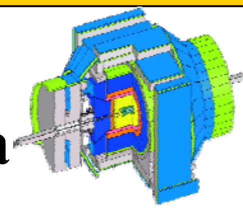
Studying the "Underlying Event" at CDF

"Leading Jet" vs Z-Boson

Quantum Chromo-Dynamics

Rick Field

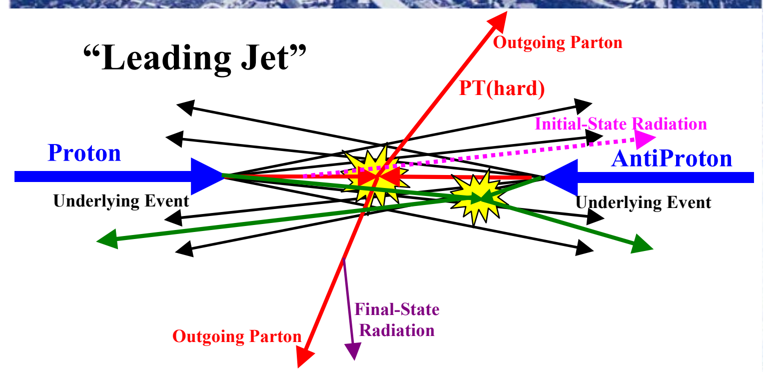
University of Florida

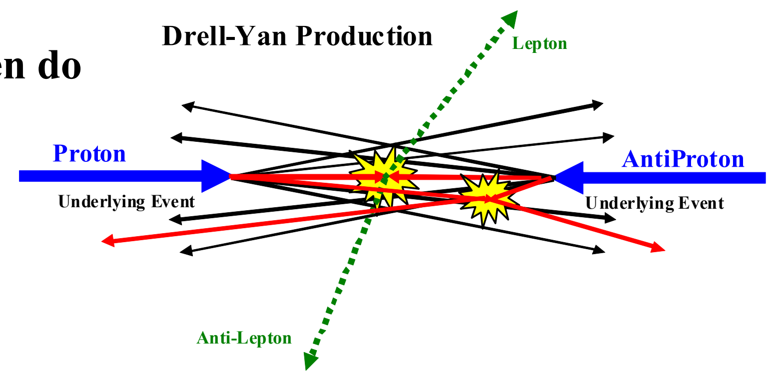


CDF Run 2

Outline of Talk

- The "Towards", "Away", and "Transverse" regions of η-ϕ space.
- Four Jet Topologies.
- The "transMAX" and "transMIN" regions.
- The "underlying event" in Drell-Yan production.
- The observables: First look at average quantities. Then do distributions.
- Look at $<p_T>$ versus Nchg in "min-bias" and Drell-Yan.
- Show some extrapolations of Drell-Yan to the LHC.





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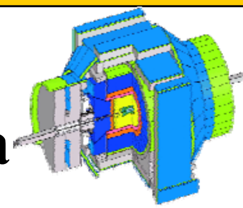

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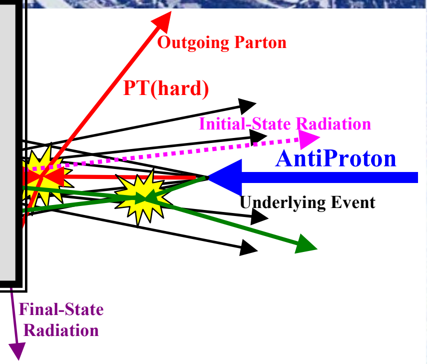
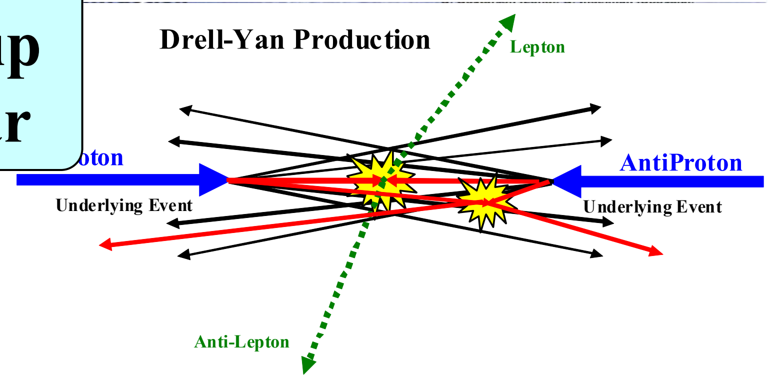
- Look at $\langle p_T \rangle$ versus Nchg in "min-...as" and Drell-Yan.
- Show some extrapolations of Drell-Yan to the LHC.

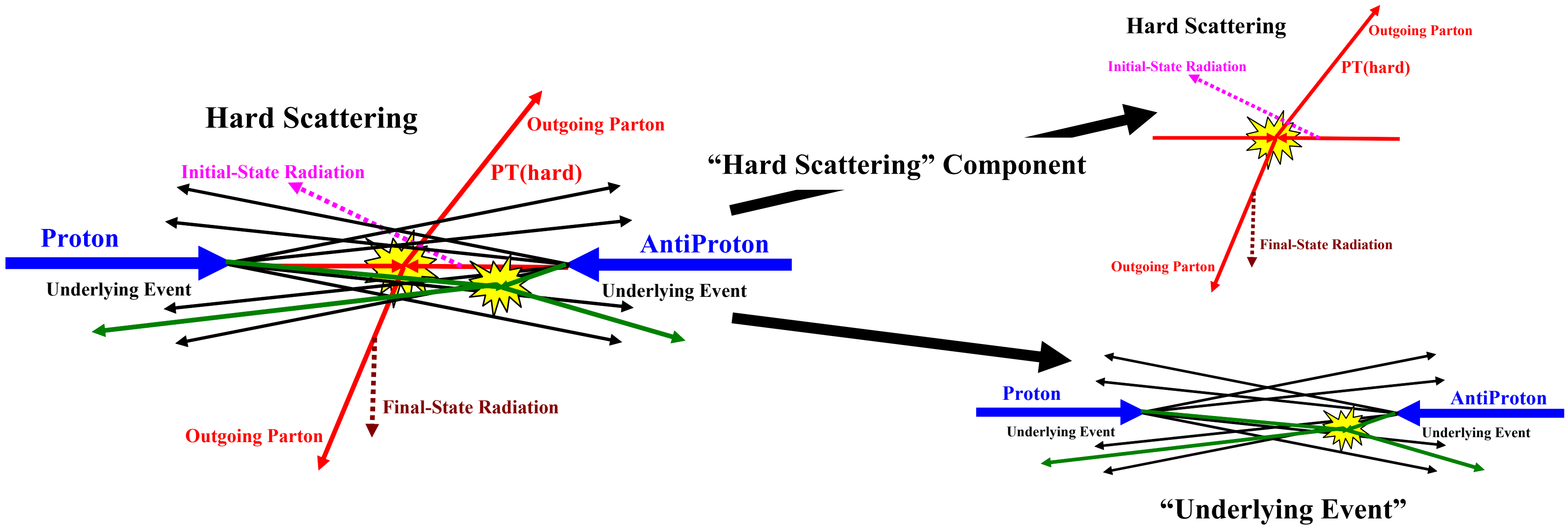
The goal is to produce data (corrected to the particle level) that can be used by the theorists to tune and improve the QCD Monte-Carlo models that are used to simulate hadron-hadron collisions.

Rick Field
Craig Group
Deepak Kar



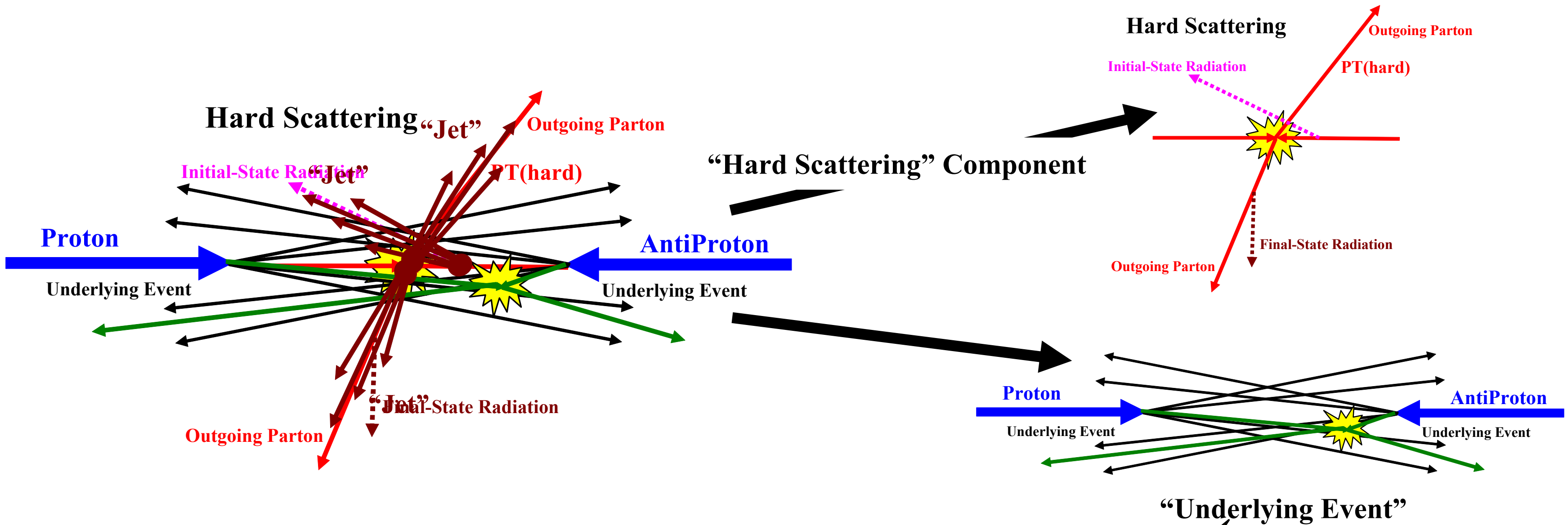


QCD Monte-Carlo Models: High Transverse Momentum Jets



- **Start with the perturbative 2-to-2 (or sometimes 2-to-3) parton-parton scattering and add initial and final-state gluon radiation (in the leading log approximation or modified leading log approximation).**
- **The "underlying event" consists of the "beam-beam remnants" and from particles arising from soft or semi-soft multiple parton interactions (MPI).**
- **Of course the outgoing colored partons fragment into hadron "jet" and inevitably "underlying event" observables receive contributions from initial and final-state radiation.**

QCD Monte-Carlo Models: High Transverse Momentum Jets



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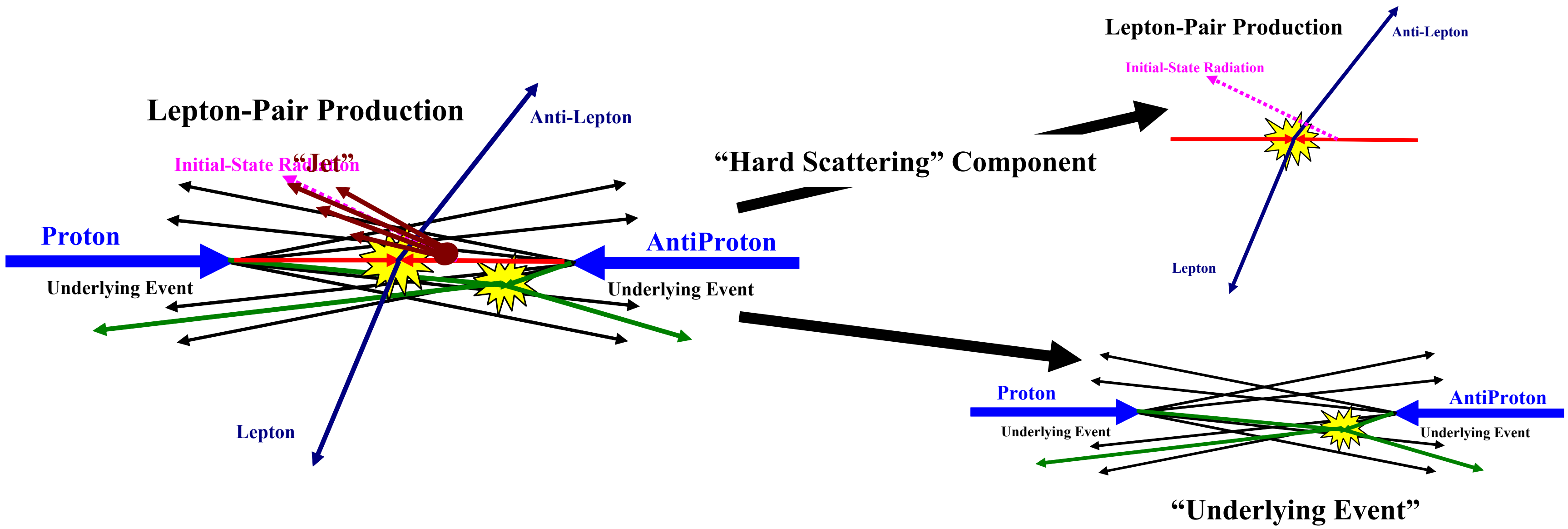
The "underlying event" is an unavoidable background to most collider observables and having good understand of it leads to more precise collider measurements!

QCD Monte-Carlo Models: Lepton-Pair Production



- **Start with the perturbative Drell-Yan muon pair production and add initial-state gluon radiation (in the leading log approximation or modified leading log approximation).**

- **The "underlying event" consists of the "beam-beam remnants" and from particles arising from soft or semi-soft multiple parton interactions (MPI).**

- **Of course the outgoing colored partons fragment into hadron "jet" and inevitably "underlying event" observables receive contributions from initial and final-state radiation.**

“Towards”, “Away”, “Transve

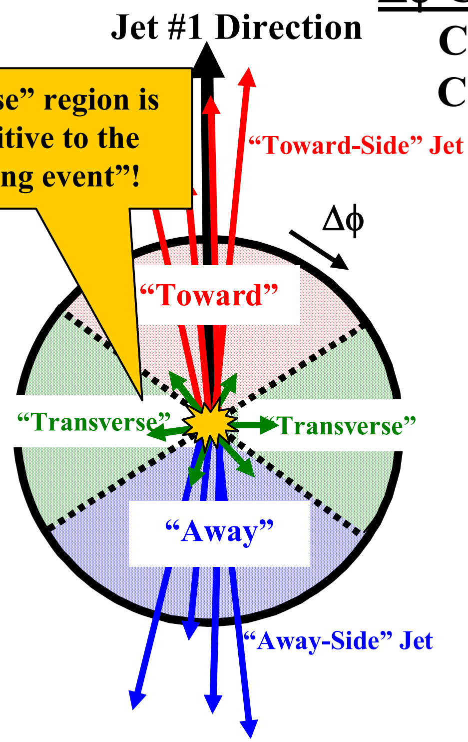
Look at the charged particle density, the charged PTsum density and the ETsum density in all 3 regions!

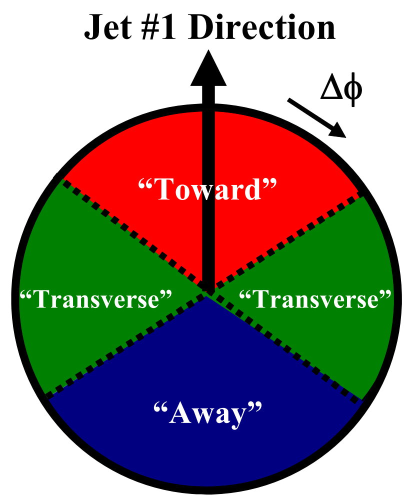
$\Delta\phi$ Correlations relative to the leading jet

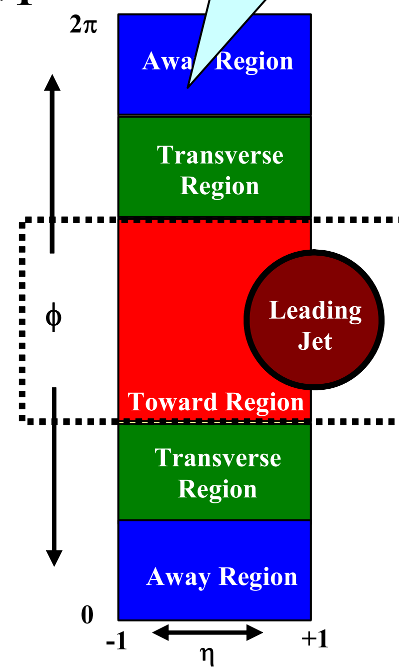
Charged particles $p_T > 0.5$ GeV/c $|\eta| < 1$

Calorimeter towers $E_T > 0.1$ GeV $|\eta| < 1$

“Transverse” region is very sensitive to the “underlying event”!







- Look at correlations in the azimuthal angle $\Delta\phi$ relative to the leading charged particle jet ($|\eta| < 1$) or the leading calorimeter jet ($|\eta| < 2$).
- Define $|\Delta\phi| < 60^o$ as “Toward”, $60^o < |\Delta\phi| < 120^o$ as “Transverse ”, and $|\Delta\phi| > 120^o$ as “Away”. Each of the three regions have area $\Delta\eta\Delta\phi = 2\times120^o = 4\pi/3$.

“Towards”, “Away”, “Transve

Look at the charged particle density, the charged PTsum density and the ETsum density in all 3 regions!

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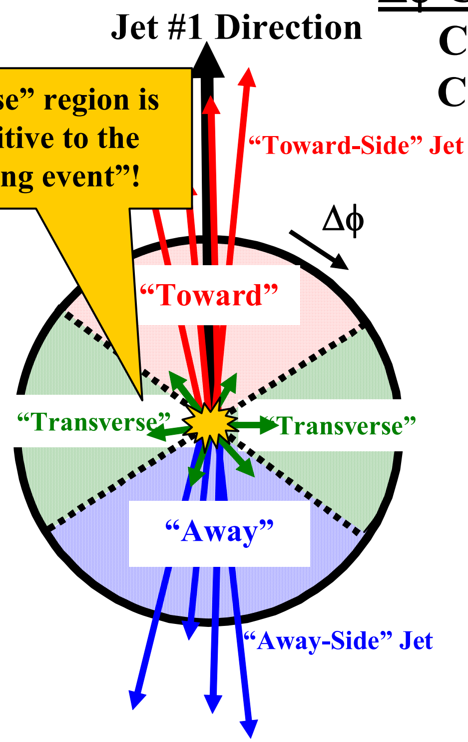

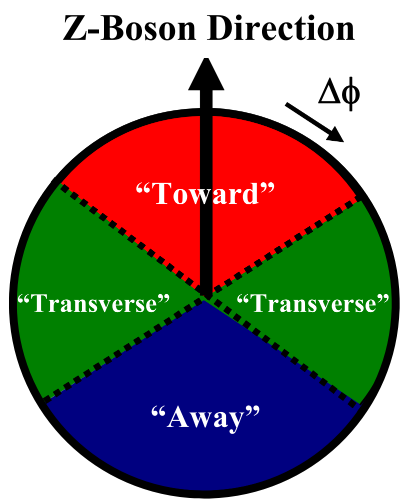

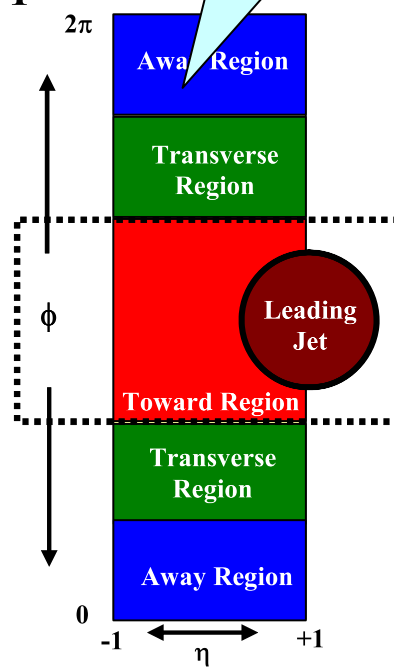

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Event Topologies

- **“Leading Jet”** events correspond to the leading calorimeter jet (MidPoint R = 0.7) in the region $|\eta| < 2$ with no other conditions.
- **“Inclusive 2-Jet Back-to-Back”** events are selected to have at least two jets with Jet#1 and Jet#2 nearly “back-to-back” ($\Delta\phi_{12} > 150^o$) with almost equal transverse energies (P_T(jet#2)/P_T(jet#1) > 0.8) with no other conditions .
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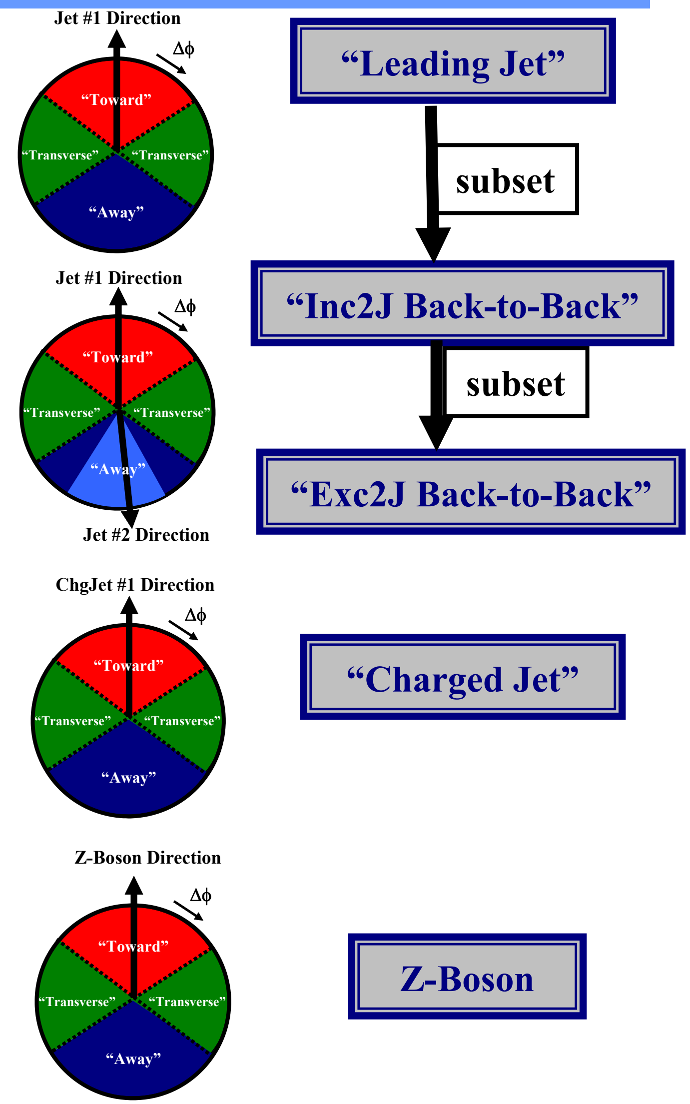
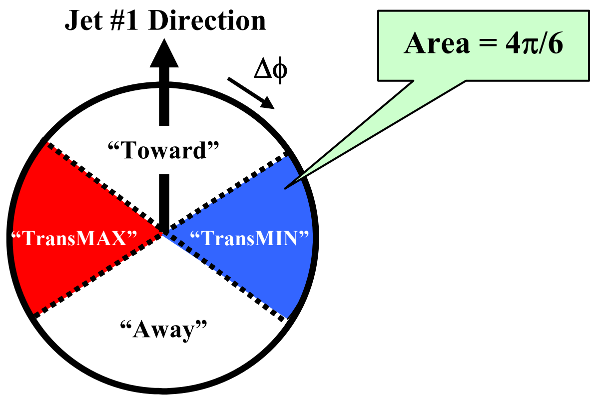
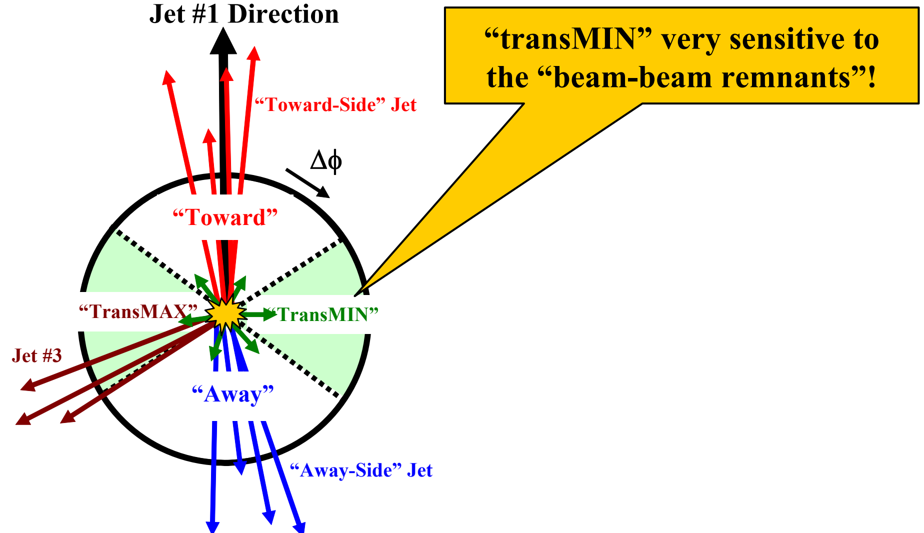
- **“Leading ChgJet”** events correspond to the leading charged particle jet (R = 0.7) in the region $|\eta| < 1$ with no other conditions.
- **“Z-Boson”** events are Drell-Yan events with 70 < M(lepton-pair) < 110 GeV with no other conditions.



"transMAX" & "transMIN"

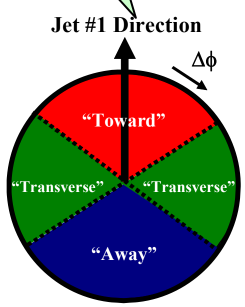


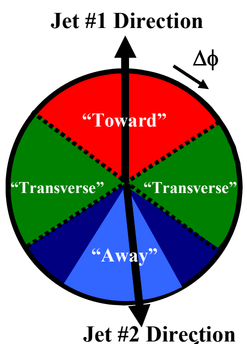


- Define the MAX and MIN "transverse" regions ("transMAX" and "transMIN") on an event-by-event basis with MAX (MIN) having the largest (smallest) density. Each of the two "transverse" regions have an area in η-ϕ space of 4π/6.
- The "transMIN" region is very sensitive to the "beam-beam remnant" and the soft multiple parton interaction components of the "underlying event".
- The difference, "transDIF" ("transMAX" minus "transMIN"), is very sensitive to the "hard scattering" component of the "underlying event" (*i.e.* hard initial and final-state radiation).
- The overall "transverse" density is the average of the "transMAX" and "transMIN" densities.

"Leading Jet" Observables at the Particle and Detector Level

"Leading Jet"





"Back-to-Back"

Observable	Particle Level	Detector Level
dNchg/dηdϕ	Number of charged particles per unit η-ϕ ($p_T > 0.5$ GeV/c, $\lvert\eta\rvert < 1$)	Number of "good" charged tracks per unit η-ϕ ($p_T > 0.5$ GeV/c, $\lvert\eta\rvert < 1$)
dPTsum/dηdϕ	Scalar p_T sum of charged particles per unit η-ϕ ($p_T > 0.5$ GeV/c, $\lvert\eta\rvert < 1$)	Scalar p_T sum of "good" charged tracks per unit η-ϕ ($p_T > 0.5$ GeV/c, $\lvert\eta\rvert < 1$)
$\langle p_T \rangle$	Average p_T of charged particles ($p_T > 0.5$ GeV/c, $\lvert\eta\rvert < 1$)	Average p_T of "good" charged tracks ($p_T > 0.5$ GeV/c, $\lvert\eta\rvert < 1$)
PTmax	Maximum p_T charged particle ($p_T > 0.5$ GeV/c, $\lvert\eta\rvert < 1$) Require Nchg ≥ 1	Maximum p_T "good" charged tracks ($p_T > 0.5$ GeV/c, $\lvert\eta\rvert < 1$) Require Nchg ≥ 1
dETsum/dηdϕ	Scalar E_T sum of all particles per unit η-ϕ (all p_T, $\lvert\eta\rvert < 1$)	Scalar E_T sum of all calorimeter towers per unit η-ϕ ($E_T > 0.1$ GeV, $\lvert\eta\rvert < 1$)
PTsum/ETsum	Scalar p_T sum of charged particles ($p_T > 0.5$ GeV/c, $\lvert\eta\rvert < 1$) divided by the scalar E_T sum of all particles (all p_T, $\lvert\eta\rvert < 1$)	Scalar p_T sum of "good" charged tracks ($p_T > 0.5$ GeV/c, $\lvert\eta\rvert < 1$) divided by the scalar E_T sum of calorimeter towers ($E_T > 0.1$ GeV, $\lvert\eta\rvert < 1$)

Also include the leading jet mass (new)!

CDF Run 1 $P_T(Z)$

PYTHIA 6.2 CTEQ5L

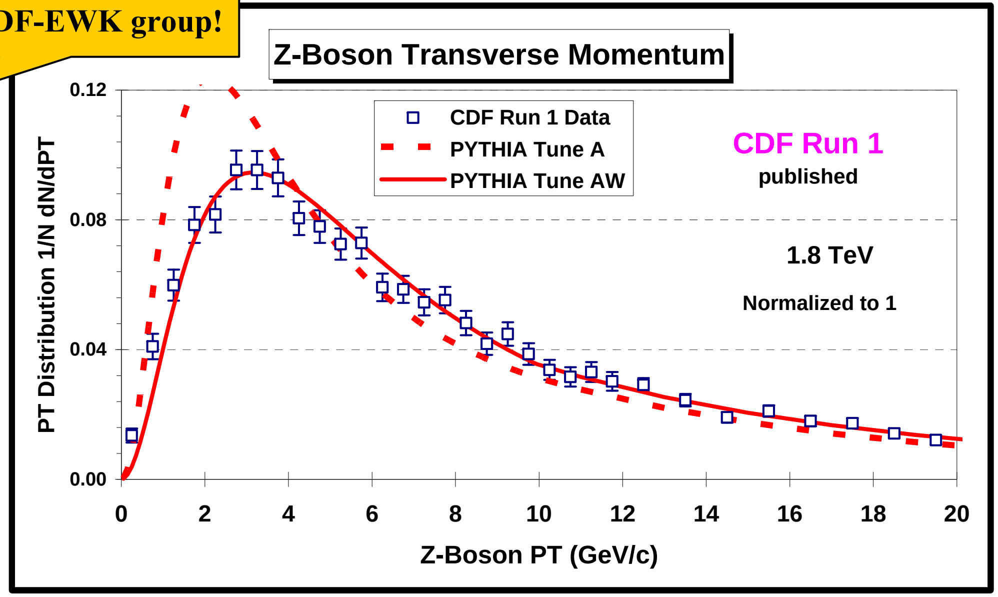
Tune used by the CDF-EWK group!

UE Parameters

ISR Parameters

Intrensic KT

Parameter	Tune A	Tune AW
MSTP(81)	1	1
MSTP(82)	4	4
PARP(82)	2.0 GeV	2.0 GeV
PARP(83)	0.5	0.5
PARP(84)	0.4	0.4
PARP(85)	0.9	0.9
PARP(86)	0.95	0.95
PARP(89)	1.8 TeV	1.8 TeV
PARP(90)	0.25	0.25
PARP(62)	1.0	1.25
PARP(64)	1.0	0.2
PARP(67)	4.0	4.0
MSTP(91)	1	1
PARP(91)	1.0	2.1
PARP(93)	5.0	15.0



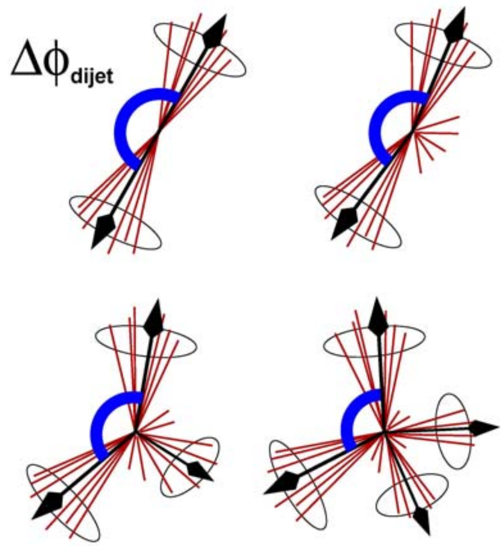
- Shows the Run 1 Z-boson p_T distribution ($<p_T(Z)> \approx 11.5$ GeV/c) compared with PYTHIA Tune A ($<p_T(Z)> = 9.7$ GeV/c), and PYTHIA Tune AW ($<p_T(Z)> = 11.7$ GeV/c).

Effective Q cut-off, below which space-like showers are not evolved.

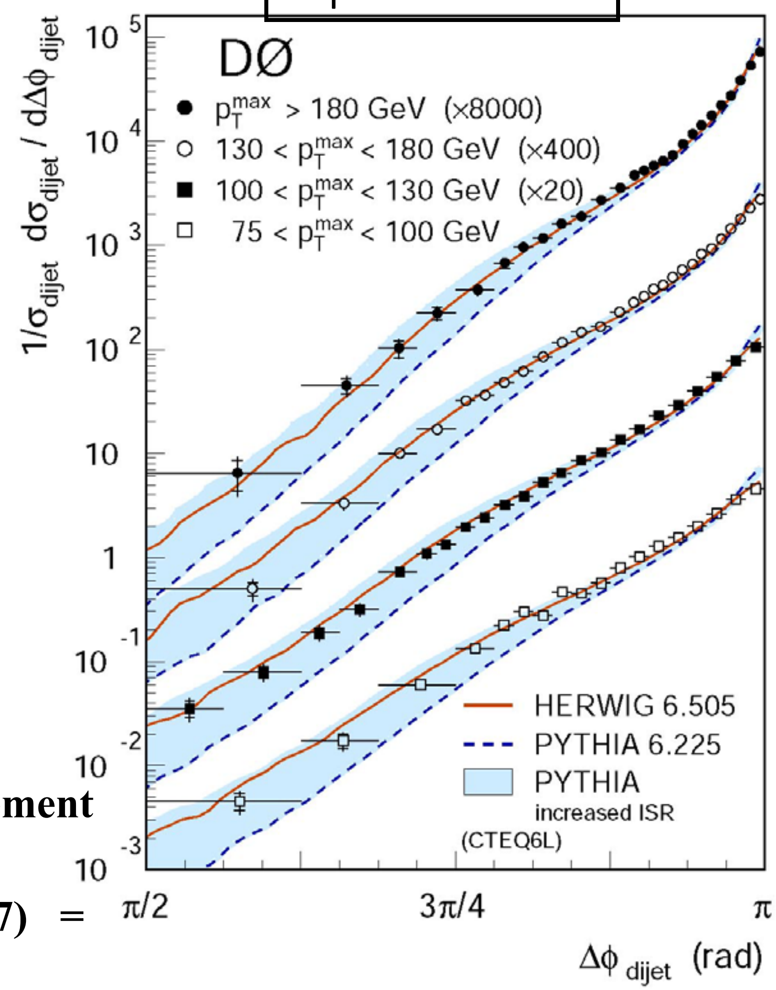
The $Q^2 = k_T^2$ in α_s for space-like showers is scaled by PARP(64)!

Jet-Jet Correlations (DØ)

Jet#1-Jet#2 Δφ Distribution



Δφ Jet#1-Jet#2



- **MidPoint Cone Algorithm (R = 0.7, f_{merge} = 0.5)**
- **$\mathcal{L}$ = 150 pb^{-1} (Phys. Rev. Lett. 94 221801 (2005))**
- **Data/NLO agreement good. Data/HERWIG agreement good.**
- **Data/PYTHIA agreement good provided PARP(67) = 1.0→4.0 (i.e. like Tune A, best fit 2.5).**

CDF Run 1 $P_T(Z)$

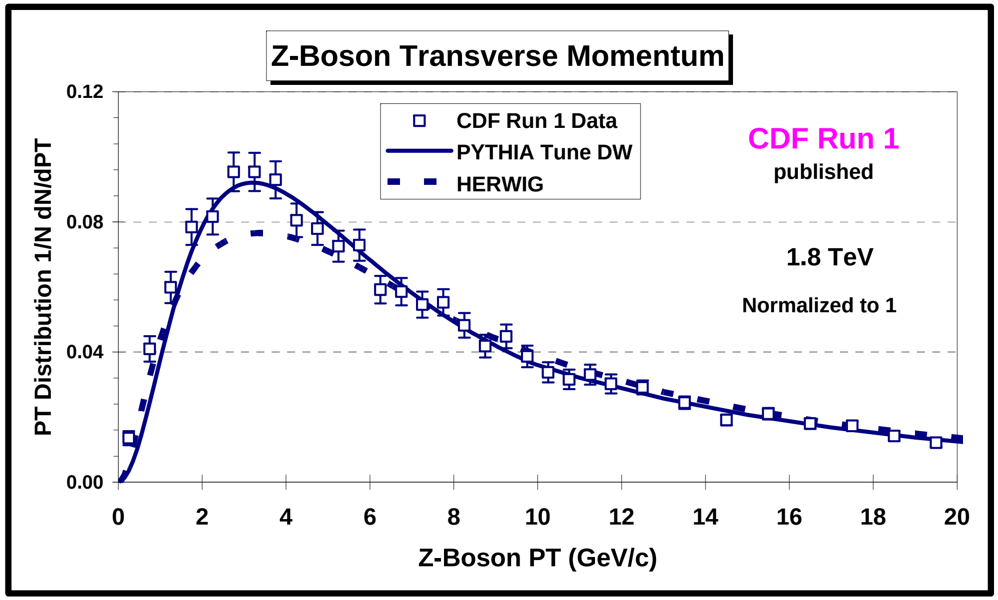
PYTHIA 6.2 CTEQ5L

Parameter	Tune DW	Tune AW
MSTP(81)	1	1
MSTP(82)	4	4
PARP(82)	1.9 GeV	2.0 GeV
PARP(83)	0.5	0.5
PARP(84)	0.4	0.4
PARP(85)	1.0	0.9
PARP(86)	1.0	0.95
PARP(89)	1.8 TeV	1.8 TeV
PARP(90)	0.25	0.25
PARP(62)	1.25	1.25
PARP(64)	0.2	0.2
PARP(67)	2.5	4.0
MSTP(91)	1	1
PARP(91)	2.1	2.1
PARP(93)	15.0	[illegible]

UE Parameters

ISR Parameters

Intrensic KT



- Shows the Run 1 Z-boson p_T distribution ($<p_T(Z)> \approx 11.5$ GeV/c) compared with PYTHIA Tune DW, and HERWIG.

Tune DW uses D0's perfered value of PARP(67)!

Tune DW has a lower value of PARP(67) and slightly more MPI!

PYTHIA 6.2 Tunes

All use LO α_s with Λ = 192 MeV!

Parameter	Tune AW	Tune DW	Tune D6
PDF	CTEQ5L	CTEQ5L	CTEQ6L
MSTP(81)	1	1	1
MSTP(82)	4	4	4
PARP(82)	2.0 GeV	1.9 GeV	1.8 GeV
PARP(83)	0.5	0.5	0.5
PARP(84)	0.4	0.4	0.4
PARP(85)	0.9	1.0	1.0
PARP(86)	0.95	1.0	1.0
PARP(89)	1.8 TeV	1.8 TeV	1.8 TeV
PARP(90)	0.25	0.25	0.25
PARP(62)	1.25	1.25	1.25
PARP(64)	0.2	0.2	0.2
PARP(67)	4.0	2.5	2.5
MSTP(91)	1	1	1
PARP(91)	2.1	2.1	2.1
PARP(93)	15.0	15.0	15.0

UE Parameters

ISR Parameter

Intrinsic KT

Uses CTEQ6L

Tune A energy dependence!

PYTHIA 6.2 Tunes

All use LO α_s with Λ = 192 MeV!

UE Parameters

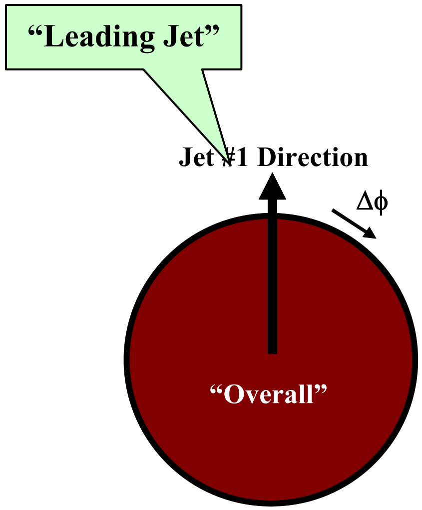
ISR Parameter

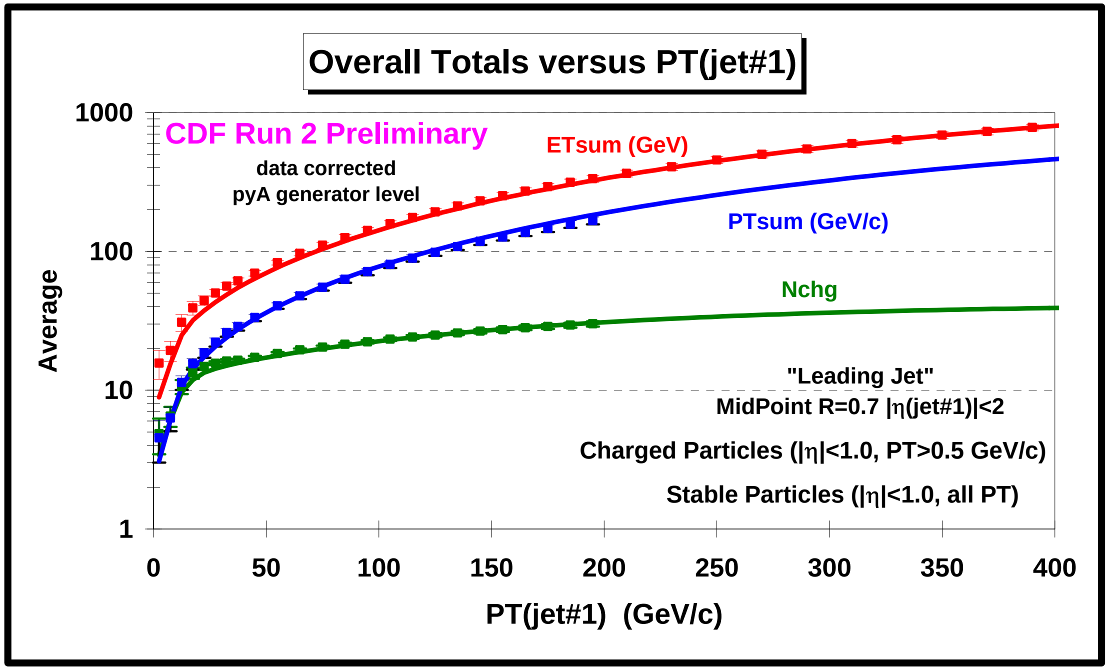
Intrinsic KT

ATLAS energy dependence!

Parameter	Tune DWT	Tune D6T	ATLAS
PDF	CTEQ5L	CTEQ6L	CTEQ5L
MSTP(81)	1	1	1
MSTP(82)	4	4	4
PARP(82)	1.9409 GeV	1.8387 GeV	1.8 GeV
PARP(83)	0.5	0.5	0.5
PARP(84)	0.4	0.4	0.5
PARP(85)	1.0	1.0	0.33
PARP(86)	1.0	1.0	0.66
PARP(89)	1.96 TeV	1.96 TeV	1.0 TeV
PARP(90)	0.16	0.16	0.16
PARP(62)	1.25	1.25	1.0
PARP(64)	0.2	0.2	1.0
PARP(67)	2.5	2.5	1.0
MSTP(91)	1	1	1
PARP(91)	2.1	2.1	1.0
PARP(93)	15.0	15.0	5.0

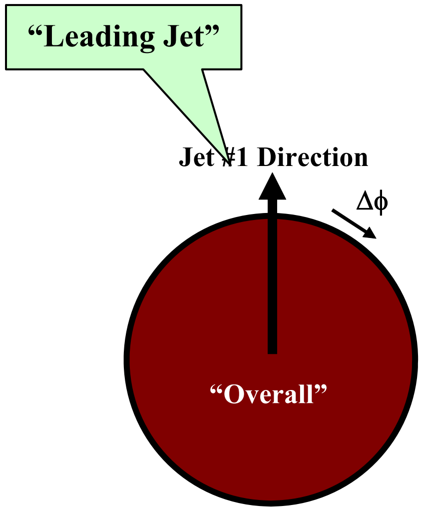
Overall Totals (|η| < 1)

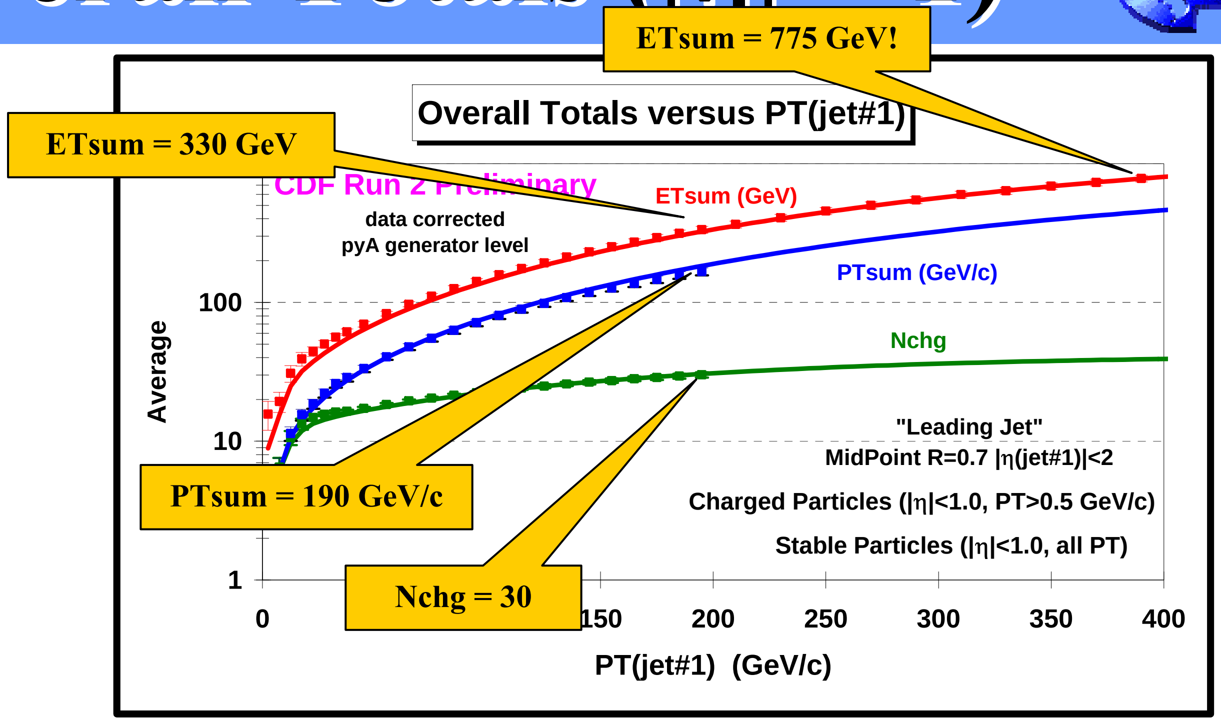




- Data at 1.96 TeV on the overall number of charged particles (p_T > 0.5 GeV/c, |η| < 1) and the overall *scalar* p_T sum of charged particles (p_T > 0.5 GeV/c, |η| < 1) and the overall *scalar* ET sum of all particles (|η| < 1) for "leading jet" events as a function of the leading jet p_T. The data are corrected to the particle level (*with errors that include both the statistical error and the systematic uncertainty*) and are compared with PYTHIA Tune A at the particle level (*i.e.* generator level)..

Overall Totals (|η| < 1)





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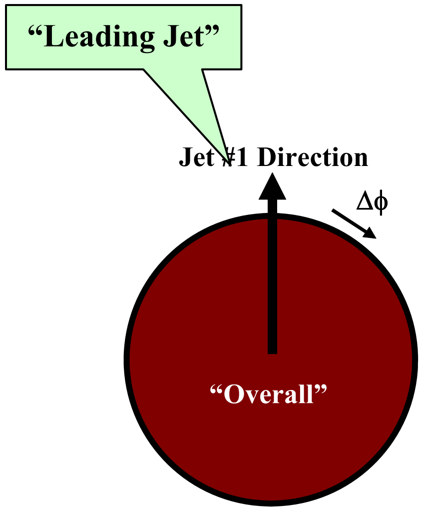

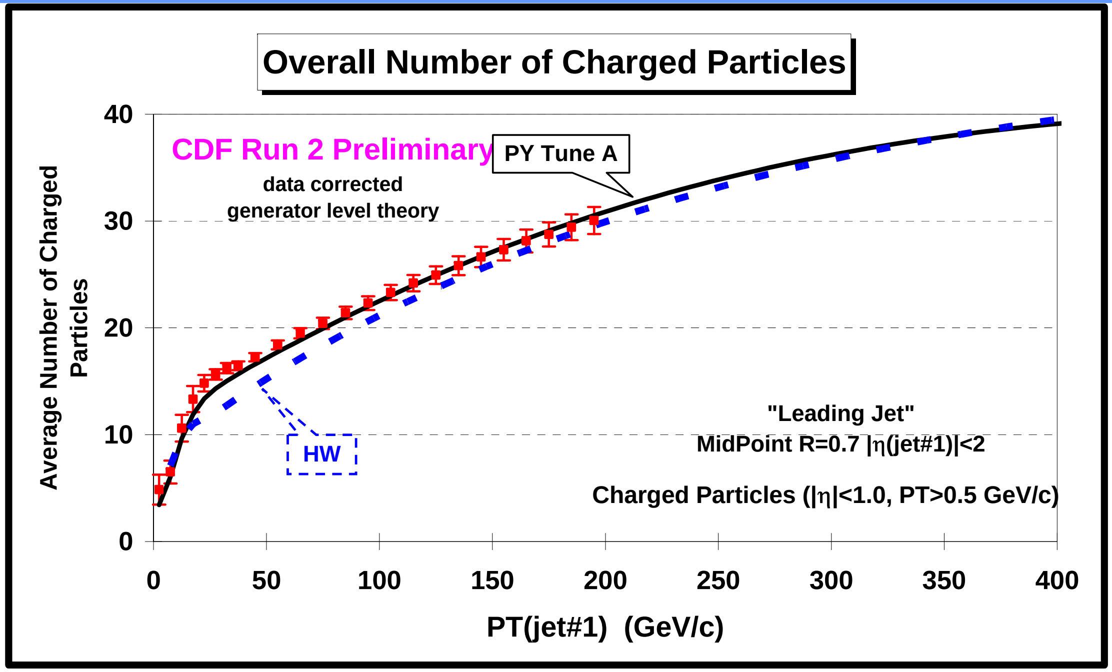

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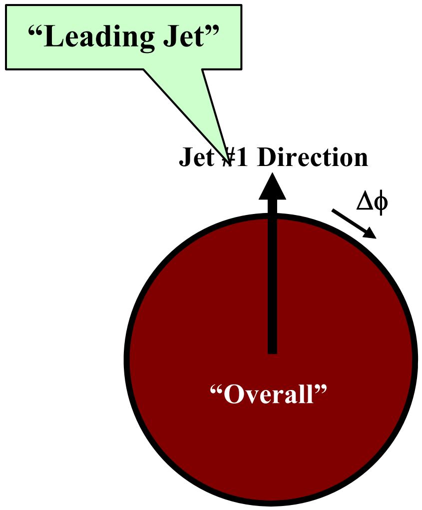
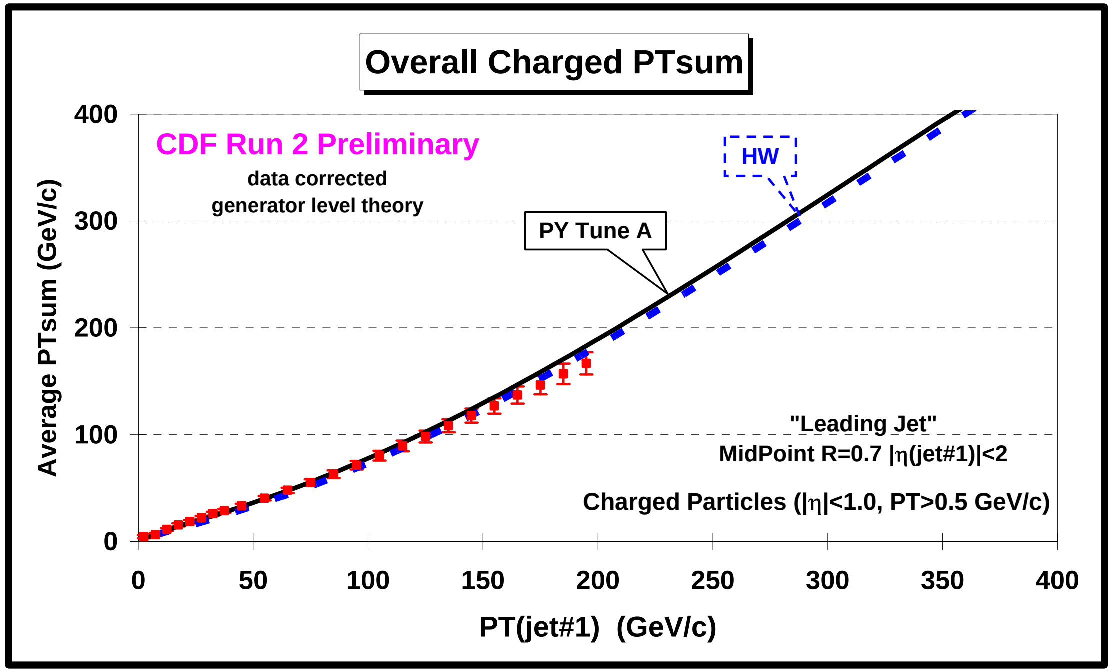
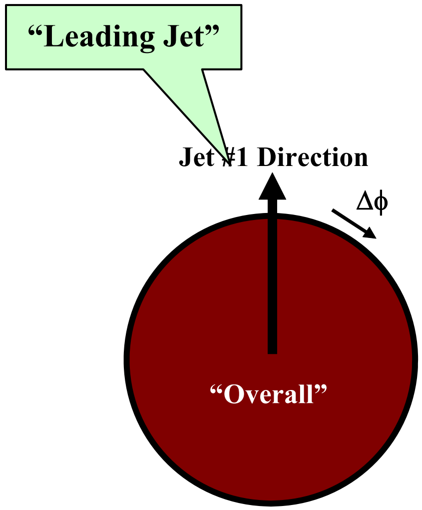
Overall Totals (|η| < 1)

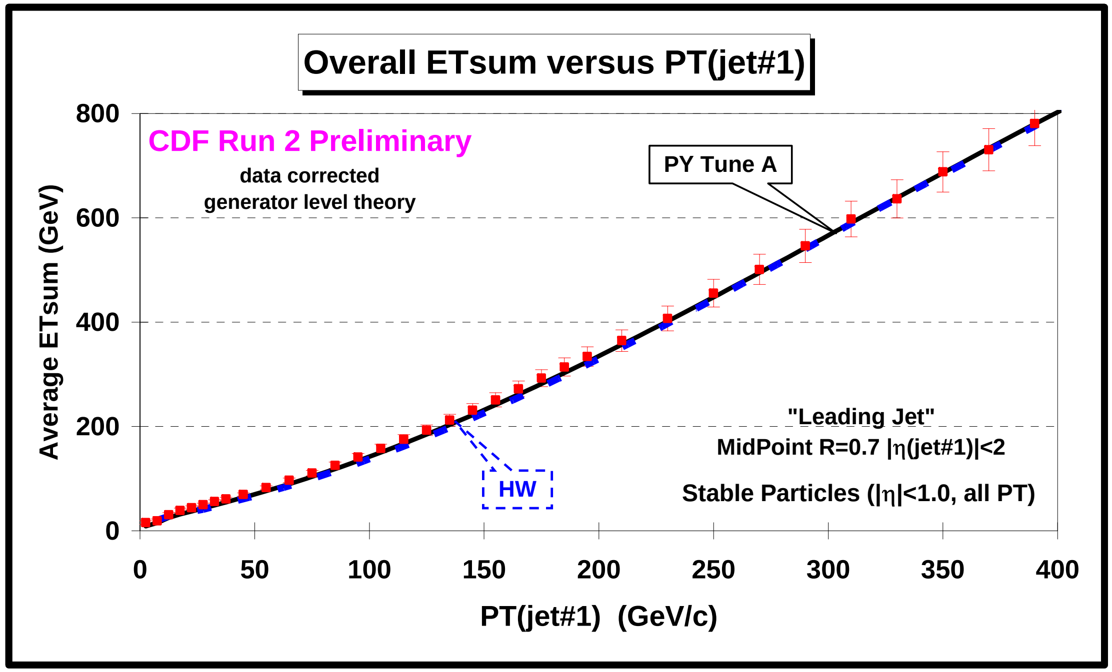




- Data at 1.96 TeV on the overall *scalar* p_T sum of charged particles (p_T > 0.5 GeV/c, |η| < 1) for "leading jet" events as a function of the leading jet p_T. The data are corrected to the particle level (*with errors that include both the statistical error and the systematic uncertainty*) and are compared with PYTHIA Tune A and HERWIG (without MPI) at the particle level (*i.e.* generator level).

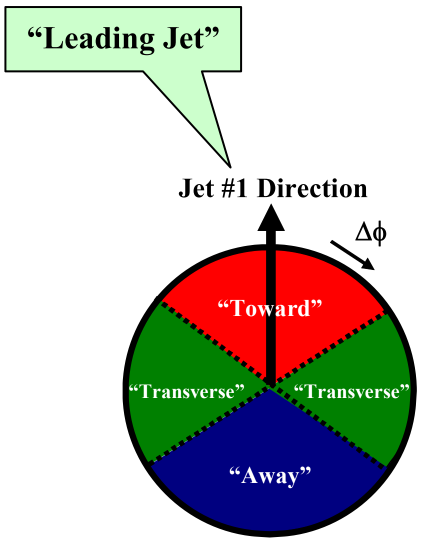
Overall Totals (|η| < 1)

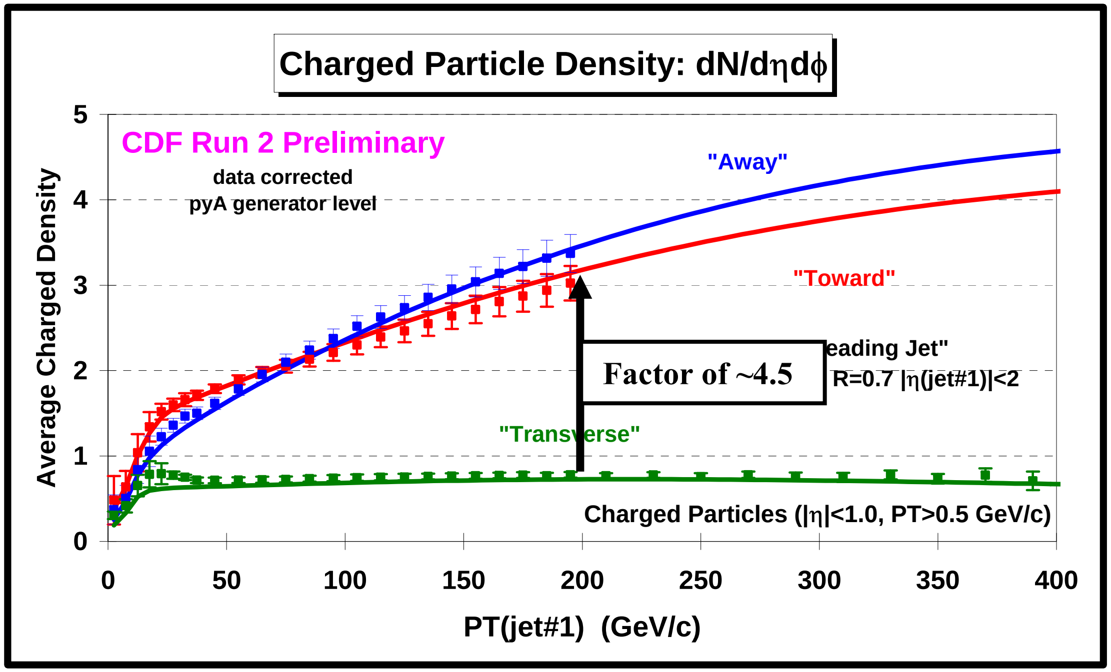




- **Data at 1.96 TeV on the overall *scalar* ET sum of all particles (|η| < 1) for "leading jet" events as a function of the leading jet p_T. The data are corrected to the particle level (*with errors that include both the statistical error and the systematic uncertainty*) and are compared with PYTHIA Tune A and HERWIG (without MPI) at the particle level (*i.e.* generator level).**

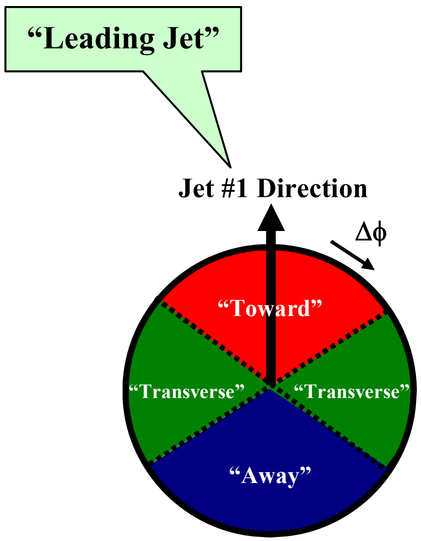
"Towards", "Away", "Transverse"

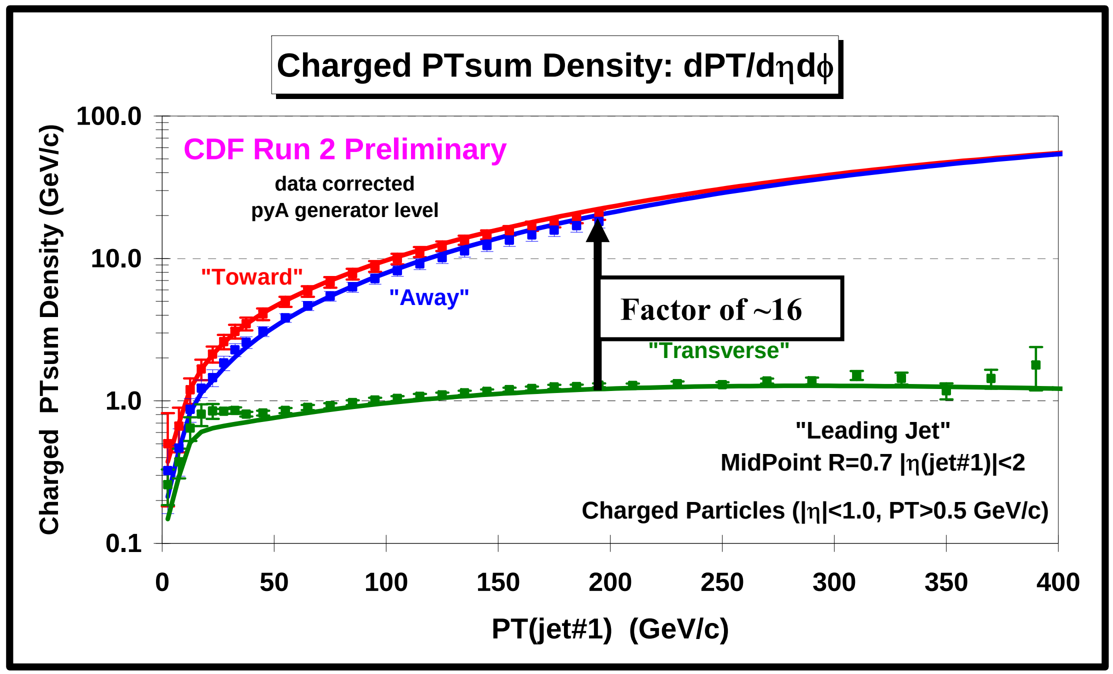




- **Data at 1.96 TeV on the density of charged particles, dN/dηdϕ, with $p_T > 0.5$ GeV/c and $|\eta| < 1$ for "leading jet" events as a function of the leading jet p_T for the "toward", "away", and "transverse" regions. The data are corrected to the particle level (*with errors that include both the statistical error and the systematic uncertainty*) and are compared with PYTHIA Tune A at the particle level (*i.e.* generator level).**

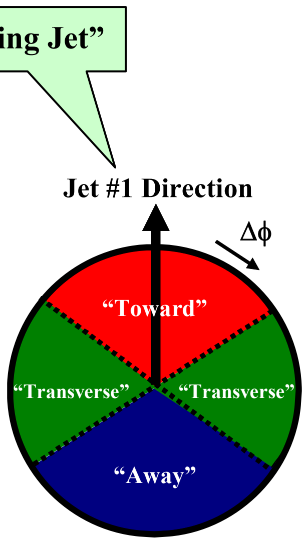
"Towards", "Away", "Transverse"

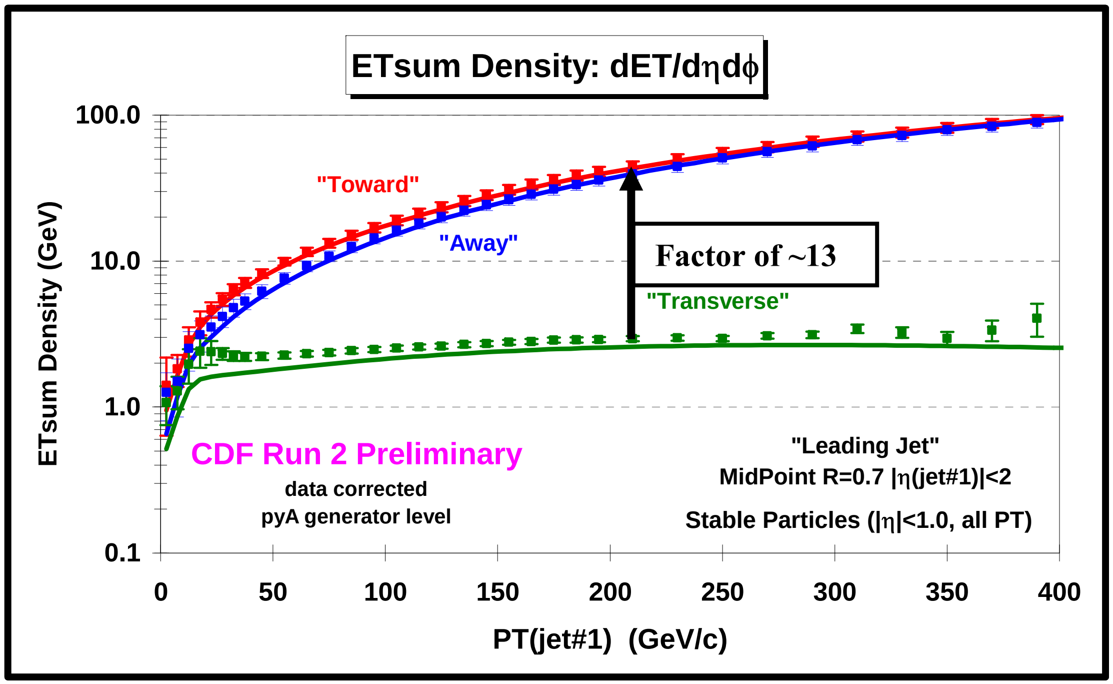




- Data at 1.96 TeV on the charged particle *scalar* p_T sum density, dPT/dηdϕ, with p_T > 0.5 GeV/c and |η| < 1 for "leading jet" events as a function of the leading jet p_T for the "toward", "away", and "transverse" regions. The data are corrected to the particle level (*with errors that include both the statistical error and the systematic uncertainty*) and are compared with PYTHIA Tune A at the particle level (*i.e.* generator level).

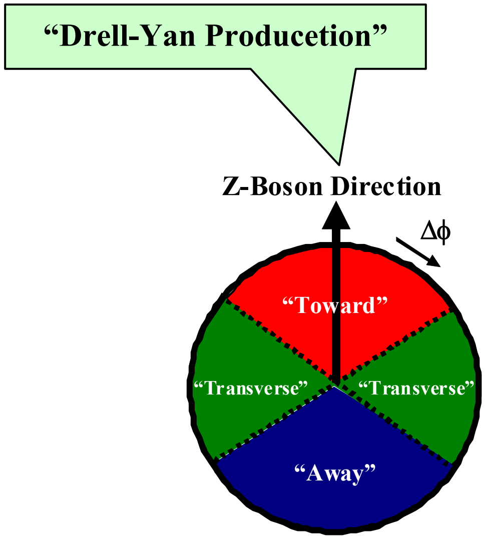
“Towards”, “Away”, “Transverse”

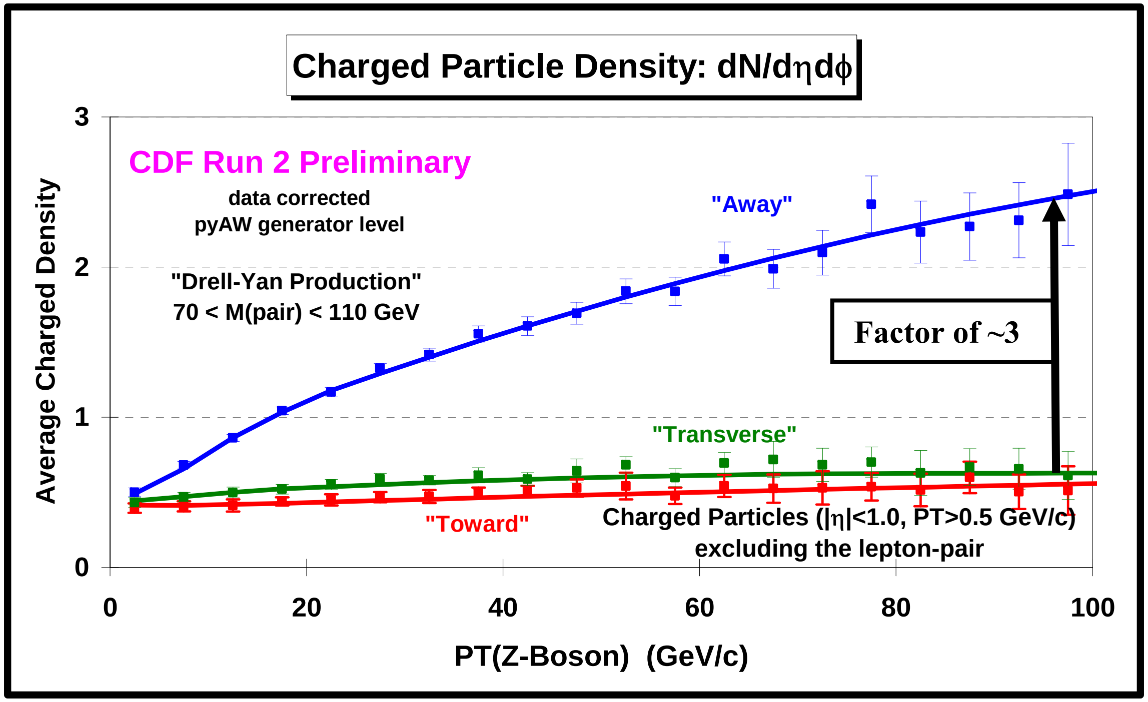




- **Data at 1.96 TeV on the particle *scalar* E_T sum density, dET/dηdϕ, for |η| < 1 for “leading jet” events as a function of the leading jet p_T for the “toward”, “away”, and “transverse” regions. The data are corrected to the particle level (*with errors that include both the statistical error and the systematic uncertainty*) and are compared with PYTHIA Tune A at the particle level (*i.e.* generator level).**

"Towards", "Away", "Transverse"



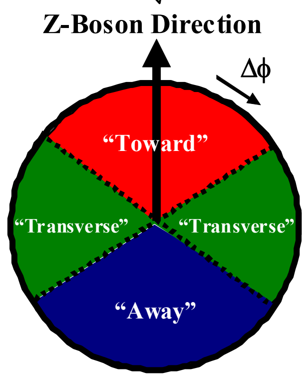


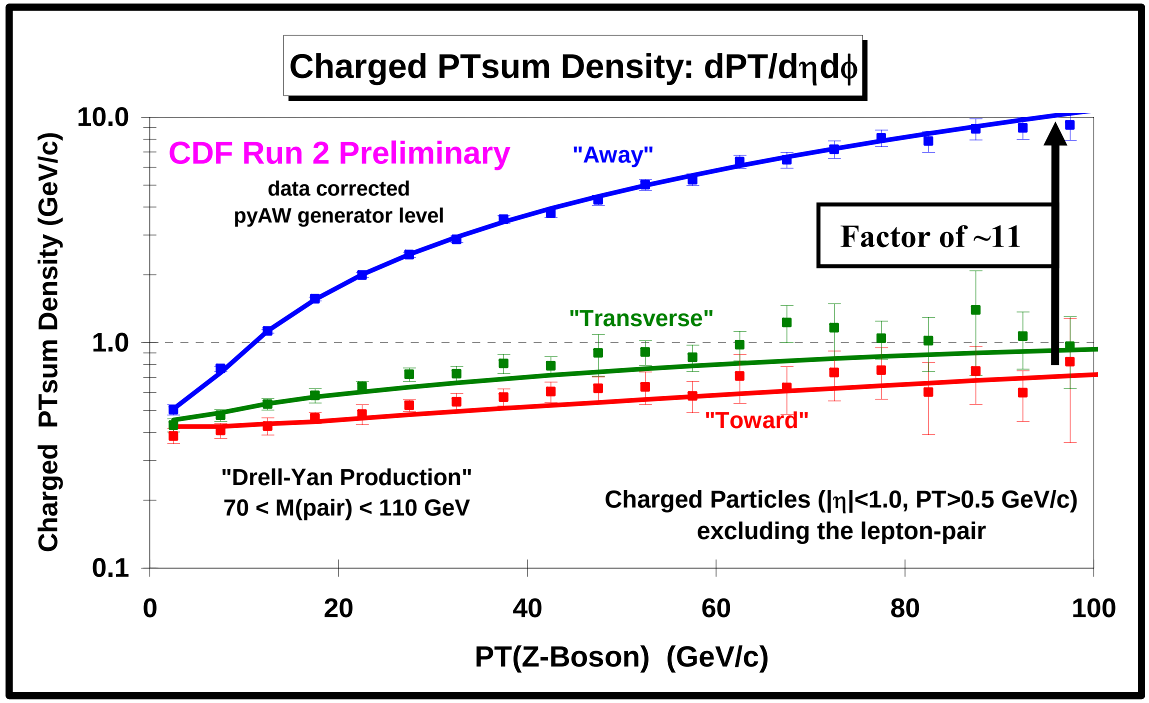
- Data at 1.96 TeV on the density of charged particles, dN/dηdϕ, with $p_T > 0.5$ GeV/c and $|\eta| < 1$ for "Z-Boson" events as a function of the leading jet p_T for the "toward", "away", and "transverse" regions. The data are corrected to the particle level (*with errors that include both the statistical error and the systematic uncertainty*) and are compared with PYTHIA Tune AW at the particle level (*i.e.* generator level).

Deepak Kar's Thesis

"Towards", "Away", "Transverse"

"Drell-Yan Producetion"

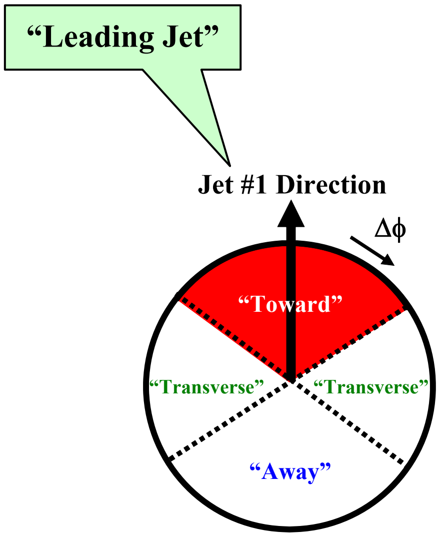


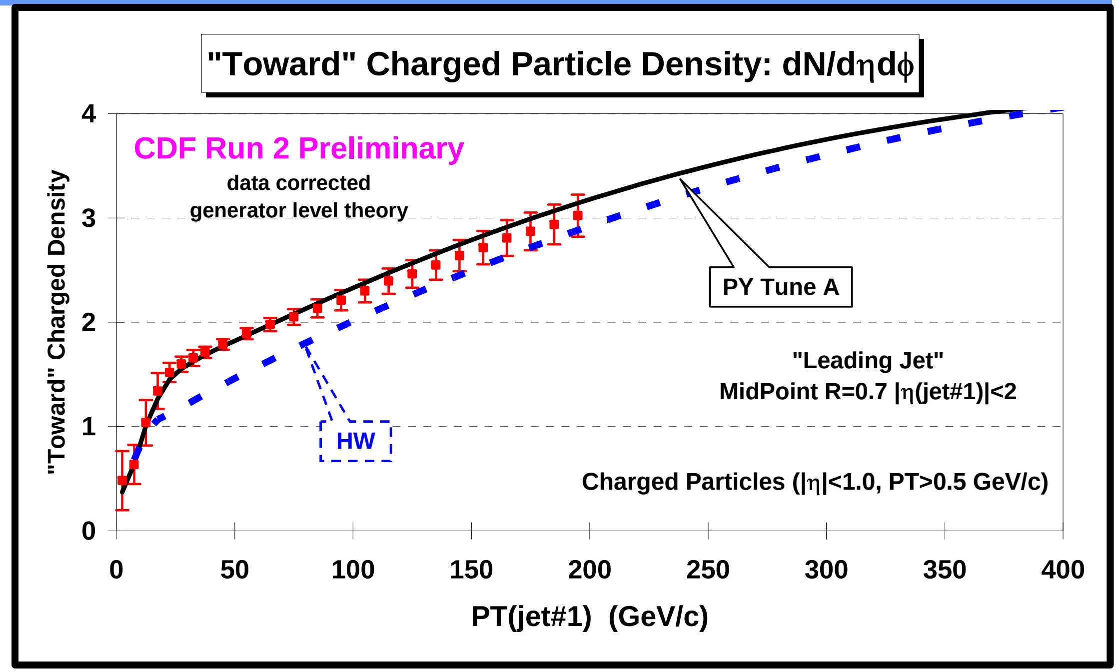


- Data at 1.96 TeV on the charged particle *scalar* p_T sum density, dPT/dηdϕ, with $p_T > 0.5$ GeV/c and $|\eta| < 1$ for "Z-Boson" events as a function of the leading jet p_T for the "toward", "away", and "transverse" regions. The data are corrected to the particle level (*with errors that include both the statistical error and the systematic uncertainty*) and are compared with PYTHIA Tune AW at the particle level (*i.e.* generator level).

Deepak Kar's Thesis

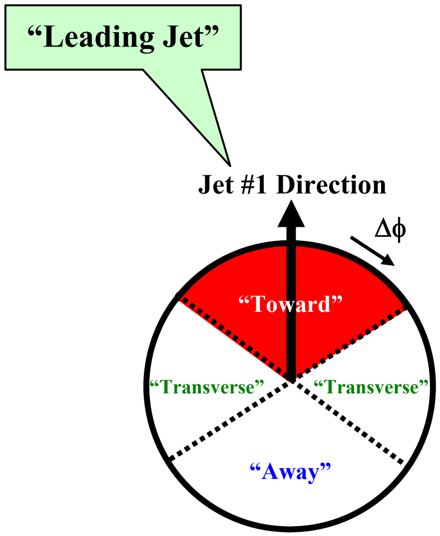
The "Toward" Region

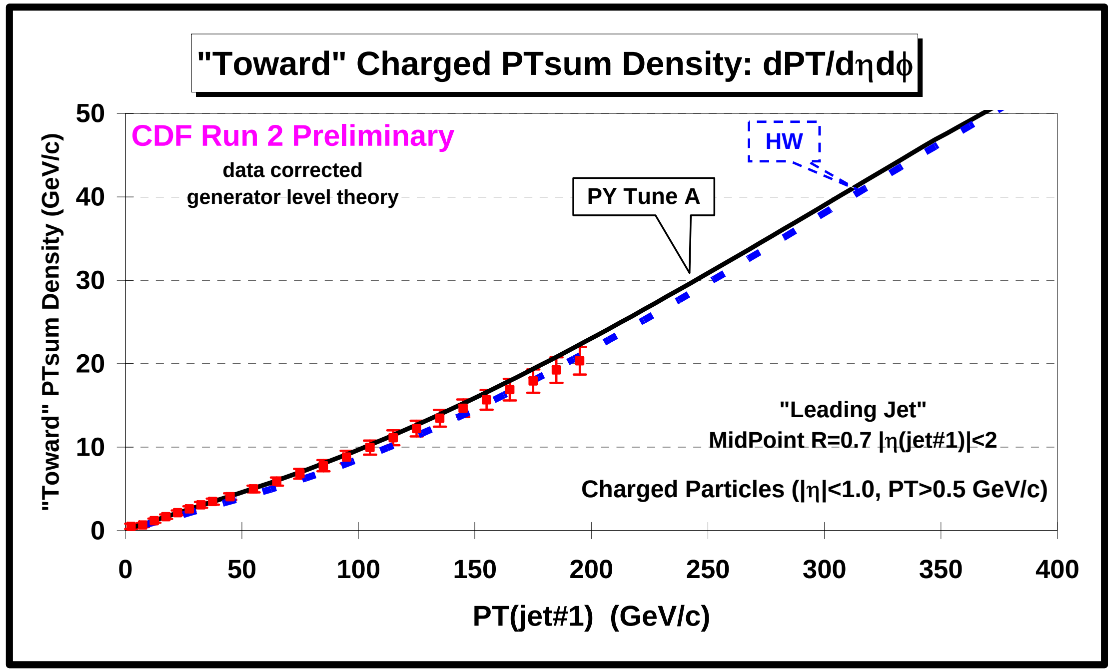




- **Data at 1.96 TeV on the density of charged particles, dN/dηdϕ, with $p_T > 0.5$ GeV/c and $|\eta| < 1$ for "leading jet" events as a function of the leading jet p_T for the "toward" region. The data are corrected to the particle level (*with errors that include both the statistical error and the systematic uncertainty*) and are compared with PYTHIA Tune A and HERWIG (without MPI) at the particle level (*i.e.* generator level).**

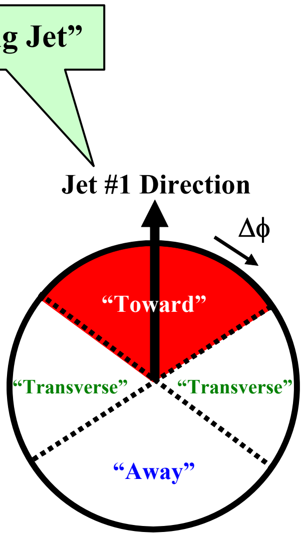
The "Toward" Region

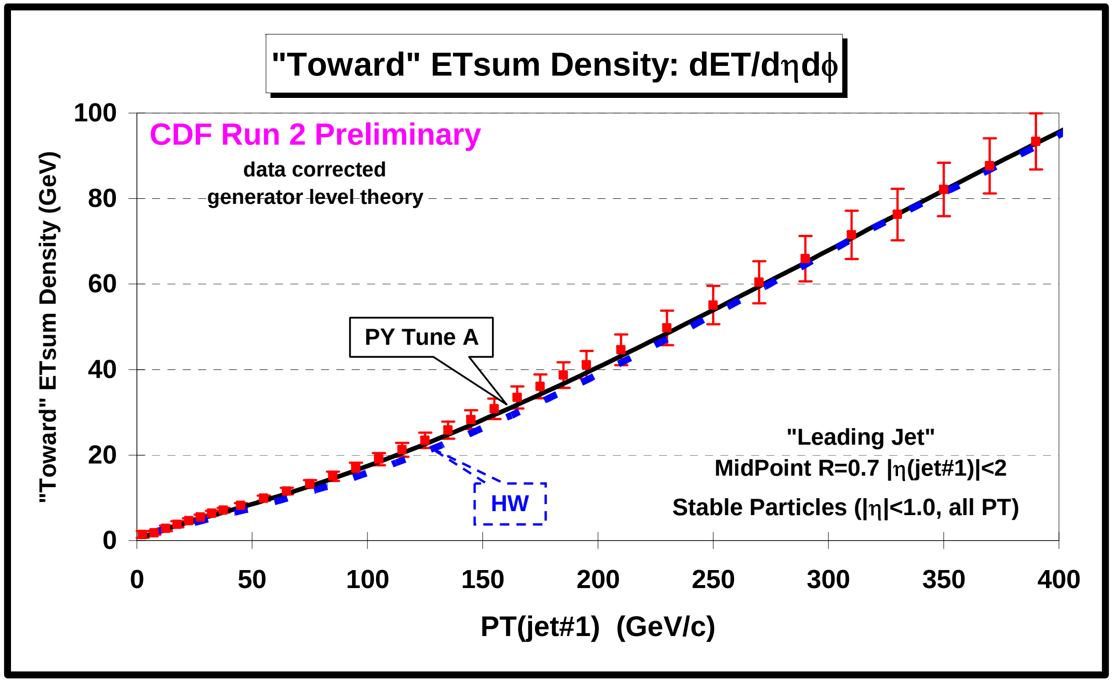




- **Data at 1.96 TeV on the charged *scalar* p_T sum density, dPT/dηdφ, with p_T > 0.5 GeV/c and |η| < 1 for "leading jet" events as a function of the leading jet p_T for the "toward" region. The data are corrected to the particle level (*with errors that include both the statistical error and the systematic uncertainty*) and are compared with PYTHIA Tune A and HERWIG (without MPI) at the particle level (*i.e.* generator level).**

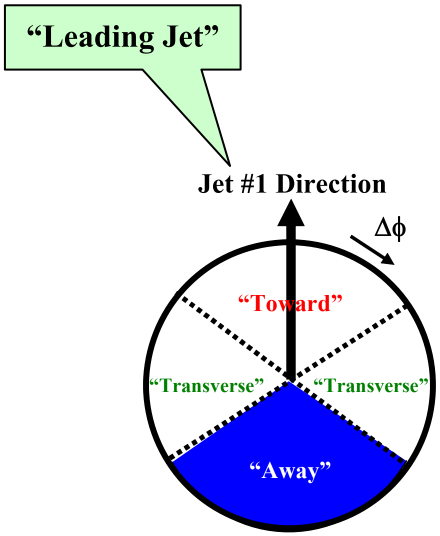
The “Toward” Region

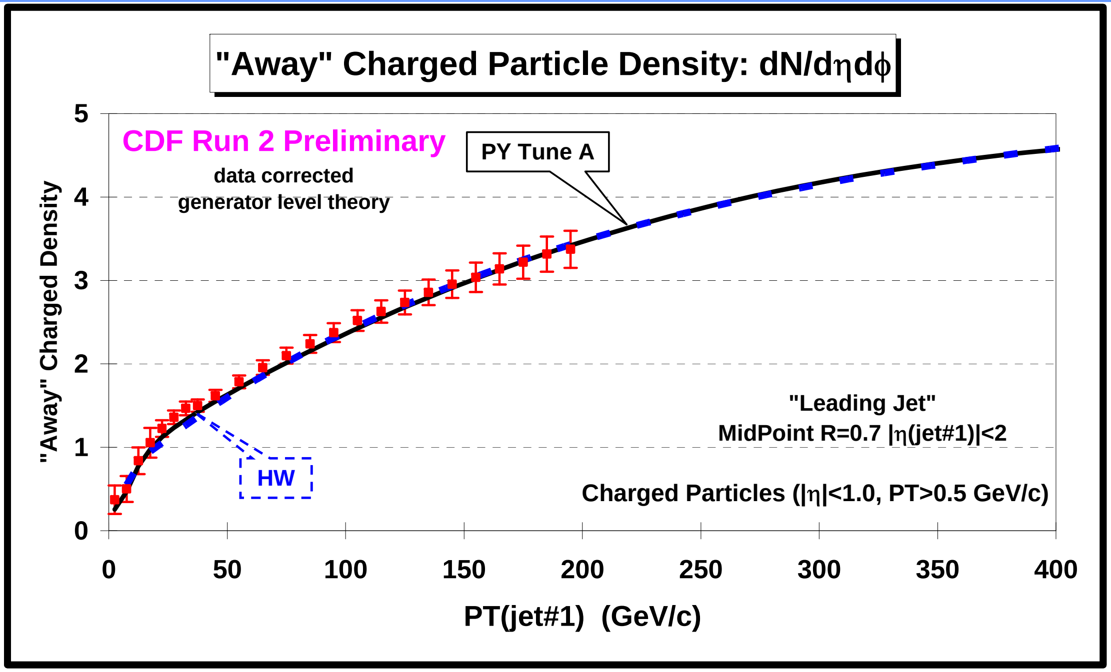




- **Data at 1.96 TeV on the *scalar* E_T sum density, dET/dηdϕ, with |η| < 1 for “leading jet” events as a function of the leading jet p_T for the “toward” region. The data are corrected to the particle level (*with errors that include both the statistical error and the systematic uncertainty*) and are compared with PYTHIA Tune A and HERWIG (without MPI) at the particle level (*i.e.* generator level).**

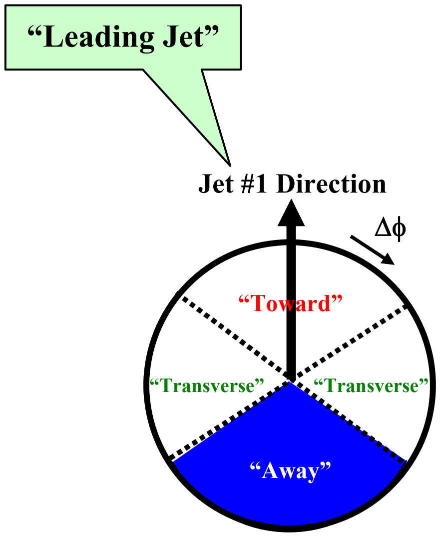
The "Away" Region

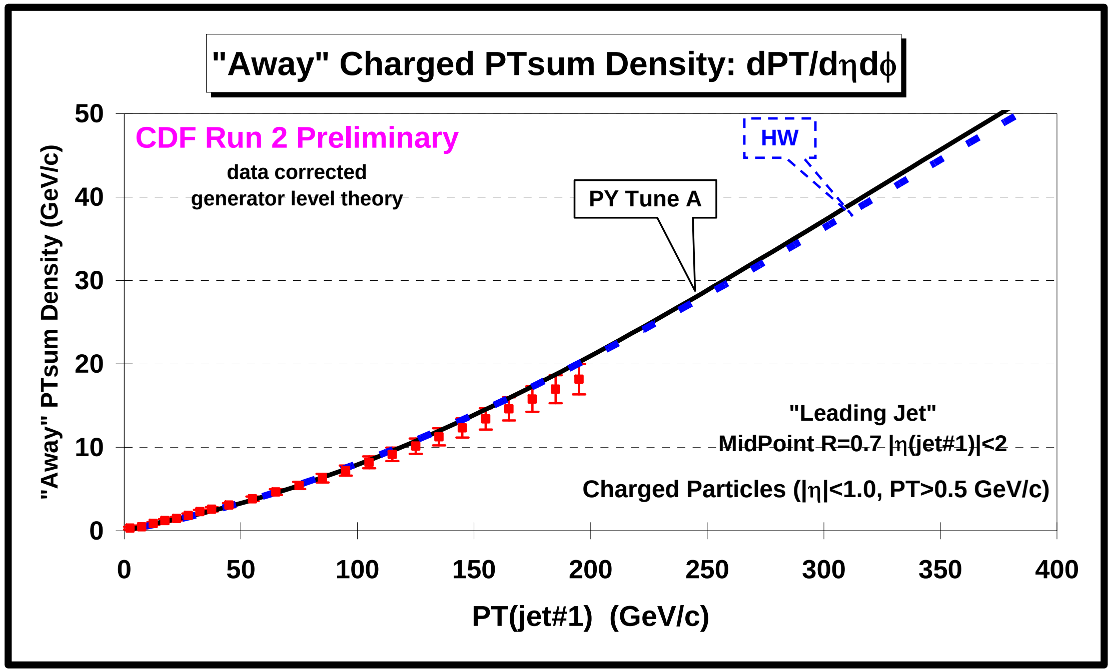




- Data at 1.96 TeV on the density of charged particles, dN/dηdϕ, with $p_T > 0.5$ GeV/c and $|\eta| < 1$ for "leading jet" events as a function of the leading jet p_T for the "away" region. The data are corrected to the particle level (*with errors that include both the statistical error and the systematic uncertainty*) and are compared with PYTHIA Tune A and HERWIG (without MPI) at the particle level (*i.e.* generator level).

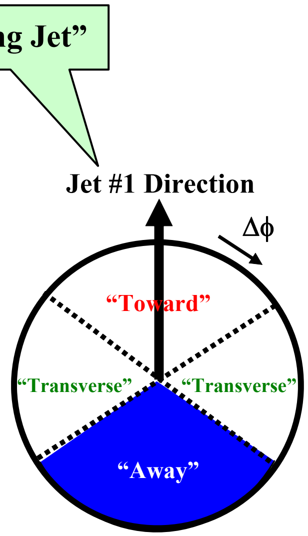
The “Away” Region

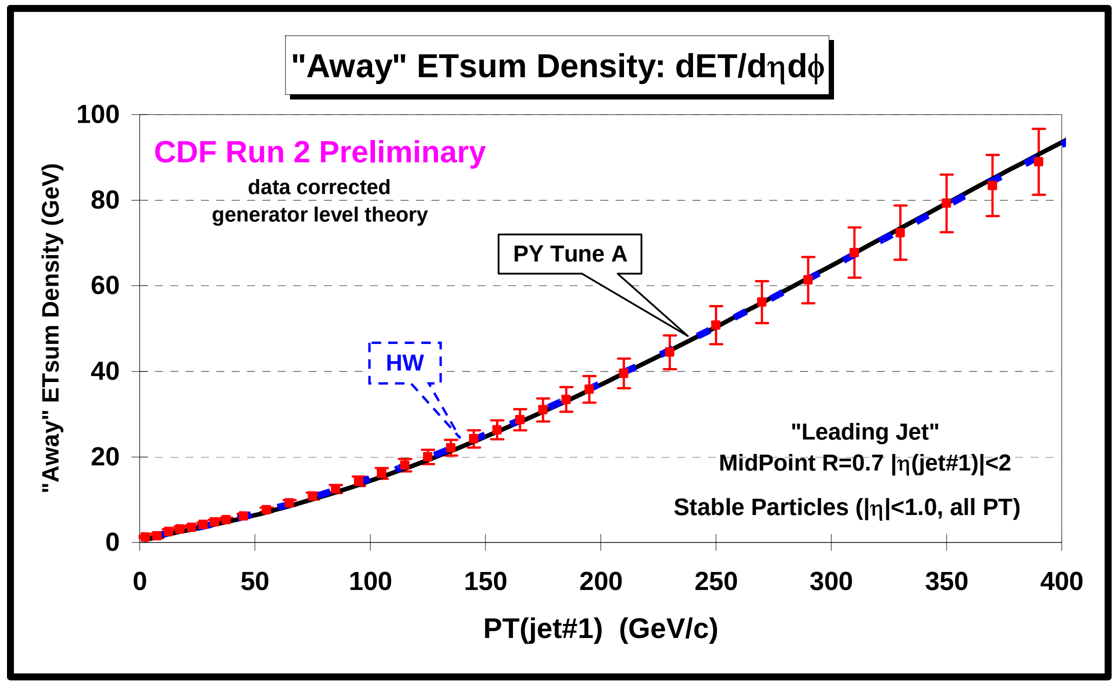




- **Data at 1.96 TeV on the charged *scalar* p_T sum density, dPT/dηdϕ, with p_T > 0.5 GeV/c and |η| < 1 for “leading jet” events as a function of the leading jet p_T for the “away” region. The data are corrected to the particle level (*with errors that include both the statistical error and the systematic uncertainty*) and are compared with PYTHIA Tune A and HERWIG (without MPI) at the particle level (*i.e.* generator level).**

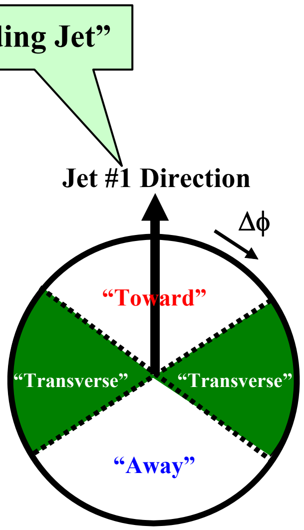
The "Away" Region

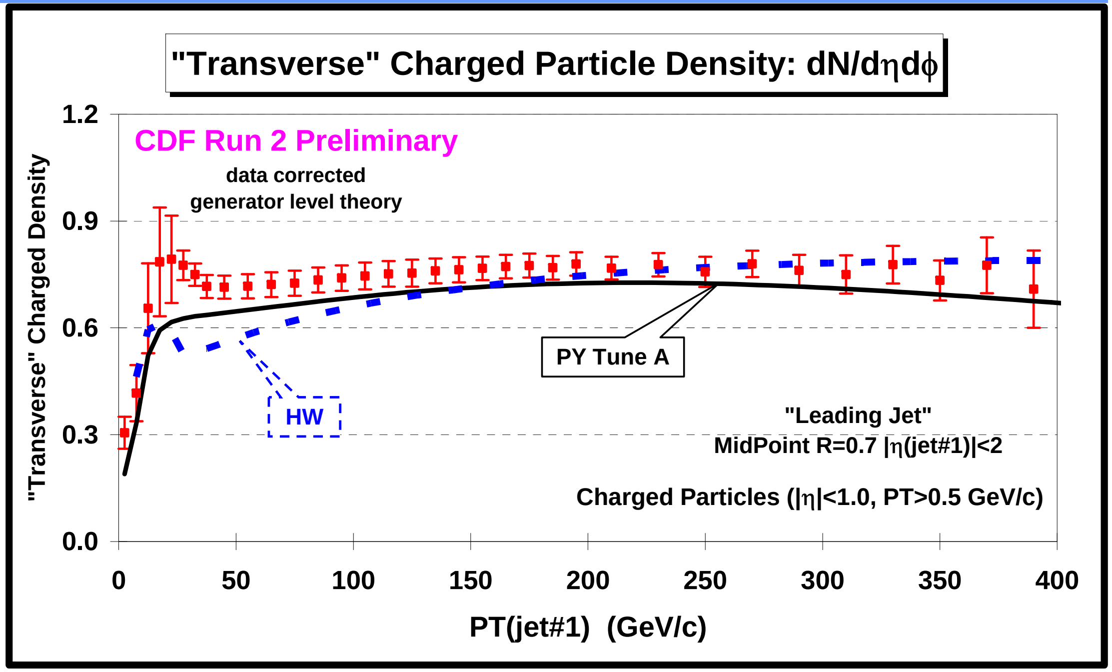




- **Data at 1.96 TeV on the *scalar* E_T sum density, dET/dηdϕ, with |η| < 1 for "leading jet" events as a function of the leading jet p_T for the "away" region. The data are corrected to the particle level (*with errors that include both the statistical error and the systematic uncertainty*) and are compared with PYTHIA Tune A and HERWIG (without MPI) at the particle level (*i.e.* generator level).**

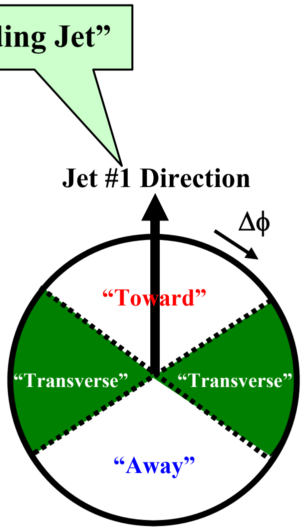
The "Transverse" Region

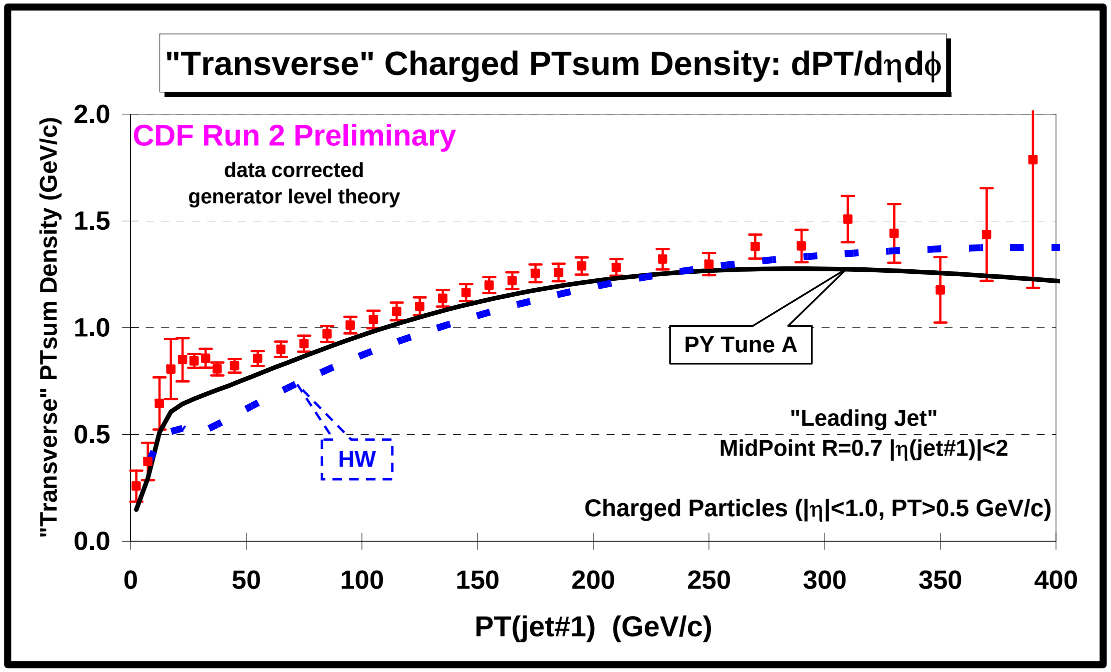




- Data at 1.96 TeV on the density of charged particles, dN/dηdφ, with $p_T > 0.5$ GeV/c and $|\eta| < 1$ for "leading jet" events as a function of the leading jet p_T for the "transverse" region. The data are corrected to the particle level (*with errors that include both the statistical error and the systematic uncertainty*) and are compared with PYTHIA Tune A and HERWIG (without MPI) at the particle level (*i.e.* generator level).

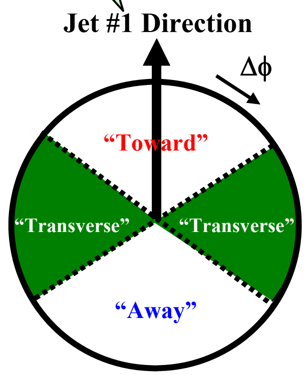
The "Transverse" Region

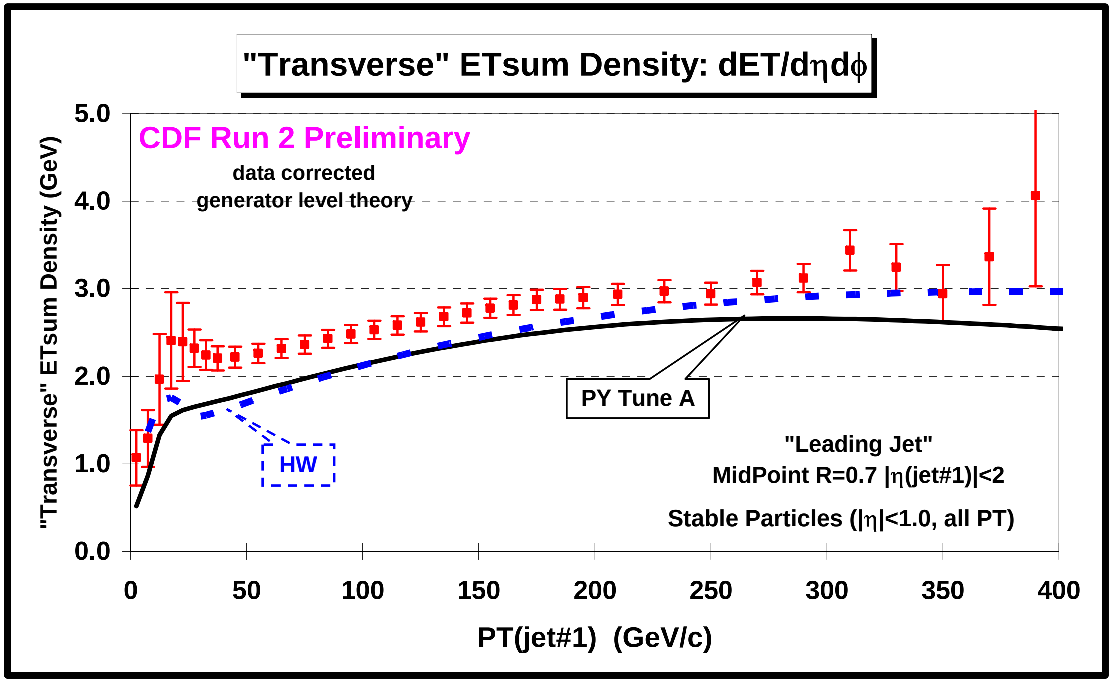




- Data at 1.96 TeV on the charged *scalar* p_T sum density, dPT/dηdϕ, with $p_T > 0.5$ GeV/c and $|\eta| < 1$ for "leading jet" events as a function of the leading jet p_T for the "transverse" region. The data are corrected to the particle level (*with errors that include both the statistical error and the systematic uncertainty*) and are compared with PYTHIA Tune A and HERWIG (without MPI) at the particle level (*i.e.* generator level).

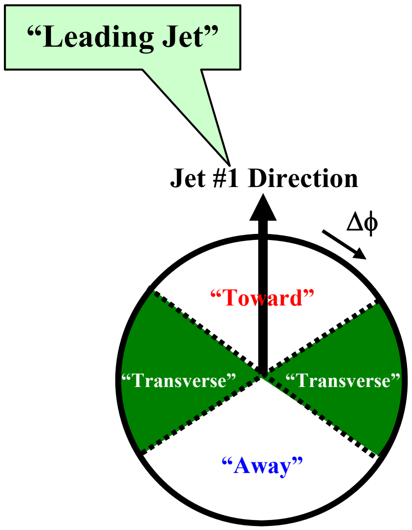
The "Transverse" Region

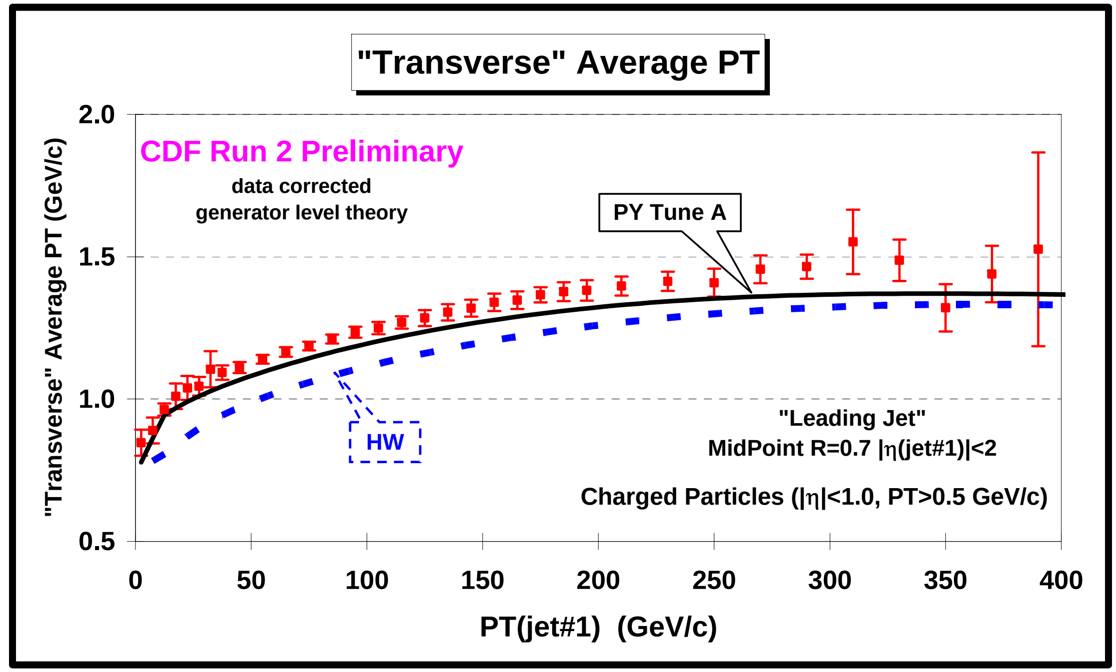




- **Data at 1.96 TeV on the *scalar* E_T sum density, dET/dηdφ, with |η| < 1 for "leading jet" events as a function of the leading jet p_T for the "transverse" region. The data are corrected to the particle level (*with errors that include both the statistical error and the systematic uncertainty*) and are compared with PYTHIA Tune A and HERWIG (without MPI) at the particle level (*i.e.* generator level).**

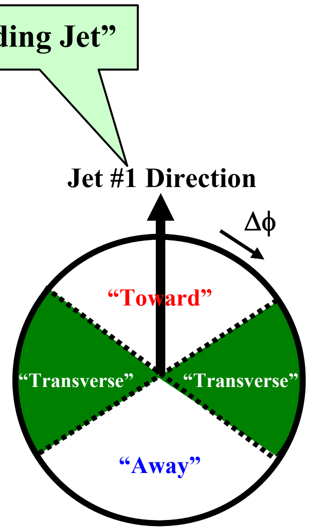
The "Transverse" Region

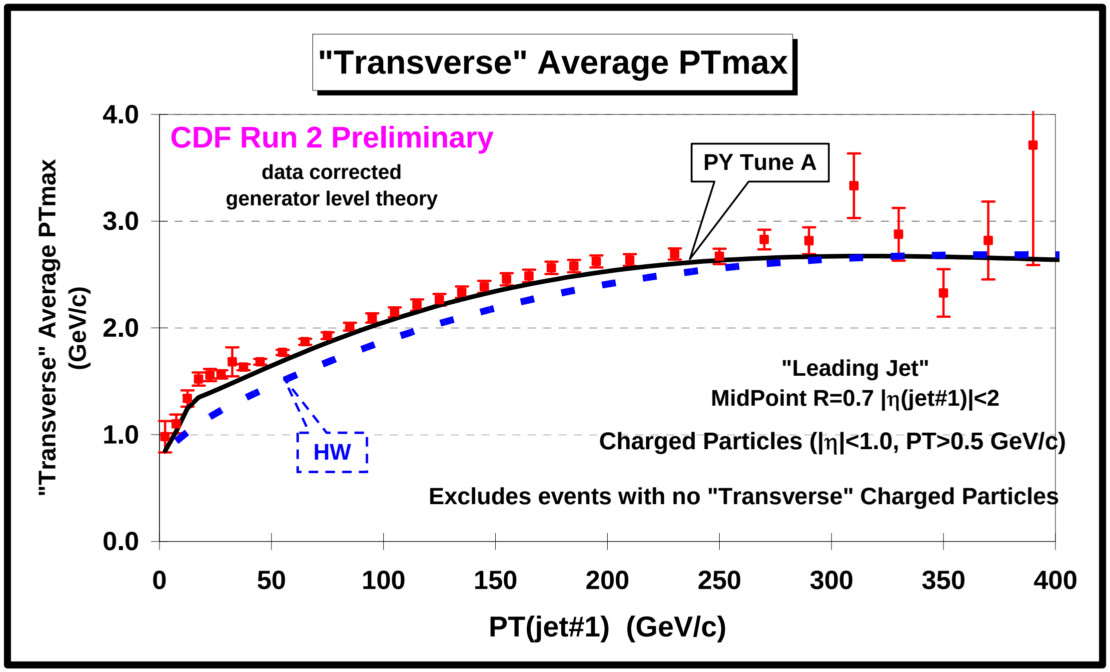




- Data at 1.96 TeV on the charged particle average p_T, with $p_T > 0.5$ GeV/c and $|\eta| < 1$ for "leading jet" events as a function of the leading jet p_T for the "transverse" region. The data are corrected to the particle level (*with errors that include both the statistical error and the systematic uncertainty*) and are compared with PYTHIA Tune A and HERWIG (without MPI) at the particle level (*i.e.* generator level).

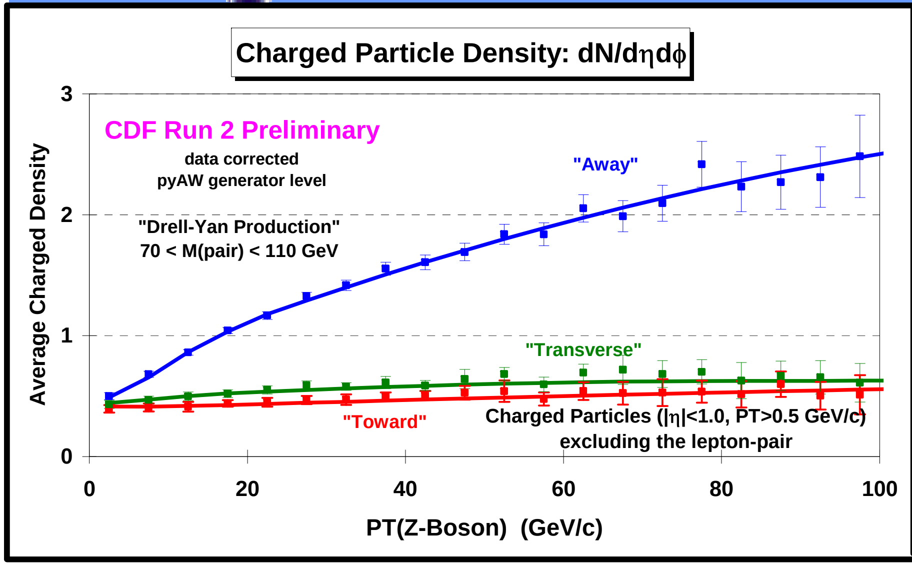
The "Transverse" Region

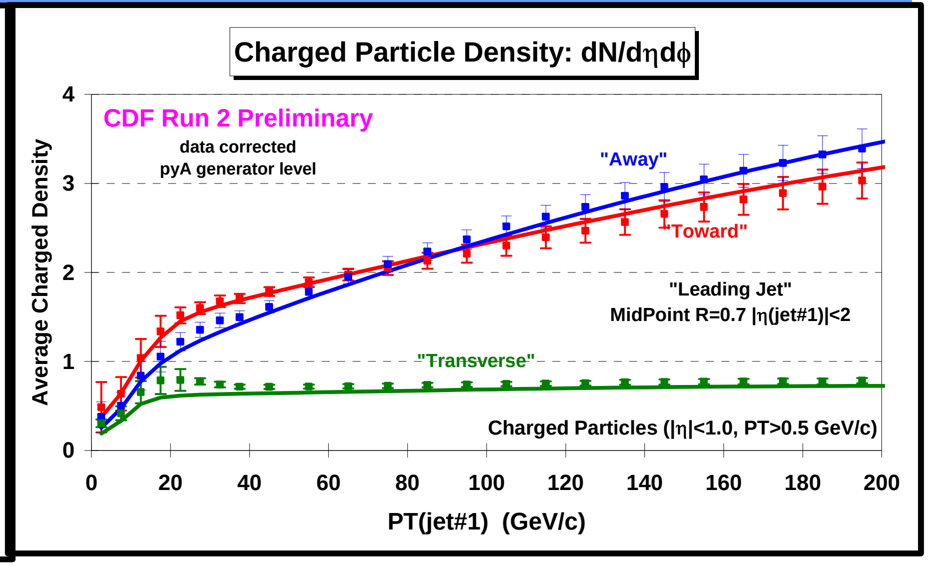


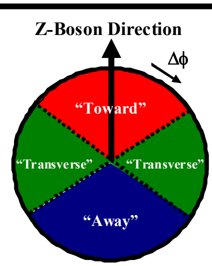


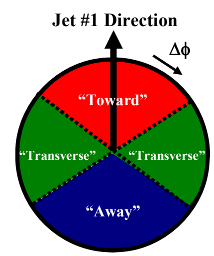
- Data at 1.96 TeV on the charged particle maximum p_T, with $p_T > 0.5$ GeV/c and $|\eta| < 1$ for "leading jet" events as a function of the leading jet p_T for the "transverse" region. The data are corrected to the particle level (*with errors that include both the statistical error and the systematic uncertainty*) and are compared with PYTHIA Tune A and HERWIG (without MPI) at the particle level (*i.e.* generator level).

"Charged Particle Density"



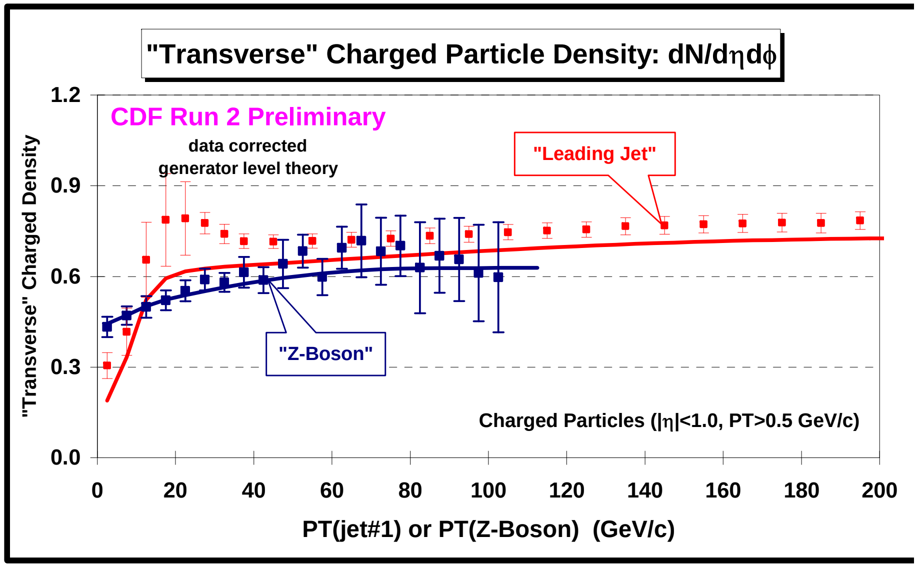


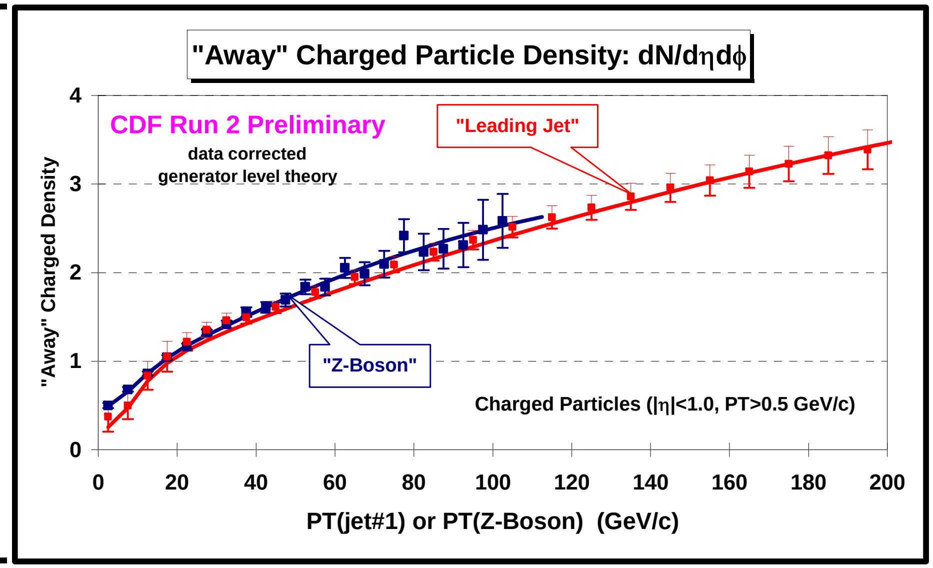


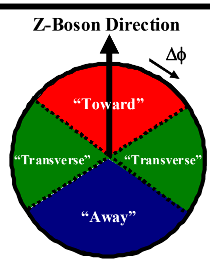


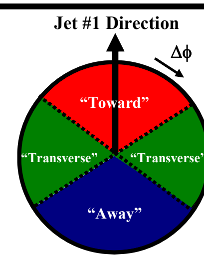
- **Data at 1.96 TeV on the density of charged particles, dN/dηdϕ, with $p_T > 0.5$ GeV/c and $|\eta| < 1$ for "Z-Boson" and "Leading Jet" events as a function of the leading jet p_T or $P_T(Z)$ for the "toward", "away", and "transverse" regions. The data are corrected to the particle level (*with errors that include both the statistical error and the systematic uncertainty*) and are compared with PYTHIA Tune AW and Tune A, respectively, at the particle level (*i.e.* generator level).**

"Charged Particle Density"



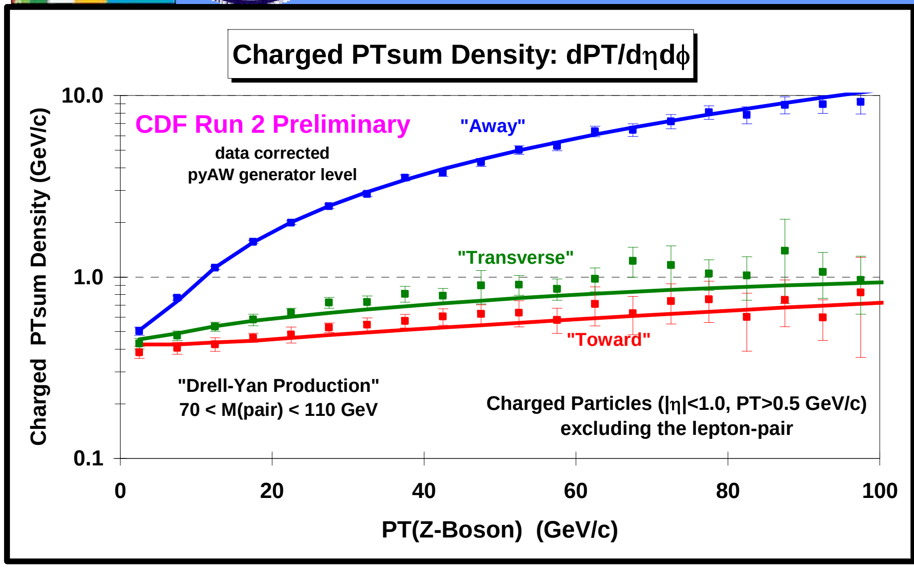


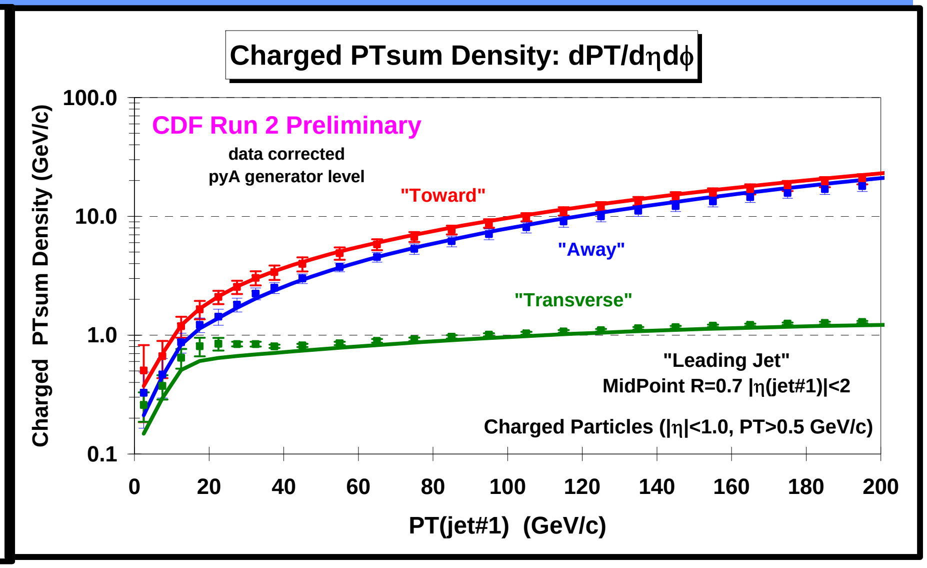


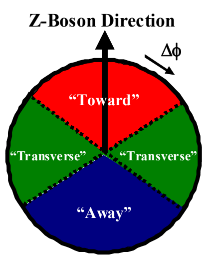


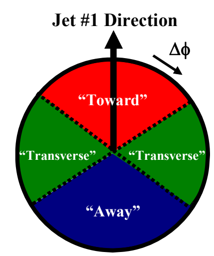
- **Data at 1.96 TeV on the density of charged particles, dN/dηdϕ, with p_T > 0.5 GeV/c and |η| < 1 for "Z-Boson" and "Leading Jet" events as a function of the leading jet p_T or P_T(Z) for the "toward", "away", and "transverse" regions. The data are corrected to the particle level (*with errors that include both the statistical error and the systematic uncertainty*) and are compared with PYTHIA Tune AW and Tune A, respectively, at the particle level (*i.e.* generator level).**

"Charged PTsum Density"



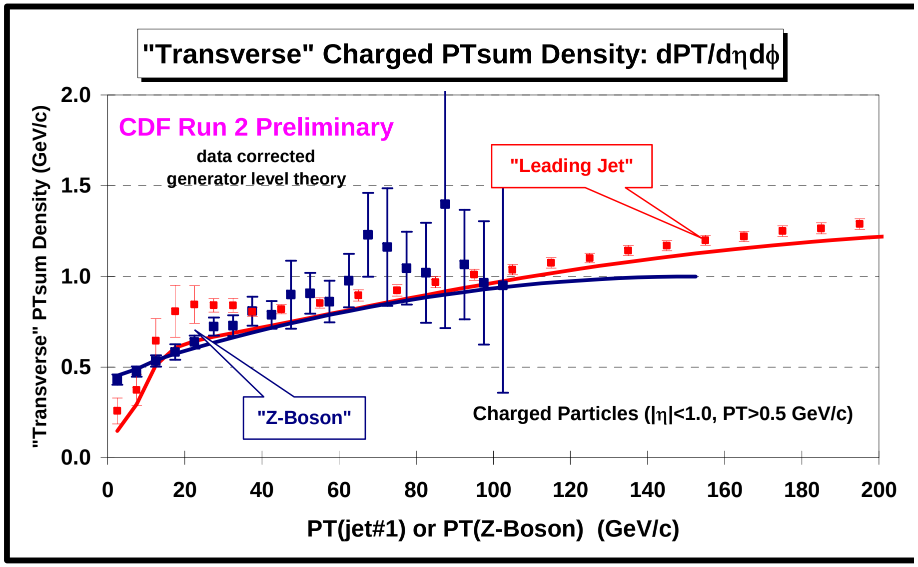


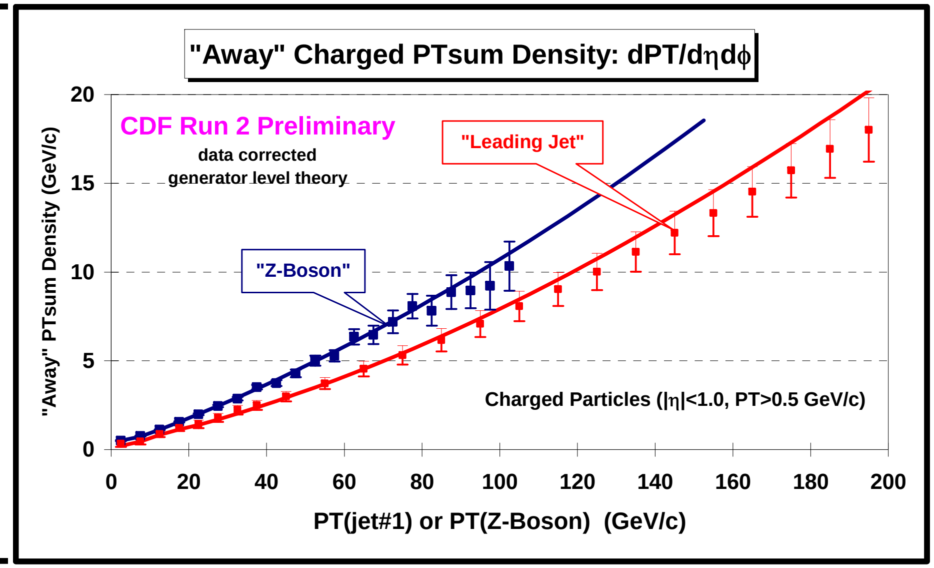


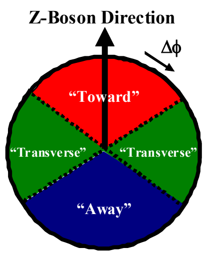


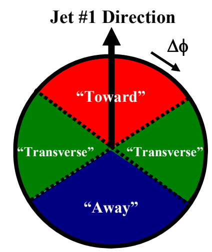
- **Data at 1.96 TeV on the charged *scalar* PTsum density, dPT/dηdϕ, with $p_T > 0.5$ GeV/c and $|\eta| < 1$ for "Z-Boson" and "Leading Jet" events as a function of the leading jet p_T or $P_T(Z)$ for the "toward", "away", and "transverse" regions. The data are corrected to the particle level (*with errors that include both the statistical error and the systematic uncertainty*) and are compared with PYTHIA Tune AW and Tune A, respectively, at the particle level (*i.e.* generator level).**

"Charged PTsum Density"



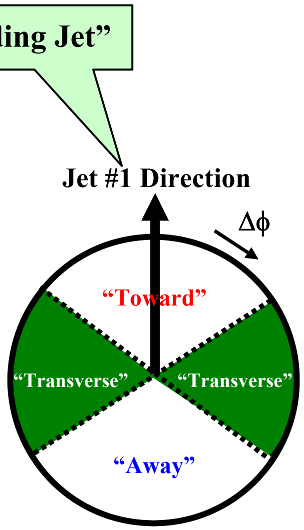


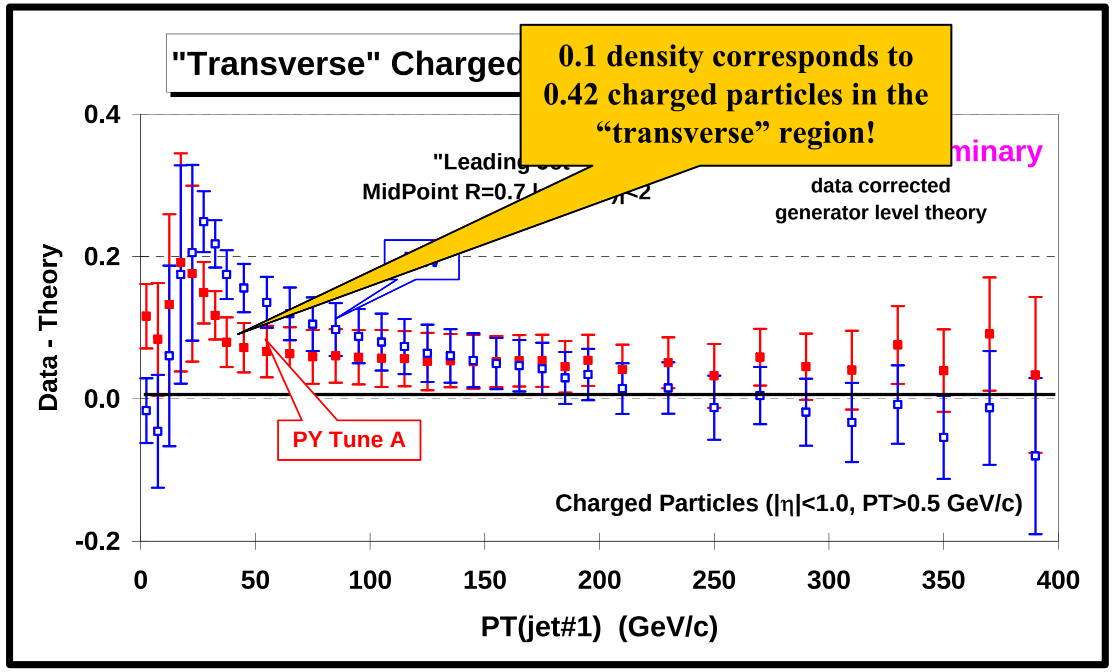




- **Data at 1.96 TeV on the charged *scalar* PTsum density, dPT/dηdϕ, with p_T > 0.5 GeV/c and |η| < 1 for "Z-Boson" and "Leading Jet" events as a function of the leading jet p_T or P_T(Z) for the "toward", "away", and "transverse" regions. The data are corrected to the particle level (*with errors that include both the statistical error and the systematic uncertainty*) and are compared with PYTHIA Tune AW and Tune A, respectively, at the particle level (*i.e.* generator level).**

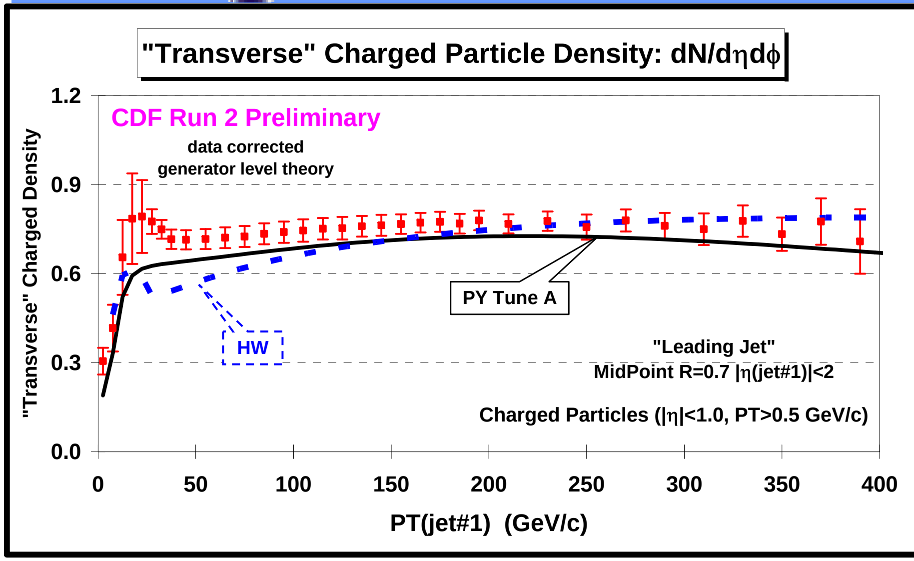
The "Transverse" Region

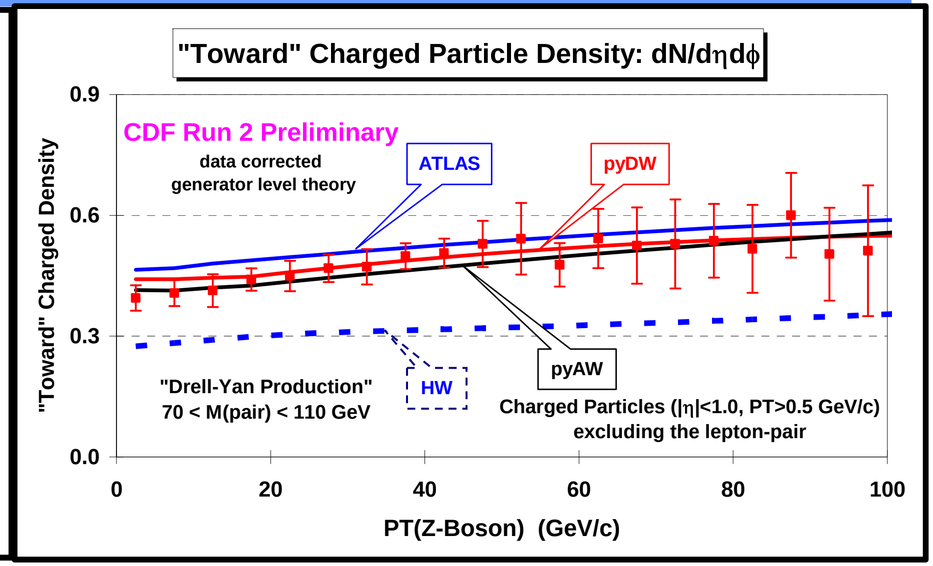


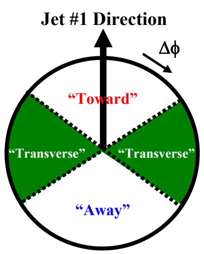


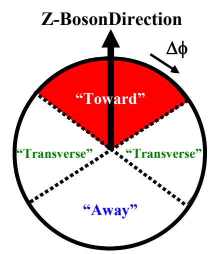
- Shows the Data - Theory for the density of charged particles, $dN/d\eta d\phi$, with $p_T > 0.5$ GeV/c and $|\eta| < 1$ for "leading jet" events as a function of the leading jet p_T for the "transverse" region for PYTHIA Tune A and HERWIG (without MPI).

"Charged Particle Density"



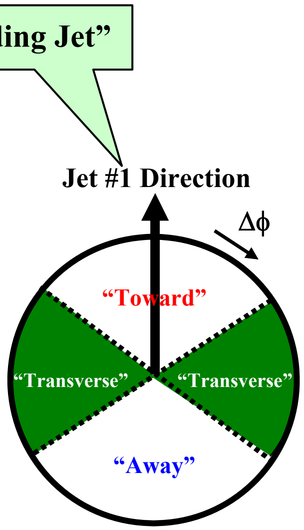


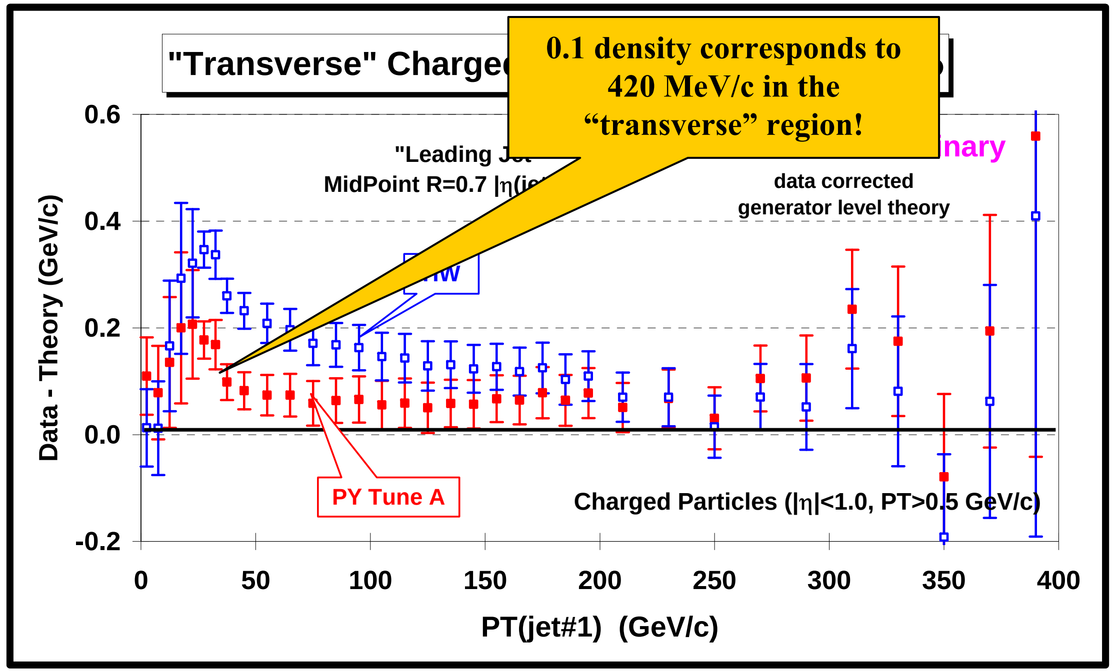




- **Data at 1.96 TeV on the density of charged particles, dN/dηdφ, with p_T > 0.5 GeV/c and |η| < 1 for the "toward" region for "Z-Boson" and the "transverse" region for "Leading Jet" events as a function of the leading jet p_T or P_T(Z). The data are corrected to the particle level (*with errors that include both the statistical error and the systematic uncertainty*) and are compared with PYTHIA Tune AW and Tune A, respectively, at the particle level (*i.e.* generator level). The Z-Boson data are also compared with PYTHIA Tune DW, the ATLAS tune, and HERWIG (without MPI)**

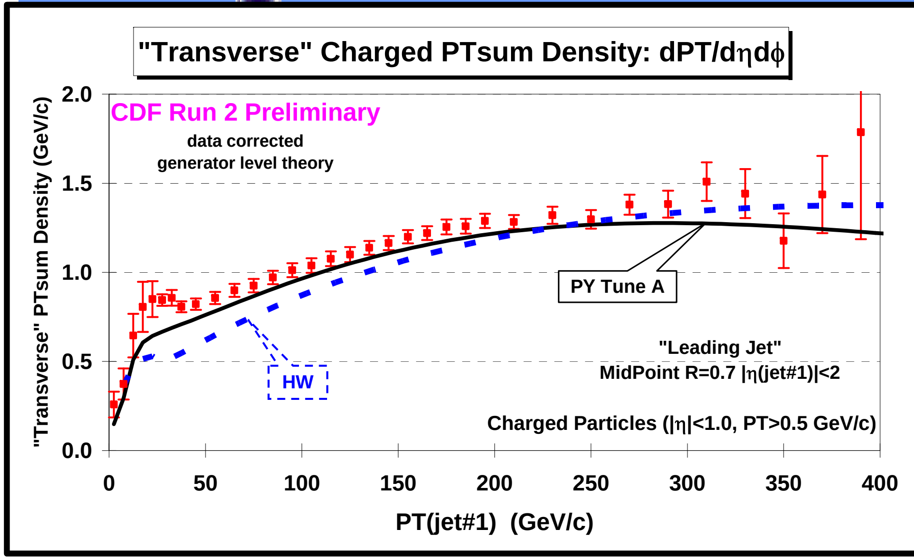
The "Transverse" Region

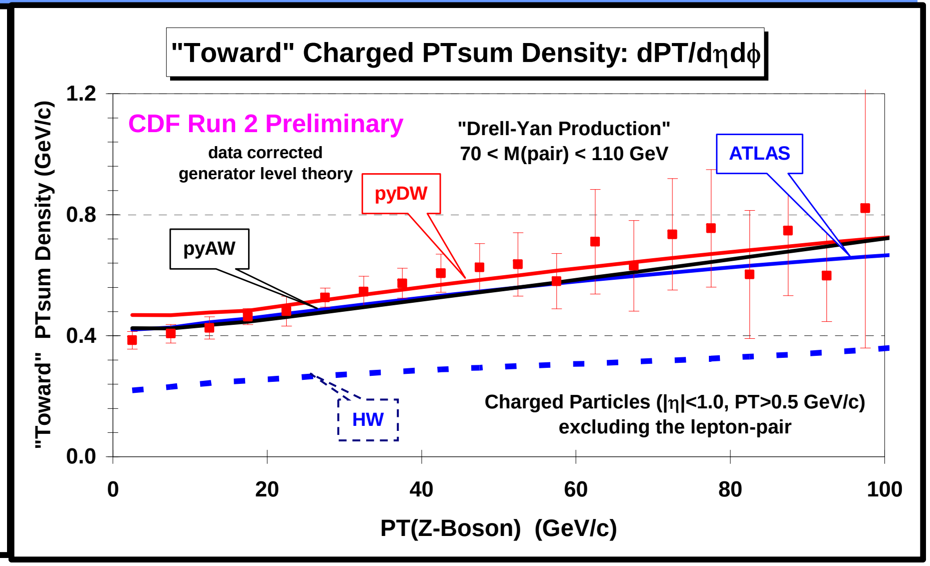


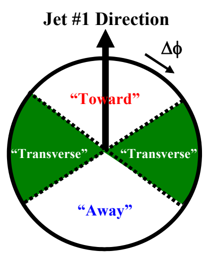


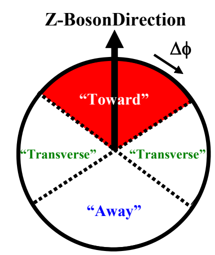
- Shows the Data - Theory for the charged *scalar* p_T sum density, $dPT/d\eta d\phi$, with $p_T > 0.5$ GeV/c and $|\eta| < 1$ for "leading jet" events as a function of the leading jet p_T for the "transverse" region for PYTHIA Tune A and HERWIG (without MPI).

“Charged PTsum Density”



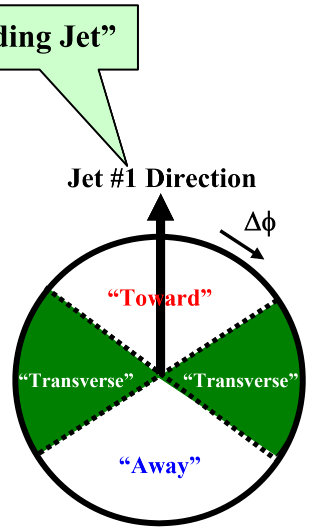


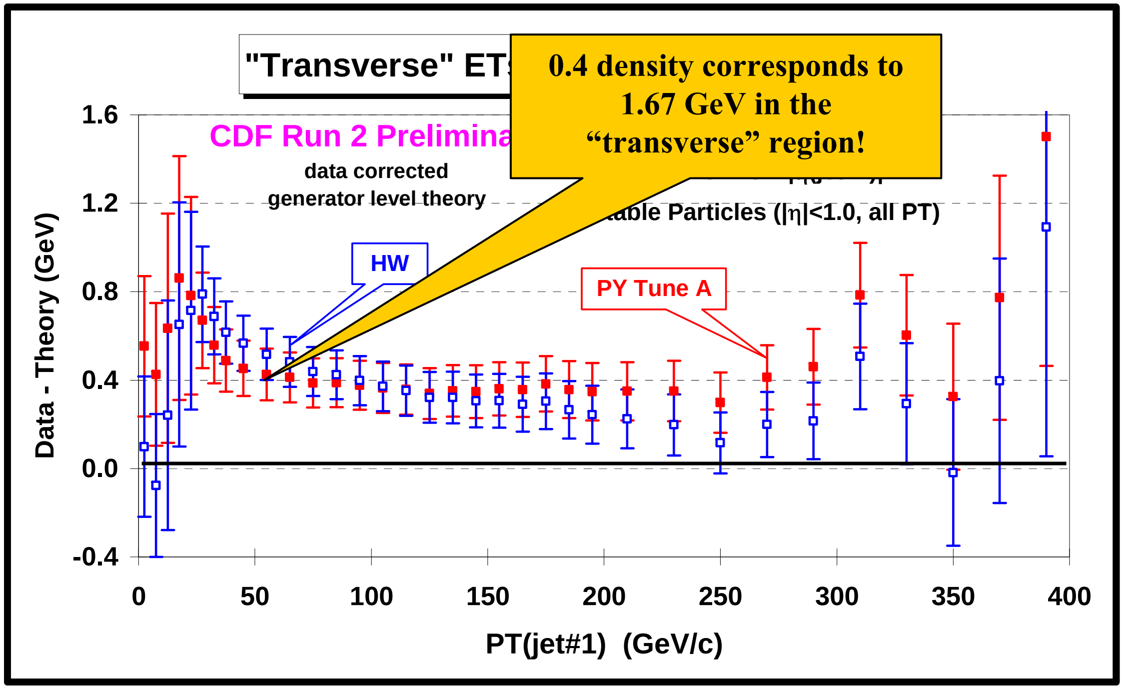




- Data at 1.96 TeV on the charged scalar PTsum density, dPT/dηdφ, with p_T > 0.5 GeV/c and |η| < 1 for the “toward” region for “Z-Boson” and the “transverse” region for “Leading Jet” events as a function of the leading jet p_T or P_T(Z). The data are corrected to the particle level (*with errors that include both the statistical error and the systematic uncertainty*) and are compared with PYTHIA Tune AW and Tune A, respectively, at the particle level (*i.e.* generator level). The Z-Boson data are also compared with PYTHIA Tune DW, the ATLAS tune, and HERWIG (without MPI)

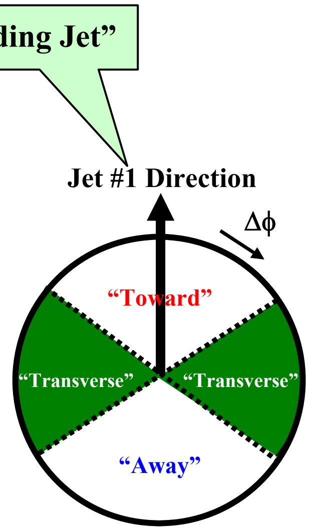
The “Transverse” Region

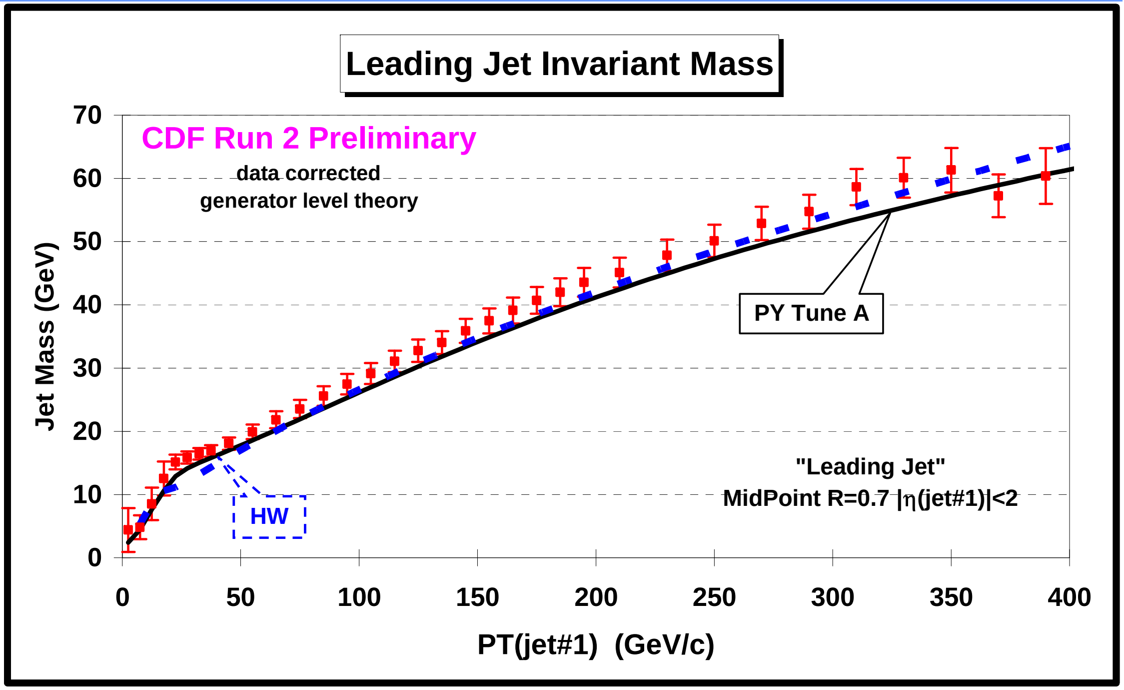




➡ Shows the Data - Theory for the *scalar* E_T sum density, dET/dηdϕ, with |η| < 1 for “leading jet” events as a function of the leading jet p_T for the “transverse” region for PYTHIA Tune A and HERWIG (without MPI).

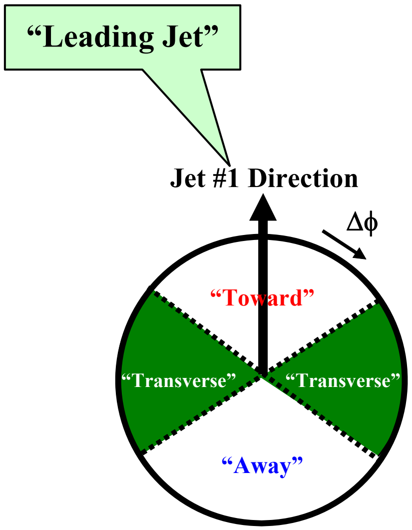
The Leading Jet Mass

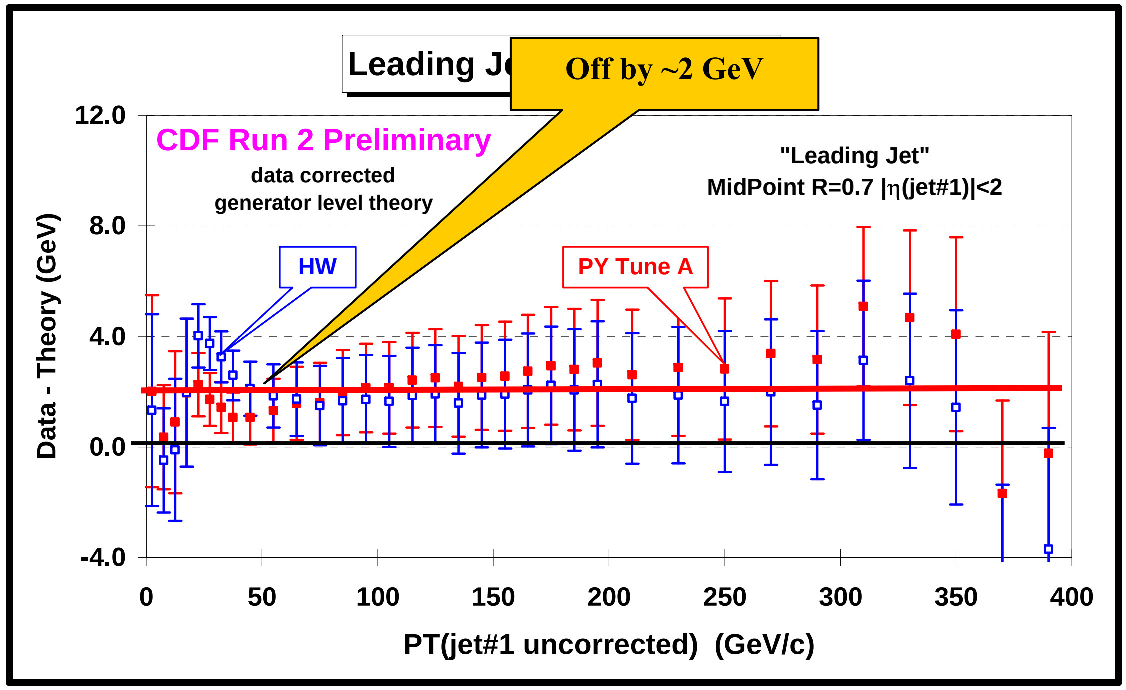




- **Shows the Data - Theory for the leading jet invariant mass for "leading jet" events as a function of the leading jet p_T for the "transverse" region for PYTHIA Tune A and HERWIG (without MPI).**

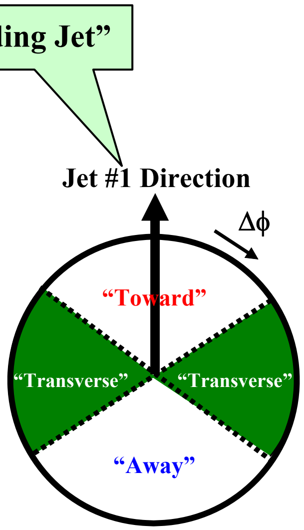
The Leading Jet Mass

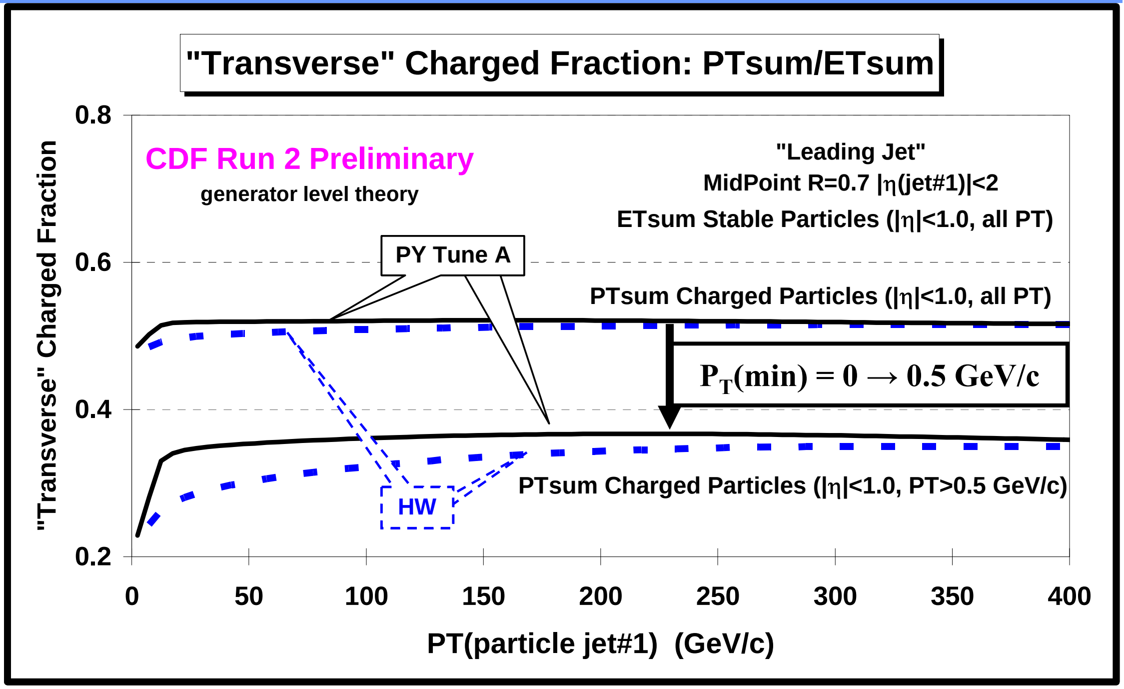




- Shows the Data - Theory for the leading jet invariant mass for "leading jet" events as a function of the leading jet p_T for the "transverse" region for PYTHIA Tune A and HERWIG (without MPI).

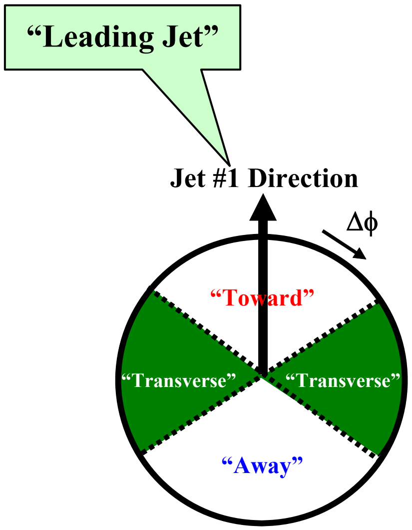
The “Transverse” Region

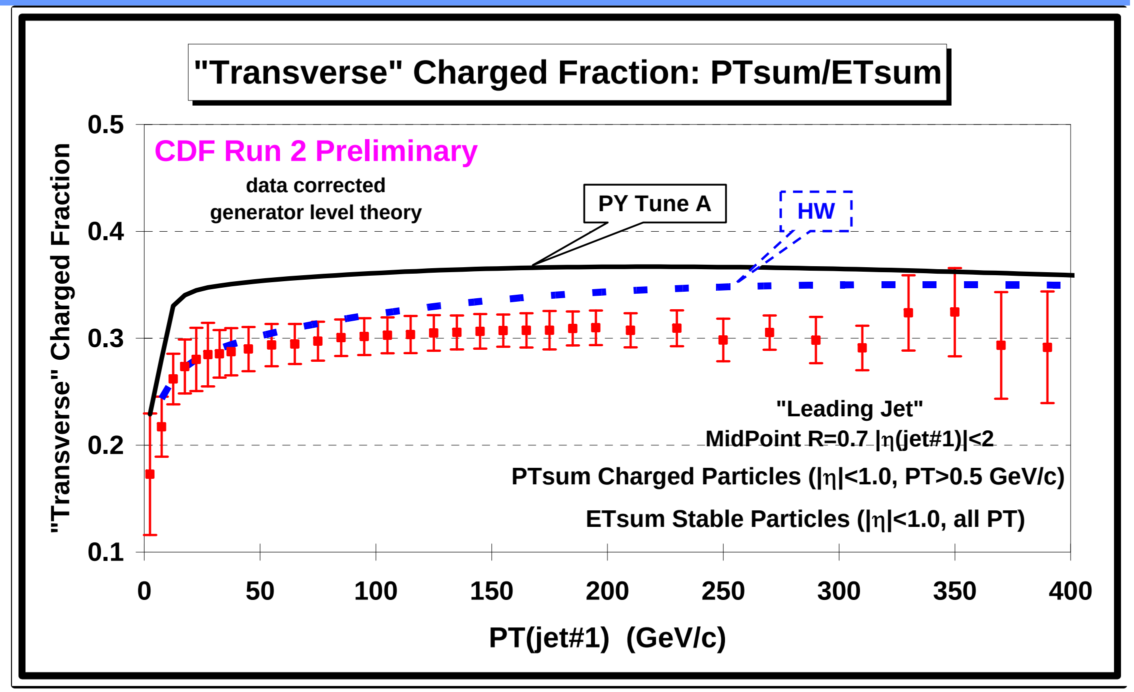




- Data at 1.96 TeV on the charged fraction, PTsum/ETsum, for PTsum ($p_T > 0.5$ GeV/c, $|\eta| < 1$) and ETsum (all p_T, $|\eta| < 1$) for “leading jet” events as a function of the leading jet p_T for the “transverse” region. The data are corrected to the particle level (*with errors that include both the statistical error and the systematic uncertainty*) and are compared with PYTHIA Tune A and HERWIG (without MPI) at the particle level (*i.e.* generator level).

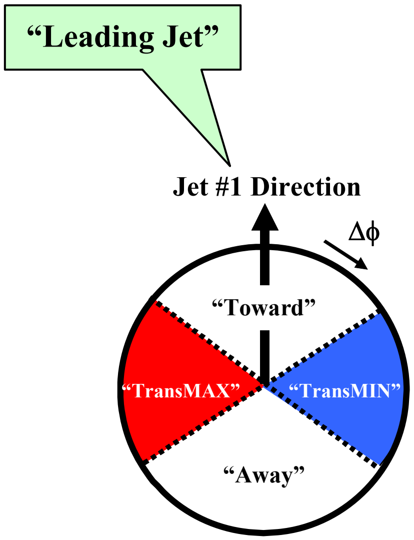
The “Transverse” Region

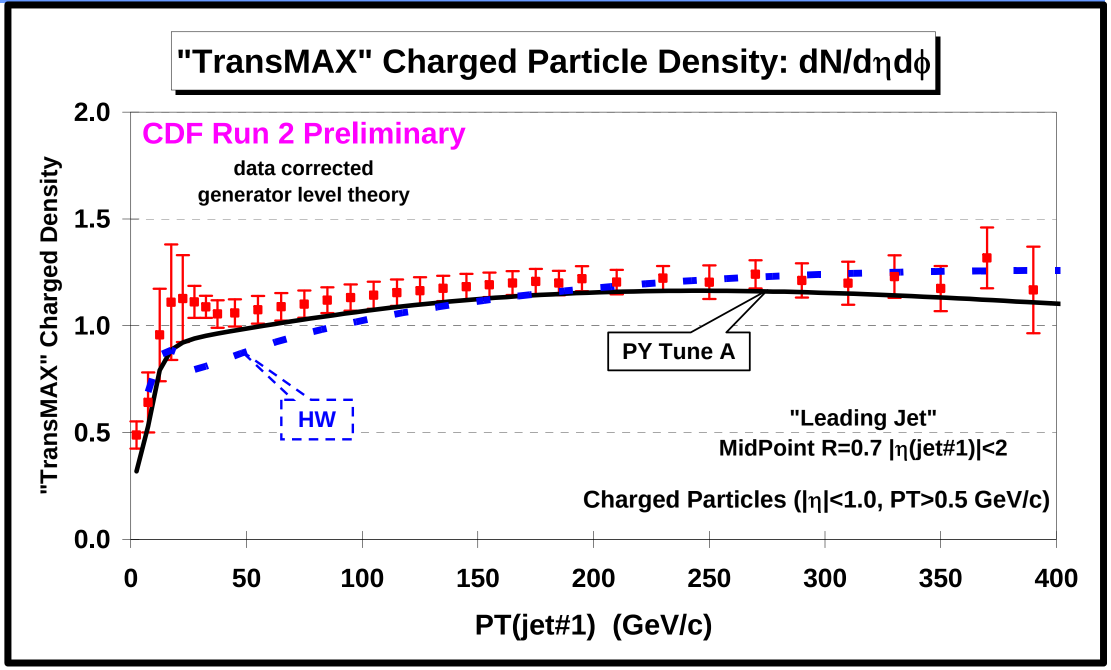




- Data at 1.96 TeV on the charged fraction, PTsum/ETsum, for PTsum (p_T > 0.5 GeV/c, $|\eta|$ < 1) and ETsum (all p_T, $|\eta|$ < 1) for “leading jet” events as a function of the leading jet p_T for the “transverse” region. The data are corrected to the particle level (*with errors that include both the statistical error and the systematic uncertainty*) and are compared with PYTHIA Tune A and HERWIG (without MPI) at the particle level (*i.e.* generator level).

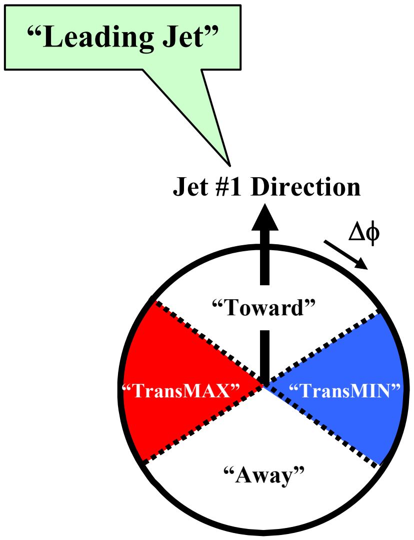
The "TransMAX/MIN" Regions

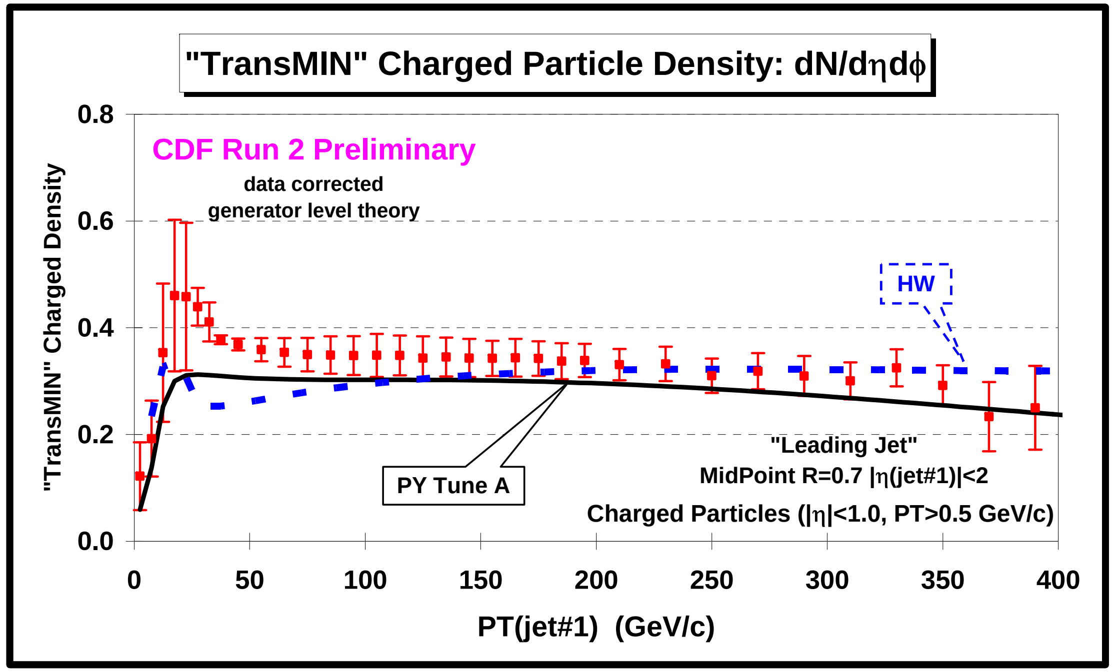




➡ **Data at 1.96 TeV on the density of charged particles, dN/dηdφ, with p_T > 0.5 GeV/c and |η| < 1 for "leading jet" events as a function of the leading jet p_T for the "transMAX" region. The data are corrected to the particle level (*with errors that include both the statistical error and the systematic uncertainty*) and are compared with PYTHIA Tune A and HERWIG (without MPI) at the particle level (*i.e.* generator level).**

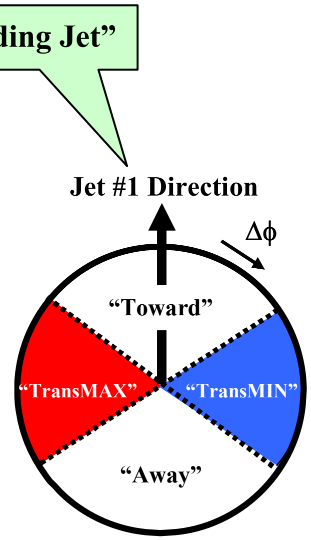
The “TransMAX/MIN” Regions

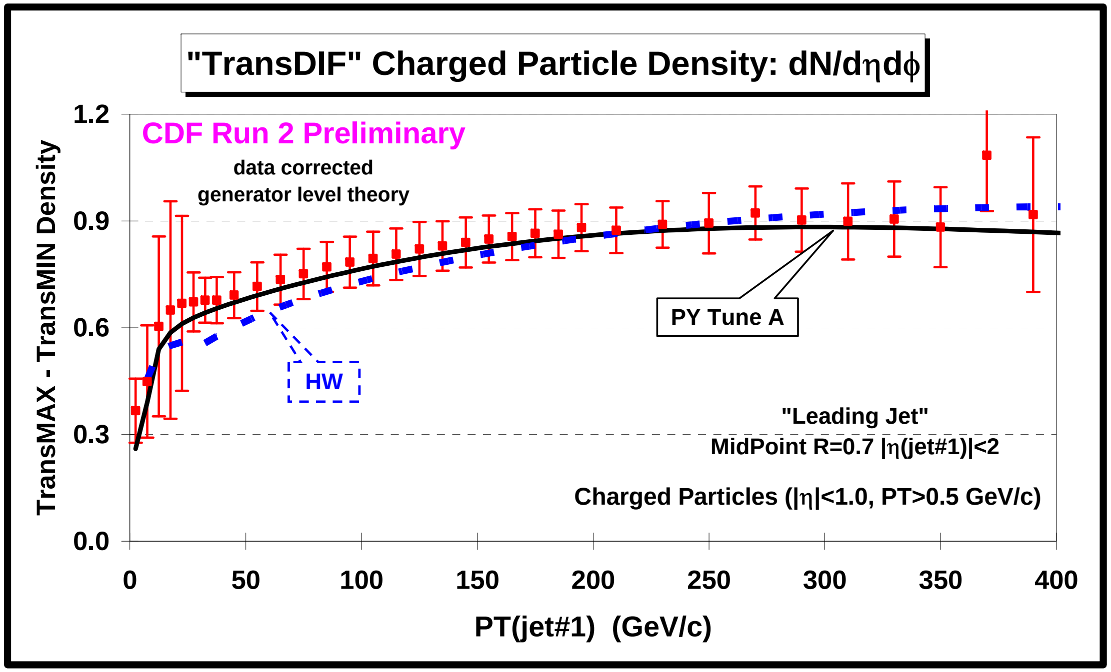




- Data at 1.96 TeV on the density of charged particles, dN/dηdφ, with $p_T > 0.5$ GeV/c and $|\eta| < 1$ for “leading jet” events as a function of the leading jet p_T for the “transMIN” region. The data are corrected to the particle level (*with errors that include both the statistical error and the systematic uncertainty*) and are compared with PYTHIA Tune A and HERWIG (without MPI) at the particle level (*i.e.* generator level).

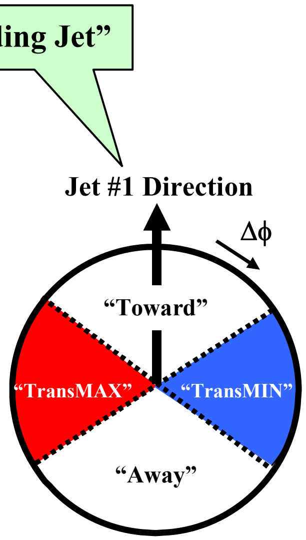
The "TransMAX/MIN" Regions

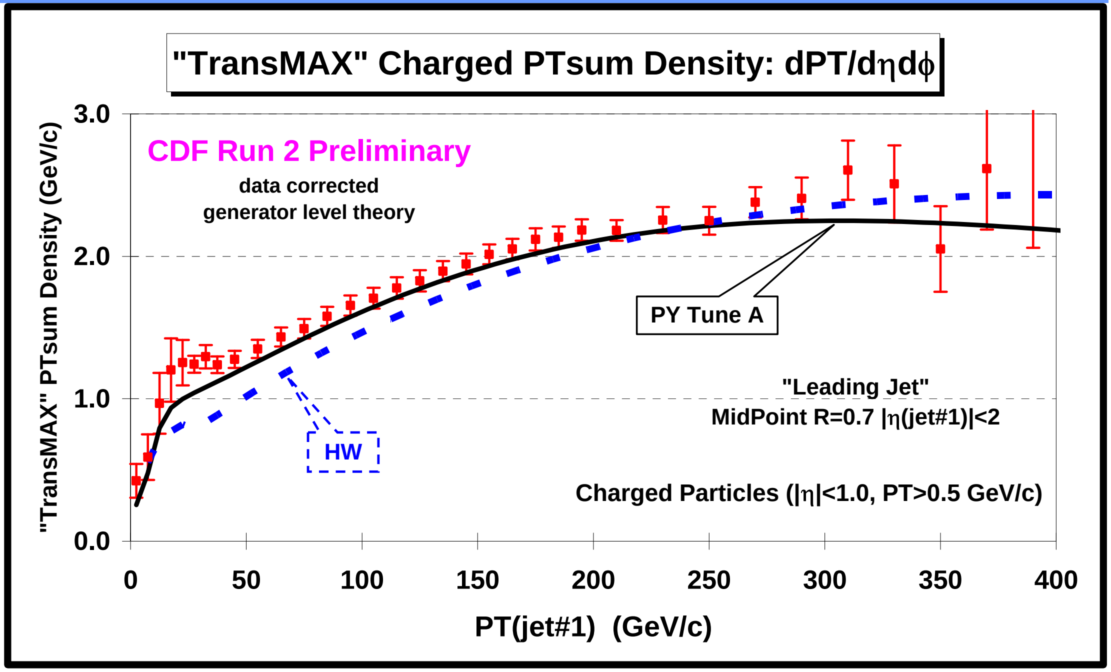




- **Data at 1.96 TeV on the density of charged particles, dN/dηdϕ, with p_T > 0.5 GeV/c and |η| < 1 for "leading jet" events as a function of the leading jet p_T for "transDIF" = "transMAX"-"transMIN. The data are corrected to the particle level (*with errors that include both the statistical error and the systematic uncertainty*) and are compared with PYTHIA Tune A and HERWIG (without MPI) at the particle level (*i.e.* generator level).**

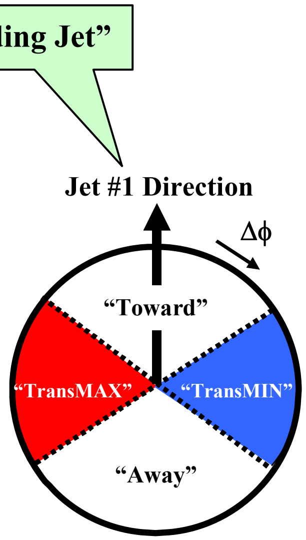
The “TransMAX/MIN” Regions

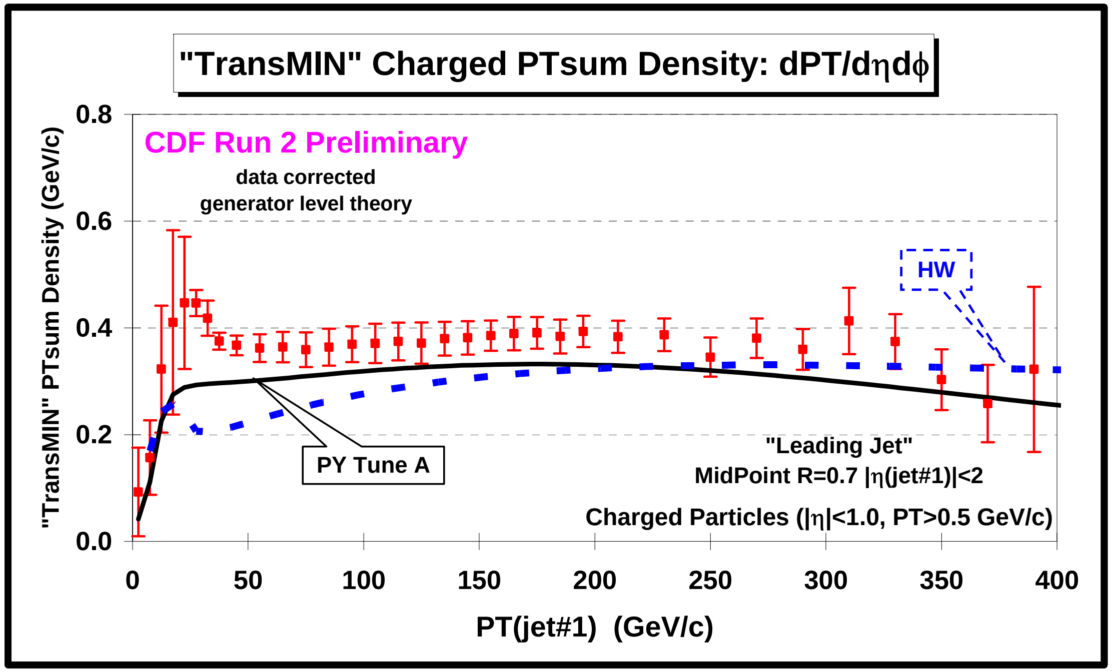




- Data at 1.96 TeV on the charged *scalar* p_T sum density, dPT/dηdϕ, with $p_T > 0.5$ GeV/c and $|\eta| < 1$ for “leading jet” events as a function of the leading jet p_T for the “transMAX” region. The data are corrected to the particle level (*with errors that include both the statistical error and the systematic uncertainty*) and are compared with PYTHIA Tune A and HERWIG (without MPI) at the particle level (*i.e.* generator level).

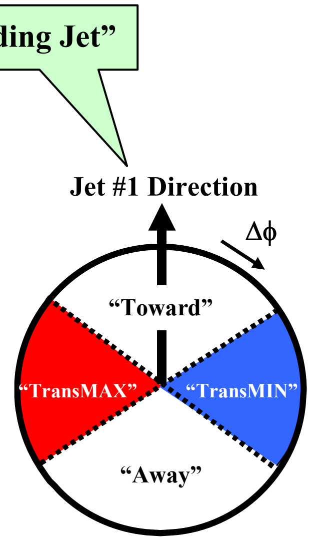
The "TransMAX/MIN" Regions

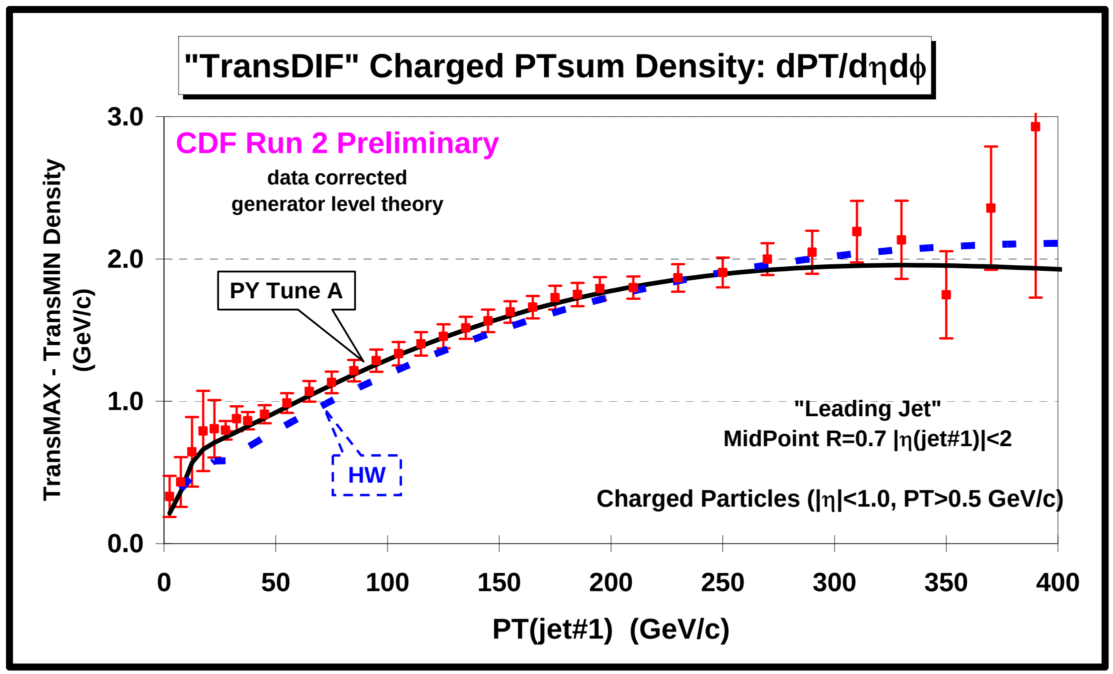




- Data at 1.96 TeV on the charged *scalar* p_T sum density, dPT/dηdϕ, with $p_T > 0.5$ GeV/c and $|\eta| < 1$ for "leading jet" events as a function of the leading jet p_T for the "transMIN" region. The data are corrected to the particle level (*with errors that include both the statistical error and the systematic uncertainty*) and are compared with PYTHIA Tune A and HERWIG (without MPI) at the particle level (*i.e.* generator level).

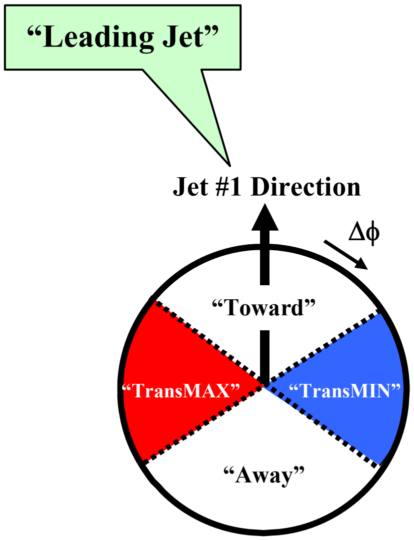
The "TransMAX/MIN" Regions

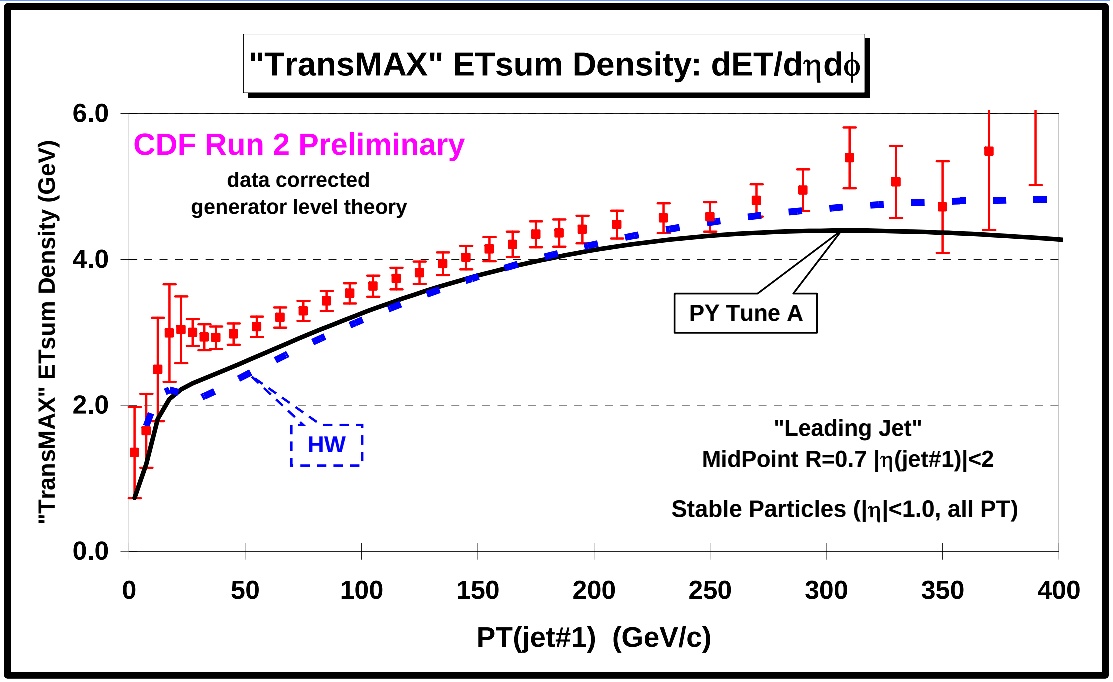




- **Data at 1.96 TeV on the charged *scalar* p_T sum density, dPT/dηdϕ, with p_T > 0.5 GeV/c and |η| < 1 for "leading jet" events as a function of the leading jet p_T for "transDIF" = "transMAX"-"transMIN". The data are corrected to the particle level (*with errors that include both the statistical error and the systematic uncertainty*) and are compared with PYTHIA Tune A and HERWIG (without MPI) at the particle level (*i.e.* generator level).**

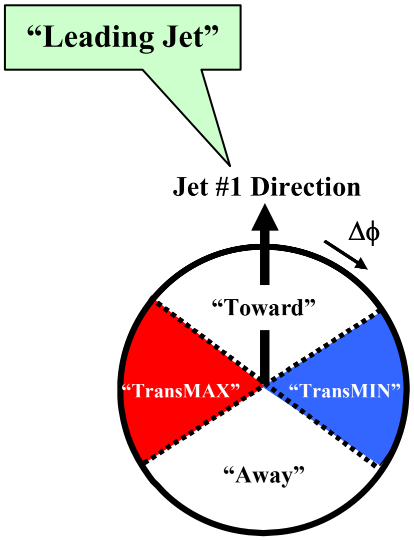
The "TransMAX/MIN" Regions

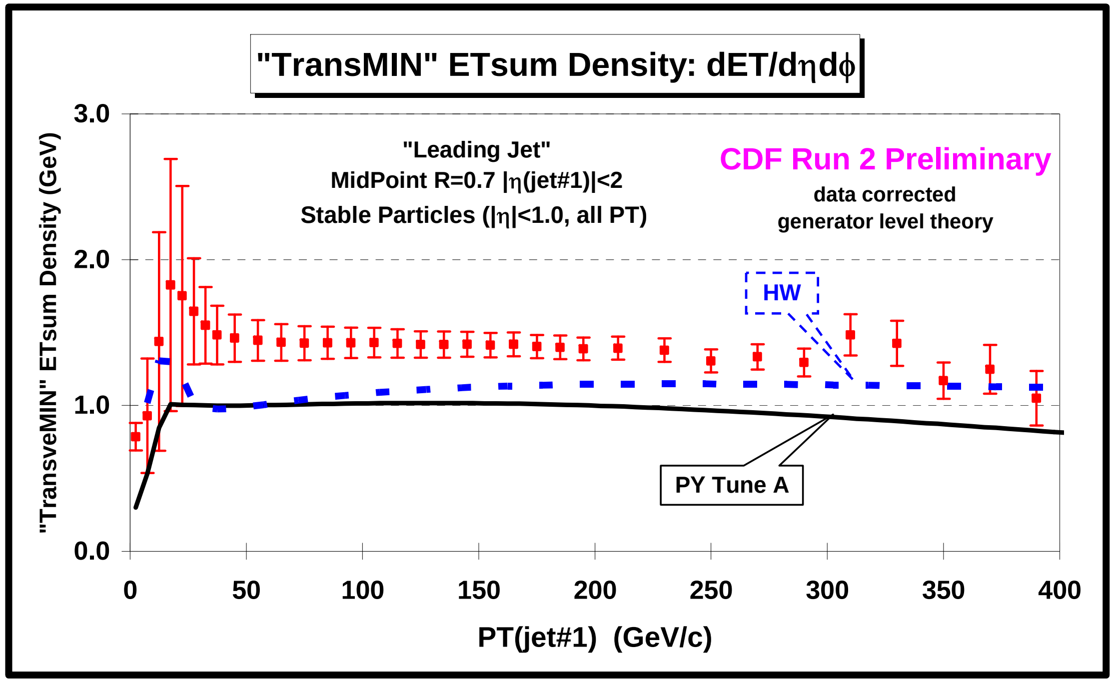




- **Data at 1.96 TeV on the *scalar* E_T sum density, dET/dηdφ, with |η| < 1 for "leading jet" events as a function of the leading jet p_T for the "transMAX" region. The data are corrected to the particle level (*with errors that include both the statistical error and the systematic uncertainty*) and are compared with PYTHIA Tune A and HERWIG (without MPI) at the particle level (*i.e.* generator level).**

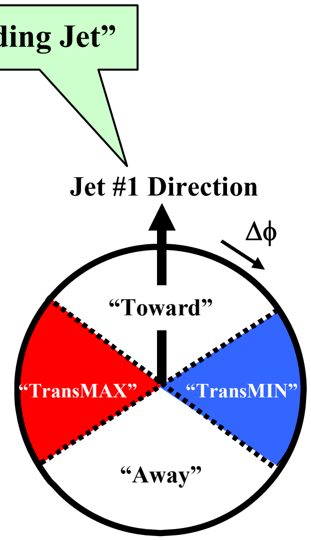
The "TransMAX/MIN" Regions

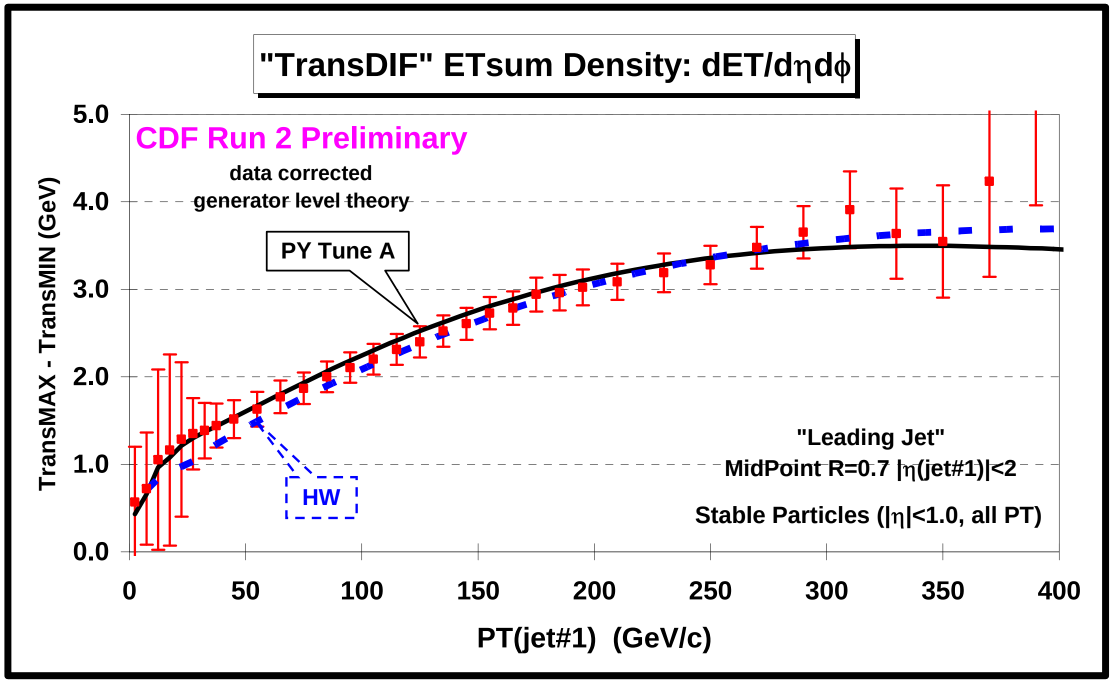




- Data at 1.96 TeV on the *scalar* E_T sum density, dET/dηdφ, with |η| < 1 for "leading jet" events as a function of the leading jet p_T for the **"transMIN"** region. The data are corrected to the particle level (*with errors that include both the statistical error and the systematic uncertainty*) and are compared with PYTHIA Tune A and HERWIG (without MPI) at the particle level (*i.e.* generator level).

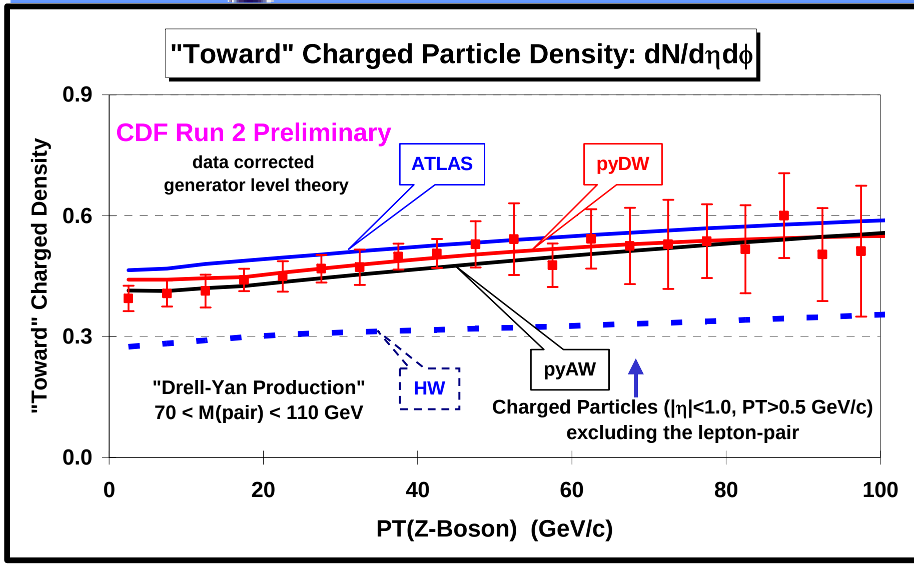
The "TransMAX/MIN" Regions

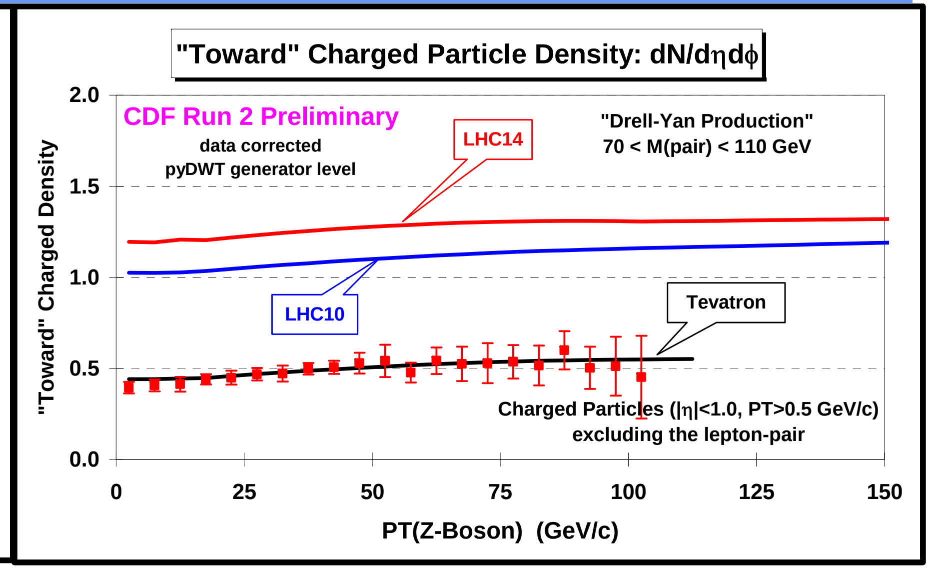


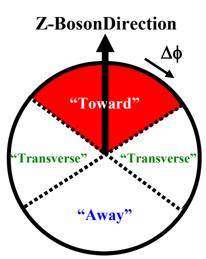


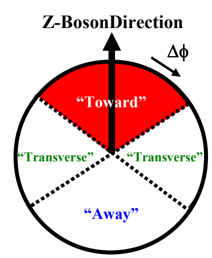
- Data at 1.96 TeV on the *scalar* E_T sum density, dET/dηdϕ, with |η| < 1 for "leading jet" events as a function of the leading jet p_T for "transDIF" = "transMAX"-"transMIN". The data are corrected to the particle level (*with errors that include both the statistical error and the systematic uncertainty*) and are compared with PYTHIA Tune A and HERWIG (without MPI) at the particle level (*i.e.* generator level).

Z-Boson: "Towards" Region



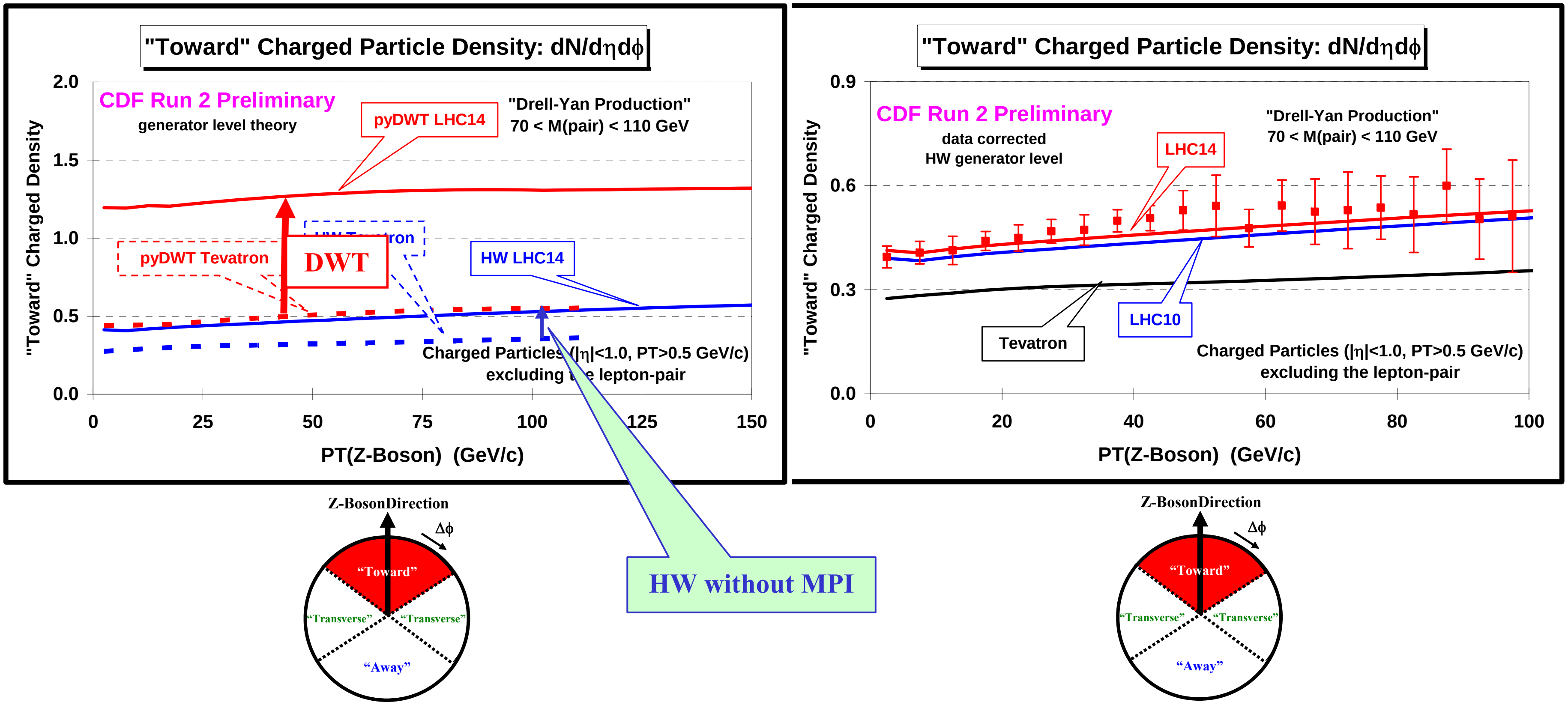






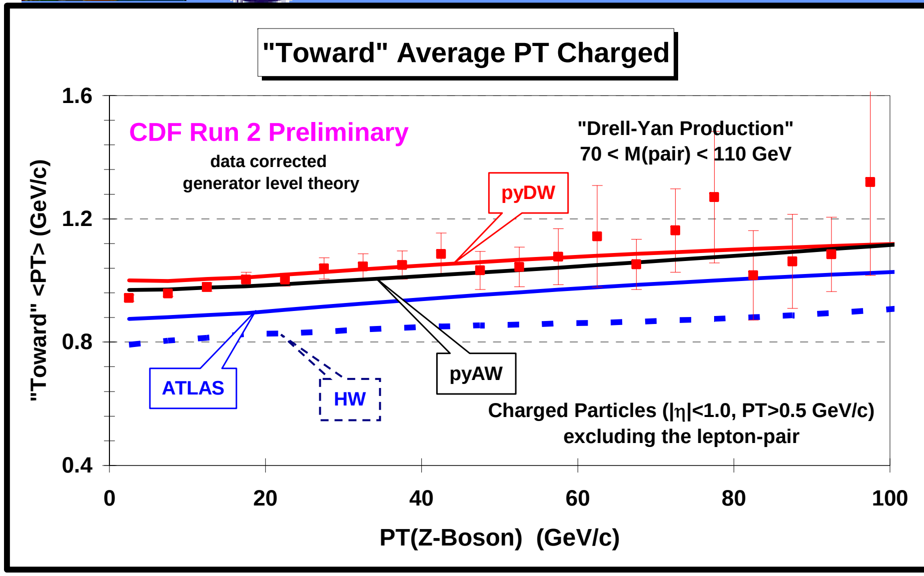
- **Data at 1.96 TeV on the density of charged particles, dN/dηdϕ, with p_T > 0.5 GeV/c and |η| < 1 for "Z-Boson" events as a function of P_T(Z) for the "toward" region. The data are corrected to the particle level (*with errors that include both the statistical error and the systematic uncertainty*) and are compared with PYTHIA Tune AW and HERWIG (without MPI) at the particle level (*i.e.* generator level).**

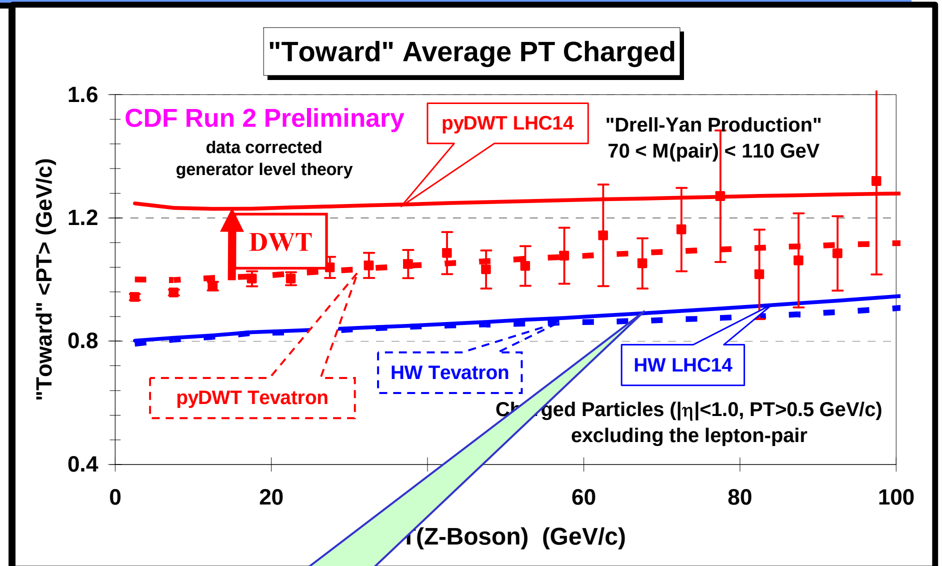
Z-Boson: "Towards" Region



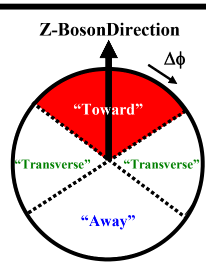
- **Data at 1.96 TeV on the density of charged particles, dN/dηdφ, with p_T > 0.5 GeV/c and |η| < 1 for "Z-Boson" events as a function of $P_T(Z)$ for the "toward" region. The data are corrected to the particle level (*with errors that include both the statistical error and the systematic uncertainty*) and are compared with PYTHIA Tune AW and HERWIG (without MPI) at the particle level (*i.e.* generator level).**

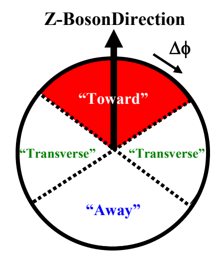
Z-Boson: "Towards" Region





HW (without MPI)
almost no change!

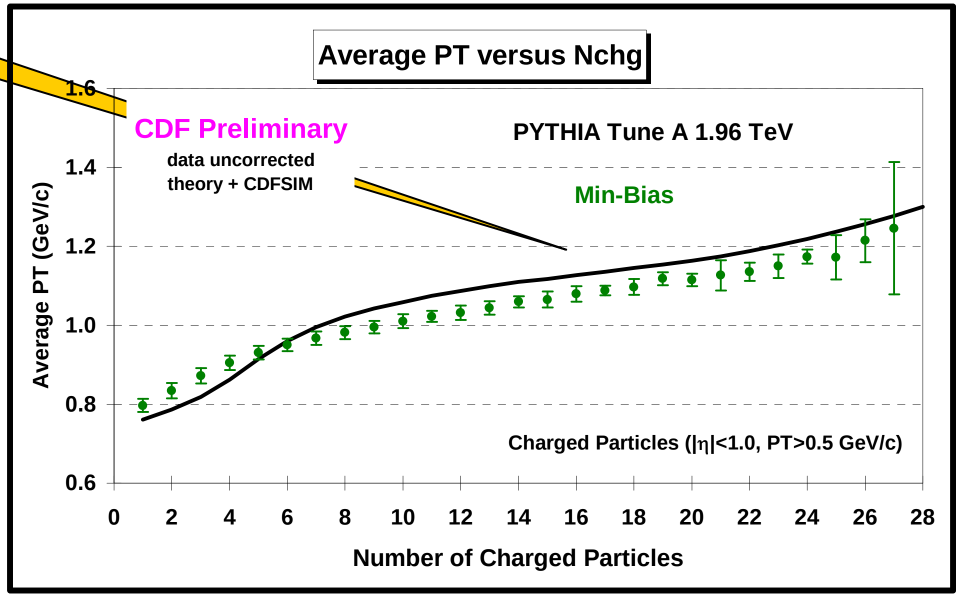




- **Data at 1.96 TeV on the average p_T of charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 1$ for "Z-Boson" events as a function of $P_T(Z)$ for the "toward" region. The data are corrected to the particle level (*with errors that include both the statistical error and the systematic uncertainty*) and are compared with PYTHIA Tune AW and HERWIG (without MPI) at the particle level (*i.e.* generator level).**

Charged <P_T> versus Nchg

The charged <PT> rises with Nchg!



- **Shows the average transverse momentum of charged particles (|η|<1, p_T>0.5 GeV) versus the number of charged particles, Nchg, at the detector level for the CDF Run 2 Min-Bias events.**

Charged <P_T> versus Nchg

The charged <PT> rises with Nchg!

Average PT versus Nchg

Non-perturbative QCD Effects and the Top Mass at the Tevatron

Peter Skands
Fermi National Accelerator Laboratory, Batavia, IL 60510-0500, USA

Daniel Wicke
Bergische Universität Wuppertal, Germany

(Dated: February 23, 2007)

The naive expectation from an uncorrelated system of strings decaying to hadrons would be that $\langle p_\perp \rangle$ should be independent of N_{ch}, and to first approximation equal to the LEP fragmentation $p_\perp$ width, the non-perturbative component of which is $\langle p_\perp \rangle_{NP} \sim 0.36$ GeV (in PYTHIA). Already at Sp$\bar{p}$S, however, and more recently at RHIC and the Tevatron, such a behaviour has been convincingly ruled out. Currently, models which successfully describe the $\langle p_\perp \rangle (N_{ch})$ distribution, such as R. Field's 'Tune A' and others [12, 13, 16], do so by incorporating very strong ad hoc correlations between final-state partons from different interactions. We emphasise that these correlations are not chosen at random but are constructed to minimise the resulting string length, i.e. similarly to our models here. Thus, although colour reconnections are not explicitly part of these models, an implicit effect with similar consequences is still needed, at a seemingly large magnitude. This observation alone serves as a significant part of the motivation for our study.

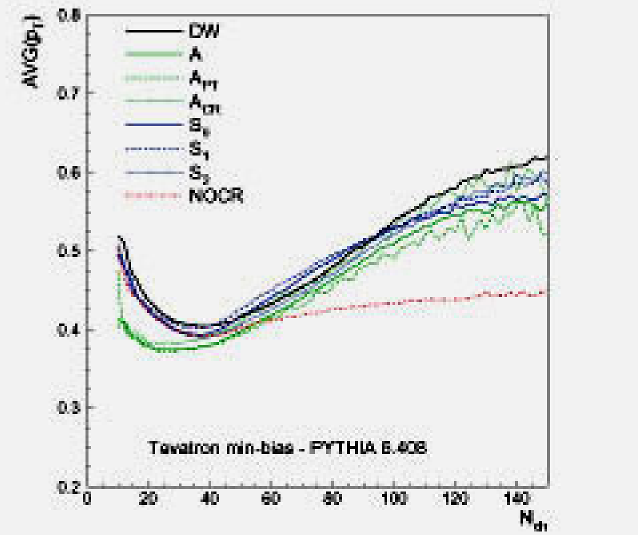
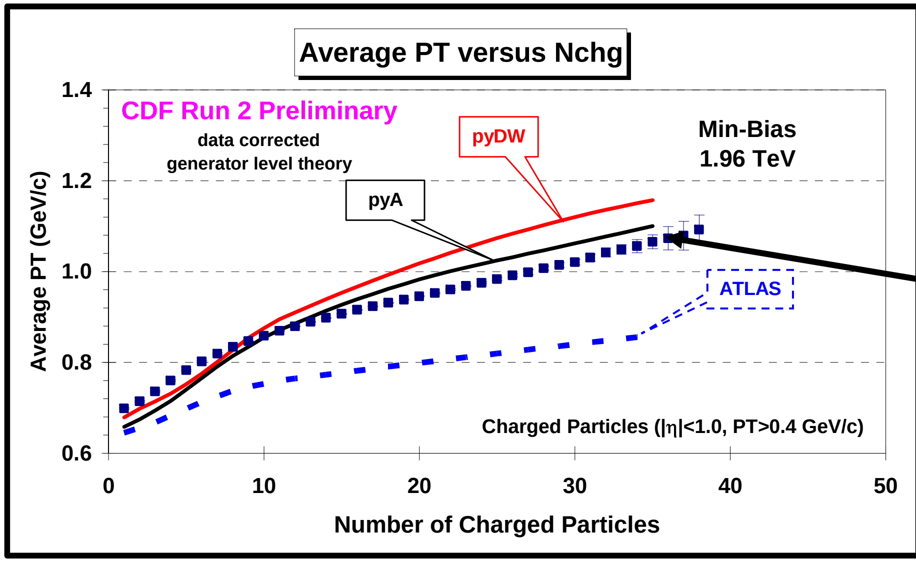
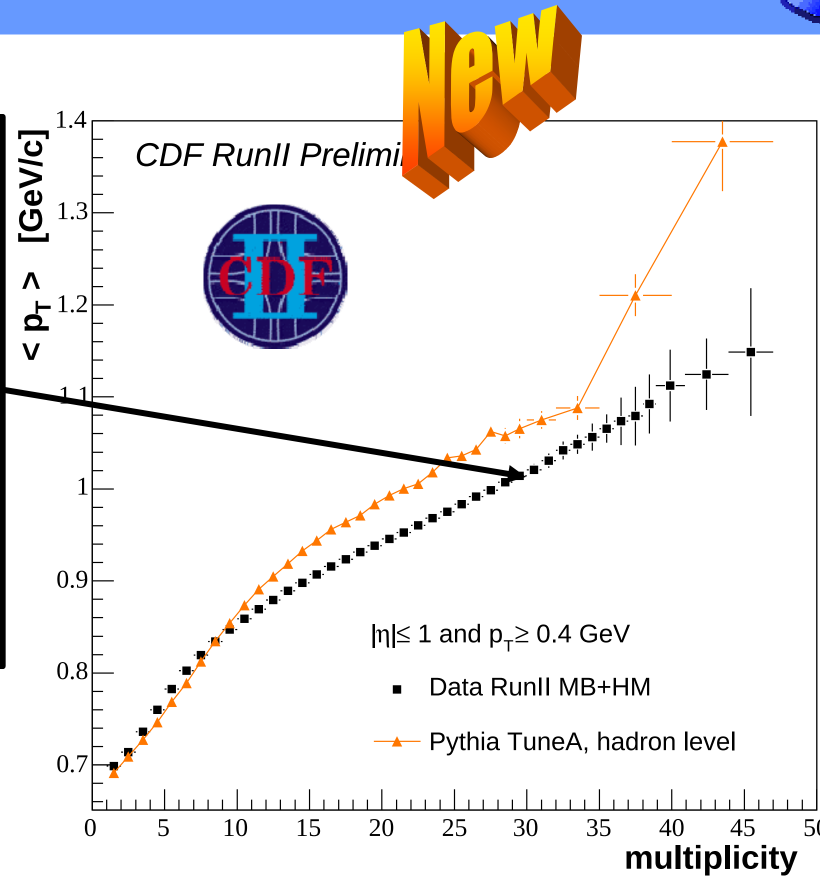


FIG. 1: Comparison of the models/tunes discussed in the text. Inelastic non-diffractive (min-bias) events in $p\bar{p}$ collisions at $\sqrt{s} = 1960$ GeV. Top: Charged multiplicity distribution. Bottom: mean $p_\perp$ as a function of charged multiplicity.

- **Shows the a... versus the n... 2 Min-Bias events.**

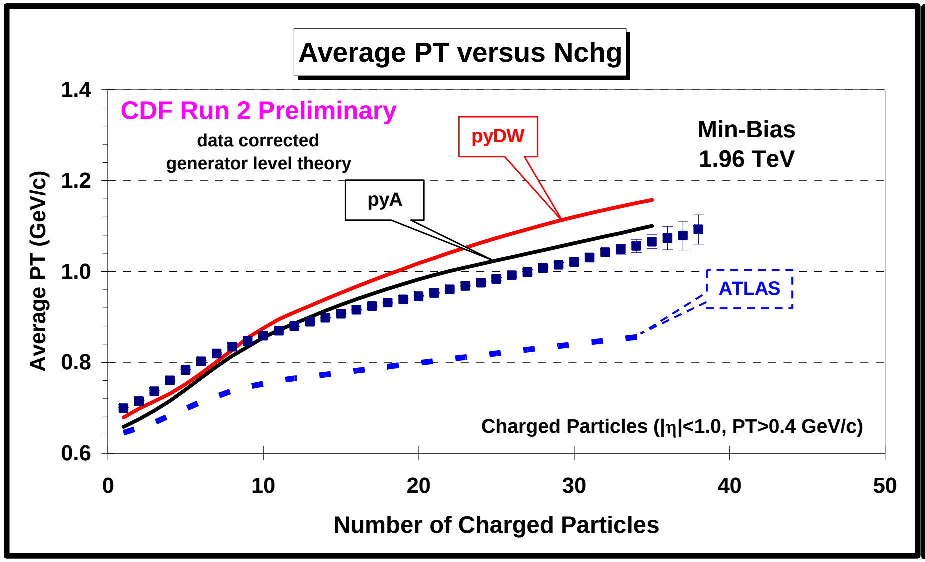
Min-Bias Correlations

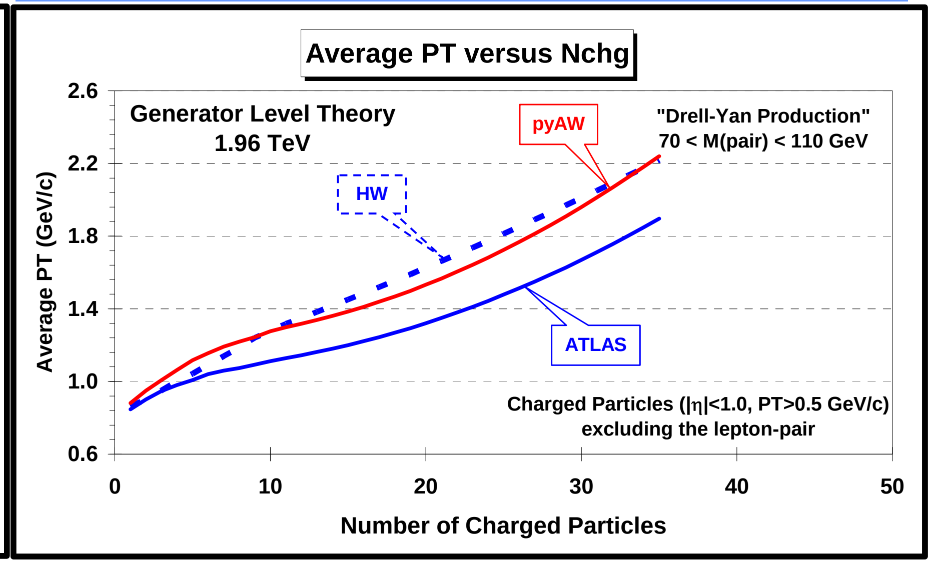


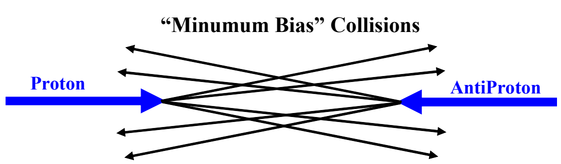


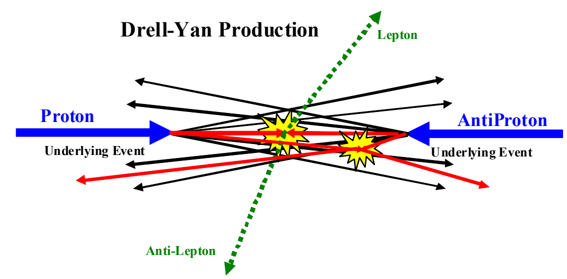
- Data at 1.96 TeV on the average p_T of charged particles versus the number of charged particles (p_T > 0.4 GeV/c, $|\eta| < 1$) for "min-bias" collisions at CDF Run 2. The data are corrected to the particle level and are compared with PYTHIA Tune A at the particle level (*i.e.* generator level).

Average PT versus Nchg





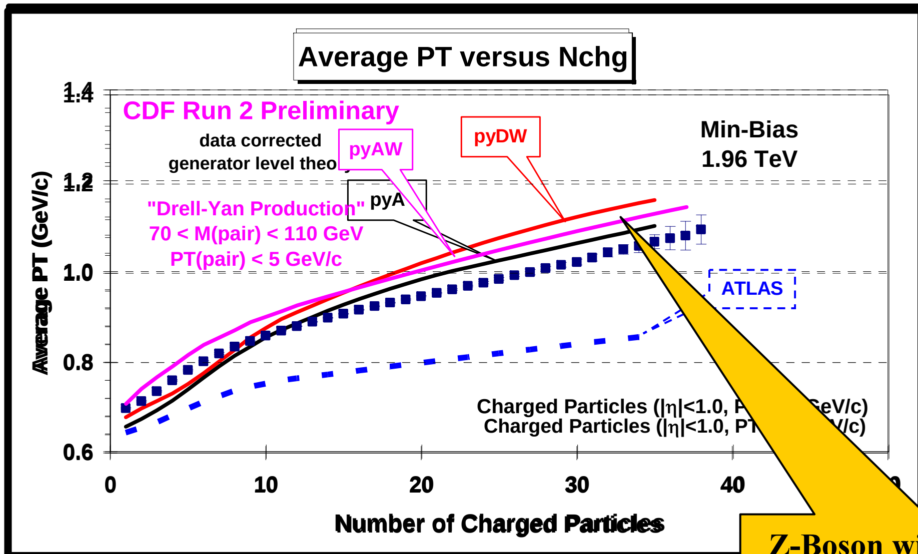


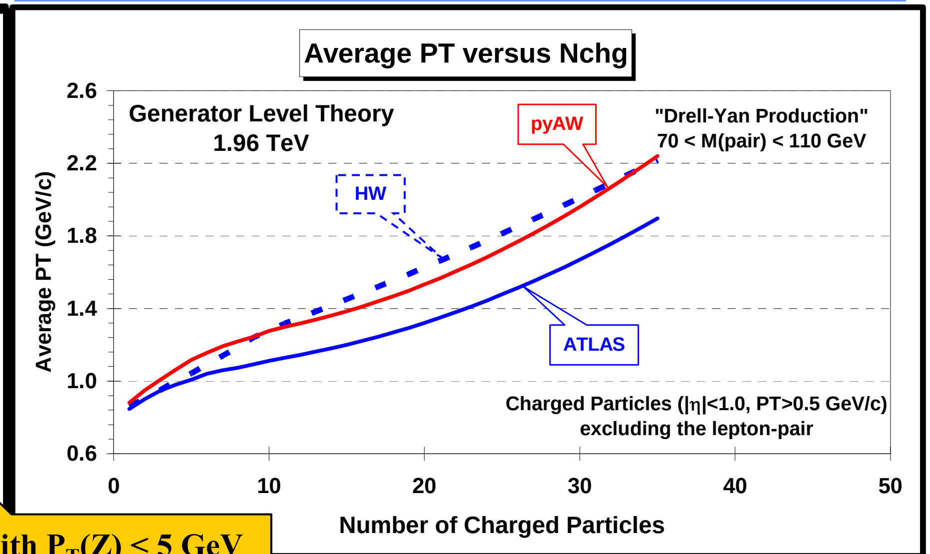


- **Data at 1.96 TeV on the average p_T of charged particles versus the number of charged particles (p_T > 0.4 GeV/c, |η| < 1) for "min-bias" collisions at CDF Run 2. The data are corrected to the particle leveland are compared with PYTHIA Tune A, Tune DW, and the ATLAS tune at the particle level (*i.e.* generator level).**

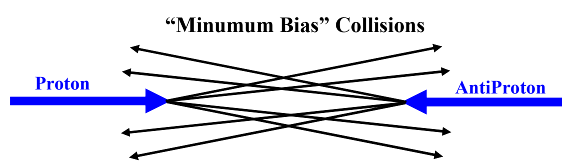
- **Particle level predictions for the average p_T of charged particles versus the number of charged particles (p_T > 0.5 GeV/c, |η| < 1, excluding the lepton-pair) for for Drell-Yan production (70 < M(pair) < 110 GeV) at CDF Run 2.**

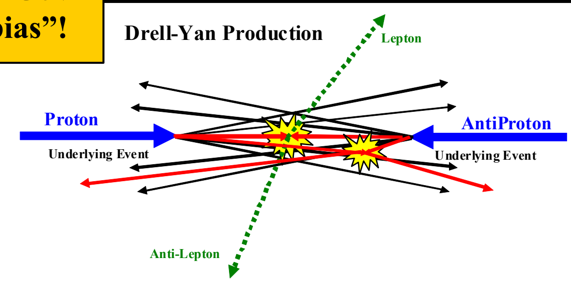
Average PT versus Nchg





Z-Boson with $P_T(Z) < 5$ GeV compared with "min-bias"!





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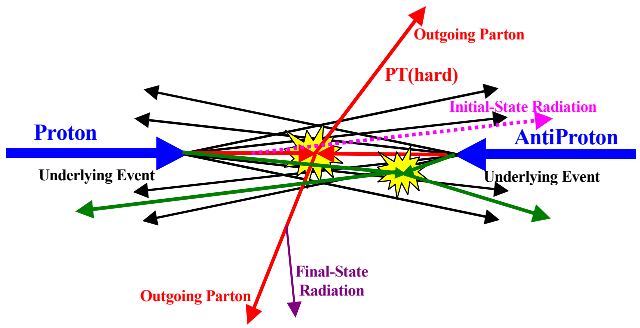
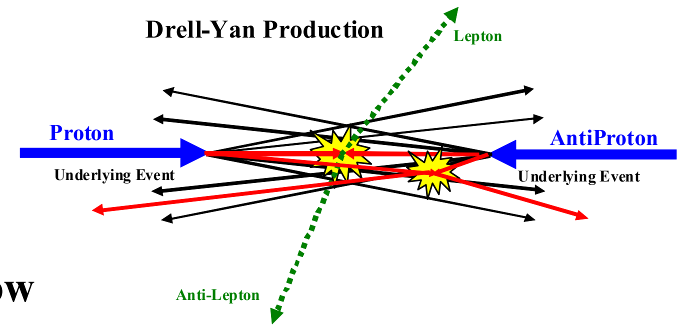
Summary

- It is important to produce a lot of plots (*corrected to the particle level*) so that the theorists can tune and improve the QCD Monte-Carlo models. If they improve the “transverse” region they might miss-up the “toward” region etc.. We need to show the whole story!
- We are making good progress in understanding and modeling the “underlying event” in jet production and in Drell-Yan. Tune A and Tune AW describe the data very well, although not perfect. However, we do not yet have a perfect fit to all the features of the CDF “underlying event” data!



- Perhaps looking at <pT> versus Nchg in Drell-Yan with 70 < Mpair) < 110 GeV and P_T(pair) < 5 GeV is a good way to look at the color connections. Data coming soon!



- There are over 128 plots to get “blessed” and then to published. So far we have only looked at average quantities. We plan to also produce distributions and flow plots.
- I plan to construct a “CDF-QCD Data for Theory” WEBsite with the “blessed” plots together with tables of the data points and errors so that people can have access to the results .

CDF-QCD Data for Theory