Modeling Min-Bias and the Underlying Event

Rick Field
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University of Oregon March 7-11, 2011
How are “min-bias” collisions related to the “underlying event”.

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Part 2
Min-Bias Collisions at the LHC

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Part 2

- How are “min-bias” collisions related to the “underlying event”.

- How well did we do at predicting the behavior of “min-bias” collisions at the LHC (900 GeV and 7 TeV)?

“Minimum Bias” Collisions

Proton

Proton

University of Oregon March 7-11, 2011

CMS

ATLAS

Oregon Terascale Workshop
March 8, 2011

Rick Field – Florida/CDF/CMS

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Tuesday, March 8, 2011
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PYTHIA 6.4 Tune Z1: CMS tune (p_T-ordered parton showers and new MPI). Comparisons with the LHC Min-Bias data.
Min-Bias Collisions at the LHC

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New Physics in Min-Bias??
Observation of long-range same-side correlations at 7 TeV.

“Minimum Bias” Collisions
Min-Bias Collisions at the LHC

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New Physics in Min-Bias??
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Strange particle production: A problem for the models?

UE&MB@CMS
\[ \sigma_{\text{tot}} = \sigma_{\text{EL}} + \sigma_{\text{IN}} \]
Proton-Proton Collisions

\[ \sigma_{\text{tot}} = \sigma_{\text{EL}} + \sigma_{\text{IN}} \]
Proton-Proton Collisions

\[ \sigma_{tot} = \sigma_{EL} + \sigma_{SD} + \sigma_{DD} + \sigma_{HC} \]
Proton-Proton Collisions

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Proton-Proton Collisions

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

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

“Soft” Hard Core (no hard scattering)
The "hard core" component contains both "hard" and "soft" collisions.

\[
\sigma_{\text{tot}} = \sigma_{\text{EL}} + \sigma_{\text{SD}} + \sigma_{\text{DD}} + \sigma_{\text{ND}}
\]
The Inelastic Non-Diffractive
The Inelastic Non-Diffractive

“Semi-hard” parton-parton collision \((p_T < \approx 2 \text{ GeV/c})\)

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The Inelastic Non-Diffractive

“Semi-hard” parton-parton collision ($p_T \lesssim 2$ GeV/c)
The Inelastic Non-Diffractive

"Semi-hard" parton-parton collision ($p_T \lesssim 2$ GeV/c)

Multiple-parton interactions (MPI)!
The Inelastic Non-Diffractive

“Semi-hard” parton-parton collision \( (p_T < \approx 2 \text{ GeV/c}) \)

Majority of “min-bias” events!

Multiple-parton interactions (MPI)!
The Inelastic Non-Diffractive

Occasionally one of the parton-parton collisions is hard ($p_T > \approx 2 \text{ GeV/c}$)

Majority of “min-bias” events!

“Semi-hard” parton-parton collision ($p_T < \approx 2 \text{ GeV/c}$)

Multiple-parton interactions (MPI)!
Select inelastic non-diffractive events that contain a hard scattering
Select inelastic non-diffractive events that contain a hard scattering

Hard parton-parton collisions is hard ($p_T > \approx 2$ GeV/c)
Select inelastic non-diffractive events that contain a hard scattering.

Hard parton-parton collisions is hard ($p_T > \approx 2 \text{ GeV}/c$)

“Semi-hard” parton-parton collision ($p_T < \approx 2 \text{ GeV}/c$)
Select inelastic non-diffractive events that contain a hard scattering.

Hard parton-parton collisions is hard ($p_T > \approx 2$ GeV/c)

1/(p_T)^4 \rightarrow 1/(p_T^2 + p_{T0}^2)^2

“Semi-hard” parton-parton collision ($p_T < \approx 2$ GeV/c)
The “Underlying Event”

Select inelastic non-diffractive events that contain a hard scattering

\[ \frac{1}{(p_T)^4} \rightarrow \frac{1}{(p_T^2 + p_T^{T0})^2} \]

Hard parton-parton collisions is hard (\( p_T > \approx 2 \text{ GeV/c} \))

“Semi-hard” parton-parton collision (\( p_T < \approx 2 \text{ GeV/c} \))

Multiple-parton interactions (MPI)!
Select inelastic non-diffractive events that contain a hard scattering.

![Diagram of proton-proton interactions with text annotations](image)

- **Hard parton-parton collisions** are hard ($p_T > \approx 2\text{ GeV/c}$).
- **“Semi-hard” parton-parton collision** ($p_T < \approx 2\text{ GeV/c}$).
- **The “underlying-event” (UE)!**
- **Multiple-parton interactions (MPI)!**

$$\frac{1}{(p_T)^4} \rightarrow \frac{1}{(p_T^2 + p_{T0}^2)^2}$$
Select inelastic non-diffractive events that contain a hard scattering

Hard parton-parton collisions is hard ($p_T > \approx 2 \text{ GeV/c}$)

The “underlying-event” (UE)!

Given that you have one hard scattering it is more probable to have MPI! Hence, the UE has more activity than “min-bias”.

Multiple-parton interactions (MPI)!

"Semi-hard" parton-parton collision ($p_T < \approx 2 \text{ GeV/c}$)

$1/(p_T^4) \rightarrow 1/(p_T^2 + p_{T0}^2)^2$
Model of $\sigma_{ND}$
Allow leading hard scattering to go to zero $p_T$ with same cut-off as the MPI!

$$\frac{1}{(p_T)^4} \rightarrow \frac{1}{(p_T^2 + p_{T0}^2)^2}$$
Model of $\sigma_{ND}$

Allow leading hard scattering to go to zero $p_T$ with same cut-off as the MPI!

Model of the inelastic non-diffractive cross section!

$1/(p_T)^4 \rightarrow 1/(p_T^2 + p_{T0}^2)^2$

“Semi-hard” parton-parton collision ($p_T \approx 2$ GeV/c)

Multiple-parton interactions (MPI)!
Fit the “underlying event” in a hard scattering process.

“Underlying Event”
Fit the “underlying event” in a hard scattering process.

1/(p_T^4) \rightarrow 1/(p_T^2 + p_{T0}^2)^2

Allow primary hard-scattering to go to p_T = 0 with same cut-off!
Fit the “underlying event” in a hard scattering process.

“Underlying Event”

“Min-Bias” (ND)

Allow primary hard-scattering to go to $p_T = 0$ with same cut-off!

$1/(p_T)^4 \rightarrow 1/(p_T^2 + p_{T0}^2)^2$

Predict MB (ND)!

+ ...
Fit the “underlying event” in a hard scattering process.

$1/(p_T)^4 \rightarrow 1/(p_T^2 + p_{T0}^2)^2$

Allow primary hard-scattering to go to $p_T = 0$ with same cut-off!

“Min-Bias” (add single & double diffraction)

Predict MB (ND)!

Predict MB (IN)!
UE Tunes

“Underlying Event”

Fit the “underlying event” in a hard scattering process.

Allow primary hard-scattering to go to $p_T = 0$ with same cut-off!

All of Rick’s tunes (except X2): A, AW, AWT, DW, DWT, D6, D6T, CW, X1, and Tune Z1, are UE tunes!

Predict MB (ND)!

Predict MB (IN)!

1/(p_T^2 + p_{T0}^2)^2

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Data at 1.96 TeV on the charged particle multiplicity ($p_T > 0.4$ GeV/c, $|\eta| < 1$) for “min-bias” collisions at CDF Run 2 (non-diffractive cross-section).
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Comparison of PYTHIA Tune A with the $p_T$ distribution of charged particles for “min-bias” collisions at CDF Run 1 (non-diffractive cross-section).
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PYTHIA Tune A 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)!
Comparison of PYTHIA Tune A with the proton-proton production of charged particles for “min-bias” collisions at CDF Run 1 (non-diffractive cross-section).

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Lots of "hard" scattering in "Min-Bias" at the Tevatron!

12% of "Min-Bias" events have $P_T(\text{hard}) > 5$ GeV/c!

1% of "Min-Bias" events have $P_T(\text{hard}) > 10$ GeV/c!

$P_T = 50$ GeV/c!
Published CDF data on the $p_T$ distribution of charged particles in Min-Bias collisions (ND) at 1.96 TeV compared with PYTHIA Tune A.
Published CDF data on the $p_T$ distribution of charged particles in Min-Bias collisions (ND) at 1.96 TeV compared with PYTHIA Tune A.
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CDF inconsistent with CMS and UA1!
Published CDF data on the $p_T$ distribution of charged particles in Min-Bias collisions (ND) at 1.96 TeV compared with PYTHIA Tune A.

CDF consistent with CMS and UA1!

Erratum November 18, 2010
“Min-Bias” (ND)

Fit MB (ND).

+ ...
Predict the “underlying event” in a hard scattering process!

“Underlying Event”

“Min-Bias” (ND)

Fit MB (ND).

...
Predict the “underlying event” in a hard scattering process!

Most of Peter Skand’s tunes: S320 Perugia 0, S325 Perugia X, S326 Perugia 6 are MB tunes!
Fit the “underlying event” in a hard scattering process!

Simultaneous fit to both MB & UE

Fit MB (ND).

“Underlying Event”

“Min-Bias” (ND)

+ …
Fit the “underlying event” in a hard scattering process!

Simultaneous fit to both MB & UE

Fit MB (ND).

“Min-Bias” (ND)

Most of Hendrik’s “Professor” tunes: ProQ20, P329 are MB+UE!

“Underlying Event”
Fit the “underlying event” in a hard scattering process!

Simultaneous fit to both MB & UE

Fit MB (ND).

Most of Hendrik’s “Professor” tunes: ProQ20, P329 are MB+UE!

The ATLAS AMBT1 Tune is an MB+UE tune, but because they include in the fit the ATLAS UE data with PTmax > 10 GeV/c (big errors) the LHC UE data does not have much pull (hence mostly an MB tune!).

“Underlying Event”

“Min-Bias” (ND)
Compared the 900 GeV ALICE data with PYTHIA **Tune DW** and **Tune S320**. Tune DW uses the old $Q^2$-ordered parton shower and the old MPI model. Tune S320 uses the new $p_T$-ordered parton shower and the new MPI model. The numbers in parentheses are the average value of $dN/d\eta$ for the region $|\eta| < 0.6$. 
Compares the 900 GeV ALICE data with PYTHIA Tune DW and Tune S320 Perugia 0. Tune DW uses the old $Q^2$-ordered parton shower and the old MPI model. Tune S320 uses the new $p_T$-ordered parton shower and the new MPI model. The numbers in parentheses are the average value of $dN/d\eta$ for the region $|\eta| < 0.6$. 
LHC MB Predictions: 900 GeV

- Compares the 900 GeV ALICE data with PYTHIA Tune DW and Tune S320 Perugia 0. Tune DW uses the old Q²-ordered parton shower and the old MPI model. Tune S320 uses the new p_T-ordered parton shower and the new MPI model. The numbers in parentheses are the average value of dN/dη for the region |η| < 0.6.
Comparing the 900 GeV ALICE data with PYTHIA Tune DW and Tune S320 Perugia 0. Tune DW uses the old $Q^2$-ordered parton shower and the old MPI model. Tune S320 uses the new $p_T$-ordered parton shower and the new MPI model. The numbers in parentheses are the average value of $dN/d\eta$ for the region $|\eta| < 0.6$. 

Off by 11%!
None of the tunes fit the ATLAS INEL $dN/d\eta$ data with $p_T > 100$ MeV! They all predict too few particles.

The ATLAS Tune AMBT1 was designed to fit the inelastic data for $N_{ch} \geq 6$ with $p_T > 0.5$ GeV/c!
None of the tunes fit the ATLAS INEL $dN/d\eta$ data with $p_T > 100$ MeV! They all predict too few particles.

The ATLAS Tune AMBT1 was designed to fit the inelastic data for $N_{ch} \geq 6$ with $p_T > 0.5$ GeV/c!
ALICE inelastic data at 900 GeV on the dN/dη distribution for charged particles (p_T > PTmin) for events with at least one charged particle with p_T > PTmin and |η| < 0.8 for PTmin = 0.15 GeV/c, 0.5 GeV/c, and 1.0 GeV/c compared with PYTHIA Tune DW at the generator level.
ALICE inelastic data at 900 GeV on the \( \text{dN/d}\eta \) distribution for charged particles (\( p_T > PT_{\text{min}} \)) for events with at least one charged particle with \( p_T > PT_{\text{min}} \) and \( |\eta| < 0.8 \) for \( PT_{\text{min}} = 0.15 \text{ GeV/c}, 0.5 \text{ GeV/c}, \) and \( 1.0 \text{ GeV/c} \) compared with PYTHIA Tune DW at the generator level.

"Minimum Bias" Collisions

The same thing occurs at 7 TeV!
ALICE, ATLAS, and CMS data coming soon.
ALICE inelastic data at 900 GeV on the $dN/d\eta$ distribution for charged particles ($p_T > PT_{\text{min}}$) for events with at least one charged particle with $p_T > PT_{\text{min}}$ and $|\eta| < 0.8$ for $PT_{\text{min}} = 0.15$ GeV/c, 0.5 GeV/c, and 1.0 GeV/c compared with PYTHIA Tune Z1 at the generator level (dashed = ND, solid = INEL).

“Minimum Bias” Collisions

Cannot trust PYTHIA 6.2 modeling of diffraction!

Diffraction contributes less at harder scales!
Generator level $dN/d\eta$ (all $p_T$). Shows the NSD = HC + DD and the HC = ND contributions for Tune DW. Also shows the CMS NSD data.
Generator level $dN/d\eta$ (all $p_T$). Shows the NSD = HC + DD and the HC = ND contributions for Tune DW. Also shows the CMS NSD data.

“Minimum Bias” Collisions

Off by 50%!
Okay if the Monte-Carlo does not fit the data what do we do?
We tune the Monte-Carlo to fit the data!

Generator level $dN/d\eta$ (all $p_T$). Shows the NSD = HC + DD and the HC = ND contributions for Tune DW. Also shows the CMS NSD data.

Off by 50%!
Okay if the Monte-Carlo does not fit the data what do we do?
We tune the Monte-Carlo to fit the data!
Be careful not to tune away new physics!
Generator level $dN/d\eta$ (all pT). Shows the NSD = HC + DD and the HC = ND contributions for Tune Z1. Also shows the CMS NSD data.

Generator level $dN/d\eta$ (all pT). Shows the NSD = HC + DD prediction for Tune Z1 and Tune X2. Also shows the CMS NSD data.

“Minimum Bias” Collisions

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Generator level $dN/d\eta$ (all $p_T$). Shows the NSD = HC + DD and the HC = ND contributions for Tune Z1. Also shows the CMS NSD data.

Generator level $dN/d\eta$ (all $p_T$). Shows the NSD = HC + DD prediction for Tune Z1 and Tune X2. Also shows the CMS NSD data.

“Minimum Bias” Collisions

Okay not perfect, but remember we do not know if the DD is correct!
**ALICE inelastic data at 900 GeV on the dN/d\(\eta\) distribution for charged particles (p_\(T\) > PTmin) for events with at least one charged particle with p_\(T\) > PTmin and |\(\eta\)| < 0.8 for PTmin = 0.15 GeV/c, 0.5 GeV/c, and 1.0 GeV/c compared with PYTHIA Tune Z1 at the generator level.**
ALICE inelastic data at 900 GeV on the dN/d\(\eta\) distribution for charged particles (p_T > \(\text{PTmin}\)) for events with at least one charged particle with p_T > \(\text{PTmin}\) and |\(\eta\)| < 0.8 for \(\text{PTmin} = 0.15 \text{ GeV/c}, 0.5 \text{ GeV/c}, \) and 1.0 GeV/c compared with PYTHIA Tune Z1 at the generator level.

“Minimum Bias” Collisions

Okay not perfect, but remember we do not know if the SD & DD are correct!
**ALICE** inelastic data at 900 GeV on the dN/d\(\eta\) distribution for charged particles (p\(T\) > PTmin) for events with at least one charged particle with p\(T\) > PTmin and |\(\eta\)| < 0.8 for PTmin = 0.15 GeV/c, 0.5 GeV/c, and 1.0 GeV/c compared with PYTHIA Tune Z1 at the generator level.

“Minimum Bias” Collisions

Okay not perfect, but remember we do not know if the SD & DD are correct!
Corrected data from CMS and ATLAS at 7 TeV for $dN/d\eta$ ($p_T > PT_{min}$, direct charged particles including leptons with no corrections for SD or DD) with at least one charged particle with $p_T > PT_{min}$ and $|\eta| < 0.8$ for $PT_{min} = 0.5$ GeV/c compared with PYTHIA Tune Z1.
Corrected data from CMS and ATLAS at 7 TeV for dN/d\(\eta\) (pT > PTmin, direct charged particles including leptons with no corrections for SD or DD) with at least one charged particle with pT > PTmin and |\(\eta\)| < 0.8 for PTmin = 0.5 GeV/c compared with PYTHIA Tune Z1.

Ratio of the corrected data from CMS and ATLAS at 7 TeV for dN/d\(\eta\) (pT > PTmin) with at least one charged particle with pT > PTmin and |\(\eta\)| < 0.8 for PTmin = 0.5 GeV/c. CMS divided by ATLAS.
Corrected data from CMS and ATLAS at 7 TeV for $dN/d\eta$ with at least one charged particle with $p_T > PT_{\text{min}}$ and $|\eta| < 0.8$ for $PT_{\text{min}} = 0.5$ GeV/c compared with PYTHIA Tune Z1.

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Ratio of the corrected data from CMS and ATLAS at 7 TeV for $dN/d\eta$ ($p_T > PT_{min}$) with at least one charged particle with $p_T > PT_{min}$ and $|\eta| < 0.8$ for $PT_{min} = 1.0$ GeV/c. CMS divided by ATLAS.
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Corrected data from CMS, ATLAS, and ALICE at 900 GeV for $dN/d\eta$ ($p_T > PT_{\text{min}}$, direct charged particles including leptons with no corrections for SD or DD) with at least one charged particle with $p_T > PT_{\text{min}}$ and $|\eta| < 0.8$ for $PT_{\text{min}} = 0.5$ GeV/c compared with PYTHIA Tune Z1
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Ratio of the corrected data from CMS, ATLAS, and ALICE at 900 GeV for $dN/d\eta$ ($p_T > PT_{\text{min}}$) with at least one charged particle with $p_T > PT_{\text{min}}$ and $|\eta| < 0.8$ for $PT_{\text{min}} = 0.5$ GeV/c. CMS divided by ATLAS and CMS divided by ALICE.
900 GeV $dN/d\eta$

Min-Bias Common Plots

- Corrected data from CMS, ATLAS, and ALICE at 900 GeV for $dN/d\eta$ (pT > PTmin, direct charged particles including leptons with no corrections for SD or DD) with at least one charged particle with pT > PTmin and $|\eta| < 0.8$ for PTmin = 0.5 GeV/c compared with PYTHIA Tune Z1.

- Ratio of the corrected data from CMS, ATLAS, and ALICE at 900 GeV for $dN/d\eta$ (pT > PTmin, direct charged, pT > 0.5 GeV/c) with at least one charged particle with pT > PTmin and $|\eta| < 0.8$ compared with PYTHIA Tune Z1.

- CMS divided by ATLAS and CMS divided by ALICE.
Corrected data from CMS, ATLAS, and ALICE at 900 GeV for $dN/d\eta$ ($p_T > PT_{\text{min}}$, direct charged particles including leptons with no corrections for SD or DD) with at least one charged particle with $p_T > PT_{\text{min}}$ and $|\eta| < 0.8$ for $PT_{\text{min}} = 1.0$ GeV/c compared with PYTHIA Tune Z1
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Ratio of the corrected data from CMS, ATLAS, and ALICE at 900 GeV for \(dN/d\eta\) (\(p_T > PT_{\text{min}}\)) with at least one charged particle with \(p_T > PT_{\text{min}}\) and \(|\eta| < 0.8\) for \(PT_{\text{min}} = 1.0\) GeV/c. CMS divided by ATLAS and CMS divided by ALICE.
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Ratio of the corrected data from CMS, ATLAS, and ALICE at 900 GeV for dN/dη (pT > PTmin, direct charged particles) with at least one charged particle with pT > PTmin and |η| < 0.8 for PTmin = 1.0 GeV/c.
Corrected data from CMS at 7 TeV for $dN/d\eta$ ($p_T > PT_{min}$, direct charged particles including leptons with no corrections for SD or DD) with at least one charged particle with $p_T > PT_{min}$ and $|\eta| < 2.4$ for $PT_{min} = 0.5$ GeV/c and 1.0 GeV/c compared with PYTHIA Tune Z1. Also shows the ATLAS data $|\eta| < 2.5$ $PT_{min} = 0.5$ GeV/c.
Corrected data from CMS at 7 TeV for $dN/d\eta$ ($p_T > PT_{\text{min}}$, direct charged particles including leptons with no corrections for SD or DD) with at least one charged particle with $p_T > PT_{\text{min}}$ and $|\eta| < 2.4$ for $PT_{\text{min}} = 0.5$ GeV/c and 1.0 GeV/c compared with PYTHIA Tune Z1. Also shows the ATLAS data $|\eta| < 2.5$ $PT_{\text{min}} = 0.5$ GeV/c.

Corrected data from CMS at 900 GeV for $dN/d\eta$ ($p_T > PT_{\text{min}}$) with at least one charged particle with $p_T > PT_{\text{min}}$ and $|\eta| < 2.4$ for $PT_{\text{min}} = 0.5$ GeV/c and 1.0 GeV/c compared with PYTHIA Tune Z1. Also shows the ATLAS data $|\eta| < 2.5$ $PT_{\text{min}} = 0.5$ GeV/c.
Corrected data from CMS at 900 GeV for dN/d\(\eta\) (pT > PTmin) with at least one charged particle with pT > PTmin and \(|\eta| < 2.4\) for PTmin = 0.5 GeV/c and 1.0 GeV/c compared with PYTHIA Tune Z1. Also shows the ATLAS data \(|\eta| < 2.5\) PTmin = 0.5 GeV/c.
Direct charged particles (including leptons) corrected to the particle level with no corrections for SD or DD.
Corrected data from CMS at 7 TeV and 900 GeV for dN/d\(\eta\) (pT > PTmin, direct charged particles including leptons with no corrections for SD or DD) with at least one charged particle with pT > PTmin and |\(\eta\)| < 0.8 for PTmin = 1.0 GeV/c compared with PYTHIA Tune Z1. The plot shows PTmin = 1.0 GeV/c divided by PTmin = 0.5 GeV/c at 900 GeV and 7 TeV.
Corrected data from CMS at 7 TeV and 900 GeV for dN/d\(\eta\) (pT > PTmin, direct charged particles including leptons with no corrections for SD or DD) with at least one charged particle with pT > PTmin and |\(\eta\)| < 0.8 for PTmin = 1.0 GeV/c compared with PYTHIA Tune Z1. The plot shows PTmin = 1.0 GeV/c divided by PTmin = 0.5 GeV/c at 900 GeV and 7 TeV.
Corrected data from CMS at 7 TeV and 900 GeV for \( dN/d\eta \) (\( p_T > PT_{\text{min}} \), direct charged particles including leptons with no corrections for SD or DD) with at least one charged particle with \( p_T > PT_{\text{min}} \) and \( |\eta| < 0.8 \) for \( PT_{\text{min}} = 1.0 \) GeV/c compared with PYTHIA Tune Z1. The plot shows \( PT_{\text{min}} = 1.0 \) GeV/c divided by \( PT_{\text{min}} = 0.5 \) GeV/c at 900 GeV and 7 TeV.

Corrected data from CMS at 7 TeV and 900 GeV for \( dN/d\eta \) (\( p_T > PT_{\text{min}} \), direct charged particles including leptons with no corrections for SD or DD) with at least one charged particle with \( p_T > PT_{\text{min}} \) and \( |\eta| < 0.8 \) for \( PT_{\text{min}} = 1.0 \) GeV/c compared with PYTHIA Tune Z1. The plot shows 7 TeV divided by 900 GeV for \( PT_{\text{min}} = 0.5 \) GeV/c and 1.0 GeV/c.
Interesting Ratios

Corrected data from CMS at 7 TeV and 900 GeV for \( \frac{dN}{d\eta} \) (\( p_T > PT_{\text{min}}, \text{direct charged particles including leptons with no corrections for SD or DD} \)) with at least one charged particle with \( p_T > PT_{\text{min}} \) and \( |\eta| < 0.8 \) for \( PT_{\text{min}} = 1.0 \text{ GeV/c} \) compared with PYTHIA Tune Z1. The plot shows \( PT_{\text{min}} = 1.0 \text{ GeV/c} \) divided by \( PT_{\text{min}} = 0.5 \text{ GeV/c} \) at 900 GeV and 7 TeV.

Corrected data from CMS at 7 TeV and 900 GeV for \( \frac{dN}{d\eta} \) (\( p_T > PT_{\text{min}}, \text{direct charged particles including leptons with no corrections for SD or DD} \)) with at least one charged particle with \( p_T > PT_{\text{min}} \) and \( |\eta| < 0.8 \) for \( PT_{\text{min}} = 1.0 \text{ GeV/c} \) compared with PYTHIA Tune Z1. The plot shows 7 TeV divided by 900 GeV for \( PT_{\text{min}} = 0.5 \text{ GeV/c} \) and 1.0 GeV/c.
Generator level charged multiplicity distribution (all pT, |η| < 2) at 900 GeV and 7 TeV. Shows the NSD = HC + DD prediction for Tune Z1. Also shows the CMS NSD data.

“Minumum Bias” Collisions
Generator level charged multiplicity distribution (all pT, \( |\eta| < 2 \)) at 900 GeV and 7 TeV. Shows the NSD = HC + DD prediction for Tune Z1. Also shows the CMS NSD data.

“Minimum Bias” Collisions

Okay not perfect! But not that bad!

Difficult to produce enough events with large multiplicity!

Tuesday, March 8, 2011
Generator level charged multiplicity distribution (all pT, |η| < 2) at 900 GeV and 7 TeV. Shows the NSD = HC + DD prediction for Tune Z1. Also shows the CMS NSD data.
Generator level charged multiplicity distribution (all $p_T$, $|\eta| < 2$) at 900 GeV and 7 TeV. Shows the NSD = HC + DD prediction for Tune Z1. Also shows the CMS NSD data.

CMS uncorrected data at 900 GeV and 7 TeV on the charged particle multiplicity distribution in the “transverse” region for charged particles ($p_T > 0.5$ GeV/c, $|\eta| < 2$) as defined by the leading charged particle jet with $P_T$(chgjet#1) > 3 GeV/c compared with PYTHIA Tune Z1 at the detector level (i.e. Theory + SIM).
Generator level charged multiplicity distribution (all pT, |η| < 2) at 900 GeV and 7 TeV. Shows the NSD = HC + DD prediction for Tune Z1. Also shows the CMS NSD data.

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Generator level charged multiplicity distribution (all pT, |η| < 2) at 900 GeV and 7 TeV. Shows the NSD = HC + DD prediction for Tune Z1. Also shows the CMS NSD data.

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Difficult to produce enough events with large multiplicity!

Difficult to produce enough events with large "transverse" multiplicity at low hard scale!
CMS uncorrected data at 7 TeV on the charged particle multiplicity distribution in the “transverse” region for charged particles ($p_T > 0.5$ GeV/c, $|\eta| < 2$) as defined by the leading charged particle jet with $P_T(chgjet#1) > 20$ GeV/c compared with PYTHIA Tune Z1 at the detector level (i.e. Theory + SIM). Also shows the CMS corrected NSD multiplicity distribution (all $p_T$, $|\eta| < 2$) compared with Tune Z1 at the generator.
CMS uncorrected data at 7 TeV on the charged particle multiplicity distribution in the “transverse” region for charged particles ($p_T > 0.5$ GeV/c, $|\eta| < 2$) as defined by the leading charged particle jet with $PT(chgjet#1) > 20$ GeV/c compared with PYTHIA Tune Z1 at the detector level (i.e. Theory + SIM). Also shows the CMS corrected NSD multiplicity distribution (all $p_T$, $|\eta| < 2$) compared with Tune Z1 at the generator.

Amazing what we are asking the Monte-Carlo models to fit!
New Physics in “Min-Bias”? 

The Inelastic Cross Section

“Semi-hard” parton-parton collision ($p_T < \approx 2$ GeV/c)

Multiple-parton interactions (MPI!)

CMS Two-Particle Correlations at 7 TeV.

Oregon Terascale Workshop
March 8, 2011

Rick Field – Florida/CDF/CMS
Two Particle Angular Correlations

\[ S_N(\Delta \eta, \Delta \varphi) = \frac{1}{N(N-1)} \frac{d^2 N_{\text{signal}}}{d\Delta \eta d\Delta \varphi} \]

\[ B_N(\Delta \eta, \Delta \varphi) = \frac{1}{N^2} \frac{d^2 N_{\text{bg}}}{d\Delta \eta d\Delta \varphi} \]

\[ R(\Delta \eta, \Delta \varphi) = \left( \frac{S_N(\Delta \eta, \Delta \varphi)}{B_N(\Delta \eta, \Delta \varphi)} - 1 \right) \]

CMS pp 7TeV

\[ \Delta \eta = \eta_1 - \eta_2 \]

\[ \Delta \varphi = \varphi_1 - \varphi_2 \]

"Minimum Bias" Collisions

Proton

Proton

Oregon Terascale Workshop
March 8, 2011

Rick Field – Florida/CDF/CMS
Two Particle Angular Correlations

Signal, $S$, is two particles in the same event.

$\Delta \eta = \eta_1 - \eta_2$

$\Delta \varphi = \varphi_1 - \varphi_2$

CMS pp 7 TeV

$p_T$-inclusive two-particle angular correlations in MinBias collisions

“Minimum Bias” Collisions

Proton

Proton
Two Particle Angular Correlations

Signal, $S$, is two particles in the same event.

Background, $B$, is two particles in two different events.

$\Delta \eta = \eta_1 - \eta_2$

$\Delta \varphi = \varphi_1 - \varphi_2$
Two Particle Angular Correlations

Signal, S, is two particles in the same event.

Background, B, is two particles in two different events.

Correlation, R, is \( \sim (S - B)/B \).
Two Particle Angular Correlations

CMS “min-bias” 7 TeV
Two Particle Angular Correlations

CMS “min-bias” 7 TeV

Bose-Einstein

Two Particles in Same Jet

Jet#1

Jet#2

x-axis

y-axis
Two Particle Angular Correlations

CMS “min-bias” 7 TeV

Bose-Einstein

Two Particles in Two Jets

Two Particles in Same Jet
Select Events with High Multiplicity

“Minimum Bias” Collisions

Proton → Proton
High Multiplicity at 7 TeV

CMS Experiment at the LHC, CERN

Data recorded: 2010-Jul-09 02:25:58.839811 GMT (04:25:58 CEST)
Run / Event: 139779 / 4994190
Average “Min-Bias”

(a) MinBias, $p_T > 0.1 \text{GeV/c}$
Two Particle Angular Correlations

Average “Min-Bias”

(a) MinBias, $p_T > 0.1\text{GeV/c}$

High Multiplicity “Min-Bias”

(c) $N > 110$, $p_T > 0.1\text{GeV/c}$
Lots of jets at high multiplicity!
Average “Min-Bias”

(a) MinBias, $p_T > 0.1\text{GeV/c}$

Cut off the peak

$R(\Delta\eta, \Delta\phi)$

$\Delta\phi$  0  2  4

$\Delta\eta$ -4 -2  0  2  4
Two Particle Angular Correlations

Average “Min-Bias”

(a) MinBias, $p_T > 0.1\text{GeV/c}$

Cut off the peak

High Multiplicity “Min-Bias”

(c) $N > 110$, $p_T > 0.1\text{GeV/c}$
Two Particle Angular Correlations

Average “Min-Bias”

(a) MinBias, $p_T > 0.1\text{GeV/c}$

High Multiplicity “Min-Bias”

(c) $N > 110, p_T > 0.1\text{GeV/c}$

Back-to-back jet correlations enhanced in high multiplicity

Two Particles in Two Jets

Jet#1

Jet#2

x-axis

y-axis

Tuesday, March 8, 2011
Observation of a Long-Range, Near-Side angular correlations at high multiplicity in pp events at intermediate $p_T$ (Ridge at $\Delta \phi \sim 0$)
Long-Range Same-Side

High Multiplicity “Min-Bias”

(d) \(N>110, 1.0\text{GeV/c}<p_T<3.0\text{GeV/c}\)

→ Observation of a Long-Range, Near-Side angular correlations at high multiplicity in pp events at intermediate \(p_T\) (Ridge at \(\Delta\phi \sim 0\))

Not there in PYTHIA8!
Long-Range Same-Side

High Multiplicity “Min-Bias”

Not there in PYTHIA8!

Also not there in PYTHIA 6 and HERWIG++!
Correlation in Heavy Ion

Collective flow phenomena:

Reaction plane

(z)

(defines $\psi_R$, direction of the impact parameter)

Pressure driven expansion

$\sim \cos(2\Delta \varphi)$ (long-range in $\eta$)

Extracted shear viscosity of the medium found to be close to theoretical lower bound $1/4\pi$

Most convincing evidence of “Perfect liquid” at RHIC!
Correlation in Heavy Ion Collisions

Long range correlations expected in “collective flow” in heavy ion collisions.

Extracted shear viscosity of the medium found to be close to theoretical lower bound $1/4\pi$.
Correlation in Heavy Ion

Long-range “Ridge”-like structure in $\Delta \eta$
Long-range “Ridge”-like structure in $\Delta\eta$ at $\Delta\phi \approx 0$!
Proton-Proton vs Au-Au

Proton-Proton Collisions 7 TeV

Gold-Gold Collisions 200 GeV

(d) $N > 110, 1.0 \text{GeV}/c < p_\perp < 3.0 \text{GeV}/c$

Similar "ridge" in high multiplicity pp (even similar $p_\perp$ dependence)
I am not ready to jump on the quark-gluon plasma bandwagon quite yet!
Are the “leading-log” or “modified leading-log” QCD Monte-Carlo Models missing an important QCD correlation?
Are the “leading-log” or “modified leading-log” QCD Monte-Carlo Models missing an important QCD correlation?

The leading jet and the incident protons form a plane (yz-plane in the figure). This is the plane of the hard scattering.

Initial & final-state radiation prefers to lie in this plane. This is a higher order effect that you can see in the $2\rightarrow3$ or $2\rightarrow4$ matrix elements, but it is not there if you do $2\rightarrow2$ matrix elements and then add radiation using a naïve leading log approximation (i.e. independent emission).
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I do not know to what extent this higher order jet-jet correlation is incorporated in the QCD Monte-Carlo models.
Jet-Jet Correlations

Are the “leading-log” or “modified leading-log” QCD Monte-Carlo Models missing an important QCD correlation?

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I do not know to what extent this higher order jet-jet correlation is incorporated in the QCD Monte-Carlo models.

I would think that this jet-jet correlation would produce a long range (in $\Delta\eta$) correlation with $\Delta\phi \approx 0$ from two particles with one in the leading jet and one in the radiated jet. Why don’t we see this in the Monte-Carlo models?
**Initial & Final-State Radiation:** There should be more particles “in-the-plane” of the hard scattering (yz-plane in the figure) than “out-of-the-plane”.
Jet-Jet Correlations

- **Initial & Final-State Radiation**: There should be more particles “in-the-plane” of the hard scattering (yz-plane in the figure) than “out-of-the-plane”.

- **I do not understand why this does not result in a long-range same-side correlation?**
Select Events with High Multiplicity

“Minimum Bias” Collisions

Proton

Proton
We need to study the structure of the high multiplicity min-bias events! Does high multiplicity imply high PT jets? Are there a class of “soft” high multiplicity events? If so what is the source of these events?
Strange Particle Production

A lot more strange mesons at large $p_T$ than predicted by the Monte-Carlo Models!

$K/\pi$ ratio fairly independent of the center-of-mass energy.

Jan Fiete Grosse-Oetringhaus
LPCC MB&UE Meeting
September 2010
Strange Particle Production

→ A lot more strange mesons at large $p_T$ than predicted by the Monte-Carlo Models!

→ $K/\pi$ ratio fairly independent of the center-of-mass energy.
Charged particle (direct, including leptons) pseudorapidity distribution, $dN/d\eta$ (ND), at 7 TeV for all $p_T$, $p_T > 0.5$ GeV/c, $p_T > 1.0$ GeV/c, $p_T > 2.0$ GeV/c, and $p_T > 3.0$ GeV/c from Tune Z1.
Charged particle (direct, including leptons) pseudorapidity distribution, dN/d\(\eta\) (ND), at 7 TeV for all \(p_T\), \(p_T > 0.5\) GeV/c, \(p_T > 1.0\) GeV/c, \(p_T > 2.0\) GeV/c, and \(p_T > 3.0\) GeV/c from Tune Z1.

Charged particle (direct, including leptons) pseudorapidity distribution, dN/d\(\eta\), at 7 TeV for all \(p_T\) from Tune Z1. Shows the individual contributions from ND, SD, DD, and INEL = ND + SD + DD.
Charged particle ratios versus $\eta$ at 7 TeV (ND all $p_T$). Shows $(\pi^+ + \pi^-)/(all\ charged)$, $(K^+ + K^-)/(all\ charged)$, proton/(all charged), antiproton/(all charged), and sum/(all charged), where sum $= \pi^+ + \pi^- + K^+ + K^- + p + \bar{p}$. 

- Charged Particle dN/d$\eta$ 7 TeV
Charged particle ratios versus $\eta$ at 7 TeV (ND all $p_T$). Shows $(\pi^+ + \pi^-)/(all\ charged)$, $(K^+ + K^-)/(all\ charged)$, proton/(all charged), antiproton/(all charged), and sum/(all charged), where sum $= \pi^+ + \pi^- + K^+ + K^- + p + p\bar{p}$.

Charged particle ratios versus $\eta$ at 7 TeV (INEL = ND + SD + DD all $p_T$). Shows $(\pi^+ + \pi^-)/(all\ charged)$, $(K^+ + K^-)/(all\ charged)$, proton/(all charged), antiproton/(all charged), and sum/(all charged), where sum $= \pi^+ + \pi^- + K^+ + K^- + p + p\bar{p}$.
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- Charged Particle Ratio: Flavor/All Charged

- Charged Particle dN/d$\eta$ 7 TeV

- Charged Particle dN/d$\eta$ 7 TeV
Charged particle ratios versus $\eta$ at 7 TeV (ND all $p_T$). Shows $(\pi^+ + \pi^-)/(all\ charged)$, $(K^+ + K^-)/(all\ charged)$, proton/(all charged), antiproton/(all charged), and sum/(all charged), where sum = $\pi^+ + \pi^- + K^+ + K^- + p + \bar{p}$.

Charged particle ratios versus $\eta$ at 7 TeV (ND $p_T > 0.5$ GeV/c). Shows $(\pi^+ + \pi^-)/(all\ charged)$, $(K^+ + K^-)/(all\ charged)$, proton/(all charged), antiproton/(all charged), and sum/(all charged), where sum = $\pi^+ + \pi^- + K^+ + K^- + p + \bar{p}$.
Charged particle ratios versus $\eta$ at 7 TeV (ND all $p_T$). Shows $(\pi^+ + \pi^-)/(all\ charged)$, $(K^+ + K^-)/(all\ charged)$, proton/(all charged), antiproton/(all charged), and sum/(all charged), where sum $= \pi^+ + \pi^- + K^+ + K^- + p + \bar{p}$.

Charged particle ratios versus $\eta$ at 7 TeV (ND $p_T > 0.5$ GeV/c). Shows $(\pi^+ + \pi^-)/(all\ charged)$, $(K^+ + K^-)/(all\ charged)$, proton/(all charged), antiproton/(all charged), and sum/(all charged), where sum $= \pi^+ + \pi^- + K^+ + K^- + p + \bar{p}$.

Charged particle ratios versus $\eta$ at 7 TeV (ND $p_T > 1.0$ GeV/c). Shows $(\pi^+ + \pi^-)/(all\ charged)$, $(K^+ + K^-)/(all\ charged)$, proton/(all charged), antiproton/(all charged), and sum/(all charged), where sum $= \pi^+ + \pi^- + K^+ + K^- + p + \bar{p}$.
Charged particle ratios versus $\eta$ at 7 TeV (ND all $p_T$). Shows $(\pi^+ + \pi^-)/(all\ charged)$, $(K^+ + K^-)/(all\ charged)$, proton/(all charged), antiproton/(all charged), and sum/(all charged), where sum $= \pi^+ + \pi^- + K^+ + K^- + p + \bar{p}$.

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Charged particle ratios versus $\eta$ at 7 TeV (ND $p_T > 0.5$ GeV/c). Shows $(\pi^+ + \pi^-)/(all\ charged)$, $(K^+ + K^-)/(all\ charged)$, proton/(all charged), antiproton/(all charged), and sum/(all charged), where sum = $\pi^+ + \pi^- + K^+ + K^- + p + \bar{p}$.

Charged particle ratios versus $\eta$ at 7 TeV (ND $p_T > 1.0$ GeV/c). Shows $(\pi^+ + \pi^-)/(all\ charged)$, $(K^+ + K^-)/(all\ charged)$, proton/(all charged), antiproton/(all charged), and sum/(all charged), where sum = $\pi^+ + \pi^- + K^+ + K^- + p + \bar{p}$.
Charged particle ratios versus $p_T$ at 7 TeV (ND $|\eta| < 2$). Shows $(\pi^+ + \pi^-)/(all\ charged)$, $(K^+ + K^-)/(all\ charged)$, $(p + p\bar{p})/(all\ charged)$, and sum/(all charged), where sum = $\pi^+ + \pi^- + K^+ + K^- + p + p\bar{p}$.
charged particle ratios versus $p_T$ at 7 TeV (ND $|\eta| < 2$). Shows $(\pi^+ + \pi^-)/(all\ charged)$, $(K^+ + K^-)/(all\ charged)$, $(p + p\bar{p})/(all\ charged)$, and sum/(all charged), where sum $= \pi^+ + \pi^- + K^+ + K^- + p + p\bar{p}$.

charged particle ratios versus $p_T$ at 7 TeV (ND $|\eta| < 0.8$). Shows $(\pi^+ + \pi^-)/(all\ charged)$, $(K^+ + K^-)/(all\ charged)$, $(p + p\bar{p})/(all\ charged)$, and sum/(all charged), where sum $= \pi^+ + \pi^- + K^+ + K^- + p + p\bar{p}$.
Charged particle ratios versus $p_T$ at 7 TeV (ND $|\eta| < 2$). Shows $(\pi^+ + \pi^-)/(all\ charged)$, $(K^+ + K^-)/(all\ charged)$, $(p + p\bar{p})/(all\ charged)$, and sum/(all charged), where sum = $\pi^+ + \pi^- + K^+ + K^- + p + p\bar{p}$.

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Charged particle ratios versus $p_T$ at 7 TeV (INEL $|\eta| < 0.8$). Shows $(\pi^+ + \pi^-)/(all\ charged)$, $(K^+ + K^-)/(all\ charged)$, $(p + p\bar{p})/(all\ charged)$, and sum/(all charged), where sum = $\pi^+ + \pi^- + K^+ + K^- + p + p\bar{p}$.
Charged Particle Ratios

Charged particle ratios versus $p_T$ at 7 TeV (ND $|\eta| < 0.8$). Shows $(\pi^+ + \pi^-)/(all \ charged)$, $(K^+ + K^-)/(all \ charged)$, $(p + p\overline{p})/(all \ charged)$, and sum/(all charged), where sum = $\pi^+ + \pi^- + K^+ + K^- + p + p\overline{p}$.

Charged particle ratios versus $p_T$ at 7 TeV (INEL $|\eta| < 0.8$). Shows $(\pi^+ + \pi^-)/(all \ charged)$, $(K^+ + K^-)/(all \ charged)$, $(p + p\overline{p})/(all \ charged)$, and sum/(all charged), where sum = $\pi^+ + \pi^- + K^+ + K^- + p + p\overline{p}$.
Charged particle (direct, including leptons) pseudorapidity distribution, dN/d\(\eta\) (ND all pT), at 7 TeV and 900 GeV from Tune Z1.
Charged Particle Ratios

- Charged particle (direct, including leptons) pseudorapidity distribution, \(dN/d\eta\) (ND all \(p_T\)), at 7 TeV and 900 GeV from Tune Z1.

- Charged particle ratios versus \(\eta\) at 900 GeV (ND all \(p_T\)). Shows \((\pi^+ + \pi^-)/(all\ charged), (K^+ + K^-)/(all\ charged), proton/(all\ charged), antiproton/(all\ charged), and sum/(all\ charged), where sum = \(\pi^+ + \pi^- + K^+ + K^- + p + p\bar{p}\).
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Charged particle ratios versus \(\eta\) at 900 GeV (ND all p\(_T\)). Shows \((\pi^+ + \pi^-)/(all\ charged), (K^+ + K^-)/(all\ charged), proton/(all\ charged), antiproton/(all\ charged), and sum/(all\ charged), where sum = \pi^+ + \pi^- + K^+ + K^- + p + p\bar{p}.

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Charged particle ratios versus $\eta$ at 7 TeV (ND all $p_T$). Shows $(\pi^+ + \pi^-)/(all\ charged)$, $(K^+ + K^-)/(all\ charged)$, proton/(all charged), antiproton/(all charged), and sum/(all charged), where sum = $\pi^+ + \pi^- + K^+ + K^- + p + \overline{p}$.
Strange Particle Production

![Graph depicting the production of strange particles versus p_t (GeV/c)](graph_image)

- Results from ALICE at different center-of-mass energies: 
  - \( \sqrt{s} = 900 \text{ GeV} \)
  - \( \sqrt{s} = 300 \text{ GeV} \)
  - \( \sqrt{s} = 540 \text{ GeV} \)
  - \( \sqrt{s} = 1000 \text{ GeV} \)
  - \( \sqrt{s} = 1800 \text{ GeV} \)

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*Oregon Terascale Workshop*
*March 8, 2011*

*Rick Field – Florida/CDF/CMS*
Strange Particle Production

Strange Particle Ratio: \((K^+ + K^-)/(\pi^+ + \pi^-)\)

PYTHIA Tune Z1 ND 900 GeV
- E735, \(\sqrt{s} = 540\) GeV
- E735, \(\sqrt{s} = 1000\) GeV
- E735, \(\sqrt{s} = 1800\) GeV

\(|p_t| < 0.8\)

Oregon Terascale Workshop
March 8, 2011

Rick Field – Florida/CDF/CMS

Page
A lot more strange mesons at large $p_T$ than predicted by the Monte-Carlo Models and a different shape of the curve!
PARJ(1) : (D = 0.10) is \( P(qq)/P(q) \), the suppression of diquark-antidiquark pair production in the colour field, compared with quark–antiquark production.

PARJ(2) : (D = 0.30) is \( P(s)/P(u) \), the suppression of s quark pair production in the field compared with u or d pair production.

PARJ(3) : (D = 0.4) is \( (P(us)/P(ud))/(P(s)/P(d)) \), the extra suppression of strange diquark production compared with the normal suppression of strange quarks.

PARJ(4) : (D = 0.05) is \( (1/3)P(ud1)/P(ud0) \), the suppression of spin 1 diquarks compared with spin 0 ones (excluding the factor 3 coming from spin counting).

Look at the affect of changing PARJ(2) from 0.3 to 0.5!
Charged particle (direct, including leptons) pseudorapidity distribution, $dN/d\eta$ (ND all $p_T$), at 7 TeV for PARJ(2) = $s/u = 0.3$ (default) and PARJ(2) = $s/u = 0.5$ from Tune Z1.
Charged Particle Ratios

Charged particle (direct, including leptons) pseudorapidity distribution, dN/dη (ND all pT), at 7 TeV for PARJ(2) = s/u = 0.3 (default) and PARJ(2) = s/u = 0.5 from Tune Z1.

Charged particle ratios versus η at 7 TeV (ND all p_T) with PARJ(2) = s/u = 0.3 (default) and PARJ(2) = s/u = 0.5 from Tune Z1. Shows (π^+ + π^-)/(all charged), (K^+ + K^-)/(all charged), proton/(all charged), antiproton/(all charged), and sum/(all charged), where sum = π^+ + π^- + K^+ + K^- + p + pbar.
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Charged particle ratios versus p_T at 7 TeV (ND |η| < 0.8) with PARJ(2) = s/u = 0.3 (default) and PARJ(2) = s/u = 0.5 from Tune Z1. Shows (π^+ + π^-)/(all charged), (K^+ + K^-)/(all charged), (p + pbar)/(all charged), and sum/(all charged), where sum = π^+ + π^- + K^+ + K^- + p + pbar.
Charged Particle Ratios

- Charged particle ratios versus $\eta$ at 7 TeV (ND all $p_T$) with PARJ(2) = s/u = 0.3 (default) and PARJ(2) = s/u = 0.5 from Tune Z1. Shows $(\pi^+ + \pi^-)/(all\ charged)$, $(K^+ + K^-)/(all\ charged)$, proton/(all charged), antiproton/(all charged), and sum/(all charged), where sum = $\pi^+ + \pi^- + K^+ + K^- + p + p\bar{p}$.

- Charged particle ratios versus $p_T$ at 7 TeV (ND $|\eta| < 0.8$) with PARJ(2) = s/u = 0.3 (default) and PARJ(2) = s/u = 0.5 from Tune Z1. Shows $(\pi^+ + \pi^-)/(all\ charged)$, $(K^+ + K^-)/(all\ charged)$, $(p + p\bar{p})/(all\ charged)$, and sum/(all charged), where sum = $\pi^+ + \pi^- + K^+ + K^- + p + p\bar{p}$.
Strange Particle Production

\[ \frac{(K^+ + K)}{(\pi^+ + \pi)} \]

- ALICE, \( \sqrt{s} = 900 \text{ GeV} \)
- E735, \( \sqrt{s} = 300 \text{ GeV} \)
- E735, \( \sqrt{s} = 540 \text{ GeV} \)
- E735, \( \sqrt{s} = 1000 \text{ GeV} \)
- E735, \( \sqrt{s} = 1800 \text{ GeV} \)

- Phojet
- Pythia - CSC 306
- Pythia - D6T 109
- Pythia - Perugia0 - 320
Strange Particle Production

Strange Particle Ratio: \((K^+ + K^-)/(\pi^+ + \pi^-)\)

PYTHIA Tune Z1 ND 900 GeV

\(|m| < 0.8\)

\(s/u = 0.5\)

ALICE, \(\sqrt{s} = 900\) GeV

E735, \(\sqrt{s} = 540\) GeV

E735, \(\sqrt{s} = 1000\) GeV

E735, \(\sqrt{s} = 1800\) GeV

\(p_T (\text{GeV}/c)\)

\(\text{PT} (\text{GeV}/c)\)

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Not good!

Plateau!
Protons & Antiprotons

ALICE preliminary
stat. error only

Jan Fiete Grosse-Oetringhaus
LPCC MB&UE Meeting
September 2010
Tune Z1 (ND) does not get this right either and this curve does not depend on PARJ(2)!
Leading charged particle ratios versus $p_T$ at 7 TeV ($|\eta| < 2.0$). Shows $(\pi^+ + \pi^-)/(\text{all charged})$, $(K^+ + K^-)/(\text{all charged})$, $(p + p\bar{p})/(\text{all charged})$, and sum/(all charged), where sum = $\pi^+ + \pi^- + K^+ + K^- + p + p\bar{p}$.
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Charged particle ratios in the “transverse” region ($p_T > 0.5$ GeV/c, $|\eta| < 2.0$) versus the leading charged particle, PTmax, at 7 TeV. Shows $(\pi^+ + \pi^-)/(\text{all charged})$, $(K^+ + K^-)/(\text{all charged})$, $(p + p\bar{p})/(\text{all charged})$, and sum/(all charged), where sum $= \pi^+ + \pi^- + K^+ + K^- + p + p\bar{p}$.
So far no luck at fitting the min-bias charged kaon to charged pion ratio. Increasing s/u produces more strange particles, but the shape of the curve versus $p_T$ is different! But I am just getting started at this!
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The Monte-Carlo models are constrained by LEP data. Must make sure that I do not destroy the agreement with the LEP data!
Summary

- So far no luck at fitting the min-bias charged kaon to charged pion ratio. Increasing s/u produces more strange particles, but the shape of the curve versus $p_T$ is different! But I am just getting started at this!

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- We need a better understanding and modeling of diffraction!
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- We need a better understanding and modeling of diffraction!
- It is difficult for the Monte-Carlo models to produce a soft event (i.e. no large hard scale) with a large multiplicity. There seems to be more “min-bias” high multiplicity soft events at 7 TeV than predicted by the models!
Min-Bias Summary

➤ We are a long way from having a Monte-Carlo model that will fit all the features of the LHC min-bias data! There are more soft particles that expected!

➤ We need a better understanding and modeling of diffraction!

➤ It is difficult for the Monte-Carlo models to produce a soft event (i.e. no large hard scale) with a large multiplicity. There seems to be more “min-bias” high multiplicity soft events at 7 TeV than predicted by the models!

➤ The models do not produce enough strange particles! I have no idea what is going on here! Also not getting the protons + antiprotons right! The Monte-Carlo models are constrained by LEP data.