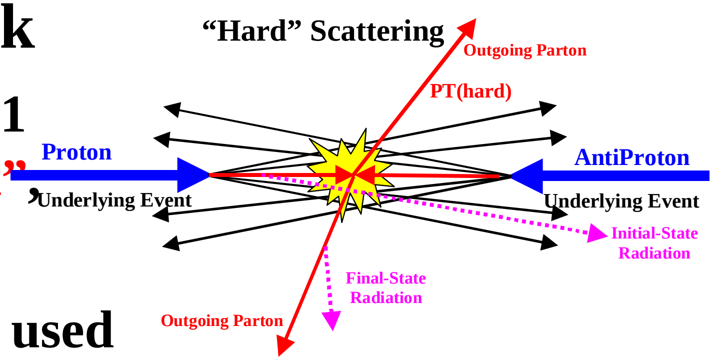
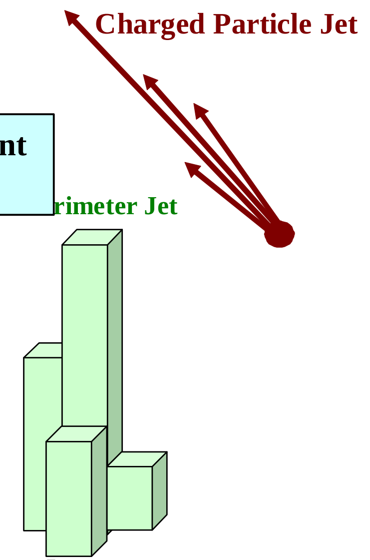
“Min-Bias” and the “Underlying Event” at CDF

Outline of Talk



- Review what we learned at CDF in Run 1 about “min-bias”, the “underlying event” and “initial-state radiation”.
- Compare the CDF Run 1 analysis which used the leading “charged particle jet” to define the “underlying event” with CDF Run 2 data.
- Study the “underlying eve … defined by the leading “calori … r jet” and compare with the “charged … ticle jet” analysis.
- Discuss PYTHIA Tune A and extrapolations to the LHC.

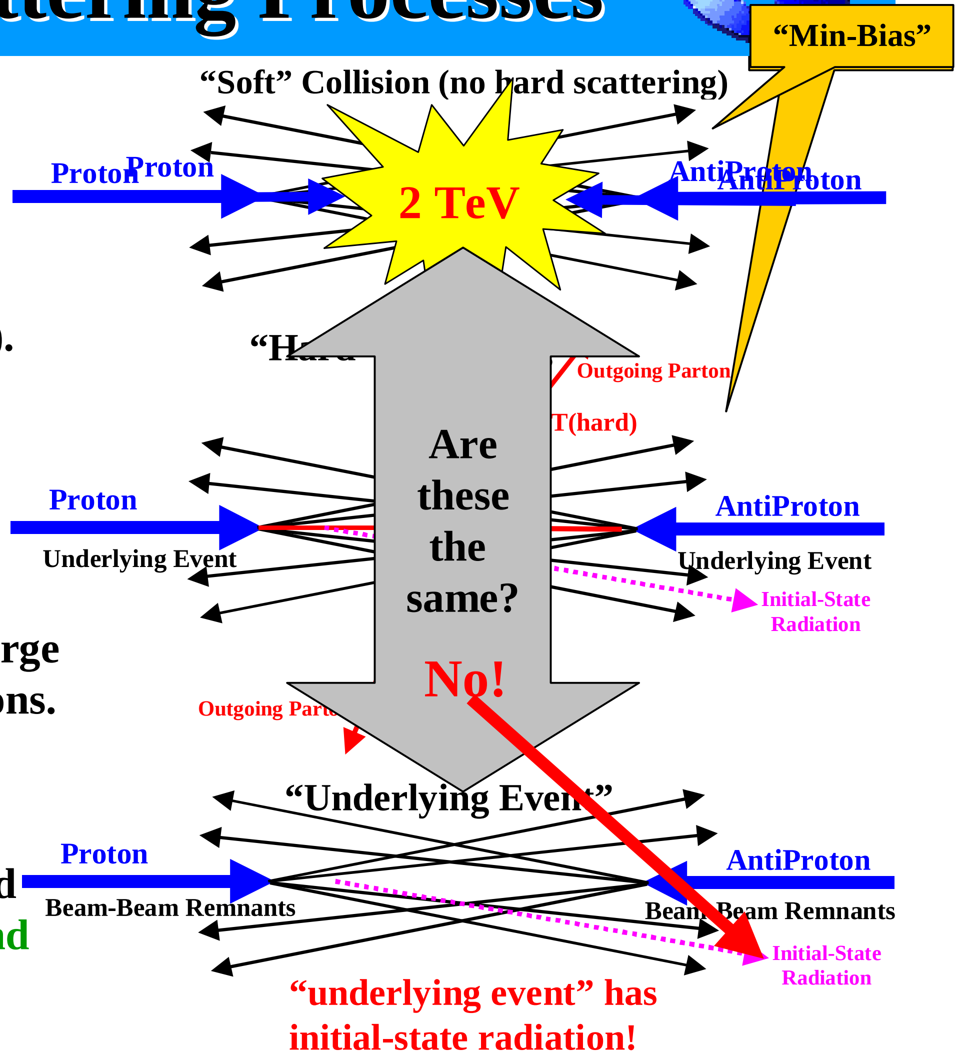
Tuned to fit the charged particle component of the “underlying event” in Run 1



JetClu R = 0.7

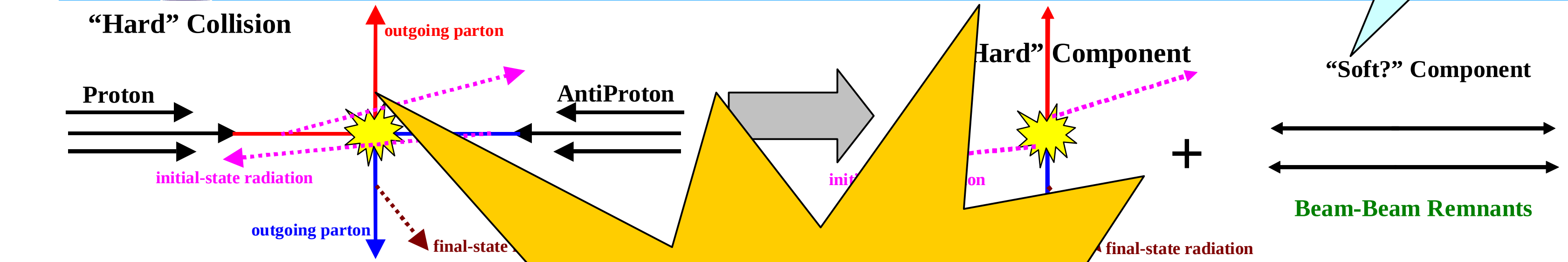
The "Underlying Event" in Hard Scattering Processes

- 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.



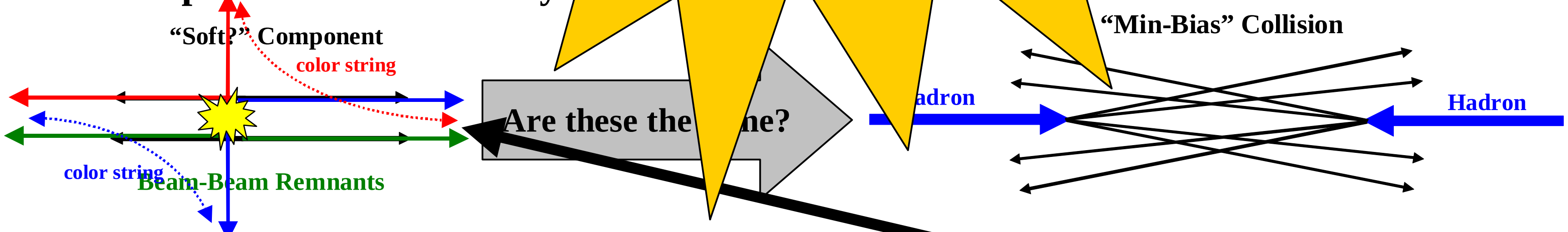
Beam-Beam Remnants

Maybe not all "soft"!



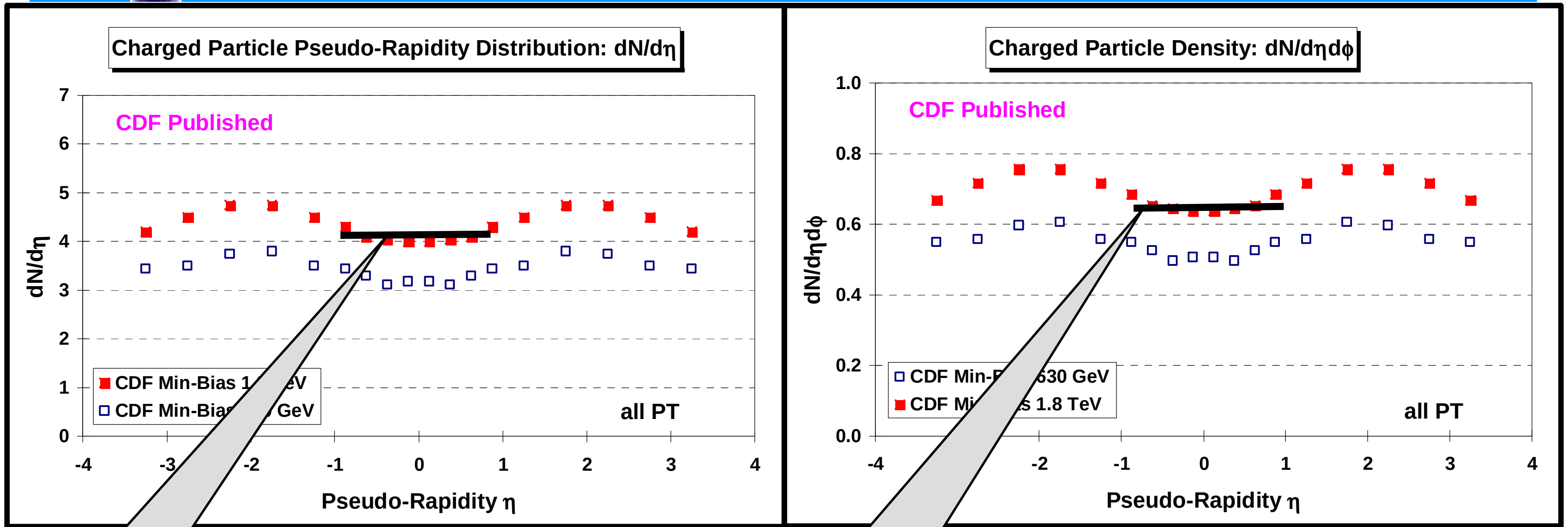
- The underlying event in a … hard" component (particles that arise from initial … rd scattered partons) and a "soft?" comp…
- Clearly? the "underlyin… hould not look like a "Min-Bias" event because of … ate radiation).
- However, perhap… for the "beam-beam remnant" component of the "underlyi…

If we are going to look at "Min-Bias" collisions as a guide to understanding the "beam-beam remnants", then we better study carefully the "Min-Bias" data!



- The "beam-beam remnant" component is, however, color connected to the "hard" component so this comparison is (at best) an approximation.

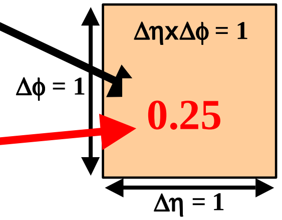
CDF Run 1 “Min-Bias” Data
Charged Particle Density



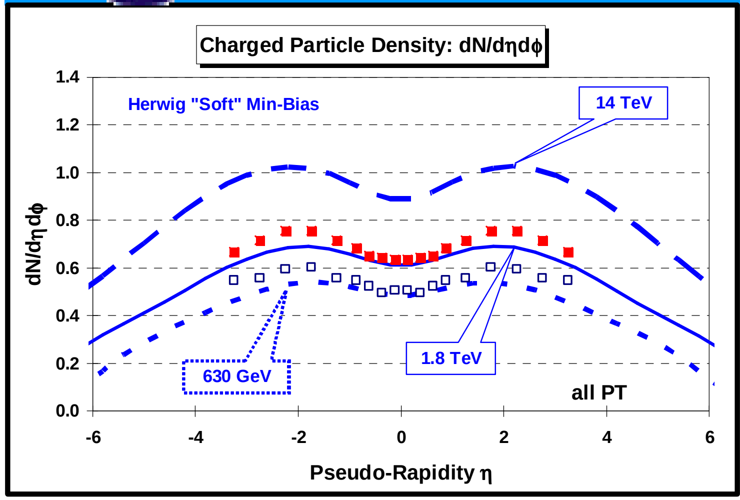
$<dN_{chg}/d\eta> = 4.2$

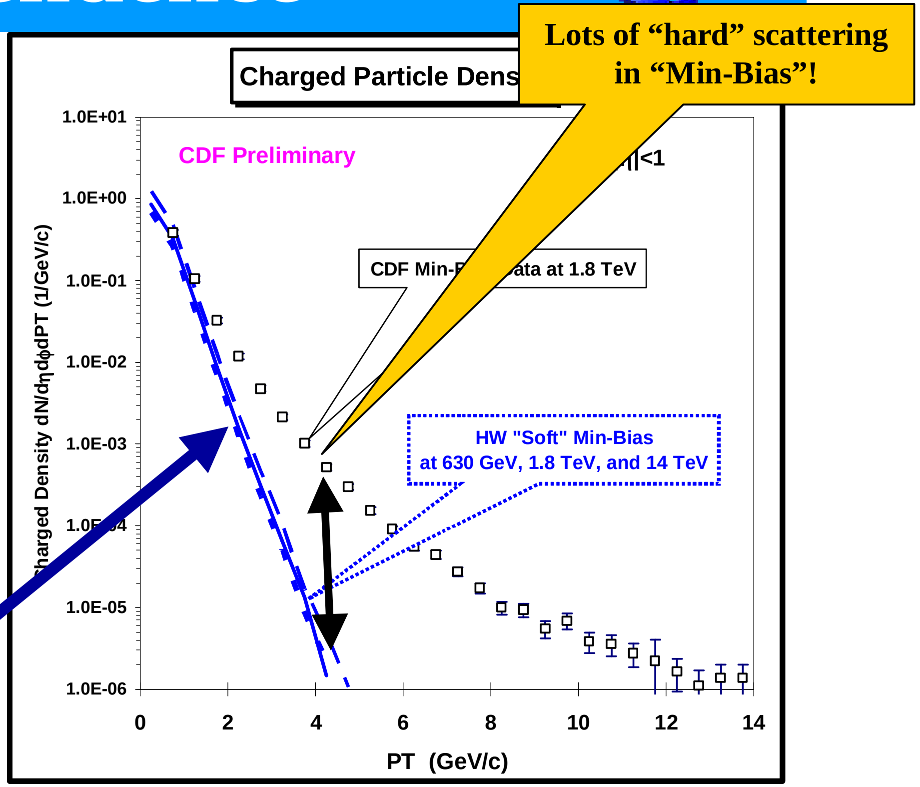
$<dN_{chg}/d\eta d\phi> = 0.67$

- F “Min-Bias” data on the … l 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).
- There are about 0.25 charged particles per unit η-φ in “Min-Bias” collisions at 1.8 TeV (|η| < 1, P_T > 0.5 GeV/c).



CDF Run 1 "Min-Bias" Data P_T Dependence



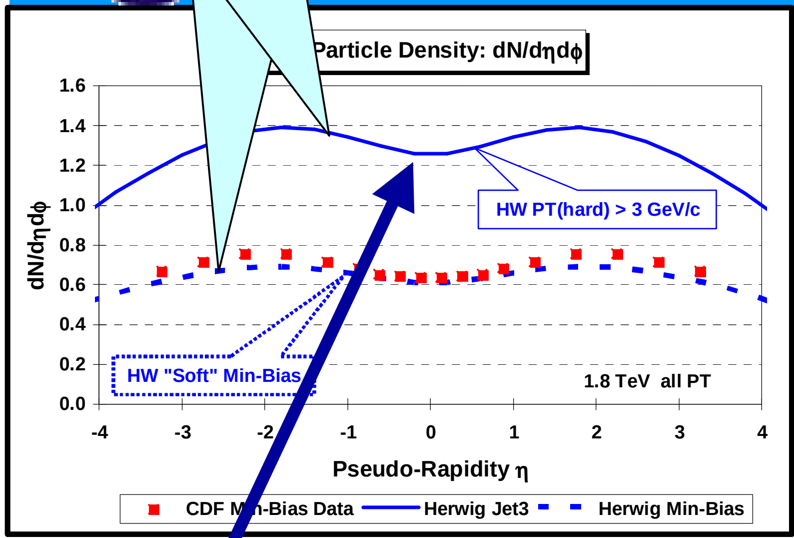


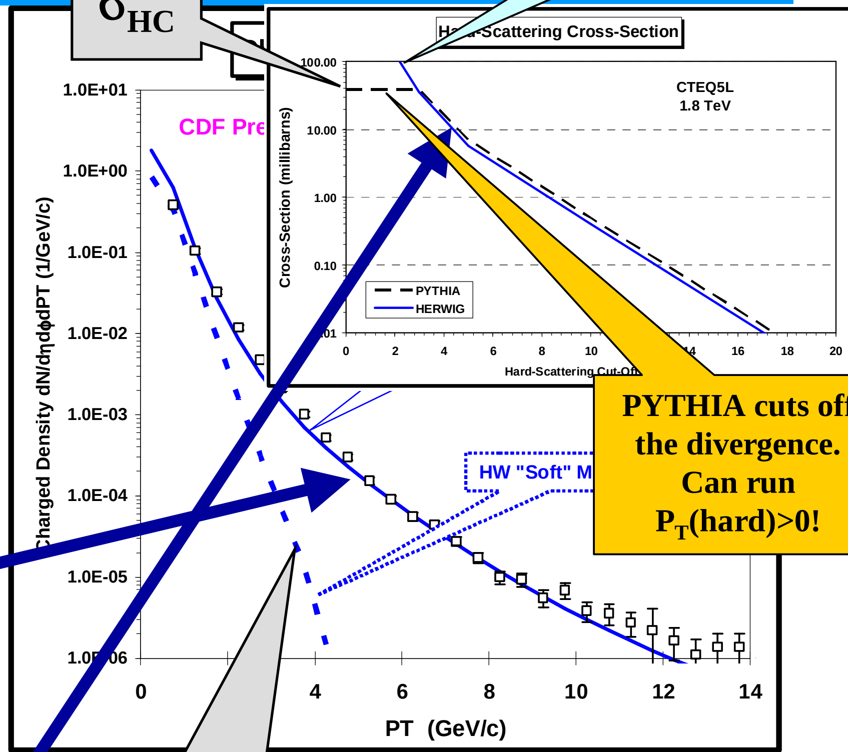
- Shows the energy dependence of the charged particle density, $dN_{chg}/d\eta d\phi$, for "Min-Bias" collisions compared with **HERWIG "Soft" Min-Bias**.
- Shows the P_T dependence of the charged particle density, $dN_{chg}/d\eta d\phi dP_T$, for "Min-Bias" collisions at 1.8 TeV collisions compared 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.

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

No easy way to "mix" HERWIG "hard" with HERWIG "soft".

HERWIG diverges!





PYTHIA cuts off the divergence. Can run P_T(hard)>0!

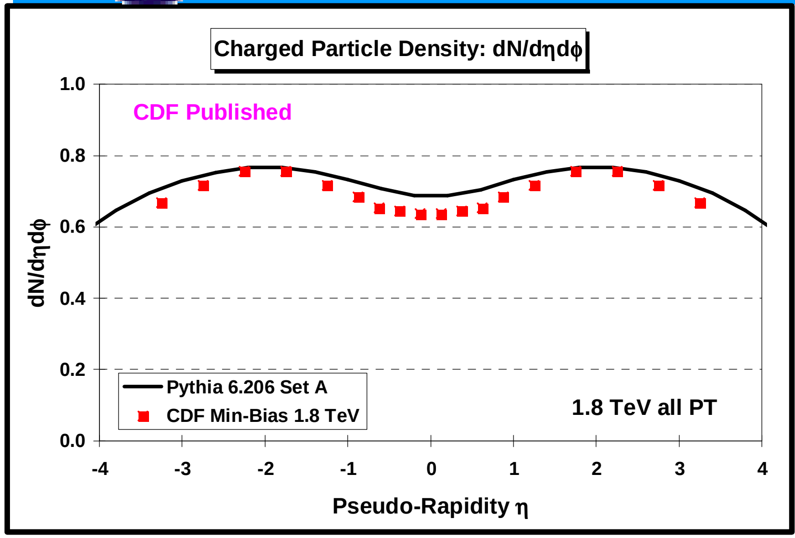
HERWIG "soft" Min-Bias does not fit the "Min-Bias" data!

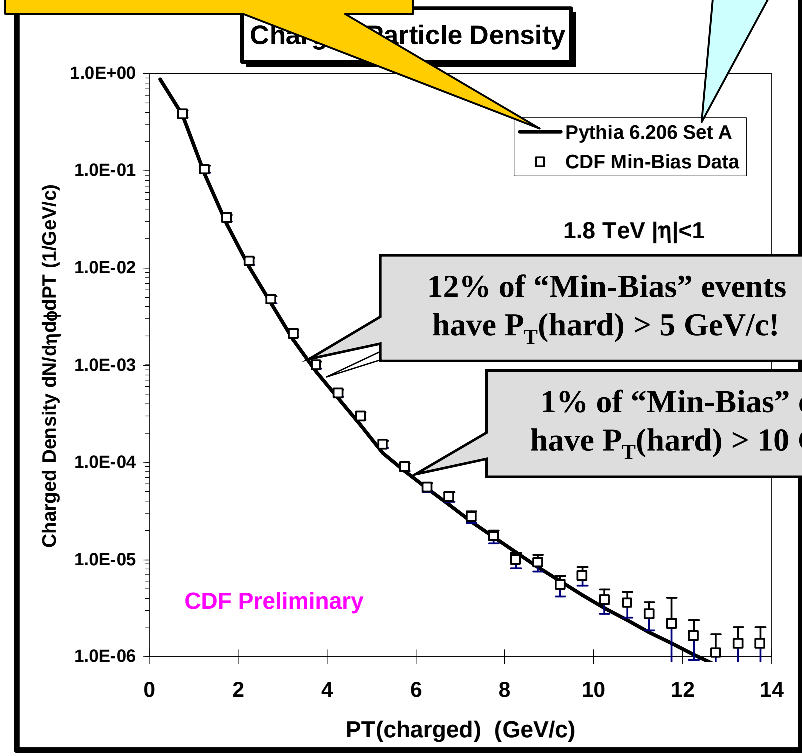
- **HERWIG "hard" QCD** with P_T(hard) > 3 GeV/c describes well the high P_T tail but produces too many charged particles overall. Not all of the "Min-Bias" collisions have a hard scattering with P_T(hard) > 3 GeV/c!
- One cannot run the HERWIG "hard" QCD Monte-Carlo with P_T(hard) < 3 GeV/c because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

PYTHIA Min-Bias “Soft” +

PYTHIA Tune A
CDF Run 2 Default

Tuned to fit the “underlying event”!





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

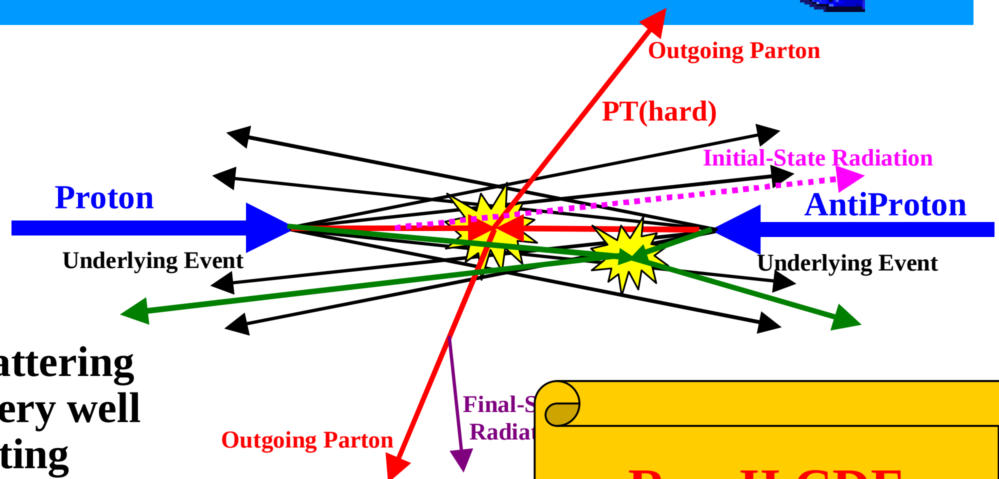
1% of “Min-Bias” events have P_T(hard) > 10 GeV/c!

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 ...ard” 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)!

Studying the "Underlying Event" at CDF

The Underlying Event:
beam-beam remnants
initial-state radiation
multiple-parton interactions



- The underlying event in a hard scattering process is a complicated and not very well understood object. It is an interesting region since it probes the interface between perturbative and non-perturbative physics.
- There are now four CDF analyses which quantitatively study the underlying event and compare with the QCD Monte-Carlo models (2 Run I and 2 Run II).
- It is important to model this region well since it is an unavoidable background to all collider observables. Also, we need a good model of "min-bias" collisions.

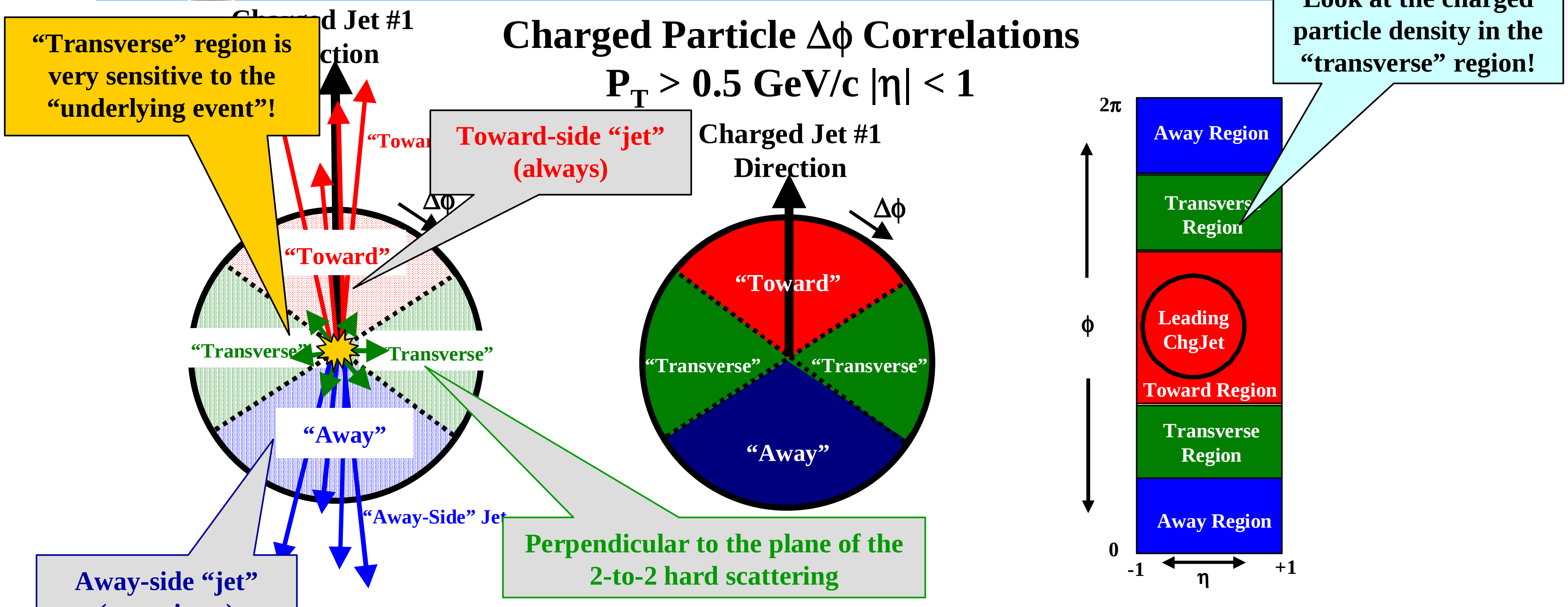
Compares 630 GeV with 1.8 TeV!

Run I CDF
"Cone Analysis"
Valeria Tano
Eve Kovacs
Joey Huston
Anwar Bhatti

Run II CDF
"Evolution of Charged Particle Jets and Calorimeter Jets"
Rick Field

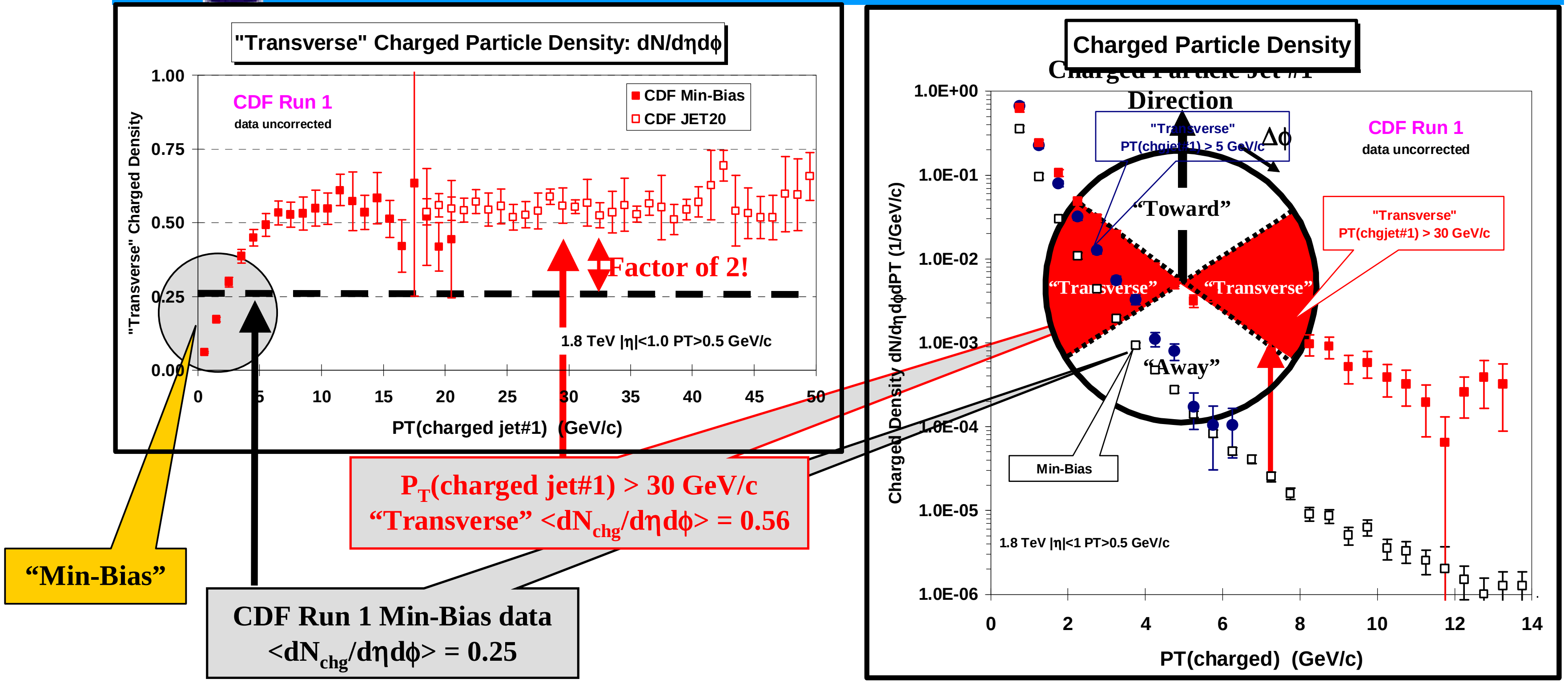
Run II CDF
"Jet Shapes & Energy Flow"
Mario Martinez

"Underlying Event" as defined by "Charged particle Jets"



- 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 Charged Particle Density "Transverse" P_T Distribution

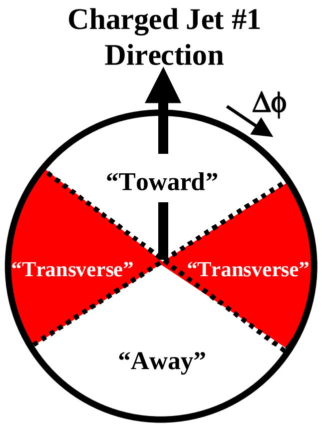


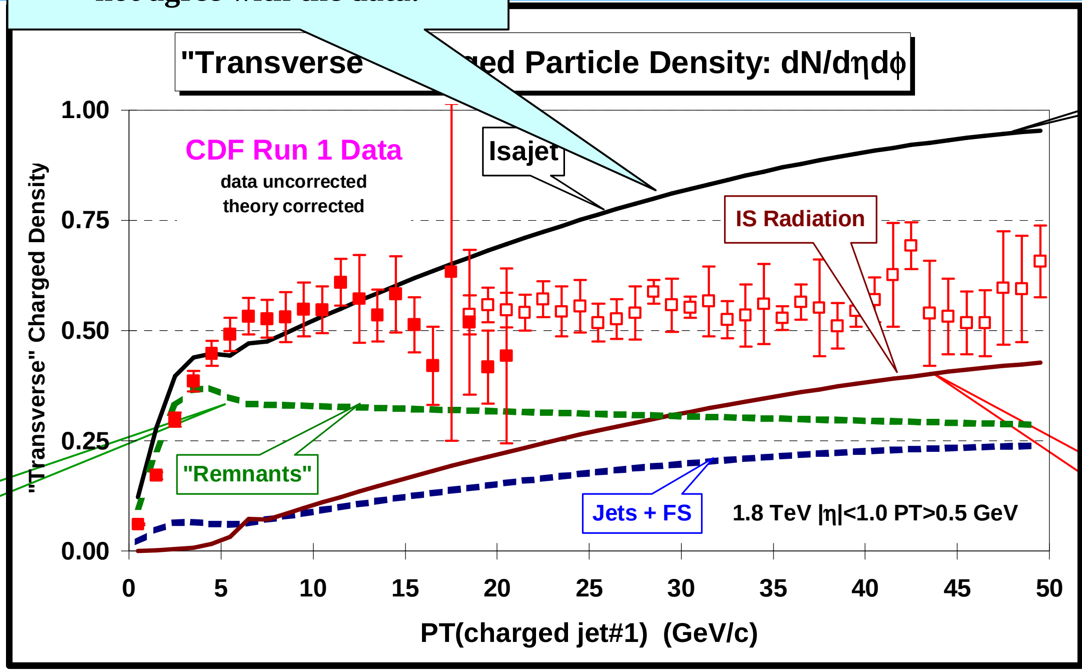
- Compares the average "transverse" charge particle density with the average "Min-Bias" charge particle density ($|\eta|<1$, $P_T>0.5$ GeV). Shows how the "transverse" charge particle density and the Min-Bias charge particle density is distributed in P_T.

ISAJET 7.32

“ ” Density

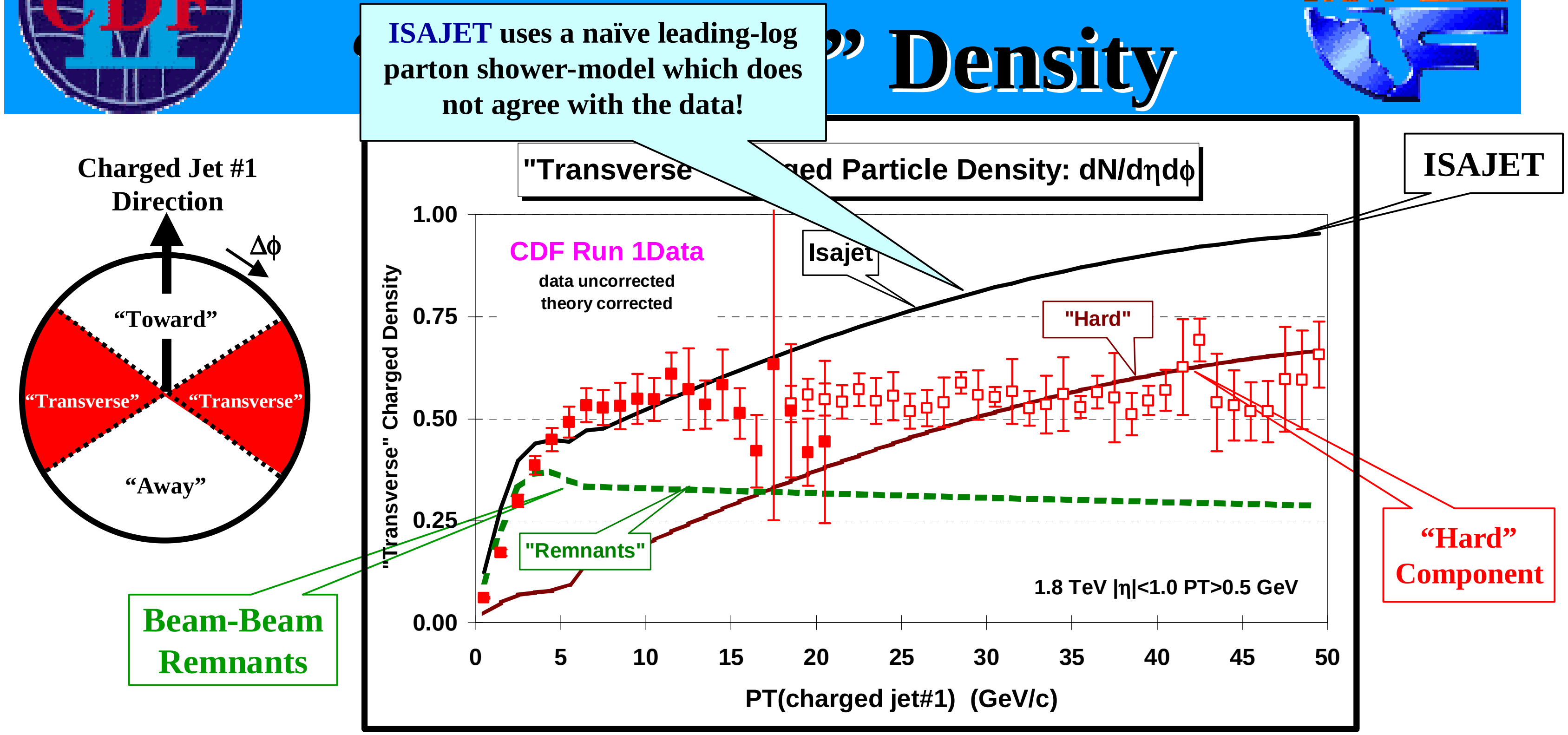
ISAJET uses a naïve leading-log parton shower-model which does not agree with the data!





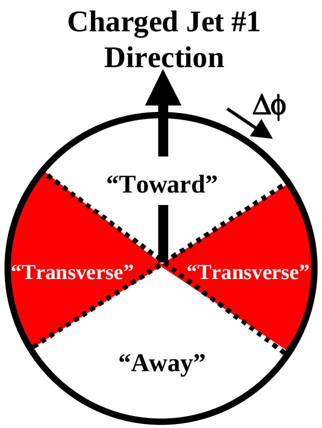
- Compares the average “transverse” charge particle density ($|\eta|<1$, $P_T>0.5$ GeV) versus P_T(charged jet#1) and the P_T distribution of the “transverse” density, $dN_{chg}/d\eta d\phi dP_T$ with the QCD hard scattering predictions of ISAJET 7.32 (default parameters with P_T(hard)>3 GeV/c) .
- The predictions of ISAJET are divided into three categories: charged particles that arise from the break-up of the beam and target (beam-beam remnants), charged particles that arise initial-state radiation, and charged particles that arise from the outgoing jets plus final-state radiation.

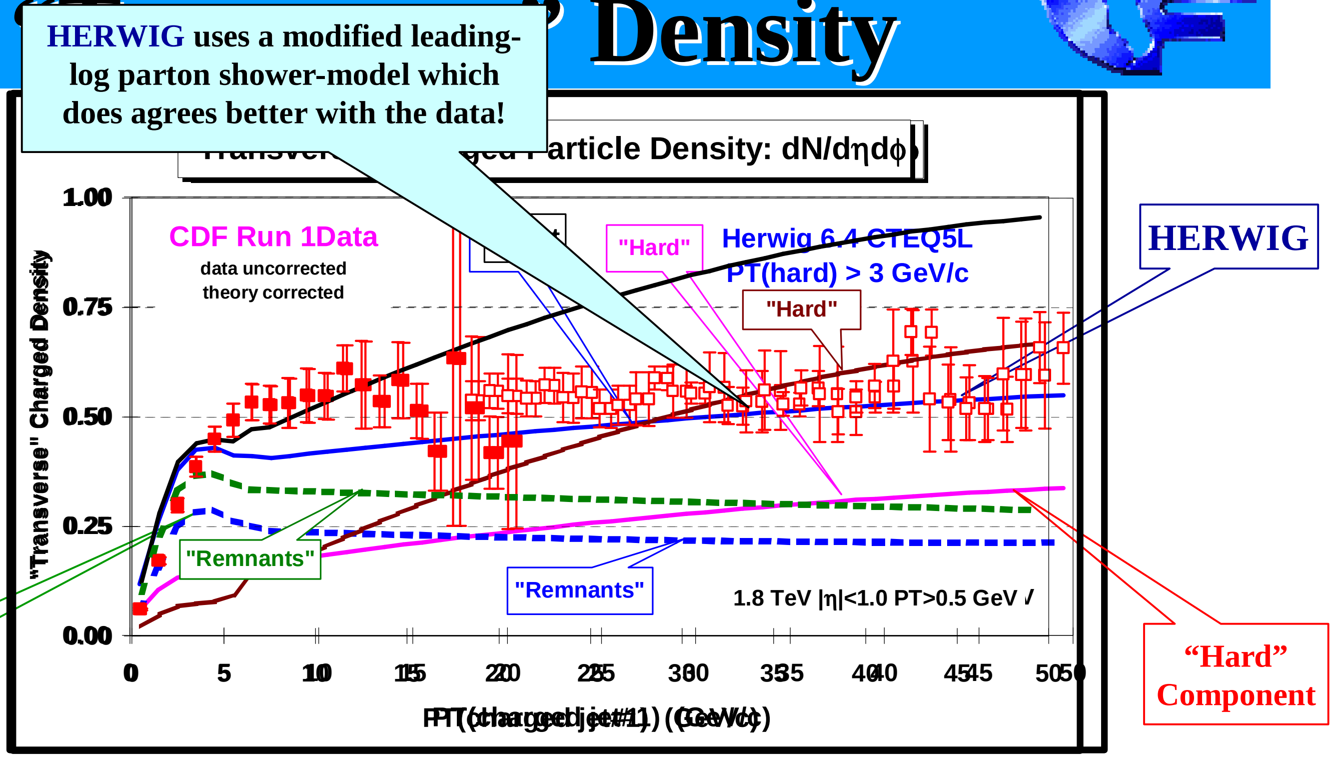
ISAJET 7.32 "Transverse" Density



- Plot shows average "transverse" charge particle density ($|\eta|<1$, $P_T>0.5$ GeV) versus P_T(charged jet#1) compared to the QCD hard scattering predictions of ISAJET 7.32 (default parameters with P_T(hard)>3 GeV/c) .
- The predictions of ISAJET are divided into two categories: charged particles that arise from the break-up of the beam and target (beam-beam remnants); and charged particles that arise from the outgoing jet plus initial and final-state radiation (hard scattering component).

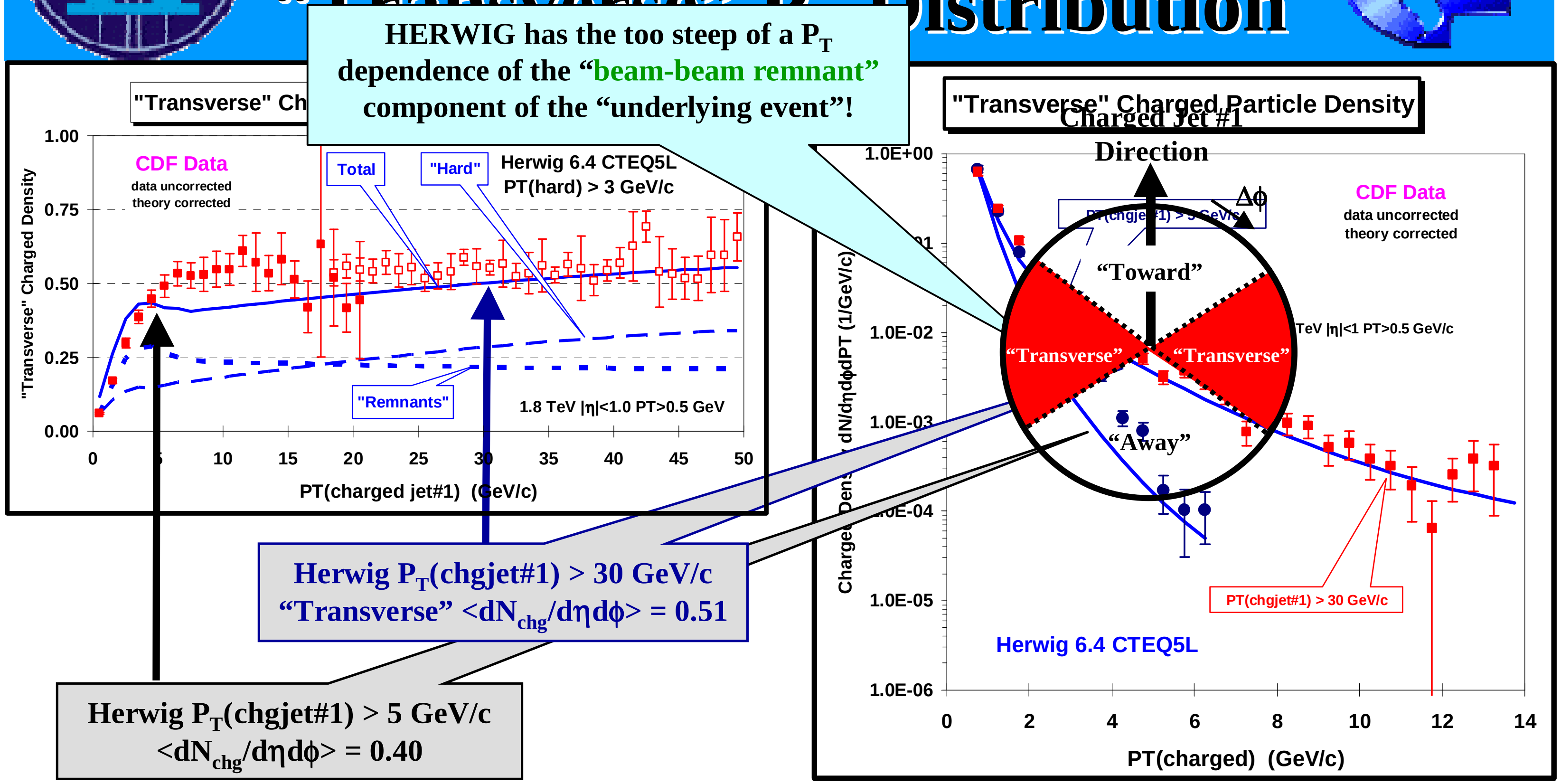
HERWIG 6.4 “T…” Density





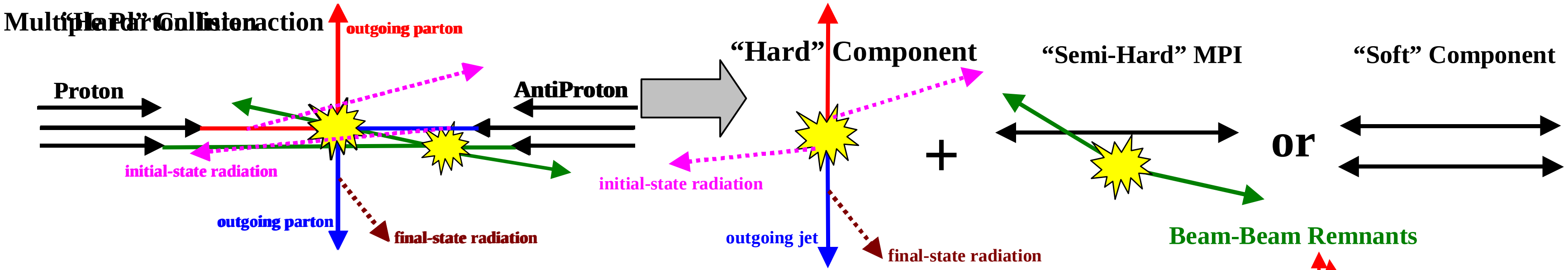
- Plot shows average “transverse” charge particle density (|η|<1, P_T>0.5 GeV) versus P_T(charged jet#1) compared to the QCD hard scattering predictions of HERWIG 5.9 (default parameters with P_T(hard)>3 GeV/c).
- The predictions of HERWIG are divided into two categories: charged particles that arise from the break-up of the beam and target (beam-beam remnants); and charged particles that arise from the outgoing jet plus initial and final-state radiation (hard scattering component).

HERWIG 6.4
“Transverse” P_T Distribution

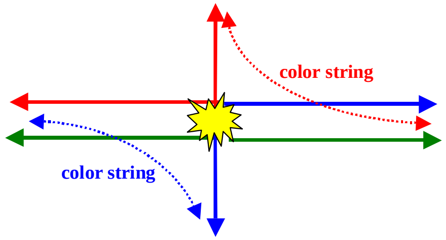


- Compares the average “transverse” charge particle density ($|\eta|<1$, $P_T>0.5$ GeV) versus P_T(charged jet#1) and the P_T distribution of the “transverse” density, $dN_{chg}/d\eta d\phi dP_T$ with the QCD hard scattering predictions of HERWIG 6.4 (default parameters with P_T(hard)>3 GeV/c. Shows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

MPI: Multiple Parton Interactions

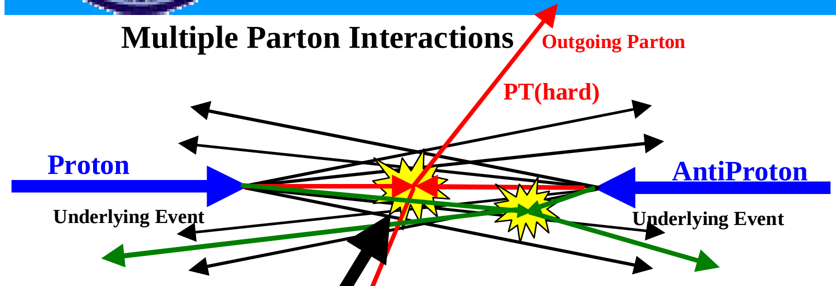


- PYTHIA models the "soft" component of the underlying event with color string fragmentation, but in addition includes a contribution arising from multiple parton interactions (MPI) in which one interaction is hard and the other is "semi-hard".



- The probability that a hard scattering events also contains a semi-hard multiple parton interaction can be varied but adjusting the cut-off for the MPI.
- One can also adjust whether the probability of a MPI depends on the P_T of the hard scattering, P_T(hard) (constant cross section or varying with impact parameter).
- One can adjust the color connections and flavor of the MPI (singlet or nearest neighbor, q-qbar or glue-glue).
- Also, one can adjust how the probability of a MPI depends on P_T(hard) (single or double Gaussian matter distribution).

PYTHIA: Multiple Parton Interaction Parameters



Pythia uses multiple parton interactions to enhance the underlying event.

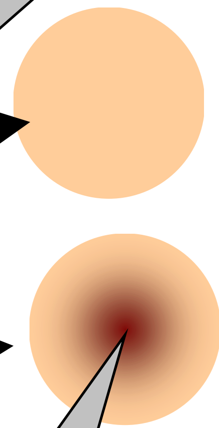
and now HERWIG!

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!

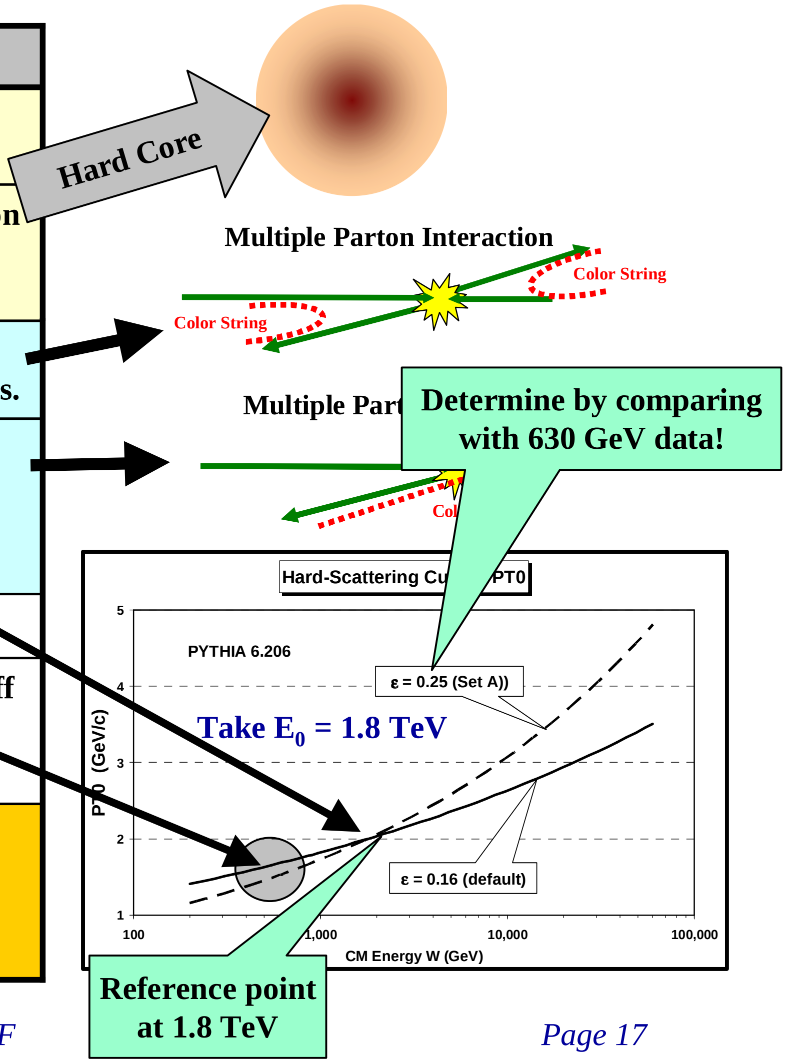


Hard Core

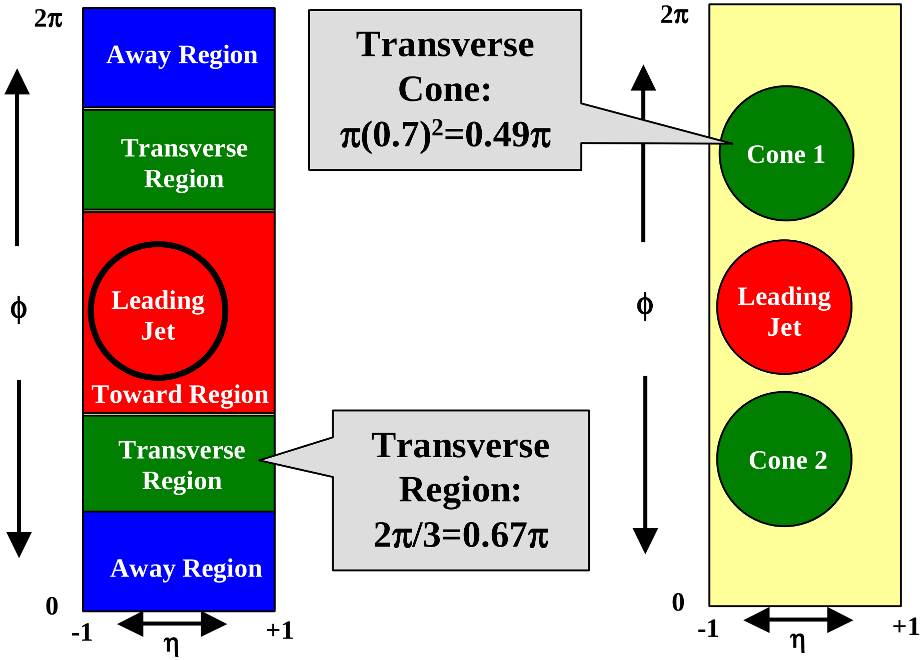
Tuning PYTHIA:
Multiple Parton Interaction Parameters

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 ... g fraction consists of**
PARP(89)	**1 TeV**	**D... ines the reference energy E_0.**
PARP(90)	**0.16**	**...etermines 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.**

Affects the amount of initial-state radiation!



"Transverse" Cones vs "Transverse" Regions

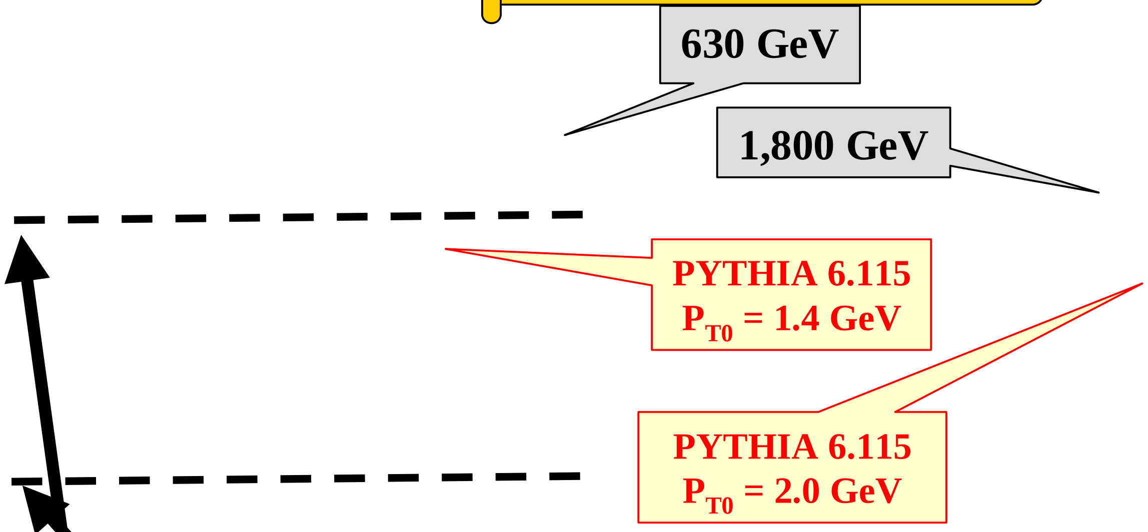


"Cone Analysis"
(Tano, Kovacs, Huston, Bhatti)

- **Sum the P_T of charged particles in two cones of radius 0.7 at the same η as the leading jet but with $|\Delta\Phi| = 90^o$.**
- **Plot the cone with the maximum and minimum PT_{sum} versus the E_T of the leading (calorimeter) jet.**

Energy Dependence of the "Underlying Event"

"Cone Analysis"
(Tano, Kovacs, Huston, Bhatti)



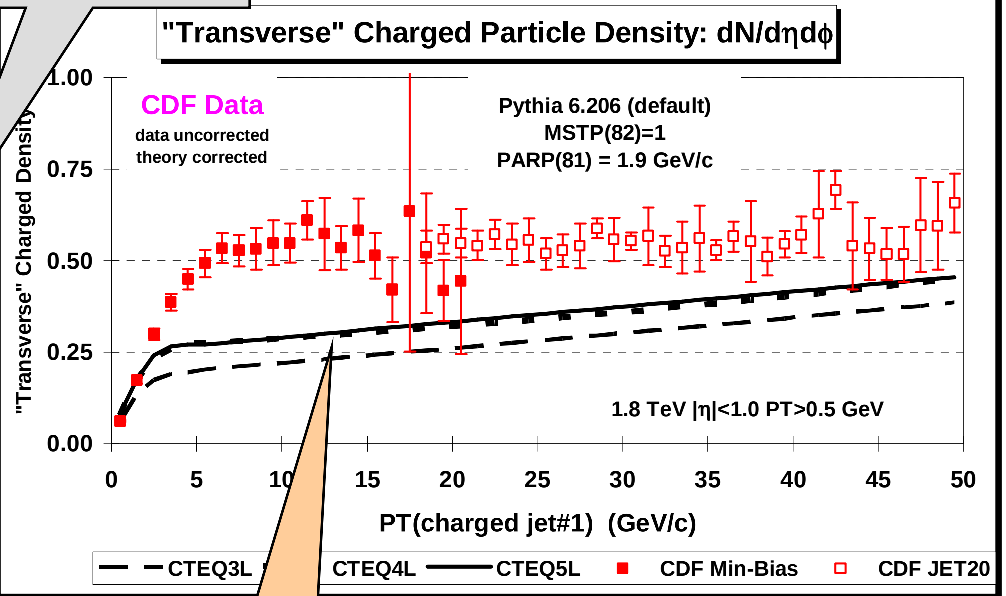
- **Sum the P_T of charged particles ($P_T > 0.4$ GeV/c) in two cones of radius 0.7 at the same η as the leading jet but with $|\Delta\Phi| = 90^o$. Plot the cone with the maximum and minimum PT_{sum} versus the E_T of the leading (calorimeter) jet.**
- **Note that PYTHIA 6.115 is tuned at 630 GeV with $P_{T0} = 1.4$ GeV and at 1,800 GeV with $P_{T0} = 2.0$ GeV. This implies that ε = PARP(90) should be around 0.3 instead of the 0.16 (default).**
- **For the MIN cone 0.25 GeV/c in radius R = 0.7 implies a PT_{sum} density of $dPT_{sum}/d\eta d\phi = 0.16$ GeV/c and 1.4 GeV/c in the MAX cone implies $dPT_{sum}/d\eta d\phi = 0.91$ GeV/c (average PT_{sum} density of 0.54 GeV/c per unit η-ϕ).**

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.

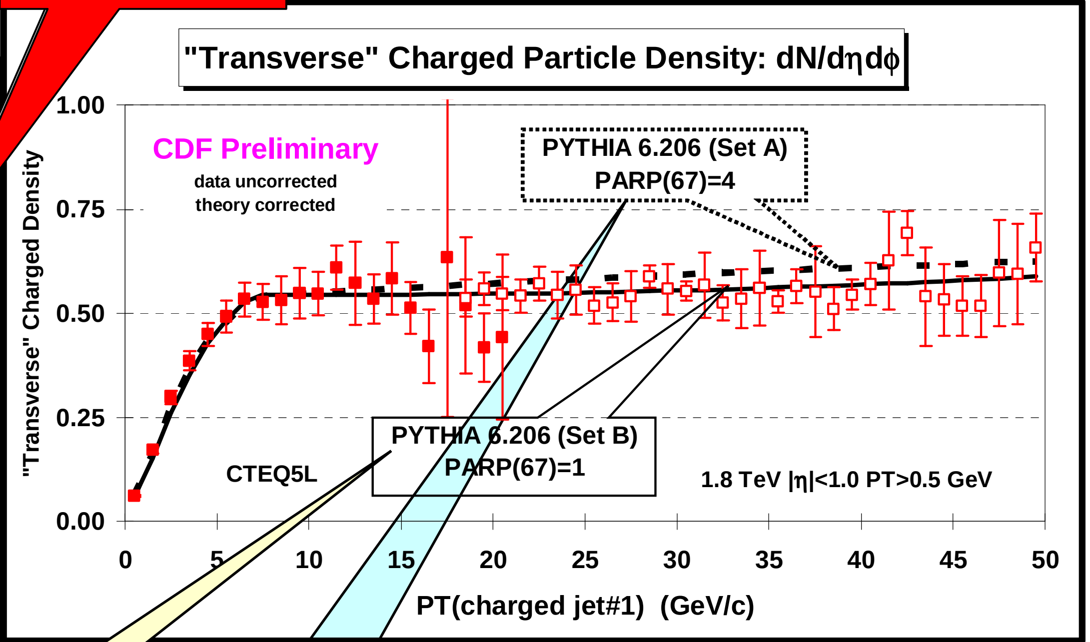
<u>Note Change</u>
PARP(67) = 4.0 (< 6.138)
PARP(67) = 1.0 (> 6.138)

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

Tuned PYTHIA 6.206

Tune A CDF Run 2 Default!

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

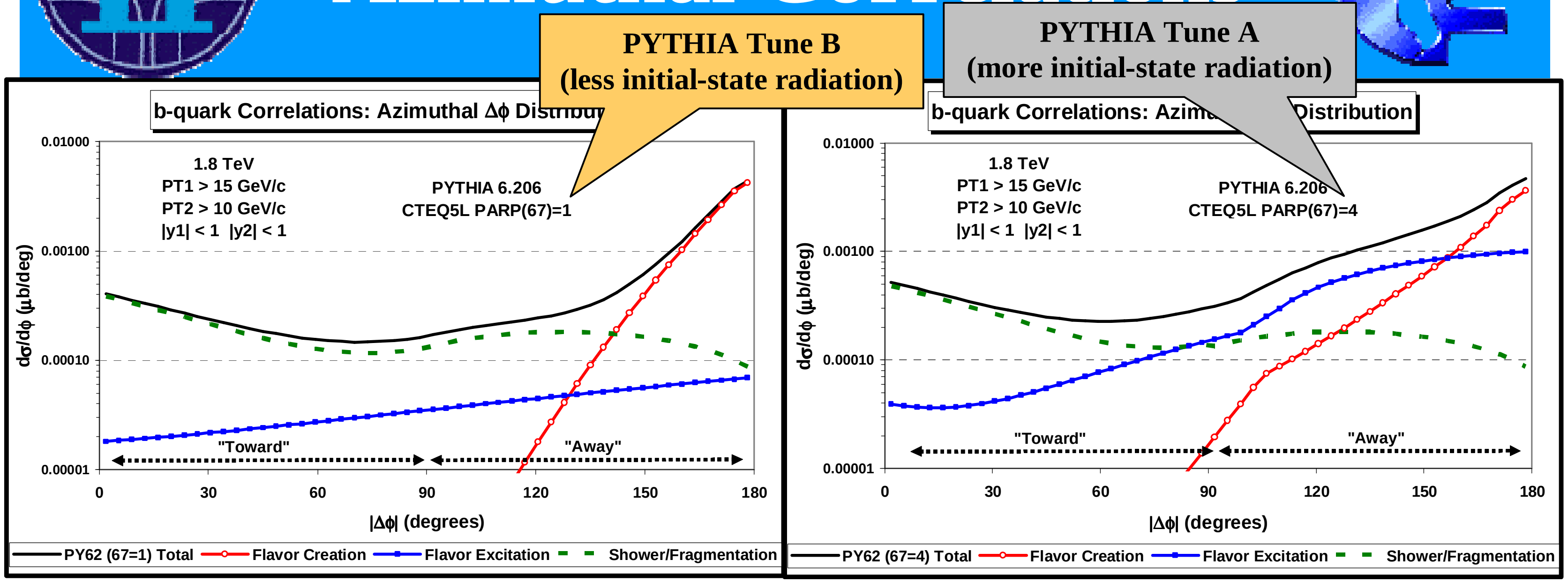


Plot shows the "Transverse" charged particle density versus P_T(chgjet#1) compared to the QCD hard scattering predictions of two tuned versions of PYTHIA 6.206 (CTEQ5L, Set B (PARP(67)=1) and Set A (PARP(67)=4)).

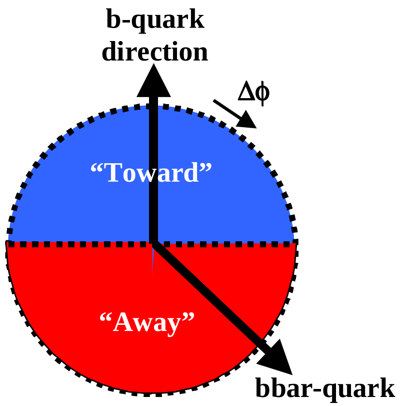
New PYTHIA default (less initial-state radiation)

Old PYTHIA default (more initial-state radiation)

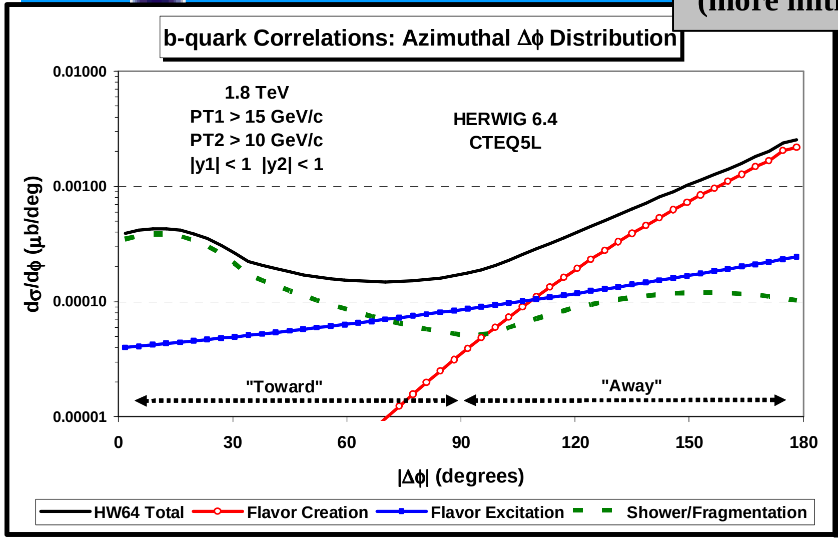
Azimuthal Correlations

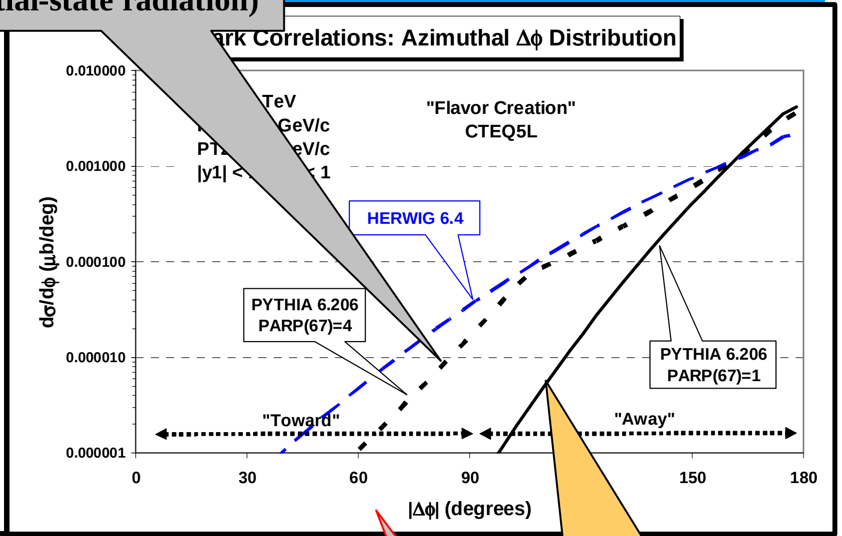


- **Predictions of PYTHIA 6.206 (CTEQ5L) with PARP(67)=1 (new default) and PARP(67)=4 (old default) for the azimuthal angle, Δϕ, between a b-quark with $PT_1 > 15$ GeV/c, $|y_1| < 1$ and bbar-quark with $PT_2 > 10$ GeV/c, $|y_2| < 1$ in proton-antiproton collisions at 1.8 TeV. The curves correspond to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



Azimuthal Correlations



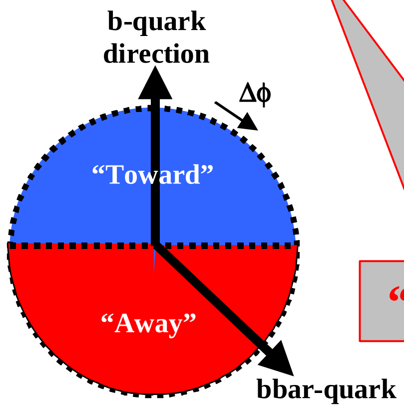


PYTHIA Tune A (more initial-state radiation)

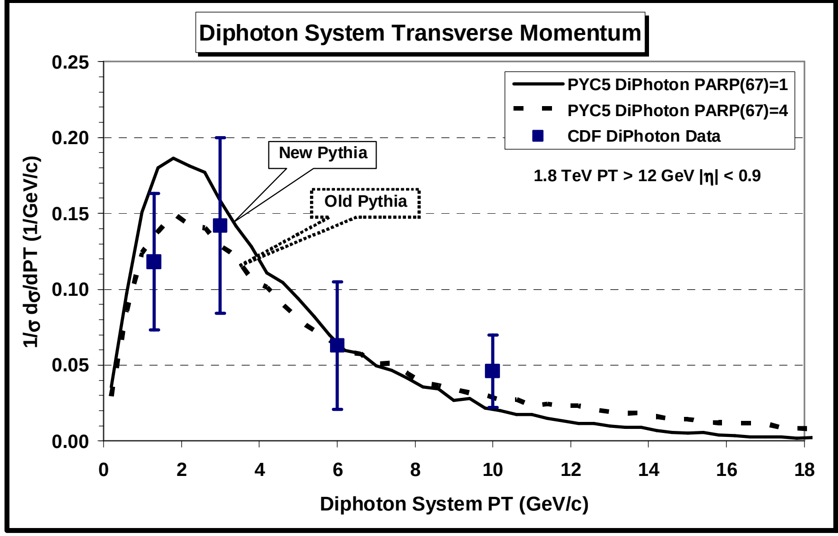
PYTHIA Tune B (less initial-state radiation)

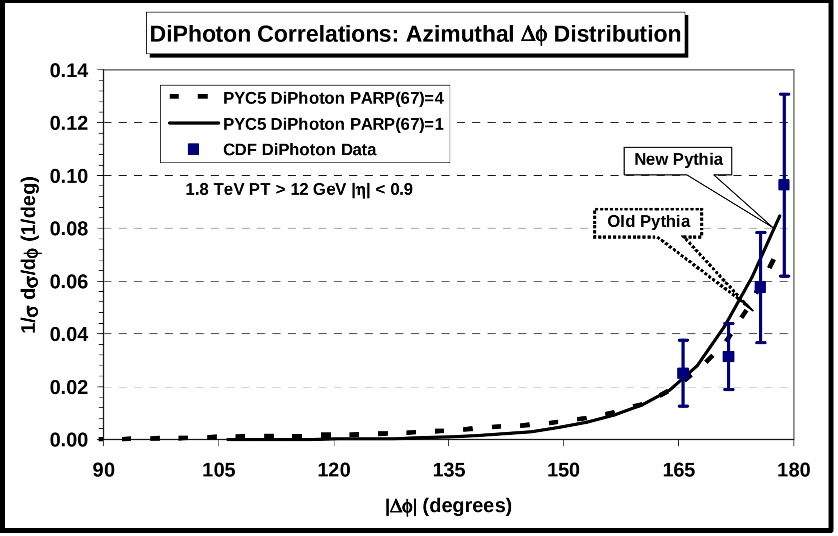
"Flavor Creation"

- **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/º) for flavor creation, flavor excitation, shower/fragmentation, and the resulting total.**

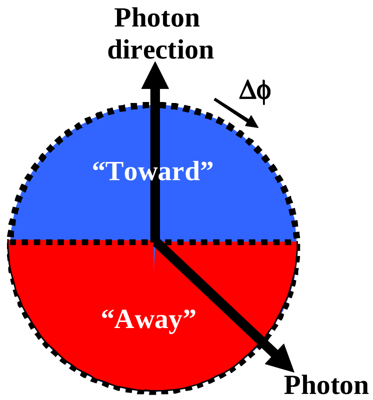


DiPhoton Correlations

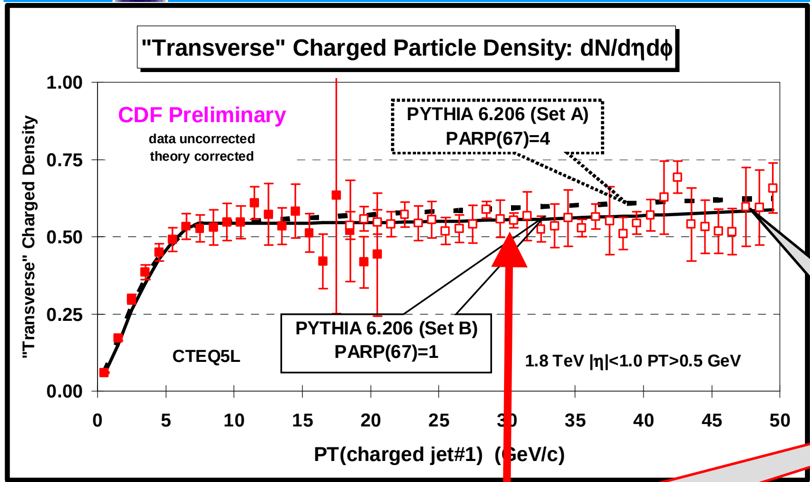


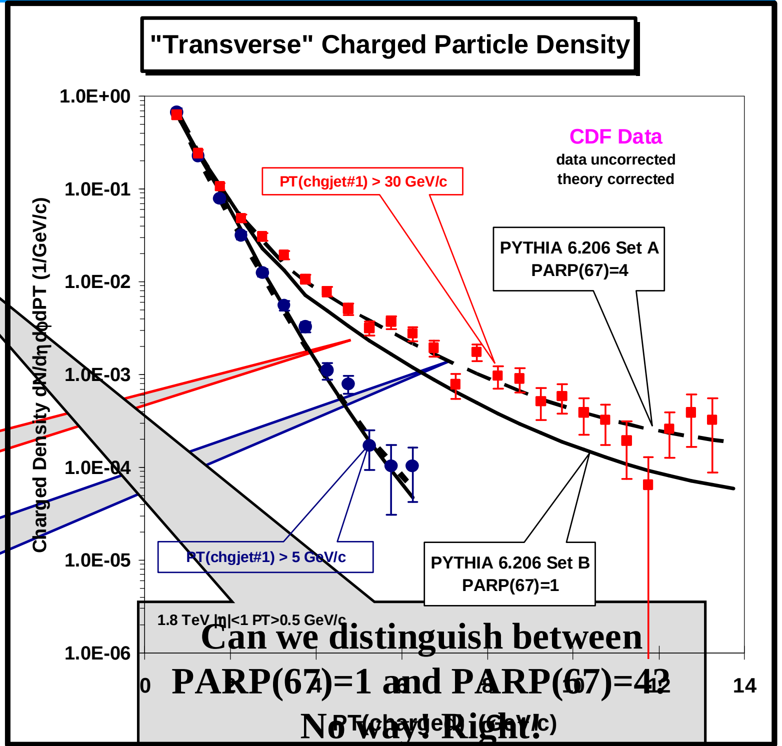


- **Predictions of PYTHIA 6.158 (CTEQ5L) with PARP(67)=1 (new default) and PARP(67)=4 (old default) for diphoton system PT and the azimuthal angle, Δϕ, between a photon with PT_1 > 12 GeV/c, $|y_1|$ < 0.9 and photon with PT_2 > 12 GeV/c, $|y_2|$< 0.9 in proton-antiproton collisions at 1.8 TeV compared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



Tuned PYTHIA 6.206 "Transverse" P_T Distribution





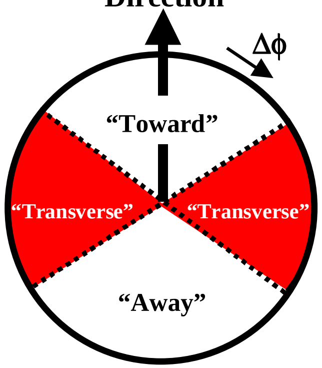
P_T(charged jet#1) > 30 GeV/c

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

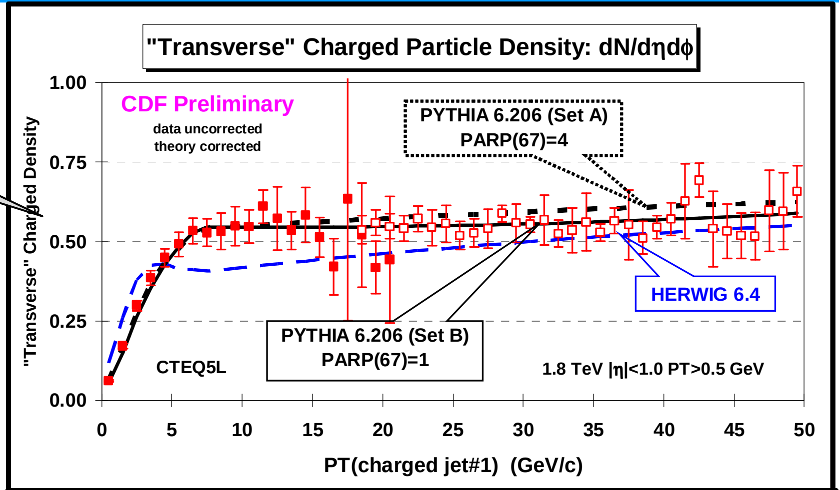
Can we distinguish between PARP(67)=1 and PARP(67)=4? No way! Right!

- 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)).

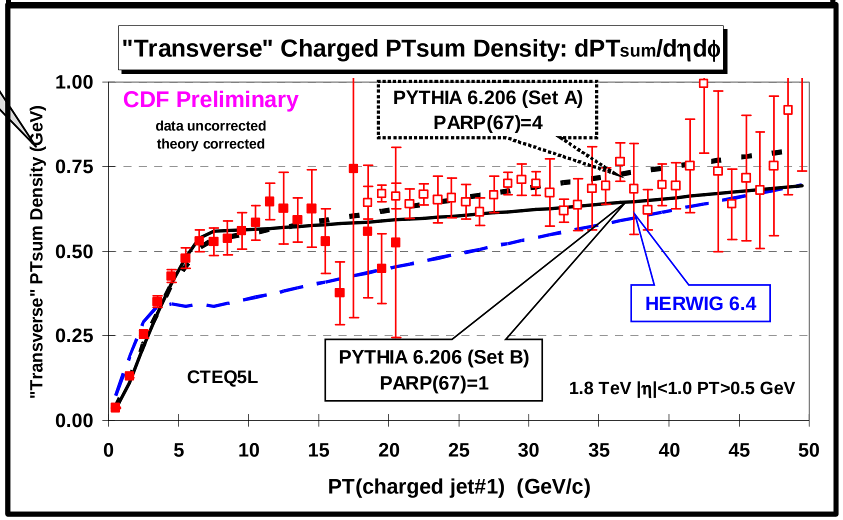
Tuned PYTHIA 6.206 vs HERWIG 6.4
“Transverse” Densities



Charged Particle Density

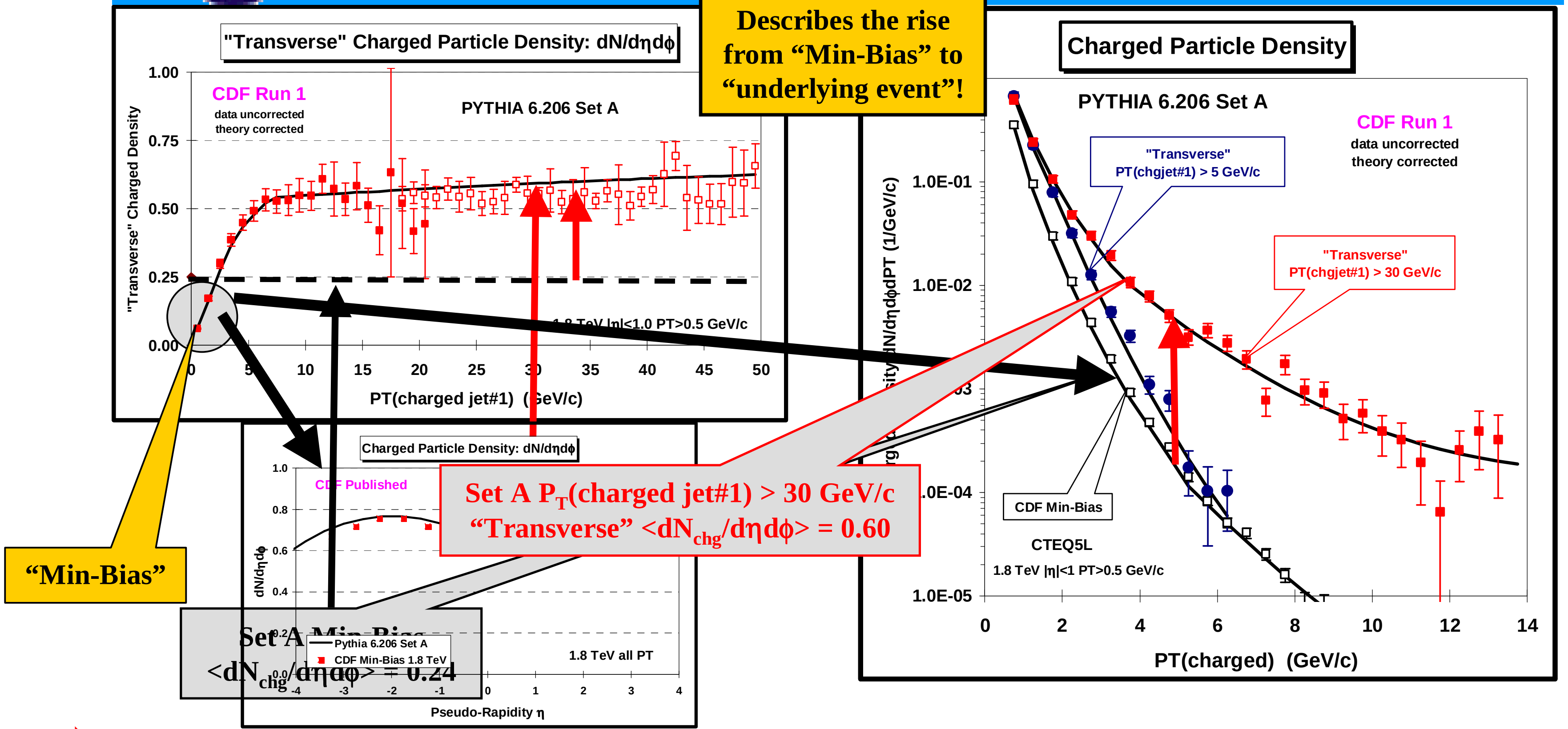


Charged PT_{sum} Density



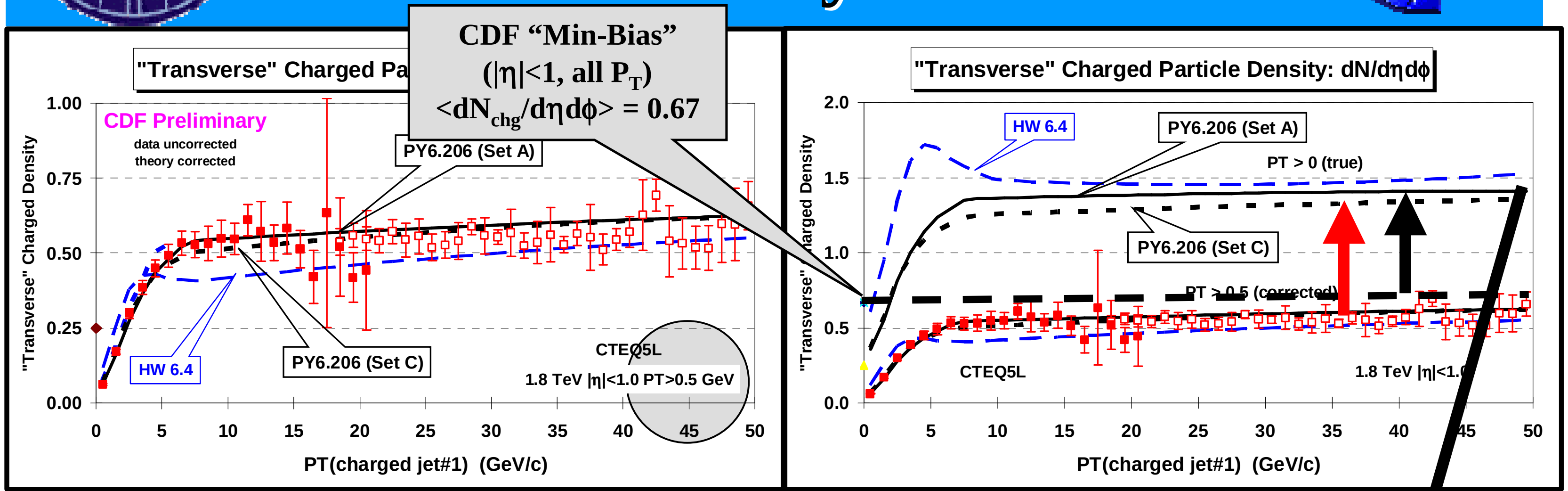
- **Plots shows CDF data on the charge particle density and the charged PT_{sum} density in the “transverse” region.**
- **The data are compared with the QCD Monte-Carlo predictions of HERWIG 6.4 (CTEQ5L, P_T(hard) > 3 GeV/c) and two tuned versions of PYTHIA 6.206 (P_T(hard) > 0).**

Tuned PYTHIA 6.206 Run 1 Tune A



- 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"!

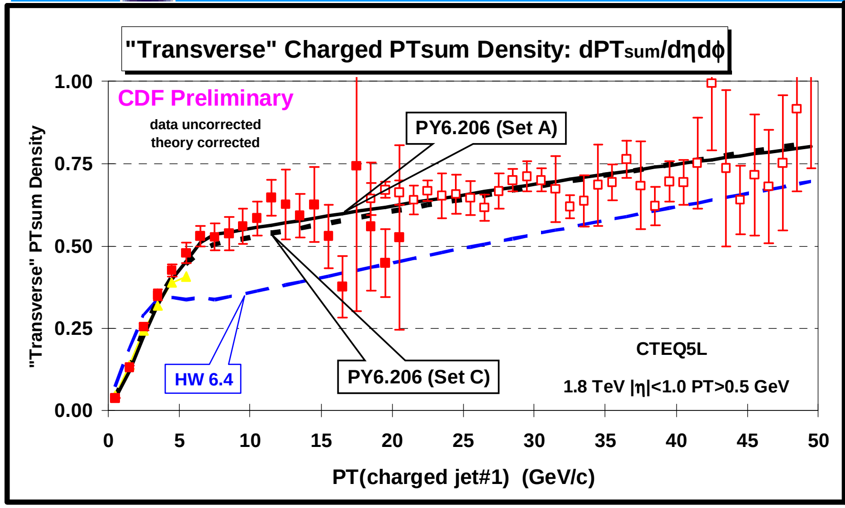
Total "Transverse" Particle Density at 1.8 TeV

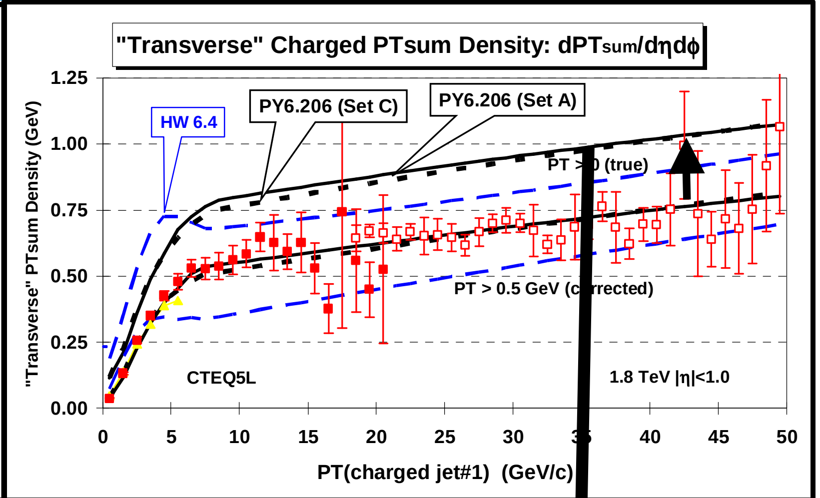


- Shows the average "transverse" charge particle density (|η|<1, P_T>0.5 GeV, corrected) and the true (|η|<1, P_T>0) "transverse" charged particle density, $dN_{chg}/d\eta d\phi$ predicted by **HERWIG 6.4** (P_T(hard) > 3 GeV/c, CTEQ5L) and two tuned versions of PYTHIA 6.206 (P_T(hard) > 0, CTEQ5L, Set A & Set C).
- There are roughly 1.4 charged particles per unit η-φ (P_T > 0) in the "transverse" region compared to 0.67 for a typical CDF "Min-Bias" collision (9 charged particles per unit η compared to 4).

2 charged particles in cone of radius R=0.7 at 1.8 TeV

Total "Transverse" PT_{sum} Density at 1.8 TeV



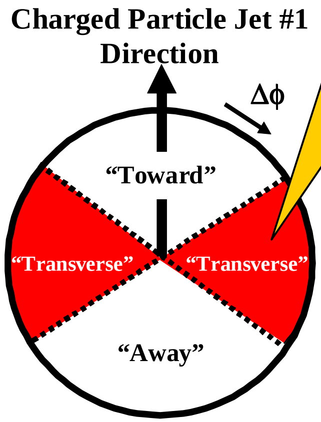


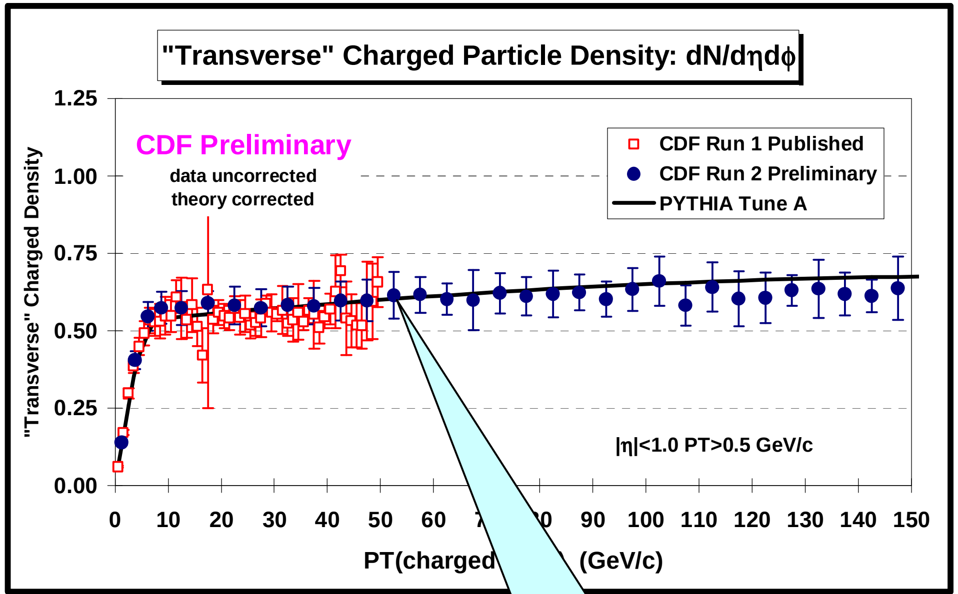
- Shows the average "transverse" charge PT_{sum} density ($|\eta|<1$, $P_T>0.5$ GeV, corrected) and the true ($|\eta|<1$, $P_T>0$) "transverse" charged PT_{sum} density, $dPT_{sum}/d\eta d\phi$ predicted by **HERWIG 6.4** (P_T(hard) > 3 GeV/c, CTEQ5L) and two **tuned** versions of **PYTHIA 6.206** (P_T(hard) > 0, CTEQ5L, Set A & Set C).
- There is roughly **1 GeV/c per unit η-φ** (P_T > 0) from charged particles in the "transverse" region for **P_T(chgjet#1) = 35 GeV/c**. **Note, however, that the "transverse" charged PT_{sum} density increases rapidly as P_T(chgjet#1) increases.**

1.5 GeV/c (charged) in cone of radius R=0.7 at 1.8 TeV

"Transverse" Cha… …rticle Density

"Transverse" region as defined by the leading "charged parti…





Excellent agreement between Run 1 and 2!

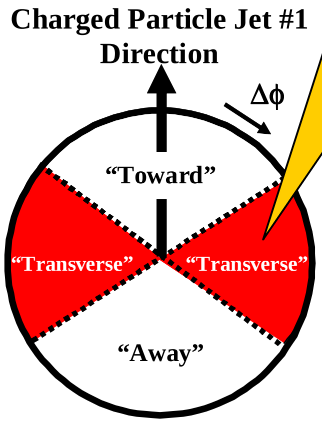
- Shows th… "transverse" charge particle den… ($|\eta|<1$, $P_T>0.5$ GeV) as a function of the transverse momentum of the leading charged pa… jet from Run 1.
- Compares the Run 2 data (**Min-Bias, JET20, JET50, JET70, JET1**… …th Run 1. The errors on the (*uncorrected*) Run 2 data include both statis… systematic uncertainties.

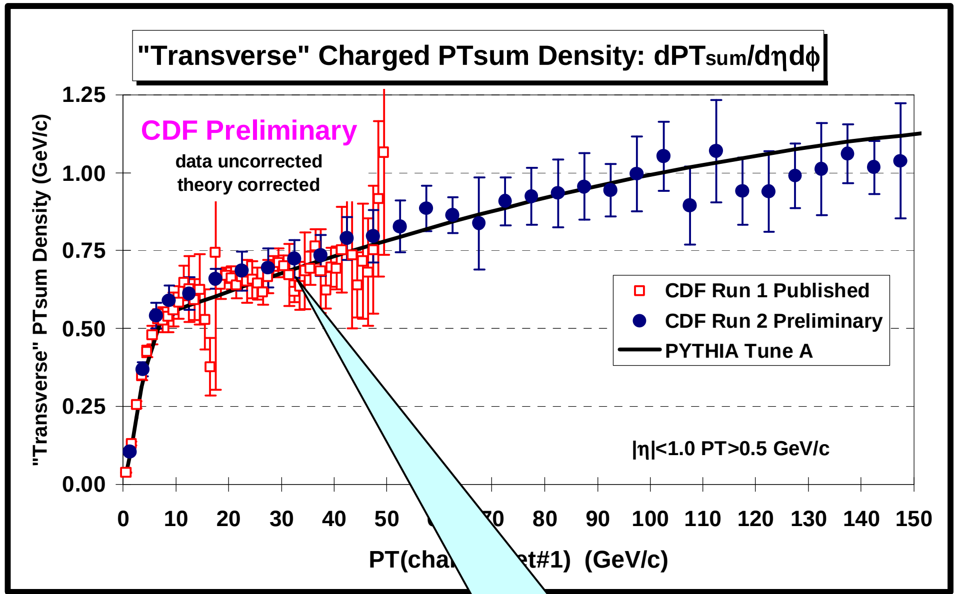
PYTHIA Tune A was tuned to fit the "underlying event" in Run I!

- Shows the prediction of **PYTHIA Tune A** at 1.96 TeV after detector simulation (*i.e.* after CDFSIM).

“Transverse” Charged PTsum Density

“Transverse” region as defined by the leading “charged parti



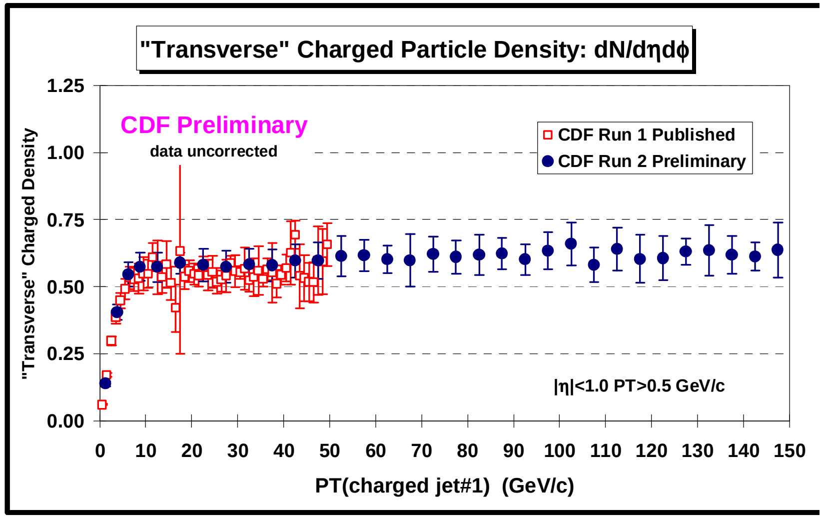


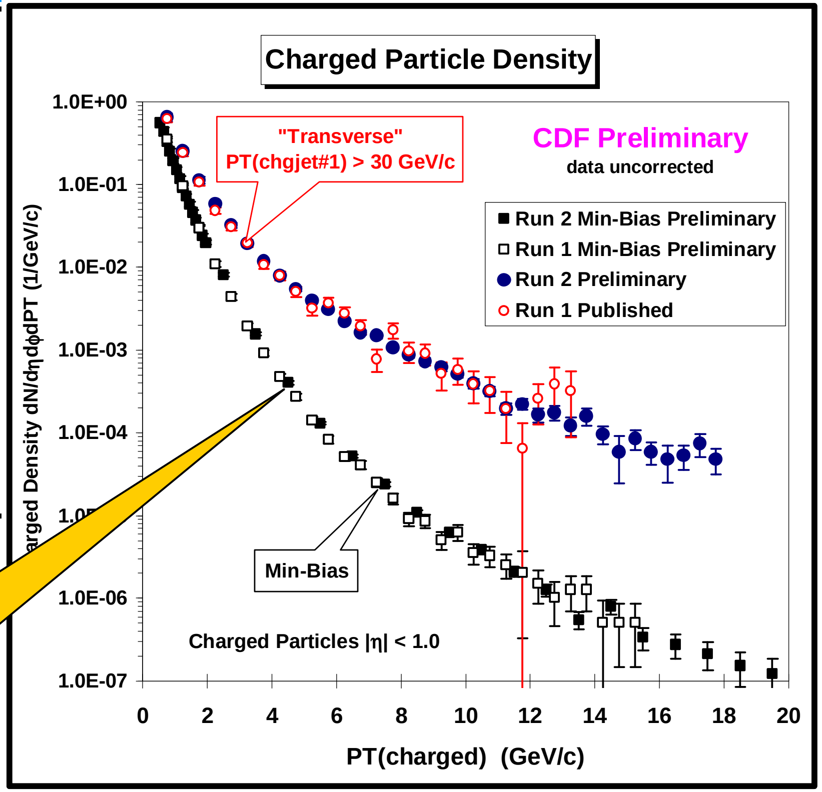
Excellent agreement between Run 1 and 2!

- Shows th “transverse” charged PTsum d y (|η|<1, P_T>0.5 GeV) as a function of the transverse momentum of the leading charge ticle jet from Run 1.
- Compares the Run 2 data (Min-Bias, JET20, JET50, JET70, JET ith Run 1. The errors on the (*uncorrected*) Run 2 data include both statistical 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!

Charged Particle Density "Transverse" P_T Distribution



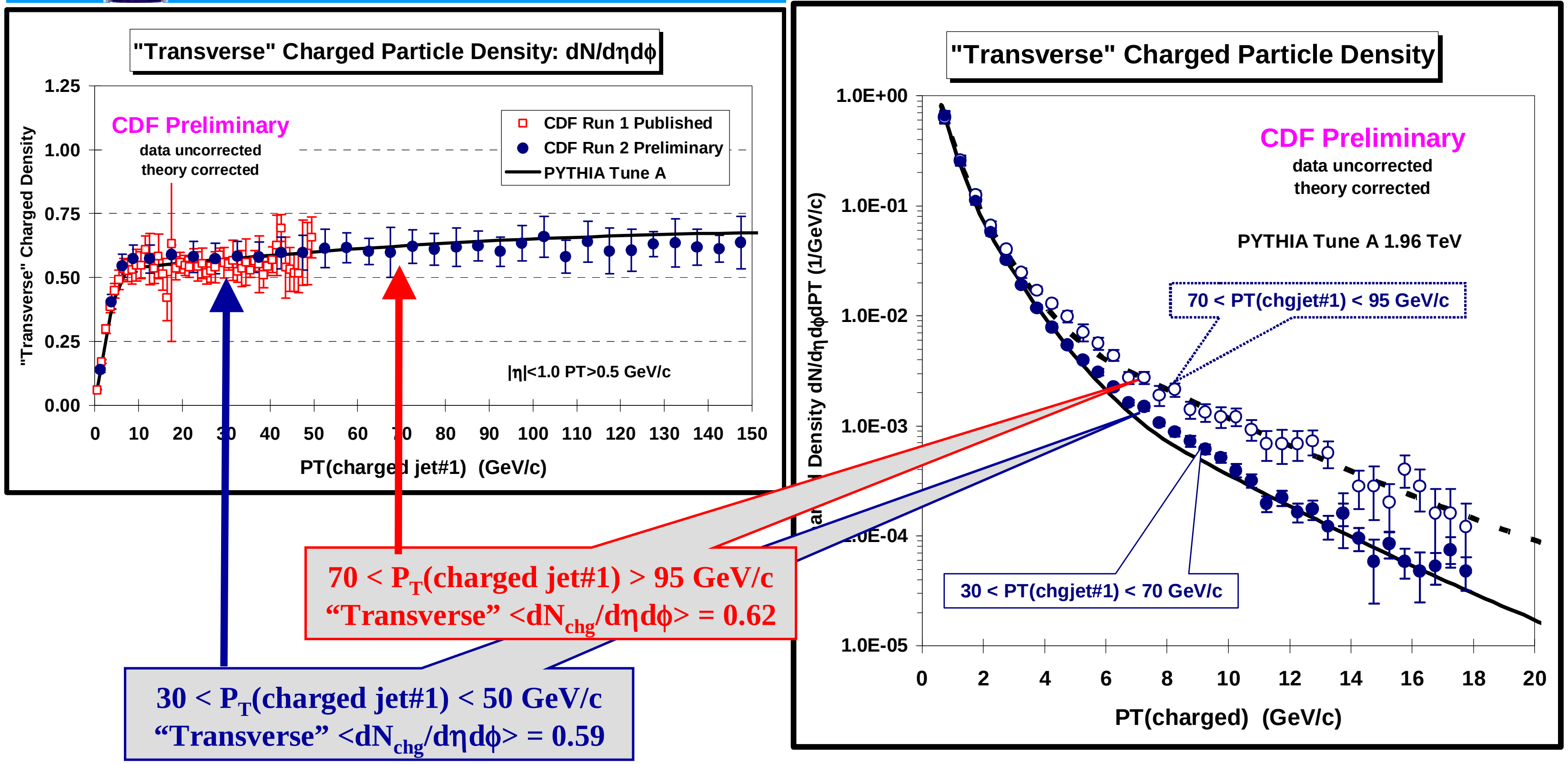


- Compares the average "transverse" charge particle density ($|\eta|<1$, $P_T>0$… GeV) versus P_T(ch… P_T distribution of t… density, $dN_{chg}/d\eta d\phi dP_T$. Shows how the "transverse" charge particle density is distributed in P_T.

Excellent agreement between Run 1 and 2!

- Compares the Run 2 data (Min-Bias, JET20, JET50, JET70, JET100) with Run 1.

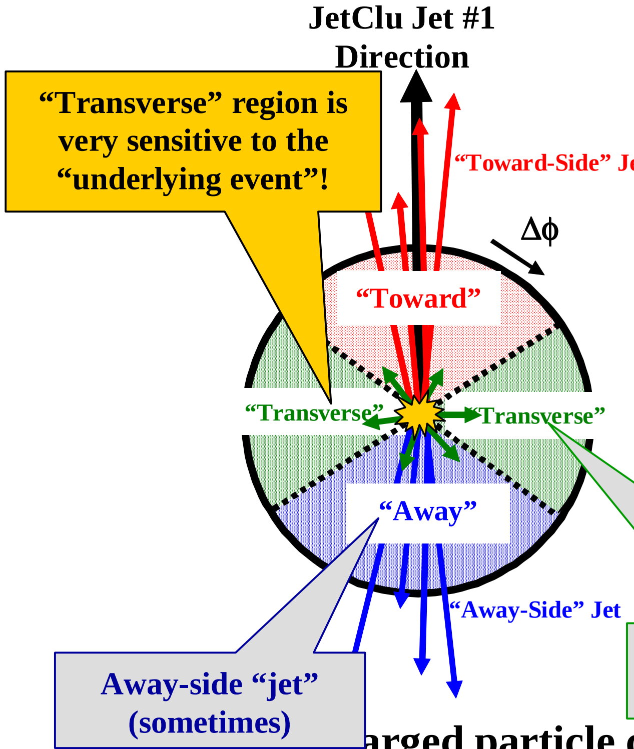
Charged Particle Density "Transverse" P_T Distribution

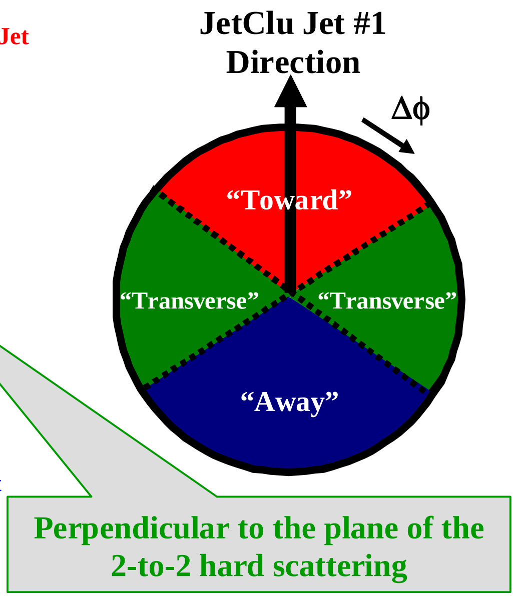


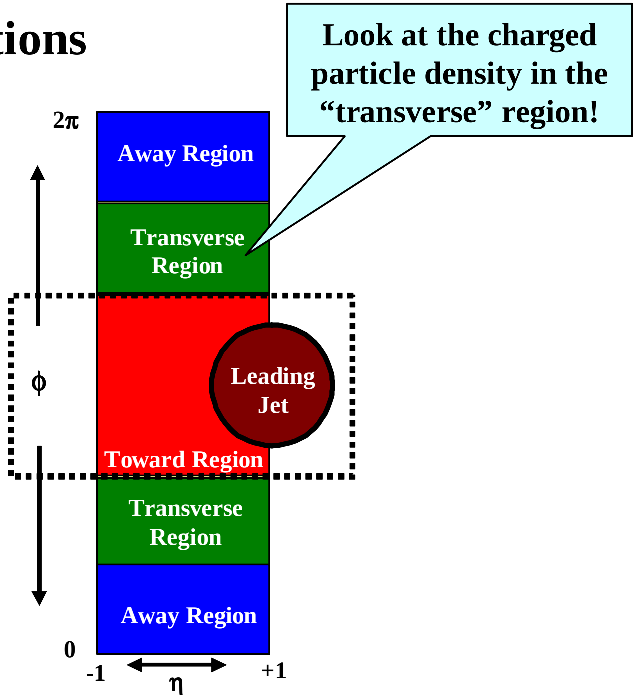
- **Compares the average "transverse" charge particle density (|η|<1, P_T>0.5 GeV) versus P_T(charged jet#1) with the P_T distribution of the "transverse" density, $dN_{chg}/d\eta d\phi dP_T$.**
- **Shows the prediction of PYTHIA Tune A at 1.96 TeV after detector simulation (*i.e.* after CDFSIM).**

"Underlying Event" as defined by "Calorimeter Jets"

Charged Particle Δφ Correlations
$P_T > 0.5$ GeV/c $|\eta| < 1$

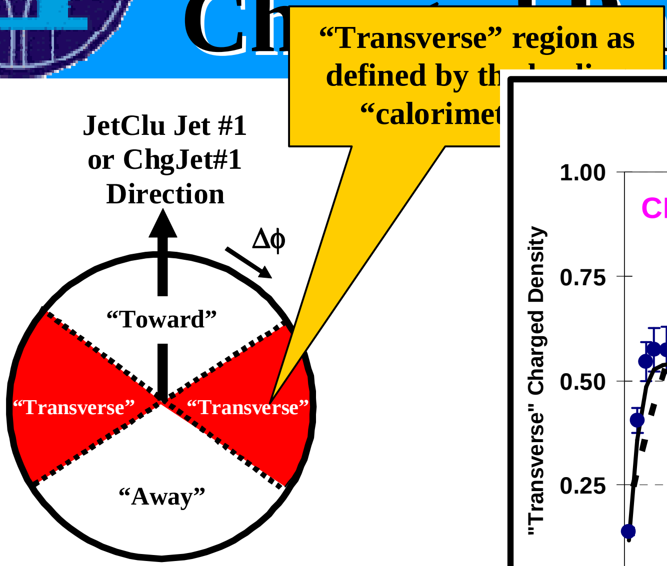


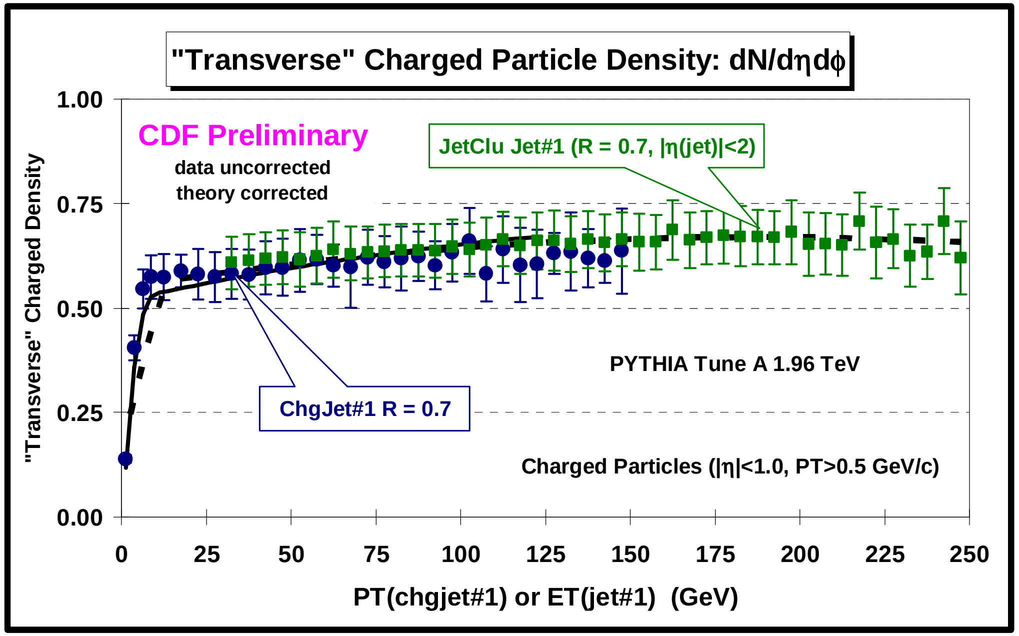




- Look at charged particle correlations in the azimuthal angle Δφ relative to the leading JetClu jet.
- Define $|\Delta\phi| < 60^o$ as "Toward", $60^o < |\Delta\phi| < 120^o$ as "Transverse", and $|\Delta\phi| > 120^o$ as "Away".
- All three regions have the same size in η-φ space, $\Delta\eta \times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

"Transverse" Charged Particle Density

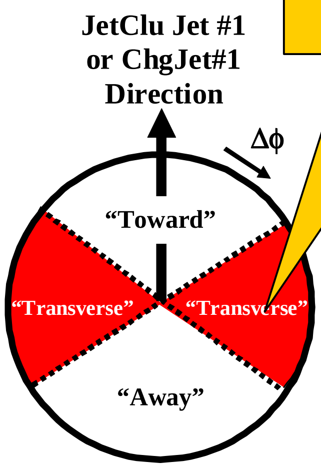


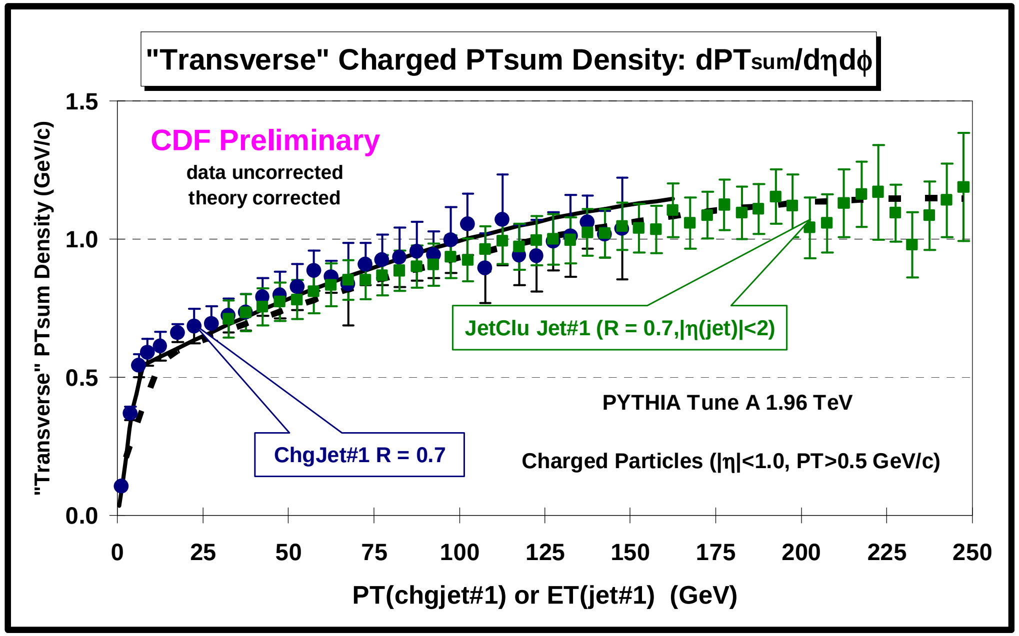


- **Shows the data on the average "transverse" charge particle density (|η|<1, PT>0.5 GeV) as a function of the transverse energy of the leading JetClu jet (R = 0.7, |η(jet)| < 2) from Run 2, compared with PYTHIA Tune A after CDFSIM.**
- **Compares the "transverse" region of the leading "charged particle jet", chgjet#1, with the "transverse" region of the leading "calorimeter jet" (JetClu R = 0.7), jet#1.**

“Transverse” Charged PTsum Density

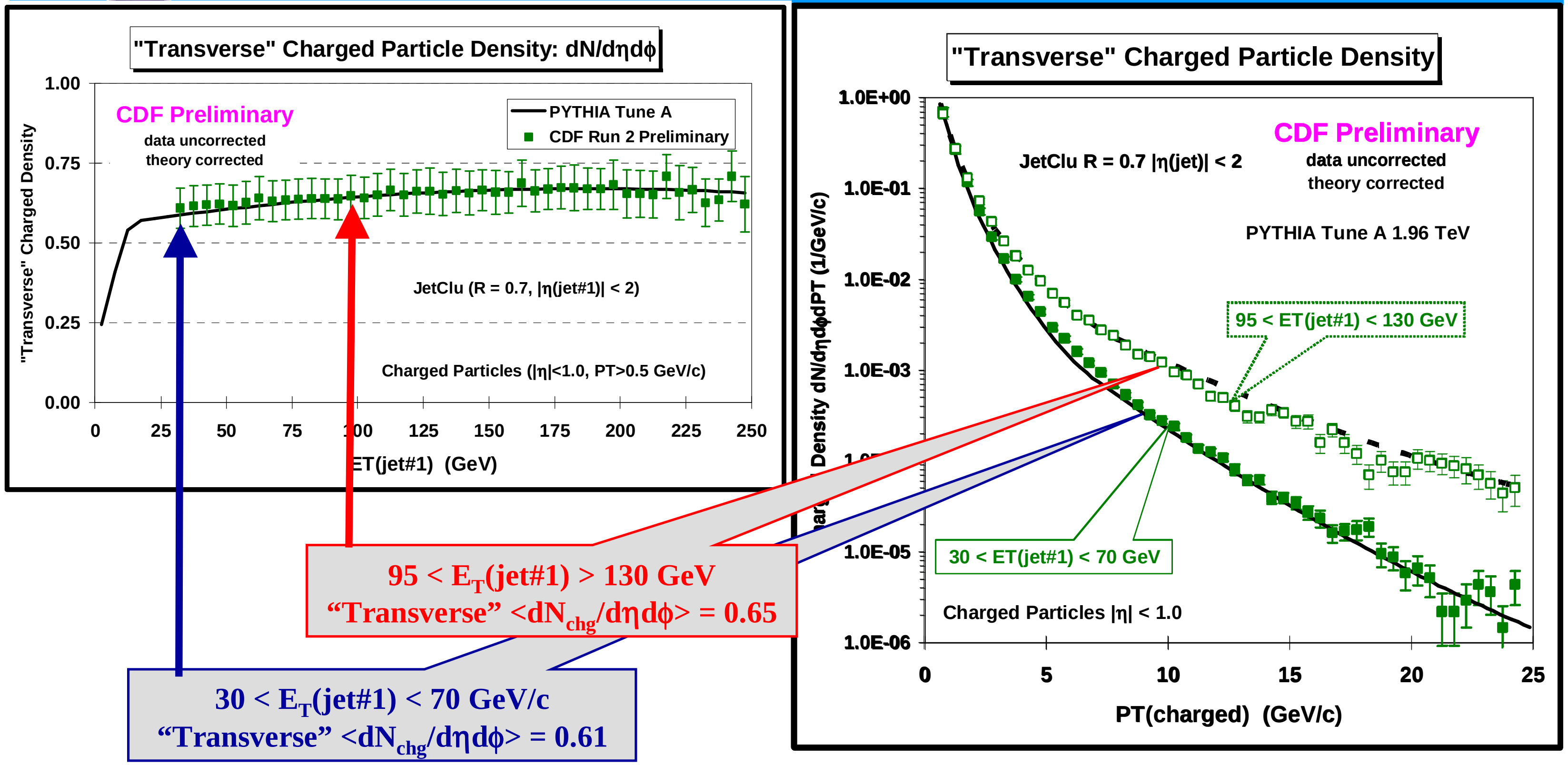
“Transverse” region as defined by the lea…
“calorimete…





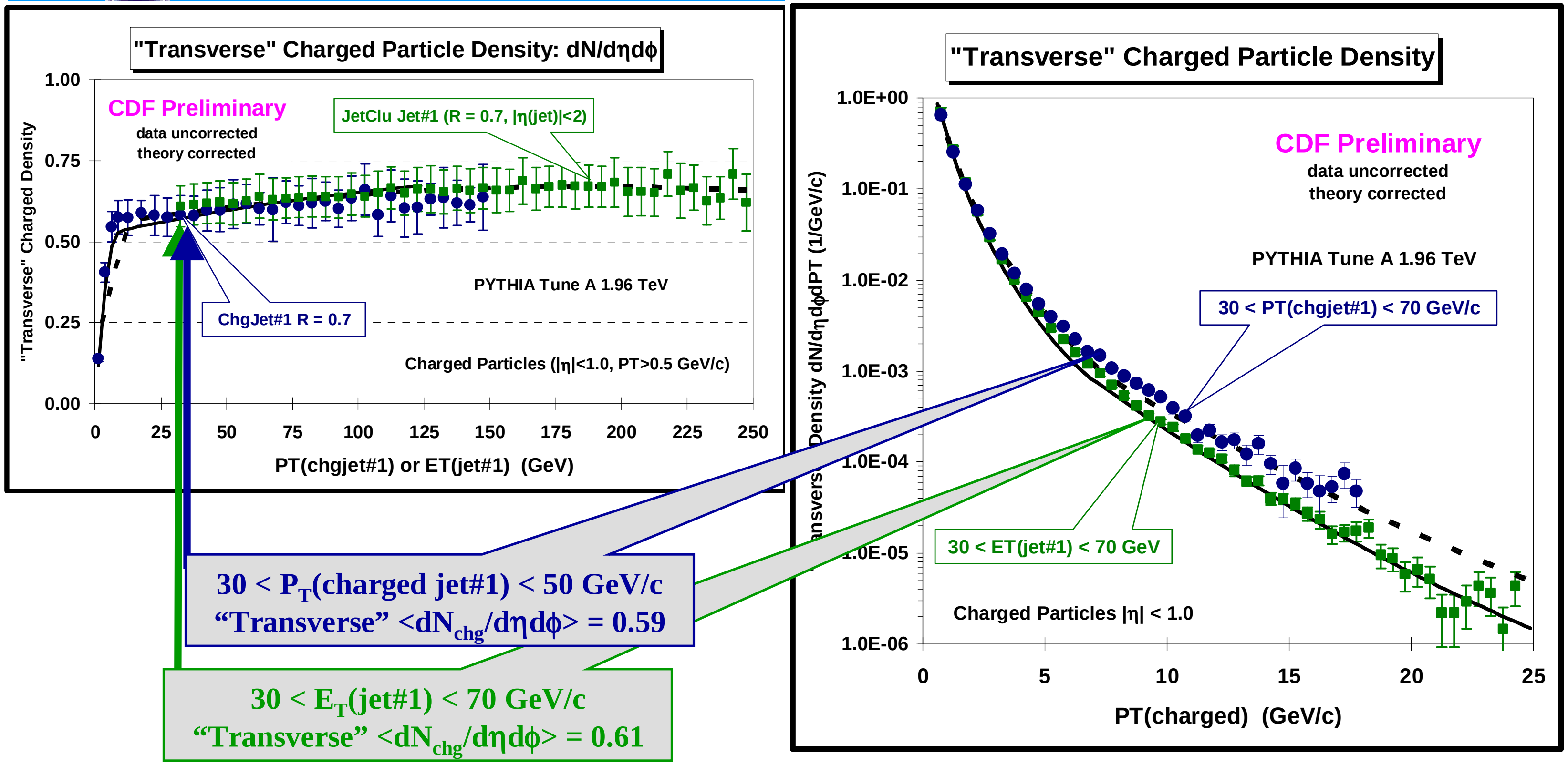
- Shows the data on the average “transverse” charged PTsum density (|η|<1, PT>0.5 GeV) as a function of the transverse energy of the leading JetClu jet (R = 0.7, |η(jet)| < 2) from Run 2, compared with **PYTHIA Tune A** after CDFSIM.
- Compares the “transverse” region of the leading **“charged particle jet”**, chgjet#1, with the “transverse” region of the leading **“calorimeter jet”** (JetClu R = 0.7), jet#1.

Charged Particle Density "Transverse" P_T Distribution



- Compares the average "transverse" charge particle density (|η|<1, P_T>0.5 GeV) versus E_T(jet#1) with the P_T distribution of the "transverse" density, $dN_{chg}/d\eta d\phi dP_T$.
- Shows the prediction of **PYTHIA Tune A** at 1.96 TeV after detector simulation (*i.e.* after CDFSIM).

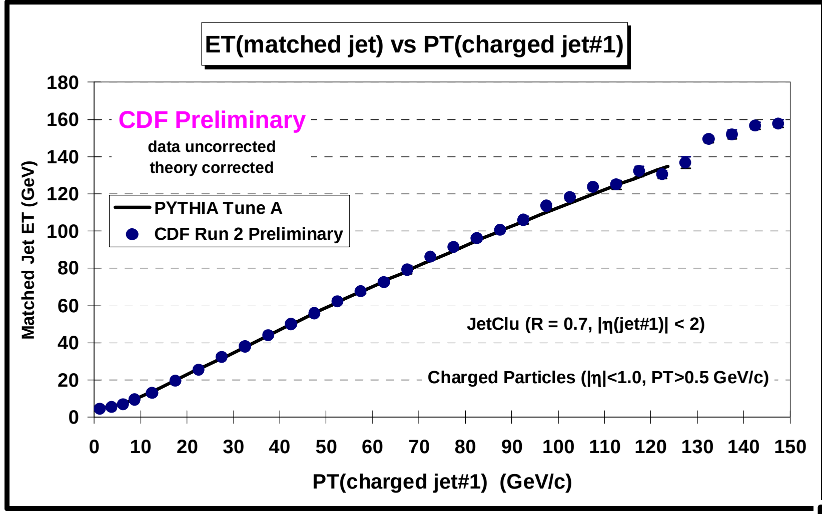
Charged Particle Density "Transverse" P_T Distribution

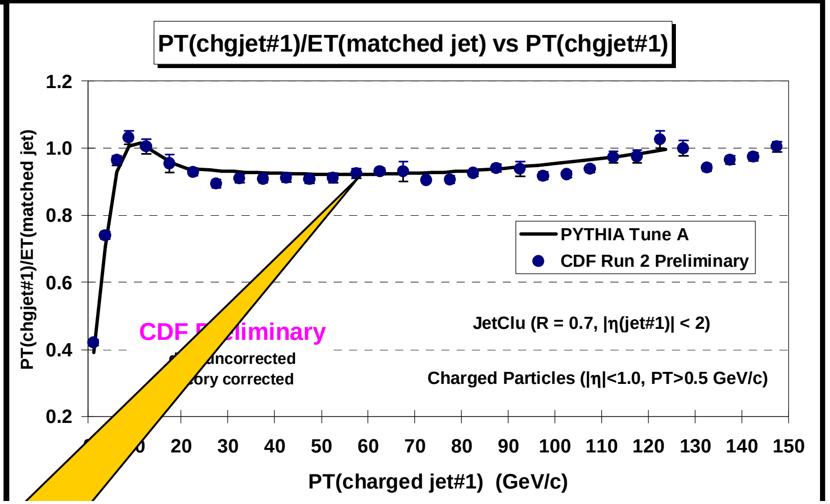


- Compares the average "transverse" as defined by "calorimeter jets" (JetClu R = 0.7) with the "transverse" region defined by "charged particle jets".
- Shows the prediction of PYTHIA Tune A at 1.96 TeV after detector simulation (*i.e.* after CDFSIM).

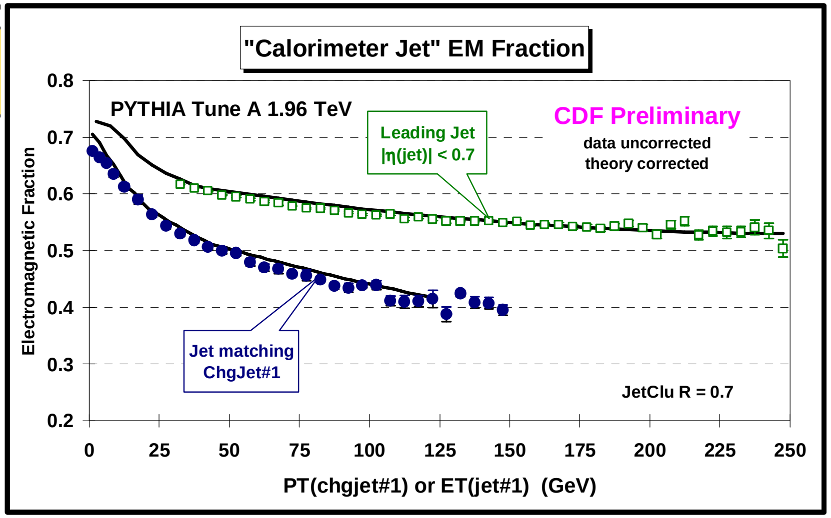
Relationship Between

“Calorimeter” and “Charged Particle” Jets





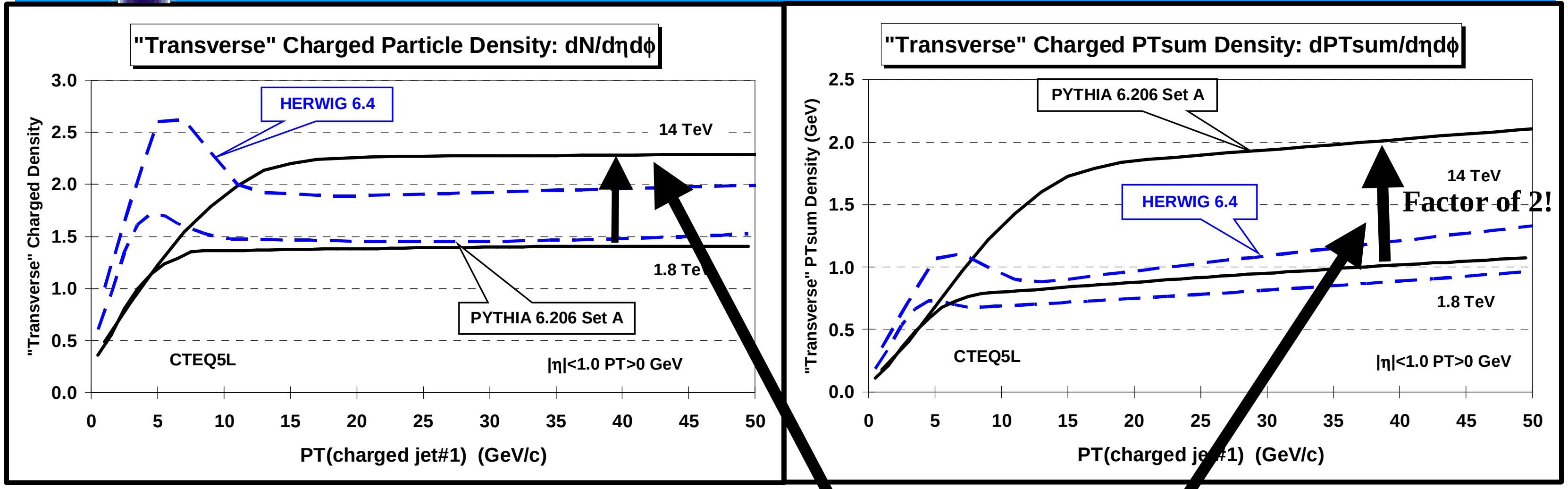
- Shows the **“matched”** JetClu jet E_T versus the transverse momentum of t
  leading **“charged particle jet”** (clo
  jet within R = 0.7 of the leading t).



- Shows the ed”
  JetClu jet
  typical Je jet.

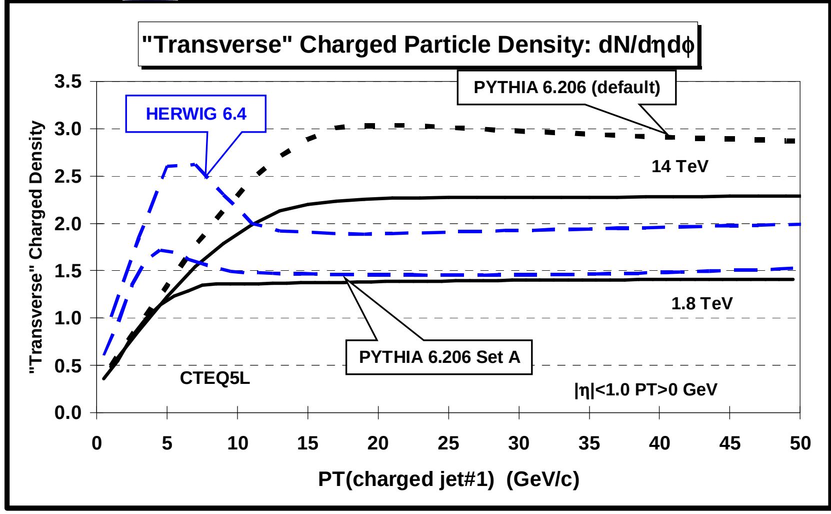
The leading chgjet comes from a JetClu jet that is, on the average, about 90% charged!

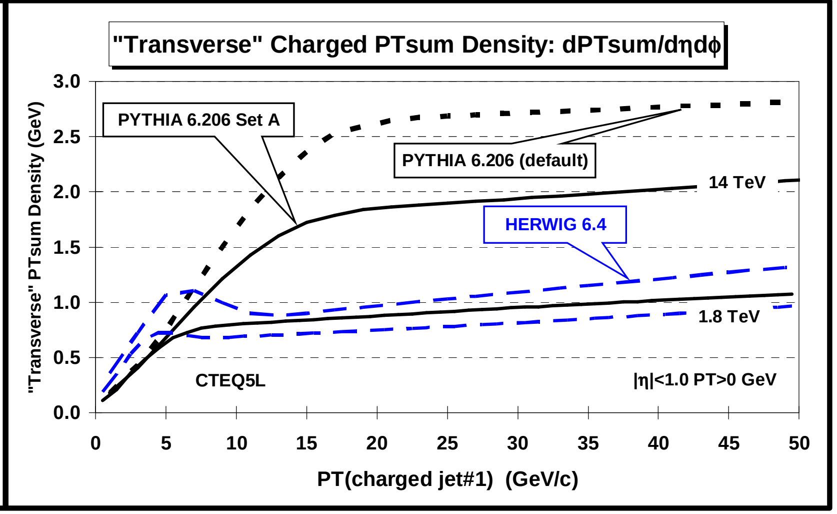
Tuned PYTHIA (Set A) LHC Predictions



- **Shows the average "transverse" charge particle and PT_{sum} density ($|\eta|<1$, $P_T>0$) versus P_T(charged jet#1) predicted by HERWIG 6.4 (P_T(hard) > 3 GeV/c, CTEQ5L). and a tuned versions of PYTHIA 6.206 (P_T(hard) > 0, CTEQ5L, Set A) at 1.8 TeV and 14 TeV.**
- **At 14 TeV tuned PYTHIA (Set A) predicts roughly 2.3 charged particles per unit η-φ (P_T > 0) in the "transverse" region (14 charged particles per unit η) which is larger than the HERWIG prediction.**
- **At 14 TeV tuned PYTHIA (Set A) predicts roughly 2 GeV/c charged PT_{sum} per unit η-φ (P_T > 0) in the "transverse" region at P_T(chgjet#1) = 40 GeV/c which is a factor of 2 larger than at 1.8 TeV and much larger than the HERWIG prediction.**

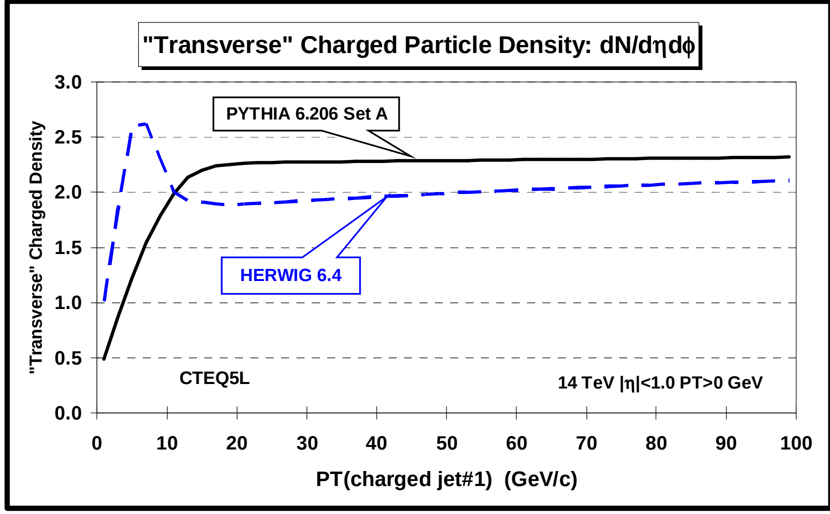
Tuned PYTHIA (Set A) LHC Predictions

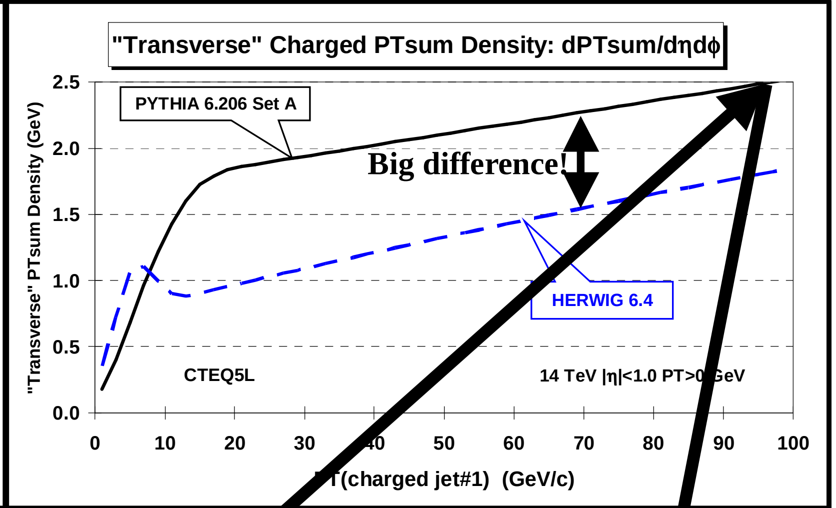




- **Shows the average "transverse" charge particle and PT_{sum} density ($|\eta|<1$, $P_T>0$) versus P_T(charged jet#1) predicted by HERWIG 6.4 (P_T(hard) > 3 GeV/c, CTEQ5L). and a tuned versions of PYTHIA 6.206 (P_T(hard) > 0, CTEQ5L, Set A) at 1.8 TeV and 14 TeV. Also shown is the 14 TeV prediction of PYTHIA 6.206 with the default value ε = 0.16.**
- **Tuned PYTHIA (Set A) predicts roughly 2.3 charged particles per unit η-ϕ ($P_T > 0$) in the "transverse" region (14 charged particles per unit η) which is larger than the HERWIG prediction and much less than the PYTHIA default prediction.**

Tuned PYTHIA (Set A) LHC Predictions

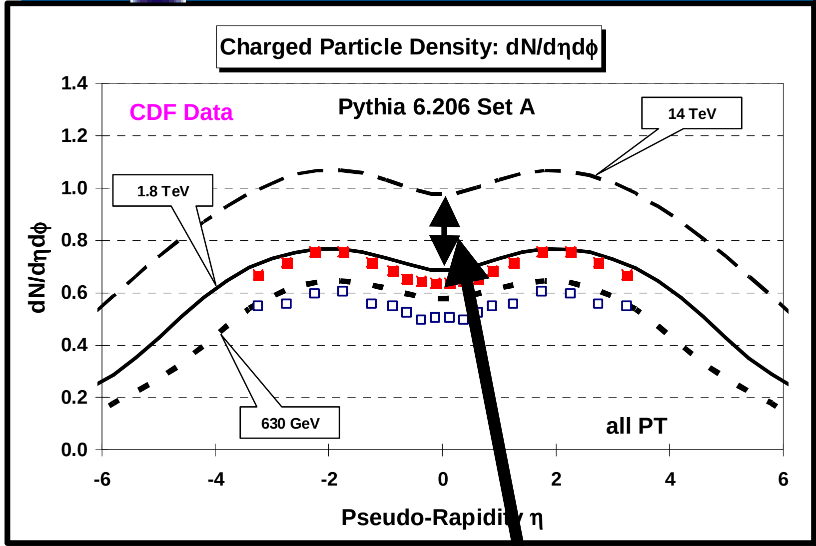


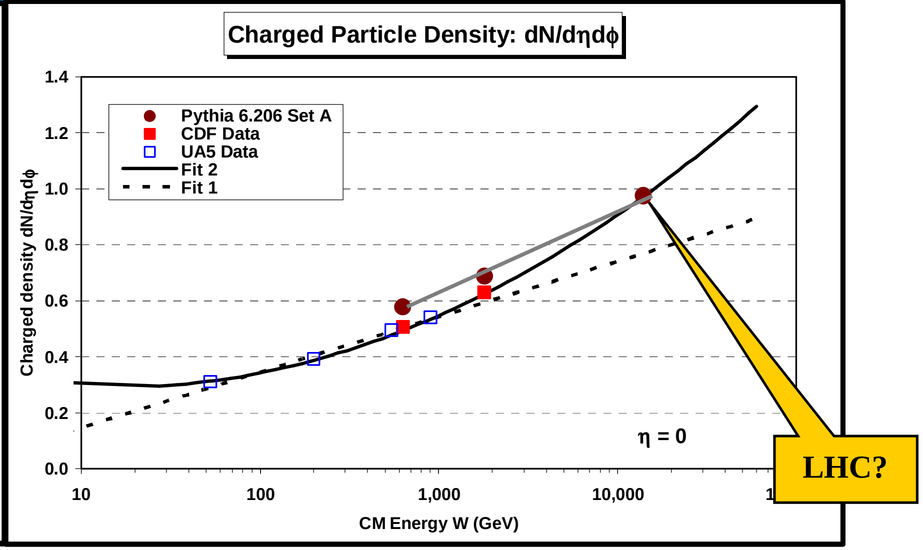


- **Shows the average "transverse" charge particle and PT_{sum} density ($|\eta|<1$, $P_T>0$) versus P_T(charged jet#1) predicted by HERWIG 6.4 (P_T(hard) > 3 GeV/c, CTEQ5L). and a tuned versions of PYTHIA 6.206 (P_T(hard) > 0, CTEQ5L, Set A) at 1.8 TeV and 14 TeV. Also shown is the 14 TeV prediction of PYTHIA 6.206 with the default value ε = 0.16.**
- **Tuned PYTHIA (Set A) predicts roughly 2.5 GeV/c per unit η-φ (P_T > 0) from charged particles in the "transverse" region for P_T(chgjet#1) = 100 GeV/c. Note, however, that the "transverse" charged PT_{sum} density increases rapidly as P_T(chgjet#1) increases.**

3.8 GeV/c (charged) in cone of radius R=0.7 at 14 TeV

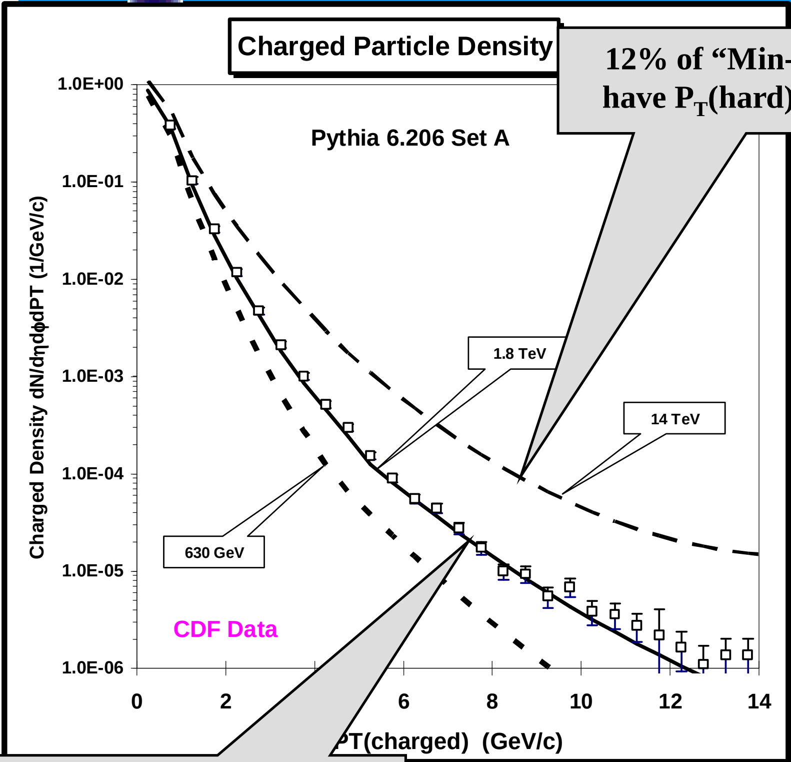
Tuned PYTHIA (Set A) LHC Predictions



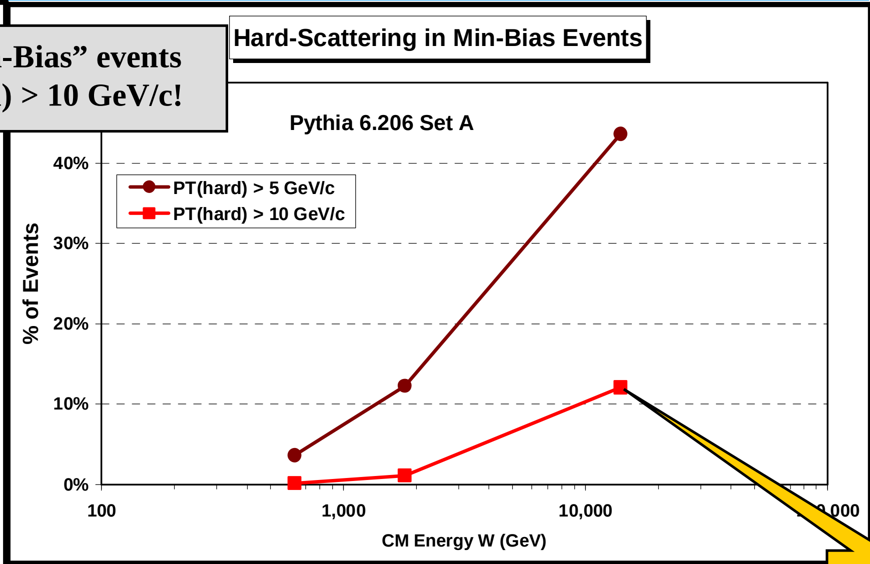


- Shows the center-of-mass energy dependence of the charged particle density, $dN_{chg}/d\eta d\phi$, for "Min-Bias" collisions compared with the a tuned version of PYTHIA 6.206 (Set A) with P_T(hard) > 0.
- PYTHIA was tuned to fit the "underlying event" in hard-scattering processes at 1.8 TeV and 630 GeV.
- PYTHIA (Set A) predicts a 42% rise in $dN_{chg}/d\eta d\phi$ at $\eta = 0$ in going from the Tevatron (1.8 TeV) to the LHC (14 TeV).

Tuned PYTHIA (Set A) LHC Predictions



12% of "Min-Bias" events have P_T(hard) > 10 GeV/c!

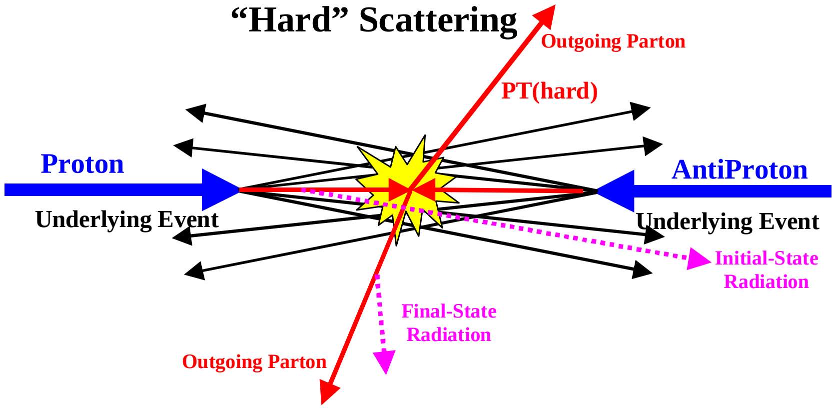


LHC?

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

- **Shows the center-of-mass energy dependence of the charged particle density, $dN_{chg}/d\eta d\phi dP_T$, for "Min-Bias" collisions compared with the a tuned version of PYTHIA 6.206 (Set A) with P_T(hard) > 0.**
- **This PYTHIA fit predicts that 1% of all "Min-Bias" events at 1.8 TeV are a result of a hard 2-to-2 parton-parton scattering with P_T(hard) > 10 GeV/c which increases to 12% at 14 TeV!**

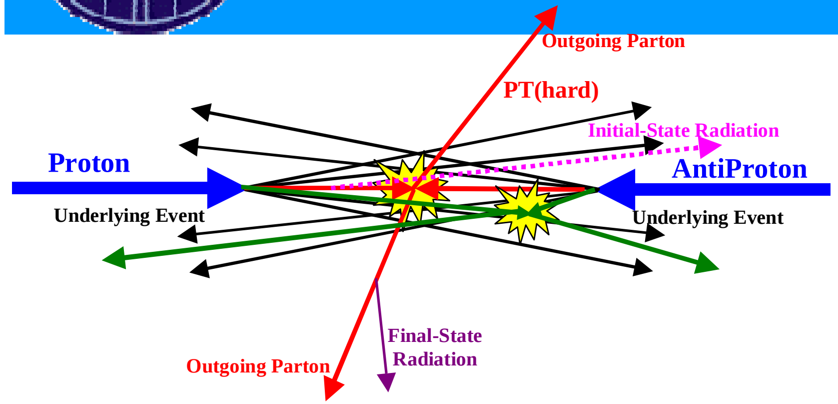
Summary & Conclusions



Initial-State Radiation

- **Systematic errors due to initial-state radiation can be estimated by comparing PYTHIA Tune A (more radiation) and PYTHIA Tune B (less radiation).**
- **But it is also important it always compare PYTHIA and HERWIG!**
- **The best is to compare all three: PYTHIA (Tune A & B) and HERWIG.**

Summary & Conclusions

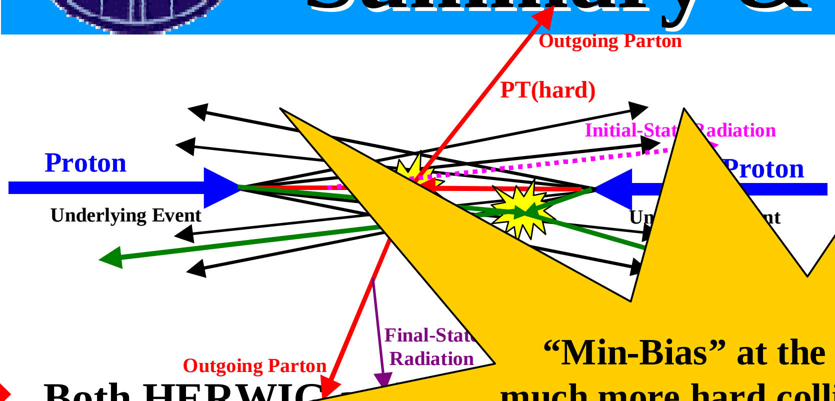


The "Underlying Event"

- **There is excellent agreement between the Run 1 and the Run 2. The "underlying event" is the same in Run 2 as in Run 1 but now we can study the evolution out to much higher energies!**
- **PYTHIA Tune A does a good job of describing the "[...] the Run 2 data as defined by "charged particle jets" and [...] "calorimeter jets". HERWIG Run 2 comparisons will b[...]oming soon!**
- **Lots more CDF Run 2 data to come including MAX/[...]IN "transverse" and MAX/MIN "cones". Also, more to come on the energy in the "underlying event"!**

Also see Mario's Run 2 "energy flow" analysis!

LHC Predictions
Summary & Conclusions



Tevatron ⟶ LHC

"Min-Bias" at the LHC contains much more hard collisions than at the Tevatron! At the Tevatron the "underlying event" is a factor of 2 more active than "Tevaron Min-Bias". At the LHC the "underlying event" will be at least a factor of 2 more active than "LHC Min-Bias"!

12 times more likely to find a 10 GeV "jet" in "Min-Bias" at the LHC!

Twice as much activity in the "underlying event" at the LHC!

- **Both HERWIG ... at η = 0 in going fr... per unit η at the Teva...**
- **The tuned PYTHIA (S... ents at th... (1.8 TeV) are the r... P_T(j... GeV/c which i...**
- **For the "underlying event" ... predictions of H...RWIG and the tuned PYTHIA (Set A) ... (f... 2!). H...WIG predicts a smaller increase in the activity of the "und...ng eve... n going from the Tevatron to the LHC.**
- **The tuned PYTHIA (Set A) predic... bout a factor of two increase at the LHC in the charged PT_{sum} density of the "underlying event" at the same P_T(jet#1) (the "transverse" charged PT_{sum} density increases rapidly as P_T(jet#1) increases).**