Multiple Parton Interactions and the Underlying Event

Session I: Experiment

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(for the CDF & CMS Collaborations)

DESY, May 18-19 2007

Some Topics

What do we know about the soft underlying event?

What do we know about hard multiple interactions?

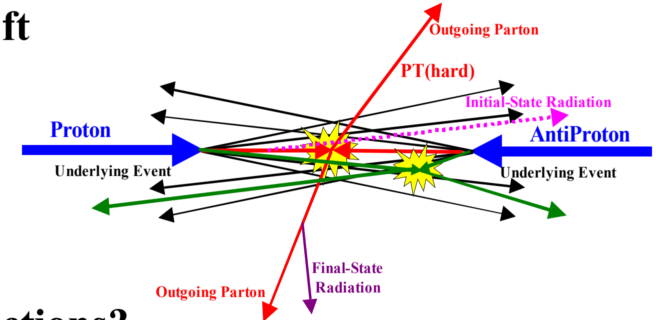
What about correlations?

What is needed for LHC predictions?

Monte-Carlo underlying event tunes.

What are the measurements needed to better understand MPI?

- Can HERA Contribute?
- What other Tevatron measurements do we need?



Quantum
Chromo-
Dynamics

Contributors

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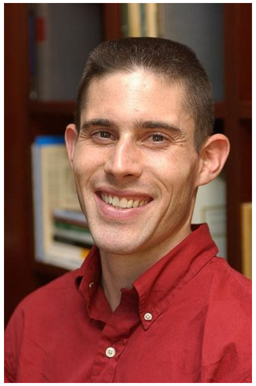
MIT Search Scheme: Vista/Sleuth

Exclusive 3 Jet Final State Challenge



Bruce Knuteson

At least 1 Jet ("trigger" jet)

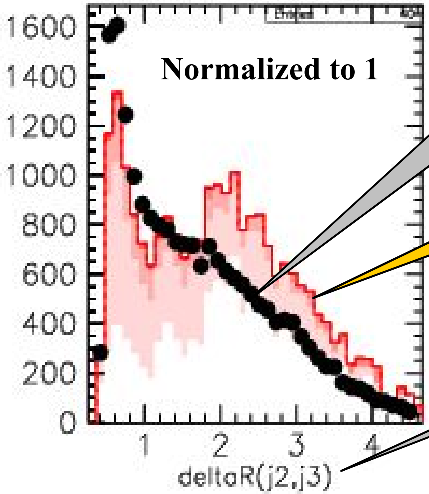
($P_T > 40$ GeV/c, $|\eta| < 1.0$)

Exactly 3 jets

($P_T > 20$ GeV/c, $|\eta| < 2.5$)

Order Jets by P_T

Jet1 highest P_T, etc.



CDF Data

PYTHIA Tune A

R(j2,j3)

Khaldoun Makhoul

Georgios Choudalakis

Markus Klute

Conor Henderson

Ray Culbertson

Gene Flanagan

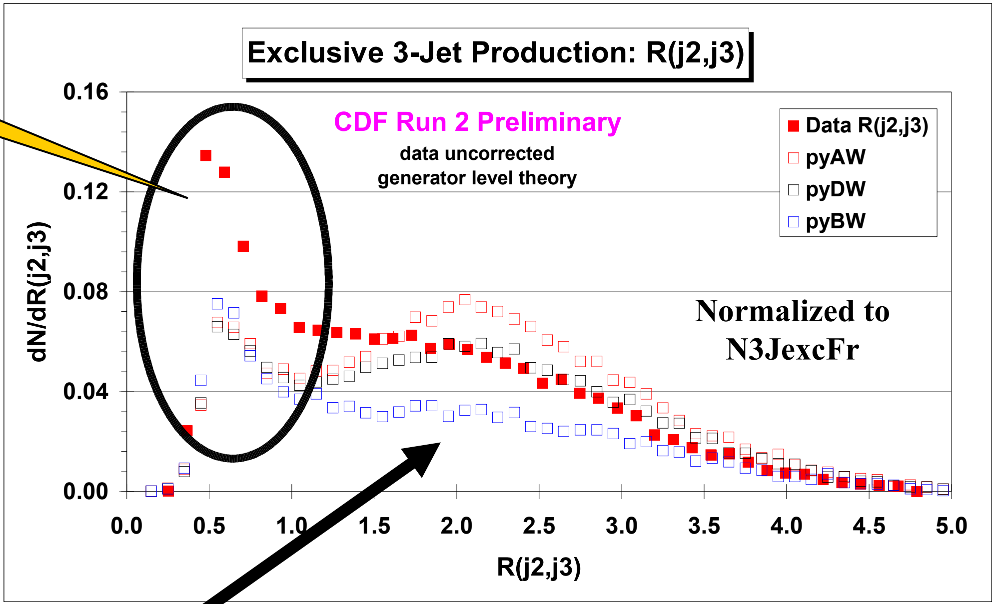
Exc3J: R(j2,j3) Normalized

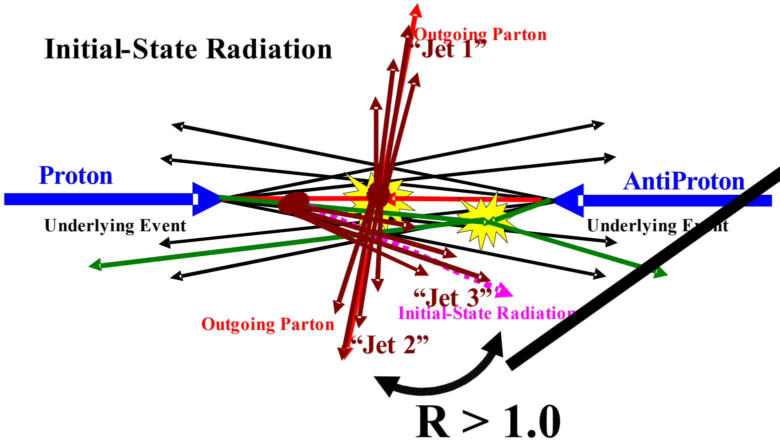
The data have more 3 jet events with small R(j2,j3)!?

Let **Ntrig40** equal s with at least one jet with P_T > 40 geV a d |η| < 1.0 (this is the "offline" trigger).

Let **N3Jexc20** equal the number of events with exactly three jets with P_T > 20 GeV/c and |η| < 2.5 which also have at least one jet with P_T > 40 GeV/c and |η| < 1.0.

Let **N3JexcFr = N3Jexc20/Ntrig40**. The is the fraction of the "offline" trigger events that are exclusive 3-jet events.





The CDF data on dN/dR(j2,j3) at 1.96 TeV compared with PYTHIA Tune AW (PARP(67)=4), Tune DW (PARP(67)=2.5), Tune BW (PARP(67)=1).

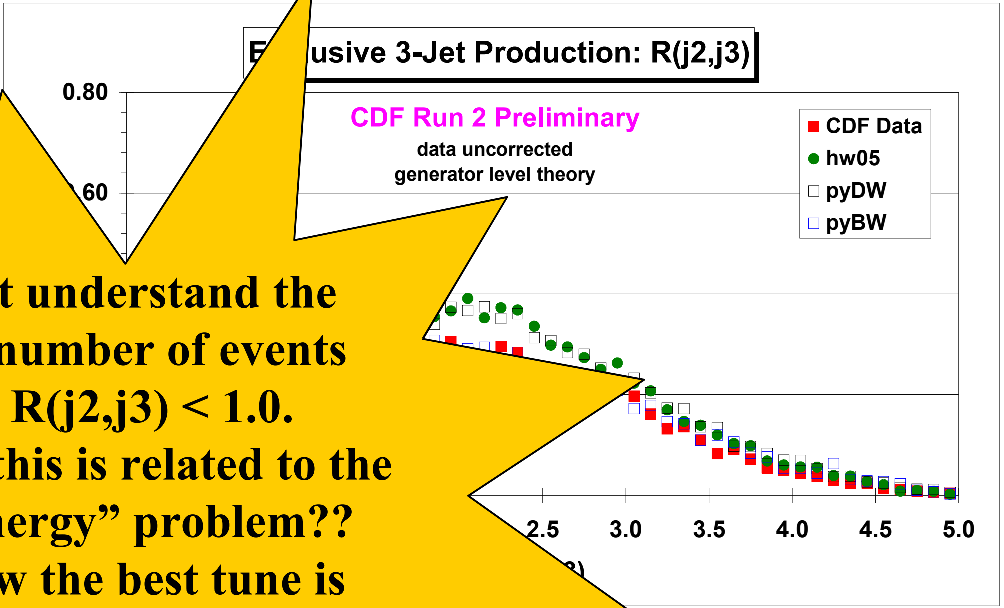
PARP(67) affects the initial-state radiation which contributes primarily to the region R(j2,j3) > 1.0.

3Jexc R(j2,j3) Normalized

Let **Ntrig40** equal the number of events with at least one jet with $P_T > 40$ geV and |η| < 1.0 (this is the “offl ” trigger).

Let **N3Jexc20** equal the nu f events with exactly three jets with P_T V and |η| < 2.5 which also have at jet with $P_T > 40$ GeV

Let **N3JexcFr = N3Jexc** the fraction of the “offline” that are exclusive 3-jet events

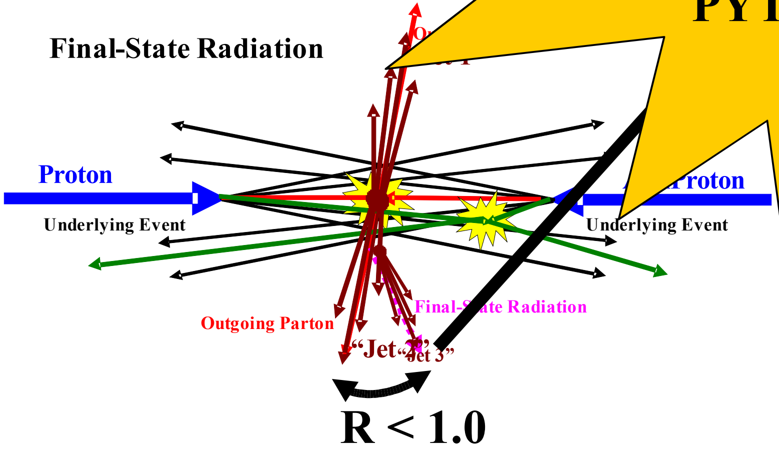


I do not understand the excess number of events with R(j2,j3) < 1.0. Perhaps this is related to the “soft energy” problem?? For now the best tune is PYTHIA Tune DW.

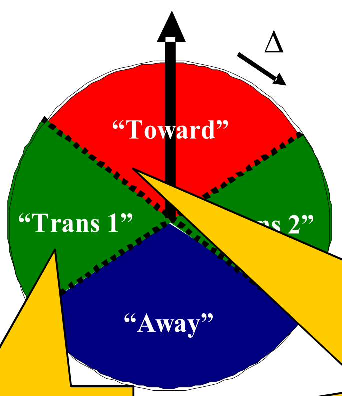
R(j2,j3) at 1.96 TeV compared V (PARP(67)=2.5) and R thou).

al-St adiation c tributes to the region R(j2,j3) 1.0.

f you ignore the normalization and normalize all the distributions to one then the data prefer **Tune BW**, but I believe this is misleading.

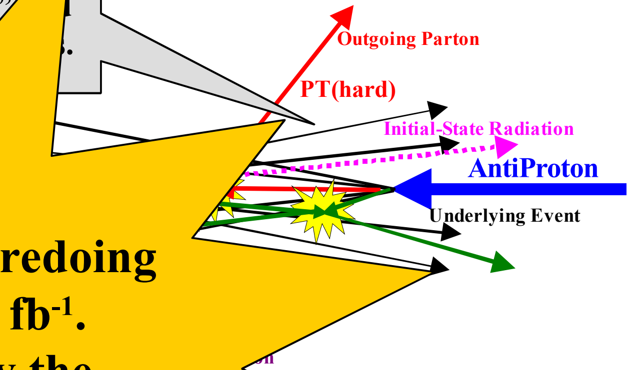


Latest CDF Run 2 "Underlying Event" Results



"Transverse" region is very sensitive to the "underlying event"!

The "underlying event" consists of hard initial & final-state radiatio plus the "beam-beam remnants" d possible mu iple parton intera s.



Craig Group and I are redoing This analysis with 1 fb^{-1}. Hope to publish it by the end of the summer!

New CDF Run 2 res

Two Classes of Ev Leading

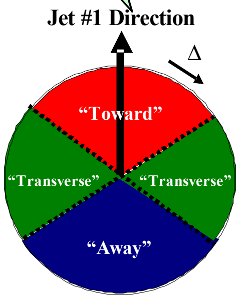
Two "Transverse" regions: "tra is rans

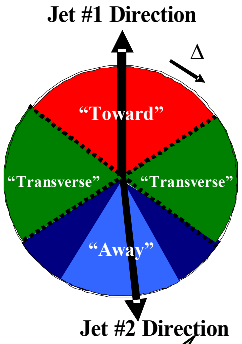
Data Corrected to the Particle vel: u ur pr CDF Ru "underlying event" analysis which used JetClu to define "je nd comp d uncorrected data with the QCD Monte-Carlo models after detector simu on, this ana ysis uses the MidPoint jet algorithm and corrects the observables to the particle le el. The corrected observables are then compared with the QCD Monde-Carlo models at the par icle level.

For the 1st time we study the energy density in the "transverse" region.

“Transverse” Observables Particle and Detector Level

“Leading Jet”

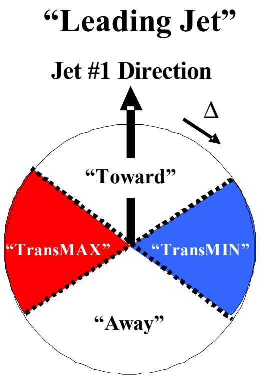


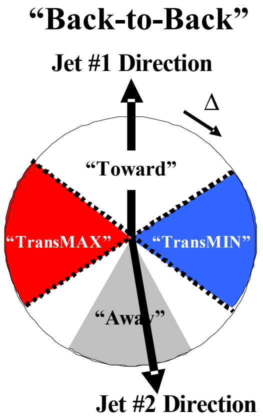


“Back-to-Back”

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, $\lvert\eta\rvert < 1$) PTmax = 0 for no charged particle	Maximum p_T “good” charged tracks ($p_T > 0.5$ GeV/c, $\lvert\eta\rvert < 1$) PTmax = 0 for no “good” charged track
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, $\lvert\eta\rvert < 1$)

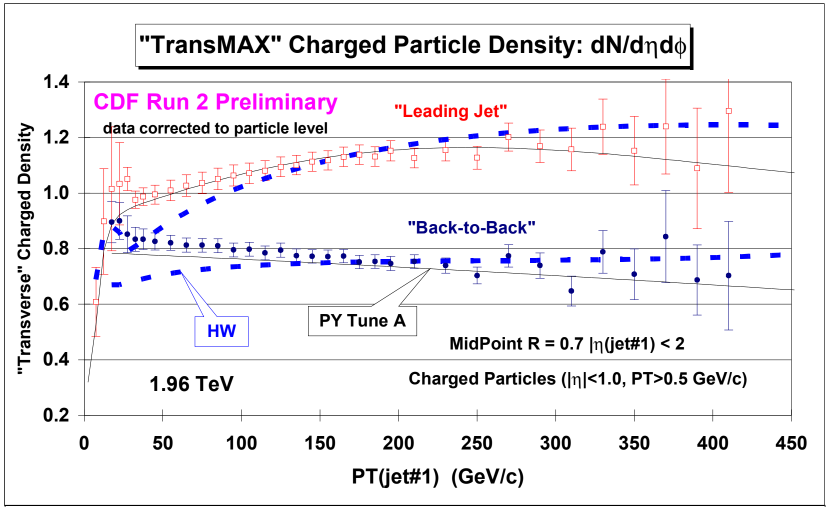
"TransMAX/MIN" Nchg Density PYTHIA Tune A vs HERWIG

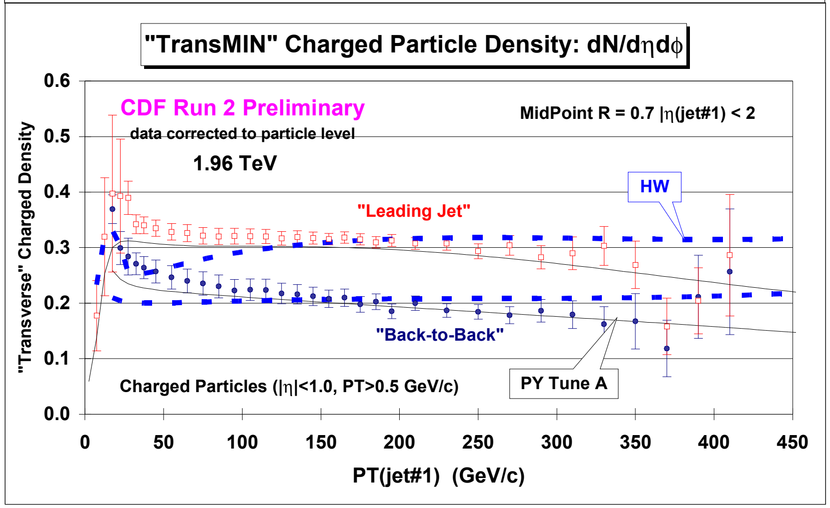




Shows the charged particle density, $dN_{chg}/d\eta d\phi$, in the "transMAX" and "transMIN" region ($p_T > 0.5$ GeV/c, $|\eta| < 1$) versus P_T(jet#1) for "Leading Jet" and "Back-to-Back" events.

Compares the (*corrected*) data with PYTHIA Tune A (with MPI) and HERWIG (without MPI) at the particle level.





CDF Run 1 $P_T(Z)$

PYTHIA 6.2 CTEQ5L

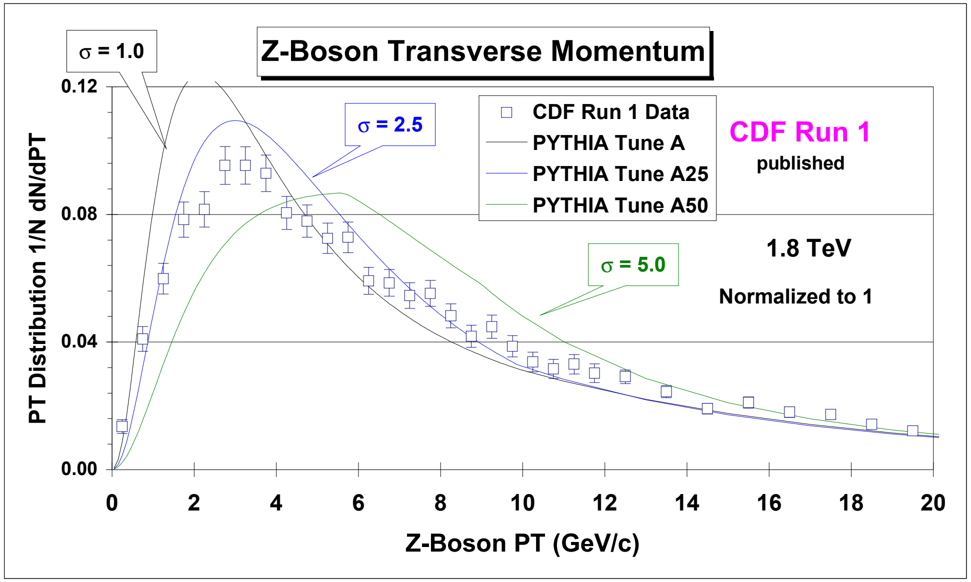
UE Parameters

ISR Parameter

Intrensic KT

Parameter	Tune A	Tune A25	Tune A50
MSTP(81)	1	1	1
MSTP(82)	4	4	4
PARP(82)	2.0 GeV	2.0 GeV	2.0 GeV
PARP(83)	0.5	0.5	0.5
PARP(84)	0.4	0.4	0.4
PARP(85)	0.9	0.9	0.9
PARP(86)	0.95	0.95	0.95
PARP(89)	1.8 TeV	1.8 TeV	1.8 TeV
PARP(90)	0.25	0.25	0.25
PARP(67)	4.0	4.0	4.0
MSTP(91)	1	1	1
PARP(91)	1.0	2.5	5.0
PARP(93)	5.0	15.0	25.0

Vary the intrensic KT!



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), Tune A25 ($<p_T(Z)> = 10.1$ GeV/c), and Tune A50 ($<p_T(Z)> = 11.2$ GeV/c).

CDF Run 1 P_T(Z)

PYTHIA 6.2 CTEQ5L

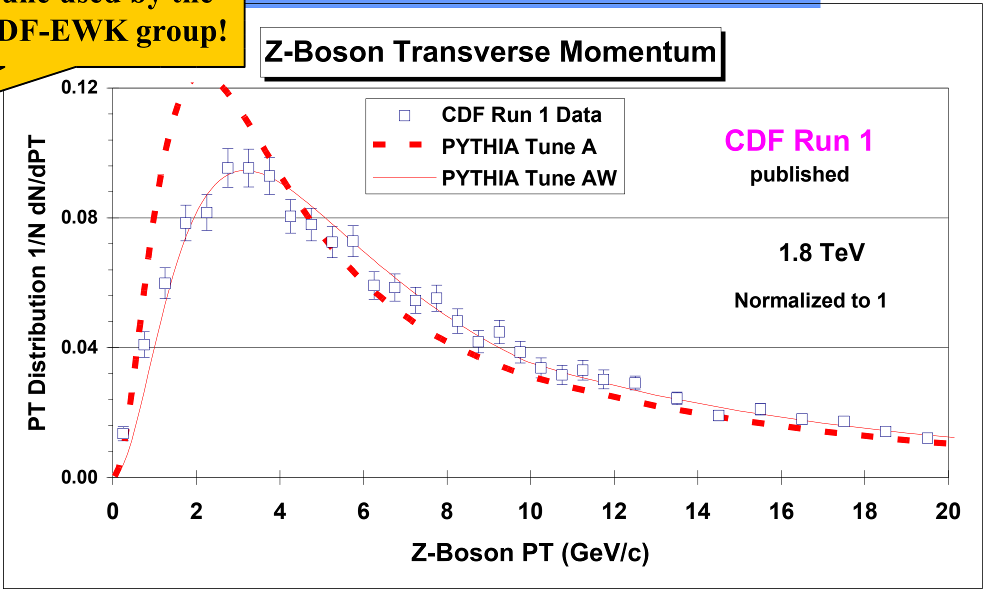
Tune used by the CDF-EWK group!

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



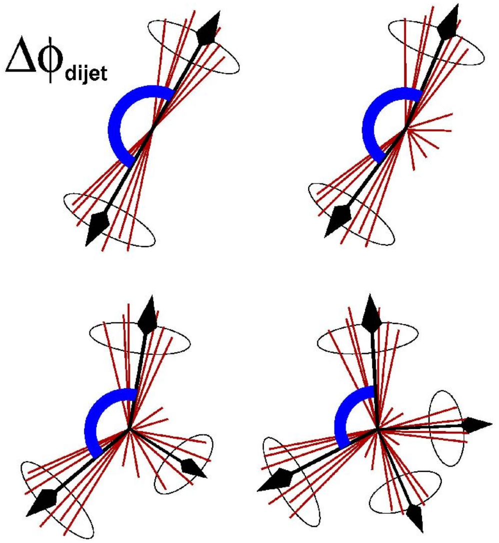
Shows the Run 1 Z-boson p_T distribution ($<p_T(Z)>$ ≈ 11.5 GeV/c) compared with PYTHIA Tune A ($<p_T(Z)>$ = 9.7 GeV/c), and PYTHIA Tune AW (Z)> = 11.7 GeV/c).

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

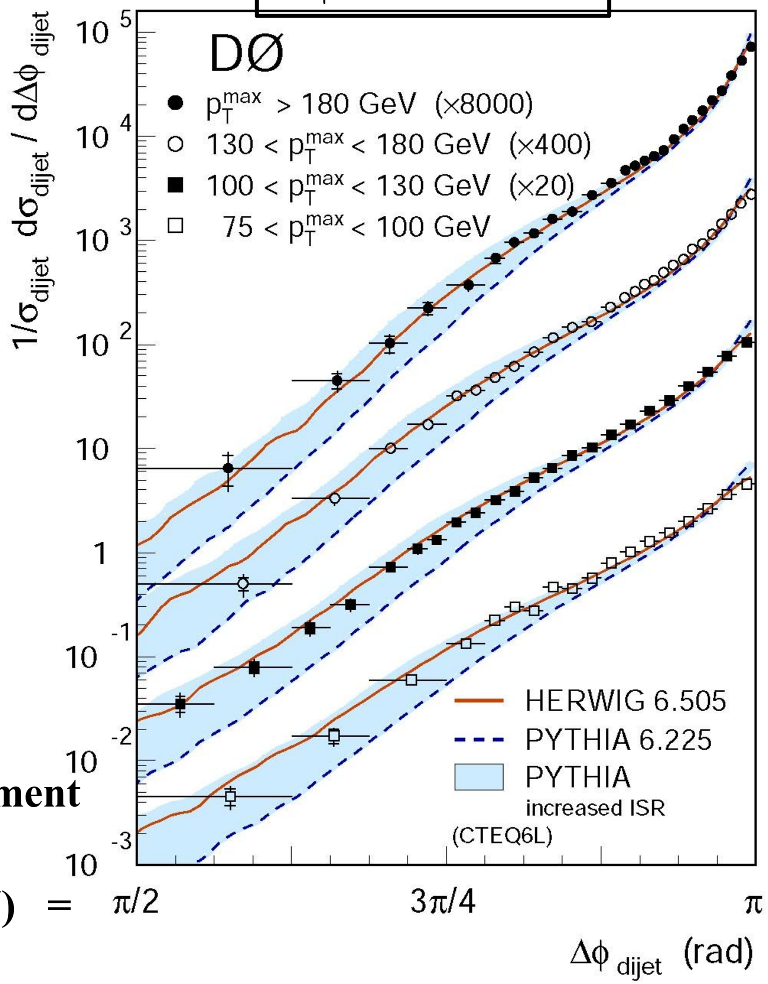
The $Q^2 = k_T^2$ in α_s for space-like showers is scaled by PARP(64)!

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)

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 $P_T(Z)$

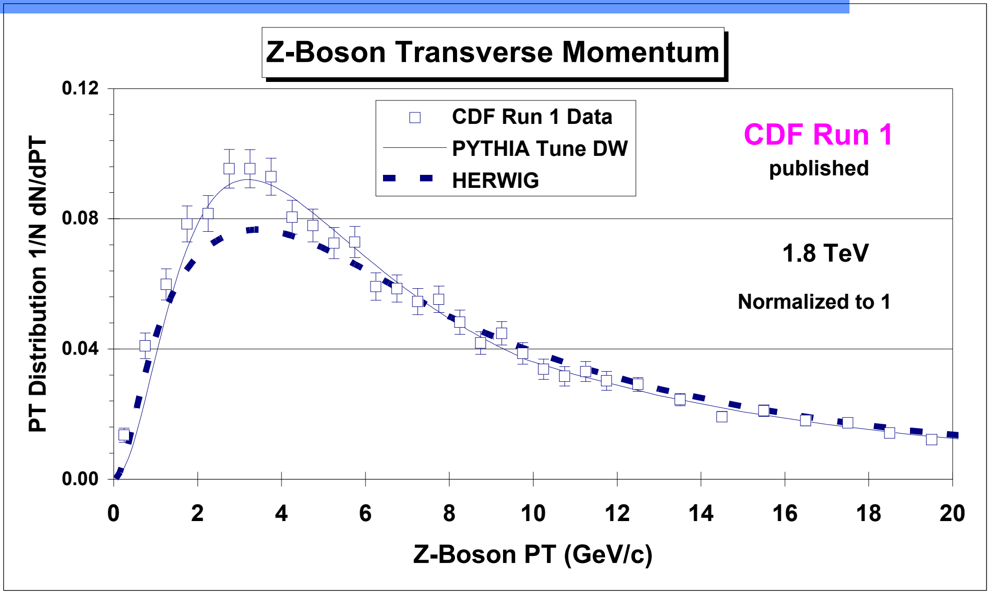
PYTHIA 6.2 CTEQ5L

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!

“Transverse” Nchg Density

PYTHIA 6.2 CTEQ5L

UE Parameters

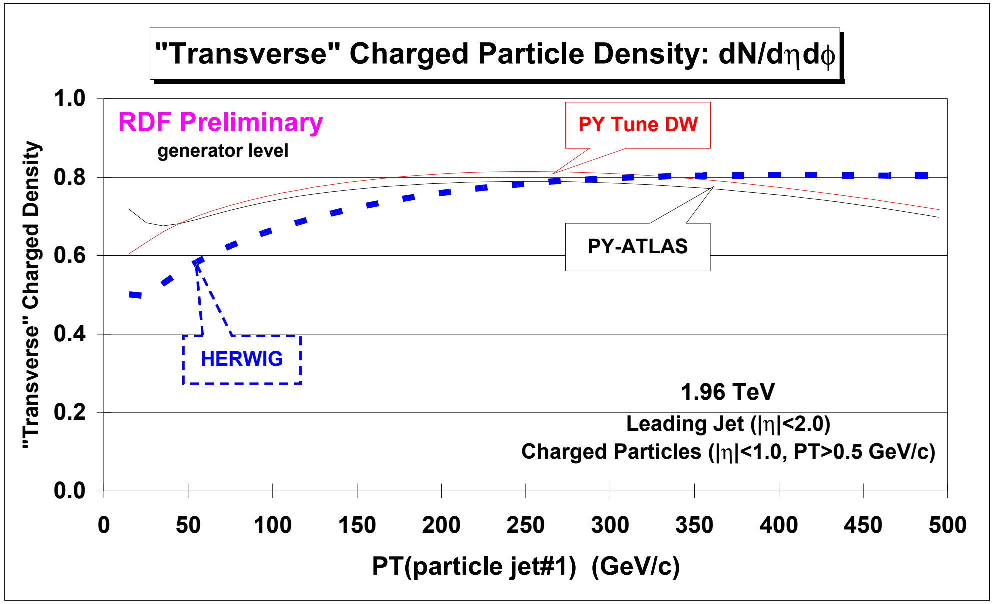
Three different amounts of MPI!

Parameter	Tune AW	Tune DW	Tune BW
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	1.0
MSTP(91)	1	1	1
PARP(91)	2.5	2.5	2/5
PARP(93)	15.0	15	15.0

ISR Parameter

Intrensic KT

Three different amounts of ISR!



Shows the “transverse” charged particle density, dN/dηdϕ, versus P_T(jet#1) for “leading jet” events at 1.96 TeV for PYTHIA Tune A, Tune AW, Tune DW, Tune BW, and HERWIG (without MPI).

Shows the “transverse” charged particle density, dN/dηdϕ, versus P_T(jet#1) for “leading jet” events at 1.96 TeV for Tune DW, ATLAS, and HERWIG (without MPI).

“Transverse” PTsum Density

PYTHIA 6.2 CTEQ5L

UE Parameters

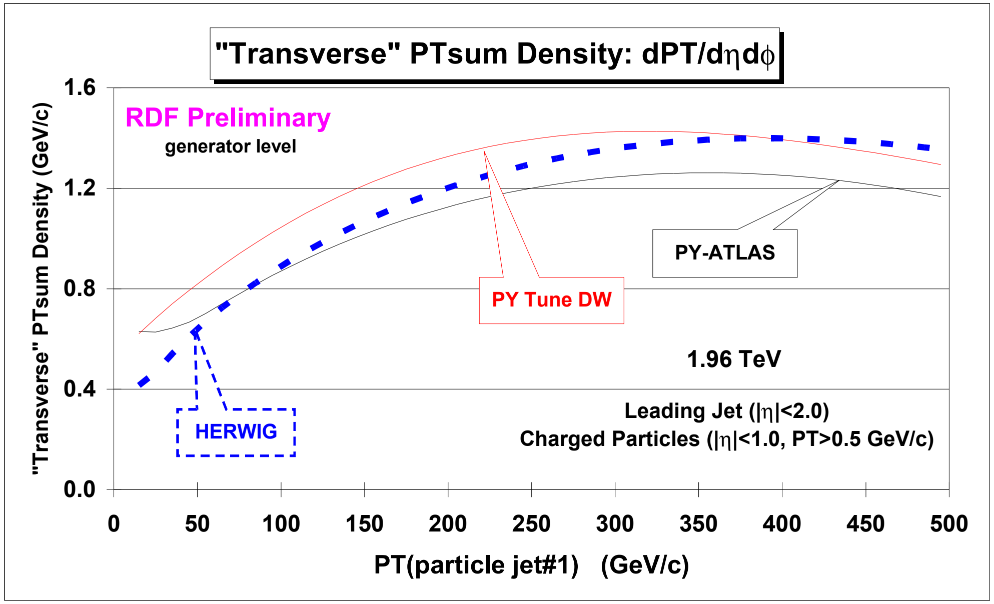
Parameter	Tune AW	Tune DW	Tune B
MSTP(81)	1	1	
MSTP(82)	4	4	4
PARP(82)	2.0 GeV	1.9 GeV	1.8 GeV
PARP(83)	0.5	0.5	0.5
PARP(84)	0.4	0.4	0.4
PARP(85)	0.9	1.0	1.0
PARP(86)	0.95	1.0	1.0
PARP(89)	1.8 TeV	1.8 TeV	1.8 TeV
PARP(90)	0.25	0.25	0.25
PARP(62)	1.25	1.25	1.25
PARP(64)	0.2	0.2	0.2
PARP(67)	4.0	2.5	1.0
MSTP(91)	1	1	1
PARP(91)	2.5	2.5	2/5
PARP(93)	15.0	15	15.0

ISR Parameter

Intrensic KT

Three different amounts of ISR!

Three different amounts of MPI!



Shows the “transverse” charged PTsum density, dPT/dηdϕ, versus P_T(jet#1) for “leading jet” events at 1.96 TeV for PYTHIA Tune A, Tune AW, Tune DW, Tune BW, and HERWIG (without MPI).

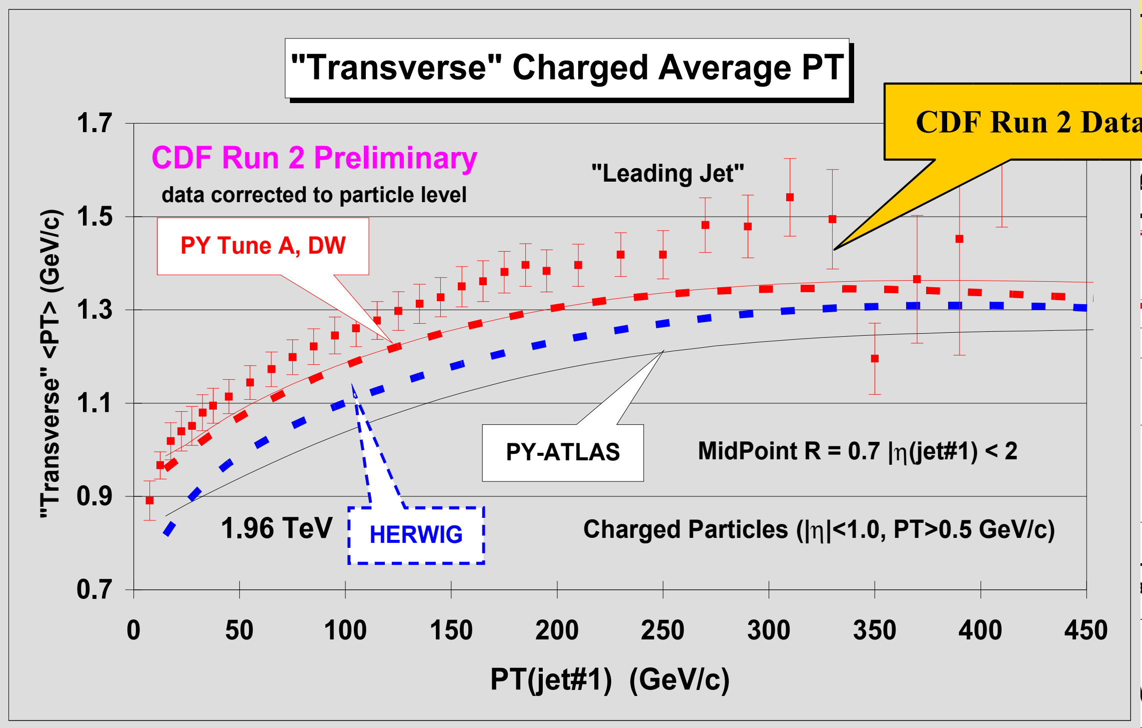
Shows the “transverse” charged PTsum density, dPT/dηdϕ, versus P_T(jet#1) for “leading jet” events at 1.96 TeV for Tune DW, ATLAS, and HERWIG (without MPI).

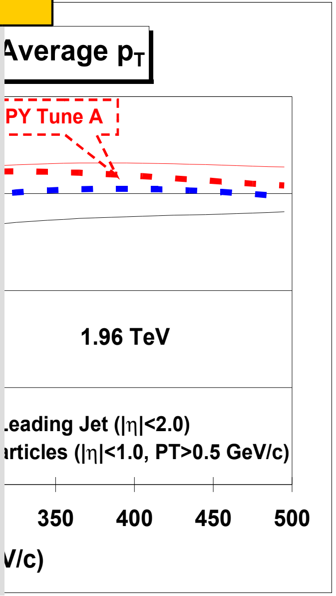
PYTHIA 6.2 Tunes

PYTHIA 6.2 CTEQ5L

Parameter	Tune A	Tune DW	Tune DWT	ATLAS
MSTP(81)	1			
MSTP(82)	4			
PARP(82)	2.0 Ge			
PARP(83)	0.5			
PARP(84)	0.4			
PARP(85)	0.9			
PARP(86)	0.95			
PARP(89)	1.8 Te			
PARP(90)	0.25			
PARP(62)	1.0			
PARP(64)	1.0			
PARP(67)	4.0			
MSTP(91)	1			
PARP(91)	1.0			
PARP(93)	5.0	15	15.0	5.0

	σ(MPI) at 1.96 TeV	σ(MPI) at 14 TeV
Tune A	309.7 mb	484.0 mb
Tune DW	351.7 mb	549.2 mb
		829.1 mb
		768.0 mb





CDF Run 2 Data!

Identical to DW at 1.96 TeV but uses ATLAS extrapolation to the LHC!

Shows the "transverse" charged average p_T, versus P_T(jet#1) for "leading jet" events at 1.96 TeV for Tune A, DW, ATLAS, and HERWIG (without MPI).

New PYTHIA 6.2 Tunes

Use LO α_s with Λ = 192 MeV!

NLO Structure Function!

Parameter	Tune DW	Tune D6	Tune QW	Tune QK
PDF	CTEQ5L	CTEQ6L	CTEQ6.1	CTEQ6.1
MSTP(2)	1	1	1	1
MSTP(33)	0	0	0	1
PARP(31)	1.0	1.0	1.0	1.8
MSTP(81)	1	1	1	1
MSTP(82)	4	4	4	4
PARP(82)	1.9 GeV	1.8 GeV	1.1 GeV	1.9 GeV
PARP(83)	0.5	0.5	0.5	0.5
PARP(84)	0.4	0.4	0.4	0.4
PARP(85)	1.0	1.0	1.0	1.0
PARP(86)	1.0	1.0	1.0	1.0
PARP(89)	1.8 TeV	1.8 TeV	1.8 TeV	1.8 TeV
PARP(90)	0.25	0.25	0.25	0.25
PARP(62)	1.25	1.25	1.25	1.25
PARP(64)	0.2	0.2	0.2	0.2
PARP(67)	2.5	2.5	2.5	2.5
MSTP(91)	1	1	1	1
PARP(91)	2.1	2.1	2.1	2.1
PARP(93)	15.0	15.0	15.0	15.0

K-factor (T. Sjostrand)

UE Parameters

Tune A energy dependence!

ISR Parameter

Intrinsic KT

New PYTHIA 6.2 Tunes

Use LO α_s with Λ = 192 MeV!

NLO Structure Function!

Parameter	Tune DWT	ATLAS	Tune D6T	Tune QWT	Tune QKT
PDF	CTEQ5L	CTEQ5L	CTEQ6L	CTEQ6.1	CTEQ6.1
MSTP(2)	1	1	1	1	1
MSTP(33)	0	0	1	1	1
PARP(31)	1.0	1.0	1.0	1.0	1.8
MSTP(81)	1	1	1	1	1
MSTP(82)	4	4	4	4	4
PARP(82)	1.9409 GeV	1.8 GeV	1.8387 GeV	1.1237 GeV	1.9409 GeV
PARP(83)	0.5	0.5	0.5	0.5	0.5
PARP(84)	0.4	0.5	0.4	0.4	0.4
PARP(85)	1.0	0.33	1.0	1.0	1.0
PARP(86)	1.0	0.66	1.0	1.0	1.0
PARP(89)	1.96 TeV	1.0 TeV	1.96 TeV	1.96 TeV	1.96 TeV
PARP(90)	0.16	0.16	0.16	0.16	0.16
PARP(62)	1.25	1.0	1.25	1.25	1.25
PARP(64)	0.2	1.0	0.2	0.2	0.2
PARP(67)	2.5	1.0	2.5	2.5	2.5
MSTP(91)	1	1	1	1	1
PARP(91)	2.1	1.0	2.1	2.1	2.1
PARP(93)	15.0	5.0	15.0	15.0	15.0

K-factor
(T. Sjostrand)

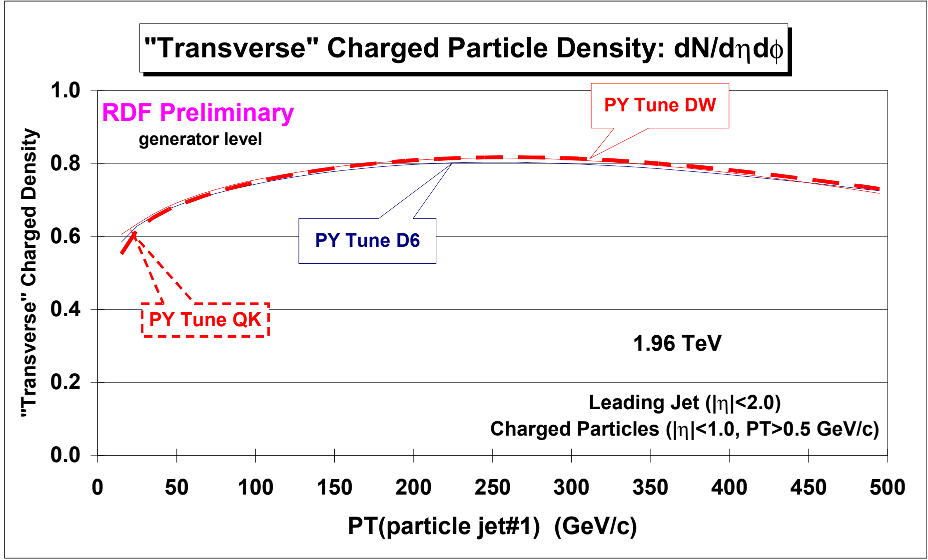
UE Parameters

ATLAS energy dependence!

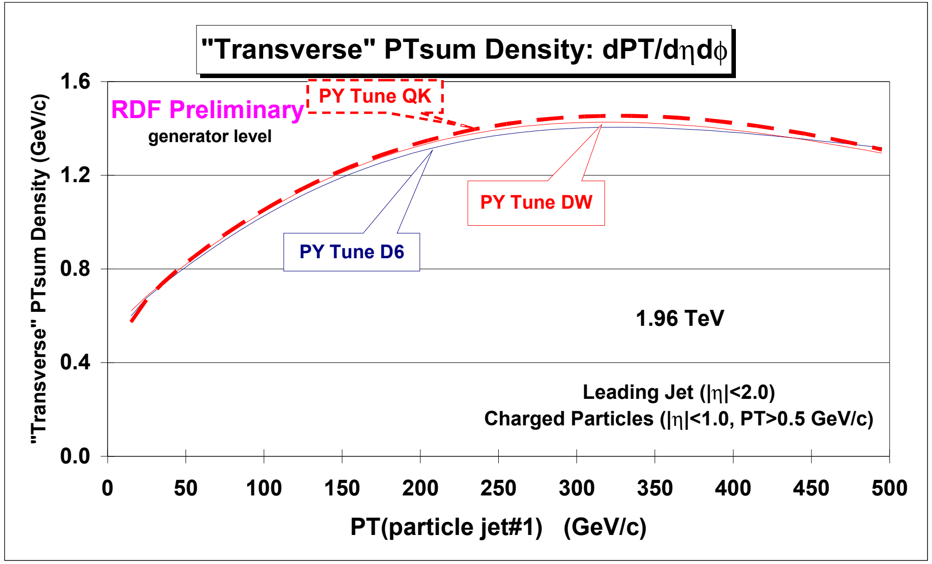
ISR Parameter

Intrinsic KT

New PYTHIA 6.2 Tunes

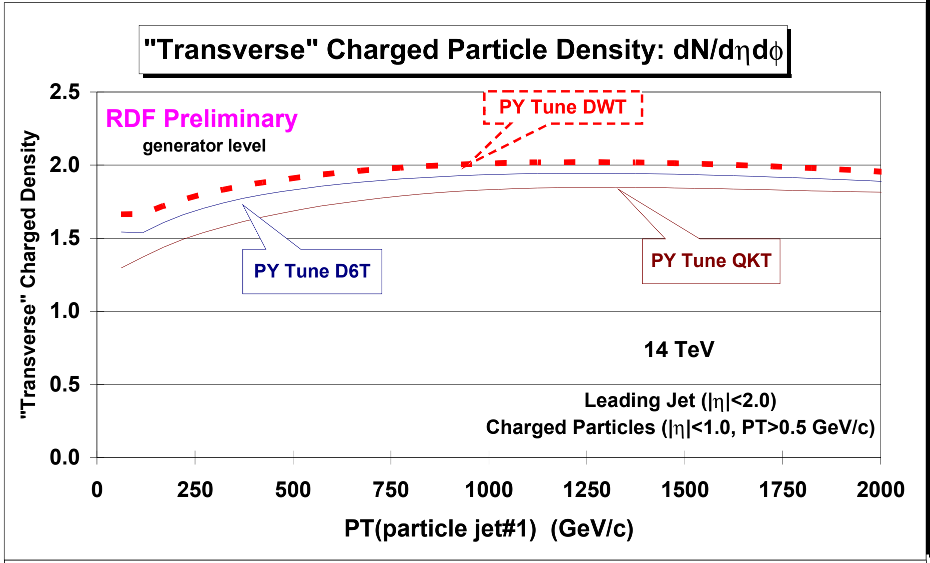


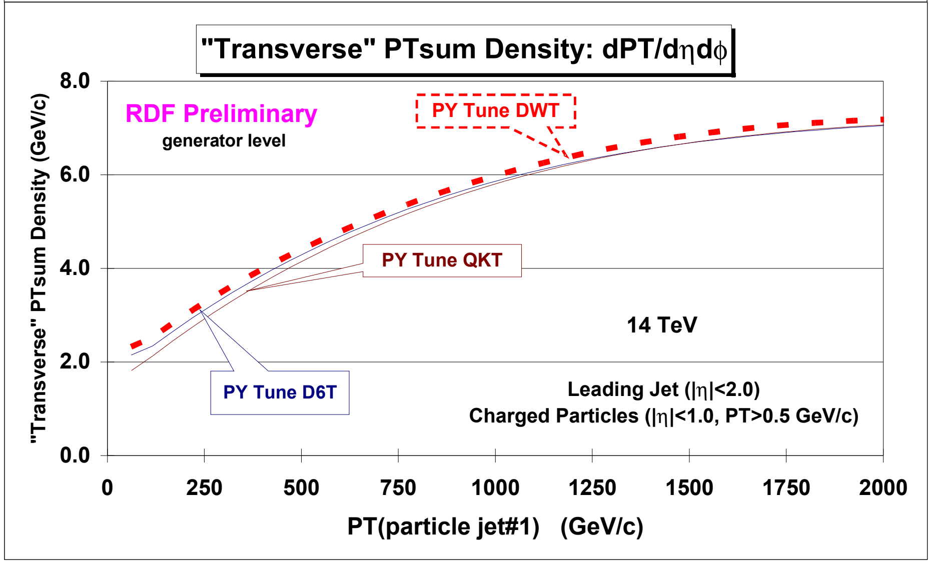
	1.96 TeV		14 TeV	
	P_{T0}(MPI) GeV	σ(MPI) mb	P_{T0}(MPI) GeV	σ(MPI) mb
Tune DW	1.9409	351.7	3.1730	549.2
Tune DWT	1.9409	351.7	2.6091	829.1
ATLAS	2.0046	324.5	2.7457	768.0
Tune D6	1.8387	306.3	3.0059	546.1
Tune D6T	1.8387	306.3	2.5184	786.5
Tune QK	1.9409	259.5	3.1730	422.0
Tune QKT	1.9409	259.5	2.6091	588.0



Average charged particle density and PTsum density in the "transverse" region (p_T > 0.5 GeV/c, |η| < 1) versus P_T(jet#1) at 1.96 TeV for PY Tune DW, Tune D6, and Tune QK.

New PYTHIA 6.2 Tunes





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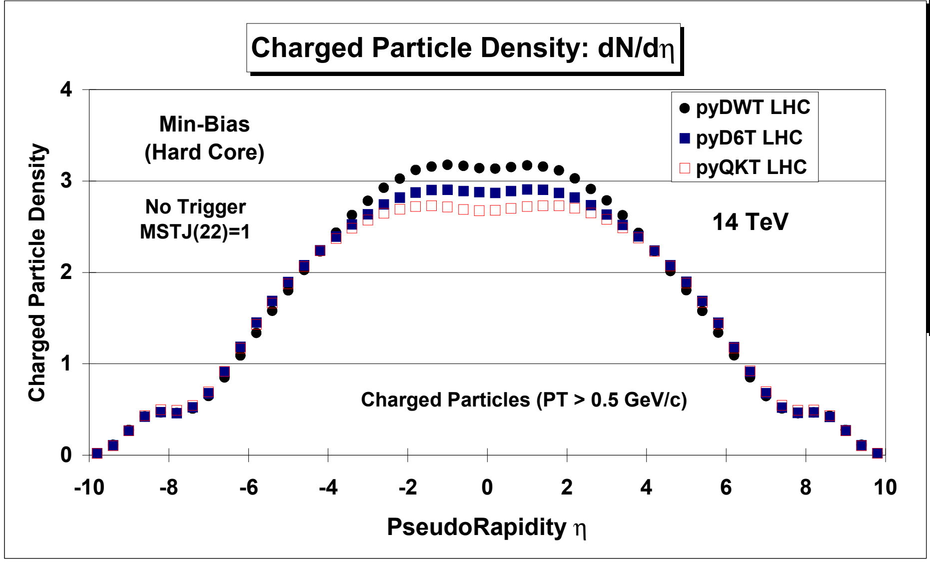
Average charged particle density and PTsum density in the "transverse" region ($p_T > 0.5$ GeV/c, $|\eta| < 1$) versus P_T(jet#1) at 14 TeV for PY Tune DWT, Tune D6T, and Tune QKT.

New PYTHIA 6.2 Tunes



	14 TeV ($p_T > 0.5$ GeV/c, $\|\eta\| < 1$)		
	<Nchg>	<PTsum> (GeV/c)	$<P_T>$ (GeV/c)
Tune DWT	6.268	7.091	1.131
Tune D6T	5.743	6.467	1.126
Tune QKT	5.361	6.115	0.982

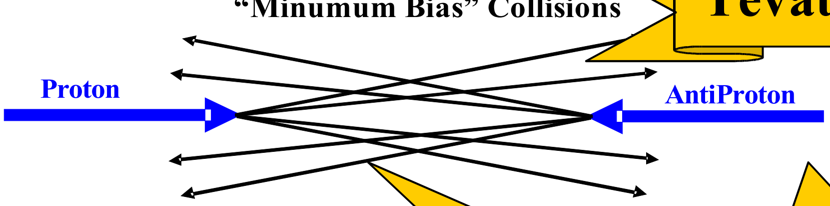
Numbers for $p_T > 0.5$ GeV/c, $|\eta| < 1$.

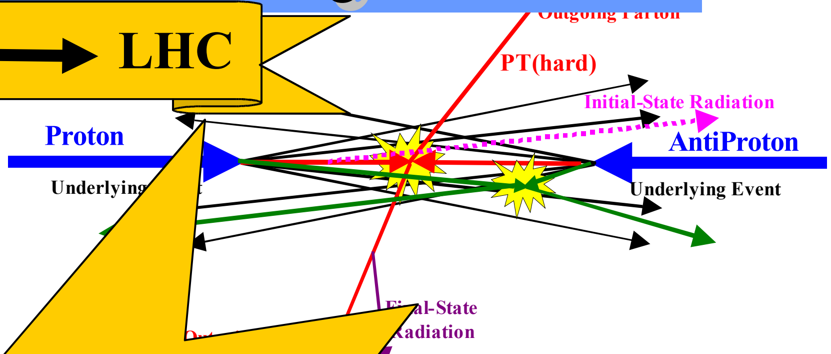
PseudoRapidity distribution, dN/dη, for charged particles with $p_T > 0.5$ GeV/c at 14 TeV for PY Tune DWT, Tune D6T, and Tune QKT. Note this is "hard core" (*i.e.* MSEL=1, P_T(hard) = 0) with no trigger and with only stable particles (*i.e.* MSTJ(22)=1). Tune D6T uses CTEQ6L (*i.e.* LHAPDF = 10042) and Tune QKT uses CTEQ6.1M (*i.e.* LHAPDF = 10100 or 10150 which are the same).

We have CTEQ6L Tune D6T
and
NLO PDF Tune QKT!

Summary

Tevatron → LHC





PYTHIA Tune DW is v… r t… CDF $P_T(Z)$ distribution and it uses the DØ prefere… from the dijet $\Delta\phi$ distributio…

PYTHIA Tune DWT … the ATLAS energy extrapolation to the LH…

PYTHIA Tune D6 a… ctively, but use CTEQ6L (*i.e.* LHAP…

PYTHIA Tune QK and QKT uses the …O PDF C…Q6.1M (*i.e.* LHAPDF = 10100 or 10150 which are the same) and use the "K-factor" to get the right amount of MPI.

We need to decide whether to use NLO PDF's (*i.e.* Tune QWT) or whether to stick with LO PDF's (*i.e.* Tune DWT or Tune D6T)!

And we need to develop a procedure to validate the Tunes!

I prefer QK and QKT over QW and QWT!