Min-Bias and the Underlying Event at the LHC

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Outline

- How well did we do at predicting the behavior of the “underlying event” at the LHC (900 GeV and 7 TeV)?
- How universal are the QCD Monte-Carlo model tunes?
- Examine the connection between the “underlying event” in a hard scattering process (UE) and “min-bias” collisions (MB).
- How well can we predict “min-bias” collisions at the LHC?

Strange particle and baryon production at the LHC.

- Strange particle: $K^+$, $K_{short}$, $\bar{K}^-$, $\bar{u}d$, $u\bar{s}$, $d\bar{s}$, $uud$, $ss$
- Baryon: $p$, $\Lambda$, $\Xi^-$, $\Xi^0$, $\Delta^+$, $\Delta^0$

$K^+$ $K_{short}$ $p$
$u\bar{s}$ $d\bar{s}$ $uud$
$\bar{K}^-$ $\bar{u}d$ $ss$

Strange particle and baryon production at the LHC.
CDF data at 1.96 TeV on the density of charged particles, $dN/d\eta d\phi$, with $p_T > 0.5$ GeV/c and $|\eta| < 1$ for “leading jet” events as a function of the leading jet $p_T$ for the “toward”, “away”, and “transverse” regions. The data are corrected to the particle level (with errors that include both the statistical error and the systematic uncertainty) and are compared with PYTHIA Tune A at the particle level (i.e. generator level).
CDF data at 1.96 TeV on the charged particle scalar $p_T$ sum density, $dP_T/d\eta d\phi$, with $p_T > 0.5$ GeV/c and $|\eta| < 1$ for “leading jet” events as a function of the leading jet $p_T$ for the “toward”, “away”, and “transverse” regions. The data are corrected to the particle level (with errors that include both the statistical error and the systematic uncertainty) and are compared with PYTHIA Tune A at the particle level (i.e. generator level).
CDF data at 1.96 TeV on the density of charged particles, $dN/d\eta d\phi$, with $p_T > 0.5$ GeV/c and $|\eta| < 1$ for “Z-Boson” and “Leading Jet” events as a function of the leading jet $p_T$ or $P_T(Z)$ for the “toward”, “away”, and “transverse” regions. The data are corrected to the particle level and are compared with PYTHIA Tune AW and Tune A, respectively, at the particle level (i.e. generator level).
CDF data at 1.96 TeV on the density of charged particles, dN/d\(\eta\)d\(\phi\), with \(p_T > 0.5\) GeV/c and \(|\eta| < 1\) for “Z-Boson” and “Leading Jet” events as a function of the leading jet \(p_T\) or \(P_T(Z)\) for the “toward”, “away”, and “transverse” regions. The data are corrected to the particle level and are compared with PYTHIA Tune AW and Tune A, respectively, at the particle level (i.e. generator level).
CDF data at 1.96 TeV on the density of charged particles, $dN/d\eta d\phi$, with $p_T > 0.5$ GeV/c and $|\eta| < 1$ for Drell-Yan production as a function of $P_T(Z)$ for the “toward”, “away”, and “transverse” regions compared with PYTHIA Tune DW.

CMS data at 7 TeV on the density of charged particles, $dN/d\eta d\phi$, with $p_T > 0.5$ GeV/c and $|\eta| < 2$ for Drell-Yan production as a function of $P_T(Z)$ for the “toward”, “away”, and “transverse” regions compared with PYTHIA Tune DW.
**Charged Particle Density**

**CDF Run 2**
- Data corrected pyDQ generator level
- Drell-Yan Production
- $70 < M(\text{pair}) < 110$ GeV

**1.96 TeV**
- Average Charged Density
- Charged Particles ($|\eta| < 1.0$, $P_T > 0.5$ GeV/c) excluding the lepton-pair

**CMS Preliminary**
- Data corrected pyDQ generator level
- Drell-Yan Production
- $60 < M(\text{pair}) < 120$ GeV

**7 TeV**
- Average Charged Density
- Charged Particles ($|\eta| < 2.0$, $P_T > 0.5$ GeV/c) excluding the lepton-pair

**CDF**
- Proton-Antiproton Collisions at 1.96 GeV
- Lepton Cuts: $p_T > 20$ GeV, $|\eta| < 1.0$
- Mass Cut: $70 < M(\text{lepton-pair}) < 110$ GeV
- Charged Particles: $p_T > 0.5$ GeV/c, $|\eta| < 1.0$

**CMS**
- Proton-Proton Collisions at 7 GeV
- Lepton Cuts: $p_T > 20$ GeV, $|\eta| < 2.4$
- Mass Cut: $60 < M(\text{lepton-pair}) < 120$ GeV
- Charged Particles: $p_T > 0.5$ GeV/c, $|\eta| < 2.0$

**New**

- CDF data at 1.96 TeV on the density of charged particles, $dN/d\eta d\phi$, with $p_T > 0.5$ GeV/c and $|\eta| < 1$ for Drell-Yan production as a function of $P_T(Z)$ for the “toward”, “away”, and “transverse” regions compared with PYTHIA Tune DW.

- CMS data at 7 TeV on the density of charged particles, $dN/d\eta d\phi$, with $p_T > 0.5$ GeV/c and $|\eta| < 2$ for Drell-Yan production as a function of $P_T(Z)$ for the “toward”, “away”, and “transverse” regions compared with PYTHIA Tune DW.
Large increase in the UE in going from 1.96 TeV to 7 TeV as predicted by PYTHIA Tune DW!

CDF: Proton-Antiproton Collisions at 1.96 GeV
Lepton Cuts: $p_T > 20$ GeV $|\eta| < 1.0$
Mass Cut: $70 < M(\text{lepton-pair}) < 110$ GeV
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CDF data at 1.96 TeV on the charged scalar PTsum density, dPT/dηdφ, with p_T > 0.5 GeV/c and |η| < 1 for “Z-Boson” and “Leading Jet” events as a function of the leading jet p_T or P_T(Z) for the “toward”, “away”, and “transverse” regions. The data are corrected to the particle level and are compared with PYTHIA Tune AW and Tune A, respectively, at the particle level (i.e. generator level).
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CDF data at 1.96 TeV on the charged PTsum density, dPT/dηdφ, with p_T > 0.5 GeV/c and |η| < 1 for Drell-Yan production as a function of PT(Z) for the “toward”, “away”, and “transverse” regions compared with PYTHIA Tune DW.

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CMS preliminary data at 900 GeV and 7 TeV on the “transverse” charged particle density, dN/dηdφ, as defined by the leading charged particle jet (chgjet#1) for charged particles with p_T > 0.5 GeV/c and |η| < 2. The data are uncorrected and compared with PYTHIA Tune DW after detector simulation.

ATLAS preliminary data at 900 GeV and 7 TeV on the “transverse” charged particle density, dN/dηdφ, as defined by the leading charged particle jet (PTmax) for charged particles with p_T > 0.5 GeV/c and |η| < 2.5. The data are corrected and compared with PYTHIA Tune DW at the generator level.
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ATLAS preliminary data at 900 GeV and 7 TeV on the “transverse” charged PTsum density, dPT/dηdφ, as defined by the leading charged particle (PTmax) for charged particles with p_T > 0.5 GeV/c and |η| < 2.5. The data are corrected and compared with PYTHIA Tune DW at the generator level.
Overall PYTHIA Tune DW is in amazingly good agreement with the Tevatron Jet production and Drell-Yan data and did a very good job in predicting the LHC Jet production and Drell-Yan data! (although not perfect)
All my previous tunes (A, DW, DWT, D6, D6T, CW, X1, and X2) were PYTHIA 6.4 tunes using the old $Q^2$-ordered parton showers and the old MPI model (really 6.2 tunes)!

I believe that it is time to move to PYTHIA 6.4 ($p_T$-ordered parton showers and new MPI model)!

**Tune Z1:** I started with the parameters of ATLAS Tune AMBT1, but I changed LO* to CTEQ5L and I varied PARP(82) and PARP(90) to get a very good fit of the CMS UE data at 900 GeV and 7 TeV.

The ATLAS Tune AMBT1 was designed to fit the inelastic data for $N_{ch} \geq 6$ and to fit the $P_{T_{\text{max}}}$ UE data with $P_{T_{\text{max}}} > 10$ GeV/c. Tune AMBT1 is primarily a min-bias tune, while Tune Z1 is a UE tune!
### PYTHIA Tune Z1

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Tune Z1 (R. Field CMS)</th>
<th>Tune AMBT1 (ATLAS)</th>
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<tbody>
<tr>
<td>Parton Distribution Function</td>
<td>CTEQ5L</td>
<td>LO*</td>
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<tr>
<td>PARP(82) – MPI Cut-off</td>
<td>1.932</td>
<td>2.292</td>
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<tr>
<td>PARP(89) – Reference energy, E0</td>
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<td>1800.0</td>
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<td>PARP(90) – MPI Energy Extrapolation</td>
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<td>PARP(77) – CR Suppression</td>
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<tr>
<td>PARP(78) – CR Strength</td>
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<tr>
<td>PARP(80) – Probability colored parton from BBR</td>
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<td>0.1</td>
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<tr>
<td>PARP(83) – Matter fraction in core</td>
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<tr>
<td>PARP(84) – Core of matter overlap</td>
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<tr>
<td>PARP(62) – ISR Cut-off</td>
<td>1.025</td>
<td>1.025</td>
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<tr>
<td>PARP(93) – primordial kT-max</td>
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<td>10.0</td>
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<td>MSTP(81) – MPI, ISR, FSR, BBR model</td>
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<tr>
<td>MSTP(82) – Double gaussian matter distribution</td>
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</tr>
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<td>MSTP(91) – Gaussian primordial kT</td>
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<td>1</td>
</tr>
<tr>
<td>MSTP(95) – strategy for color reconnection</td>
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<td>6</td>
</tr>
</tbody>
</table>

Parameters not shown are the PYTHIA 6.4 defaults!
CMS preliminary data at 900 GeV and 7 TeV on the “transverse” charged particle density, $dN/d\eta d\phi$, as defined by the leading charged particle jet (chgjet#1) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 2.0$. The data are corrected and compared with PYTHIA Tune Z1 at the generator level.

Very nice agreement!
ATLAS published data at 900 GeV and 7 TeV on the “transverse” charged particle density, \(dN/d\eta d\phi\), as defined by the leading charged particle (\(P_T^{\text{max}}\)) for charged particles with \(p_T > 0.5\) GeV/c and \(|\eta| < 2.5\). The data are corrected and compared with PYTHIA Tune Z1 at the generator level.

ATLAS published data at 900 GeV and 7 TeV on the “transverse” charged PTsum density, \(dP_T/d\eta d\phi\), as defined by the leading charged particle (\(P_T^{\text{max}}\)) for charged particles with \(p_T > 0.5\) GeV/c and \(|\eta| < 2.5\). The data are corrected and compared with PYTHIA Tune Z1 at the generator level.

ATLAS publication – arXiv:1012.0791
December 3, 2010
CMS preliminary data at 7 TeV on the “transverse” charged particle density, dN/dηdφ, as defined by the leading charged particle jet (chgjet#1) for charged particles with p_T > 0.5 GeV/c and |η| < 2.0 together with the ATLAS published data at 7 TeV on the “transverse” charged particle density, dN/dηdφ, as defined by the leading charged particle (PTmax) for charged particles with p_T > 0.5 GeV/c and |η| < 2.5 The data are corrected and compared with PYTHIA Tune Z1 at the generator level.

Amazing agreement!
ALICE preliminary data at 900 GeV and 7 TeV on the “transverse” charged particle density, dN/dηdφ, as defined by the leading charged particle (PTmax) for charged particles with p_T > 0.5 GeV/c and |η| < 0.8. The data are corrected and compared with PYTHIA Tune Z1 at the generator level.

ALICE preliminary data at 900 GeV and 7 TeV on the “transverse” charged PTsum density, dPT/dηdφ, as defined by the leading charged particle (PTmax) for charged particles with p_T > 0.5 GeV/c and |η| < 0.8. The data are corrected and compared with PYTHIA Tune Z1 at the generator level.
A CMS data at 900 GeV on the “transverse” charged particle density, $dN/d\eta d\phi$, as defined by the leading charged particle jet (chgjet#1) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 2.0$. The data are corrected and compared with PYTHIA Tune Z1 at the generator level.

A CDF data at 1.96 TeV on the “transverse” charged particle density, $dN/d\eta d\phi$, as defined by the leading calorimeter jet (jet#1) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 1.0$. The data are corrected and compared with PYTHIA Tune Z1 at the generator level.
CMS data at 900 GeV and 7 TeV on the “transverse” charged PTsum density, $dPT/d\eta d\phi$, as defined by the leading charged particle jet (chgjet#1) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 2.0$. The data are corrected and compared with PYTHIA Tune Z1 at the generator level.

CDF data at 1.96 TeV on the “transverse” charged PTsum density, $dPT/d\eta d\phi$, as defined by the leading calorimeter jet (jet#1) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 1.0$. The data are corrected and compared with PYTHIA Tune Z1 at the generator level.
**PYTHIA Tune Z1**

**Charged Particle Density: dN/d\(\eta d\phi\)**

- **CDF Run 2**
  - Data corrected pyZ1 generator level
  - Drell-Yan Production
  - 70 < M(pair) < 110 GeV

- **CMS Preliminary**
  - Data corrected pyZ1 generator level
  - Drell-Yan Production
  - 60 < M(pair) < 120 GeV

**Z-Boson Direction**

- **Columbia University**
- **August 29, 2011**

- **CMS data at 1.96 TeV** on the density of charged particles, dN/d\(\eta d\phi\), with \(p_T > 0.5\) GeV/c and \(|\eta| < 1\) for Drell-Yan production as a function of \(p_T(Z)\) for the “toward”, “away”, and “transverse” regions compared with PYTHIA Tune Z1.

- **CMS data at 7 TeV** on the density of charged particles, dN/d\(\eta d\phi\), with \(p_T > 0.5\) GeV/c and \(|\eta| < 2\) for Drell-Yan production as a function of \(p_T(Z)\) for the “toward”, “away”, and “transverse” regions compared with PYTHIA Tune Z1.
Tune Z1 describes the energy dependence fairly well!

**CDF data at 1.96 TeV** on the density of charged particles, \(dN/d\eta d\phi\), with \(p_T > 0.5\) GeV/c and \(|\eta| < 1\) for Drell-Yan production as a function of \(P_T(Z)\) for the “toward”, “away”, and “transverse” regions compared with PYTHIA Tune Z1.

**CMS data at 7 TeV** on the density of charged particles, \(dN/d\eta d\phi\), with \(p_T > 0.5\) GeV/c and \(|\eta| < 2\) for Drell-Yan production as a function of \(P_T(Z)\) for the “toward”, “away”, and “transverse” regions compared with PYTHIA Tune Z1.
CDF data at 1.96 TeV on the charged PTsum density, dPT/dηdϕ, with p_T > 0.5 GeV/c and |η| < 1 for Drell-Yan production as a function of P_T(Z) for the “toward”, “away”, and “transverse” regions compared with PYTHIA Tune Z1.

CMS data at 7 TeV on the charged PTsum density, dPT/dηdϕ, with p_T > 0.5 GeV/c and |η| < 2 for Drell-Yan production as a function of P_T(Z) for the “toward”, “away”, and “transverse” regions compared with PYTHIA Tune Z1.
PYTHIA Tune Z1

CDF data at 1.96 TeV on the charged PTsum density, dPT/dηdφ, with p_T > 0.5 GeV/c and |η| < 1 for Drell-Yan production as a function of P_T(Z) for the “toward”, “away”, and “transverse” regions compared with PYTHIA Tune Z1.

CMS data at 7 TeV on the charged PTsum density, dPT/dηdφ, with p_T > 0.5 GeV/c and |η| < 2 for Drell-Yan production as a function of P_T(Z) for the “toward”, “away”, and “transverse” regions compared with PYTHIA Tune Z1.
PYTHIA Tune Z1

"Transverse" Charged PTsum Density: $dPT/d\eta\phi$

RDF Preliminary data corrected pyZ1 generator level

CDF 1.96 TeV

CMS 7 TeV

CMS 900 GeV

Charged Particles ($PT>0.5$ GeV/c)

CDF 1.96 TeV

CMS 7 TeV

CMS Preliminary data corrected pyZ1 generator level

Drell-Yan Production

Charged Particles ($|\eta|<2.0$, $PT>0.5$ GeV/c)

Drell-Yan Production

Charged Particles ($PT>0.5$ GeV/c)

CMS 7 TeV

CDF 1.96 TeV

RDF Preliminary data corrected pyZ1 generator level

Drell-Yan Production

Charged Particles ($PT>0.5$ GeV/c)

What about Min-Bias?

PIC 2011, Vancouver

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Overall amazingly good agreement with the LHC and Tevatron Jet production and Drell-Yan! (although not perfect yet)

What about Min-Bias?
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

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”.

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

Multiple-parton interactions (MPI)!

\(1/(p_T)^4 \rightarrow 1/(p_T^2 + p_{T_0}^2)^2\)
Model of $\sigma_{ND}$

Model of the inelastic non-diffractive cross section!

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

1/(p_T^4) $\rightarrow$ 1/(p_T^2 + p_T^2)^2

Multiple-parton interactions (MPI)!

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

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

1/(p_T)^4 \rightarrow 1/(p_T^2 + p_T^0)^2

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

Predict MB (ND)!

Predict MB (IN)!

1/(p_T^2 + p_T^0)^2
CMS NSD data on the charged particle rapidity distribution at 7 TeV compared with PYTHIA Tune Z1. The plot shows the average number of particles per NSD collision per unit $\eta$, $(1/N_{NSD}) \, dN/d\eta$.

ALICE NSD data on the charged particle rapidity distribution at 900 GeV compared with PYTHIA Tune Z1. The plot shows the average number of particles per INEL collision per unit $\eta$, $(1/N_{INEL}) \, dN/d\eta$.

“Minimum Bias” Collisions

Okay not perfect, but remember we know that SD and DD are not modeled well!
CMS NSD data on the charged particle rapidity distribution at 7 TeV compared with PYTHIA Tune Z1. The plot shows the average number of charged particles per NSD collision per unit η, \((1/N_{NSD}) dN/dη\).

“Minimum Bias” Collisions

CMS NSD data on the charged particle rapidity distribution at 7 TeV compared with PYTHIA Tune Z1. The plot shows the average number of charged particles per NSD collision per unit η–φ, \((1/N_{NSD}) dN/dηdφ\).
Shows the density of charged particles in the “transverse” region as a function of PT_{max} for charged particles (All p_T, |η| < 2) at 7 TeV from PYTHIA Tune Z1.

CMS NSD data on the charged particle rapidity distribution at 7 TeV compared with PYTHIA Tune Z1. The plot shows the average number of charged particles per NSD collision per unit η−ϕ, \((1/N_{NSD}) \, dN/dηdϕ\).
**MB versus UE**

- **ATLAS data** on the density of charged particles in the “transverse” region as a function of PTmax for charged particles (pT > 0.1 GeV/c, |η| < 2.5) at 7 TeV compared with PYTHIA Tune Z1.

- **CMS NSD data** on the charged particle rapidity distribution at 7 TeV compared with PYTHIA Tune Z1. The plot shows the average number of charged particles per NSD collision per unit η–φ, (1/N_{NSD}) dN/dηdφ.

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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.

“Minumum Bias” Collisions

Okay not perfect! But not that bad!

Difficult to produce enough events with large multiplicity!
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.

Difficult to produce enough events with large multiplicity!

CMS corrected data at 900 GeV and 7 TeV on the charged particle multiplicity distribution in the region for charged particles (all $p_T$, $|\eta| < 2$) as defined by the leading charged particle jet with $p_T(chgjet#1) > 3$ GeV/c compared with PYTHIA Tune Z1 at the generator level.

Difficult to produce enough events with large “transverse” multiplicity at low hard scale!
Do we need a separate tune for each center-of-mass energy? 900 GeV, 1.96 TeV, 7 TeV, etc.

PYTHIA Tune DW did a nice (although not perfect) job predicting the LHC Jet Production and Drell-Yan UE data. I am still hoping for a single tune that will describe all energies!

Do we need a separate tune for each hard QCD subprocess? Jet Production, Drell-Yan Production, etc.

The same tune can describe both Jet Production and Drell-Yan!

Do we need separate tunes for “Min-Bias” (MB) and the “underlying event” (UE) in a hard scattering process?

PHTHIA Tune Z1 does fairly well at both the UE and MB, but you cannot expect such a naïve approach to be perfect!
CMS NSD data on the K_{short} rapidity distribution at 7 TeV and 900 GeV compared with PYTHIA Tune Z1. The plot shows the average number of K_{short} per NSD collision per unit Y, \(\frac{1}{N_{NSD}} dN/dY\).

CMS NSD data on the K_{short} rapidity distribution at 900 GeV and the ALICE point at Y = 0 (INEL) compared with PYTHIA Tune Z1. The ALICE point is the average number of K_{short} per INEL collision per unit Y at Y = 0, \(\frac{1}{N_{INEL}} dN/dY\).

→ No overall shortage of Kaons in PYTHIA Tune Z1!
ALICE INEL data on the charged kaon rapidity distribution at 900 GeV compared with PYTHIA Tune Z1. The plot shows the average number of charged kaons per INEL collision per unit Y at Y = 0, \((1/N_{\text{INEL}})\, dN/dY\).

ALICE INEL data on the charged kaon to charged pion rapidity ratio at 900 GeV compared with PYTHIA Tune Z1.

\[
\frac{(K^+ + K^-)}{(\pi^+ + \pi^-)} = \frac{\text{Strange Meson}}{\text{Non-strange Meson}}
\]

“Minimum Bias” Collisions

No overall shortage of Kaons in PYTHIA Tune Z1!
**Kaon Production**

ALICE INEL data on the charged kaon rapidity distribution at 900 GeV compared with PYTHIA Tune Z1. The plot shows the average number of charged kaons per INEL collision per unit Y at Y = 0, \((1/N_{\text{INEL}}) dN/dY\).

ALICE INEL data on the charged kaon to charged pion rapidity ratio at 900 GeV compared with PYTHIA Tune Z1.

\[
\frac{(K^+ + K^-)}{(\pi^+ + \pi^-)} = \text{Strange Meson} / \text{Non-strange Meson}
\]

“Minimum Bias” Collisions

No overall shortage of Kaons in PYTHIA Tune Z1!
**Particle Ratios versus PT**

**PT Particle Ratio: Kaons/Pions**

- ALICE Data
- PYTHIA Tune Z1 & Z1C

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

- ALICE INEL (|Y| < 0.75) 900 GeV
- Tune qq/q: 0.1, us/s: 0.4 - 0.8

**Rapidity Distribution Ratio: Kaons/Pions**

- ALICE Data
- PYTHIA Tune Z1 & Z1C

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

- ALICE INEL (all pT)
- Tune Z1C
- qq/q: 0.1 - 0.12
- us/s: 0.4 - 0.8

**Tails of the p_T distribution. Way off due to the wrong p_T!**

**ALICE INEL data** on the charged kaon to charged pions ratio versus p_T at 900 GeV (|Y| < 0.75) compared with PYTHIA Tune Z1 & Z1C.

**PYTHIA p_T dependence off on Kaons!**

**“Minimum Bias” Collisions**

K^+ \quad u \quad \bar{s} \quad K^- \quad \bar{u} \quad s

**PYTHIA**
CMS NSD data on the Lambda+AntiLambda rapidity distribution at 7 TeV and 900 GeV compared with PYTHIA Tune Z1. The plot shows the average number of particles per NSD collision per unit Y, \((1/N_{NSD}) \, dN/dY\).

CMS NSD data on the Lambda+AntiLambda to 2Kshort rapidity ratio at 7 TeV compared with PYTHIA Tune Z1.

\[
\frac{(\Lambda + \bar{\Lambda})}{2K_{short}} = \text{Single-strange Baryon Strange Meson}
\]

“Minimum Bias” Collisions

Oops! Not enough Lambda’s in PYTHIA Tune Z1!
CMS NSD data on the Cascade$^-$
+AntiCascade$^-$ rapidity distribution at 7 TeV and 900 GeV compared with PYTHIA Tune Z1. The plot shows the average number of particles per NSD collision per unit Y, $(1/N_{NSD}) dN/dY$.

CMS data on the Cascade$^-$+AntiCascade$^-$ to 2Kshort rapidity ratio at 7 TeV compared with PYTHIA Tune Z1.

$\frac{\Xi^- + \Xi^-}{2K_{short}} = \text{Double-strange Baryon Strange Meson}$

“Minimum Bias” Collisions

Yikes! Way too few Cascade’s in PYTHIA Tune Z1!
Particle Ratios versus PT

ALICE INEL data on the Proton+AntiProton to charged pions ratio versus p_T at 900 GeV (|Y| < 0.75) compared with PYTHIA Tune Z1 & Z1C.

PYTHIA way off on the p_T dependence of Protons!

"Minimum Bias" Collisions

PYTHIA way off on the p_T dependence of Protons!
Strange Particle & Baryon Yields: PYTHIA is off on the overall yield of Lambda’s and Cascades (MC below the data) and too high on the proton yield. Difficult to fix this without destroying agreement with LEP!

PT Distributions: PYTHIA does not describe correctly the $p_T$ distributions of heavy particles (MC softer than the data). None of the fragmentation parameters I have looked at changes the $p_T$ distributions. Hence, if one looks at particle ratios at large $p_T$ you can see big discrepancies between data and MC (out in the tails of the distributions).

Factorization: Are we seeing a breakdown in factorization between $e^+e^-$ annihilations and hadron-hadron collisions! Is something happening in hadron-hadron collisions that does not happen in $e^+e^-$ annihilations?

Herwig++ & Sherpa: Before making any conclusions about fragmentation one must check the predictions of Herwig++ and Sherpa carefully!
looks at particle ratios at large $p_T$ you can see big discrepancies between data and MC (out in the tails of the distributions!)

**Factorization:** Are we seeing a breakdown in factorization between $e^+e^-$ annihilations and hadron-hadron collisions! Is something happening in hadron-hadron collisions that does not happen in $e^+e^-$ annihilations?

**Herwig++ & Sherpa:** Before making any conclusions about fragmentation one must check the predictions of Herwig++ and Sherpa carefully!
Before making any conclusion about $e^+e^-$ versus pp collisions one must check the predictions of Herwig++ and Sherpa!

Sherpa does better than PYTHIA 8!

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