



Jet and Jet Shapes in CMS

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(on behalf of CMS collaboration)

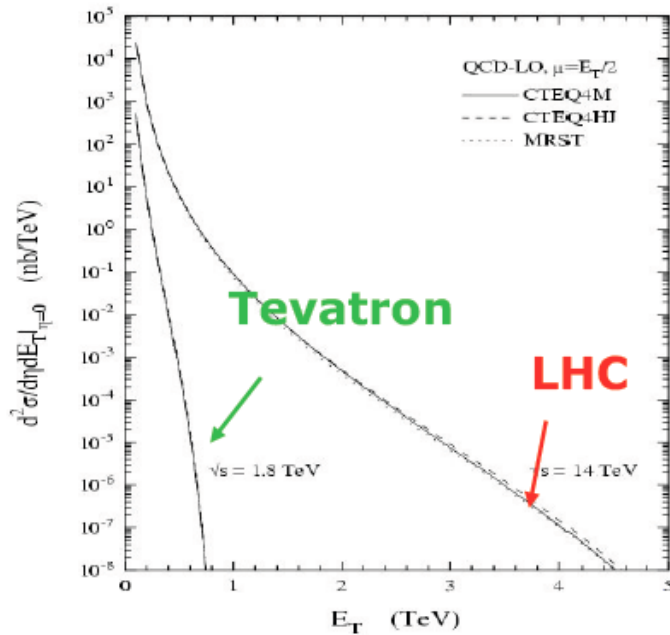


Outline of the talk



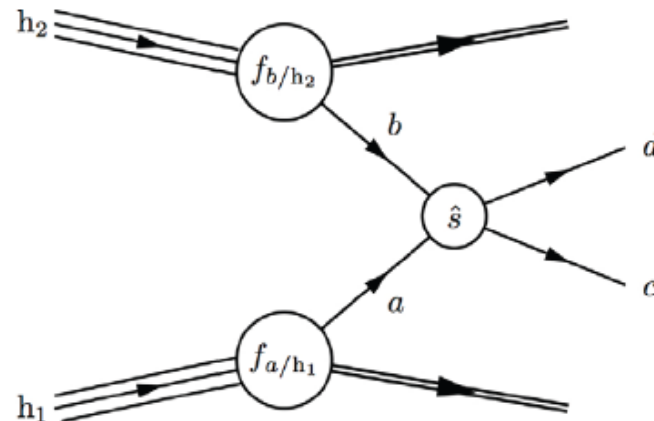
- ❑ Introducing Jet Shapes - definitions of observables
- ❑ Measurements in previous collider experiments.
- ❑ Jet shape measurements:
 - ❑ Charged component structure
 - ❑ Integrated jet shapes
- ❑ Sensitivities to PYTHIA tunes and Jet Fragmentation
- ❑ Quark / gluon shape differences
- ❑ Summary

Hadronic interactions



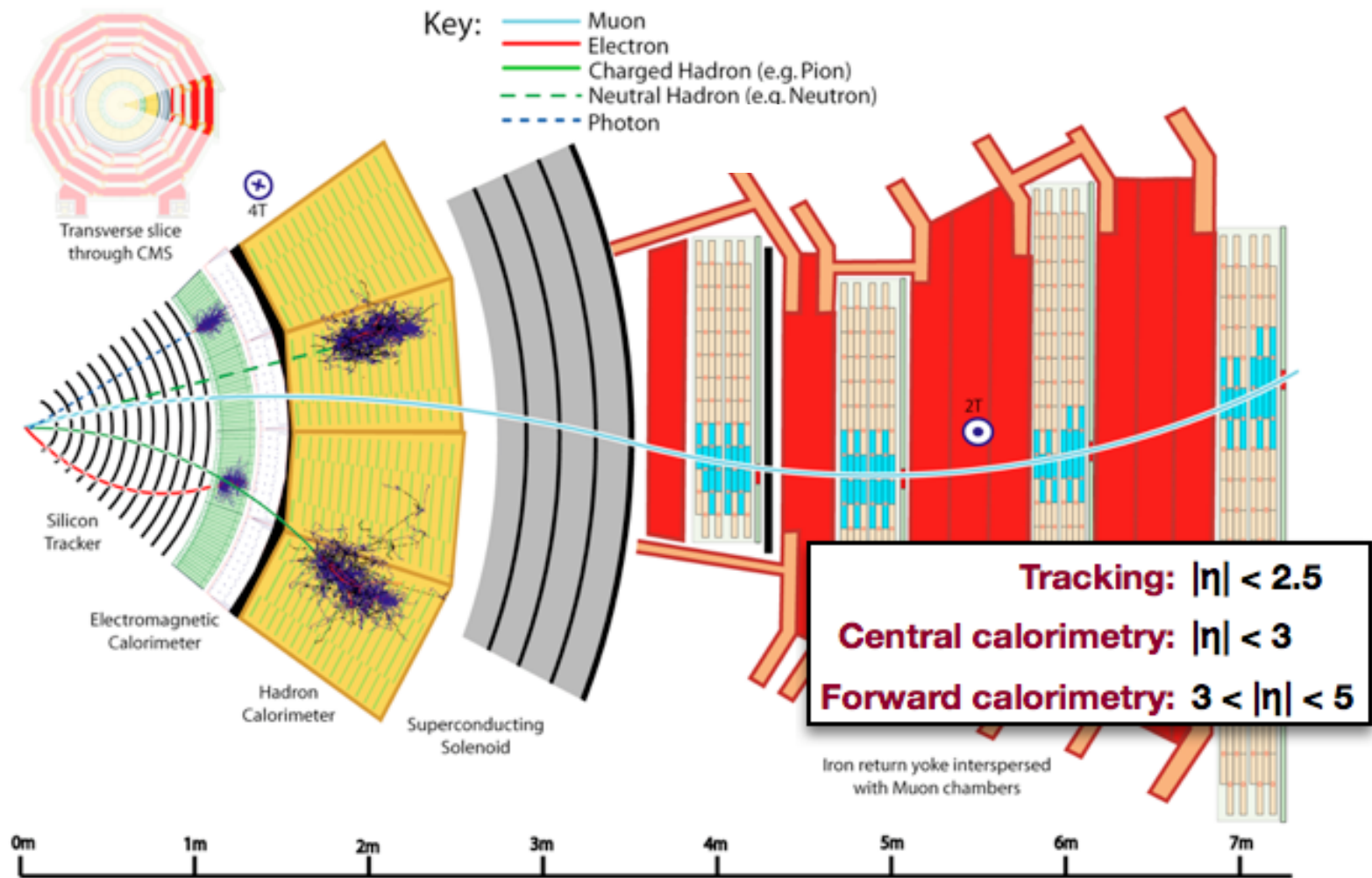
Hadron Colliders:

- Provide a broad band of energies that allow us to scan the phase space.
- Confront QCD in the new energy regimes not explored earlier.
- Hard interactions involve 2 partons.
- Rest goes into underlying event
- Jets
 - Hadrons (or tracks or energy deposits in calorimeters)
 - Mostly close to direction of initial parton





The Compact Muon Solenoid

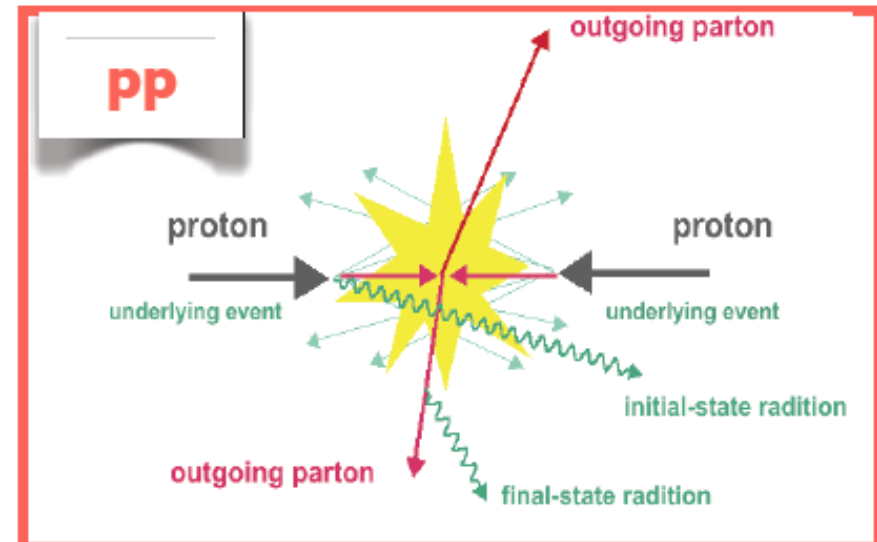
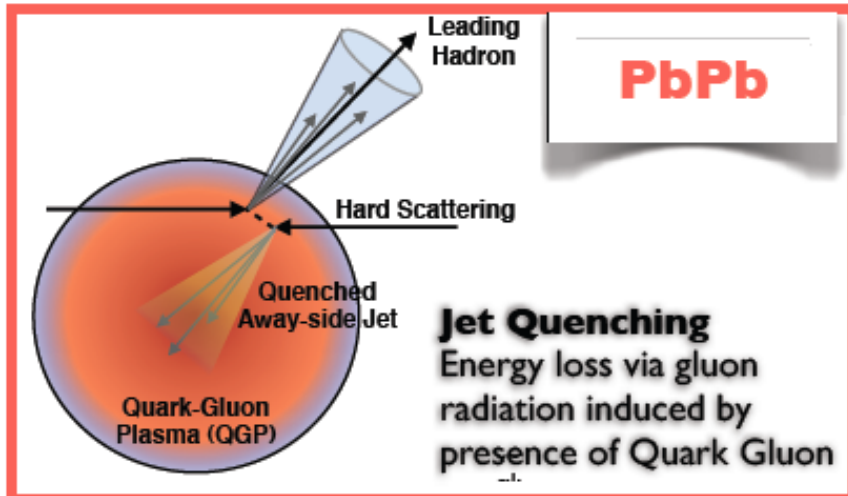


Motivation (Jet shapes)

Jet shapes measure the average distribution of energy flow as a function of the distance away from the jet axis.

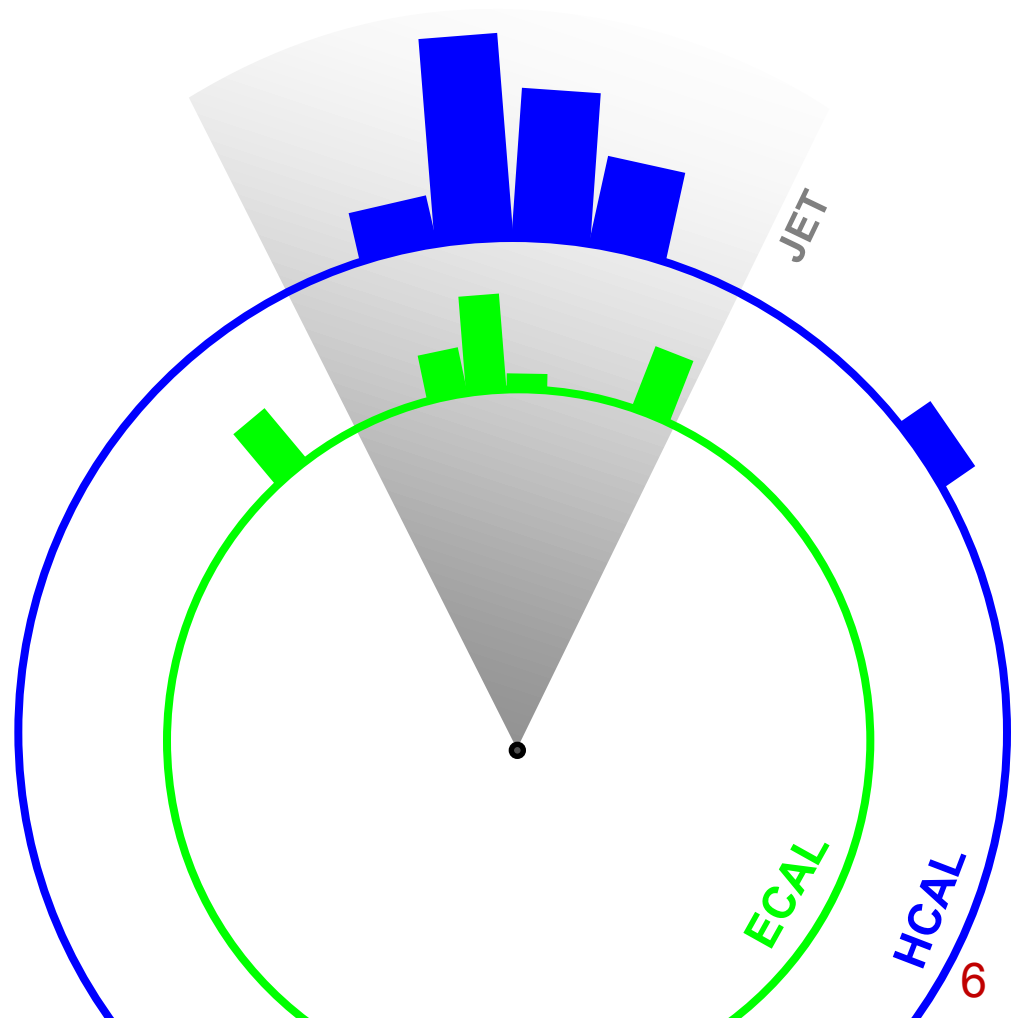
- ❑ Test showering models in Monte Carlo generators.
- ❑ Discriminates between different underlying event models.
- ❑ Sensitive to the quark / gluon jet mixture.
- ❑ Provide insight into performance of jet clustering algorithms.
- ❑ Jet shapes can discriminate between competing models of jet quenching which have all successfully described leading particle suppression in Relativistic Heavy Ion Collider (RHIC) data.

arXiv:0810.2807 (Ivan Vitev (LANL) and et. al)



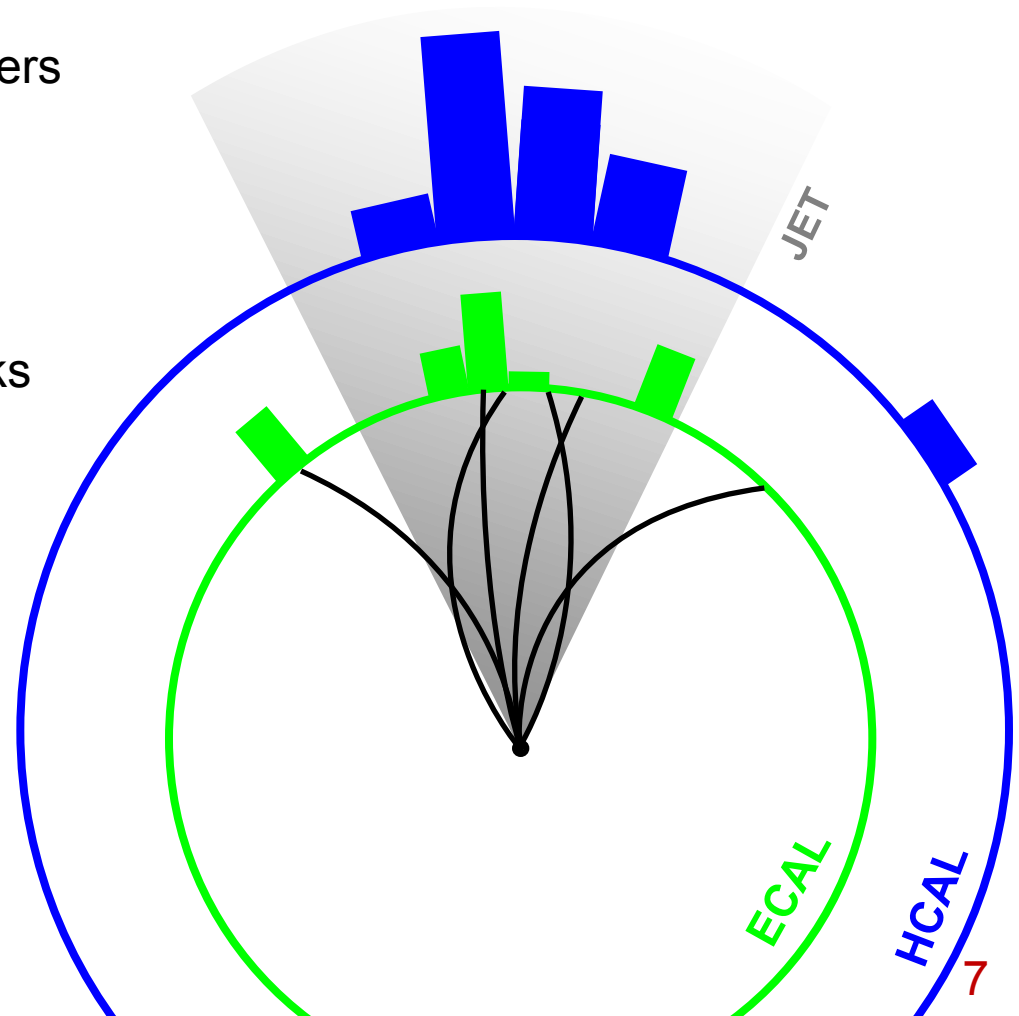
Jet Reconstruction at CMS

- 1. Calorimeter Jets:** calorimeter towers



1. Calorimeter Jets: calorimeter towers

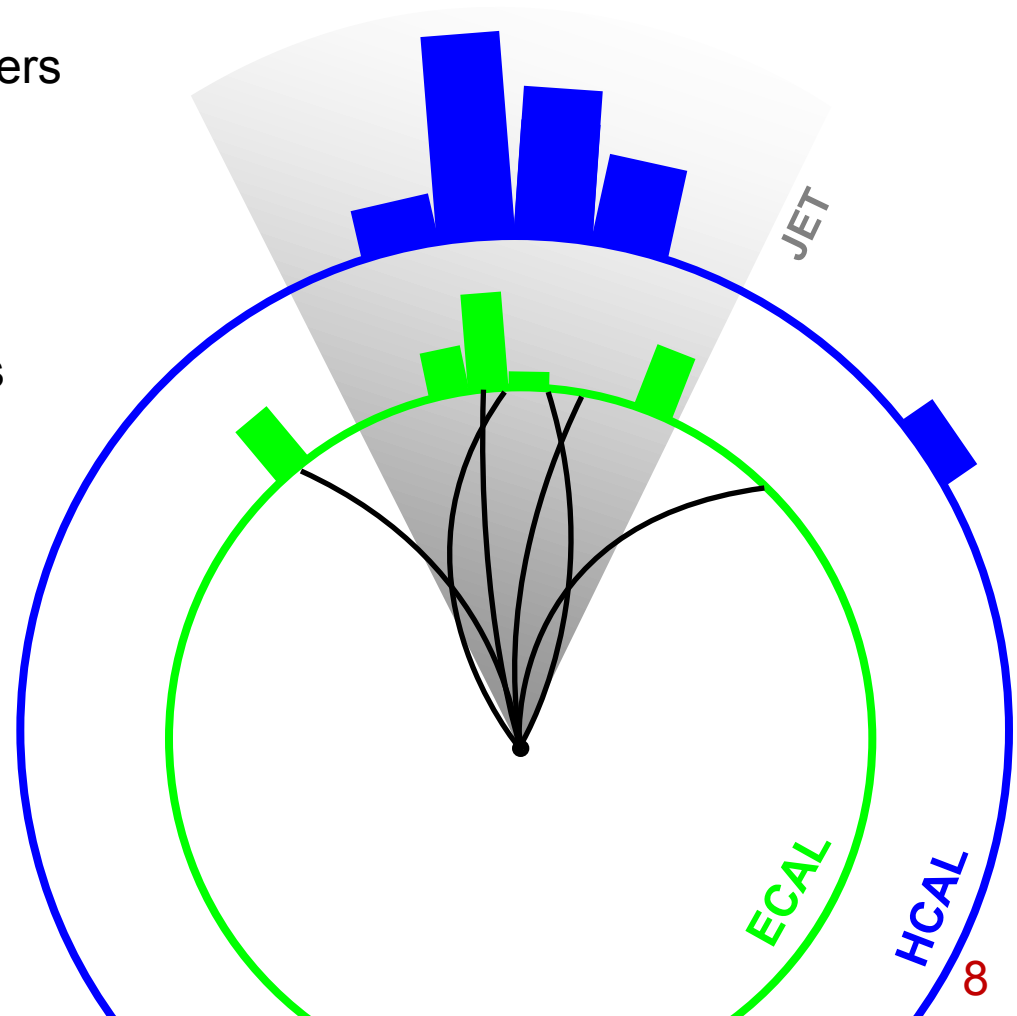
2. **Jet Plus Tracks:** correct for tracks



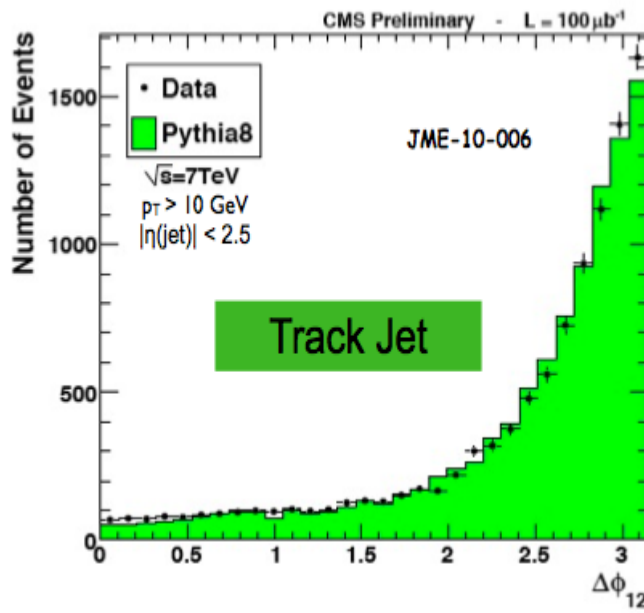
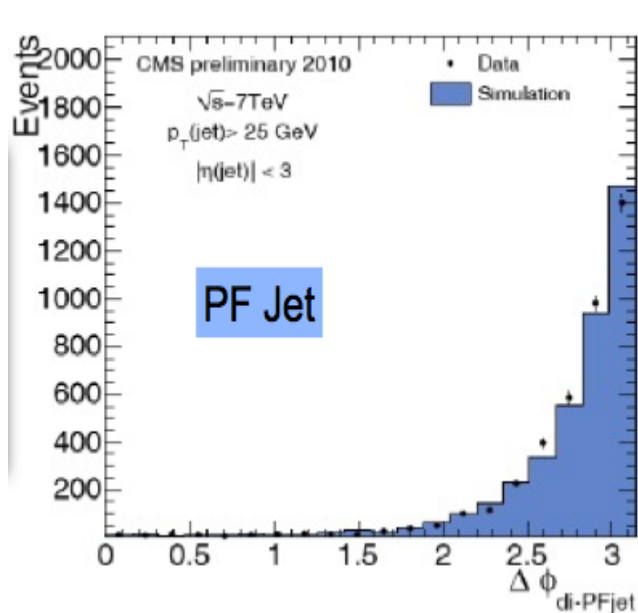
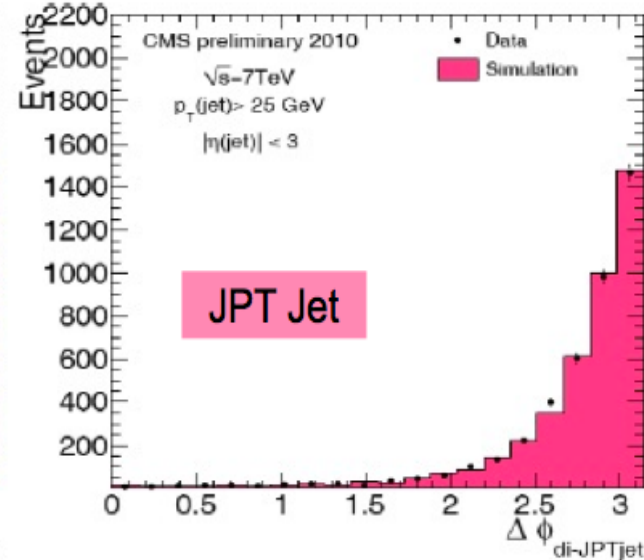
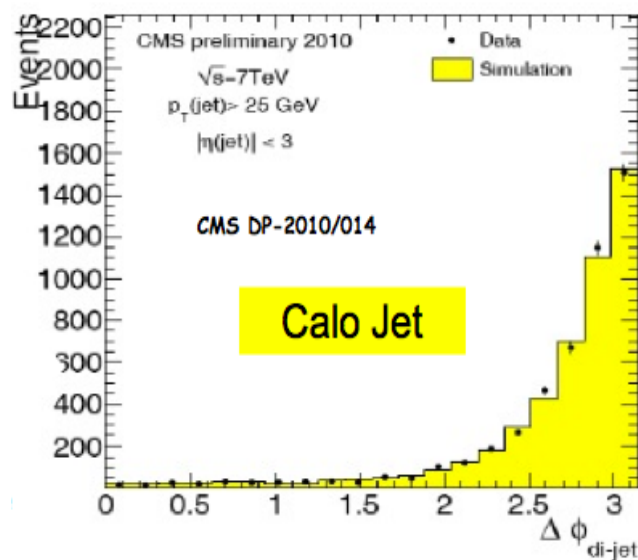
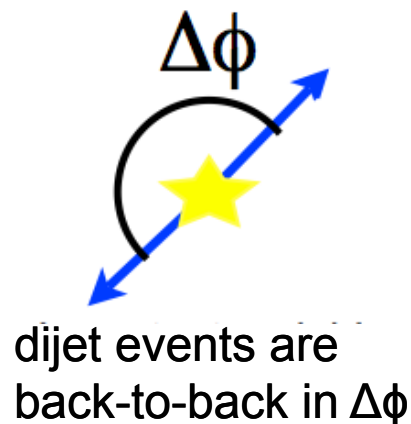
1. Calorimeter Jets: calorimeter towers

2. Jet Plus Tracks: correct for tracks

3. Particle Flow



Dijet $\Delta\phi$ in Data and MC



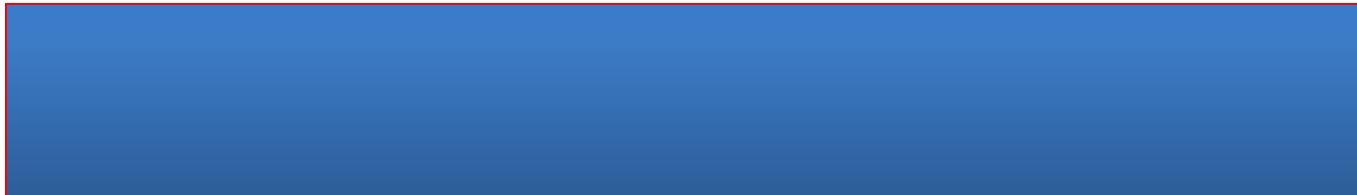
➤ Good agreement for all jet types between data and MC

Measuring jet shapes

- Two different methods have been used in CMS to measure the internal structure of jets (Jet shapes):
 - ◆ Jet charged component structure at 7 TeV
(based on the original CMS PAS QCD-08-002)
 - ◆ Classical jet shape analysis at 7 TeV
(based on the original CMS PAS QCD-08-005)

The following observables are used to characterize the structure of jets.

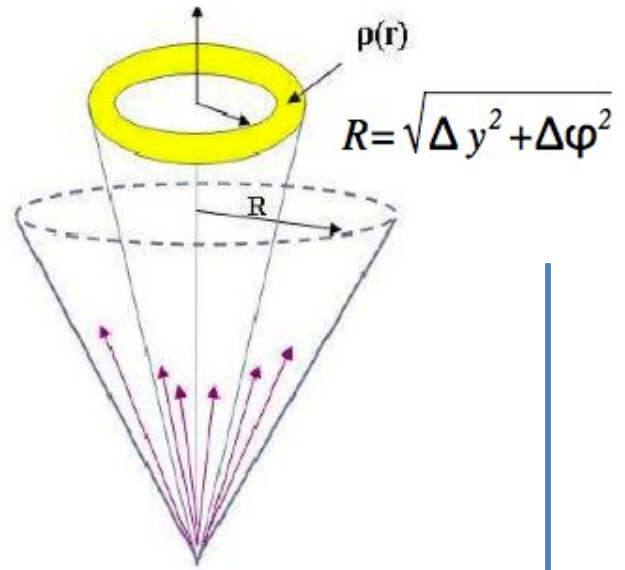
- Charged particle multiplicity in jet (N_{ch}).
- Charged particle transverse shape variable (δR^2)
A measure of the width of a jet in the η - Φ plane.



$$\langle \delta \eta_{\text{jet}}^2 \rangle (p_T) = \frac{\sum_{i \in \text{jet}} (\eta_i - \langle \eta \rangle)^2 \cdot p_T^i}{\sum_{i \in \text{jet}} p_T^i}$$

$$\langle \delta \phi_{\text{jet}}^2 \rangle (p_T) = \frac{\sum_{i \in \text{jet}} (\phi_i - \langle \phi \rangle)^2 \cdot p_T^i}{\sum_{i \in \text{jet}} p_T^i}$$

Classical Jet Shapes Measurements



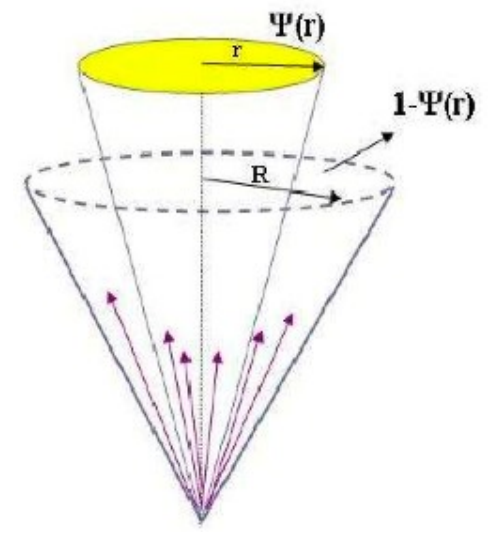
Differential Jet Shape

Definition: The average fraction of the jet transverse momentum inside an annulus in the y - ϕ plane of inner (outer) radius $r-\Delta r/2$ ($r+\Delta r/2$) concentric to the jet axis.

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

Definition: Integrated jet shape is defined as the average fraction of jet transverse momentum inside a cone of radius r concentric to the jet axis.

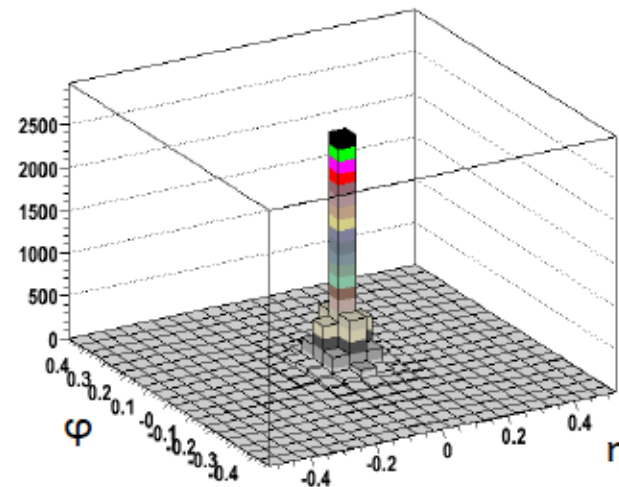
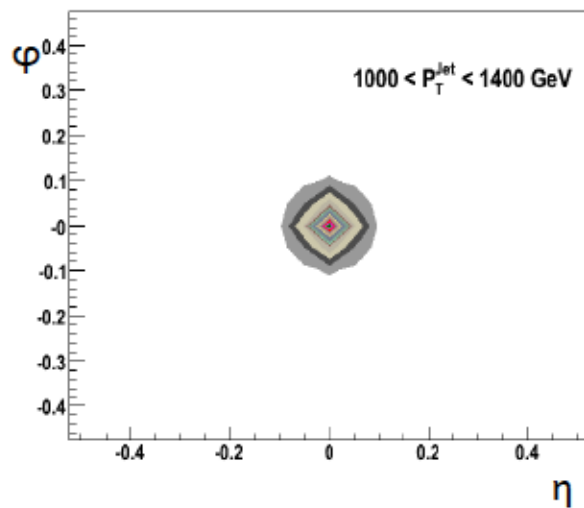
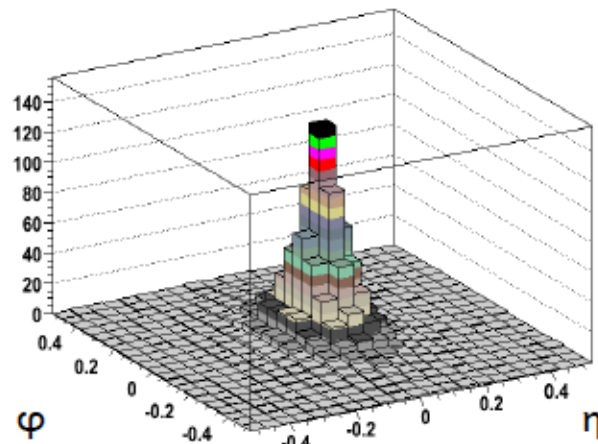
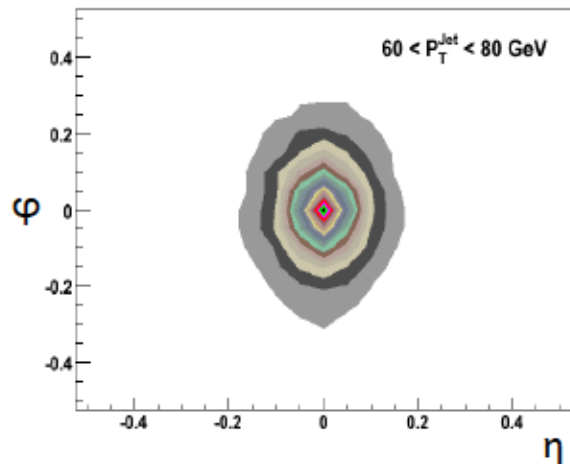
$$\Psi(r) = \frac{1}{N_{jets}} \sum_{jets} \frac{P_T(0; r)}{P_T^{jet}(0, R)}$$



Integrated Jet Shape

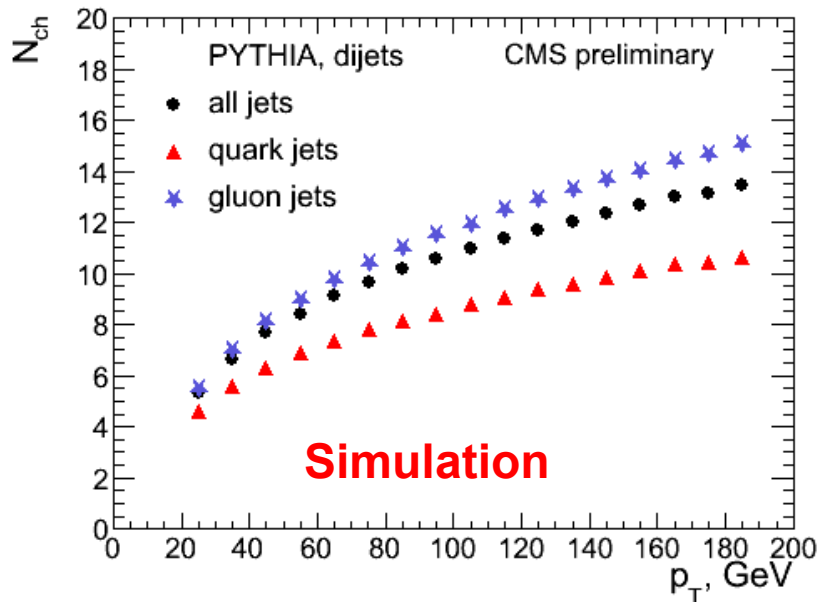
- ❑ Condition on the Technical Trigger bits:
Coincidence for jets with low transverse momentum ($p_T < 40$ GeV) a minimum bias trigger was used which requires activity in both beam scintillator counters located at $3.23 < |\eta| < 4.65$ in coincidence with colliding proton bunches.
- ❑ Jets are reconstructed from
 - ❑ using calorimeter tower information (**calojets**) or
 - ❑ using a combination of information from the calorimeters and the tracker (**jet+track** algorithm).
- ❑ Jets were selected requiring at least one of the leading jets within $|\eta| < 1$.
- ❑ The two leading jets pass satisfy the jet Id criteria to get rid of the noise.
- ❑ Anti-kT cone algorithm applied with cone size=0.7
- ❑ After jet energy correction is applied the corrected jets satisfy: $p_T > 15$ GeV.

Calorimeter Jet Shapes in η - ϕ plane



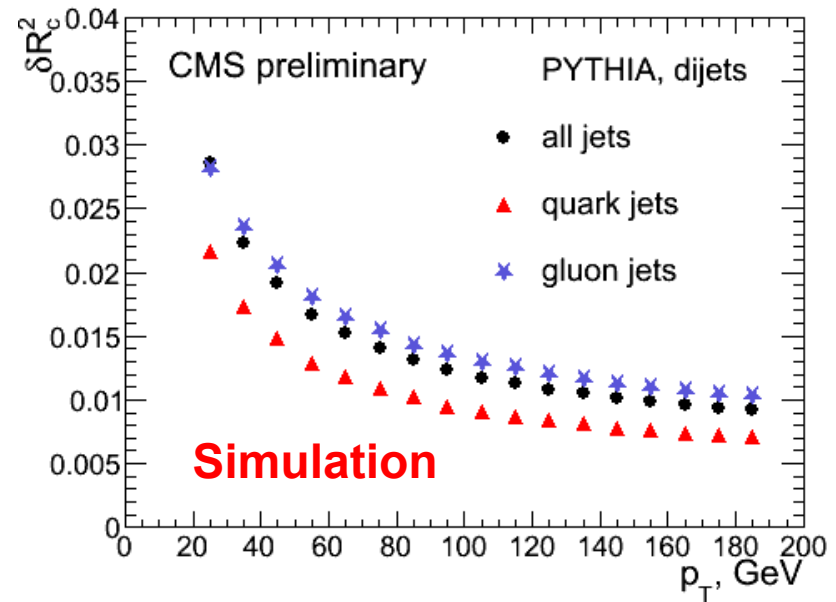
- Jet shape in ϕ direction is wider due to bending of charged particles in B field.

PYTHIA, $|\eta| < 1$
Detector level



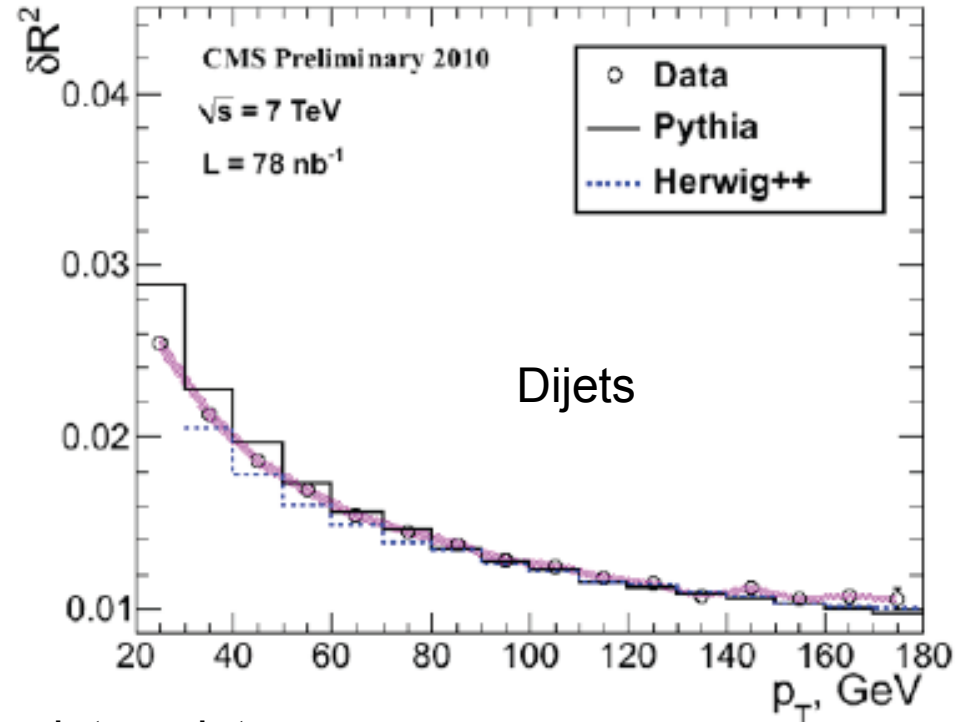
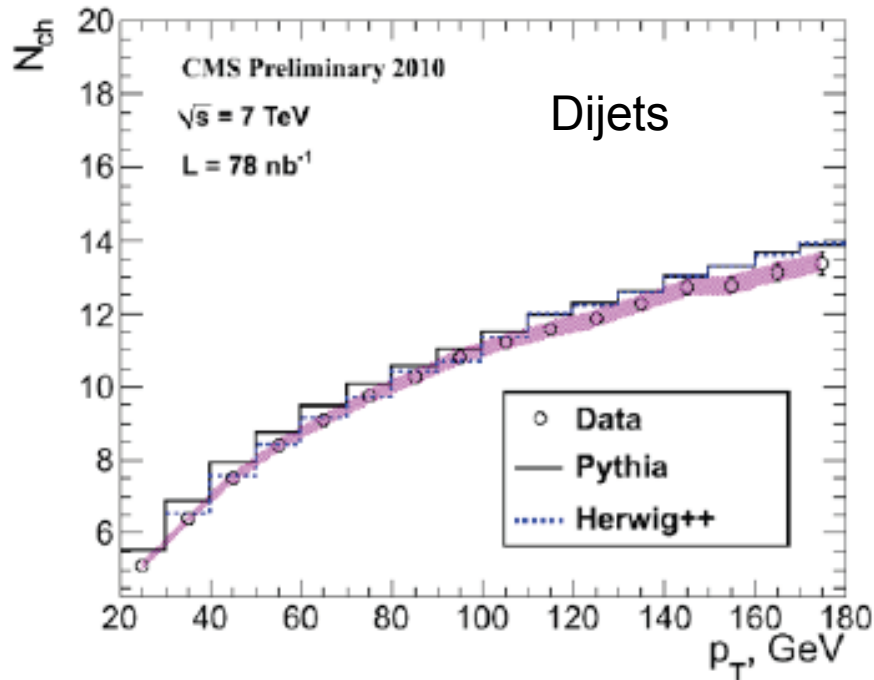
- The combination with minimum:

$$\square \delta R^2(\text{parton}, \text{jet}) = \delta R^2(i_1, j_1) + \delta R^2(i_2, j_2)$$



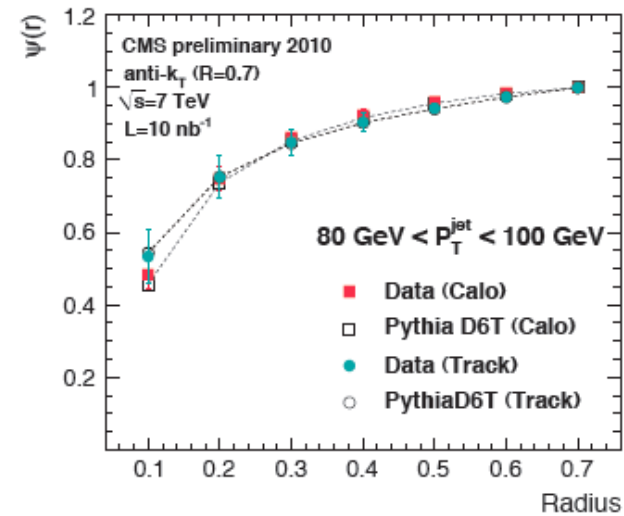
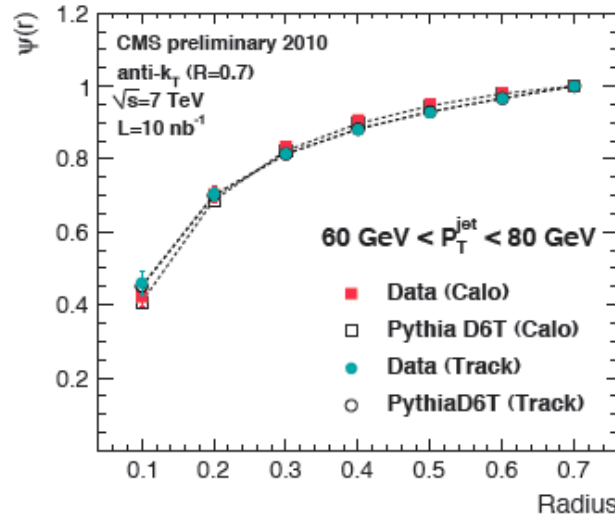
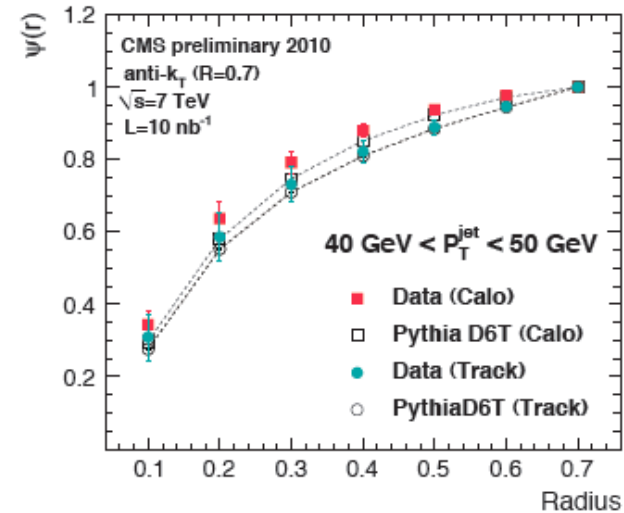
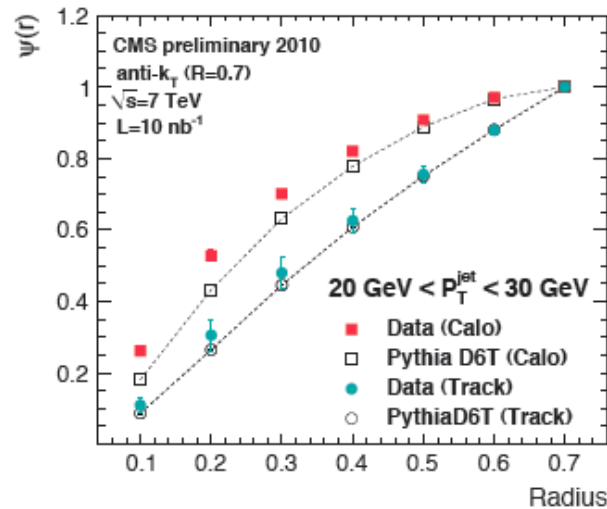
- The mean charged particle multiplicity increases whereas the transverse jet shape δR^2 drops as a function of the jet transverse momentum.

Data, PYTHIA, HERWIG jets with $|\eta| < 1$ (detector level)



- Statistical uncertainty is assigned to data points.
- Systematic uncertainty due to jet energy scale is shown with a pink band.
- At low jet transverse momentum ($20 < p_T < 50 \text{ GeV}$) the measured jets are a few percent broader than predicted by Herwig++ and narrower than predicted by Pythia D6T.

Integrated jet shapes



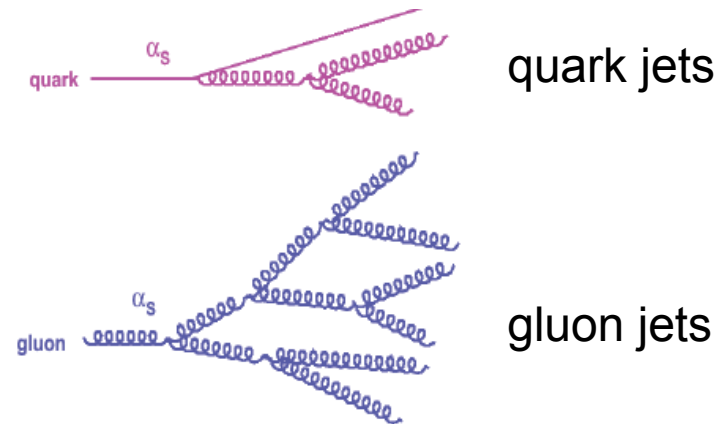
The integrated jet shape increase with p_T indicating that the constituents of the jets are more collimated at increasing p_T .

Quark and gluon jet shape differences

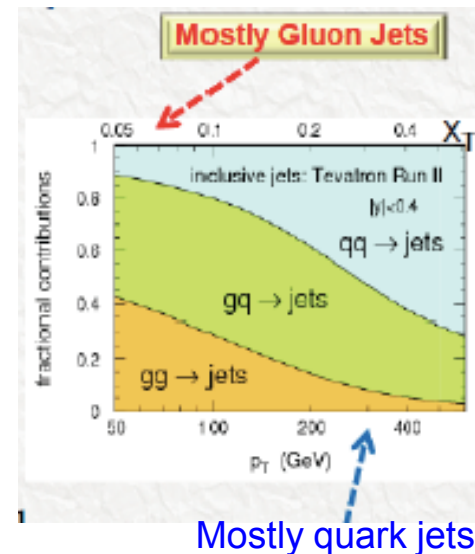
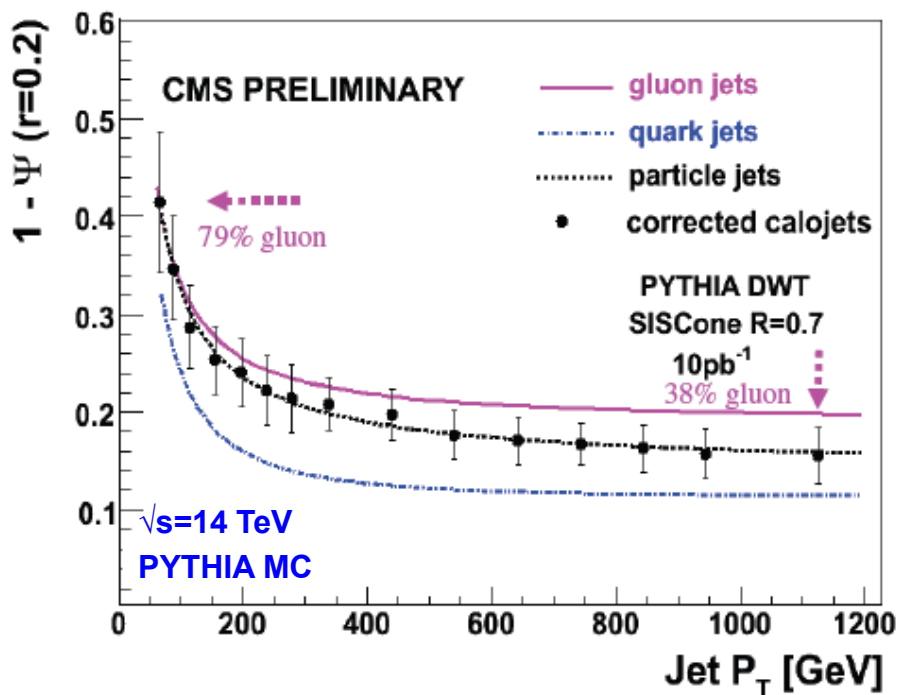
- Jet shapes are sensitive to quark-gluon jet mixture.
 - Can separate quark and gluon jets in a statistical way.
- Quark and Gluons jets radiate proportionally to their color factors
 - C_F : strength of gluon coupling to quarks.
 - C_A : strength of gluon coupling.

$$\left| \text{quark} \rightarrow \text{quark} + \text{gluon} \right|^2 \sim C_F = 4/3$$

$$\left| \text{gluon} \rightarrow \text{gluon} + \text{gluon} \right|^2 \sim C_A = 3$$



- In QCD, quark jets are expected to be narrower than gluon jets, but both get narrower with increasing jet p_T .
- Jets initiated by quarks and gluons are also expected to have different average multiplicities and p_T spectra of constituents.



At small p_T , jet production is dominated by gg and gq scattering due to higher gluon probability density at low x.

Observations:

- ❑ Quark jets are narrower than gluon jets.
- ❑ Fraction of gluon initiated jets decreases with increasing jet p_T .
- ❑ Mixture of quark and gluon initiated jets changes with jet p_T , contributing to the jet shape dependence on p_T .
- ❑ The constituents of the jets become more collimated with increasing jet p_T .



Summary and Outlook



- ❑ The internal structure of the jet was measured in early pp collisions using CMS Detector
- ❑ The data are in general in agreement with QCD-inspired event generators.
- ❑ The measured data are described within the uncertainty of the measurement of a few percents by current leading order QCD Simulation event generators, Pythia and Herwig up to the highest transverse momenta observed
- ❑ The differences between quark and gluon jets are studied.
- ❑ Future plan includes probing the jet shapes with particle flow algorithm for more precise measurements.
- ❑ An updated Physics Analysis Summary with latest data in under way.



Back up



- ❑ Jet energy scale.
- ❑ Calorimeter Response and Transverse Shower Shape
 - The measured jet shapes depend on the calorimeter response to hadrons and on the transverse showering. There is uncertainty due to simulation of these effects.
 - Data driven approach to estimate the sensitivity of the jet shapes to the calorimeter resolution by looking track jet shapes and calorimeter level jet shapes.
 - Hadrons deposit energy in several neighboring towers. This transverse showering affects the measured jet shapes.
- ❑ Jet fragmentation
 - The calorimeter response simulation, and hence jet shape corrections, depends on the fragmentation model.
 - To determine systematic uncertainty due to the fragmentation model we compared the jet shape correction factors for Pythia D6T and Herwig++.