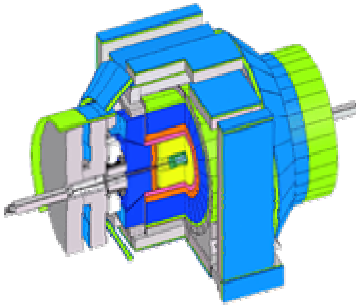
C2CR07

Rick Field

University of Florida

(*for the CDF Collaboration*)

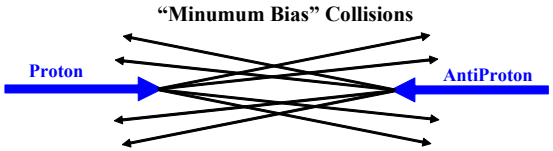
Min-Bias at the Tevatron



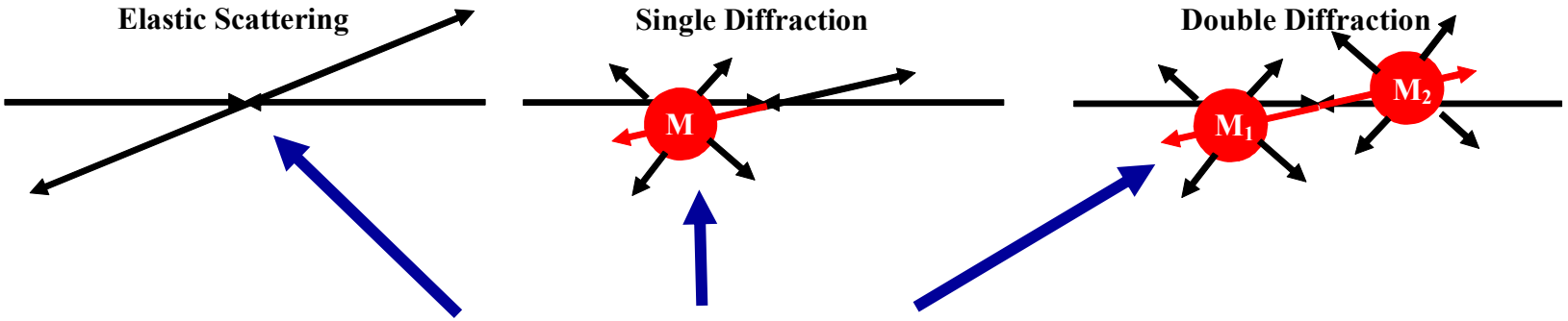
CDF Run 2

Outline of Talk

- What is Min-Bias? Does it really exist?
- "Jets" in Min-Bias Collisions. Clear Jet structure as low as 1 GeV/c!
- Extrapolating Tevatron Min-Bias to the LHC.
- Using Pile-Up collisions to Study Min-Bias. Is Pile-Up Unbiased?



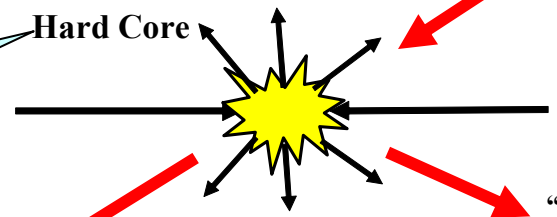
Proton-AntiProton Collisions at the Tevatron

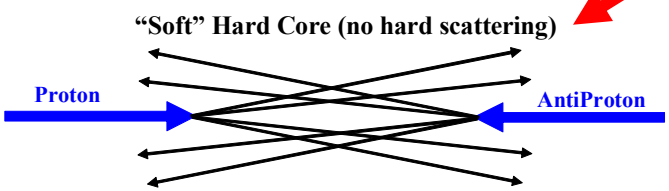


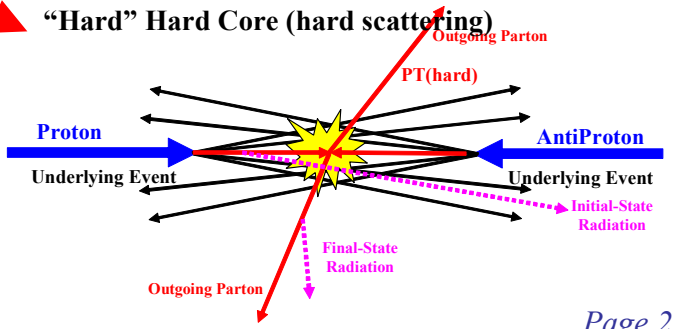
$$\sigma_{tot} = \sigma_{EL} + \sigma_{SD} + \sigma_{DD} + \sigma_{HC}$$

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

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

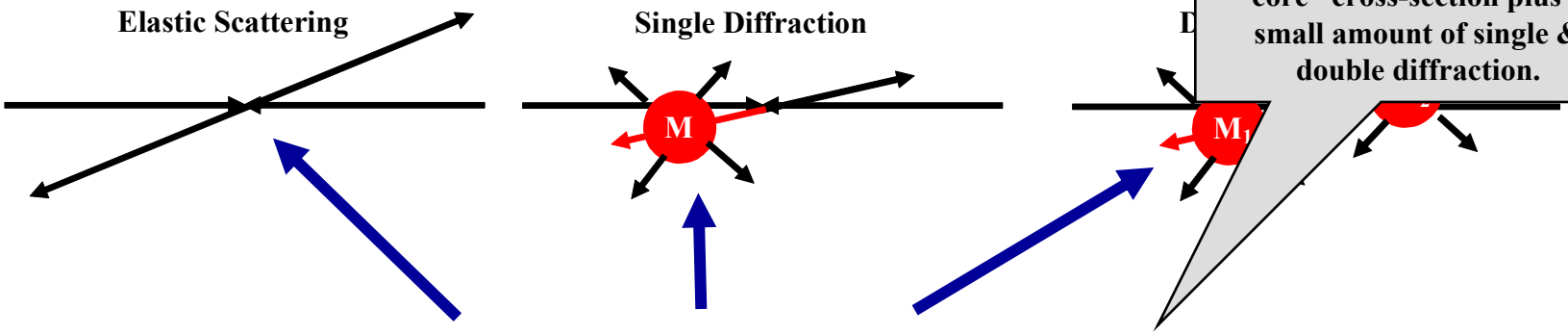






Proton-AntiProton Collisions at the Tevatron

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



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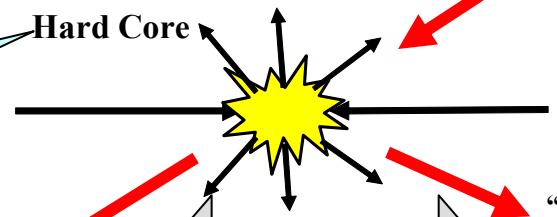
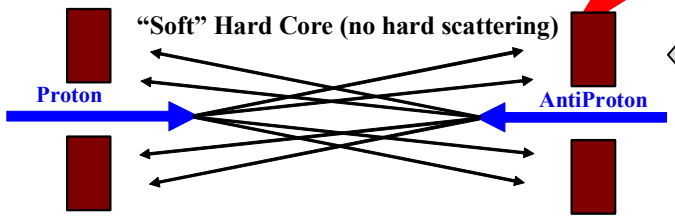
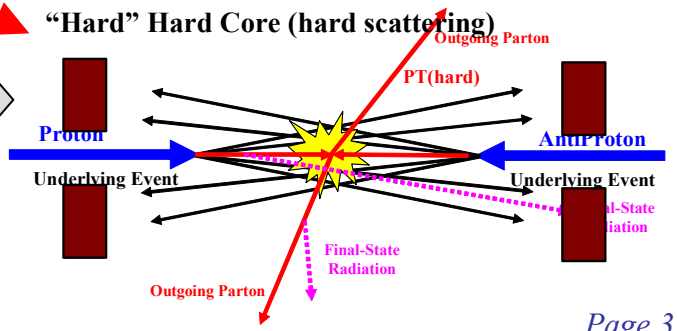


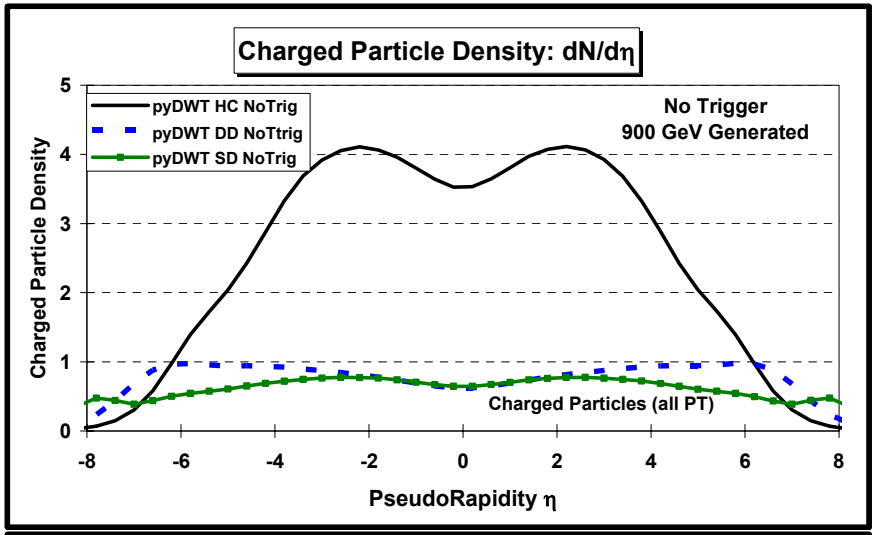
CDF "Min-Bias" trigger
1 charged particle in forward BBC
AND
1 charged particle in backward BBC

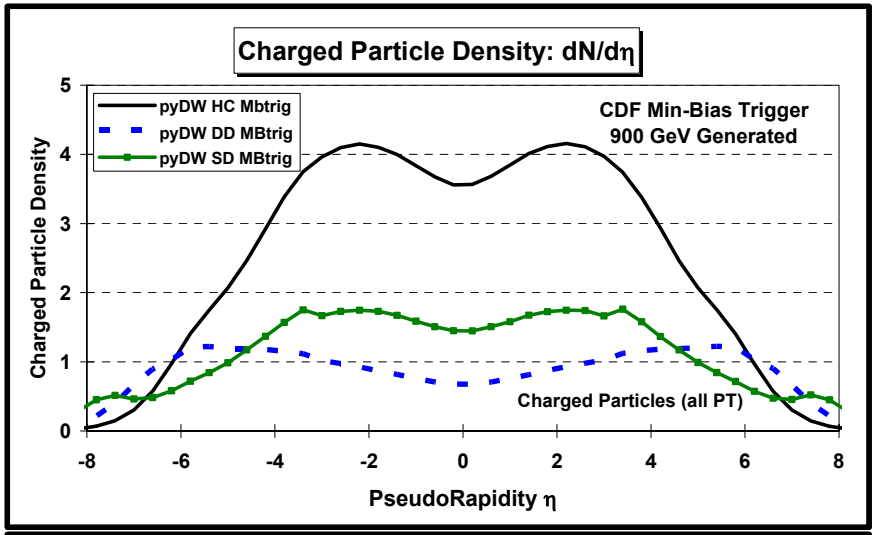


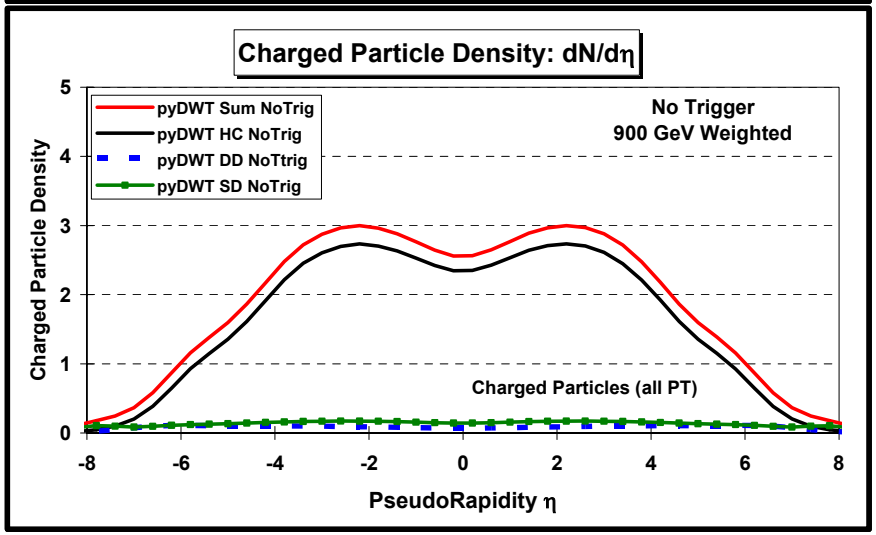
Beam-Beam Counters
$3.2 < |\eta| < 5.9$

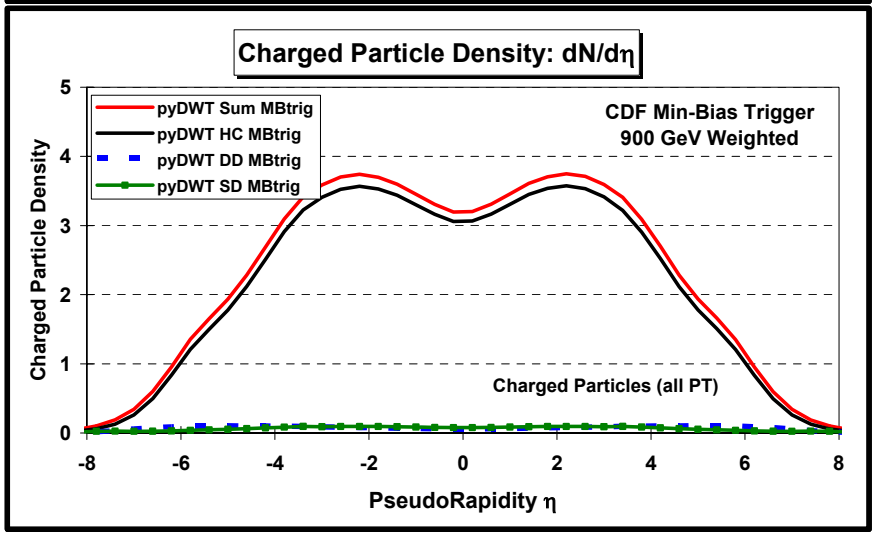


No-Bias vs Min-Bias

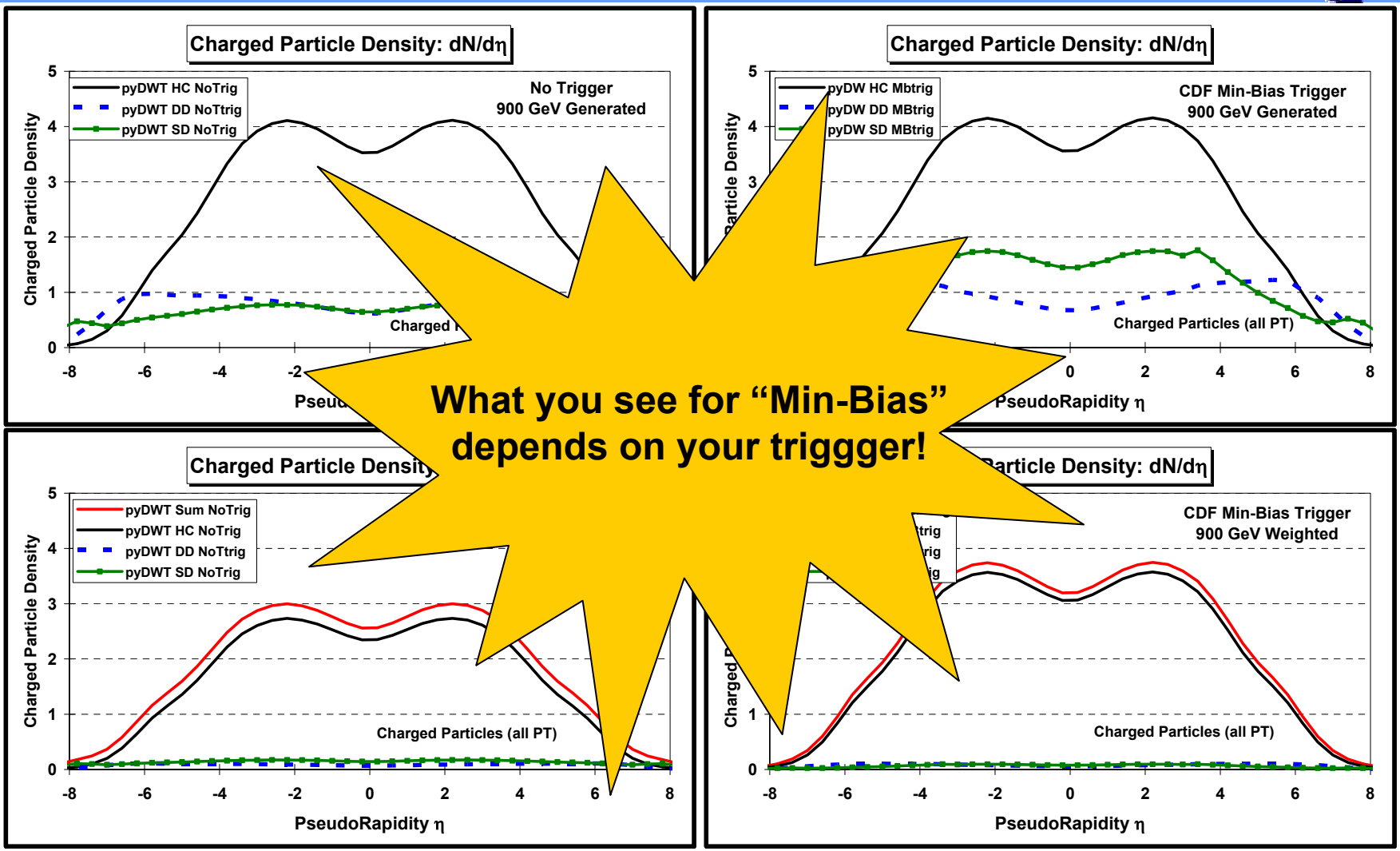






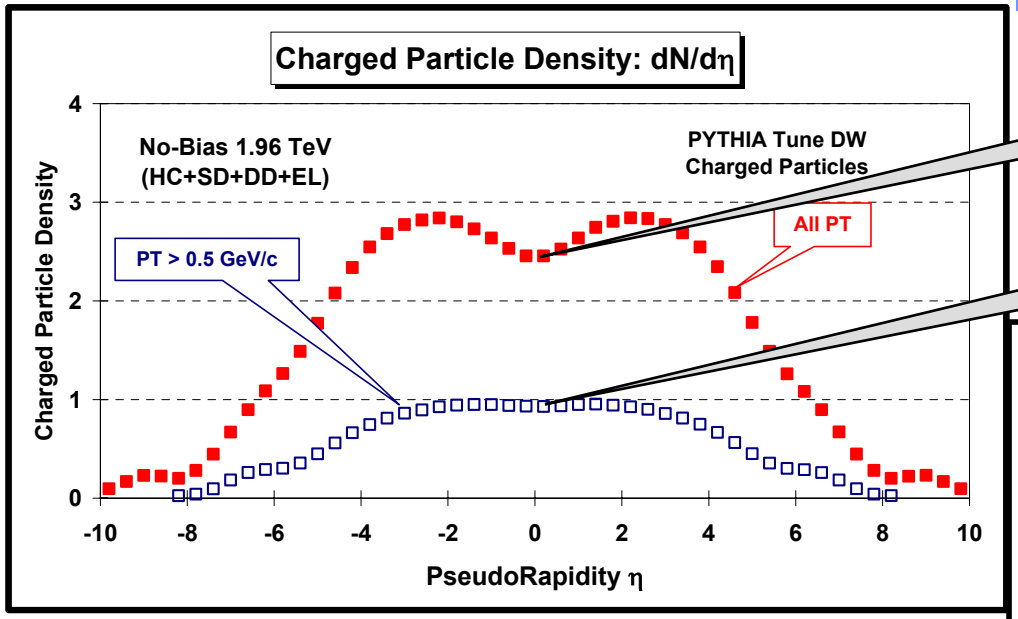


No-Bias vs Min-Bias



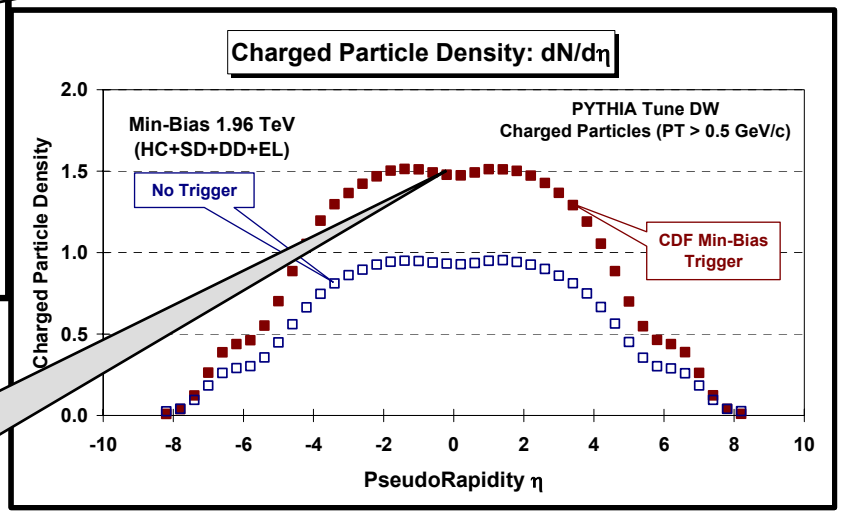
What you see for "Min-Bias" depends on your triggger!

No-Bias vs Min-Bias



About 2.5 charged particles per unit η at η = 0.

About 0.9 charged particles (p_T > 0.5 GeV/c) per unit η at η = 0.

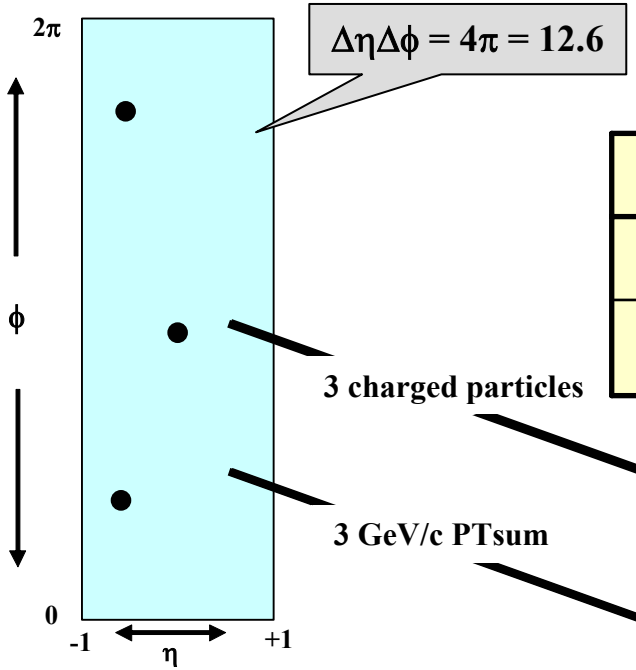


- **Charged particle (all p_T) pseudo-rapidity distribution, $dN_{chg}/d\eta d\phi$, at 1.96 TeV with no trigger (*i.e.* no-bias) from PYTHIA Tune DW.**

About 1.5 charged particles (p_T > 0.5 GeV/c) per unit η at η = 0 with CDF min-bias trigger.

- **Charged particle (p_T > 0.5 GeV/c) pseudo-rapidity distribution, $dN_{chg}/d\eta d\phi$, at 1.96 TeV with the CDF Min-Bias trigger from PYTHIA Tune DW.**

Particle Densities



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

CDF Run 2 "Min-Bias"

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

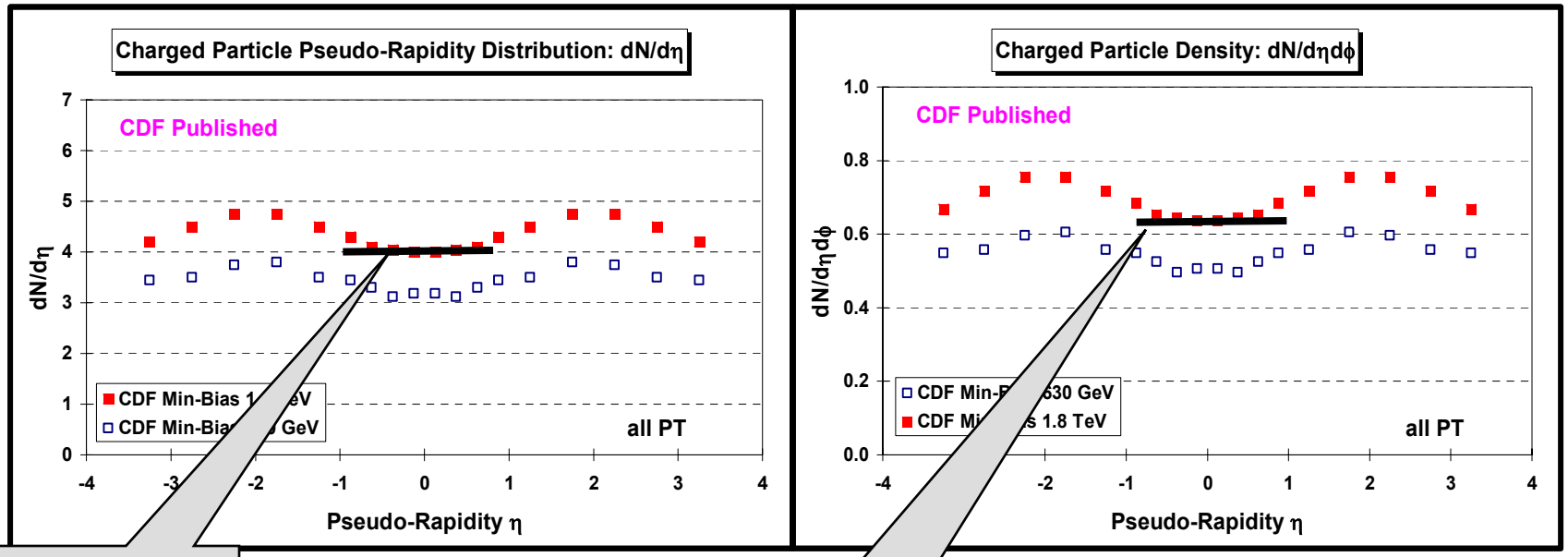
Divide by 4π

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

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

- **Study the charged particles ($p_T > 0.5$ GeV/c, $|\eta| < 1$) and form the charged particle density, $dN_{chg}/d\eta d\phi$, and the charged scalar p_T sum density, $dPT_{sum}/d\eta d\phi$.**

CDF "Min-Bias" Data
Charged Particle Density



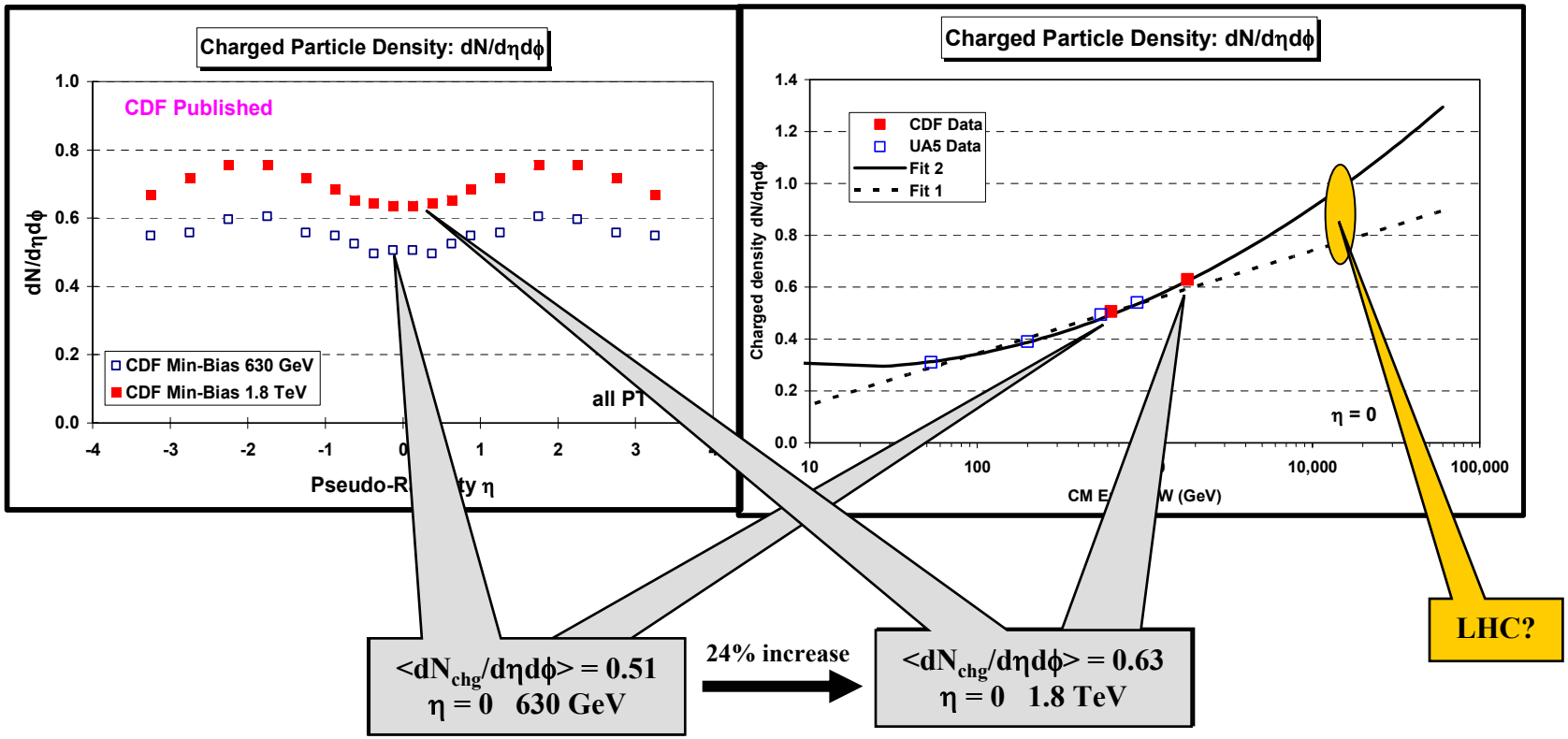
$\langle dN_{chg}/d\eta \rangle = 4.2$

$\langle dN_{chg}/d\eta d\phi \rangle = 0.67$

- Shows CDF "Min-Bias" data on the number of charged particles per unit pseudo-rapidity at 630 and 1,800 GeV. There are about 4.2 charged particles per unit η in "Min-Bias" collisions at 1.8 TeV ($|\eta| < 1$, all P_T).

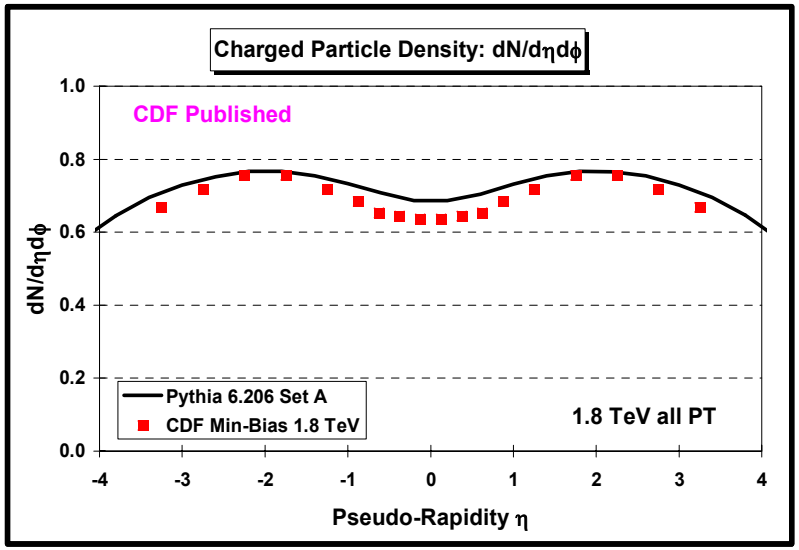
- Convert to charged particle density, $dN_{chg}/d\eta d\phi$, by dividing by 2π. There are about 0.67 charged particles per unit η-ϕ in "Min-Bias" collisions at 1.8 TeV ($|\eta| < 1$, all P_T).

CDF "Min-Bias" Data Energy Dependence



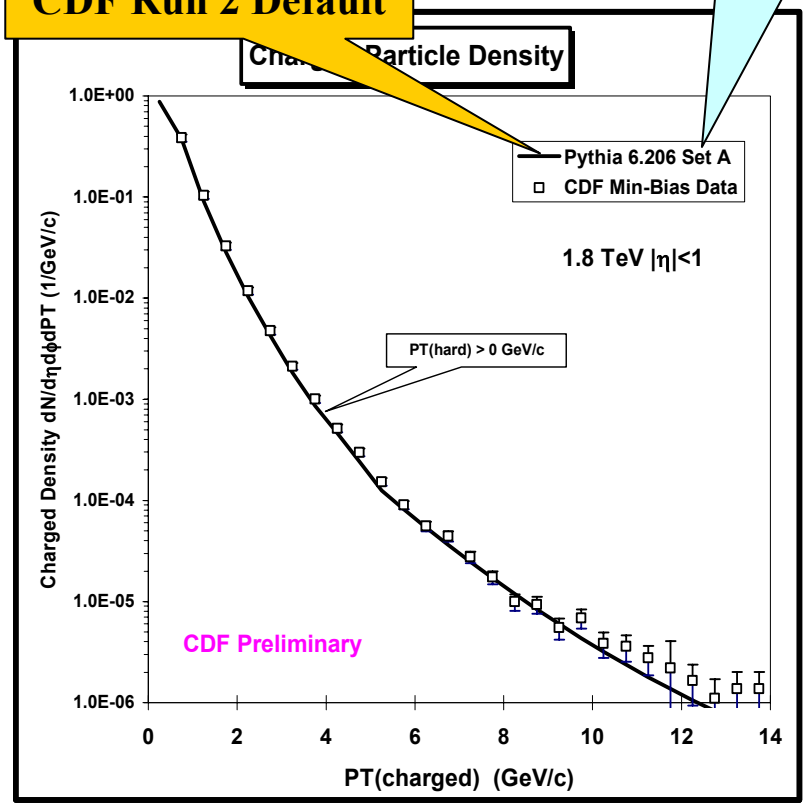
- Shows the center-of-mass energy dependence of the charged particle density, $dN_{chg}/d\eta d\phi$, for "Min-Bias" collisions at $\eta = 0$. Also show a log fit (Fit 1) and a $(\log)^2$ fit (Fit 2) to the CDF plus UA5 data.
- What should we expect for the LHC?

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



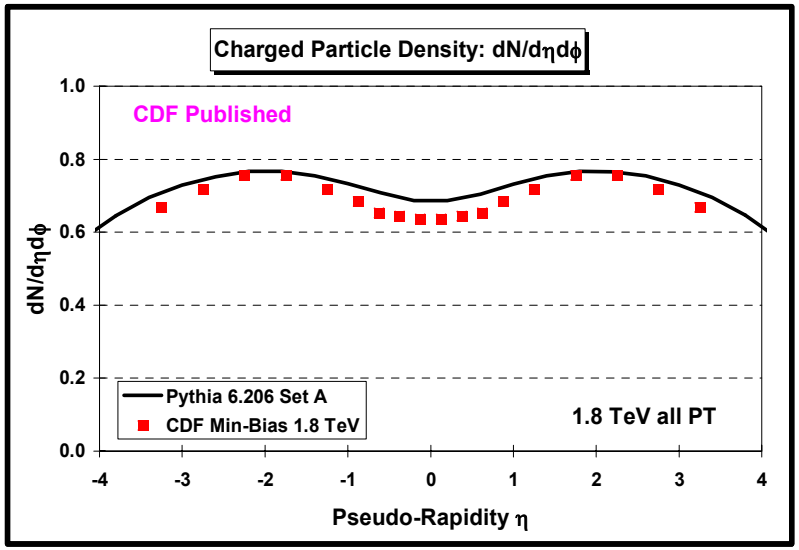
PYTHIA Tune A
CDF Run 2 Default

Tuned to fit the "underlying event"!



- PYTHIA regulates the perturbative 2-to-2 parton-parton cross sections with cut-off parameters which allows one to run with P_T(hard) > 0. One can simulate both "hard" and "soft" collisions in one program.
- The relative amount of "hard" versus "soft" depends on the cut-off and can be tuned.

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



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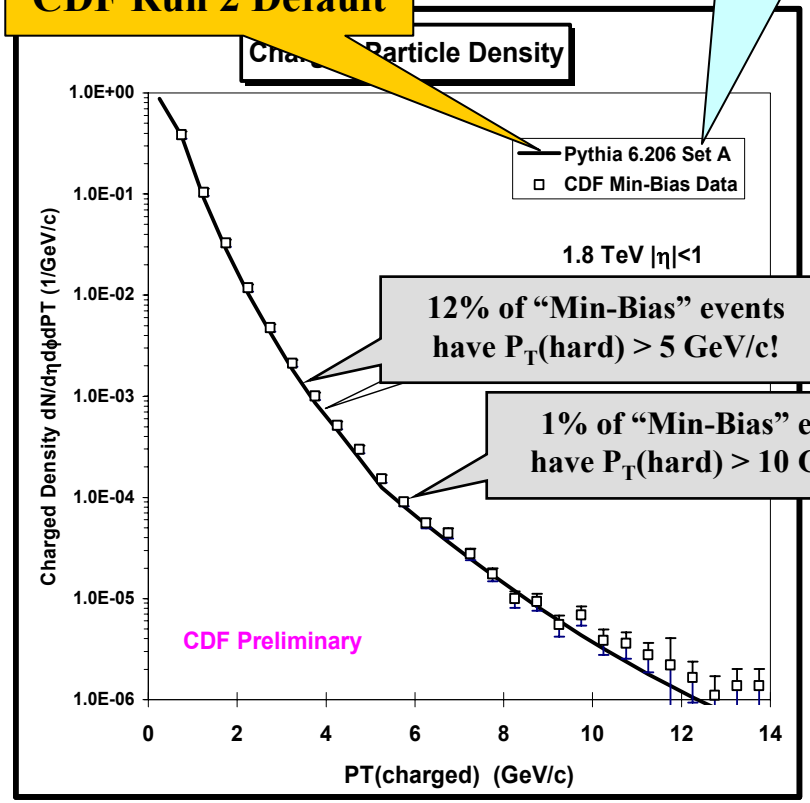


12% of "Min-Bias" events have P_T(hard) > 5 GeV/c!

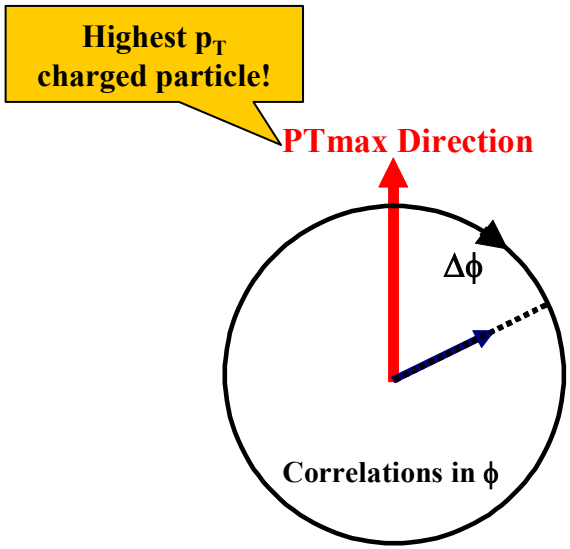
1% of "Min-Bias" events have P_T(hard) > 10 GeV/c!

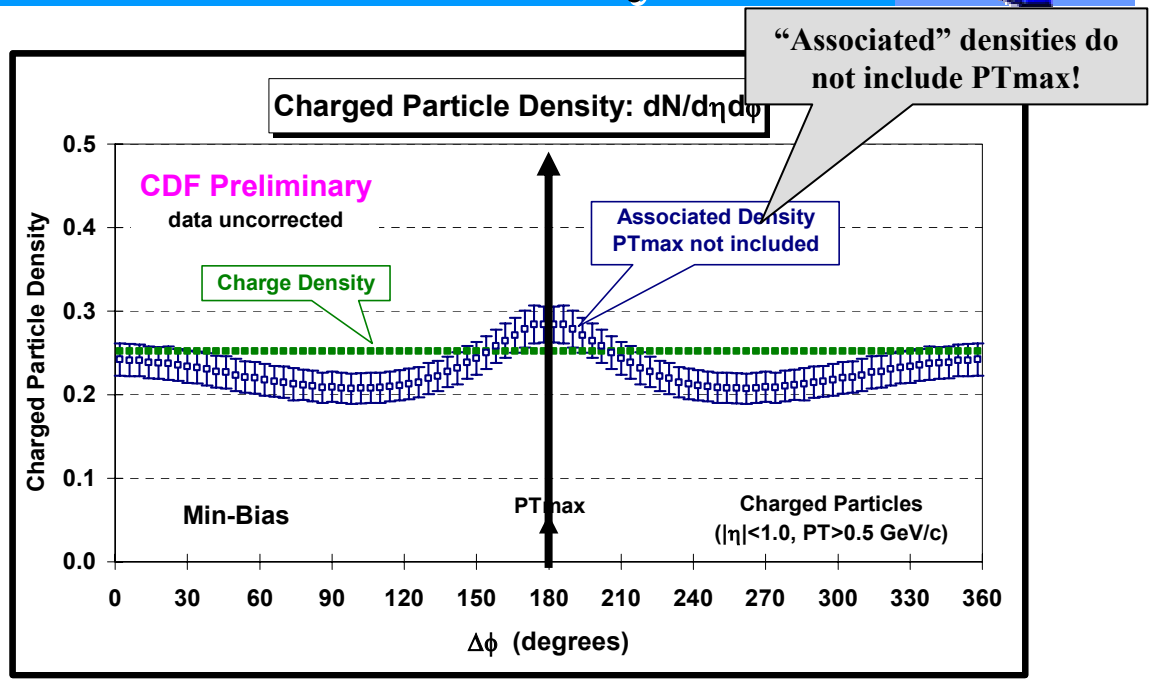
- PYTHIA regulates the perturbative 2-to-2 parton-parton cross sections with cut-off par one to run with P_T(mulate both "hard" and "soft" collisio one program.

Lots of "hard" scattering in "Min-Bias"!

- 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)!

Min-Bias "Associated" Charged Particle Density

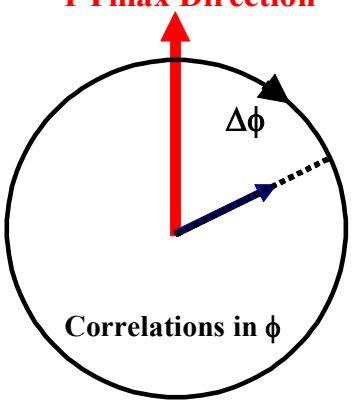




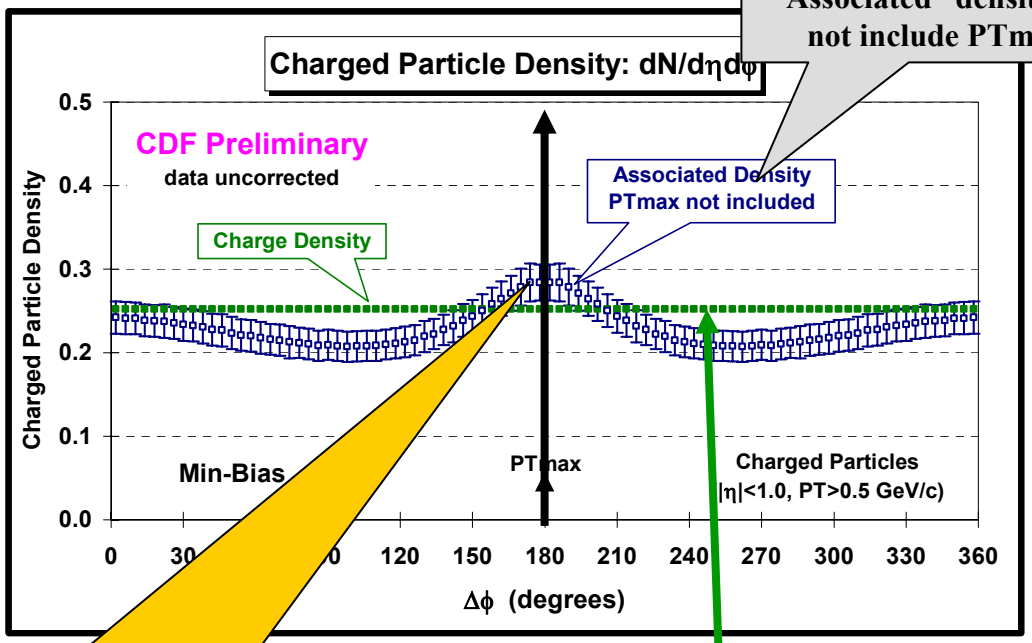
- Use the **maximum p_T charged particle in the event, PTmax**, to define a direction and look at the the "associated" density, $dN_{chg}/d\eta d\phi$, in **"min-bias" collisions** ($p_T > 0.5$ GeV/c, $|\eta| < 1$).
- Shows the data on the **Δϕ dependence of the "associated" charged particle density**, $dN_{chg}/d\eta d\phi$, for charged particles ($p_T > 0.5$ GeV/c, $|\eta| < 1$, *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.**

Min-Bias "Associated" Charged Particle Density

Highest p_T charged particle!



"Associated" densities do not include PTmax!

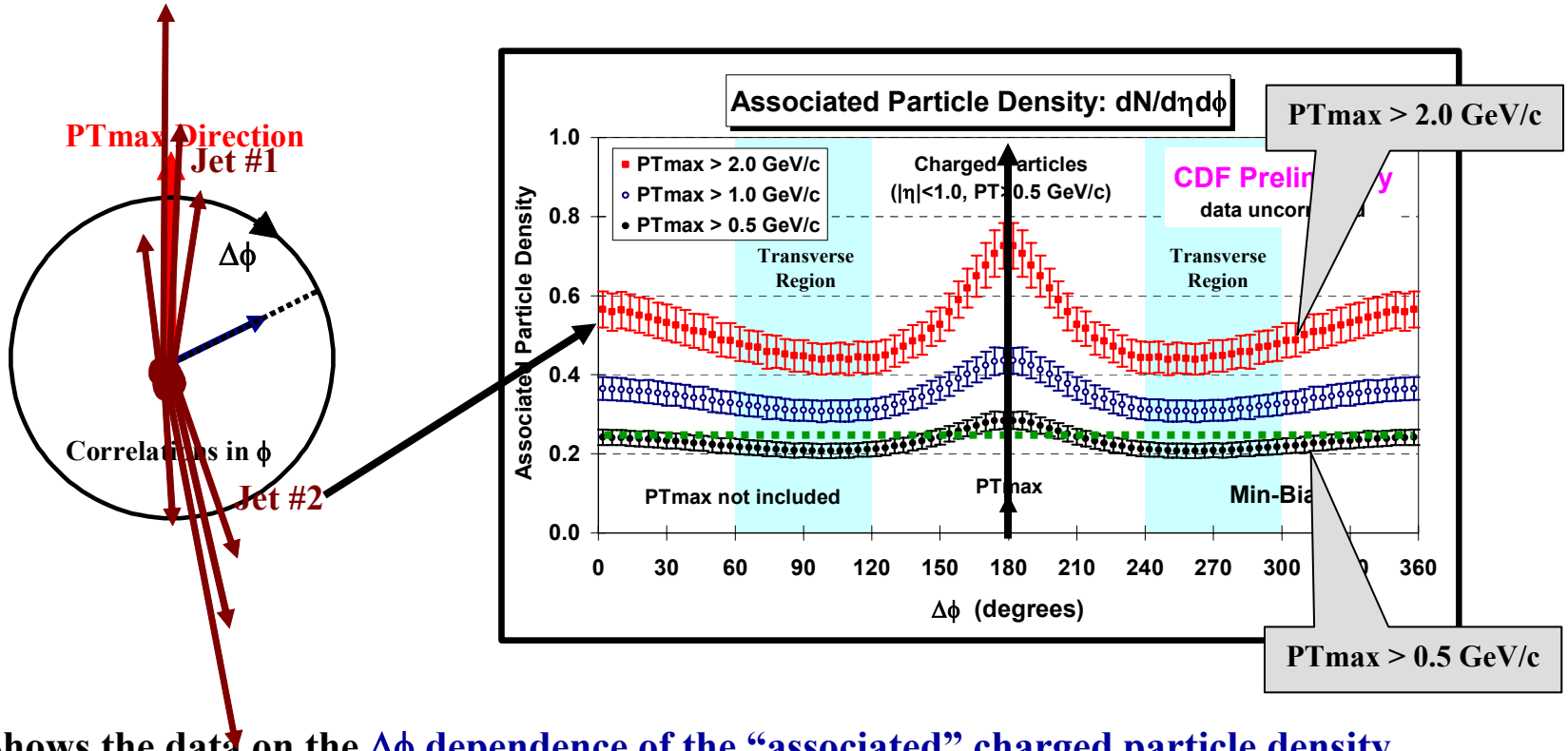


- Use the m… charged p… e event, PTmax, to define a direction and look at th… in "min-bias" collisions (p_T > 0.5 GeV/c, |η…

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

- Shows th… ociated" 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.

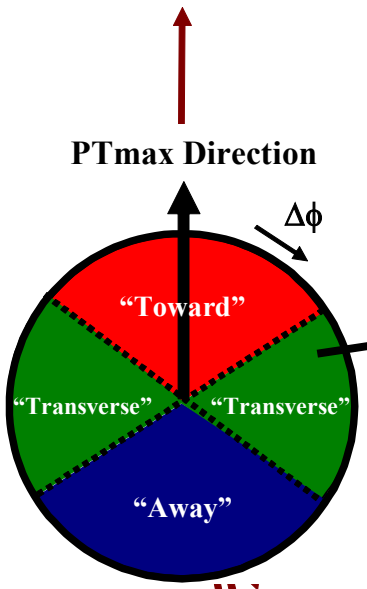
Min-Bias "Associated" Charged Particle Density

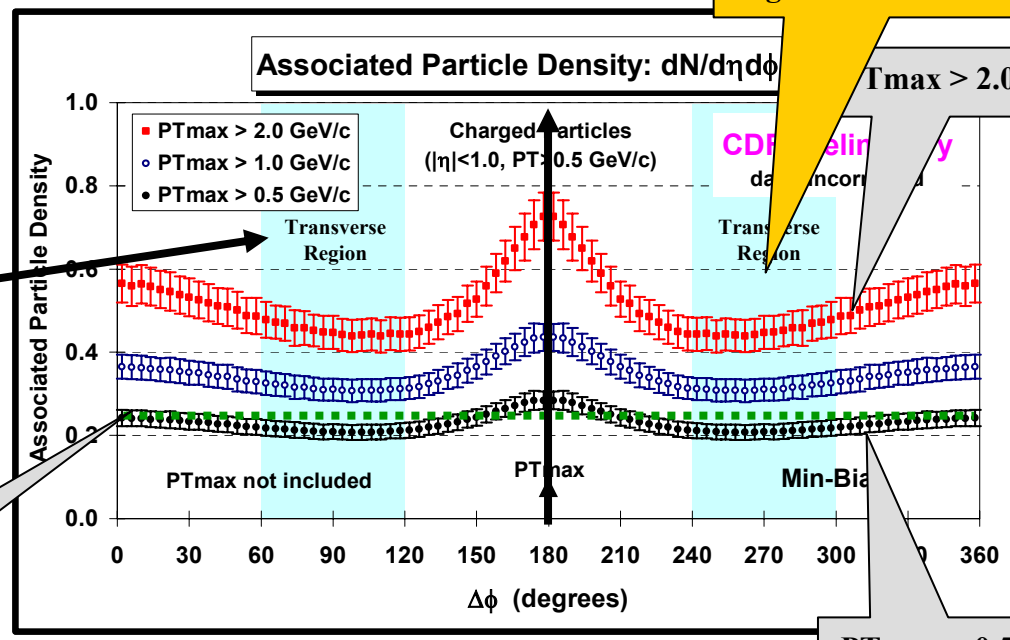


- Shows the data on the Δϕ dependence of the "associated" charged particle density, $dN_{chg}/d\eta d\phi$, for charged particles (p_T > 0.5 GeV/c, |η| < 1, *not including PTmax*) relative to PTmax (rotated to 180°) for "min-bias" events with PTmax > 0.5, 1.0, and 2.0 GeV/c.

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

Min-Bias "Associated" Charged Particle Density





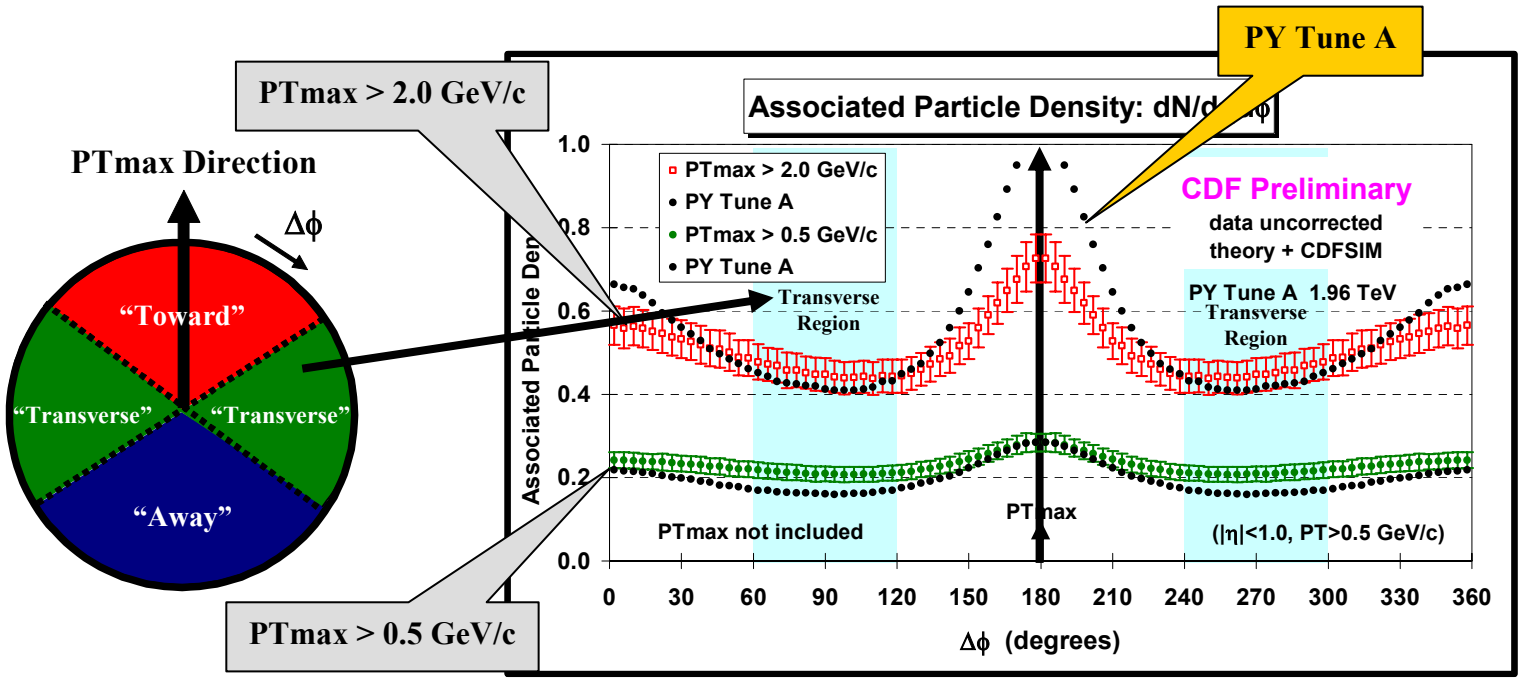
Rapid rise in the particle density in the "transverse" region as PTmax increases!

Ave Min-Bias
0.25 per unit η-ϕ

PTmax > 0.5 GeV/c

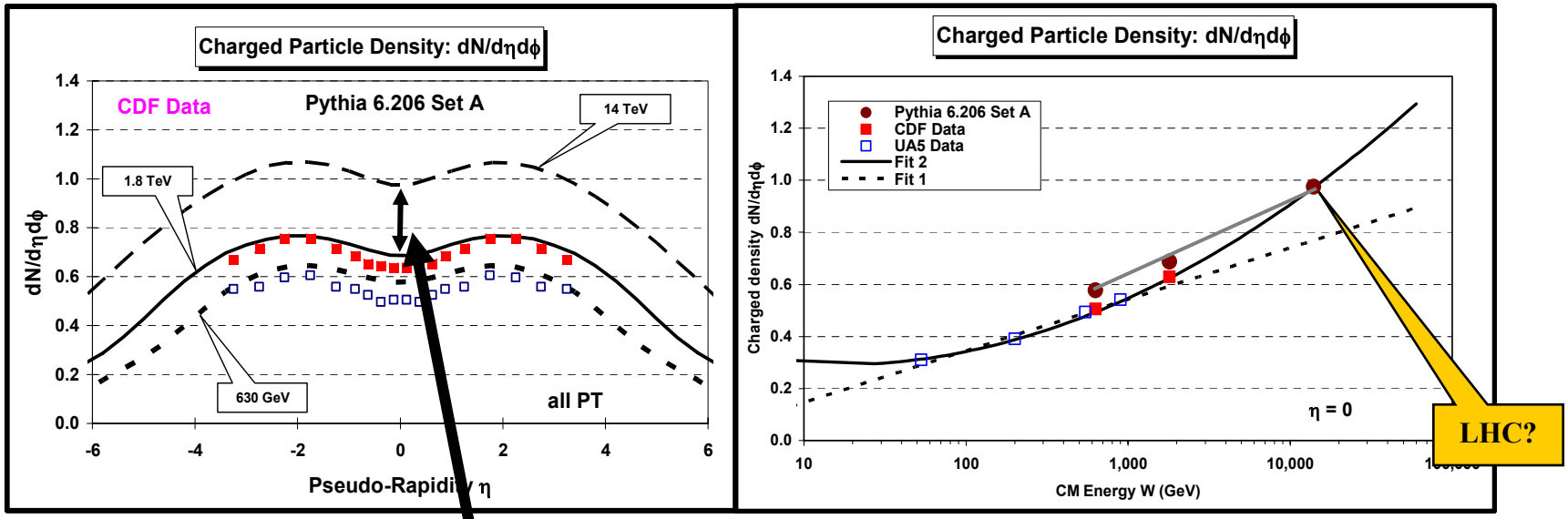
- Shows the data on the Δϕ dependence of the "associated" charged particle density, $dN_{chg}/d\eta d\phi$, for charged particles ($p_T > 0.5$ GeV/c, $|\eta| < 1$, *not including PTmax*) relative to PTmax (rotated to 180°) for "min-bias" events with PTmax > 0.5, 1.0, and 2.0 GeV/c.
- Shows "jet structure"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

Min-Bias "Associated" Charged Particle Density



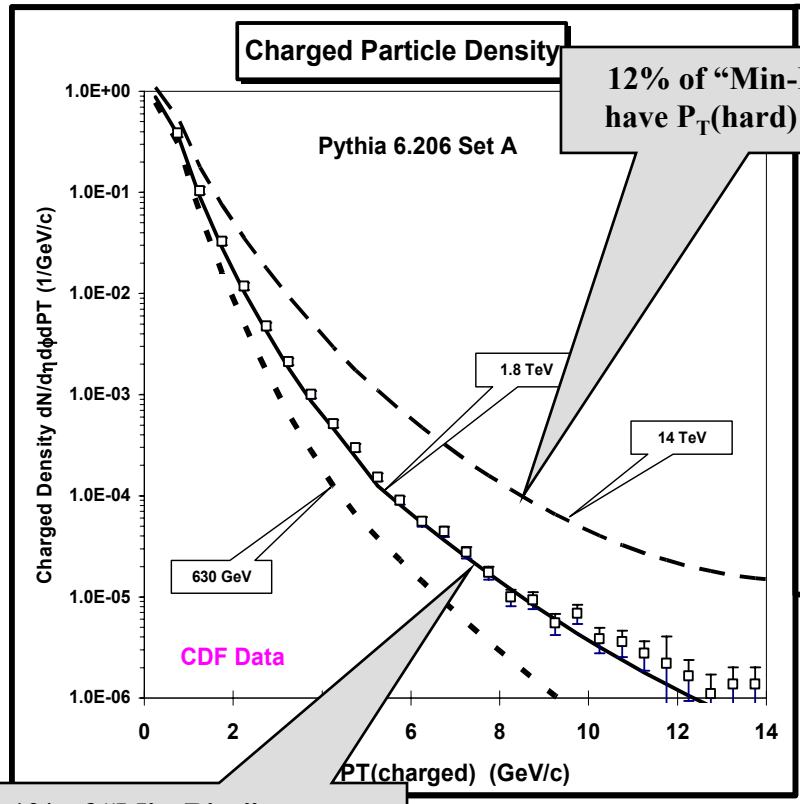
- Shows the data on the Δϕ dependence of the "associated" charged particle density, $dN_{chg}/d\eta d\phi$, for charged particles (p_T > 0.5 GeV/c, |η| < 1, *not including PTmax*) relative to PTmax (rotated to 180°) for "min-bias" events with PTmax > 0.5 GeV/c and PTmax > 2.0 GeV/c compared with PYTHIA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

PYTHIA Tune A
LHC Min-Bias Predictions



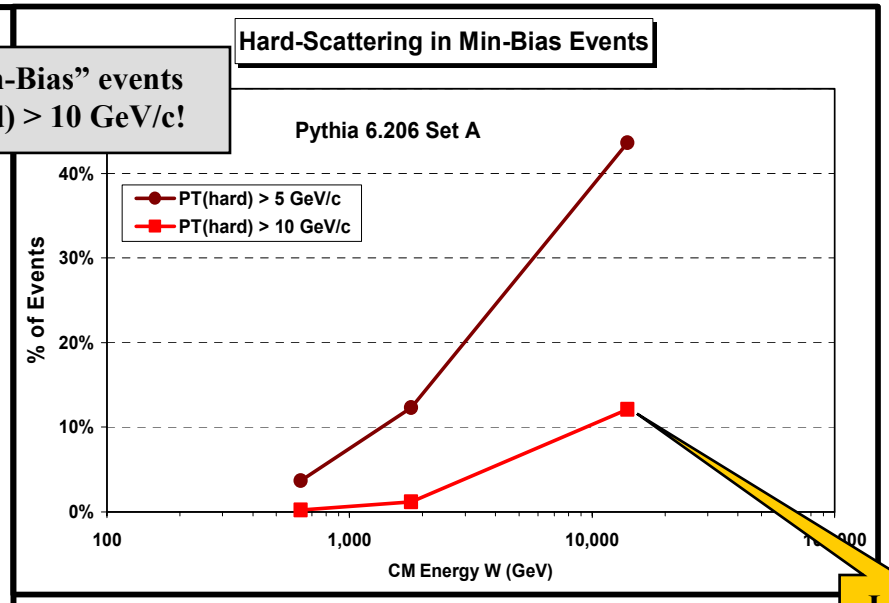
- Shows the center-of-mass energy dependence of the charged particle density, $dN_{chg}/d\eta d\phi$, for "Min-Bias" collisions compared with PYTHIA Tune A with $P_T(\text{hard}) > 0$.
- PYTHIA was tuned to fit the "underlying event" in hard-scattering processes at 1.8 TeV and 630 GeV.
- PYTHIA Tune A predicts a 42% rise in $dN_{chg}/d\eta d\phi$ at $\eta = 0$ in going from the Tevatron (1.8 TeV) to the LHC (14 TeV). Similar to HERWIG "soft" min-bias, 4 charged particles per unit η becomes 6.

PYTHIA Tune A
LHC Min-Bias Predictions



12% of "Min-Bias" events have P_T(hard) > 10 GeV/c!

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

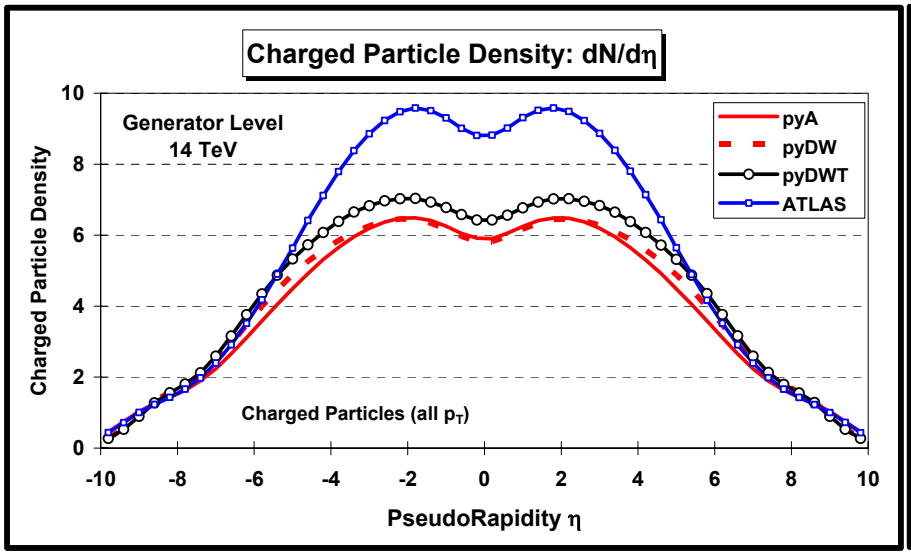


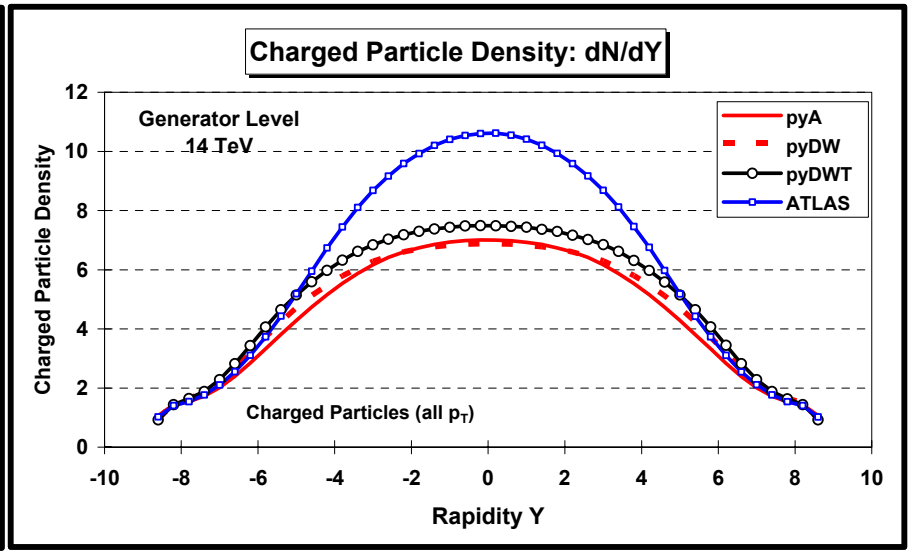
LHC?

- Shows the center-of-mass energy dependence of the charged particle density, $dN_{chg}/d\eta d\phi dP_T$, for "Min-Bias" collisions compared with PYTHIA Tune A with P_T(hard) > 0.

- PYTHIA Tune A predicts that 1% of all "Min-Bias" events at 1.8 TeV are a result of a hard 2-to-2 parton-parton scattering with P_T(hard) > 10 GeV/c which increases to 12% at 14 TeV!

PYTHIA 6.2 Tunes
LHC Min-Bias Predictions



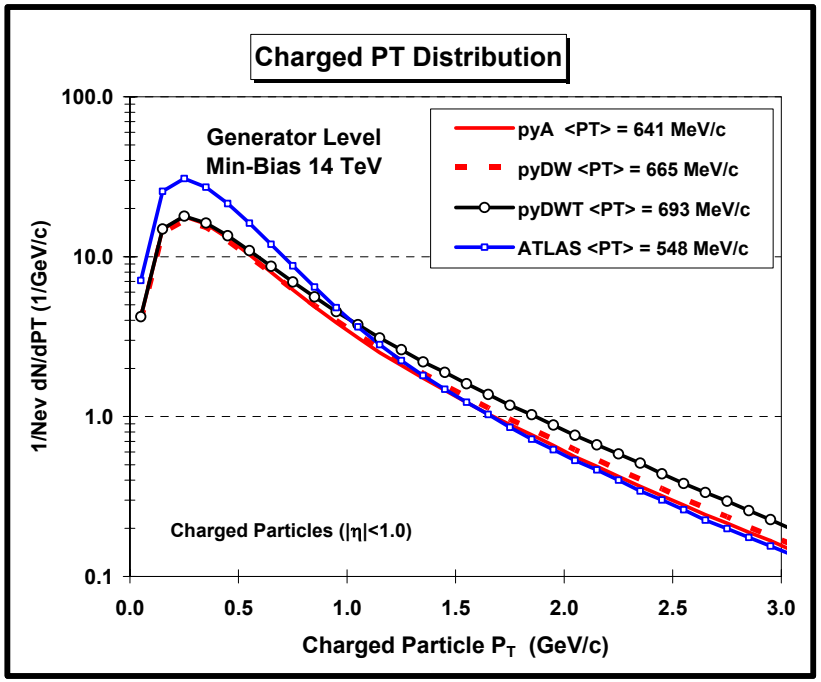


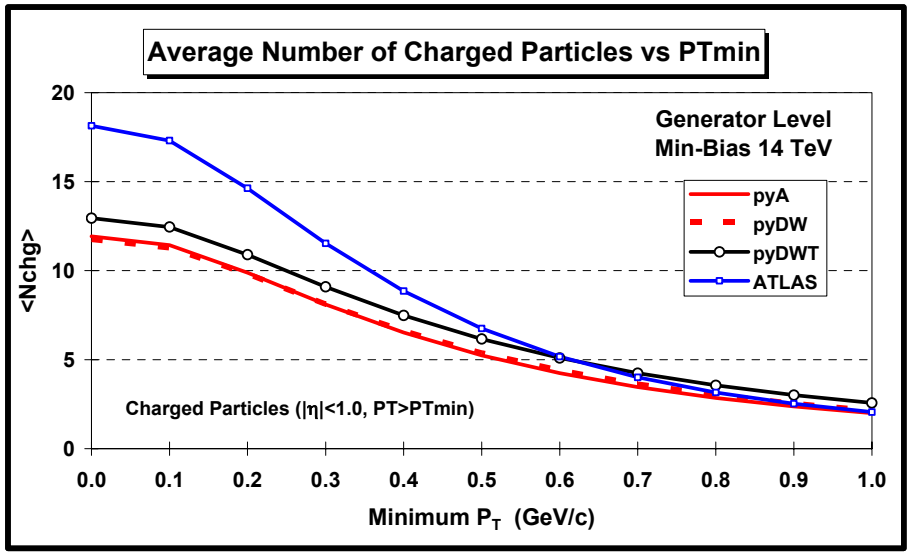
- **Shows the predictions of PYTHIA Tune A, Tune DW, Tune DWT, and the ATLAS tune for the charged particle density dN/dη and dN/dY at 14 TeV (all p_T).**

- **PYTHIA Tune A and Tune DW predict about 6 charged particles per unit η at η = 0, while the ATLAS tune predicts around 9.**

- **PYTHIA Tune DWT is identical to Tune DW at 1.96 TeV, but extrapolates to the LHC using the ATLAS energy dependence.**

PYTHIA 6.2 Tunes
LHC Min-Bias Predictions

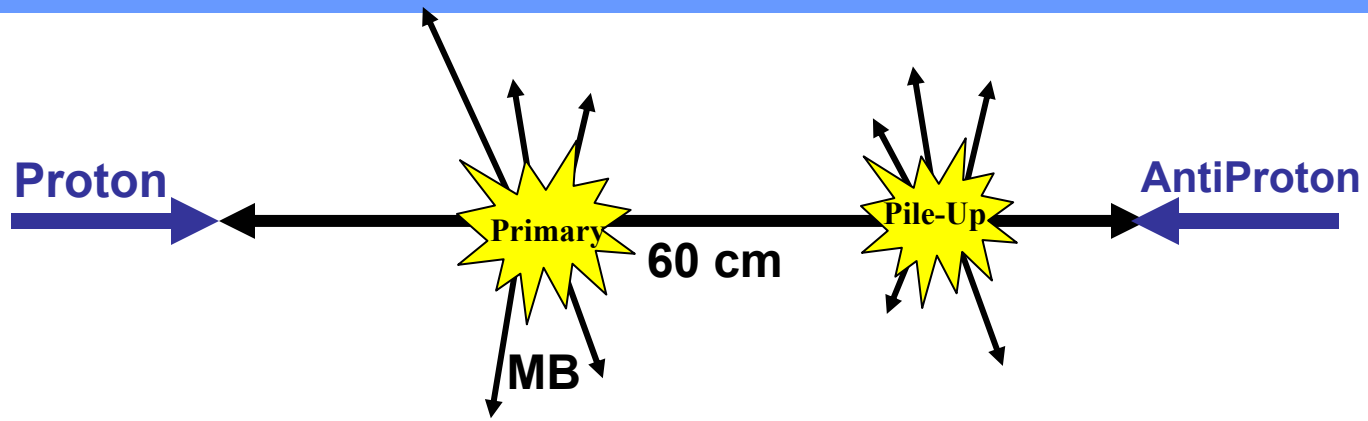




- **Shows the predictions of PYTHIA Tune A, Tune DW, Tune DWT, and the ATLAS tune for the charged particle p_T distribution at 14 TeV ($|\eta| < 1$) and the average number of charged particles with $p_T > p_T^{min}$ ($|\eta| < 1$).**

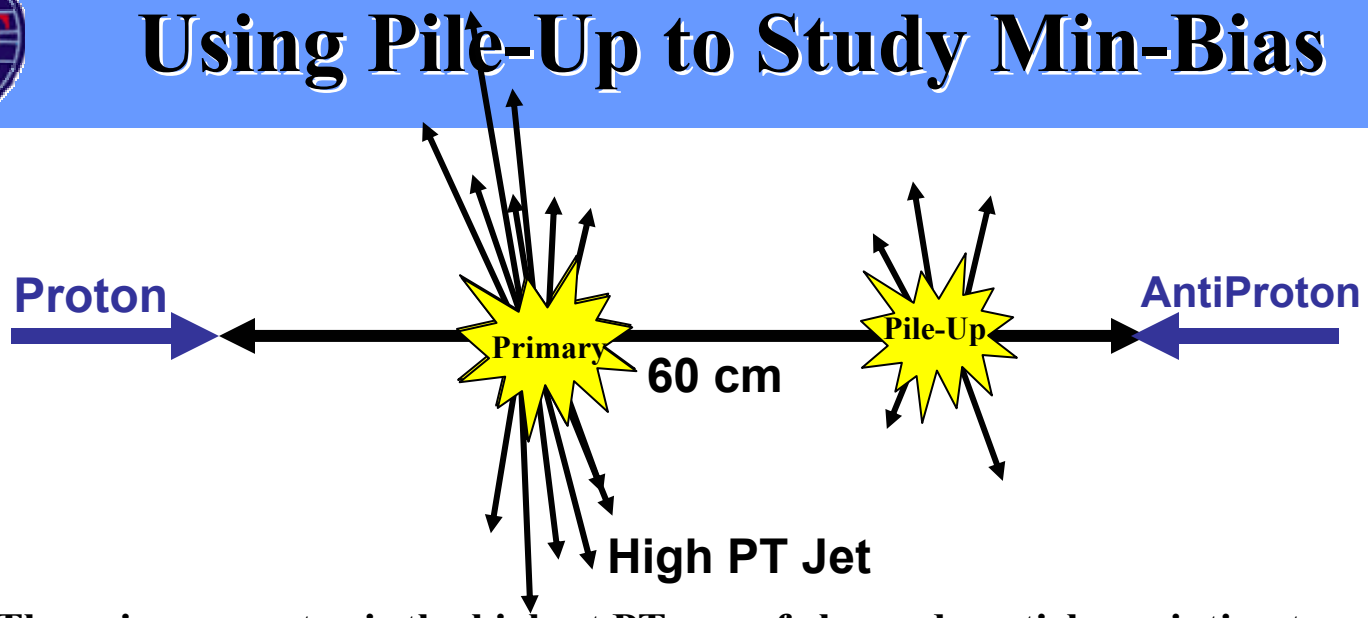
- **The ATLAS tune has many more "soft" particles than does any of the CDF Tunes. The ATLAS tune has $\langle p_T \rangle = 548$ MeV/c while Tune A has $\langle p_T \rangle = 641$ MeV/c (100 MeV/c more per particle)!**

Using Pile-Up to Study Min-Bias



- The primary vertex is the highest PTsum of charged particles pointing towards it.
- Normally one only includes those charged particles which point back to the primary vertex.
- However, the primary vertex is presumably the collision that satisfied the trigger and is hence biased.
- Perhaps the pile-up is not biases and can serve as a new type of "Min-Bias" collisions.

Using Pile-Up to Study Min-Bias



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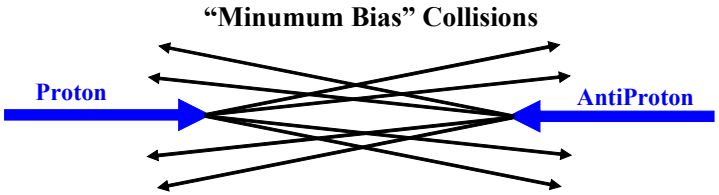
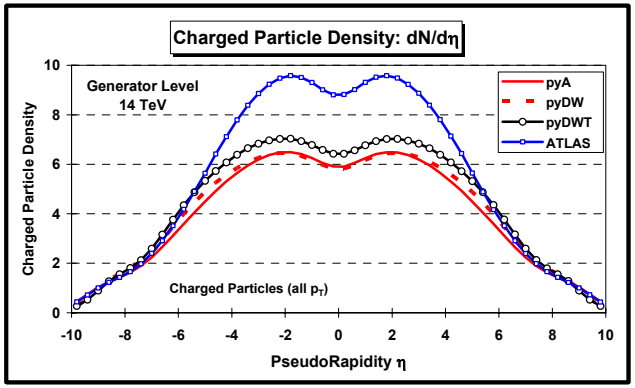
- Normally one only includes those charged particles which point back to the primary vertex.
- However, the primary vertex is presumably the collision that satisfied the trigger and is hence biased.
- Perhaps the pile-up is not biases and can serve as a new type of "Min-Bias" collisions.
- This assumes that the pile-up is not affected by the trigger (*i.e.* it is the same for all primary processes).

Summary and Conclusions

- "Min-Bias" is not well defined. What you see depends on what you trigger on! Every trigger produces some biases.



- We have learned a lot about "Min-Bias" at the Tevatron, but we do not know what to expect at the LHC. **This will depend on the Min-Bias Trigger!**



- Very preliminary results seem to show that pile-up conspires to help give you what you ask for (*i.e.* satisfy your "trigger" or your event selection)!

If true this means the pile-up is not the same for all processes. It is process (*i.e.* trigger) dependent!

I must double check my analysis and get it "blessed" before you can trust what I have shown!