# Measurement of Classical Jet Shape in pp Collisions

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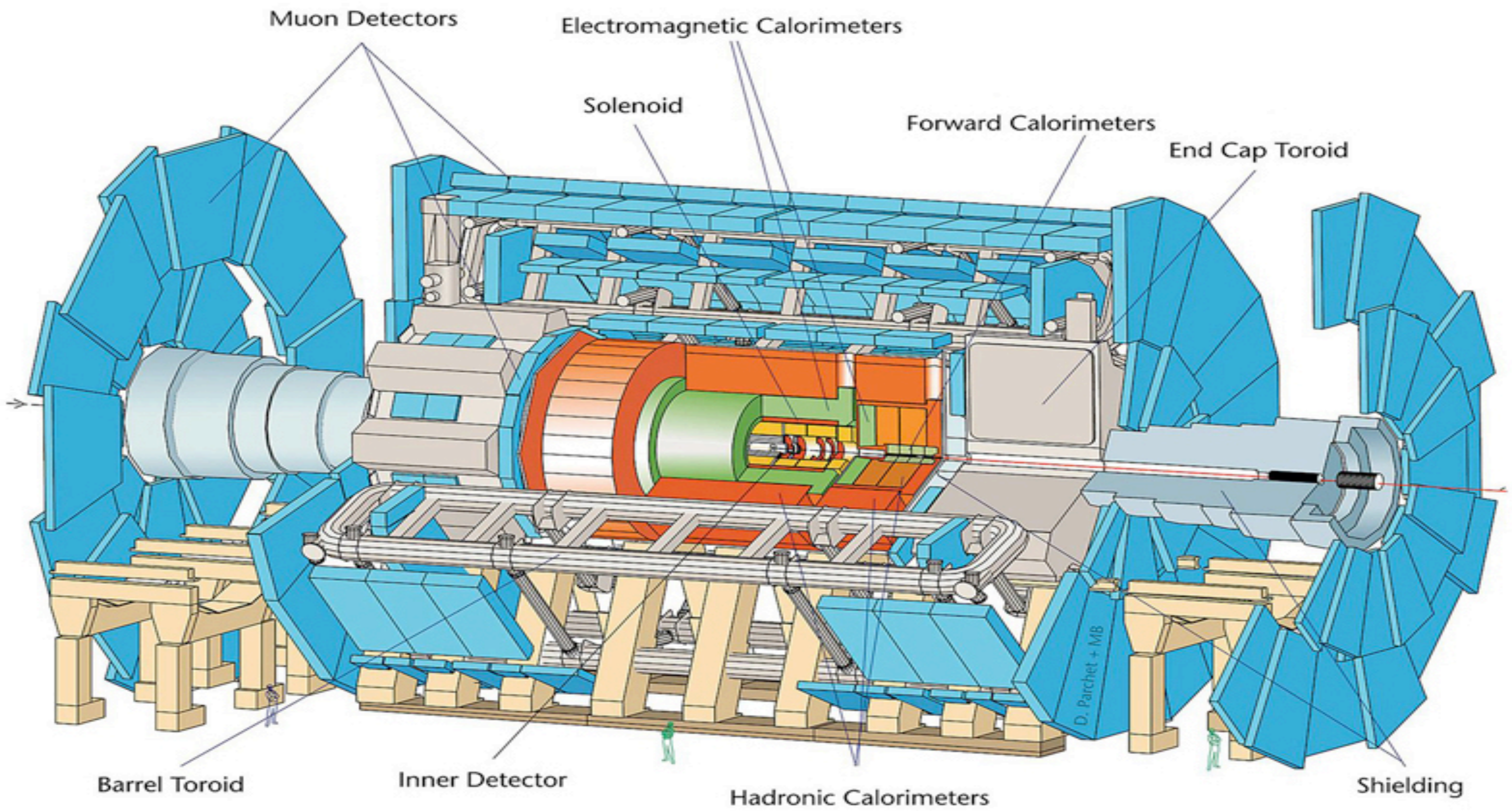
# CMS overview



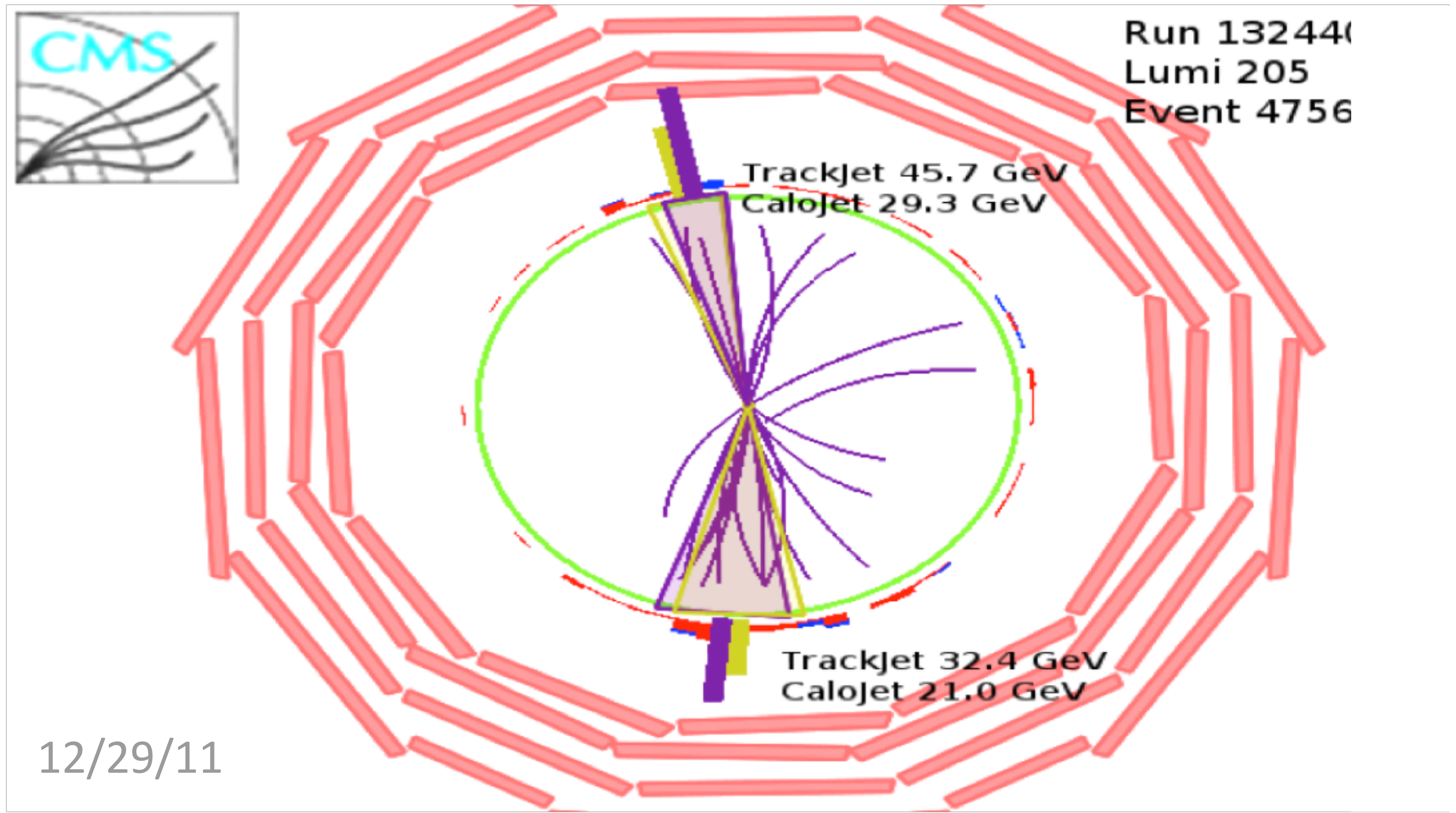

- Muon chambers outside 3.8 T magnet, interleaved with iron return yoke

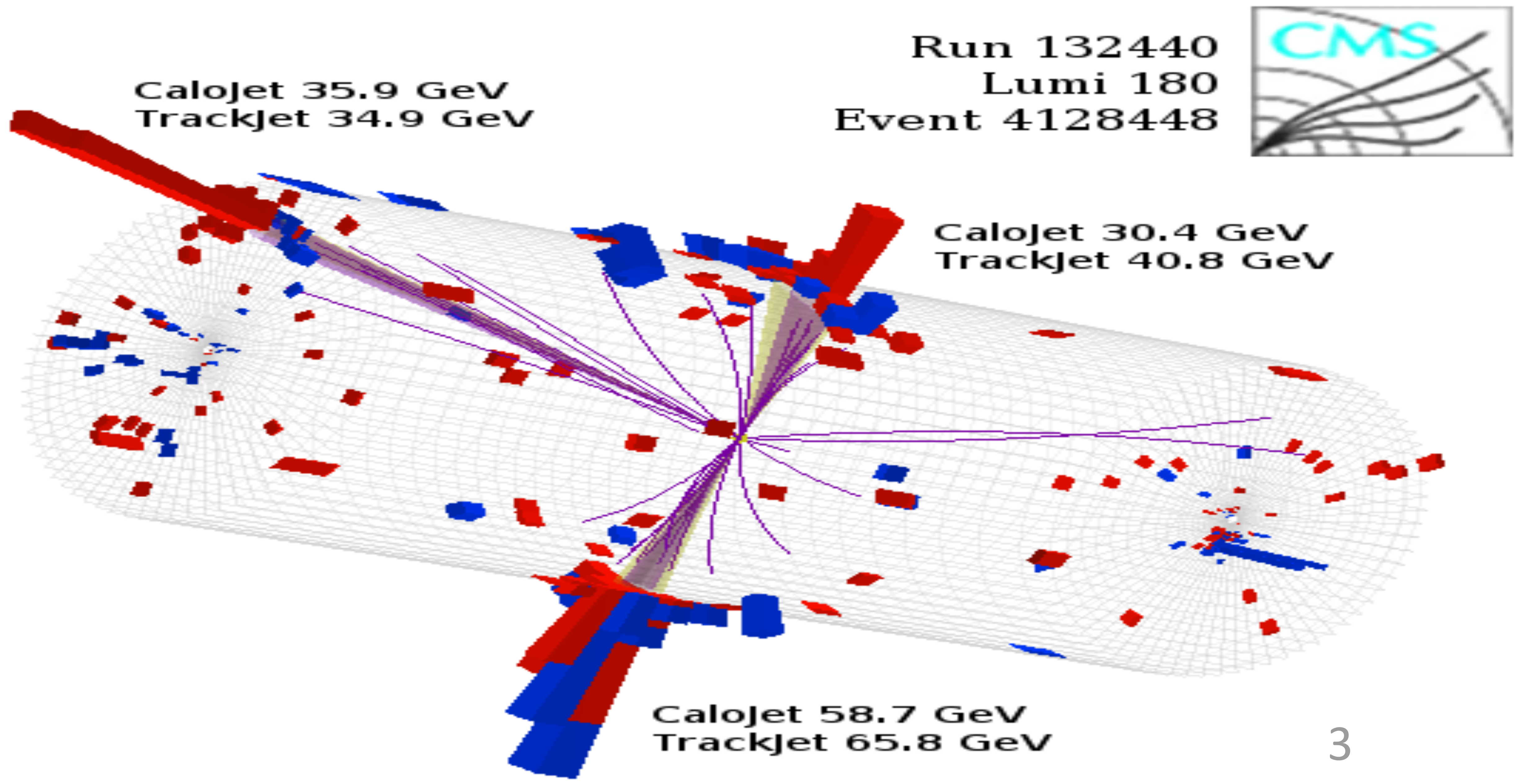
Tracking, ECAL and HCAL all embedded the solenoid magnet:

- Precise silicon pixel and silicon strip tracking system at $|\eta| < 2.4$
- Fine-grained lead tungstate crystal ECAL at $|\eta| < 3.0$
- Barrel+end cap HCAL up to $|\eta| < 3$, hadronic forward up to $|\eta| < 5$

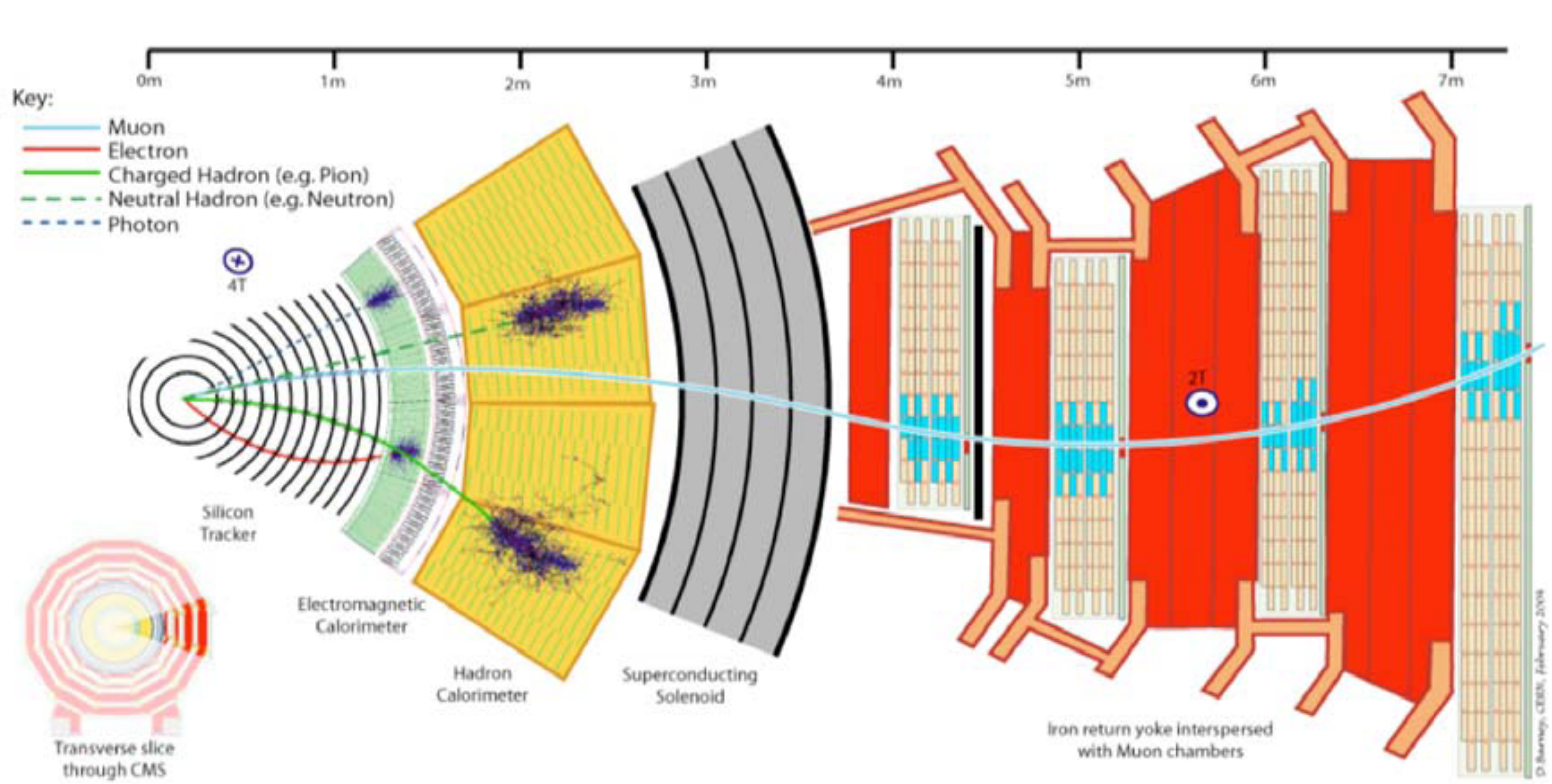
# Jets in CMS

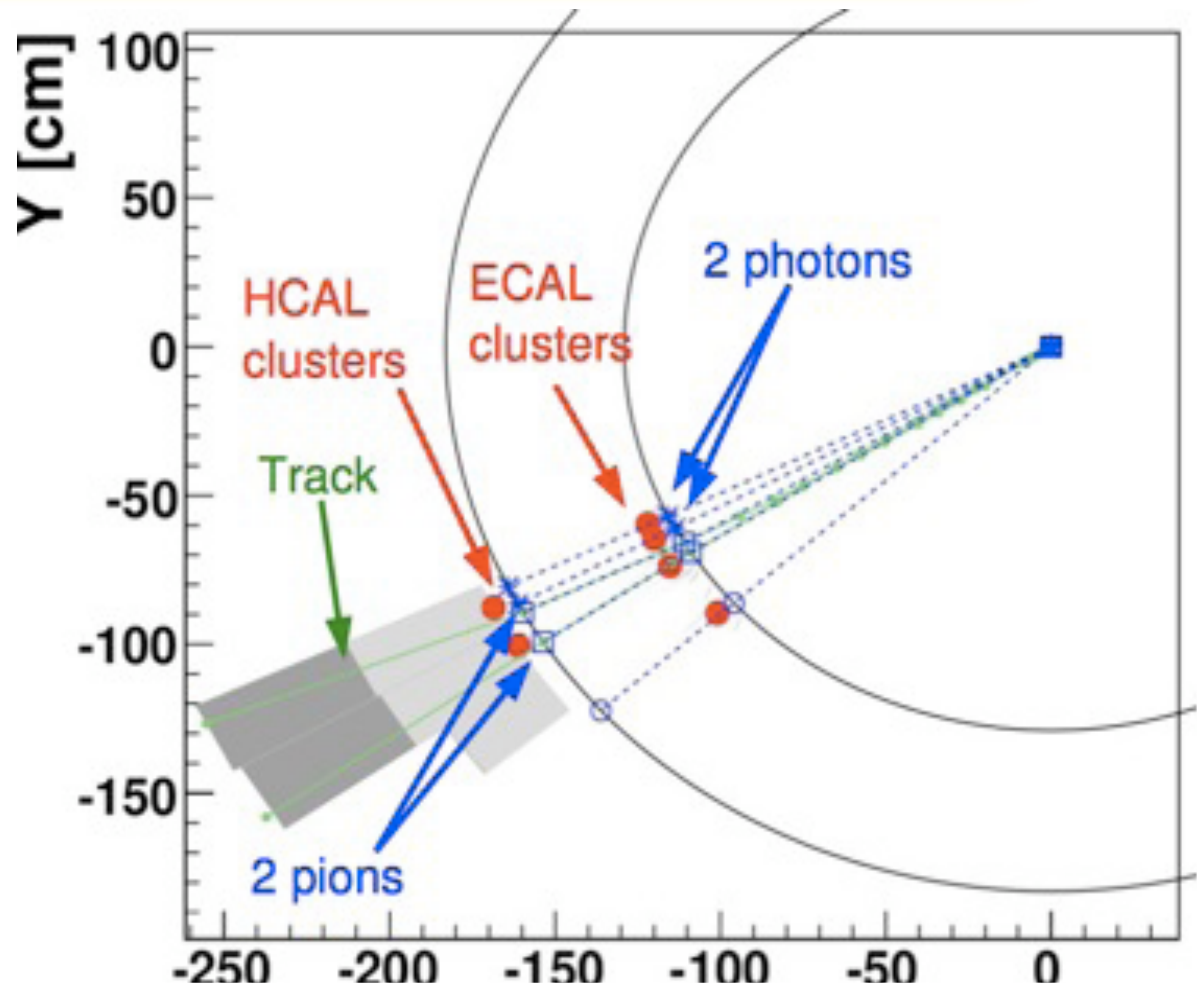
- Jets are experimental signatures of quarks and gluons from hard collision.
- Four types of jets are reconstructed using the **anti-$k_T$** clustering algorithm with the size parameter *R=0.5* or *0.7*.
  - Calorimeter jets are reconstructed using energy deposits in the ECAL and HCAL cells.
  - Jet-Plus-Track jets correct calorimeter jets with tracking information.
  - Particle Flow (PF) jets algorithm combines the information from all CMS sub-detectors to identify and reconstruct all particles.
  - Track jets are reconstructed from tracks of charged particles.



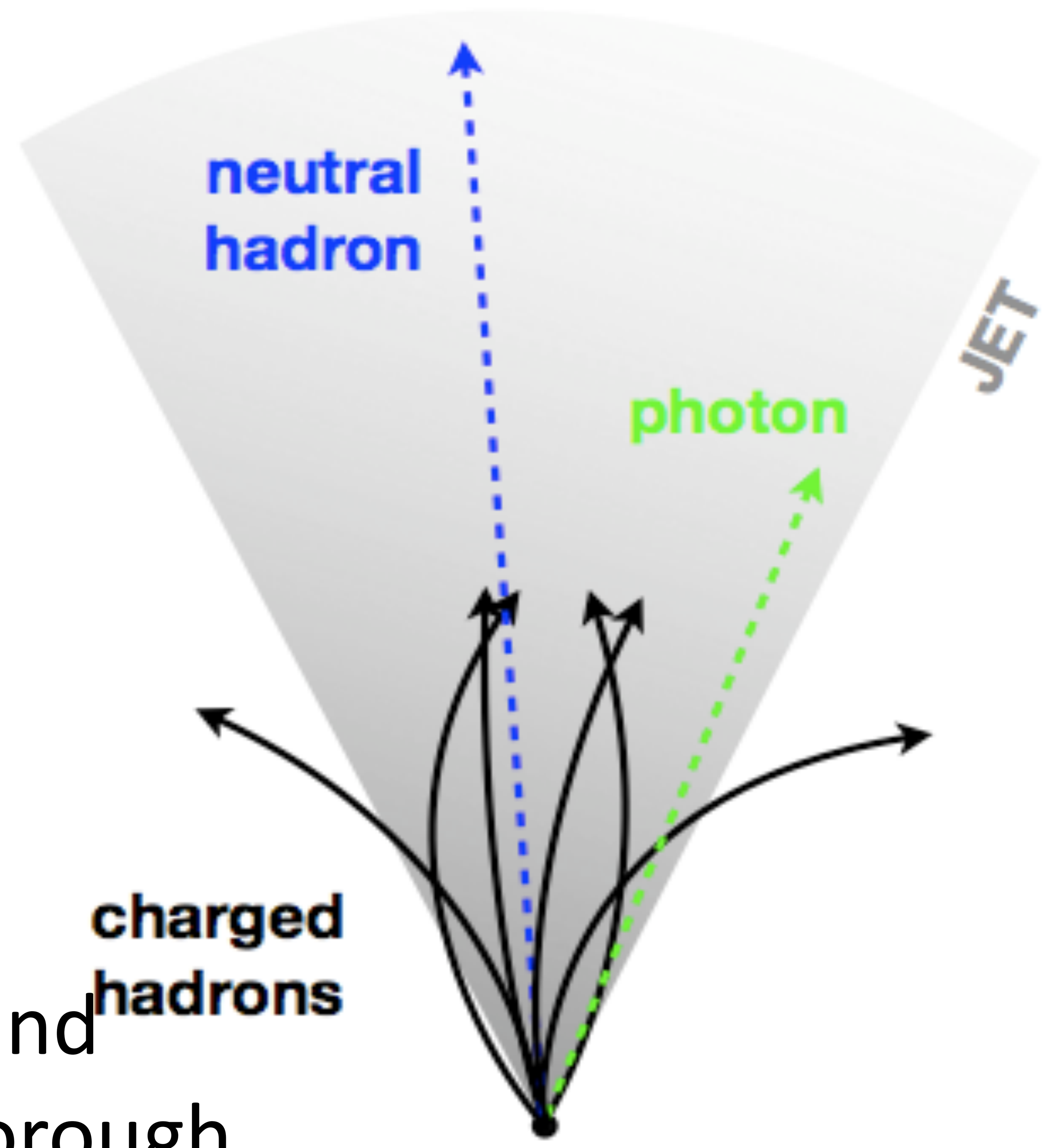
# Particle Flow Jets (PF Jets)




✧PFCandidate combines information from various detectors to make the best combined estimation of particle properties

- ➢ECAL cluster
- ➢HCAL cluster
- ➢Propogate track to cluster
  - ✓Both EM and Had cluster (Charged Hadrons)
  - ✓ECAL clusters, no track (Photons)
  - ✓HCAL clusters, no track (Neutral Hadrons)




✧The particle-flow event reconstruction aims at reconstructing and identifying all stable particles in the event, with athorough combination of all CMS sub-detectors.

# Motivation

✧ The transverse momentum profile of a jet, jet shapes, measure the average energy flow as a function of distance away from the jet axis.

✧Test showering models in MC generators.

✧Discriminate between different underlying event (UE) models.

✧Sensitive to the quark/gluon jet mixture.

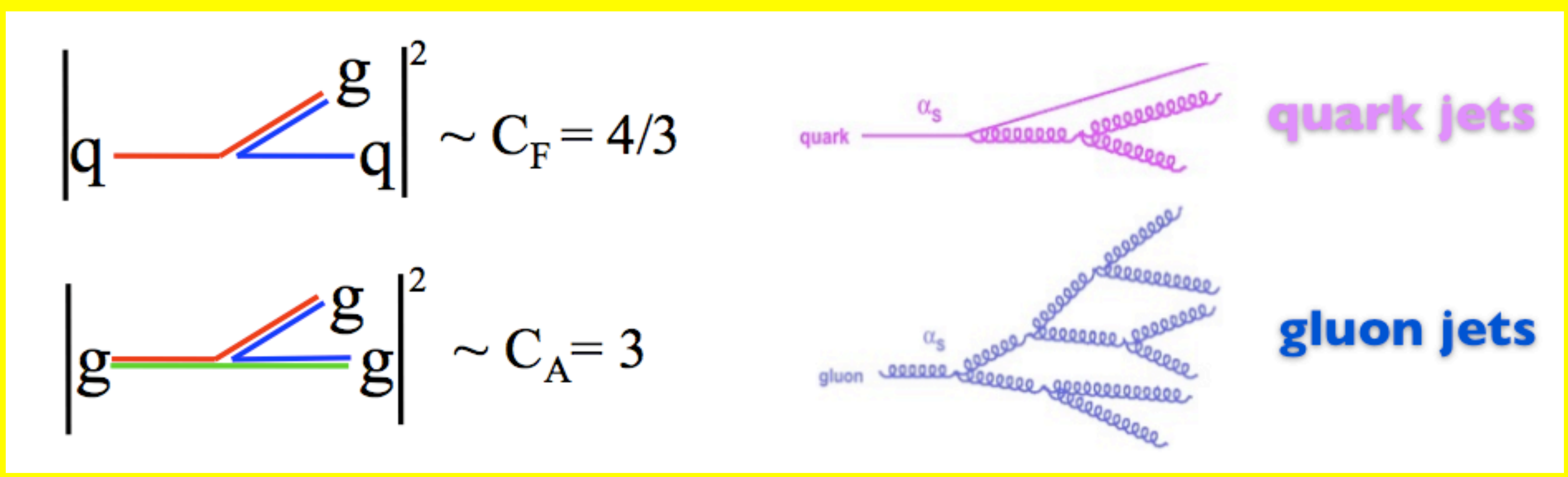
✧Provide insight into performance of jet clustering algorithms.

# Quark Gluon Seperation

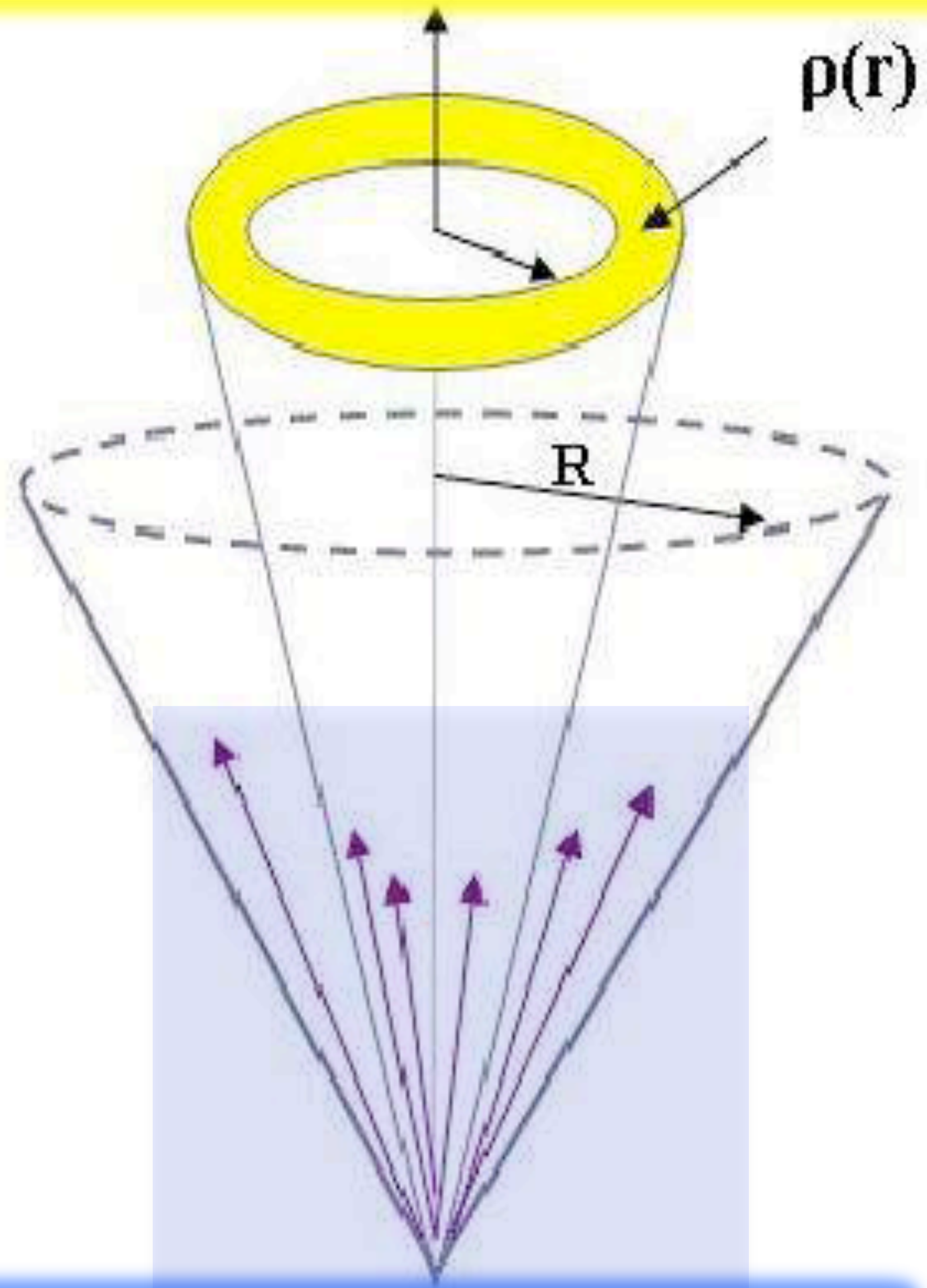
- ✧ Jet Shapes are sensitive to quark/gluon jet mixture
- ✧ Quark and Gluon jets radiate proportionally to their color factors.

  $C_F$ = strength of gluon coupling to quarks

  $C_A$ = strength of gluon self coupling
- ✧ In QCD, quarks jets are expected be narrower than gluon jets



# Classical Jet Shape : Definition




### Differential Jet Shape

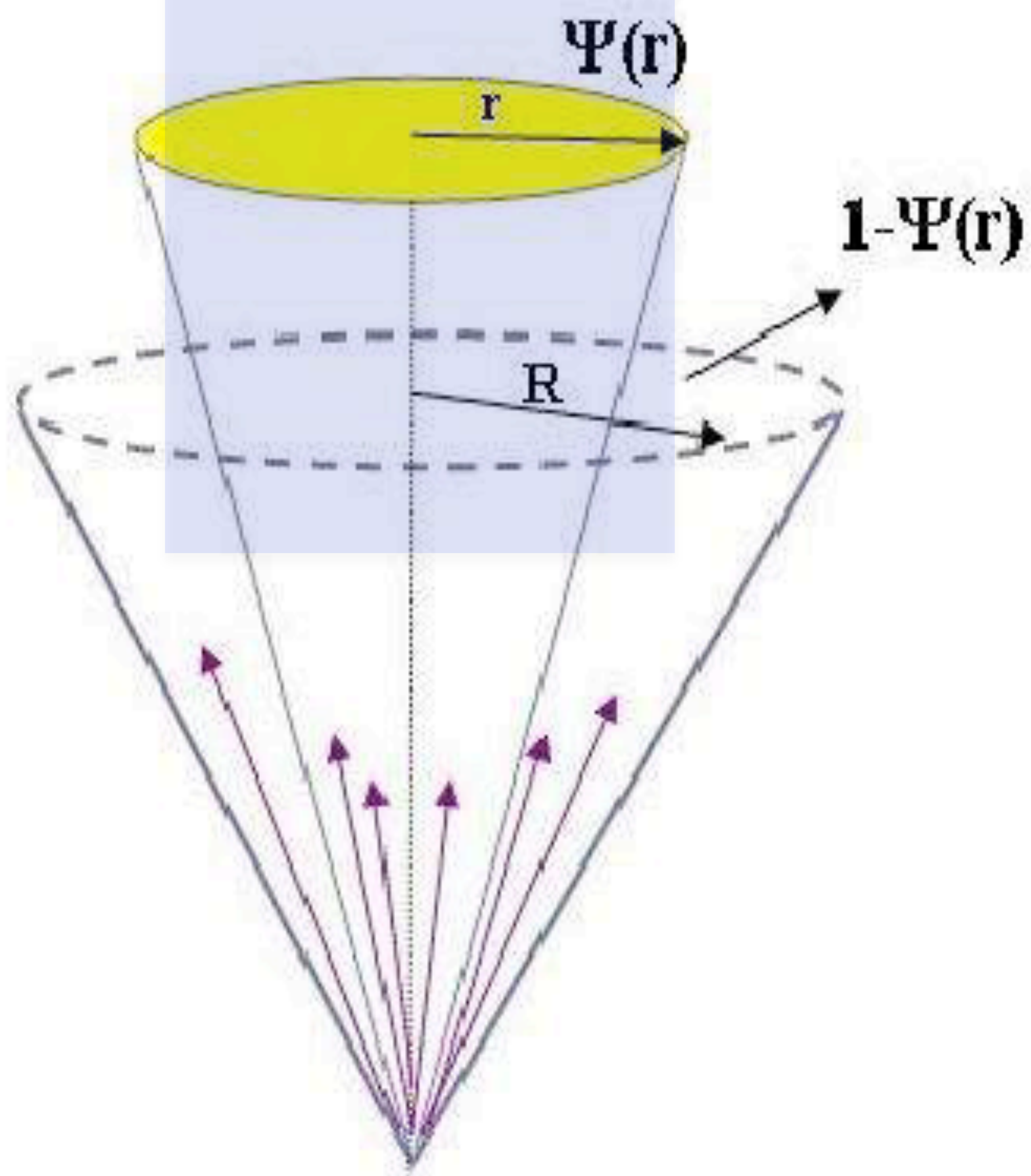
**Definition:** The average fraction of the jet's transverse momentum that lies inside an annulus in the yΦ plane of inner (outer) radius rΔr/2 (r+Δr/2) concentric to the jet cone.

$$\rho(r) \equiv \frac{1}{\delta r}\frac{1}{N_{jets}}\sum_{jets}\frac{p_T(r-\delta r/2, r+\delta r/2)}{P_T(0,R)}$$

### Integrated Jet Shape

**Definition :** The average fraction of jet transverse momentum that lies inside a cone of radius r concentric to the jet axis.

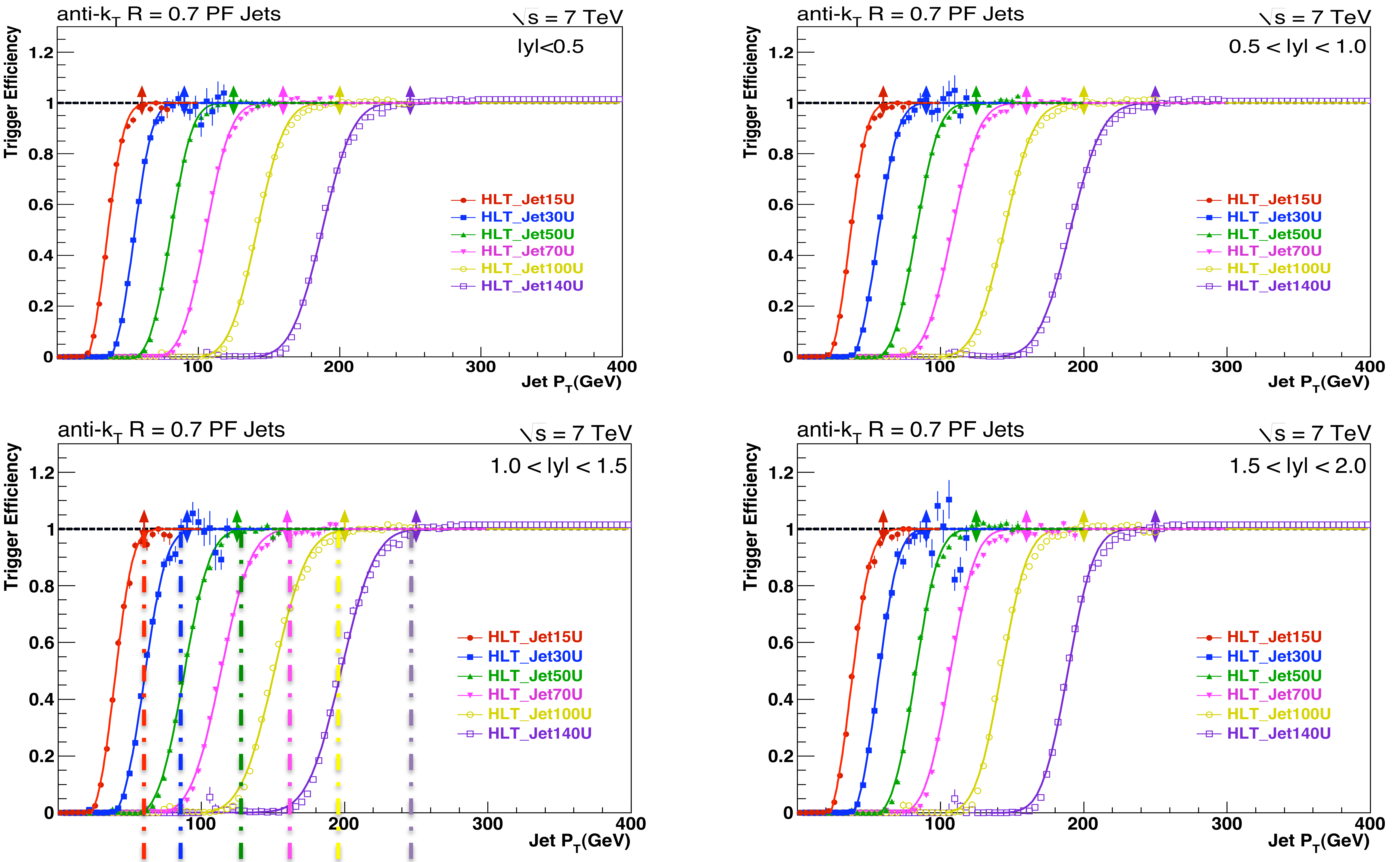
$$\Psi(r) = \frac{1}{N_{jets}}\Sigma_{jets}\frac{P_T(0,r)}{P_T^{jet}(0,R)}$$



# Event Selection

- ✧ Cleaning
  - ➢ HBHENoiseFilter to remove non physics events
  - ➢ MET/$E_T$ < 0.5 to remove fake jets
  - ➢ Loose PFJETID cuts to remove jet which contain fake energy.
- ✧ Vertex Selection Criteria
  - ➢ Number of Degrees Freedom (ndof > 4)
  - ➢ Z position of the vertex ( |z|<24 cm)
  - ➢ Radial position of vertex (|rho|< 2 cm)
- ✧ Jet Selection
  - ➢ Inclusive jets (PFJetID+ $P_T^{corrected\ jet}$> 8 GeV)
  - ➢ Anti-$K_T$ PFJets are reconstructed with R=0.7 size
  - ➢ used HLT Jet Triggers
  - ➢ Used rapidity bins and $P_T$ bins

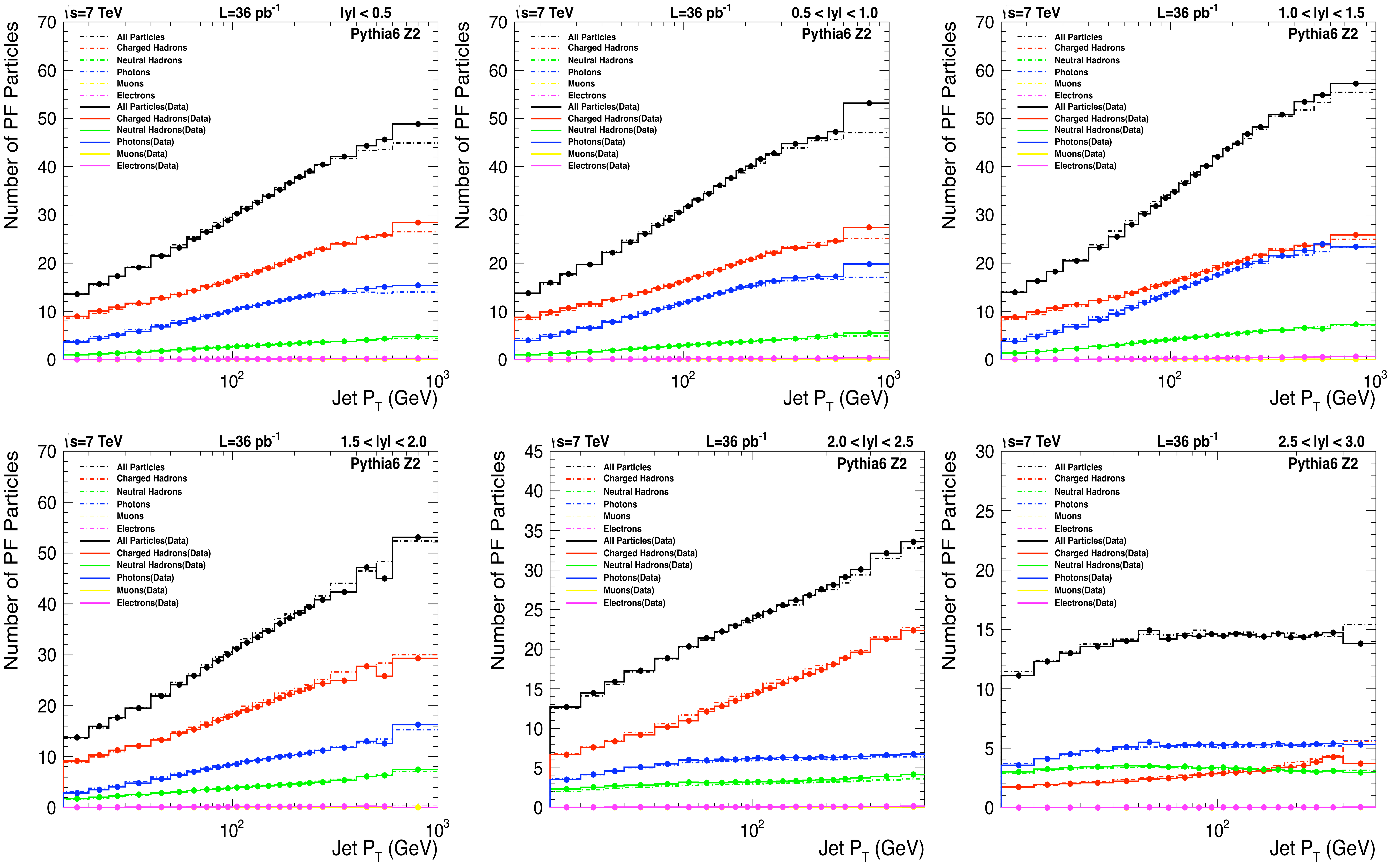
# Trigger Turn-on Curves




Trigger Efficiencies look nicely pletauing at unity at high P$_T$'s

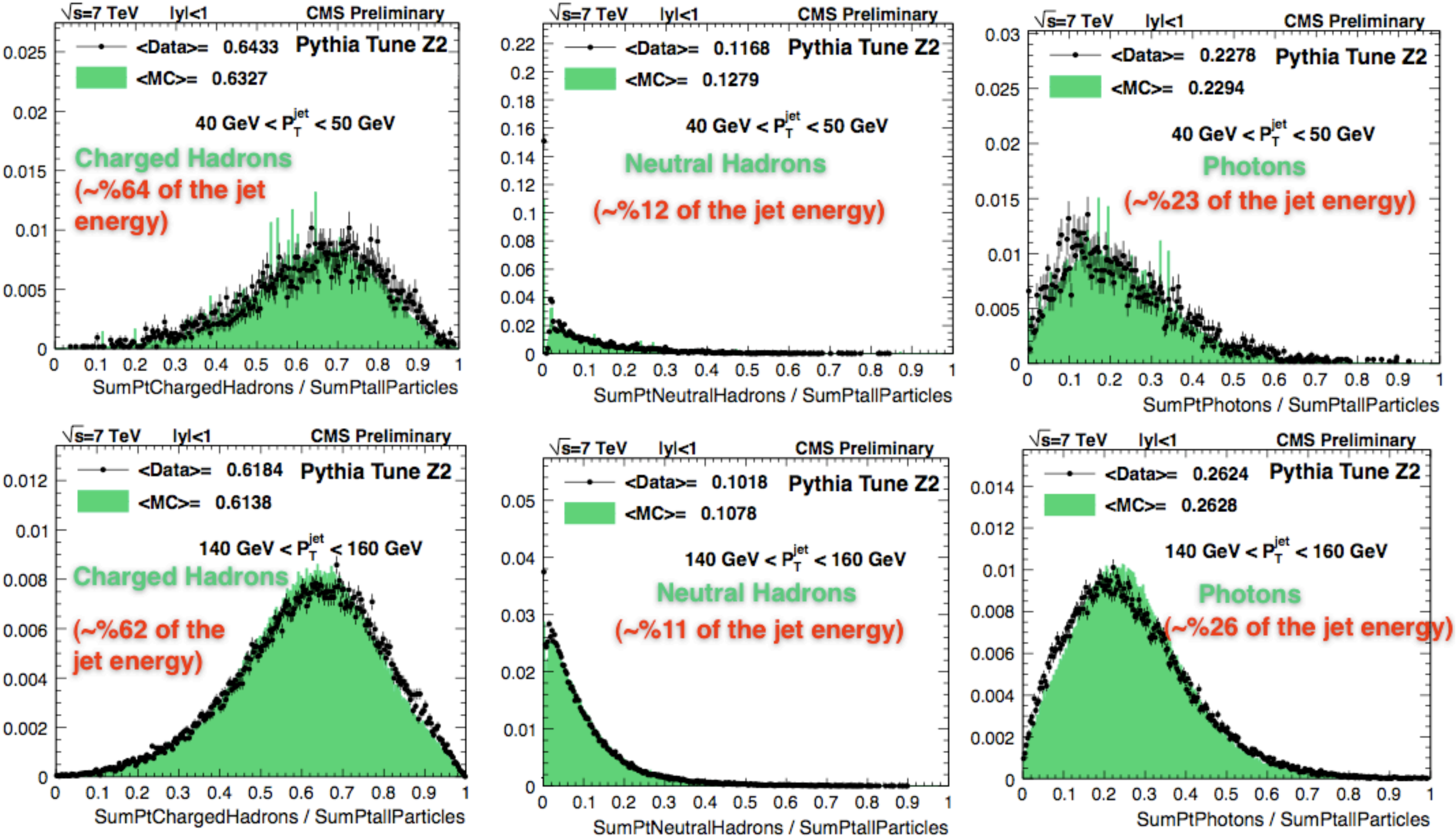
60 90 125 160 200 250 (GeV)

# Multiplicity



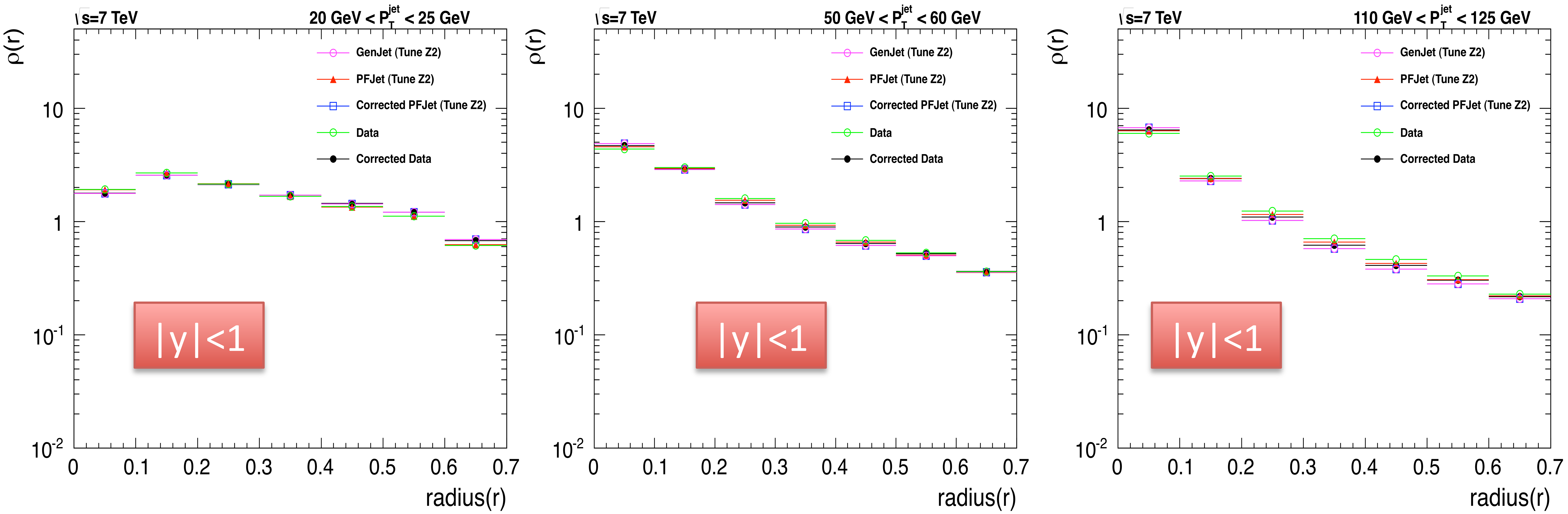

Multiplicity in a jet increases as a function of $P_T$ for Pythia6 Z2

# Sum $P_T$ Fraction




Reconstructed PF objects carry expected fraction of the jet energy

# Differential Jet Shapes




Gen/PF ratios are used to correct the reconstructed data

✧Corrected Reco and Gen distributions should agree by construction.

➢Smearing of jets in and out of a given $P_T$ bin

Detector is not perfect, so reconstructed energy is smeared (broader shapes after reco)

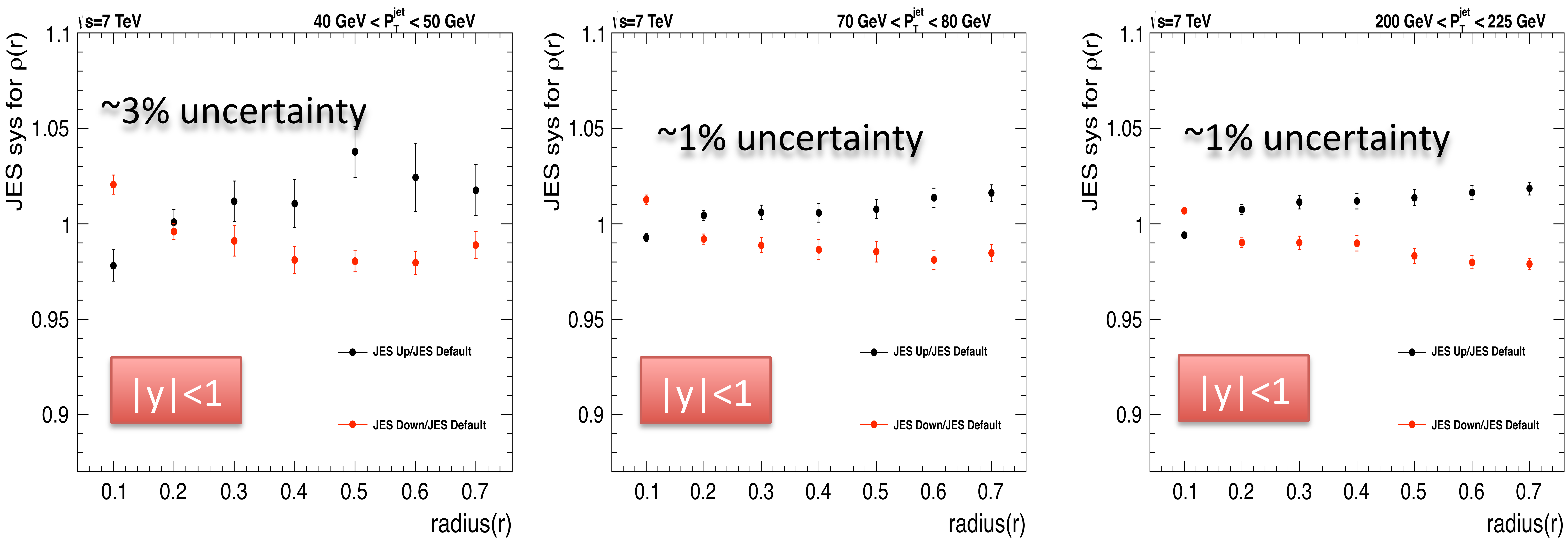
➢Difference in the reconstruction of particles.

# Systematics

- ✓ Jet Energy Scale
- ✓ Unfolding Based Systematics
- ✓ Single Particle Response

# Jet Energy Scale

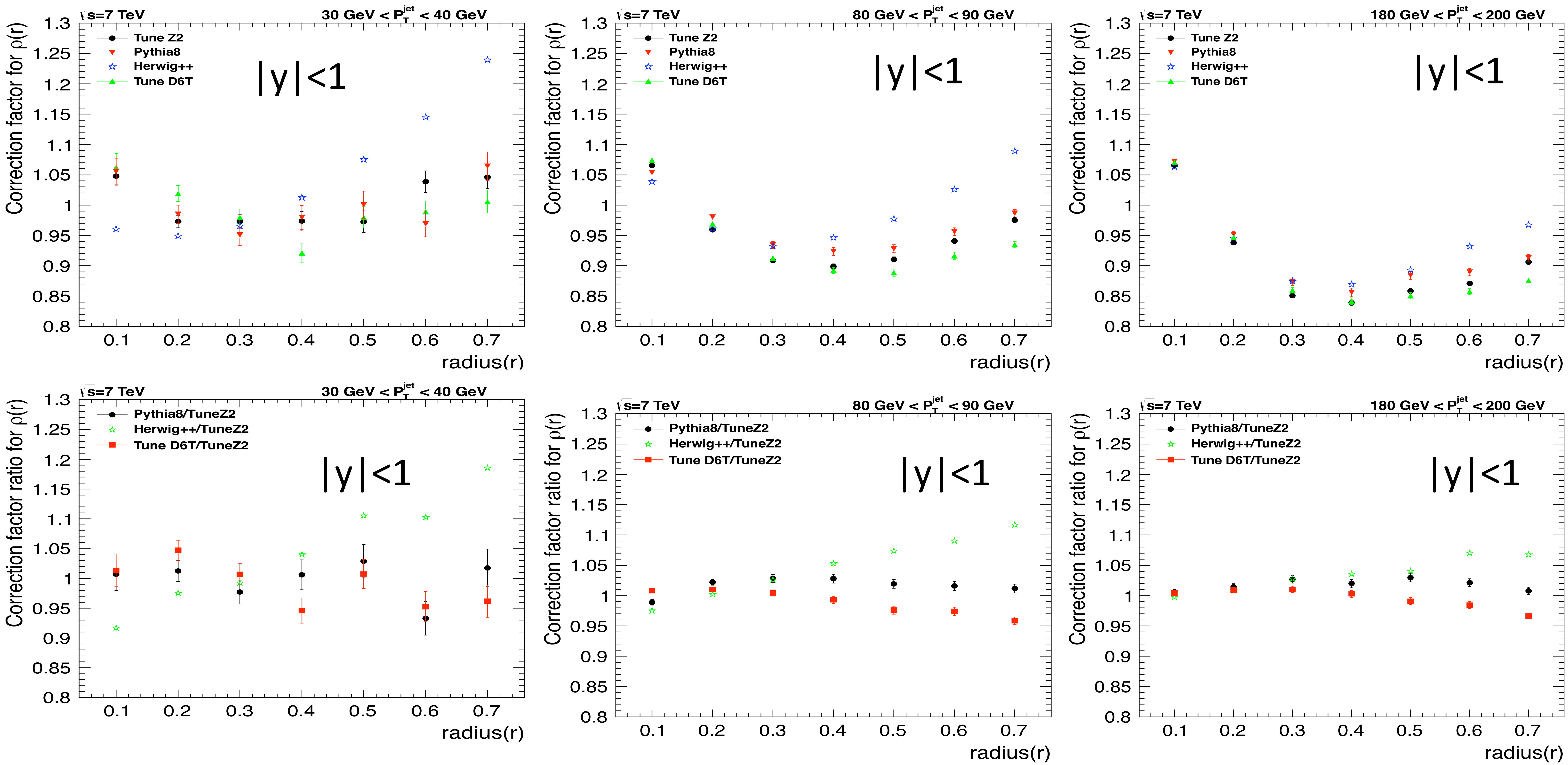
We used official JES uncertainty which depends on the $P_T$ and η. The Jet Shape in the bins of corrected $P_T$ of the jets and jet can move in an out of the bin If the jet energy scale changes.




This uncertainty results in a maximum uncertainty of 3-5% for Differential jet shape variable at the very low $P_T$

# Unfolding Correction Factors

The unfolding corrections were determined using Pythia6 (Tune Z2). We compare the correction factors obtained using other event generators and assign the largest difference from Tune Z2 in the correction factors as systematic uncertainty.




The uncertainty is typically about 5% except for the lowest $P_T$ bins where it reaches as high as 15%.

# Single Particle Response

✧Charged Hadrons are scaled to simulate impact of changing tracking efficiency

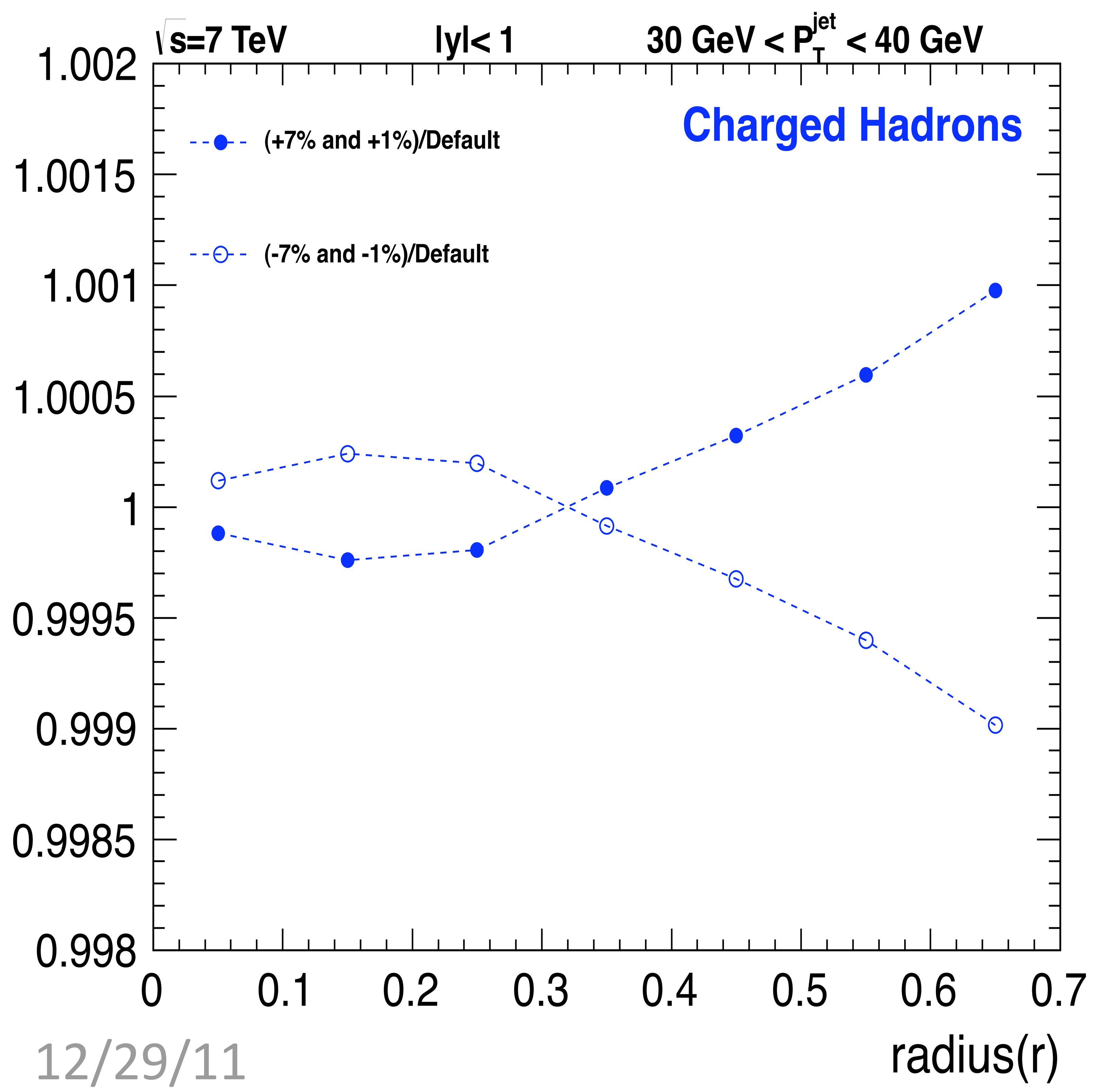
- ➢| η| < 2.3 : scale by ±1% if p <1.5 GeV and ±0.7% if p >1.5 GeV
- ➢| η| ≥2.3 : scale by ±5%

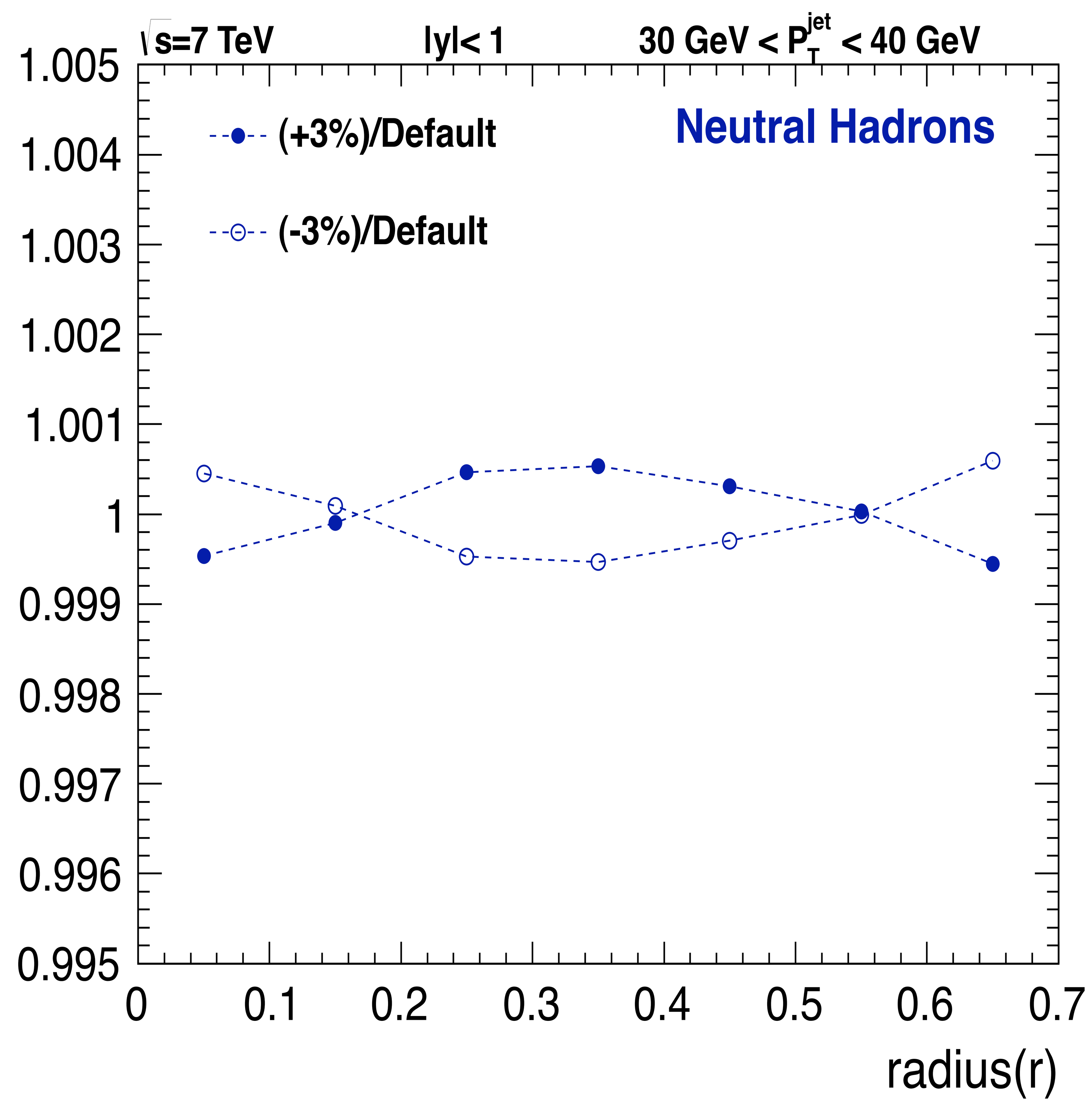
✧Neutral Hadrons are scaled to simulate impact of changing HCAL+ECAL scale

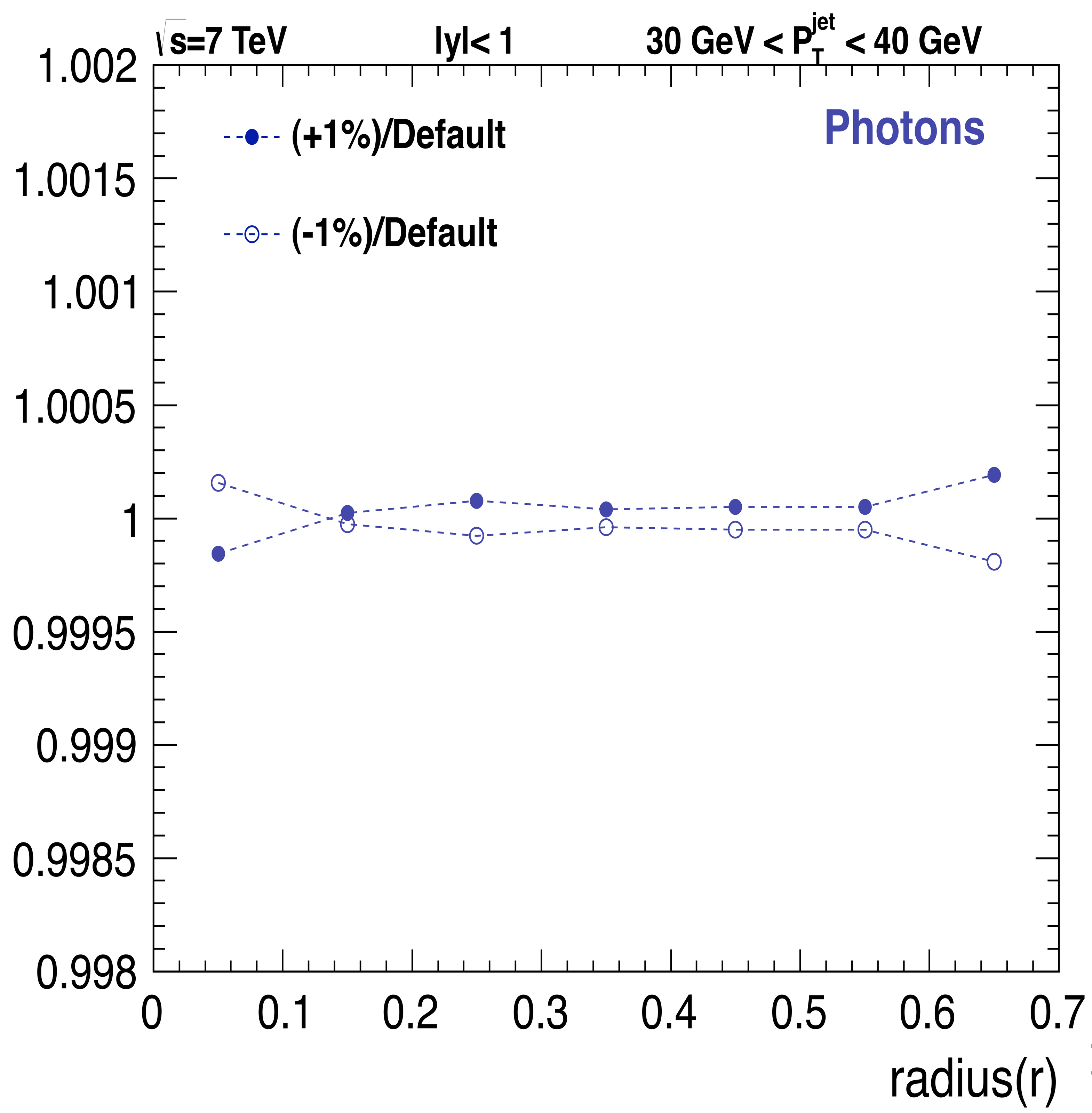
- ➢| η| <1.3 : scale by ±3%
- ➢| η| ≥1.3 : scale by ±5%

✧Photons to simulate impact of changing ECAL scale (to photons)

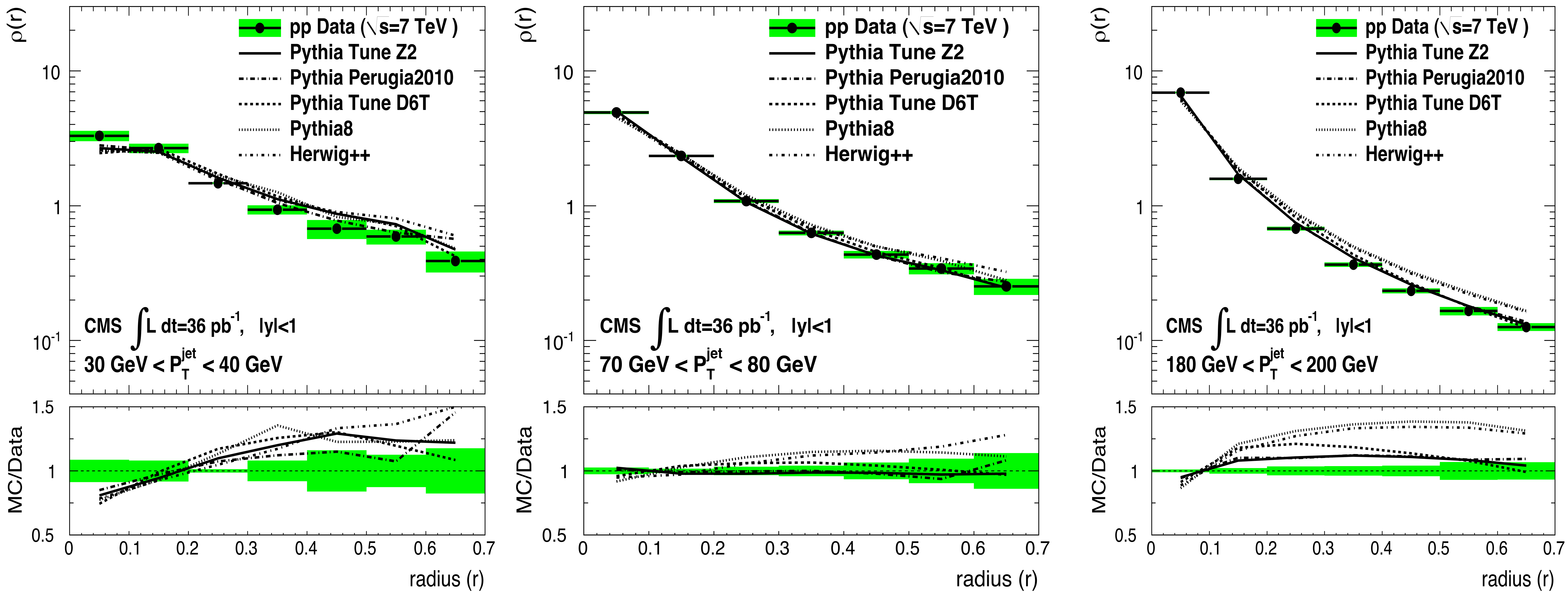
- ➢| η| <1.3 : scale by ±1%
- ➢| η| ≥1.3 : scale by ±3%



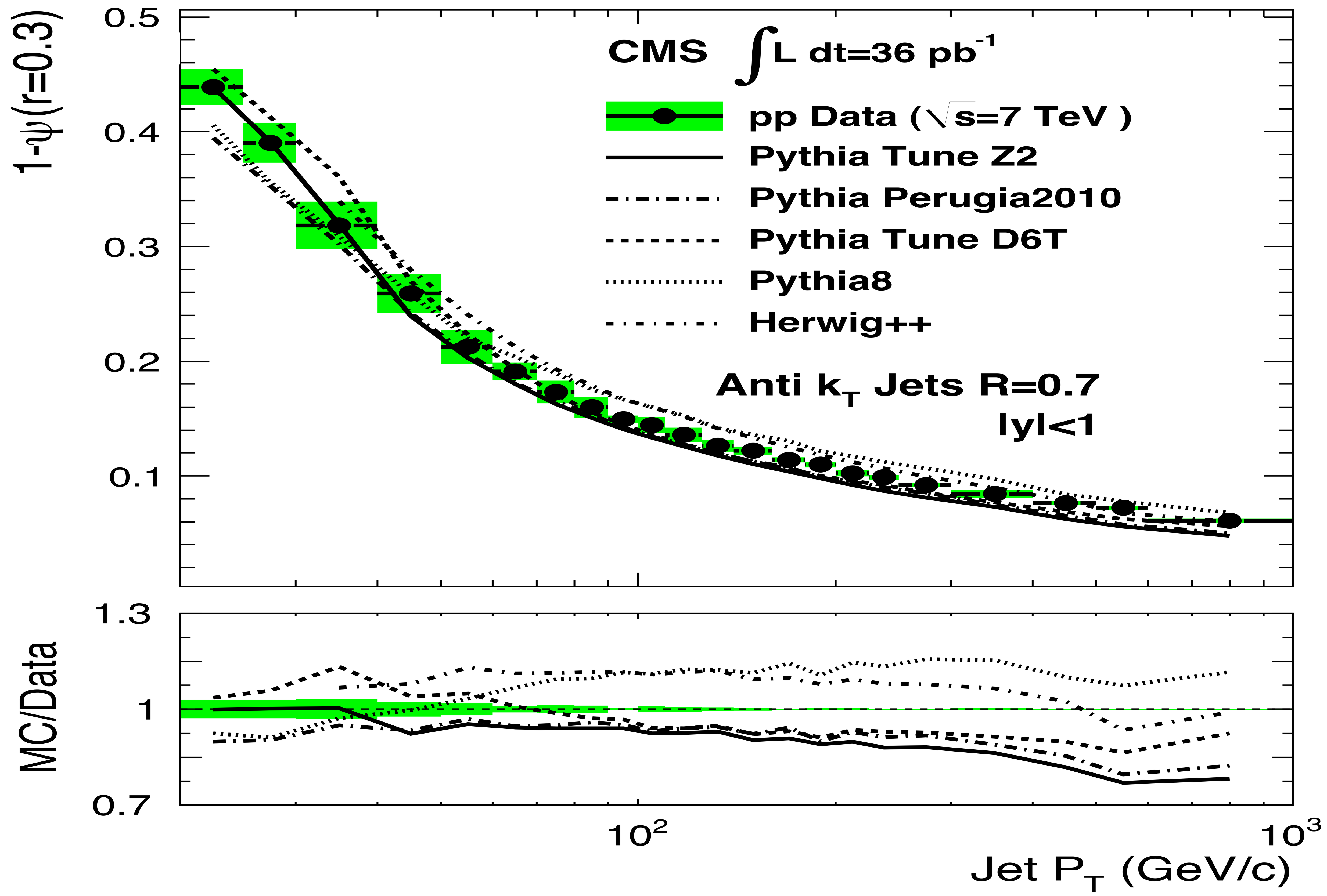
# Final Differential Jet Shape

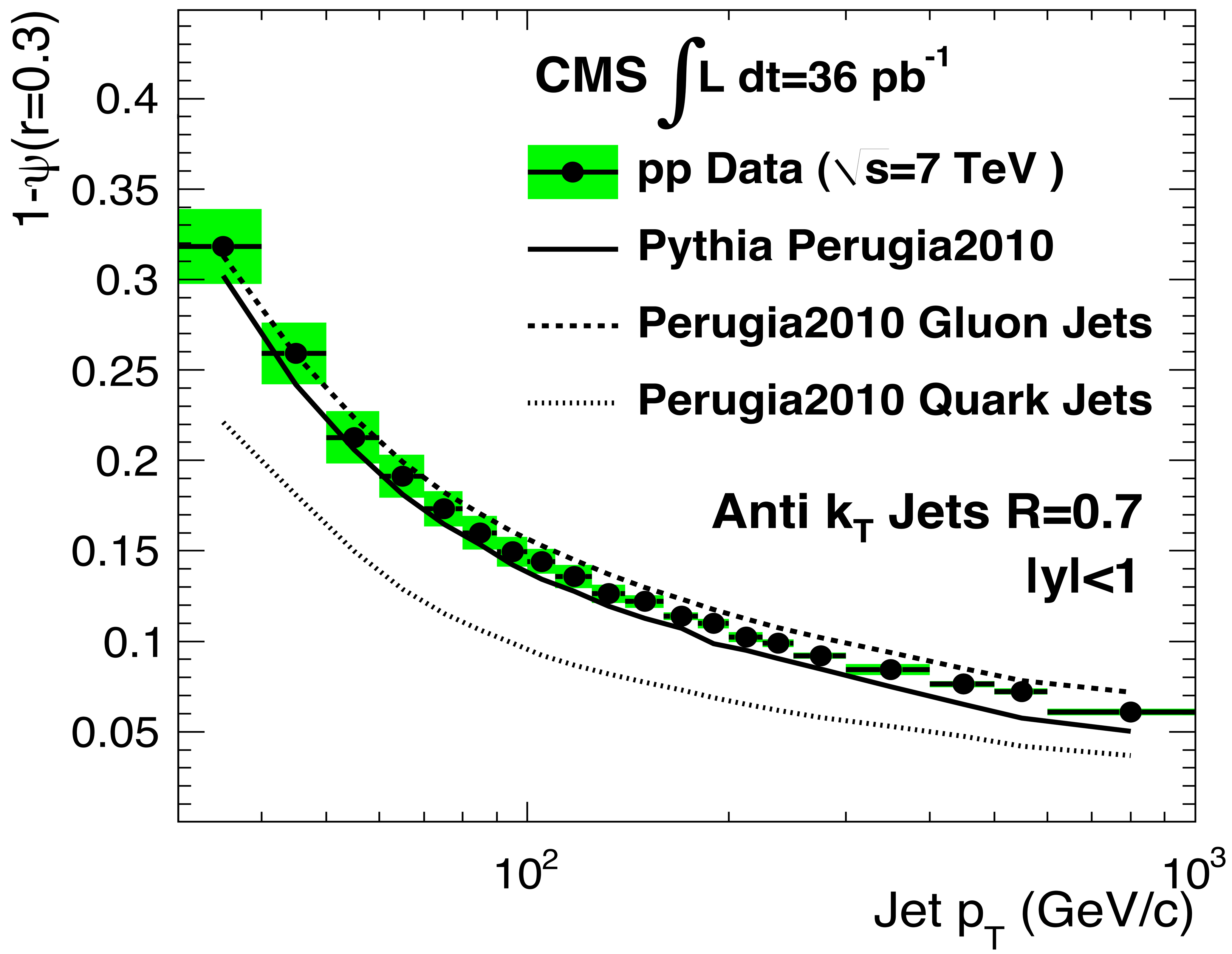



The differential jet shapes from data and different MC generators are compared.

- ✓As expected jets become more collimated with increasing jet $P_T$.
- ✓At the low $P_T$ event generators differ from each other.
- ✓The Data/MC agreement is better at the high $P_T$.

# Final Integrated Jet Shape




Out of cone energy outside the cone size R=0.3 is shown for unfolded data and compared with different MC event generators for the central region

✓Perugia 2010 gives a better description of data

qg sensitivity was investigated by matching outgoing partons with jets within **ΔR<0.7.**

✓Quark jets are narrower than the gluon jets.
✓Fraction of gluon initiated jets decreases with the increasing jet $P_{T.}$

# Conclusion

- The first measurement of jet shapes in pp collisions at √s =7 TeV using 36 $pb^{-1}$ of data collected during 2010 with PF jets.
- Jet shape measurements are observed to follow the trends expected from QCD as a function of the jet transverse momentum.
- We observe that Pythia6 with Perugia 2010 tune best describes the data.
  - Several QCD inspired Monte Carlo event generators and tunes were compared with data.
  - The Tune Z2 (Pythia6) describes the initial CMS soft $P_T$ data very well but predicts slightly narrower jets than those in data at high transverse momenta.

✓ *"Shapes, Tranverse Size, and Chaerged Hadron Multiplicity of Jets in pp Collisions at √s= 7 TeV"* CMS Collaboration, JHEP (expected March 2012)

✓ *"Measurement of Transverse Momentum Distribution Within Jets in pp Collisions at √s=7TeV using reconstructed Particles" A. Bhatti,V. O'Dell, K. Hatakeyama,K. Ozdemir and P.Kurt, CMS AN AN-10-463*