Detector optimization and reconstruction

Emilia Leogrande (CERN),
on behalf of the CLICdp Collaboration

BSM direct searches Meeting
21/02/2018

Introduction

CDR studies [arXiv:1202.5940] were based on two detector concepts derived from ILC

- CLIC_ILD (featuring a TPC)
- CLIC_SiD (all-Silicon tracking system)

Further optimization studies led to a new single model, suited for high-energy collisions: CLICdet

The talk is divided in the following sessions:

1. DETECTOR DESIGN
2. OBJECT RECONSTRUCTION
3. DETECTOR PERFORMANCES
4. THE CLICdet AS A DELPHES CARD

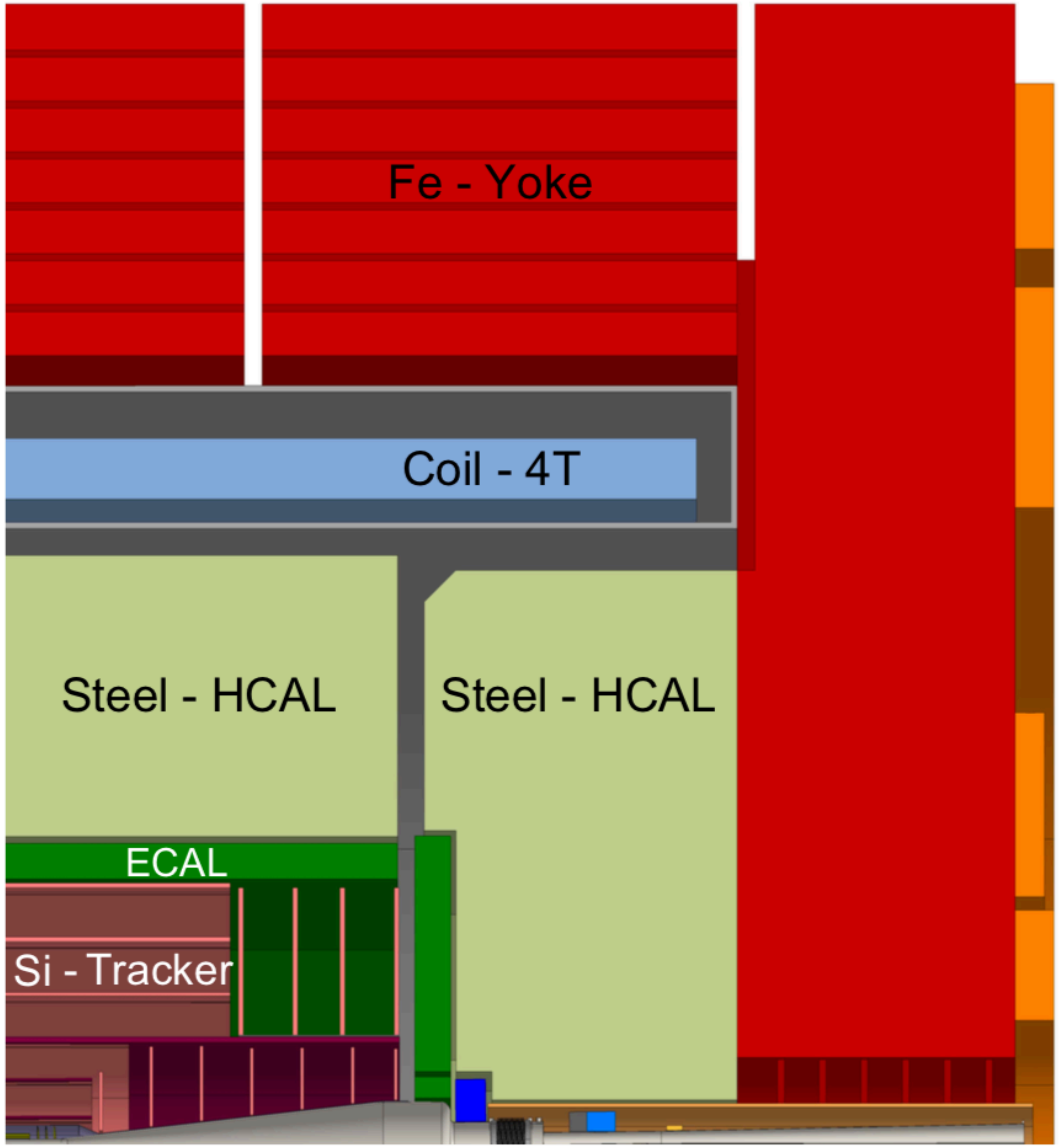
CLICdet design is optimized for the 3TeV environment

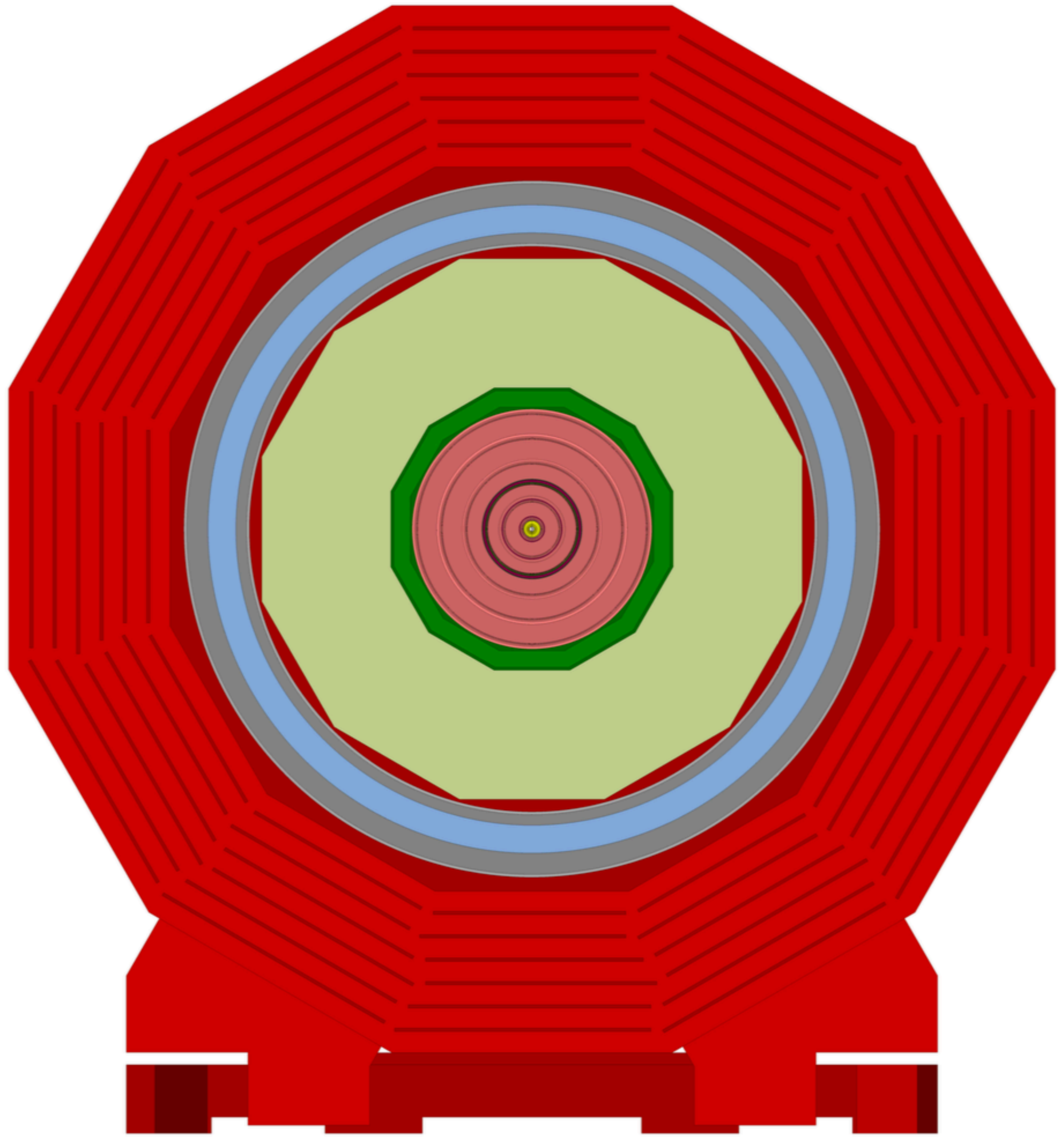
- Crossing angle = 20 mrad
- Magnetic field = 4 T

The CLICdet model features the following components

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

Detector layout and main parameters

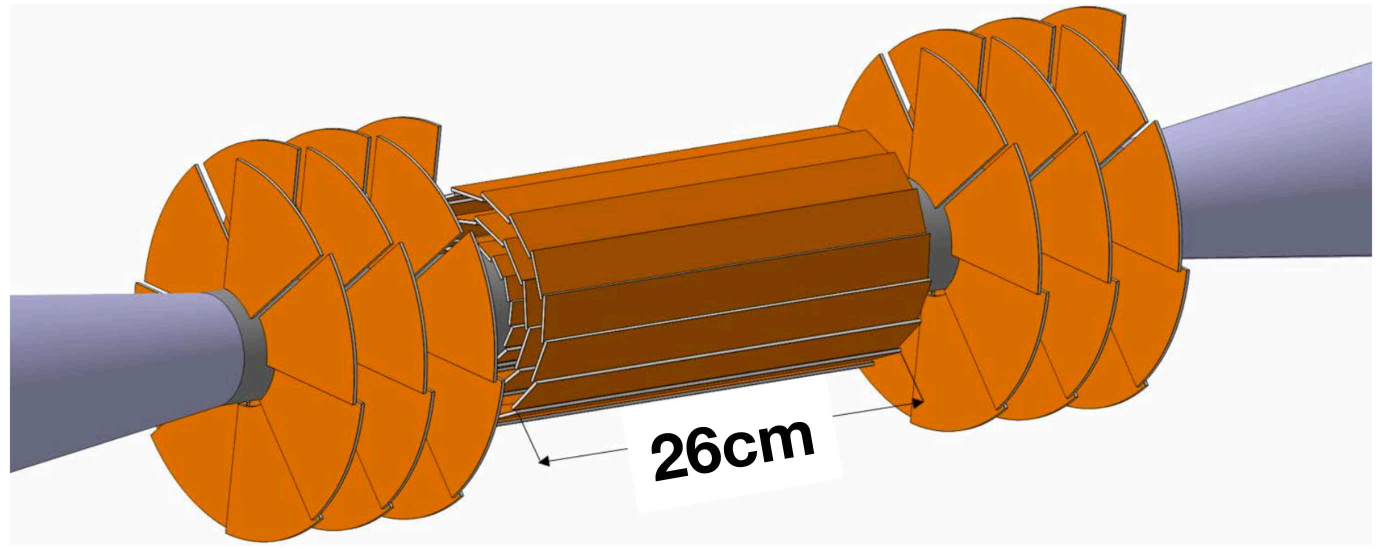




Concept	CLICdet
Vertex inner radius [mm]	31
Tracker technology	Silicon
Tracker half length [m]	2.2
Tracker outer radius [m]	1.5
ECAL absorber	W
ECAL X_0	22
ECAL barrel r_{min} [m]	1.5
ECAL barrel Δr [mm]	202
ECAL endcap z_{min} [m]	2.31
ECAL endcap Δz [mm]	202
HCAL absorber barrel / endcap	Fe / Fe
HCAL λ_{I}	7.5
HCAL barrel r_{min} [m]	1.74
HCAL barrel Δr [mm]	1590
HCAL endcap z_{min} [m]	2.45
HCAL endcap Δz [mm]	1590
Solenoid field [T]	4
Solenoid bore radius [m]	3.5
Solenoid length [m]	8.3
Overall height [m]	12.9
Overall length [m]	11.4
Overall weight [t]	8100

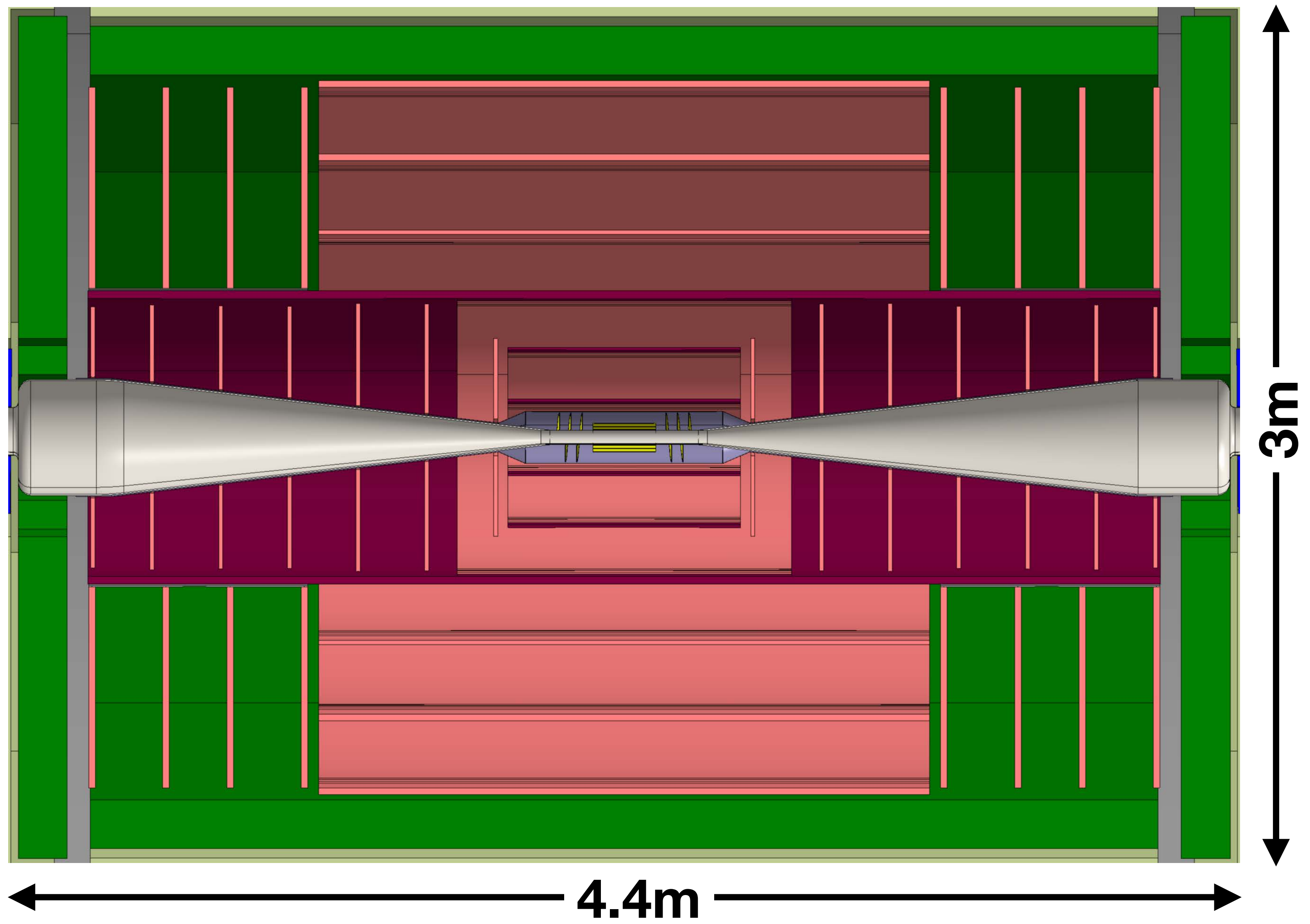
Vertex detector

- Silicon pixels 25x25 μm²
- single point resolution = 3 μm
- 3 barrel double layers
- 3 sets of double spirals
- material budget: 0.2%X0 per layer

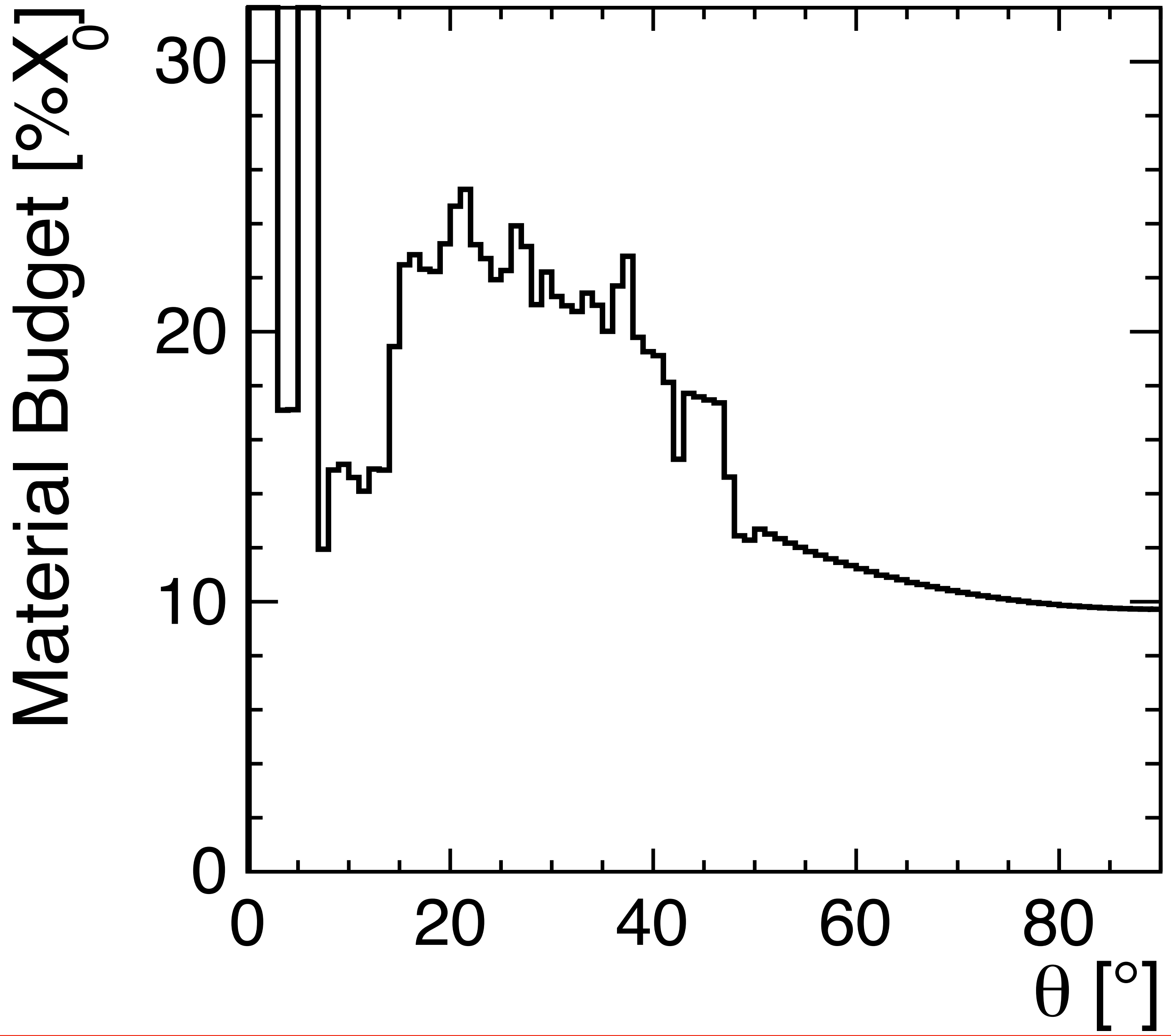


Tracker detector

- Silicon pixels and microstrips
- inner tracker
  - 3 barrel layers, 7 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:
  - detector: ~1%X_0 per layer
  - support&cables: ~2.5%X_0

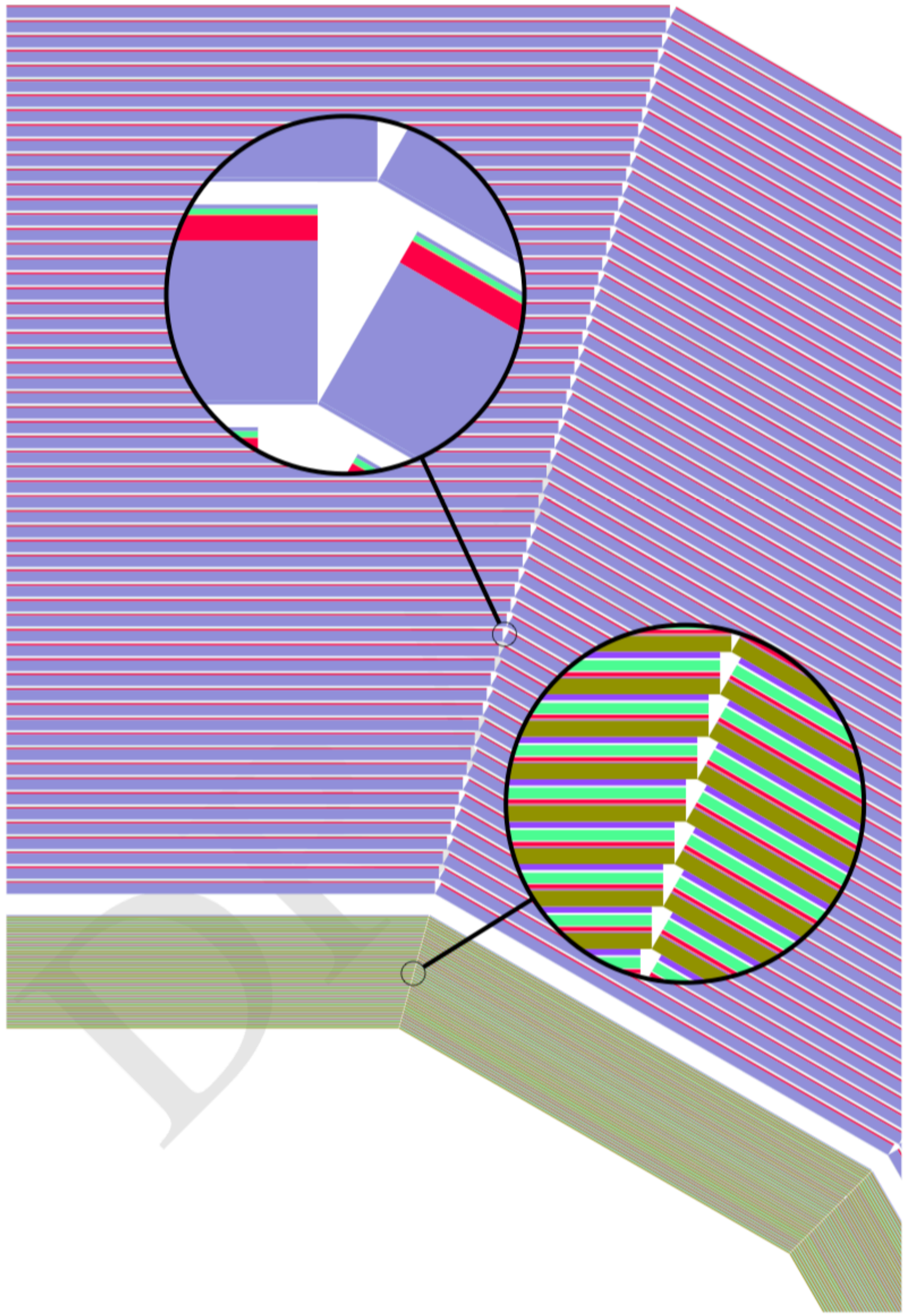


Total material budget [vertex+tracker]



The ECal and HCal

Particle flow calorimetry requires high-granularity calorimeters



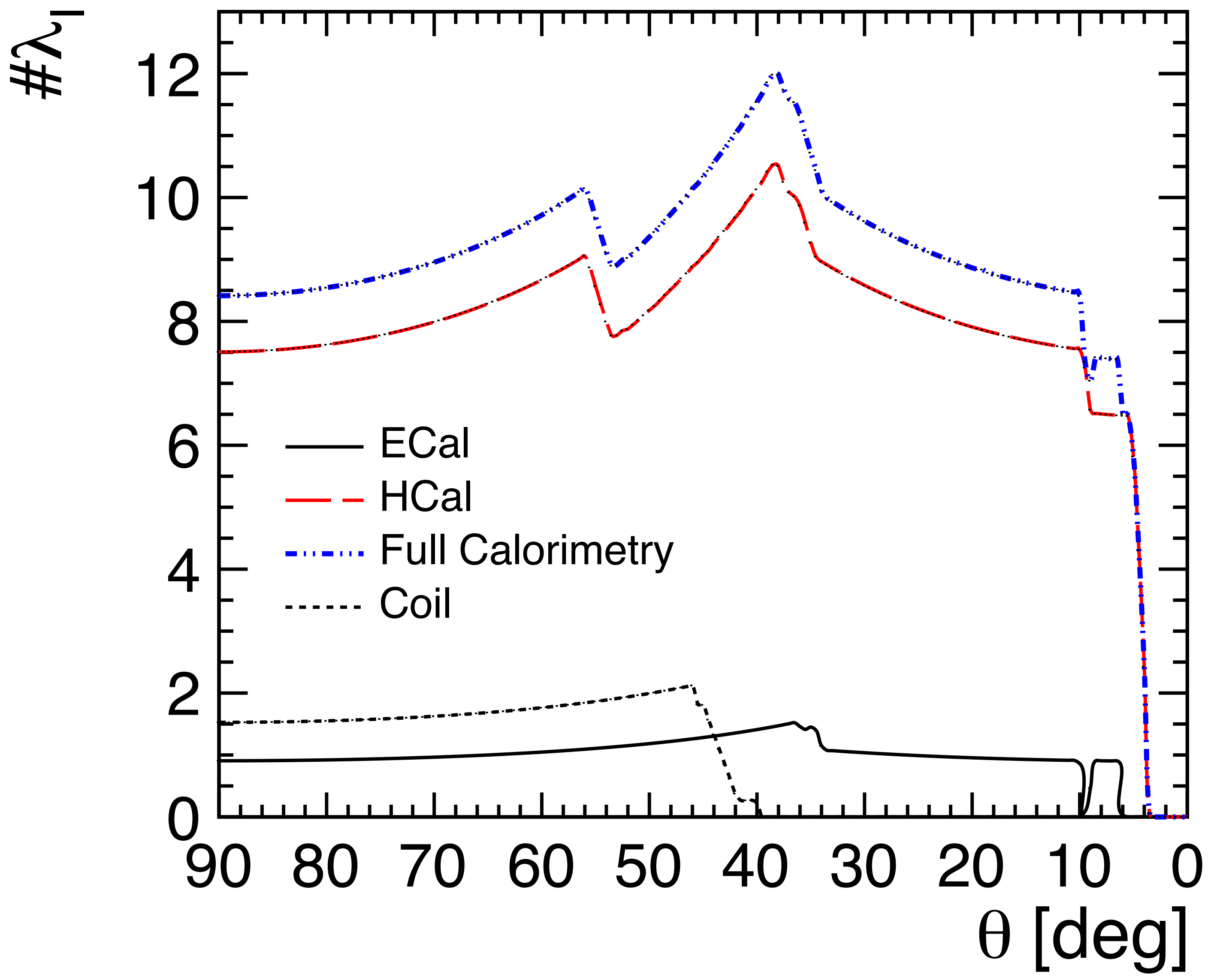
ECal

- 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
- 60 layers (19mm thick steel plates)
- $7.5\lambda_I$

Total thickness [ECal+HCal]



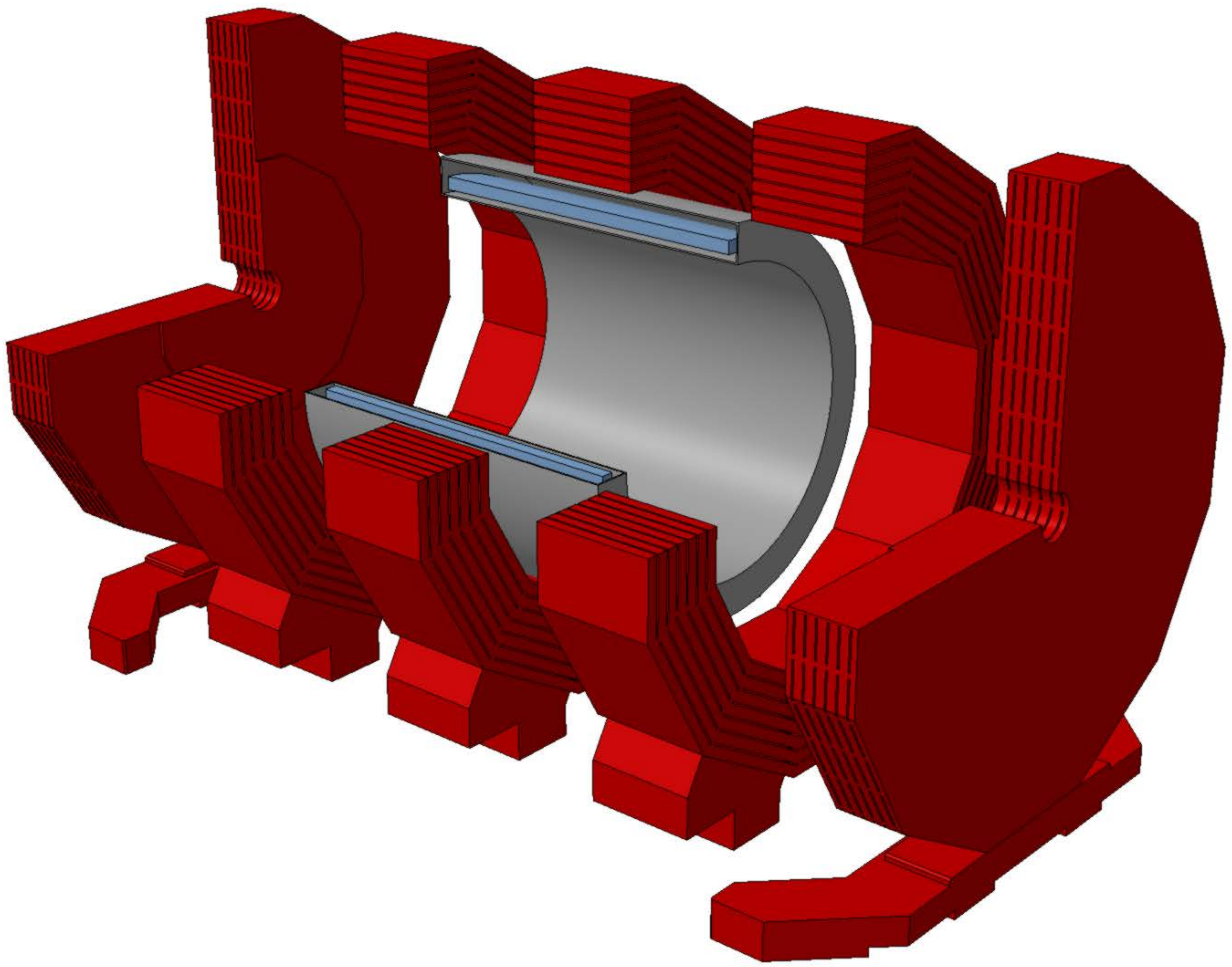
The magnet and muon system

The magnet system

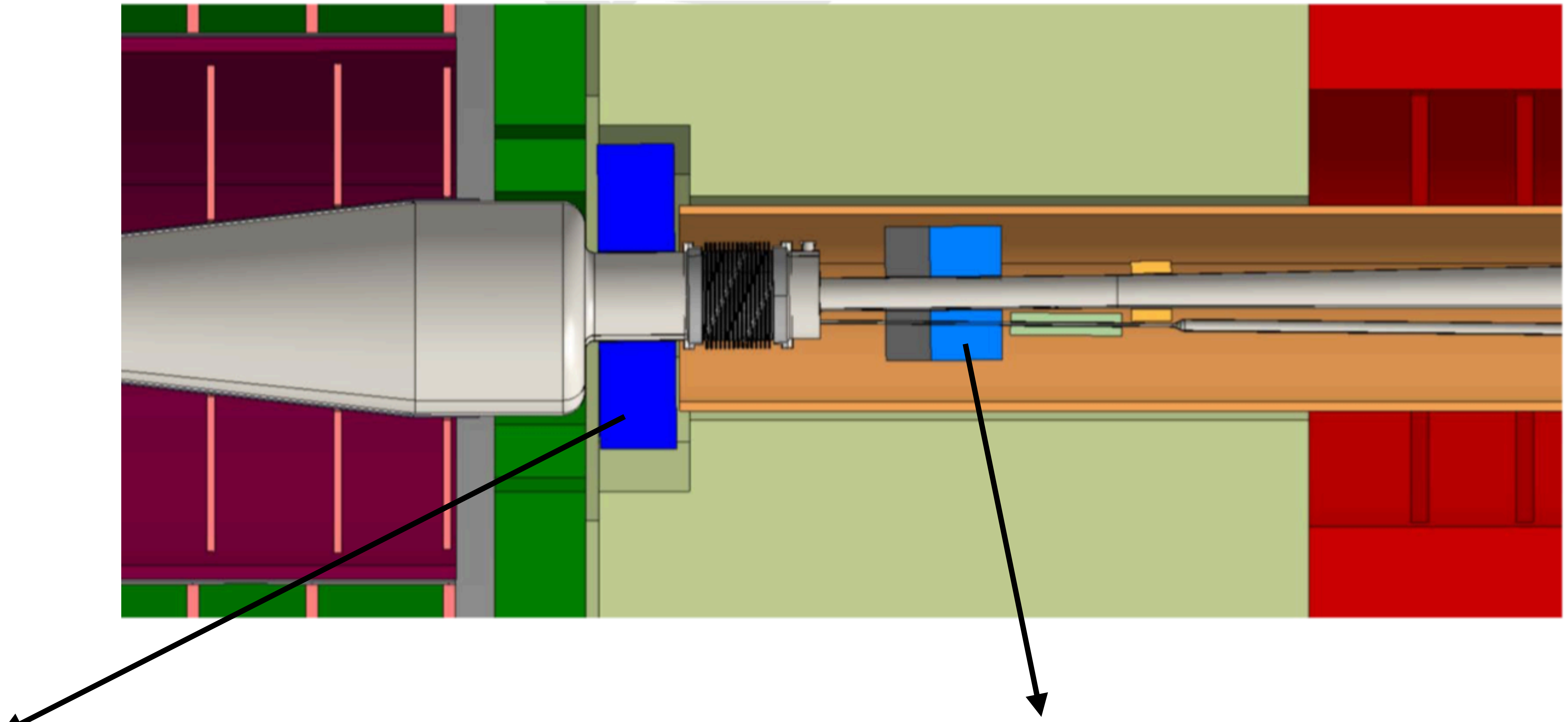
- ☆ superconducting coil
  - ✦ 4T field
- ☆ return yoke
  - ✦ barrel: 1.5T field
  - ✦ endcap: no field

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



FCal: LumiCal and BeamCal

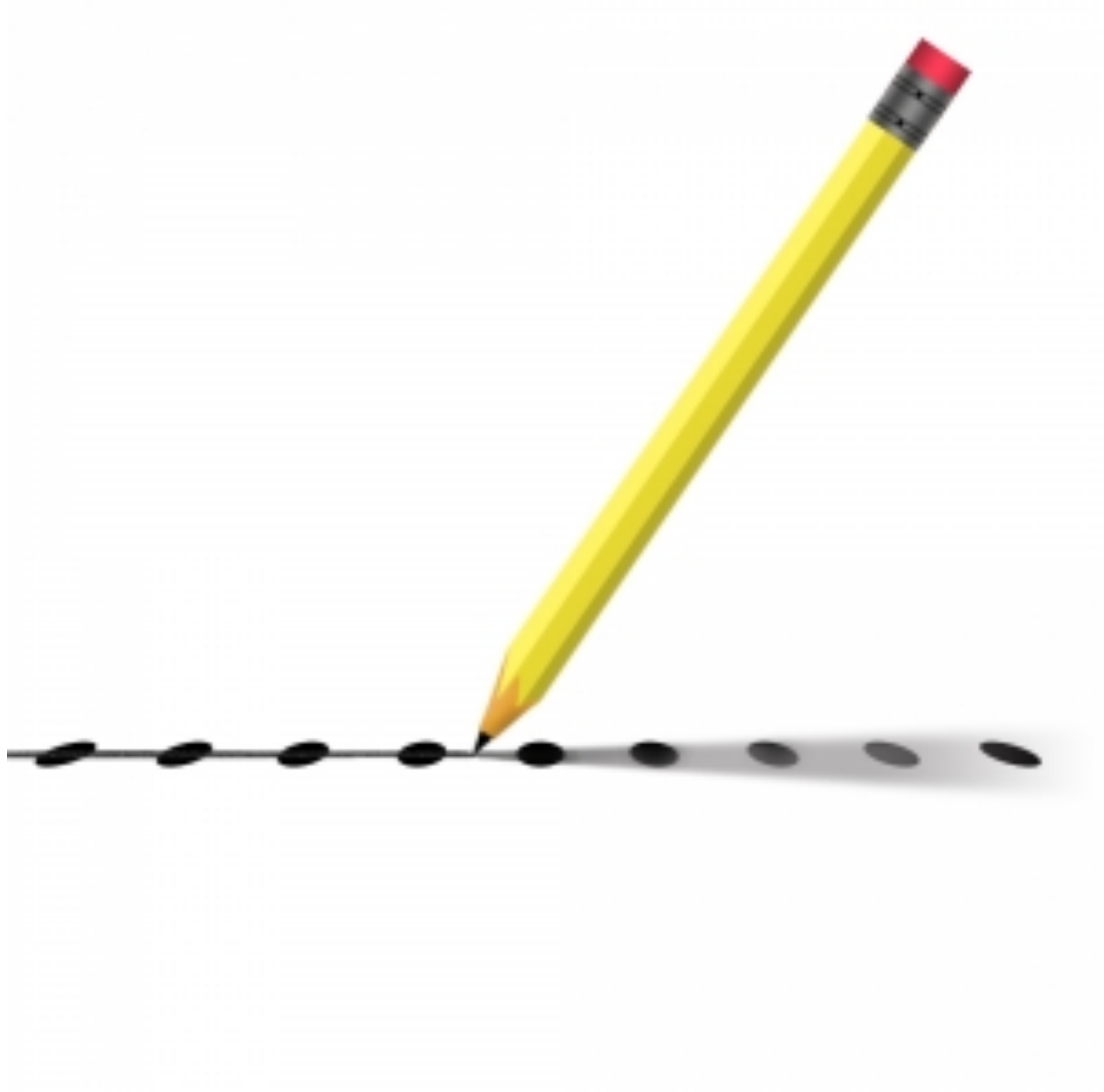


LumiCal

- Si-W calorimeter
- 40 layers (3.5mm thick W plates)
- transverse segmentation
  - 64 radial
  - 48 azimuthal
- θ coverage: (39,134)mrad

BeamCal

- Diamond-W calorimeter
- 40 layers (3.5mm thick W plates)
- cell size 8x8 mm^2
- θ coverage: (10,46)mrad
- 100mm thick graphite layer on the side facing the IP



Tracks

- Conformal mapping for pattern recognition

Calorimeter clusters

- Pandora Particle Flow Algorithm (PFA)

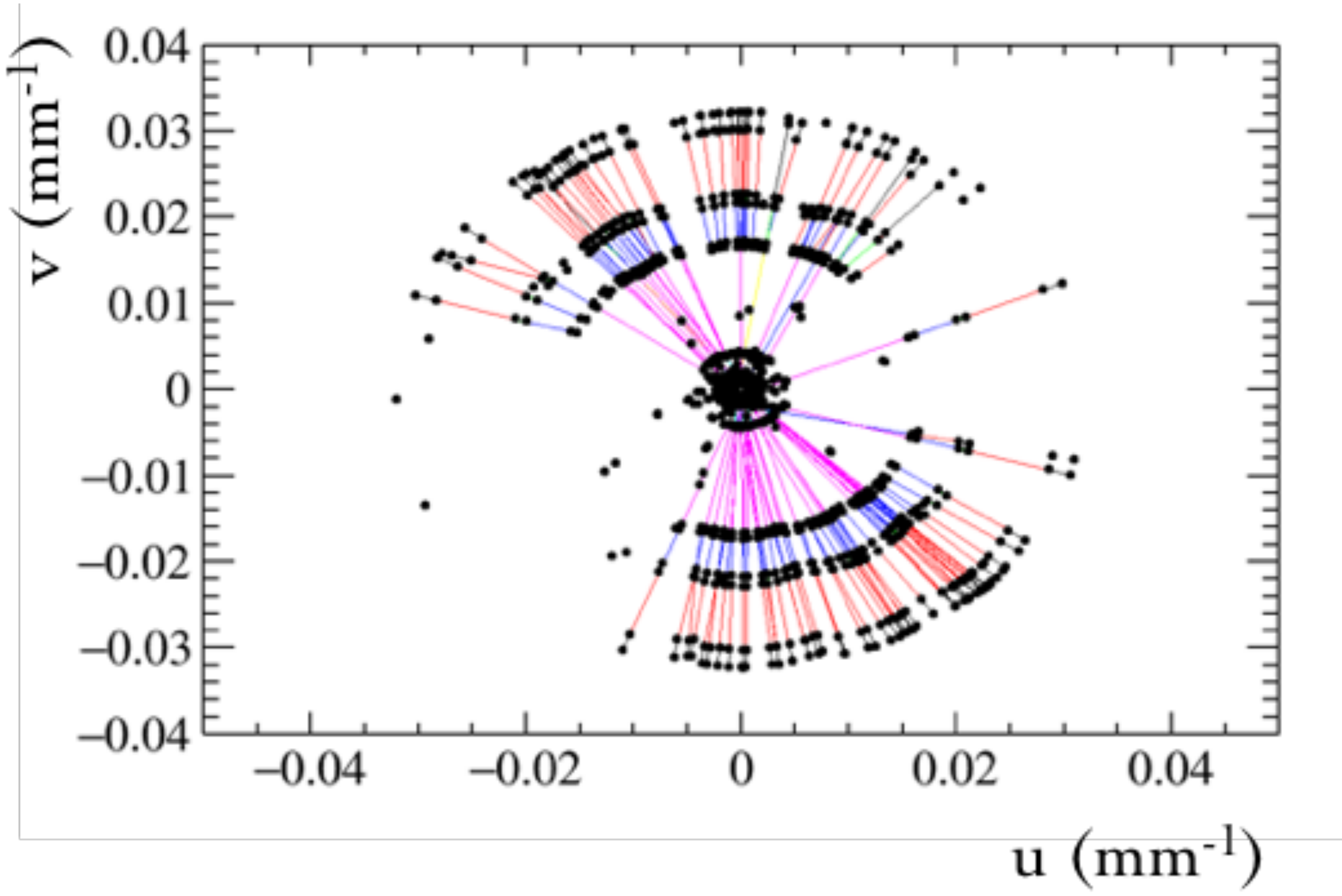
Flavour tagging

- Vertex finding + Jet Clustering Algorithm

Track reconstruction: conformal mapping

- Conformal mapping applies a geometry transform that maps circles in the x,y plane passing through the origin into straight lines in the u,v plane

$$u = \frac{x}{x^2 + y^2} \qquad v = \frac{y}{x^2 + y^2}$$

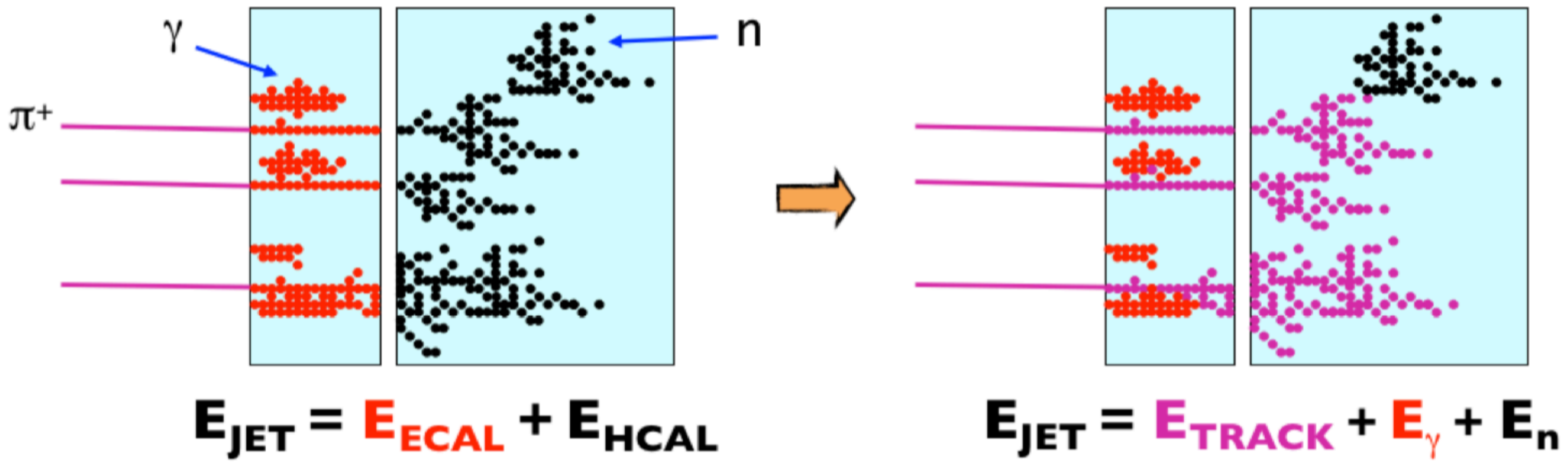


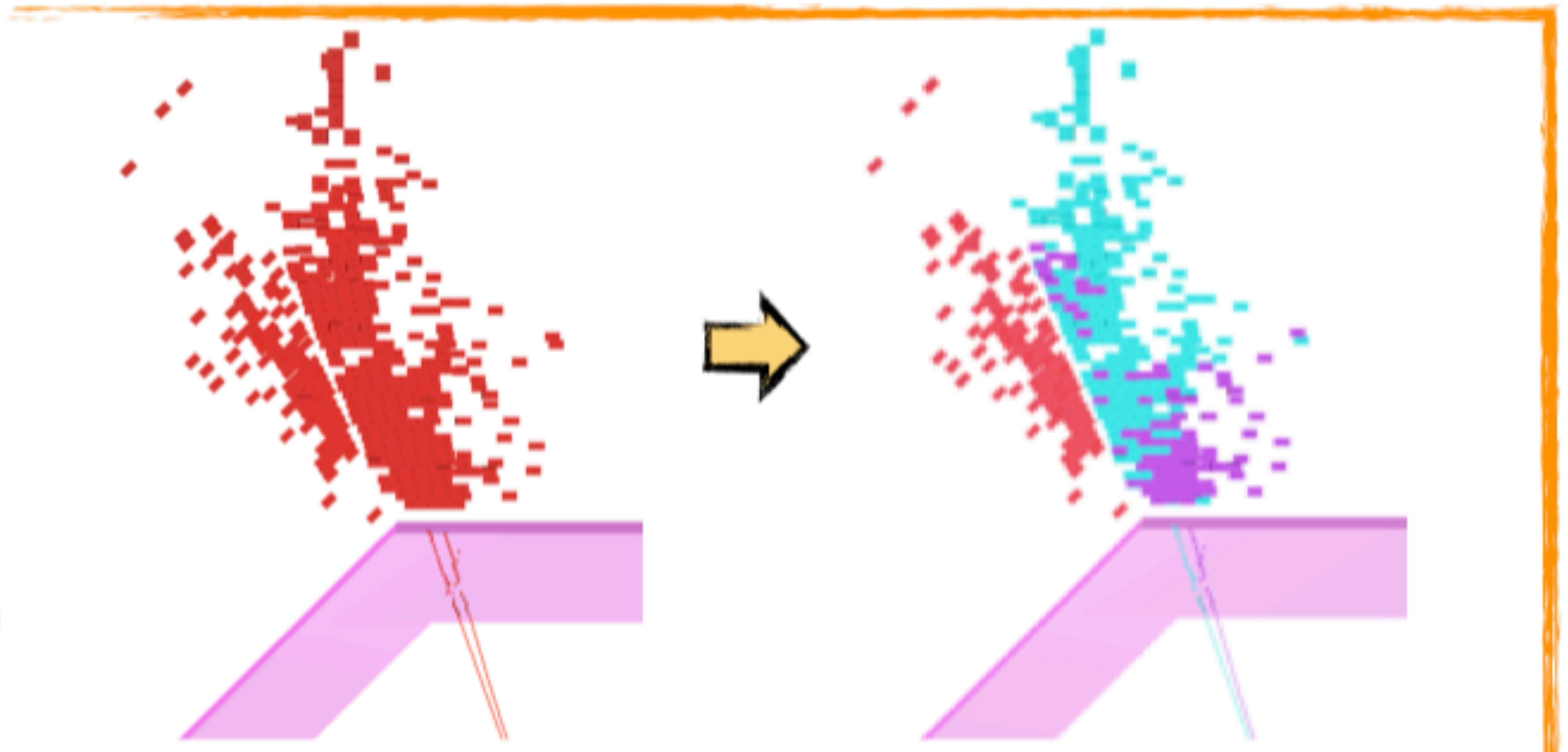
- Cellular automaton used to perform straight line search

Calorimeter clusters reconstruction: Pandora PFA

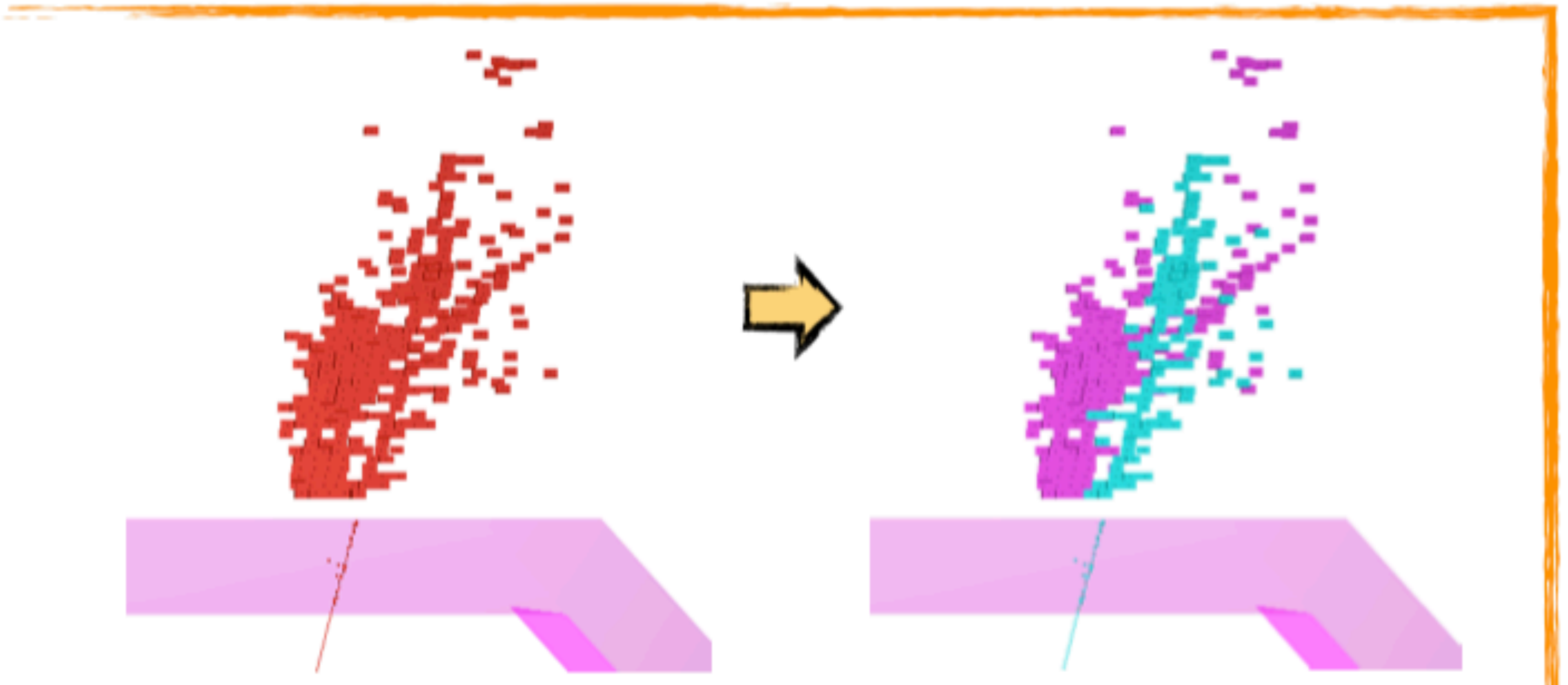
Typical jet composition: 62% charged hadrons, 27% photons, 10% long-lived neutral hadrons, 1% neutrinos

- The Pandora PFA is based on tracing the paths of individual particles through the detector
- The energy and momentum for each particle can then be extracted from the subdetector system in which we expect the measurement to be most accurate





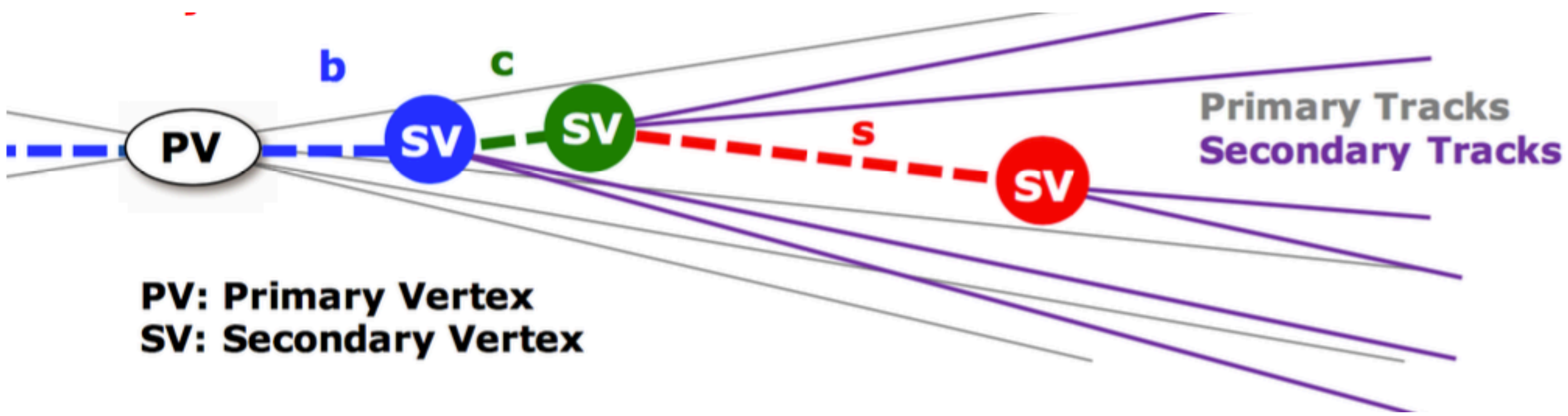
1. Multiple tracks associated to single cluster – split cluster.

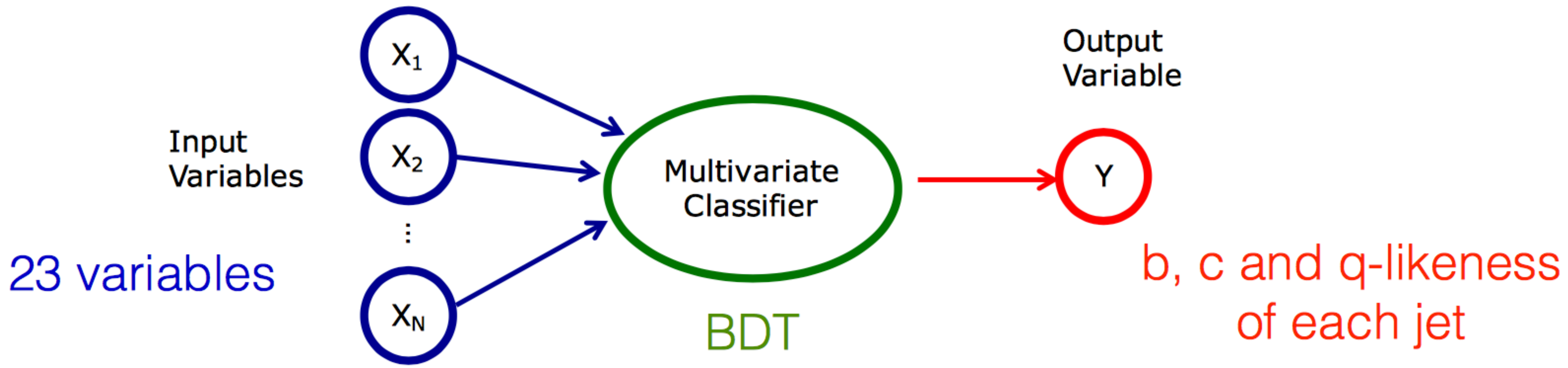


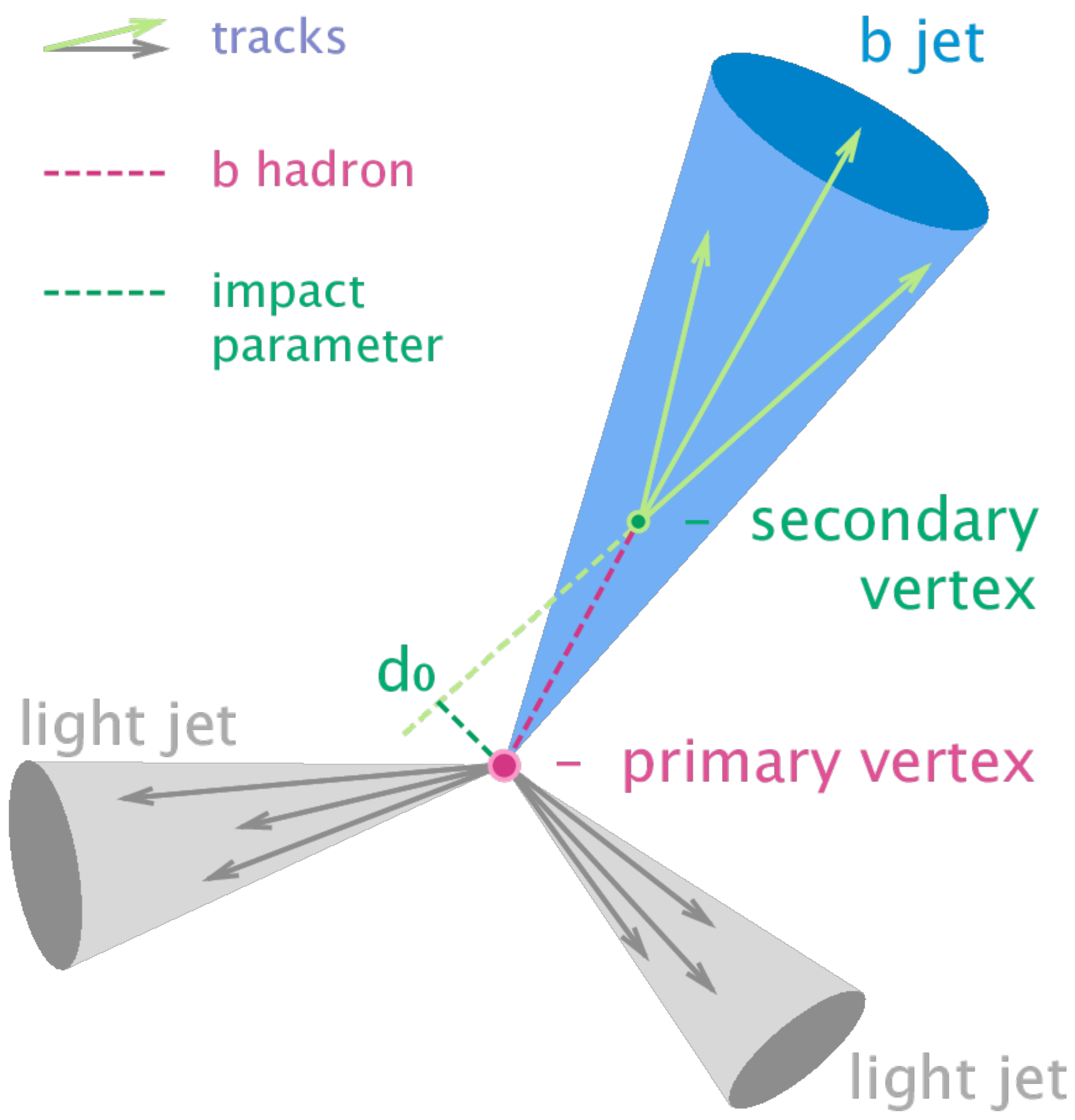
2. Cluster energy much greater than track momentum – split cluster.

Flavour tagging

- Vertex finder reconstructs primary and secondary vertices
- Jet clustering algorithm (Valencia) is applied
- Jets and vertices are fed into a BDT to get the flavourness of each jet



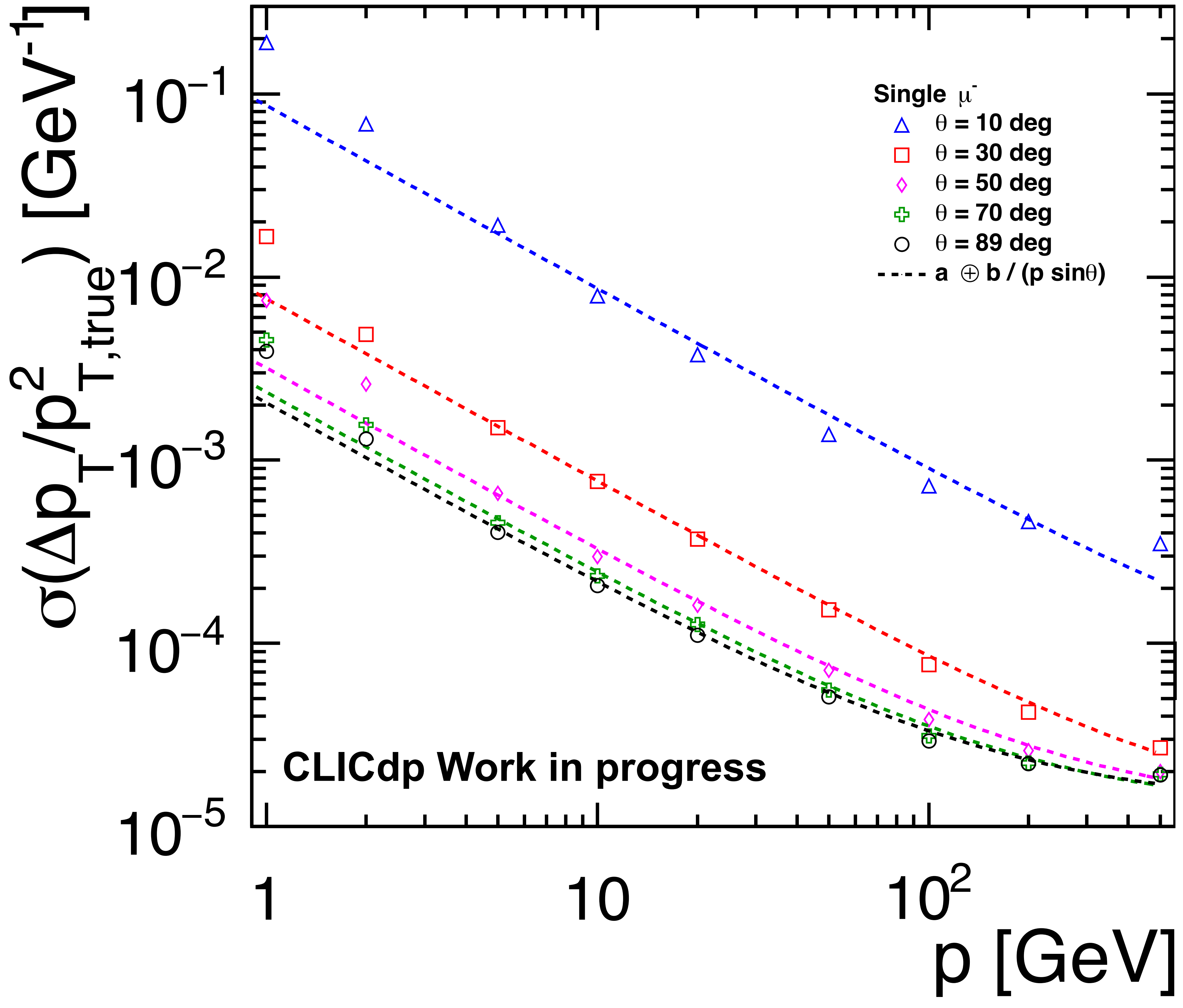


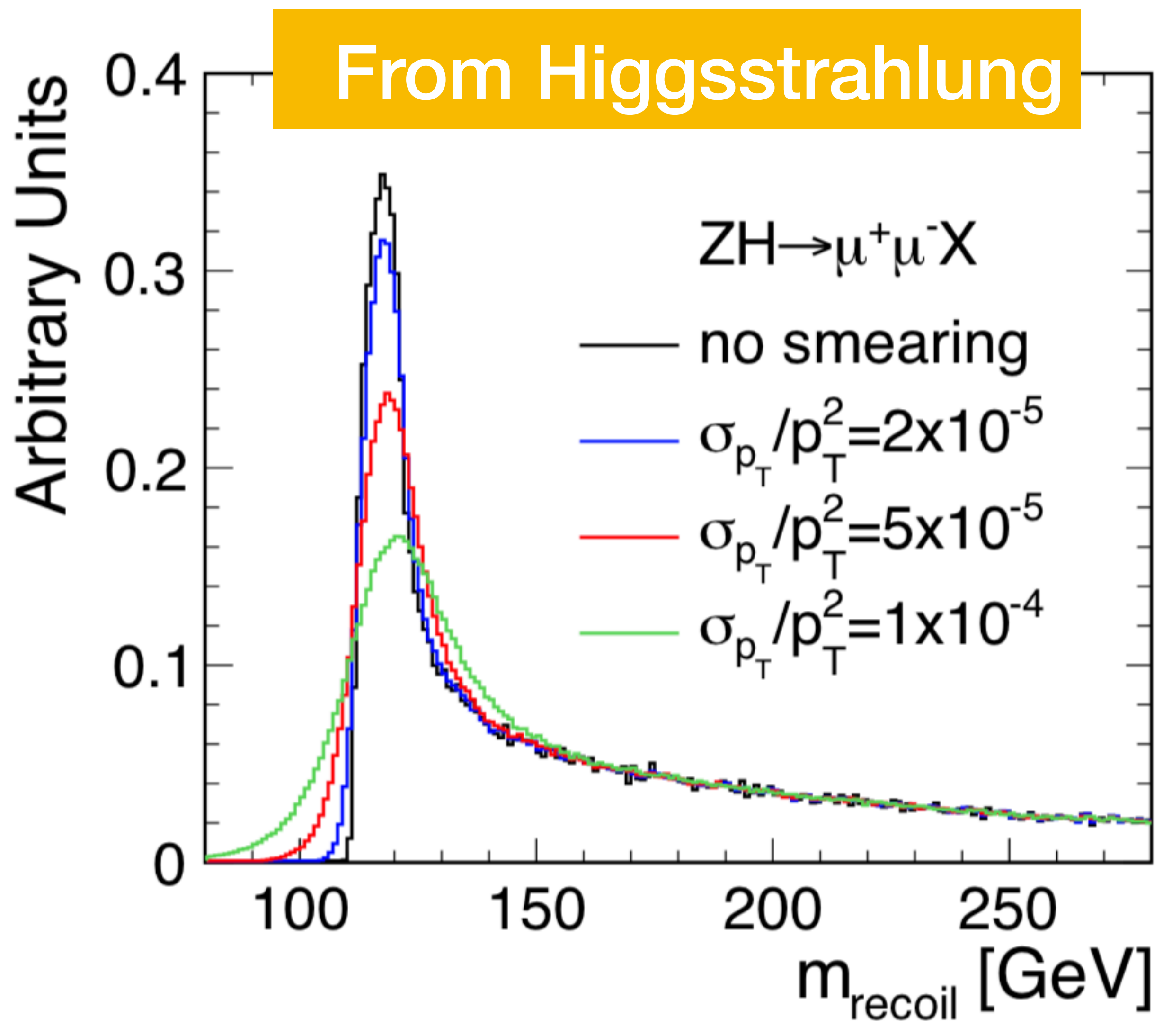


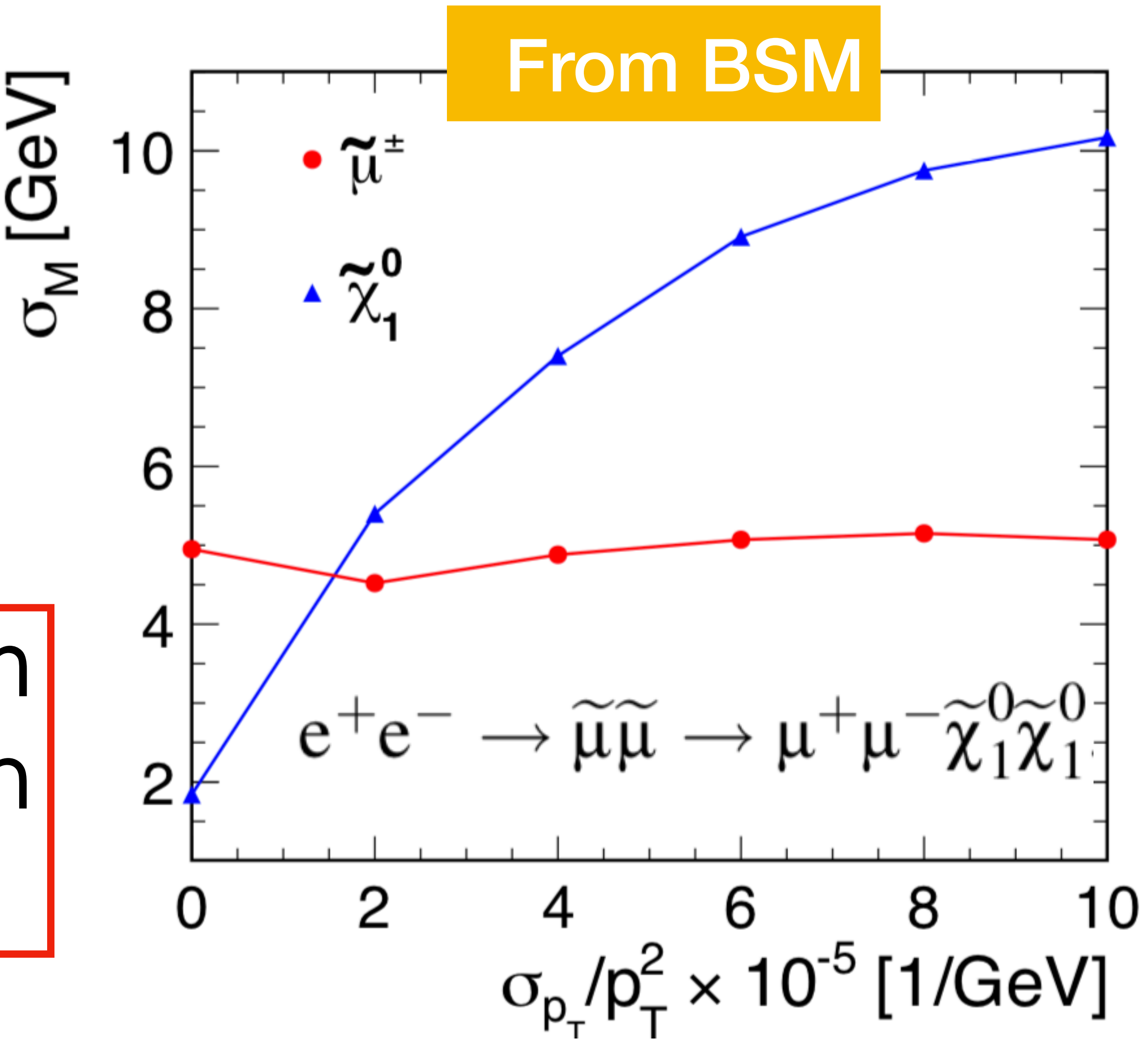
Detector performances are studied in full simulation with the iLCSoft (Linear Collider community software)

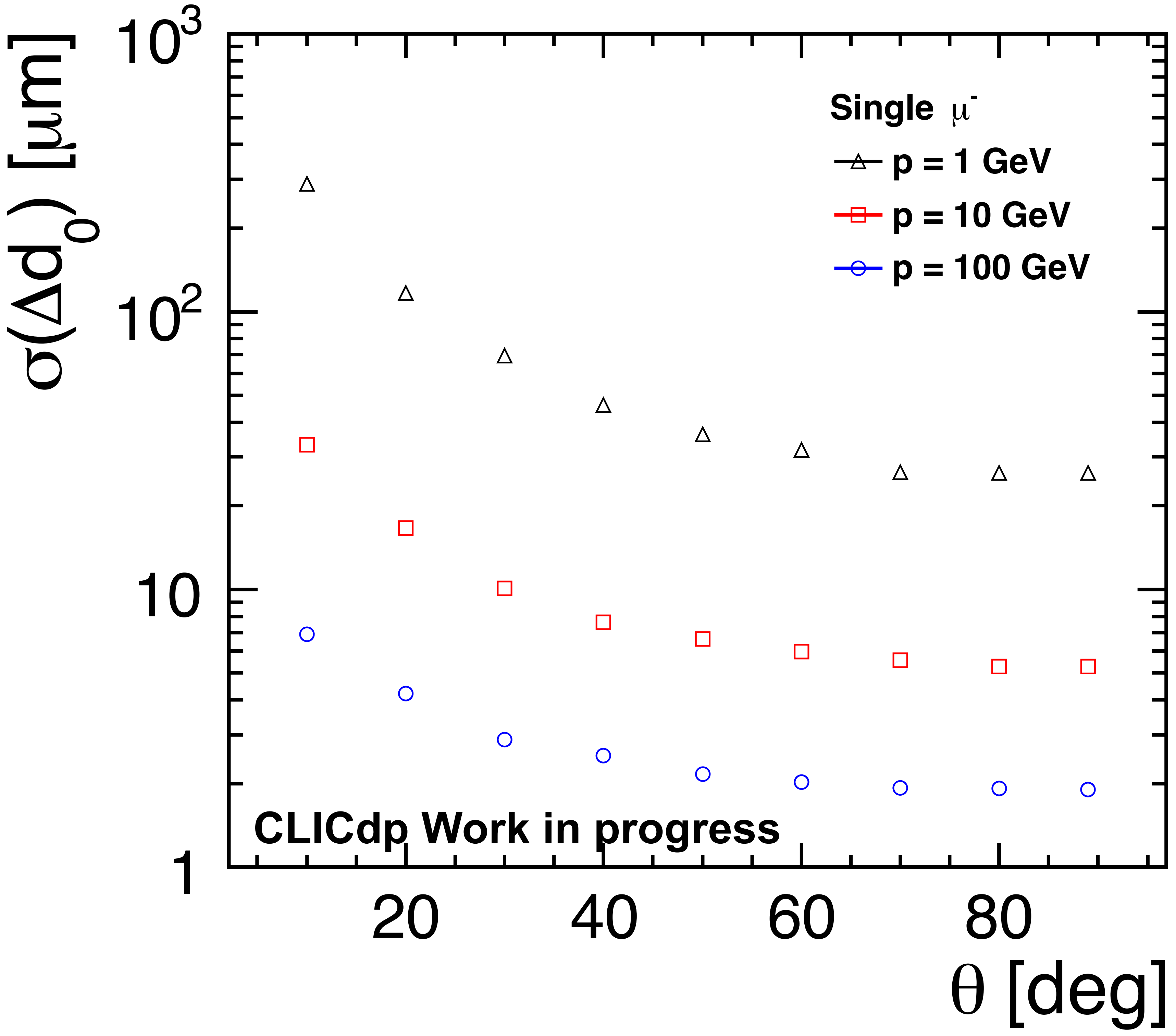
- Tracking performances
  - p_T and impact parameter resolution
  - single particle efficiency (prompt and displaced)
- PFO performances
  - jet energy resolution
  - W/Z mass separation
- Flavour tagging
  - misidentification efficiency for beauty
  - misidentification efficiency for charm
- Forward Calorimeter
  - LumiCal angular resolution
  - BeamCal reconstruction efficiency

Transverse momentum and impact parameter resolutions









- ☆ Achieved transverse momentum resolution 2×10^{-5} GeV^{-1} for high energy muons in the barrel

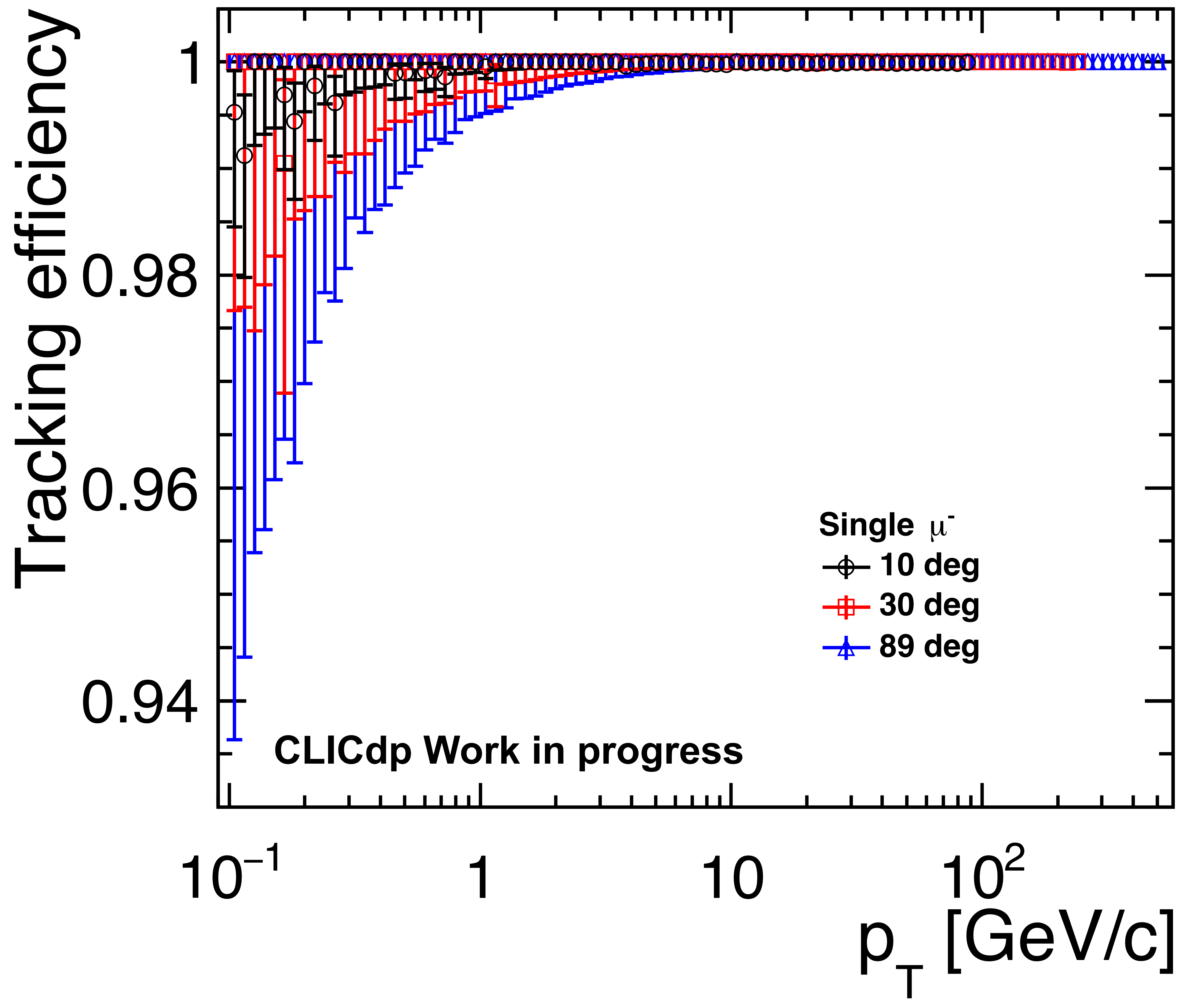
$$\sigma(d_0) = \sqrt{a^2 + b^2 \cdot \mathrm{GeV}^2/(p^2 \sin^3\theta)}$$

- ☆ Achieved d_0 resolution 2μm for high energy muons in the barrel
  - ✦ to identify heavy-flavor quark states and tau leptons

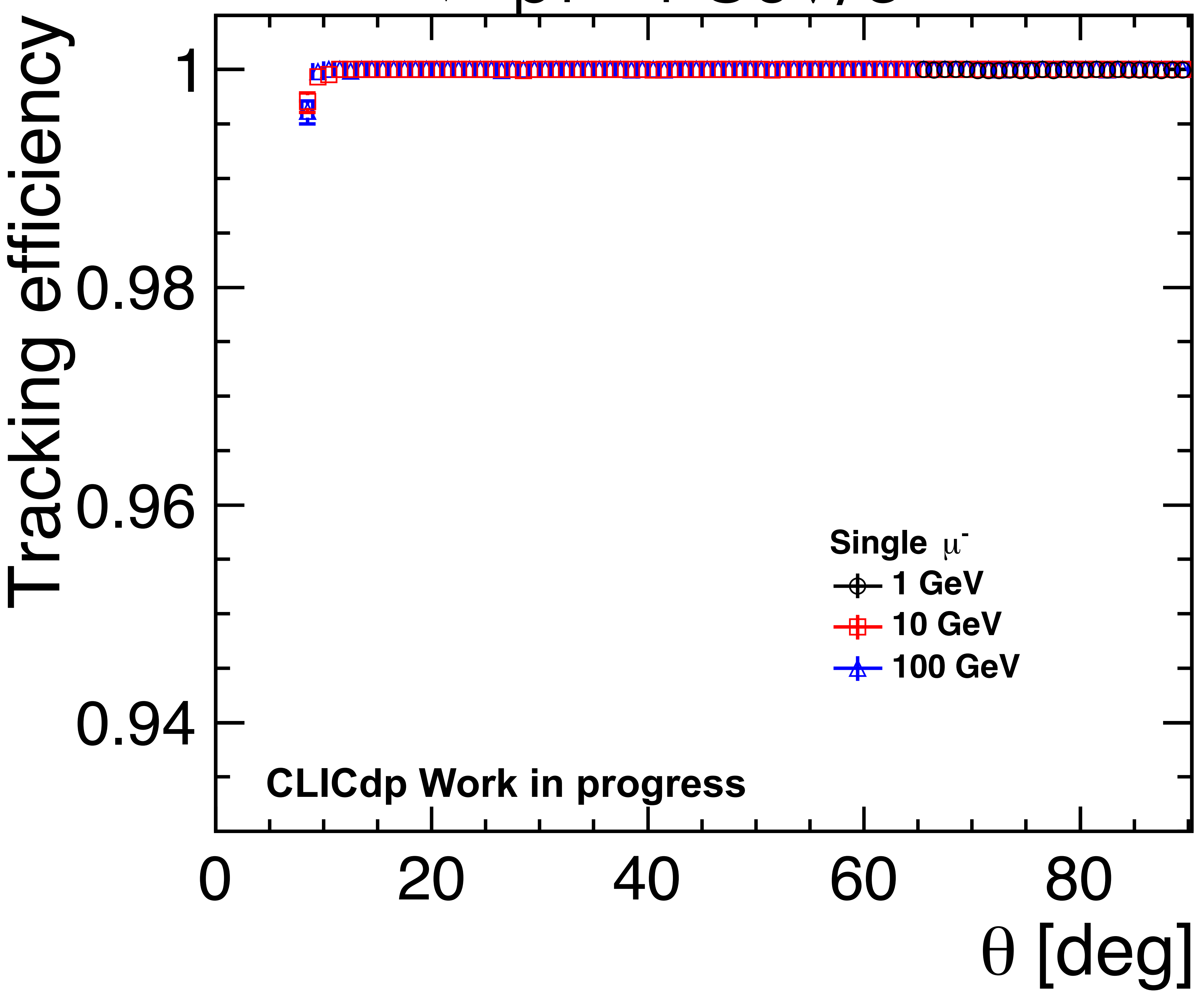
Tracking efficiency for single muons

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

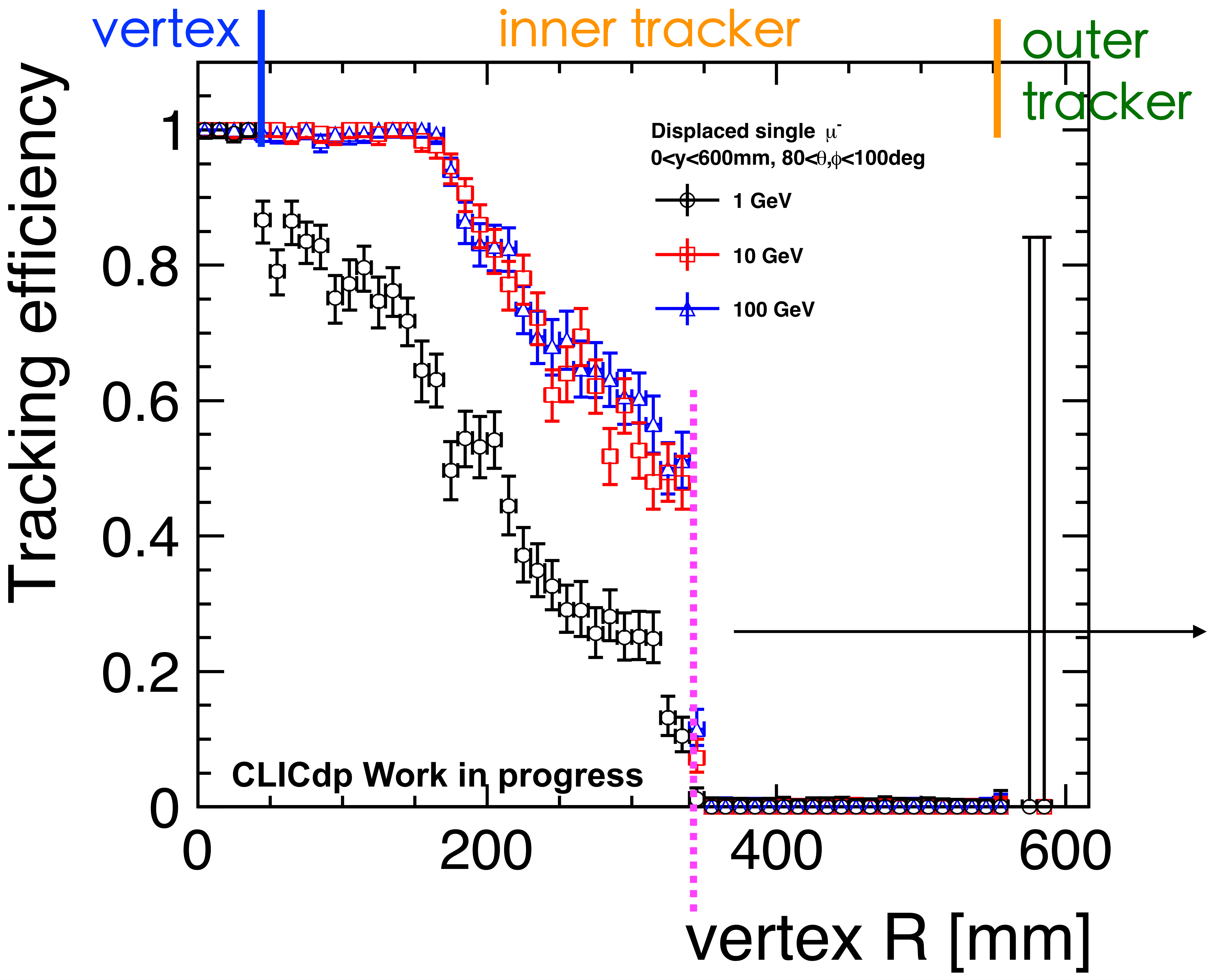


☆ Efficiency = 100% for single muons above 1GeV/c and for the full acceptance above 10deg

Tracking efficiency for displaced tracks

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

- ☆ Conformal mapping turns circles through the origin in (x,y) into straight lines in (u,v)
- ☆ => quadratic terms to include displaced tracks, but eventually χ^2 breaks down



- ☆ Major strategy change
  - ☆ broader search angle than for prompt tracks
  - ☆ inverted order search: from tracker to vertex hits

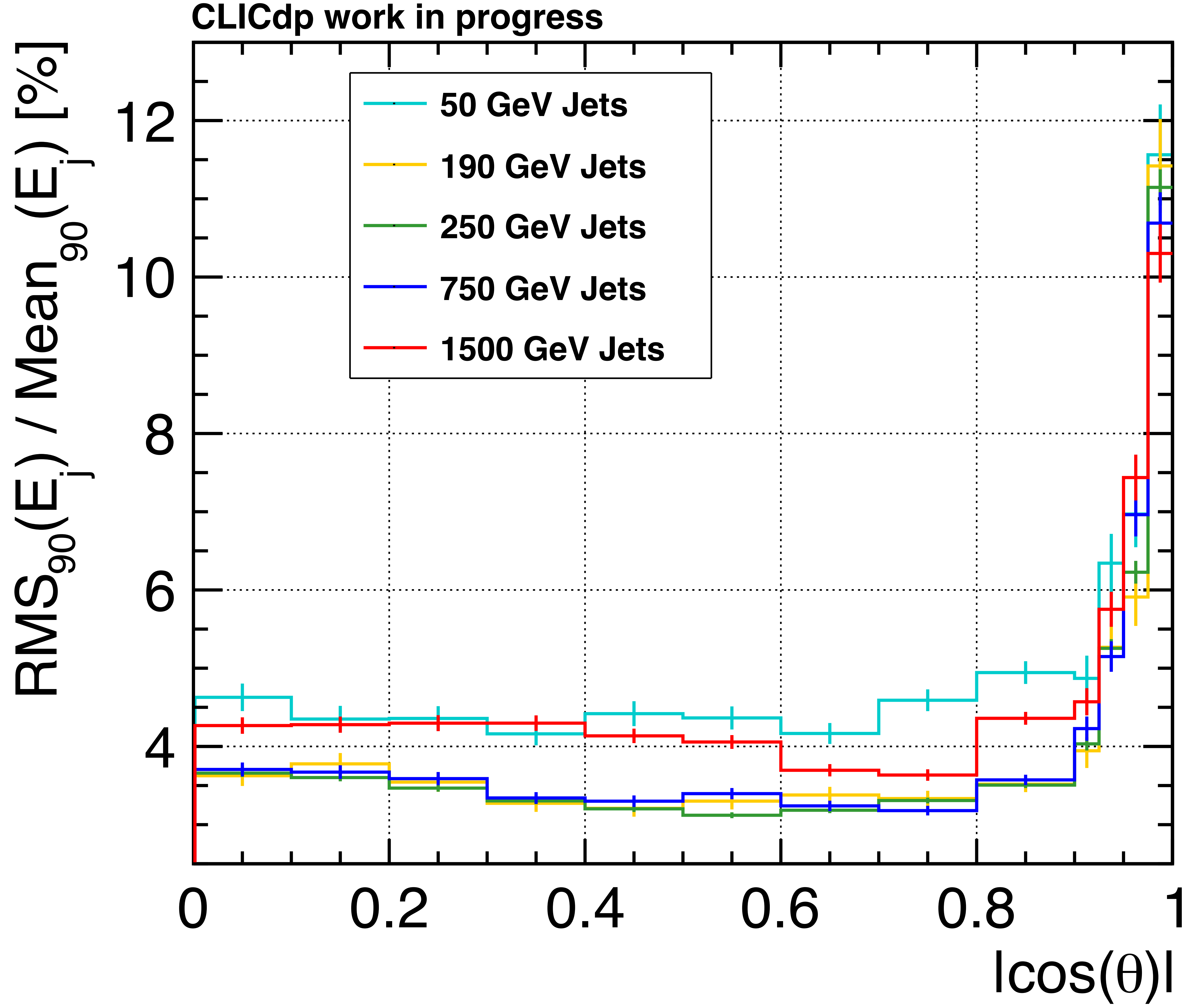
Cuts for this plot:

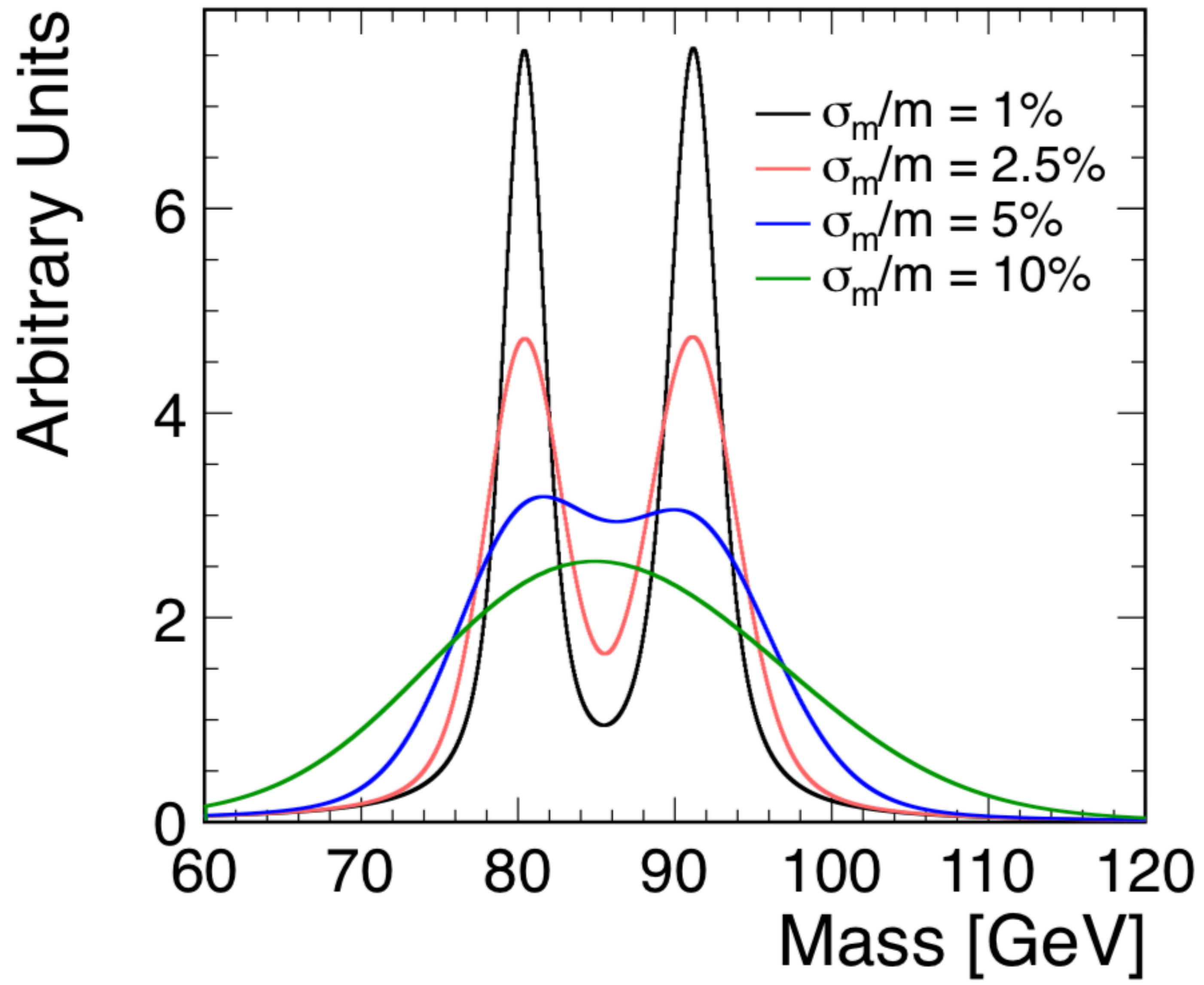
- ✦ $10 < \theta < 170$ deg
- ✦ $p_T > 1$ GeV/c

Min nr hits required for displaced tracks = 5 to reduce the combinatorics

Jet energy resolution

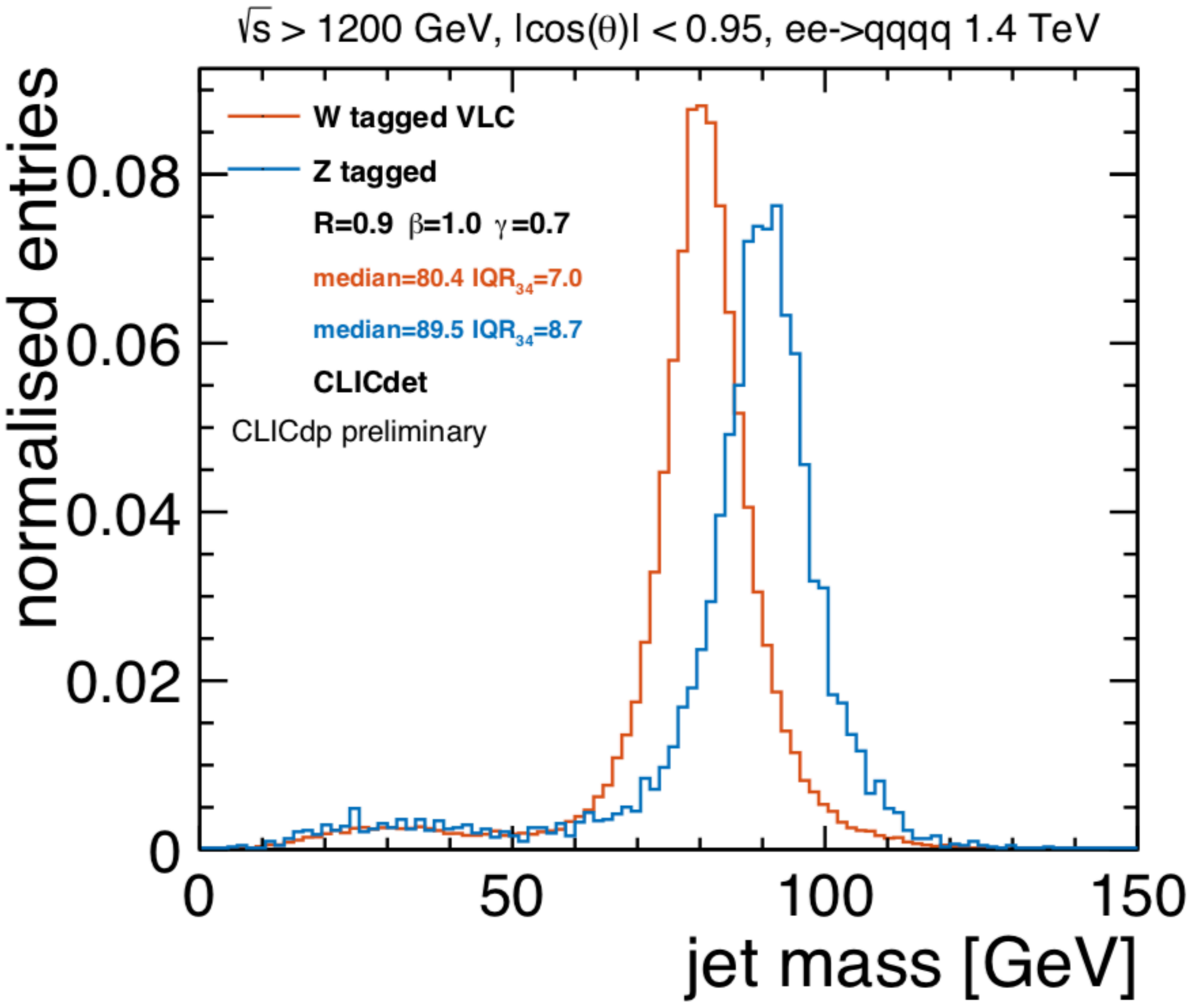
- Resolution per single jet (_j) = $\frac{\mathrm{RMS}_{90}(E_j)}{\mathrm{mean}_{90}(E_j)} = \frac{\mathrm{RMS}_{90}(E_{jj})}{\mathrm{mean}_{90}(E_{jj})}\sqrt{2}$ ⟶ (no jet reconstruction at this stage)

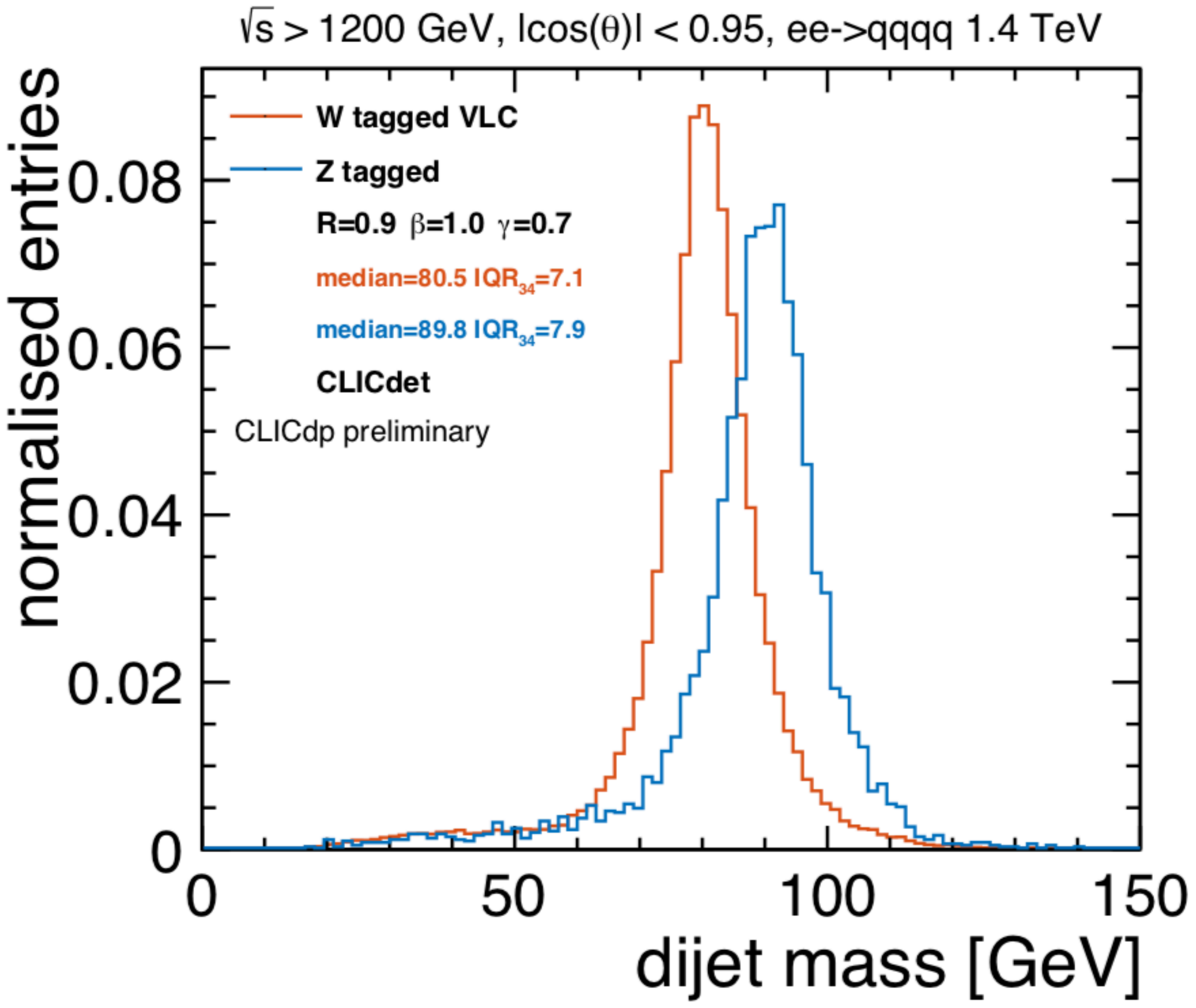




☆ Ideal W/Z mass separation requires $\sigma_m/m = 2.5\%$, which translates into jet energy resolution $\sigma_E/E = 3.5\%$

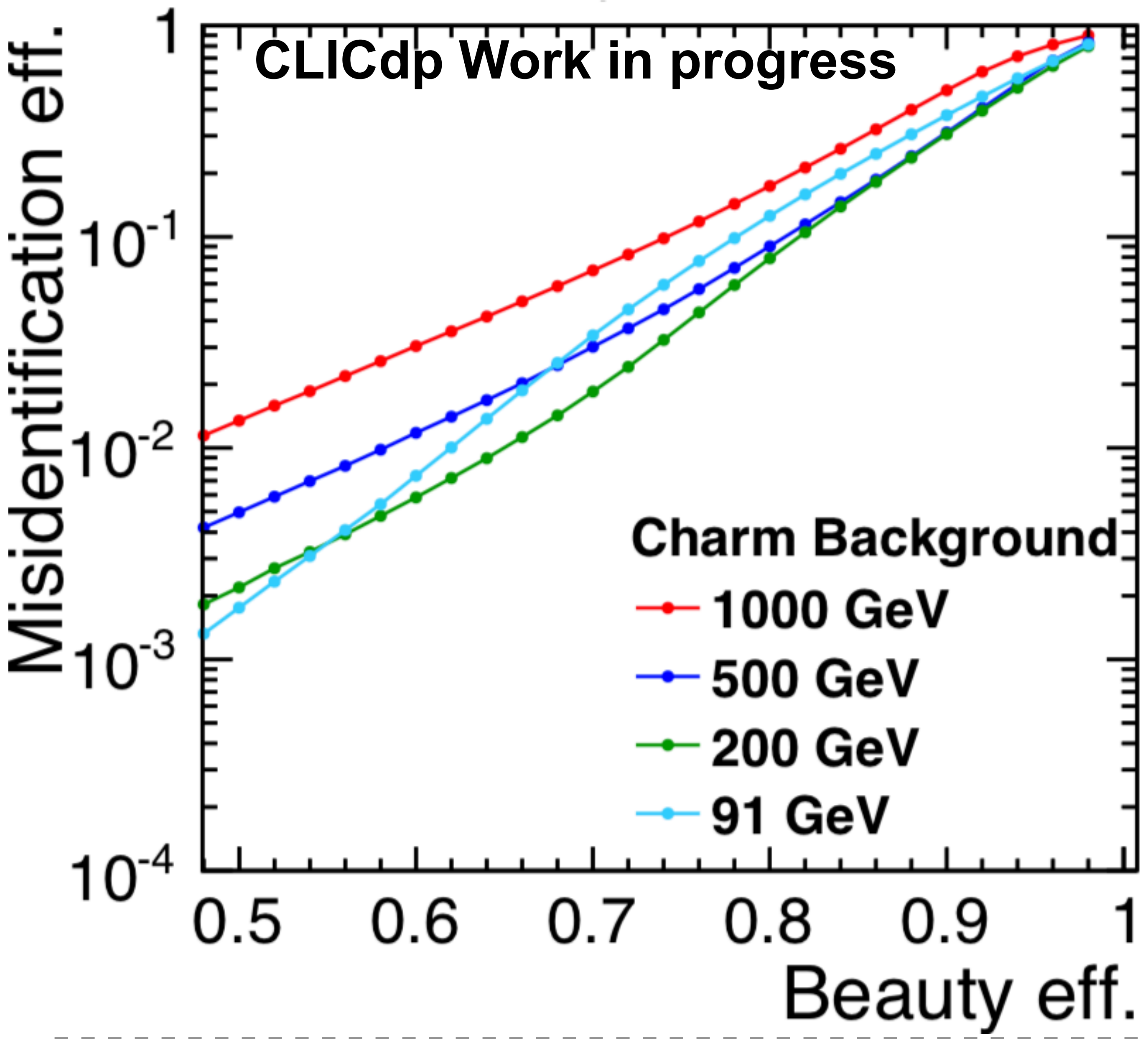
W/Z mass separation

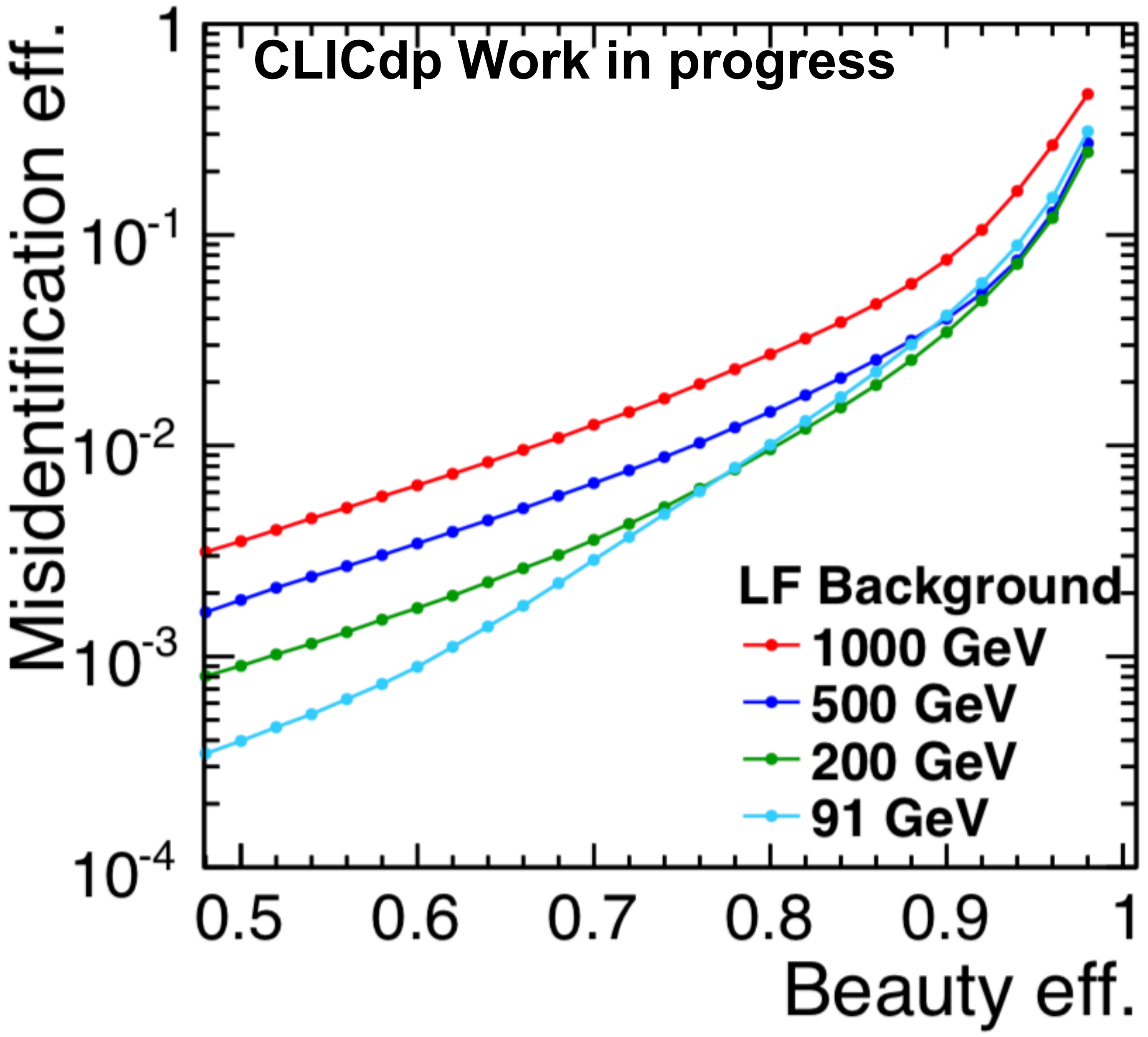




☆ Dijet mass (four exclusive jets) helps to reduce the low-mass bump

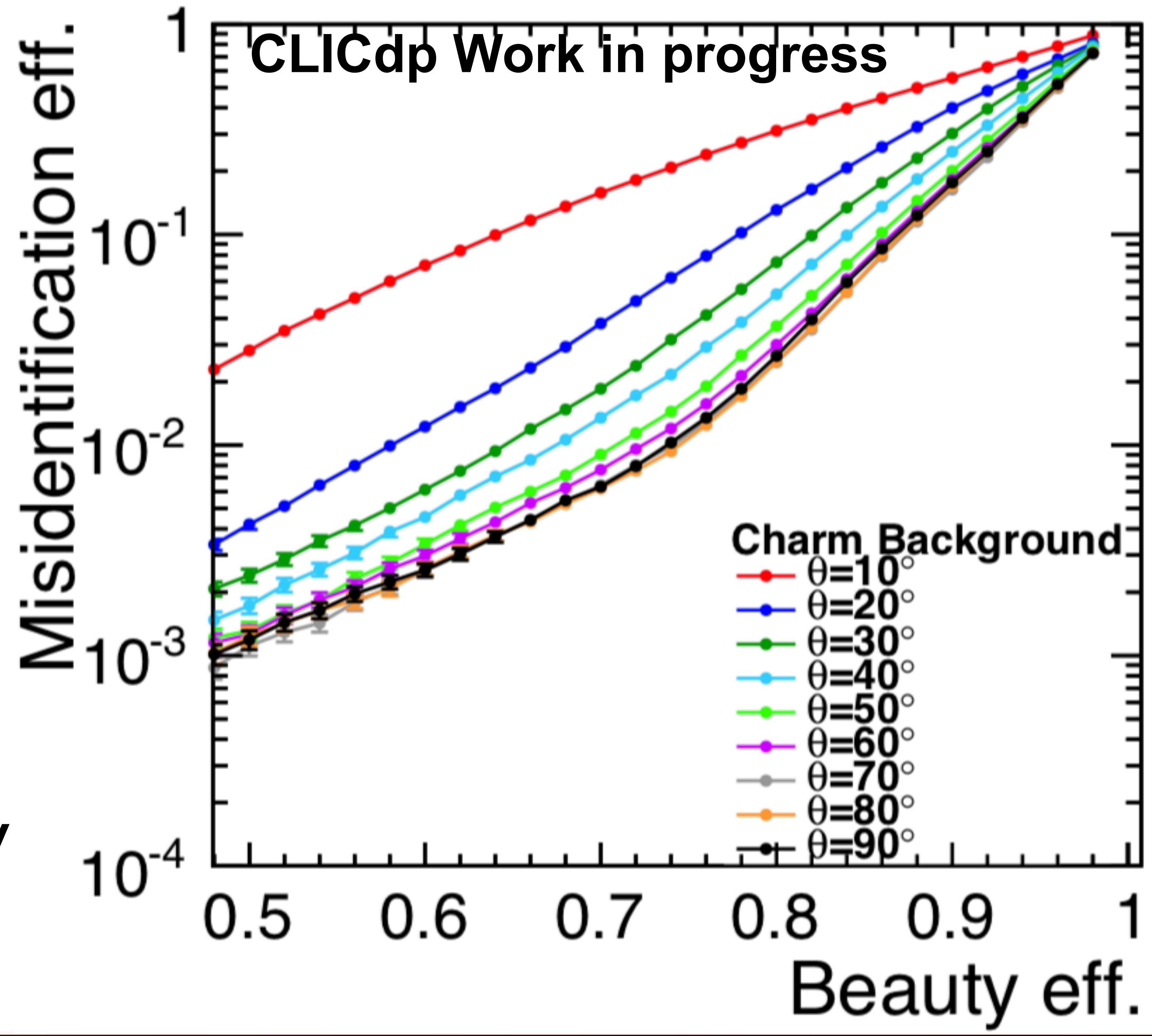
b-tagging

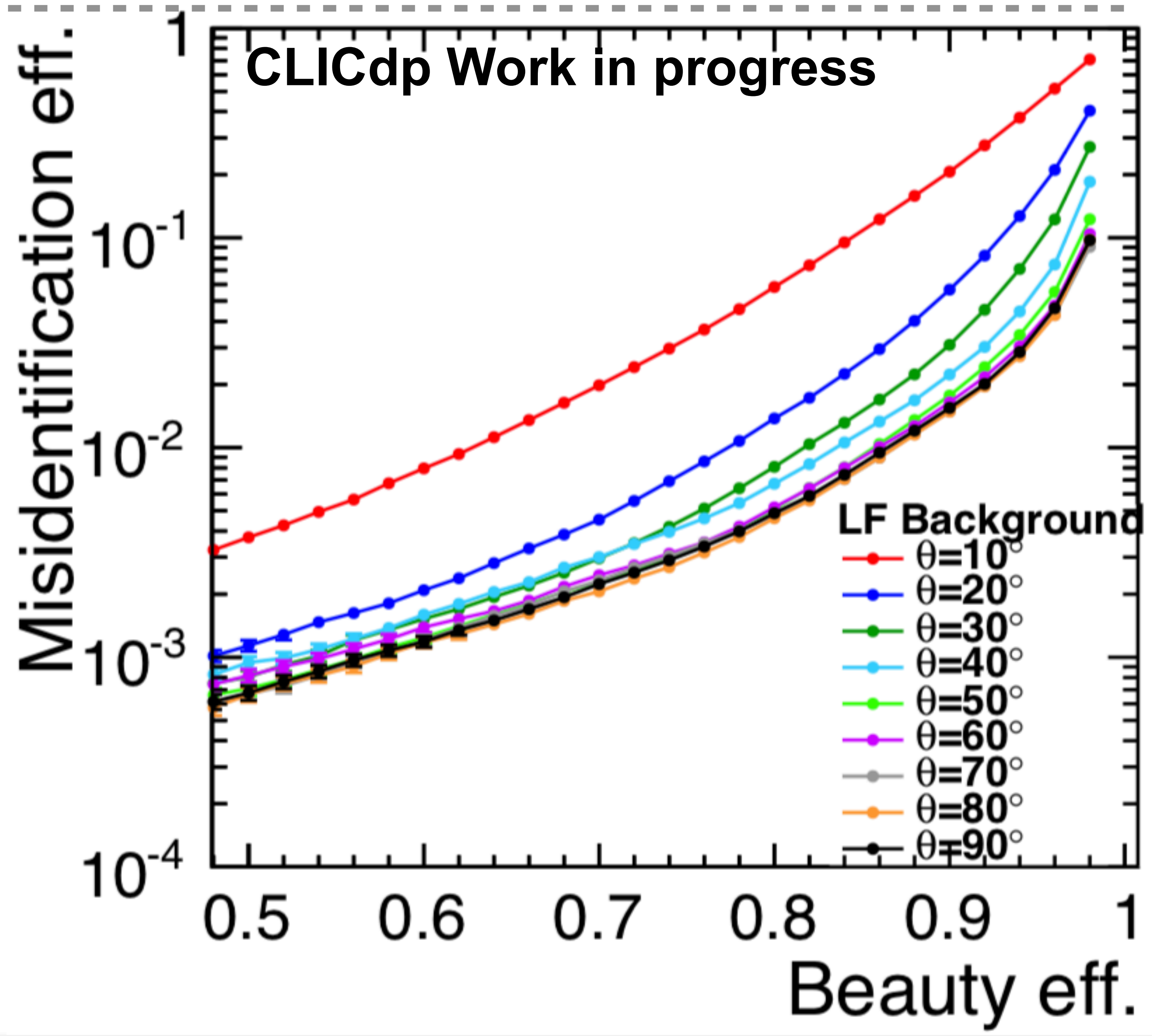




Energy dependence

dijets distributed in 10-90deg angle

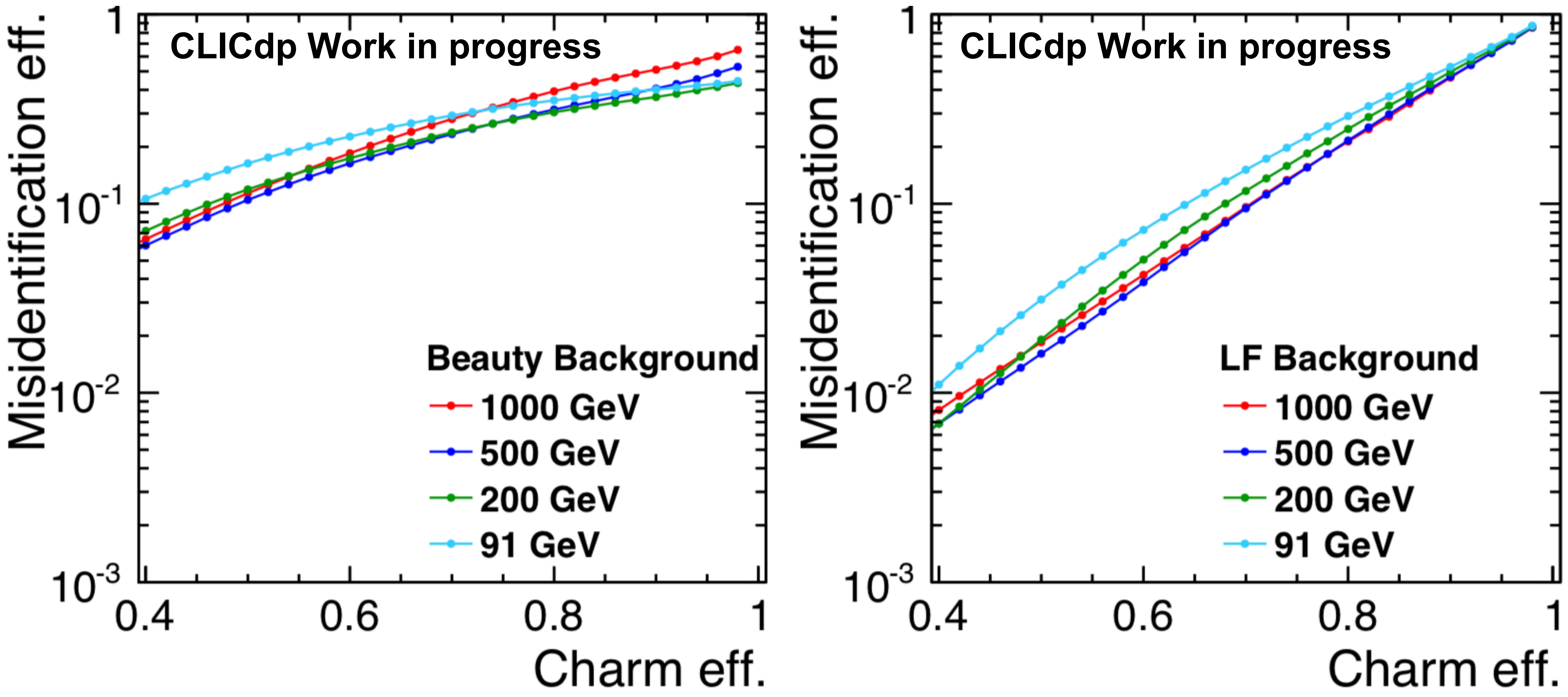




Polar angle dependence

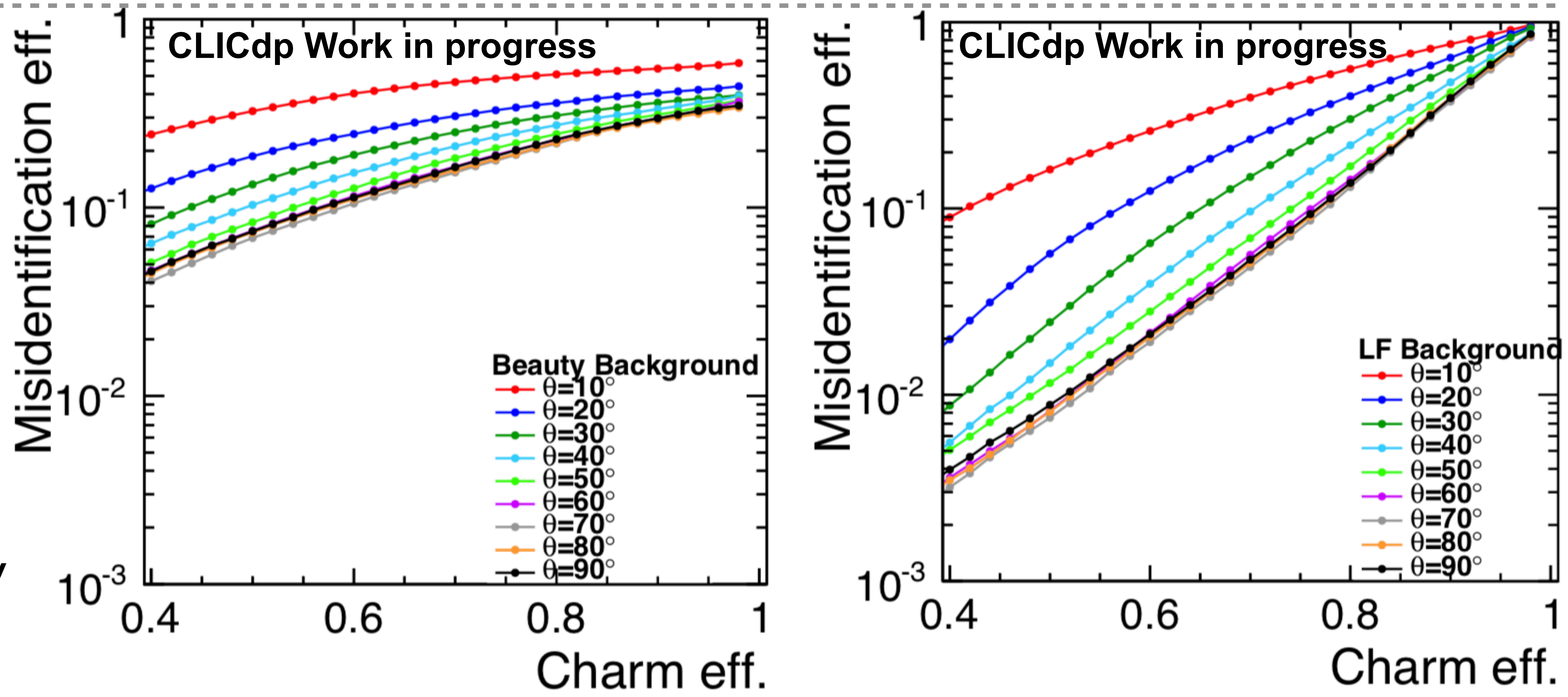
dijets events at sqrt(s) = 200GeV

c-tagging



Energy dependence

dijets distributed in 10-90deg angle

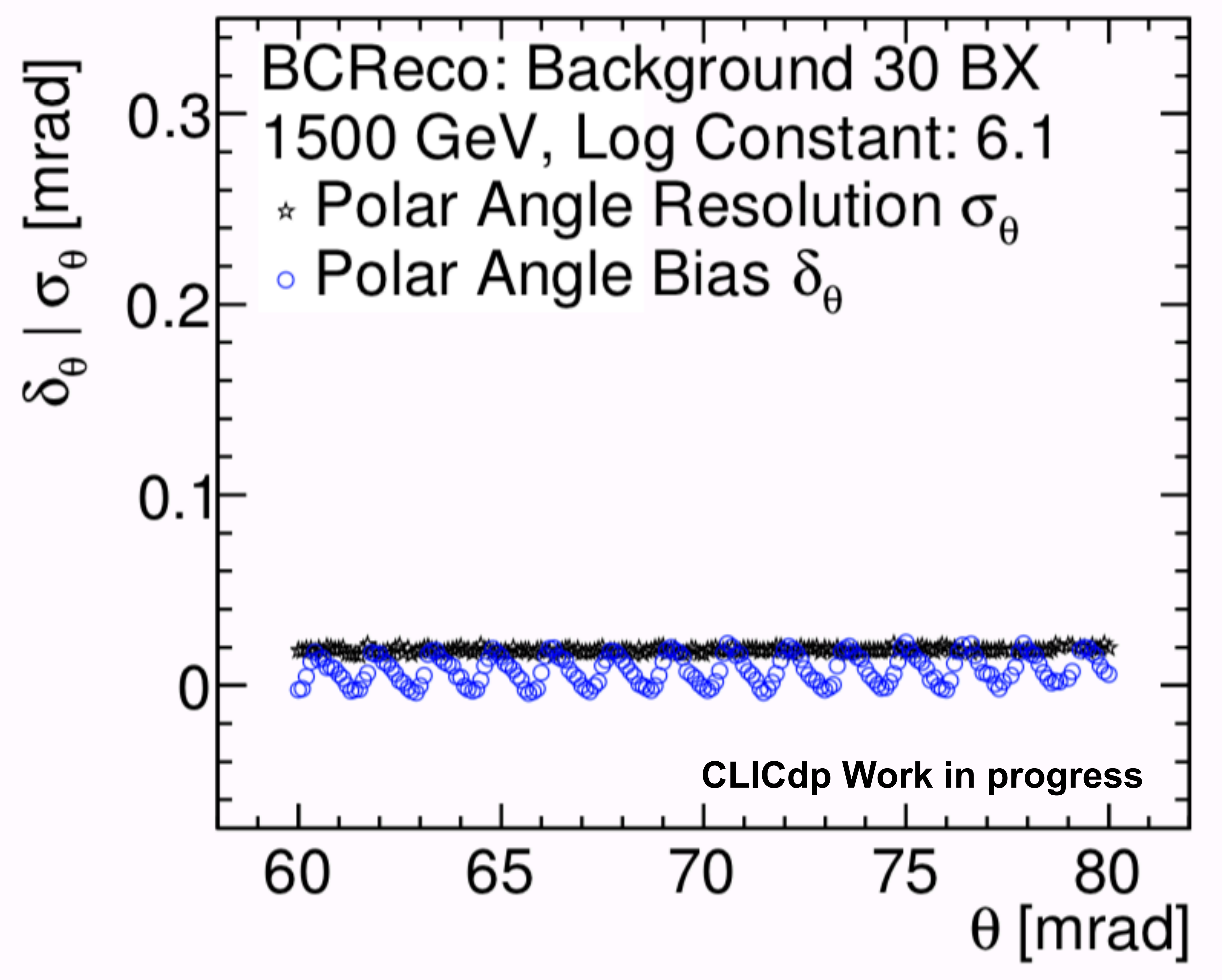


Polar angle dependence

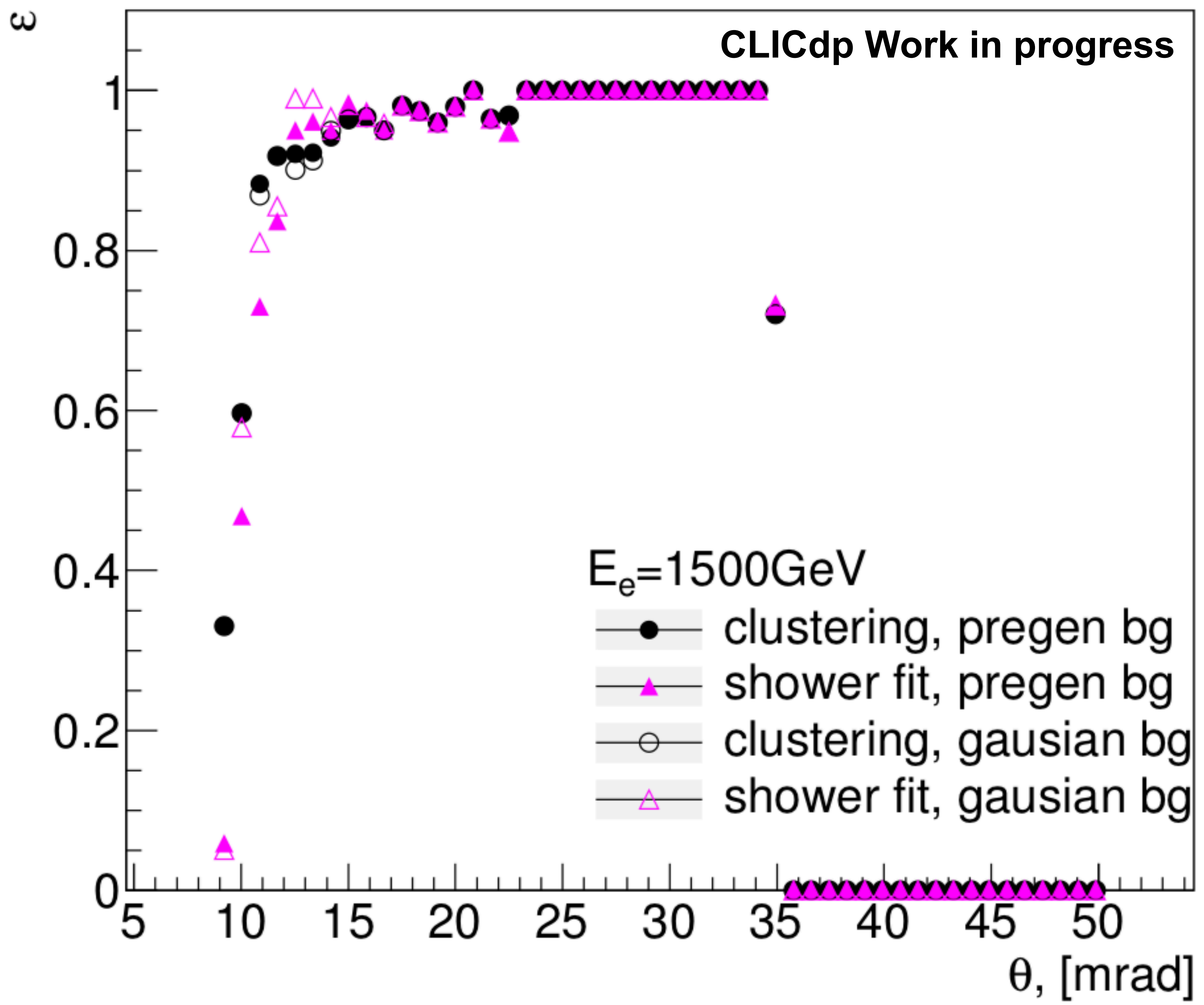
dijets events at sqrt(s) = 200GeV

Forward Calorimeters performances

- LumiCal
  - LumiCal clustering not feasible for γγ->hadrons overlay
  - => BeamCal reconstruction applied to LumiCal



- BeamCal
  - 1.5TeV electrons with 40BX incoherent pairs (e+e-) overlaid



SECTION 4: THE CLICdet AS A DELPHES CARD

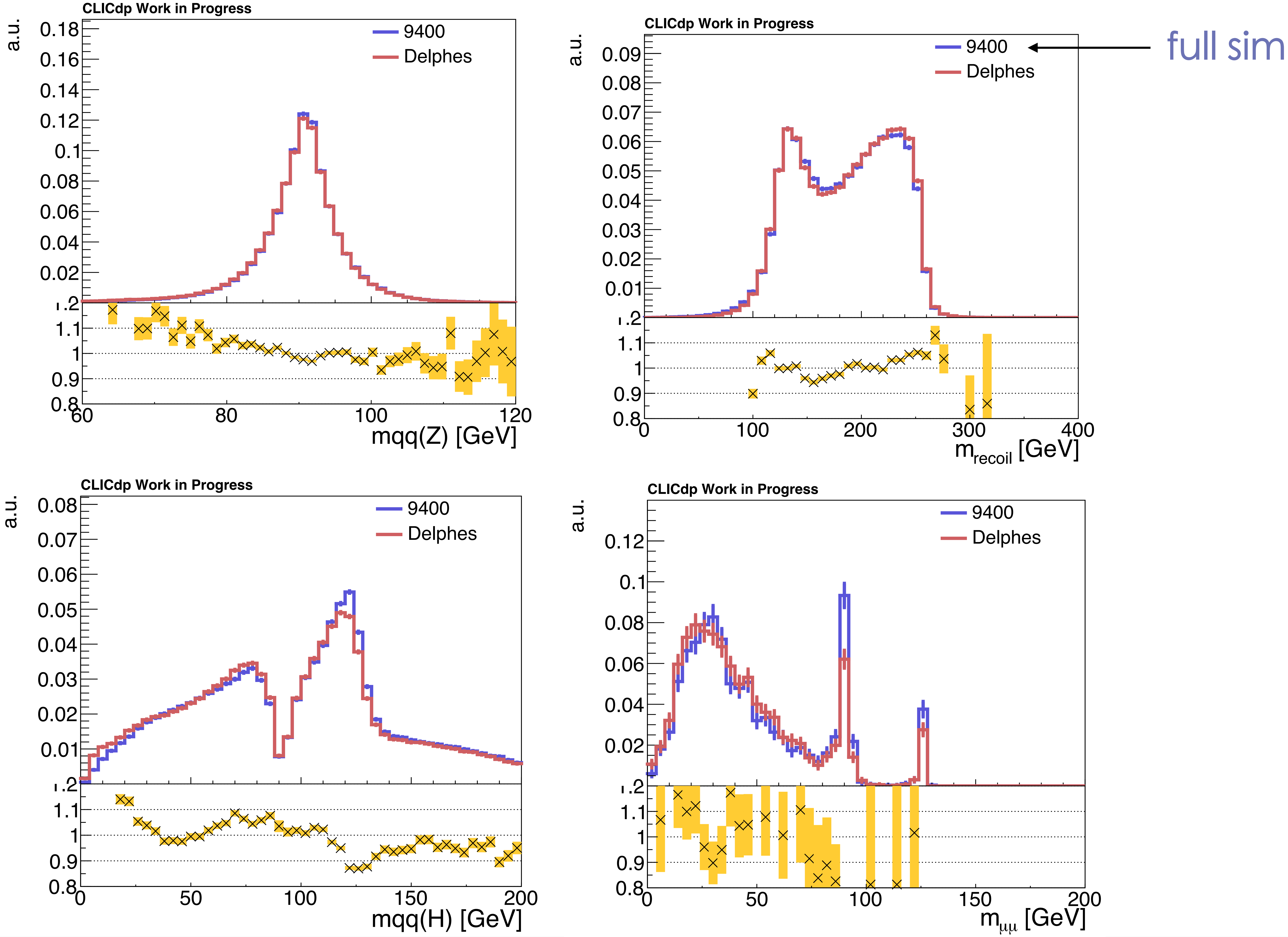
Fast detector simulation using a parametrization of the detector geometry, detector response and reconstruction of composite objects including efficiencies

DELPHES
fast simulation

- CLICdet as a Delphes Card
  - validation and performance
    - inputs: tracking resolutions and efficiency, calorimeter segmentation and resolutions, single particle PFOs efficiency and isolation, b,c,tau tagging
  - current status, documentation and links

Validation and performance of the CLICdet Delphes Card

Validation: HZ with Z → qq, H → inclusive at 350 GeV



Status, documentation and useful links

- Current status of the CLICdet Delphes Card
  - good performance for jets and observables based on multiple jets kinematics
  - work in progress for improving the lepton performances
  - invariant masses are well reproduced
  - widths are still under investigation
  - impact of γγ->hadrons at higher center of mass to be investigated

from Ulrike Schnoor (ulrike.schnoor@cern.ch)

- My fork on github: *https://github.com/uschnoor/delphes*
- Documentation: *https://cp3.irmp.ucl.ac.be/projects/delphes/wiki/WorkBook*
- How to use the current code with MadGraph (CLICdet adjustments not yet shipped with official code): *https://twiki.cern.ch/twiki/bin/view/CLIC/DelphesMadgraphForBSMReport*

If you want to know more...

...about the detector model:

- CLICdet: the post-CDR CLIC detector model
  - https://cds.cern.ch/record/2234145/files/CLICdp-Draft-2016-025.pdf?version=1

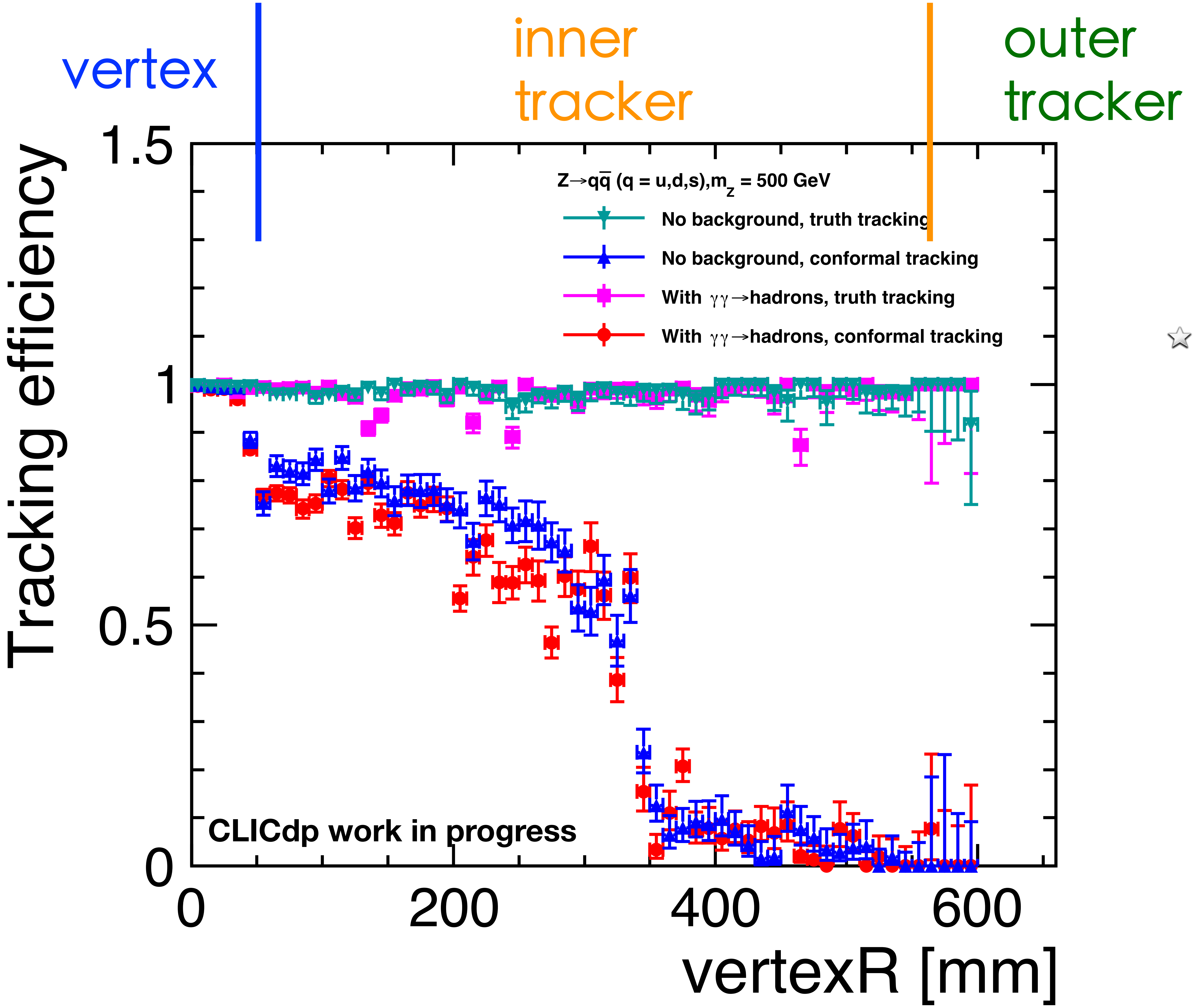
...about the object reconstruction & detector performances:

- Tracking
  - https://indico.cern.ch/event/656356/contributions/2845846/attachments/1587763/2511105/CLICWorkshop2018.pdf
- Calorimeters
  - https://indico.cern.ch/event/656356/contributions/2855848/attachments/1589352/2514491/180125_CLIC2018_PandoraPFA_Weber.pdf
- Flavour tagging
  - https://indico.cern.ch/event/656356/contributions/2845847/attachments/1587769/2511115/Flavour_tagging_CLICdet_IGarcia.pdf
- Forward calorimeters
  - https://indico.cern.ch/event/656356/contributions/2845848/attachments/1587779/2511136/180123_CLICWeek_Fcal.pdf
- Note in preparation

Special thanks to Philipp Roloff, Andre Sailer, Ulrike Schnoor and Matthias Weber

BACKUP SLIDES

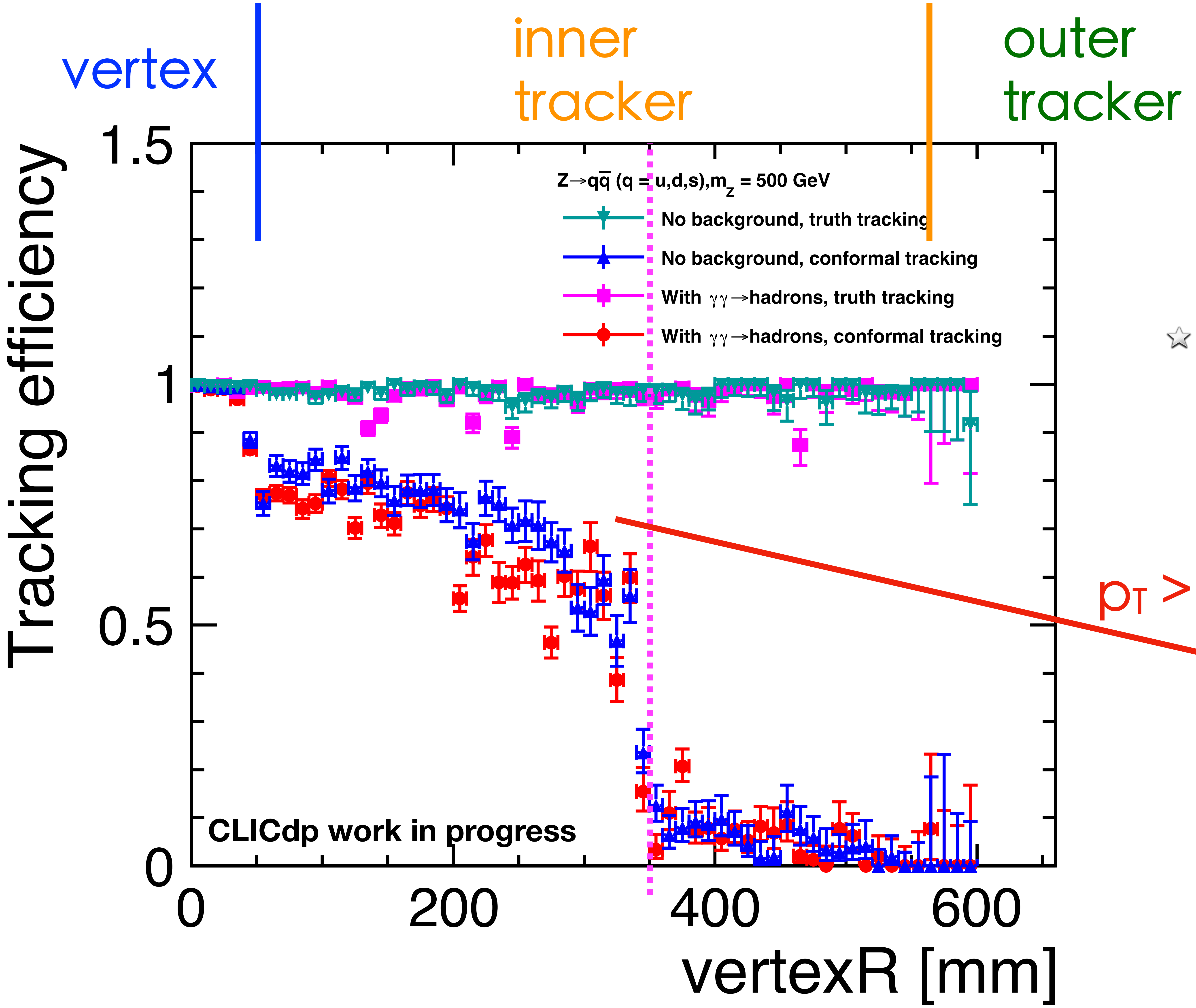
Tracking efficiency for displaced tracks: Zuds @ 500 GeV



- pT > 1 GeV/c
- 10 < θ < 170 deg
- purity > 75%

- Efficiency independent on background

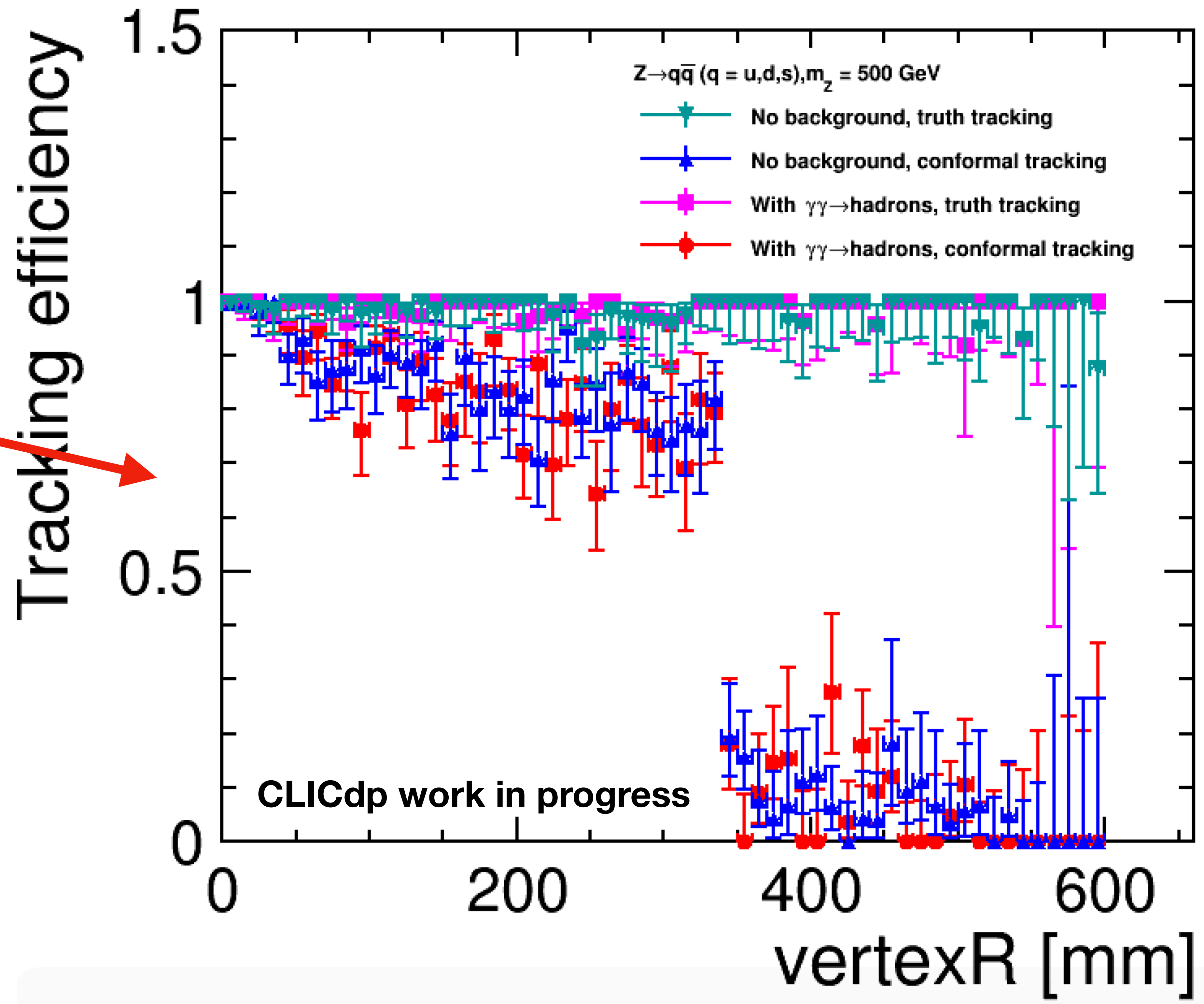
Tracking efficiency for displaced tracks: Zuds @ 500 GeV



- ~~pT > 1 GeV/c~~
- $10 < \theta < 170$ deg
- purity > 75%

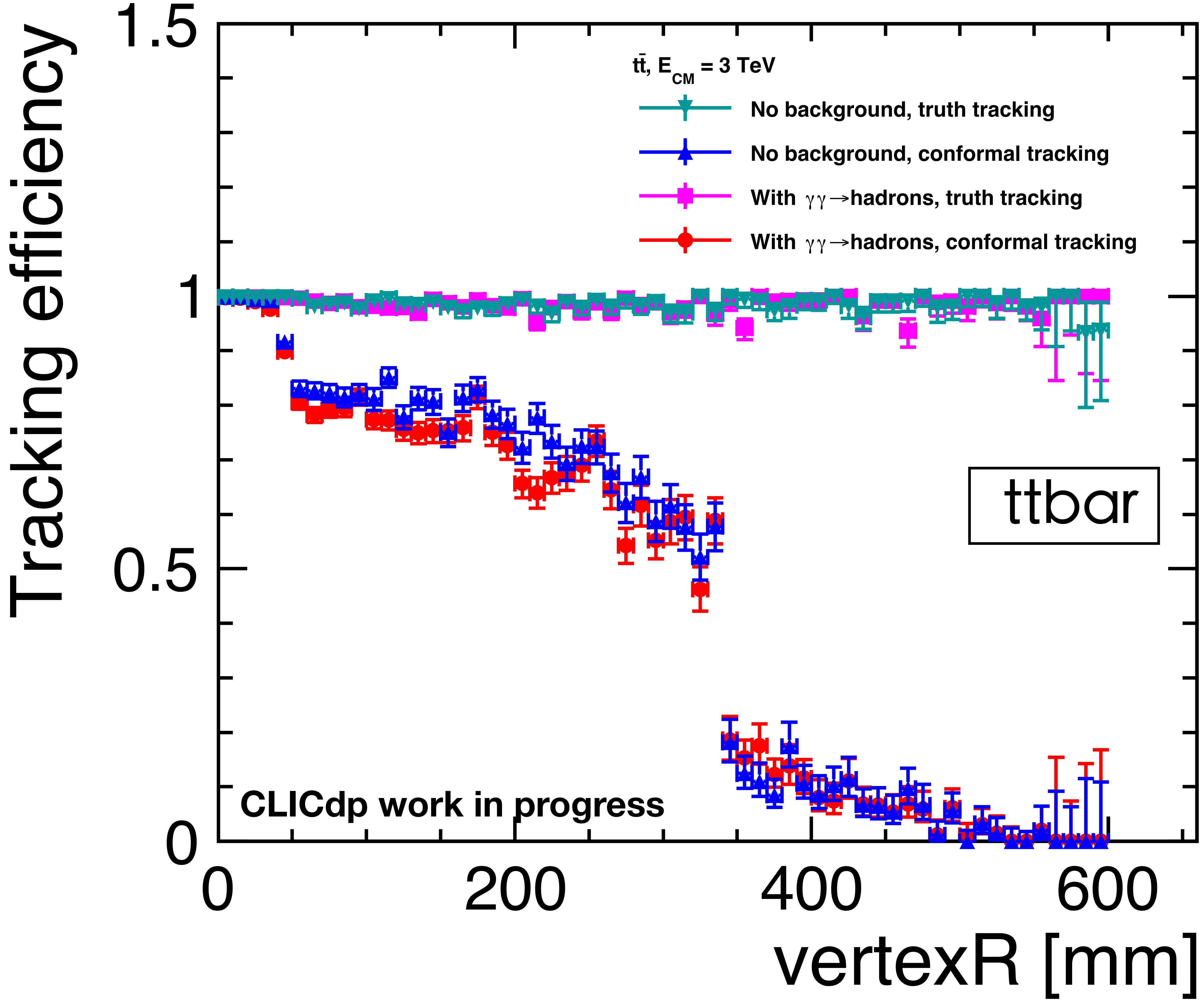
- Efficiency independent on background

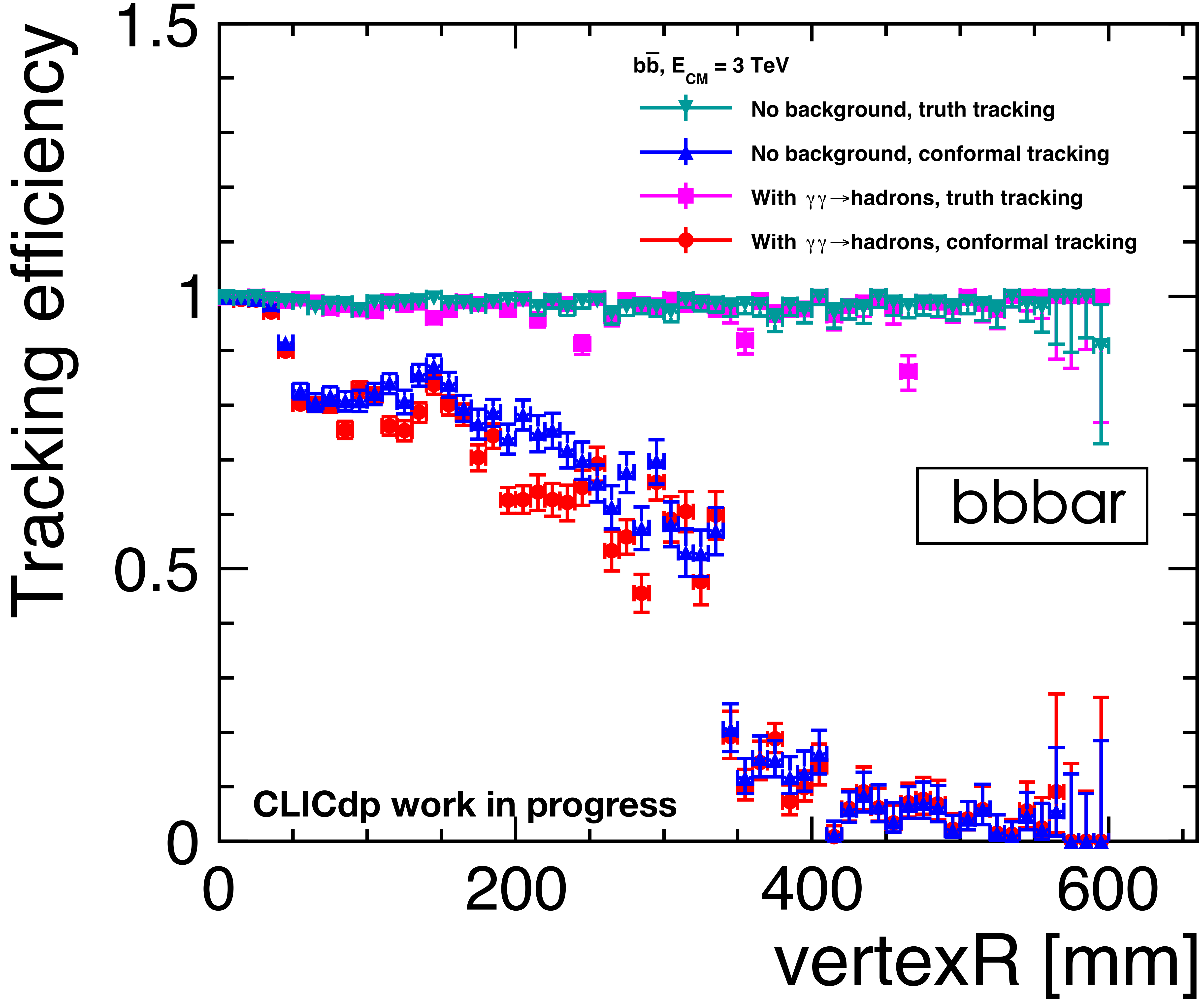
$p_T > 5$ GeV

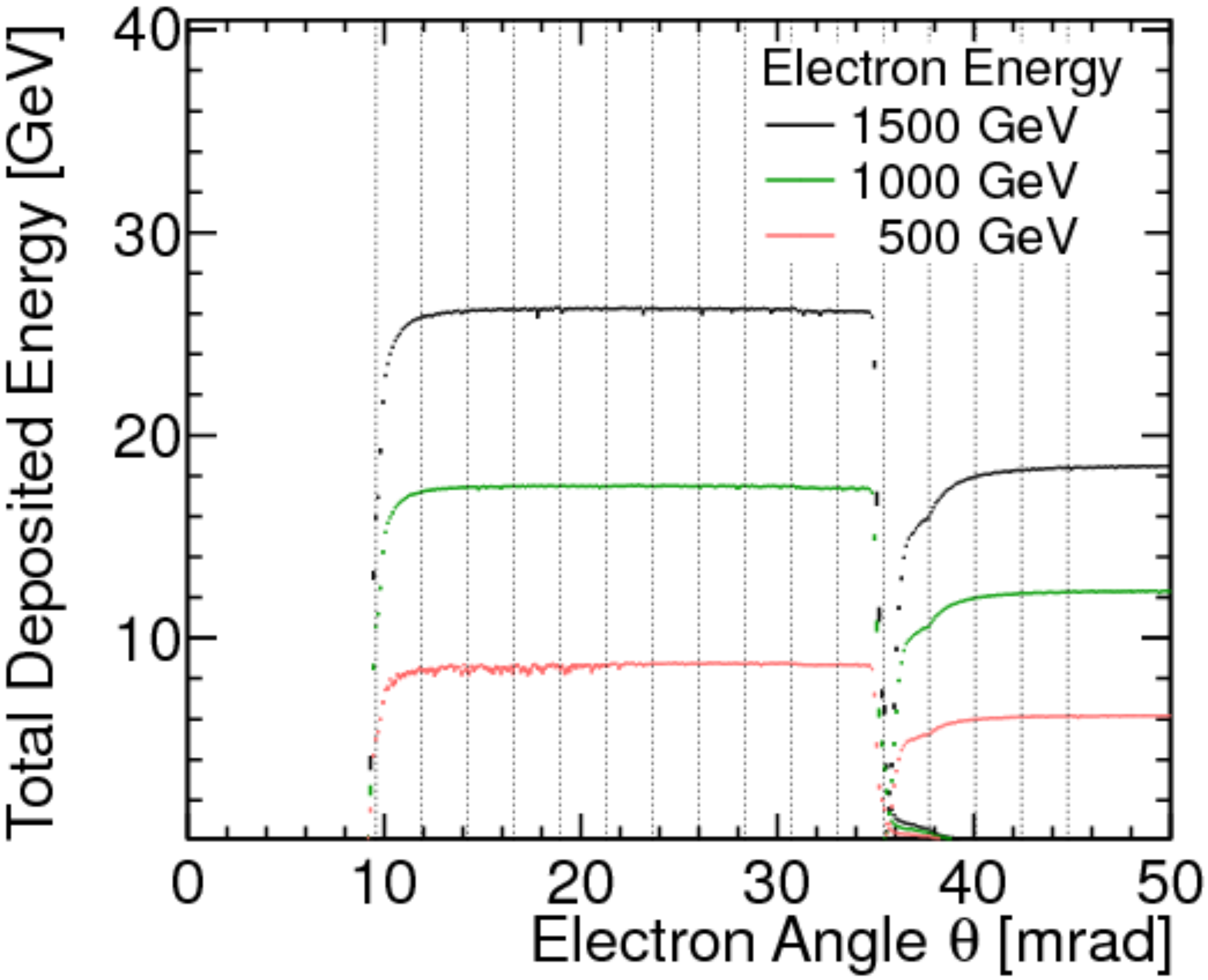


Tracking efficiency for displaced tracks: $t\bar{t}$, $b\bar{b}$ @ 3 TeV

- pT > 1 GeV/c
- 10 < θ < 170 deg
- purity > 75%







Total Deposited Energy [GeV]
40
30
20
10
0
10
20
30
40
50
Electron Angle θ [mrad]
Electron Energy
1500 GeV
1000 GeV
500 GeV