The CLD (CLIC-like Detector) for FCC-ee

Emilia Leogrande (CERN),
with contributions from Konrad Elsener and Oleksandr Viazlo
and help from the CLICdp Collaboration

Detector Design Meeting
30/01/2018

Introduction

The CLD is derived from the most recent CLIC detector model (CLICdet)

- Silicon pixel vertex detector
- Silicon tracker
- Silicon-tungsten ECal
- Scintillator-steel HCal
- Superconducting solenoid interleaved with RPC muon chambers

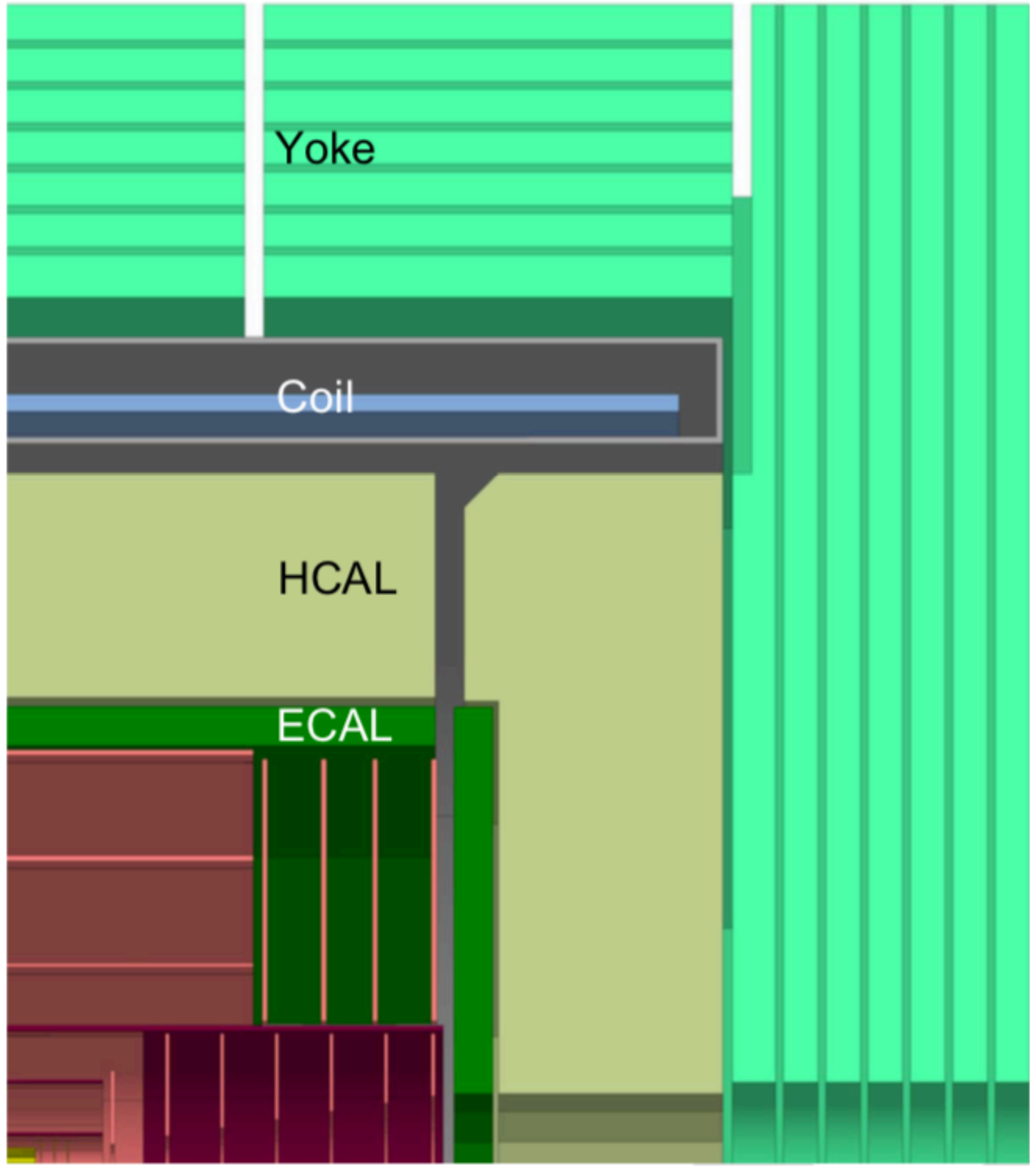
Constraints from the MDI at FCC-ee

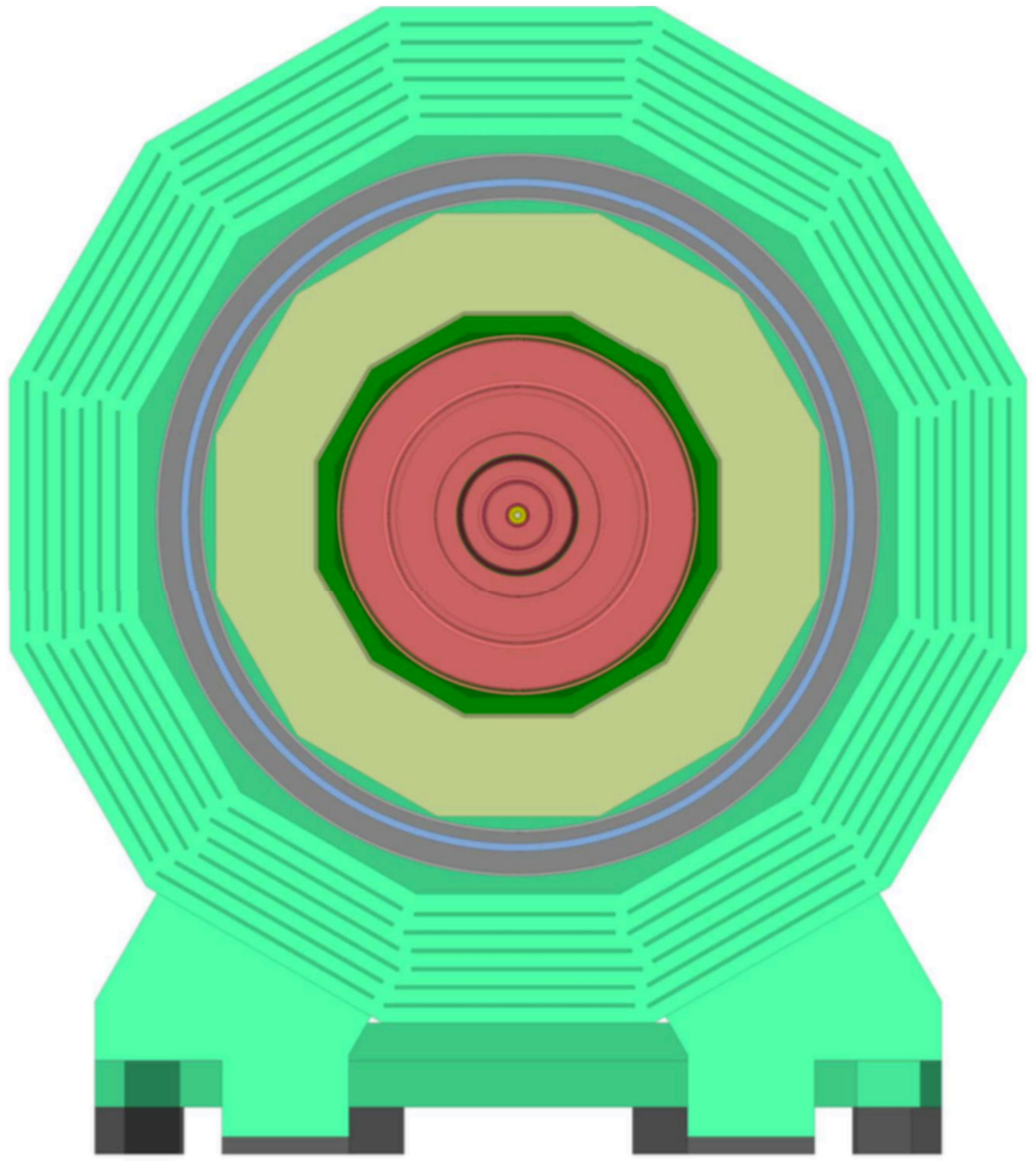
- Detector solenoidal field 2T (4T for CLIC)
  - Outer tracker radius increased to 2.15m (1.5m for CLIC)
- Beampipe radius 15mm (29mm for CLIC)
  - Inner vertex radius decreased to 17mm (31mm for CLIC)
- Max collision energy 365GeV (3TeV for CLIC)
  - Hadronic calorimeter depth reduced to $5.5\lambda_I$ ($7.5\lambda_I$ for CLIC)
- Layout respects the 150mrad cone reserved for beam- and MDI-equipment

Constraints from the continuous operation at a circular collider

- Power pulsing not possible
- Need for detailed engineering studies on cooling systems

Detector layout and main parameters

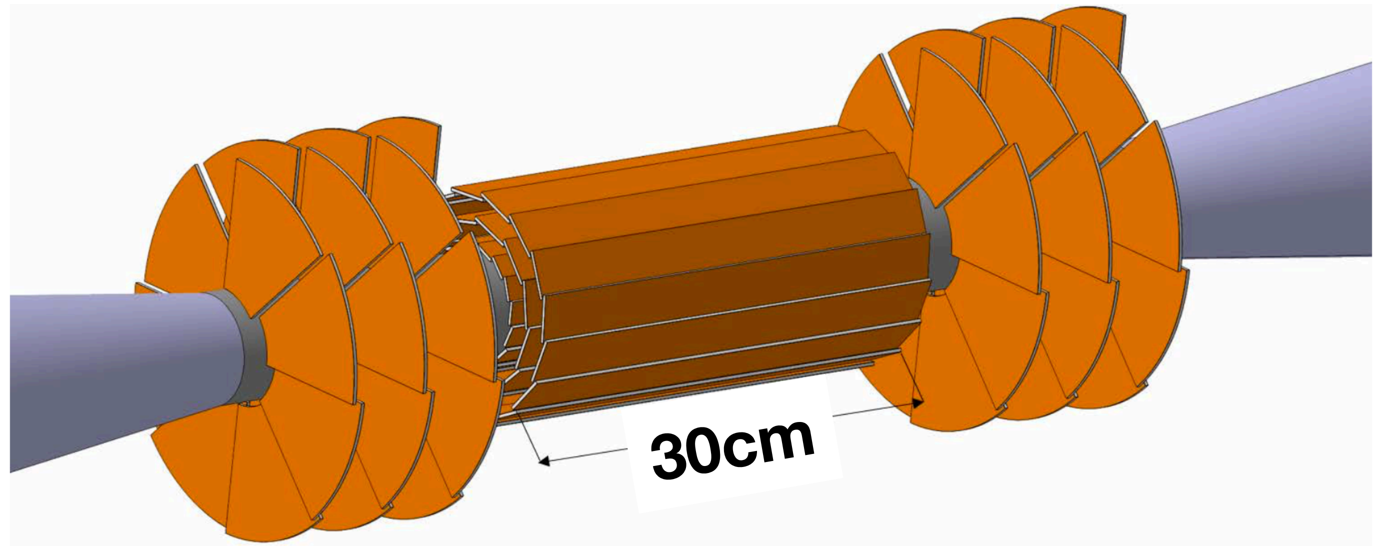




Concept	CLICdet	CLD
Vertex inner radius [mm]	31	17
Tracker technology	Silicon	Silicon
Tracker half length [m]	2.2	2.2
Tracker outer radius [m]	1.5	2.1
Inner tracker support cylinder radius [m]	0.575	0.675
ECAL absorber	W	W
ECAL X_0	22	22
ECAL barrel r_{min} [m]	1.5	2.15
ECAL barrel Δr [mm]	202	202
ECAL endcap z_{min} [m]	2.31	2.31
ECAL endcap Δz [mm]	202	202
HCAL absorber	Fe	Fe
HCAL λ_I	7.5	5.5
HCAL barrel r_{min} [m]	1.74	2.40
HCAL barrel Δr [mm]	1590	1166
HCAL endcap z_{min} [m]	2.4	2.4
HCAL endcap Δz [mm]	1590	1166
Solenoid field [T]	4	2
Solenoid bore radius [m]	3.5	3.7
Solenoid length [m]	8.3	7.4
Overall height [m]	12.9	12.0
Overall length [m]	11.4	7.5

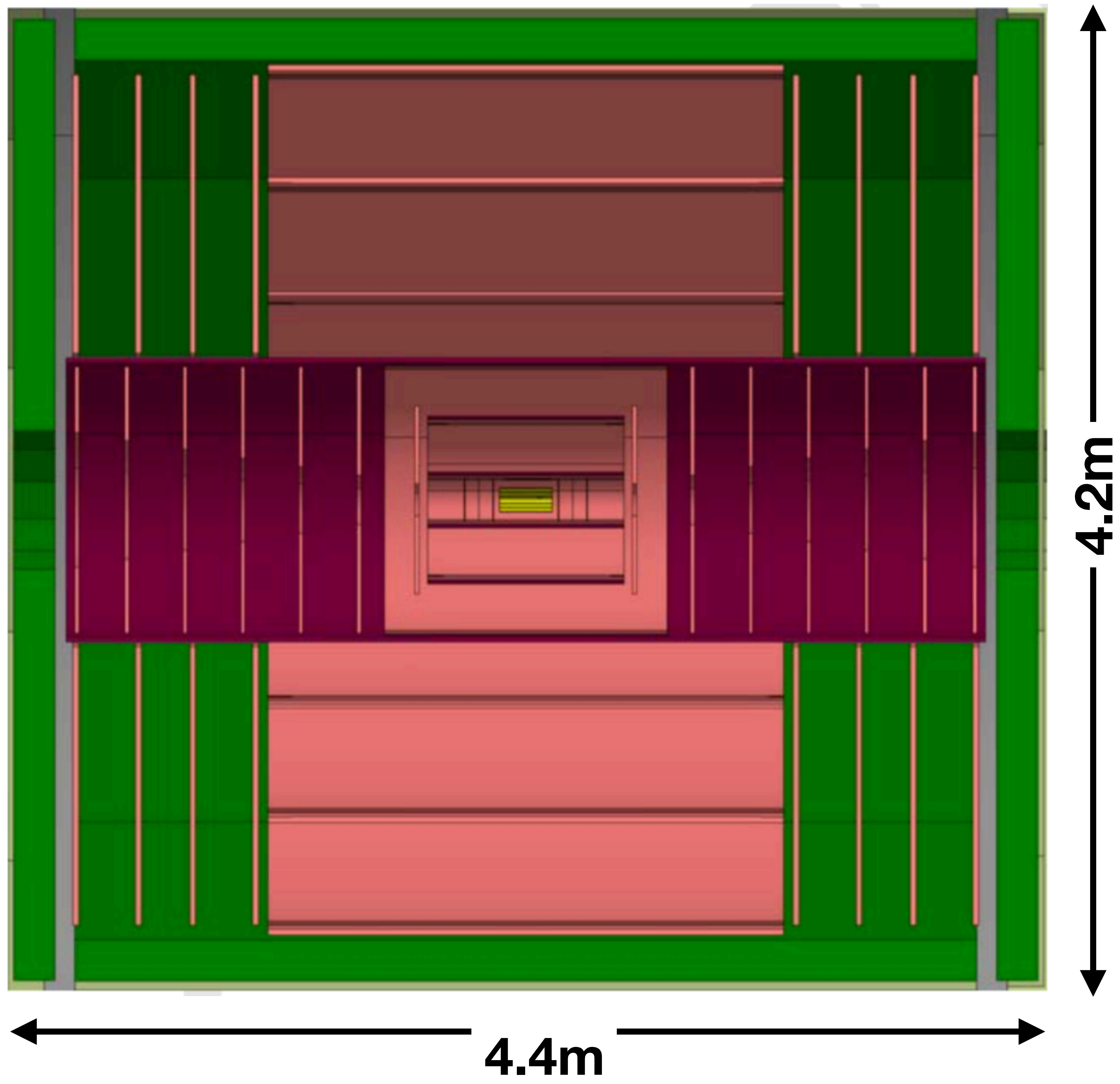
Vertex detector

- Silicon pixels 25x25 μm^2
- single point resolution = 3 μm
- 3 barrel double layers
- 3 sets of double disks
- material budget: 0.3%X0 per layer

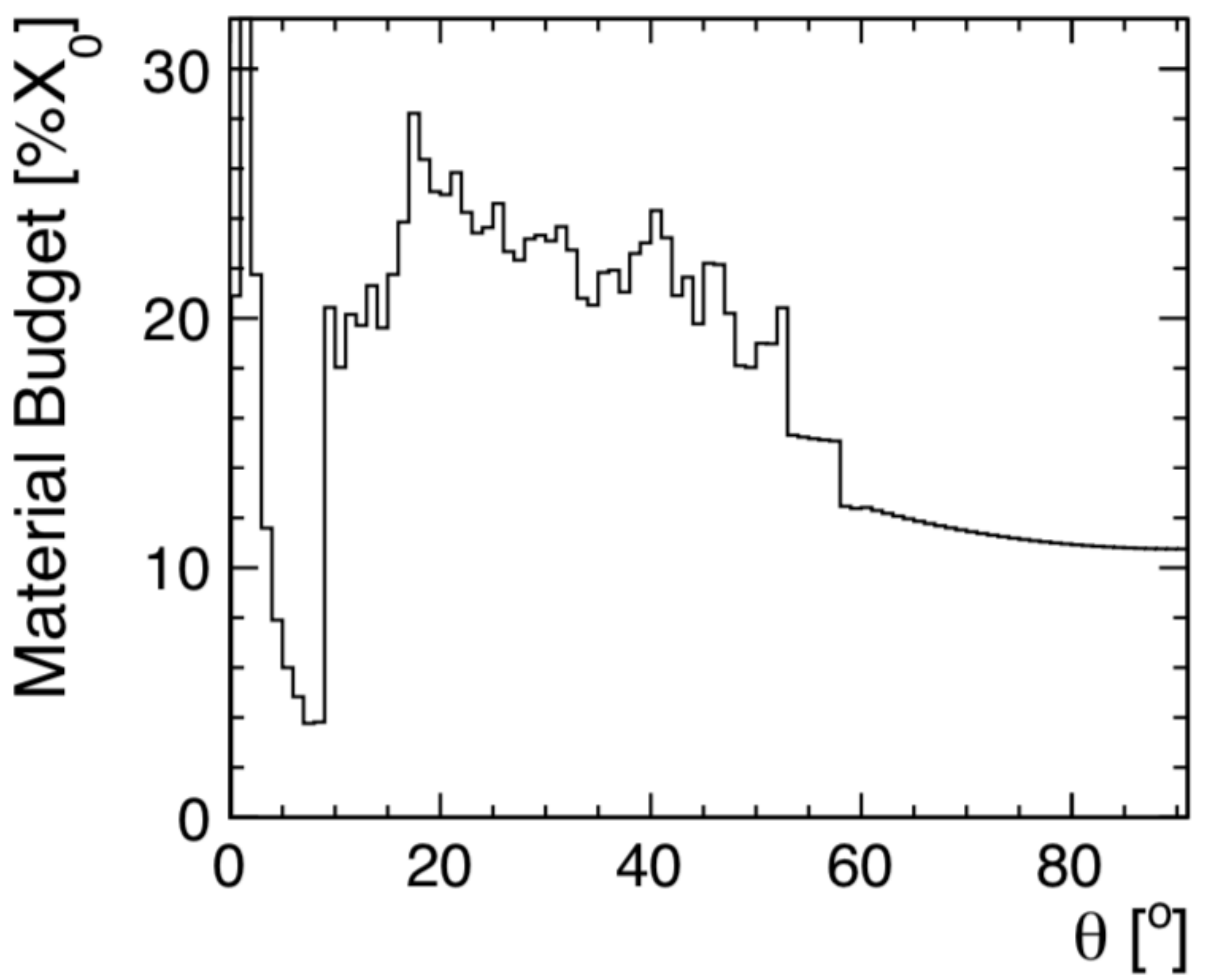


Tracker detector

- Silicon pixels and microstrips
- inner tracker
  - 3 barrel layers, 5 disks
- outer tracker
  - 3 barrel layers, 4 disks
- single point resolution:
  - 1st inner disk: 5 μm x 5 μm
  - all others: 7 μm x 90 μm
- material budget:
  - barrel: 1.2%X_0 per layer
  - endcap: 1.4%X_0 per layer



Total material budget [vertex+tracker]



The ECal and HCal

Particle flow calorimetry requires high-granularity calorimeters

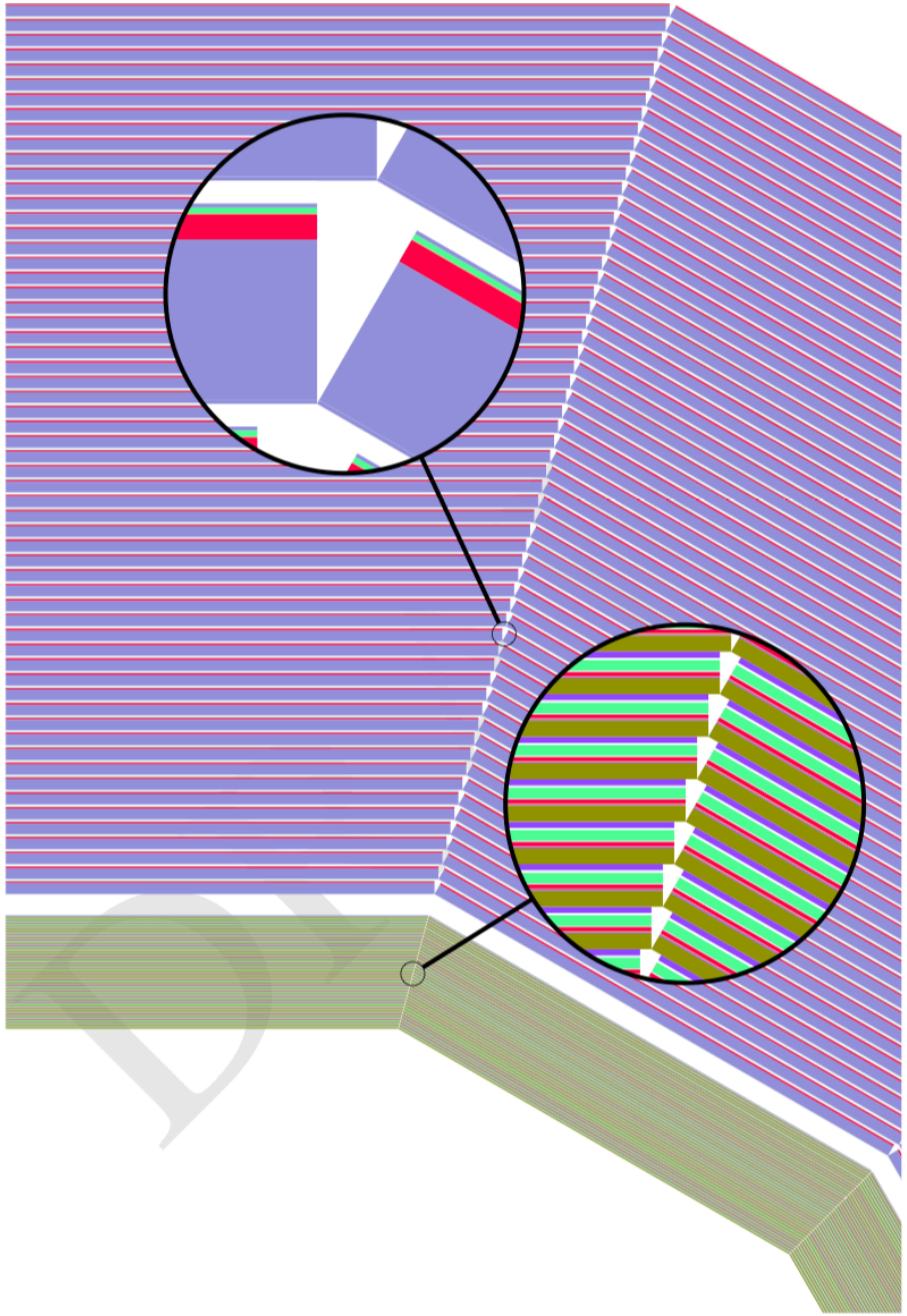
ECal

- Si-W sampling calorimeter
- cell size 5 x 5 mm^2
- 40 layers (1.9mm thick W plates)
- $22X_0$

HCal

- Scintillator-steel sampling calorimeter
- cell size 30 x 30 mm^2
- 44 layers (19mm thick steel plates)
- $5.5\lambda_I$

Combined thickness ECal + HCal = $6.5\lambda_I$

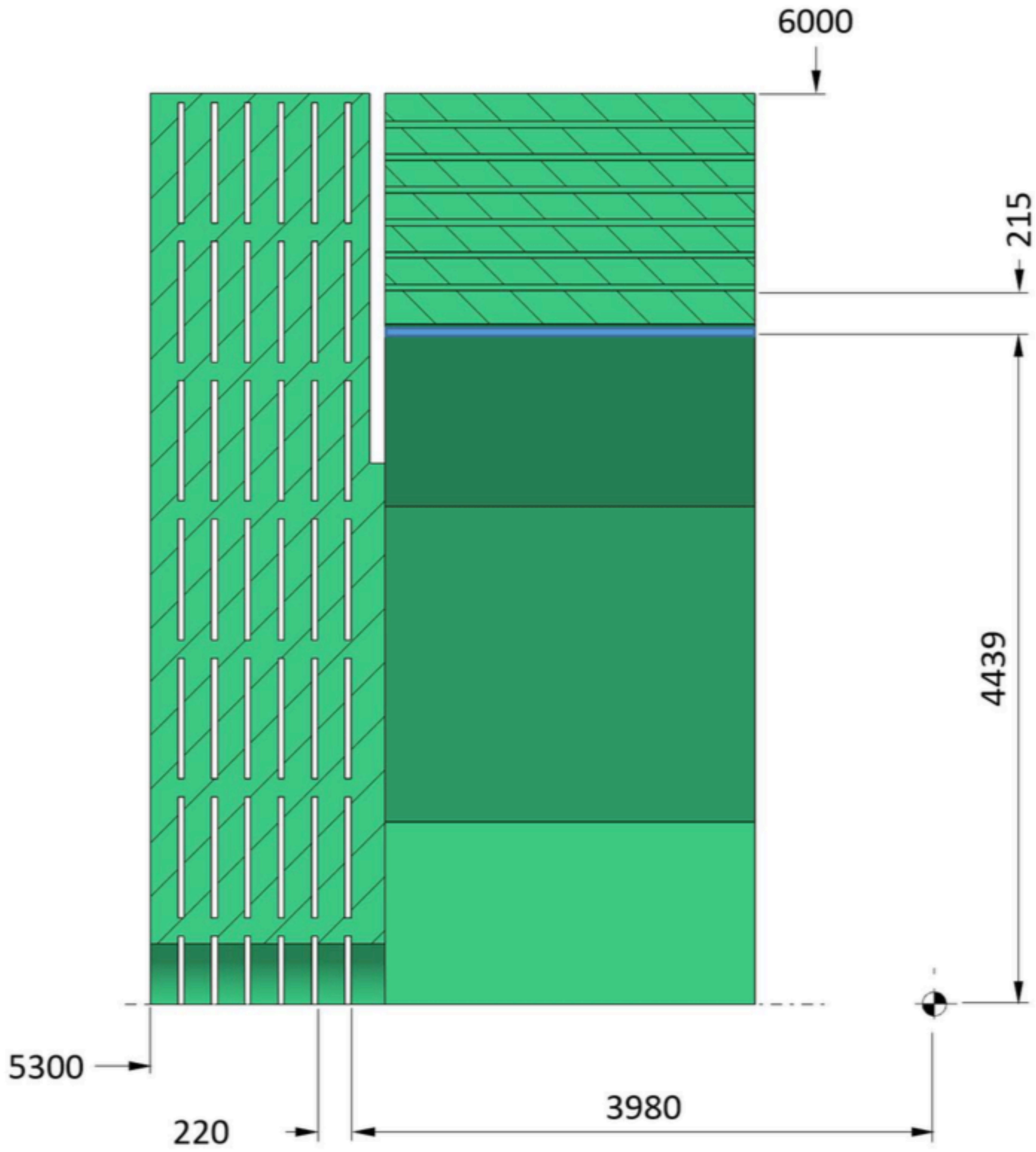


The magnet system

- superconducting coil
  - 2T field
- return yoke
  - barrel: 1T field
  - endcap: no field in the simulation at the moment

The muon system

- RPC chambers
  - 6 layers
  - additional possible 7th layer as close as possible to the coil, as tailcatcher for hadron showers
  - cell size 30 x 30 mm^2

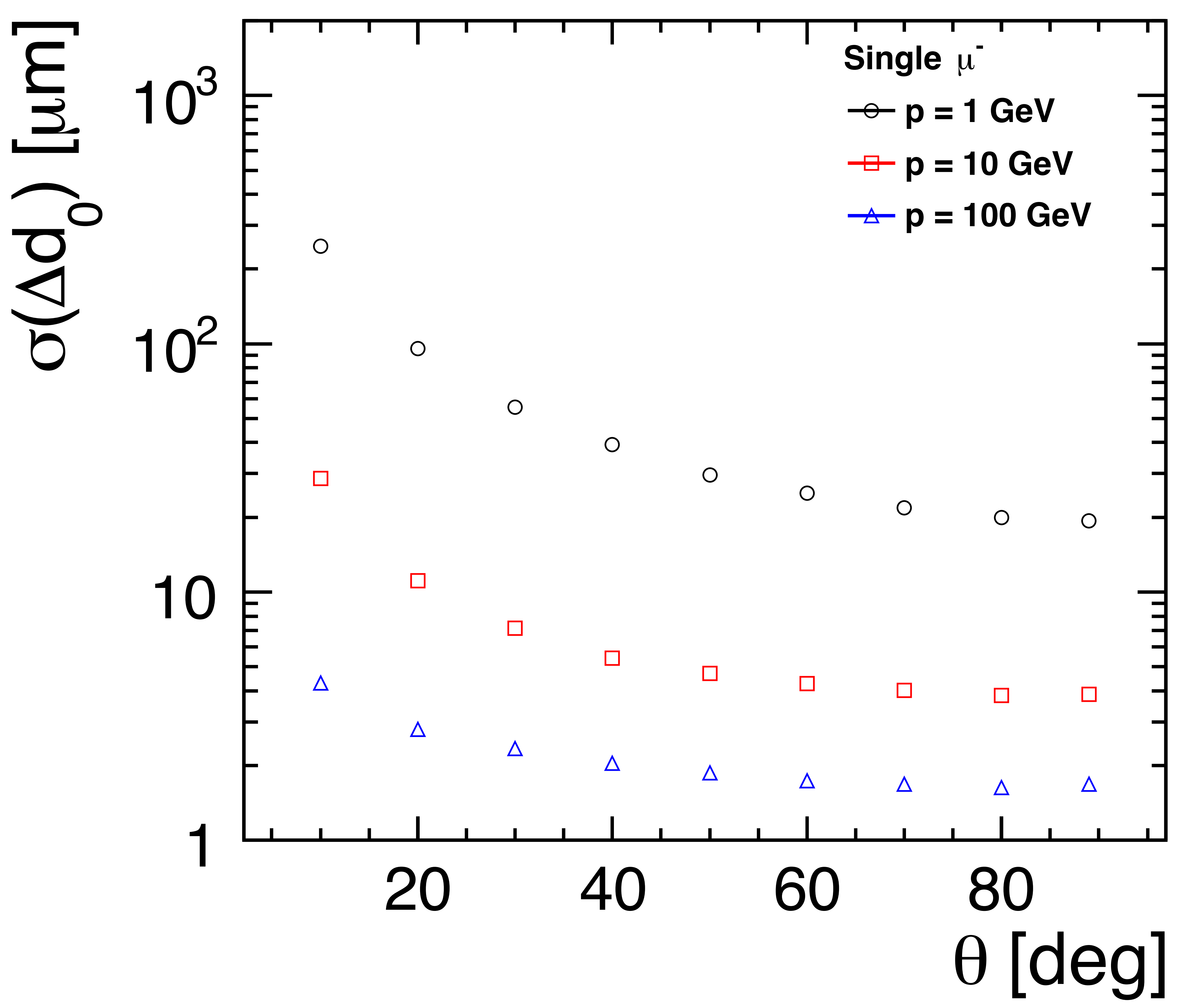


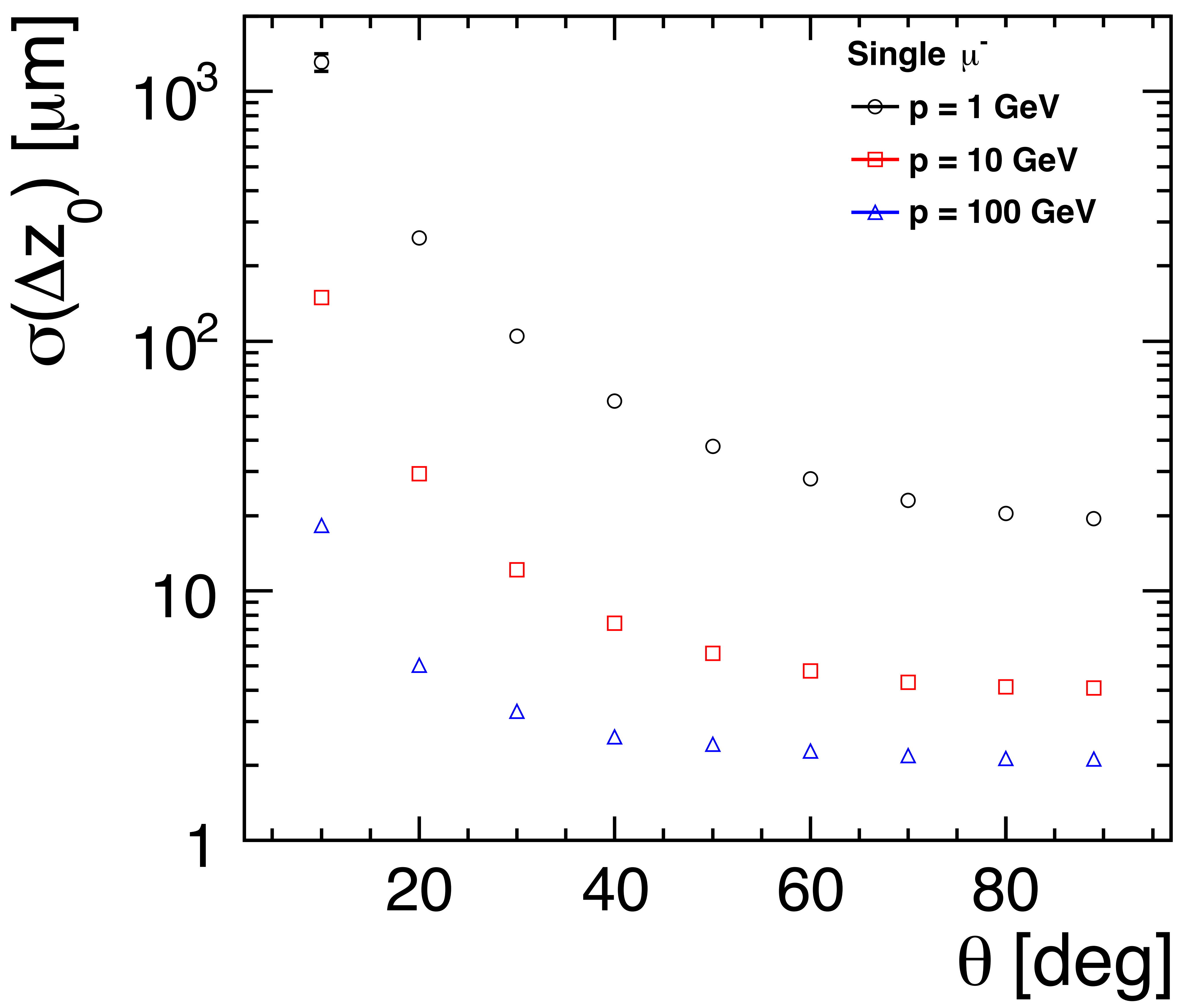
Detector performances are studied in full simulation with the iLCSoft (Linear Collider community software)

- Tracking performances
  - impact parameter resolution
  - angular resolution
  - momentum resolution
  - single particle efficiency
  - complex events efficiency
- Calorimeters performances
  - photon energy resolution
  - kaon energy resolution
  - jet energy resolution
  - photon ID efficiency
  - charged particles efficiency

Impact parameter resolution

- Resolution = σ of the Gaussian fit of distribution (reco - true)
- Statistics used: 10k muons at fixed energy and θ for each datapoint

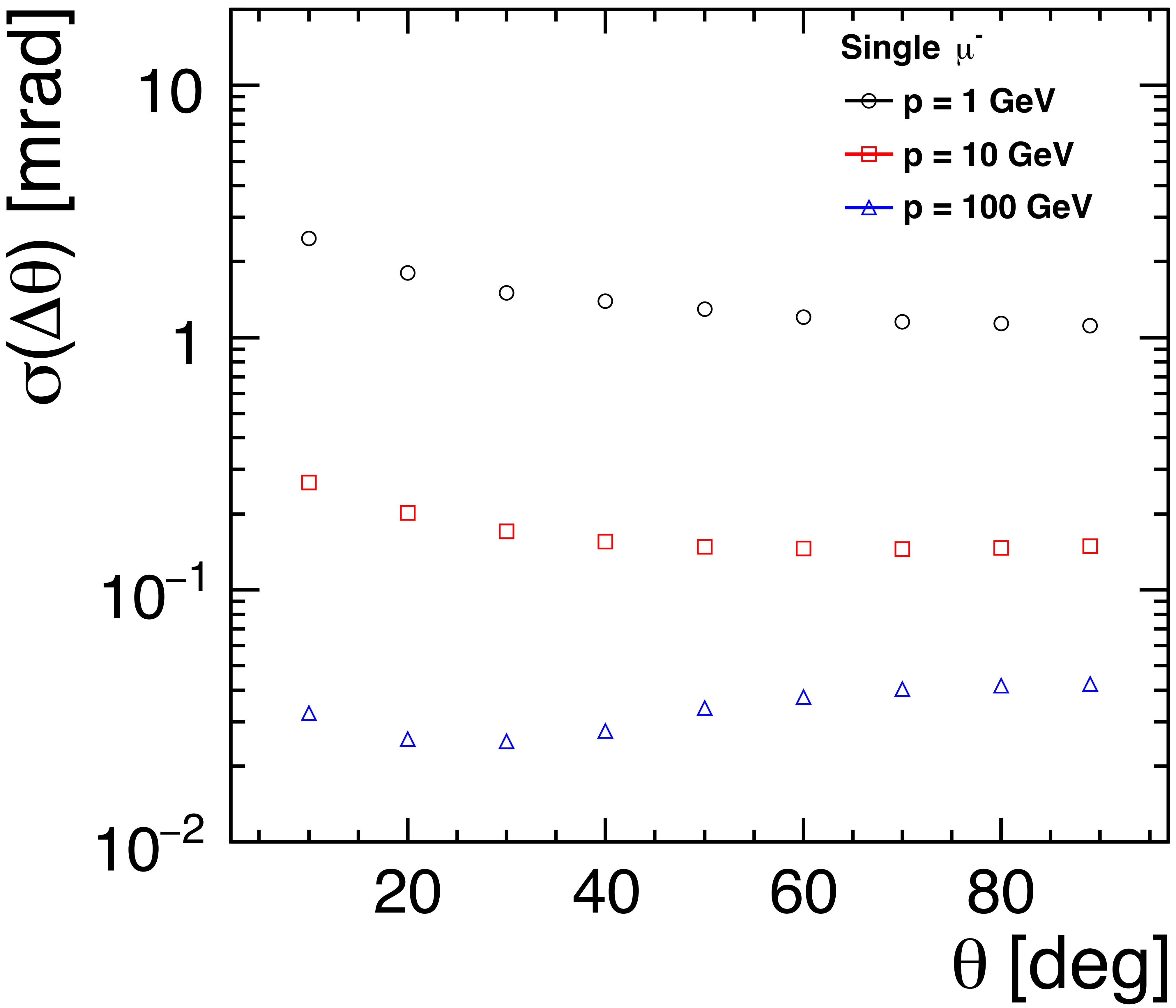


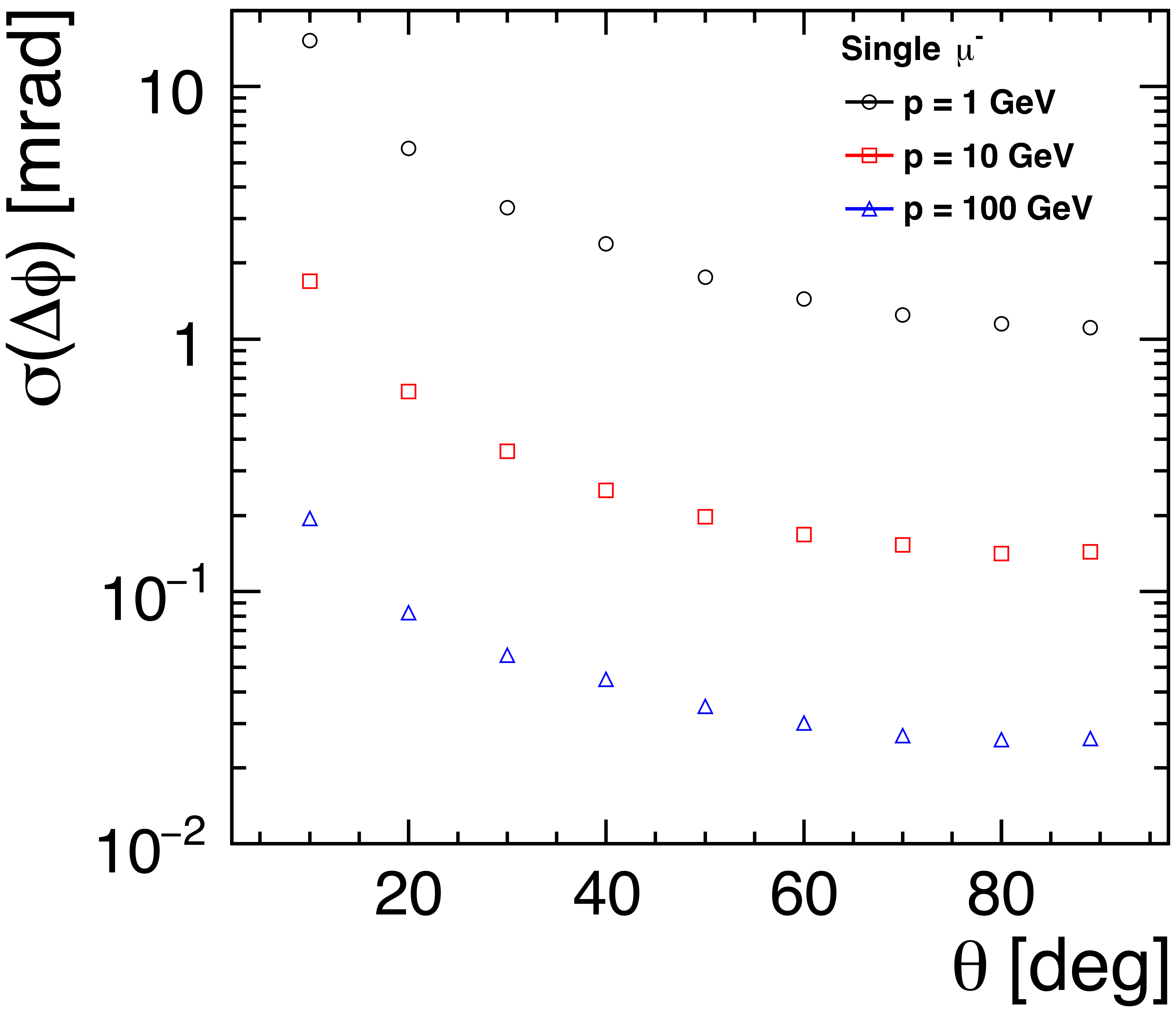


☆ Achieved transverse impact parameter resolution below 2μm and longitudinal impact parameter resolution ~2μm for 100GeV muons in the barrel

Angular resolution

- Resolution = σ of the Gaussian fit of distribution (reco - true)
- Statistics used: 10k muons at fixed energy and θ for each datapoint

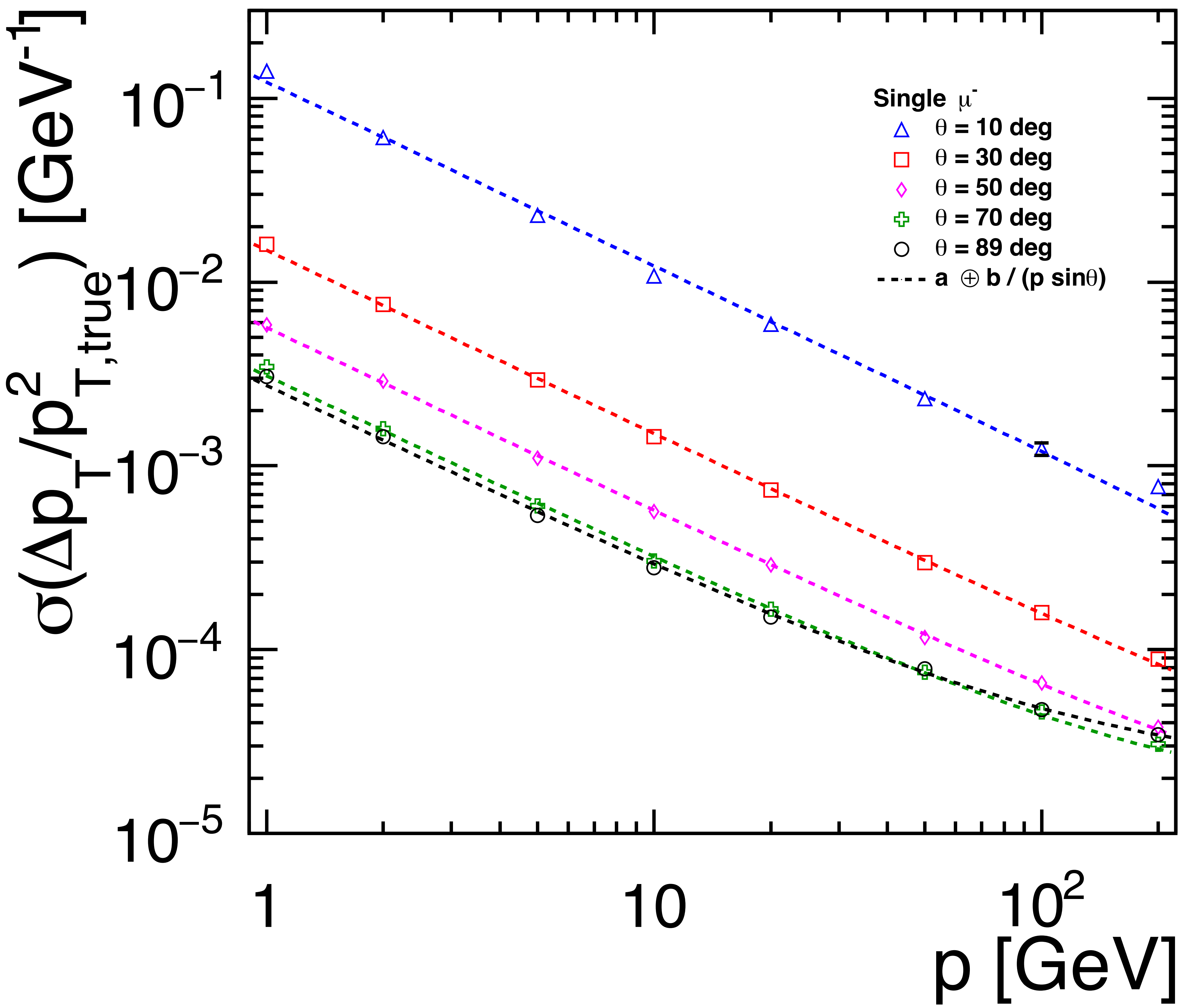


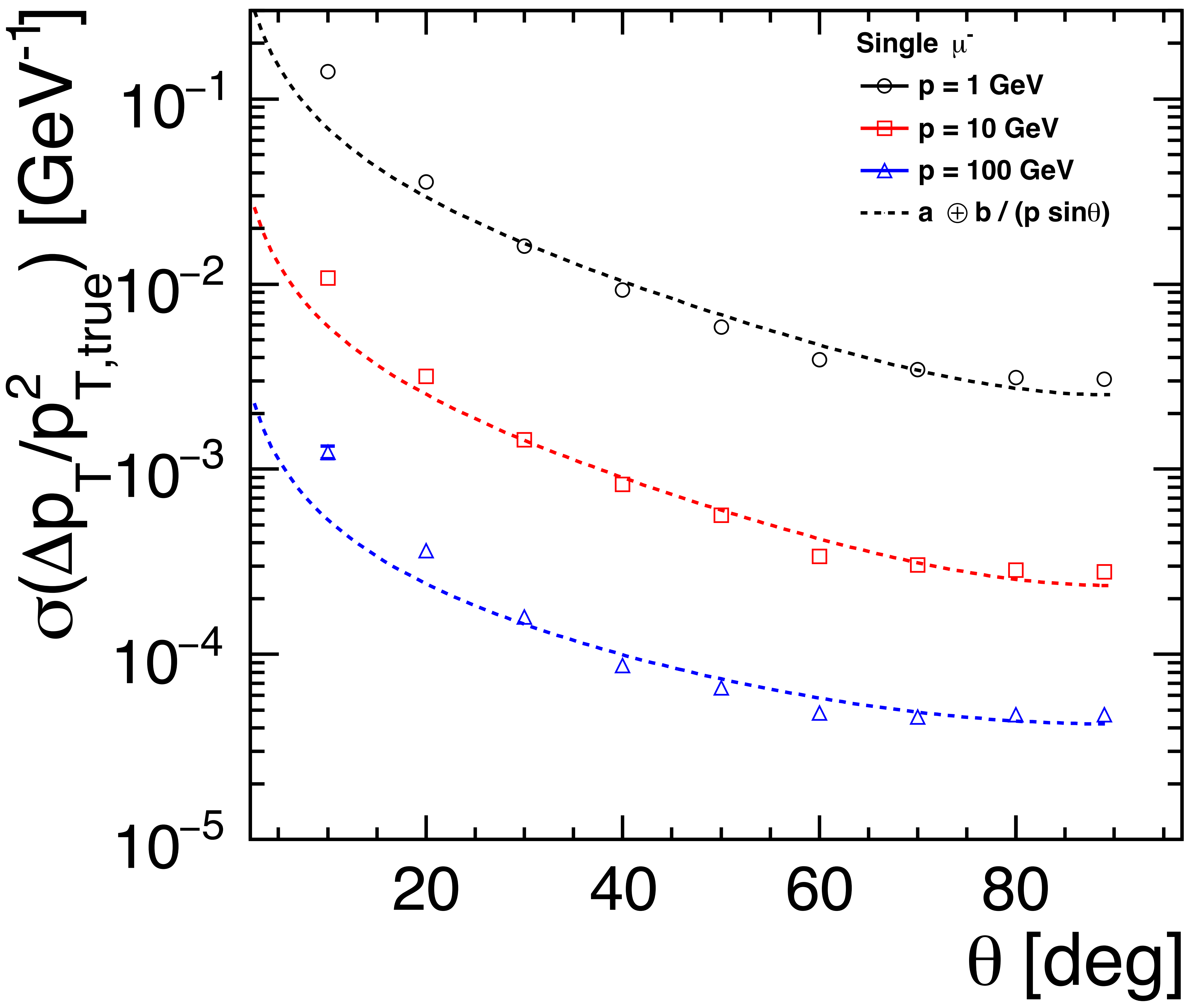


☆ Achieved θ resolution of 0.04mrad and φ resolution ~0.03mrad for 100GeV muons in the barrel

Momentum resolution

- Resolution = σ of the Gaussian fit of distribution (reco - true)/true^2
- Statistics used: 10k muons at fixed energy and θ for each datapoint



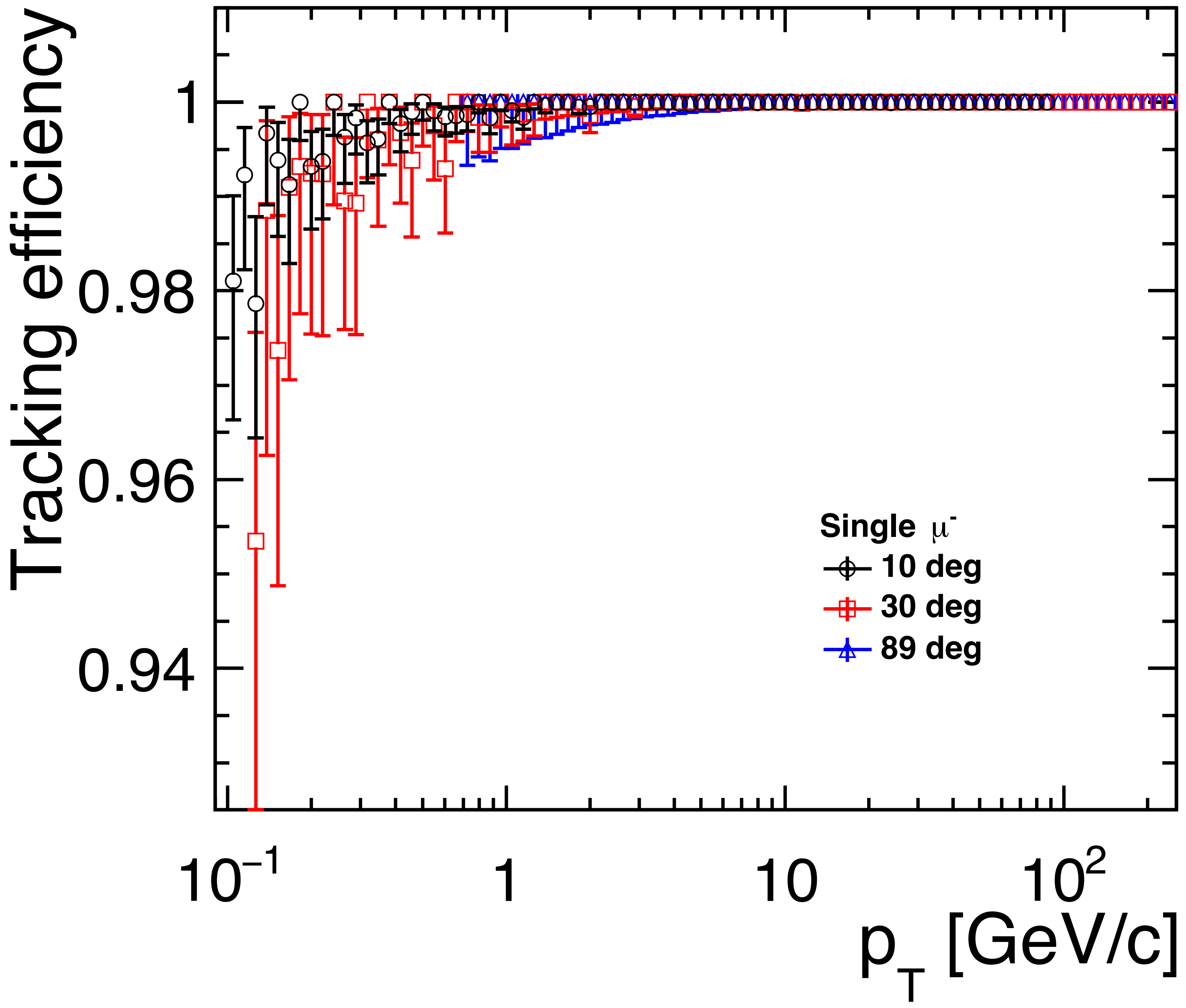


☆ Achieved momentum resolution of 4×10^{-5} GeV^{-1} for 100GeV muons in the barrel

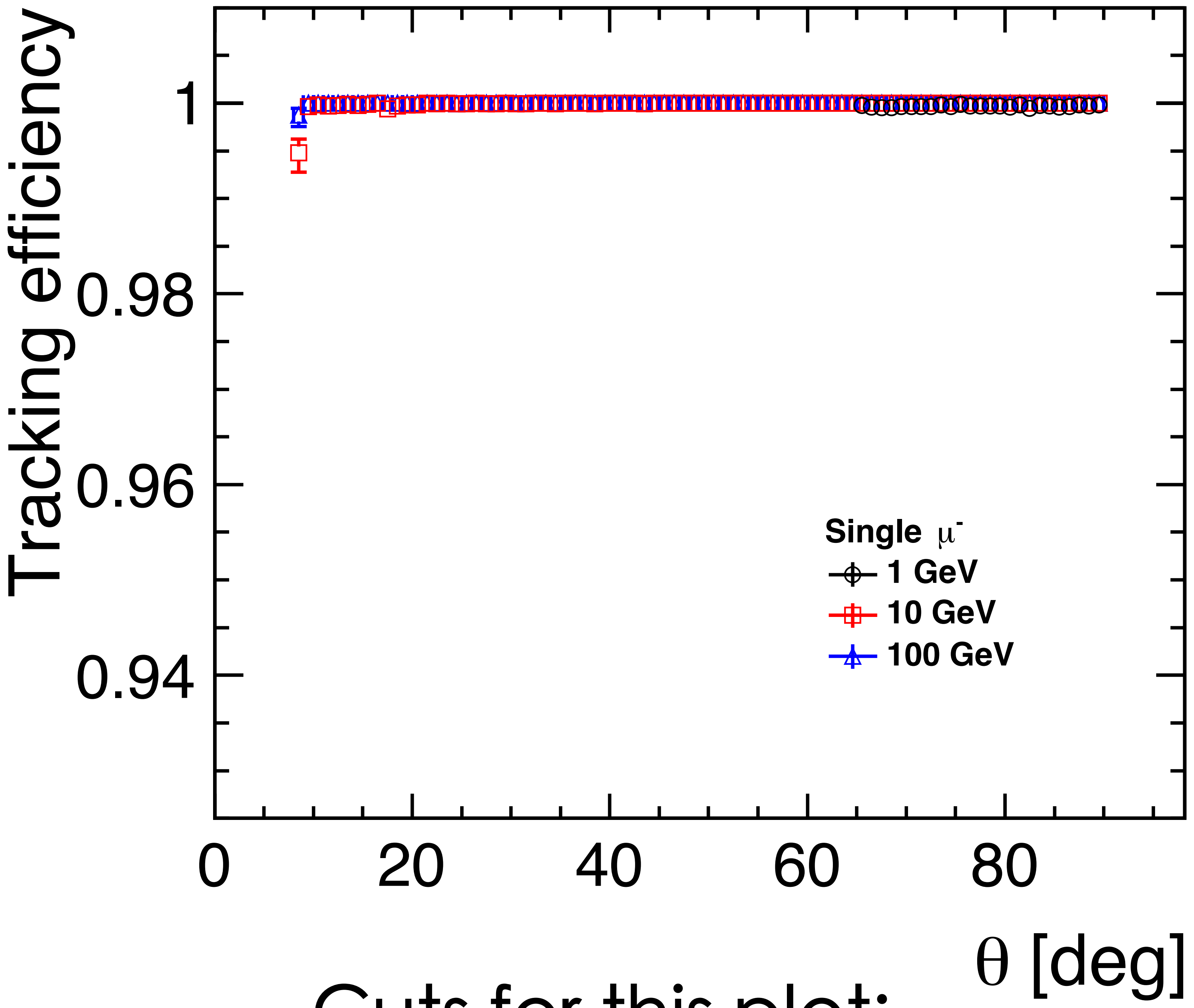
Tracking efficiency for single muons

- Efficiency = fraction of reconstructed particles out of the reconstructable MC particles
- Statistics used: 2M muons for each dataset
  - vs pT: fixed θ, linear energy distribution 1-500GeV
  - vs θ: fixed energy, isotropic angular distribution 0-90deg

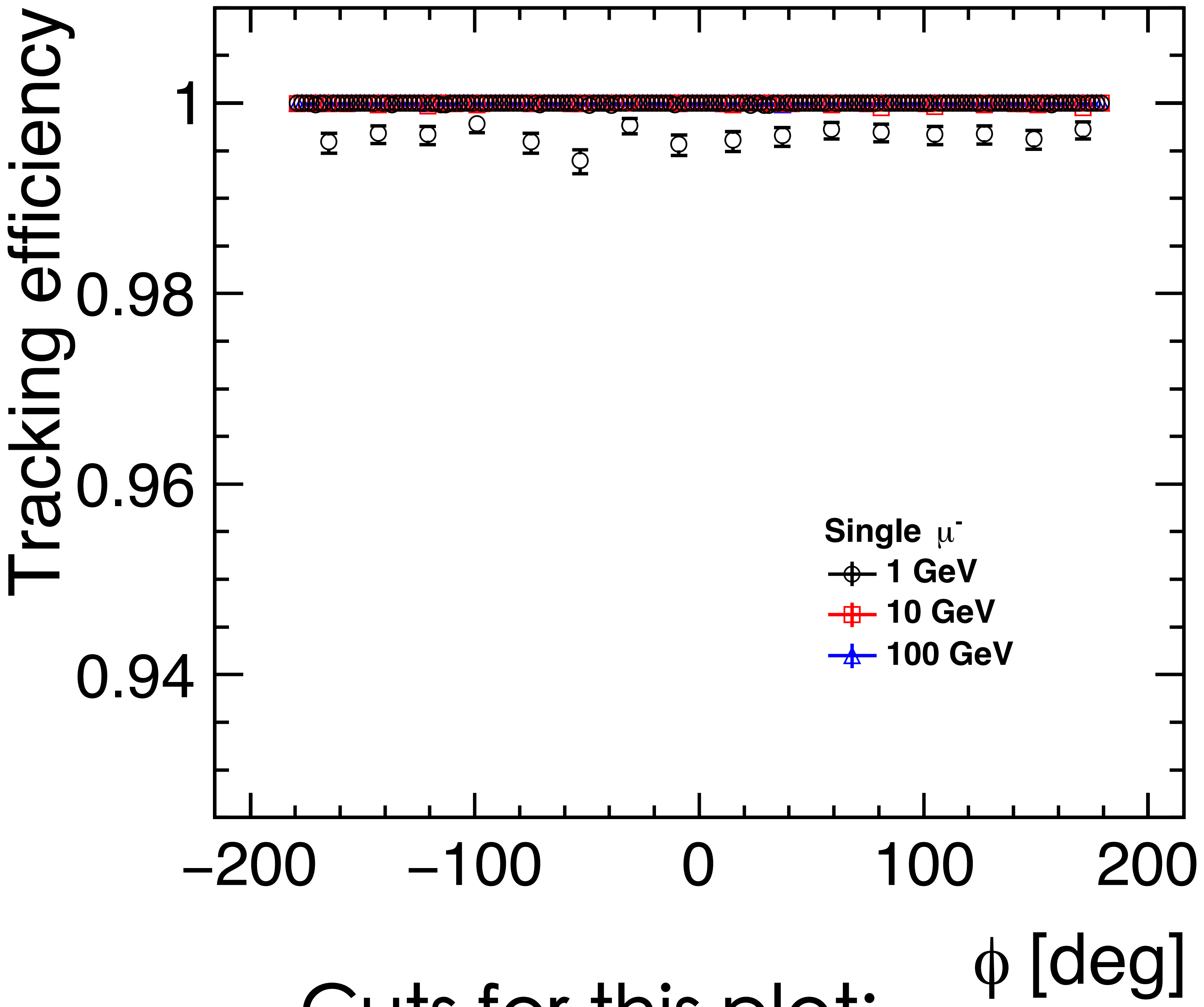
- stable
- pT > 0.1 GeV/c
- |cosθ| < 0.99
- N unique hits >=4



Cuts for this plot:
- prompt μ



Cuts for this plot:
- prompt μ
- pT > 1 GeV/c



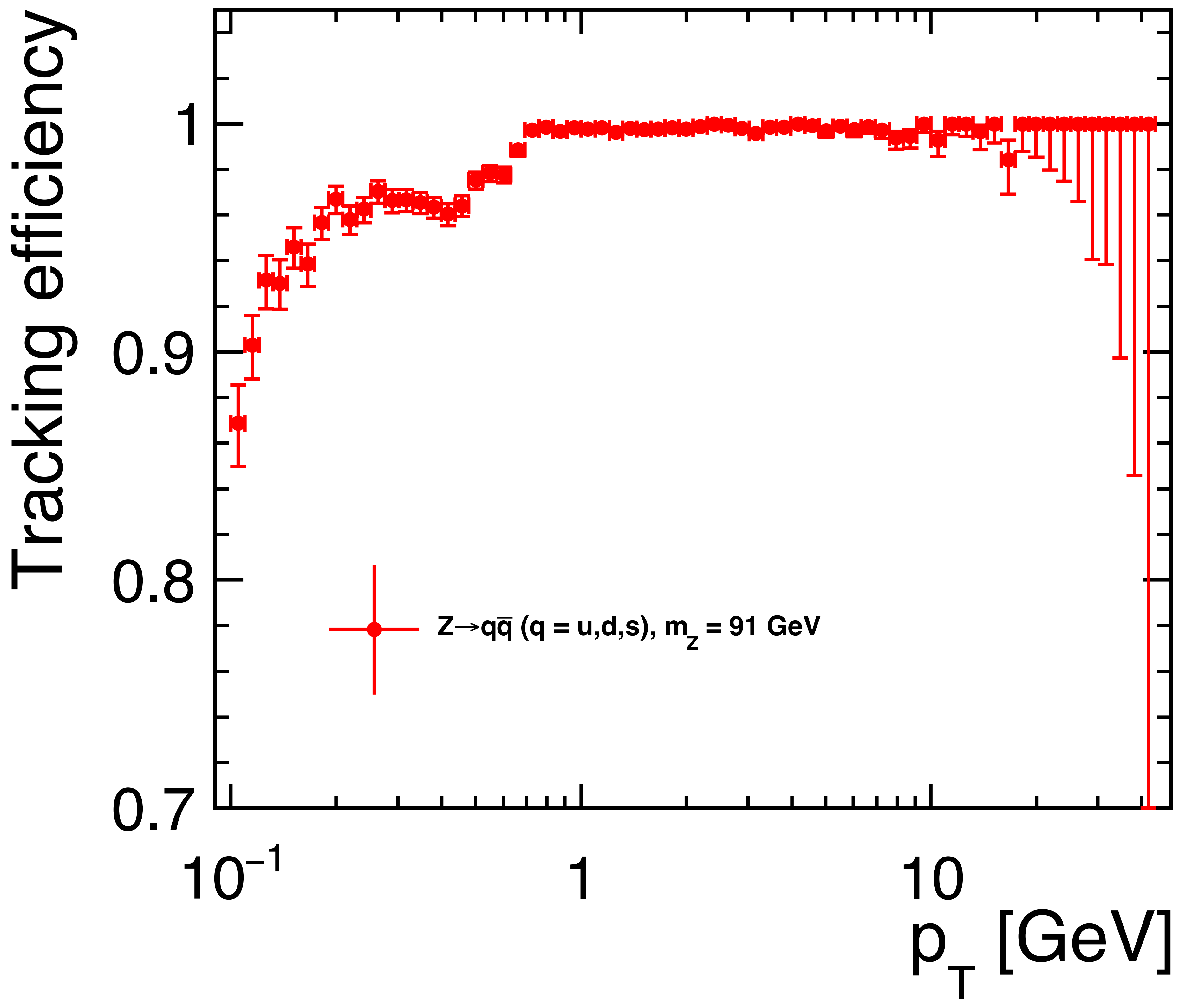
Cuts for this plot:
- prompt μ
- pT > 1 GeV/c

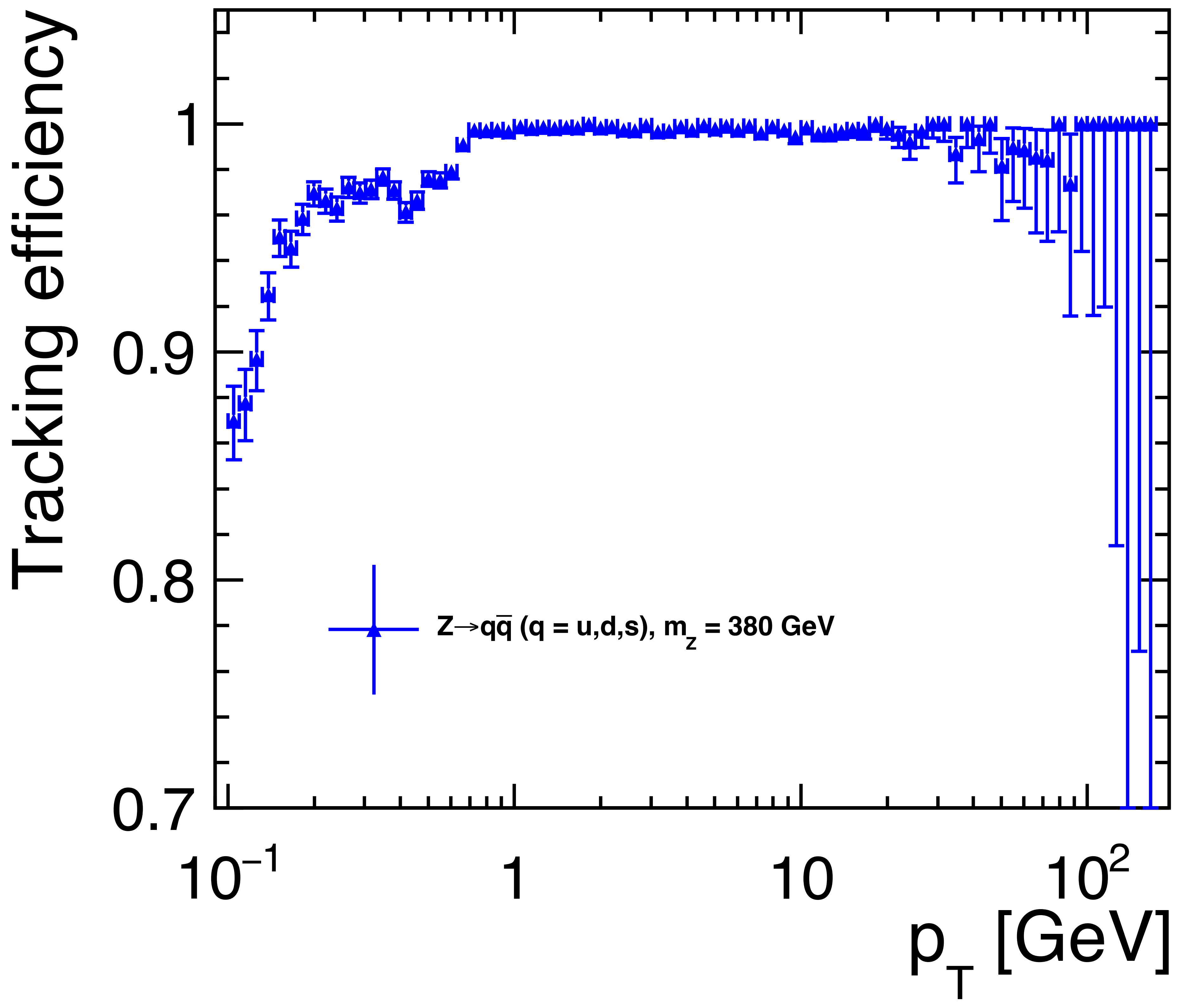
- Efficiency = fraction of pure reconstructed particles out of the reconstructable MC particles

pure:
- purity >= 75%
- purity: highest fraction of track hits belonging to the same MCparticle

reconstructable:
- stable
- pT > 0.1 GeV/c
- |cosθ| < 0.99
- N unique hits >=4

- Statistics used for both samples: ~4200 events

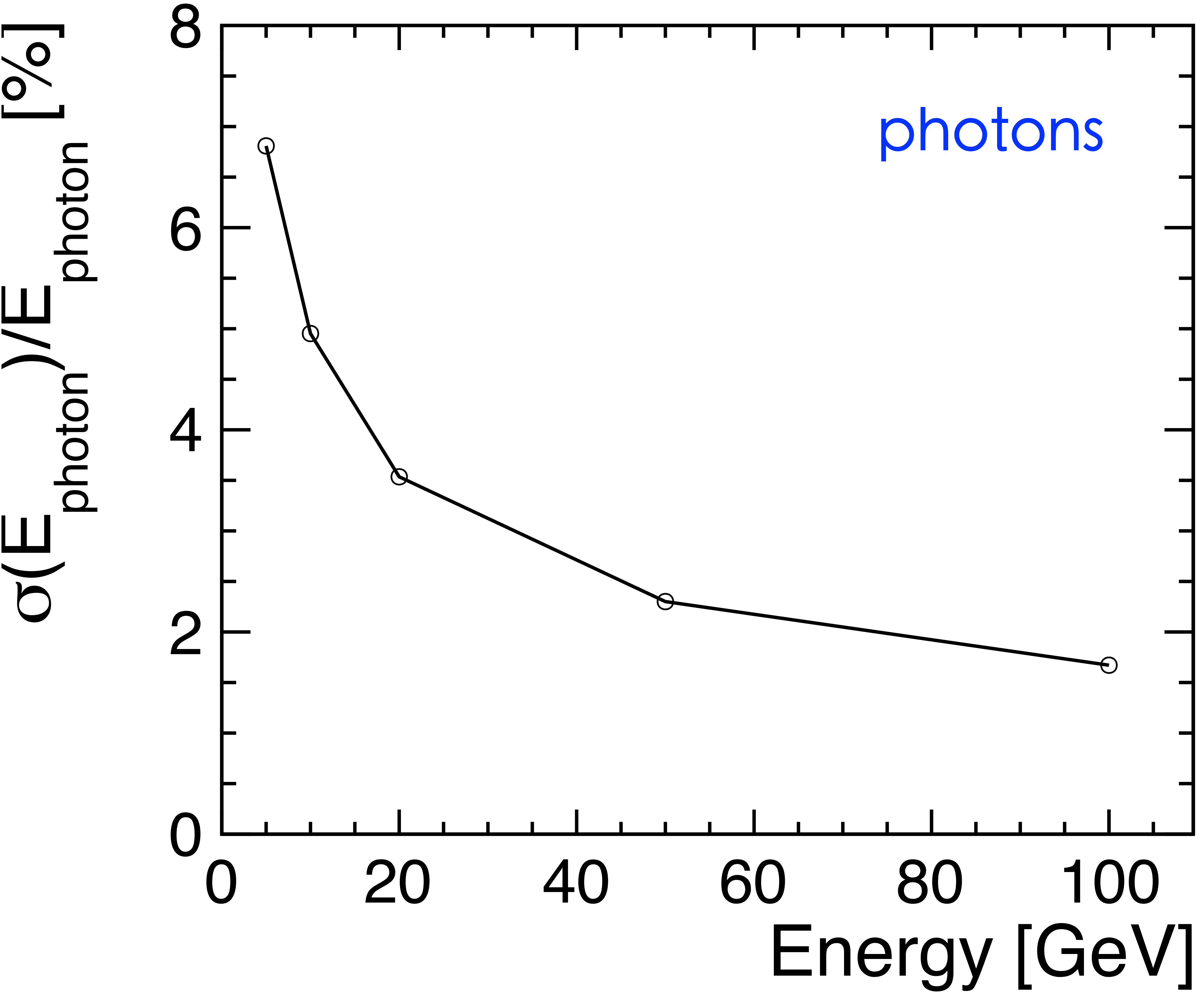


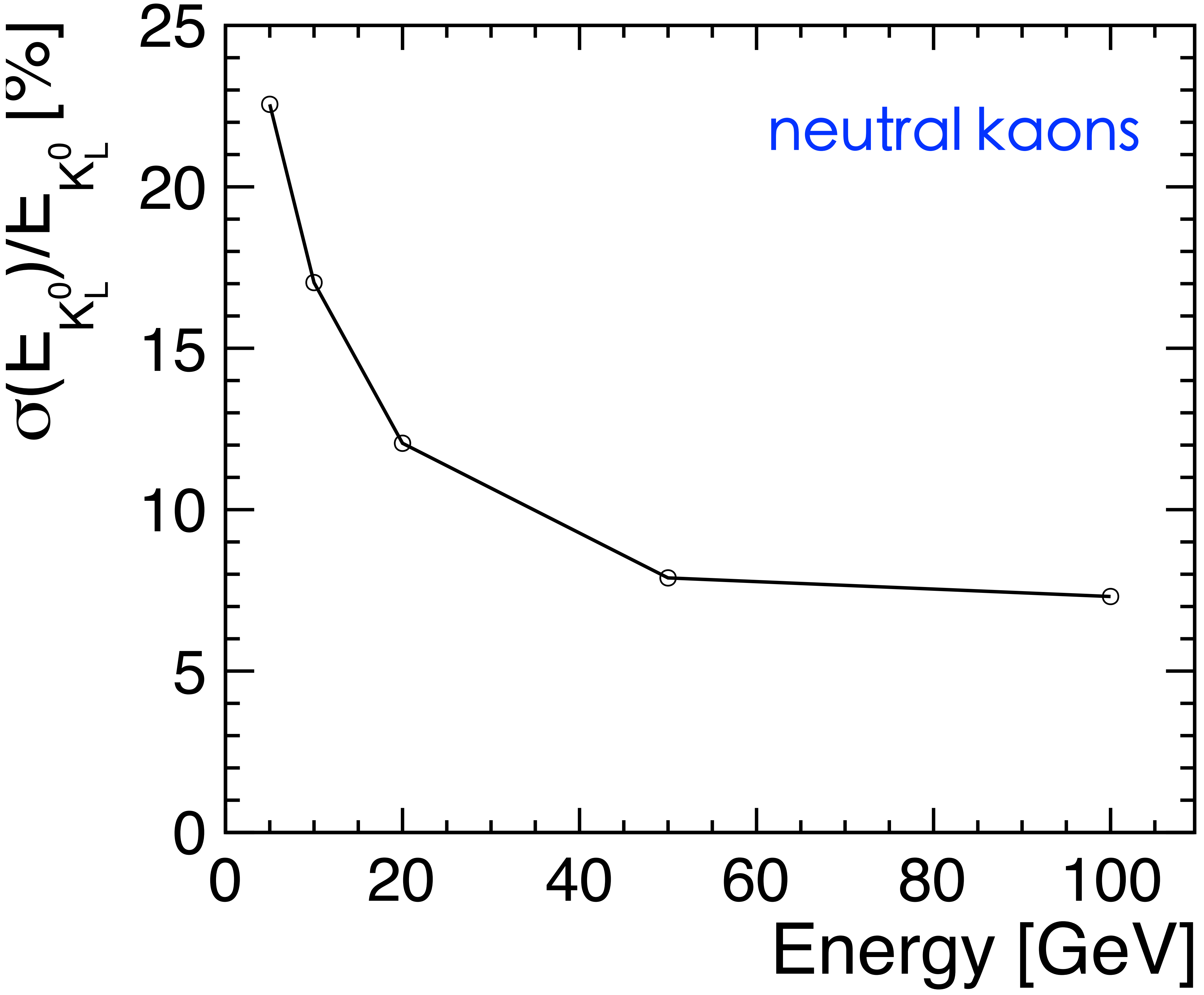


Cuts for both plots:
- 10 < θ < 170 deg
- vertex R < 50 mm

Single particle energy resolution: photons and kaons

- Resolution = σ of the Gaussian fit of distribution (reco - true) / true
- Statistics used: 100k events per datapoint





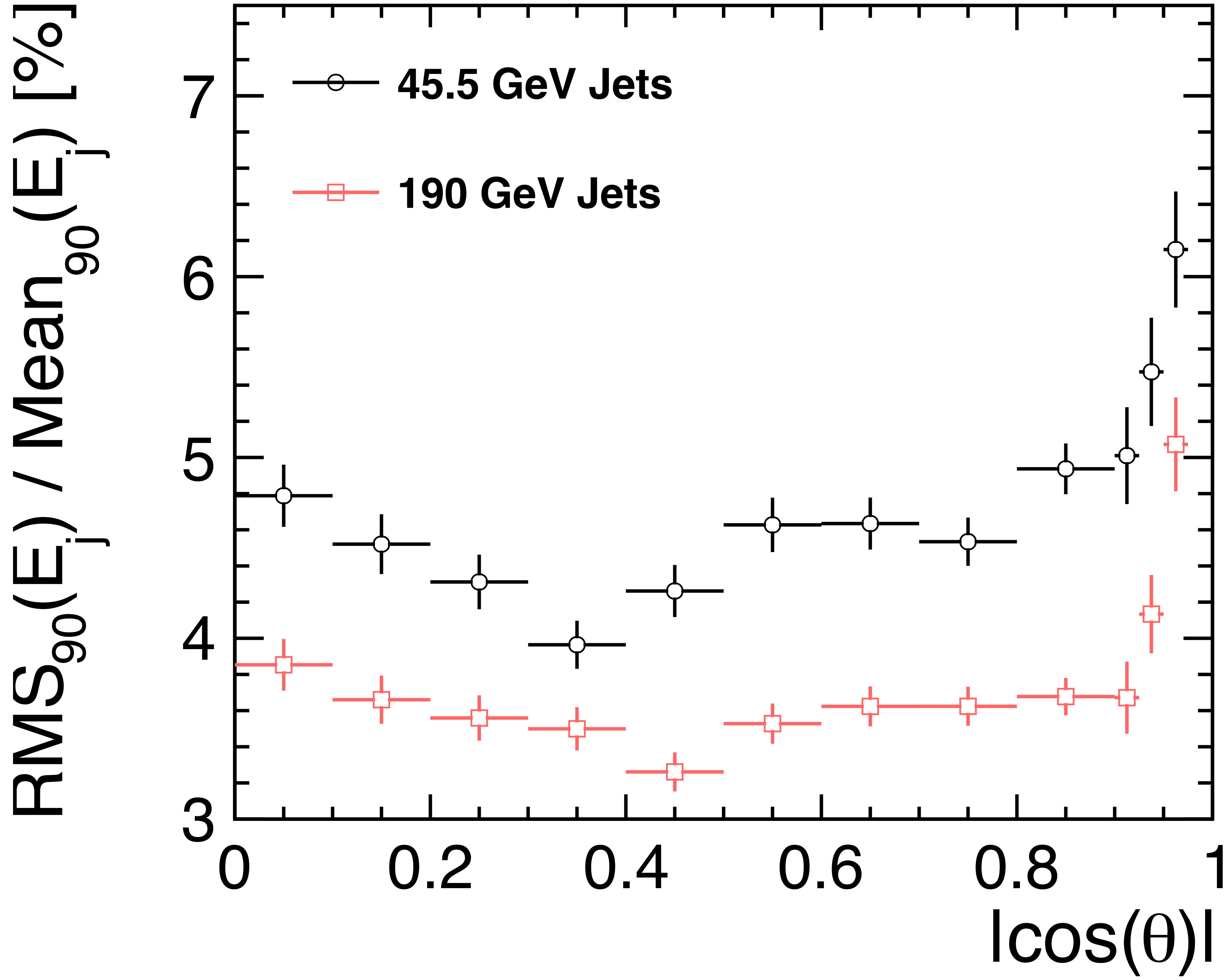
Cuts for both plots:
- $60 < \theta < 120$ deg

☆ Achieved energy resolution of 1.7% for 100GeV photons and 7.3% for 100GeV neutral kaons

Jet energy resolution

- Resolution per single jet (_j) = $\frac{RMS_{90}(E_j)}{mean_{90}(E_j)} = \frac{RMS_{90}(E_{jj})}{mean_{90}(E_{jj})}\sqrt{2}$ ⟶ (no jet reconstruction at this stage)

- Statistics used: 10k Zuds events



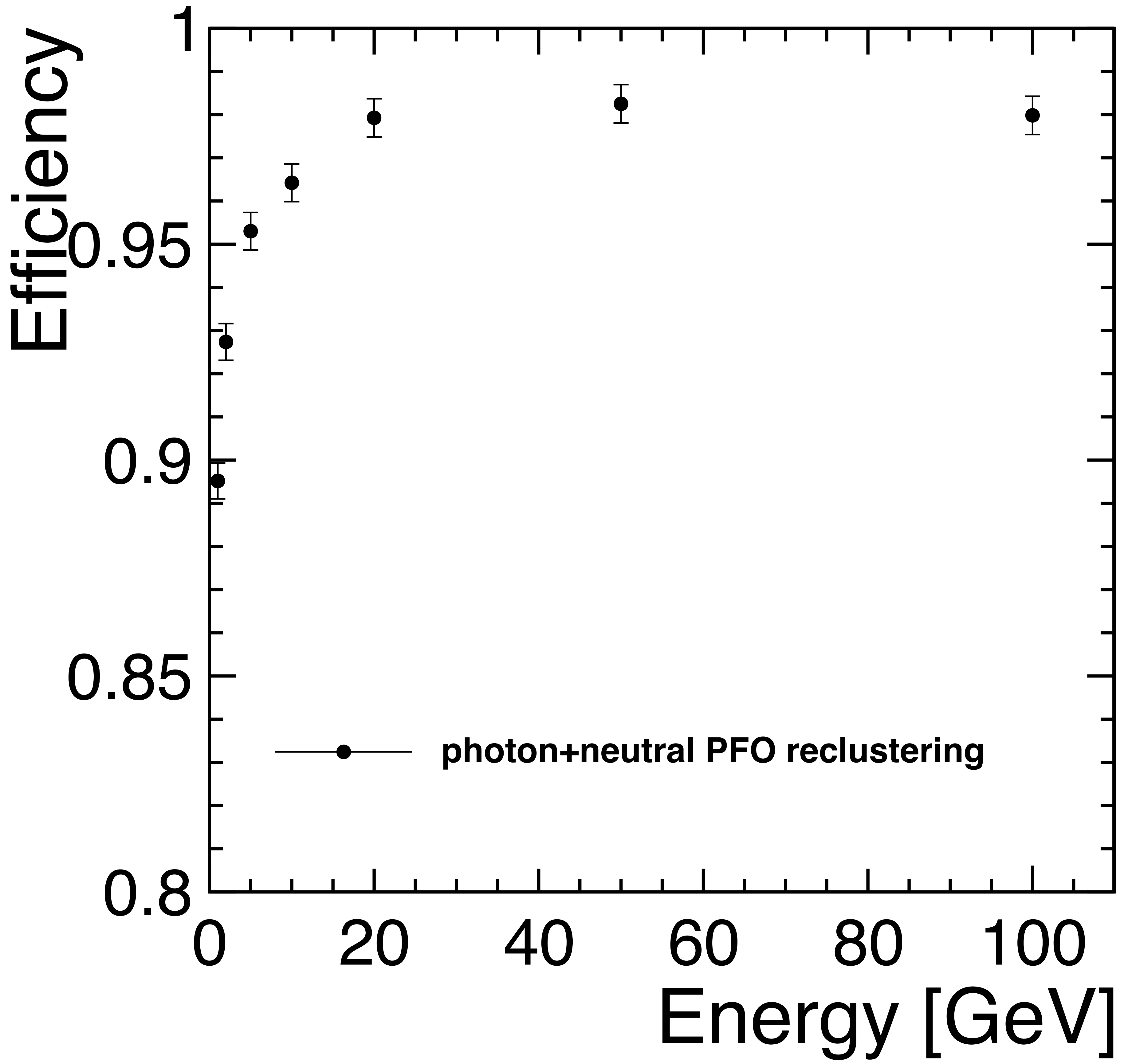
- Jet energy resolution varies within less than 1% in the whole acceptance, except the very forward region. But this is expected due to the angular coverage
- Achieved jet energy resolution 4-5% for 45.5GeV jets and 3-4% for 190GeV jets for |cosθ|< 0.95

Single particle PID efficiency: photons

- Statistics used: 100k events for each datapoint
  - particle guns with fixed energy and flat cosθ distribution

☆ Reconstructed PFO is efficient if:
- reconstructed PFO and true particle of the same type
- angular matching: $\Delta\theta < 0.01$rad and $\Delta\varphi < 0.02$rad
  - values driven by calorimeter angular resolution
- energy matching: 0.75 * sqrt(E) = 5 * σ(ECal)

PROBLEM: if >=2 neutral reconstructed PFOs per true particle
- no angular matching
- RECLUSTERING: sum of all the energies of PFOs in a cone:
  - if neutral PFOs are photons:
    $\Delta\theta < 0.01$rad and $\Delta\varphi < 0.2$rad
    (defined by looking at events where γ convert)
  - else for non-photons:
    $\Delta\theta < 0.035$rad and $\Delta\varphi < 0.2$rad
    (needed to recover inefficiency due to calorimeter transition region)

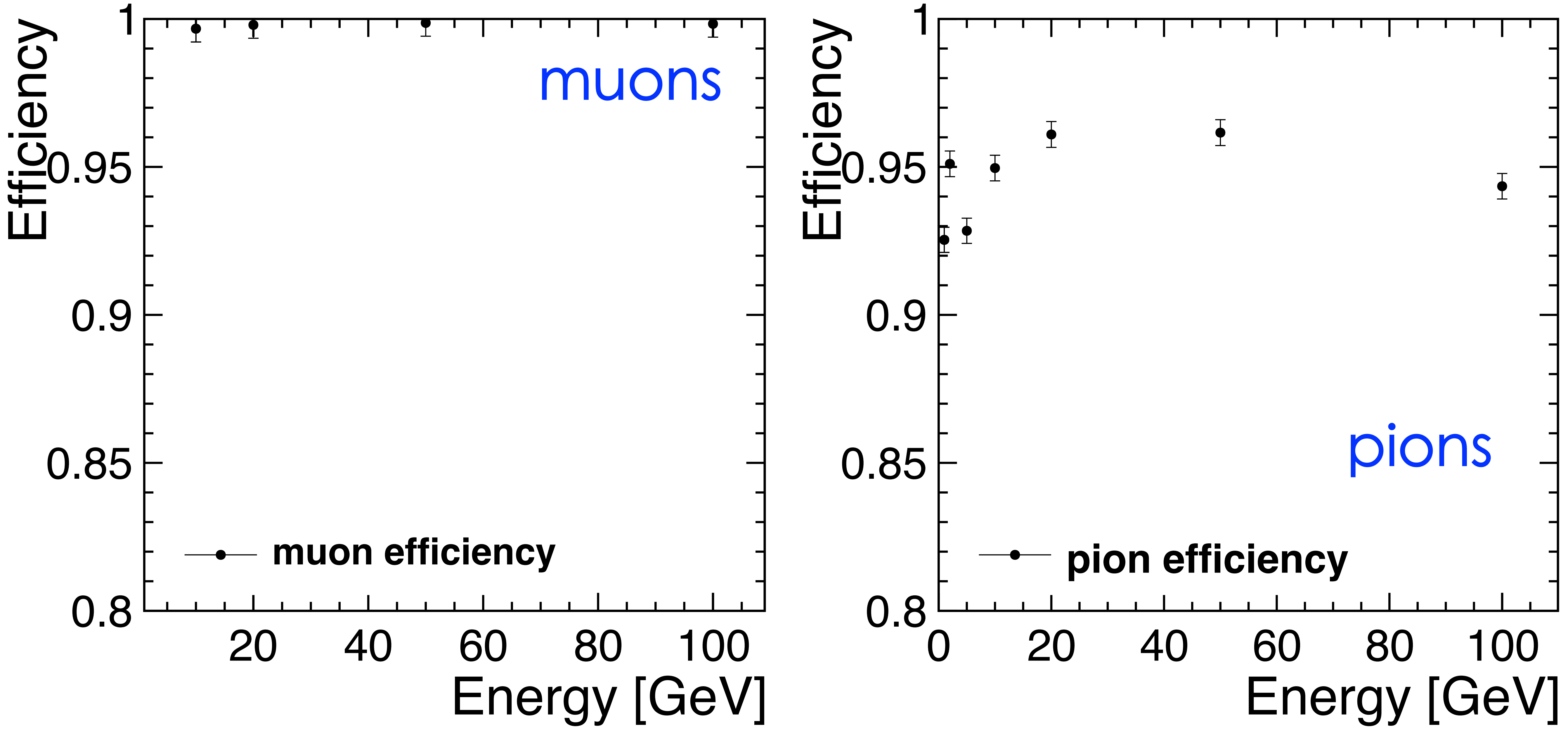


☆ Achieved photon PID efficiency of 98% for energies above 20GeV

Single particle PID efficiency: charged particles

- Statistics used: 100k events for each datapoint
  - particle guns with fixed energy and flat cosθ distribution

- Reconstructed PFO is efficient if:
  - reconstructed PFO and true particle of the same type
  - angular matching: $\Delta\theta < 0.01$rad and $\Delta\varphi < 0.02$rad
    - values driven by calorimeter angular resolution
  - energy matching: |pT_truth - pT_PFO| < 5% pT_truth



- Achieved 100% muon PID efficiency for all energies, 95% pion above 20GeV

- Studies on electron PID efficiency on going (more complicated due to Bremsstrahlung)

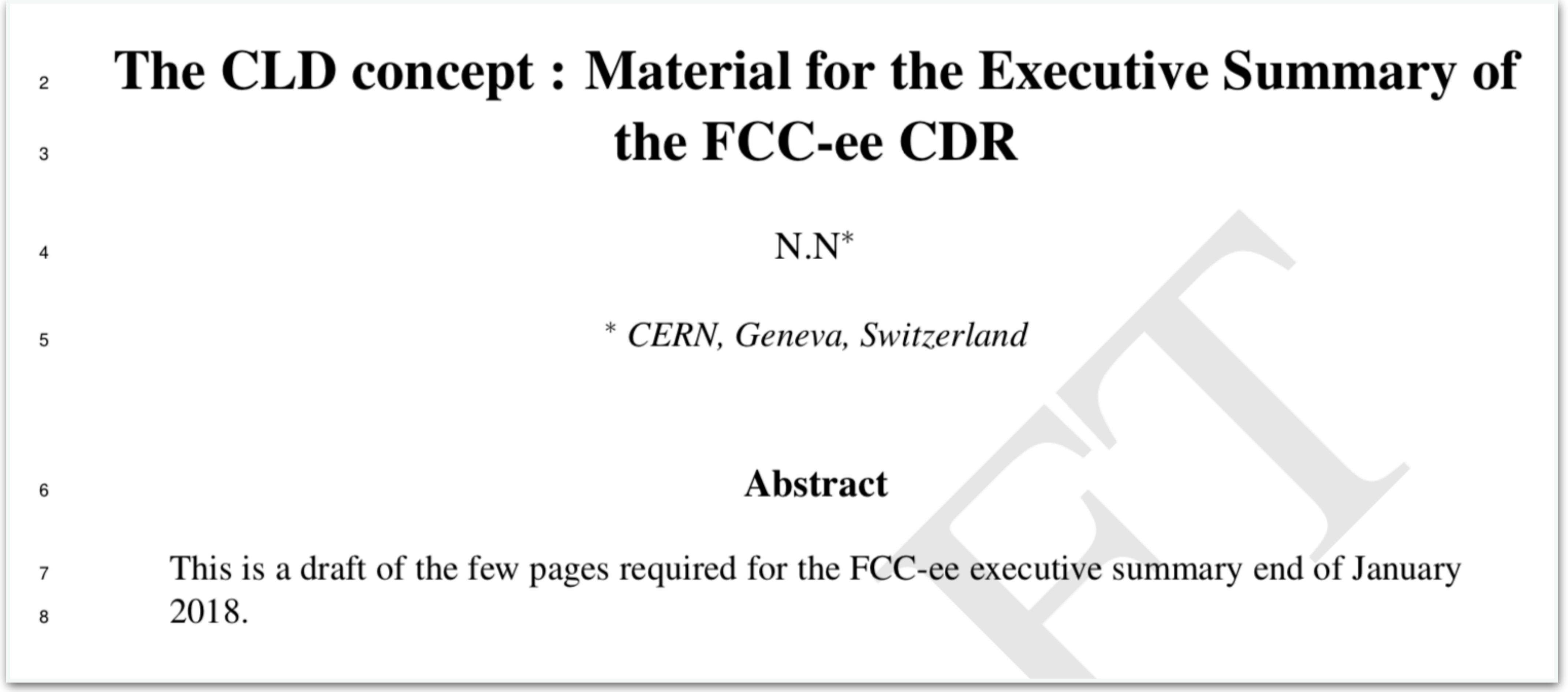
Summary

The CLD design is finalized for the CDR

- ☆ Overall dimensions settled
- ☆ Requirements from the MDI fulfilled
- ☆ What is missing: detailed engineering studies for the impact of the cooling systems (no power pulsing)

Detector performances obtained in full simulation

- ☆ Tracking resolution
  - ✦ impact parameter, angles, momentum
- ☆ Tracking efficiency
  - ✦ single particles and complex events
  - ✦ what is missing: overlay of e^+e^- background and synchrotron radiation photons
- ☆ Energy resolution
  - ✦ single particles and jets
- ☆ PID efficiency
  - ✦ photons
  - ✦ charged particles



The CLD concept : Material for the Executive Summary of the FCC-ee CDR

N.N*

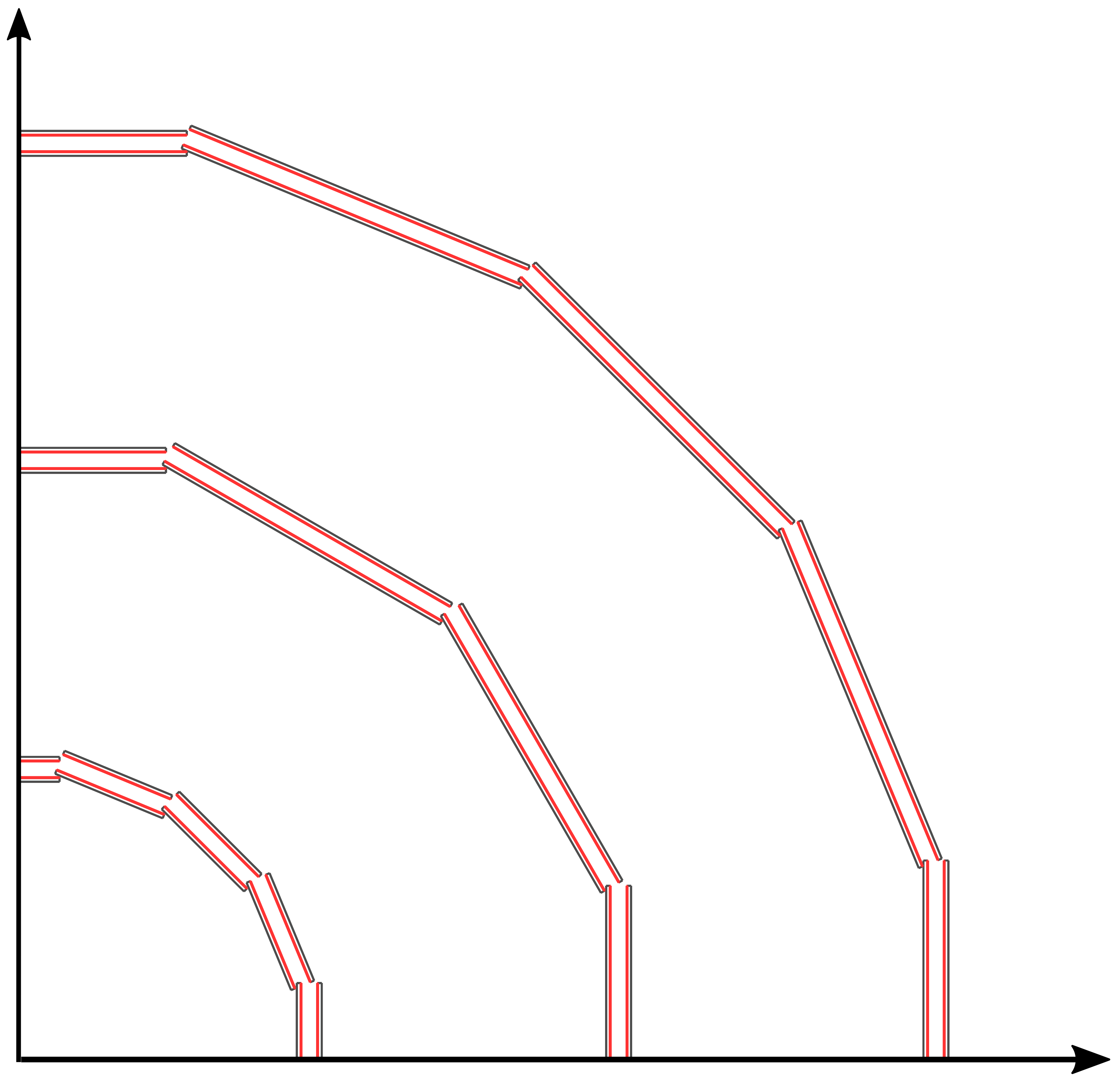
* *CERN, Geneva, Switzerland*

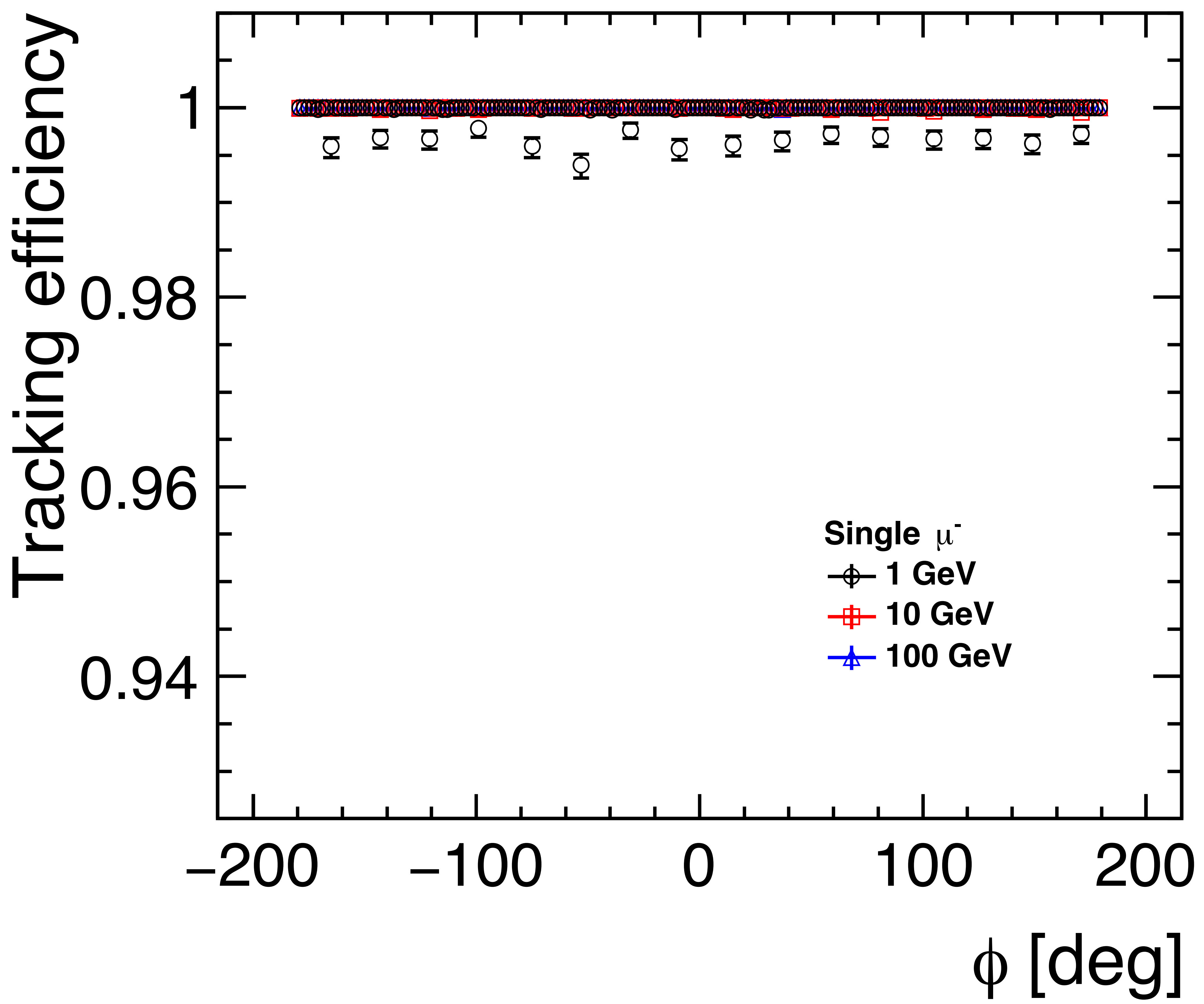
Abstract

This is a draft of the few pages required for the FCC-ee executive summary end of January 2018.

BACKUP SLIDES

Single muon efficiency vs φ





Single particle PID efficiency: charged particles