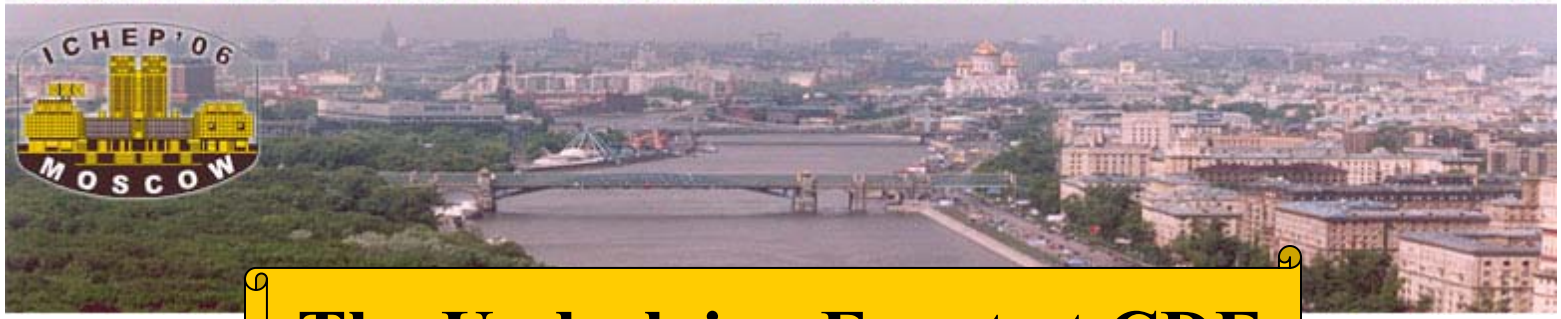
ICHEP06

XXXIII INTERNATIONAL CONFERENCE ON HIGH ENERGY PHYSICS

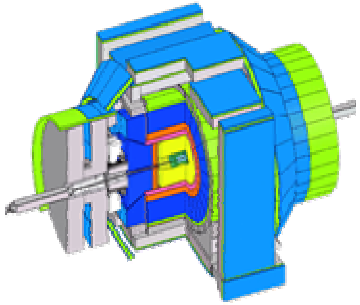


The Underlying Event at CDF

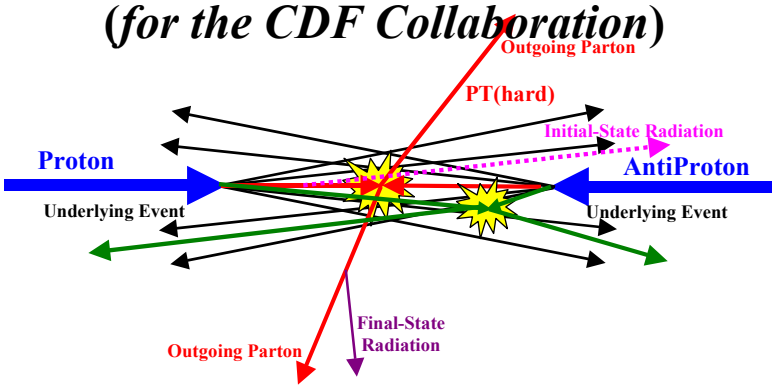
Rick Field

University of Florida

(for the CDF Collaboration)



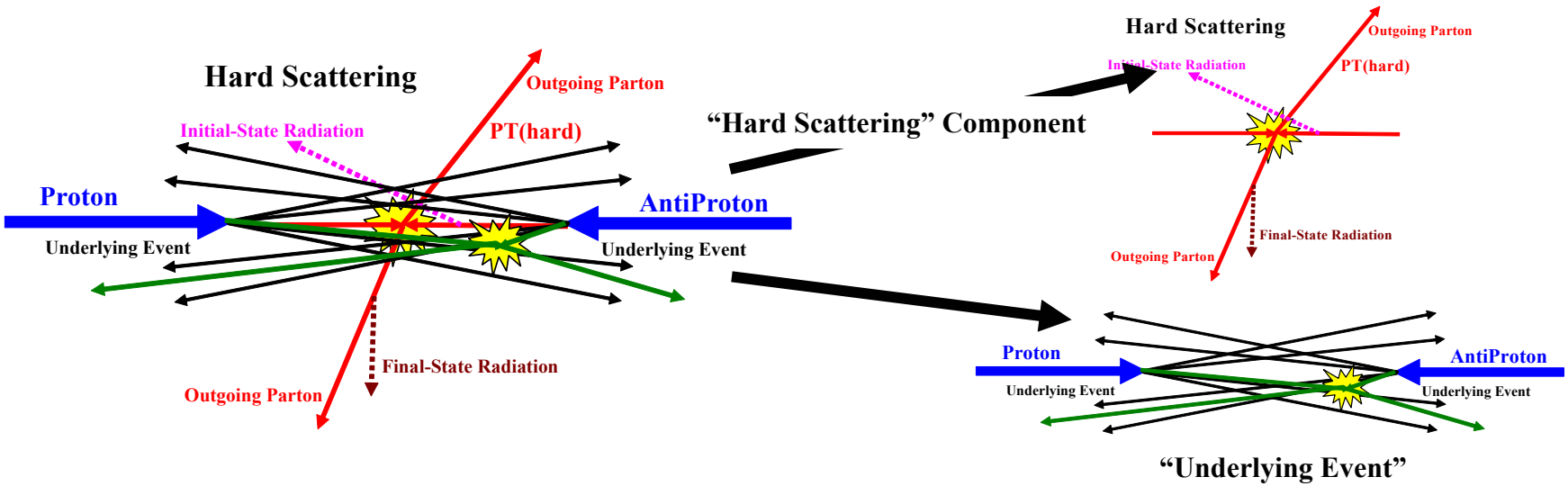
CDF Run 2



Quantum Chromo-Dynamics

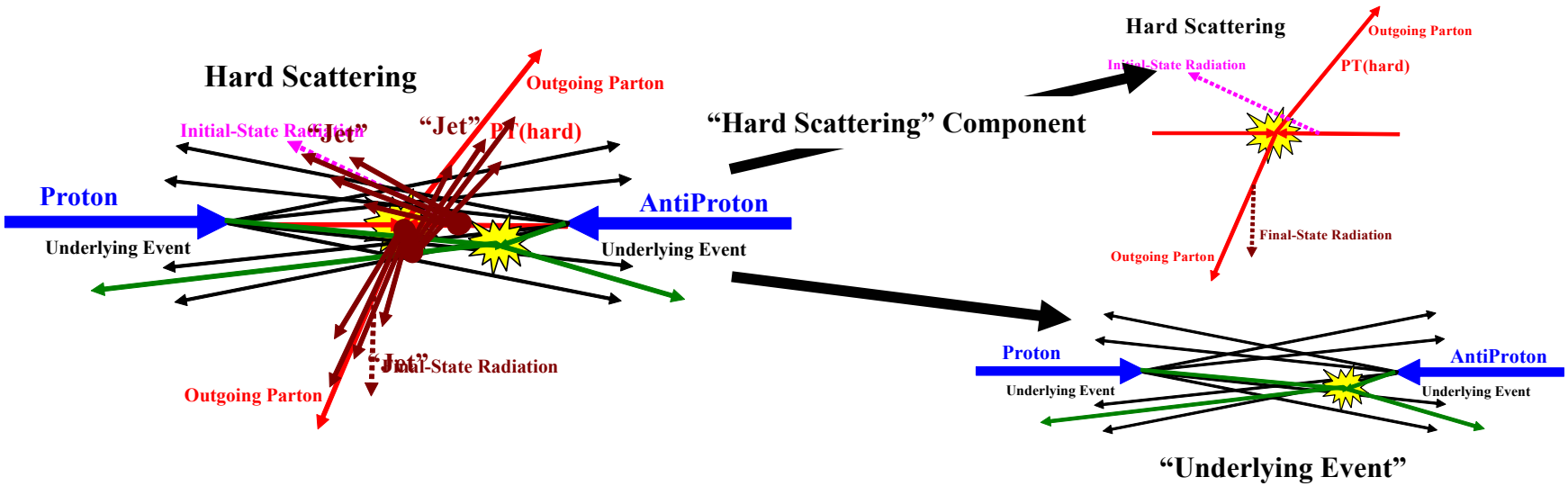
Tuning the Models & Extrapolating to the LHC

QCD Monte-Carlo Models: High Transverse Momentum Jets



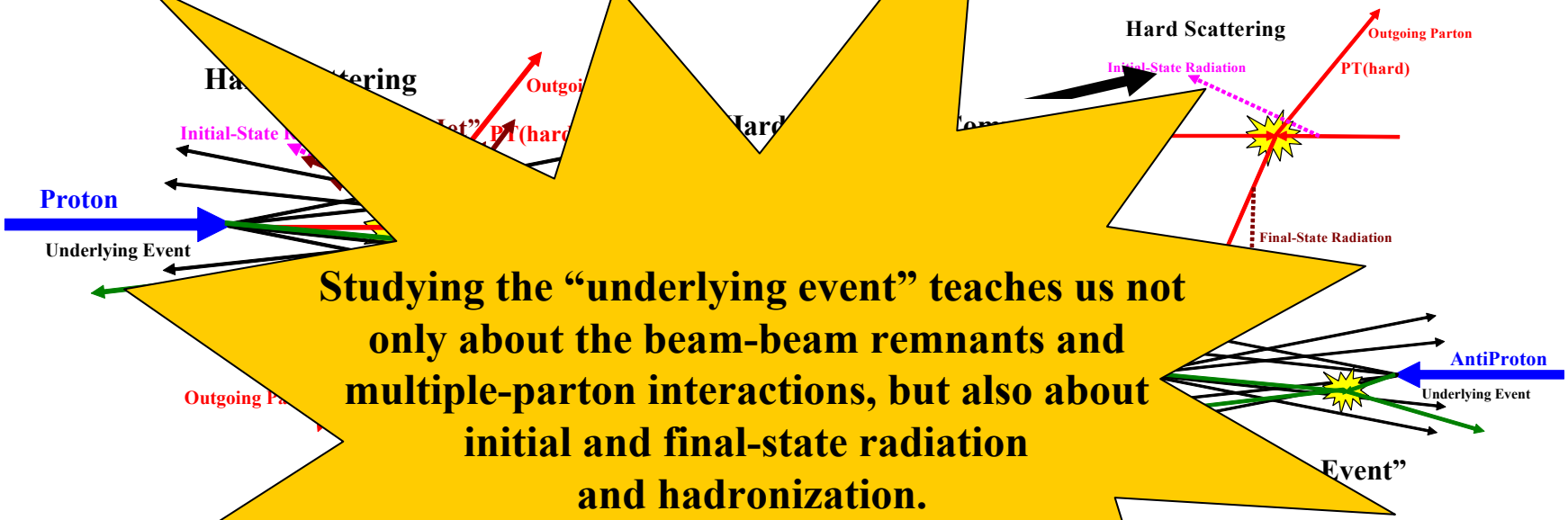
- Start with the perturbative 2-to-2 (or sometimes 2-to-3) parton-parton scattering and add initial and final-state gluon radiation (in the leading log approximation or modified leading log approximation).
- The "underlying event" consists of the "beam-beam remnants" and from particles arising from soft or semi-soft multiple parton interactions (MPI).

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.

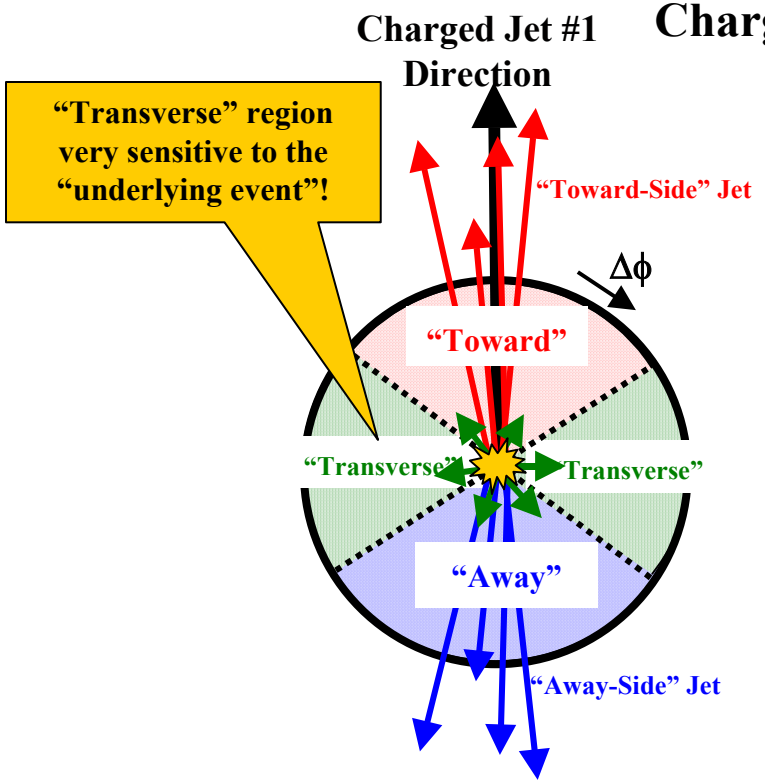
QCD Monte-Carlo Models: High Transverse Momentum Jets



Studying the "underlying event" teaches us not only about the beam-beam remnants and multiple-parton interactions, but also about initial and final-state radiation and hadronization.

- Start with the perturbative 2- ... ing and add initial and final-state gluon radiation (in the ... ied ... approximation).
- The "underlying event" co... of the ... eam r... and from p... les arising from soft or semi-soft multiple parton interactions (...
- Of course the outgoing colored partons ... ent into hadr... "jet" and inevitably "underlying event" observables receive contributions from i... al and final-state radiation.

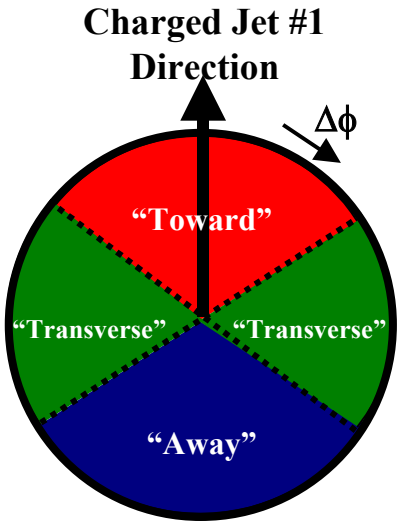
Evolution of Charged Jets "Underlying Event"

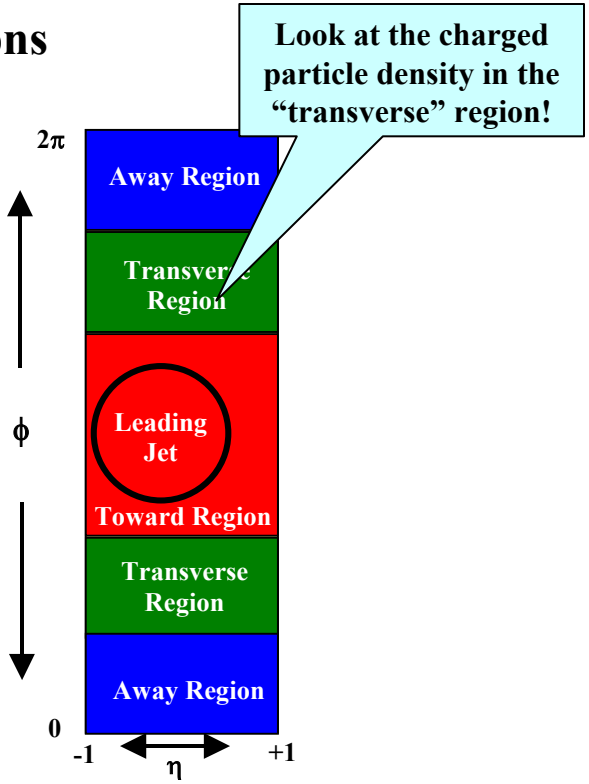


Charged Particle Δϕ Correlations

$P_T > 0.5$ GeV/c $|\eta| < 1$

CDF Run 1 Analysis





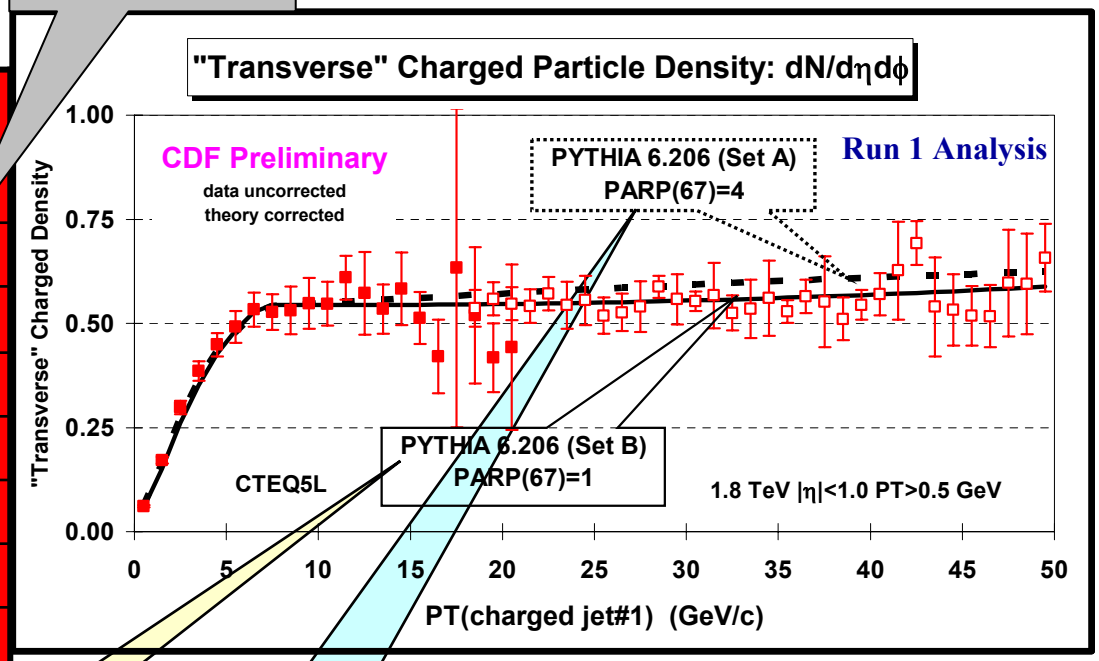
- Look at charged particle correlations in the azimuthal angle Δϕ relative to the leading charged particle jet.
- Define $|\Delta\phi| < 60^o$ as "Toward", $60^o < |\Delta\phi| < 120^o$ as "Transverse", and $|\Delta\phi| > 120^o$ as "Away".
- All three regions have the same size in η-ϕ space, $\Delta\eta x \Delta\phi = 2x120^o = 4\pi/3$.

Run 1 PYTHIA Tune A

PYTHIA 6.206 CTEQ5L

Parameter	Tune B	Tune A
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(67)	1.0	4.0

CDF Default!



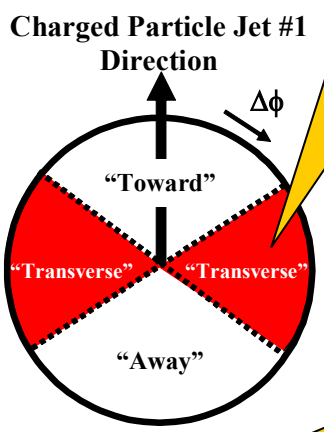
Plot shows the "transverse" charged particle density versus P_T(chgjet#1) compared to the QCD hard scattering predictions of two tuned versions of PYTHIA 6.206 (CTEQ5L, Set B (PARP(67)=1) and Set A (PARP(67)=4)).

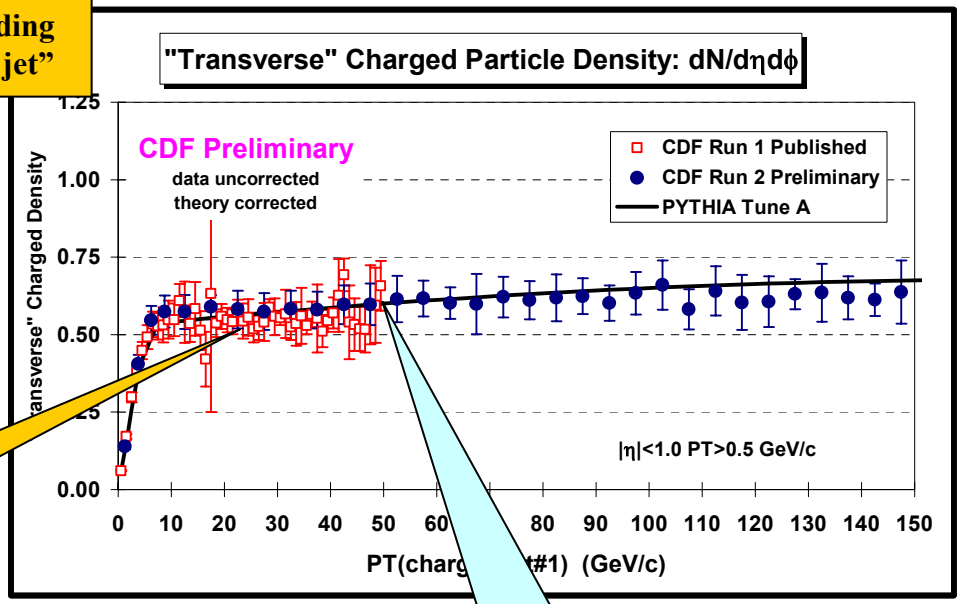
New PYTHIA default
(less initial-state radiation)

Old PYTHIA default
(more initial-state radiation)

"Transverse" Charged Particle Density

"Transverse" region as defined by the leading "charged particle jet"





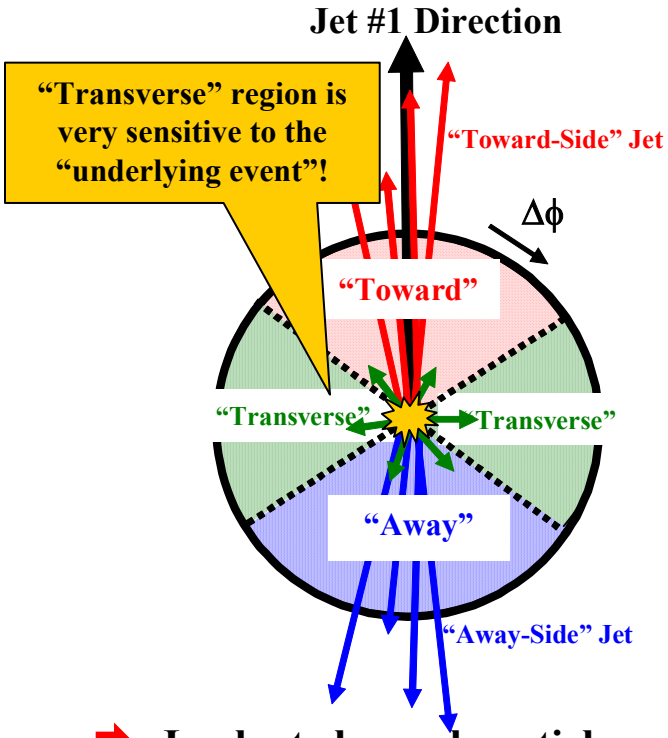
Excellent agreement between Run 1 and 2!

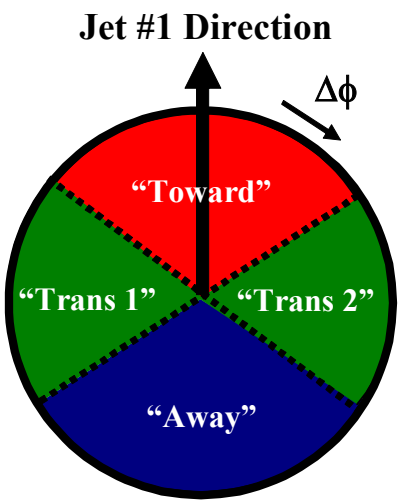
- Shows the data on the average "transverse" charge particle dens η|<1, p_T>0.5 GeV) as a function of the transverse momentum of the leading charged pa jet from Run 1.
- Compares the Run 2 data (Min-Bias, JET20, JET50, JET70, JET1 h Run 1. The errors on the (*uncorrected*) Run 2 data include both statis systematic uncertainties.
- Shows the prediction of PYTHIA Tune A at 1.96 TeV after detector simulation (*i.e.* after CDFSIM).

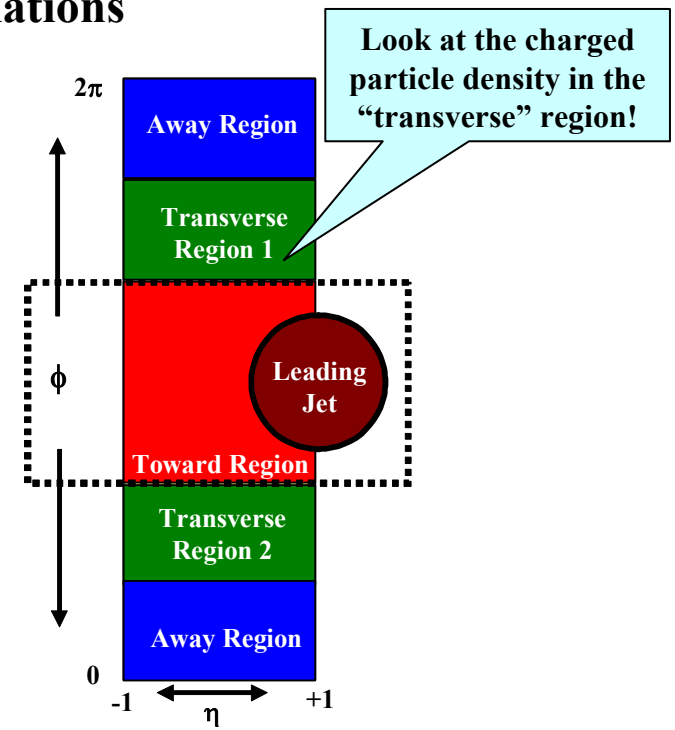
PYTHIA Tune A was tuned to fit the "underlying event" in Run I!

The "Transverse" Regions as defined by the Leading Jet

Charged Particle $\Delta\phi$ Correlations
$p_T > 0.5$ GeV/c $|\eta| < 1$

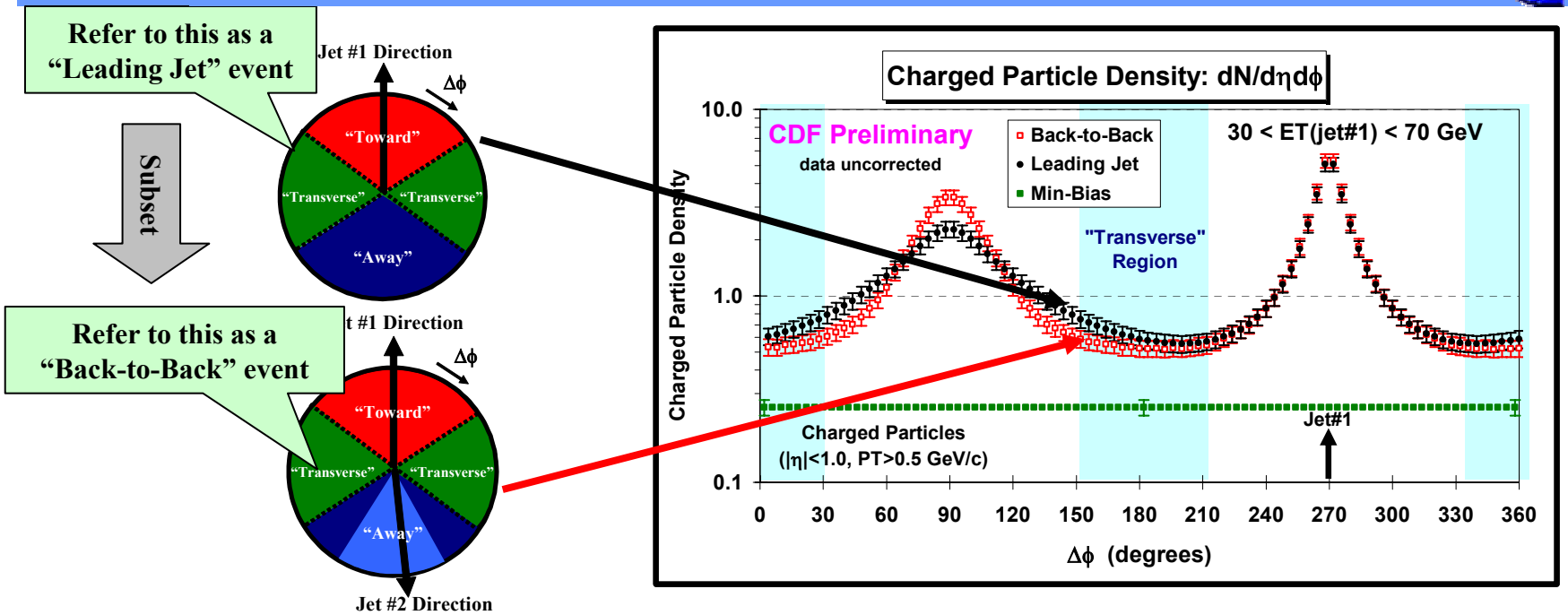






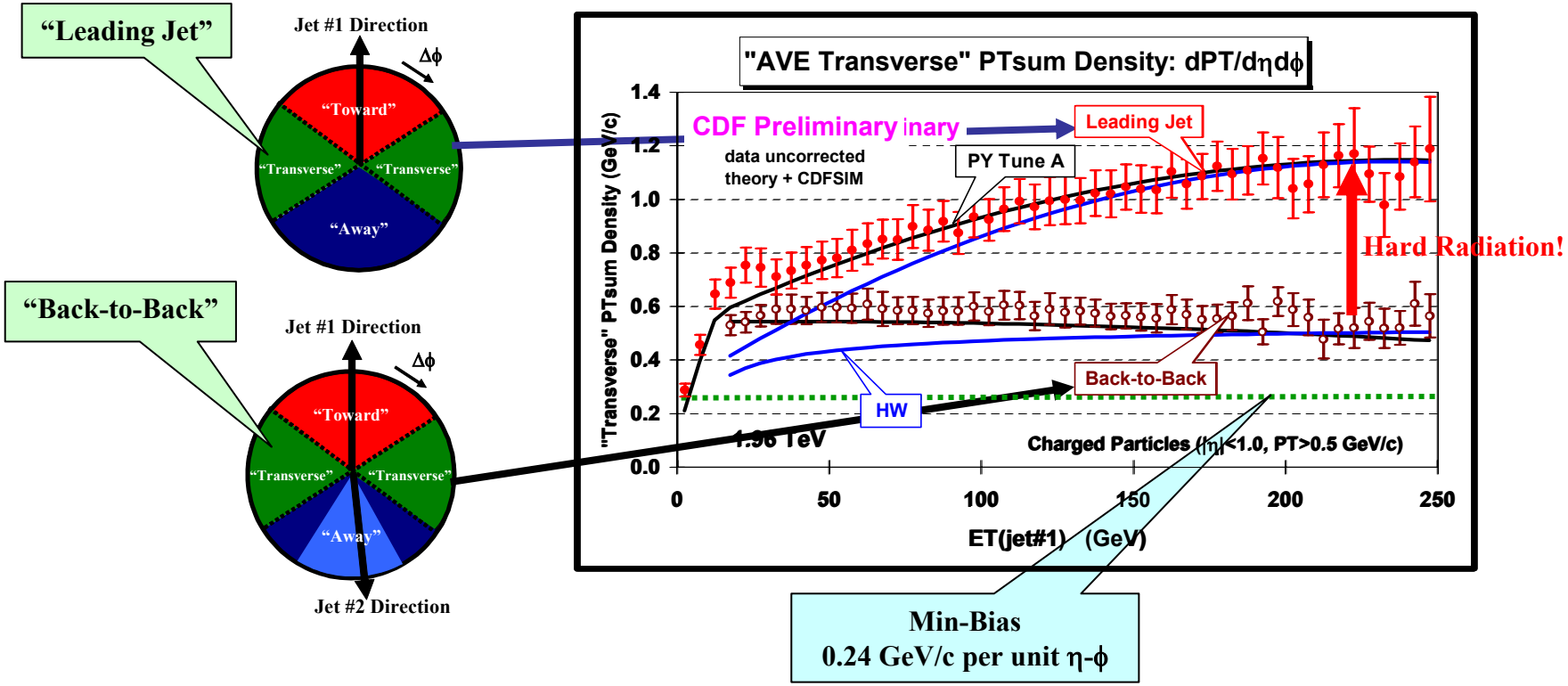
- Look at charged particle correlations in the azimuthal angle $\Delta\phi$ relative to the leading calorimeter jet (JetClu R = 0.7, $|\eta| < 2$).
- Define $|\Delta\phi| < 60^o$ as "Toward", $60^o < -\Delta\phi < 120^o$ and $60^o < \Delta\phi < 120^o$ as "Transverse 1" and "Transverse 2", and $|\Delta\phi| > 120^o$ as "Away". Each of the two "transverse" regions have area $\Delta\eta\Delta\phi = 2x60^o = 4\pi/6$. The overall "transverse" region is the sum of the two transverse regions ($\Delta\eta\Delta\phi = 2x120^o = 4\pi/3$).

Charged Particle Density Δϕ Dependence



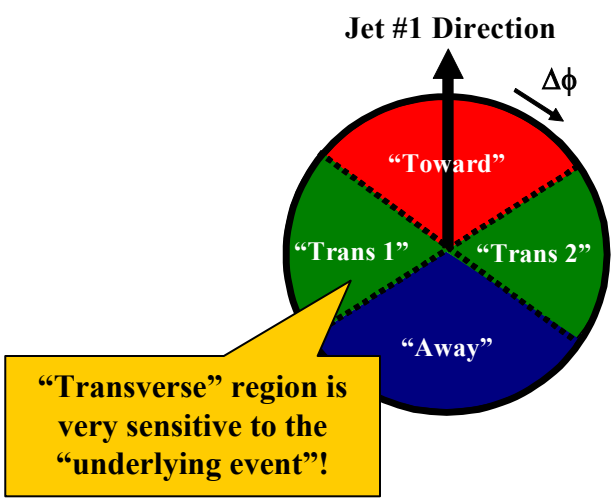
- Look at the "transverse" region as defined by the leading jet (JetClu R = 0.7, $|\eta| < 2$) or by the leading two jets (JetClu R = 0.7, $|\eta| < 2$). "Back-to-Back" events are selected to have at least two jets with Jet#1 and Jet#2 nearly "back-to-back" ($\Delta\phi_{12} > 150^o$) with almost equal transverse energies (E_T(jet#2)/E_T(jet#1) > 0.8) and with E_T(jet#3) < 15 GeV.
- Shows the Δϕ dependence of the charged particle density, $dN_{chg}/d\eta d\phi$, for charged particles in the range $p_T > 0.5$ GeV/c and $|\eta| < 1$ relative to jet#1 (rotated to 270°) for 30 < E_T(jet#1) < 70 GeV for "Leading Jet" and "Back-to-Back" events.

"Transverse" PTsum Density vs E_T(jet#1)

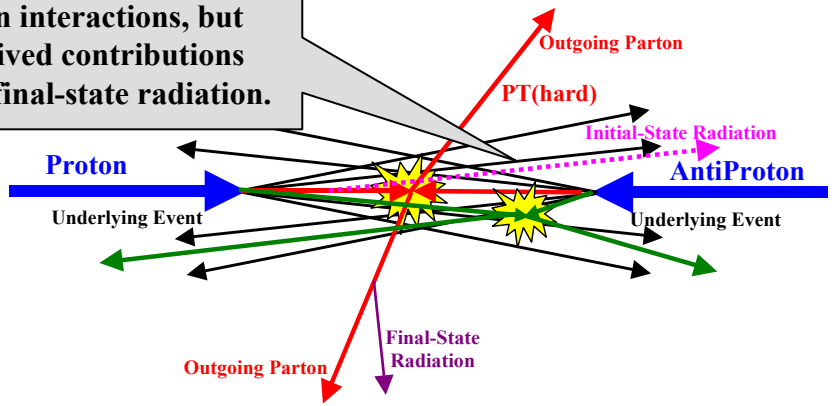


- Shows the average charged PTsum density, $dPT_{sum}/d\eta d\phi$, in the "transverse" region (p_T > 0.5 GeV/c, $|\eta| < 1$) versus E_T(jet#1) for "Leading Jet" and "Back-to-Back" events.
- Compares the (*uncorrected*) data with PYTHIA Tune A and HERWIG (*without MPI*) after CDFSIM.

Latest CDF Run 2 "Underlying Event" Results



The "underlying event" consists of the "beam-beam remnants" and possible multiple parton interactions, but inevitably received contributions from initial and final-state radiation.

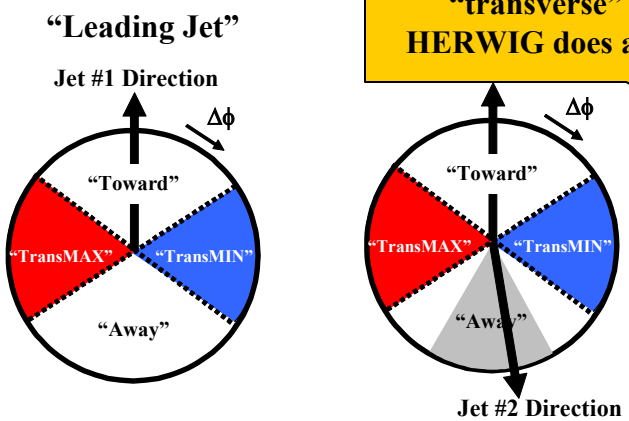


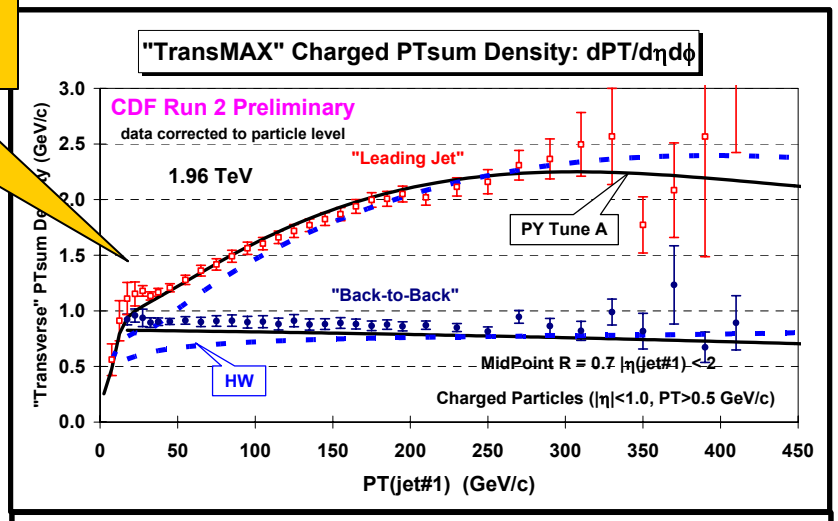
Latest CDF Run 2 Results (L = 385 pb^{-1}) :

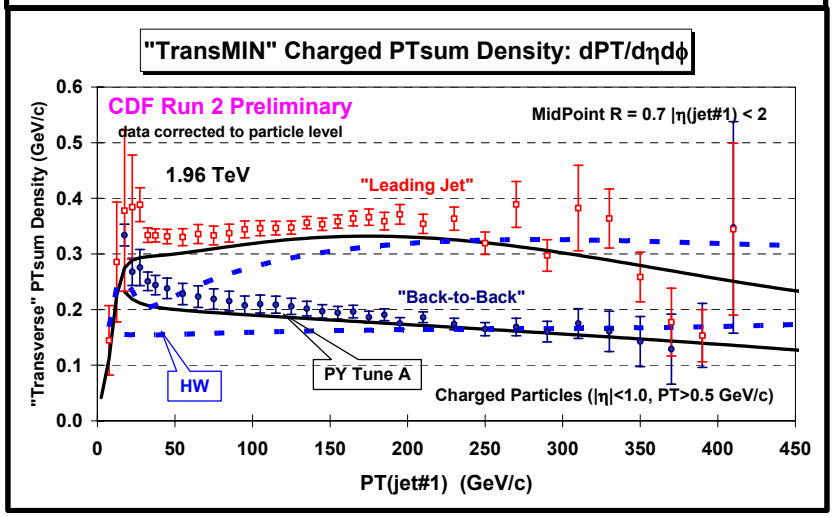
- **Two Classes of Events:** "Leading Jet" and "Back-to-Back".
- **Two "Transverse" regions:** "transMAX", "transMIN", "transDIF".
- **Data Corrected to the Particle Level:** unlike our previous CDF Run 2 "underlying event" analysis which used JetClu to define "jets" and compared uncorrected data with the QCD Monte-Carlo models after detector simulation, this analysis uses the MidPoint jet algorithm and corrects the observables to the particle level. The corrected observables are then compared with the QCD Monde-Carlo models at the particle level.
- For the 1st time we study the energy density in the "transverse" region.

"TransMAX/MIN" PTsum Density PYTHIA vs HERWIG

PYTHIA Tune A does a fairly good job fitting the PTsum density in the "transverse" region! HERWIG does a poor job!







- Shows the charged particle PTsum density, $dPT_{sum}/d\eta d\phi$, 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

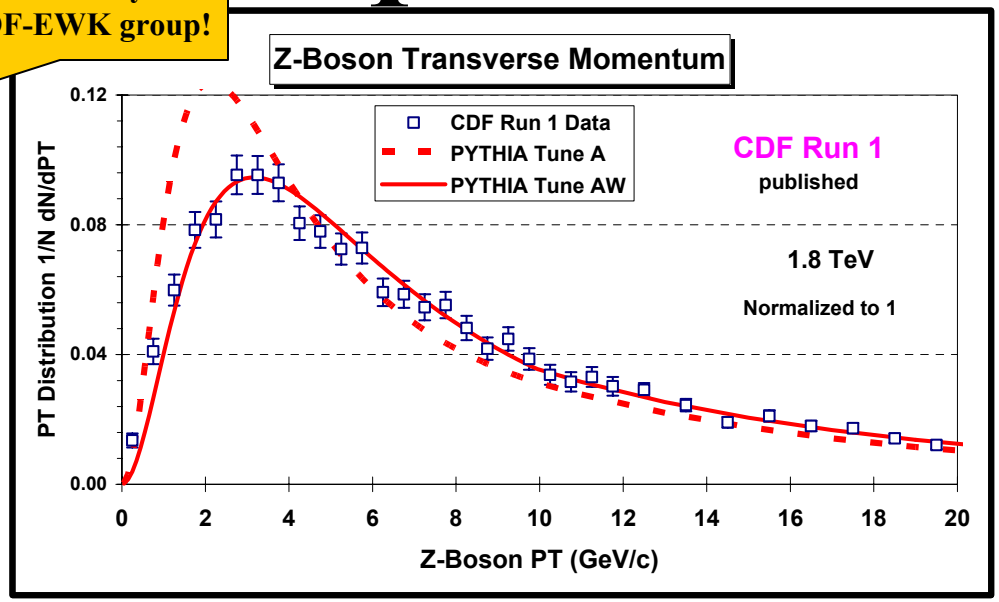
Parameter	Tune A	Tune AW
MSTP(81)	1	1
MSTP(82)	4	4
PARP(82)	2.0 GeV	2.0 GeV
PARP(83)	0.5	0.5
PARP(84)	0.4	0.4
PARP(85)	0.9	0.9
PARP(86)	0.95	0.95
PARP(89)	1.8 TeV	1.8 TeV
PARP(90)	0.25	0.25
PARP(62)	1.0	1.25
PARP(64)	1.0	0.2
PARP(67)	4.0	4.0
MSTP(91)	1	1
PARP(91)	1.0	2.1
PARP(93)	5.0	15.0

Tune used by the CDF-EWK group!

UE Parameters

ISR Parameters

Intrensic KT



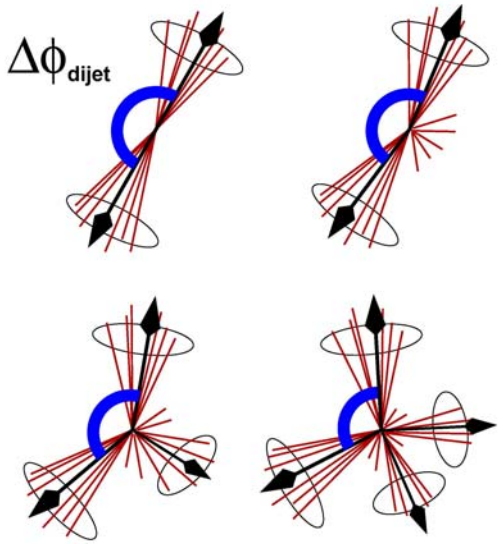
- **Shows the Run 1 Z-boson p_T distribution ($\langle p_T(Z)\rangle \approx 11.5$ GeV/c) compared with PYTHIA Tune A ($\langle p_T(Z)\rangle = 9.7$ GeV/c), and PYTHIA Tune AW ($\langle p_T(Z)\rangle = 11.7$ GeV/c).**

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

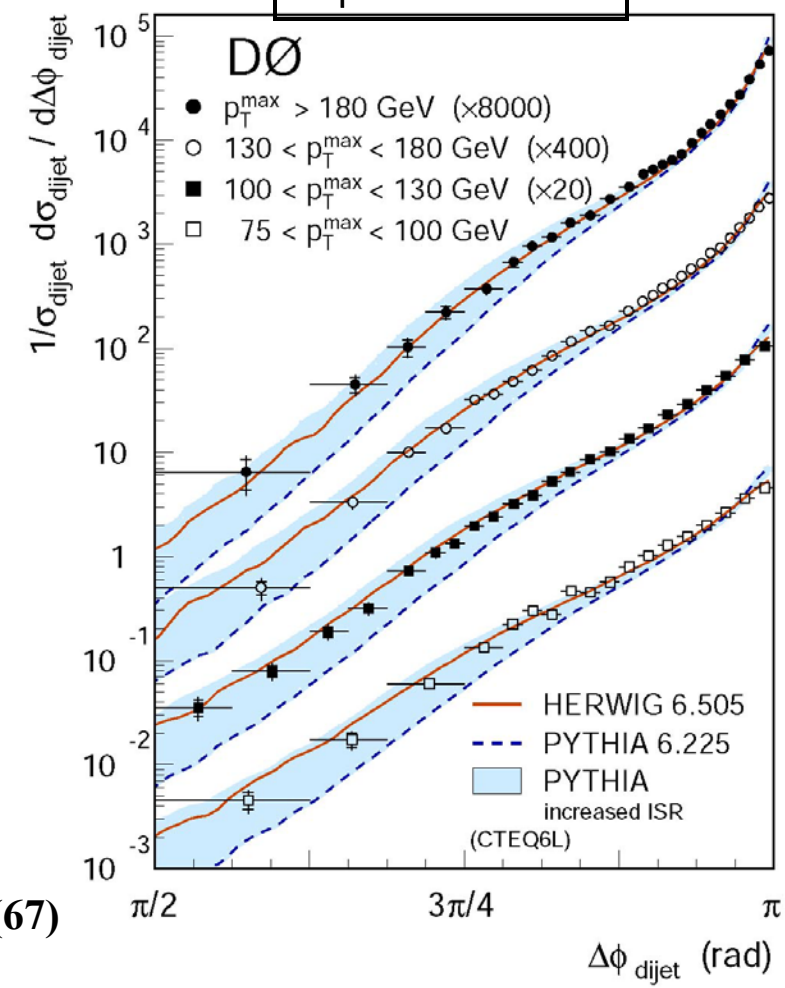
The $Q^2 = k_T^2$ in α_s for space-like showers is scaled by PARP(64)!

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 $P_T(Z)$

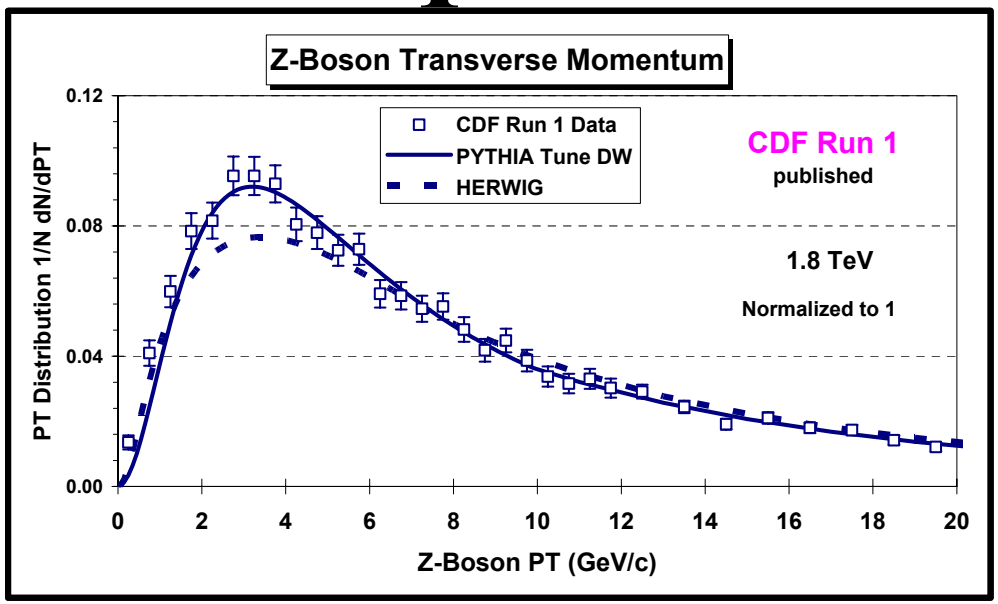
PYTHIA 6.2 CTEQ5L

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	5.0

UE Parameters

ISR Parameters

Intrensic KT



➡ Shows the Run 1 Z-boson p_T distribution ($\langle p_T(Z)\rangle \approx 11.5$ 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!

CDF Run 1 $P_T(Z)$

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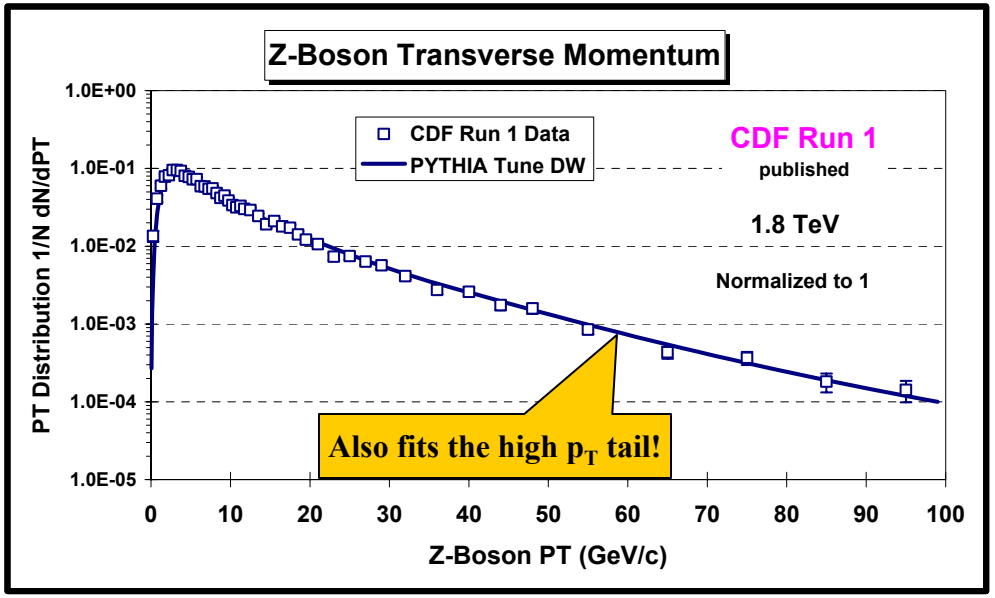

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Tune DW has a lower value of PARP(67) and slightly more MPI!

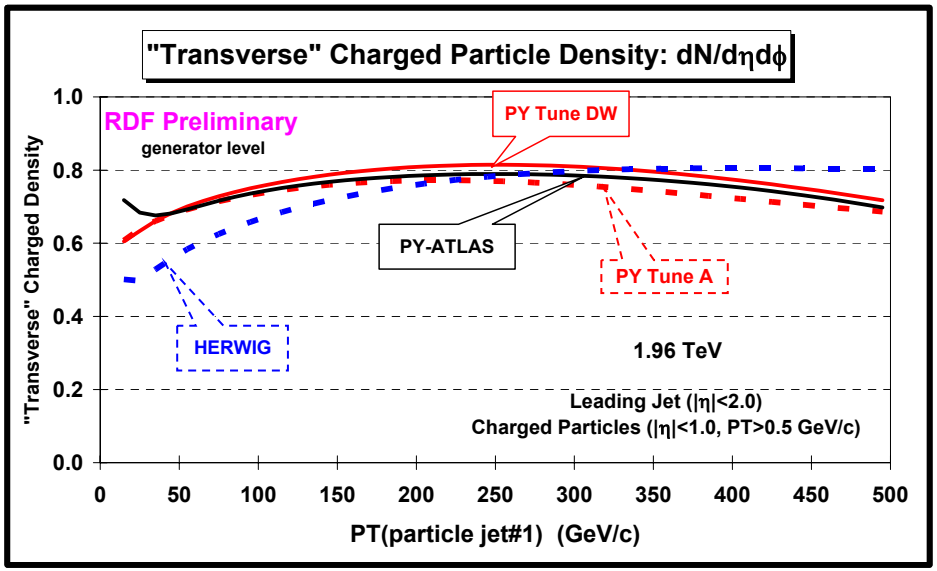
PYTHIA 6.2 Tunes

PYTHIA 6.2 CTEQ5L

Parameter	Tune A	Tune DW	Tune DWT	ATLAS
MSTP(81)	1	1	1	1
MSTP(82)	4	4	4	4
PARP(82)	2.0 GeV	1.9 GeV	1.9409 GeV	1.8 GeV
PARP(83)	0.5	0.5	0.5	0.5
PARP(84)	0.4	0.4	0.4	0.5
PARP(85)	0.9	1.0	1.0	0.33
PARP(86)	0.95	1.0	1.0	0.66
PARP(89)	1.8 TeV	1.8 TeV	1.96 TeV	1.0 TeV
PARP(90)	0.25	0.25	0.16	0.16
PARP(62)	1.0	1.25	1.25	1.0
PARP(64)	1.0	0.2	0.2	1.0
PARP(67)	4.0	2.5	2.5	1.0
MSTP(91)	1	1	1	1
PARP(91)	1.0	2.1	2.1	1.0
PARP(93)	5.0	15	15.0	5.0

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

	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
Tune DWT	351.7 mb	829.1 mb
ATLAS	324.5 mb	768.0 mb



➡ Shows the "transverse" charged particle density, dN/dηdφ, versus P_T(jet#1) for "leading jet" events at 1.96 TeV for Tune A, 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	1	1	1
MSTP(82)	4	4	4	4
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PARP(85)	0.9	1.0	1.0	0.33
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PARP(89)	1.8 TeV	1.8 TeV	1.96 TeV	1.0 TeV
PARP(90)	0.25	0.25	0.16	0.16
PARP(62)	1.0	1.25	1.25	1.0
PARP(64)	1.0	0.2	0.2	1.0
PARP(67)	4.0	2.5	2.5	1.0
MSTP(91)	1	1	1	1
PARP(91)	1.0	2.1	2.1	1.0
PARP(93)	5.0	15	15.0	5.0

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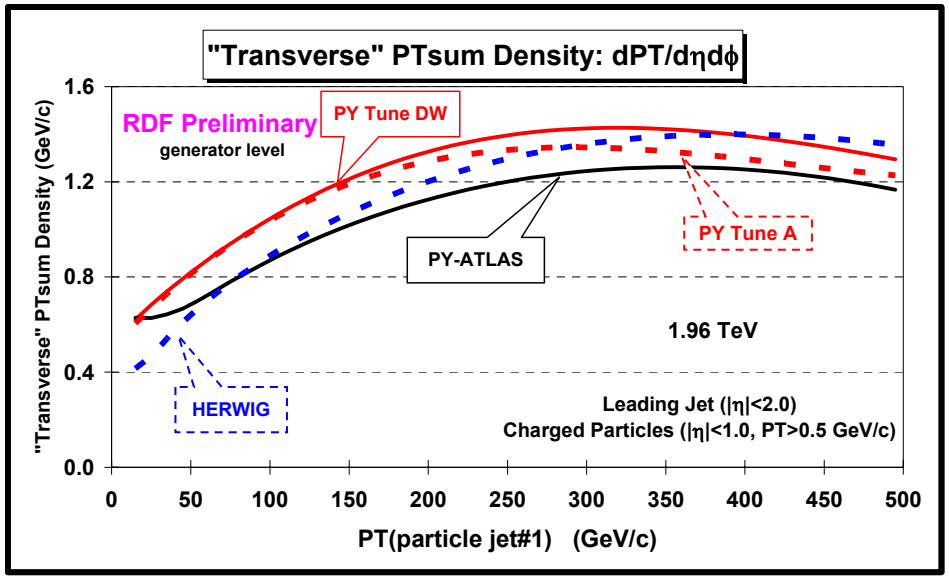


➡ Shows the "transverse" charged PTsum density, dPT/dηdϕ, versus P_T(jet#1) for "leading jet" events at 1.96 TeV for Tune A, DW, ATLAS, and HERWIG (without MPI).

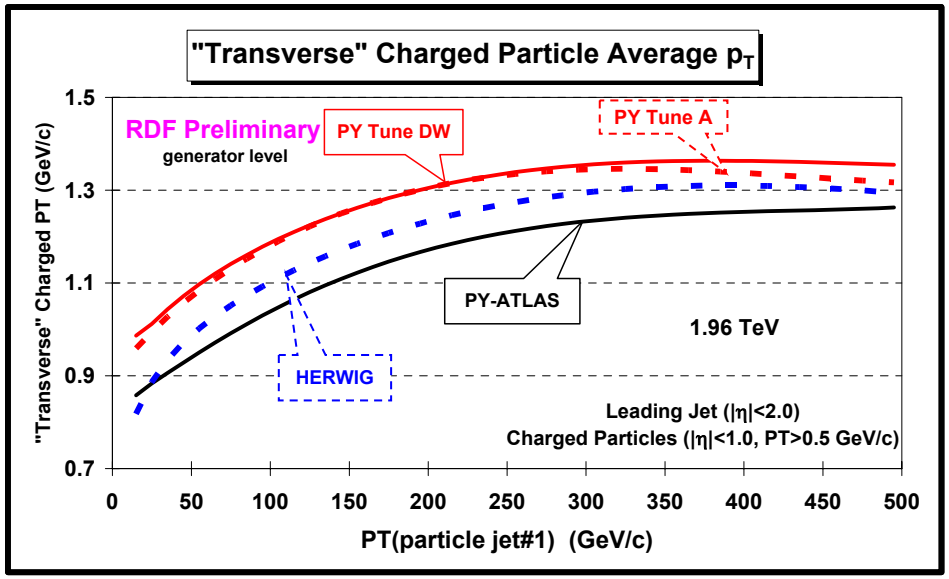
PYTHIA 6.2 Tunes

PYTHIA 6.2 CTEQ5L

Parameter	Tune A	Tune DW	Tune DWT	ATLAS
MSTP(81)	1	1	1	1
MSTP(82)	4	4	4	4
PARP(82)	2.0 GeV	1.9 GeV	1.9409 GeV	1.8 GeV
PARP(83)	0.5	0.5	0.5	0.5
PARP(84)	0.4	0.4	0.4	0.5
PARP(85)	0.9	1.0	1.0	0.33
PARP(86)	0.95	1.0	1.0	0.66
PARP(89)	1.8 TeV	1.8 TeV	1.96 TeV	1.0 TeV
PARP(90)	0.25	0.25	0.16	0.16
PARP(62)	1.0	1.25	1.25	1.0
PARP(64)	1.0	0.2	0.2	1.0
PARP(67)	4.0	2.5	2.5	1.0
MSTP(91)	1	1	1	1
PARP(91)	1.0	2.1	2.1	1.0
PARP(93)	5.0	15	15.0	5.0

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

	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
Tune DWT	351.7 mb	829.1 mb
ATLAS	324.5 mb	768.0 mb



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PYTHIA 6.2 Tunes

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Parameter	Tune A	Tune DW	Tune DWT	ATLAS
MSTP(81)	1	1	1	1
MSTP(82)	4	4	4	4
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PARP(83)				
PARP(84)				
PARP(85)				
PARP(86)				
PARP(89)	1.8			
PARP(90)				
PARP(62)				
PARP(64)				
PARP(67)				
MSTP(91)				
PARP(91)				
PARP(93)				

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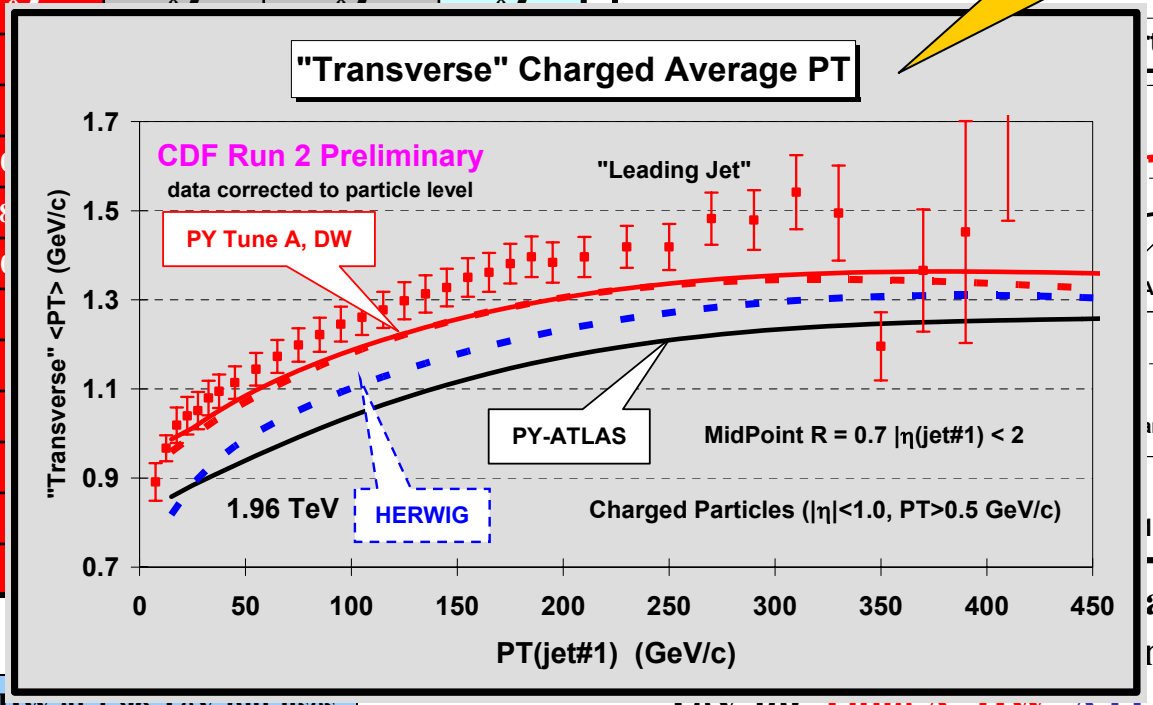
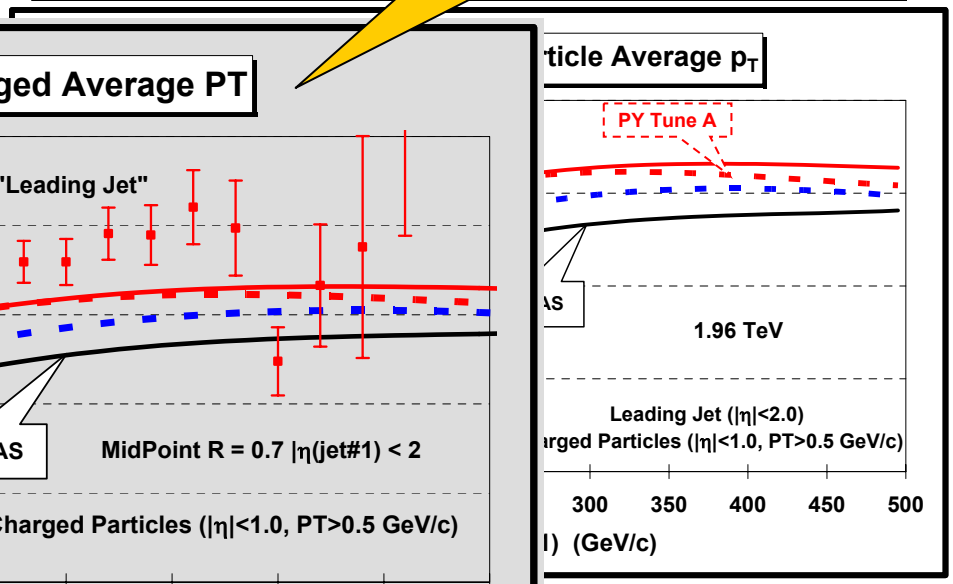
Tune DWT	351.7 mb	829.1 mb
ATLAS	3	768.0 mb

CDF Run 2 Data!





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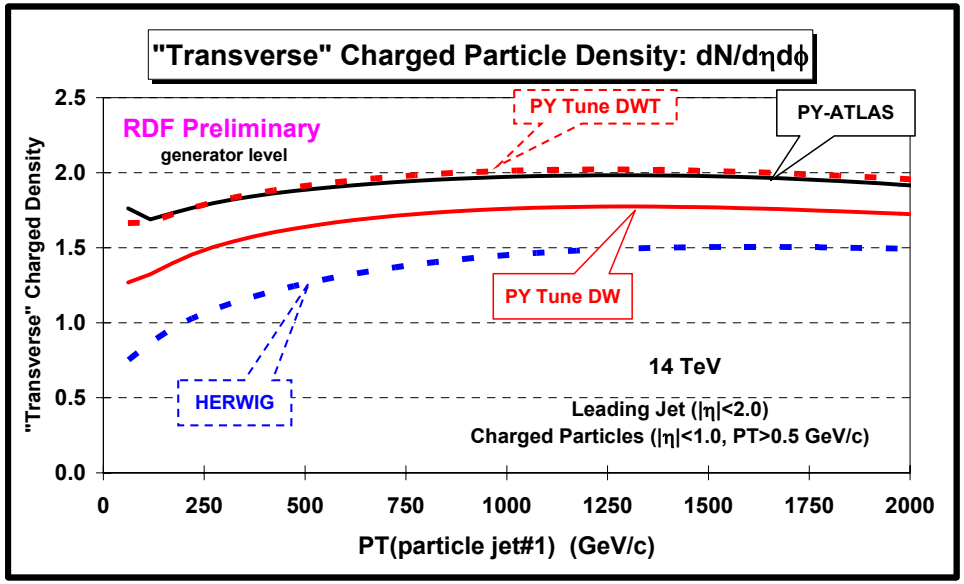

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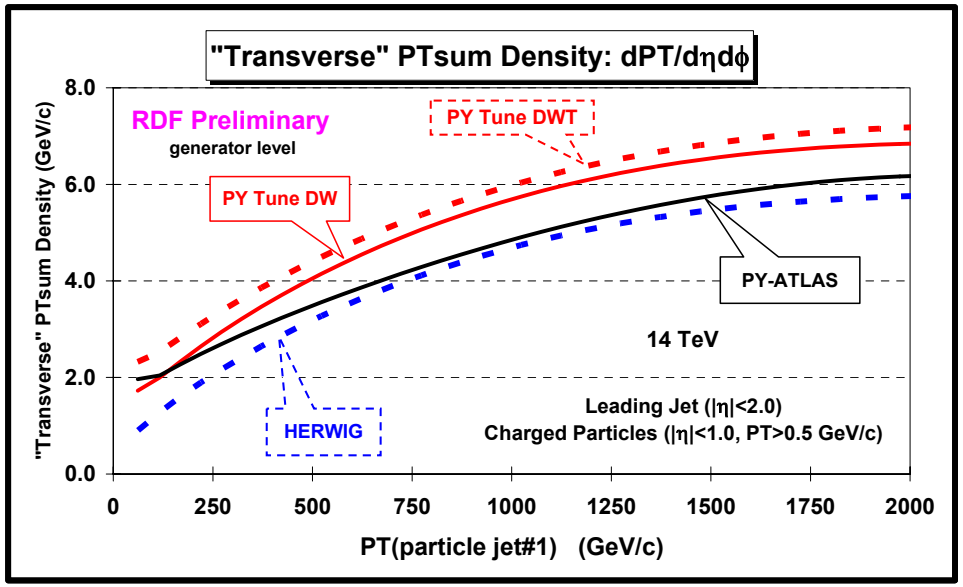

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MSTP(91)	1	1	1	1
PARP(91)	1.0	2.1	2.1	1.0
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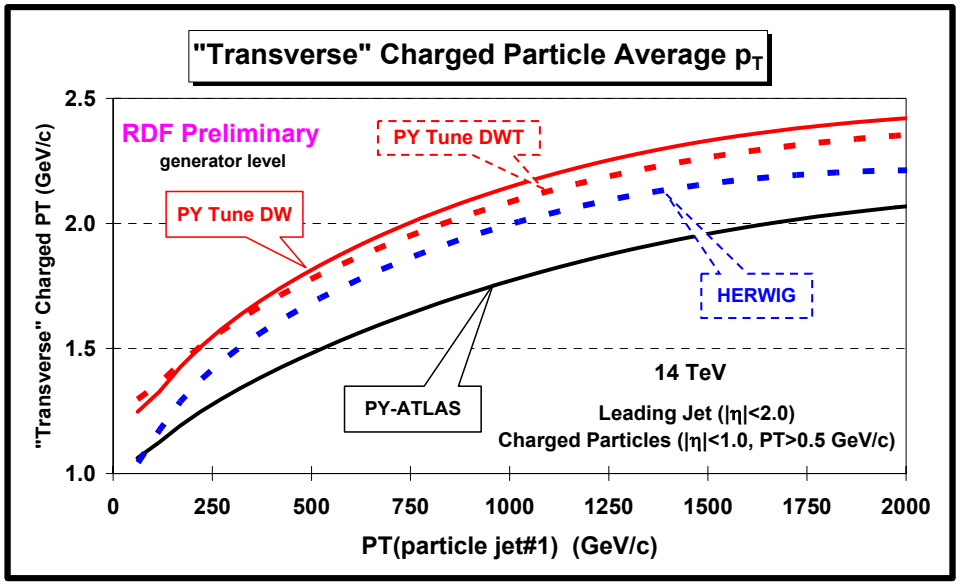

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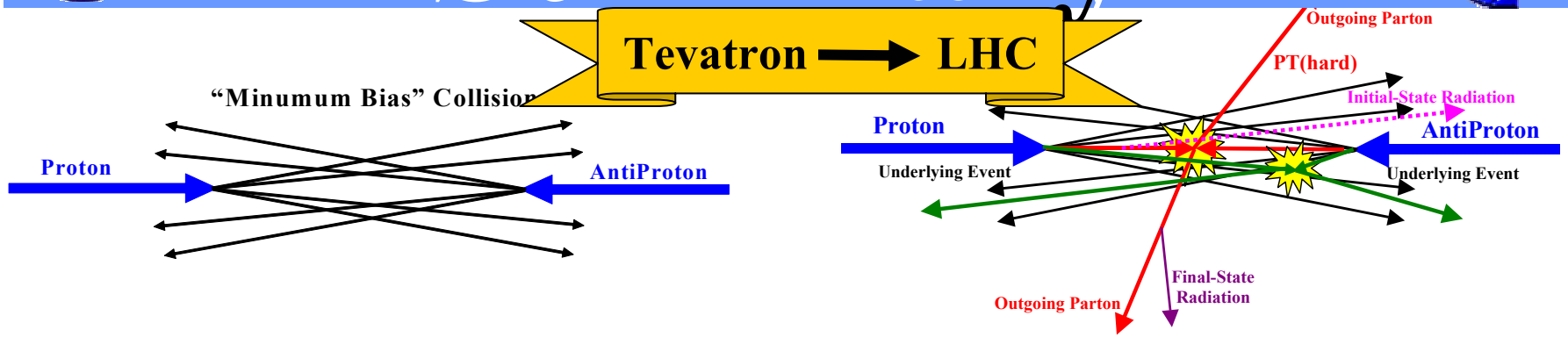
Summary



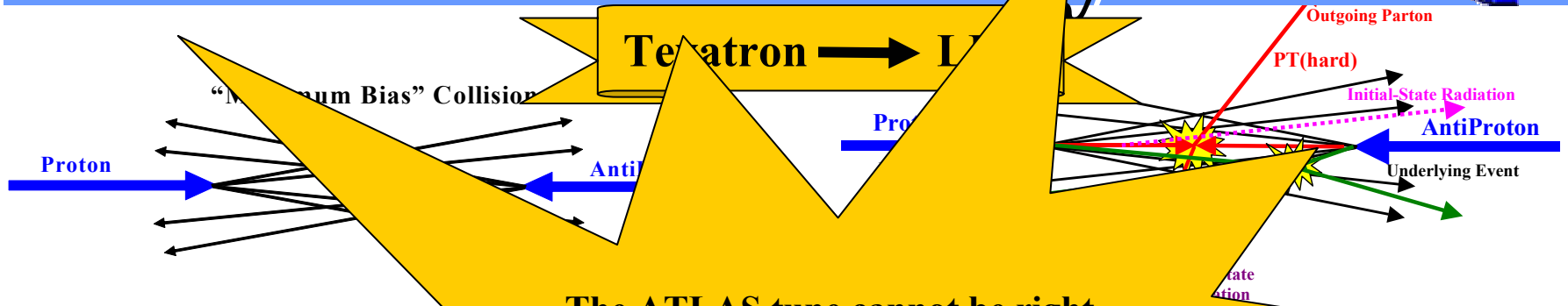
- **The ATLAS tune is "goofy"! It produces too many "soft" particles. The charged particle <p_T> is too low and does not agree with the CDF Run 2 data. The ATLAS tune agrees with <N_{chg}> but not with <PT_{sum}> at the Tevatron.**

- **PYTHIA Tune DW is very similar to Tune A except that it fits the CDF $P_T(Z)$ distribution and it uses the DØ prefered value of PARP(67) = 2.5 (determined from the dijet $\Delta\phi$ distribution).**

- **PYTHIA Tune DWT is identical to Tune DW at 1.96 TeV but uses the ATLAS energy extrapolation to the LHC (*i.e.* PARP(90) = 0.16).**

Summary

Tevatron → L



The ATLAS tune cannot be right because it does not fit the Tevatron data. Right now I like Tune DW. Probably no tune will fit the LHC data. That is why we plan to measure MB&UE at CMS and retune the Monte-Carlo models!

- **The A ged particle <p e ATLAS tune agrees with <p**
- **PYTHIA DF $P_T(Z)$ distr tion and it uses t rmined from the dijet $\Delta\phi$ distribution).**
- **PYTHIA Tune DWT s identical t DW at V but uses the TLAS energy extrapolation to the LHC (*i.e.* PA = 0.16).**