Detector Performance Parameterisation

(with Delphes)

Michele Selvaggi

CERN

FCC Hadron Detector Meeting

28/09/2016

Status

- Latest version of **FCC-hh detector layout** (see Werner's talk) has been implemented in Delphes.

- Compared to Delphes card implemented by H. Gray and F. Moortgat small changes have applied:

  - smaller detector/magnetic field

  - tracking/muon **resolution formulae** have been updated according to tkLayout parameterisation/analytical derivation

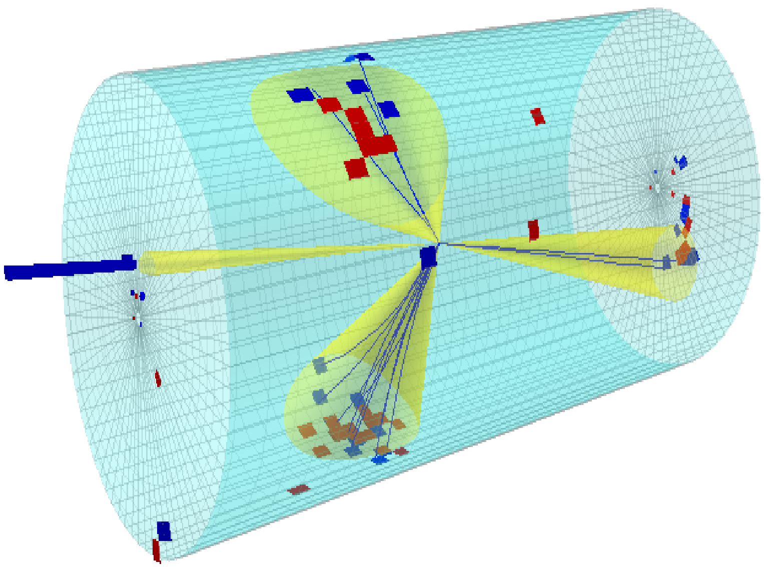
  - ECAL/HCAL layouts/resolution kept same
  - object (e-mu-gamma-b-tau) **efficiencies** also similar

- Goal here is to **present the performance** of reconstructed objetcs as obtained with the latest FCC-hh detector card

What is Delphes?

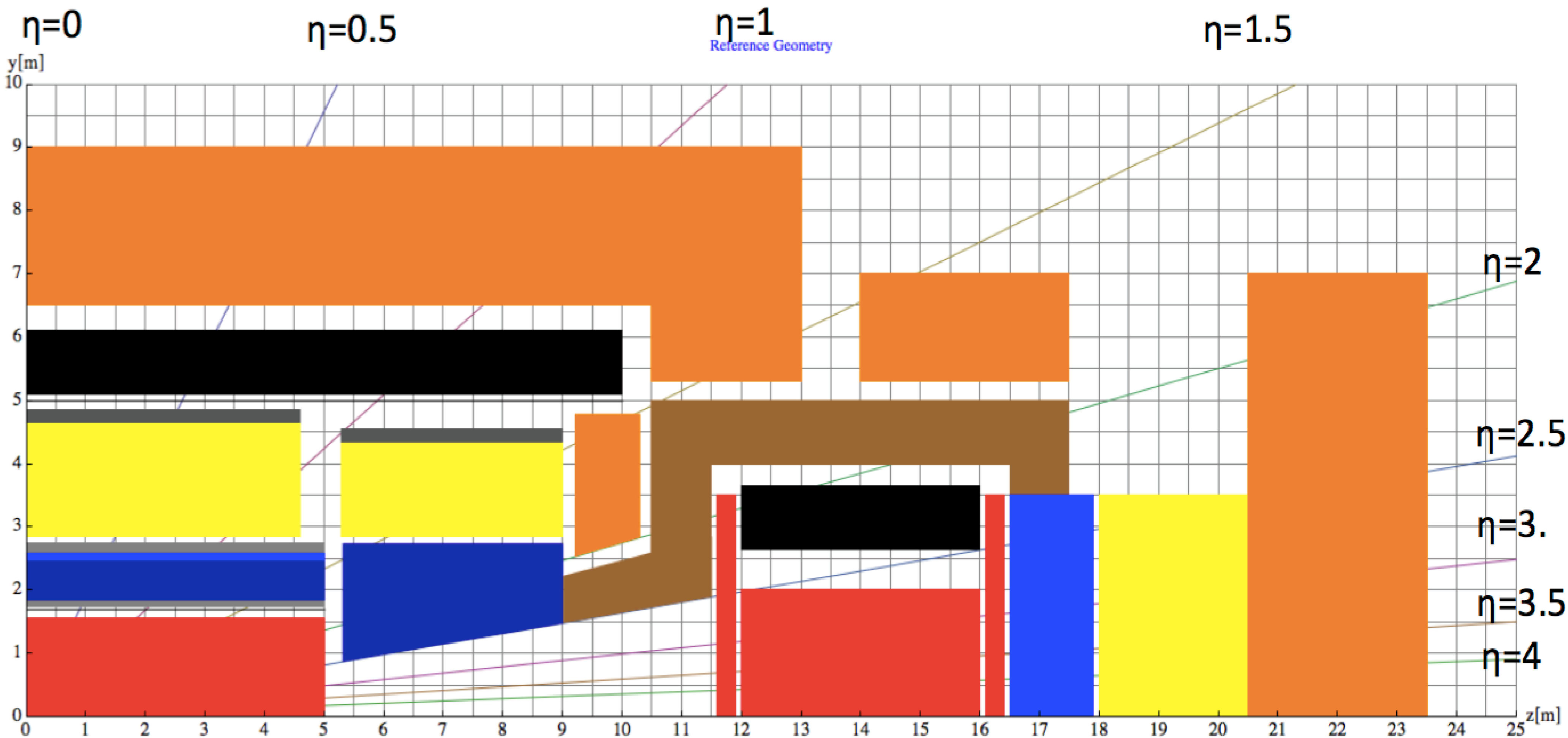
- **Delphes** is a **modular framework** that simulates of the response of a multipurpose detector in a **parameterized** fashion

- **Includes**:
  - charged particle **propagation** in magnetic field
  - electromagnetic and hadronic **calorimeters**
  - particle-flow candidates



- **Provides**:
  - leptons (electrons and muons)
  - photons
  - jets and missing transverse energy (particle-flow)
  - taus and b's

Detector Layout

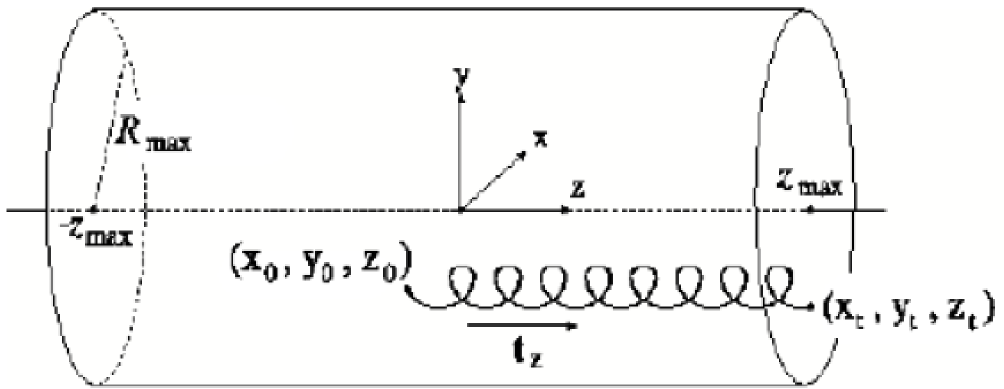


W. Riegler layout, proposed 13/08/2016

Particle Propagation

- Propagation parameters FCC-hh (CMS):

  - magnetic field, B = 4T (4T)
  - radius, R = 1.5 m (1.29 m)
  - half-length, z_{max} = 5.0 m (3.0 m)



- Both tracker resolution and efficiency are provided as function of (p_T , eta, phi, p) and particle pdg Code.

  tracker resolution given by tkLayout,

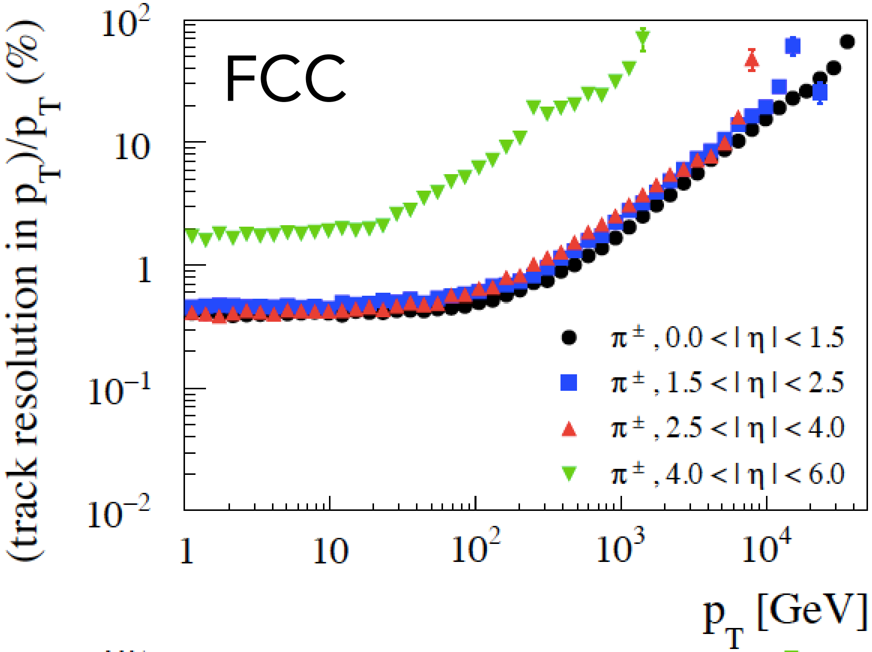
  efficiences are ad hoc for now (inspired by ALTAS, CMS).

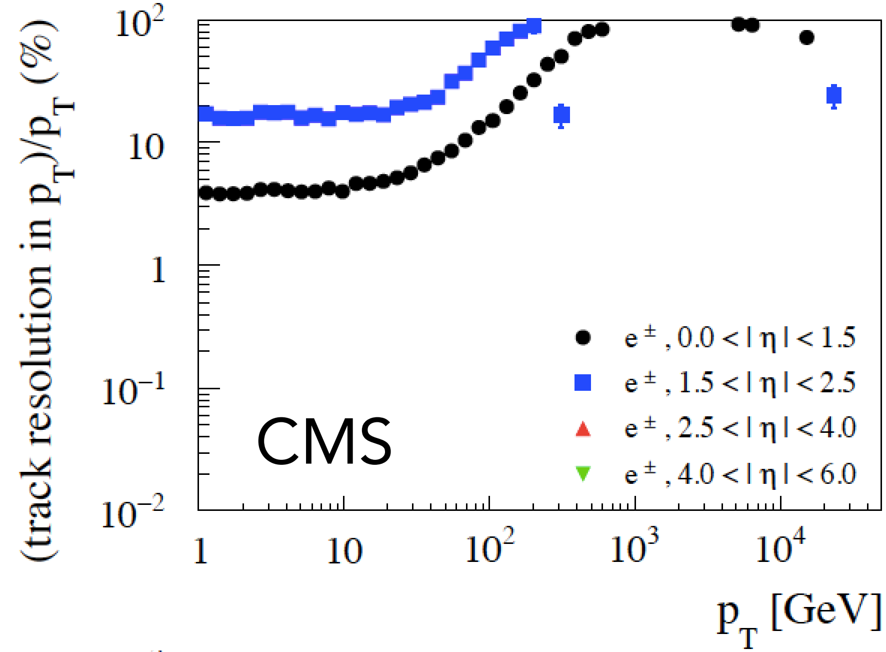
- Muons are special, at this stage they are treated according to combined tracker + muon

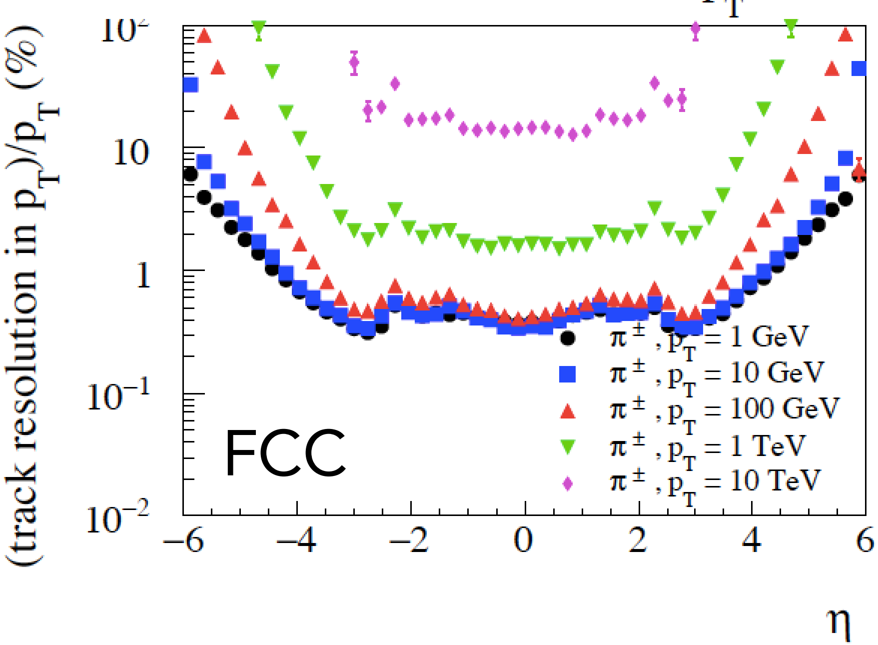
  |eta| < 2: extended analytical resolution derived by Werner for eta = 0

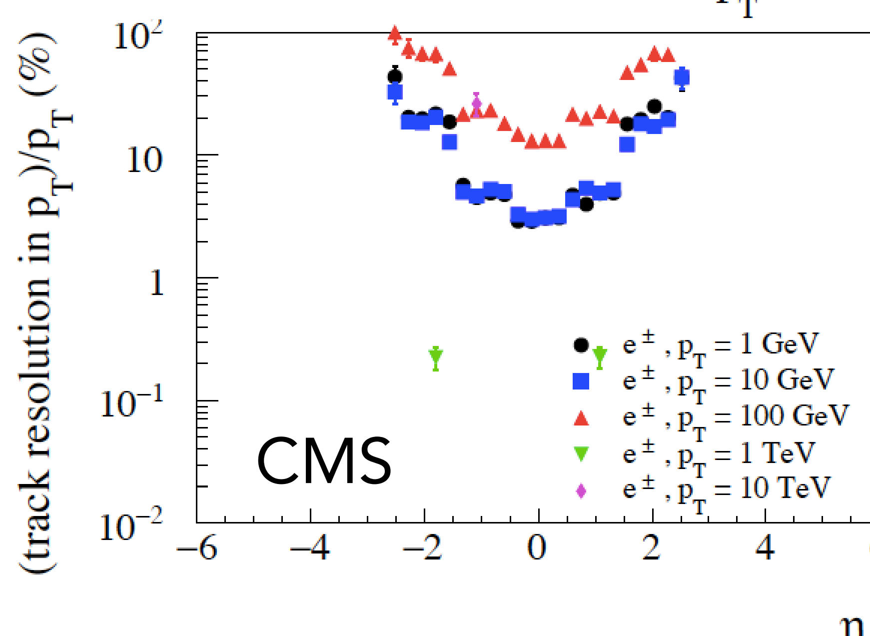
  |eta| > 2: pure tracker resolution (tkLayout)

Tracking Resolution

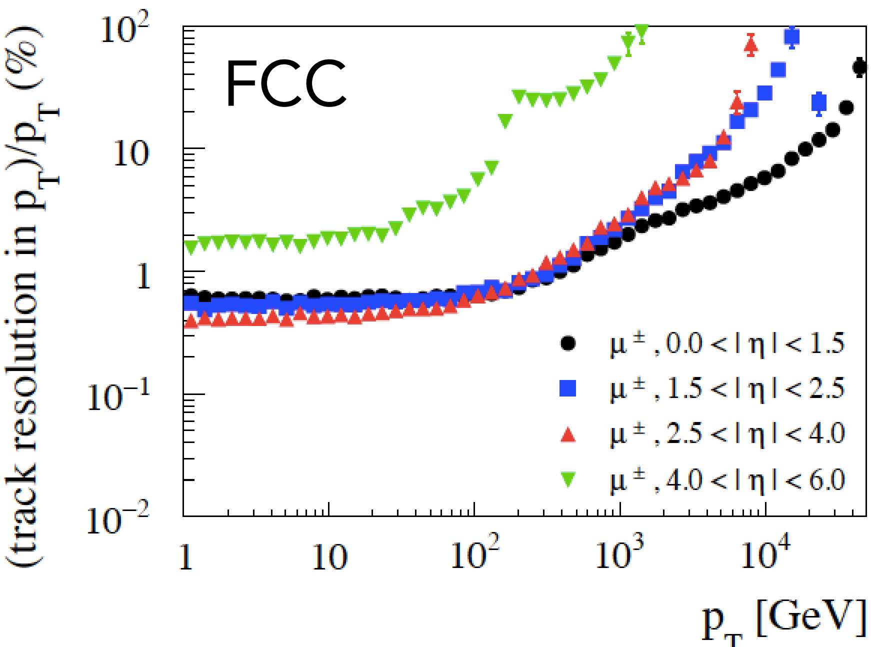


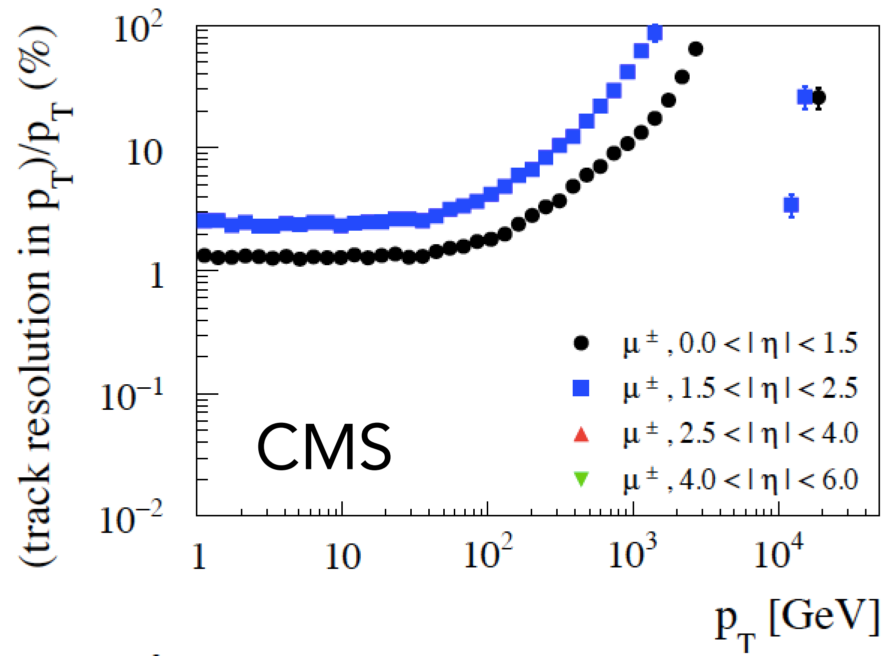


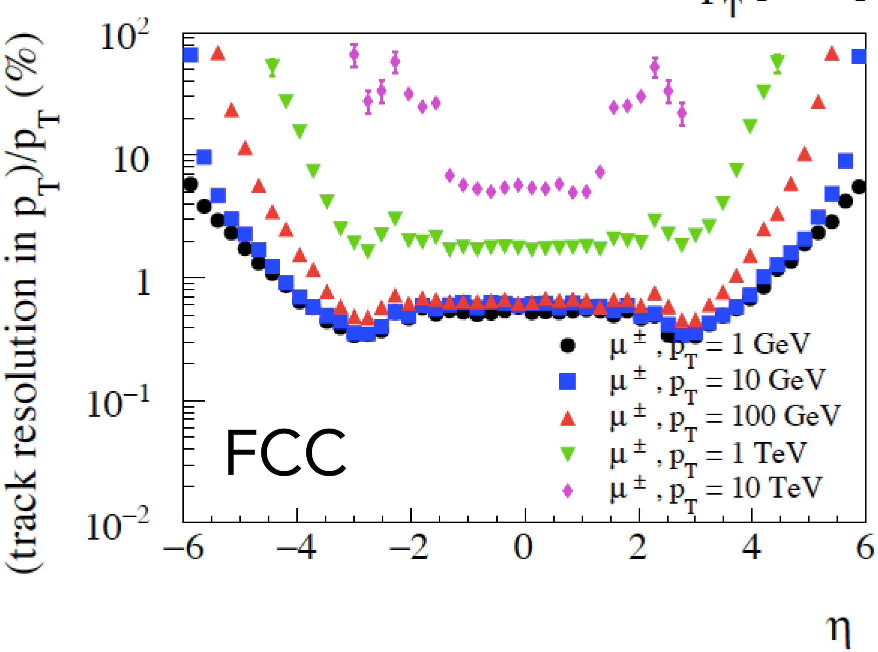


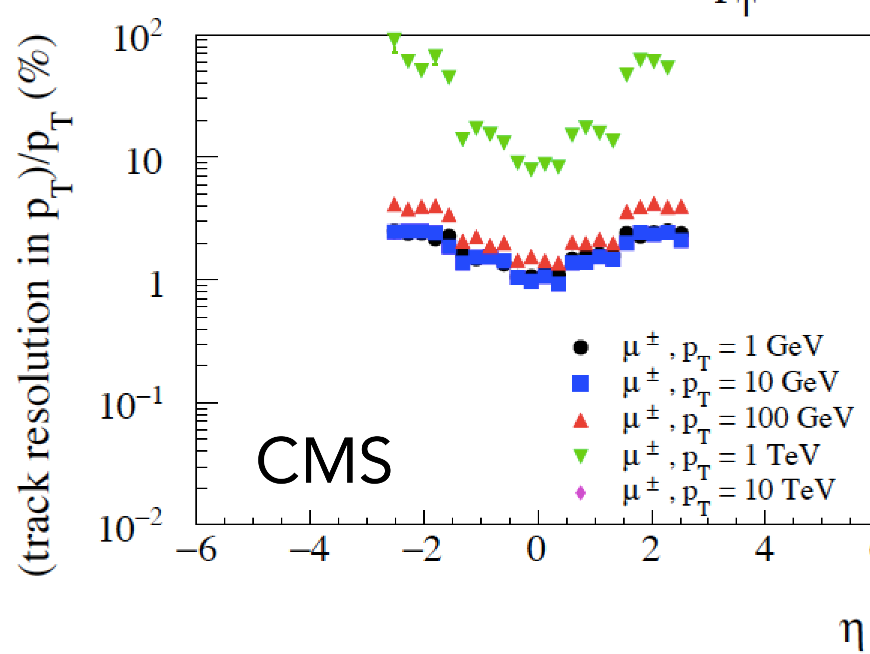


Muon Resolution









Calorimetry

- ECAL/HCAL **segmentation is specified** in eta/phi coordinates
- Each particle that reaches the calorimeters **deposits a fraction of its energy** in one ECAL cell (f_{EM}) and HCAL cell (f_{HAD}), depending on its type:

particles	f_{EM}	f_{HAD}
e γ π^0	1	0
Long-lived neutral hadrons (K^0_S , Λ^0)	0.3	0.7
ν μ	0	0
others	0	1

- Particle energy is **smeared** according to the calorimeter cell it reaches with typical resolution:

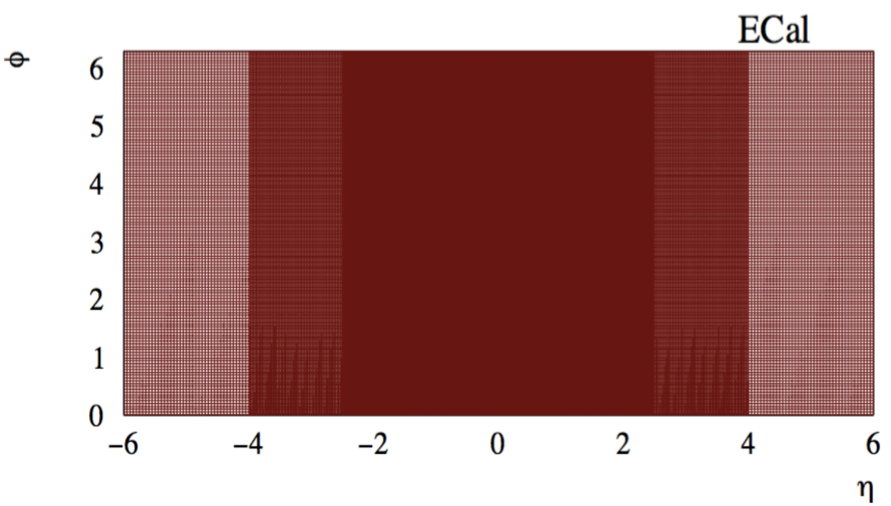
$$\left(\frac{\sigma}{E}\right)^2 = \left(\frac{S(\eta)}{\sqrt{E}}\right)^2 + \left(\frac{N(\eta)}{E}\right)^2 + C(\eta)^2$$

No Energy sharing between the neighboring cells
No longitudinal segmentation, no shower
No effect of magnetic field

ECAL (I)

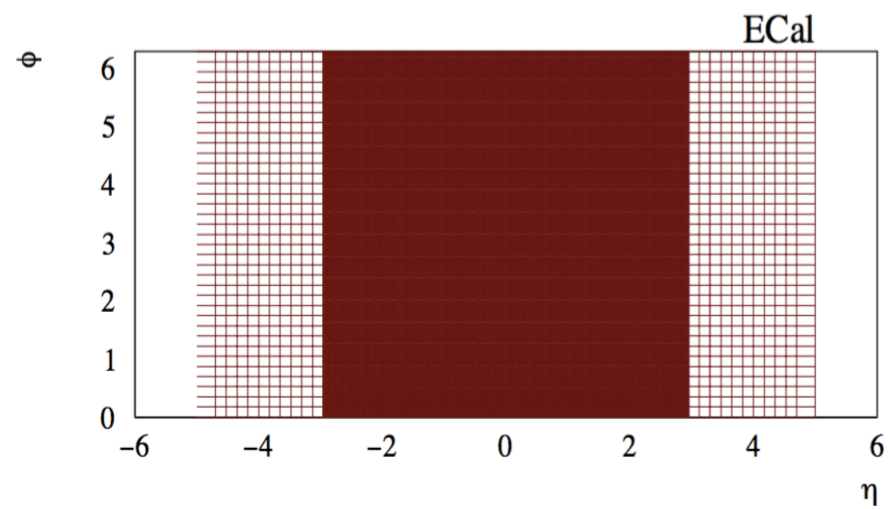
FCC

	$\sigma_{(\eta,\phi)}$	$\sigma(E)/E$
$0.0 < \|\eta\| < 2.5$	0.0125×0.0125	$\frac{10\%}{\sqrt{E}} + 1\%$
$2.5 < \|\eta\| < 4.0$	0.025×0.025	$\frac{10\%}{\sqrt{E}} + 1\%$
$4.0 < \|\eta\| < 6.0$	0.05×0.05	$\frac{10\%}{\sqrt{E}} + 1\%$

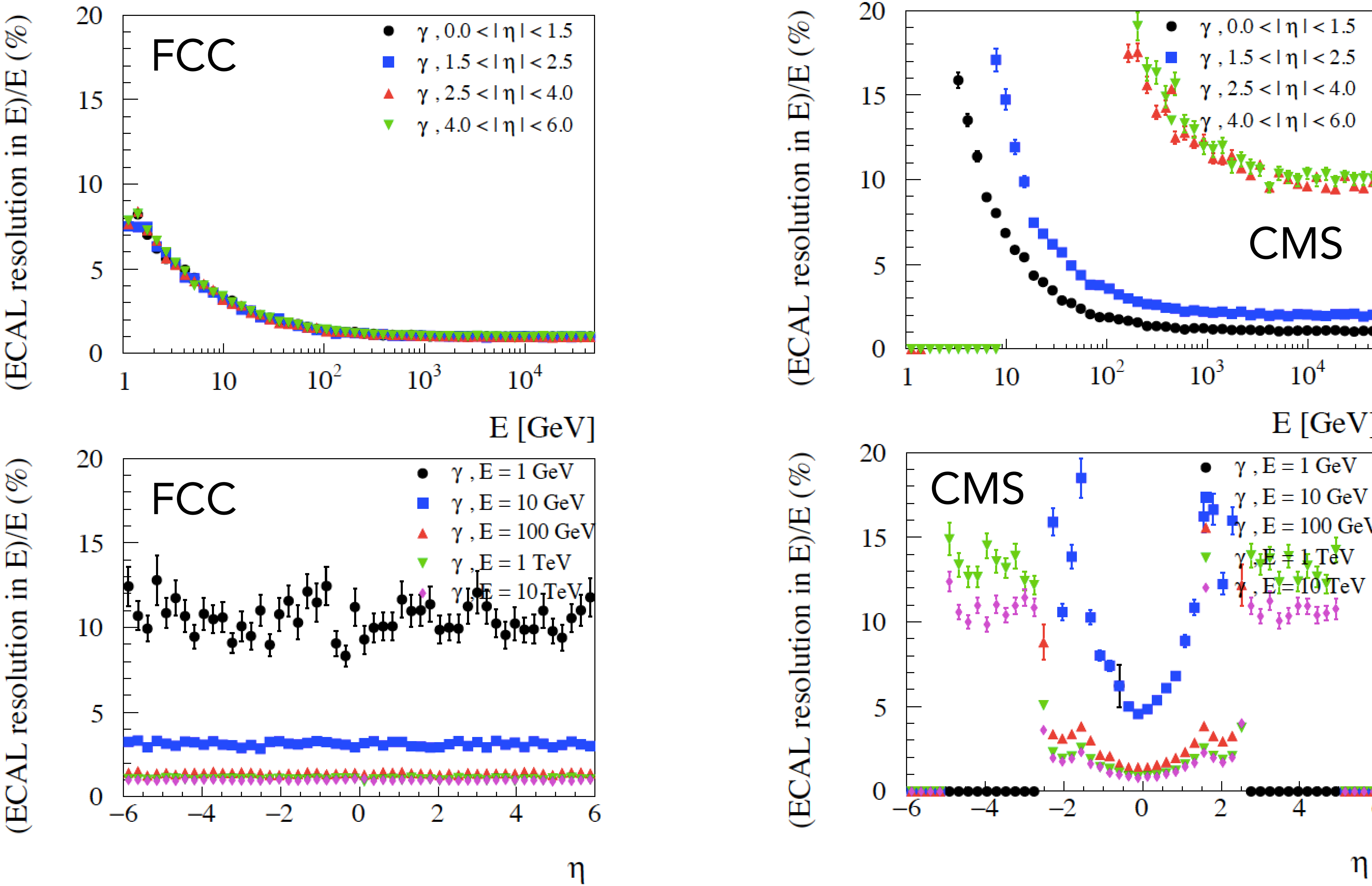


CMS

	$\sigma_{(\eta,\phi)}$	$\sigma(E)/E$
$0.0 < \|\eta\| < 1.5$	0.02×0.02	$\frac{11\%}{\sqrt{E}} + 1\%$
$1.5 < \|\eta\| < 2.5$	0.02×0.02	$\frac{11\%}{\sqrt{E}} + 1\%$
$2.5 < \|\eta\| < 5.0$	$0.175 \times (0.175 - 0.35)$	$\frac{270\%}{\sqrt{E}} + 13\%$



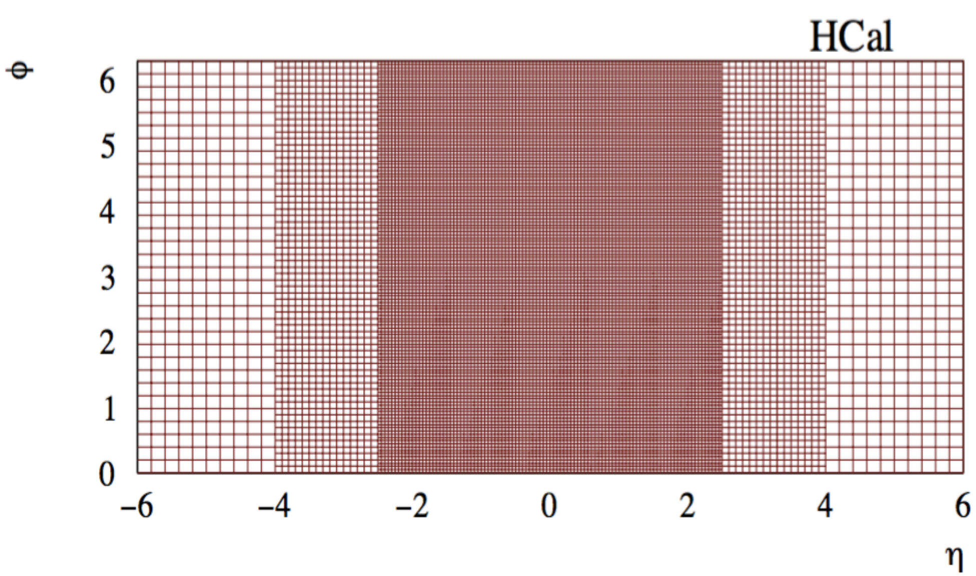
ECAL (II)


FCC
CMS
(ECAL resolution in E)/E (%)
E [GeV]
η
γ , 0.0 < | η | < 1.5
γ , 1.5 < | η | < 2.5
γ , 2.5 < | η | < 4.0
γ , 4.0 < | η | < 6.0
γ , E = 1 GeV
γ , E = 10 GeV
γ , E = 100 GeV
γ , E = 1 TeV
γ , E = 10 TeV

HCAL (I)

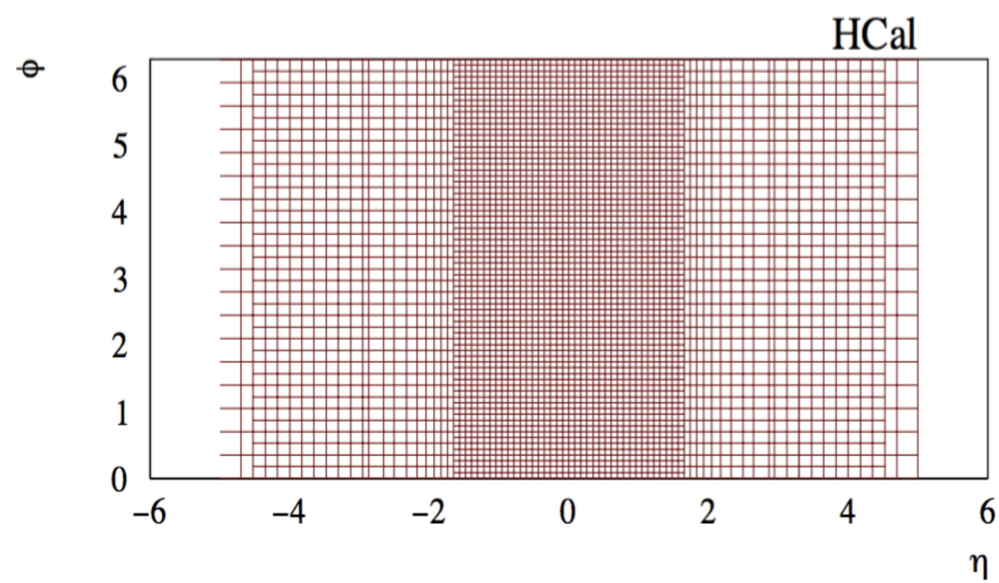
FCC

	$\sigma_{(\eta,\phi)}$	$\sigma(E)/E$
$0.0 < \lvert\eta\rvert < 2.5$	0.05×0.05	$\frac{50\%}{\sqrt{E}} + 3\%$
$2.5 < \lvert\eta\rvert < 4.0$	0.1×0.1	$\frac{50\%}{\sqrt{E}} + 3\%$
$4.0 < \lvert\eta\rvert < 6.0$	0.2×0.2	$\frac{100\%}{\sqrt{E}} + 5\%$

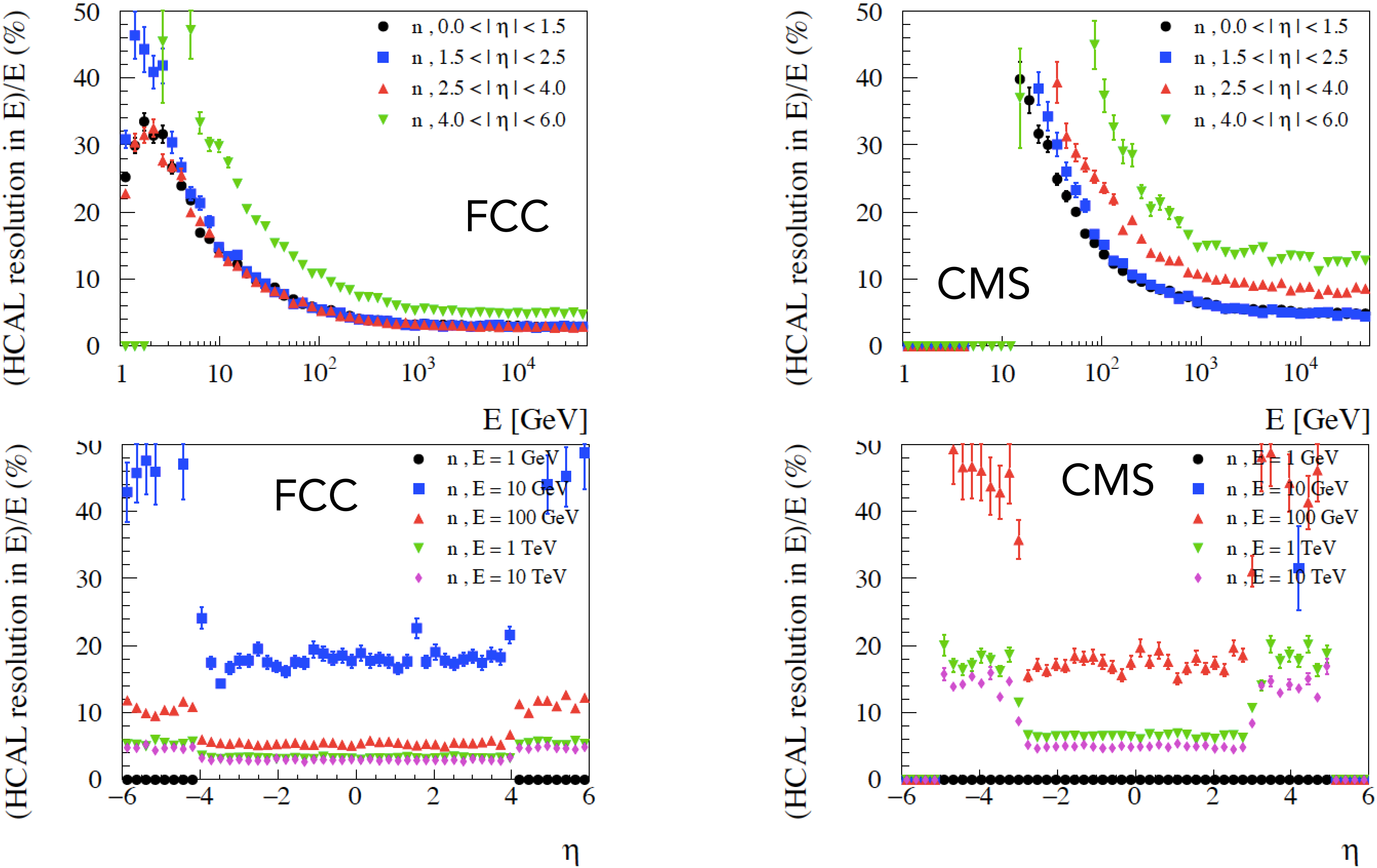


CMS

	$\sigma_{(\eta,\phi)}$	$\sigma(E)/E$
$0.0 < \lvert\eta\rvert < 1.5$	0.1×0.1	$\frac{150\%}{\sqrt{E}} + 5\%$
$1.5 < \lvert\eta\rvert < 3.0$	0.2×0.2	$\frac{150\%}{\sqrt{E}} + 5\%$
$3.0 < \lvert\eta\rvert < 5.0$	$0.175 \times (0.175 - 0.35)$	$\frac{270\%}{\sqrt{E}} + 13\%$

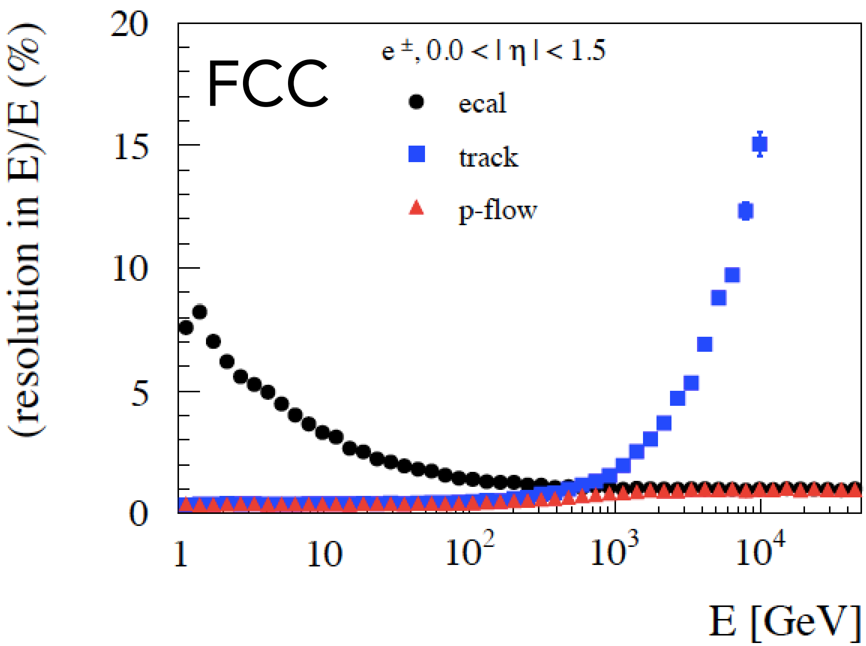


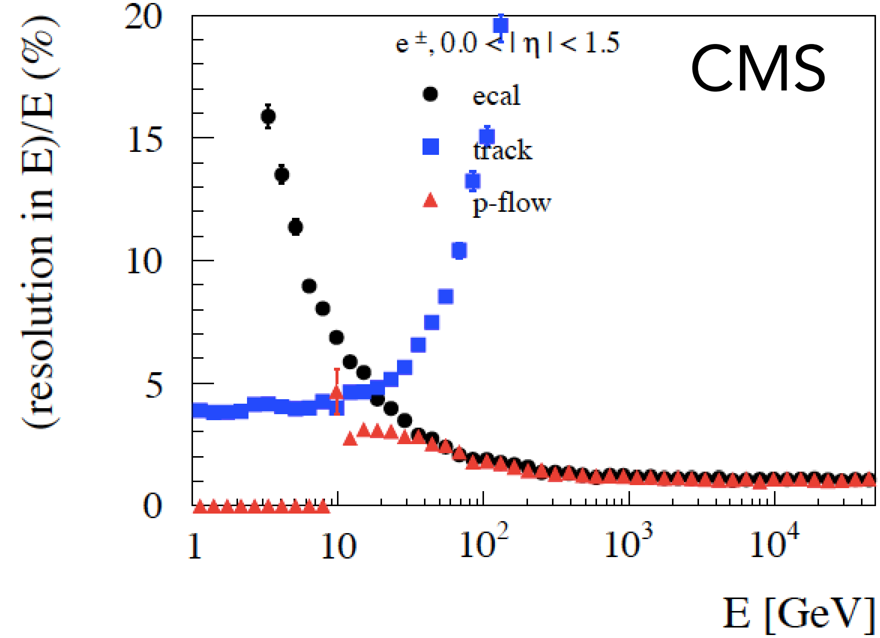
HCAL (II)

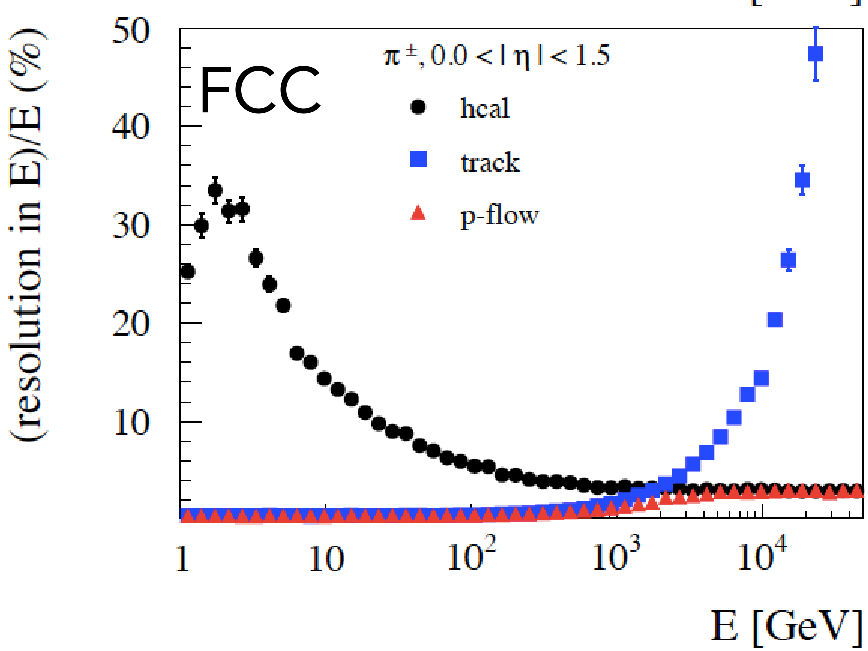


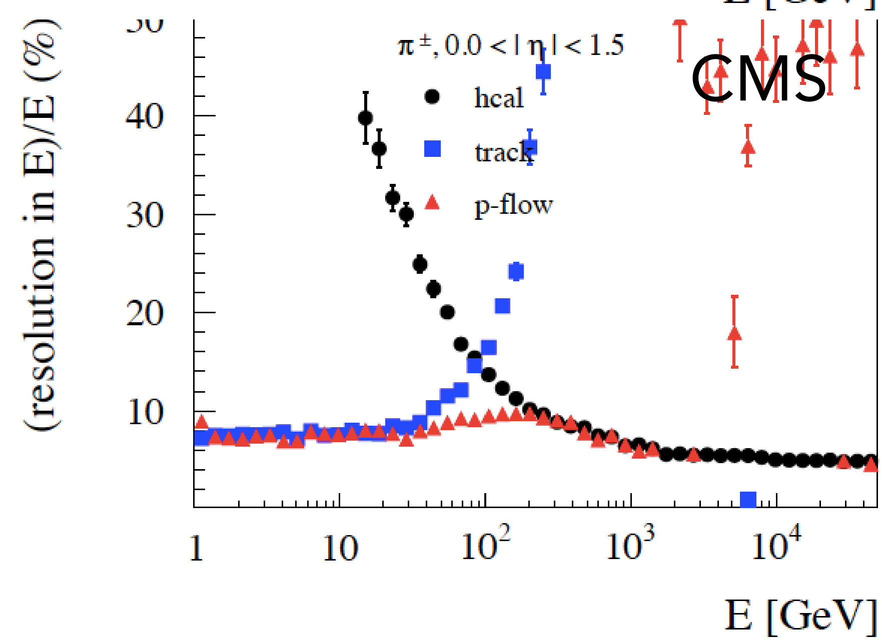
FCC
CMS
(HCAL resolution in E)/E (%)
E [GeV]
η
n , 0.0 < | η | < 1.5
n , 1.5 < | η | < 2.5
n , 2.5 < | η | < 4.0
n , 4.0 < | η | < 6.0
n , E = 1 GeV
n , E = 10 GeV
n , E = 100 GeV
n , E = 1 TeV
n , E = 10 TeV

Particle-Flow (I)

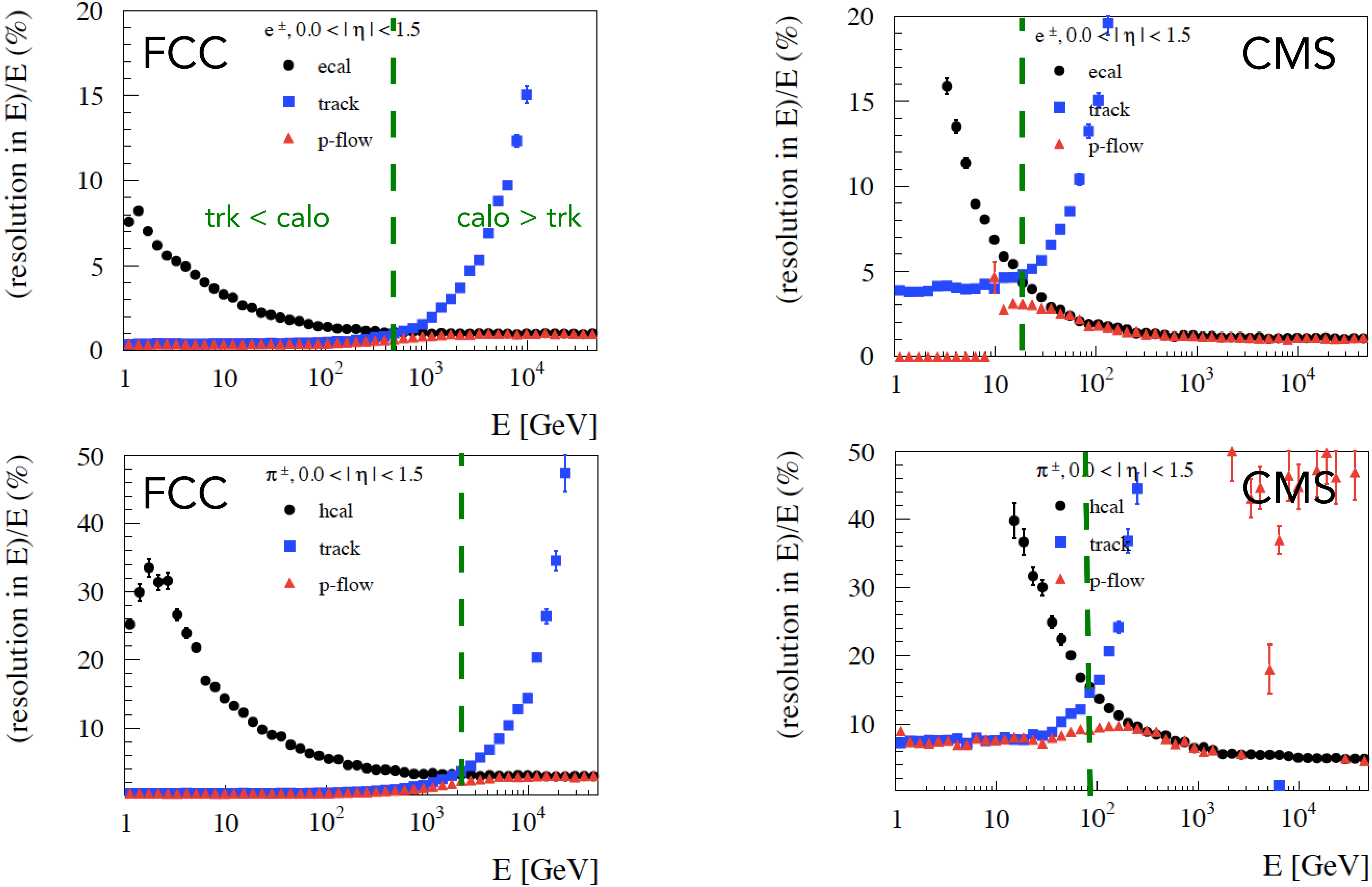




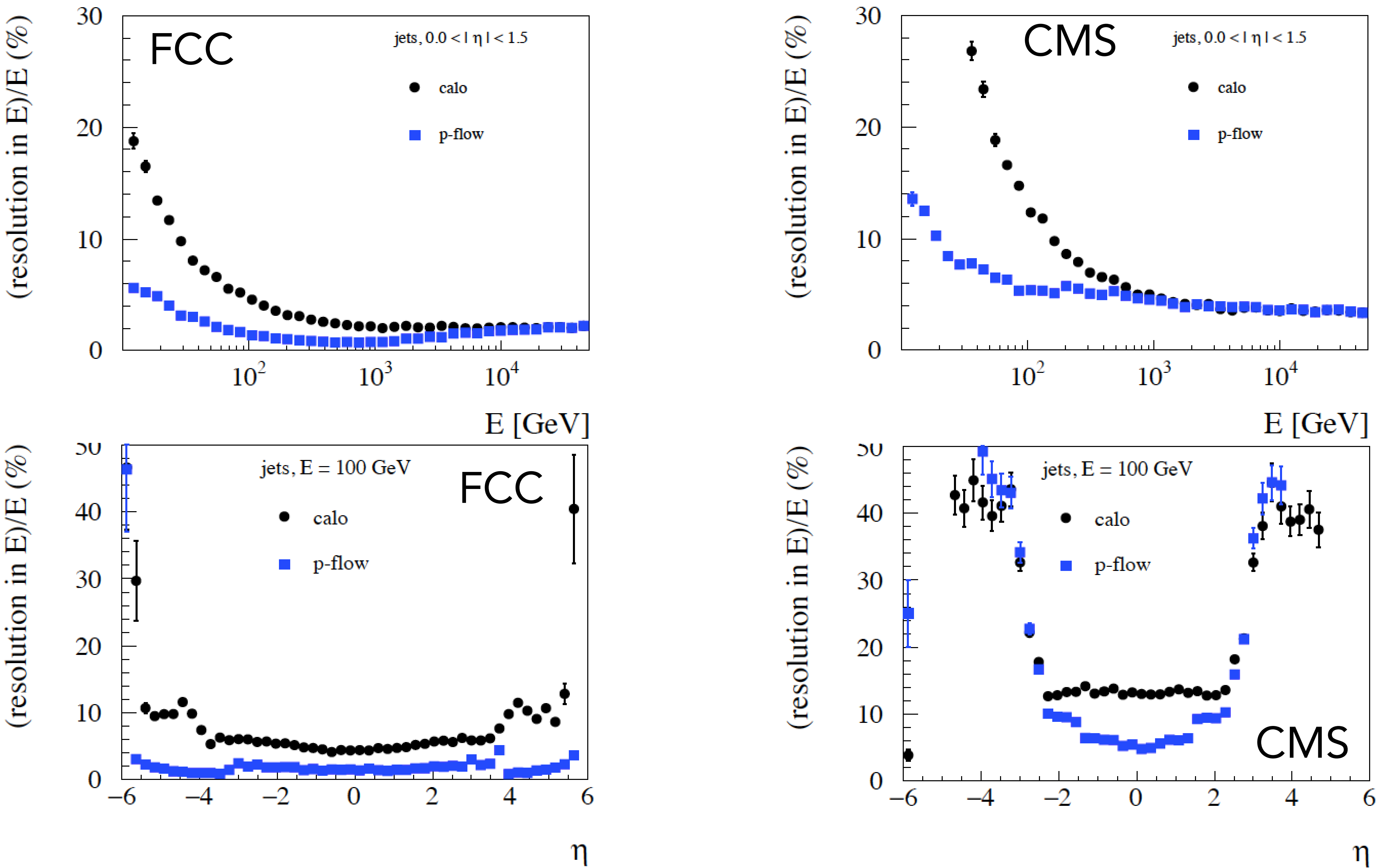




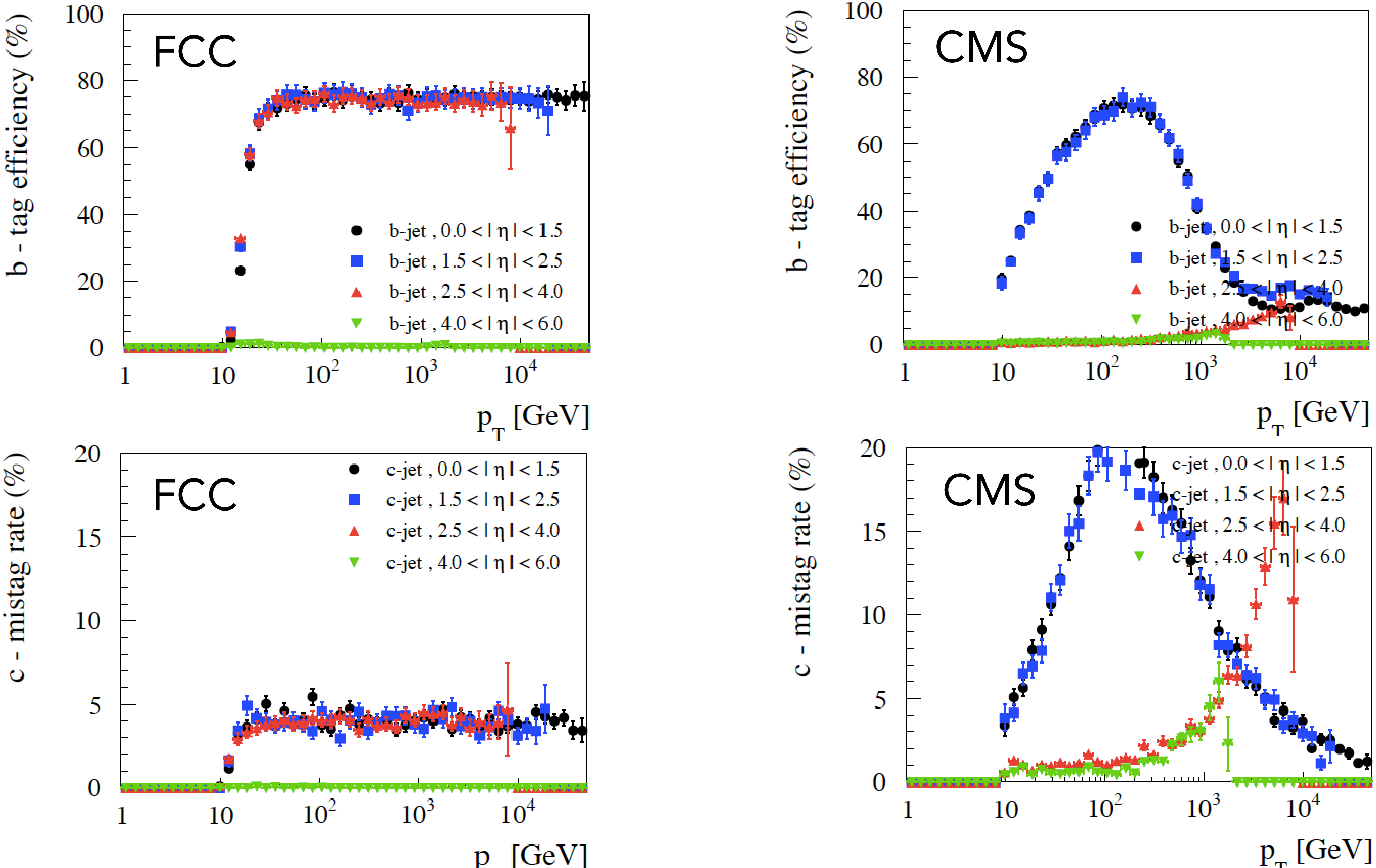
Particle-Flow (I)



Particle-Flow (II)



B-Tagging



FCC
b - tag efficiency (%)
b-jet , 0.0 < | η | < 1.5
b-jet , 1.5 < | η | < 2.5
b-jet , 2.5 < | η | < 4.0
b-jet , 4.0 < | η | < 6.0
p_T [GeV]
CMS
FCC
c - mistag rate (%)
c-jet , 0.0 < | η | < 1.5
c-jet , 1.5 < | η | < 2.5
c-jet , 2.5 < | η | < 4.0
c-jet , 4.0 < | η | < 6.0
CMS

Conclusions & plans

- Subset of validation plots of the present FCC Delphes card have been shown
- Goal should be to freeze the card ASAP
- Before that, these points should be addressed:

  - tracker/muon resolution resolution
  - calorimeter performance (too optimistic? high eta performance?)
  - object reco = id/trigger efficiencies (not shown here)

- Will circulate a report containing all interesting plots (including efficiencies):

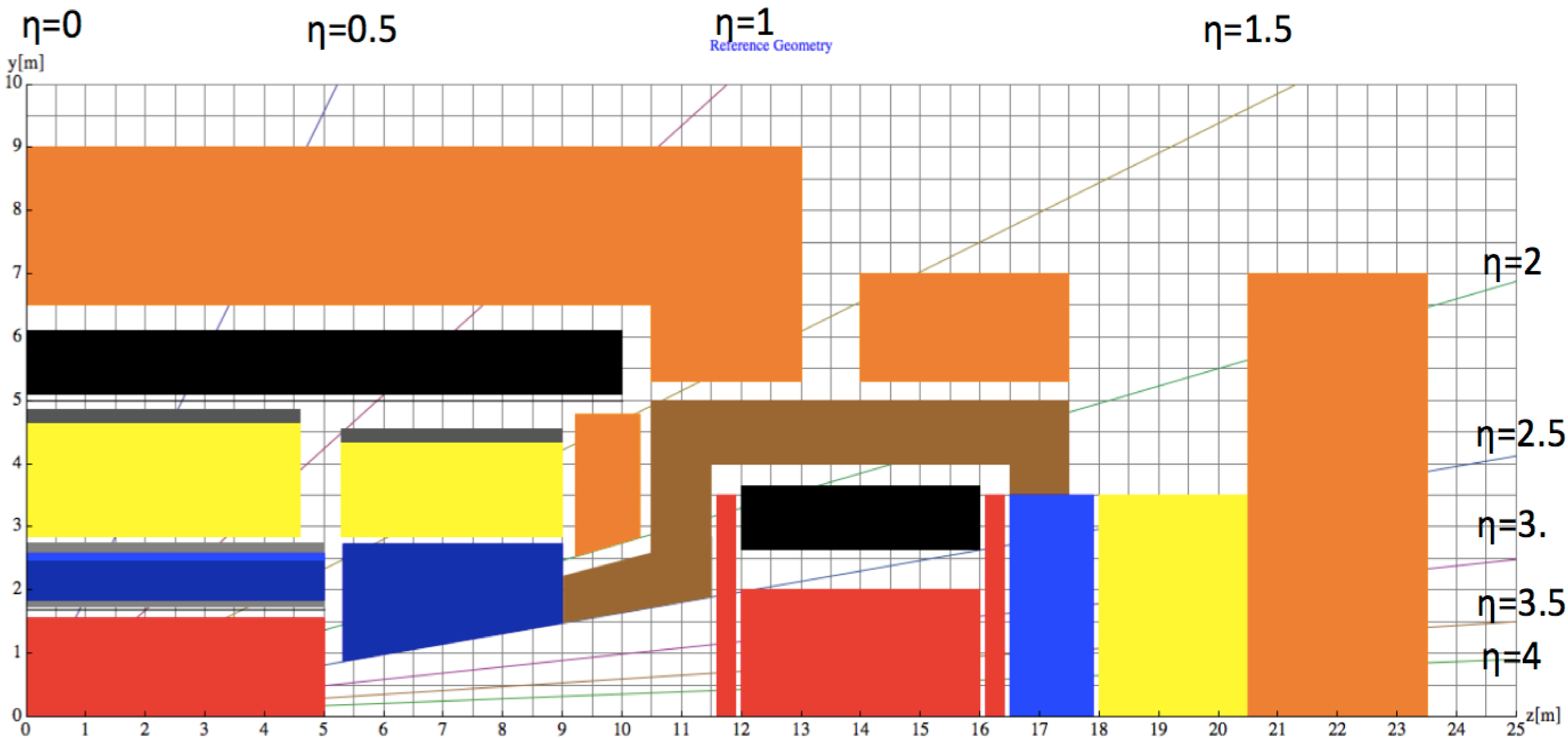
PLEASE HAVE A LOOK AT THEM AND SEND COMMENTS

- Once the detector configuration is freezed, we can start doing some physics…

- Start with a full, simple and well documented example of a physics analysis in FCCSW+Delphes (for instance H-> 4l, H->γγ, …)

Back-up

Detector Layout



W. Riegler layout, proposed 13/08/2016

Muon resolution

$$\sigma_y = \frac{1}{\sqrt{3}} L_{Calo}\,\theta_0$$

Muon System standalone

$$\frac{\Delta p}{p} = \frac{2p}{0.3 L_1 B}\sqrt{\theta_0^2 + \sigma_{theta}^2} \qquad \theta_0 = \frac{0.0136}{\beta p[GeV/c]}\sqrt{\frac{L_{Calo}}{X0_{Calo}}}\left(1 + 0.038\log\frac{L_{Calo}}{X0_{Calo}}\right)$$

Inner Tracker

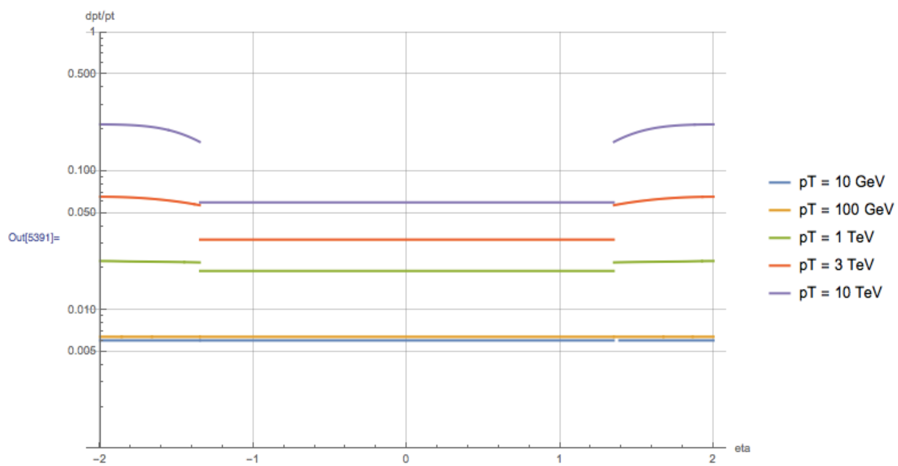
$$\frac{\Delta p}{p} = \frac{p}{0.3B}\,\frac{\sigma}{L_0^2}\sqrt{\frac{720N^3}{(N-1)(N+1)(N+2)(N+3)}} \approx \frac{p}{0.3B}\,\frac{\sigma}{L_0^2}\sqrt{\frac{720}{N+5}} \qquad N \gg 1$$

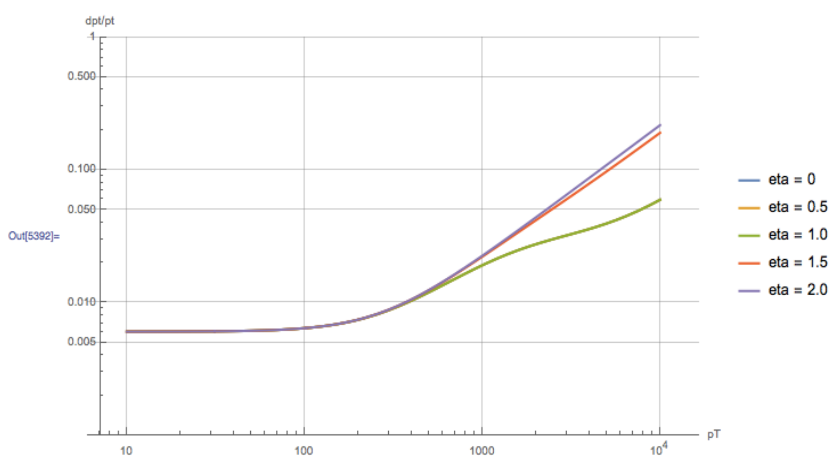
Combined

$$\frac{\Delta p}{p} = \frac{p}{0.3B}\,\frac{\sigma_0}{L_0^2}\sqrt{\frac{720N^3(c_1\sigma_0^2 + c_2\sigma_1^2)}{(N+1)(N+2)(c_3\sigma_0^2 + c_4\sigma_1^2)}} \qquad (211)$$

$$\begin{aligned}
c_1 &= 2[2N(L_0^2 - 3L_0L_1 + 3L_1^2) + L_0^2] \\
c_2 &= L_0^2(N+1)(N+2) \\
c_3 &= 3\left[L_0^2(3N^3 - N - 2) - 12L_0L_1(2N^3 - N^2 - N) + 12L_1^2(7N^3 - N^2 - N)\right] + 60N^3\frac{L_1^4}{L_0^2} - 120N^3\frac{L_1^3}{L_0} \\
c_4 &= L_0^2(N-1)(N+1)(N+2)(N+3)
\end{aligned}$$

Muon resolution





- $|\eta| < 1.35$

  sin(θ) dependence cancels out.
  -> resolution flat over η

- $1.35 < |\eta| < 2.0$

  jump due to muon station being closer

- $2.0 < |\eta| < 6.0$

  simply assume tracker resolution

Particle-Flow

- Idea: Reproduce realistically the performances of the Particle-Flow algorithm.

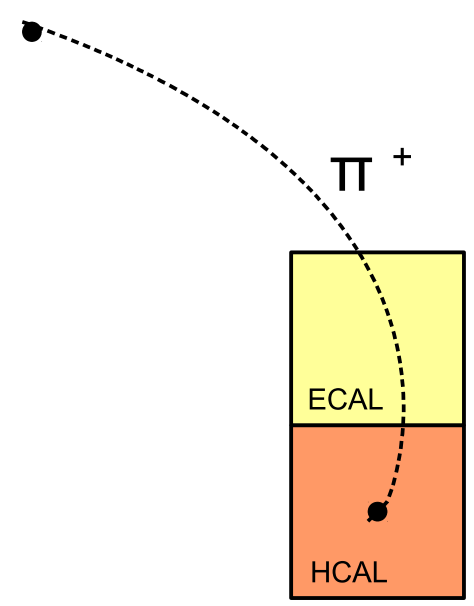
- In practice, in DELPHES use **tracking and calo** info to reconstruct high reso. input objects for later use (jets, E_T^{miss}, H_T)

→ If σ (trk) < σ (calo) (low energy)

Example: A pion of 10 GeV

$E^{HCAL}(\pi^+) = 9$ GeV

$E^{TRK}(\pi^+) = 11$ GeV



Particle-Flow algorithm creates:

PF-track, with energy $E^{PF\text{-}trk} = 11$ GeV

Separate neutral and charged calo deposits has crucial implications for pile-up subtraction

Particle-Flow

- Idea: Reproduce realistically the performances of the Particle-Flow algorithm.

- In practice, in DELPHES use **tracking and calo** info to reconstruct high reso. input objects for later use (jets, E_T^{miss}, H_T)

→ If **σ(trk) < σ(calo) (low energy)**

Example: A pion of 10 GeV

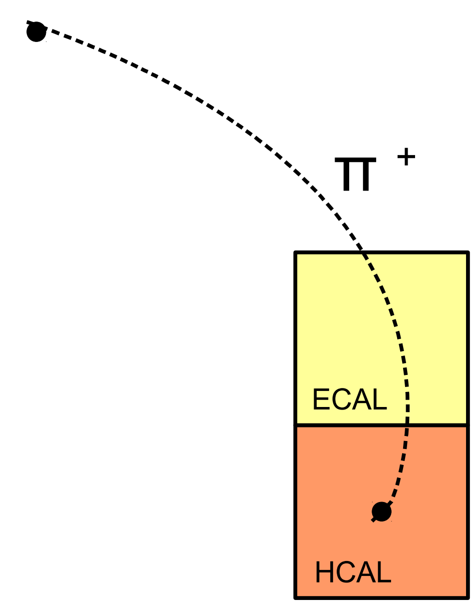
$E^{HCAL}(\pi^{+}) = 15$ GeV

$E^{TRK}(\pi^{+}) = 11$ GeV

Particle-Flow algorithm creates:

PF-track, with energy $E^{PF\text{-}trk} = 11$ GeV

PF-tower, with energy $E^{PF\text{-}tower} = 4$ GeV



Separate neutral and charged calo deposits has crucial implications for pile-up subtraction

Particle-Flow

- Idea: Reproduce realistically the performances of the Particle-Flow algorithm.

- In practice, in DELPHES use **tracking and calo** info to reconstruct high reso. input objects for later use (jets, E_T^{miss}, H_T)

→ If **σ (trk) > σ (calo) (high energy)**

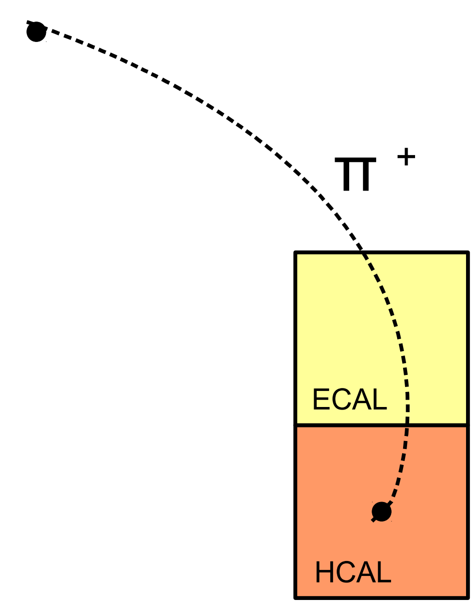
Example: A pion of 500 GeV

$E^{HCAL}(\pi^+) = 550$ GeV

$E^{TRK}(\pi^+) = 400$ GeV

Particle-Flow algorithm creates:

PF-track, with energy $E^{PF\text{-}trk} = 550$ GeV
and no PF-tower



Separate neutral and charged calo deposits has crucial implications for pile-up subtraction