



# ICHEP 2016



## The Underlying Event & MC Tunes at the LHC



Rick Field

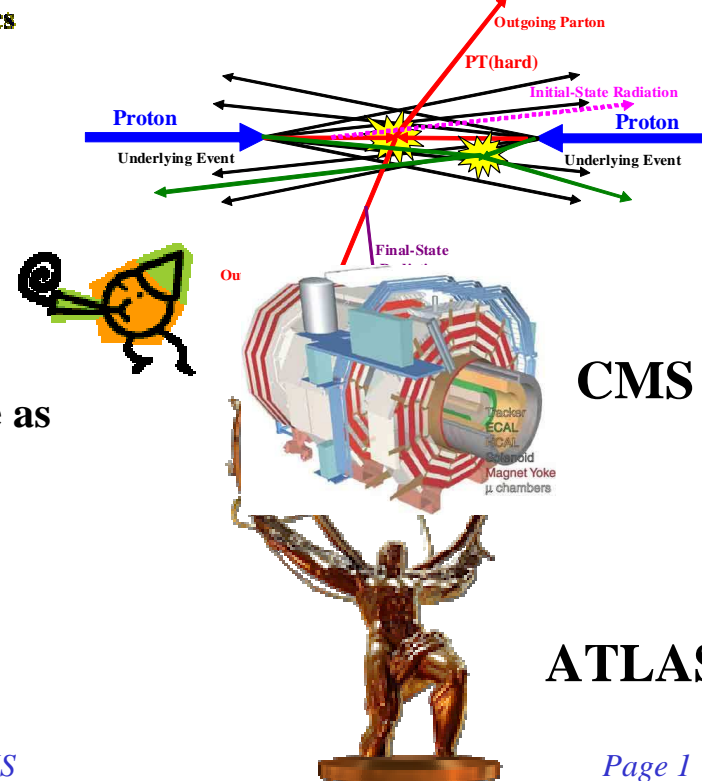
University of Florida

### Outline of Talk

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

ICHEP  
2016CHICAGO  
AUGUST 3-10, 2016

- ➔ **ATLAS:** The UE in Z-Boson production at 7 TeV.
- ➔ **CMS UE Tunes:** Two PYTHIA 6 tunes, three PYTHIA 8 tunes, and one HERWIG++ tune from the CMS “Physics Comparisons & Generator Tunes” subgroup.
- ➔ **HERWIG 7 Tunes:** Tune CUETHS1-CTEQ6L (the same as the CMS HW++ tune CUETHS1-CTEQ6L except using HW7. HW7 Default Tune using the MMHT2014 PDF.
- ➔ **Simultaneous UE-MB-DPS Tunes:** Can we fit UE data, MB data, and DPS sensitive with one universal tune?





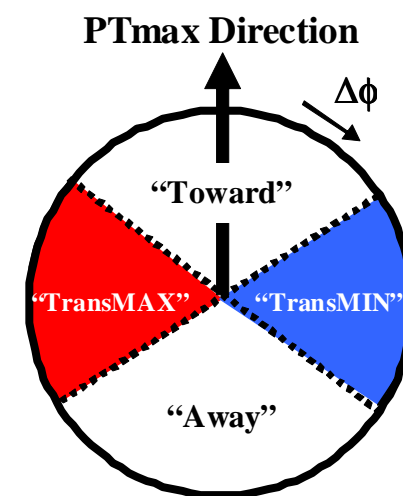
# UE Observables



➡ **“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  $\eta$ - $\phi$  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  $\eta$ - $\phi$  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

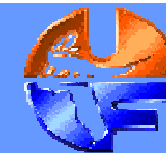


$$\text{“Transverse” Density} = \text{“transAVE” Density} = (\text{“transMAX” Density} + \text{“transMIN” Density})/2$$

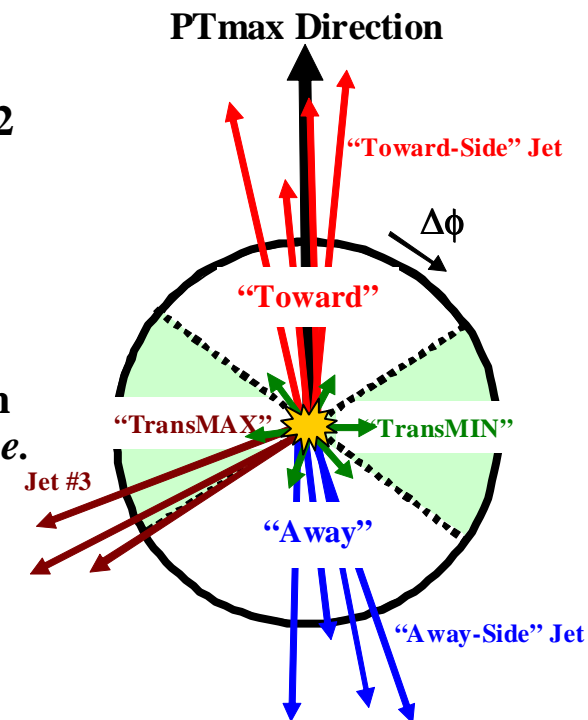
$$\text{“TransDIF” Density} = \text{“transMAX” Density} - \text{“transMIN” Density}$$



# “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.

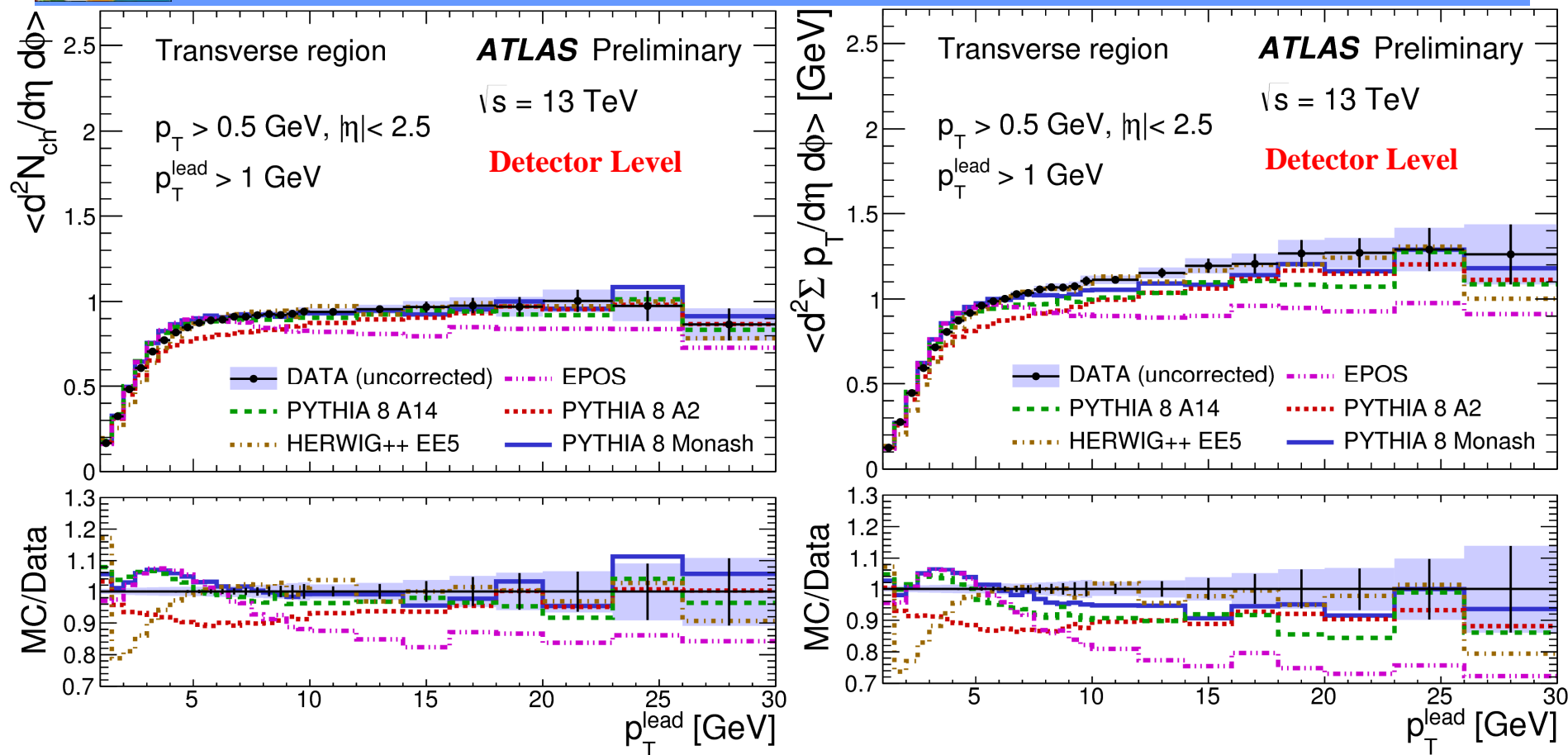
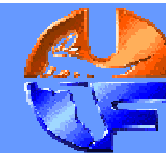
“TransDIF” density more sensitive to ISR & FSR.

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

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



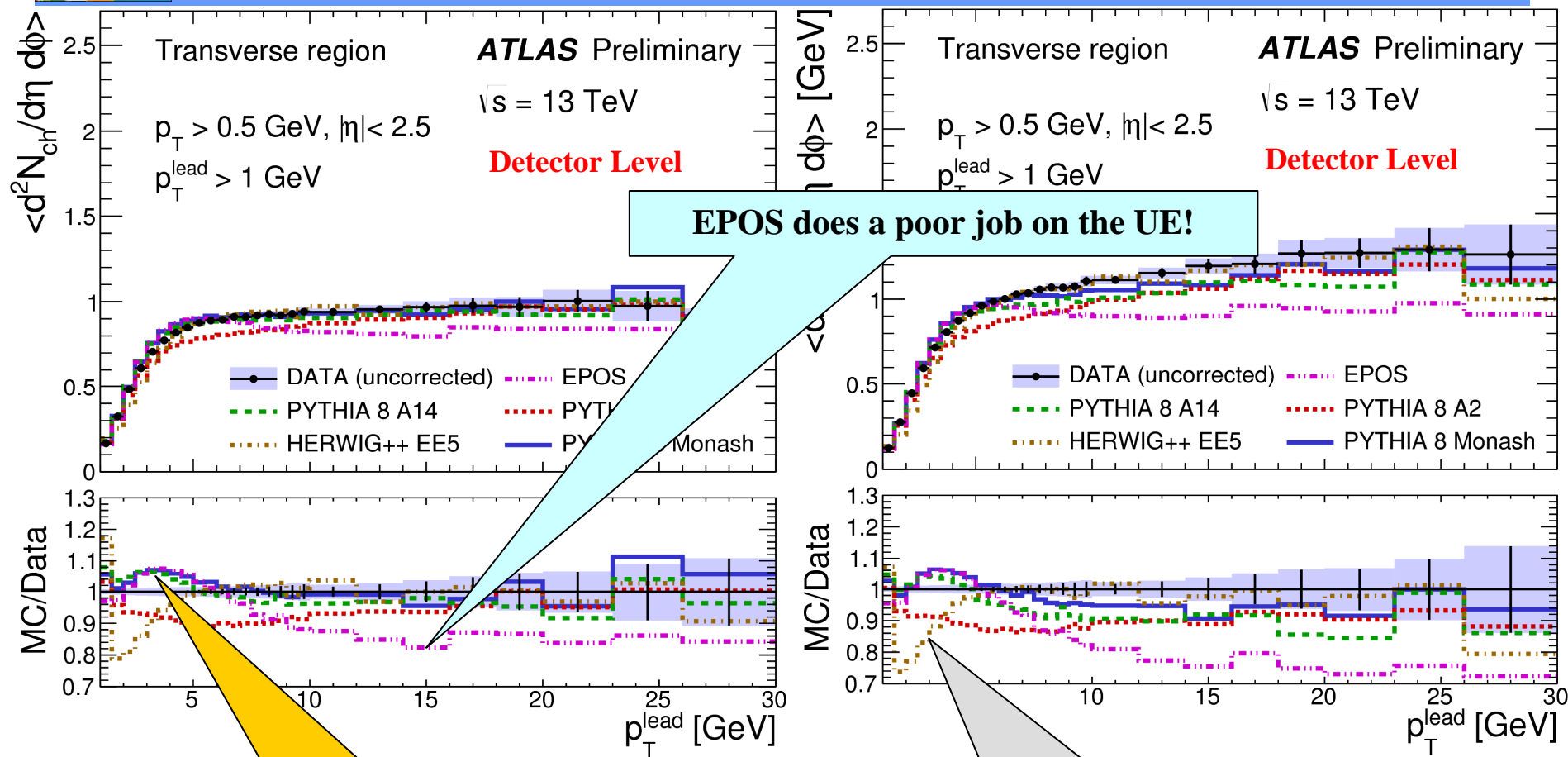
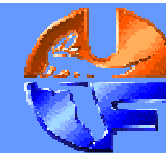
# ATLAS 13 TeV UE Data



➔ **ATLAS data at 13 TeV** on the charged particle density (left) 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



EPOS does a poor job on the UE!

→ **ATLAS data** 13 TeV on the charged particle density (left)  
“transverse”  
GeV/c and  
simulation.

Monash doing well except leading charged

charged PTsum density in the  
Very strange behavior by HERWIG++  
in the turn on region!



# The UE in Z-Boson Production



EUROPEAN ORGANISATION FOR NUCLEAR RESEARCH (CERN)  
**Eur. Phys. J. C (2014) 74:3195**  
 (arXiv:1409.3433v2)

ATLAS CERN

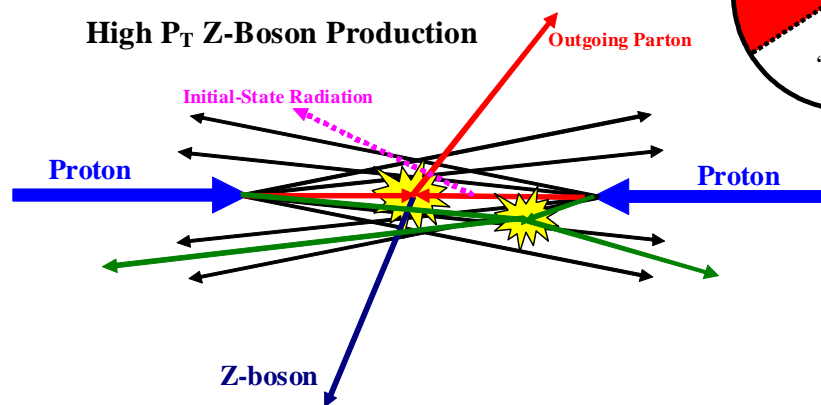
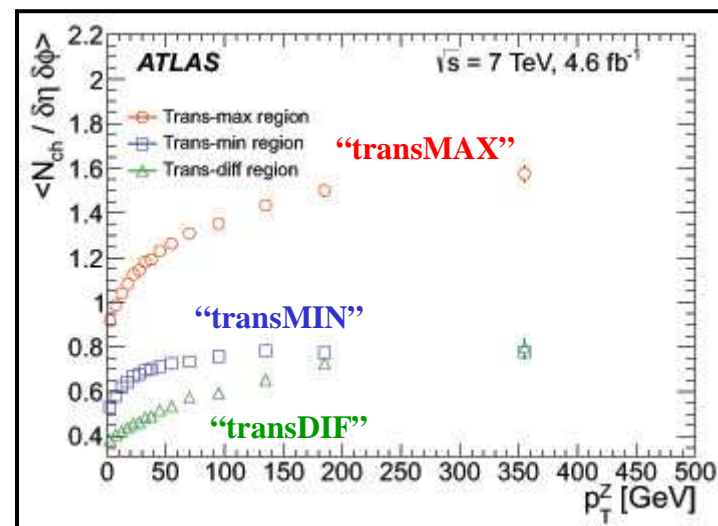
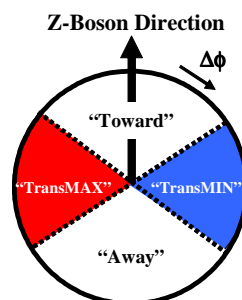
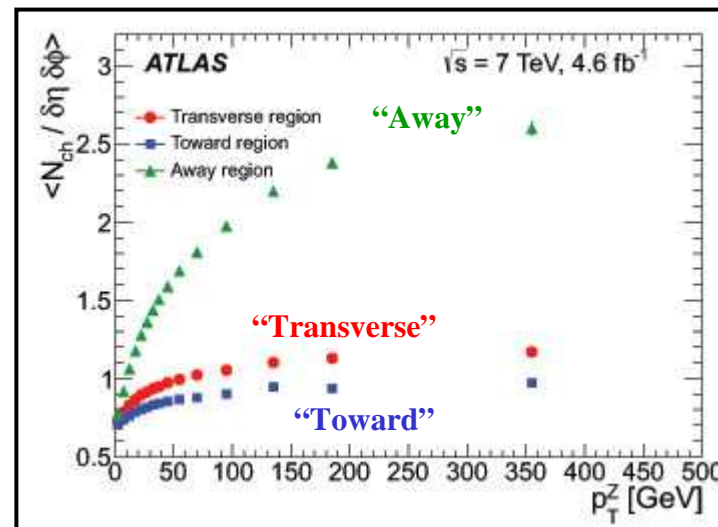
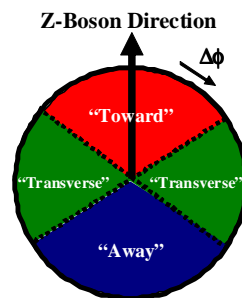
CERN-PH-EP-2014-162  
 Submitted to: EPJC

**Measurement of distributions sensitive to the underlying event in inclusive Z-boson production in  $pp$  collisions at  $\sqrt{s} = 7$  TeV with the ATLAS detector**

The ATLAS Collaboration

**Abstract**

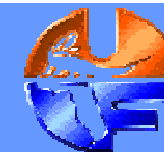
A measurement of charged-particle distributions sensitive to the properties of the underlying event is presented for an inclusive sample of events containing a Z-boson, decaying to an electron or muon pair. The measurement is based on data collected using the ATLAS detector at the LHC in proton-proton collisions at a centre-of-mass energy of 7 TeV with an integrated luminosity of  $4.6 \text{ fb}^{-1}$ . Distributions of the charged particle multiplicity and of the charged particle transverse momentum are measured in regions of azimuthal angle defined with respect to the Z-boson direction. The measured distributions are compared to similar distributions measured in jet events, and to the predictions of various Monte Carlo generators implementing different underlying event models.







# The UE in Z-Boson Production



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ATLAS

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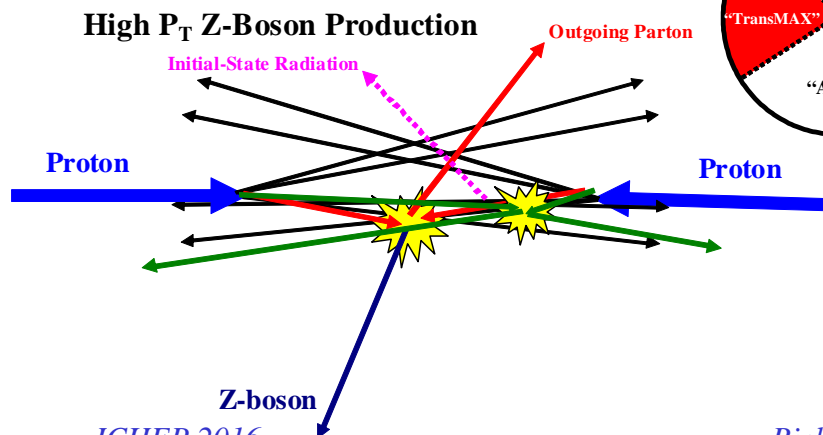
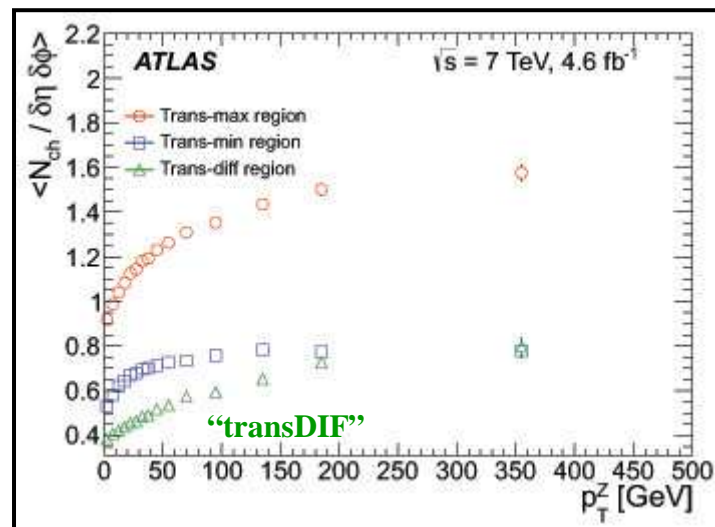
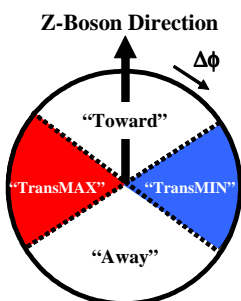
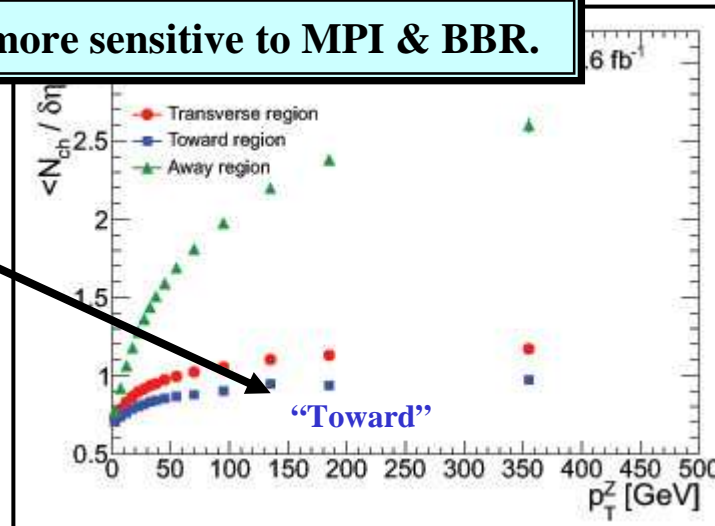
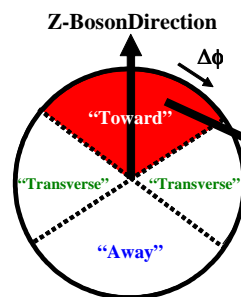
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“Toward” and “TransMIN” densities more sensitive to MPI & BBR.





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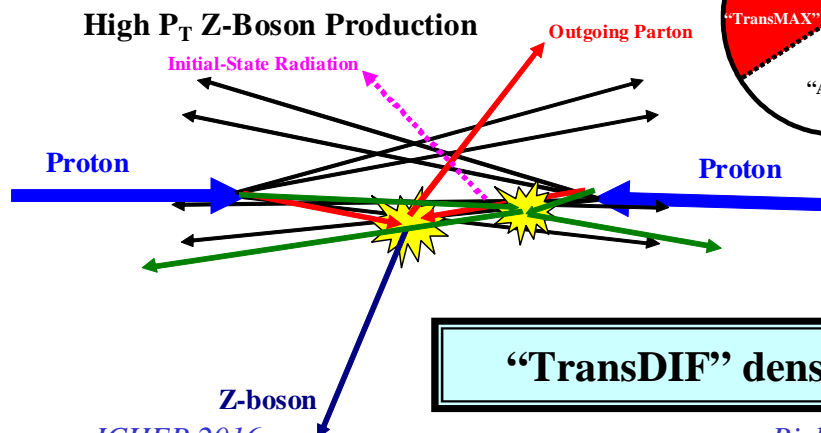
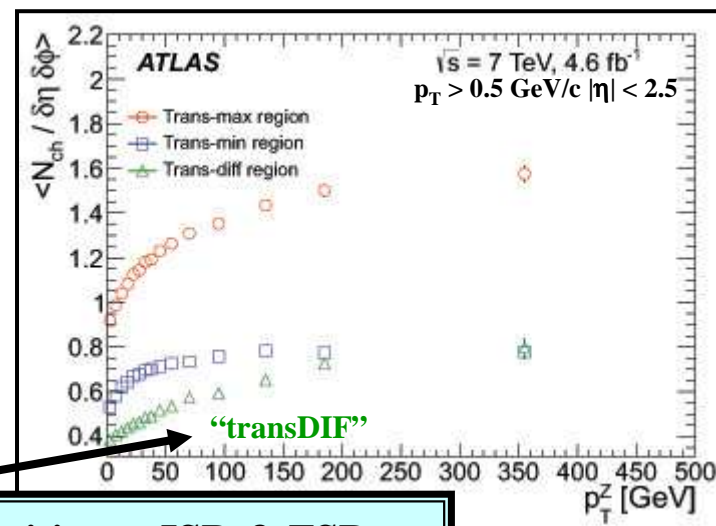
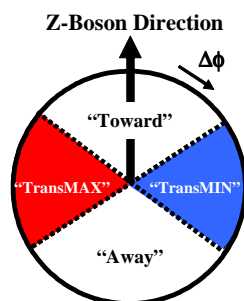
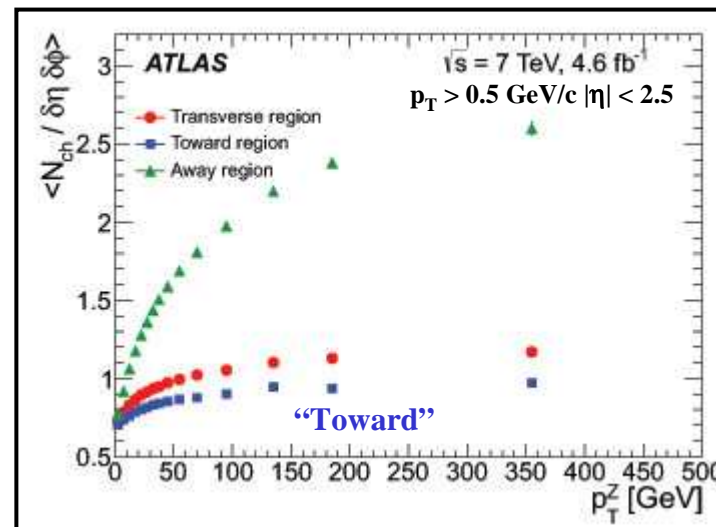
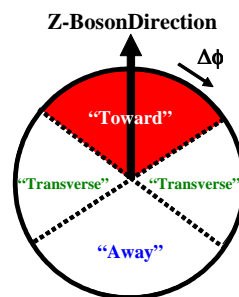
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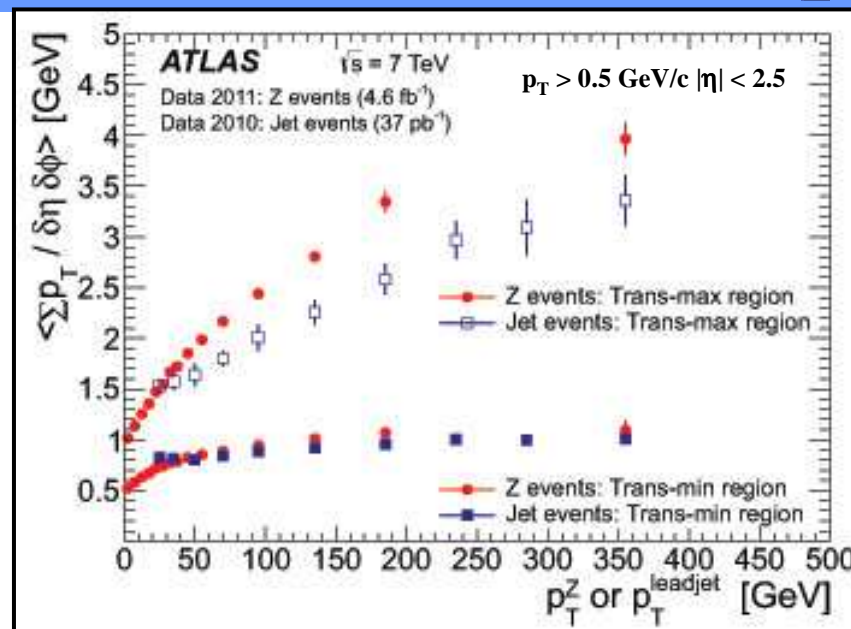
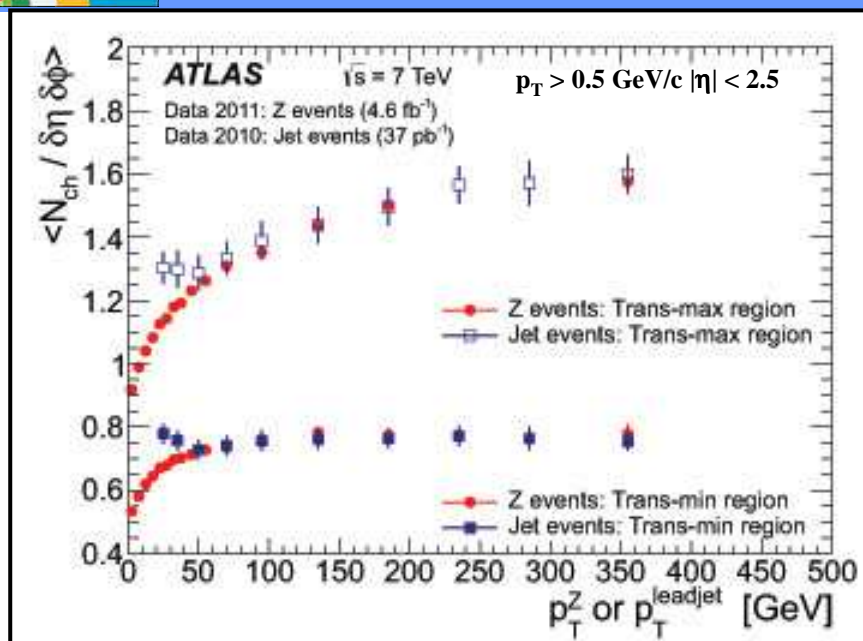


**"TransDIF" density more sensitive to ISR & FSR.**





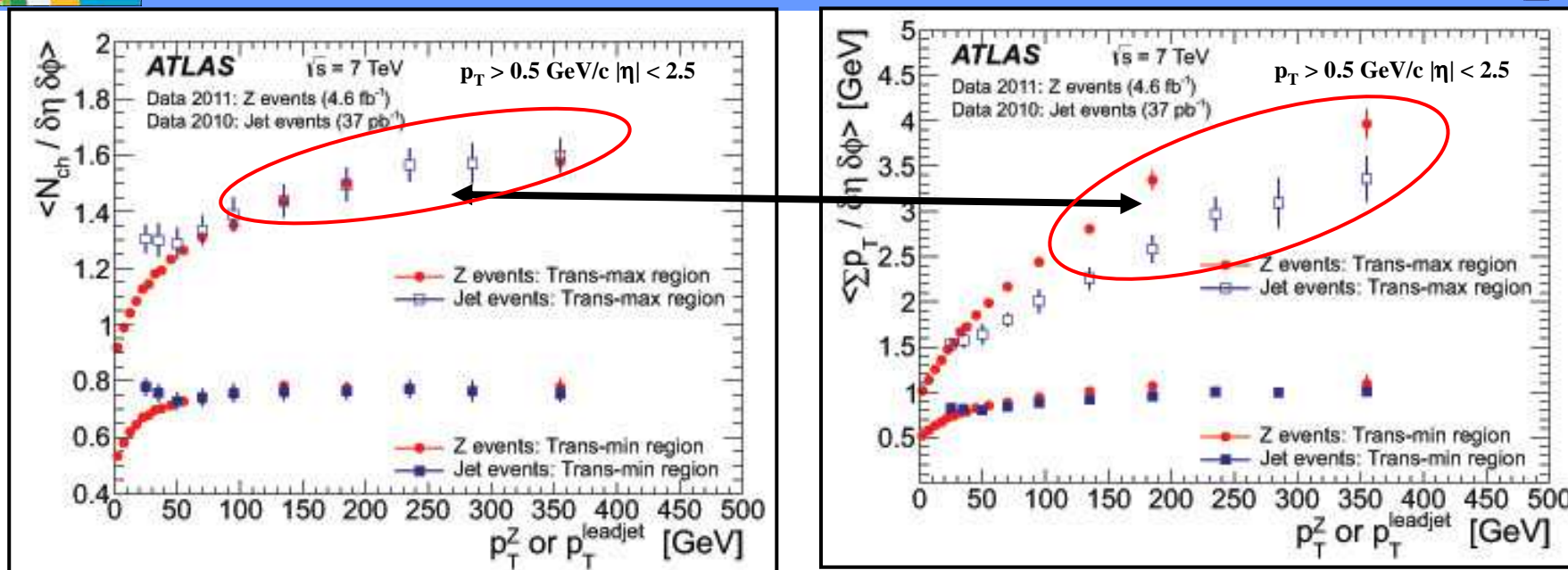
# Z-Boson versus “Leading Jet”



➡ ATLAS data at 7 TeV on the charged particle density and charged PTsum density for the “transMAX” and “transMIN” regions for “Z-Boson” events and for “Leading Jet” events as a function of the leading jet  $p_T$  or  $P_T(Z)$ .



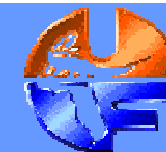
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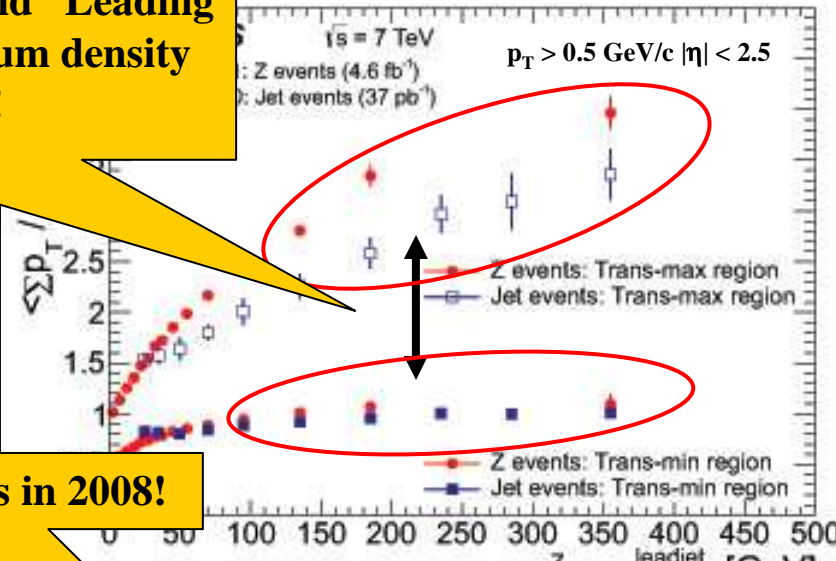
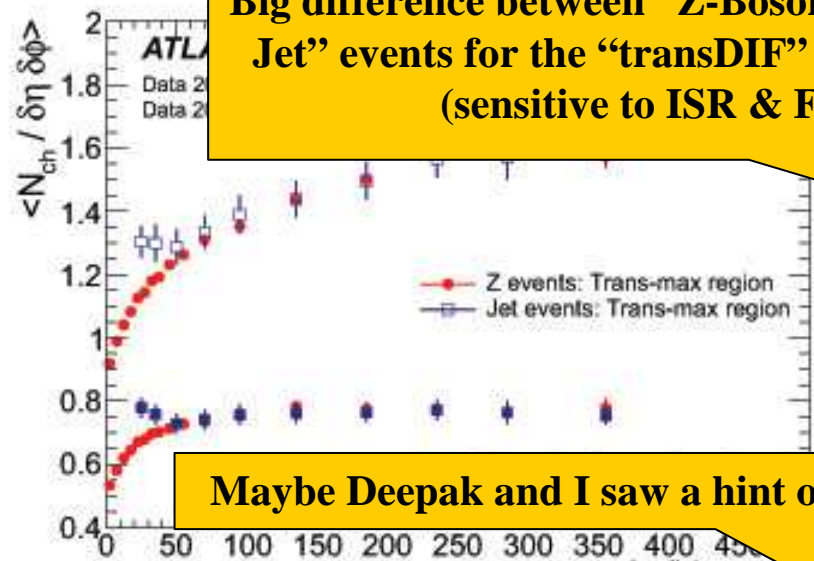
➡ **ATLAS data at 7 TeV on the charged particle density and charged PTsum density for the “transMAX” and “transMIN” regions for “Z-Boson” events and for “Leading Jet” events as a function of the leading jet  $p_T$  or  $P_T(Z)$ .**



# Z-Boson versus “Leading Jet”

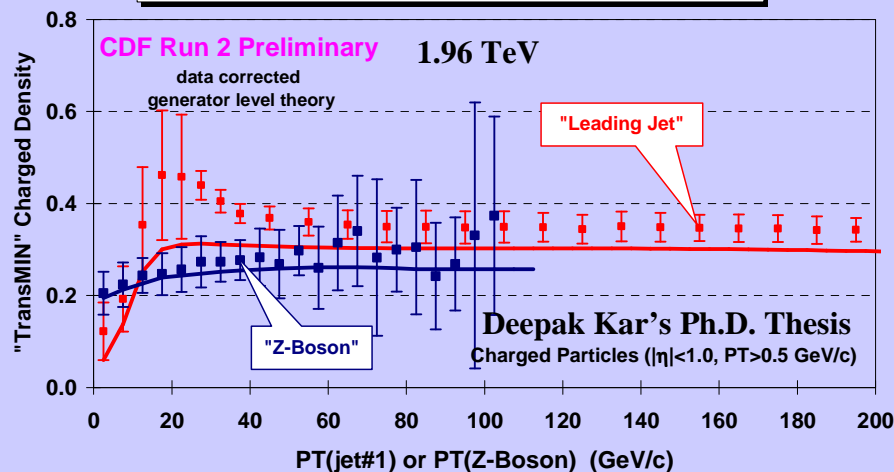


Big difference between “Z-Boson” and “Leading Jet” events for the “transDIF” PTsum density (sensitive to ISR & FSR)!

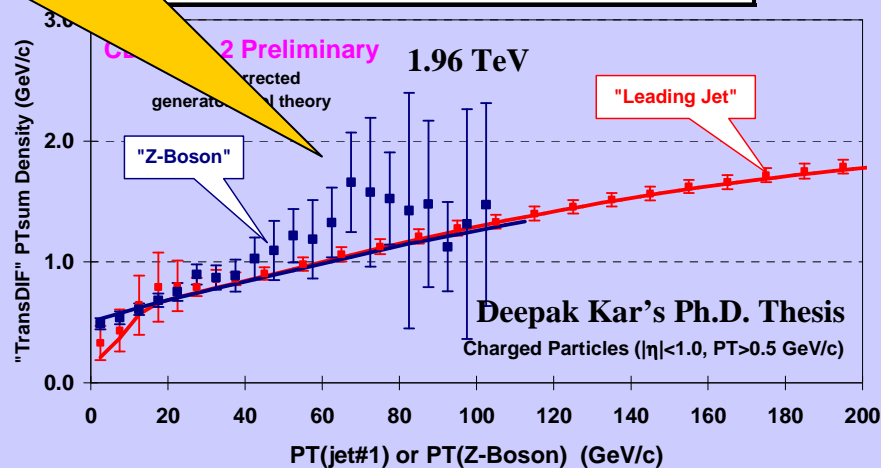


Maybe Deepak and I saw a hint of this in 2008!

“TransMIN” Charged Particle Density:  $dN/d\eta d\phi$

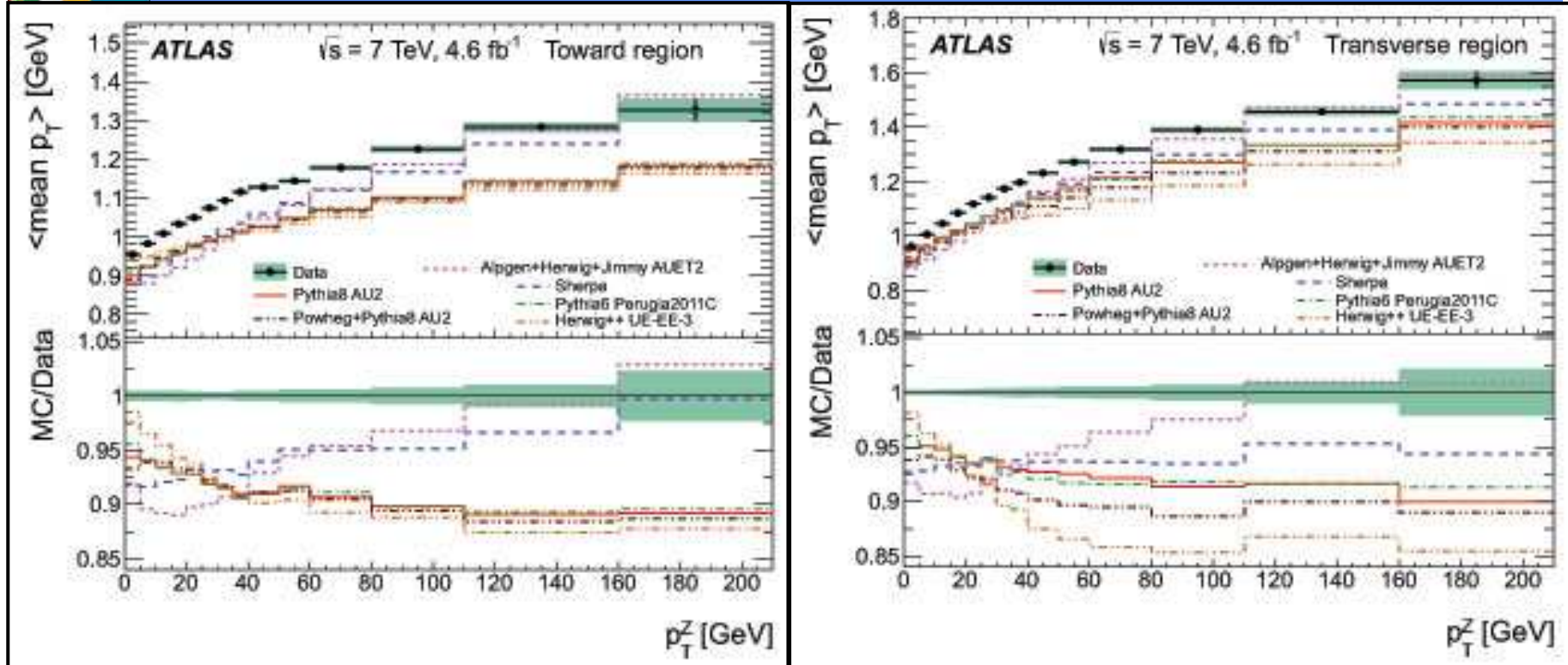
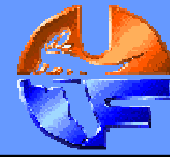


“TransDIF” Charged PTsum Density:  $dPT/d\eta d\phi$





# The UE in Z-Boson Production

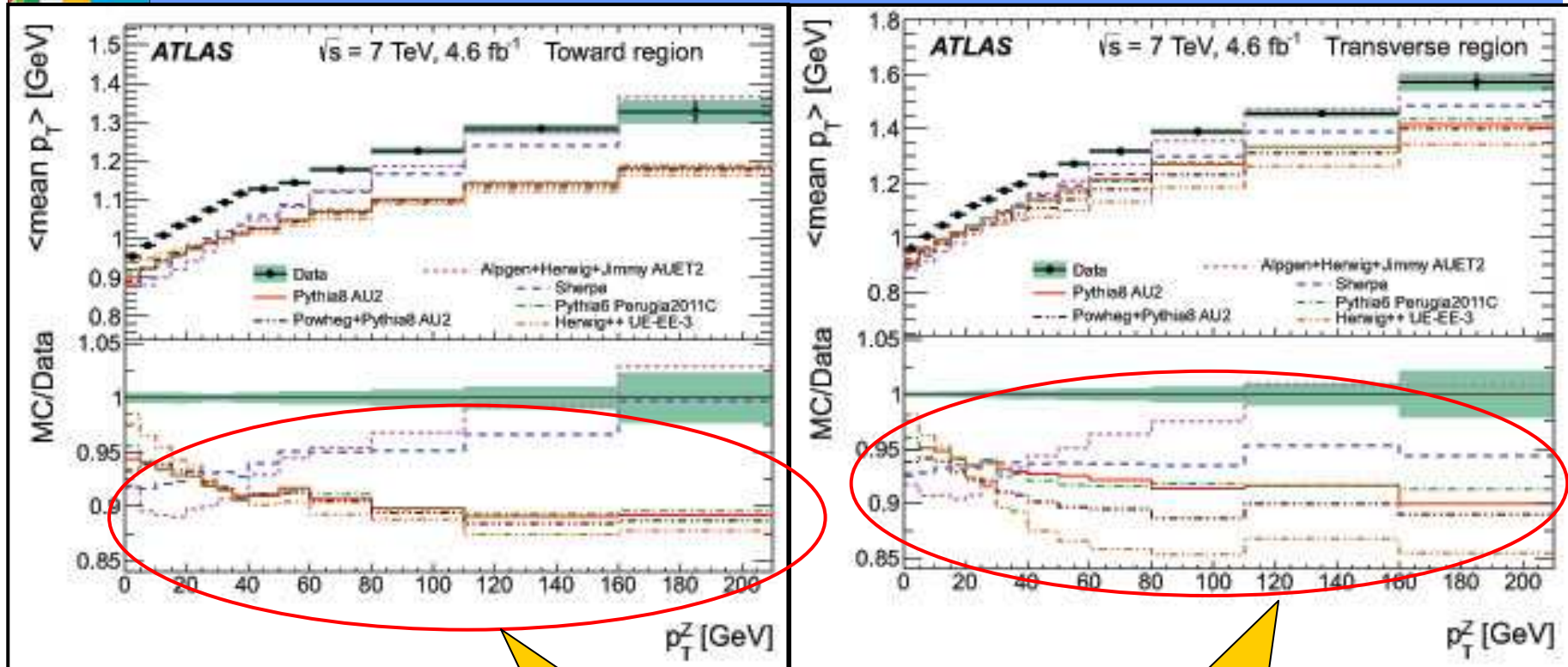
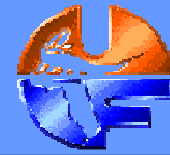


➡ ATLAS data at 7 TeV on the average charged particle  $p_T$  for the “**Toward**” and “**Transverse**” regions for “Z-Boson” events as a function of  $P_T(Z)$ .





# The UE in Z-Boson Production



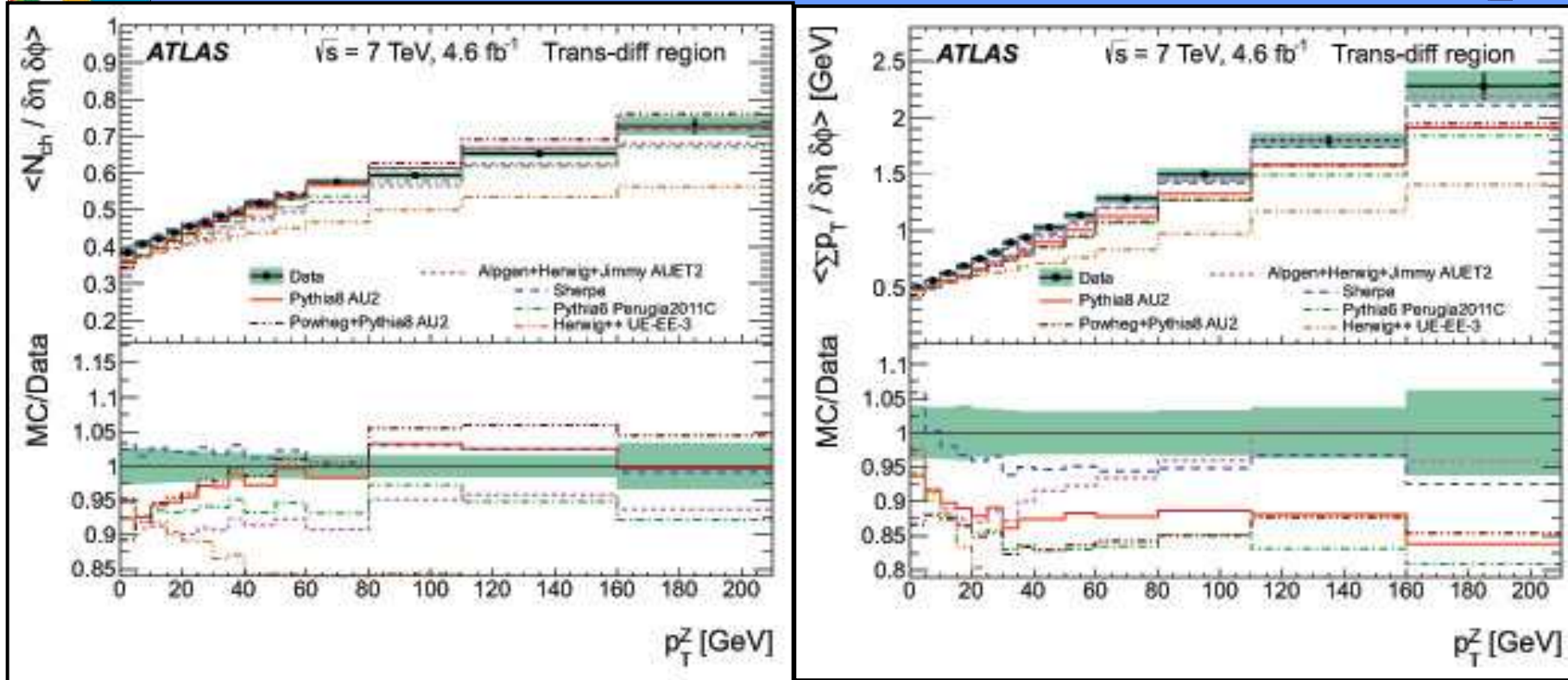
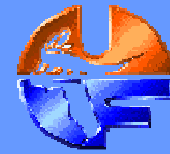
➡ ATLAS data at 7 TeV on the average charged particle  $p_T$  for the “Toward” and “Transverse” regions for “Z-boson” events as a function of  $p_T^Z$

**The QCD Monte-Carlo models are doing poorly on this!**





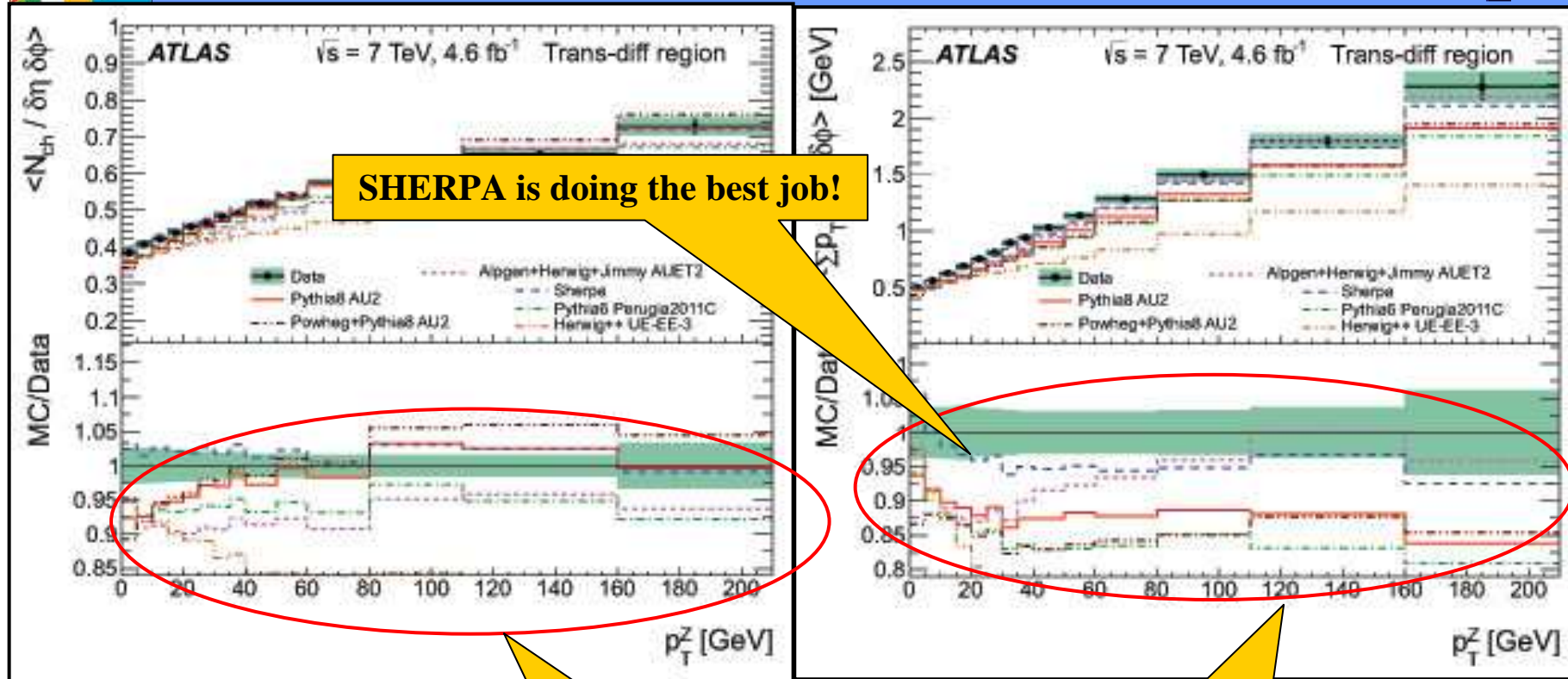
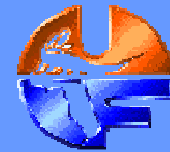
# The UE in Z-Boson Production



➔ ATLAS data at 7 TeV on the charged particle and PTsum densities for “**tranDIF**” for “Z-Boson” events as a function of  $P_T(Z)$ .

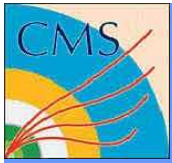


# The UE in Z-Boson Production

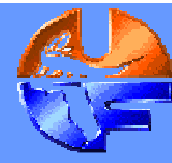


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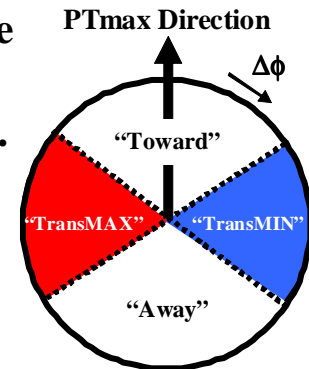
The QCD Monte-Carlo models are doing poorly on this!



# CMS UE Tunes

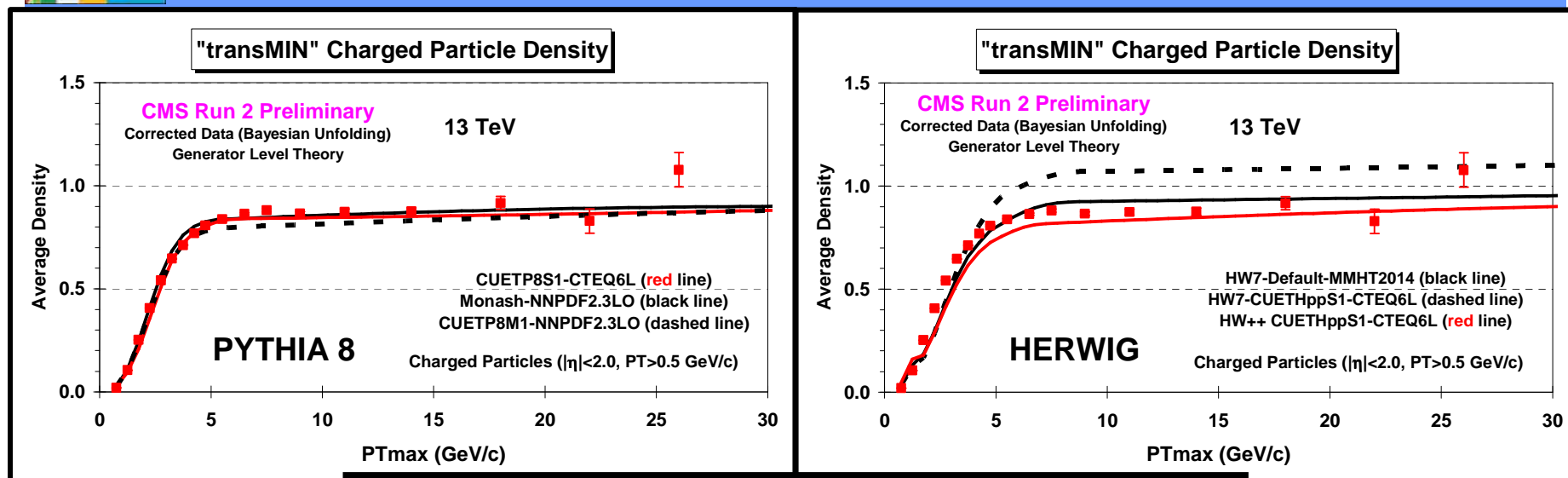


- ➔ **PYTHIA 6.4 Tune CUETP6S1-CTEQ6L:** Start with Tune Z2\*-lep and tune to the CDF PTmax “transMAX” and “transMIN” UE data at 300 GeV, 900 GeV, and 1.96 TeV and the CMS PTmax “transMAX” and “transMIN” UE data at 7 TeV.
- ➔ **PYTHIA 6.4 Tune CUETP6S1-HERAPDF1.5LO:** Start with Tune Z2\*-lep and tune 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. **Bug in HW++!**





# “transMIN” NchgDen



“TransMIN” density more sensitive to MPI & BBR.

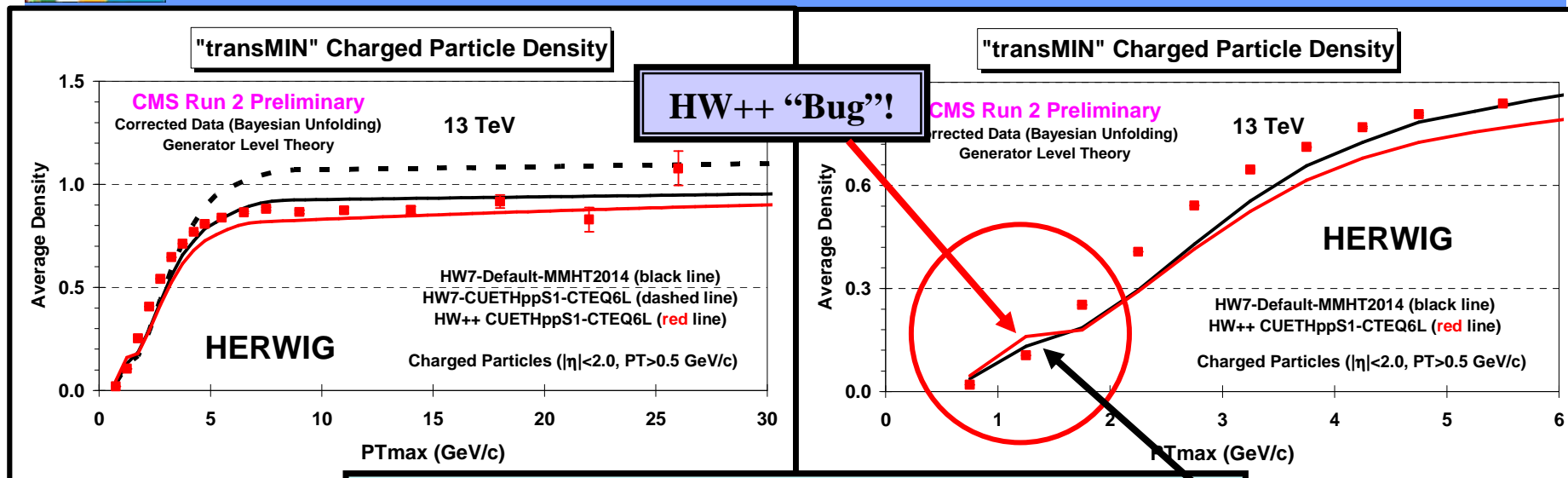
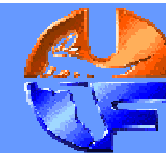
- ➔ CMS corrected data at 13 TeV on the “transMIN” charged particle density with  $p_T > 0.5$  GeV/c and  $|\eta| < 2.0$  as defined by the leading charged particle, as a function of the transverse momentum of the leading charged particle, PTmax. The data are compared with the PYTHIA 8 tune **CUETP8S1-CTEQ6L**, tune CUETP8M1-NNPDF2.3LO, and tune Monash at the generator level.

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# “transMIN” NchgDen



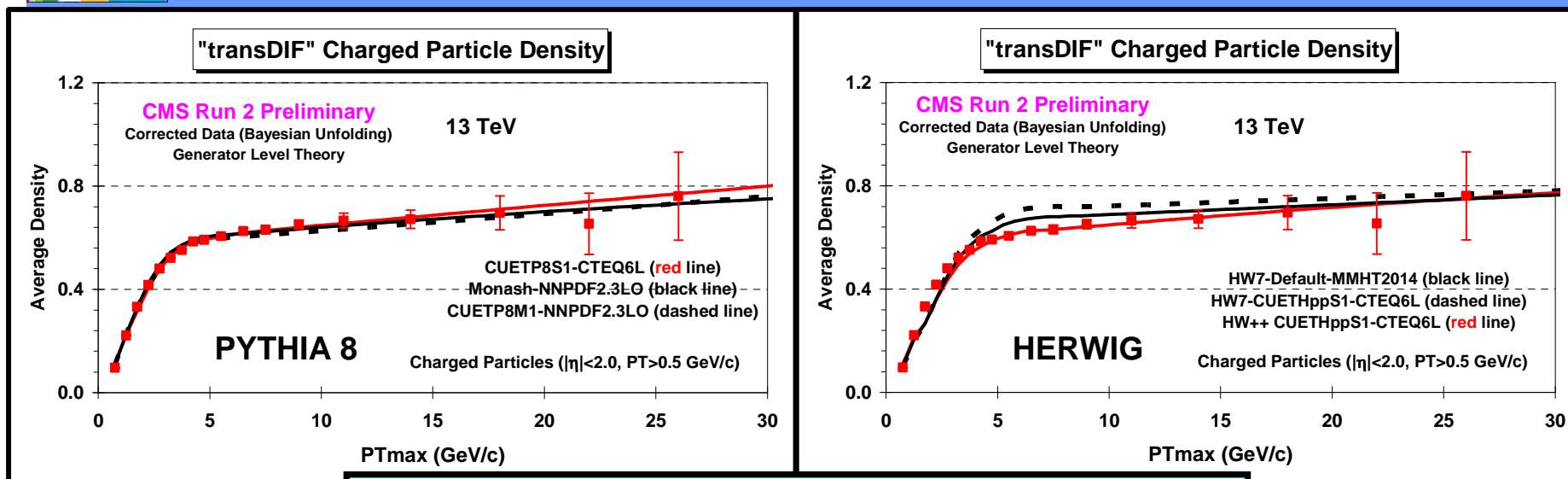
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- ➔ CMS corrected data at 13 TeV on the “transMIN” charged particle density with  $p_T > 0.5$  GeV/c and  $|\eta| < 2.0$  as defined by the leading charged particle, as a function of the transverse momentum of the leading charged particle, PTmax. The data are compared with the HW++ tune **CUETHppS1-CTEQ6L**, and the HW7 tune CUETHppS1-CTEQ6L, and the HW7 default tune (MMHT2014) at the generator level.





# “transDIF” NchgDen



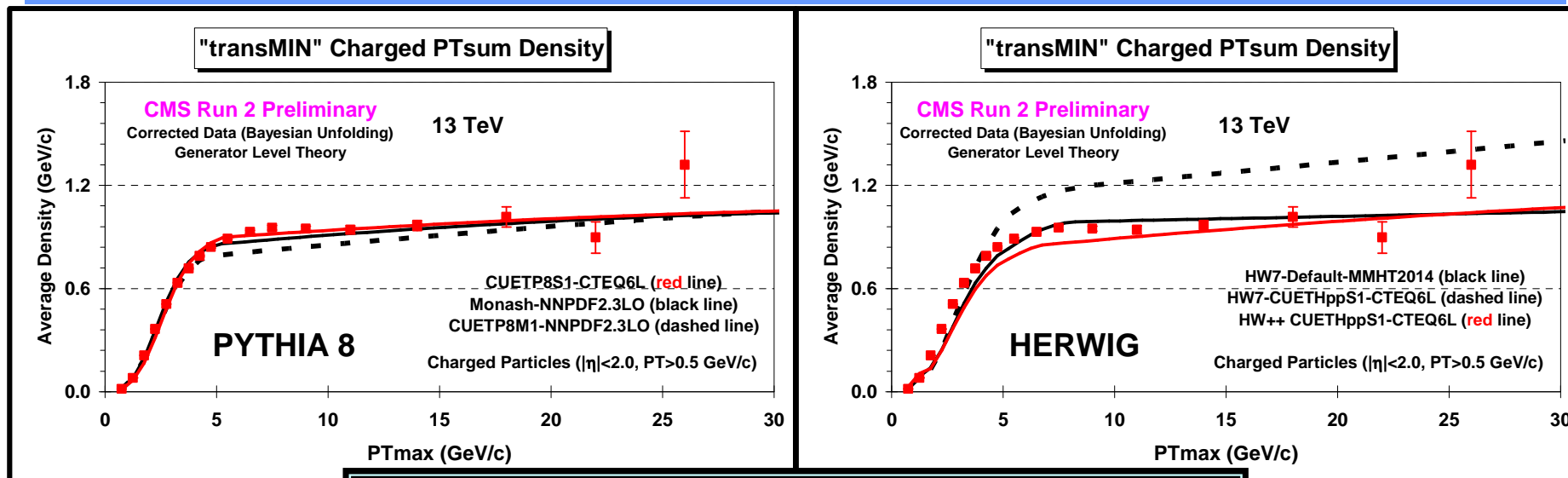
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- ➔ CMS corrected data at 13 TeV on the “transDIF” charged particle density with  $p_T > 0.5$  GeV/c and  $|\eta| < 2.0$  as defined by the leading charged particle, as a function of the transverse momentum of the leading charged particle,  $PT_{max}$ . The data are compared with the HW++ tune **CUETHppS1-CTEQ6L**, and the HW7 tune CUETHppS1-CTEQ6L, and the HW7 default tune (MMHT2014) at the generator level.



# “transMIN” PTsumDen



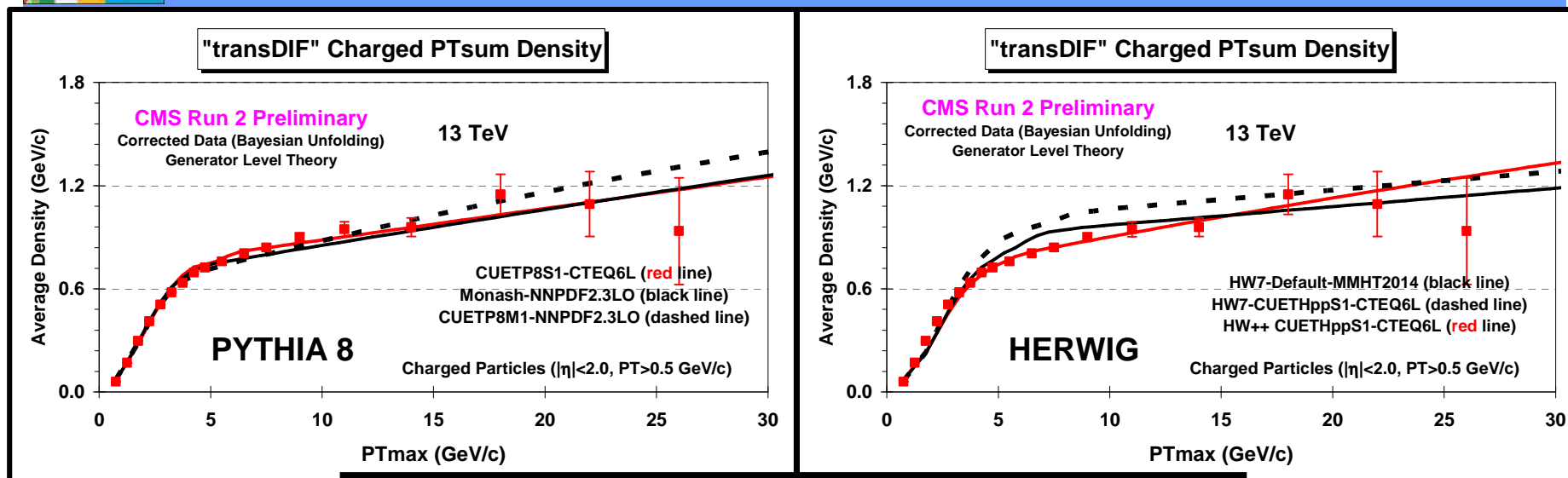
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# “transDIF” PTsumDen



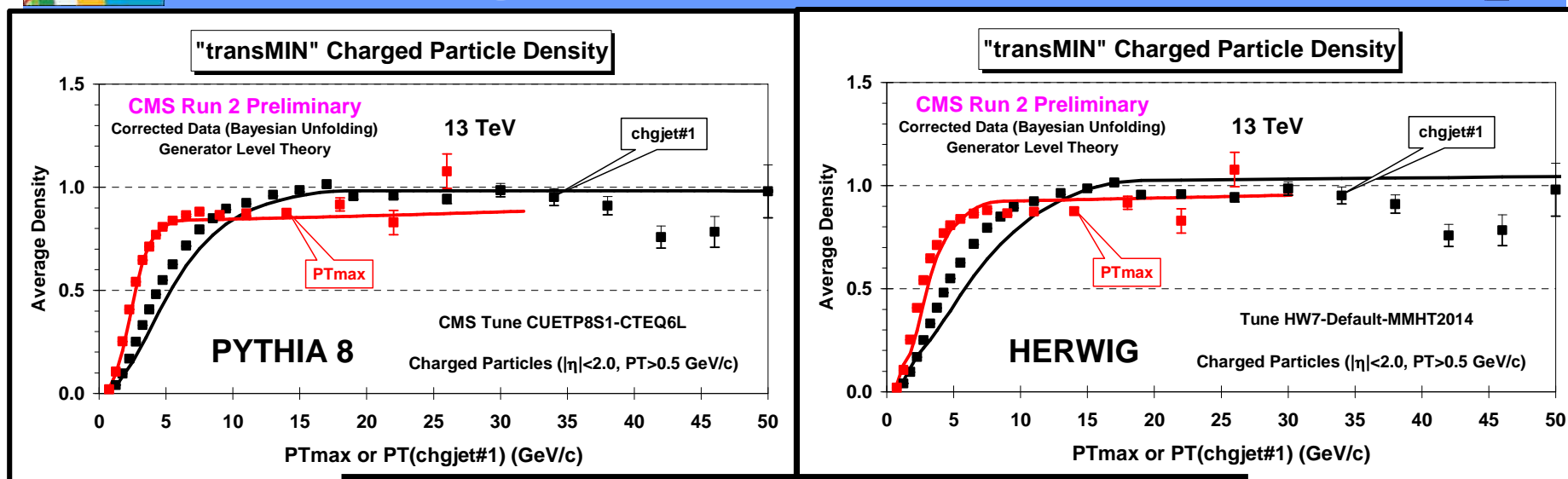
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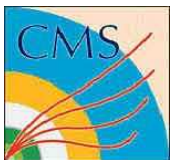
# ChgJet#1 vs PTmax



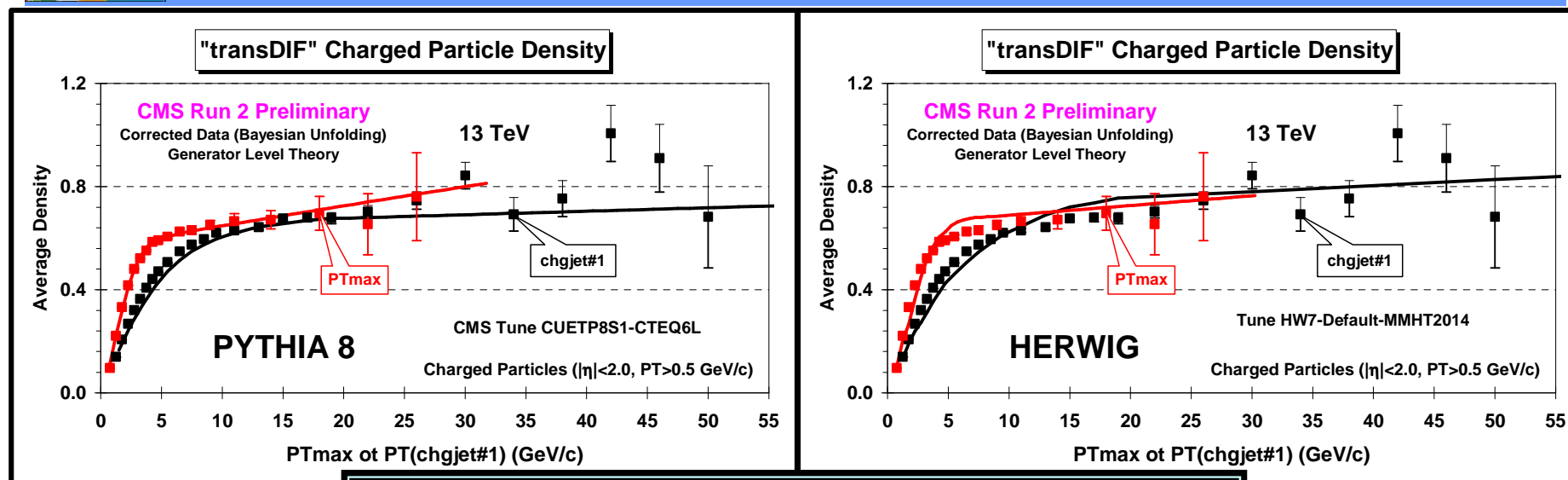
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# ChgJet#1 vs PTmax



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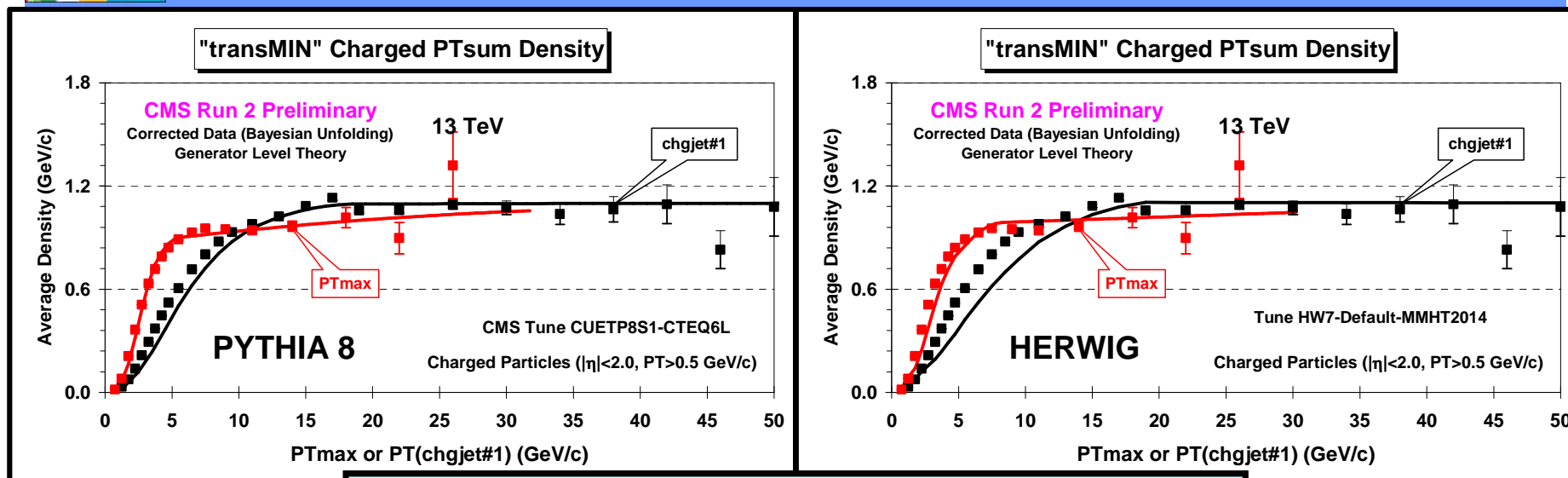
➔ CMS corrected data at 13 TeV on the "transDIF" charged particle density with  $p_T > 0.5$  GeV/c and  $|\eta| < 2.0$  as defined by the leading charged particle,  $PT_{max}$ , and as defined by the leading charged particle jet,  $chgjet\#1$ . The data are compared with the PYTHIA 8 tune CUETP8S1-CTEQ6L at the generator level.

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# ChgJet#1 vs PTmax



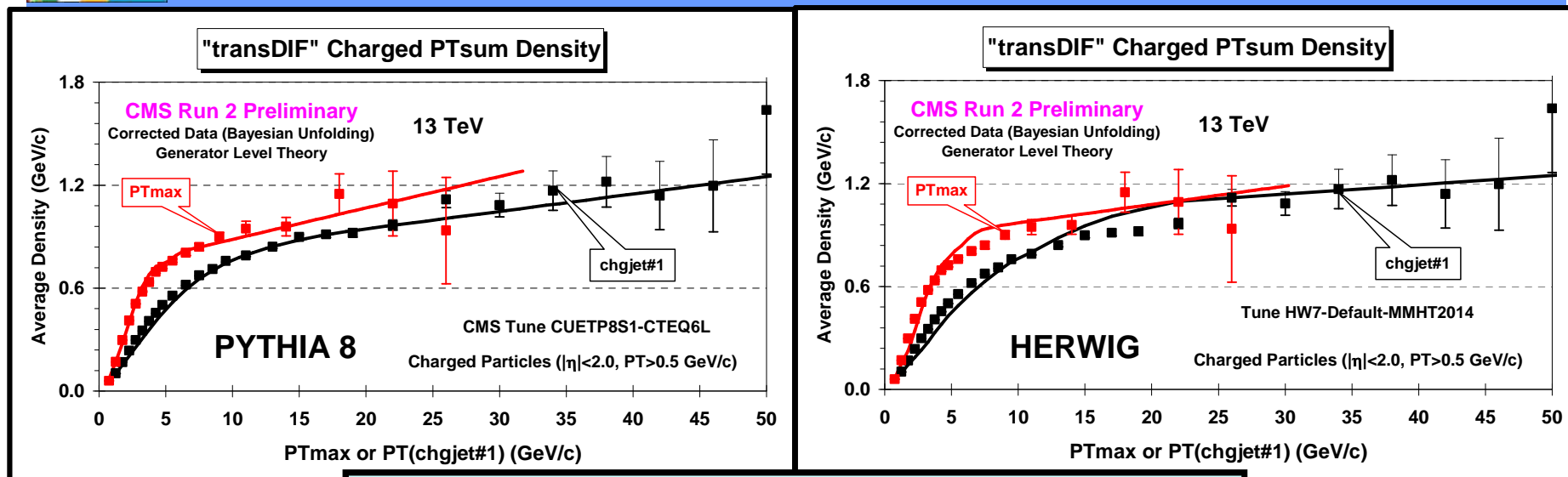
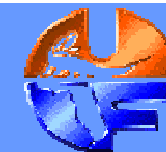
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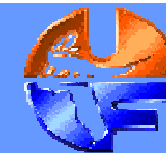
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# Energy Flow



Available on the CERN CDS information server

CMS PAS FSQ-15-006

## CMS Physics Analysis Summary

Contact: cms-pag-conveners-fsq@cern.ch

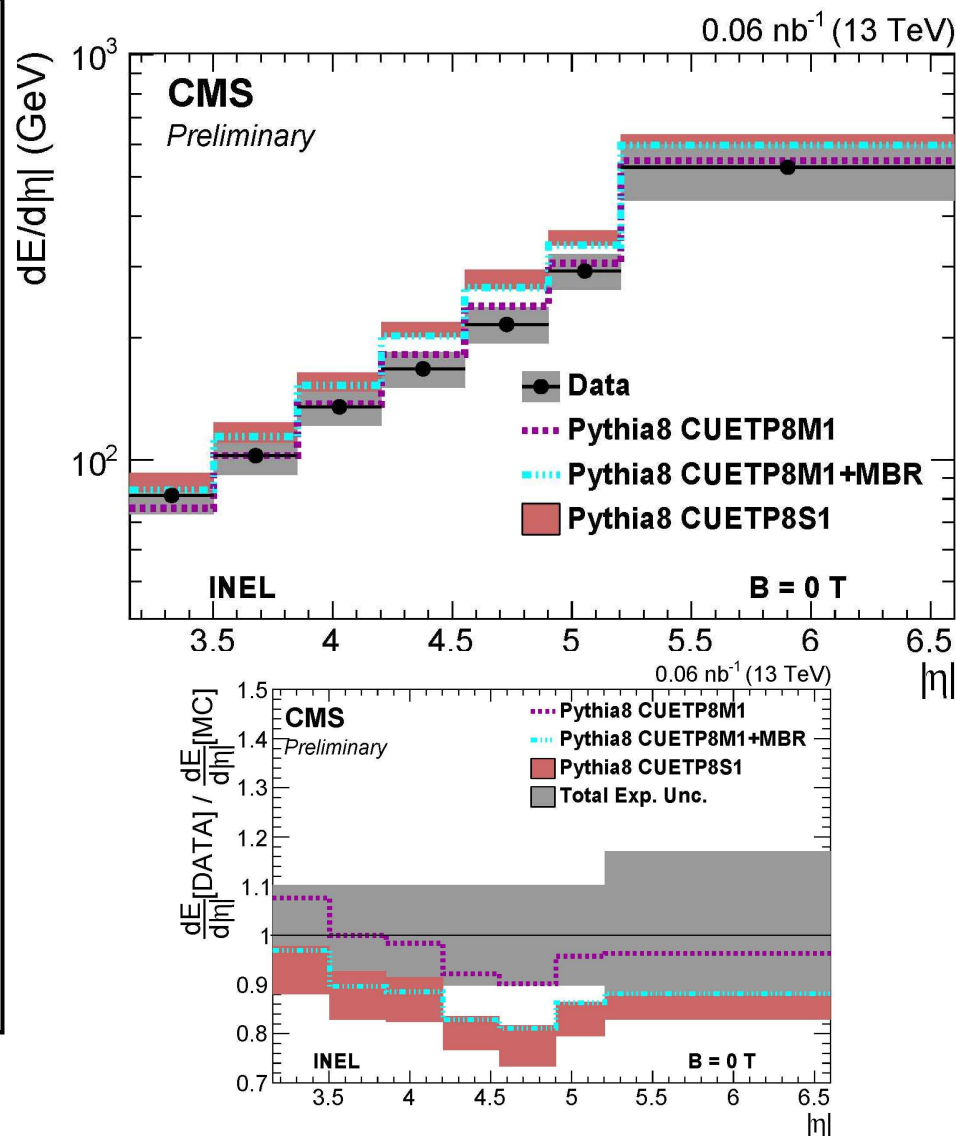
2016/04/14

Measurement of the pseudorapidity dependence of the energy and transverse energy density in pp collisions at  $\sqrt{s} = 13$  TeV with CMS

The CMS Collaboration

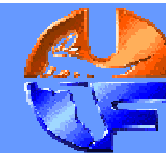
### Abstract

The measurement of the energy flow is presented in the pseudorapidity range  $3.15 < |\eta| < 6.6$  in proton-proton collisions at the LHC for the centre-of-mass energy of  $\sqrt{s} = 13$  TeV. The data have been obtained during several periods of low luminosity operation in 2015. The energy flow,  $dE/d\eta$ , as well as the transverse energy density,  $dE_T/d\eta$ , are studied as a function of pseudorapidity for soft-inclusive-inelastic and non-single-diffractive-enhanced events. The results are compared to models tuned to describe high-energy hadronic interactions and to earlier pp data at  $\sqrt{s} = 900$  GeV and 7 TeV. Comparison to the earlier data allows to test the hypothesis of the limiting fragmentation.





# Energy Flow



Available on the CERN CDS information server

CMS PAS FSQ-15-006

## CMS Physics Analysis Summary

Contact: cms-pag-conveners-fsq@cern.ch

2016/04/14

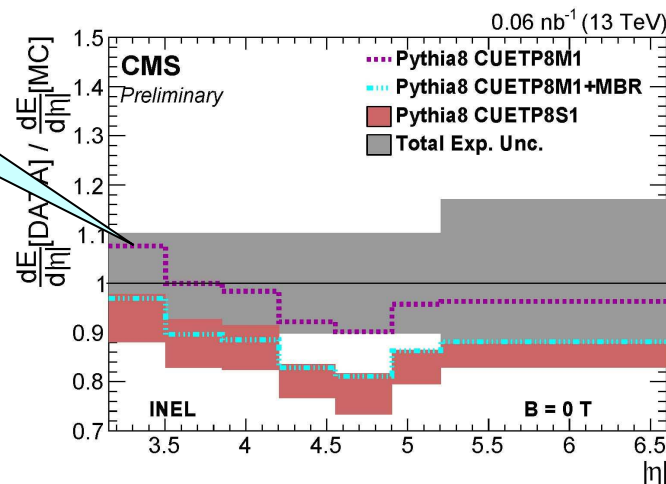
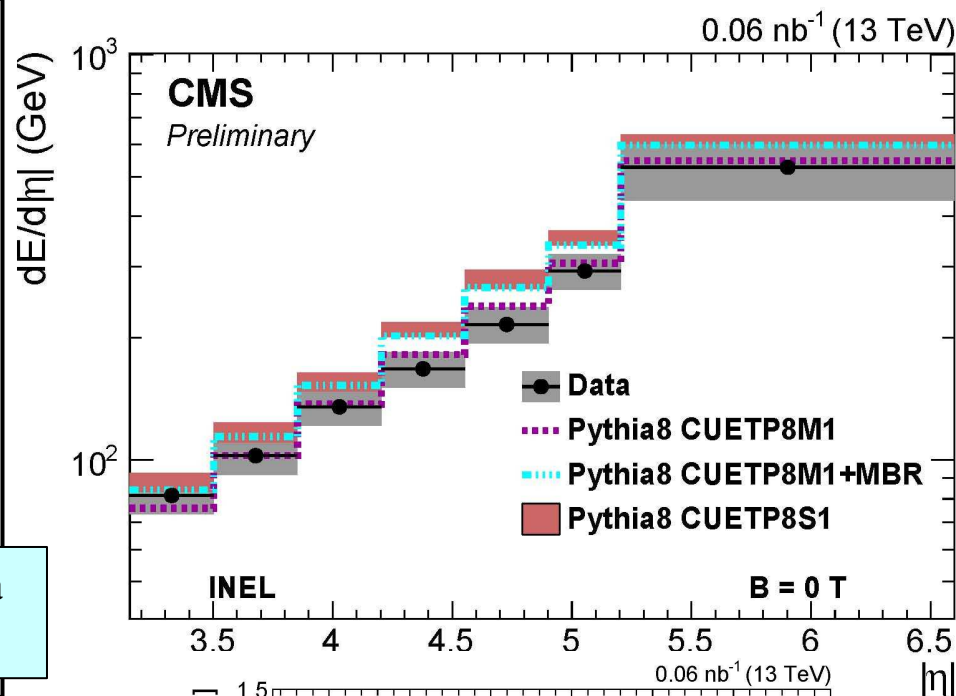
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The CMS Collab

**CUETP8M1 does a fairly good job!**

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# Forward Energy Distribution



Available on the CERN CDS information server

CMS PAS FSQ-16-002

## CMS Physics Analysis Summary

Contact: cms-pag-conveners-fsq@cern.ch

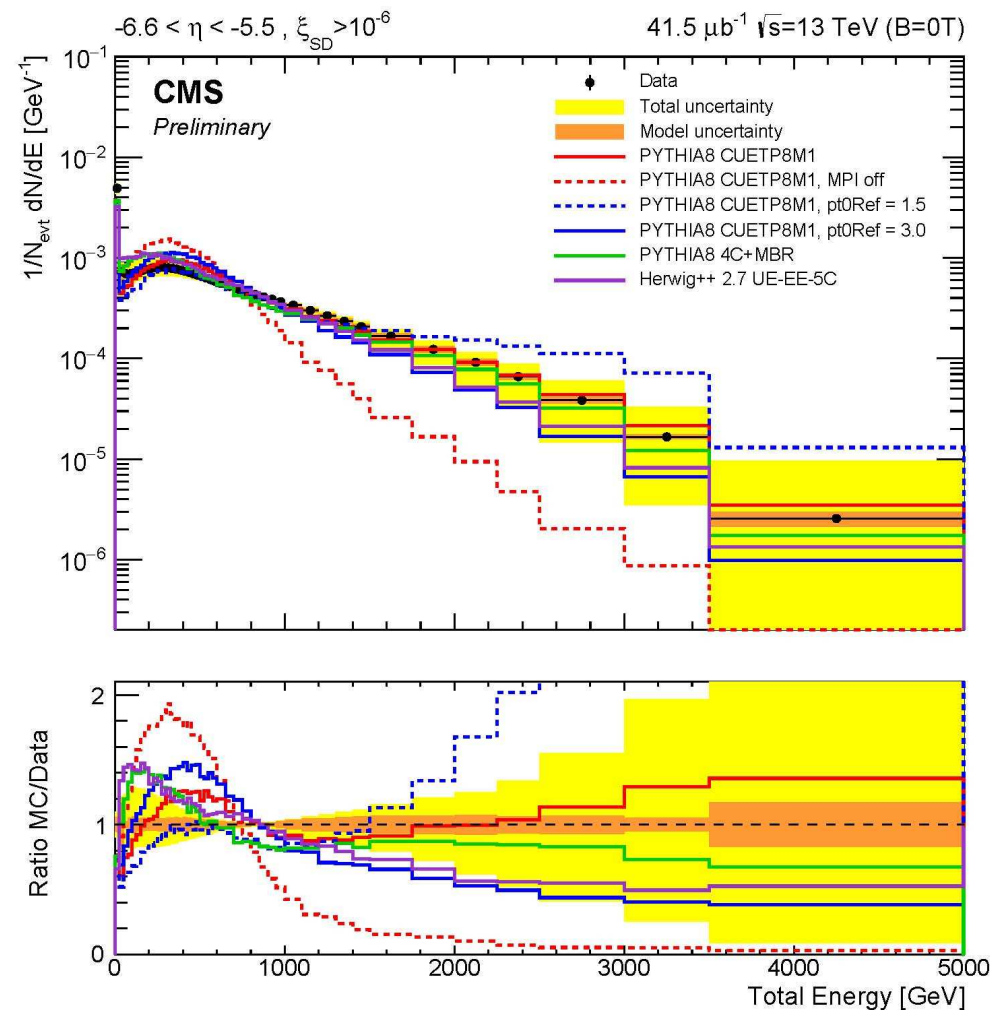
2016/04/11

### Measurement of the energy distribution in the very forward direction at 13 TeV with CMS

The CMS Collaboration

#### Abstract

The event-by-event energy deposition into the very forward acceptance,  $-6.6 < \eta < -5.2$ , of CMS is measured and characterized in proton-proton collisions at 13 TeV. Data from the electromagnetic and hadronic sections of the CASTOR calorimeter are used for this purpose. The results are corrected to stable particle level and presented independently for the electromagnetic as well as the hadronic component of the hadronic multiparticle production. The data are sensitive to the production of neutral and charged mesons, which is a key ingredient for the modeling of cosmic ray induced extensive air showers at ultra-high energies. The presented data are relevant for the fraction of primary energy converted into secondary muons. Furthermore, the data are sensitive to the characteristics of multi-parton interactions.







# Forward Energy Distribution



Available on the CERN CDS information server

CMS PAS FSQ-16-002

## CMS Physics Analysis Summary

Contact: cms-pag-conver

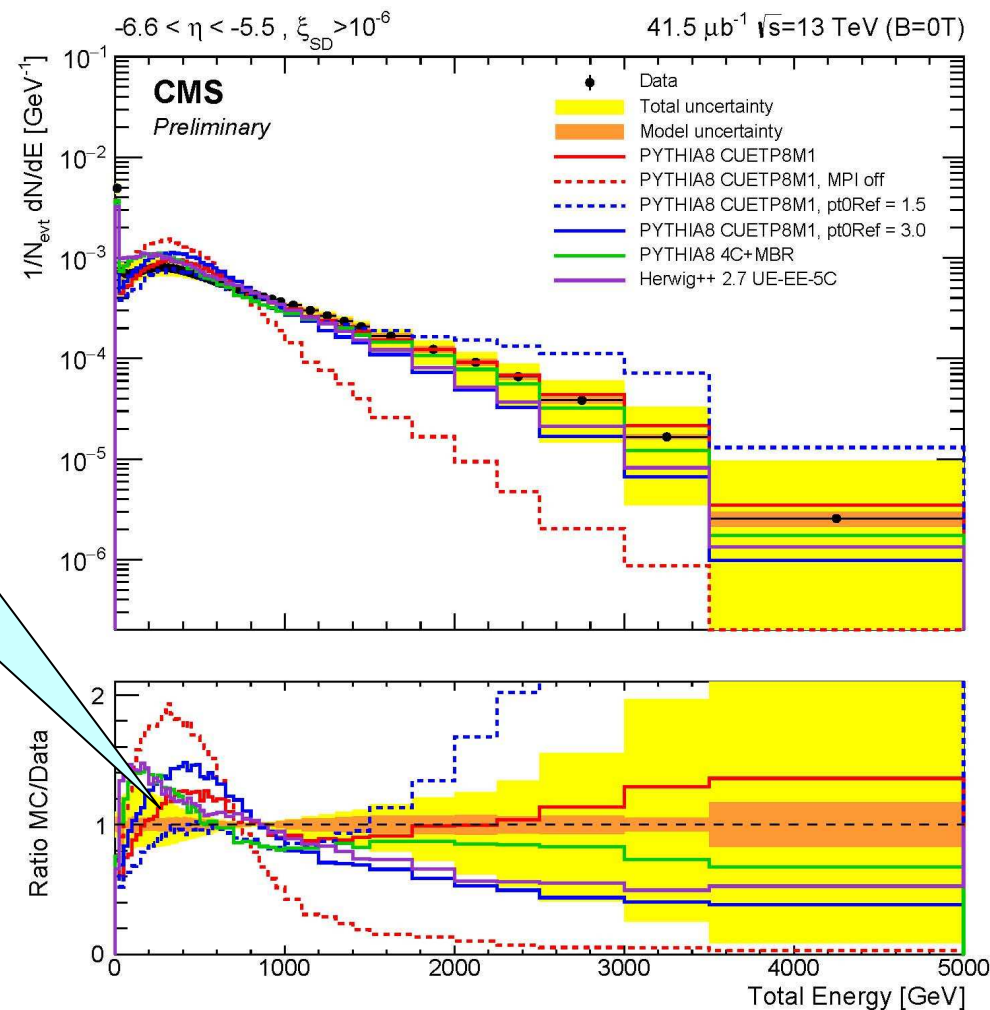
**CUETP8M1 does a fairly good job, but overestimates the soft energy!**

Measurement of the energy distribution in the very forward direction at 13 TeV with the CMS calorimeter

The CMS Collaboration

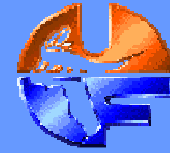
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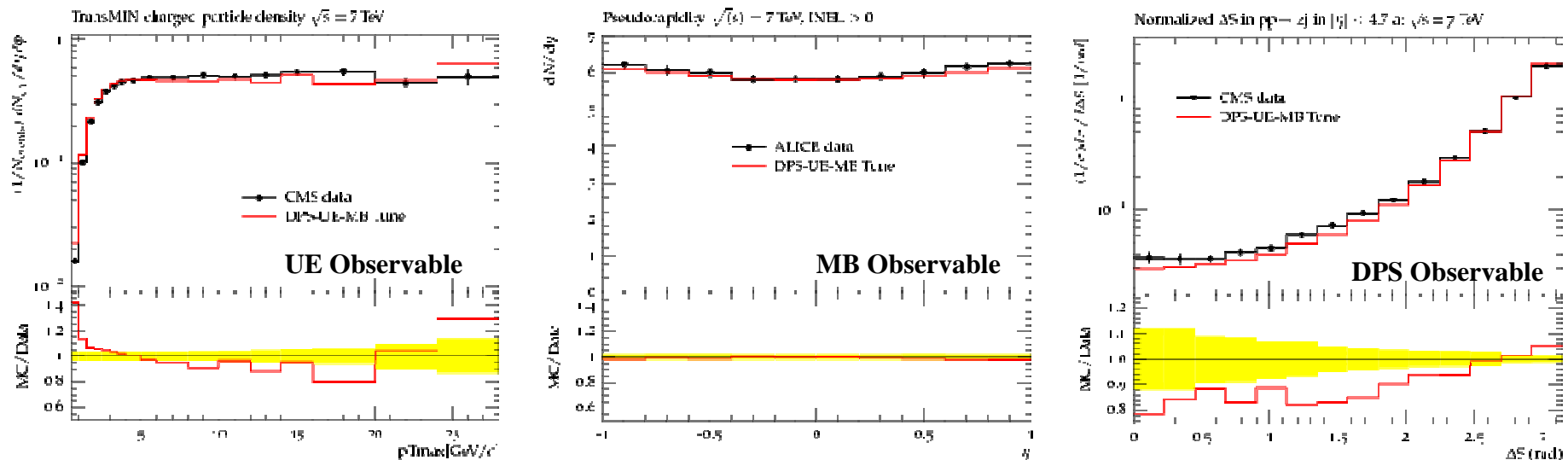




# Simultaneous UE-MB-DPS Tune



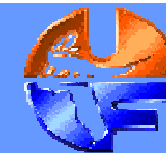
Paolo Gunnellini and the CMS PC&GT Team



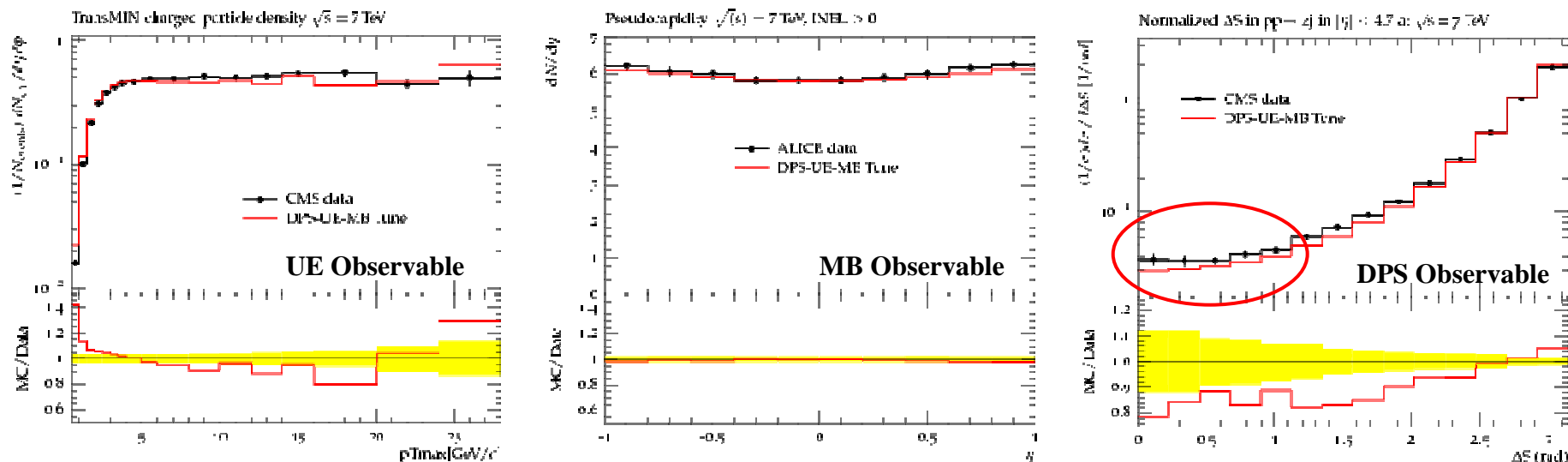
- ➔ **Simultaneous UE-MB-DPS Tune at 7 TeV:** Simultaneously fit the CMS  $pT_{max}$  UE data, the ALICE  $dN/d\eta$  data, and the CMS  $pp \rightarrow 4j$  DPS data starting with PYTHIA 8 tune CUETP8M1-NNPDF2.3LO and vary three parameters (MultipartonInteractions:pT0Ref, MultipartonInteractions:expPow, ColourReconnection:range). Weight all data equally.



# Simultaneous UE-MB-DPS Tune



Paolo Gunnellini and the CMS PC&GT Team

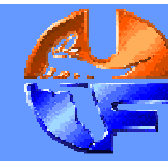


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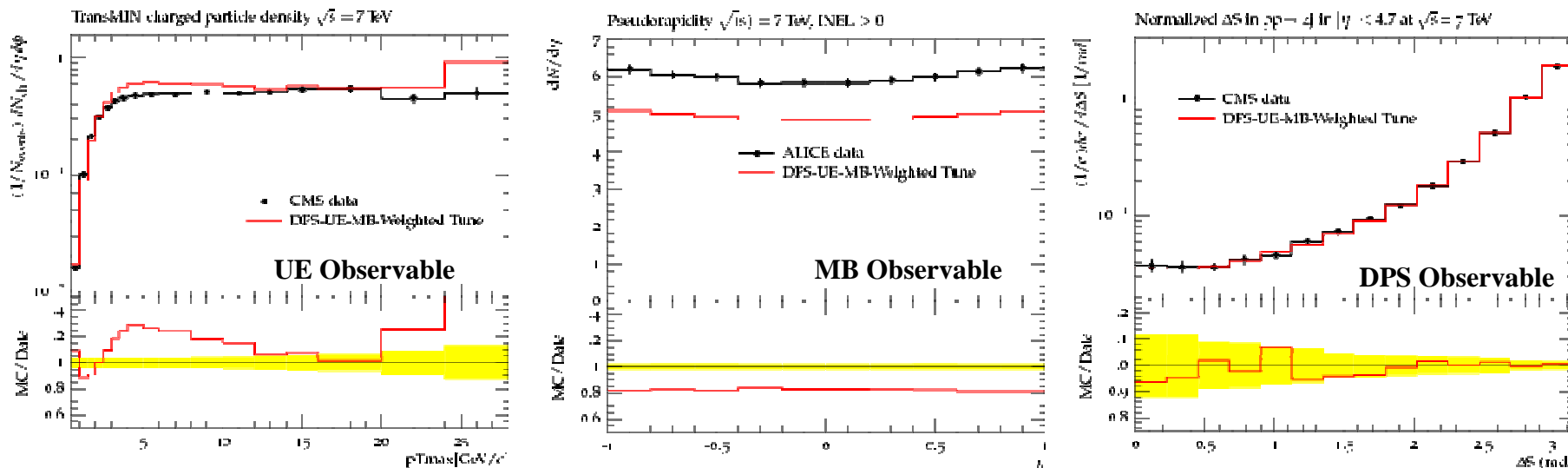
**UE and MB are good, but DPS is bad!**



# Simultaneous UE-MB-DPS Tune



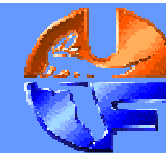
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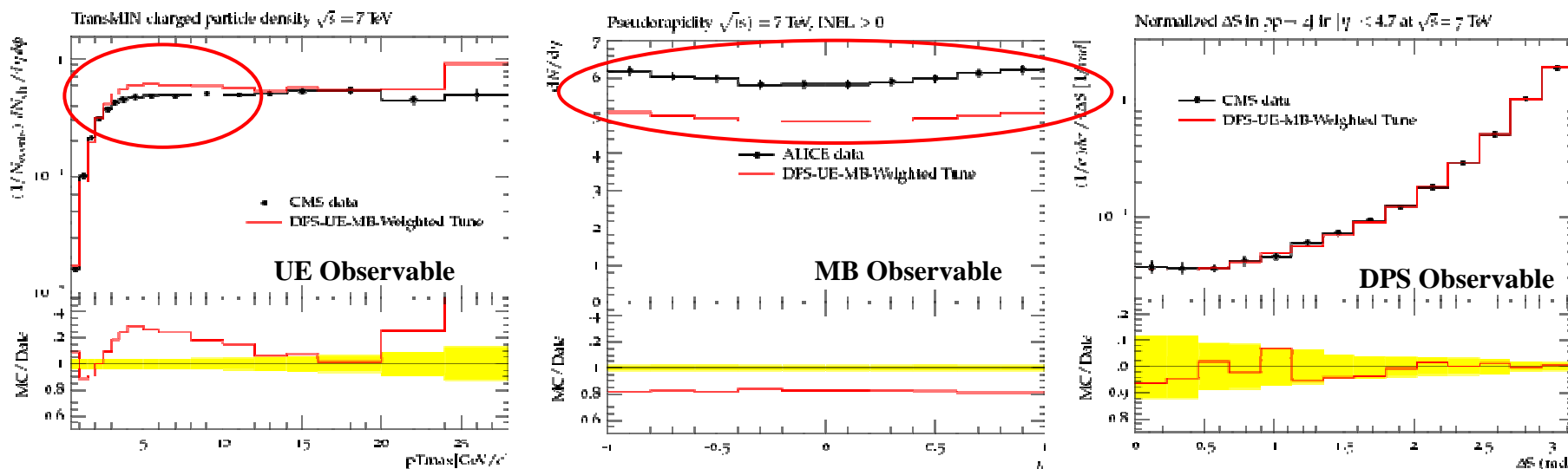
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# Simultaneous UE-MB-DPS Tune



Paolo Gunnellini and the CMS PC&GT Team



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**DPS is good, but UE and MB are bad!**





# Summary & Conclusions



- ➔ No one QCD Monte-Carlo model describes everything perfectly.
- ➔ The PYTHIA 8 tunes such as CUETP8S1, CUETP8M1, and Monash, describe fairly well both the underlying event and the non-diffractive contribution to MB observables. **We need to work on tuning the diffractive models!**
- ➔ The CMS HW++ Tune CUETHS1-CTEQ6L fits the UE “plateau” region very well, but cannot use it because of the HW++ “bug”. Big change in going from HW++ to HW7! Must re-tune. The HW7 Default Tune is not bad! But could do better!
- ➔ Tunes that use NPDF2.3LO PDF do a better job in the forward region due to the low-x gluon distribution.
- ➔ Hard multi-jet production in Z-Boson events at large  $P_T(Z)$  is not modeled very well by the QCD Monte-Carlo models (SHERPA is doing the best). **This is not a UE problem!**
- ➔ **I do not understand why we cannot simultaneously fit both the UE and the DPS sensitive observables with the same tune. We will continue to work on this.**
- ➔ **The CMS PC&GT group is actively working of improved PYTHIA 8, HERWIG 7, and SHARPA tunes!**

