Determination of Jet Energy Absolute Scale Using Data-driven Techniques

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LPC Physics Forum
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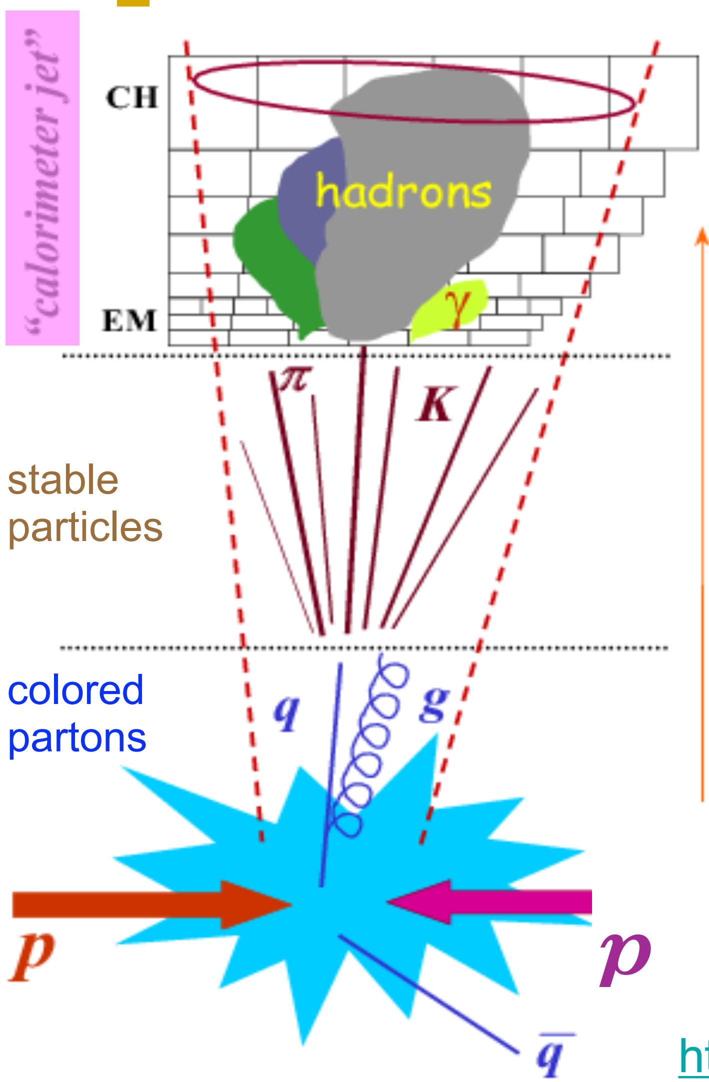
Outline of this talk



- ✦ Jet corrections overview
- ✦ Absolute correction
  - jet response
  - p_T balance technique
  - photon/Z + jet calibration
- ✦ Combining corrections and extrapolation

The public CMS results can be found here:
https://twiki.cern.ch/twiki/bin/view/CMS/PhysicsResults

Jet corrections in CMS

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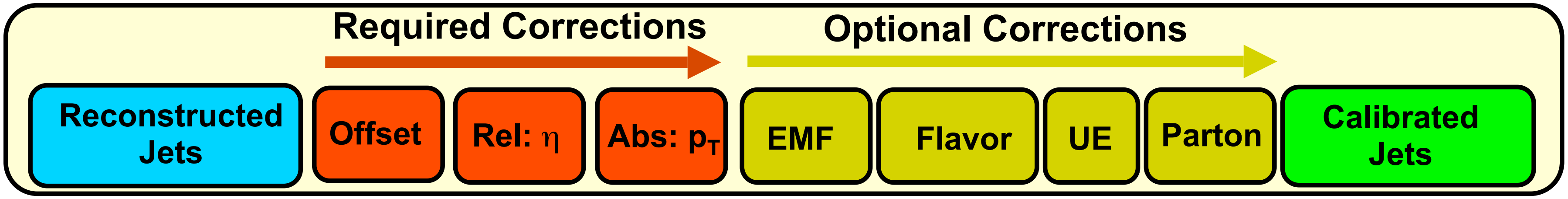

- Correct for each factor in a fixed sequence up to a level chosen by user.
- Factorization facilitates the use of data-driven corrections.
  - Breaking the correction into pieces that are naturally measured in collider data:
    - **Offset**: pile-up and noise measured in min-bias events.
    - **Relative**: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

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

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 the uncorrected jets

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

Absolute correction: p_T dependence

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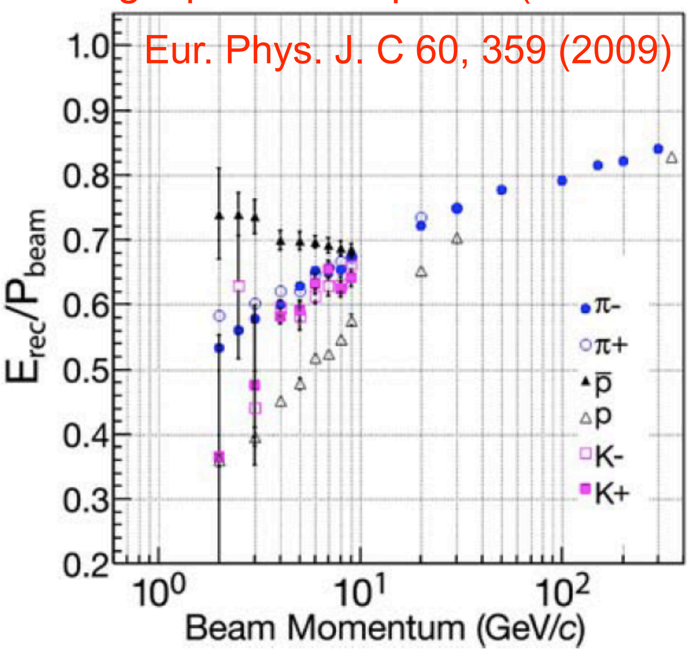
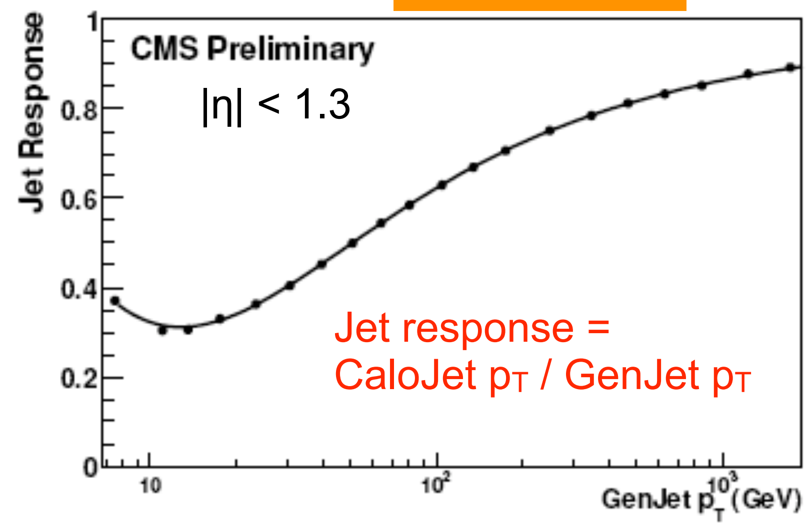
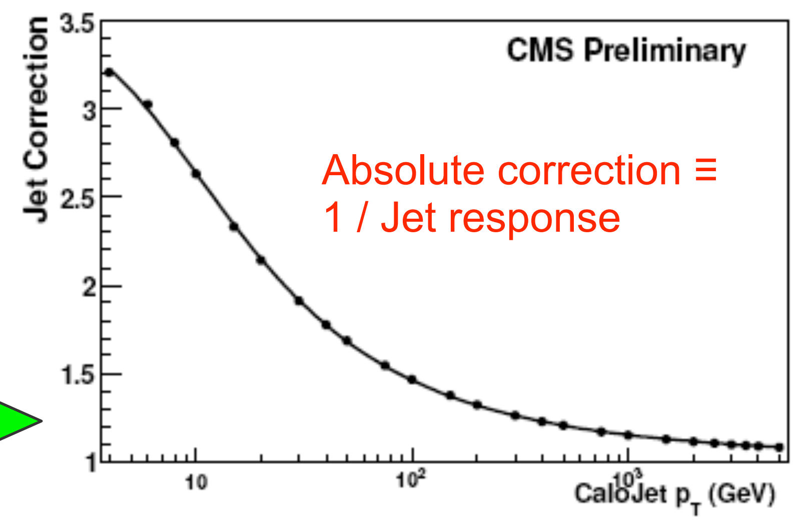
Single particle response (test beam)



Calorimeter response ≠ 1

From CMS simulation of dijet events





✦**Goal:** to correct the observed calorimeter jet energy back to the true jet energy of the stable particles in the jet in the control region (|η|<1.3).

Derivation of absolute correction from data

Use momentum conservation:

• can use conservation of transverse momentum directly in collision data

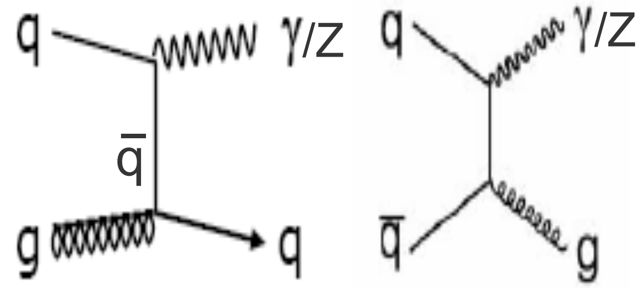
• by exploiting processes in which the p_T of a well-calibrated reference object is balanced by exactly one jet

• photon and Z boson are excellent reference objects:

- γ p_T is precisely measured in ECAL

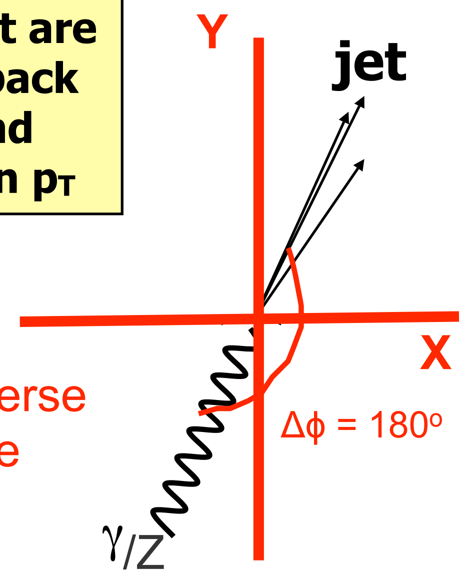
- Z boson p_T is measured with good precision from its decay to $e^+e^-/\mu^+\mu^-$

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



Feynman diagrams for γ/Z+jet production at LHC

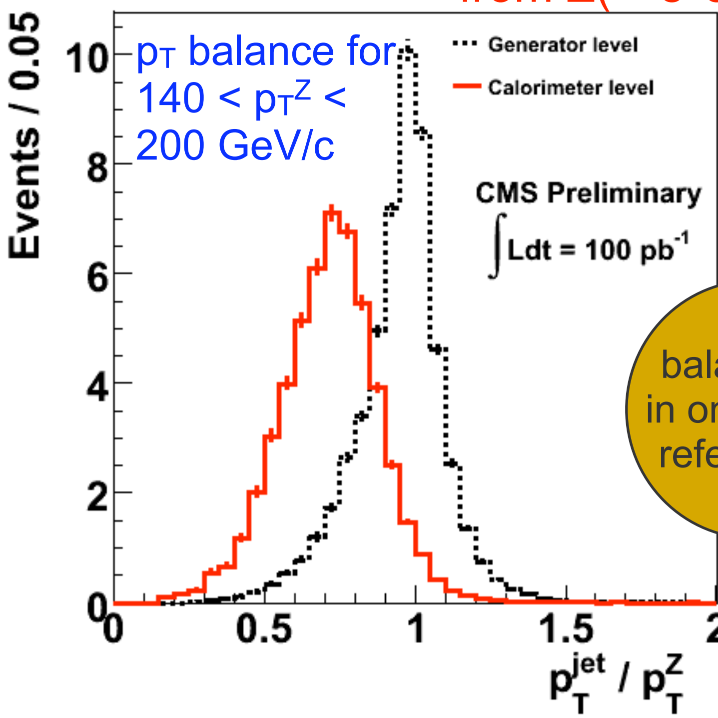
γ/Z and jet are back-to-back in ϕ, and balance in p_T

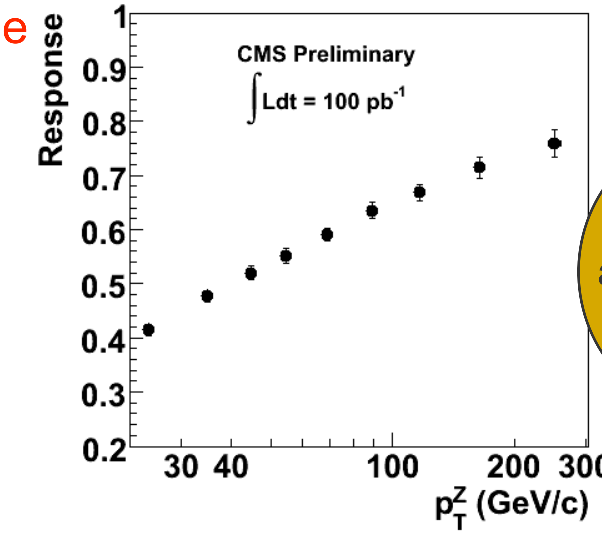


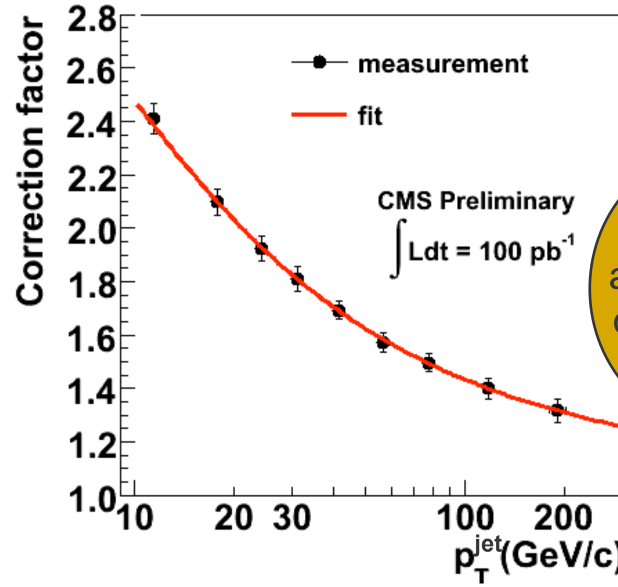
Transverse plane

p_T balance: jet response and correction

from $Z(\rightarrow e^+e^-)$+jet sample







✦Jet response, p_T^{jet}/p_T^Z, peaks at
- •1 for MC generated particle jets
- • < 1 for calorimeter jets

✦The response increases logarithmically with p_T.

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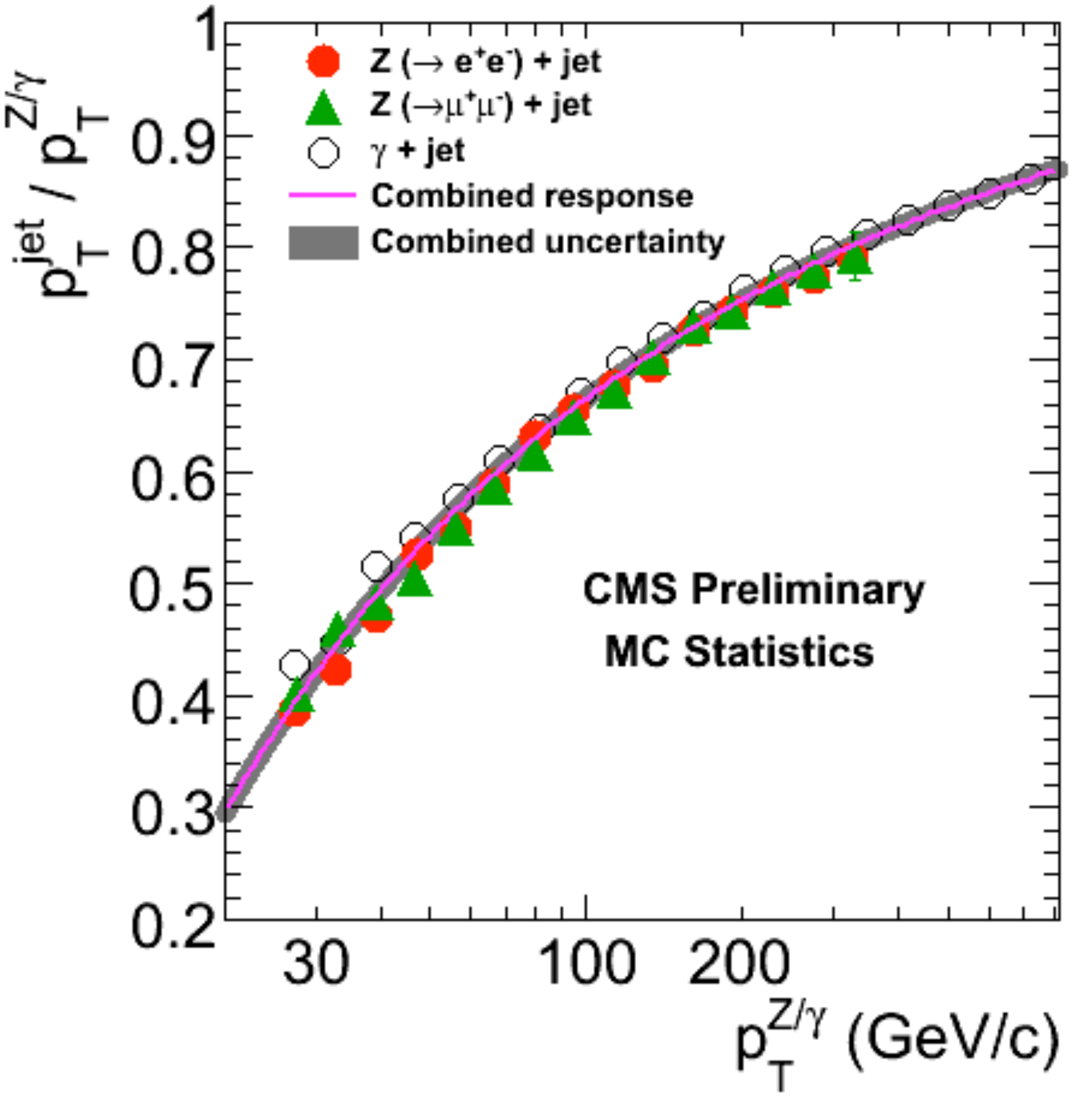
Comparison of response from different samples



- Jet response derived from **photon+jet** and **Z+jet** are similar.
- We now discuss how to combine them to derive a single absolute correction.
  - First we must transform them to the desired type of correction.

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Transformation function

- γ/Z + jet events are rich in quarks
  - ➡ Quark jets have larger response than gluon jets which dominate many samples
- γ/Z + jet p_T balance corrects back to the parton level.
  - ➡ But the absolute correction is defined to be to the particle jet level
- The transformation function corrects for these effects using MC.
  - ➡ Makes the absolute correction applicable to the jet flavor mix of dijet events
  - ➡ Makes the absolute correction to the particle jet level, not the parton level

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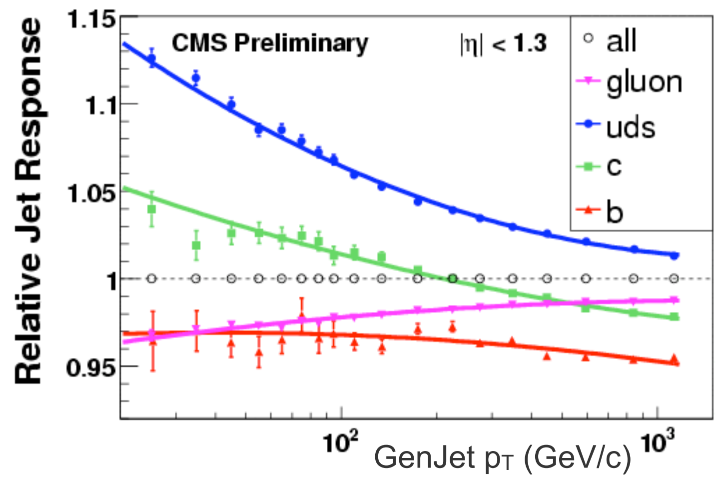
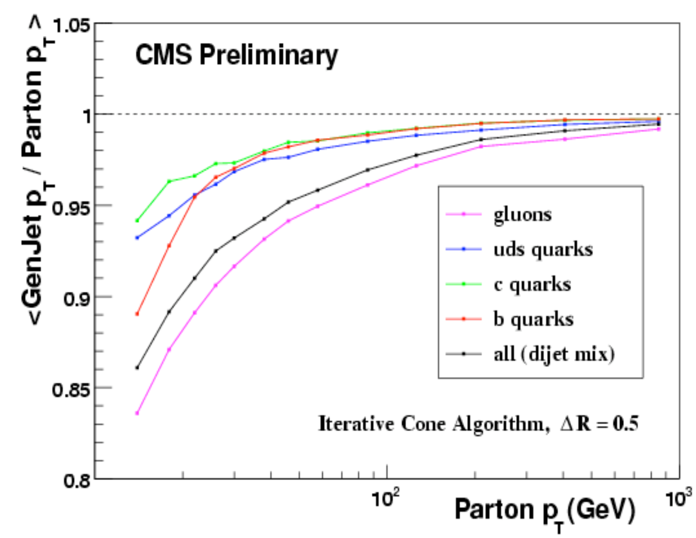
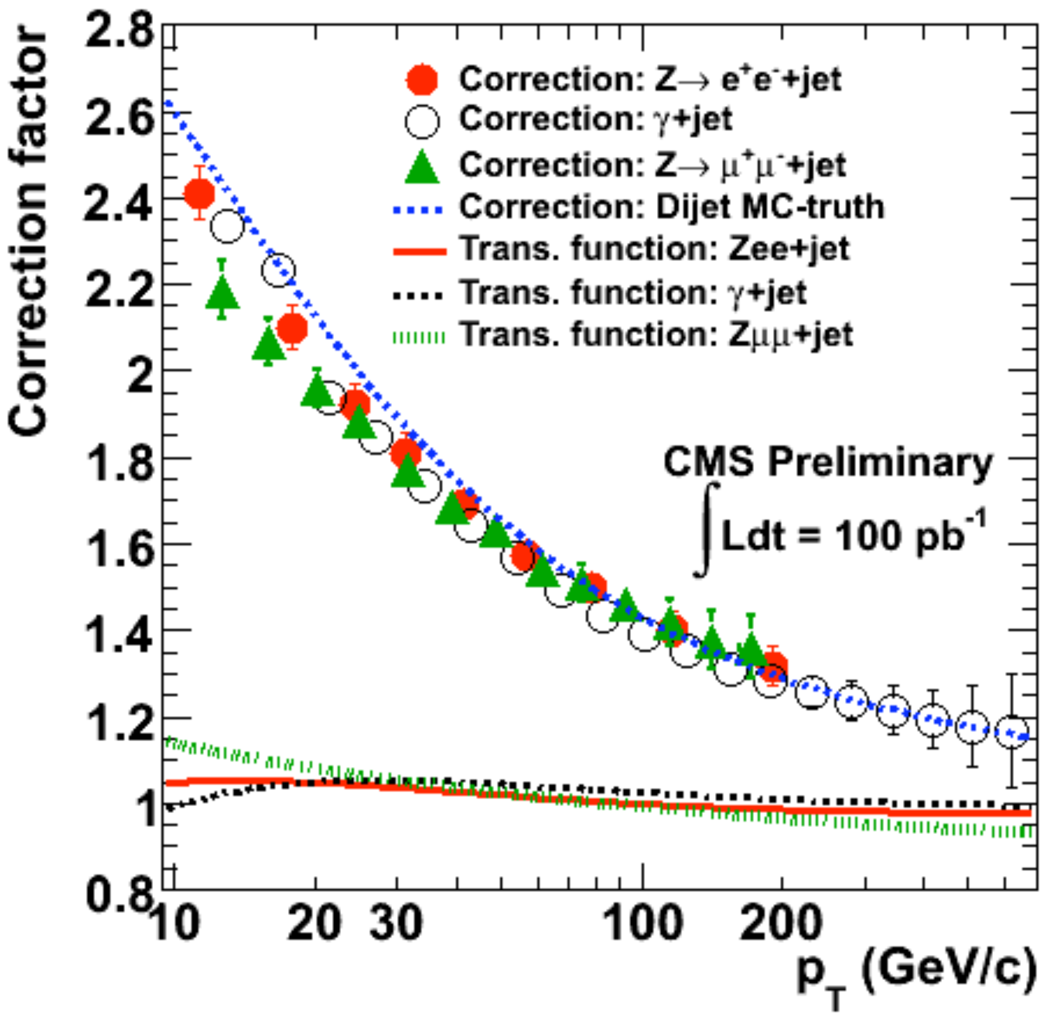
Flavor Corrections



Parton Corrections



Initial correction & transformation function



- ✦Points are initial corrections from each sample.
- ✦Transformation function is the dijet Monte Carlo curve divided by a fit to the points.
- ✦The transformation function maps each data-driven correction to a correction at the particle jet level for the QCD dijet sample.

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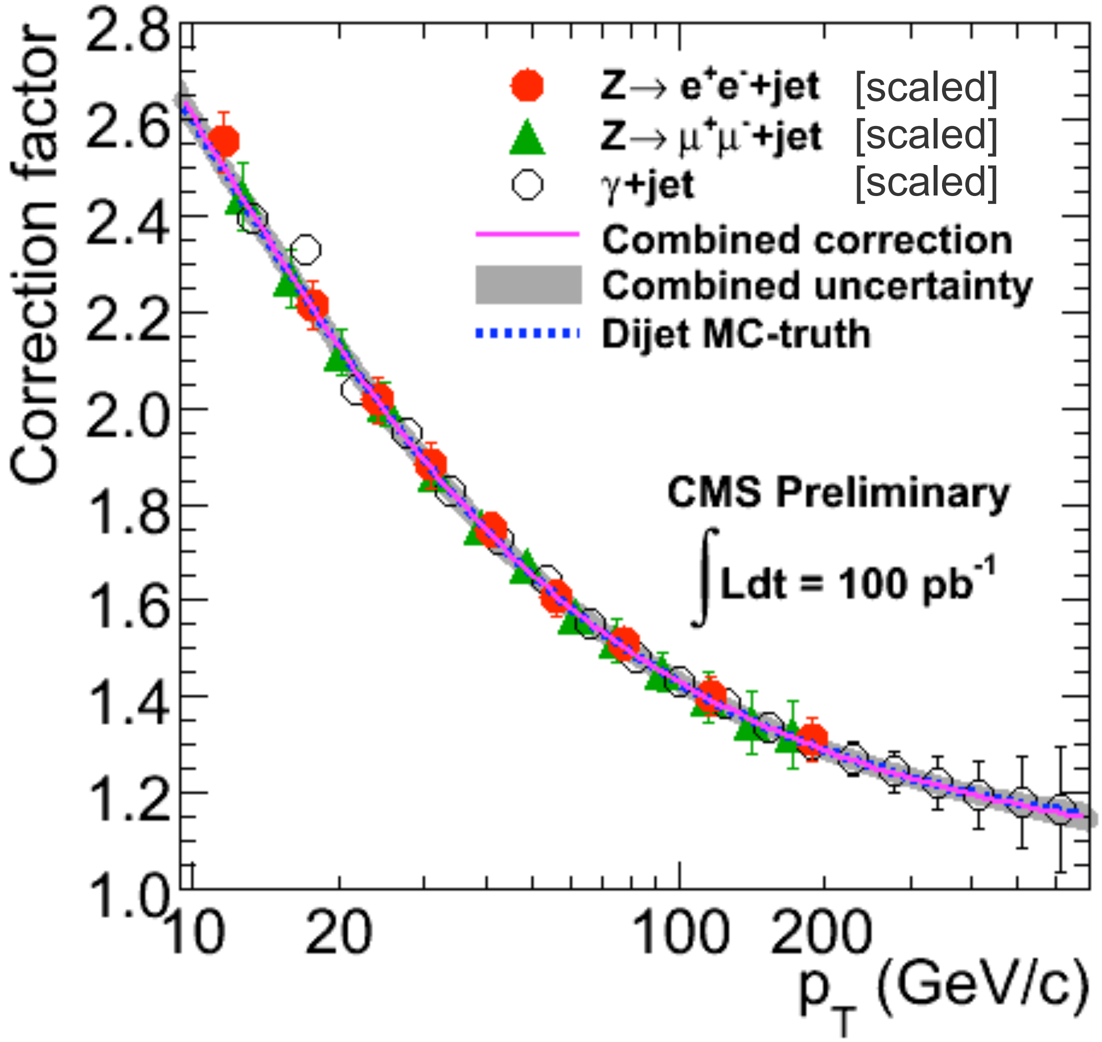
Combined absolute correction



- ✦The data-driven corrections have been scaled using the transformation functions.
- ✦The combined correction uses all available calibration statistics, and therefore has smaller statistical uncertainty (shown).

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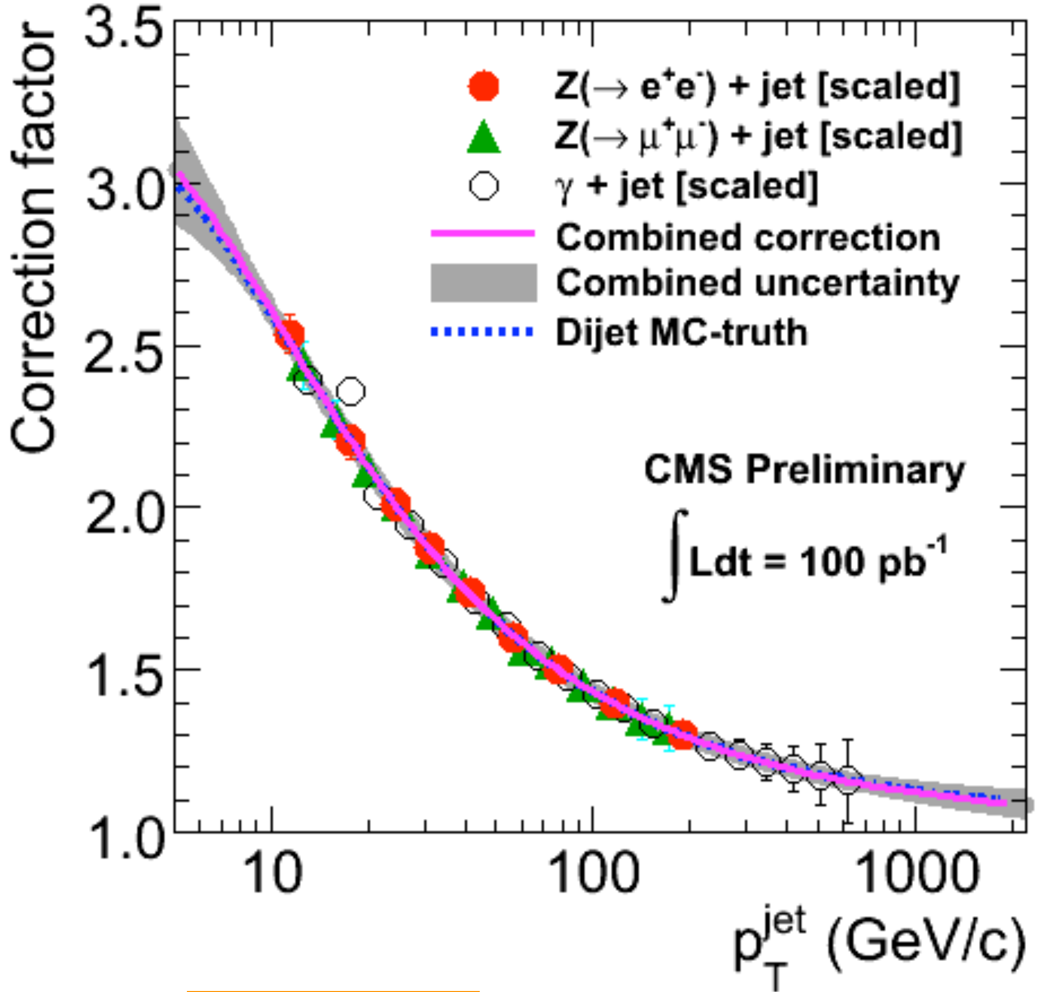
Extrapolation to higher and lower p_T values



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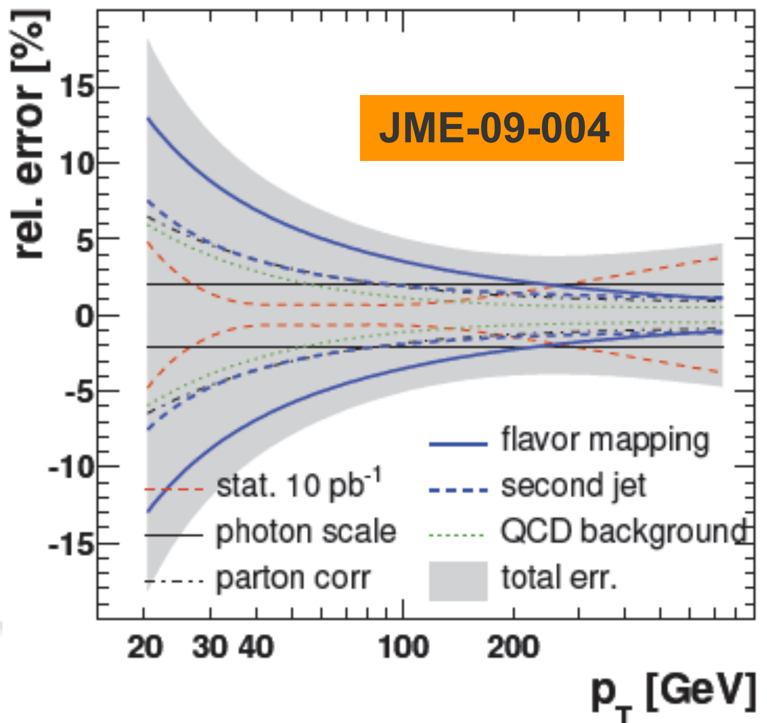
✦QCD dijet can be used to extrapolate the correction beyond the region of data.

- Once the MC agrees with data in the region of overlap.
- Here they agree by construction.

✦If the real data disagrees with MC, then we will normalize MC curve to match data in the region of overlap.

Systematic uncertainties

Current estimates of JES uncertainty

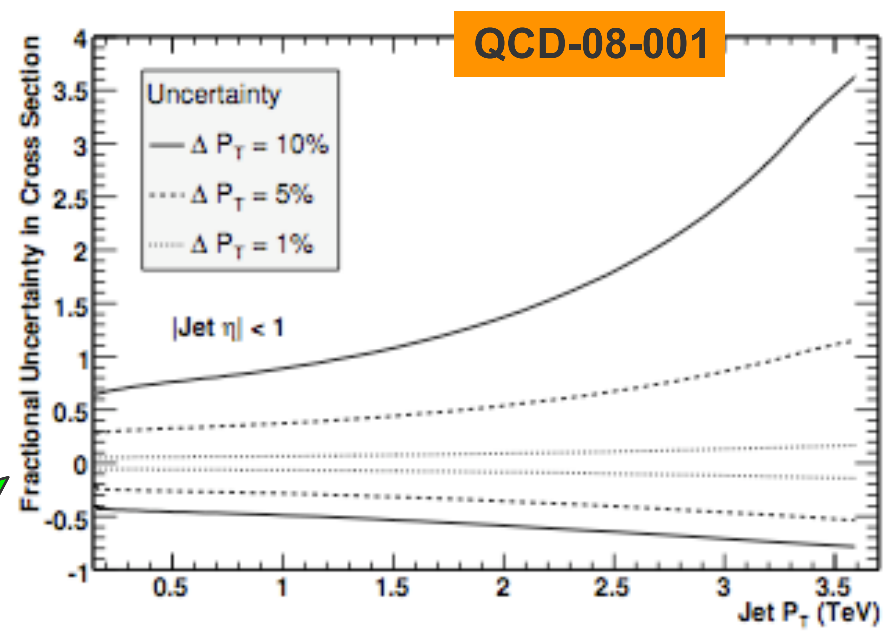


The JES uncertainty has profound consequences !!!

Inclusive jet cross section: JES uncertainty leads to a much larger uncertainty in jet x-section.

✦JetMET expects a ~10% uncertainty in the jet energy scale in the beginning of data taking !

✦The syst. uncertainty is comparable to the size of the transformation function itself.



Summary

✓ **Jet cross section at LHC is several orders of magnitude higher than any other process**

-Jets will be the first objects to be observed and most frequent at CMS!!!
-Jet final states are critical both for studying detector performance and for "re-discovery" of the Standard Model (and tuning of our Monte Carlo).

✓ **Jets need to be calibrated before they can be used for physics**

-The absolute correction is the crucial part of this calibration.
-Data driven techniques developed and demonstrated to work in MC.
-Use p_T balance in photon+jet and Z+jet events to measure jet p_T.
-Default calibration corrects the measured jet energy to the particle level.

✓ **Establishing JES with reasonable systematic uncertainty at startup is a challenging task.**

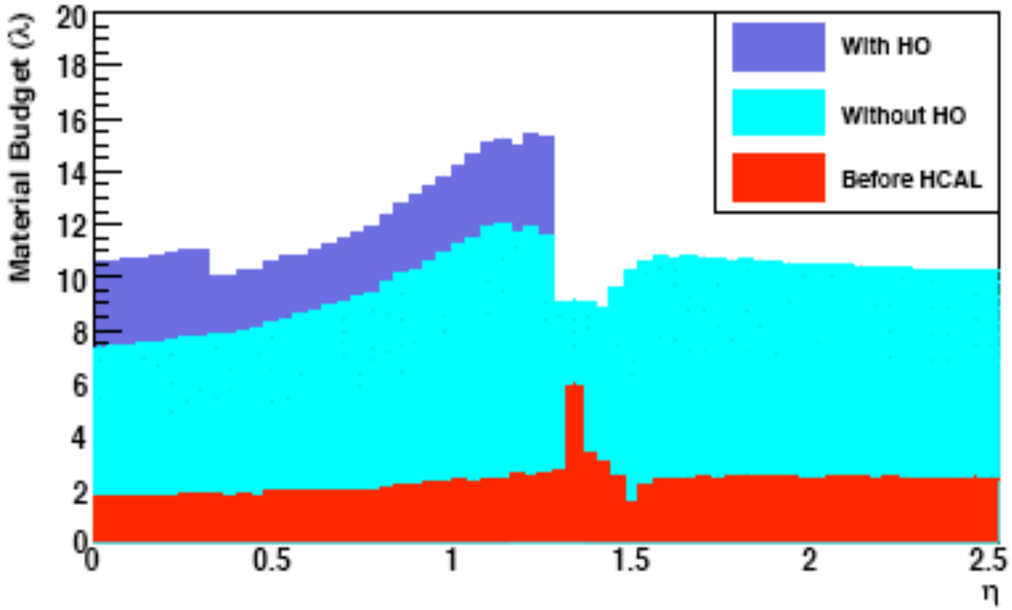
-We are ready for first encounter with real data !!!

End of Talk ! Thank You !

Backup

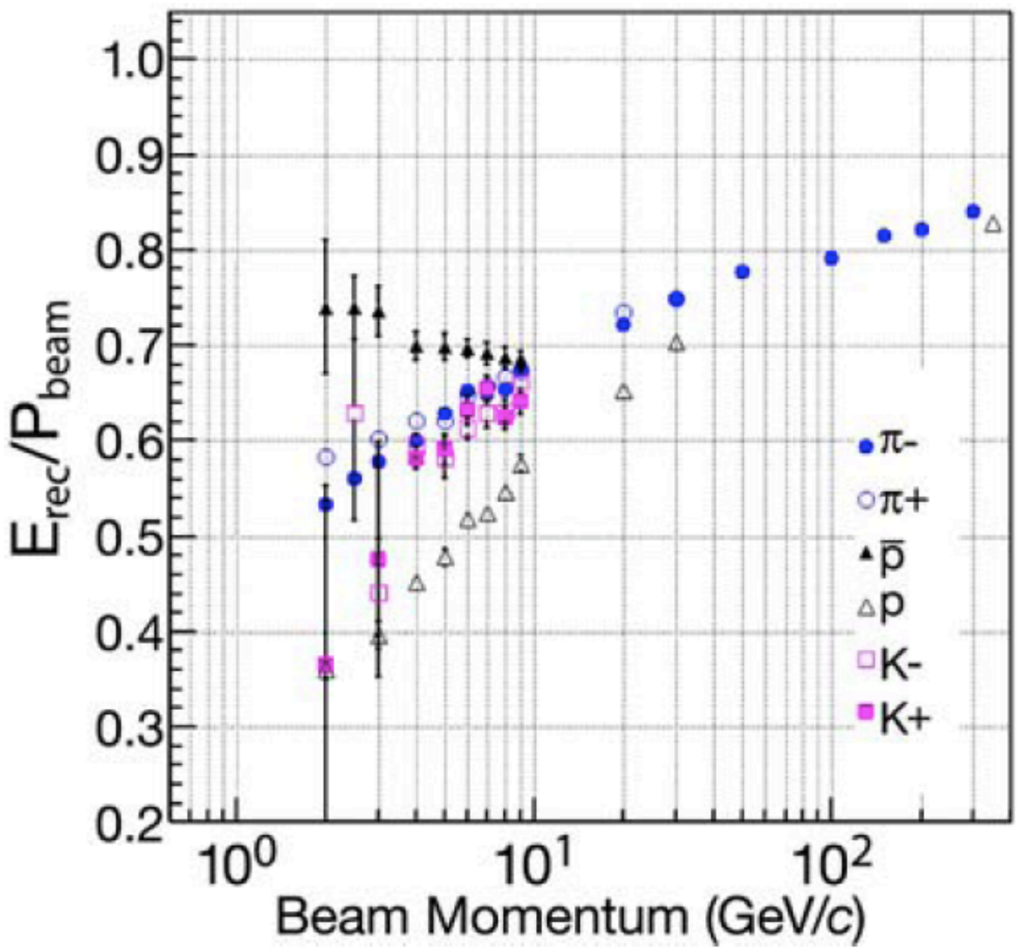
Material budget of the calorimeter

Thickness of HCAL in terms of interaction lengths



7-8 Interaction Lengths at η=0 with HCAL alone and is insufficient to fully contain the shower generated by pions above 100 GeV

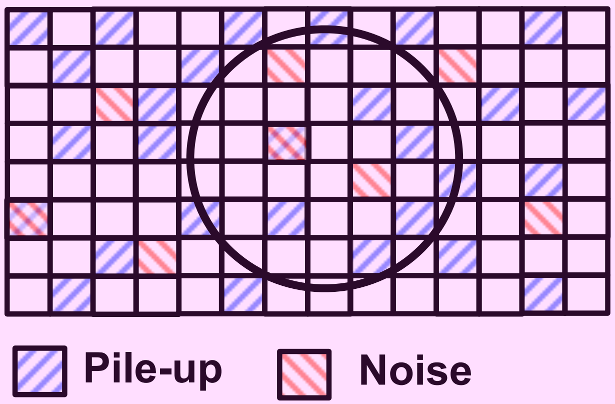
Calorimeter response in test beam data

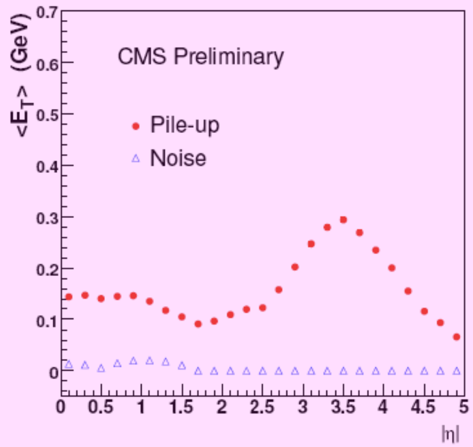


- The figure shows the combined response of EB+HB calorimeter to different particles as a function of beam momentum.
- The response is normalized to 1 for electron.
- At 100 GeV/c, the pion response is 80 % of the electron response.
- The proton response is always lower than the pion response.
- In collision data the response is expected to be lower than in test beam because of additional material in front of the calorimeter.
- The calorimeter response is clearly non-linear.

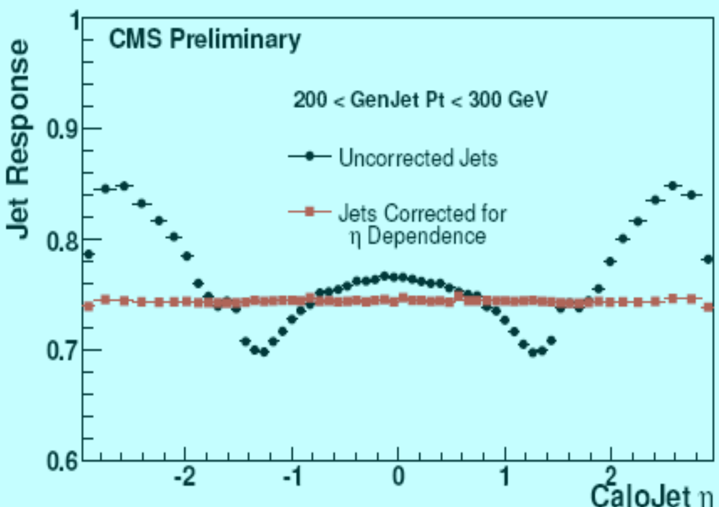
Required corrections

Offset in Jet Area In Calorimeter





Relative Correction in η



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} ?

Absolute Correction in p_T

The absolute correction flattens the jet response in p_T, corrects the energy of the jet back to the particle level in control region (|η| <1.3)

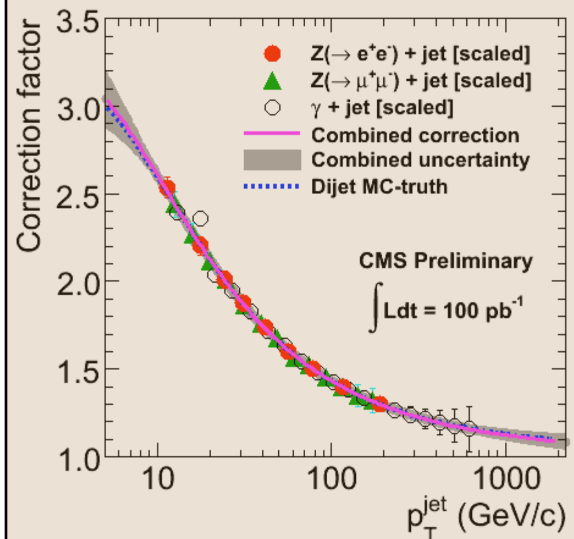


Fig: Jet energy absolute scale correction obtained by combining results from γ+jet and Z+jet samples, and extrapolation using dijet MC.

Absolute correction from γ/Z + jet p_T balance

- **Plan:** measure jet correction from p_T balance in γ/Z+jet events
  - -Jet in the control region: $|\eta| < 1.3$
  - -Use standard γ / Z reconstruction
  - -Select clean events with
    - $\Delta\phi > \pi - 0.2$,
    - extra jet $p_T < 0.1\, p_T^{\gamma/Z}$
- γ + jet p_T balance
  - -The γ p_T is measured in ECAL, which is calibrated using test beam electrons and with *in situ* calibrations with $\pi^0 \to \gamma\gamma$, $Z \to e^+e^-$
  - -Can measure jet correction up to $p_T < 600$ GeV with $\int L = 100\ pb^{-1}$.
- Z + jet p_T balance
  - -Z p_T is measured precisely in the ECAL (for $Z \to e^+e^-$ channel) or in the muon chamber (for $Z \to \mu^+\mu^-$ channel)
  - -Can measure jet correction up to $p_T < 300$ GeV/c with 100 pb^{-1}.

Jet correction parameterization

- The absolute correction is the inverse of the jet response.
- We plot the correction vs mean uncorrected jet p_T in the bins of Z p_T.
- Fit parameterization:

$$C(p_T) = a_0 + \frac{a_1}{[log(p_T)]^{a_2} + a_3}$$

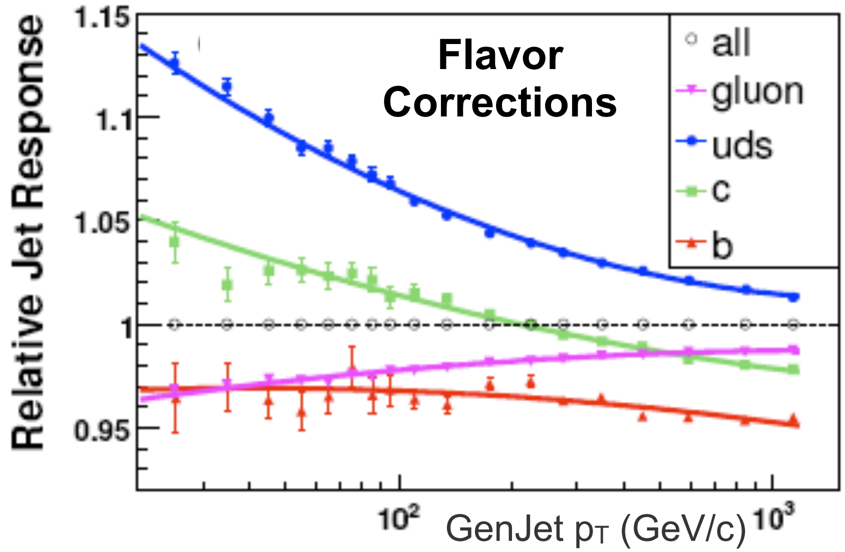
Steps to measure absolute correction

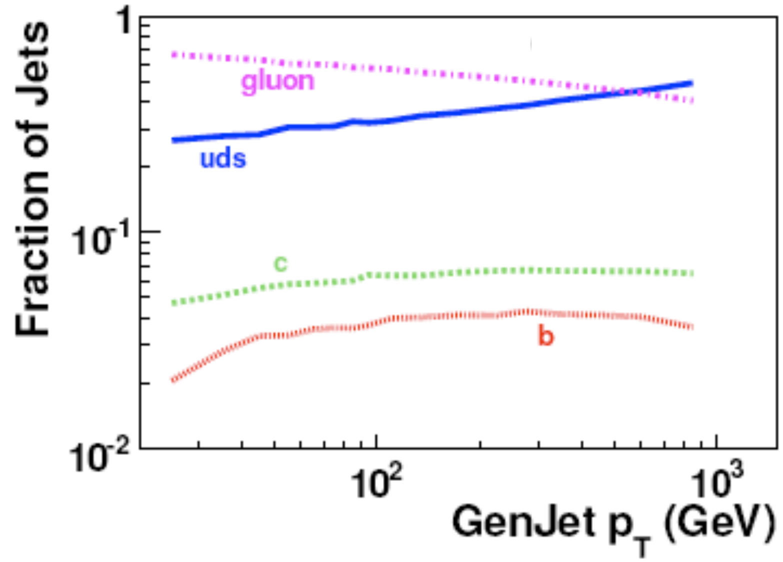
- ✦ γ / Z + jet p_T balance
  - Measures jet corrections to the parton level for special mix of quarks/ gluons.
  - Doesn't measure jet corrections over the complete p_T range needed.
- ✦ Need to transform corrections to particle jet level for a "generic" jet
- ✦ Need to extrapolate to higher jet p_T we need for QCD jet analysis.

Plan

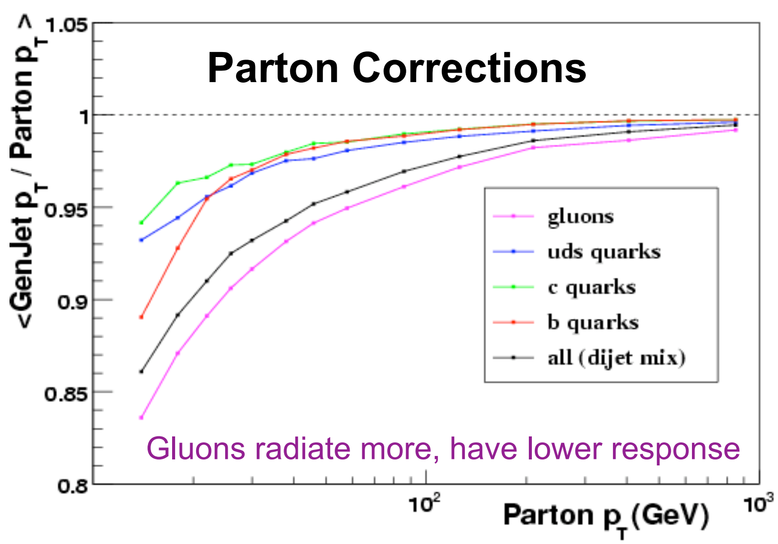
- Measure nominal correction ($p_T^{\gamma,Z}$ / p_T^{JET}) for γ and Z.
- Transform to jet correction at the particle jet level for QCD dijet mix of quarks and gluons using the MC
- Combine converted corrections together based on errors
- Extrapolate to higher jet pt with the QCD MC correction curve

Optional corrections: Flavor and Parton



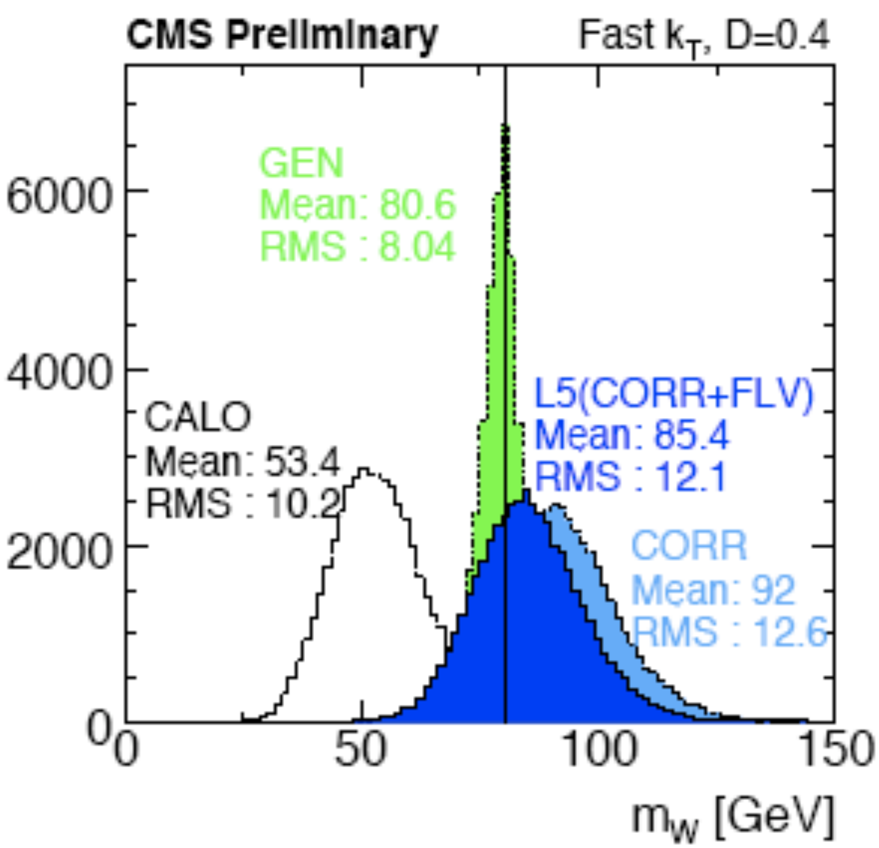


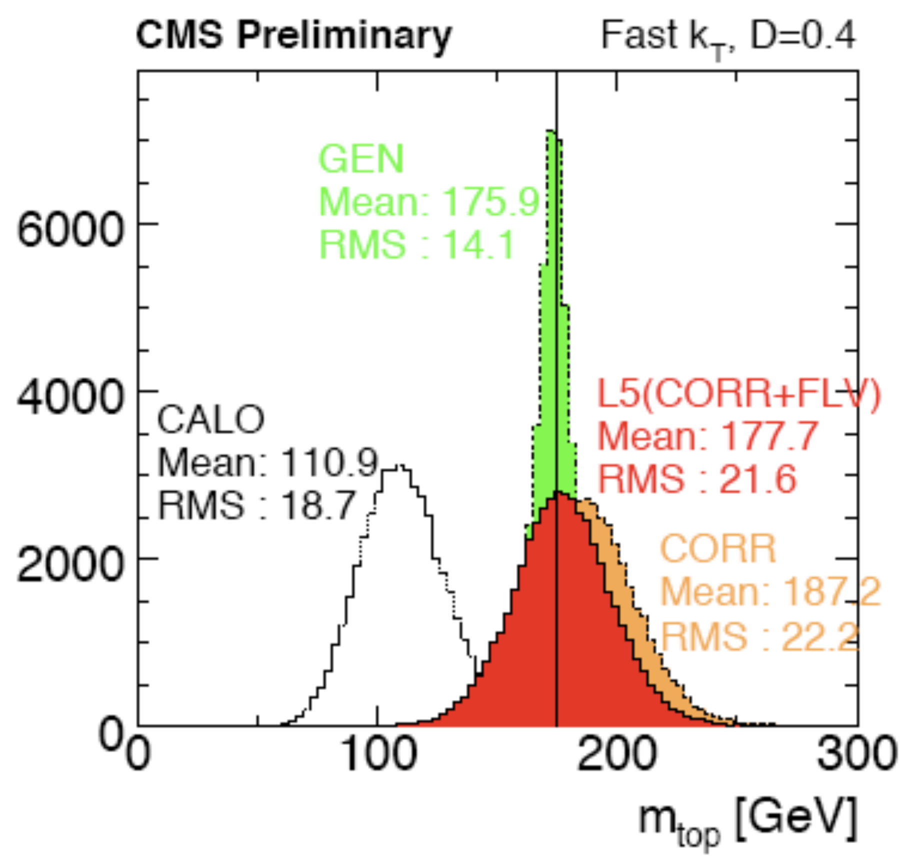
Fraction of jets of each flavor in the QCD dijet sample



- ✦ Light quarks have higher response than gluons as they fragment into higher p_T particles
  - –QCD dijet events have mostly gluons
  - – γ/Z+jet events are rich in quarks, have higher jet response
- ✦ The parton correction is intended to provide correction between the GenJet and parton level jet for parton showering and hadronization.

Does the Jet Energy Calibration work?





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