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Detector performance and object reconstruction at a Muon Collider

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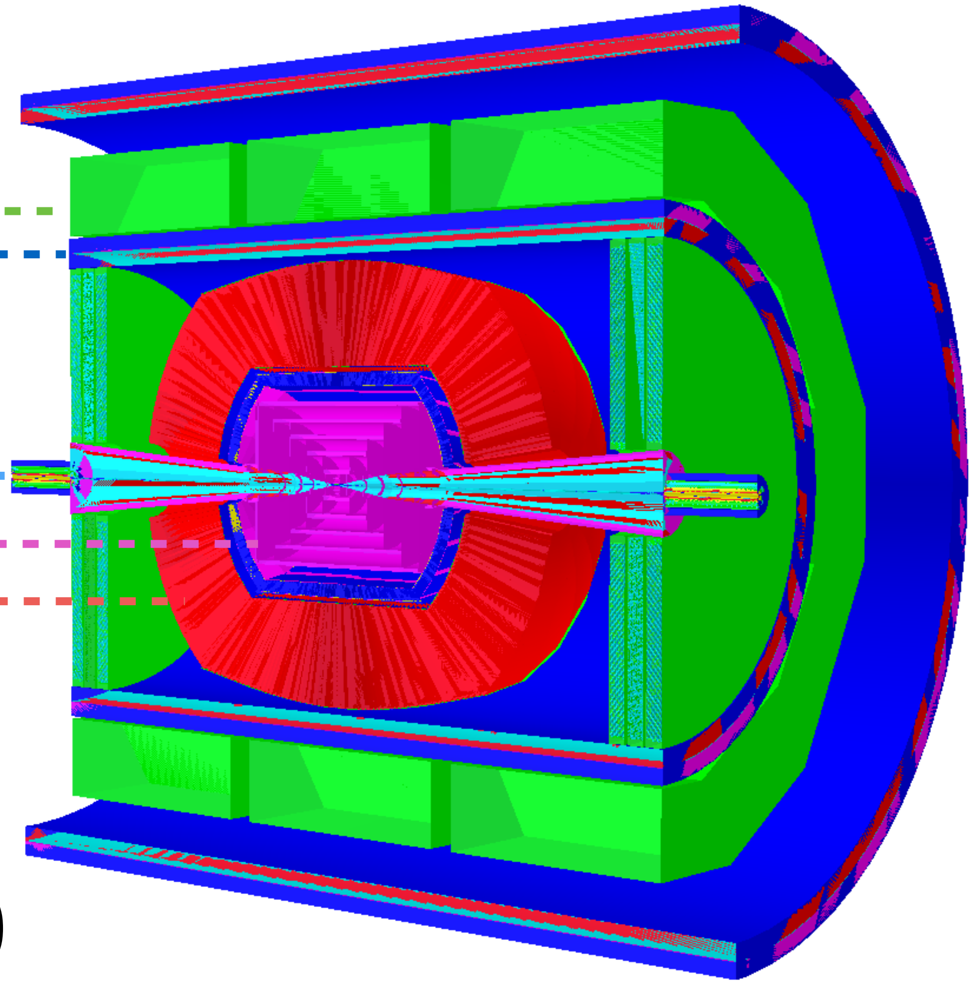
Detector response simulation

A detailed simulation of the potential detector at the Muon Collider is necessary to assess the achievable precision of future physics measurements

Making use of the simulation/reconstruction tools previously developed within the MAP (Muon Accelerator Program) **program:**

- **based on the ILCroot package:** supports signal + MARS background merging

Detailed detector geometry and magnetic field map used for full simulation:



- **muon** detector *(skipped for now)*
- **magnetic coil** *(3.57 T)*
- **nozzle** *(simulated in MARS)*
- **vertexing + tracking** detectors
- **calorimeter**

Two versions of beam background considered:

- 62.5 GeV $\mu^{\pm}$ beams (Higgs Factory)
- 750 GeV $\mu^{\pm}$ beams (High Energy Muon Collider)

Tracking: VXD

Beam pipe: Beryllium *(Be)*

thickness: 400 μm

Nozzles: for background suppression

material: Tungsten *(W)*

gap between nozzles: 12 cm

R_{min}: 1 cm

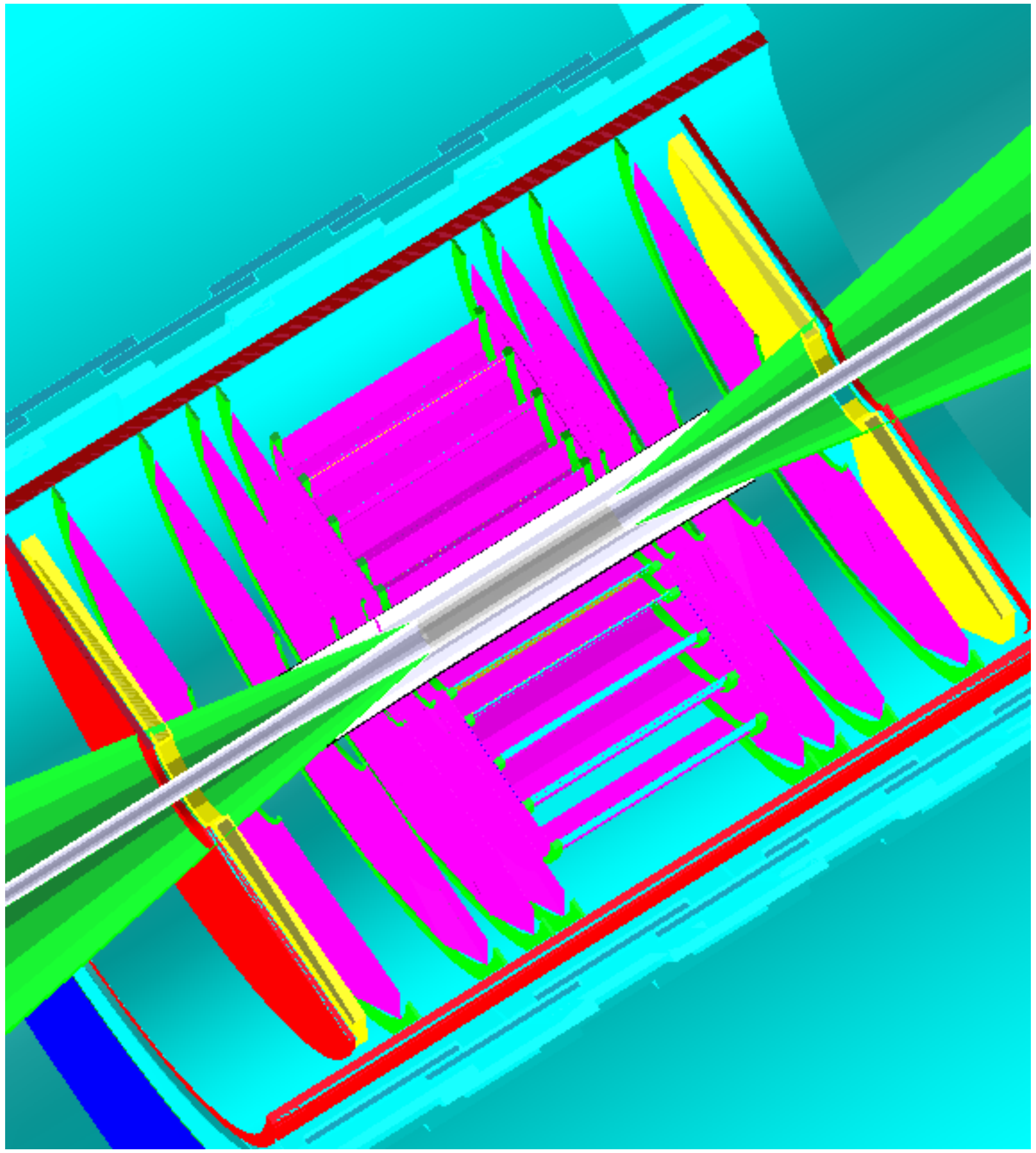
Vertexing detector (VXD): precise tracking

***Si* pixel sensors:** 20×20 μm pitch

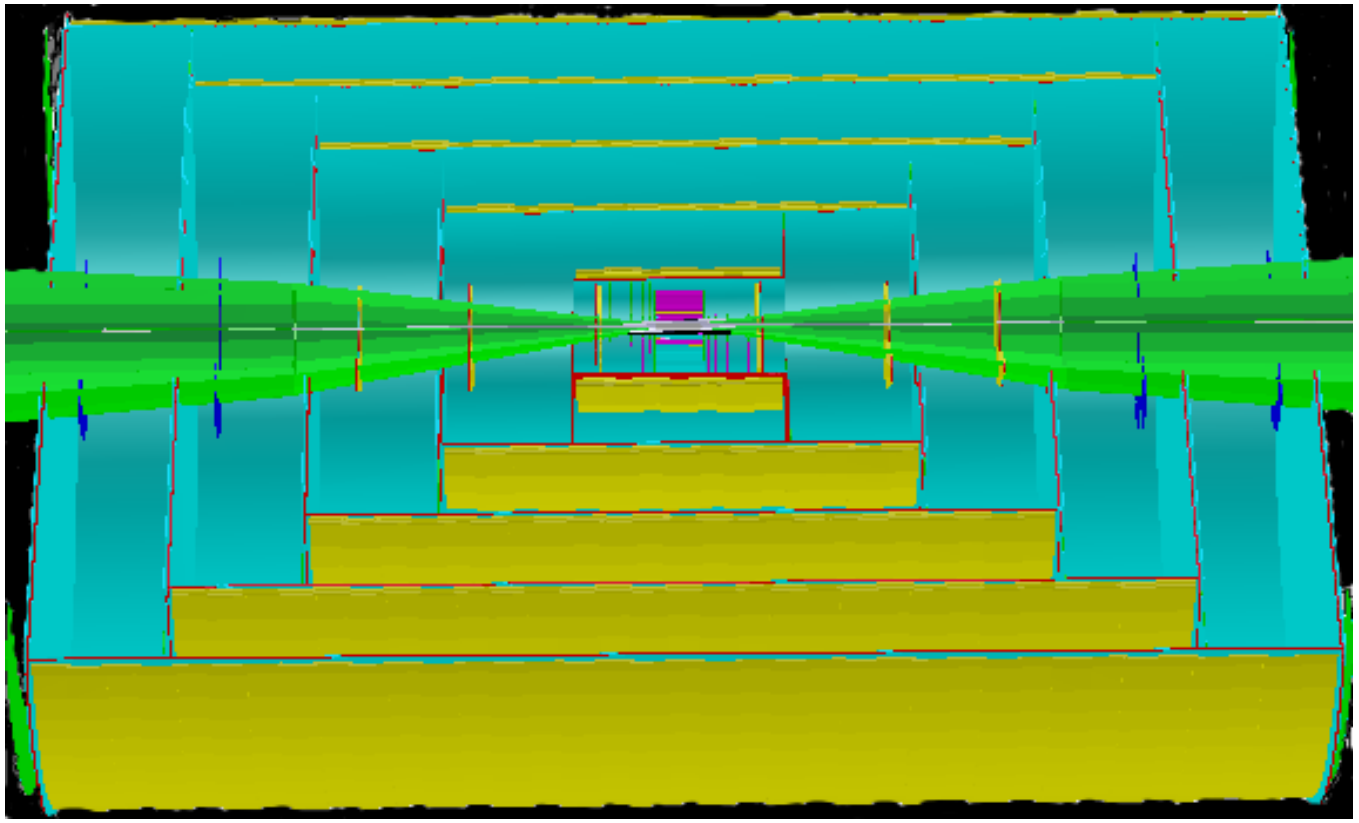
R: 3-13 cm **L:** 42 cm

Granularity:

• **Barrel:**	5 layers	*(75 μm thick)*
• **Endcap:**	2 × 4 disks	*(100 μm thick)*



Tracking: SiT+FTD



Silicon Tracker (SiT):

***Si* pixel sensors:** 50×50 μm pitch

- **thickness:** 200 μm

R: 20-120 cm **L:** 330 cm

- **Barrel:** 5 layers
- **Endcap:** 2 × (4 +3) disks

Forward Tracking Detector (FTD):

***Si* pixel sensors:** 50×50 μm pitch

- **thickness:** 200 μm
- **Endcap:** 2 × 3 disks

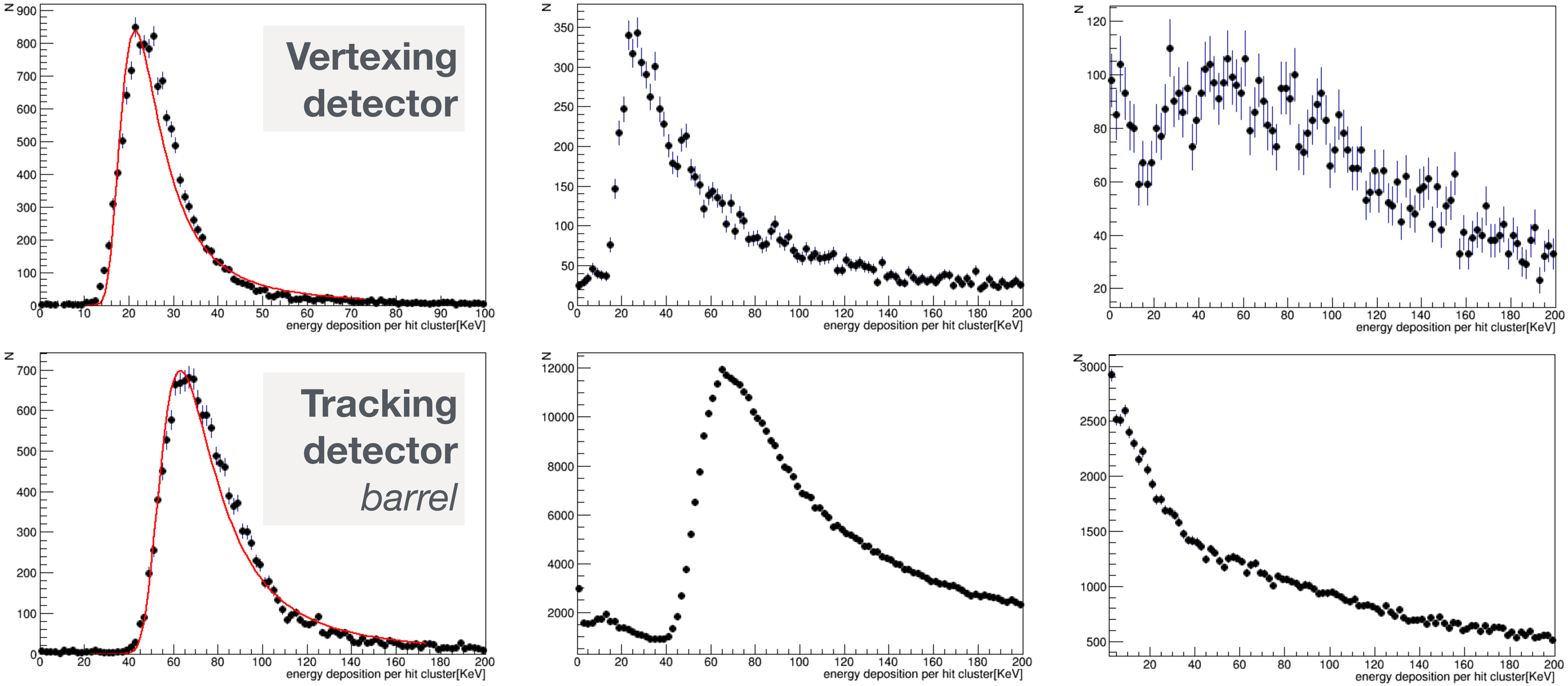
Hit simulation with GEANT4:

- full simulation chain in place: **hits** → **sdigits** → **digits**
- noise, electronic thresholds, saturation effects are included

Energy release in the tracker

Simulated energy deposited in the tracker by signal and background particles

Interaction Point muons | **Background:** 62.5 GeV | **Background:** 750 GeV


Vertexing detector

Tracking detector *barrel*

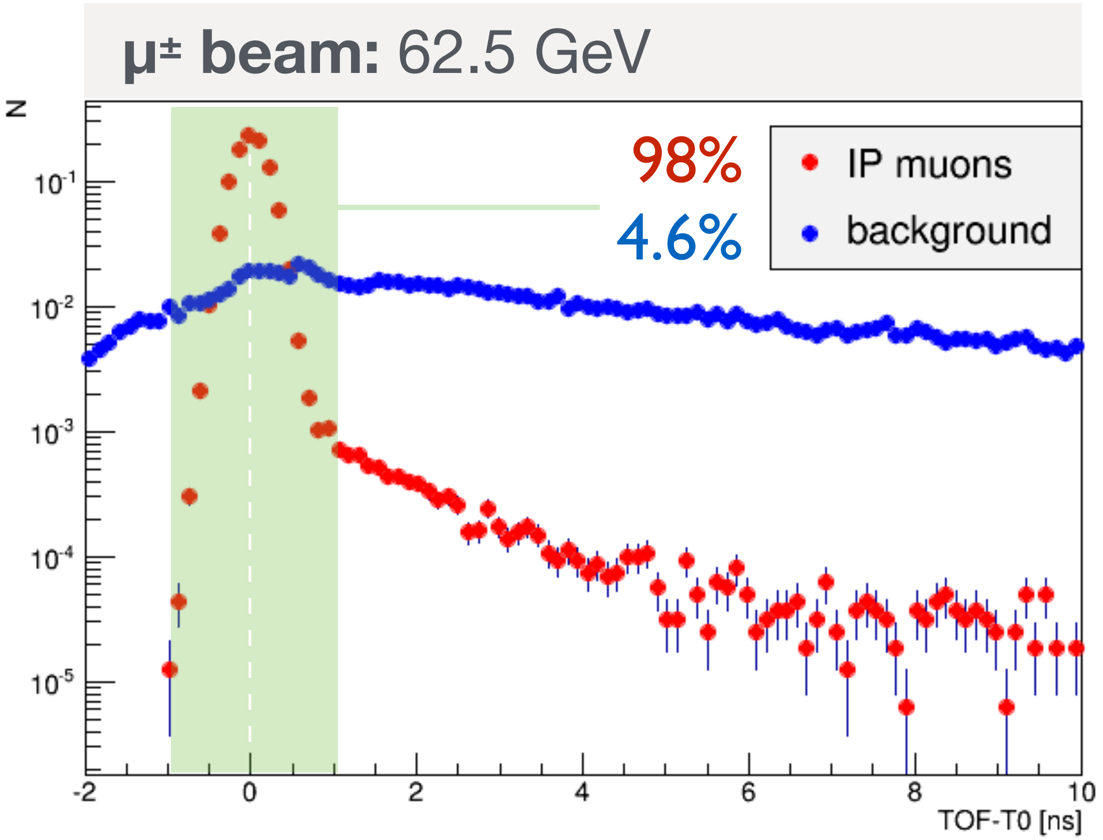
Energy deposition profiles are similar between the signal and background

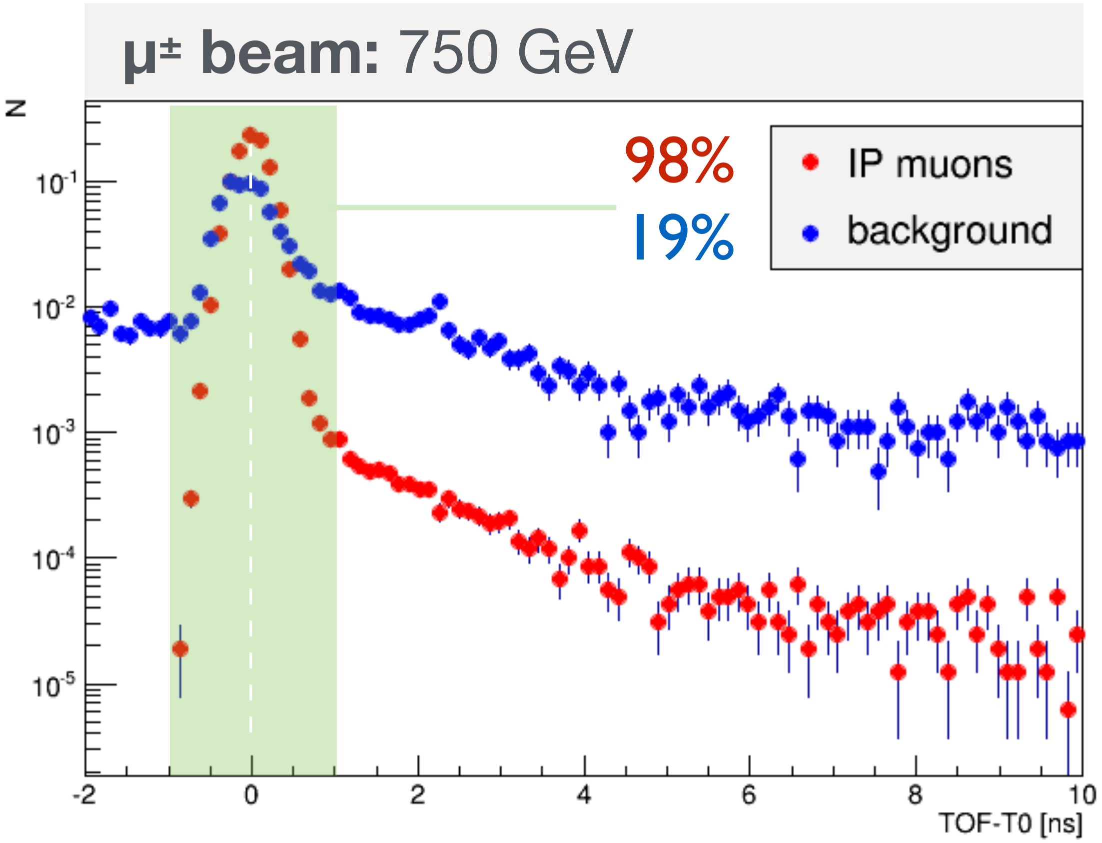
Hit density in the Higgs-factory mode is a serious issue: timing can help

Time of flight in the tracker

Simulated time of arrival of particles in the detector module

- **reference T0:** time of photons arriving from the IP to the detector


μ± beam: 62.5 GeV


μ± beam: 750 GeV

Selecting a 2 ns time window around the expected arrival time allows to reject up to 95% of background hits in the tracker

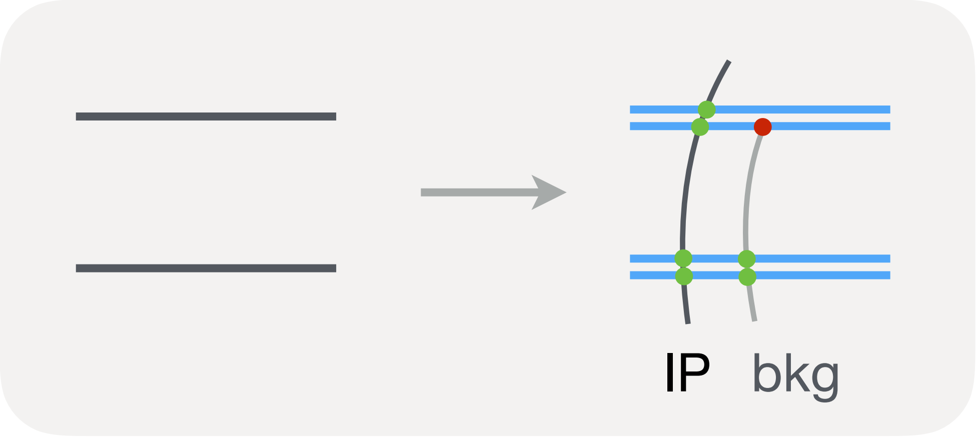
At 750 GeV the IP muons are potentially leaking through the nozzles gap

↳ **most likely explanation:** to be verified by a detailed study of the particles' origin

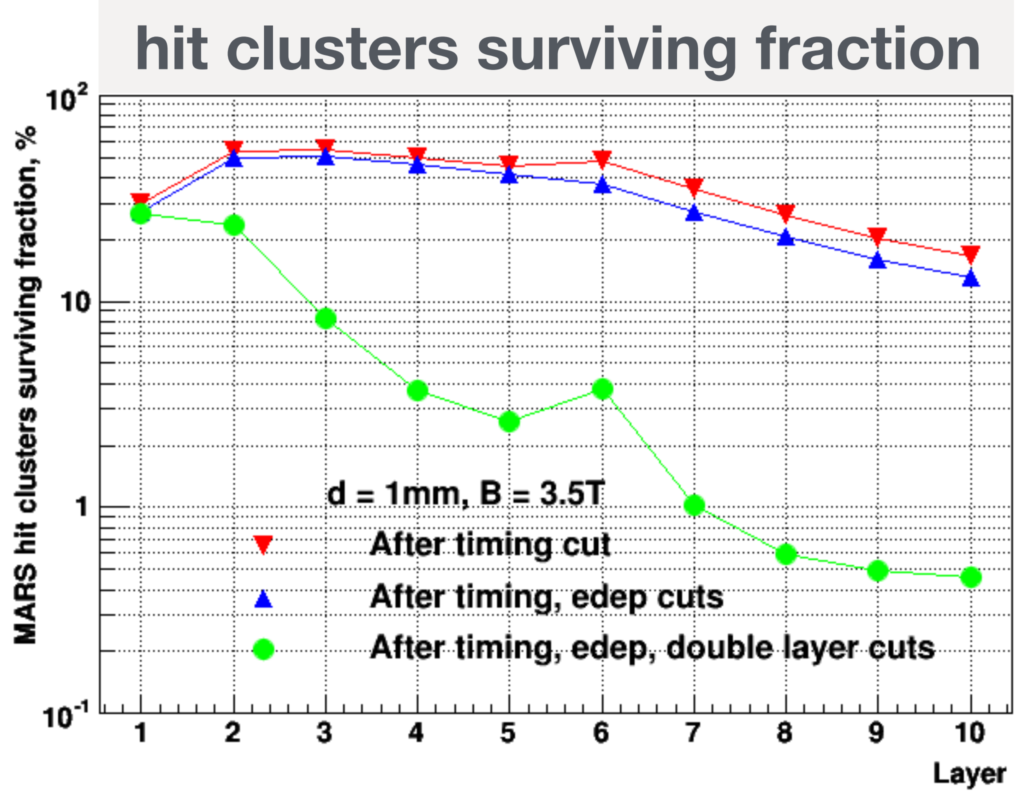
Double layers in the tracker

Further background suppression possible with a double layer design

- soft background tracks have lower probability of surviving till the second sublayer
- only pairs of hits in 2 sublayers are read out



Effect of the cut with 1 mm distance between sublayers studied at 750 GeV [V. Di Benedetto et al 2018 JINST 13 P09004]


hit clusters surviving fraction


hit clusters density

Hit density $\leq 10/\text{cm}^2$ in the tracker except for the first 2 VXD layers

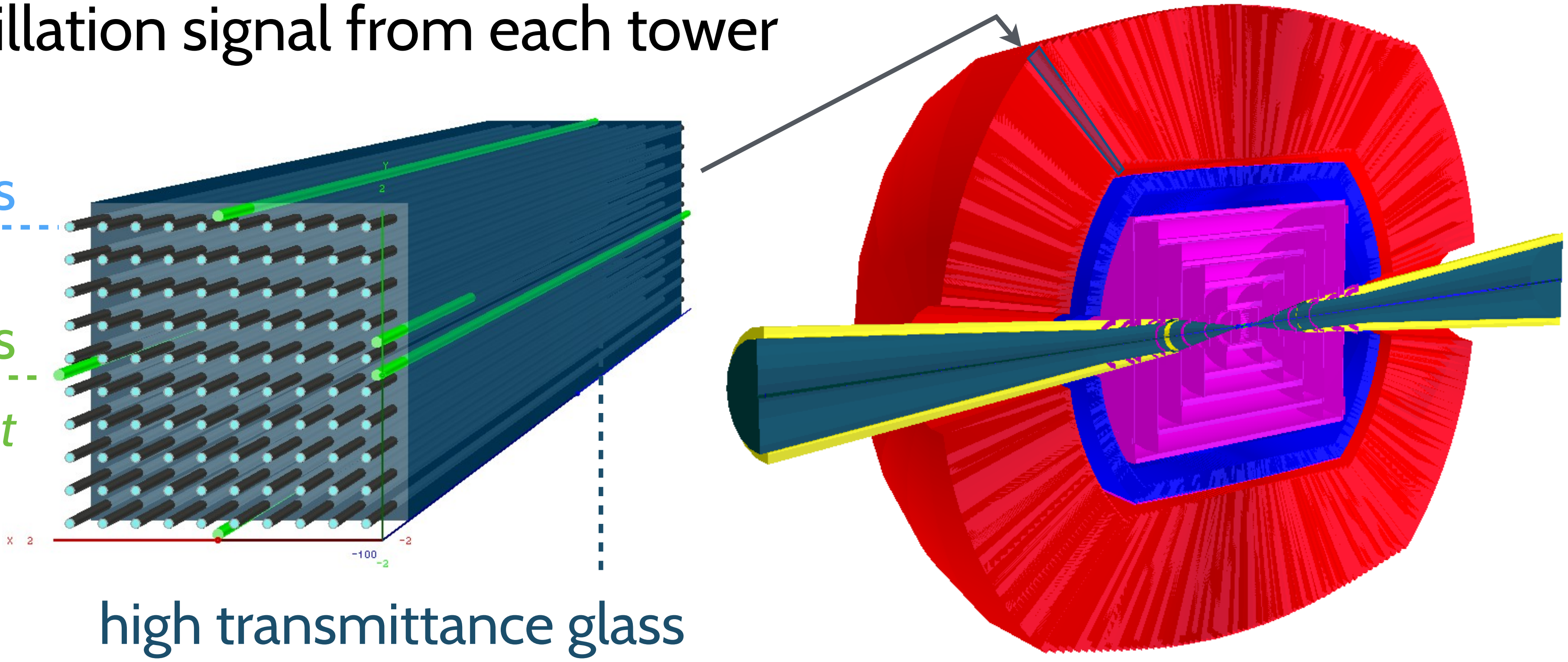
ADRIANO calorimeter

Dual readout calorimeter: measuring Cerenkov + scintillation light simultaneously

↳ electromagnetic fraction of the shower can be determined in each event

Fully projective geometry: 23.6K towers

- 1 Cerenkov + 1 Scintillation signal from each tower



scintillating fibers

wavelength-shifting fibers

for transport of Cerenkov light

high transmittance glass

Cerenkov and Scintillation hits are simulated separately, digitized independently

- photodetector noise, wavelength-dependent light attenuation and collection efficiency taken into account during digitization

Clusters of digitized signals used for jet reconstruction

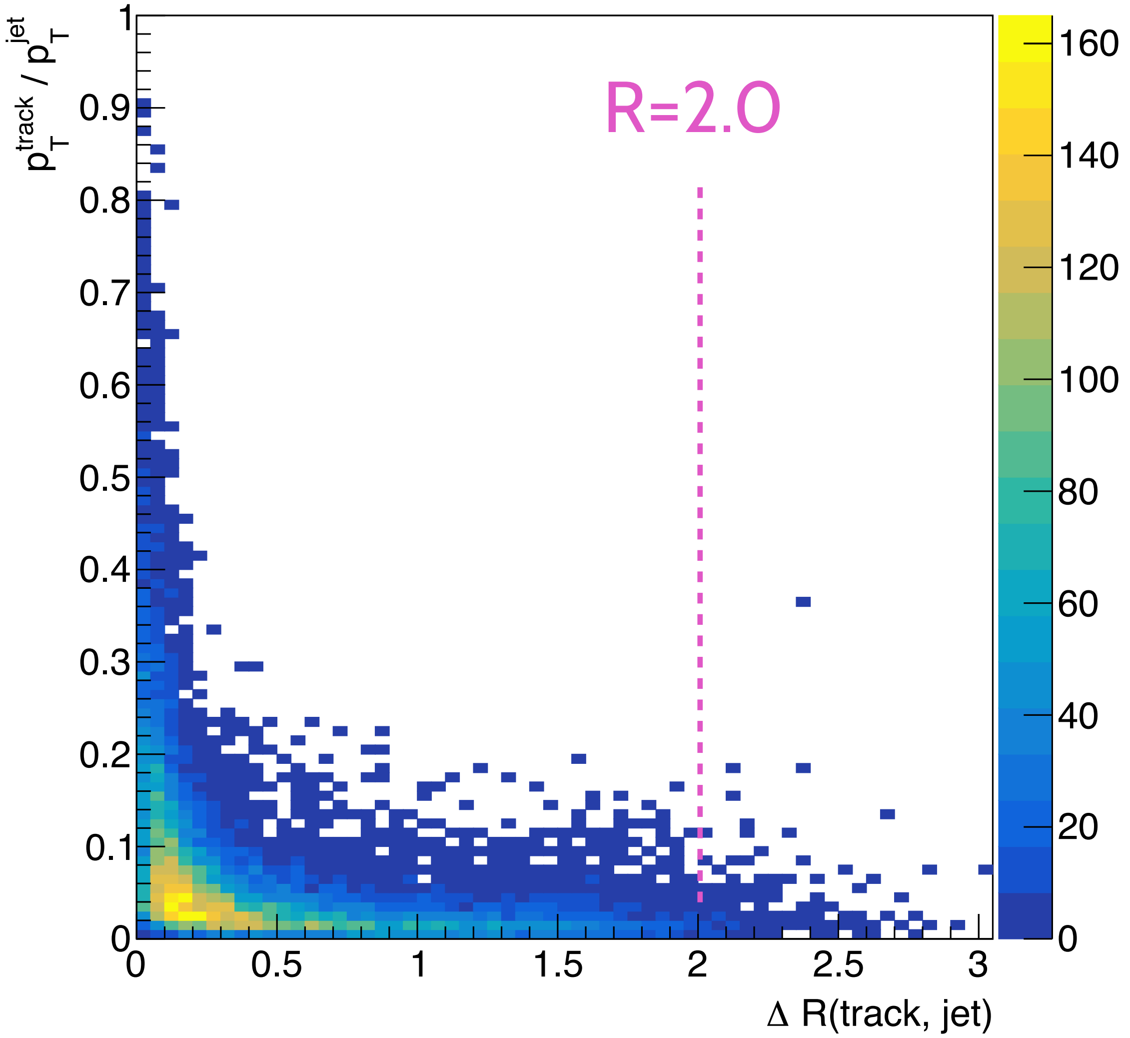
Jet clustering

Building jets from reconstructed tracks + calorimeter clusters

- **tested on H→bb signal events at √s=125 GeV** (no background)
- **clear environment for testing the technical implementation**

Jet clustering using a cone algorithm:

- size parameter: **R=2.0**
- most tracks contained within the jet cone of ΔR = 2.0
- jets are rather wide due to no boost



Jet acceptance requirements:

- $p_T \geq 10$ GeV
- $|\eta| \leq 2.5$

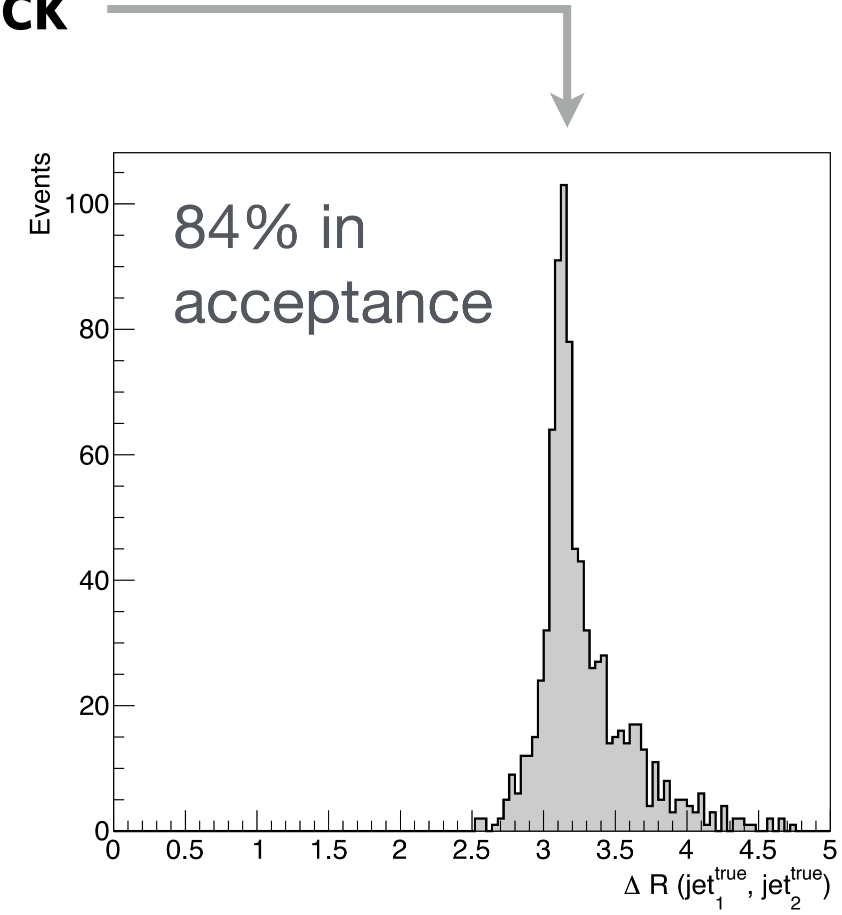
This is the first attempt of looking at jets:

- clustering parameters to be optimised in the presence of background

Jet clustering: angular properties

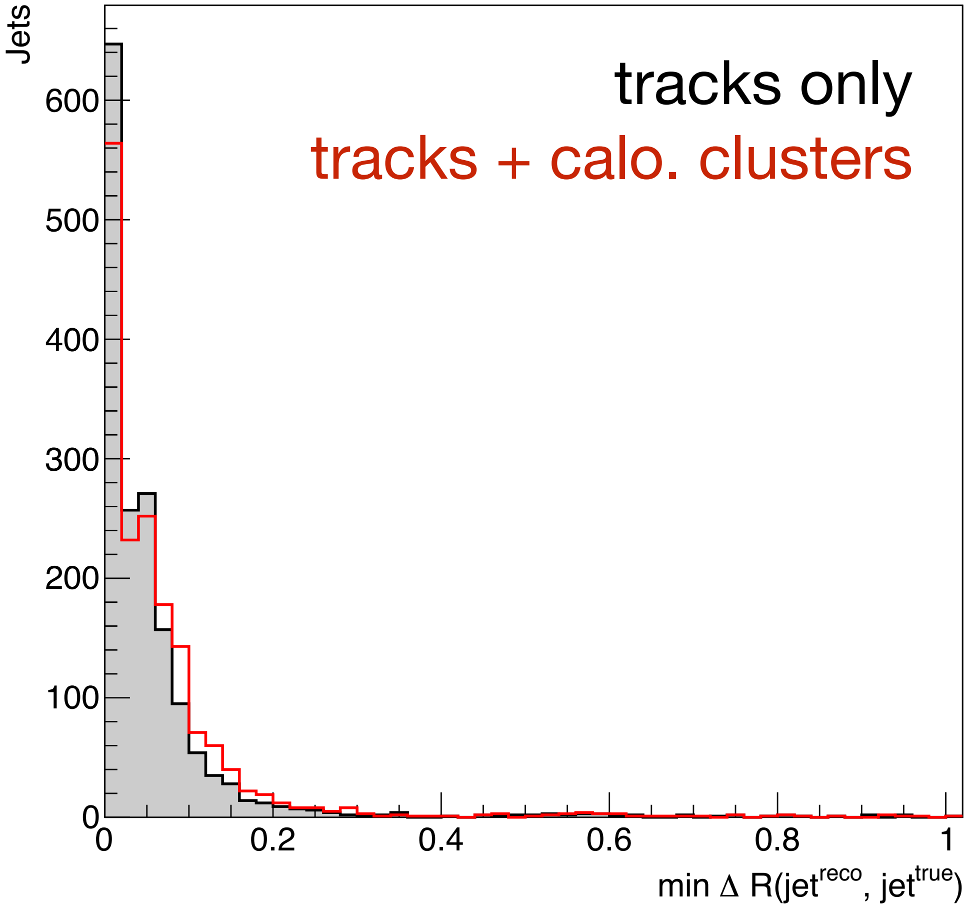
Jets from H→bb decays expected to be back to back

- true-level jets clustered from all the final-state particles in an event



Ensuring consistency between the reconstructed tracks and calorimeter clusters

- comparing jets clustered from different sets of input objects

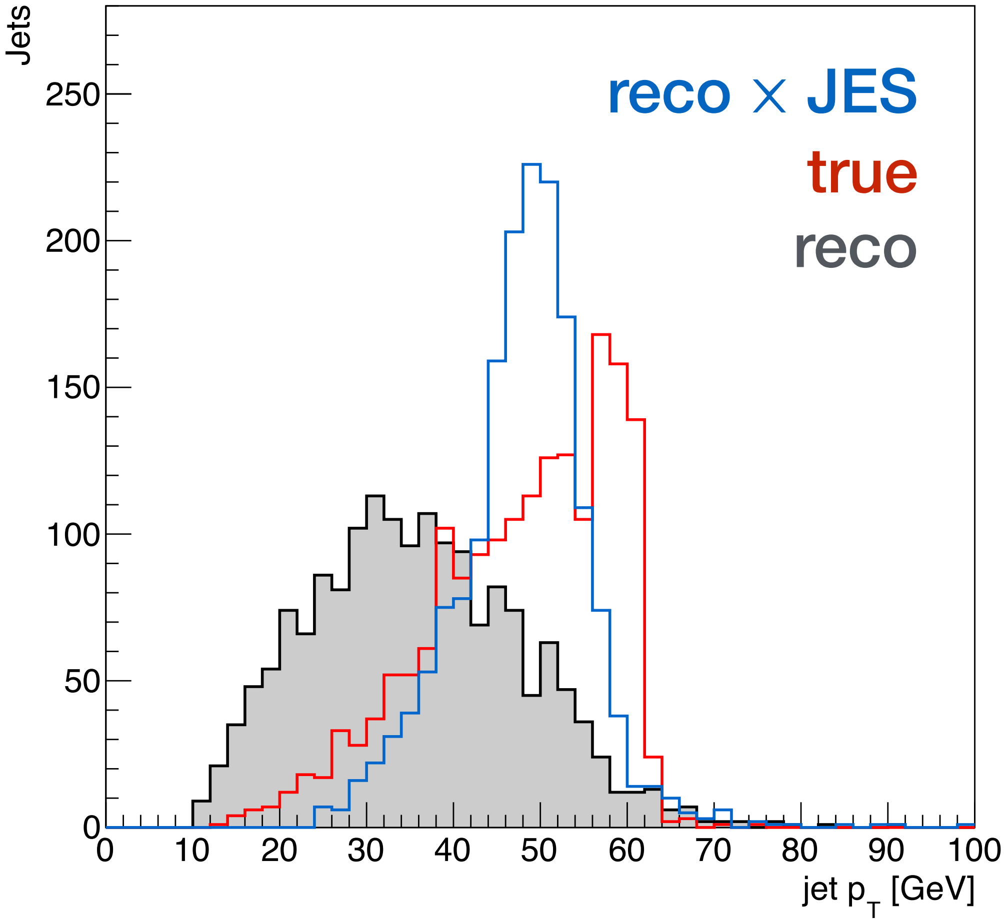


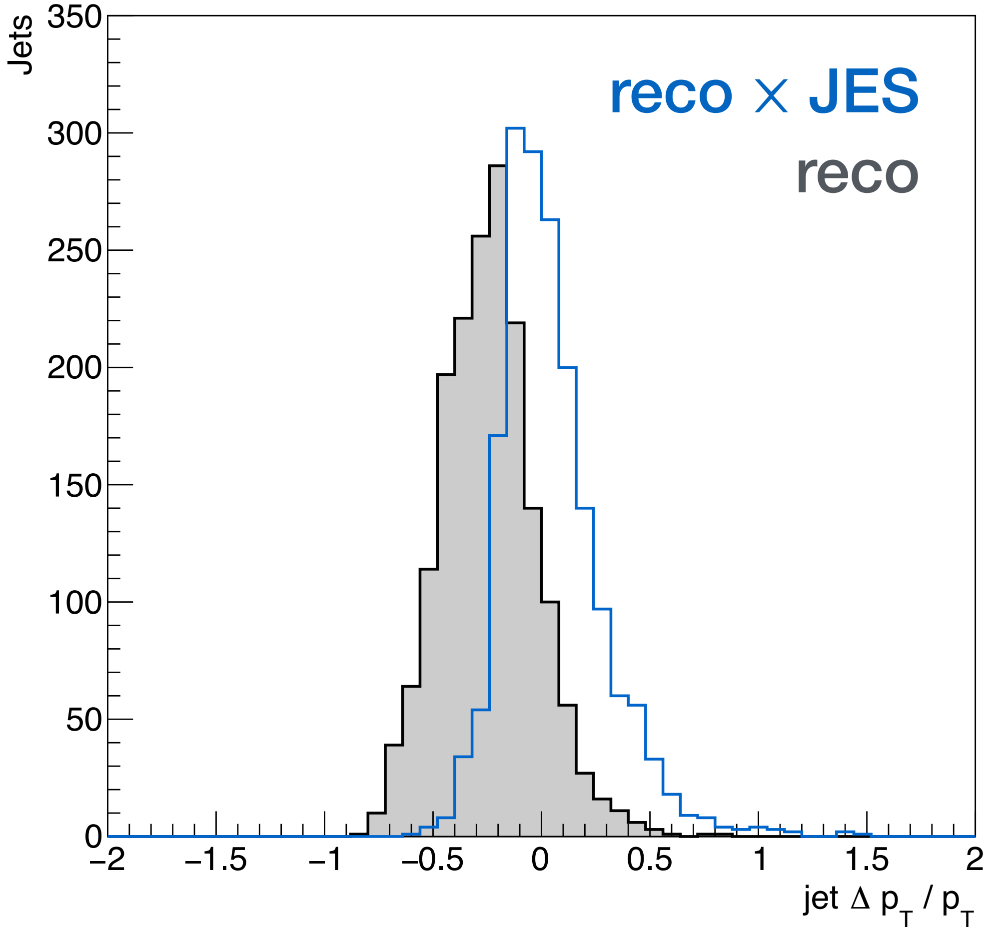
Reconstructed jets are close to the true-level jets
↳ jet direction is properly reconstructed

Jet clustering: momentum

The reconstructed jet p_T spectrum looks significantly different from the true jets

- jet energy scale improves the agreement
- further calibration of the calorimeter energy response might be needed





JES improves the central value

- resolution is still suboptimal

Conclusions

- Full chain of the detector simulation (tracker + calorimeter) is implemented in the ILCroot framework
- Signal can be combined with the beam background at the detector level
- Beam background creates a very large number of hits in the tracker

  ↳ can be suppressed by selecting only hits in a ~2ns time window
- Jet clustering implemented for the first time, allowing to do detailed studies of specific physics processes at a Muon Collider
- Still a lot of space for improvements at the event reconstruction side

  ↳ great potential for future studies