Calibration of Jet Energy Scale for CMS

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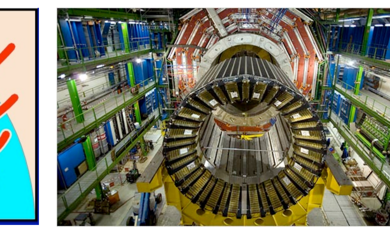

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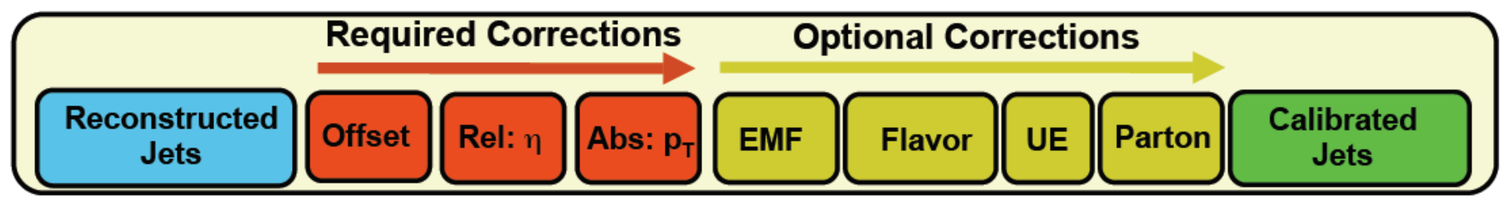
Why do we need to calibrate jets?

✦Because the calorimeter response is non-linear in p_T and non-uniform across the detector.
✦**Jet energy scale is the most important source of systematic uncertainty related to jets**.

Jet energy calibration workflow in CMS



✦ Correct for each factor in a fixed sequence up to a level chosen by user.
✦ Factorization facilitates the use of data-driven corrections.
- Breaking the correction into pieces that are naturally measured in collider data:
  - **Offset**: pile-up and noise measured in min-bias events.
  - **Relative**: jet response vs. η relative to barrel found using dijet balance.
  - **Absolute**: jet response vs. P_T found in barrel using γ / Z + jet.

$$p_T^{corrected} = \left(Abs(p_T \cdot Rel(\eta, p_T))\right) \times \left(Rel(\eta, p_T)\right) \times \left(p_T - \text{offset}\right)$$

Absolute correction is applied to the jets which have already been corrected for η dependence

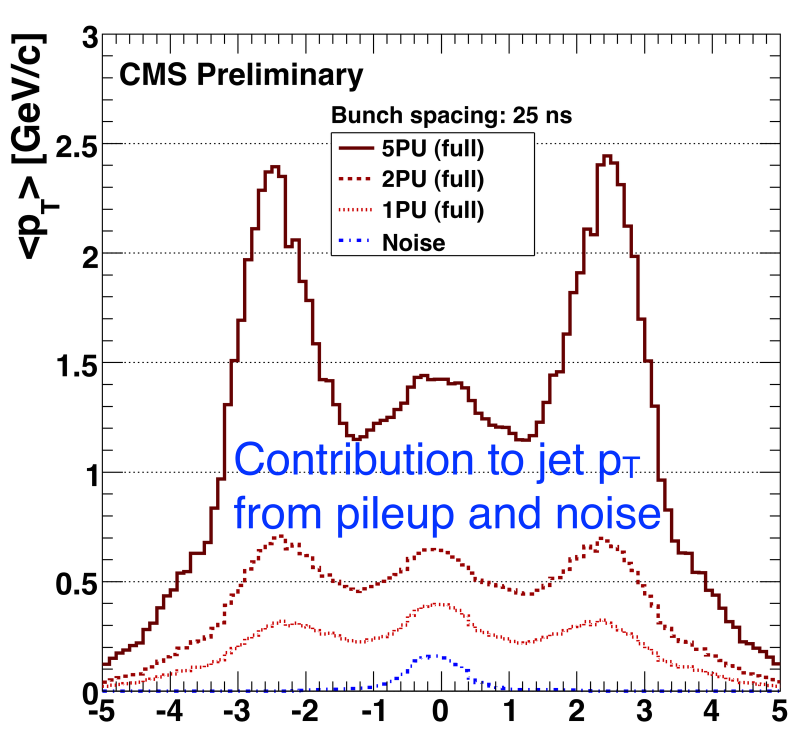
Relative correction is applied to the jets which have already been "offset" corrected

Offset correction is applied to uncorrected jets

The required corrections bring back the jet to the particle level with flavor composition of the QCD dijet events

This workflow and all the plots/materials presented here are for calorimeter jets. Similar approach can be applied to other types of jets.

Offset correction from minimum-bias events



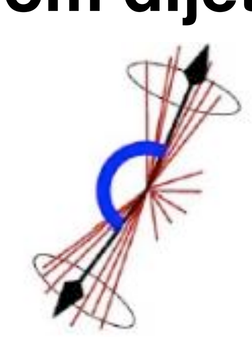
✦**Purpose:** Correct for energy from noise and pile up
✦**Plan:** Measure offset correction directly from early collision data

✦**Pile-up**
- Refers to the energy from additional pp collisions, occurring close enough in time to the hard scatter to be included in the calorimeter energy within the jet
- Statistically independent: not correlated with hard scatter
- Increases with luminosity

✦ **Calorimeter noise**
- Refers to any noise above the calorimeter cell and tower thresholds for towers included in jet

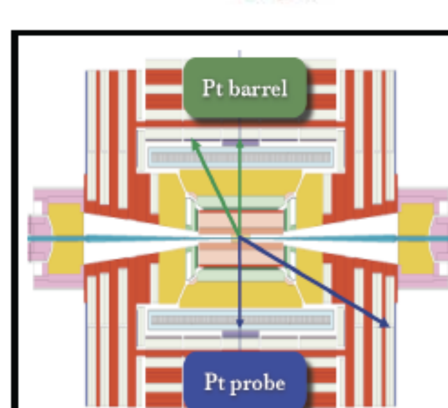
Relative correction in η from dijet p_T balance

✦**Purpose:** Correct for relative response (r) of jets vs. η
- Make response flat vs. η
- Equal to response in |jet η|<1.3



The two jets are back-to-back in ϕ.

The relative correction provides answer to the question: if a particle jet with p_T^{gen} at a given η is measured in CMS with p_T^{cal}, what would be measured in the control region for the same input p_T^{gen} ?



$$p_T^{dijet} = \frac{p_T^{probe} + p_T^{barrel}}{2}$$

$$B = \frac{p_T^{probe} - p_T^{barrel}}{p_T^{dijet}}$$

$$r = \frac{2 + \langle B \rangle}{2 - \langle B \rangle} \qquad r_{th} = \left\langle \frac{p_T^{probe}}{p_T^{barrel}} \right\rangle$$

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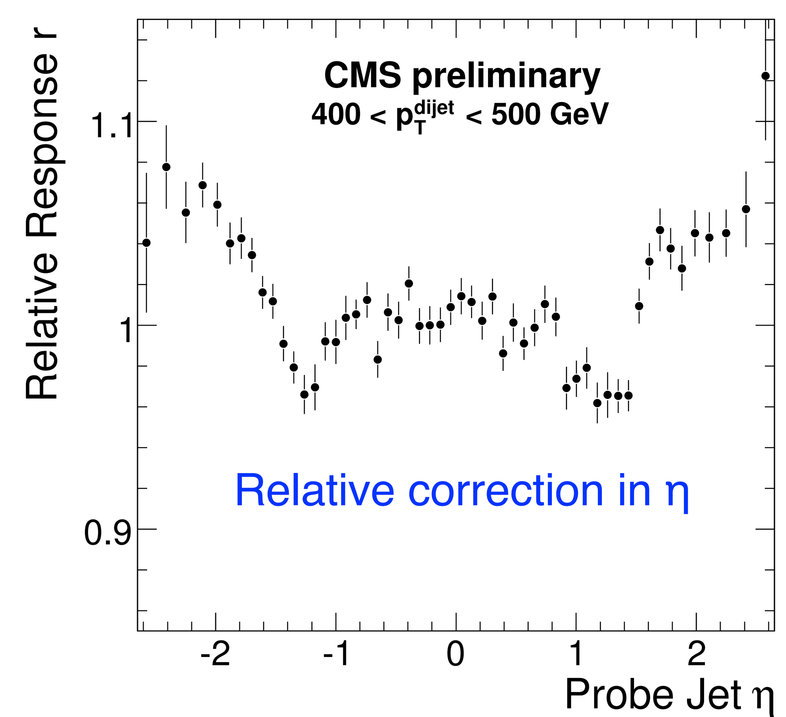
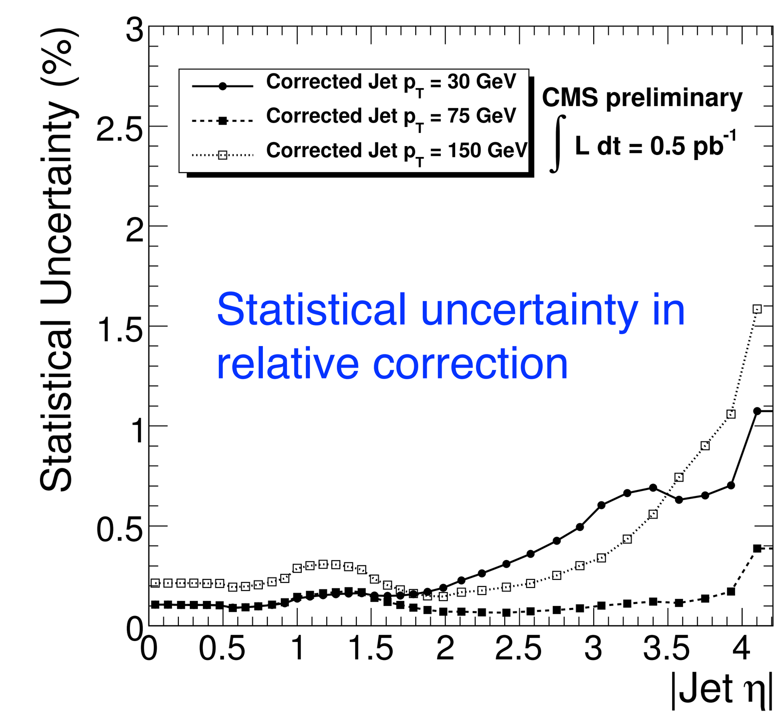
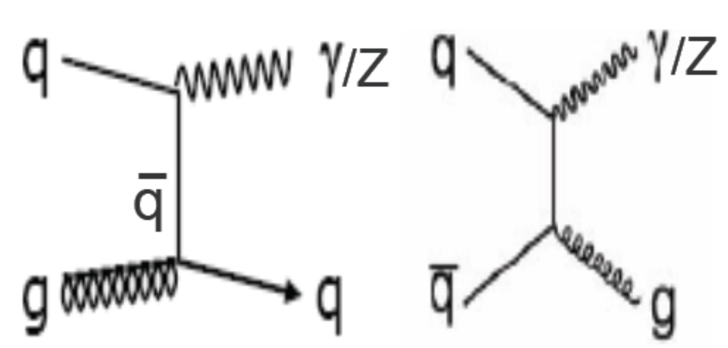




Absolute correction from γ/Z + jet p_T balance

✦**Goal:** to correct the observed calorimeter jet energy back to the parton jet level in the control region (|η|<1.3).

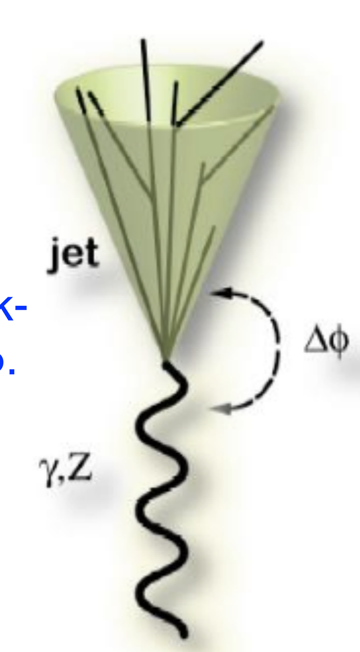


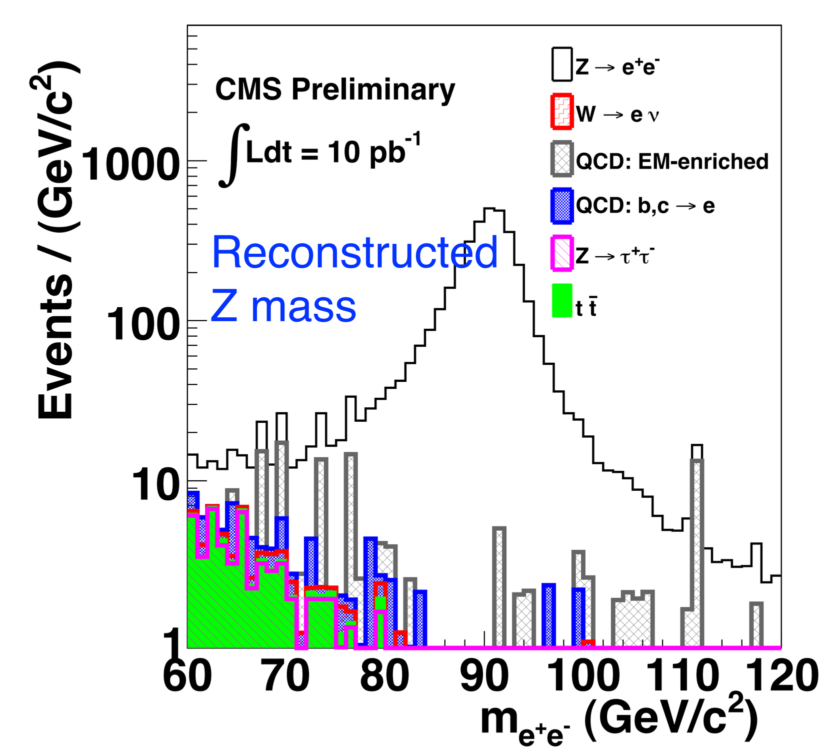
Leading order Feynman diagrams for γ/Z+jet production at LHC

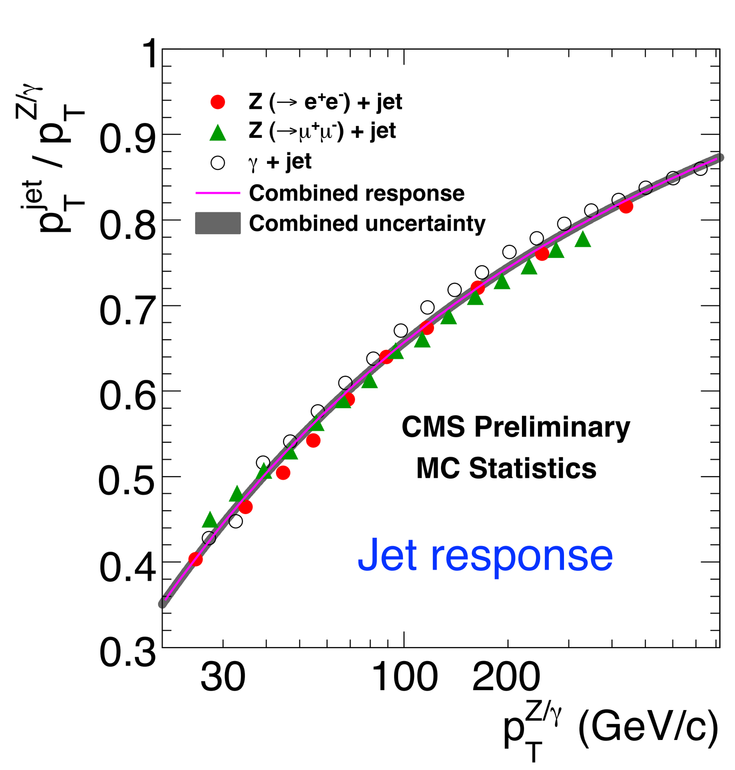
✦**Use of momentum conservation:**
- can use conservation of transverse momentum directly in collision data
- by exploiting processes in which the p_T of a well-calibrated reference object is balanced by exactly one jet
- photon and Z boson are excellent reference objects:
  - Photon p_T is measured precisely in the electromagnetic calorimeter
  - Z boson p_T is measured with good precision from its decay to $e^+e^-/\mu^+\mu^-$

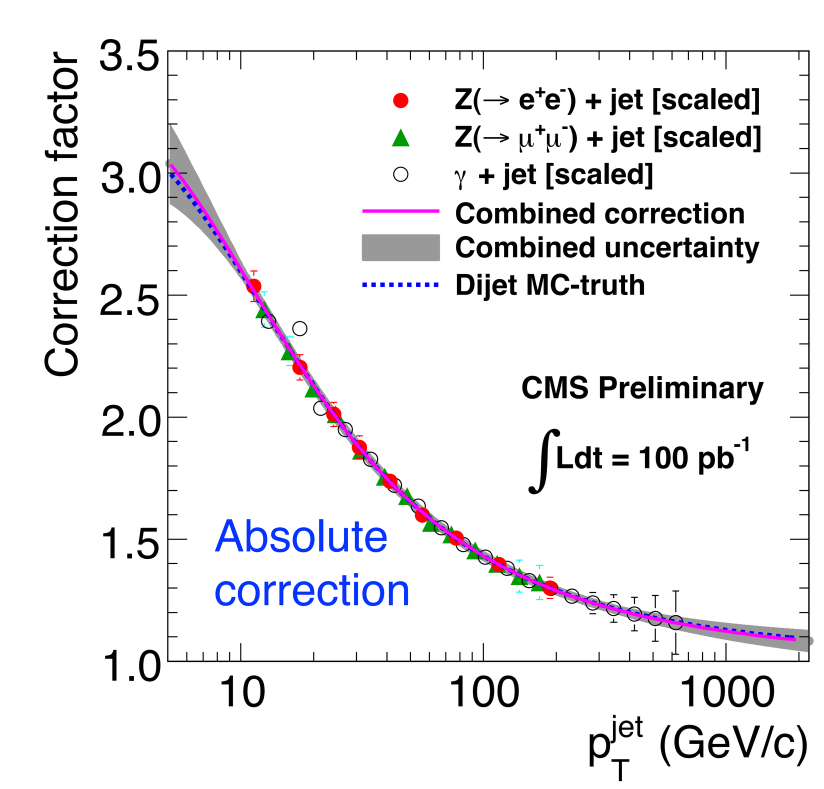
➡can evaluate true jet p_T in a γ/Z+jet event

The jet and γ/Z are back-to-back in ϕ.









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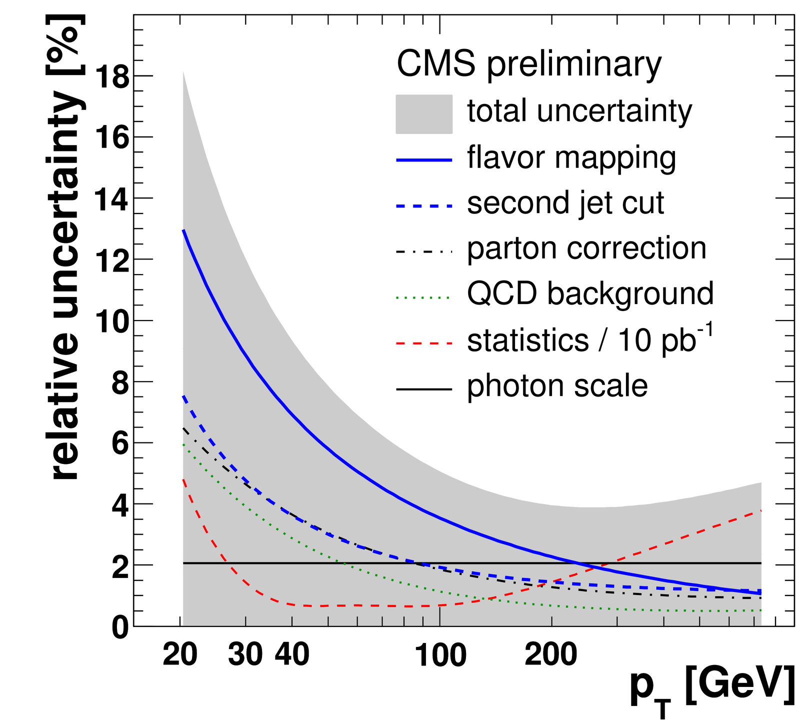
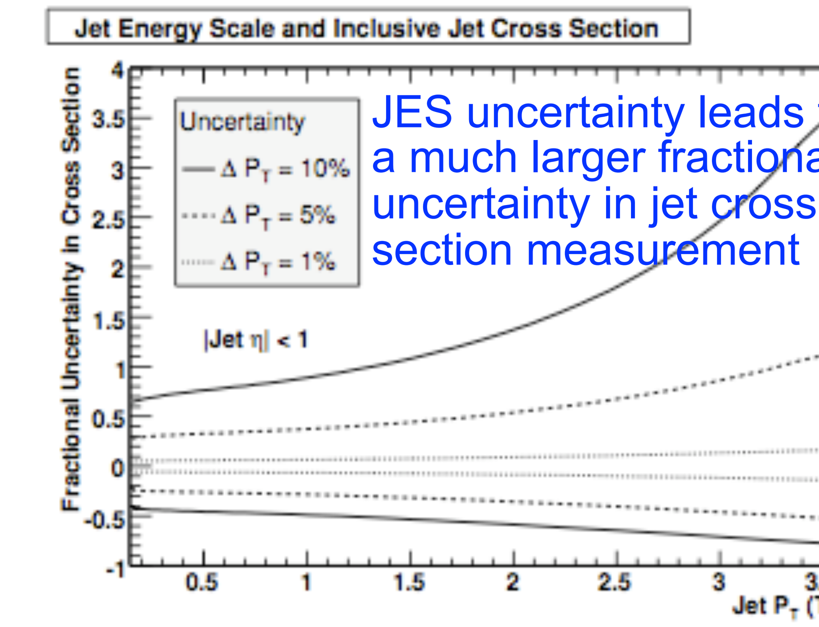
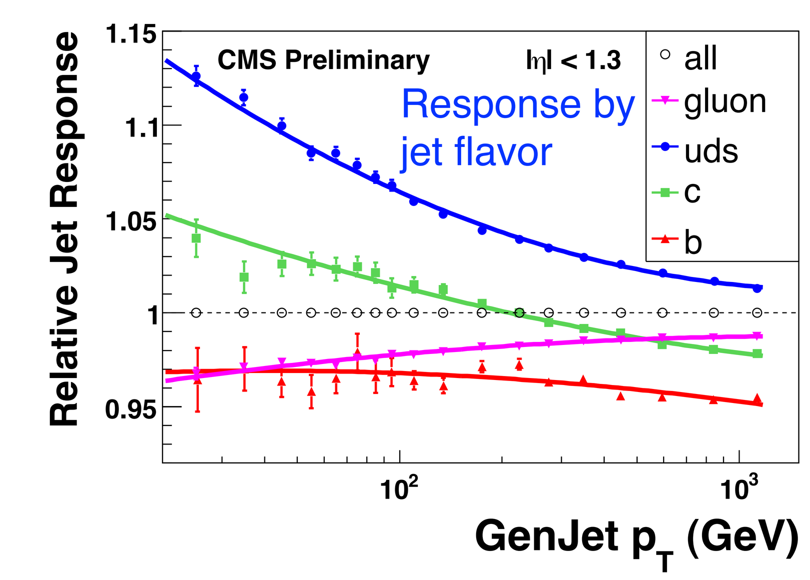


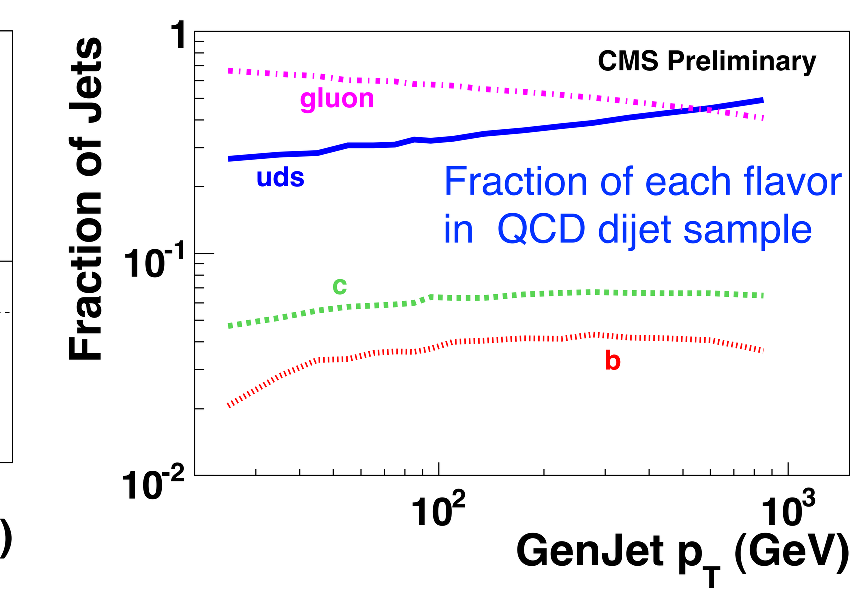
Current estimates of Jet Energy Scale systematic uncertainty using γ+jet events.



The Jet Energy Scale uncertainty has profound consequences !!!

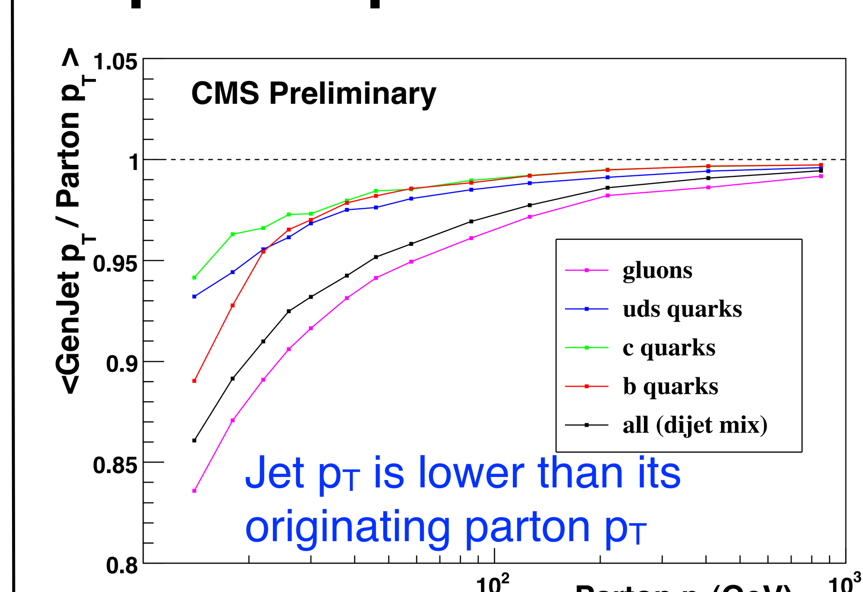
Optional flavor dependent corrections





✦The optional flavor correction is intended to correct a jet to the particle level assuming the jet originated from a specific parton flavor
- Light quarks have higher response than gluons because they fragment into higher momentum particles
- QCD dijet events have mostly gluons, therefore lower jet response
- γ/Z + jet events are rich in quarks, have higher jet response

Optional parton corrections from Monte Carlo



✦Parton correction attempts to correct the jet p_T back to its originating parton level.
✦Conceptually intended to provide correction between the GenJet and parton level jet for any parton shower and hadronization effects.

Summary

☑**Jets need to be calibrated before they can be used for physics**
- Data driven techniques developed & demonstrated to work in Monte Carlo

☑**Establishing Jet Energy Scale with reasonable uncertainty at startup is a challenging task**
- We are ready for first encounter with real data !