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?

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Definition</th>
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<tr>
<td>2-to-2</td>
<td>Two outgoing partons</td>
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<td>ISR</td>
<td>Initial State radiation</td>
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<td>FSR</td>
<td>Final State Radiation</td>
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<tr>
<td>HARD</td>
<td>2-to-2 + ISR + FSR</td>
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<td>BBR</td>
<td>Bean-Beam Remnants</td>
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<td>MPI</td>
<td>Multiple Parton Interactions</td>
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<tr>
<td>Pile-up</td>
<td>Additional proton-antiproton collisions</td>
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<td>MB</td>
<td>“Minimum-Bias” collisions</td>
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<tr>
<td>UE(1)</td>
<td>BBR + MPI</td>
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<tr>
<td>UE(2)</td>
<td>BBR + MPI + ISR</td>
</tr>
<tr>
<td>UE(3)</td>
<td>BBR + MPI + ISR + FSR</td>
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<tr>
<td>UE(4)</td>
<td>MB (does not make sense!)</td>
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</tbody>
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- 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

(\(p_T > 0.5 \text{ GeV/c}, |\eta| < 1\))

- Look at the “transverse” region as defined by the leading calorimeter jet (JetClu \(R = 0.7, |\eta| < 2\)).
- Study the charged particles (\(p_T > 0.5 \text{ GeV/c}, |\eta| < 1\)) and form the charged particle density, \(dN_{\text{ch}}/d\eta d\phi\), and the charged scalar \(p_T\) sum density, \(dP_{\text{Tsum}}/d\eta d\phi\).
- 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**

![Graph of MAX/MIN Transverse Charge Density: dN/dηdφ vs ET(jet#1) for PYTHIA Tune A.]

**HERWIG**

![Graph of MAX/MIN Transverse Charge Density: dN/dηdφ vs ET(jet#1) for HERWIG.]

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

HERWIG agrees with the data for $E_T(jet\#1) > 100$
“Leading Jet” Charge Density: $30 < E_T(j\#1) < 70$ GeV

PYTHIA Tune A

HERWIG

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

HERWIG has too few charged particles in the “transverse” region!
Charged PTsum density for “leading jet” events with $30 < E_T(\text{jet#1}) < 70$ GeV versus PYTHIA Tune A and HERWIG.

**PYTHIA Tune A vs HERWIG: PTsum Density $dP_T/d\eta d\phi$**

- **PYTHIA Tune A**
  - Charged Particles $(|\eta|<1.0, P_T>0.5 \text{ GeV/c})$
  - Leading Jet $30 < E_T(\text{jet#1}) < 70$ GeV

- **HERWIG**
  - Charged Particles $(|\eta|<1.0, P_T>0.5 \text{ GeV/c})$
  - Leading Jet $30 < E_T(\text{jet#1}) < 70$ GeV

**HERWIG does not have enough charged PTsum in the “transverse” region!**
HERWIG: PTsum Density \(dPT/d\eta d\phi\)

- (left) Shows the generator level predictions of HERWIG for the \(\Delta \phi\) dependence of the charged scalar PTsum density (\(|\eta|<1, \ p_T>0.5\) GeV/c) relative to the leading jet for \(P_T(\text{jet#1}) > 30\) GeV/c.

- (right) Shows the generator level predictions of HERWIG for the \(\Delta \phi\) dependence of the overall scalar PTsum density (\(|\eta|<1, \ p_T>0\)) relative to the leading jet for \(P_T(\text{jet#1}) > 30\) GeV/c.

- The contributions from the “beam-beam remnants” (BBR), initial-state radiation (ISR), and the 2-to-2 hard scattering plus final-state radiation (2-to-2+FSR) are shown.
HERWIG: PTsum Density $dP_T/d\eta d\phi$

- *(left)* Shows the generator level predictions of HERWIG for the $\Delta \phi$ dependence of the overall scalar PTsum density ($|\eta|<1$, $p_T>0$) 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 $\Delta \phi$ dependence of the “beam-beam remnant” (BBR) contribution to the overall PTsum density ($|\eta|<1$, $p_T>0$) 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 $dE_T/d\eta d\phi$**

- **(left)** Shows the generator level predictions of HERWIG for the $\Delta \phi$ dependence of the overall *scalar* ETsum density ($|\eta|<1$, $p_T>0$) relative to the leading jet for $E_T(\text{jet#1}) > 30$ GeV/c.

- **(right)** Shows the generator level predictions of HERWIG for the $\Delta \phi$ dependence of the ETsum density minus the PTsum density ($|\eta|<1$, $p_T>0$) relative to the leading jet for $P_T(\text{jet#1}) > 30$ GeV/c.

- The contributions from the "beam-beam remnants" (BBR), initial-state radiation (ISR), and the 2-to-2 hard scattering plus final-state radiation (2-to-2+FSR) are shown.
PYTHIA Tune A vs HERWIG: PTsum Density $dP_T/d\eta d\phi$

- **(left)** Shows the generator level predictions of PYTHIA Tune A and HERWIG for the $\Delta\phi$ 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 $dN/d\eta d\phi$**

- *(left)* Shows the generator level predictions of HERWIG for the $\Delta \phi$ dependence of the charged particle density ($|\eta|<1$, $p_T>0.5$ 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 $\Delta \phi$ dependence of the overall particle density ($|\eta|<1$, $p_T>0$) 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 final-state radiation (2-to-2+FSR) are shown.
PYTHIA Tune A vs HERWIG: Number Density $dN/d\eta d\phi$

- **(left)** Shows the generator level predictions of PYTHIA Tune A and HERWIG for the $\Delta \phi$ 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 Region”**

- *(left)* Shows the generator level predictions of PYTHIA Tune A and HERWIG for the $\Delta \phi$ dependence of the charged *scalar* PTsum density ($|\eta|<1$, $p_T>0.5$ 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 Region”**

- *(left)* Shows the generator level predictions of PYTHIA Tune A and HERWIG for the $\Delta \phi$ dependence of the charged particle density ($|\eta|<1$, $p_T>0.5$ GeV/c) relative to the leading jet for $P_T(\text{jet#1}) > 30$ 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!
(left) Shows the generator level predictions of PYTHIA Tune A and HERWIG for the $\Delta \phi$ dependence of the overall scalar PTsum density ($|\eta|<1$, $p_T>0$) 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”

- (left) Shows the Run 2 data on the $\Delta \phi$ dependence of the charged scalar PTsum density ($|\eta|<1, p_T>0.5$ 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 $\Delta \phi$ dependence of the charged scalar PTsum density ($|\eta|<1, p_T>0.5$ 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)

- (left) Shows the generator level predictions of JIMMY (MPI, $P_{T\text{min}}=1.8$ GeV/c) and HERWIG (BBR) for the $\Delta \phi$ dependence of the charged scalar PTsum density ($|\eta|<1$, $p_T>0.5$ GeV/c) relative to the leading jet for $P_T(jet#1) > 30$ GeV/c.

- (right) Shows the predictions of JIMMY (MPI, $P_{T\text{min}}=1.8$ 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!).

No BBR and no MPI!
Leading Jet “sucks-up” MPI particles!
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 $\Delta \phi$ dependence of the charged scalar PTsum density ($|\eta|<1, p_T>0.5$ 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 $\Delta \phi$ dependence of the scalar ETsum density ($|\eta|<1, p_T>0$ 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)!
JIMMY tuned to agree with PYTHIA Tune A!

PYTHIA Tune A vs JIMMY: “Transverse Region”

- (left) Shows the generator level predictions of PYTHIA Tune A and JIMMY ($P_T \text{min}=1.8 \text{ GeV/c}$) for the $\Delta \phi$ dependence of the charged scalar PTsum density ($|\eta|<1, p_T>0.5 \text{ GeV/c}$) relative to the leading jet with $P_T(\text{jet#1}) > 30 \text{ GeV/c}$. JIMMY and PYTHIA Tune A agree in the “transverse” region.

- (right) Shows the generator level predictions of PYTHIA Tune A and JIMMY ($P_T \text{min}=1.8 \text{ GeV/c}$) for the $\Delta \phi$ dependence of the charged particle density ($|\eta|<1, p_T>0.5 \text{ GeV/c}$) relative to the leading jet with $P_T(\text{jet#1}) > 30 \text{ GeV/c}$.

- By only varying $P_T \text{min}$ 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.

JIMMY produces more charged particles than PYTHIA Tune A!
**PYTHIA Tune A vs JIMMY: “Transverse Region”**

- *(left)* Shows the generator level predictions of PYTHIA Tune A and JIMMY ($P_{T\text{min}}=1.8$ GeV/c) for the $\Delta\phi$ dependence of the scalar ETsum density ($|\eta|<1$, $p_T>0$) relative to the leading jet for $P_T(\text{jet#1}) > 30$ GeV/c.

- *(right)* Shows the generator level predictions of PYTHIA Tune A (dashed), HERWIG *(high, mid, low)*, and JIMMY ($P_{T\text{min}}=1.8$ GeV/c) for overall scalar PTsum density ($|\eta|<1$, $p_T>0$) in the “transverse” region versus $P_T(\text{jet#1})$.

- The tuned JIMMY is very similar to HERWIG “high” *(i.e. BBR x 2.0)*.
- The tuned JIMMY produces a lot more ETsum ($p_T>0$) in the “transverse” region than does PYTHIA Tune A!
(left) Shows the generator level predictions of PYTHIA Tune A (dashed) and JIMMY (P_{Tmin}=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).

(right) Shows the generator level predictions of PYTHIA Tune A (dashed) and JIMMY (P_{Tmin}=1.8 GeV/c) for charged scalar PTsum density (|\eta|<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 final-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 ($P_{T_{\text{min}}}=1.8$ 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) \((p_T>0 \text{ GeV/c})\) versus \(p_T(\text{jet#1})\) 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) \((p_T>0 \text{ GeV/c})\) versus \(p_T(\text{jet#1})\).
- Note that the BBR and MPI contribution to jets varies rapidly over the range \(P_T(\text{jet}) < 100 \text{ GeV/c}\).
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.

CDF Run 1 and Run 2 “jet UE” contribution 1.56 GeV ± 30%.
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 $15 < E_T(\text{jet#1}) < 100$ GeV, then too much UE activity for $E_T(\text{jet#1}) > 100$ 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 $UE(2) = BBR+MPI+ISR$. 