RHIC & AGS
Annual Users' Meeting

"Min-Bias" and the "Underlying Event" From RHIC to the LHC

Rick Field
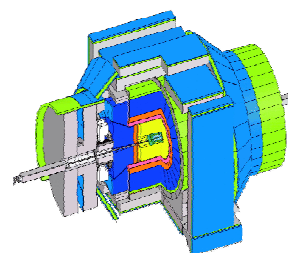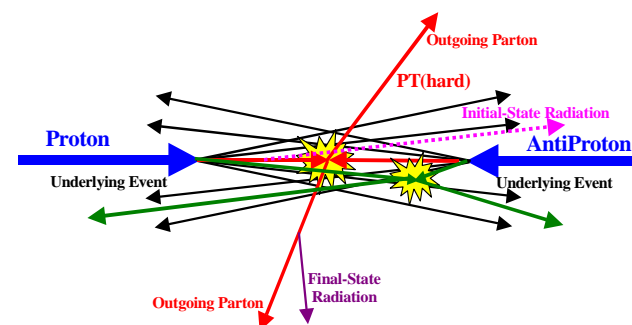## University of Florida

BNL June 2, 2009

Outline of Talk

➡ **What is the "underlying event"?**

➡ **The QCD Monte-Carlo Model tunes.**

➡ **The Pythia MPI energy scaling parameter PARP(90).**

➡ **Extrapolations from the Tevatron to RHIC and the LHC.**

➡ **The "underlying event" at STAR.**
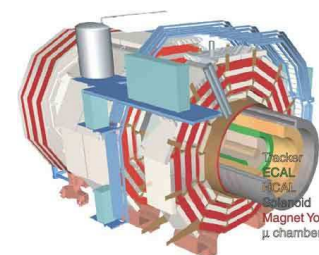
➡ **LHC predictions!**

➡ **Summary & Conclusions.**

Quantum Chromo- Dynamics

Outgoing Parton

PT(hard)

Initial-State Radiation

Proton

AntiProton

Underlying Event

Underlying Event

Final-State Radiation

Outgoing Parton

CDF Run 2

CMS at the LHC

"Min-Bias" and the "Underlying Event" From RHIC to the LHC

Rick Field
University of Florida

BNL June 2, 2009

Amplitude Analysis of the Reaction $K^-p \to \pi^- Y^{*+}(1385)$†

M. Aguilar-Benitez,* S. U. Chung, R. L. Eisner, and R. D. Field

Brookhaven National Laboratory, Upton, New York 11973

(Received 19 June 1972)

We present a model-independent amplitude analysis of the reaction $K^-p \to \pi^- Y^{*+}(1385)$ at 3.9 and 4.6 GeV/c incident momenta. By observing the two-step decay of the $Y^{*+}(1385)$ we determine the magnitudes and two relative phases of the four independent transversity amplitudes which describe the reaction. These amplitudes are found to be in rough agreement with the predictions of the naïve quark model; however, the predictions do not hold exactly.
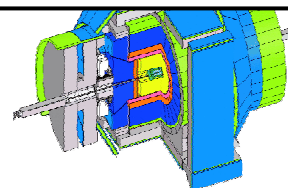
➡ What is

➡ The QCD

➡ The Pyth
parame
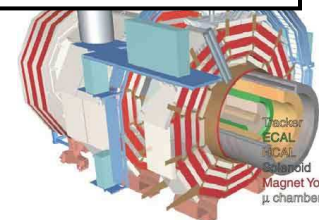
➡ Extrapol
to RHIC

➡ The "underlying event" at **STAR**.

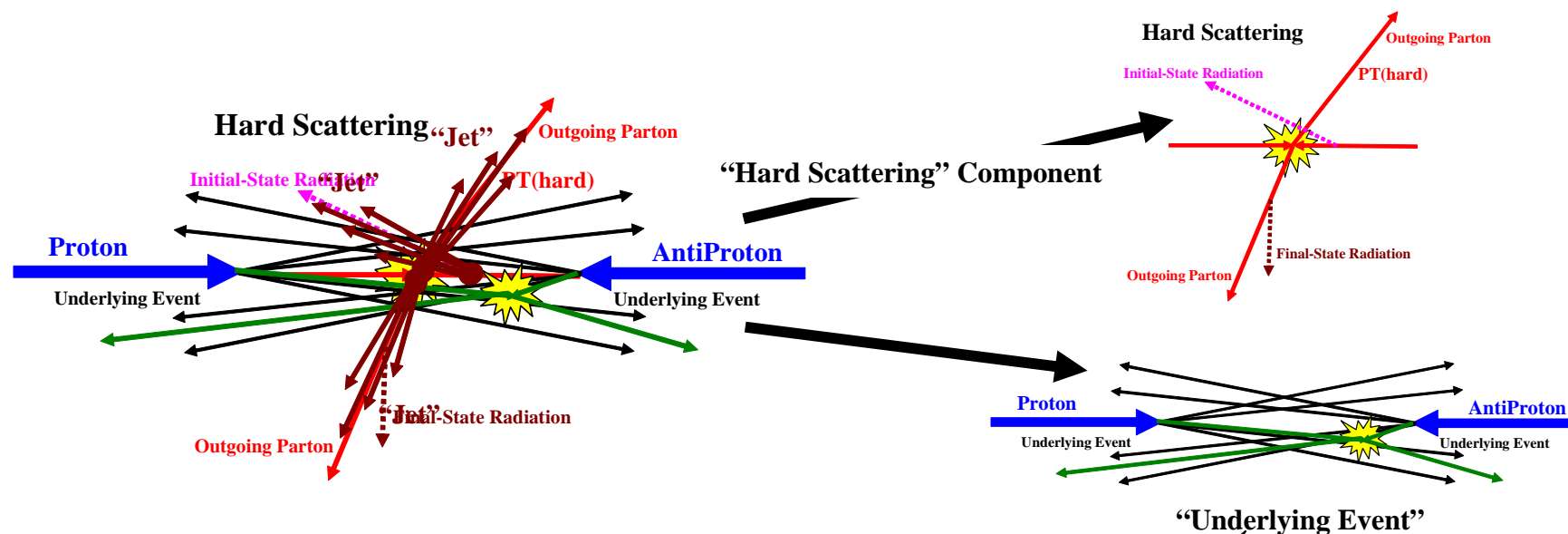➡ LHC predictions!

➡ Summary & Conclusions.
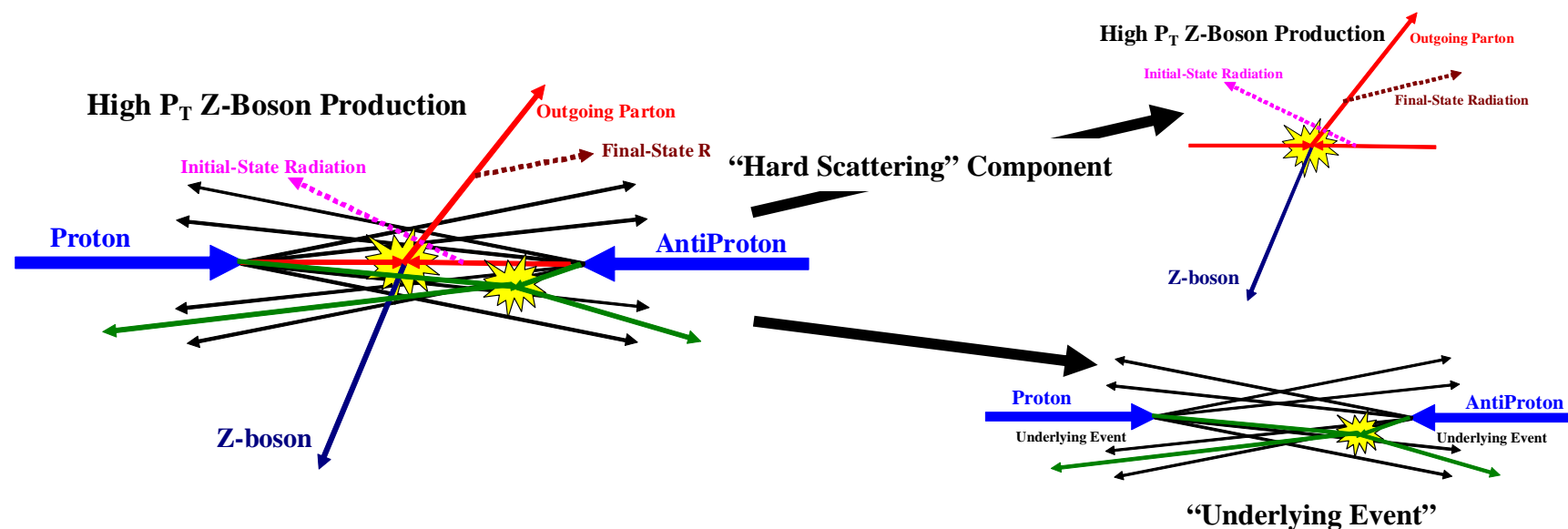
CDF Run 2

CMS at the LHC

QCD Monte-Carlo Models: High Transverse Momentum Jets

➡️ **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 ... articles arising from soft or semi-soft multiple parton interactions (MPI).**

➡️ **Of course the outgoing colored parton ... ly "underlying event" observables receive contributions from ...**

> **The "underlying event" is an unavoidable background to most collider observables and having good understand of it leads to more precise collider measurements!**

High P$_T$ Z-Boson Production

Outgoing Parton

Final-State R

Initial-State Radiation

Proton

AntiProton

Z-boson

"Hard Scattering" Component

High P$_T$ Z-Boson Production

Outgoing Parton

Initial-State Radiation

Final-State Radiation

Z-boson

Proton

AntiProton

Underlying Event

Underlying Event

"Underlying Event"

➡ **Start with the perturbative Drell-Yan muon pair production and add initial-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-state radiation.**

Proton-AntiProton Collisions at the Tevatron

Elastic Scattering

Single Diffraction

D

M

M₁
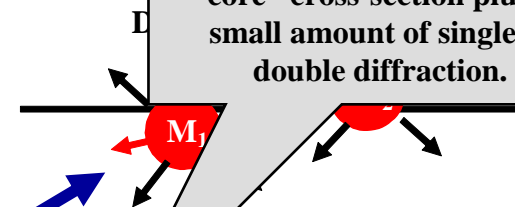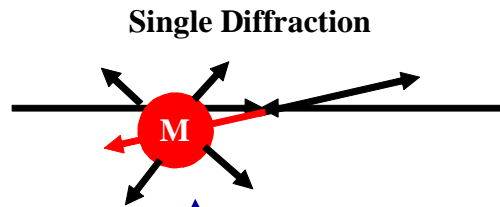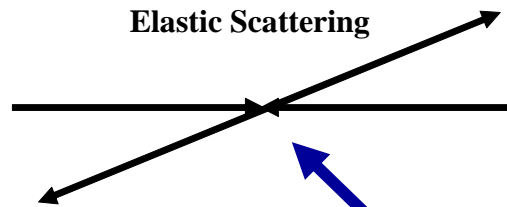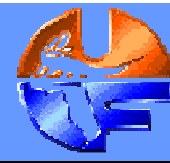
The CDF "Min-Bias" trigger picks up most of the "hard core" cross-section plus a small amount of single & double diffraction.

$$\sigma_{tot} = \sigma_{EL} + \sigma_{SD} + \sigma_{DD} + \sigma_{HC}$$

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

The "hard core" component contains both "hard" and "soft" collisions.

"Inelastic Non-Diffractive Component"

Hard Core

CDF "Min-Bias" trigger
1 charged particle in forward BBC
AND
1 charged particle in backward BBC

"Soft" Hard Core (no hard scattering)

"Hard" Hard Core (hard scattering)

Outgoing Parton

PT(hard)

Proton

AntiProton

Proton

AntiProton

Underlying Event

Underlying Event

Final-State Radiation

Final-State Radiation

Outgoing Parton

Beam-Beam Counters
3.2 < |η| < 5.9

Particle Densities

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

2π

ϕ

0

-1 η $+1$

3 charged particles

3 GeV/c PTsum

Charged Particles
$p_T > 0.5$ GeV/c $|\eta| < 1$

CDF Run 2 "Min-Bias"

	CDF Run 2 "Min-Bias" Observable	Average	Average Density per unit η-ϕ
N_{chg}	Number of Charged Particles ($p_T > 0.5$ GeV/c, $|\eta| < 1$)	3.17 +/- 0.31	0.252 +/- 0.025
PTsum (GeV/c)	Scalar p_T sum of Charged Particles ($p_T > 0.5$ GeV/c, $|\eta| < 1$)	2.97 +/- 0.23	0.236 +/- 0.018

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

Divide by 4π

$dPT_{sum}/d\eta d\phi = 3/4\pi$ GeV/c = 0.24 GeV/c

➡ **Study the charged particles ($p_T > 0.5$ GeV/c, $|\eta| < 1$) and form the charged particle density, $dN_{chg}/d\eta d\phi$, and the charged scalar p_T sum density, $dPT_{sum}/d\eta d\phi$.**
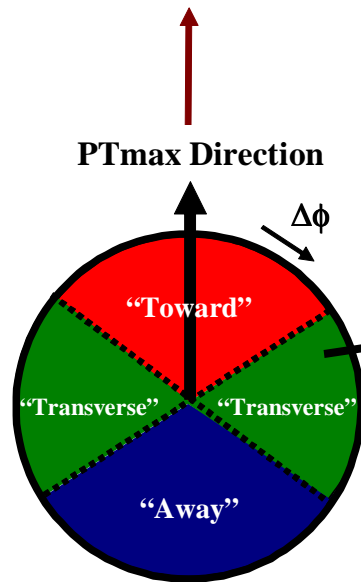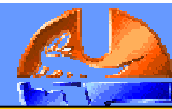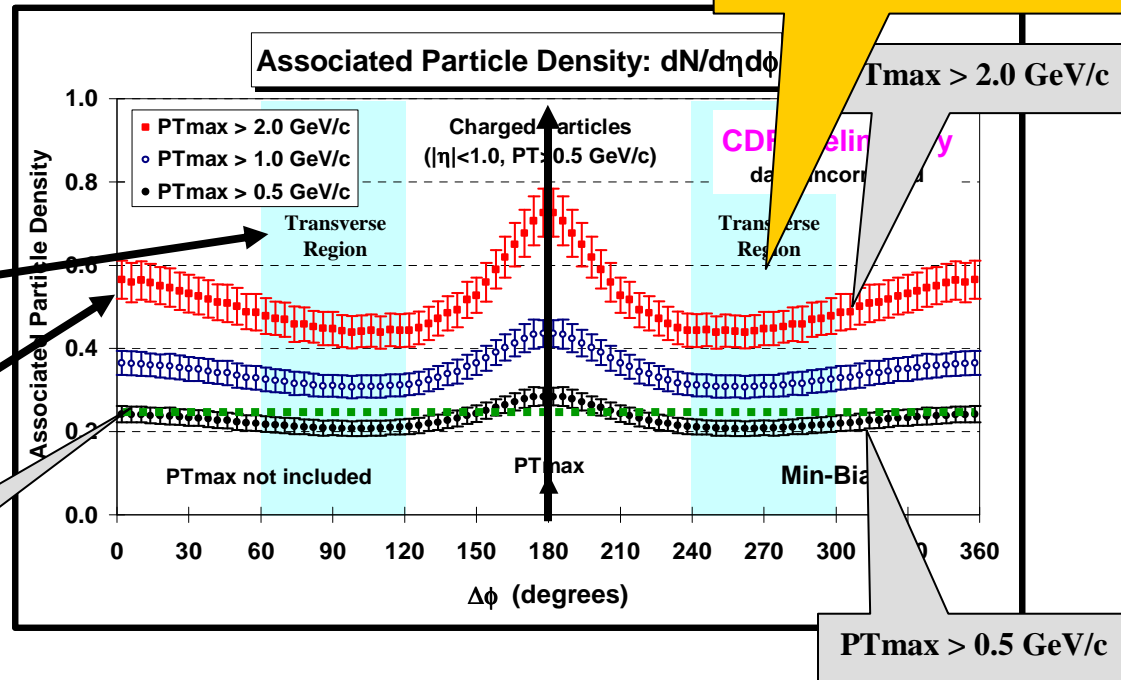
Rapid rise in the particle density in the "transverse" region as PTmax increases!

PTmax Direction

Δφ

"Toward"

"Transverse" "Transverse"

"Away"

Associated Particle Density: dN/dηdφ

PTmax > 2.0 GeV/c

- ■ PTmax > 2.0 GeV/c
- ○ PTmax > 1.0 GeV/c
- • PTmax > 0.5 GeV/c

Charged Particles (|η|<1.0, PT>0.5 GeV/c)

CDF Preliminary data uncorrected

Transverse Region

Transverse Region

PTmax not included

PTmax

Min-Bias

Associated Particle Density

Δφ (degrees)

PTmax > 0.5 GeV/c

Ave Min-Bias 0.25 per unit η-φ

➡ **Shows the data on the Δφ dependence of the "associated" charged particle density,** $dN_{chg}/d\eta d\phi$, **for charged particles** ($p_T > 0.5$ GeV/c, |η| < 1, *not including PTmax*) **relative to PTmax (rotated to 180°) for "min-bias" events with PTmax > 0.5, 1.0, and 2.0 GeV/c.**

➡ **Shows "jet structure" in "min-bias" collisions** (*i.e.* **the "birth" of the leading two jets!**).

Associated Charged Particle Density: dNⁿ/dηdφ

PTmax Direction

Shows the Δφ dependence of the "associated" charged particle density, $dN_{chg}/d\eta d\phi$, for charged particles ($p_T > 0.5$ GeV/c, $|\eta| < 1$, *not including PTmax*) relative to PTmax (rotated to 180º) for "min-bias" events at 1.96 TeV with PTmax > 0.5, 1.0, 2.0, 5.0, and 10.0 GeV/c from PYTHIA Tune A (generator level).

Associated Charged Particle Density: dN/dηdφ

Associated Charged Particle Density: dN/dηdφ
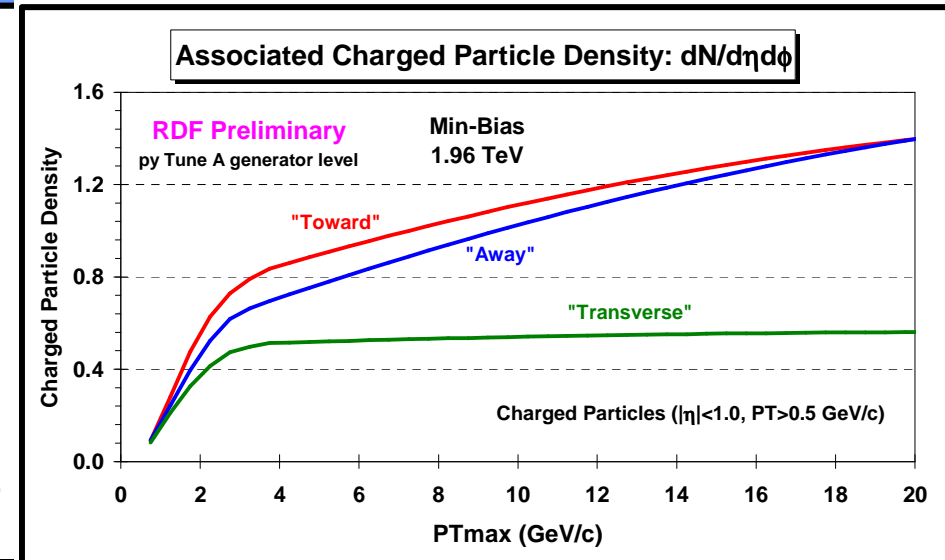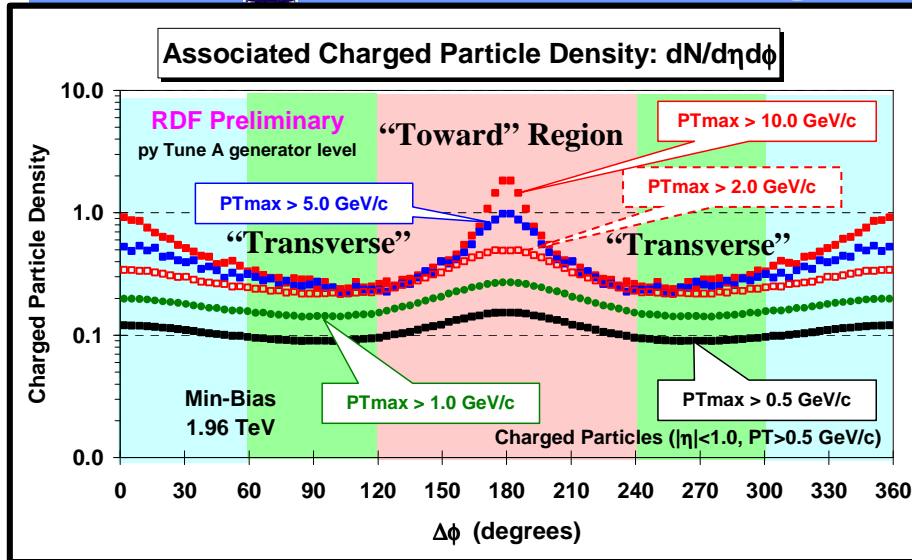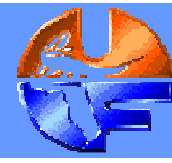
➡ **Shows the Δφ dependence of the "associated" charged particle density**, dNchg/dηdφ, for charged particles (p_T > 0.5 GeV/c, |η| < 1, *not including PTmax*) relative to PTmax (rotated to 180°) for **"min-bias" events at 1.96 TeV** with PTmax > 0.5, 1.0, 2.0, 5.0, and 10.0 GeV/c from **PYTHIA Tune A** (generator level).

➡ **Shows the "associated" charged particle density in the "toward", "away" and "transverse" regions as a function of PTmax for charged particles (p_T > 0.5 GeV/c, |η| < 1, *not including PTmax*) for "min-bias" events at 1.96 TeV from PYTHIA Tune A** (generator level).

Charged Particle Δφ Correlations

$P_T > 0.5$ GeV/c $|\eta| < 1$

Charged Jet #1 Direction

"Transverse" region very sensitive to the "underlying event"!

"Toward-Side" Jet

Δφ

"Toward"

"Transverse"   "Transverse"

"Away"

"Away-Side" Jet

CDF Run 1 Analysis

Charged Jet #1 Direction
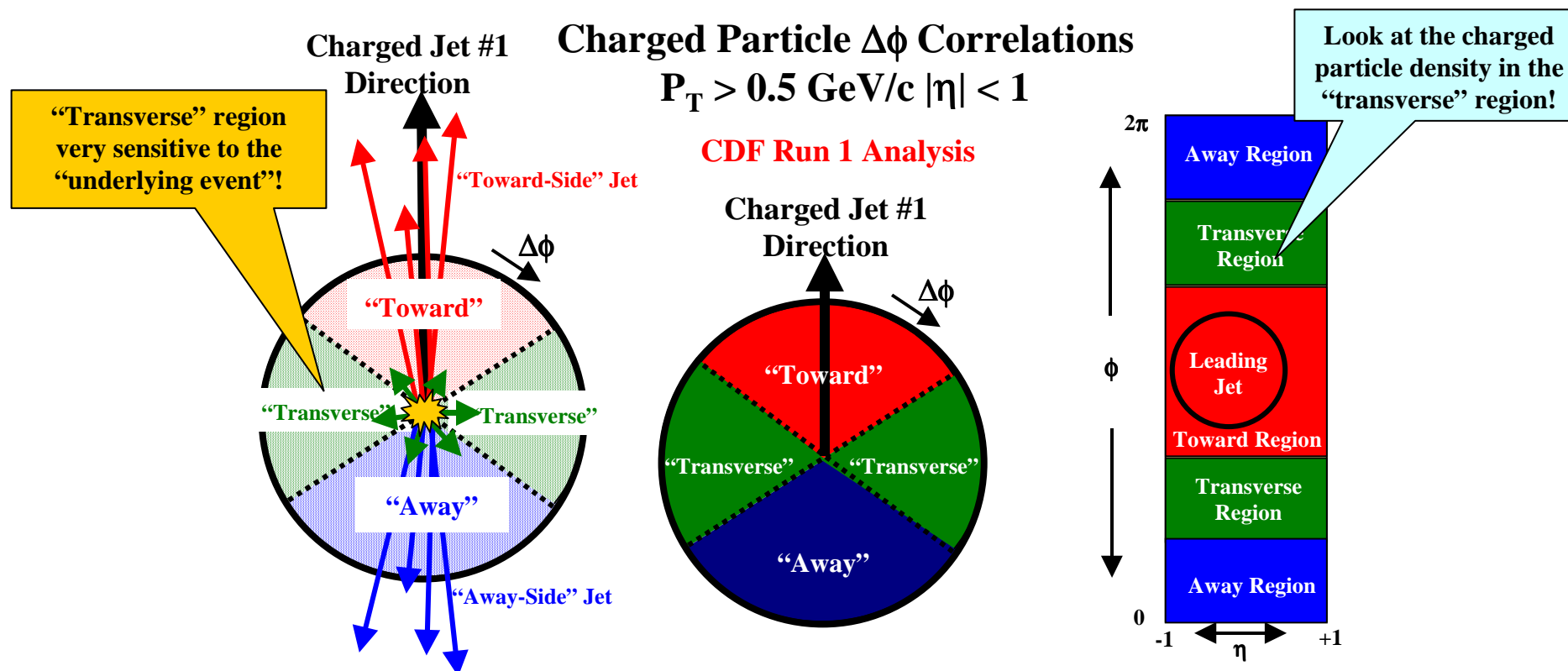
Δφ

"Toward"

"Transverse"   "Transverse"

"Away"

Look at the charged particle density in the "transverse" region!

2π

Away Region

Transverse Region

Leading Jet

Toward Region

Transverse Region

Away Region

φ

0

-1   η   +1

➡ Look at charged particle correlations in the azimuthal angle Δφ relative to the leading charged particle jet.

➡ Define $|\Delta\phi| < 60^o$ as "Toward", $60^o < |\Delta\phi| < 120^o$ as "Transverse", and $|\Delta\phi| > 120^o$ as "Away".

➡ All three regions have the same size in η-φ space, $\Delta\eta \times \Delta\phi = 2 \times 120^o = 4\pi/3$.

PYTHIA 6.206 Defaults
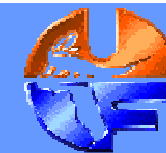
PYTHIA default parameters

MPI constant probability scattering
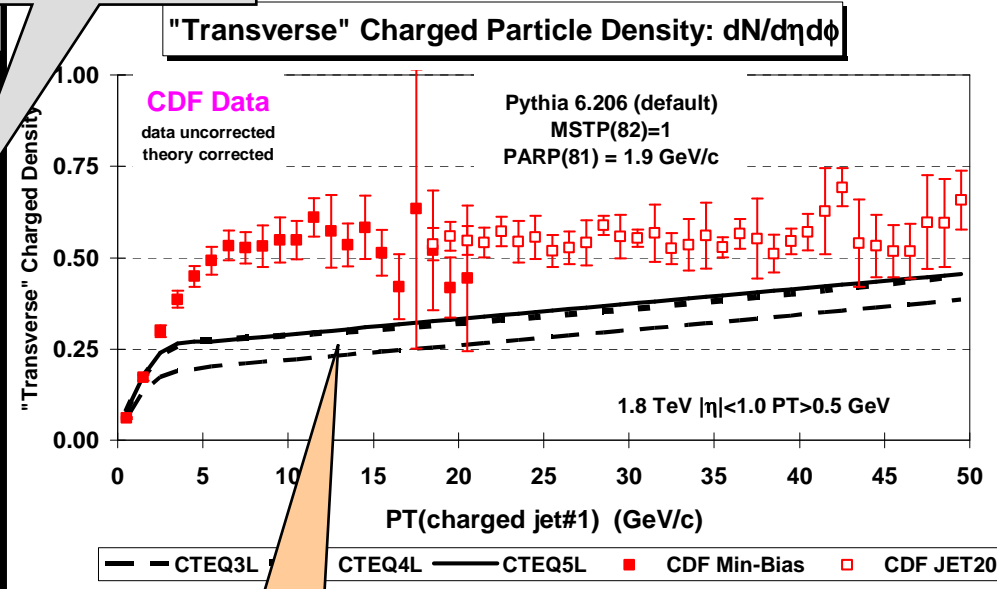
Parameter	6.115	6.125	6.158	6.206
MSTP(81)	1	1	1	1
MSTP(82)	1	1	1	1
PARP(81)	1.4	1.9	1.9	1.9
PARP(82)	1.55	2.1	2.1	1.9
PARP(89)		1,000	1,000	1,000
PARP(90)		0.16	0.16	0.16
PARP(67)	4.0	4.0	1.0	1.0

"Transverse" Charged Particle Density: dN/dηdφ

CDF Data
data uncorrected
theory corrected

Pythia 6.206 (default)
MSTP(82)=1
PARP(81) = 1.9 GeV/c

1.8 TeV |η|<1.0 PT>0.5 GeV

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

— — CTEQ3L   ···· CTEQ4L   —— CTEQ5L   ■ CDF Min-Bias   □ CDF JET20

➡ **Plot shows the "Transverse" charged particle density versus P_T(chgjet#1)** compared to the QCD hard scattering predictions of **PYTHIA 6.206** (P_T(hard) > 0) using the **default** parameters for multiple parton interactions and CTEQ3L, CTEQ4L, and CTEQ5L.

Note Change
PARP(67) = 4.0 (< 6.138)
PARP(67) = 1.0 (> 6.138)

Default parameters give very poor description of the "underlying event"!

Tuning PYTHIA:
Multiple Parton Interaction Parameters

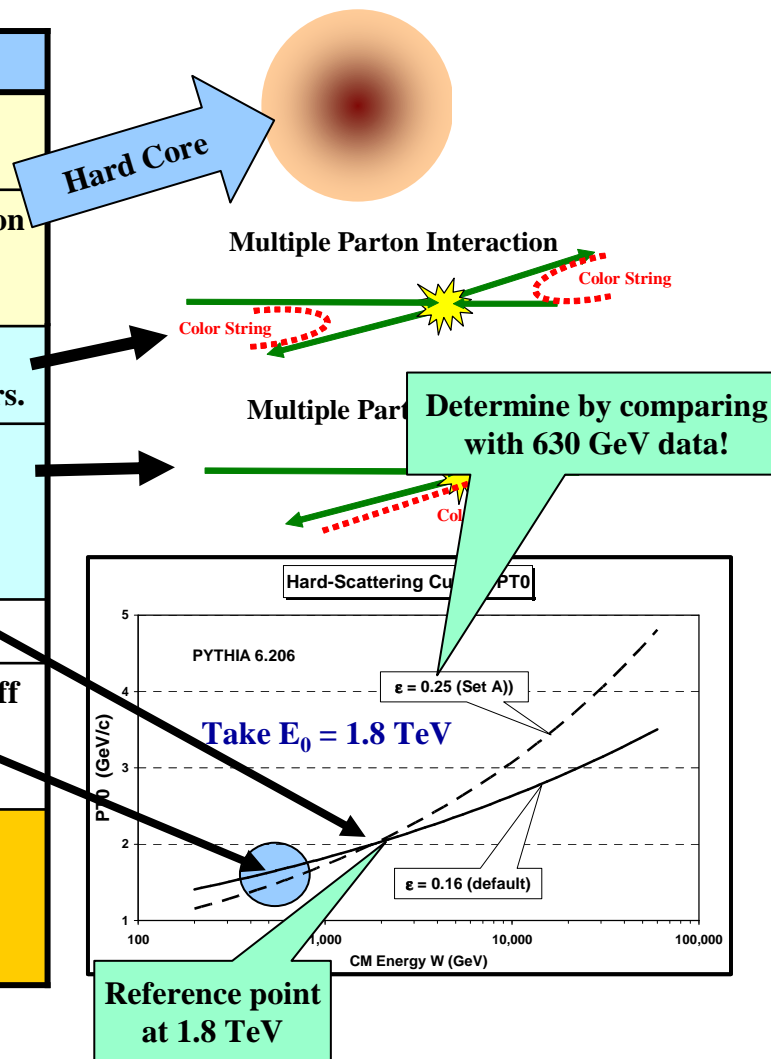| Parameter	Default	Description
PARP(83)	0.5	Double-Gaussian: Fraction of total hadronic matter within PARP(84)
PARP(84)	0.2	Double-Gaussian: Fraction of the overall hadron radius containing the fraction PARP(83) of the total hadronic matter.
PARP(85)	0.33	Probability that the MPI produces two gluons with color connections to the "nearest neighbors.
PARP(86)	0.66	Probability that the MPI produces two gluons either as described by PARP(85) or as a closed ... g fraction consists of
PARP(89)	1 TeV	D...nes the reference energy E_0.
PARP(90)	0.16	Determines the energy dependence of the cut-off P_{T0} as follows $P_{T0}(E_{cm}) = P_{T0}(E_{cm}/E_0)^\varepsilon$ with $\varepsilon = PARP(90)$
PARP(67)	1.0	A scale factor that determines the maximum parton virtuality for space-like showers. The larger the value of PARP(67) the more initial-state radiation.

Hard Core

Multiple Parton Interaction

Color String

Color String

Multiple Part...

Col...

Affects the amount of initial-state radiation!

Determine by comparing with 630 GeV data!

Take E_0 = 1.8 TeV

Hard-Scattering Cu... PT0

PYTHIA 6.206

$\varepsilon = 0.25$ (Set A))

$\varepsilon = 0.16$ (default)

PT0 (GeV/c)

CM Energy W (GeV)

Reference point at 1.8 TeV

Run 1 PYTHIA Tune A

PYTHIA 6.206 CTEQ5L

CDF Default!

Parameter	Tune B	Tune A
MSTP(81)	1	1
MSTP(82)	4	4
PARP(82)	1.9 GeV	2.0 GeV
PARP(83)	0.5	0.5
PARP(84)	0.4	0.4
PARP(85)	1.0	0.9
PARP(86)	1.0	0.95
PARP(89)	1.8 TeV	1.8 TeV
PARP(90)	0.25	0.25
PARP(67)	1.0	4.0

"Transverse" Charged Particle Density: dN/dηdφ

CDF Preliminary
data uncorrected
theory corrected

PYTHIA 6.206 (Set A)
PARP(67)=4   **Run 1 Analysis**

"Transverse" Charged Density

PYTHIA 6.206 (Set B)
PARP(67)=1

CTEQ5L

1.8 TeV |η|<1.0 PT>0.5 GeV

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

0.00 0.25 0.50 0.75 1.00

0   5   10   15   20   25   30   35   40   45   50

➡ **Plot shows the "transverse" charged particle density versus P_T(chgjet#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)).**

New PYTHIA default (less initial-state radiation)

Old PYTHIA default (more initial-state radiation)

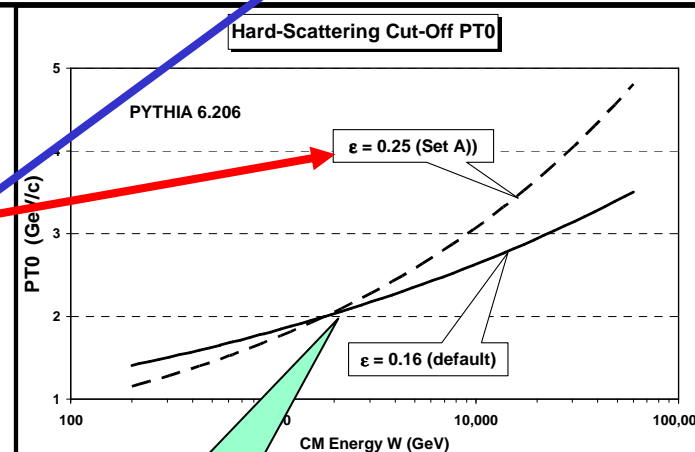**"Transverse" Charged PTsum Density: $dPT_{sum}/d\eta d\phi$**

HERWIG 6.4
$\varepsilon = 0.25$
$\varepsilon = 0.16$
$\varepsilon = 0$
Pythia 6.206 (Set A)
CTEQ5L
630 GeV $|\eta|<1.0$ PT>0.4 GeV

"Min Transverse" PTsum Density: $dPT_{sum}/d\eta d\phi$

Pythia 6.206 (Set A)
$\varepsilon = 0.25$
HERWIG 6.4
$\varepsilon = 0.16$
$\varepsilon = 0$
CTEQ5L
630 GeV $|\eta|<1.0$ PT>0.4 GeV

Hard-Scattering Cut-Off PT0

PYTHIA 6.206
$\varepsilon = 0.25$ (Set A))
$\varepsilon = 0.16$ (default)
Reference point $E_0 = 1.8$ TeV
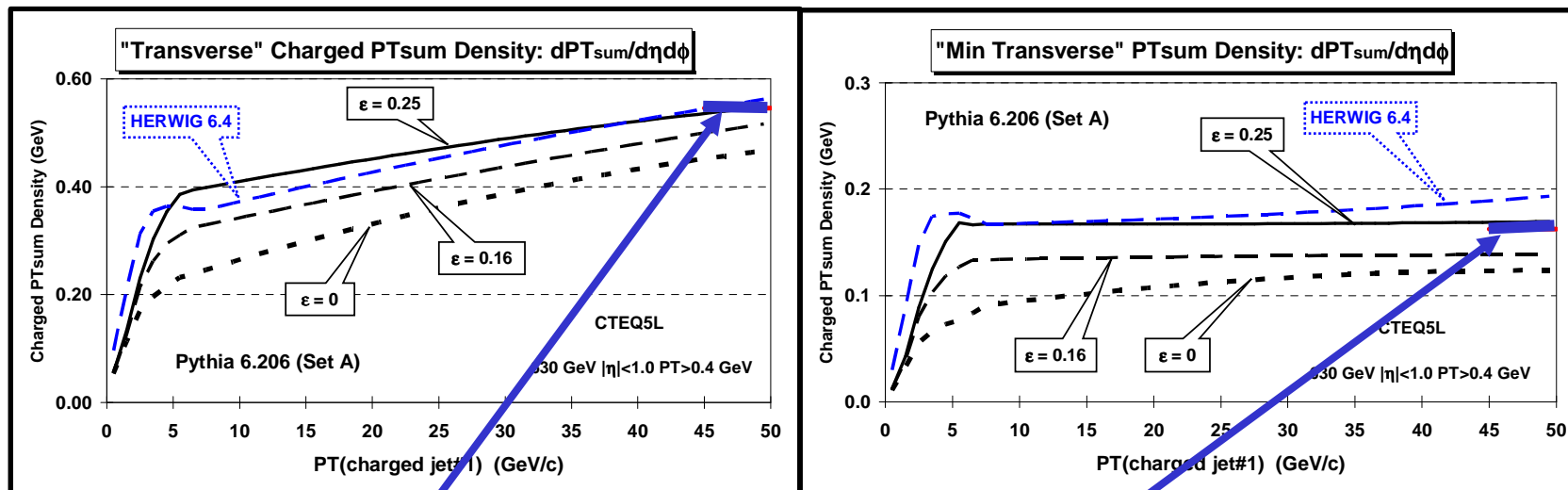
➡ **Shows the "transverse" charged PT$_{sum}$ density ($|\eta|<1$, $P_T>0.4$ GeV) versus P_T(charged jet#1) at 630 GeV predicted by HERWIG 6.4 (P_T(hard) > 3 GeV/c, CTEQ5L) and a tuned version of PYTHIA 6.206 (P_T(hard) > 0, CTEQ5L, Set A, $\varepsilon = 0$, $\varepsilon = 0.16$ (default) and $\varepsilon = 0.25$ (preferred)).**
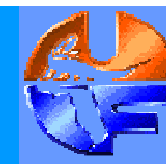
➡ **Also shown are the PT$_{sum}$ densities (0.16 GeV/c and 0.54 GeV/c) determined from the Tano, Kovacs, Huston, and Bhatti "transverse" cone analysis at 630 GeV.**
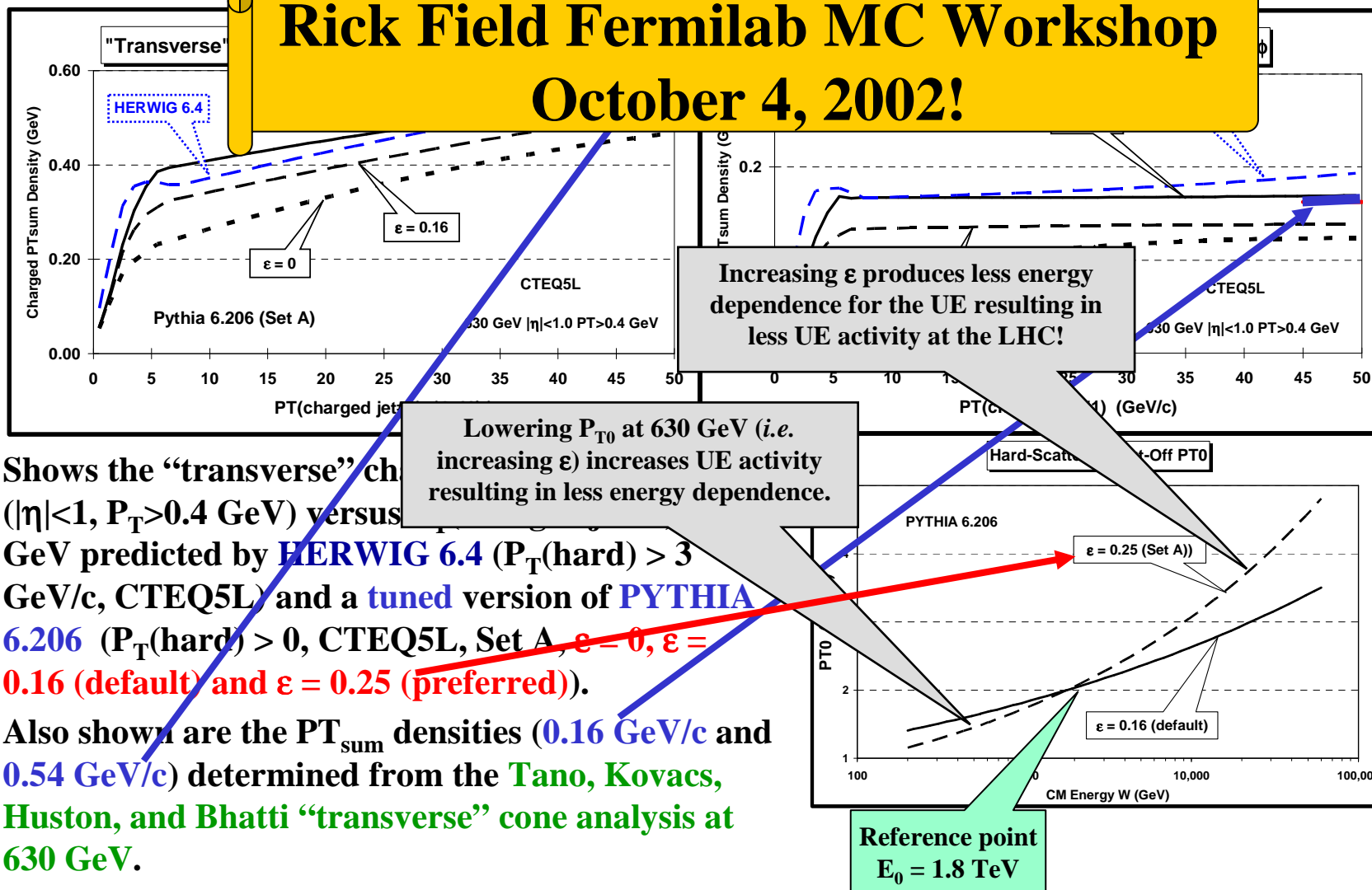
Rick Field Fermilab MC Workshop October 4, 2002!

"Transverse" ... HERWIG 6.4 ... ε = 0.16 ... ε = 0 ... Pythia 6.206 (Set A) ... CTEQ5L ... 630 GeV |η|<1.0 PT>0.4 GeV

Charged PTsum Density (GeV)

PT(charged jet...)

Increasing ε produces less energy dependence for the UE resulting in less UE activity at the LHC!

Lowering P_{T0} at 630 GeV (*i.e.* increasing ε) increases UE activity resulting in less energy dependence.

Hard-Scatt... ...-Off PT0

PYTHIA 6.206

ε = 0.25 (Set A))

PT0

ε = 0.16 (default)

CM Energy W (GeV)

Reference point E_0 = 1.8 TeV

➡ **Shows the "transverse" ch... (|η|<1, P_T>0.4 GeV) versus ... GeV predicted by HERWIG 6.4 (P_T(hard) > 3 GeV/c, CTEQ5L) and a tuned version of PYTHIA 6.206 (P_T(hard) > 0, CTEQ5L, Set A, ε = 0, ε = 0.16 (default) and ε = 0.25 (preferred)).**

➡ **Also shown are the PT_{sum} densities (0.16 GeV/c and 0.54 GeV/c) determined from the Tano, Kovacs, Huston, and Bhatti "transverse" cone analysis at 630 GeV.**
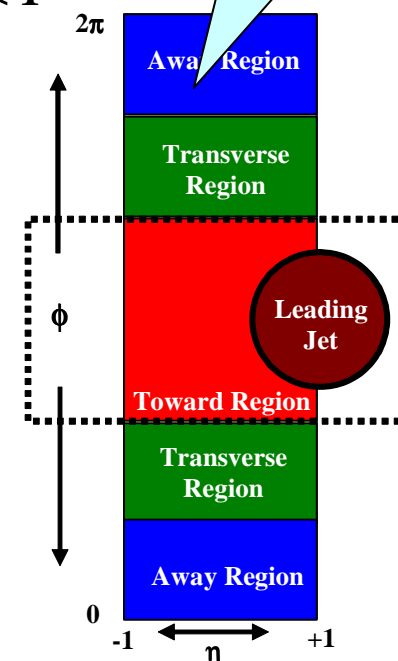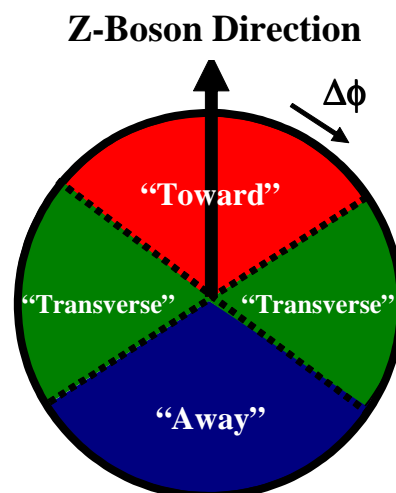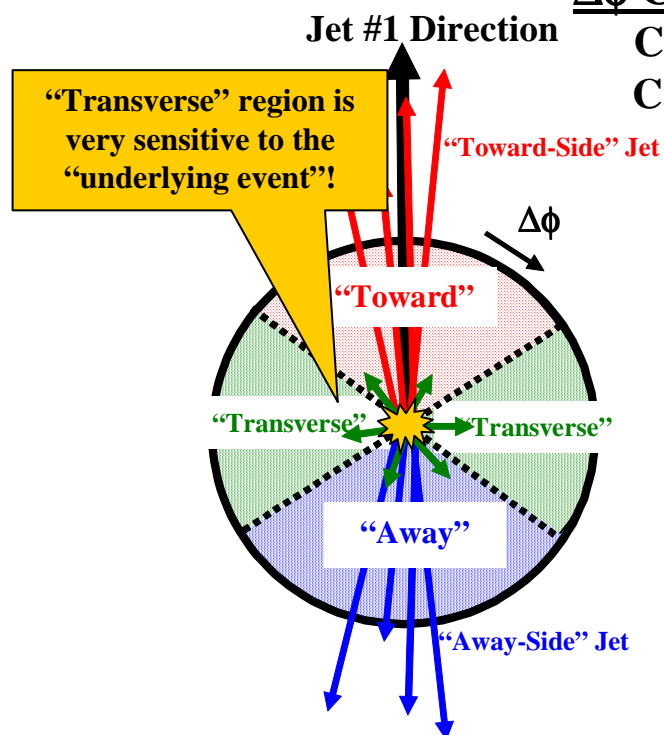
Look at the charged particle density, the charged PTsum density and the ETsum density in all 3 regions!

Δφ Correlations relative to the leading jet
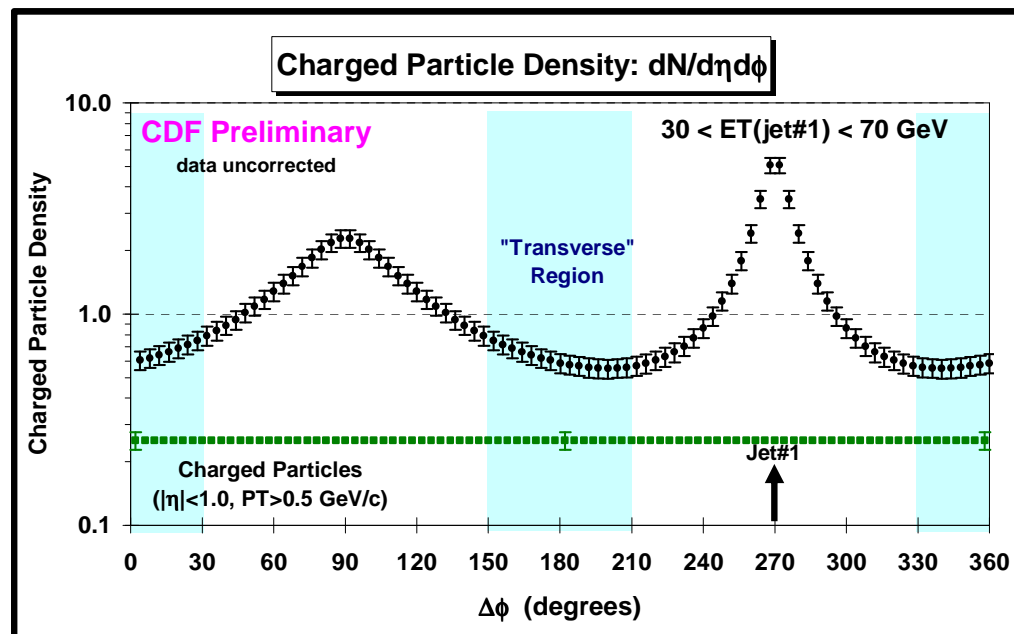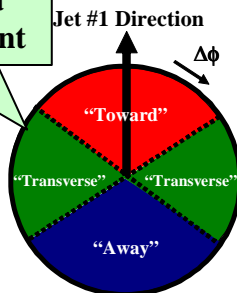
Charged particles $p_T > 0.5$ GeV/c $|\eta| < 1$

Calorimeter towers $E_T > 0.1$ GeV $|\eta| < 1$

Jet #1 Direction

"Transverse" region is very sensitive to the "underlying event"!

"Toward-Side" Jet

Δφ

"Toward"

"Transverse" "Transverse"

"Away"

"Away-Side" Jet

Z-Boson Direction

Δφ

"Toward"

"Transverse" "Transverse"

"Away"

2π

Away Region

Transverse Region

φ

Leading Jet

Toward Region

Transverse Region

0

Away Region

-1 η +1

➡ **Look at correlations in the azimuthal angle Δφ relative to the leading charged particle jet ($|\eta| < 1$) or the leading calorimeter jet ($|\eta| < 2$).**

➡ **Define $|\Delta\phi| < 60^o$ as "Toward", $60^o < |\Delta\phi| < 120^o$ as "Transverse ", and $|\Delta\phi| > 120^o$ as "Away". Each of the three regions have area $\Delta\eta\Delta\phi = 2\times120^o = 4\pi/3$.**
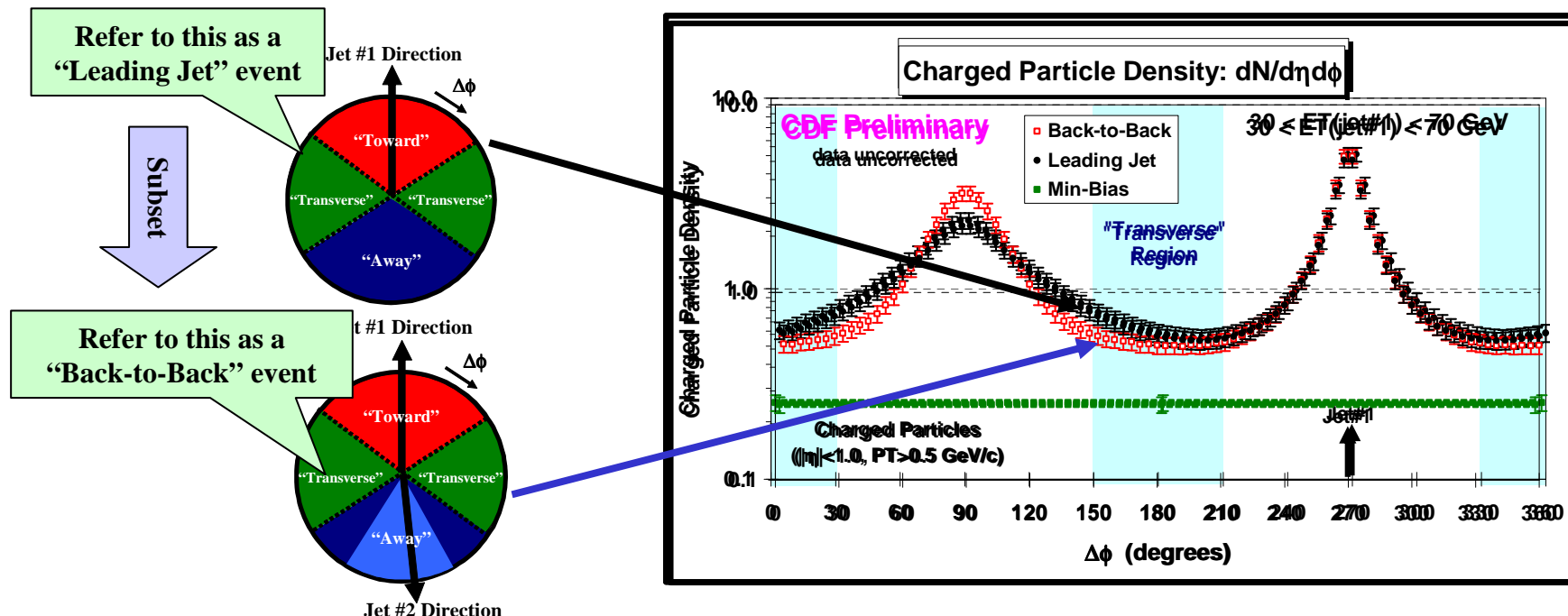
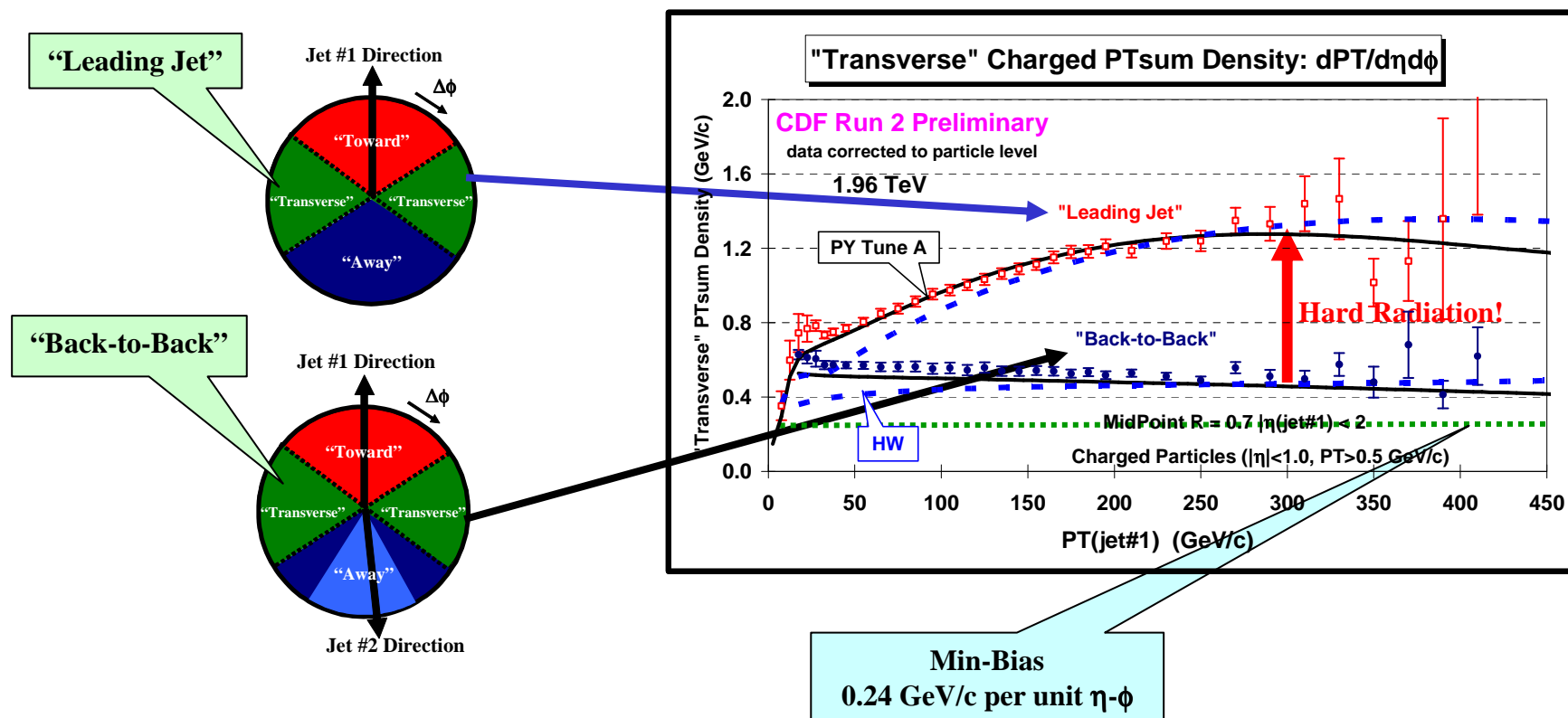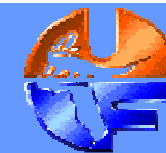# Charged Particle Density Δφ Dependence

Refer to this as a "Leading Jet" event

Look at the **"transverse" region** as defined by the leading jet (JetClu R = 0.7, |η| < 2) or by the leading two jets (JetClu R = 0.7, |η| < 2). **"Back-to-Back"** events are selected to have at least two jets with Jet#1 and Jet#2 nearly "back-to-back" ($\Delta\phi_{12} > 150°$) with almost equal transverse energies ($E_T(jet\#2)/E_T(jet\#1) > 0.8$) and with $E_T(jet\#3) < 15$ GeV.

Shows the **Δφ dependence of the charged particle density**, $dN_{chg}/d\eta d\phi$, for charged particles in the range $p_T > 0.5$ GeV/c and |η| < 1 relative to jet#1 (rotated to 270°) for 30 < $E_T(jet\#1)$ < 70 GeV for **"Leading Jet"** and **"Back-to-Back"** events.

Refer to this as a "Leading Jet" event

Subset

Refer to this as a "Back-to-Back" event

Jet #1 Direction

Δφ

"Toward"

"Transverse" "Transverse"

"Away"

Jet #1 Direction

Δφ

"Toward"

"Transverse" "Transverse"

"Away"

Jet #2 Direction

Charged Particle Density: dN/dηdφ

CDF Preliminary
data uncorrected

□ Back-to-Back
● Leading Jet
● Min-Bias

$30 < E_T(jet\#1) < 70$ GeV

"Transverse" Region

Charged Particles
($|\eta|<1.0$, PT>0.5 GeV/c)

Jet#1

Charged Particle Density

Δφ (degrees)

➡️ Look at the **"transverse" region** as defined by the leading jet (JetClu R = 0.7, $|\eta| < 2$) or by the leading two jets (JetClu R = 0.7, $|\eta| < 2$). **"Back-to-Back"** events are selected to have at least two jets with Jet#1 and Jet#2 nearly "back-to-back" ($\Delta\phi_{12} > 150°$) with almost equal transverse energies ($E_T(jet\#2)/E_T(jet\#1) > 0.8$) and with $E_T(jet\#3) < 15$ GeV.

➡️ Shows the **Δφ dependence of the charged particle density**, $dN_{chg}/d\eta d\phi$, for charged particles in the range $p_T > 0.5$ GeV/c and $|\eta| < 1$ relative to jet#1 (rotated to 270°) for 30 < $E_T(jet\#1) < 70$ GeV for **"Leading Jet"** and **"Back-to-Back"** events.

"Leading Jet"

Jet #1 Direction

Δφ

"Toward"
"Transverse" "Transverse"
"Away"

"Back-to-Back"

Jet #1 Direction

Δφ

"Toward"
"Transverse" "Transverse"
"Away"

Jet #2 Direction

"Transverse" Charged PTsum Density: dPT/dηdφ

CDF Run 2 Preliminary
data corrected to particle level
1.96 TeV

"Leading Jet"

PY Tune A

Hard Radiation!

"Back-to-Back"

HW

MidPoint R = 0.7 |η(jet#1)| < 2
Charged Particles (|η|<1.0, PT>0.5 GeV/c)

Transverse" PTsum Density (GeV/c)

PT(jet#1) (GeV/c)

Min-Bias
0.24 GeV/c per unit η-φ

➡ **Shows the average charged PTsum density, $dPT_{sum}/d\eta d\phi$, in the "transverse" region (p_T > 0.5 GeV/c, $|\eta| < 1$) versus P_T(jet#1) for "Leading Jet" and "Back-to-Back" events.**

➡ **Compares the (*corrected*) data with PYTHIA Tune A and HERWIG (without MPI) at the particle level (*i.e.* generator level).**

CDF Run 1 P$_T$(Z)
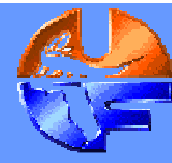
PYTHIA 6.2 CTEQ5L
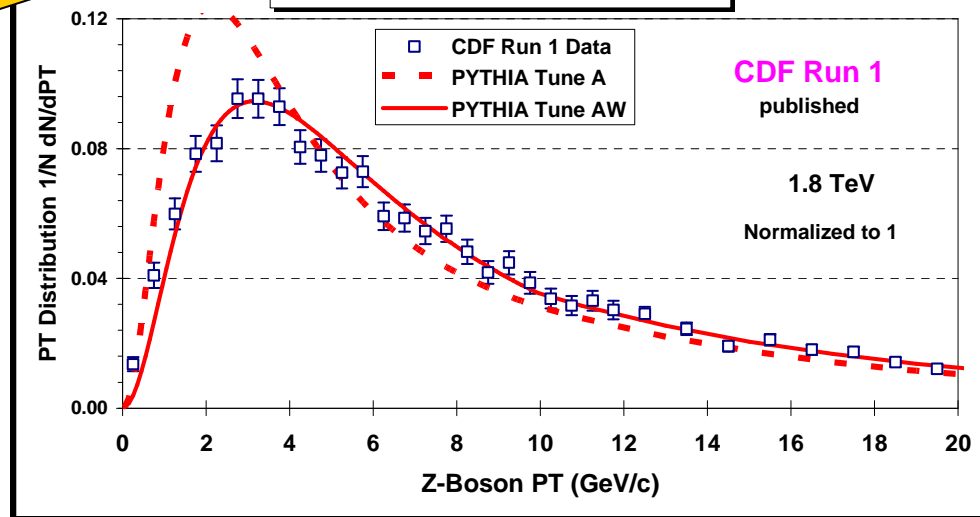
Tune used by the CDF-EWK group!

UE Parameters

ISR Parameters

Intrensic KT

Parameter	Tune A	Tune AW
MSTP(81)	1	1
MSTP(82)	4	4
PARP(82)	2.0 GeV	2.0 GeV
PARP(83)	0.5	0.5
PARP(84)	0.4	0.4
PARP(85)	0.9	0.9
PARP(86)	0.95	0.95
PARP(89)	1.8 TeV	1.8 TeV
PARP(90)	0.25	0.25
PARP(62)	1.0	1.25
PARP(64)	1.0	0.2
PARP(67)	4.0	4.0
MSTP(91)	1	1
PARP(91)	1.0	2.1
PARP(93)	5.0	15.0

Z-Boson Transverse Momentum

- □ CDF Run 1 Data
- ▪ ▪ PYTHIA Tune A
- — PYTHIA Tune AW

CDF Run 1

published

1.8 TeV

Normalized to 1

➡ **Shows the Run 1 Z-boson p$_T$ distribution ($<$p$_T$(Z)$>$ ≈ 11.5 GeV/c) compared with PYTHIA Tune A ($<$p$_T$(Z)$>$ = 9.7 GeV/c), and PYTHIA Tune AW ($<$p$_T$(Z)$>$ = 11.7 GeV/c).**

Effective Q cut-off, below which space-like showers are not evolved.

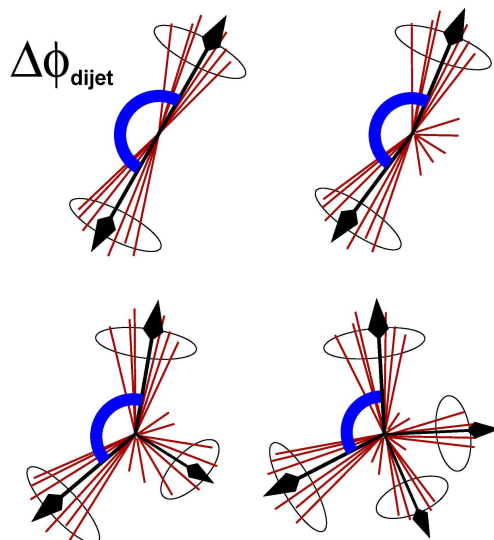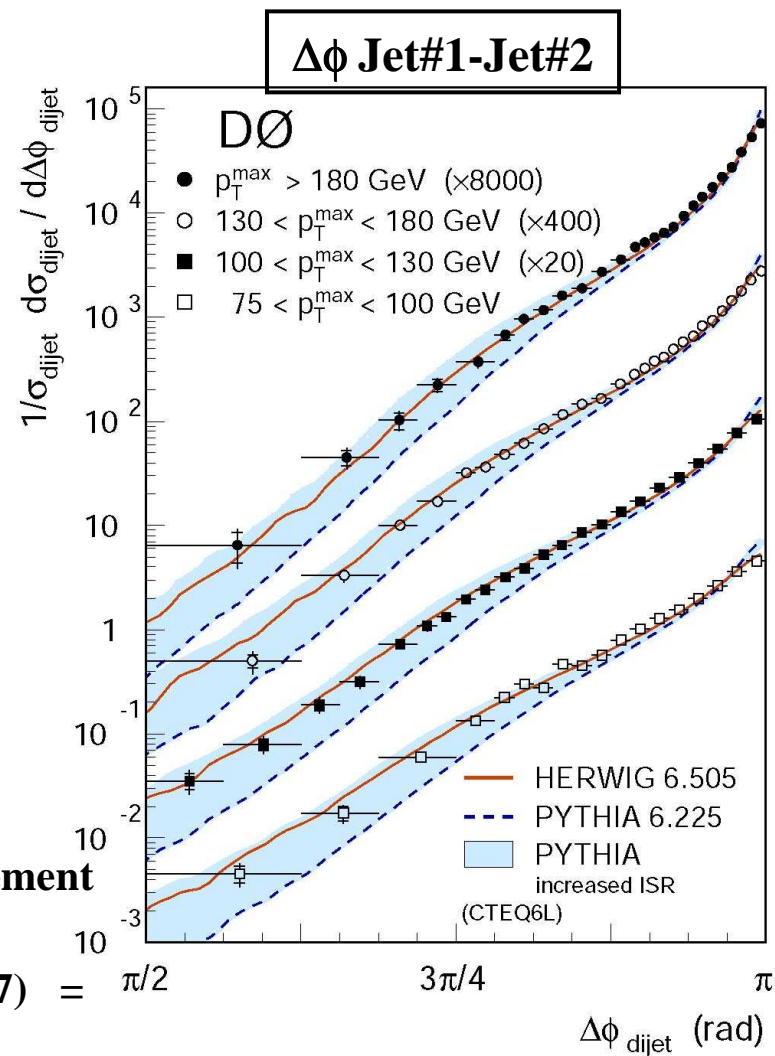**The Q^2 = k$_T^2$ in α$_s$ for space-like showers is scaled by PARP(64)!**

Jet#1-Jet#2 Δφ Distribution

$\Delta\phi_{dijet}$

$\boxed{\Delta\phi \text{ Jet\#1-Jet\#2}}$

$1/\sigma_{dijet} \; d\sigma_{dijet} / d\Delta\phi_{dijet}$

DØ
- ● $p_T^{max} > 180$ GeV $(\times 8000)$
- ○ $130 < p_T^{max} < 180$ GeV $(\times 400)$
- ■ $100 < p_T^{max} < 130$ GeV $(\times 20)$
- □ $75 < p_T^{max} < 100$ GeV

HERWIG 6.505
PYTHIA 6.225
PYTHIA increased ISR
(CTEQ6L)

$\pi/2 \qquad 3\pi/4 \qquad \pi$

$\Delta\phi_{dijet}$ (rad)

➡ **MidPoint Cone Algorithm (R = 0.7, f$_{merge}$ = 0.5)**

➡ **$\mathcal{L}$ = 150 pb^{-1} (Phys. Rev. Lett. 94 221801 (2005))**

➡ **Data/NLO agreement good. Data/HERWIG agreement good.**

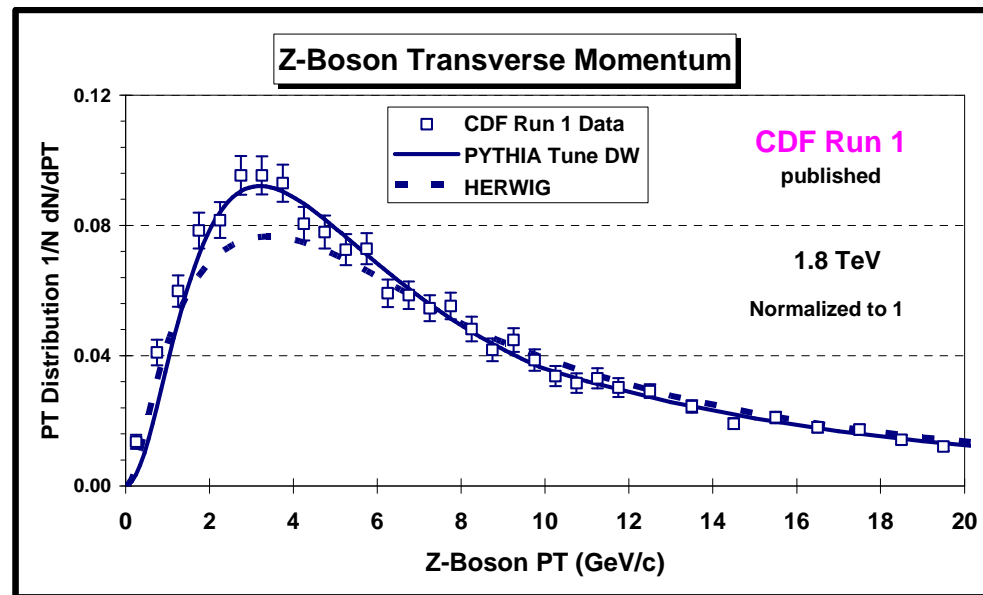➡ **Data/PYTHIA agreement good provided PARP(67) = 1.0→4.0 (i.e. like Tune A, best fit 2.5).**

PYTHIA 6.2 CTEQ5L

UE Parameters

ISR Parameters

Intrensic KT

Parameter	Tune DW	Tune AW
MSTP(81)	1	1
MSTP(82)	4	4
PARP(82)	1.9 GeV	2.0 GeV
PARP(83)	0.5	0.5
PARP(84)	0.4	0.4
PARP(85)	1.0	0.9
PARP(86)	1.0	0.95
PARP(89)	1.8 TeV	1.8 TeV
PARP(90)	0.25	0.25
PARP(62)	1.25	1.25
PARP(64)	0.2	0.2
PARP(67)	2.5	4.0
MSTP(91)	1	1
PARP(91)	2.1	2.1
PARP(93)	15.0	5.0

Z-Boson Transverse Momentum

□ CDF Run 1 Data
— PYTHIA Tune DW
- - - HERWIG

CDF Run 1
published

1.8 TeV

Normalized to 1

PT Distribution 1/N dN/dPT

Z-Boson PT (GeV/c)

➡ **Shows the Run 1 Z-boson p_T distribution ($<p_T(Z)>$ ≈ 11.5 GeV/c) compared with PYTHIA Tune DW, and HERWIG.**

Tune DW uses D0's perfered value of PARP(67)!

Tune DW has a lower value of PARP(67) and slightly more MPI!

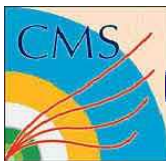# PYTHIA 6.2 Tunes

All use LO α_s with Λ = 192 MeV!

UE Parameters

ISR Parameter

Intrinsic KT

Uses CTEQ6L

Tune A energy dependence!

Parameter	Tune AW	Tune DW	Tune D6
PDF	CTEQ5L	CTEQ5L	CTEQ6L
MSTP(81)	1	1	1
MSTP(82)	4	4	4
PARP(82)	2.0 GeV	1.9 GeV	1.8 GeV
PARP(83)	0.5	0.5	0.5
PARP(84)	0.4	0.4	0.4
PARP(85)	0.9	1.0	1.0
PARP(86)	0.95	1.0	1.0
PARP(89)	1.8 TeV	1.8 TeV	1.8 TeV
PARP(90)	0.25	0.25	0.25
PARP(62)	1.25	1.25	1.25
PARP(64)	0.2	0.2	0.2
PARP(67)	4.0	2.5	2.5
MSTP(91)	1	1	1
PARP(91)	2.1	2.1	2.1
PARP(93)	15.0	15.0	15.0

All use LO α_s with Λ = 192 MeV!

UE Parameters

ISR Parameter

Intrinsic KT

ATLAS energy dependence!

Parameter	Tune DWT	Tune D6T	ATLAS
PDF	CTEQ5L	CTEQ6L	CTEQ5L
MSTP(81)	1	1	1
MSTP(82)	4	4	4
PARP(82)	1.9409 GeV	1.8387 GeV	1.8 GeV
PARP(83)	0.5	0.5	0.5
PARP(84)	0.4	0.4	0.5
PARP(85)	1.0	1.0	0.33
PARP(86)	1.0	1.0	0.66
PARP(89)	1.96 TeV	1.96 TeV	1.0 TeV
PARP(90)	0.16	0.16	0.16
PARP(62)	1.25	1.25	1.0
PARP(64)	0.2	0.2	1.0
PARP(67)	2.5	2.5	1.0
MSTP(91)	1	1	1
PARP(91)	2.1	2.1	1.0
PARP(93)	15.0	15.0	5.0

All use LO α$_s$ with Λ = 192 MeV!

UE Parameters

Parameter	Tune DWT	Tune D6T	
PDF	CT	CTEQ6L	L
MSTP(81)		1	
		4	

Tune A

These are "old" PYTHIA 6.2 tunes!
There are new 6.420 tunes by
Peter Skands (Tune S320, update of S0)
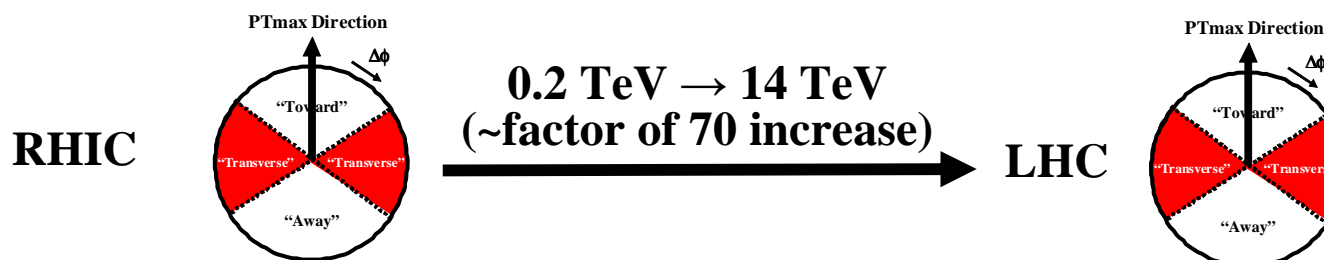**Peter Skands (Tune N324, N0CR)**
Hendrik Hoeth (Tune P329, "Professor")

PARP

MSTP

PAR 2.

PA 15.0

Tune D

e D6

Tune D6T
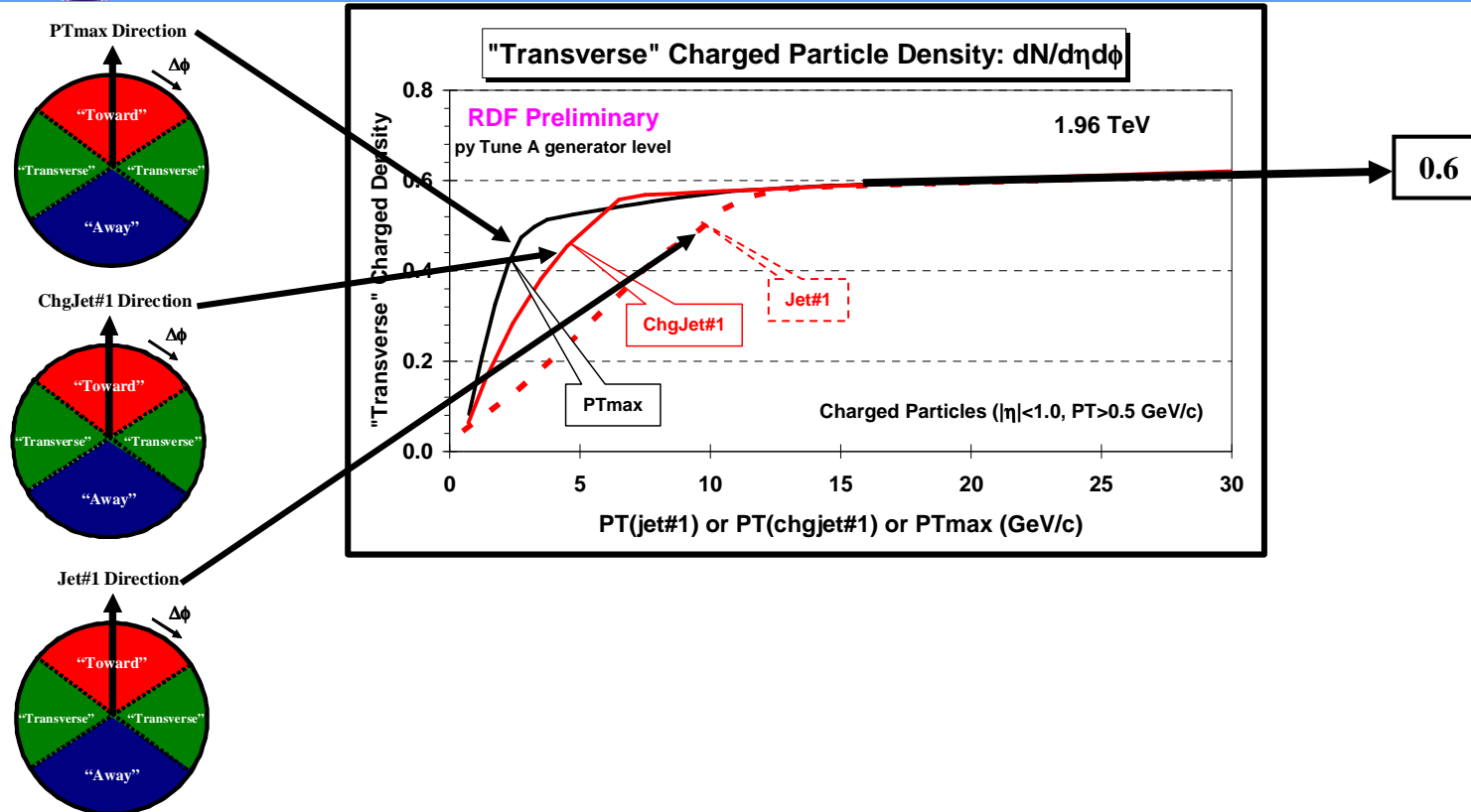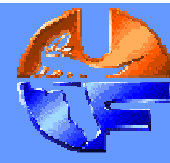
➡️ **Shows the charged particle density in the "transverse" region for charged particles ($p_T > 0.5$ GeV/c, $|\eta| < 1$) at 1.96 TeV as defined by PTmax, PT(chgjet#1), and PT(jet#1) from PYTHIA Tune A at the particle level (*i.e.* generator level).**
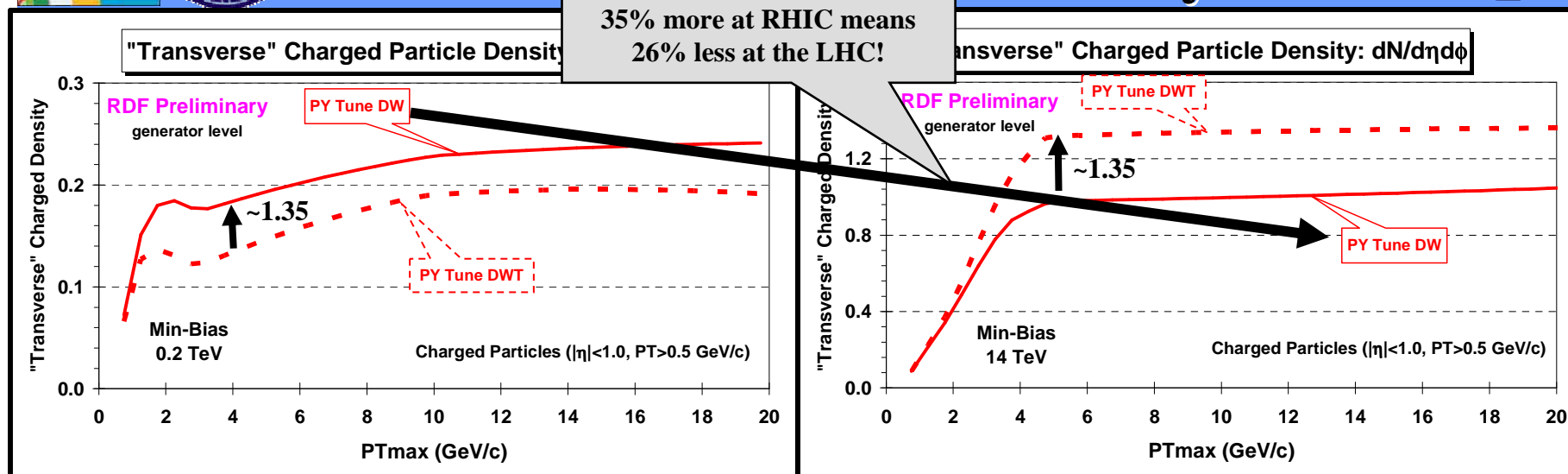
35% more at RHIC means
26% less at the LHC!

"Transverse" Charged Particle Density: dN/dηdφ

Left plot:
- y-axis: "Transverse" Charged Density (0.0 to 0.3)
- x-axis: PTmax (GeV/c) (0 to 20)
- RDF Preliminary generator level
- PY Tune DW
- PY Tune DWT
- ~1.35
- Min-Bias 0.2 TeV
- Charged Particles (|η|<1.0, PT>0.5 GeV/c)

Right plot:
- y-axis: "Transverse" Charged Density (0.0 to 1.2+)
- x-axis: PTmax (GeV/c) (0 to 20)
- RDF Preliminary generator level
- PY Tune DWT
- PY Tune DW
- ~1.35
- Min-Bias 14 TeV
- Charged Particles (|η|<1.0, PT>0.5 GeV/c)

RHIC

PTmax Direction
Δφ
"Toward"
"Transverse" "Transverse"
"Away"

0.2 TeV → 14 TeV
(~factor of 70 increase)

LHC

PTmax Direction
Δφ
"Toward"
"Transverse" "Transverse"
"Away"

➡ **Shows the "associated" charged particle density in the "transverse" regions as a function of PTmax for charged particles (p_T > 0.5 GeV/c, $|\eta|$ < 1, *not including PTmax*) for "min-bias" events at 0.2 TeV and 14 TeV from PYTHIA Tune DW and Tune DWT at the particle level (*i.e.* generator level). The STAR data from RHIC favors Tune DW!**

Min-Bias "Associated" Charged Particle Density
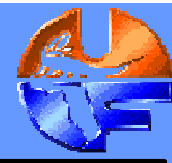
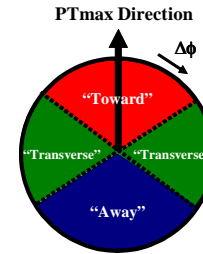**About a factor of 2 increase in the "transverse" region!**

Associated Charged Particle Density

Charged Particle Density: dN/dηdφ

RDF Preliminary
py Tune DW generator level

Min-Bias 1.96 TeV

"Toward"

"Away"

"Transverse"

Charged Particles (|η|<1.0, PT>0.5 GeV/c)

RDF Preliminary
DW generator level

Min-Bias 14 TeV

"Toward"

"Away"

"Transverse"

Charged Particles (|η|<1.0, PT>0.5 GeV/c)
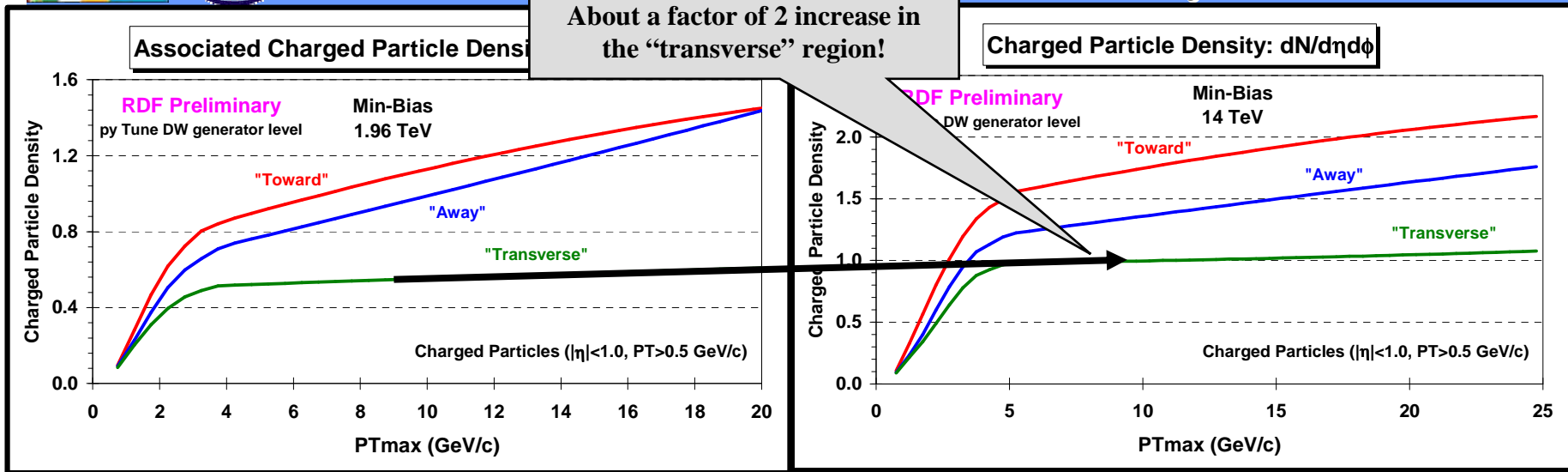
Tevatron
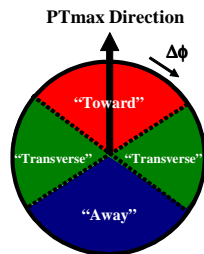
1.96 TeV → 14 TeV (~factor of 7 increase)

LHC

➡ **Shows the "associated" charged particle density in the "toward", "away" and "transverse" regions as a function of PTmax for charged particles ($p_T > 0.5$ GeV/c, $|η| < 1$, *not including PTmax*) for "min-bias" events at 1.96 TeV and at 14 TeV from PYTHIA Tune DW at the particle level (*i.e.* generator level).**

About a factor of 2.7 increase in the "transverse" region!

Associated Charged Particle Density: dN/dηdφ

Associated Charged Particle Density: dN/dηdφ

RDF Preliminary
py Tune DW generator level
Min-Bias
1.96 TeV

"Toward"

"Away"

"Transverse"

Charged Particles (|η|<1.0, PT>0.5 GeV/c)

RDF Preliminary
py Tune DW generator level
Min-Bias
0.2 TeV

"Away"

"Toward"

"Transverse"

Charged Particles (|η|<1.0, PT>0.5 GeV/c)

PTmax (GeV/c)

PTmax (GeV/c)
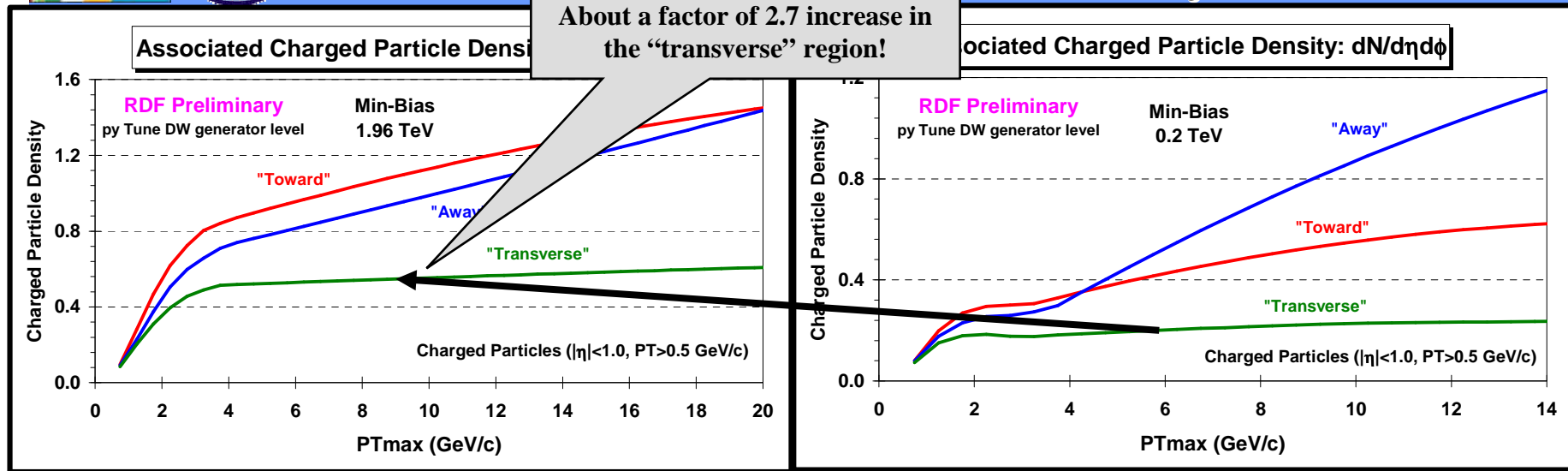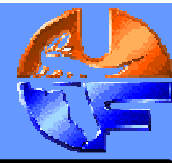
Tevatron
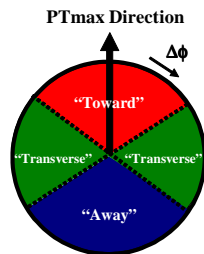
1.96 TeV ← 0.2 TeV
(~factor of 10 increase)

RHIC
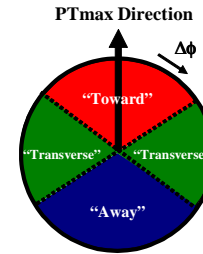
➡ Shows the "associated" charged particle density in the "toward", "away" and "transverse" regions as a function of PTmax for charged particles (p_T > 0.5 GeV/c, $|\eta|$ < 1, *not including PTmax*) for "min-bias" events at 1.96 TeV and at 0.2 TeV from PYTHIA Tune DW at the particle level (*i.e.* generator level).

"Transverse" Charged Particle Density: dN/dηdφ
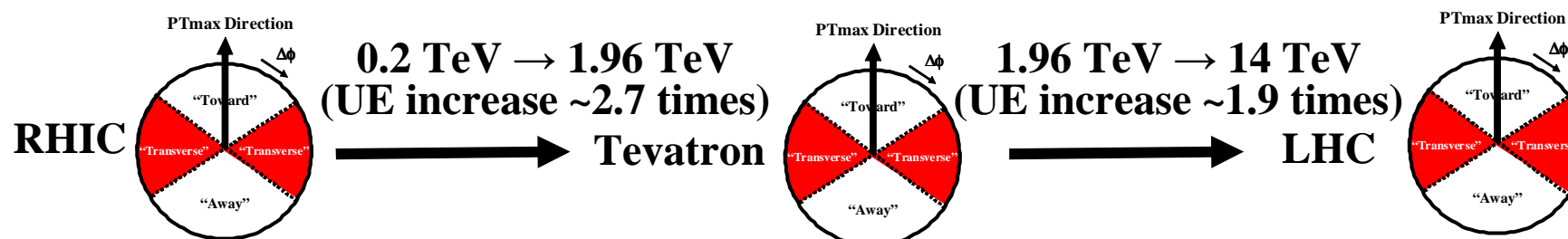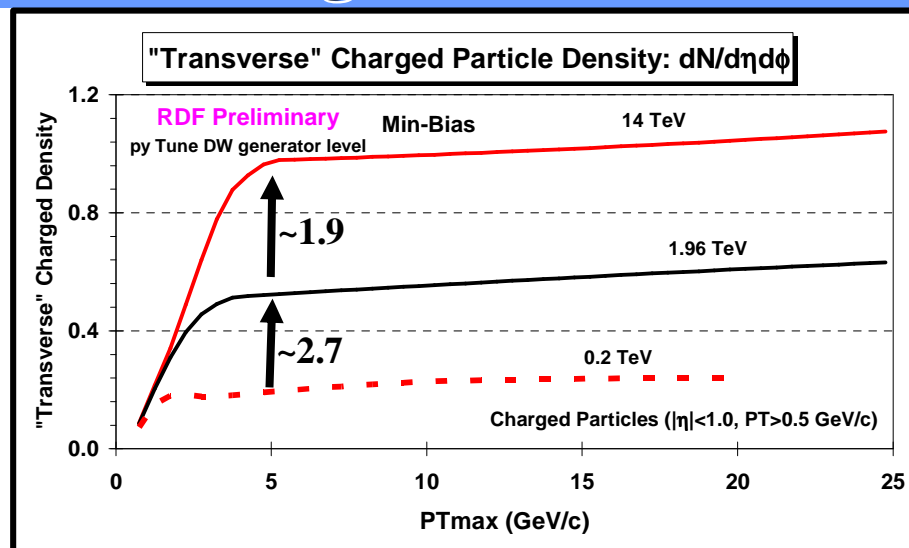
➡ Shows the "associated" charged particle density in the **"transverse"** region as a function of PTmax for charged particles ($p_T > 0.5$ GeV/c, $|\eta| < 1$, *not including PTmax*) for "min-bias" events at 0.2 TeV, 1.96 TeV and 14 TeV predicted by PYTHIA **Tune DW** at the particle level (*i.e.* generator level).

1ˢᵗ Workshop on Energy Scaling in Hadron-Hadron Collisions

1st Joint Workshop on
Energy Scaling of Hadron Collisions:
Theory / RHIC / Tevatron / LHC

APRIL 27-29, 2009, FERMILAB

Welcome & Exhortation

Peter Skands (Fermilab)

Peter Skands!

1st Joint Workshop on Energy Scaling of Hadron Collisions

27-29 April 2009   Fermilab

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Monday, 27 April 2009

| 08:00 09:00 | [0] **Welcome & Exhortation** by Peter SKANDS (Fermilab) (09:15 - 10:00) | slides |
10:00	[1] **Rick's view of hadron collisions** by Rick FIELD (U Florida) (10:00 - 10:45)	slides
	break (10:45 - 11:15)	
11:00	[2] **RHIC's view of hadron collisions** by Renee FATEMI (U Kentucky) (11:15 - 12:00)	slides
12:00 13:00	*** Lunch *** (12:00 - 13:30)	
	...eory models of hadron collisions by Peter SKANDS (Fermilab) (13:30 - 14:15)	slides
14:00	..3] **The Art and Science of Tuning** by Hendrik HOETH (Lund U) (14:15 - 15:00)	slides

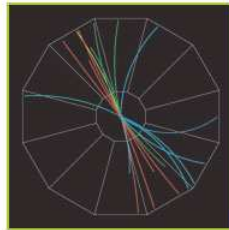**Renee Fatemi gave a talk on the "underlying event at STAR!**

"On the Boarder" restaurant, Aurora, IL
April 27, 2009
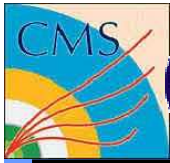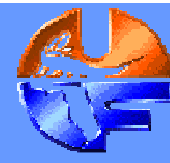
RHIC's View of Hadron Collisions

P-P Collisions at RHIC
STAR Detector and Triggers
Hard Scattering at RHIC kinematics
The STAR Jet-Finders
Underlying Event at STAR

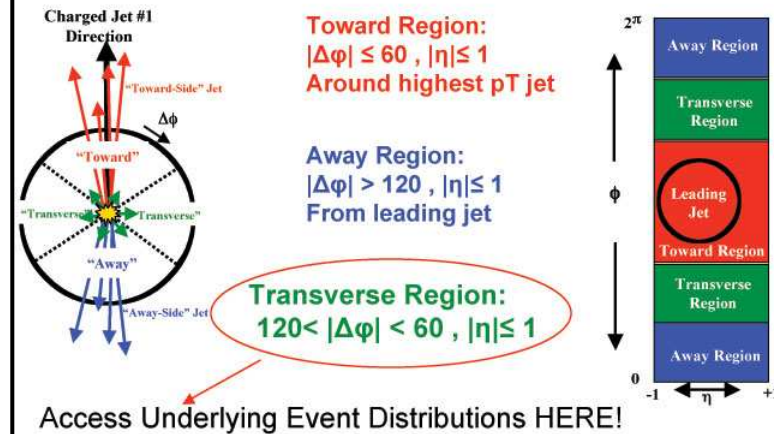*Renee Fatemi*
For the STAR Collaboration

UK

1st Joint Workshop on Energy Scaling of Hadron Collisions
April 27, 2009

STAR

How can we measure the UE?
Lets do what RICK did!

1st look at Back-to-Back Di-Jet Events in which the jet energies are relatively close so as to minimize radiation in transverse region.

Charged Jet #1 Direction

"Toward-Side" Jet
$\Delta\phi$
"Toward"
"Transverse"   "Transverse"
"Away"
"Away-Side" Jet

Toward Region:
$|\Delta\varphi| \leq 60$, $|\eta| \leq 1$
Around highest pT jet

Away Region:
$|\Delta\varphi| > 120$, $|\eta| \leq 1$
From leading jet

Transverse Region:
$120 < |\Delta\varphi| < 60$, $|\eta| \leq 1$

Access Underlying Event Distributions HERE!

2π
Away Region
Transverse Region
Leading Jet
Toward Region
Transverse Region
Away Region
ϕ
0
-1 η +1

➡ **At STAR they have measured the "underlying event at W = 200 GeV ($|\eta| < 1$, $p_T > 0.2$ GeV) and compared their uncorrected data with PYTHIA Tune A + STAR-SIM.**
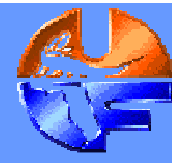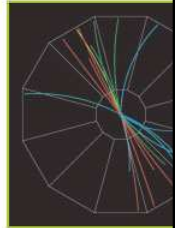
RHIC

Conclusions

I. Hadron Collisions at RHIC take place at an order of magnitude smaller $\sqrt{s}$ than the Tevatron. Nevertheless, jets are observed and reconstructed down to pT=5 GeV and are well described by pQCD

II. Comparisons between several jetfinders reveal consistent results

III. Interest in the Underlying Event at RHIC Kinematics is driven by the need for jet energy scale corrections as well as pure physics interests (see talks by M. Lisa and H. Caines)

IV. UE at RHIC appears to be independent of jet pT and decoupled from hard interaction

V. CDF Tune A provides an excellent description of the UE at $\sqrt{s}$ =200 GeV (thanks Rick!)

VI. Underlying Event distributions in general smaller than those at CDF. Tower & Track Multiplicities are the exception, but this may be due to the 0.2 (STAR) versus 0.5 GeV (CDF) pT/Et cut-off.

VII. For a cone jet with R=0.7 UE contributes 0.5-0.9 GeV.

VIII. Comparison of Leading Jet and Back-to-Back distributions indicate that large angle radiation contributions are small at RHIC energies.

➡ **At STAR** ... 2 GeV) **and comp**...

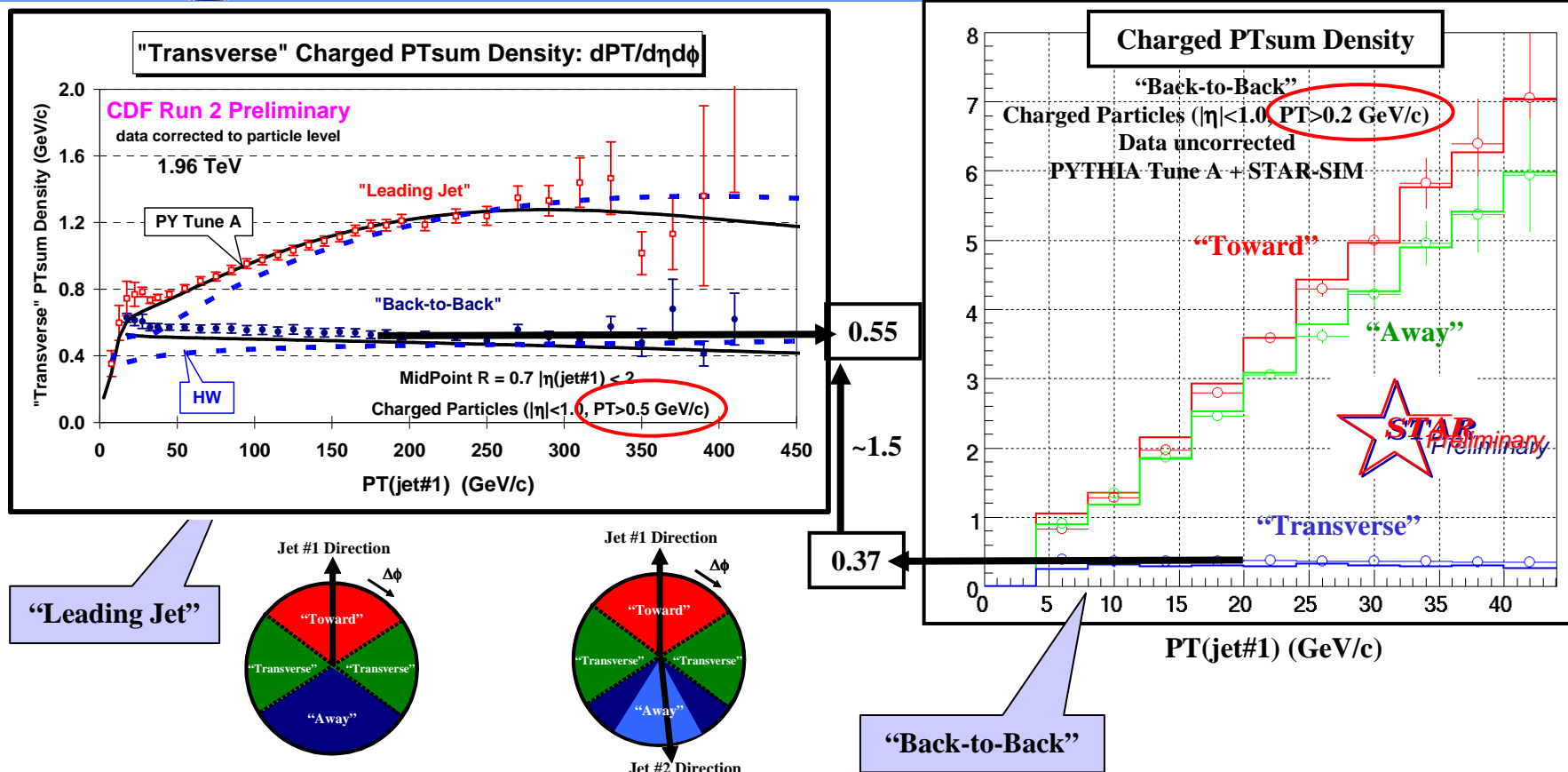➡️ **Data on the charged particle *scalar* p_T sum density, dPT/dηdϕ, as a function of the leading jet p_T for the "toward", "away", and "transverse" regions compared with PYTHIA Tune A.**

"Transverse" Charged PTsum Density: dPT/dηdφ

CDF Run 2 Preliminary
data corrected to particle level
1.96 TeV

"Leading Jet"

PY Tune A

"Back-to-Back"

MidPoint R = 0.7 |η(jet#1) < 2
Charged Particles (|η|<1.0, PT>0.5 GeV/c)

HW

"Transverse" PTsum Density (GeV/c)

PT(jet#1) (GeV/c)

Charged PTsum Density

"Back-to-Back"
Charged Particles (|η|<1.0, PT>0.2 GeV/c)
Data uncorrected
PYTHIA Tune A + STAR-SIM

"Toward"

"Away"

STAR Preliminary

"Transverse"

PT(jet#1) (GeV/c)

"Leading Jet"

Jet #1 Direction
Δφ
"Toward"
"Transverse"   "Transverse"
"Away"

Jet #1 Direction
Δφ
"Toward"
"Transverse"   "Transverse"
"Away"
Jet #2 Direction

"Back-to-Back"

0.55

~1.5

0.37
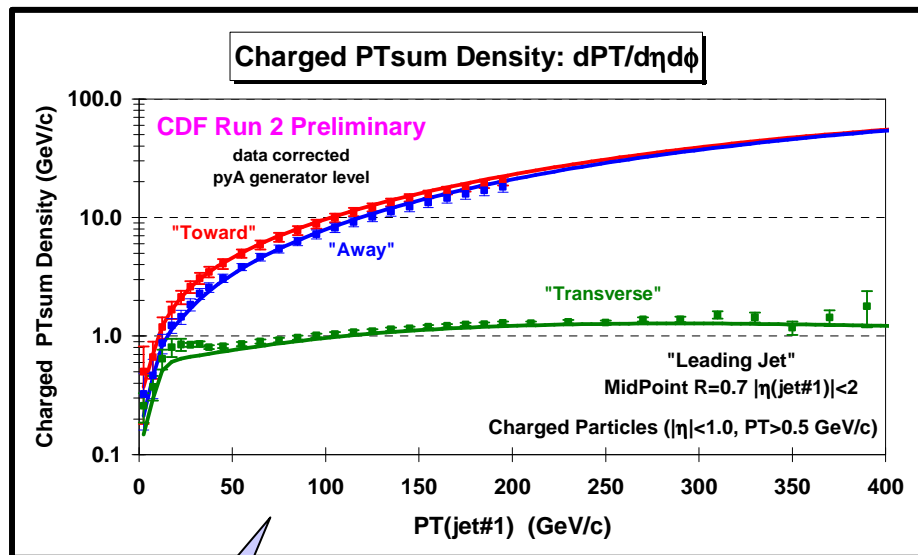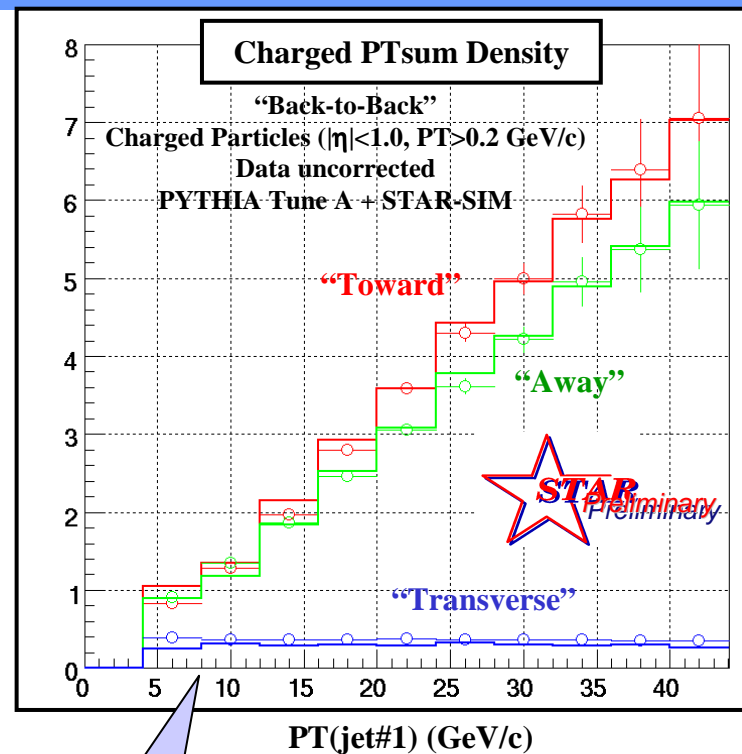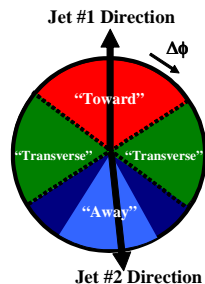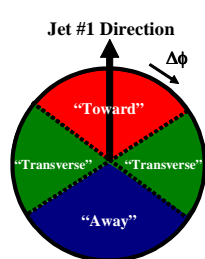
➡ **Data on the charged particle *scalar* p_T sum density, dPT/dηdφ, as a function of the leading jet p_T for the "toward", "away", and "transverse" regions compared with PYTHIA Tune A.**
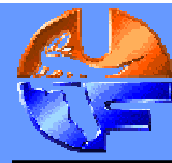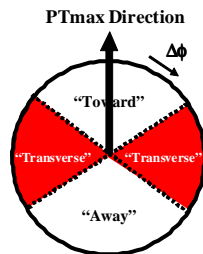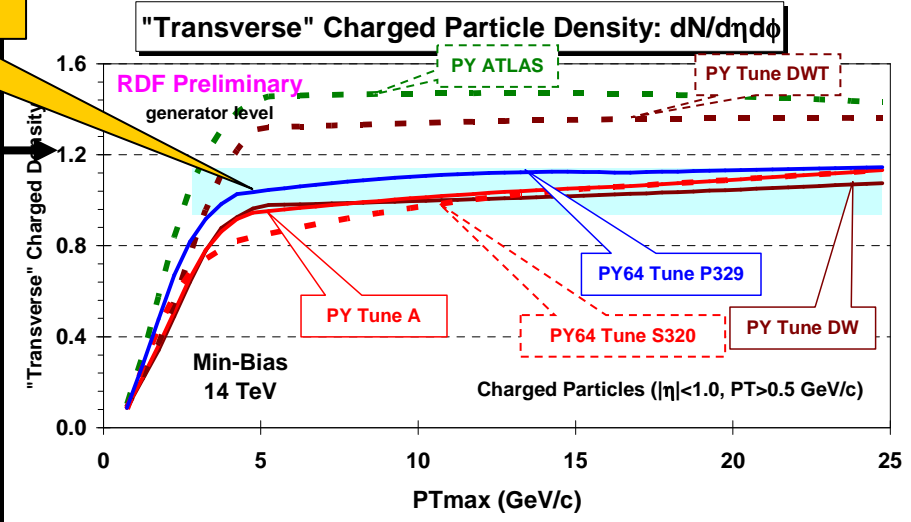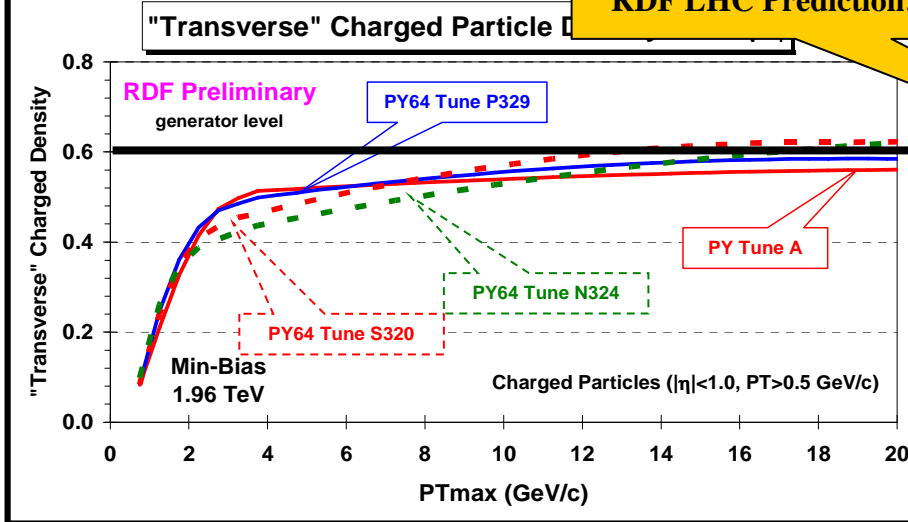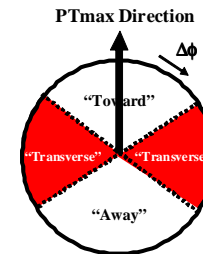
Min-Bias "Associated" Charged Particle Density

RDF LHC Prediction!

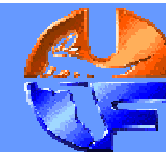➡ **Shows the "associated" charged particle density in the "transverse" region as a function of PTmax for charged particles ($p_T > 0.5$ GeV/c, $|\eta| < 1$, *not including PTmax*) for "min-bias" events at 1.96 TeV from PYTHIA Tune A, Tune S320, Tune N324, and Tune P329 at the particle level (*i.e.* generator level).**

➡ **Extrapolations of PYTHIA Tune A, Tune DW, Tune DWT, Tune S320, Tune P329, and pyATLAS to the LHC.**
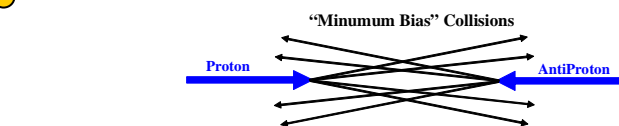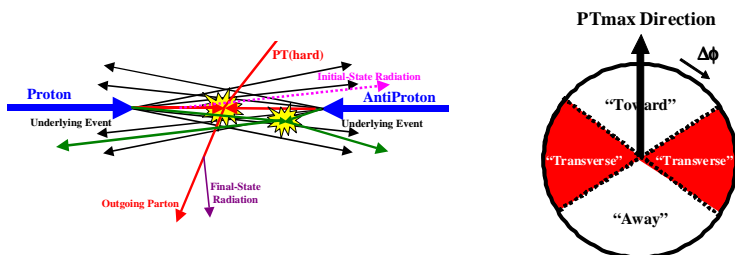
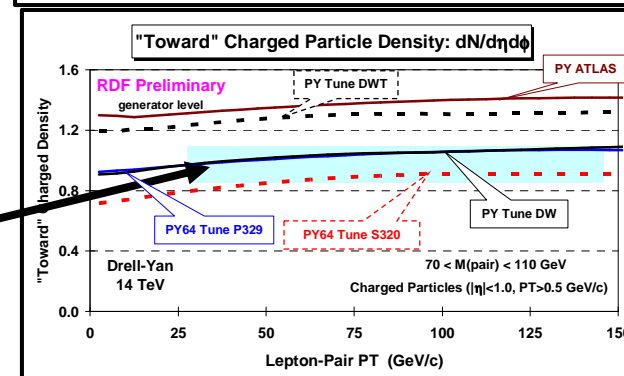I believe because of the **STAR** analysis we are now in a position to make some predictions at the LHC!

"Minumum Bias" Collisions

Proton → ← AntiProton

➡️ **The amount of activity in "min-bias" collisions.**

PTmax Direction

Δφ

"Toward"

"Transverse" "Transverse"

"Away"

PT(hard)
Initial-State Radiation
Proton → Underlying Event ← AntiProton Underlying Event
Outgoing Parton
Final-State Radiation

➡️ **The amount of activity in the "underlying event" in hard scattering events.**

Z-Boson Direction

Δφ

"Toward"

"Transverse" "Transverse"

"Away"

Drell-Yan Production
Lepton
Proton → Underlying Event ← AntiProton Underlying Event
Anti-Lepton

➡️ **The amount of activity in the "underlying event" in Drell-Yan events.**

Charged Particle Density: dN/dη

RDF Preliminary
generator level

PY64 Tune P329
PY64 Tune S320
PY Tune A

Charged Particles (PT>0.5 GeV/c)
Min-Bias 14 TeV

Charged Particle Density (y-axis: 0.0 – 4.0)
PseudoRapidity η (x-axis: -8 to 8)

"Transverse" Charged Particle Density: dN/dηdφ

RDF Preliminary
generator level

PY ATLAS
PY Tune DWT
PY Tune A
PY64 Tune P329
PY64 Tune S320
PY Tune DW

Min-Bias 14 TeV
Charged Particles (|η|<1.0, PT>0.5 GeV/c)

"Transverse" Charged Density (y-axis: 0.0 – 1.6)
PTmax (GeV/c) (x-axis: 0 to 25)

"Toward" Charged Particle Density: dN/dηdφ

RDF Preliminary
generator level

PY Tune DWT
PY ATLAS
PY64 Tune P329
PY64 Tune S320
PY Tune DW

Drell-Yan 14 TeV
70 < M(pair) < 110 GeV
Charged Particles (|η|<1.0, PT>0.5 GeV/c)

"Toward" Charged Density (y-axis: 0.0 – 1.6)
Lepton-Pair PT (GeV/c) (x-axis: 0 to 150)

I believe because of the **STAR** analysis we are now in a position to make some predictions for the LHC!

"Minimum Bias"

Proton

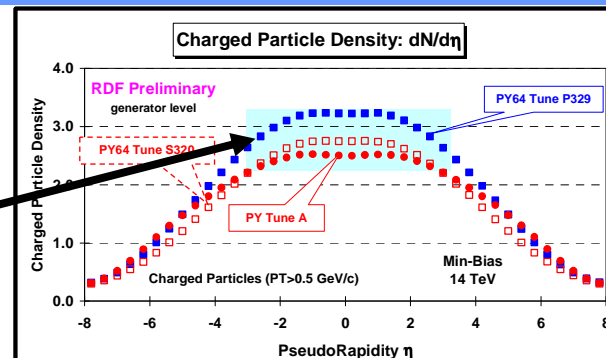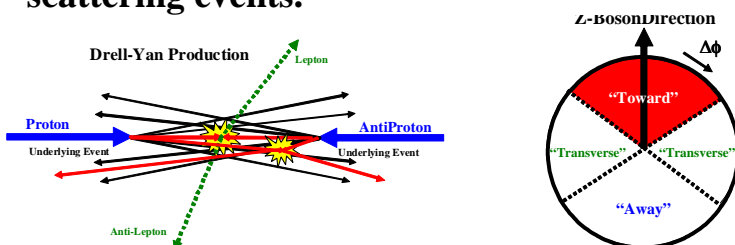➡ The amount of activity in "minimum bias"
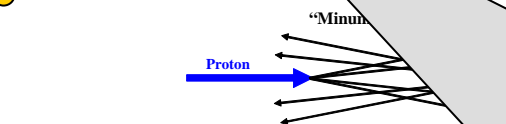
Proton

Underlying Event

Outgoing Parton

Final-State Radiation

➡ The amount of activity in "hard scattering events"

Drell-Yan Production

Lepton

Proton

Underlying Event

AntiProton

Underlying Event

Anti-Lepton

"Transverse"

"Transverse"

"Away"
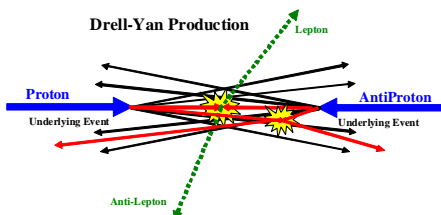
➡ The amount of activity in the "underlying event" in Drell-Yan events.

If the LHC data are not in the range shown here then we learn new physics!

Charged Particle Density: dN/dη

RDF Preliminary
generator level

PY64 Tune P329

PY64 Tune S320

PY Tune A

Charged Particles (PT>0.5 GeV/c)

Min-Bias
14 TeV

Density: dN/dηdφ

ATLAS

PY Tune DWT

PY64 Tune P329

S320

PY Tune DW

Charged Particles (|η|<1.0, PT>0.5 GeV/c)

PTmax (GeV/c)

Charged Particle Density: dN/dηdφ

RDF P
generator

PY Tune DWT

PY ATLAS

PY64 Tune P329

PY64 Tune S320

PY Tune DW

Drell-Yan
14 TeV

70 < M(pair) < 110 GeV

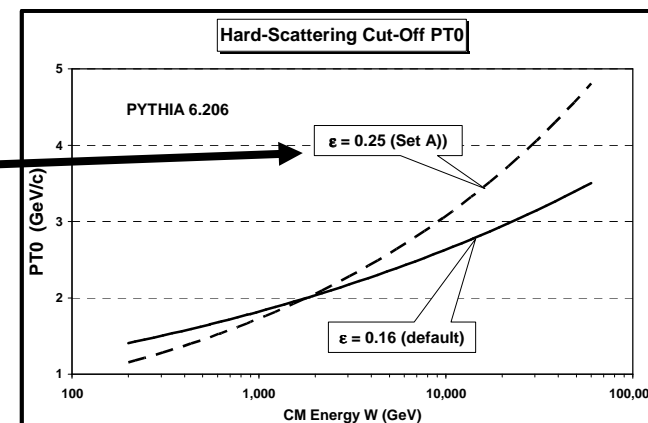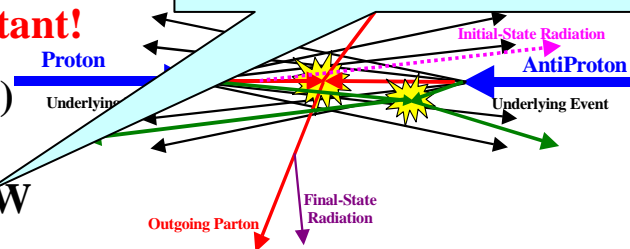Charged Particles (|η|<1.0, PT>0.5 GeV/c)

Lepton-Pair PT (GeV/c)

Summary & Conclus...

➡ **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 PARP(90) = 0.16 is not correct and the value should be closer to the Tune A value of 0.25.

➡ All tunes with the default value 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 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!**

However, I believe that the better fits to the LEP fragmentation data at high z will lead to small improvements of Tune A at the Tevatron!

Initial-State Radiation

Proton   AntiProton

Underlying Event   Underlying Event

Final-State Radiation

Outgoing Parton

Hard-Scattering Cut-Off PT0

PYTHIA 6.206

PT0 (GeV/c)

$\varepsilon = 0.25$ (Set A))

$\varepsilon = 0.16$ (default)

CM Energy W (GeV)

UE&MB@CMS