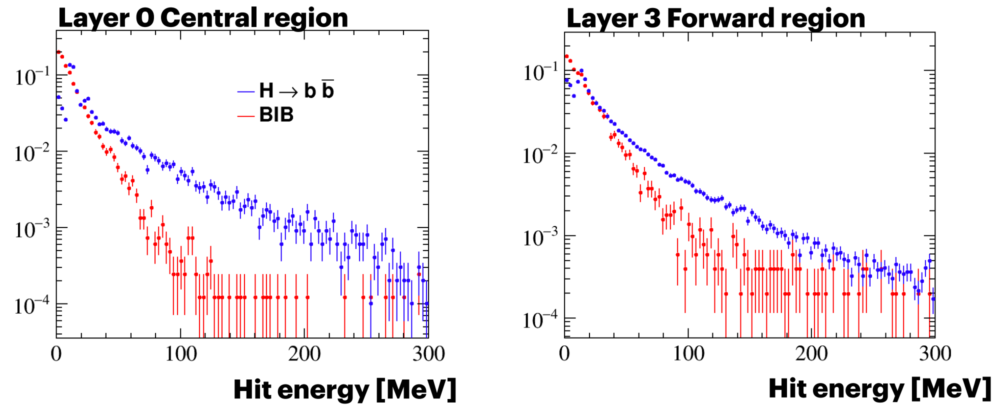
Crilin prototype at LNF

Crilin barrel implementation in Geant4

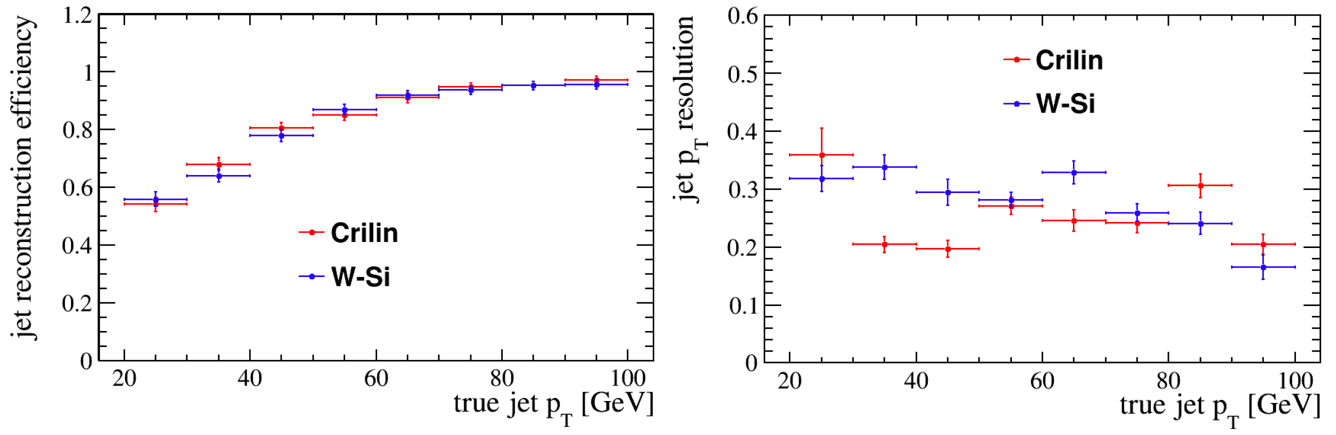


5. Energy thresholds

- The Crilin ECAL barrel has been implemented in the full simulation.
- The acquisition time window of ±250 ps is applied.
- Energy thresholds are applied as a function of the layer and of the region (forward or central).
- Thresholds are obtained as $E_{TH} = E_{BIB} + 2\sigma_{BIB}$, where E_{BIB} is the average energy of the BIB distribution, and σ_{BIB} is the standard deviation.



6. Performance comparison



The performance obtained with Crilin is at the same level of the high-segmented W-Si calorimeter (but the money cost of Crilin is a factor 10 less!)

- The performance is evaluated on objects of primary interest for Muon Collider Physics: hadronic jets.
- A (not-fully optimized) Particle Flow algorithm that involves both calorimeter and tracker is employed for jet reconstruction.

7. Conclusions

- The **beam-induced background (BIB)** at a Muon Collider poses specific requirements on the detector development.
- **Precise timing measurement** (<100 ps resolution) and **longitudinal segmentation** are important features for a calorimeter at a Muon Collider.
- **A 5-layers PbF_2 calorimeter (Crilin)** is proposed as ECAL barrel
- The performance on the jet reconstruction obtained with Crilin is compared with the one from a highly segmented W-Si sampling calorimeter.
- Since the performance is limited by the BIB, **the two calorimeters have similar efficiencies/resolutions, but Crilin cost a factor 10 less than W-Si.**
- Real cell prototypes of Crilin are being built and tested at LNF in Italy!

References

[1] https://map.fnal.gov/
[2] Phys. Procedia **37** (2012) 2015
[3] 2020 *JINST* **15** P05001
[4] Fermilab-FN-1058-APC (2018)
[5] https://github.com/iLCSoft
[6] CERN-2012-003