Workshop on Early Physics Opportunities at the LHC

"Min-Bias" and the "Underlying Event"

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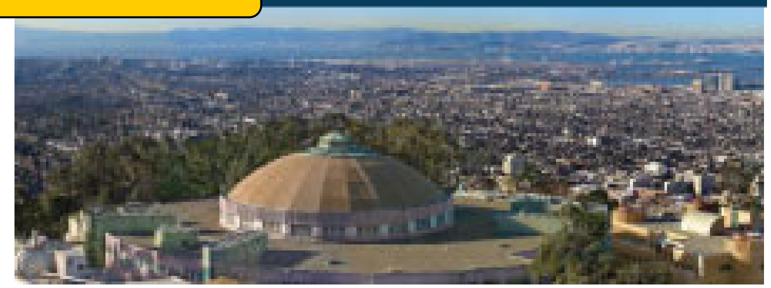


LBNL May 6, 2009

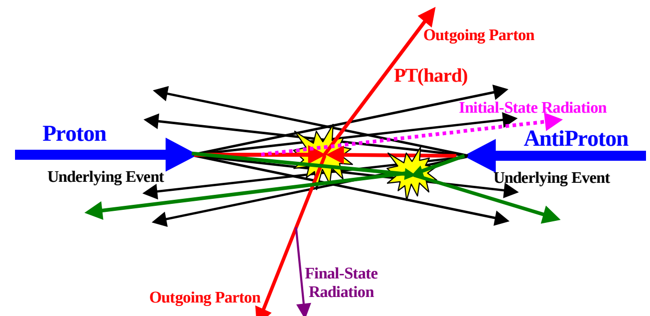
Rick Field

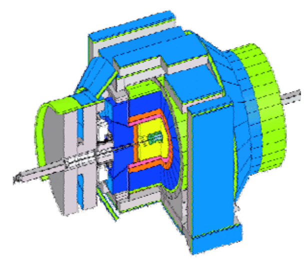
University of Florida

Outline of Talk

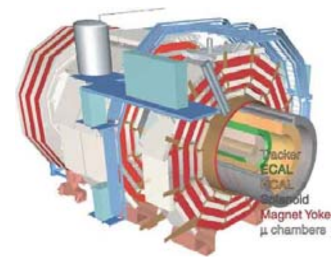
- The QCD Monte-Carlo Model tunes.
- The Pythia MPI energy scaling parameter PARP(90).
- "Min-Bias" and the "underlying event" at the LHC.
- The "underlying event" in Drell-Yan lepton-pair production.
- LHC predictions!
- Summary & Conclusions.
- Early LHC Thesis Projects.

Quantum Chromo-Dynamics



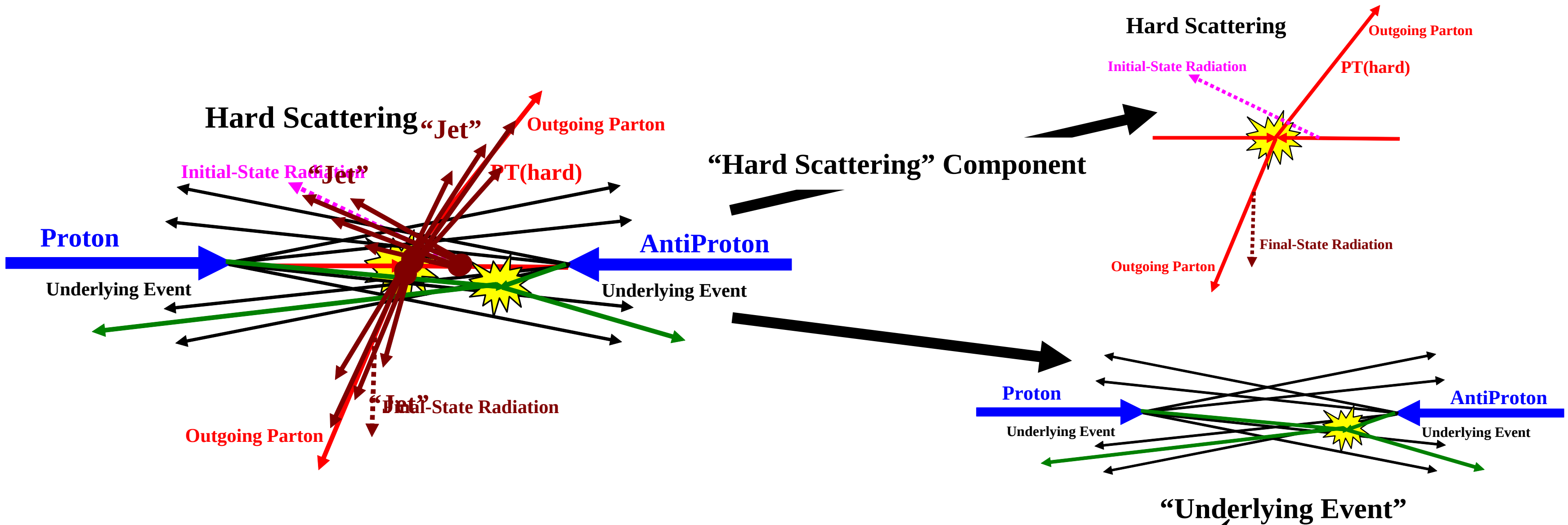


CDF Run 2



CMS at the LHC

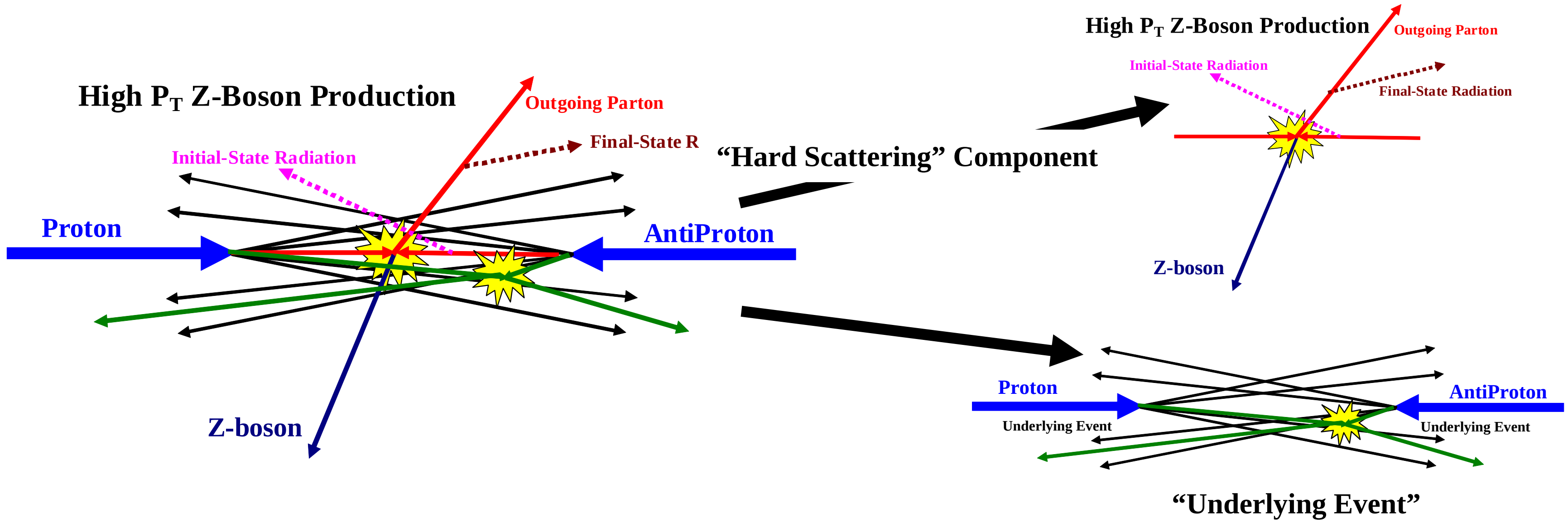
QCD Monte-Carlo Models: High Transverse Momentum Jets



- **Start with the perturbative 2-to-2 (or sometimes 2-to-3) parton-parton scatter 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 ply "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!

QCD Monte-Carlo Models: Lepton-Pair Production



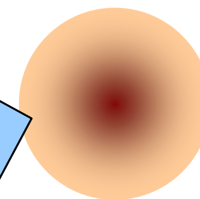
- **Start with the perturbative Drell-Yan muon pair production and add initial-state gluon radiation (in the leading log approximation or modified leading log approximation).**
- **The "underlying event" consists of the "beam-beam remnants" and from particles arising from soft or semi-soft multiple parton interactions (MPI).**
- **Of course the outgoing colored partons fragment into hadron "jet" and inevitably "underlying event" observables receive contributions from initial-state radiation.**

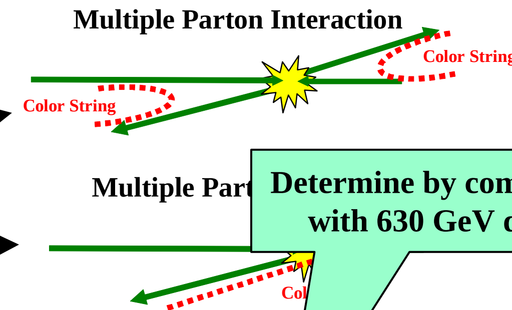
Tuning PYTHIA:
Multiple Parton Interaction Parameters

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... ines the reference energy E_0.
PARP(90)	0.16	...etermines 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.

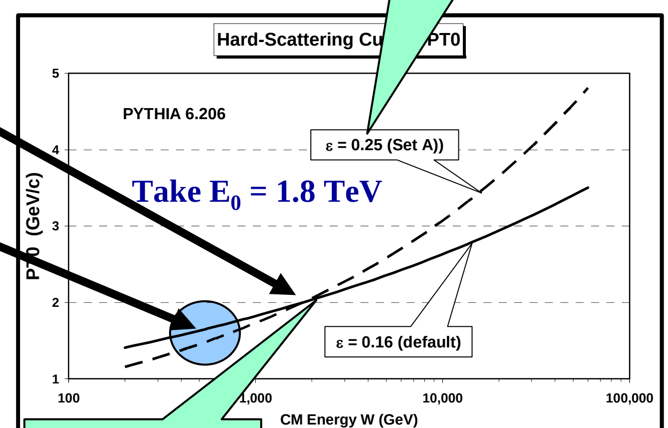
Affects the amount of initial-state radiation!

Hard Core



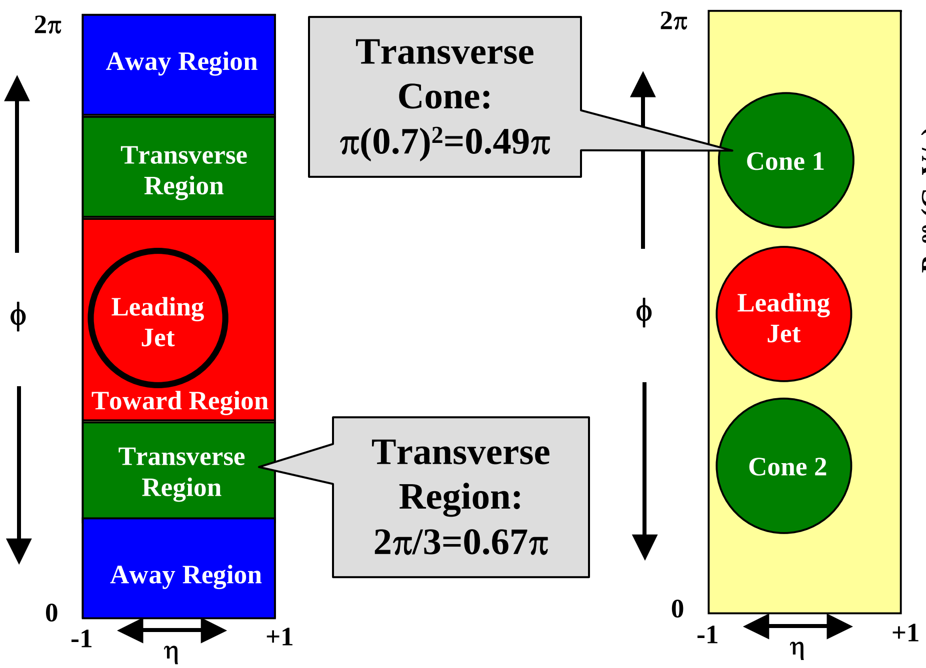


Determine by comparing with 630 GeV data!

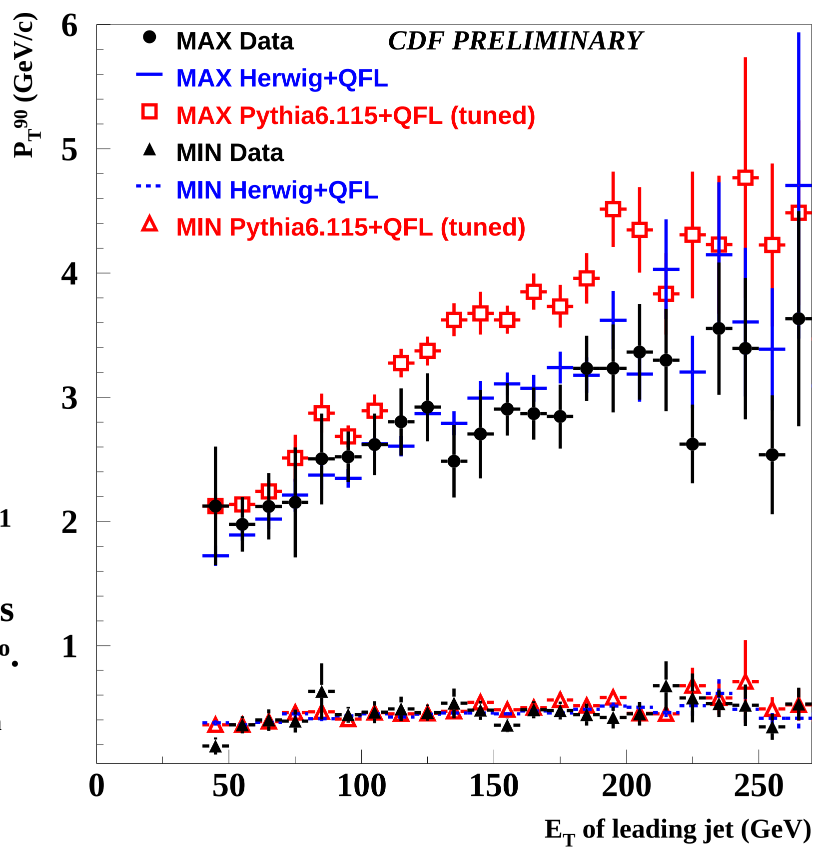


Reference point at 1.8 TeV

"Transverse" Cones vs "Transverse" Regions

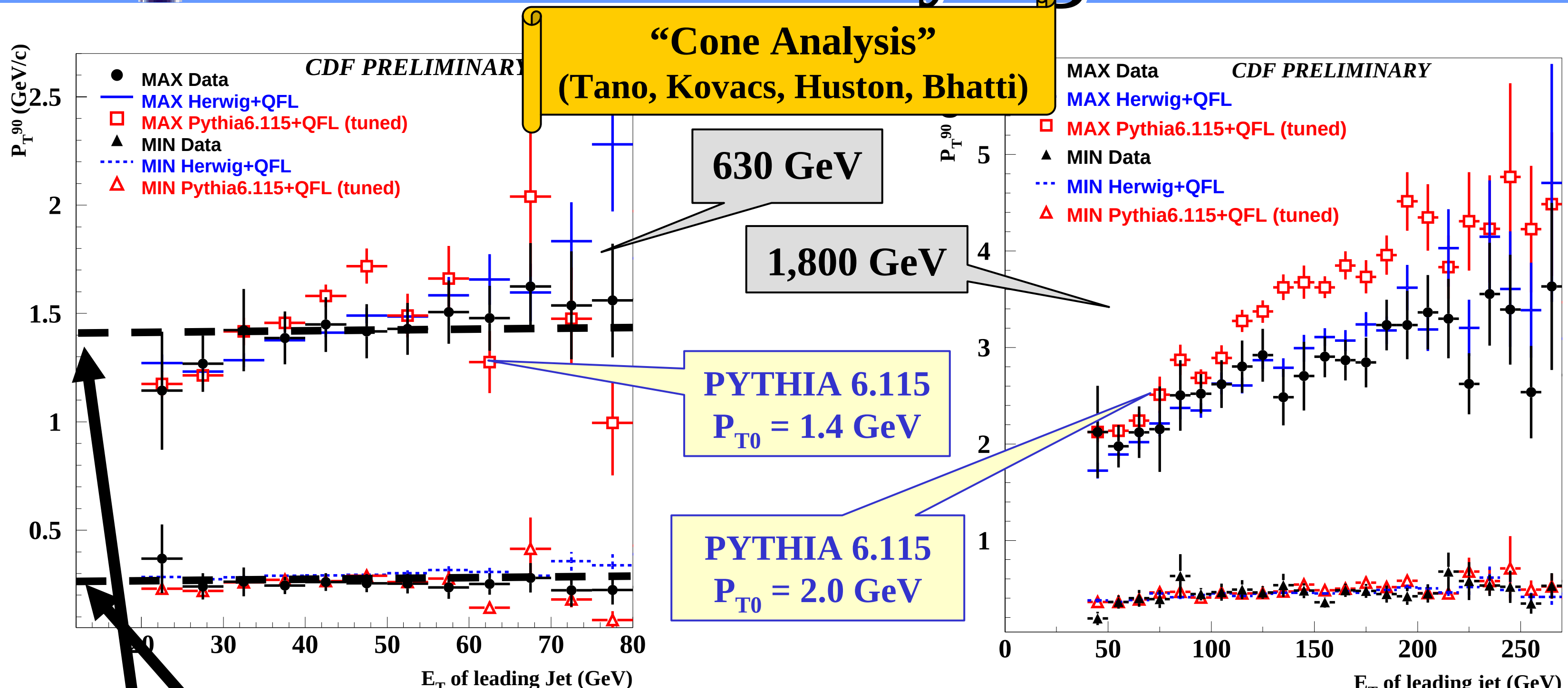


"Cone Analysis"
(Tano, Kovacs, Huston, Bhatti)



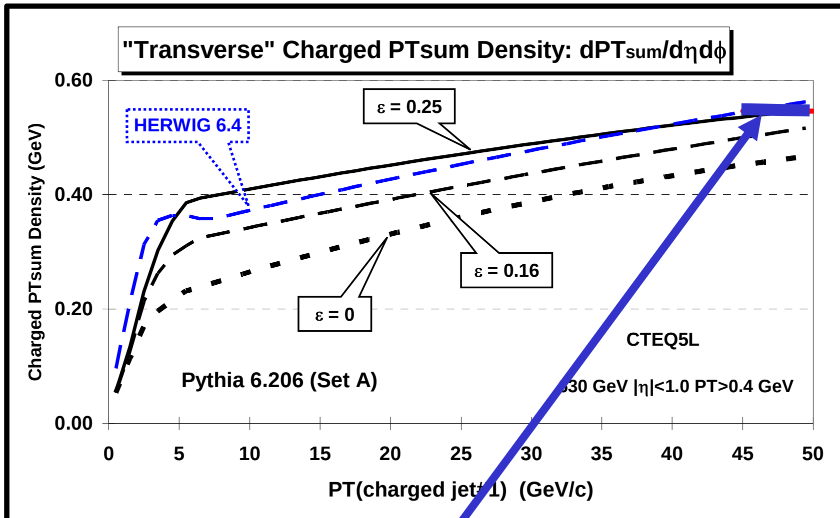
- Sum the P_T of charged particles in two cones of radius 0.7 at the same η as the leading jet but with |ΔΦ| = 90º.
- Plot the cone with the maximum and minimum PT_{sum} versus the E_T of the leading (calorimeter) jet.

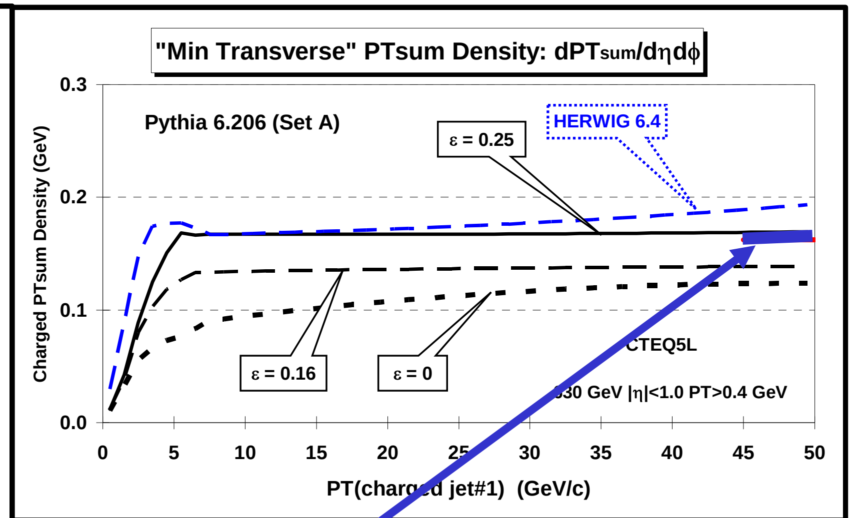
Energy Dependence of the "Underlying Event"



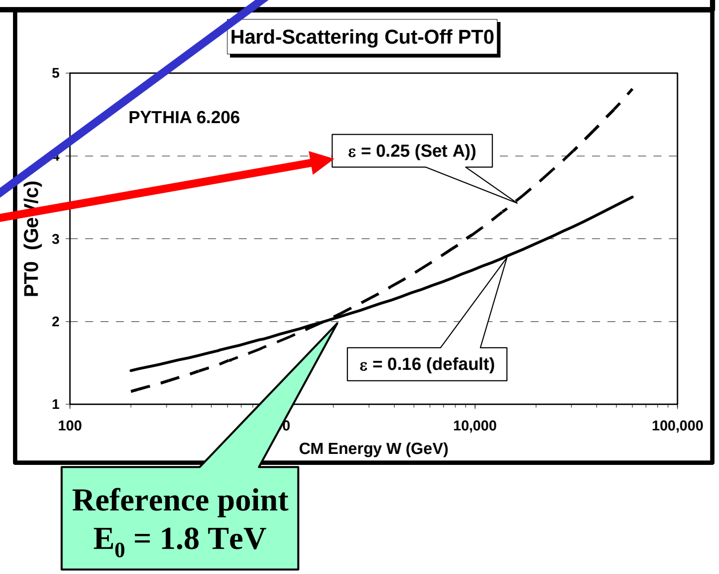
- Sum the P_T of charged particles (p_T > 0.4 GeV/c) in two cones of radius 0.7 at the same η as the leading jet but with |ΔΦ| = 90º. Plot the cone with the maximum and minimum PT_{sum} versus the E_T of the leading (calorimeter) jet.
- Note that PYTHIA 6.115 is tuned at 630 GeV with P_{T0} = 1.4 GeV 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

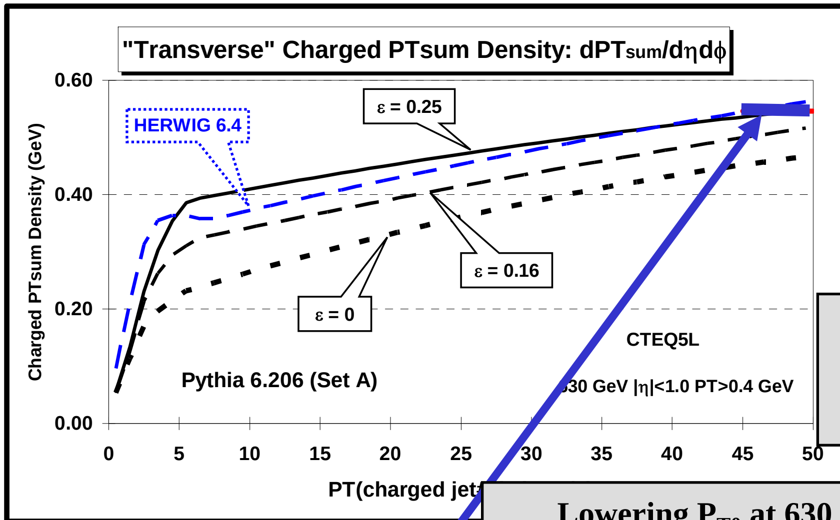


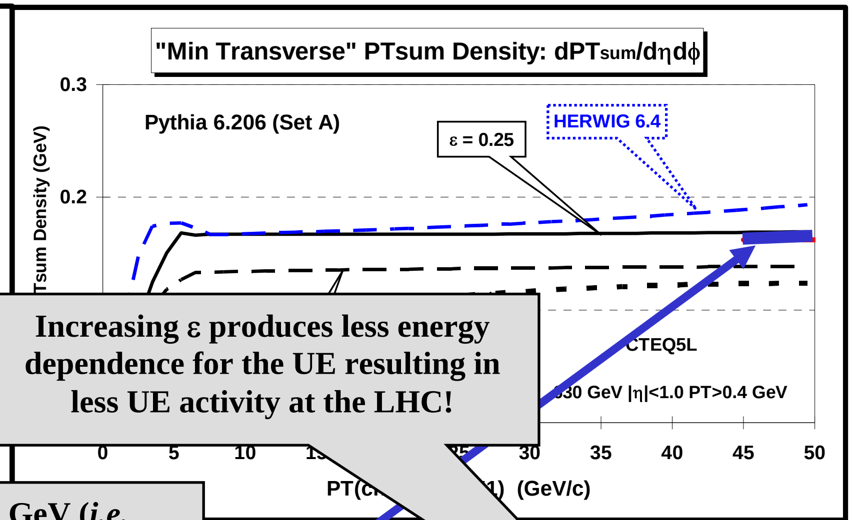


- Shows the "transverse" charged PT_{sum} density ($|\eta|<1$, $P_T>0.4$ GeV) versus P_T(charged jet#1) at 630 GeV predicted by HERWIG 6.4 (P_T(hard) > 3 GeV/c, CTEQ5L) and a tuned version of PYTHIA 6.206 (P_T(hard) > 0, CTEQ5L, Set A, $\varepsilon = 0$, $\varepsilon = 0.16$ (default) and $\varepsilon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



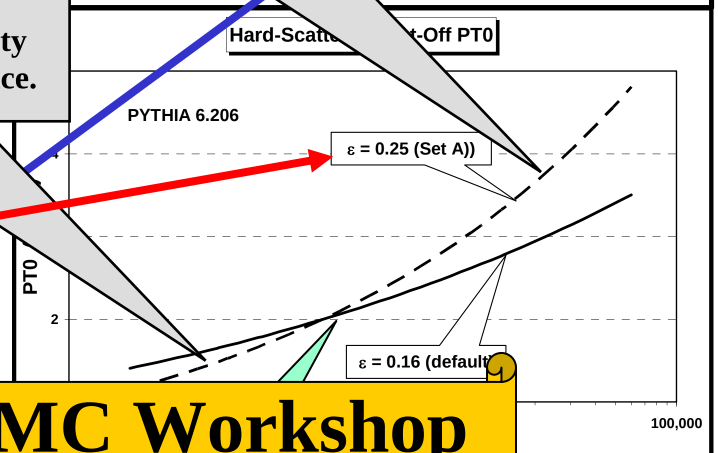
"Transverse" Charged Densities Energy Dependence





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.



- 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… densities (0.16 GeV/c and 0.54 GeV/c) … analysis at 63…

Rick Field Fermilab MC Workshop October 4, 2002!

PYTHIA 6.2 Tunes

All use LO α_s with Λ = 192 MeV!

UE Parameters

ISR Parameter

Intrinsic KT

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

Uses CTEQ6L

Tune A energy dependence!

PYTHIA 6.2 Tunes

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

PYTHIA 6.2 Tunes

All use LO α_s with Λ = 192 MeV!

UE Parameters

Parameter	Tune DWT	Tune D6T	ATLAS
PDF	CTEQ5L	CTEQ6L	CTEQ5L
MSTP(81)	1	1	1
MSTP(82)	4	4	4
[illegible]	1.9409 GeV	1.8387 [illegible]	1.8 GeV
[illegible]	0.5	[illegible]	0.5
[illegible]	0.4	[illegible]	[illegible]
[illegible]	1.0	[illegible]	[illegible]
[illegible]	1.0	[illegible]	[illegible]
[illegible]	1.96 TeV	[illegible]	1.0 TeV
PARP(90)	0.16	0.16	0.16
PARP(62)	1.25	1.25	1.0
PARP(64)	[illegible]	0.2	1.0
[illegible]	[illegible]	2.5	1.0
[illegible]	[illegible]	1	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	15.0	[illegible]

Tune A

Tune AW

Tune B

Tune BW

Tune D

Tune DW

Tune D6

Tune D6T

PYTHIA 6.2 Tunes

All use LO α_s with Λ = 192 MeV!

UE Parameters

Parameter	Tune DWT	Tune D6T	
PDF	CT	CTEQ6L	L
MSTP(81)		1	
PARP(			
MSTP			
PAR		2.	
PA		15.0	

Tune A

Tune D

Tune D6T

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")

Peter's Pythia Tunes WEBsite

Peter's Pythia Plots

February 2009 © P. Z. Skands

Navigate these pages by using the menu to the left. More plots will be added, as new tunes become available, and as the available data increases. The default for each topic is a comparison of a small number of tunes to available data (or just to each other if no data exists), but look for links at the top of each page for comparisons with more models.

Apr 2009: Full descriptions and parameters of the "Perugia" tunes (submitted to the Perugia MPI workshop proceedings)
Dec 2007: Some interesting min-bias distributions for early LHC runs (submitted to the 2007 Les Houches workshop proceedings)

The tunes currently available on the plots are (numbered as in PYTUNE):

Tunes using Q2-ordered model

- 100: **A**: Rick Field's Tune A to Tevatron Underlying-Event Data. Uses the "old" UE and shower models, with a double-gaussian matter profile, 1 GeV of primordial kT, and near-maximal color correlations. [Oct 2002]
- 103: **DW**: Rick Field's Tune DW to Tevatron Underlying-Event and Drell-Yan Data. Similar to Tune A, but has 2 GeV of primordial kT and uses a very small renormalization scale for initial-state radiation (i.e., more ISR radiation). It also has completely maximal color correlations. [Apr 2006]
- 104: **DWT**: Variant of DW using the Pythia 6.2 default collider energy scaling (has worse agreement with Tevatron energy scaling quantities than DW). [Apr 2006]
- 106: **ATLAS-DC2** ("Rome"): first ATLAS tune of the Q2-ordered showers and old UE framework. Does not give very good agreement with Tevatron min-bias quantities.
- 107: **A-CR**: variant of Tune A using the Pythia 6.2 default color connections but with the new "color annealing" color reconnection model applied as an afterburner. Is intended as an example of strong color reconnections. [Mar 2007]
- 108: **D6**: Rick Field's Tune D6 to Tevatron data, using CTEQ6L1 PDFs.
- 110: **A-Pro**: Tune A with LEP tune from Professor. [Oct 2008]
- 113: **DW-Pro**: Tune DW with LEP tune from Professor. [Oct 2008]
- 114: **DWT-Pro**: Tune DWT with LEP tune from Professor. [Oct 2008]
- 116: **ATLAS-DC2-Pro**: ATLAS-DC2 with LEP tune from Professor. [Oct 2008]
- 117: **A-CR-Pro**: Tune A-CR with LEP tune from Professor. [Oct 2008]
- 118: **D6-Pro**: Tune D6 with LEP tune from Professor. [Oct 2008]
- 129: **Pro-Q20**: Tune of the Q2-ordered showers and old UE framework made with Professor, an automated tuning tool. [Feb 2009]

Tunes intermediate between Q2- and pT-ordered models

- 201: **A-PT**: Retune of Tune A with pT-ordered final-state showers. [Mar 2007]
- 211: **A-PT-Pro**: Tune A-PT with LEP tune from Professor. [Oct 2008]
- 221: **Perugia A-PT**: "Perugia" update of A-PT-Pro. [Feb 2009]
- 226: **Perugia A6-PT**: "Perugia" update of A-PT-Pro, using CTEQ6L1 PDFs. [Feb 2009]

Tunes using pT-ordered model

- 300: **S0**: First Sandhoff-Skands Tune of the "new" UE and shower framework, with a smoother matter profile than Tune A, 2 GeV of primordial kT, and "colour annealing" color reconnections. Uses the default Pythia energy scaling rather than that of Tune A. [Apr 2006]
- 303: **S0A**: A variant of S0 which is identical to S0 at the Tevatron, but which uses the Tune A energy scaling of the UE activity. [Apr 2006]
- 304: **NOCR**: Sandhoff-Skands "best try" without color reconnections. Gives less good agreement with Tevatron data. [Apr 2006]
- 306: **ATLAS-CSC**: first ATLAS tune of the pT-ordered showers and new UE framework. Does not give very good agreement with Tevatron min-bias quantities.
- 313: **S0A-Pro**: A variant of S0A revamped with a comprehensive retune of the fragmentation parameters to LEP data (by the "Professor" tool, hence the name). [Oct 2008]
- 314: **NOCR-Pro**: NOCR with LEP tune from Professor. [Oct 2008]
- 320: **Perugia 0**: "Perugia" update of S0-Pro. [Feb 2009]
- 321: **Perugia HARD**: Systematically "hard" variant of Perugia 0. [Feb 2009]
- 322: **Perugia SOFT**: Systematically "soft" variant of Perugia 0. [Feb 2009]
- 323: **Perugia 3**: Variant of Perugia 0 with different ISR/MPI balance and different collider energy scaling. [Feb 2009]
- 324: **Perugia NOCR**: "Perugia" update of NOCR-Pro. [Feb 2009]
- 325: **Perugia X**: Variant of Perugia 0 using MRST LO* PDFs. [Feb 2009]
- 326: **Perugia 6**: Variant of Perugia 0 using CTEQ6L1 PDFs. [Feb 2009]
- 329: **Pro-pT0**: Tune of the pT-ordered showers and new UE framework made with Professor, an automated tuning tool. [Feb 2009]

➡ **http://home.fnal.gov/~skands/leshouches-plots/**

Peter's Pythia Tunes WEBsite

Peter's Pyth…

February 2009 © P…

Navigate these pages by using the menu to the lef… become available, and as the available data increas… comparison of a small number of tunes to available … but look for links at the top of each page for compar…

Apr 2009: Full descriptions and parameters of the "P… MPI workshop proceedings)
Dec 2007: Some interesting min-bias distributions fo… Houches workshop proceedings)

The tunes currently available on the plots are (numb…

Tunes using Q2-ordered model…

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- 103: **DW**: Rick Field's Tune DW to Tevatron U… to Tune A, but has 2 GeV of primordial kT and… initial-state radiation (i.e., more ISR radiation)… correlations. [Apr 2006]
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- 108: **D6**: Rick Field's Tune D6 to Tevatron data…
- 110: **A-Pro**: Tune A with LEP tune from Profes…
- 113: **DW-Pro**: Tune DW with LEP tune from P…
- 114: **DWT-Pro**: Tune DWT with LEP tune from…
- 116: **ATLAS-DC2-Pro**: ATLAS-DC2 with LEP t…

…Oct 2008]
…2008]
… framework made with

…pT-ordered models

…owers. [Mar 2007]
…Oct 2008]
…09]
…CTEQ6L1 PDFs. [Feb 2009]

…shower framework, with a …T, and "colour annealing" color …er than that of Tune A. [Apr

…atron, but which uses the Tune

…nnections. Gives less good

…ers and new UE framework. … quantities.

…nsive retune of the …ool, hence the name). [Oct

… 2008]

…ia 0. [Feb 2009]
…a 0. [Feb 2009]
…balance and different collider

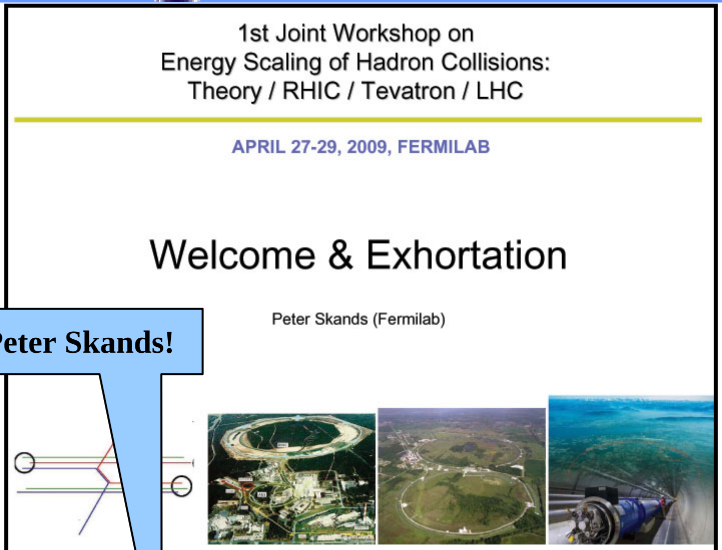
…2009]
…s. [Feb 2009]
…. [Feb 2009]
…E framework made with

Parameter	Type	S0A-Pro	P-0	P-HARD	P-SOFT	P-3	P-NOCR	P-X	P-6
MSTP(51)	PDF	7	7	7	7	7	7	20650	10042
MSTP(52)	PDF	1	1	1	1	1	1	2	2
MSTP(64)	ISR	2	3	3	2	3	3	3	3
PARP(64)	ISR	1.0	1.0	0.25	2.0	1.0	1.0	2.0	1.0
MSTP(67)	ISR	2	2	2	2	2	2	2	2
PARP(67)	ISR	4.0	1.0	4.0	0.5	1.0	1.0	1.0	1.0
MSTP(70)	ISR	2	2	0	1	0	2	2	2
PARP(62)	ISR	-	-	1.25	-	1.25	-	-	-
PARP(81)	ISR	-	-	-	1.5	-	-	-	-
MSTP(72)	ISR	0	1	1	0	2	1	1	1
PARP(71)	FSR	4.0	2.0	4.0	1.0	2.0	2.0	2.0	2.0
PARJ(81)	FSR	0.257	0.257	0.3	0.2	0.257	0.257	0.257	0.257
PARJ(82)	FSR	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
MSTP(81)	UE	21	21	21	21	21	21	21	21
PARP(82)	UE	1.85	2.0	2.3	1.9	2.2	1.95	2.2	1.95
PARP(89)	UE	1800	1800	1800	1800	1800	1800	1800	1800
PARP(90)	UE	0.25	0.26	0.30	0.24	0.32	0.24	0.23	0.22
MSTP(82)	UE	5	5	5	5	5	5	5	5
PARP(83)	UE	1.6	1.7	1.7	1.5	1.7	1.8	1.7	1.7
MSTP(88)	BR	0	0	0	0	0	0	0	0
PARP(79)	BR	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
PARP(80)	BR	0.01	0.05	0.01	0.05	0.03	0.01	0.05	0.05
MSTP(91)	BR	1	1	1	1	1	1	1	1
PARP(91)	BR	2.0	2.0	1.0	2.0	1.5	2.0	2.0	2.0
PARP(93)	BR	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
MSTP(95)	CR	6	6	6	6	6	6	6	6
PARP(78)	CR	0.2	0.33	0.37	0.15	0.35	0.0	0.33	0.33
PARP(77)	CR	0.0	0.9	0.4	0.5	0.6	0.0	0.9	0.9
MSTJ(11)	HAD	5	5	5	5	5	5	5	5
PARJ(21)	HAD	0.313	0.313	0.34	0.28	0.313	0.313	0.313	0.313
PARJ(41)	HAD	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49
PARJ(4…)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.2	1.2
PARJ(46)	HAD	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
PARJ(47)	HAD	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0

PS, Proceedings of the Perugia MPI Workshop 2008

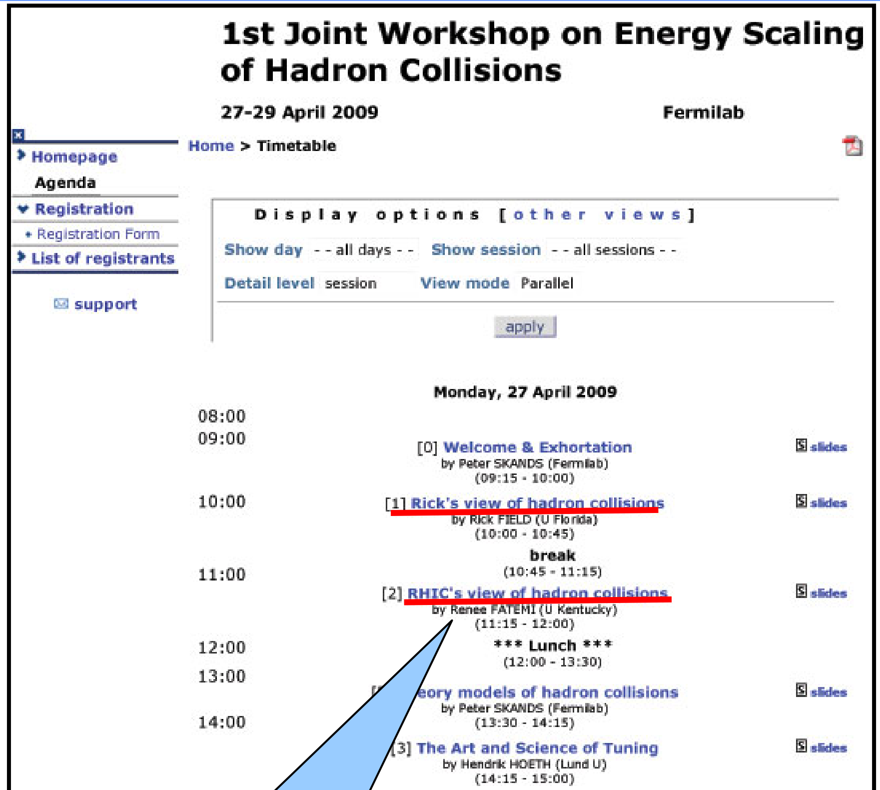
➡ **http://home.fnal.gov/~skands/leshouches-plots/**

1st Workshop on Energy Scaling in Hadron-Hadron Collisions



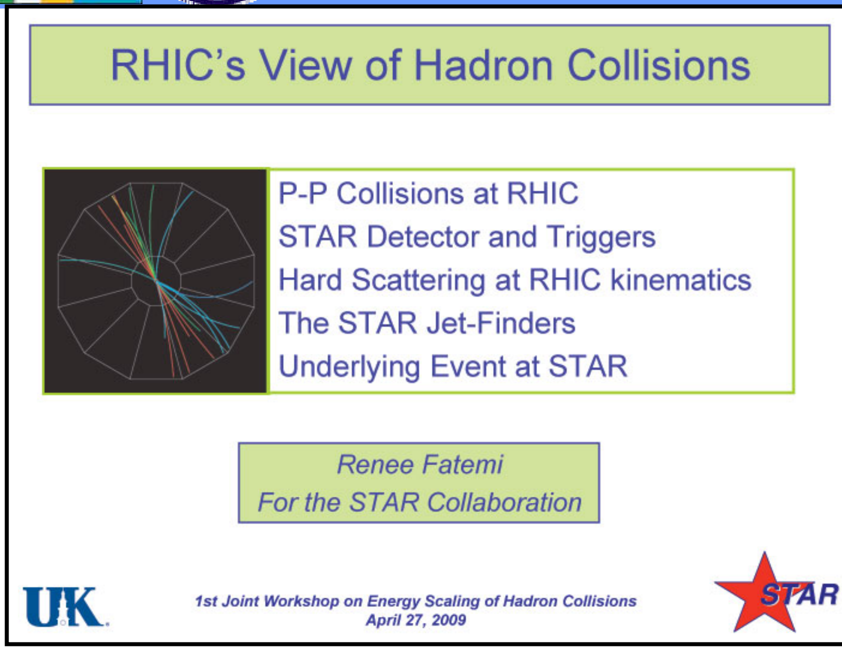
Peter Skands!

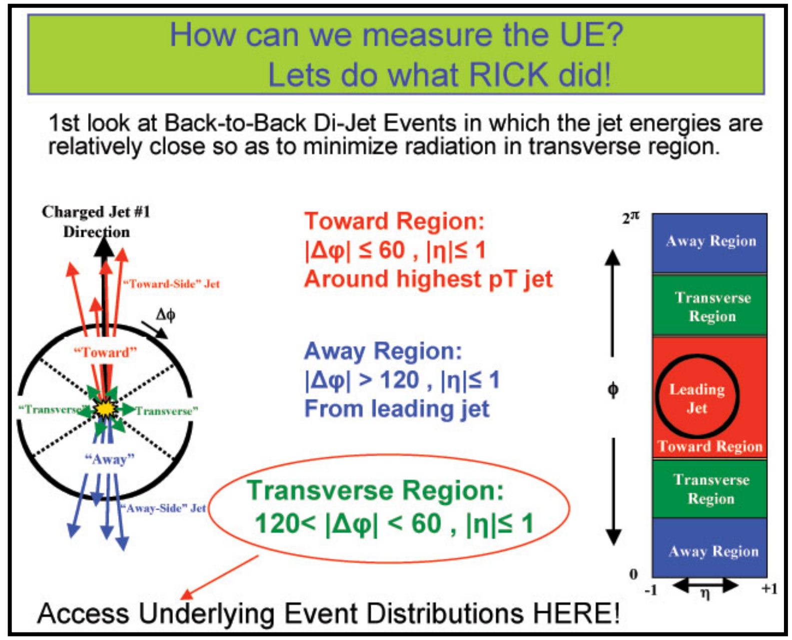
"On the Boarder" restaurant, Aurora, IL
April 27, 2009



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

The “Underlying Event” at STAR

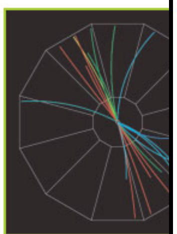




➡ **At STAR they have measured the “underlying event at W = 200 GeV (|η| < 1, p_T > 0.2 GeV) and compared with Pythia Tune A.**

The "Underlying Event" at STAR

RHIC



ergies are
egion.

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.

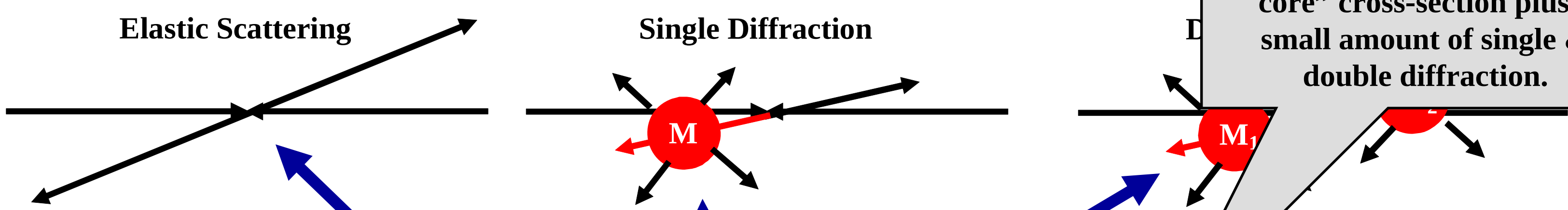
VII. For a cone jet with R=0.7 UE contributes 0.5-0.9 GeV.

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

UK

- **At STAR ... 2 GeV) and com...**

Proton-AntiProton Collisions at the Tevatron



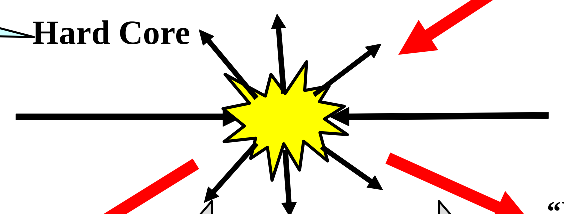
The CDF "Min-Bias" trigger picks up most of the "hard core" cross-section plus a small amount of single & double diffraction.

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

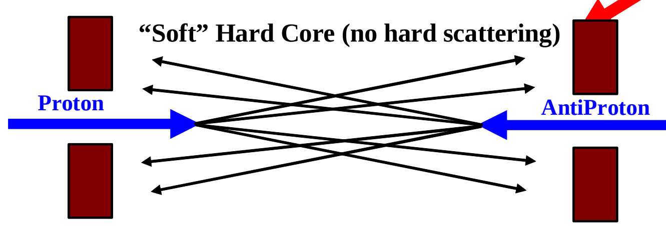
1.8 TeV: 78mb = 18mb + 9mb + (4-7)mb + (47-44)mb

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

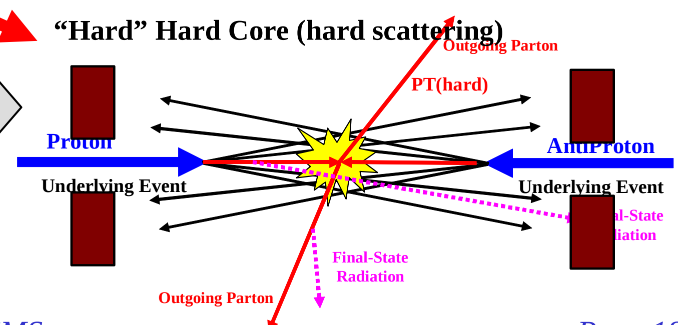
"Inelastic Non-Diffractive Component"



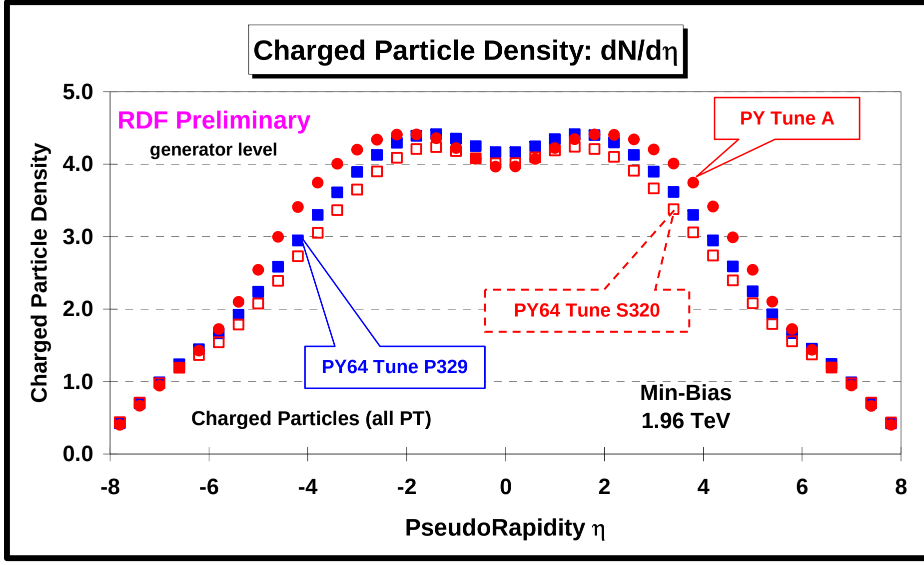
CDF "Min-Bias" trigger
1 charged particle in forward BBC
AND
1 charged particle in backward BBC

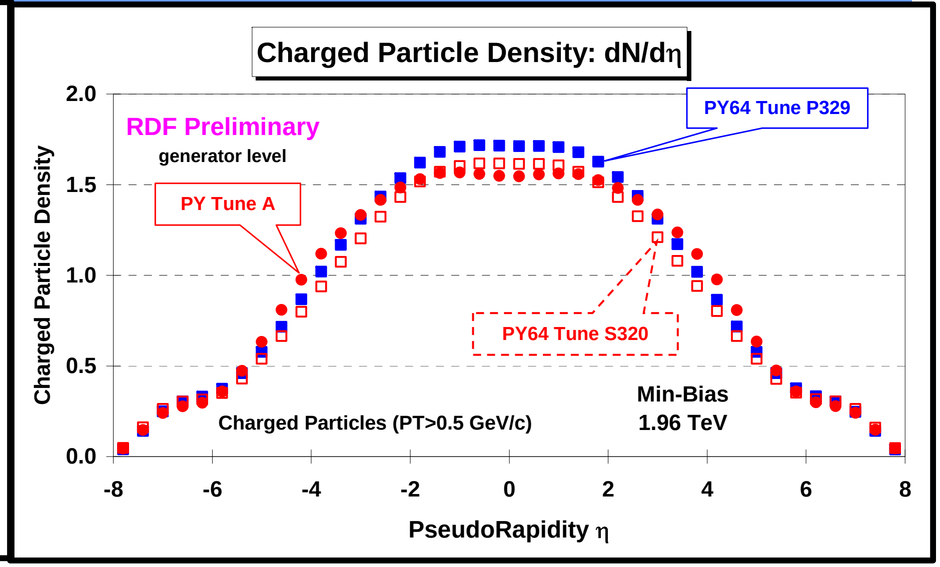


Beam-Beam Counters
$3.2 < |\eta| < 5.9$



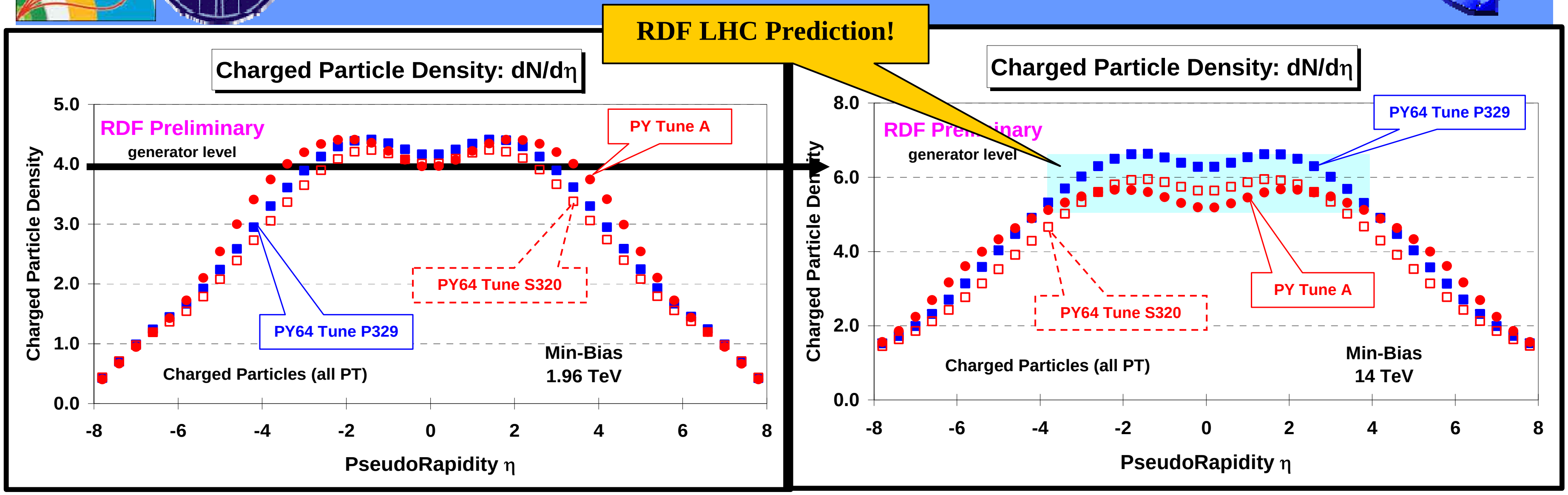
Charged Particle Density: dN/dη





- **Charged particle (all p_T) pseudo-rapidity distribution, $dN_{chg}/d\eta d\phi$, at 1.96 TeV for inelastic non-diffractive collisions from PYTHIA Tune A, Tune S320, and Tune P324.**
- **Charged particle (p_T>0.5 GeV/c) pseudo-rapidity distribution, $dN_{chg}/d\eta d\phi$, at 1.96 TeV for inelastic non-diffractive collisions from PYTHIA Tune A, Tune S320, and Tune P324.**

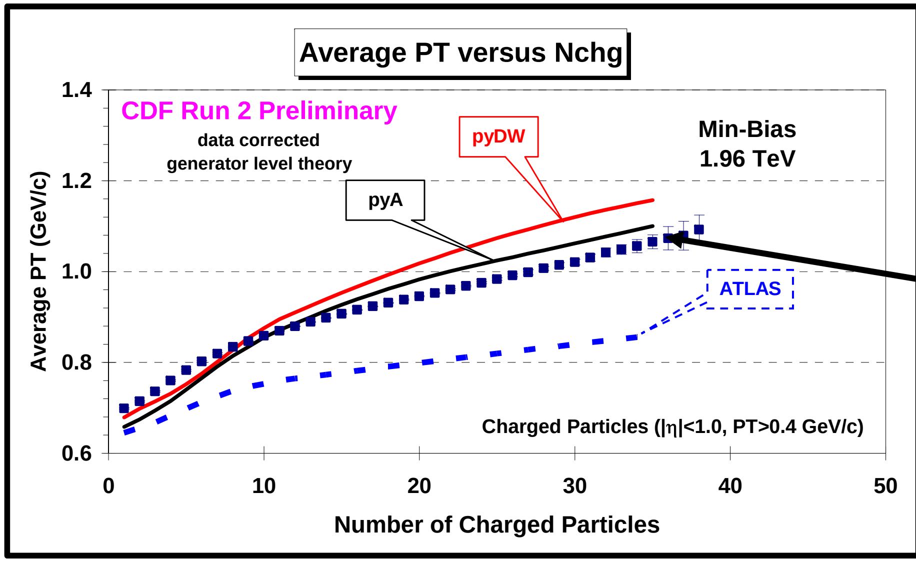
Charged Particle Density: dN/dη

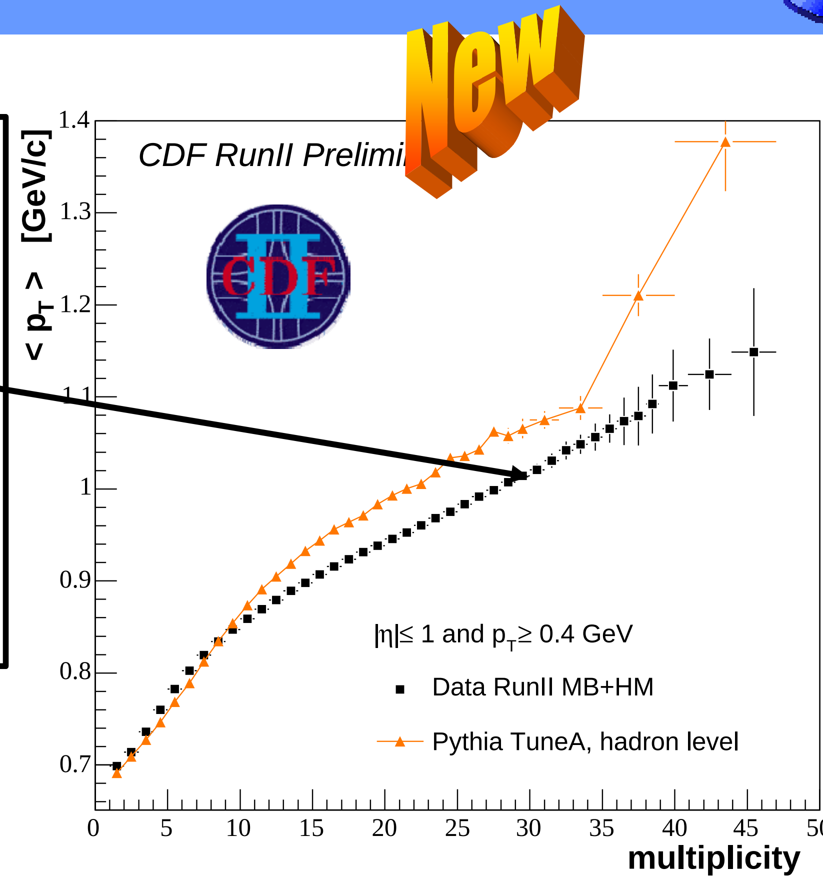


- Charged particle (all p_T) pseudo-rapidity distribution, $dN_{chg}/d\eta d\phi$, at 1.96 TeV for inelastic non-diffractive collisions from PYTHIA Tune A, Tune S320, and Tune P324.

- Extrapolations of PYTHIA Tune A, Tune S320, and Tune P329 to the LHC.

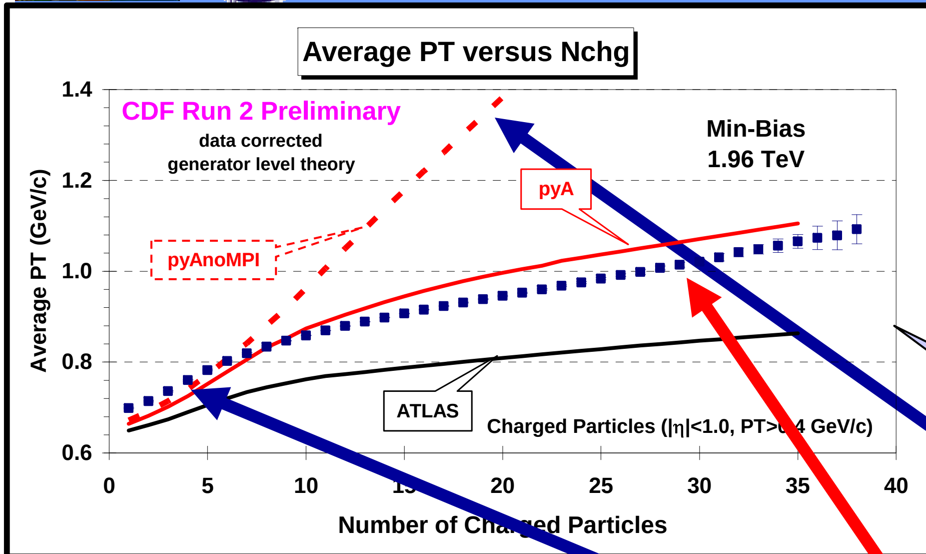
Min-Bias Correlations





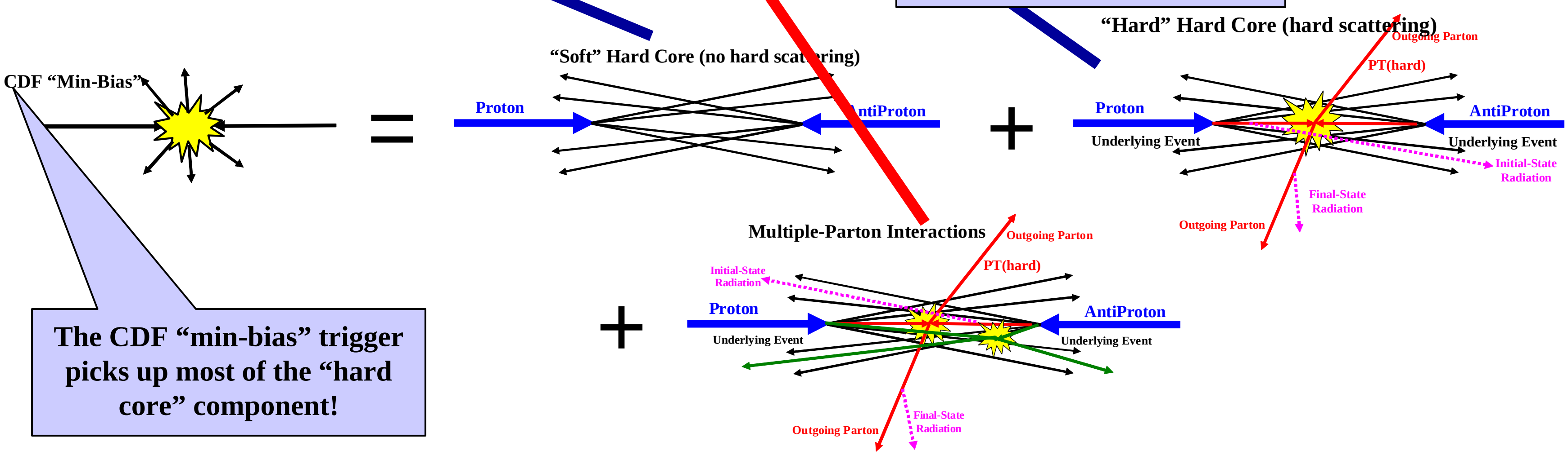
- Data at 1.96 TeV on the average p_T of charged particles versus the number of charged particles (p_T > 0.4 GeV/c, |η| < 1) for "min-bias" collisions at CDF Run 2. The data are corrected to the particle level and are compared with PYTHIA Tune A at the particle level (*i.e.* generator level).

Min-Bias: Average PT versus Nchg

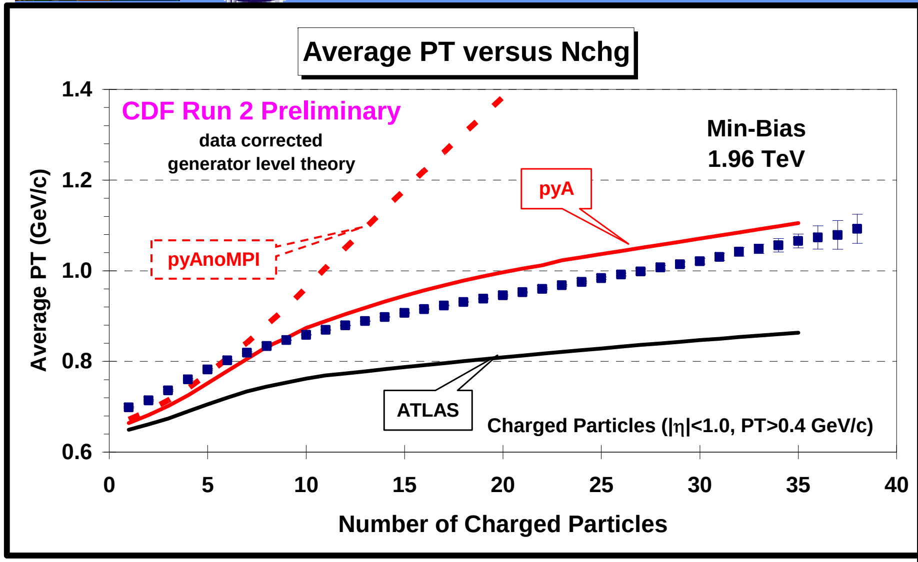


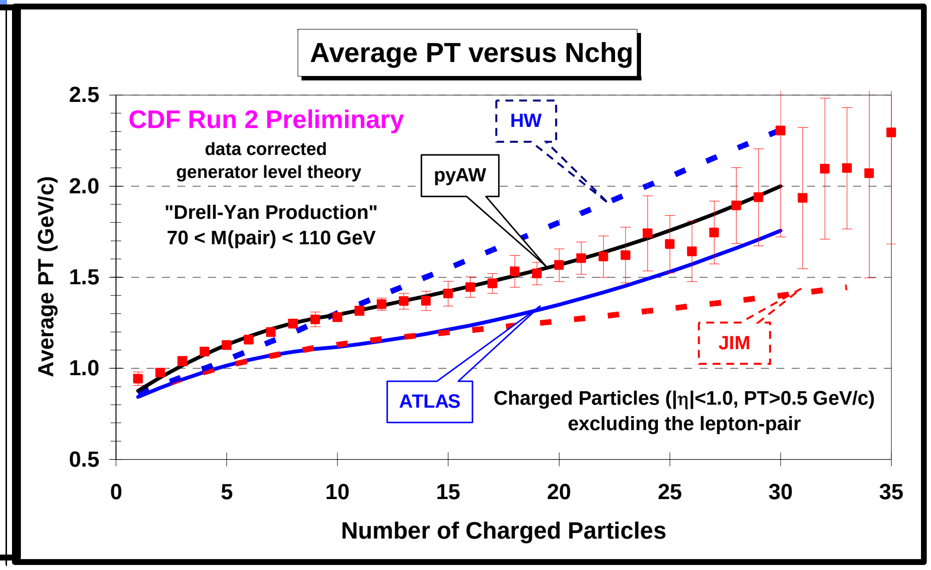
- Beam-beam remnants (*i.e.* soft hard core) produces low multiplicity and small $<p_T>$ with $<p_T>$ independent of the multiplicity.
- Hard scattering (with no MPI) produces large multiplicity and large $<p_T>$.
- Hard scattering (with MPI) produces large multiplicity and medium $<p_T>$.

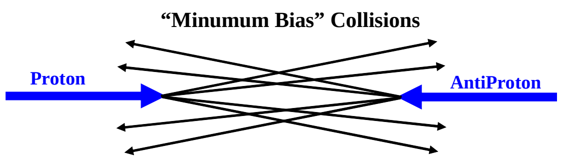
This observable is sensitive to the MPI tuning!

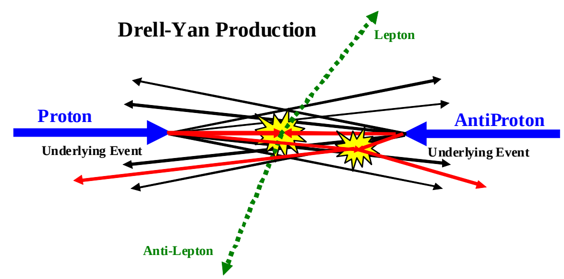


Average PT versus Nchg





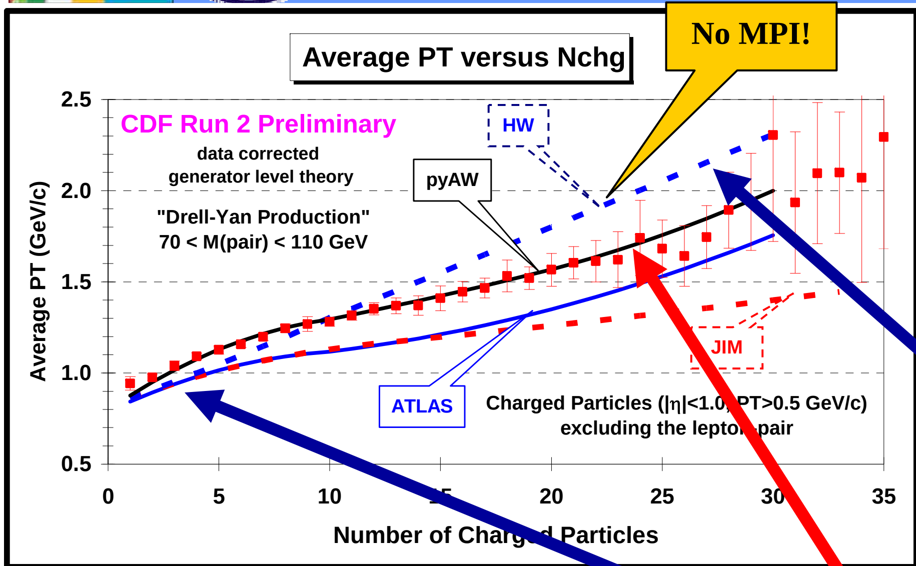




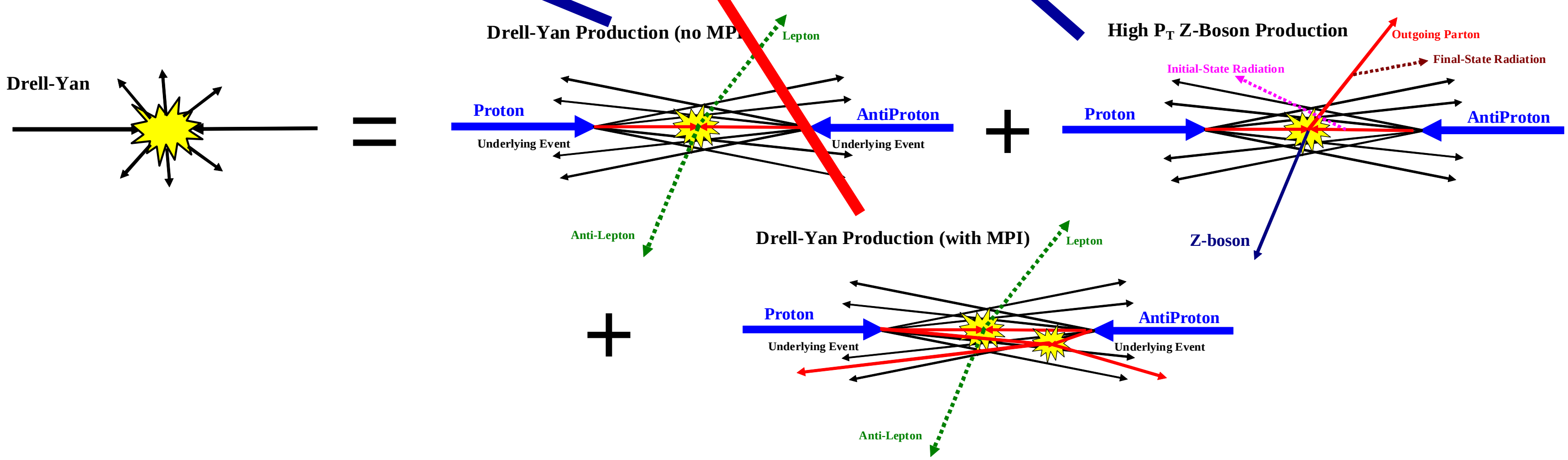
- **Data at 1.96 TeV on the average p_T of charged particles versus the number of charged particles (p_T > 0.4 GeV/c, |η| < 1) for "min-bias" collisions at CDF Run 2. The data are corrected to the particle leveland are compared with PYTHIA Tune A, Tune DW, and the ATLAS tune at the particle level (*i.e.* generator level).**

- **Particle level predictions for the average p_T of charged particles versus the number of charged particles (p_T > 0.5 GeV/c, |η| < 1, excluding the lepton-pair) for for Drell-Yan production (70 < M(pair) < 110 GeV) at CDF Run 2.**

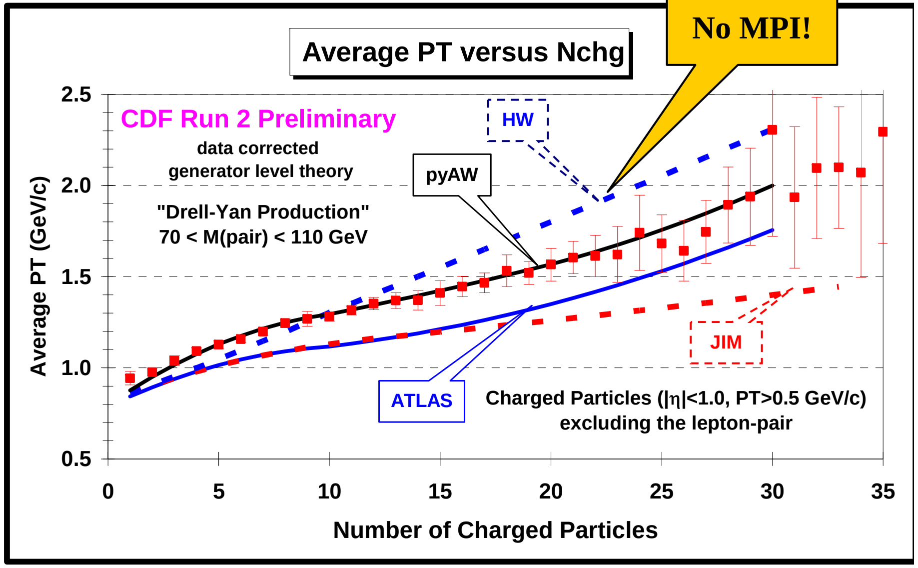
Average PT versus Nchg

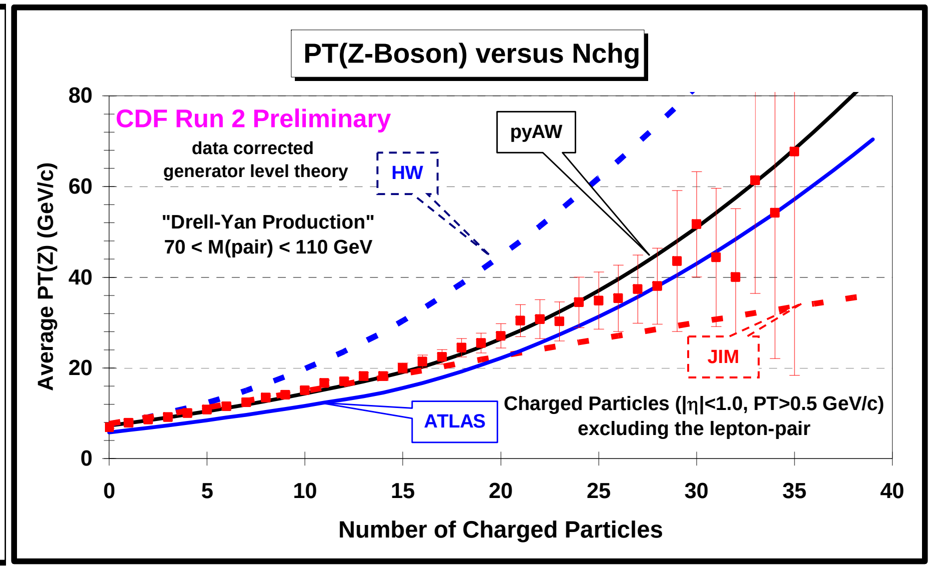


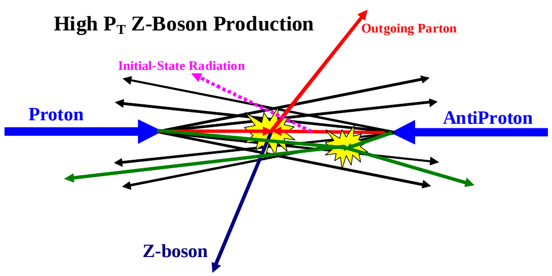
- Z-boson production (with low p_T(Z) and no MPI) produces low multiplicity and small $<p_T>$.
- High p_T Z-boson production produces large multiplicity and high $<p_T>$.
- Z-boson production (with MPI) produces large multiplicity and medium $<p_T>$.



Average PT(Z) versus Nchg



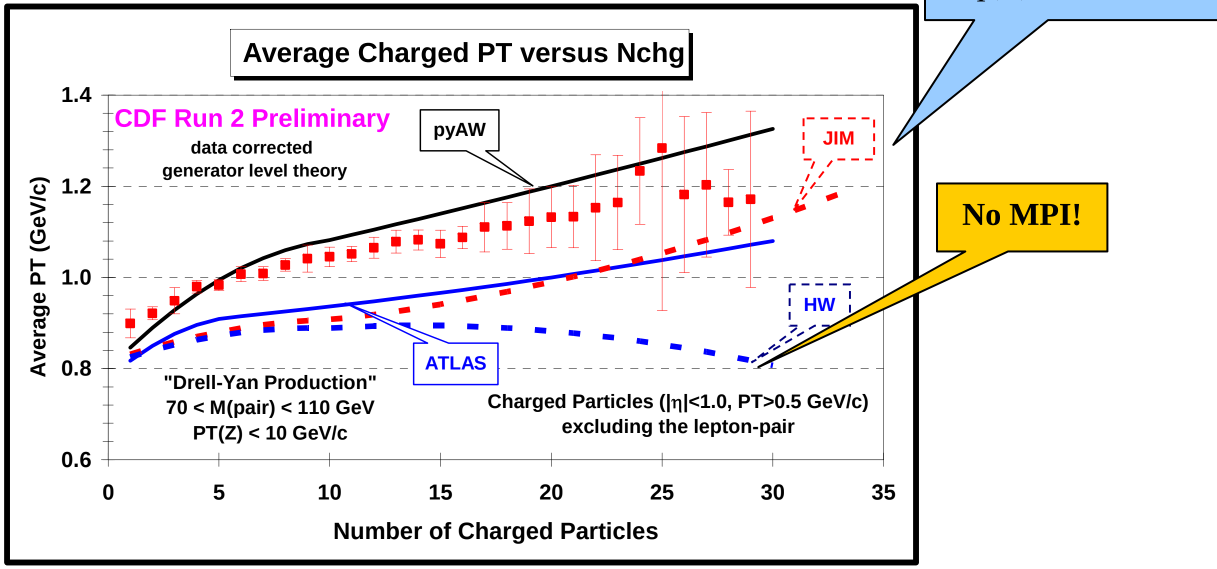


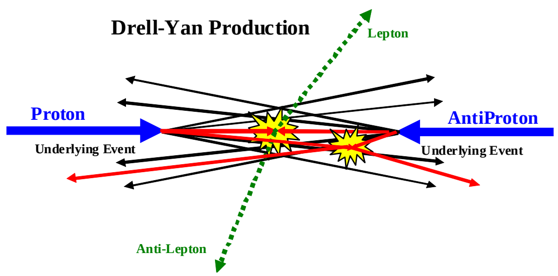


- **Predictions for the average P_T(Z-Boson) versus the number of charged particles (p_T > 0.5 GeV/c, |η| < 1, excluding the lepton-pair) for for Drell-Yan production (70 < M(pair) < 110 GeV) at CDF Run 2.**

- **Data on the average p_T of charged particles versus the number of charged particles (p_T > 0.5 GeV/c, |η| < 1, excluding the lepton-pair) for for Drell-Yan production (70 < M(pair) < 110 GeV) at CDF Run 2. The data are corrected to the particle level and are compared with various Monte-Carlo tunes at the particle level (*i.e.* generator level).**

Average PT versus Nchg

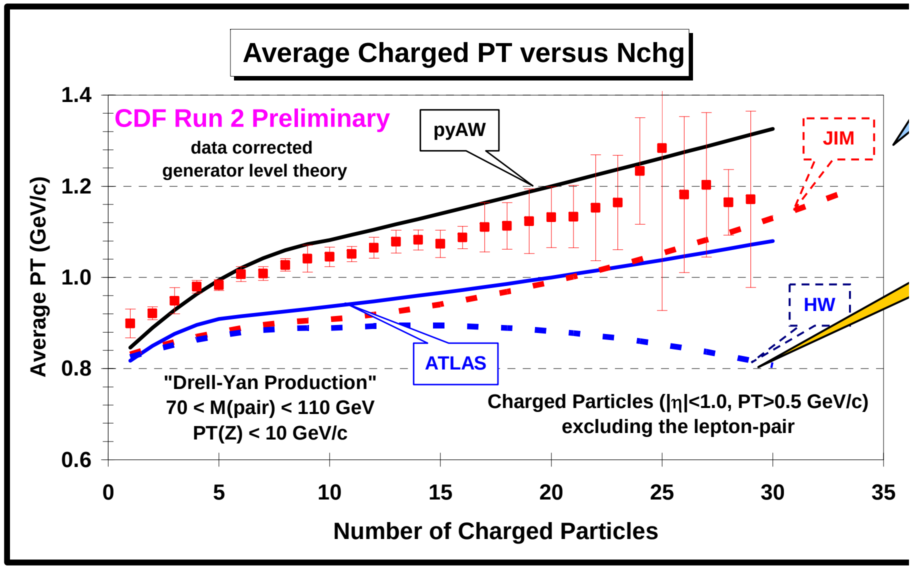


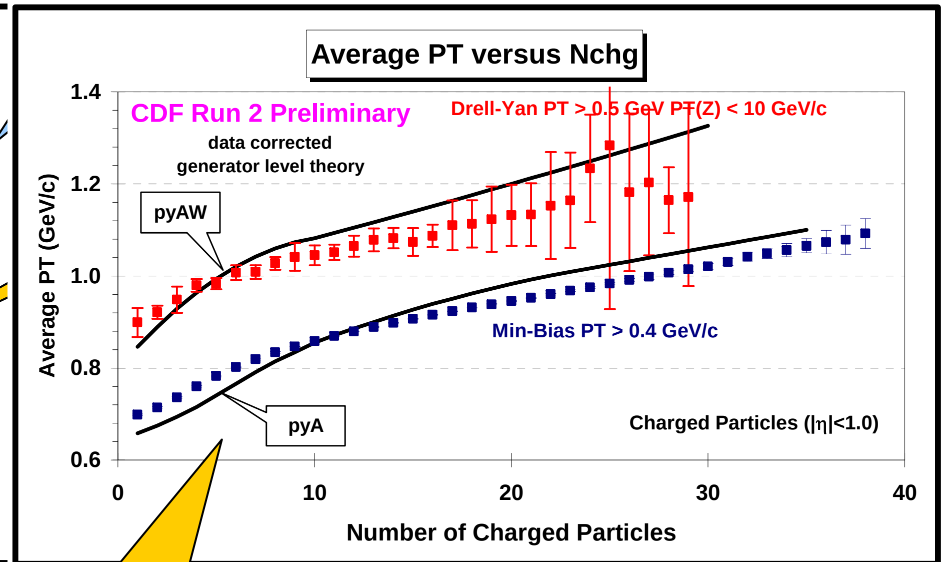


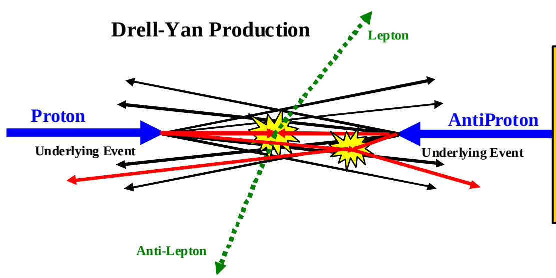
- **Data the average p_T of charged particles versus the number of charged particles (p_T > 0.5 GeV/c, |η| < 1, excluding the lepton-pair) for for Drell-Yan production (70 < M(pair) < 110 GeV, P_T(pair) < 10 GeV/c) at CDF Run 2. The data are corrected to the particle level and are compared with various Monte-Carlo tunes at the particle level (*i.e.* generator level).**

Average PT versus Nchg

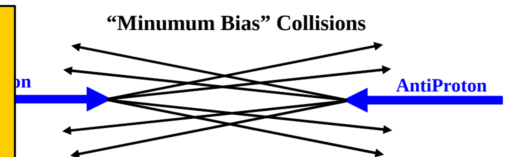
$P_T(Z) < 10$ GeV/c





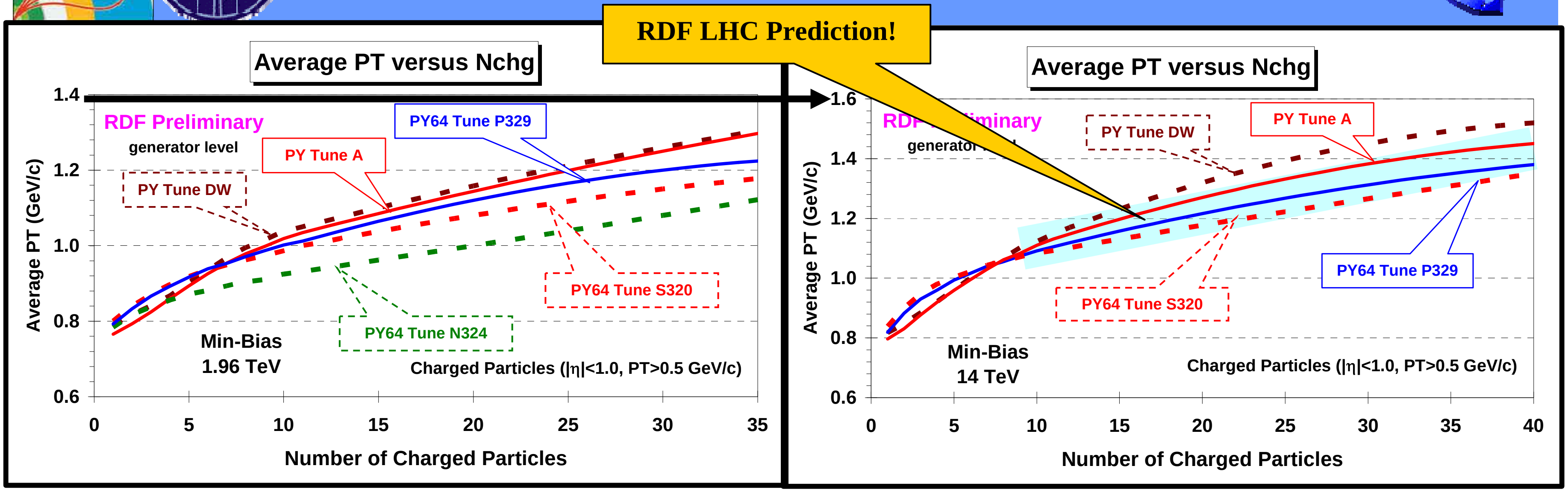


Remarkably similar behavior! Perhaps indicating that MPI playing an important role in both processes.



- **Data the average p_T of charged particles versus the number of charged particles ($p_T > 0.5$ GeV/c, $|\eta| < 1$, excluding the lepton-pair) for for Drell-Yan production (70 < M(pair) < 110 GeV, P_T(pair) < 10 GeV/c) at CDF Run 2. The data are corrected to the particle level and are compared with various Monte-Carlo tunes at the particle level (*i.e.* generator level).**

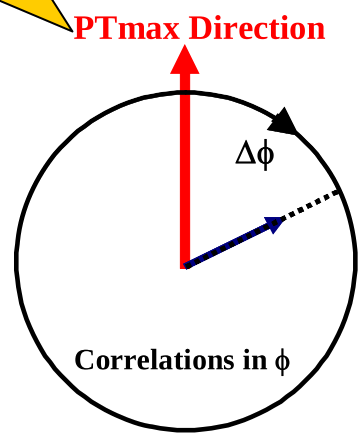
Min-Bias: Average PT versus Nchg



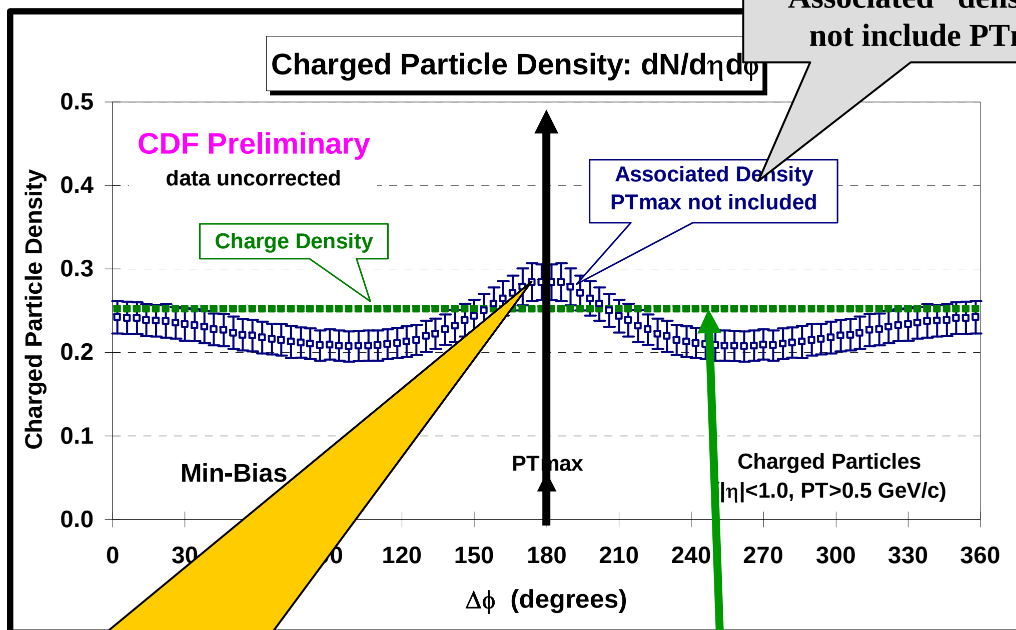
- The average p_T of charged particles versus the number of charged particles (p_T > 0.5 GeV/c, |η| < 1) for "min-bias" collisions at 1.96 TeV from PYTHIA Tune A, Tune DW, Tune S320, Tune N324, and Tune P324.
- Extrapolations of PYTHIA Tune A, Tune DW, Tune S320, and Tune P324 to the LHC.

CDF Run 2 Min-Bias "Associated" Charged Particle Density

Highest p_T charged particle!



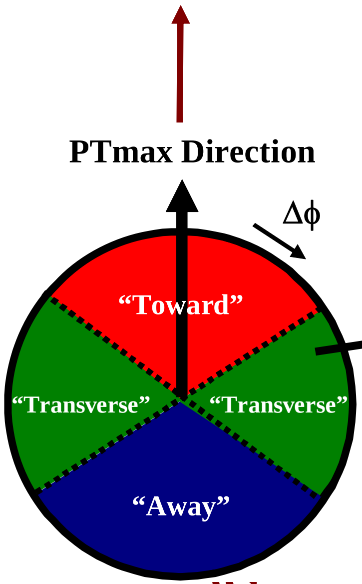
"Associated" densities do not include PTmax!

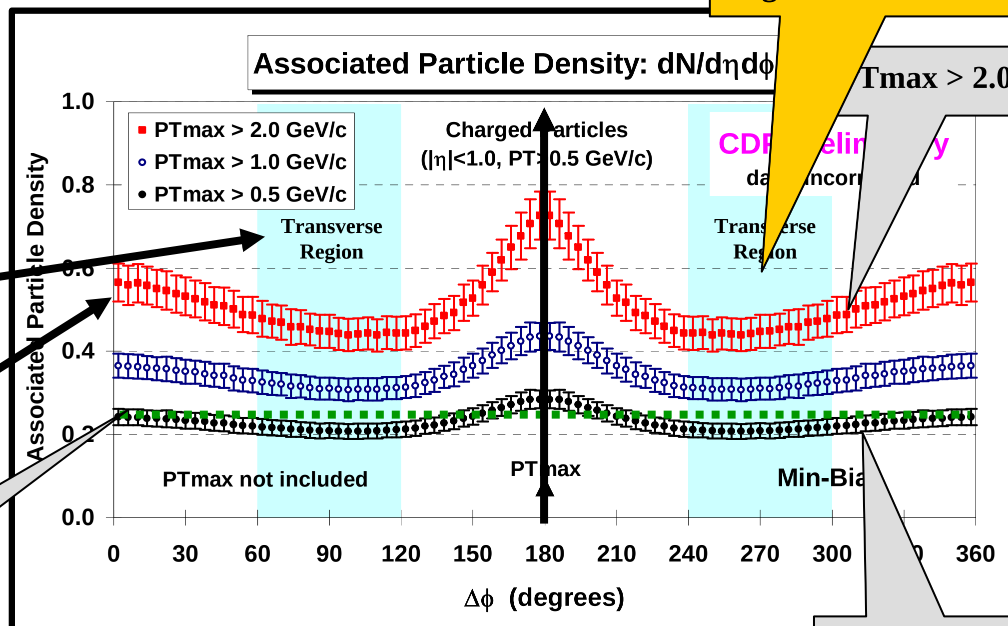


It is more probable to find a particle accompanying PTmax than it is to find a particle in the central region!

- Use the m... charged par... event, **PTmax**, to define a direction and look at the the ... in-bias" collisions (p_T > 0.5 GeV/c, |η| < 1).
- Shows the ...iated" 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. Also shown is the average charged particle density, $dN_{chg}/d\eta d\phi$, for "min-bias" events.

CDF Run 2 Min-Bias "Associated" Charged Particle Density





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

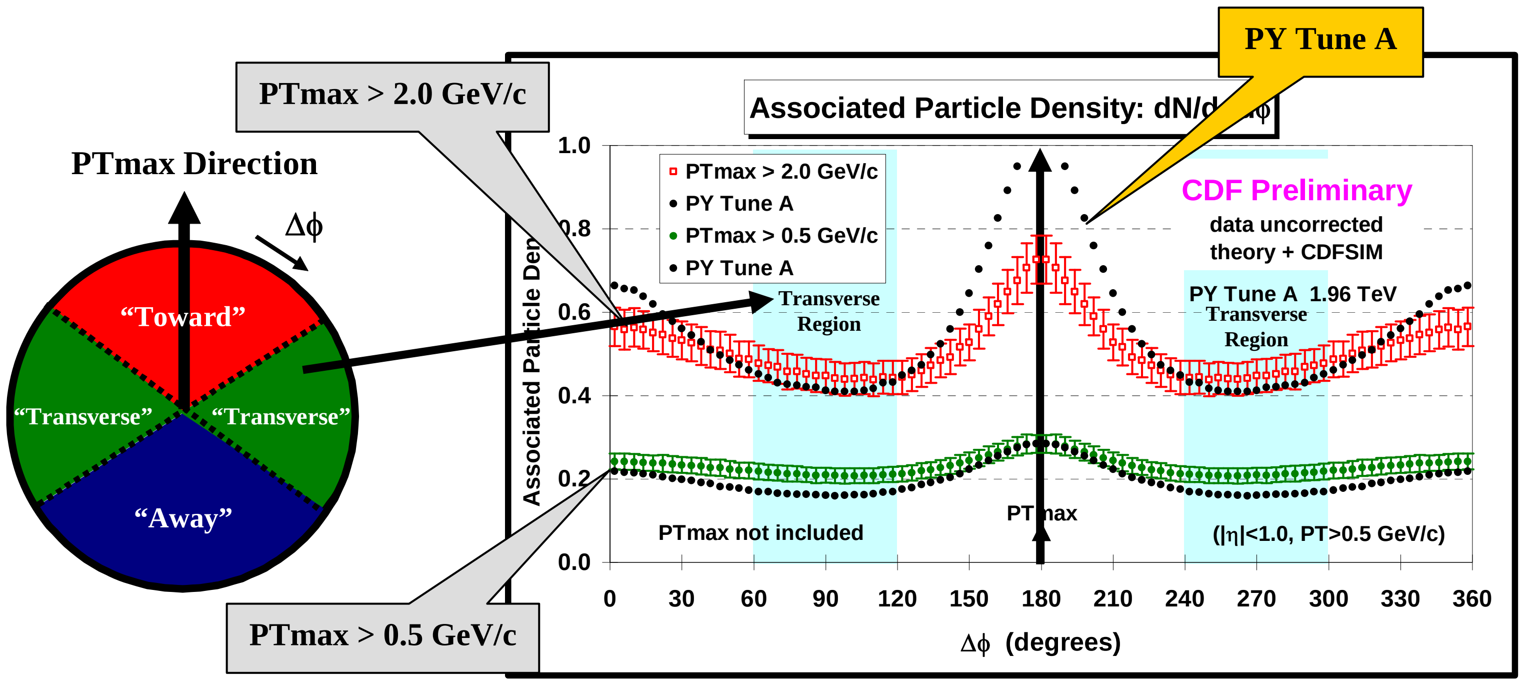
PTmax > 2.0 GeV/c

PTmax > 0.5 GeV/c

Ave Min-Bias 0.25 per unit η-ϕ

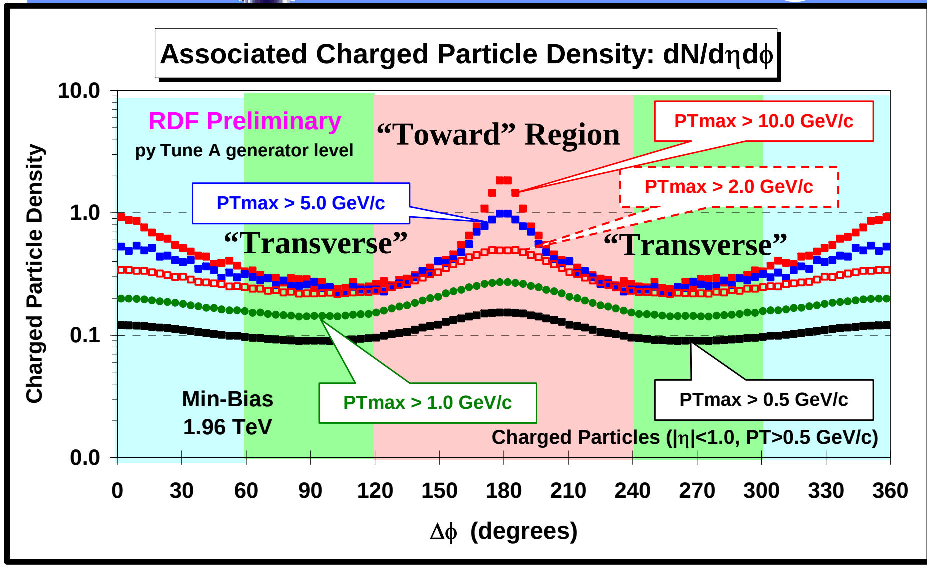
- **Shows the data on the Δϕ dependence of the "associated" charged particle density, $dN_{chg}/d\eta d\phi$, for charged particles (p_T > 0.5 GeV/c, |η| < 1, *not including PTmax*) relative to PTmax (rotated to 180°) for "min-bias" events with PTmax > 0.5, 1.0, and 2.0 GeV/c.**
- **Shows "jet structure"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

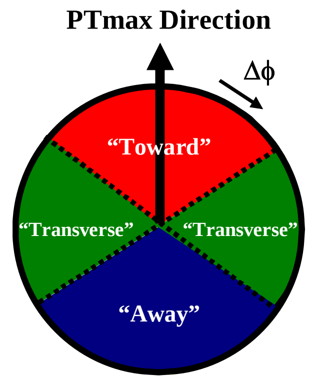
CDF Run 2 Min-Bias "Associated" Charged Particle Density



- 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 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").

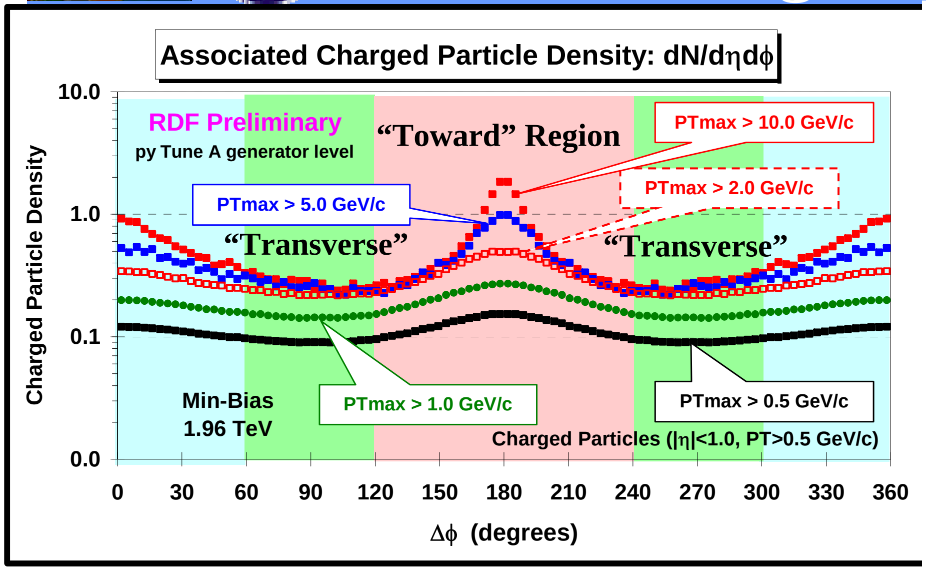
Min-Bias "Associated" Charged Particle Density

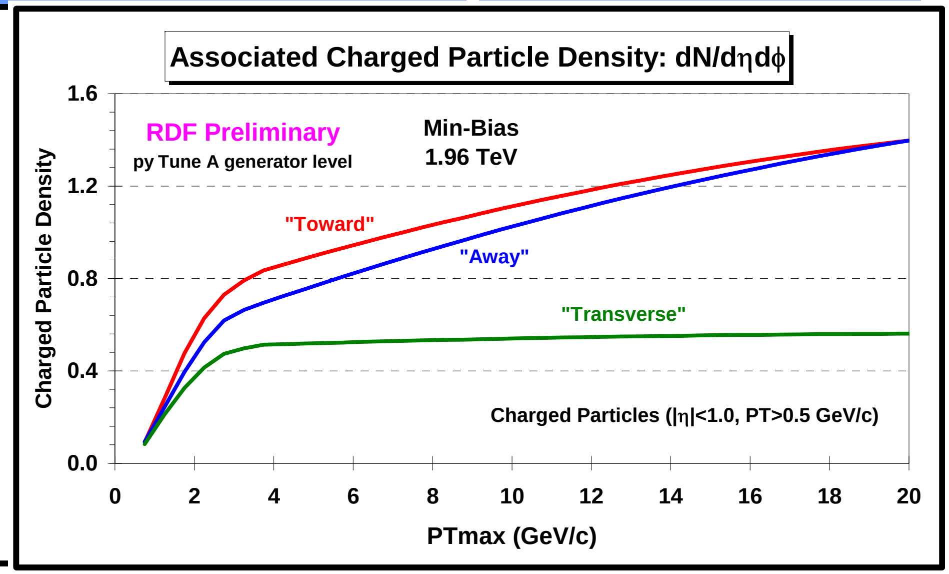




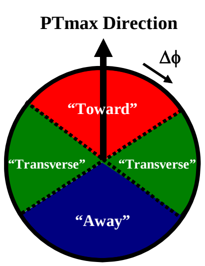
- Shows the **Δφ dependence of the "associated" charged particle density**, **dNchg/dηdφ**, **for charged particles (p_T > 0.5 GeV/c, |η| < 1, *not including PTmax*) relative to PTmax (rotated to 180°) for "min-bias" events at 1.96 TeV with PTmax > 0.5, 1.0, 2.0, 5.0, and 10.0 GeV/c from PYTHIA Tune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

Min-Bias "Associated" Charged Particle Density



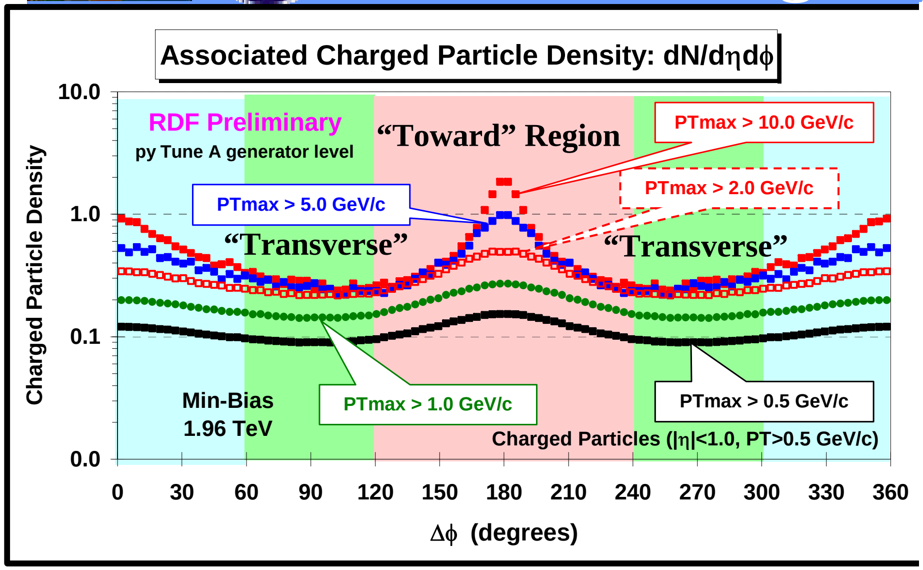


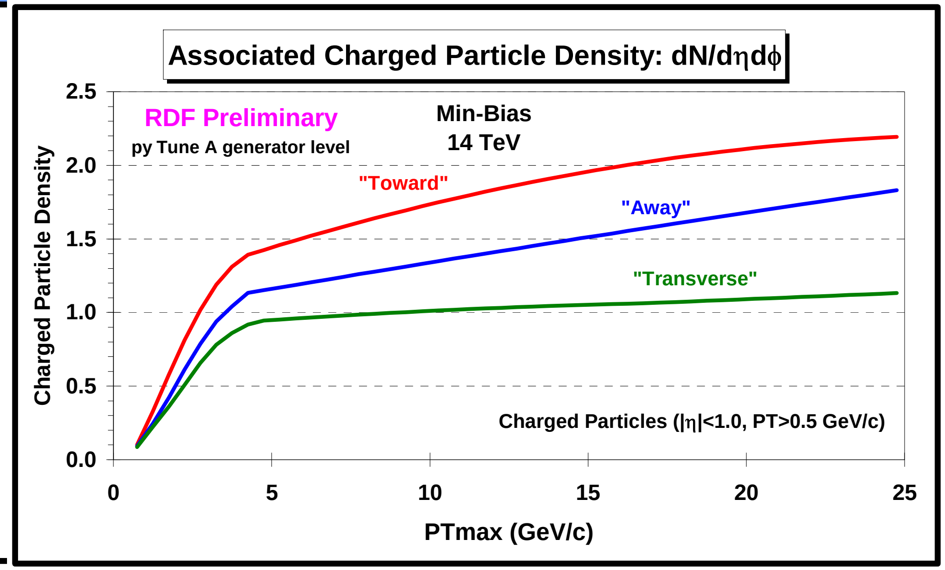
- **Shows the Δφ dependence of the "associated" charged particle density, $dN_{chg}/d\eta d\phi$, for charged particles (p_T > 0.5 GeV/c, |η| < 1, *not including PTmax*) relative to PTmax (rotated to 180°) for "min-bias" events at 1.96 TeV with PTmax > 0.5, 1.0, 2.0, 5.0, and 10.0 GeV/c from PYTHIA Tune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



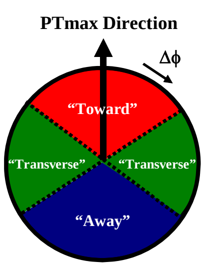
- **Shows the "associated" charged particle density in the "toward", "away" and "transverse" regions as a function of PTmax for charged particles (p_T > 0.5 GeV/c, |η| < 1, *not including PTmax*) for "min-bias" events at 1.96 TeV from PYTHIA Tune A (generator level).**

Min-Bias "Associated" Charged Particle Density



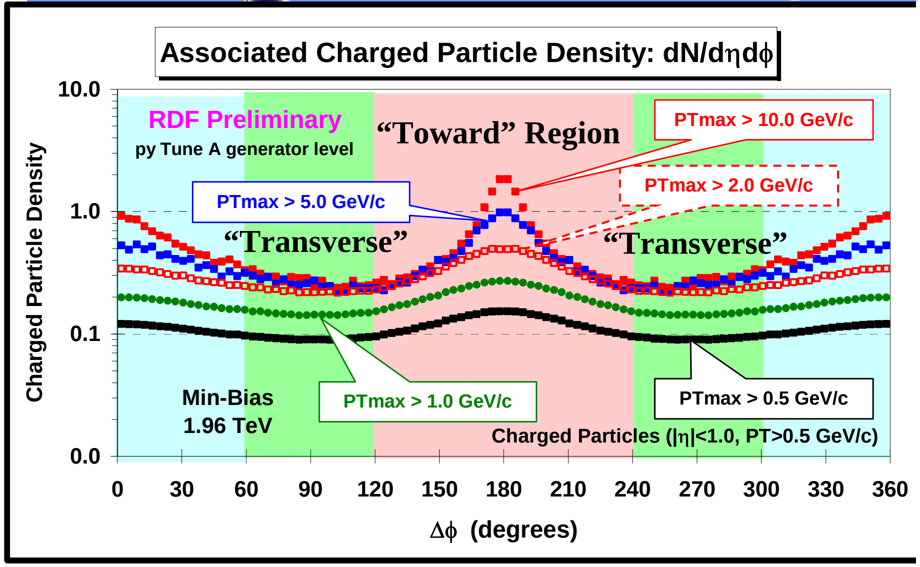


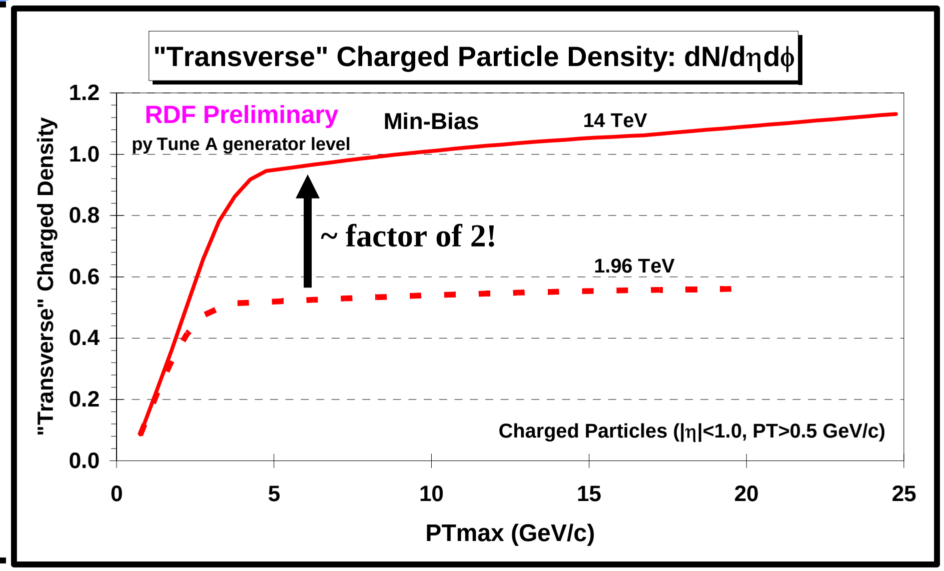
- Shows the **Δφ dependence of the "associated" charged particle density**, **$dN_{chg}/d\eta d\phi$, for charged particles (p_T > 0.5 GeV/c, $|\eta|$ < 1, *not including PTmax*) relative to PTmax (rotated to 180°) for "min-bias" events at 1.96 TeV with PTmax > 0.5, 1.0, 2.0, 5.0, and 10.0 GeV/c from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



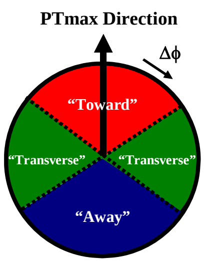
- **Shows the "associated" charged particle density in the "toward", "away" and "transverse" regions as a function of PTmax for charged particles (p_T > 0.5 GeV/c, $|\eta|$ < 1, *not including PTmax*) for "min-bias" events at 1.96 TeV from PYTHIA Tune A (generator level).**

Min-Bias "Associated" Charged Particle Density



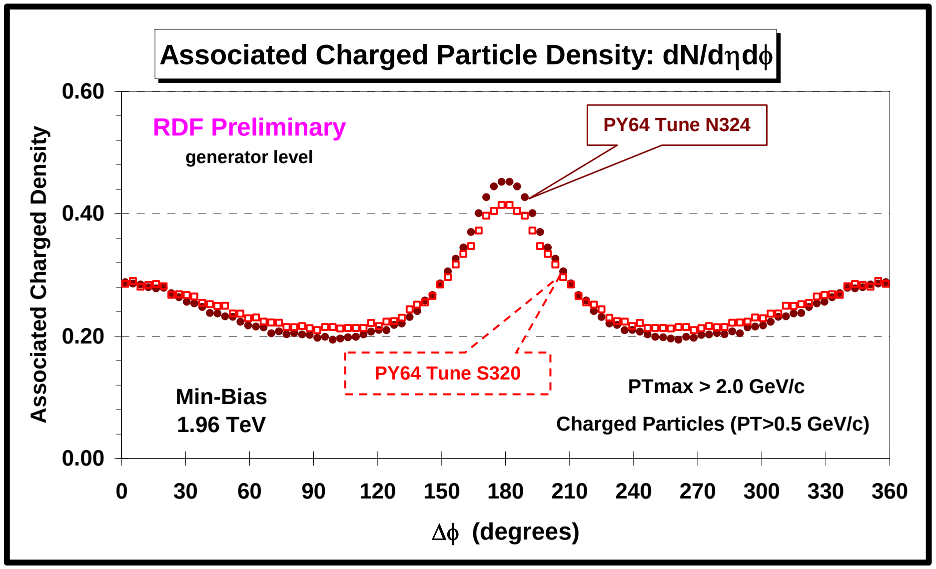


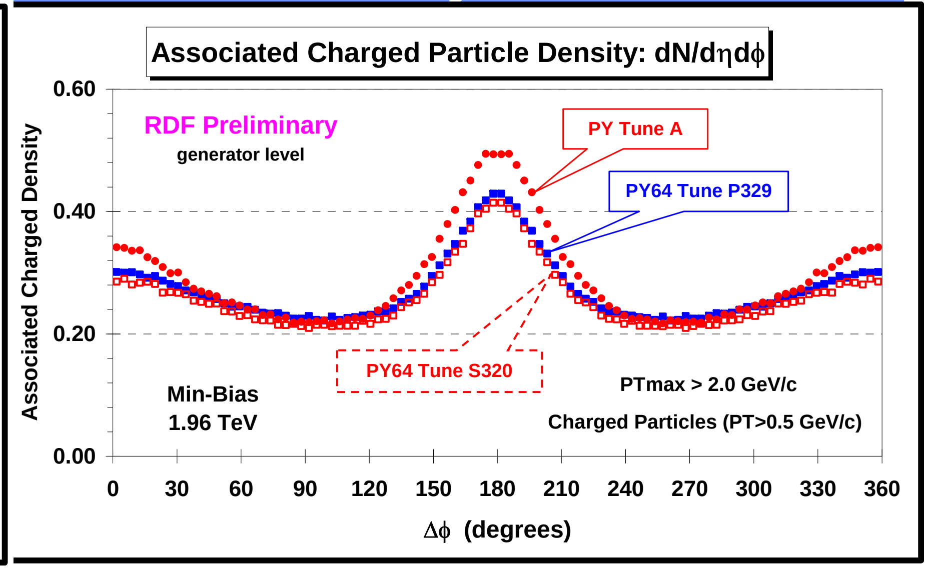
- Shows the **Δϕ dependence of the "associated" charged particle density**, $dN_{chg}/d\eta d\phi$, for charged particles (p_T > 0.5 GeV/c, |η| < 1, *not including PTmax*) relative to PTmax (rotated to 180°) for **"min-bias" events at 1.96 TeV** with PTmax > 0.5, 1.0, 2.0, 5.0, and 10.0 GeV/c from **PYTHIA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

Min-Bias "Associated" Charged Particle Density

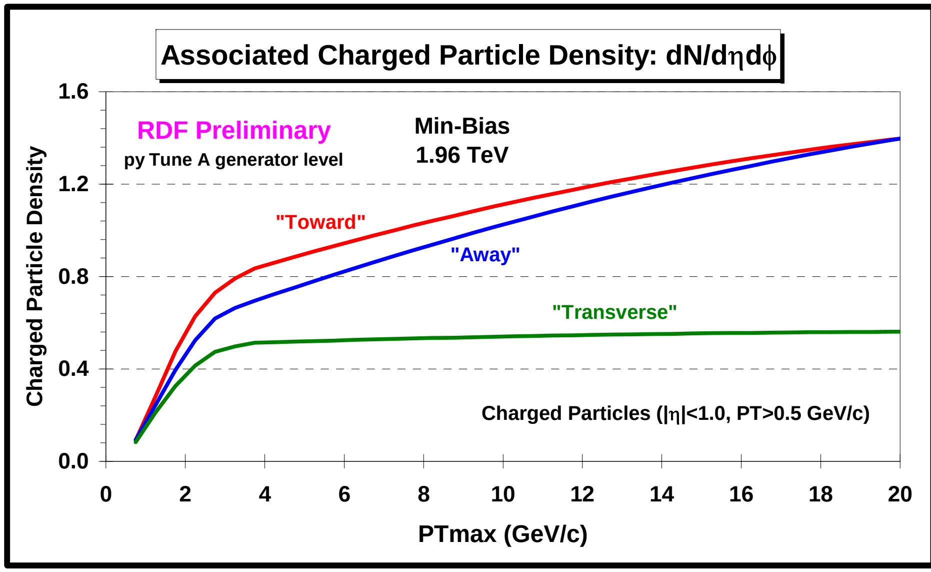


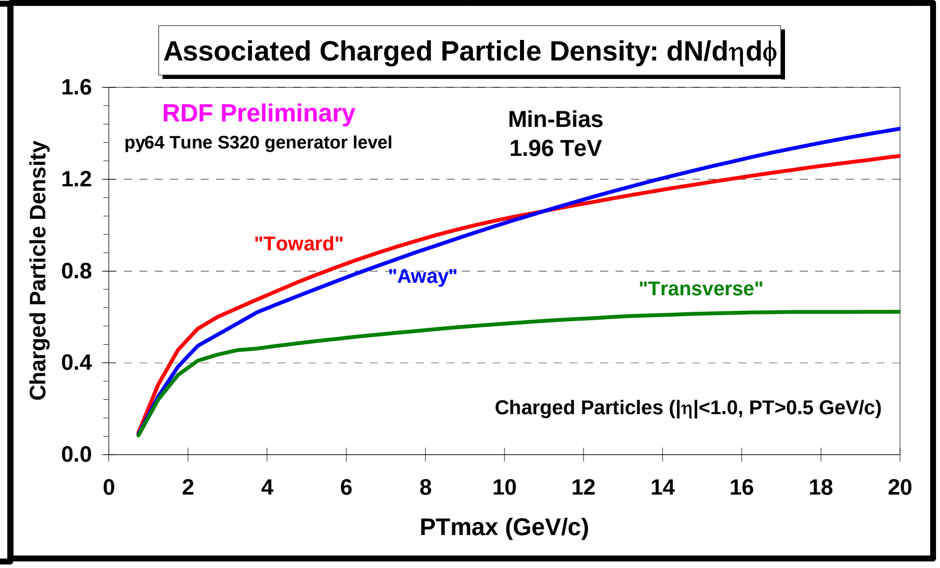


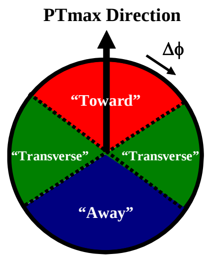
- Shows the Δϕ dependence of the "associated" charged particle density, dNchg/dηdϕ, for charged particles (p_T > 0.5 GeV/c, |η| < 1, *not including PTmax*) relative to PTmax (rotated to 180°) for "min-bias" events at 1.96 TeV with PTmax > 0.5 GeV/c for PYTHIA Tune A, Tune S320, Tune P320 (generator level).

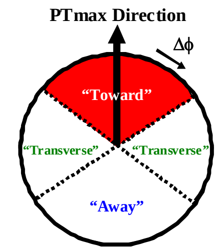
- Shows the Δϕ dependence of the "associated" charged particle density, dNchg/dηdϕ, for charged particles (p_T > 0.5 GeV/c, |η| < 1, *not including PTmax*) relative to PTmax (rotated to 180°) for "min-bias" events at 1.96 TeV with PTmax > 2.0 GeV/c for PYTHIA Tune A, Tune S320, Tune P320 (generator level).

Min-Bias "Associated" Charged Particle Density



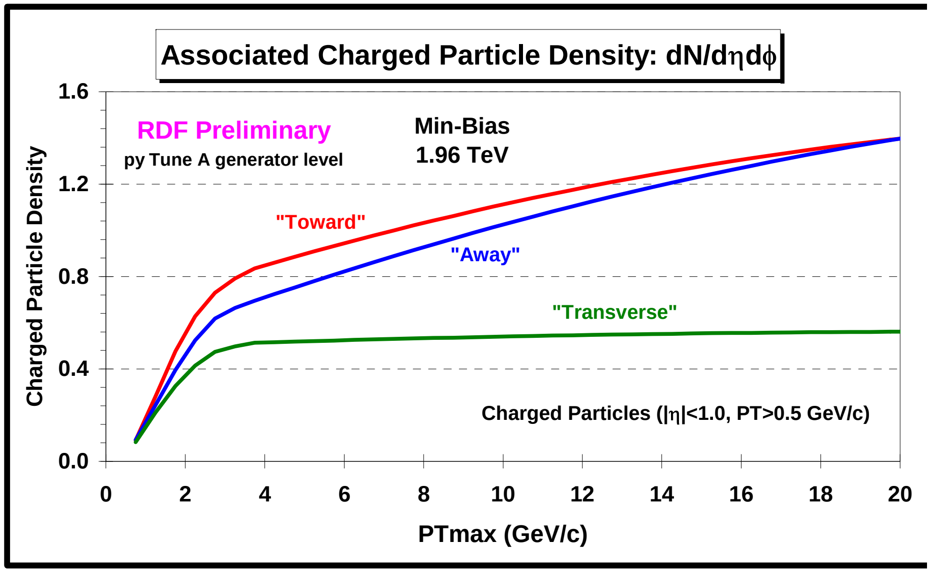


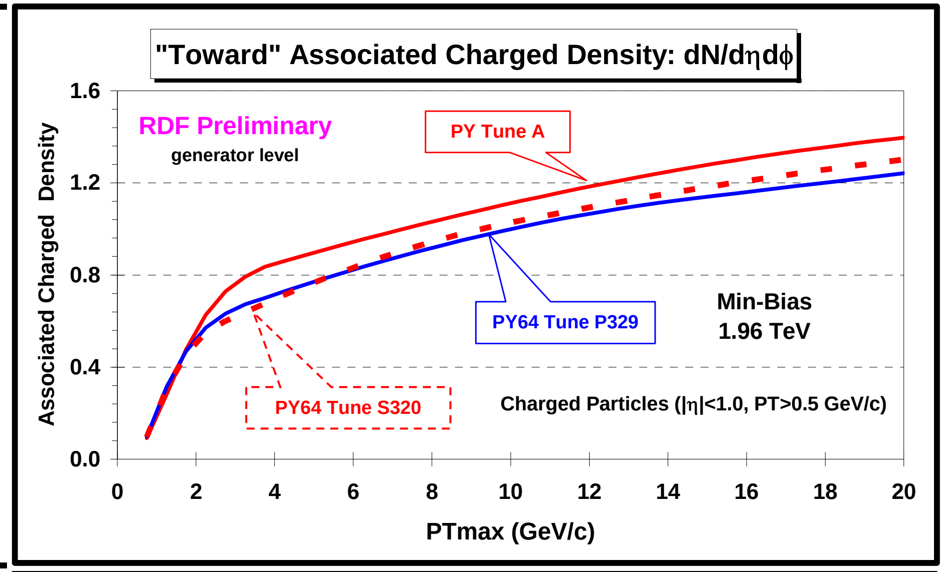


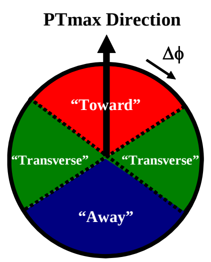


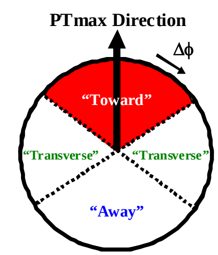
- **Shows the "associated" charged particle density in the "toward", "away" and "transverse" regions as a function of PTmax for charged particles (p_T > 0.5 GeV/c, |η| < 1, *not including PTmax*) for "min-bias" events at 1.96 TeV from PYTHIA Tune A and Tune S320 at the particle level (*i.e.* generator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

Min-Bias "Associated" Charged Particle Density



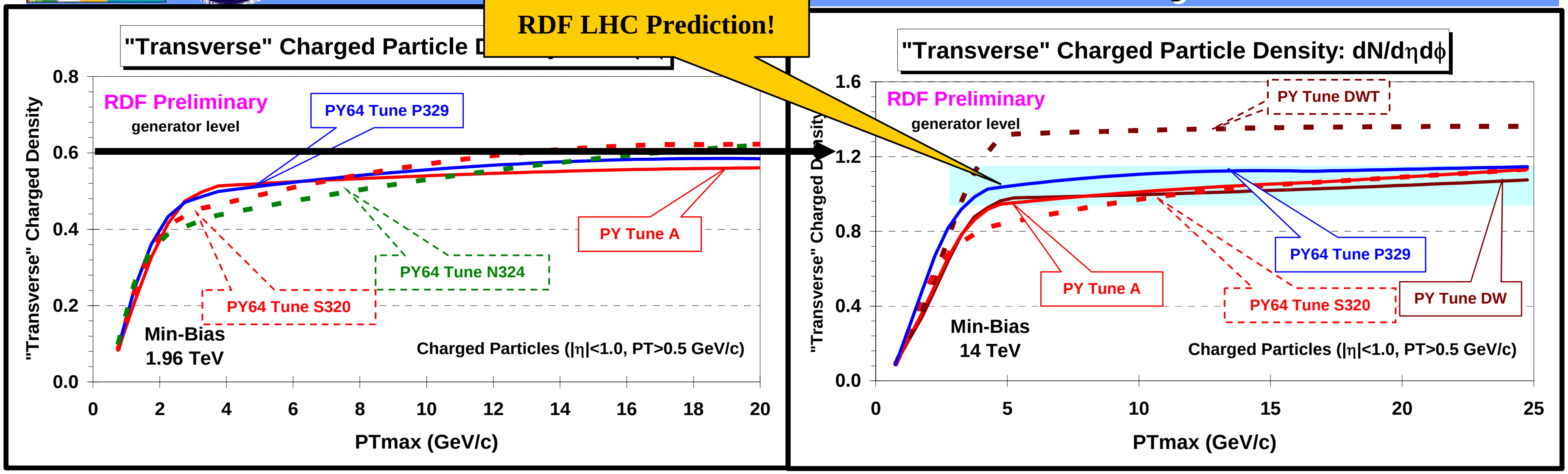


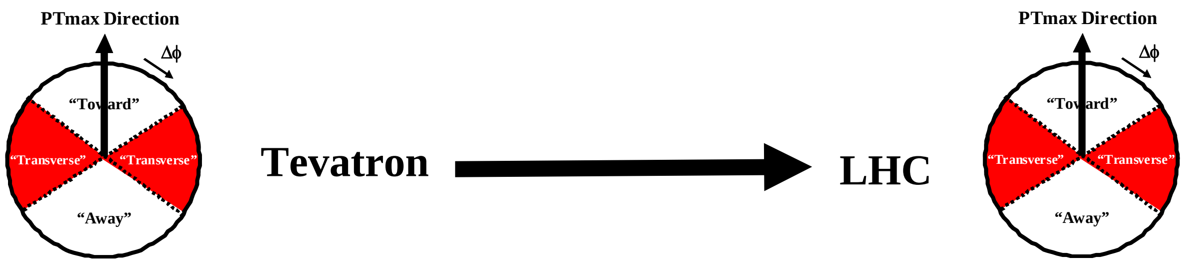




- **Shows the "associated" charged particle density in the "toward", "away" and "transverse" regions as a function of PTmax for charged particles (p_T > 0.5 GeV/c, |η| < 1, *not including PTmax*) for "min-bias" events at 1.96 TeV from PYTHIA Tune A and Tune S320 at the particle level (*i.e.* generator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

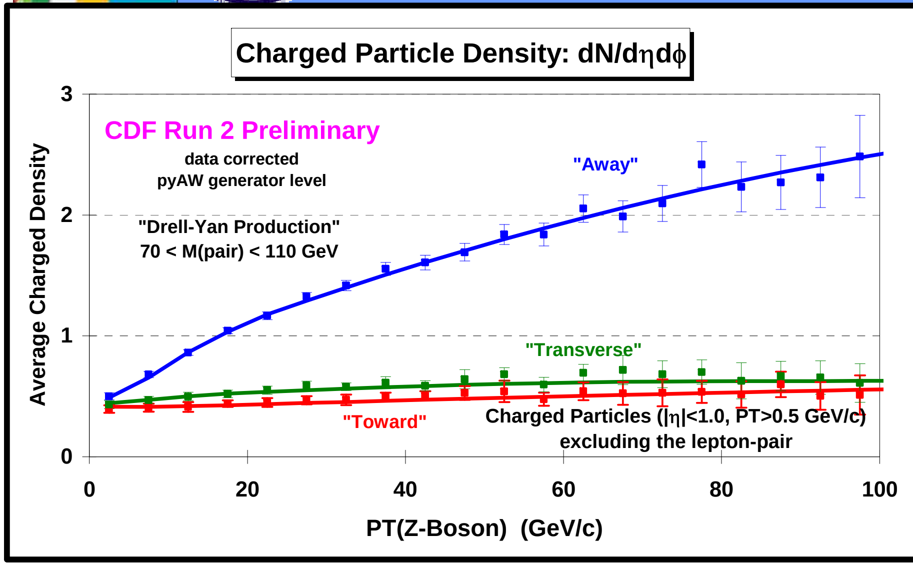
Min-Bias "Associated" Charged Particle Density

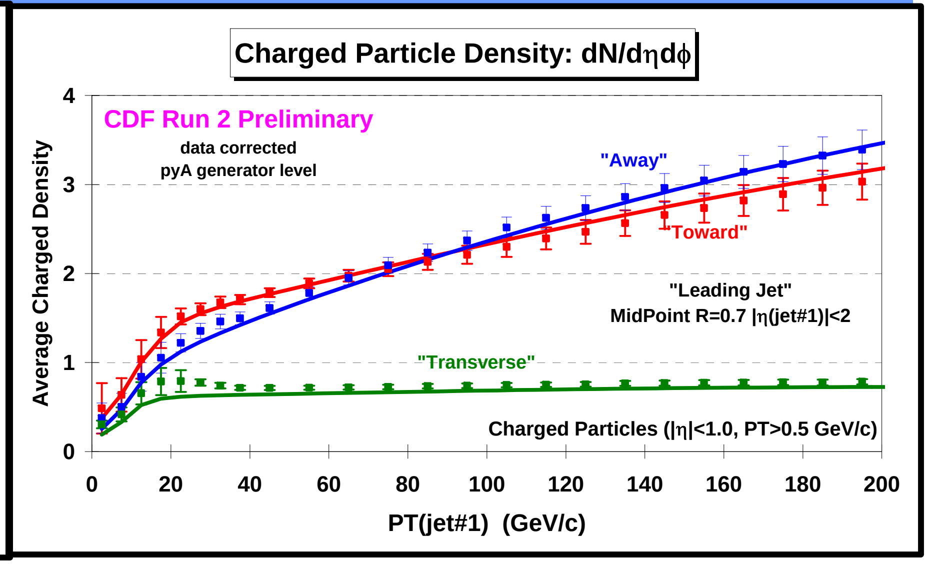


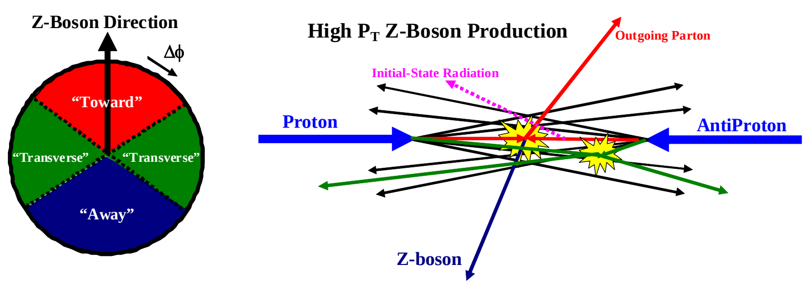


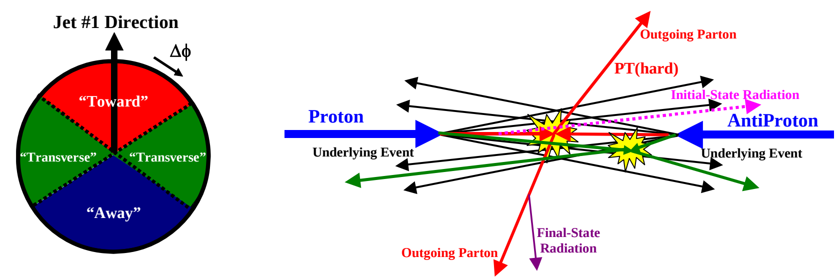
- **Shows the "associated" charged particle density in the "transverse" region as a function of PTmax for charged particles (p_T > 0.5 GeV/c, |η| < 1, *not including PTmax*) for "min-bias" events at 1.96 TeV from PYTHIA Tune A, Tune S320, Tune N324, and Tune P329 at the particle level (*i.e.* generator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

Charged Particle Density



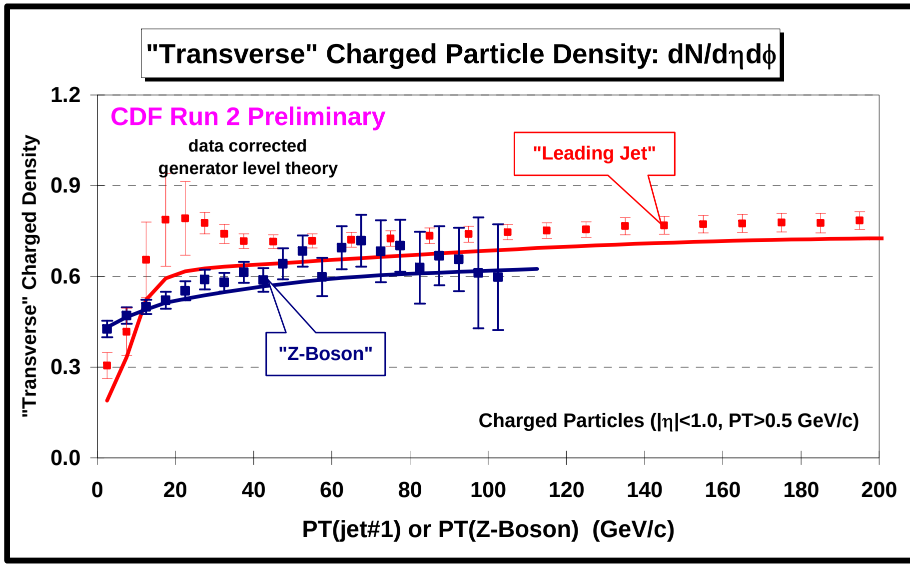


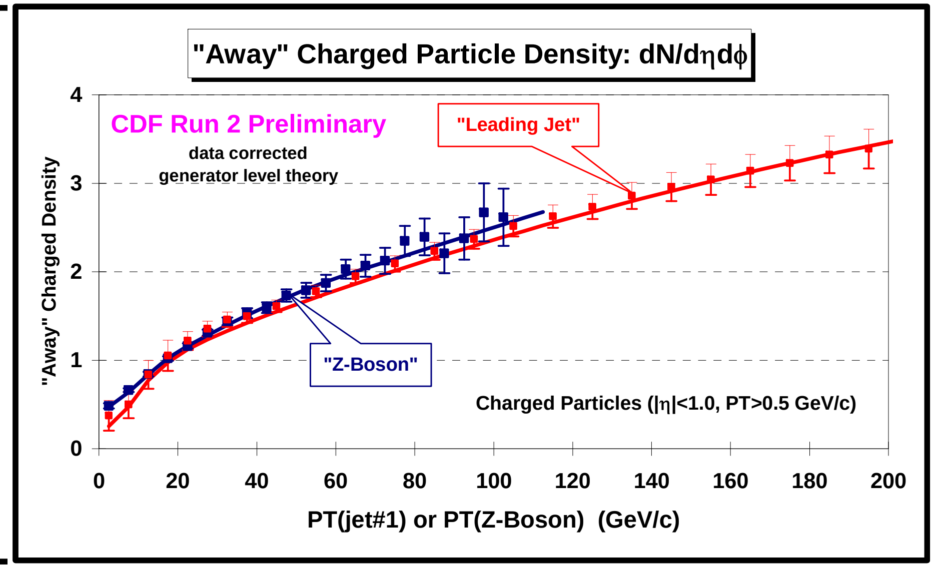


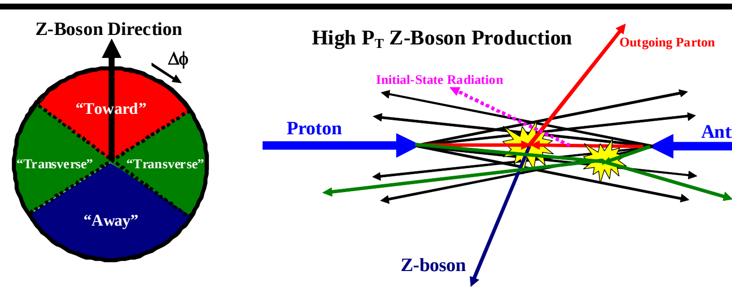


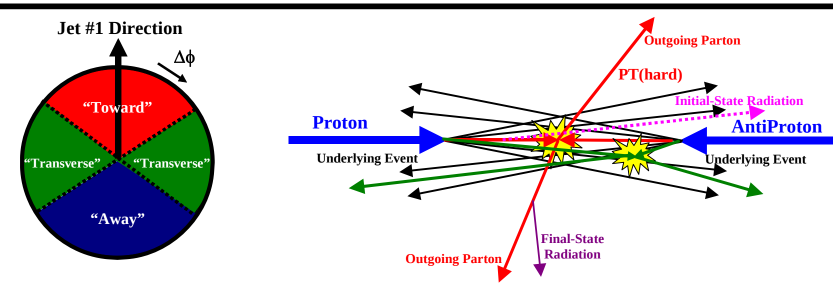
- **Data at 1.96 TeV on the density of charged particles, dN/dηdϕ, with $p_T > 0.5$ GeV/c and $|\eta| < 1$ for "Z-Boson" and "Leading Jet" events as a function of the leading jet p_T or $P_T(Z)$ for the "toward", "away", and "transverse" regions. The data are corrected to the particle level (*with errors that include both the statistical error and the systematic uncertainty*) and are compared with PYTHIA Tune AW and Tune A, respectively, at the particle level (*i.e.* generator level).**

Charged Particle Density



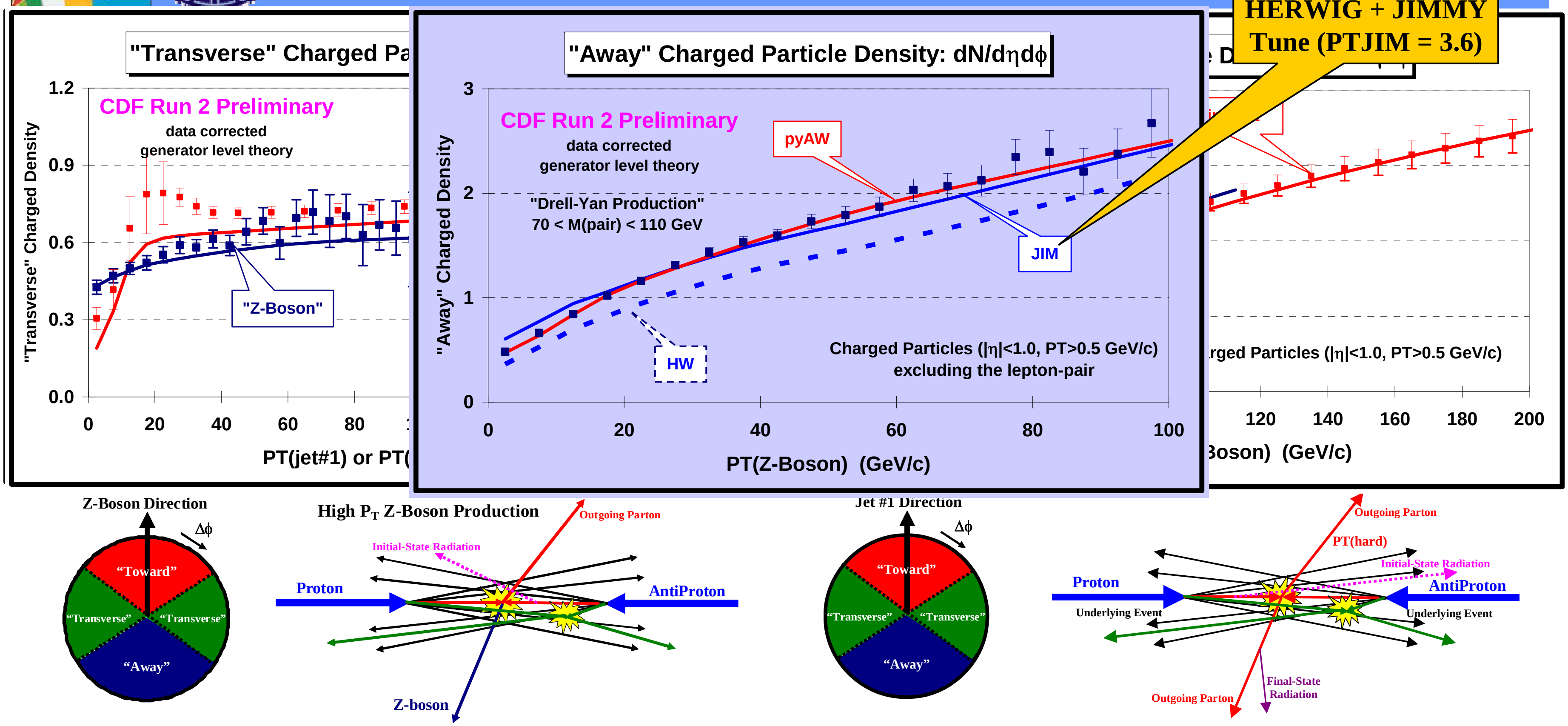






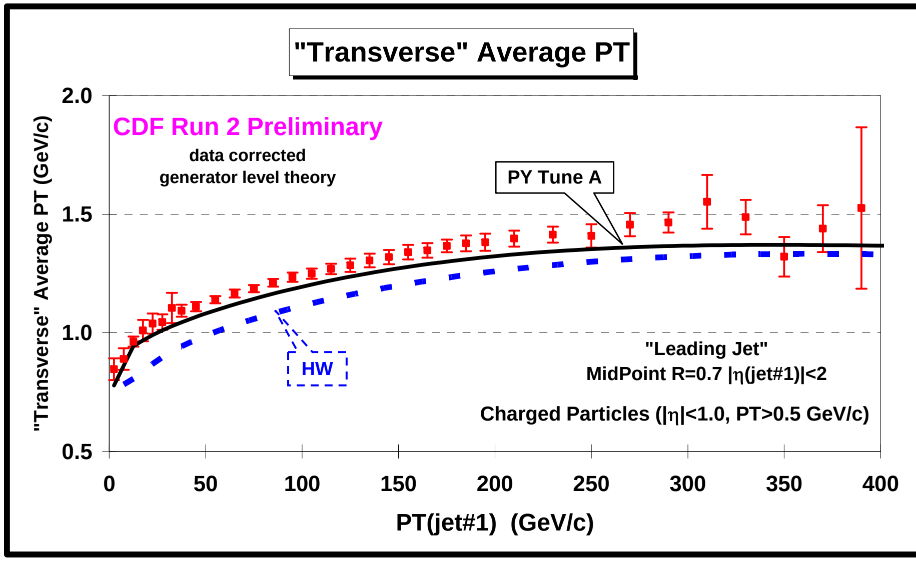
- **Data at 1.96 TeV on the density of charged particles, dN/dηdφ, with p_T > 0.5 GeV/c and |η| < 1 for "Z-Boson" and "Leading Jet" events as a function of the leading jet p_T or P_T(Z) for the "toward", "away", and "transverse" regions. The data are corrected to the particle level (*with errors that include both the statistical error and the systematic uncertainty*) and are compared with PYTHIA Tune AW and Tune A, respectively, at the particle level (*i.e.* generator level).**

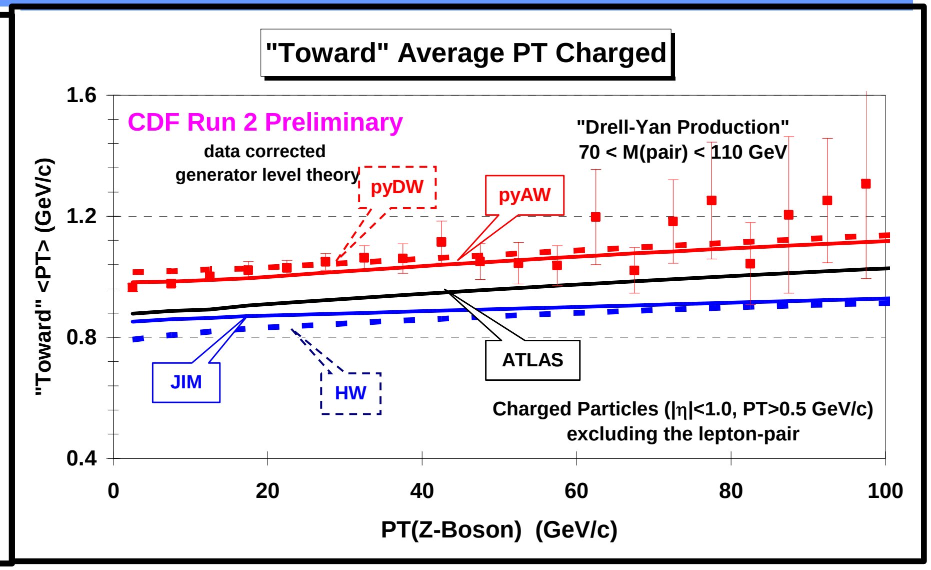
Charged Particle Density

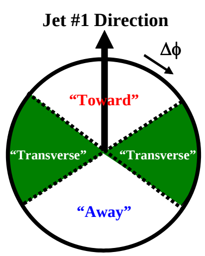


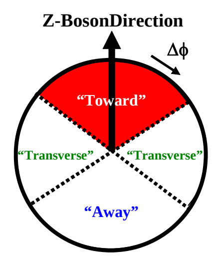
- Data at 1.96 TeV on the density of charged particles, dN/dηdϕ, with p_T > 0.5 GeV/c and |η| < 1 for "Z-Boson" and "Leading Jet" events as a function of the leading jet p_T or P_T(Z) for the "toward", "away", and "transverse" regions. The data are corrected to the particle level (*with errors that include both the statistical error and the systematic uncertainty*) and are compared with PYTHIA Tune AW and Tune A, respectively, at the particle level (*i.e.* generator level).

Charged Particle $<p_T>$



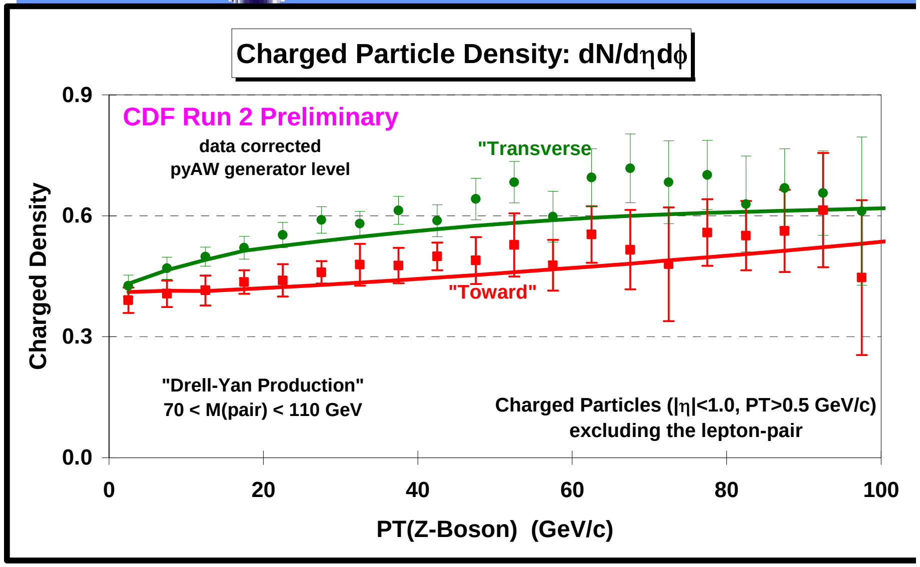


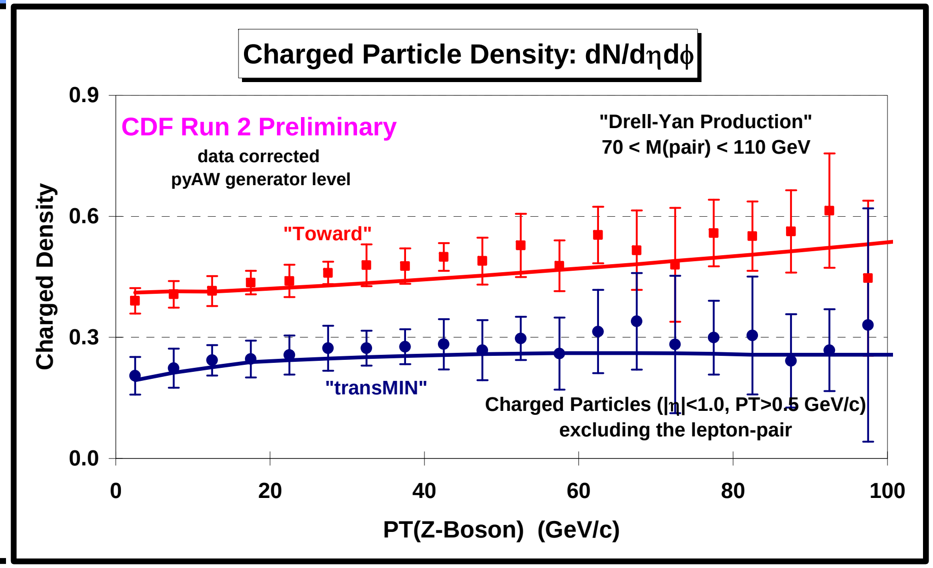


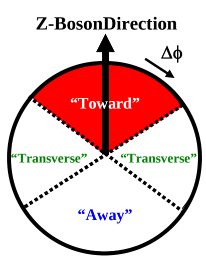


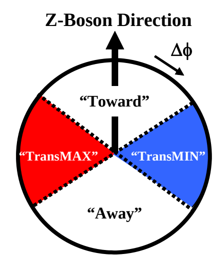
- **Data at 1.96 TeV on the charged particle average p_T, with p_T > 0.5 GeV/c and |η| < 1 for the "toward" region for "Z-Boson" and the "transverse" region for "Leading Jet" events as a function of the leading jet p_T or P_T(Z). The data are corrected to the particle level (*with errors that include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

Z-Boson: "Towards", Transverse", & "TransMIN" Charge Density



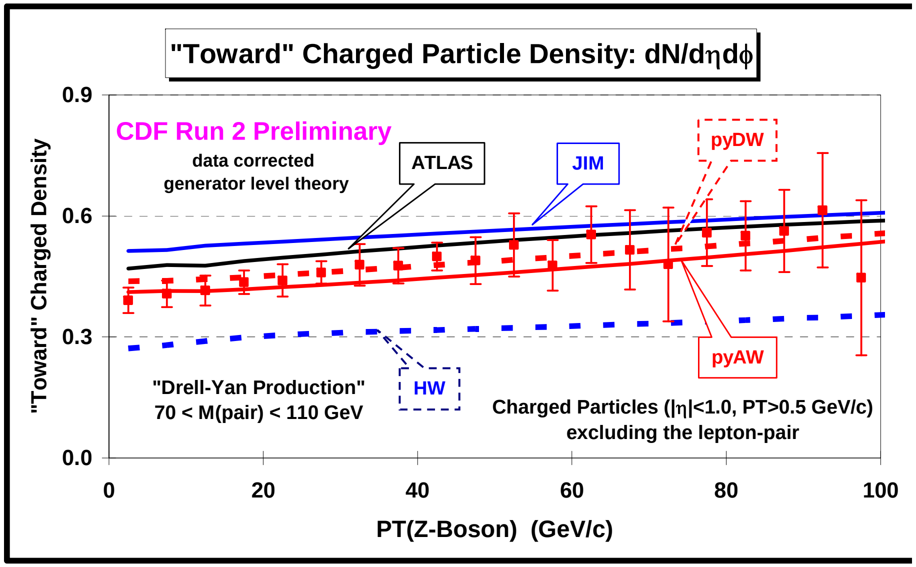


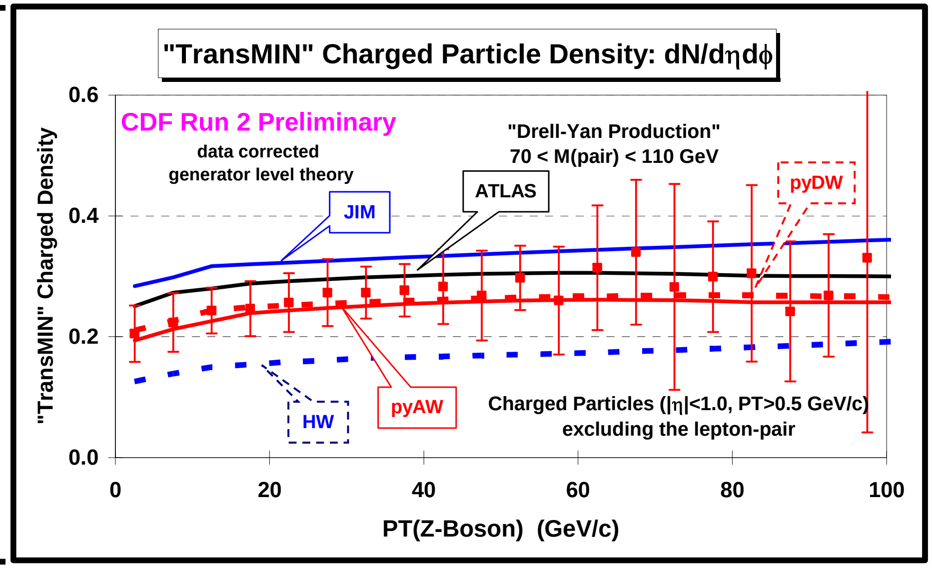


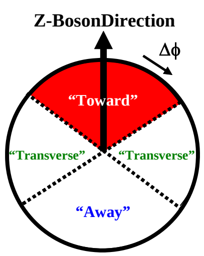


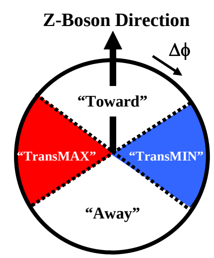
- **Data at 1.96 TeV on the density of charged particles, dN/dηdφ, with p_T > 0.5 GeV/c and |η| < 1 for "Z-Boson" events as a function of P_T(Z) for the "toward" and "transverse" regions. The data are corrected to the particle level (*with errors that include both the statistical error and the systematic uncertainty*) and are compared with PYTHIA Tune AW and HERWIG (without MPI) at the particle level (*i.e.* generator level).**

Z-Boson: “Towards”, Transverse”, & “TransMIN” Charge Density



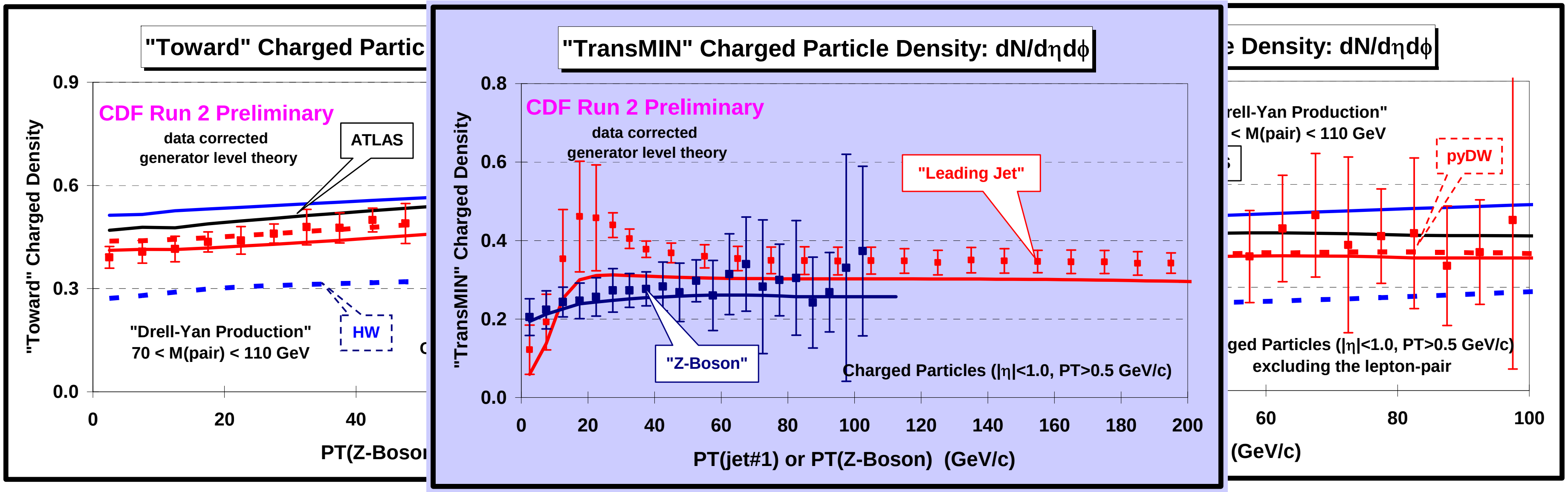


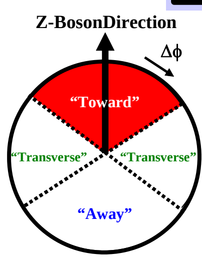


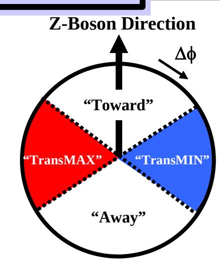


- **Data at 1.96 TeV on the density of charged particles, dN/dηdφ, with p_T > 0.5 GeV/c and |η| < 1 for “Z-Boson” events as a function of $P_T(Z)$ for the “toward” and “transverse” regions. The data are corrected to the particle level (*with errors that include both the statistical error and the systematic uncertainty*) and are compared with PYTHIA Tune AW and HERWIG (without MPI) at the particle level (*i.e.* generator level).**

Z-Boson: “Towards”, Transverse”, & “TransMIN” Charge Density

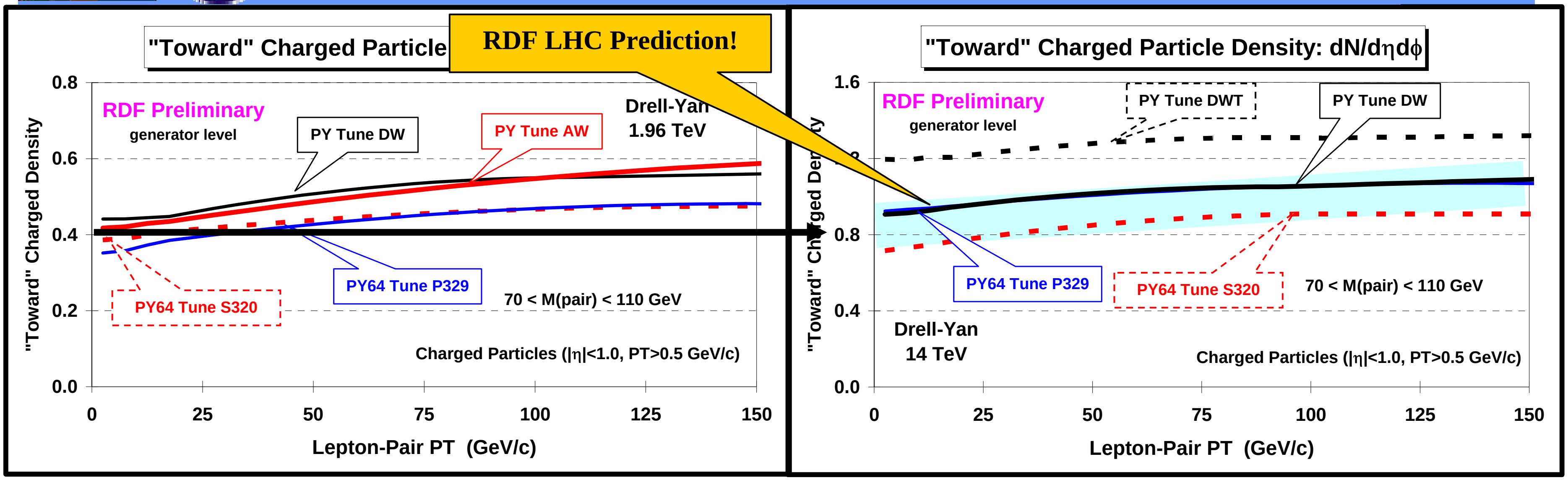


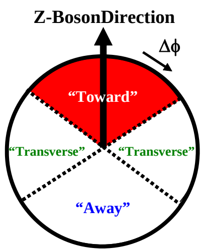




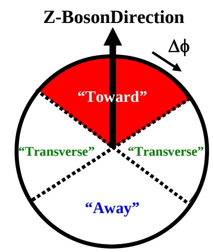
- **Data at 1.96 TeV on the density of charged particles, dN/dηdϕ, with p_T > 0.5 GeV/c and |η| < 1 for “Z-Boson” events as a function of P_T(Z) for the “toward” and “transverse” regions. The data are corrected to the particle level (*with errors that include both the statistical error and the systematic uncertainty*) and are compared with PYTHIA Tune AW and HERWIG (without MPI) at the particle level (*i.e.* generator level).**

Z-Boson: "Towards" Region



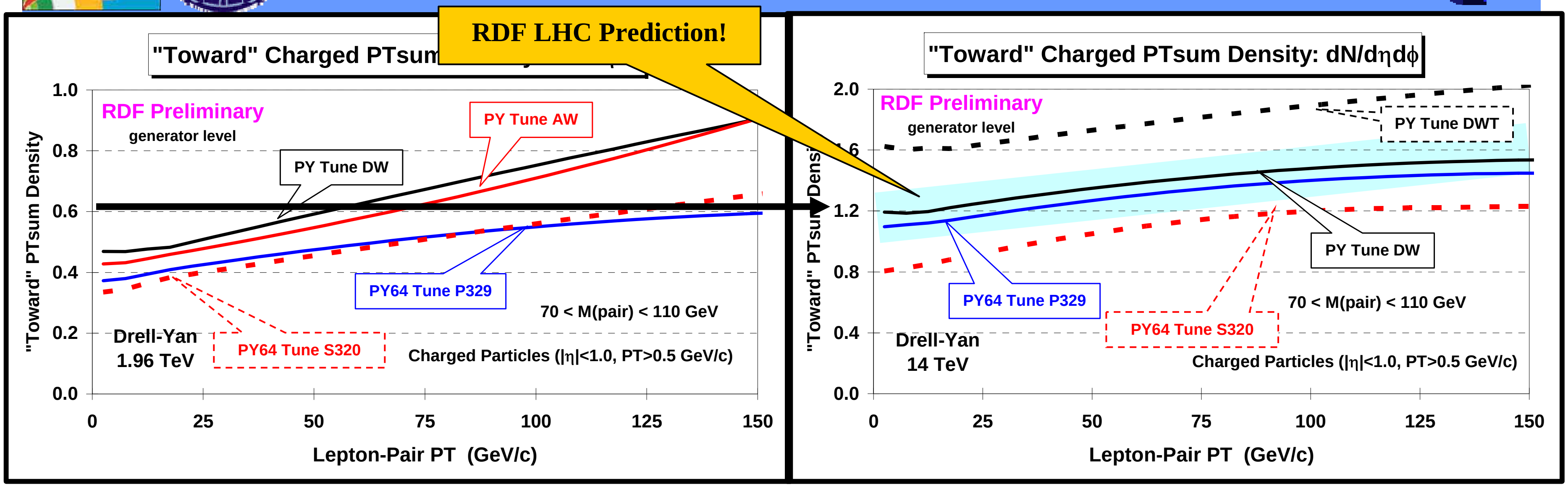


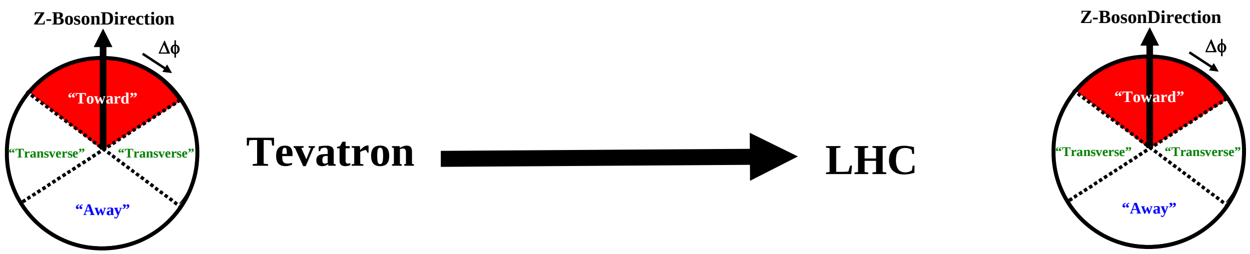
Tevatron → LHC



- **Data at 1.96 TeV on the density of charged particles, dN/dηdϕ, with p_T > 0.5 GeV/c and |η| < 1 for "Z-Boson" events as a function of $P_T(Z)$ for the "toward" region from PYTHIA Tune AW, Tune DW, Tune S320, and Tune P329 at the particle level (*i.e.* generator level).**
- **Extrapolations of PYTHIA Tune AW, Tune DW, Tune DWT, Tune S320, and Tune P329 to the LHC.**

Z-Boson: "Towards" Region



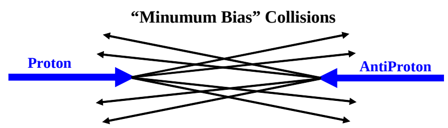


- Data at 1.96 TeV on the charged PTsum density, dPT/dηdφ, with $p_T > 0.5$ GeV/c and $|\eta| < 1$ for "Z-Boson" events as a function of $P_T(Z)$ for the "toward" region from PYTHIA Tune AW, Tune DW, Tune S320, and Tune P329 at the particle level (*i.e.* generator level).

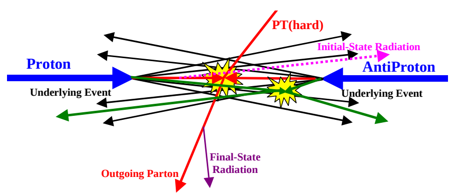
- Extrapolations of PYTHIA Tune AW, Tune DW, Tune DWT, Tune S320, and Tune P329 to the LHC.

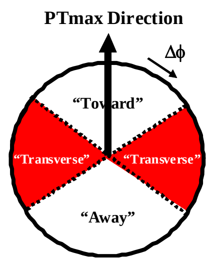
LHC Predictions

I believe we are now in a position to make some predictions at the LHC!

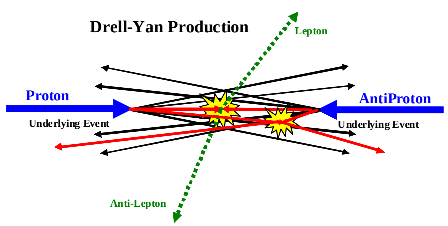


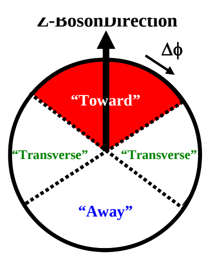
- The amount of activity in "min-bias" collisions.



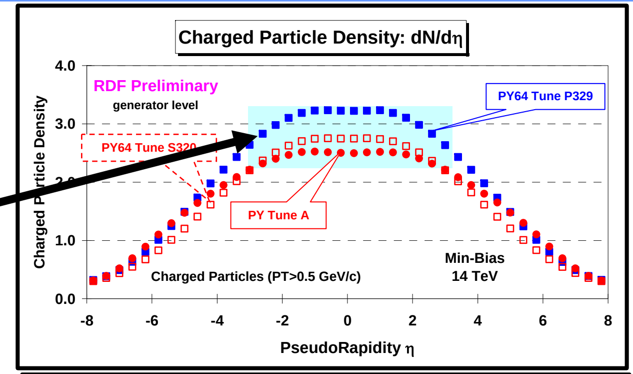


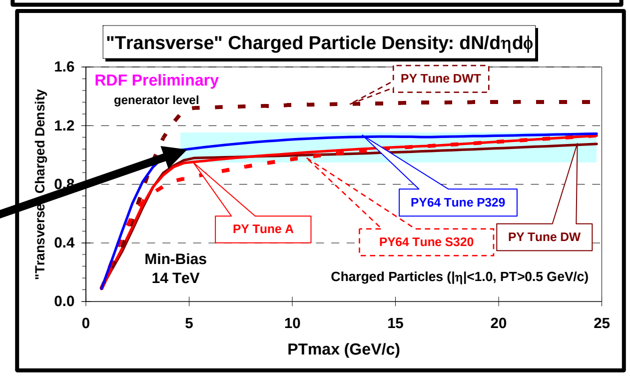
- The amount of activity in the "underlying event" in hard scattering events.

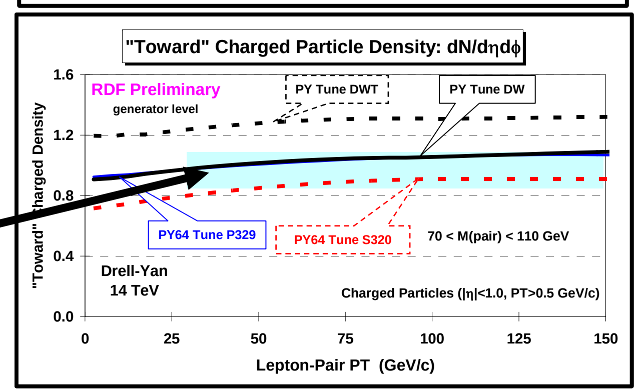




- The amount of activity in the "underlying event" in Drell-Yan events.

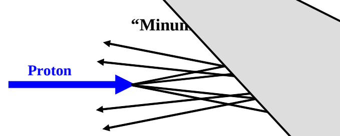




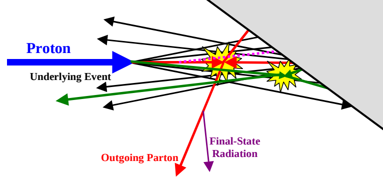


LHC Predictions

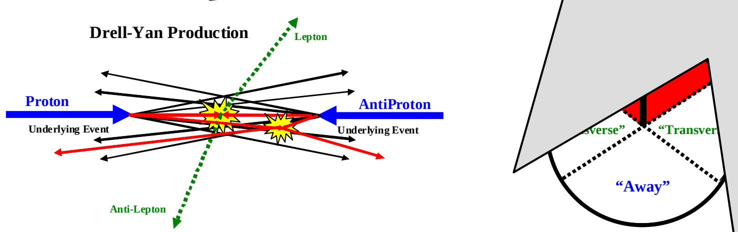
I believe we are now in a position to make some predictions at the LHC!



- The amount of activity in "mi

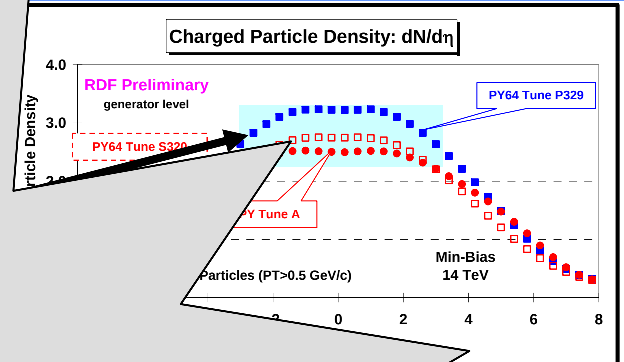


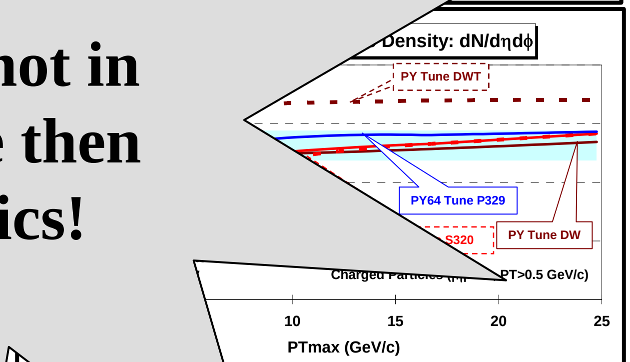
- The amount of acti scattering eve

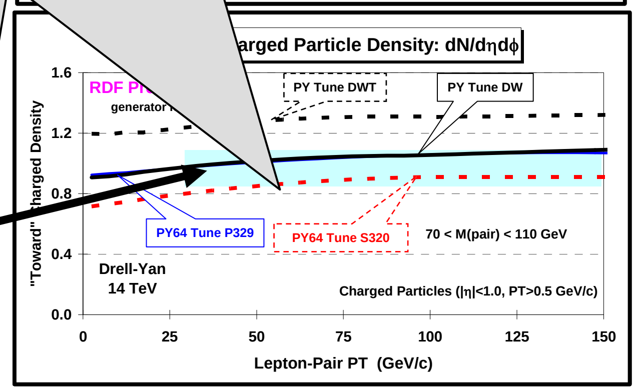


- The amount of activity in the "underlying ev" in Drell-Yan events.

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

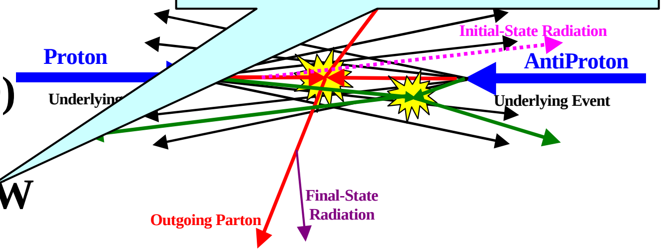




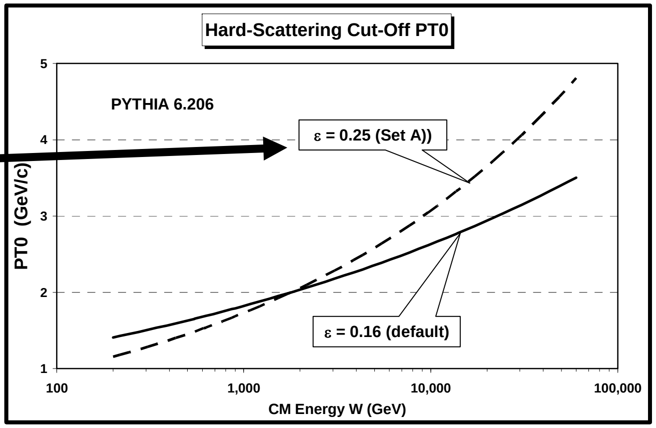


Summary & Conclus…

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!



- We are making good progress in understanding and modeling the "underlying event".
- 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.



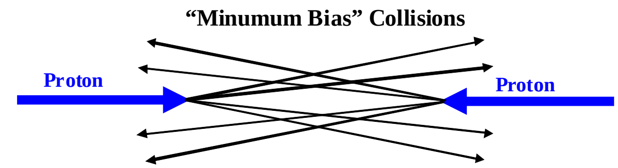
- All tunes with the default value PARP(90) = 0.16 are wrong and are overestimating the activity of min-bias and the underlying event at the LHC! This includes all the ATLAS tunes!

- 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!

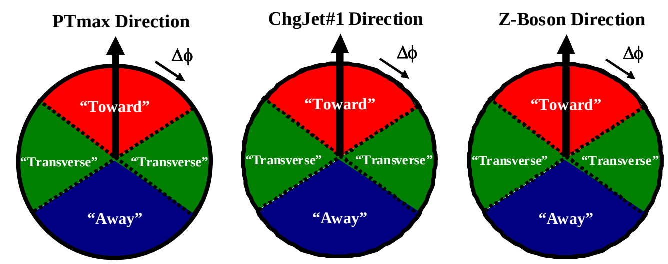
UE&MB@CMS

Early LHC Thesis Projects

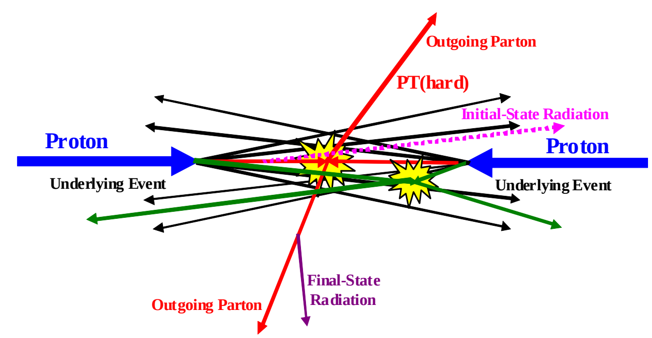
Thesis 1: Measure dNchg/dη and <PT> versus Nchg in “min-bias” collisions.



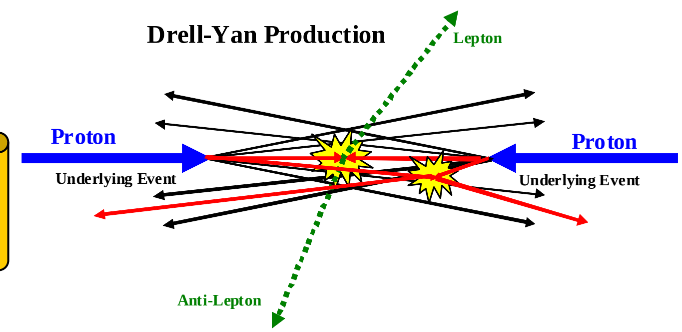
Thesis 2: Measure the “toward”, “away”, and “transverse” region as a function of PTmax in “min-bias” collisions.



Thesis 3: Measure the “toward”, “away”, and “transverse” region as a function of PT(chgjet#1).



Thesis 4: Measure the “toward”, “away”, and “transverse” region as a function of PT(Z) for Z-boson production.



Thesis 5: Measure PT(Z) and <p_T> versus Nchg for Z-boson production (all PT(Z), PT(Z) < 10 GeV/c).