Outline of Talk

- What is Min-Bias? Does it really exist?
- “Jets” in Min-Bias Collisions. Clear Jet structure as low as 1 GeV/c!
- Extrapolating Tevatron Min-Bias to the LHC.
- Using Pile-Up collisions to Study Min-Bias. Is Pile-Up Unbiased?
Proton-AntiProton Collisions at the Tevatron

\[ \sigma_{\text{tot}} = \sigma_{\text{EL}} + \sigma_{\text{SD}} + \sigma_{\text{DD}} + \sigma_{\text{HC}} \]

1.8 TeV: 78mb = 18mb + 9mb + (4-7)mb + (47-44)mb

The “hard core” component contains both “hard” and “soft” collisions.

“Soft” Hard Core (no hard scattering)

“Hard” Hard Core (hard scattering)
Proton-AntiProton Collisions at the Tevatron

Elastic Scattering

Single Diffraction

Double Diffraction

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The “hard core” component contains both “hard” and “soft” collisions.

CDF “Min-Bias” trigger picks up most of the “hard core” cross-section plus a small amount of single & double diffraction.

The CDF “Min-Bias” trigger
1 charged particle in forward BBC
AND
1 charged particle in backward BBC

“Hard” Hard Core (hard scattering)

“Soft” Hard Core (no hard scattering)

Beam-Beam Counters 3.2 < |\eta| < 5.9
No-Bias vs Min-Bias

Charged Particle Density: $dN/d\eta$

No Trigger
900 GeV Generated

CDF Min-Bias Trigger
900 GeV Generated

No Trigger
900 GeV Weighted

CDF Min-Bias Trigger
900 GeV Weighted
No-Bias vs Min-Bias

Charged Particle Density: $dN/d\eta$

What you see for “Min-Bias” depends on your trigger!
No-Bias vs Min-Bias

Charged particle (all $p_T$) pseudo-rapidity distribution, $dN_{chg}/d\eta d\phi$, at 1.96 TeV with no trigger (i.e. no-bias) from PYTHIA Tune DW.

About 2.5 charged particles per unit $\eta$ at $\eta = 0$.

About 0.9 charged particles ($p_T > 0.5$ GeV/c) per unit $\eta$ at $\eta = 0$.

Charged particle ($p_T > 0.5$ GeV/c) pseudo-rapidity distribution, $dN_{chg}/d\eta d\phi$, at 1.96 TeV with the CDF Min-Bias trigger from PYTHIA Tune DW.

About 1.5 charged particles ($p_T > 0.5$ GeV/c) per unit $\eta$ at $\eta = 0$ with CDF min-bias trigger.
Study the charged particles ($p_T > 0.5$ GeV/c, $|\eta| < 1$) and form the charged particle density, $dN_{chg}/d\eta d\phi$, and the charged scalar $p_T$ sum density, $dPT_{sum}/d\eta d\phi$. 

<table>
<thead>
<tr>
<th>Observable</th>
<th>Average</th>
<th>Average Density per unit $\eta-\phi$</th>
</tr>
</thead>
<tbody>
<tr>
<td>N$_{chg}$ Number of Charged Particles ($p_T &gt; 0.5$ GeV/c, $</td>
<td>\eta</td>
<td>&lt; 1$)</td>
</tr>
<tr>
<td>PT$_{sum}$ Scalar $p_T$ sum of Charged Particles ($p_T &gt; 0.5$ GeV/c, $</td>
<td>\eta</td>
<td>&lt; 1$)</td>
</tr>
</tbody>
</table>

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

$dN_{chg}/d\eta d\phi = 3/4\pi = 0.24$

$dPT_{sum}/d\eta d\phi = 3/4\pi$ GeV/c = 0.24 GeV/c
Shows CDF “Min-Bias” data on the number of charged particles per unit pseudo-rapidity at 630 and 1,800 GeV. There are about **4.2 charged particles per unit η in “Min-Bias” collisions at 1.8 TeV (|η| < 1, all P_T)**.

Convert to charged particle density, \( \frac{dN_{\text{chg}}}{d\eta d\phi} \), by dividing by \( 2\pi \). There are about **0.67 charged particles per unit η-ϕ in “Min-Bias” collisions at 1.8 TeV (|η| < 1, all P_T)**.
Shows the center-of-mass energy dependence of the charged particle density, $dN_{\text{chg}}/d\eta d\phi$, for “Min-Bias” collisions at $\eta = 0$. Also show a log fit (Fit 1) and a $(\log)^2$ fit (Fit 2) to the CDF plus UA5 data.

What should we expect for the LHC?
PYTHIA Tune A Min-Bias “Soft” + ”Hard”

PYTHIA regulates the perturbative 2-to-2 parton-parton cross sections with cut-off parameters which allows one to run with $P_T^{(hard)} > 0$. One can simulate both “hard” and “soft” collisions in one program.

The relative amount of “hard” versus “soft” depends on the cut-off and can be tuned.
PYTHIA Tune A Min-Bias
“Soft” + ”Hard”

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The relative amount of “hard” versus “soft” depends on the cut-off and can be tuned.

This PYTHIA fit predicts that 12% of all “Min-Bias” events are a result of a hard 2-to-2 parton-parton scattering with $P_T(hard) > 5$ GeV/c (1% with $P_T(hard) > 10$ GeV/c)!
Use the maximum $p_T$ charged particle in the event, $PT_{max}$, to define a direction and look at the the “associated” density, $dN_{chg}/d\eta d\phi$, in “min-bias” collisions ($p_T > 0.5$ GeV/c, $|\eta| < 1$).

Shows the data on the $\Delta \phi$ 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 $PT_{max}$) relative to $PT_{max}$ (rotated to $180^\circ$) for “min-bias” events. Also shown is the average charged particle density, $dN_{chg}/d\eta d\phi$, for “min-bias” events.
Use the maximum p_T charged particle in the event, PTmax, to define a direction and look at the "associated" density, dNchg/d\(\eta\)d\(\phi\), in "min-bias" collisions (p_T > 0.5 GeV/c, |\(\eta\)| < 1).

- "Associated" densities do not include PTmax!

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

- Shows the CDF Preliminary data uncorrected 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, dNchg/d\(\eta\)d\(\phi\), for "min-bias" events.
Min-Bias “Associated” Charged Particle Density

- Shows the data on the $\Delta \phi$ dependence of the “associated” charged particle density, $dN_{\text{ch}}/d\eta d\phi$, for charged particles ($p_T > 0.5 \text{ GeV/c}, |\eta| < 1$, not including $PT_{\text{max}}$) relative to $PT_{\text{max}}$ (rotated to 180$^\circ$) for “min-bias” events with $PT_{\text{max}} > 0.5, 1.0, \text{ and } 2.0 \text{ GeV/c}$.

- Shows “jet structure” in “min-bias” collisions (i.e. the “birth” of the leading two jets!).
Min-Bias “Associated” Charged Particle Density

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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”).
PYTHIA Tune A
LHC Min-Bias Predictions

- Shows the center-of-mass energy dependence of the charged particle density, $dN_{\text{chg}}/d\eta d\phi$, for “Min-Bias” collisions compared with PYTHIA Tune A with $P_T(\text{hard}) > 0$.
- PYTHIA was tuned to fit the “underlying event” in hard-scattering processes at 1.8 TeV and 630 GeV.
- PYTHIA Tune A predicts a 42% rise in $dN_{\text{chg}}/d\eta d\phi$ at $\eta = 0$ in going from the Tevatron (1.8 TeV) to the LHC (14 TeV). Similar to HERWIG “soft” min-bias, 4 charged particles per unit $\eta$ becomes 6.
PYTHIA Tune A
LHC Min-Bias Predictions

- Charged Particle Density
  - Shows the center-of-mass energy dependence of the charged particle density, $dN_{\text{chg}}/d\eta d\phi dP_T$, for “Min-Bias” collisions compared with PYTHIA Tune A with $P_T(\text{hard}) > 0$.

- PYTHIA Tune A predicts that 1% of all “Min-Bias” events at 1.8 TeV are a result of a hard 2-to-2 parton-parton scattering with $P_T(\text{hard}) > 10$ GeV/c which increases to 12% at 14 TeV!

- PYTHIA Tune A predicts that 1% of all “Min-Bias” events at 1.8 TeV are a result of a hard 2-to-2 parton-parton scattering with $P_T(\text{hard}) > 10$ GeV/c which increases to 12% at 14 TeV!
Shows the predictions of PYTHIA Tune A, Tune DW, Tune DWT, and the ATLAS tune for the charged particle density $dN/d\eta$ and $dN/dY$ at 14 TeV (all $p_T$).

PYTHIA Tune A and Tune DW predict about 6 charged particles per unit $\eta$ at $\eta = 0$, while the ATLAS tune predicts around 9.

PYTHIA Tune DWT is identical to Tune DW at 1.96 TeV, but extrapolates to the LHC using the ATLAS energy dependence.
The ATLAS tune has many more “soft” particles than does any of the CDF Tunes. The ATLAS tune has $<p_T> = 548$ MeV/c while Tune A has $<p_T> = 641$ MeV/c (100 MeV/c more per particle)!

Shows the predictions of PYTHIA Tune A, Tune DW, Tune DWT, and the ATLAS tune for the charged particle $p_T$ distribution at 14 TeV ($|\eta| < 1$) and the average number of charged particles with $p_T > p_T^{\text{min}}$ ($|\eta| < 1$).
The primary vertex is the highest PTsum of charged particles pointing towards it.

- Normally one only includes those charged particles which point back to the primary vertex.
- However, the primary vertex is presumably the collision that satisfied the trigger and is hence biased.
- Perhaps the pile-up is not biases and can serve as a new type of “Min-Bias” collisions.
Using Pile-Up to Study Min-Bias

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- Normally one only includes those charged particles which point back to the primary vertex.
- However, the primary vertex is presumably the collision that satisfied the trigger and is hence biased.
- Perhaps the pile-up is not biased and can serve as a new type of “Min-Bias” collisions.
- This assumes that the pile-up is not affected by the trigger (i.e. it is the same for all primary processes).
Summary and Conclusions

- “Min-Bias” is not well defined. What you see depends on what you trigger on! Every trigger produces some biases.

- We have learned a lot about “Min-Bias” at the Tevatron, but we do not know what to expect at the LHC. This will depend on the Min-Bias Trigger!

- Very preliminary results seem to show that pile-up conspires to help give you what you ask for (i.e. satisfy your “trigger” or your event selection)! If true this means the pile-up is not the same for all processes. It is process (i.e. trigger) dependent!

I must double check my analysis and get it “blessed” before you can trust what I have shown!