QCD@LHC 2015

Soft QCD and MPI

QCD@LHC

1st-5th September 2015
Queen Mary, London

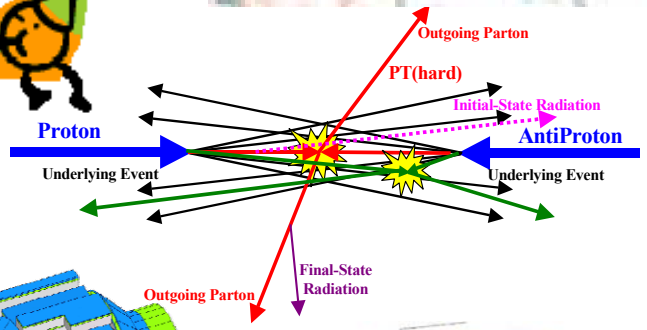
Rick Field

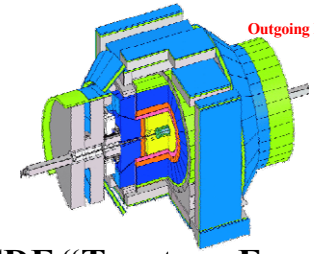
University of Florida

Quantum Chromo-Dynamics

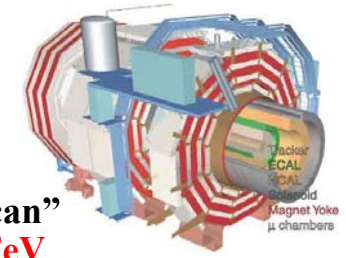
Outline of Talk

- **UE Studies:** Past, present, and future.
- **CMS UE Tunes:** Two PYTHIA 6 tunes, three PYTHIA 8 tunes, and one HERWIG++ tune from the CMS "Physics Comparisons & Generator Tunes" subgroup.
- **The Energy Dependence of the UE:** Detailed look at the energy dependence of the UE and the extrapolation to 13 TeV.
- **Predictions at 13 TeV:** Compare the CMS PYTHIA 8 tunes with the Skands Monash tune and the PYTHIA 6 Tune Z2* at 13 TeV.
- **MB & UE Data 13 TeV:** Look at the early MB data from CMS and ATLAS and the early UE data from ATLAS.



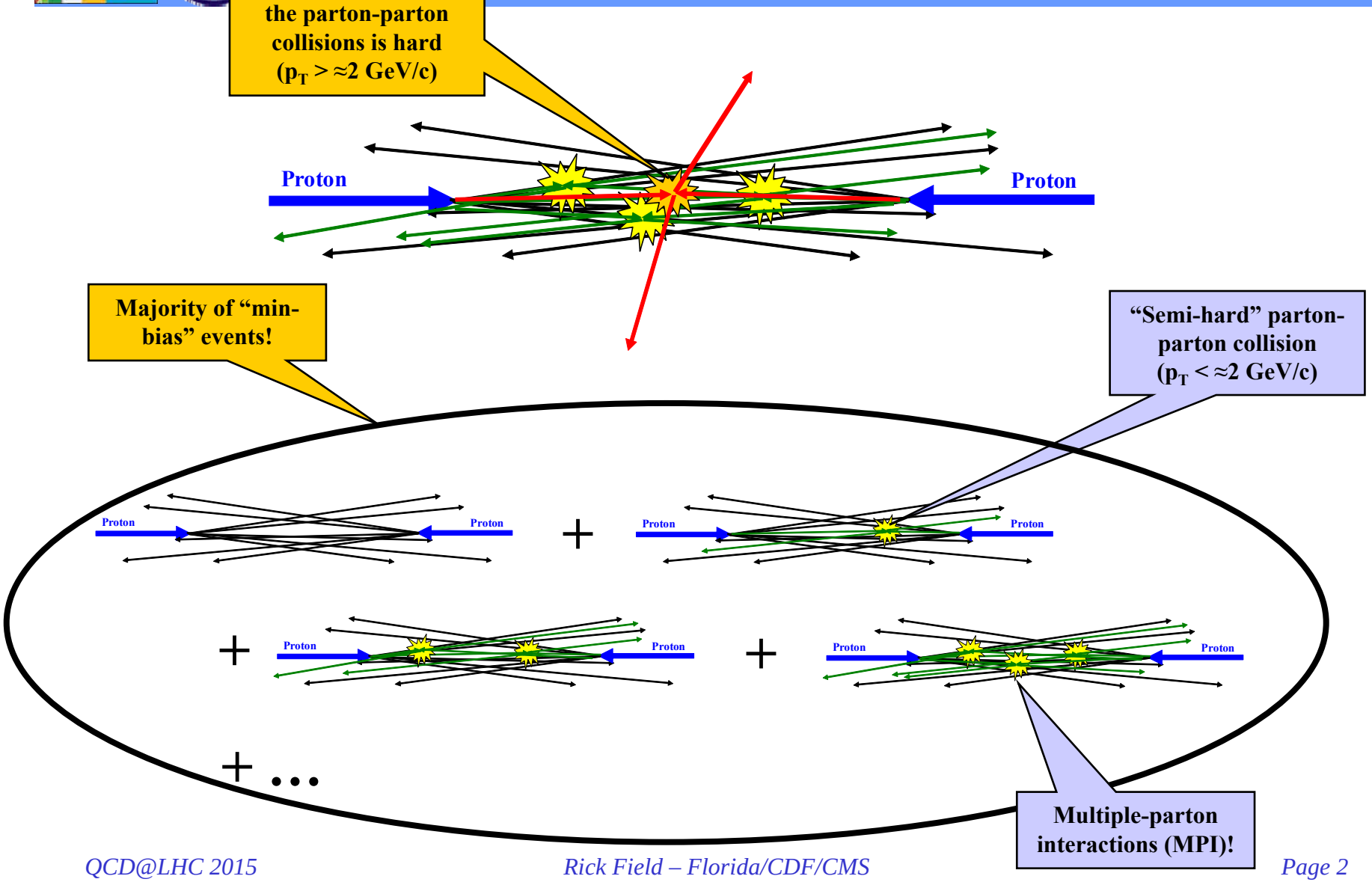


CDF "Tevatron Energy Scan"
300 GeV, 900 GeV, 1.96 TeV



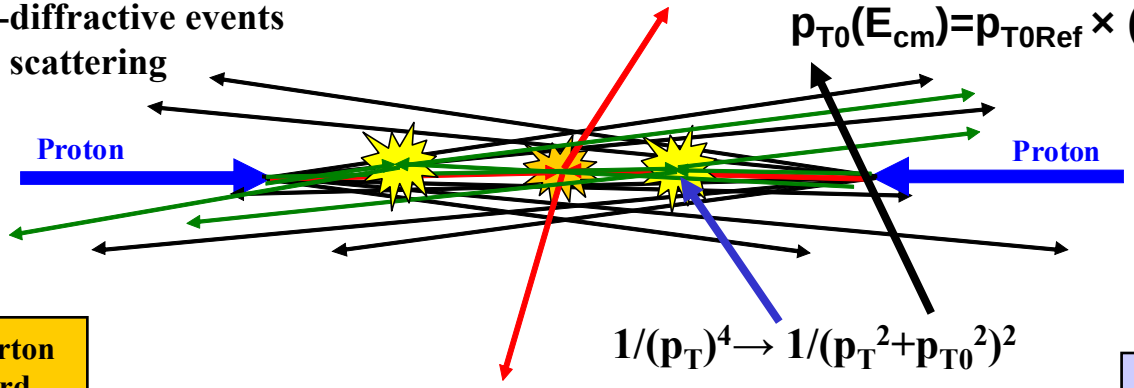
CMS at the LHC
900 GeV, 7 TeV, 13 TeV

The Inelastic Non-Diffractive Cross-Section



The "Underlying Event"

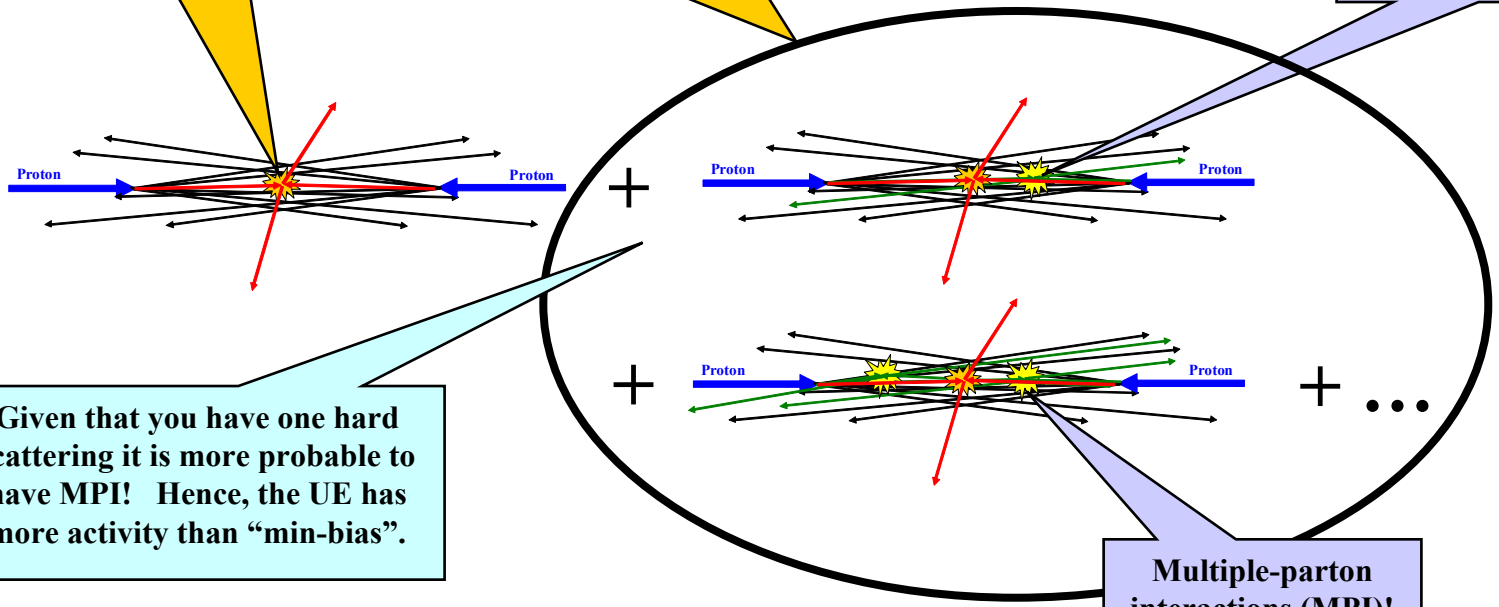
Select inelastic non-diffractive events that contain a hard scattering



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

The "underlying-event" (UE)!

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



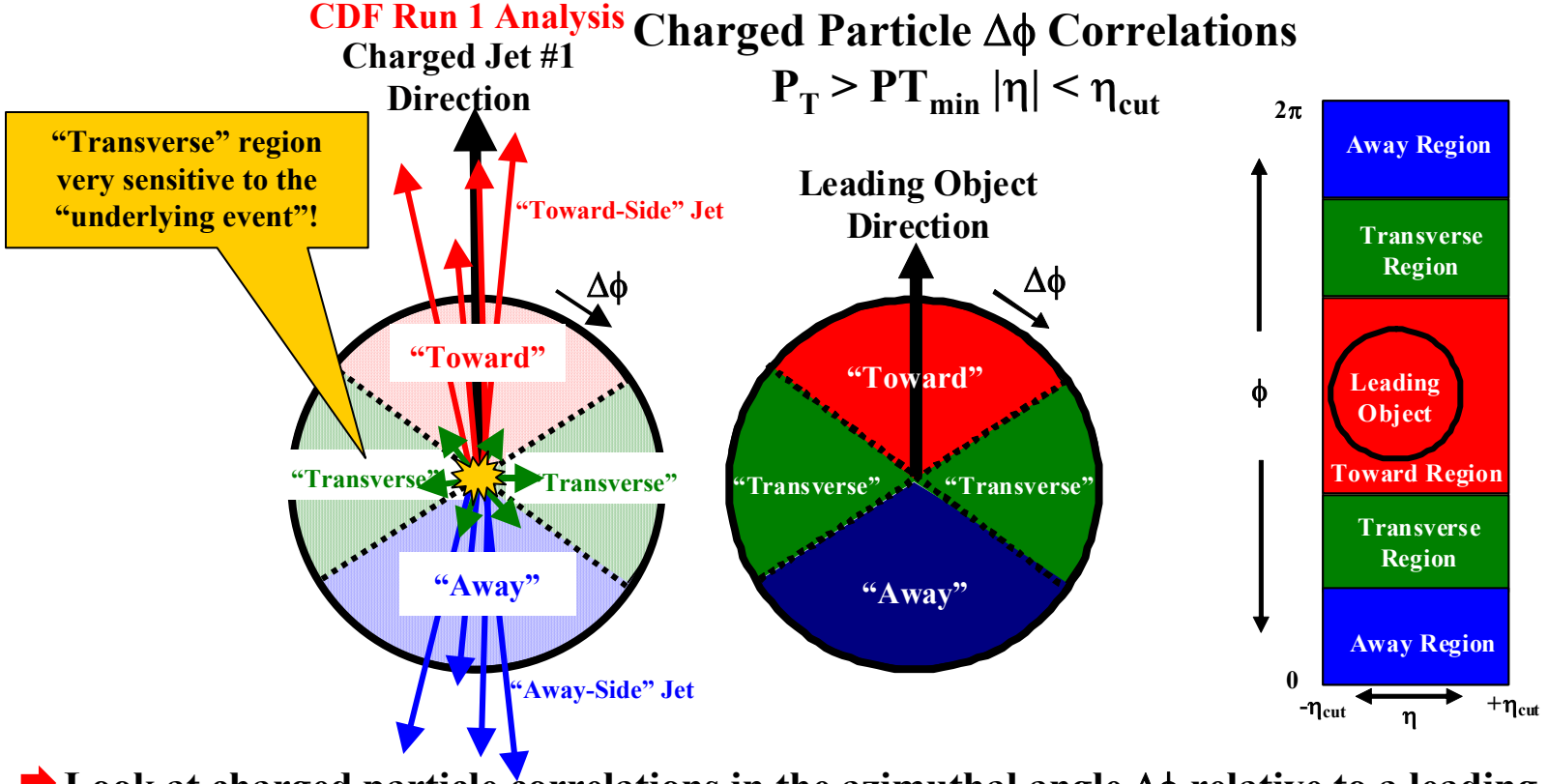
Given that you have one hard scattering it is more probable to have MPI! Hence, the UE has more activity than "min-bias".

Multiple-parton interactions (MPI)!

Traditional Approach

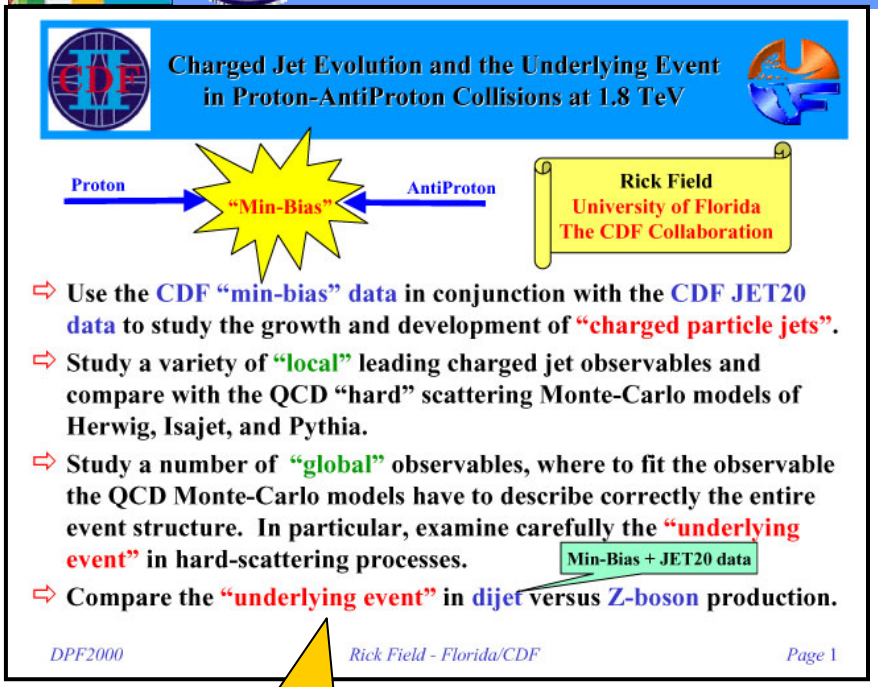
CDF Run 1 Analysis **Charged Particle Δϕ Correlations**

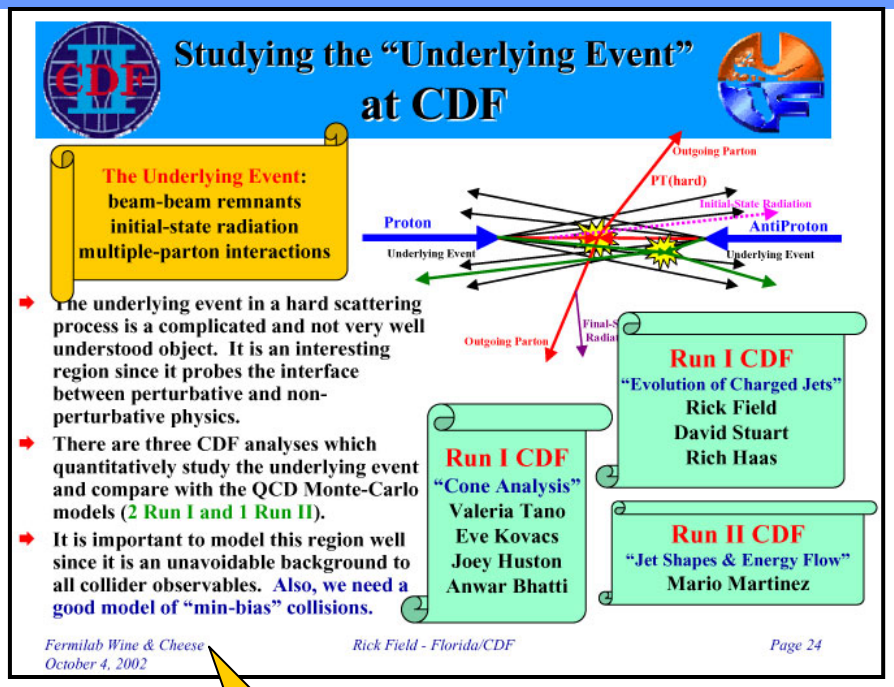
$P_T > PT_{min}$ $|\eta| < \eta_{cut}$



- Look at charged particle correlations in the azimuthal angle Δϕ relative to a leading object (*i.e.* CaloJet#1, ChgJet#1, PTmax, Z-boson). For CDF PTmin = 0.5 GeV/c η_{cut} = 1.0 or 0.8.
- Define $|\Delta\phi| < 60^o$ as "Toward", $60^o < |\Delta\phi| < 120^o$ as "Transverse", and $|\Delta\phi| > 120^o$ as "Away".
- All three regions have the same area in η-ϕ space, $\Delta\eta \times \Delta\phi = 2\eta_{cut} \times 120^o = 2\eta_{cut} \times 2\pi/3$. Construct densities by dividing by the area in η-ϕ space.

Early Studies of the UE



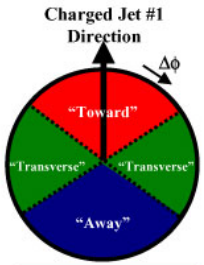


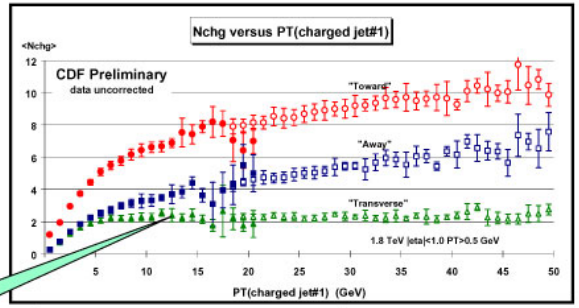
DPF 2000: My first presentation on the "underlying event"!

First CDF UE Studies
Rick Field Wine & Cheese Talk
October 4, 2002

My First Talk on the UE

DiJet: Charged Multiplicity versus PT(chgjet#1)





Underlying event "plateau"

Refer to the Min-Bias + JET20 data as the "dijet" data.

⇨ Dijet data on the average number of "toward" ($|\Delta\phi|<60^o$), "transverse" ($60<|\Delta\phi|<120^o$), and "away" ($|\Delta\phi|>120^o$) charged particles ($P_T > 0.5$ GeV, $|\eta| < 1$, including jet#1) as a function of the transverse momentum of the leading charged particle jet. Each point corresponds to the <Nchg> in a 1 GeV bin. The (open) points are the Min-Bias (JET20) data. The errors on the (*uncorrected*) data include statistical and correlated systematic uncertainties.

DPF2000 *Rick Field - Florida/CDF* *Page*

The Underlying Event: Summary & Conclusions

The "Underlying Event"

⇨ The underlying event is very similar in dijet and the Z-boson production as predicted by the QCD Monte-Carlo models. The "toward" region in Z-boson production is a direct measure of the underlying event.

⇨ The number of charged particles per unit rapidity (height of the "plateau") is at least twice that observed in "soft" collisions at the same corresponding energy.

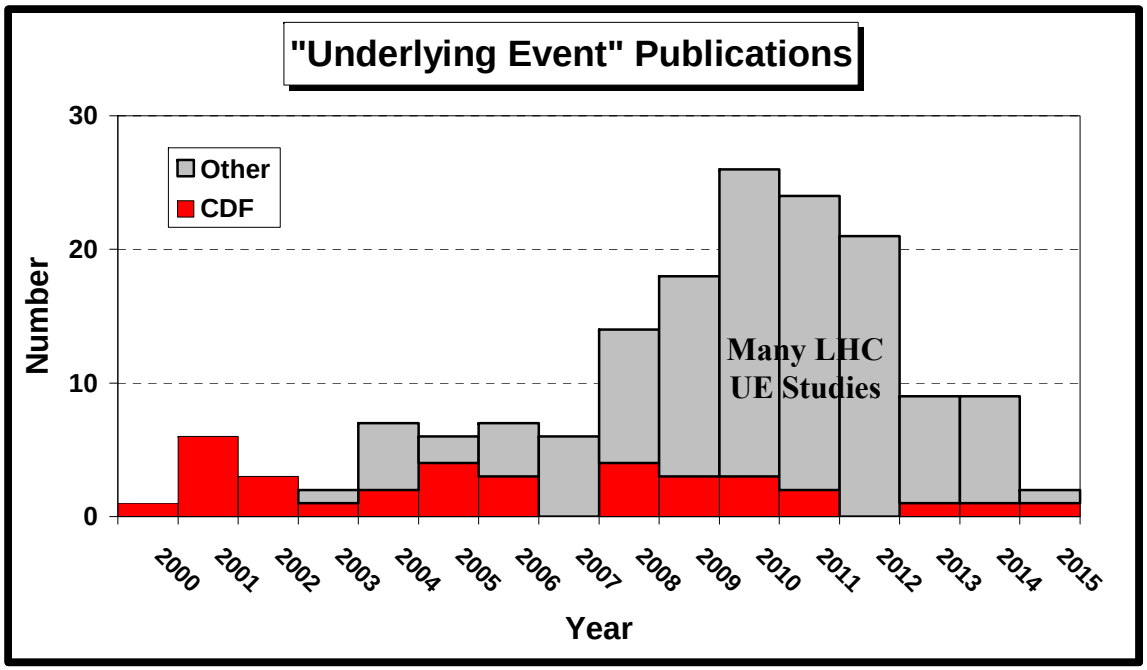
⇨ None of the QCD Monte-Carlo models correctly describe the underlying event. Herwig and Pythia 6.125 do not have enough activity in the underlying event. Pythia 6.115 has about the right amount of activity in the underlying event, but as a result produces too much overall multiplicity. Isajet has a lot of activity in the underlying event, but with the wrong dependence on P_T(jet#1) or P_T(Z). None of the Monte-carlo models have the correct P_T dependence of the beam-beam remnant component of the underlying event.

DPF2000 *Rick Field - Florida/CDF* *Page 36*

Need to "tune" the QCD MC models!

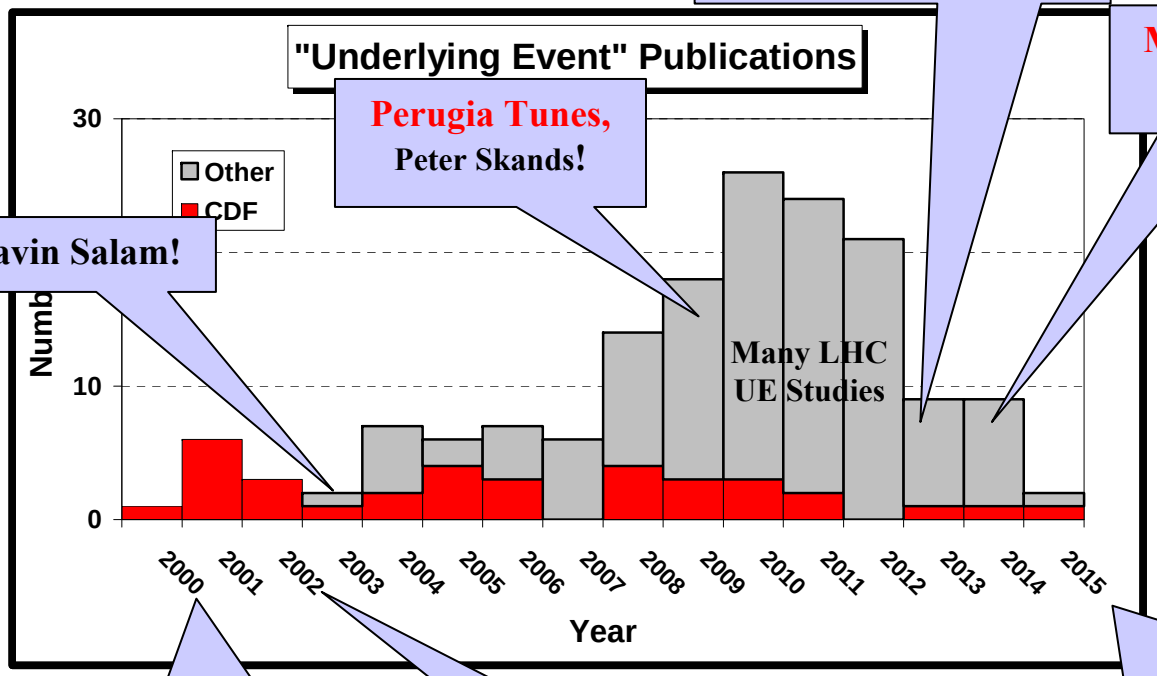
My first look at the "underlying event plateau"!

UE Publications



➡ **Publications on the "underlying event" (2000-2015).**

UE Publications



HERWIG++ UE Tune, M. Seymour and A. Siódmok!

Monash Tune, Peter Skands!

Perugia Tunes, Peter Skands!

Gavin Salam!

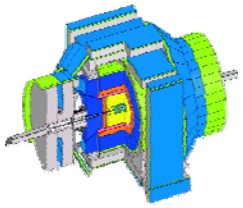
➡ Publications on t… derlying ev…

The Underlying Event in Large Transverse Momentum Charged Jet and Z−boson Production at CDF, R. Field, published in the proceedings of DPF 2000.

A Study of the Energy Dependence of the Underlying Event in Proton-Antiproton Collisions, CDF Collaboration, submitted to Phys. Rev. D. (August 24, 2015)!

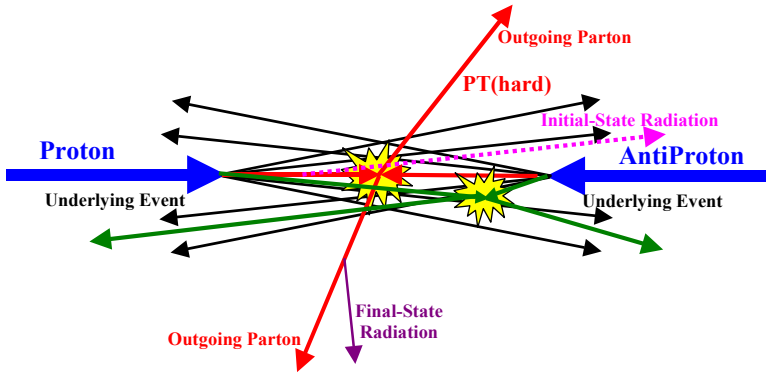
Charged Jet Evolution and the Underlying Event in Proton-Antiproton Collisions at 1.8 TeV, CDF Collaboration, Phys. Rev. D65 (2002) 092002.

Latest CDF UE Publication



CDF Run 2
Tevatron Energy Scan
300 GeV, 900 GeV, 1.96 TeV

Sorry to be so slow!!



Draft PRD Version 6

Submitted to PRD

A Study of the Energy Dependence of the Underlying Event in Proton-Antiproton Collisions

The CDF Collaboration

August 2, 2015

Abstract

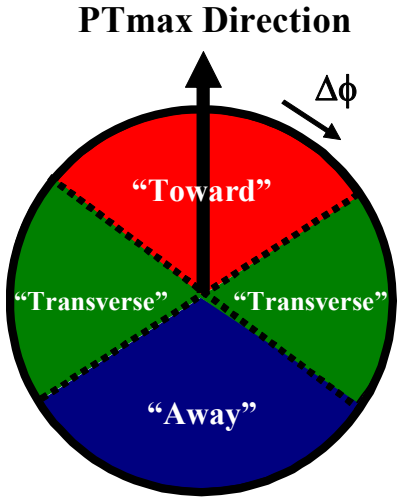
We study charged particle production ($p_T > 0.5$ GeV/c, $|\eta| < 0.8$) in proton-antiproton collisions at 300 GeV, 900 GeV, and 1.96 TeV. We use the direction of the charged particle with the largest transverse momentum in each event to define three regions of η-ϕ space; "toward", "away", and "transverse". The average number and the average scalar p_T sum of charged particles in the transverse region are sensitive to the modeling of the "underlying event". The transverse region is divided into a MAX and MIN transverse region, which helps separate the "hard component" (initial and final-state radiation) from the "beam-beam remnant" and multiple parton interaction components of the scattering. The center-of-mass energy dependence of the various components of the event are studied in detail. The data presented here can be used to constrain and improve QCD Monte Carlo models, resulting in more precise predictions at the LHC energies of 13 and 14 TeV.

The goal is to produce data (corrected to the particle level) that can be used by the theorists to tune and improve the QCD Monte-Carlo models that are used to simulate hadron-hadron collisions.

http://arxiv.org/abs/1508.05340

UE Observables

➡ **"Transverse" Charged Particle Density:** Number of charged particles ($p_T > 0.5$ GeV/c, $|\eta| < \eta_{cut}$) in the "transverse" region as defined by the leading charged particle, PTmax, divided by the area in η-ϕ space, $2\eta_{cut} \times 2\pi/3$, averaged over all events with at least one particle with $p_T > 0.5$ GeV/c, $|\eta| < \eta_{cut}$.



➡ **"Transverse" Charged PTsum Density:** Scalar p_T sum of the charged particles ($p_T > 0.5$ GeV/c, $|\eta| < \eta_{cut}$) in the "transverse" region as defined by the leading charged particle, PTmax, divided by the area in η-ϕ space, $2\eta_{cut} \times 2\pi/3$, averaged over all events with at least one particle with $p_T > 0.5$ GeV/c, $|\eta| < \eta_{cut}$.

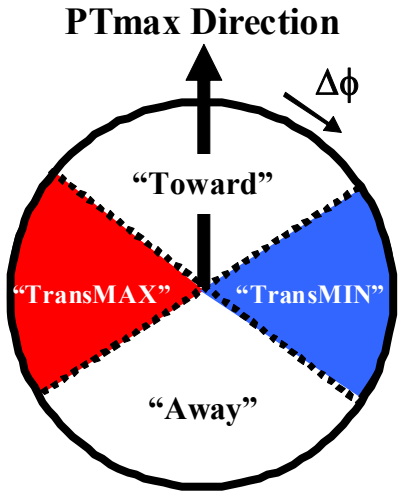
➡ **"Transverse" Charged Particle Average P_T:** Event-by-event $\langle p_T \rangle$ = PTsum/Nchg for charged particles ($p_T > 0.5$ GeV/c, $|\eta| < \eta_{cut}$) in the "transverse" region as defined by the leading charged particle, PTmax, averaged over all events with at least one particle in the "transverse" region with $p_T > 0.5$ GeV/c, $|\eta| < \eta_{cut}$.

➡ **Zero "Transverse" Charged Particles:** If there are no charged particles in the "transverse" region then Nchg and PTsum are zero and one includes these zeros in the average over all events with at least one particle with $p_T > 0.5$ GeV/c, $|\eta| < \eta_{cut}$. However, if there are no charged particles in the "transverse" region then the event is not used in constructing the "transverse" average p_T.

UE Observables

➡ **"transMAX" and "transMIN" Charged Particle Density:** Number of charged particles ($p_T > 0.5$ 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, $2\eta_{cut} \times 2\pi/6$, averaged over all events with at least one particle with $p_T > 0.5$ GeV/c, $|\eta| < \eta_{cut}$.

➡ **"transMAX" and "transMIN" Charged PTsum Density:** Scalar p_T sum of charged particles ($p_T > 0.5$ 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, $2\eta_{cut} \times 2\pi/6$, averaged over all events with at least one particle with $p_T > 0.5$ GeV/c, $|\eta| < \eta_{cut}$.



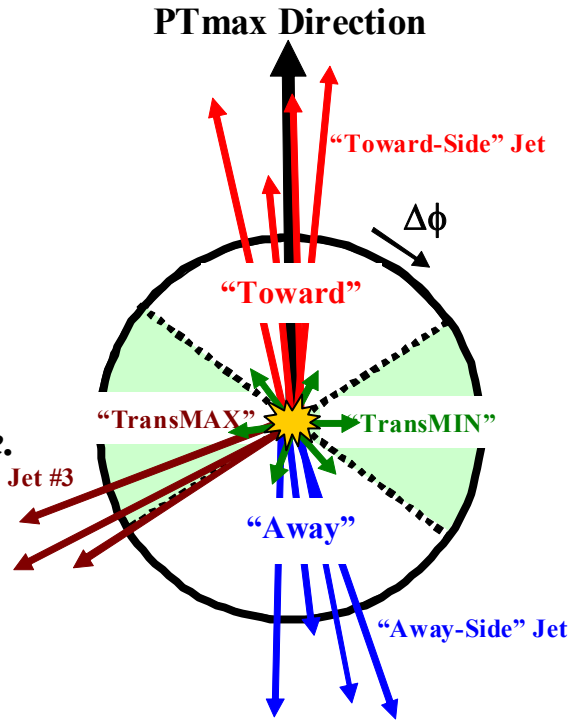
Note: The overall "transverse" density is equal to the average of the "transMAX" and "TransMIN" densities. The "TransDIF" Density is the "transMAX" Density minus the "transMIN" Density

"Transverse" Density = "transAVE" Density = ("transMAX" Density + "transMIN" Density)/2

"TransDIF" Density = "transMAX" Density - "transMIN" Density

"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.

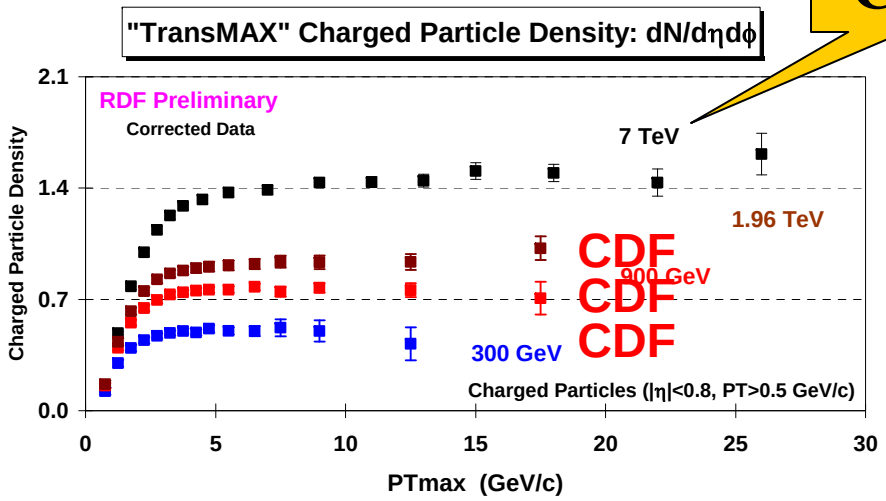
"TransDIF" density more sensitive to ISR & FSR.

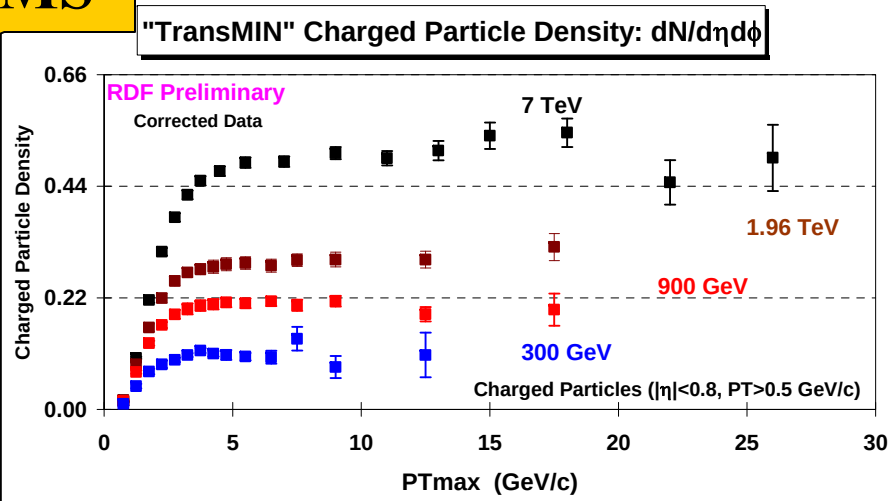
0 ≤ "TransDIF" ≤ 2×"TransAVE"

"TransDIF" = "TransAVE" if "TransMIX" = 3×"TransMIN"

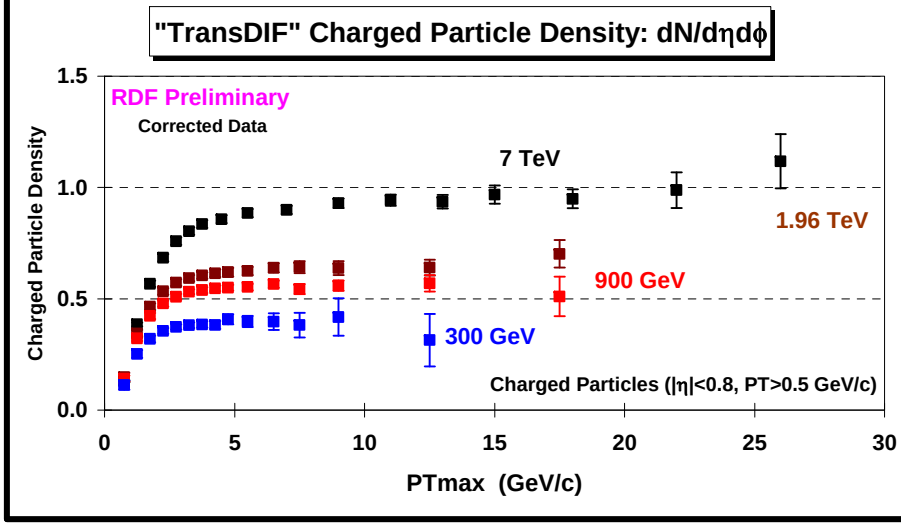
"transMAX/MIN" NchgDen

CMS

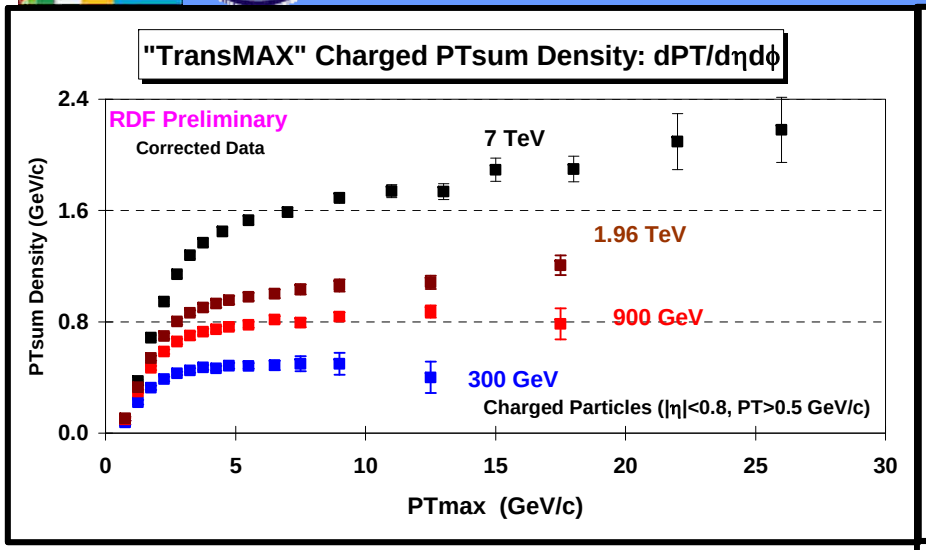


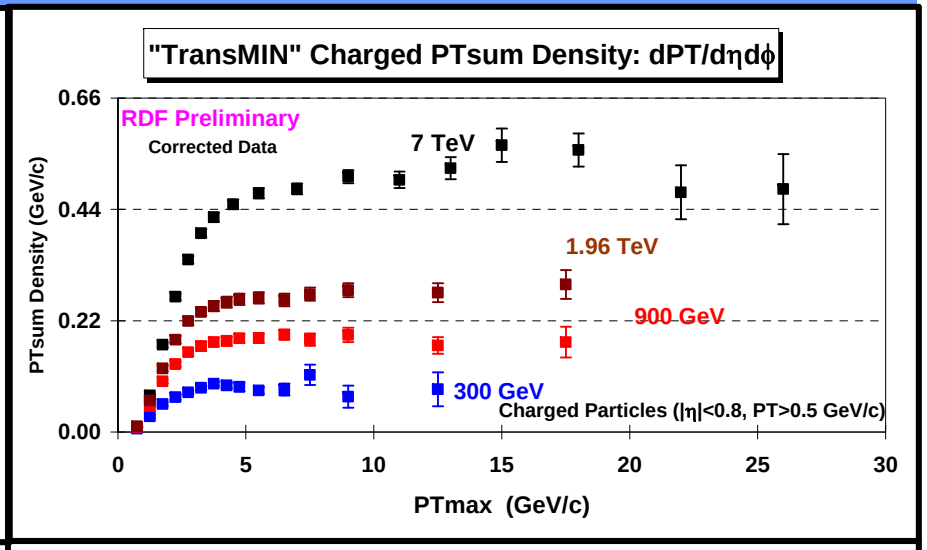


➡ **Corrected CMS data at 7 TeV and CDF data at 1.96 TeV, 900 GeV, and 300 GeV on the charged particle density in the "transMAX", "transMIN", and "transDIF" regions as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$. The data are corrected to the particle level with errors that include both the statistical error and the systematic uncertainty.**

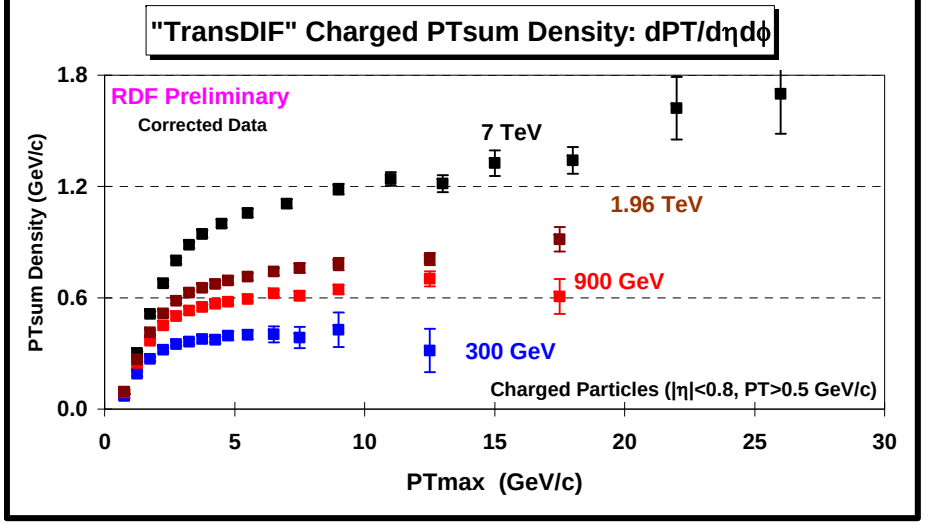


"transMAX/MIN" PTsumDen

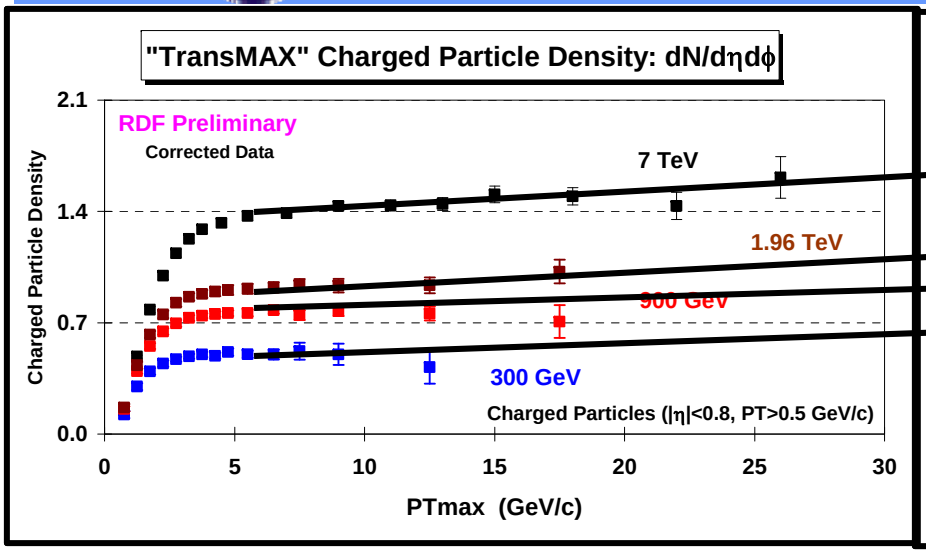


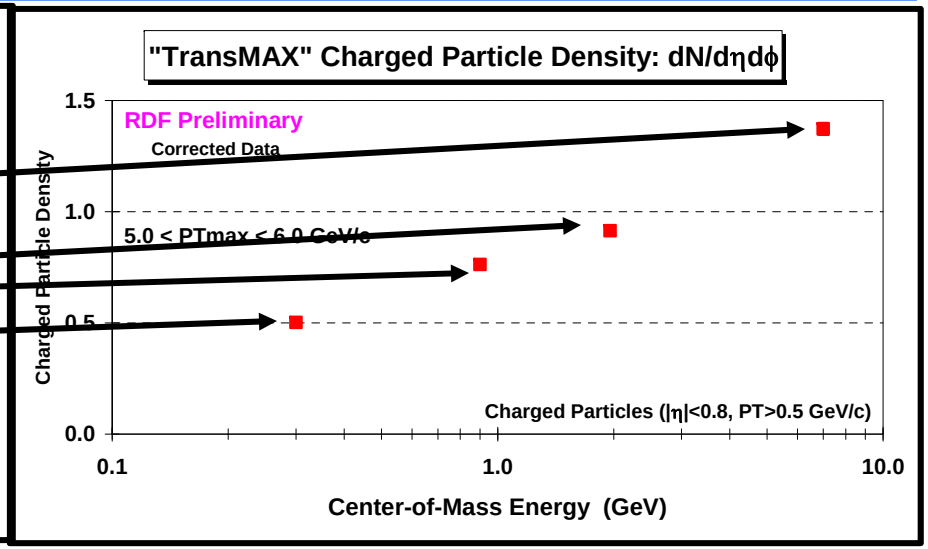


➡ **Corrected CDF data at 1.96 TeV, 900 GeV, and 300 GeV on the charged PTsum density in the "transMAX", "transMIN", and "transDIF" regions as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$. The data are corrected to the particle level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



"transMAX" NchgDen vs E_{cm}

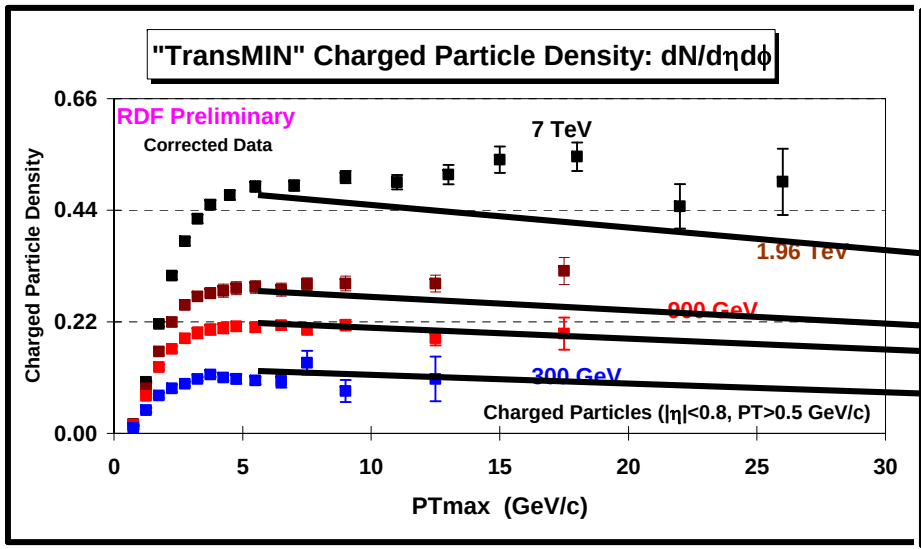


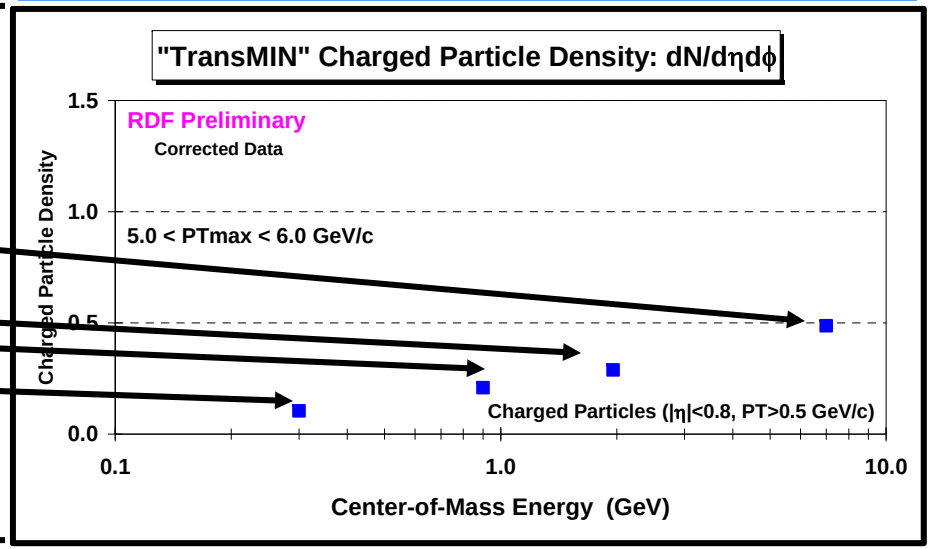


➡ **Corrected CMS data at 7 TeV and CDF data at 1.96 TeV, 900 GeV, and 300 GeV on the charged particle density in the "transMAX" region as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$. The data are corrected to the particle level with errors that include both the statistical error and the systematic uncertainty.**

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

"transMIN" NchgDen vs E_{cm}

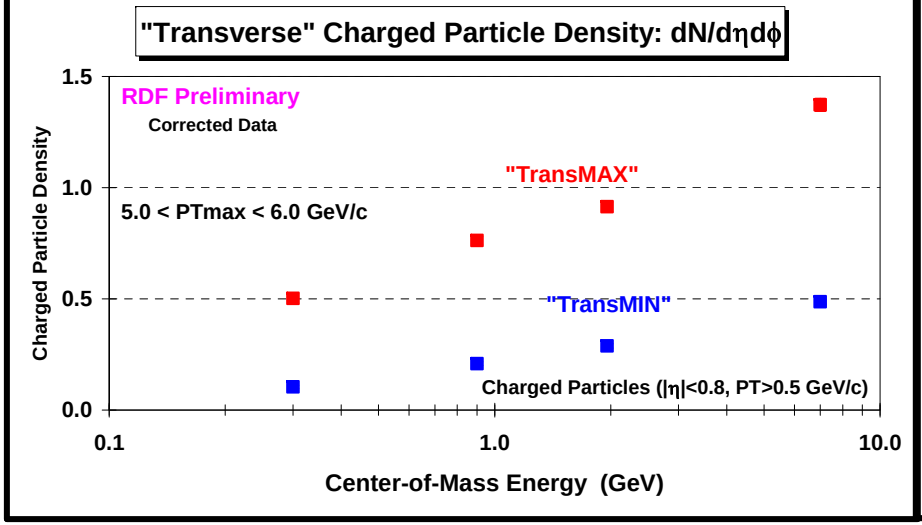


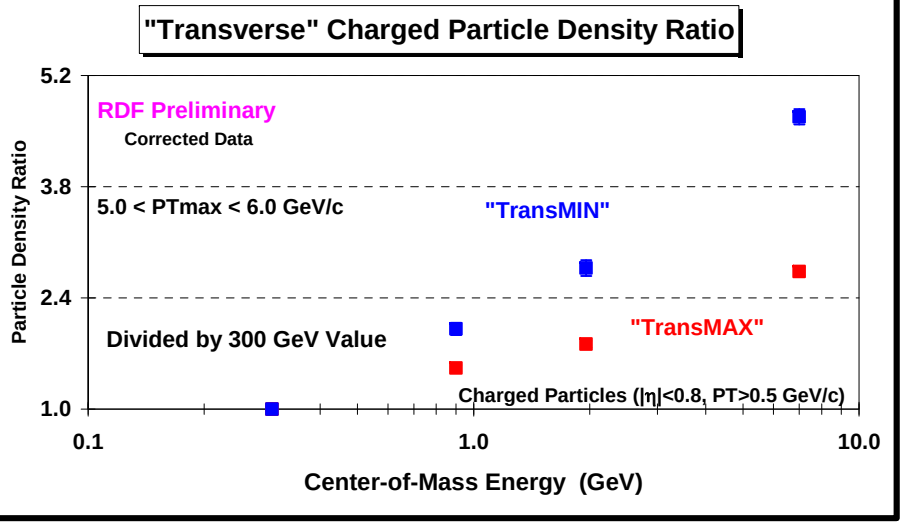


➡ **Corrected CMS data at 7 TeV and CDF data at 1.96 TeV, 900 GeV, and 300 GeV on the charged particle density in the "transMIN" region as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$. The data are corrected to the particle level with errors that include both the statistical error and the systematic uncertainty.**

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

"Transverse" NchgDen vs E_{cm}

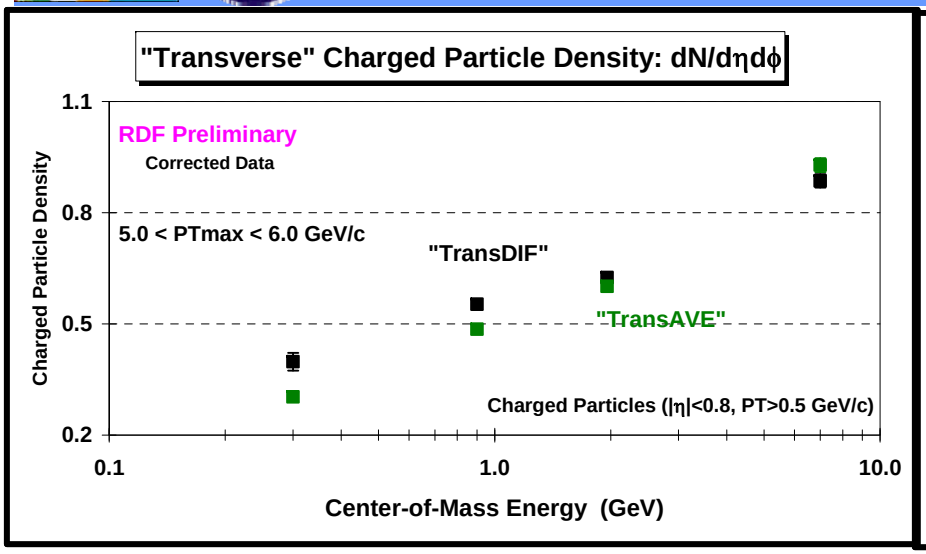


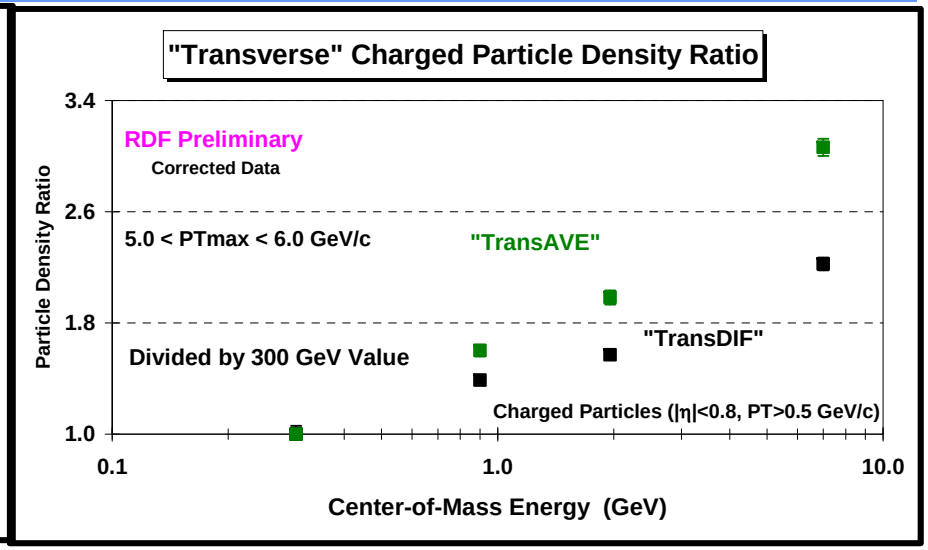


➡ **Corrected CMS data at 7 TeV and CDF data at 1.96 TeV, 900 GeV, and 300 GeV on the charged particle density in the "transMAX" and "transMIN" regions as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$ with $5 < PTmax < 6$ GeV/c. The data are plotted versus the center-of-mass energy (*log scale*).**

➡ **Ratio of CMS data at 7 TeV and 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" and "transMIN" regions as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$ with $5 < PTmax < 6$ GeV/c. The data are plotted versus the center-of-mass energy (*log scale*).**

"Transverse" NchgDen vs E_{cm}

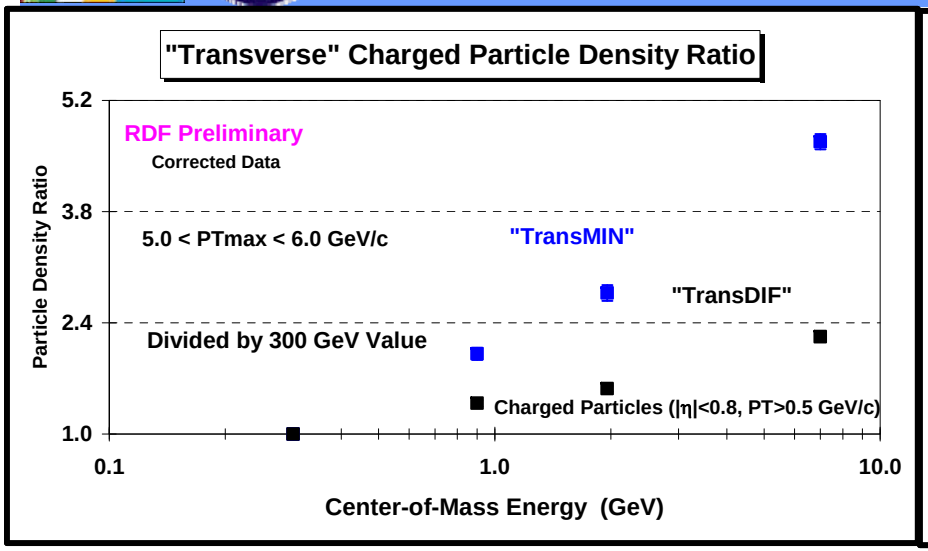


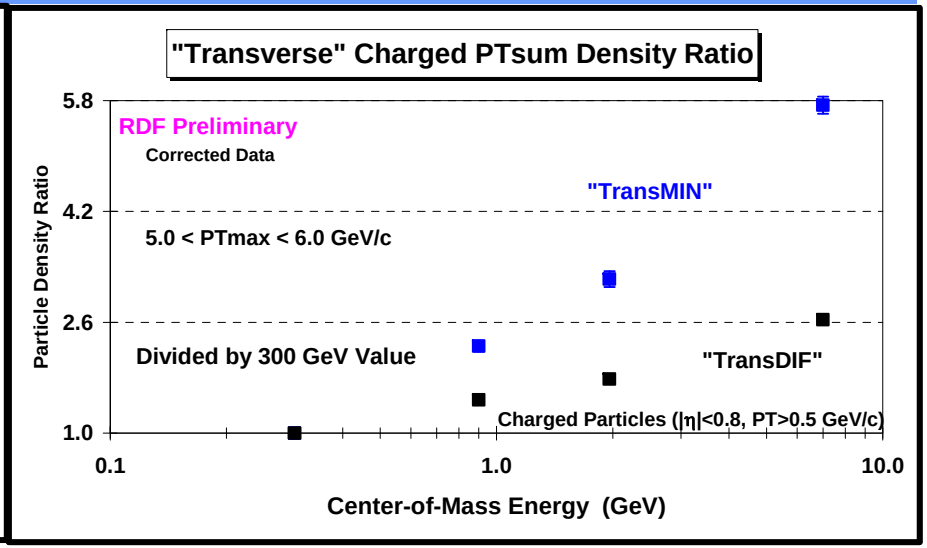


➡ **Corrected CMS data at 7 TeV and CDF data at 1.96 TeV, 900 GeV, and 300 GeV on the charged particle density in the "transAVE" and "transDIF" regions as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$ with $5 < PTmax < 6$ GeV/c. The data are plotted versus the center-of-mass energy (*log scale*).**

➡ **Ratio of CMS data at 7 TeV and CDF data at 1.96 TeV, 900 GeV, and 300 GeV to the value at 300 GeV for the charged particle 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 $|\eta| < 0.8$ with $5 < PTmax < 6$ GeV/c. The data are plotted versus the center-of-mass energy (*log scale*).**

"TransMIN/DIF" vs E_{cm}

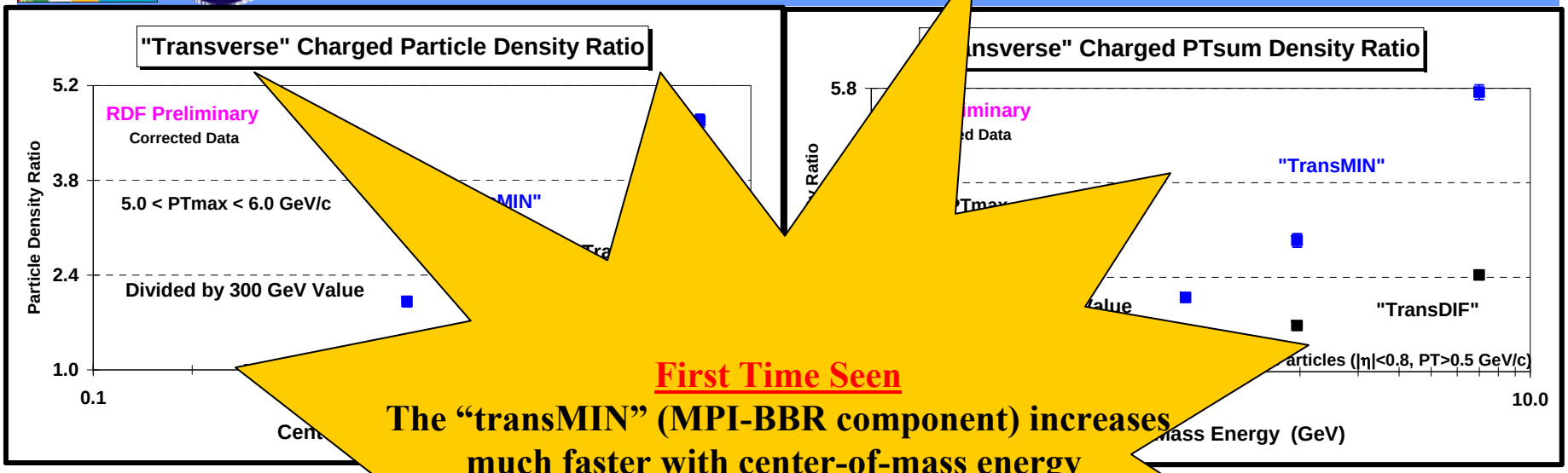




➡ **Ratio of CMS data at 7 TeV and CDF data at 1.96 TeV, 900 GeV, and 300 GeV to the value at 300 GeV for the charged particle density in the "transMIN", and "transDIF" regions as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$ with $5 < PTmax < 6$ GeV/c. The data are plotted versus the center-of-mass energy (*log scale*).**

➡ **Ratio of CMS data at 7 TeV and 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*).**

"TransMIN/DIF" vs E_{cm}

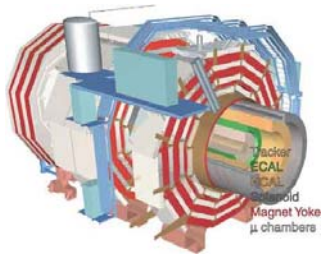


First Time Seen

The "transMIN" (MPI-BBR component) increases much faster with center-of-mass energy than the "transDIF" (ISR-FSR component)!

➡ **Ratio of CMS data at 7 TeV and CDF data at 1.96 TeV, 900 GeV, a GeV to the value at 300 GeV for th e charged PTsum density in the "transMIN", and "transDI and "transDIF" regions as defined by the leading charge d by ding charged particle (PTmax) for charged particle ax) for ed particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$ with $5 <$ max $<$ and $|\eta| <$ with $5 <$ PTmax < 6 GeV/c. The data are plotted versus the c. The data are plotted versus the center-of-mass energy (*log scale*).** r-of-mass energy (*log scale*).

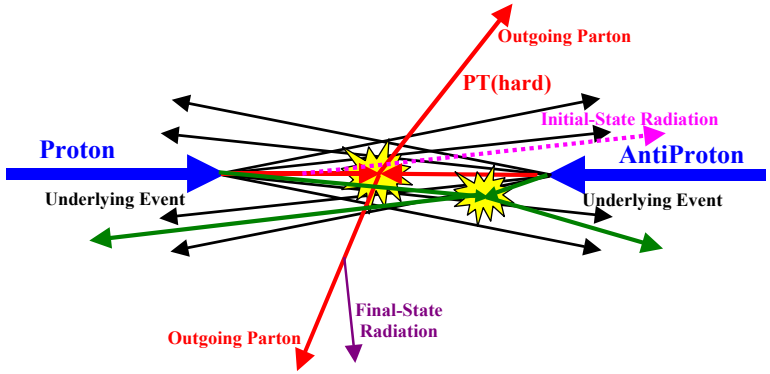
CMS Tuning Publication



CMS at the LHC

900 GeV, 2.96 TeV, 7 TeV, 8 TeV, 13 TeV

Sorry to be so slow!!



http://arxiv.org/abs/soon!

To be submitted to JHEP CMS PAPER GEN-14-001

DRAFT
CMS Paper

The content of this note is intended for CMS internal use and distribution only

2015/08/12
Head Id: 234706
Archive Id: 299863P
Archive Date: 2014/04/01
Archive Tag: trunk

CMS underlying event and double parton scattering tunes

The CMS Collaboration

Abstract

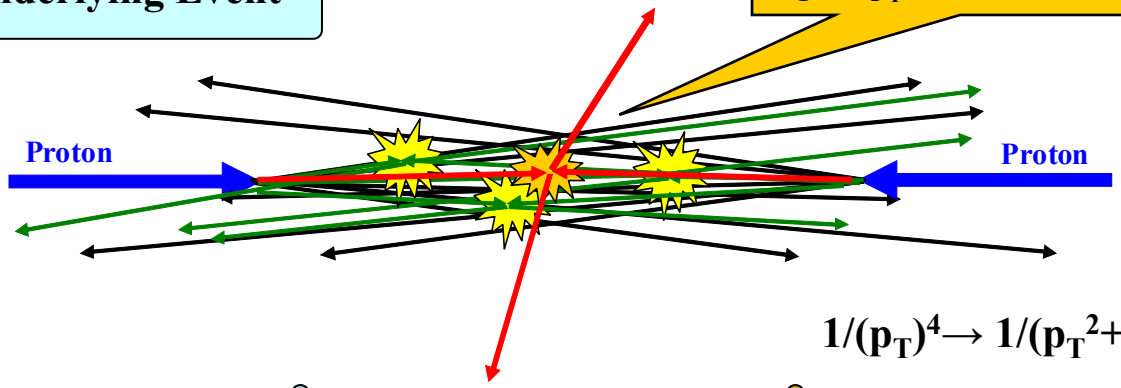
Three new PYTHIA-8 underlying event (UE) tunes are constructed, one using the CTEQ6L1 parton distribution function (PDF), one using HERAPDF 1.5 leading order (LO), and one using the NNPDF2.3LO PDF; two new PYTHIA-6 UE tunes, one for the CTEQ6L PDF and one for the HERAPDF 1.5 LO, and one new HERWIG ++ UE tune for the CTEQ6L1 PDF are also available. Simultaneous fits to CDF UE data at 300 GeV, 900 GeV, and 1.96 TeV, together with CMS UE data at 7 TeV, check the UE models and constrain their parameters, providing thereby more precise predictions for proton-proton collisions at 13 TeV. In addition, several new double-parton scattering (DPS) tunes are investigated when the values of the UE parameters from fits to observables are consistent with the values determined from fitting DPS-sensitive observables. Also examined is how well the new UE tunes predict "minimum bias" (MB) events, jet and Drell–Yan ($q\bar{q} \rightarrow Z/\gamma^* \rightarrow$ lepton-antilepton+jets) observables, as well as the MB and UE observables at 13 TeV.

UE Tunes and MB

"Underlying Event"

Allow primary hard-scattering to go to $p_T = 0$ with same cut-off!

Fit the "underlying event" in a hard scattering process.

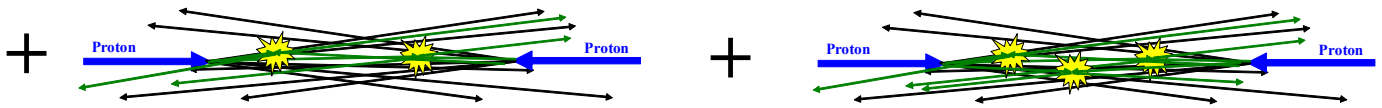


$1/(p_T)^4 \rightarrow 1/(p_T^2+p_{T0}^2)^2$

"Min-Bias" (add single & double diffraction)

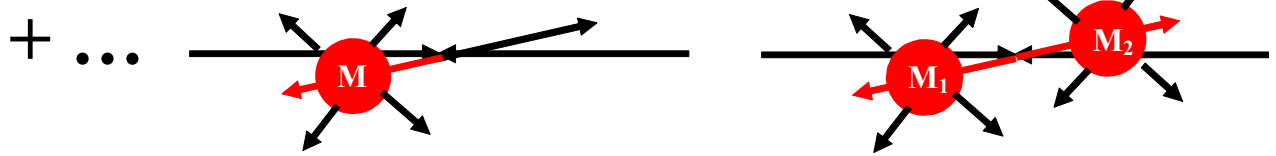
Predict MB (ND)!

Predict MB (IN)!



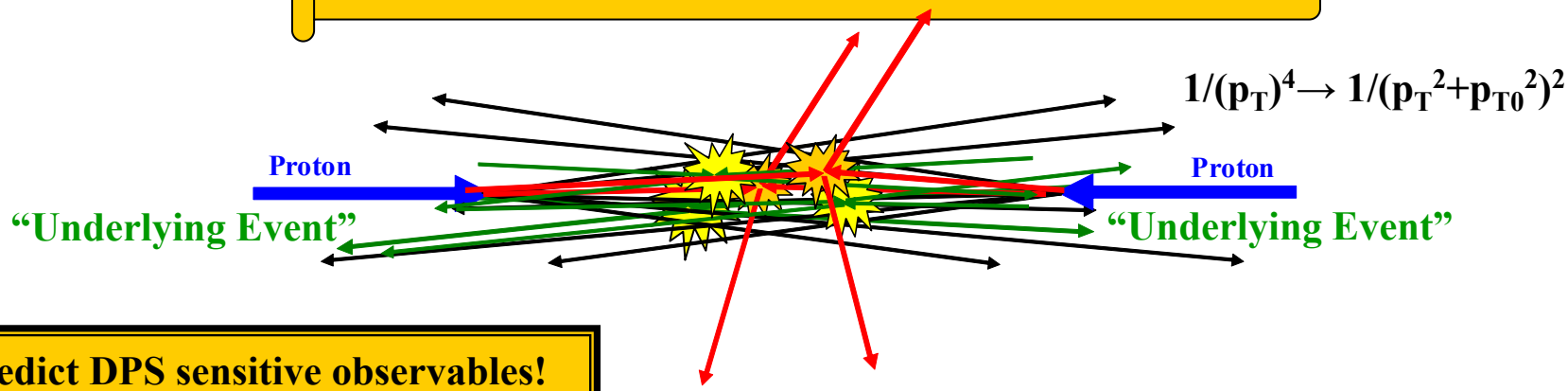
Single Diffraction

Double Diffraction



UE Tunes and DPS

DPS: Double Parton Scattering

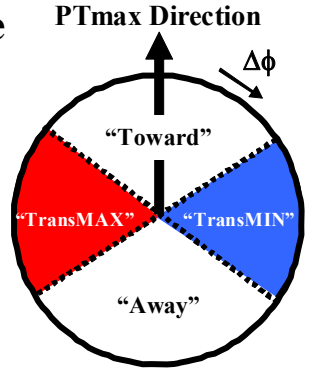


Predict DPS sensitive observables!

Most of the time MPI are much "softer" than the primary "hard" scattering, however, occasionally two "hard" 2-to-2 parton scatterings can occur within the same hadron-hadron. This is referred to as double parton scattering (DPS).

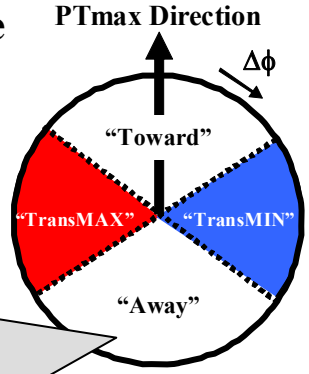
Fit the "underlying event" in a hard scattering process.

CMS UE Tunes



- **PYTHIA 6.4 Tune CUETP6S1-CTEQ6L:** Start with Tune Z2*-lep and tune to the CDF PTmax "transMAX" and "transMIN" UE data at 300 GeV, 900 GeV, and 1.96 TeV and the CMS PTmax "transMAX" and "transMIN" UE data at 7 TeV.
- **PYTHIA 6.4 Tune CUETP6S1-HERAPDF1.5LO:** Start with Tune Z2*-lep and tune to the CDF PTmax "transMAX" and "transMIN" UE data at 300 GeV, 900 GeV, and 1.96 TeV and the CMS PTmax "transMAX" and "transMIN" UE data at 7 TeV.
- **PYTHIA 8 Tune CUETP8S1-CTEQ6L:** Start with Corke & Sjöstrand Tune 4C and tune to the CDF PTmax "transMAX" and "transMIN" UE data at 900 GeV, and 1.96 TeV and the CMS PTmax "transMAX" and "transMIN" UE data at 7 TeV. **Exclude 300 GeV data.**
- **PYTHIA 8 Tune CUETP8S1-HERAPDF1.5LO:** Start with Corke & Sjöstrand Tune 4C and tune to the CDF PTmax "transMAX" and "transMIN" UE data at 900 GeV, and 1.96 TeV and the CMS PTmax "transMAX" and "transMIN" UE data at 7 TeV. **Exclude 300 GeV data.**
- **PYTHIA 8 Tune CUETP8M1-NNPDF2.3LO:** Start with the Skands Monash-NNPDF2.3LO tune and tune to the CDF PTmax "transMAX" and "transMIN" UE data at 900 GeV, and 1.96 TeV and the CMS PTmax "transMAX" and "transMIN" UE data at 7 TeV. **Exclude 300 GeV data.**
- **HERWIG++ Tune CUETHS1-CTEQ6L:** Start with the Seymour & Siódmok UE-EE-5C tune and tune to the CDF PTmax "transMAX" and "transMIN" UE data at 900 GeV, and 1.96 TeV and the CMS PTmax "transMAX" and "transMIN" UE data at 7 TeV.

CMS UE Tunes



➡ **PYTHIA 6.4 Tune CUETP6S1-CT[illegible]6L:** Start with [illegible]Z2*-lep and tune to the CDF P[illegible] "transMAX" and "[illegible]IN" UE d[illegible] GeV, 900 GeV, and 1.96 TeV a[illegible]MS PTmax [illegible]X" ar[illegible]N" UE da[illegible] TeV.

➡ **PYTHIA 6.4 [illegible]6S1** [illegible]p and tune to the CDF[illegible] GeV, 900 GeV, and 1.96 TeV data at 7[illegible]" UE

➡ **PY[illegible]** [illegible]nd tune to the CDF P[illegible]eV and the CMS PTmax "t[illegible] data.

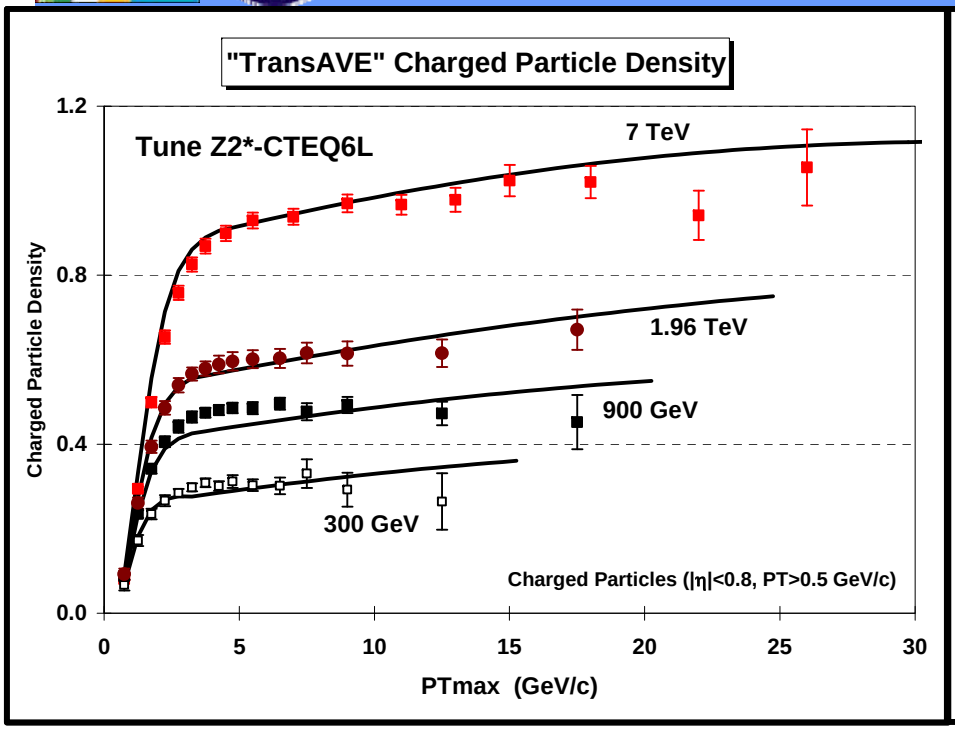
➡ **PYTHIA 8 Tu[illegible]** [illegible]e 4C and tune to the CDF[illegible] [illegible]nd the CMS P[illegible] [illegible]e 300 GeV data.

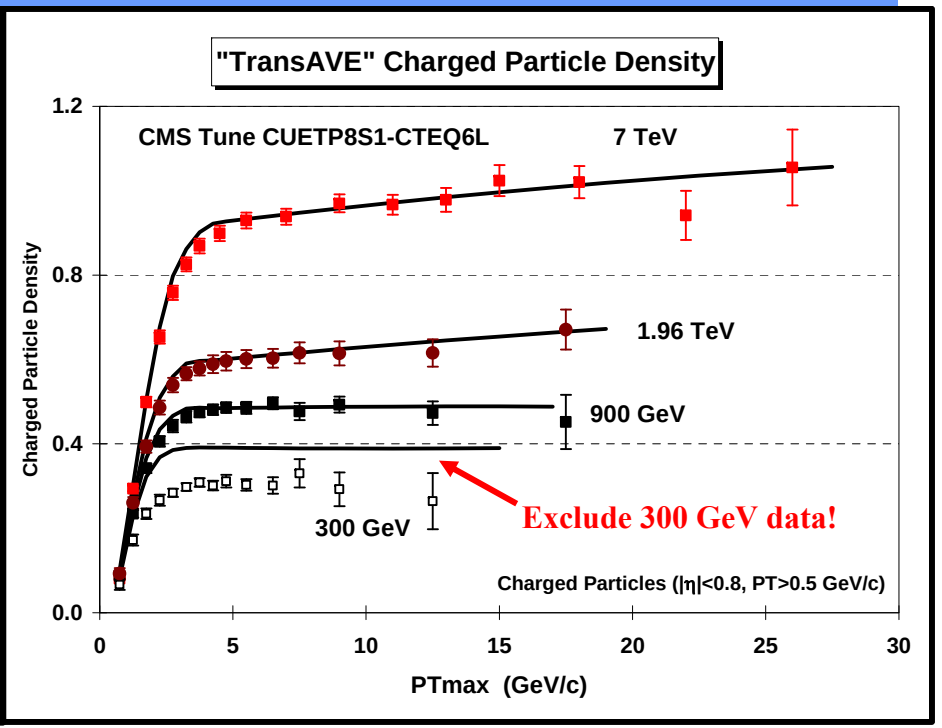
➡ **PYTHIA 8 Tune CUET[illegible]** [illegible]ash-NNPDF2.3LO tune and tune to the CDF P[illegible] [illegible]no[illegible]' UE d[illegible]0 GeV, and 1.96 TeV and the CMS PTmax [illegible]sMA[illegible]ransM[illegible] data at 7 T[illegible] xclude 300 GeV data.

➡ **HERWIG++ Tune CUETHS1-CT[illegible]** Start with[illegible]eymour & Siódm[illegible]k UE-EE-5C tune and tune to the CDF PTmax "tran[illegible]X" and "trans[illegible]N" UE data at 900 GeV, and 1.96 TeV and the CMS PTmax "transMAX'[illegible] "transMIN" U[illegible] data at 7 TeV.

See talk on Saturday morning by Frank Siegert entitled, "Overview of MC Tuning to LHC Data"

CUETP8S1-CTEQ6L

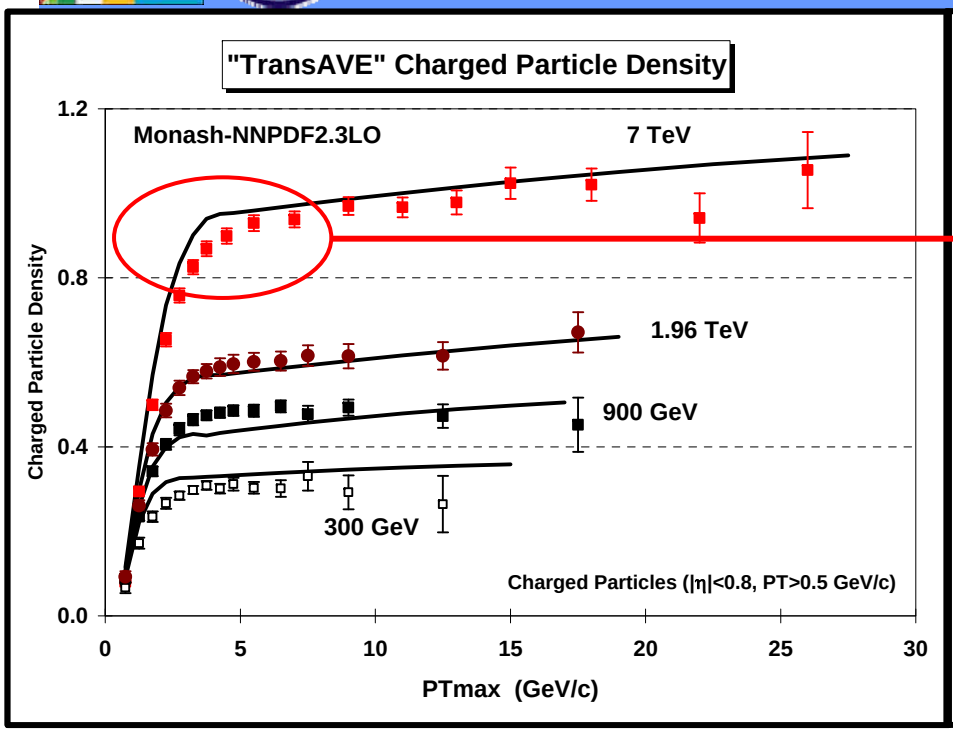


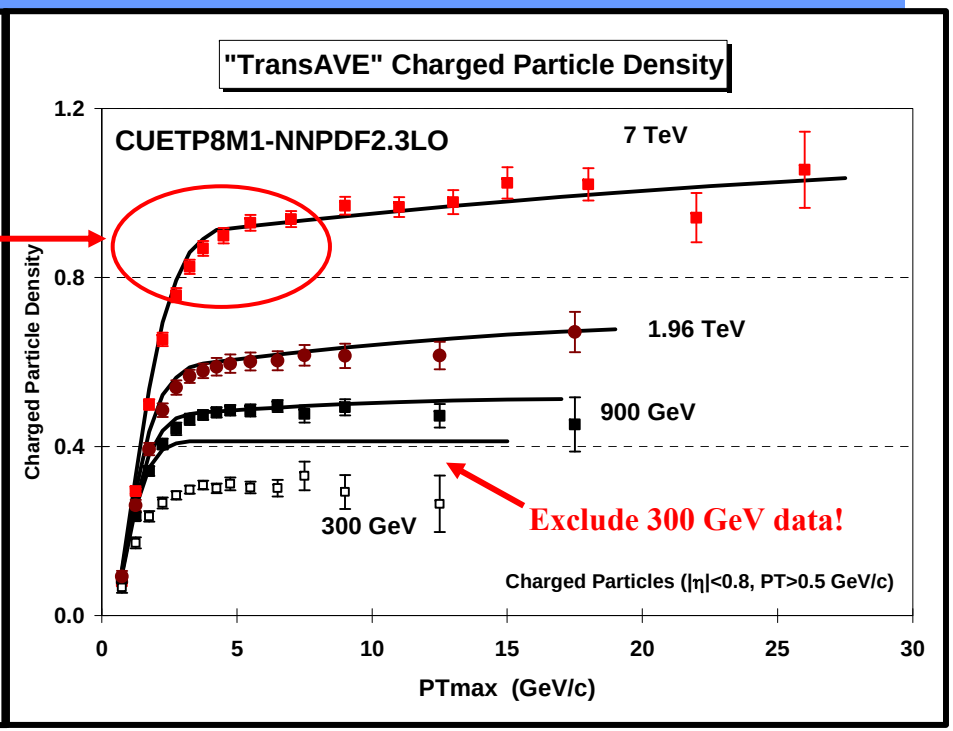


➡ **CMS data at 7 TeV and CDF data at 1.96 TeV, 900 GeV, and 300 GeV on the charged particle density in the "transAVE" region as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$. The data are compared with PYTHIA 6.4 Tune Z2*.**

➡ **CMS data at 7 TeV and CDF data at 1.96 TeV, 900 GeV, and 300 GeV on the charged particle density in the "transAVE" region 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 compared with PYTHIA 8 Tune CUETP8S1-CTEQ6L (excludes 300 GeV in fit).**

CUETP8M1-NNPDF2.3LO

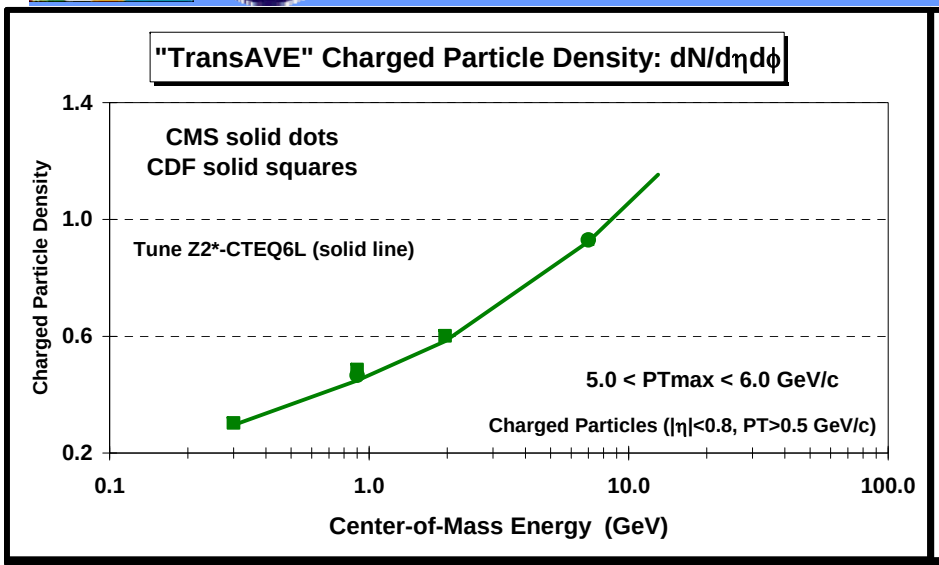


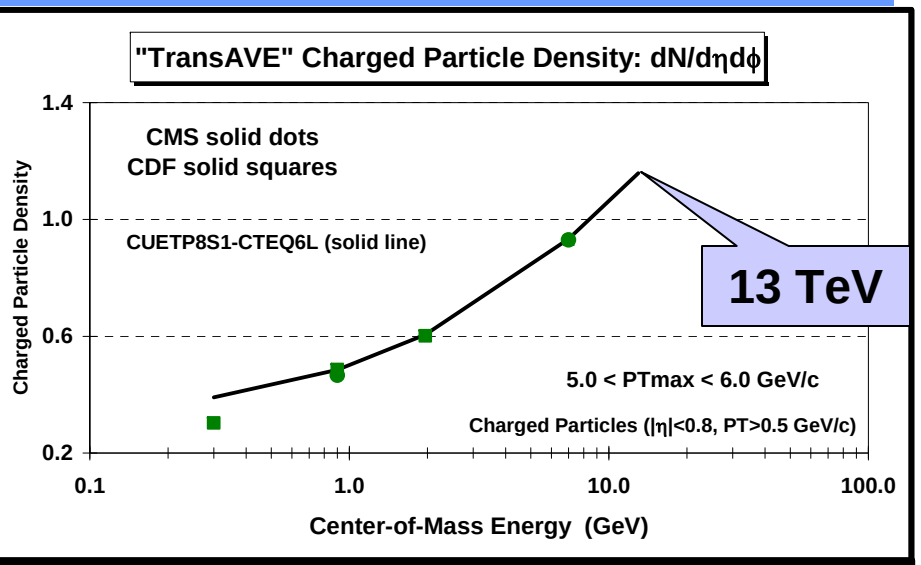


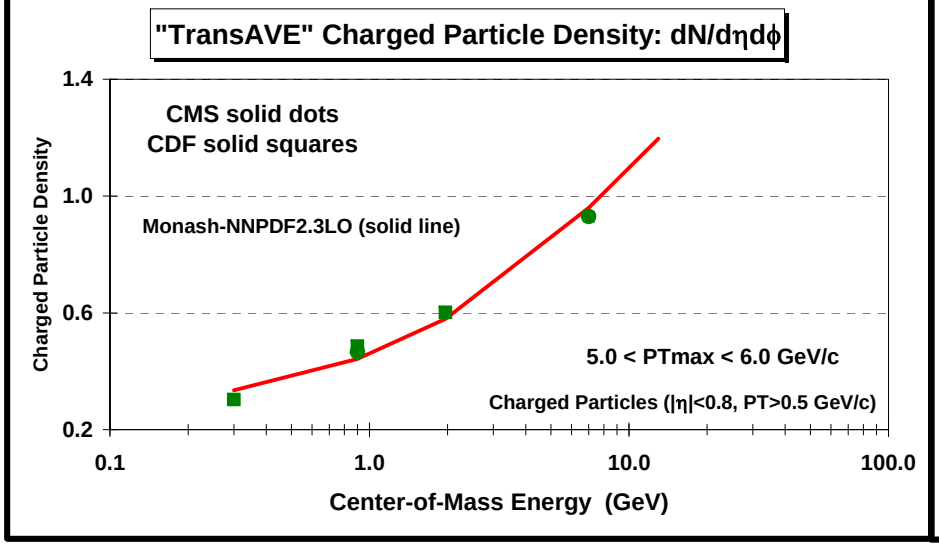
➡ **CMS data at 7 TeV and CDF data at 1.96 TeV, 900 GeV, and 300 GeV on the charged particle density in the "transAVE" region as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$. The data are compared with the PYTHIA 8 Tune Monash-NNPDF2.3LO.**

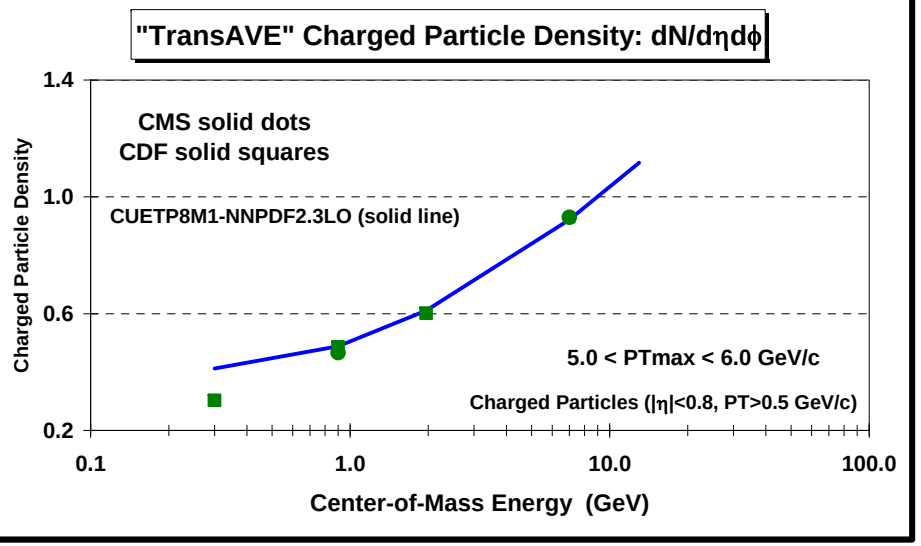
➡ **CMS data at 7 TeV and CDF data at 1.96 TeV, 900 GeV, and 300 GeV on the charged particle density in the "transAVE" region as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$. The data are compared with the PYTHIA 8 Tune CUETP8M1-NNPDF2.3LO (excludes 300 GeV in fit).**

Energy Dependence

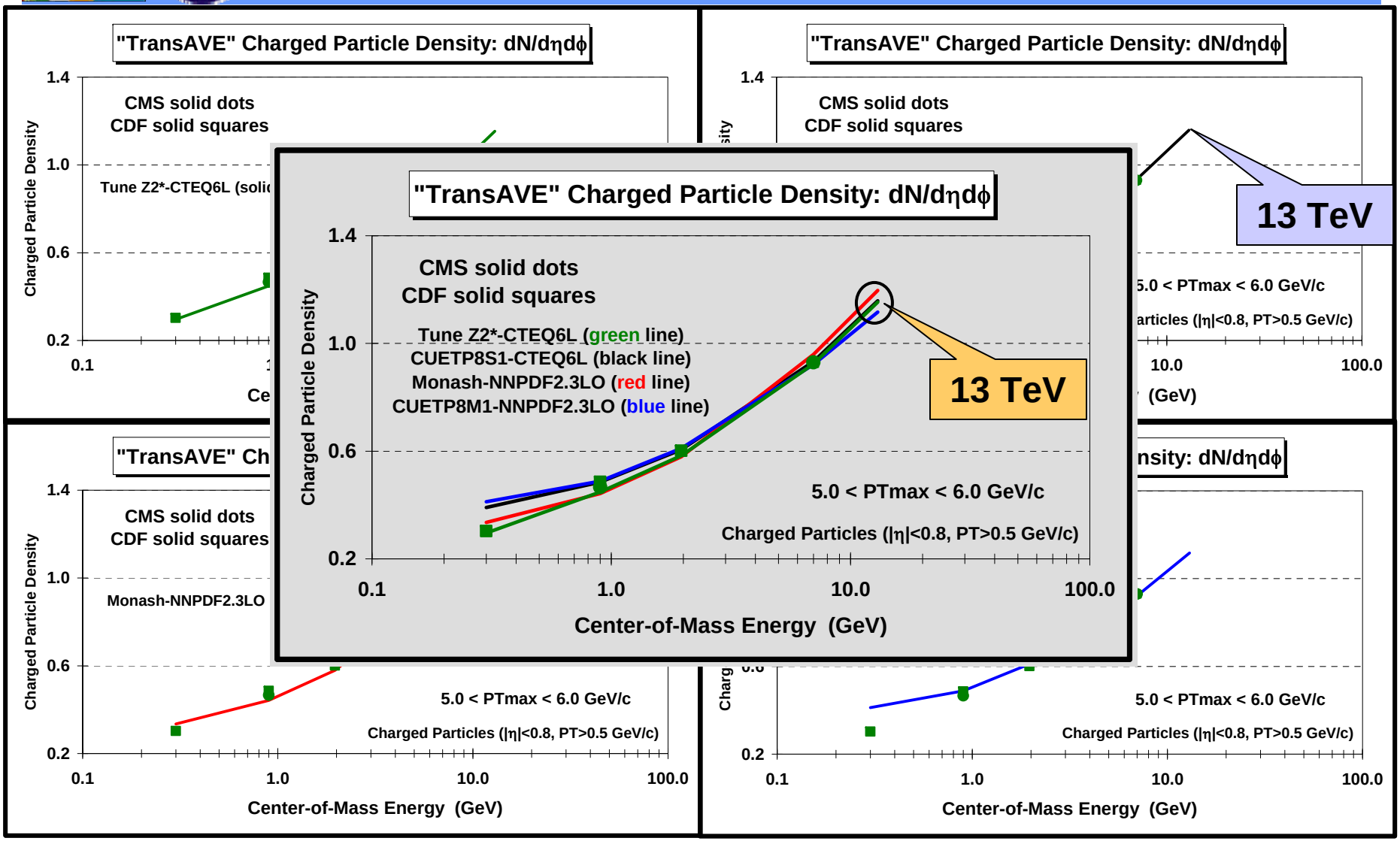




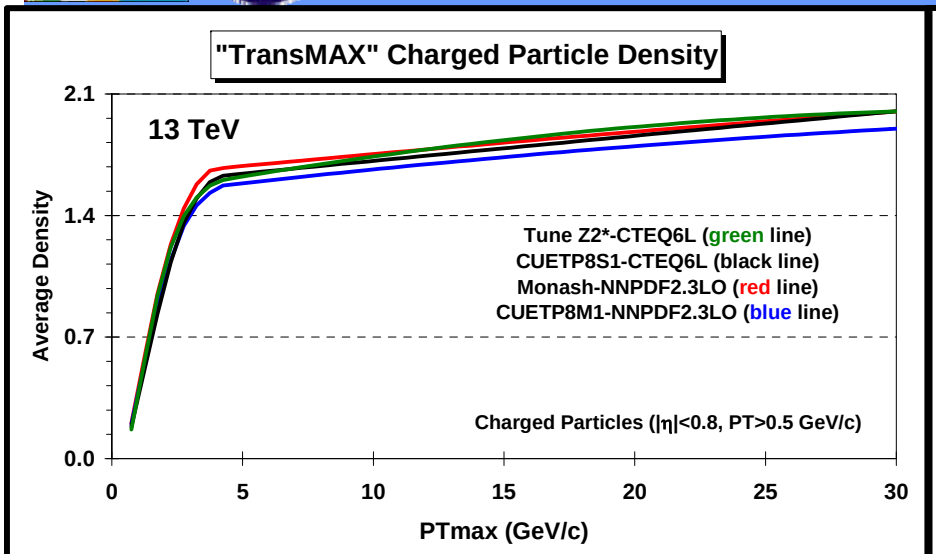


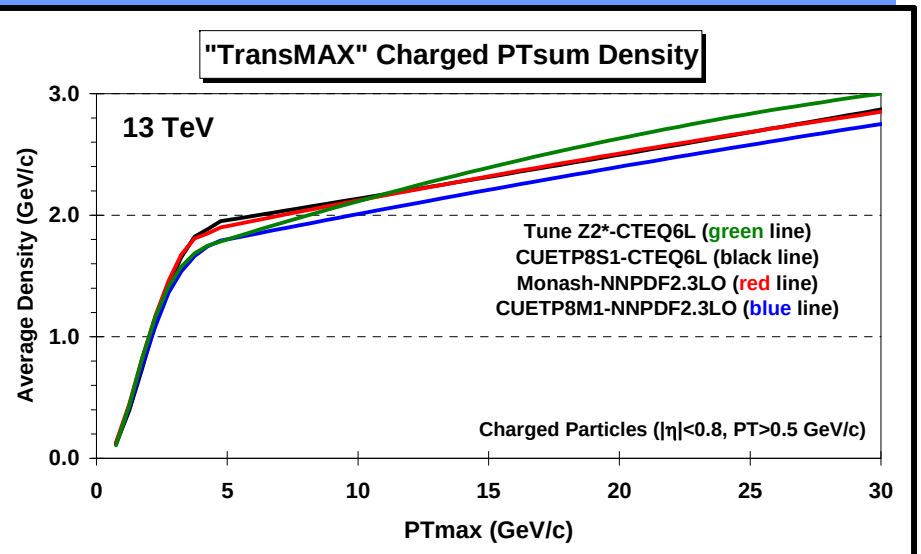


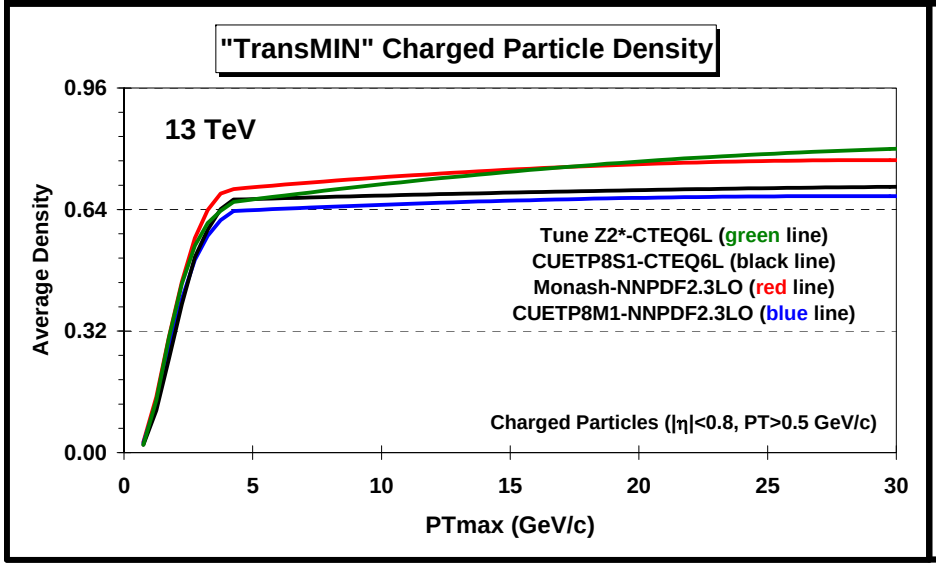
Energy Dependence

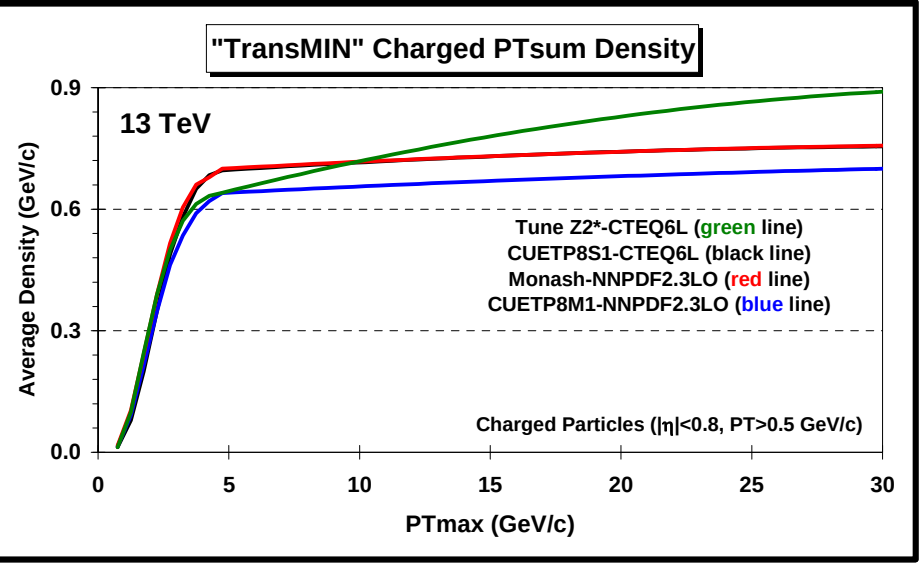


Predictions at 13 TeV

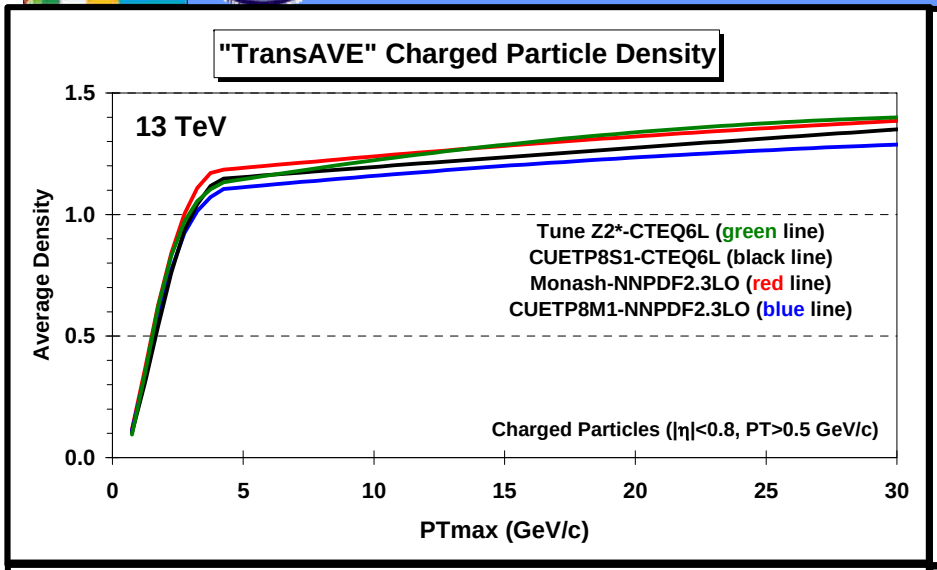


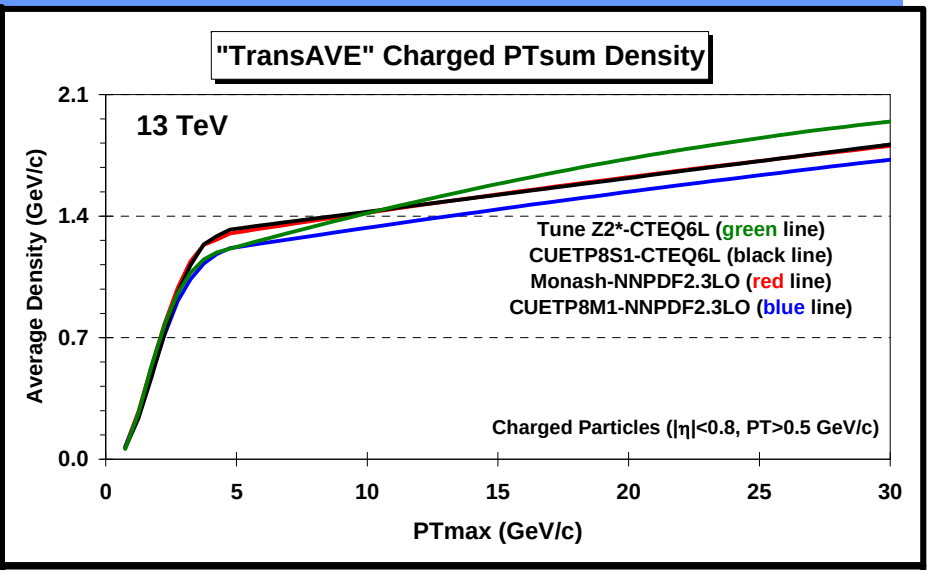


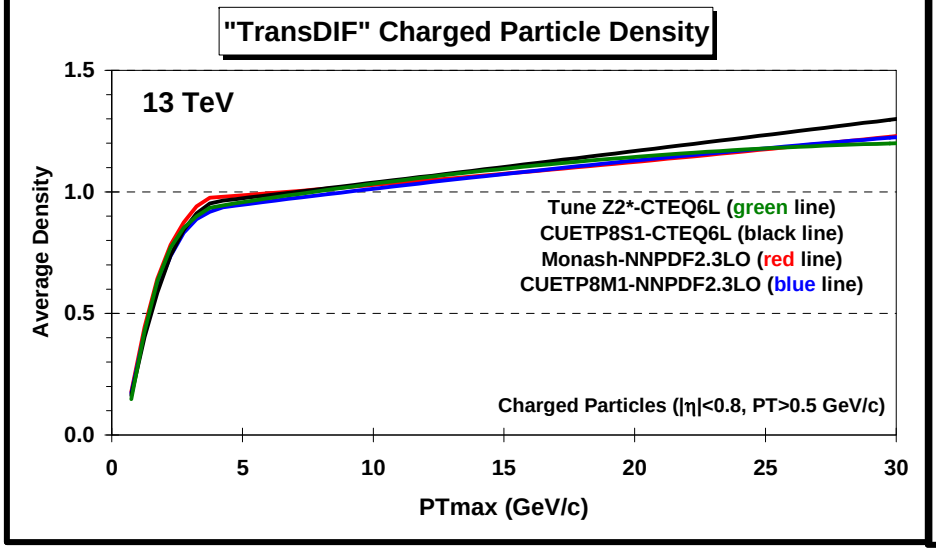


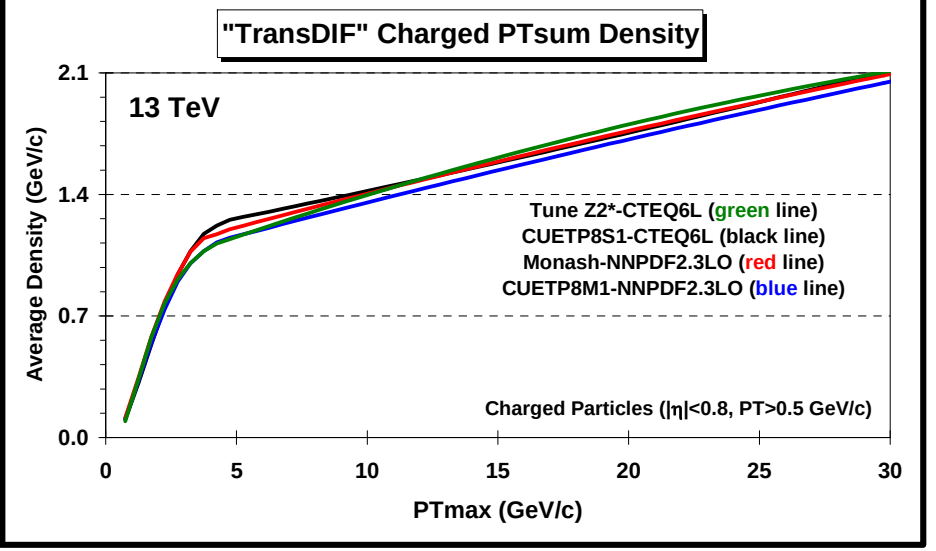


Predictions at 13 TeV

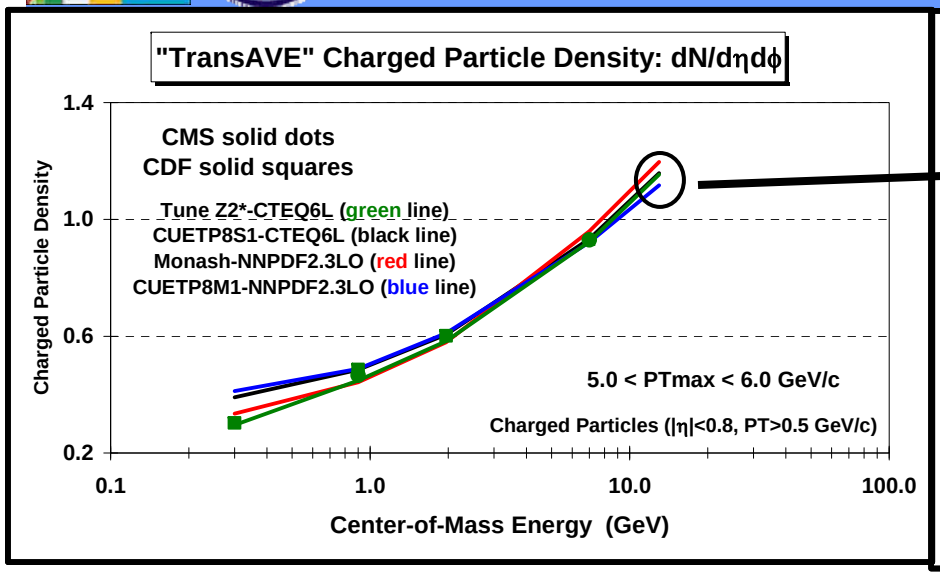


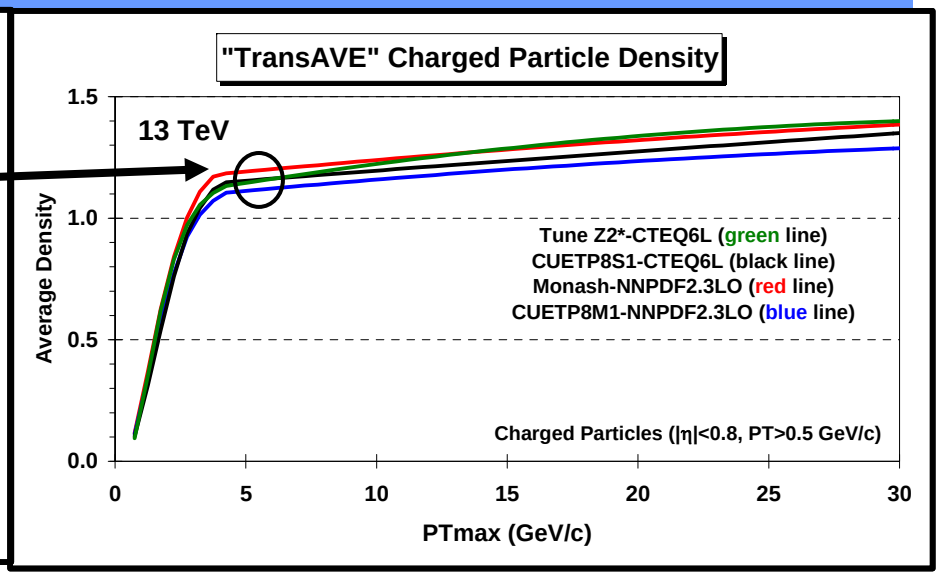






Predictions at 13 TeV

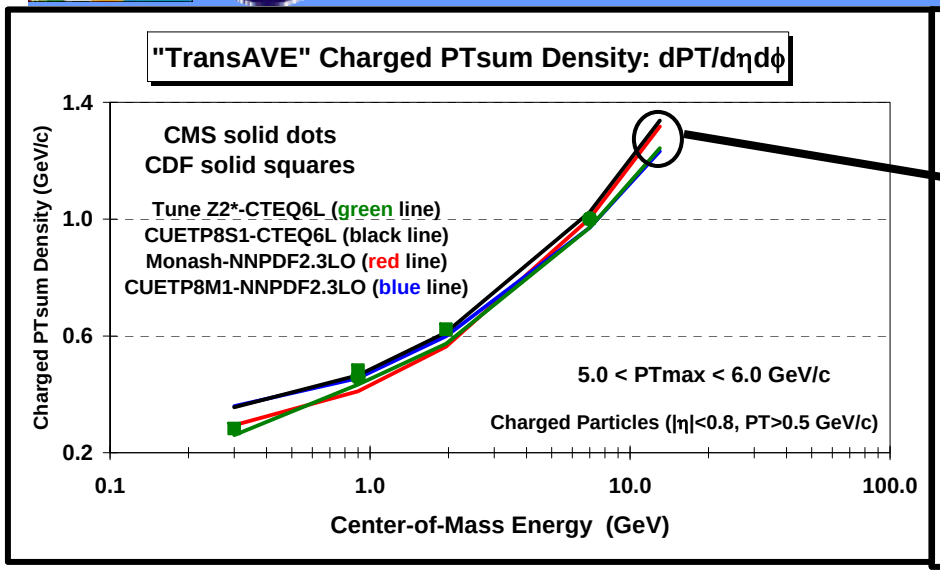


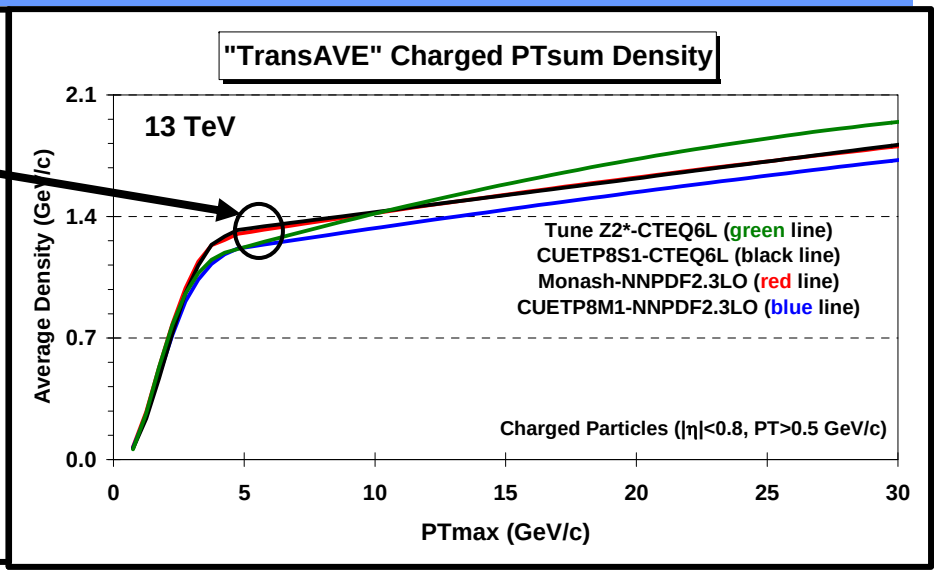


- **CMS and CDF data on the charged particle density in the "transAVE" region as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$ with $5 < PTmax < 6$ GeV/c. The data are plotted versus the center-of-mass energy (*log scale*). The data are compared with PYTHIA 6 Tune Z2* and PYTHIA 8 Tune CUETP8S1, Tune Monash, and Tune CUETP8M1.**

- **CMS data at 7 TeV and CDF data at 1.96 TeV, 900 GeV, and 300 GeV on the charged particle density in the "transAVE" region 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 compared with PYTHIA 6 Tune Z2* and PYTHIA 8 Tune CUETP8S1, Tune Monash, and Tune CUETP8M1.**

Predictions at 13 TeV

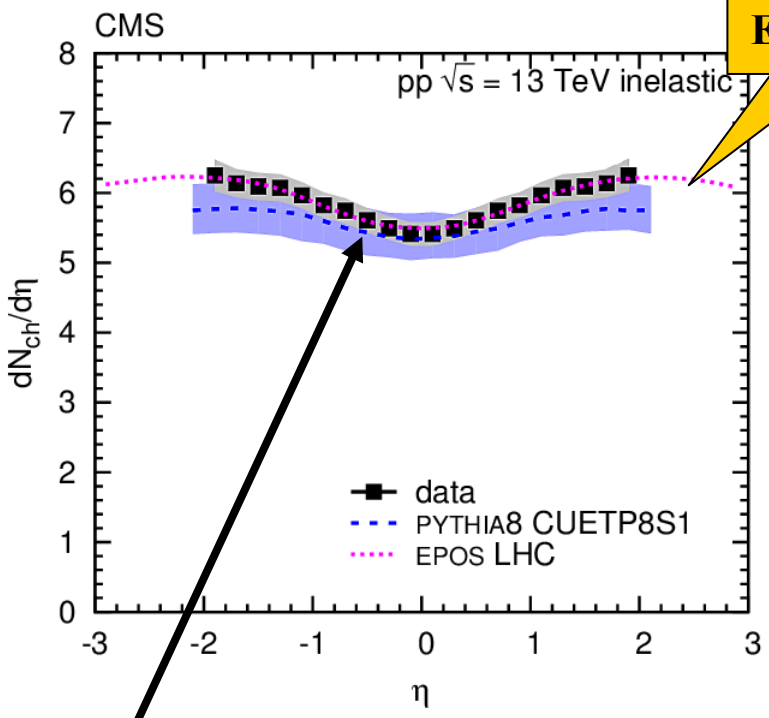




- **CMS and CDF data on the charged PTsum density in the "transAVE" region as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$ with $5 < PTmax < 6$ GeV/c. The data are plotted versus the center-of-mass energy (*log scale*). The data are compared with PYTHIA 6 Tune Z2* and PYTHIA 8 Tune CUETP8S1, Tune Monash, and Tune CUETP8M1.**

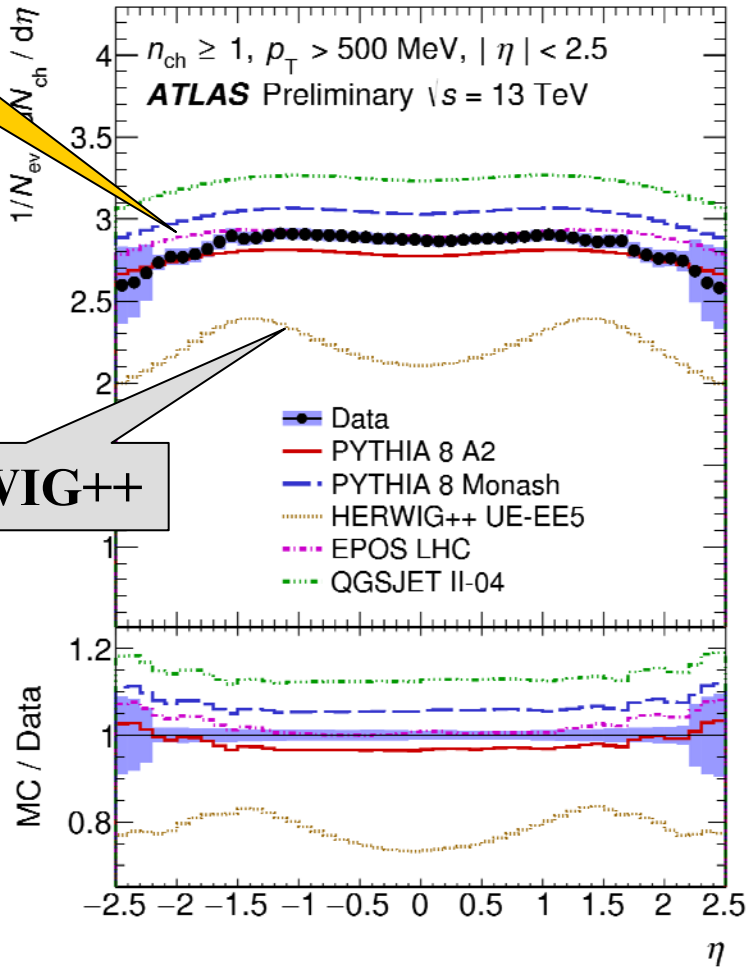
- **CMS data at 7 TeV and CDF data at 1.96 TeV, 900 GeV, and 300 GeV on the charged PTsum density in the "transAVE" region as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$. The data are compared with PYTHIA 6 Tune Z2* and PYTHIA 8 Tune CUETP8S1, Tune Monash, and Tune CUETP8M1.**

MB at 13 TeV: dN/dη



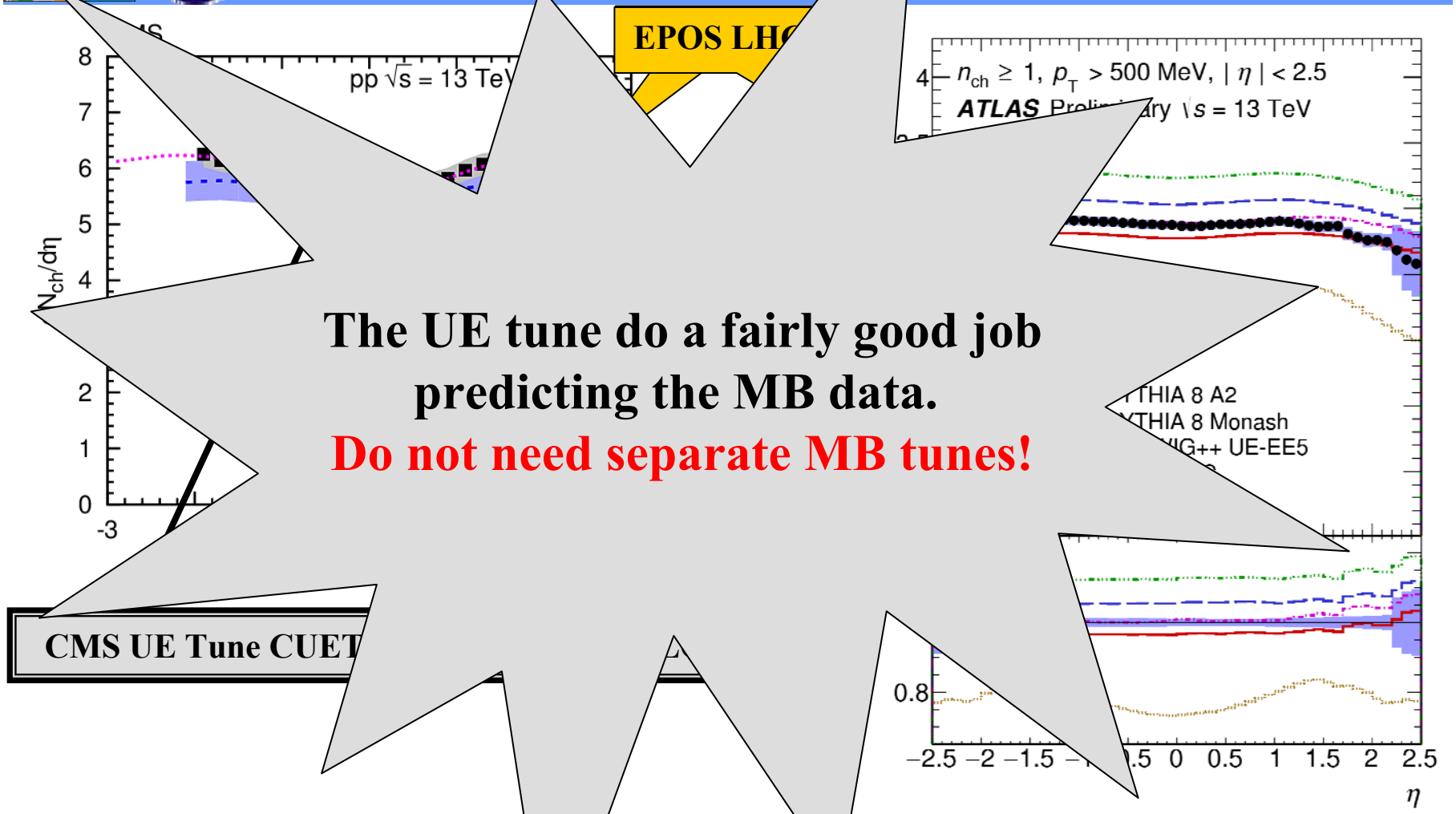
EPOS LHC

HERWIG++



CMS UE Tune CUETP8S1-HERAPDF1.5LO.

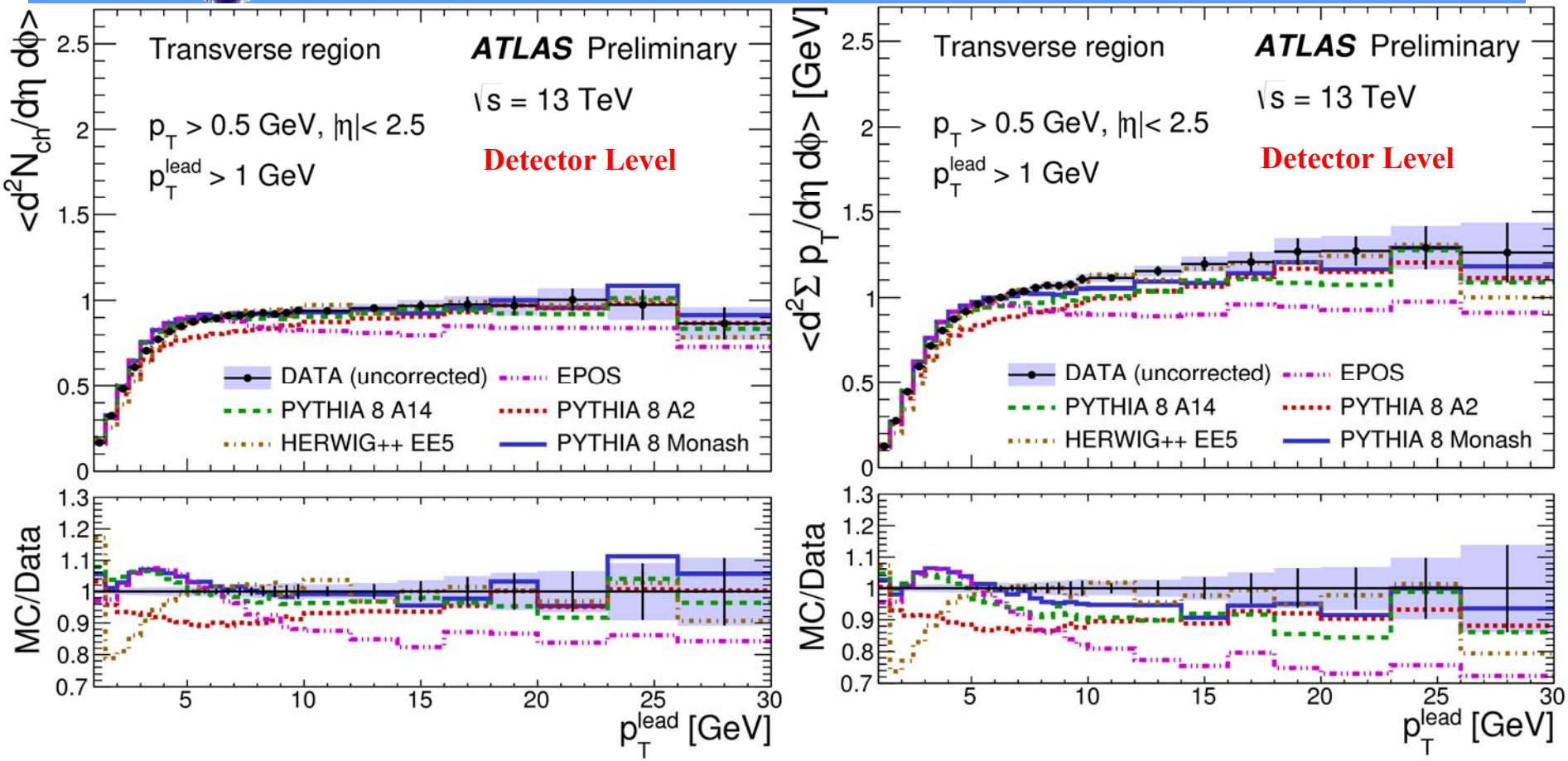
MB at 13 TeV: dN/dη



The UE tune do a fairly good job predicting the MB data.

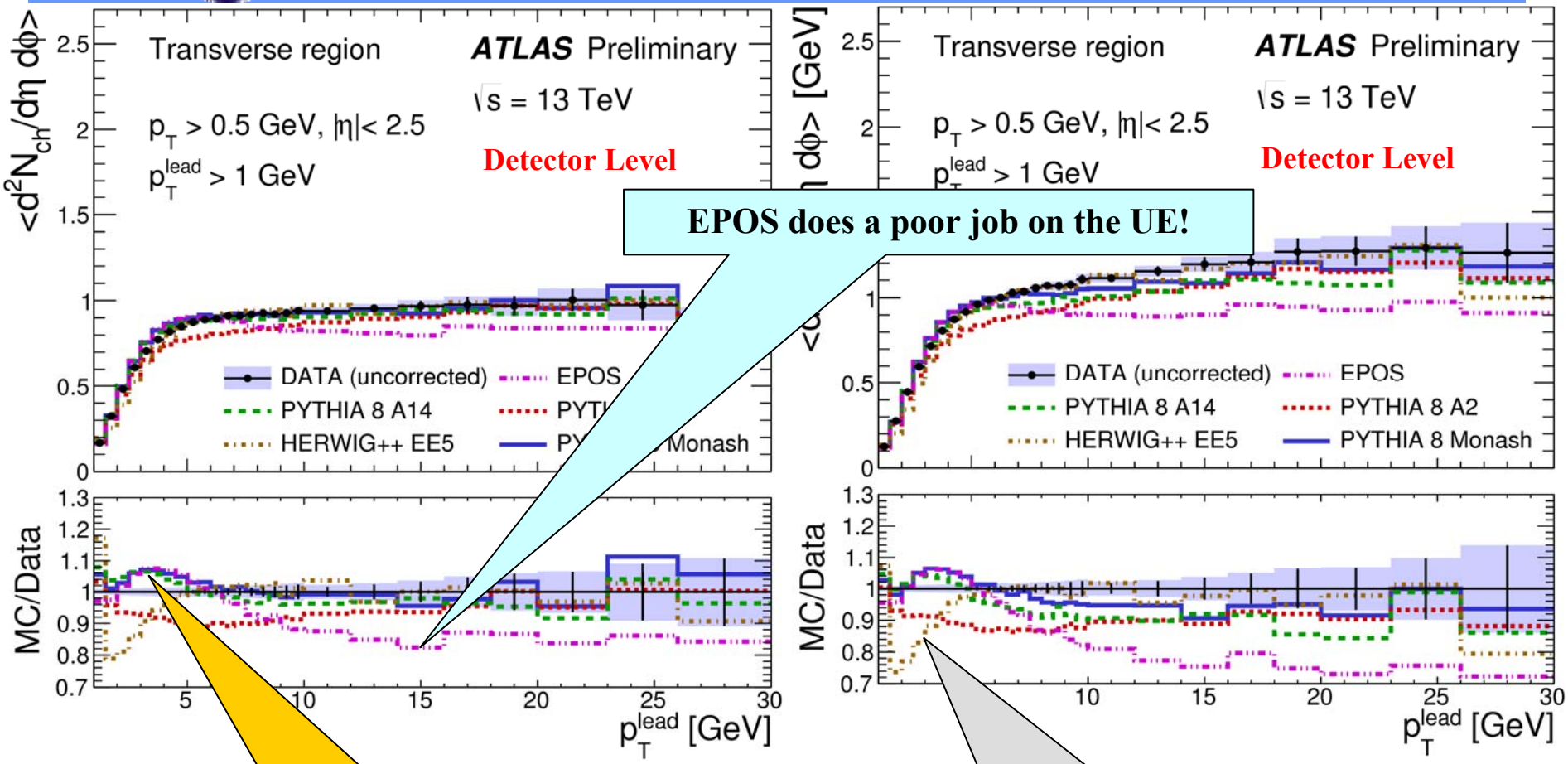
Do not need separate MB tunes!

ATLAS 13 TeV UE Data



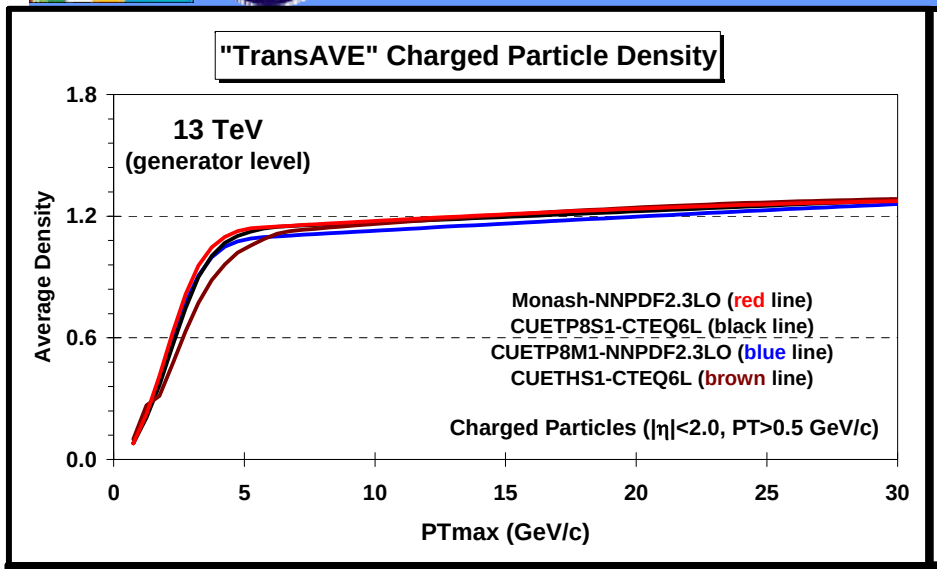
➡ **ATLAS data at 13 TeV on the charged particle density (keft) and charged PTsum density in the "transAVE" region as defined by the leading charged particle for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 2.5$. The data are uncorrected and compared with the MC models after detector simulation.**

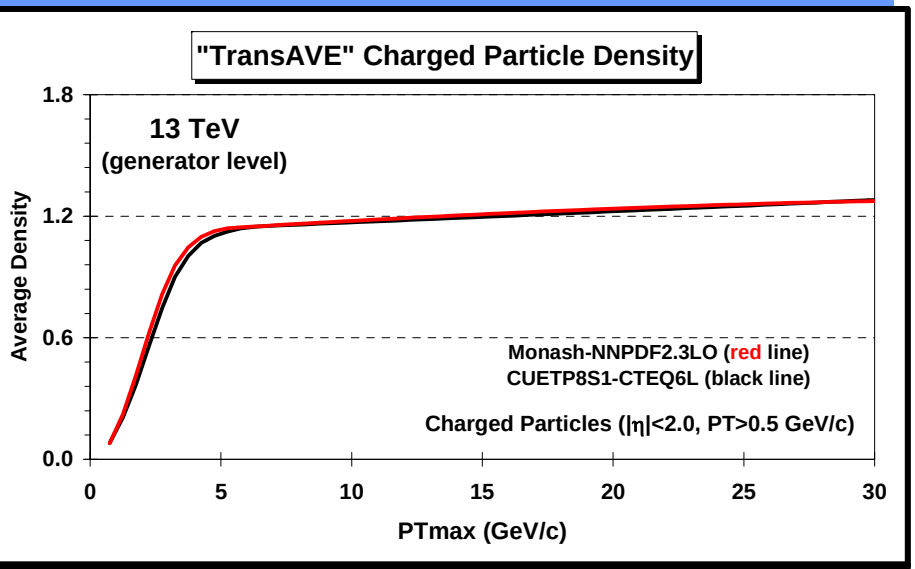
ATLAS 13 TeV UE Data

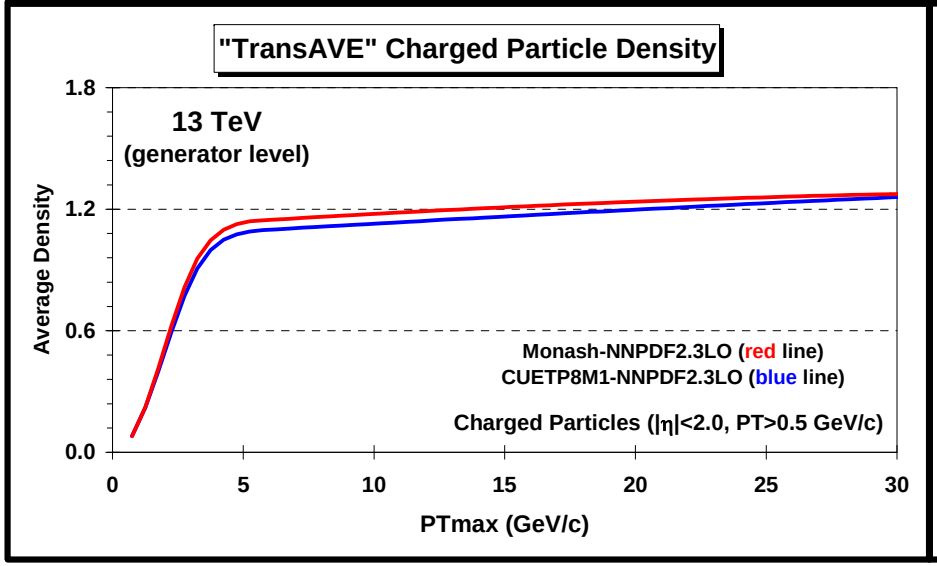


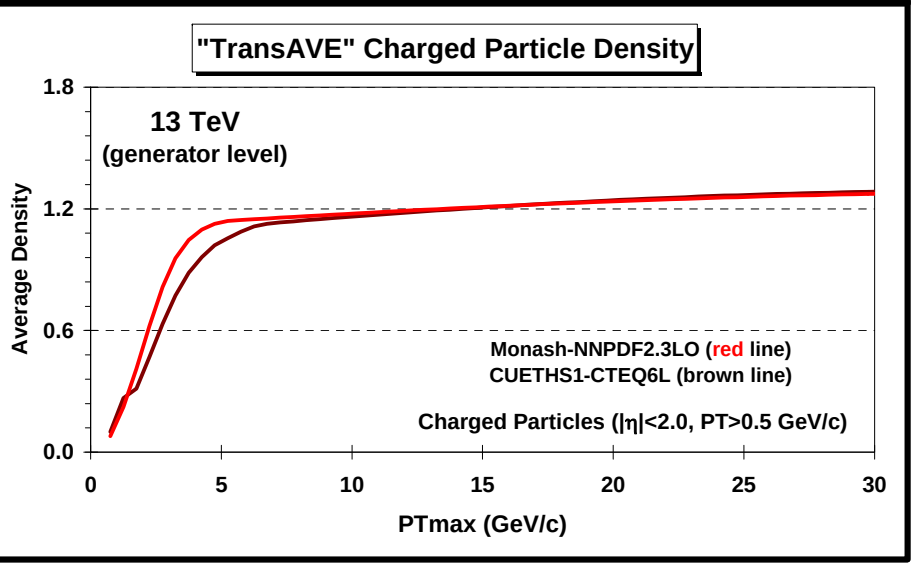
➡ ATLAS data … eV on the charged particle density (keft) … rged PTsum density in the "transA… …ading charged p… …rected and com… GeV/c a… simulation.

More 13 TeVPredictions

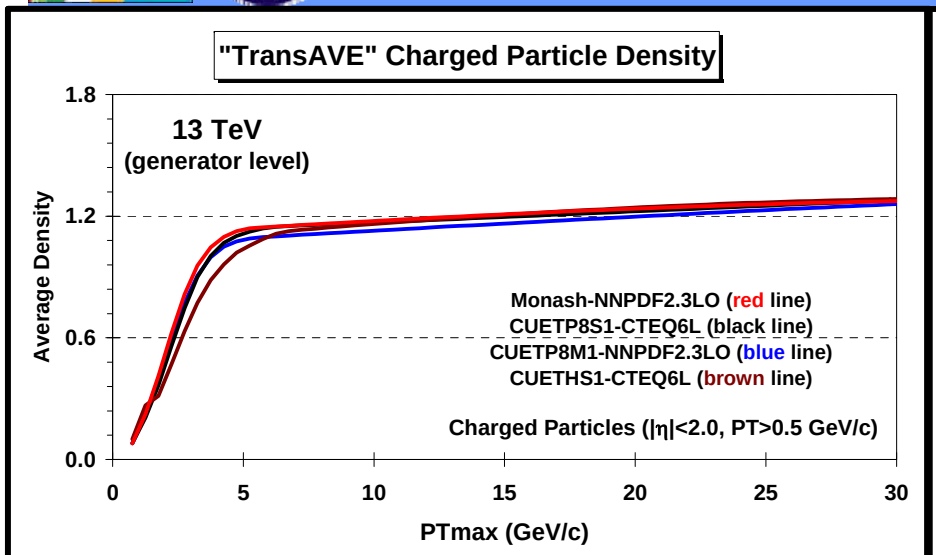


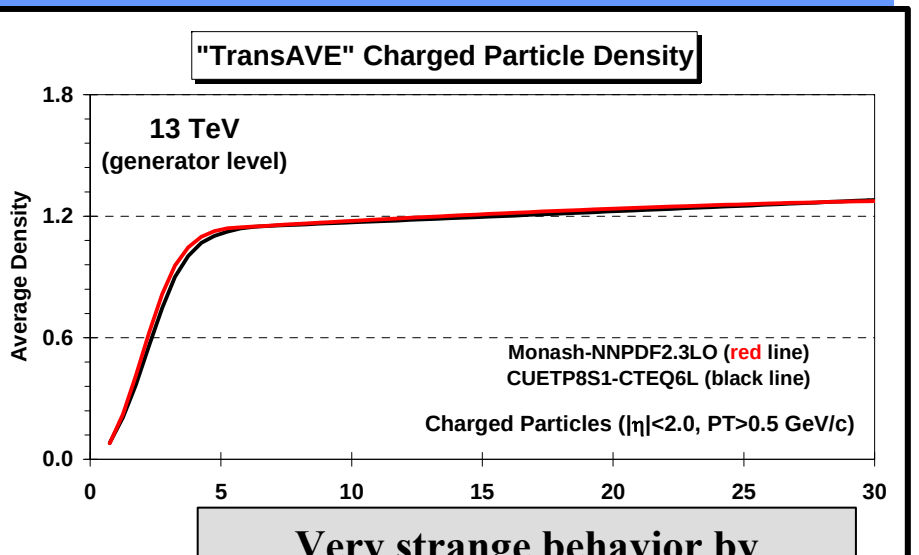


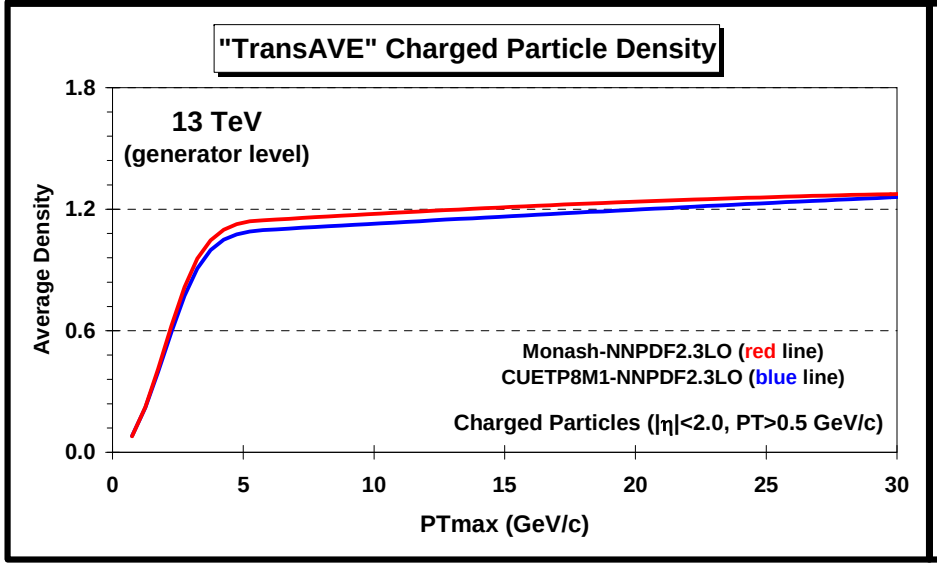


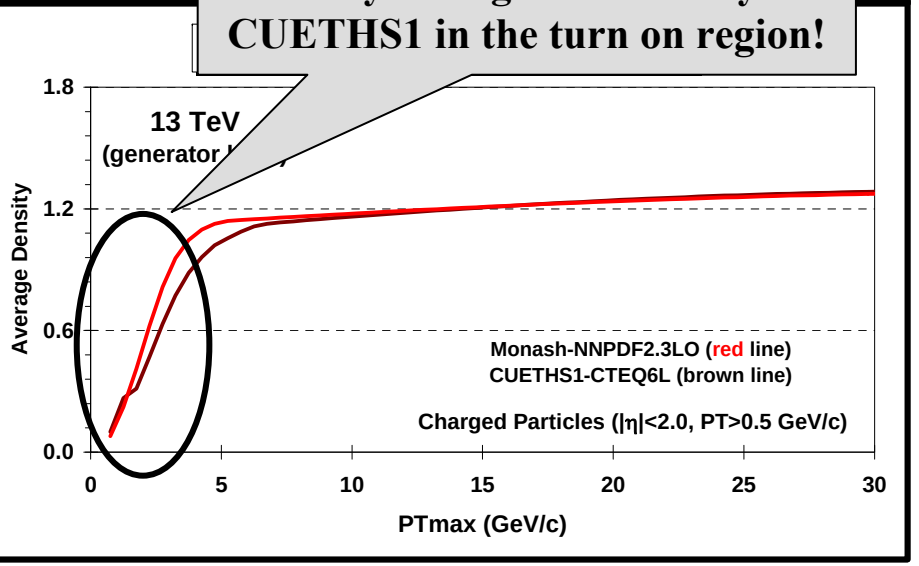


More 13 TeVPredictions



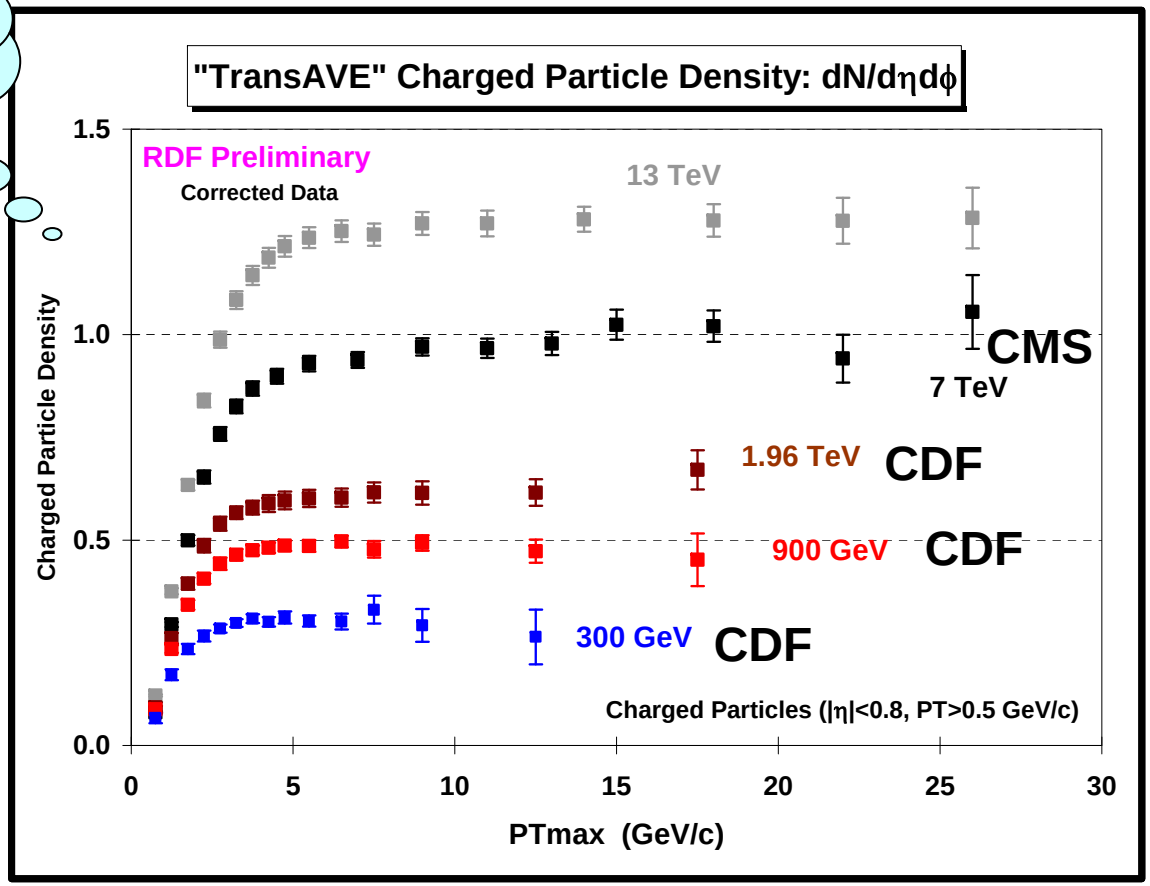






"Tevatron" to the LHC

My dream!

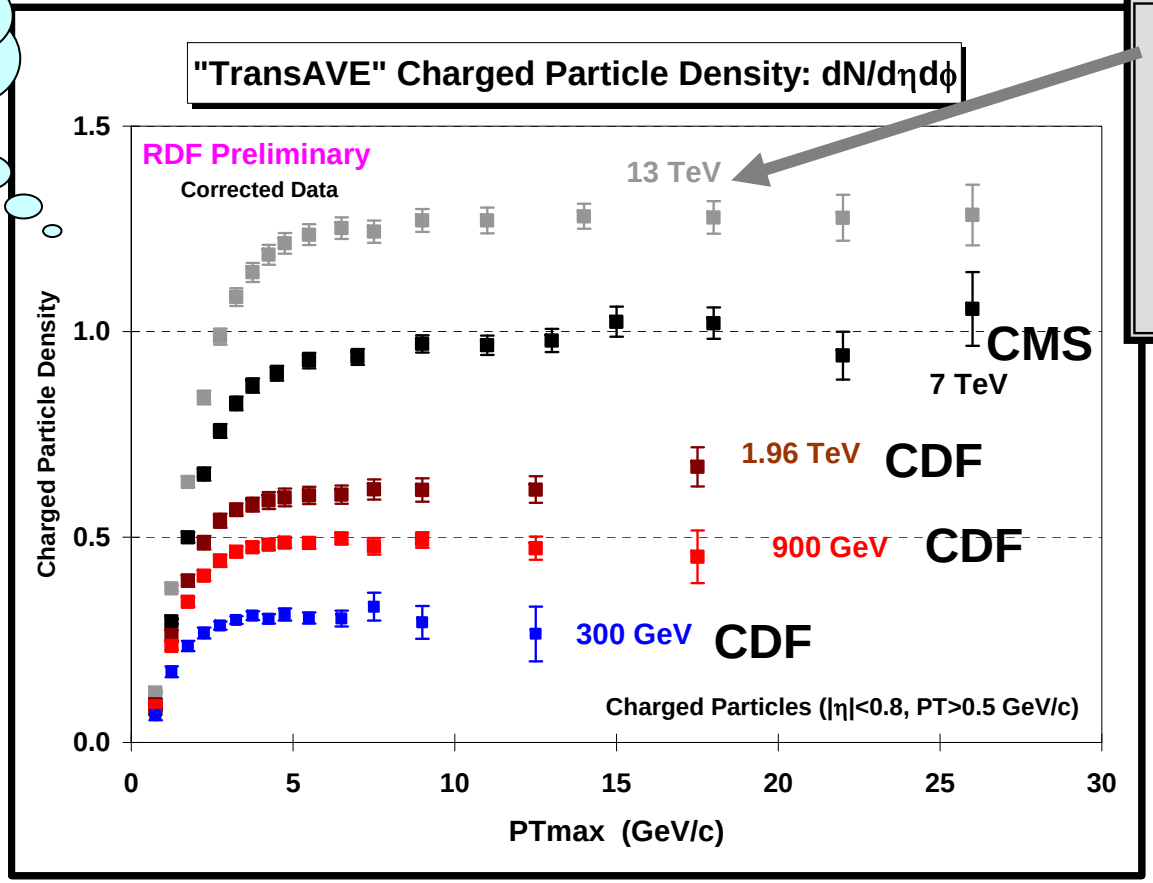


Mapping out the Energy Dependence of the UE

(300 GeV, 900 GeV, 1.96 TeV, 7 TeV, 13 TeV)

"Tevatron" to the LHC

My dream!



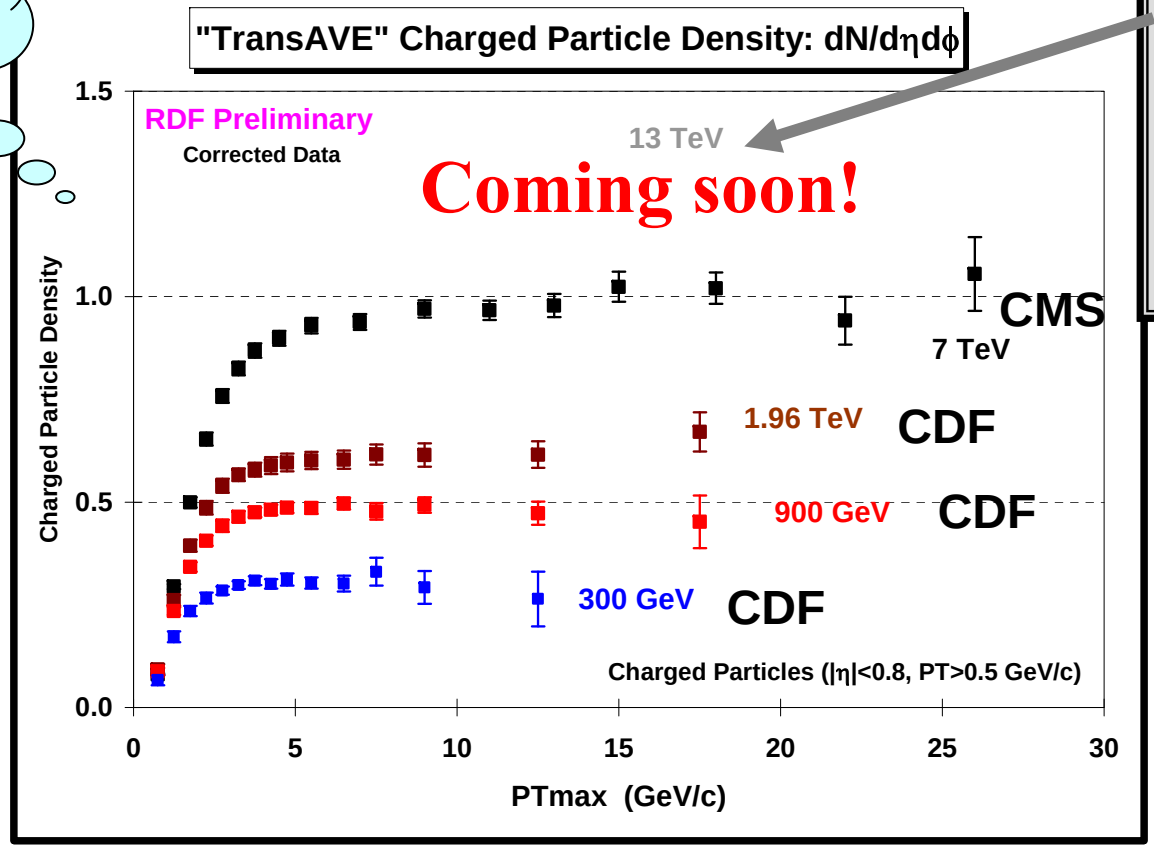
Fake data generated by Rick using the Monash tune with the statistics we currently have at CMS!

Mapping out the Energy Dependence of the UE

(300 GeV, 900 GeV, 1.96 TeV, 7 TeV, 13 TeV)

"Tevatron" to the LHC

My dream!



13 TeV UE data coming soon from both ATLAS and CMS!

Mapping out the Energy Dependence of the UE

(300 GeV, 900 GeV, 1.96 TeV, 7 TeV, 13 TeV)

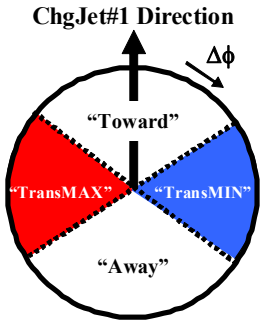
UE@CMS 13 TeV

UE@13TeV

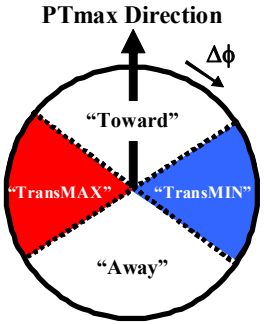
Livio Fano' (University of Perugia)
Diego Ciangottini (University of Perugia)
Rick Field (University of Florida)
Doug Rank (University of Florida)
Sunil Bansal (Panjab University Chandigarh)

University of Perugia

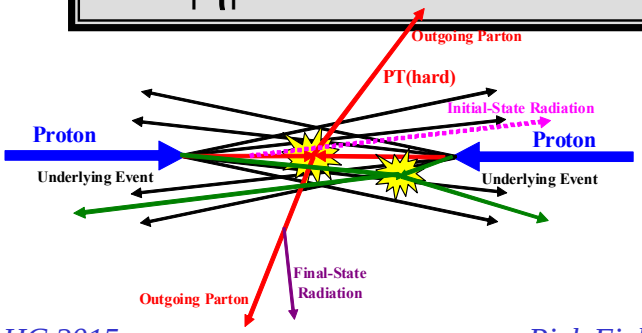
➡ Measure the "Underlying Event" at 13 TeV at CMS



Measure the UE observables as defined by the leading charged particle jet, chgjet#1, for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 2.0$.



Measure the UE observables as defined by the leading charged particle, PTmax, for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 2.0$ and $|\eta| < 0.8$.



UE&MB@CMS

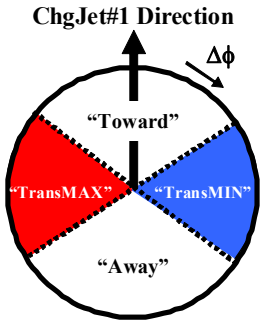
Livio & Rick were part of the CMS Run 1 UE&MB team!

UE@CMS 13 TeV

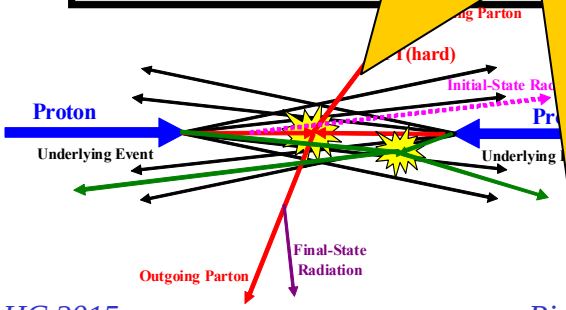
UE@13TeV

Livio [illegible]' (University of Perus[illegible]
Diego Ciang[illegible] (University of P[illegible]
Rick Field [illegible]ity of Flor[illegible]
Doug Rank ([illegible]f Fl[illegible]
Sunil Bansal (Panjab[illegible]

Sorry to be slow! We hope to have the CMS "Common Plots" finished for the LPCC UE&MB meeting on November 19 and 20!



Meas[illegible]sure the UE observables as define[illegible]ned by the leading charged [illegible]rticle, PTmax, for chg[illegible]harged particles with p_T > particles with p[illegible]5 GeV/c and $|\eta| < 2.0$ and and $|\eta| < 2.0$. [illegible]< 0.8.



UE&MB@CMS

Livio & Rick were part of the CMS Run 1 UE&MB team!