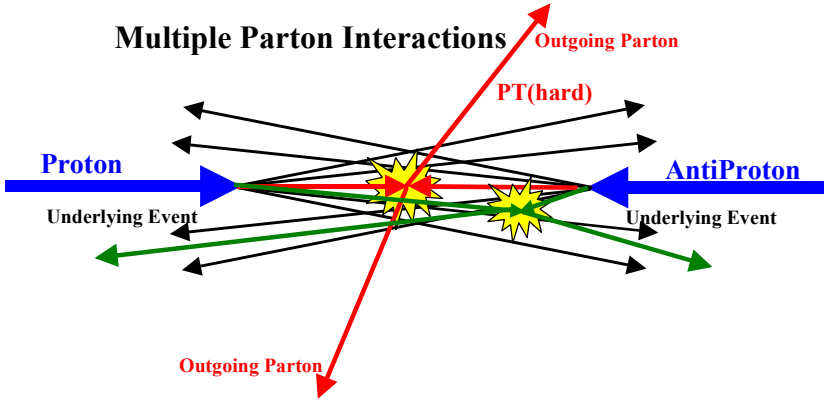
# The Universality of PYTHIA Tune A

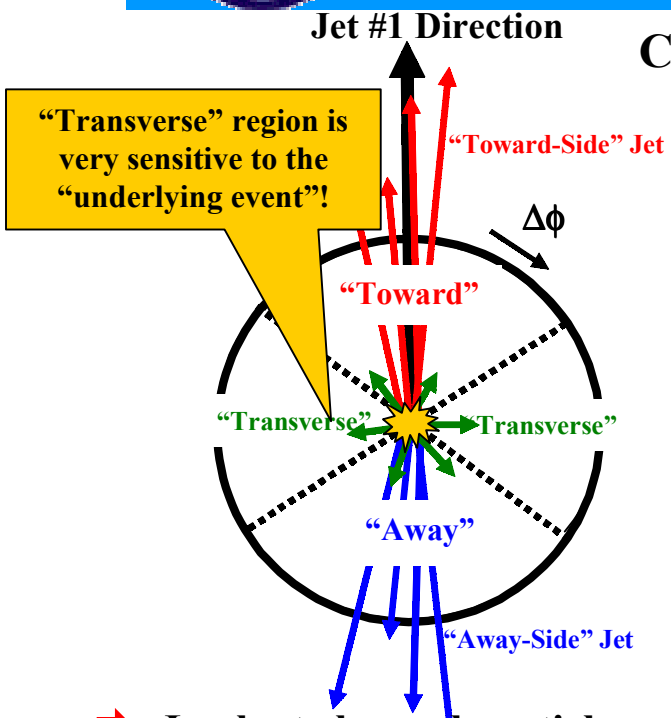
- We would like to have a "universal" tune of PYTHIA!
  - QCD Hard Scattering
  - Direct Photon Production
  - Z-Boson Production
  - Heavy Flavor Production




## Outline of Talk

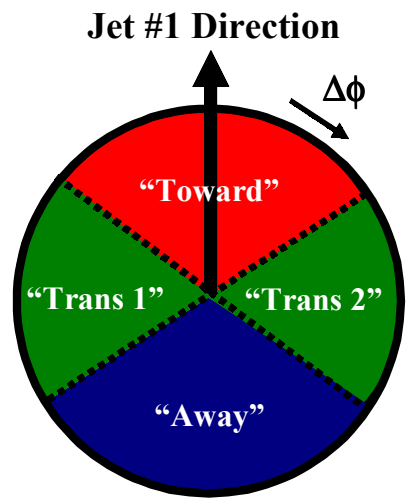
- Review of PYTHIA Tune A (tuned on CDF Run 1 data) .
- Show some comparisons with CDF Run 2 data.
- Discuss the progress toward a "universal" tune.
  - Must specify PDF!
  - Must specify MPI parameters!
  - Must specify $Q^2$ scale!
  - Must specify intrinsic kT!

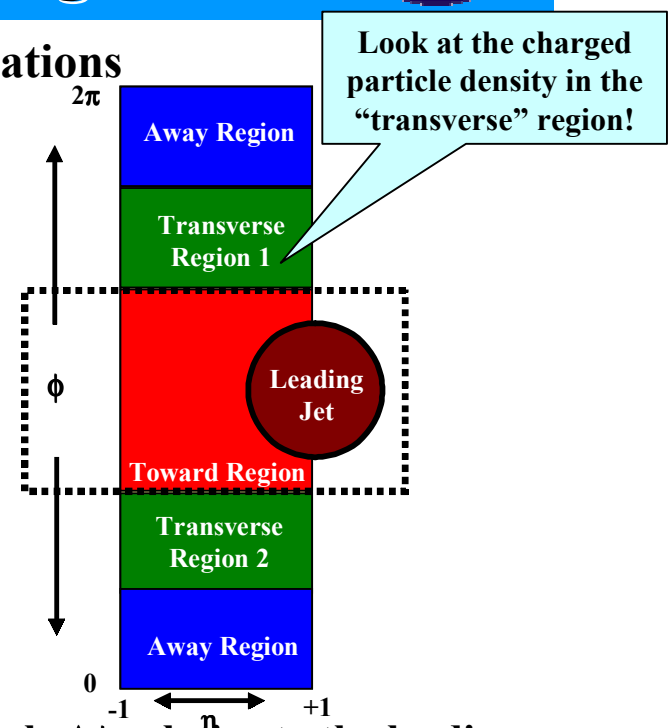
# The "Transverse" Regions
## as defined by the Leading Jet




**Charged Particle Δφ Correlations**

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

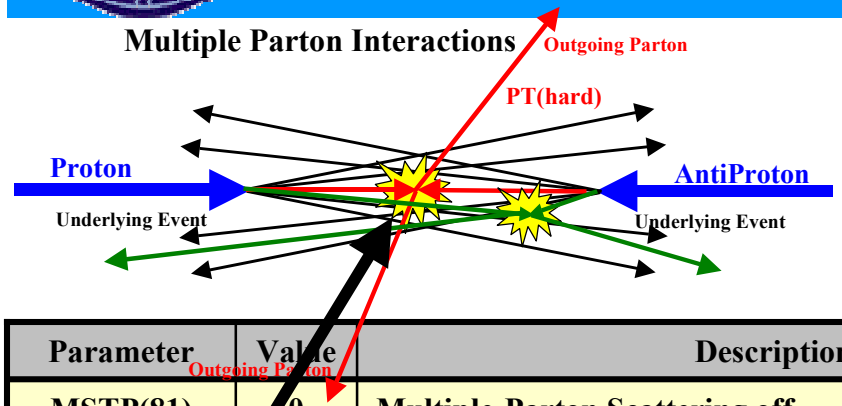



- Look at charged particle correlations in the azimuthal angle Δφ relative to the leading calorimeter jet (JetClu R = 0.7, $|\eta| < 2$).
- Define $|\Delta\phi| < 60^o$ as "Toward", $60^o < -\Delta\phi < 120^o$ and $60^o < \Delta\phi < 120^o$ as "Transverse 1" and "Transverse 2", and $|\Delta\phi| >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

# PYTHIA: Multiple Parton Interaction Parameters

Multiple Parton Interactions




Pythia uses multiple parton interactions to enhance the underlying event.

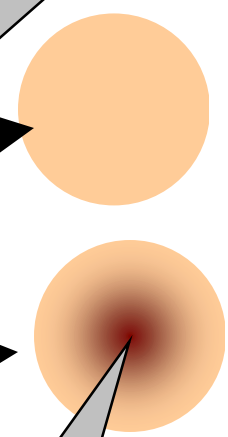
and now HERWIG!

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!

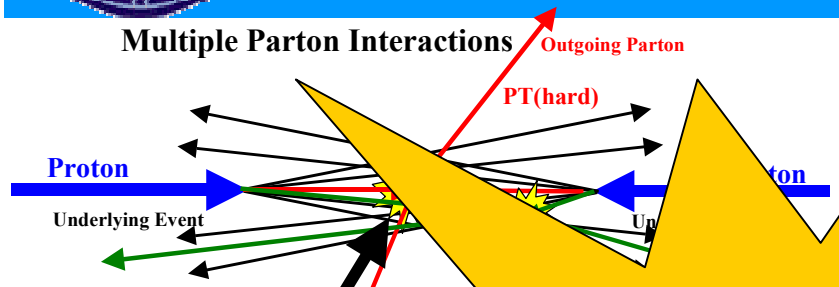
Multiple parton interaction more likely in a hard (central) collision!



Hard Core

# PYTHIA: Multiple Parton Interaction Parameters

Multiple Parton Interactions




ia uses multiple parton
teractions to enhance
ng event.

and now HERWIG!

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

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 |
| | 3 | Multiple inte pa parameter a ter onsist a single Ga mat ibuti a smooth off $P_{T0}$=PARP(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(84)), with a smooth turn-off $P_{T0}$=PARP(82) |

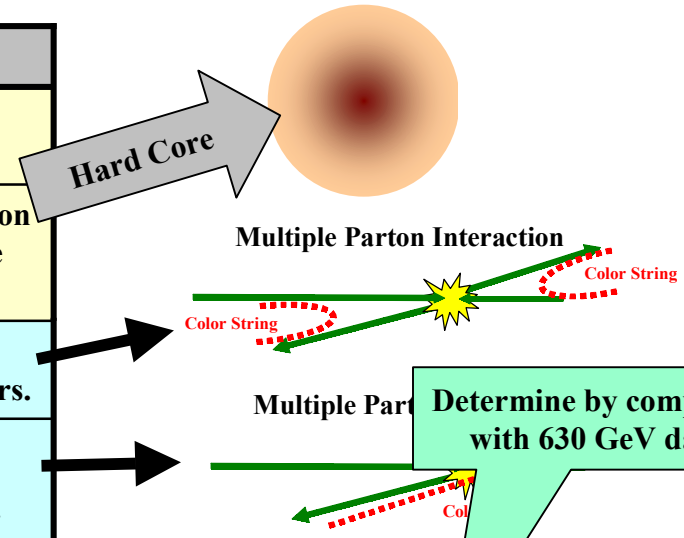
Multiple parton interaction more likely in a hard (central) collision!

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

Hard Core

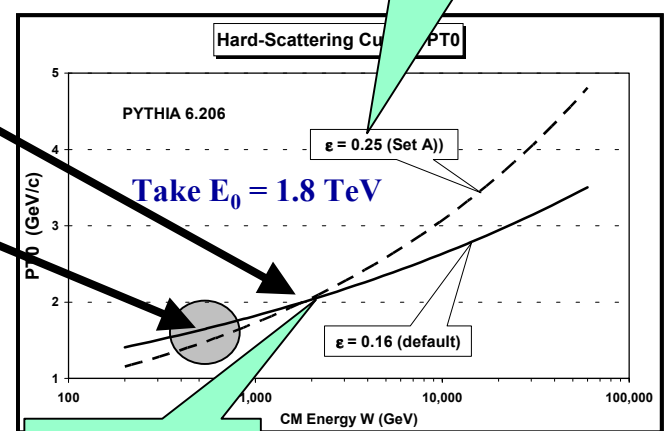
# Tuning PYTHIA:
## Multiple Parton Interaction Parameters

| 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 nes 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 $\varepsilon$ = PARP(90) |
| PARP(67) | 1.0 | A scale factor that determines the maximum parton virtuality for space-like showers. The rger the value of PARP(67) the more initial-st adiation. |




Affects the amount of initial-state radiation!

Determine by comparing with 630 GeV data!




Multiplies $Q^2$ scale (for some processes)!

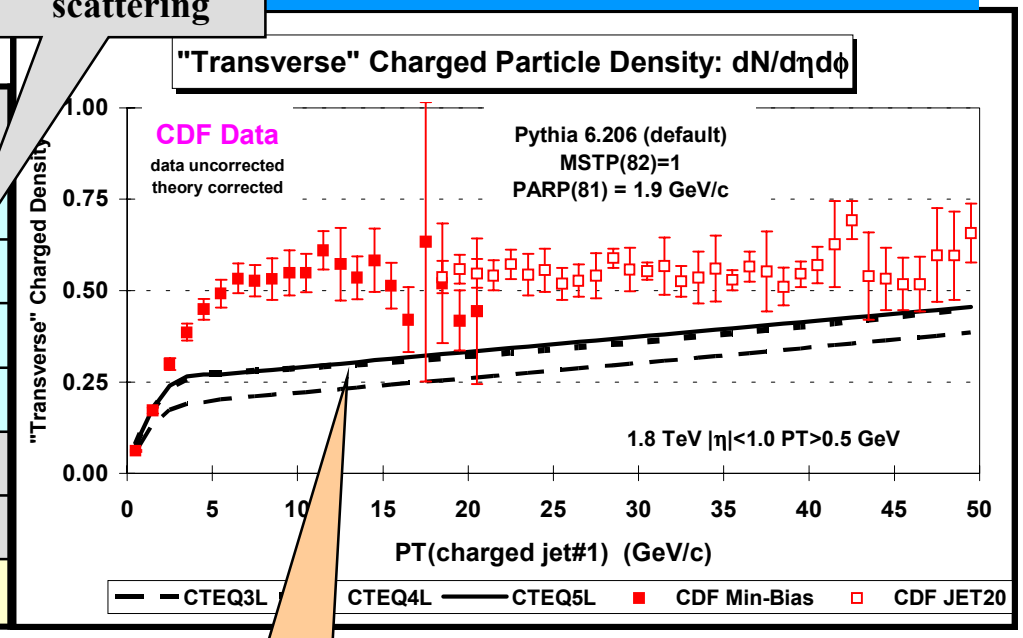
Reference point at 1.8 TeV

# PYTHIA 6.206 Defaults

**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 |

**MPI constant probability scattering**




➡ **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)

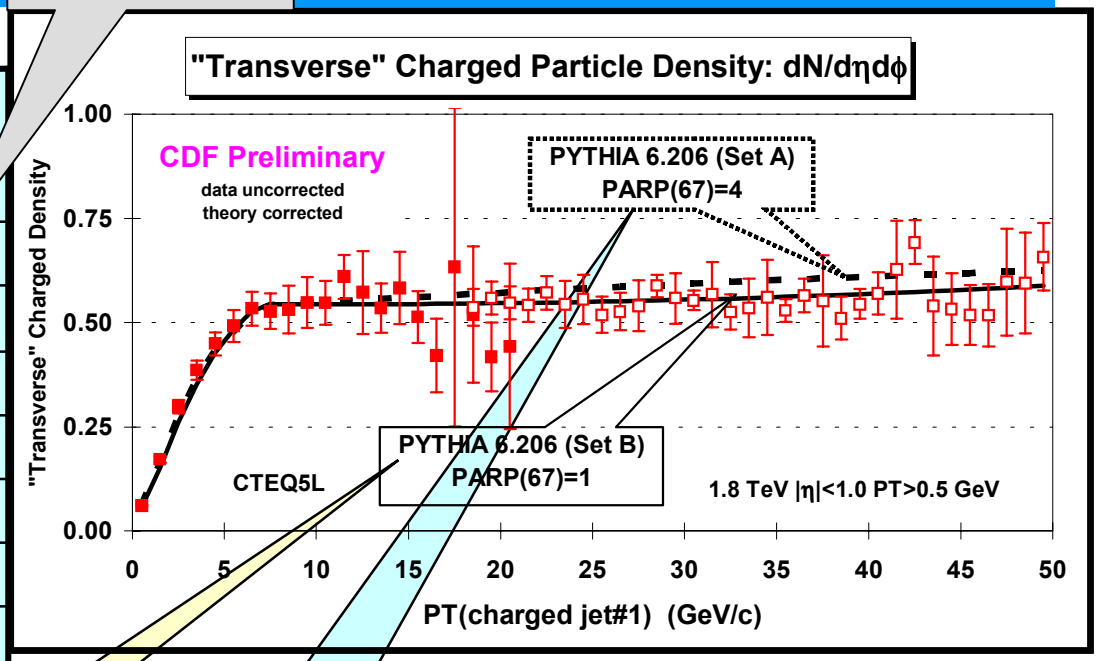
**Default parameters give very poor description of the "underlying event"!**

# 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

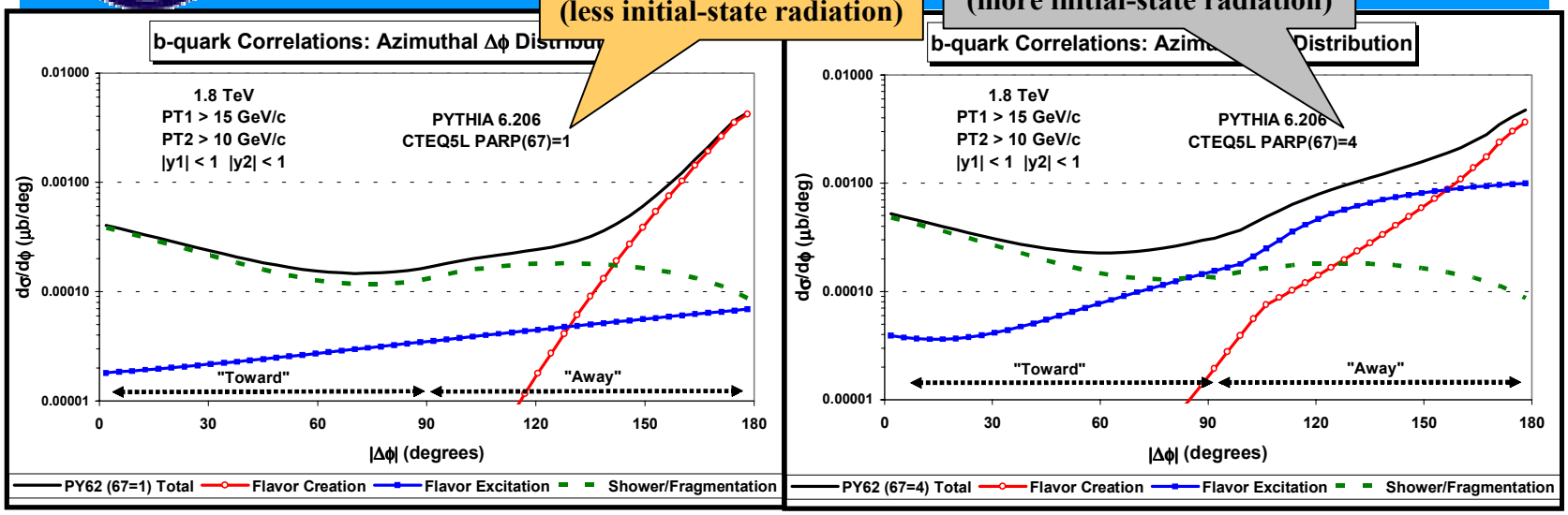



Plot shows the "Transverse" charged particle density versus $P_T$(chgjet#1) compared to the QCD hard scattering predictions of two tuned versions of PYTHIA 6.206 (CTEQ5L, Set B (PARP(67)=1) and Set A (PARP(67)=4)).

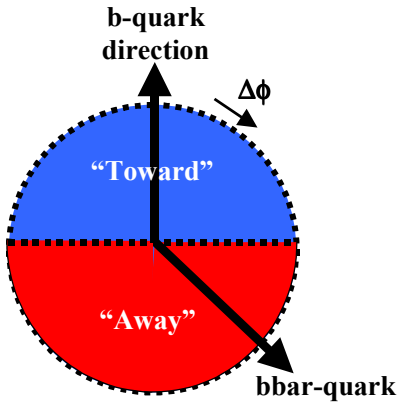
New PYTHIA default
(less initial-state radiation)

Old PYTHIA default
(more initial-state radiation)

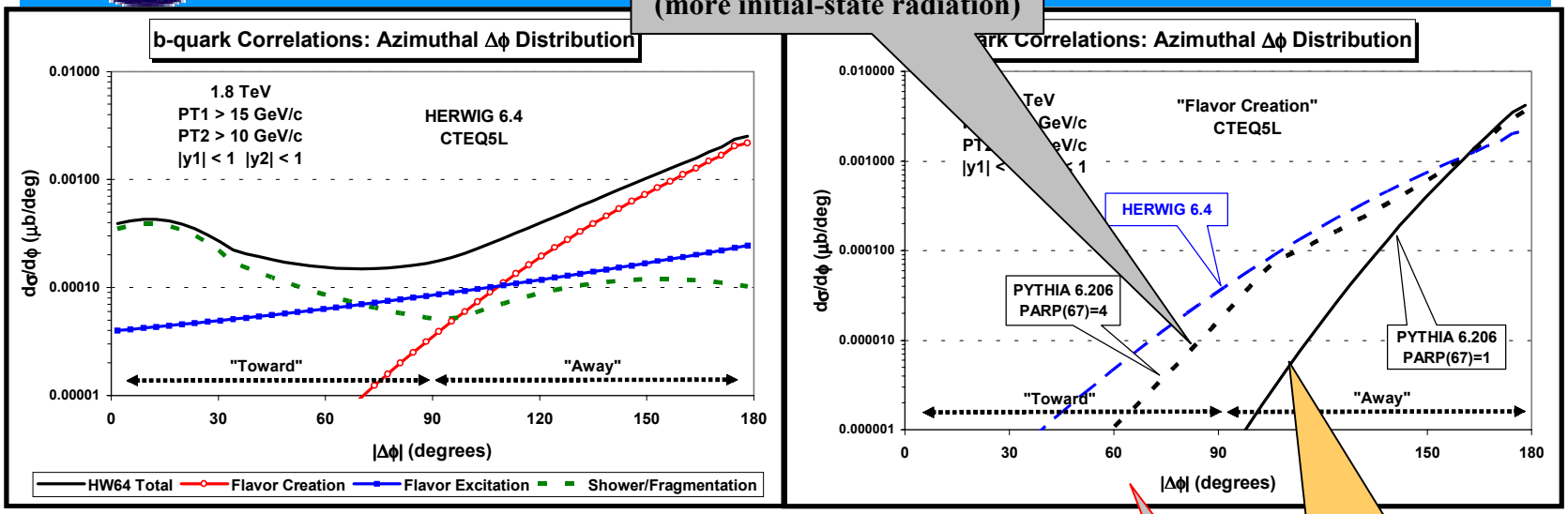
# Azimuthal Correlations




- **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.**



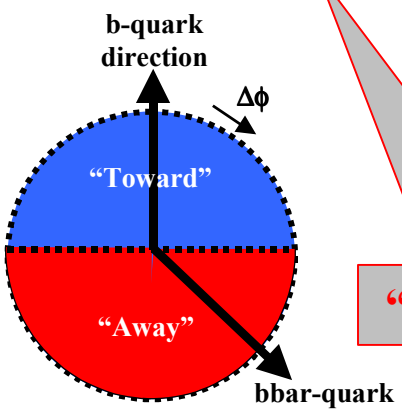
# Azimuthal Correlations




Old PYTHIA default
(more initial-state radiation)

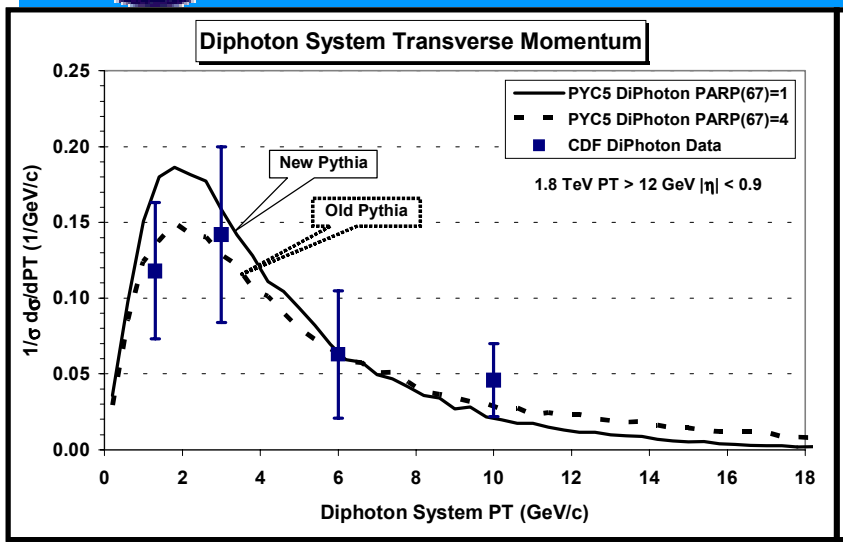
New PYTHIA default
(less initial-state radiation)

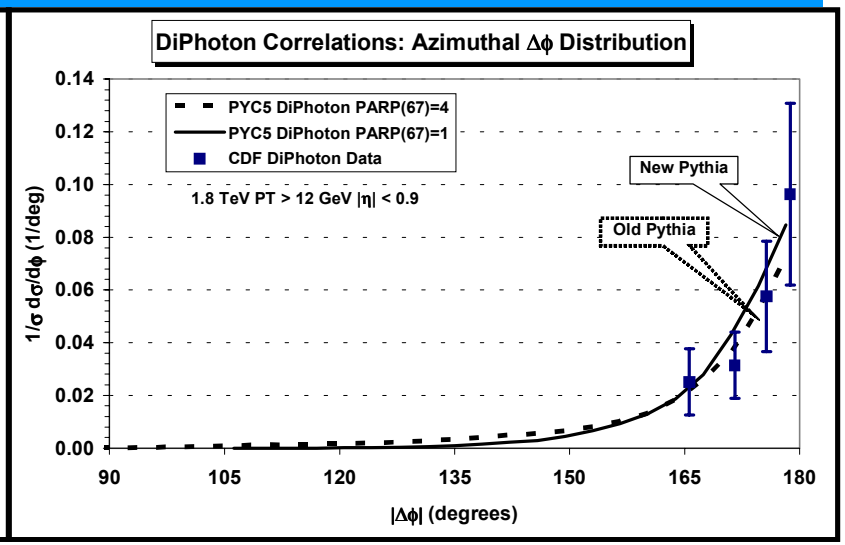
- **Predictions of HERWIG 6.4 (CTEQ5L) for the azimuthal angle, Δϕ, between a b-quark with $PT_1 > 15$ GeV/c, $|y_1| < 1$ and bbar-quark with $PT_2 > 10$ GeV/c, $|y_2|<1$ in proton-antiproton collisions at 1.8 TeV. The curves correspond to dσ/dΔϕ (μb/°) for flavor creation, flavor excitation, shower/fragmentation,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



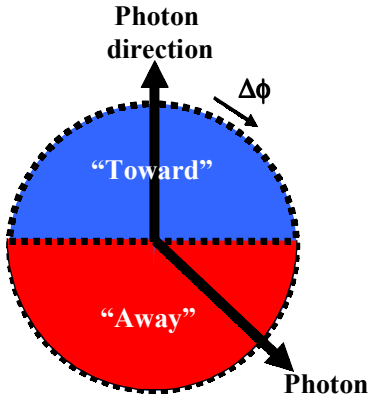

**"Flavor Creation"**

# DiPhoton Correlations

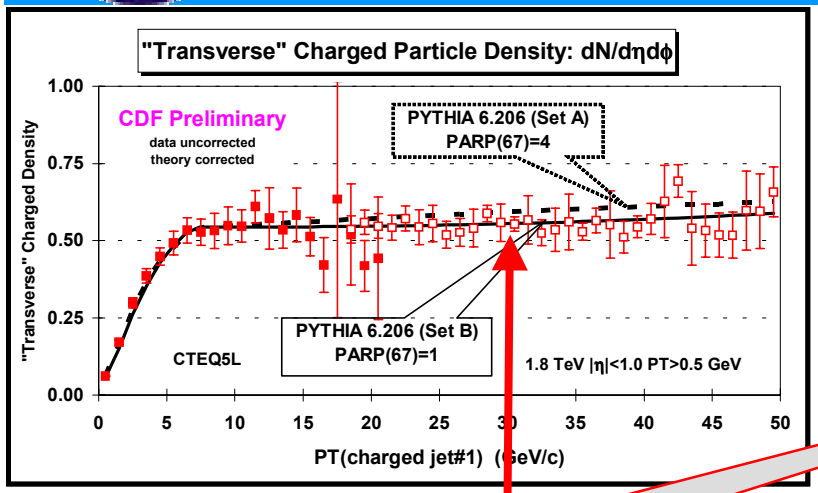


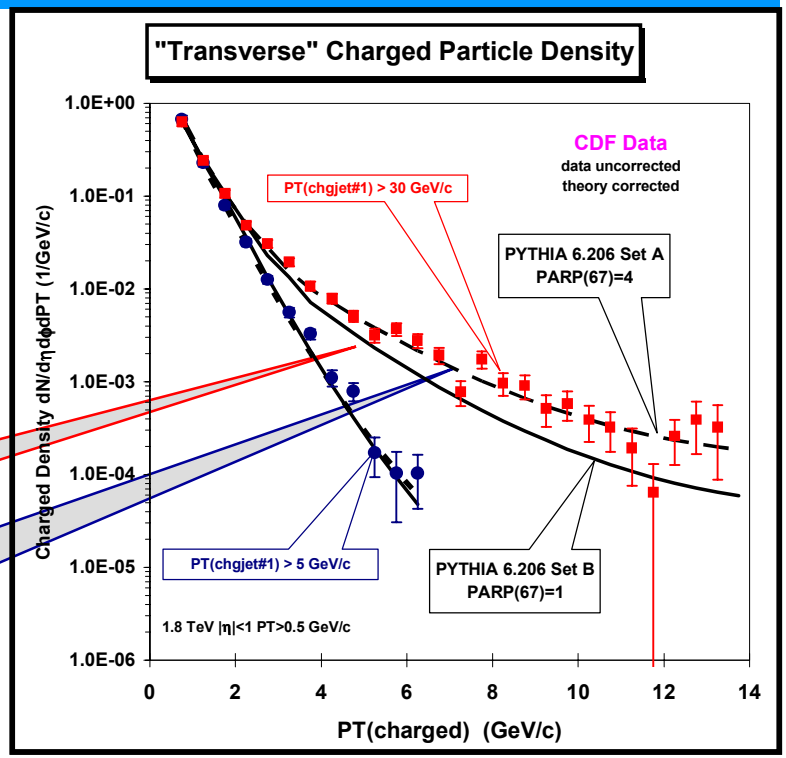




- **Predictions of PYTHIA 6.158 (CTEQ5L) with PARP(67)=1 (new default) and PARP(67)=4 (old default) for diphoton system PT and the azimuthal angle, Δφ, between a photon with $PT_1 > 12$ GeV/c, $|y_1| < 0.9$ and photon with $PT_2 > 12$ GeV/c, $|y_2| < 0.9$ in proton-antiproton collisions at 1.8 TeV compared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



# Tuned PYTHIA 6.206 "Transverse" $P_T$ Distribution



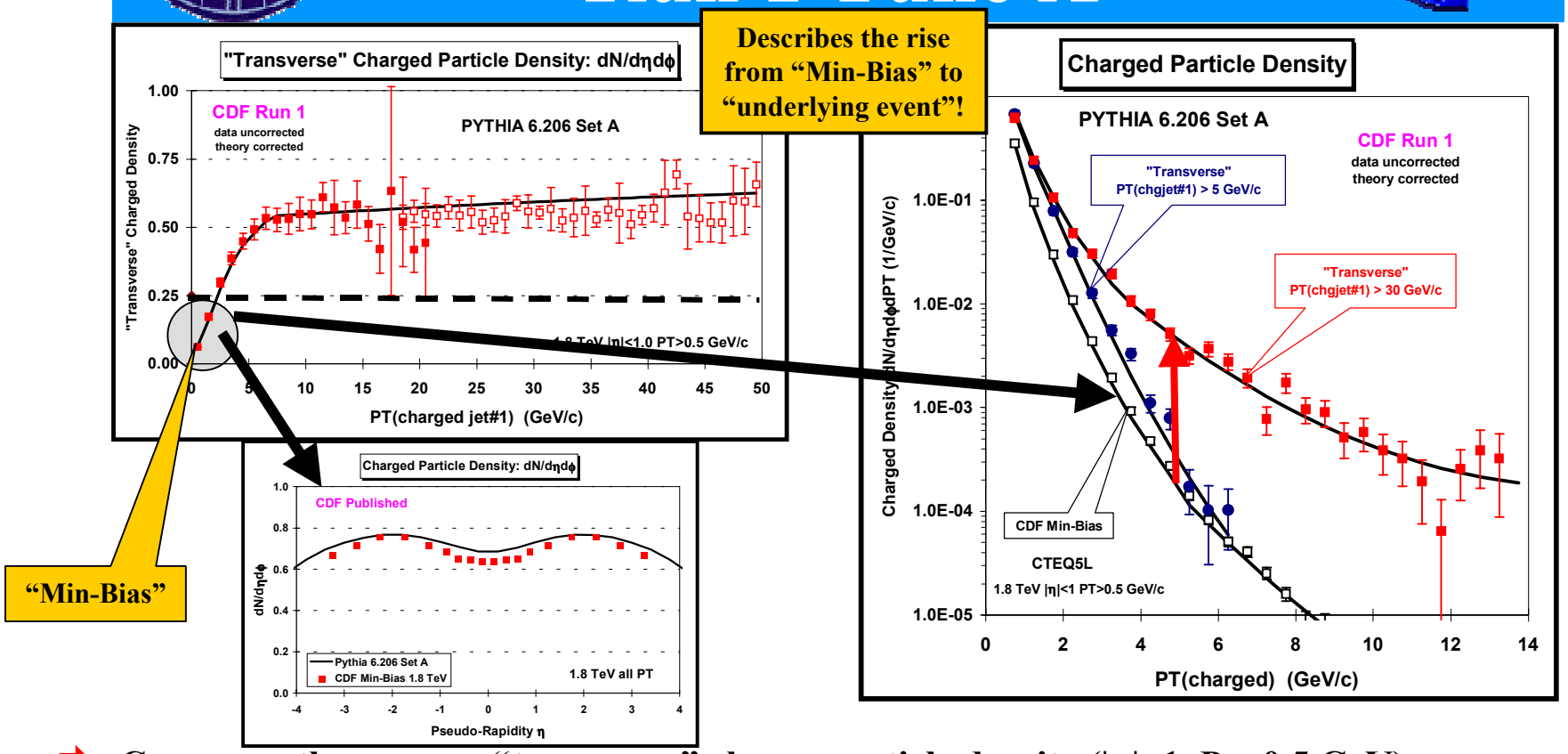




$P_T$(charged jet#1) > 30 GeV/c

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

- **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
# Run 1 Tune A

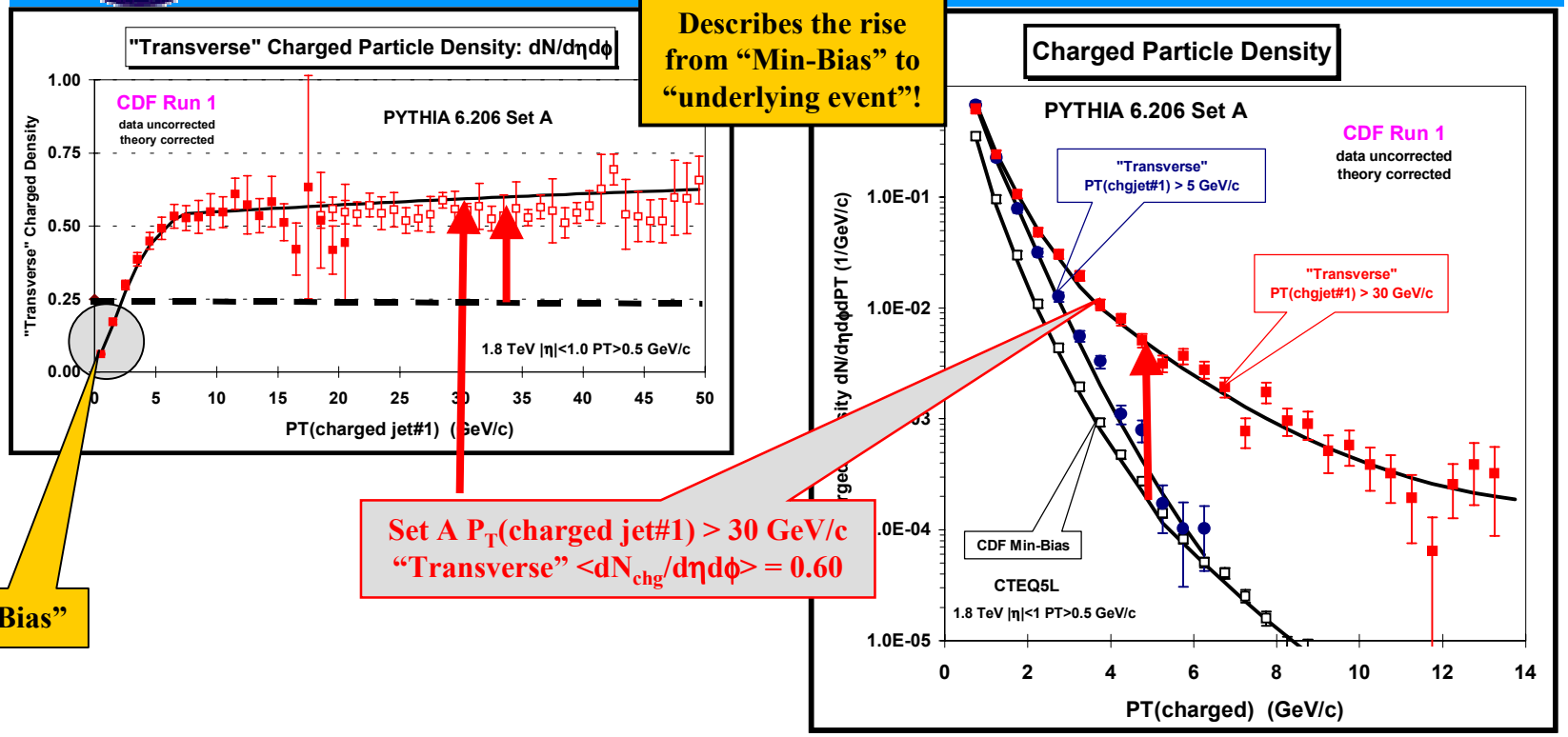



**Describes the rise from "Min-Bias" to "underlying event"!**

**"Min-Bias"**

➡ **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"!**

# Tuned PYTHIA 6.206
# Run 1 Tune A



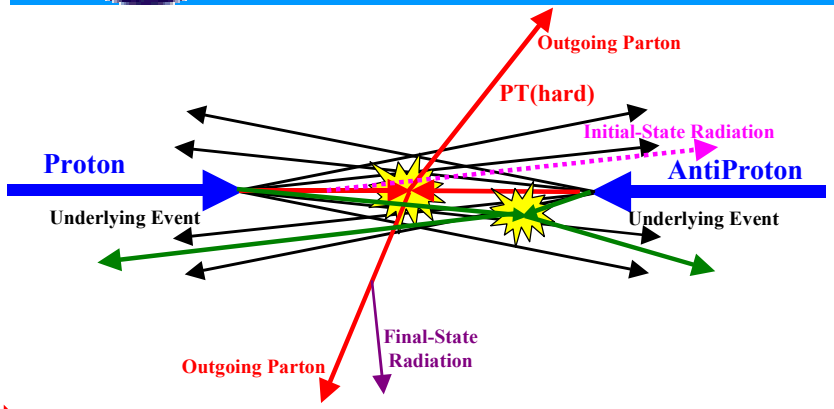

**Describes the rise from "Min-Bias" to "underlying event"!**

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

**"Min-Bias"**

➡ **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"!**

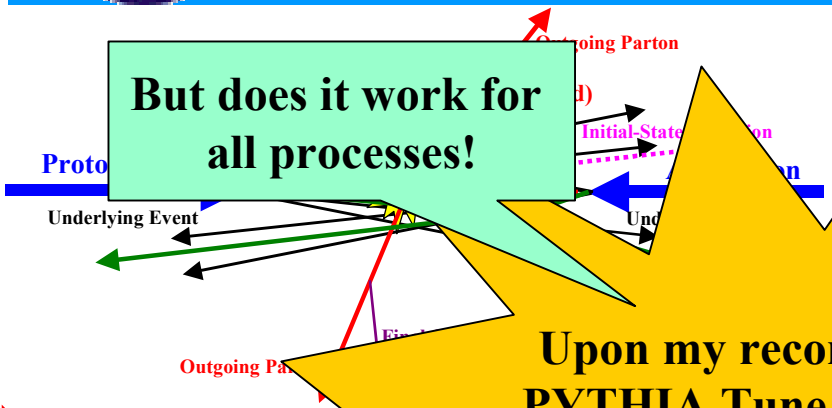
# Run 1 Summary




**"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.**

# Run 1 Summary



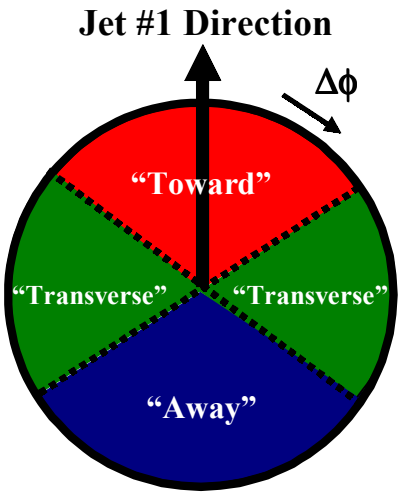

But does it work for all processes!

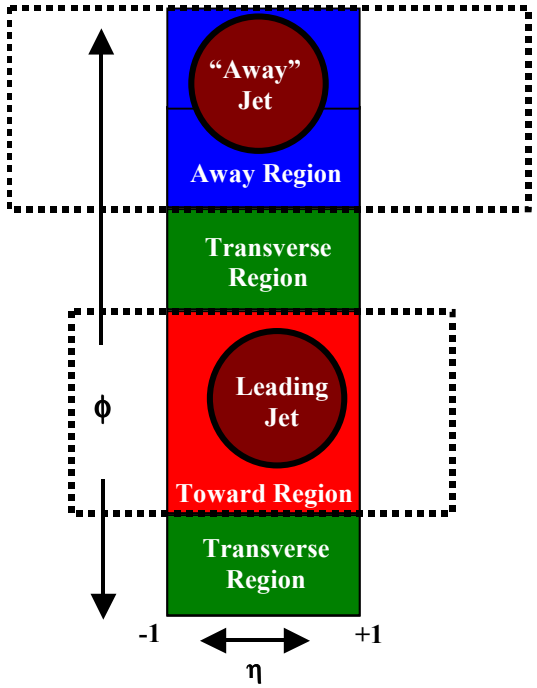
"Min-Bias" and
derlying Event"

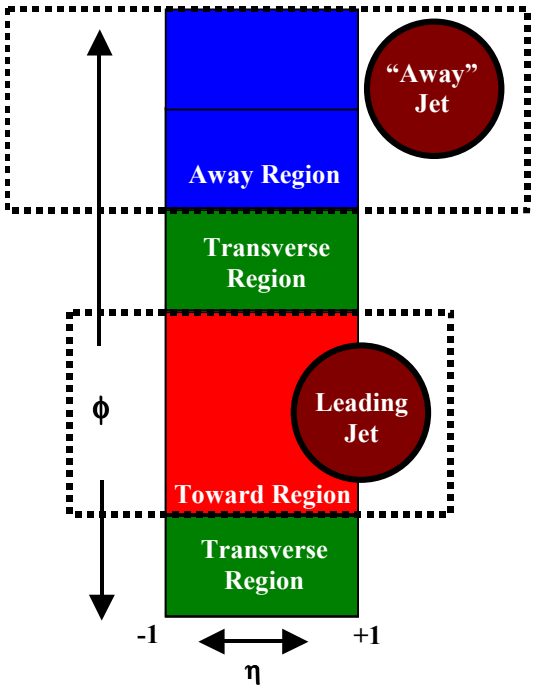
Upon my recommendation PYTHIA Tune A was chosen as the default parameterization in Run 2 at CDF!

- PYTHIA (tune "A "min-bias" collisions and the "underlying un I data.
- PYTHIA (tune "A" ludes both "soft" and "hard" scatt
- Both ISAJET and HERWI dence of the "beam-beam remnant" component of th ev d hen not have enough beam-beam remnants with $P_T$ > .5 GeV
- PYTHIA tune "A" is slightly favor ver tune 3", but eventually the best fit may be somewhere in between. The initial- te radiation in tune "A" with PARP(67) = 4 (used in all Run I simulations) looks more ike HERWIG's initial-state radiation.

# CDF Run 2
# Calorimeter Jet Analysis

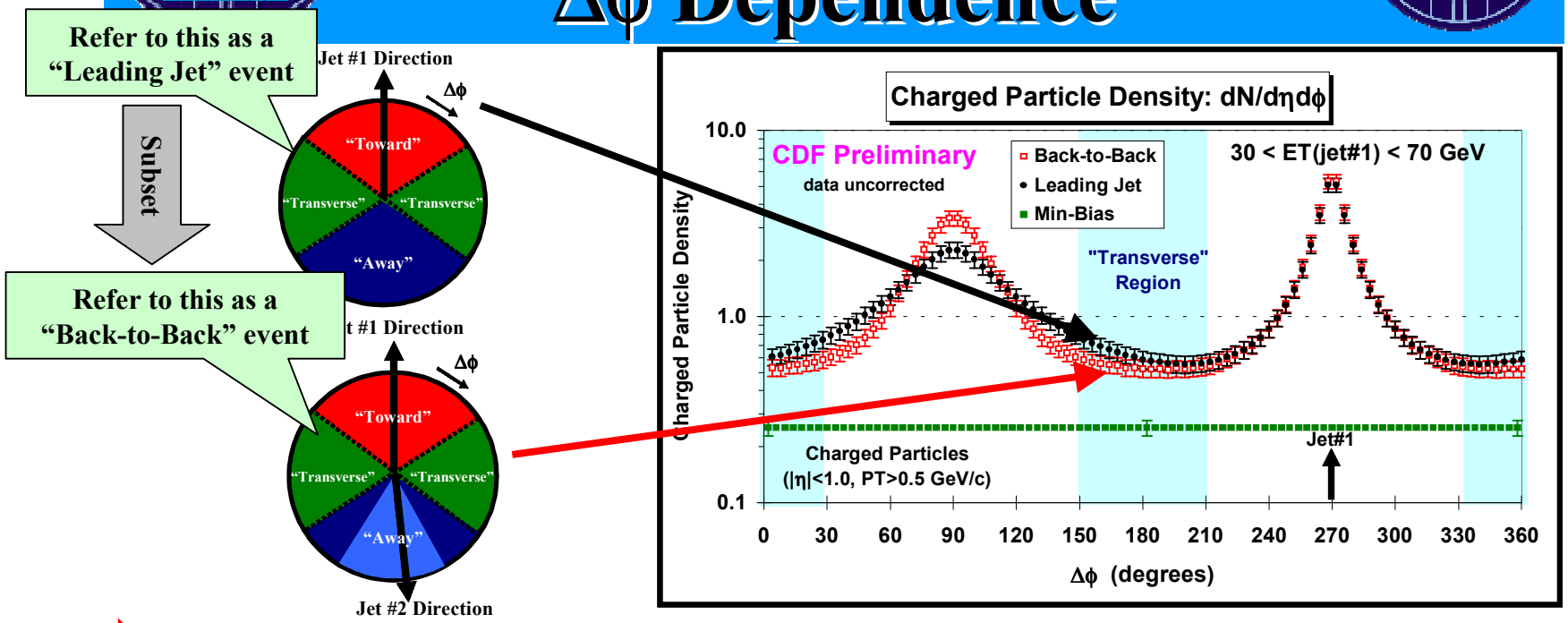


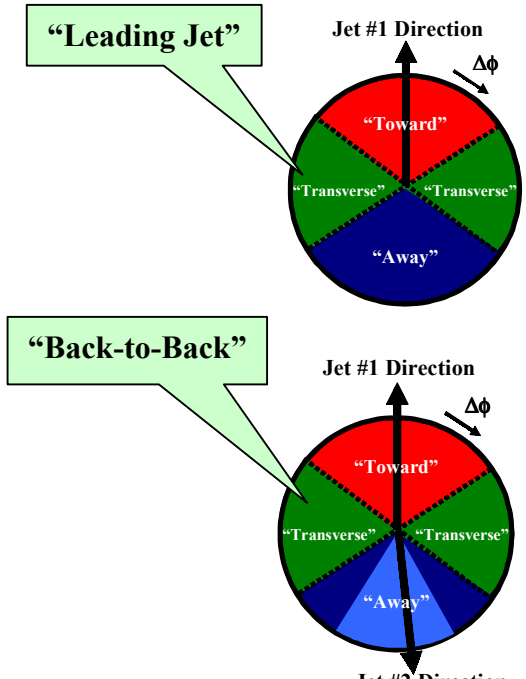

- Study the $\Delta\phi$ distribution of the charged particle density, **dNchg/dηdϕ**, and the charged scalar $p_T$ sum density, **dPTsum/dηdϕ**, for charged particles in the region $p_T > 0.5$ GeV/c, $|\eta| < 1$).
- Study the average charged particle and PTsum density in the **"toward"**, **"transverse"**, and **"away"** regions versus $E_T$(jet#1).

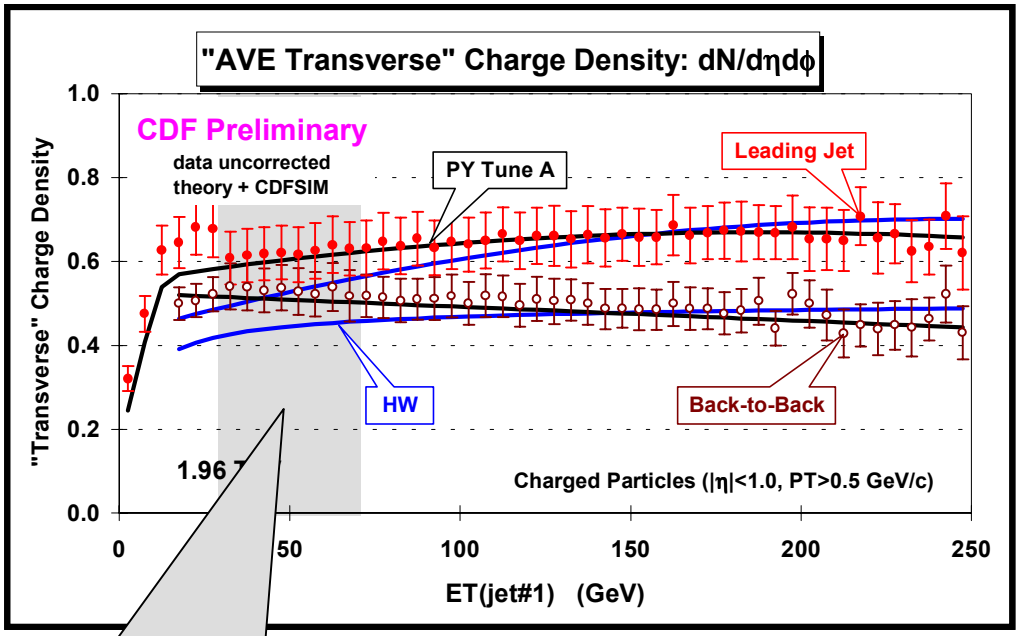
# Charged Particle Density
# Δϕ Dependence




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

# "Transverse" Charge Density
# PYTHIA Tune A vs HERWIG



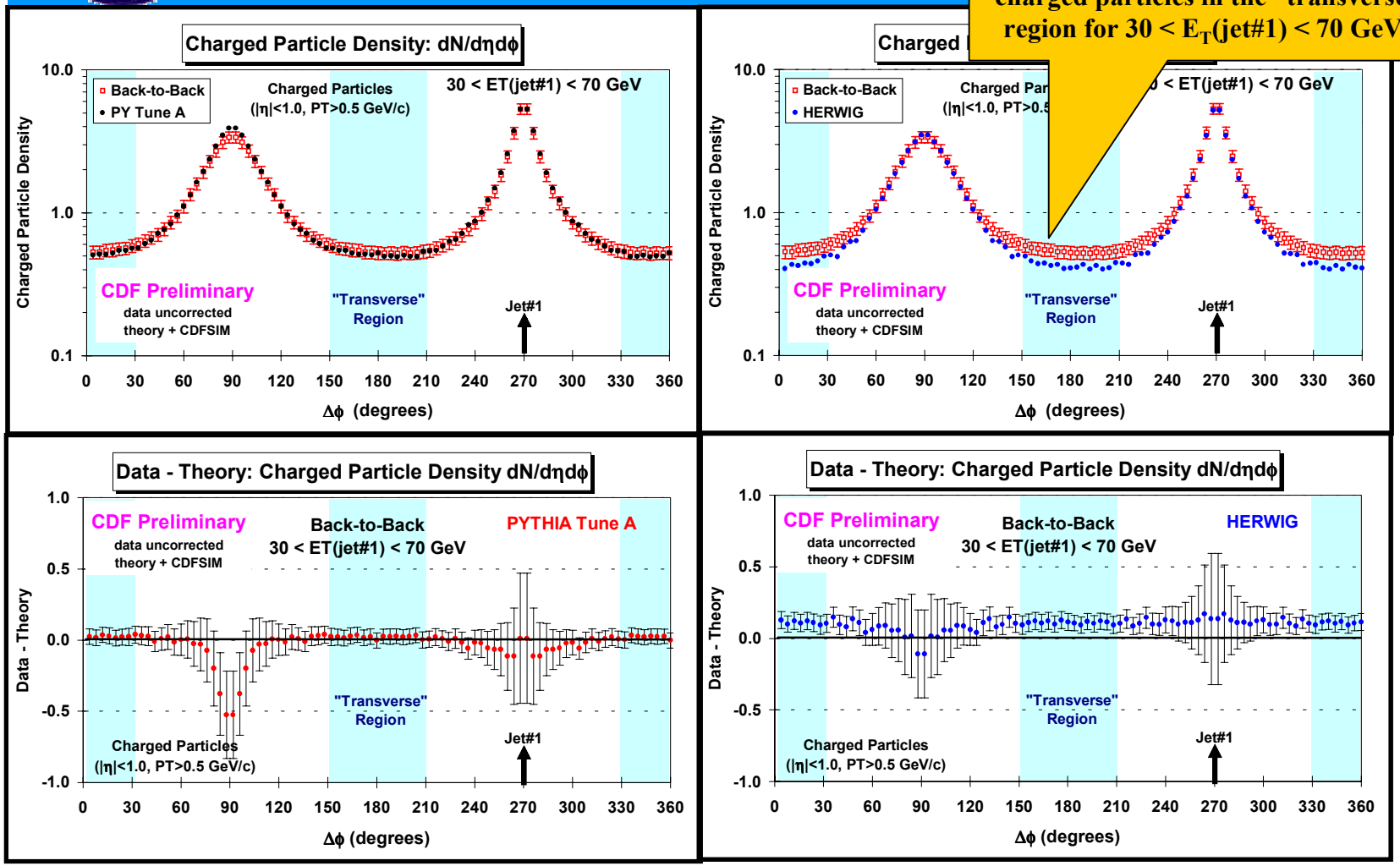




Now look in detail at "back-to-back" events in the region 30 < $E_T$(jet#1) < 70 GeV!

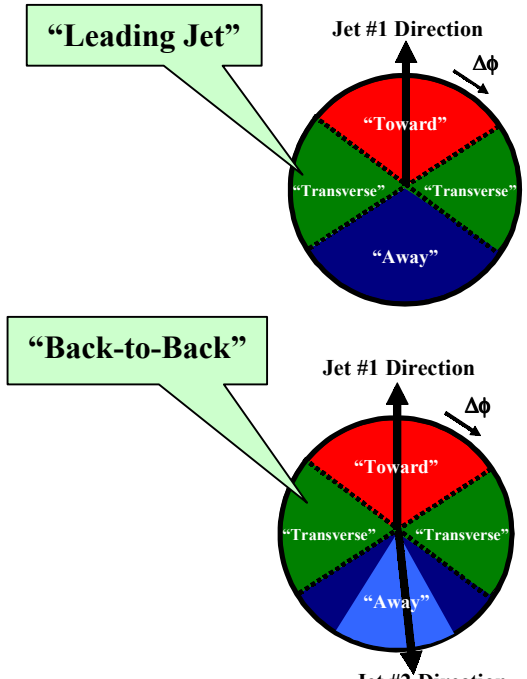
- Shows the average charged particle density, $dN_{chg}/d\eta d\phi$, in the "transverse" region ($p_T$ > 0.5 GeV/c, $|\eta|$ < 1) versus $E_T$(jet#1) for "Leading Jet" and "Back-to-Back" events.
- Compares the (*uncorrected*) data with PYTHIA Tune A and HERWIG after CDFSIM.

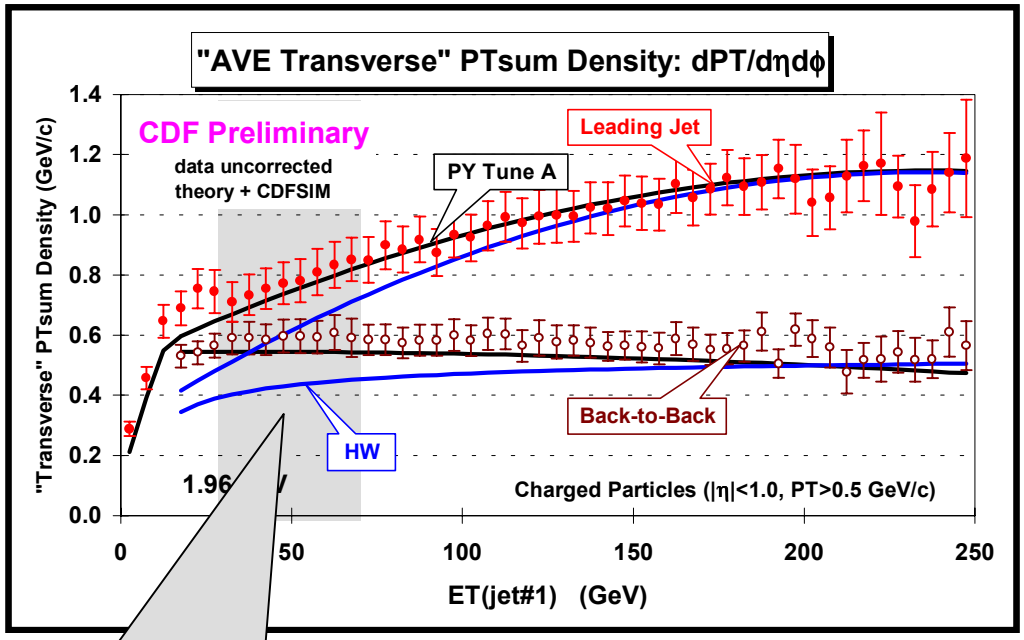
# Charged Particle Density
# PYTHIA Tune A vs HE

HERWIG (*without multiple parton interactions*) produces too few charged particles in the "transverse" region for 30 < $E_T$(jet#1) < 70 GeV!



# "Transverse" PTsum Density
# PYTHIA Tune A vs HERWIG



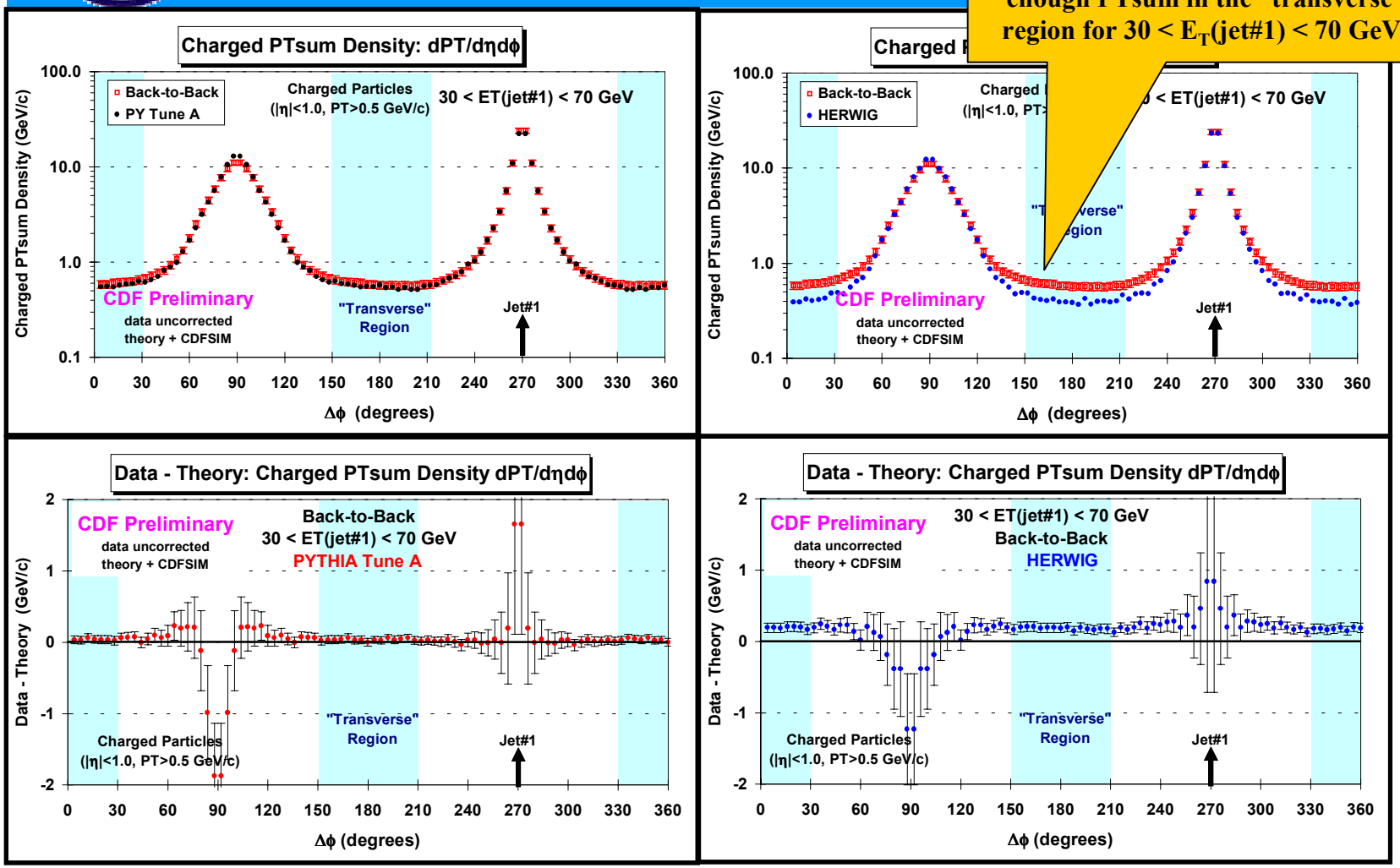




Now look in detail at "back-to-back" events in the region 30 < $E_T$(jet#1) < 70 GeV!

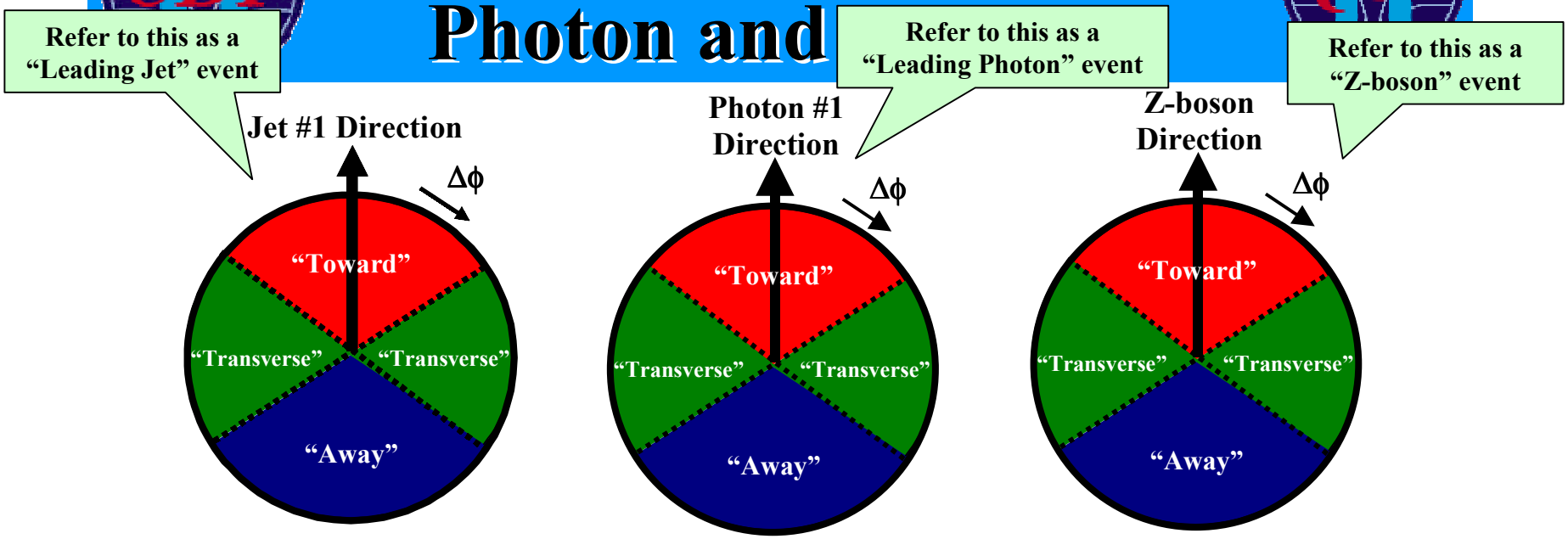
- Shows the average charged PTsum density, $dPT_{sum}/d\eta d\phi$, in the "transverse" region ($p_T$ > 0.5 GeV/c, $|\eta|$ < 1) versus $E_T$(jet#1) for "Leading Jet" and "Back-to-Back" events.
- Compares the (*uncorrected*) data with PYTHIA Tune A and HERWIG after CDFSIM.

# Charged PTsum Density
# PYTHIA Tune A vs HE

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



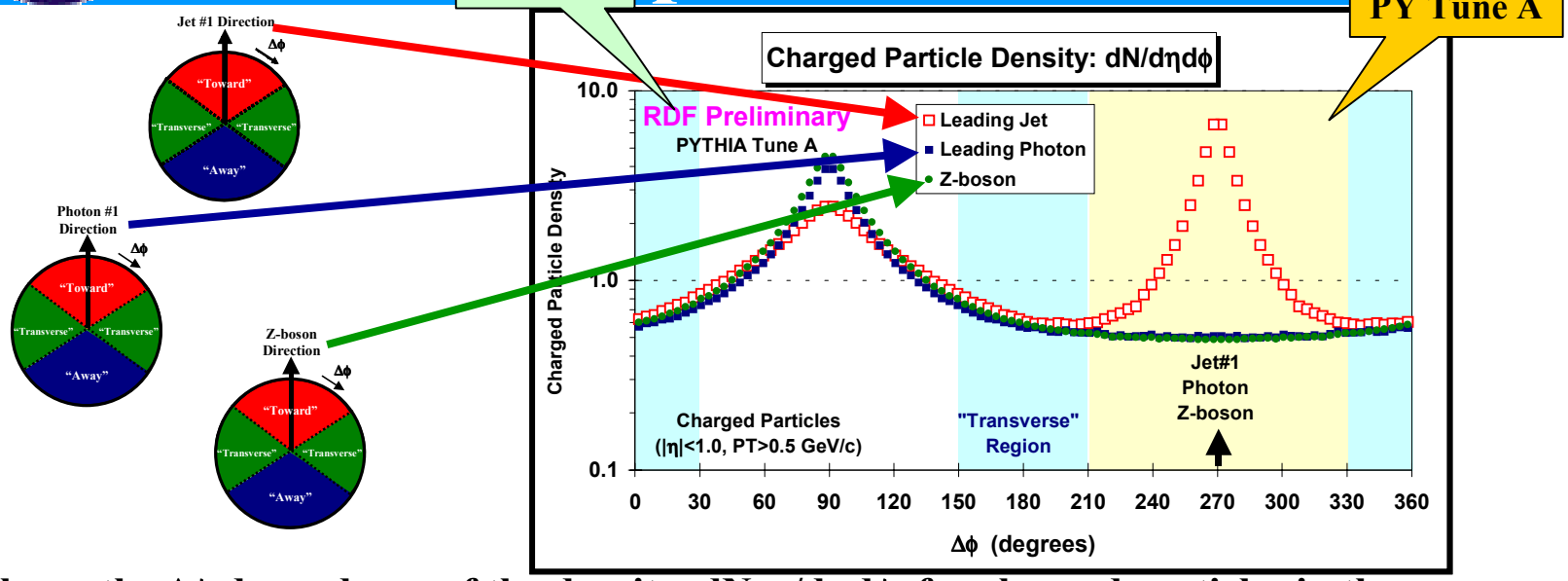
# New CDF Run 2 Analysis Photon and




- Study the Δϕ distribution of the charged particle density, dNchg/dηdϕ, and the charged scalar $p_T$ sum density, dPTsum/dηdϕ, 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

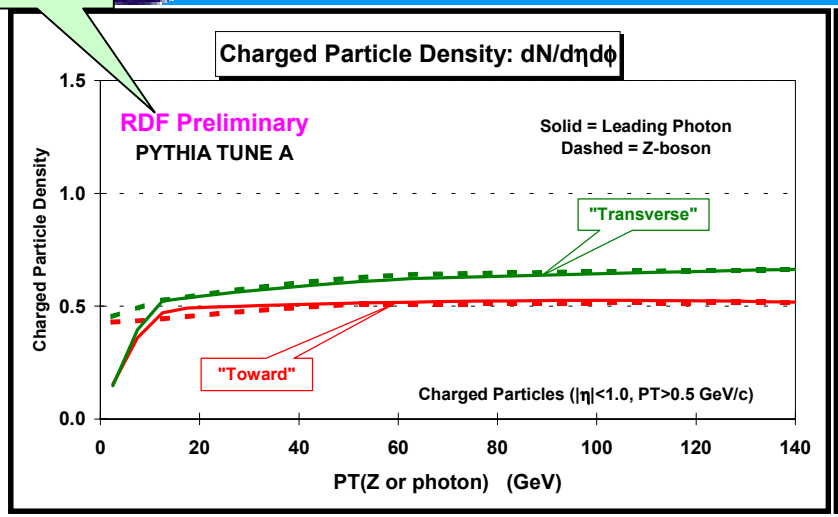


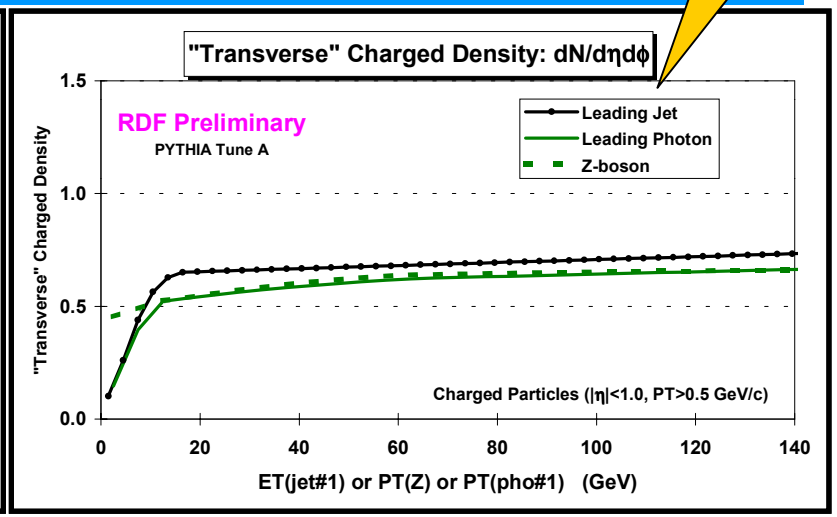

- Shows the Δφ dependence of the density, $dN_{chg}/d\eta d\phi$, for charged particles in the range $p_T > 0.5$ GeV/c and $|\eta| < 1$ relative to jet#1 (rotated to 270°) for $E_T$(jet#1) > 30 GeV for "Leading Jet" events from PYTHIA Tune A.
- Shows the Δφ dependence of the density, $dN_{chg}/d\eta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

# "Towards" and "Transverse" Particle Densities

rdfsoft!

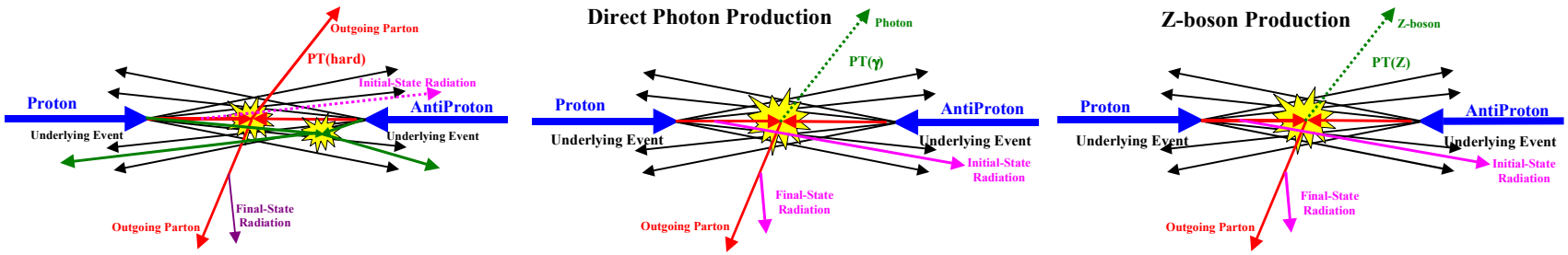
PY Tune A




- **Shows the average charged particle density, $dN_{chg}/d\eta d\phi$, in the "toward" and "transverse" region ($p_T > 0.5$ GeV/c, $|\eta| < 1$) versus $P_T$(pho#1) for "Leading Photon" events (*solid*) and versus $P_T$(Z) for "Z-boson" events (*dashed*) at 1.96 TeV from PYTHIA Tune A.**
- **Shows the average charged particle density, $dN_{chg}/d\eta d\phi$, in the "transverse" region ($p_T > 0.5$ GeV/c, $|\eta| < 1$) versus $P_T$(pho#1) for "Leading Photon" events (*solid*) and versus $P_T$(Z) for "Z-boson" events (*dashed*) and versus $E_T$(jet#!) for "Leading Jet" events (dots) at 1.96 TeV from PYTHIA Tune A.**

# Summary




- **I am working on a "universal" PYTHIA Run 2 tune: QCD jets, direct photons, Z and W bosons, Drell-Yan, heavy flavor production, etc..**
- **I am just getting started, but so far I have seen no major problems with PYTHIA Tune A except that I should have included a larger intrinsic $k_T$ (*I used the default*).**
- **In addition to specifying the PDF and the MPI parameters, one will have to 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.**

**I have hear rumors of problems, but I have to see it myself!**