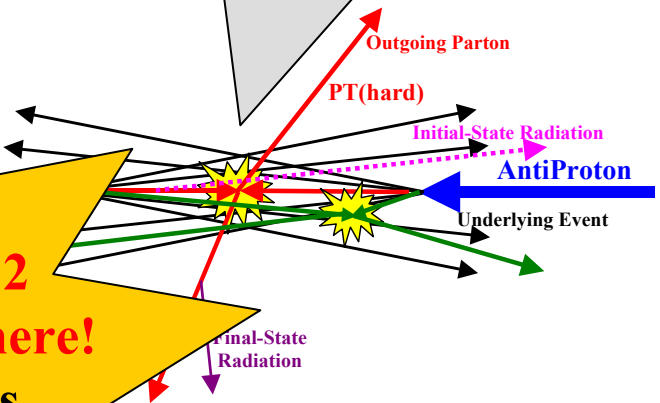
The "Underlying Event" in Run 2 at CDF

The "underlying event" consists of hard initial & final-state radiation plus the "beam-beam remnants" and possible multiple parton interactions.



CERN MC4LHC Workshop

July 2003

During the workshop t[illegible]eorists, ATLA[illegible]MS experimenters, and I constr[illegible]"wish l[illegible]ata from CDF relating to "[illegible] "underlying event" and I promi[illegible] and make the d[illegible]

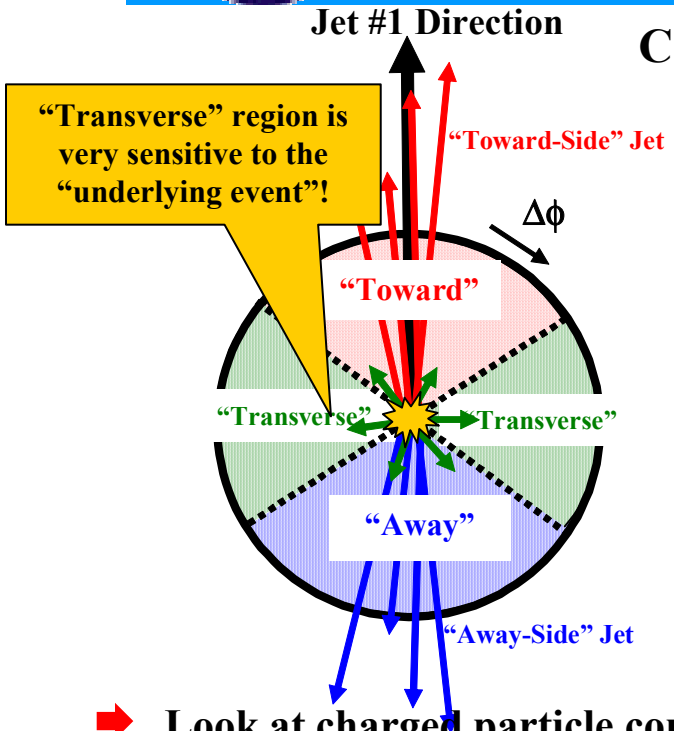
Much more new Run 2 results than I can show here!

I will show a few plots of each type and give a preview of more to come!

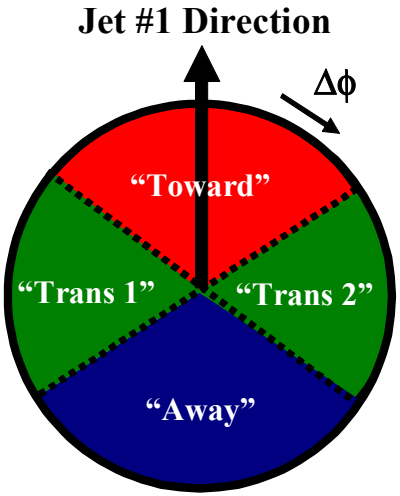
New CDF Run 2 resu[illegible]

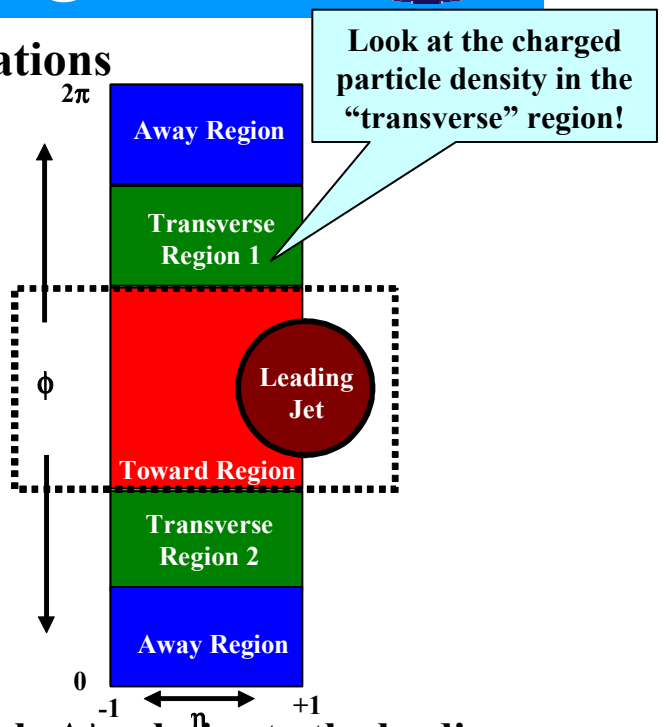
- **Two Classes of E[illegible]-Back".**
- **Two "Transverse" regio[illegible]N", "transDIF".**
- **PTmax and PTmaxT di[illegible]an[illegible]ages.**
- **Δϕ Distributions: "Density" an[illegible]Assoc[illegible]d Density".**
- **$\langle p_T \rangle$ versus charged multiplici[illegible] "min-b[illegible]s" and the "transverse" region.**
- **Correlations between the two "[illegible]ransverse" regions: "trans1" vs "trans2".**

The "Transverse" Regions
as defined by the Leading Jet



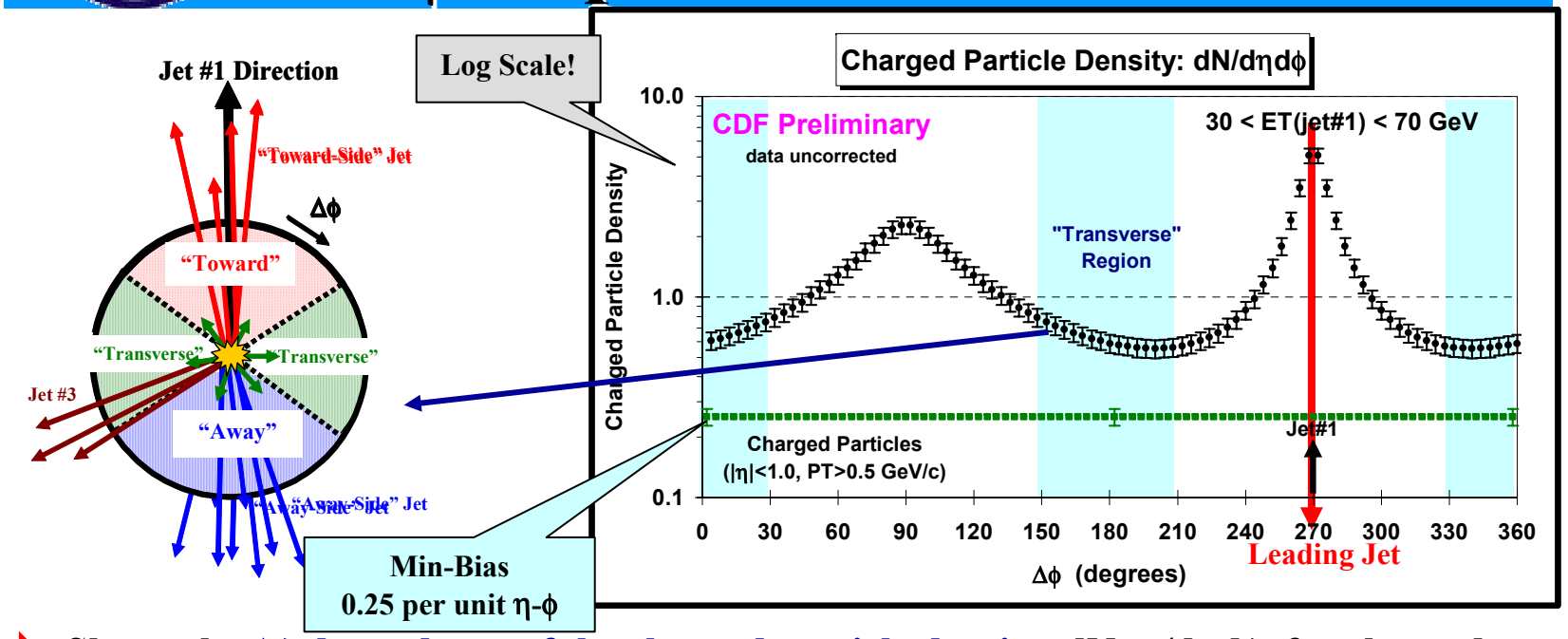
Charged Particle Δφ Correlations
$p_T > 0.5$ GeV/c $|\eta| < 1$





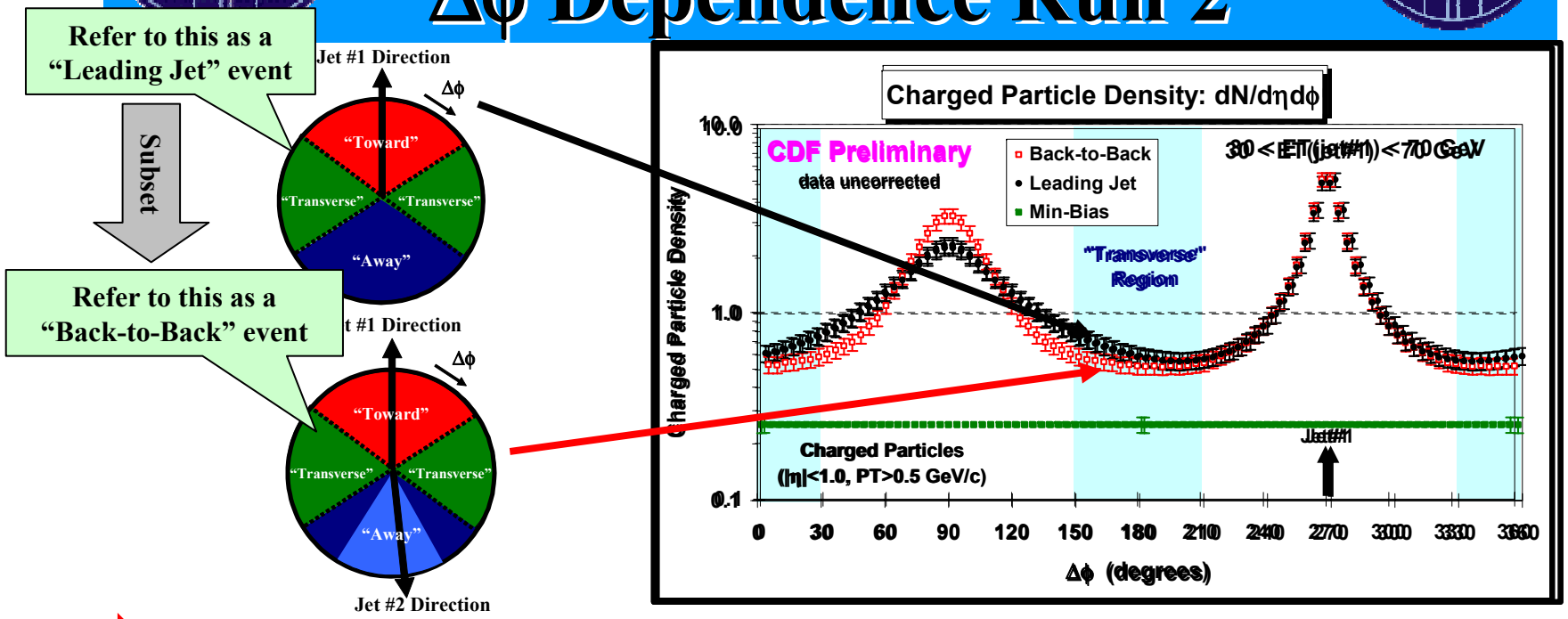
- Look at charged particle correlations in the azimuthal angle Δφ relative to the leading calorimeter jet (JetClu R = 0.7, $|\eta| < 2$).
- Define $|\Delta\phi| < 60^o$ as "Toward", $60^o < -\Delta\phi < 120^o$ and $60^o < \Delta\phi < 120^o$ as "Transverse 1" and "Transverse 2", and $|\Delta\phi| >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

Charged Particle Density Δϕ Dependence Run 2



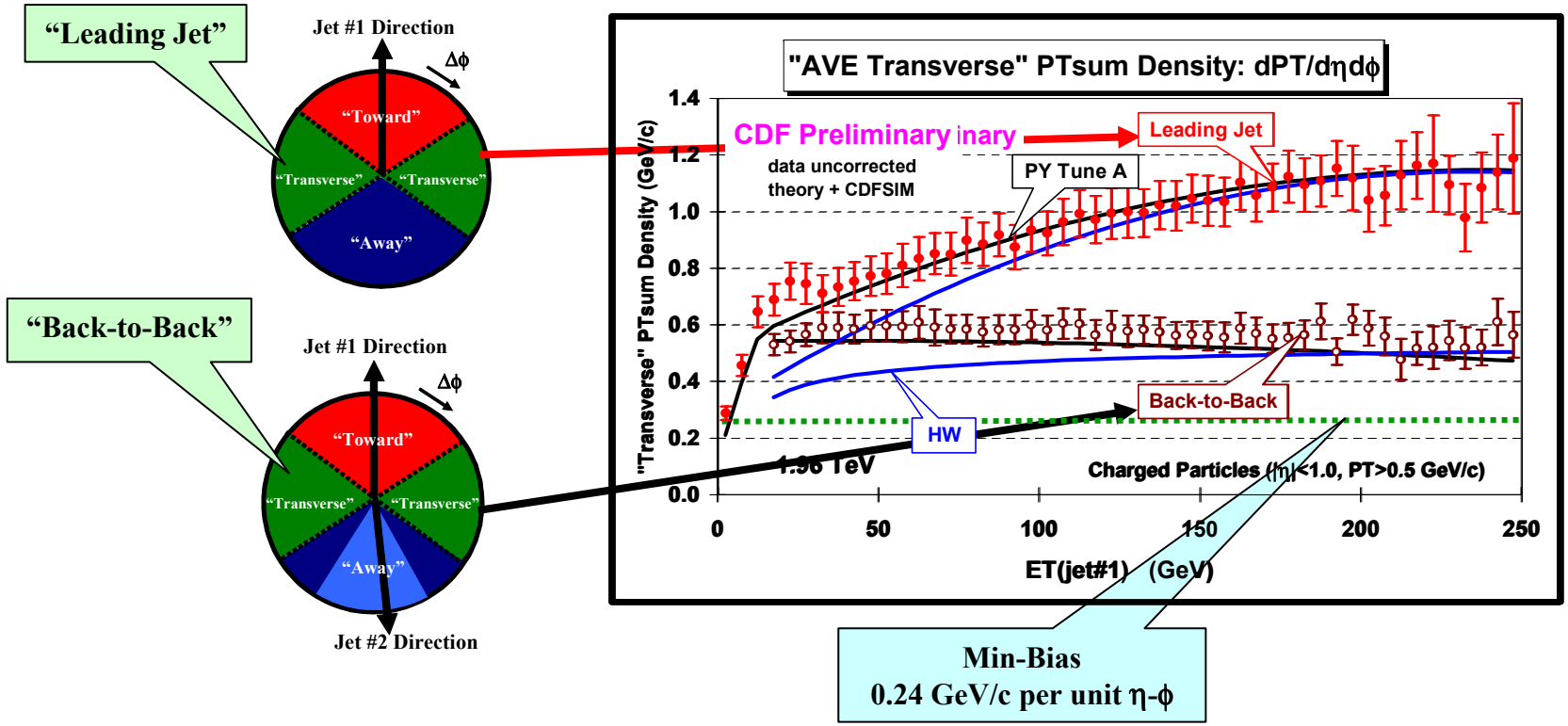
- Shows the Δϕ dependence of the charged particle density, $dN_{chg}/d\eta d\phi$, for charged particles in the range $p_T > 0.5$ GeV/c and $|\eta| < 1$ relative to jet#1 (rotated to 270°) for "leading jet" events $30 < E_T(\text{jet\#1}) < 70$ GeV.
- Also shows charged particle density, $dN_{chg}/d\eta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

Charged Particle Density Δϕ Dependence Run 2



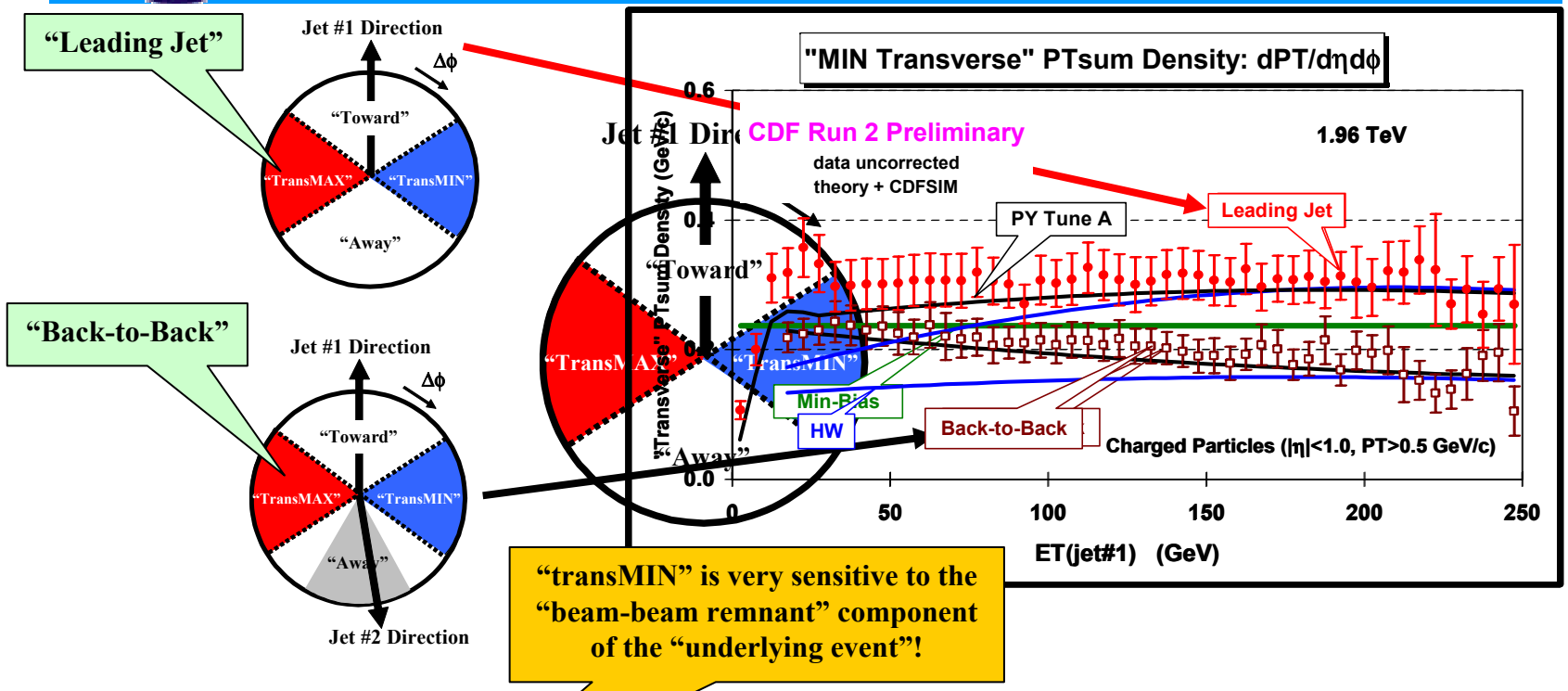
- Look at the "transverse" region as defined by the leading jet or by the leading two jets (JetClu R = 0.7, $|\eta| < 2$). "Back-to-Back" events are selected to have at least two jets with $E_T > 15$ GeV with Jet#1 and Jet#2 nearly "back-to-back" ($\Delta\phi_{12} > 150^o$) with almost equal transverse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

"Transverse" PTsum Density 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.

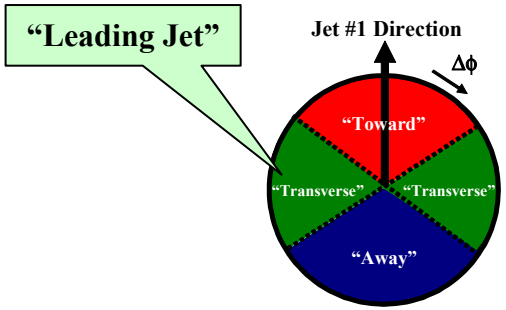
"TransMIN" PTsum Density versus E_T(jet#1)

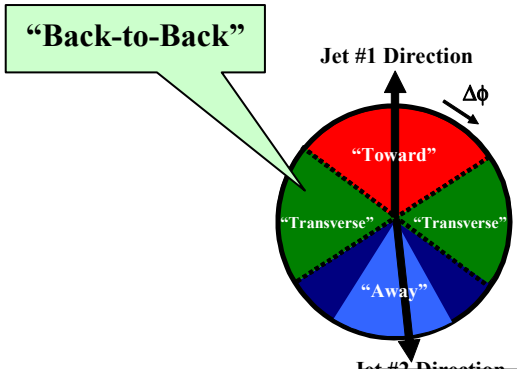


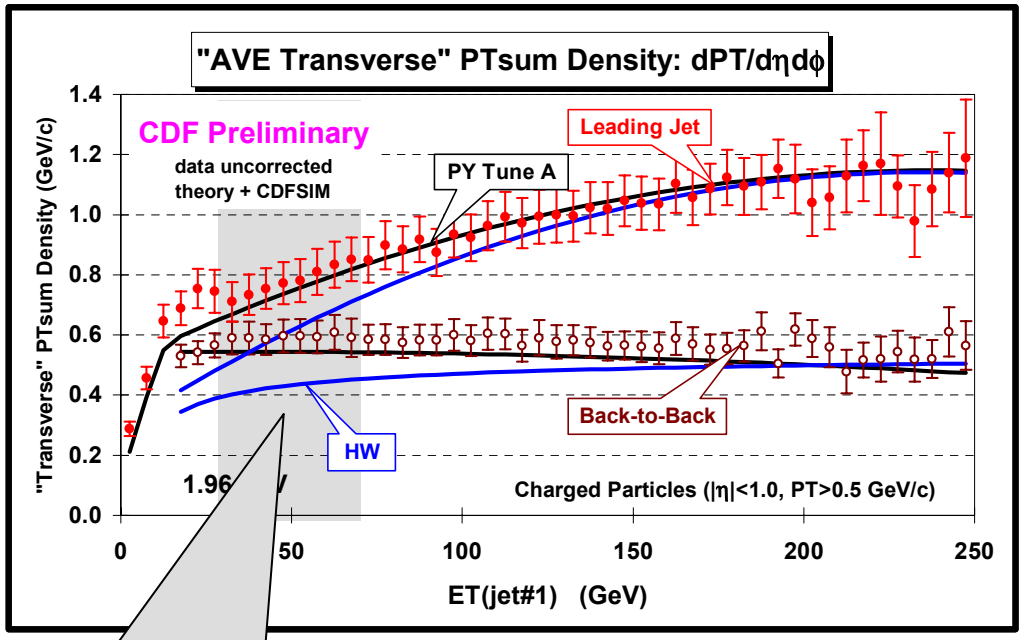
"transMIN" is very sensitive to the "beam-beam remnant" component of the "underlying event"!

- Use the leading jet to defin[illegible]MAX and MIN "transverse" regions on an event-by-event basis with MAX ([illegible]IN) 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







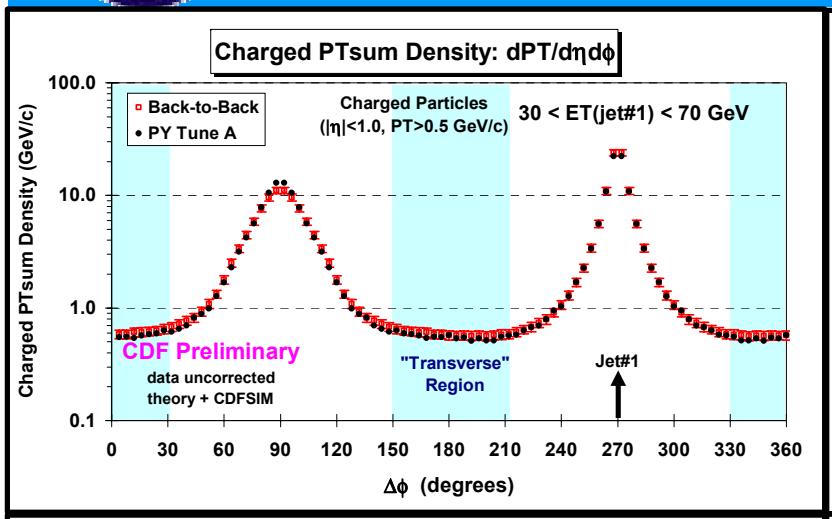
Now look in detail at "back-to-back" events in the region $30 < E_T(\text{jet\#1}) < 70$ GeV!

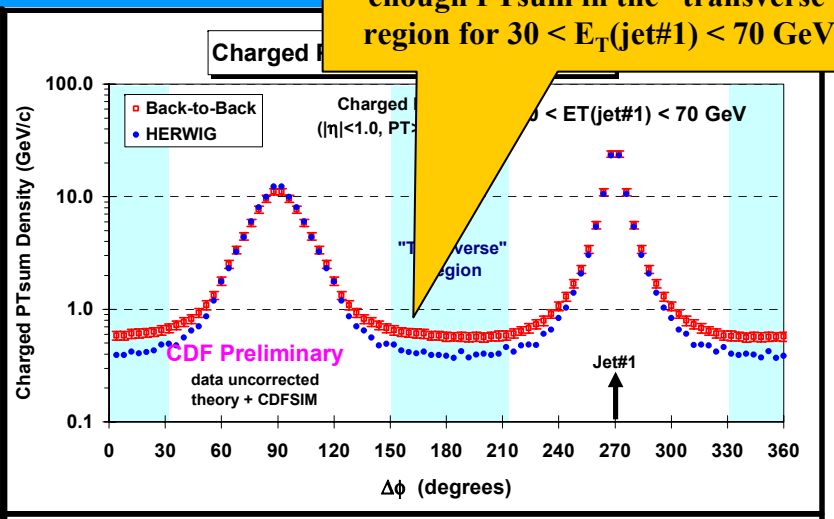
- Shows the average charged PTsum density, $dPT_{sum}/d\eta d\phi$, in the "transverse" region ($p_T > 0.5$ GeV/c, $|\eta| < 1$) versus E_T(jet#1) for "Leading Jet" and "Back-to-Back" events.
- Compares the (*uncorrected*) data with PYTHIA Tune A and HERWIG after CDFSIM.

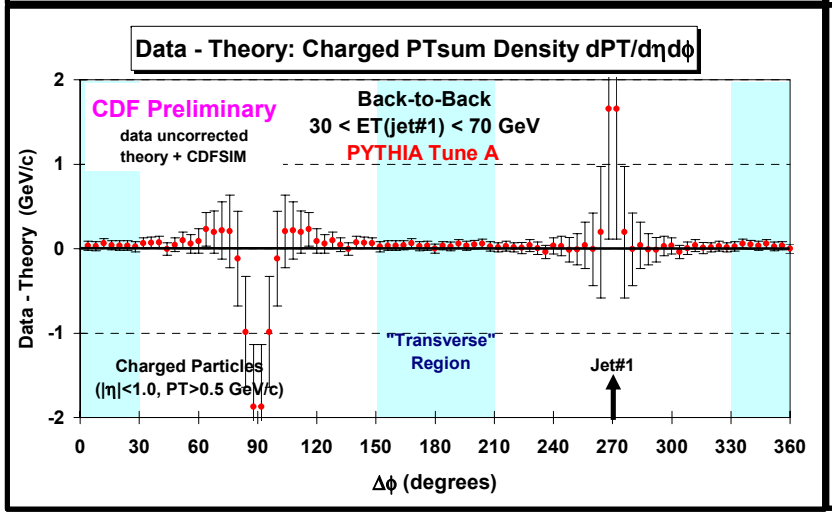
Charged PTsum Density

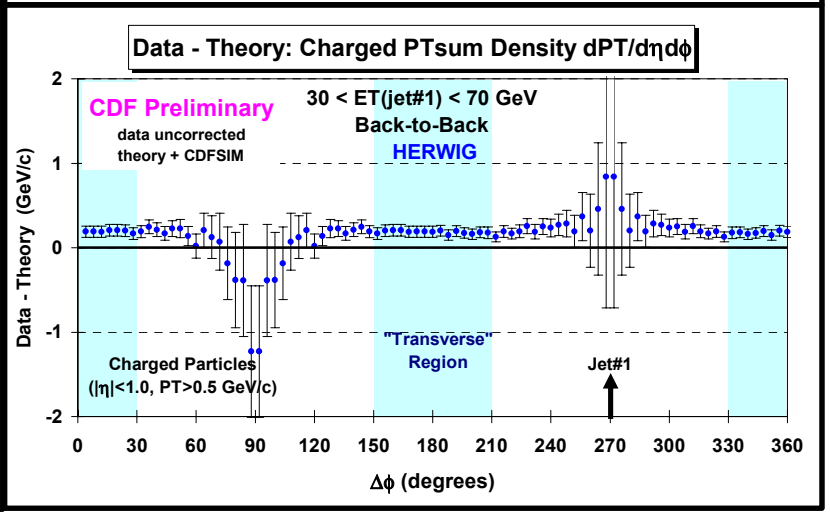
PYTHIA Tune A vs HE

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

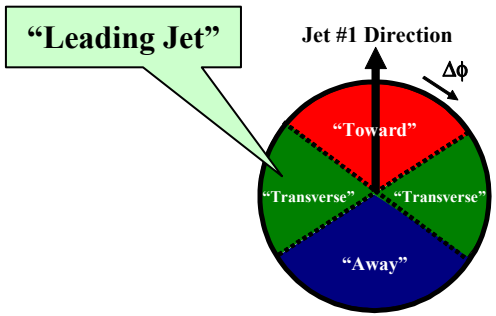


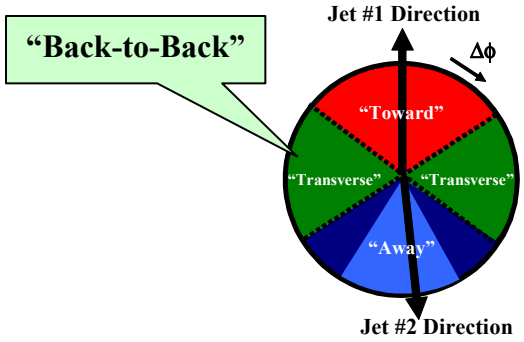






Summary

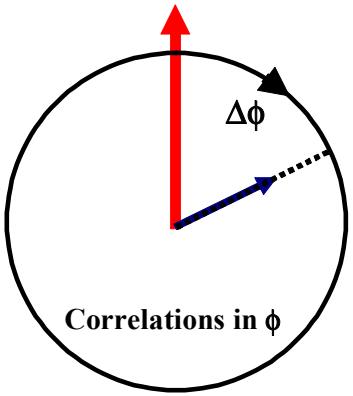




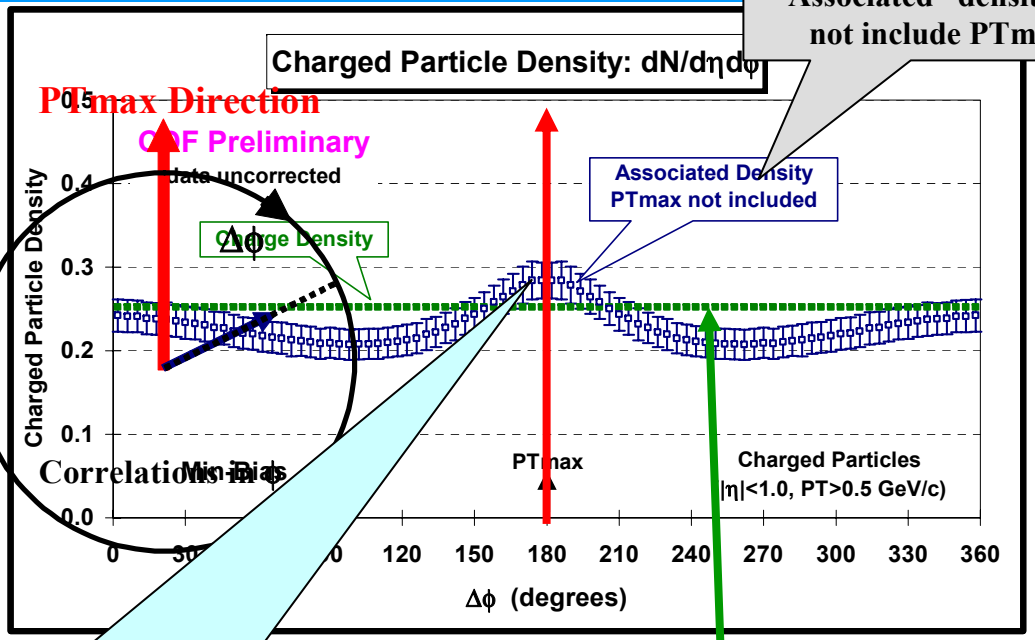
- **"Back-to-Back" events have less "hard scattering" (*initial and final state radiation*) component in the "transverse" region which allows for a closer look at the "beam-beam remnant" and multiple parton scattering component of the "underlying" event.**
- **PYTHIA Tune A (*with multiple parton scattering*) does a much better job in describing the "back-to-back" events than does HERWIG (*without multiple parton scattering*).**

Min-Bias "Associated" Charged Particle Density

Highest p_T charged particle!



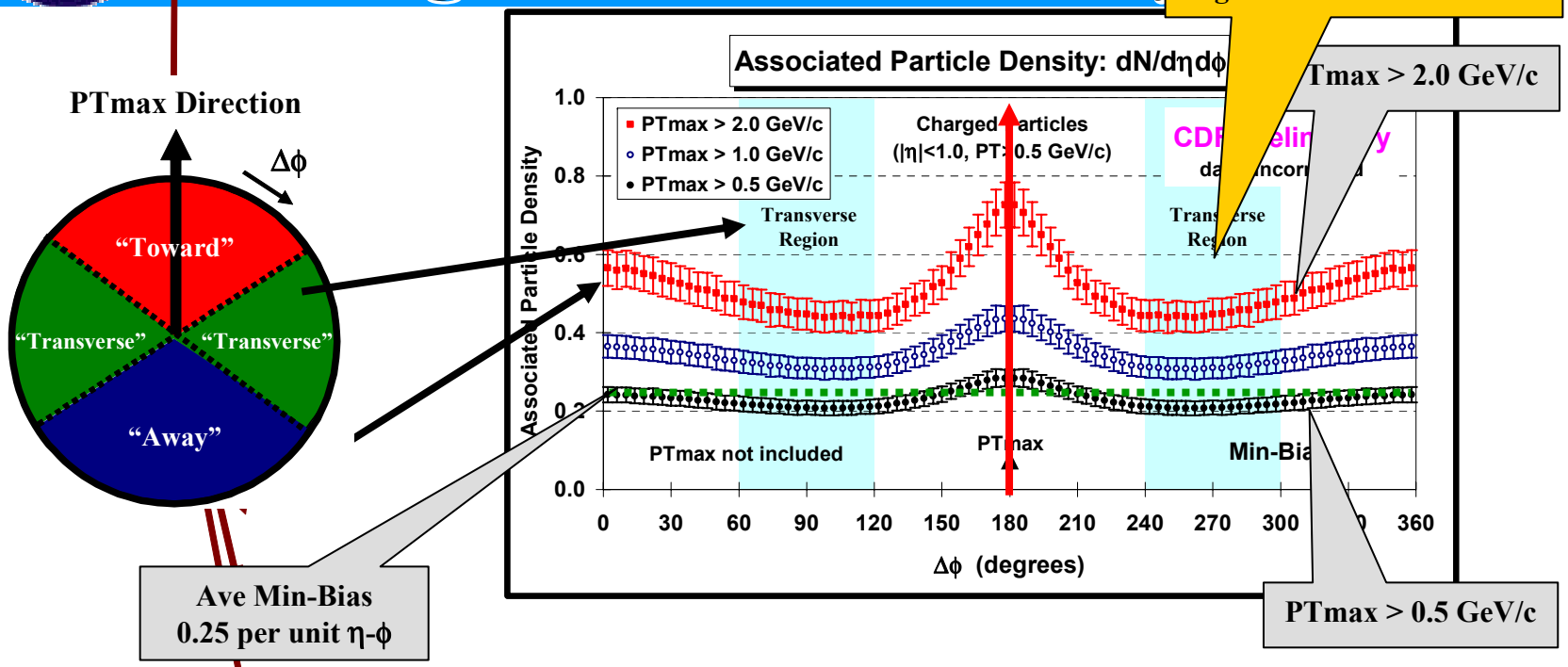
"Associated" densities do not include PTmax!



- Use the maximum p_T charged particle in the event, PTmax, to define a direction and look at the charged particle density in "min-bias" collisions ($p_T > 0.5$ GeV/c, |η|
- Shows 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.

It is more probable to find a particle accompanying PTmax than it is to find a particle in the central region!

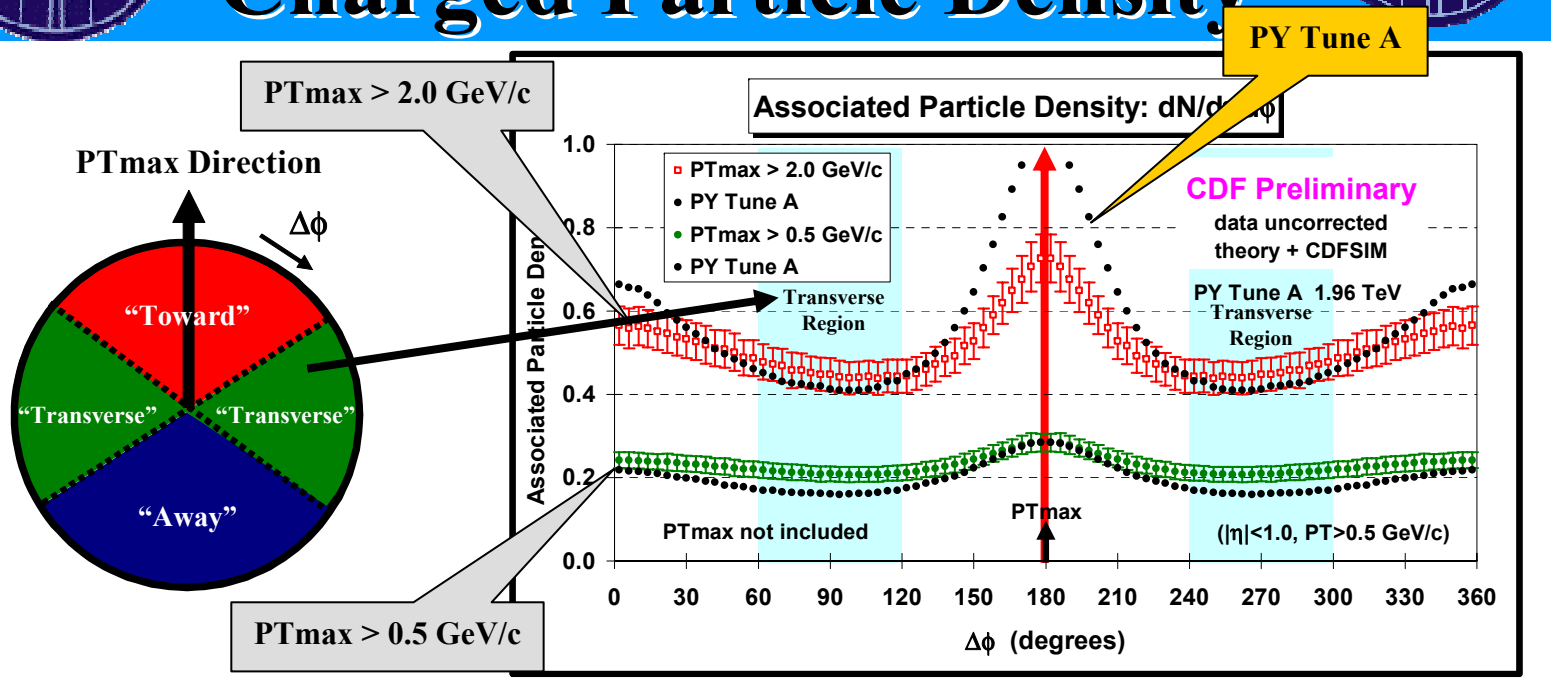
Min-Bias "Associated" Charged Particle Density



- 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, 1.0, and 2.0 GeV/c.

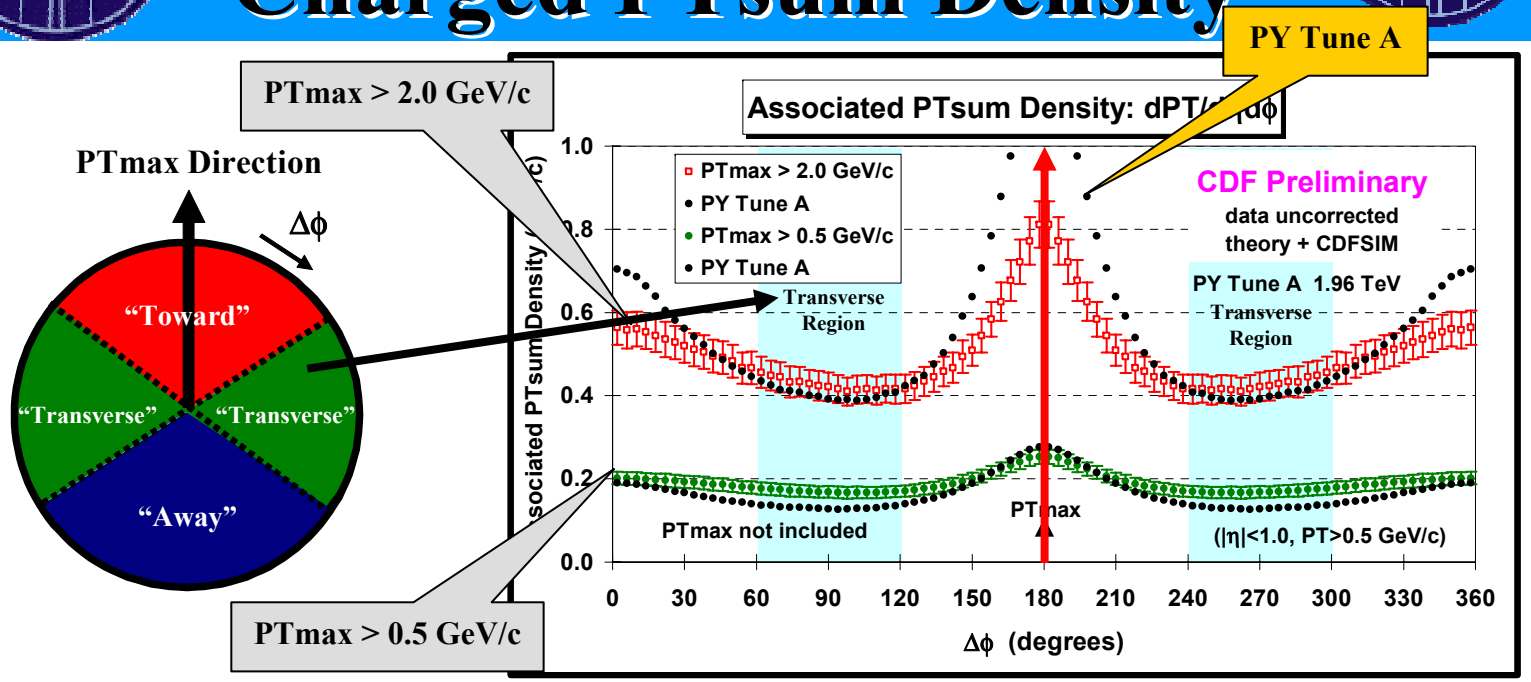
- Shows "jet structure" in "min-bias" collisions (*i.e.* the "birth" of the leading two jets!).

Min-Bias "Associated" Charged Particle Density



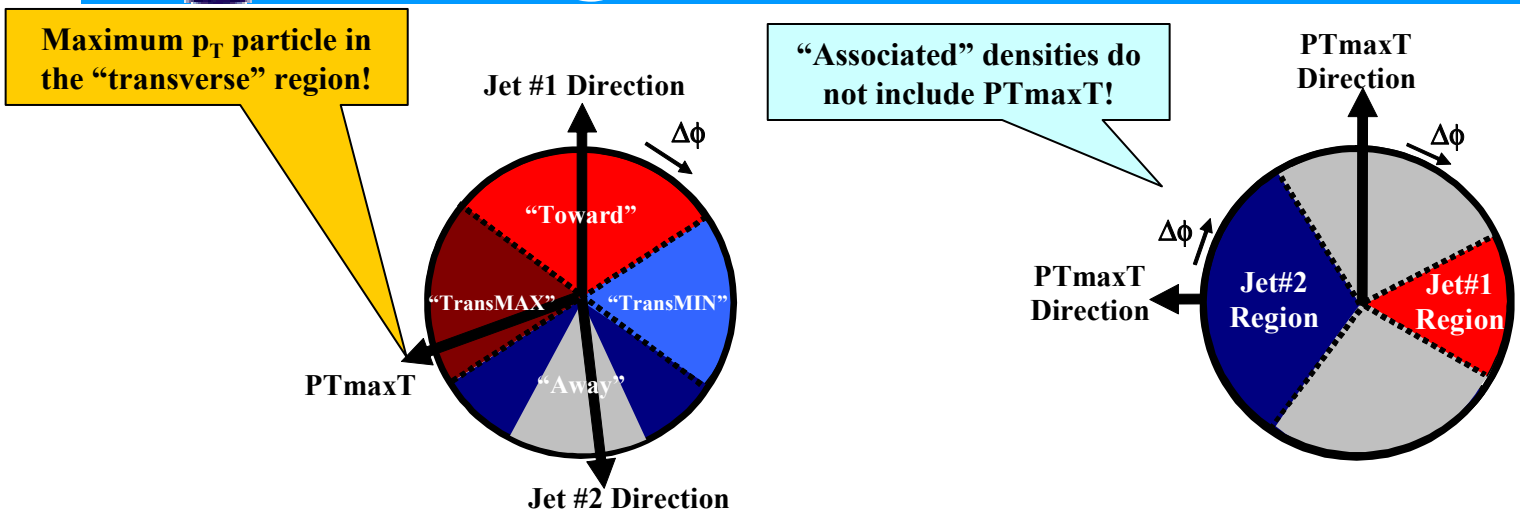
- Shows the data on the Δφ dependence of the "associated" charged particle density, $dN_{chg}/d\eta d\phi$, for charged particles ($p_T > 0.5$ GeV/c, $|\eta| < 1$, *not including PTmax*) relative to PTmax (rotated to 180°) for "min-bias" events with PTmax > 0.5 GeV/c and PTmax > 2.0 GeV/c compared with 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



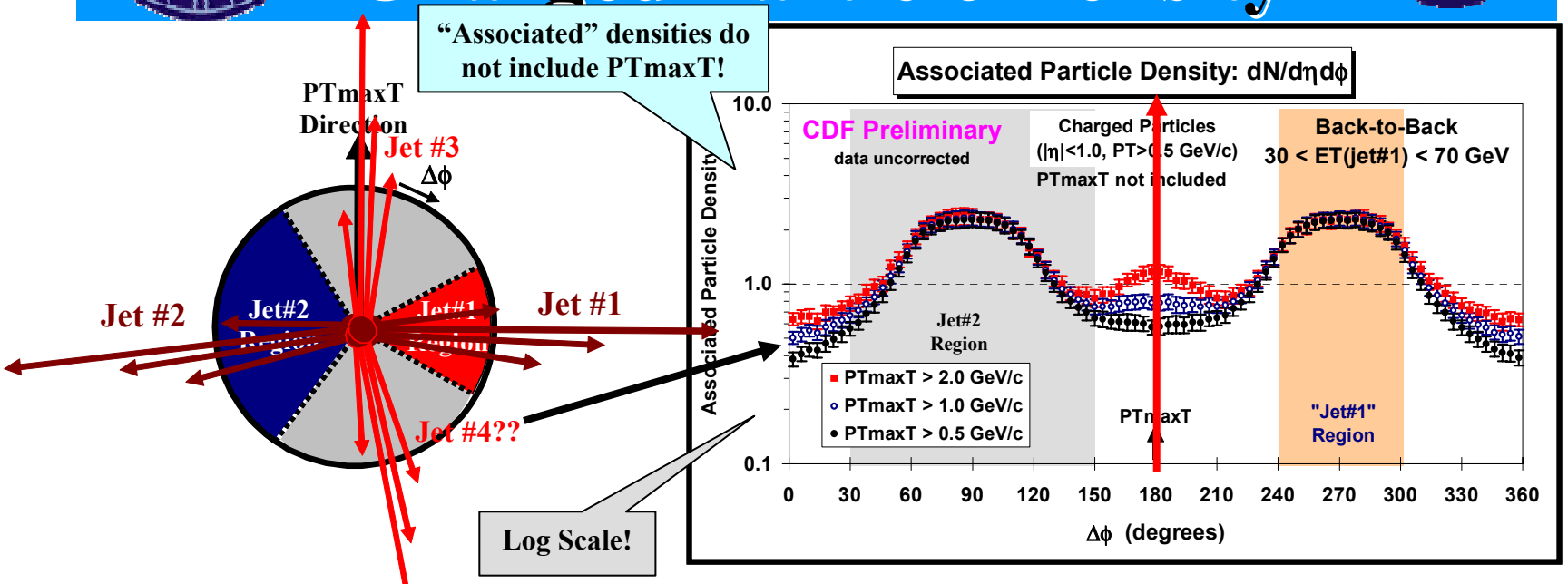
- Shows the data on the Δφ dependence of the "associated" charged PTsum density, $dPT_{sum}/d\eta d\phi$, for charged particles ($p_T > 0.5$ GeV/c, $|\eta| < 1$, *not including PTmax*) relative to PTmax (rotated to 180°) for "min-bias" events with PTmax > 0.5 GeV/c and PTmax > 2.0 GeV/c compared with 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").

Back-to-Back "Associated" Charged Particle Densities



- 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°).

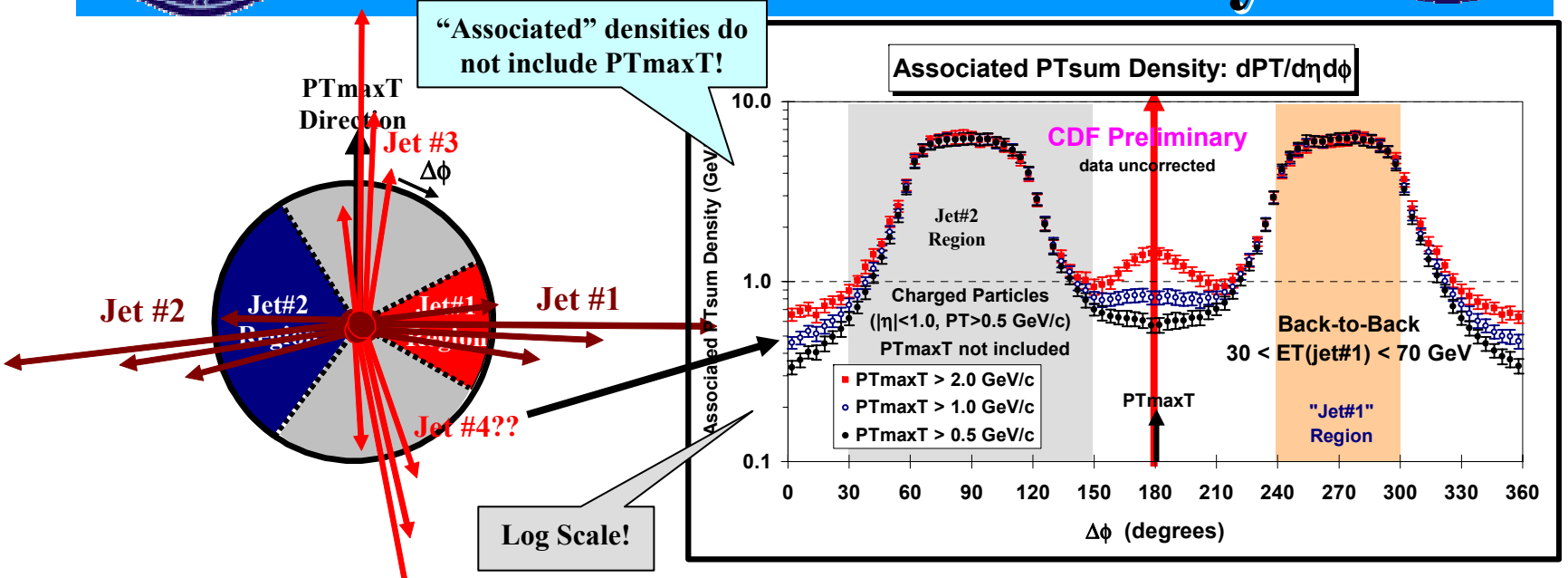
Back-to-Back "Associated" Charged Particle Density



- 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 $30 < E_T(\text{jet\#1}) < 70$ GeV .

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

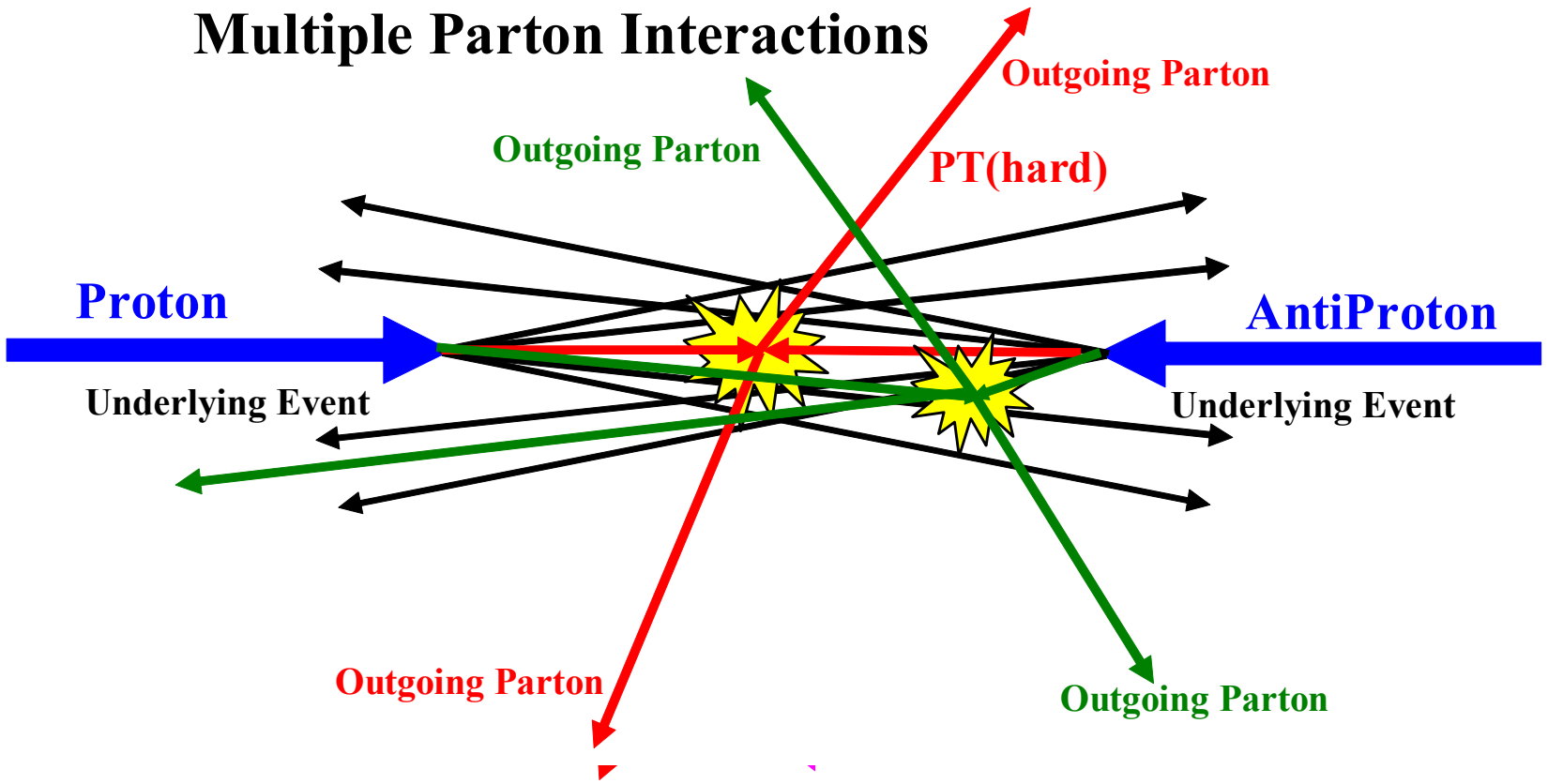
Back-to-Back "Associated" Charged PTsum Density



- Look at the Δφ dependence of the "associated" charged particle density, $dPT_{sum}/d\eta d\phi$ 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 $30 < E_T(\text{jet\#1}) < 70$ GeV .

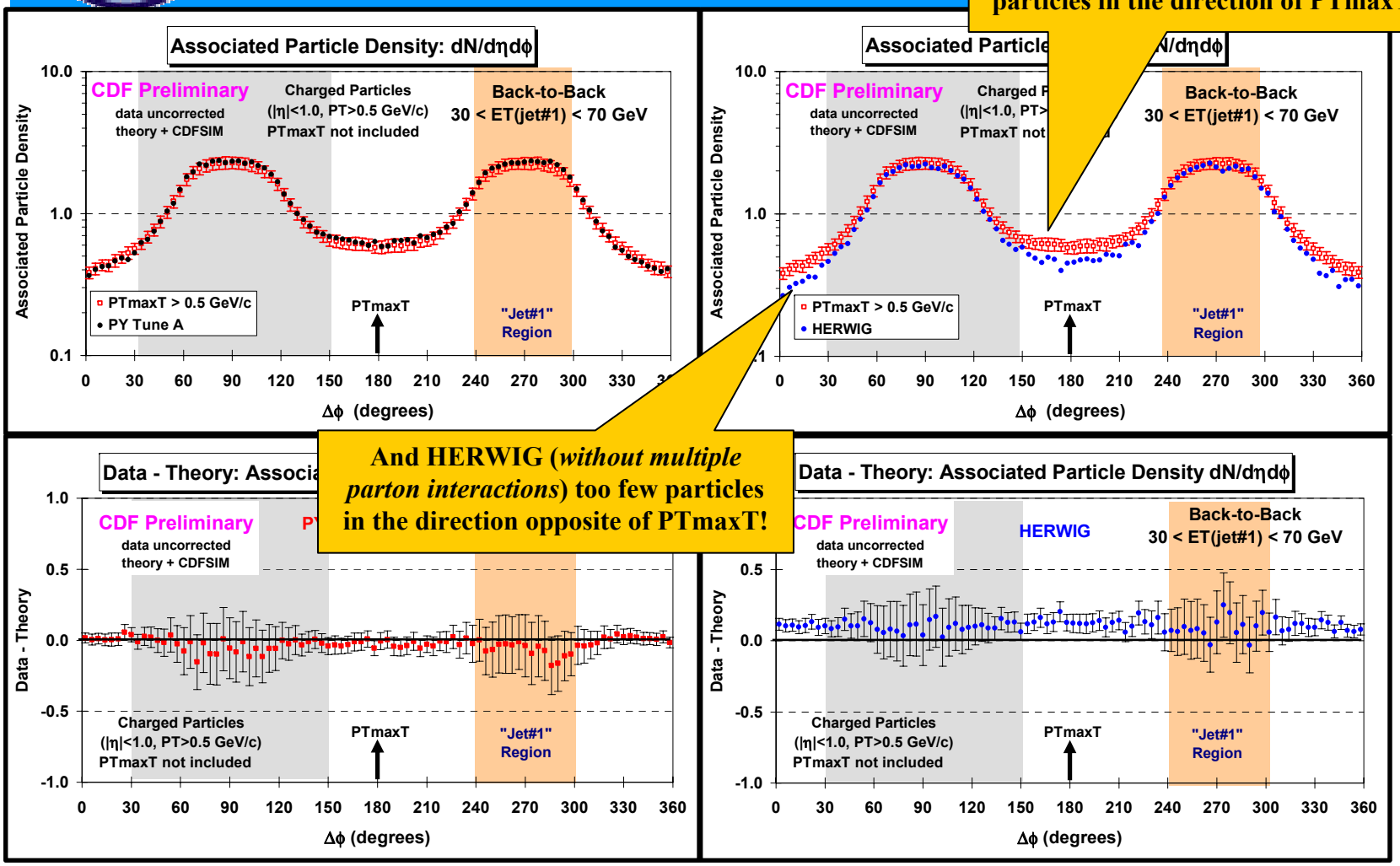
- Shows "jet structure" in the "transverse" region (*i.e.* the "birth" of the 3rd & 4th jet).

Jet Topologies



180°) 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°) for "back-to-back events" with $30 < E_T(\text{jet\#1}) < 70$ GeV.

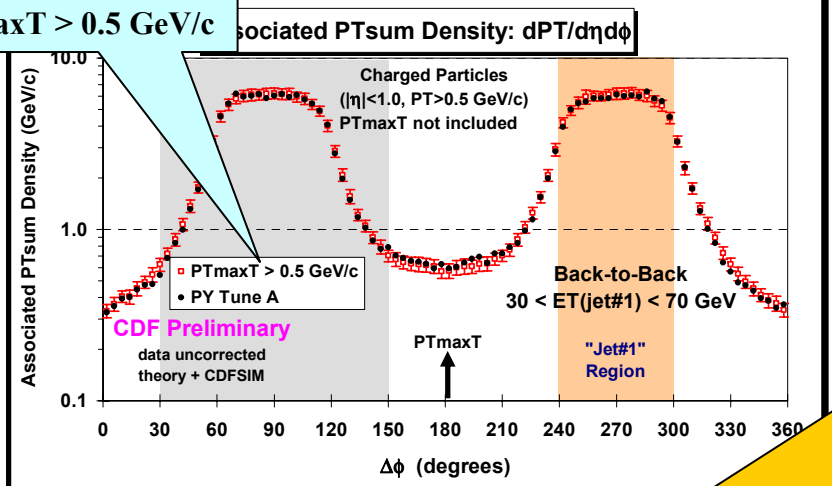
"Associated" Charge Density
PYTHIA Tune A vs HE

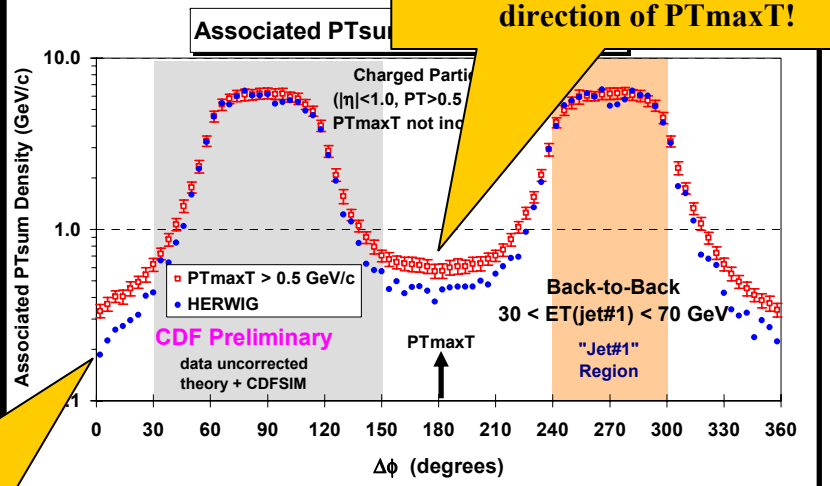


"Associated" PTsum Density
PYTHIA Tune A vs HERW

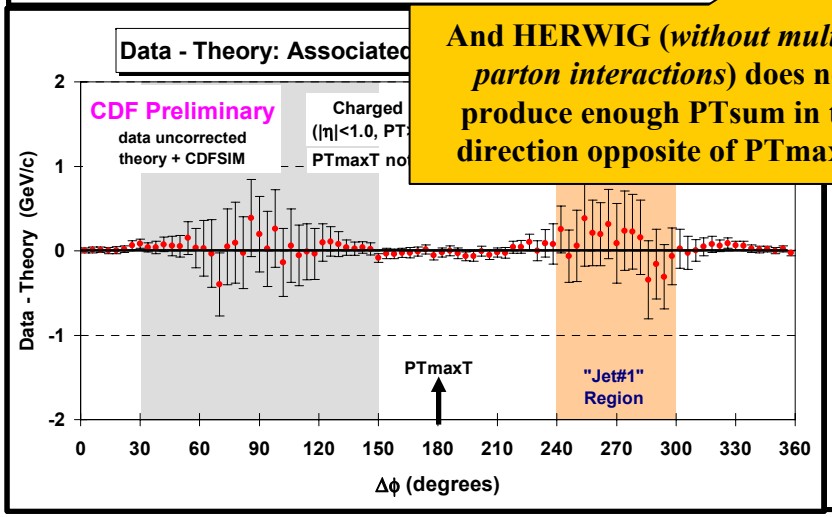
PTmaxT > 0.5 GeV/c

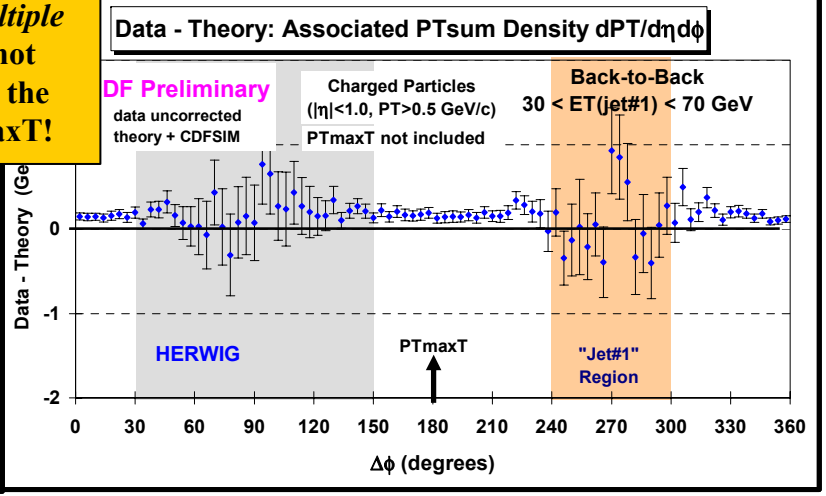
HERWIG (*without multiple parton interactions*) does not produce enough "associated" PTsum in the direction of PTmaxT!





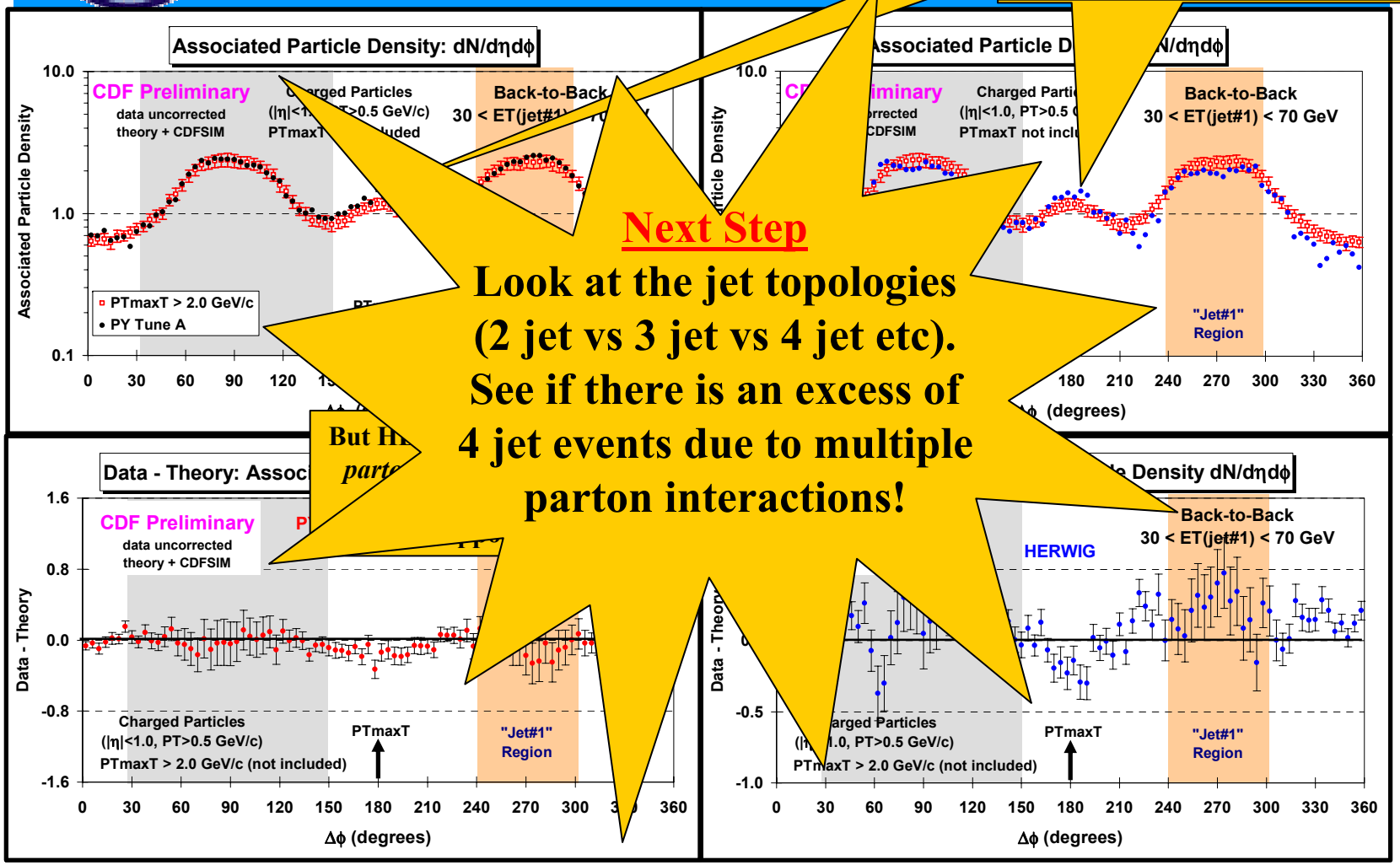
And HERWIG (*without multiple parton interactions*) does not produce enough PTsum in the direction opposite of PTmaxT!





"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!



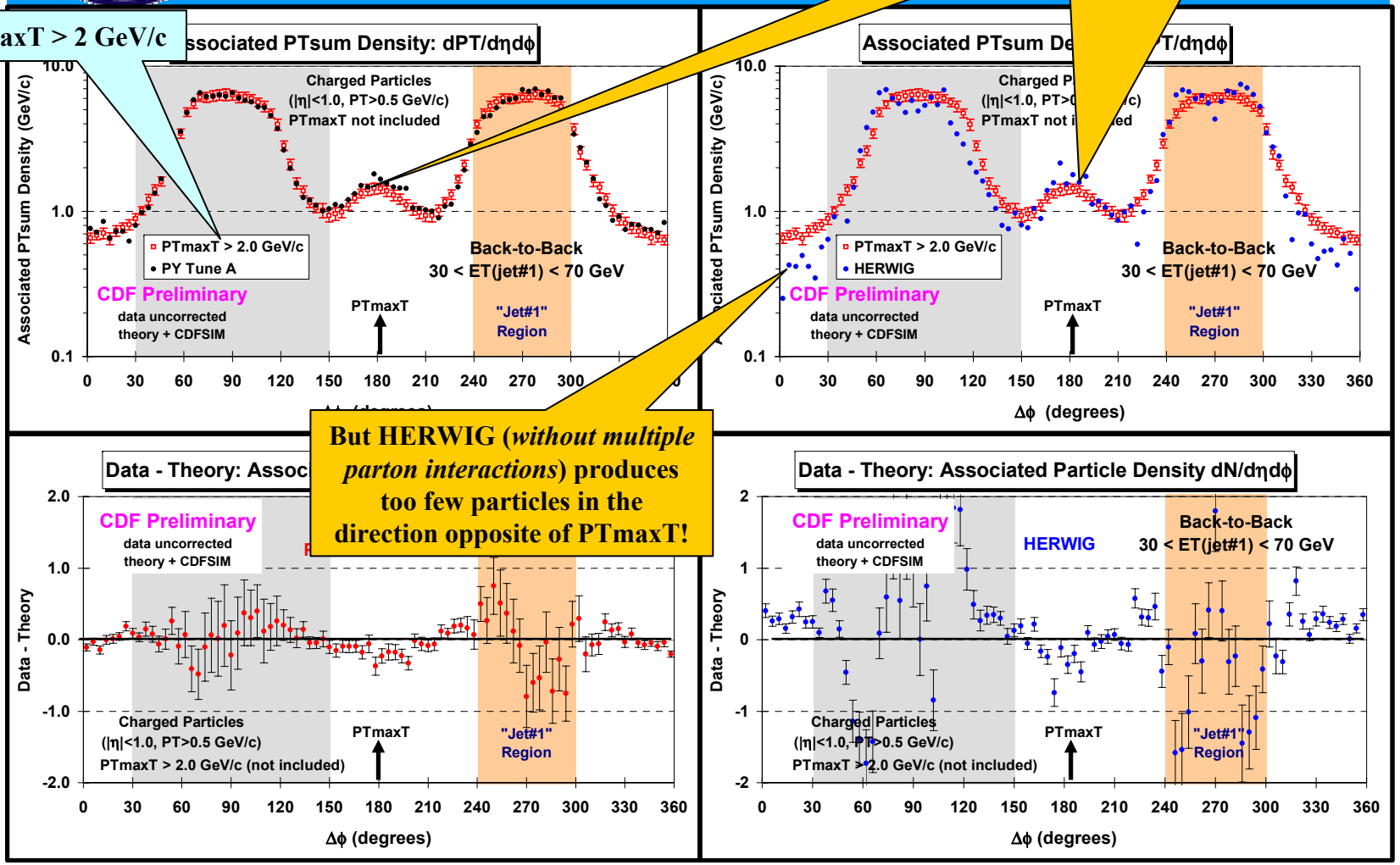
Next Step

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

PTmaxT > 2 GeV/c

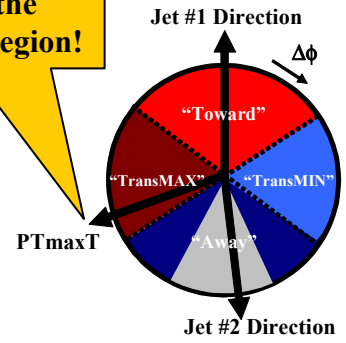
For PTmaxT > 2.0 GeV both PYTHIA and HERWIG produce slightly too much "associated" PTsum in the direction of PTmaxT!



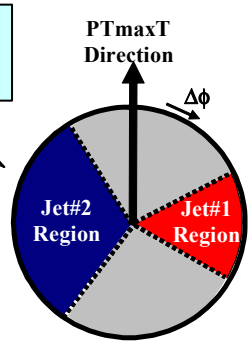
But HERWIG (*without multiple parton interactions*) produces too few particles in the direction opposite of PTmaxT!

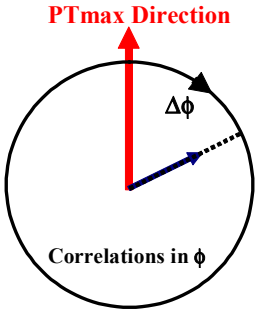
Summary

Max p_T in the "transverse" region!



"Associated" densities do not include PTmaxT!

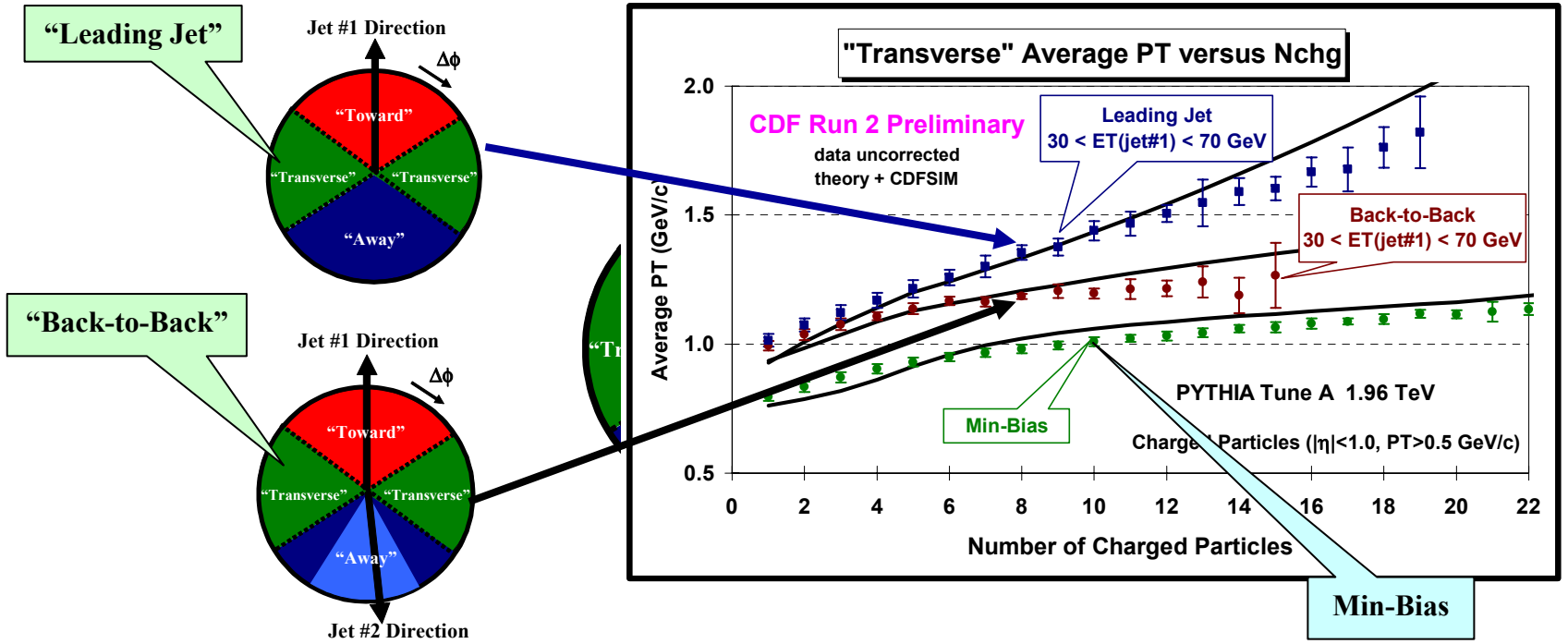




- The "associated" densities show strong correlations (*i.e.* jet structure) in the "transverse" region both for "Leading Jet" and "Back-to-Back" events.
- The "birth" of the 1st jet in "min-bias" collisions looks very similar to the "birth" of the 3rd jet in the "transverse" region of hard scattering "Back-to-Back" events.

Question: Is the topology 3 jet or 4 jet?

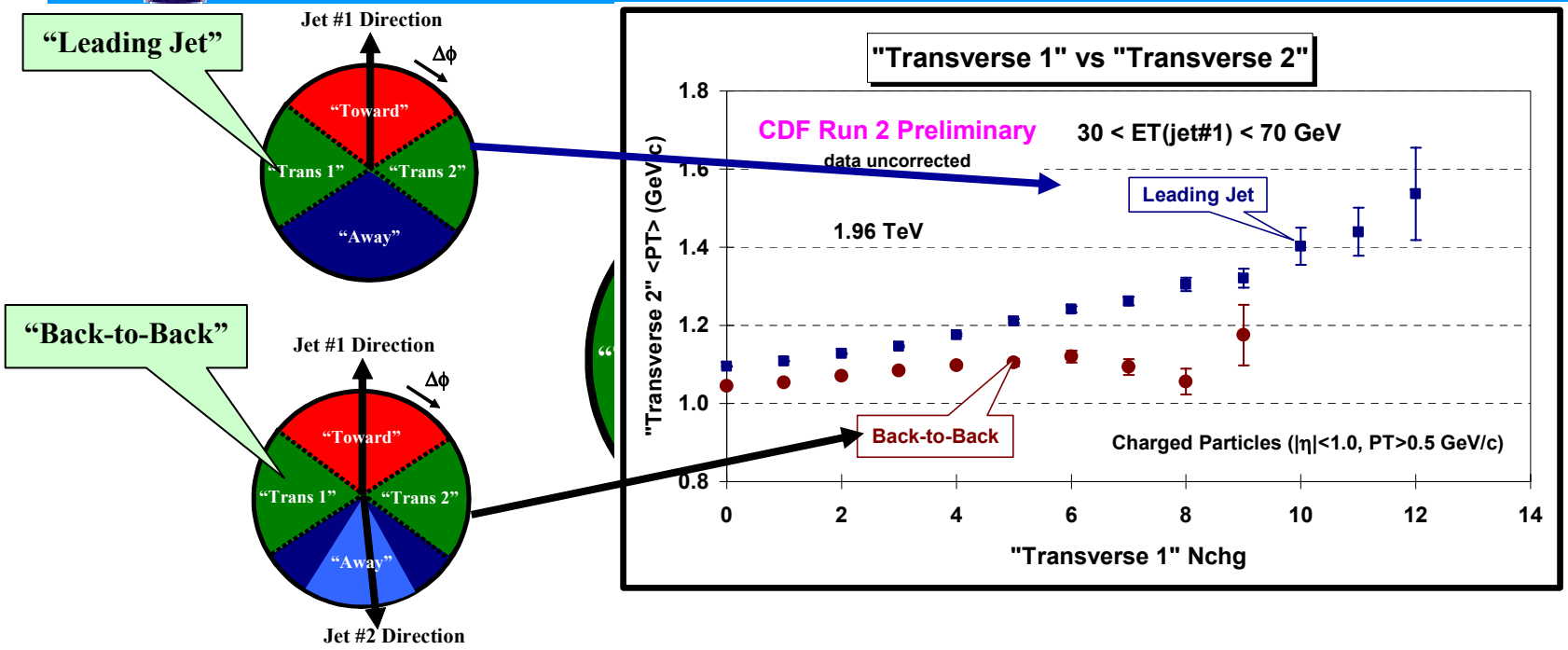
"Transverse" $\langle p_T \rangle$ versus "Transverse" Nchg



- Look at the $\langle p_T \rangle$ of particles in the "transverse" region ($p_T > 0.5$ GeV/c, $|\eta| < 1$) versus the number of particles in the "transverse" region: $\langle p_T \rangle$ vs Nchg.

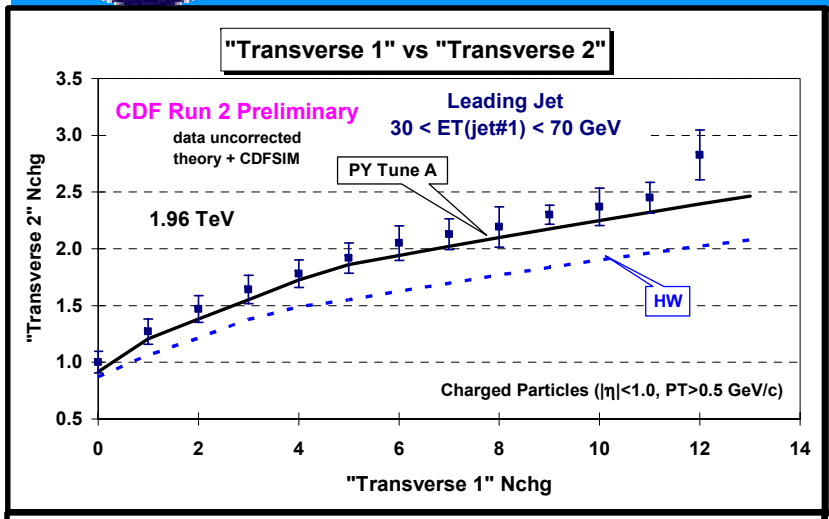
- Shows $\langle p_T \rangle$ versus Nchg in the "transverse" region ($p_T > 0.5$ GeV/c, $|\eta| < 1$) for "Leading Jet" and "Back-to-Back" events with $30 < E_T(\text{jet\#1}) < 70$ GeV compared with "min-bias" collisions.

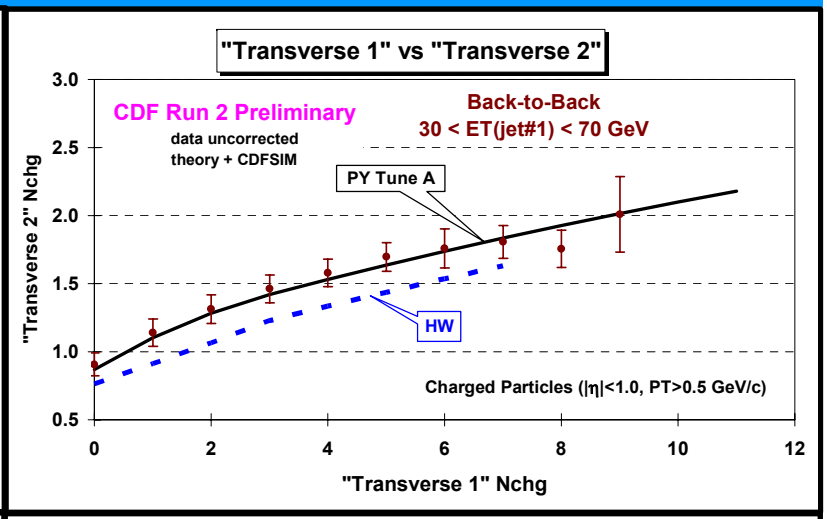
"Transverse 1" Region vs "Transverse 2" Region

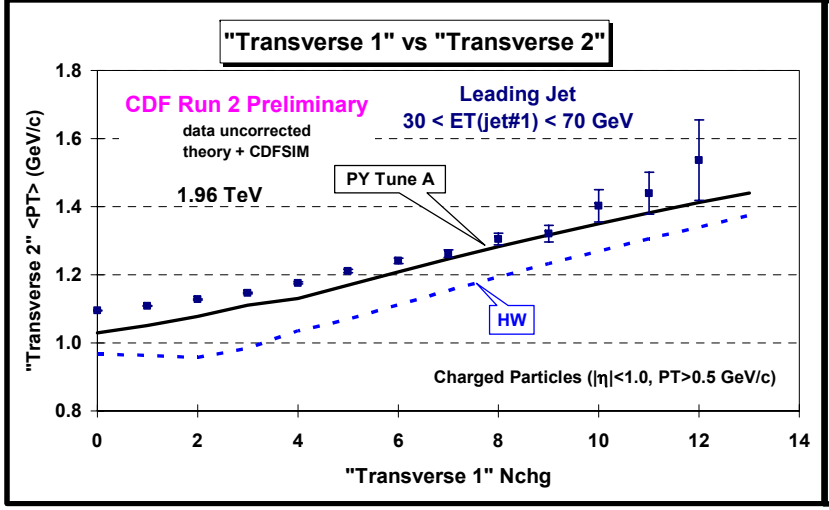


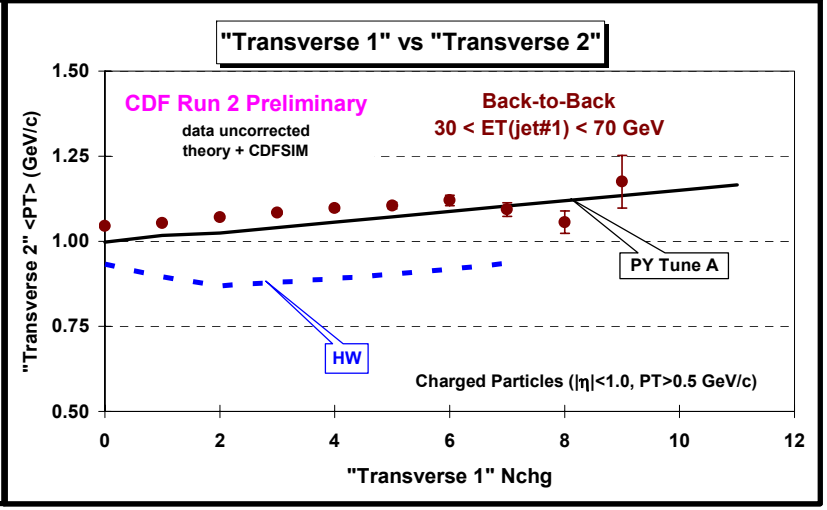
- Use the leading jet to define two "transverse" regions and look at the correlations between "transverse 1" and "transverse 2".
- Shows the average p_T of charged particles in the "transverse 2" region versus the number of charged particles in the "transverse 1" region for $p_T > 0.5$ GeV/c and $|\eta| < 1$ for "Leading Jet" and "Back-to-Back" events.

"Transverse 1" Region vs "Transverse 2" Region

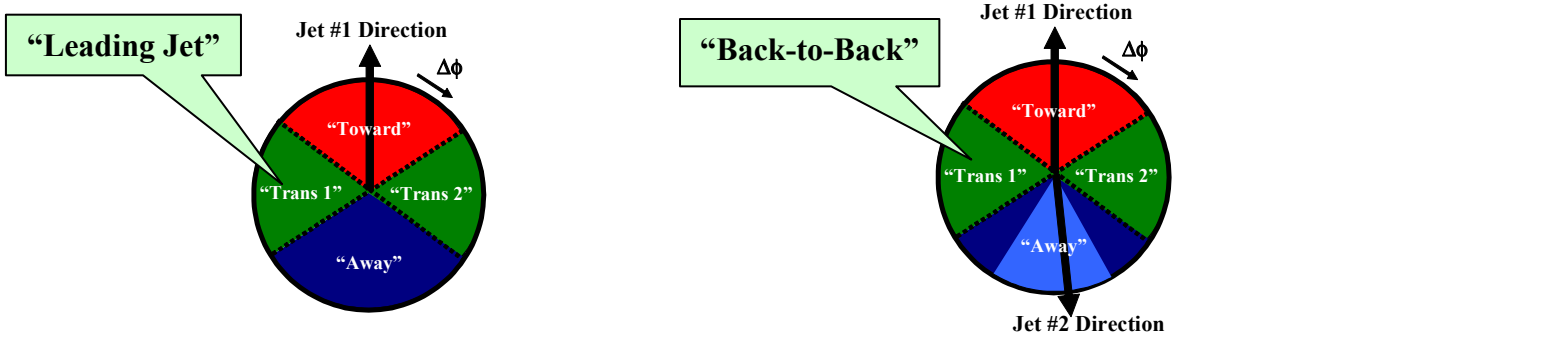








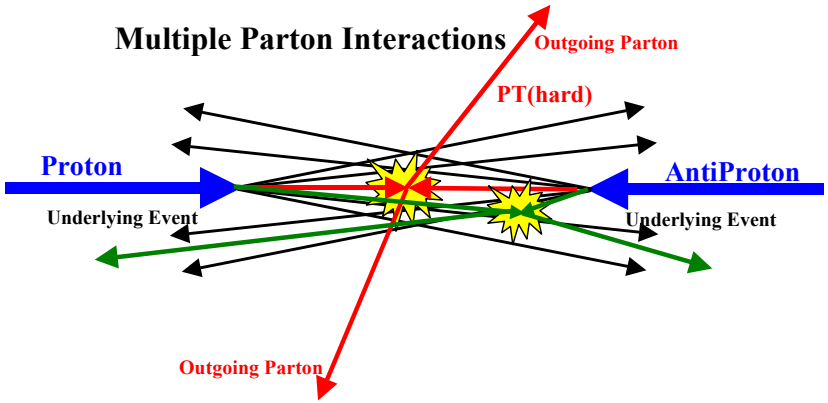
Summary



- There are some interesting correlations between the "transverse 1" and "transverse 2" regions both for "Leading-Jet" and "Back-to-Back" events!
- PYTHIA Tune A (*with multiple parton scattering*) does a much better job in describing these correlations than does HERWIG (*without multiple parton scattering*).

Question: Is this a probe of multiple parton interactions?

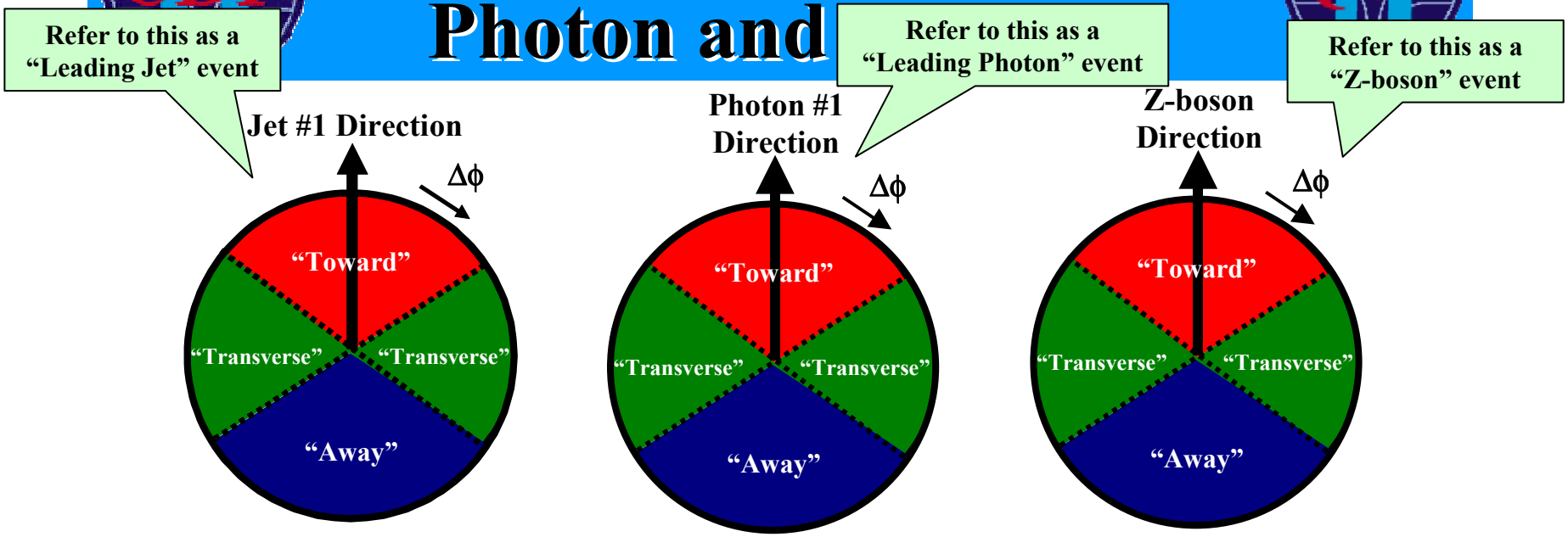
The Universality of PYTHIA Tune A



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

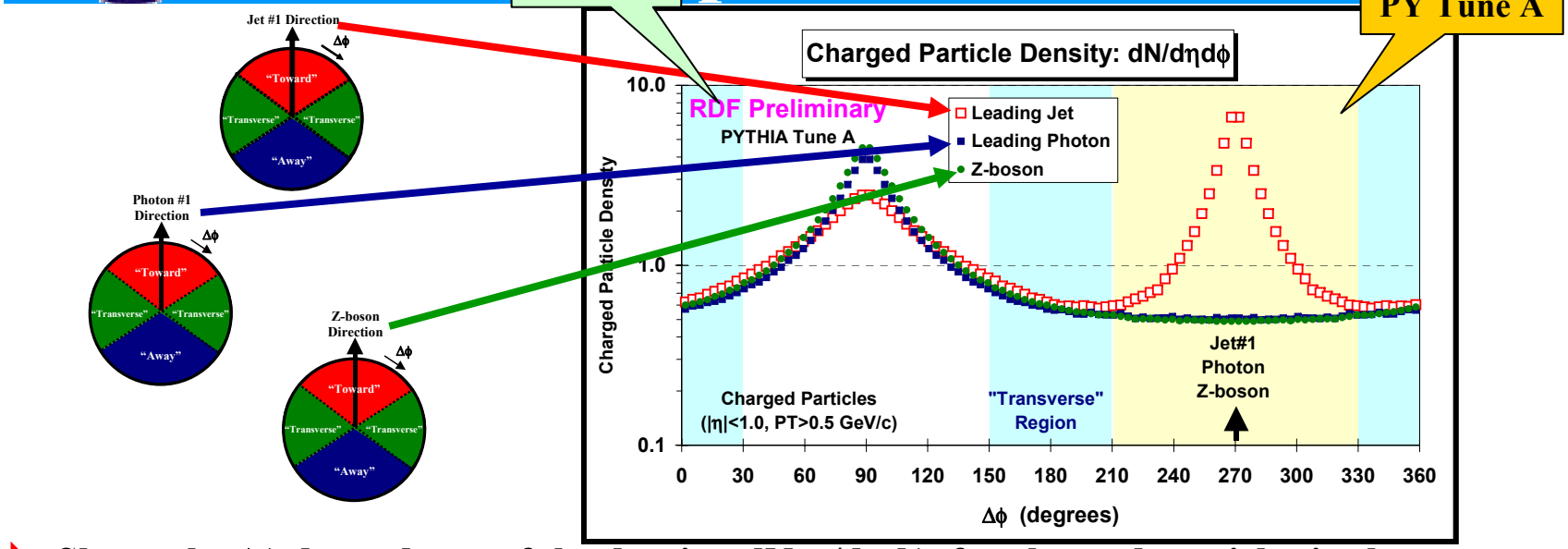
- I working on a "universal" PYTHIA Run 2 tune!
  - Must specify the PDF!
  - Must specify MPI parameters!
  - Must specify Q^2 scale!
  - Must specify intrinsic kT!

New CDF Run 2 Analysis Photon and



- 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

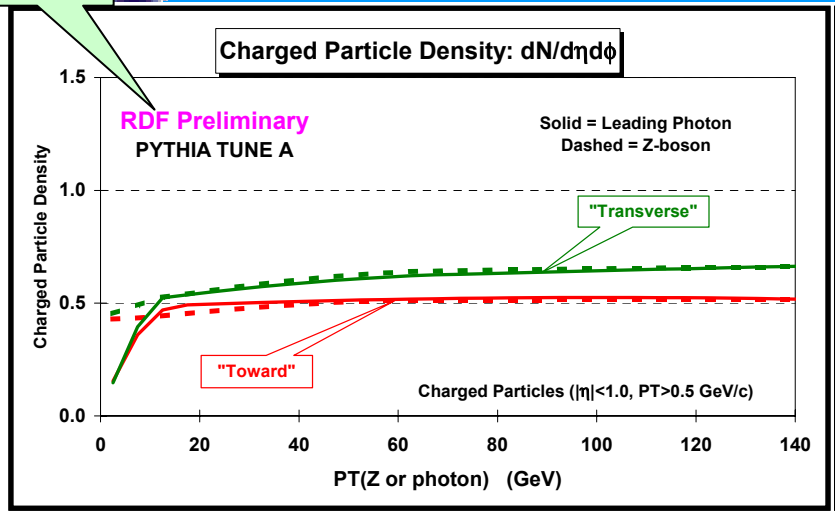


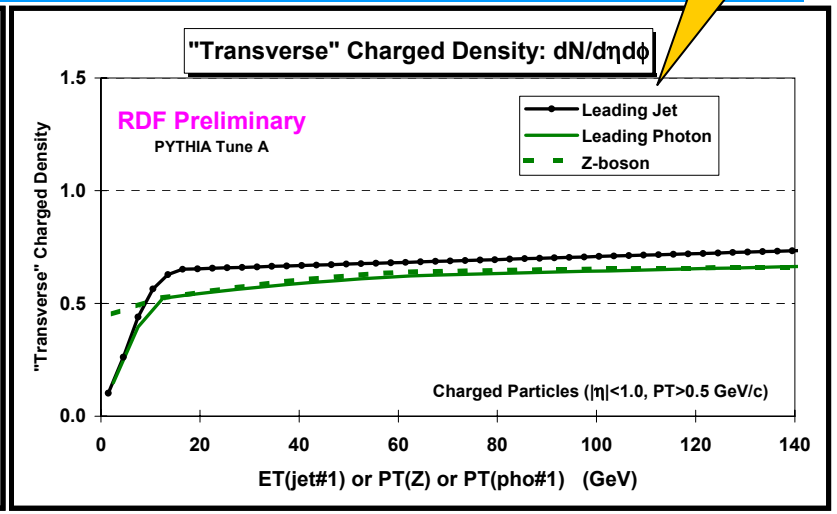
- Shows the Δφ dependence of the density, $dN_{chg}/d\eta d\phi$, for charged particles in the range $p_T > 0.5$ GeV/c and $|\eta| < 1$ relative to jet#1 (rotated to 270°) for $E_T(\text{jet\#1}) > 30$ GeV for "Leading Jet" events from PYTHIA Tune A.
- Shows the Δφ dependence of the density, $dN_{chg}/d\eta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

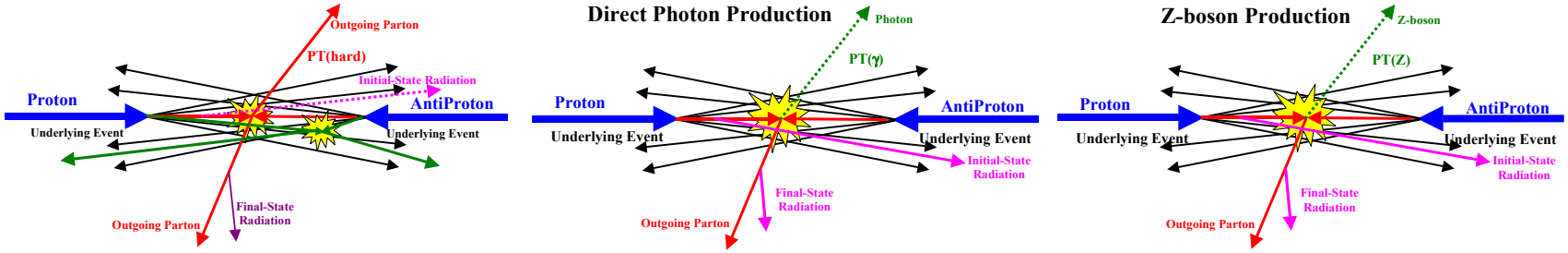
PY Tune A





- **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.**