Limitations on the predictions for p_T-balance in events with a Z-boson and jets

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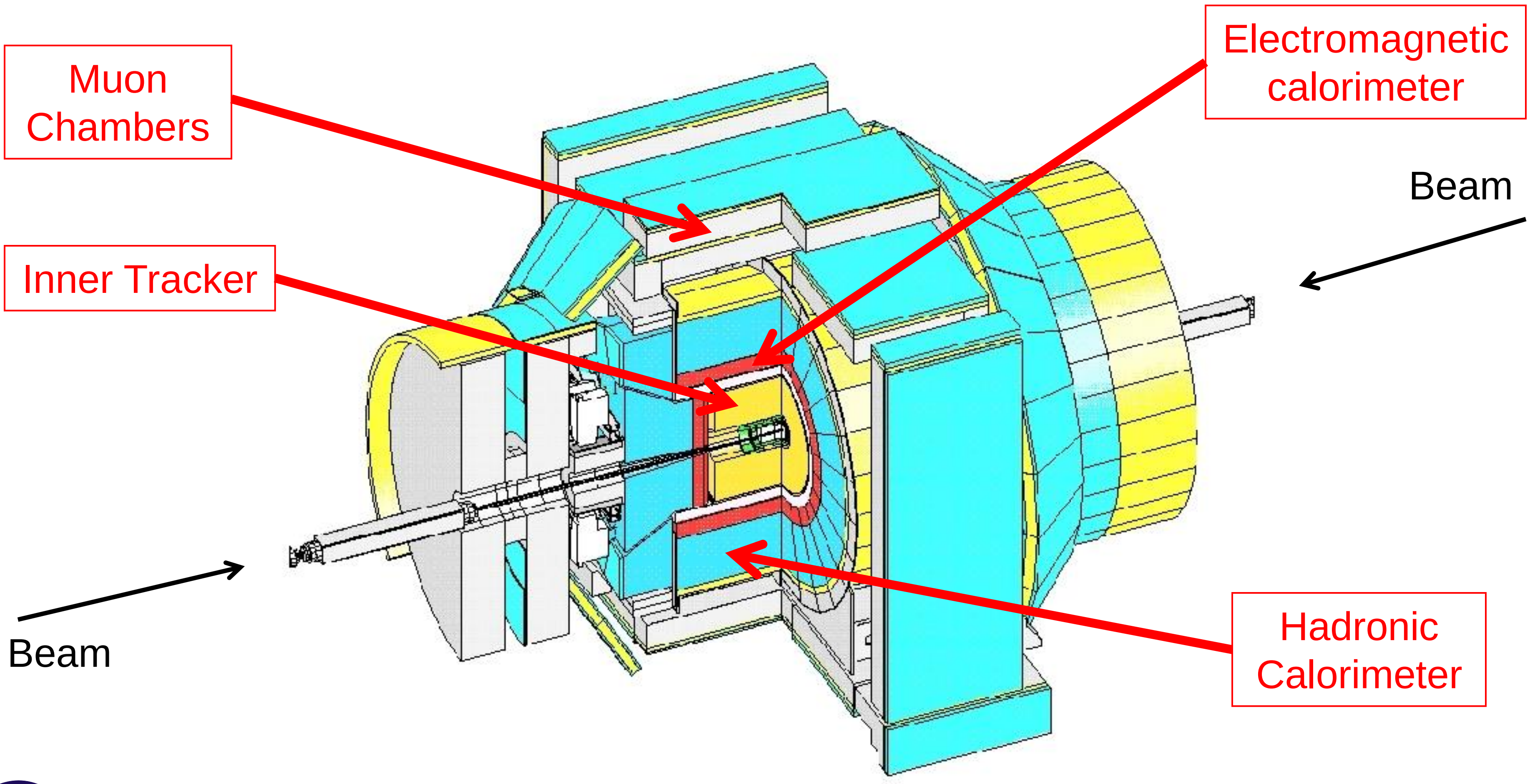
Introduction

- We focus on aspects of the Monte Carlo (MC) simulations which affect jet energy
  - Jet p_T
  - Top mass
  - Missing-E_T
  - Background Estimates
  - Di-jet invariant mass
- Accurate description of multi-jet final states is important for the discovery potential of the LHC experiments.
- Identify and measure theoretical uncertainties contributing to the jet energy measurements
  - Renormalization and factorization scales
  - Choice of PDFs
  - Initial and final state radiation (FSR and ISR)
  - Leading–log parton shower (PS)
- Indicate which elements of the MC simulations (PYTHIA) have to be improved to get more accurate predictions

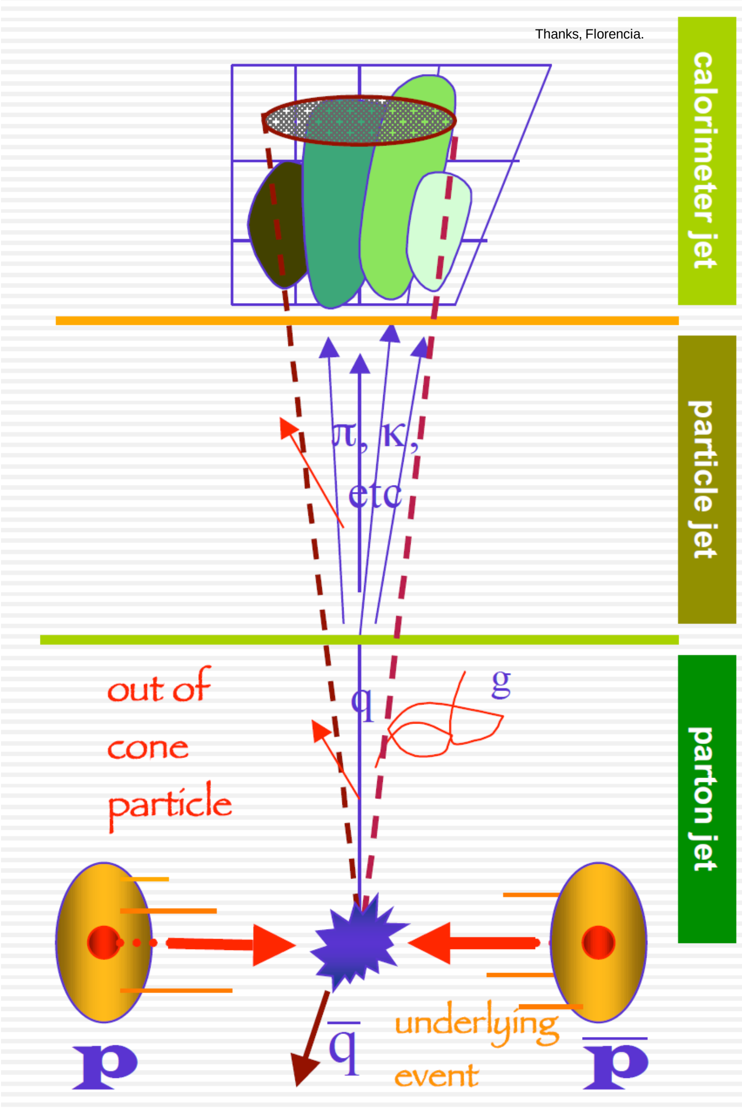
The CDF II Detector

- **4.62 fb^{-1} of pp-bar** collisions from the Tevatron accelerator

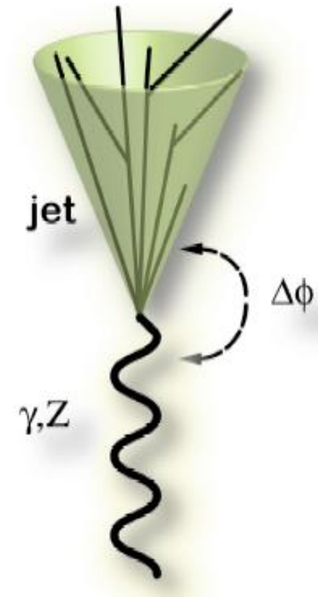


Definition of a jet and JES

- 4-momenta of the calorimeter towers are grouped into "calorimeter jets" using jet clustering algorithm (JETCLU, cone = 0.4, 0.7,1.0).
- Energy (momentum) of a calorimeter jet is normalized to that of a particle or parton jet (called JES)
- Corrections account for
  - Instrumental effects
  - Physics effects
  - Jet clustering algorithm
- Uncertainties are included in JES

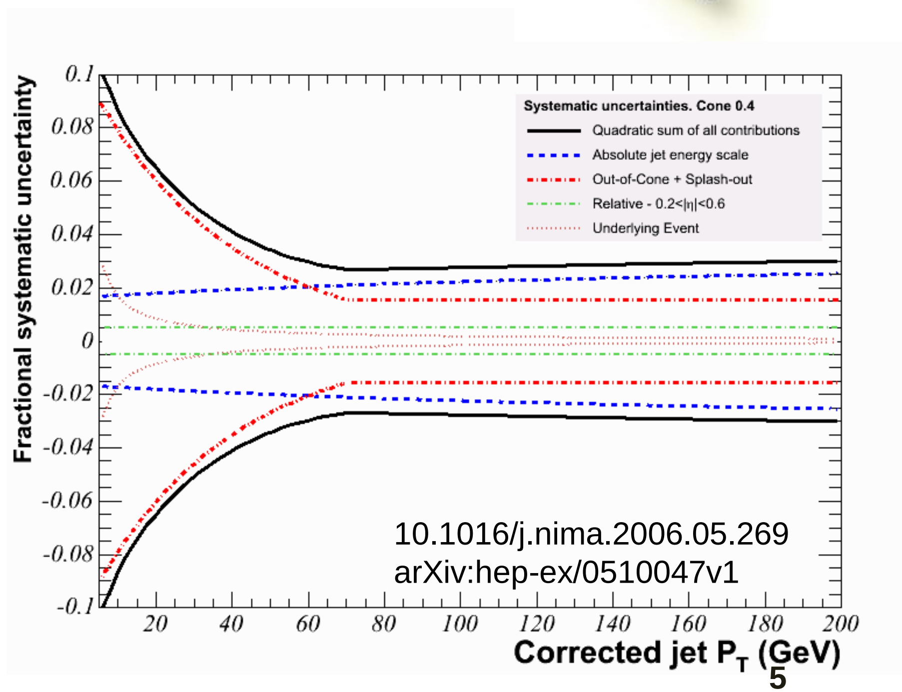


Analysis technique



- P_T-balance in events with a Z-boson and a Jet
  - Uncertainties and features of theory predictions for the $P_T(jet)/P_T(Z)$ as a function of $P_T(Z)$
- Jet Energy Scale at CDF State-of-art measurement with 300 pb^{-1}

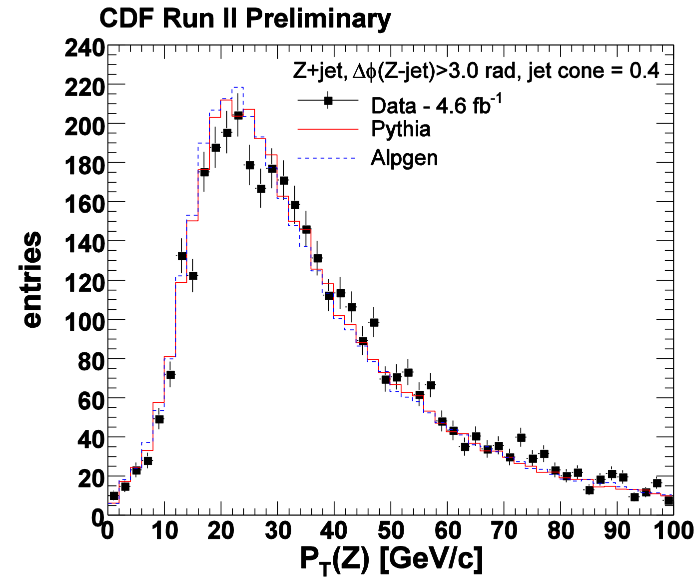
- Now we revisit individual uncertainties caused by SM simulations, PYTHIA, using a high-statistics dataset
- Out-of-Cone (dashed red) dominates at low P_T

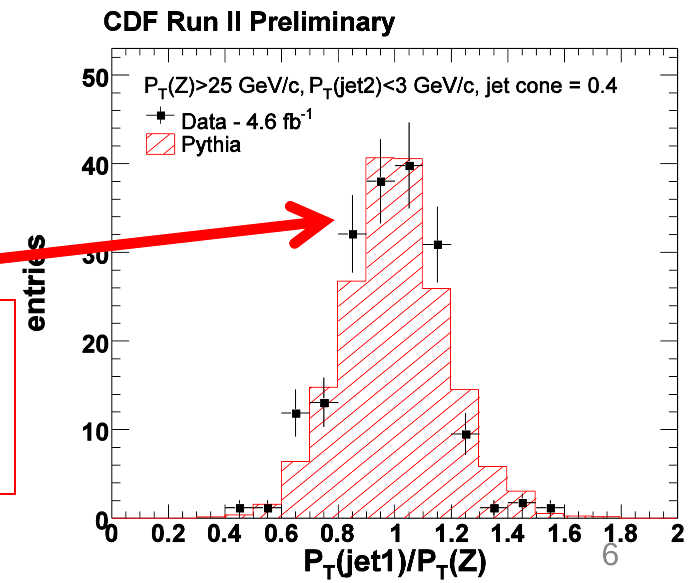


Event Selection

Z-boson is back-to-back to a jet:

- $Z \rightarrow e^+e^-$
- $Z \rightarrow \mu^+\mu^-$
- $80 < M(Z) < 100$ GeV
- JETCLU clustering (cone sizes: 0.4, 0.7, & 1.)
- PT(jet1) > 8 GeV
- $0.2 < |\eta(\text{jet1})| < 0.8$
- $P_T(\text{jet2}) < 8$ GeV
- $|\Delta\phi(Z - \text{jet1})| > 3.0$ rad.
- $P_T(Z) > 25$ GeV (to avoid soft, poorly measured jets)

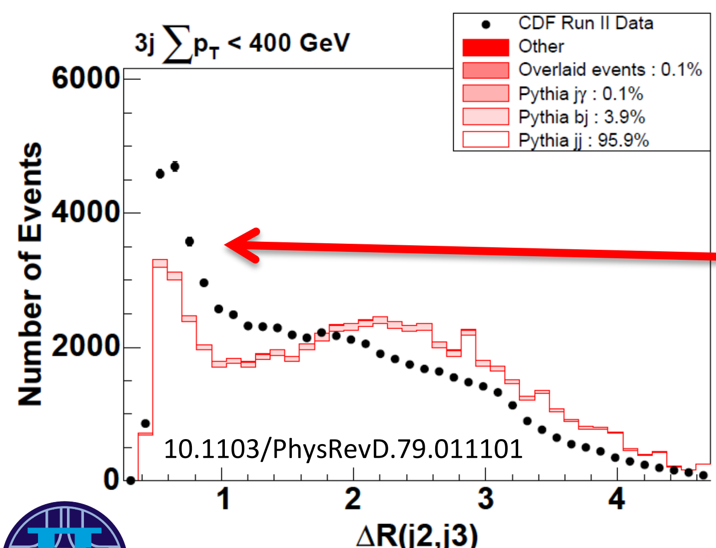




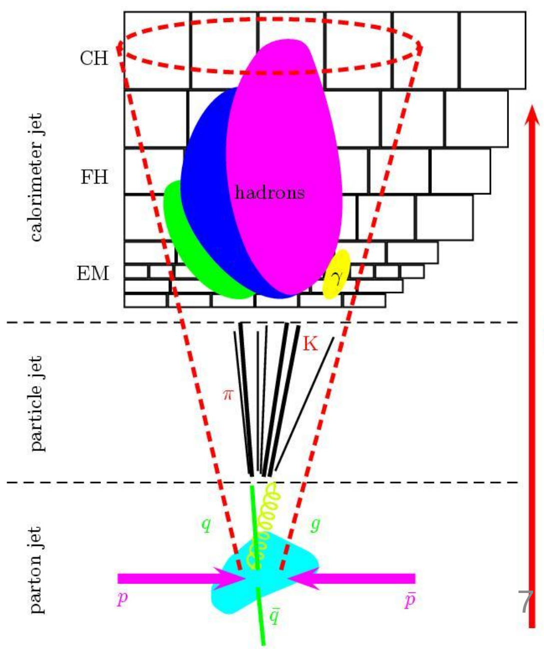
P_T(jet)/P_T(Z): good agreement when P_T(jet2) < 3 GeV: Perfect 2-body system

SM Predictions (MC generators)

PYTHIA (stand-alone) (used to establish JES)	**ALPGEN+PYTHIA (Matrix Elements & Parton Shower calculations)**
Exact ME for Z+0p + a correction to Initial State Radiation	Exact ME's for up to 4 partons
No need for jet-parton matching	Jet-parton matching is @ 15 GeV for cone-0.4 jets to avoid double-counting
Same UE, Same PDF (CTEQ5L), same showering	

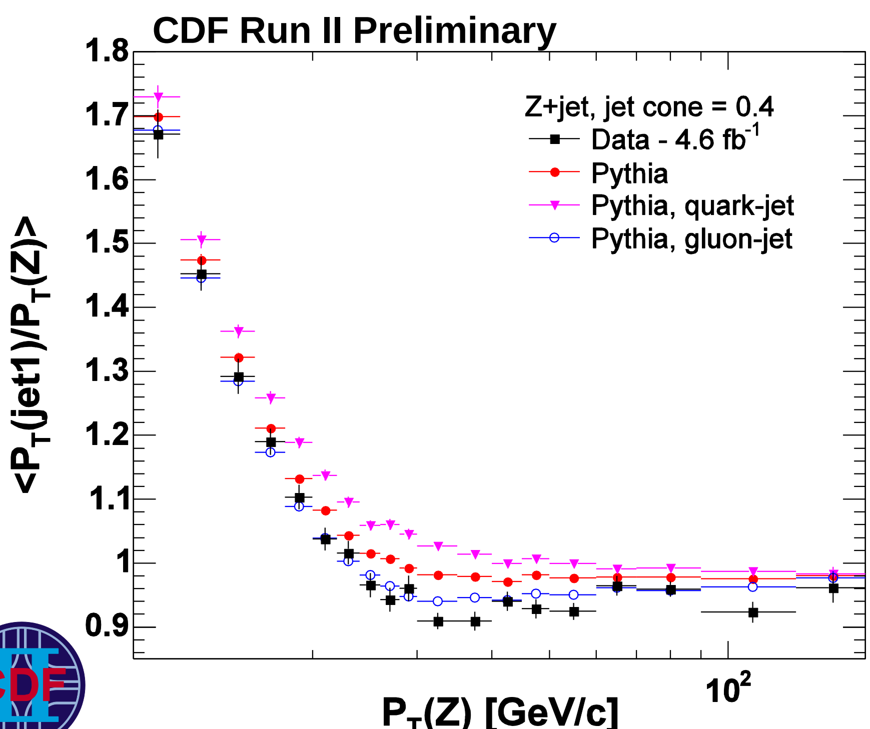


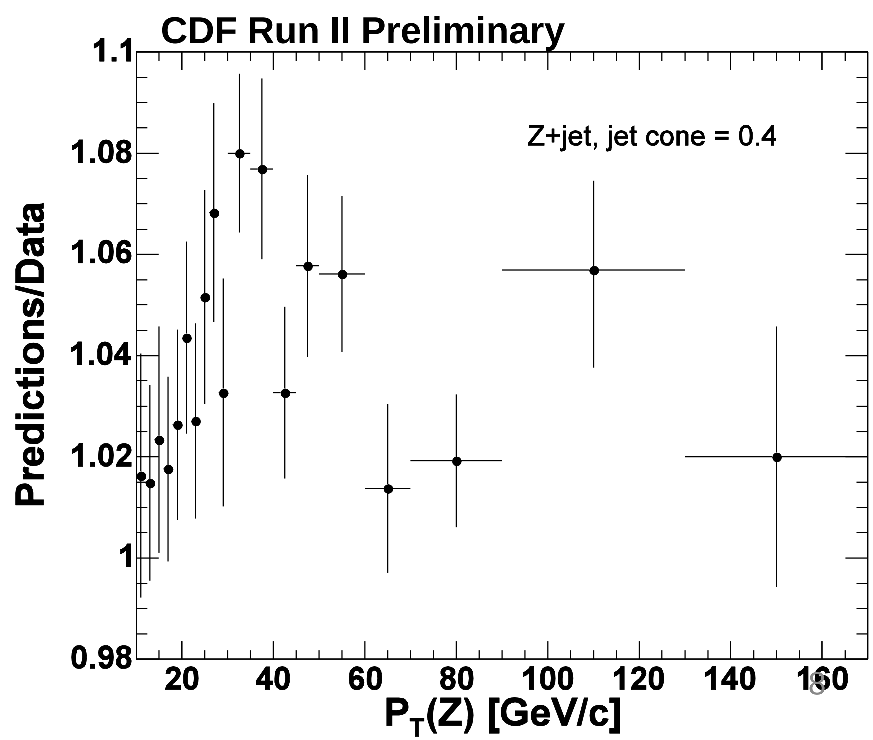
Stand-alone parton showering does not describe hard radiation at large angles well. Correctly described with ME for Z+2p calculation (e.g. Alpgen)



Observed P_T-balance

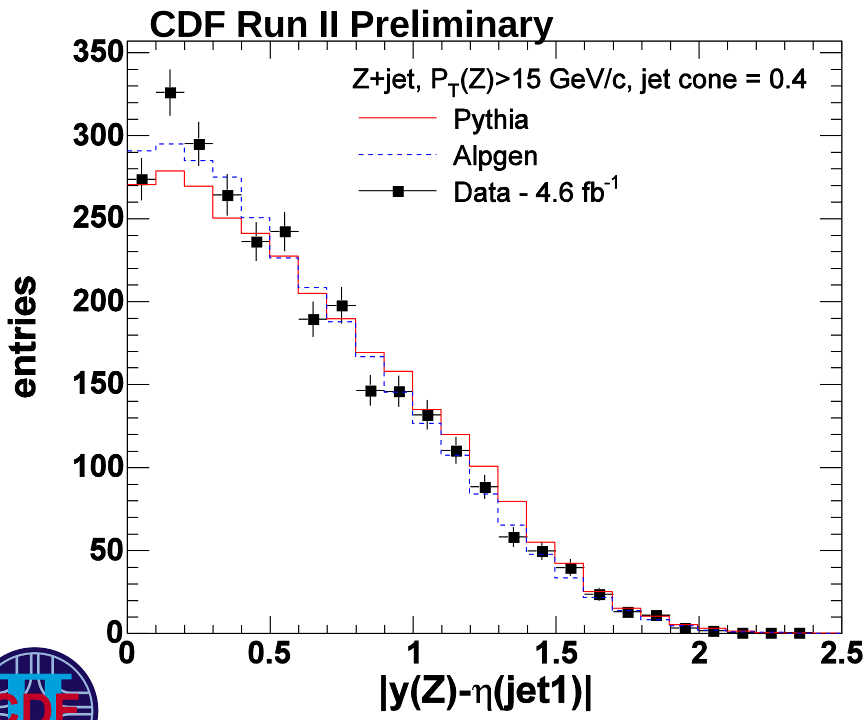
- Jets in Pythia samples have 4.7% more energy than in data for $P_T(Z) > 25$ GeV
- Measured energy is sensitive to the fraction of quark and gluon jets.
- Is the mix of quark and gluon jet properly modeled?
- Do PDF's and tree-level diagrams give the right fraction?

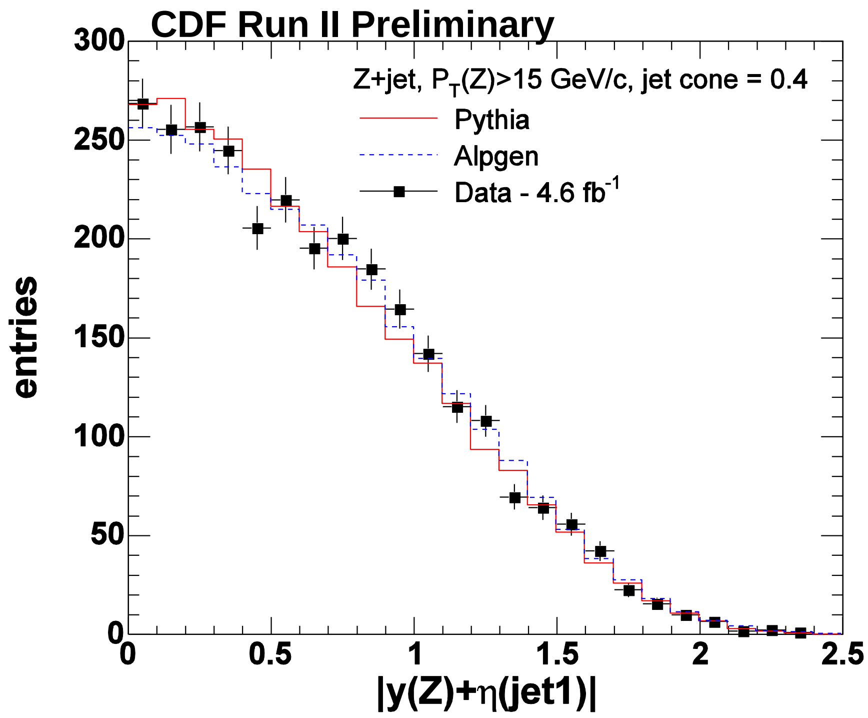




Validation: rapidity distributions

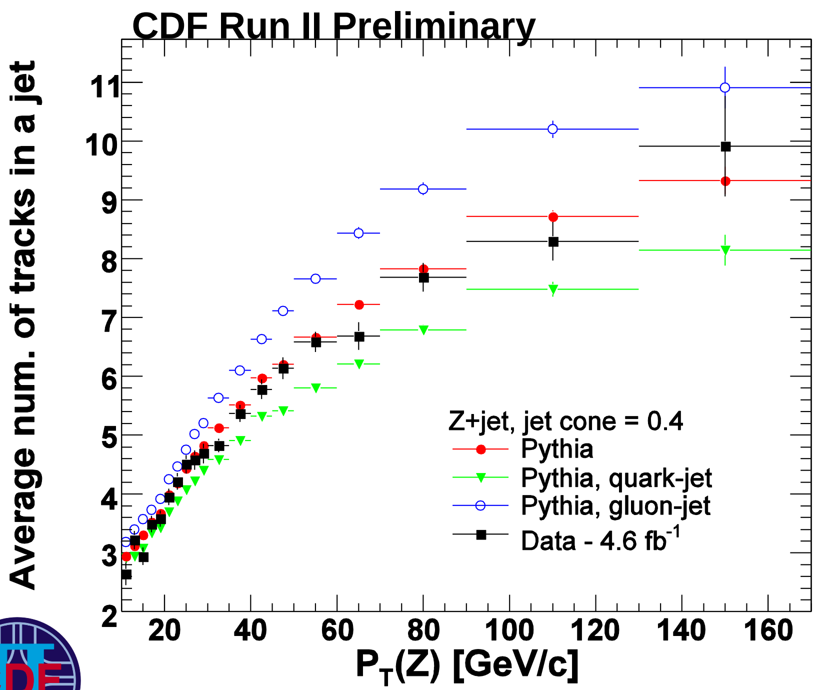
- The rapidity distributions are sensitive to PDF’s and contributions from qg→Zq and qqbar→Zg diagrams
- Pythia and Alpgen describe data well
- ME and PDFs are correct in Pythia

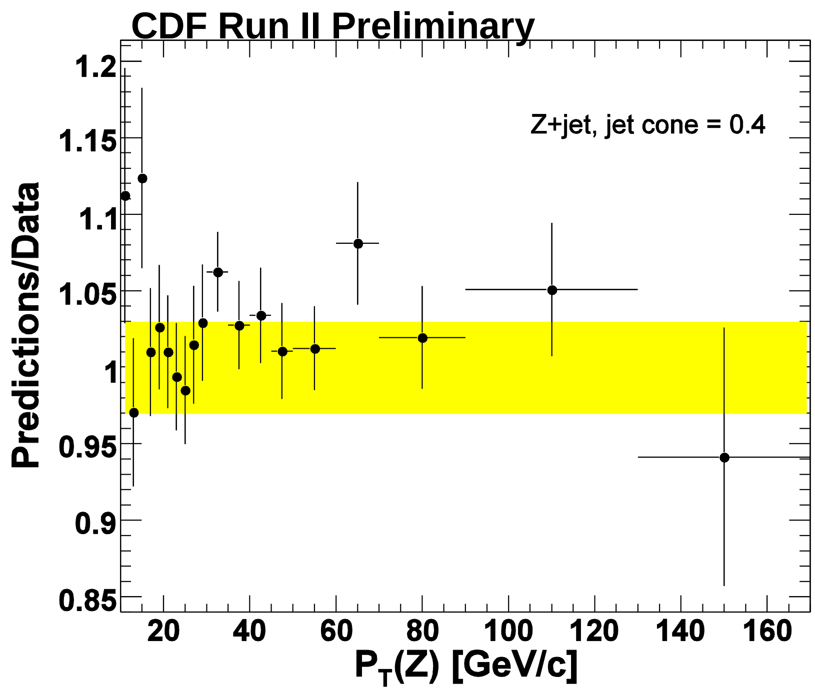




Validation: # of tracks

- Number of tracks observed within the jet cone
- Pythia describes in-cone hadronization and fragmentation accurately
- Many other studies of shower properties
- **In-cone radiation is well modeled; quark-gluon fraction is correct**





Summary of Uncertainties

- We have went the uncertainties on the SM MC simulations
- The uncertainty due to large-angle parton radiation (FSR) is the largest on the theoretical predictions

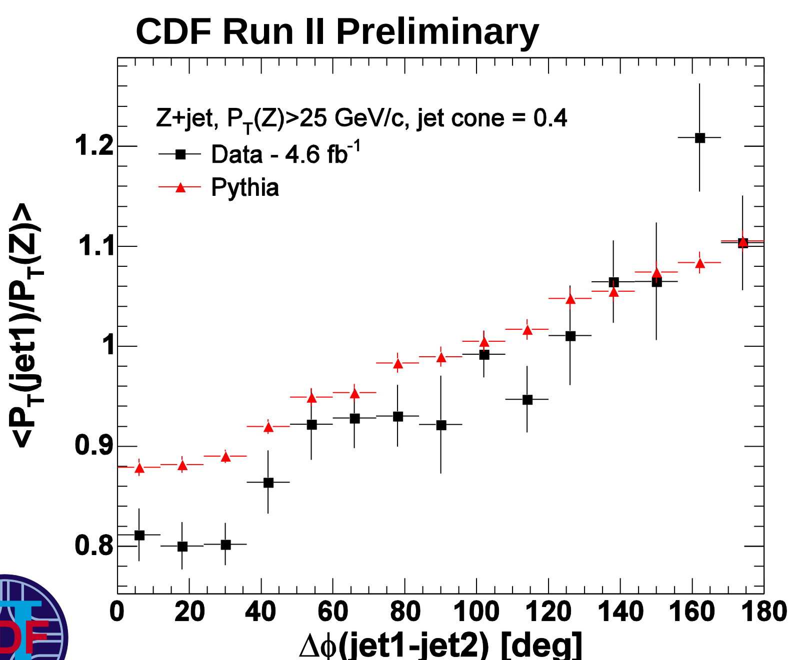
CDF Run II Preliminary

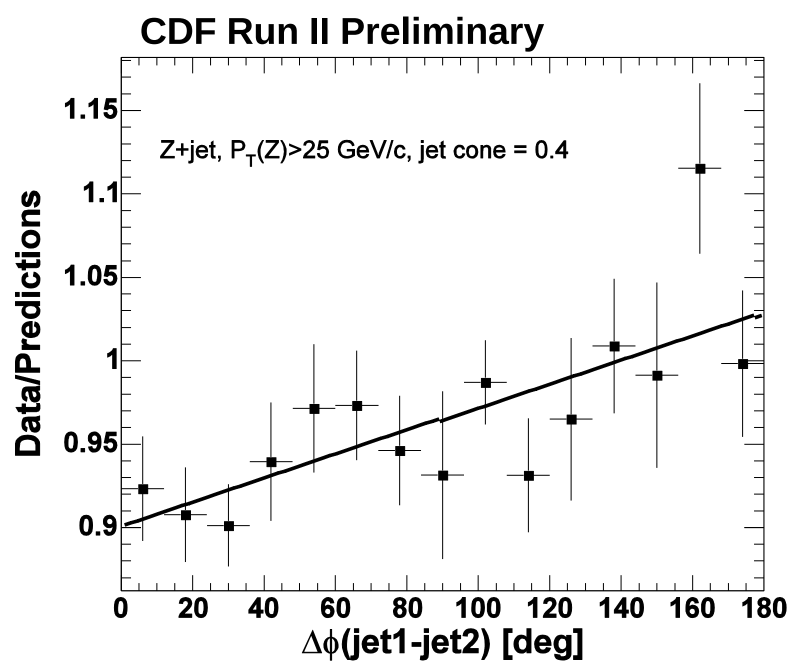
Source of uncertainty	jet cone = 0.4	jet cone = 0.7	jet cone = 1.0
renormalization and factorization scales	+0.9 -0.0	+0.9 -0.4	$\pm$0.4
FSR parameters in PYTHIA	$\pm$0.4	$\pm$0.1	$\pm$0.1
ME's and parton-jet matching	+0.8 -0.0	+1.1 -0.0	+0.8 -0.0
single particle response	$\pm$2.5	$\pm$2.5	$\pm$2.5
multiple proton interactions	+1.0 -0.0	+1.2 -0.0	+1.2 -0.0
large-angle FSR, limitation of PS	+0.0 -2.9	+0.0 -0.2	+1.7 -0.0
Estimate of the total variation	+3.0 -3.8	+3.1 -2.5	+3.4 -2.5
The observed discrepancy	+4.7	+3.2	+2.0

The table presents variation of the MC prediction of <P_T(jet)/P_T(Z)> in % (percent) and the difference between data and PYTHIA predictions (The observed discrepancy).

Uncertainty on the out-of-cone radiation

- Study out-of cone radiation with correlations between P_T-balance and properties of the 2nd jet.
- Data indicates that PYTHIA underestimated the amount of out-of-cone radiation (large-angle FSR)
- Discrepancy becomes smaller with larger jet cone sizes.
- Overall, impressive agreement between the LO simulation and data





Conclusions

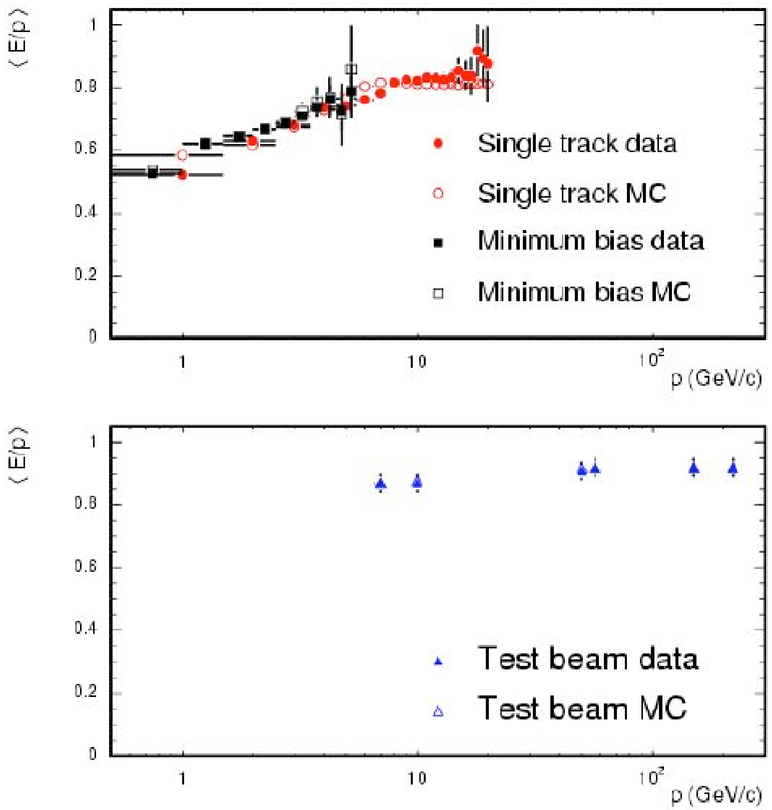
- We have investigated the systematic uncertainties affecting the measurements of jet energies
- Overall, PYTHIA describes data very well
- Parton radiation at large angles is the largest source of uncertainty on the predictions
- A new generation of SM simulations (and new tunes) promise more accurate predictions:
  - MC@NLO
  - Powheg
  - New parton showers and their tunes in Pythia and Herwig

Backup

Single Particle response

- G-Flash shower parameterization was tuned with single beam and minimum bias data

HAD (~70% of a jet)



EM (~30% of a jet)