Outline of Talk

- Ricky & Sally.
- The Berkeley Years – Rick & Jimmie.
- The early days of Feynman-Field Phenomenology.
- Mapping out the energy dependence of the UE: Tevatron to the LHC.
- Early LHC UE predictions.
- From 7 GeV/c pions to 1 TeV jets!
My mother was born on May 10, 1922, in Houston Texas. She died on Sunday November 6, 2011 in Malibu, California at age 89.

Margaret Field in “The Man From Planet X” (1951)

http://www.youtube.com/watch?v=896jnOb1fcI
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R. D. Field
University of California, Berkeley, 1962-66 (undergraduate)
University of California, Berkeley, 1966-71 (graduate student)

Rick Field 1964

Rick & Jimmie 1968
The Berkeley Years

R. D. Field
University of California, Berkeley, 1962-66 (undergraduate)
University of California, Berkeley, 1966-71 (graduate student)

My sister Sally!

Rick Field 1964

me

Rick & Jimmie 1968
The Berkeley Years

R. D. Field
University of California, Berkeley, 1962-66 (undergraduate)
University of California, Berkeley, 1966-71 (graduate student)

Volume 31B, number 9
PHYSICS LETTERS
27 April 1970

BACKWARD np SCATTERING WITH A POLARIZED TARGET

P. R. ROBRISH, O. CHAMBERLAIN, R. D. FIELD Jr., R. Z. FUZESY, W. GORN, C. C. MOREHOUSE
T. POWELL, S. ROCK, S. SHANNON, G. SHAPIRO and H. WEISBERG
University of California, Lawrence Radiation Laboratory, Berkeley, California 94720, USA

and

M. J. LONGO
University of Michigan, Ann Arbor, Michigan 48104, USA

Received 16 March 1970
The Berkeley Years

R. D. Field
University of California, Berkeley, 1962-66 (undergraduate)
University of California, Berkeley, 1966-71 (graduate student)

Evidence on Duality and Exchange Degeneracy from Finite-Energy Sum Rules:
$K^{-}n \rightarrow \pi^{-}\Lambda$ and $\pi^{+}n \rightarrow K^{+}\Lambda$

R. D. Field, Jr. and J. D. Jackson
Department of Physics and Lawrence Radiation Laboratory, University of California, Berkeley, California 94720
(Received 5 April 1971)

Using finite-energy sum rules for the reactions $K^{-}n \rightarrow \pi^{-}\Lambda$ and $\pi^{+}n \rightarrow K^{+}\Lambda$, we determine the effective “pole” parameters of the $K^{*}$ and $K^{**}$ Regge trajectories from a knowledge of the low-energy resonances and their couplings. The resonance parameters and the $D(\Delta F)$ ratio for the $\frac{3}{2}^{-}$ baryon octet are varied somewhat to test the sensitivity of the high-energy predictions; $\frac{1}{2}^{-}$ octet couplings within the range of values found empirically in other reactions are preferred in our solution. We find that the $s$-channel resonances in $K^{-}\pi^{-}\Lambda$ do add in such a way as to produce predominantly real amplitudes at high energies as predicted by duality diagrams. We find, however, that these predictions are not satisfied exactly.

Received 16 March 1970
The Berkeley Years

R. D. Field
University of California, Berkeley, 1962-66 (undergraduate)
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Evidence on Duality and Exchange Degeneracy from Finite-Energy Sum Rules:
$K\bar{n} \rightarrow \pi^-\Lambda$ and $\pi^+ n \rightarrow K^+\Lambda$

Using finite-energy sum rules for the reactions $K\bar{n} \rightarrow \pi^-\Lambda$ and $\pi^+ n \rightarrow K^+\Lambda$, we determine the effective “pole” parameters of the $K^*$ and $K^{**}$ Regge trajectories from a knowledge of $(\sigma_{\theta} + F)$.

The finite-energy sum rule for the reaction $\pi^+ n \rightarrow K^+\Lambda$ do not predict the Regge trajectory predicted recently.

My Ph.D. advisor!

me  Bob Cahn  J.D.J  Chris Quigg
Before Feynman-Field

Rick & Jimmie 1968

Rick & Jimmie 1970

Rick & Jimmie 1972 (pregnant!)
Before Feynman-Field

Rick & Jimmie at CALTECH 1973
Toward and Understanding of Hadron-Hadron Collisions

Feynman-Field Phenomenology

From 7 GeV/c $\pi^0$'s to 1 TeV Jets.
The early days of trying to understand and simulate hadron-hadron collisions.

Feynman and Field
The Feynman-Field Days

1973-1983


My 1st graduate student!
What happens when two hadrons collide at high energy?

Most of the time the hadrons ooze through each other and fall apart \(\text{i.e. no hard scattering}\). The outgoing particles continue in roughly the same direction as initial proton and antiproton.

Occasionally there will be a large transverse momentum meson. Question: Where did it come from?

We assumed it came from quark-quark elastic scattering, but we did not know how to calculate it!

“Black-Box Model”
What happens when two hadrons collide at high energy?

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---

Feynman quote from FF1
“The model we shall choose is not a popular one, so that we will not duplicate too much of the work of others who are similarly analyzing various models (e.g. constituent interchange model, multiperipheral models, etc.). We shall assume that the high $P_T$ particles arise from direct hard collisions between constituent quarks in the incoming particles, which fragment or cascade down into several hadrons.”

“Black-Box Model”
Quark-Quark distributions determined from deep-inelastic lepton-hadron collisions

Quark Fragmentation Functions determined from e+e- annihilations

Quark-Quark Cross-Section Unknown! Determined from hadron-hadron collisions.

No gluons!

FF1 1977
Quark Distribution Functions determined from deep-inelastic lepton-hadron collisions

FF1 1977

Feynman quote from FF1
“Because of the incomplete knowledge of our functions some things can be predicted with more certainty than others. Those experimental results that are not well predicted can be “used up” to determine these functions in greater detail to permit better predictions of further experiments. Our papers will be a bit long because we wish to discuss this interplay in detail.”

Quark Fragmentation Functions determined from e⁺e⁻ annihilations

No gluons!
Quark-Quark Black-Box Model

Predict particle ratios

**FF1 1977**

Predict increase with increasing CM energy $W$

"Beam-Beam Remnants"

Predict overall event topology (FFF1 paper 1977)

7 GeV/c $\pi^0$'s!
Telegram from Feynman

July 1976

ICS IPHIINA ISS
ILSE FK WUI 19 0249
FMS PASADENA CA
UWA1971 PSX555 3103834N 7290
U8N6 CO FRXX 015
CHAKONI X MONTELANC
RICK FIELD CALTECH
PASADENA / CALIF
Saw Cronin Ann now convinced were right track quick write
FEY
NKH
Telegram from Feynman

July 1976

SAW CRONIN AM NOW CONVINCED WE'RE RIGHT TRACK QUICK WRITE

FEYNMAN
July 1976

Letter from Feynman

ÉCOLE D'ÉTÉ
DE PHYSIQUE THÉORIQUE

F - 74310 LES HOCHUES

Prof. Rick Field
High Energy Physics
California Institute of Technology
1201 California St.
PASADENA, CALIF. 91100

ETATS UNIS
July 22, 1976

Dear Rick,

If you got my telegram you know how impressed I am by what I learned from Cronin and from your letter (which I got). We must proceed with all speed to write it up and I will come in to see you next week.

Before I left, you gave me a figure for...
Dear Rick,

If you got my telegram you know how surprised I am by what I learned from Bronin and from your letter (which I got). We must proceed with all speed to write it up & I will come in to see you next week.

Before I left you gave me a figure for

Spelling?
It is fun.

Because mail here is bailed up in France, try a telegram. ECOLE D'ETE DE PHYSIC
F-74310 LES HOUCHES

just read the number for A in d²B/dε² = A/3ε². Instead
it is for B/3ε² say "B in 2700 mb" or whatever. Just
a few words.

Onward,
Dick Feynman.
It is fun!

It is fun.

Because mail here is bailed up in France, try a telegram.

Ecole d'ete de Physic
F-74310 les Houches

Just read the number for $A$ in $d\sigma/\hat{t} = A/\hat{t}^2$. If instead it is for $3/3\pi$, say "B in 2700 mb" or whatever. Just a few words.

Onward,

Dick Feynman.
Quark & Gluon Fragmentation Functions
Q^2 dependence predicted from QCD

Parton Distribution Functions
Q^2 dependence predicted from QCD

Quark & Gluon Cross-Sections
Calculated from QCD

QCD Approach: Quarks & Gluons

Parton Distribution Functions
Q^2 dependence predicted from QCD

QCD Approach: Quarks & Gluons

Parton Distribution Functions
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Quark & Gluon Cross-Sections
Calculated from QCD

Physoc Guest Lecture
Glasgow October 17, 2013

Rick Field – Florida/CDF/CMS

Page 25
Feynman quote from FFF2

“We investigate whether the present experimental behavior of mesons with large transverse momentum in hadron-hadron collisions is consistent with the theory of quantum-chromodynamics (QCD) with asymptotic freedom, at least as the theory is now partially understood.”
Proton-Proton or Proton-Antiproton Colliders:

\[ \text{Hadron} \rightarrow \text{???} \rightarrow \text{Hadron} \]

\[ E_{\text{beam}} = \frac{1}{2} E_{\text{beam}} + \frac{1}{2} E_{\text{beam}} \]

\[ E_{\text{CM}} \sim \frac{1}{3} E_{\text{beam}} + \frac{1}{6} E_{\text{beam}} + \frac{1}{6} E_{\text{beam}} \]
Monte-Carlo Simulation of Hadron-Hadron Collisions

- Color singlet proton collides with a color singlet antiproton.

- A red quark gets knocked out of the proton and a blue antiquark gets knocked out of the antiproton.

- At short times \((\text{small distances})\) the color forces are weak and the outgoing partons move away from the beam-beam remnants.

- At long times \((\text{large distances})\) the color forces become strong and quark-antiquark pairs are pulled out of the vacuum and hadrons are formed.

- The resulting event consists of hadrons and leptons in the form of two large transverse momentum outgoing jets plus the beam-beam remnants.
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---

**Physoc Guest Lecture**
**Glasgow October 17, 2013**
Monte-Carlo Simulation of Hadron-Hadron Collisions

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- The resulting event consists of hadrons and leptons in the form of two large transverse momentum outgoing jets plus the beam-beam remnants.
1st transparency

- Model:
  - Proton
  - Target
  - Quark-Quark Collision
  - $p_{\text{jet}}$ and $p_{\text{jet}}$?

- Need:
  1. Quark distribution in hadron (Pion?)
  2. The way quark makes hadron jet
    - From experiments with leptoquarks
  3. Quark-Quark scattering cross-section

- Try to fit all correlative experiments with no new parameters.

Last transparency

- Work in Progress
  - a) More detailed calculations
  - b) Theory of $q \rightarrow$ hadron cascade

- Future
  - Protons & baryons at high $p_T$.
  - Single jet at high $p_T$.
  - Nuclear targets.

- Are we really in trouble from appearance of quarks?
- Unify theory to that of main collision at low $p_T$. 

“Feynman-Field Jet Model”
A Parameterization of the Properties of Jets

Field-Feynman 1978

- Assumed that jets could be analyzed on a “recursive” principle.
- Let $f(\eta)d\eta$ be the probability that the rank 1 meson leaves fractional momentum $\eta$ to the remaining cascade, leaving quark “b” with momentum $P_1 = \eta_1 P_0$.
- Assume that the mesons originating from quark “b” are distributed in precisely the same way as the mesons which came from quark a (i.e. same function $f(\eta)$), leaving quark “c” with momentum $P_2 = \eta_2 P_1 = \eta_2 \eta_1 P_0$.
- Add in flavor dependence by letting $\beta_u =$ probability of producing u-ubar pair, $\beta_d =$ probability of producing d-dbar pair, etc.
- Let $F(z)dz$ be the probability of finding a meson (independent of rank) with fractional momentum $z$ of the original quark “a” within the jet.

Original quark with flavor “a” and momentum $P_0$
Assumed that jets could be analyzed on a “recursive” principle.

Let \( f(\eta) d\eta \) be the probability that the rank 1 meson *leaves* fractional momentum \( \eta \) to the remaining cascade, leaving quark “b” with momentum \( P_1 = \eta_1 P_0 \).

Assume that the mesons originating from quark “b” are distributed in precisely the same way as the mesons which came from quark a (*i.e.* same function \( f(\eta) \)), leaving quark “c” with momentum \( P_2 = \eta_2 P_1 = \eta_2 \eta_1 P_0 \).

Add in flavor dependence by letting \( \beta_u = \) probability of producing u-ubar pair, \( \beta_d = \) probability of producing d-dbar pair, etc.

Let \( F(z) dz \) be the probability of finding a meson (*independent of rank*) with fractional momentum \( z \) of the original quark “a” within the jet.
Fig. 1. An $e^+e^-$ Annihilation

- Rank
  1. $b\bar{c}$
  2. $ab$
  3. $cd$

New pair creation

Field (color field)

- Begin
  - quark
  - antiquark

Gathering to make "mesons"

which decay to

$\pi$, $K$, $\gamma$
Fig. 1. An $e^+e^-$ Annihilation

R. P. Feynman
ISMD, Kaysersberg,
France, June 12, 1977

Feynman quote from FF2
“The predictions of the model are reasonable enough physically that we expect it may be close enough to reality to be useful in designing future experiments and to serve as a reasonable approximation to compare to data. We do not think of the model as a sound physical theory, ....”
Monte-Carlo Simulation of Hadron-Hadron Collisions

FF1-FFF1 (1977) “Black-Box” Model

F1-FFF2 (1978) QCD Approach

FF2 (1978) Monte-Carlo simulation of “jets”

FFFW “FieldJet” (1980) QCD “leading-log order” simulation of hadron-hadron collisions

“FF” or “FW” Fragmentation

[yesterday]

ISAJET ("FF" Fragmentation)

HERWIG ("FW" Fragmentation)

PYTHIA 6.4

[the past]

today

SHERPA

PYTHIA 8

HERWIG++

Acquired 4728 nb\(^{-1}\) during 8 hour “owl” shift!


My wife Jimmie on shift with me!
High $P_T$ Jets

Predict large "jet" cross-section

Feynman, Field, & Fox (1978)

CDF (2006)

Feynman quote from FFF

"At the time of this writing, there is still no sharp quantitative test of QCD. An important test will come in connection with the phenomena of high $P_T$ discussed here."

CDF Run II Preliminary

Midpoint ($R_{cone}=0.7$, $f_{merge}=0.75$, $R_{sep}=1.3$)

$0.1 < |y| < 0.7$

$\int L = 1.04 \text{ fb}^{-1}$

Systematic uncertainty

Data corrected to hadron level

NLO pQCD EKS CTEQ 6.1M ($\mu = 200 \text{ GeV}$) $P_T^{jet}(\text{GeV/c})$
Proton-antiproton collisions at 2 TeV.

- Define $E_H$ to be the amount of energy required to light a 60 Watt light bulb for 1 second ($E_H = 60$ Joules). $1 \text{ TeV} = 10^{12} \text{ ev} = 1.6 \times 10^{-7} \text{ Joules}$ and hence $E_H = 3.75 \times 10^8 \text{ TeV}$.

- A proton-antiproton collisions at 2 TeV is equal to about $3.2 \times 10^{-7} \text{ Joules}$ which corresponds to about $1/200,000,000 \ E_H$! The energy is not high in every day standards but it is concentrated at a small point (*i.e.* large energy density).

- The mass energy of a proton is about 1 GeV and the mass energy of a pion is about 140 MeV. Hence 2 TeV is equivalent to about 2,000 proton masses or about 14,000 pion masses and **lots of hadrons** are produced in a typical collision.
Proton-antiproton collisions at 2 TeV.

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The mass energy of a proton is about 1 GeV and the mass energy of a pion is about 140 MeV. Hence 2 TeV is equivalent to about 2,000 proton masses or about 14,000 pion masses and lots of hadrons are produced in a typical collision.
The z-axis is defined to be the beam axis with the xy-plane being the “transverse” plane.

\( \theta_{cm} \) is the center-of-mass scattering angle and \( \phi \) is the azimuthal angle. The “transverse” momentum of a particle is given by \( P_T = P \cos(\theta_{cm}) \).

Use \( \eta \) and \( \phi \) to determine the direction of an outgoing particle, where \( \eta \) is the “pseudo-rapidity” defined by \( \eta = -\log(\tan(\theta_{cm}/2)) \).
CDF DiJet Event: $M(jj) \approx 1.4$ TeV

$E_{T}^{\text{jet1}} = 666$ GeV  $E_{T}^{\text{jet2}} = 633$ GeV
$E_{\text{sum}} = 1,299$ GeV  $M(jj) = 1,364$ GeV

Proton-Antiproton Collisions at 1.96 TeV

$CDF$ Run II Preliminary

Jet Et1 = 666 GeV  (corr)
583 GeV  (raw)

$\eta_{1} = 0.31$  (detector)
0.43  (corr z)

Jet Et2 = 633 GeV  (corr)
546 GeV  (raw)

$\eta_{2} = -0.30$  (detector)
-0.19  (corr z)

$M(jj)/E_{cm} \approx 70\%!!$
Start with the perturbative 2-to-2 (or sometimes 2-to-3) parton-parton scattering and add initial and final-state gluon radiation (in the leading log approximation or modified leading log approximation).

The “underlying event” consists of the “beam-beam remnants” and from particles arising from soft or semi-soft multiple parton interactions (MPI).

Of course the outgoing colored partons fragment into hadron “jet” and inevitably “underlying event” observables receive contributions from initial and final-state radiation.
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The “underlying event” consists of the “beam-beam remnants” and the particles arising from soft or semi-soft multiple parton interactions (MPI).

Of course the outgoing colored partons fragment into hadron “jet” and inevitably “underlying event” observables receive contributions from them. The “underlying event” is an unavoidable background to most collider observables and having good understand of it leads to more precise collider measurements!
Traditional Approach

Look at charged particle correlations in the azimuthal angle $\Delta \phi$ relative to a leading object (i.e. CaloJet#1, ChgJet#1, PTmax, Z-boson). For CDF $P_T \text{min} = 0.5 \text{ GeV}/c \eta_{\text{cut}} = 1$.

- Define $|\Delta \phi| < 60^\circ \text{ as "Toward"}$, $60^\circ < |\Delta \phi| < 120^\circ \text{ as "Transverse"}$, and $|\Delta \phi| > 120^\circ \text{ as "Away"}$.
- All three regions have the same area in $\eta$-$\phi$ space, $\Delta \eta \times \Delta \phi = 2\eta_{\text{cut}} \times 120^\circ = 2\eta_{\text{cut}} \times 2\pi/3$. Construct densities by dividing by the area in $\eta$-$\phi$ space.
Plot shows the “transverse” charged particle density versus $P_T(\text{charged jet#1})$ compared to the QCD hard scattering predictions of two tuned versions of PYTHIA 6.206 (CTEQ5L, Set B (PARP(67)=1) and Set A (PARP(67)=4)).

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Tune B</th>
<th>Tune A</th>
</tr>
</thead>
<tbody>
<tr>
<td>MSTP(81)</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>MSTP(82)</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>PARP(82)</td>
<td>1.9 GeV</td>
<td>2.0 GeV</td>
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<tr>
<td>PARP(83)</td>
<td>0.5</td>
<td>0.5</td>
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<tr>
<td>PARP(84)</td>
<td>0.4</td>
<td>0.4</td>
</tr>
<tr>
<td>PARP(85)</td>
<td>1.0</td>
<td>0.9</td>
</tr>
<tr>
<td>PARP(86)</td>
<td>1.0</td>
<td>0.95</td>
</tr>
<tr>
<td>PARP(89)</td>
<td>1.8 TeV</td>
<td>1.8 TeV</td>
</tr>
<tr>
<td>PARP(90)</td>
<td>0.25</td>
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</tr>
<tr>
<td>PARP(67)</td>
<td>1.0</td>
<td>4.0</td>
</tr>
</tbody>
</table>

CDF Preliminary data uncorrected theory corrected

1.8 TeV $|\eta|<1.0$ $P_T>0.5$ GeV

Run 1 Analysis

PT(charged jet#1) (GeV/c)

0 5 10 15 20 25 30 35 40 45 50

"Transverse" Charged Density: $dN/d\eta d\phi$
The forefront of science is moving from the US to CERN (Geneva, Switzerland).

The LHC is designed to collide protons with protons at a center-of-mass energy of 14 TeV (seven times greater energy than Fermilab)!
The LHC at CERN

Proton

14 TeV

Proton

6 miles
The LHC at CERN

14 TeV

Me at CMS!

CMS at the LHC

Proton

6 miles

Proton

Physoc Guest Lecture
Glasgow October 17, 2013

Rick Field – Florida/CDF/CMS

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7 TeV on 7 TeV proton-proton collider, 27km ring
  • 7 times higher energy than the Tevatron at Fermilab
    • Aim for 5 TeV for 2008
    • 100 times higher design luminosity than Tevatron (L=10^{34}cm^{-2}s^{-1})

1232 superconducting 8.4T dipole magnets @ T=1.9ºK
  • Largest cryogenic structure, 40 ktons of mass to cool

4 experiments

Start Date:
September 10, 2008
Incident of September 19th 2008

- Very impressive start-up with beam on September 10, 2008!
- While making the last step of the dipole circuit in sector 34, to 9.3kA. At 8.7kA, development of resistive zone in the dipole bus bar splice between Q24 R3 and the neighboring dipole. Electrical arc developed which punctured the helium enclosure.

The LHC repairs in detail

14 months of repair!
Shows the “associated” charged particle density in the “transverse” region as a function of PTmax for charged particles ($p_T > 0.5$ GeV/c, $|\eta| < 1$, not including PTmax) in “min-bias” events at 0.2 TeV, 0.9 TeV, 1.96 TeV, 7 TeV, 10 TeV, 14 TeV predicted by PYTHIA Tune DW at the particle level (i.e. generator level).
 Shows the “associated” charged particle density in the “transverse” region as a function of \( \text{PTmax} \) for charged particles (\( p_T > 0.5 \text{ GeV/c}, |\eta| < 1 \), *not including PTmax*) for “min-bias” events at 0.2 TeV, 0.9 TeV, 1.96 TeV, 7 TeV, 10 TeV, 14 TeV predicted by PYTHIA Tune DW at the particle level (*i.e.* generator level).
Conclusions November 2009

- We are making good progress in understanding and modeling the “underlying event”. RHIC data at 200 GeV are very important!

- The new Pythia \( p_T \) ordered tunes (py64 S320 and py64 P329) are very similar to Tune A, Tune AW, and Tune DW. At present the new tunes do not fit the data better than Tune AW and Tune DW. However, the new tune are theoretically preferred!

- It is clear now that the default value \( \text{PARP}(90) = 0.16 \) is not correct and the value should be closer to the Tune A value of 0.25.

- The new and old PYTHIA tunes are beginning to converge and I believe we are finally in a position to make some legitimate predictions at the LHC!

- All tunes with the default value \( \text{PARP}(90) = 0.16 \) are wrong and are overestimating the activity of min-bias and the underlying event at the LHC! This includes all my “T” tunes and the (old) ATLAS tunes!

- Need to measure “Min-Bias” and the “underlying event” at the LHC as soon as possible to see if there is new QCD physics to be learned!
November 20th 2009
- First beams around again

November 29th 2009
- Both beams accelerated to 1.18 TeV simultaneously

December 8th 2009
- 2x2 accelerated to 1.18 TeV
- First collisions at $E_{cm} = 2.36$ TeV!

December 14th 2009
- Stable 2x2 at 1.18 TeV
- Collisions in all four experiments

LHC - highest energy collider

900 GeV
Fake data (from MC) at 900 GeV on the “transverse” charged particle density, $dN/d\eta d\phi$, as defined by the leading charged particle (PTmax) and the leading charged particle jet (chgjet#1) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 2$. The fake data (from PYTHIA Tune DW) are generated at the particle level (i.e. generator level) assuming 0.5 M min-bias events at 900 GeV (361,595 events in the plot).
“Transverse” Charge Density

900 GeV → 7 TeV
(UE increase ~ factor of 2)

~0.4 → ~0.8

Shows the charged particle density in the “transverse” region for charged particles ($p_T > 0.5$ GeV/c, $|\eta| < 2$) at 900 GeV and 7 TeV as defined by $\text{PT}_{\text{max}}$ from PYTHIA Tune DW and at the particle level (i.e. generator level).
Fake data (from MC) at 900 GeV on the “transverse” charged particle density, $dN/d\eta d\phi$, as defined by the leading charged particle (PTmax) and the leading charged particle jet (chgjet#1) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 2$. The fake data (from PYTHIA Tune DW) are generated at the particle level (i.e. generator level) assuming 0.5 M min-bias events at 900 GeV (361,595 events in the plot).
Fake data (from MC) at 900 GeV on the “transverse” charged particle density, \( dN/d\eta d\phi \), as defined by the leading charged particle (PTmax) and the leading charged particle jet (chgjet#1) for charged particles with \( p_T > 0.5 \text{ GeV/c} \) and \(|\eta| < 2\). The fake data (from PYTHIA Tune DW) are generated at the particle level (i.e. generator level) assuming 0.5 M min-bias events at 900 GeV (361,595 events in the plot).

CMS preliminary data at 900 GeV on the “transverse” charged particle density, \( dN/d\eta d\phi \), as defined by the leading charged particle (PTmax) and the leading charged particle jet (chgjet#1) for charged particles with \( p_T > 0.5 \text{ GeV/c} \) and \(|\eta| < 2\). The data are uncorrected and compared with PYTHIA Tune DW after detector simulation (216,215 events in the plot).
First collisions with beam energies of 3.5 TeV ($E_{cm} = 7$ TeV)! Factor of 4.5 higher energy than the Tevatron.
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Stable Beams at $E_{cm} = 7$ TeV!

Comments 30-03-2010 13:22:57:

- Stable beams!

LHC Operation in CCC: 77600, 70480

PM Status B1: ENABLED
PM Status B2: ENABLED

Proton 7 TeV Proton
First collisions with beam energies of 3.5 TeV (Ecm = 7 TeV)! Factor of 4.5 higher energy than the Tevatron.

Stable Beams at Ecm = 7 TeV!
CMS Experiment at the LHC, CERN

Data recorded: 2010-Mar-30 11:04:33.951111 GMT(13:04:33 CEST)
Run: 132440
Event: 3109399
Lumi section: 139
Orbit: 36205120
Crossing: 1
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 \(|\eta| < 2\). 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, \(dN/d\eta d\phi\), as defined by the leading charged particle jet (PTmax) for charged particles with \(p_T > 0.5\) GeV/c and \(|\eta| < 2.5\). The data are corrected and compared with PYTHIA Tune DW at the generator level.
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 \(|\eta| < 2\). The data are uncorrected and compared with PYTHIA Tune DW after detector simulation.

Ratio of 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 \(|\eta| < 2\). The data are uncorrected and compared with PYTHIA Tune DW after detector simulation.
Ratio of 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 $|\eta| < 2$. The data are uncorrected and compared with PYTHIA Tune DW after detector simulation.

Ratio of the ATLAS 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 (PTmax) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 2.5$. The data are corrected and compared with PYTHIA Tune DW at the generator level.
I am surprised that the Tunes did not do a better job of predicting the “underlying event” at 900 GeV and 7 TeV!
How well did we do at predicting the “underlying event” at 900 GeV and 7 TeV?

I am surprised that the Tunes did as well as they did at predicting the behavior of the “underlying event” at 900 GeV and 7 TeV!
CMS DiJet Event: $M(jj) \approx 2$ TeV

$E_{T,jet1} = 1.099$ TeV  $E_{T,jet2} = 935$ GeV  $M(jj) = 2.05$ TeV

$M(jj)/E_{cm} \approx 29\%$

But $M(jj) > 2$ TeV!

Proton-Proton Collisions at 7 TeV
7 GeV $\pi^0$'s $\rightarrow$ 1 TeV Jets

Jet 1 $p_T = 1.099$ TeV
Jet 2 $p_T = 935$ GeV

CMS

Run 144112 Event 1189490855
$M_{jj} \sim 2.05$ TeV

7 GeV/c $\pi^0$'s!
7 GeV $\pi^0$'s $\rightarrow$ 1 TeV Jets

CMS

Rick & Jimmie ISMD - Chicago 2013
7 GeV $\pi^0$'s $\rightarrow$ 1 TeV Jets