Jet Measurements at DØ

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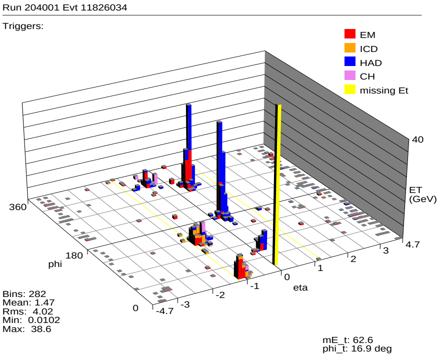
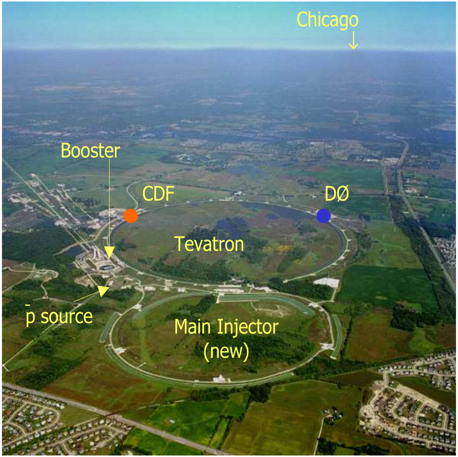
Outline

- Tevatron & DØ
- Experimental Jets
  - Jet algorithms
  - Jet Energy Scale Calibration
- Jet Measurements

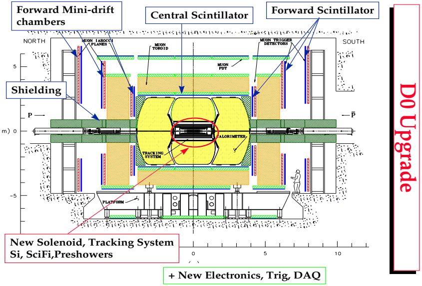


Fermi National Accelerator Laboratory, Batavia, Illinois, USA



Tevatron accelerator

- $\sqrt{s} = 1.96$TeV
- $\mathcal{L}_{max} = 2.95 * 10^{32}\text{cm}^{-2}\text{s}^{-1}$
- 2 collider experiments



Comparison of hadron colliders

Past - CERN

- ISR(pp), $\sqrt{s} = 62$GeV, $\mathcal{L}_{\text{record}} = 140 * 10^{30}\text{cm}^{-2}\text{s}^{-1}$
- S$p\bar{p}$S($p\bar{p}$), $\sqrt{s} = 540$GeV, $\mathcal{L} \sim 2 * 10^{30}\text{cm}^{-2}\text{s}^{-1}$

Present - Fermilab

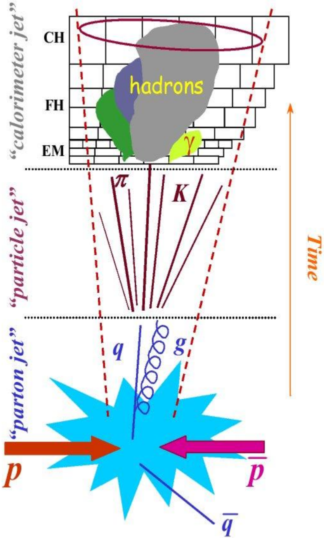
- TeVatron($p\bar{p}$), $\sqrt{s} = 1.96$TeV (Run II), $\mathcal{L}_{\text{record}} = 295 * 10^{30}\text{cm}^{-2}\text{s}^{-1}$ (Run IIb)

Future - CERN

- LHC(pp) (scheduled to start in 2008), $\sqrt{s} = 14$TeV, $\mathcal{L}_{\text{plan}} = 10^{34}\text{cm}^{-2}\text{s}^{-1}$

Jets

Jets are collections of highly collimated particles



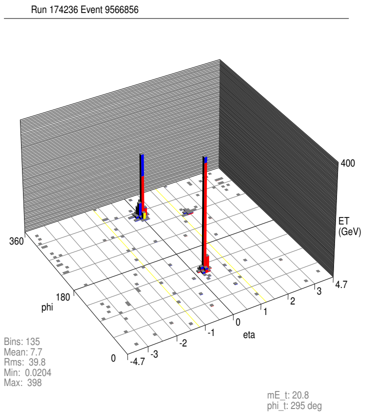
- Calorimeter jet
  - interaction of hadrons with calorimeter
  - collection of calorimeter cell energies
- Particle jet
  - after hadronization and fragmentation
  - effect of hadronization is soft ⇒ allows comparison between particle and parton jets
- Parton jet
  - hard scattering
  - additional showers

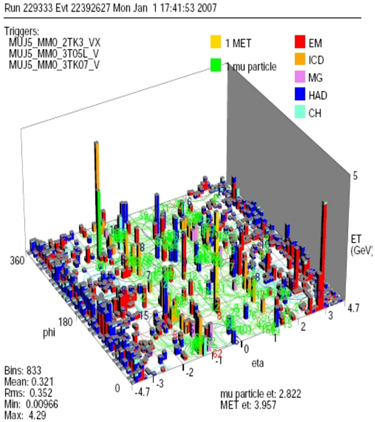
Why Jets?

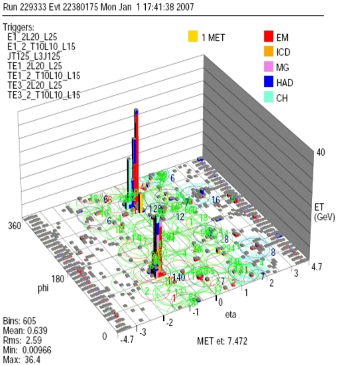
- Jet production cross-section is dominant part of the total cross-section
- Described by pQCD (?)
  - Structure of hadrons (protons)
  - Parton showering
  - α_S
  - ...
- Background to other interesting processes
  - SM - top, Higgs
  - Beyond SM - SUSY & others $\rightarrow$ multijets, lepton(s) + jets, jets + missing energy topologies

Jet Algorithms - Experimental Issue

Compare nice dijet event with some noisy one (more than 20 'jets' on the right!!) - need a common tool for jet finding







List of requirements on the algorithm (hep-ex/0005012)

1. The same algorithm for both theory and experiment
2. Theoretical requirements
3. Experimental requirements
   - Detector independence
   - CPU efficiency
   - Easy to calibrate

Two (main) classes of jet algorithms at hadron colliders - cone vs kT

DØ uses RunII Cone Algorithm:

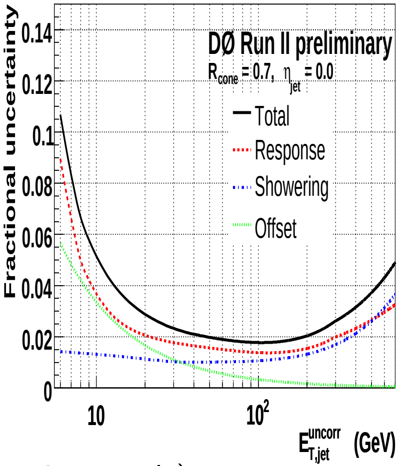
$$\Delta R \leq \sqrt{(y_{\text{ptcl}} - y_{\text{jet}})^2 + (\phi_{\text{ptcl}} - \phi_{\text{jet}})^2},\ \Delta R = 0.5, 0.7$$

See backup slides for details

Jet Energy Scale Correction

$$E^{\text{corr}} = \frac{E^{\text{meas}} - O}{R \cdot S}$$

- Offset (O) coming from calorimeter noise, underlying event, multiple interactions and pile-up
- Response (R) of the calorimeter to jets
- Showering (S) is a fraction of energy deposited outside the jet cone



RunIIa Preliminary JES error 2-3%
RunIIa Final JES aims at 0.5-1.5% (for γ+jet sample)
NB: In some cases, JES is no longer the dominant uncertainty

JES more detailed

1. Calibrate EM calorimeter
   - $Z \rightarrow e^+e^-$ (fixed to LEP values)
   - Correct γ for differences between e and γ
2. Substract offset energy coming from underlying event, multiple interactions, noise or pile-up - estimated by measuring the average energy in the calorimeter in zero and minimum bias data
3. Measure calorimeter response to hadronic jets in γ+jet events
   - EM Scale calibrated
   - 'Clean events' - jet and photon balanced in p_T
   - Limited by max photon $p_T \sim$ 250GeV $\Rightarrow$ extrapolate towards higher p_T
   - Use dijets for endcap calorimeters - one jet in central (calibrated) is balanced by second jet in endcap
4. Correct for showering outside the jet cone due to detector effects

See: http://www-d0.fnal.gov/phys_id/jes/public/plots_v7.1/

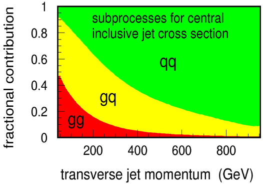
Jet Measurements at DØ

1. Inclusive Jet Cross-section
2. Dijets
   - Dijet mass
   - Dijet angular distribution
   - Dijet azimuthal decorrelations
3. Multijets
   - Threejets + more
4. Jets + Vector Bosons
5. Jets + $\not{E}_T$

NB: Results not presented can be found at:

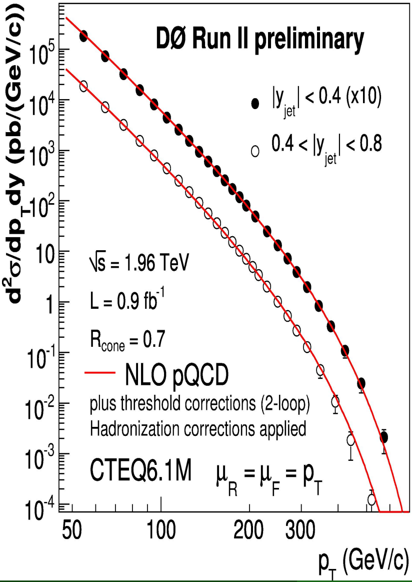
http://www-d0.fnal.gov/Run2Physics/WWW/results.htm

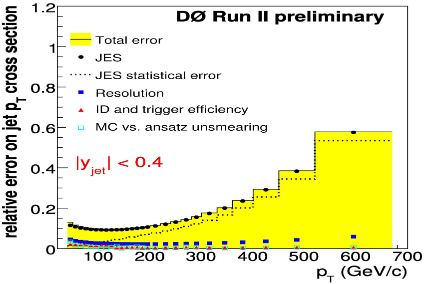
Inclusive Jet p_T Spectrum

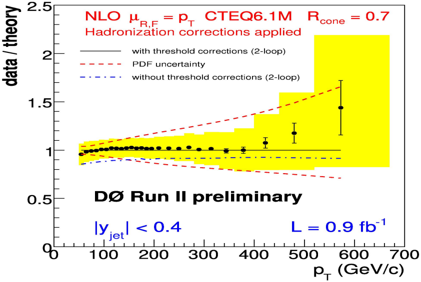


- Curiosity of excess of high p_T jets by CDF in RunI
- PDF not well constrained at high x (especially gluon) - increased gluon density can explain the CDF result
- Highest energy available - jet $p_T > 600$GeV
- The nature of the basic interaction between quarks and gluons
- Possible new physics - quark substructure, ...

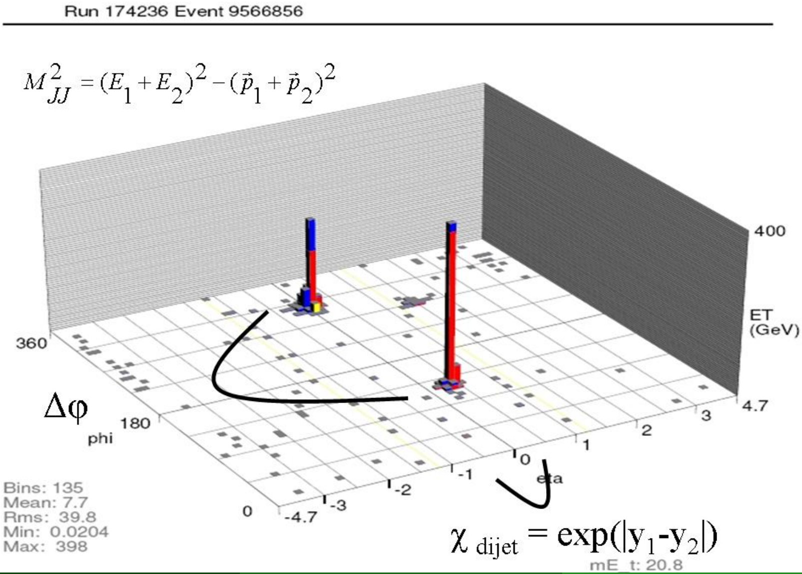
Inclusive Jet Cross-section







Dijet System

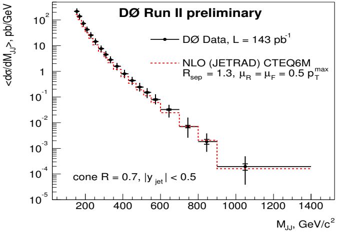


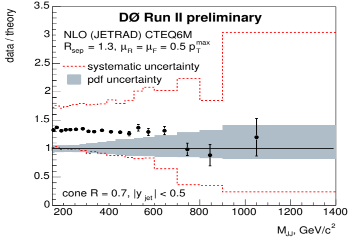
Dijet Mass and Dijet Angular Distribution

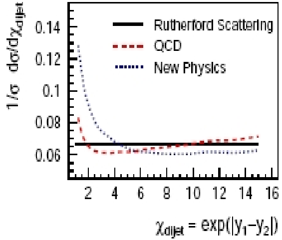
To be updated & approved

$$\chi_{\text{dijet}} = \exp(|y_1 - y_2|),$$

$$y = \frac{1}{2}\ln\left(\frac{1+\beta\cos\theta}{1-\beta\cos\theta}\right),\ \beta = \frac{|\vec{p}|}{E}$$

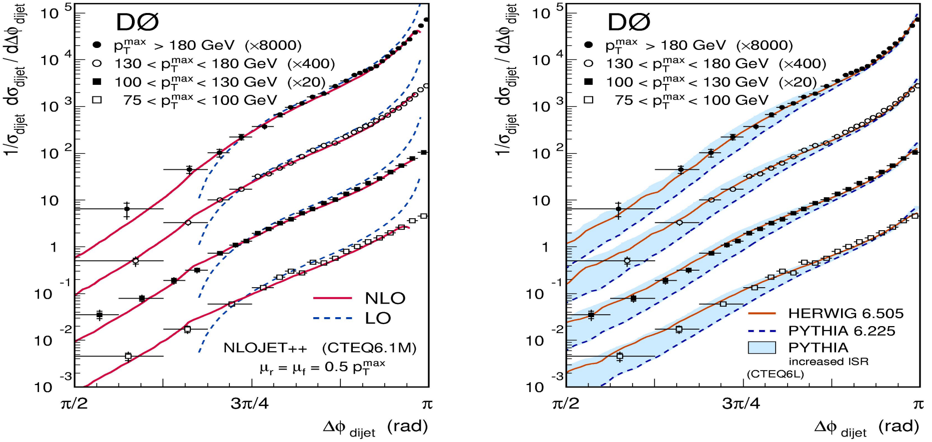






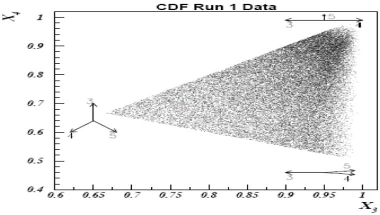
Dijet Azimuthal Decorrelations ($\Delta\phi$)

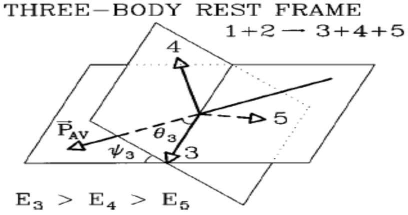
LO QCD - two back-to-back jets. Any additional radiation causes decorrelation in $\Delta\phi$ - sensitive to higher order corrections without measuring the additional jet(s).



Threejets

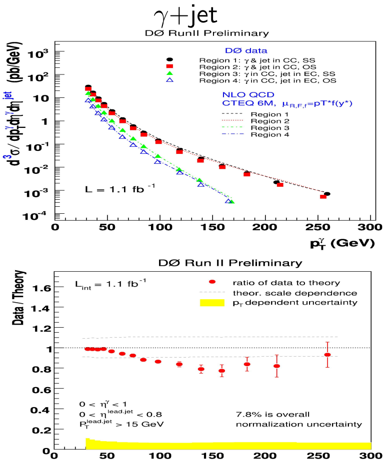
- Theory also available at NLO
- 8 variables needed to describe the final state in its CMS
- M_{3jet} - mass of 3 jets, in CMS $M_{\text{3jet}} = E_3 + E_4 + E_5$
- X_3, X_4 - distribution of energies among the 3 jets $X_i = \frac{2E_i}{M_{\text{3jet}}}$ (because of $\sum_i X_i = 2$, X_5 is not independent)
- Angles:
  $\cos\theta_3 = \frac{\vec{P}_{AV}\cdot\vec{P}_3}{|\vec{P}_{AV}|\cdot|\vec{P}_3|}$, $\cos\psi_3 = \frac{(\vec{P}_3\times\vec{P}_{AV})\cdot(\vec{P}_4\times\vec{P}_5)}{|\vec{P}_3\times\vec{P}_{AV}||\vec{P}_4\times\vec{P}_5|}$, $\vec{P}_{AV} = \vec{p} - \vec{\bar{p}}$
- Masses of individual jets (dimensionless)
  $f_i = m_i/M_{\text{3jet}},\ i = 3, 4, 5$



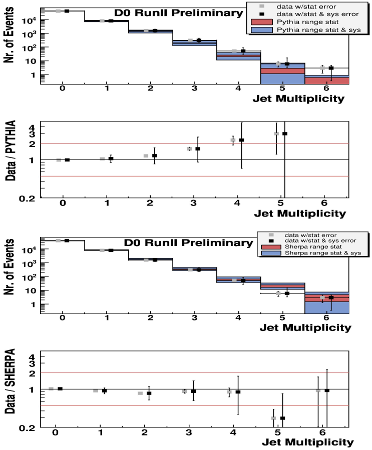


Jets + γ, W, Z

- Jet and VB balanced in p_T $\Rightarrow$ calibration purposes $\Rightarrow$ important to understand higher order corrections, test of MC generators
- $W + c$ jet - sensitivity to s quark PDF
- Backround to various processes

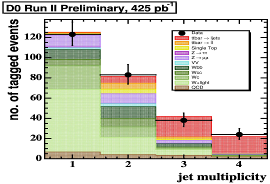


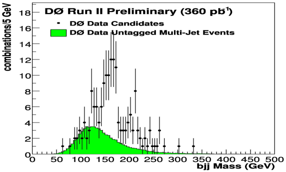
Z+jet(s) - Pythia/Sherpa comparison



Other Jet Measurements

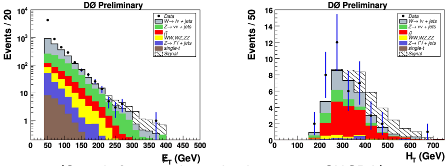
SM: top quark pair production, single top, Higgs searches - jets everywhere ;-)





Beyond the SM (SUSY, LED, . . .) are tested and limits for new particles masses are set in various channels:

- SUSY, LED - multijets + $\not{E}_T$
- Technicolor $p\bar{p} \rightarrow e^- + 2$jets
- Leptoquarks
- . . .



(Search for squarks and sgluinos in mSUGRA)

Summary

- Jets dominate the final states at hadron colliders ⇒ their understanding is essential - many searches for the Higgs boson and physics beyond the Standard Model involve jets
- DØ Jet Energy Scale under development should reduce uncertainties in QCD measurements
- QCD theory well proved in inclusive jet p_{T} spectrum measurement, dijet system, $\gamma+$ jet ⇒ going to multijets

Back-up slides

DØ RunII Cone Algorithm

Proceeds in two steps:

1. Preclustering - to find seeds for the main algorithm (DØ specific values for example)
   - Get list of items (calorimeter towers, MC particles, MC partons) orderded by p_{T}
   - Take the leading item with $p_{\mathrm{T}} > 500\mathrm{MeV}$, form a cone with $\Delta R = \sqrt{\Delta y^2 + \Delta\phi^2} = 0.3$
   - Remove all items with $p_{\mathrm{T}} > 1\mathrm{MeV}$ lying in the cone from the initial list and put it into a new precluster
   - Compute precluster properties (using E-scheme)
   - Continue until there are no avaiable items in the initial list

   - Keep preclusters with $p_{\mathrm{T}} > 1\mathrm{GeV}$
2. RunII Cone Algorithm
   - Takes two lists - list of preclusters and the complete list of items
   - Preclusters serve as **seeds** where the algorithm starts in $y \times \phi$ plane
   - **Protojets** are found by an iterative procedure - cone of radius R_{cone} is formed around the seed, all items in the cone are added to a protojet-candidate and the candidate's axis is computed. If the axis differs from the original one, the original protojet is replaced by the protojet-candidate and procedure is repeated until a stable solution is found
   - Procedure is repeated for the remaining list of seeds
   - **Midpoints** are added to reduce sensitivity to soft radiation. Between each pair of protojets, new seeds are added and the same procedure as for seeds is repeated
   - In RunII Cone Algorithm, the items are not removed from the initial list - the same item can end up in more then one protojet $\longrightarrow$ **splitting/merging** condition is applied to decide which item will end up in which jet

   - Finally, the jet parameters are recomputed using the E-scheme

Main parameters:

- Radius of Cone ($R_{\mathrm{cone}} = 0.5, 0.7$)
- splitting/merging fraction (50% - if two protojets share more than 50% of the lower p_{T} protojet, they will be merged, otherwise the common items will be split into two separated jets
- Minimal jet $p_{\mathrm{T}} = 6\mathrm{GeV}$