Predicting "Min-Bias" and the "Underlying Event" at the LHC

Extrapolations from the Tevatron to RHIC and the LHC

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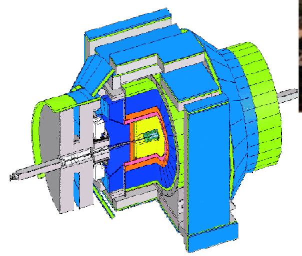
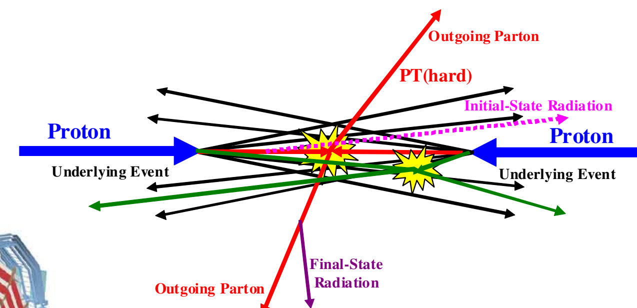
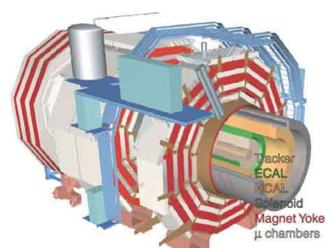
Outline of Talk

- Review of the CDF PYTHIA Tunes.
- The PYTHIA MPI energy scaling parameter PARP(90).
- The "underlying event" at STAR. Extrapolations to RHIC.
- Predicting MB from the activity in the UE. Relationship between MB and the UE.
- How precise is precise?
- Associated Density $\Delta\phi$ plots.
- QCD Monte-Carlo Models - Overall Goal.



CDF Run 2

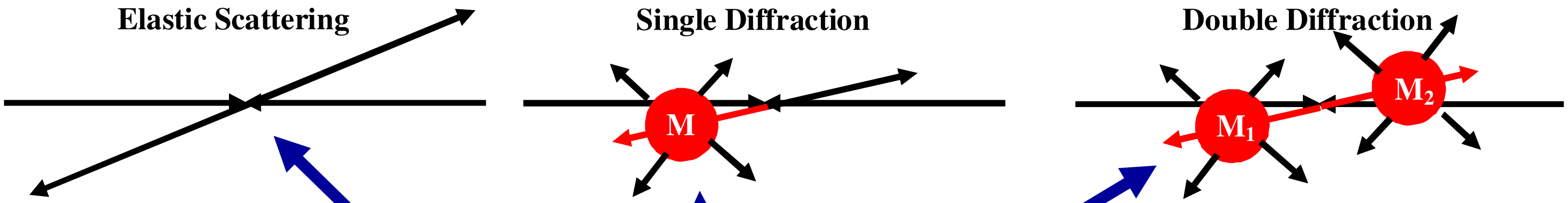




CMS at the LHC

UE&MB@CMS

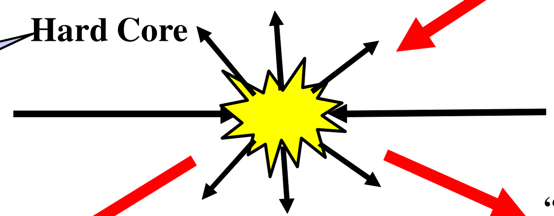
Proton-Proton Collisions

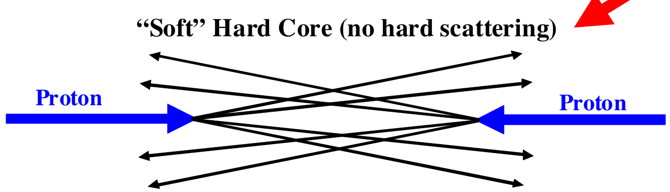


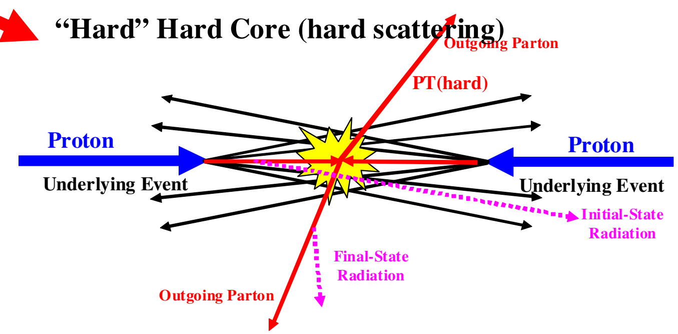
$$\sigma_{tot} = \sigma_{EL} + \sigma_{SD} + \sigma_{DD} + \sigma_{ND}$$

"Inelastic Non-Diffractive Component"

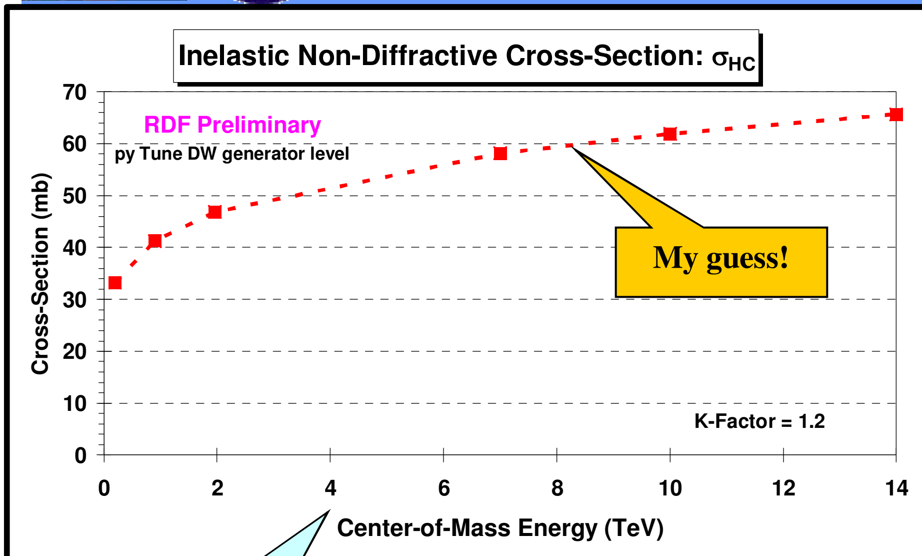
The "hard core" component contains both "hard" and "soft" collisions.



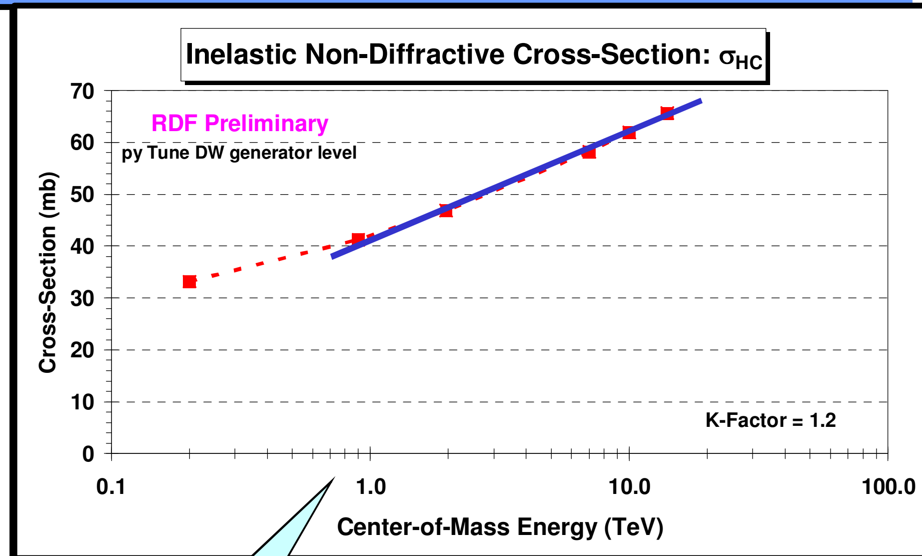




Inelastic Non-Diffractive Cross-Section



Linear scale!

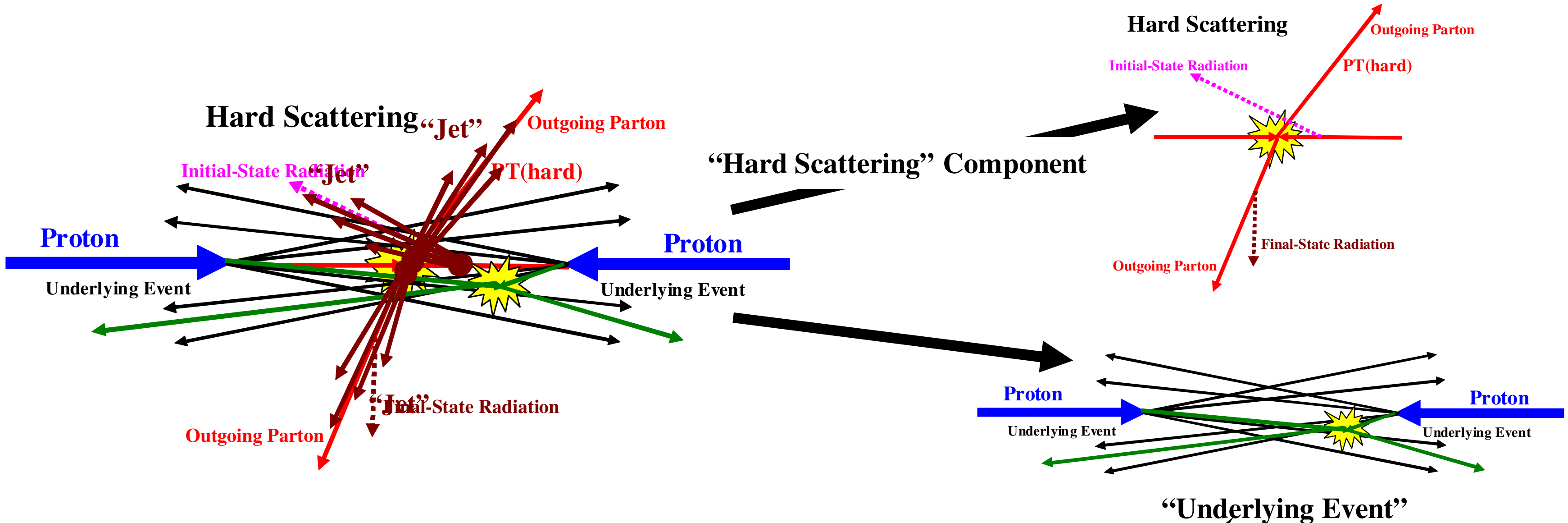


Log scale!

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

- **The inelastic non-diffractive cross section versus center-of-mass energy from PYTHIA (×1.2).**
- **σ_{HC} varies slowly. Only a 13% increase between 7 TeV (≈ 58 mb) and 14 teV (≈ 66 mb). Linear on a log scale!**

QCD Monte-Carlo Models: High Transverse Momentum Jets

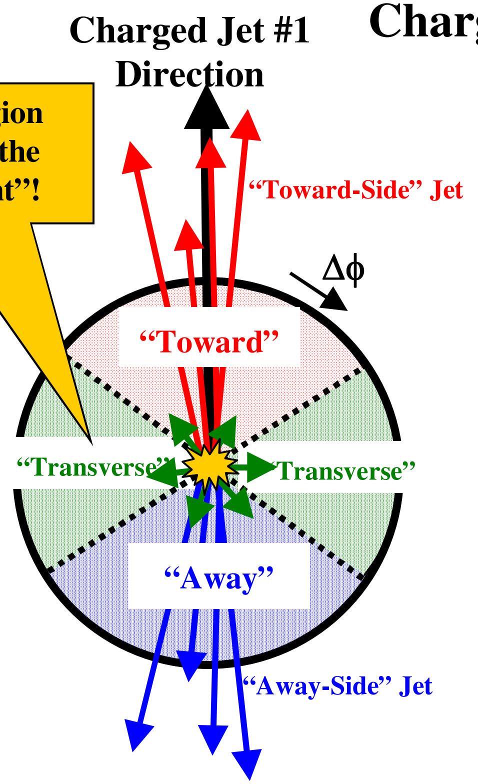


- **Start with the perturbative 2-to-2 (or sometimes 2-to-3) parton-parton scatteri g and add initial and final-state gluon radiation (in the leading log approximation or modified leadin approximation).**
- **The "underlying event" consists of the "beam-beam remnants" and articles arising from soft or semi-soft multiple parton interactions (MPI).**
- **Of course the outgoing colored parton ly "underlying event" observables receive contributions fron**

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

CDF Run 1: Evolution of Charged Jets "Underlying Event"

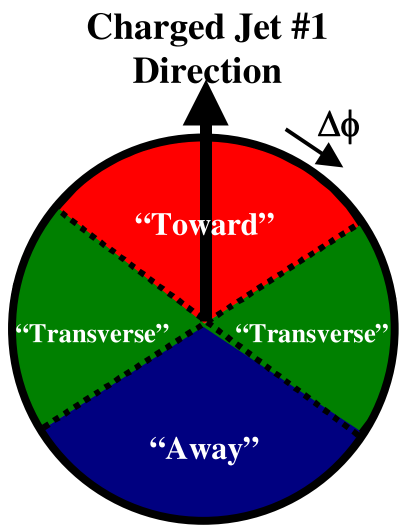
"Transverse" region very sensitive to the "underlying event"!



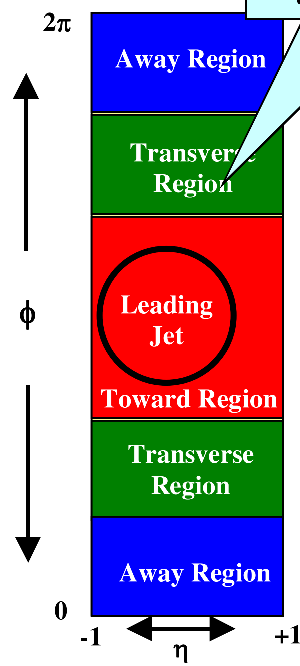
Charged Particle Δϕ Correlations

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

CDF Run 1 Analysis



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



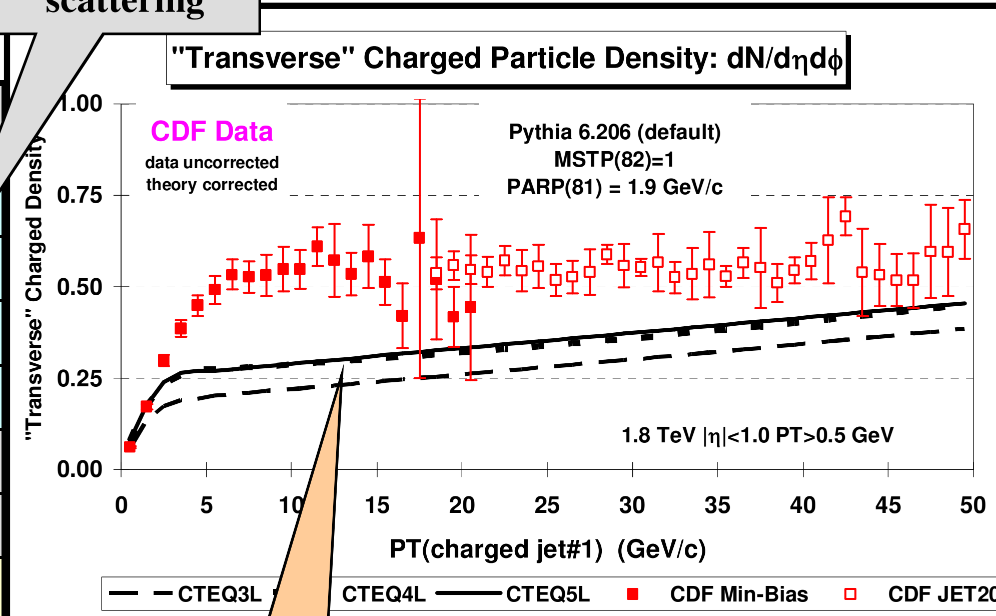
- Look at charged particle correlations in the azimuthal angle Δϕ relative to the leading charged particle jet.
- Define $|\Delta\phi| < 60^o$ as "Toward", $60^o < |\Delta\phi| < 120^o$ as "Transverse", and $|\Delta\phi| > 120^o$ as "Away".
- All three regions have the same size in η-ϕ space, $\Delta\eta x \Delta\phi = 2x120^o = 4\pi/3$.

PYTHIA 6.206 Defaults

MPI constant probability scattering

PYTHIA default parameters

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



- 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)

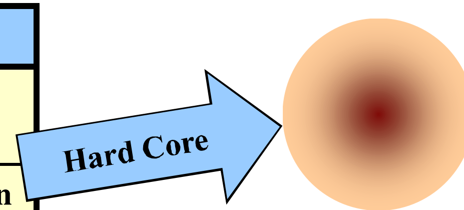
Default parameters give very poor description of the "underlying event"!

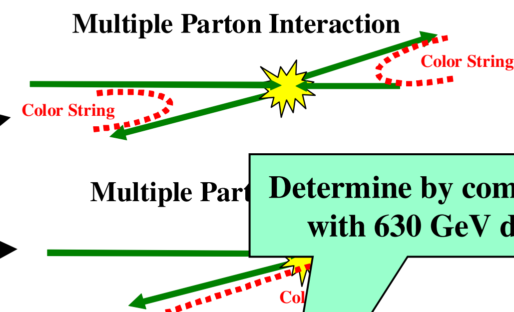
Tuning PYTHIA:
Multiple Parton Interaction Parameters

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	Pr… …uces two gluons w… …nearest neighbors.
PARP(86)	0.66	Prob… …y t… …luons ei… …s des… …closed …l loop. T… …g fraction consists of …ark-antiqua… …rs.
PARP(89)	1 Te…	Determin… …reference energy E_0.
PARP(82)	…9 GeV/c	The c… …ff P_{T0} that regulates the 2-to-2 sc… …ring divergence $1/PT^4 \rightarrow 1/(PT^2+P_{T0}^2)^2$
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 ε = 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.

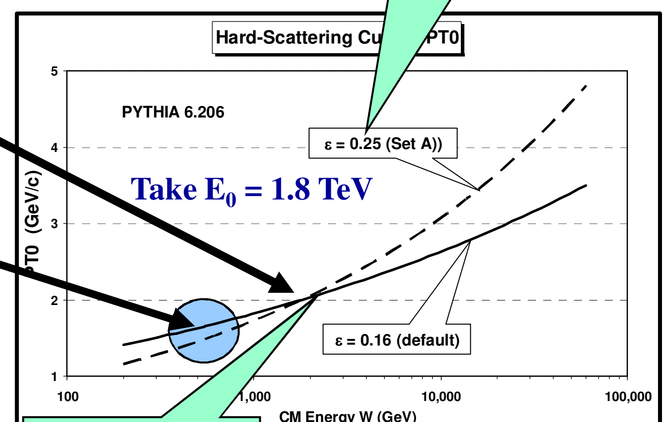
Determines the energy dependence of the MPI!

Affects the amount of initial-state radiation!



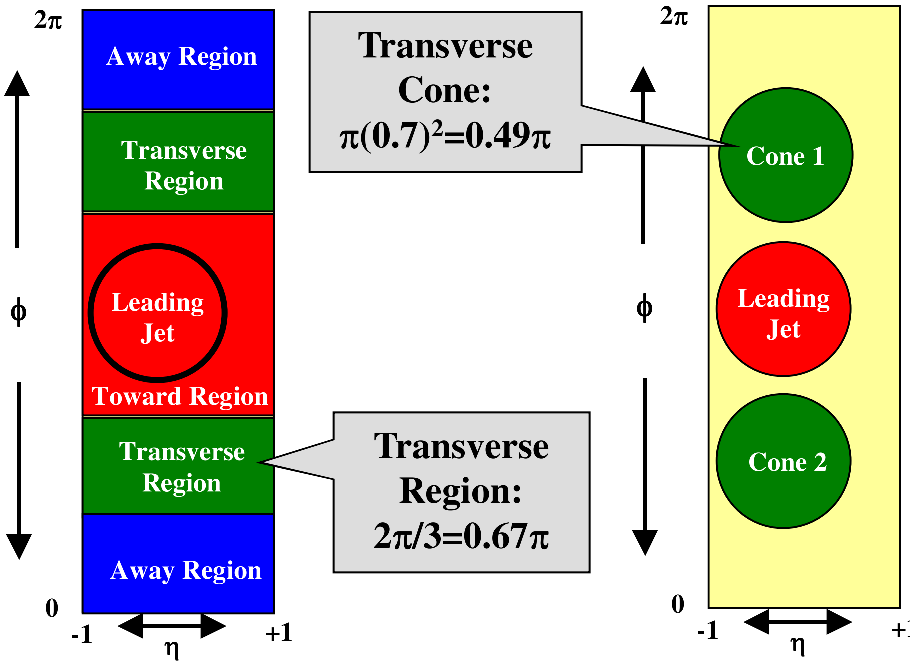


Determine by comparing with 630 GeV data!

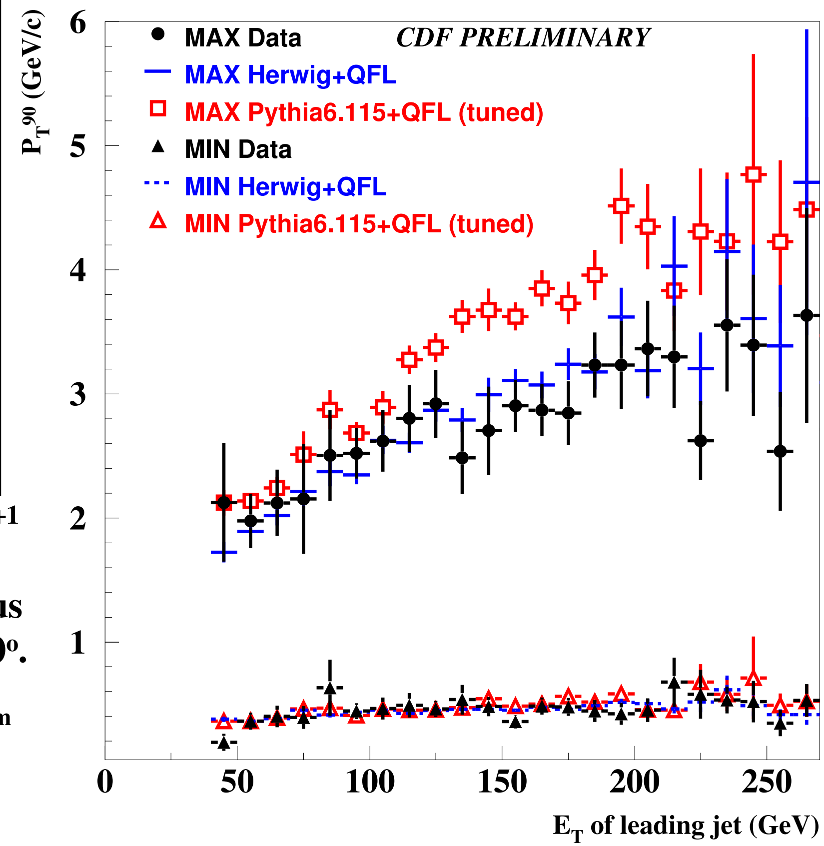


Reference point at 1.8 TeV

"Transverse" Cones vs "Transverse" Regions

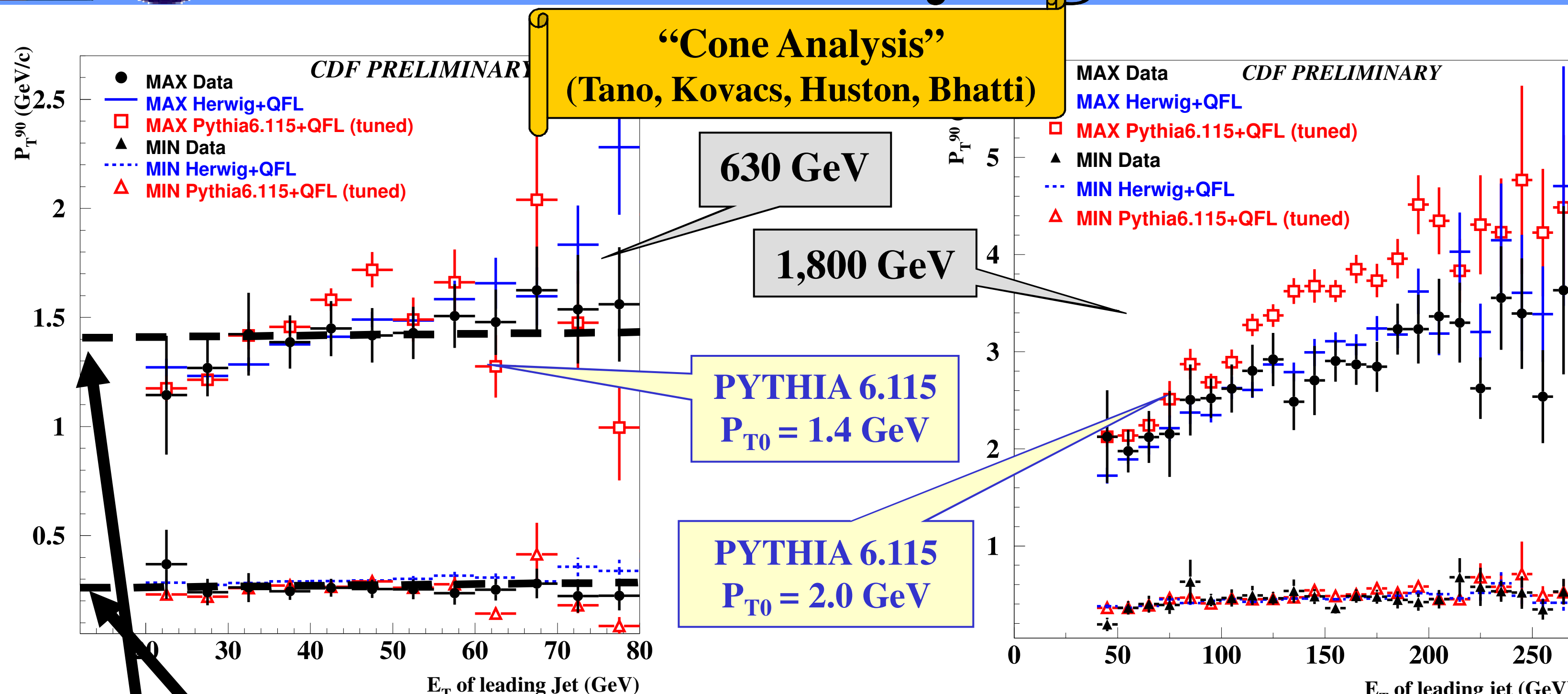


"Cone Analysis"
(Tano, Kovacs, Huston, Bhatti)



- Sum the P_T of charged particles in two cones of radius 0.7 at the same η as the leading jet but with $|\Delta\Phi| = 90^o$.
- Plot the cone with the maximum and minimum PT_{sum} versus the E_T of the leading (calorimeter) jet.

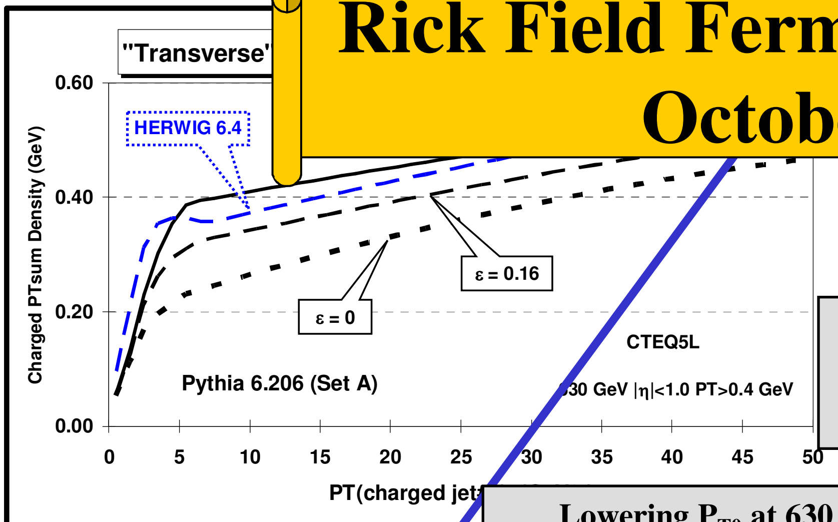
Energy Dependence of the "Underlying Event"

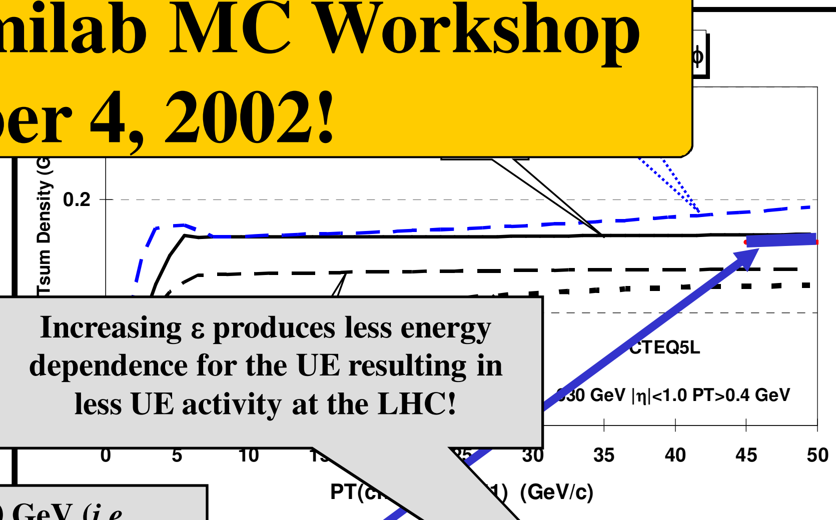


- Sum the P_T of charged particles ($p_T > 0.4$ GeV/c) in two cones of radius 0.7 at the same η as the leading jet but with $|\Delta\Phi| = 90^o$. Plot the cone with the maximum and minimum PT_{sum} versus the E_T of the leading (calorimeter) jet.
- Note that PYTHIA 6.115 is tuned at 630 GeV with $P_{T0} = 1.4$ GeV and at 1,800 GeV with $P_{T0} = 2.0$ GeV. This implies that ε = PARP(90) should be around 0.30 instead of the 0.16 (default).
- For the MIN cone 0.25 GeV/c in radius R = 0.7 implies a PT_{sum} density of $dPT_{sum}/d\eta d\phi = 0.16$ GeV/c and 1.4 GeV/c in the MAX cone implies $dPT_{sum}/d\eta d\phi = 0.91$ GeV/c (average PT_{sum} density of 0.54 GeV/c per unit η-ϕ).

"Transverse" Charged Densities Energy Dependence

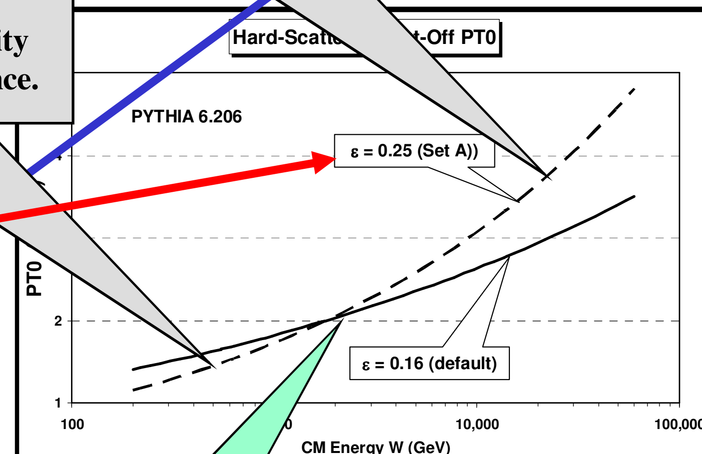
Rick Field Fermilab MC Workshop October 4, 2002!





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.



Reference point E_0 = 1.8 TeV

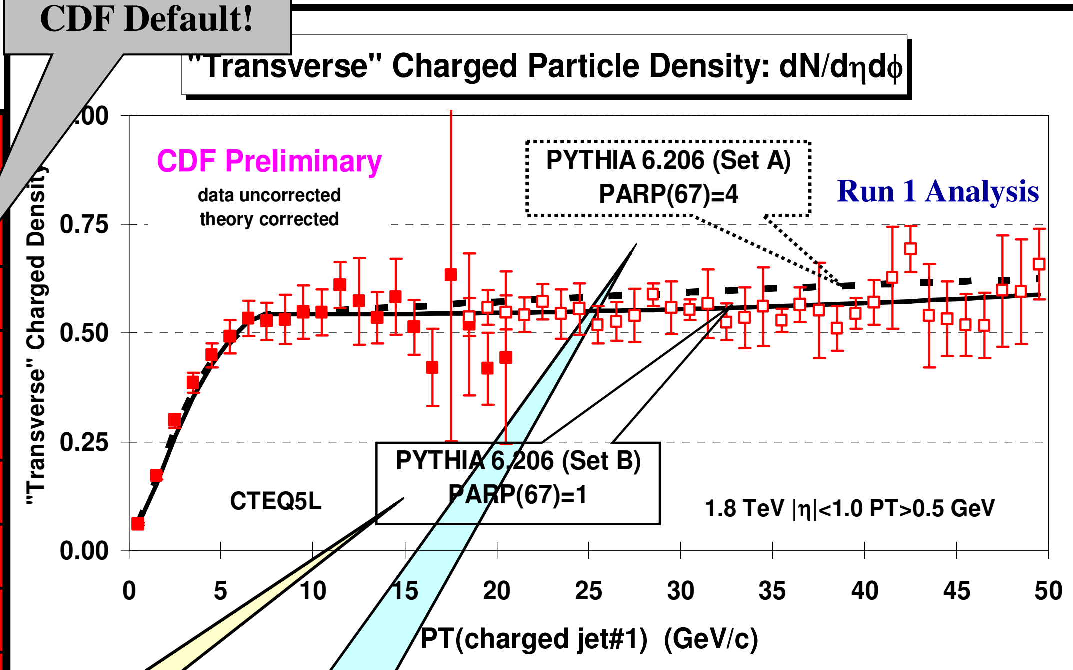
- Shows the "transverse" ch... ($|\eta|<1$, $P_T>0.4$ GeV) versus ... GeV predicted by **HERWIG 6.4** (P_T(hard) > 3 GeV/c, CTEQ5L) and a **tuned** version of **PYTHIA 6.206** (P_T(hard) > 0, CTEQ5L, Set A, ε = 0, ε = 0.16 (default) and ε = 0.25 (preferred)).
- Also shown are the PT_{sum} densities (0.16 GeV/c and 0.54 GeV/c) determined from the Tano, Kovacs, Huston, and Bhatti "transverse" cone analysis at 630 GeV.

Run 1 PYTHIA Tune A

PYTHIA 6.206 CTEQ5L

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

CDF Default!



➡ 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)

CDF Run 1 $P_T(Z)$

PYTHIA 6.2 CTEQ5L

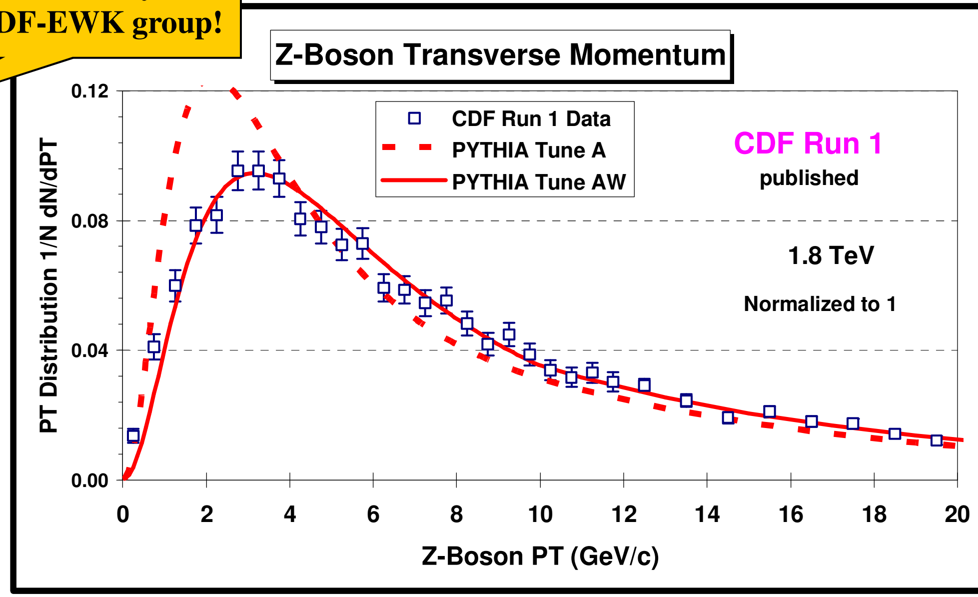
Tune used by the CDF-EWK group!

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

UE Parameters

ISR Parameters

Intrensic KT



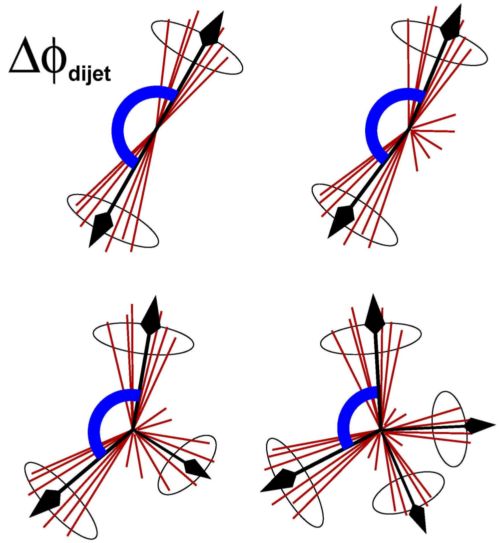
- Shows the Run 1 Z-boson p_T distribution ($<p_T(Z)> \approx 11.5$ GeV/c) compared with PYTHIA Tune A ($<p_T(Z)> = 9.7$ GeV/c), and PYTHIA Tune AW ($<p_T(Z)> = 11.7$ GeV/c).

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

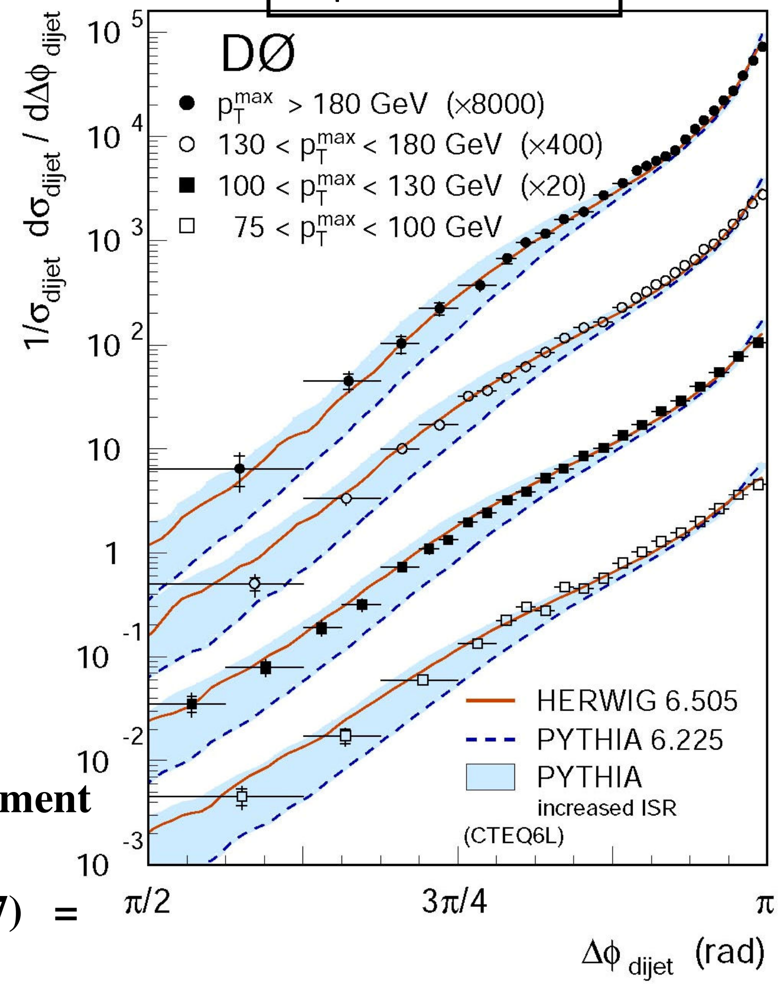
The $Q^2 = k_T^2$ in α_s for space-like showers is scaled by PARP(64)!

Jet-Jet Correlations (DØ)

Jet#1-Jet#2 Δφ Distribution



Δφ Jet#1-Jet#2



- **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).**

CDF Run 1 $P_T(Z)$

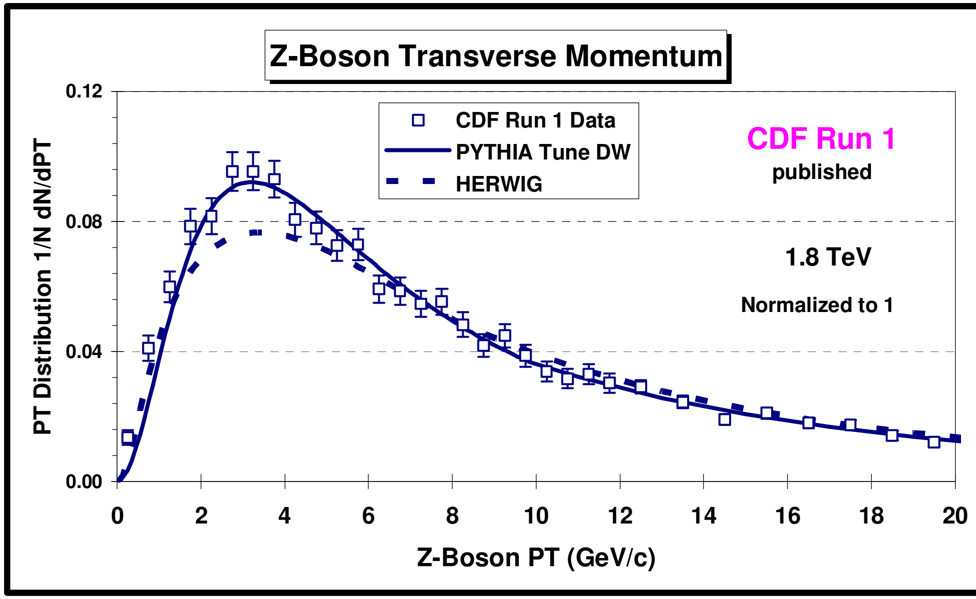
PYTHIA 6.2 CTEQ5L

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

UE Parameters

ISR Parameters

Intrensic KT



- Shows the Run 1 Z-boson p_T distribution ($<p_T(Z)> \approx 11.5$ 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 Para[illegible]

Intrinsic KT

Parameter	Tu[illegible] AW	Tune DW	[illegible]D6
PDF	C[illegible]	CTEQ5L	[illegible]Q6L
MSTP(81)	[illegible]	1	[illegible]
[illegible]P(82)	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
PAR[illegible]	[illegible]	[illegible]	[illegible]
MST[illegible]	[illegible]	[illegible]	1
PA[illegible]	[illegible]	2[illegible]	2.1
P[illegible]P(93)	[illegible]	15.0	15.0

[illegible]ses CTEQ6L

[illegible]pendence!

None of the CDF Tunes included any "min-bias" data in the determination of the parameters!

PYTHIA 6.2 Tunes

All use LO α_s with Λ = 192 MeV!

UE Parameters

Tune A

Tune D

Tune D6T
CMS

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")

“Towards”, “Away”, “Transve

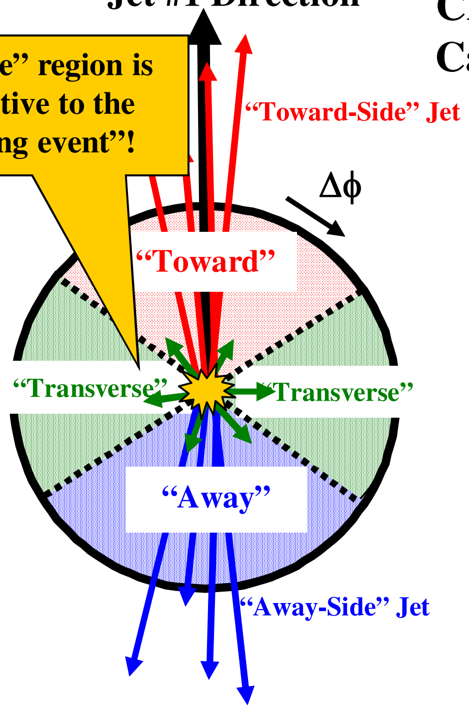
Look at the charged particle density, the charged PTsum density and the ETsum density in all 3 regions!

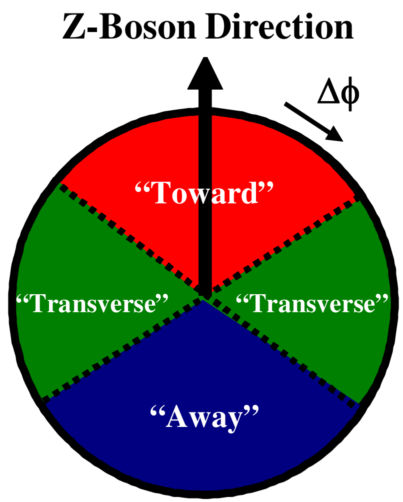
$\Delta\phi$ Correlations relative to the leading jet

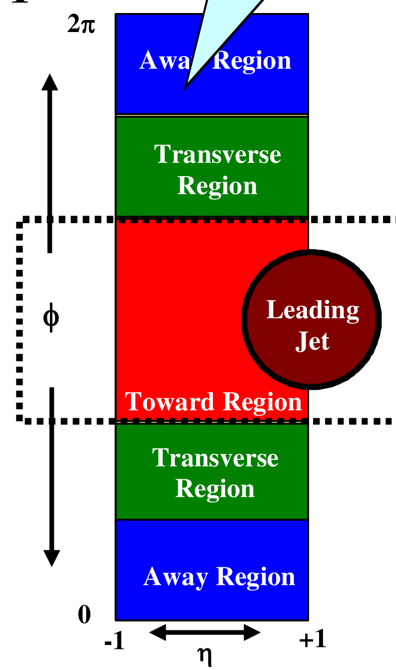
Charged particles $p_T > 0.5$ GeV/c $|\eta| < 1$

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

“Transverse” region is very sensitive to the “underlying event”!



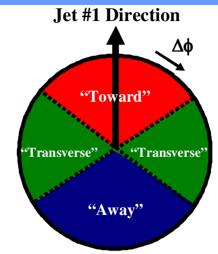


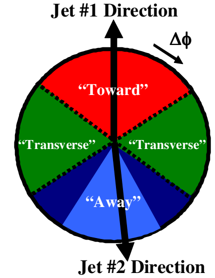


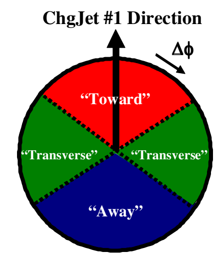
- Look at correlations in the azimuthal angle $\Delta\phi$ relative to the leading charged particle jet ($|\eta| < 1$) or the leading calorimeter jet ($|\eta| < 2$).
- Define $|\Delta\phi| < 60^o$ as “Toward”, $60^o < |\Delta\phi| < 120^o$ as “Transverse ”, and $|\Delta\phi| > 120^o$ as “Away”. Each of the three regions have area $\Delta\eta\Delta\phi = 2\times120^o = 4\pi/3$.

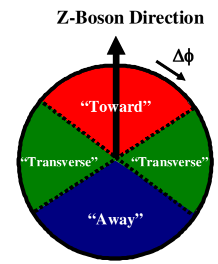
Event Topologies

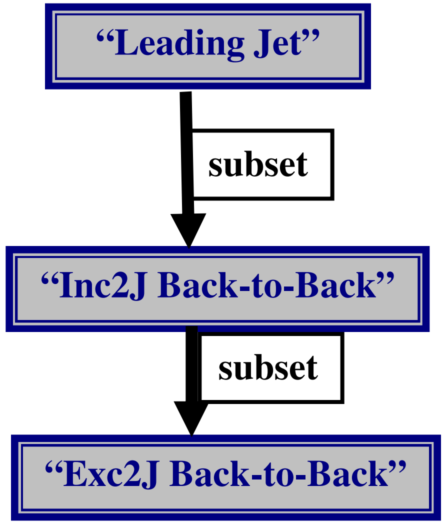
- **"Leading Jet"** events correspond to the leading calorimeter jet (MidPoint R = 0.7) in the region $|\eta| < 2$ with no other conditions.
- **"Inclusive 2-Jet Back-to-Back"** events are selected to have at least two jets with Jet#1 and Jet#2 nearly "back-to-back" ($\Delta\phi_{12} > 150^o$) with almost equal transverse energies (P_T(jet#2)/P_T(jet#1) > 0.8) with no other conditions .
- **"Exclusive 2-Jet Back-to-Back"** events are selected to have at least two jets with Jet#1 and Jet#2 nearly "back-to-back" ($\Delta\phi_{12} > 150^o$) with almost equal transverse energies (P_T(jet#2)/P_T(jet#1) > 0.8) and P_T(jet#3) < 15 GeV/c.
- **"Leading ChgJet"** events correspond to the leading charged particle jet (R = 0.7) in the region $|\eta| < 1$ with no other conditions.
- **"Z-Boson"** events are Drell-Yan events with 70 < M(lepton-pair) < 110 GeV with no other conditions.







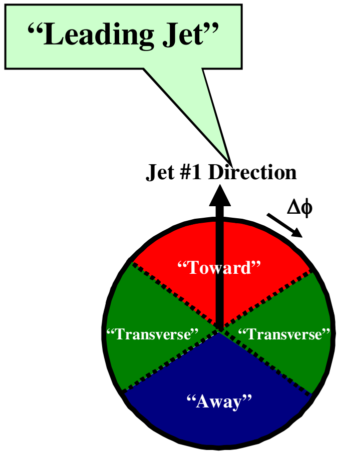


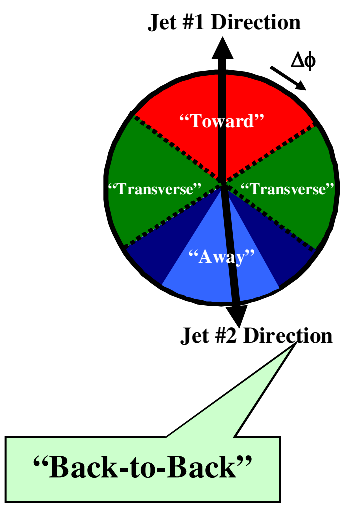


"Charged Jet"

Z-Boson

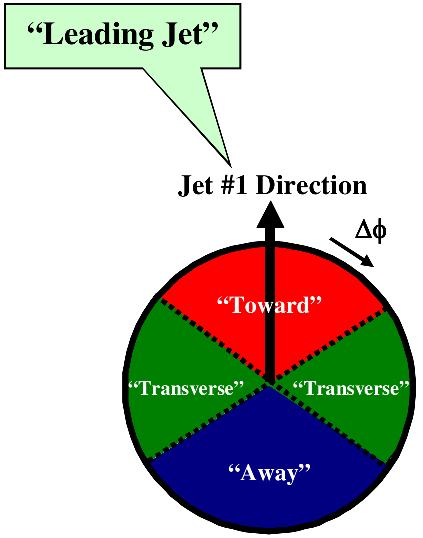
Observables at the Particle and Detector Level

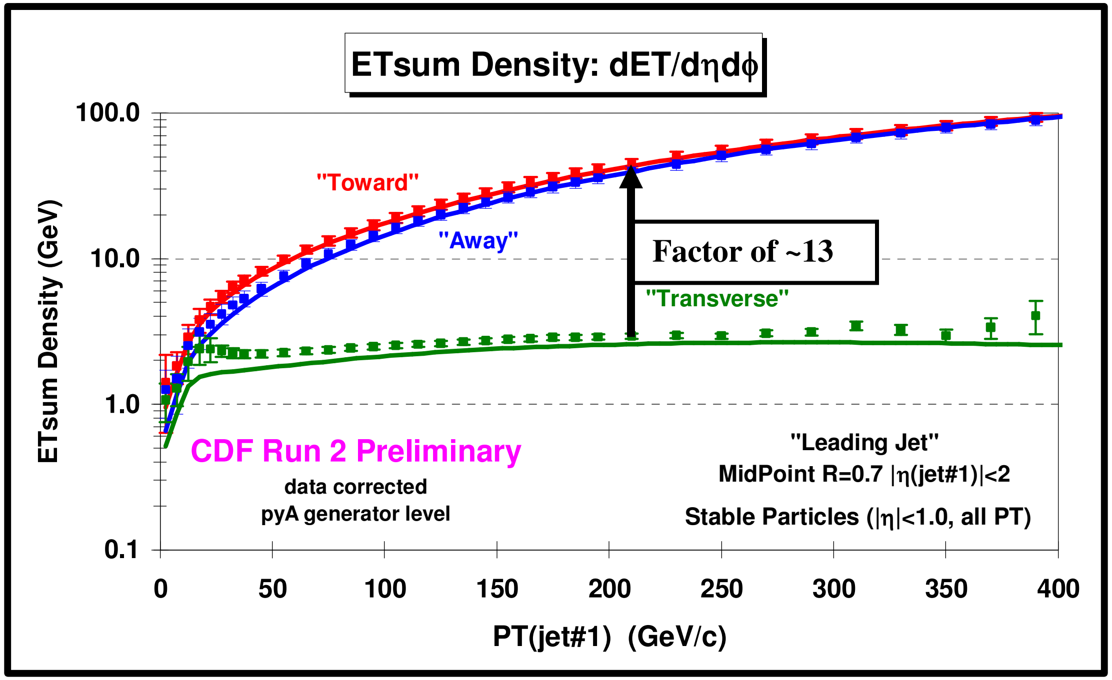




Observable	Particle Level	Detector Level
dNchg/dηdφ	Number of charged particles per unit η-φ ($p_T > 0.5$ GeV/c, $\lvert\eta\rvert < 1$)	Number of "good" charged tracks per unit η-φ ($p_T > 0.5$ GeV/c, $\lvert\eta\rvert < 1$)
dPTsum/dηdφ	Scalar p_T sum of charged particles per unit η-φ ($p_T > 0.5$ GeV/c, $\lvert\eta\rvert < 1$)	Scalar p_T sum of "good" charged tracks per unit η-φ ($p_T > 0.5$ GeV/c, $\lvert\eta\rvert < 1$)
$<p_T>$	Average p_T of charged particles ($p_T > 0.5$ GeV/c, $\lvert\eta\rvert < 1$)	Average p_T of "good" charged tracks ($p_T > 0.5$ GeV/c, $\lvert\eta\rvert < 1$)
PTmax	Maximum p_T charged particle ($p_T > 0.5$ GeV/c, $\lvert\eta\rvert < 1$) Require Nchg ≥ 1	Maximum p_T "good" charged tracks ($p_T > 0.5$ GeV/c, $\lvert\eta\rvert < 1$) Require Nchg ≥ 1
dETsum/dηdφ	Scalar E_T sum of all particles per unit η-φ (all p_T, $\lvert\eta\rvert < 1$)	Scalar E_T sum of all calorimeter towers per unit η-φ ($E_T > 0.1$ GeV, $\lvert\eta\rvert < 1$)
PTsum/ETsum	Scalar p_T sum of charged particles ($p_T > 0.5$ GeV/c, $\lvert\eta\rvert < 1$) divided by the scalar E_T sum of all particles (all p_T, $\lvert\eta\rvert < 1$)	Scalar p_T sum of "good" charged tracks ($p_T > 0.5$ GeV/c, $\lvert\eta\rvert < 1$) divided by the scalar E_T sum of calorimeter towers ($E_T > 0.1$ GeV, $\lvert\eta\rvert < 1$)

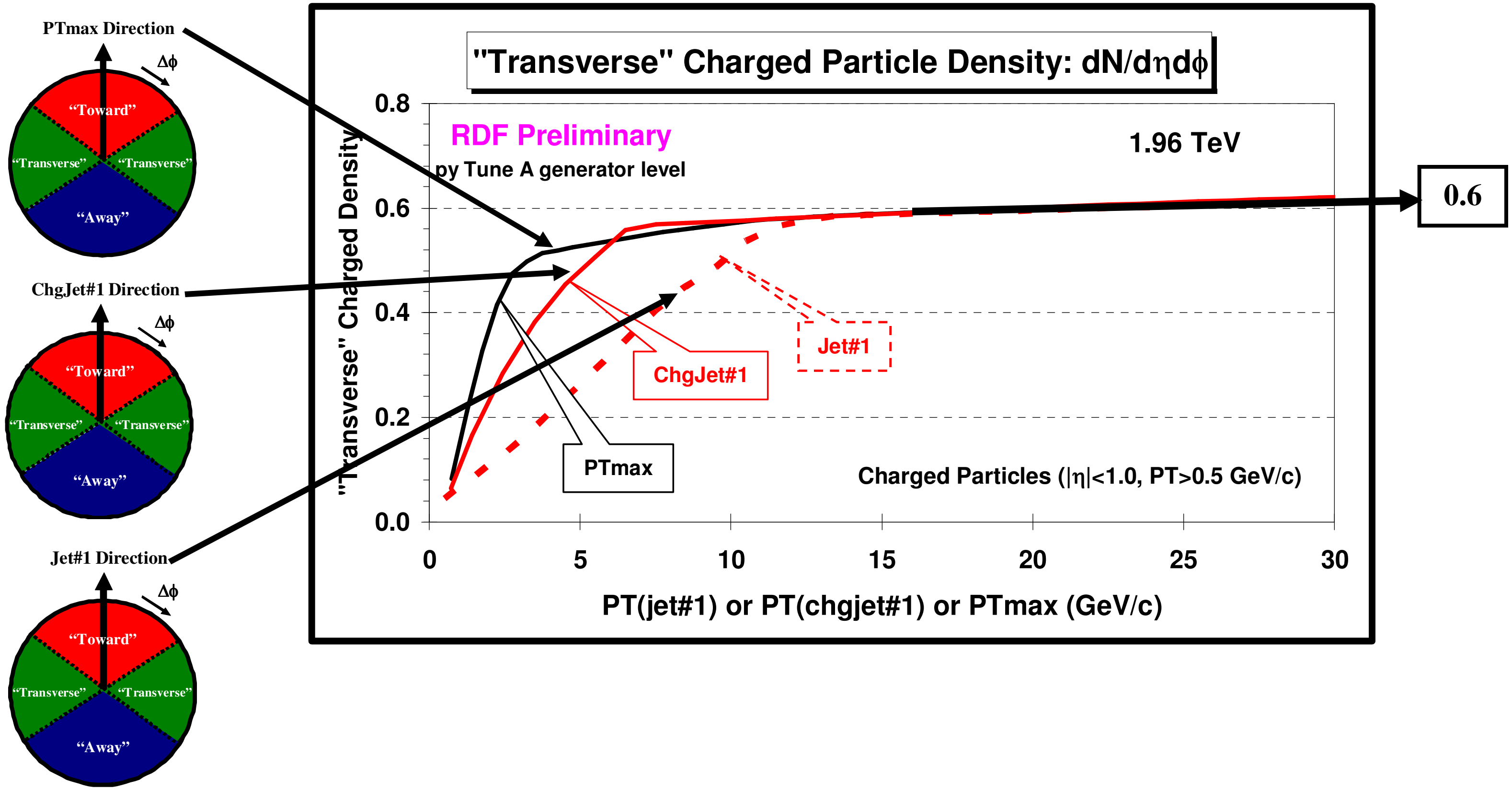
"Towards", "Away", "Transverse"





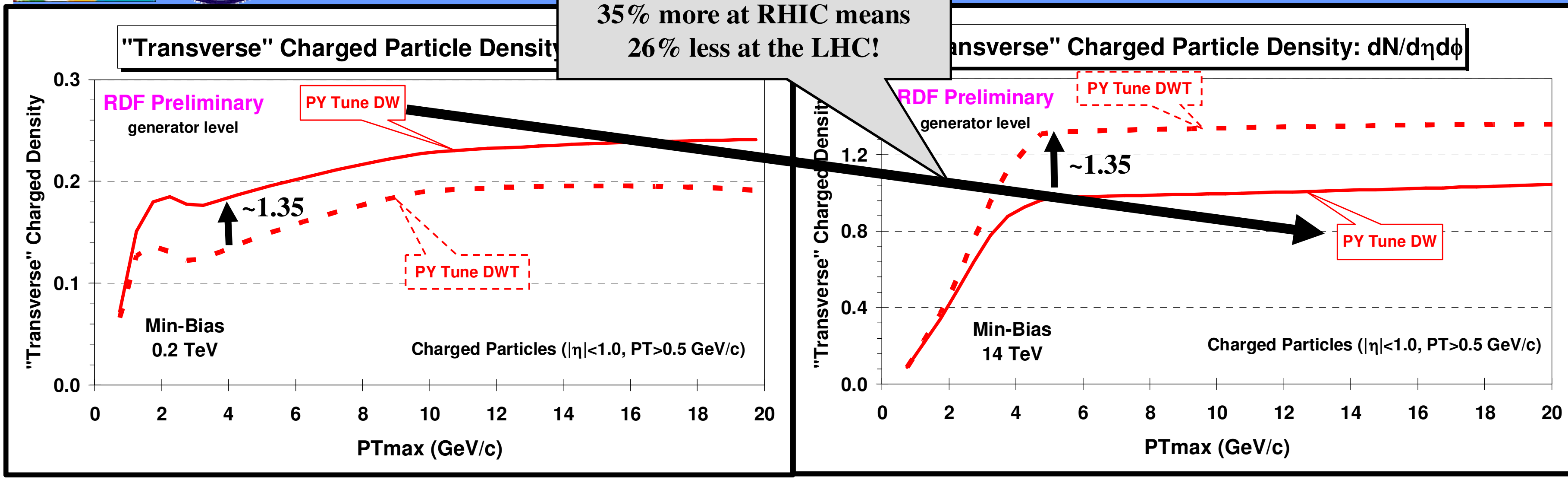
- Data at 1.96 TeV on the particle *scalar* E_T sum density, dET/dηdφ, for |η| < 1 for "leading jet" events as a function of the leading jet p_T for the "toward", "away", and "transverse" regions. The data are corrected to the particle level (*with errors that include both the statistical error and the systematic uncertainty*) and are compared with PYTHIA Tune A at the particle level (*i.e.* generator level).

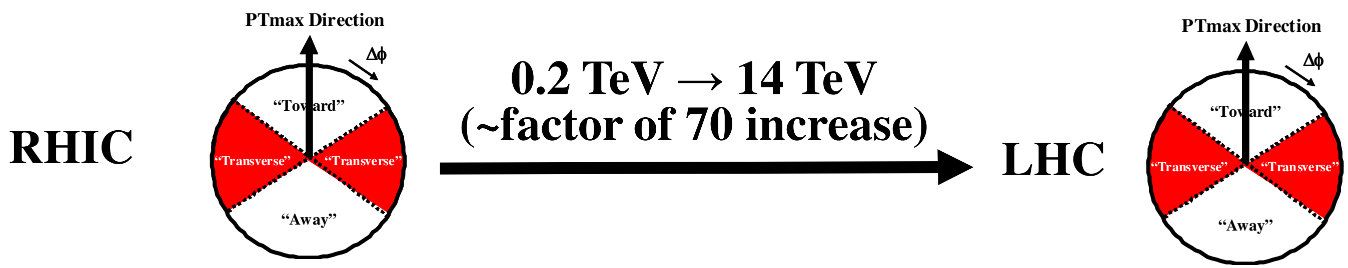
"Transverse" Charged Density



➡ 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).

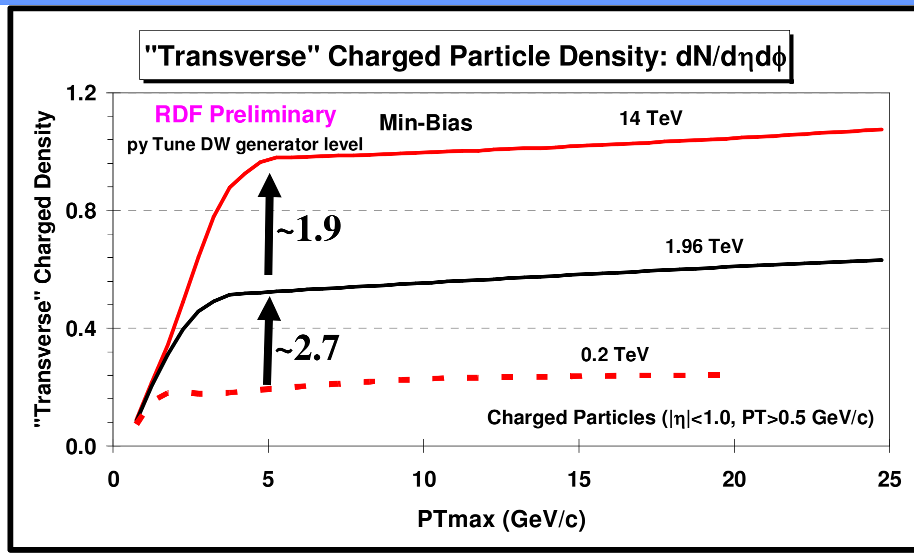
Min-Bias "Associated" Charged Particle Density



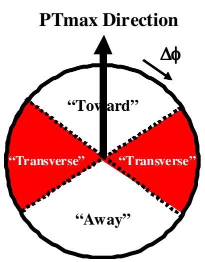


- Shows the "associated" charged particle density in the "transverse" regions as a function of PTmax for charged particles ($p_T > 0.5$ GeV/c, $|\eta| < 1$, *not including PTmax*) for "min-bias" events at 0.2 TeV and 14 TeV from PYTHIA Tune DW and Tune DWT at the particle level (*i.e.* generator level).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

Min-Bias "Associated" Charged Particle Density

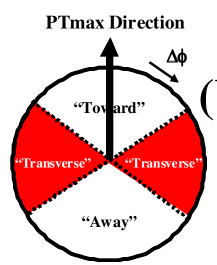


RHIC



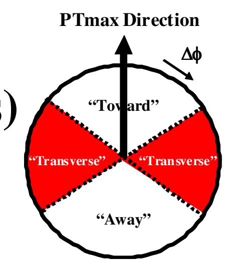
0.2 TeV → 1.96 TeV (UE increase ~2.7 times)

Tevatron



1.96 TeV → 14 TeV (UE increase ~1.9 times)

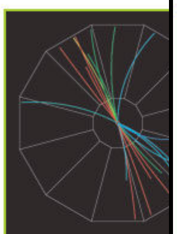
LHC



- **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).**

The "Underlying Event" at STAR

RHIC



UK

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.

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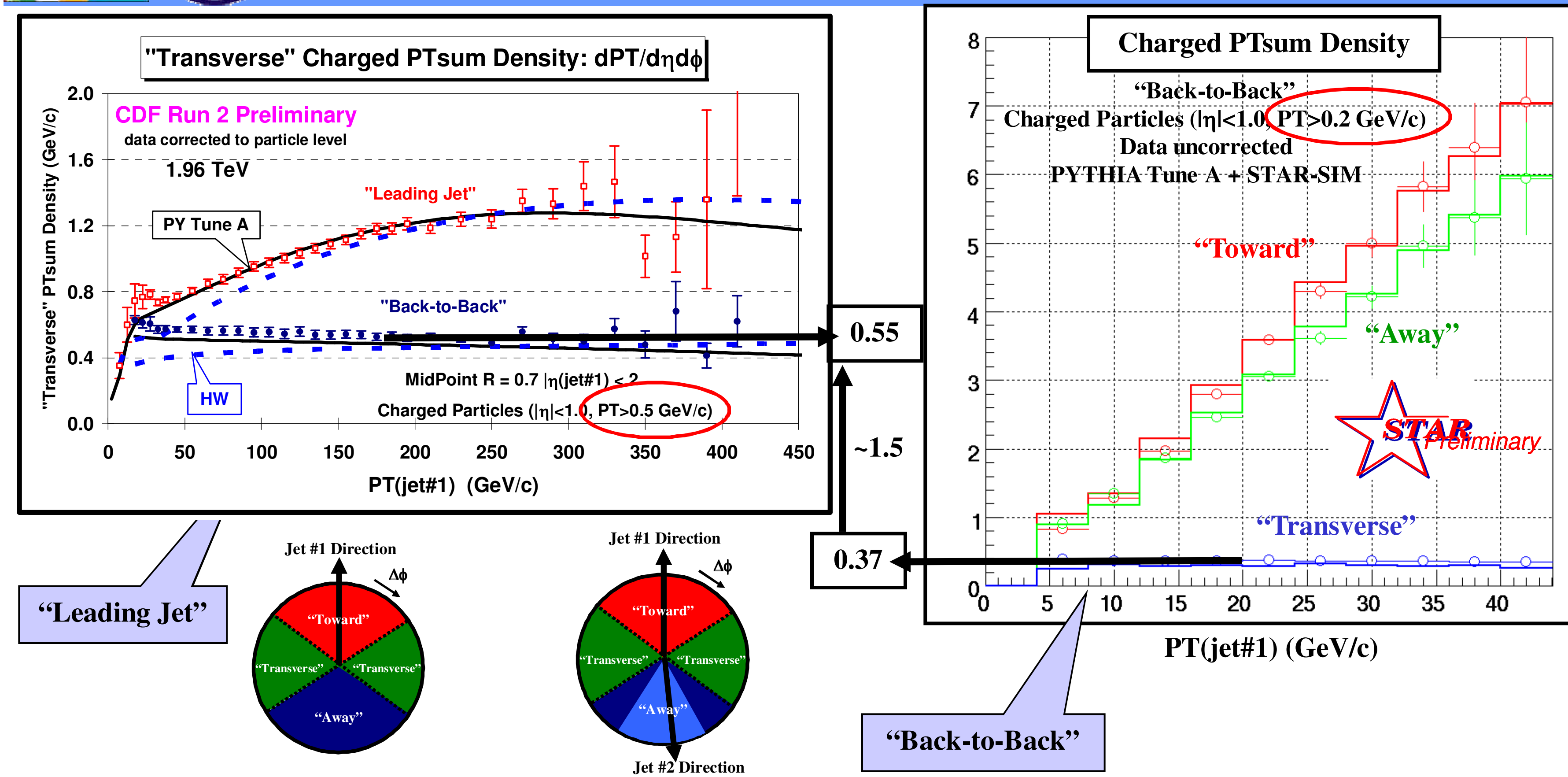
egion.

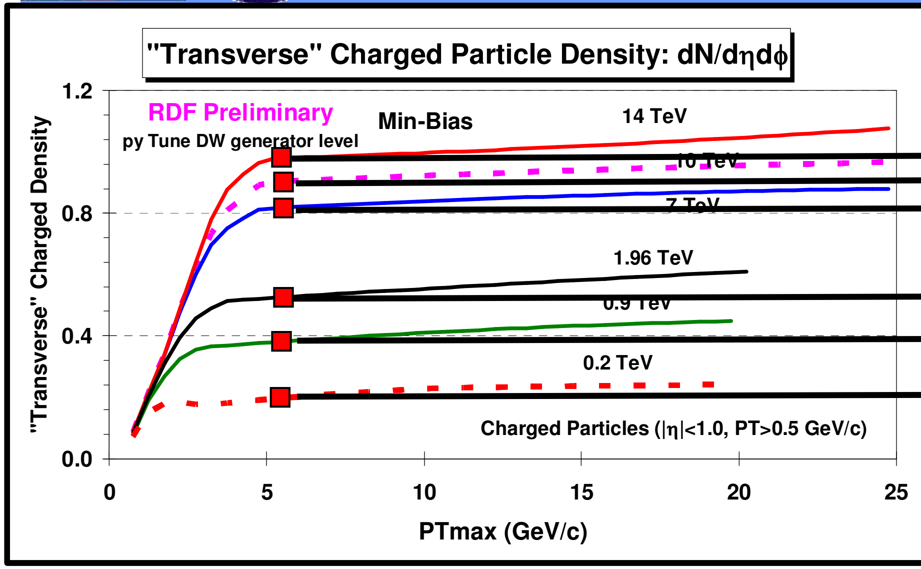
➡ **At STAR** ... **2 GeV)**
and com

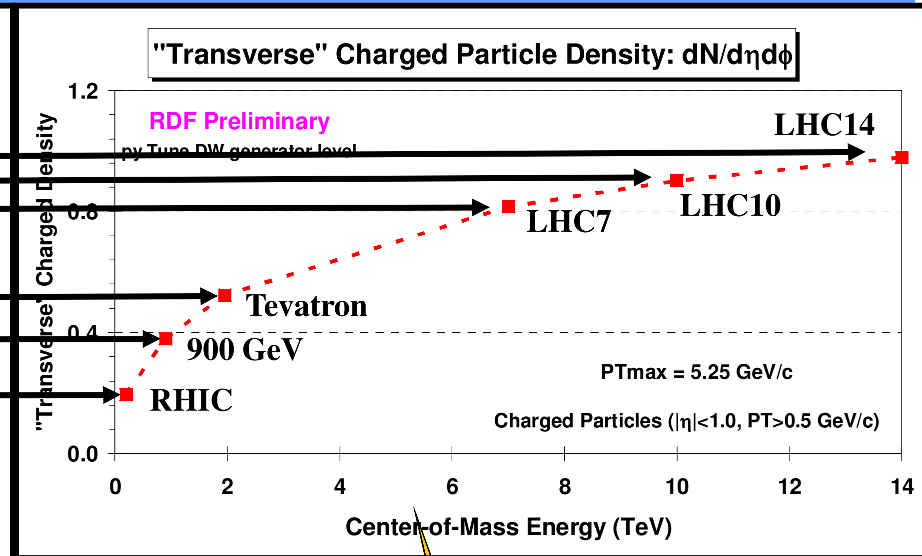
The "Underlying Event" at STAR



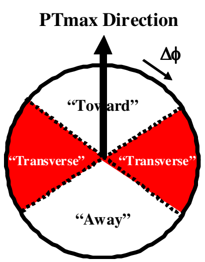
- **Data on the charged particle *scalar* p_T sum density, dPT/dηdφ, as a function of the leading jet p_T for the "toward", "away", and "transverse" regions compared with PYTHIA Tune A.**

Min-Bias "Associated" Charged Particle Density



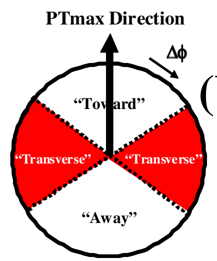


RHIC



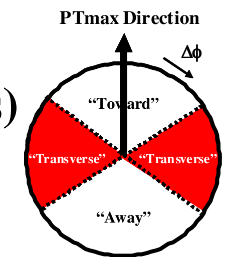
0.2 TeV → 1.96 TeV (UE increase ~2.7 times)

Tevatron



1.96 TeV → 14 TeV (UE increase ~1.9 times)

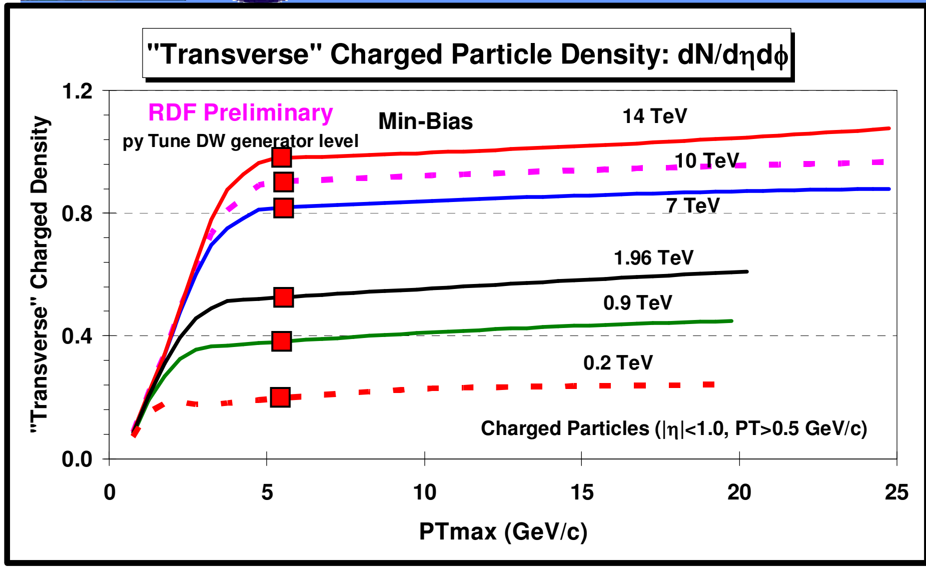
LHC

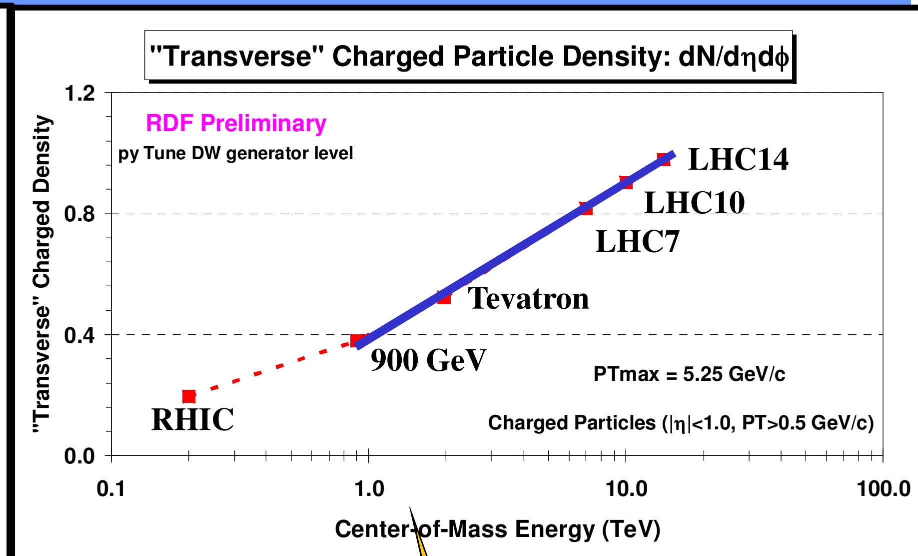


- **Shows the "associated" charged particle density in the "transverse" region a[…] function of PTmax for charged particles (p_T > 0.5 GeV/c, |η| < 1, *not including PTmax*) for "min-[…]s" events at 0.2 TeV, 0.9 TeV, 1.96 TeV, 7 TeV, 10 TeV, 14 TeV predicted by PYTHIA Tun[…] at the particle level (*i.e.* generator level).**

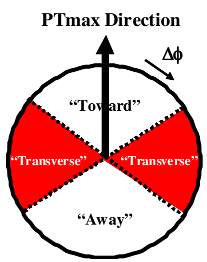
Linear scale!

Min-Bias “Associated” Charged Particle Density





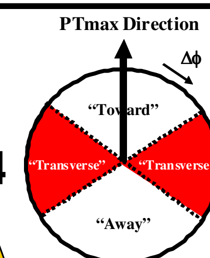
LHC7



7 TeV → 14 TeV
(UE increase ~20%)

Linear on a log plot!

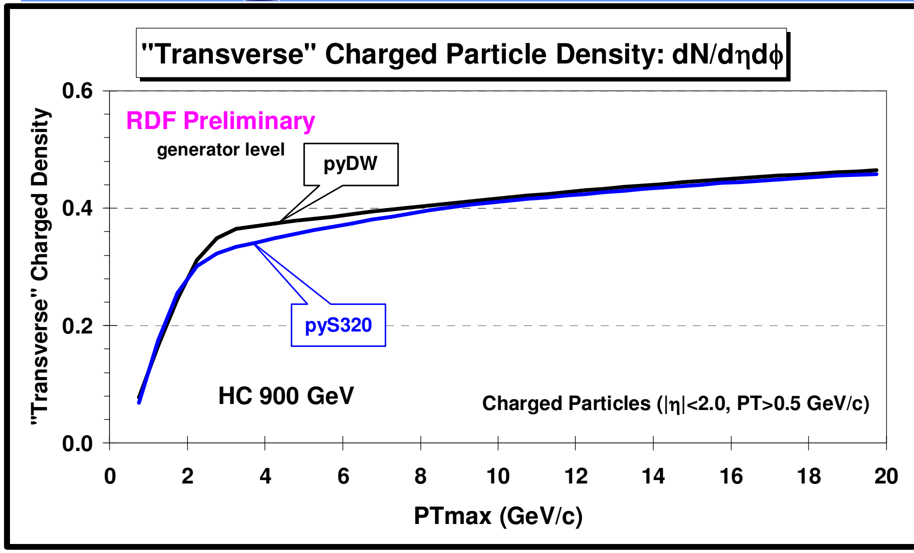
LHC14

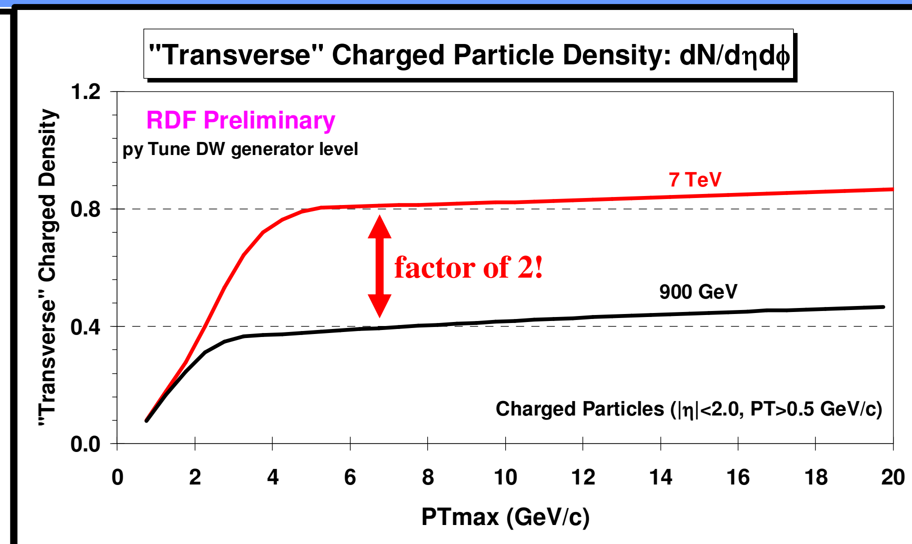


Log scale!

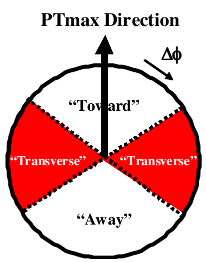
- **Shows the “associated” charged particle density in the “transverse” region as a function of PTmax for charged particles (p_T > 0.5 GeV/c, |η| < 1, *not including PTmax*) for “min-bias” events at 0.2 TeV, 0.9 TeV, 1.96 TeV, 7 TeV, 10 TeV, 14 TeV predicted by PYTHIA Tune DW at the particle level (*i.e.*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

“Transverse” Charge Density



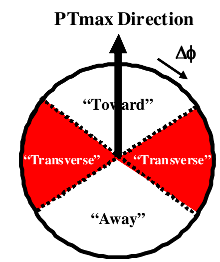


LHC
900 GeV



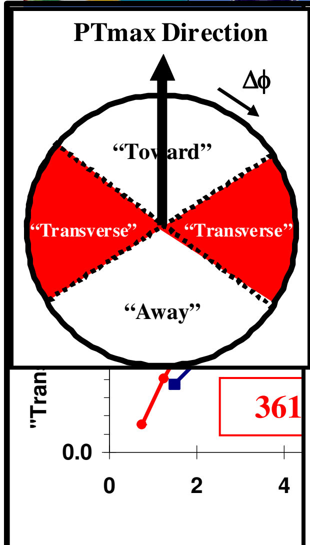
900 GeV → 7 TeV
(UE increase ~ factor of 2.1)

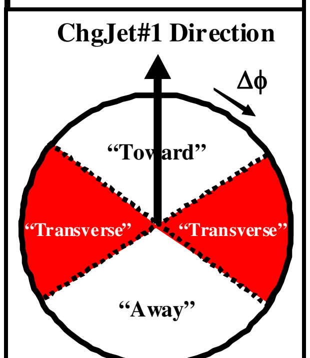
LHC
7 TeV

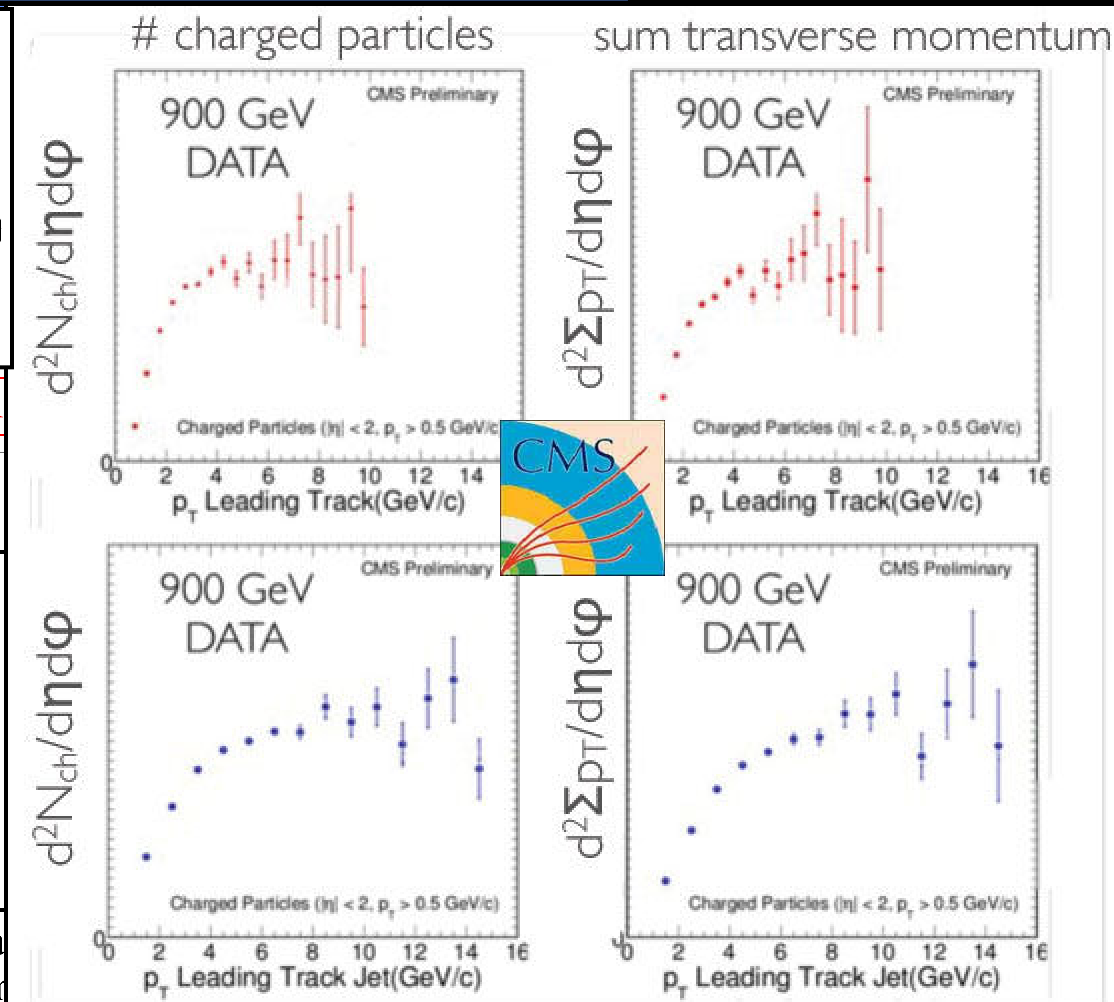


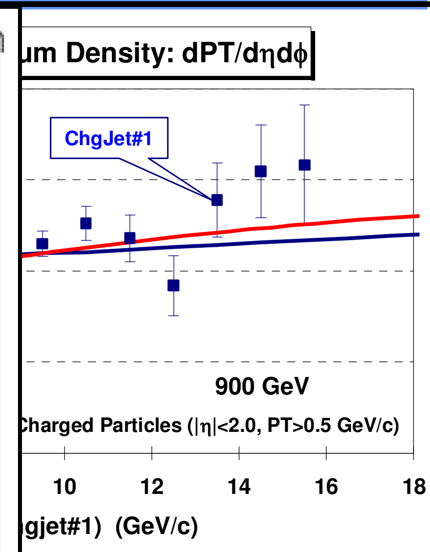
- **Shows the charged particle density in the “transverse” region for charged particles (p_T > 0.5 GeV/c, |η| < 2) at 900 GeV as defined by PTmax from PYTHIA Tune DW and Tune S320 at the particle level (*i.e.* generator level).**

"Transverse" Charged Particle Density









900 GeV on the
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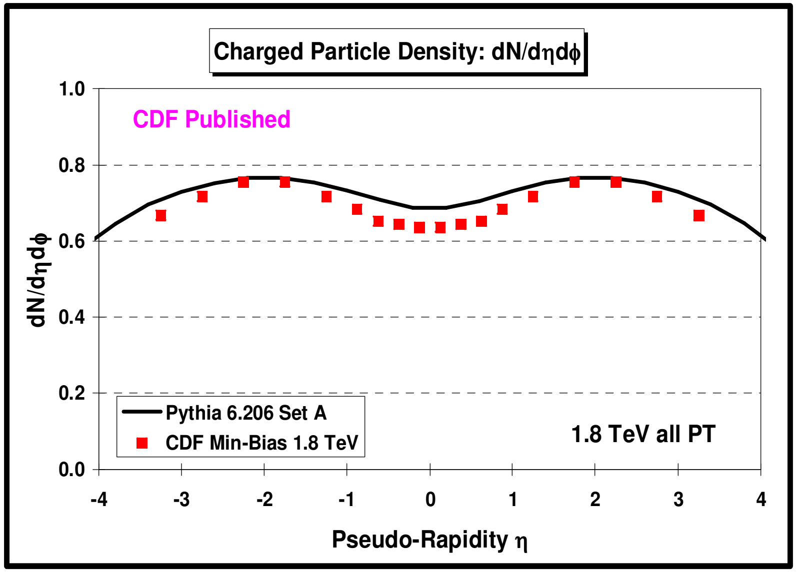
|η| < 2. The fake
he DW) are generated
generator level)
s events at 900 GeV

generated a
level) assum
900 GeV (361,595 eve

Talk by Edward Wenger Yesterday

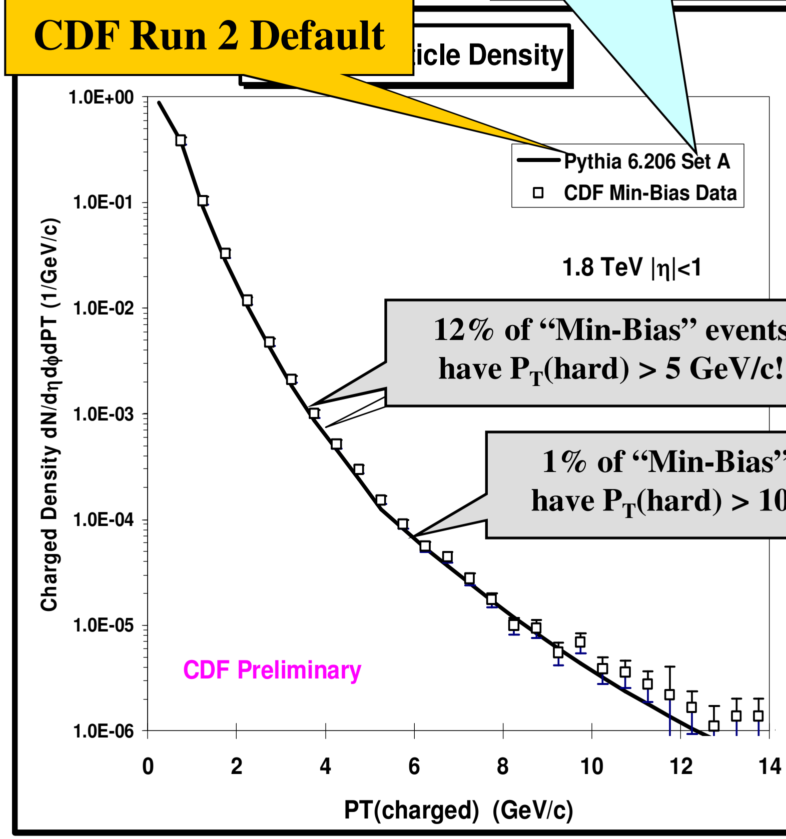
the plot).

PYTHIA Tune A Min-Bias "Soft" + "Hard"



PYTHIA Tune A
CDF Run 2 Default

Tuned to fit the CDF Run 1 "underlying event"!



12% of "Min-Bias" events have P_T(hard) > 5 GeV/c!

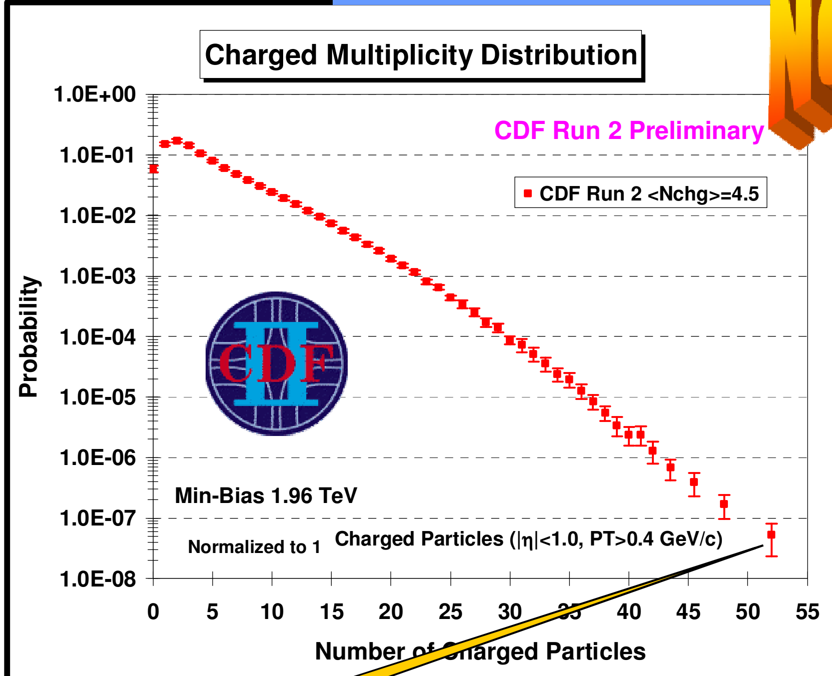
1% of "Min-Bias" events have P_T(hard) > 10 GeV/c!

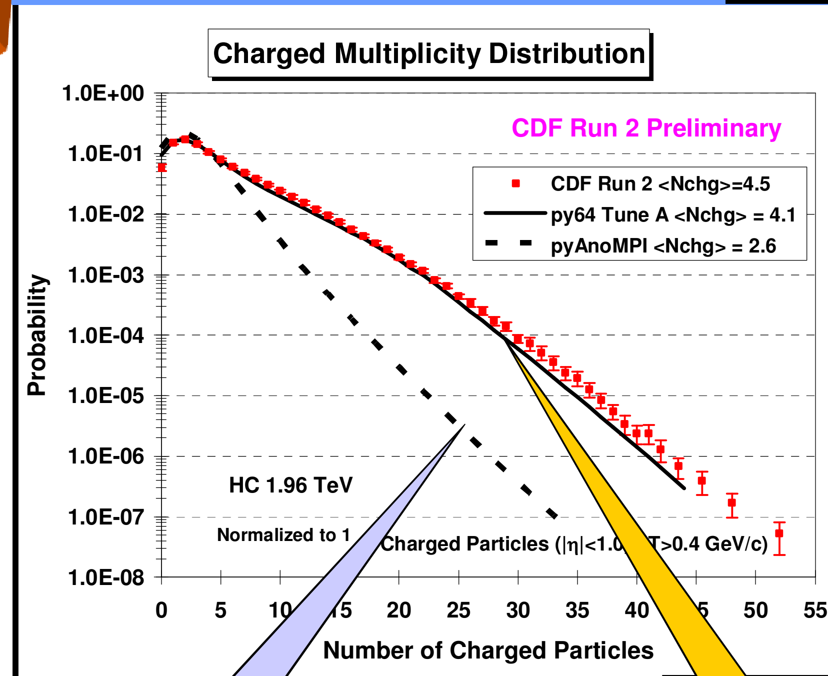
- **PYTHIA regulates the perturbative 2-to-2 parton-parton cross sections with cut-off** … **one to run with** … **ulate both "hard" and "soft" collisio** … **one program.**

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

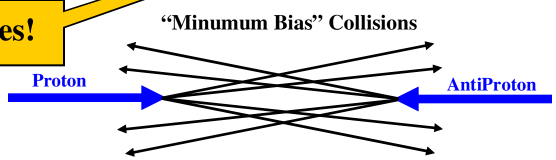
- **The relative amount of** … **rd" versus "soft" depends on the cut-off and can be tuned.**
- **This PYTHIA fit predicts that 12% of all "Min-Bias" events are a result of a hard 2-to-2 parton-parton scattering with P_T(hard) > 5 GeV/c (1% with P_T(hard) > 10 GeV/c)!**

Charged Particle Multiplicity





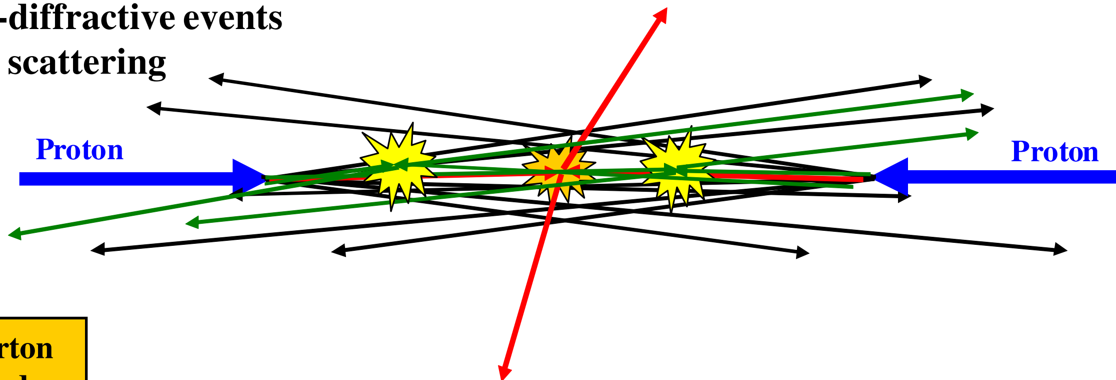
7 decades!



- Data at 1.96 TeV on the charged particle multiplicity ($p_T > 0.4$ GeV/c, $|\eta| < 1$) for "min-bias" collisions at CDF Run 2.
- The data are compared with PYTHIA Tune A and Tune A without multiple parton interactions (pyAnoMPI).

The "Underlying Event"

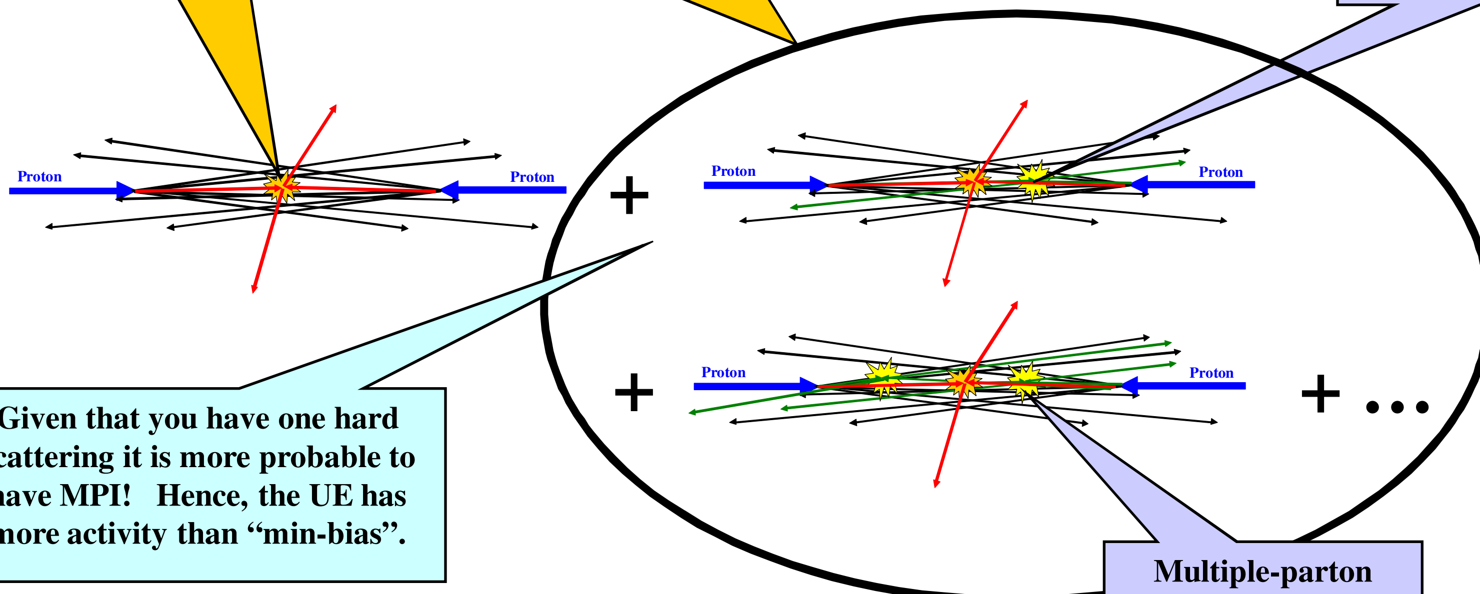
Select inelastic non-diffractive events that contain a hard scattering



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

The "underlying-event" (UE)!

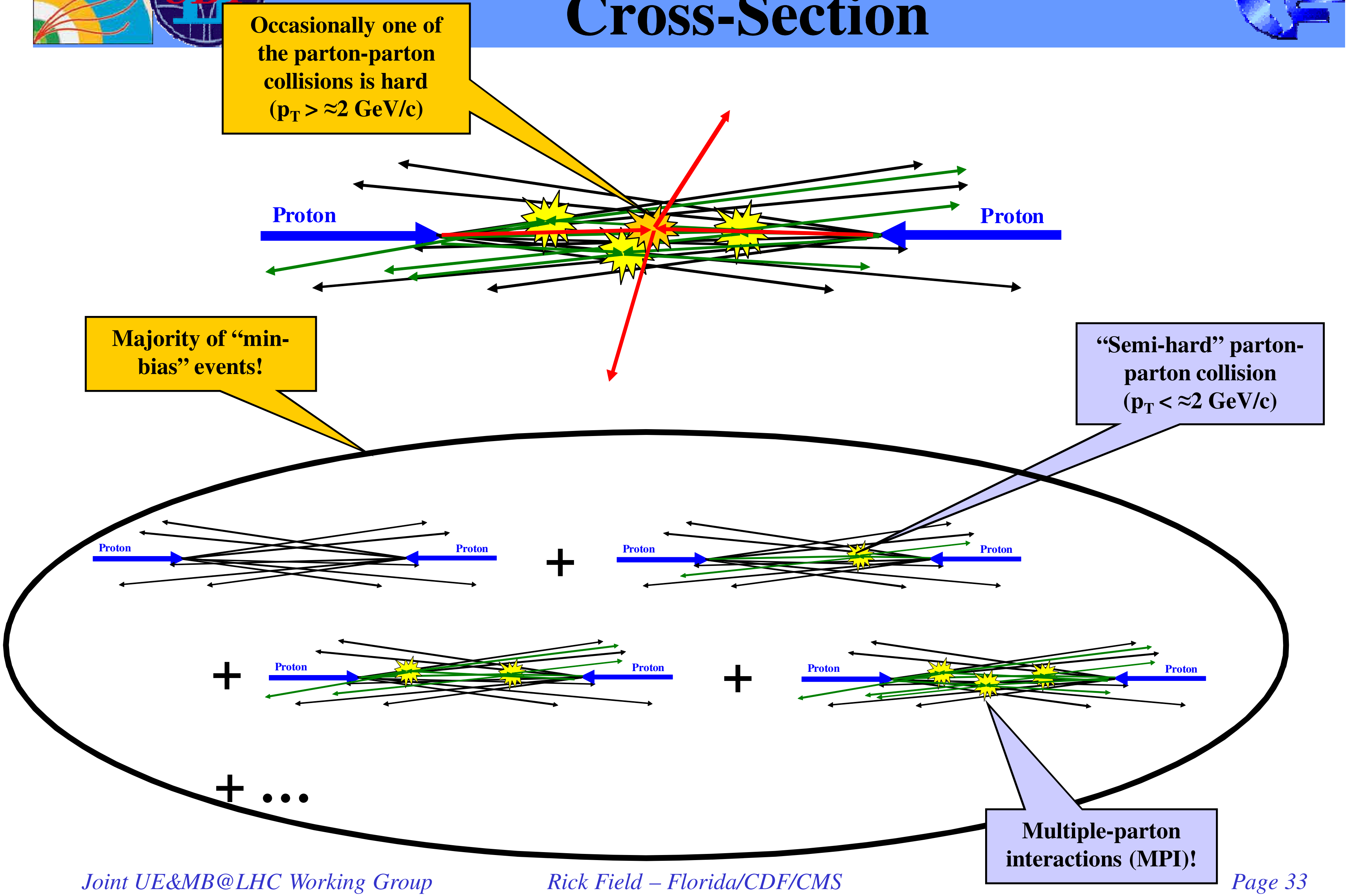
"Semi-hard" parton-parton collision ($p_T < \approx 2$ GeV/c)



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

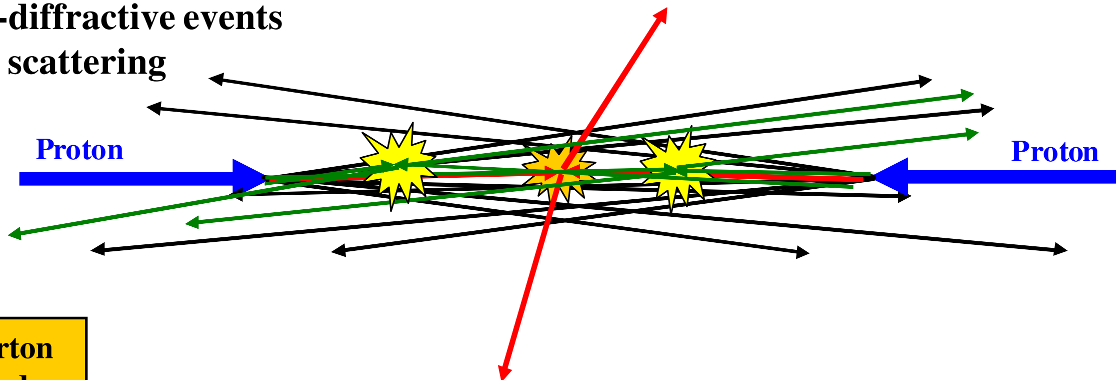
Multiple-parton interactions (MPI)!

The Inelastic Non-Diffractive Cross-Section



The "Underlying Event"

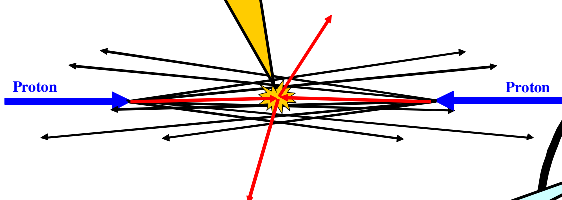
Select inelastic non-diffractive events that contain a hard scattering

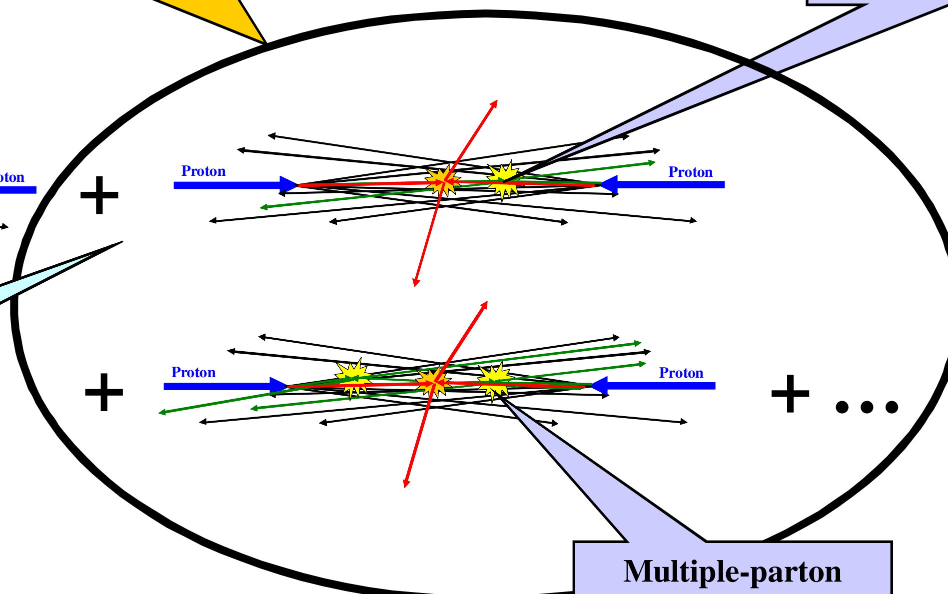


Hard parton-parton collisions is hard ($p_T > \approx 2$ GeV/c)

The "underlying-event" (UE)!

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





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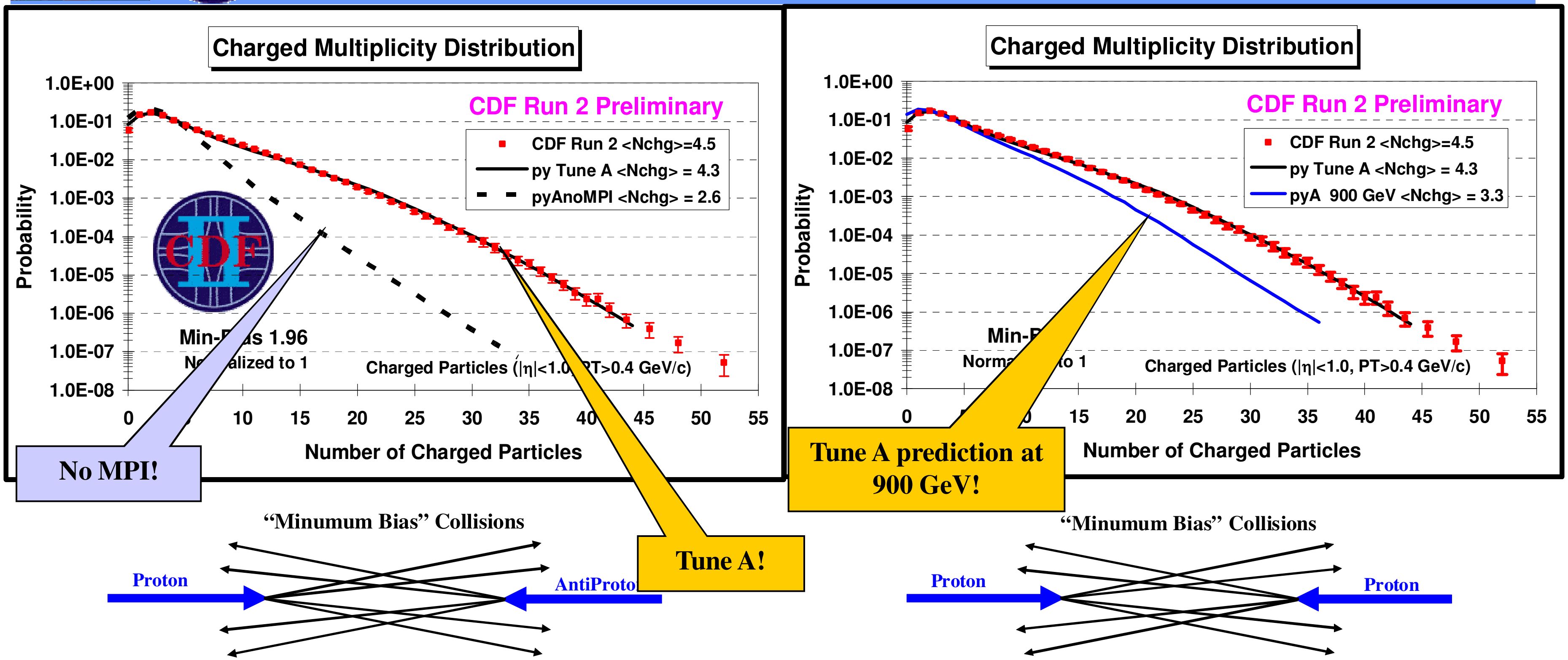
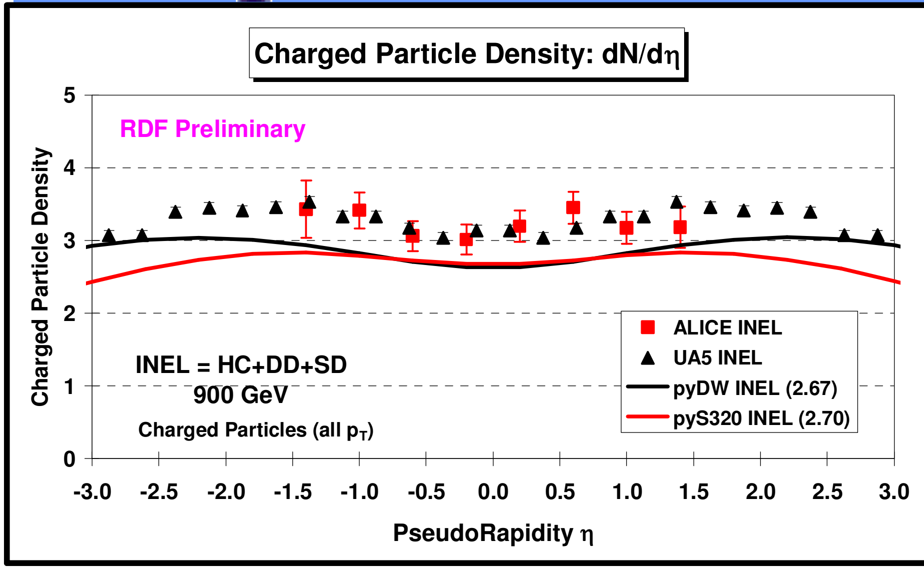
Multiple-parton interactions (MPI)!

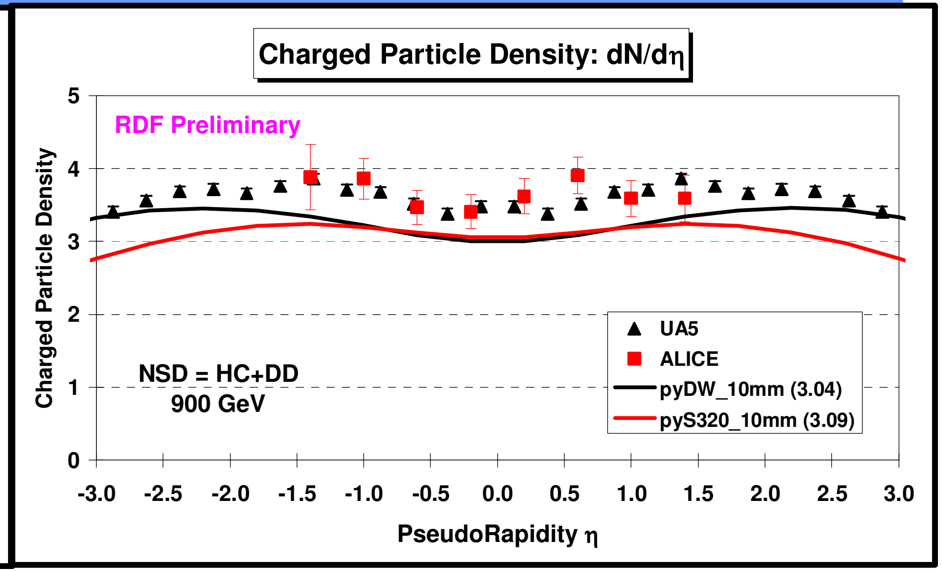
Charged Particle Multiplicity



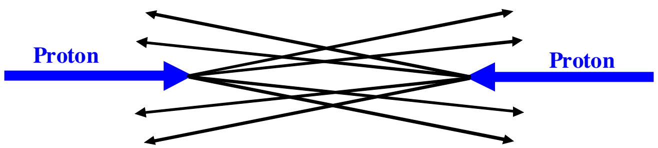
- **Data at 1.96 TeV on the charged particle multiplicity ($p_T > 0.4$ GeV/c, $|\eta| < 1$) for "min-bias" collisions at CDF Run 2.**
- **The data are compared with PYTHIA Tune A and Tune A without multiple parton interactions (pyAnoMPI).**
- **Prediction from PYTHIA Tune A for proton-proton collisions at 900 GeV.**

LHC Predictions: 900 GeV

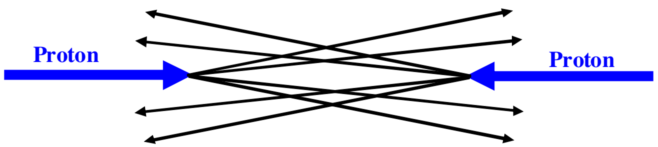




"Minumum Bias" Collisions



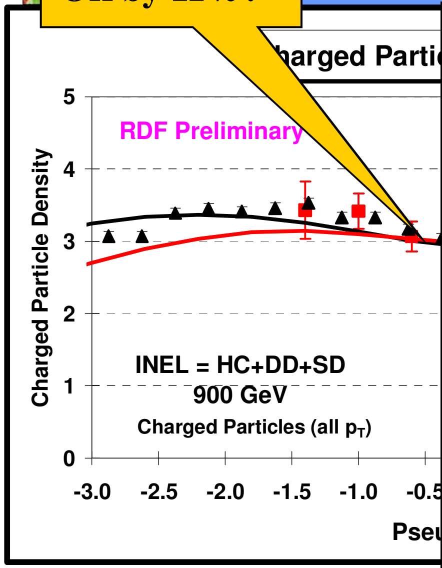
"Minumum Bias" Collisions

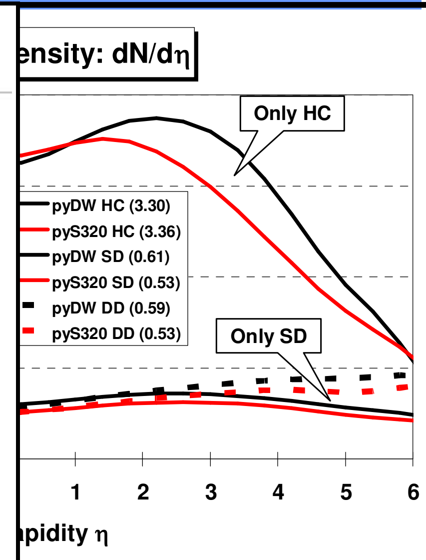


- Compares the 900 GeV data with my favorite PYTHIA Tunes (Tune DW and Tune S320 Perugia 0). Tune DW uses the old Q^2-ordered parton shower and the old MPI model. Tune S320 uses the new p_T-ordered parton shower and the new MPI model. The numbers in parentheses are the average value of dN/dη for the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

LHC Predictions: 900 GeV

Off by 11%!





CMS dN/dη

BBC NEWS

LHC high-energy results published

By Jason Palmer
Science and technology reporter, BBC News

The results from the highest-energy particle experiments carried out at the Large Hadron Collider (LHC) in December have begun to yield their secrets.

Scientists from the LHC's Compact Muon Solenoid detector have now totted up all of the resulting particle interactions.

They wrote in the Journal of High Energy Physics that the run created more particles than theory predicted.

However, the glut of particles should not affect results as the experiment runs to even higher energies this year.

The LHC is designed to smash together particles and atoms circling its 27km-tunnel in a bid to find evidence of further particles that underpin the field of physics as it is currently formulated.

The December announcement of particle beam energies in excess of one trillion electron volts made the LHC the world's highest-energy particle accelerator.

Particle particulars

That makes the new results a unique look at the field of high-energy physics. The experiments, smashing protons into each other, produced a few more subatomic particles known as pions and kaons than the team was expecting.

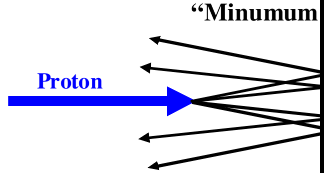
"The level is somewhat higher than the most popular models had predicted, and it looks like it is going to increase with energy a little bit more steeply than we expected," said Gunther Roland, a CMS collaboration scientist from the Massachusetts Institute of Technology in the US.

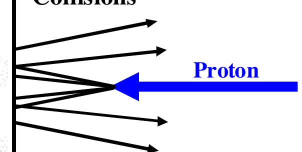
"I think it's not going to be a problem, but it is one of the many things that we need to know as we move toward searches for the most rare particles and new physics," Professor Roland told BBC News.

He added that the "extra" particles will be more of an issue when, later in 2010, the LHC dedicates itself to collisions involving ions of the element lead, a markedly heavier pair of targets resulting in an even larger array of particles on impact.

"We'll know much more about that in two or three months when we look at the next higher energy of 7 TeV (trillion electron volts)."

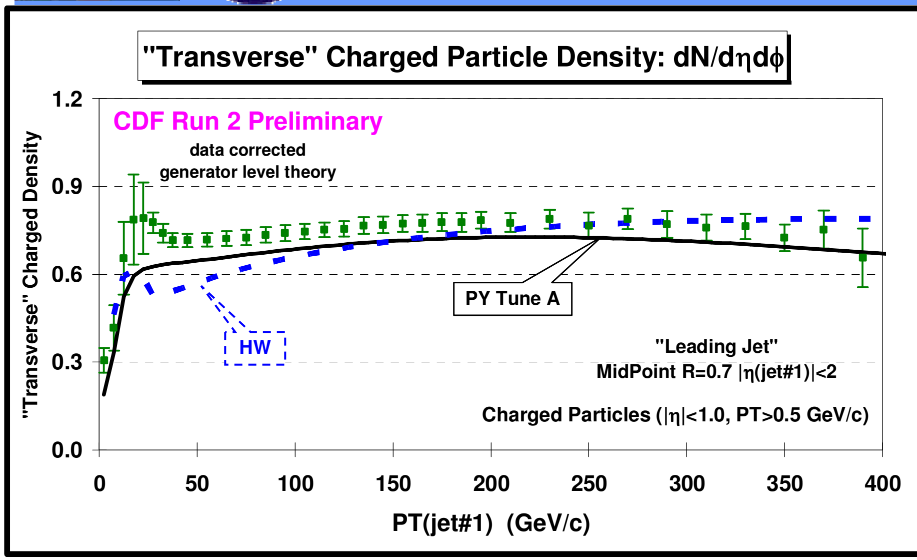
"Minumum ... " Collisions



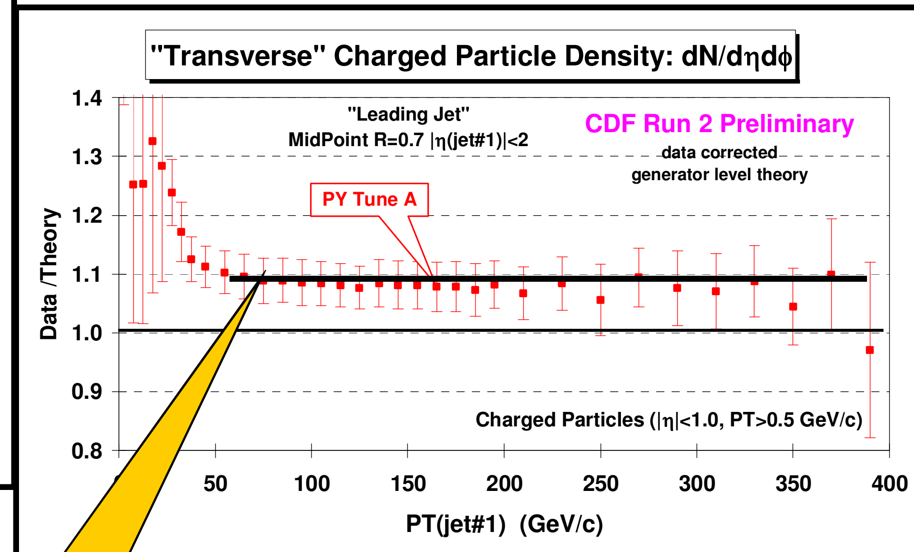


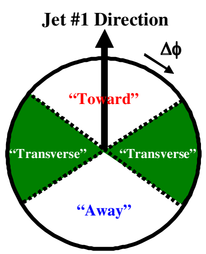
- **Shows the individ ... he DW and Tune S320 Perugia 0. T ... e of dN/dη for the region |η| < 0.6. I ... and SD contributions! I ... he HC component. We need to look at observables where only HC contributes!**

"Transverse" Charged Particle Density



A Closer Look!

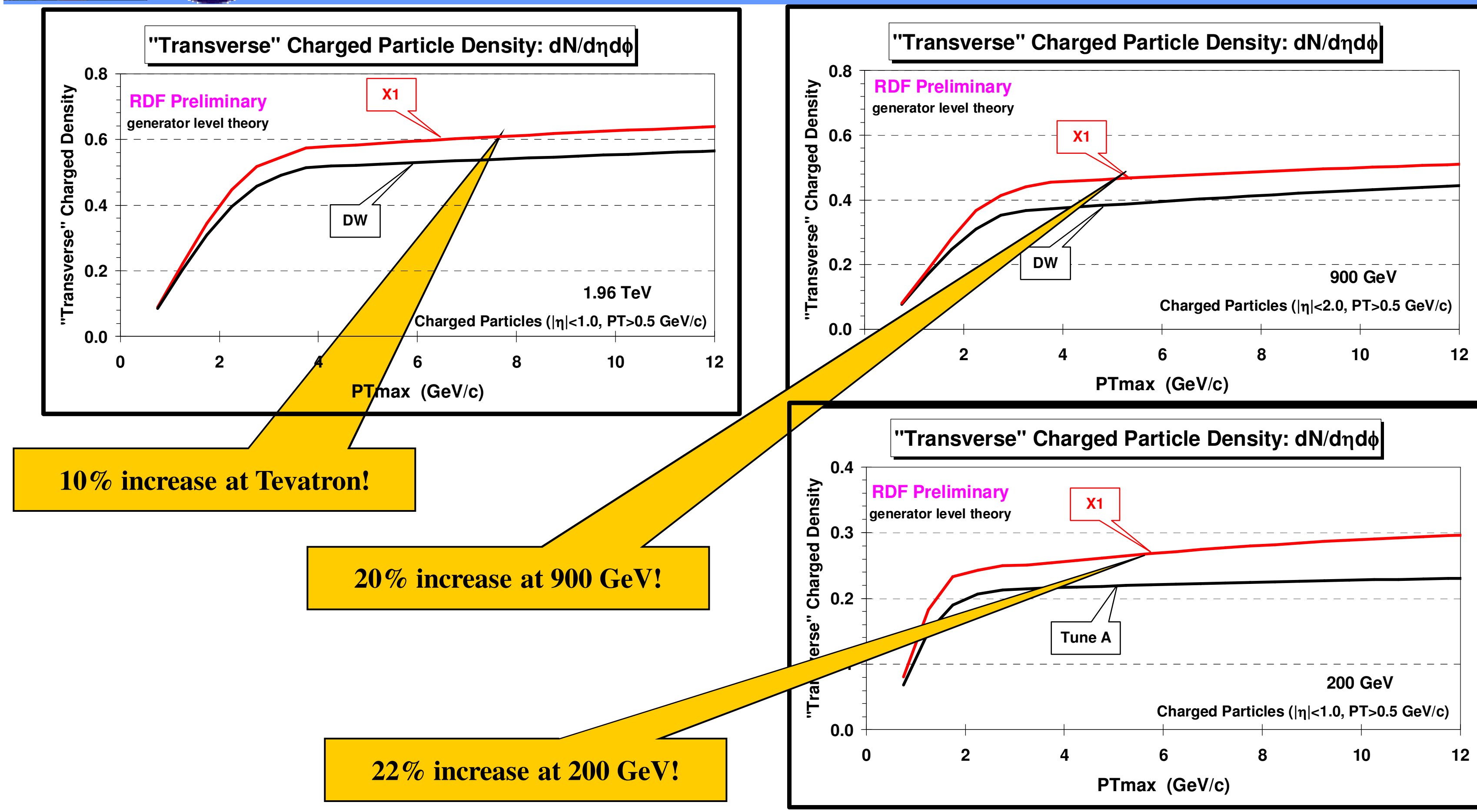




Room for 10% increase!

- **Data at 1.96 TeV on the charged particle density, with p_T > 0.5 GeV/c and |η| < 1 for the "transverse" region for "Leading Jet" events as a function of the leading jet p_T. The data are corrected to the particle level (*with errors that include both the statistical error and the systematic uncertainty*) and are compared with PYTHIA Tune A and HERWIG (without MPI) at the generator level (*i.e.* particle level).**

PYTHIA Tune X1

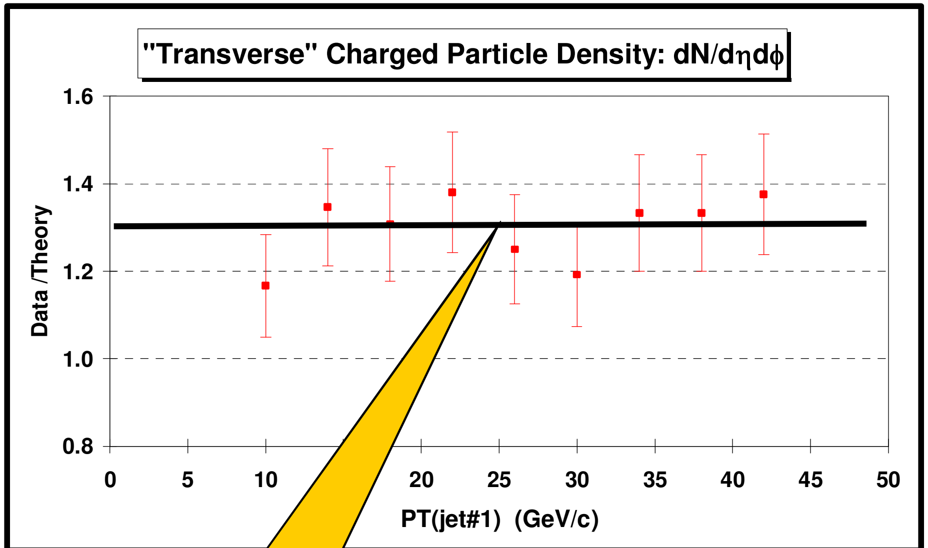


- Tune X1 (modify Tune DW slightly, PYTHIA 6.42). Uses old Q^2 ordered shower and old UE model. Change p_{T0} = PARP(82) slightly at the Tevtron. Change ε = PARP(90).

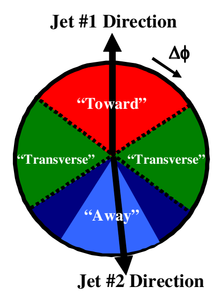
Change color connection back to those in Tune A.

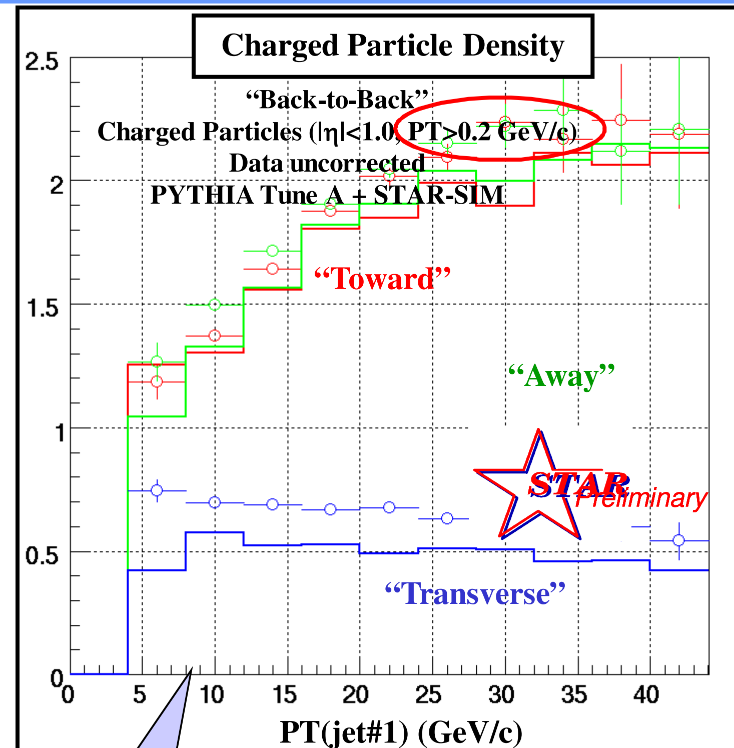
The "Underlying Event" at STAR

A Closer Look!



Room for 30% increase!

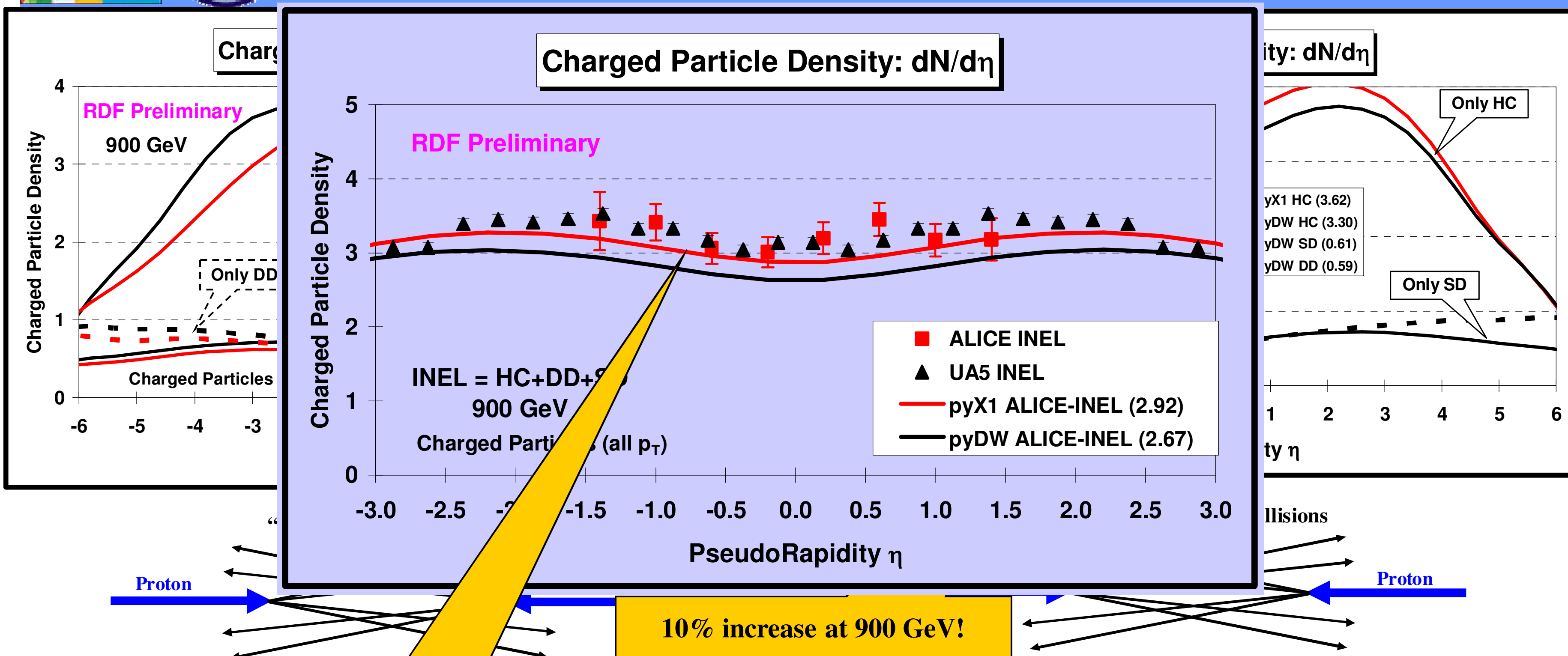




"Back-to-Back"

- Data at 200 GeV on the charged particle density, dN/dηdϕ, as a function of the leading jet p_T for the "toward", "away", and "transverse" regions compared with PYTHIA Tune A.

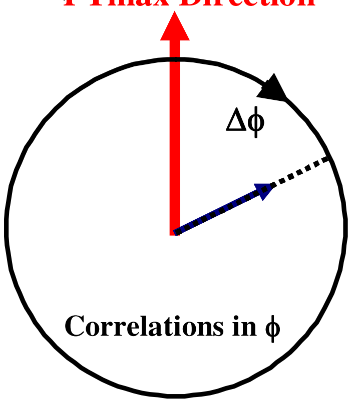
LHC Predictions: 900 GeV



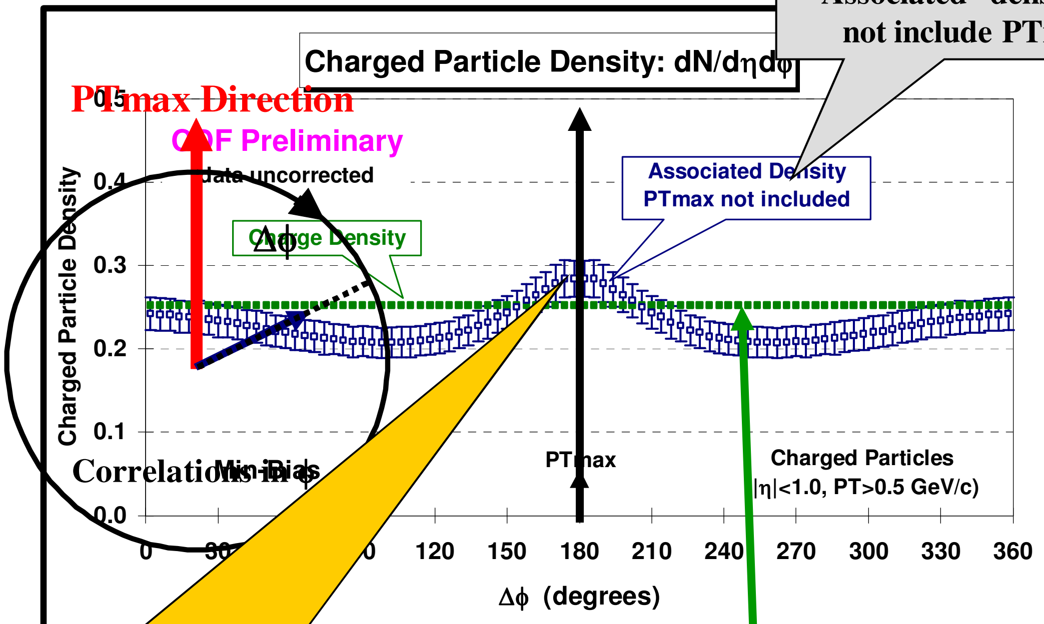
- Shows the individual HC, DD, and SD predictions of PYTHIA Tune DW and Tune S320. Numbers in parentheses are the average value of dN/dη for the region |η| < 0.6

Min-Bias “Associated” Charged Particle Density

Highest p_T charged particle!



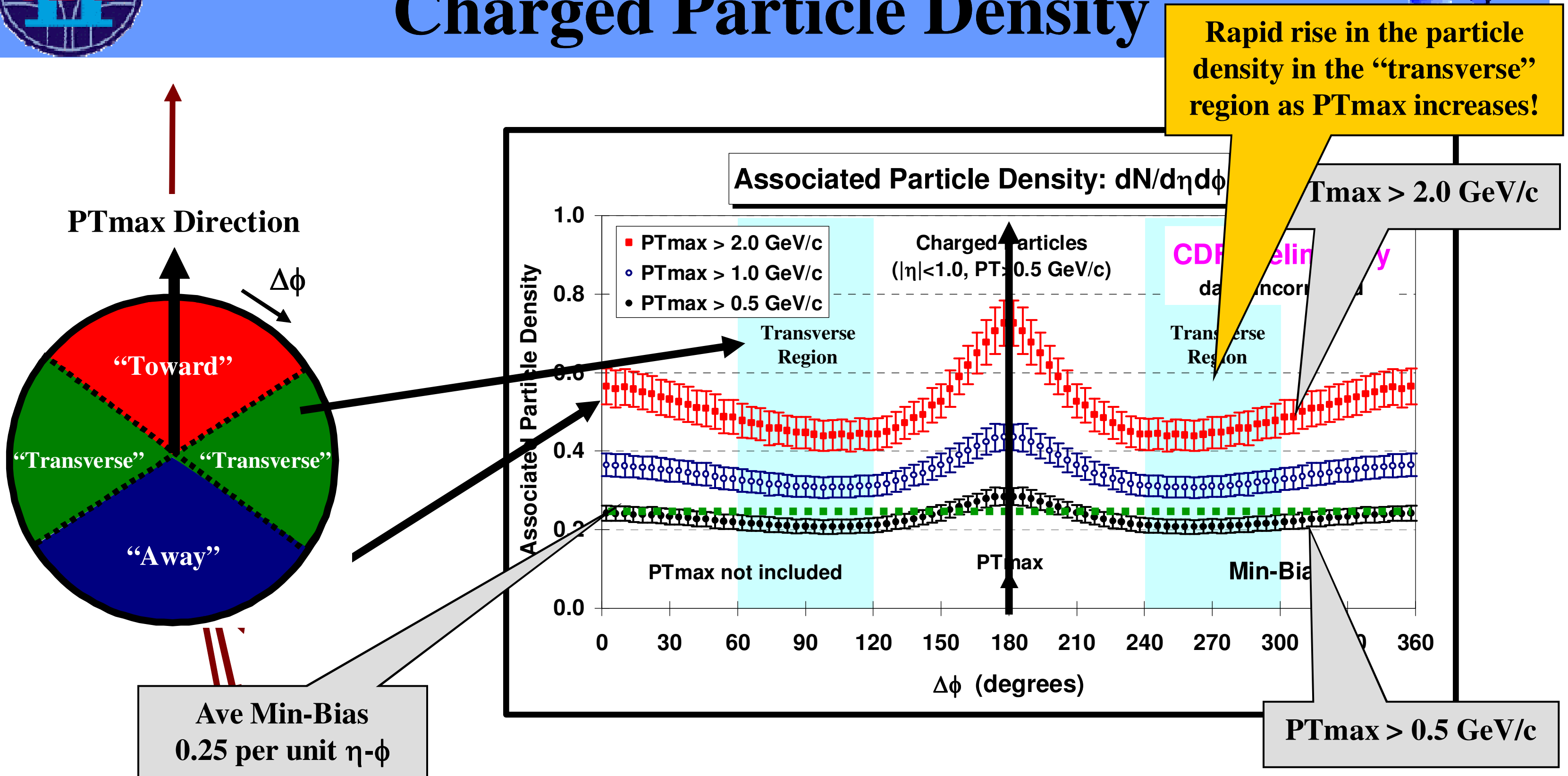
“Associated” densities do not include PTmax!



- Use the m… …, PTmax, to define a direction and look at the the … n-bias” collisions (p_T > 0.5 GeV/c, |η| < 1).
- Shows the … iated” 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. Also shown is the average charged particle density, dNchg/dηdϕ, for “min-bias” events.

It is more probable to find a particle accompanying PTmax than it is to find a particle in the central region!

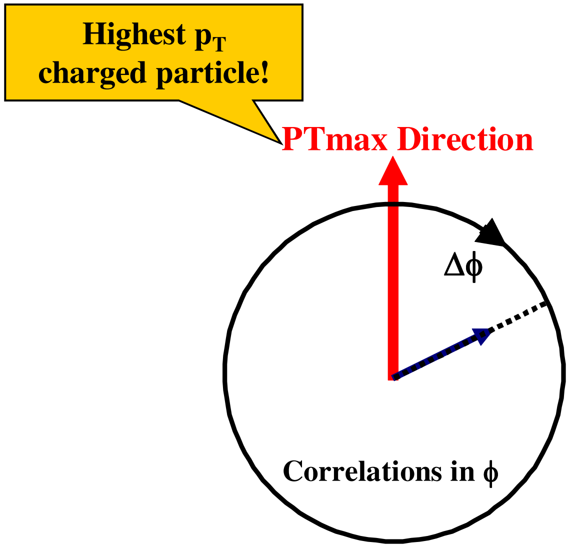
Min-Bias "Associated" Charged Particle Density

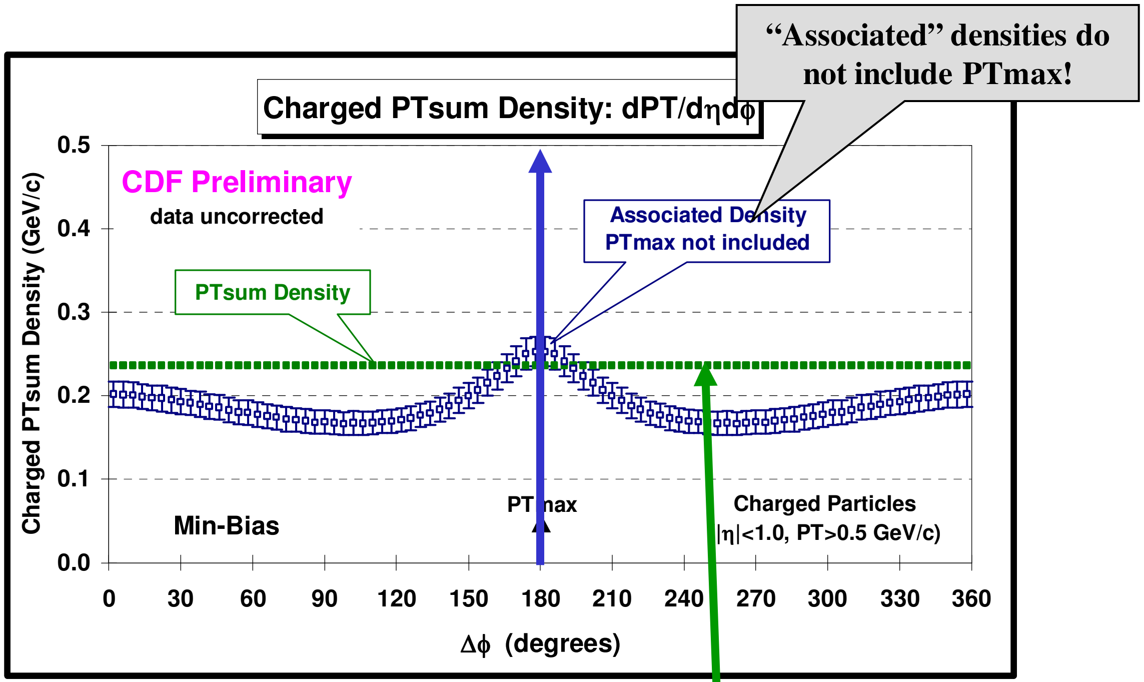


- Shows the data on the Δϕ dependence of the "associated" charged particle density, dNchg/dηdϕ, for charged particles (p_T > 0.5 GeV/c, |η| < 1, *not including PTmax*) relative to PTmax (rotated to 180°) for "min-bias" events with PTmax > 0.5, 1.0, and 2.0 GeV/c.

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

Min-Bias "Associated" Charged PTsum Density

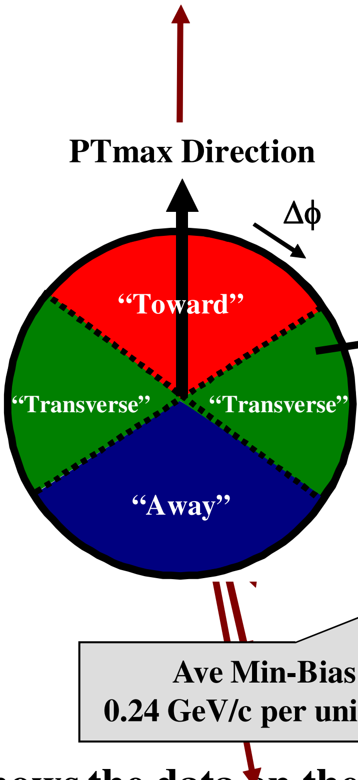


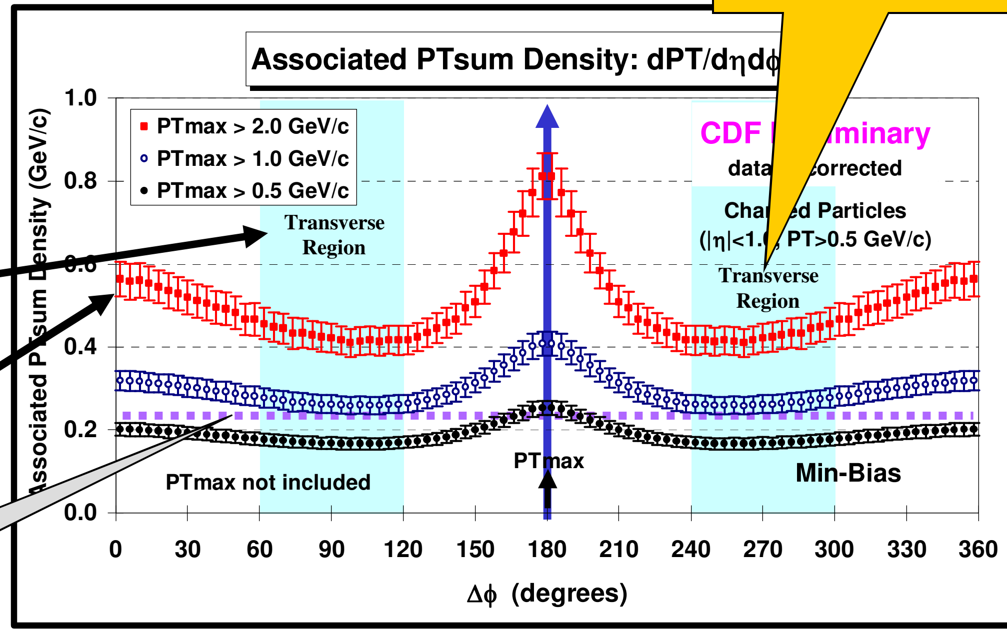


- Use the **maximum p_T charged particle in the event, PTmax**, to define a direction and look at the the "associated" PTsum density, dPTsum/dηdφ.
- Shows the data on the **Δφ dependence of the "associated" charged PTsum density**, dPTsum/dηdφ, for charged particles ($p_T > 0.5$ GeV/c, |η| < 1, *not including PTmax*) relative to PTmax (rotated to 180°) for **"min-bias" events**. **Also shown is the average charged particle density, dPTsum/dηdφ, for "min-bias" events.**

Min-Bias "Associated" Charged PTsum Density

Rapid rise in the PTsum density in the "transverse" region as PTmax increases!

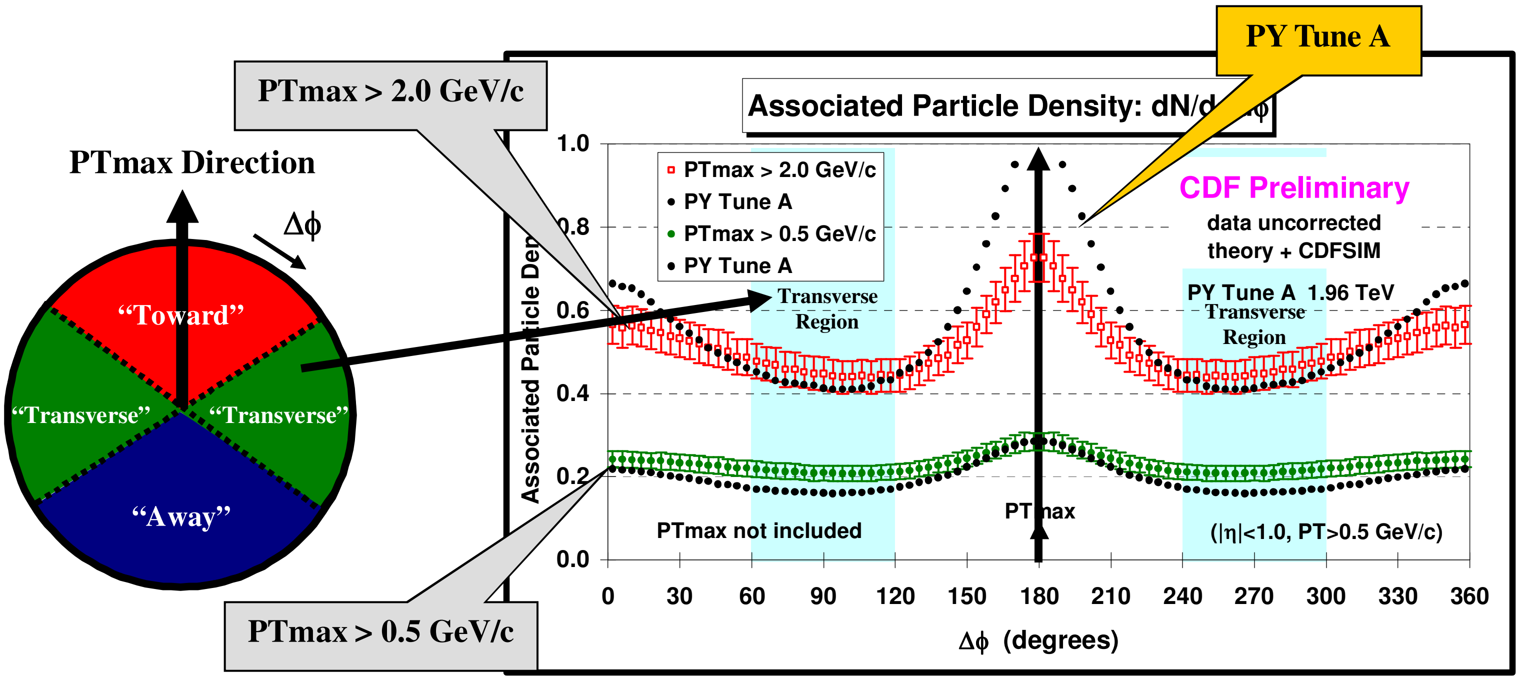




Ave Min-Bias
0.24 GeV/c per unit η-ϕ

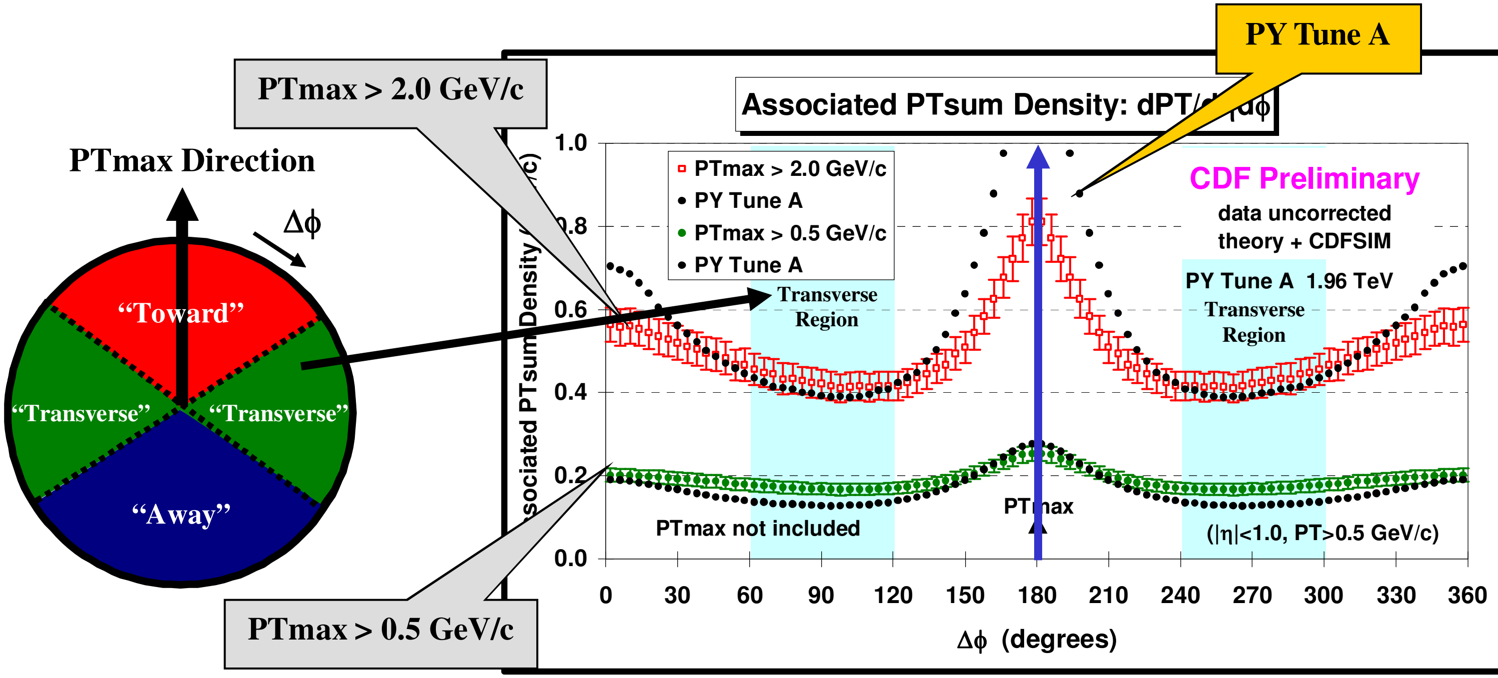
- Shows the data on the Δϕ dependence of the "associated" charged PTsum density, dPTsum/dηdϕ, for charged particles (p_T > 0.5 GeV/c, |η| < 1, *not including PTmax*) relative to PTmax (rotated to 180°) for "min-bias" events with PTmax > 0.5, 1.0, and 2.0 GeV/c.
- Shows "jet structure" in "min-bias" collisions (*i.e.* the "birth" of the leading two jets!).

Min-Bias "Associated" Charged Particle Density



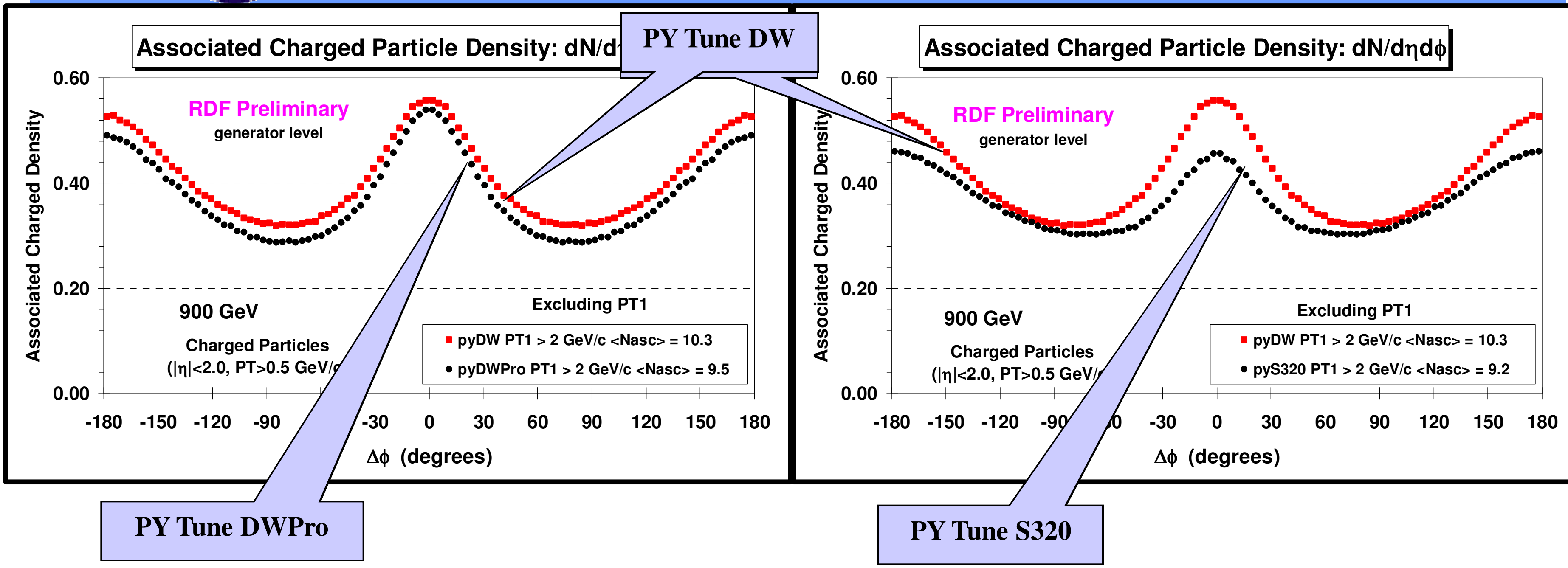
- Shows the data on the **Δϕ dependence of the "associated" charged particle density**, dNchg/dηdϕ, for charged particles ($p_T > 0.5$ GeV/c, $|\eta| < 1$, *not including PTmax*) relative to PTmax (rotated to 180°) for **"min-bias" events** with PTmax > 0.5 GeV/c and PTmax > 2.0 GeV/c compared with **PYTHIA Tune A** (after CDFSIM).
- **PYTHIA Tune A** predicts a larger correlation than is seen in the "min-bias" data (*i.e.* Tune A "min-bias" is a bit too "jetty").

Min-Bias "Associated" Charged PTsum Density



- Shows the data on the **Δϕ dependence of the "associated" charged PTsum density**, dPTsum/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** with PTmax > 0.5 GeV/c and PTmax > 2.0 GeV/c compared with **PYTHIA Tune A** (after CDFSIM).
- **PYTHIA Tune A** predicts a larger correlation than is seen in the "min-bias" data (*i.e.* **Tune A "min-bias" is a bit too "jetty"**).

“Associated” Charged Particle Density



- **Shows the Δϕ dependence of the “associated” charged particle density, dNchg/dηdϕ, for charged particles (p_T > 0.5 GeV/c, |η| < 2, *not including PTmax*) relative to PTmax at 900 GeV with PTmax > 2.0 GeV/c from PYTHIA Tune DW, Tune DWPro, and Tune S320 (generator level).**

My Dream!

The Goal – QCD MC

- Do not want a separate MC tune for MB at each energy (200 GeV. 630 G... 900 GeV, 1.96 TeV, and ...V)!

  Want "universal" t... predicts corr... energy dependence o...

- Do not want a separate MC... (200 GeV. 630 GeV, 900 GeV...

  Want "univ... energy depende...

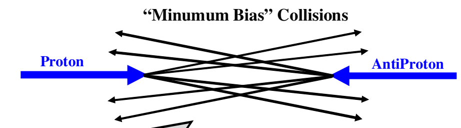
- Do not want a separate ... Yan!

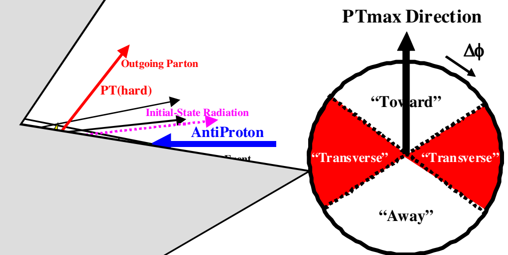
  Want "universal" t... processes!

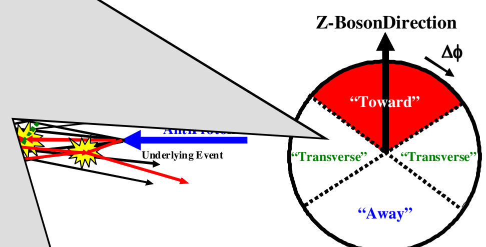
- Do not want a separate tune for ...

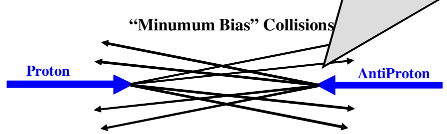
  Want "universal" tune that des... both the UE!

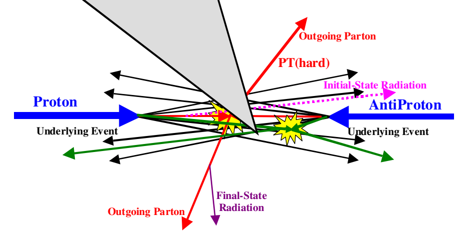
Stay tuned! UE studies at 900 GeV coming soon from CMS and ATLAS.











How precise does this have to be before one considers it a great success?