HERWIG, JIMMY, and PYTHIA Tune A

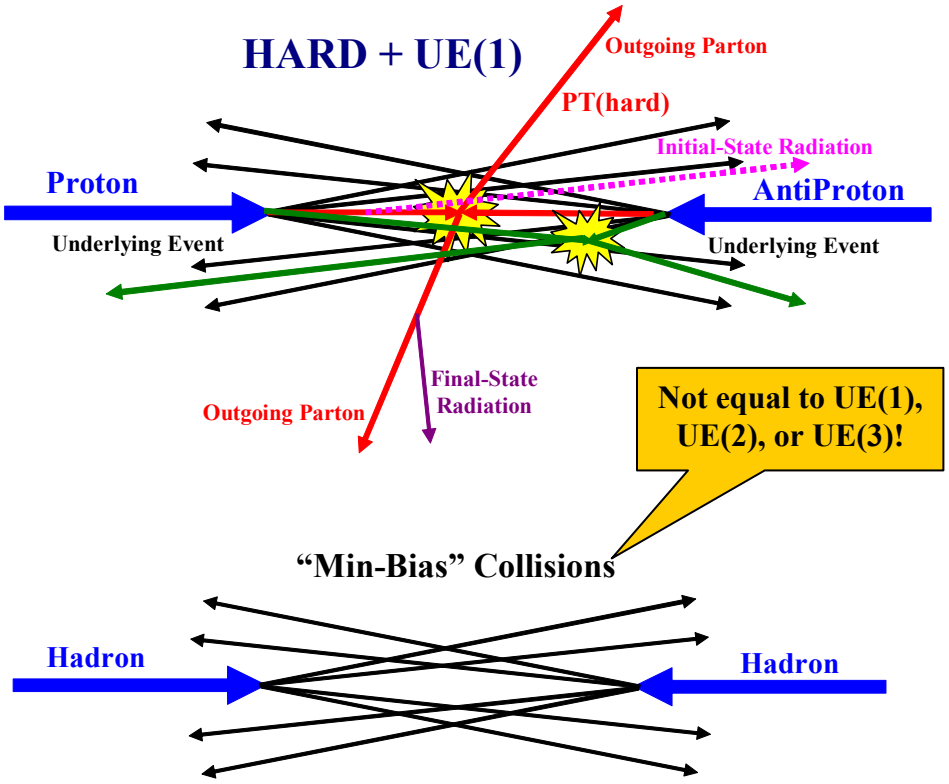
Outline of Talk

- **Discuss the definition of the "underlying event" (UE).**
- **Use HERWIG to identify the particles coming from the "beam-beam remnants" (BBR) and the particles coming from initial-state radiation (ISR).**
- **Examine some differences between HERWIG and PYTHIA Tune A.**
- **Tune JIMMY multiple parton interactions (MPI) to agree with PYTHIA Tune A.**
- **Study the BBR, MPI, and ISR contribution to the "transverse" region and to "jets".**
- **Discuss problems with JIMMY (*i.e.* no BBR, too "soft", Q^2 dependence).**

The "Underlying Event"

- **What is your definition of the "underlying event" in a hard scattering process?**

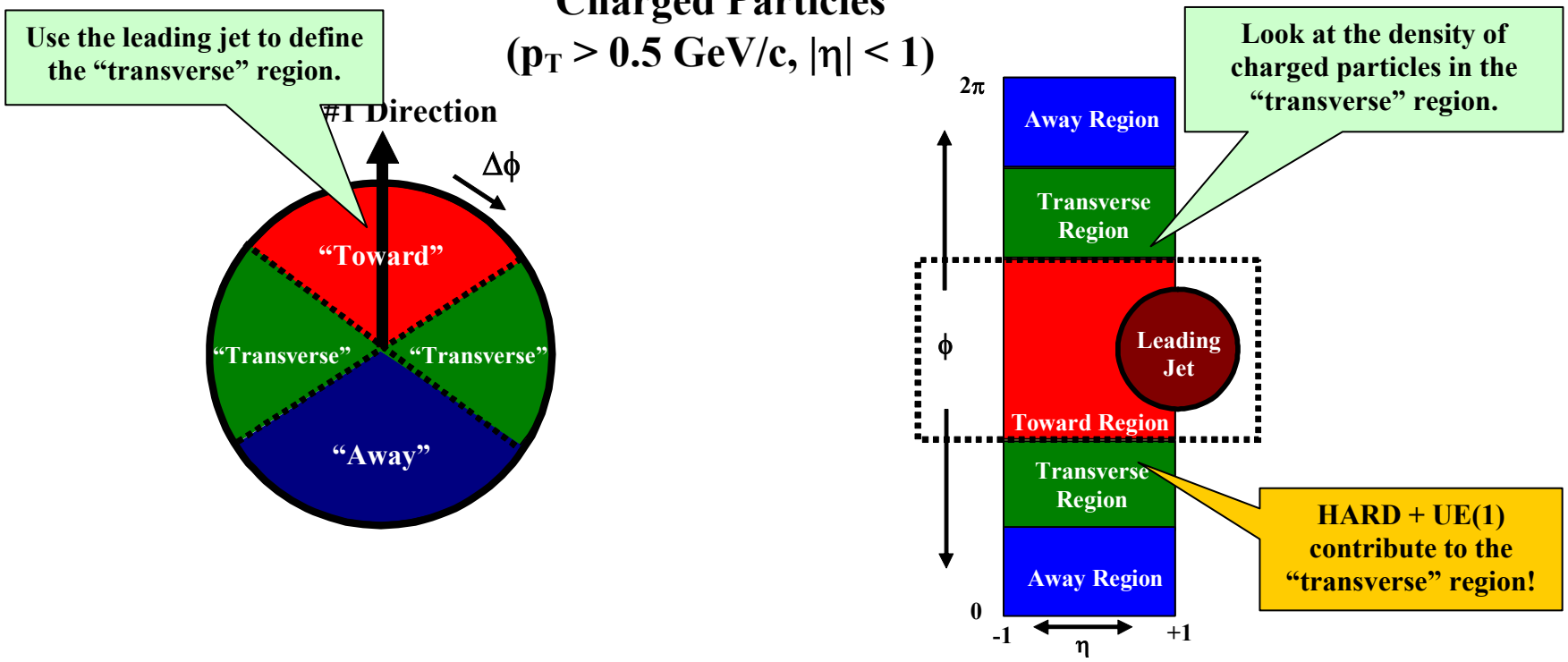
Acronym	Definition
2-to-2	Two outgoing partons
ISR	Initial State radiation
FSR	Final State Radiation
HARD	2-to-2 + ISR + FSR
BBR	Bean-Beam Remnants
MPI	Multiple Parton Interactions
Pile-up	Additional proton-antiproton collisions
MB	"Minimum-Bias" collisions
UE(1)	BBR + MPI
UE(2)	BBR + MPI + ISR
UE(3)	BBR + MPI + ISR + FSR
UE(4)	MB (does not make sense!)



- **My definition is UE(1), but for some jet corrections you might want UE(2) or UE(3). No observable directly measures UE(1)!**
- **Drell-Yan and low p_T Z-boson production measure UE(2)!**

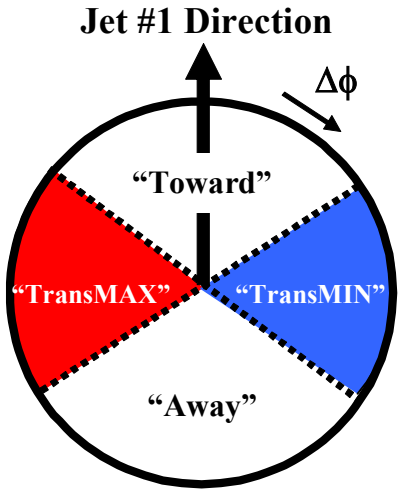
The "Transverse" Region

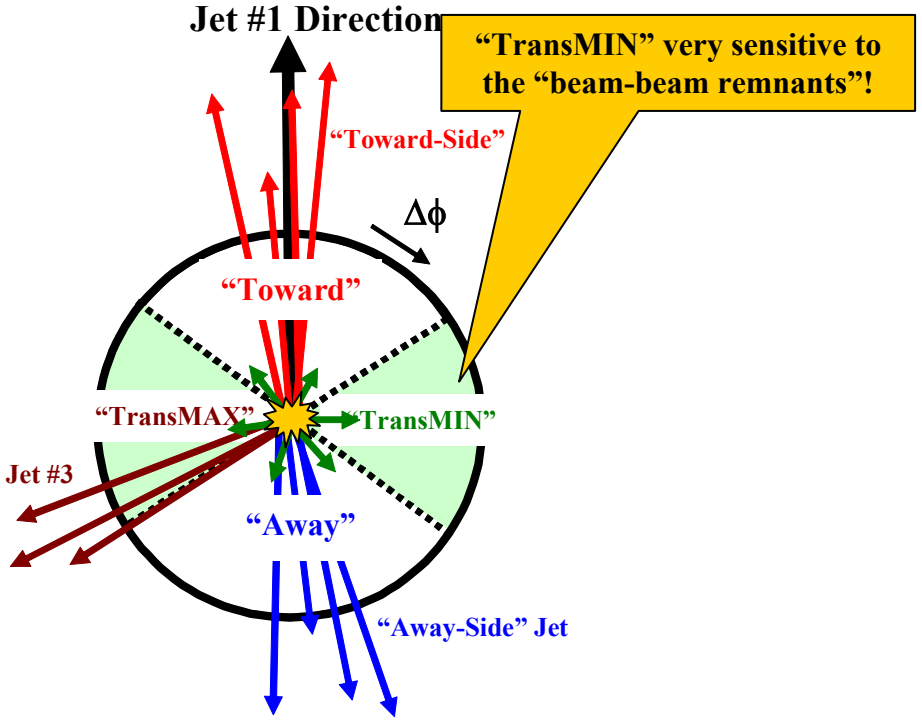
Charged Particles ($p_T > 0.5$ GeV/c, $|\eta| < 1$)



- **Look at the "transverse" region as defined by the leading calorimeter jet (JetClu R = 0.7, $|\eta| < 2$).**
- **Study the charged particles ($p_T > 0.5$ GeV/c, $|\eta| < 1$) and form the charged particle density, dNchg/dηdφ, and the charged scalar p_T sum density, dPTsum/dηdφ.**
- **Note that the "transverse" region is not UE(1) or UE(2) or UE(3)!**

"MAX/MIN Transverse" Densities

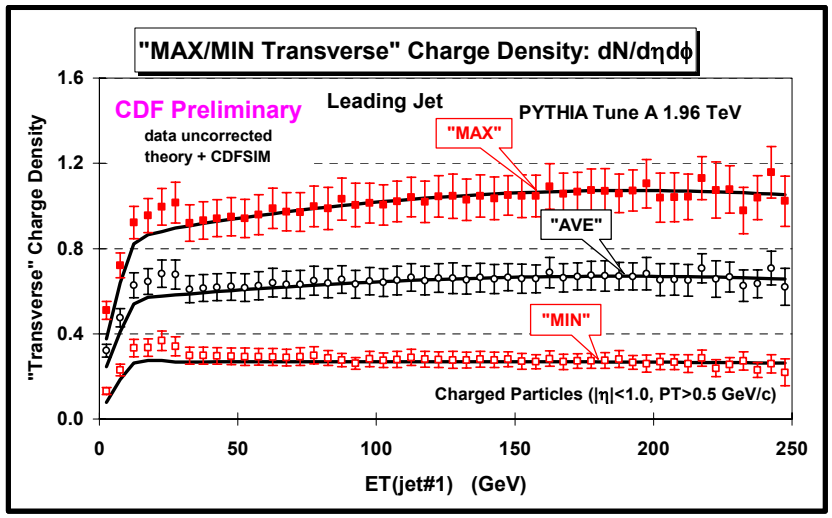




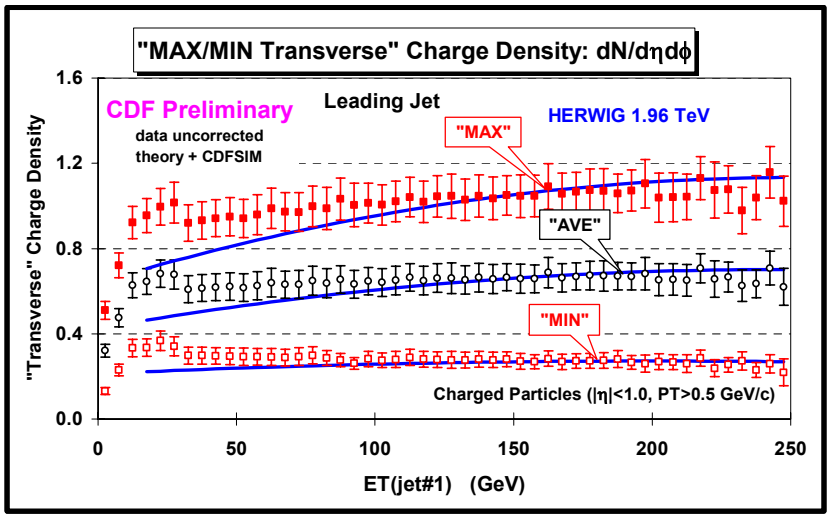
- **Define the MAX and MIN "transverse" regions on an event-by-event basis with MAX (MIN) having the largest (smallest) density.**
- **The "transMIN" region is very sensitive to the "beam-beam remnant" and multiple parton interaction components of the "underlying event".**
- **The difference, "transMAX" minus "transMIN", is very sensitive to the "hard scattering" component of the "underlying event" (*i.e.* hard initial and final-state radiation).**

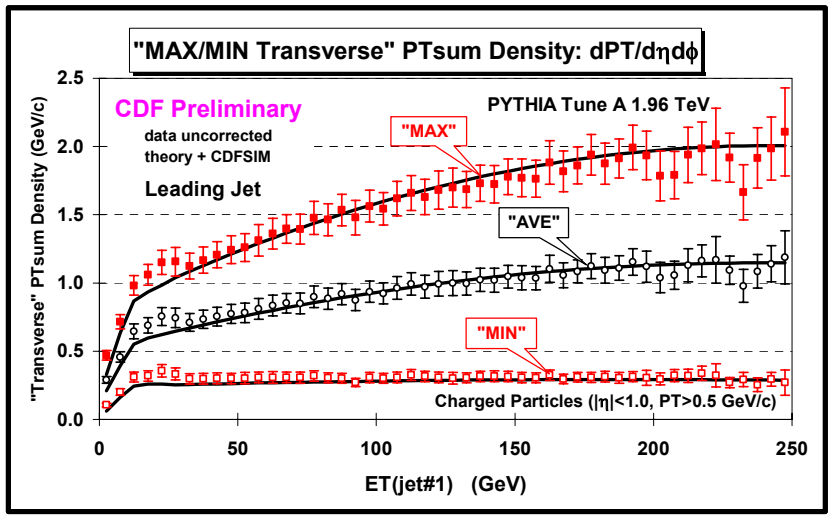
Leading Jet: "MAX & MIN Transverse" Densities

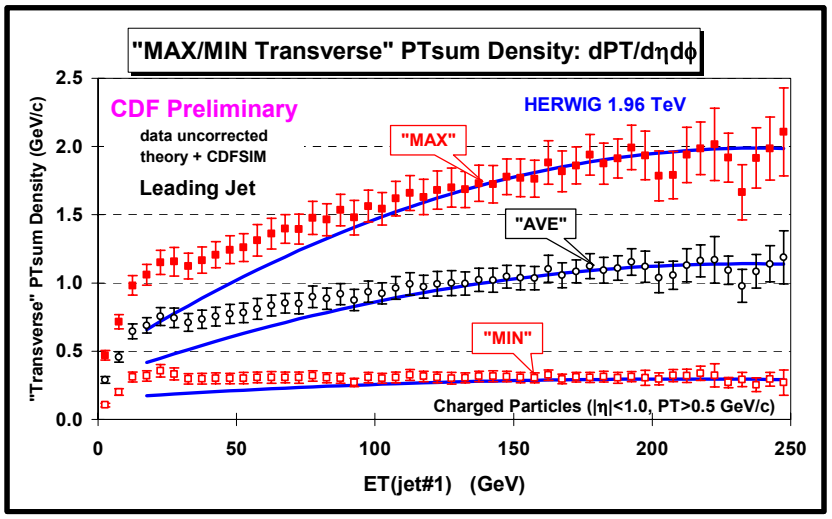
PYTHIA Tune A



HERWIG





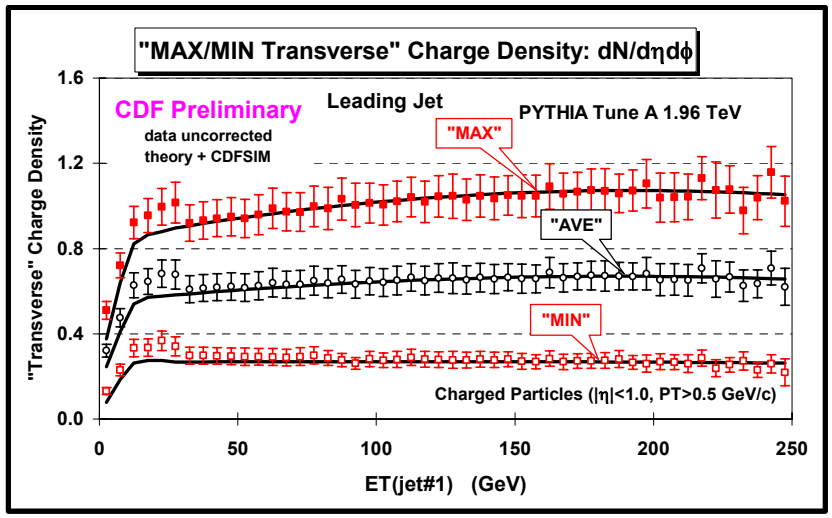


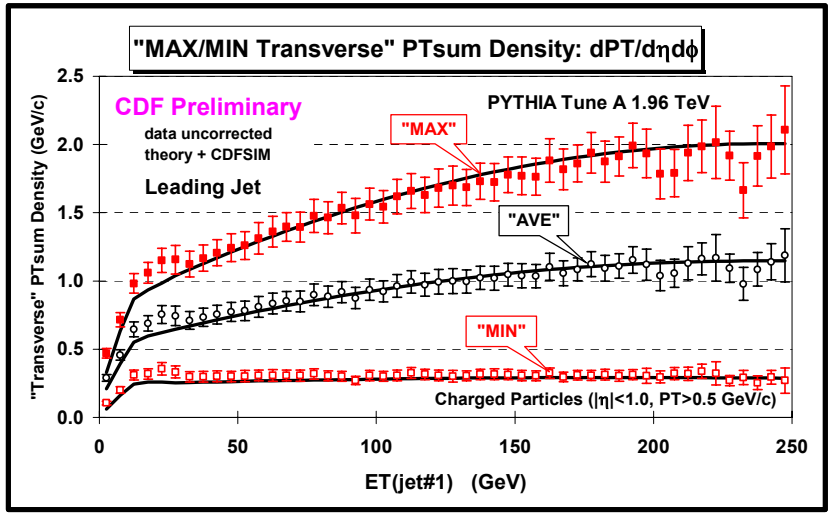
Charged particle density and PTsum density for "leading jet" events versus E_T(jet#1) for Tune A and HERWIG.

Leading Jet: "MAX & MIN Transverse" Dens

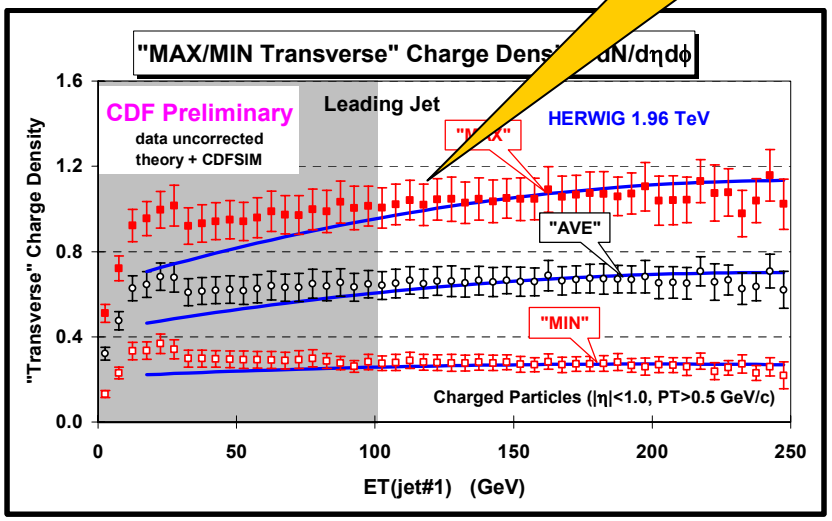
HERWIG agrees with the data for $E_T(\text{jet\#1}) > 100$

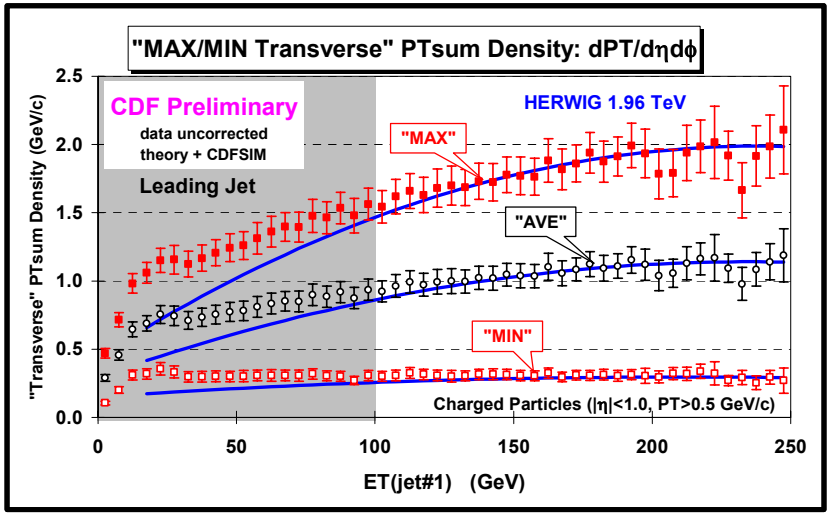
PYTHIA Tune A





HERWIG



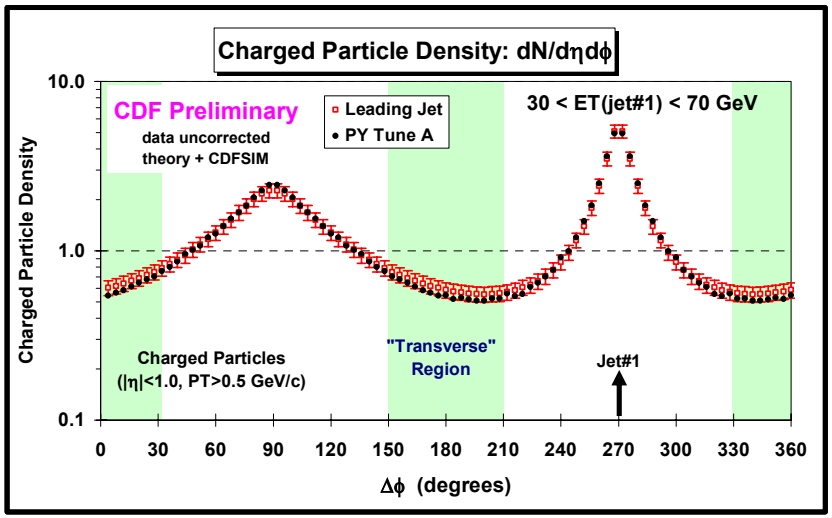


Charged particle density and PTsum density for "leading jet" events versus $E_T(\text{jet\#1})$ for Tune A and HERWIG.

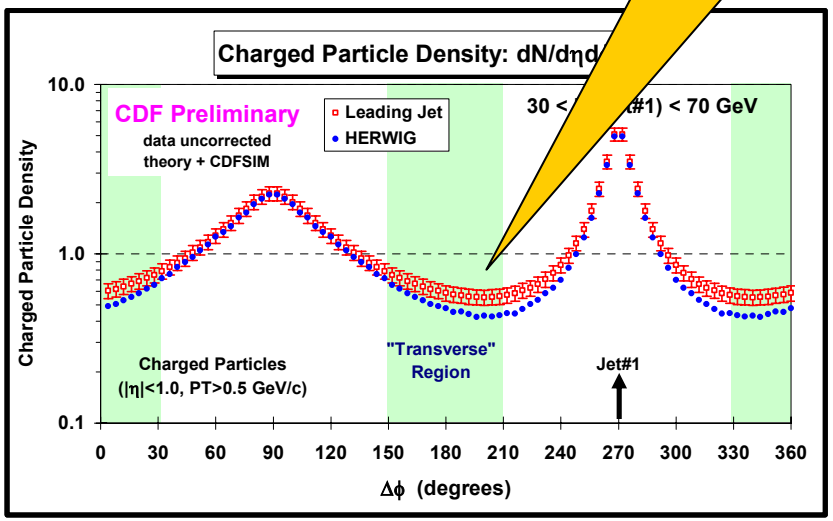
"Leading Jet" Charge Density: 30 < E_T(jet#1) < 9

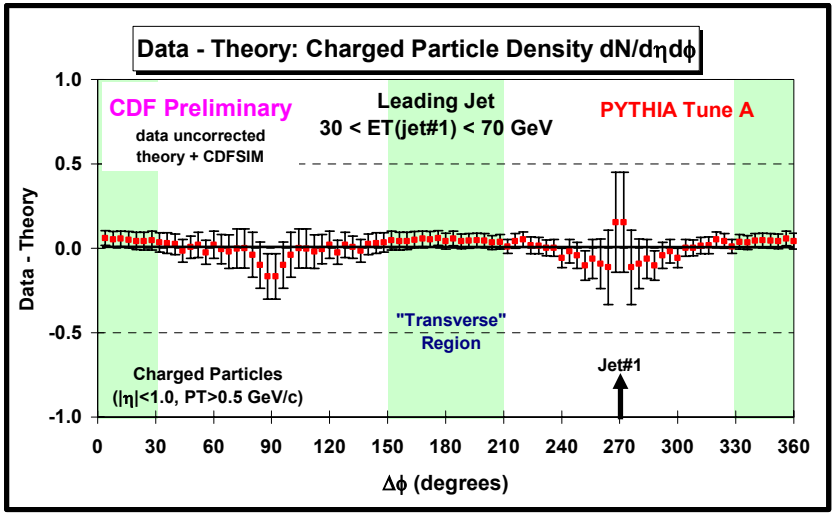
HERWIG has too few charged particles in the "transverse" region!

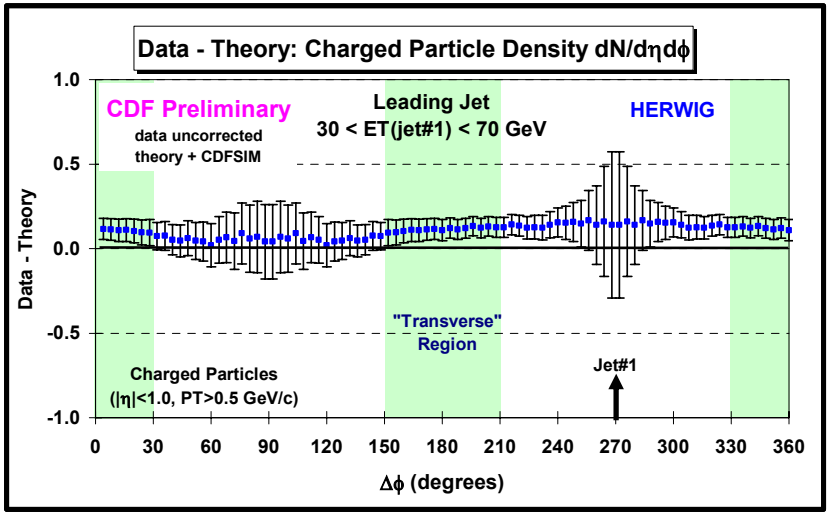
PYTHIA Tune A



HERWIG





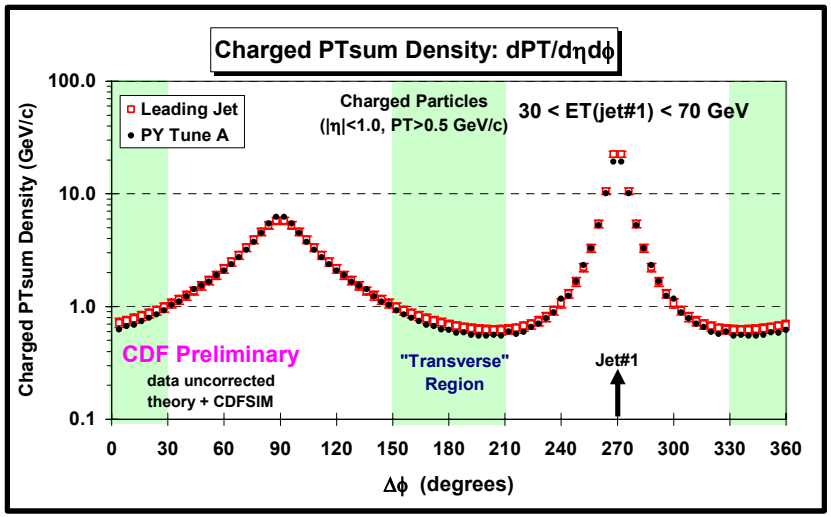


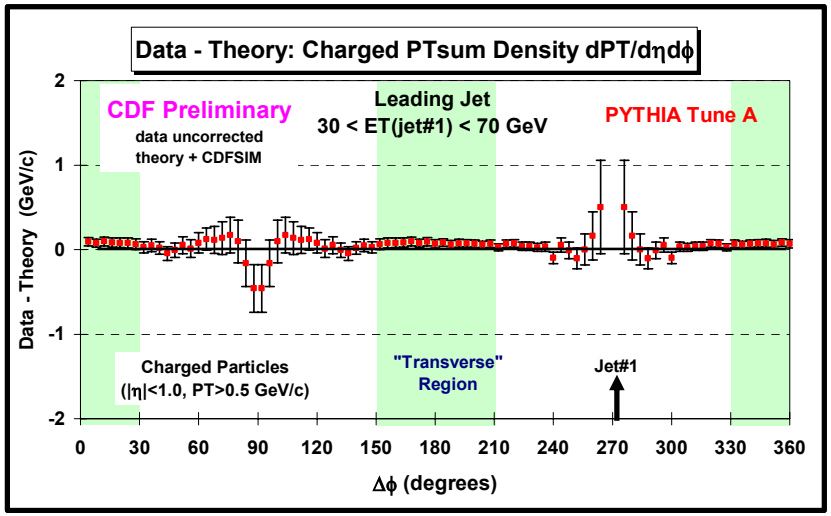
Charged particle density for "leading jet" events with 30 < E_T(jet#1) < 70 GeV versus PYTHIA Tune A and HERWIG.

PYTHIA Tune A vs HERWIG: PTsum Density dP

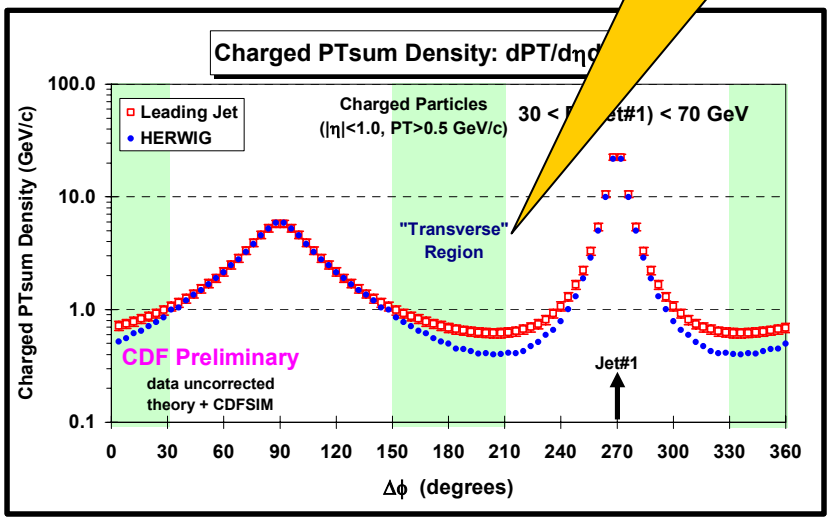
HERWIG does not have enough charged PTsum in the "transverse" region!

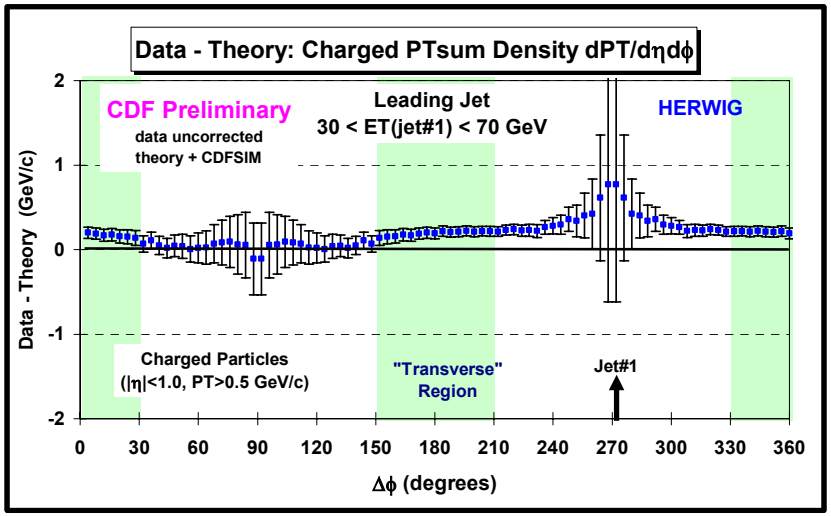
PYTHIA Tune A





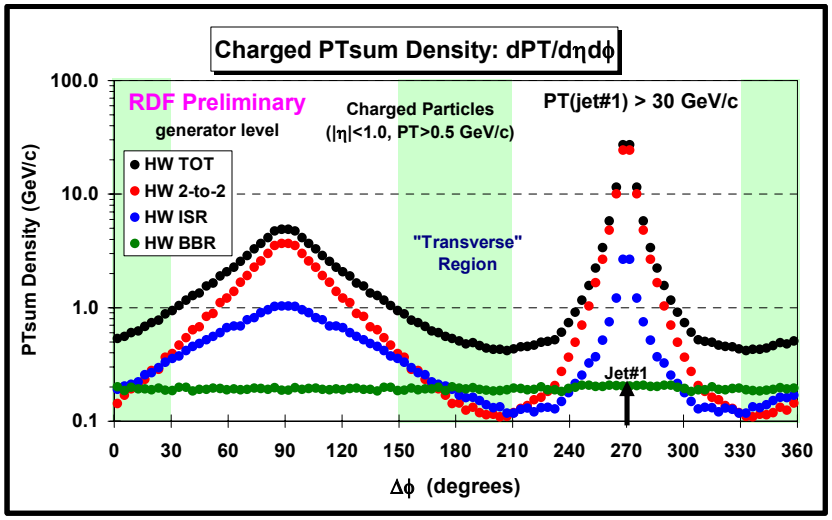
HERWIG

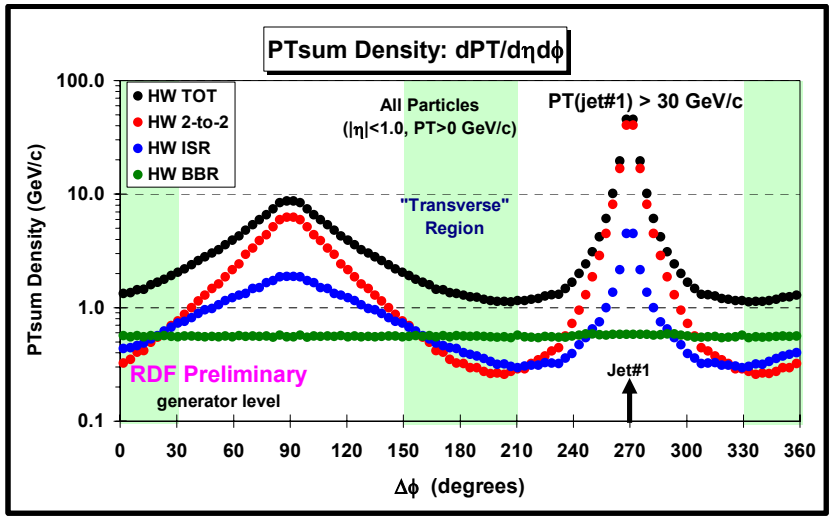




Charged particle density for "leading jet" events with $30 < E_T(\text{jet\#1}) < 70$ GeV versus PYTHIA Tune A and HERWIG.

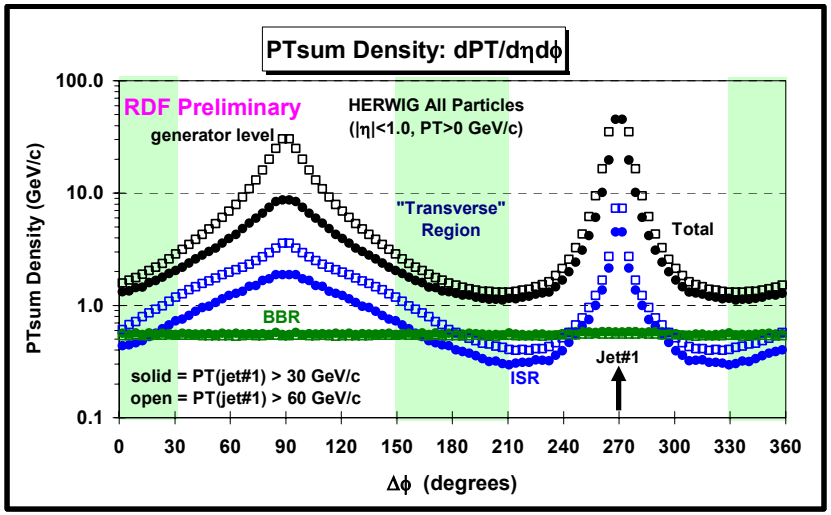
HERWIG: PTsum Density dPT/dηdϕ

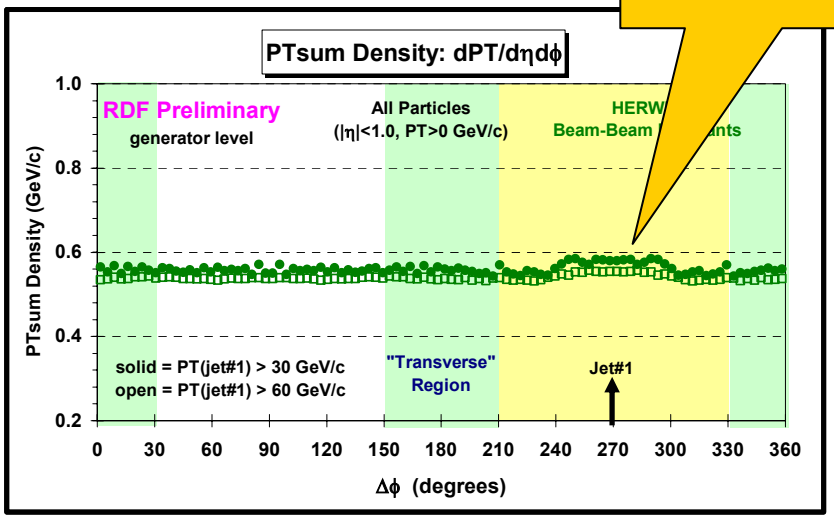




- (*left*) Shows the generator level predictions of HERWIG for the Δϕ dependence of the charged *scalar* PTsum density (|η|<1, p_T>0.5 GeV/c) relative to the leading jet for P_T(jet#1) > 30 GeV/c.
- (*right*) Shows the generator level predictions of HERWIG for the Δϕ dependence of the overall *scalar* PTsum density (|η|<1, p_T>0) relative to the leading jet for P_T(jet#1) > 30 GeV/c.
- The contributions from the "beam-beam remnants" (BBR), initial-state radiation (ISR), and the 2-to-2 hard scattering plus finial-state radiation (2-to-2+FSR) are shown.

HERWIG: PTsum Density dPT/dηdϕ

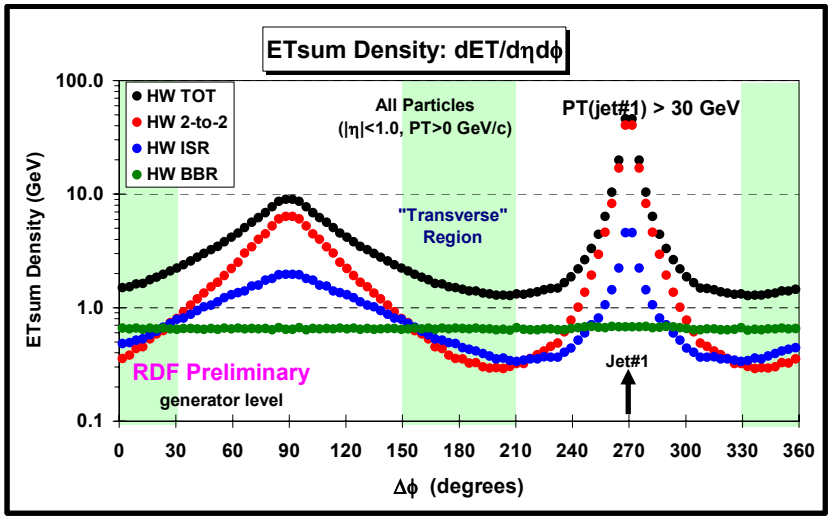


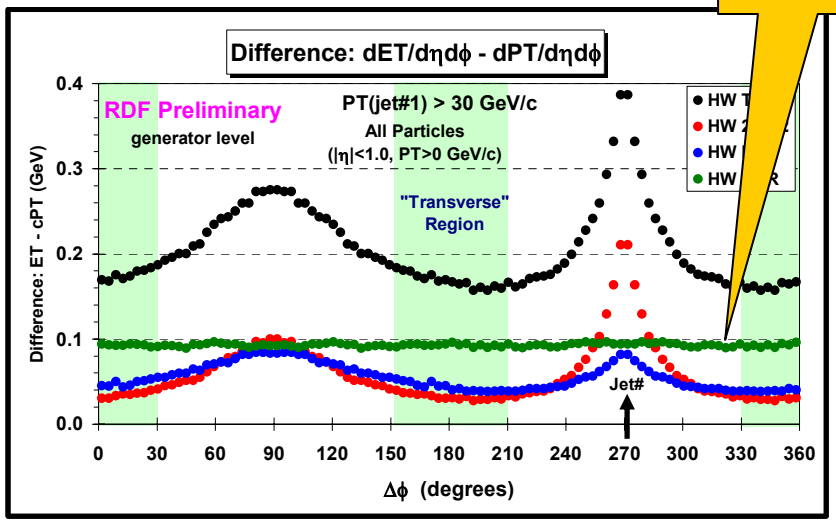


Leading jet is trying to "suck up" the BBR without much success!

- (*left*) Shows the generator level predictions of HERWIG for the Δϕ dependence of the overall *scalar* PTsum density (|η|<1, p_T>0) relative to the leading jet for P_T(jet#1) > 30 GeV/c and for P_T(jet#1) > 60 GeV/c.
- (*right*) Shows the generator level predictions of HERWIG for the Δϕ dependence of the "beam-beam remnant" (BBR) contribution to the overall PTsum density (|η|<1, p_T>0) relative to the leading jet for P_T(jet#1) > 30 GeV/c and for P_T(jet#1) > 60 GeV/c. I was wrong! For HERWIG the BBR component is, on the average, essentially azimuthally symmetric (not enough p_T for the leading jet to "suck up").

HERWIG: ETsum Density dET/dηdϕ



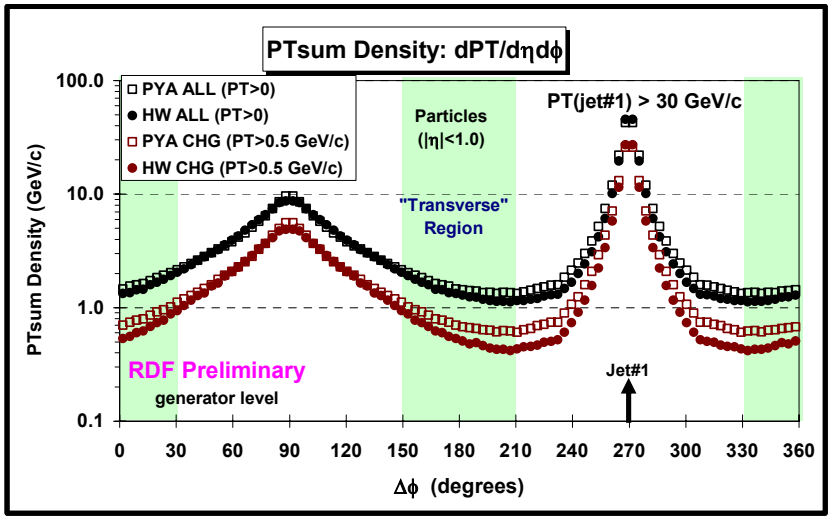


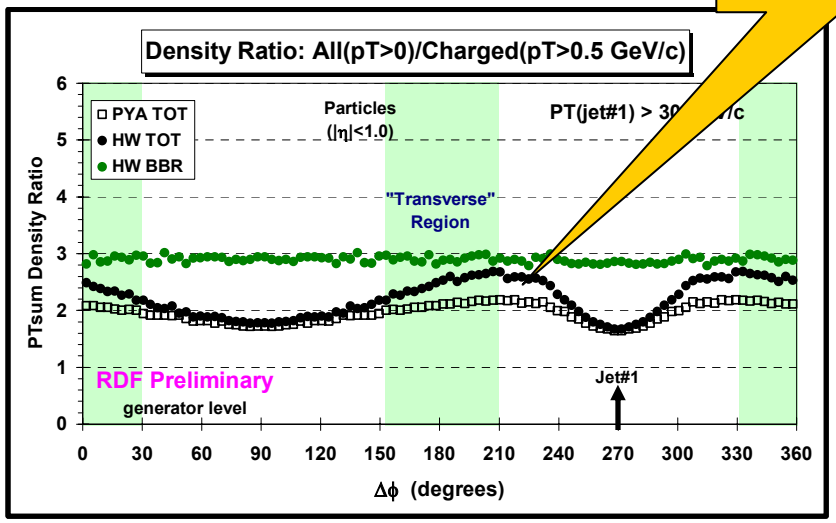
100 MeV difference for BBR!

- (*left*) Shows the generator level predictions of HERWIG for the Δϕ dependence of the overall *scalar* ETsum density (|η|<1, p_T>0) relative to the leading jet for E_T(jet#1) > 30 GeV/c.
- (*right*) Shows the generator level predictions of HERWIG for the Δϕ dependence of the ETsum density minus the PTsum density (|η|<1, p_T>0) relative to the leading jet for P_T(jet#1) > 30 GeV/c.
- The contributions from the "beam-beam remnants" (BBR), initial-state radiation (ISR), and the 2-to-2 hard scattering plus finial-state radiation (2-to-2+FSR) are shown.

PYTHIA Tune A vs HERWIG: PTsum Density dPT/d

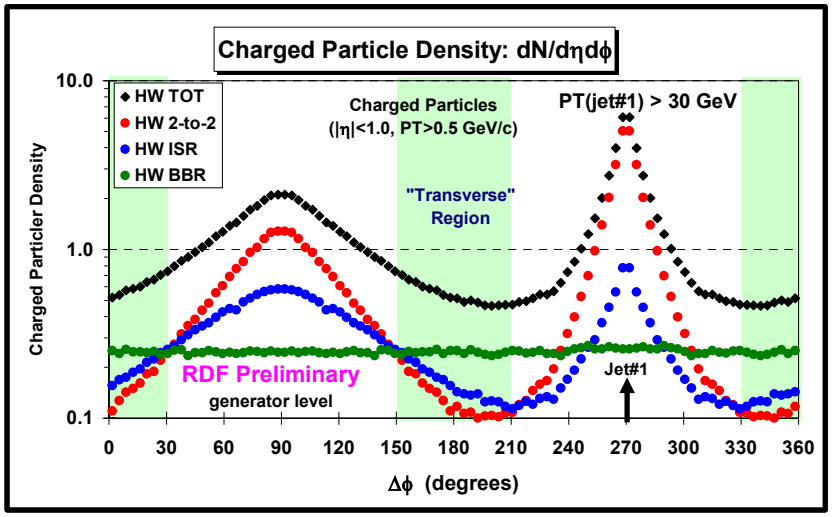
PYTHIA Tune A and HERWIG are different!

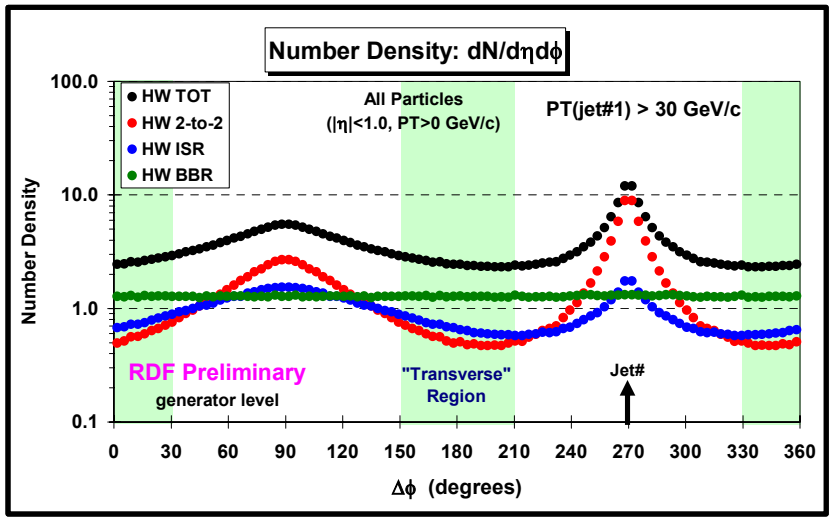




- (*left*) Shows the generator level predictions of PYTHIA Tune A and HERWIG for the Δϕ dependence of the charged *scalar* PTsum density ($|\eta|<1$, $p_T>0.5$ GeV/c) and the overall *scalar* PTsum density ($|\eta|<1$, $p_T>0$) relative to the leading jet for P_T(jet#1) > 30 GeV/c.
- (*right*) Ratio of the overall PTsum density ($|\eta|<1$, $p_T>0$) to the charged PTsum density ($|\eta|<1$, $p_T>0.5$ GeV/c) relative to the leading jet for PYTHIA Tune A and HERWIG. The BBR component of HERWIG is also shown.
- Note that PYTHIA Tune A and HERWIG differ in the extrapolation from p_T > 0.5 GeV/c to p_T > 0!

HERWIG: Number Density dN/dηdϕ

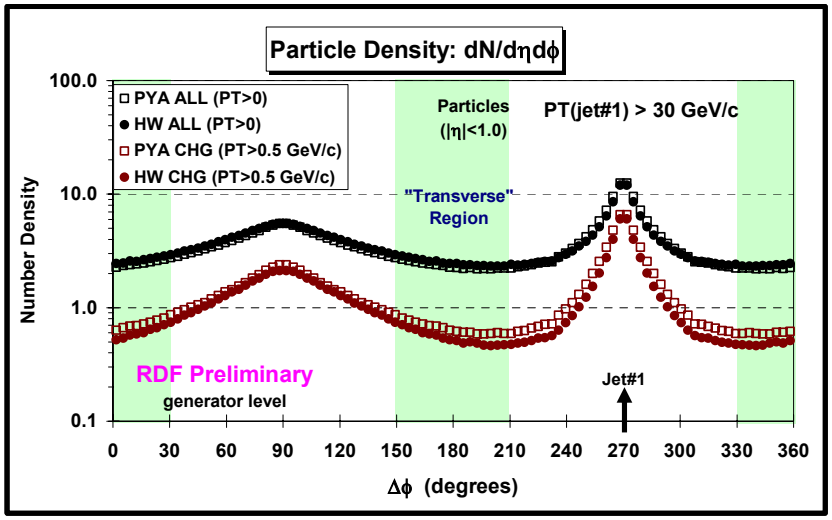


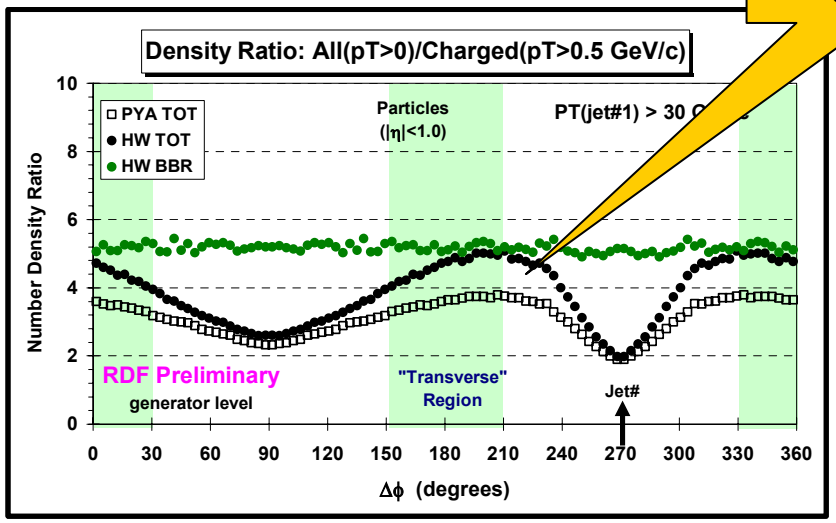


- (*left*) Shows the generator level predictions of HERWIG for the Δϕ dependence of the charged particle density (|η|<1, p_T>0.5 GeV/c) relative to the leading jet for P_T(jet#1) > 30 GeV/c.
- (*right*) Shows the generator level predictions of HERWIG for the Δϕ dependence of the overall particle density (|η|<1, p_T>0) relative to the leading jet for P_T(jet#1) > 30 GeV/c.
- The contributions from the "beam-beam remnants" (BBR), initial-state radiation (ISR), and the 2-to-2 hard scattering plus finial-state radiation (2-to-2+FSR) are shown.

PYTHIA Tune A vs HERWIG: Number Density dN/dη

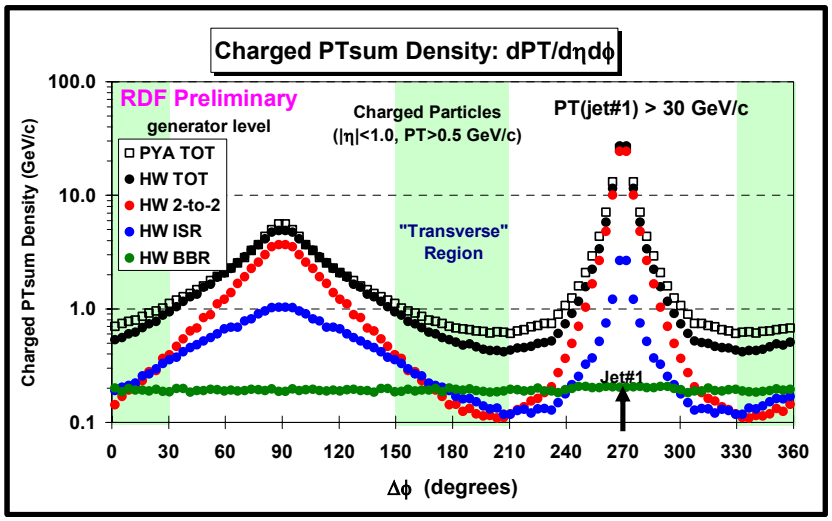
PYTHIA Tune A and HERWIG are different!

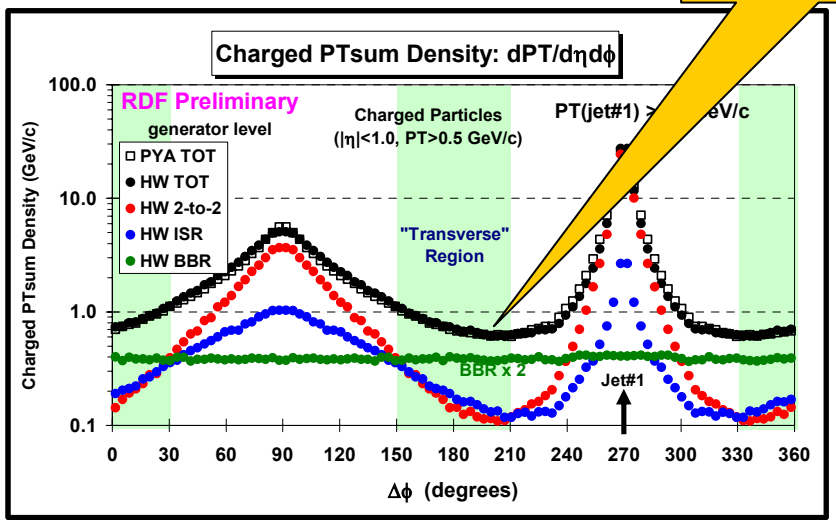




- (*left*) Shows the generator level predictions of PYTHIA Tune A and HERWIG for the Δϕ dependence of the charged particle density ($|\eta|<1$, $p_T>0.5$ GeV/c) and the overall particle density ($|\eta|<1$, $p_T>0$) relative to the leading jet for P_T(jet#1) > 30 GeV/c.
- (*right*) Ratio of the overall particle density ($|\eta|<1$, $p_T>0$) to the charged particle density ($|\eta|<1$, $p_T>0.5$ GeV/c) relative to the leading jet for PYTHIA Tune A and HERWIG. The BBR component of HERWIG is also shown.
- Note that PYTHIA Tune A and HERWIG differ in the extrapolation from p_T > 0.5 GeV/c to p_T > 0!

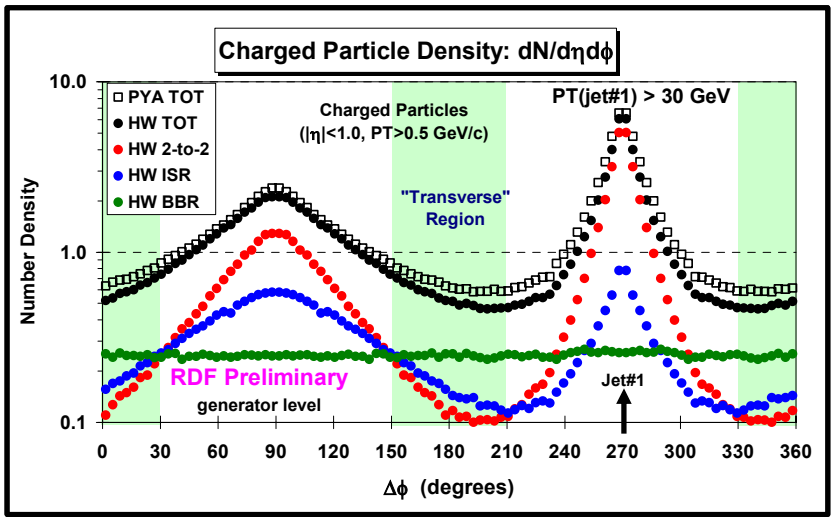
PYTHIA Tune A vs HERWIG: "Transverse Regio

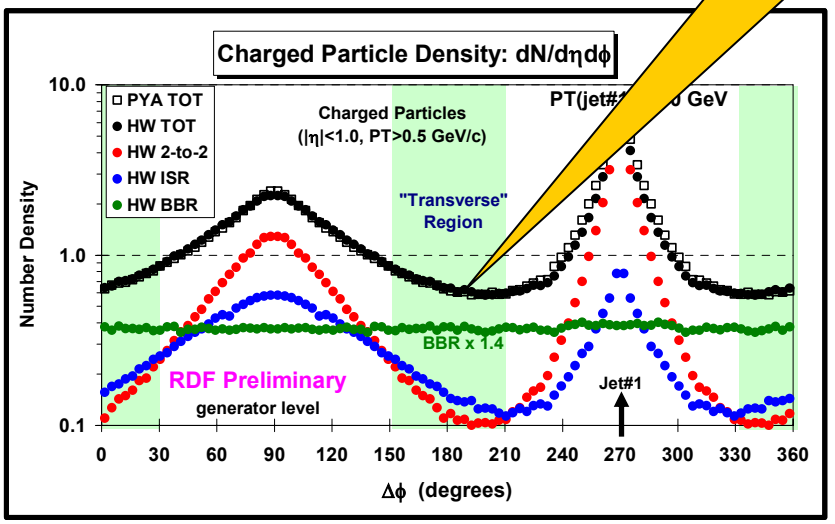




- (*left*) Shows the generator level predictions of PYTHIA Tune A and HERWIG for the Δϕ dependence of the charged *scalar* PTsum density (|η|<1, p_T>0.5 GeV/c) relative to the leading jet for P_T(jet#1) > 30 GeV/c.
- (*right*) Same as (*left*) but with HERWIG BBR increased by a factor of 2.0. The multiple parton interactions in PYTHIA Tune A result in a factor of 2 increase in the PTsum of BBR charged particles (p_T>0.5 GeV/c) over HERWIG!
- HW "Low" = BBR plus HERWIG extrapolation to p_T = 0.
- HW "High" = BBR x 2.0 plus HERWIG extrapolation to p_T = 0.
- HW "High" agrees with PYTHIA Tune A for the charged PTsum (p_T>0.5 GeV/c) in the "transverse" region!

PYTHIA Tune A vs HERWIG: "Transverse Regi

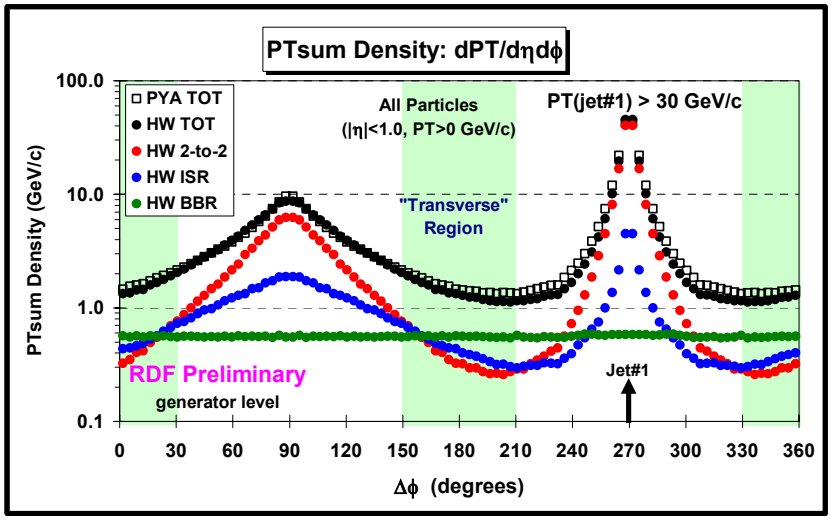


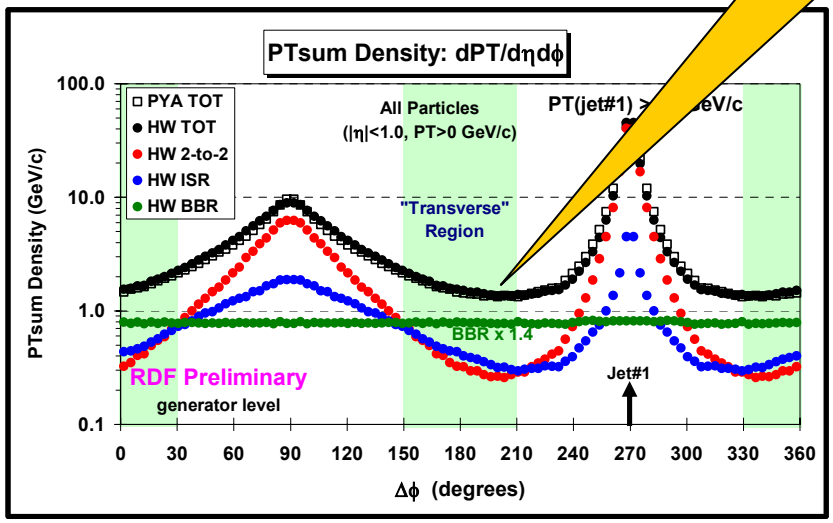


- **(*left*) Shows the generator level predictions of PYTHIA Tune A and HERWIG for the Δϕ dependence of the charged particle density (|η|<1, p_T>0.5 GeV/c) relative to the leading jet for P_T(jet#1) > 30 GeV/c.**
- **(*right*) Same as (*left*) but with HERWIG BBR increased by a factor of 1.4.**
- **HERWIG now agrees with PYTHIA Tune A in the "transverse" region. The multiple parton interactions in PYTHIA Tune A result in a 40% increase in the number of BBR charged particles (p_T>0.5 GeV/c) over HERWIG!**
- **HERWIG particles are "softer" than PYTHIA Tune A! Cannot make both the charged particle density (p_T>0.5 GeV) and the charged PTsum density agree with PYTHIA Tune A!**

PYTHIA Tune A vs HERWIG: "Transverse Regio

HERWIG BBR adjusted to agree with PYTHIA Tune

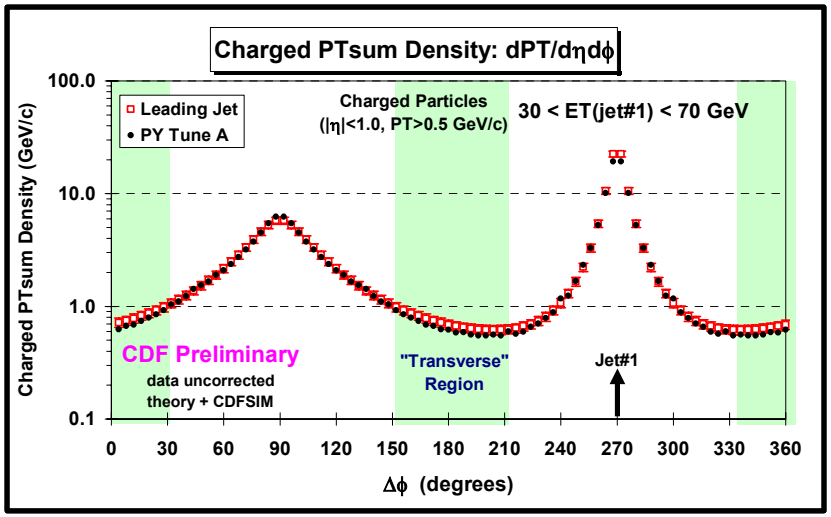


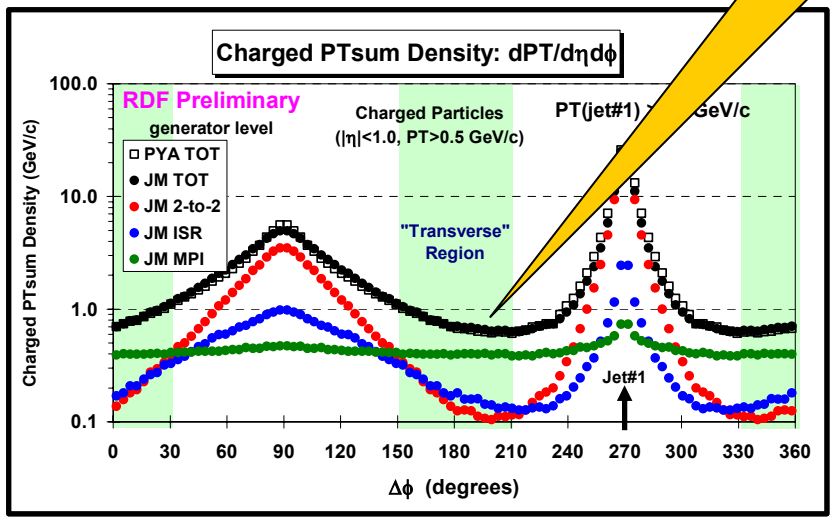


- (*left*) Shows the generator level predictions of PYTHIA Tune A and HERWIG for the Δϕ dependence of the overall *scalar* PTsum density (|η|<1, p_T>0) relative to the leading jet for P_T(jet#1) > 30 GeV/c.
- (*right*) Same as (*left*) but with HERWIG BBR increased by a factor of 1.4. The multiple parton interactions in PYTHIA Tune A result in a 40% increase in the PTsum of all BBR particles (p_T>0) over HERWIG!
- HW "Mid" = BBR x 1.4 (assumes PYTHIA Tune A extrapolation to p_T = 0).
- HW "Mid" agrees with PYTHIA Tune A for the overall PTsum (p_T>0) in the "transverse" region!

PYTHIA Tune A vs JIMMY: "Transverse Region

JIMMY tuned to agree with PYTHIA Tune A!



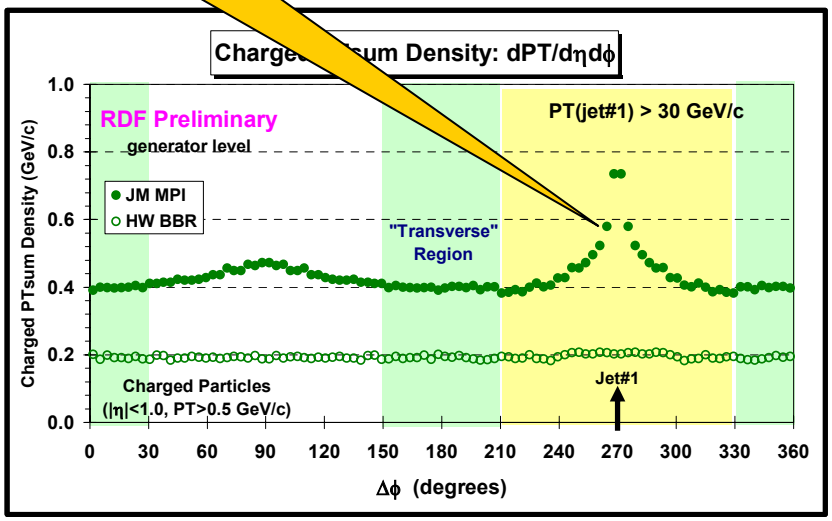


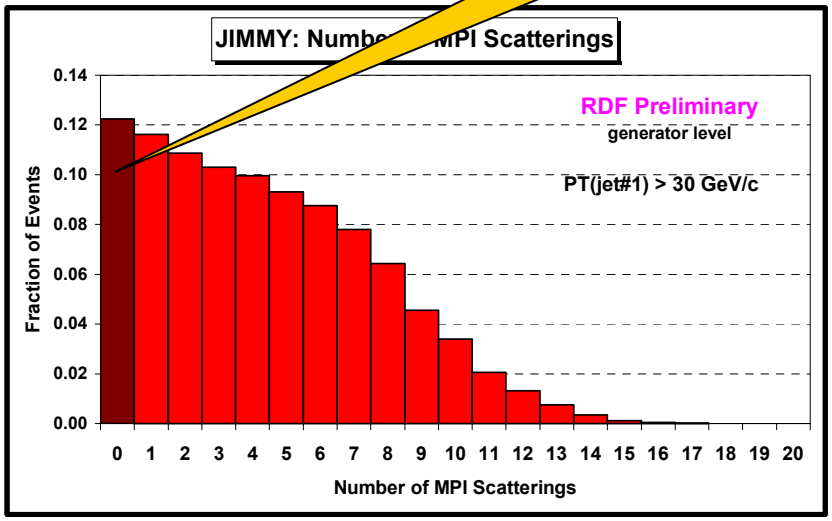
- (*left*) Shows the Run 2 data on the Δφ dependence of the charged *scalar* PTsum density (|η|<1, p_T>0.5 GeV/c) relative to the leading jet for 30 < E_T(jet#1) < 70 GeV/c compared with PYTHIA Tune A (*after CDFSIM*).
- (*right*) Shows the generator level predictions of PYTHIA Tune A and JIMMY ($P_T$min=1.8 GeV/c) for the Δφ dependence of the charged *scalar* PTsum density (|η|<1, p_T>0.5 GeV/c) relative to the leading jet for P_T(jet#1) > 30 GeV/c. JIMMY and PYTHIA Tune A agree in the "transverse" region.
- For JIMMY the contributions from the multiple parton interactions (MPI), initial-state radiation (ISR), and the 2-to-2 hard scattering plus finial-state radiation (2-to-2+FSR) are shown.

JIMMY (MPI) vs HERWIG (BBR)

Leading Jet "sucks-up" MPI particles!

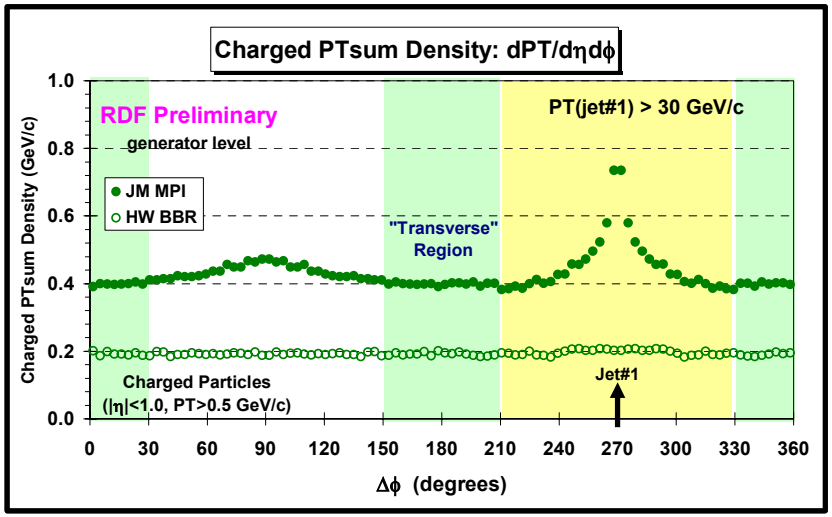
No BBR and no MPI!

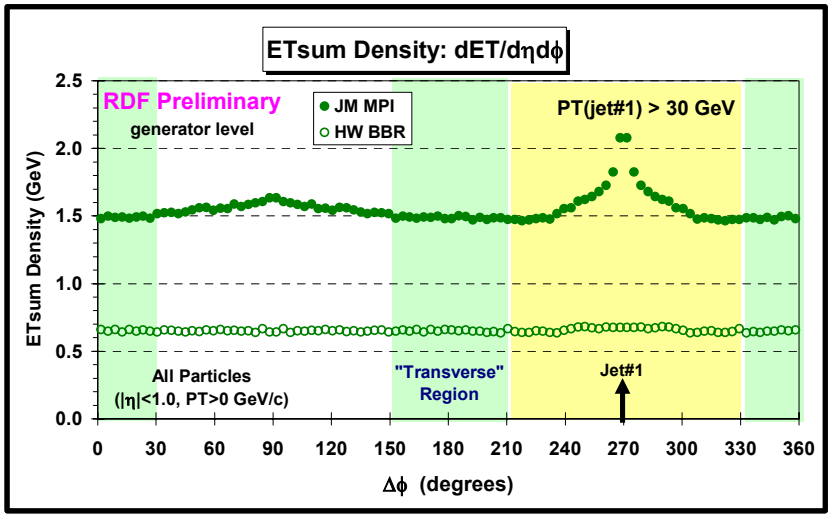




- (*left*) Shows the generator level predictions of JIMMY (MPI, $P_T$min=1.8 GeV/c) and HERWIG (BBR) for the Δφ dependence of the charged *scalar* PTsum density (|η|<1, p_T>0.5 GeV/c) relative to the leading jet for P_T(jet#1) > 30 GeV/c.
- (*right*) Shows the predictions of JIMMY (MPI, $P_T$min=1.8 GeV/c) for the number of multiple parton interactions (MPI) for P_T(jet#1) > 30 GeV/c.
- Note that JIMMY has no BBR. When the number of MPI is equal to zero the event has no BBR and no MPI! This cannot be right! JIMMY should include HERWIG BBR whenever the number of MPI scatterings is zero.
- I tried to make HERWIG produce BBR whenever JIMMY produced no MPI scattering but I was not successful (need help from the authors!).

JIMMY (MPI) vs HERWIG (BBR)



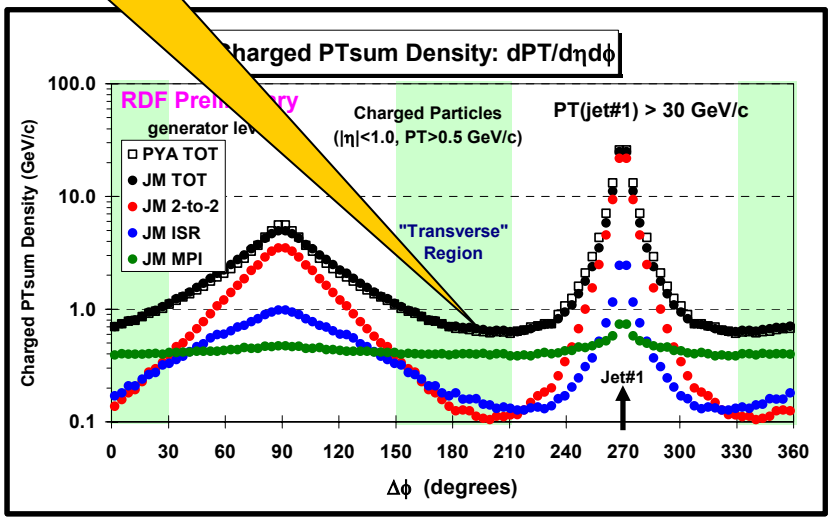


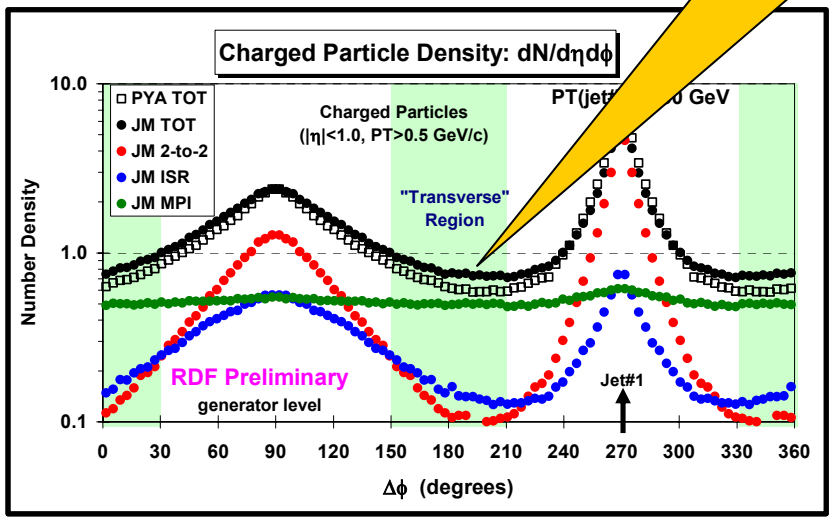
- (*left*) Shows the generator level predictions of JIMMY (MPI, $P_T$min=1.8 GeV/c) and HERWIG (BBR) for the Δϕ dependence of the charged *scalar* PTsum density (|η|<1, p_T>0.5 GeV/c) relative to the leading jet for P_T(jet#1) > 30 GeV/c.
- (*right*) Shows the generator level predictions of JIMMY (MPI, $P_T$min=1.8 GeV/c) and HERWIG (BBR) for the Δϕ dependence of the *scalar* ETsum density (|η|<1, p_T>0 GeV/c) relative to the leading jet for P_T(jet#1) > 30 GeV/c.
- For PTsum in the "transverse" region JIMMY (MPI) is similar to HW "High" (*i.e.* HERWIG BBR x 2.0)!

PYTHIA Tune A vs JIMMY: "Transverse Regi

JIMMY tuned to agree with PYTHIA Tune A!

Tuned JIMMY produces more charged particles than PYTHIA Tune A!

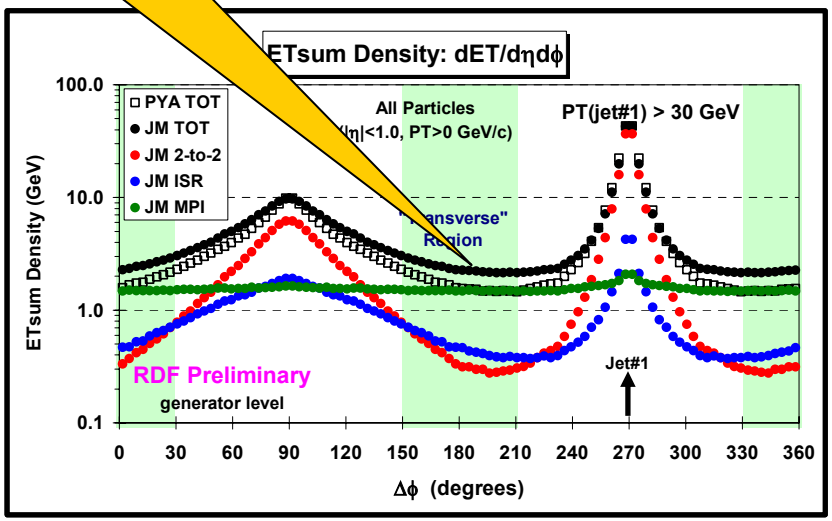


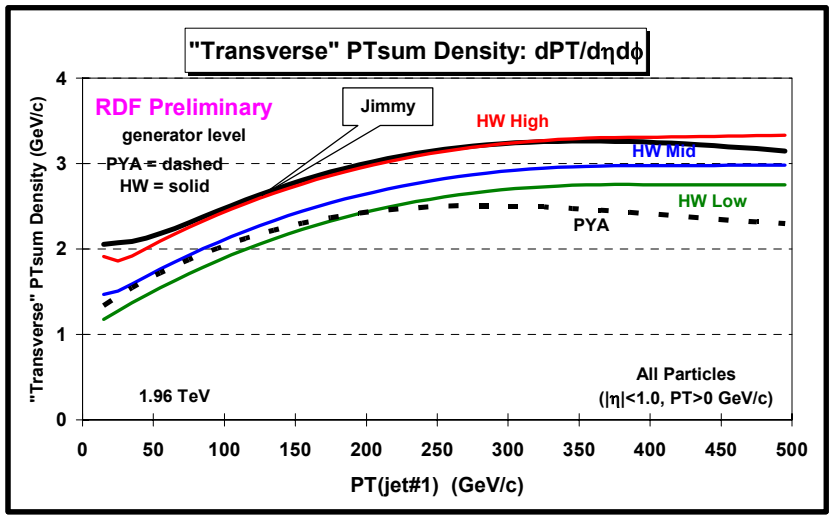


- (*left*) Shows the generator level predictions of PYTHIA Tune A and JIMMY ($P_T$min=1.8 GeV/c) for the Δϕ dependence of the charged *scalar* PTsum density (|η|<1, p_T>0.5 GeV/c) relative to the leading jet with P_T(jet#1) > 30 GeV/c. JIMMY and PYTHIA Tune A agree in the "transverse" region.
- (*right*) Shows the generator level predictions of PYTHIA Tune A and JIMMY ($P_T$min=1.8 GeV/c) for the Δϕ dependence of the charged particle density (|η|<1, p_T>0.5 GeV/c) relative to the leading jet with P_T(jet#1) > 30 GeV/c.
- By only varying $P_T$min I cannot make JIMMY and PYTHIA Tune A agree for both the PTsum density and the number density. JIMMY produces a softer p_T distribution.

Tuned JIMMY produces more ETsum than PYTHIA Tune A!

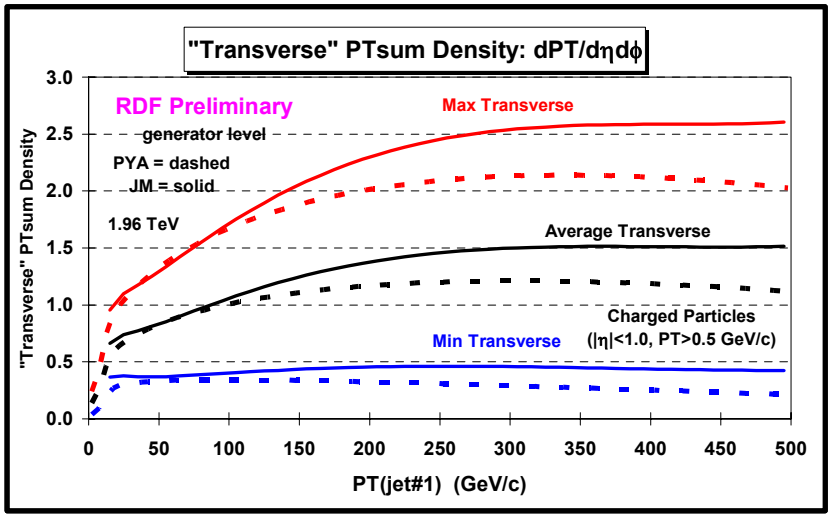
THIA Tune A vs JIMMY: "Transverse Region"

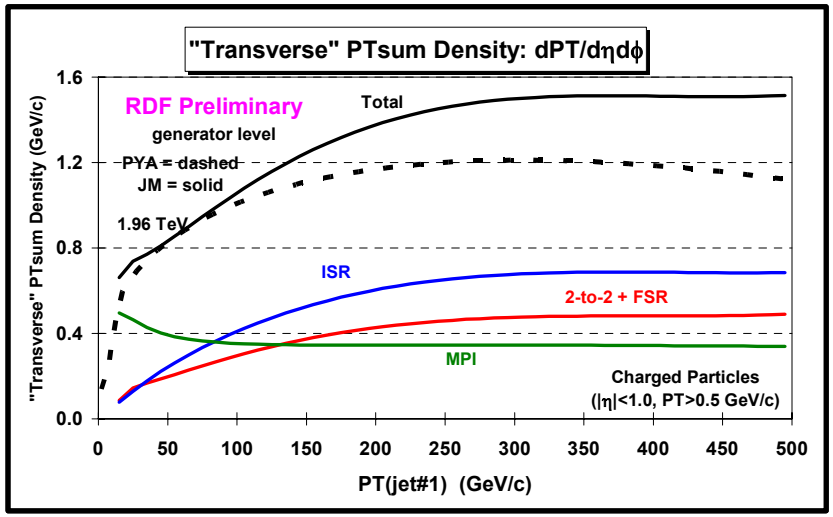




- (*left*) Shows the generator level predictions of PYTHIA Tune A and JIMMY ($P_T$min=1.8 GeV/c) for the Δϕ dependence of the *scalar* ETsum density (|η|<1, p_T>0) relative to the leading jet for P_T(jet#1) > 30 GeV/c.
- (*right*) Shows the generator level predictions of PYTHIA Tune A (dashed), HERWIG (high, mid, low), and JIMMY ($P_T$min=1.8 GeV/c) for overall scalar PTsum density (|η|<1, p_T>0) in the "transverse" region versus P_T(jet#1).
- The tuned JIMMY is very similar to HERWIG "high" (*i.e.* BBR x 2.0).
- The tuned JIMMY produces a lot more ETsum (pT>0) in the "transverse" region than does PYTHIA Tune A!

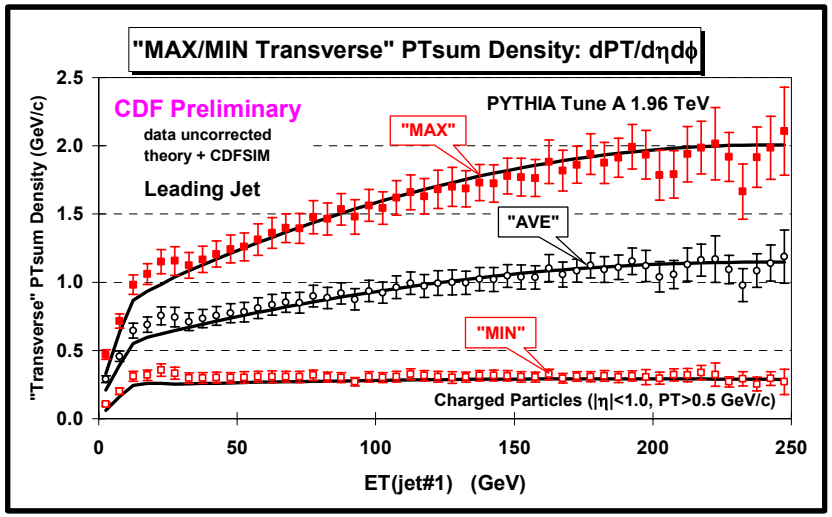
PYTHIA Tune A vs JIMMY: "Transverse Region"

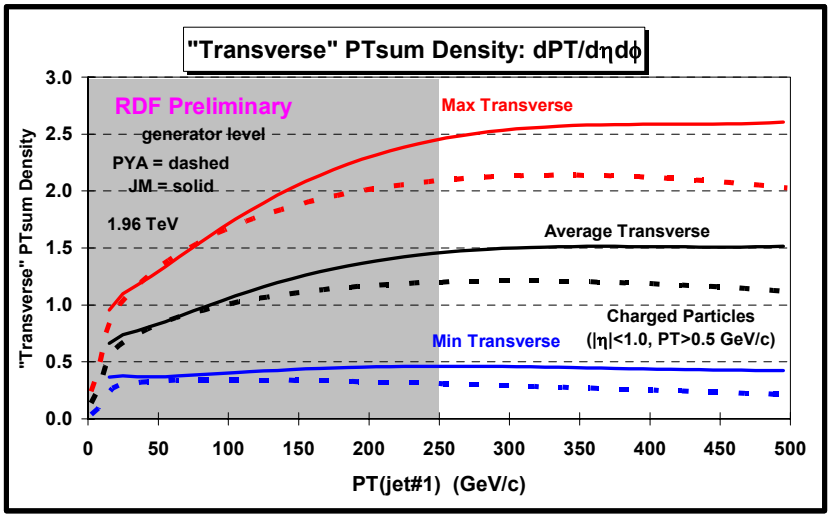




- **(*left*) Shows the generator level predictions of PYTHIA Tune A (*dashed*) and JIMMY ($P_T$min=1.8 GeV/c) for charged *scalar* PTsum density (|η|<1, p_T>0.5 GeV/c) in the MAX/MIN/AVE "transverse" region versus P_T(jet#1).**
- **(*right*) Shows the generator level predictions of PYTHIA Tune A (dashed) and JIMMY ($P_T$min=1.8 GeV/c) for charged *scalar* PTsum density (|η|<1, p_T>0.5 GeV/c) in the AVE "transverse" region versus P_T(jet#1). For JIMMY the contributions from the multiple parton interactions (MPI), initial-state radiation (ISR), and the 2-to-2 hard scattering plus finial-state radiation (2-to-2+FSR) are shown.**

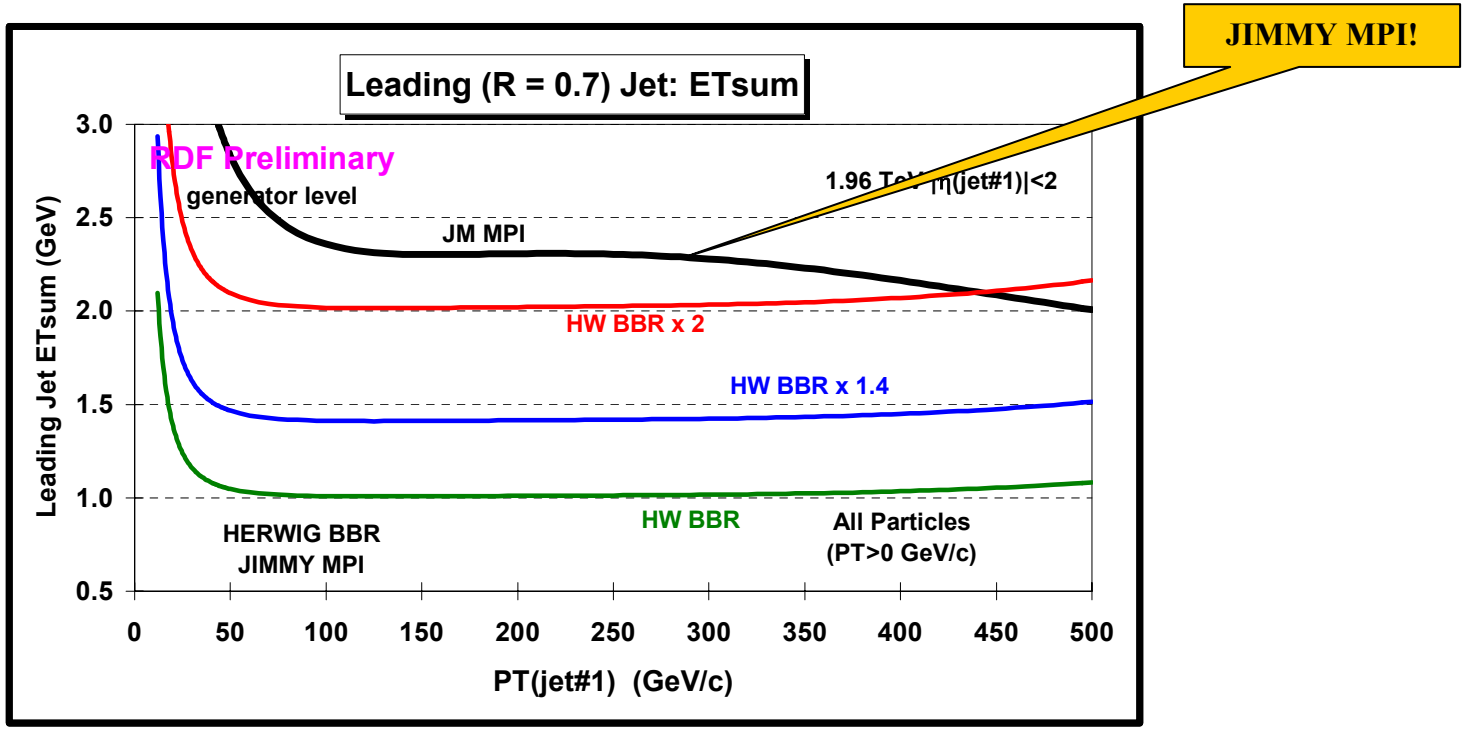
PYTHIA Tune A vs JIMMY: "Transverse Region"





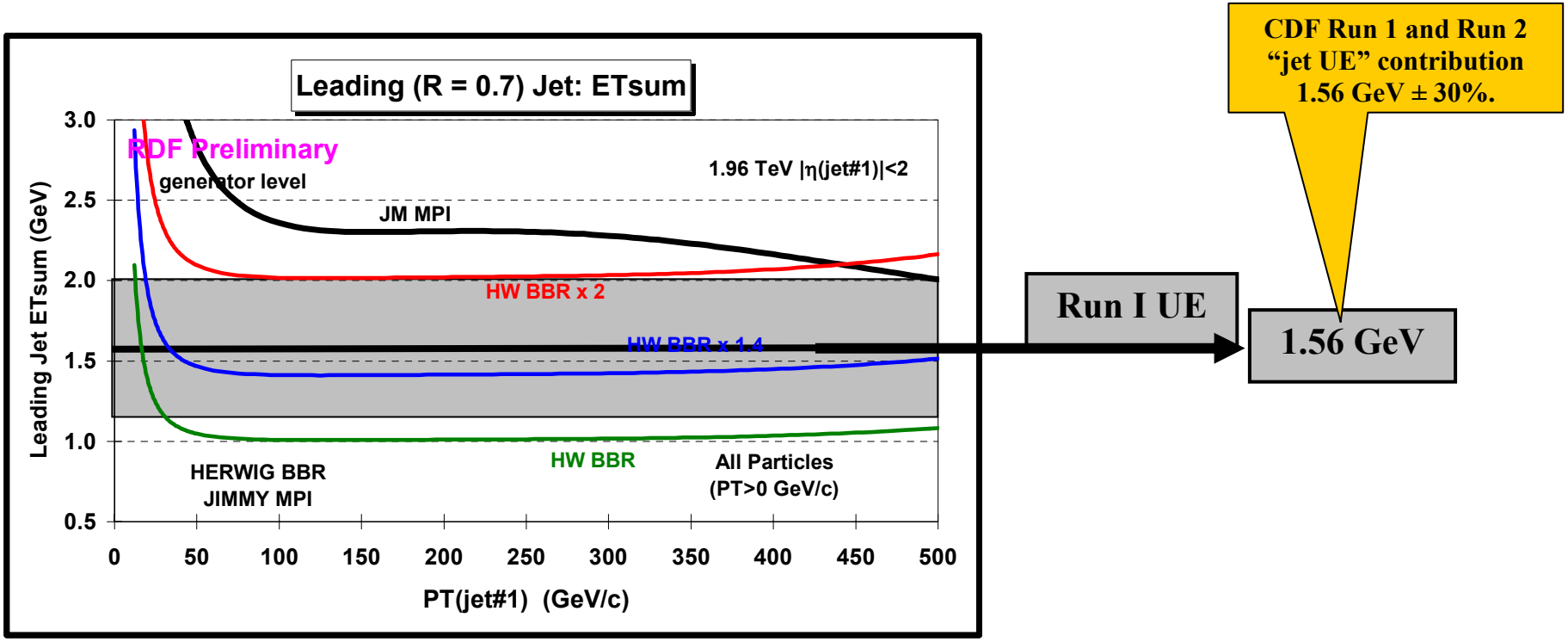
- **(*left*) Run 2 data for charged *scalar* PTsum density ($|\eta|<1$, $p_T>0.5$ GeV/c) in the MAX/MIN/AVE "transverse" region versus P_T(jet#1) compared with PYTHIA Tune A (*after CDFSIM*).**
- **(*right*) Shows the generator level predictions of PYTHIA Tune A (*dashed*) and JIMMY ($P_T$min=1.8 GeV/c) for charged *scalar* PTsum density ($|\eta|<1$, $p_T>0.5$ GeV/c) in the MAX/MIN/AVE "transverse" region versus P_T(jet#1).**
- **The tuned JIMMY now agrees with PYTHIA for P_T(jet#1) < 100 GeV but produces much more activity than PYTHIA Tune A (and the data?) in the "transverse" region for P_T(jet#1) > 100 GeV!**

BBR and MPI Contribution to Jets



- Shows the generator level predictions of HERWIG for the overall *scalar* ETsum of BBR particles within jet#1 (leading jet) (p_T>0 GeV/c) versus p_T(jet#1) for three levels of HERWIG BBR (high, mid, low).
- Shows the generator level predictions of JIMMY for the overall *scalar* ETsum of MPI particles within jet#1 (leading jet) (p_T>0 GeV/c) versus p_T(jet#1) .
- Note that the BBR and MPI contribution to jets varies rapidly over the range P_T(jet) < 100 GeV/c.

BBR and MPI Contribution to Jets



- **Shows the generator level predictions of HERWIG for the overall *scalar* ETsum of BBR particles within jet#1 (leading jet) (p_T>0 GeV/c) versus p_T(jet#1) for three levels of HERWIG BBR (high, mid, low).**
- **Shows the generator level predictions of JIMMY for the overall *scalar* ETsum of MPI particles within jet#1 (leading jet) (p_T>0 GeV/c) versus p_T(jet#1) .**
- **Note that the BBR and MPI contribution to jets varies rapidly over the range P_T(jet) < 100 GeV/c.**

Summary & Plans

- **Problems with JIMMY:**
  - **No BBR or MPI when the number of MPI scatterings is equal to zero.**
  - **Too "soft"! Need to decrease the number of MPI scatterings and make then "harder".**
  - **Problem with the Q^2 dependence. If you make things agree for 15 < E_T(jet#1) < 100 GeV, then too much UE activity for E_T(jet#1) > 100 GeV!**

- **Next Step:**
  - **Work with the authors to fix the problems with JIMMY.**
  - **Study the calorimeter tower energy density in the "transverse region" and compare with HERWIG, JIMMY, and PYTHIA Tune A.**
  - **Study Drell-Yan and low p_T Z-boson production which looks directly at UE(2) = BBR+MPI+ISR.**