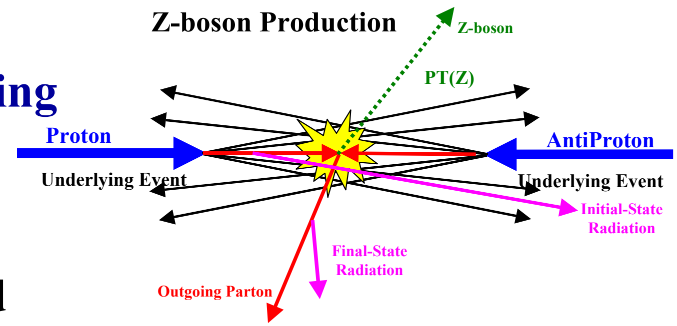
"Min-Bias" and the "Underlying Event" in Run 2 at CDF and the LHC

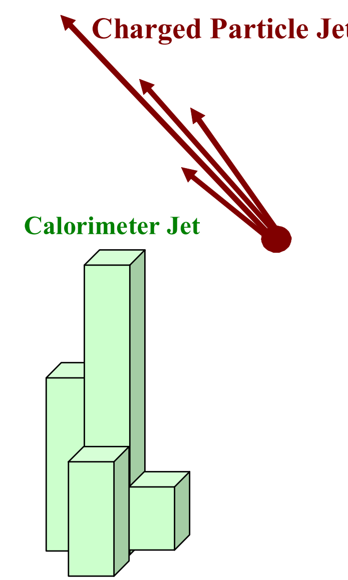
Outline of Talk

- **Discuss briefly the components of the "underlying event" of a hard scattering as described by the QCD parton-shower Monte-Carlo Models.**



- **Review the CDF Run 1 analysis which was used the multiple parton interaction parameters in PYTHIA (*i.e.* Tune A and Tune B).**

- **Study the "underlying event" in CDF Run 2 as defined by the leading calorimeter jet and compare with PYTHIA Tune A (*with MPI*) and HERWIG (*without MPI*).**



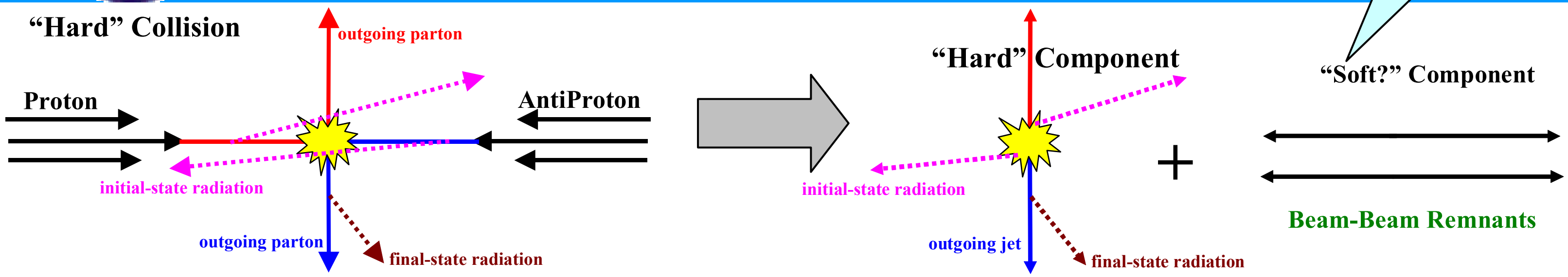
JetClu R = 0.7

- **Discuss the universality of PYTHIA Tune A.**
  Direct Photon Production – Z-boson Production – etc.

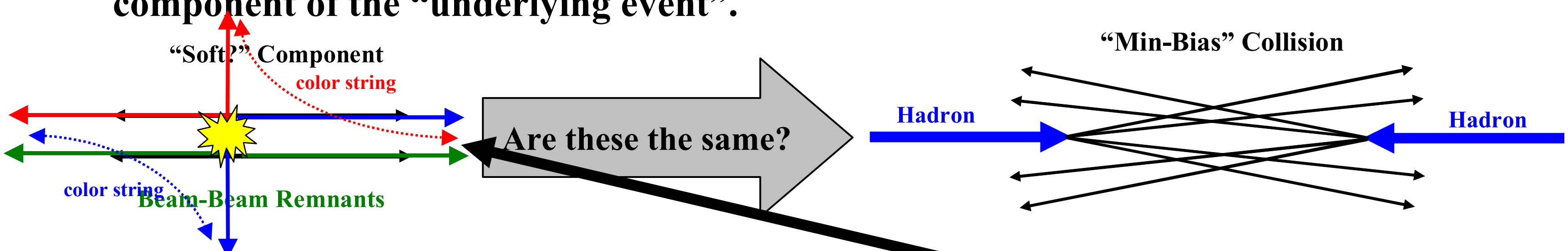
- **Discuss extrapolations of HERWIG and PYTHIA Tune A to the LHC.**

Beam-Beam Remnants

Maybe not all "soft"!

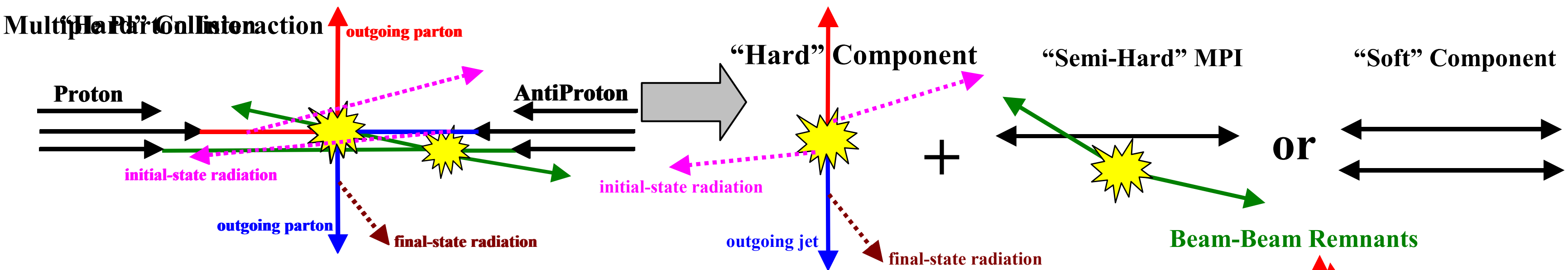


- **The underlying event in a hard scattering process has a "hard" component (particles that arise from initial & final-state radiation and from the outgoing hard scattered partons) and a "soft?" component ("beam-beam remnants").**
- **Clearly? the "underlying event" in a hard scattering process should not look like a "Min-Bias" event because of the "hard" component (*i.e.* initial & final-state radiation).**
- **However, perhaps "Min-Bias" collisions are a good model for the "beam-beam remnant" component of the "underlying event".**

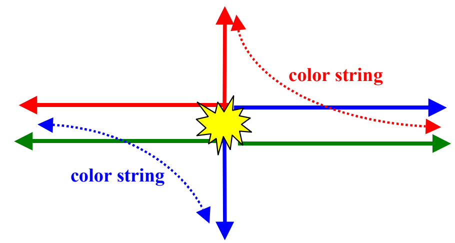


- **The "beam-beam remnant" component is, however, color connected to the "hard" component so this comparison is (at best) an approximation.**

MPI: Multiple Parton Interactions



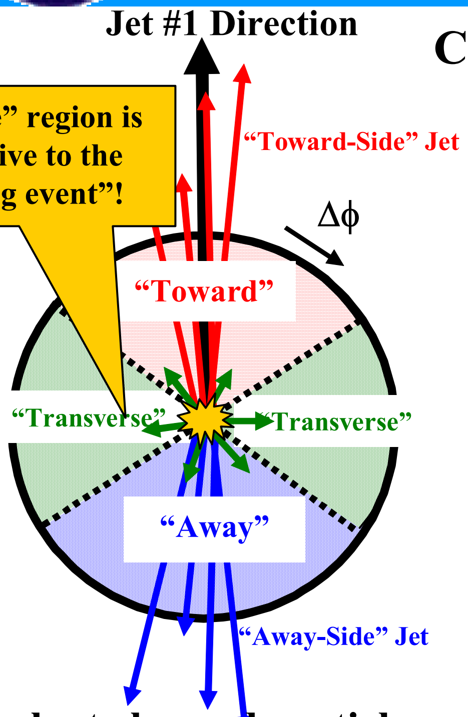
- PYTHIA models the “soft” component of the underlying event with color string fragmentation, but in addition includes a contribution arising from multiple parton interactions (**MPI**) in which one interaction is hard and the other is “semi-hard”.



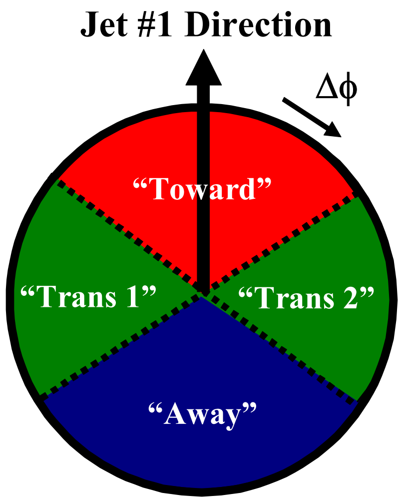
- The probability that a hard scattering events also contains a semi-hard multiple parton interaction can be varied but adjusting the **cut-off for the MPI**.
- One can also adjust whether the probability of a MPI depends on the P_T of the hard scattering, P_T(hard) (**constant cross section or varying 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**).

The "Transverse" Regions as defined by the Leading Jet

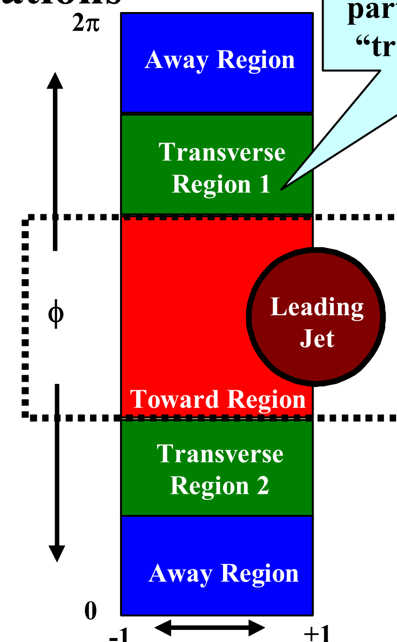
"Transverse" region is very sensitive to the "underlying event"!



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

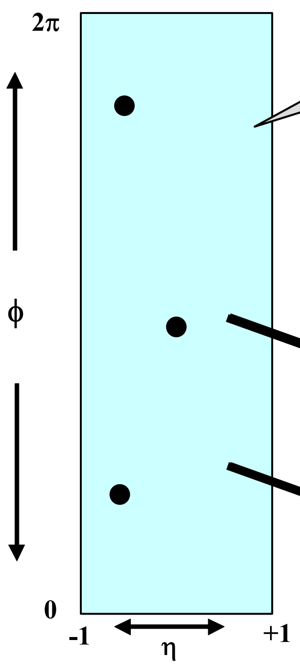


Look at the charged particle density in the "transverse" region!



- Look at charged particle correlations in the azimuthal angle Δφ relative to the leading calorimeter jet (JetClu R = 0.7, |η| < 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 $\Delta\eta\Delta\phi = 2\text{x}60^o = 4\pi/6$. The overall "transverse" region is the sum of the two transverse regions ($\Delta\eta\Delta\phi = 2\text{x}120^o = 4\pi/3$).

Particle Densities



$\Delta\eta\Delta\phi = 4\pi = 12.6$

Charged Particles

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

CDF Run 2 "Min-Bias"

	CDF Run 2 "Min-Bias" Observable	Average	Average Density per unit η-φ
Nchg	Number of Charged Particles ($p_T > 0.5$ GeV/c, $\lvert\eta\rvert < 1$)	3.17 +/- 0.31	0.252 +/- 0.025
PTsum (GeV/c)	Scalar p_T sum of Charged Particles ($p_T > 0.5$ GeV/c, $\lvert\eta\rvert < 1$)	2.97 +/- 0.23	0.236 +/- 0.018

Divide by 4π

3 charged particles

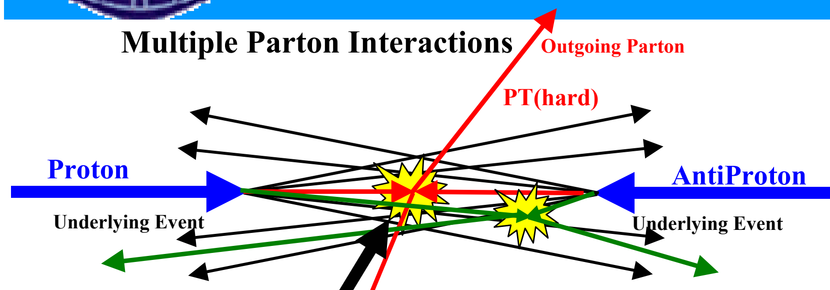
$dNchg/d\eta d\phi = 3/4\pi = 0.24$

3 GeV/c PTsum

$dPTsum/d\eta d\phi = 3/4\pi$ GeV/c = 0.24 GeV/c

- **Study the charged particles ($p_T > 0.5$ GeV/c, $|\eta| < 1$) and form the charged particle density, $dN_{chg}/d\eta d\phi$, and the charged scalar p_T sum density, $dPT_{sum}/d\eta d\phi$.**

PYTHIA: Multiple Parton Interaction Parameters



Pythia uses multiple parton interactions to enhance the underlying event.

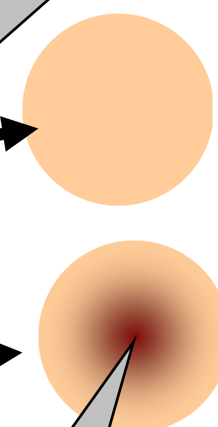
and now HERWIG!

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!

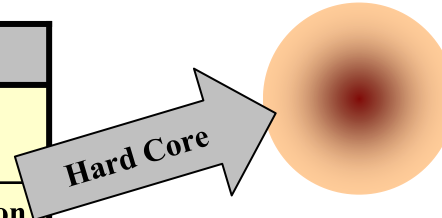


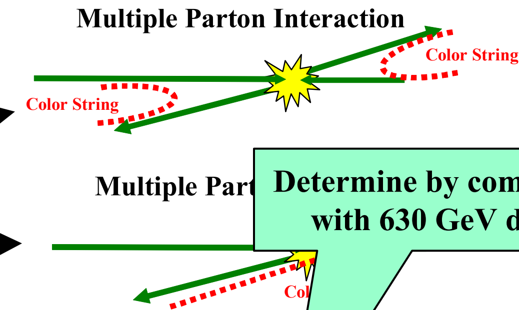
Hard Core

Tuning PYTHIA:
Multiple Parton Interaction Parameters

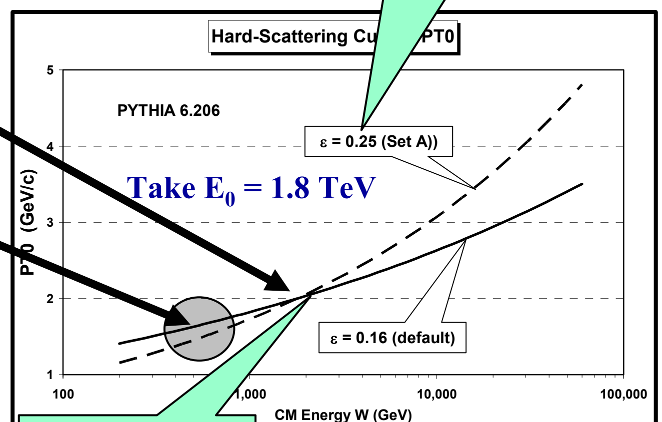
Parameter	Default	Description
PARP(83)	0.5	Double-Gaussian: Fraction of total hadronic matter within PARP(84)
PARP(84)	0.2	Double-Gaussian: Fraction of the overall hadron radius containing the fraction PARP(83) of the total hadronic matter.
PARP(85)	0.33	Probability that the MPI produces two gluons with 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!





Determine by comparing with 630 GeV data!



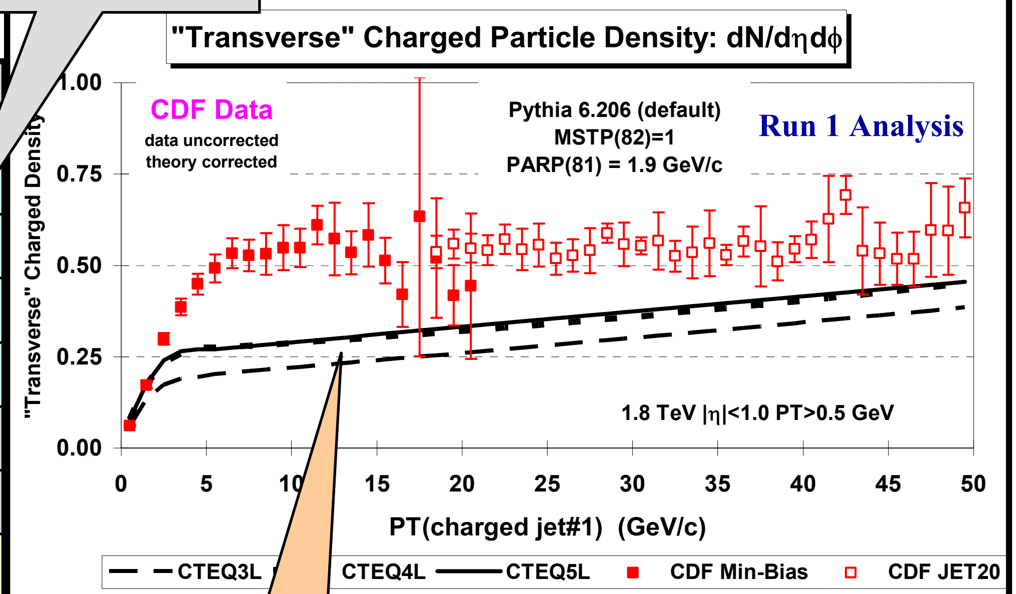
Reference point at 1.8 TeV

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)

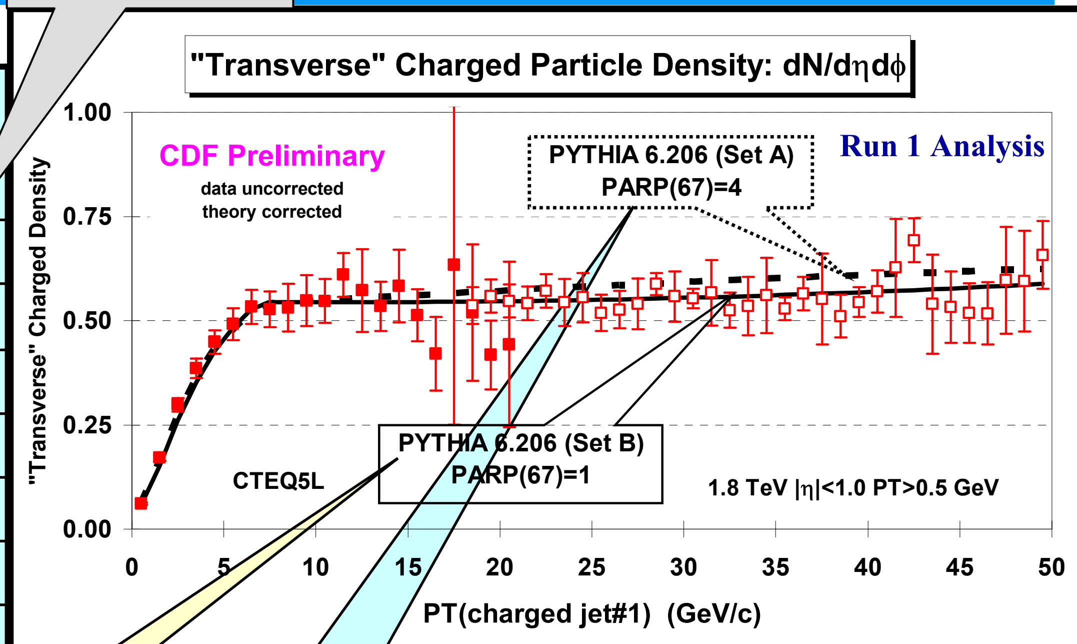
Default parameters give very poor description of the "underlying event"!

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

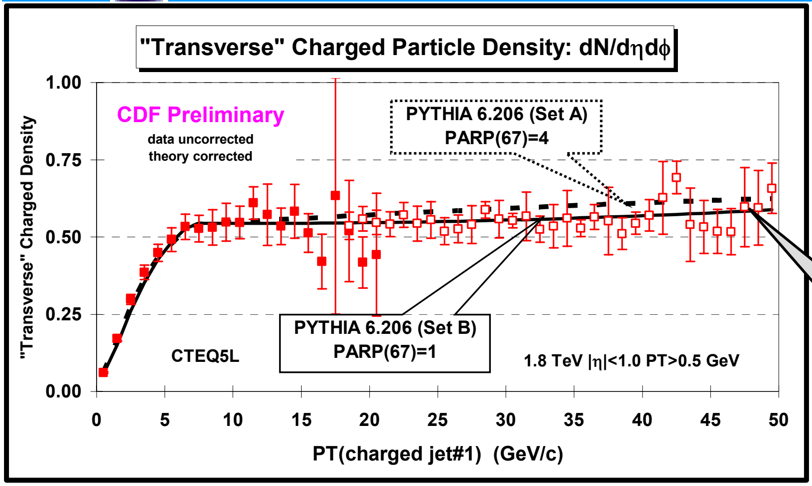


- Plot shows the "Transverse" charged particle density versus P_T(chgjet#1) compared to the QCD hard scattering predictions of two tuned versions of PYTHIA 6.206 (CTEQ5L, Set B (PARP(67)=1) and Set A (PARP(67)=4)).

New PYTHIA default
(less initial-state radiation)

Old PYTHIA default
(more initial-state radiation)

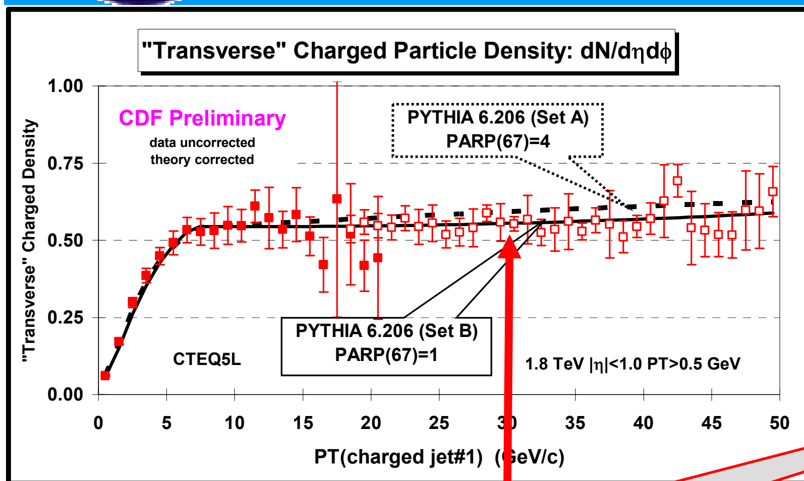
Tuned PYTHIA 6.206 "Transverse" P_T Distribution

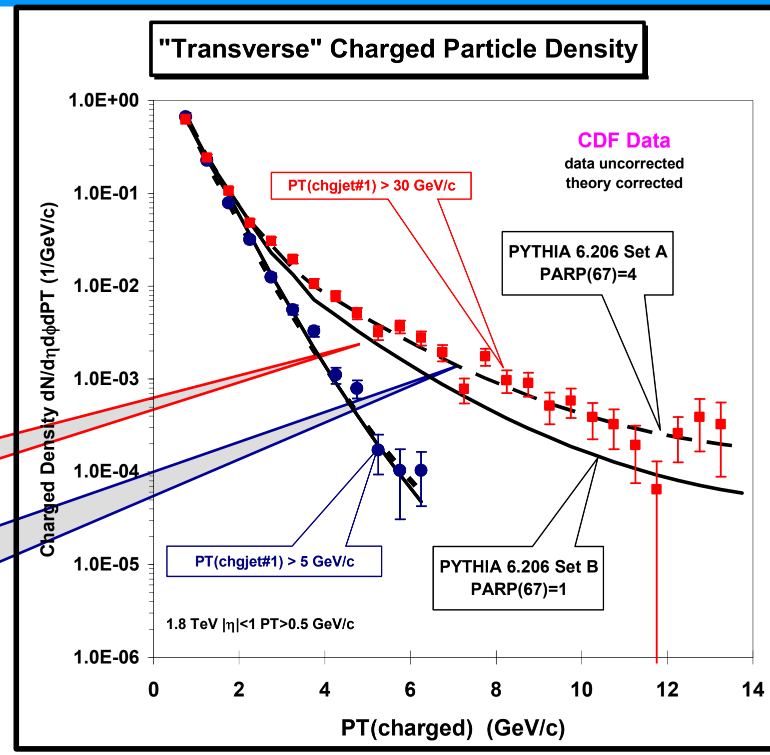


Can we distinguish between PARP(67)=1 and PARP(67)=4? No way! Right!

- 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 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 "Transverse" P_T Distribution



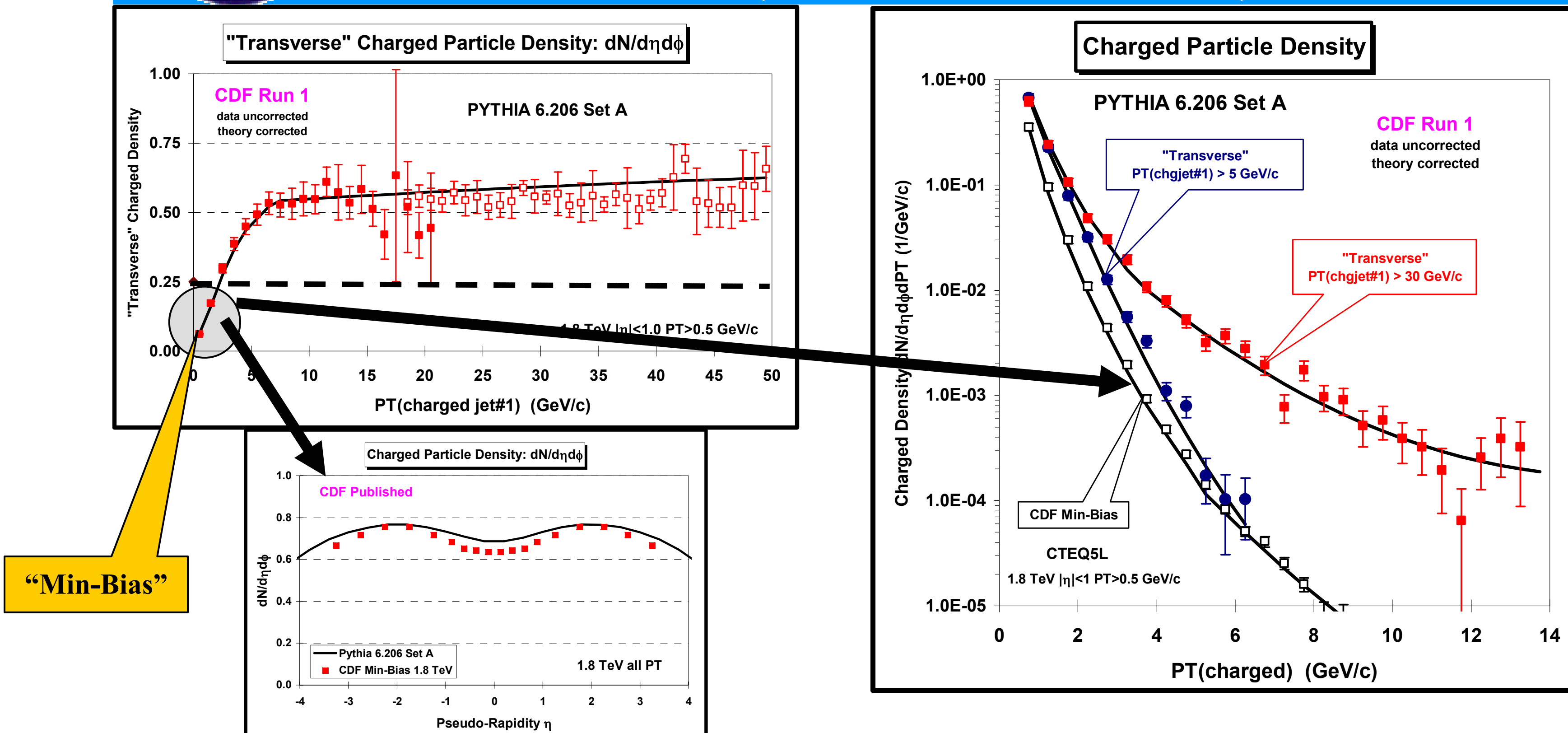


P_T(charged jet#1) > 30 GeV/c

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

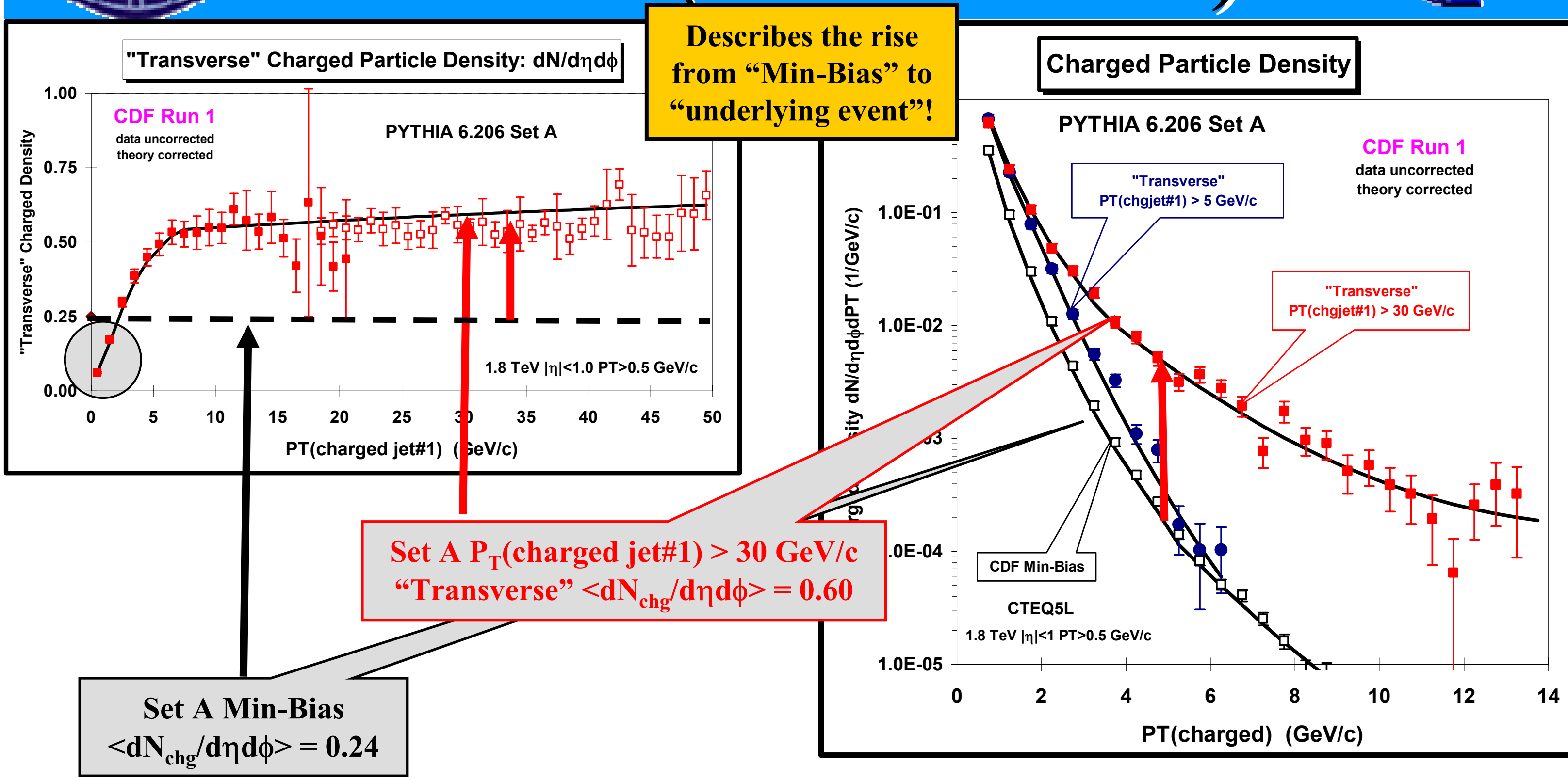
- Compares the average "transverse" charge particle density ($|\eta|<1$, $P_T>0.5$ GeV) versus P_T(charged jet#1) and the P_T distribution of the "transverse" density, $dN_{chg}/d\eta d\phi dP_T$ with the QCD Monte-Carlo predictions of two tuned versions of PYTHIA 6.206 (P_T(hard) > 0, CTEQ5L, Set B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

PYTHIA 6.206
Tune A (CDF 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" 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!**

PYTHIA 6.206
Tune A (CDF Default)



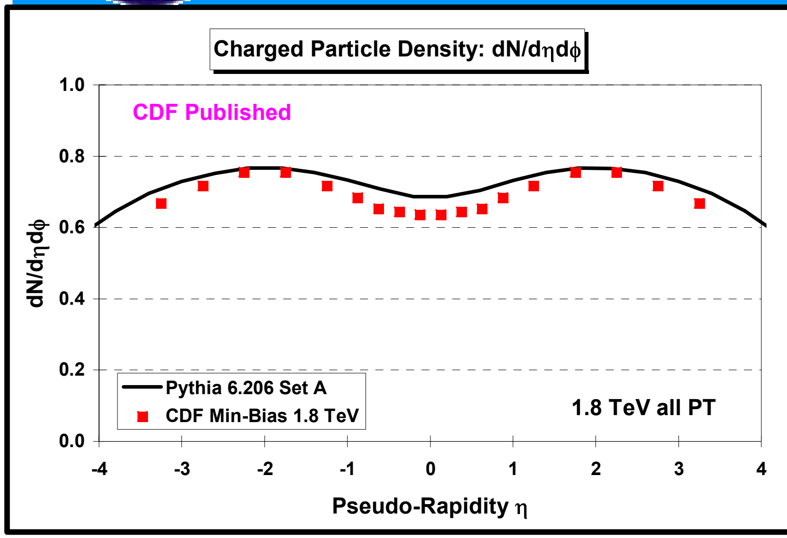
- **Compares the average "transverse" charge particle density ($|\eta|<1$, $P_T>0.5$ GeV) versus P_T(charged jet#1) and the P_T distribution of the "transverse" and "Min-Bias" densities with the QCD Monte-Carlo predictions of a tuned version of PYTHIA 6.206 (P_T(hard) > 0, CTEQ5L, Set A). Describes "Min-Bias"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

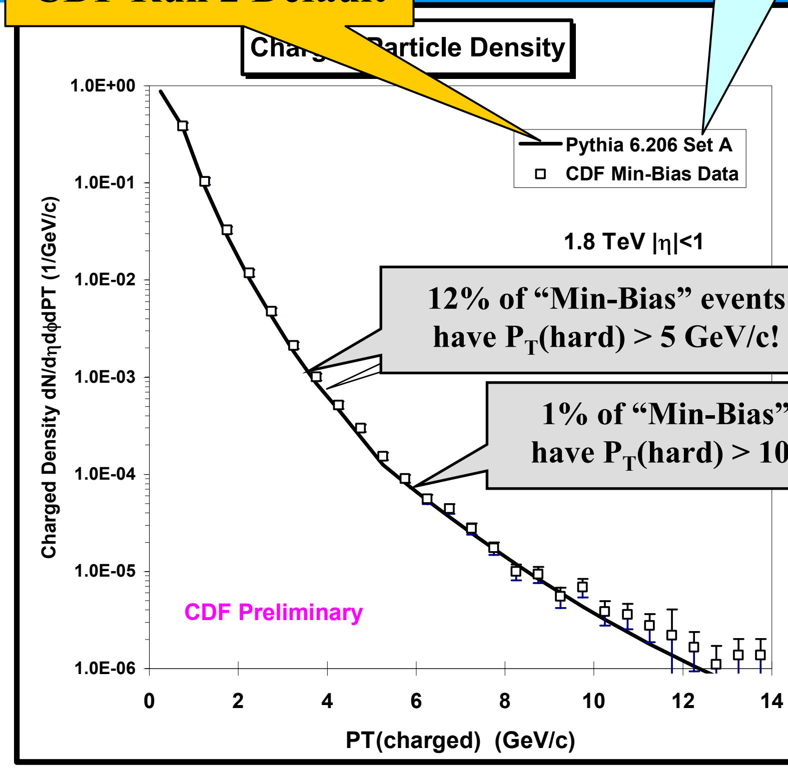
PYTHIA Min-Bias

“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!

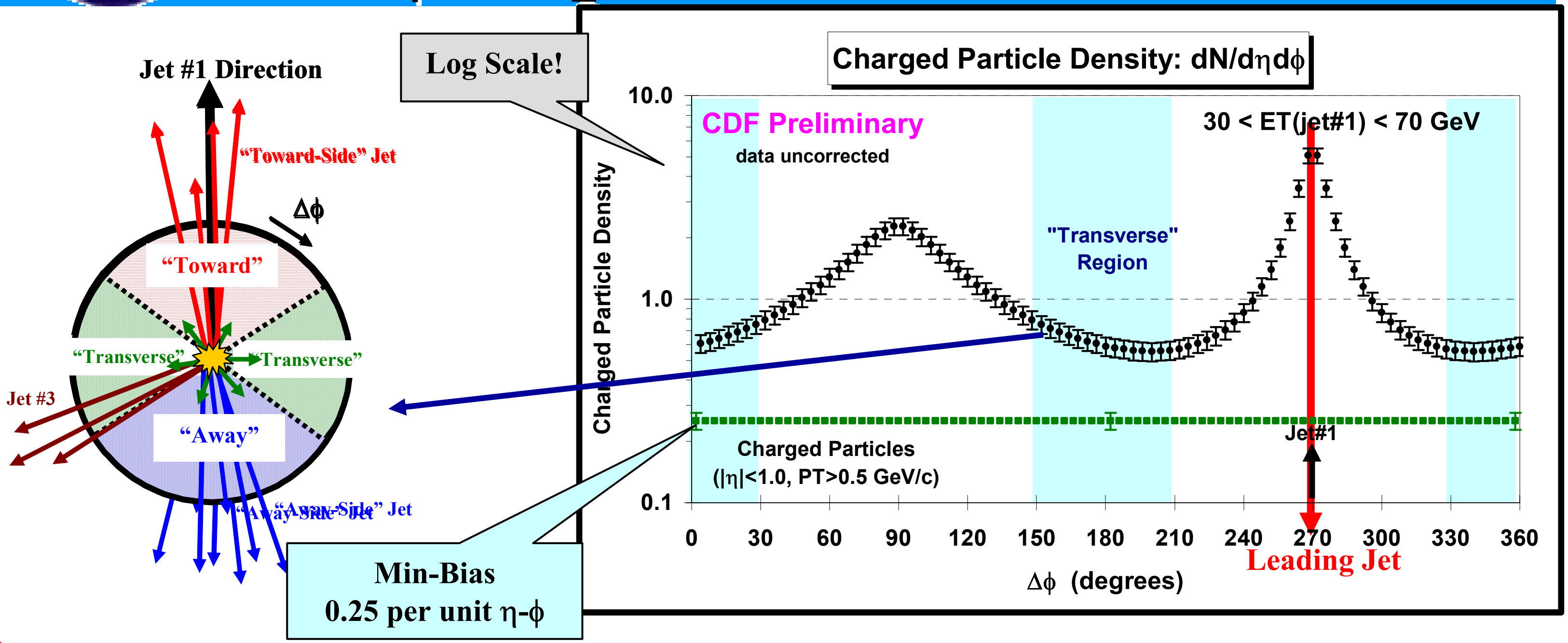
1% of “Min-Bias” events have P_T(hard) > 10 GeV/c!

- 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.

Lots of “hard” scattering in “Min-Bias”!

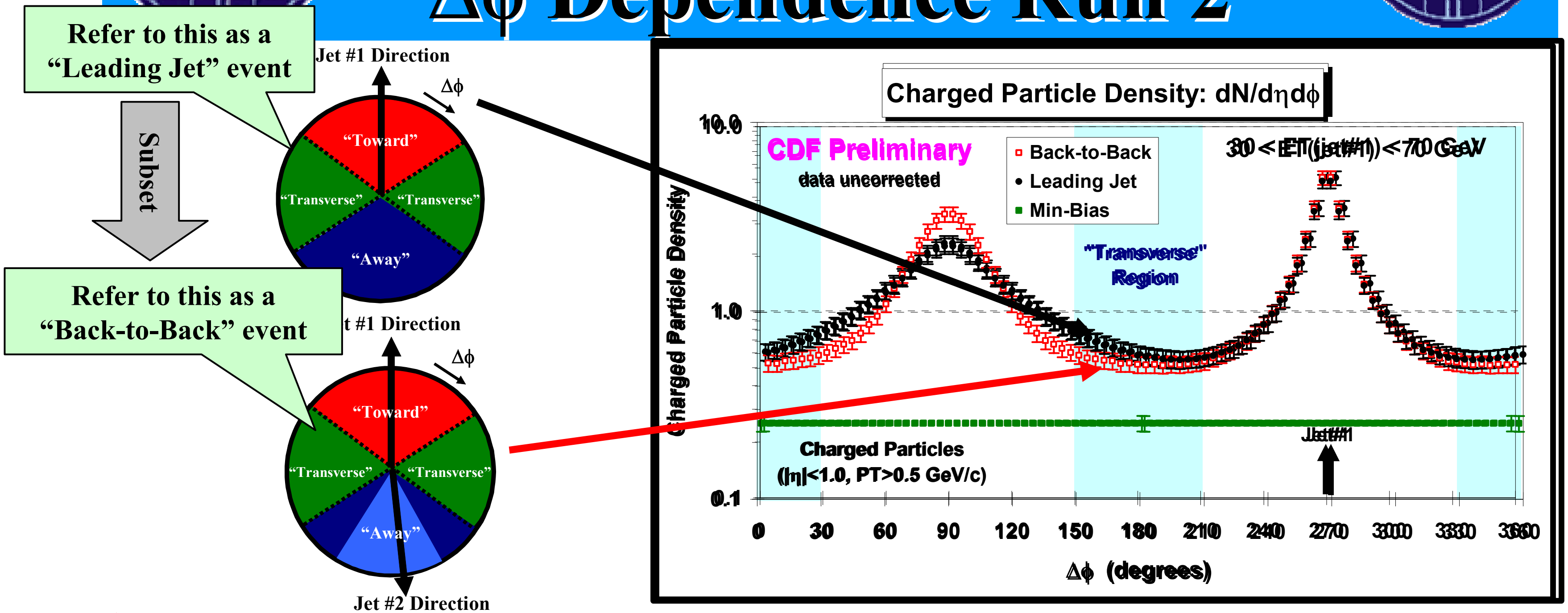
- The relative amount of “hard” versus “soft” depends on the cut-off and can be tuned.
- This PYTHIA fit predicts that 12% of all “Min-Bias” events are a result of a hard 2-to-2 parton-parton scattering with P_T(hard) > 5 GeV/c (1% with P_T(hard) > 10 GeV/c)!

Charged Particle Density Δφ Dependence Run 2



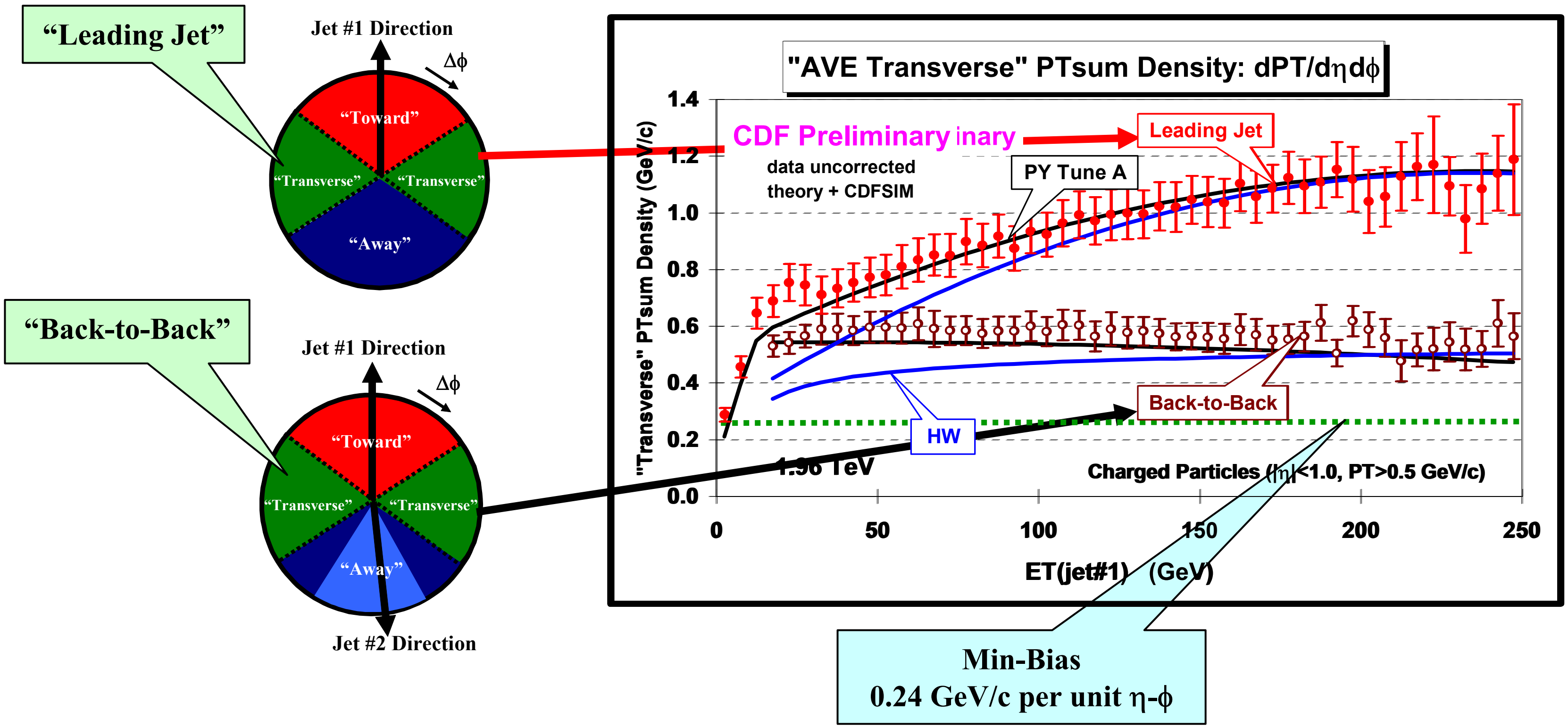
- Shows the **Δφ dependence of the charged particle density**, $dN_{chg}/d\eta d\phi$, for charged particles in the range $p_T > 0.5$ GeV/c and $|\eta| < 1$ relative to jet#1 (rotated to 270°) for **"leading jet"** events $30 < E_T(\text{jet\#1}) < 70$ GeV.
- Also shows charged particle density, $dN_{chg}/d\eta d\phi$, for charged particles in the range $p_T > 0.5$ GeV/c and $|\eta| < 1$ for **"min-bias"** collisions.

Charged Particle Density $\Delta\phi$ Dependence Run 2



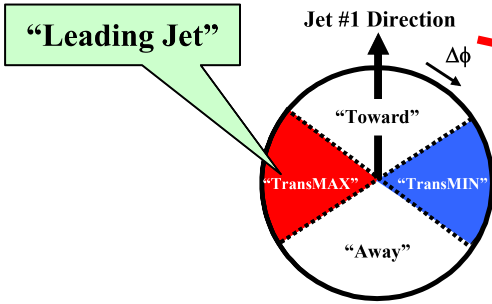
- Look at the "transverse" region as defined by the leading jet (JetClu R = 0.7, $|\eta| < 2$) or by the leading two jets (JetClu R = 0.7, $|\eta| < 2$). "Back-to-Back" events are selected to have at least two jets with Jet#1 and Jet#2 nearly "back-to-back" ($\Delta\phi_{12} > 150^o$) with almost equal transverse energies (E_T(jet#2)/E_T(jet#1) > 0.8).
- Shows the $\Delta\phi$ 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.

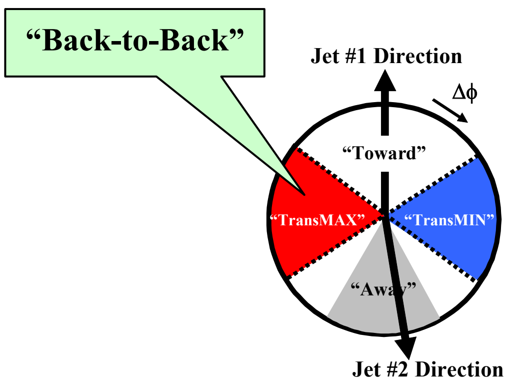
"Transverse" PTsum Density versus E_T(jet#1) Run 2

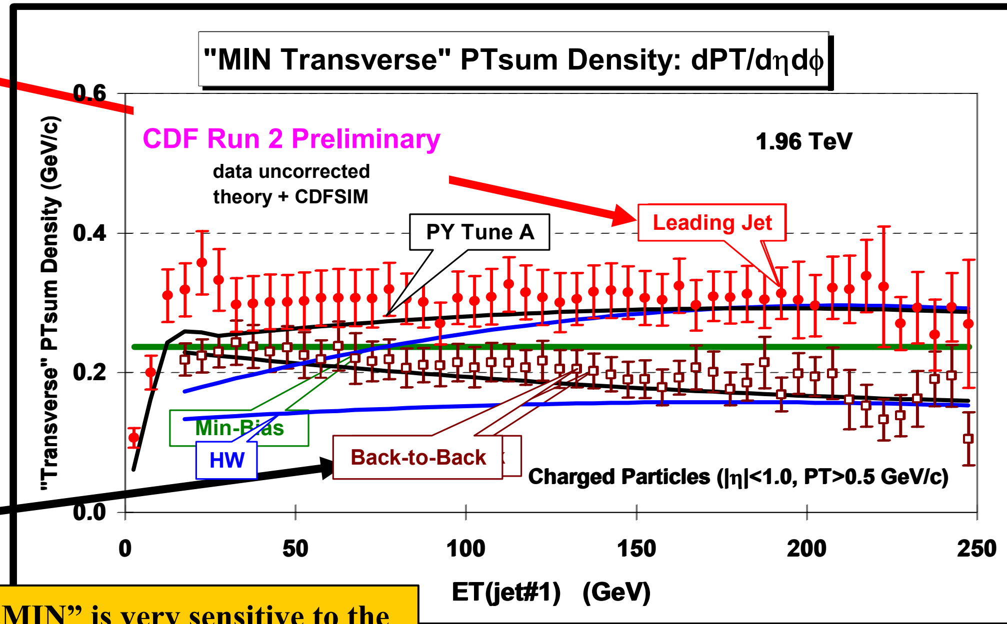


- Shows the **average charged PTsum density**, $dPT_{sum}/d\eta d\phi$, in the **"transverse" region** ($p_T > 0.5$ GeV/c, $|\eta| < 1$) versus E_T(jet#1) for **"Leading Jet"** and **"Back-to-Back"** events.
- Compares the (*uncorrected*) data with **PYTHIA Tune A** and **HERWIG** after CDFSIM.

"TransMIN" PTsum Density versus E_T(jet#1)



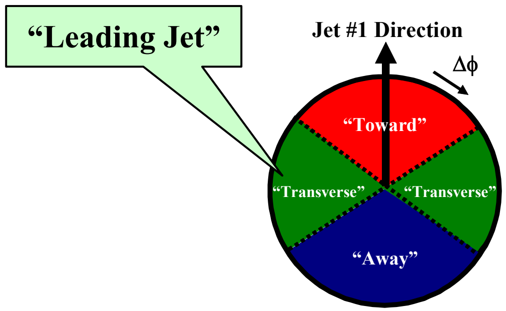


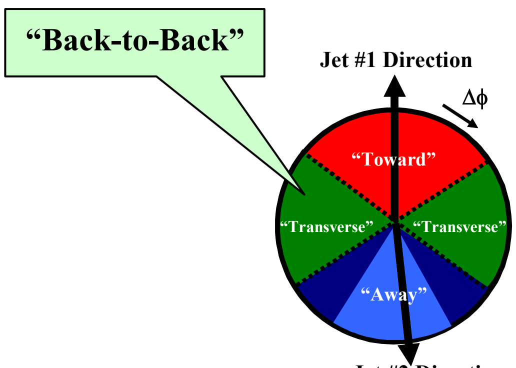


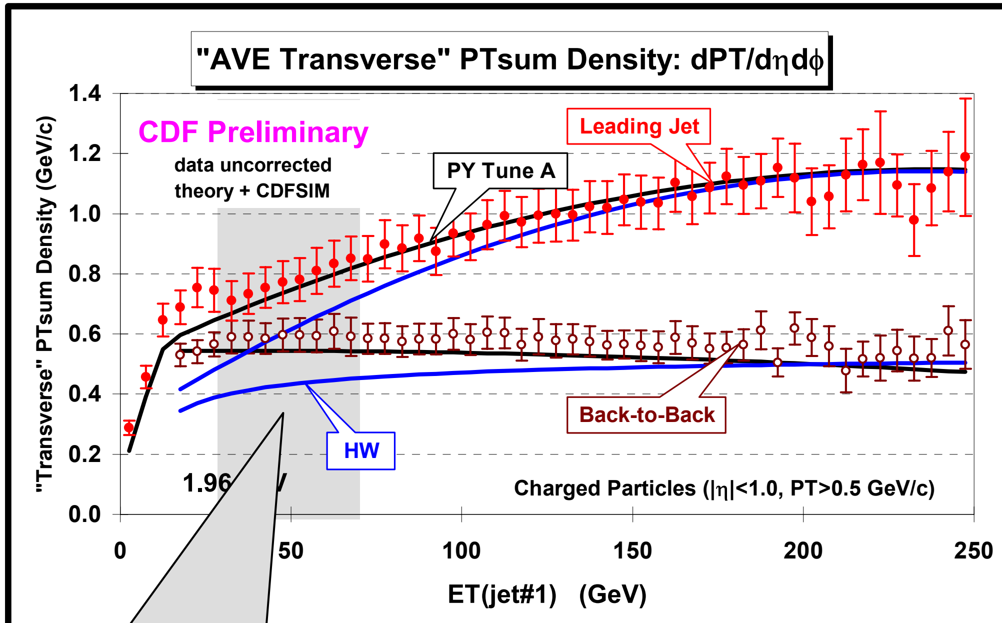
"transMIN" is very sensitive to the "beam-beam remnant" component of the "underlying event"!

- Use the leading jet to define the MAX and MIN "transverse" regions on an event-by-event basis with MAX (MIN) having the largest (smallest) charged particle density.
- Shows the "transMIN" charge particle density, $dN_{chg}/d\eta d\phi$, for $p_T > 0.5$ GeV/c, $|\eta| < 1$ versus E_T(jet#1) for "Leading Jet" and "Back-to-Back" events.

"Transverse" PTsum Density PYTHIA Tune A vs HERWIG





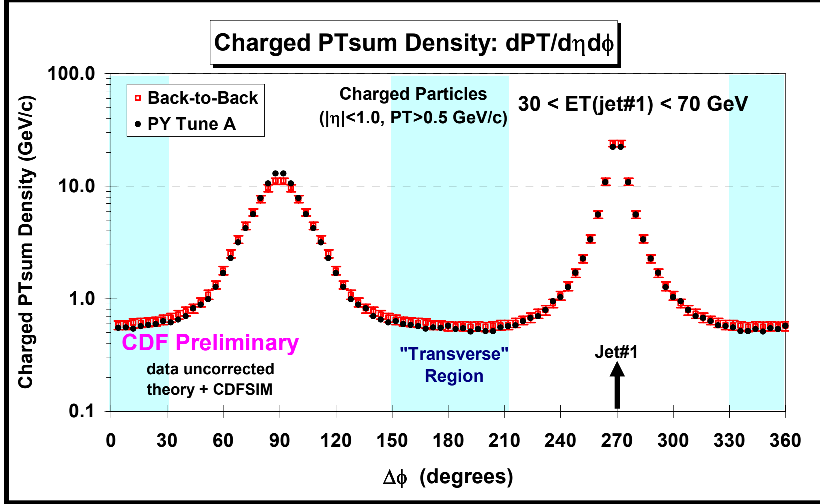


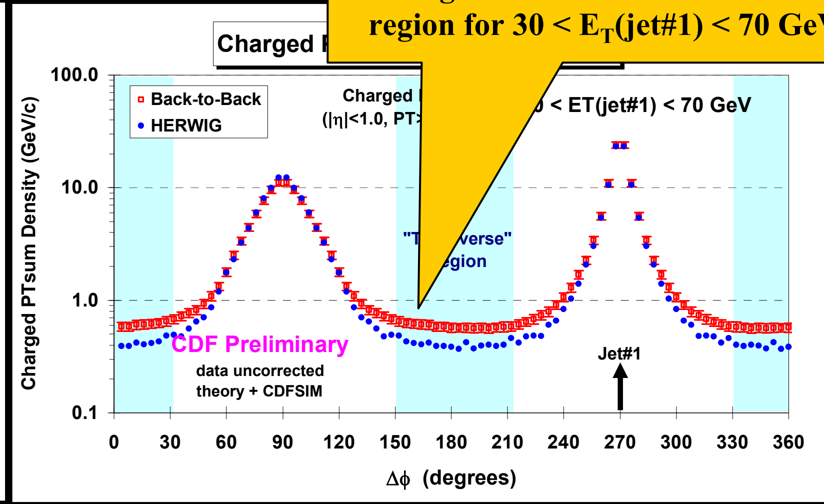
Now look in detail at "back-to-back" events in the region $30 < E_T(\text{jet\#1}) < 70$ GeV!

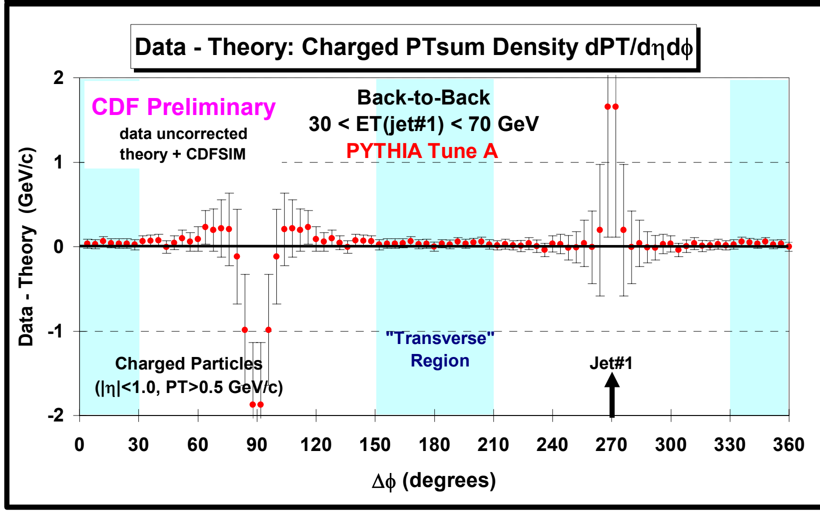
- Shows the **average charged PTsum density**, $dPT_{sum}/d\eta d\phi$, in the **"transverse" region** ($p_T > 0.5$ GeV/c, $|\eta| < 1$) versus E_T(jet#1) for **"Leading Jet"** and **"Back-to-Back"** events.
- Compares the (*uncorrected*) data with **PYTHIA Tune A** and **HERWIG** after CDFSIM.

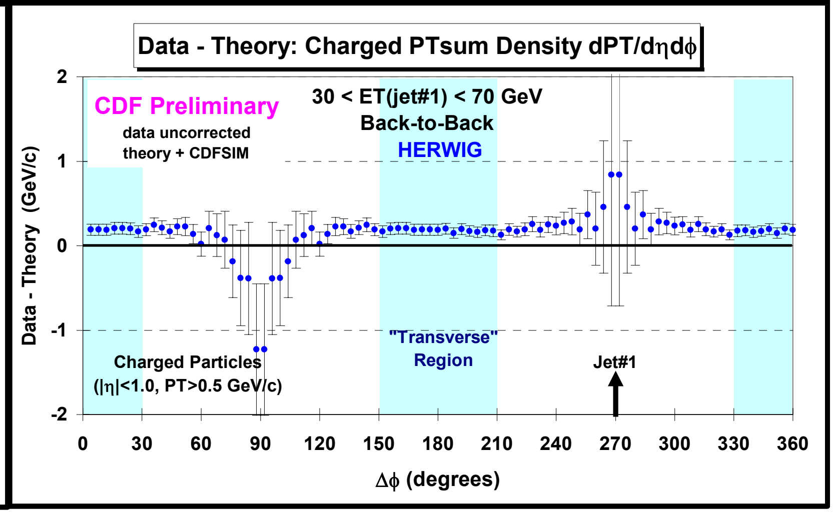
Charged PTsum Density PYTHIA Tune A vs HERWIG

HERWIG (*without multiple parton interactions*) does not produces enough PTsum in the "transverse" region for 30 < E_T(jet#1) < 70 GeV!

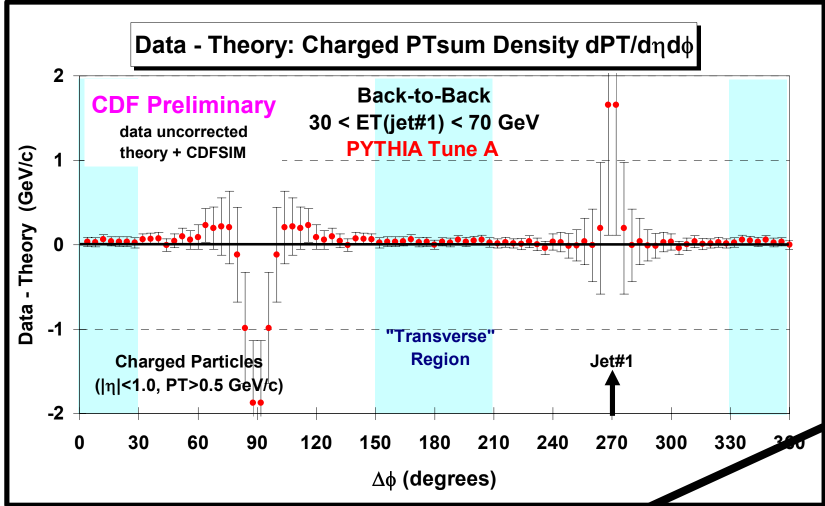


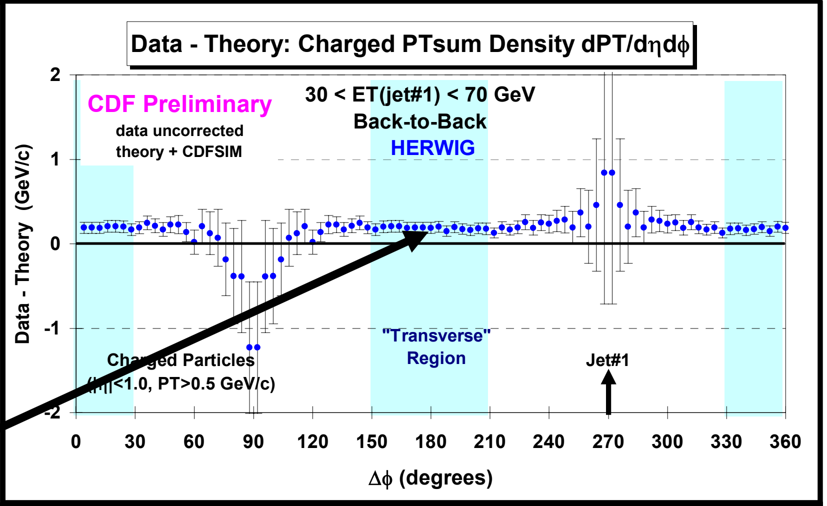


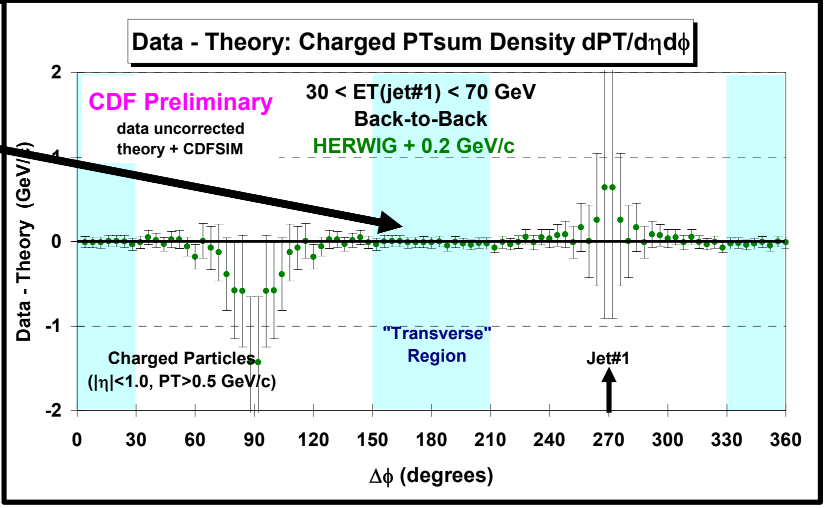




Charged PTsum Density
PYTHIA Tune A vs HERWIG





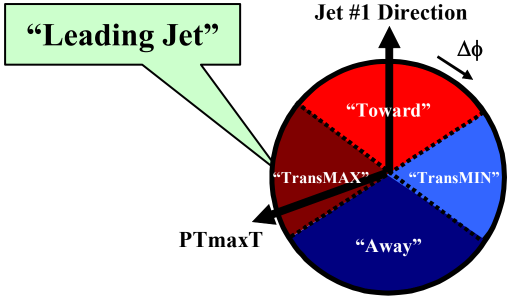


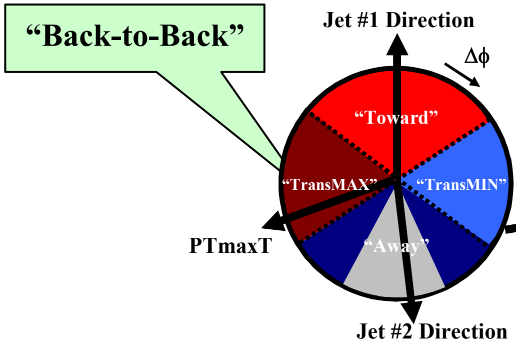
dPT/dηdφ + 0.2 GeV/c

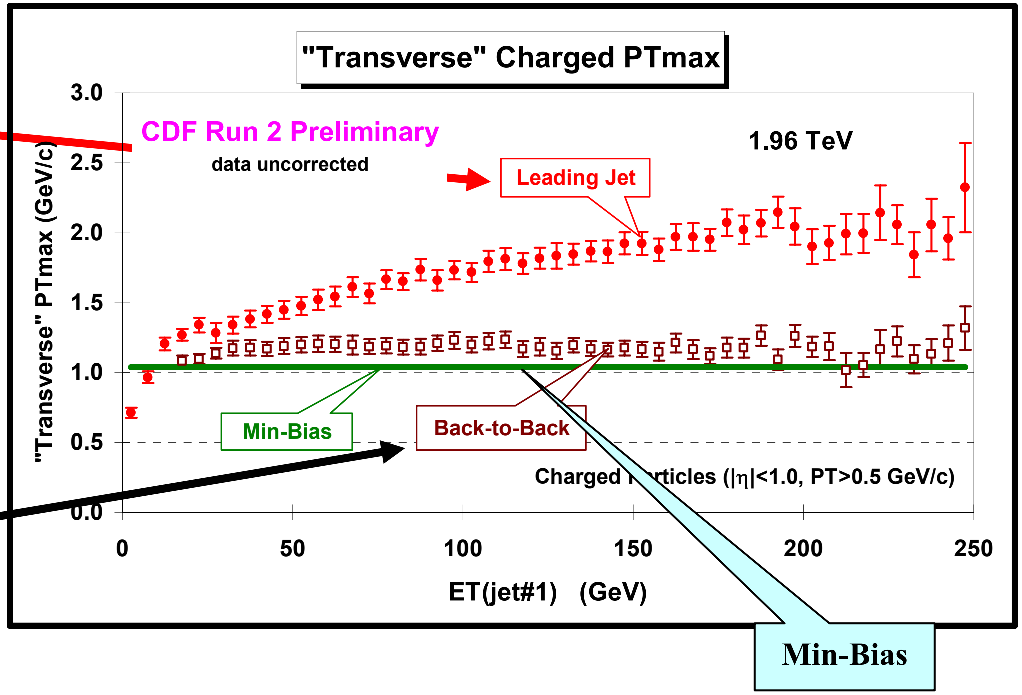
308 MeV in R = 0.7 cone!

- Add 0.2 GeV/c per unit η-φ to HERWIG scalar PTsum density, $dPT_{sum}/d\eta d\phi$.
- This corresponds to $0.2 \times 4\pi$ = 2.5 GeV/c in the entire range $p_T > 0.5$ GeV/c, $|\eta| < 1$.

"Transverse" PTmax versus E_T(jet#1)



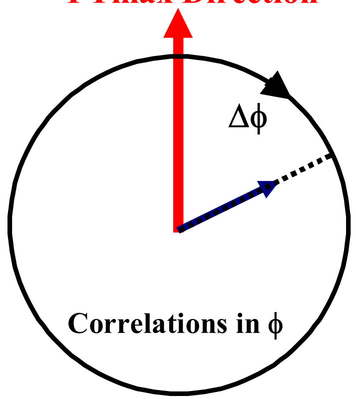




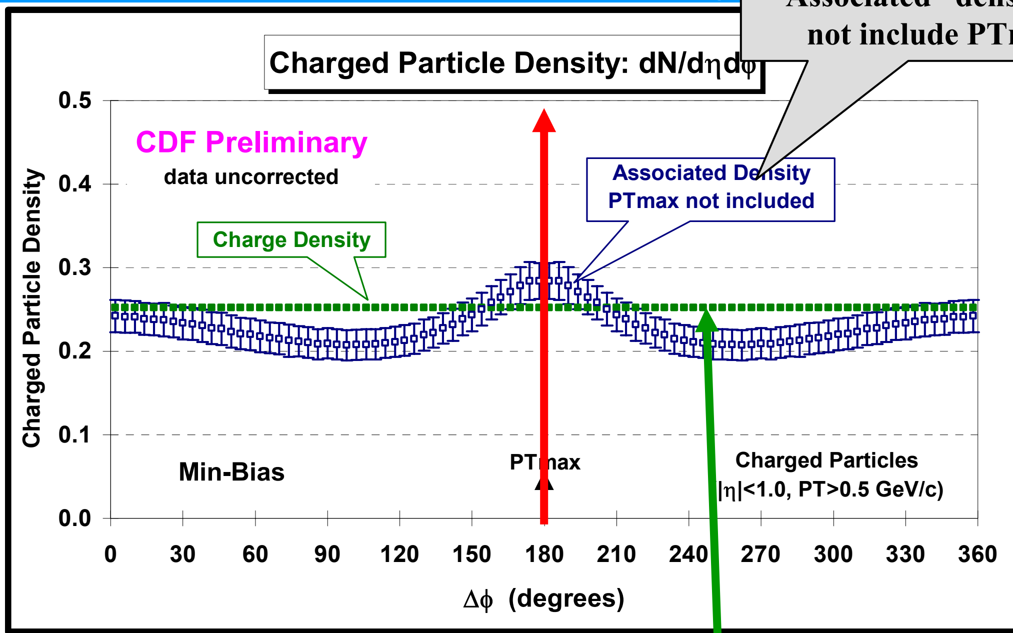
- Use the leading jet to define the "transverse" region and look at the **maximum p_T charged particle in the "transverse" region, PTmaxT.**
- Shows the **average PTmaxT, in the "transverse" region** ($p_T > 0.5$ GeV/c, $|\eta| < 1$) versus E_T(jet#1) for **"Leading Jet"** and **"Back-to-Back"** events compared with the **average maximum p_T particle, PTmax, in "min-bias"** collisions ($p_T > 0.5$ GeV/c, $|\eta| < 1$).

Min-Bias "Associated" Charged Particle Density

Highest p_T charged particle!

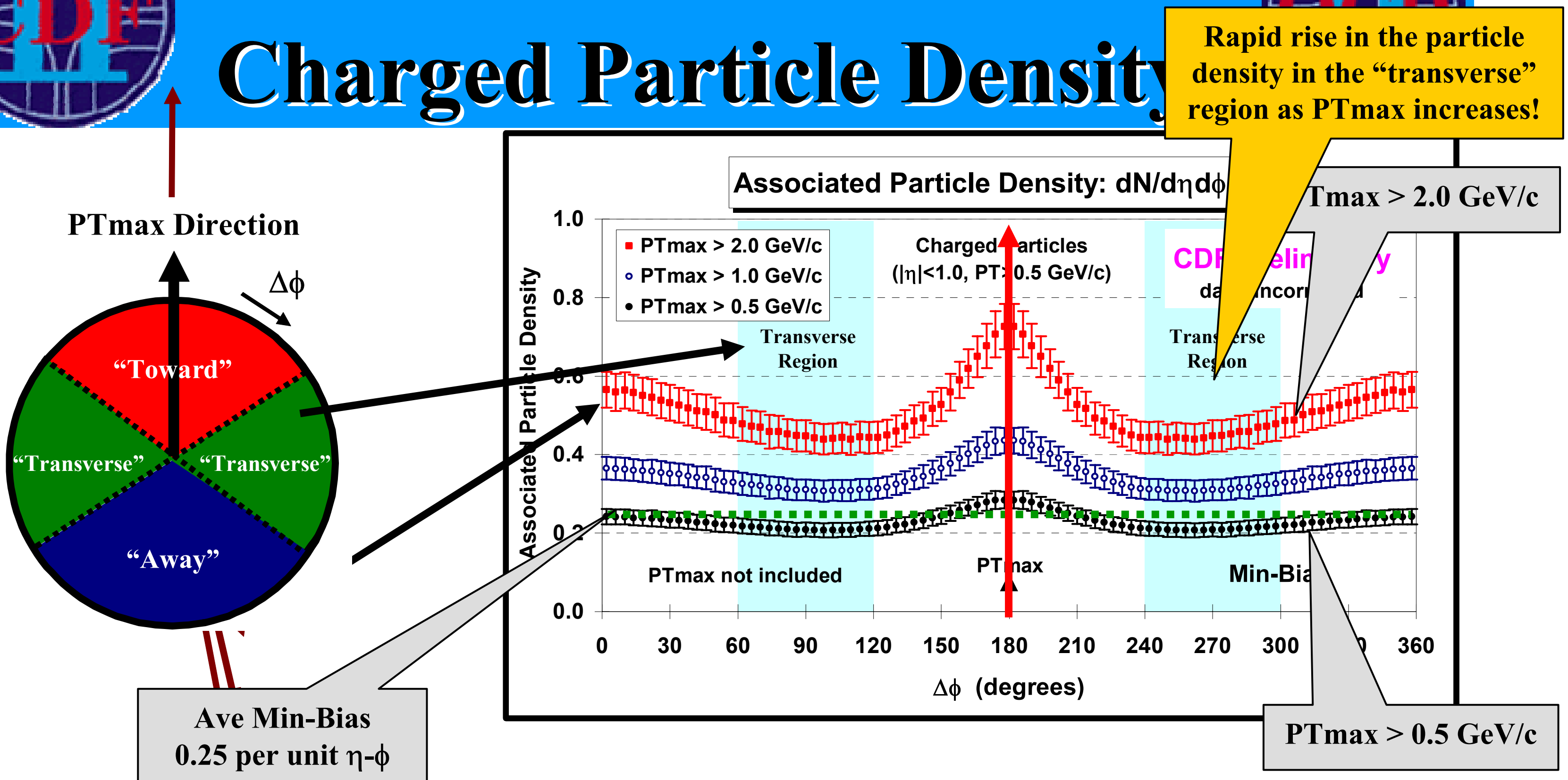


"Associated" densities do not include PTmax!



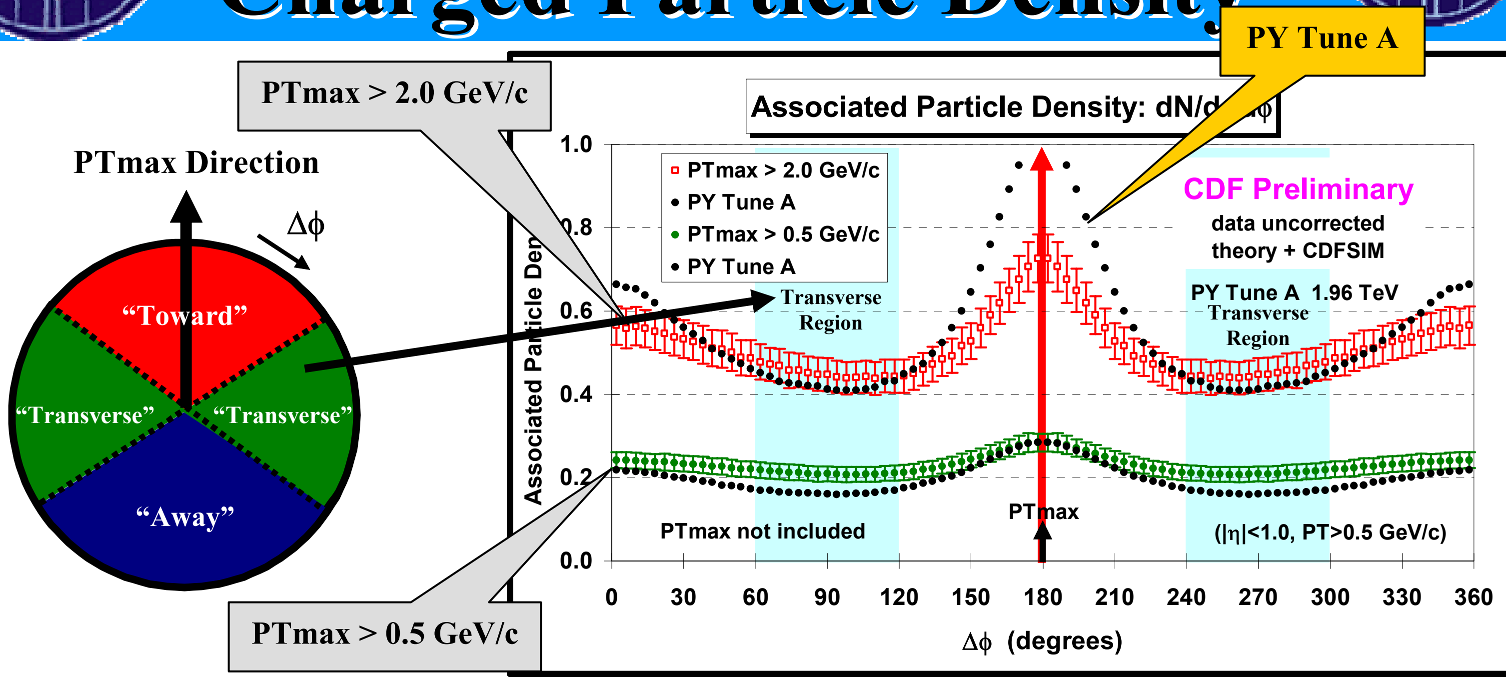
- Use the **maximum p_T charged particle in the event, PTmax**, to define a direction and look at the the "associated" density, $dN_{chg}/d\eta d\phi$, in **"min-bias" collisions** ($p_T > 0.5$ GeV/c, $|\eta| < 1$).
- Shows the data on the **Δϕ dependence of the "associated" charged particle density**, $dN_{chg}/d\eta d\phi$, for charged particles ($p_T > 0.5$ GeV/c, $|\eta| < 1$, *not including PTmax*) relative to PTmax (rotated to 180°) for **"min-bias" events**. **Also shown is the average charged particle density, $dN_{chg}/d\eta d\phi$, for "min-bias" events.**

Min-Bias "Associated" Charged Particle Density



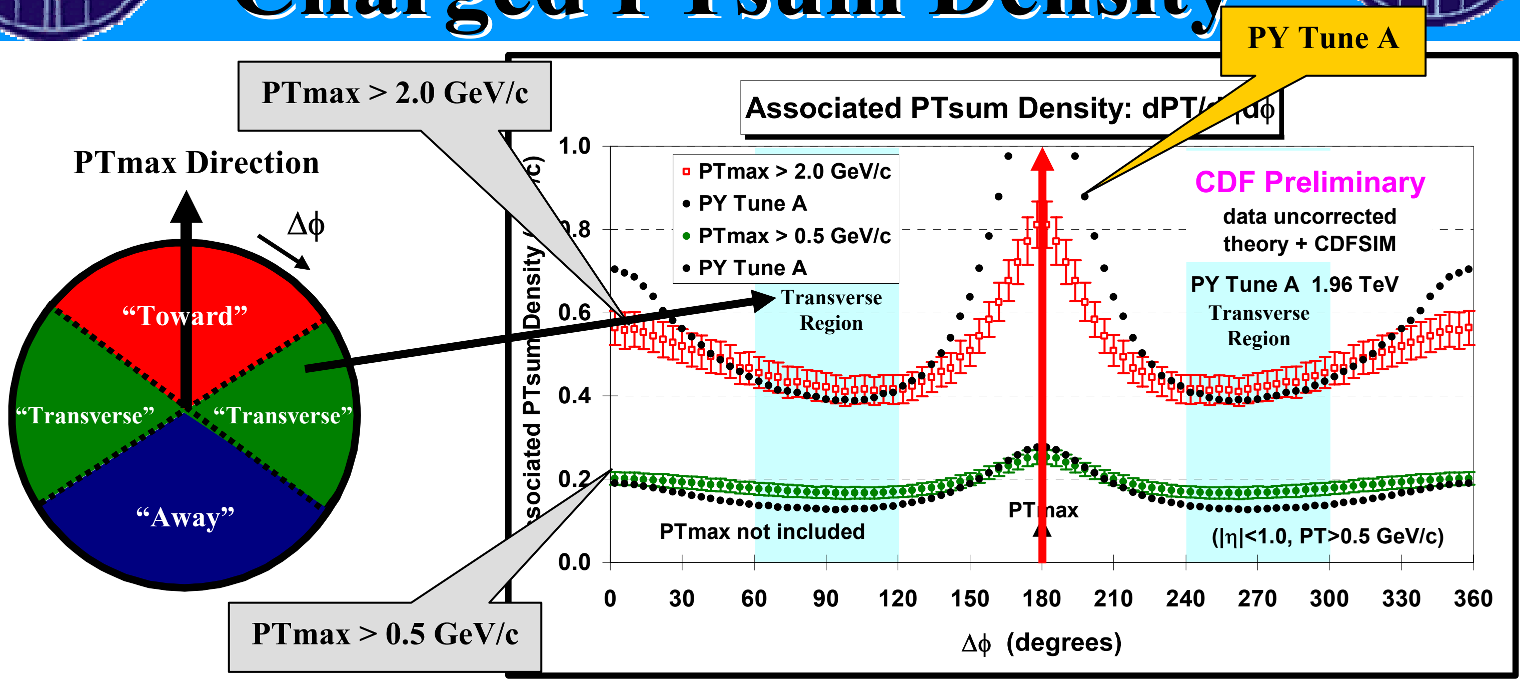
- Shows the data on the **Δφ dependence of the "associated" charged particle density**, $dN_{chg}/d\eta d\phi$, for charged particles (p_T > 0.5 GeV/c, |η| < 1, *not including PTmax*) relative to PTmax (rotated to 180°) for **"min-bias" events** with PTmax > 0.5, 1.0, and 2.0 GeV/c.
- Shows **"jet structure" in "min-bias" collisions** (*i.e.* **the "birth" of the leading two jets!**).

Min-Bias "Associated" Charged Particle Density



- Shows the data on the Δφ dependence of the "associated" charged particle density, $dN_{chg}/d\eta d\phi$, for charged particles ($p_T > 0.5$ GeV/c, $|\eta| < 1$, *not including PTmax*) relative to PTmax (rotated to 180°) for "min-bias" events with PTmax > 0.5 GeV/c and PTmax > 2.0 GeV/c compared with PYTHIA Tune A (after CDFSIM).
- PYTHIA Tune A predicts a larger correlation than is seen in the "min-bias" data (*i.e.* Tune A "min-bias" is a bit too "jetty").

Min-Bias "Associated" Charged PTsum Density

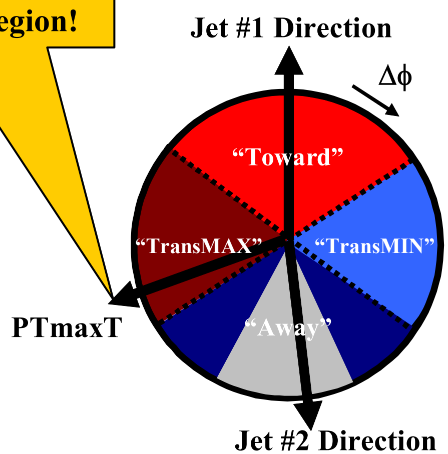


- Shows the data on the **Δϕ dependence of the "associated" charged PTsum density**, dPTsum/dηdϕ, for charged particles ($p_T > 0.5$ GeV/c, $|\eta| < 1$, *not including PTmax*) relative to PTmax (rotated to 180°) for **"min-bias" events** with PTmax > 0.5 GeV/c and PTmax > 2.0 GeV/c compared with **PYTHIA Tune A** (after CDFSIM).

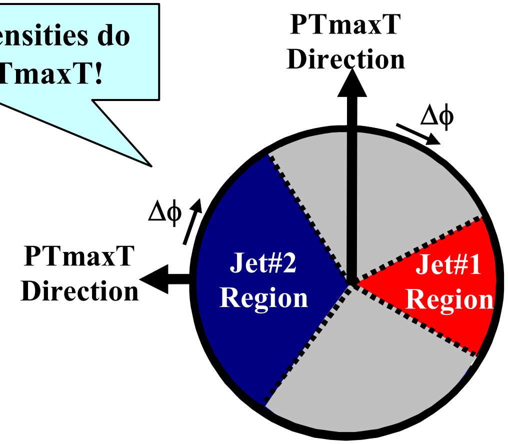
- **PYTHIA Tune A** predicts a larger correlation than is seen in the "min-bias" data (*i.e.* Tune A "min-bias" is a bit too "jetty").

Back-to-Back "Associated" Charged Particle Densities

Maximum p_T particle in the "transverse" region!

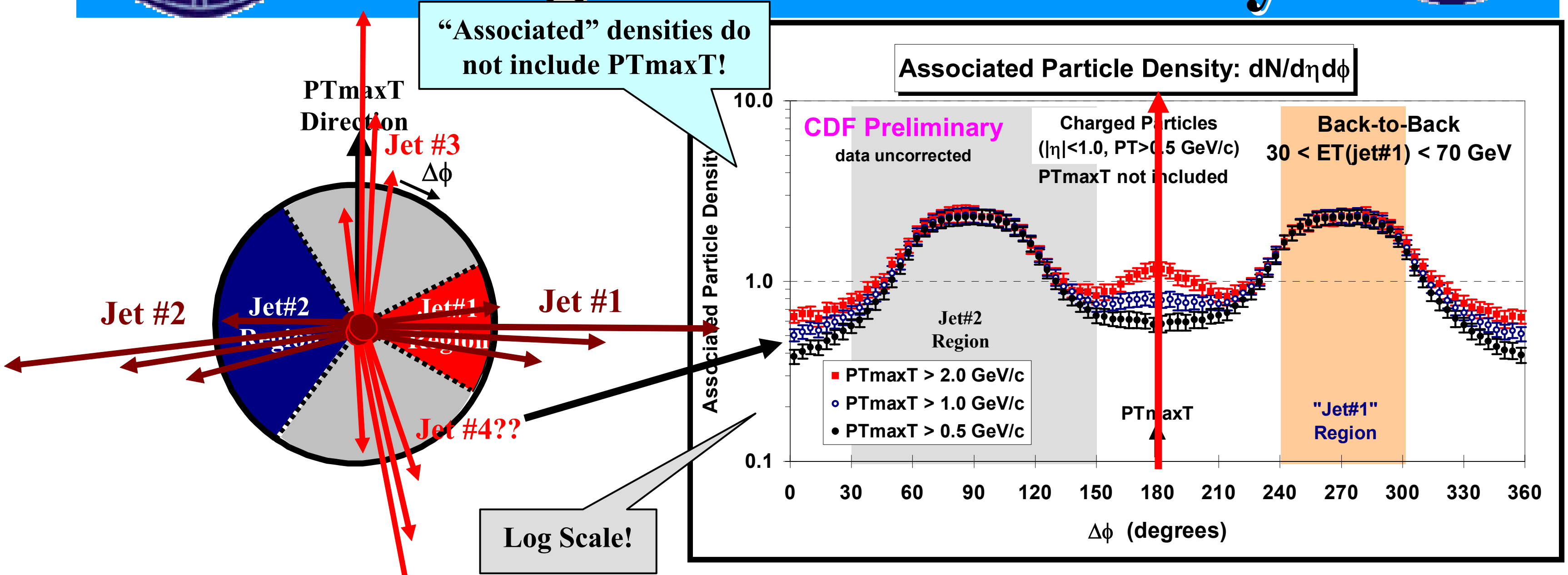


"Associated" densities do not include PTmaxT!



- Use the leading jet in "back-to-back" events to define the "transverse" region and look at the maximum p_T charged particle in the "transverse" region, PTmaxT.
- Look at the Δϕ dependence of the "associated" charged particle and PTsum densities, $dN_{chg}/d\eta d\phi$ and $dPT_{sum}/d\eta d\phi$ for charged particles ($p_T > 0.5$ GeV/c, $|\eta| < 1$, *not including PTmaxT*) relative to PTmaxT.
- Rotate so that PTmaxT is at the center of the plot (*i.e.* 180°).

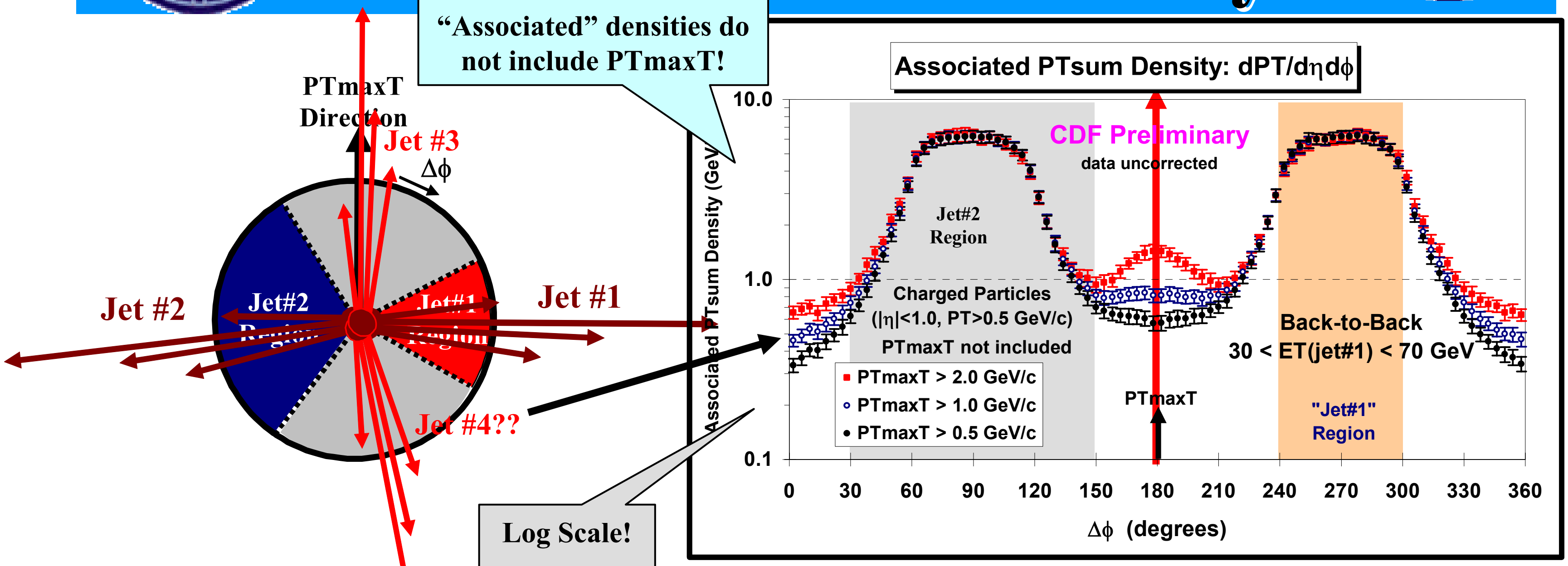
Back-to-Back "Associated" Charged Particle Density



- **Look at the Δφ dependence of the "associated" charged particle density, $dN_{chg}/d\eta d\phi$ for charged particles ($p_T > 0.5$ GeV/c, $|\eta| < 1$, *not including PTmaxT*) relative to PTmaxT (rotated to 180°) for PTmaxT > 0.5 GeV/c, PTmaxT > 1.0 GeV/c and PTmaxT > 2.0 GeV/c, for "back-to-back" events with 30 < E_T(jet#1) < 70 GeV .**

- **Shows "jet structure" in the "transverse" region (*i.e.* the "birth" of the 3rd & 4th jet).**

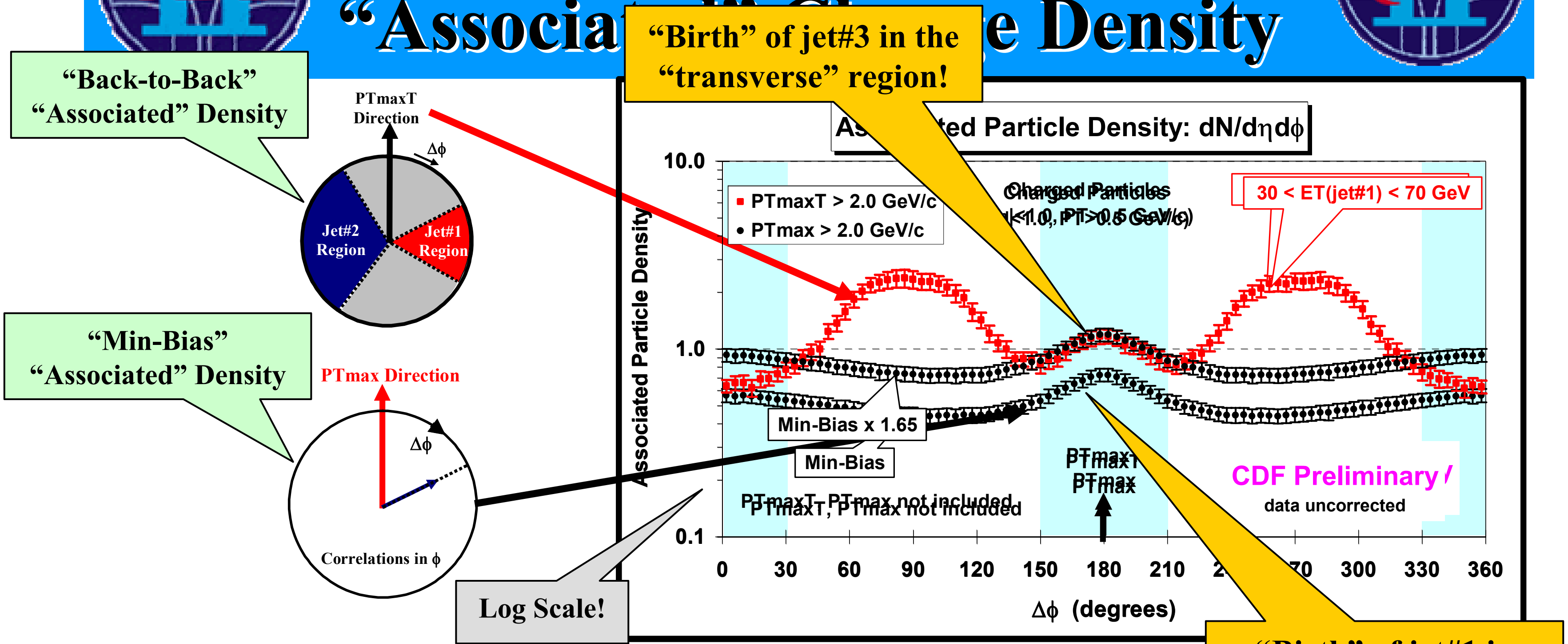
Back-to-Back "Associated" Charged PTsum Density



- Look at the Δϕ dependence of the "associated" charged particle density, dPTsum/dηdϕ for charged particles ($p_T > 0.5$ GeV/c, $|\eta| < 1$, *not including PTmaxT*) relative to PTmaxT (rotated to 180°) for PTmaxT > 0.5 GeV/c, PTmaxT > 1.0 GeV/c and PTmaxT > 2.0 GeV/c, for "back-to-back" events with $30 < E_T(\text{jet\#1}) < 70$ GeV .

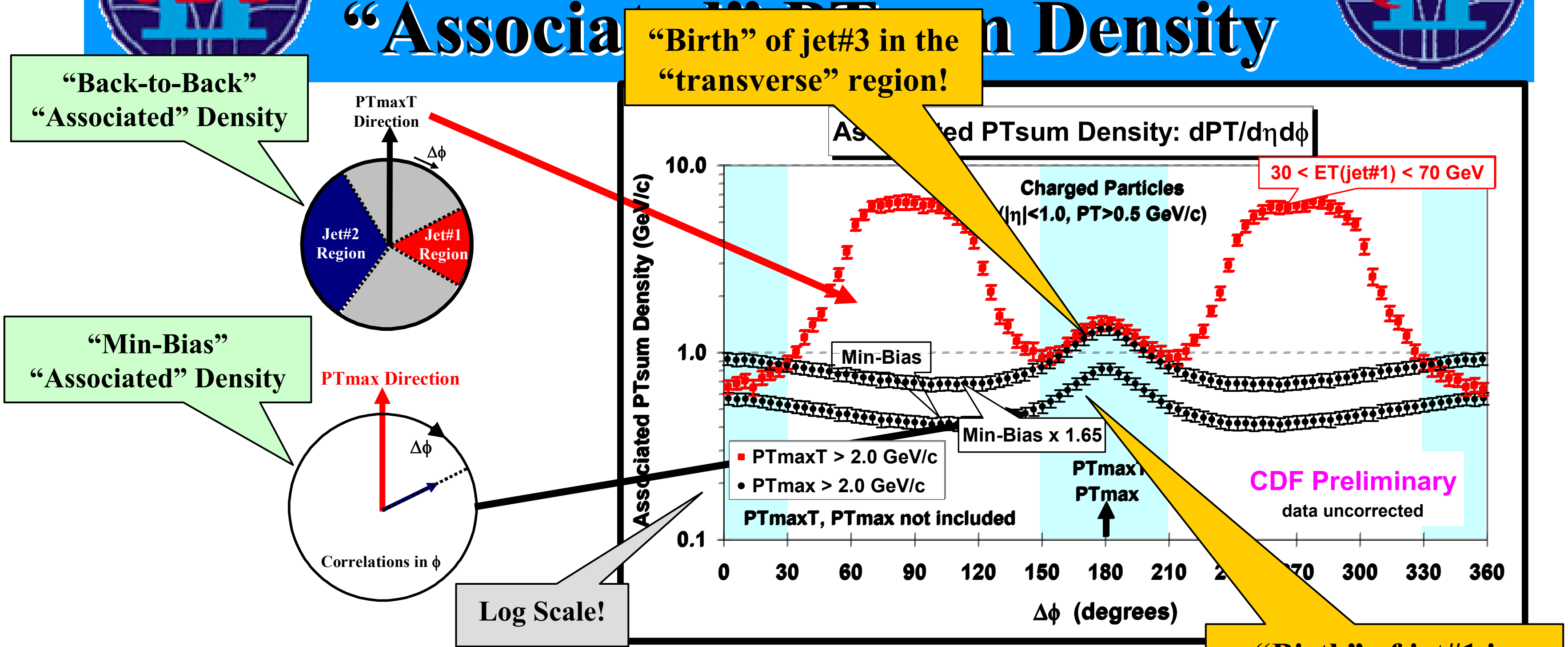
- Shows "jet structure" in the "transverse" region (*i.e.* the "birth" of the 3rd & 4th jet).

“Back-to-Back” vs “MinBias” “Associa… e Density



- Shows the Δϕ dependence of the “associated” charged particle densi… $p_T > 0.5$ GeV/c, $|\eta| < 1$ (*not including PTmaxT*) relative to PTmaxT (rotated to 180°) for PTmaxT > 2.0 GeV/c, for “back-to-back” events with $30 < E_T(\text{jet\#1}) < 70$ GeV.
- Shows the data on the Δϕ dependence of the “associated” charged particle density, dNchg/dηdϕ, $p_T > 0.5$ GeV/c, $|\eta| < 1$ (*not including PTmax*) relative to PTmax (rotated to 180°) for “min-bias” events with PTmax > 2.0 GeV/c.

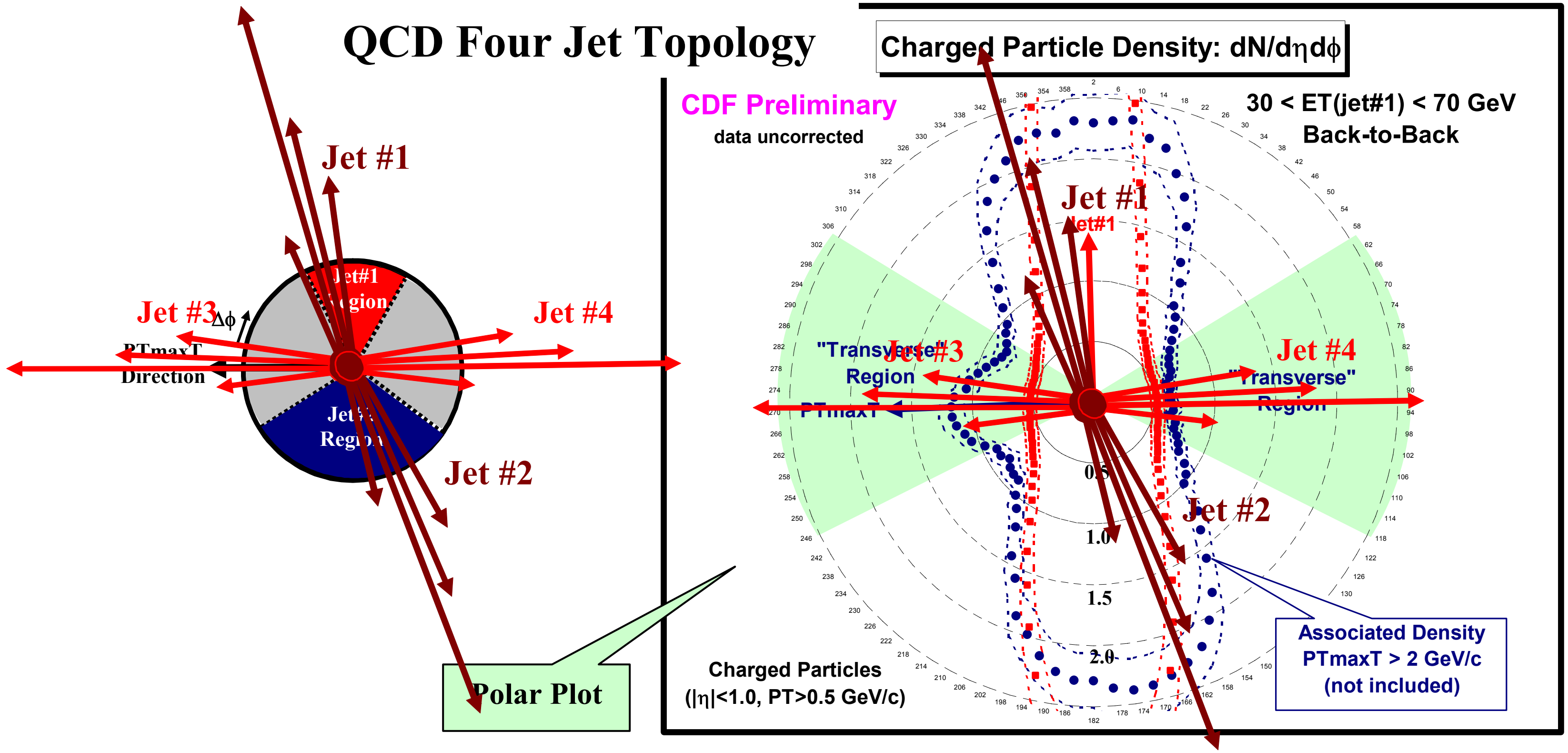
“Back-to-Back” vs “MinBias” “Associa… n Density



- Shows the **Δϕ dependence of the “associated” charged particle densi…** $p_T > 0.5$ GeV/c, $|\eta| < 1$ (*not including PTmaxT*) relative to PTmaxT (… for PTmaxT > 2.0 GeV/c, for **“back-to-back” events with 30 < E_T(jet#1) < 70 GeV**.

- Shows the data on the **Δϕ dependence of the “associated” charged particle density**, dNchg/dηdϕ, $p_T > 0.5$ GeV/c, $|\eta| < 1$ (*not including PTmax*) relative to PTmax (rotated to 180°) for **“min-bias” events** with PTmax > 2.0 GeV/c.

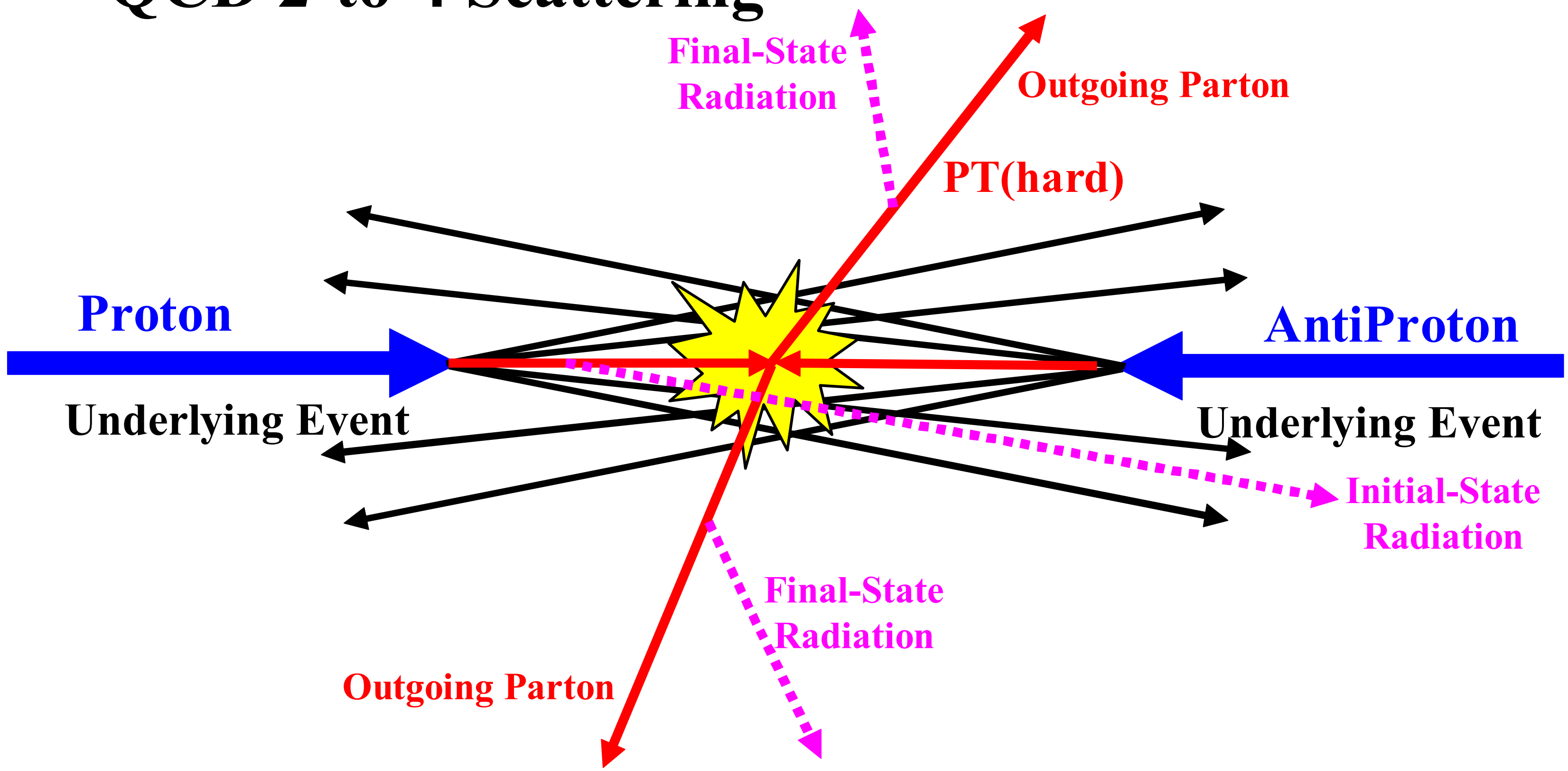
Jet Topologies



- **Shows the Δφ dependence of the "associated" charged particle density, dNchg/dηdφ, $p_T > 0.5$ GeV/c, $|\eta| < 1$, PTmaxT > 2.0 GeV/c (*not including PTmaxT*) relative to PTmaxT (rotated to 180°) and the charged particle density, dNchg/dηdφ, $p_T > 0.5$ GeV/c, $|\eta| < 1$, relative to jet#1 (rotated to 270°) for "back-to-back events" with 30 < E_T(jet#1) < 70 GeV.**

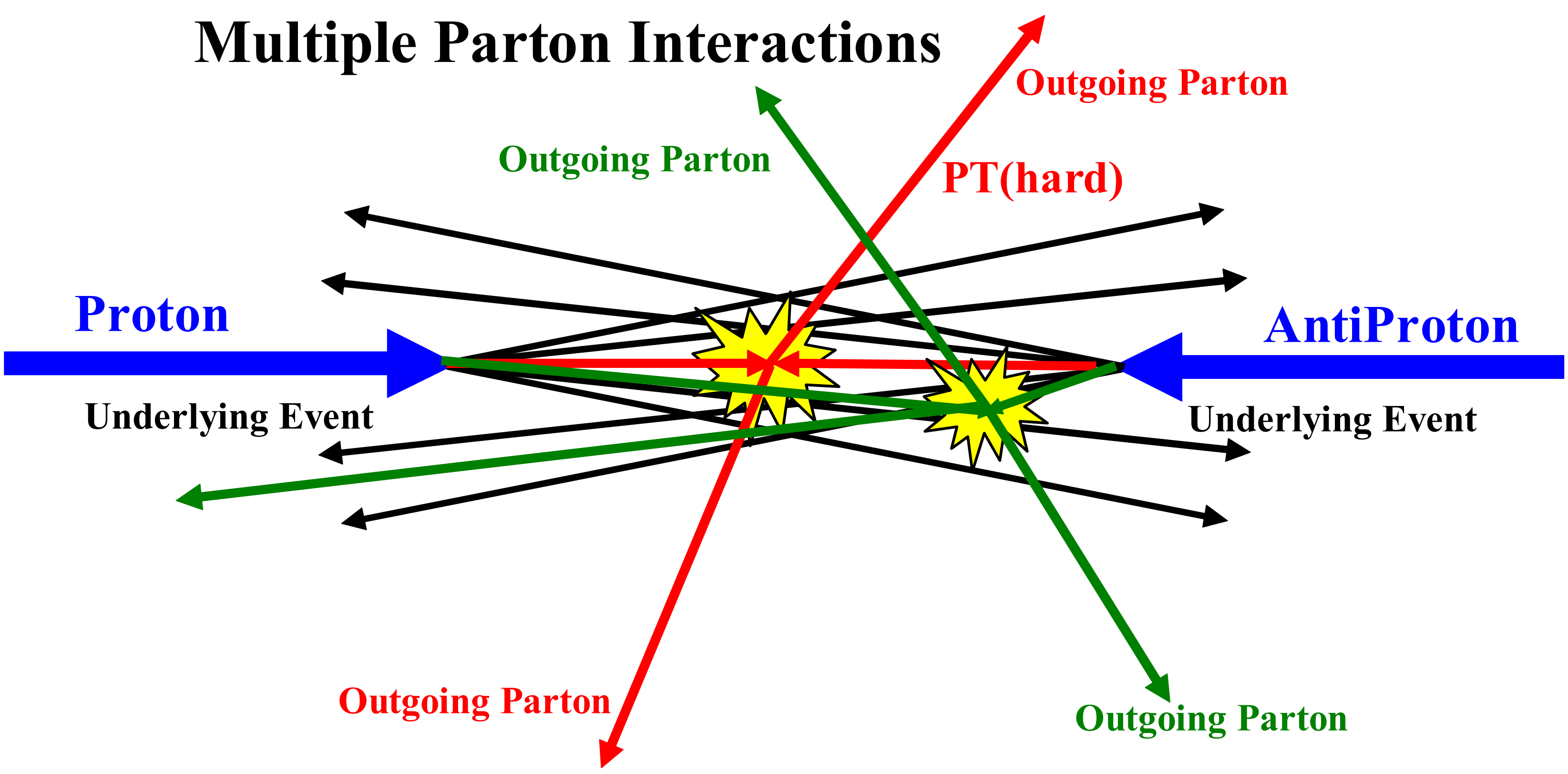
Jet Topologies

QCD 2-to-4 Scattering



180°) and the charged particle density, dNchg/dηdφ, $p_T > 0.5$ GeV/c, $|\eta| < 1$, relative to jet#1 (rotated to 270°) for "back-to-back events" with $30 < E_T(\text{jet\#1}) < 70$ GeV.

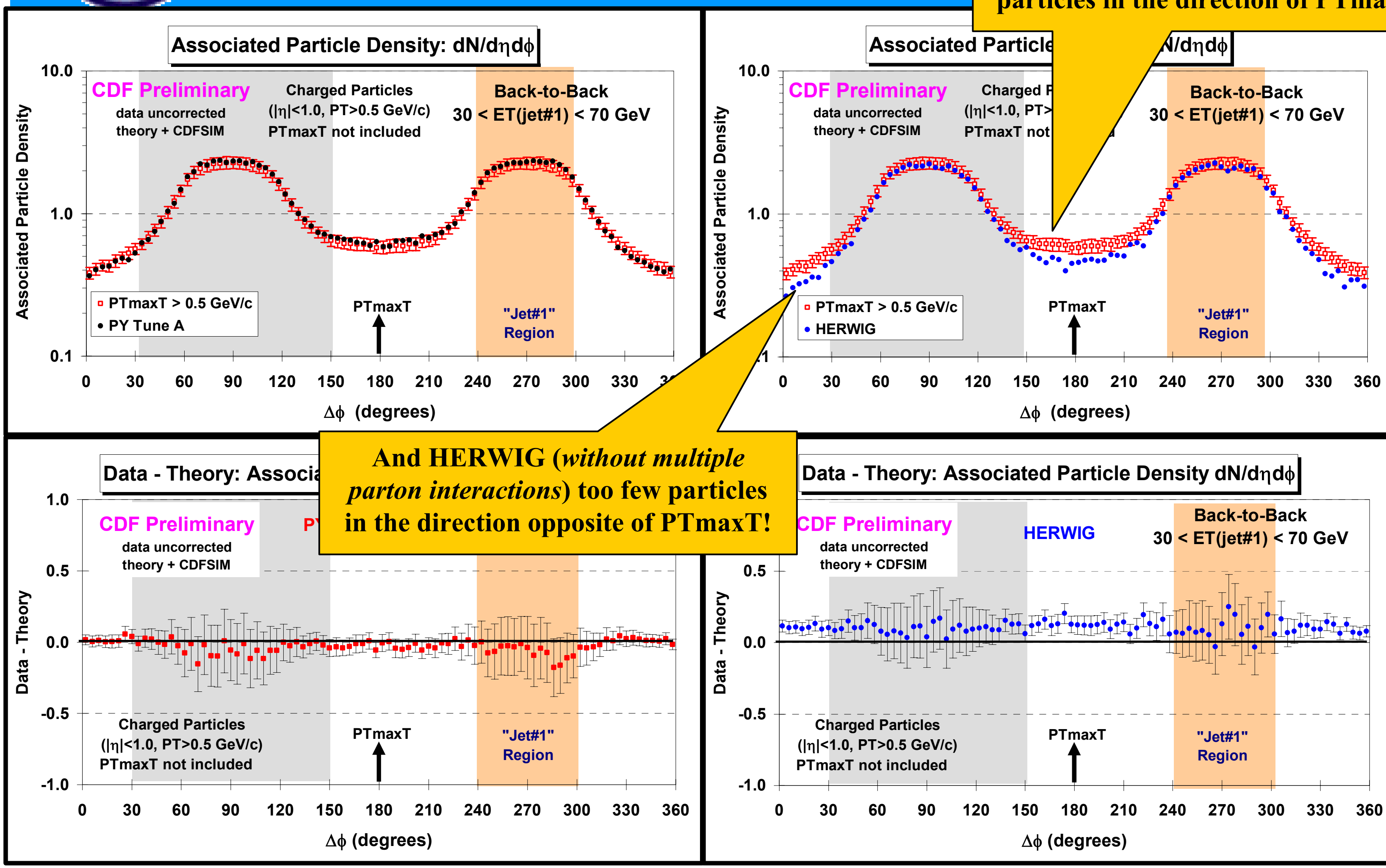
Jet Topologies



180^o) and the charged particle density, $dN_{chg}/d\eta d\phi$, $p_T > 0.5$ GeV/c, $|\eta| < 1$, relative to jet#1 (rotated to 270^o) for "back-to-back events" with $30 < E_T(\text{jet\#1}) < 70$ GeV.

"Associated" Charge Density PYTHIA Tune A vs HE[RWIG]

HERWIG (*without multiple parton interactions*) too few "associated" particles in the direction of PTmaxT!



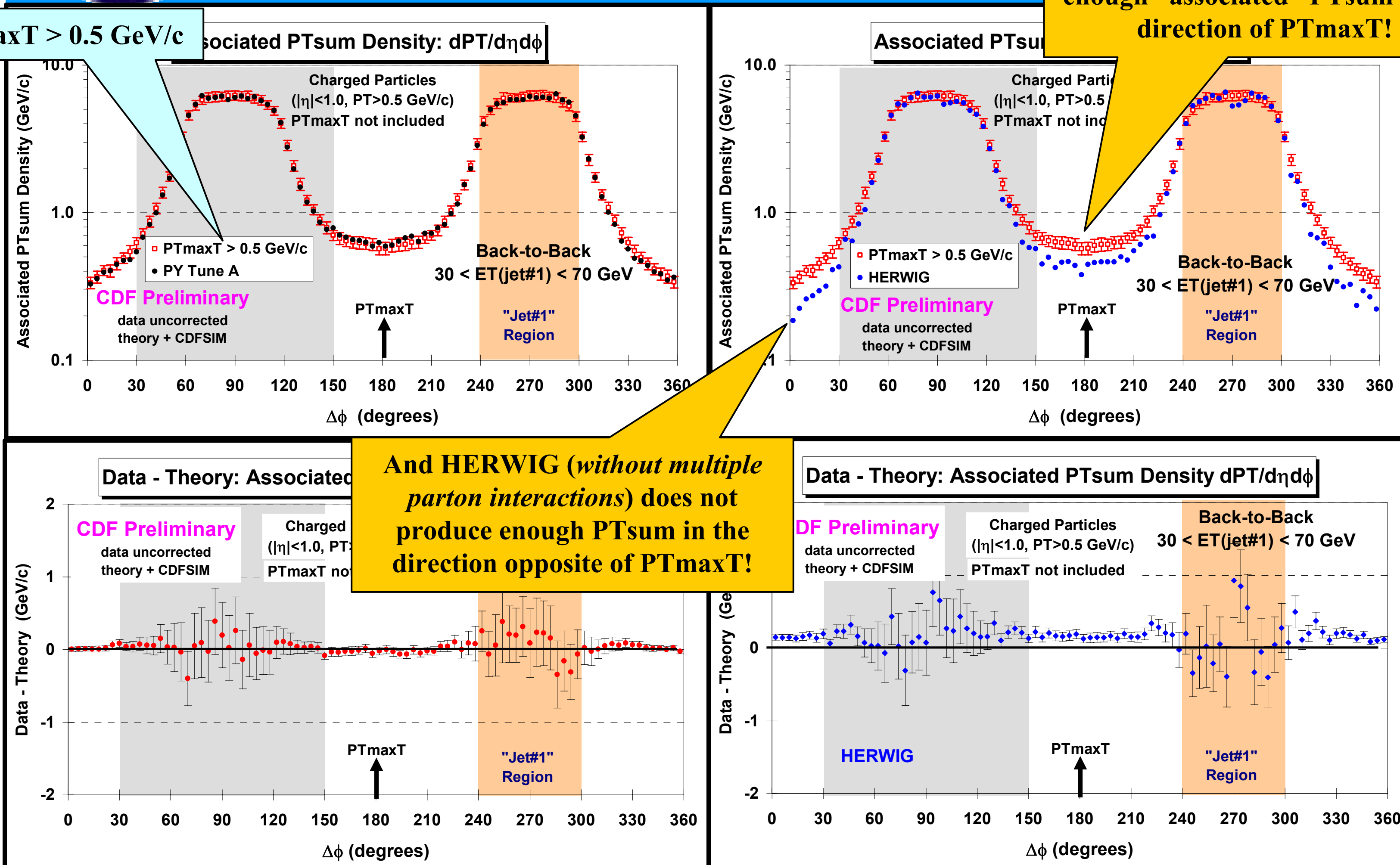
And HERWIG (*without multiple parton interactions*) too few particles in the direction opposite of PTmaxT!

"Associated" PTsum Density PYTHIA Tune A vs HERWIG

PTmaxT > 0.5 GeV/c

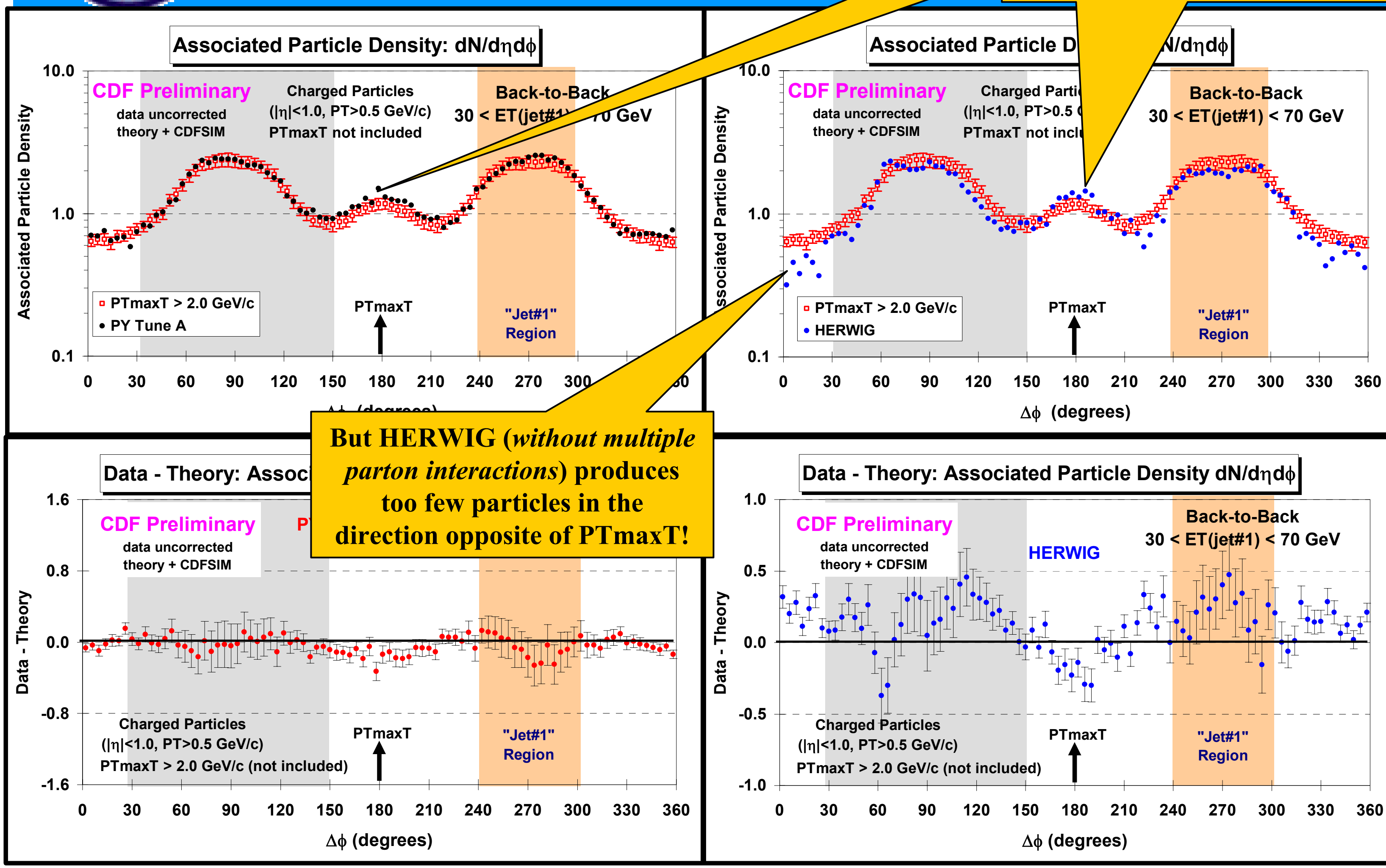
HERWIG (*without multiple parton interactions*) does not produce enough "associated" PTsum in the direction of PTmaxT!

And HERWIG (*without multiple parton interactions*) does not produce enough PTsum in the direction opposite of PTmaxT!



“Associated” Charge De...
PYTHIA Tune A vs HE...

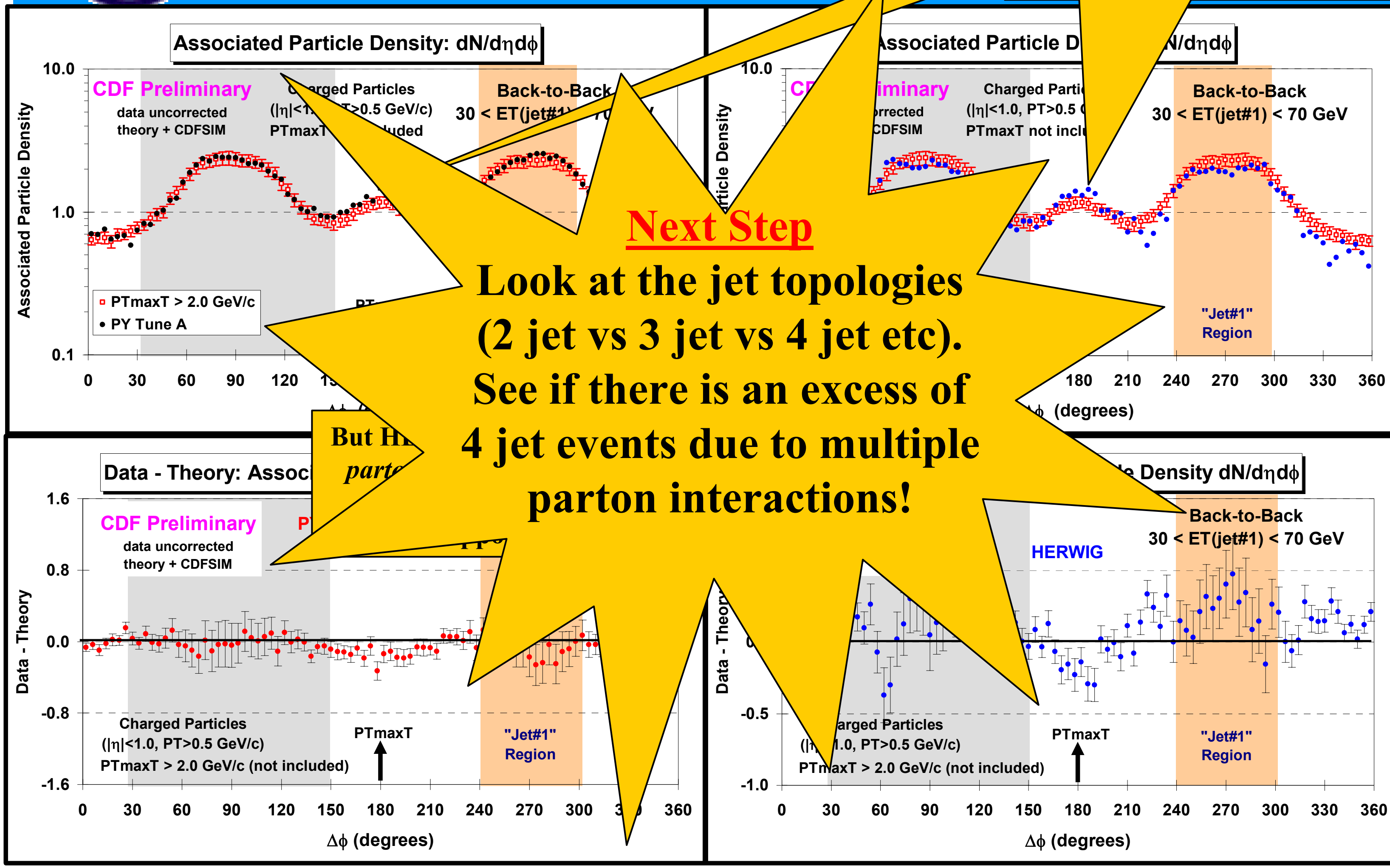
For PTmaxT > 2.0 GeV both PYTHIA and HERWIG produce slightly too many “associated” particles in the direction of PTmaxT!



But HERWIG (*without multiple parton interactions*) produces too few particles in the direction opposite of PTmaxT!

"Associated" Charge De... PYTHIA Tune A vs HE...

For PTmaxT > 2.0 GeV both PYTHIA and HERWIG produce slightly too many "associated" particles in the direction of PTmaxT!



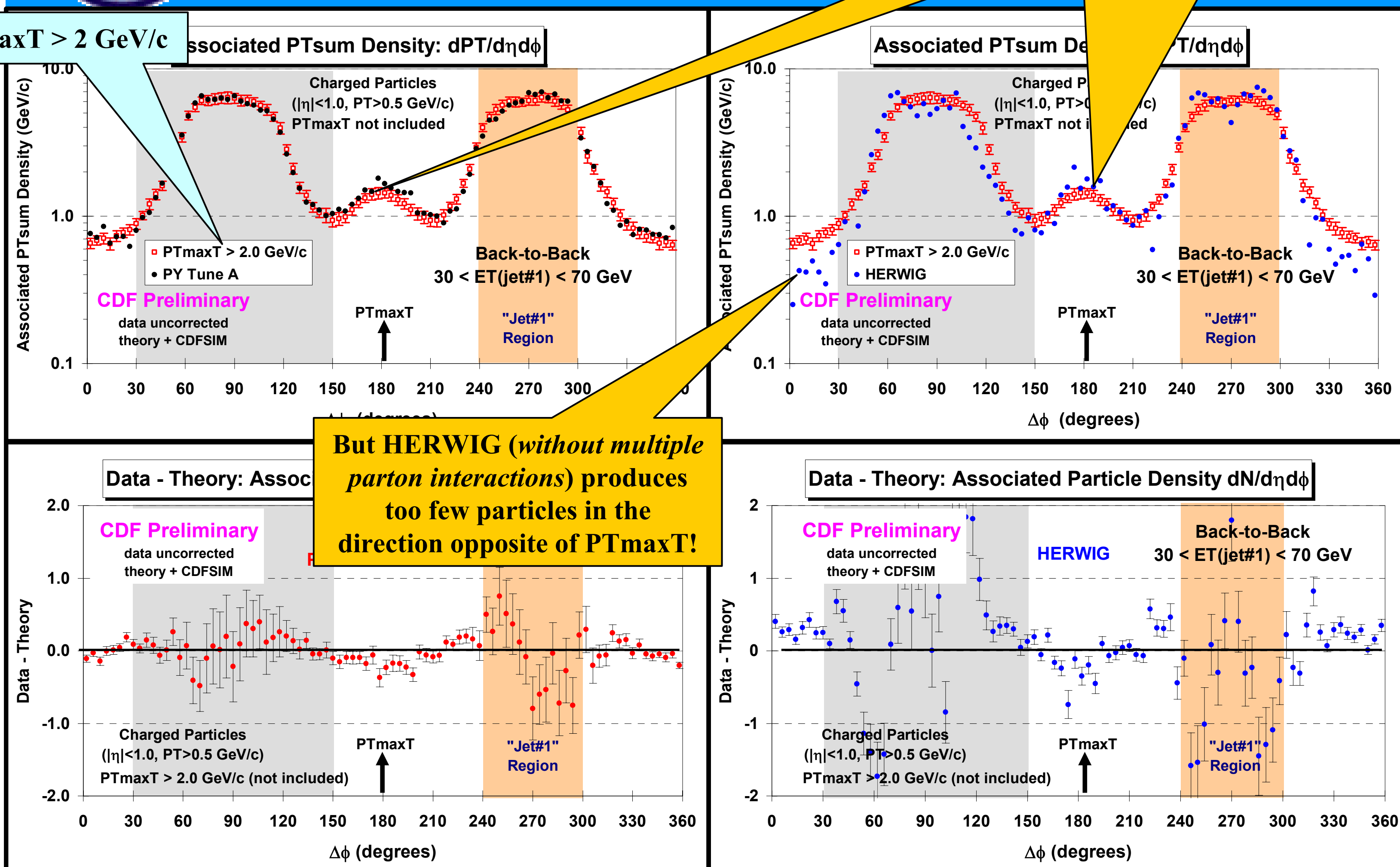
Next Step

Look at the jet topologies (2 jet vs 3 jet vs 4 jet etc). See if there is an excess of 4 jet events due to multiple parton interactions!

“Associated” PTsum De
PYTHIA Tune A vs HE

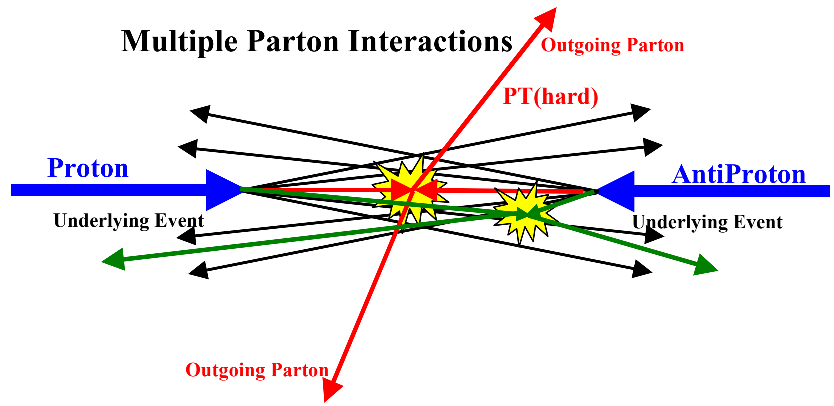
For PTmaxT > 2.0 GeV both PYTHIA and HERWIG produce slightly too much “associated” PTsum in the direction of PTmaxT!

PTmaxT > 2 GeV/c



But HERWIG (*without multiple parton interactions*) produces too few particles in the direction opposite of PTmaxT!

The Universality of PYTHIA Tune A



- We would like to have a "universal" tune of PYTHIA!
  - QCD Hard Scattering
  - Direct Photon Production
  - Z-Boson Production
  - Heavy Flavor Production

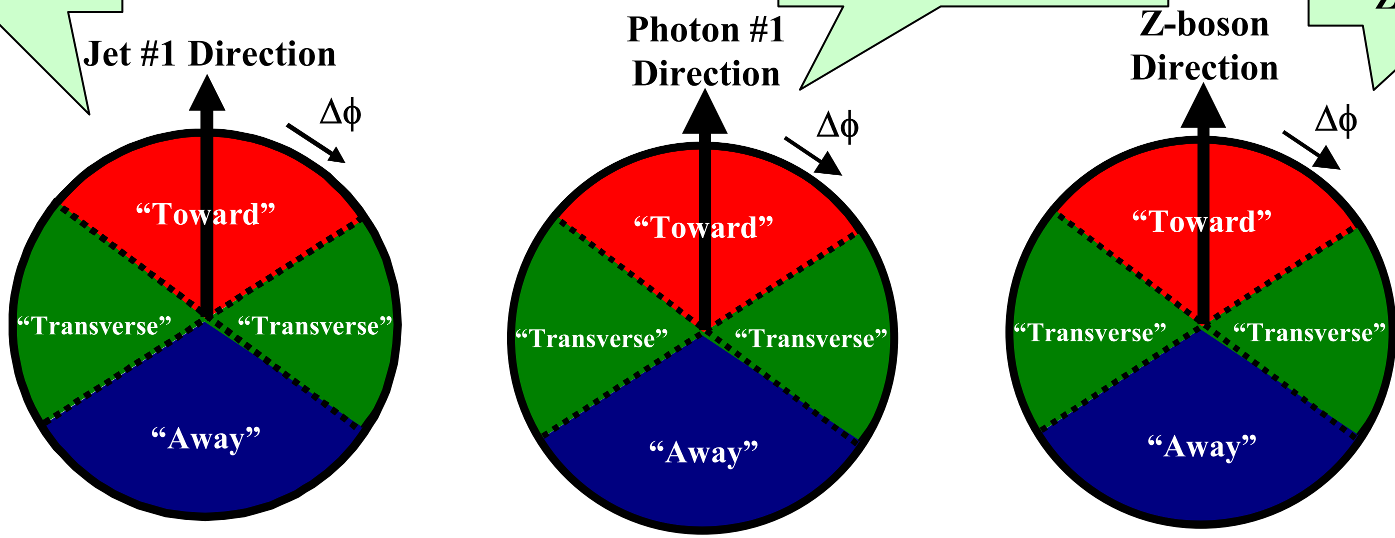
- I working on a "universal" PYTHIA Run 2 tune!
  - Must specify the PDF!
  - Must specify MPI parameters!
  - Must specify Q^2 scale!
  - Must specify intrinsic kT!

New CDF Run 2 Analysis
Photon and

Refer to this as a "Leading Jet" event

Refer to this as a "Leading Photon" event

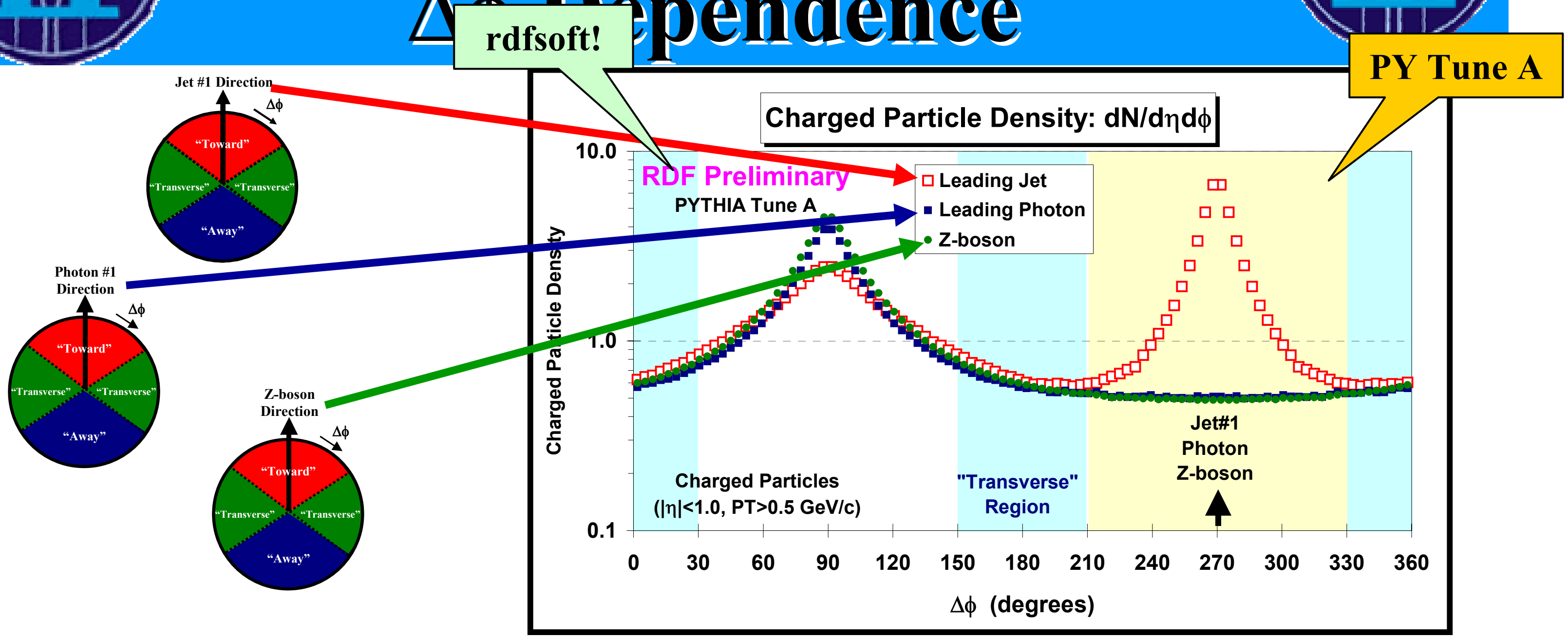
Refer to this as a "Z-boson" event



- **Study the $\Delta\phi$ distribution of the charged particle density, $dNchg/d\eta d\phi$, and the charged scalar p_T sum density, $dPTsum/d\eta d\phi$, for charged particles in the region $p_T > 0.5$ GeV/c, $|\eta| < 1$) in "leading jet" events. and "leading photon" events! and "Z-boson" events!**

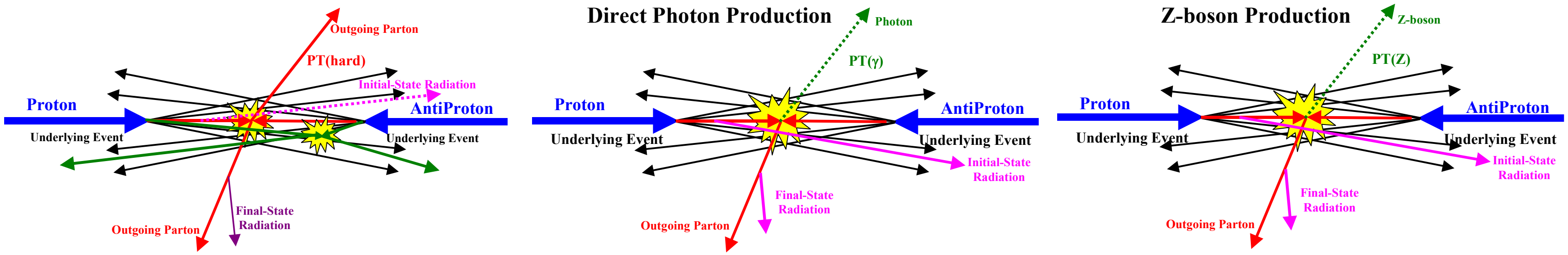
- **Study the average charged particle and PTsum density in the "toward", "transverse", and "away" regions versus E_T(jet#1) in "leading jet" events.and "leading photon" events! and "Z-boson" events!**

Charged Particle Density Δϕ Dependence



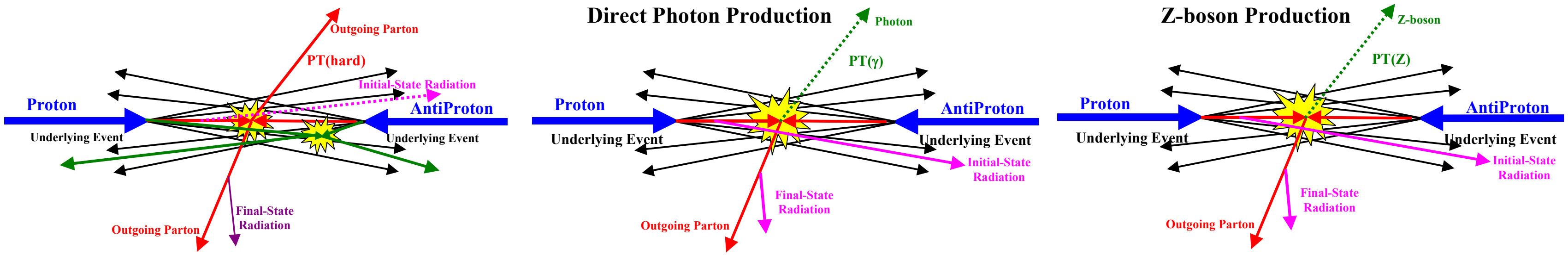
- Shows the Δϕ dependence of the density, $dN_{chg}/d\eta d\phi$, for charged particles in the range $p_T > 0.5$ GeV/c and $|\eta| < 1$ relative to jet#1 (rotated to 270°) for E_T(jet#1) > 30 GeV for "Leading Jet" events from PYTHIA Tune A.
- Shows the Δϕ dependence of the density, $dN_{chg}/d\eta d\phi$, for charged particles in the range $p_T > 0.5$ GeV/c and $|\eta| < 1$ relative to pho#1 (rotated to 270°) for P_T(pho#1) > 30 GeV for "Leading Photon" events from PYTHIA Tune A.
- Shows the Δϕ dependence of the density, $dN_{chg}/d\eta d\phi$, for charged particles in the range $p_T > 0.5$ GeV/c and $|\eta| < 1$ relative to the Z (rotated to 270°) for P_T(Z) > 30 GeV for "Z-boson" events from PYTHIA Tune A.

Not “Blessed” Yet!

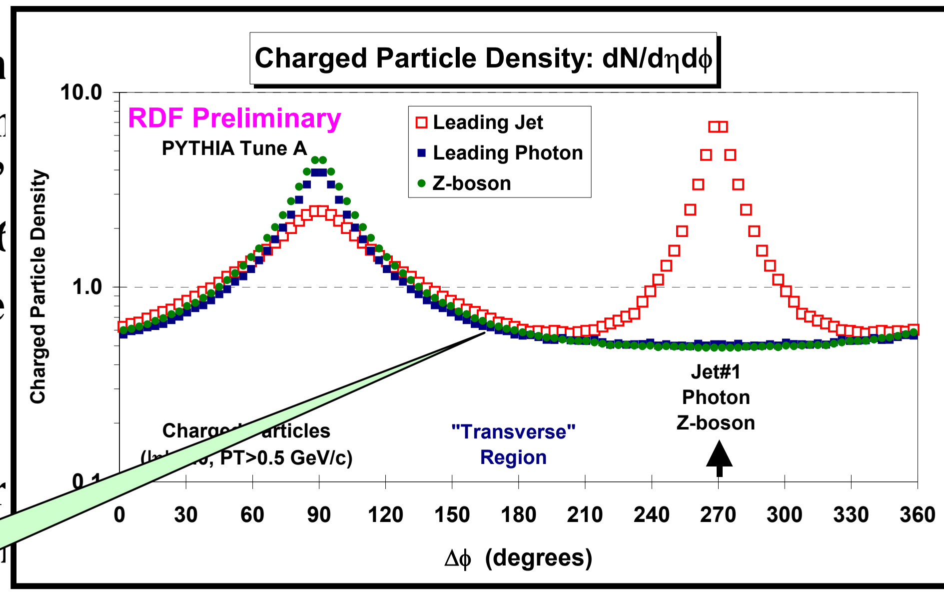


- **PYTHIA Tune A agrees well with the density, dNchg/dηdφ, for charged particles and the *scalar* PTsum density, dPTsum/dηdφ, for the region $p_T > 0.5$ GeV/c and $|\eta| < 1$ in the “toward” and “transverse” regions for both direct photon and Z-boson events at 1.96 TeV.**
- **However, I probably should increase the intrensic k_T. PYTHIA Tune A uses the default value.**
- **In addition to specifying the PDF and the MPI parameters, one must specify the Q^2 scale for each process. For Tune A $Q^2 = 4p_T^2$ for QCD jets and direct photons and $Q^2 = M_z^2$ for Z-boson production.**

Not “Blessed” Yet!

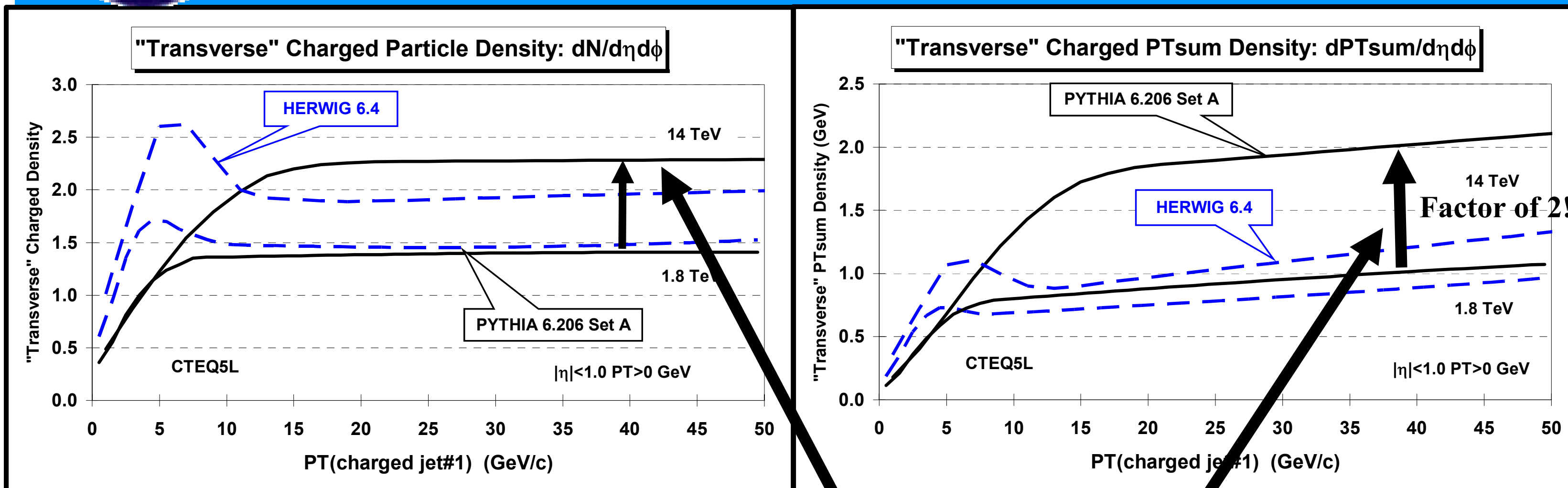


- PYTHIA Tune A agrees well with particles and the *scalar* PTsum der GeV/c and |η| < 1 in the “toward” photon and Z-boson events at 1.96
- However, I probably should incre the default value.
- In addition to specifying the PDF the Q^2 scale for each process. For photons and $Q^2 = M_Z^2$ for Z-boson



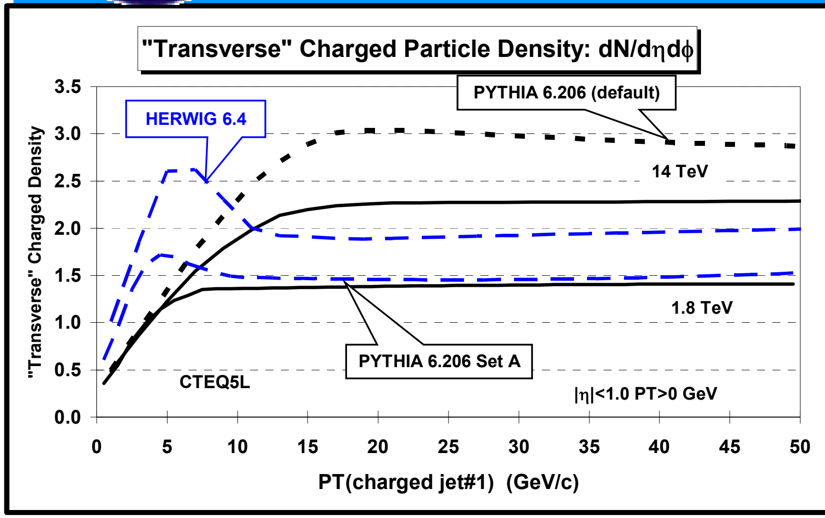
The data looks like PYTHIA Tune A!

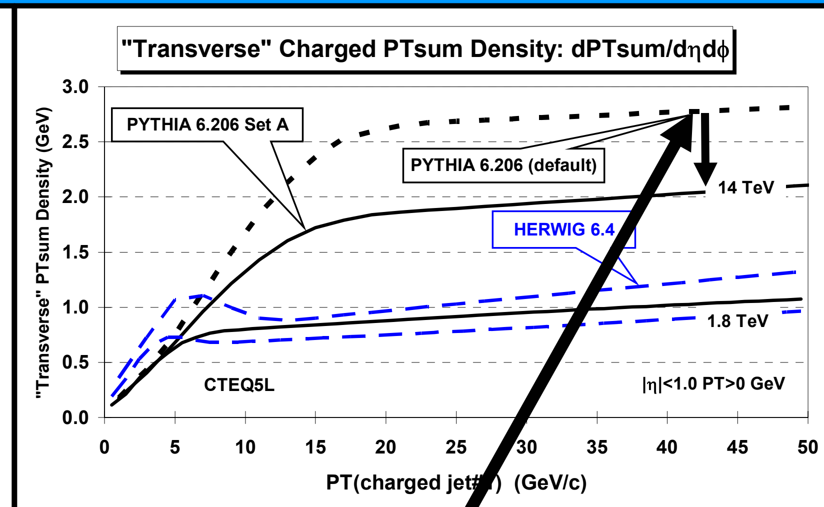
PYTHIA Tune A LHC Predictions



- 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 **PYTHIA Tune A** (P_T(hard) > 0, CTEQ5L) at 1.8 TeV and 14 TeV.
- At 14 TeV tuned **PYTHIA Tune 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 Tune 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.

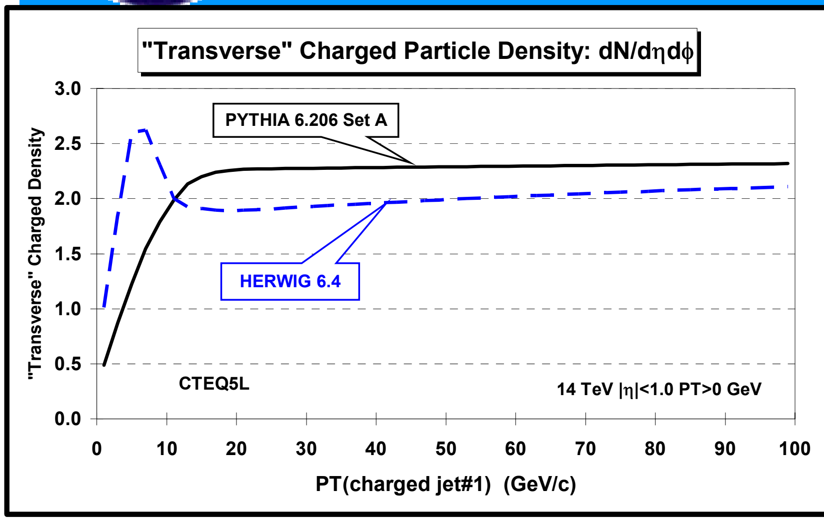
PYTHIA Tune A
LHC Predictions

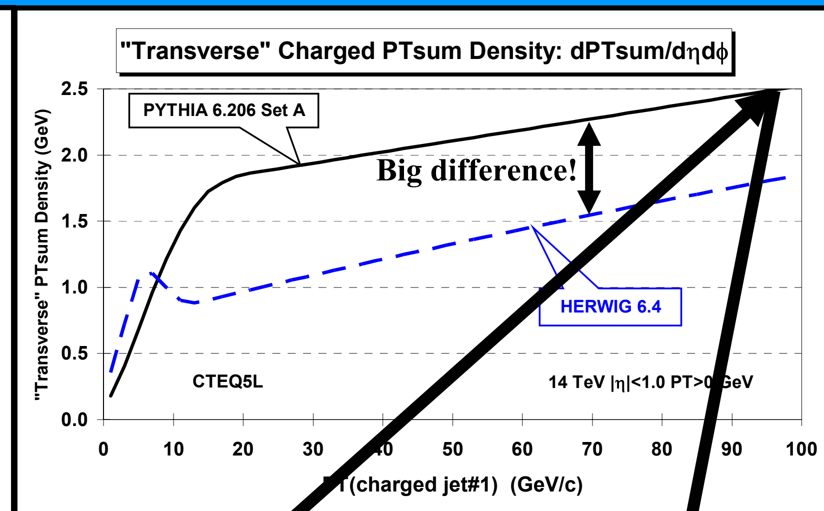




- **Shows the average "transverse" charge particle and PT_{sum} density ($|\eta|<1$, $P_T>0$) versus P_T(charged jet#1) predicted by HERWIG 6.4 (P_T(hard) > 3 GeV/c, CTEQ5L). and PYTHIA Tune A (P_T(hard) > 0, CTEQ5L) at 1.8 TeV and 14 TeV. Also shown is the 14 TeV prediction of PYTHIA 6.206 with the default value $\varepsilon = 0.16$.**
- **PYTHIA Tune 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.**

PYTHIA Tune A LHC Predictions



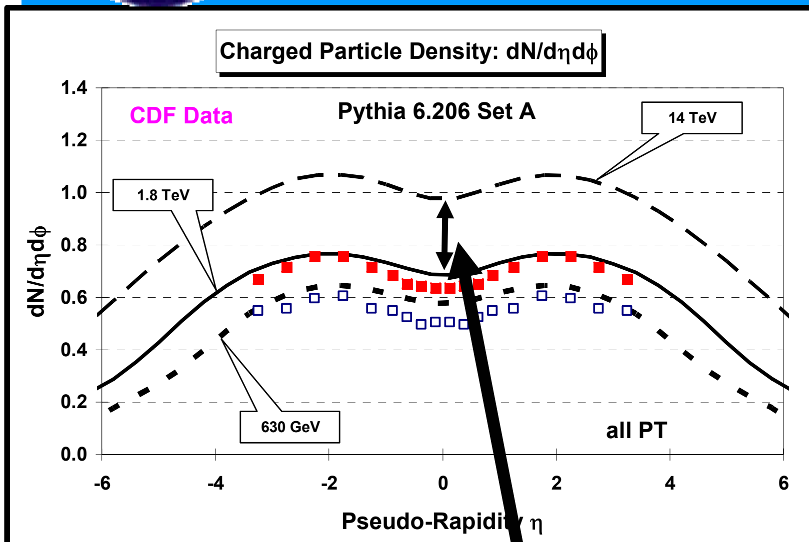


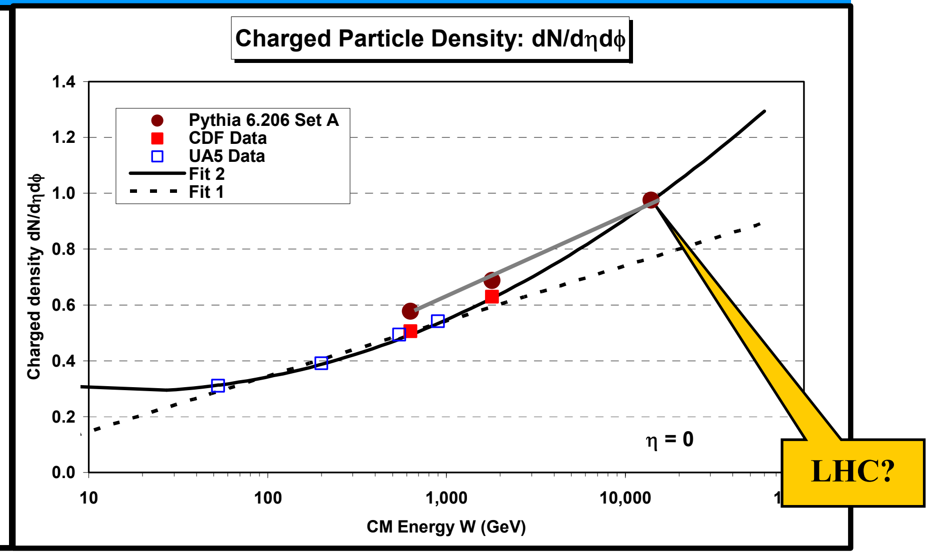
- **Shows the average "transverse" charge particle and PT_{sum} density ($|\eta|<1$, $P_T>0$) versus P_T(charged jet#1) predicted by HERWIG 6.4 (P_T(hard) > 3 GeV/c, CTEQ5L). and a PYTHIA Tune A (P_T(hard) > 0, CTEQ5L) at 1.8 TeV and 14 TeV.**

- **PYTHIA Tune 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 as P_T(chgjet#1) increases.**

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

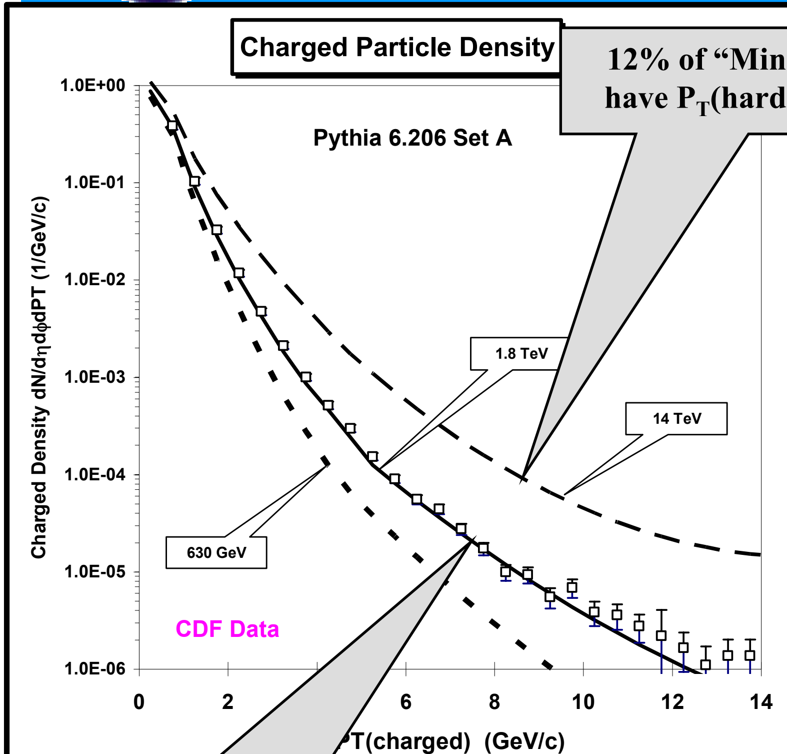
PYTHIA Tune A
LHC Predictions



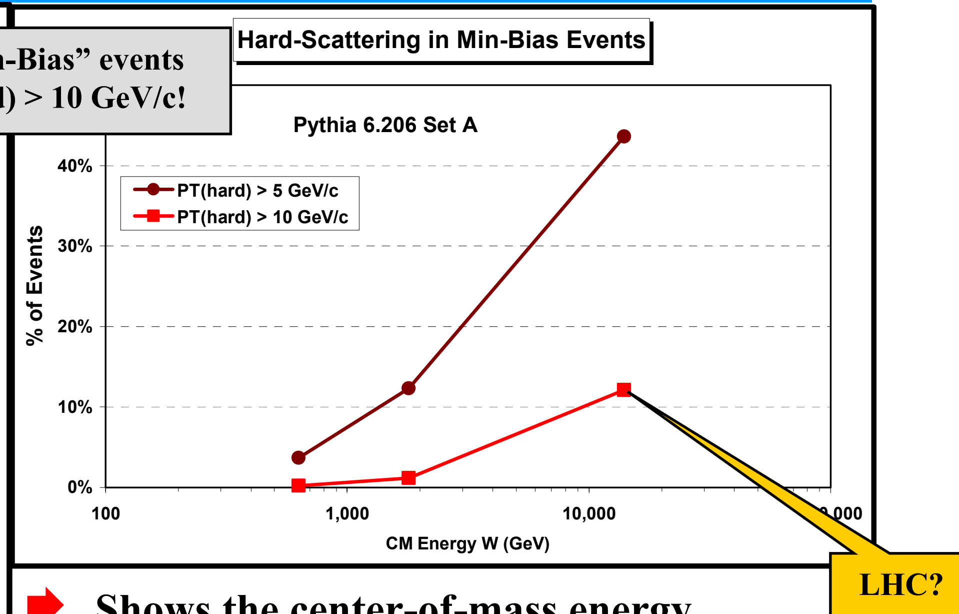


- **Shows the center-of-mass energy dependence of the charged particle density, $dN_{chg}/d\eta d\phi$, for "Min-Bias" collisions compared with PYTHIA Tune A with P_T(hard) > 0.**
- **PYTHIA was tuned to fit the "underlying event" in hard-scattering processes at 1.8 TeV and 630 GeV.**
- **PYTHIA Tune 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).**

PYTHIA Tune A LHC Predictions



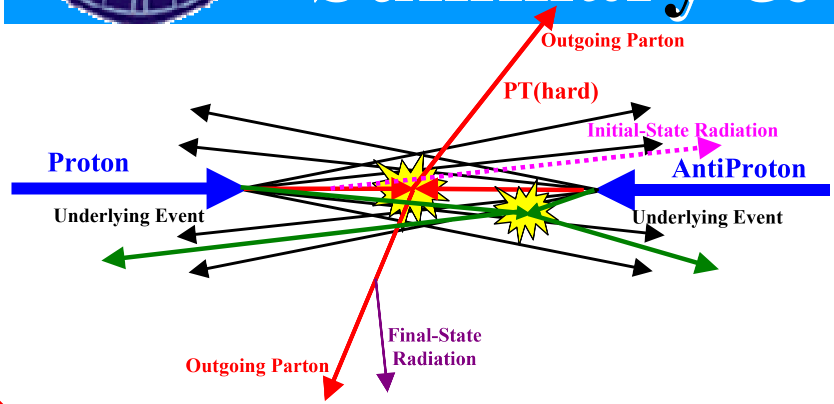
12% of "Min-Bias" events have P_T(hard) > 10 GeV/c!



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 PYTHIA Tune A with P_T(hard) > 0.
- PYTHIA Tune A 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!

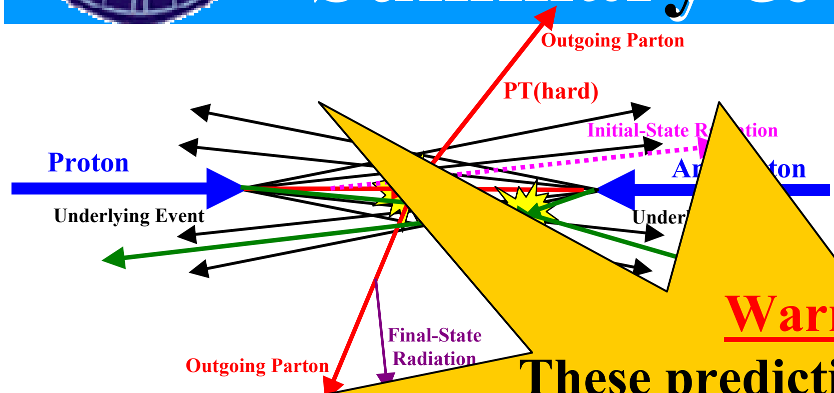
LHC Predictions
Summary & Conclusions



Tevatron → LHC

- **PYTHIA Tune A predict a 40-45% rise in $dN_{chg}/d\eta d\phi$ at $\eta = 0$ in going from the Tevatron (1.8 TeV) to the LHC (14 TeV). 4 charged particles per unit η at the Tevatron becomes 6 per unit η at the LHC.**
- **PYTHIA Tune A predicts that 1% of all "Min-Bias" events at the Tevatron (1.8 TeV) are the result of a hard 2-to-2 parton-parton scattering with P_T(hard) > 10 GeV/c which increases to 12% at LHC (14 TeV)!**
- **For the "underlying event" in hard scattering processes the predictions of HERWIG and PYTHIA Tune A differ greatly (factor of 2!). HERWIG predicts a smaller increase in the activity of the "underlying event" in going from the Tevatron to the LHC.**
- **PYTHIA Tune A predicts about a factor of two increase in the charged PT_{sum} density of the "underlying event" in going from the Tevatron to the LHC.**

LHC Predictions
Summary & Conclusions



Tevatron → LHC

Warning!

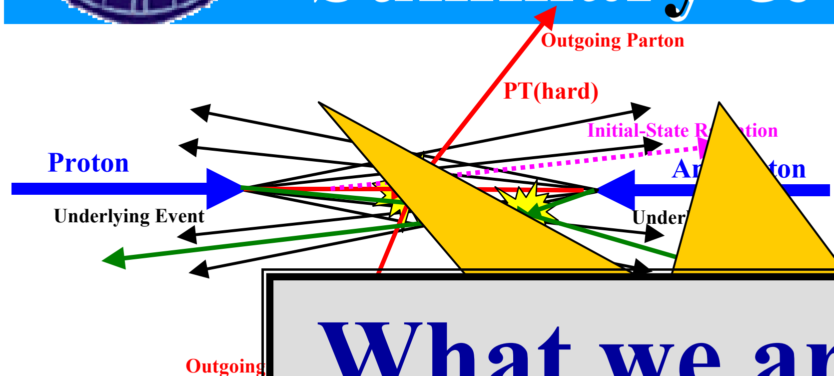
These predictions cannot be trusted! We need to improve the modeling of the "beam-beam" remnants and "multiple-parton interactions".

…likely…

- **PYTHIA Tune A** … ng from the Tevatron (1.8 TeV) … nit η at the Tevatron becomes 6 per unit η a…
- **PYTHIA Tune A** pre… are the result of a … P_T(hard) > … increases to 12% at LHC (14…
- For the "underlying event" i… d… ring … sses th… edictions of HERWIG and **PYTHIA Tune A** differ gre…ly (fact… 2!). … WIG pred…ts a smaller increase in the activity of the "underlying event" … going fr… the Tevatron to the LHC.
- **PYTHIA Tune A** predicts about a fa…or of two increase in the charged PT_{sum} density of the "underlying event" in going from the Tevatron to the LHC.

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

LHC Predictions Summary & Conclusions



Tevatron ⟶ LHC

What we are learning at the Tevatron will result in improved models!

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  Tevatron (1. … **Tevatron**
  becomes 6 p
- **PYTHIA Tu**
  are the resu
  increases to 12% at LHC (14 …
- **For the "underlying event" i   rd   ring   sses th   edictions of HERWIG and PYTHIA Tune A differ gre   ly (fact   2!).   WIG pred   ts a   aller increase in the activity of the "underlying event"   going fr   the Teva   on to the LHC.**
- **PYTHIA Tune A predicts about a fa   or of two increase in the charged PT_{sum} density of the "underlying event" in going from the Tevatron to the LHC.**

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lying event"
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