



Toward an Understanding of Hadron-Hadron Collisions



From Feynman-Field to the LHC



Rick Field University of Florida



Lecture 3: Tomorrow Evening

- Before Feynman-Field Phenomenology: The Berkeley years.
- The early days of Feynman-Field Phenomenology.
- From 7 GeV/c π^0 's to 1 TeV Jets!



Feynman



Field

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Data at 1.96 TeV on the charged particle multiplicity (p_T > 0.4 GeV/c, |η| < 1) for "min-bias" collisions at CDF Run 2 (non-diffractive cross-section).</p>

The data are compared with PYTHIA Tune A and Tune A without multiple parton interactions (pyAnoMPI).

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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.

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 $|\eta| < 0.6.$

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ATLAS INEL dN/dŋ $\sqrt{s} = 0.9 \text{ TeV}$ $\sqrt{s} = 7.0 \text{ TeV}$

 None of the tunes fit the ATLAS INEL dN/dη data with PT > 100 MeV! They all predict too few particles.

The ATLAS Tune AMBT1 was designed to fit the inelastic data for Nchg ≥ 6 with p_T > 0.5 GeV/c!



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Generator level dN/dη (all pT). Shows the NSD = HC + DD and the HC = ND contributions for Tune DW. Also shows the CMS NSD data.

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 \Rightarrow ALICE inelastic data at 900 GeV on the dN/d η 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 DW at the generator level.

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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 Z1 at the generator level (dashed = ND, solid = INEL).</p>

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- 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 η, (1/N_{NSD}) dN/dη.
- 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 η, (1/N_{INEL}) dN/dη.

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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 Z1 at the generator level.

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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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- 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.
- 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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 Shows the density of charged particles in the "transverse" region as a function of PTmax 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.

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ATLAS data on the density of charged particles in the "transverse" region as a function of PTmax for charged particles (p_T > 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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Baryon & Strange Particle Production at the LHC

Strange Particle Production in Proton-Proton Collisions at 900 GeV with ALICE at the LHC, arXiv:1012.3257 [hep-ex] December 18, 2010.

- Production of Pions, Kaons and Protons in pp Collisions at 900 GeV with ALICE at the LHC, arXiv:1101.4110 [hep-ex] January 25, 2011.
- Strange Particle Production in pp Collisions at 900 GeV and 7 TeV, CMS Paper: arXiv:1102.4282 [hep-ex] Feb 21, 2011, submitted to JHEP.

Step 1: Look at the overall particle yields (all pT).

Step 2: Look at the ratios of the overall particle yields (all p_T).

$(\mathbf{K}^{+}+\mathbf{K}^{-})$	Strange Meson	K _{short}	Strange Meson		
$(\pi^+ + \pi)$	Non-strange Meson	$(\pi^+ + \pi$	Non-strange Meson	n	
$(\mathbf{p} + \overline{\mathbf{p}})$	_ Non-strange Baryon	$(\Lambda + \overline{\Lambda})$	Single-strange Baryon	$(\Xi + \overline{\Xi})$	Double-strange Baryon
$(\pi^+ + \pi)$	Non-strange Meson	2K _{short}	Strange Meson	$2\mathbf{K}_{\mathrm{short}}$	– Strange Meson

Step 3: Look at the p_T dependence of the particle yields and ratios.

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- ➤ 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, (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, (1/N_{INEL}) dN/dY.

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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_{INEL}) dN/dY.

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ALICE INEL data on the charged kaon to charged pion rapidity ratio at 900 GeV compared with 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_{INEL}) dN/dY.

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

dN/dY, versus Y from $-2 \rightarrow 2$.

Warning: I am not plotting what CMS actually measures!

|Y| from $0 \rightarrow 2$.

I am old and I like to see both sides so I assumed symmetry about Y = 0 and plotted the same data on both sides $(Y \rightarrow -Y)$. The way CMS does it is the correct way! But my way helps me see better what is going on. Please refer to the CMS publication for the official plots!

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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.

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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.

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

"Minimum Bias" Collisions

Yikes! Way too few Cascade's in PYTHIA Tune Z1!

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PYTHIA Fragmentation Parameters

Can we increase the overall rate of strange baryons by varying a few fragmentation parameters?

UNDER CONSTRUCTION

- 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. Notation: PARJ(1) = qq/q
- 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. Notation: PARJ(2) = s/u.
- PARJ(3): (D = 0.4) is (P(us)/P(ud))/(P(s)/P(u)), the extra suppression of strange diquark production compared with the normal suppression of strange quarks.
 Notation: PARJ(3) = us/u.

This work is very preliminary!

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PYTHIA Fragmentation Parameters

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- 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, (1/N_{NSD}) dN/dY.
- ➤ CMS dNSD ata on the K_{short} rapidity distribution at 7 TeV and 900 GeV compared with PYTHIA Tune Z1C. The plot shows the average number of K_{short} per NSD collision per unit Y, (1/N_{NSD}) dN/dY.

For Kaon production Tune Z1 and Z1C are almost identical!

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- 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, (1/N_{NSD}) dN/dY.
- CMS dNSD ata on the K_{short} rapidity distribution at 7 TeV and 900 GeV compared with PYTHIA Tune Z1C. The plot shows the average number of K_{short} per NSD collision per unit Y, (1/N_{NSD}) dN/dY.

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- 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 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.

Not bad! Many more Lambda's in PYTHIA Tune Z1C!

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- 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 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.

Not bad! Many more Lambda's in PYTHIA Tune Z1C!

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- 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 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 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 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.

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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 NSD data on the Cascade-+AntiCascaderapidity 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.

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- ➤ CMS NSD data on the K_{short} transverse momentum distribution at 7 TeV compared with PYTHIA Tune Z1 & Z1C. The plot shows the average number of particles per NSD collision per unit p_T, (1/N_{NSD}) dN/dp_T for |Y| < 2.</p>
- CMS NSD data on the Lambda+AntiLambda transverse momentum distribution at 7 TeV compared with PYTHIA Tune Z1 & Z1C. The plot shows the average number of particles per NSD collision per unit p_T, (1/N_{NSD}) dN/dp_T for |Y| < 2.</p>

PYTHIA Tune Z1 & Z1C are a bit off on the p_T **dependence!**

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CMS NSD data on the Cascade⁻+AntiCascade⁻ transverse momentum distribution at 7 TeV compared with PYTHIA Tune Z1 & Z1C. The plot shows the average number of particles per NSD collision per unit p_T, (1/N_{NSD}) dN/dp_T for |Y| < 2.</p> CMS NSD data on the Cascade⁻+AntiCascade⁻ transverse momentum distribution at 7 TeV (normalized to 1) compared with PYTHIA Tune Z1 & Z1C.

"Minimum Bias" Collisions

PYTHIA Tune Z1 & Z1C are a bit off on the p_T **dependence!**

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CMS NSD data on the Lambda+AntiLambda to 2K_{short} ratio versus p_T at 7 TeV (|Y| < 2) compared with PYTHIA Tune Z1 & Z1C.

ALICE INEL data on the Lambda+AntiLambda to $2K_{short}$ ratio versus p_T at 900 GeV (|Y| < 0.75) compared with PYTHIA Tune Z1 & Z1C.

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 Shows the density of charged particles in the "transverse" region as a function of PTmax 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.

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Shows the density of charged particles in the "transverse" region as a function of PTmax for charged particles (All p_T, |η| < 2) at 7 TeV from PYTHIA Tune Z1.

Shows the density of particles in the "transverse" region as a function of PTmax for charged particles (All p_T, |η| < 2) at 7 TeV from PYTHIA Tune Z1.

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Shows the density of K_{short} particles in the "transverse" region as a function of PTmax for charged particles (All p_T , $|\eta| < 2$) at 7 TeV from PYTHIA Tune Z1.

Shows the K_{short} pseudo-rapidity distribution (all p_T) at 7 TeV from PYTHIA Tune Z1. The plot shows the average number of particles per ND collision per unit η-φ, (1/N_{ND}) dN/dηdφ.

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Shows the density of P+antiP particles in the "transverse" region as a function of PTmax for charged particles (All p_T , $|\eta| < 2$) at 7 TeV from PYTHIA Tune Z1.

Shows the P+antiP pseudo-rapidity distribution (all p_T) at 7 TeV from PYTHIA Tune Z1. The plot shows the average number of particles per ND collision per unit η-φ, (1/N_{ND}) dN/dηdφ.

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Shows the density of A+antiA particles in the "transverse" region as a function of PTmax for charged particles (All p_T , $|\eta| < 2$) at 7 TeV from PYTHIA Tune Z1.

Shows the A+antiA pseudo-rapidity distribution (all p_T) at 7 TeV from PYTHIA Tune Z1. The plot shows the average number of particles per ND collision per unit η-φ, (1/N_{ND}) dN/dηdφ.

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Not too hard to get the overall yields of baryons and strange particles roughly right at 900 GeV and 7 TeV. Tune Z1C does a fairly good job with the overall particle yields at 900 GeV and 7 TeV.

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)! "Minimum Bias" Collisions

Fragmentation Summary

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ATLAS Tuning Effort: Fragmentation Proton flavor tuning at the one of the four stages.

Other Fragmentation Tuning: There is additional tuning involving jet shapes, FSR, and ISR that I did not have time to include in this talk.

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Fragmentation Summary

K_{short} ▶ Not too hard to get the overall yields of K Λ baryons and strange particles roughly right ud s 11/ d <u>s</u> + d at 900 GeV and 7 TeV. Tune Z **C** does a p Ξ the overa fairly good le 1111 dss yields at 900 G Warning! The Tune Z1C fragmentation **V**stributions PT Distributions: DX parameters may cause problems of heavy fitting the LEP data. If so ration we must understand why! **⊲**nce, if one parameters N We do not want one tune for looks at particle tween e⁺e⁻ and another one for data and MC **Bias**" Collisions hadron-hadron collisions! ➡ATLAS Tuning Effort **Proton** flavor tuning at the of *i* the ages ere is additional tuning involving jet Other Fragmentation Tuning: shapes, FSR, and ISR that I did not have time to include in this talk.

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