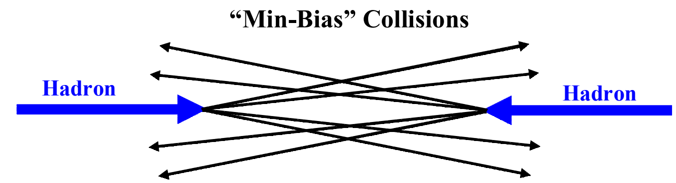
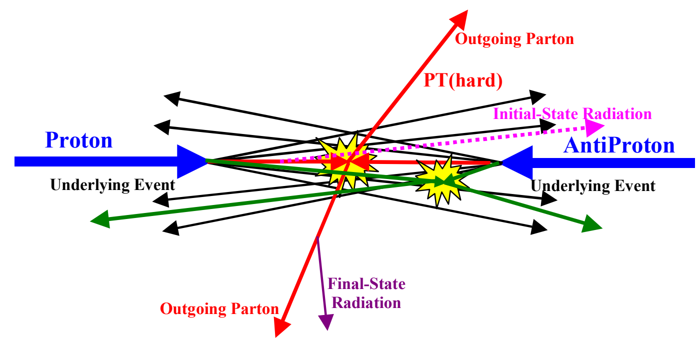
PYTHIA 6.2 “Tunes” for Run II

Outline of Talk

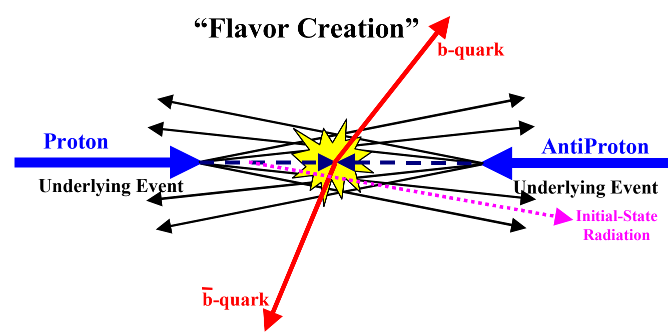
- **“Min-Bias” Generators**



- **The “Underlying Event in Hard Scattering Processes**

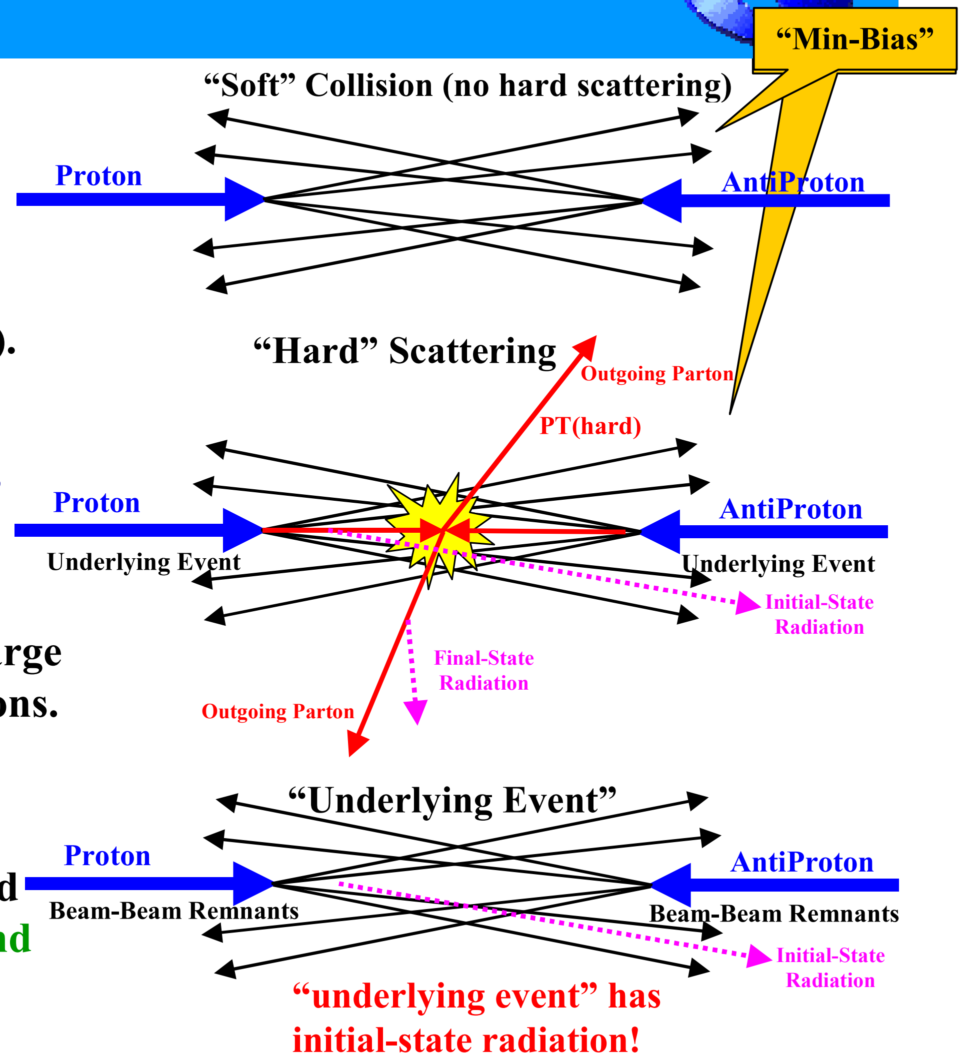


- **Initial-State Radiation and b-bbar Correlations**

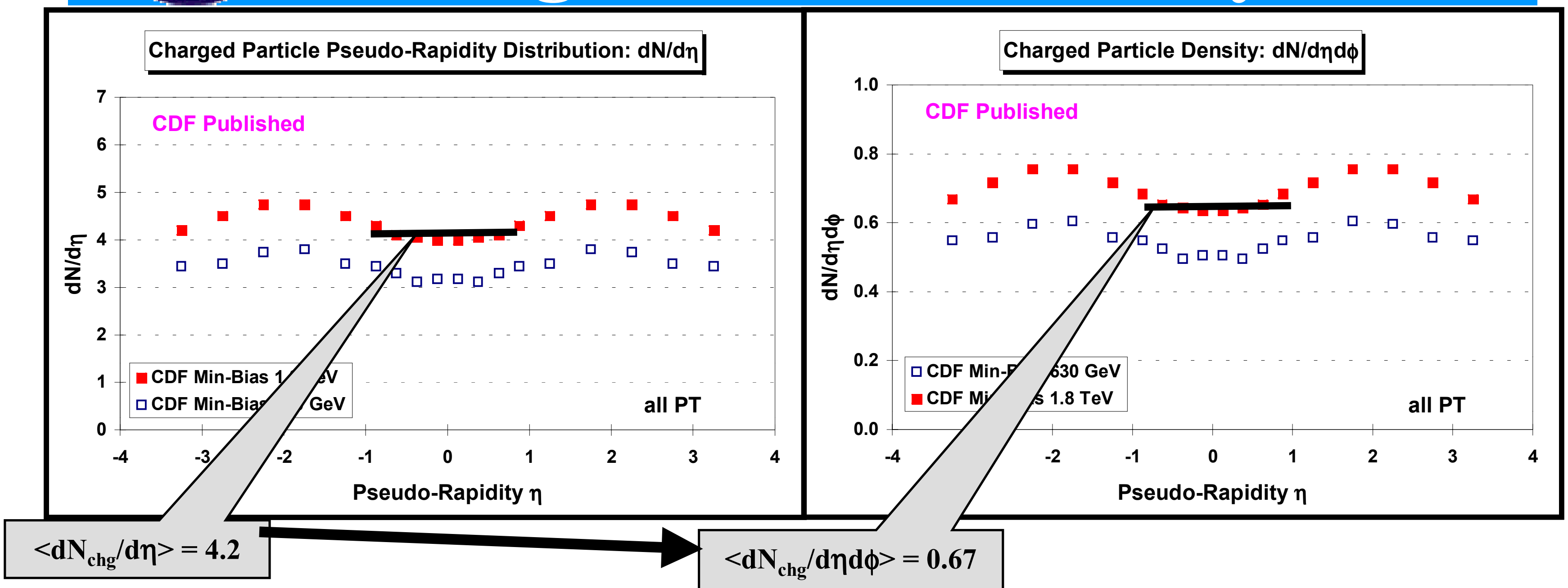


"Min-Bias" & "Underlying Event"

- What happens when a high energy proton and an antiproton collide?
- Most of the time the proton and antiproton ooze through each other and fall apart (*i.e.* no hard scattering). The outgoing particles continue in roughly the same direction as initial proton and antiproton. A "Min-Bias" collision.
- Occasionally there will be a "hard" parton-parton collision resulting in large transverse momentum outgoing partons. Also a "Min-Bias" collision.
- The "underlying event" is everything except the two outgoing hard scattered "jets". It is an unavoidable background to many collider observables.

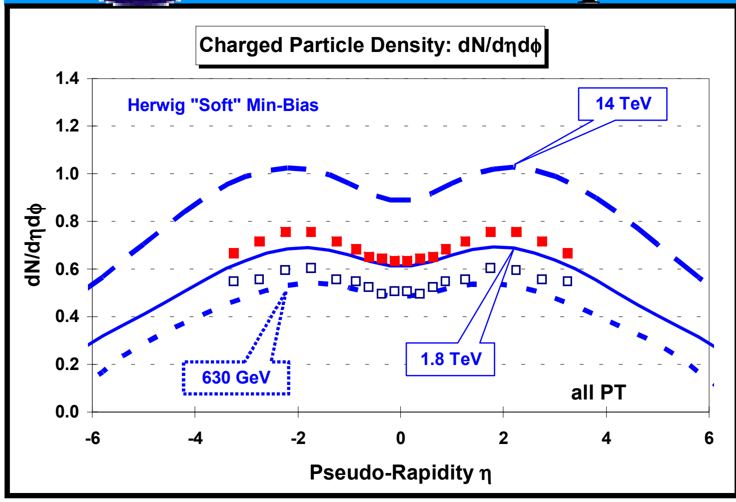


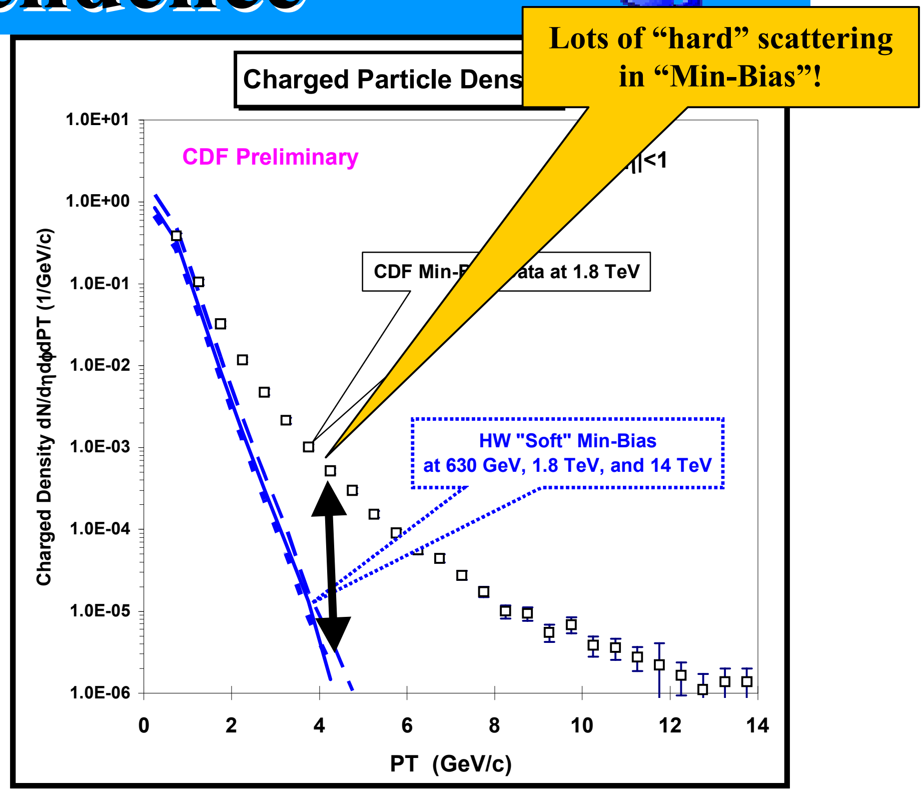
CDF "Min-Bias" Data
Charged Particle Density



- Shows CDF "Min-Bias" data on the number of charged particles per unit pseudo-rapidity at 630 and 1,800 GeV. There are about **4.2 charged particles per unit η in "Min-Bias" collisions at 1.8 TeV** (|η| < 1, all P_T).
- Convert to charged particle density, $dN_{chg}/d\eta d\phi$, by dividing by 2π. There are about **0.67 charged particles per unit η-ϕ in "Min-Bias" collisions at 1.8 TeV** (|η| < 1, all P_T).

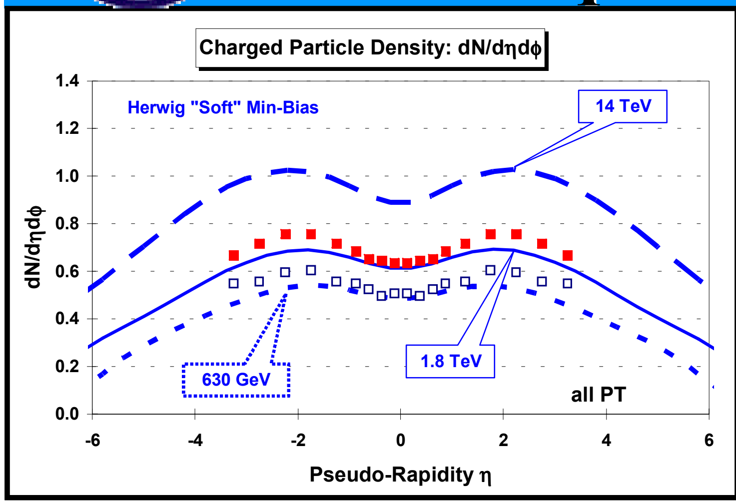
CDF "Min-Bias" Data
P_T Dependence

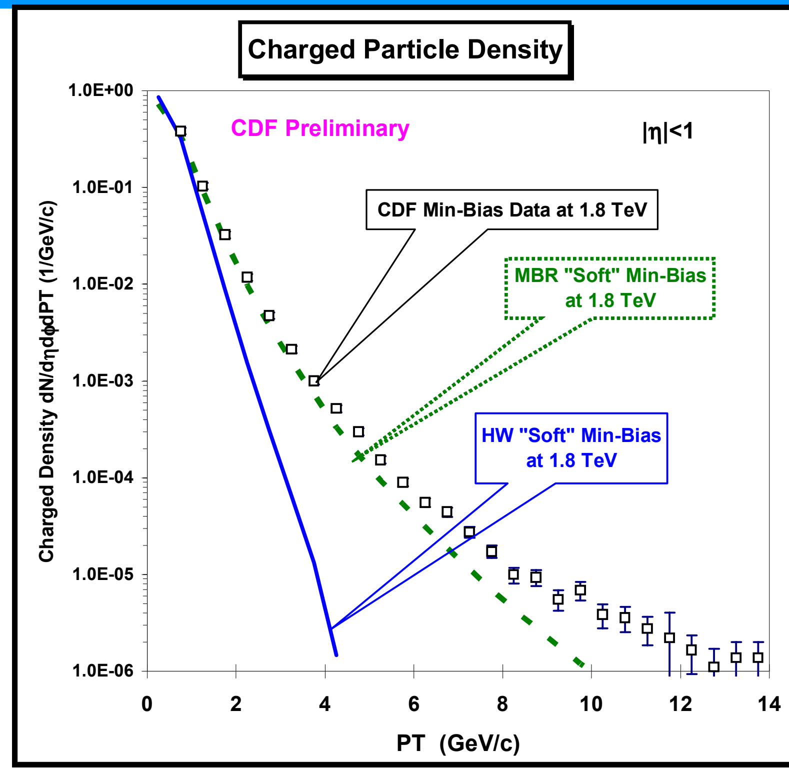




- Shows the energy dependence of the charged particle density, $dN_{chg}/d\eta d\phi$, for "Min-Bias" collisions compared with **HERWIG "Soft" Min-Bias**.
- Shows the P_T dependence of the charged particle density, $dN_{chg}/d\eta d\phi dP_T$, for "Min-Bias" collisions at 1.8 TeV collisions compared with **HERWIG "Soft" Min-Bias**.
- **HERWIG "Soft" Min-Bias** does not describe the "Min-Bias" data! **The "Min-Bias" data contains a lot of "hard" parton-parton collisions** which results in many more particles at large P_T than are produces by any "soft" model.

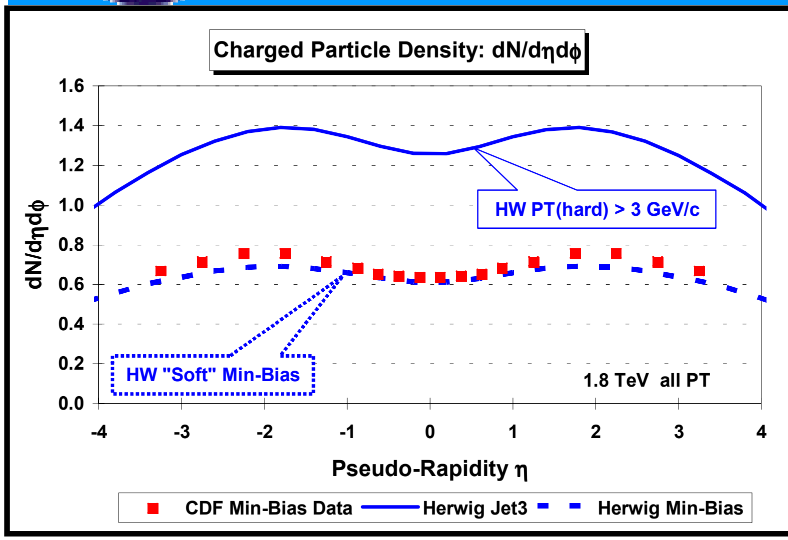
CDF "Min-Bias" Data
P_T Dependence

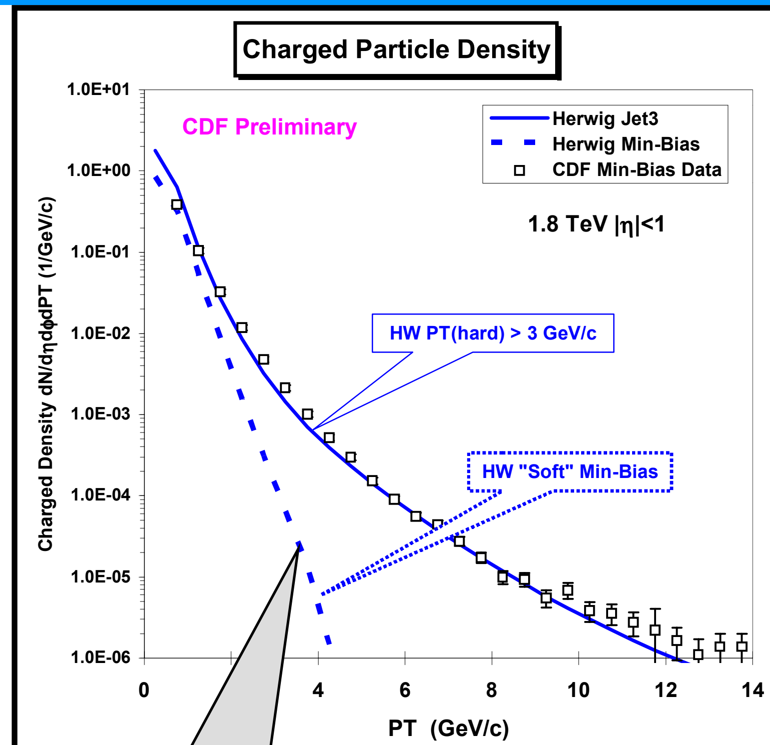




- Shows the energy dependence of the charged particle density, $dN_{chg}/d\eta d\phi$, for "Min-Bias" collisions compared with HERWIG "Soft" Min-Bias.
- Shows the P_T dependence of the charged particle density, $dN_{chg}/d\eta d\phi dP_T$, for "Min-Bias" collisions at 1.8 TeV collisions compared with HERWIG "Soft" Min-Bias and MBR.
- Although MBR has a harder P_T distribution it is a "soft" model and has no hard scattering. MBR does nt describe the correlation in the "min-bias" data (*i.e.* the data have "jets") and MBR does not.

Min-Bias: Combining "Hard" and "Soft" Collisions

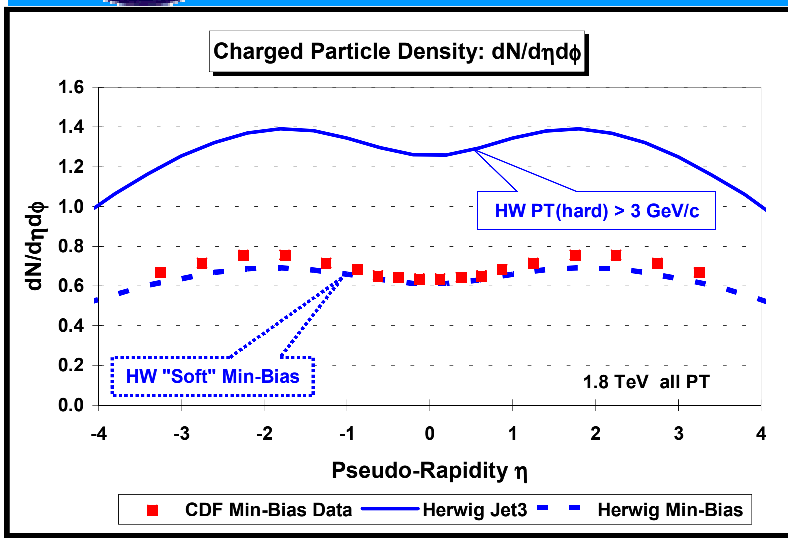


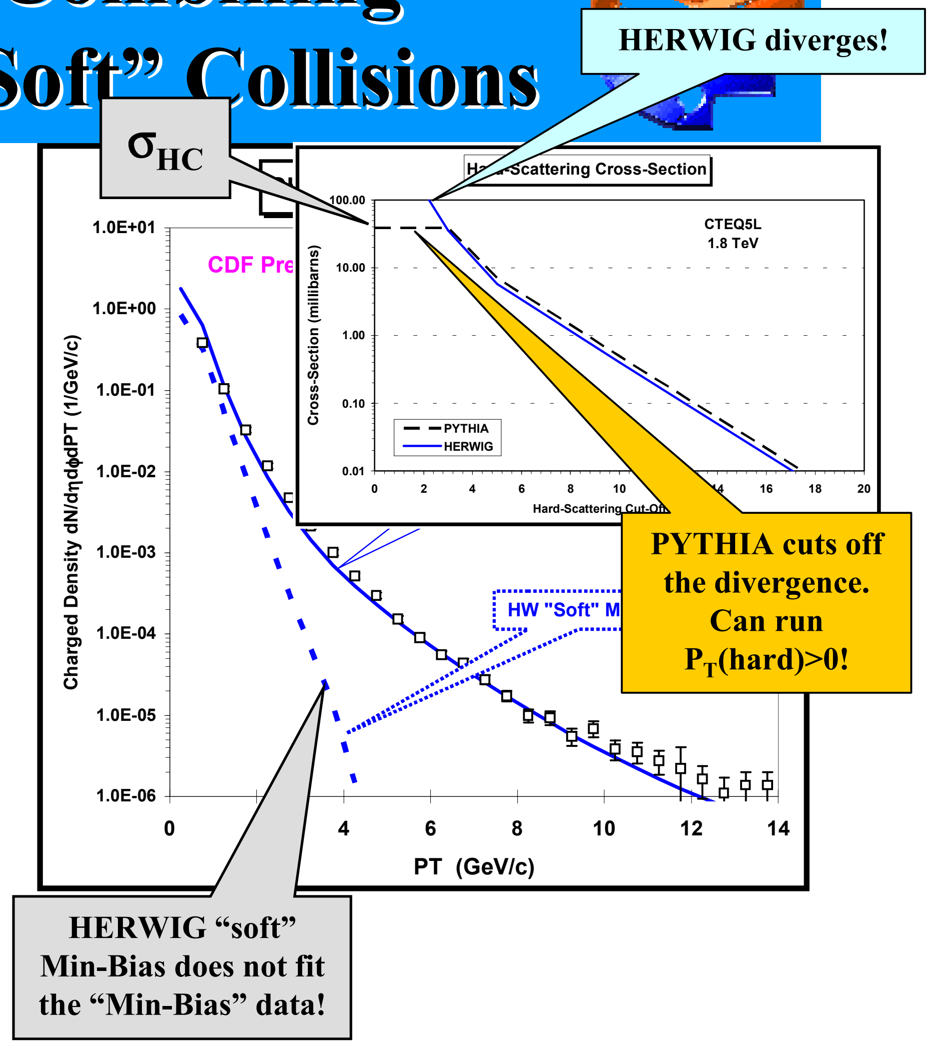


HERWIG "soft" Min-Bias does not fit the "Min-Bias" data!

- **HERWIG "hard" QCD with P_T(hard) > 3 GeV/c describes well the high P_T tail but produces too many charged particles overall. Not all of the "Min-Bias" collisions have a hard scattering with P_T(hard) > 3 GeV/c!**
- **One cannot run the HERWIG "hard" QCD Monte-Carlo with P_T(hard) < 3 GeV/c because the perturbative 2-to-2 cross-sections diverge like $1/P_T(\text{hard})^4$?**

Min-Bias: Combining "Hard" and "Soft" Collisions



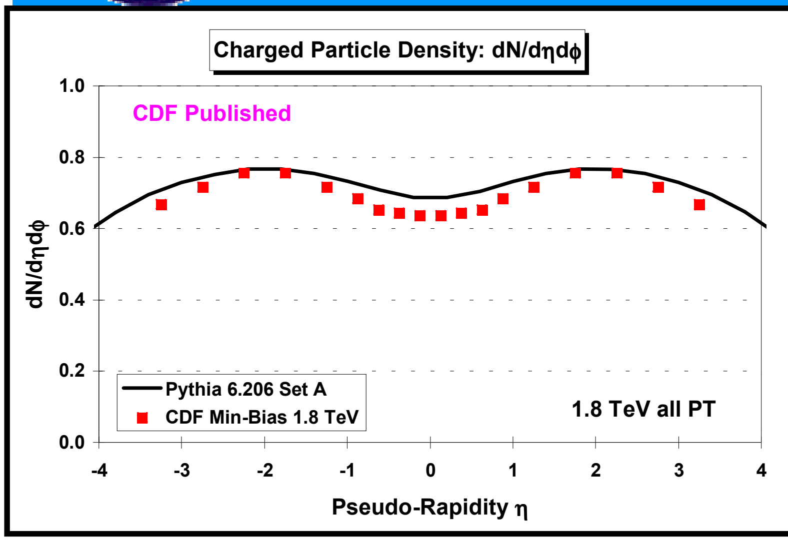


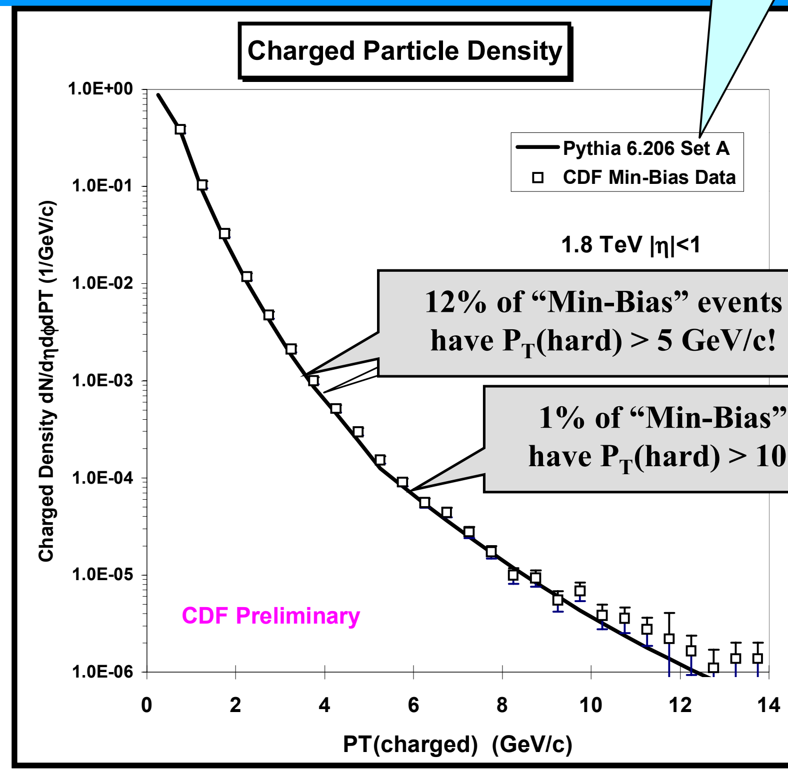
- **HERWIG "hard" QCD** with P_T(hard) > 3 GeV/c describes well the high P_T tail but produces too many charged particles overall. Not all of the "Min-Bias" collisions have a hard scattering with P_T(hard) > 3 GeV/c!

- One cannot run the HERWIG "hard" QCD Monte-Carlo with P_T(hard) < 3 GeV/c because the perturbative 2-to-2 cross-sections diverge like $1/P_T(\text{hard})^4$?

PYTHIA Min-Bias "Soft" + "Hard"

Tuned to fit the "underlying event"!





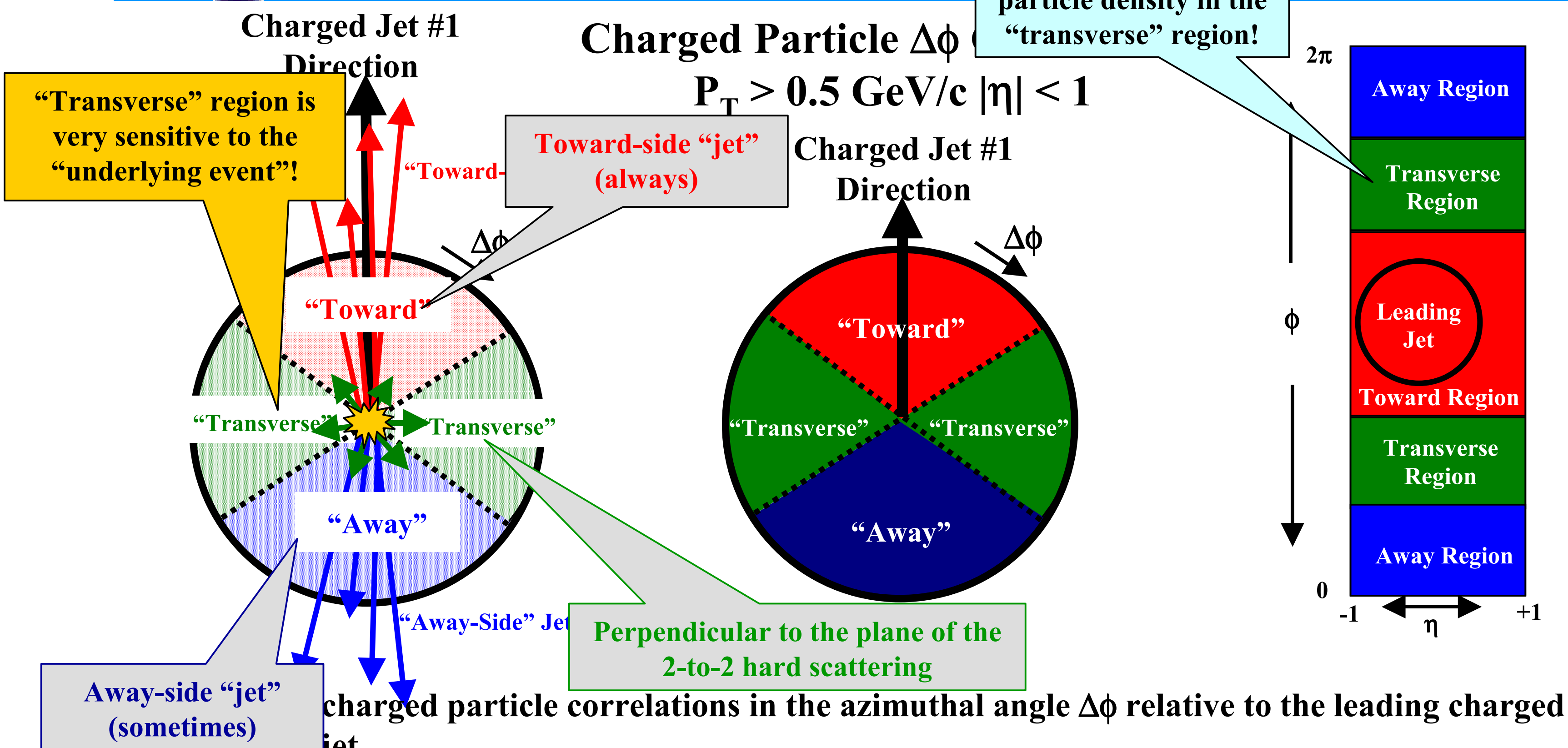
12% of "Min-Bias" events have P_T(hard) > 5 GeV/c!

1% of "Min-Bias" events have P_T(hard) > 10 GeV/c!

Lots of "hard" scattering in "Min-Bias"!

- PYTHIA regulates the perturbative 2-to-2 parton-parton cross sections with cut-off par… one to run with P_T(… mulate both "hard" and "soft" collisio… one program.
- The relative amount of …rd" versus "soft" depends on the cut-off and can be tuned.
- This PYTHIA fit predicts that 12% of all "Min-Bias" events are a result of a hard 2-to-2 parton-parton scattering with P_T(hard) > 5 GeV/c (1% with P_T(hard) > 10 GeV/c)!

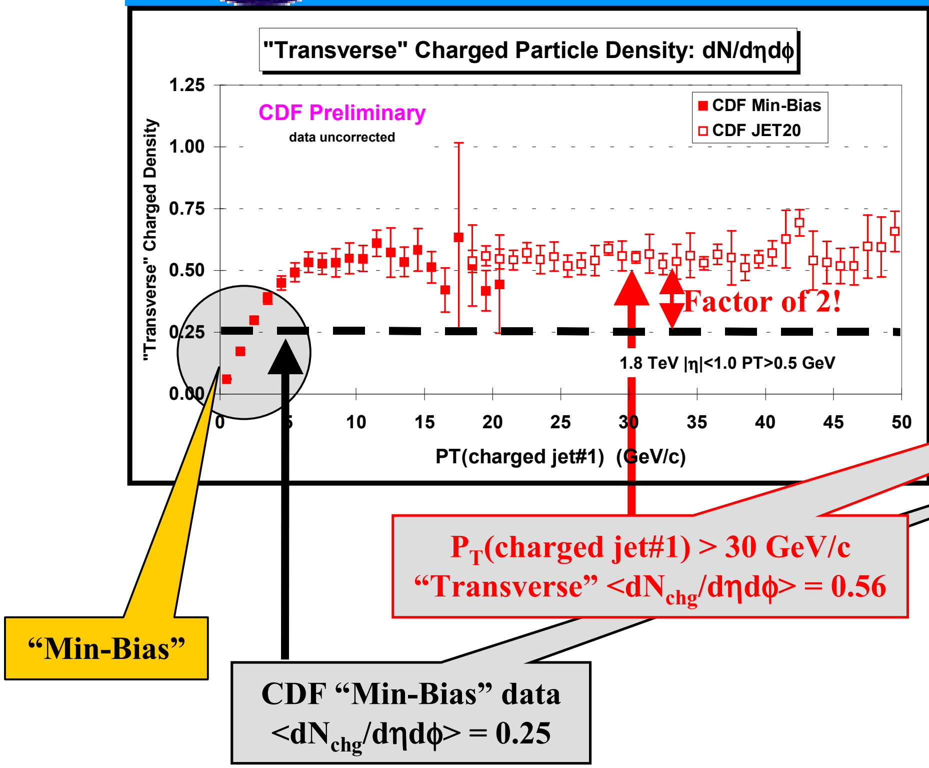
Evolution of Charged Jets
“Underlying Event”

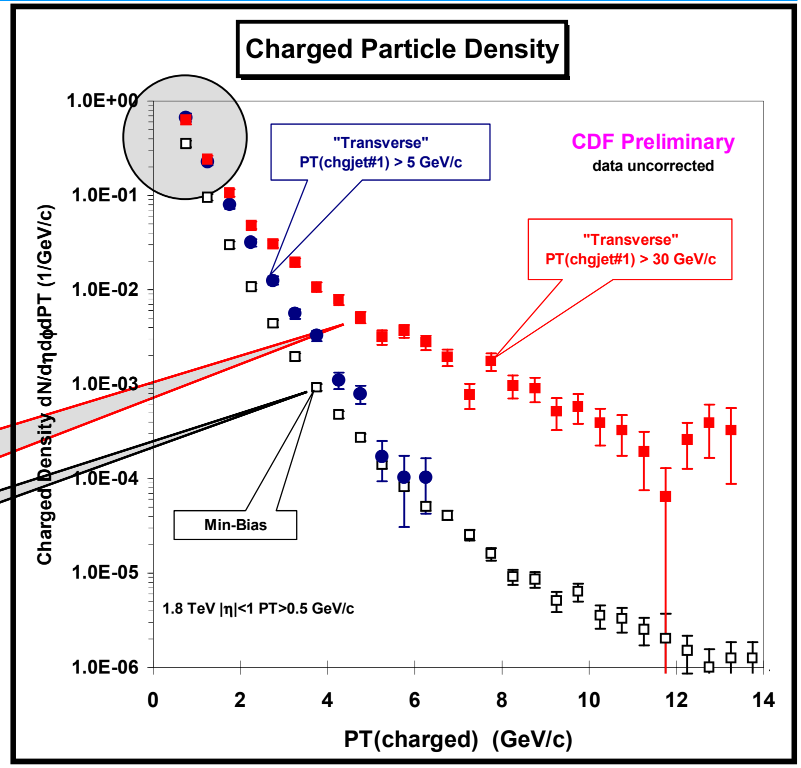


charged particle correlations in the azimuthal angle Δϕ relative to the leading charged particle jet.

- Define |Δϕ| < 60° as “Toward”, 60° < |Δϕ| < 120° as “Transverse”, and |Δϕ| > 120° as “Away”.
- All three regions have the same size in η-ϕ space, ΔηxΔϕ = 2x120° = 4π/3.

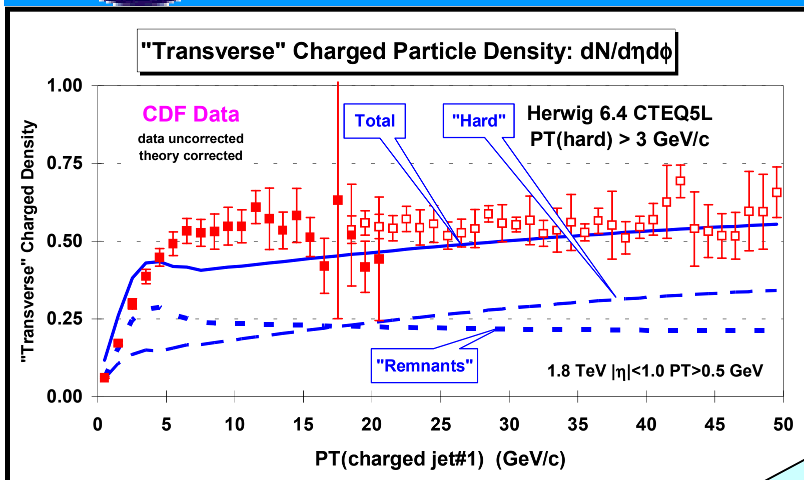
Charged Particle Density "Transverse" P_T Distribution

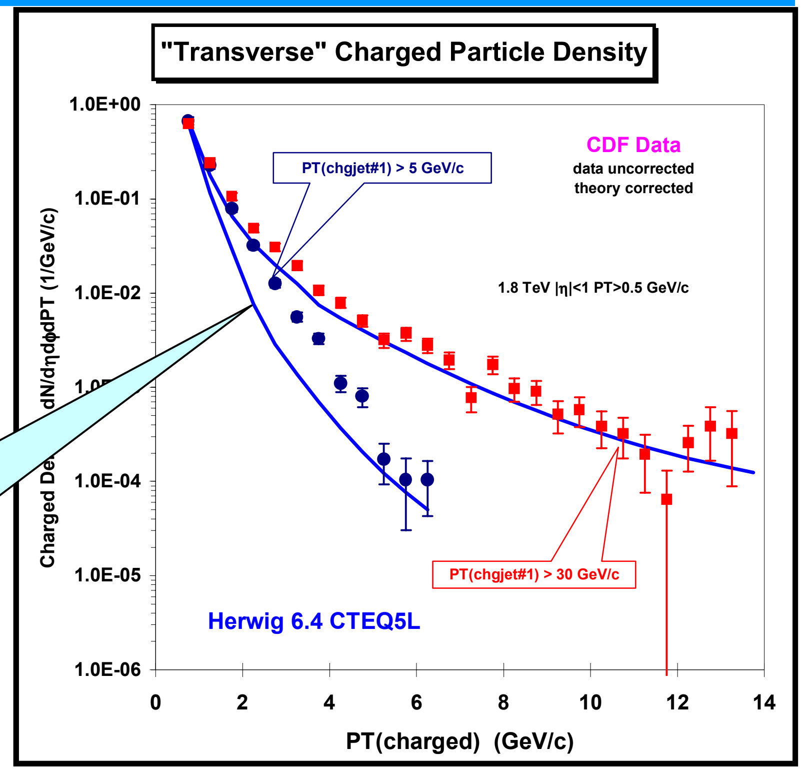




- Compares the average "transverse" charge particle density with the average "Min-Bias" charge particle density ($|\eta|<1$, $P_T>0.5$ GeV). Shows how the "transverse" charge particle density and the Min-Bias charge particle density is distributed in P_T.

HERWIG 6.4
"Transverse" P_T Distribution



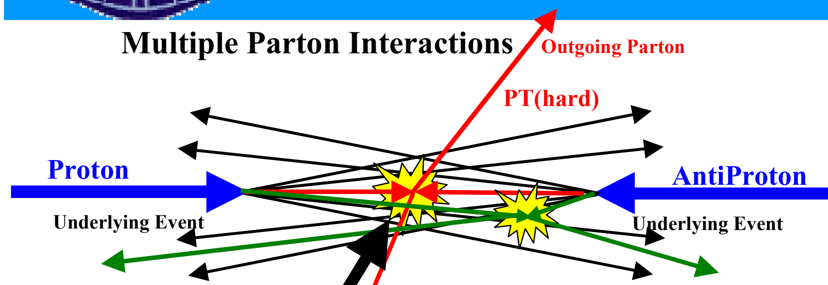


HERWIG has the too steep of a P_T dependence of the "beam-beam remnant" component of the "underlying event"!

- **Compares the average "transverse" charge particle density (|η|<1, P_T>0.5 GeV) versus P_T(charged jet#1) and the P_T distribution of the "transverse" density, $dN_{chg}/d\eta d\phi dP_T$ with the QCD hard scattering predictions of HERWIG 6.4 (default parameters with P_T(hard)>3 GeV/c. Shows how the "transverse" charge particle density is distributed in P_T.**

PYTHIA: Multiple Parton Interaction Parameters

Multiple Parton Interactions



Pythia uses multiple parton interactions to enhance the underlying event.

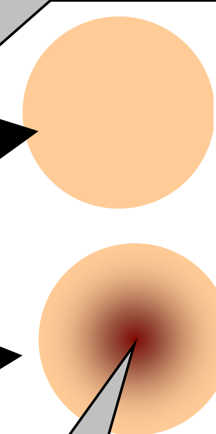
and now HERWIG!

Jimmy: MPI
J. M. Butterworth
J. R. Forshaw
M. H. Seymour

Parameter	Value	Description
MSTP(81)	0	Multiple-Parton Scattering off
	1	Multiple-Parton Scattering on
MSTP(82)	1	Multiple interactions assuming the same probability, with an abrupt cut-off $P_T$min=PARP(81)
	3	Multiple interactions assuming a varying impact parameter and a hadronic matter overlap consistent with a single Gaussian matter distribution, with a smooth turn-off P_{T0}=PARP(82)
	4	Multiple interactions assuming a varying impact parameter and a hadronic matter overlap consistent with a double Gaussian matter distribution (governed by PARP(83) and PARP(84)), with a smooth turn-off P_{T0}=PARP(82)

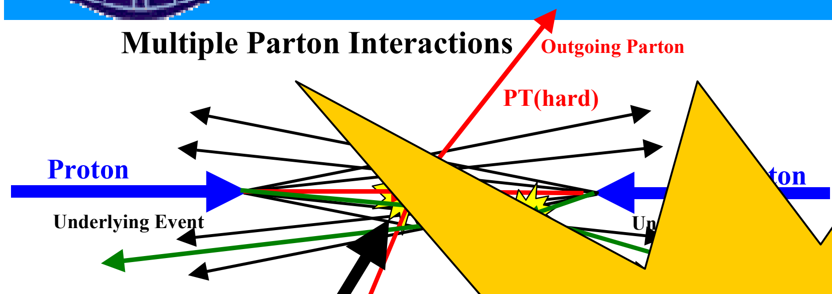
Same parameter that cuts-off the hard 2-to-2 parton cross sections!

Multiple parton interaction more likely in a hard (central) collision!



Hard Core

PYTHIA: Multiple Parton Interaction Parameters



Pythia uses multiple parton interactions to enhance the underlying event.

and now HERWIG!

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J. M. Butterworth
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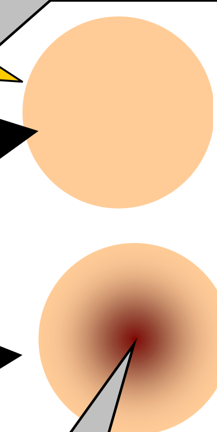
Note that since the same cut-off parameters govern both the primary hard scattering and the secondary MPI interaction, changing the amount of MPI also changes the amount of hard primary scattering in PYTHIA Min-Bias events!

Parameter	Value	
MSTP(81)	0	
	1	M…
MSTP(82)	1	Multi… a…
	3	Multiple inte… pa… parameter a… te… consiste… a single Ga… mat… ibuti… a smooth … off P_{T0}=PA…P(82)
	4	Multiple interactions a… ing a varyi… mpact parameter and a hadro… matter overla… consistent with a double Gaussian matt… distribution (governed by PARP(83) and PARP(8…), with a smooth turn-off P_{T0}=PARP(82)

Same parameter that cuts-off the hard 2-to-2 parton cross sections!

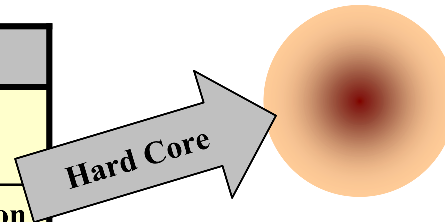
Multiple parton interaction more likely in a hard (central) collision!

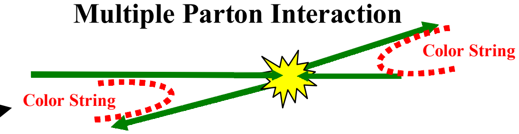


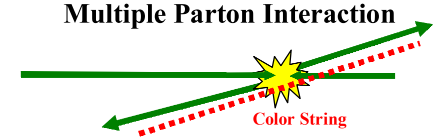
Hard Core

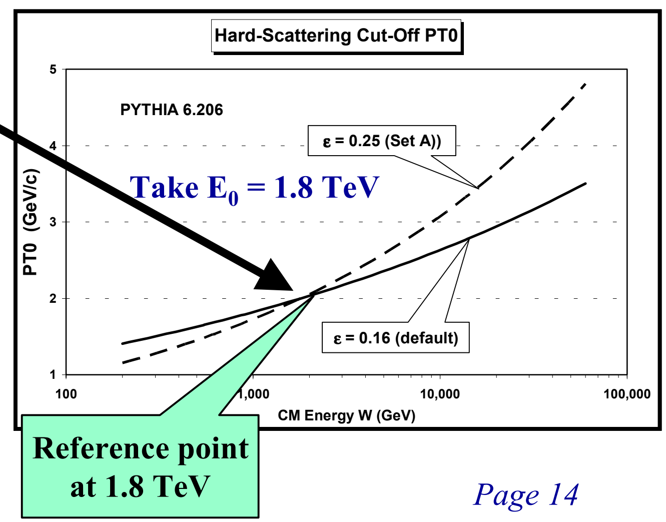
PYTHIA: Multiple Parton Interaction Parameters

Parameter	Default	Description
PARP(83)	0.5	Double-Gaussian: Fraction of total hadronic matter within PARP(84)
PARP(84)	0.2	Double-Gaussian: Fraction of the overall hadron radius containing the fraction PARP(83) of the total hadronic matter.
PARP(85)	0.33	Probability that the MPI produces two gluons with color connections to the "nearest neighbors.
PARP(86)	0.66	Probability that the MPI produces two gluons either as described by PARP(85) or as a closed gluon loop. The remaining fraction consists of quark-antiquark pairs.
PARP(89)	1 TeV	Determines the reference energy E_0.
PARP(90)	0.16	Determines the energy dependence of the cut-off P_{T0} as follows $P_{T0}(E_{cm}) = P_{T0}(E_{cm}/E_0)^{\varepsilon}$ with ε = PARP(90)
PARP(67)	1.0	A scale factor that determines the maximum parton virtuality for space-like showers. The larger the value of PARP(67) the more initial-state radiation.







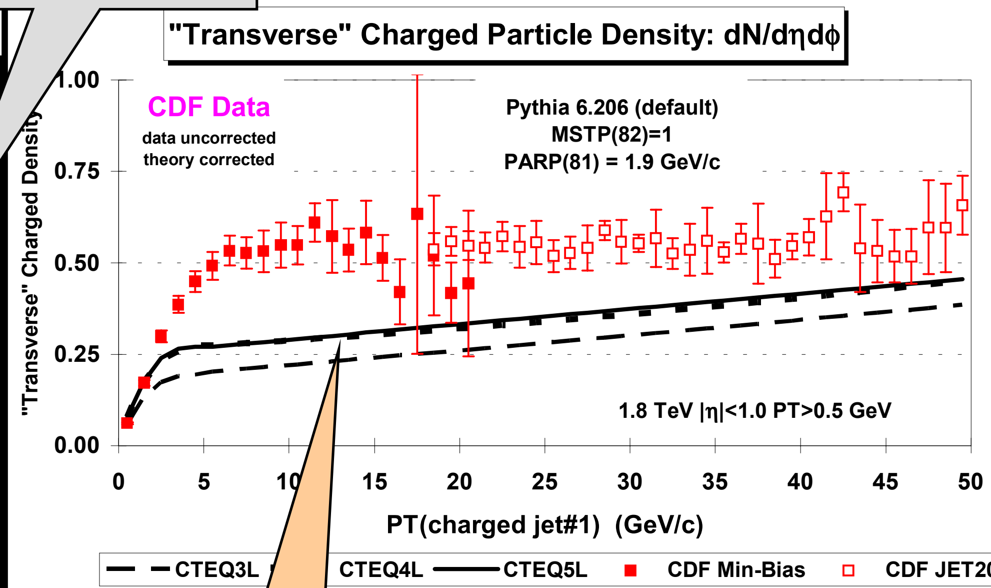


PYTHIA 6.206 Defaults

MPI constant probability scattering

PYTHIA default parameters

Parameter	6.115	6.125	6.158	6.206
MSTP(81)	1	1	1	1
MSTP(82)	1	1	1	1
PARP(81)	1.4	1.9	1.9	1.9
PARP(82)	1.55	2.1	2.1	1.9
PARP(89)		1,000	1,000	1,000
PARP(90)		0.16	0.16	0.16
PARP(67)	4.0	4.0	1.0	1.0

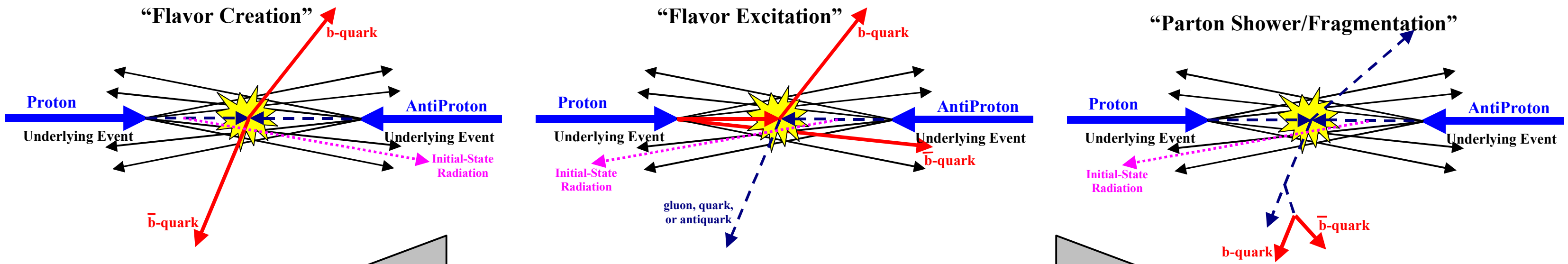


- Plot shows the "Transverse" charged particle density versus P_T(chgjet#1) compared to the QCD hard scattering predictions of PYTHIA 6.206 (P_T(hard) > 0) using the default parameters for multiple parton interactions and CTEQ3L, CTEQ4L, and CTEQ5L.

Note Change
PARP(67) = 4.0 (< 6.138)
PARP(67) = 1.0 (> 6.138)

Default parameters give very poor description of the "underlying event"!

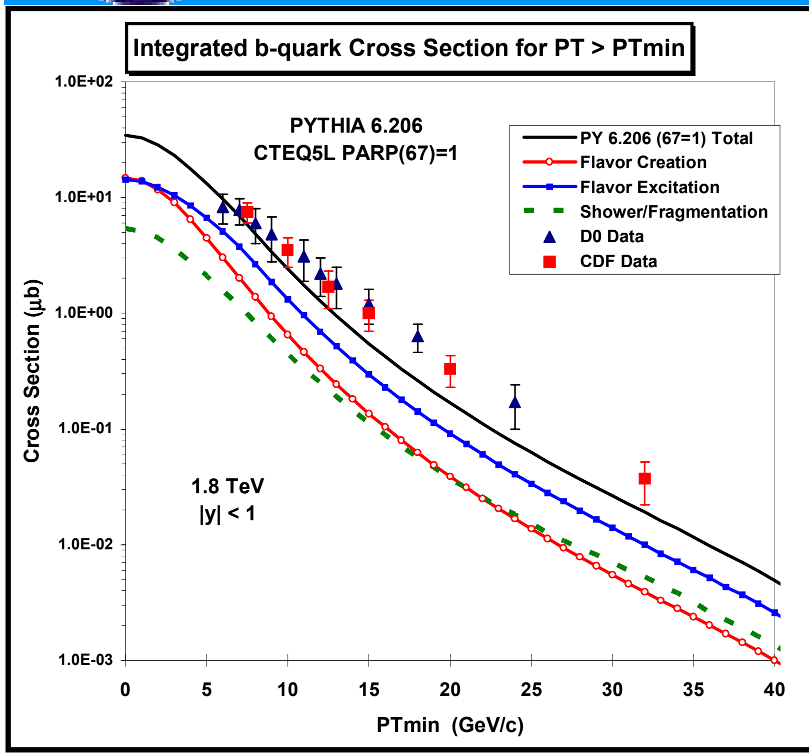
b-Quark Production at the Tevatron

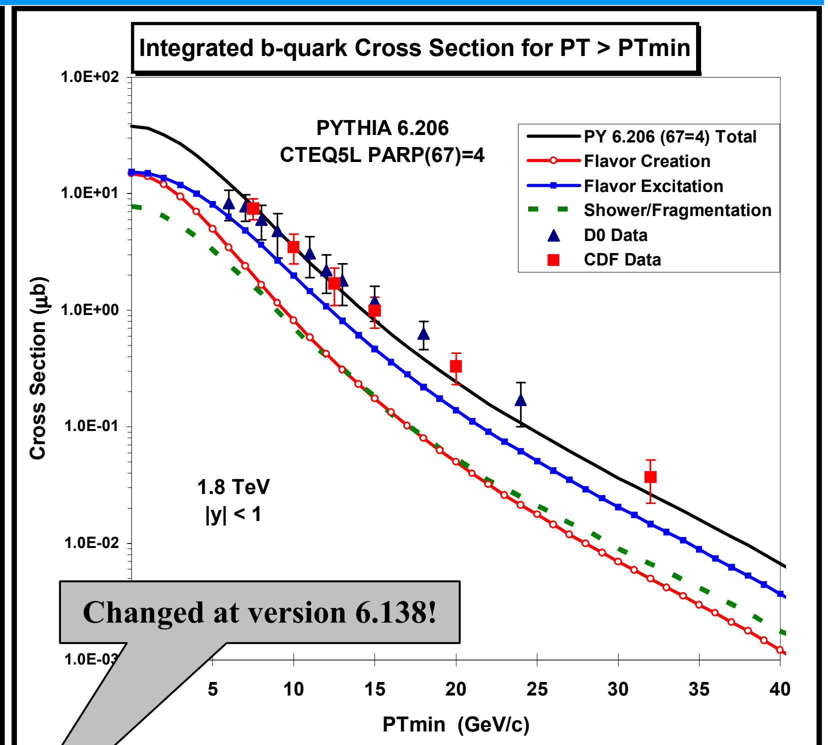


All three sources are important at the Tevatron!

- **The QCD leading-log Monte-Carlo models do a fairly good job in describing b-quark data at the Tevatron. The QCD Monte-Carlo models do a much better job fitting the b data than most people realize!**
- **Clearly all three sources are important at the Tevatron.**
- **"Nothing is goofy" (*Rick Field, CDF B Group Talk, March 9, 2001*).**
- **Next step is to study in detail b-bbar correlations and the compare the predictions of HERWIG, ISAJET, and PYTHIA in order to understand how reliable the estimates are.**
- **Want to know what the leading-log QCD Monte-Carlo Models predict, how stable the estimates are, and how they compare with data. Also, if it is possible we would like to tune the Monte-Carlo models to fit the data.**

Inclusive b-quark Cross Section

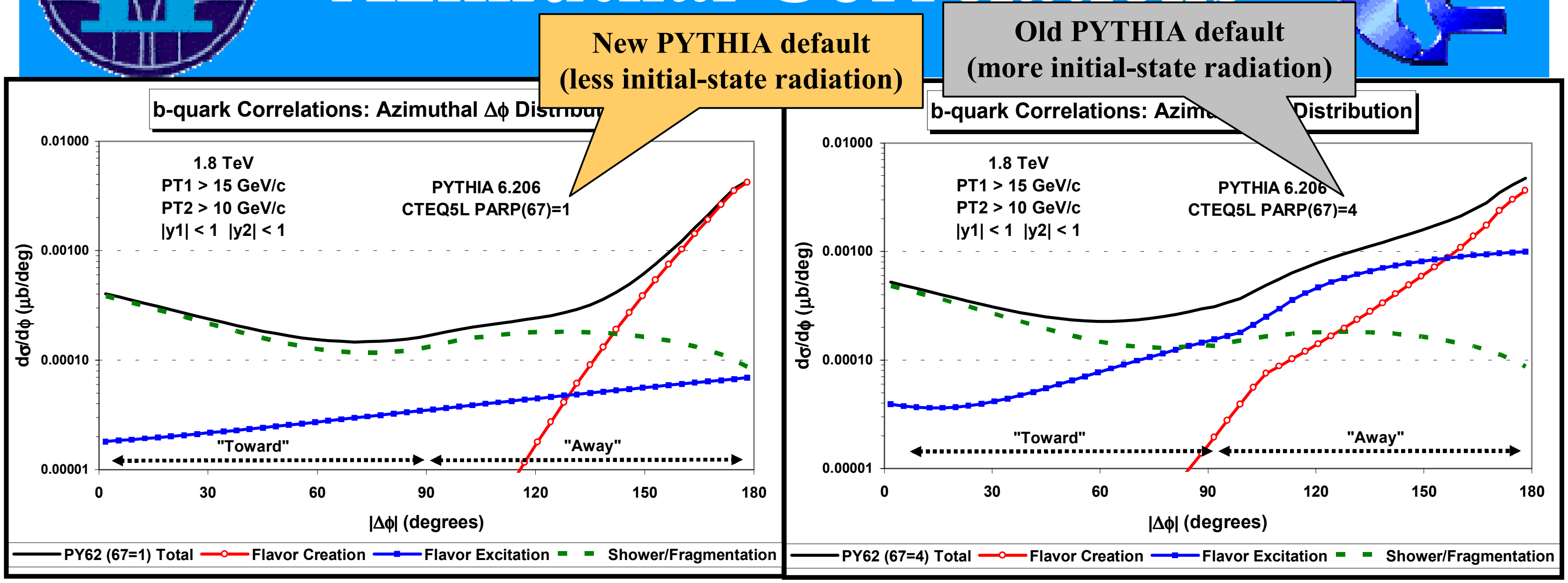




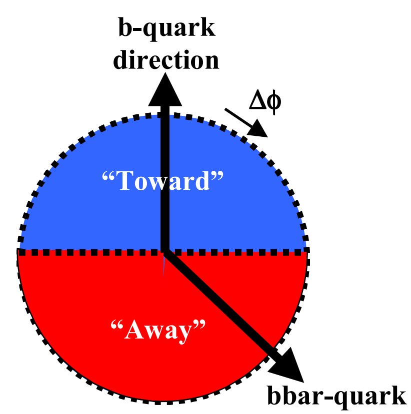
Changed at version 6.138!

- **Data on the integrated b-quark total cross section (P_T > PTmin, |y| < 1) for proton-antiproton collisions at 1.8 TeV compared with the QCD Monte-Carlo model predictions of PYTHIA 6.206 (CTEQ5L) with PARP(67)=1 (new default) and PARP(67)=4 (old default). The four curves correspond to the contribution from flavor creation, flavor excitation, shower/fragmentation, and the resulting total. PARP(67) is a scale factor that governs the amount of large angle initial-state radiation. Larger values of PARP(67) results in more large angle initial-state radiation!**

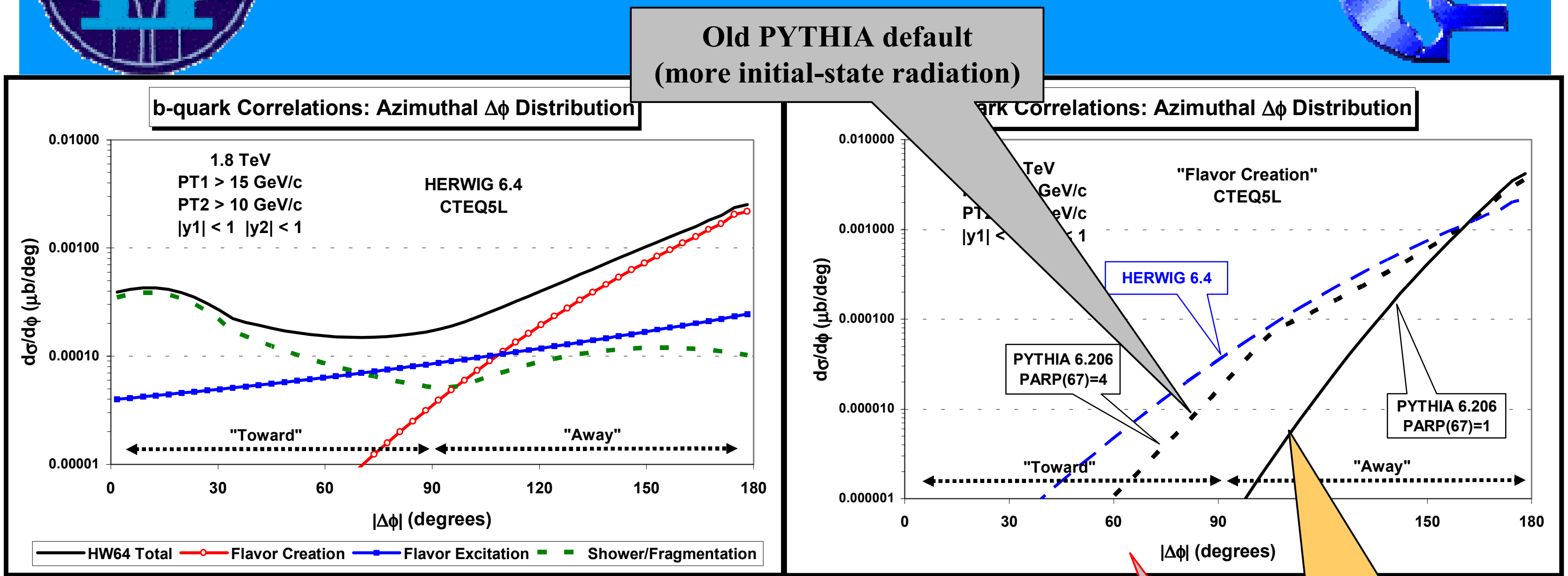
Azimuthal Correlations



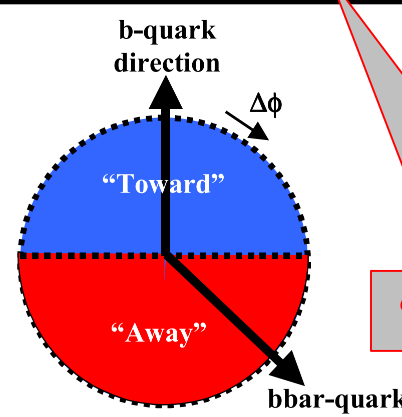
- Predictions of PYTHIA 6.206 (CTEQ5L) with PARP(67)=1 (new default) and PARP(67)=4 (old default) for the azimuthal angle, Δφ, between a b-quark with PT_1 > 15 GeV/c, $|y_1| < 1$ and bbar-quark with PT_2 > 10 GeV/c, $|y_2|<1$ in proton-antiproton collisions at 1.8 TeV. The curves correspond to dσ/dΔφ (μb/°) for flavor creation, flavor excitation, shower/fragmentation, and the resulting total.



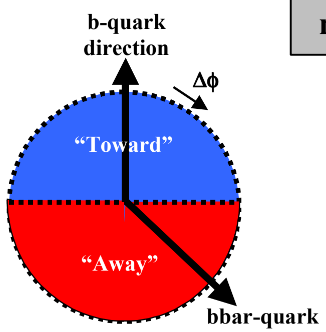
Azimuthal Correlations



- Predictions of HERWIG 6.4 (CTEQ5L) for the azimuthal angle, Δφ, between a b-quark with $PT_1 > 15$ GeV/c, $|y_1| < 1$ and bbar-quark with $PT_2 > 10$ GeV/c, $|y_2|<1$ in proton-antiproton collisions at 1.8 TeV. The curves correspond to dσ/dΔφ (μb/°) for flavor creation, flavor excitation, shower/fragmentation, and the resulting total.

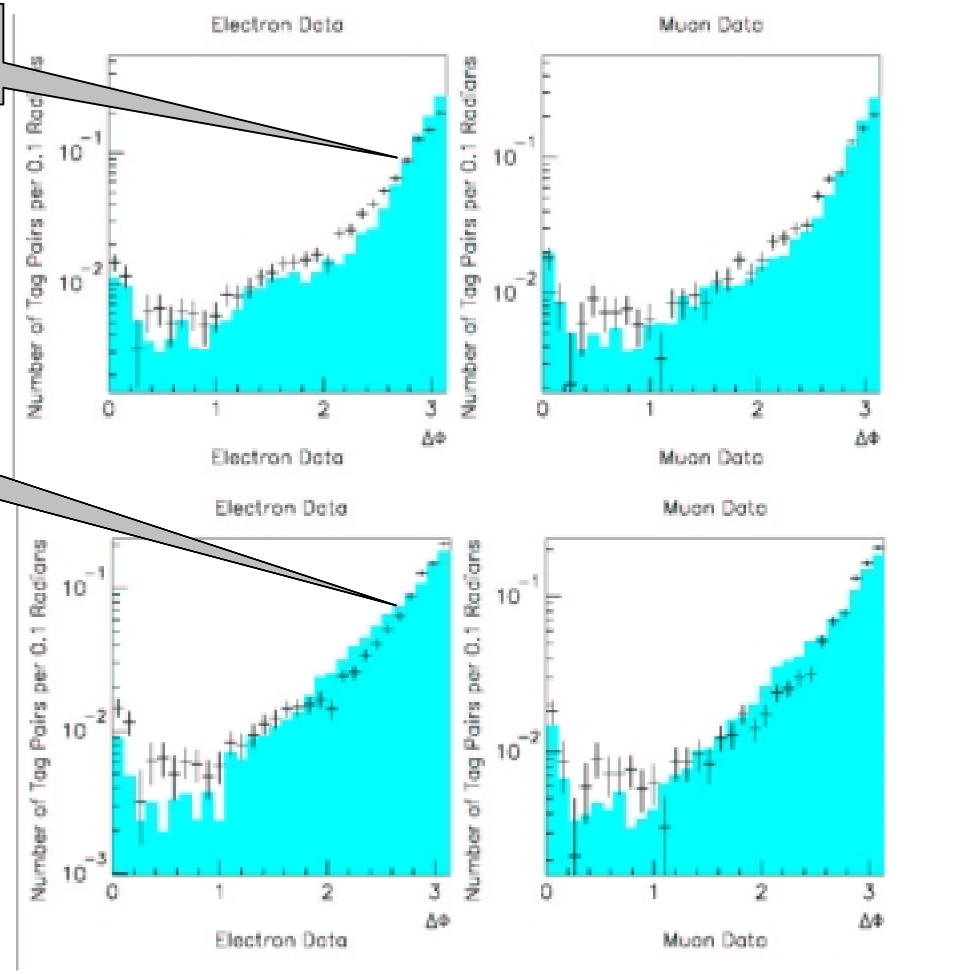


CDF Run I Analysis Azimuthal Correlations



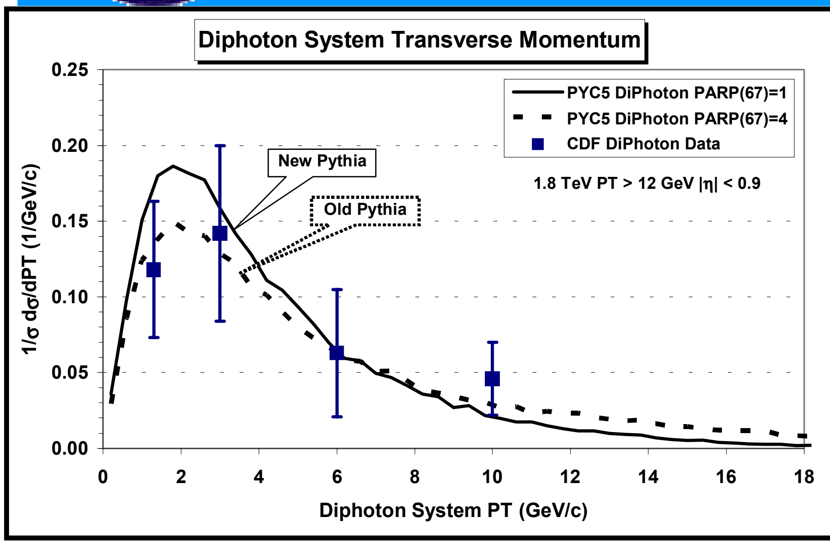
PARP(67) = 1
maybe too narrow?

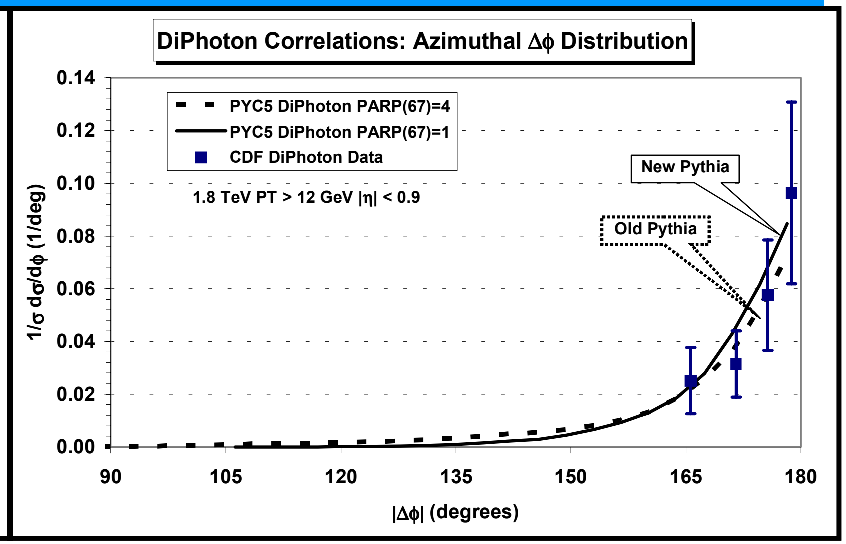
PARP(67) = 4
maybe too broad?



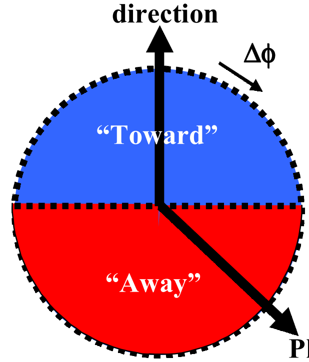
- **Kevin Lannon** **preliminary unblessed CDF Run I analysis** **of the azimuthal angle, Δφ, between a b-quark $|y_1| < 1$ and bbar-quark $|y_2|<1$ in proton-antiproton collisions at 1.8 TeV.**

DiPhoton Correlations





- Predictions of PYTHIA 6.158 (CTEQ5L) with PARP(67)=1 (new default) and PARP(67)=4 (old default) for diphoton system PT and the azimuthal angle, Δϕ, between a photon with $PT_1 > 12$ GeV/c, $|y_1| < 0.9$ and photon with $PT_2 > 12$ GeV/c, $|y_2| < 0.9$ in proton-antiproton collisions at 1.8 TeV compared with CDF data.

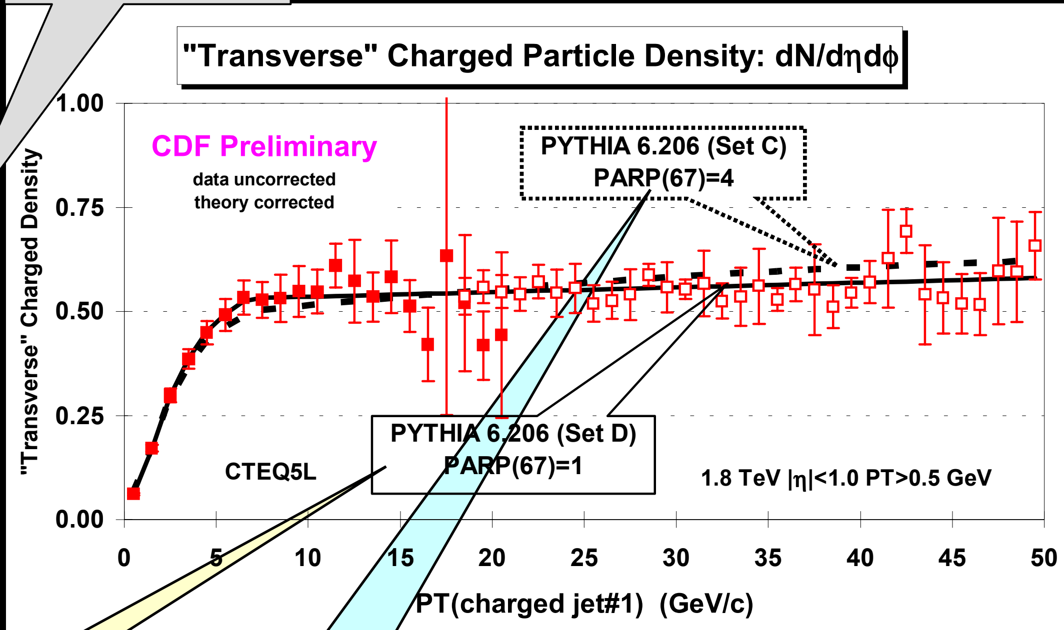


Tuned PYTHIA 6.206

PYTHIA 6.206 CTEQ5L

Parameter	Tune D	Tune C
MSTP(81)	1	1
MSTP(82)	3	3
PARP(82)	1.6 GeV	1.7 GeV
PARP(85)	1.0	1.0
PARP(86)	1.0	1.0
PARP(89)	1.8 TeV	1.8 TeV
PARP(90)	0.25	0.25
PARP(67)	1.0	4.0

Single Gaussian



- **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 D (PARP(67)=1) and Set C (PARP(67)=4)).**

New PYTHIA default (less initial-state radiation)

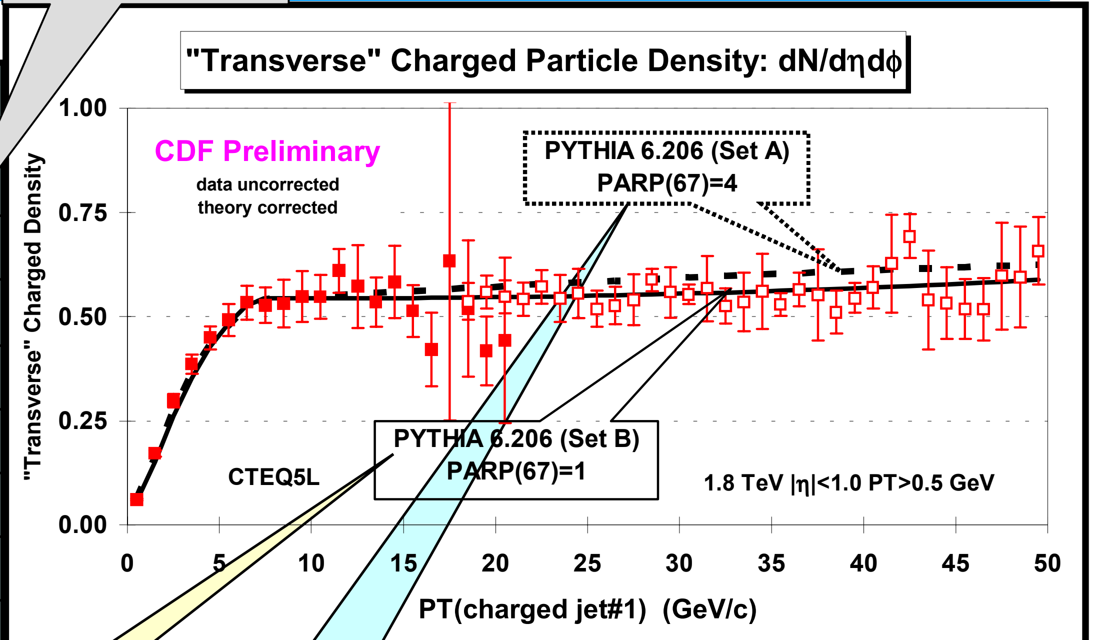
Old PYTHIA default (more initial-state radiation)

Tuned PYTHIA 6.206

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

Double Gaussian

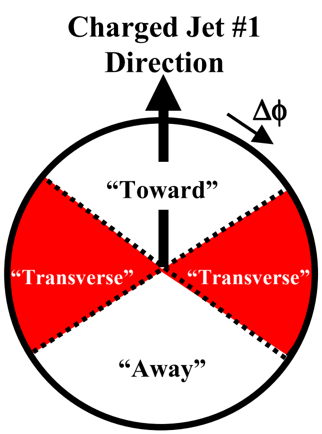


- Plot shows the **"Transverse" charged particle density versus P_T(chgjet#1)** compared to the QCD hard scattering predictions of two **tuned** versions of **PYTHIA 6.206** (CTEQ5L, **Set B** (PARP(67)=1) and **Set A** (PARP(67)=4)).

New PYTHIA default (less initial-state radiation)

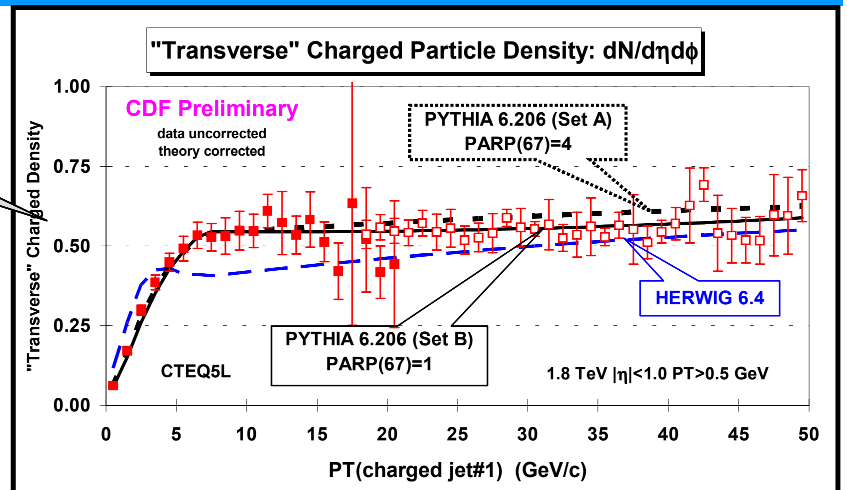
Old PYTHIA default (more initial-state radiation)

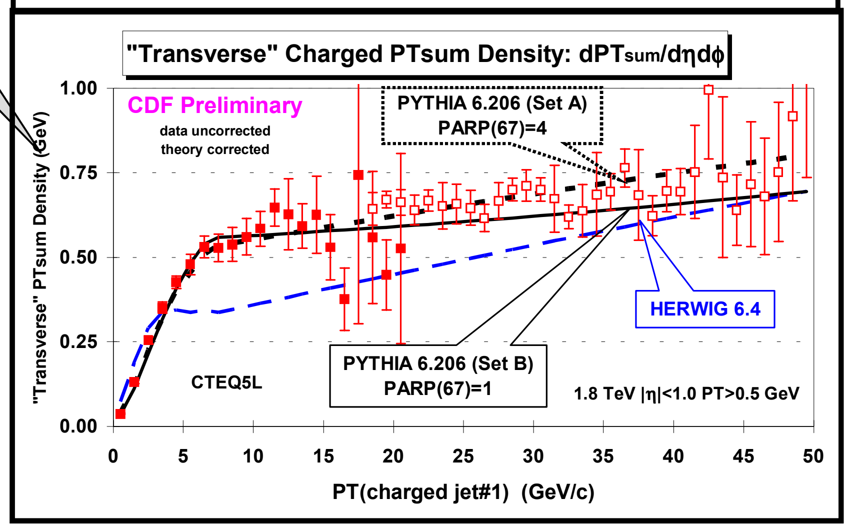
Tuned PYTHIA 6.206 vs HERWIG 6.4
"Transverse" Densities



Charged Particle Density

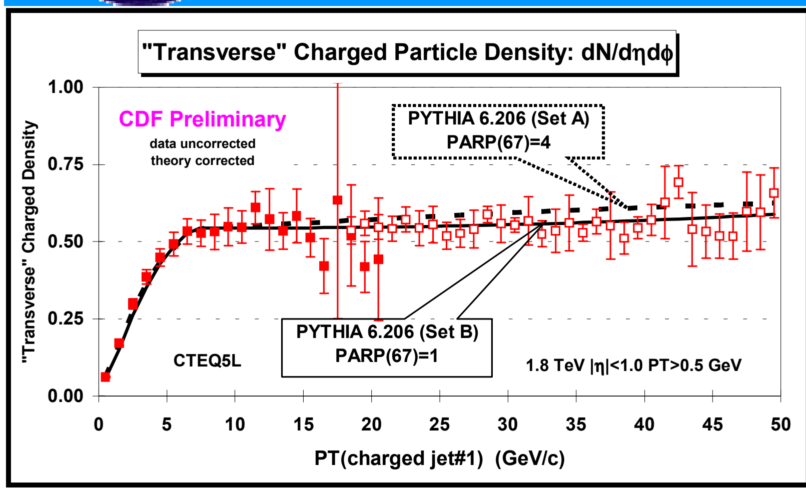
Charged PT_{sum} Density

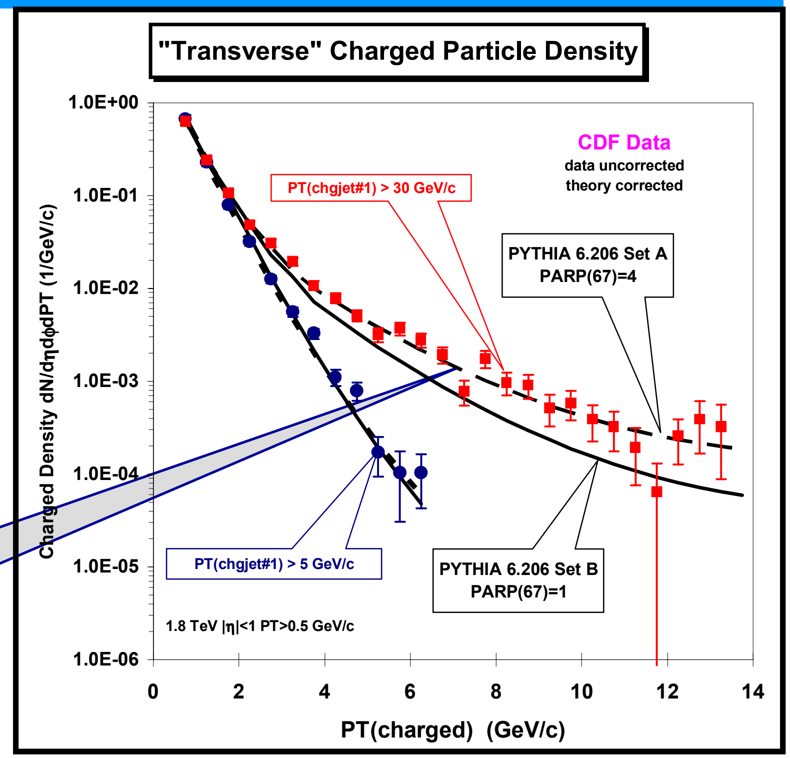




- **Plots shows CDF data on the charge particle density and the charged PT_{sum} density in the "transverse" region.**
- **The data are compared with the QCD Monte-Carlo predictions of HERWIG 6.4 (CTEQ5L, P_T(hard) > 3 GeV/c) and two tuned versions of PYTHIA 6.206 (P_T(hard) > 0).**

Tuned PYTHIA 6.206 "Transverse" P_T Distribution

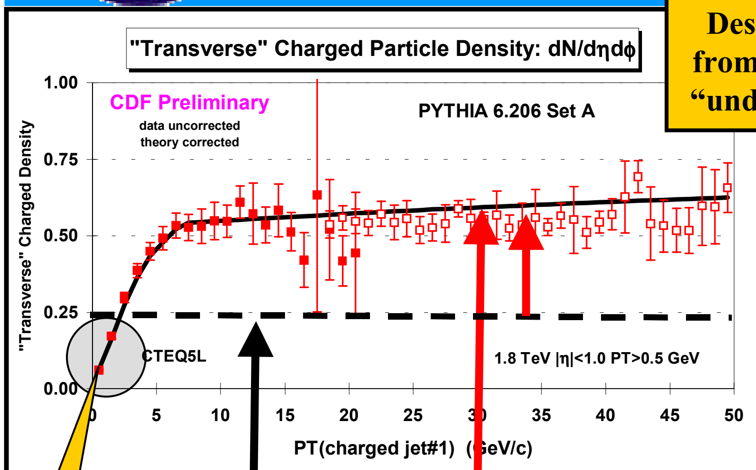




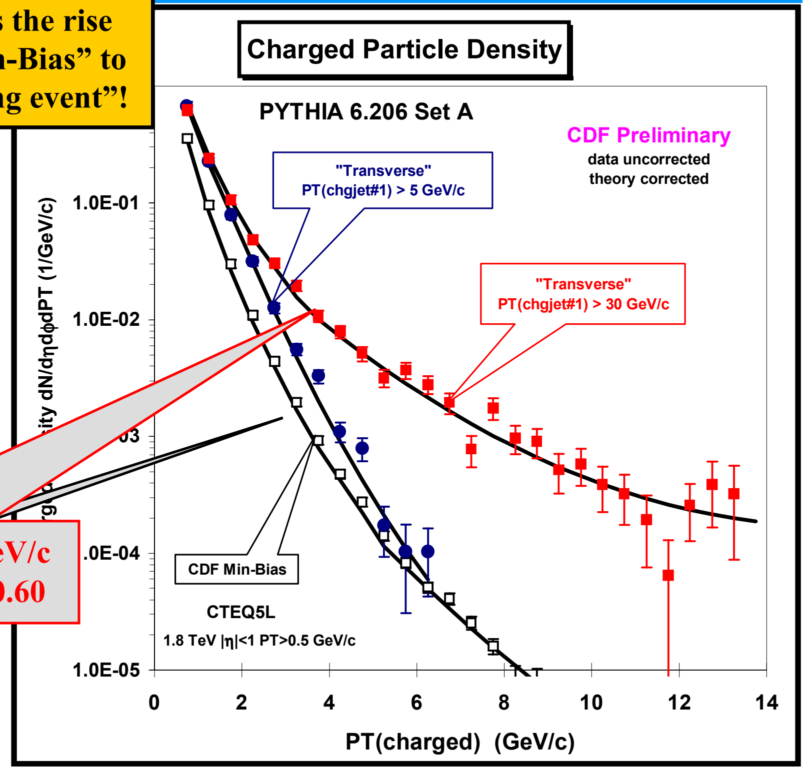
PARP(67)=4.0 (old default) is favored over PARP(67)=1.0 (new default)!

- **Compares the average "transverse" charge particle density (|η|<1, P_T>0.5 GeV) versus P_T(charged jet#1) and the P_T distribution of the "transverse" density, $dN_{chg}/d\eta d\phi dP_T$ with the QCD Monte-Carlo predictions of two tuned versions of PYTHIA 6.206 (P_T(hard) > 0, CTEQ5L, Set B (PARP(67)=1) and Set A (PARP(67)=4)).**

Tuned PYTHIA 6.206 Set A



Describes the rise from “Min-Bias” to “underlying event”!



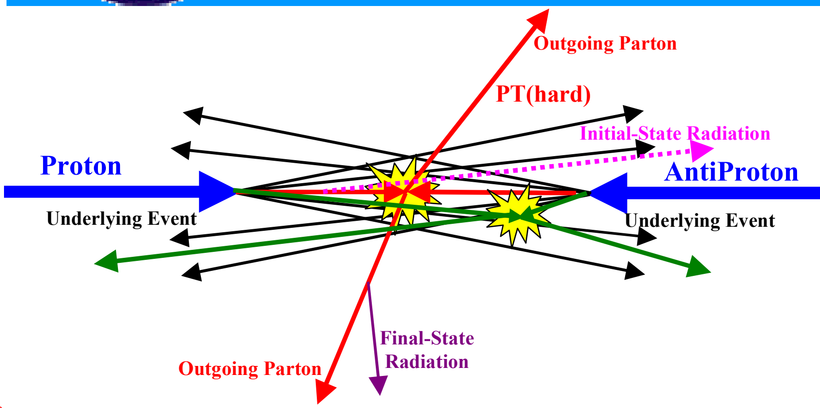
Set A P_T(charged jet#1) > 30 GeV/c
“Transverse” $\langle dN_{chg}/d\eta d\phi \rangle = 0.60$

“Min-Bias”

Set A Min-Bias
$\langle dN_{chg}/d\eta d\phi \rangle = 0.24$

- Compares the average “transverse” charge particle density ($|\eta|<1$, $P_T>0.5$ GeV) versus P_T(charged jet#1) and the P_T distribution of the “transverse” and “Min-Bias” densities with the QCD Monte-Carlo predictions of a tuned version of PYTHIA 6.206 (P_T(hard) > 0, CTEQ5L, Set A). Describes “Min-Bias” collisions! Describes the “underlying event”!

Summary



"Min-Bias" and the "Underlying Event"

- **PYTHIA (tune "A" and "B") does a good job of describing both "min-bias" collisions and the "underlying event" in hard scattering processes in the Run I data.**
- **PYTHIA (tune "A" or "B") is the only "min-bias" generator that includes both "soft" and "hard" scattering.**
- **Both ISAJET and HERWIG have the too steep of a P_T dependence of the "beam-beam remnant" component of the "underlying event" and hence do not have enough beam-beam remnants with $P_T > 0.5$ GeV/c.**
- **PYTHIA tune "A" is slightly favored over tune "B", but eventually the best fit may be somewhere in between. The initial-state radiation in tune "A" with PARP(67) = 4 (used in all Run I simulations) looks more like HERWIG's initial-state radiation.**

Recommendations

- I suggest the tune set "A" be used as the default for PYTHIA for the first round of Run II simulations.
- Although PYTHIA set "A" does a better job on the "underlying event" that HERWIG I suggest that you continue to run both HERWIG and PYTHIA.
- PYTHIA set "B" can be compared with set "A" to determine how sensitive a given analysis is to the initial-state radiation.
- In addition to MBR one should use PYTHIA (set "A" or "B") to generate "min-bias" collisions.

Run II Monte-Carlo Simulations

- The "underlying-event" is only part of the overall event.
- It is very important to compare at least two Monte-carlo estimates..

- In Run I the systematic error due to initial-state radiation was overestimated.

- As we study the Run II data I will update and improve the PYTHIA tunes.
- See my "tunes" WEBsite at

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

Recommendations

- I know what tune "A" is doing.
- Reproduces Run I data.
- PARP(67) = 4 was used in Run I.

Run II Monte-Carlo Simulations

- I suggest the tune set "A" be used as the default for PYTHIA for the first round of Run II simulations.
- Although PYTHIA se… " does a better job on the "under… …ent" that HERWIG I suggest th… continue to run both … PYTHIA.
- PYTHIA set "B" can be … set "A" to determine h… given analysis is to … initial-… radiation.
- In addition to MBR one should use PYTHIA (set "A" or "B") to genera… "min-bias" collisions.

…e "underlying-event" is only part of …overall …

…ortant to compare at least …arlo estimates..

…tematic error due to …adiation was overestimated.

Warning! Some of the preliminary comparisons of PYTHIA (set "A") with Run II data indicate that there is not enough sumET in the "underlying event". I do not understand this!

- …e s… …he Run II data I will update and …rove th… …YTHIA tunes.
- S… my "tunes" WEBsite at http://www.phys.ufl.edu/~rfield/cdf/tunes/rdf_tunes.html