# Detector target performance

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# Outline

- Overview of the 3 TeV detector performance.
- Initial studies with the 10 TeV detector.

# 3 TeV detector concept

hadronic calorimeter

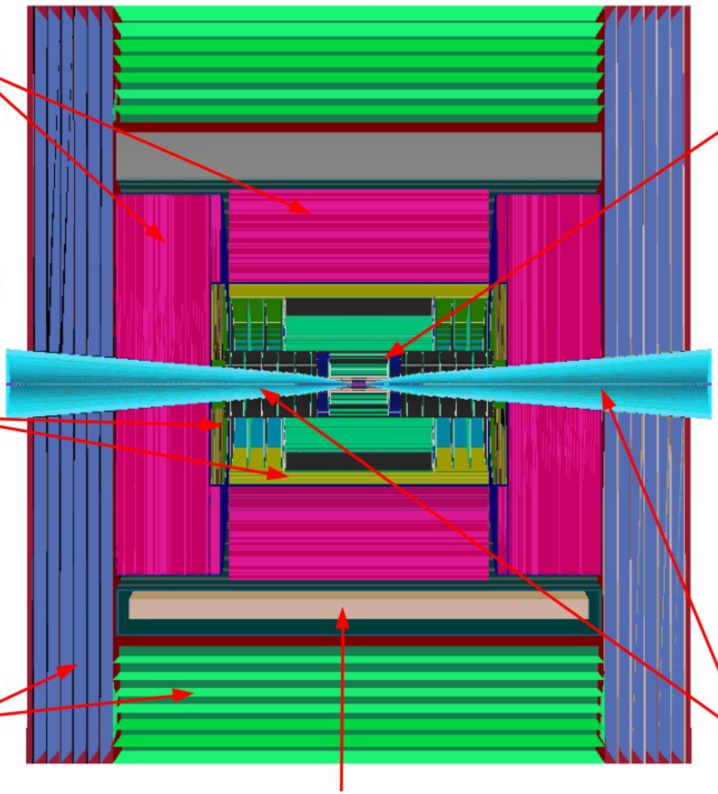
- 60 layers of 19-mm steel absorber + plastic scintillating tiles;
- 30x30 $mm^2$ cell size;
- 7.5 $\lambda_I$.

electromagnetic calorimeter

- 40 layers of 1.9-mm W absorber + silicon pad sensors;
- 5x5 $mm^2$ cell granularity;
- 22 $X_0$ + 1 $\lambda_I$.

muon detectors

- 7-barrel, 6-endcap RPC layers interleaved in the magnet's iron yoke;
- 30x30 $mm^2$ cell size.




tracking system

- Vertex Detector:
  - double-sensor layers (4 barrel cylinders and 4+4 endcap disks);
  - 25x25 $\mu m^2$ pixel Si sensors.
- Inner Tracker:
  - 3 barrel layers and 7+7 endcap disks;
  - 50 µm x 1 mm macro-pixel Si sensors.
- Outer Tracker:
  - 3 barrel layers and 4+4 endcap disks;
  - 50 µm x 10 mm micro-strip Si sensors.

shielding nozzles

- Tungsten cones + borated polyethylene cladding.

# Studies with the 3 TeV detector

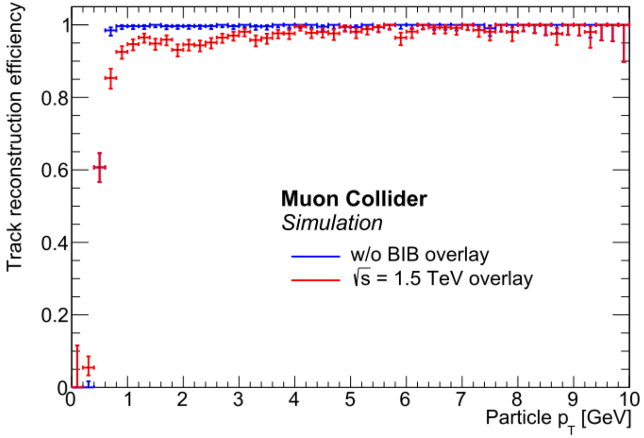
- Focused on main physics objects: tracks, muons, photons, jets.

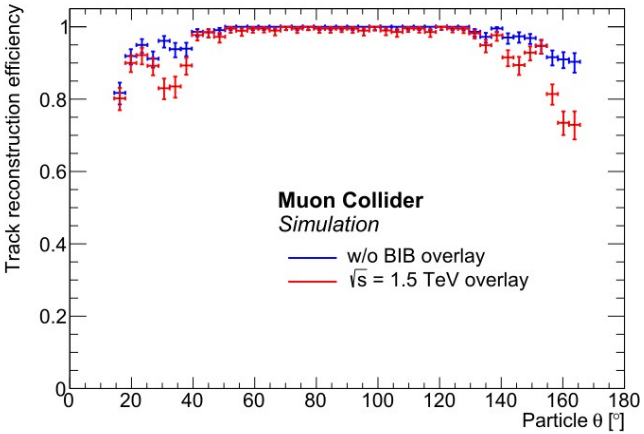
- Initial studies with particle guns w/o BIB (identified a problem in the material of the tracker geometry) and then w/ BIB. The outcome was that BIB mitigation measures were needed and the reconstruction algorithms for all the considered physics objects required revision or fine-tuning.

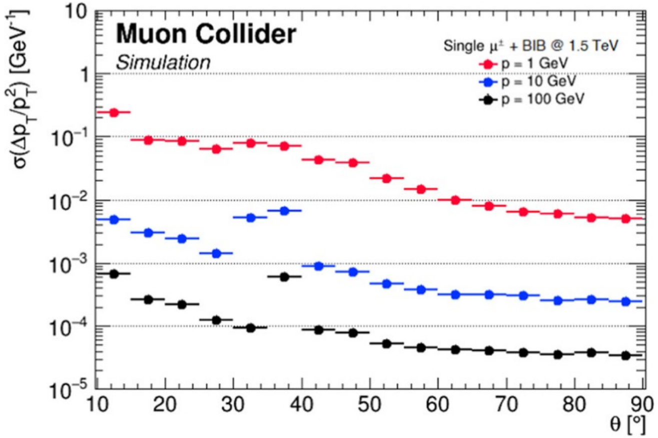
- Finally, the detector performance was assessed reconstructing a set of benchmark Higgs boson channels and estimating the statistical sensitivity on $\sigma_H \times$ BR:
  - $H \to WW^*$;
  - $H \to ZZ^*$;
  - $H \to b\bar{b}$;
  - $H \to \mu\mu$;
  - $H \to \gamma\gamma$;
  - double Higgs $HH \to b\bar{b}b\bar{b}$.

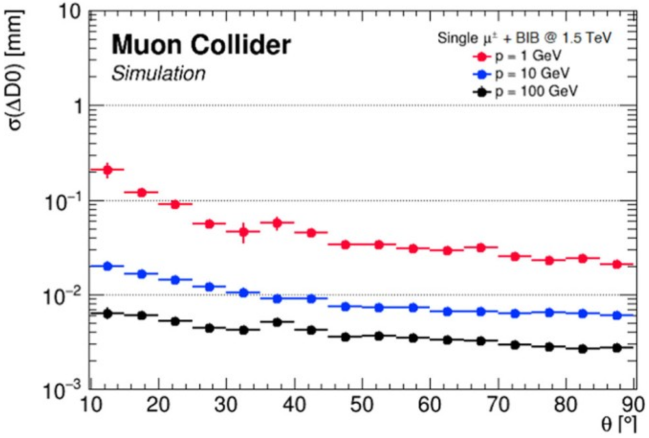
# Track reconstruction at 3 TeV

single muon samples



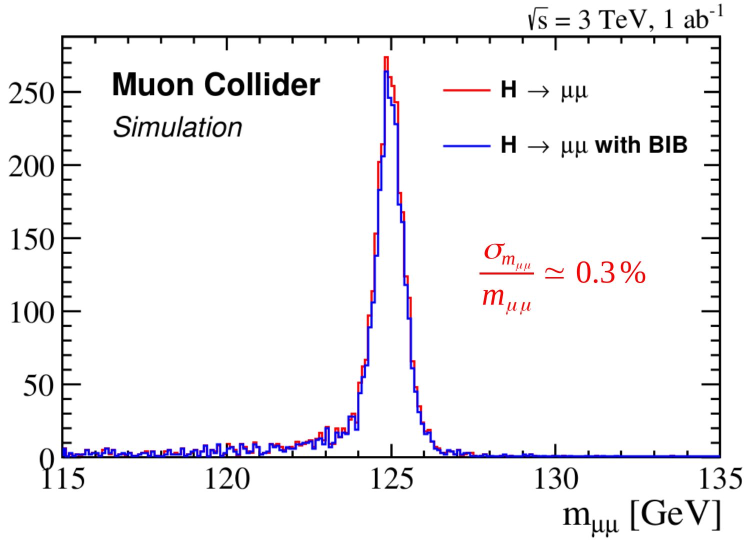



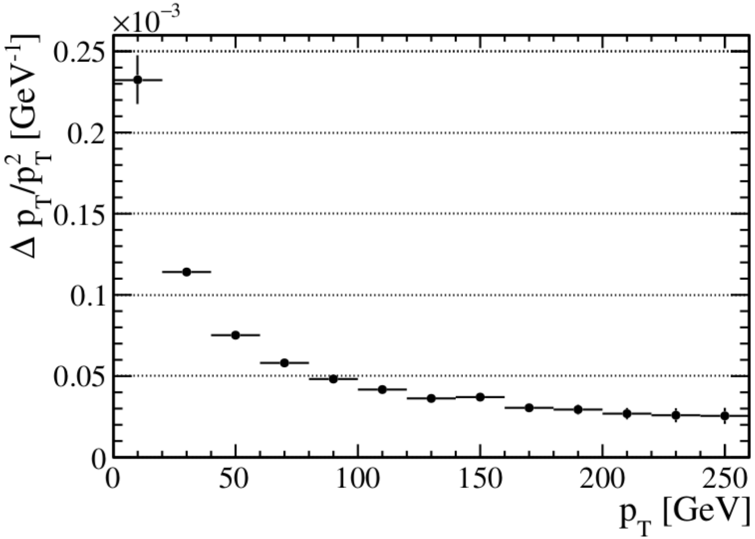



# Muon reconstruction at 3 TeV

$\mu\mu \to H\nu\bar{\nu} \to \mu\mu\nu\bar{\nu}$

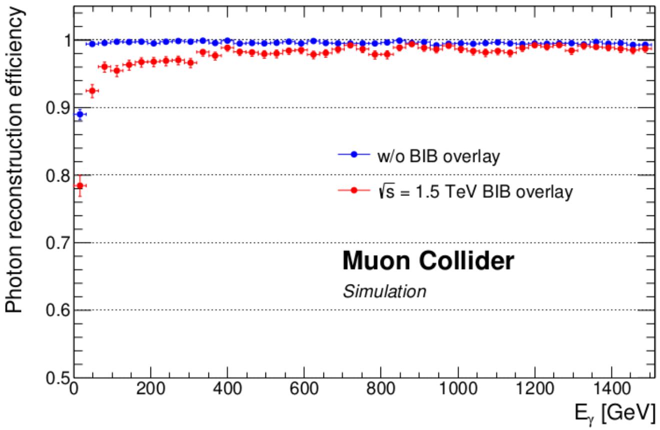


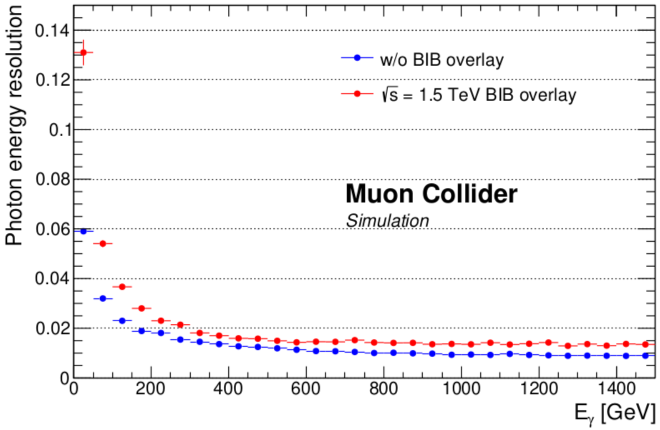




- The reconstruction of high-energy muons produced in $H \to \mu\mu$ decay is not affected by the beam-induced background.

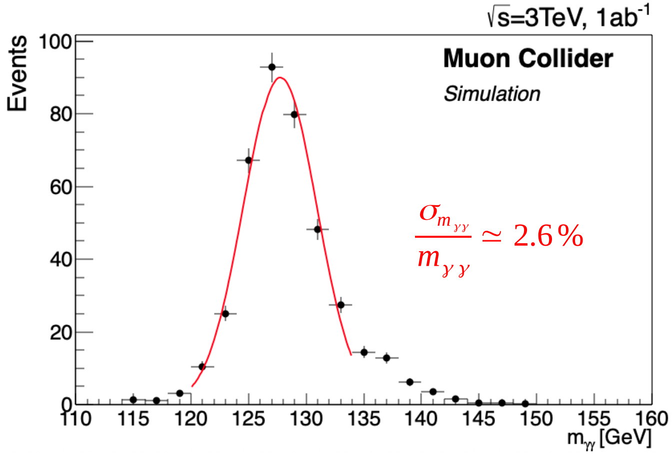
# Photon reconstruction at 3 TeV

single photon sample



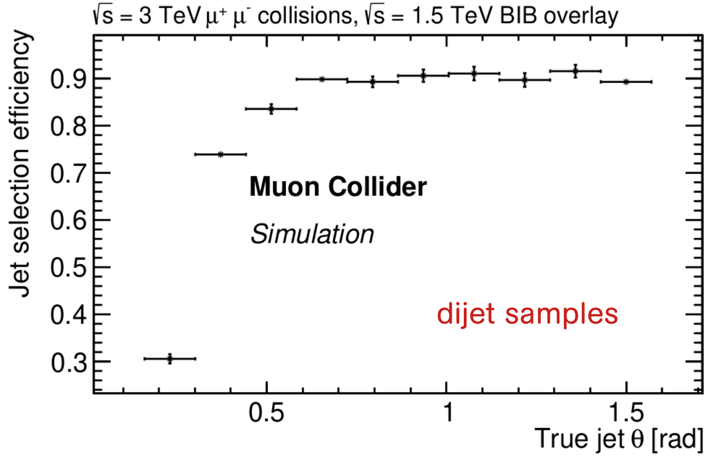



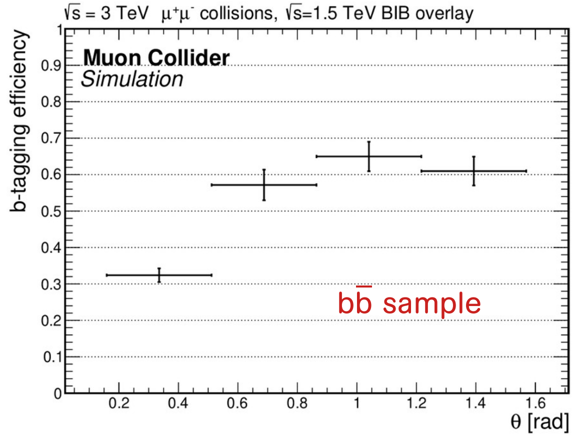

$\mu\mu \rightarrow H\nu\bar{\nu} \rightarrow \gamma\gamma\nu\bar{\nu}$

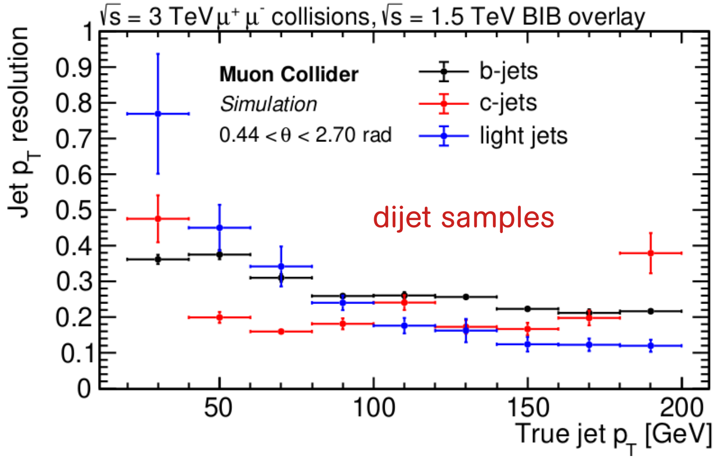


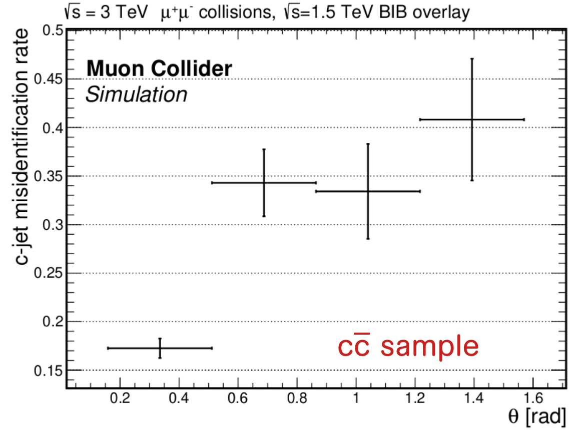

- High-energy photon reconstruction is not significantly impacted by the beam-induced background

# Jet reconstruction and tagging at 3 TeV



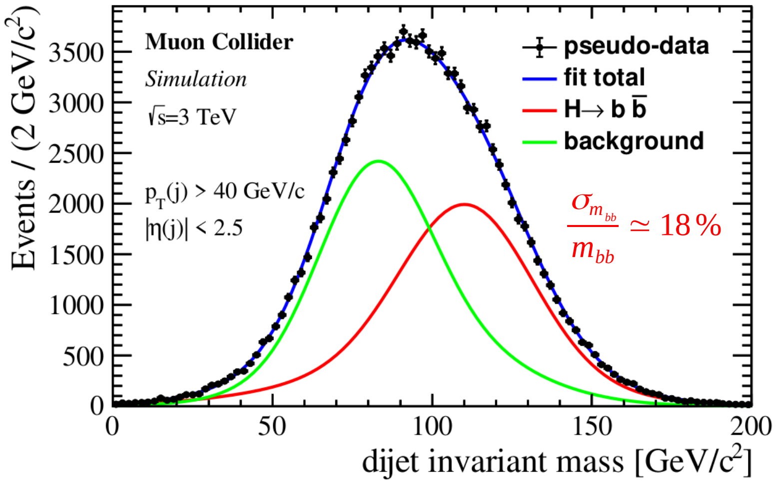



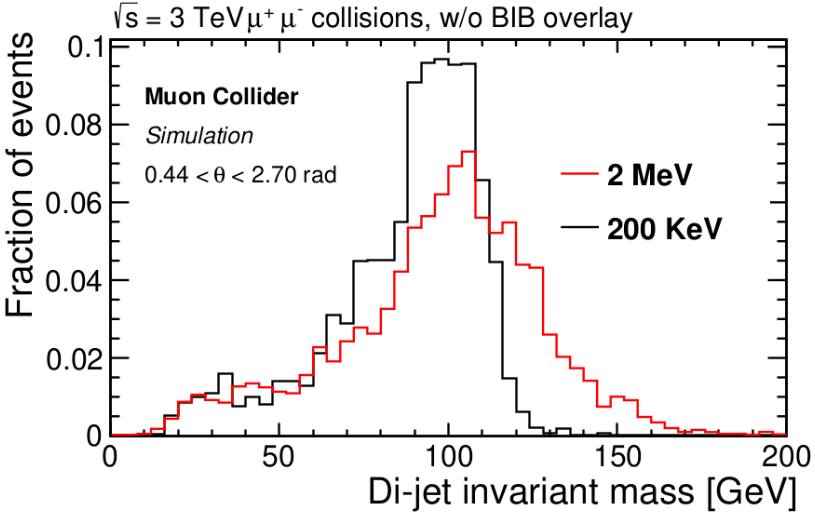



# Jet reconstruction at 3 TeV

$\mu\mu \rightarrow H\nu\bar{\nu} \rightarrow b\bar{b}\nu\bar{\nu}$




- The case is different for hadronic jets that are reconstructed using also low-energy objects: the energy threshold of 2 MeV for the calorimeter hits affects the energy resolution.

# Detector performance with physics channels

physics objects performance from Higgs boson decays (E $\sim$ 100 GeV) with BIB

| **Object** | Requirements |
|---|---|
| muons | $\frac{\Delta p_T}{p_T} = 0.4\%$ |
| photons | $\frac{\Delta E}{E} = 3\%$ |
| jets | $\frac{\Delta p_T}{p_T} = 15\%$ |
| $b$-jets | $\frac{\Delta p_T}{p_T} = 15\%$<br>$b$ efficiency = 60 %<br>$c$ mistag = 20 % |
| $b$-jets (for $\lambda_3$) | $\frac{\Delta p_T}{p_T} = 10\%$<br>$b$ efficiency = 76 %<br>$c$ mistag = 20% |

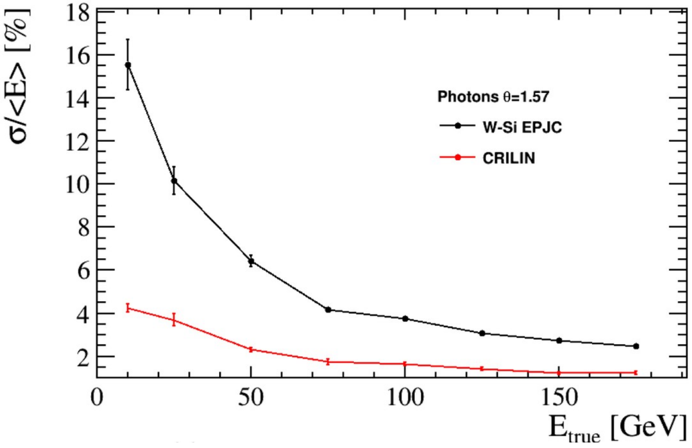
- A performance table has been produced for the physics objects used in the Higgs boson analyses (theses of L. Buoninconti, L. Castelli, G. Da Molin, L. Giambastiani, A. Montella) with the full simulation including BIB effects.
- Due to limited personpower a prioritization had to be done on the Higgs channels/physics objects to be studied. Some important object are still missing: electrons, taus, missing energy.

# Final considerations on the 3 TeV detector

- The results on the Higgs boson production cross sections with the full simulation and BIB are competitive with those of the $e^+e^-$ colliders and indicate that the BIB effects on the detector response can be minimized to a degree that does not compromise the detector performance.

- The limiting factors remain detector calibration and reconstruction algorithms, which are not yet fully optimized. Below an example of the photon energy resolution that can be achieved with an optimization of the cell energy threshold of the CRILIN electromagnetic calorimeter.

photon energy resolution



# 10 TeV detector concept

## hadronic calorimeter

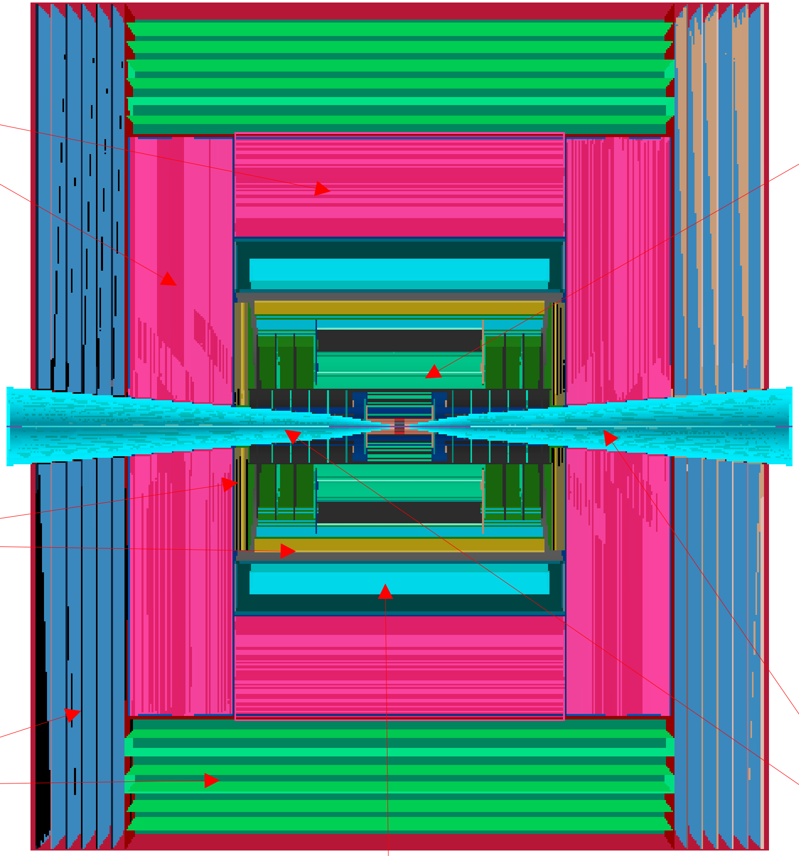
- 70 layers of 19-mm steel absorber + plastic scintillating tiles;
- 30x30 mm$^2$ cell size;
- 8.8 $\lambda_I$.

## electromagnetic calorimeter

- 51 layers of 1.9-mm W absorber + silicon pad sensors;
- 5x5 mm$^2$ cell granularity;
- 28 $X_0$ + 1 $\lambda_I$.

## muon detectors

- 7-barrel, 6-endcap RPC layers interleaved in the magnet's iron yoke;
- 30x30 mm$^2$ cell size.



superconducting solenoid (5T)

## tracking system

- Vertex Detector:
  - double-sensor layers (4 barrel cylinders and 4+4 endcap disks);
  - 50-µm thick, 25x25 µm$^2$ pixel Si sensors.
- Inner Tracker:
  - 3 barrel layers and 7+7 endcap disks;
  - 100-µm thick, 50x50 µm$^2$ pixel Si sensors.
- Outer Tracker:
  - 3 barrel layers and 4+4 endcap disks;
  - 100-µm thick, 50x50 µm$^2$ pixel Si sensors.

## shielding nozzles

- Tungsten cones + borated polyethylene cladding.

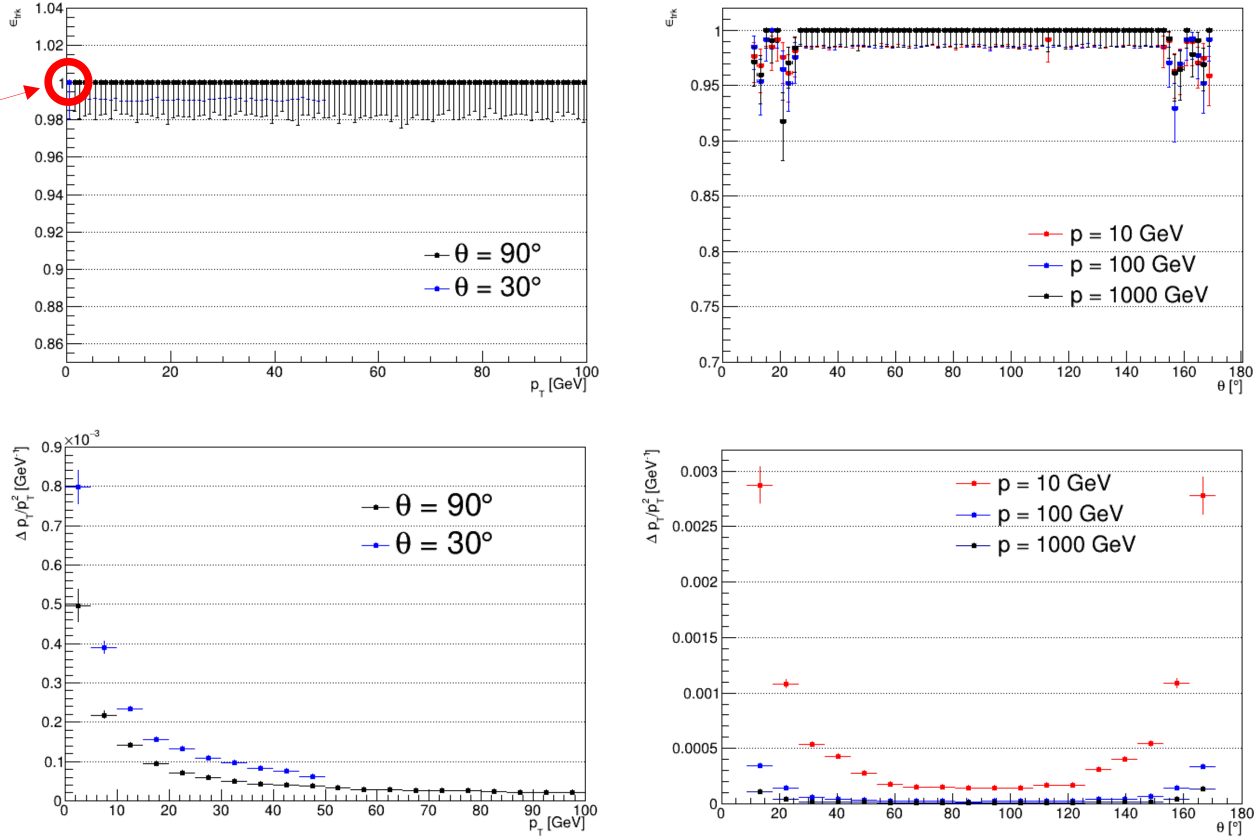
# Studies with the 10 TeV detector

- Using the MUSIC detector concept, which features:
  - ECAL inside the solenoid to have high energy resolution for electromagnetic objects and jets, and HCAL moved outside to make room for a deeper ECAL and a larger tracker;
  - a magnetic field of 5 T.
- No systematic performance studies with the BIB yet: the FLUKA sample at 10 TeV is not fully validated and an optimized nozzle for 10 TeV is not available to generate a new sample.
- In the following, first look at the detector performance with particle guns w/o BIB:
  - track reconstruction performance with muon guns;
  - photon reconstruction performance with a photon gun.

# Track reconstruction at 10 TeV (I)

single muon samples w/o BIB

inefficiency for muons with p = 1 GeV at $\theta$ = 90°

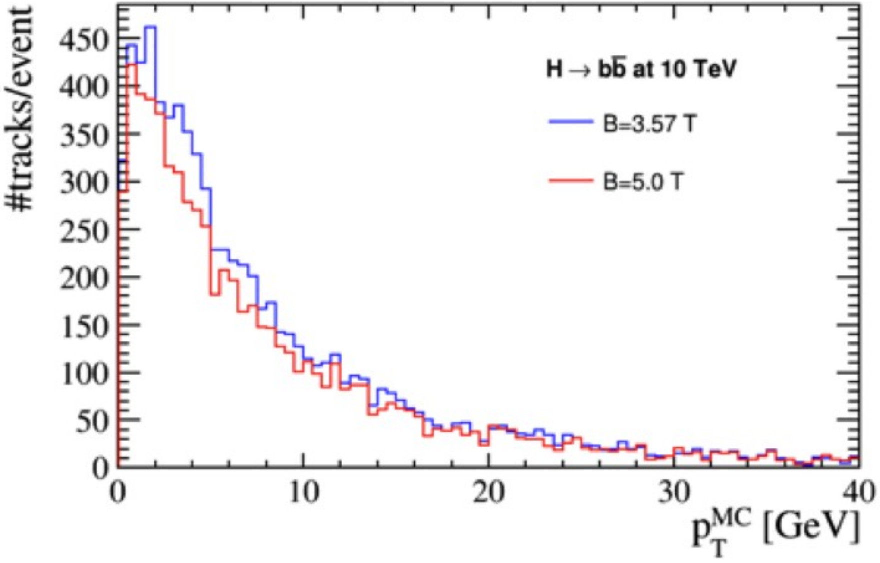



tracker radius = 1.68 m

B field = 5 T

# Track reconstruction at 10 TeV (II)

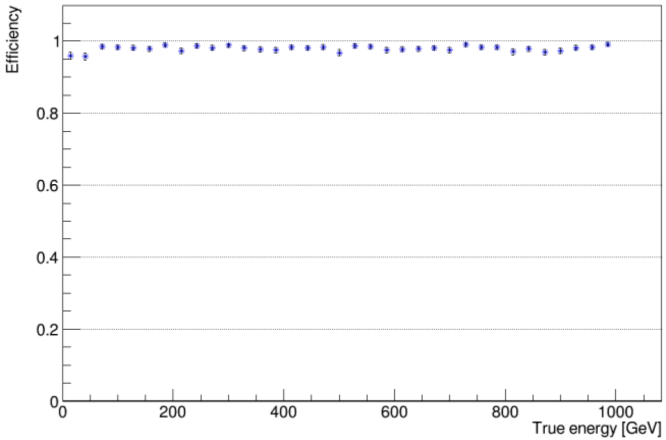
generator-level charged particles
inside the $H \to b\bar{b}$ jets

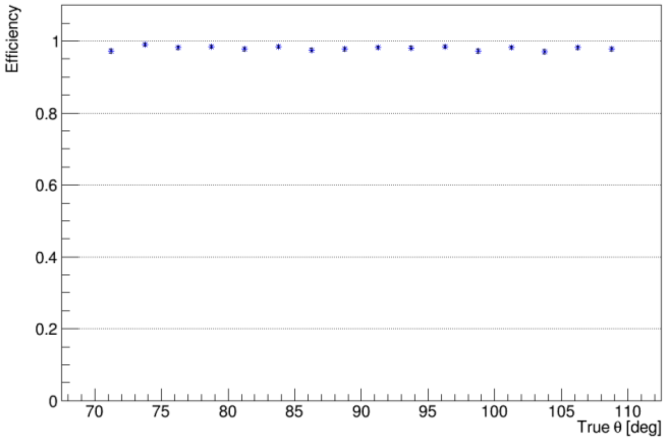


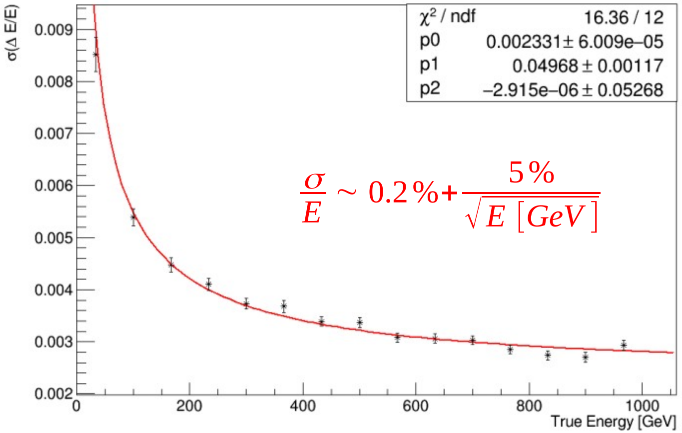

- Charged particles inside jets in $H \to b\bar{b}$ events have on average soft momenta, we can't afford to loose tracks with $p_T \sim 1$ GeV.
- Optimization of the magnetic field value seems necessary.

# Photon reconstruction at 10 TeV

single photon sample  w/o BIB




- NB:This study uses the CRILIN calorimeter.
- More details this afternoon:

  C. Giraldin, “Evaluation of electromagnetic calorimeter performance using CRILIN technology for a 10 TeV Muon Collider”.

# Summary and outlook

- We have evaluated the performance of the 3 TeV detector using physic channels.
- We have a detector concept for 10 TeV and the tools to study its performance.
- The first step will be to determine the optimal value for the magnetic field and produce a realistic field map (see the next talk by A. Bersani), which is needed for the detector studies and the BIB generation.
- Once the magnetic field value and the nozzle are defined, we will generate a new BIB sample and pursue a plan of detector studies that aligns with the timing of the EU strategy update (see the discussion in the next session).