Min-Bias Jets: The Evolution of Jets from 0.5 to 100 GeV

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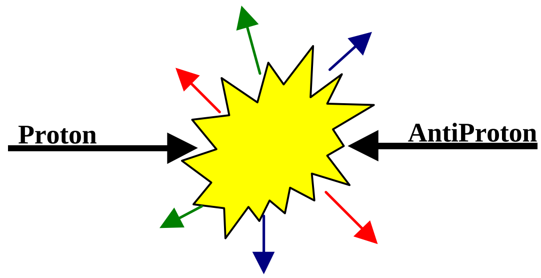
plus
Bologna Group (N. Moggi, F. Rimondi, S. Zucchelli)

Talk by Rick Field Presented at the QCD Meeting March 25, 1999



- **Study the CDF "Min-Bias" Data with the goal of finding a Monte-Carlo Generator that will fit the data. Would like to describe (approximately) all the features of the entire inelastic ("hard core") cross section (low PT and high PT)!**
- **Look at the data (plot many observables) and compare to Herwig and Isajet and Pythia.**
- **For now consider only charged particles in the region, $PT > 0.5$ GeV $|\eta| < 1$, where efficiency is good.**
- **In this talk I will concentrate on Jets ("Jet" = circular region).**
- **Plot distributions: PT(jet#1) (connect with Jet20 data).**
- **Look at PT(jet#1) dependence (plot averages versus PTjet#1): <PTmax>, <Njet>, <NchgJet#1>, <PTjet#2>, <PTjet#3>, <JetSize>, etc..**
- **Look at Jet Development as function of PT(jet#1): Nchg(Jet#1), Jet Size, N-flow and PT-flow relative to Jet#1 direction, "Fragmentation Functions".**
- **Many more transparencies than I can show in this talk! All 30 transparencies are on the WEB.**

http://www.phys.ufl.edu/~rfield/cdf/QCD_Talk2.html

Min-Bias Data – Inelastic Cross-Section

Inelastic "Hard Core" Cross Section:

$$\sigma_{tot} = \sigma_{elastic} + \sigma_{inelastic}$$

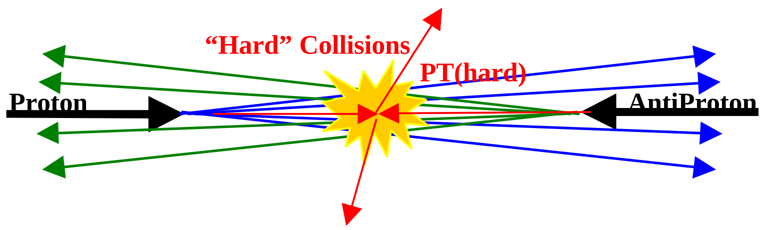
$$\sigma_{inelastic} = \sigma_{HC} + \sigma_{SD} + \sigma_{DD}$$

Hard Core | Single Diffraction | Double Diffraction

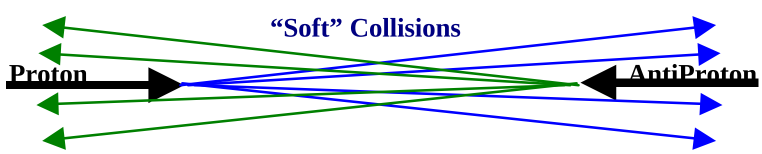
Inelastic "Hard Core" Cross Section at 1.8 TeV:

$$\sigma_{HC} = \sigma_{inelastic} - \sigma_{SD} - \sigma_{DD} = 60\text{ mb} - 9\text{ mb} - 1\text{ mb} = 50\text{ mb}$$

Want to describe (approximately) the entire "hard core" part of the inelastic cross section, σ_{HC}, which has a QCD "hard scattering" component that becomes infinite as PT(hard) becomes small,



and may also have a "soft collision" component (not calculable from perturbation theory).



Two possible approaches:

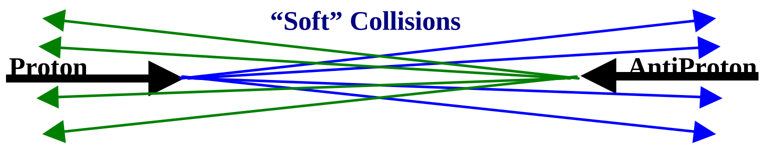
- **Two Component Model:**
  σ(inelastic HC) =
  σ("hard perturbative", $P_T > P_T$min) + σ("soft", everything else)

- **One Component Model:**
  σ(inelastic HC) =
  σ("hard perturbative", all PT but remove the divergences)

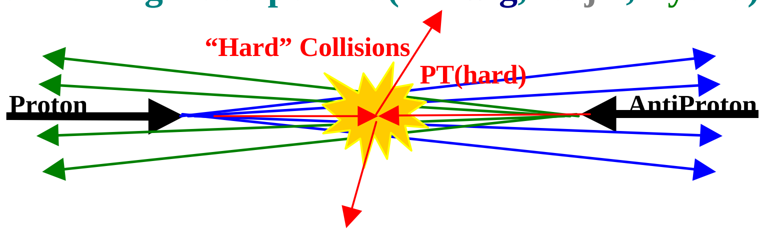
QCD MC – Herwig, Isajet, Pythia

"Soft Collision" Component (Herwig, Isajet):

Herwig and Isajet provide a "Soft Collision" generator for simulating Min-Bias events. They produce roughly 4 charged particles per unit η and have no correlations (except resonances).



QCD "Hard Scattering" Component (Herwig, Isajet, Pythia):

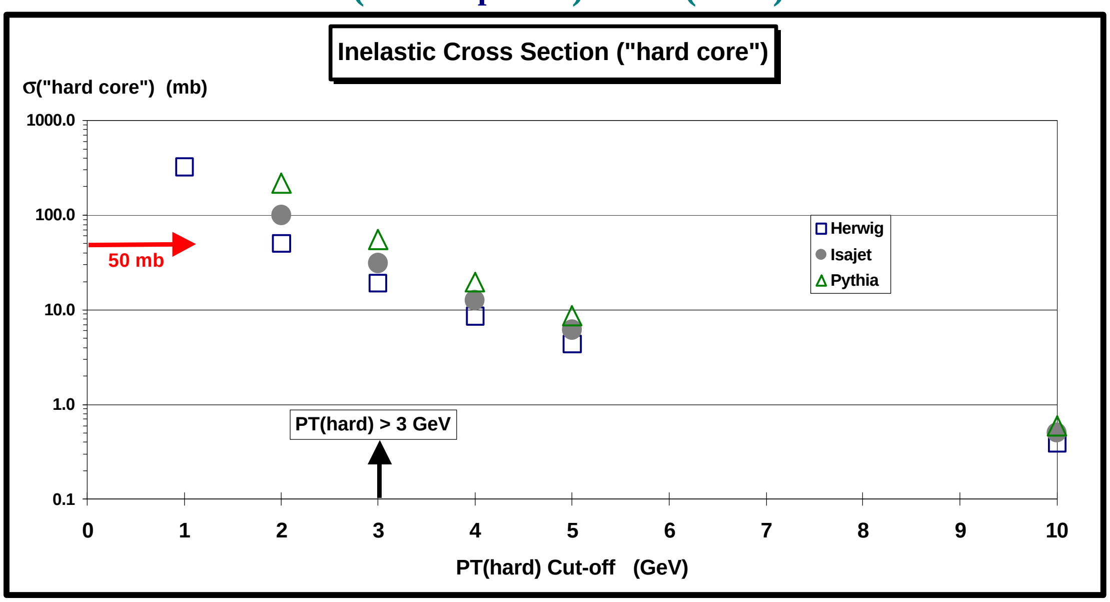


Herwig QCDJET3: Herwig QCD 2-2 parton-parton "hard" scattering with P_T(hard) > 3 GeV (σ = 19.3 mb).

Isajet QCDJET3: Isajet QCD 2-2 parton-parton "hard" scattering with P_T(hard) > 3 GeV (σ = 31.1 mb).

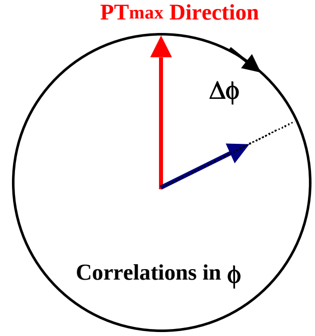
Pythia QCDJET3: Pythia QCD 2-2 parton-parton "hard" scattering with P_T(hard) > 3 GeV (σ = 55.1 mb).

Inelastic Cross-Section (HC component) vs PT(hard) Cut-off:



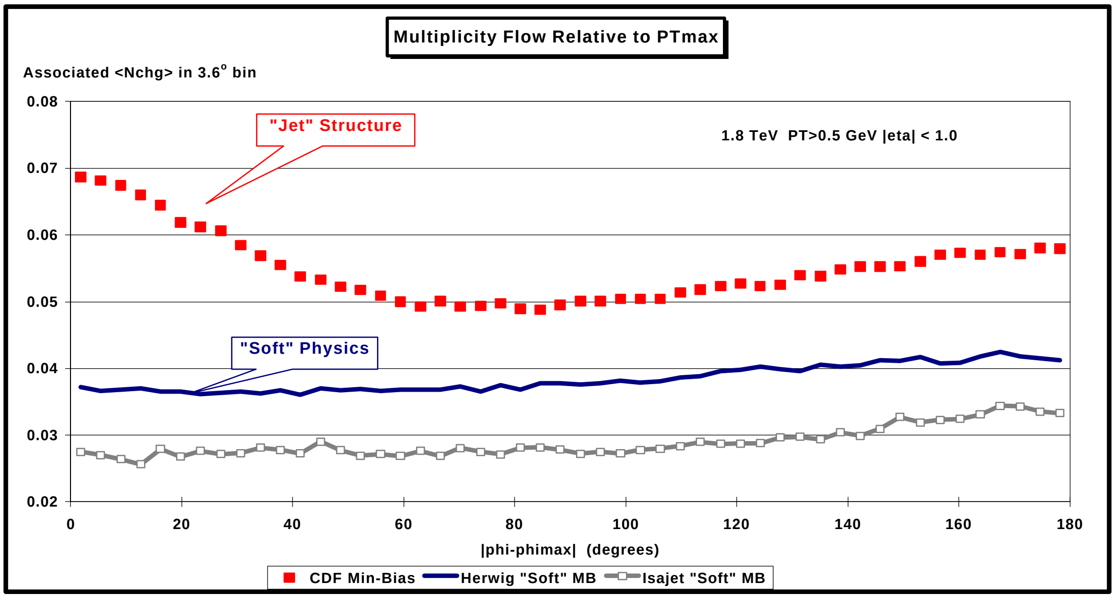
QCD perturbative cross section becomes infinite as PT(hard) cut-off goes to zero.

MB Jets – N-Flow & PT-Flow Relative to PTmax



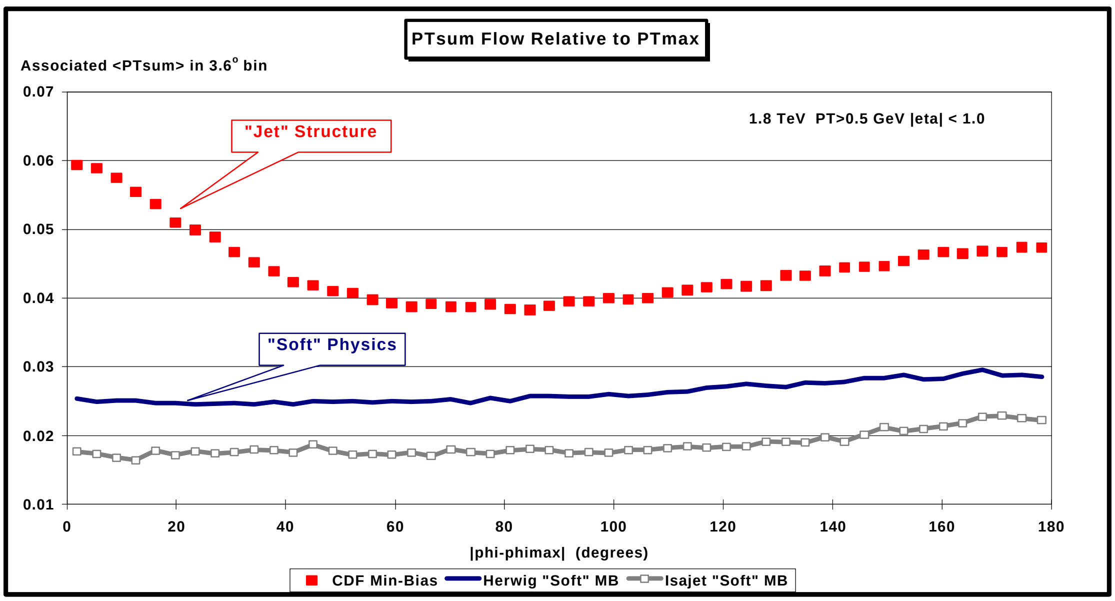
Define PTmax to be the highest PT charged particle in the event (PT > 0.5 GeV, |h| < 1) and look at correlations in azimuthal angle φ.

<Nchg> Produced in Association with PTmax versus $|\phi-\phi_{max}|$:



Does not include PTmax (Nchg >=2)

<PTsum> Produced in Association with PTmax versus $|\phi-\phi_{max}|$:



Does not include PTmax (Nchg >=2)

MB Jets – Jet Algorithm

Examine "Circular Regions" in η-ϕ space with "distance" defined by

$$d = \sqrt{\Delta h^2 + \Delta f^2}$$

Use a Simple Jet Algorithm ("Jet" = circular region):

- **Order Charged Particles (PT > 0.5 GeV |η| < 1)**
- **Start with highest P_T particle and include in the "Jet" all particles (PT > 0.5 GeV |η| < 1) within radius R = 0.7**
- **Go to the next highest P_T particle (not already included in a previous jet) and include in the "Jet" all particles (PT > 0.5 GeV |η| < 1) within radius R = 0.7 (not already included in a previous jet)**
- **Continue until all particles are in a jet**

Example (6 particles, 5 jets):

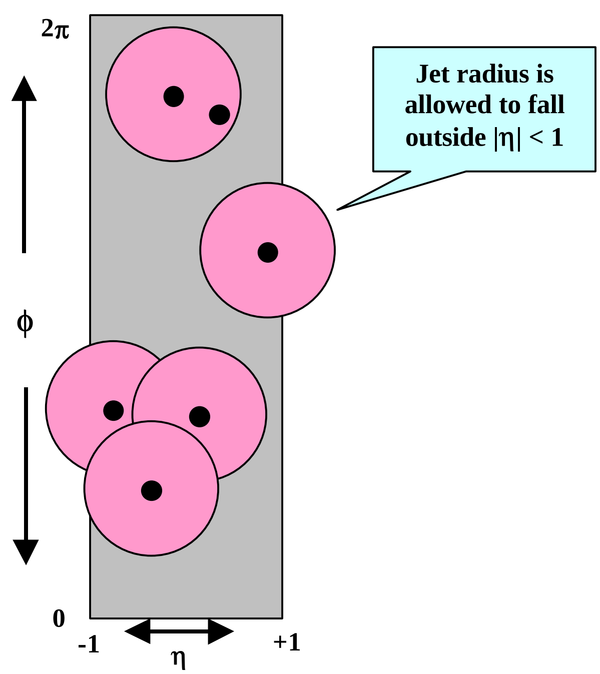
The maximum number of jets is

~ 2(2)(2π)/(π(0.7)²) ~ 16

Jets have a momentum given by

$$\vec{P}_{jet} = \sum_{i=1}^{N_j} \vec{p}_i \,,$$

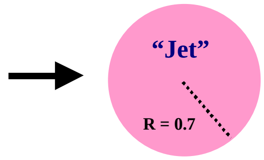
where Nj = NchgJet is the number of charged particles in the jet and



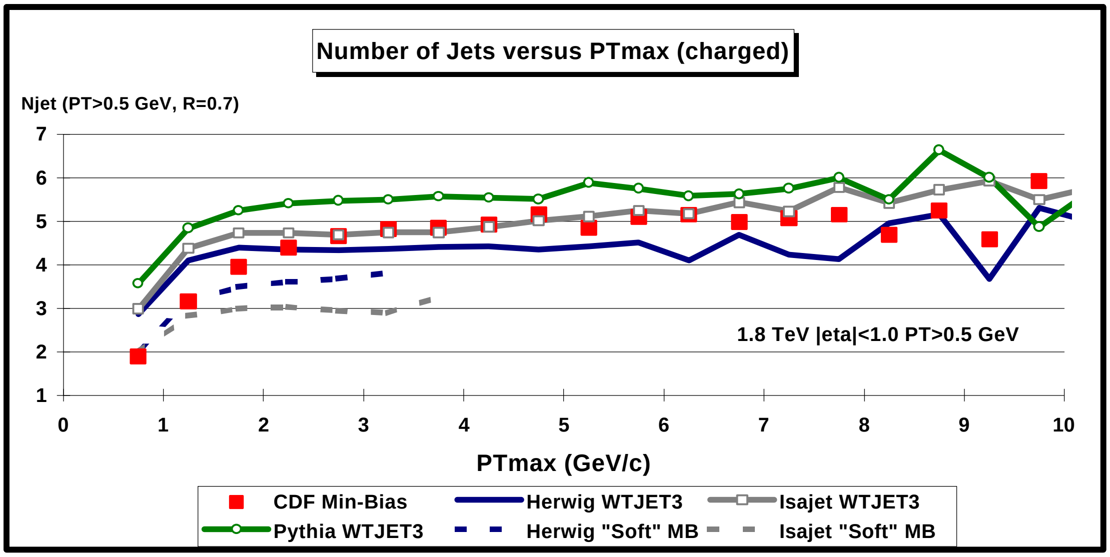
$$P_T(jet) = \sqrt{P_x(jet)^2 + P_y(jet)^2}$$

Min-Bias Data – Dependence on PTmax

"Jet" = Circular Region

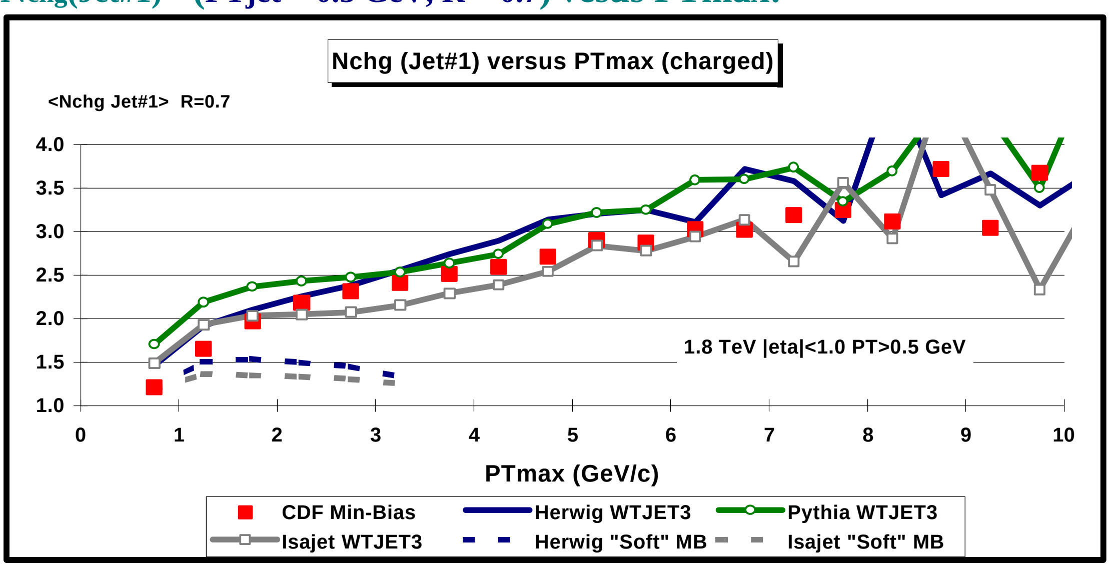


<Njet> (PTjet > 0.5 GeV, R = 0.7) versus PTmax:



CDF Data plus QCD Monte-Carlo Predictions.

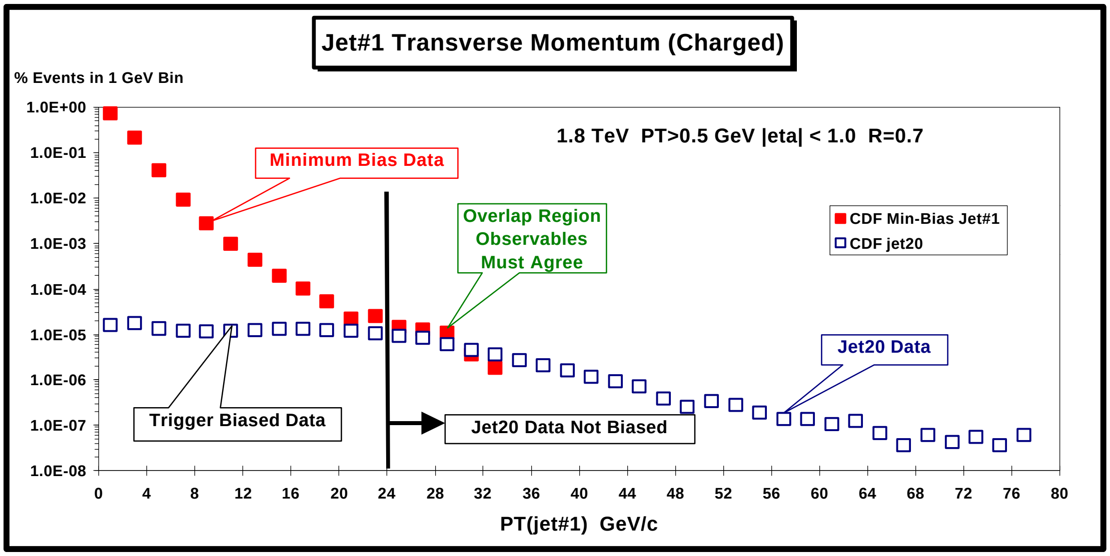
<Nchg(Jet#1)> (PTjet > 0.5 GeV, R = 0.7) vesus PTmax:



CDF Data plus QCD Monte-Carlo Predictions.

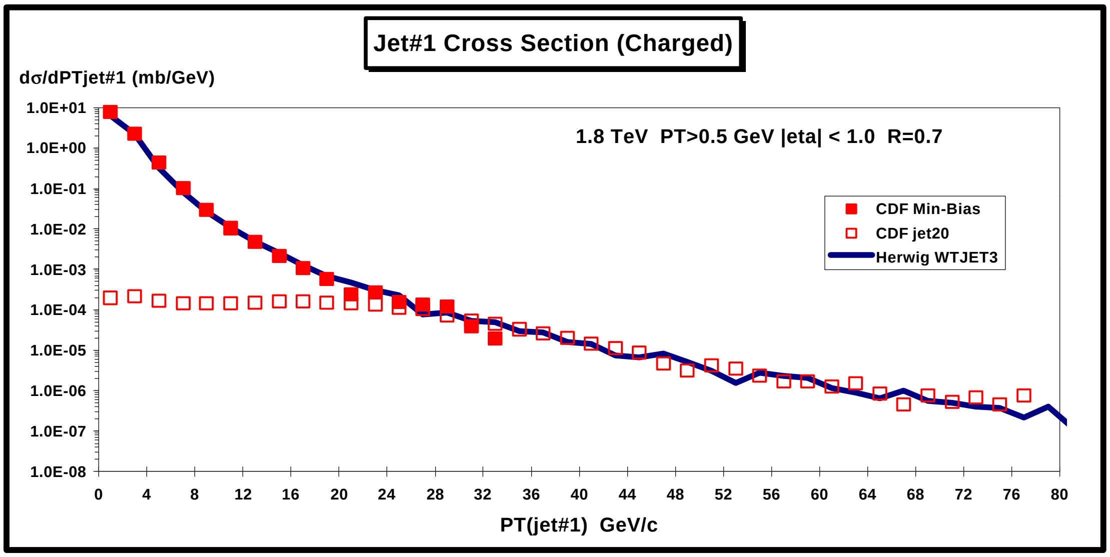
MB Jets – Jet#1 Cross-Section

Jet#1 Transverse Momentum Distribution (R = 0.7):



CDF Min-Bias Data normalized to 1. Use this plot to determine the relative normalization between the Min-Bias data and the Jet20 data.

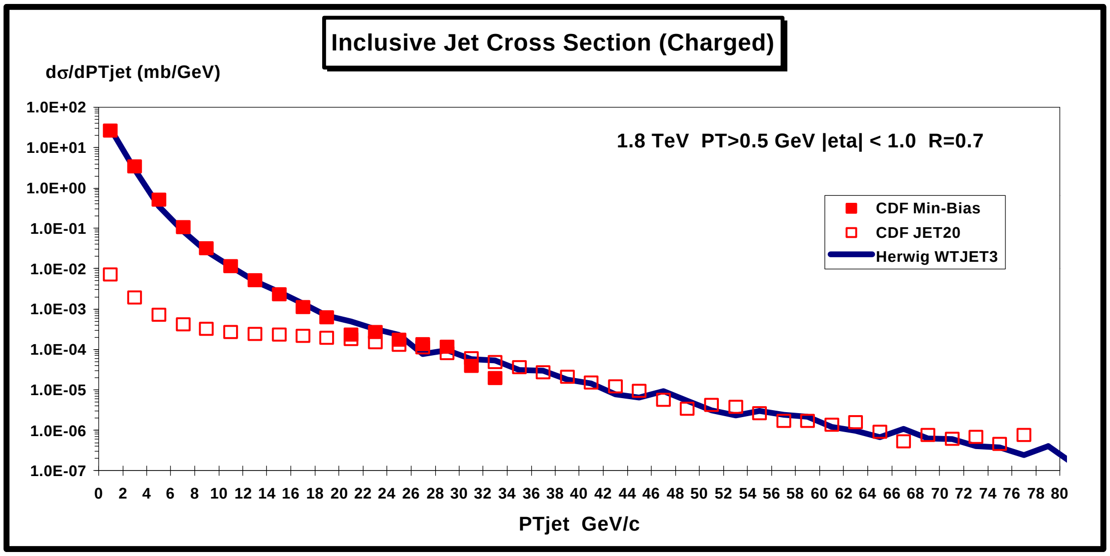
Jet#1 Differential Cross-Section (mb/GeV, R = 0.7):



Normalize CDF data to the Herwig QCDJET3 Jet#1 differential cross section which corresponds to σ_{inel} = 19.2 mb.

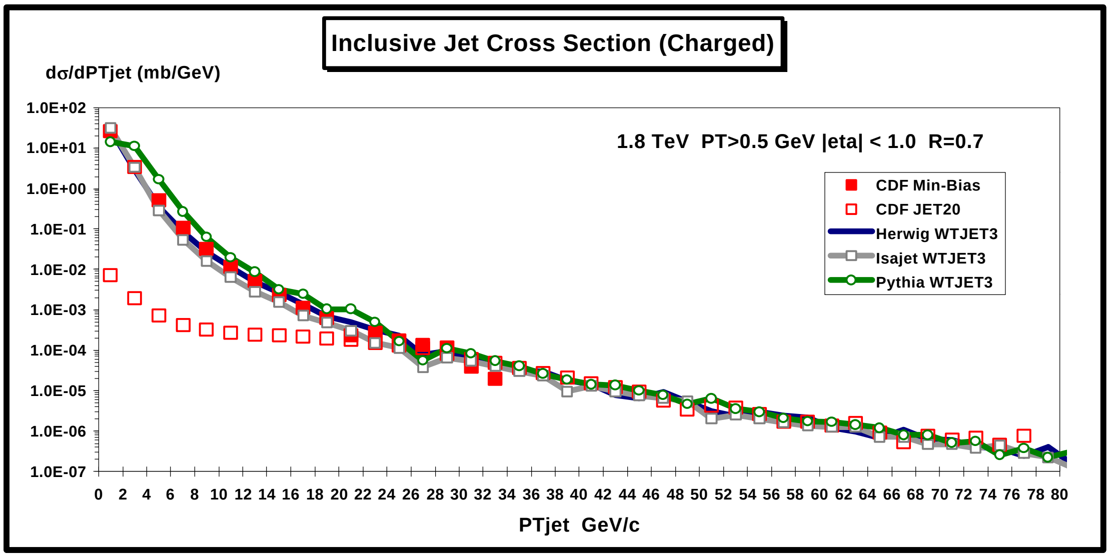
MB Jets – Inclusive Jet Cross-Section

Inclusive Charged Jet Cross-Section (mb/GeV, R = 0.7):



CDF Min-Bias Data and Jet 20 Data normalization fixed from Jet#1 differential cross-section.

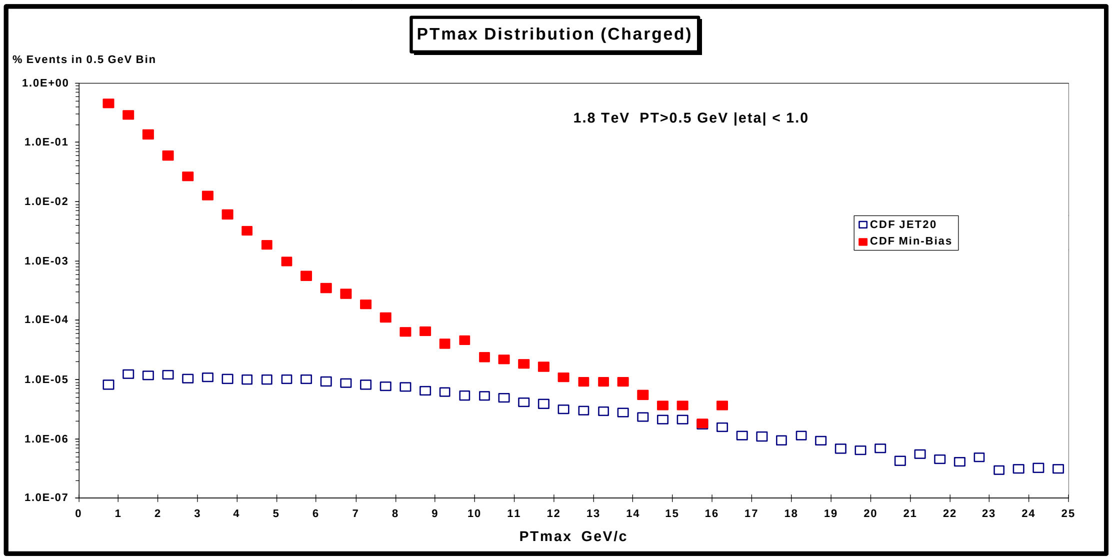
Inclusive Charged Jet Cross-Section (mb/GeV, R = 0.7):



Herwig, Isajet, Pythia.

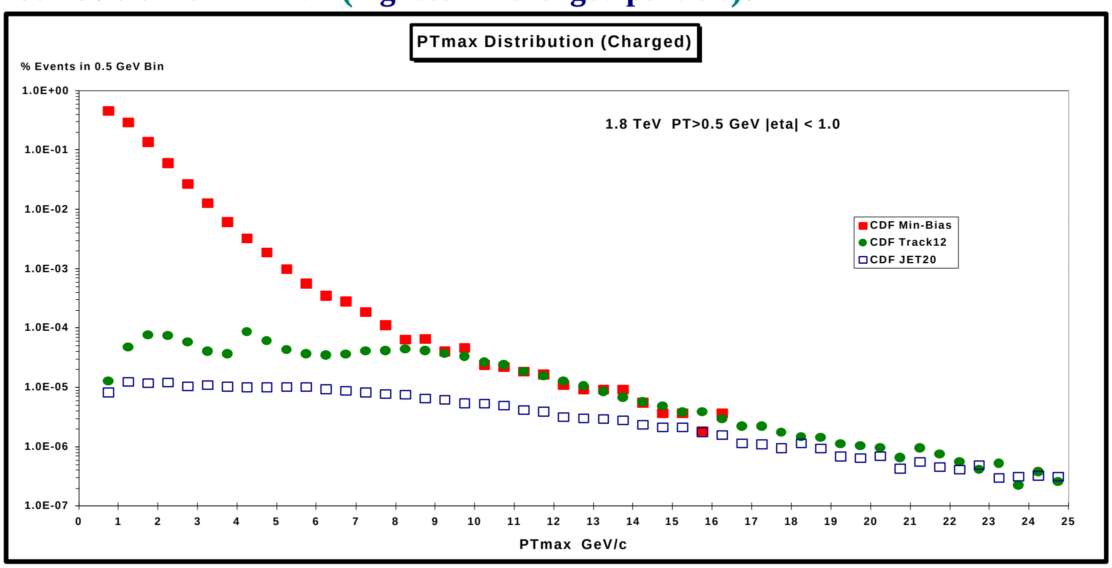
Min-Bias Data – PTmax Cross Section

Distribution of PTmax (highest PT charged particle):



CDF Min-Bias Data normalized to 1. Relative normalization between the Min-Bias data and the Jet20 data comes from the Jet#1 momentum distribution plot.

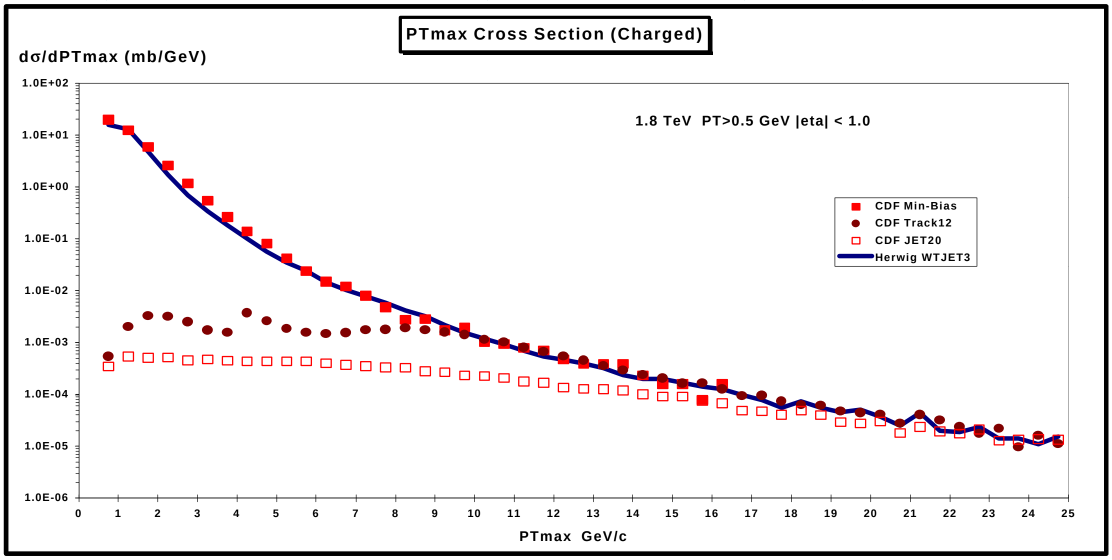
Distribution of PTmax (highest PT charged particle):



CDF Min-Bias Data normalized to 1. The relative normalization between the Min-Bias data and the Jet20 data comes from the Jet#1 momentum distribution plot. The relative normalization between the Min-Bias data and the Track 12 data comes from this plot.

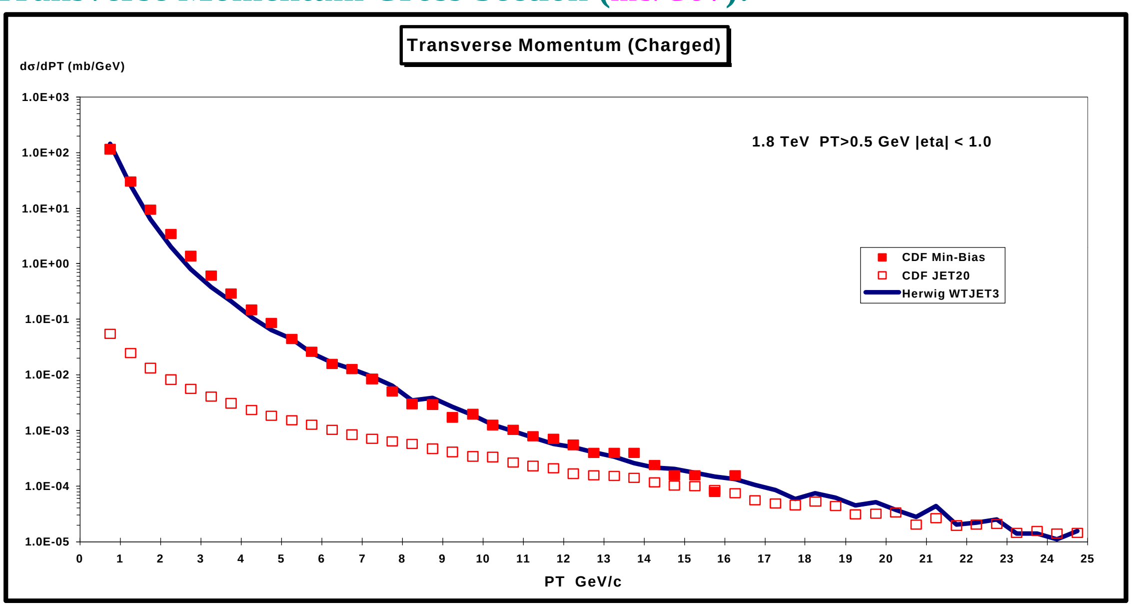
Min-Bias Data – Differential Cross Sections

PTmax (highest PT charged particle) Cross Section (mb/GeV):



CDF Min-Bias Data normalization fixed from Jet#1 PT distribution. Relative normalization between the Min-Bias data and the Jet20 data comes from the Jet#1 PT distribution plot and relative normalization between the Min-Bias data and the Track12 data comes from this plot.

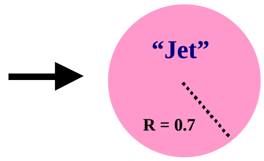
Transverse Momentum Cross Section (mb/GeV):



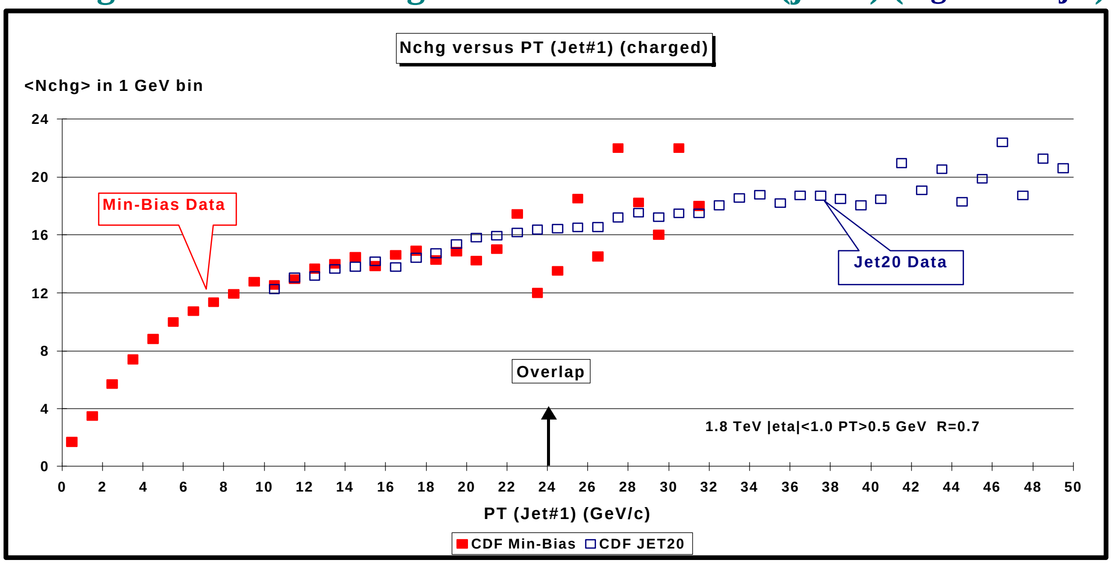
CDF Min-Bias Data normalization fixed from Jet#1 PT distribution. Relative normalization between the Min-Bias data and the Jet20 data comes from the Jet#1 PT distribution.

CDF Data – <Nchg> vs PT(jet#1)

"Jet" = Circular Region

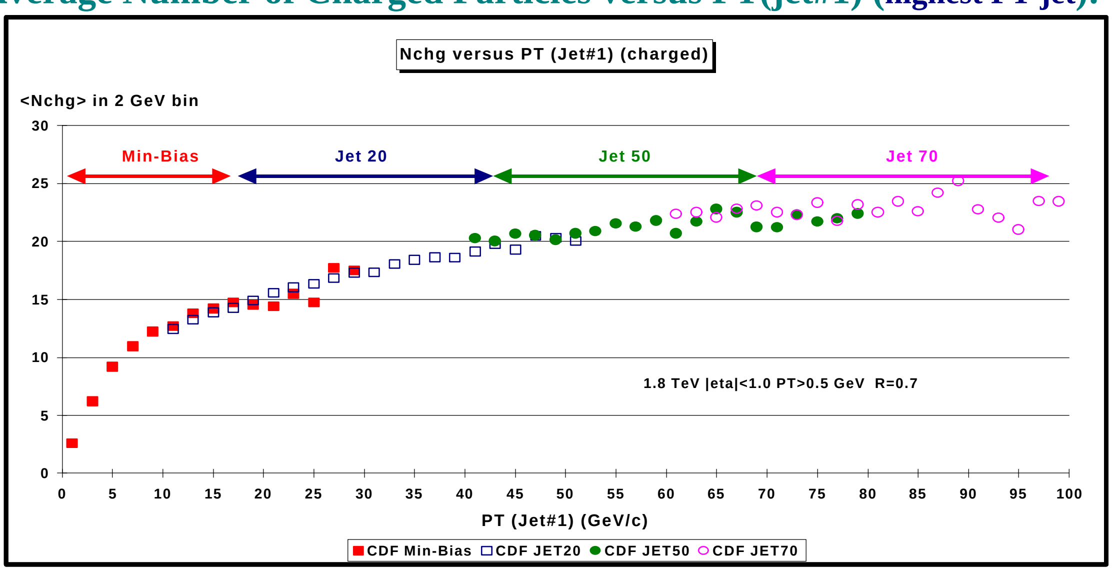


Average Number of Charged Particles versus PT(jet#1) (highest PT jet):



CDF Data Only

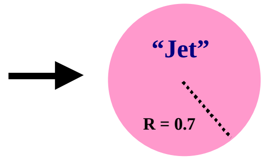
Average Number of Charged Particles versus PT(jet#1) (highest PT jet):



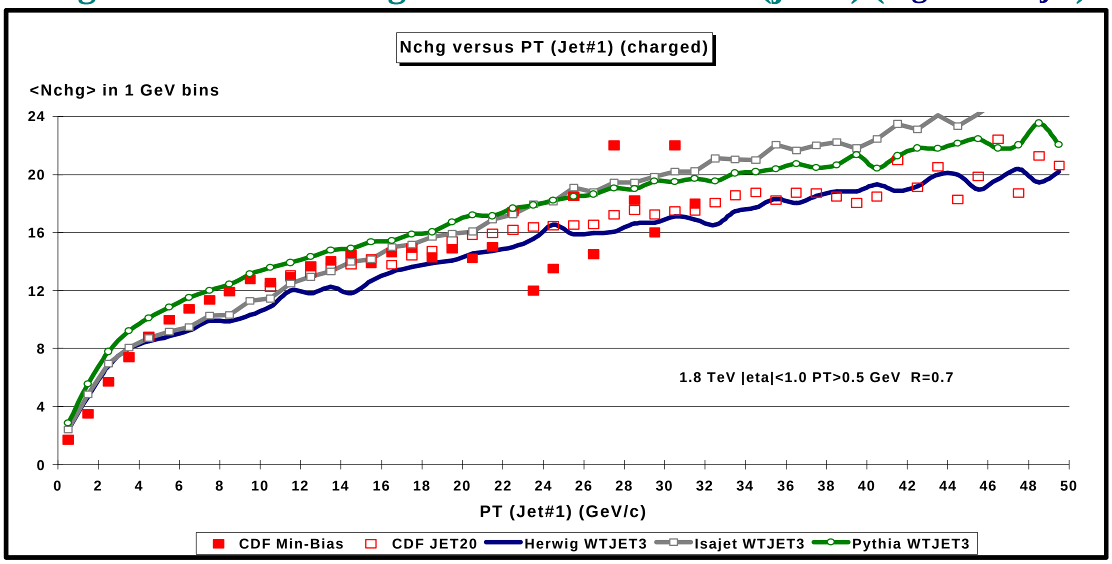
CDF Data Only

QCD-MC Predictions – <Nchg> vs PT(jet#1)

"Jet" = Circular Region

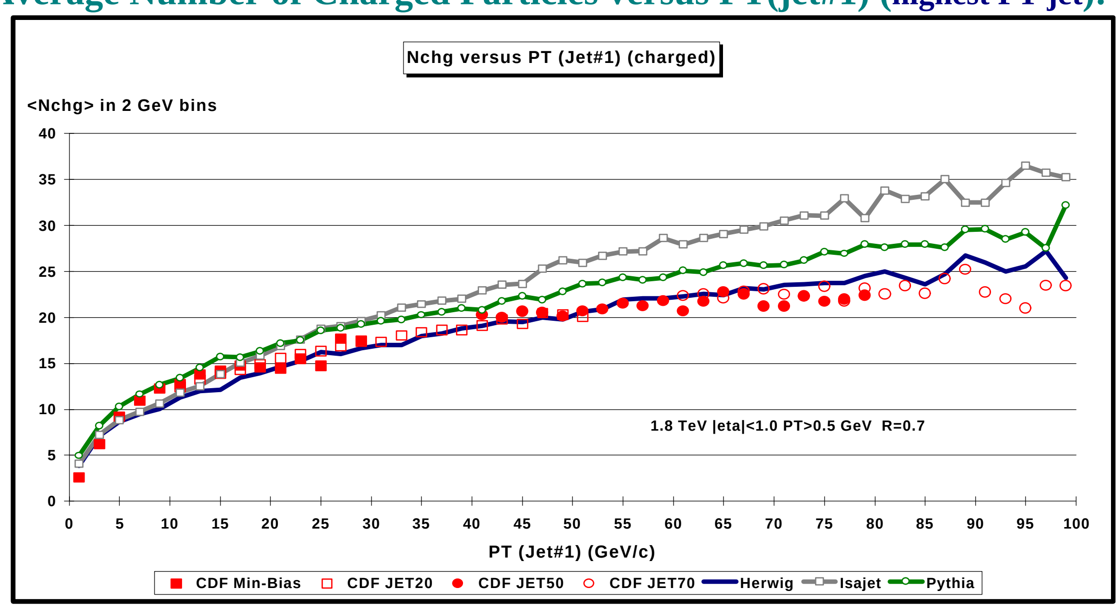


Average Number of Charged Particles versus PT(jet#1) (highest PT jet):



CDF Data plus QCD Monte-Carlo Predictions

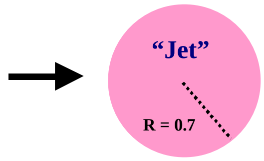
Average Number of Charged Particles versus PT(jet#1) (highest PT jet):



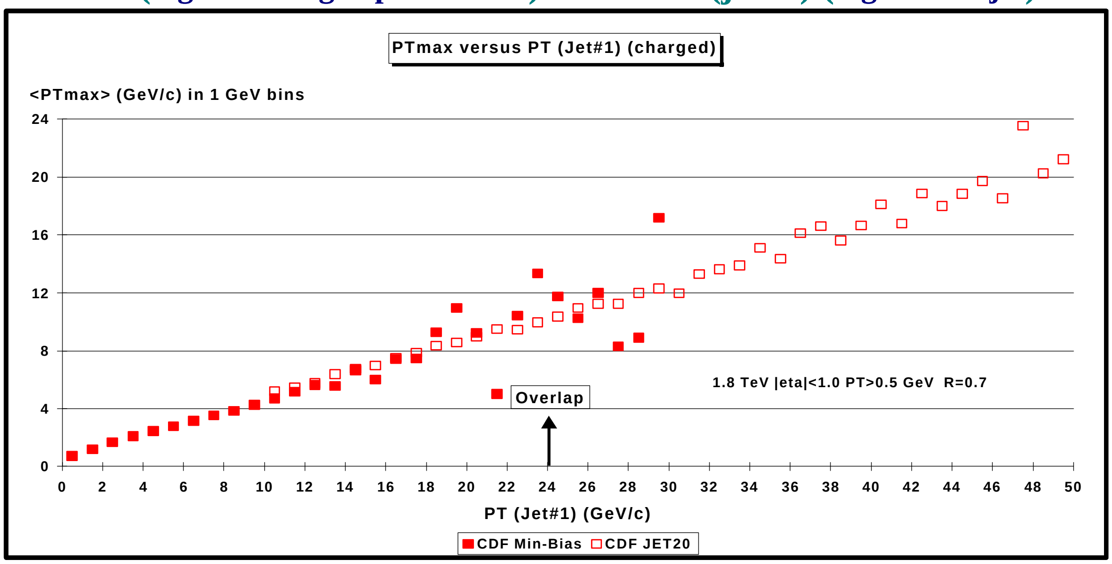
CDF Data plus QCD Monte-Carlo Predictions

CDF Data – <PTmax> vs PT(jet#1)

"Jet" = Circular Region

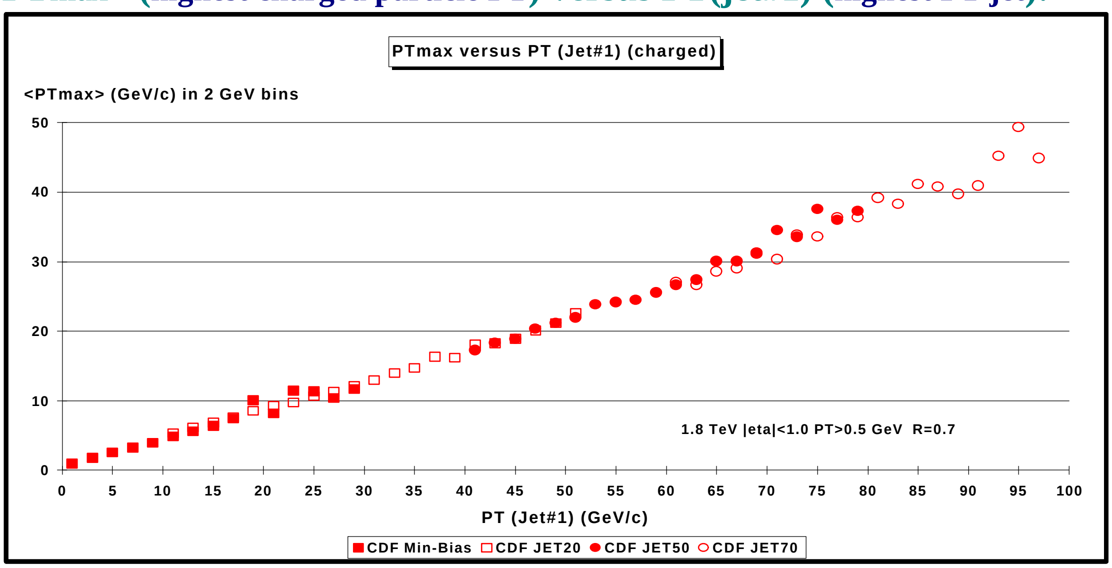


<PTmax> (highest charged particle PT) versus PT(jet#1) (highest PT jet):



CDF Data only

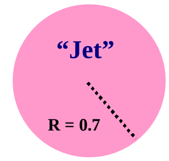
<PTmax> (highest charged particle PT) versus PT(jet#1) (highest PT jet):



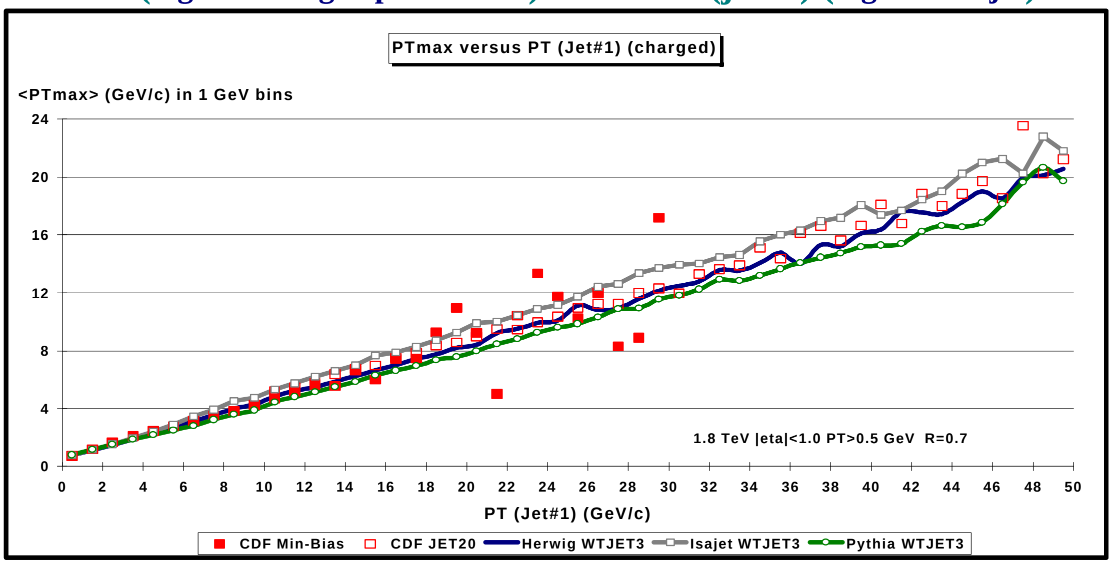
CDF Data only

QCD-MC Predictions – <PTmax> vs PT(jet#1)

"Jet" = Circular Region

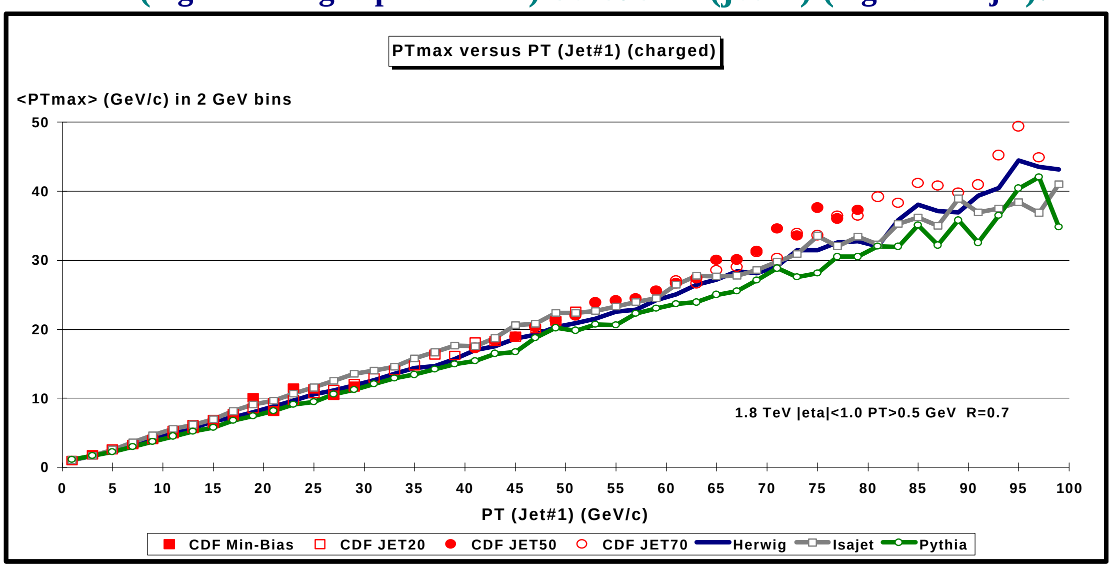


<PTmax> (highest charged particle PT) versus PT(jet#1) (highest PT jet):



CDF Data plus QCD Monte-Carlo Predictions

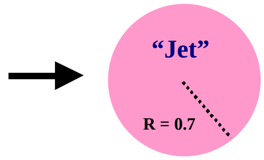
<PTmax> (highest charged particle PT) versus PT(jet#1) (highest PT jet):



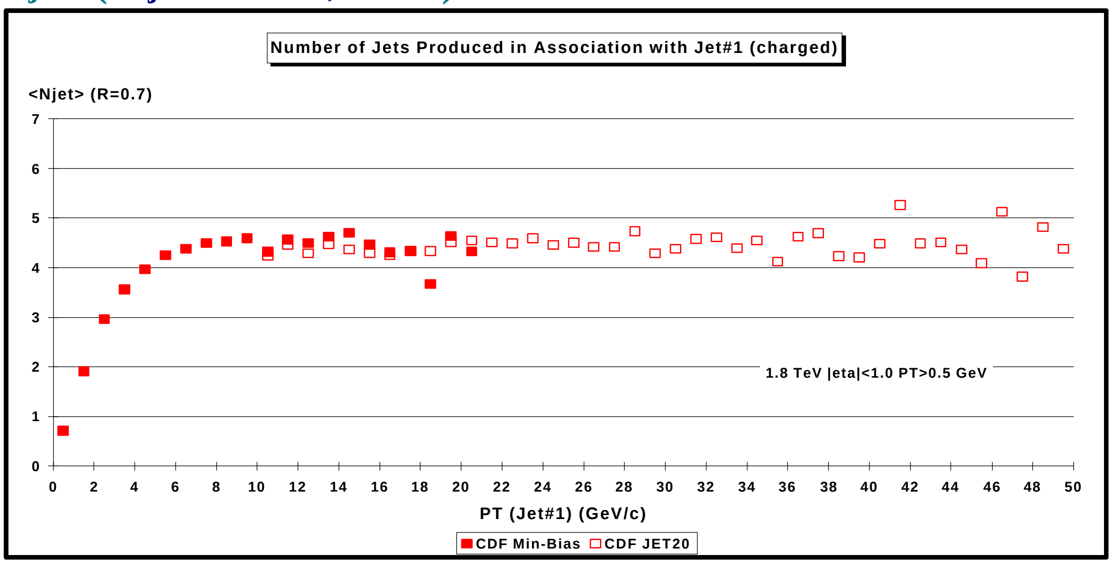
CDF Data plus QCD Monte-Carlo Predictions

CDF Data - Number of Jets Produced in Association with Jet#1

"Jet" = Circular Region

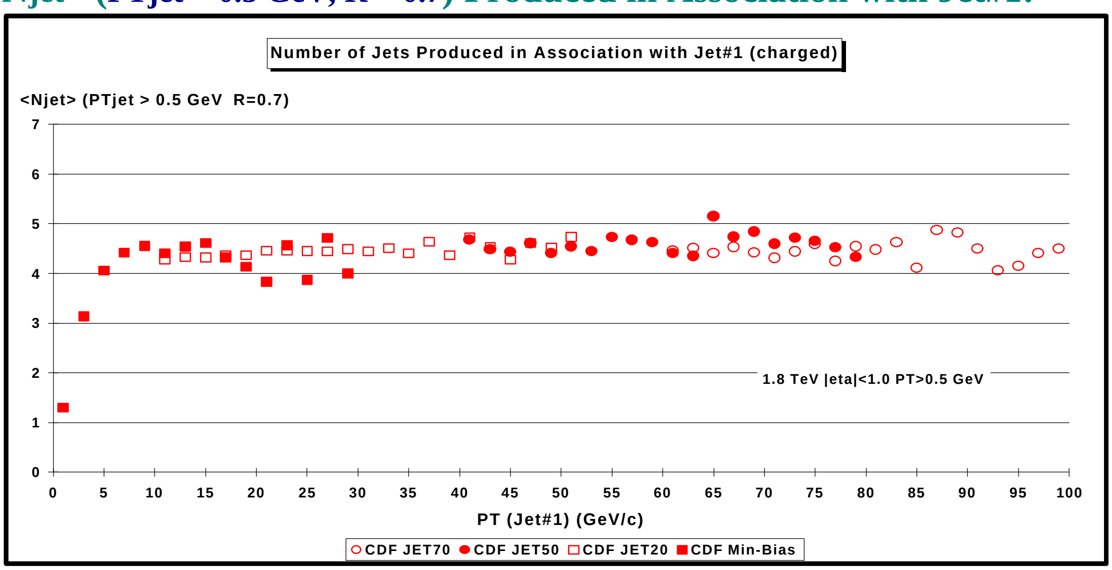


<Njet> (PTjet > 0.5 GeV, R = 0.7) Produced in Association with Jet#1:



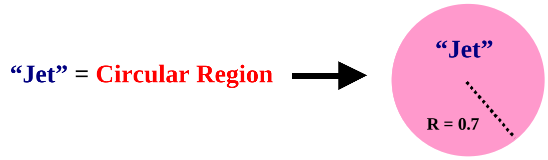
CDF Data (Jet#1 not included).

<Njet> (PTjet > 0.5 GeV, R = 0.7) Produced in Association with Jet#1:

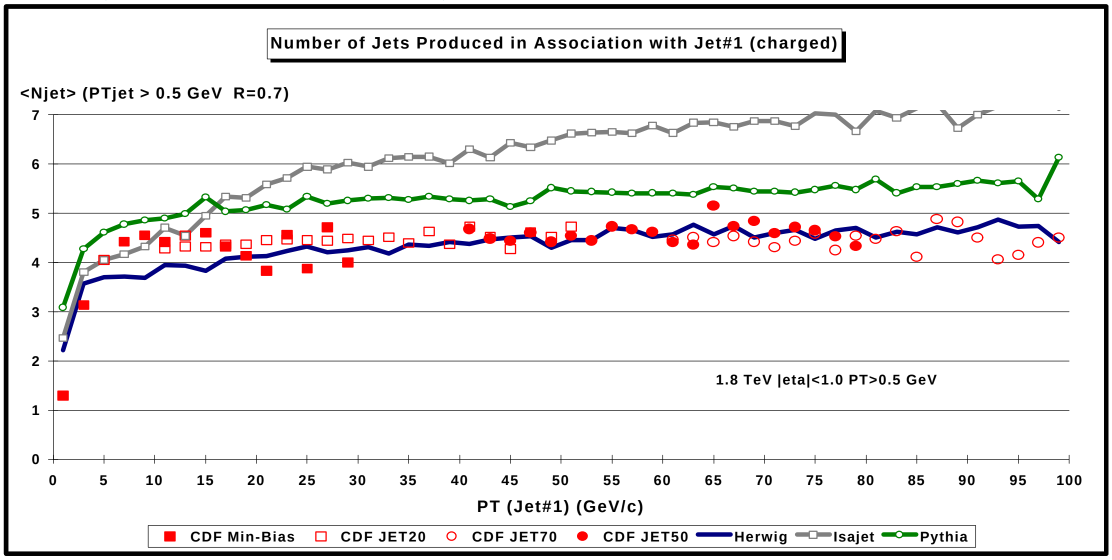


CDF Data (Jet#1 not included).

QCD-MC Predictions - Number of Jets Produced in Association with Jet#1

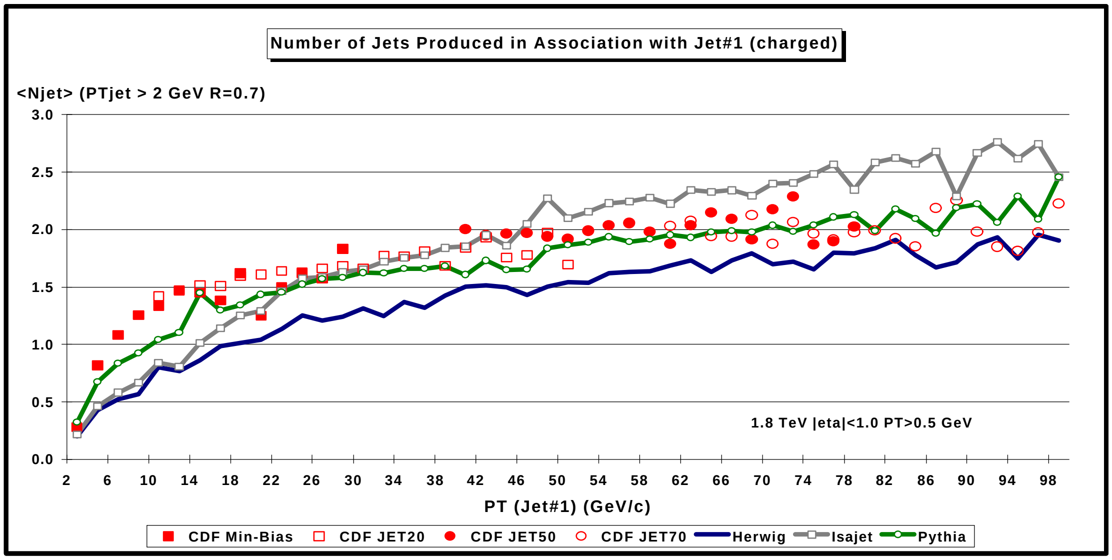


<Njet> (PTjet > 0.5 GeV, R = 0.7) Produced in Association with Jet#1:



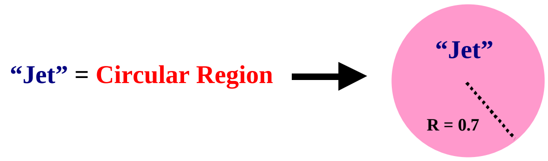
CDF Data plus QCD Monte-Carlo Predictions (Jet#1 not included).

<Njet> (PTjet > 2.0 GeV, R = 0.7) Produced in Association with Jet#1:

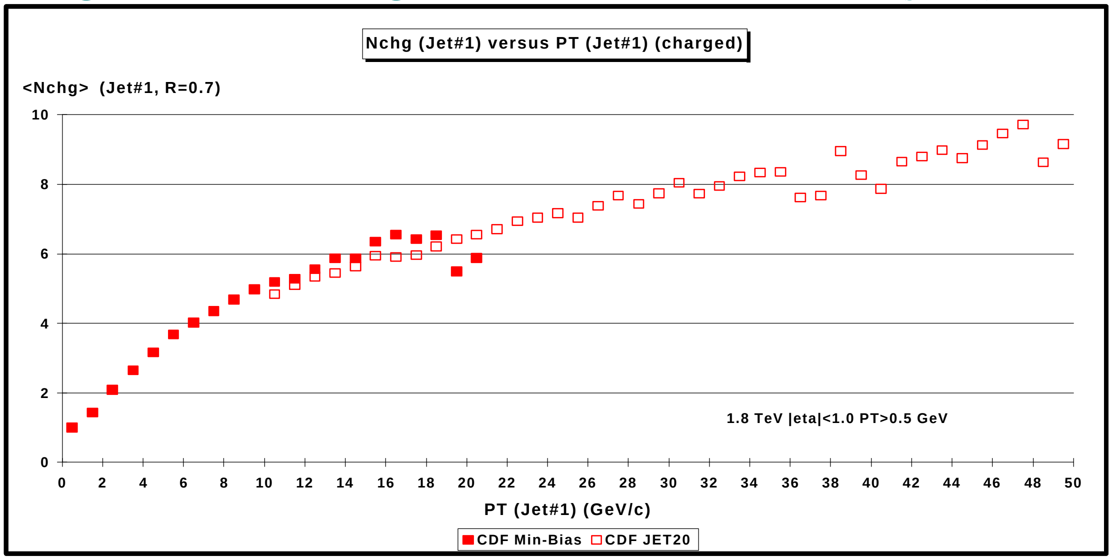


CDF Data plus QCD Monte-Carlo Predictions (Jet#1 not included).

CDF Data – <NchgJet#1> vs PT(jet#1)

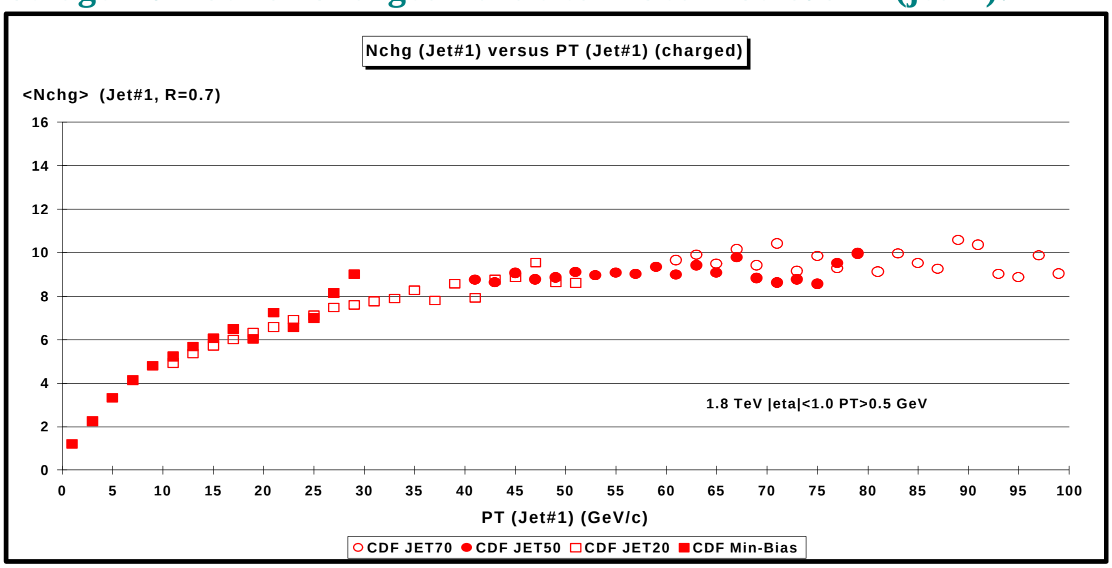


Average Number of Charged Particles in Jet#1 versus PT(jet#1):



CDF Data Only

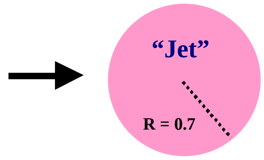
Average Number of Charged Particles in Jet#1 versus PT(jet#1):



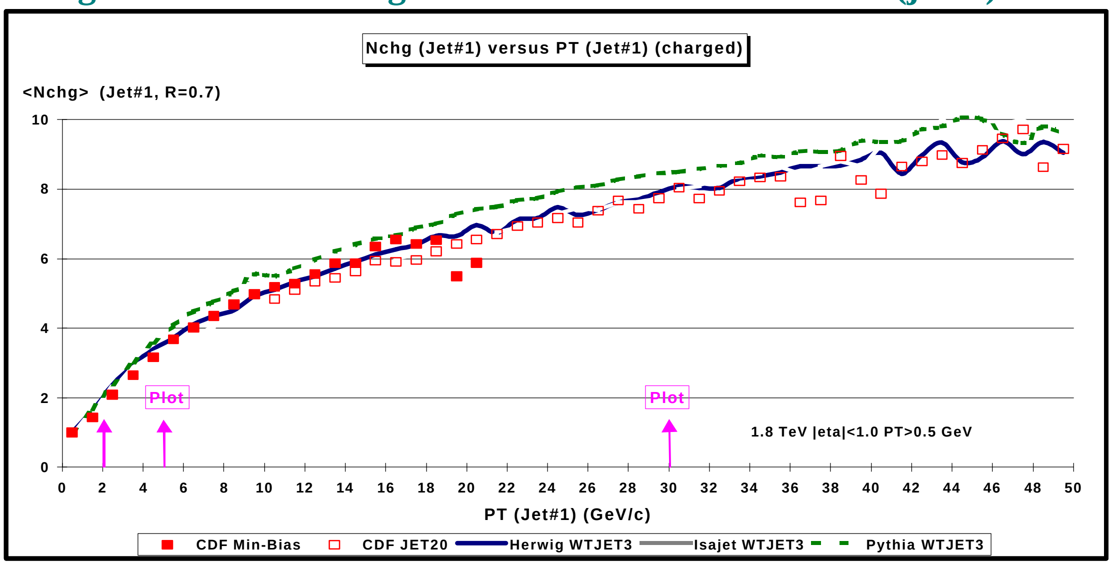
CDF Data Only

QCD-MC Predictions – <NchgJet#1> vs PT(jet#1)

"Jet" = Circular Region

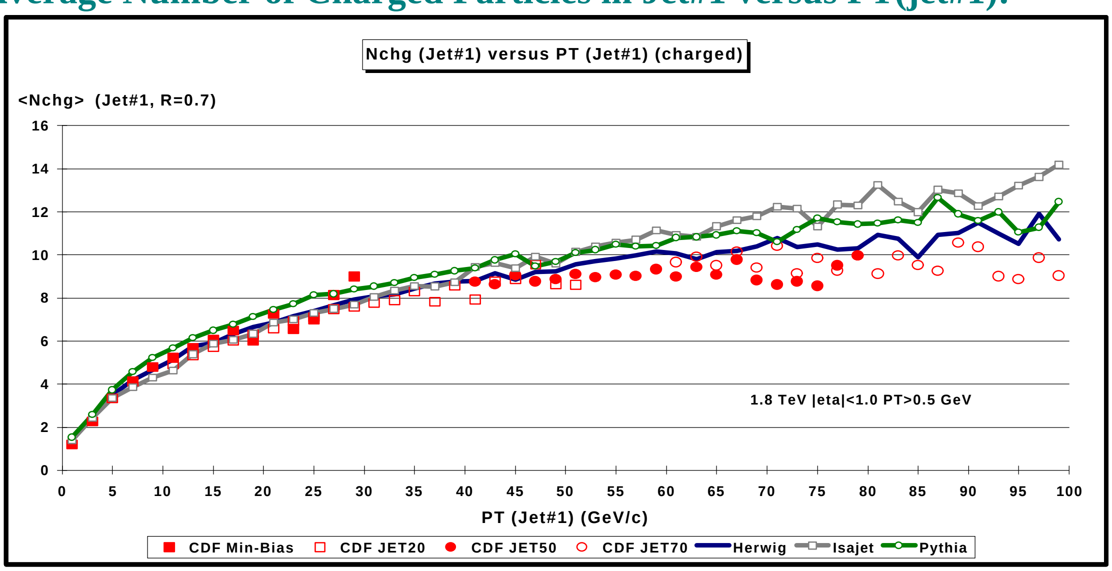


Average Number of Charged Particles in Jet#1 versus PT(jet#1):



CDF Data plus QCD Monte-Carlo Predictions

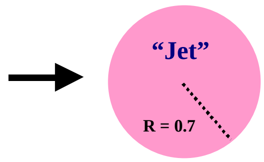
Average Number of Charged Particles in Jet#1 versus PT(jet#1):



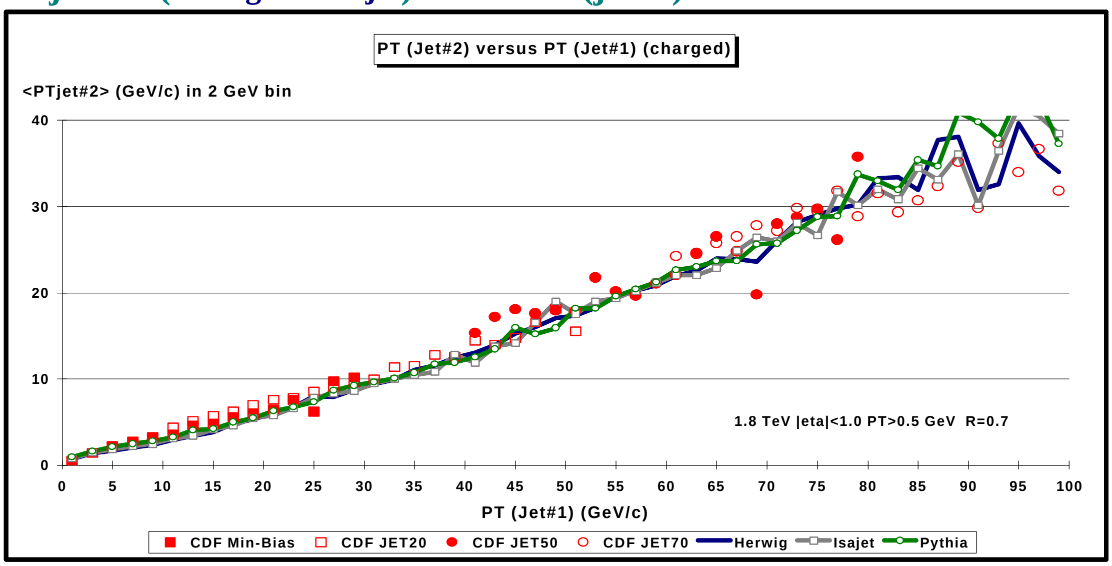
CDF Data plus QCD Monte-Carlo Predictions

QCD-MC Predictions – <PTjet#2> & <PTjet#3> versus PT(jet#1)

"Jet" = Circular Region

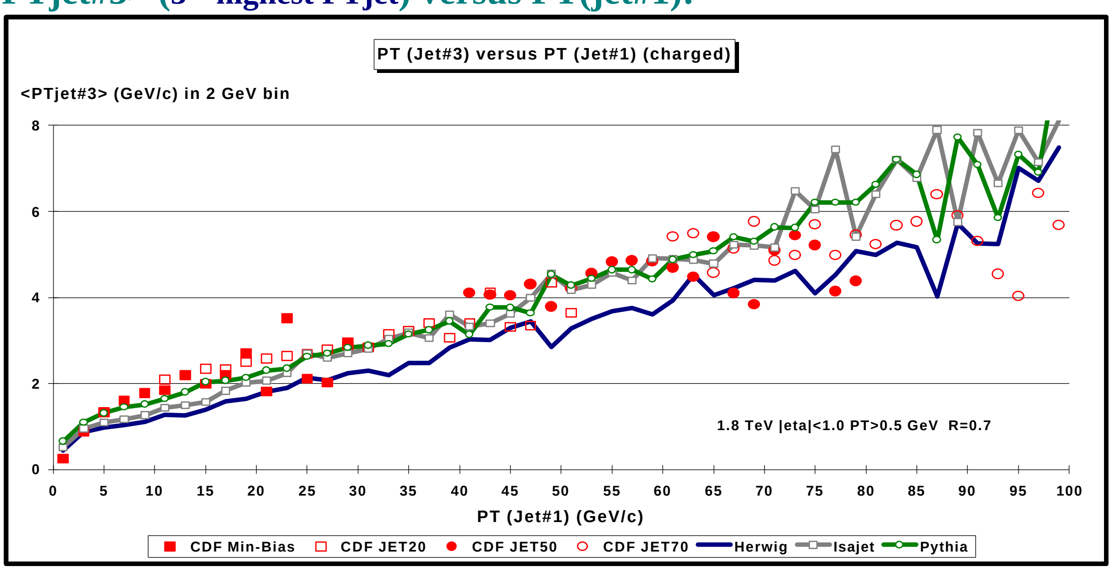


<PTjet#2> (2nd highest PTjet) versus PT(jet#1):



CDF Data plus QCD Monte-Carlo Predictions

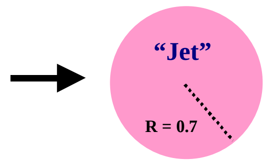
<PTjet#3> (3rd highest PTjet) versus PT(jet#1):



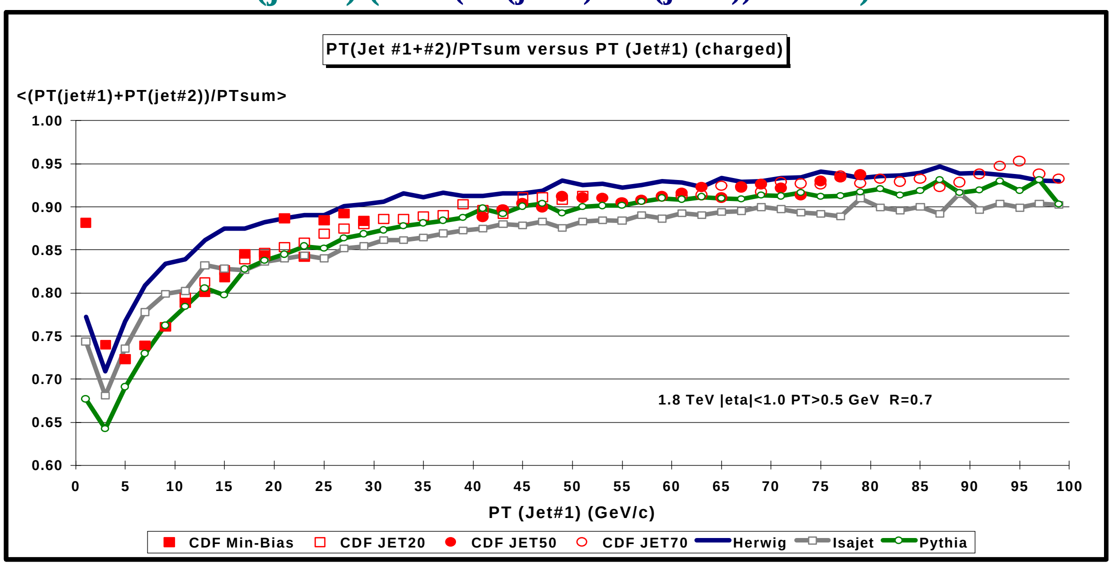
CDF Data plus QCD Monte-Carlo Predictions

QCD-MC Predictions – <R12> & <RJ21> versus PT(jet#1)

"Jet" = Circular Region

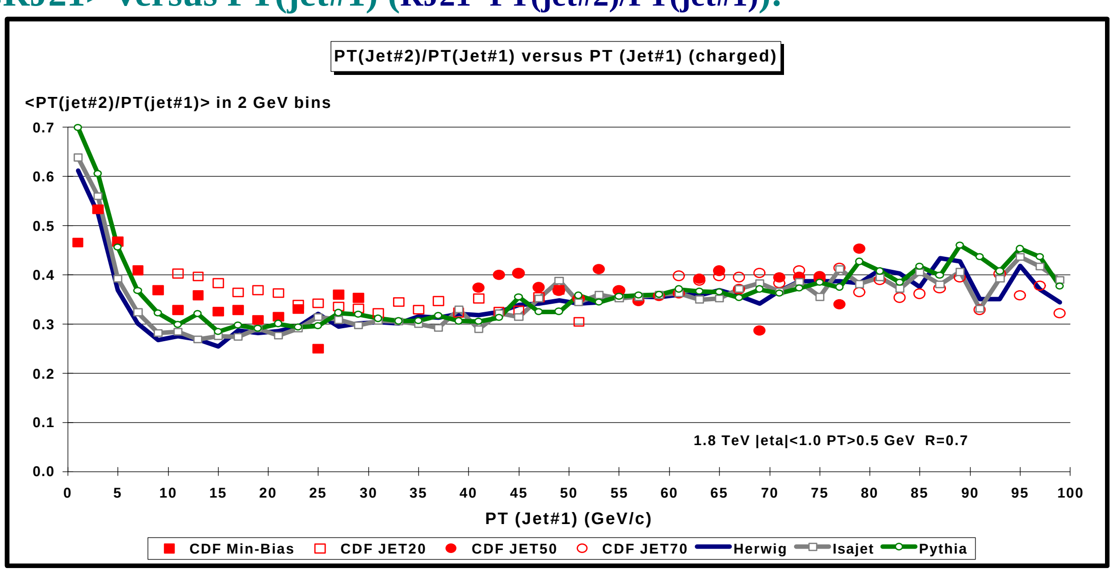


<R12> versus PT(jet#1) (R12=(PT(jet#1)+PT(jet#2))/PTsum):



CDF Data plus QCD Monte-Carlo Predictions

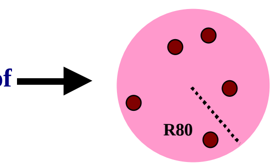
<RJ21> versus PT(jet#1) (RJ21=PT(jet#2)/PT(jet#1)):



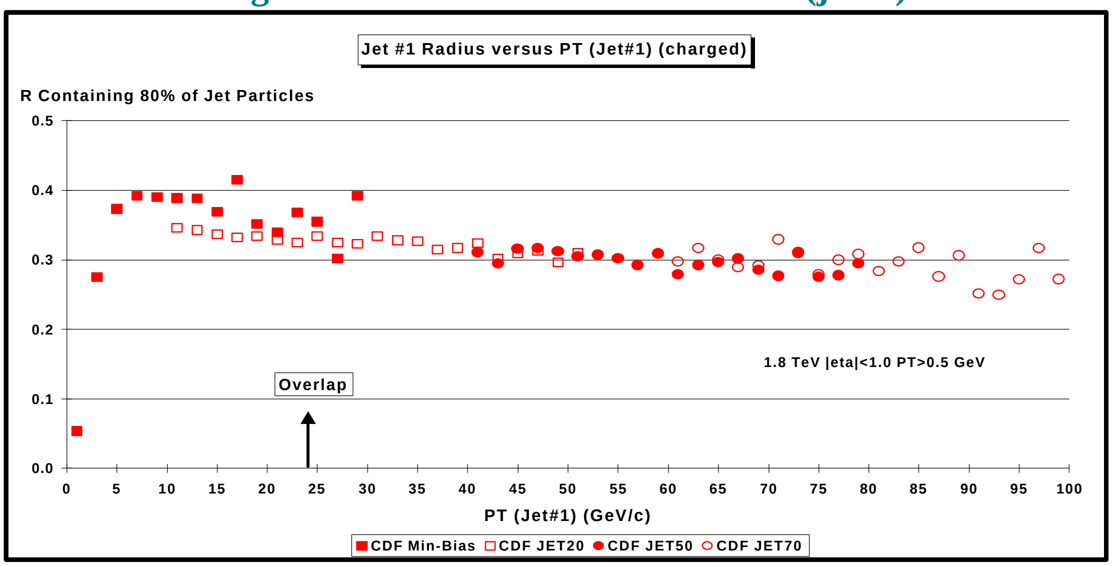
CDF Data plus QCD Monte-Carlo Predictions

MB Jets – "Jet Size" versus PT(jet#1)

Radius containing 80% of Jet Particles

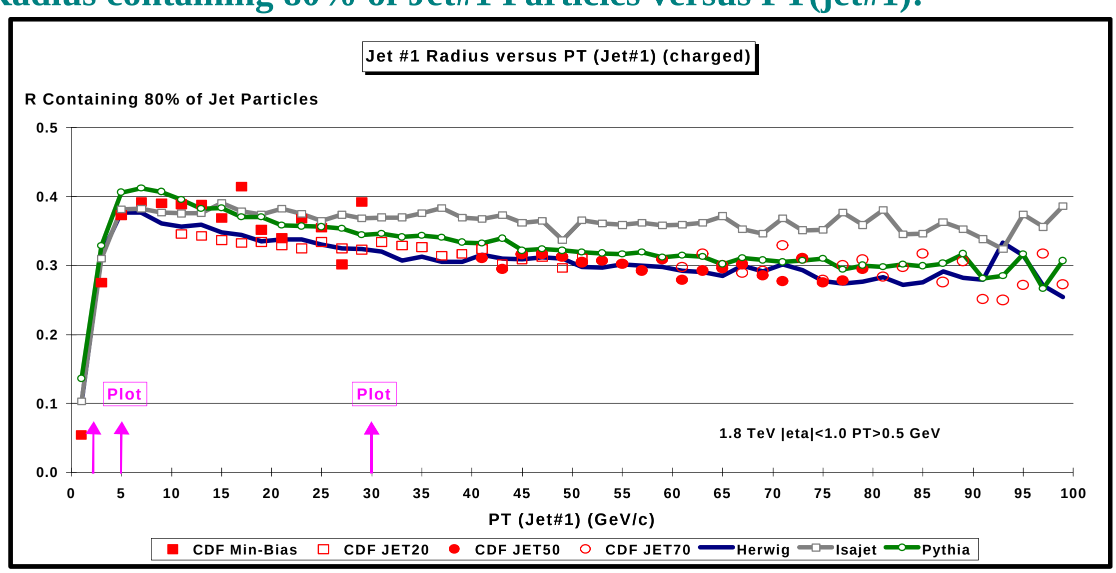


Radius containing 80% of Jet#1 Particles versus PT(jet#1):



CDF Data only.

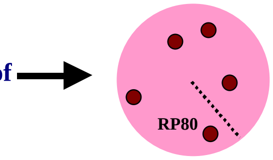
Radius containing 80% of Jet#1 Particles versus PT(jet#1):



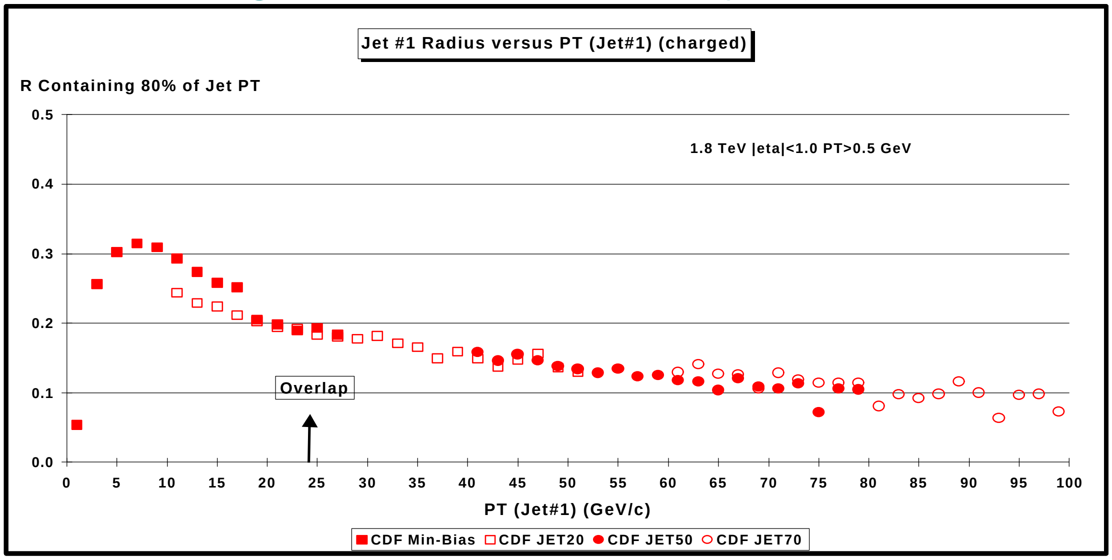
CDF Data plus QCD Monte-Carlo Predictions.

MB Jets – "Jet Size" versus PT(jet#1)

Radius containing 80% of Jet PT

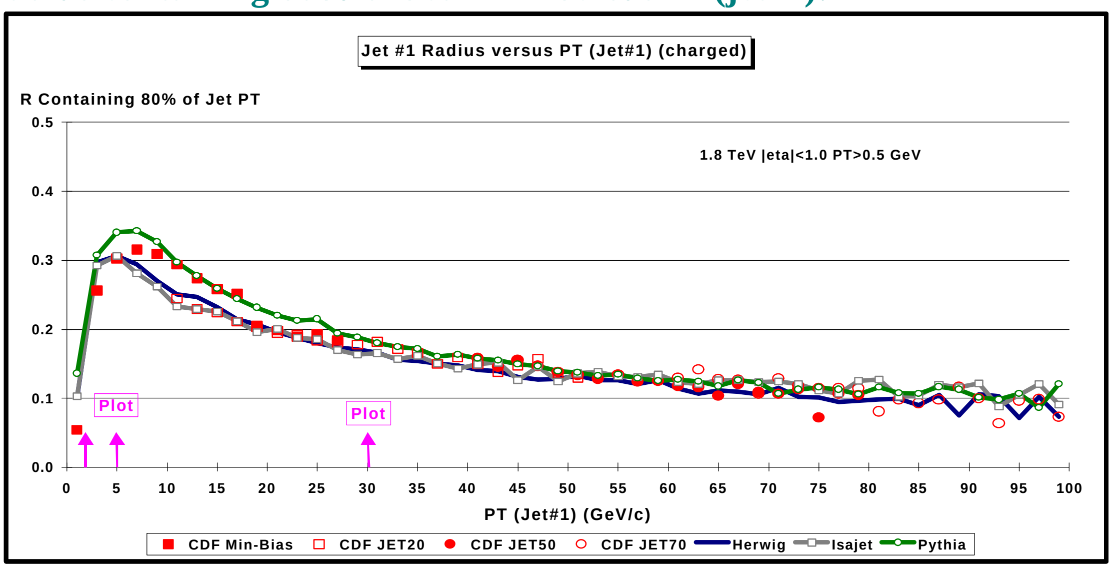


Radius containing 80% of Jet#1 PT versus PT(jet#1):



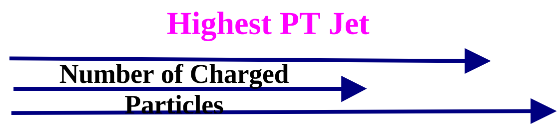
CDF Data only.

Radius containing 80% of Jet#1 PT versus PT(jet#1):

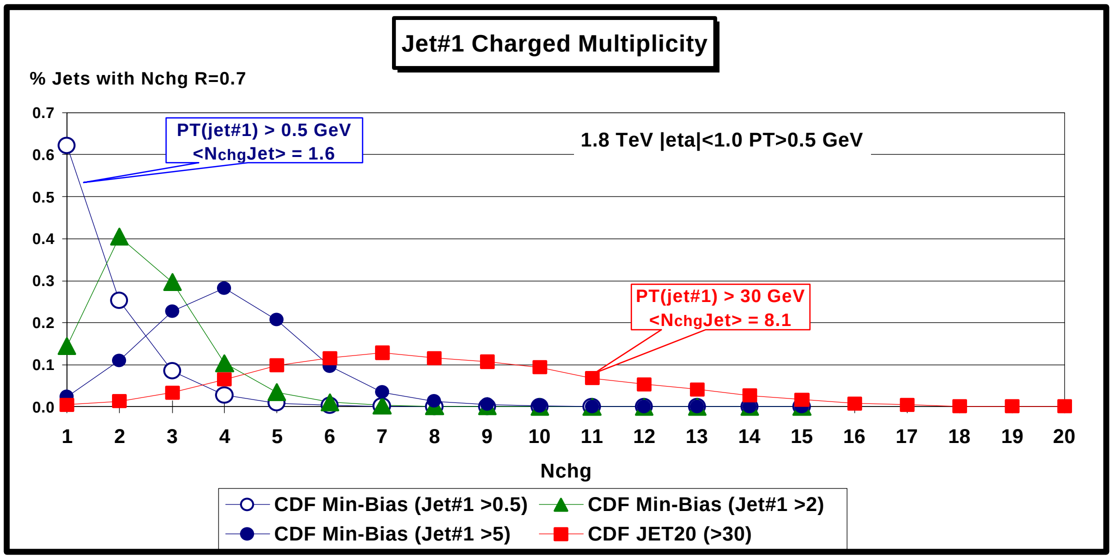


CDF Data plus QCD Monte-Carlo Predictions.

Jet Evolution – Jet#1 Charged Multiplicity

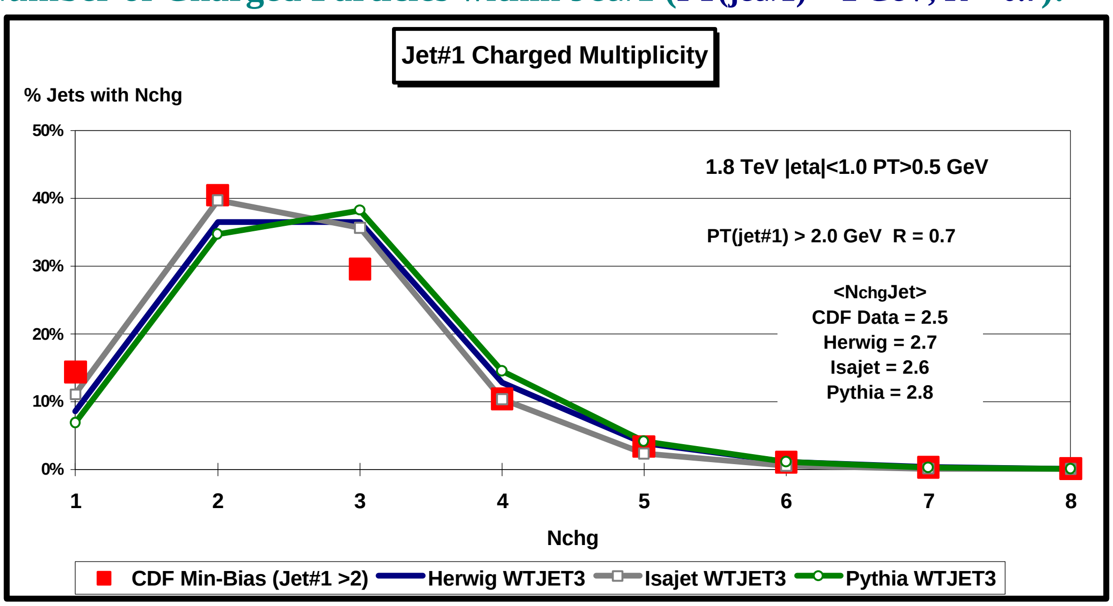


Number of Charged Particles within Jet#1 (R = 0.7):

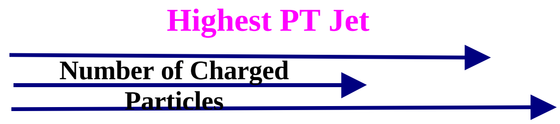


CDF Data

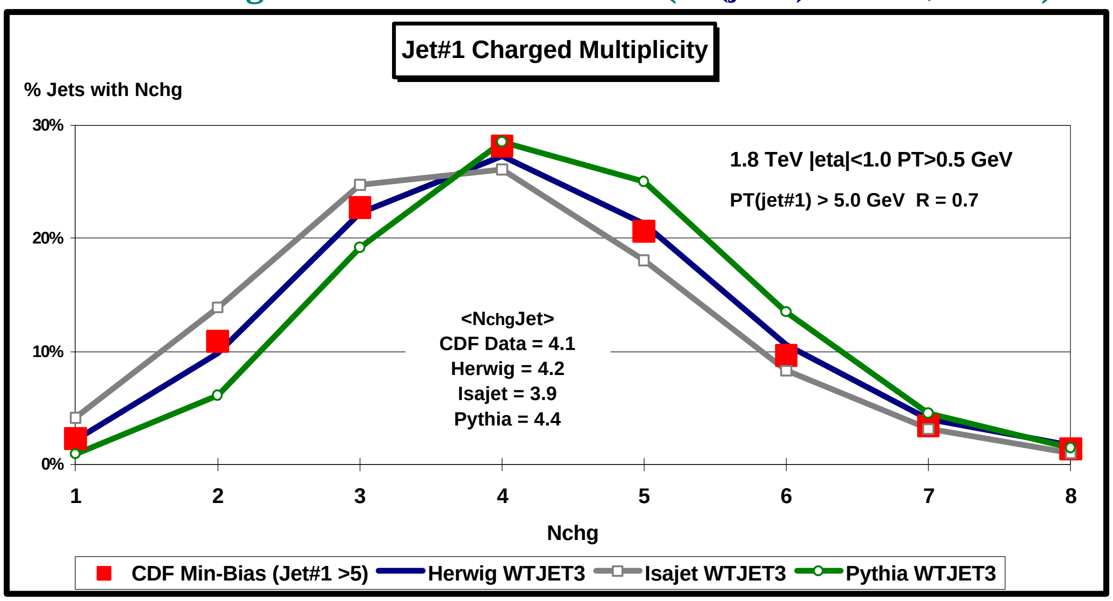
Number of Charged Particles within Jet#1 (PT(jet#1) > 2 GeV, R = 0.7):



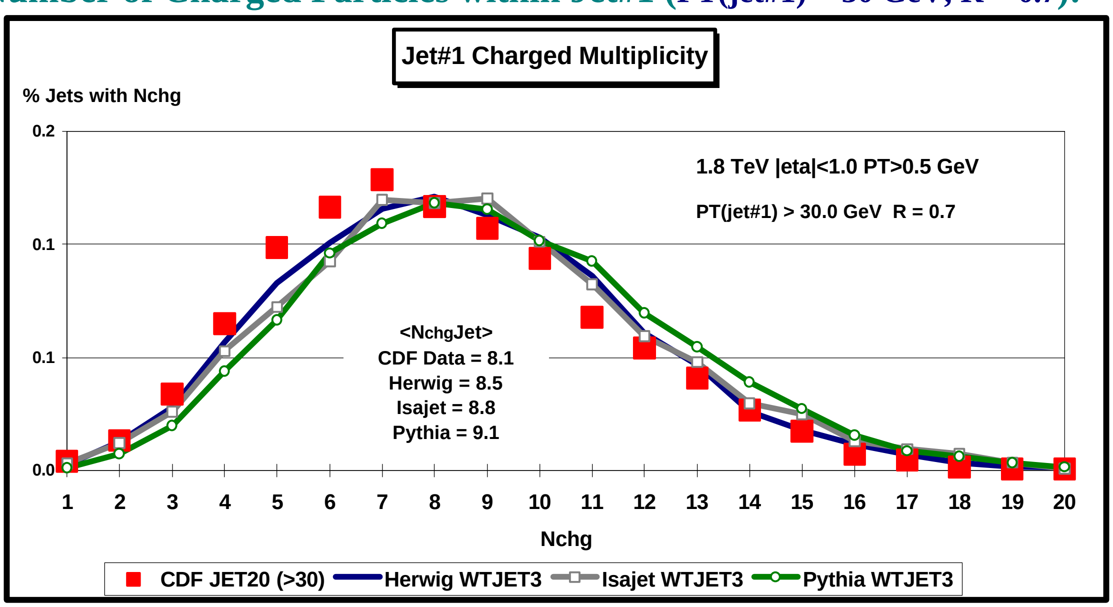
Jet Evolution – Jet#1 Charged Multiplicity



Number of Charged Particles within Jet#1 (PT(jet#1) > 5 GeV, R = 0.7):



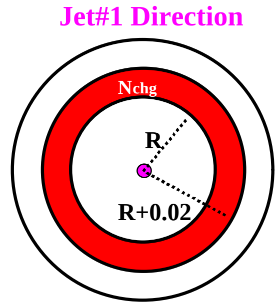
Number of Charged Particles within Jet#1 (PT(jet#1) > 30 GeV, R = 0.7):



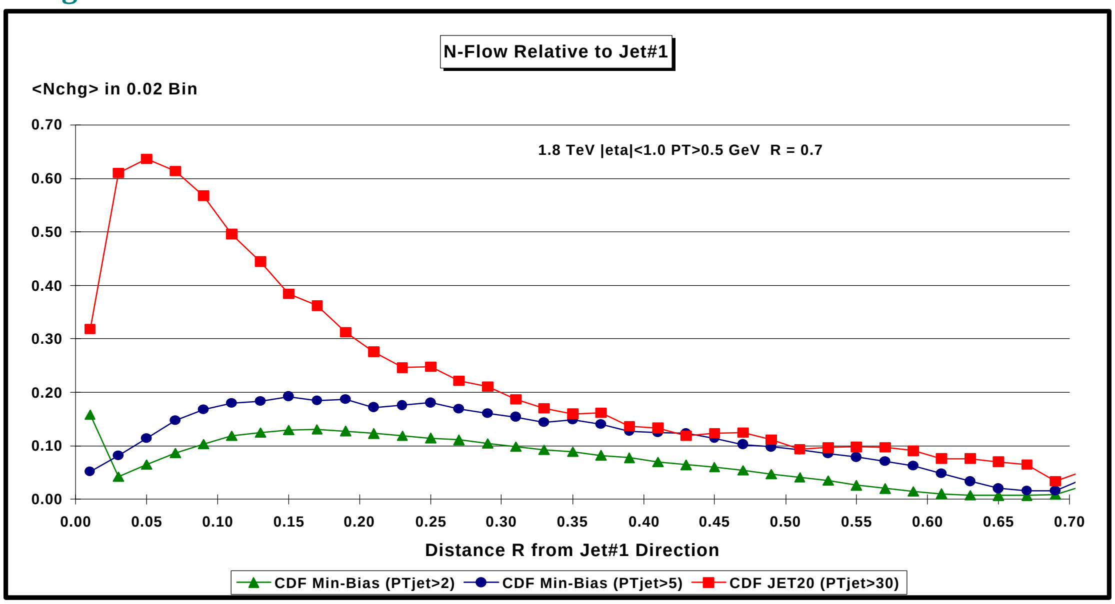
Jet Evolution – Jet#1 Radial N-Flow

Look at the distribution of charged particles around the direction of Jet#1 where

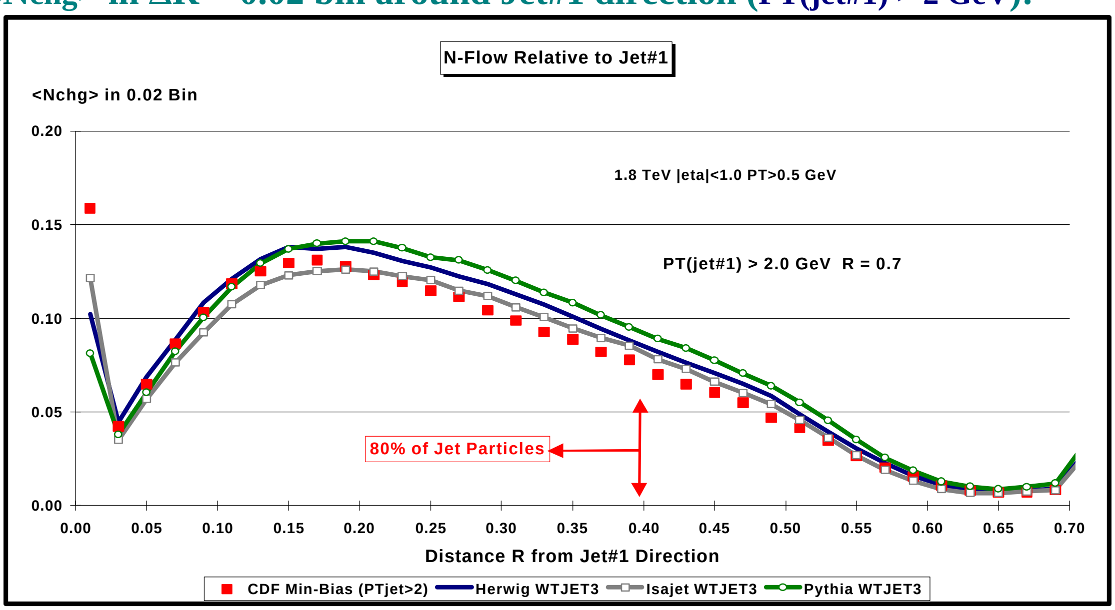
$$R_i = \sqrt{(h_i - h_{jet})^2 + (f_i - f_{jet})^2}$$



<Nchg> in ΔR = 0.02 bin around Jet#1 direction:



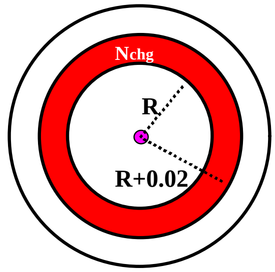
<Nchg> in ΔR = 0.02 bin around Jet#1 direction (PT(jet#1) > 2 GeV):



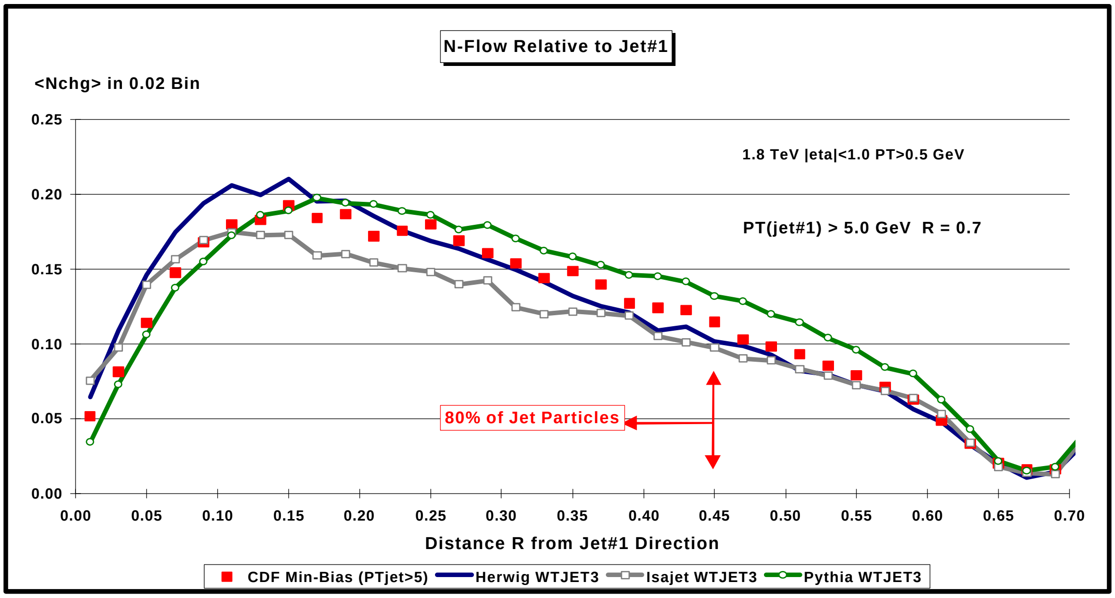
Jet Evolution – Jet#1 Radial N-Flow

Look at the distribution of charged particles around the direction of Jet#1 where

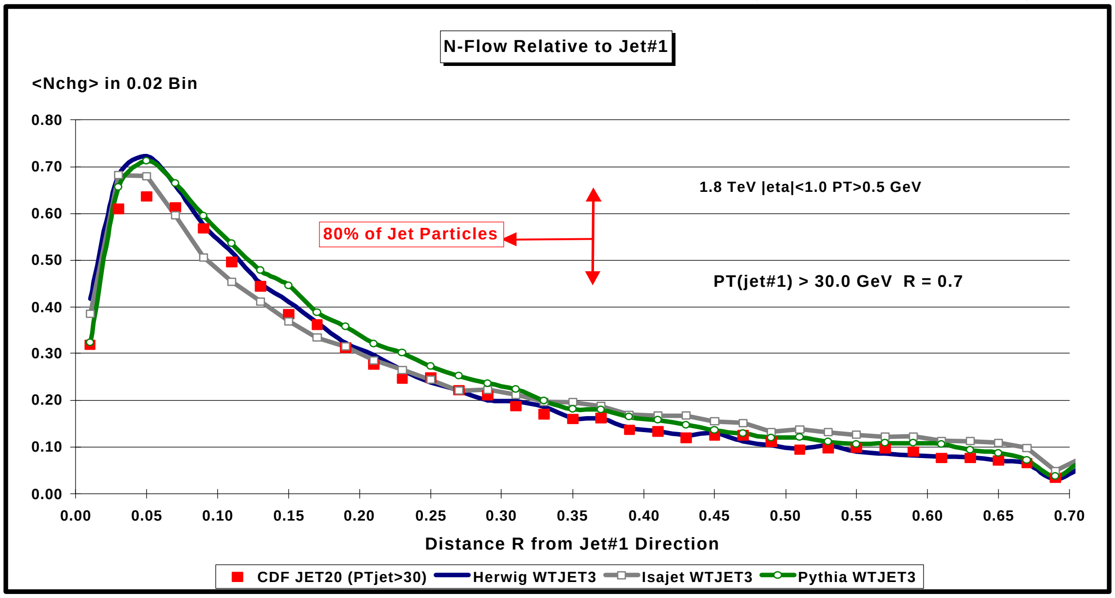
$$R_i = \sqrt{(\eta_i - \eta_{jet})^2 + (\phi_i - \phi_{jet})^2}$$



<Nchg> in ΔR = 0.02 bin around Jet#1 direction (PT(jet#1) > 5 GeV):



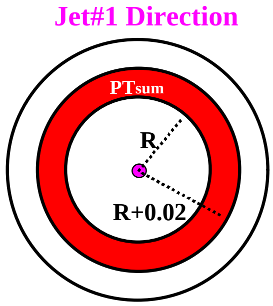
<Nchg> in ΔR = 0.02 bin around Jet#1 direction (PT(jet#1) > 30 GeV):



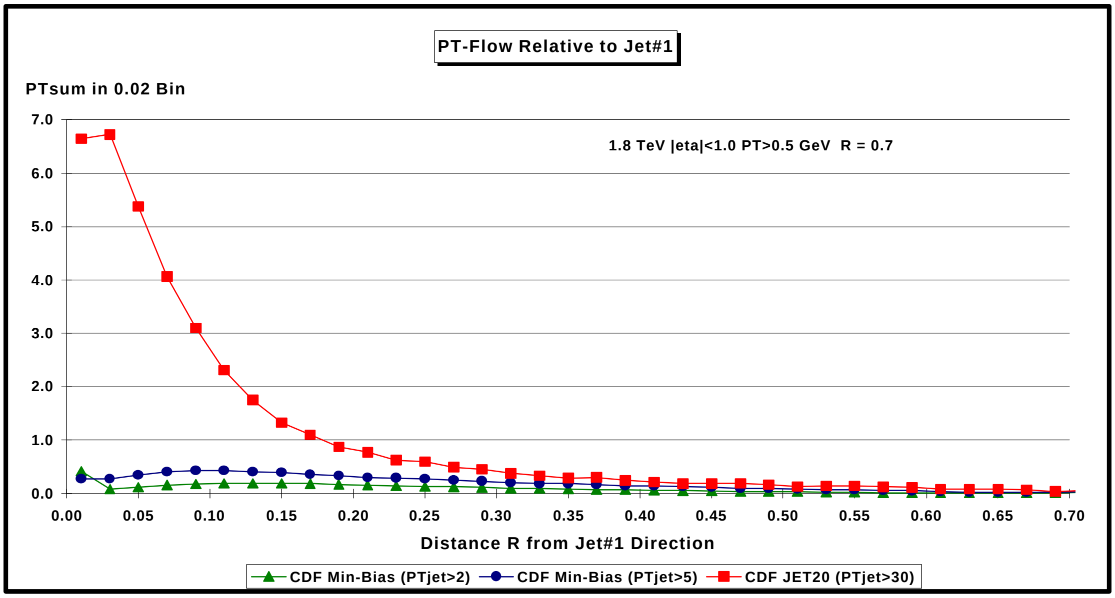
Jet Evolution – Jet#1 Radial PT-Flow

Look at the distribution of charged particle transverse momentum around the direction of Jet#1 where

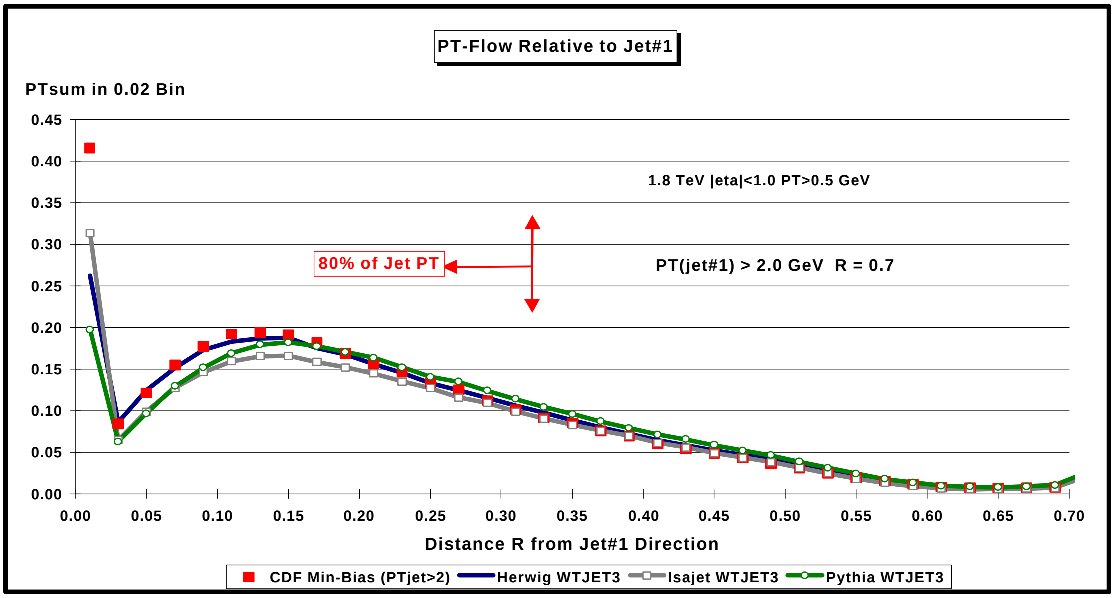
$$R_i = \sqrt{(\eta_i - \eta_{jet})^2 + (\phi_i - \phi_{jet})^2}$$



<PTsum> in ΔR = 0.02 bin around Jet#1 direction:



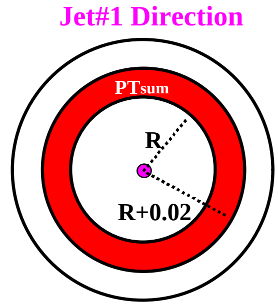
<PTsum> in ΔR = 0.02 bin around Jet#1 direction (PT(jet#1) > 2 GeV):



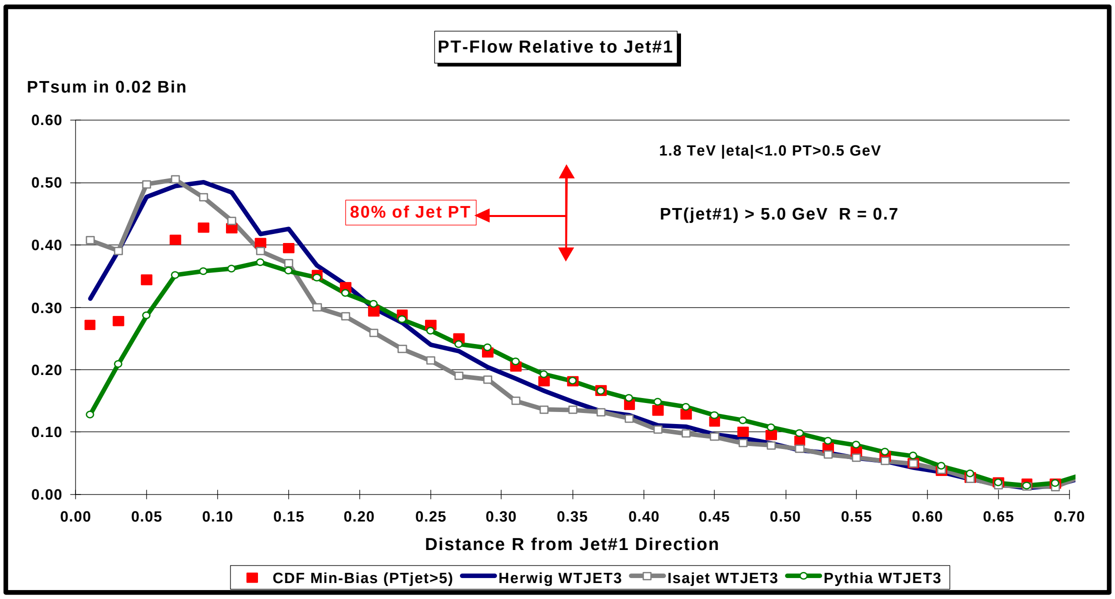
Jet Evolution – Jet#1 Radial PT-Flow

Look at the distribution of charged particle transverse momentum around the direction of Jet#1 where

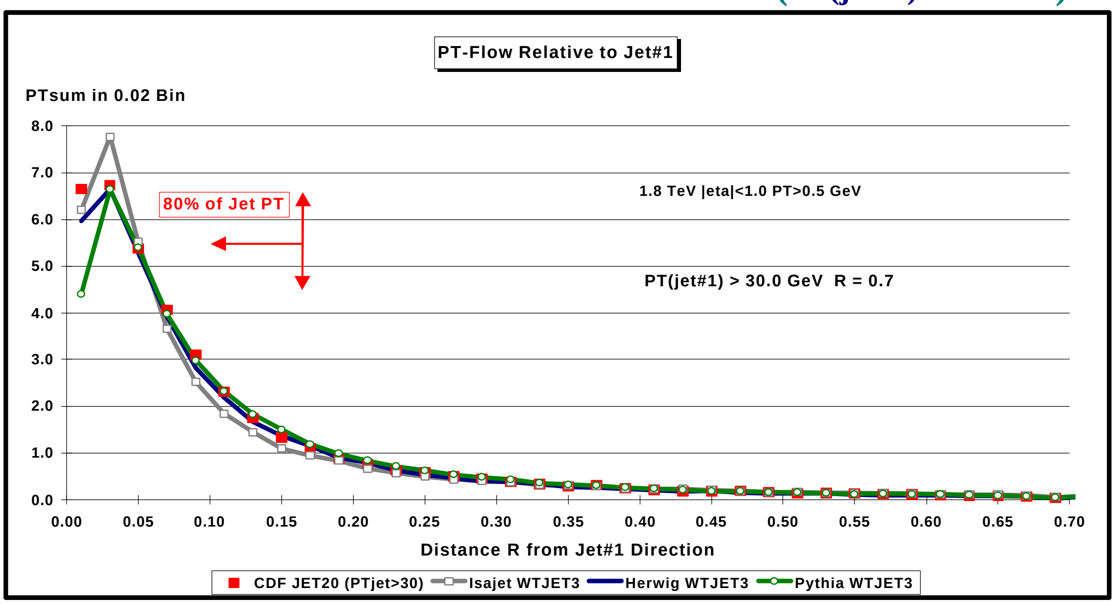
$$R_i = \sqrt{(\eta_i - \eta_{jet})^2 + (\phi_i - \phi_{jet})^2}$$



<PTsum> in ΔR = 0.02 bin around Jet#1 direction (PT(jet#1) > 5 GeV):

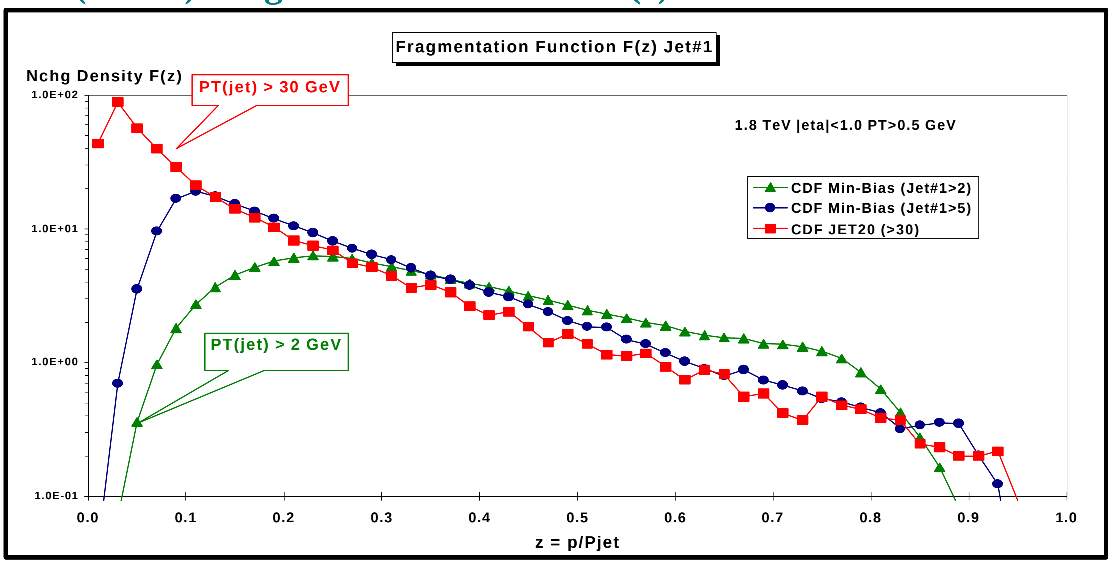


<PTsum> in ΔR = 0.02 bin around Jet#1 direction (PT(jet#1) > 30 GeV):



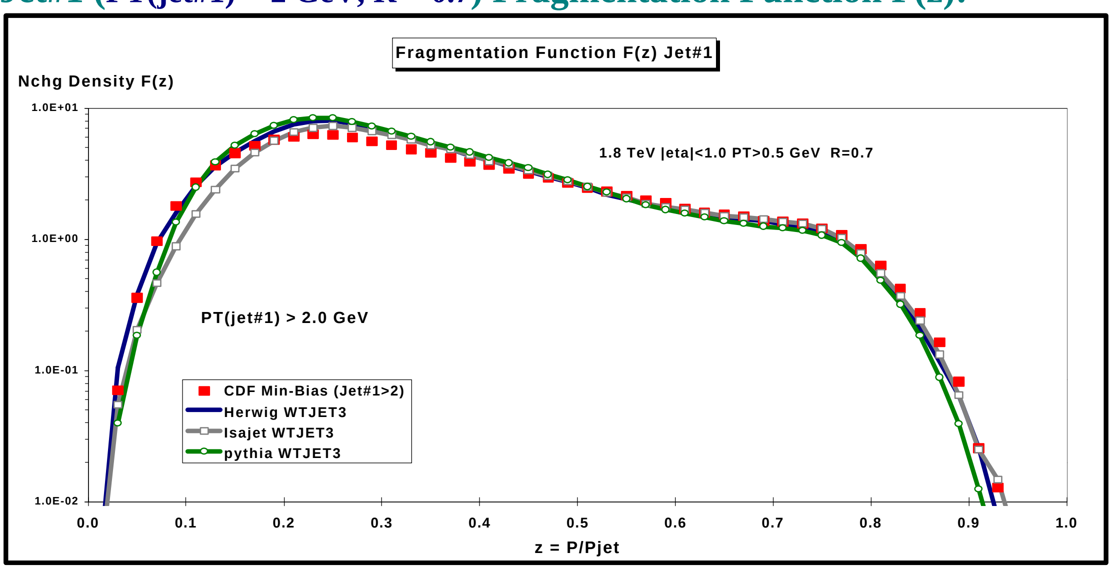
Jet Evolution – Jet#1 Fragmentation Function

Jet#1 (R = 0.7) Fragmentation Function F(z):



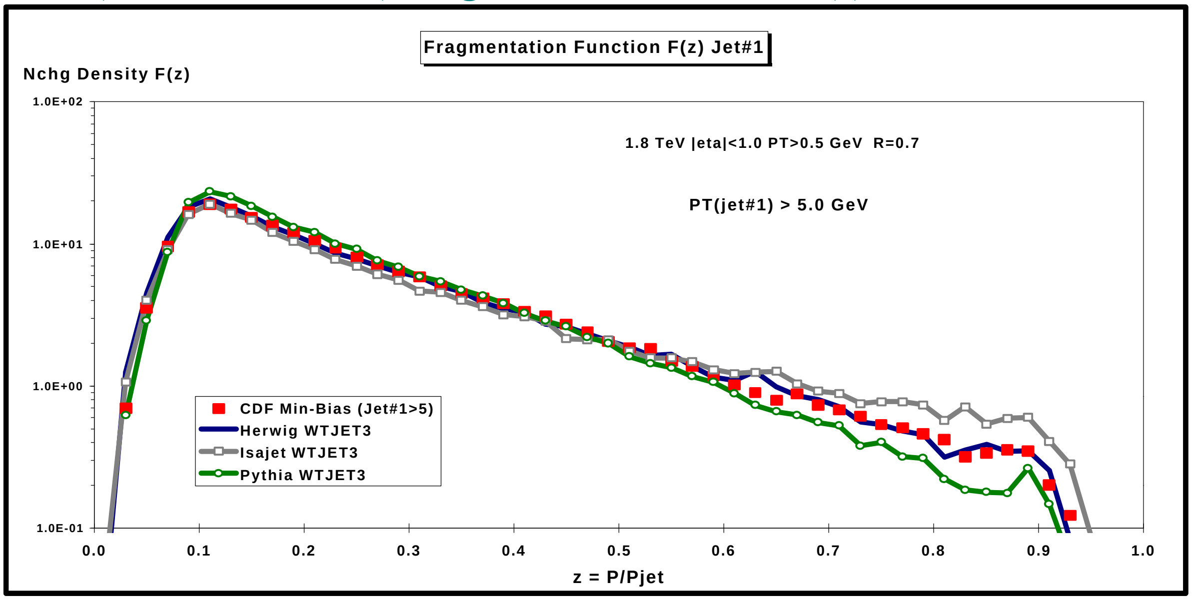
CDF Data

Jet#1 (PT(jet#1) > 2 GeV, R = 0.7) Fragmentation Function F(z):



Jet Evolution – Jet#1 Fragmentation Function

Jet#1 (PT > 5 GeV, R = 0.7) Fragmentation Function F(z):



Jet#1 (PT > 30 GeV, R = 0.7) Fragmentation Function F(z):