



# ICHEP 2012



## Energy Dependence of the UE

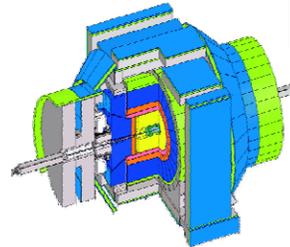


**Rick Field**  
University of Florida

**Q**uantum  
**C**hromo-  
**D**ynamics

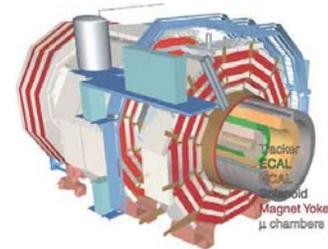
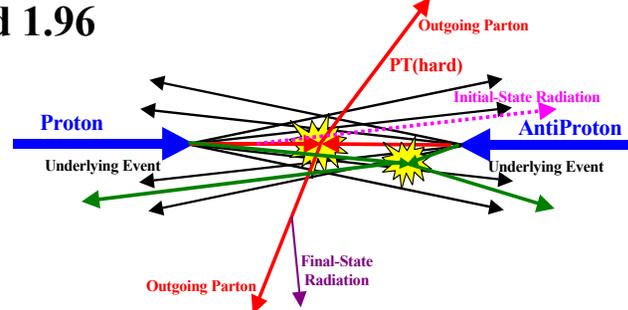
### Outline of Talk

- ➔ CDF PYTHIA 6.2 Tevatron Tune DW predictions.
- ➔ CMS PYTHIA 6.4 LHC Tune Z1.
- ➔ LPCC MB&UE working group “common plots”.
- ➔ New UE data at 300 GeV, 900 GeV, and 1.96 TeV from the Tevatron Energy-Scan.
- ➔ New comparisons with PYTHIA 6.2 Tune DW and PYTHIA 6.4 Tune Z1.
- ➔ Much more coming soon!



Melbourne July 4-11, 2012

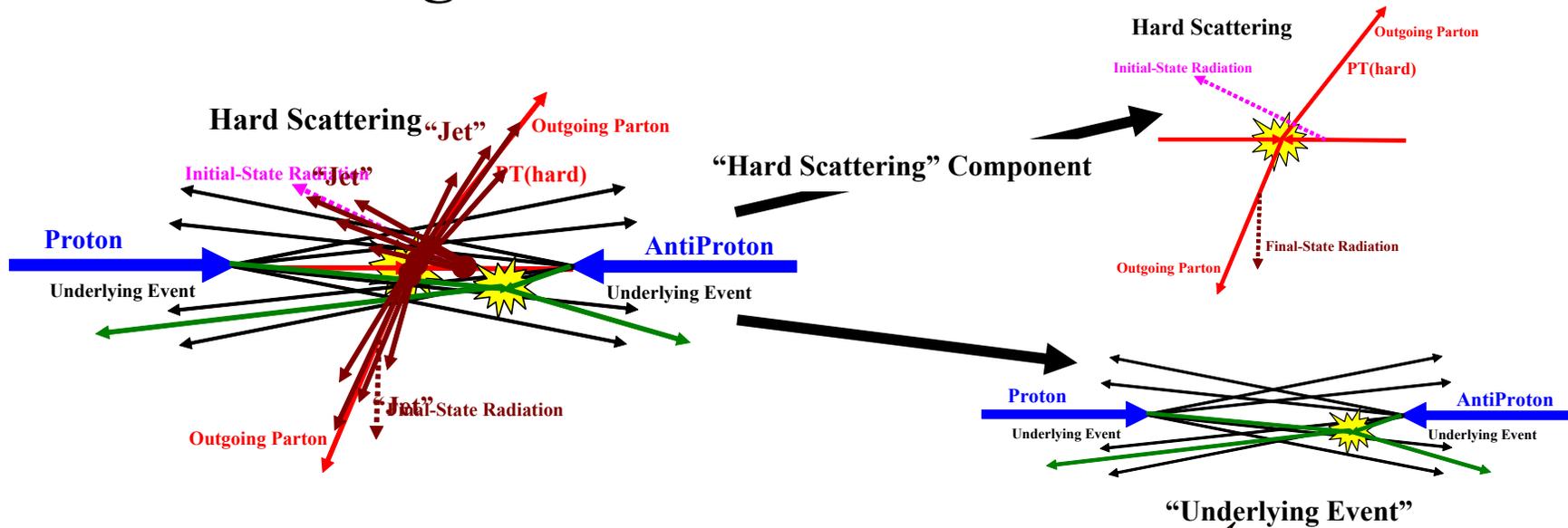
CDF Run 2  
300 GeV, 900 GeV, 1.96 TeV



CMS at the LHC  
900 GeV, 7 & 8 TeV



# QCD Monte-Carlo Models: High Transverse Momentum Jets



- ➔ Start with the perturbative 2-to-2 (or sometimes 2-to-3) parton-parton scattering and add initial and final-state gluon radiation (in the leading log approximation or modified leading log approximation).
- ➔ The “underlying event” consists of the “beam-beam remnants” and MPI particles arising from soft or semi-soft multiple parton interactions (MPI).
- ➔ Of course the outgoing colored parton observables receive contributions from the underlying event.

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

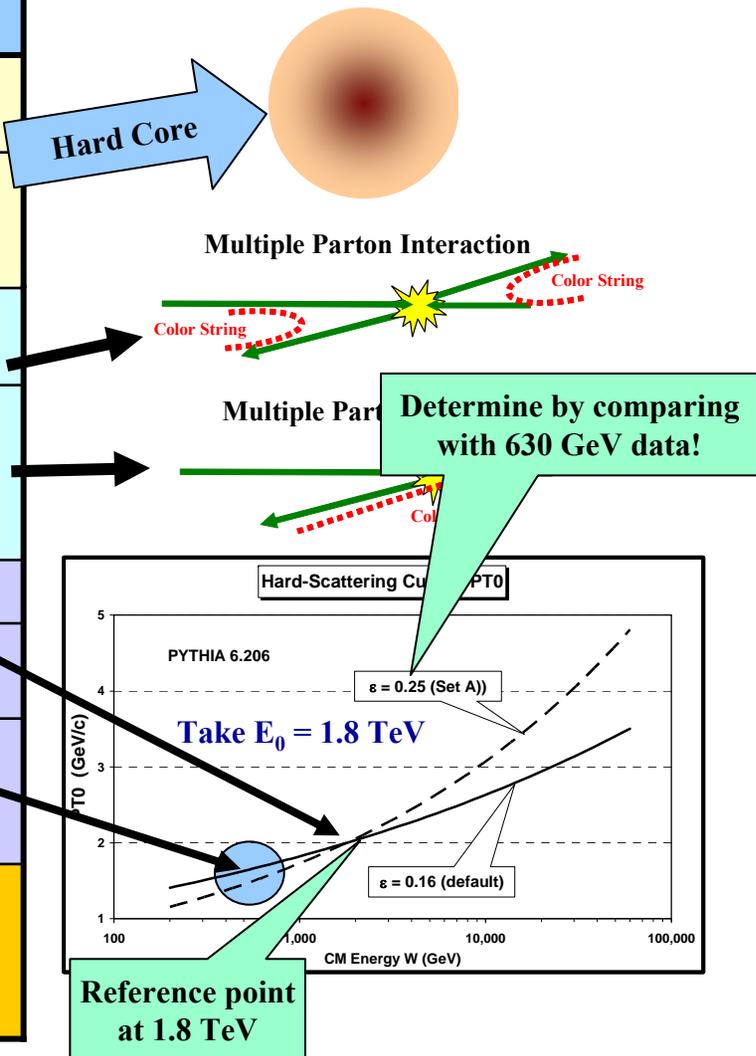


# Tuning PYTHIA 6.2: Multiple Parton Interaction Parameters



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 nearest neighbors.
PARP(86)	0.66	Probability that the MPI produces two gluons either as described by PARP(85) or as a closed loop. The remaining fraction consists of quark-antiquark pairs.
PARP(89)	1 TeV	Determines the reference energy $E_0$ .
PARP(82)	0.9 GeV/c	The cut-off $P_{T0}$ that regulates the 2-to-2 scattering 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 $P_{T0}(E_{cm}) = P_{T0}(E_{cm}/E_0)^\epsilon$ with $\epsilon = \text{PARP}(90)$
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!



# Traditional Approach

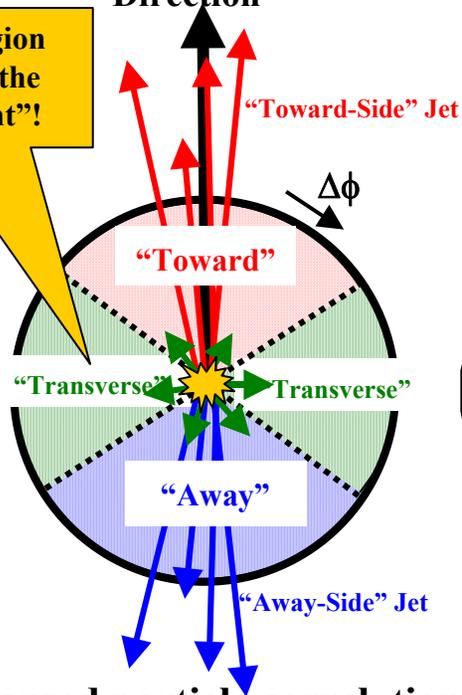


## CDF Run 1 Analysis Charged Particle $\Delta\phi$ Correlations

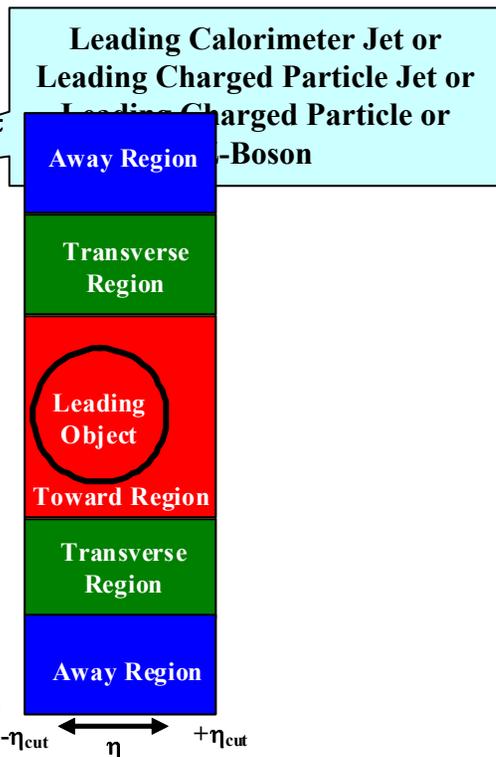
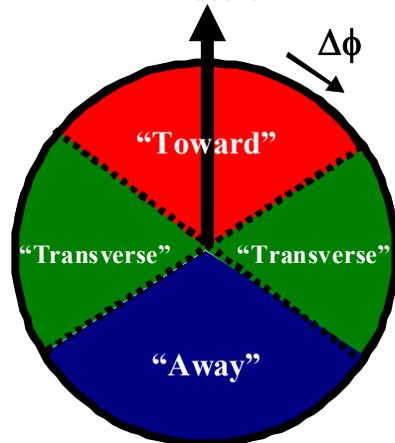
Charged Jet #1  
Direction

$$P_T > P_{T\min} \quad |\eta| < \eta_{\text{cut}}$$

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



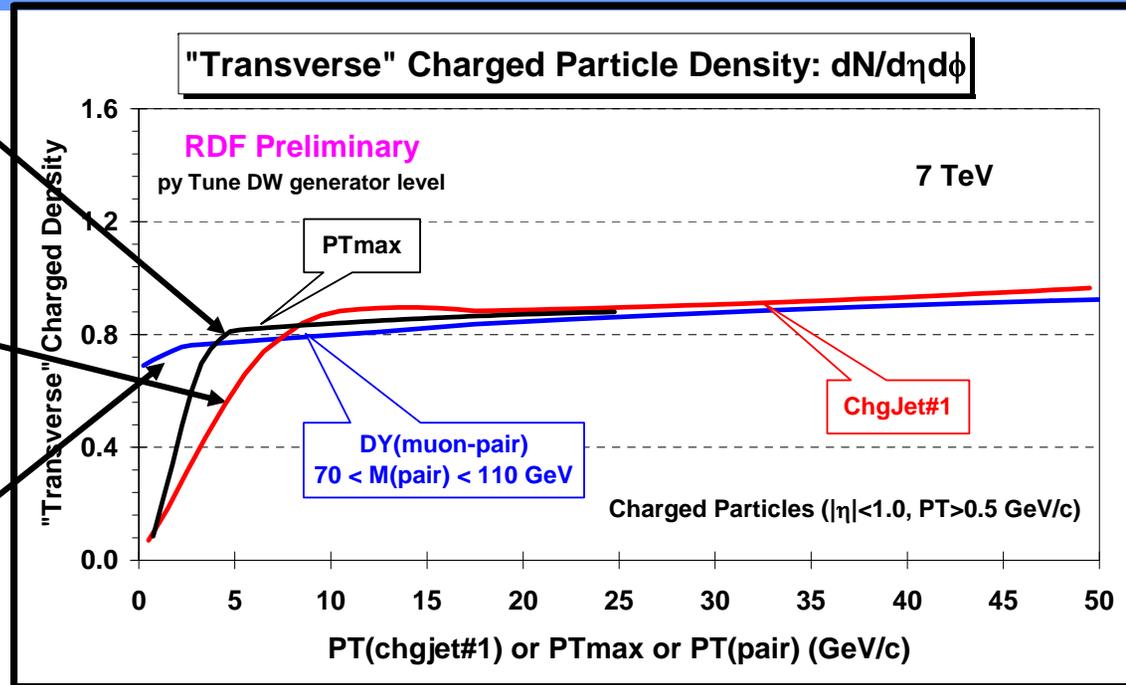
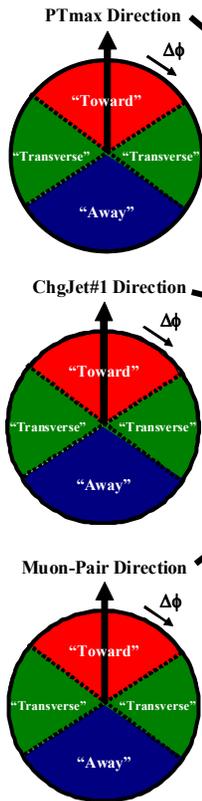
Leading Object  
Direction



- ➔ Look at charged particle correlations in the azimuthal angle  $\Delta\phi$  relative to a leading object (*i.e.* CaloJet#1, ChgJet#1,  $P_{T\max}$ , Z-boson). For CDF  $P_{T\min} = 0.5 \text{ GeV}/c$   $\eta_{\text{cut}} = 1$ .
- ➔ Define  $|\Delta\phi| < 60^\circ$  as “Toward”,  $60^\circ < |\Delta\phi| < 120^\circ$  as “Transverse”, and  $|\Delta\phi| > 120^\circ$  as “Away”.
- ➔ All three regions have the same area in  $\eta$ - $\phi$  space,  $\Delta\eta \times \Delta\phi = 2\eta_{\text{cut}} \times 120^\circ = 2\eta_{\text{cut}} \times 2\pi/3$ . Construct densities by dividing by the area in  $\eta$ - $\phi$  space.



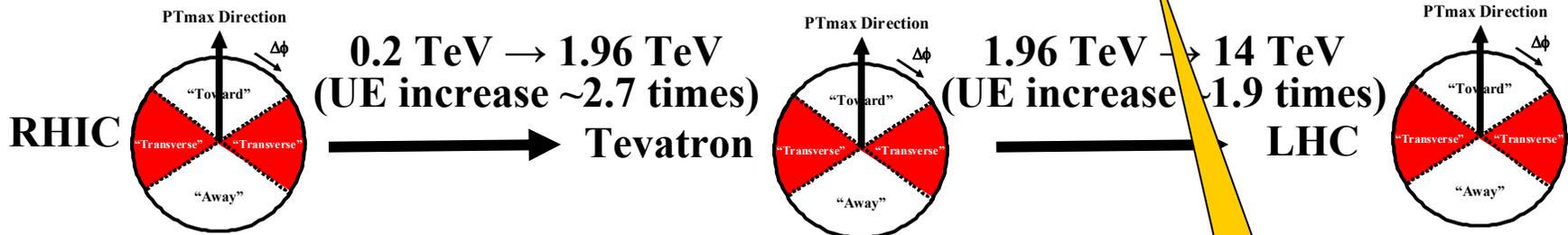
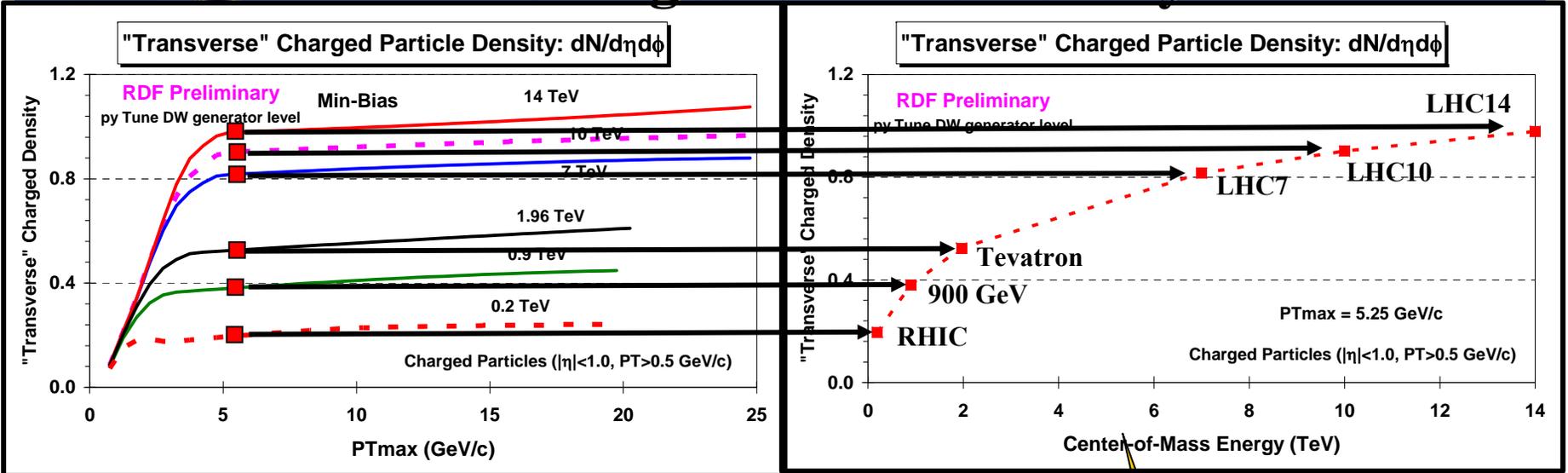
# “Transverse” Charged Density



- ➔ Shows the charged particle density in the “transverse” region for charged particles ( $p_T > 0.5 \text{ GeV}/c, |\eta| < 1$ ) at 7 TeV as defined by PTmax, PT(chgjet#1), and PT(muon-pair) from PYTHIA Tune DW at the particle level (*i.e.* generator level). Charged particle jets are constructed using the Anti-KT algorithm with  $d = 0.5$ .



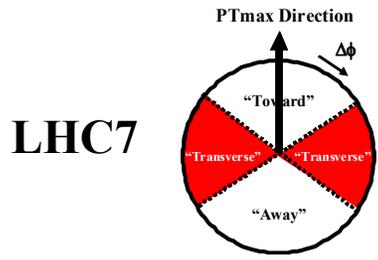
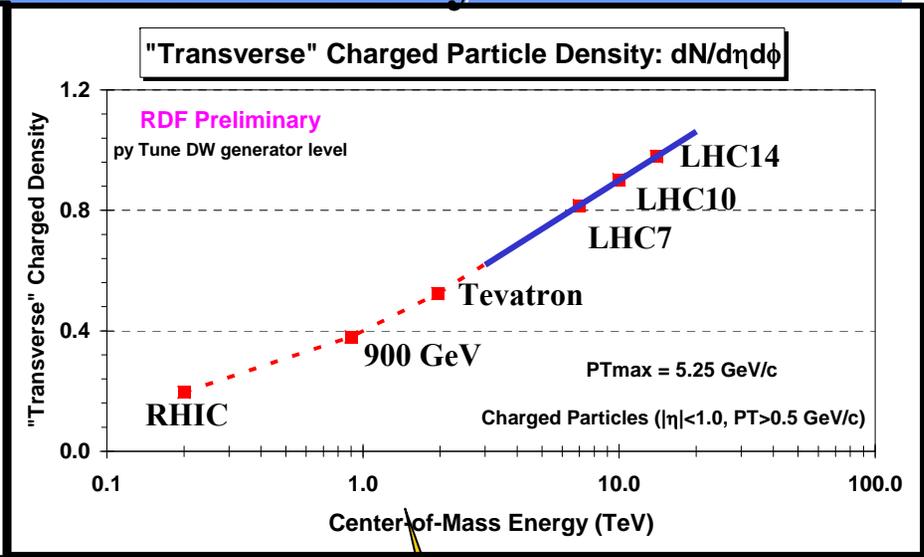
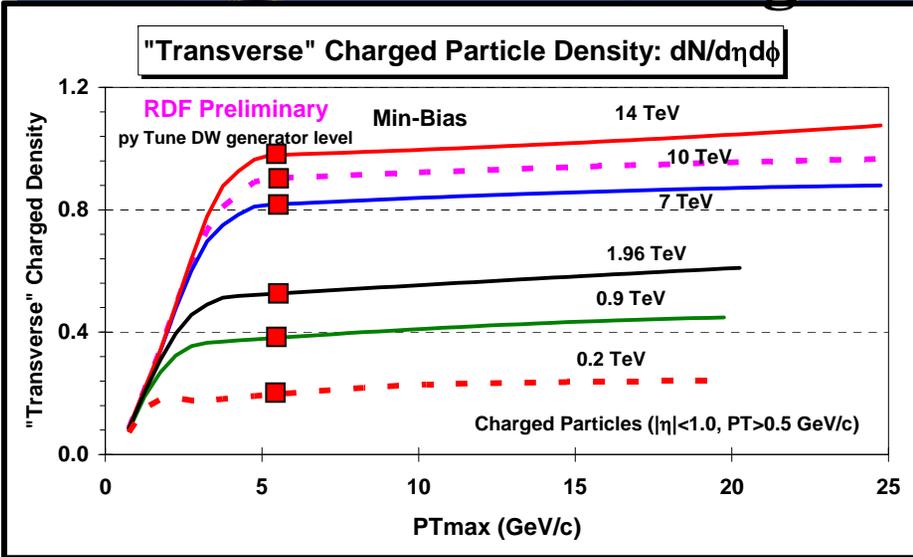
# Min-Bias “Associated” Charged Particle Density



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

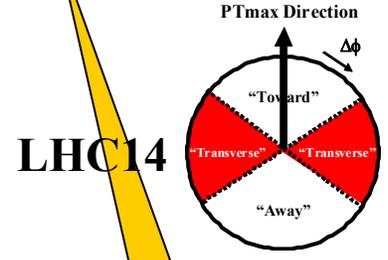


# Min-Bias “Associated” Charged Particle Density



7 TeV  $\rightarrow$  14 TeV  
(UE increase  $\sim 20\%$ )

Linear on a log plot!

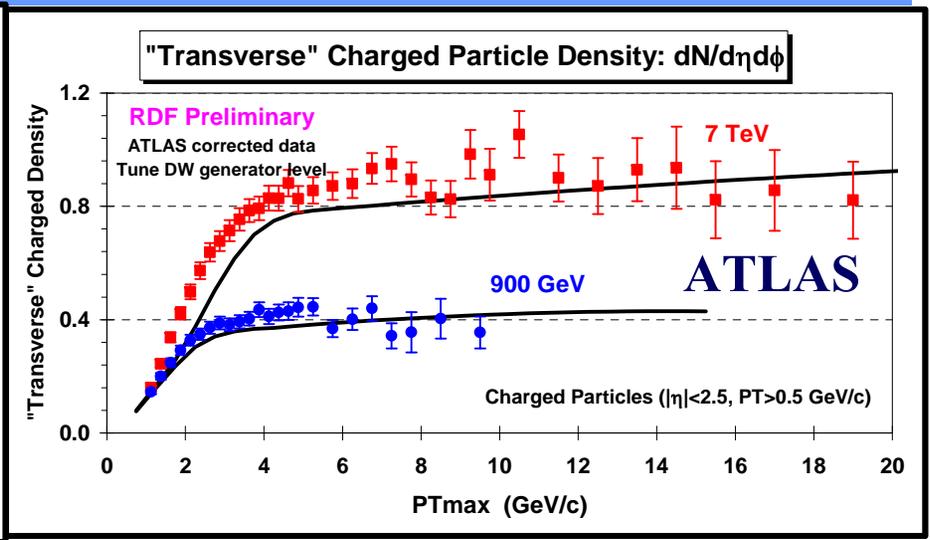
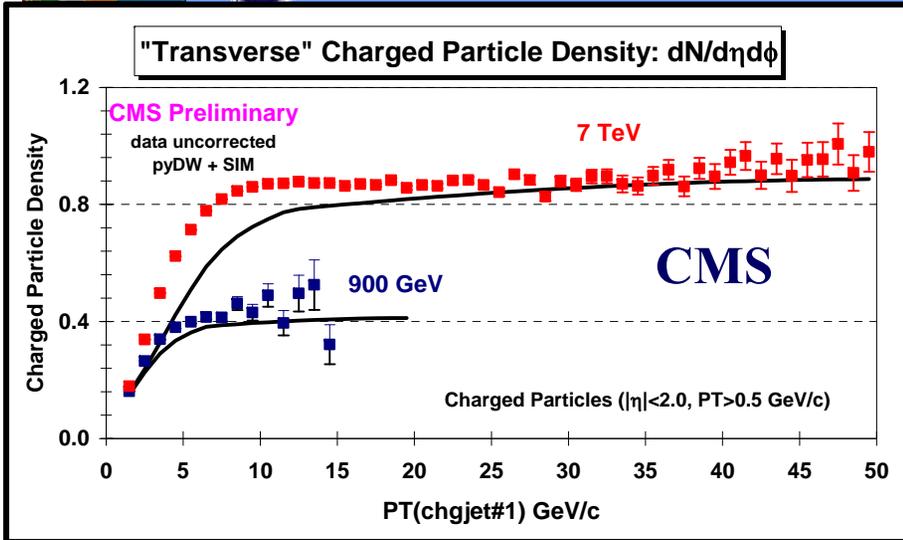


- Shows the “associated” charged particle density in the “transverse” region as a function of PTmax for charged particles ( $p_T > 0.5 \text{ GeV}/c, |\eta| < 1$ , not including PTmax) “min-bias” events at 0.2 TeV, 0.9 TeV, 1.96 TeV, 7 TeV, 10 TeV, 14 TeV predicted by PYTHIA at the particle level (i.e.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

Log scale!

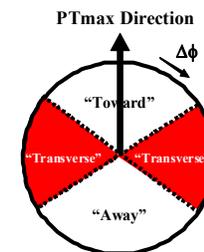
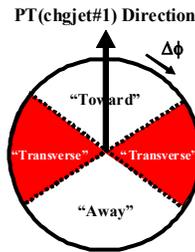


# PYTHIA Tune DW



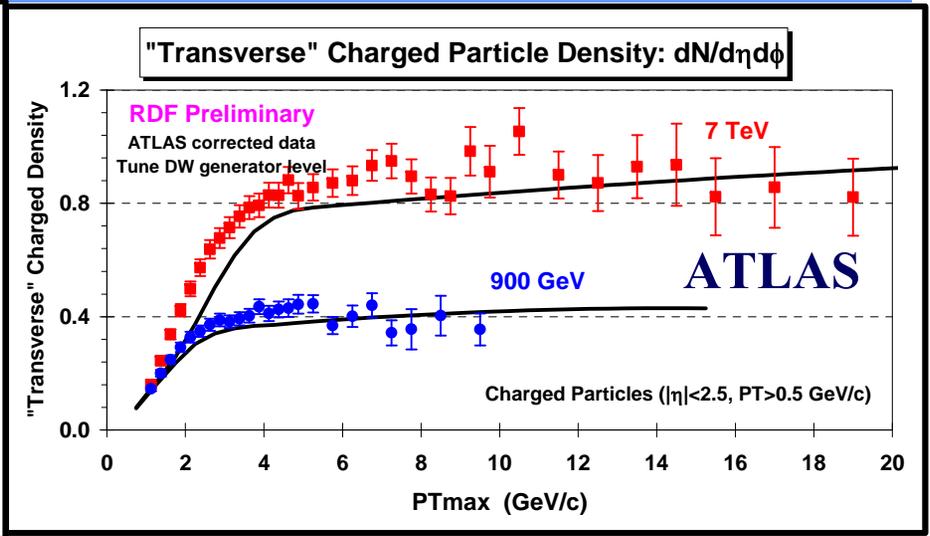
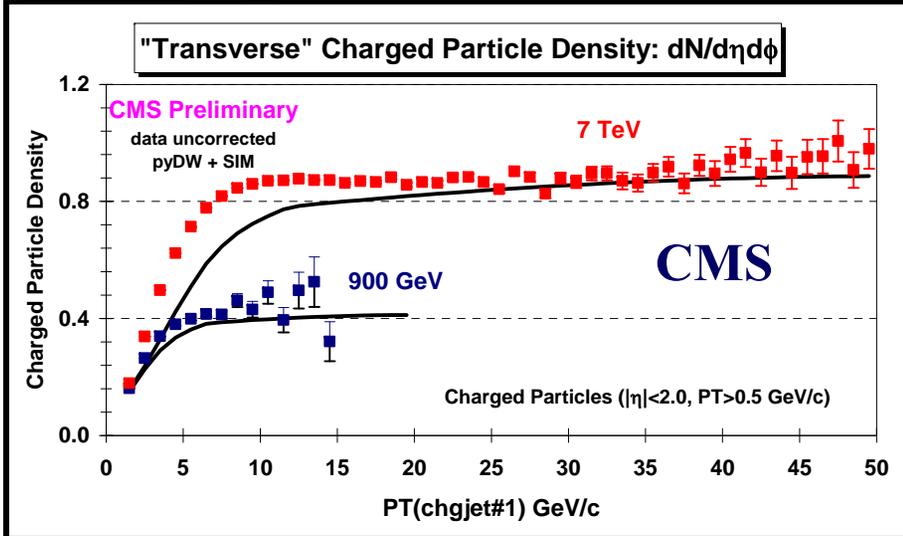
➔ CMS preliminary data at 900 GeV and 7 TeV on the “transverse” charged particle density,  $dN/d\eta d\phi$ , as defined by the leading charged particle jet (chgjet#1) for charged particles with  $p_T > 0.5$  GeV/c and  $|\eta| < 2$ . The data are uncorrected and compared with PYTHIA Tune DW after detector simulation.

➔ ATLAS preliminary data at 900 GeV and 7 TeV on the “transverse” charged particle density,  $dN/d\eta d\phi$ , as defined by the leading charged particle (PTmax) for charged particles with  $p_T > 0.5$  GeV/c and  $|\eta| < 2.5$ . The data are corrected and compared with PYTHIA Tune DW at the generator level.

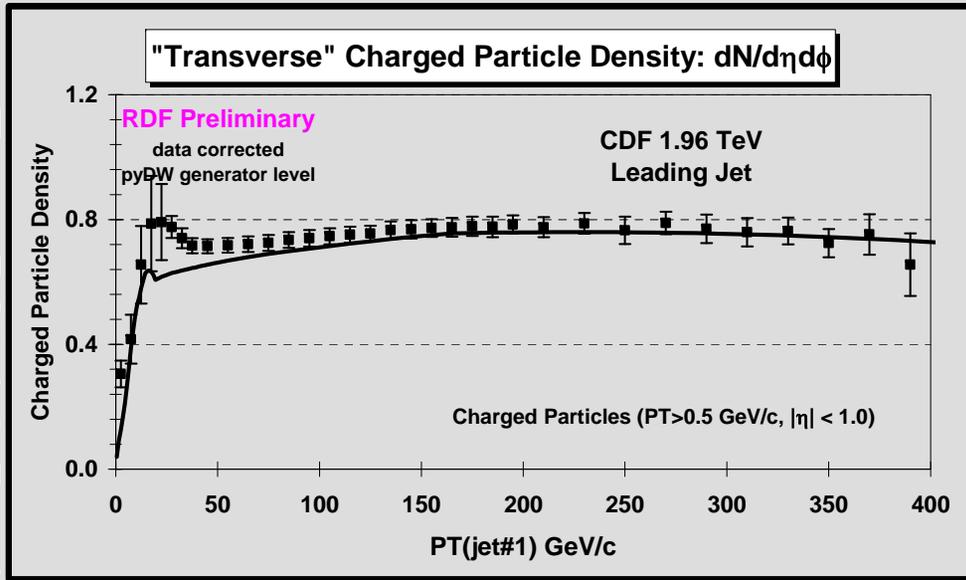
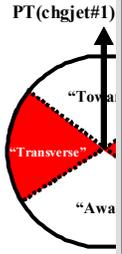




# PYTHIA Tune DW



→ CMS preliminary data on the “transverse”  $dN/d\eta d\phi$ , as defined by the leading particle jet (chgjet#) with  $p_T > 0.5$  GeV/c uncorrected and compared with PYTHIA Tune DW after detector effects.

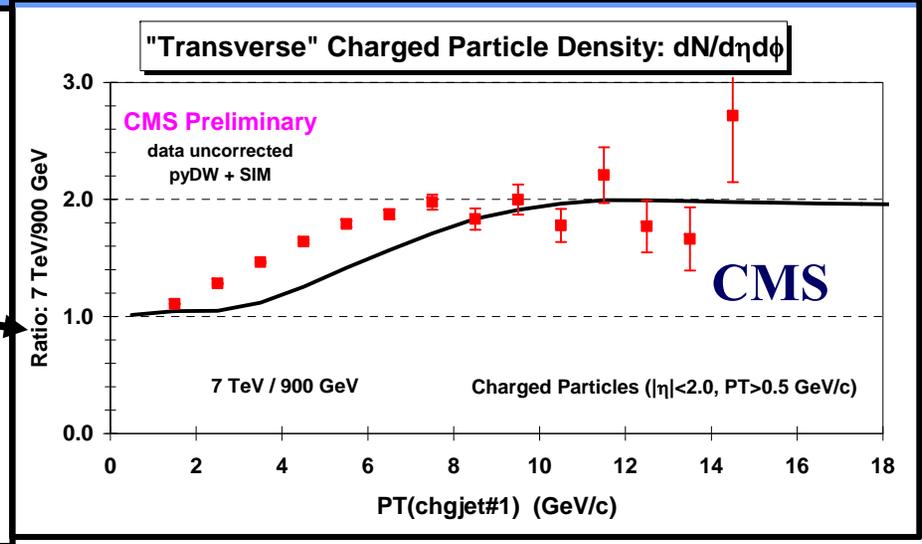
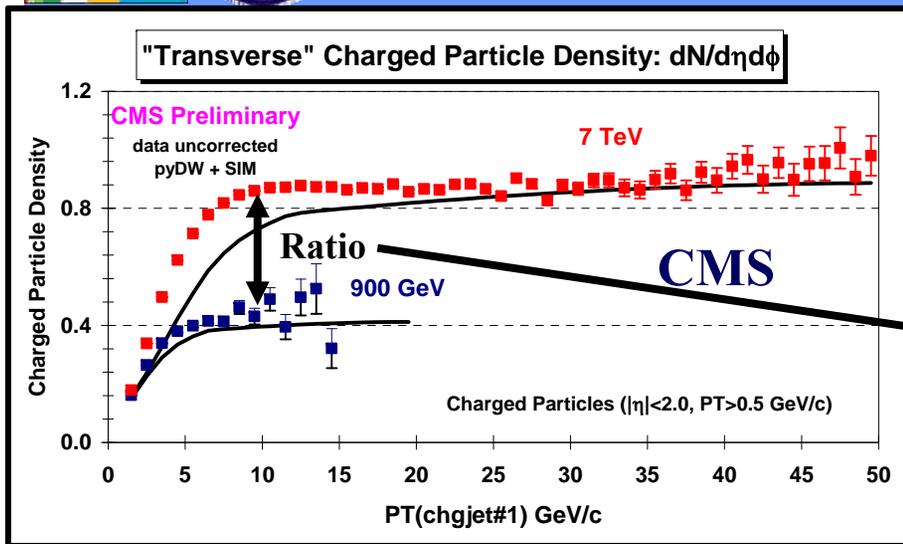


data at 900 GeV and 7 TeV. The data are defined by the leading particle jet (chgjet#) for charged particles with  $|\eta| < 2.5$ . The data are compared with PYTHIA Tune DW after detector effects.



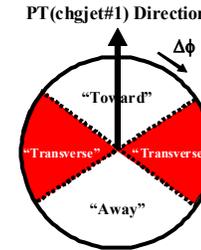
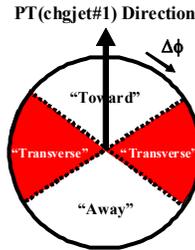


# PYTHIA Tune DW



➔ CMS preliminary data at 900 GeV and 7 TeV on the “transverse” charged particle density,  $dN/d\eta d\phi$ , as defined by the leading charged particle jet (chgjet#1) for charged particles with  $p_T > 0.5$  GeV/c and  $|\eta| < 2$ . The data are uncorrected and compared with PYTHIA Tune DW after detector simulation.

➔ Ratio of CMS preliminary data at 900 GeV and 7 TeV on the “transverse” charged particle density,  $dN/d\eta d\phi$ , as defined by the leading charged particle jet (chgjet#1) for charged particles with  $p_T > 0.5$  GeV/c and  $|\eta| < 2$ . The data are uncorrected and compared with PYTHIA Tune DW after detector simulation.

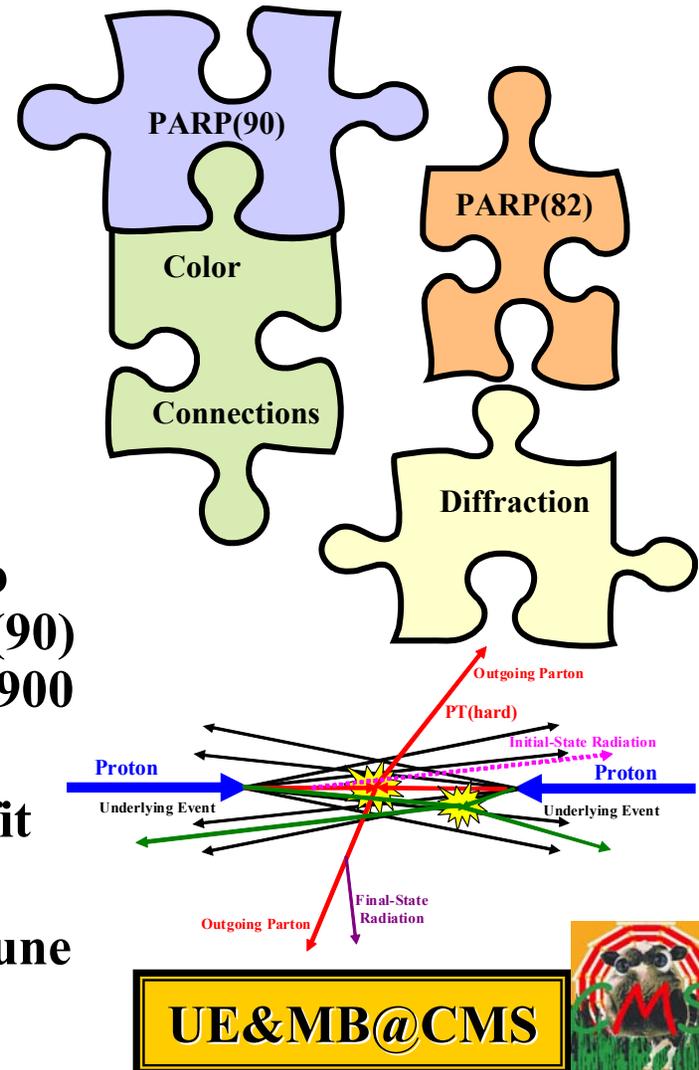




# PYTHIA Tune Z1



- ➔ All my previous tunes (A, DW, DWT, D6, D6T, CW, X1, and X2) were PYTHIA 6.4 tunes using the old  $Q^2$ -ordered parton showers and the old MPI model (really 6.2 tunes)!
- ➔ I believe that it is time to move to PYTHIA 6.4 ( $p_T$ -ordered parton showers and new MPI model)!
- ➔ **Tune Z1:** I started with the parameters of ATLAS Tune AMBT1, but I changed  $LO^*$  to CTEQ5L and I varied PARP(82) and PARP(90) to get a very good fit of the CMS UE data at 900 GeV and 7 TeV.
- ➔ The ATLAS Tune AMBT1 was designed to fit the inelastic data for  $N_{chg} \geq 6$  and to fit the  $PT_{max}$  UE data with  $PT_{max} > 10$  GeV/c. Tune AMBT1 is primarily a min-bias tune, while Tune Z1 is a UE tune!





# PYTHIA Tune Z1

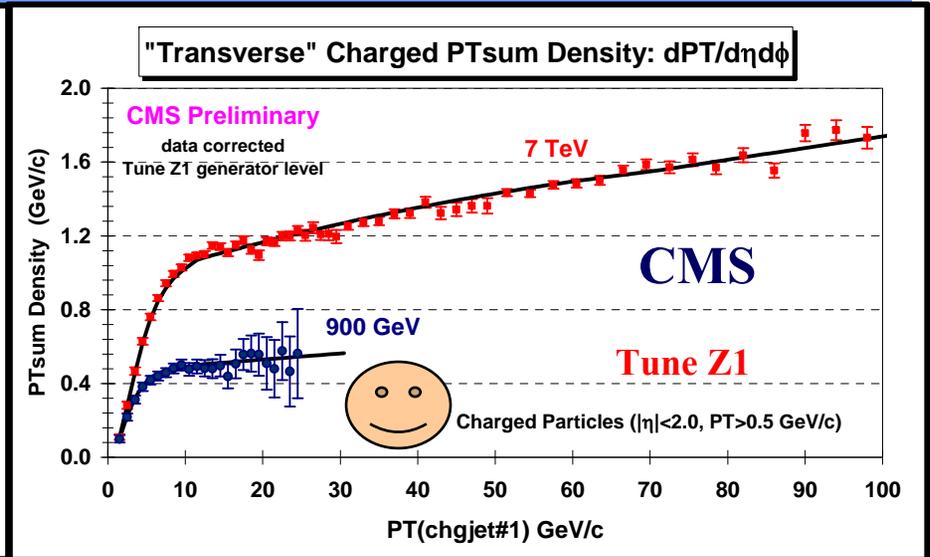
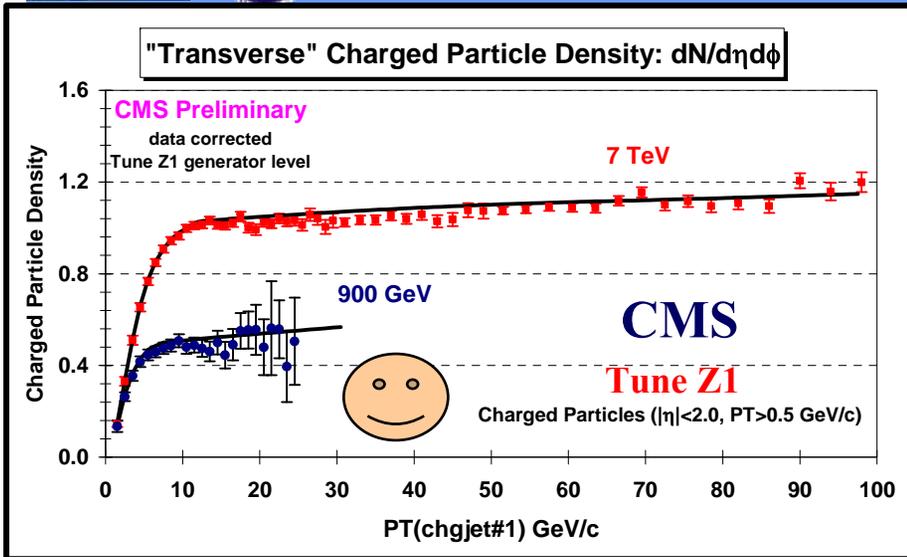


Parameters not shown are the PYTHIA 6.4 defaults!

Parameter	Tune Z1 (R. Field CMS)	Tune AMBT1 (ATLAS)
<b>Parton Distribution Function</b>	<b>CTEQ5L</b>	<b>LO*</b>
<b>PARP(82) – MPI Cut-off</b>	<b>1.932</b>	<b>2.292</b>
<b>PARP(89) – Reference energy, E0</b>	<b>1800.0</b>	<b>1800.0</b>
<b>PARP(90) – MPI Energy Extrapolation</b>	<b>0.275</b>	<b>0.25</b>
<b>PARP(77) – CR Suppression</b>	<b>1.016</b>	<b>1.016</b>
<b>PARP(78) – CR Strength</b>	<b>0.538</b>	<b>0.538</b>
<b>PARP(80) – Probability colored parton from BBR</b>	<b>0.1</b>	<b>0.1</b>
<b>PARP(83) – Matter fraction in core</b>	<b>0.356</b>	<b>0.356</b>
<b>PARP(84) – Core of matter overlap</b>	<b>0.651</b>	<b>0.651</b>
<b>PARP(62) – ISR Cut-off</b>	<b>1.025</b>	<b>1.025</b>
<b>PARP(93) – primordial kT-max</b>	<b>10.0</b>	<b>10.0</b>
<b>MSTP(81) – MPI, ISR, FSR, BBR model</b>	<b>21</b>	<b>21</b>
<b>MSTP(82) – Double gaussian matter distribution</b>	<b>4</b>	<b>4</b>
<b>MSTP(91) – Gaussian primordial kT</b>	<b>1</b>	<b>1</b>
<b>MSTP(95) – strategy for color reconnection</b>	<b>6</b>	<b>6</b>

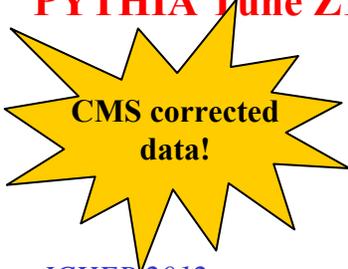


# CMS UE Data

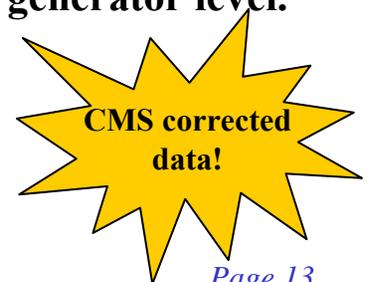


➔ CMS preliminary data at 900 GeV and 7 TeV on the “transverse” charged particle density,  $dN/d\eta d\phi$ , as defined by the leading charged particle jet (chgjet#1) for charged particles with  $p_T > 0.5 \text{ GeV}/c$  and  $|\eta| < 2.0$ . The data are corrected and compared with **PYTHIA Tune Z1** at the generator level.

➔ CMS preliminary data at 900 GeV and 7 TeV on the “transverse” charged PTsum density,  $dPT/d\eta d\phi$ , as defined by the leading charged particle jet (chgjet#1) for charged particles with  $p_T > 0.5 \text{ GeV}/c$  and  $|\eta| < 2.0$ . The data are corrected and compared with **PYTHIA Tune Z1** at the generator level.

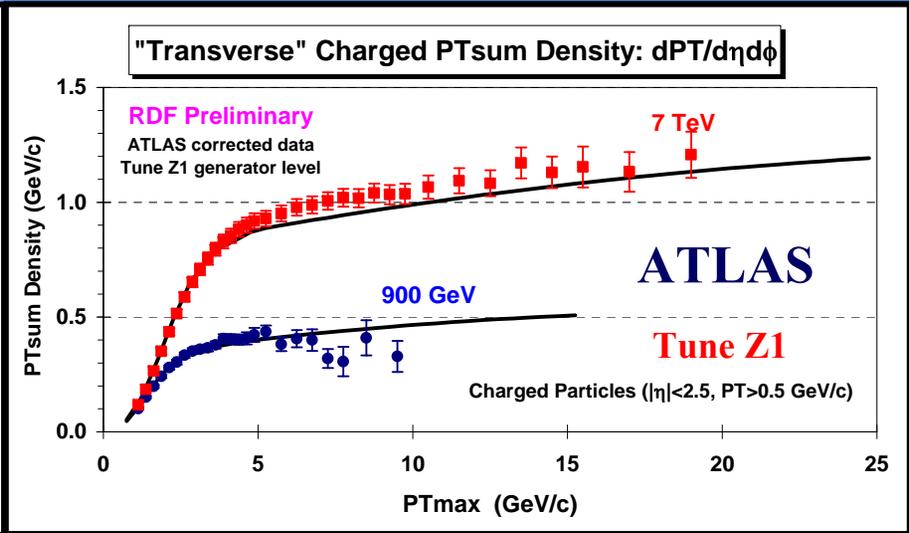
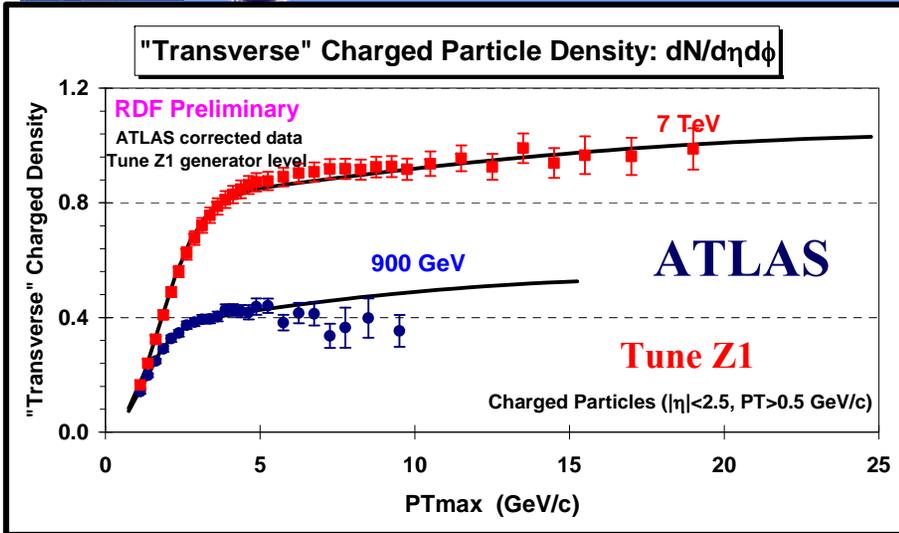


Very nice agreement!





# ATLAS UE Data



➔ **ATLAS published data at 900 GeV and 7 TeV** on the “transverse” charged particle density,  $dN/d\eta d\phi$ , as defined by the leading charged particle ( $PT_{max}$ ) for charged particles with  $p_T > 0.5$  GeV/c and  $|\eta| < 2.5$ . The data are corrected and compared with **PYTHIA Tune Z1** at the generator level.

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**ATLAS publication – arXiv:1012.0791**  
*December 3, 2010*

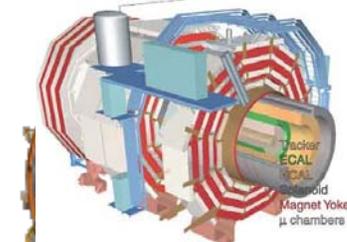
# LPCC

# MB&UE Working Group

LHC Physics Centre at CERN

## MB & UE Common Plots

Quantum  
Chromo-  
Dynamics



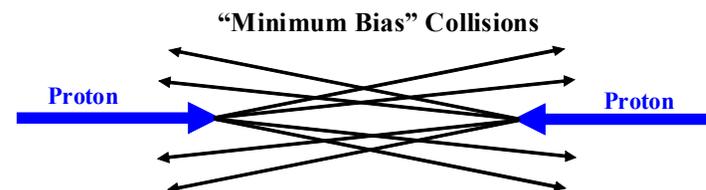
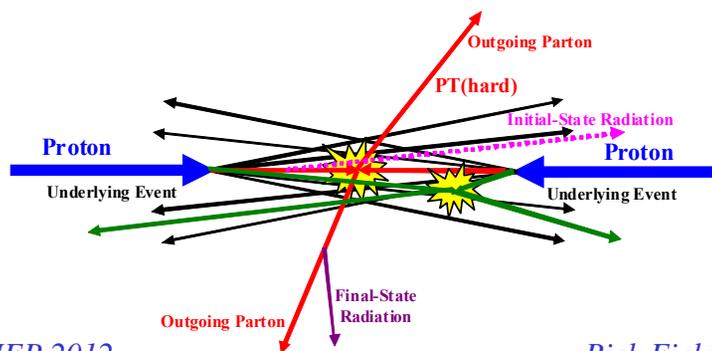
CMS



ATLAS

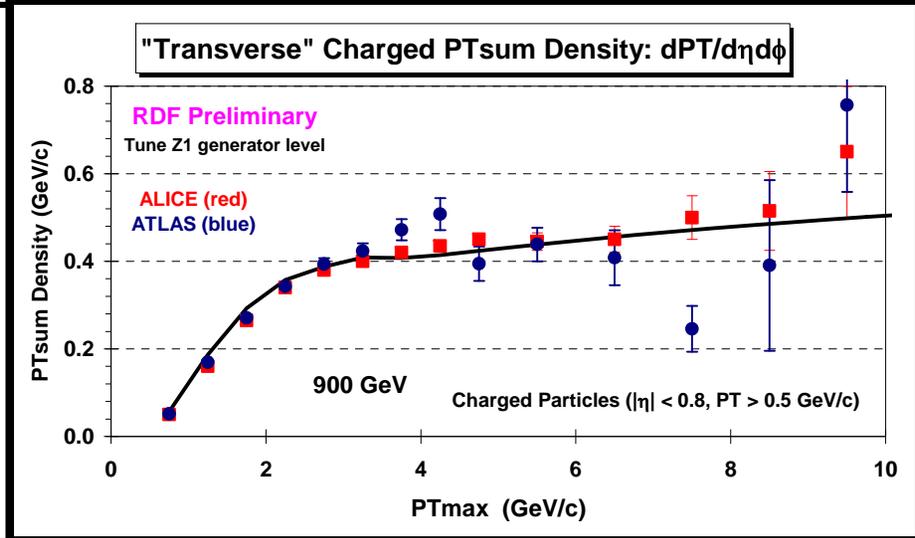
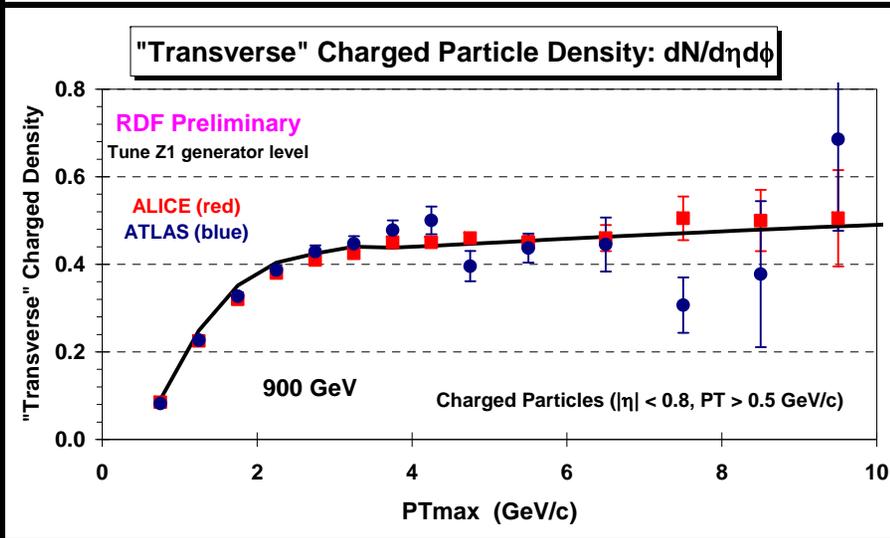
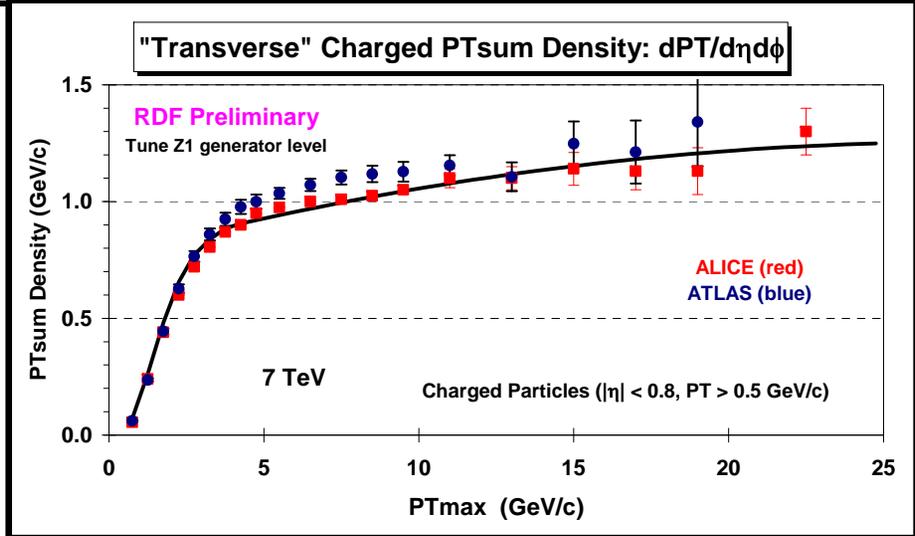
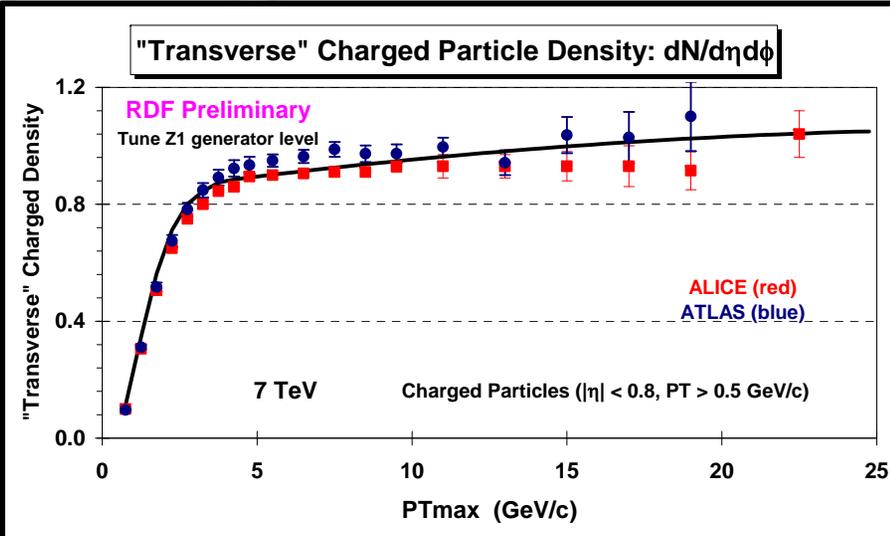


➔ The LPCC MB&UE Working Group has suggested several MB&UE “Common Plots” the all the LHC groups can produce and compare with each other.



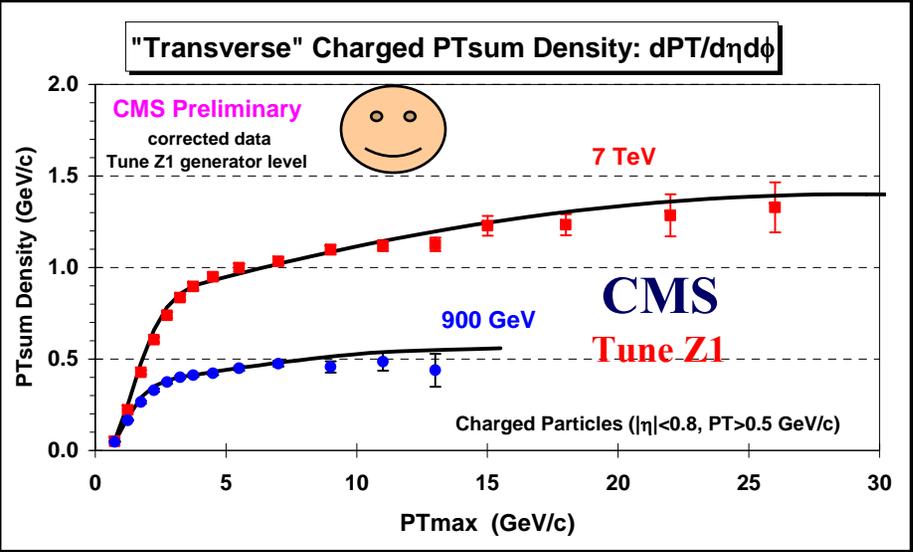
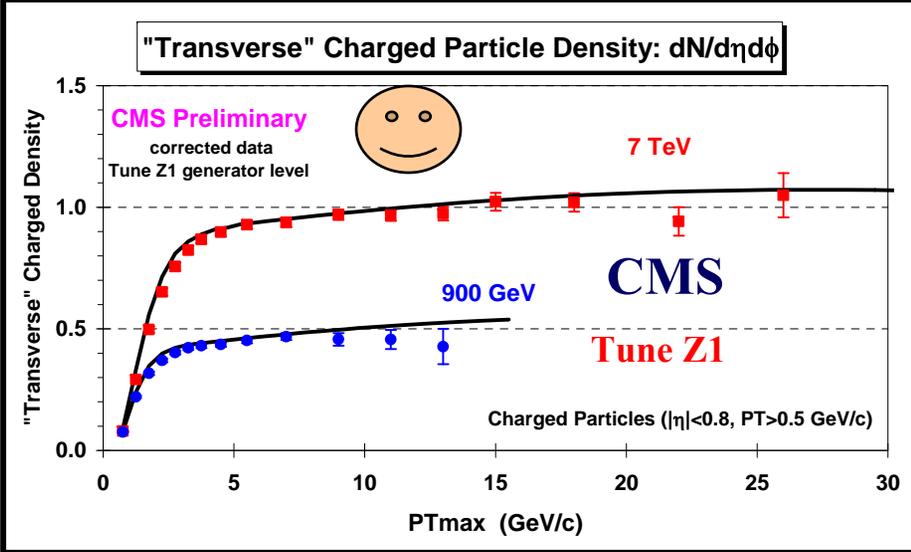


# ALICE-ATLAS UE





# New CMS UE Data

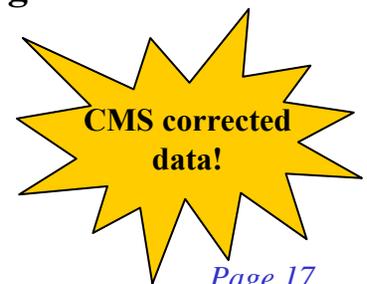


→ CMS preliminary data at 900 GeV and 7 TeV on the “transverse” charged particle density,  $dN/d\eta d\phi$ , as defined by the leading charged particle ( $PT_{max}$ ) for charged particles with  $p_T > 0.5 \text{ GeV}/c$  and  $|\eta| < 0.8$ . The data are corrected and compared with **PYTHIA Tune Z1** at the generator level.

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Very nice agreement!

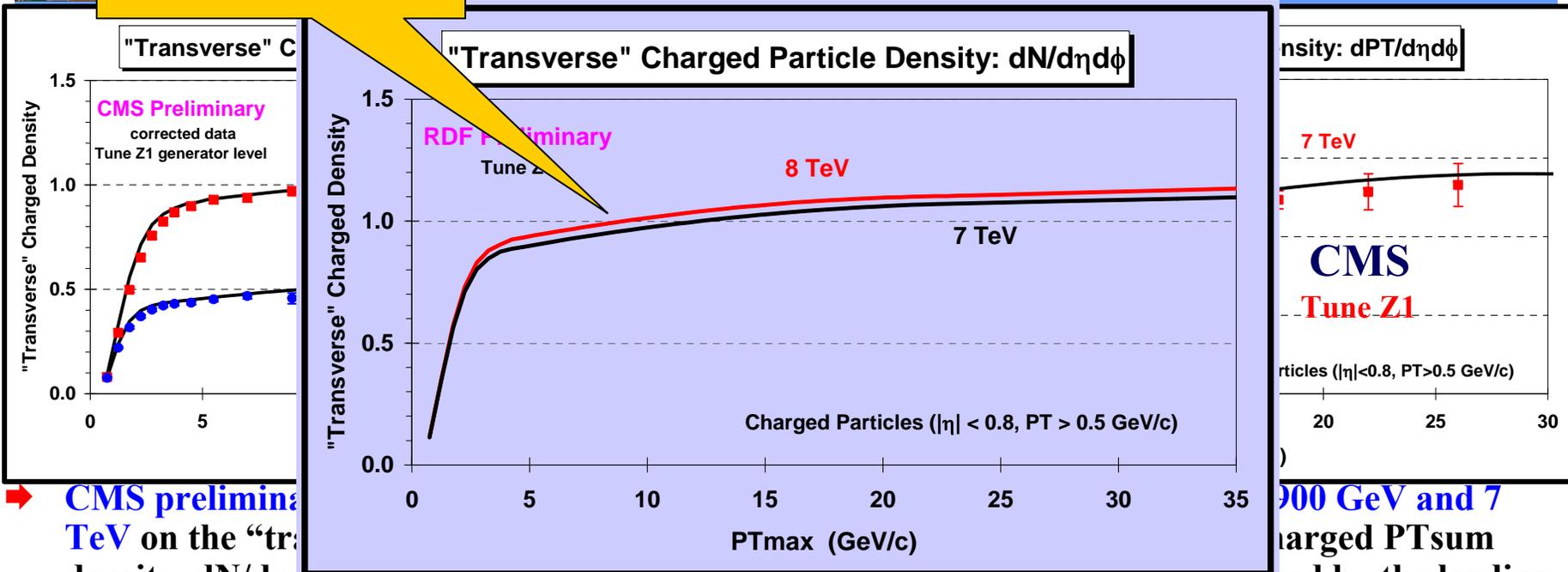




# New CMS UE Data

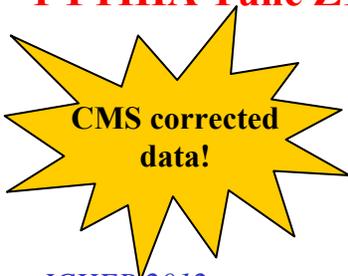


Less than 4% change!

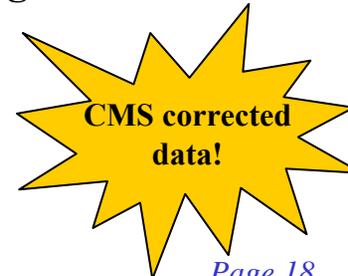


→ CMS preliminary data for 7 TeV on the “transverse” charged particle density,  $dN/d\eta d\phi$ , as defined by the leading charged particle (PTmax) for charged particles with  $p_T > 0.5$  GeV/c and  $|\eta| < 0.8$ . The data are corrected and compared with **PYTHIA Tune Z1** at the generator level.

→ CMS preliminary data for 8 TeV on the “transverse” charged particle density,  $dN/d\eta d\phi$ , as defined by the leading charged particle (PTmax) for charged particles with  $p_T > 0.5$  GeV/c and  $|\eta| < 0.8$ . The data are corrected and compared with **PYTHIA Tune Z1** at the generator level.

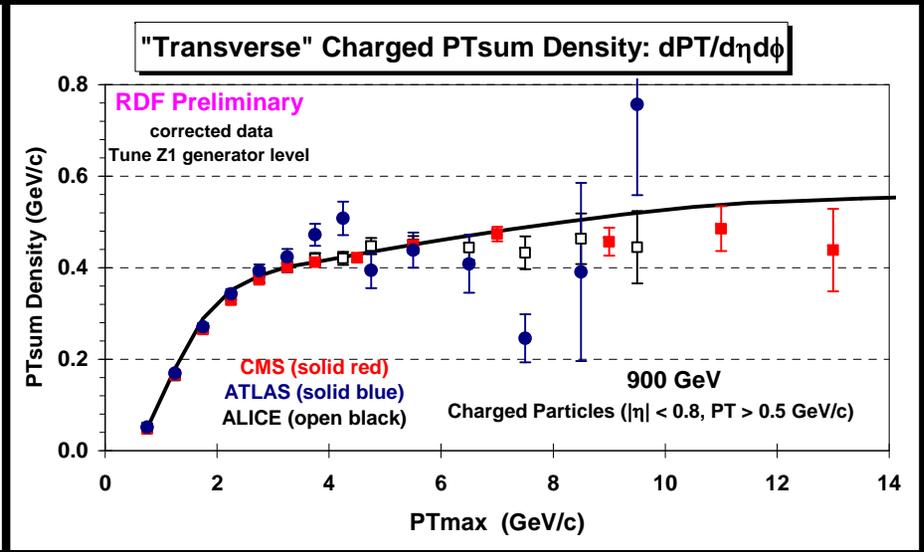
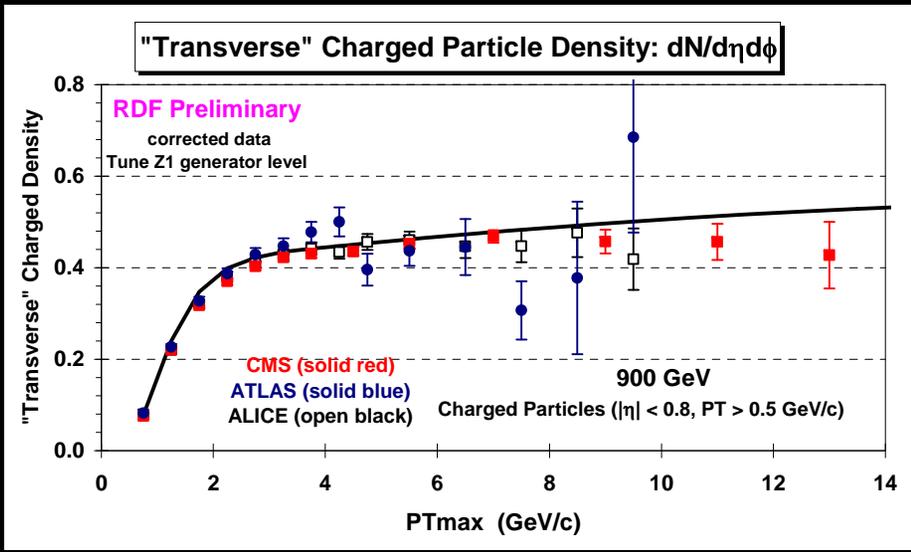
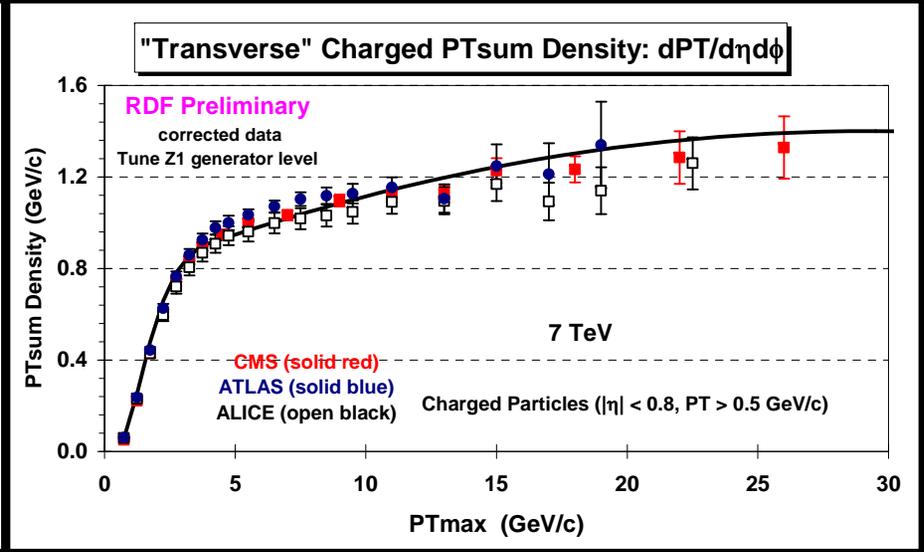
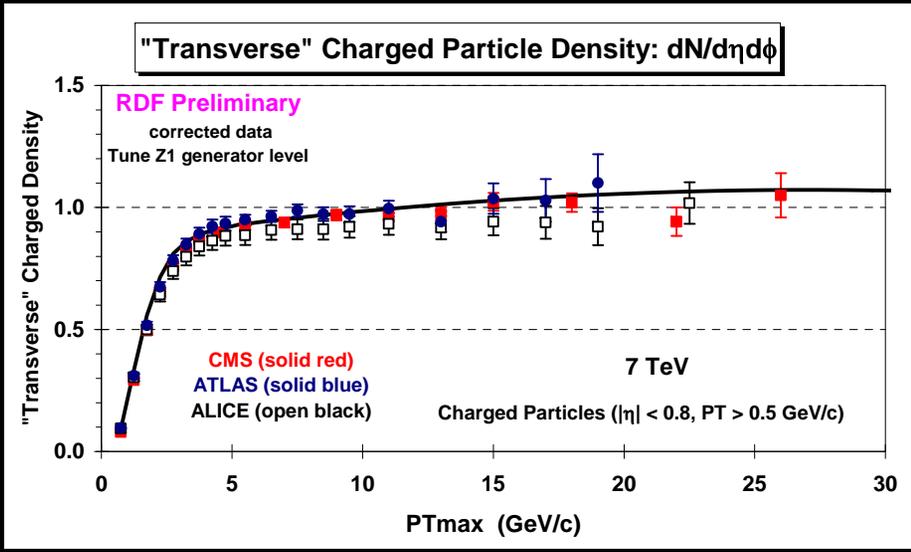


Very nice agreement!



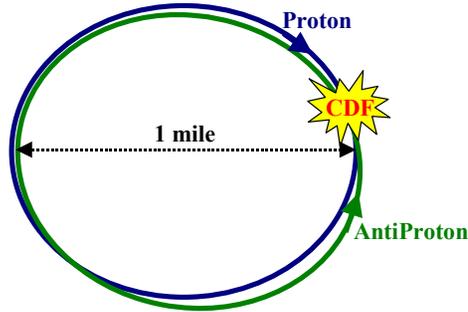
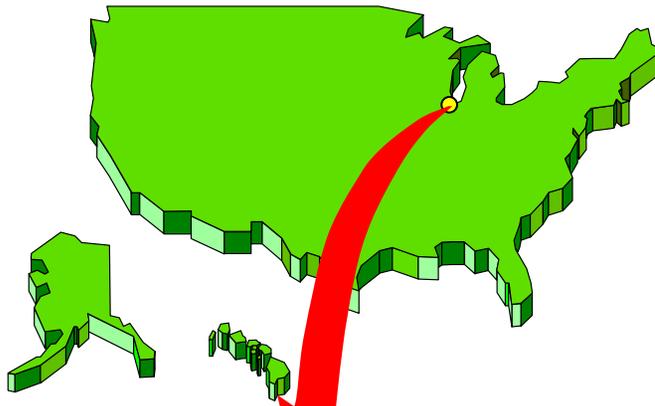


# UE Common Plots





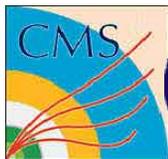
# Tevatron Energy Scan



➔ Just before the shutdown of the Tevatron CDF has collected more than 10M “min-bias” events at several center-of-mass energies!

**300 GeV 12.1M MB Events**

**900 GeV 54.3M MB Events**

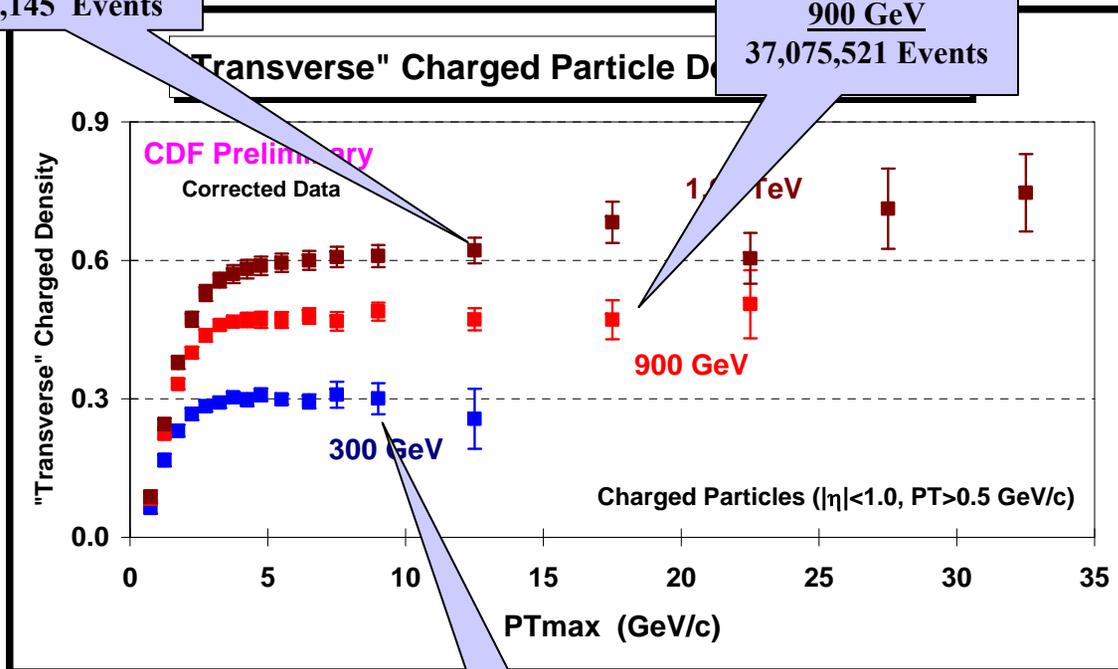
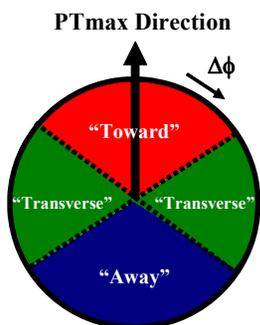


# New CDF UE Data



**1.96 TeV**  
25,371,145 Events

**900 GeV**  
37,075,521 Events

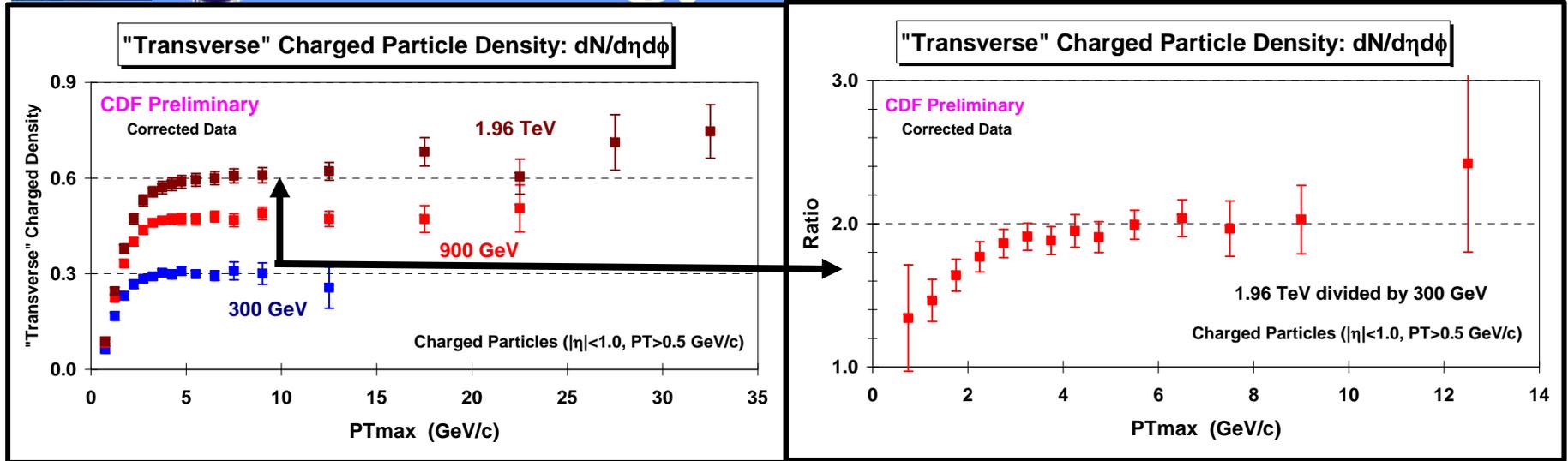


➔ **New Corrected CDF data at 300 GeV, 900 GeV, and 1.96 TeV on the "transverse" charged particle density,  $dN/d\eta d\phi$ , as defined by the leading charged particle (PTmax) for charged particles with  $p_T > 0.5 \text{ GeV/c}$  and  $|\eta| < 1.0$ .**

**300 GeV**  
7,233,840 Events



# Energy Dependence

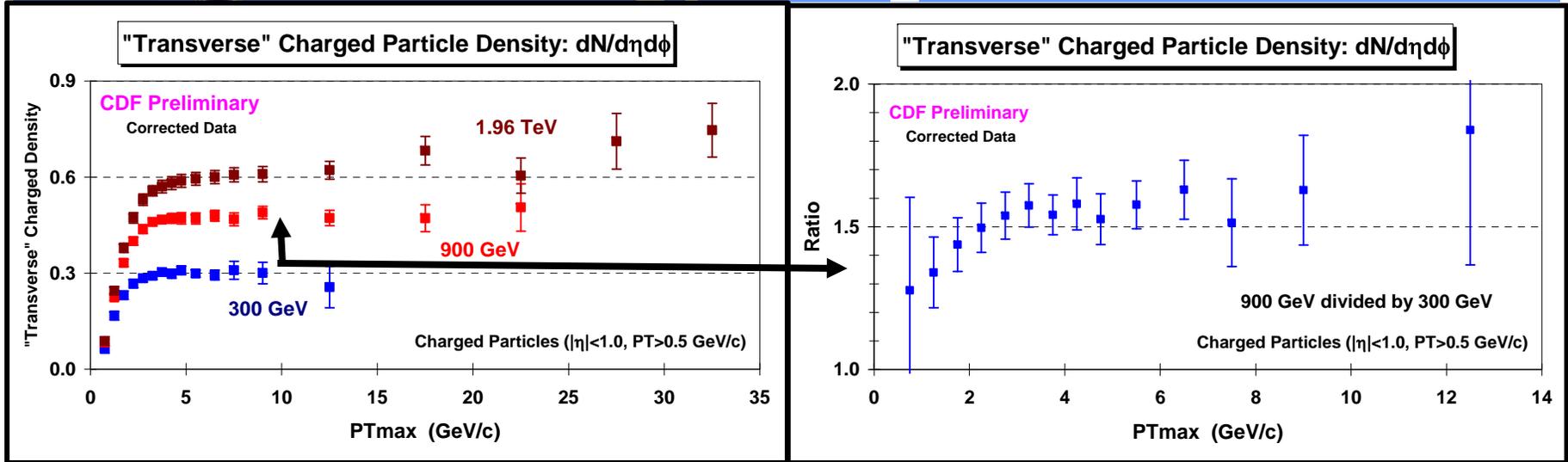


➔ **New Corrected CDF data at 300 GeV, 900 GeV, and 1.96 TeV** on the “transverse” charged particle density,  $dN/d\eta d\phi$ , as defined by the leading charged particle (PTmax) for charged particles with  $p_T > 0.5 \text{ GeV}/c$  and  $|\eta| < 1.0$ .

➔ **Ratio of the CDF data at 300 GeV and 1.96 TeV** on the “transverse” charged particle density,  $dN/d\eta d\phi$ , as defined by the leading charged particle (PTmax) for charged particles with  $p_T > 0.5 \text{ GeV}/c$  and  $|\eta| < 1.0$ . Shows 1.96 TeV divided by 300 GeV.



# Energy Dependence

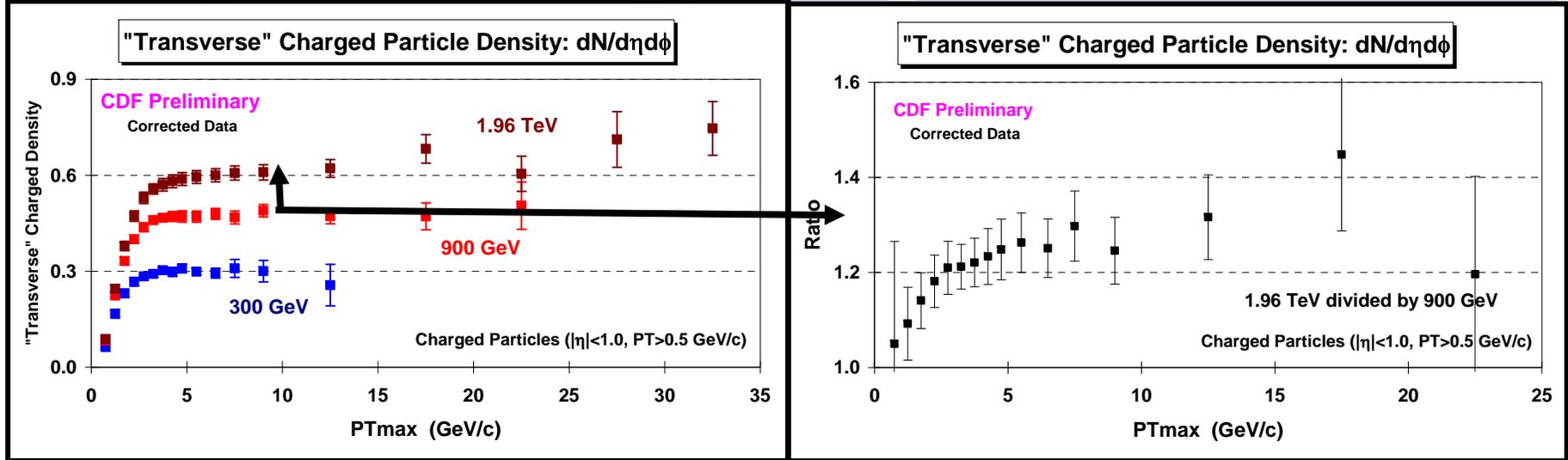


➔ **New Corrected CDF data at 300 GeV, 900 GeV, and 1.96 TeV** on the “transverse” charged particle density,  $dN/d\eta d\phi$ , as defined by the leading charged particle (PTmax) for charged particles with  $p_T > 0.5 \text{ GeV}/c$  and  $|\eta| < 1.0$ .

➔ **Ratio of the CDF data at 300 GeV and 900 GeV** on the “transverse” charged particle density,  $dN/d\eta d\phi$ , as defined by the leading charged particle (PTmax) for charged particles with  $p_T > 0.5 \text{ GeV}/c$  and  $|\eta| < 1.0$ . Shows 900 GeV divided by 300 GeV.



# Energy Dependence

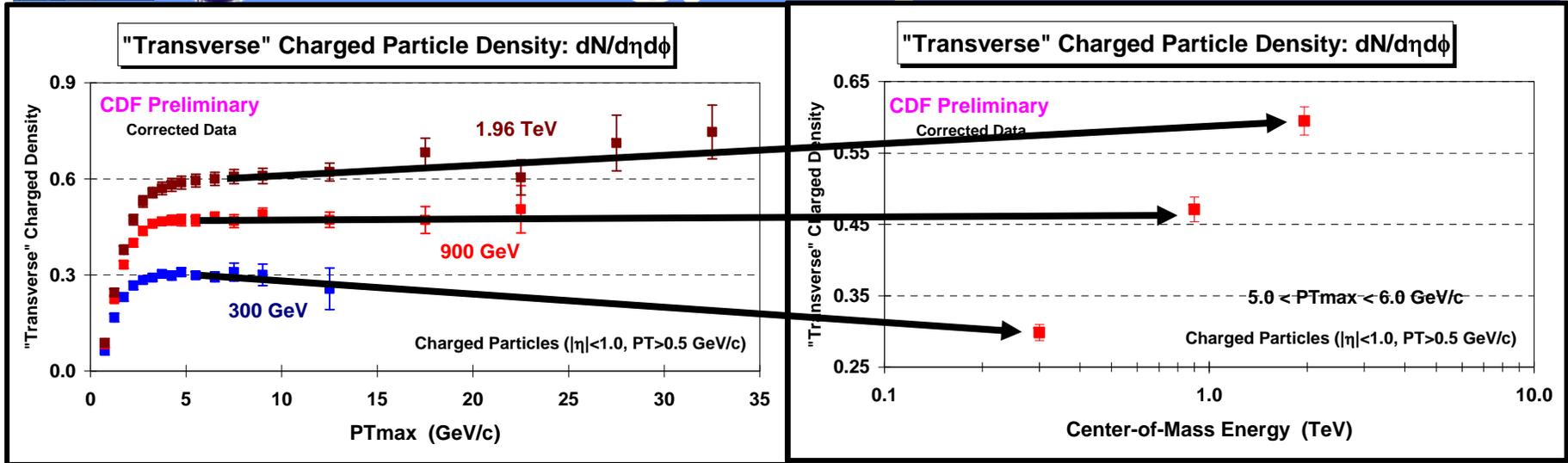


➔ **New Corrected CDF data at 300 GeV, 900 GeV, and 1.96 TeV** on the “transverse” charged particle density,  $dN/d\eta d\phi$ , as defined by the leading charged particle (PTmax) for charged particles with  $p_T > 0.5$  GeV/c and  $|\eta| < 1.0$ .

➔ **Ratio of the CDF data at 900 GeV and 1.96 TeV** on the “transverse” charged particle density,  $dN/d\eta d\phi$ , as defined by the leading charged particle (PTmax) for charged particles with  $p_T > 0.5$  GeV/c and  $|\eta| < 1.0$ . Shows 1.96 TeV divided by 900 GeV.



# Energy Dependence

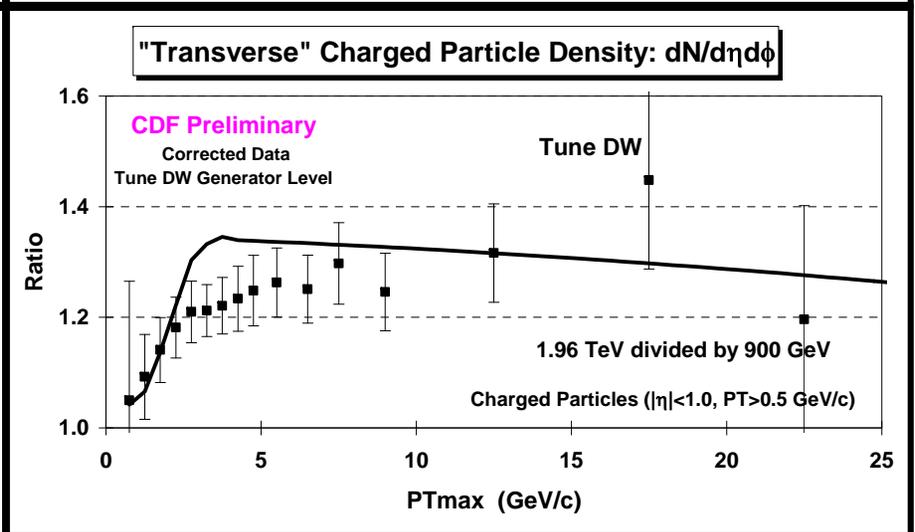
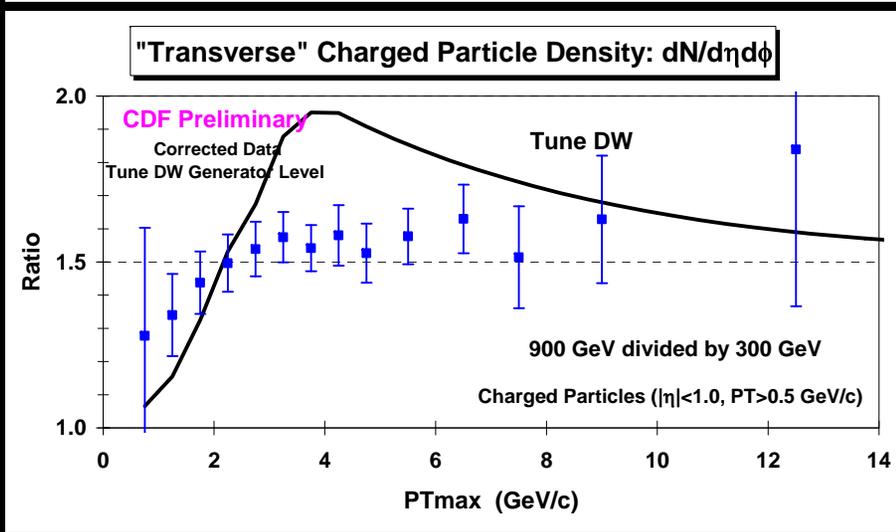
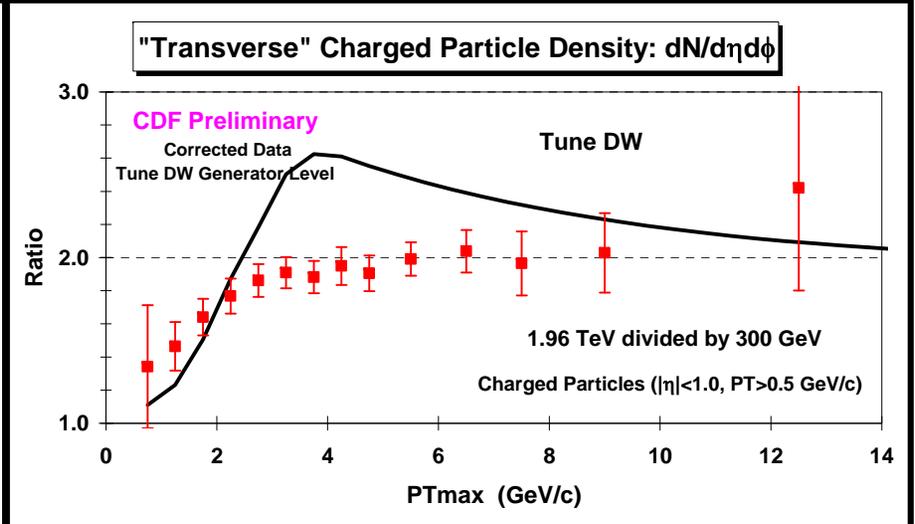
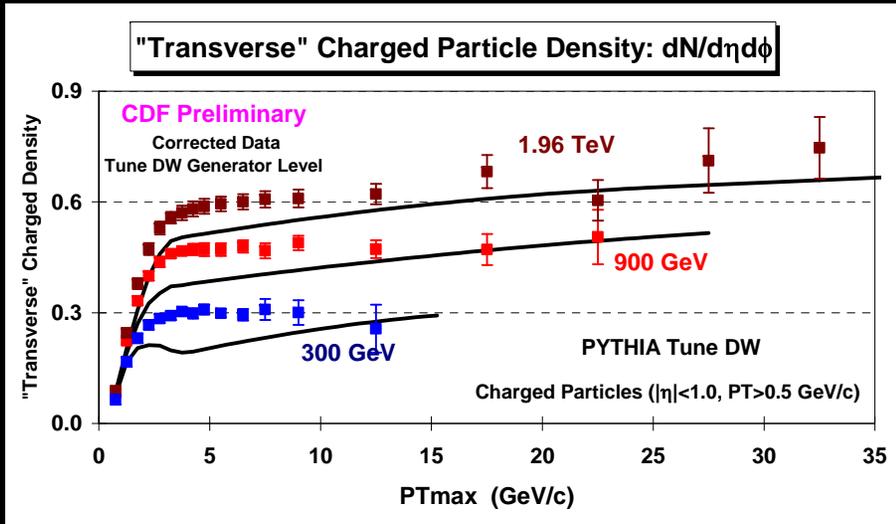


➔ **New Corrected CDF data at 300 GeV, 900 GeV, and 1.96 TeV** on the “transverse” charged particle density,  $dN/d\eta d\phi$ , as defined by the leading charged particle ( $PT_{max}$ ) for charged particles with  $p_T > 0.5$  GeV/c and  $|\eta| < 1.0$ .

➔ **New Corrected CDF data at 300 GeV, 900 GeV, and 1.96 TeV** on the “transverse” charged particle density,  $dN/d\eta d\phi$ , as defined by the leading charged particle ( $PT_{max}$ ) for charged particles with  $p_T > 0.5$  GeV/c and  $|\eta| < 1.0$  for  $5.0 < PT_{max} < 6.0$  GeV/c.

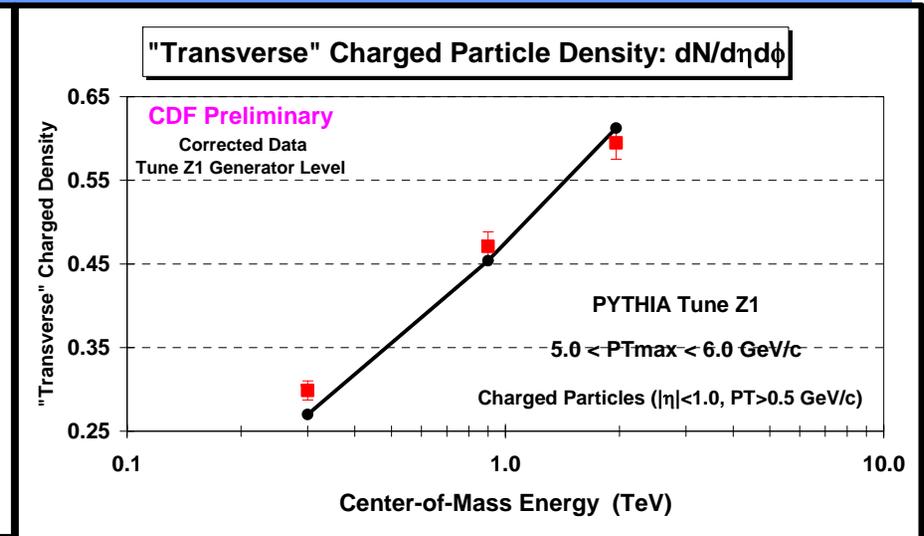
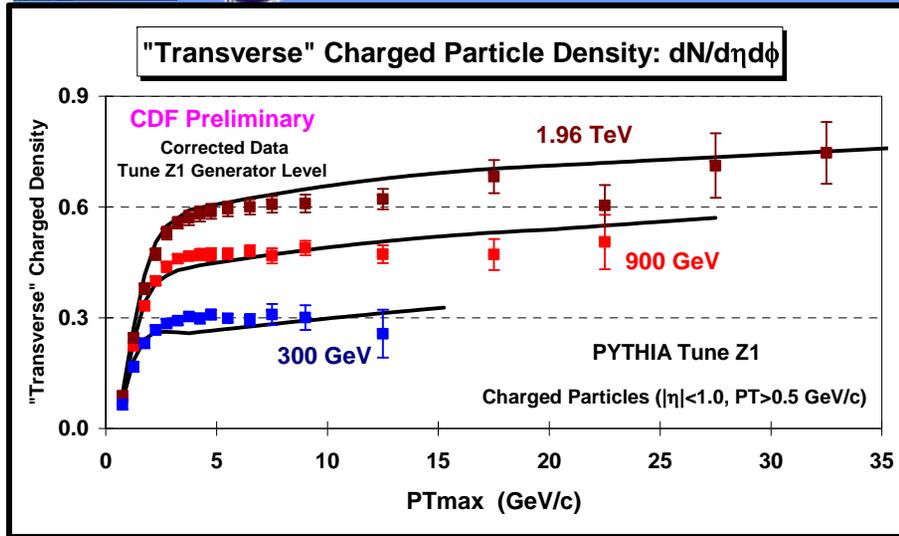


# PYTHIA 6.2 Tune DW



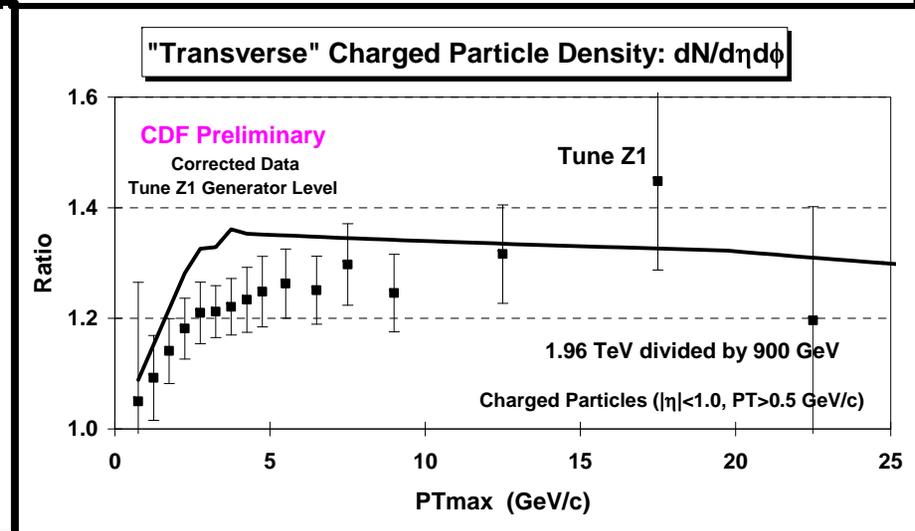
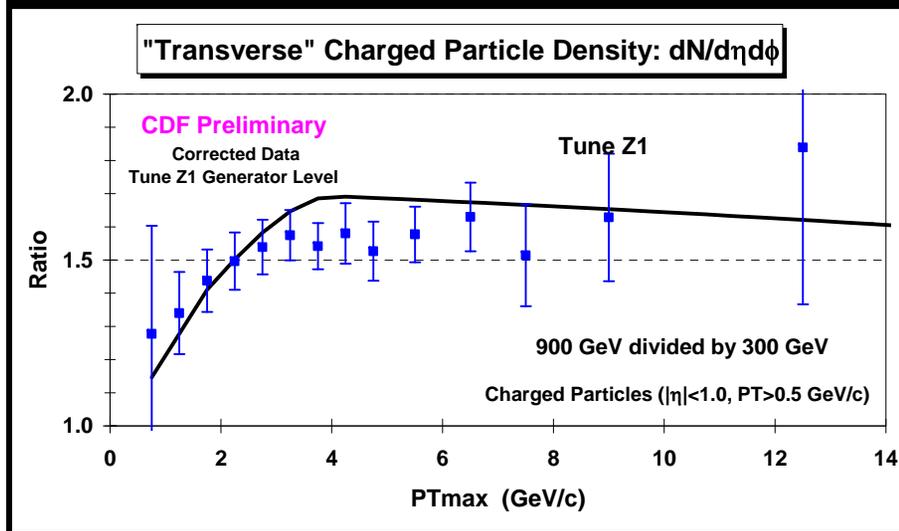
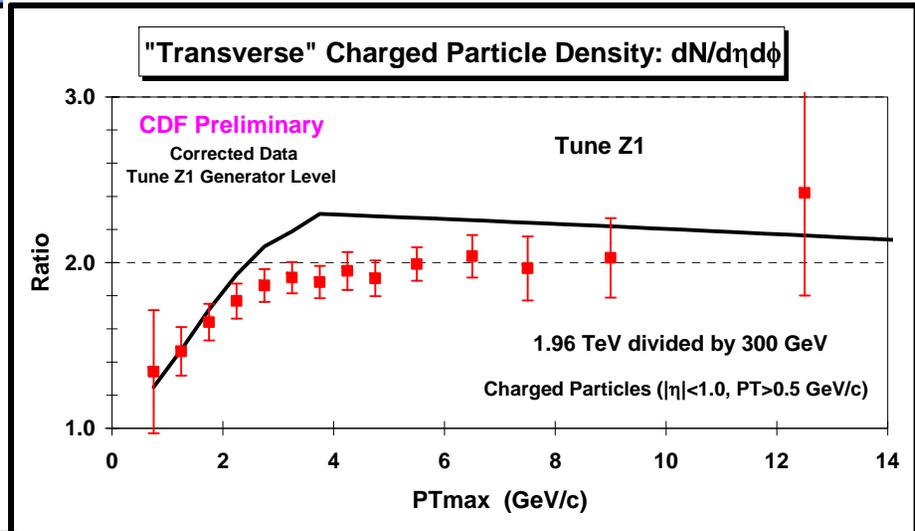
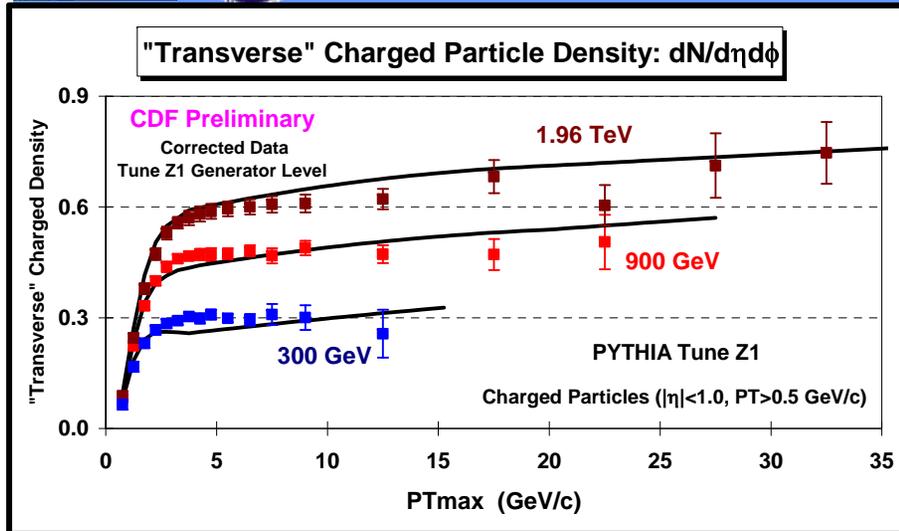


# PYTHIA 6.4 Tune Z1





# PYTHIA 6.4 Tune Z1



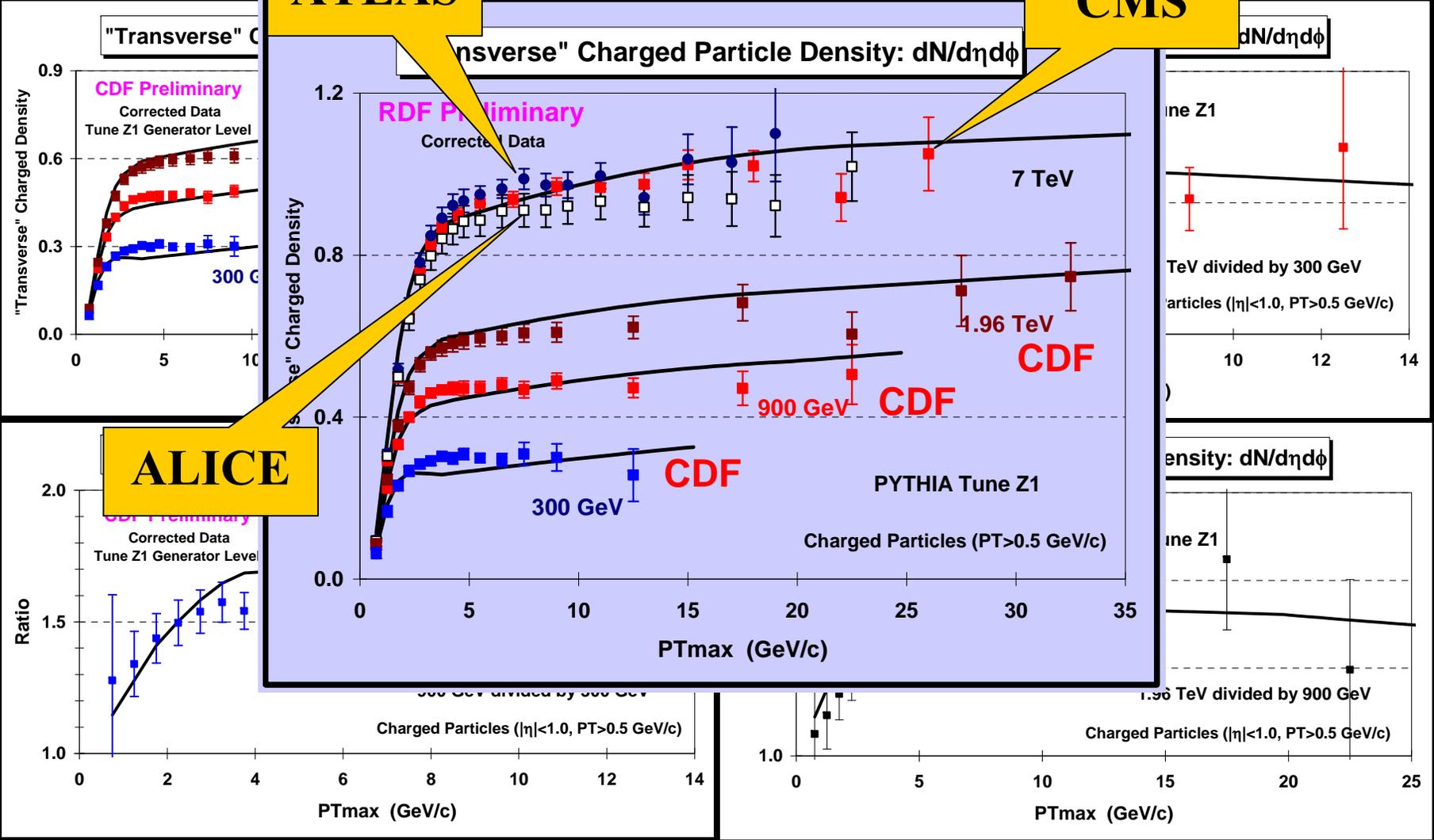


# PYTHIA 6.4 Tune Z1



**ATLAS**

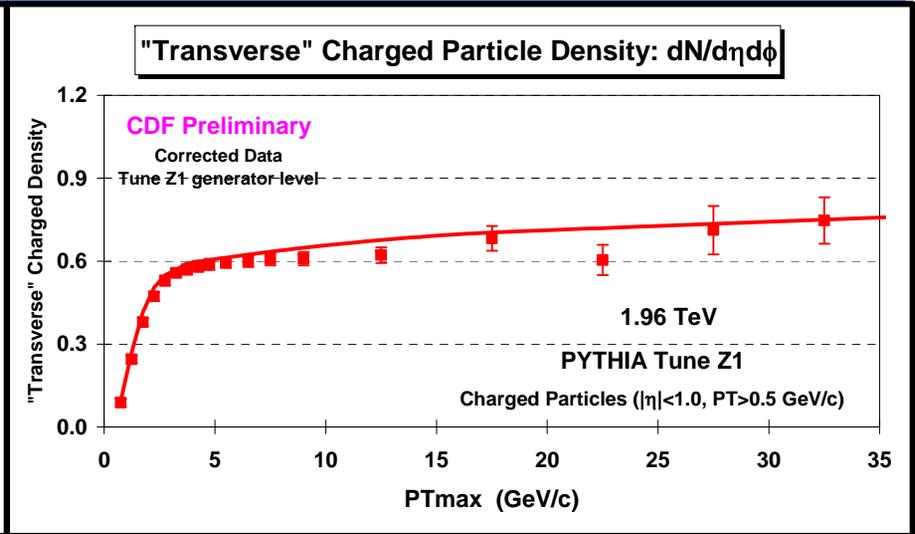
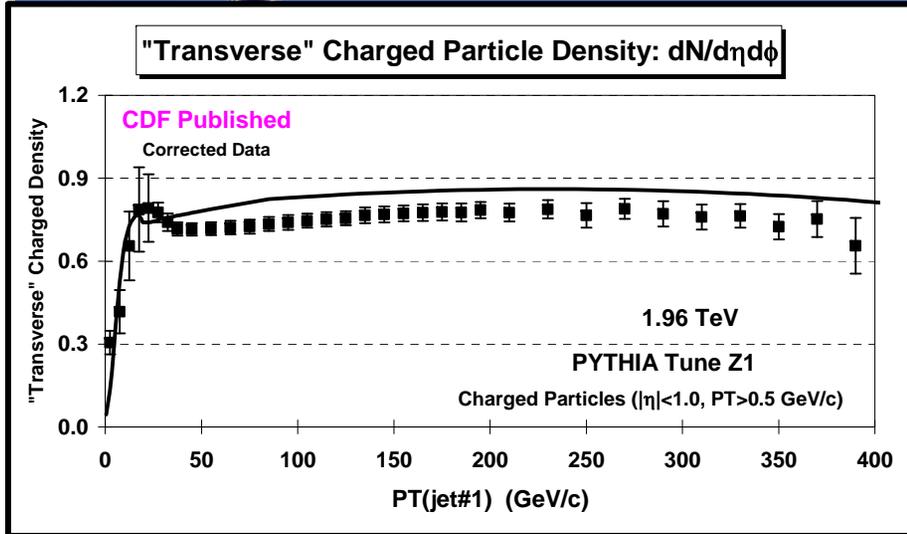
**CMS**



**ALICE**



# PTmax versus Leading Jet



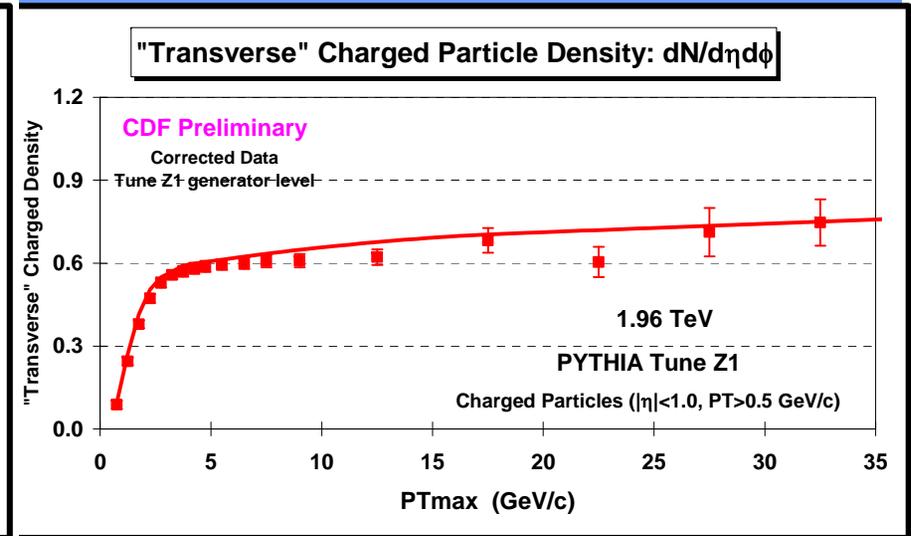
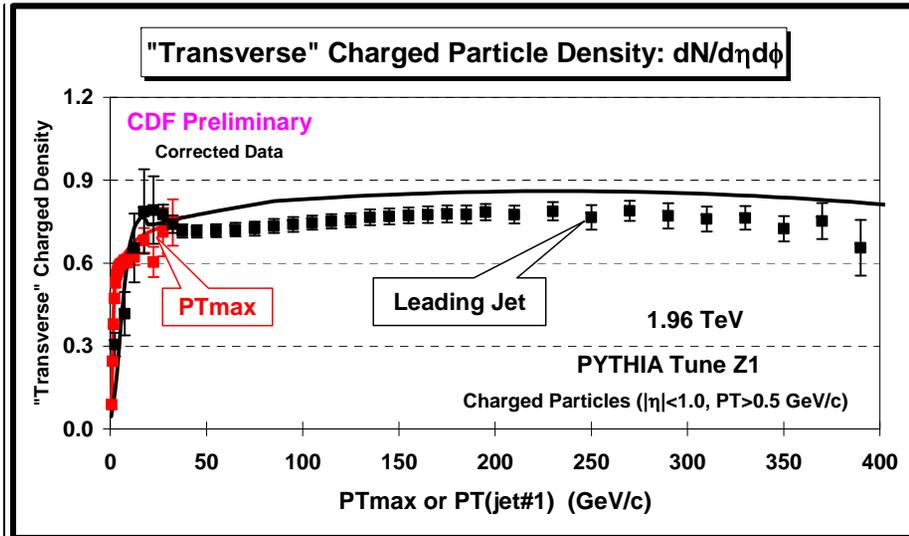
➔ **Published CDF Run 2 data at 1.96 TeV** on the “transverse” charged particle density,  $dN/d\eta d\phi$ , as defined by the leading calorimeter jet (jet#1) for charged particles with  $p_T > 0.5$  GeV/c and  $|\eta| < 1.0$  compared with PYTHIA Tune Z1.

➔ **New CDF data 1.96 TeV** on the “transverse” charged particle density,  $dN/d\eta d\phi$ , as defined by the leading charged particle ( $PTmax$ ) for charged particles with  $p_T > 0.5$  GeV/c and  $|\eta| < 1.0$  compared with PYTHIA Tune Z1.





# PTmax versus Leading Jet



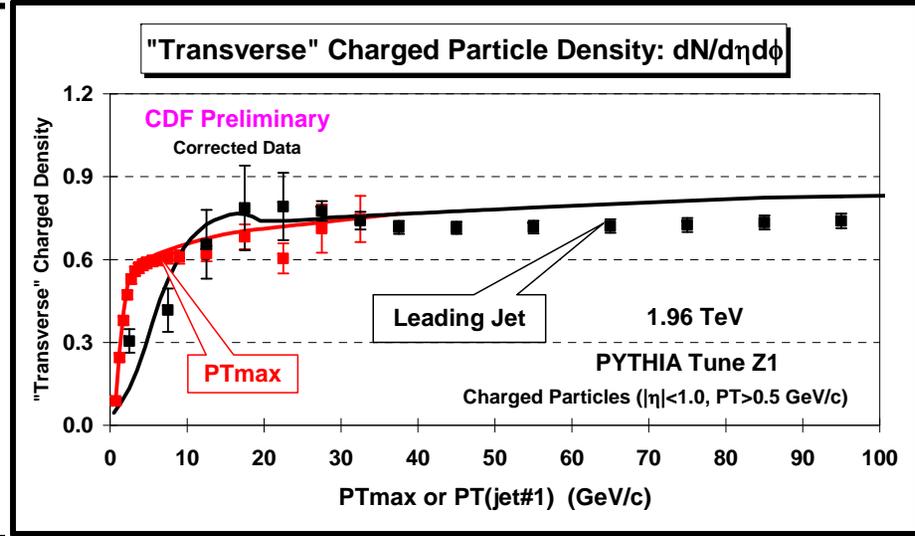
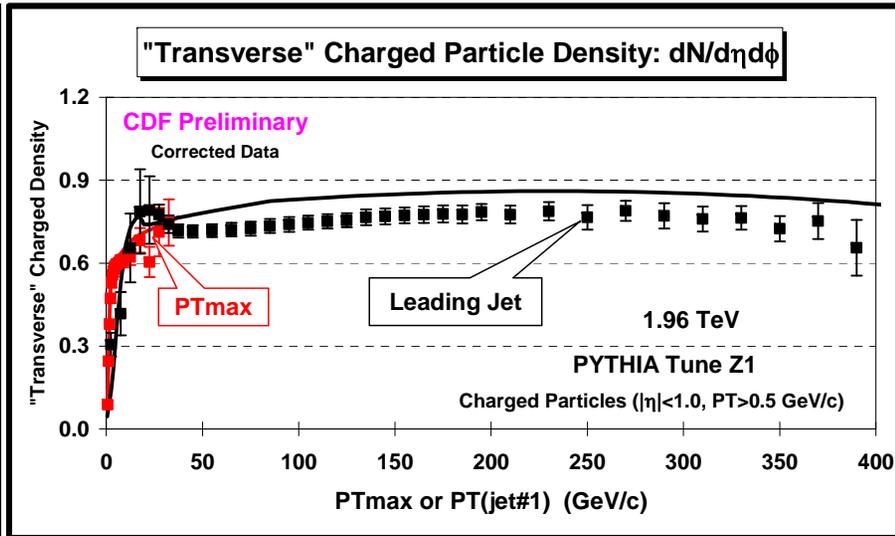
➔ **Published CDF Run 2 data at 1.96 TeV** on the “transverse” charged particle density,  $dN/d\eta d\phi$ , as defined by the leading calorimeter jet (jet#1) for charged particles with  $p_T > 0.5$  GeV/c and  $|\eta| < 1.0$  compared with PYTHIA Tune Z1.

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# PTmax versus Leading Jet



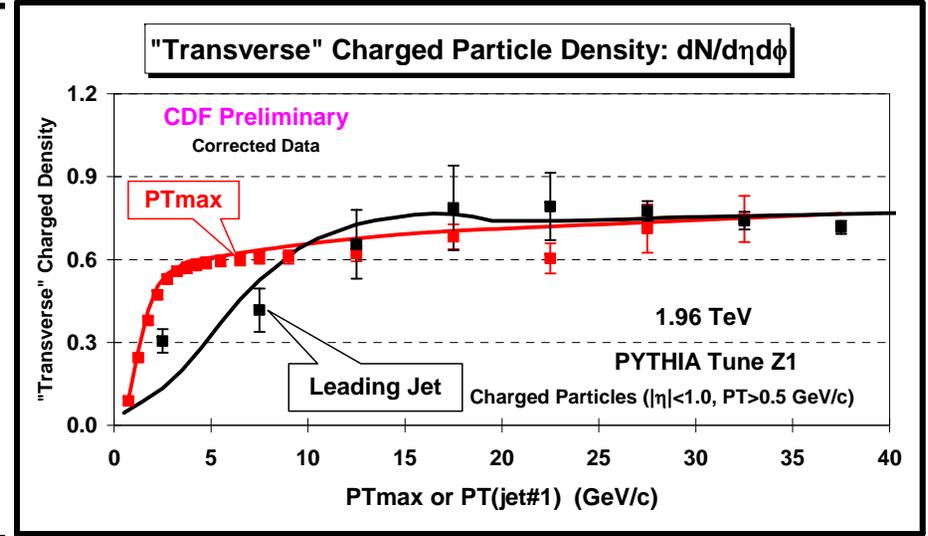
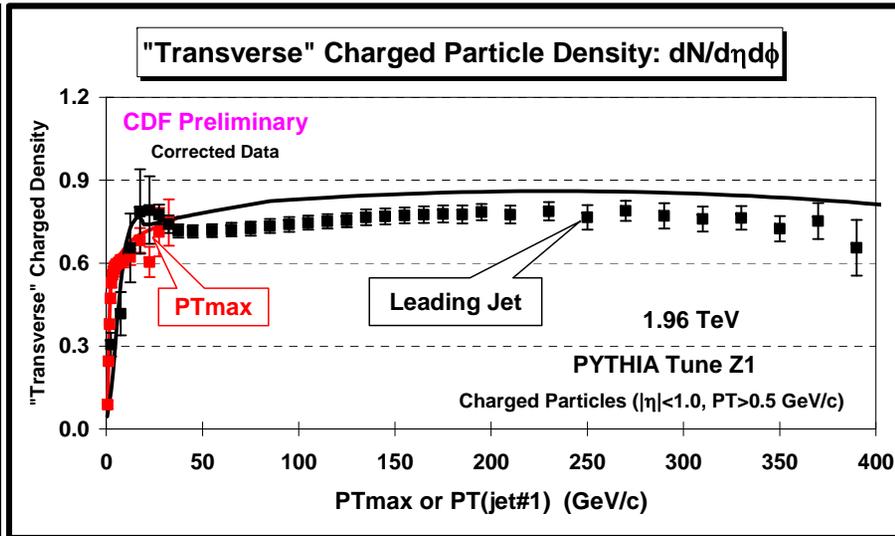
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Yikes!  
???



# PTmax versus Leading Jet



➔ **Published CDF Run 2 data at 1.96 TeV** on the "transverse" charged particle density,  $dN/d\eta d\phi$ , as defined by the leading calorimeter jet (jet#1) for charged particles with  $p_T > 0.5 \text{ GeV/c}$  and  $|\eta| < 1.0$  with PYTHIA Tune Z1

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Yikes! ???

Okay  
No inconsistency  
But need to understand!





# More Coming Soon!



- ➔ **CDF - Many More UE Observables:** Nchg density, PTsum density, average  $p_T$ , “toward”, “away”, “transverse”, “transMAX”, “transMIN”, distributions, etc..
- ➔ **CDF - Two  $\eta$  Ranges:** Must do ( $p_T > 0.5 \text{ GeV}/c$ ,  $|\eta| < 0.8$ ) as well as ( $p_T > 0.5 \text{ GeV}$ ,  $|\eta| < 1$ ).
- ➔ **CDF - Min-Bias:** Many MB observables: Multiplicity,  $dN/d\eta$ ,  $p_T$  distribution,  $\langle p_T \rangle$  versus Nchg, etc.

Soon we will have MB & UE data at 300 GeV, 900 GeV, 1.96 TeV, 7 TeV, and 8 TeV!  
We can study the energy dependence more precisely than ever before!

