Measuring the Dijet Mass Cross Section at DØ

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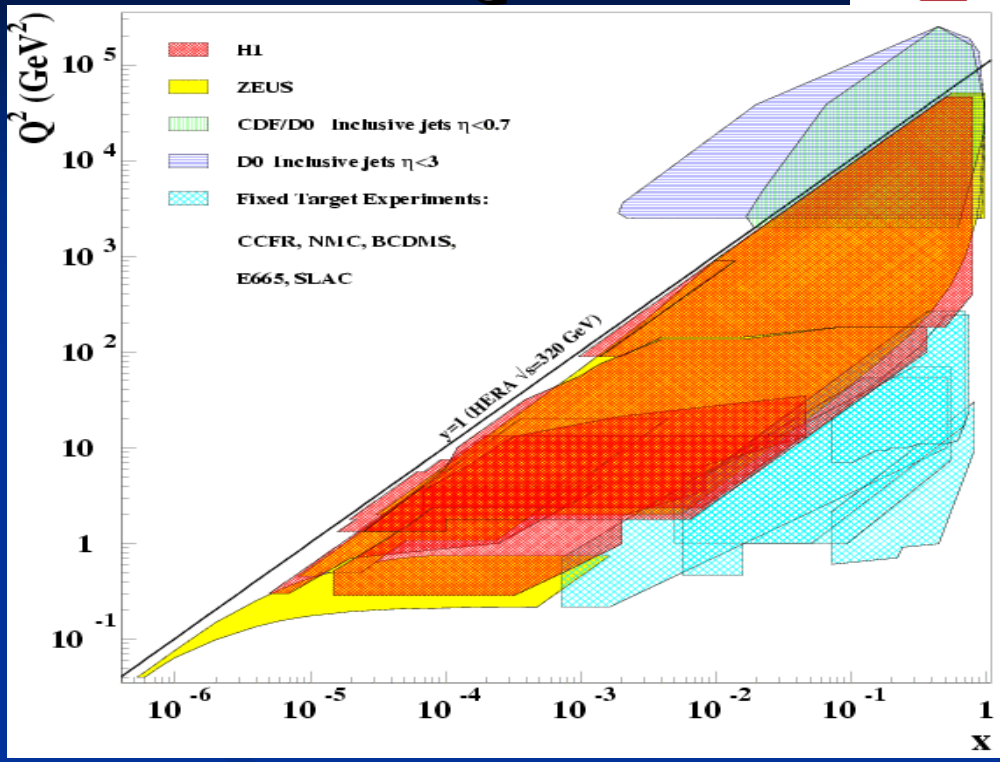
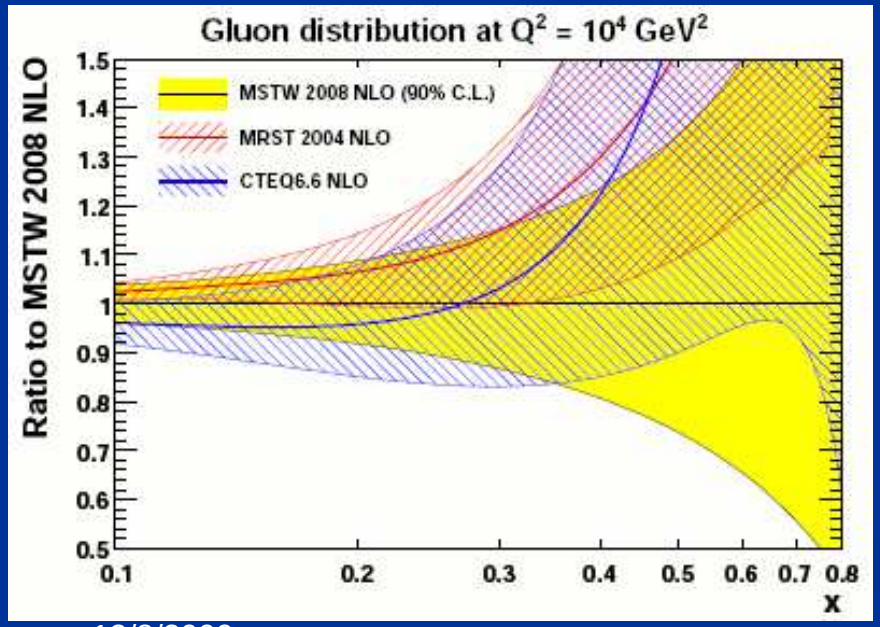
Outline

- Why should we care?
- What is the dijet mass?
- How to calculate the dijet mass cross section?
- Results
  - What they mean
  - Why it's important

Motivation: Test QCD

Improved measurement of gluon parton distribution functions

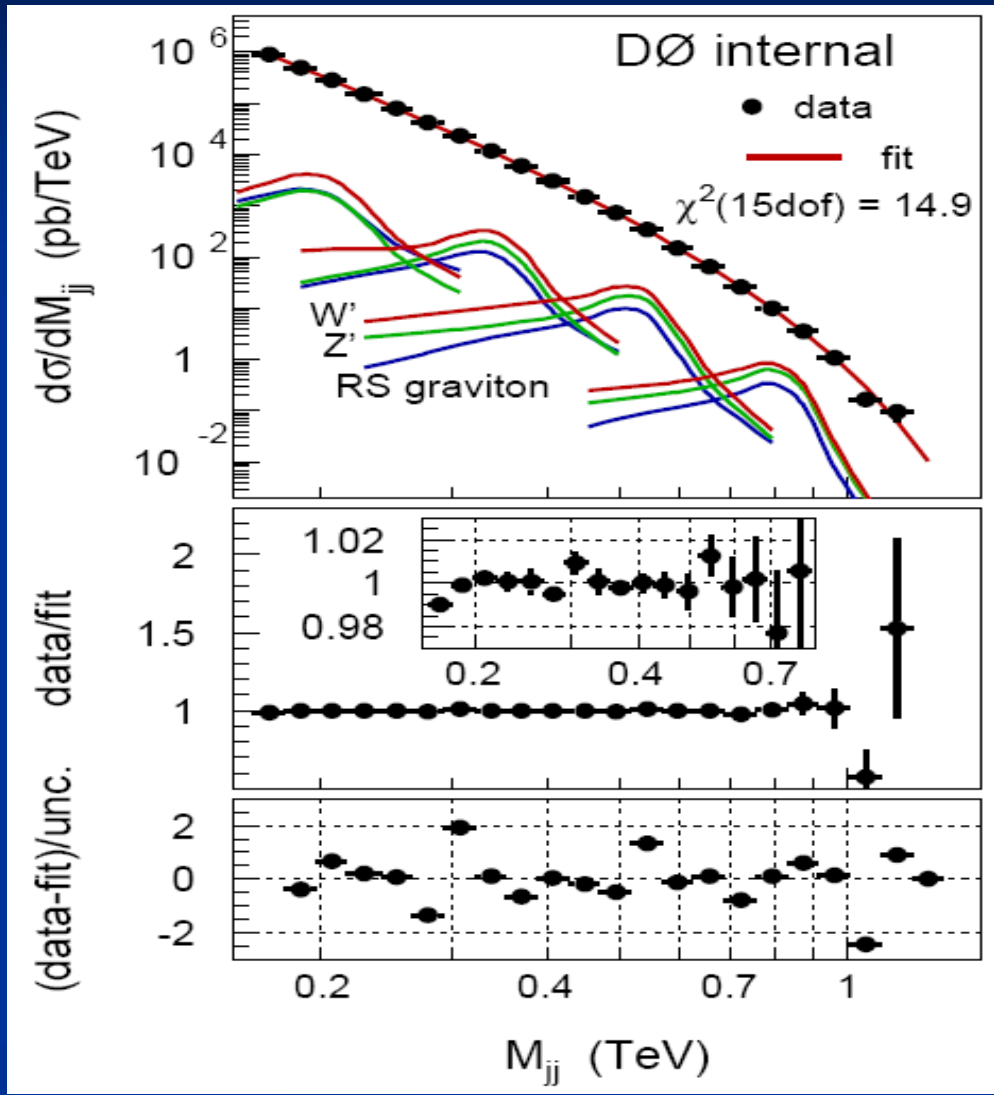




Kinematic region complements fixed target experiments

Motivation: New Physics

- Can search for physics beyond the SM
  - Exotic particles that decay to 2 jets
  - Quark compositeness



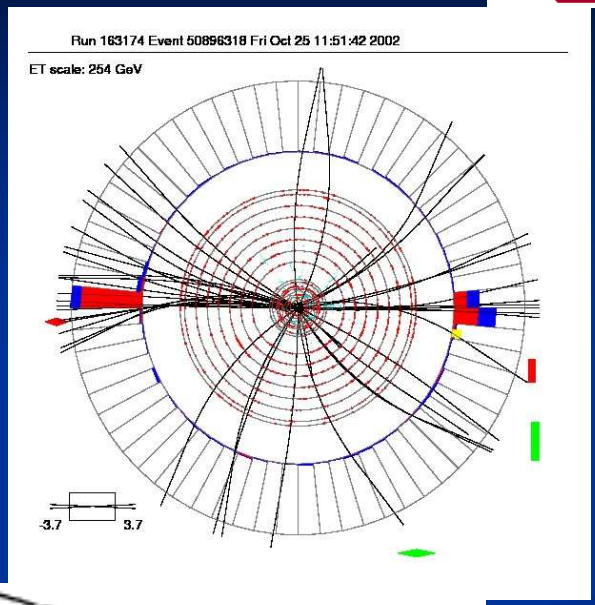
Dijet Mass

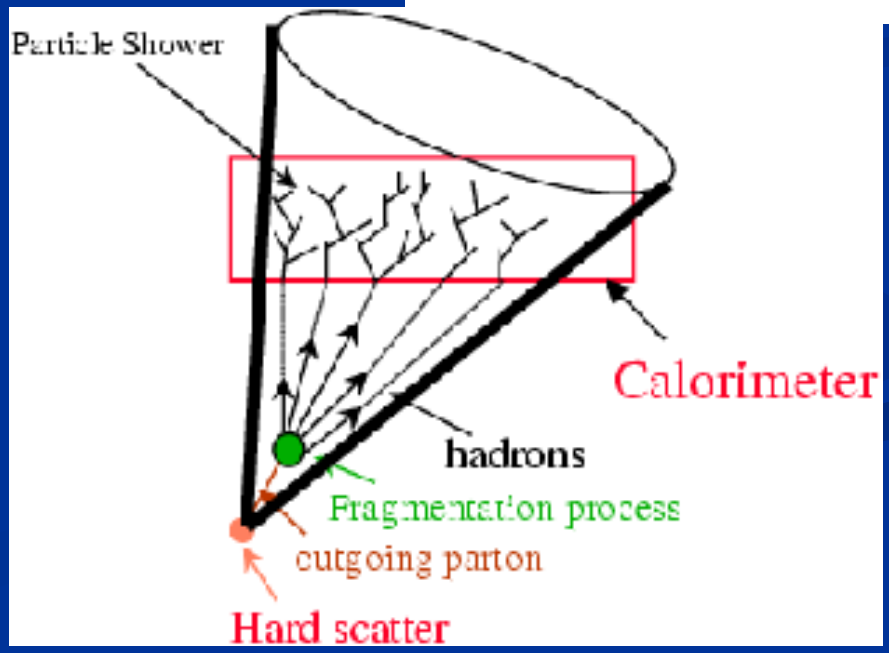
- Mass is calculated using the two highest p_T jets in an event
  - Jets of particles formed from hard scattering of hadrons
  - Jets were reconstructed with DØ Run II cone algorithm
- Use the standard invariant mass formula ($M^2 = E^2 - p^2$)

How Jets Are Formed

- Two partons from a proton and antiproton collide
- Partons fragment, produce shower of more partons
- Hadronization
- Define jet by using cone:

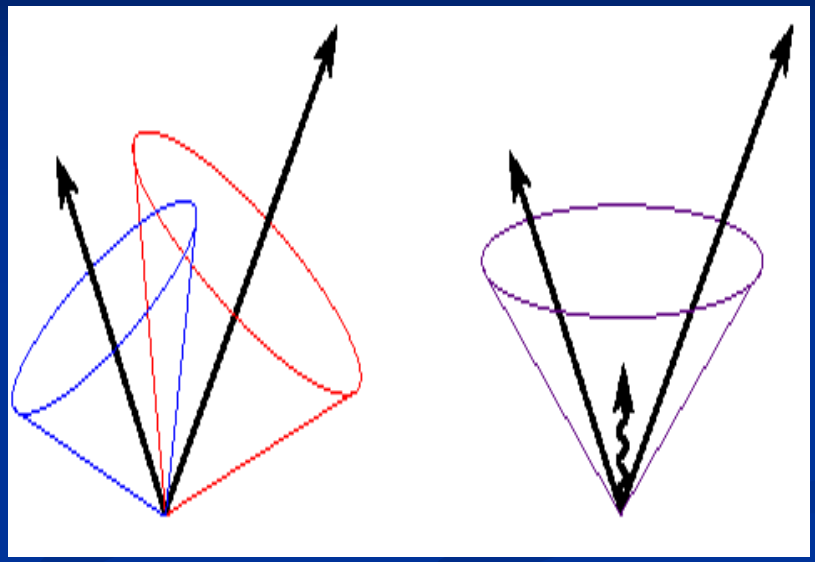
$$R = \sqrt{\Delta y^2 + \Delta \phi^2}$$



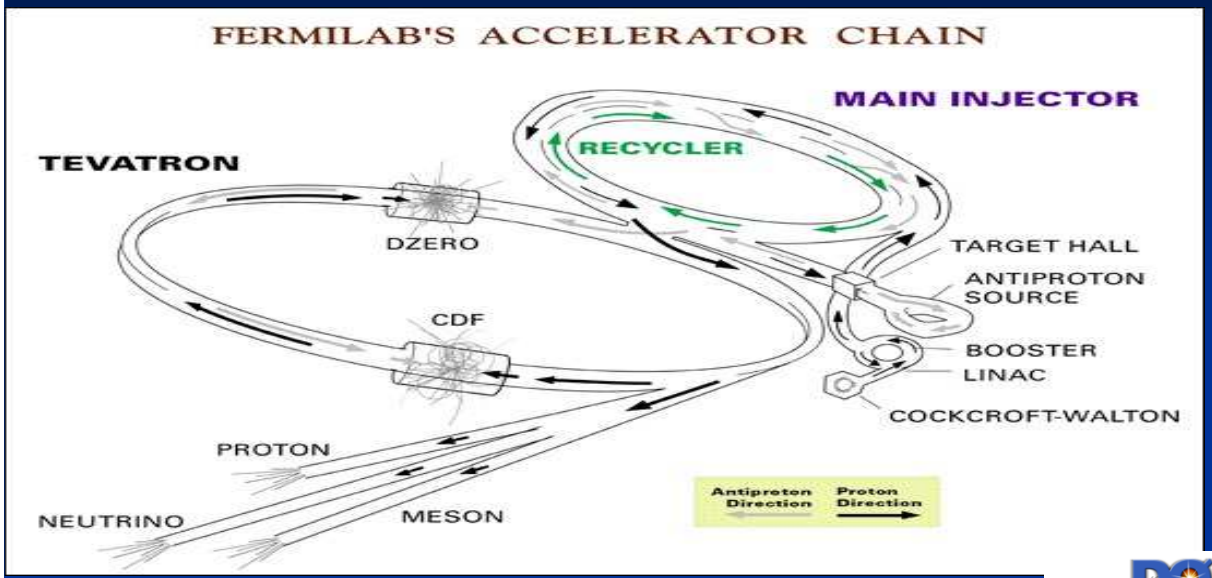


DØ Run II
Cone Algorithm

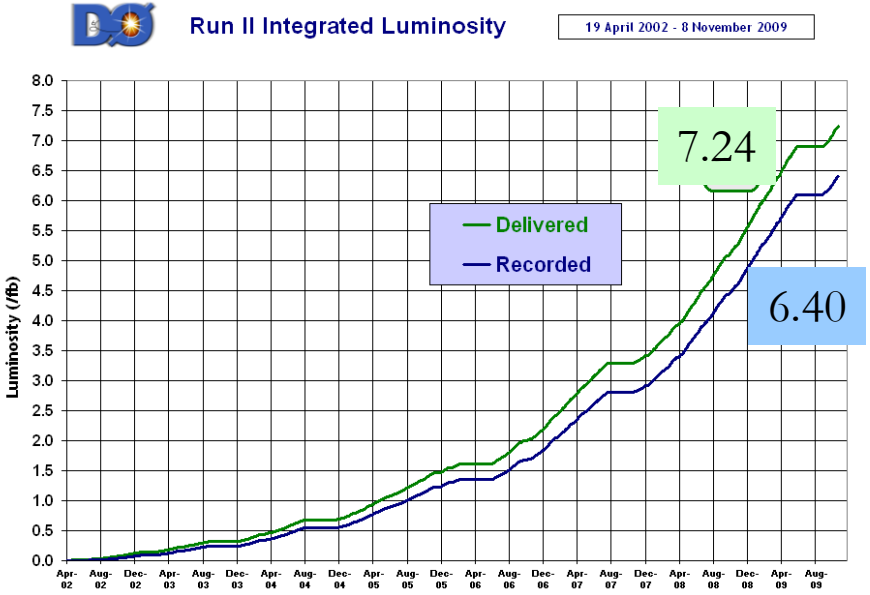
- Uses massive jets
  - Calculated by using four vector of tower *i,* measured from interaction point: (E_i, p_{xi}, p_{yi}, p_{zi})
  - All towers then added together (E-Scheme)
- Uses seeds
  - Starts with some energy above a threshold
  - Saves computing time
- Uses a midpoint algorithm to be infrared safe
  - Chooses a point between 2 jets, looks for energy , forms new seed
  - Takes into account collinear/soft gluon effects



Tevatron

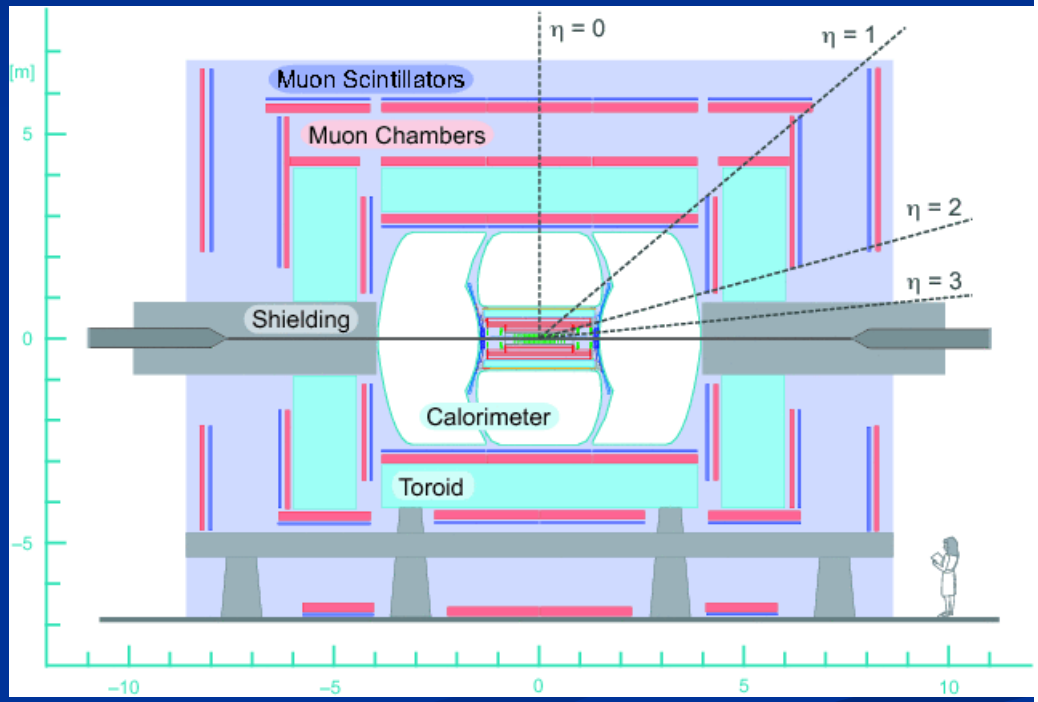


- DZero has ~7 fb^{-1} on tape
- ~ 2 fb^{-1} recorded in 2008 alone
- Current data-taking efficiency ~ 90%



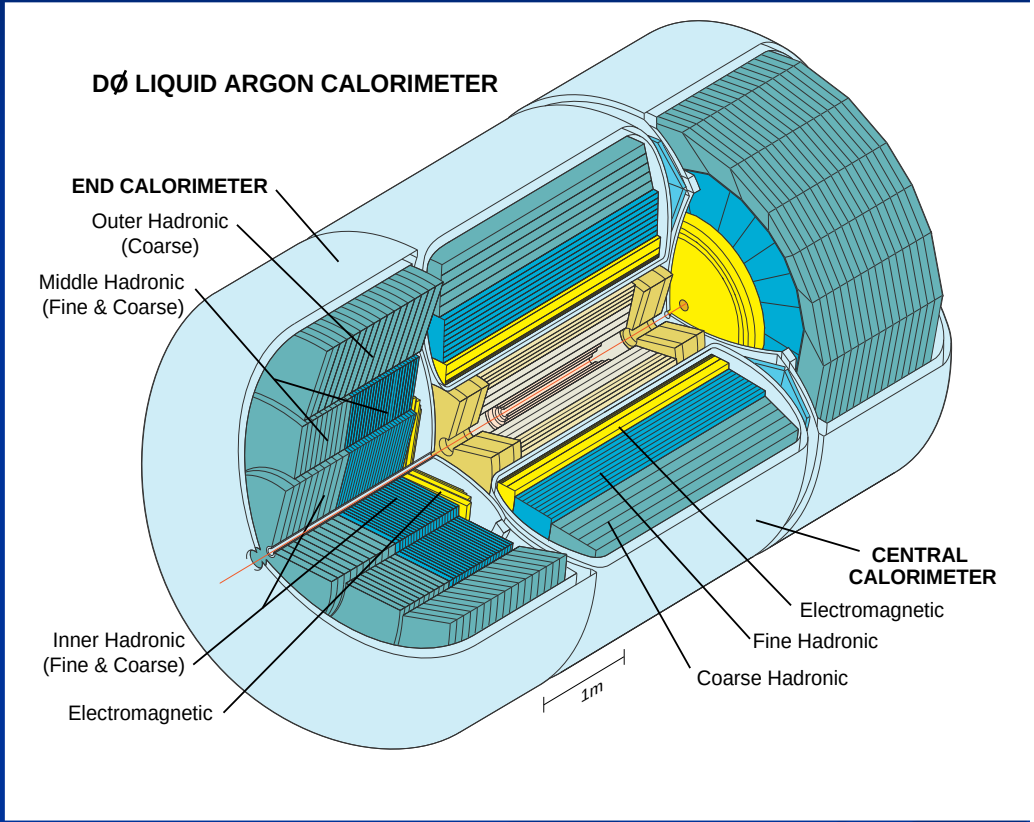
DØ Detector

- Tracker and Magnet
  - Silicon Microstrip Tracker
  - Central Fiber Tracker
- Calorimeter
  - Central
  - End cap
- Muon



Calorimeter

- Most important for this analysis
- Liquid argon/uranium sampling calorimeter
  - Measures energies of particles
  - Finely segmented: $\Delta\eta \times \Delta\varphi = 0.1 \times 0.1$
- Three main sections, each in own cryostat
  - Central (CC), 2 endcap (EC)



Analysis

$$\frac{d^2\sigma}{dM_{JJ}\,dy_{\max}} = \frac{C}{L \cdot \Delta M_{JJ} \cdot \Delta y_{\max}} \cdot \sum_{i=1}^{N} \frac{1}{\varepsilon_{vtx}}$$

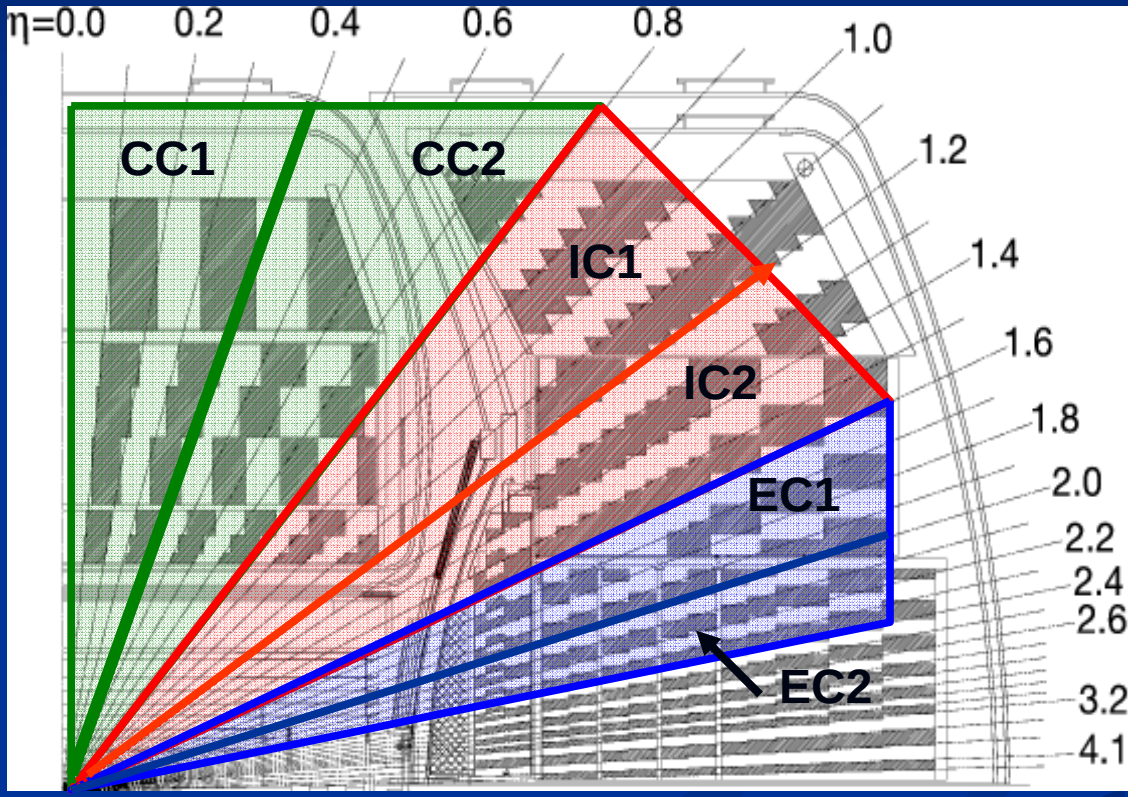
Data/Event Selection
Corrections
Uncertainties
Final Results

Data Set

- Run IIa data set, taken from 2004-2005
- Luminosity: ~ 700 pb^{-1}
- Same data set as several other analyses
  - Systematics limited analysis
  - Allows for easy combination and comparisons
  - Well calibrated data set
- Events must have 2 or more jets
  - Jets in a well understood region of the detector
  - Jets and events determined using quality cuts

Rapidity Bins (Δy_{max})

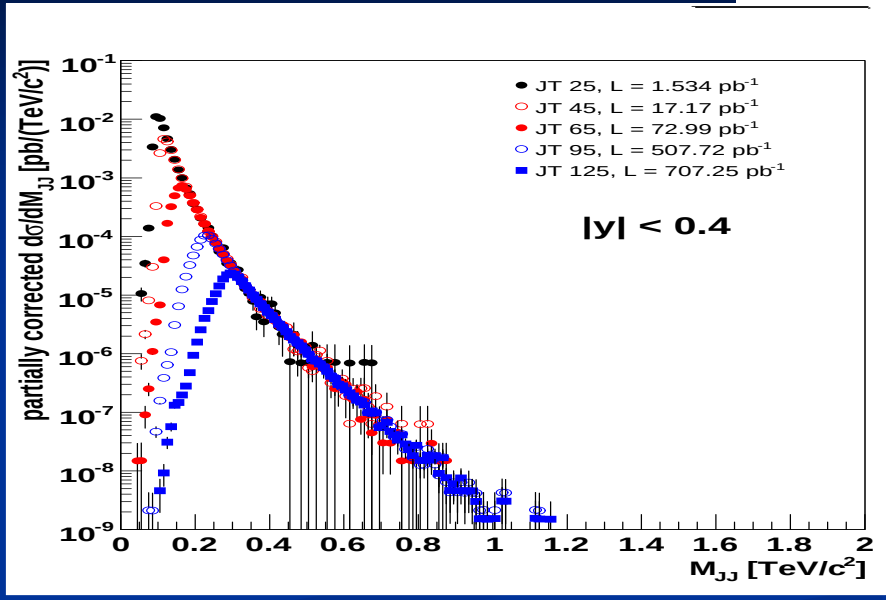
- Rapidity: $y = \frac{1}{2}\ln\left(\frac{E + p_z}{E - p_z}\right)$
- Bins used:
  - Central:
    $|y| < 0.4$ (CC1) ,
    $0.4 < |y|_{max} < 0.8$ (CC2)
  - ICR:
    $0.8 < |y|_{max} < 1.2$ (IC1)
    $1.2 < |y|_{max} < 1.6$ (IC2)
  - End Cap:
    $1.6 < |y|_{max} < 2.0$ (EC1)
    $2.0 < |y|_{max} < 2.4$ (EC2)

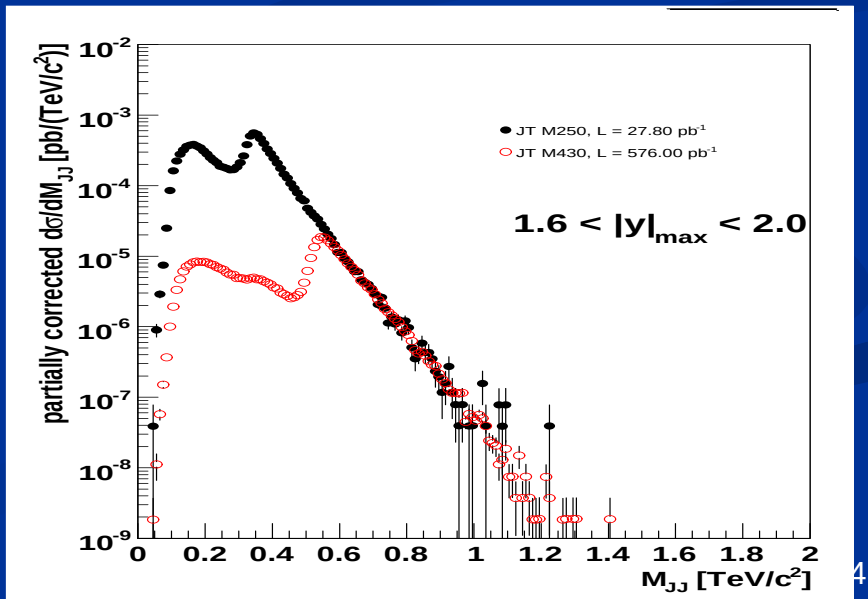


η = - ln (tan(θ/2))

Triggers

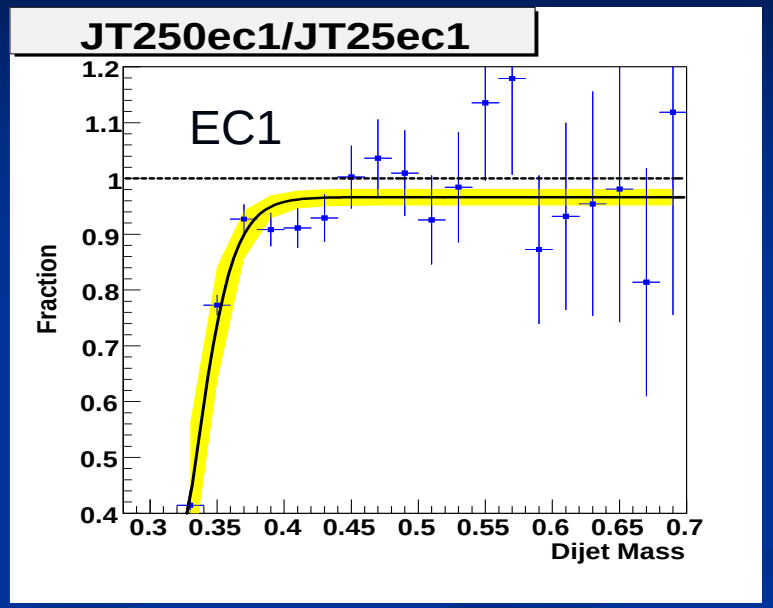
- 2 sets of triggers jet events:
  - Single jet: p_T > 25, 45, 65, 95, 125 GeV (CC and ICR)
  - Dijet Mass: M_{JJ} > 250, 430 GeV (EC)
- Use triggers in efficient region for ease of calculation

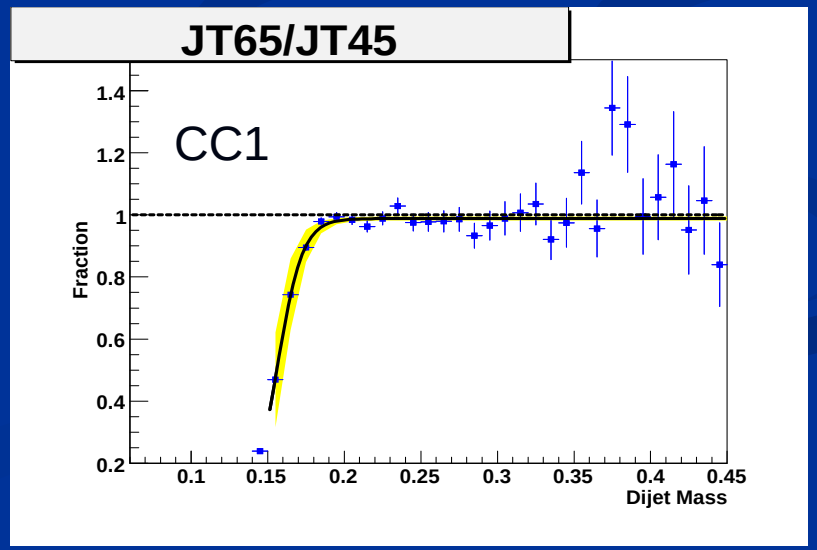




Trigger Efficiency

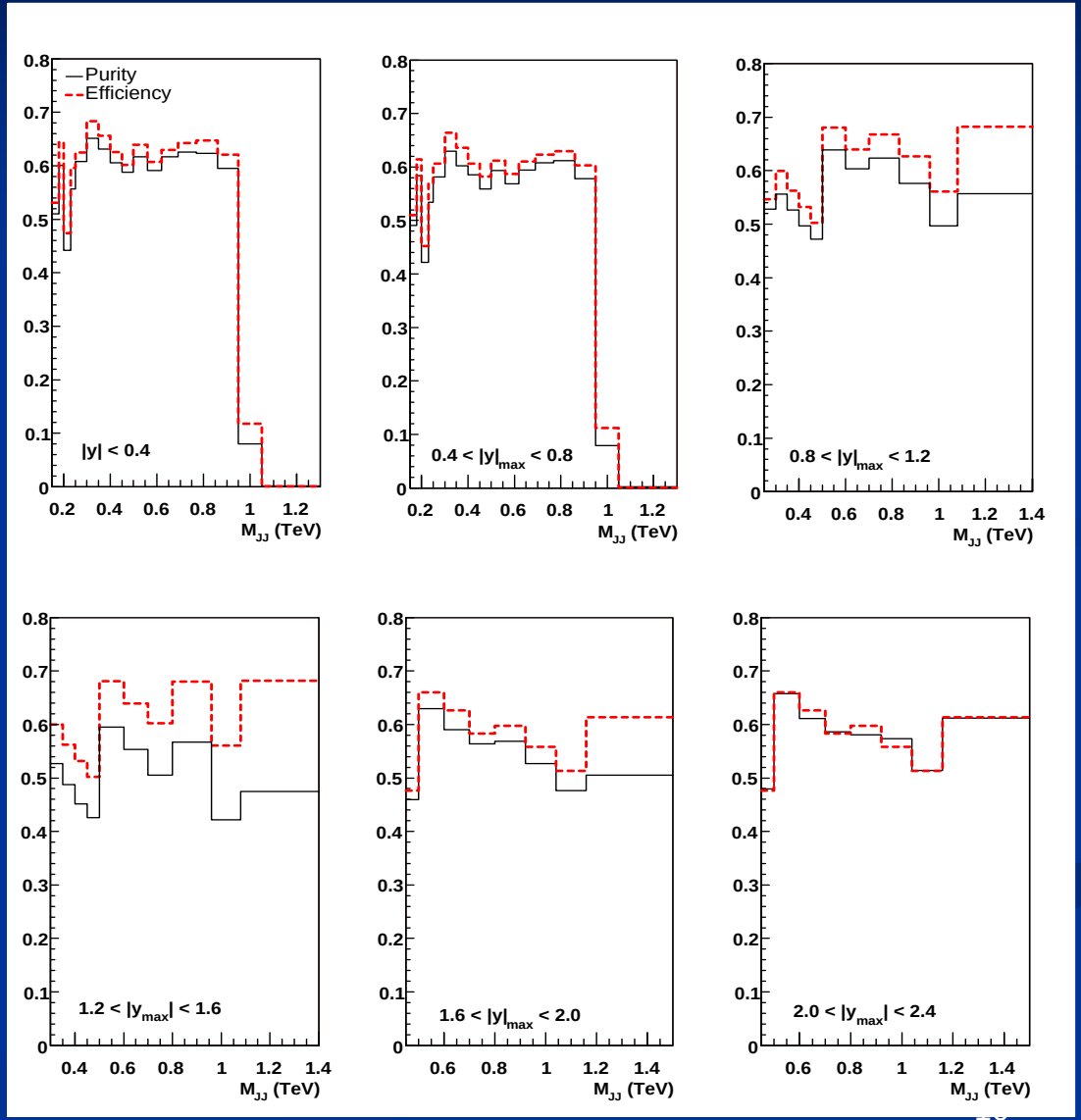
- Absolute Efficiency
  - Determined by comparing independent triggers
- Relative Efficiency
  - Determined by comparing correlated triggers where lower trigger is 100% efficient
- Can use the relative turn-ons in this analysis





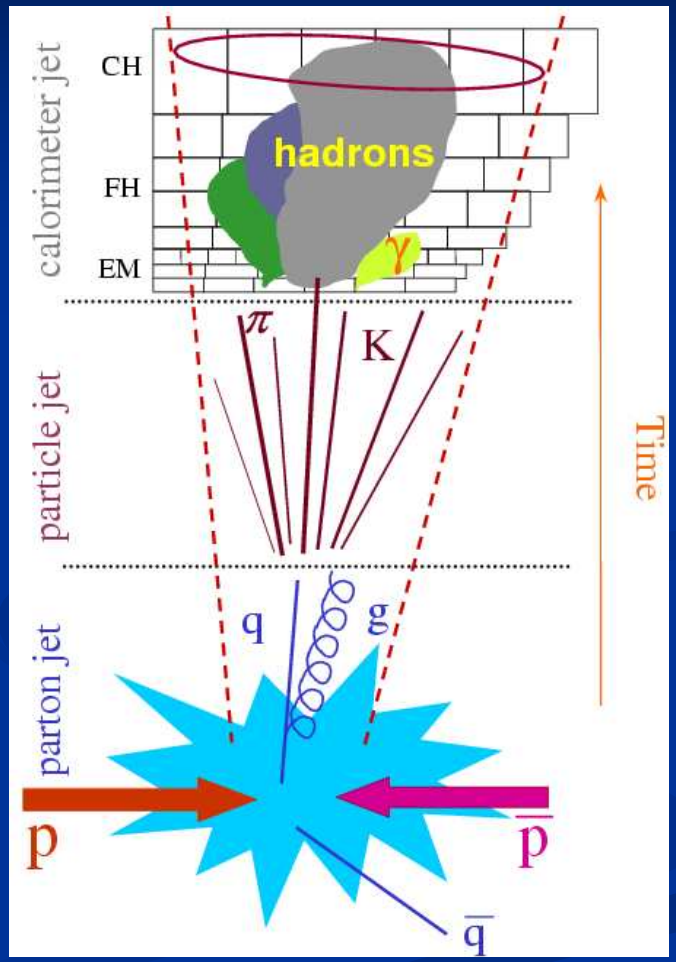
Mass Bins (ΔM_{JJ})

- The width is approximately 2σ of mass resolution
- Purity and efficiency optimized (~60%)
- Only 1 trigger per mass bin



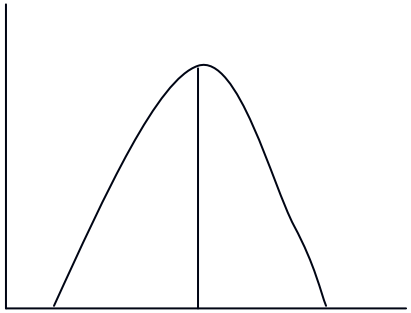
Corrections (C, ε_{vtx})

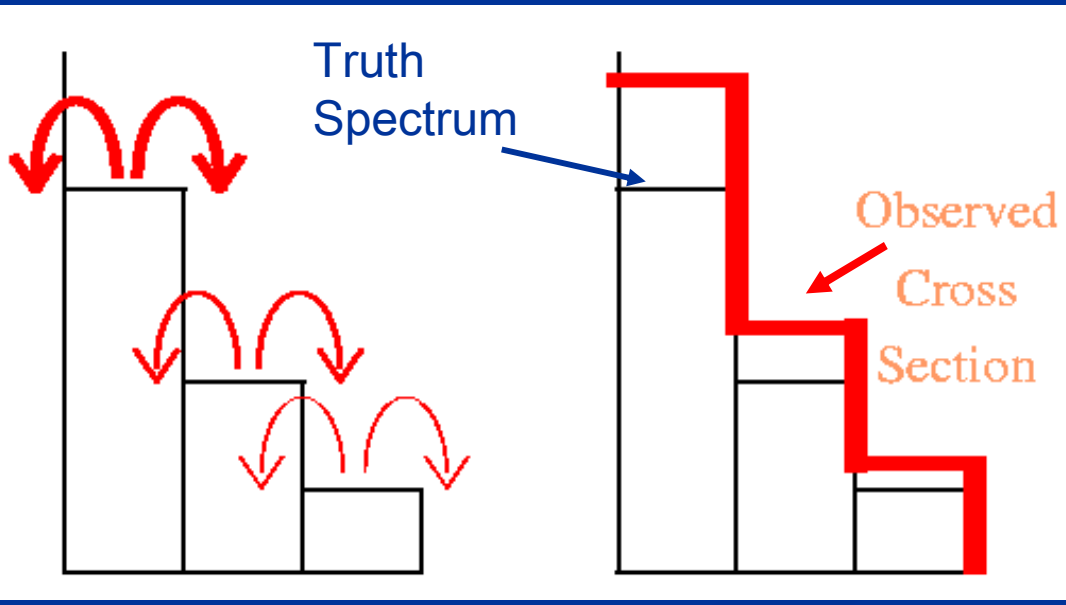
- Reminder: Goal is to measure the particle level jets
  - Need to remove the detector effects from data
- Correct for
  - Jet Energy Scale
  - vertex efficiency
- All other corrections determined using MC
  - DØJetSim



Corrections Cont

A steeply falling spectrum will have events that will preferentially migrate from a lower mass to a higher mass





Resolution effects cause "smearing" of measured values

Unsmearing includes:

-p_T resolutions
-η/φ resolutions
-Misvertexing
-Jet ID efficiency
-Muon/neutrino energies

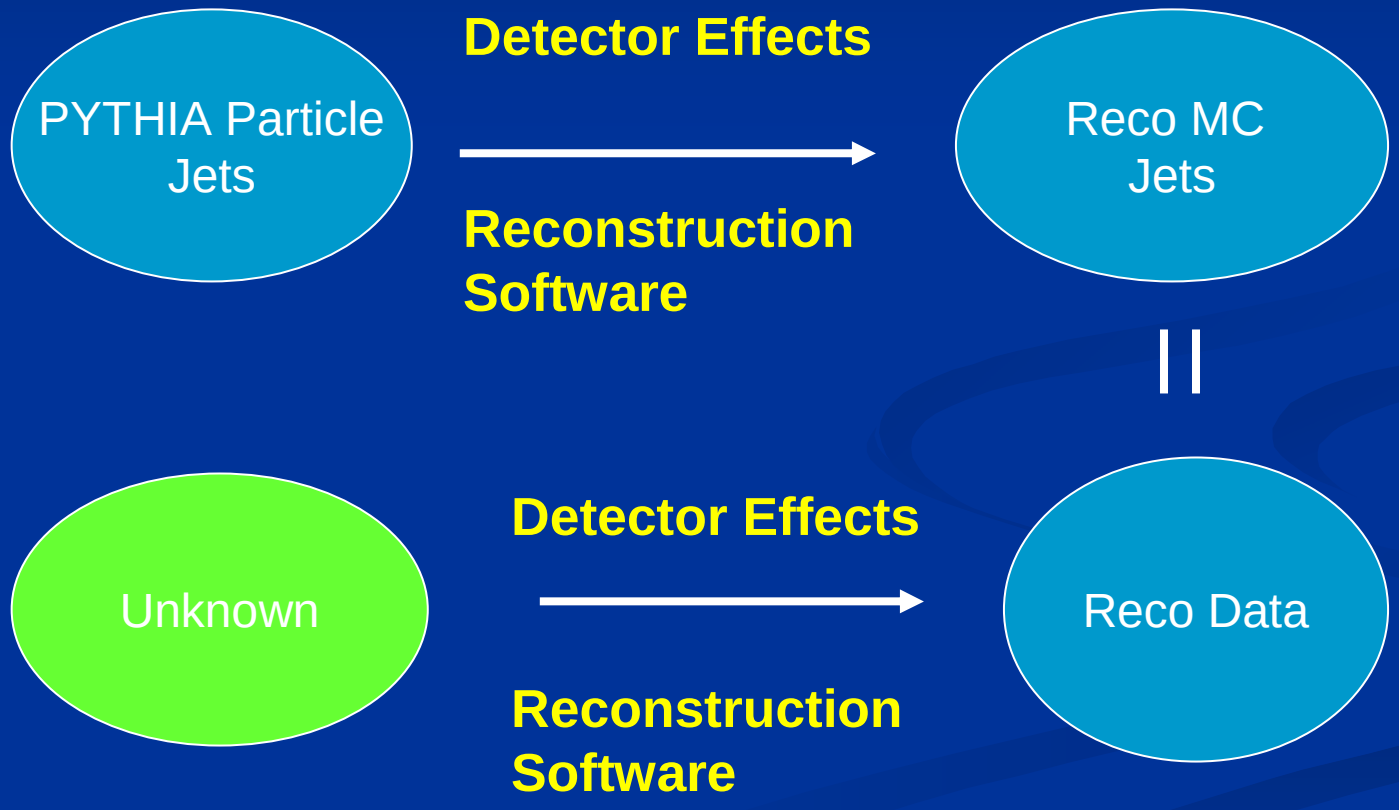
DØJetSim

- DØJetSim is a fast detector simulation written specifically for jet analyses
  - Uses what we know about jets from data (e.g. p_T resolutions)
  - Uses PYTHIA particles
  - Smear particles using jet information
  - Reweight to data
- We use JetSim to calculate all systematic uncertainties and unsmearing corrections

Correction Procedure

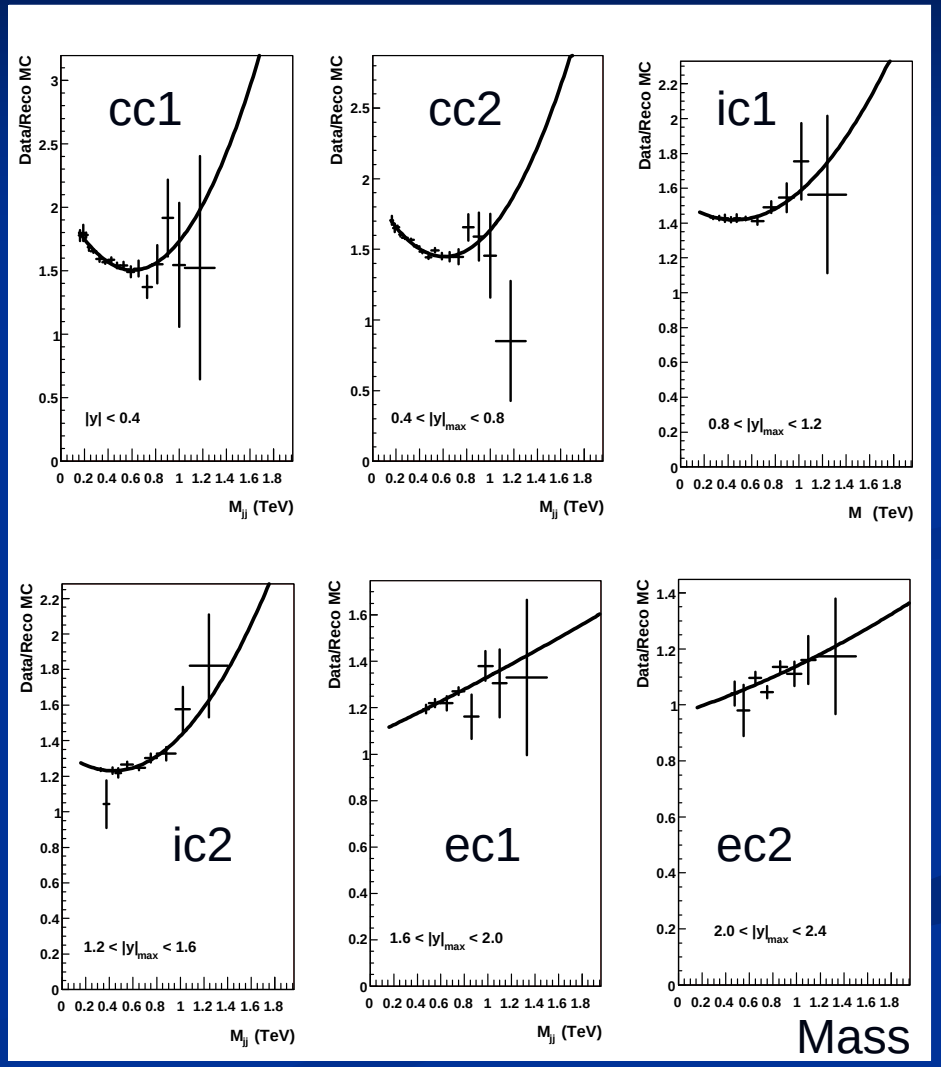
- Correct Data for JES and ε_{vtx}
- Reweight Reco MC to reco Data
  - Determine function based on control plots
  - Apply function at parton level, check output
  - Repeat
- Final correction factor: truth/reco MC

Why Reweight?



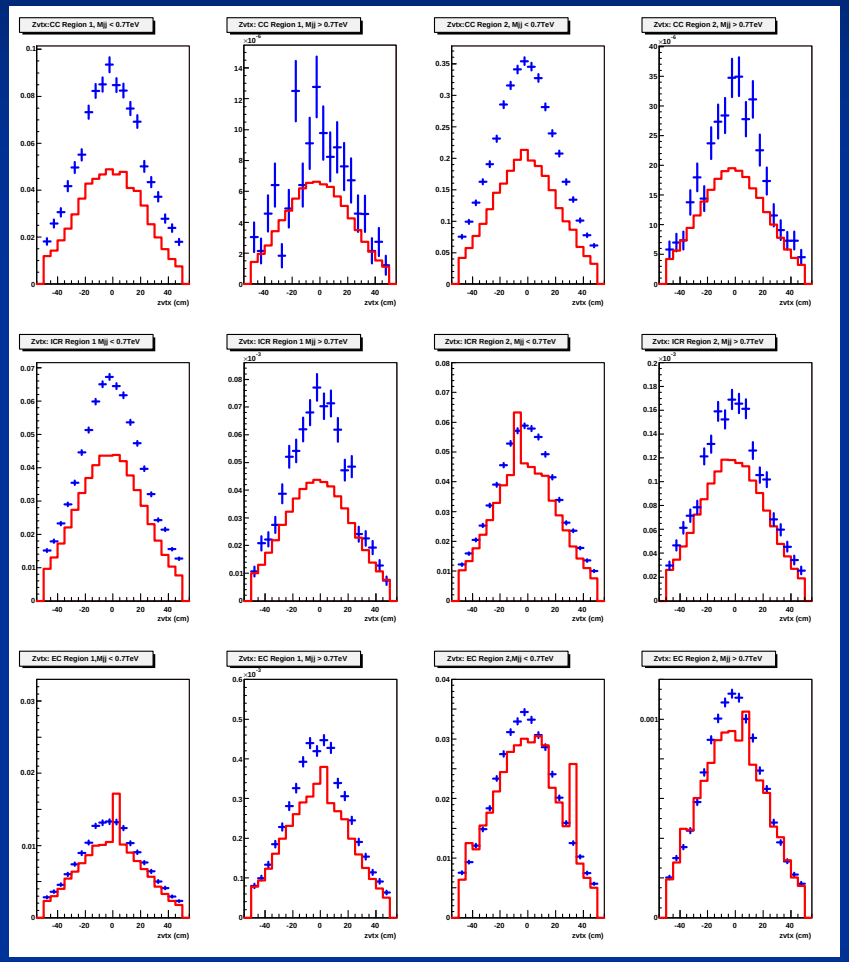
Reweighting

- Choose variable to reweight in
  - Distributions important to calculation of dijet mass
- Find function that works for all regions
- Test function
- Repeat

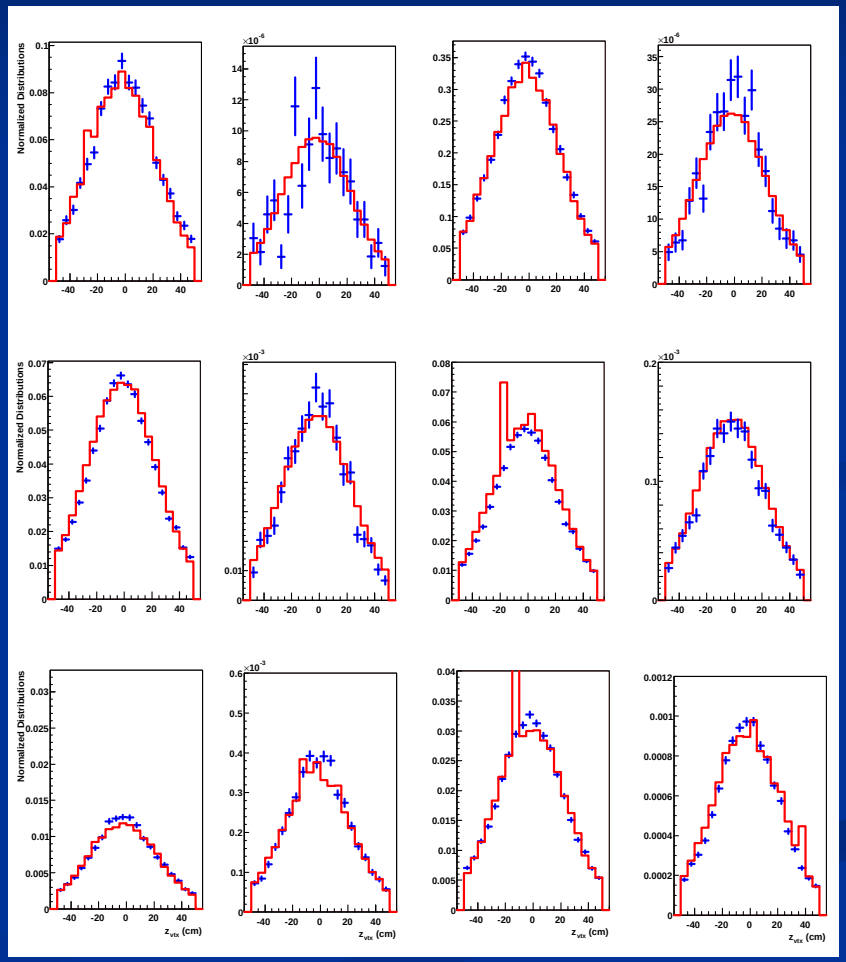


Control Plots

Before reweighting

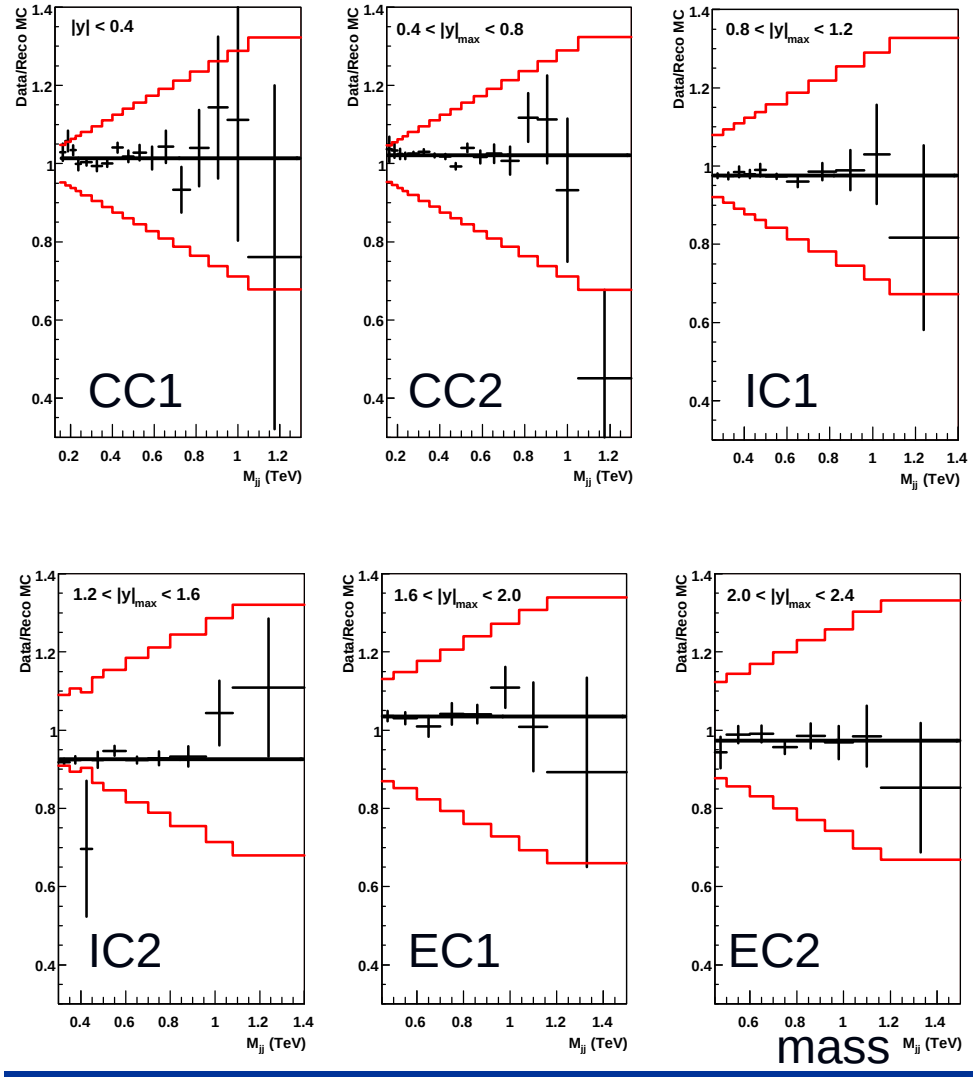


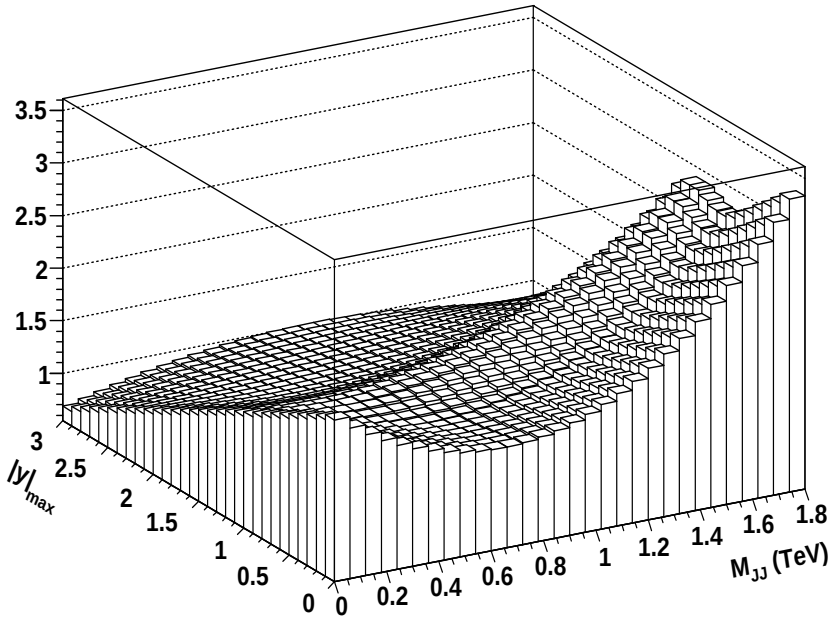
After reweighting



z_{vtx}

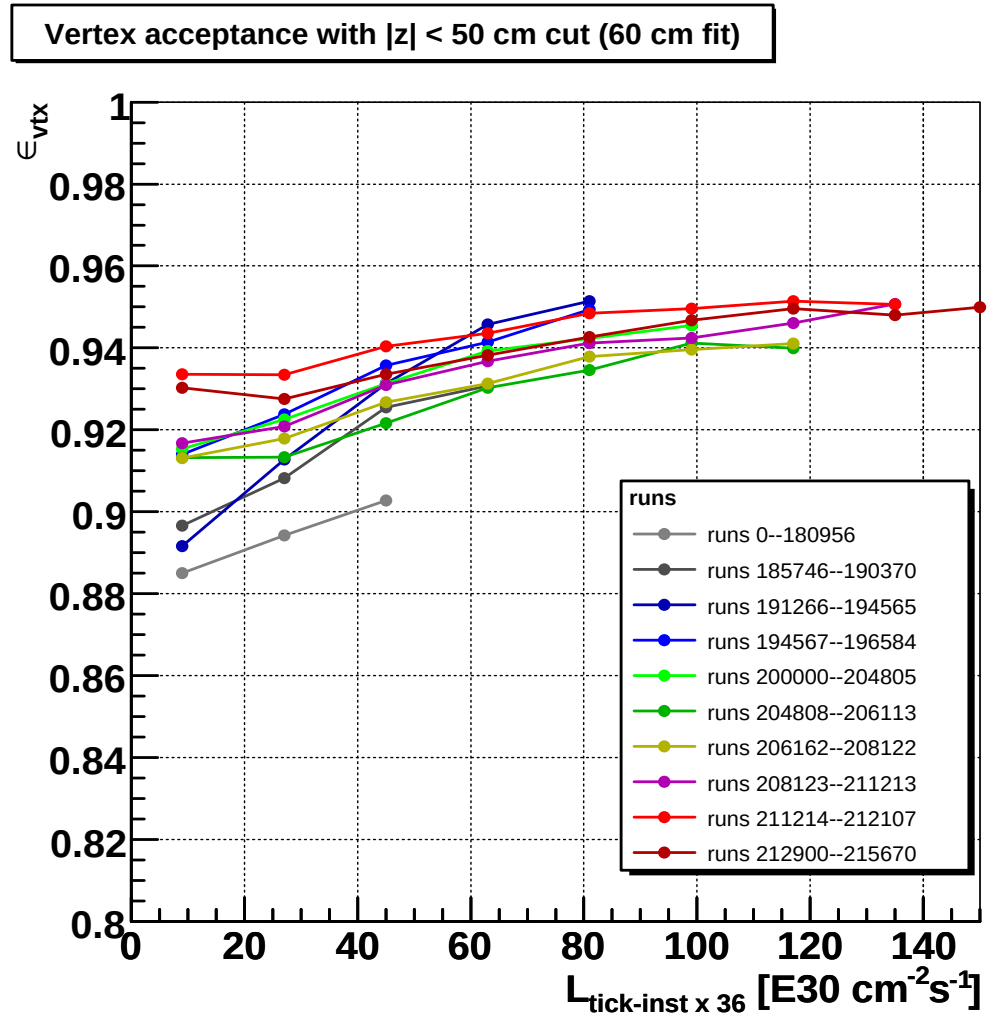
Final Reweighting





Vertex Efficiency

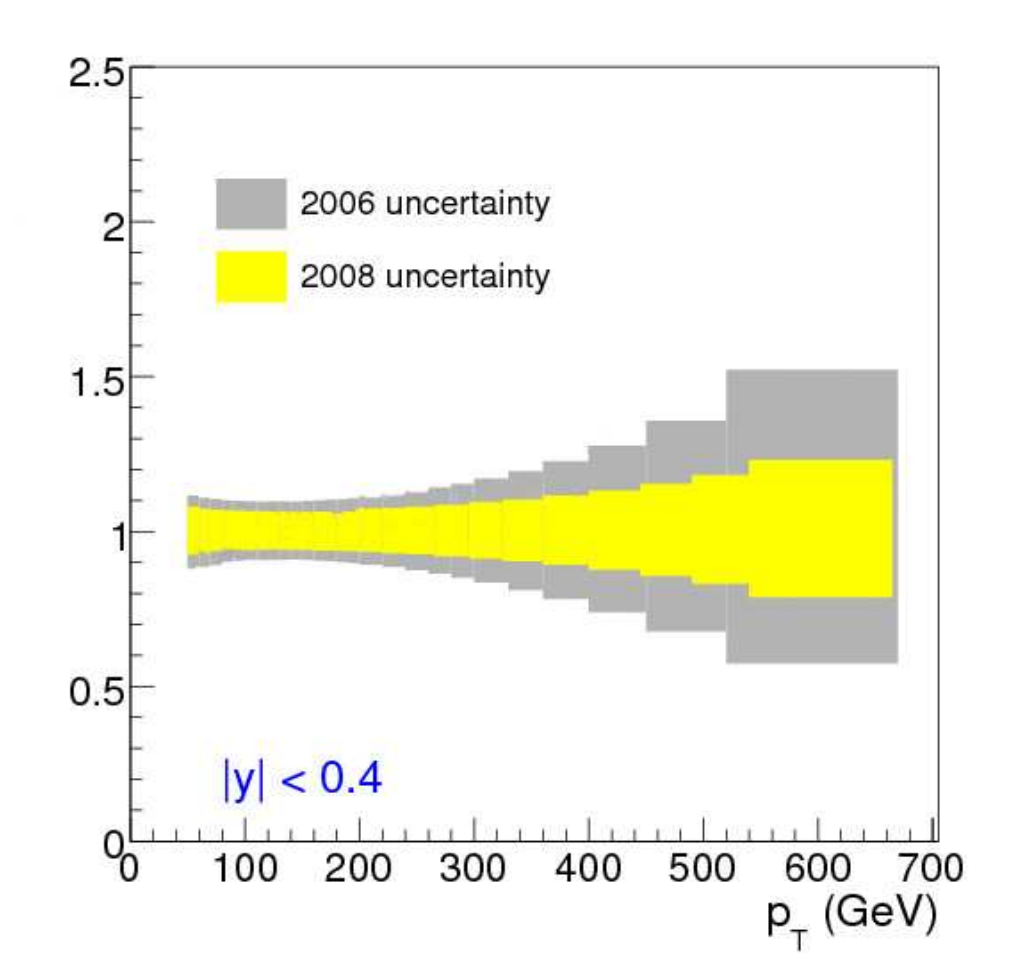
- Vertex Efficiency ~ 93% ($|z_{vtx}| < 50$ cm)
  - Determined using luminous region of detector (DØ Note 5142)
  - Depends on luminosity and running period



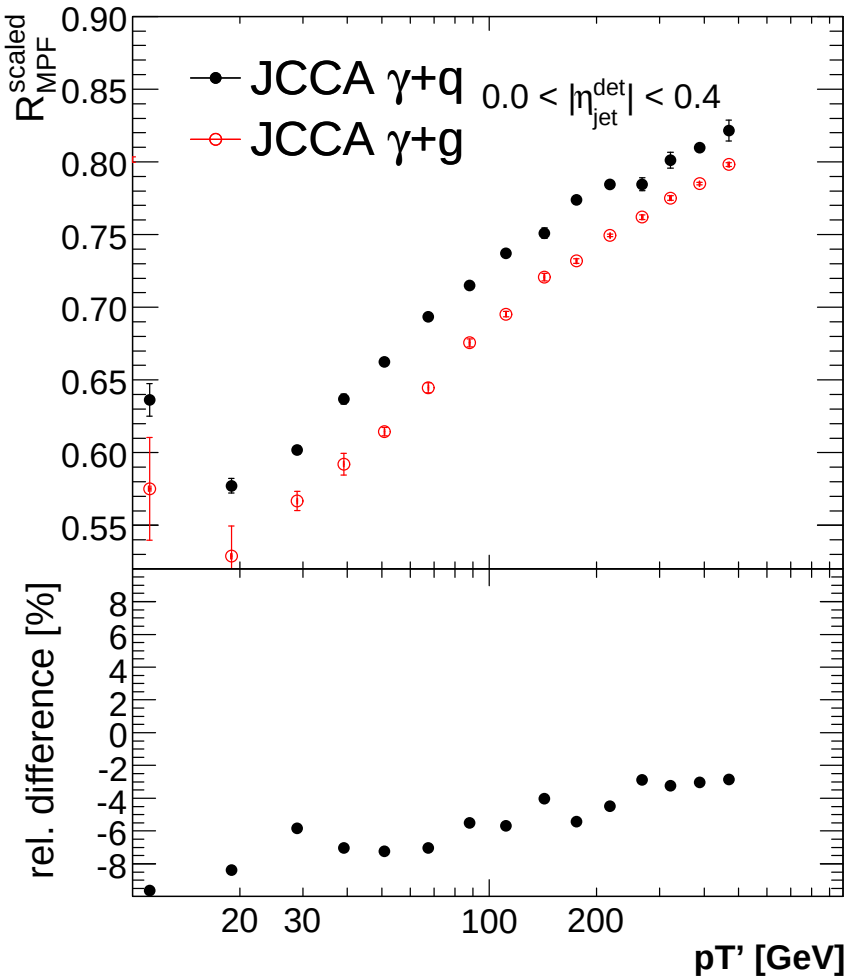
Jet Energy Scale

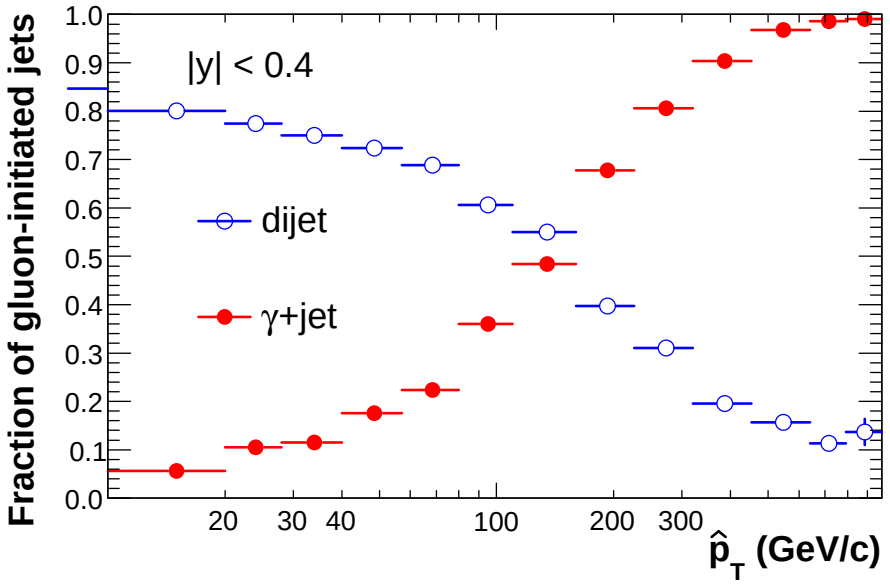
- Jet Energy Scale returns the measured calorimeter jet energy to the particle level (γ + jet sample)

  $E_{ptcl} = [(E_{cal} - Offset)/(F_\eta * R * S)] * k_{bias}$
- *Offset* : noise + pile-up + multiple interactions
- Response (R): Conversion of calorimeter readout to energy in central region
- Relative response (F_η): Response of the rest of the calorimeter
- Showering (S): Correction for in and out of cone showering
- Other bias (k_{bias}): All other corrections.



Dijet Energy Scale

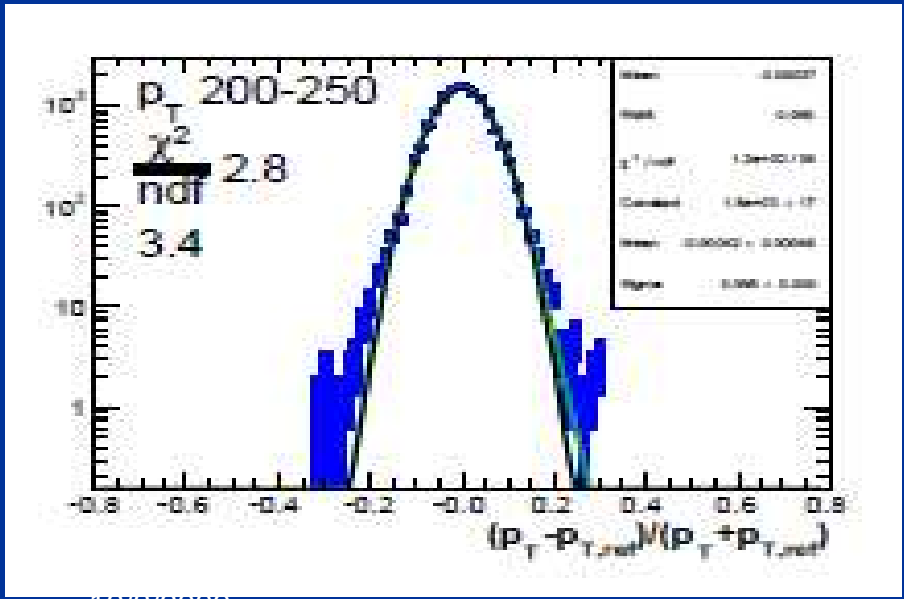




Need a different JES for γ + jet sample and dijet sample
J4S corrects all 4 components of jet four vector

p_T Resolutions

- Largest effect of smearing
- Measured directly from data
- Use dijet asymmetry variable to determine resolutions (symmetric by construction)

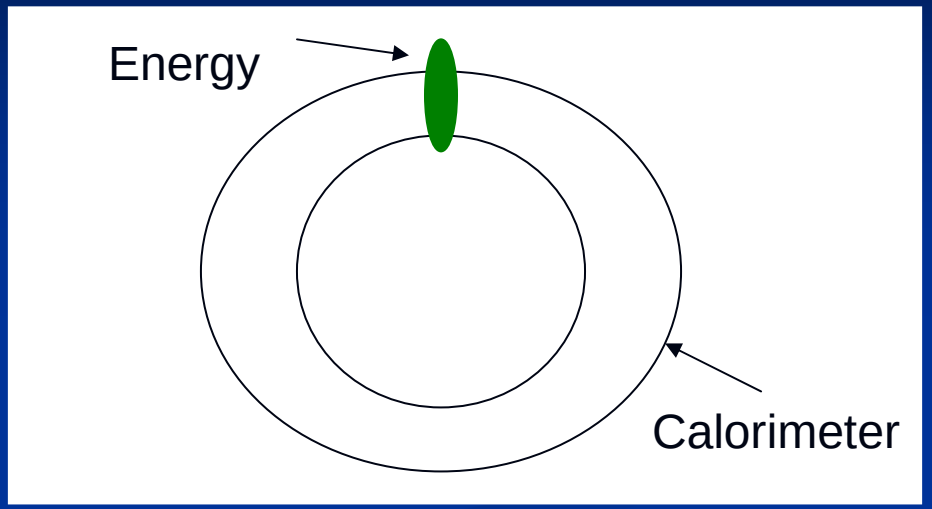


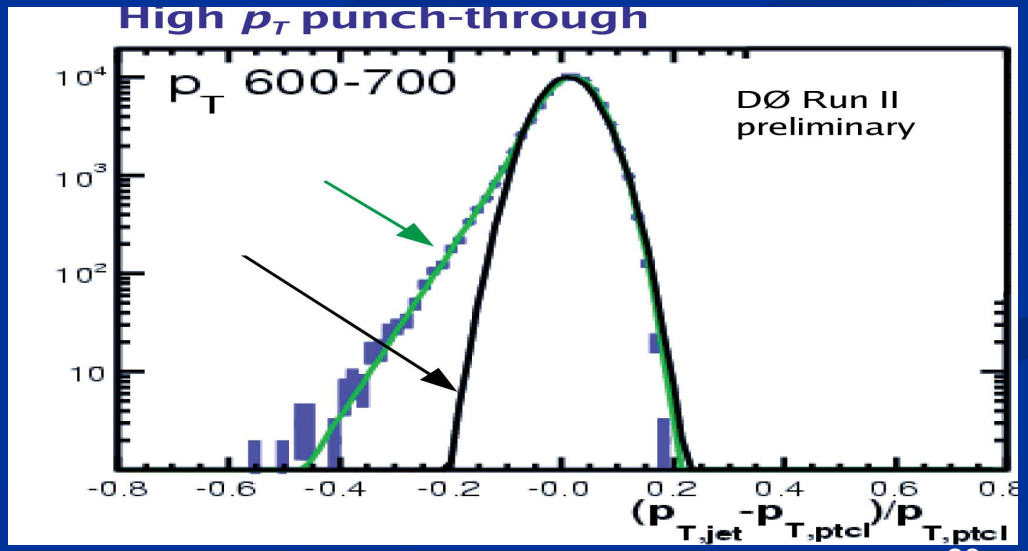
$$A = \frac{| p_{T,1} - p_{T,2} |}{p_{T,1} + p_{T,2}}$$

$$\frac{\sigma(p_T)}{p_T} = \sqrt{2}\,A$$

p_T Resolutions

- Found “tails” in MC: Leads to asymmetric distribution
  - Correct for these, but the effect is small
  - Includes miscalibration and “punch through”



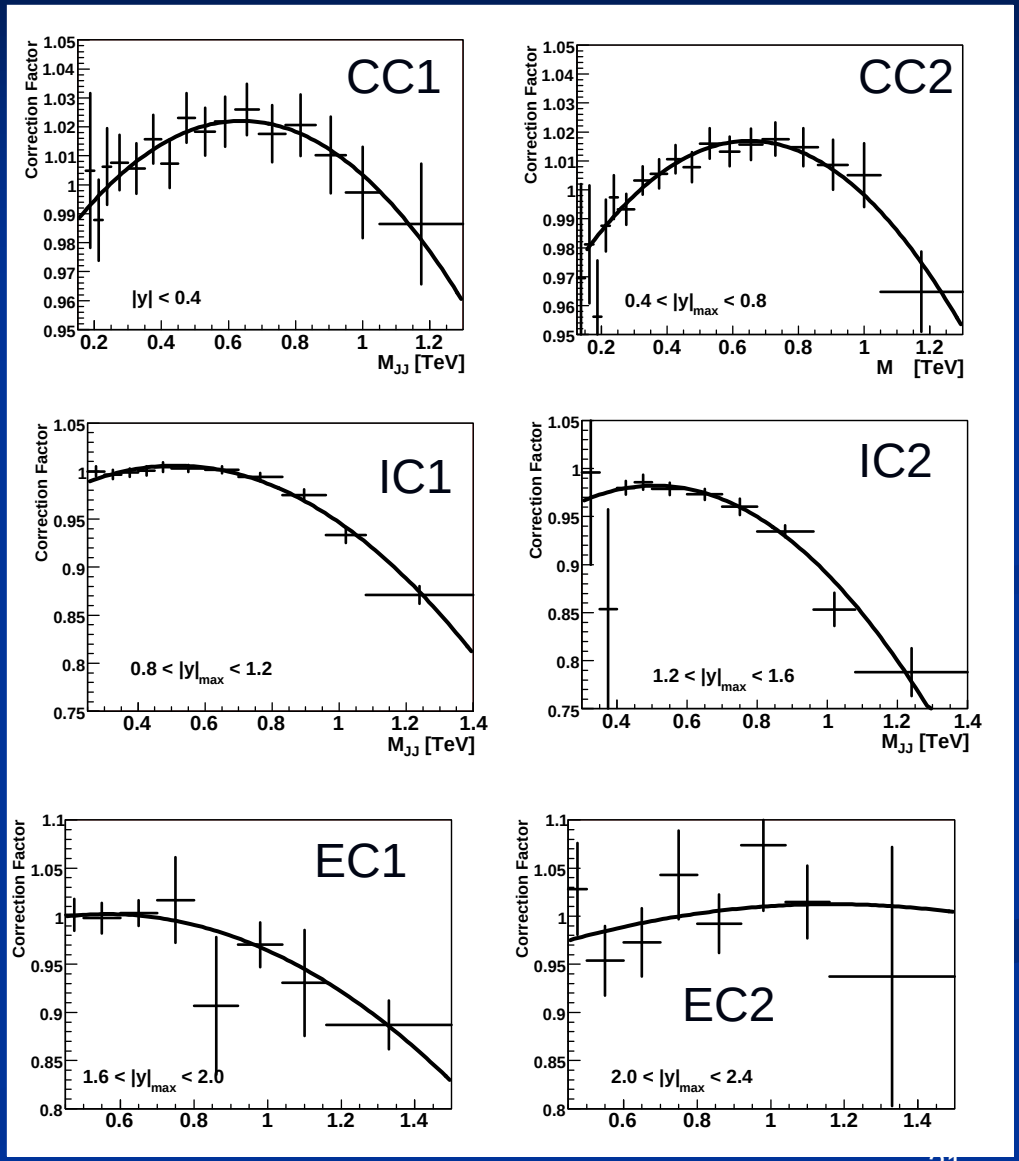


Other Corrections

- All other effects determined by taking the ratio in MC with and without the effect turned on
  - Vertex position
  - Vertex misidentification
  - Jet identification
  - η/φ resolutions

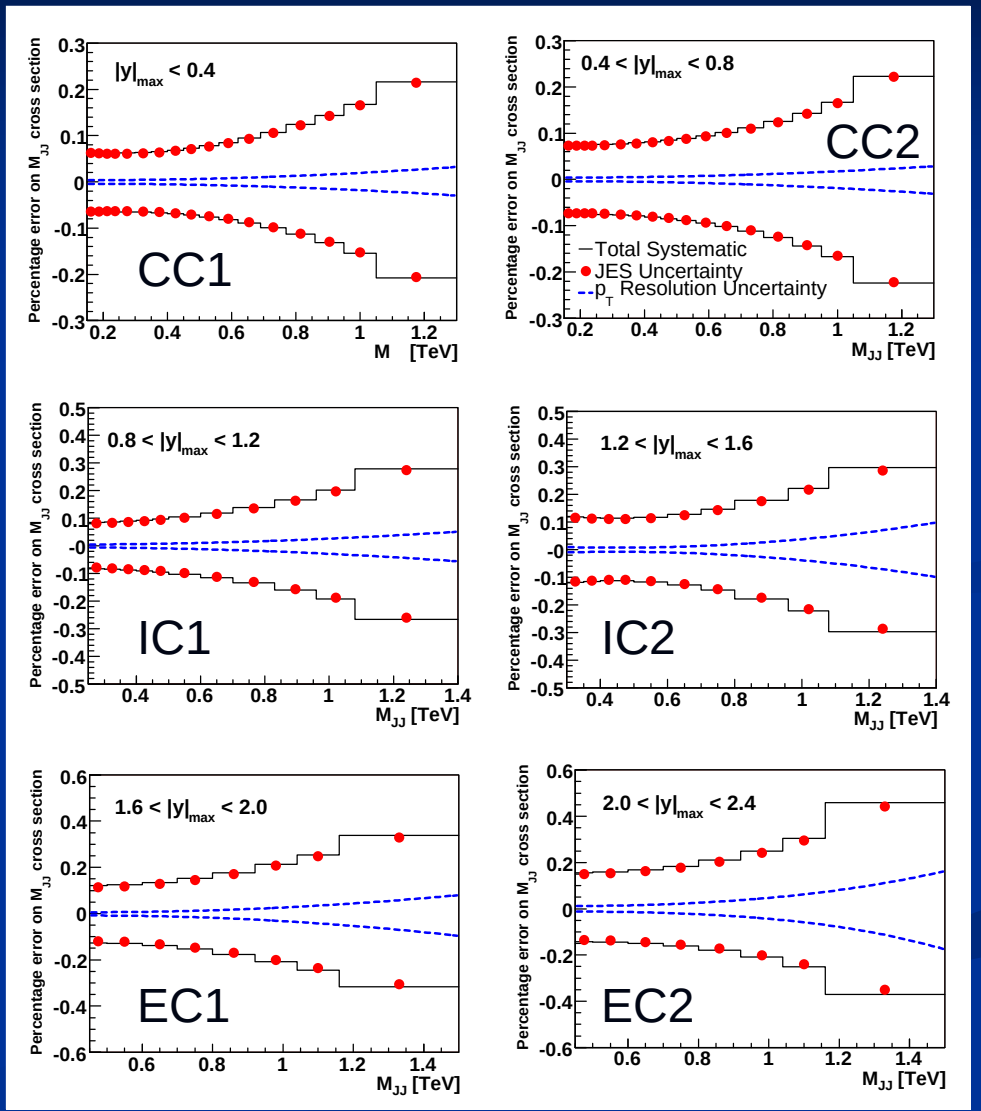
Total Correction

- Total correction in each region:
  - Central: 1- 4%
  - ICR: 1-12%, 1-22%
  - EC: 1-12%, 5%



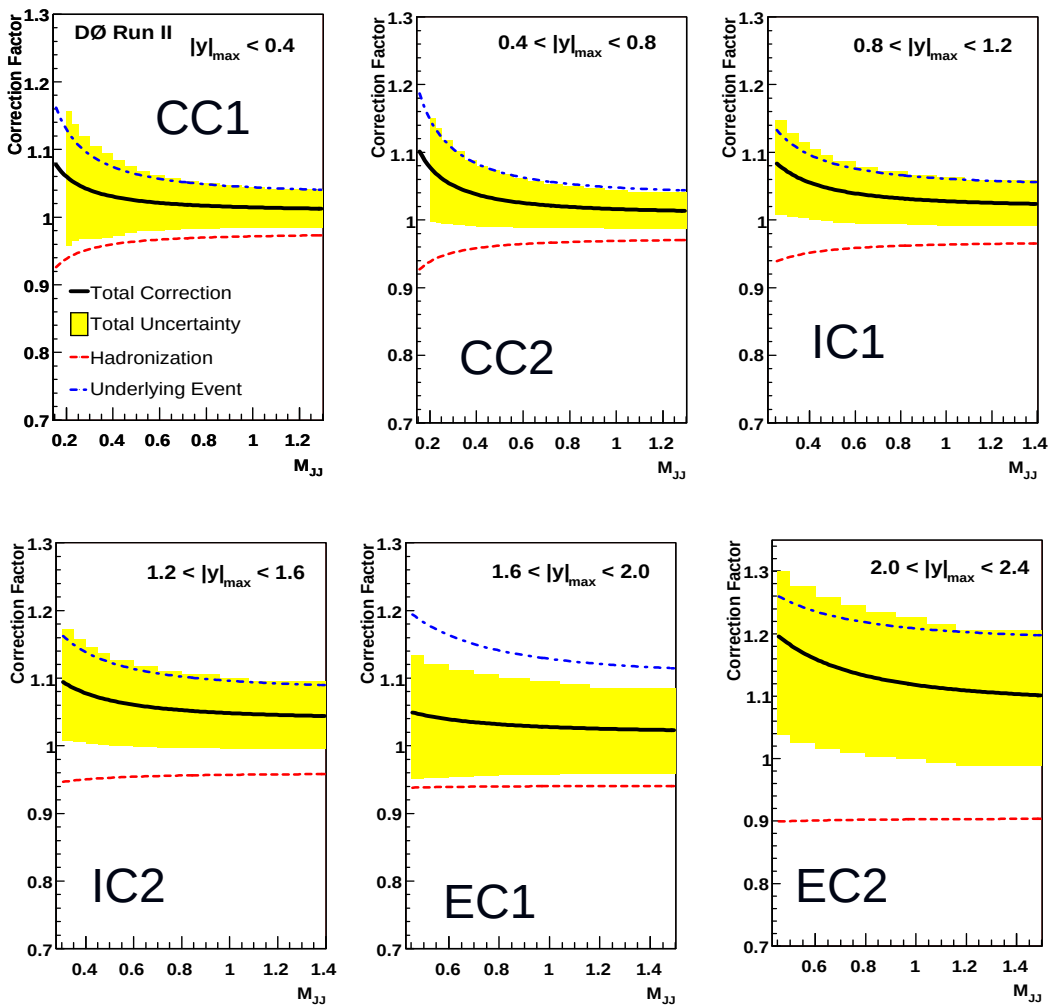
Systematic Uncertainties

- Largest uncertainties due to Jet Energy Scale and p_T resolutions
- Uncertainties due to other effects are 2% or less
  - Misvertexing, Jet ID eff, angular resolutions, etc
- Total uncertainty determined by adding all sources in quadrature



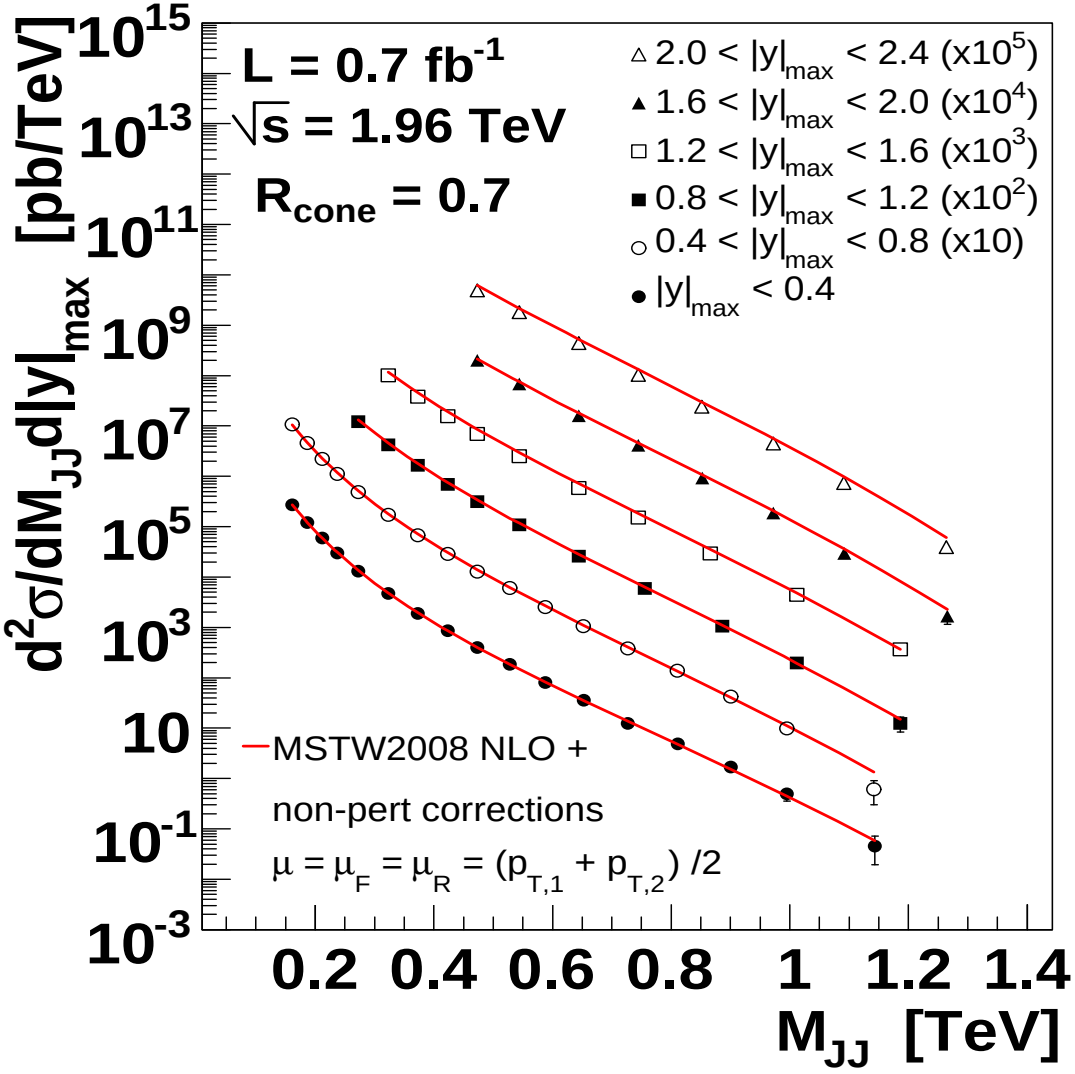
Corrections for Theory Effects

- Theory is calculated on parton level, must correct up to particle level
- Underlying event
  - Correction for soft interactions from remaining partons
- Hadronization
  - Corrects for energy that went into making hadrons but didn't make it into the cone
- Total correction is fit to product

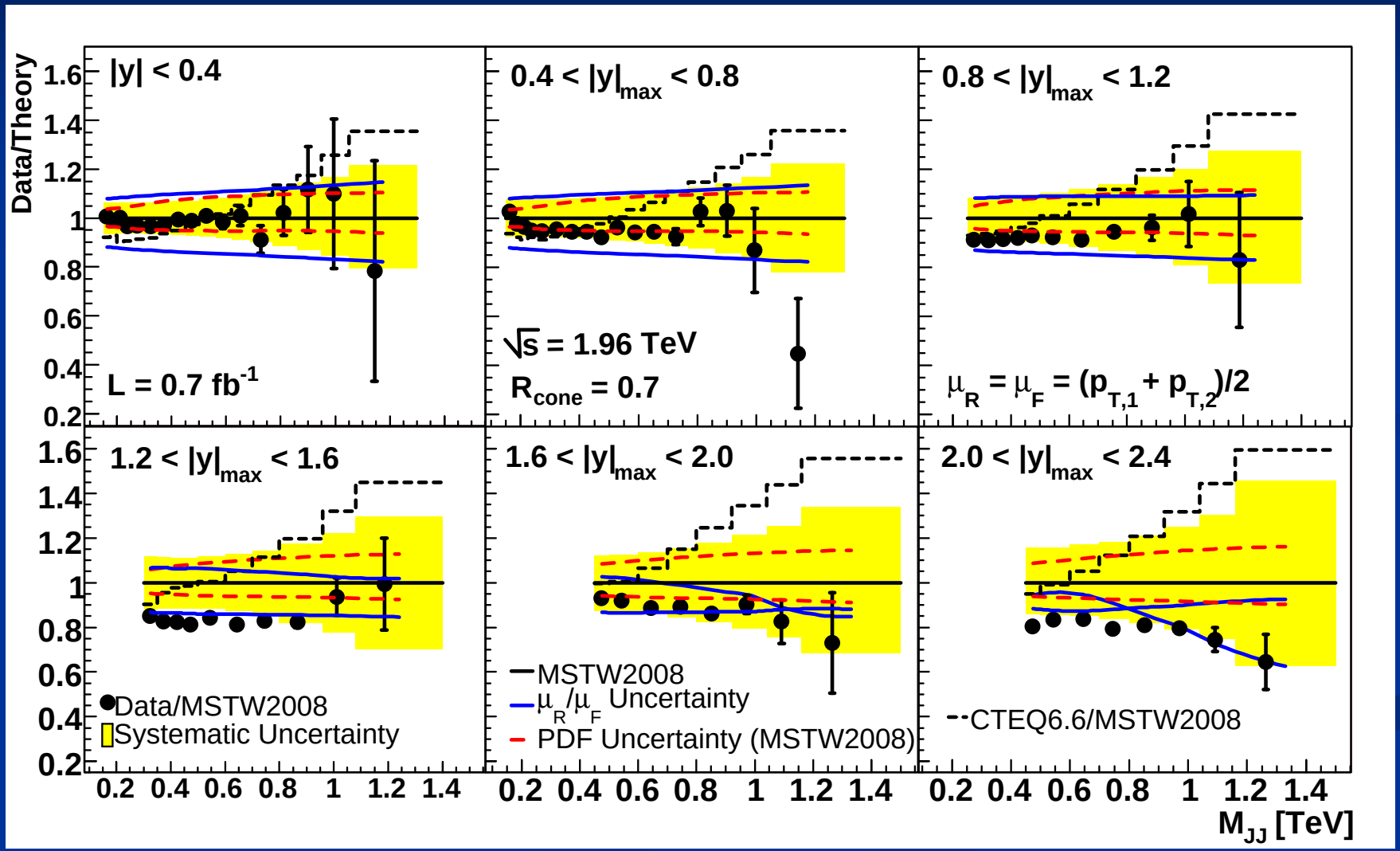


Final Results

- Fully corrected particle level data
- Theory corrected to particle level



Comparison to Theory

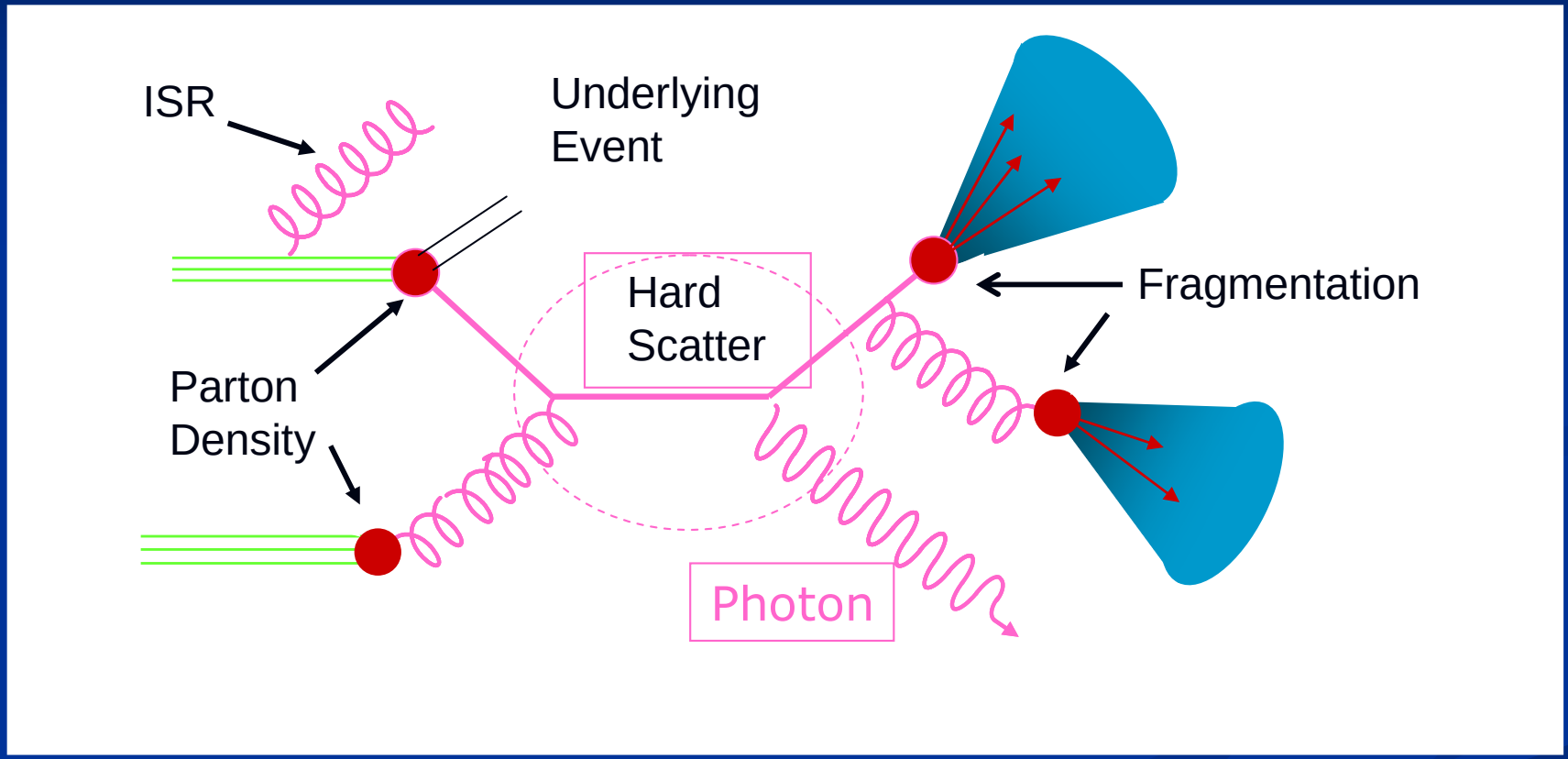


Importance of Result

- World's best measurement to date
  - Smaller uncertainties by 30% or more
  - First measurement in $y > 1.0$
- Confirms understanding of proton structure
  - No obvious new physics
- Can reduce PDF uncertainties

Backups

QCD Event



$$\sigma(p\bar{p} \to X) = \sum_{ij} \int dx_1 dx_2 \, f_i(x_1, \mu_F) \, f_j(x_2, \mu_F) \hat{\sigma}(ij \to X)$$

Data Set

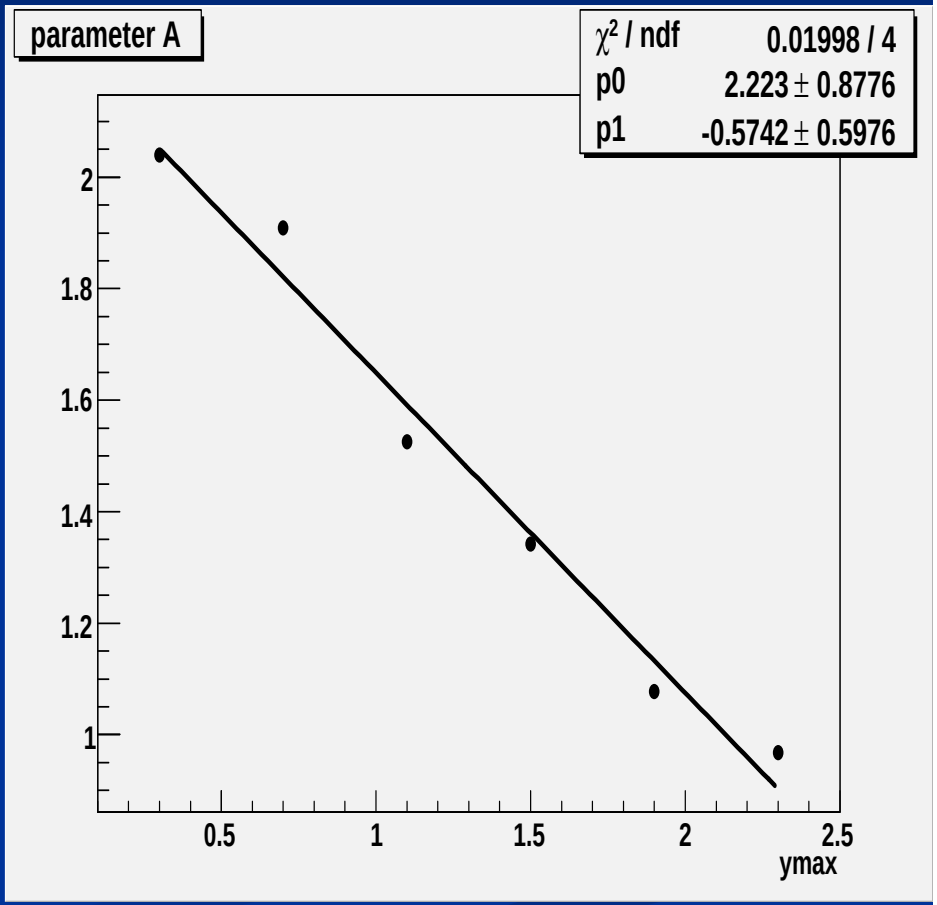
- Run IIa data set: p17.09.01/p17.09.03, runs 191000 – 213064
  - No cable swap data
  - No data before the 2004 shutdown
- Luminosity: ~ 700 pb^{-1}
  - Systematically limited analysis – want the best understood data set
  - Same data set as Inclusive Jets, Dijet Chi, p17 J4S/JES
- Using roottuples produced from CAF trees
  - Processed with final J4S
  - Used v2006-10-10 dq_defs

Event Selection

- Events must have 2 or more jets
- Events must pass good event selections
  - Remove bad LBNs/bad runs
  - Calfail flags set to false
  - $|z_{vtx}| < 50$ cm, $n_{tracks} > 2$
  - Jets must pass standard p17 jet id cuts (DØ Note 4919)
  - Both jets must have $p_T > 40$ GeV
  - $MET/p_T < 0.7$ for all jets (cuts out cosmics)
- Bin according to most forward jet
  - Central: $|y| < 0.4$ and $0.4 < |y_{max}| < 0.8$
  - ICR: $0.8 < |y_{max}| < 1.2$ and $1.2 < |y_{max}| < 1.6$
  - EC: $1.6 < |y_{max}| < 2.0$ and $2.0 < |y_{max}| < 2.4$

Now look at ymax dependence of terms

- Mostly a linear dependence; use this as a starting point
- Change the slope/intercept as needed to flatten out the mass ratios



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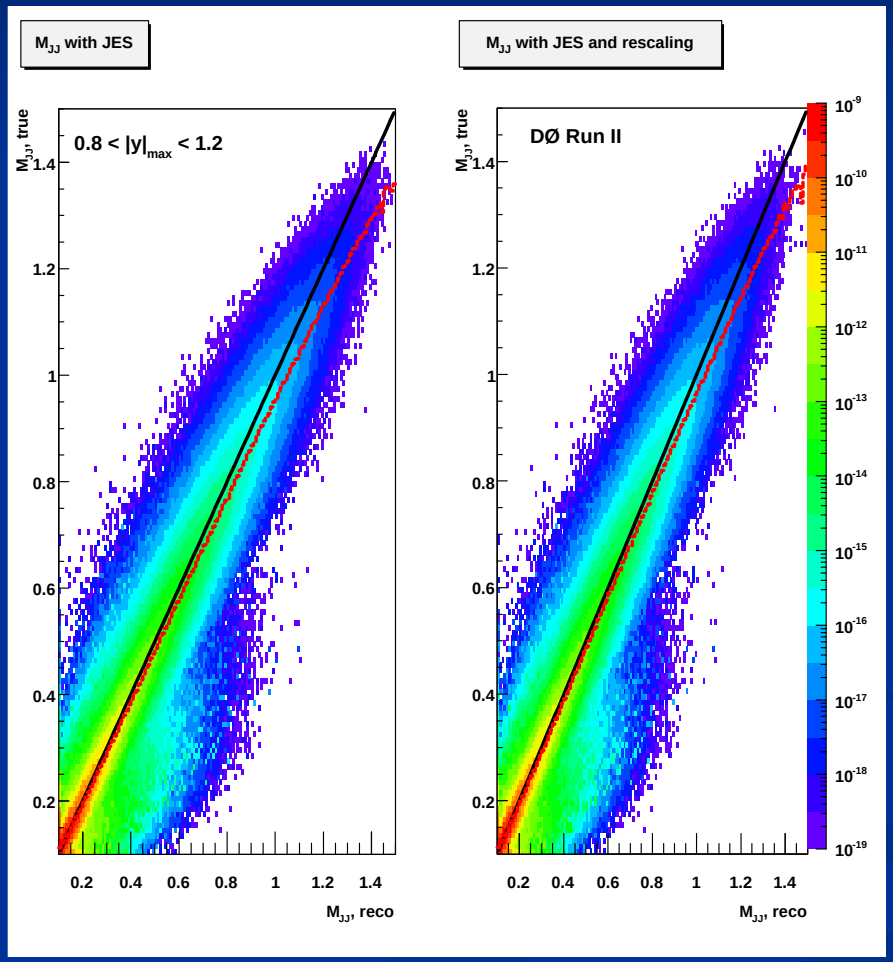
- Showering (S): Correction for in and out of cone showering
- Other bias (k_{bias}): All other corrections. Includes the dijet sample differences

Rescaling

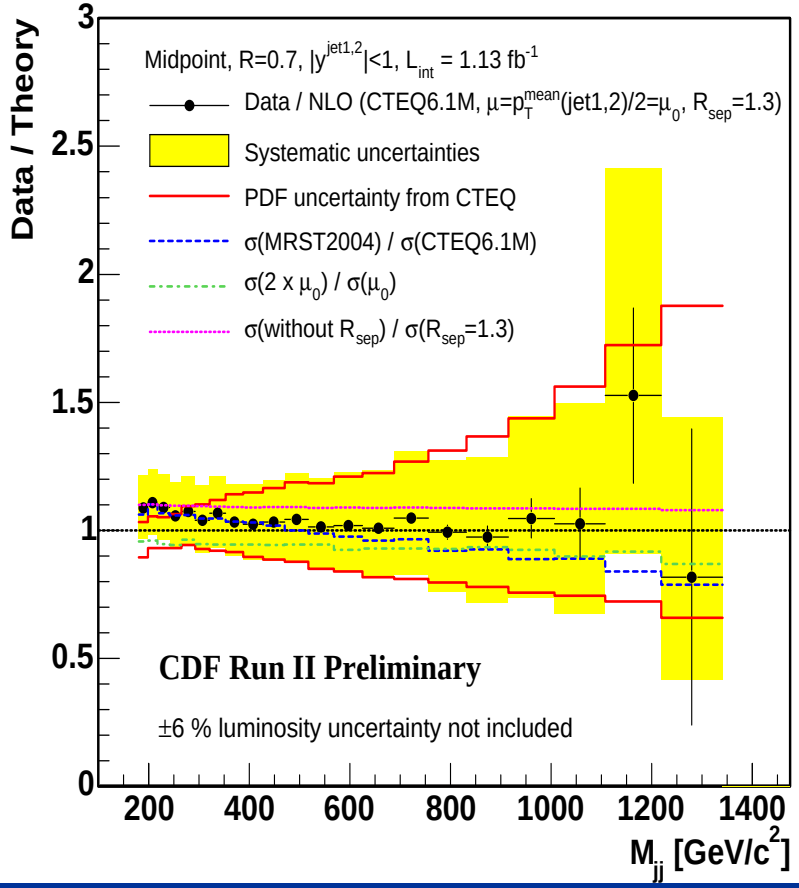
- What does it do?
  - Minor refinement to unsmearing
  - Helps with bin migrations, moves masses from a higher mass bin to a lower mass bin in order to bring the true mass and reco mass into agreement
  - Greatest benefit is in more accurate statistical uncertainties
- How is it determined?
  - Fit the profile plot with a function similar to:

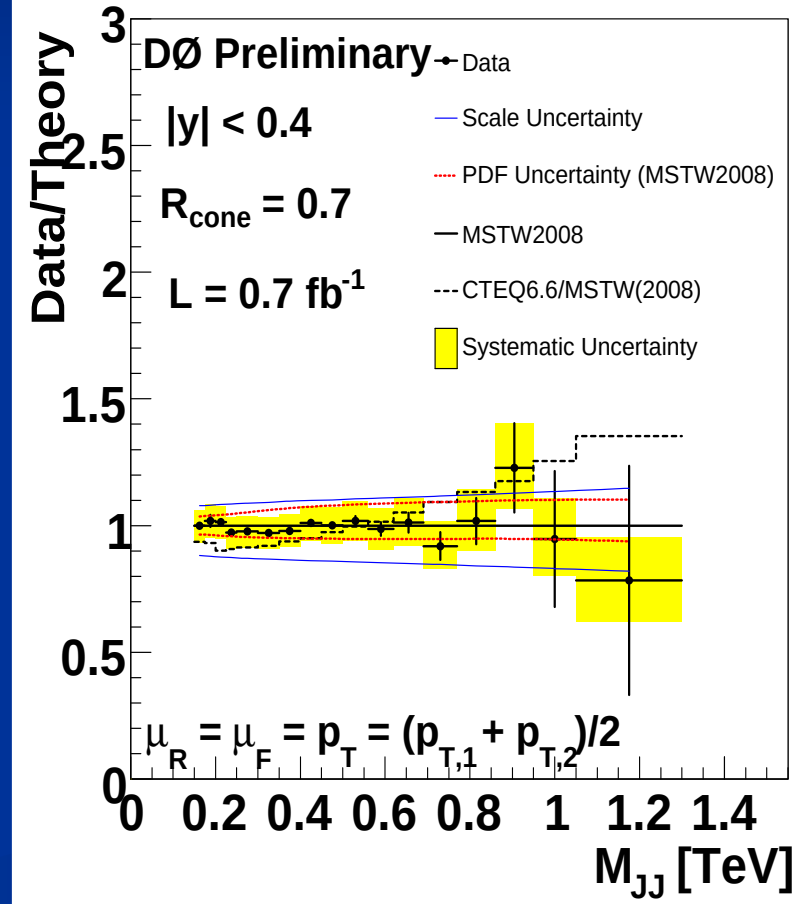
    M_{JJ} rescaled = M_{JJ} reco-(0.004+1.875*ymax)*(M_{JJ}reco)^2

Rescaling effects in the CC region



Comparison to Other Results





Other Work

B Physics

- Study the decay: $B^0 \rightarrow J/\psi\ K^{*+}\ \pi^-$
  - Current PDG value: 8×10^{-4} +/- 4×10^{-4}
  - Take a ratio between B^+ and B^0
    - B^+ is well measured
  - Can also measure $B^0 \rightarrow J/\psi\ K^0\ \rho$, $B^0 \rightarrow J/\psi\ K^0\ \pi\ \pi$
- Wrote all the analysis code
  - Histogramming code
  - Spreadsheet to calculate the various branching fractions

Service Work

- Level 2 Trigger System
  - Maintained monitoring software
  - On-call expert
  - Trained new experts
- DAQ shifts
- Data reprocessing
  - Part of team to use grid computing on a large scale at D0
  - Tested/troubleshot new sites