



Cosmic QCD 2013



Energy Dependence of the "Underlying Event"

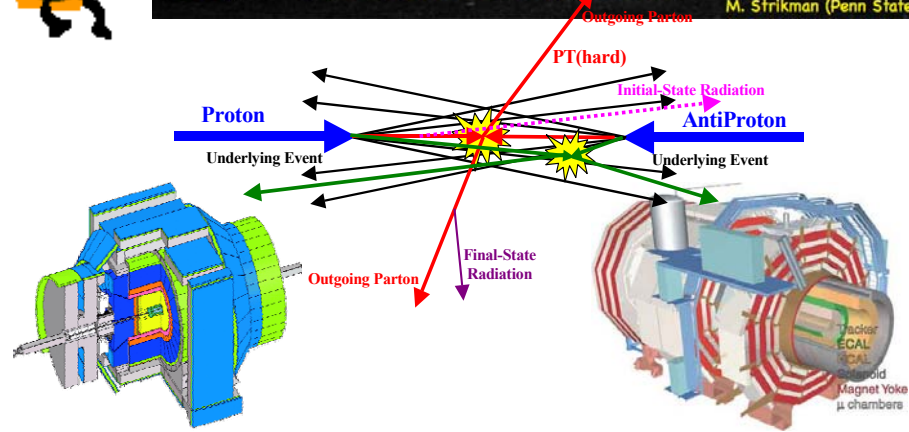
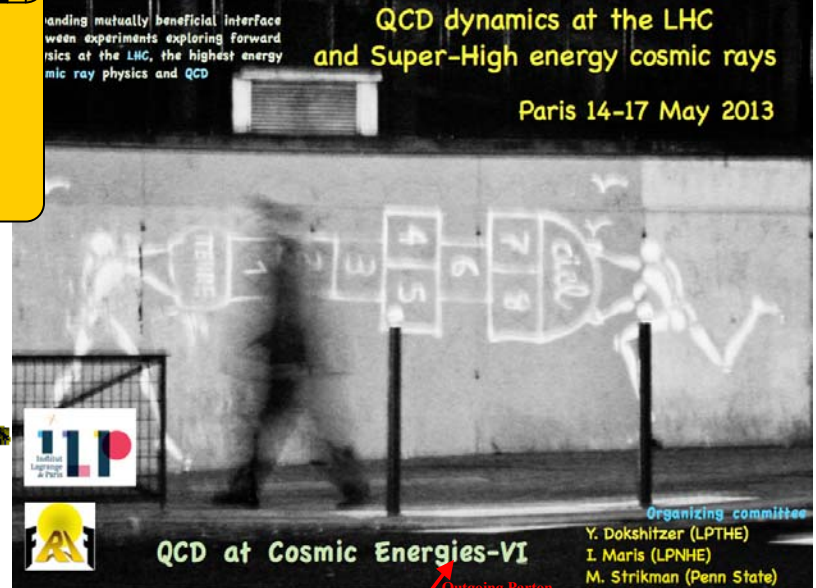


Rick Field
University of Florida

Outline of Talk



- ➔ New **CDF** UE data from the **Tevatron Energy Scan**.
- ➔ Comparisons with **PYTHIA 6.4 Tune Z1**.
- ➔ New **CMS** UE data.
- ➔ Mapping out the energy dependence: **Tevatron to the LHC!**
- ➔ New **CDF** MB data.
- ➔ New **UE-MB** comparisons!
- ➔ **Summary & Conclusions**.



CDF Run 2

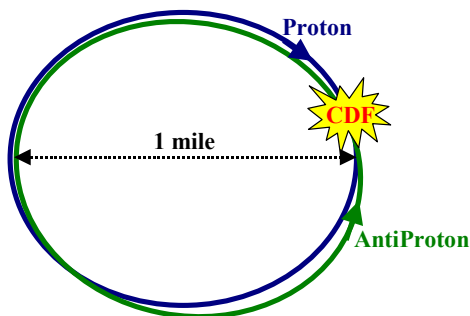
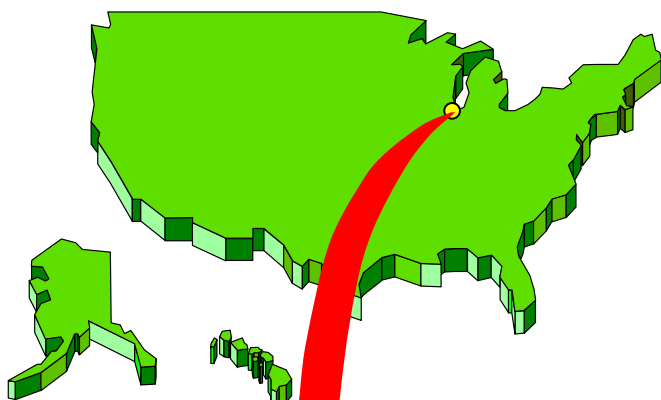
300 GeV, 900 GeV, 1.96 TeV

CMS at the LHC

900 GeV, 7 & 8 TeV



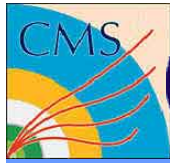
Tevatron Energy Scan



➔ 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

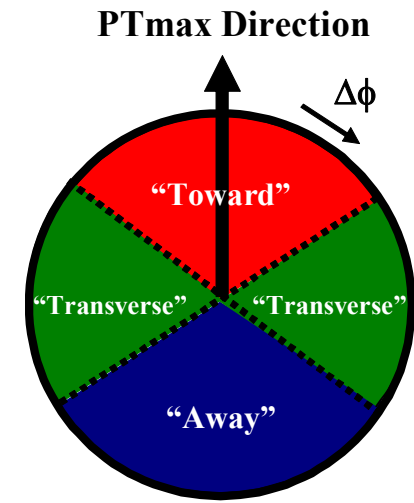
900 GeV 54.3M MB Events



UE Observables



- ➔ **“Transverse” Charged Particle Density:** Number of charged particles ($p_T > 0.5 \text{ GeV}/c$, $|\eta| < \eta_{\text{cut}}$) in the “transverse” region as defined by the leading charged particle, PT_{max} , divided by the area in η - ϕ space, $2\eta_{\text{cut}} \times 2\pi/3$, averaged over all events with at least one particle with $p_T > 0.5 \text{ GeV}/c$, $|\eta| < \eta_{\text{cut}}$.
- ➔ **“Transverse” Charged PT_{sum} Density:** Scalar p_T sum of the charged particles ($p_T > 0.5 \text{ GeV}/c$, $|\eta| < \eta_{\text{cut}}$) in the “transverse” region as defined by the leading charged particle, PT_{max} , divided by the area in η - ϕ space, $2\eta_{\text{cut}} \times 2\pi/3$, averaged over all events with at least one particle with $p_T > 0.5 \text{ GeV}/c$, $|\eta| < \eta_{\text{cut}}$.
- ➔ **“Transverse” Charged Particle Average P_T :** Event-by-event $\langle p_T \rangle = PT_{\text{sum}}/N_{\text{chg}}$ for charged particles ($p_T > 0.5 \text{ GeV}/c$, $|\eta| < \eta_{\text{cut}}$) in the “transverse” region as defined by the leading charged particle, PT_{max} , averaged over all events with at least one particle in the “transverse” region with $p_T > 0.5 \text{ GeV}/c$, $|\eta| < \eta_{\text{cut}}$.
- ➔ **Zero “Transverse” Charged Particles:** If there are no charged particles in the “transverse” region then N_{chg} and PT_{sum} are zero and one includes these zeros in the average over all events with at least one particle with $p_T > 0.5 \text{ GeV}/c$, $|\eta| < \eta_{\text{cut}}$. However, if there are no charged particles in the “transverse” region then the event is not used in constructing the “transverse” average p_T .



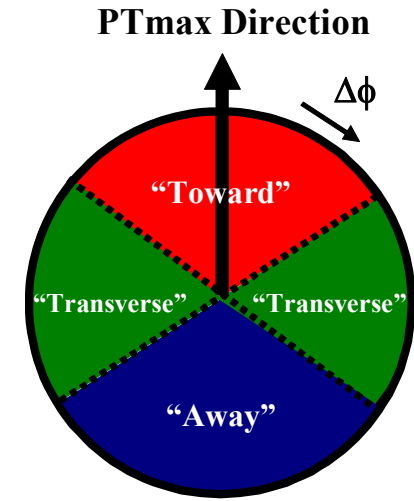
$$\eta_{\text{cut}} = 1.0 \text{ and } \eta_{\text{cut}} = 0.8$$



UE Observables



- ➔ **“Toward” Charged Particle Density:** Number of charged particles ($p_T > 0.5 \text{ GeV}/c$, $|\eta| < 0.8$) in the “toward” region (not including PTmax) as defined by the leading charged particle, PTmax, divided by the area in η - ϕ space, $2\eta_{\text{cut}} \times 2\pi/3$, averaged over all events with at least one particle with $p_T > 0.5 \text{ GeV}/c$, $|\eta| < \eta_{\text{cut}}$.
- ➔ **“Toward” Charged PTsum Density:** Scalar p_T sum of the charged particles ($p_T > 0.5 \text{ GeV}/c$, $|\eta| < 0.8$) in the “toward” region (not including PTmax) as defined by the leading charged particle, PTmax, divided by the area in η - ϕ space, $2\eta_{\text{cut}} \times 2\pi/3$, averaged over all events with at least one particle with $p_T > 0.5 \text{ GeV}/c$, $|\eta| < \eta_{\text{cut}}$.
- ➔ **“Away” Charged Particle Density:** Number of charged particles ($p_T > 0.5 \text{ GeV}/c$, $|\eta| < 0.8$) in the “away” region as defined by the leading charged particle, PTmax, divided by the area in η - ϕ space, $2\eta_{\text{cut}} \times 2\pi/3$, averaged over all events with at least one particle with $p_T > 0.5 \text{ GeV}/c$, $|\eta| < \eta_{\text{cut}}$.
- ➔ **“Away” Charged PTsum Density:** Scalar p_T sum of the charged particles ($p_T > 0.5 \text{ GeV}/c$, $|\eta| < 0.8$) in the “away” region as defined by the leading charged particle, PTmax, divided by the area in η - ϕ space, $2\eta_{\text{cut}} \times 2\pi/3$, averaged over all events with at least one particle with $p_T > 0.5 \text{ GeV}/c$, $|\eta| < \eta_{\text{cut}}$.



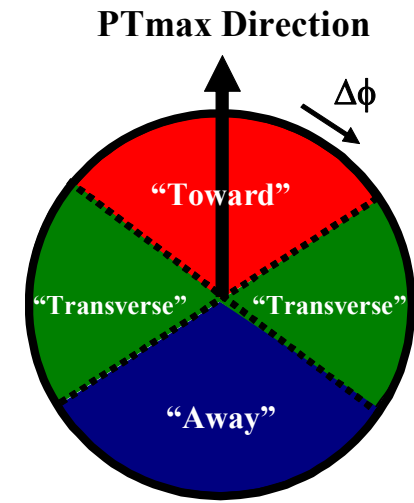
$$\eta_{\text{cut}} = 0.8$$



UE Observables



- ➔ **Overall “Associated” Charged Particle Density:** Number of charged particles ($p_T > 0.5 \text{ GeV}/c$, $|\eta| < 0.8$, not including PTmax) as defined by the leading charged particle, PTmax, divided by the area in η - ϕ space, $2\eta_{\text{cut}} \times 2\pi$, averaged over all events with at least one particle with $p_T > 0.5 \text{ GeV}/c$, $|\eta| < \eta_{\text{cut}}$.
- ➔ **Overall “Associated” Charged PTsum Density:** Scalar p_T sum of the charged particles ($p_T > 0.5 \text{ GeV}/c$, $|\eta| < 0.8$, not including PTmax) as defined by the leading charged particle, PTmax, divided by the area in η - ϕ space, $2\eta_{\text{cut}} \times 2\pi$, averaged over all events with at least one particle with $p_T > 0.5 \text{ GeV}/c$, $|\eta| < \eta_{\text{cut}}$.



Note: The overall “associated” density is equal to the average of the “Towards”, “Away”, and “Transverse” densities.

$$\text{Overall “Associated” Density} = (\text{“Towards” Density} + \text{“Away” Density} + \text{“Transverse” Density})/3$$

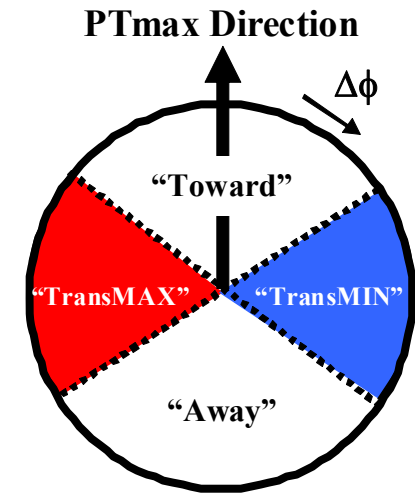
$$\eta_{\text{cut}} = 0.8$$



UE Observables



- ➔ **“transMAX” and “transMIN” Charged Particle Density:** Number of charged particles ($p_T > 0.5 \text{ GeV}/c$, $|\eta| < 0.8$) in the the maximum (minimum) of the two “transverse” regions as defined by the leading charged particle, PTmax, divided by the area in η - ϕ space, $2\eta_{\text{cut}} \times 2\pi/6$, averaged over all events with at least one particle with $p_T > 0.5 \text{ GeV}/c$, $|\eta| < \eta_{\text{cut}}$.
- ➔ **“transMAX” and “transMIN” Charged PTsum Density:** Scalar p_T sum of charged particles ($p_T > 0.5 \text{ GeV}/c$, $|\eta| < 0.8$) in the the maximum (minimum) of the two “transverse” regions as defined by the leading charged particle, PTmax, divided by the area in η - ϕ space, $2\eta_{\text{cut}} \times 2\pi/6$, averaged over all events with at least one particle with $p_T > 0.5 \text{ GeV}/c$, $|\eta| < \eta_{\text{cut}}$.



Note: The overall “transverse” density is equal to the average of the “transMAX” and “TransMIN” densities. The “TransDIF” Density is the “transMAX” Density minus the “transMIN” Density

$$\text{“Transverse” Density} = \text{“transAVE” Density} = (\text{“transMAX” Density} + \text{“transMIN” Density})/2$$

$$\text{“TransDIF” Density} = \text{“transMAX” Density} - \text{“transMIN” Density}$$

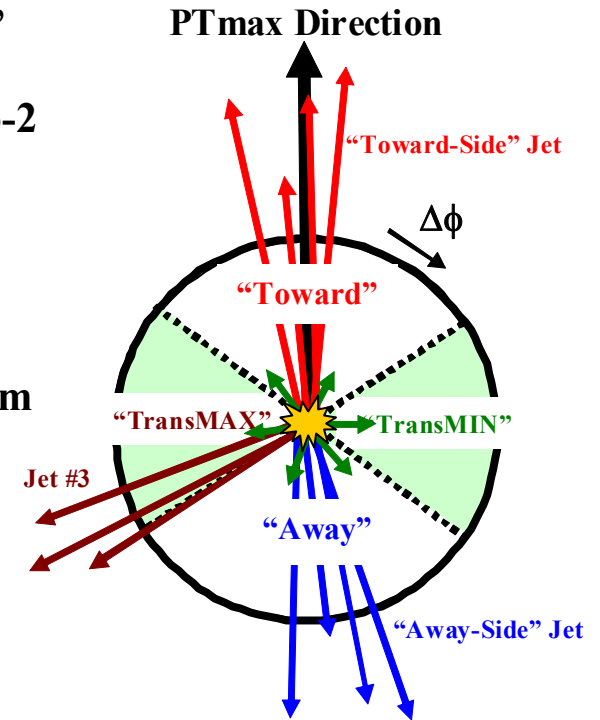
$$\eta_{\text{cut}} = 0.8$$



“transMIN” & “transDIF”



- ➔ The “toward” region contains the leading “jet”, while the “away” region, on the average, contains the “away-side” “jet”. The “transverse” region is perpendicular to the plane of the hard 2-to-2 scattering and is very sensitive to the “underlying event”. For events with large initial or final-state radiation the “transMAX” region defined contains the third jet while both the “transMAX” and “transMIN” regions receive contributions from the MPI and beam-beam remnants. Thus, the “transMIN” region is very sensitive to the multiple parton interactions (MPI) and beam-beam remnants (BBR), while the “transMAX” minus the “transMIN” (*i.e.* “transDIF”) is very sensitive to initial-state radiation (ISR) and final-state radiation (FSR).



“TransMIN” density more sensitive to MPI & BBR.

“TransDIF” density more sensitive to ISR & FSR.

$$0 \leq \text{“TransDIF”} \leq 2 \times \text{“TransAVE”}$$

$$\text{“TransDIF”} = \text{“TransAVE”} \text{ if } \text{“TransMIX”} = 3 \times \text{“TransMIN”}$$

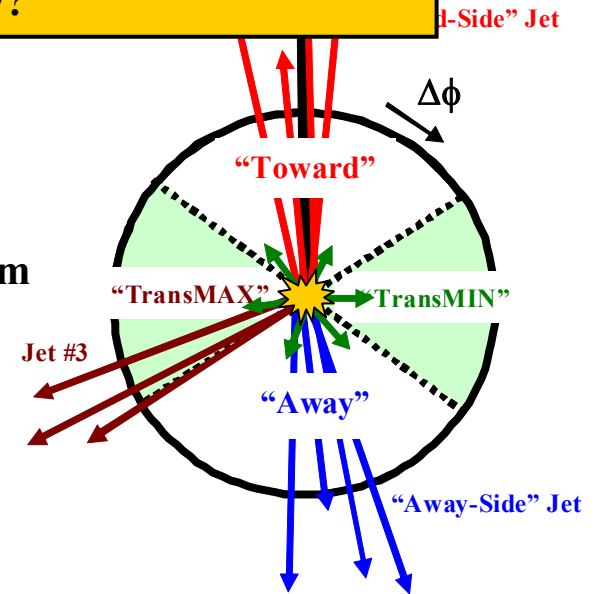


“transMIN” & “transDIF”



➔ **Question:** Do you expect the energy dependence of the “transMIN” and “transDIF” densities to be the same? Or do you expect that one of the two densities will increase faster with increasing energy than the other? Which one and why?

scattering and is very sensitive to the underlying event. For events with large initial or final-state radiation the “transMAX” region defined contains the third jet while both the “transMAX” and “transMIN” regions receive contributions from the MPI and beam-beam remnants. Thus, the “transMIN” region is very sensitive to the multiple parton interactions (MPI) and beam-beam remnants (BBR), while the “transMAX” minus the “transMIN” (*i.e.* “transDIF”) is very sensitive to initial-state radiation (ISR) and final-state radiation (FSR).



“TransMIN” density more sensitive to MPI & BBR.

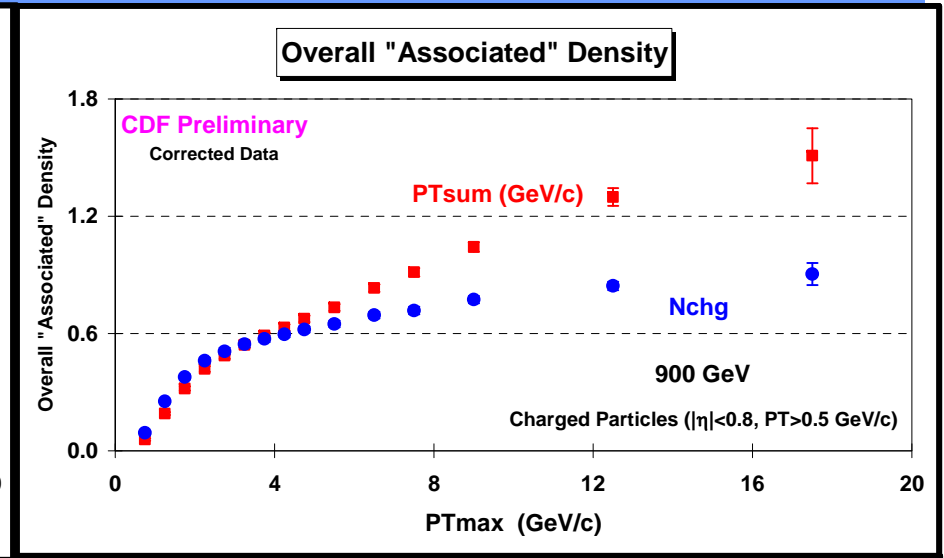
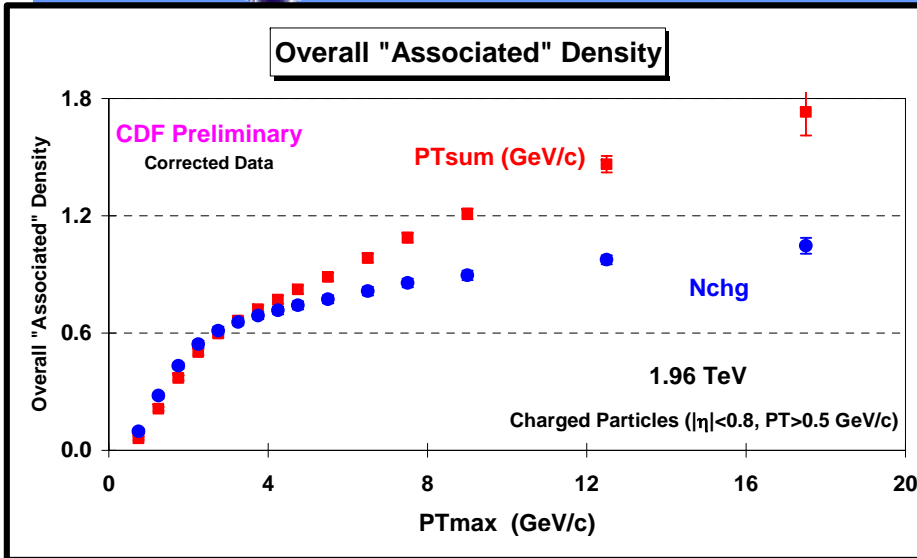
“TransDIF” density more sensitive to ISR & FSR.

$$0 \leq \text{“TransDIF”} \leq 2 \times \text{“TransAVE”}$$

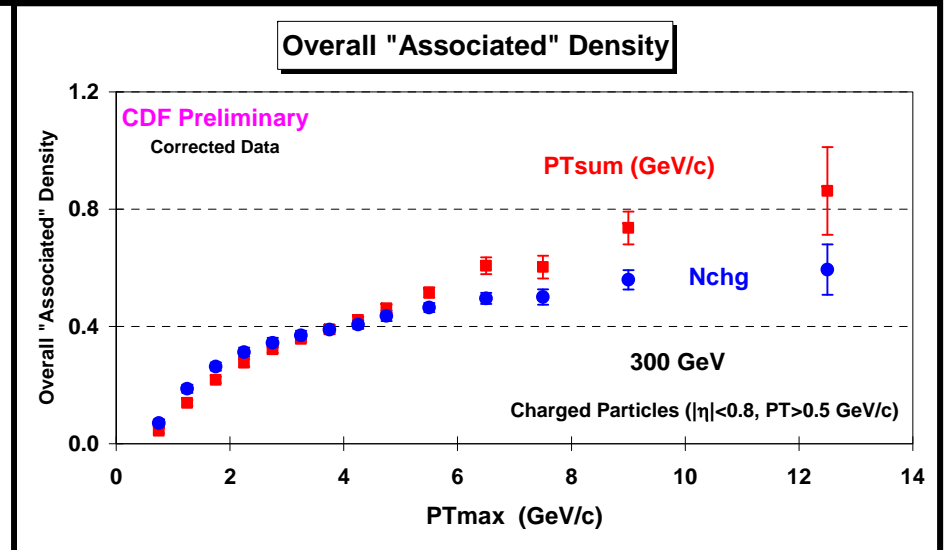
$$\text{“TransDIF”} = \text{“TransAVE”} \text{ if } \text{“TransMIX”} = 3 \times \text{“TransMIN”}$$

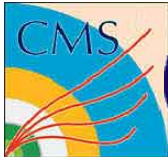


Overall "Associated" Density

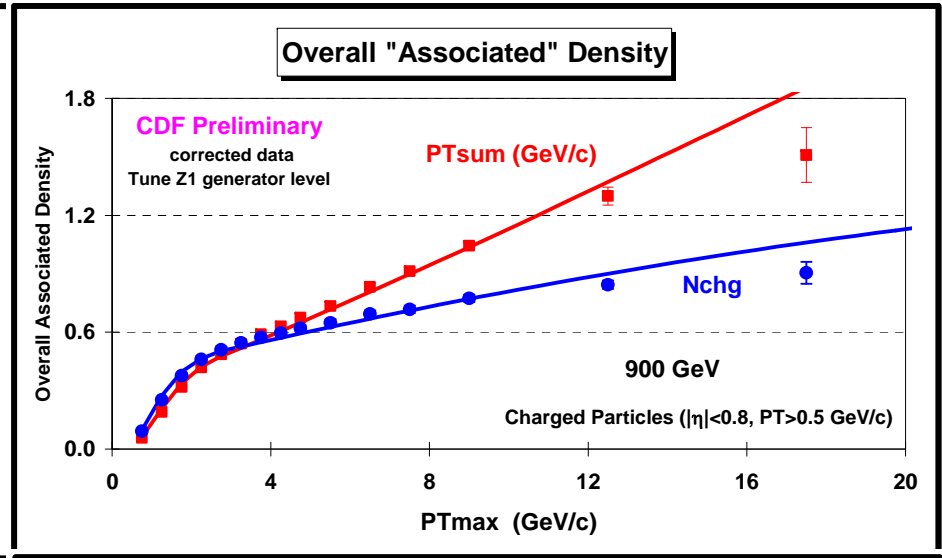
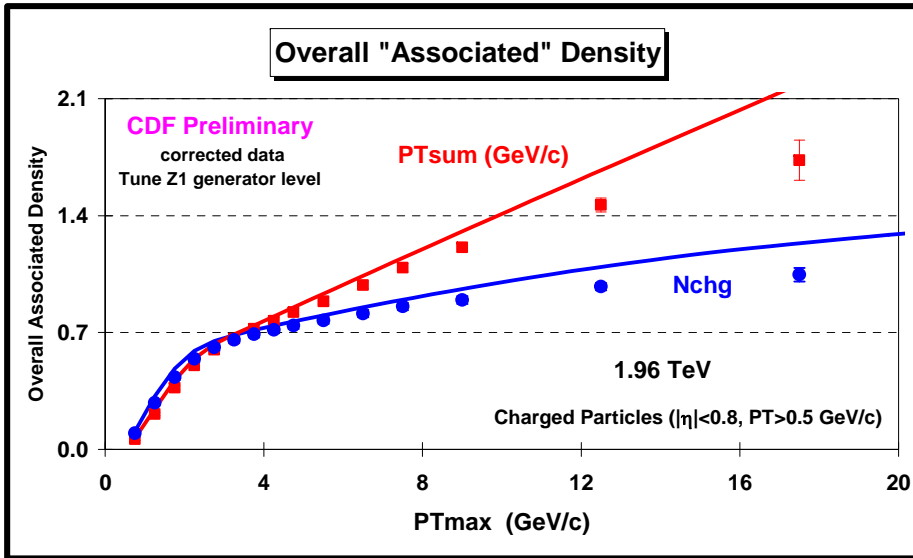


➔ **Corrected CDF data at 1.96 TeV, 900 GeV, and 300 GeV** on the overall "associated" charged particle and charged PTsum density as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$. The data are corrected to the particle level with errors that include both the statistical error and the systematic uncertainty.

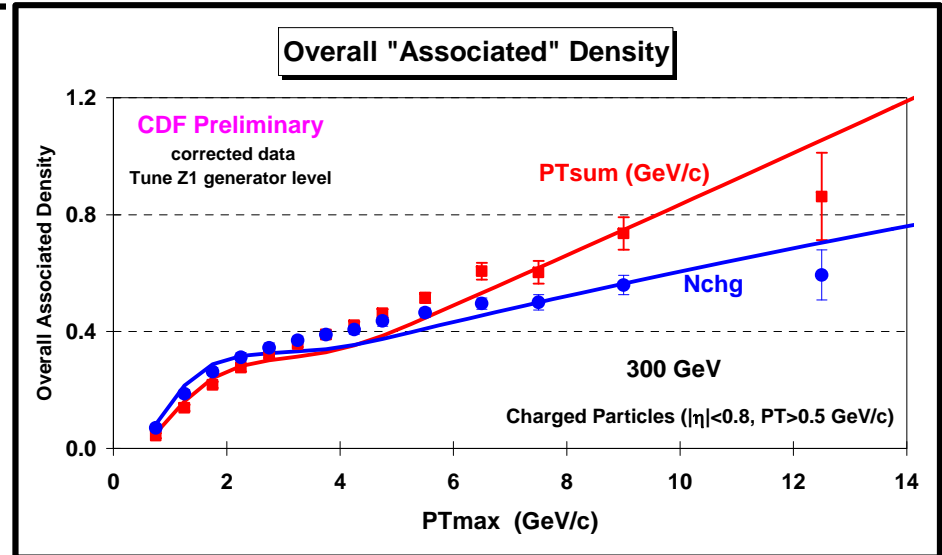




Overall "Associated" Density

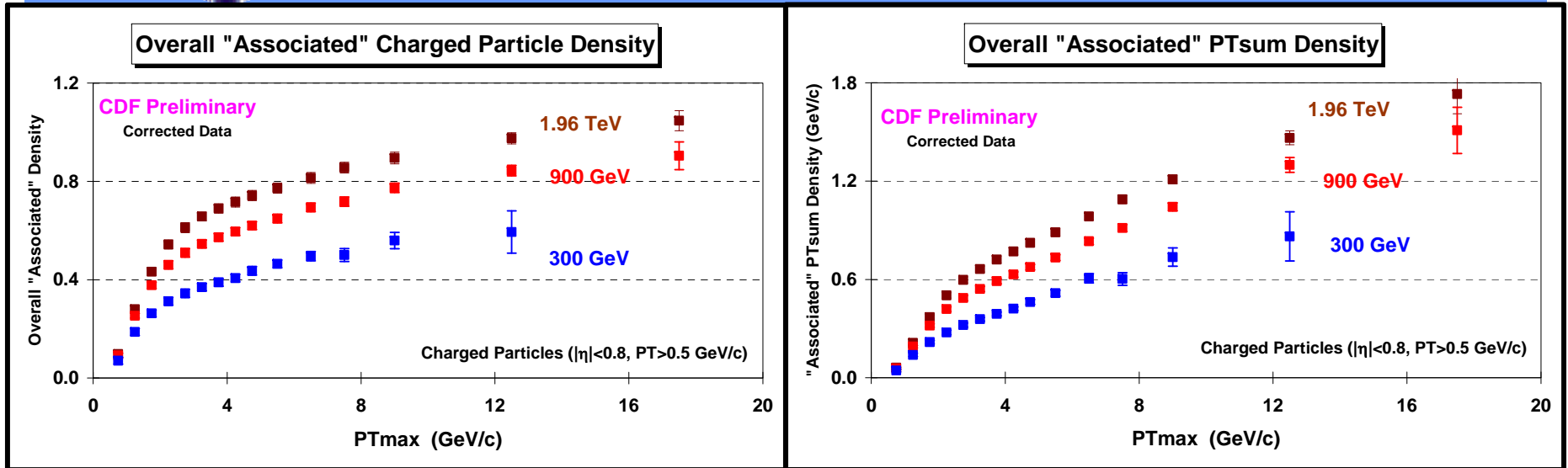


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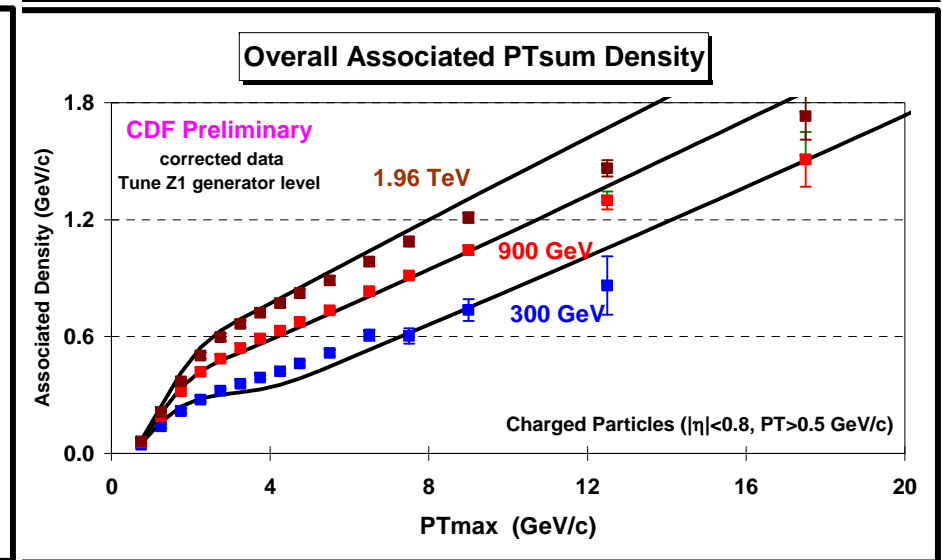
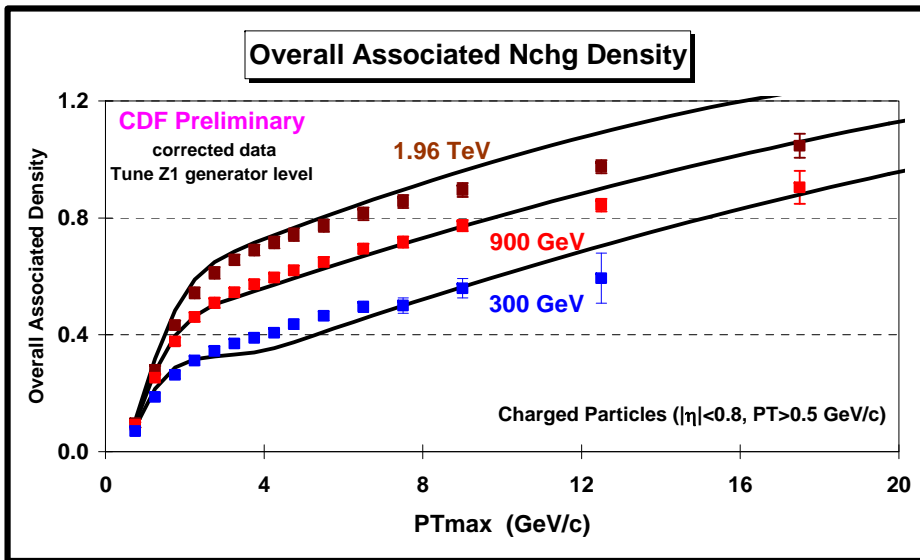
Overall “Associated” Density



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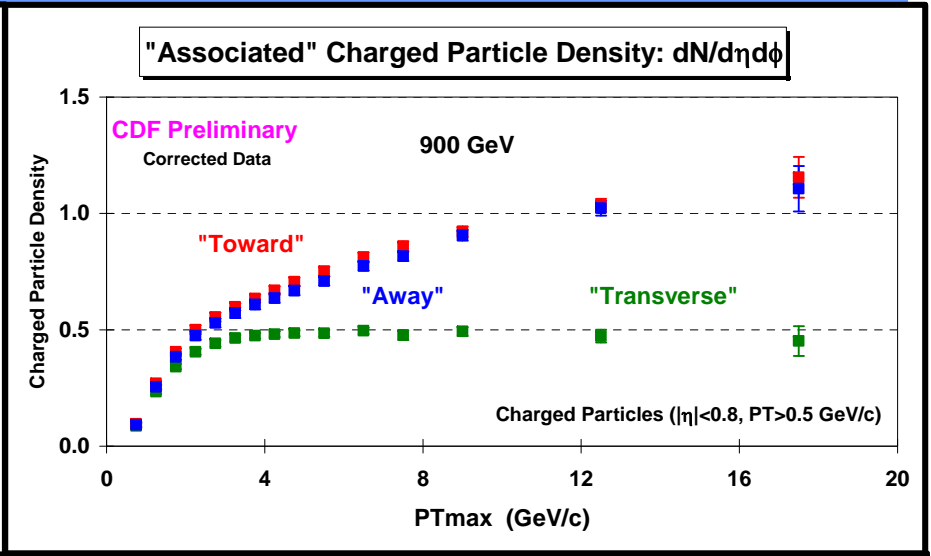
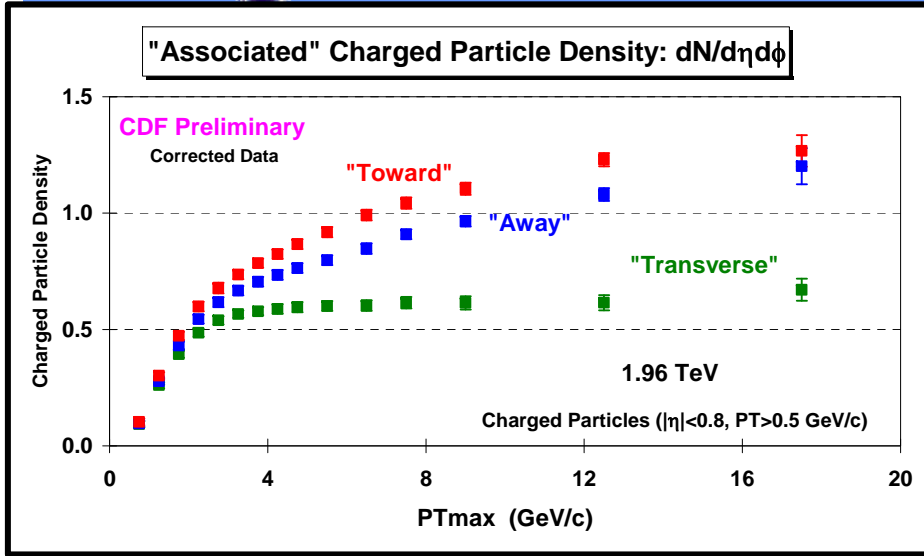
Overall “Associated” Density



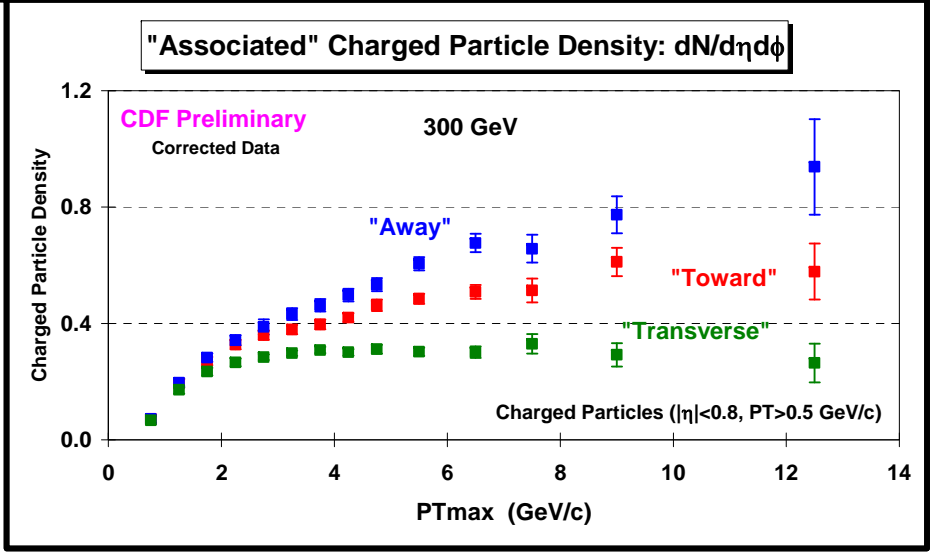
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“Associated” Charged Particle Density

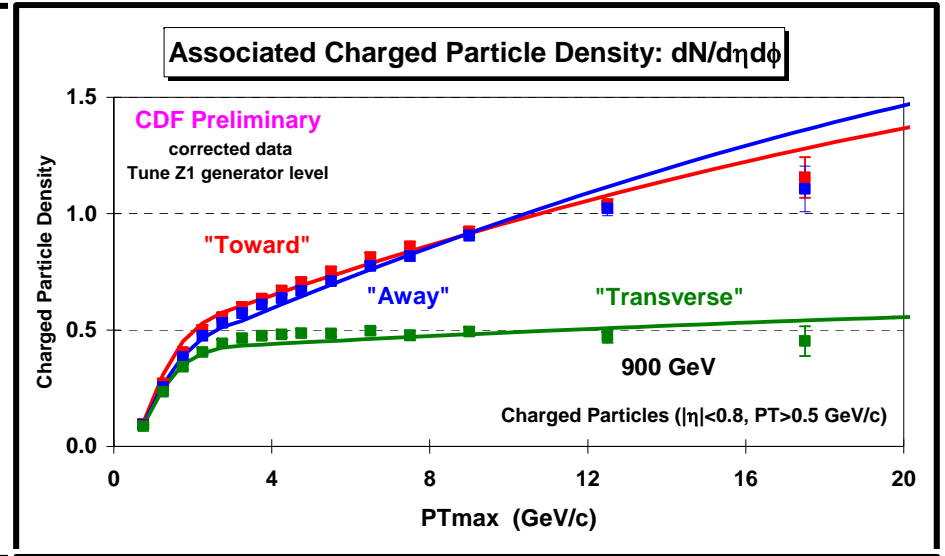
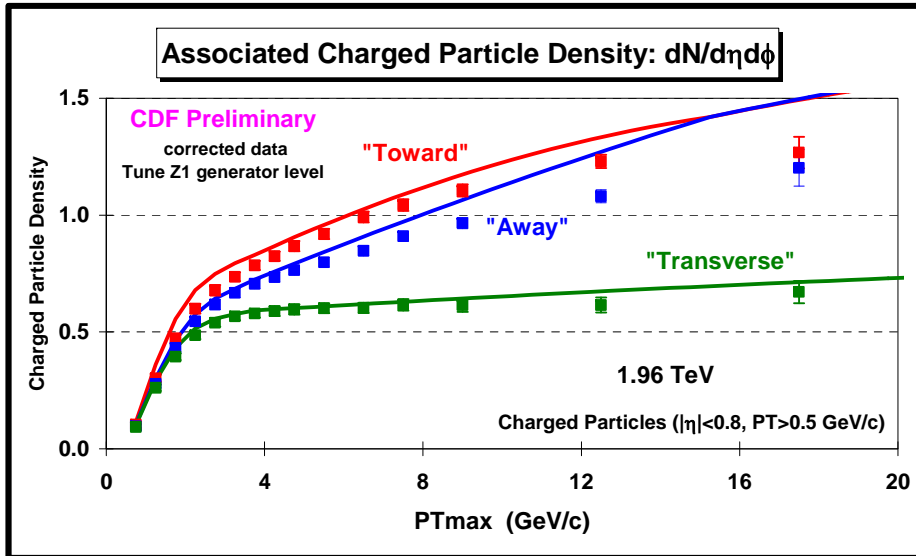


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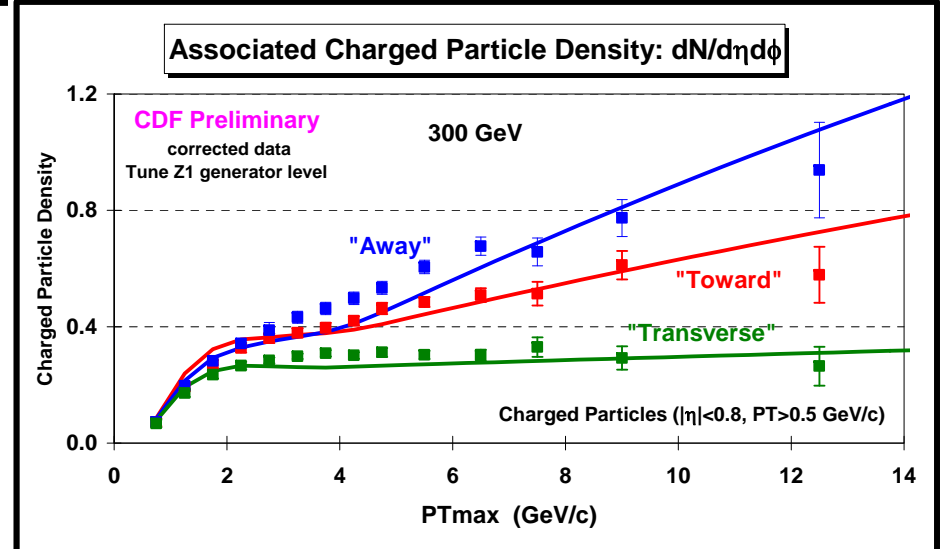


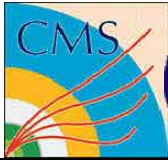


“Associated” Charged Particle Density

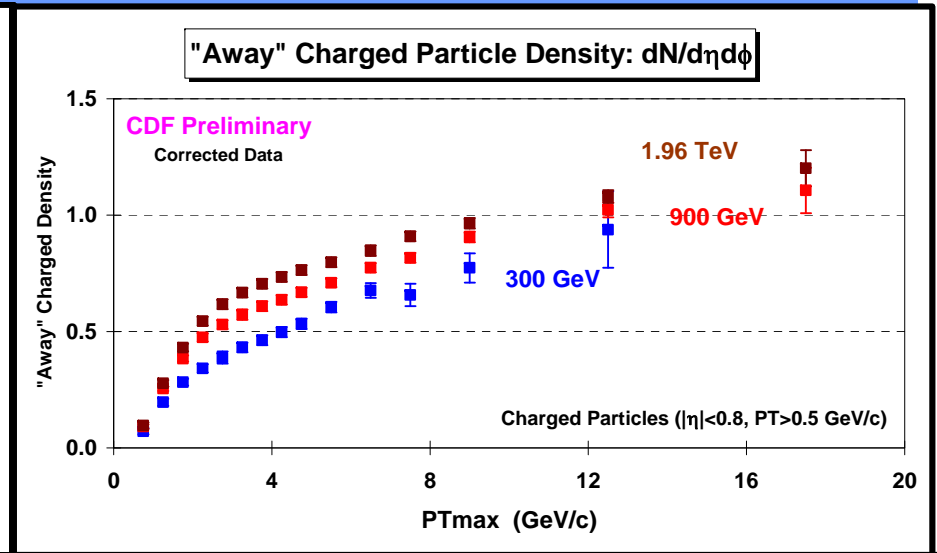
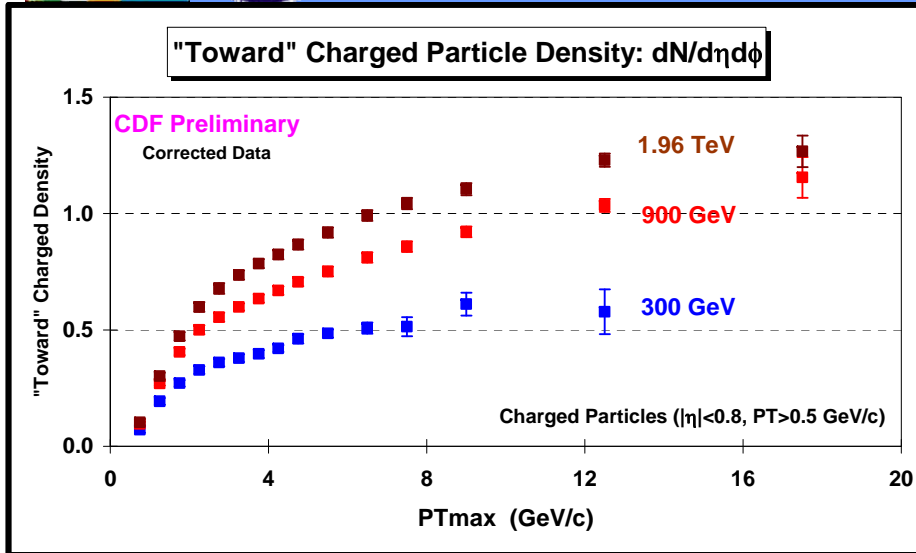


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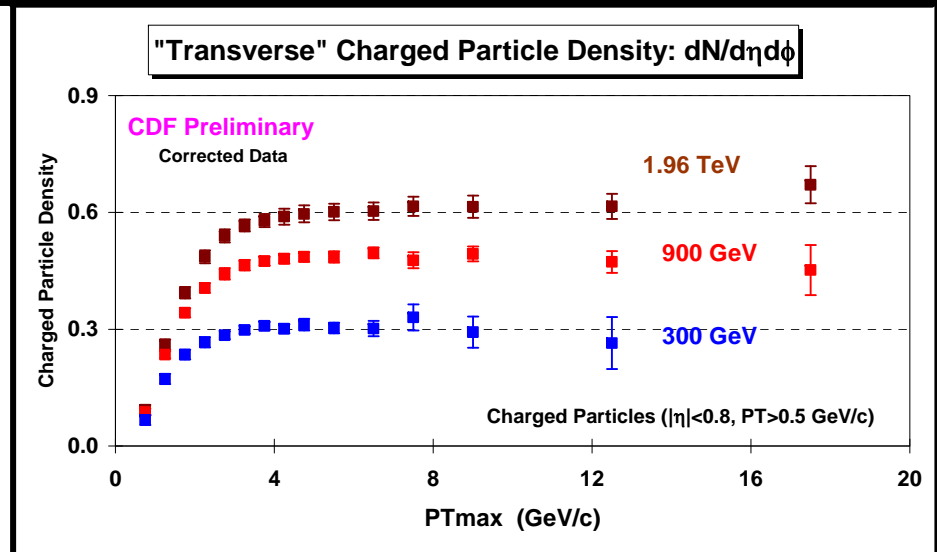




“Associated” Charged Particle Density

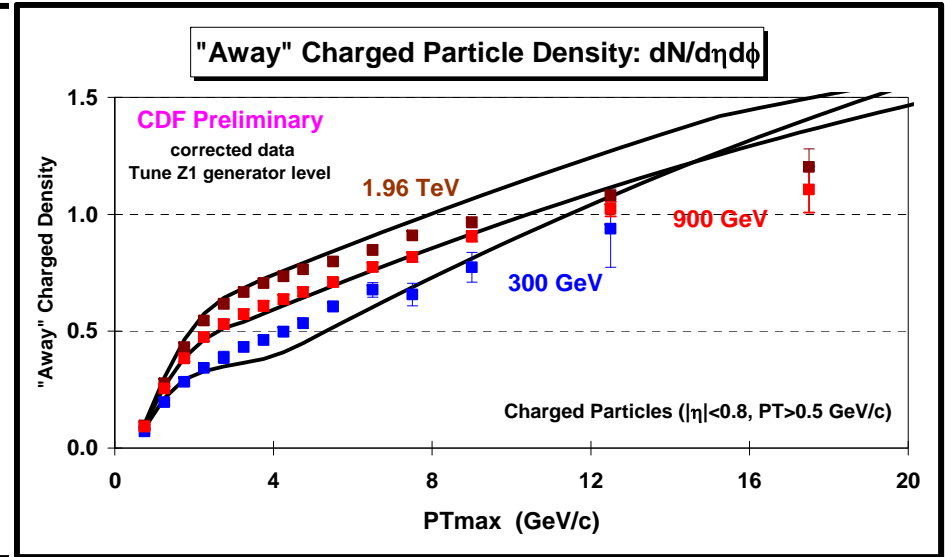
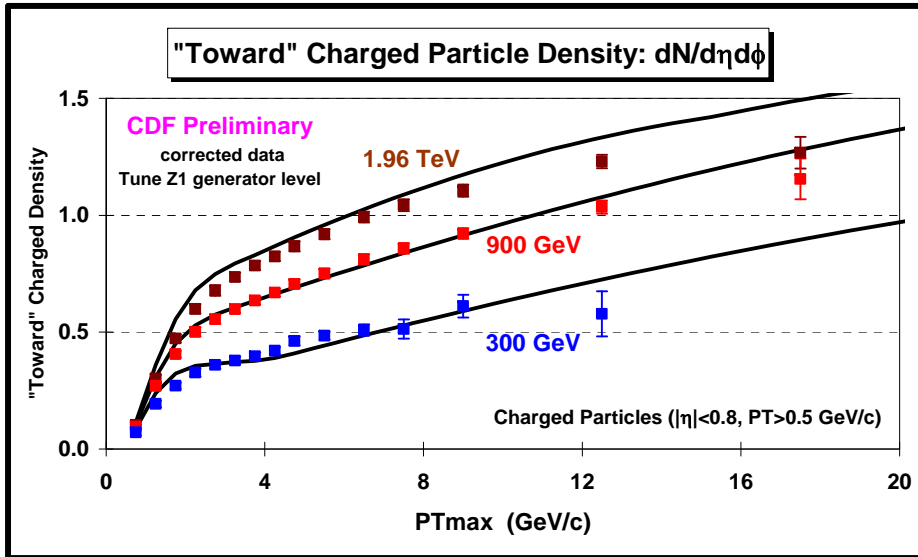


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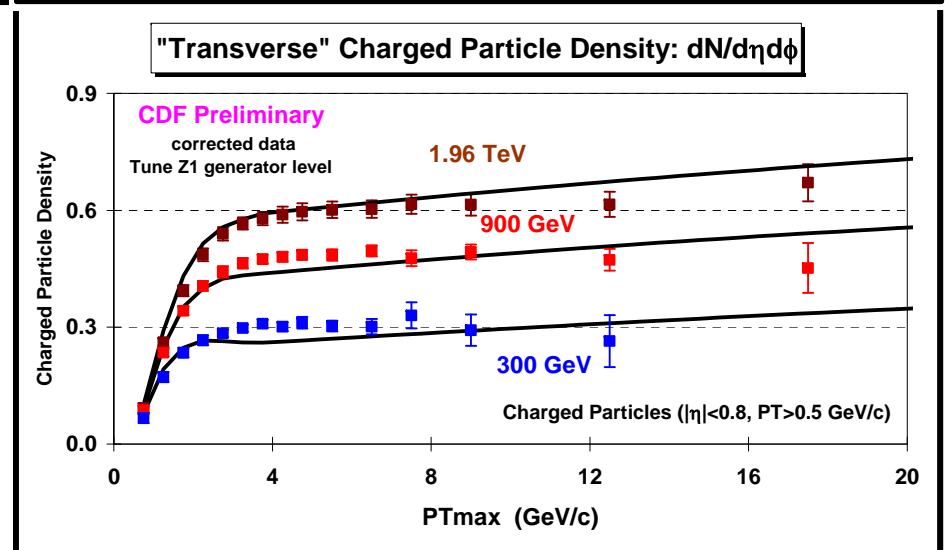




“Associated” Charged Particle Density

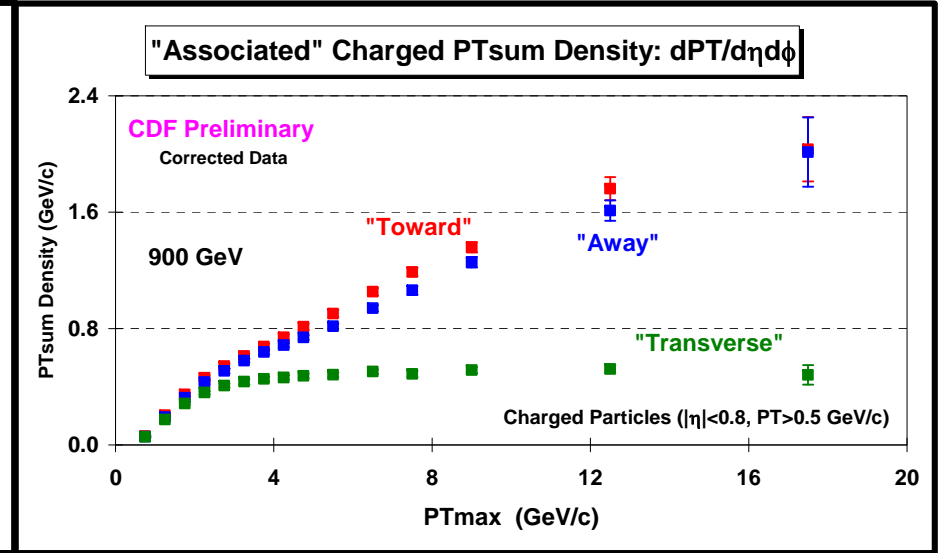
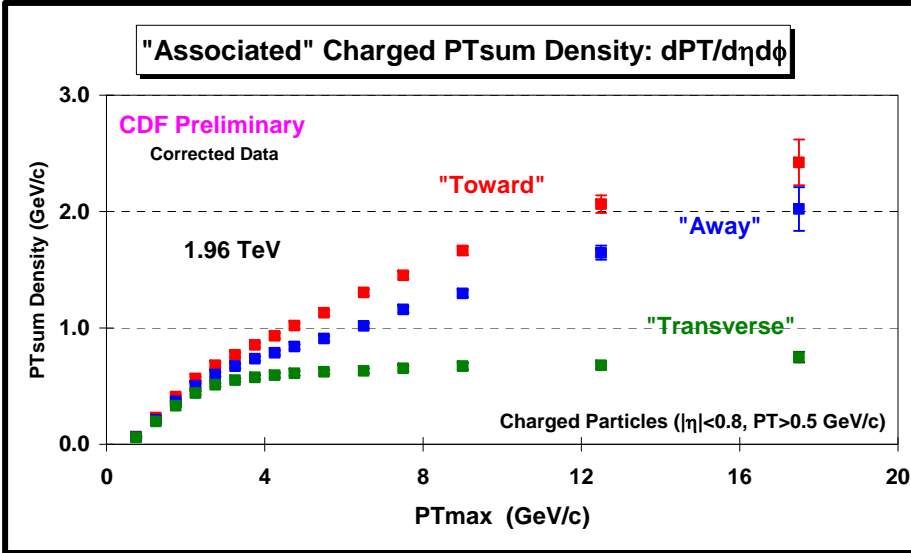


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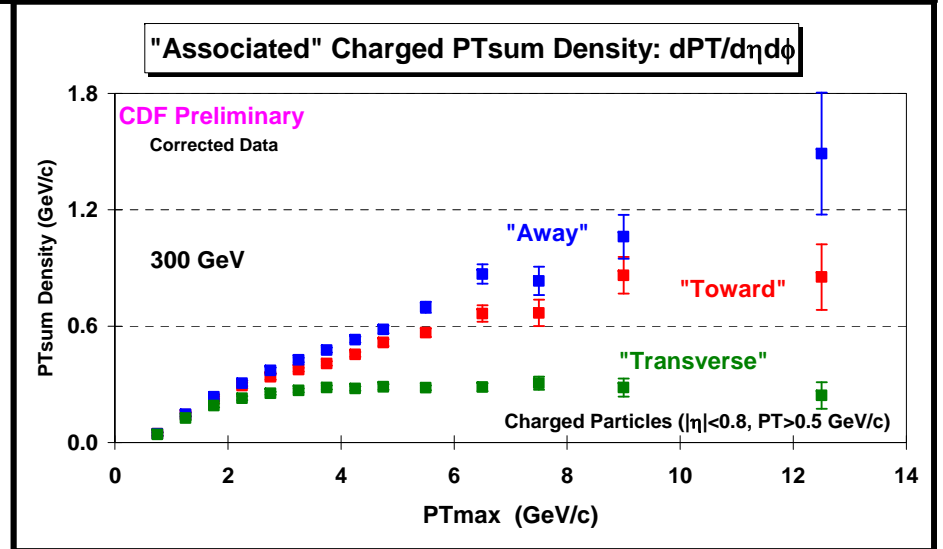


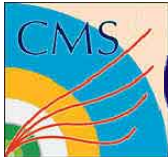


“Associated” Charged PTsum Density

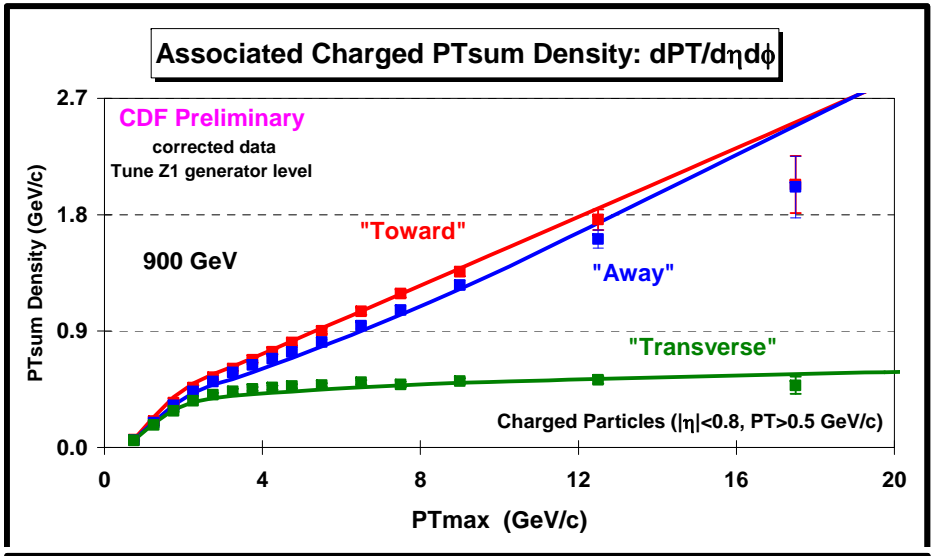
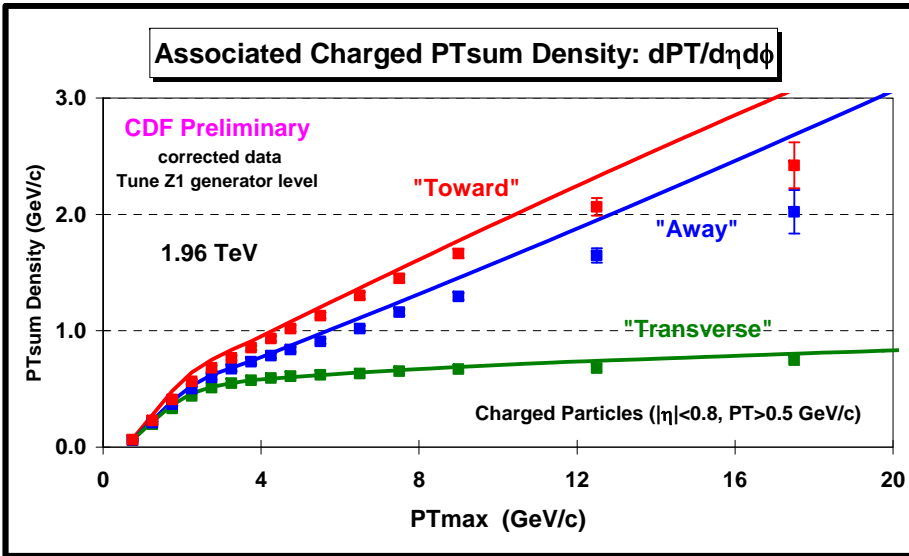


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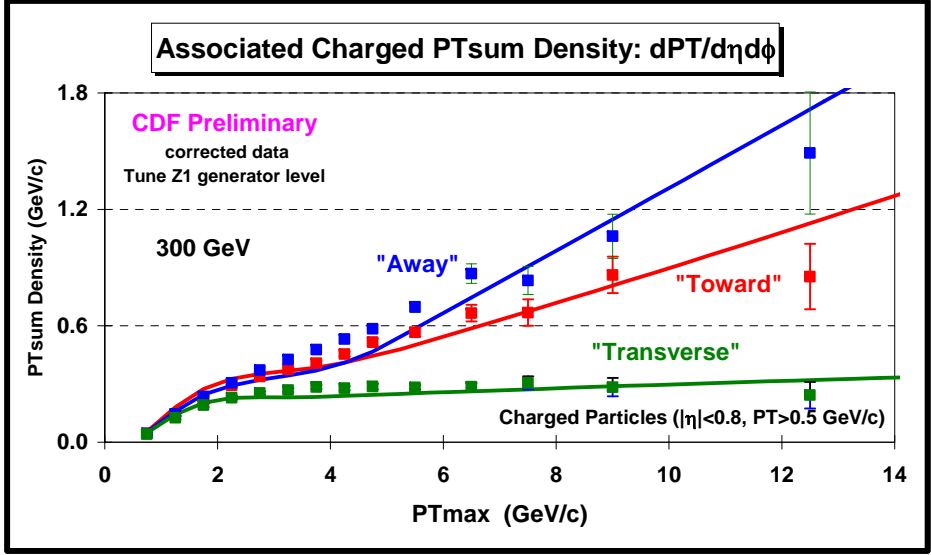




“Associated” Charged PTsum Density

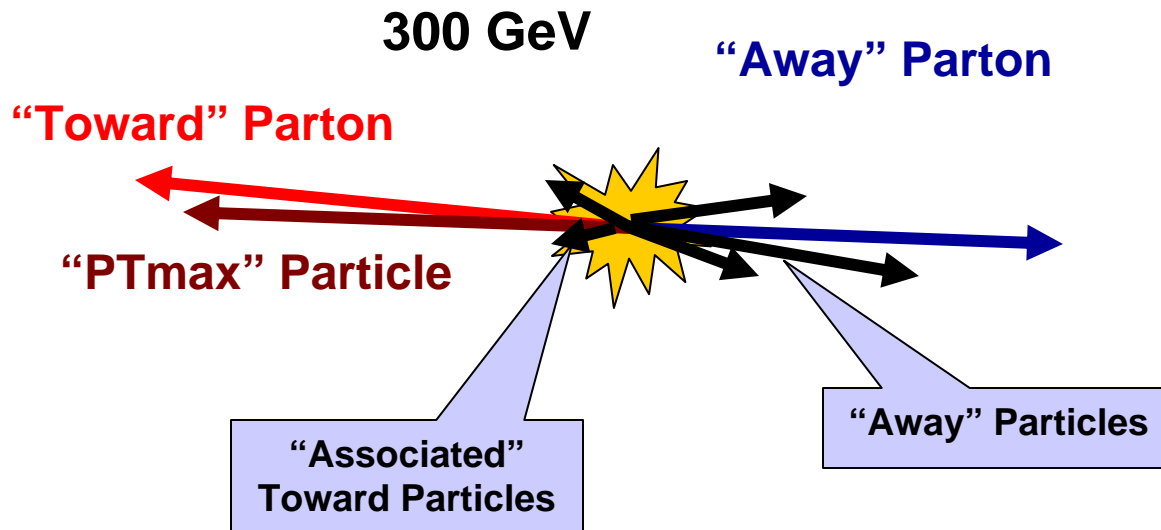


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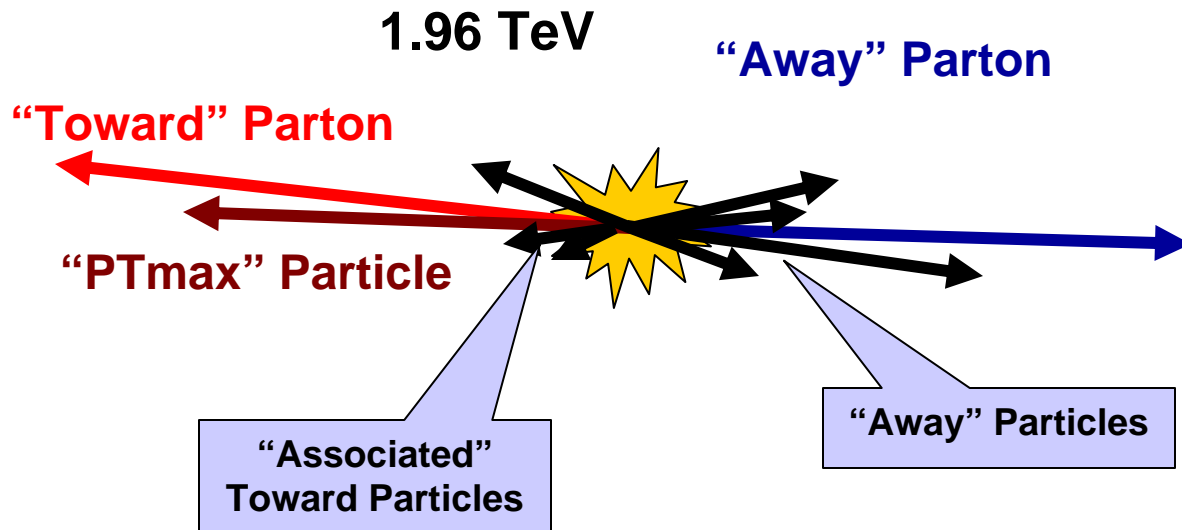
“Toward” Associated Density



- ➔ At low center-of-mass energies PTmax carries almost all the momentum of the “toward” parton (*i.e.* $z \approx 1$) leaving very little momentum for the other particles in the “jet”.



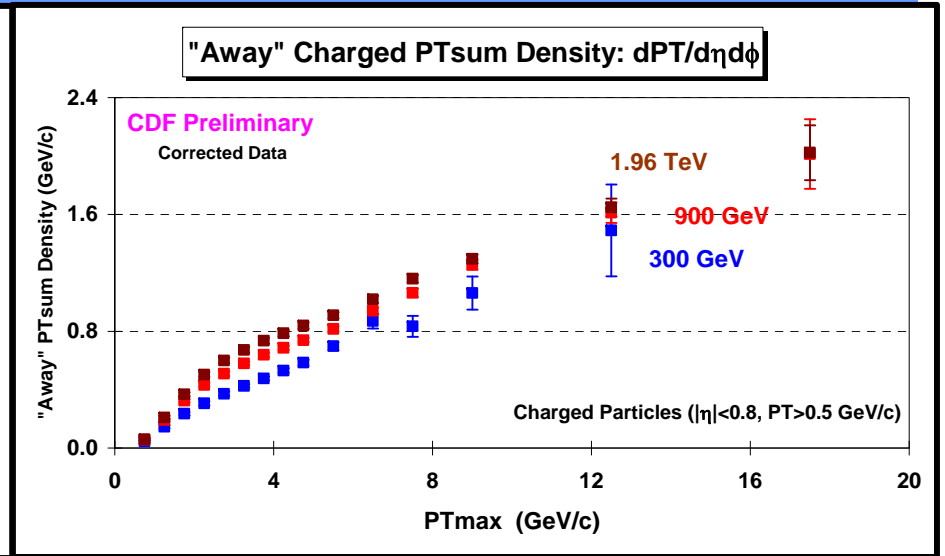
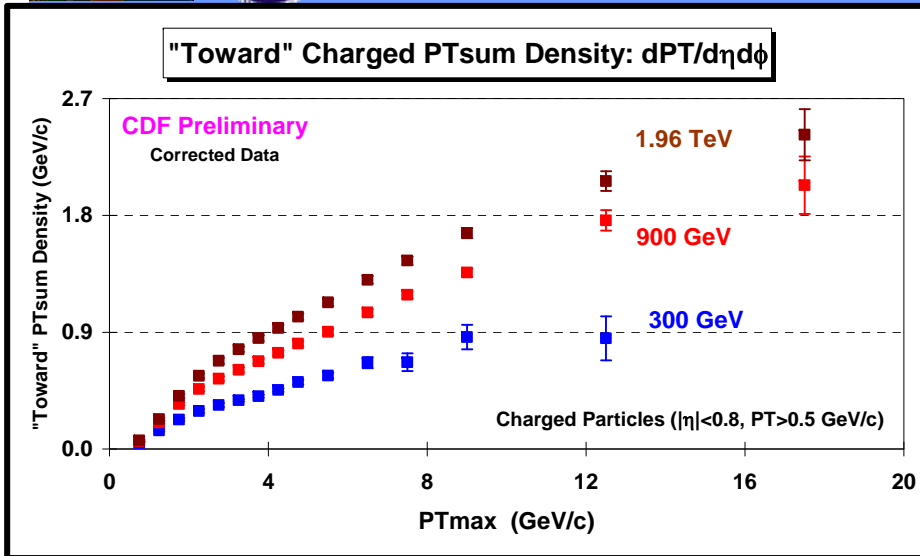
“Toward” Associated Density



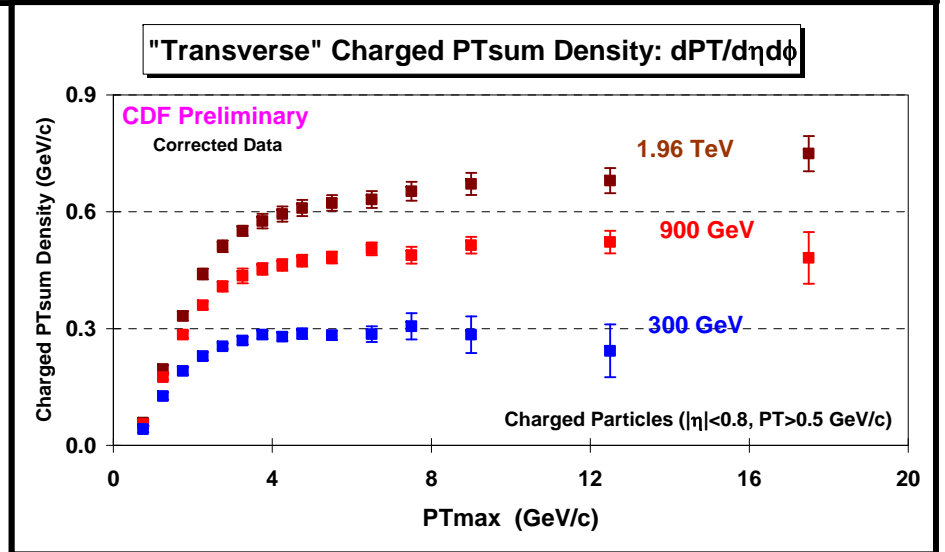
- ➔ At higher center-of-mass energies the same PT_{max} carries less of the momentum of the “toward” parton (*i.e.* $z < 1$) leaving more momentum for the other particles in the “jet”.



“Associated” Charged PTsum Density

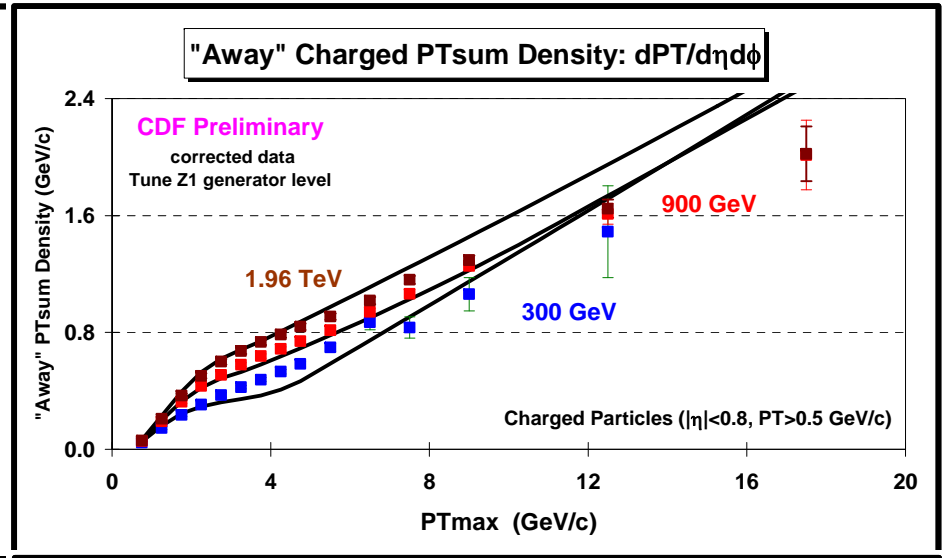
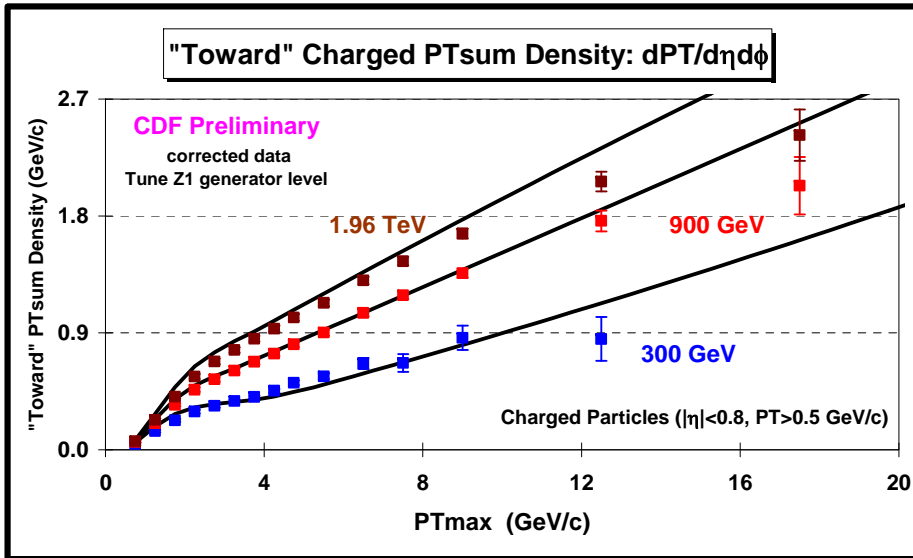


➔ **Corrected CDF data at 1.96 TeV, 900 GeV, and 300 GeV** on the “associated” charged PTsum density in the “**toward**”, “**away**”, and “**transverse**” regions as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5 \text{ GeV}/c$ and $|\eta| < 0.8$. The data are corrected to the particle level with errors that include both the statistical error and the systematic uncertainty.





“Associated” Charged PTsum Density

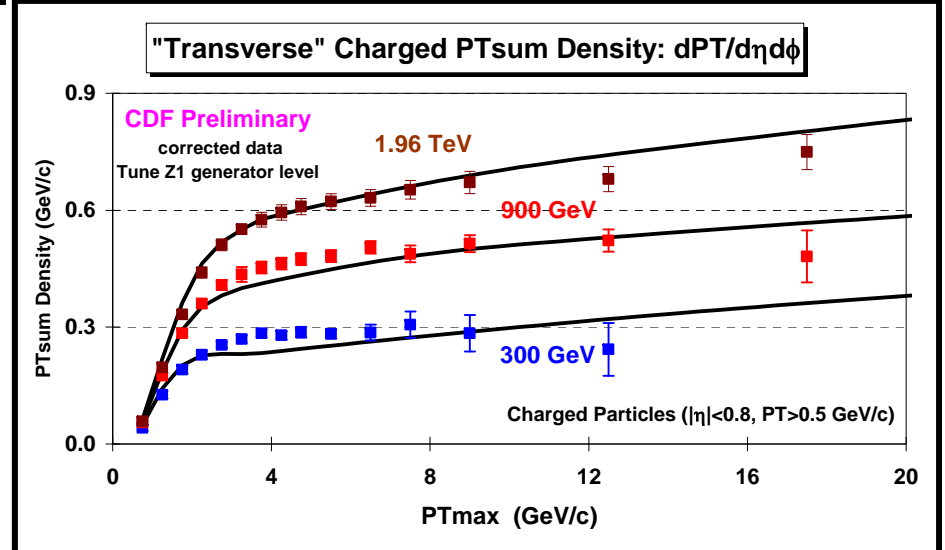


➔ **Corrected CDF data at 1.96 TeV, 900 GeV, and 300 GeV** on the “associated” charged PTsum density in the “**toward**”, “**away**”, and “**transverse**” regions as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$. The data are corrected to the particle level with errors that include both the statistical error and the systematic uncertainty.

The data are compared with PYTHIA

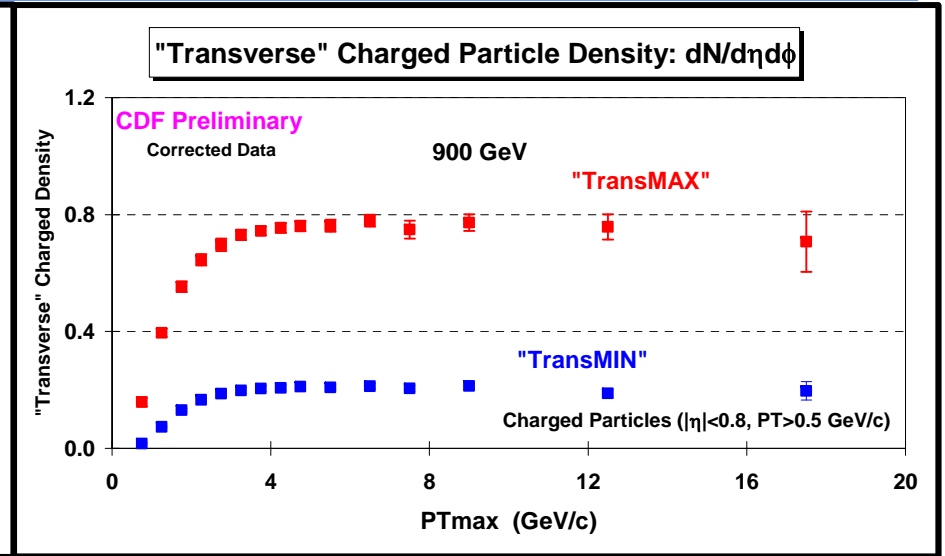
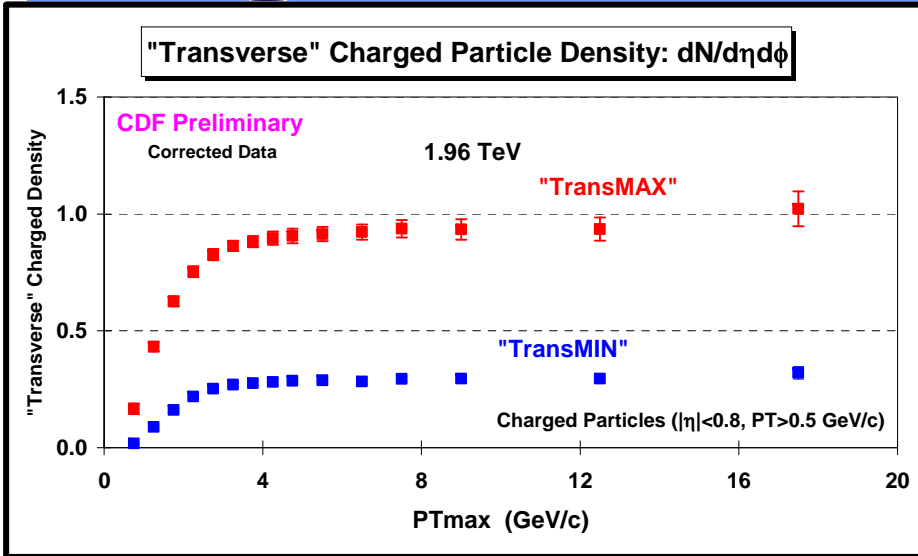
Tune Z1.

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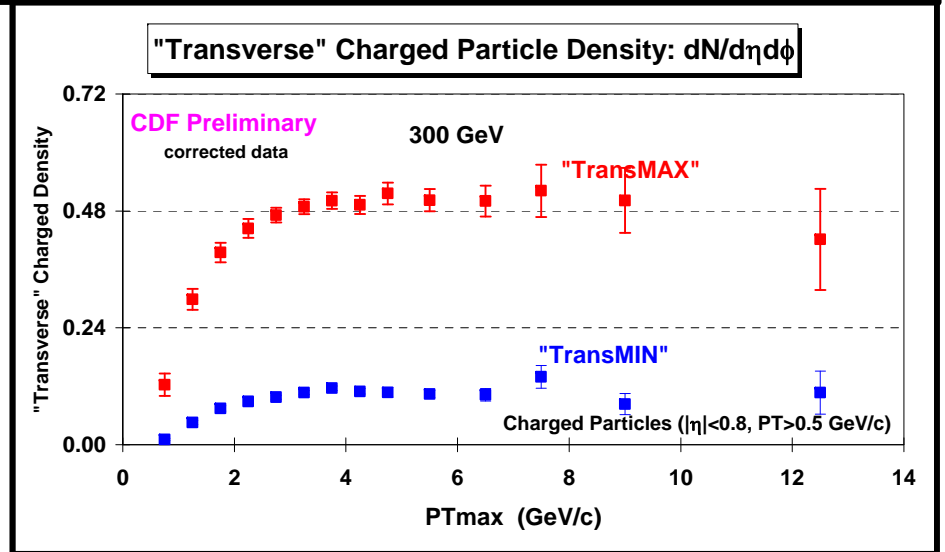


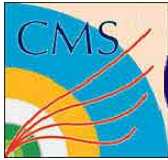


“transMAX/MIN” NchgDen

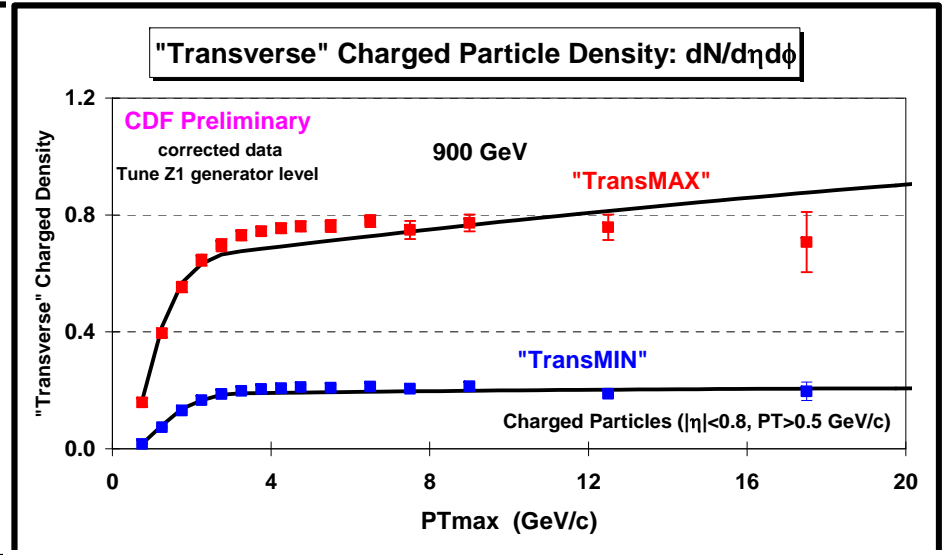
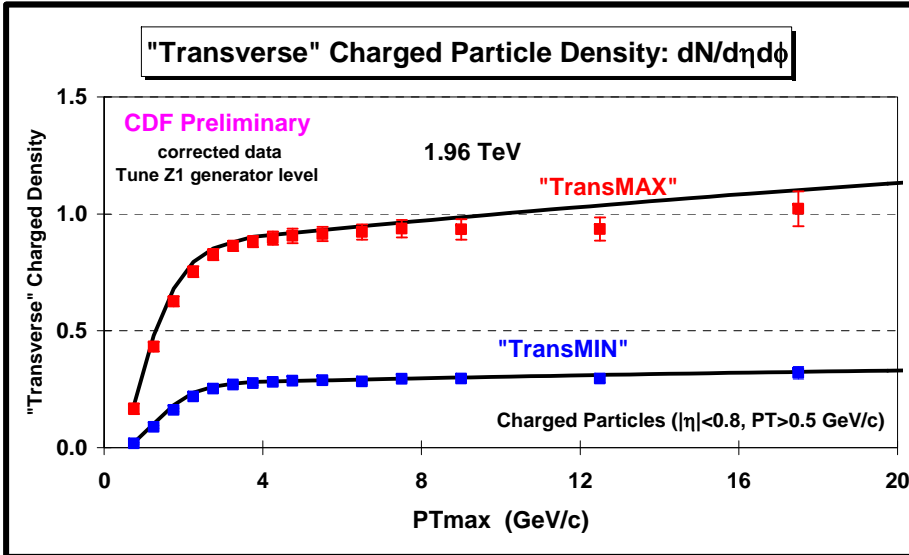


➔ **Corrected CDF data at 1.96 TeV, 900 GeV, and 300 GeV** on the charged particle density in the “**transMAX**” and “**transMIN**” regions as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$. The data are corrected to the particle level with errors that include both the statistical error and the systematic uncertainty.





"transMAX/MIN" NchgDen

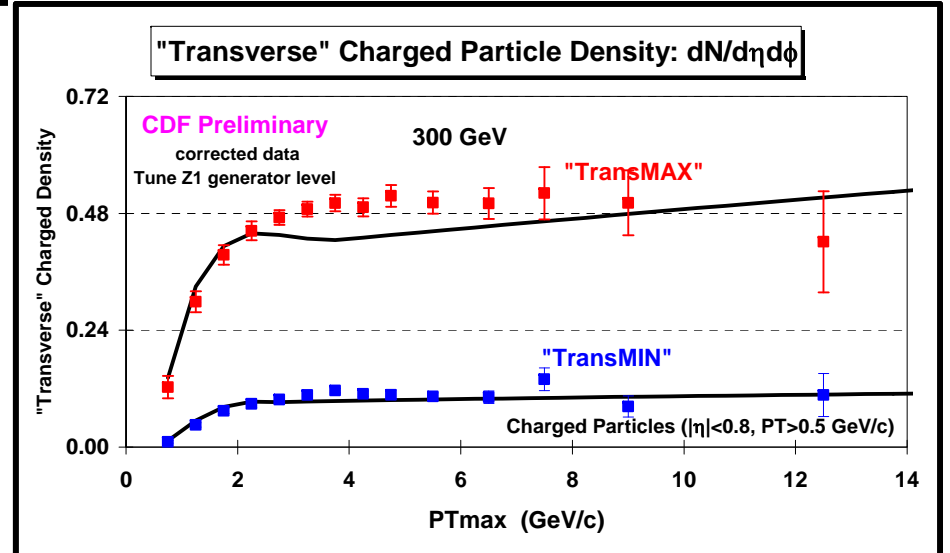


➔ **Corrected CDF data at 1.96 TeV, 900 GeV, and 300 GeV** on the charged particle density in the **"transMAX"** and **"transMIN"** regions as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$. The data are corrected to the particle level with errors that include both the statistical error and the systematic uncertainty.

The data are compared with PYTHIA

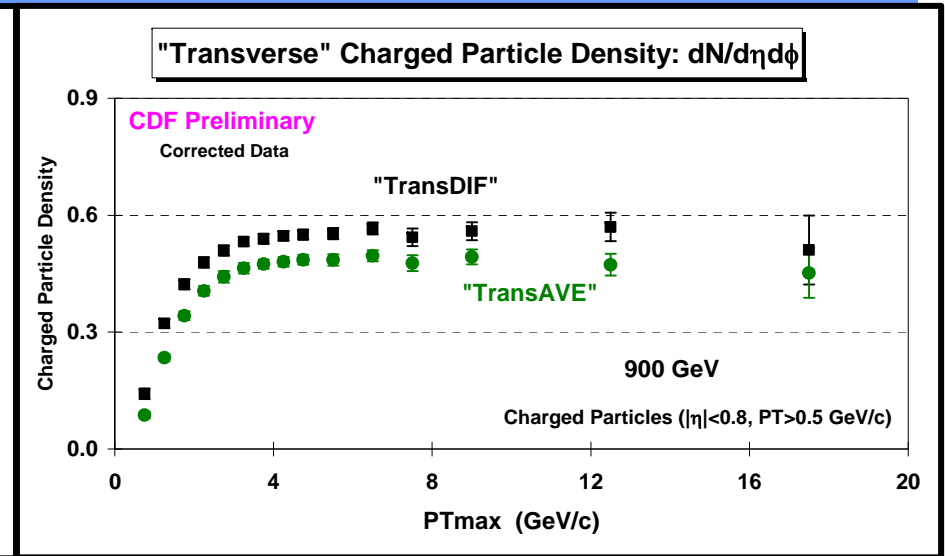
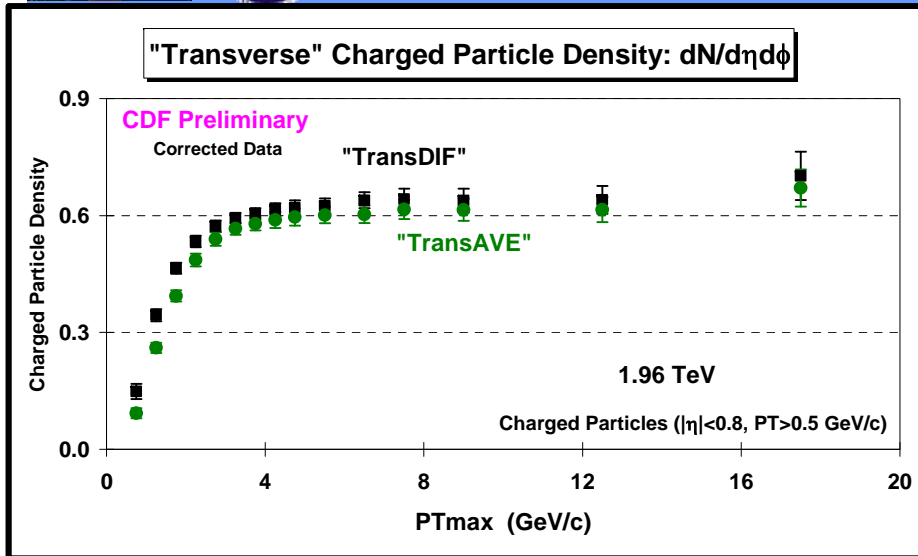
Tune Z1.

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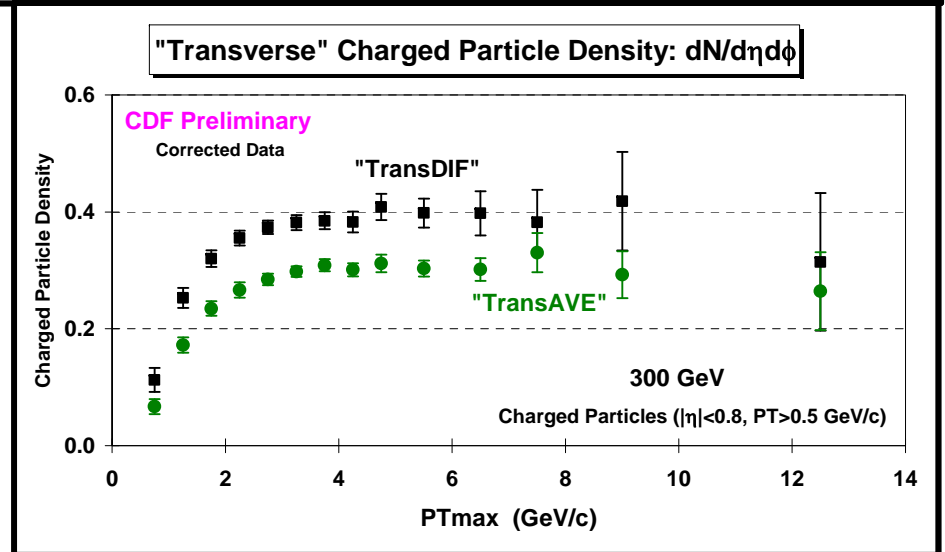


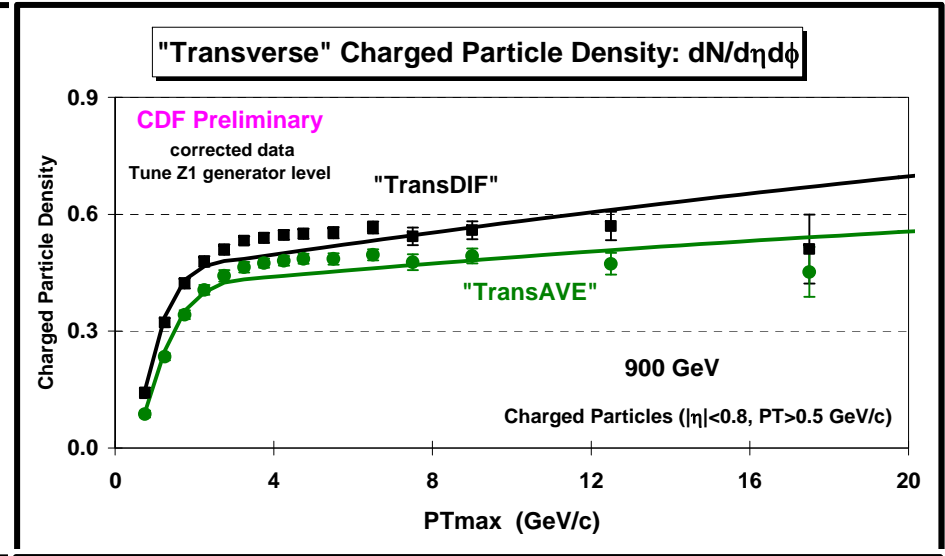
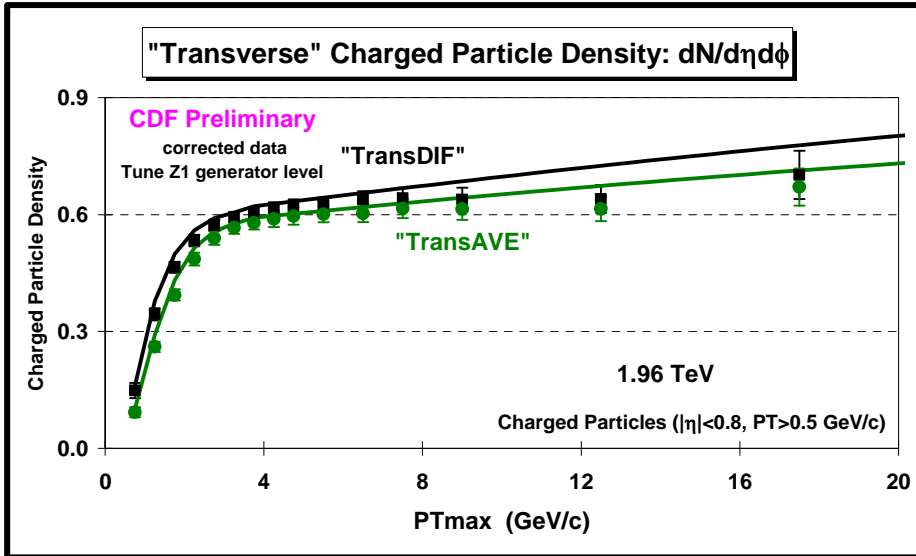


“transDIF/AVE” NchgDen

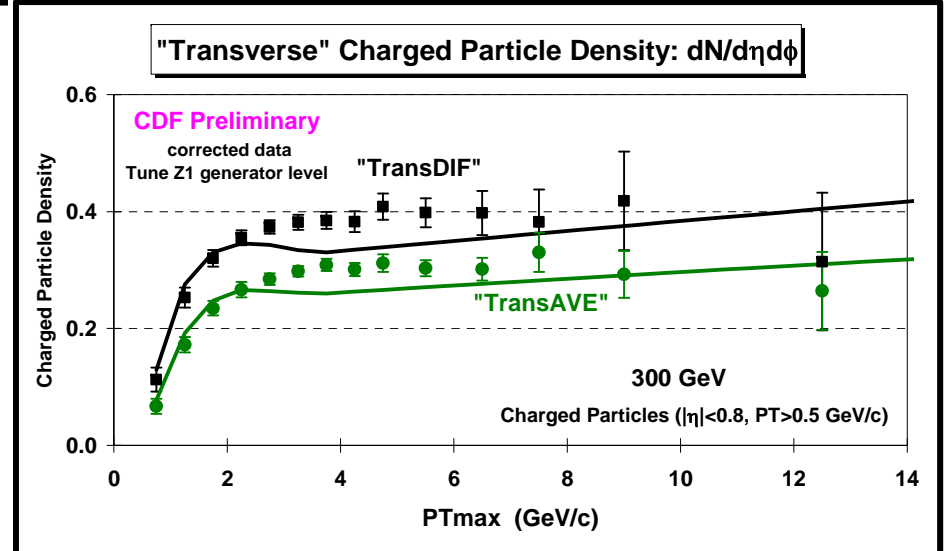


➔ **Corrected CDF data at 1.96 TeV, 900 GeV, and 300 GeV** on the charged particle density in the “transAVE” and “transDIF” regions as defined by the leading charged particle (P_{Tmax}) for charged particles with $p_T > 0.5 \text{ GeV}/c$ and $|\eta| < 0.8$. The data are corrected to the particle level with errors that include both the statistical error and the systematic uncertainty.



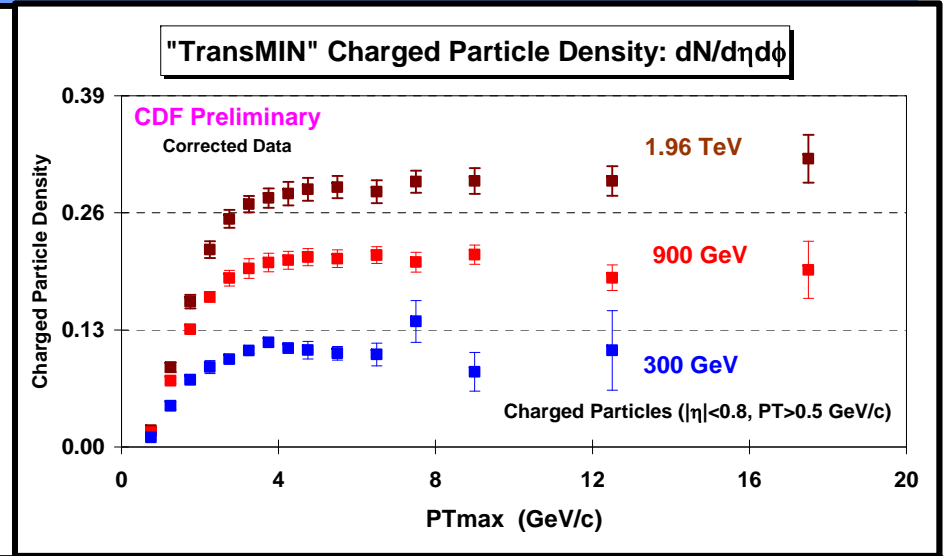
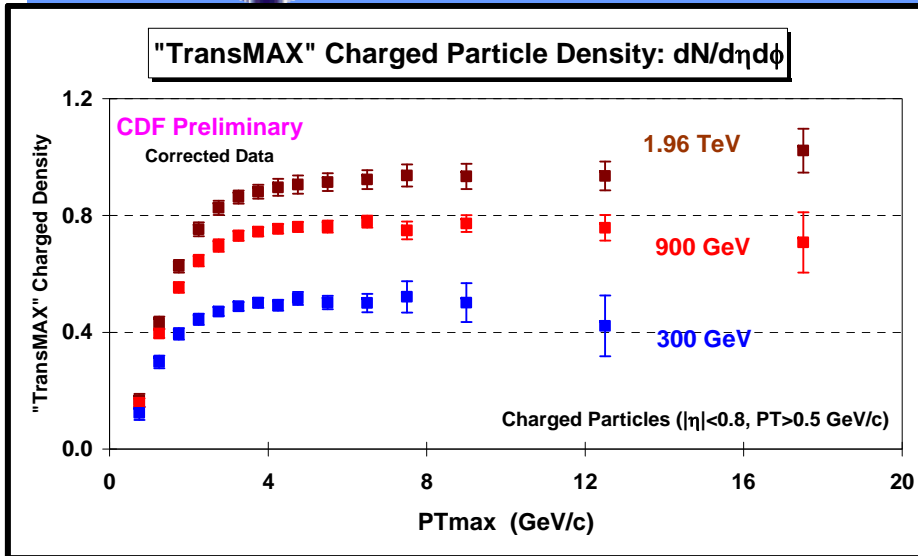


➔ **Corrected CDF data at 1.96 TeV, 900 GeV, and 300 GeV** on the charged particle density in the “transAVE” and “transDIF” regions as defined by the leading charged particle (PT_{max}) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$. The data are corrected to the particle level with errors that include both the statistical error and the systematic uncertainty. The data are compared with PYTHIA **Tune Z1**.

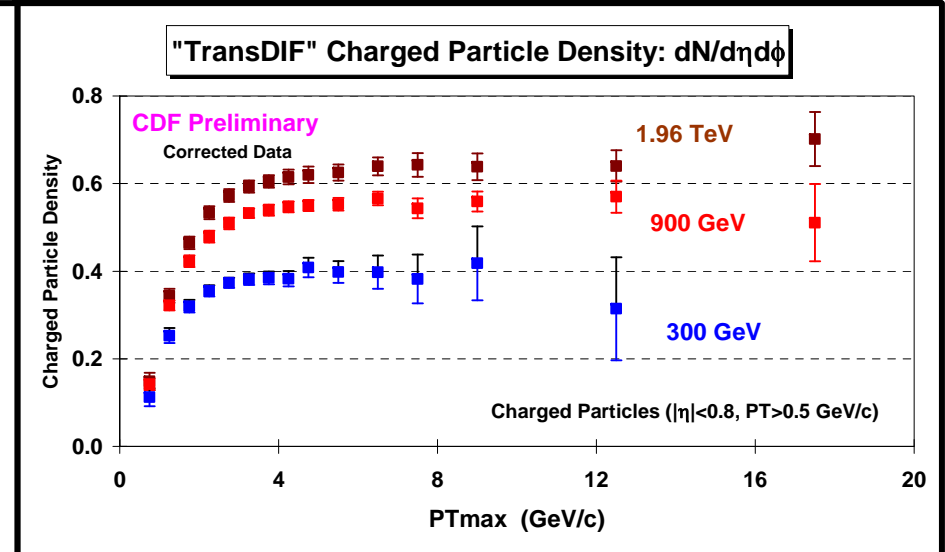


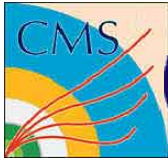


“transMAX/MIN” NchgDen

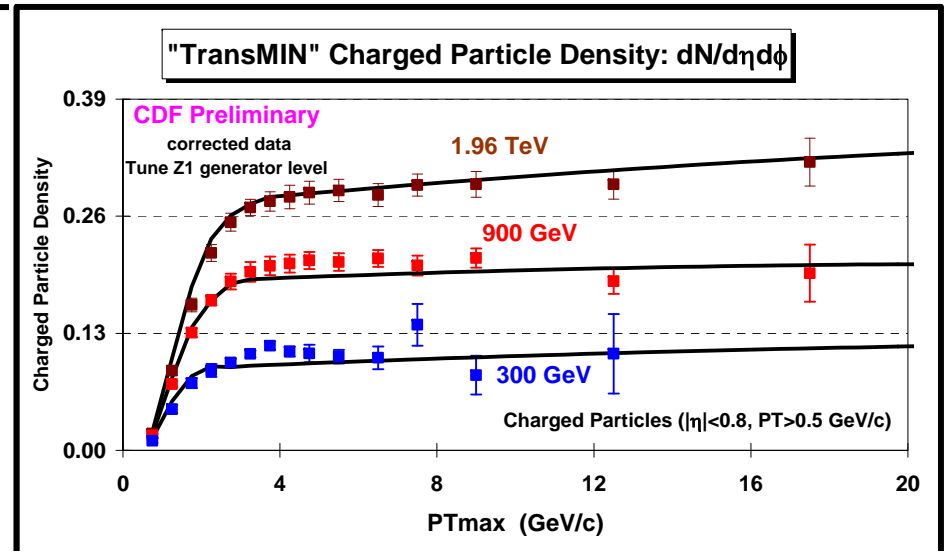
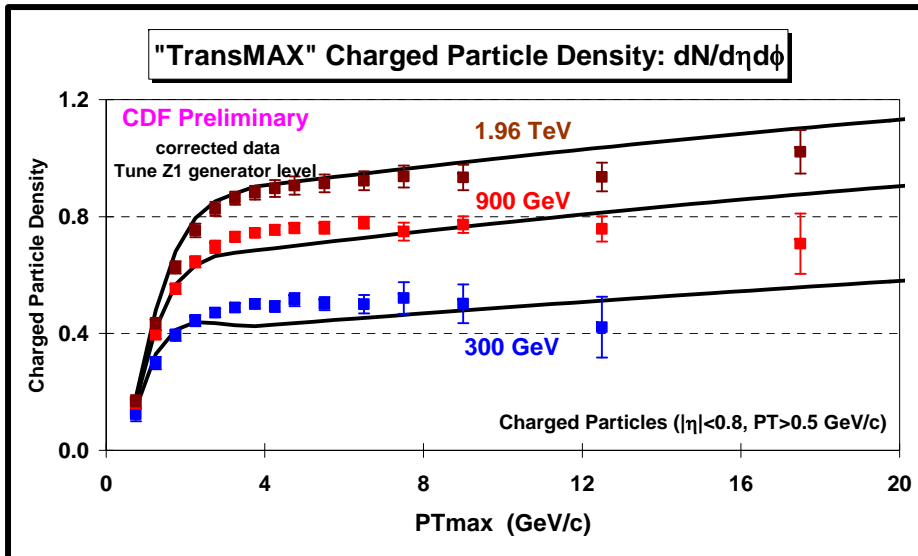


➔ **Corrected CDF data at 1.96 TeV, 900 GeV, and 300 GeV on the charged particle density in the “transMAX”, “transMIN”, and “transDIF” regions as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5 \text{ GeV}/c$ and $|\eta| < 0.8$. The data are corrected to the particle level with errors that include both the statistical error and the systematic uncertainty.**

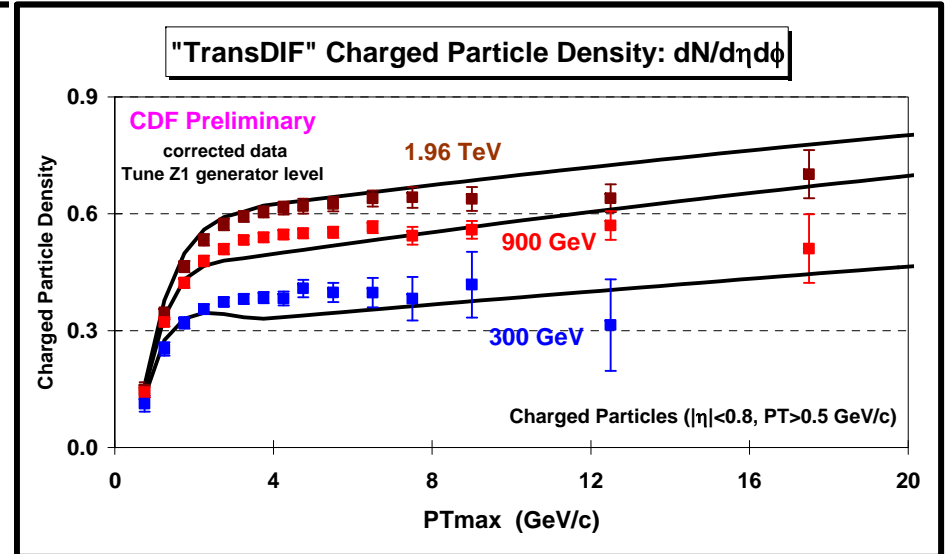




“transMAX/MIN” NchgDen

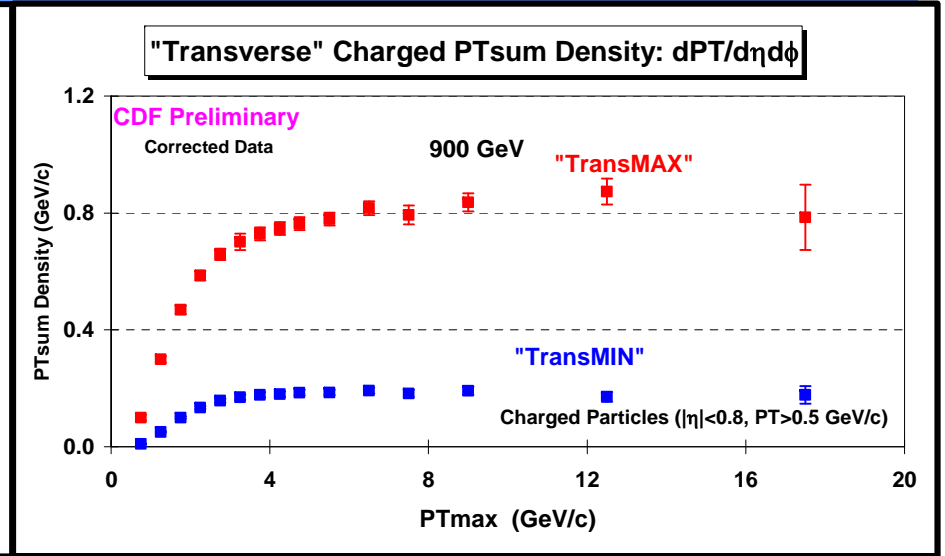
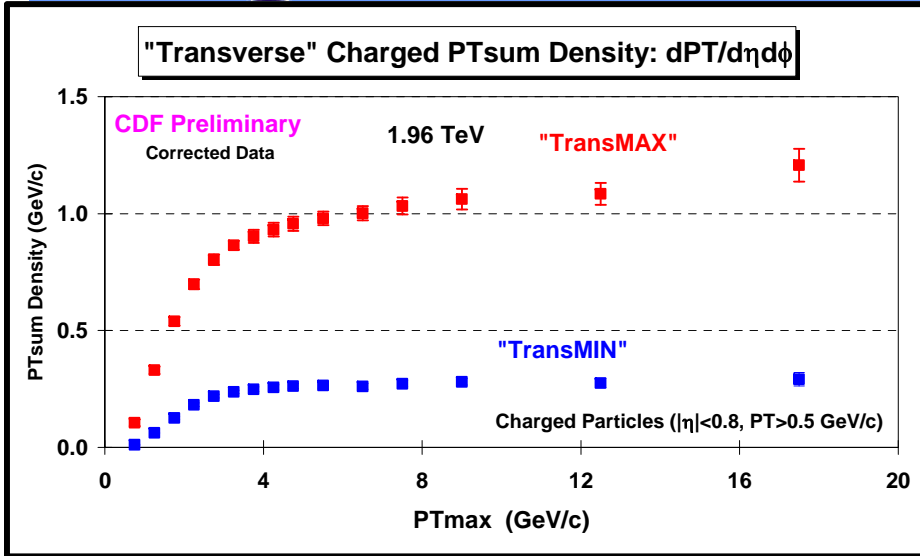


➔ **Corrected CDF data at 1.96 TeV, 900 GeV, and 300 GeV** on the charged particle density in the “**transMAX**”, “**transMIN**”, and “**transDIF**” regions as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5 \text{ GeV}/c$ and $|\eta| < 0.8$. The data are corrected to the particle level with errors that include both the statistical error and the systematic uncertainty. The data are compared with PYTHIA **Tune Z1**.

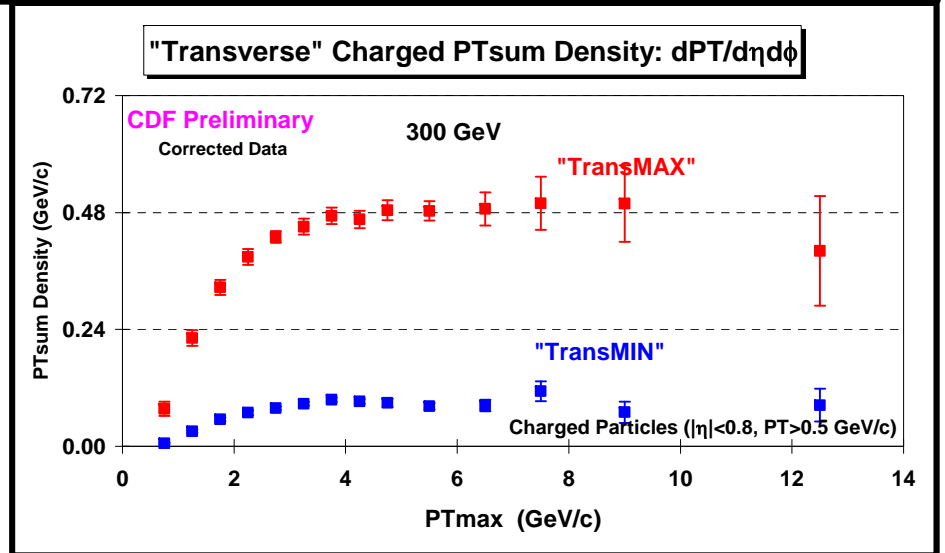


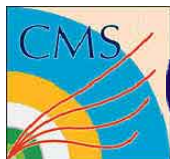


“transMAX/MIN” PTsumDen

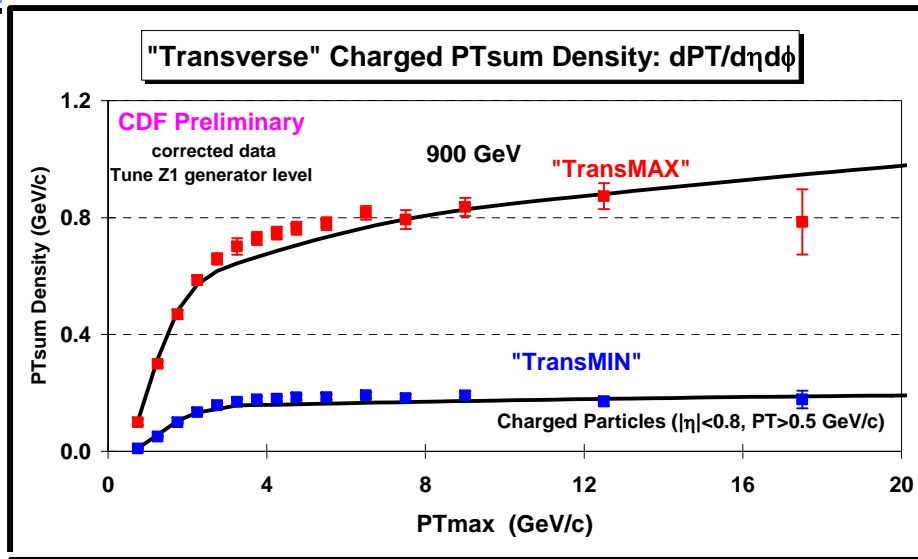
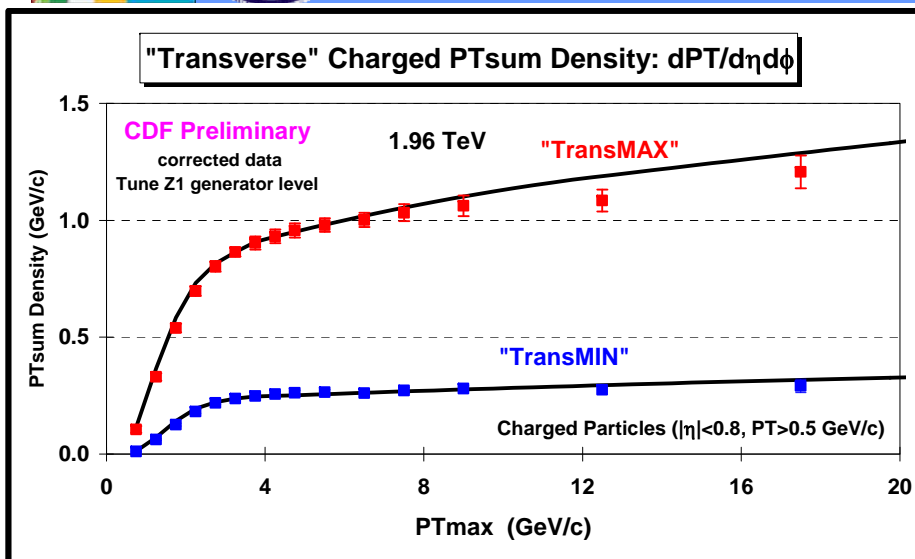


➔ **Corrected CDF data at 1.96 TeV, 900 GeV, and 300 GeV on the charged PTsum density in the “transMAX” and “transMIN” regions as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$. The data are corrected to the particle level with errors that include both the statistical error and the systematic uncertainty.**





“transMAX/MIN” PTsumDen

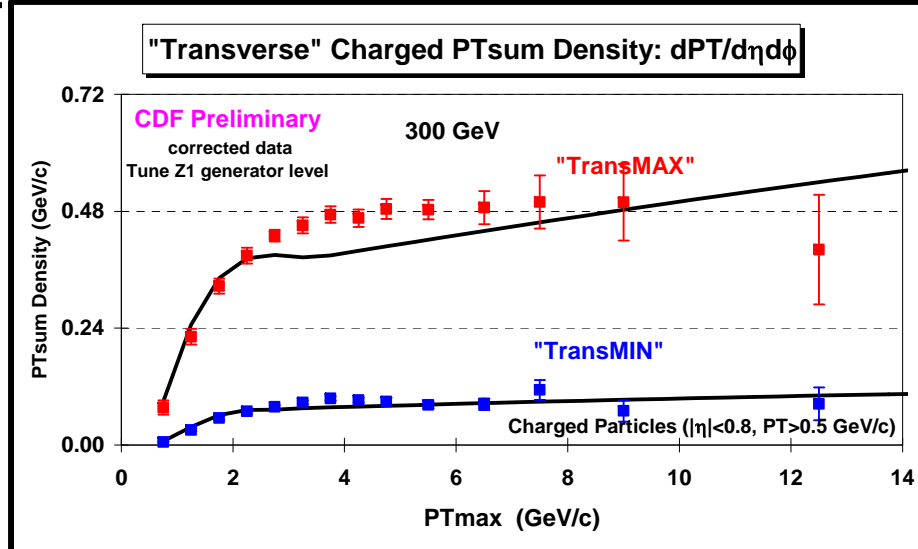


➔ **Corrected CDF data at 1.96 TeV, 900 GeV, and 300 GeV** on the charged PTsum density in the “transMAX” and “transMIN” regions as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$. The data are corrected to the particle level with errors that include both the statistical error and the systematic uncertainty.

The data are compared with PYTHIA

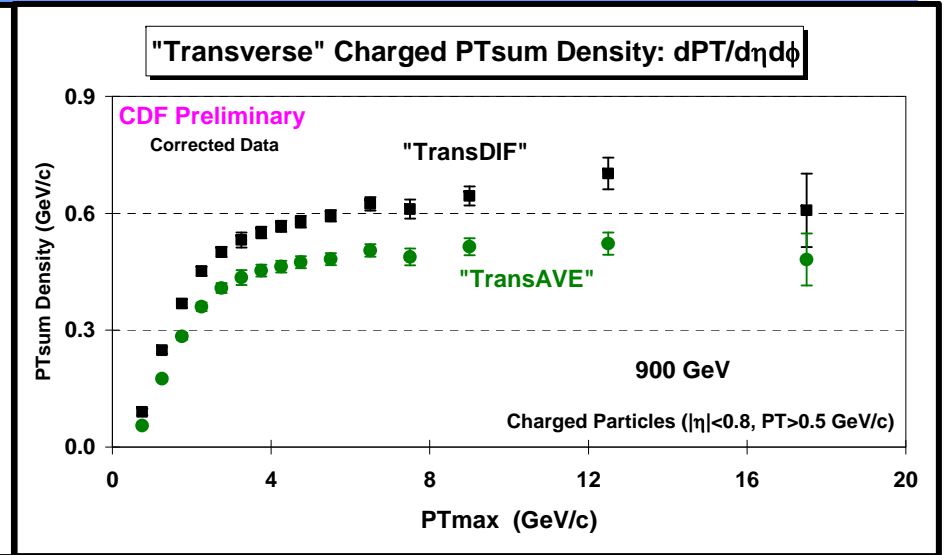
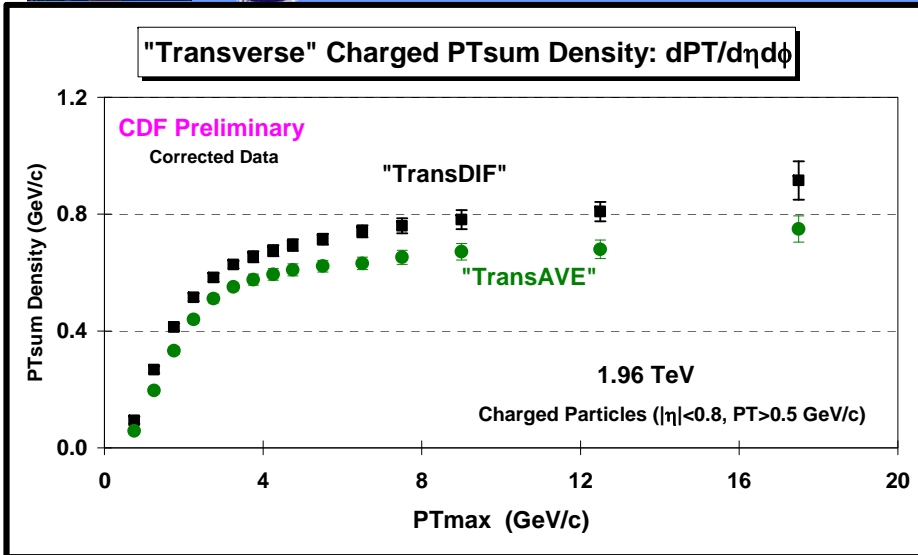
Tune Z1.

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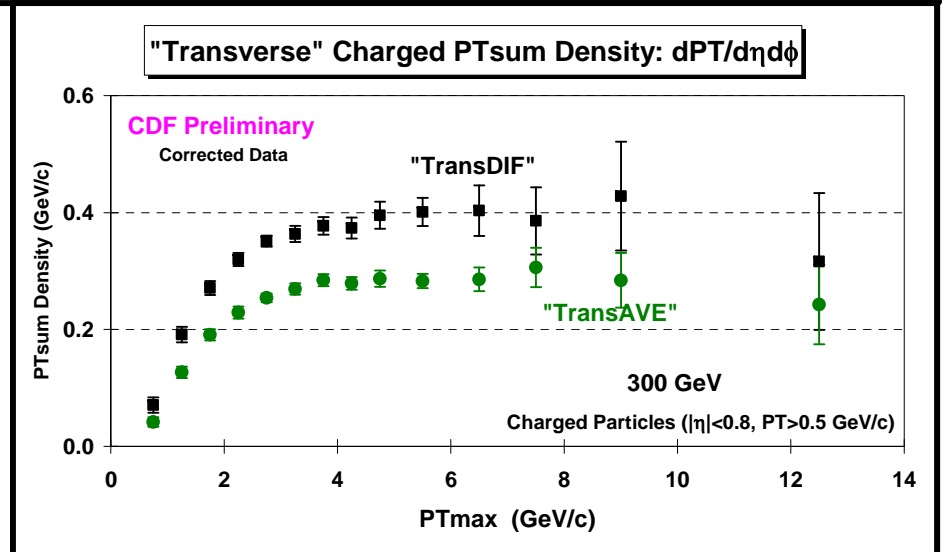


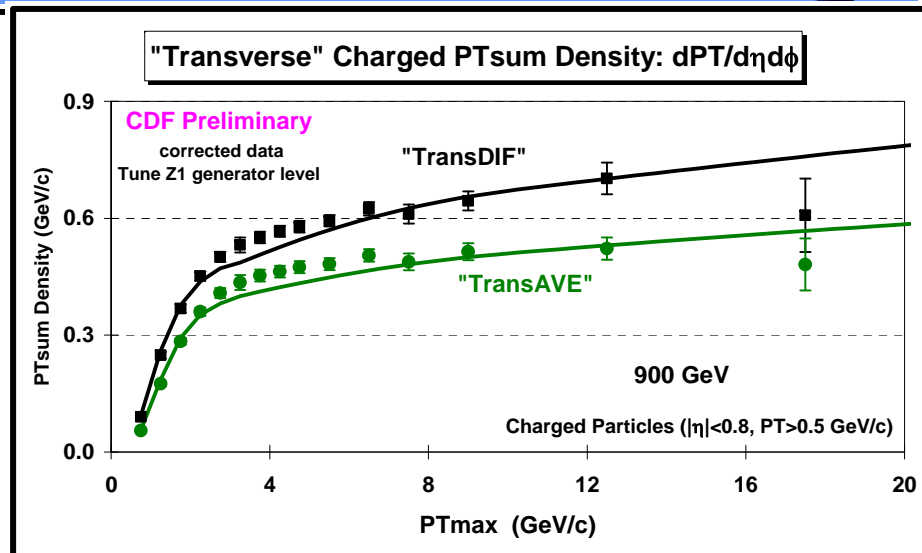
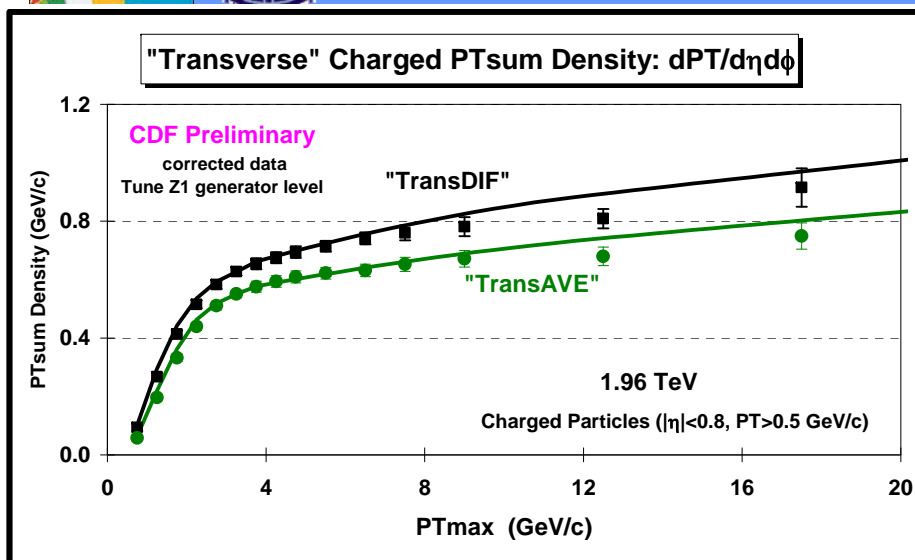


“transDIF/AVE” PTsumDen

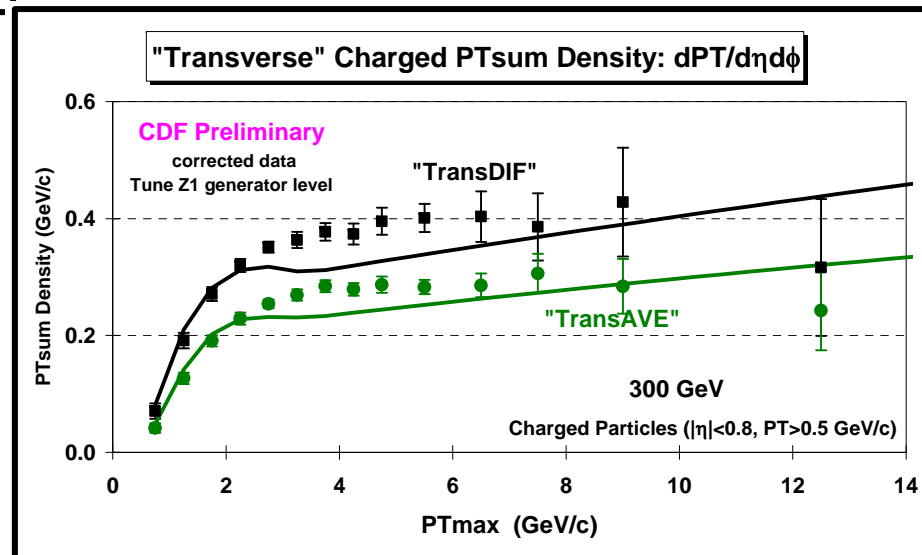


➔ **Corrected CDF data at 1.96 TeV, 900 GeV, and 300 GeV** on the charged PTsum density in the “transAVE” and “transDIF” regions as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$. The data are corrected to the particle level with errors that include both the statistical error and the systematic uncertainty.



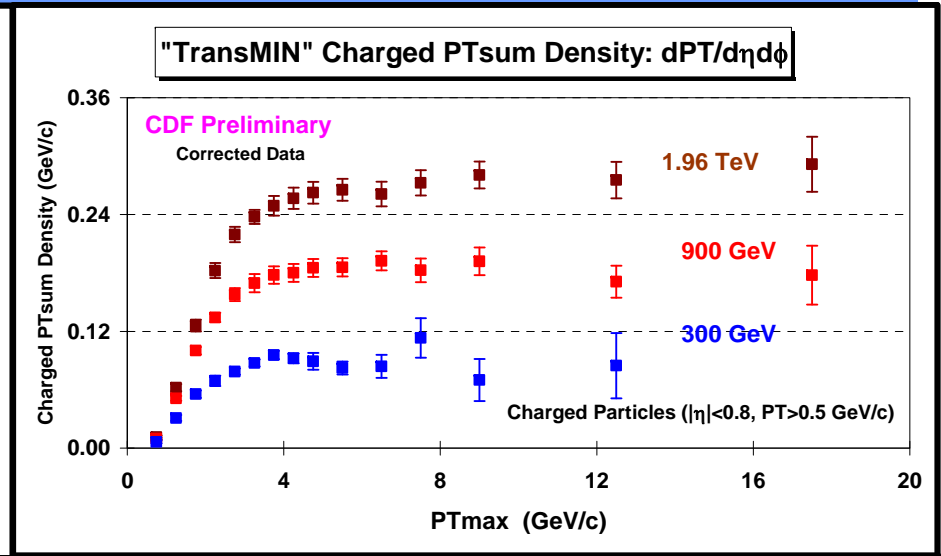
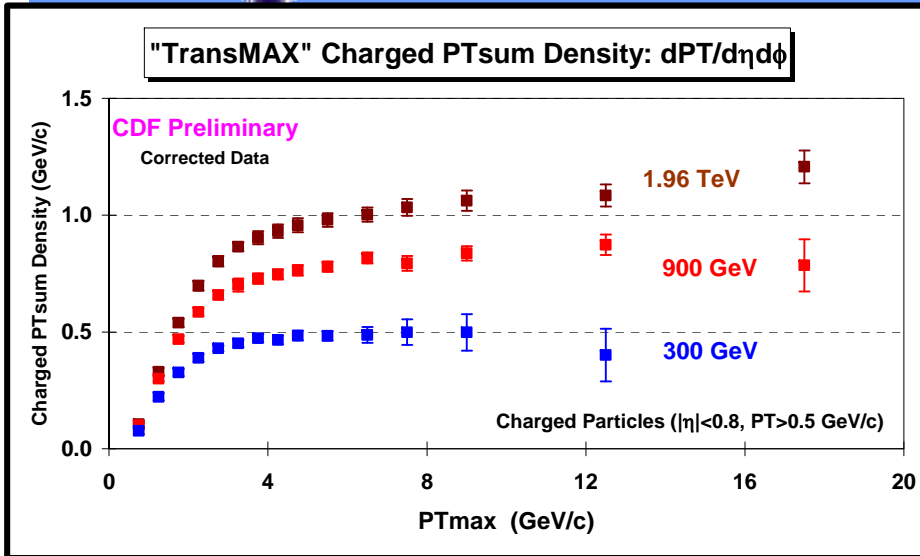


➔ **Corrected CDF data at 1.96 TeV, 900 GeV, and 300 GeV** on the charged PTsum density in the “transAVE” and “transDIF” regions as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$. The data are corrected to the particle level with errors that include both the statistical error and the systematic uncertainty. The data are compared with PYTHIA **Tune Z1**.

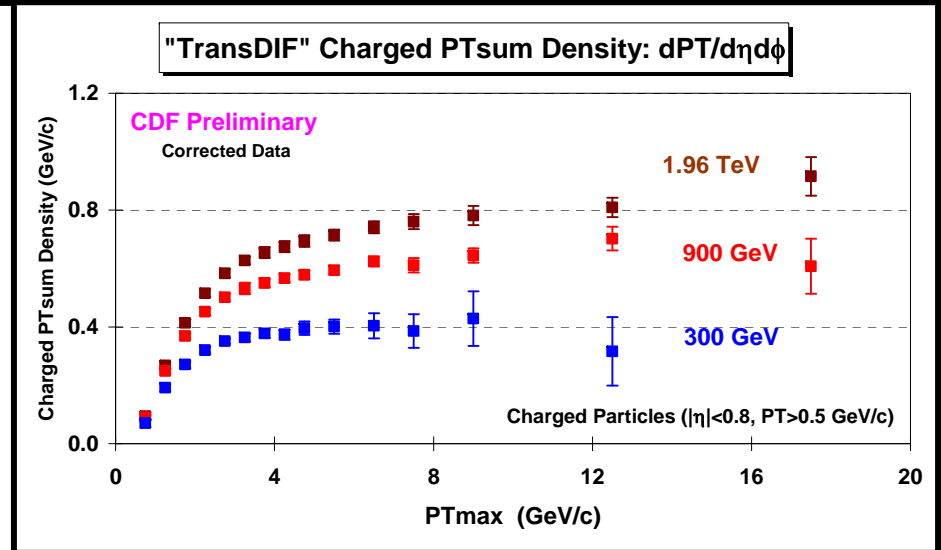


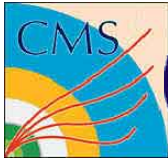


“transMAX/MIN” PTsumDen

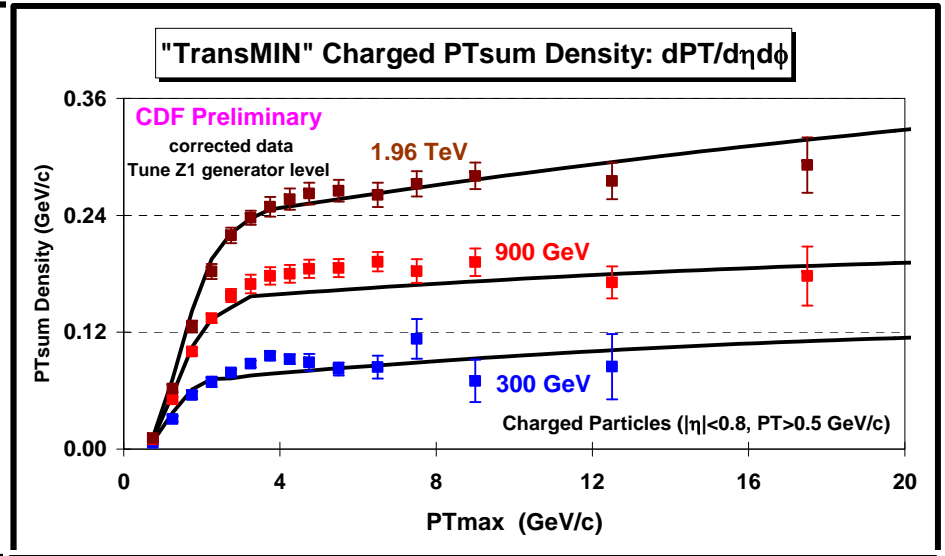
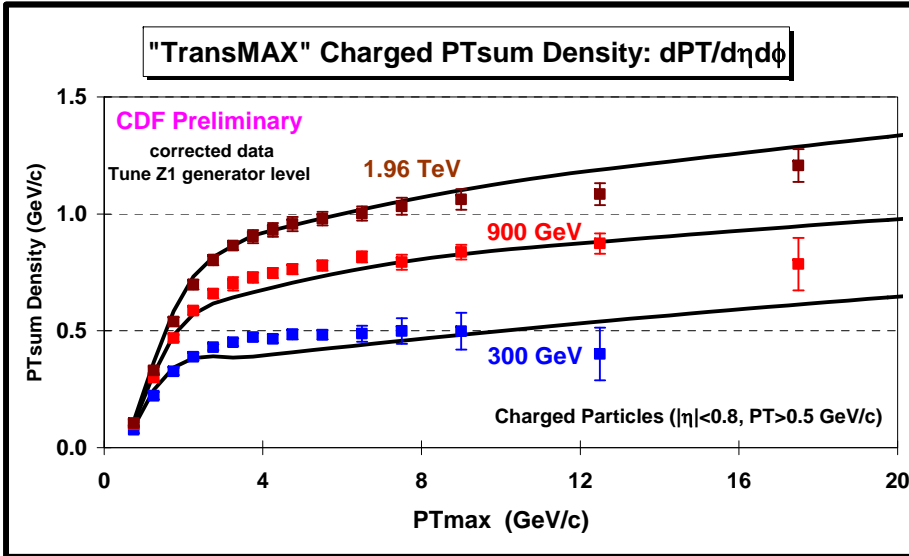


➔ **Corrected CDF data at 1.96 TeV, 900 GeV, and 300 GeV on the charged PTsum density in the “transMAX”, “transMIN”, and “transDIF” regions as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$. The data are corrected to the particle level with errors that include both the statistical error and the systematic uncertainty.**

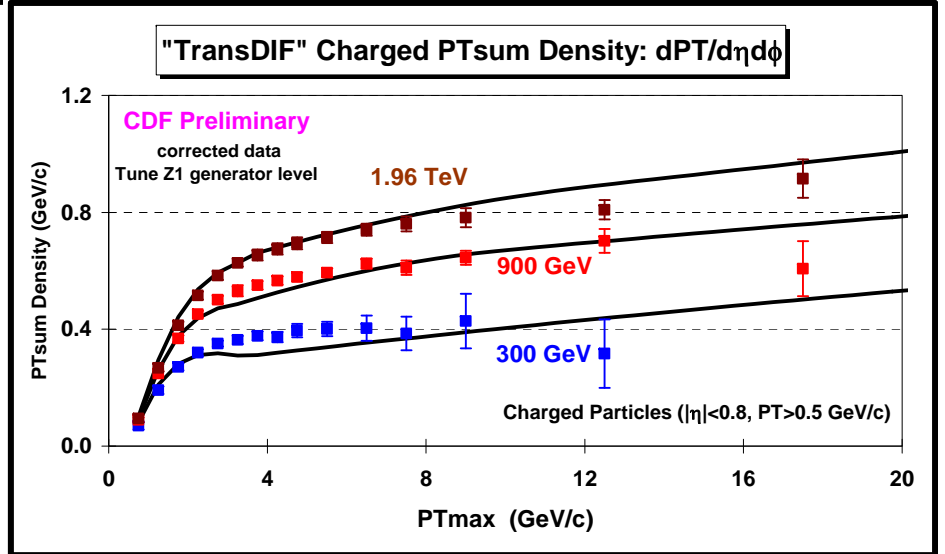




“transMAX/MIN” PTsumDen

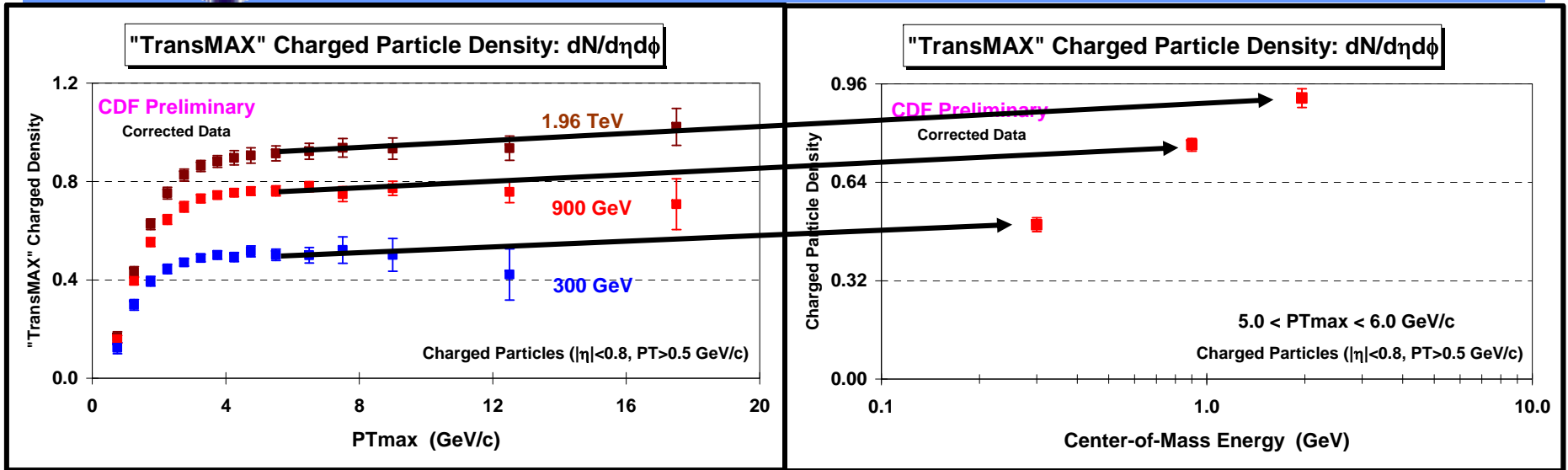


➔ **Corrected CDF data at 1.96 TeV, 900 GeV, and 300 GeV** on the charged PTsum density in the “transMAX”, “transMIN”, and “transDIF” regions as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$. The data are corrected to the particle level with errors that include both the statistical error and the systematic uncertainty. The data are compared with PYTHIA **Tune Z1**.





“transMAX” NchgDen vs E_{cm}

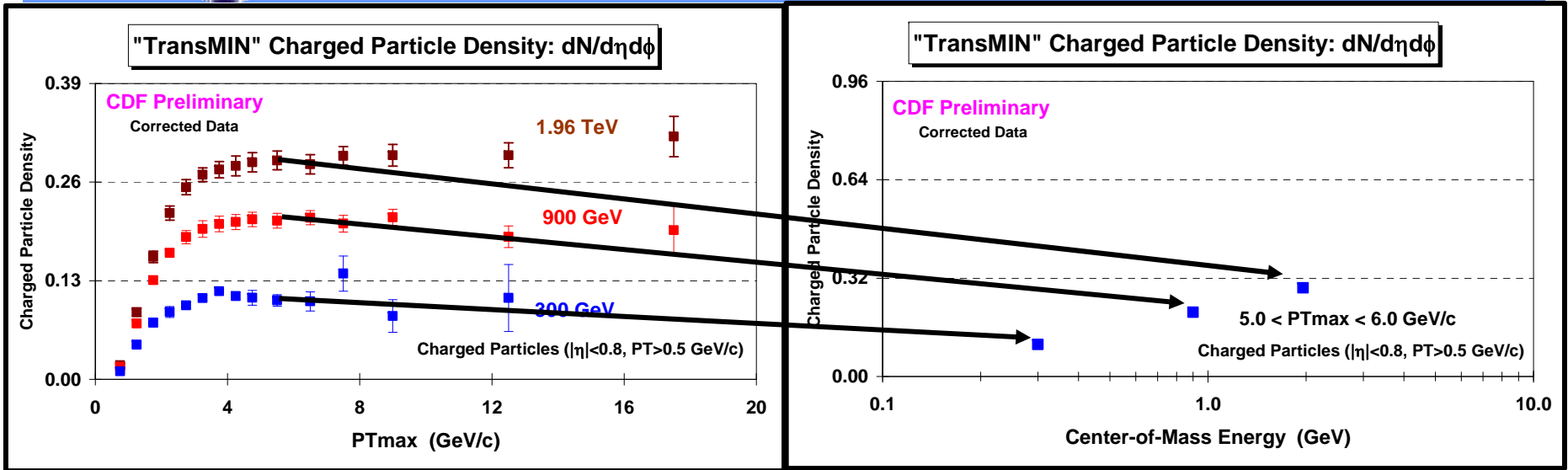


➔ **Corrected CDF data at 1.96 TeV, 900 GeV, and 300 GeV** on the charged particle density in the “transMAX” region as defined by the leading charged particle (PT_{max}) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$. The data are corrected to the particle level with errors that include both the statistical error and the systematic uncertainty.

➔ **Corrected CDF data on the charged particle density in the “transMAX” region** as defined by the leading charged particle (PT_{max}) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$ with $5 < PT_{max} < 6$ GeV/c. The data are plotted versus the center-of-mass energy (*log scale*).



“transMIN” NchgDen vs E_{cm}

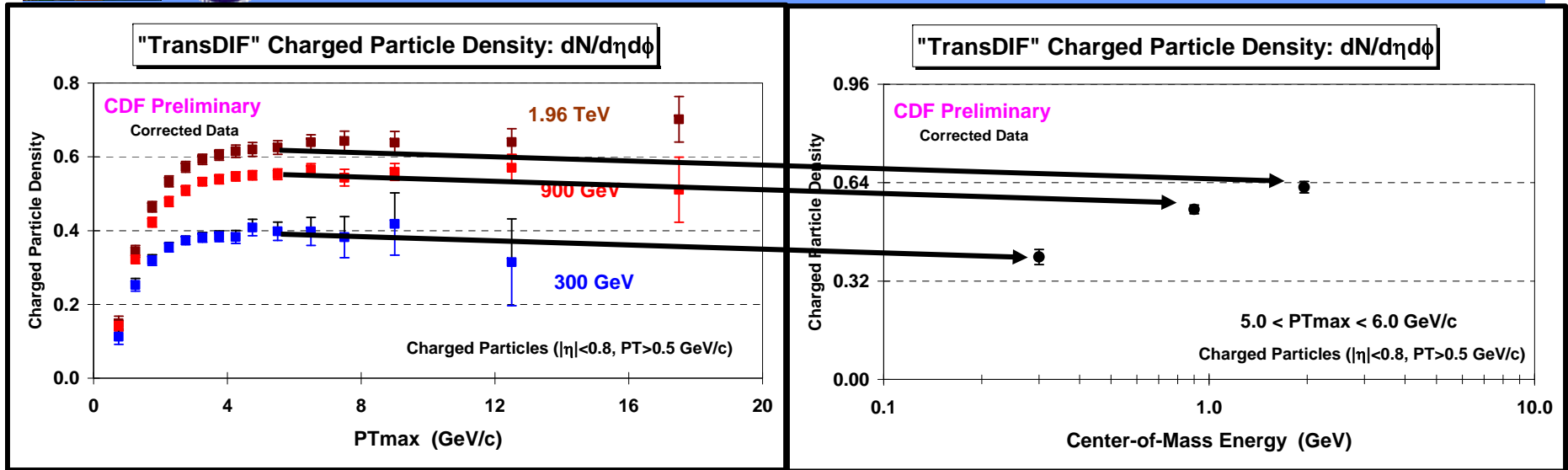


➔ **Corrected CDF data at 1.96 TeV, 900 GeV, and 300 GeV** on the charged particle density in the “transMIN” region as defined by the leading charged particle (PT_{max}) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$. The data are corrected to the particle level with errors that include both the statistical error and the systematic uncertainty.

➔ **Corrected CDF data on the charged particle density in the “transMIN” region** as defined by the leading charged particle (PT_{max}) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$ with $5 < PT_{max} < 6$ GeV/c. The data are plotted versus the center-of-mass energy (*log scale*).



“transDIF” NchgDen vs E_{cm}

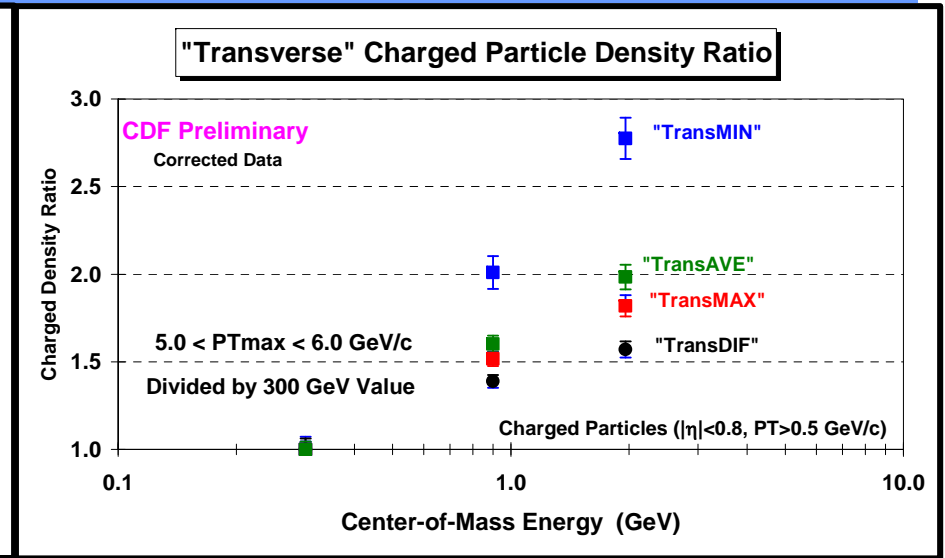
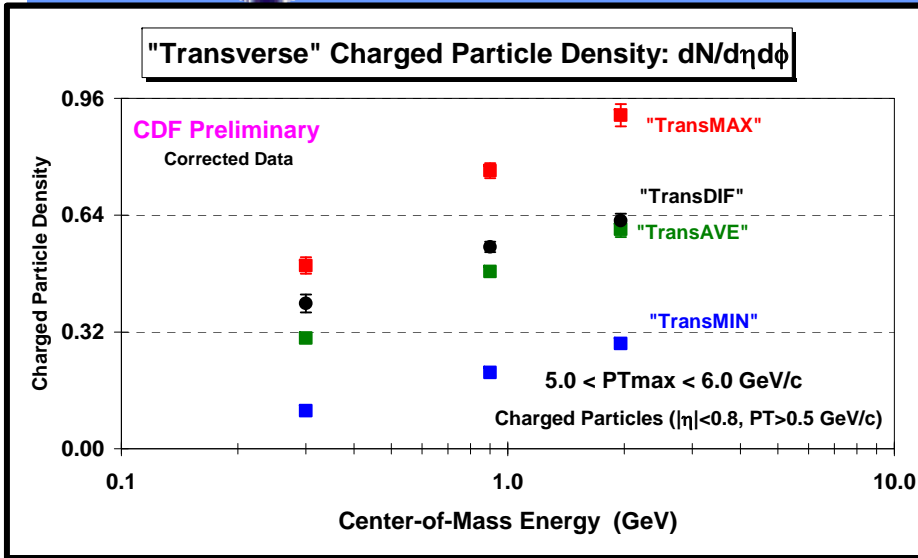


➔ **Corrected CDF data at 1.96 TeV, 900 GeV, and 300 GeV** on the charged particle density in the “transDIF” region as defined by the leading charged particle (PT_{max}) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$. The data are corrected to the particle level with errors that include both the statistical error and the systematic uncertainty.

➔ **Corrected CDF data on the charged particle density in the “transDIF” region** as defined by the leading charged particle (PT_{max}) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$ with $5 < PT_{max} < 6$ GeV/c. The data are plotted versus the center-of-mass energy (*log scale*).

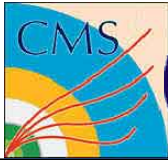


“Transverse” NchgDen vs E_{cm}

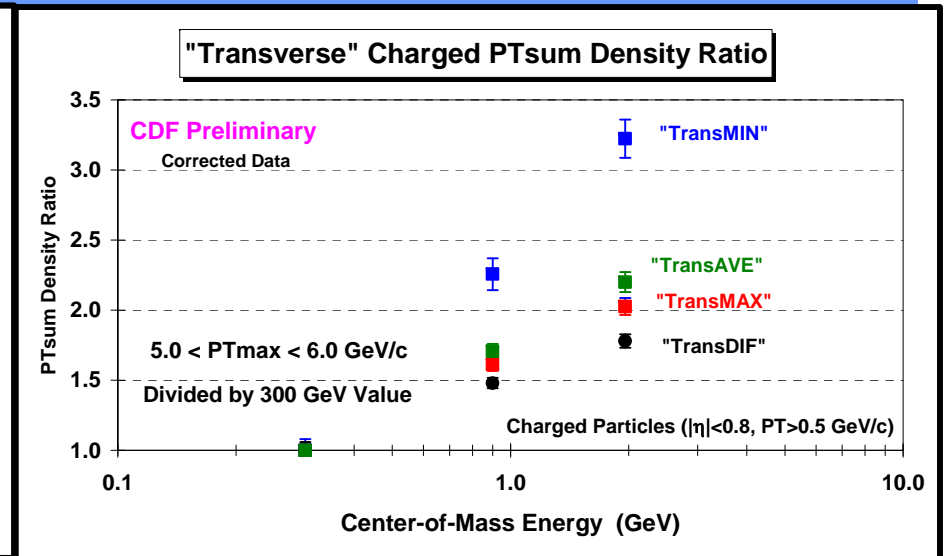
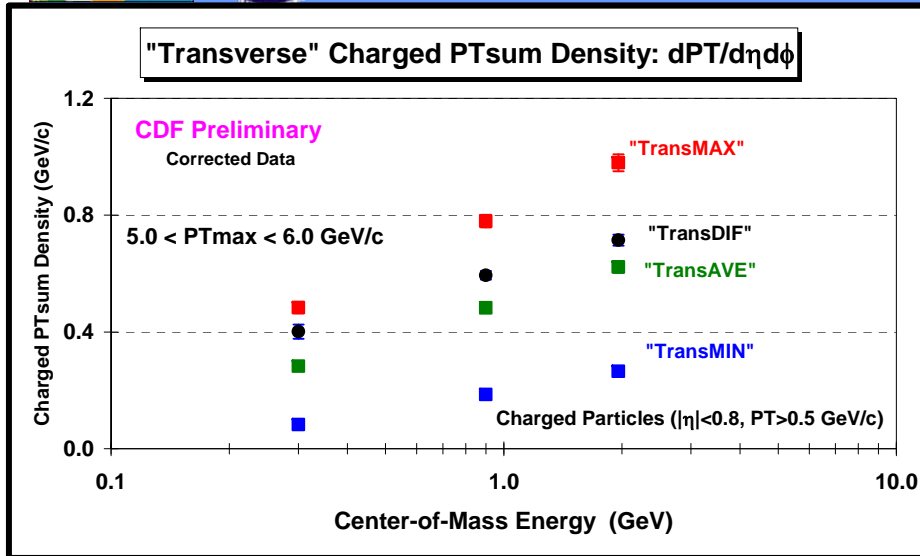


➔ **Corrected CDF data at 1.96 TeV, 900 GeV, and 300 GeV** on the charged particle density in the “**transMAX**”, “**transMIN**”, “**transAVE**”, and “**transDIF**” regions as defined by the leading charged particle (PT_{max}) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$ with $5 < PT_{max} < 6$ GeV/c. The data are plotted versus the center-of-mass energy (*log scale*).

➔ **Ratio of CDF data at 1.96 TeV, 900 GeV, and 300 GeV to the value at 300 GeV** for the charged particle density in the “**transMAX**”, “**transMIN**”, “**transAVE**”, and “**transDIF**” regions as defined by the leading charged particle (PT_{max}) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$ with $5 < PT_{max} < 6$ GeV/c. The data are plotted versus the center-of-mass energy (*log scale*).



“Transverse” PTsumDen vs E_{cm}

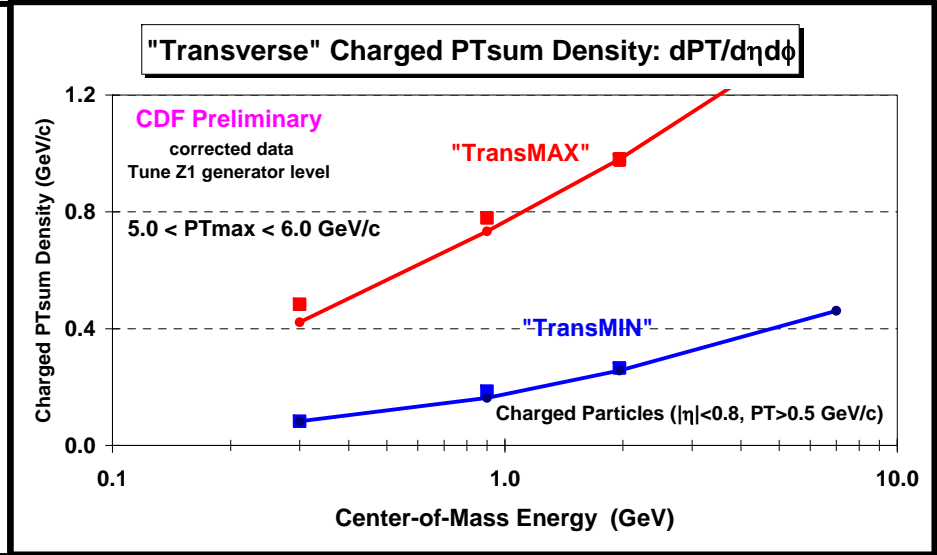
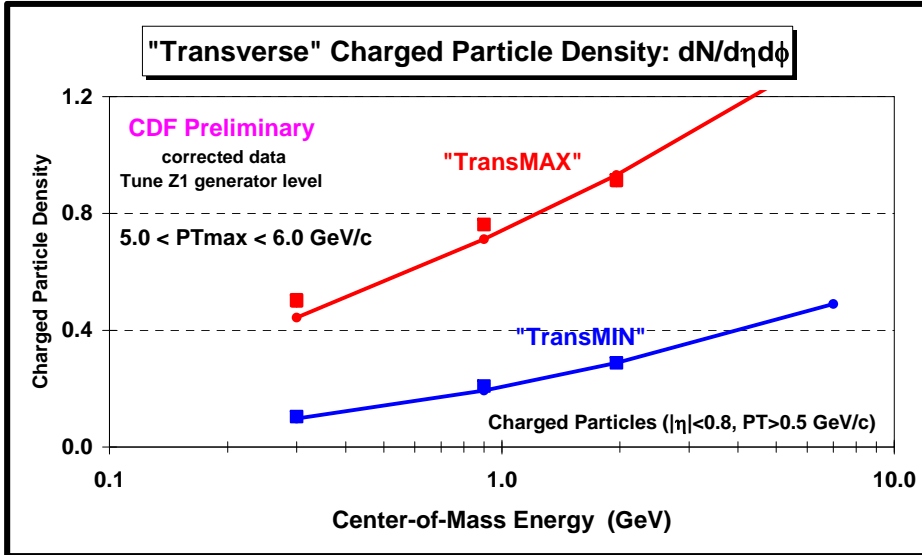


➔ **Corrected CDF data at 1.96 TeV, 900 GeV, and 300 GeV on the charged PTsum density in the “transMAX”, “transMIN”, “transAVE”, and “transDIF” regions as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$ with $5 < PTmax < 6$ GeV/c. The data are plotted versus the center-of-mass energy (*log scale*).**

➔ **Ratio of CDF data at 1.96 TeV, 900 GeV, and 300 GeV to the value at 300 GeV for the charged PTsum density in the “transMAX”, “transMIN”, “transAVE”, and “transDIF” regions as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$ with $5 < PTmax < 6$ GeV/c. The data are plotted versus the center-of-mass energy (*log scale*).**



“TransMAX/MIN” vs E_{cm}

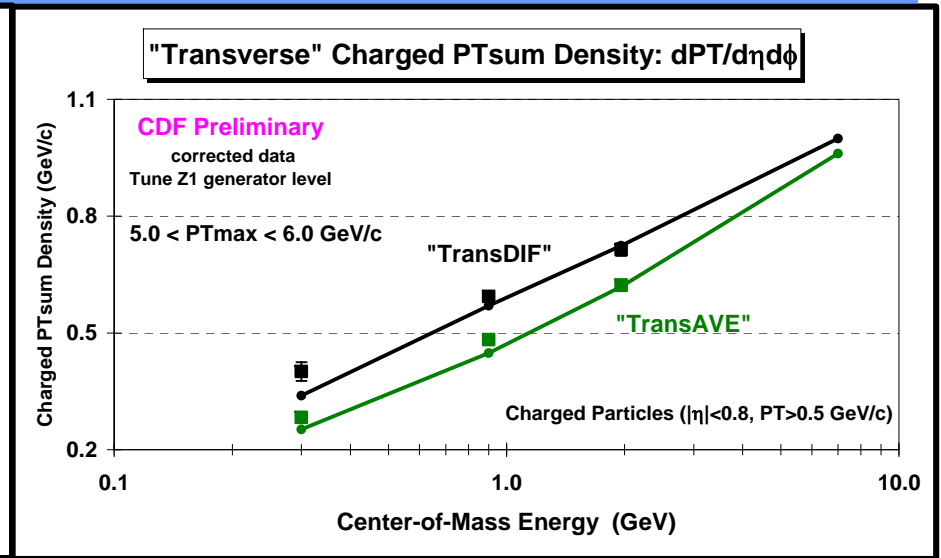
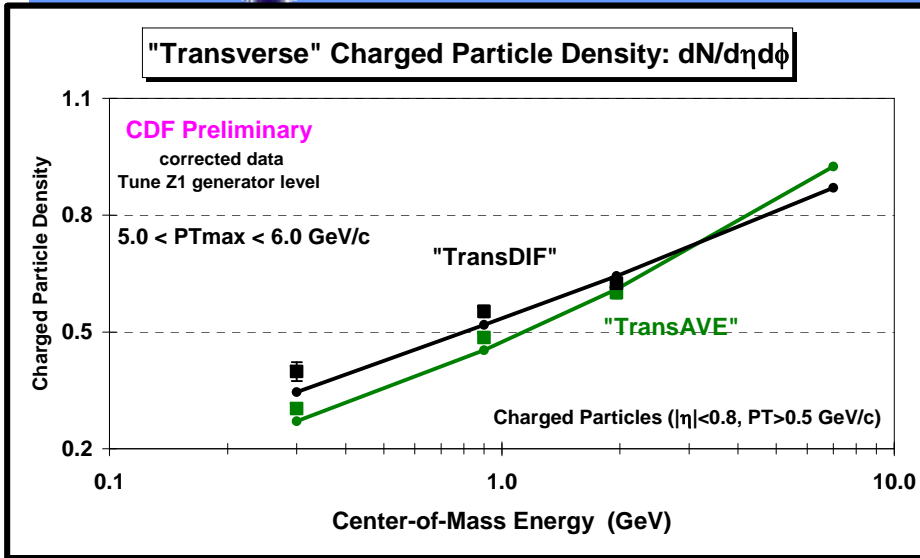


➔ **Corrected CDF data at 1.96 TeV, 900 GeV, and 300 GeV on the charged particle density in the “transMAX”, and the “transMIN”, regions as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$ with $5 < PTmax < 6$ GeV/c. The data are plotted versus the center-of-mass energy (*log scale*). The data are compared with PYTHIA 6.4 **Tune Z1**.**

➔ **Corrected CDF data at 1.96 TeV, 900 GeV, and 300 GeV on the charged PTsum density in the “transMAX”, and the “transMIN”, regions as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$ with $5 < PTmax < 6$ GeV/c. The data are plotted versus the center-of-mass energy (*log scale*). The data are compared with PYTHIA 6.4 **Tune Z1**.**



“TransDIF/AVE” vs E_{cm}

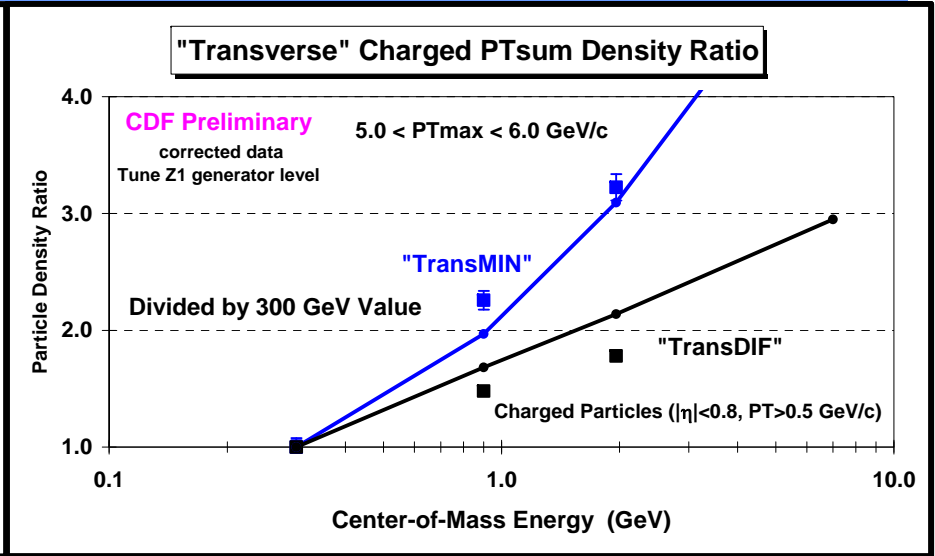
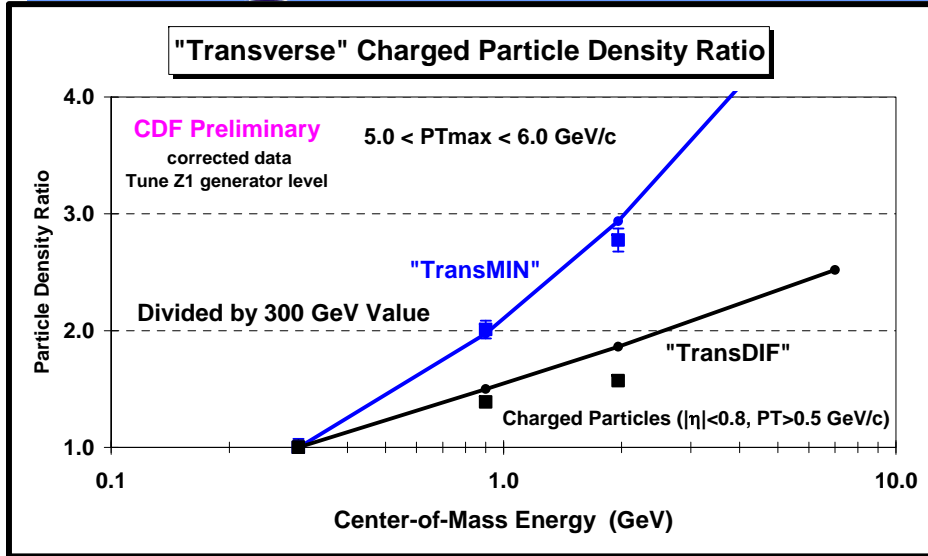


➔ **Corrected CDF data at 1.96 TeV, 900 GeV, and 300 GeV on the charged particle density in the “transAVE”, and the “transDIF”, regions as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$ with $5 < PT_{max} < 6$ GeV/c. The data are plotted versus the center-of-mass energy (*log scale*). The data are compared with PYTHIA 6.4 **Tune Z1**.**

➔ **Corrected CDF data at 1.96 TeV, 900 GeV, and 300 GeV on the charged PTsum density in the “transAVE”, and the “transDIF”, regions as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$ with $5 < PT_{max} < 6$ GeV/c. The data are plotted versus the center-of-mass energy (*log scale*). The data are compared with PYTHIA 6.4 **Tune Z1**.**



“TransMIN/DIF” vs E_{cm}

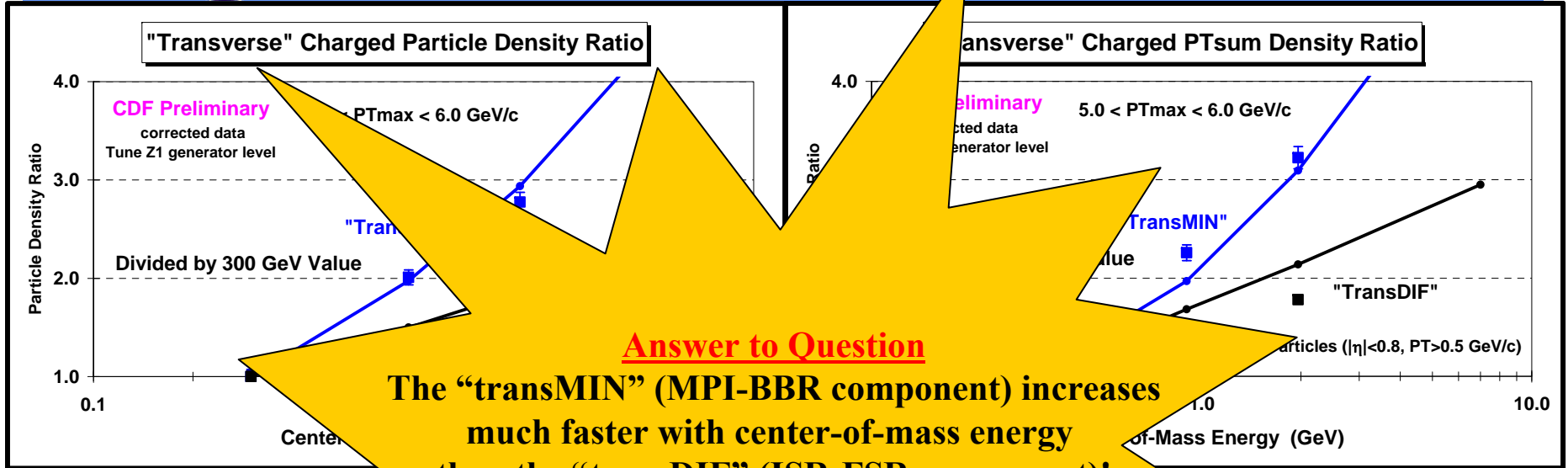


➔ **Ratio of CDF data at 1.96 TeV, 900 GeV, and 300 GeV to the value at 300 GeV for the charged particle density in the “transMIN”, and “transDIF” regions as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$ with $5 < PTmax < 6$ GeV/c. The data are plotted versus the center-of-mass energy (*log scale*). The data are compared with PYTHIA 6.4 **Tune Z1**.**

➔ **Ratio of CDF data at 1.96 TeV, 900 GeV, and 300 GeV to the value at 300 GeV for the charged PTsum density in the “transMIN”, and “transDIF” regions as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$ with $5 < PTmax < 6$ GeV/c. The data are plotted versus the center-of-mass energy (*log scale*). The data are compared with PYTHIA 6.4 **Tune Z1**.**



“TransMIN/DIF” vs E_{cm}



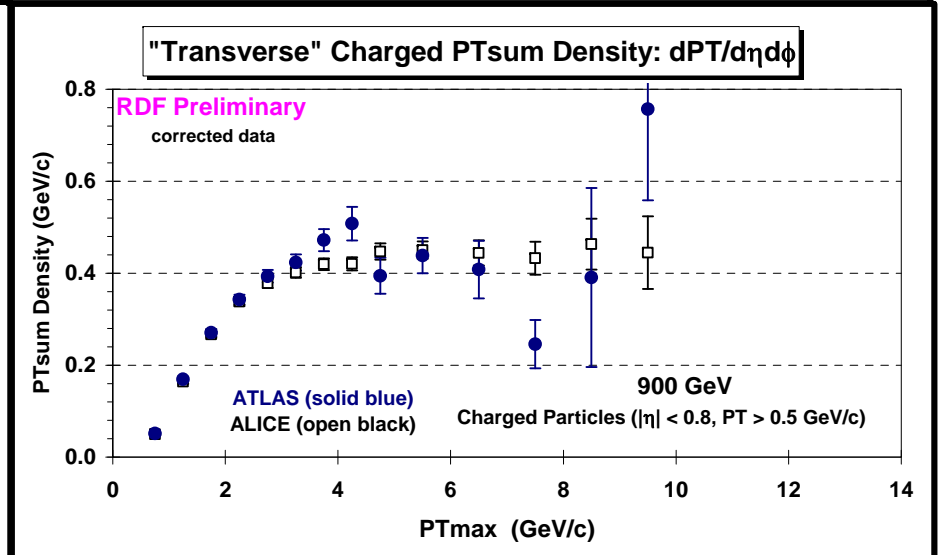
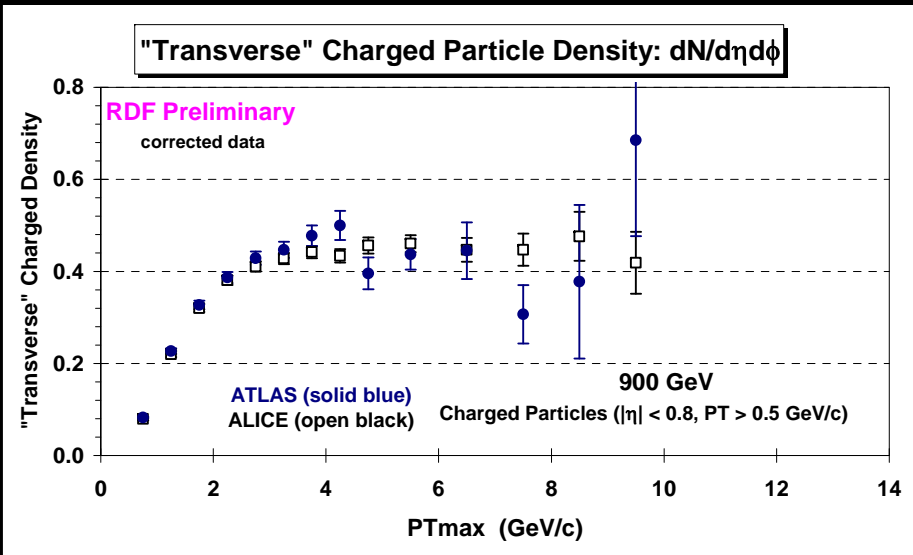
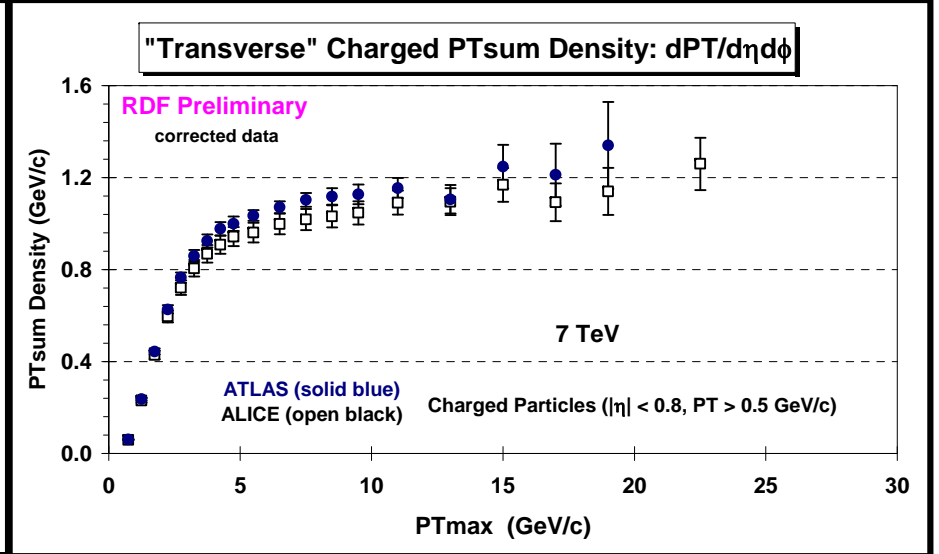
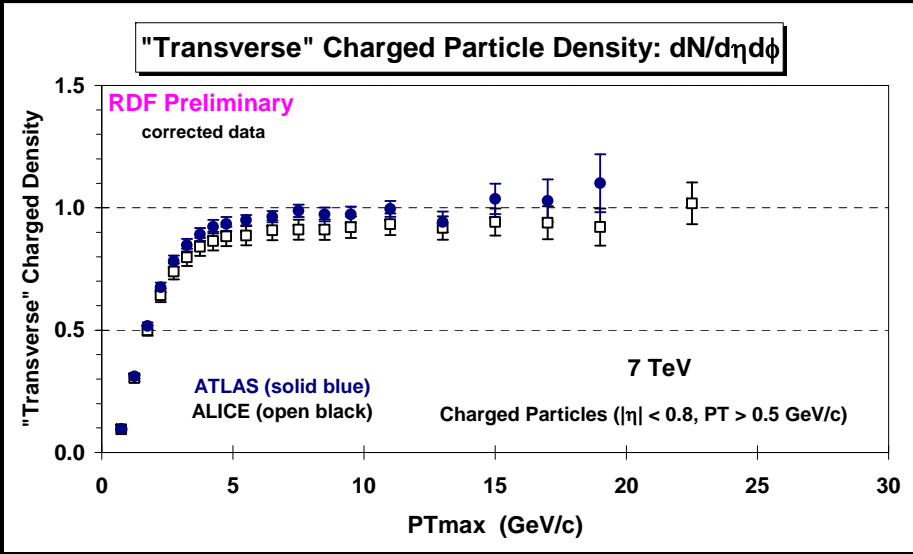
Answer to Question
 The “transMIN” (MPI-BBR component) increases much faster with center-of-mass energy than the “transDIF” (ISR-FSR component)!

Duh!!

→ **Ratio of CDF data at 26 TeV, 900 GeV, and 300 GeV to the charged particle density in the “transMIN”, and “transDIF” regions as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$ with $5 < PTmax < 6$ GeV/c. The data are plotted versus the center-of-mass energy (log scale). The data are compared with PYTHIA 6.4 Tune Z1.**

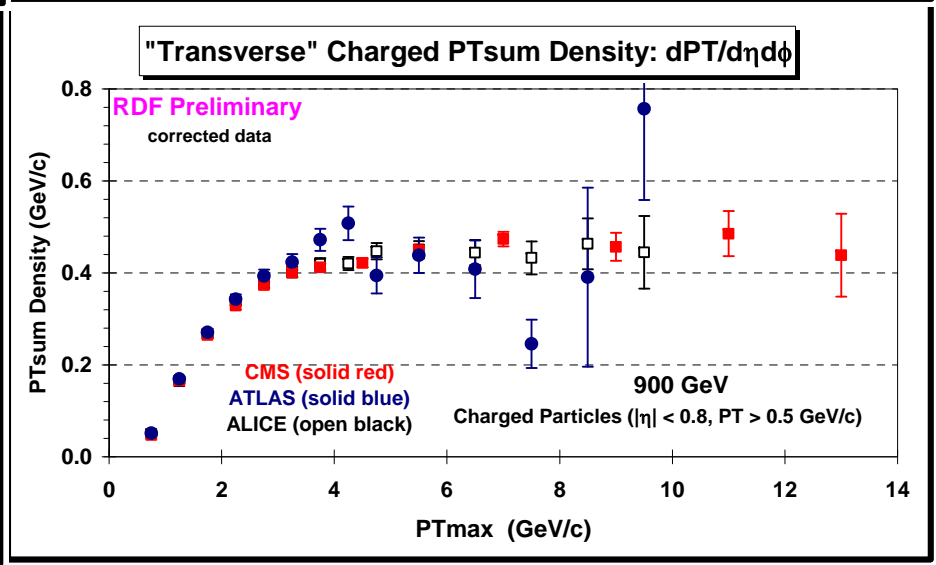
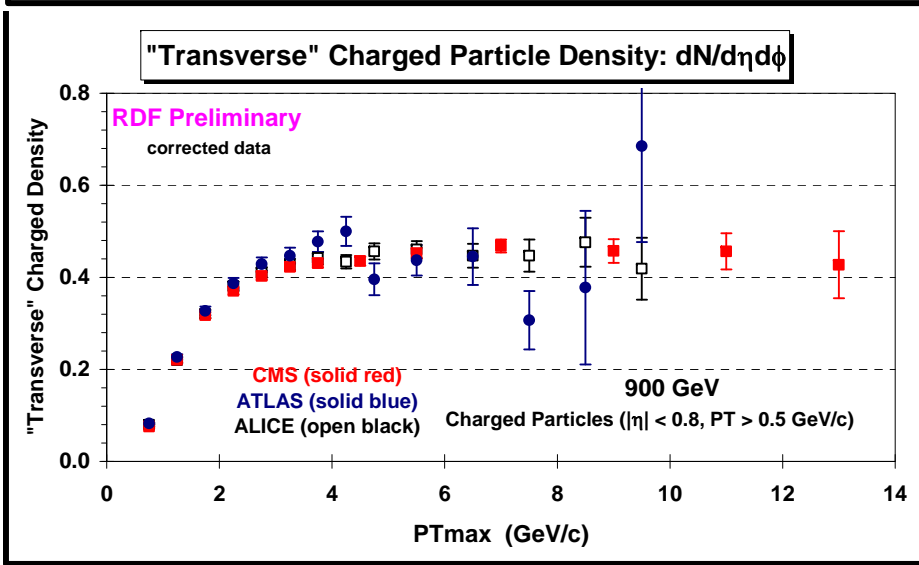
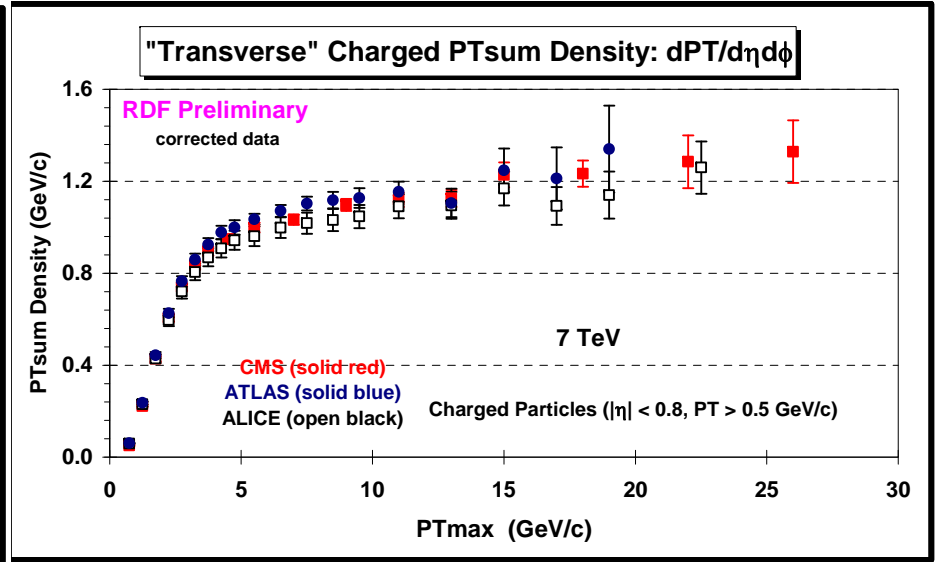
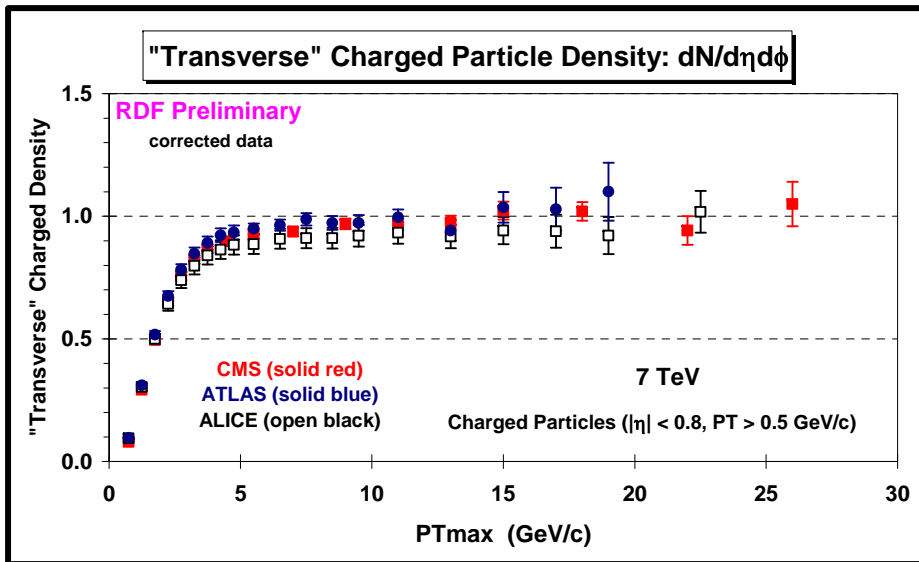


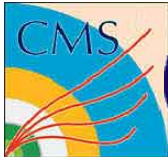
UE Common Plots



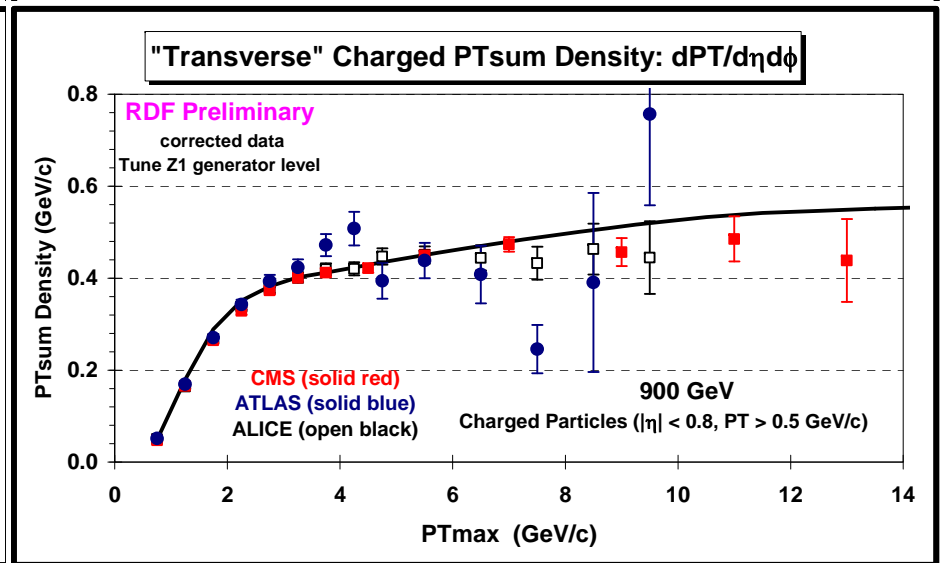
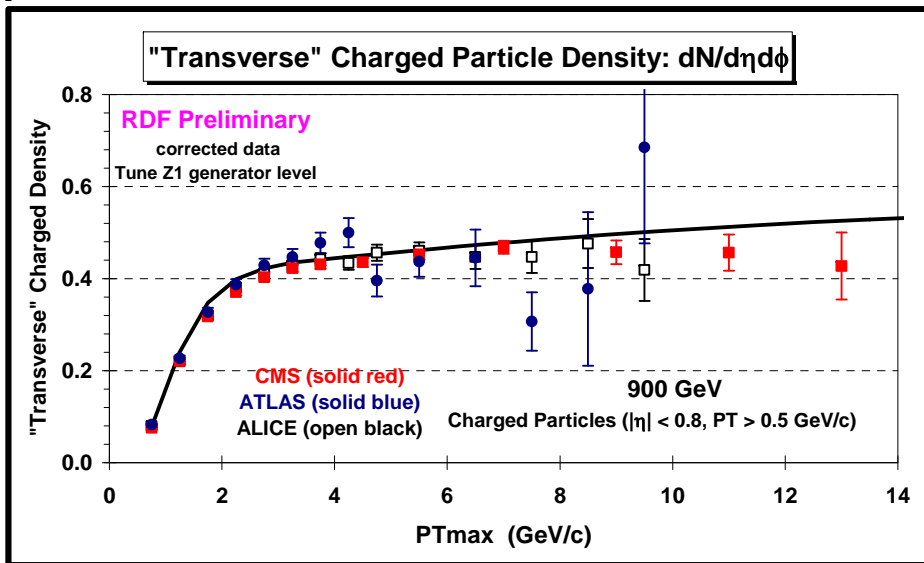
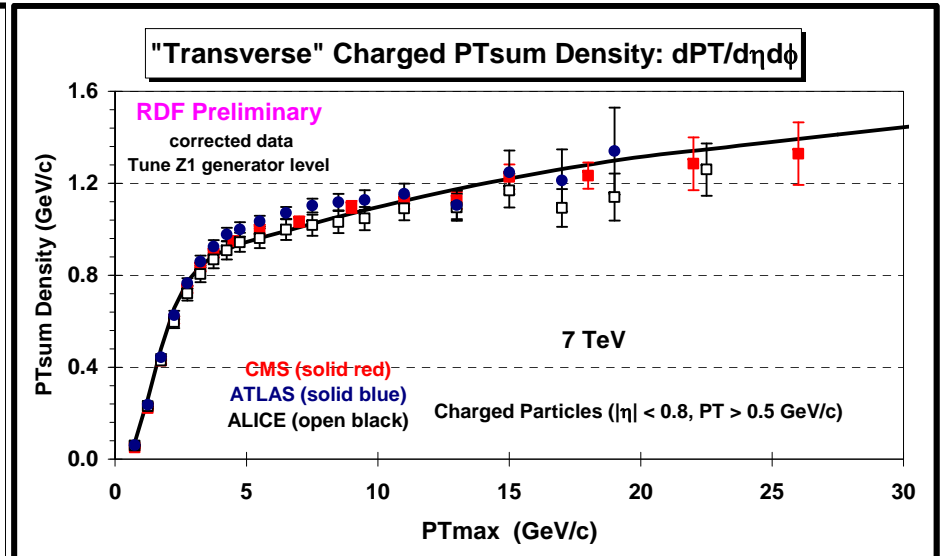
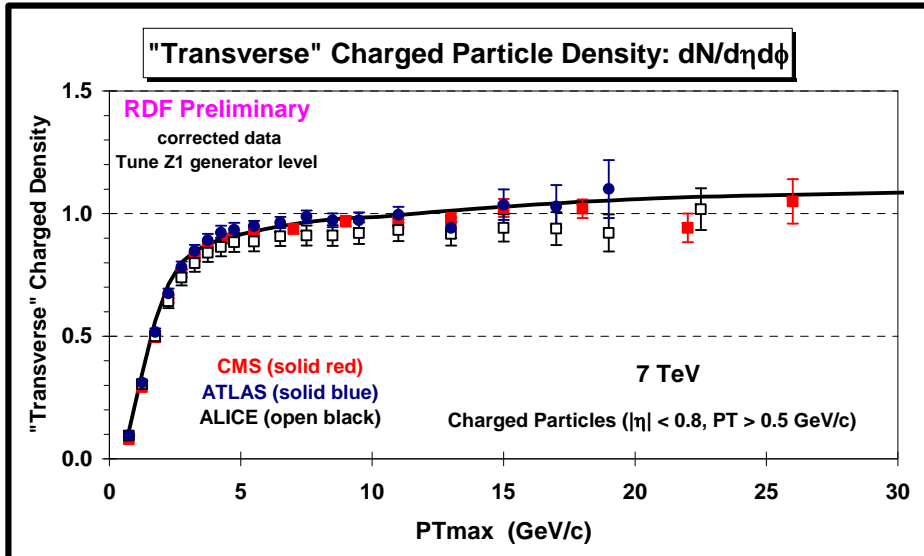


UE Common Plots



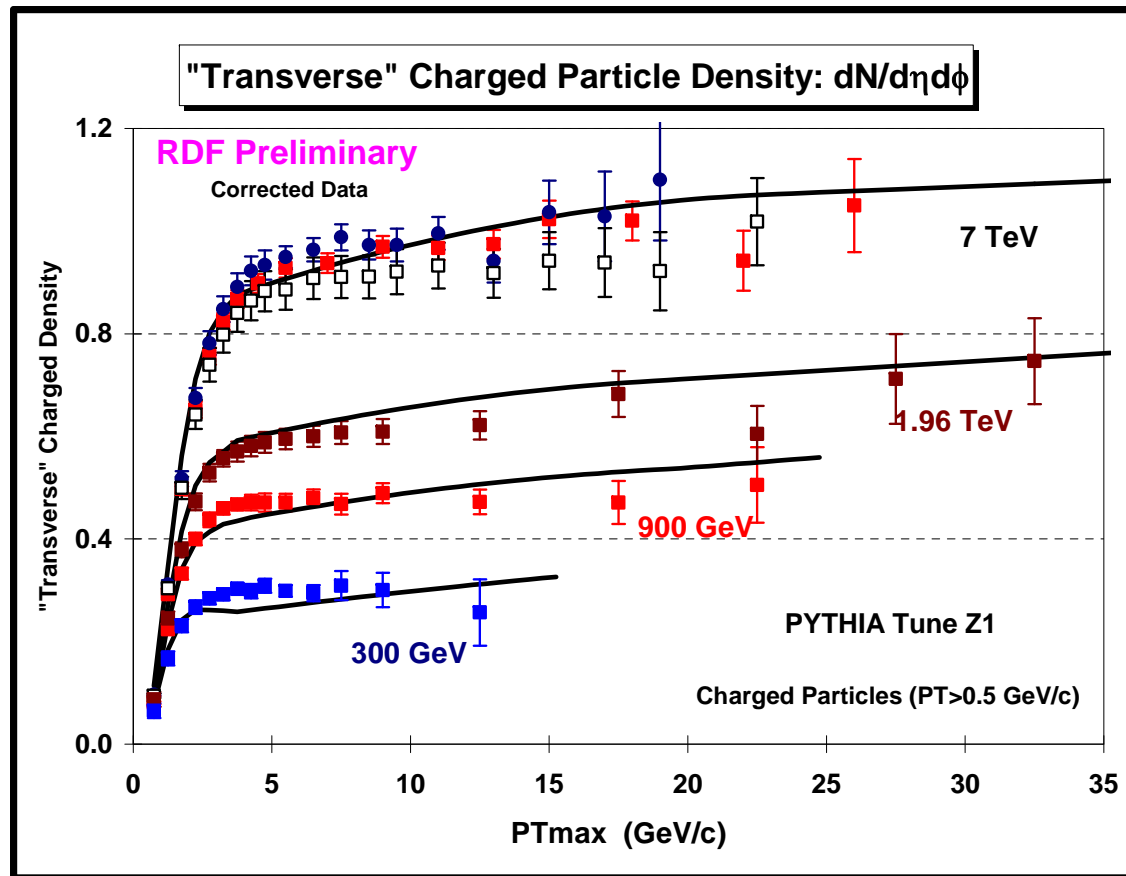


UE Common Plots





“Tevatron” to the LHC





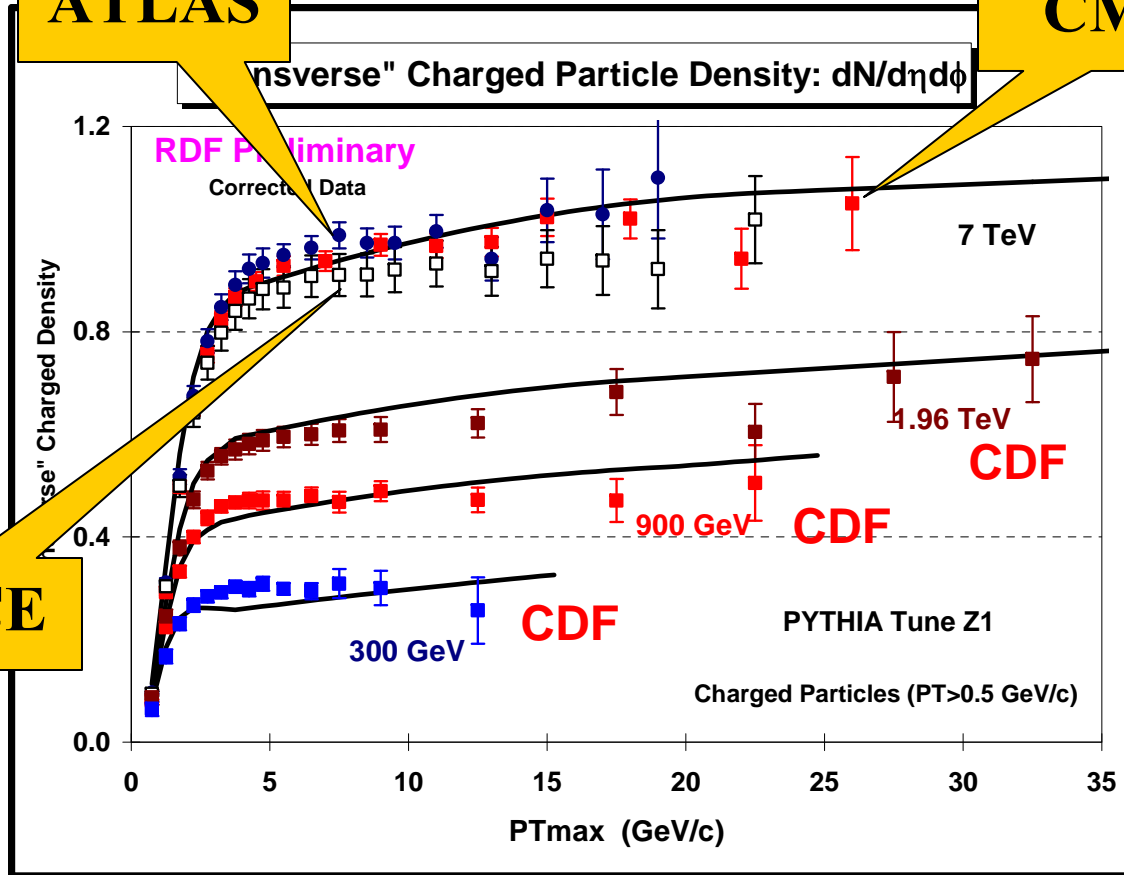
“Tevatron” to the LHC



ATLAS

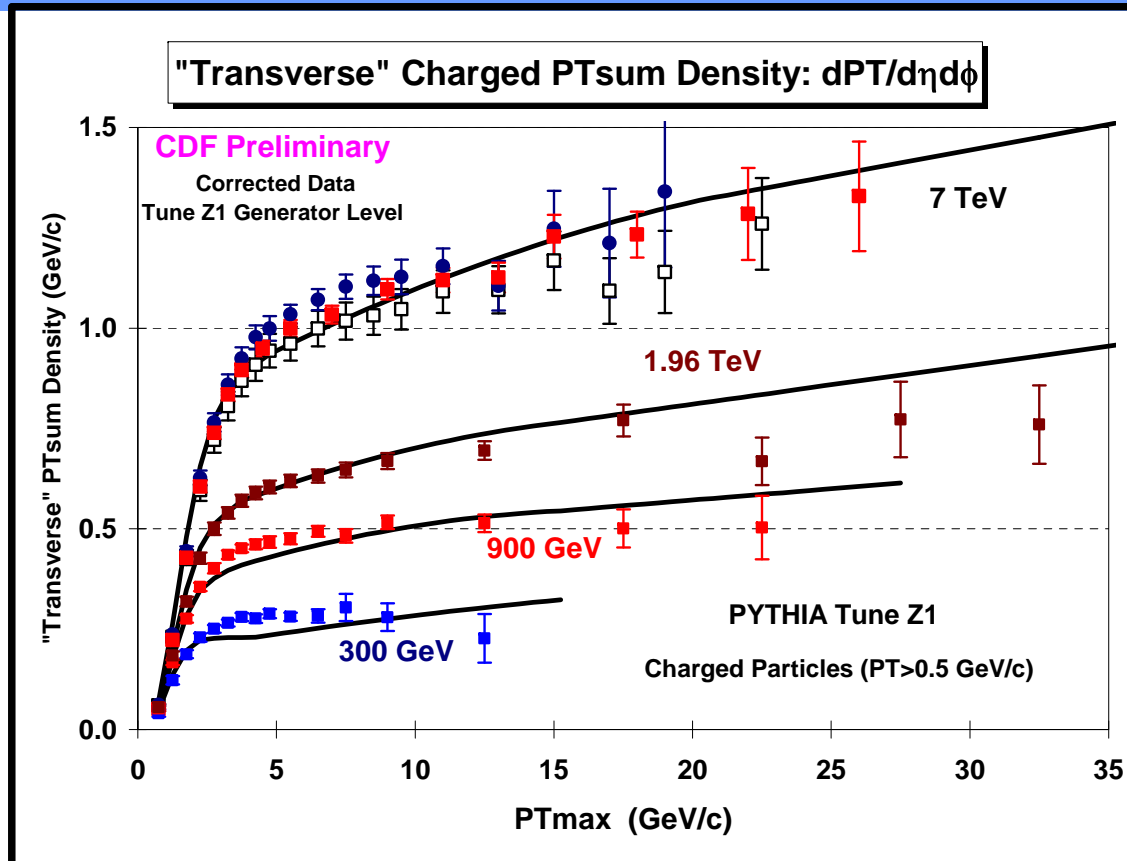
CMS

ALICE



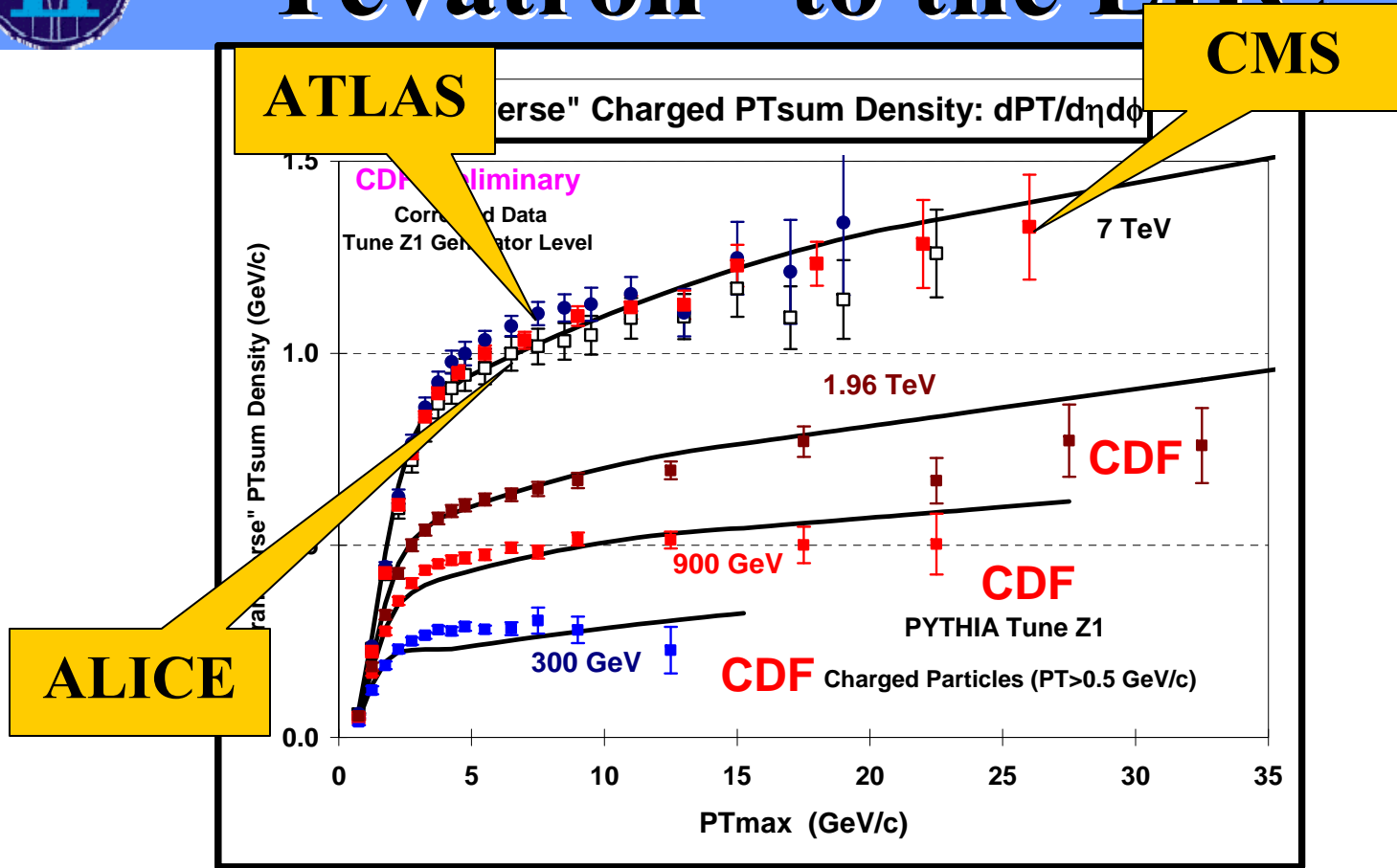


“Tevatron” to the LHC



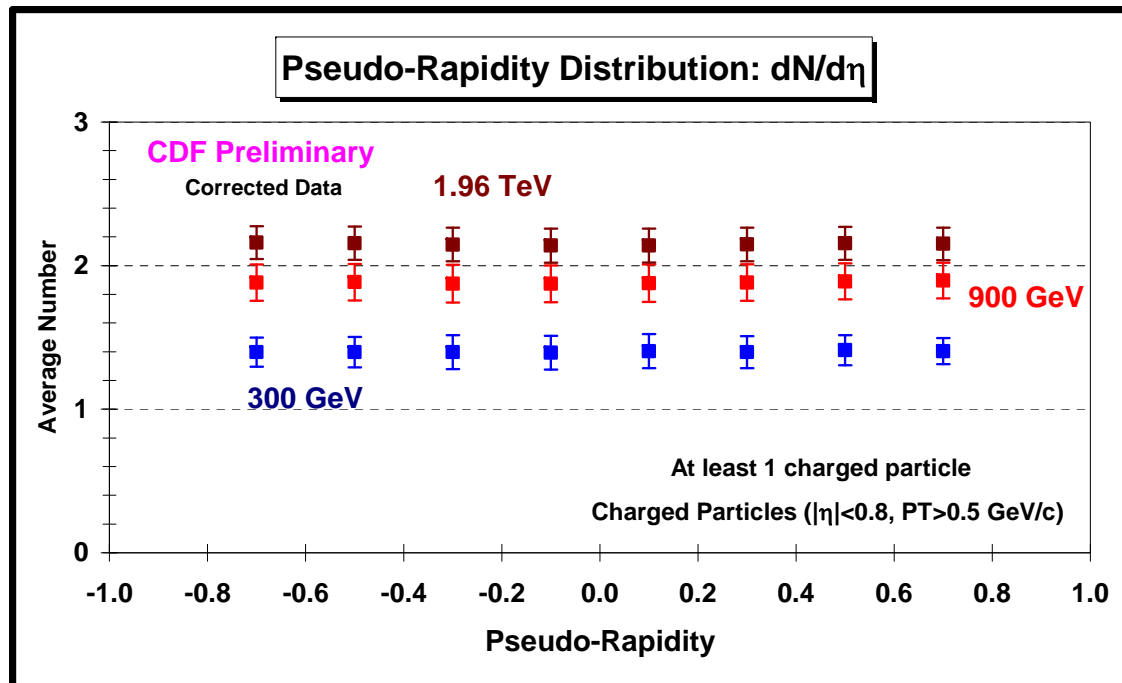


“Tevatron” to the LHC





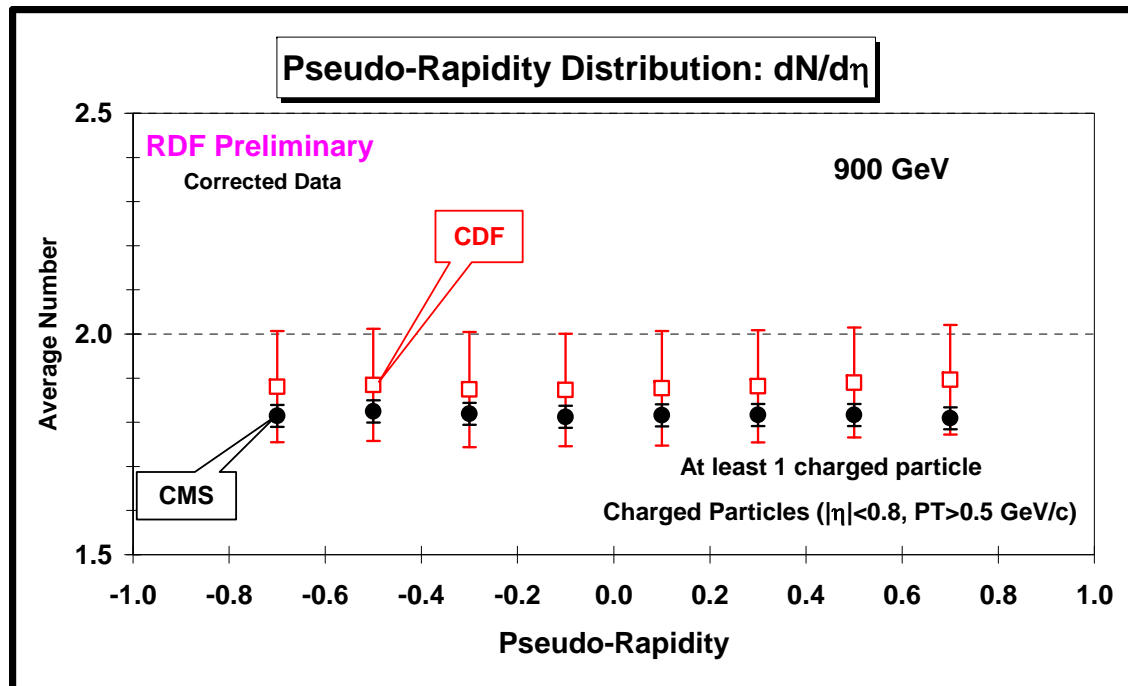
New CDF MB Data



- ➔ **New Corrected CDF data at 300 GeV, 900 GeV, and 1.96 TeV** on on pseudo-rapidity distribution of charged particles, $dN/d\eta$, with $p_T > 0.5 \text{ GeV}/c$. Events are required to have at least one charged particle with $|\eta| < 0.8$ and $p_T > 0.5 \text{ GeV}/c$. The data are corrected to the particle level with errors that include both the statistical error and the systematic uncertainty.



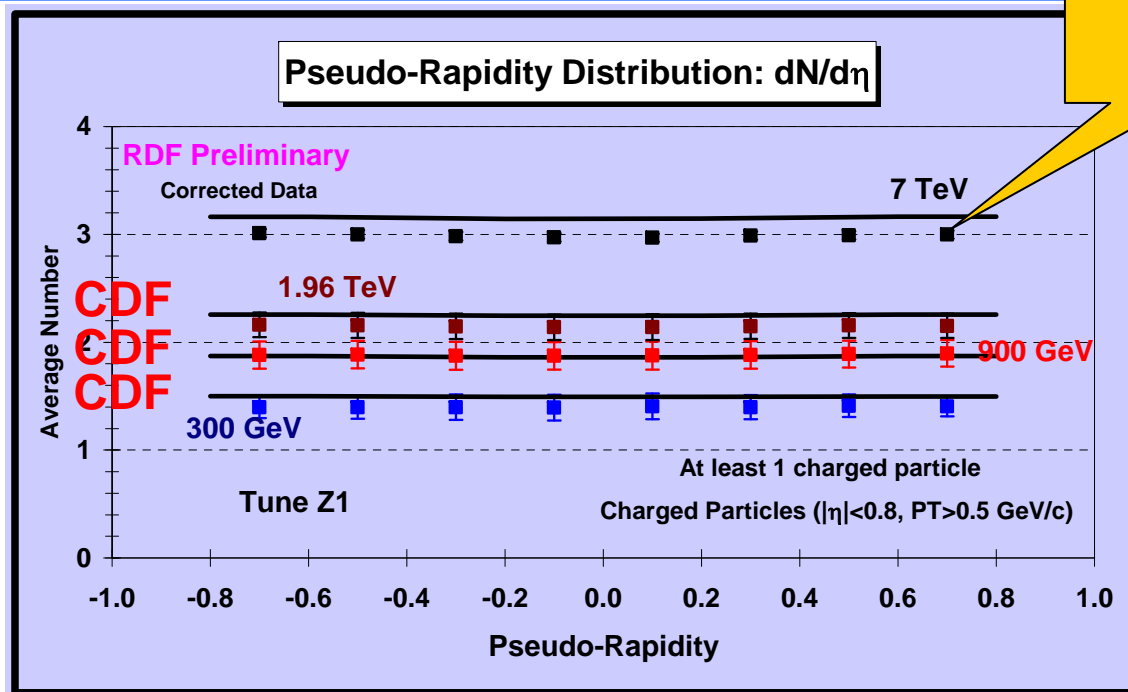
New CDF MB Data



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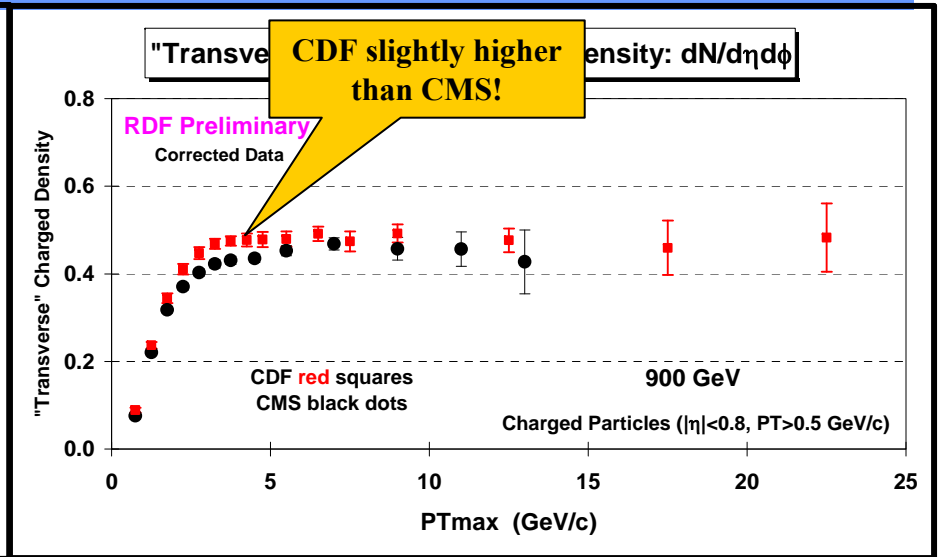
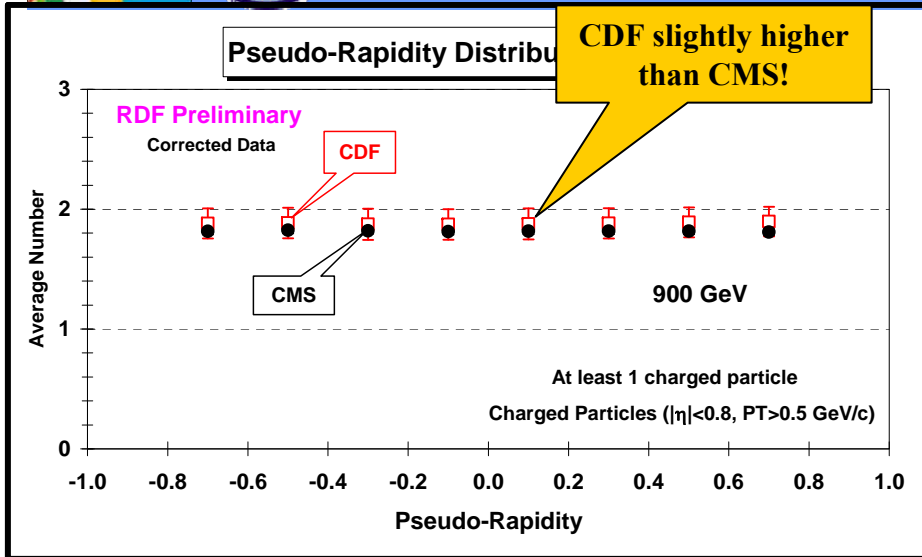
New CDF MB Data



- ➔ **New Corrected CDF data at 300 GeV, 900 GeV, and 1.96 TeV** on on pseudo-rapidity distribution of charged particles, $dN/d\eta$, with $p_T > 0.5 \text{ GeV}/c$. Events are required to have at least one charged particle with $|\eta| < 0.8$ and $p_T > 0.5 \text{ GeV}/c$. The data are corrected to the particle level with errors that include both the statistical error and the systematic uncertainty.



CDF versus CMS

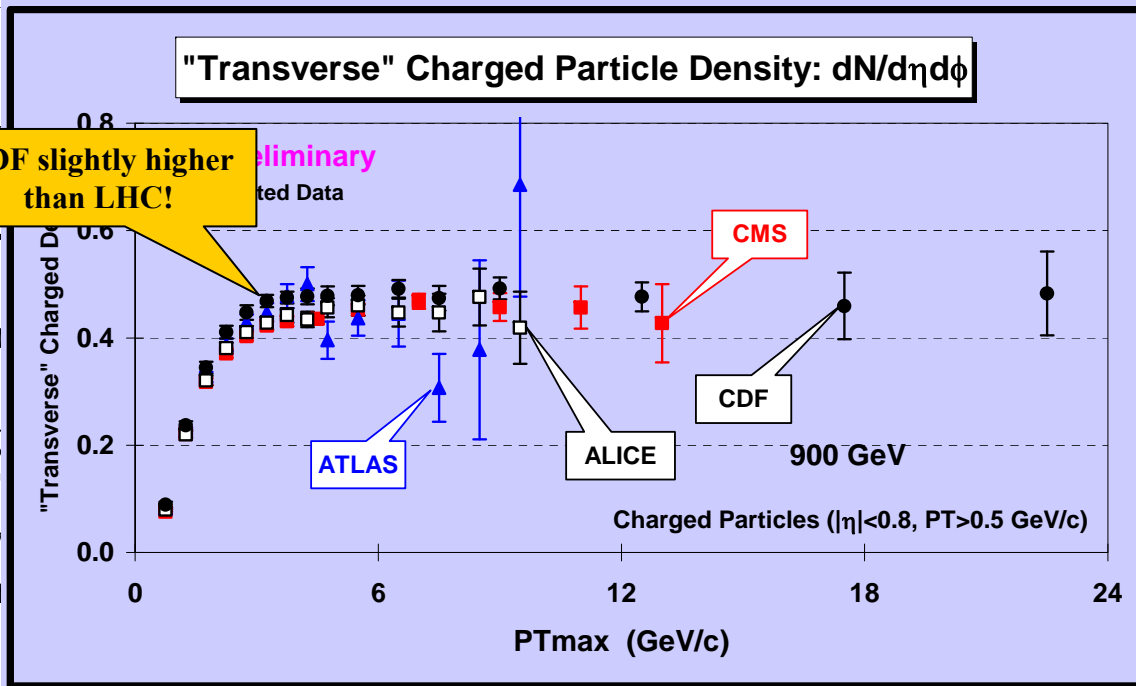
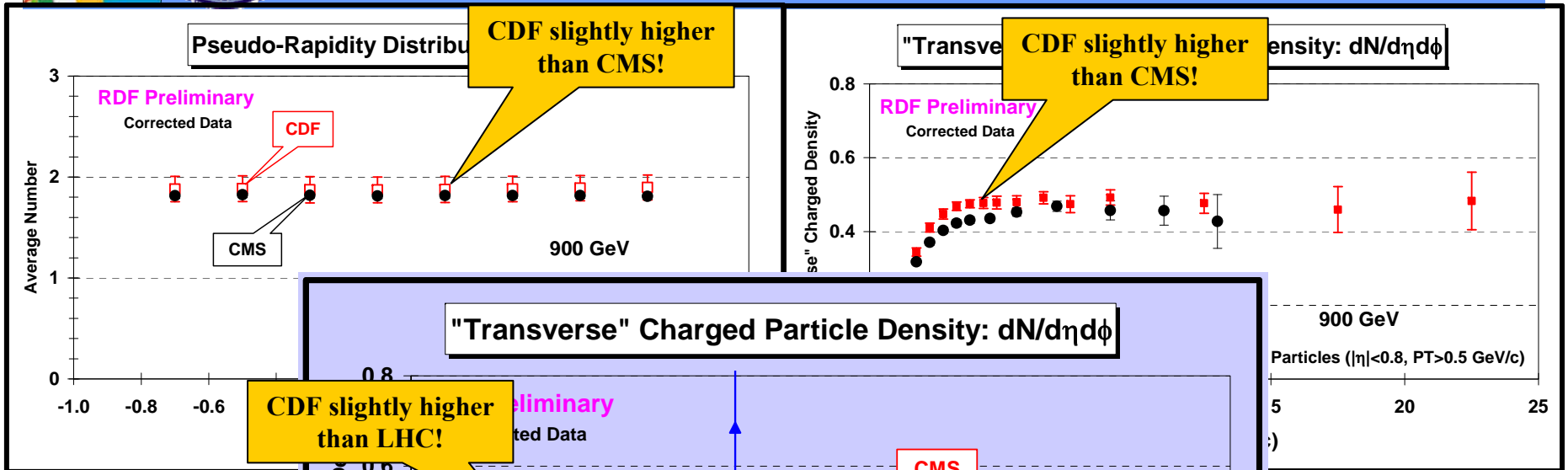


➔ **CDF and CMS data at 900 GeV** on the pseudo-rapidity distribution, $dN/d\eta$, for charged with $p_T > 0.5 \text{ GeV}/c$ and $|\eta| < 0.8$ for events with at least one charged particle with $p_T > 0.5 \text{ GeV}/c$ and $|\eta| < 0.8$. The data are corrected to the particle level with errors that include both the statistical error and the systematic uncertainty.

➔ **CDF and CMS data at 900 GeV/c** on the charged particle density in the "transverse" region 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 to the particle level with errors that include both the statistical error and the systematic uncertainty.



CDF versus CMS

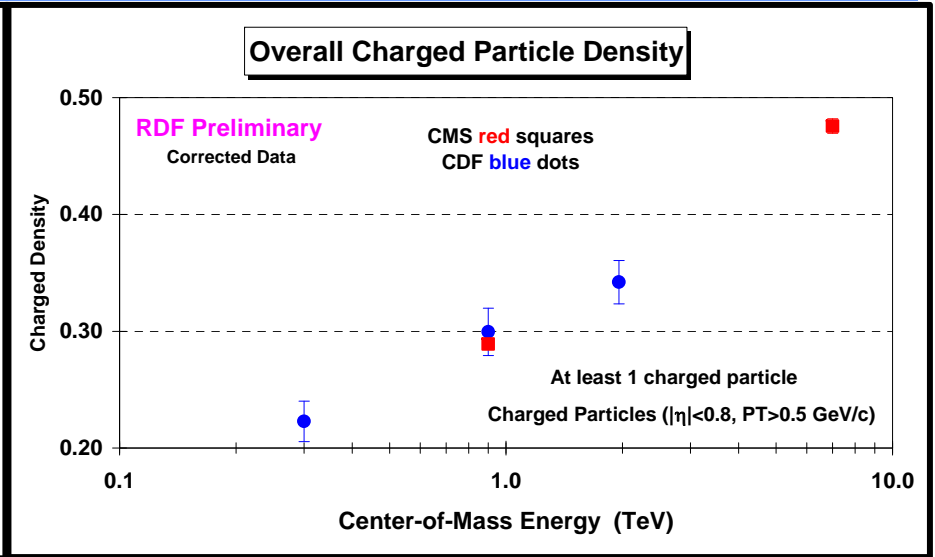
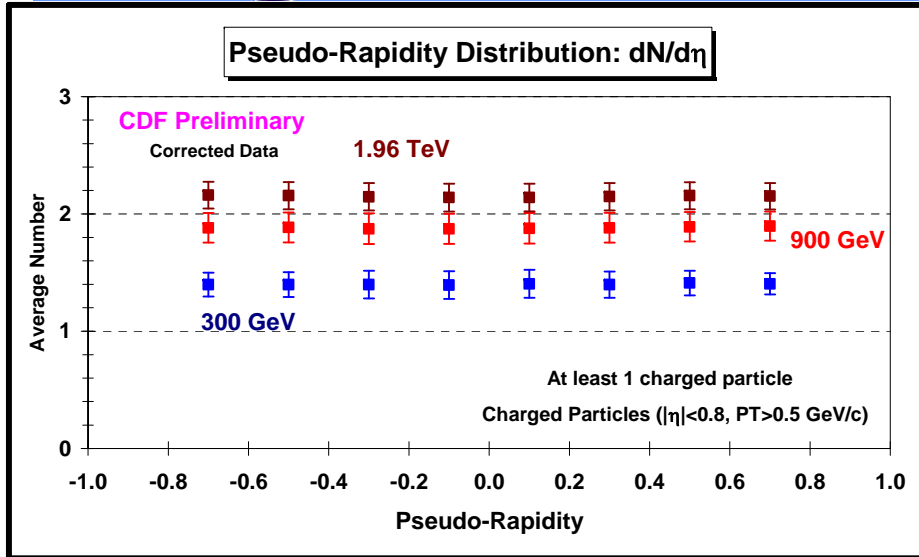


➔ **CDF and CMS** rapidity distribution $p_T > 0.5$ GeV/c and $|\eta| < 0.8$. The particle level with statistical error and uncertainty.

GeV/c on the the "transverse" leading charged particles with $|\eta| < 0.8$. The data are level with errors and



Overall Charged Particle Density

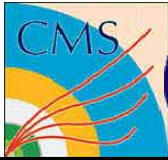


➔ **Corrected CDF data** on the pseudo-rapidity distribution, $dN/d\eta$, for charged with $p_T > 0.5 \text{ GeV}/c$ and $|\eta| < 0.8$ for events with at least one charged particle with $p_T > 0.5 \text{ GeV}/c$ and $|\eta| < 0.8$.

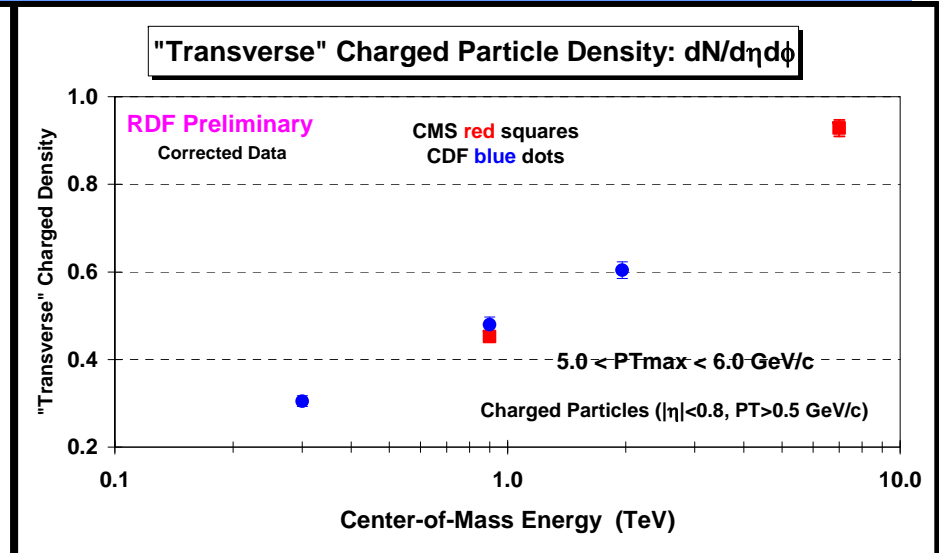
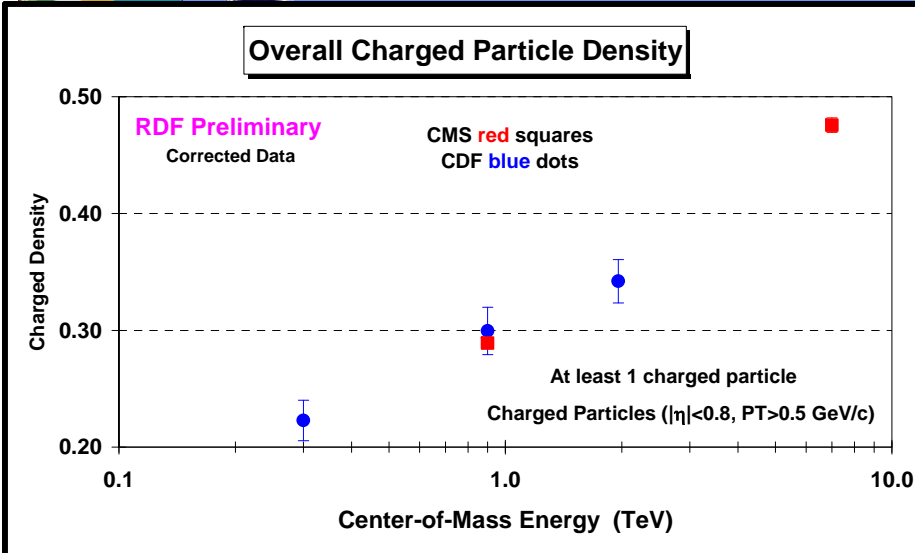
➔ **Corrected CDF and CMS data** overall density of charged particles with $p_T > 0.5 \text{ GeV}/c$ and $|\eta| < 0.8$ for events with at least one charged particle with $p_T > 0.5 \text{ GeV}/c$ and $|\eta| < 0.8$ plotted versus the center-of-mass energy (*log scale*). The data are corrected to the particle level with errors that include both the statistical error and the systematic uncertainty.

Ecm	Nchg	error	NchgDen	error
300 GeV	2.241	0.175	0.223	0.017
900 GeV	3.012	0.203	0.300	0.020
1.96 TeV	3.439	0.186	0.342	0.019

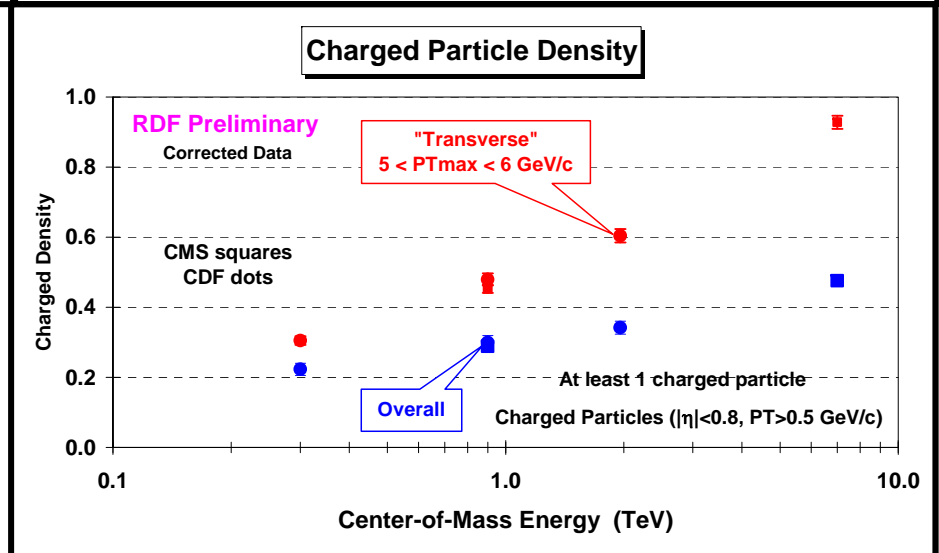
$$N_{chg} = \int_{-0.8}^{0.8} \frac{dN}{d\eta} d\eta$$



MB versus the UE

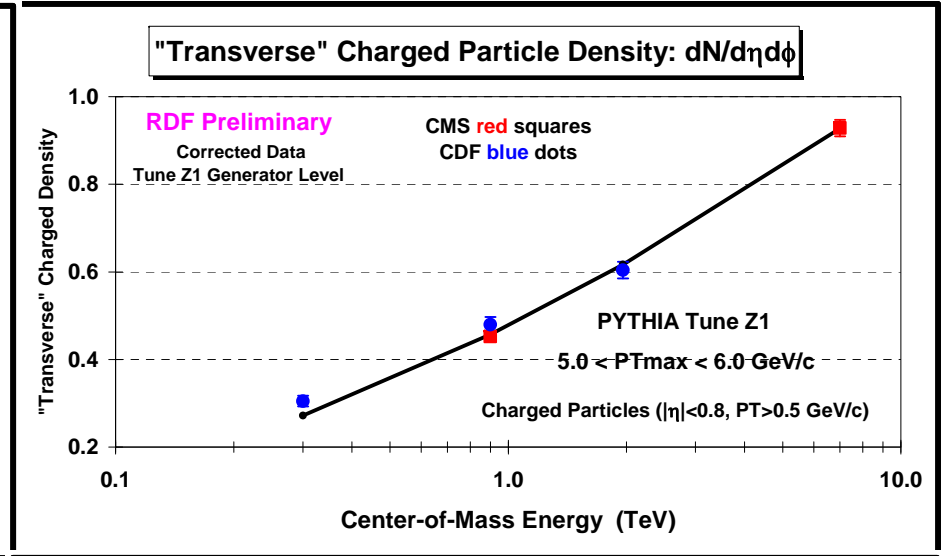
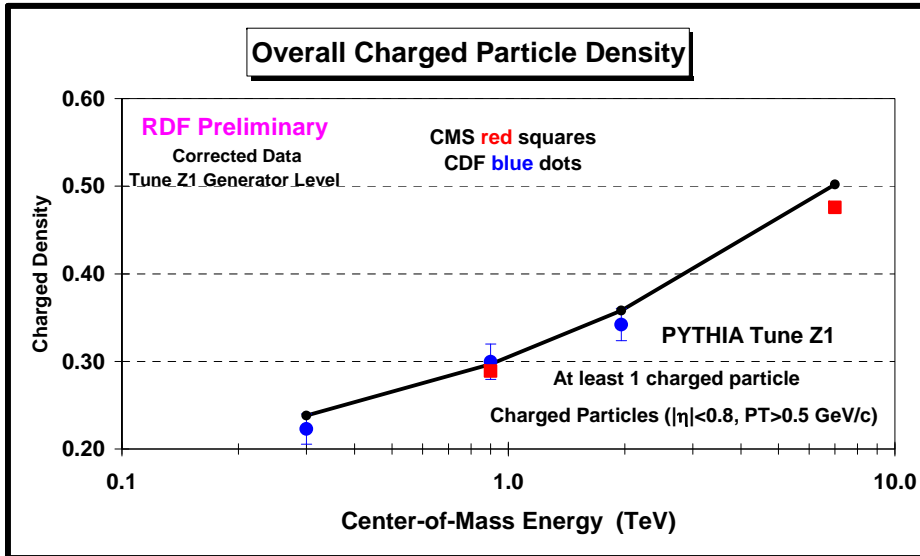


➔ **Corrected CDF and CMS data** on the overall density of charged particles with $p_T > 0.5 \text{ GeV}/c$ and $|\eta| < 0.8$ for events with at least one charged particle with $p_T > 0.5 \text{ GeV}/c$ and $|\eta| < 0.8$ and on the charged particle density, in the "transverse" region as defined by the leading charged particle (p_{Tmax}) for charged particles with $p_T > 0.5 \text{ GeV}/c$ and $|\eta| < 0.8$ with $5 < p_{Tmax} < 6 \text{ GeV}/c$. The data are plotted versus the center-of-mass energy (*log scale*).

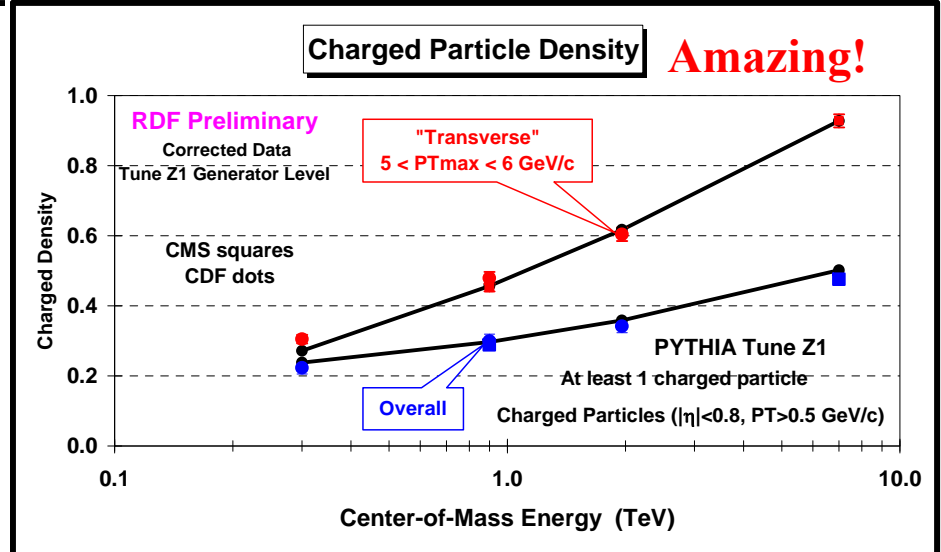




MB versus the UE

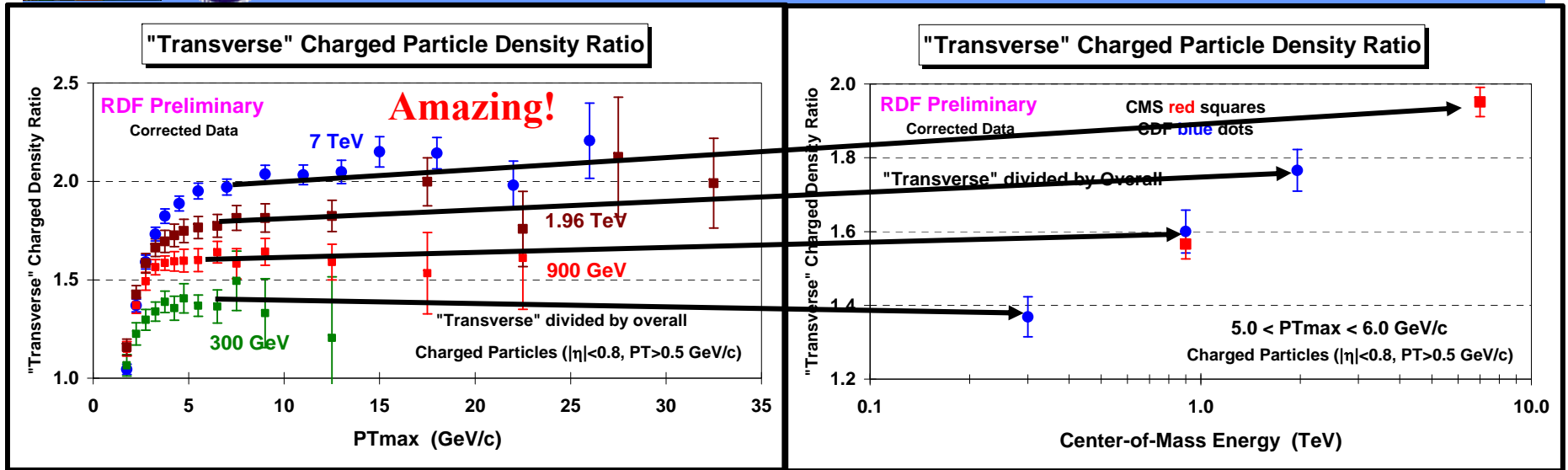


➔ **Corrected CDF and CMS data on the overall density of charged particles with $p_T > 0.5 \text{ GeV}/c$ and $|\eta| < 0.8$ for events with at least one charged particle with $p_T > 0.5 \text{ GeV}/c$ and $|\eta| < 0.8$ and on the charged particle density, in the "transverse" region as defined by the leading charged particle (p_{Tmax}) for charged particles with $p_T > 0.5 \text{ GeV}/c$ and $|\eta| < 0.8$ with $5 < p_{Tmax} < 6 \text{ GeV}/c$. The data are plotted versus the center-of-mass energy (*log scale*).**





“Transverse”/Overall

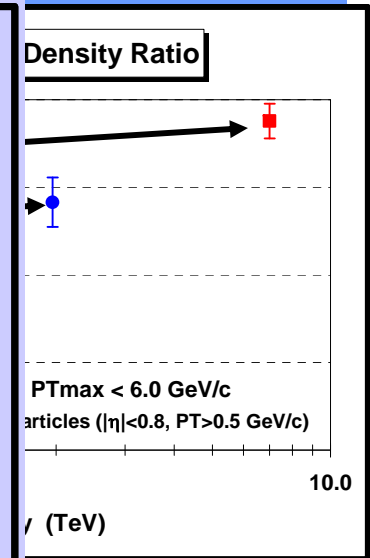
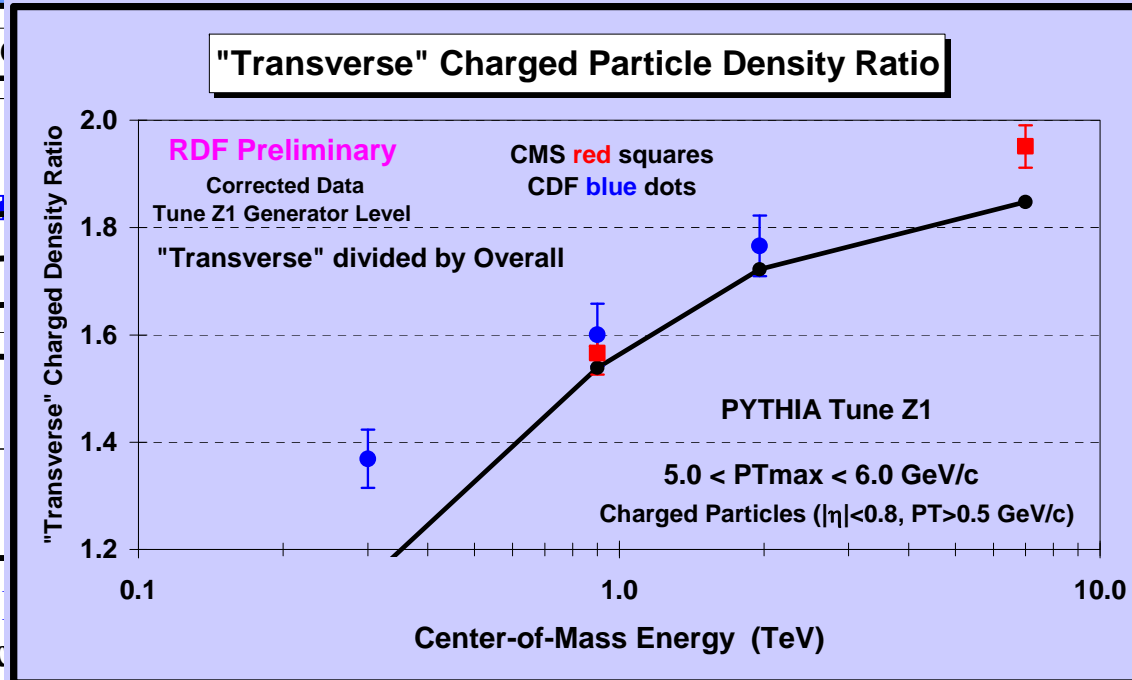
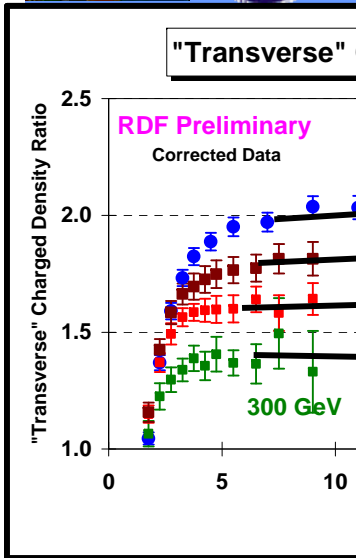


➔ **Corrected CDF and CMS data** on the charged particle density ratio, in the “transverse” region as defined by the leading charged particle (PT_{max}) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$. The ratio corresponds to the “transverse” charged particle density divided by the overall charged particle density.

➔ **Corrected CDF and CMS data** on the charged particle density ratio, in the “transverse” region as defined by the leading charged particle (PT_{max}) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$ for $5 < PT_{max} < 6$ GeV/c. The ratio corresponds to the “transverse” charged particle density divided by the overall charged particle density. The data are plotted versus the center-of-mass energy (*log scale*).

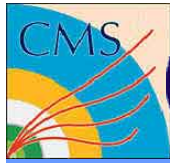


“Transverse”/Overall



➔ **Corrected CDF** data on the “transverse” region as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5 \text{ GeV}/c$ and $|\eta| < 0.8$. The ratio corresponds to the “transverse” charged particle density divided by the overall charged particle density.

data on the “transverse” region as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5 \text{ GeV}/c$ and $|\eta| < 0.8$ for $5 < PT_{\text{max}} < 6 \text{ GeV}/c$. The ratio corresponds to the “transverse” charged particle density divided by the overall charged particle density. The data are plotted versus the center-of-mass energy (*log scale*).



Summary & Conclusions



- ➔ The **“transMIN”** (MPI-BBR component) increases much faster with center-of-mass energy than the **“transDIF”** (ISR-FSR component)! Previously we only knew the energy dependence of **“transAVE”**.
- ➔ The **“transverse”** (*i.e.* **“transAVE”**) increases faster with center-of-mass energy than the **overall charged density** ($N_{chg} \geq 1$)!

**Soon we will have a lot of 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!**



Summary & Conclusions



➔ The “**transMIN**” (MPI-BBR component) increases much faster with center-of-mass energy than **transD** (FSR component)! Previously we saw the “**transMIN**”.

➔ The “**transMIN**” mass effects

What we are learning should allow for a deeper understanding of MPI which will result in more precise predictions at the future LHC energy of 13 TeV!

See **8 TeV!**
 We can now predict **more precisely than before!**