SM@LHC 2016

Minimum Bias at 13 TeV

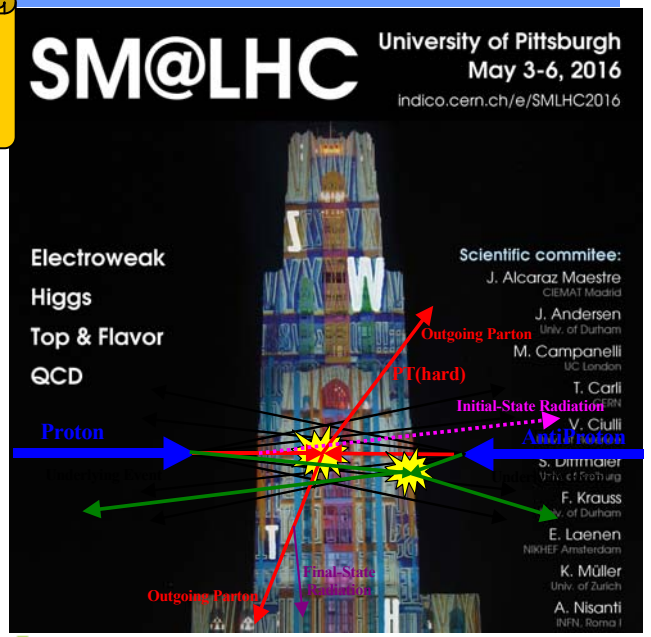
Rick Field

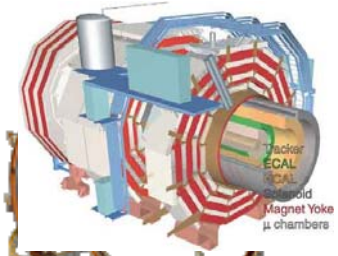
University of Florida

Quantum Chromo-Dynamics

Outline of Talk

- **C2CR07:** My Min-Bias talk at Lake Tahoe in 2007.
- **MB-UE-DPS:** Relationships between Min-Bias (MB), the underlying event (UE), and double parton scattering (DPS).
- **CMS UE Tunes:** Two PYTHIA 6 tunes, three PYTHIA 8 tunes, and one HERWIG++ tune from the CMS "Physics Comparisons & Generator Tunes" subgroup.
- **MB@13TeV:** Some MB measurements from the LHC and comparisons.
- **Simultaneous UE-MB-DPS Tunes:** Can we fit UE data, MB data, and DPS sensitive with one universal tune?





CMS

ALICE

LHCb

ATLAS

SM@LHC 2016

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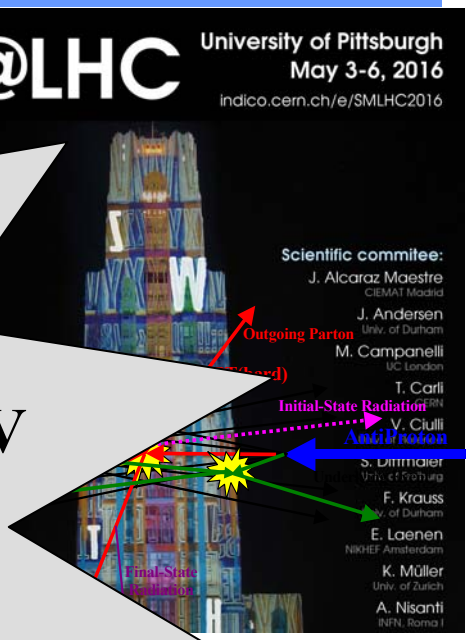
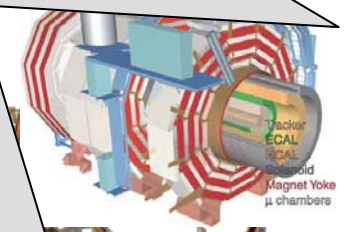
Rick Field
Univ. of Florida



There is a lot of nice MB data at 13 TeV with a variety of trigger and selection criteria.

I apologize for not being able to show everything!

- **C**
- **MB-UE** underlying
- **CMS UE T** 8 tunes. "Ph
- **MB@13TeV:** Some M and comparisons.
- **Simultaneous UE-MB-DPS Tunes** ve fit UE data, MB data, and DPS sensitive one universal tune?



CMS

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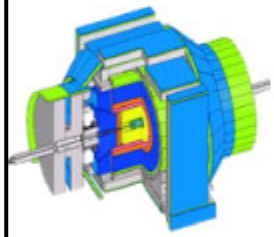
Colliders to Cosmic Rays 2007

C2CR07

Rick Field
University of Florida
(for the CDF Collaboration)

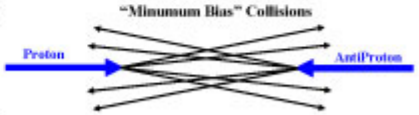
Min-Bias at the Tevatron



CDF Run 2

Outline of Talk

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



Quantum Chromo-Dynamics

C2CR07-Lake Tahoe
February 28, 2007

Rick Field – Florida/CDF

Page 1

Rick Field
"Min-Bias" talk
February 28, 2007

9 Years ago!

Organized by Robin Erbacher and the UC Davis group!

C2CR07

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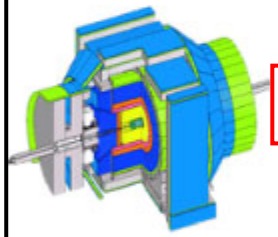

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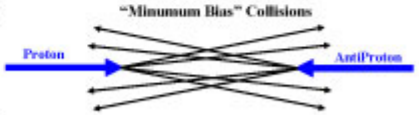

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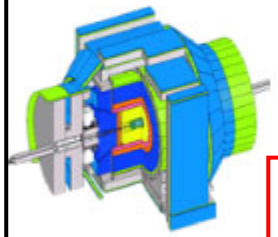

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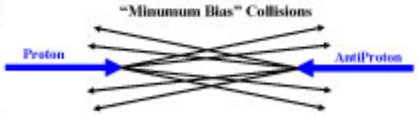

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Min-Bias at the Tevatron

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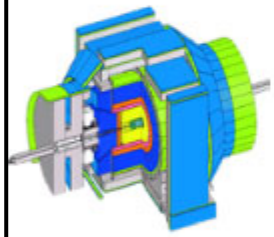

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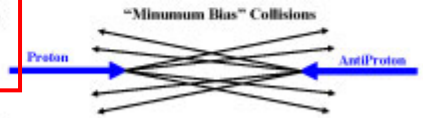

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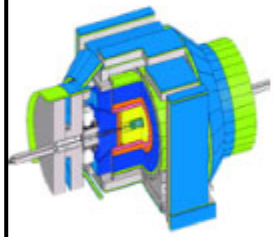

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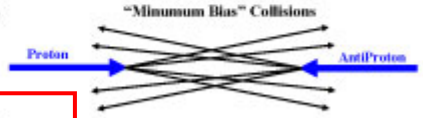

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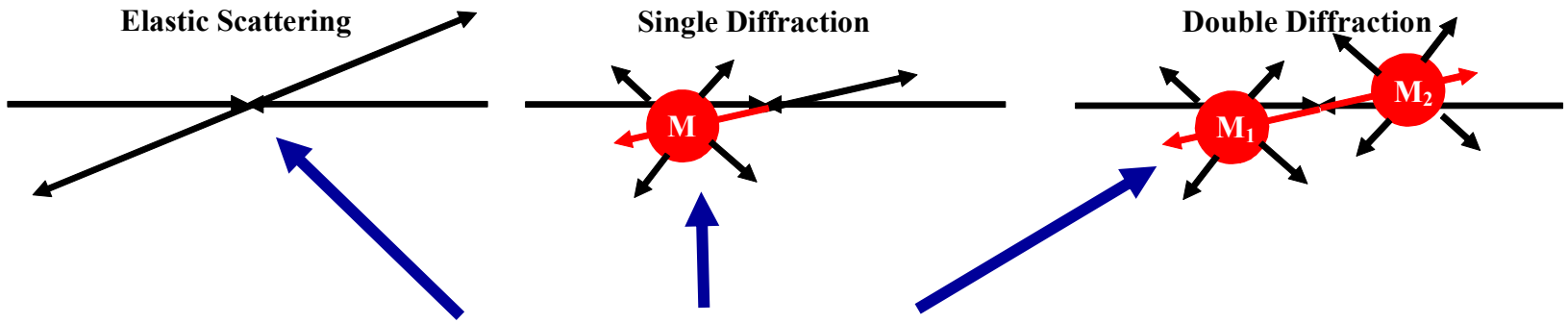
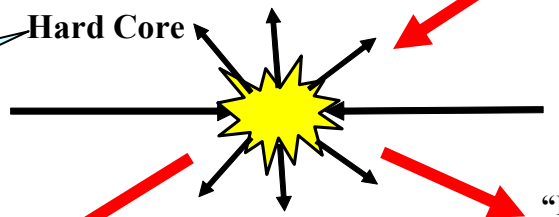
Proton-AntiProton Collisions at the Tevatron

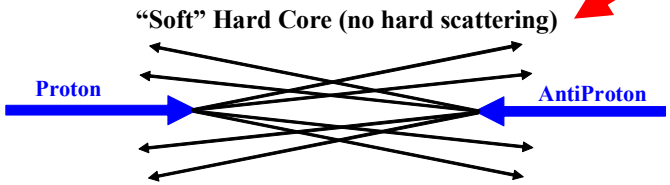


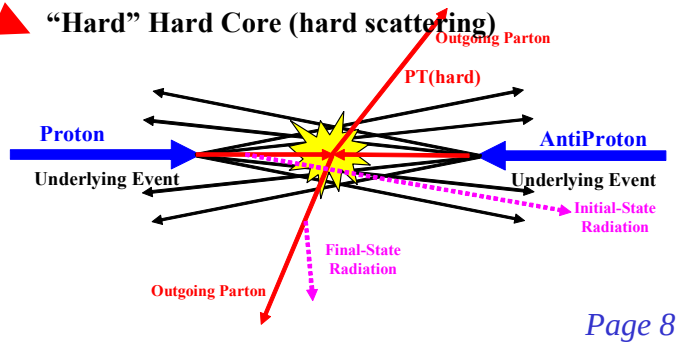
$$\sigma_{tot} = \sigma_{EL} + \sigma_{SD} + \sigma_{DD} + \sigma_{HC}$$

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

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







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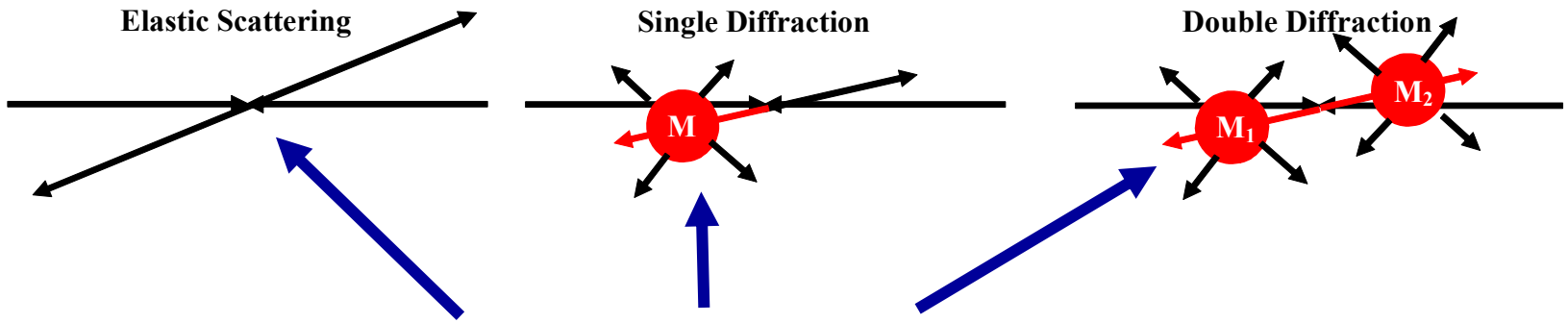

$$\sigma_{tot} = \sigma_{EL} + \sigma_{SD} + \sigma_{DD} + \sigma_{ND}$$

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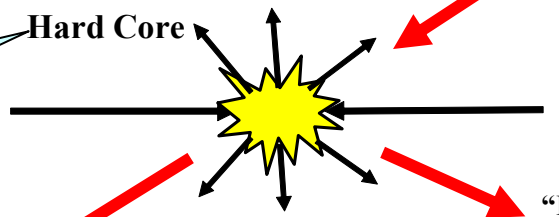
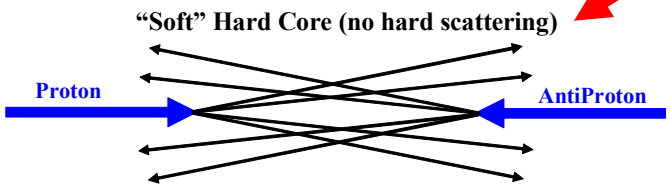
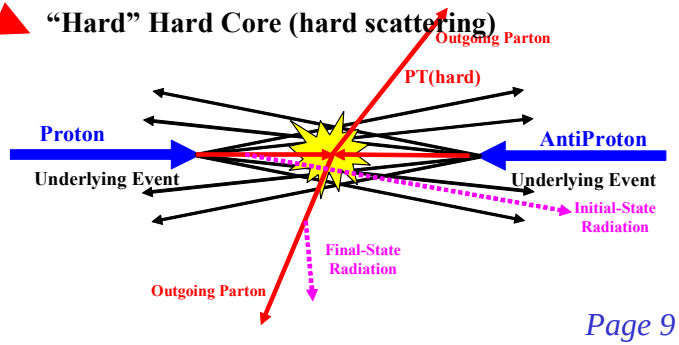
The "hard core" component contains both "hard" and "soft" collisions.

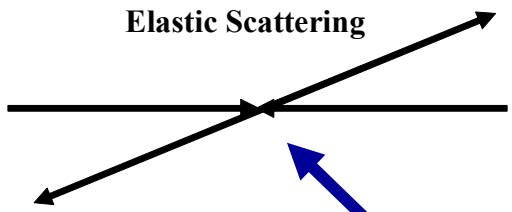
Inelastic "Non-Diffractive"

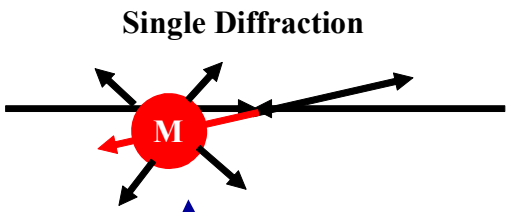


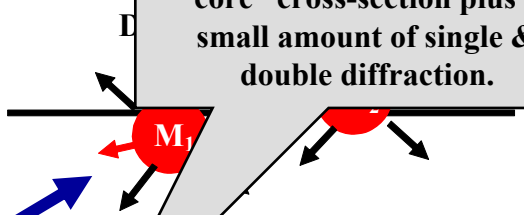




Proton-AntiProton Collisions at the Tevatron



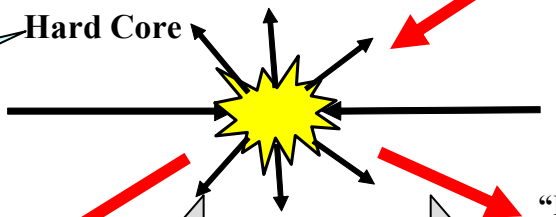




The CDF "Min-Bias" trigger picks up most of the "hard core" cross-section plus a small amount of single & double diffraction.

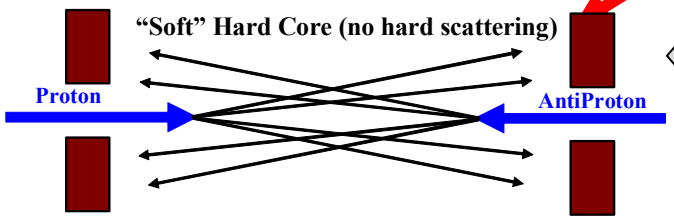
$$\sigma_{tot} = \sigma_{EL} + \sigma_{SD} + \sigma_{DD} + \sigma_{ND}$$

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

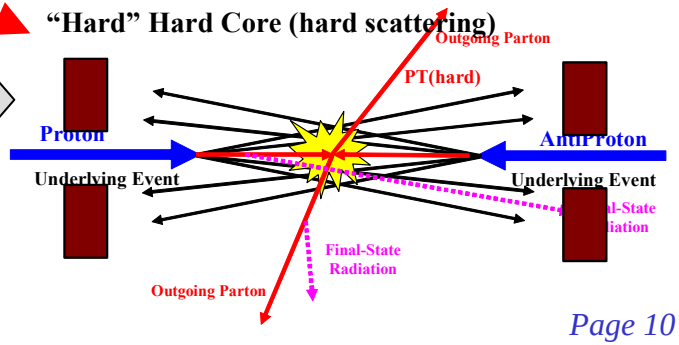


The "hard core" component contains both "hard" and "soft" collisions.

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

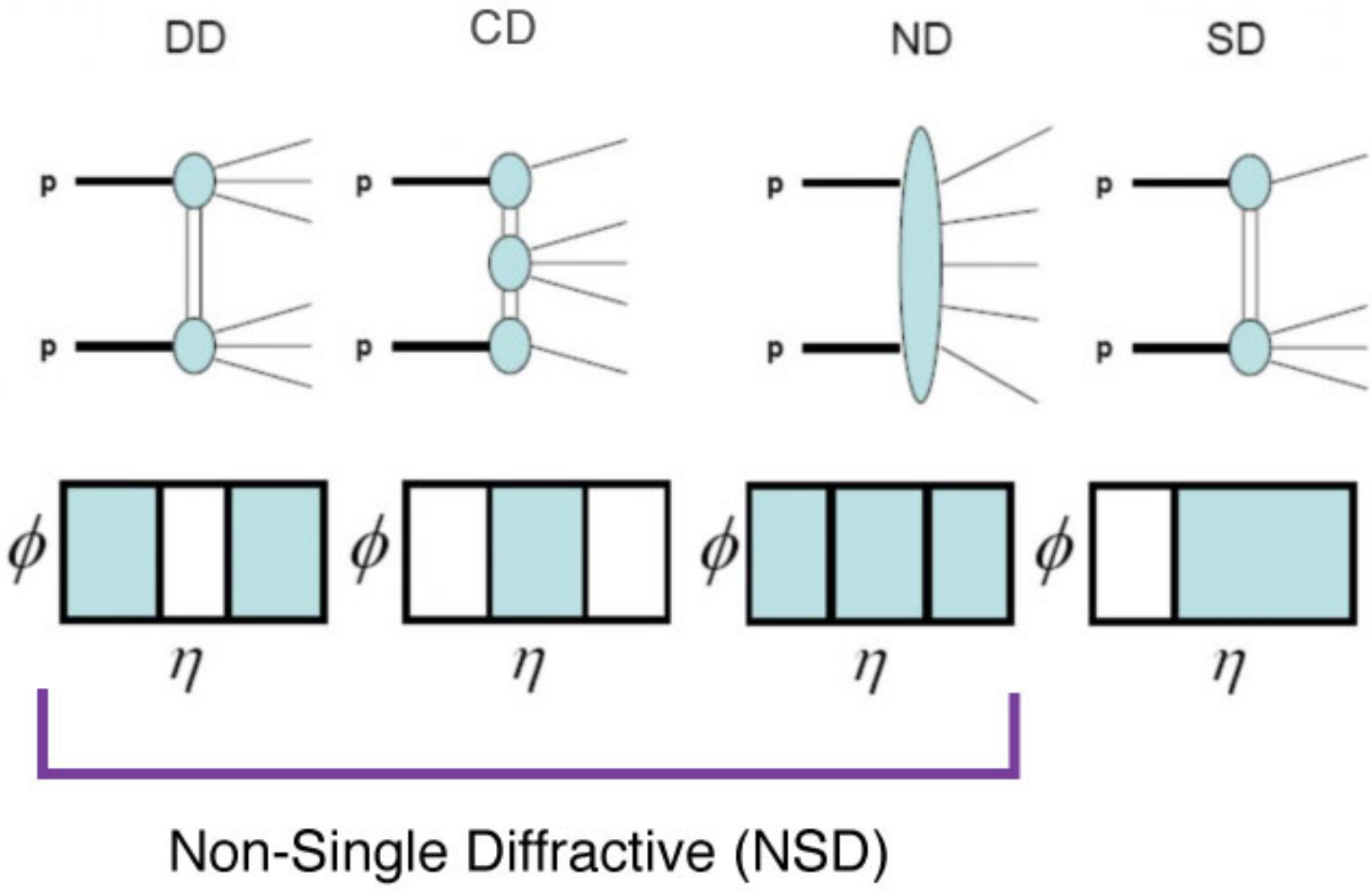


Beam-Beam Counters
$3.2 < |\eta| < 5.9$

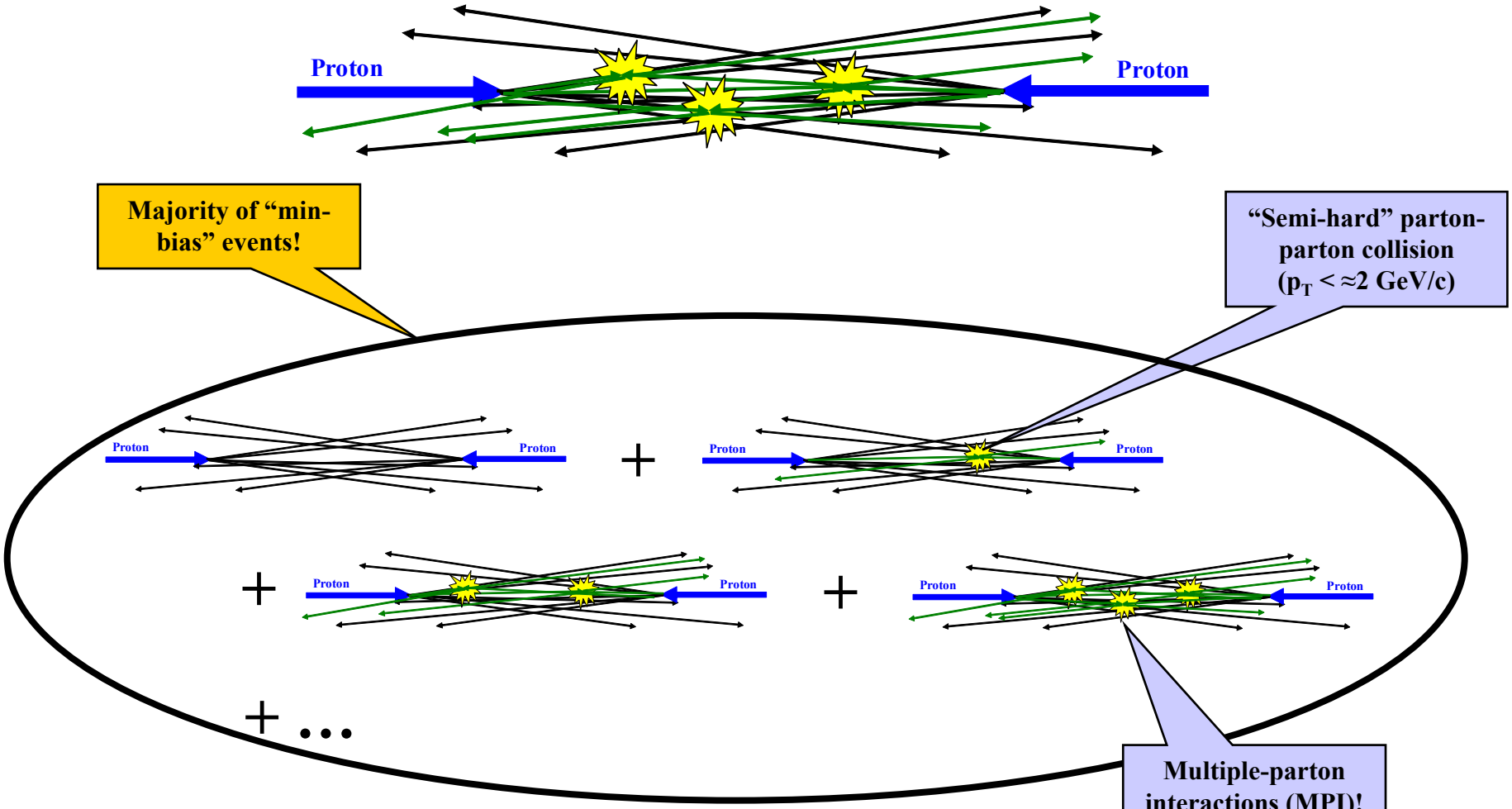


Inelastic Collisions

Today's terminology courtesy of Juan M. G. Luyando, Benoit Roland, and Paolo Gunnellini.



The Inelastic Non-Diffractive Cross-Section



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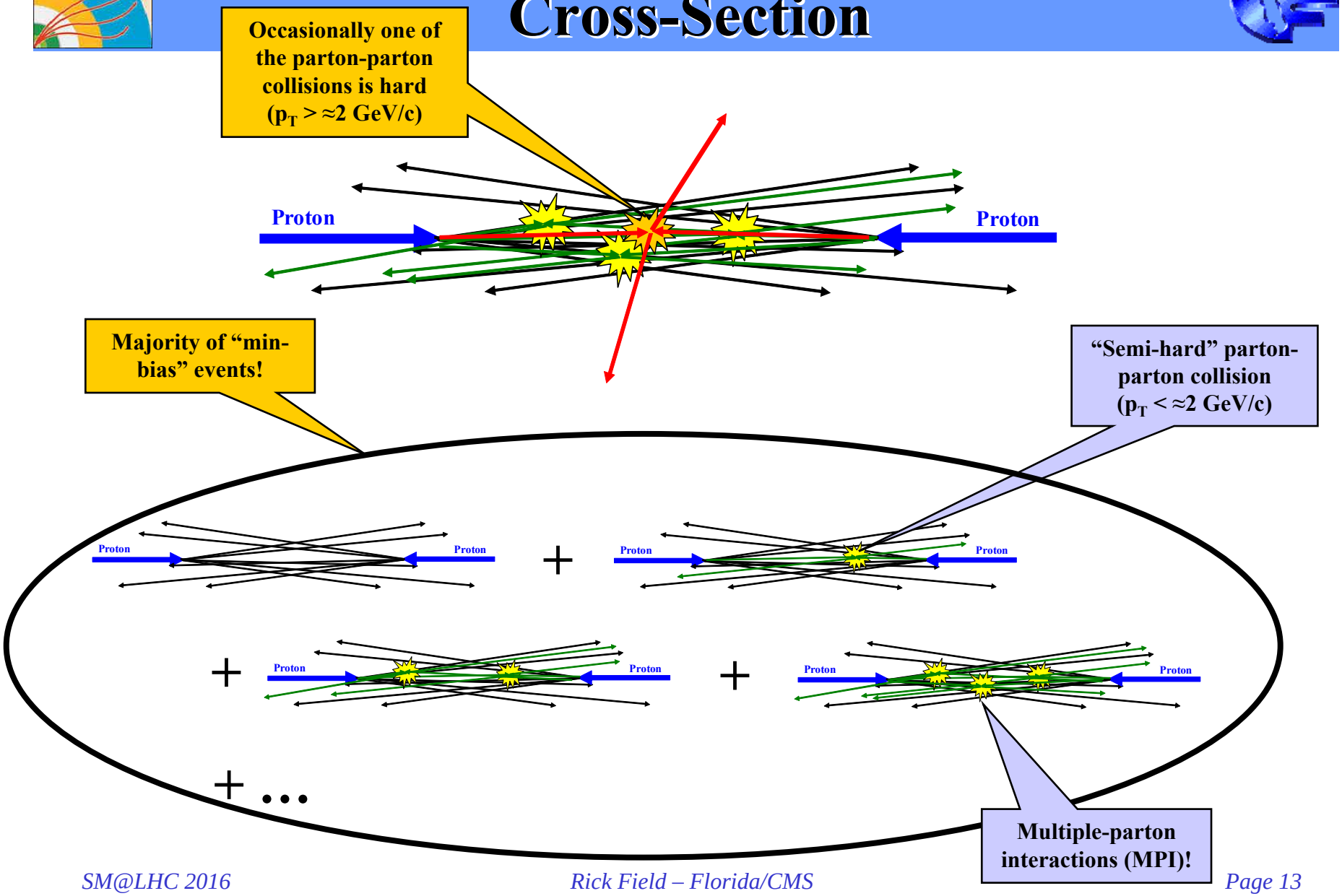
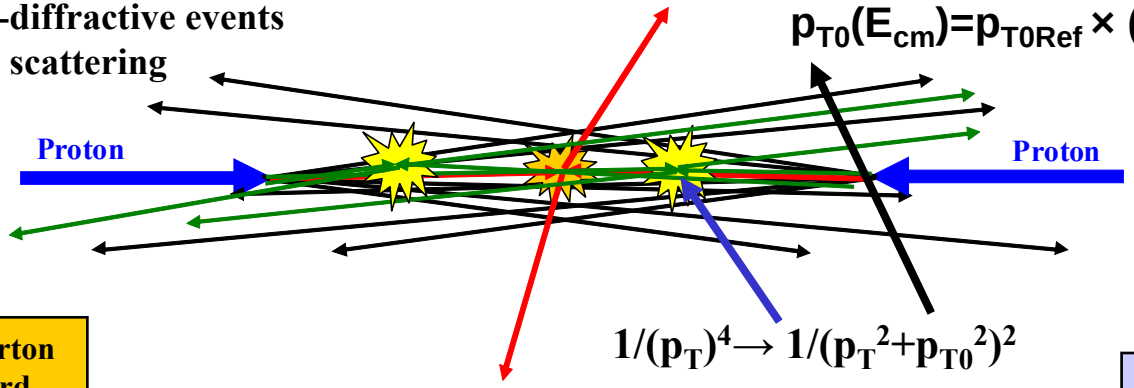


The "Underlying Event"

Select inelastic non-diffractive events that contain a hard scattering



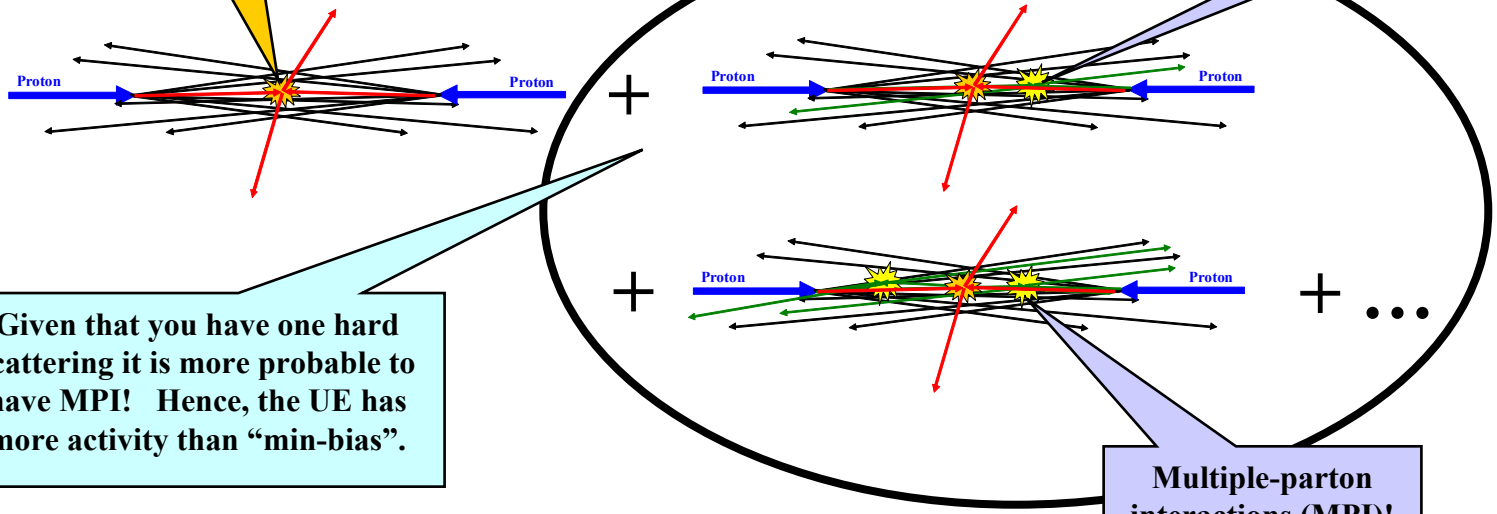
$p_{T0}(E_{cm})=p_{T0Ref} \times (E_{cm}/E_{cmRef})^{ecmPow}$

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

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".

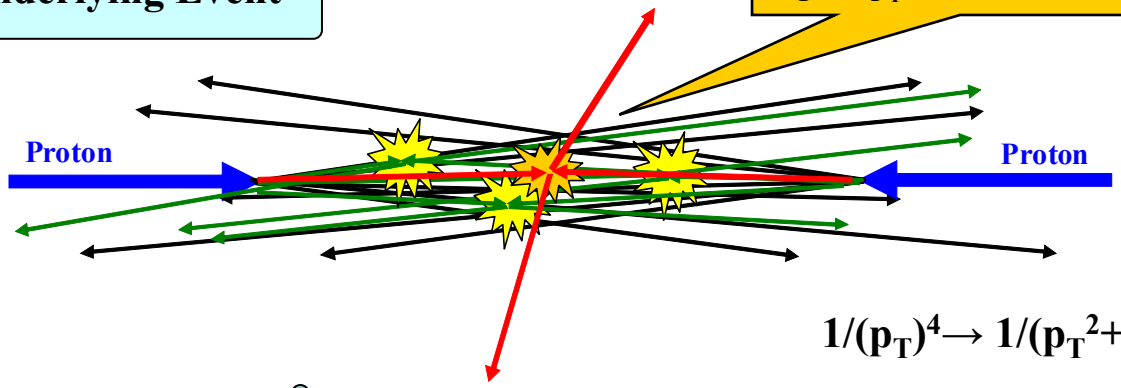
Multiple-parton interactions (MPI)!

UE Tunes and MB

"Underlying Event"

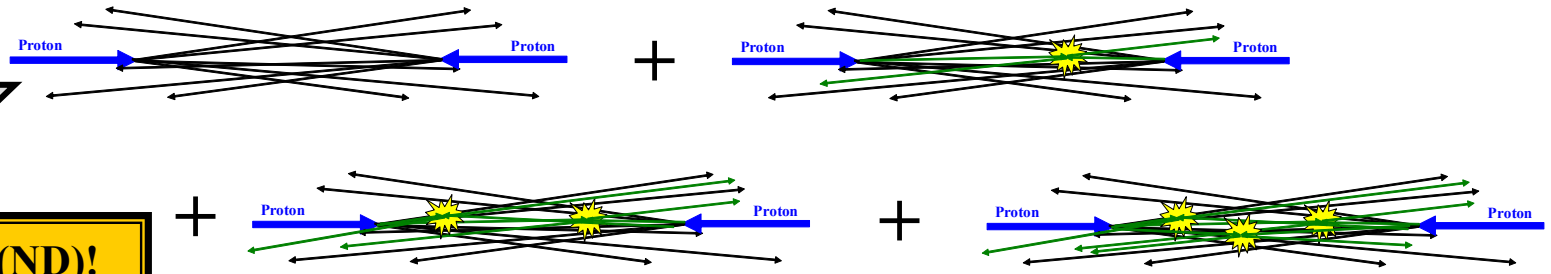
Allow primary hard-scattering to go to $p_T = 0$ with same cut-off!

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



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

"Min-Bias" (ND)



Predict MB (ND)!

UE Tunes and MB

"Underlying Event"

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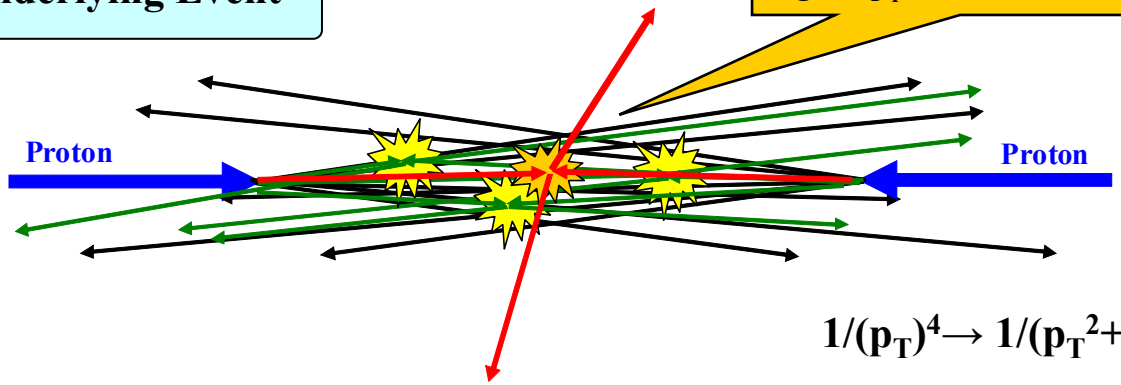
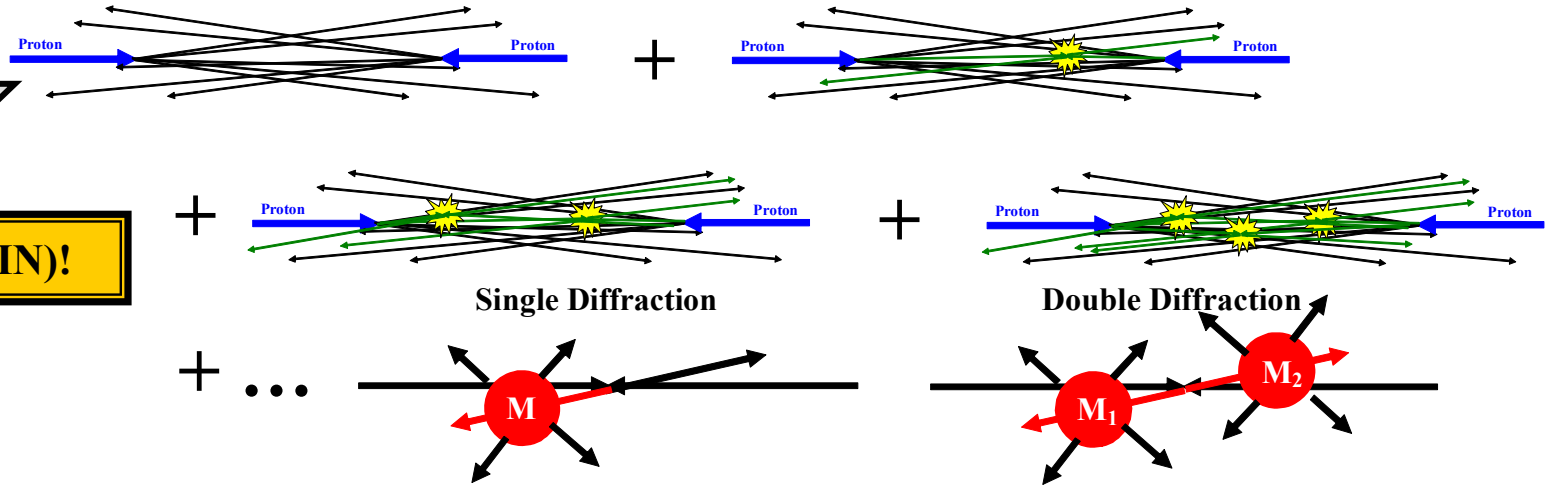


$1/(p_T)^4 \rightarrow 1/(p_T^2+p_{T0}^2)^2$

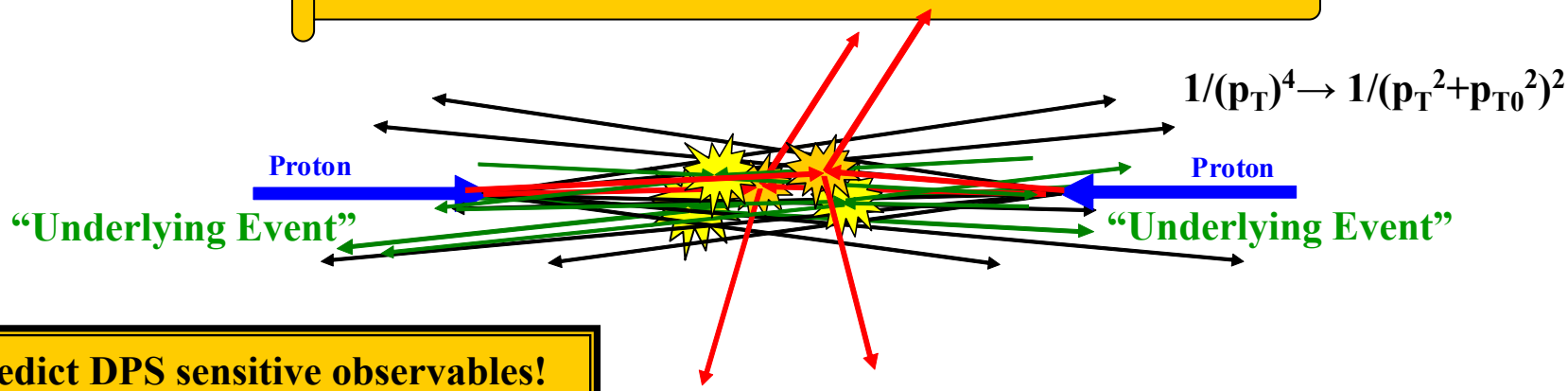
"Min-Bias" (add single & double diffraction)



Predict MB (IN)!

UE Tunes and DPS

DPS: Double Parton Scattering

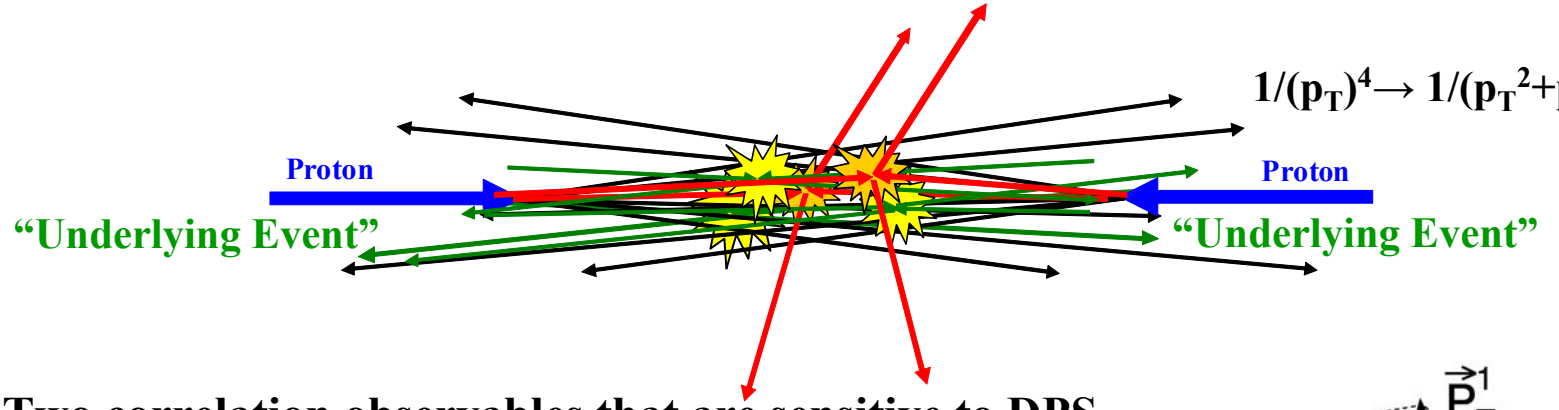


Predict DPS sensitive observables!

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.

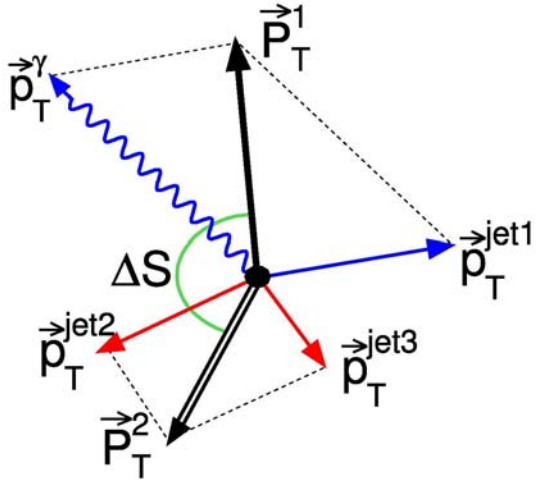
DPS Observables



➡ **Two correlation observables that are sensitive to DPS are ΔS and Δ^{rel}pT defined as follows:**

$$\Delta S = \arccos\left(\frac{\vec{p}_T(object\#1)\cdot\vec{p}_T(object\#2)}{\left|\vec{p}_T(object\#1)\right|\times\left|\vec{p}_T(object\#2)\right|}\right)$$

$$\Delta^{rel} p_T = \frac{\left|\vec{p}_T^{\,jet\#1}+\vec{p}_T^{\,jet\#2}\right|}{\left|\vec{p}_T^{\,jet\#1}\right|+\left|\vec{p}_T^{\,jet\#2}\right|)}$$

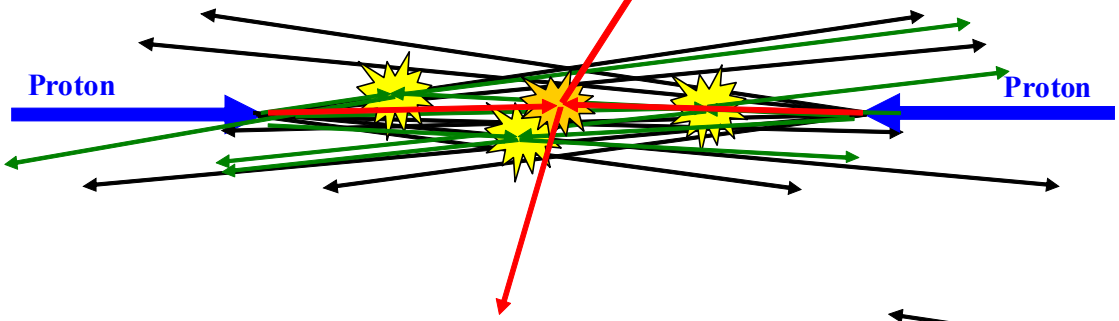


For γ+3jets object#1 is the photon and the leading jet (jet1) and object#2 is jet2 and jet3. For W+dijet production object#1 is the W-boson and object#2 dijet. For 4-jet production object#1 is hard-jet pair and object#2 is the soft-jet pair. For $\Delta^{rel}p_T$ in W+dijet production jet#1 and jet#2 are the two dijets, while in 4-jet production jet#1 and jet#2 are the softer two jets.

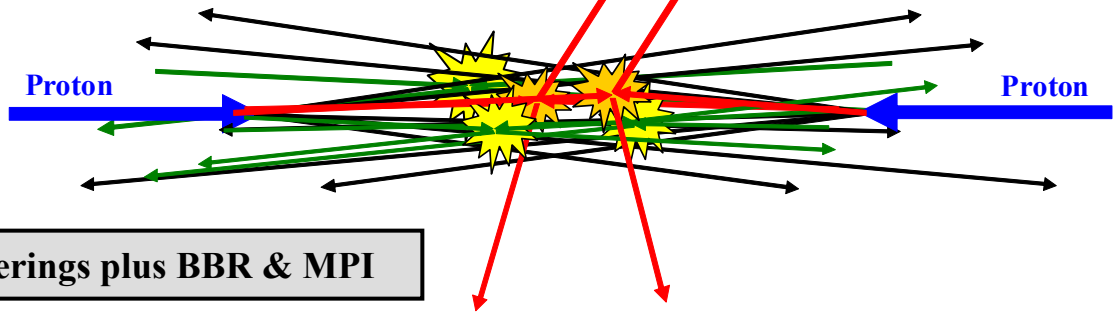
Universal UE-MB-DPS Tune

My dream!

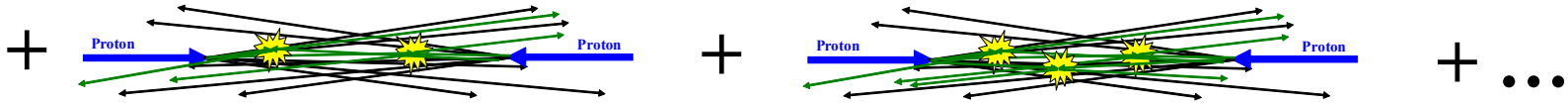
"Underlying Event" — One hard scattering plus BBR & MPI



DPS — Two hard scatterings plus BBR & MPI

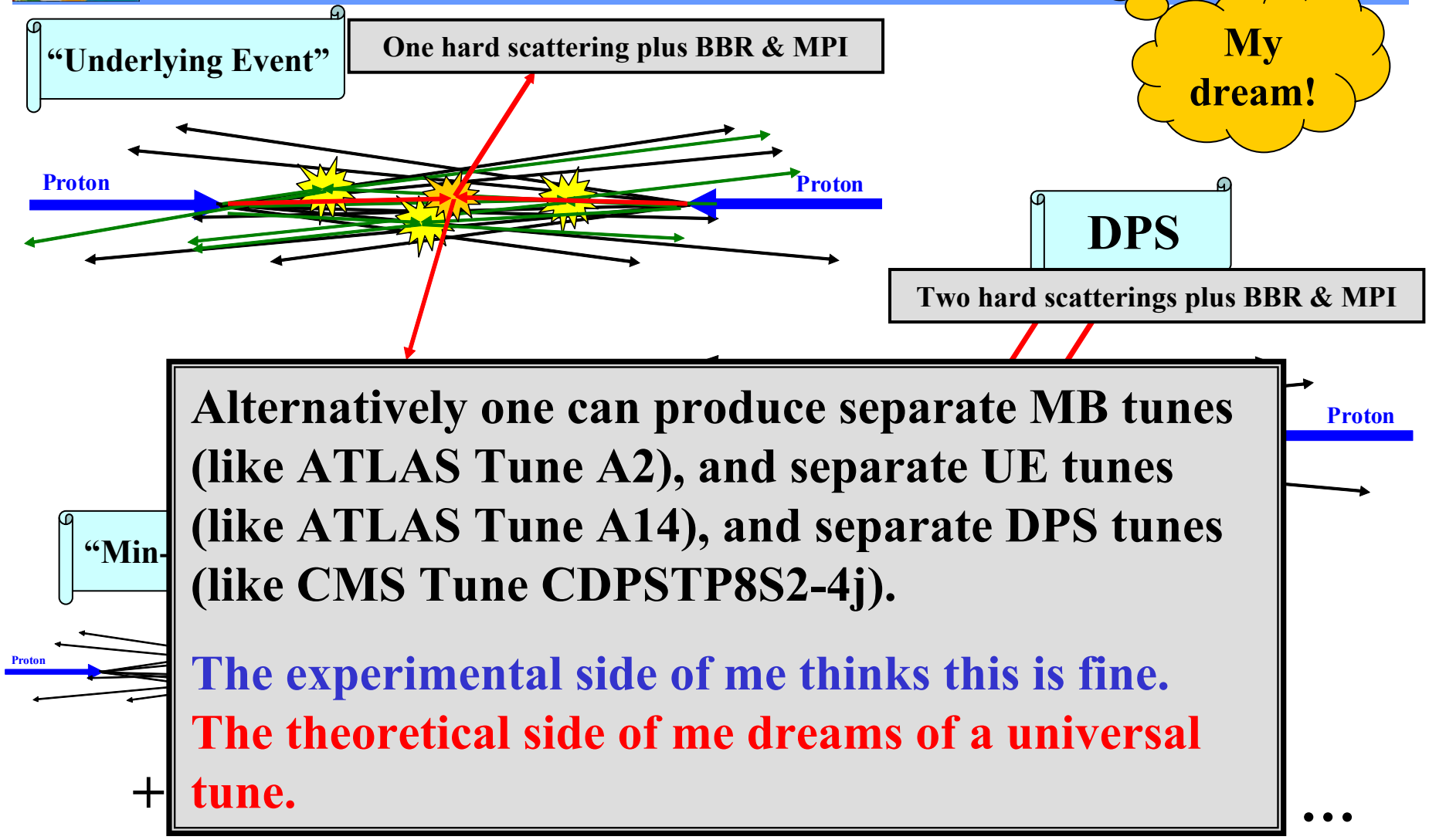


"Min-Bias" (ND) — No hard scatterings plus BBR & MPI



Universal UE-MB-DPS Tune

My dream!



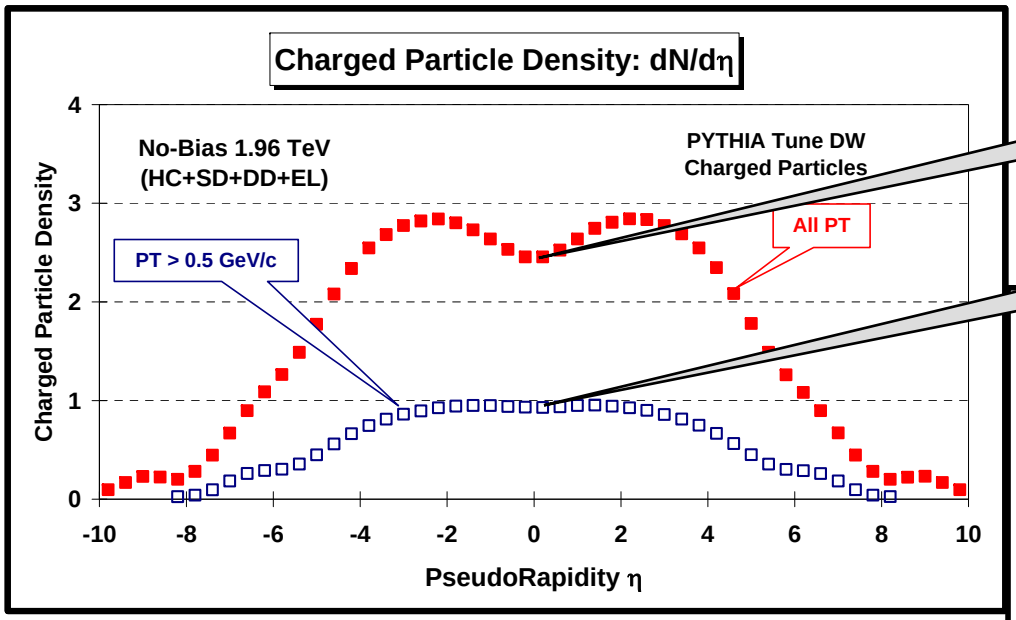
Alternatively one can produce separate MB tunes (like ATLAS Tune A2), and separate UE tunes (like ATLAS Tune A14), and separate DPS tunes (like CMS Tune CDPSTP8S2-4j).

The experimental side of me thinks this is fine.

The theoretical side of me dreams of a universal tune.

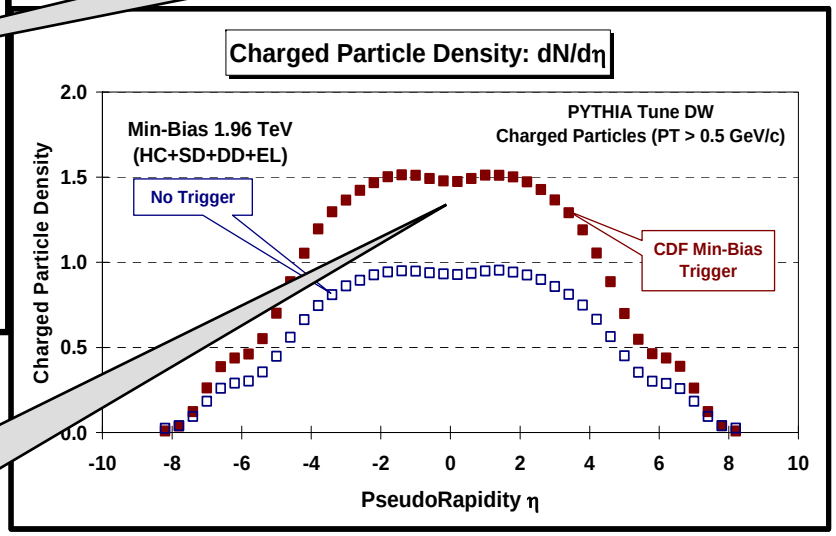
No-Bias vs Min-Bias

Rick Field C2CR07
February 28, 2007



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

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



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

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

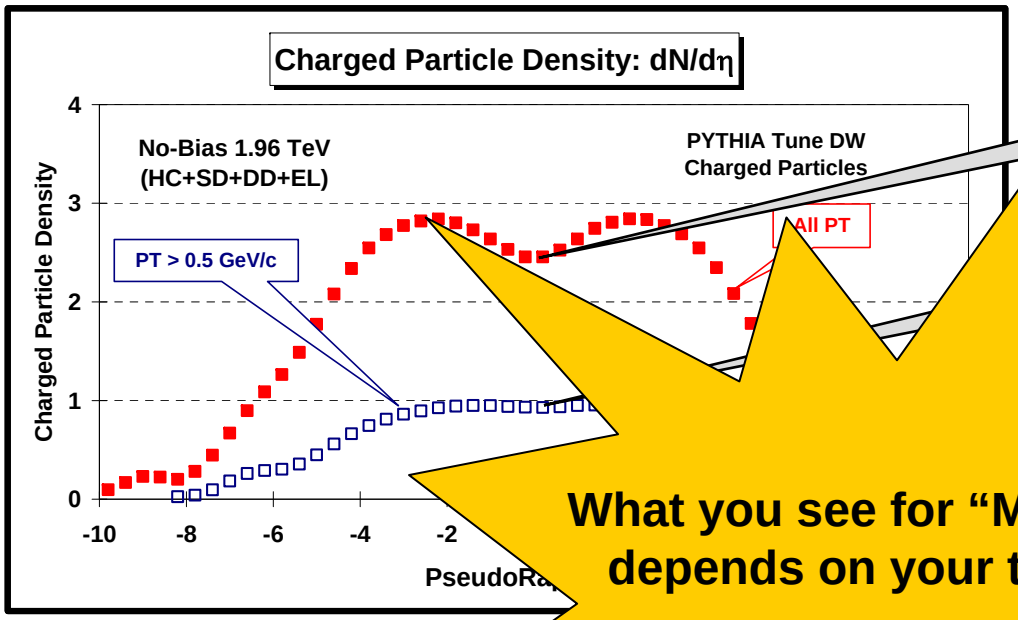
➡ Charged particle (p_T > 0.5 GeV/c) pseudo-rapidity distribution, $dN_{chg}/d\eta$, at 1.96 TeV with the CDF Min-Bias trigger from PYTHIA Tune DW.

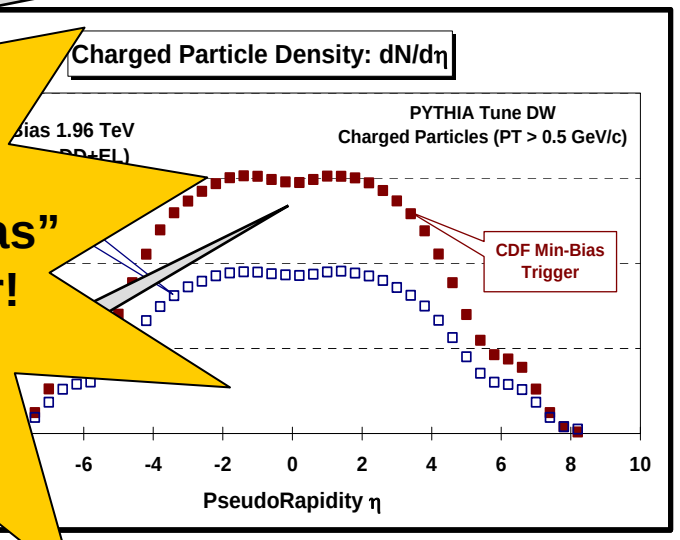
No-Bias vs Min-Bias

Rick Field C2CR07
February 28, 2007

About 2.5 charged particles per unit η at $\eta = 0$.

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





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

➡ Charged particle (all … distribution, $dN_{chg}/d\eta$, at 1.96 … trigger (*i.e.* no-bias) from PY… DW.

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

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

Min-Bias Particle Types

With cτ = 10mm

pyDWT HC+SD+DD 10mm		
Type	All Eta	|eta|<1
pi+	25.450	3.704
pi0	28.250	4.140
pi-	24.720	3.694
K+	3.107	0.395
K-	2.996	0.391
photon	4.041	0.672
Klong	2.967	0.383
Kshort	2.971	0.384
e(-)	0.027	0.005
e(+)	0.028	0.005
mu-	0.007	0.002
mu+	0.007	0.002
nue	0.006	0.001
nueb	0.006	0.001
numu	0.006	0.001
numub	0.006	0.001
sig+	0.162	0.015
sig-	0.137	0.015
p	2.909	0.211
n	2.435	0.209
cas-	0.047	0.005
cas0	0.048	0.005
lamda	0.727	0.065
sig+b	0.131	0.015
sig-b	0.129	0.015
pb	1.776	0.208
nb	1.770	0.209
cas-b	0.045	0.005
cas0b	0.045	0.005
lamdab	0.568	0.065
Omeg-	0.001	0.000
Omeg-b	0.001	0.000
nutau	0.001	0.000
nutaub	0.001	0.000
All	105.53	14.83
chg	61.68	8.69

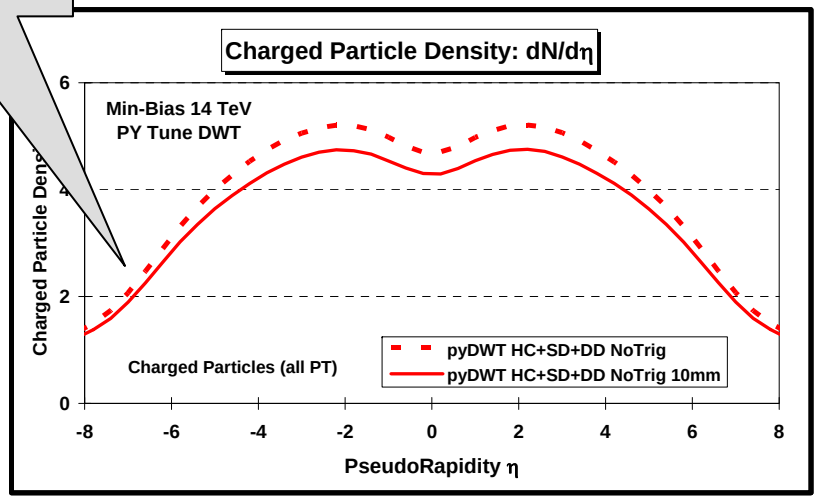
With Stable Particle

pyDWT HC+SD+DD Stable		
ALL	All Eta	|eta|<1
pi+	28.130	4.090
pi0	30.840	4.503
pi-	27.490	4.082
K+	3.101	0.395
K-	2.992	0.390
photon	4.041	0.668
Klong	2.962	0.383
e(-)	0.029	0.005
e(+)	0.029	0.005
mu-	0.007	0.002
mu+	0.007	0.002
nue	0.007	0.001
nueb	0.007	0.002
numu	0.006	0.001
numub	0.006	0.001
p	3.512	0.266
n	2.945	0.257
pb	2.264	0.263
nb	2.193	0.256
nutau	0.001	0.000
nutaub	0.001	0.000
All	110.57	15.57
chg	67.56	9.50

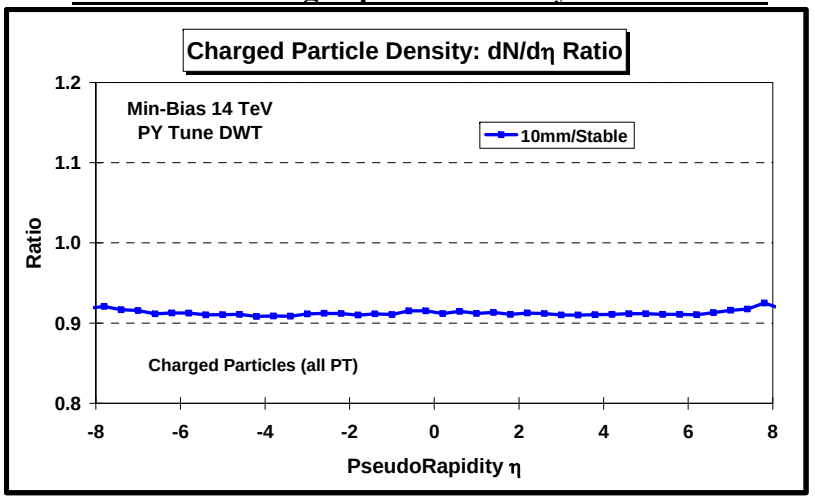
This is a bigger effect than I expected!

➡ **Using cτ = 10 mm reduces the charged particle density by almost 10%! Mostly from $K_s \to \pi^+\pi^-$ (68.6%) and $\Lambda \to p\pi^-$ (64.2%).**

charged particle density: 10mm vs Stable



Ratio of the charged particle density: 10mm/Stable



Corrected MB Observables

- **Option 1: Use the Monte-Carlo to correct for the trigger bias and for the detector effects. MB observables corrected to the no trigger particle level.**
- **Option 2: Define the trigger at the particle level. Use the Monte-Carlo to correct for the detector effects. MB observables corrected to the triggered particle level.**

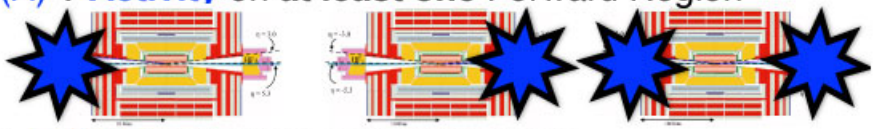
CMS PAS FSQ-15-008

(A) At least 1 charged particle { $p_T > 0.5$ GeV, $|\eta| < 2.4$

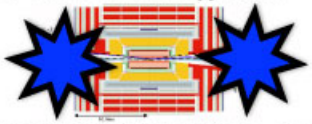
- **Inclusive**: (A)

  ✦ **Activity**: at least 1 particle with E > 5 GeV
  ✦ **Veto**: no particle with E > 5 GeV

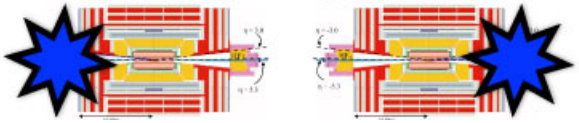
- **Inelastic enhanced**: (A) + **Activity** on **at least one** Forward Region



- **NSD enhanced**: (A) + **Activity** on **both** Forward Regions

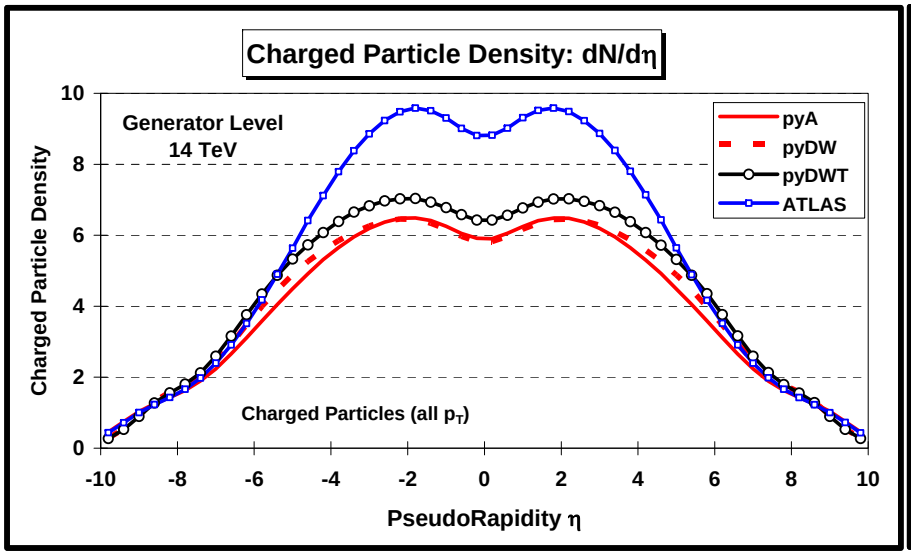


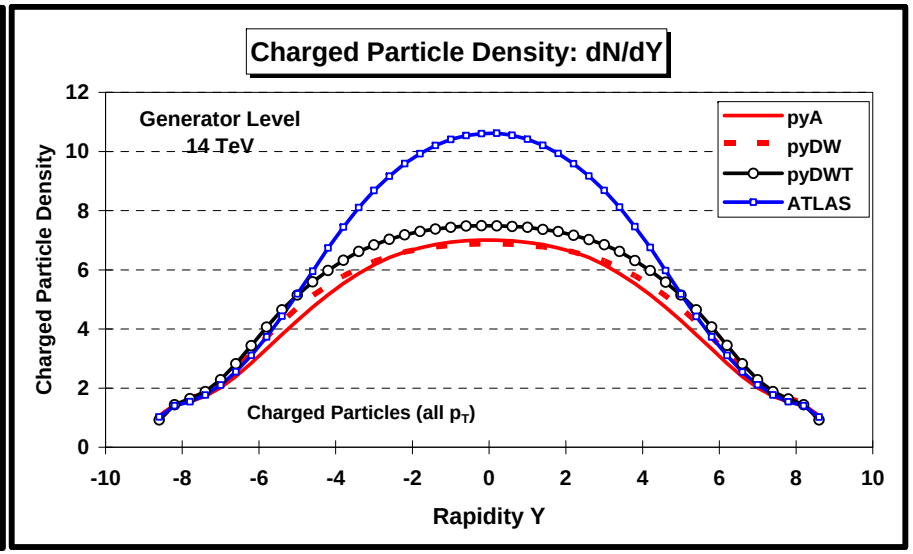
- **SD enhanced**: (A) + **Activity** on one Forward Region **and** **Veto** on the other side



PYTHIA 6.2 Tunes
LHC Min-Bias Predictions

Rick Field C2CR07
February 28, 2007





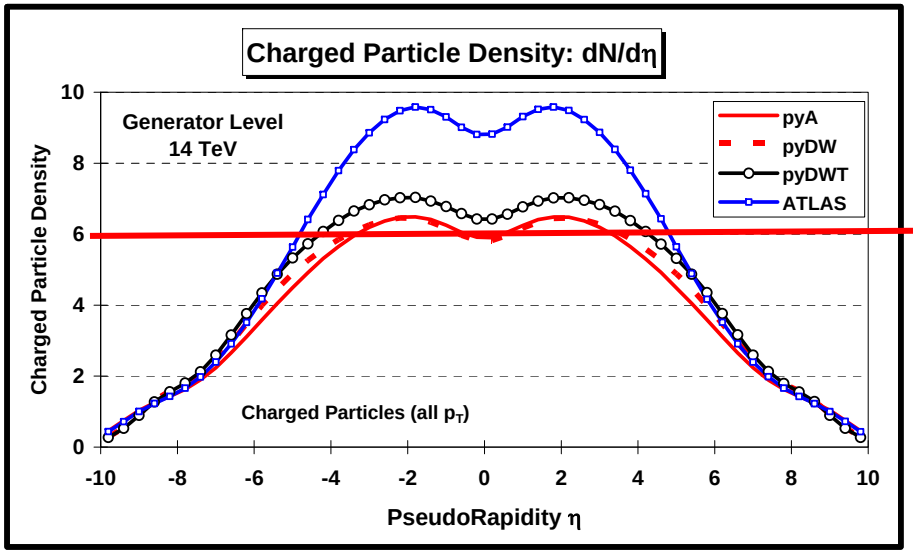
➡ **Shows the predictions of PYTHIA Tune A, Tune DW, Tune DWT, and the ATLAS tune for the charged particle density dN/dη and dN/dY at 14 TeV (all p_T).**

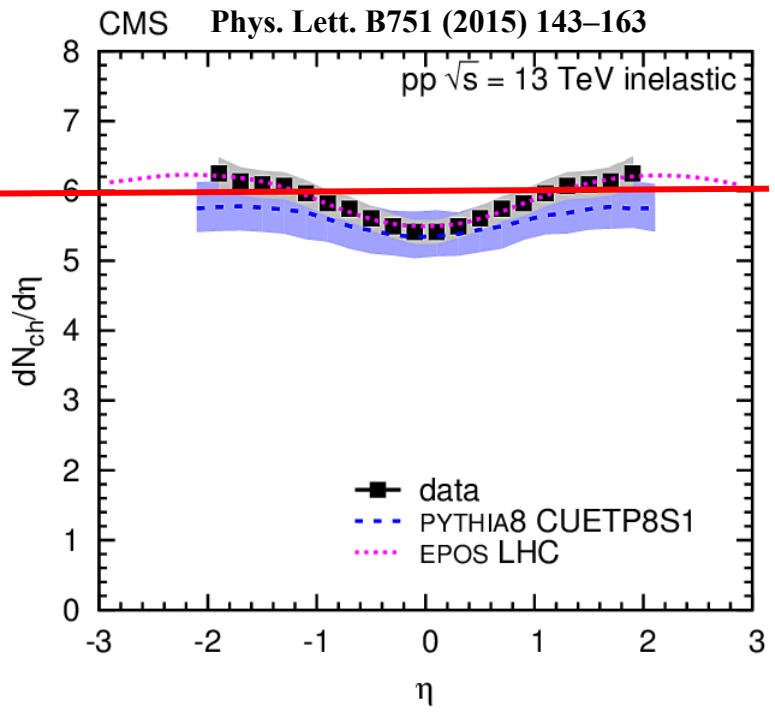
➡ **PYTHIA Tune A and Tune DW predict about 6 charged particles per unit η at η = 0, while the ATLAS tune predicts around 9.**

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

PYTHIA 6.2 Tunes
LHC Min-Bias Predictions

Rick Field C2CR07
February 28, 2007





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

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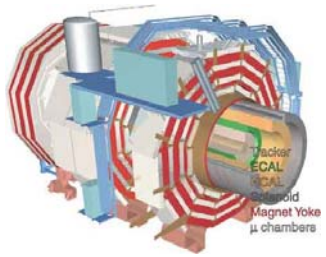
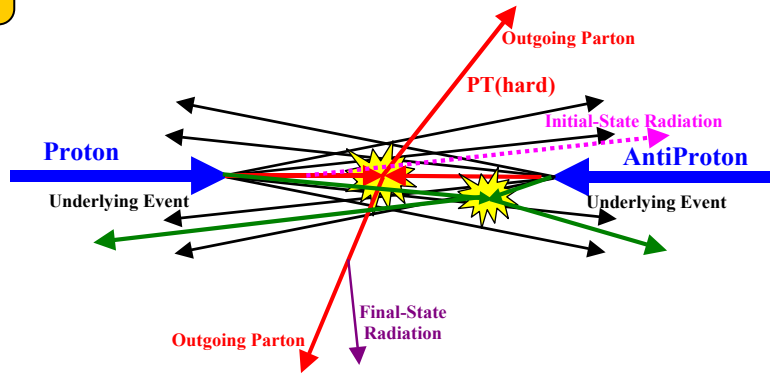
CMS Tuning Publication



CMS at the LHC

PC&GT

Physics Comparisons & Generstor Tunes



Available on the CERN CDS information server **CMS PAS GEN-14-001**

CMS Physics Analysis Summary

Contact: cms-pag-conveners-generators@cern.ch 2014/04/29

Underlying Event Tunes and Double Parton Scattering

Eur. Phys. J. C76 (2016) 155

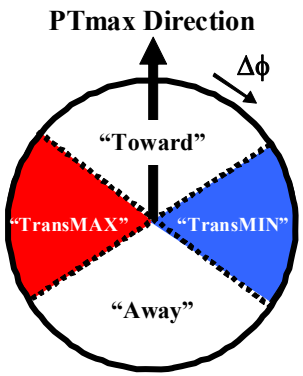
The CMS Collaboration

Abstract

Using the "Rivet" and "Professor" framework, we construct a new PYTHIA 6 tune using the CTEQ6L1 PDF and two new PYTHIA 8 UE tunes (one using CTEQ6L1 and one using the HERAPDF1.5LO). By simultaneously fitting CDF data from $\bar{p}p$ collisions at 300 GeV, 900 GeV, and 1.96 TeV together with CMS data for pp collisions at 7 TeV, we test the Underlying Event (UE) models and constrain their parameters, allowing for more precise predictions at 13 TeV and 14 TeV. The consistency of these new tunes with measurements of double-parton scattering (DPS) is also investigated.

Hannes Jung, Paolo Gunnellini, Rick Field

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.

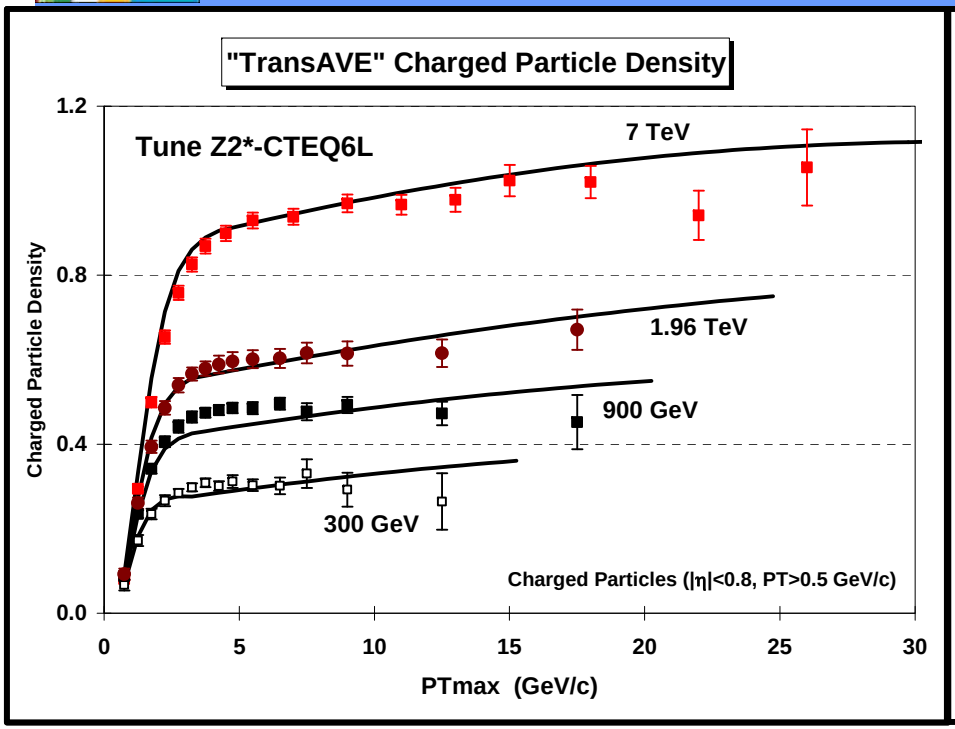
➡ **PYTHIA 8 Tune CUETP8S1-CTEQ6L:** Start with Corke & Sjöstrand Tune 4C and tune to the CDF PTmax "transMAX" and "transMIN" UE data at 900 GeV, and 1.96 TeV and the CMS PTmax "transMAX" and "transMIN" UE data at 7 TeV. **Exclude 300 GeV data.**

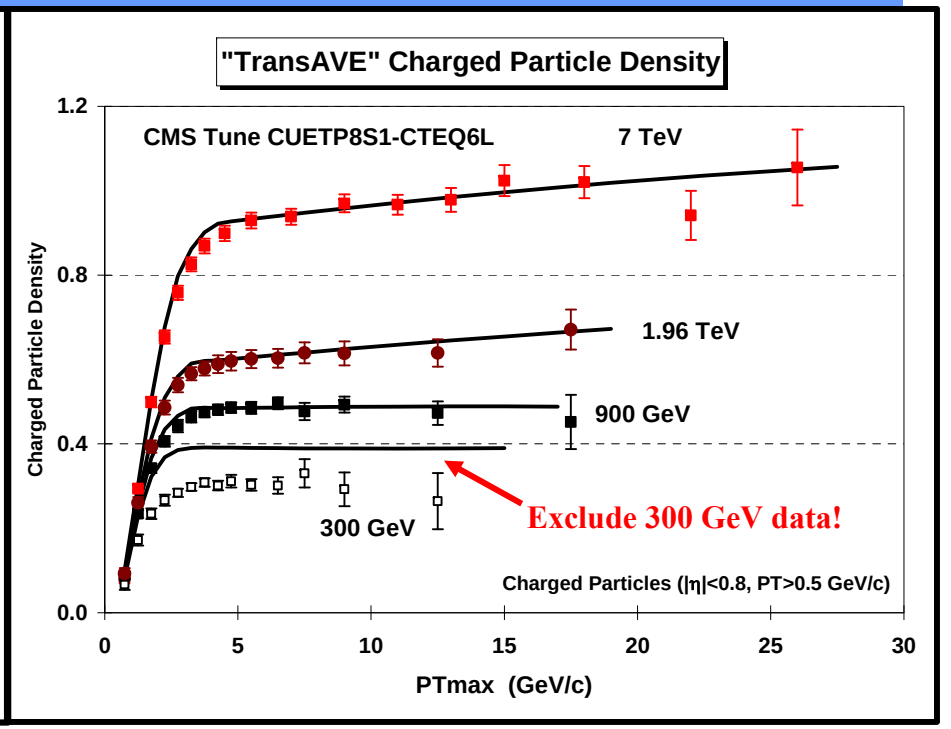
➡ **PYTHIA 8 Tune CUETP8S1-HERAPDF1.5LO:** Start with Corke & Sjöstrand Tune 4C and tune to the CDF PTmax "transMAX" and "transMIN" UE data at 900 GeV, and 1.96 TeV and the CMS PTmax "transMAX" and "transMIN" UE data at 7 TeV. **Exclude 300 GeV data.**

➡ **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.

CUETP8S1-CTEQ6L

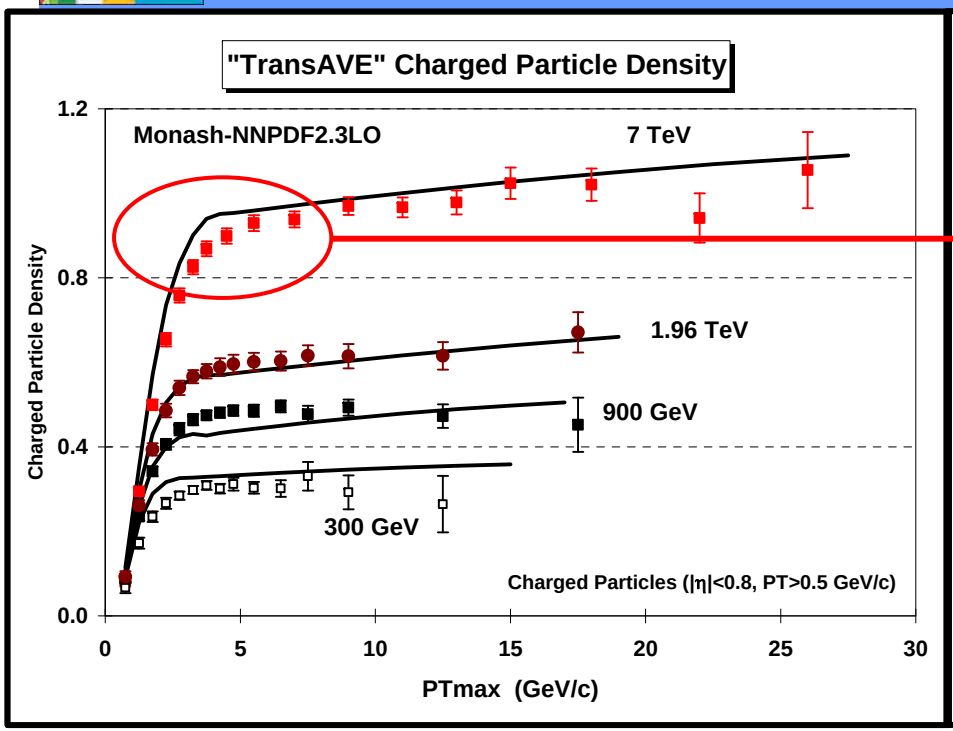


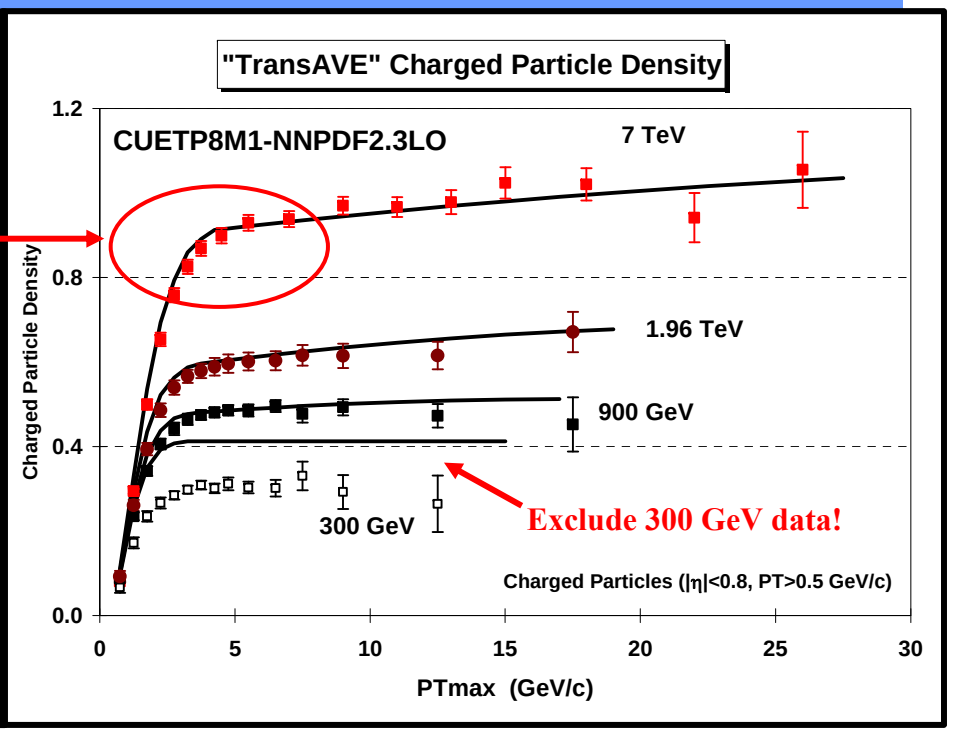


➡ **CMS data at 7 TeV and CDF data at 1.96 TeV, 900 GeV, and 300 GeV on the charged particle density in the "transAVE" region as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$. The data are compared with PYTHIA 6.4 Tune Z2*.**

➡ **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



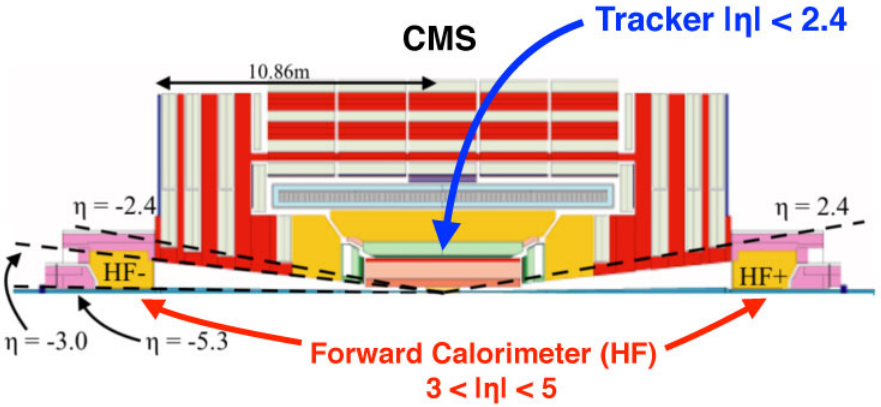


➡ **CMS data at 7 TeV and CDF data at 1.96 TeV, 900 GeV, and 300 GeV on the charged particle density in the "transAVE" region as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$. The data are compared with the PYTHIA 8 Tune Monash-NNPDF2.3LO.**

➡ **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).**

CMS MB Trigger Selections

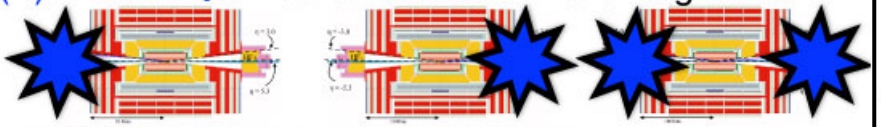
CMS PAS FSQ-15-008



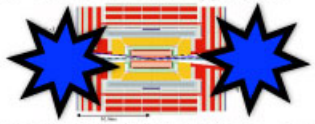
(A) At least 1 charged particle { $p_T > 0.5$ GeV, $|\eta| < 2.4$

- ✦ **Activity**: at least 1 particle with E > 5 GeV
- ✦ **Veto**: no particle with E > 5 GeV

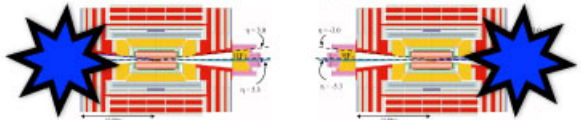
- **Inclusive**: (A)
- **Inelastic enhanced**: (A) + **Activity** on **at least one** Forward Region



- **NSD enhanced**: (A) + **Activity** on **both** Forward Regions



- **SD enhanced**: (A) + **Activity** on one Forward Region **and** **Veto** on the other side



Available on the CERN CDS information server — **CMS PAS FSQ-15-008**

CMS Physics Analysis Summary

Contact: cms-pag-conveners-fsq@cern.ch — 2016/04/11

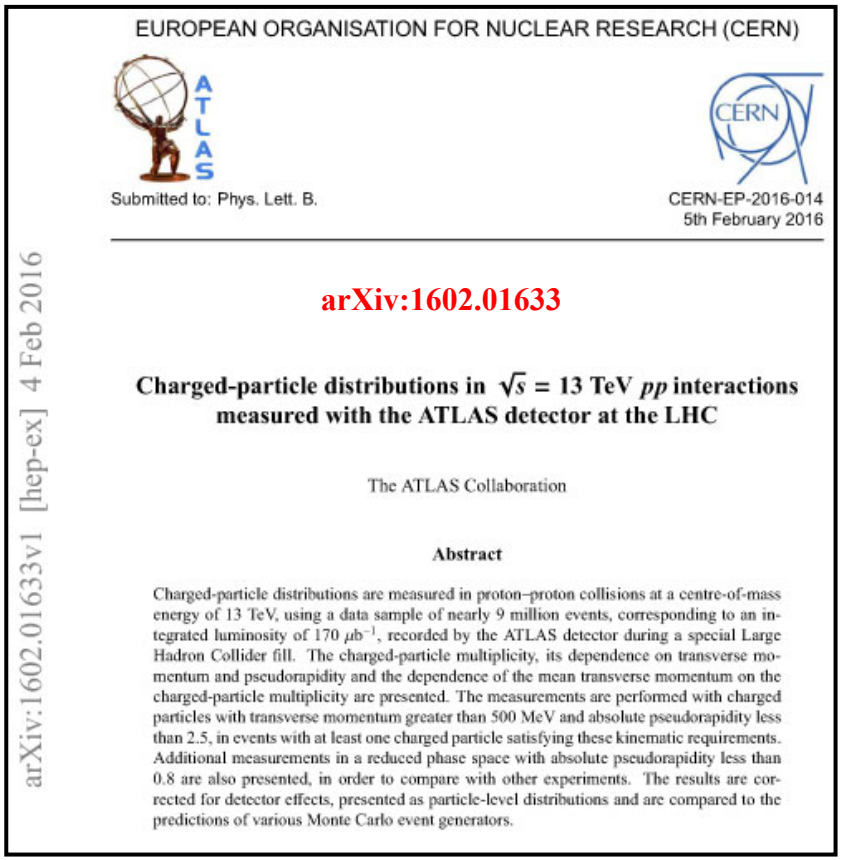
Measurement of pseudorapidity distributions of charged particles in proton-proton collisions at $\sqrt{s} = 13$ TeV by the CMS experiment.

The CMS Collaboration

Abstract

Pseudorapidity distributions of charged particles, $dN_{ch}/d\eta$, produced in proton-proton collisions at a centre-of-mass energy $\sqrt{s} = 13$ TeV are measured in the pseudorapidity range $|\eta| < 2.4$ for charged particles with a transverse momentum $p_T > 0.5$ GeV. Measurements are presented for four event categories. The first two categories correspond to inclusive and inelastic-enhanced event samples. The other two categories are disjoint subsets of the inelastic-enhanced event sample that are either enhanced or depleted in single diffractive dissociation events. The measurements are compared to predictions from Monte Carlo event generators which were tuned to describe the underlying event properties at lower centre-of-mass energies.

ATLAS MB Measurements



EUROPEAN ORGANISATION FOR NUCLEAR RESEARCH (CERN)

Submitted to: Phys. Lett. B.

CERN-EP-2016-014
5th February 2016

arXiv:1602.01633

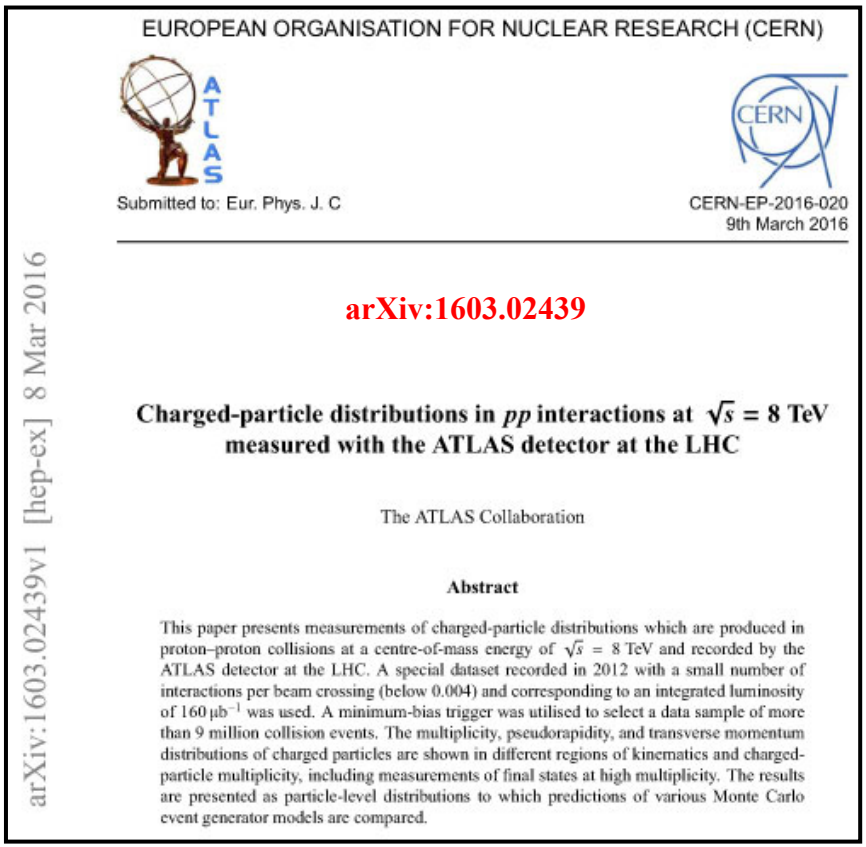
Charged-particle distributions in $\sqrt{s}$ = 13 TeV pp interactions measured with the ATLAS detector at the LHC

The ATLAS Collaboration

Abstract

Charged-particle distributions are measured in proton–proton collisions at a centre-of-mass energy of 13 TeV, using a data sample of nearly 9 million events, corresponding to an integrated luminosity of 170 μb^{-1}, recorded by the ATLAS detector during a special Large Hadron Collider fill. The charged-particle multiplicity, its dependence on transverse momentum and pseudorapidity and the dependence of the mean transverse momentum on the charged-particle multiplicity are presented. The measurements are performed with charged particles with transverse momentum greater than 500 MeV and absolute pseudorapidity less than 2.5, in events with at least one charged particle satisfying these kinematic requirements. Additional measurements in a reduced phase space with absolute pseudorapidity less than 0.8 are also presented, in order to compare with other experiments. The results are corrected for detector effects, presented as particle-level distributions and are compared to the predictions of various Monte Carlo event generators.

arXiv:1602.01633v1 [hep-ex] 4 Feb 2016



EUROPEAN ORGANISATION FOR NUCLEAR RESEARCH (CERN)

Submitted to: Eur. Phys. J. C

CERN-EP-2016-020
9th March 2016

arXiv:1603.02439

Charged-particle distributions in pp interactions at $\sqrt{s}$ = 8 TeV measured with the ATLAS detector at the LHC

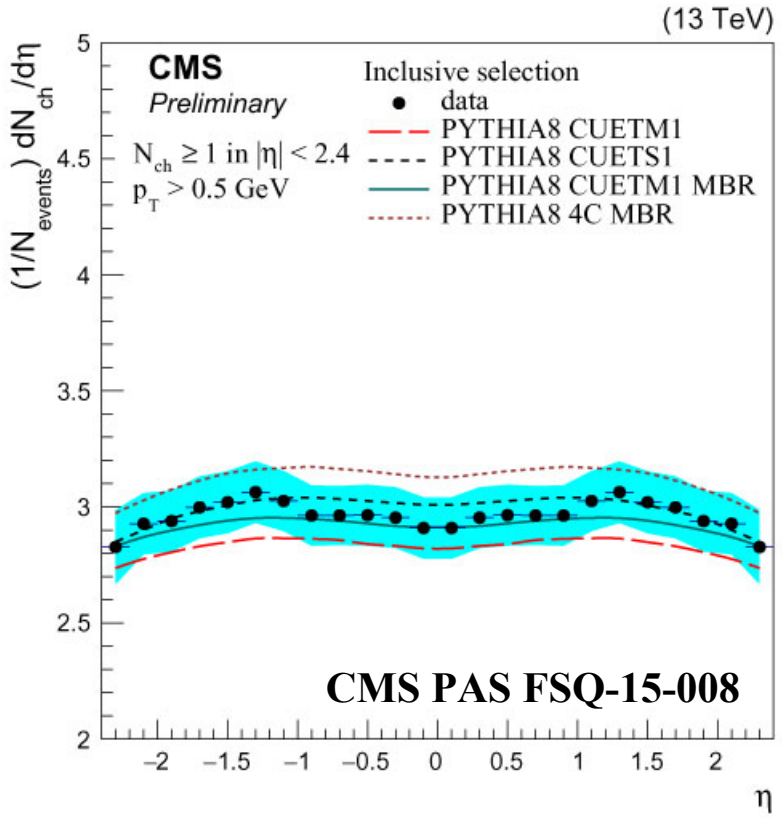
The ATLAS Collaboration

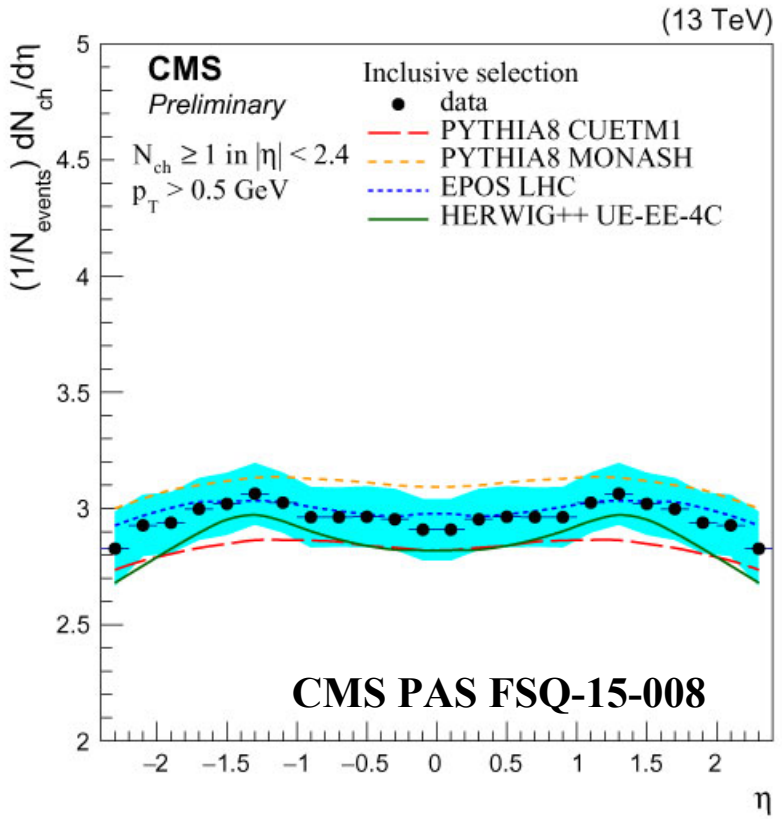
Abstract

This paper presents measurements of charged-particle distributions which are produced in proton–proton collisions at a centre-of-mass energy of $\sqrt{s}$ = 8 TeV and recorded by the ATLAS detector at the LHC. A special dataset recorded in 2012 with a small number of interactions per beam crossing (below 0.004) and corresponding to an integrated luminosity of 160 μb^{-1} was used. A minimum-bias trigger was utilised to select a data sample of more than 9 million collision events. The multiplicity, pseudorapidity, and transverse momentum distributions of charged particles are shown in different regions of kinematics and charged-particle multiplicity, including measurements of final states at high multiplicity. The results are presented as particle-level distributions to which predictions of various Monte Carlo event generator models are compared.

arXiv:1603.02439v1 [hep-ex] 8 Mar 2016

13 TeV "Inclusive" dN/dη



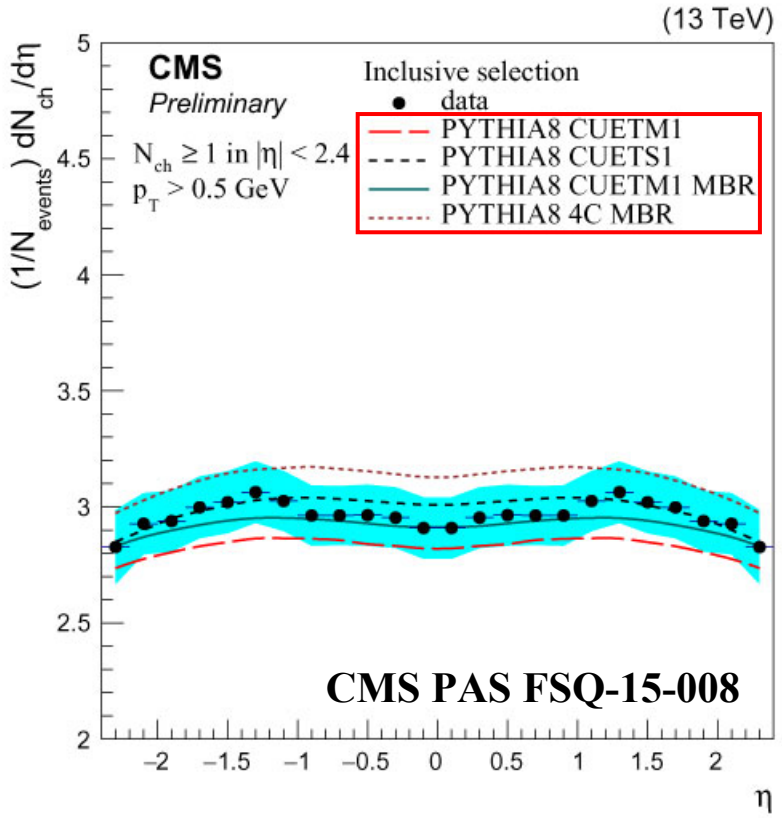


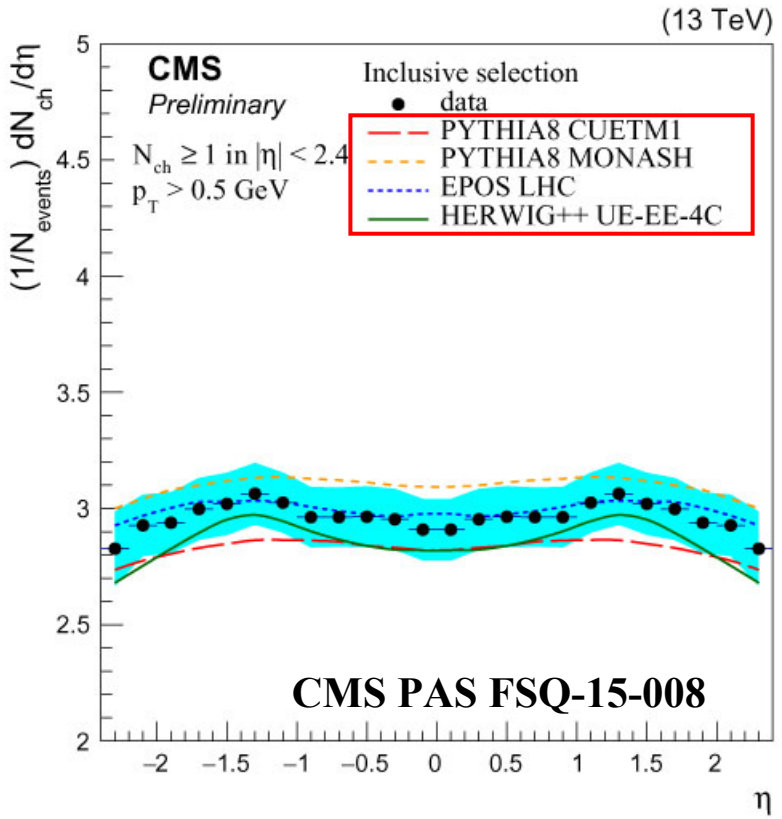
➡ **CMS "inclusive" data at 13 TeV on the charged particle density, dN/dη, with $p_T > 0.5$ GeV/c and $|\eta| < 2.4$ for events with at least one charged particle with $p_T > 0.5$ GeV/c and $|\eta| < 2.4$. The data are corrected to the particle level and compared with several MC models at generator level.**

- **Inclusive**: (A)

(A) At least 1 charged particle { $p_T > 0.5$ GeV, $|\eta| < 2.4$

13 TeV "Inclusive" dN/dη



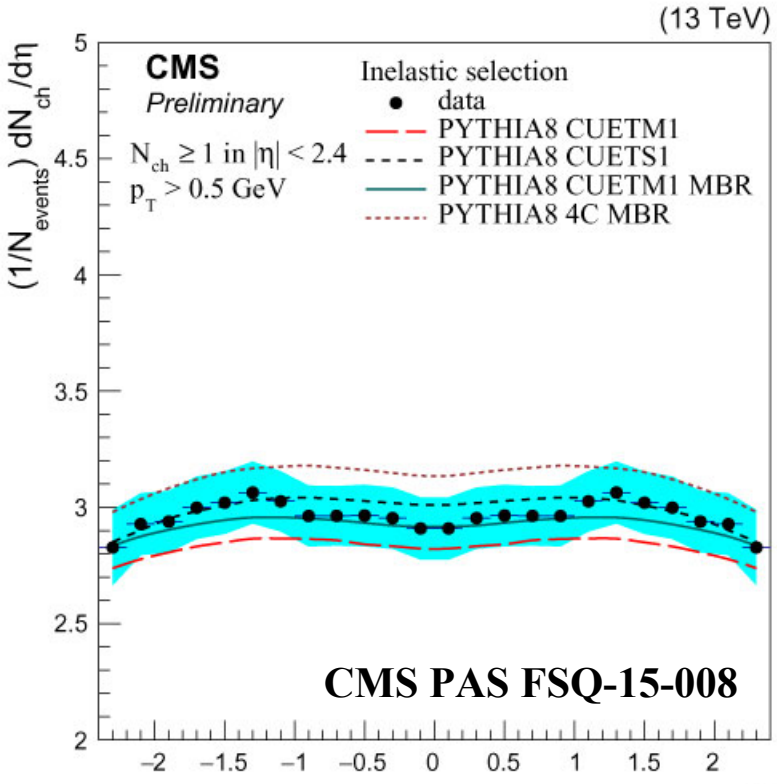


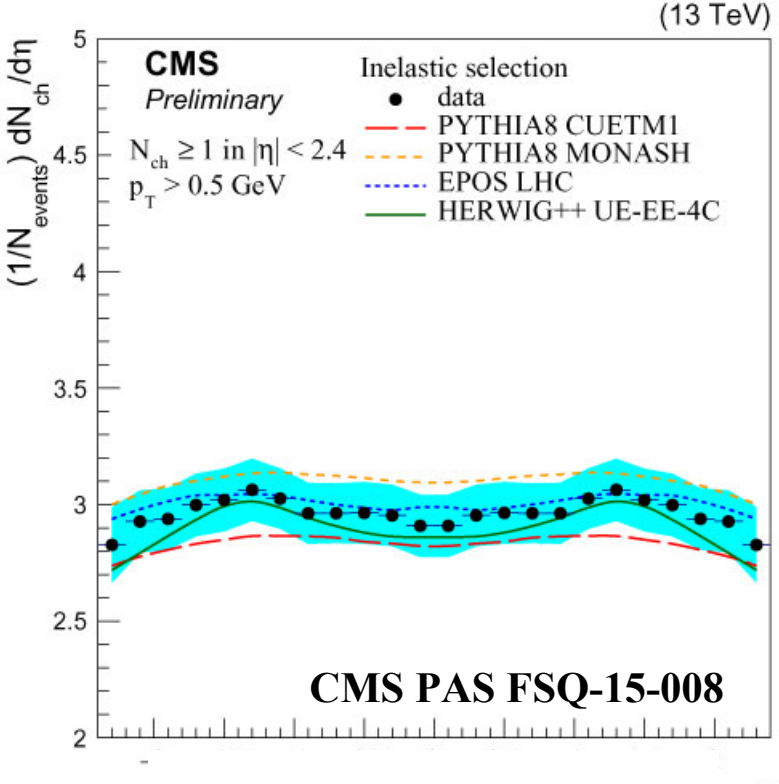
➡ **CMS "inclusive" data at 13 TeV on the charged particle density, dN/dη, with $p_T > 0.5$ GeV/c and $|\eta| < 2.4$ for events with at least one charged particle with $p_T > 0.5$ GeV/c and $|\eta| < 2.4$. The data are corrected to the particle level and compared with several MC models at generator level.**

- **Inclusive**: (A)

(A) At least 1 charged particle $\begin{cases} p_T > 0.5 \text{ GeV} \\ |\eta| < 2.4 \end{cases}$

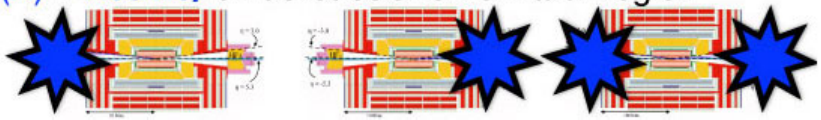
13 TeV "Inelastic" dN/dη



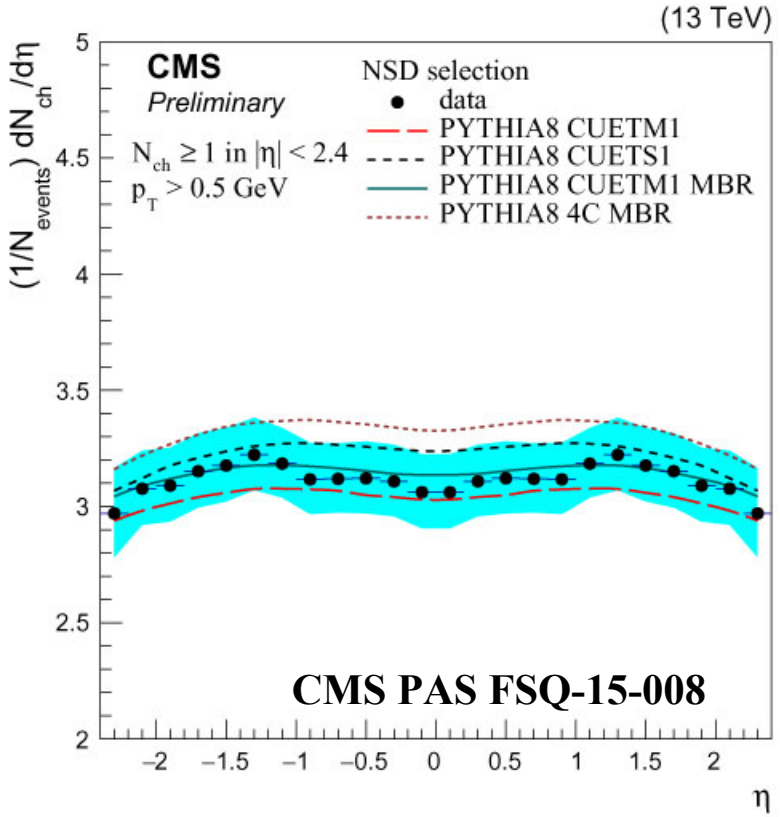


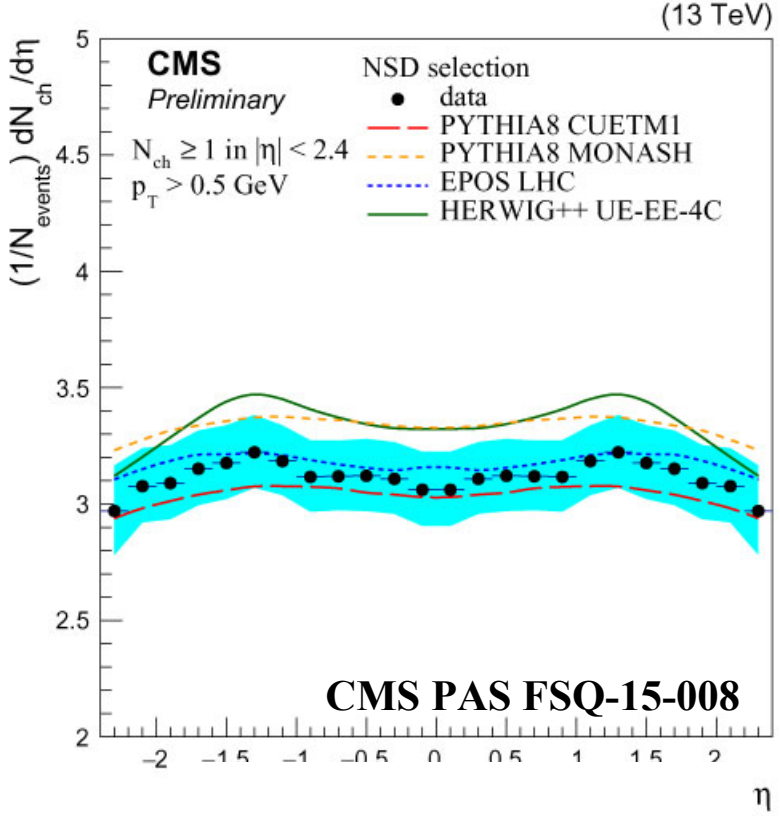
➡ **CMS "inelastic enhanced" data at 13 TeV on the charged particle density, dN/dη, with $p_T > 0.5$ GeV/c and $|\eta| < 2.4$ for events with at least one charged particle with $p_T > 0.5$ GeV/c and $|\eta| < 2.4$. The data are corrected to the particle level and compared with several MC models at generator level.**

- **Inelastic enhanced**: (A) + **Activity** on **at least one** Forward Region



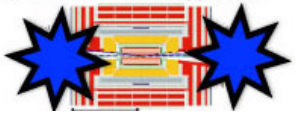
13 TeV "NSD Enhanced" dN/dη



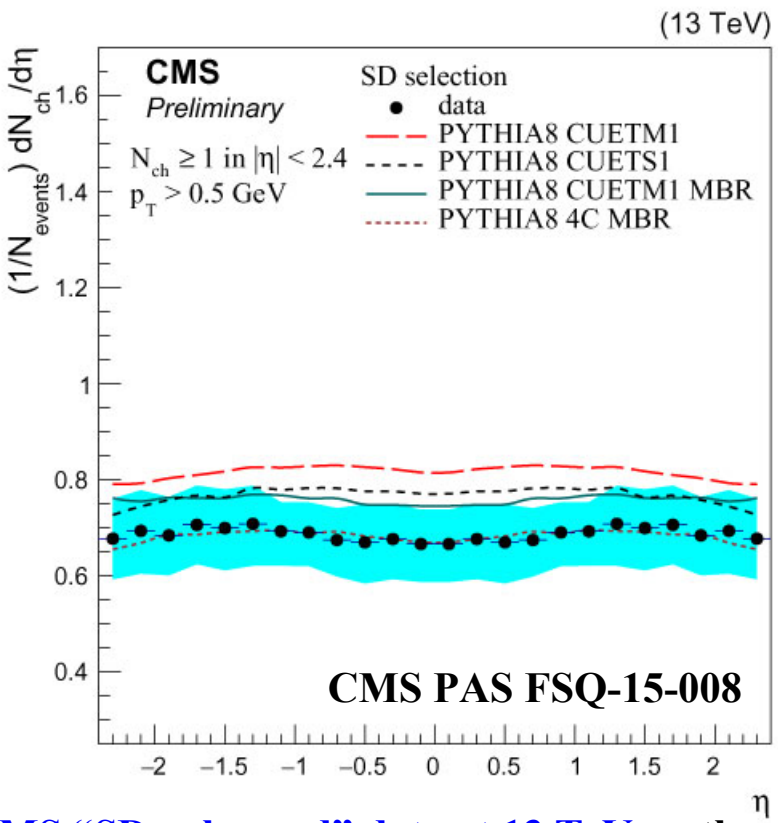


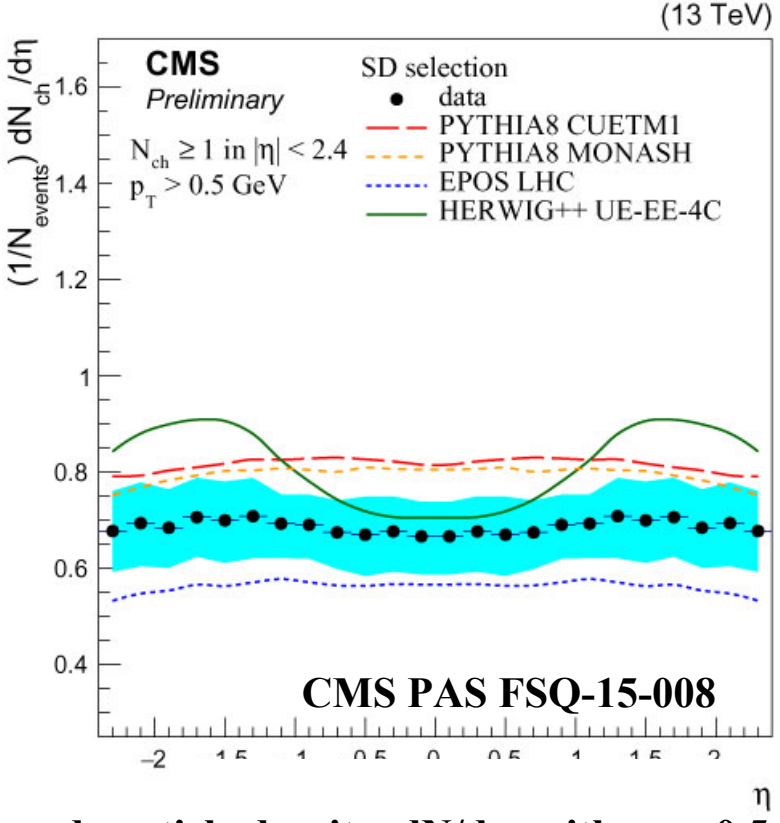
➡ **CMS "NSD enhanced" data at 13 TeV on the charged particle density, dN/dη, with $p_T > 0.5$ GeV/c and $|\eta| < 2.4$ for events with at least one charged particle with $p_T > 0.5$ GeV/c and $|\eta| < 2.4$. The data are corrected to the particle level and compared with several MC models at generator level.**

- **NSD enhanced**: (A) + **Activity** on **both** Forward Regions



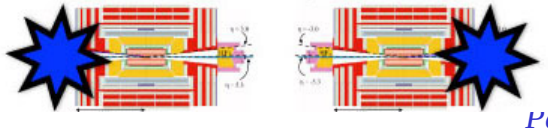
13 TeV "SD Enhanced" dN/dη



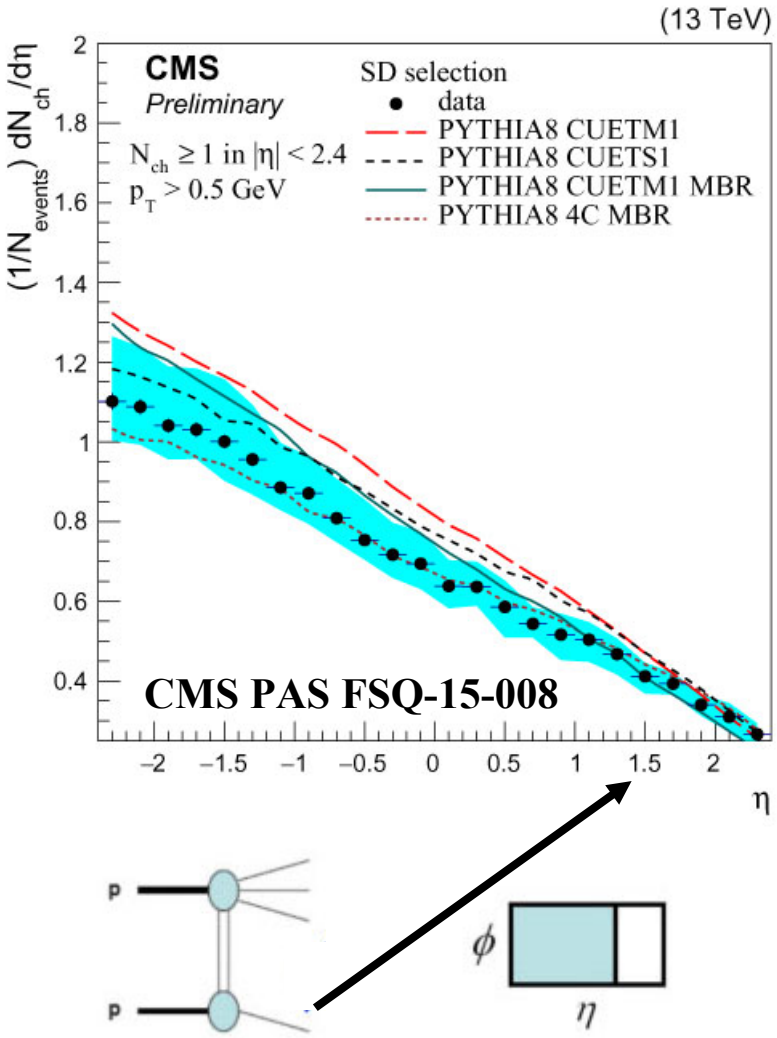


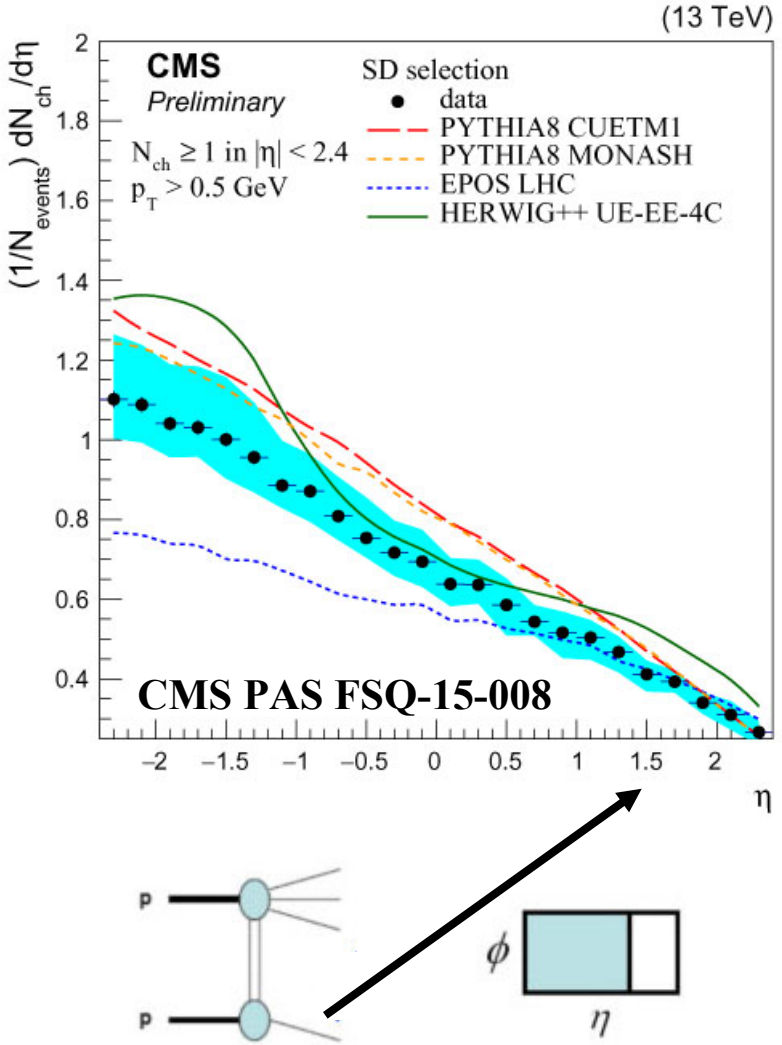
➡ **CMS "SD enhanced" data at 13 TeV on the charged particle density, dN/dη, with $p_T > 0.5$ GeV/c and $|\eta| < 2.4$ for events with at least one charged particle with $p_T > 0.5$ GeV/c and $|\eta| < 2.4$. The data are corrected to the particle level and compared with several MC models at generator level.**

- **SD enhanced**: (A) + **Activity** on one Forward Region **and Veto** on the other side

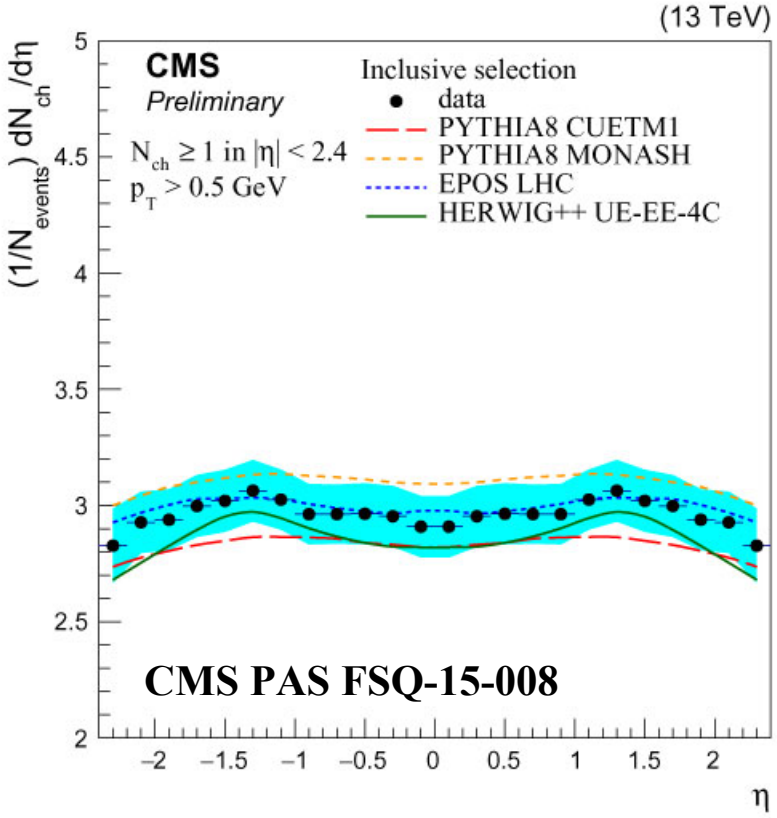


13 TeV "SD Enhanced" dN/dη

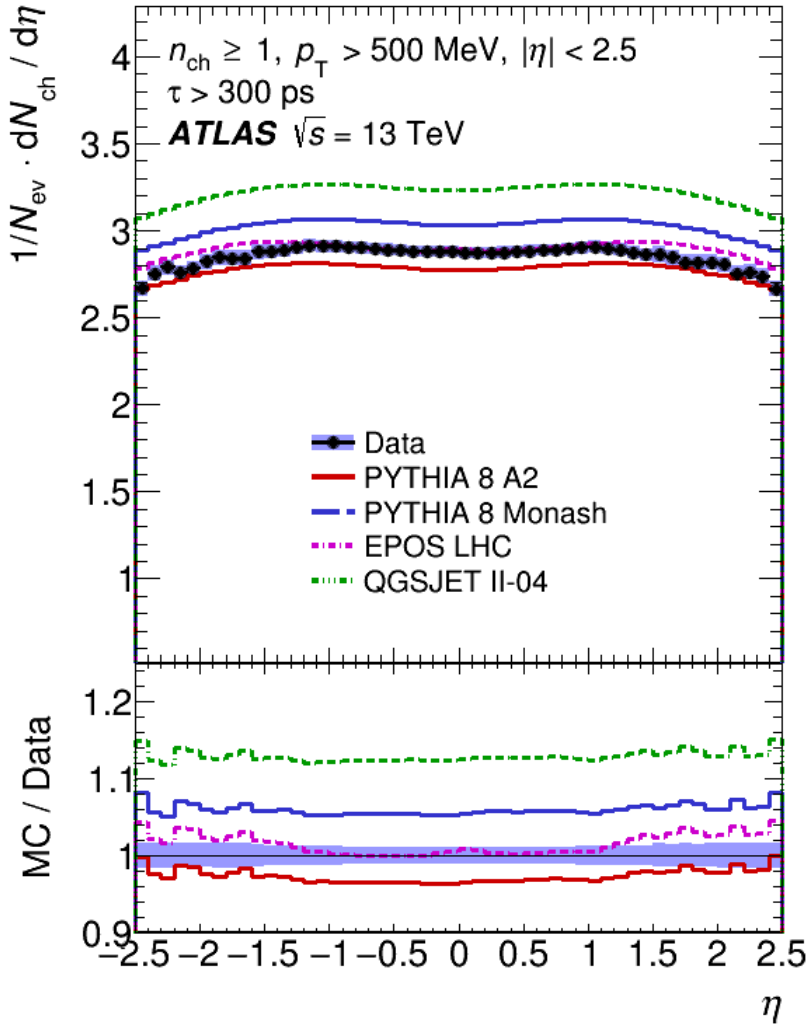




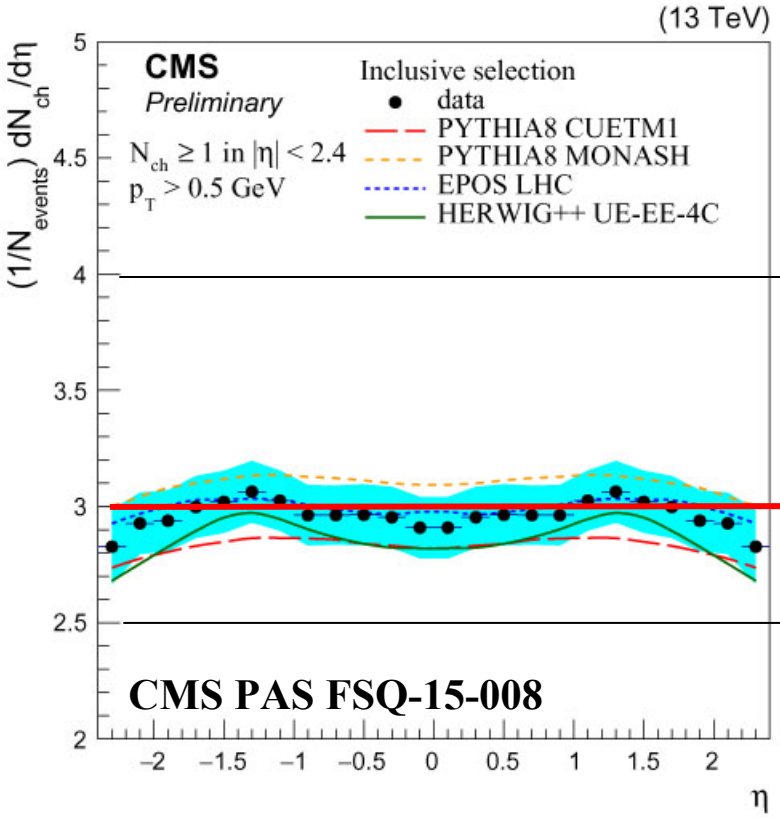
MB at 13 TeV: dN/dη



arXiv:1602.01633



MB at 13 TeV: dN/dη



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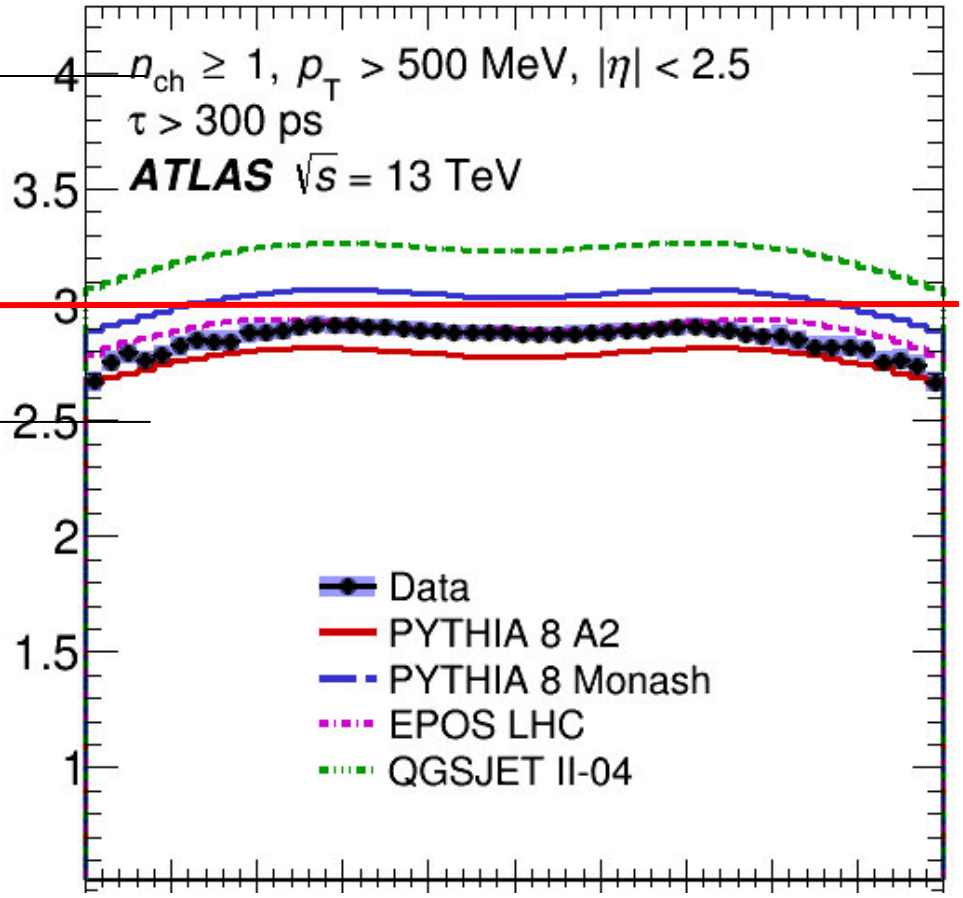
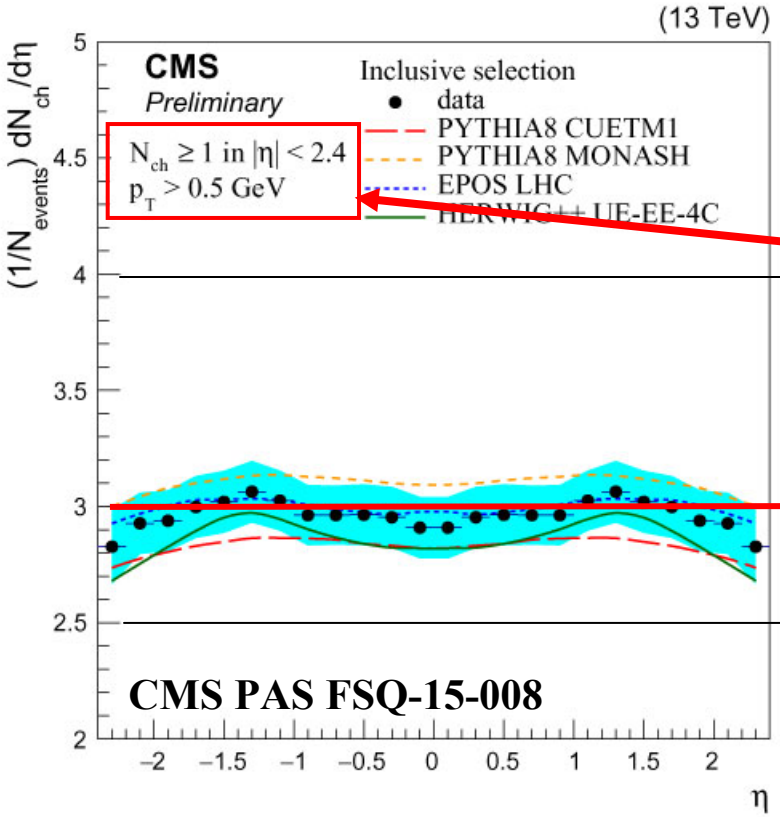
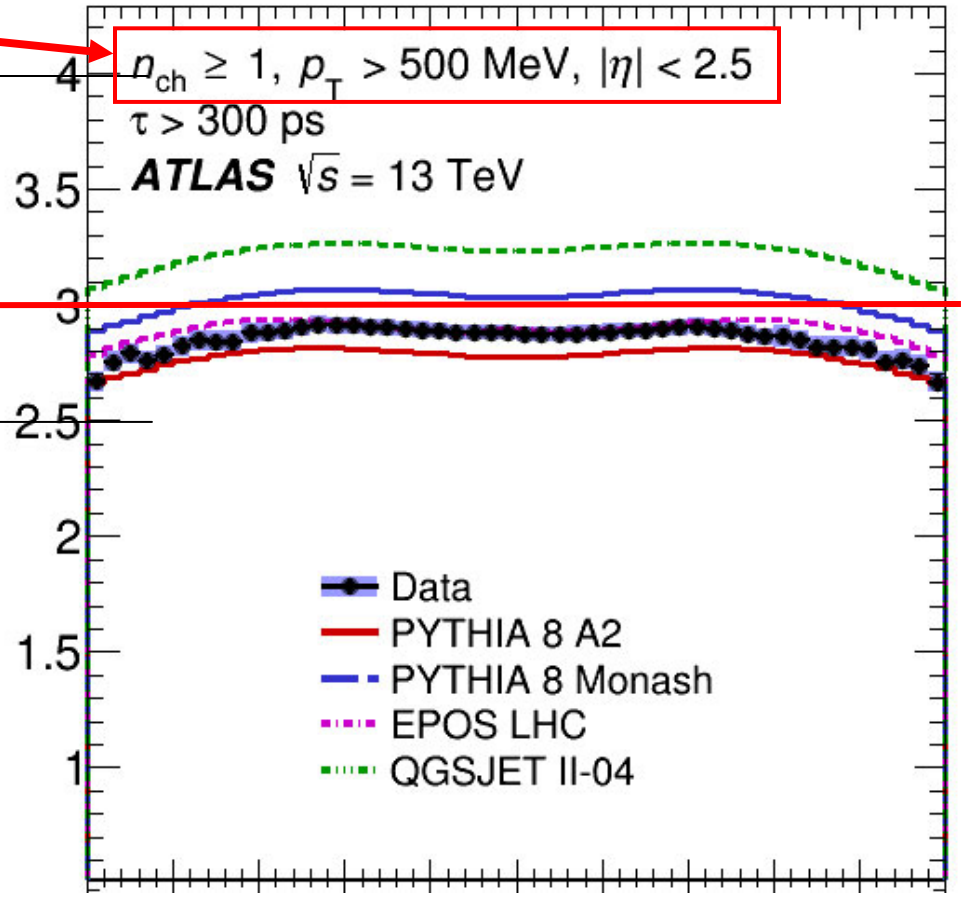


MB at 13 TeV: dN/dη

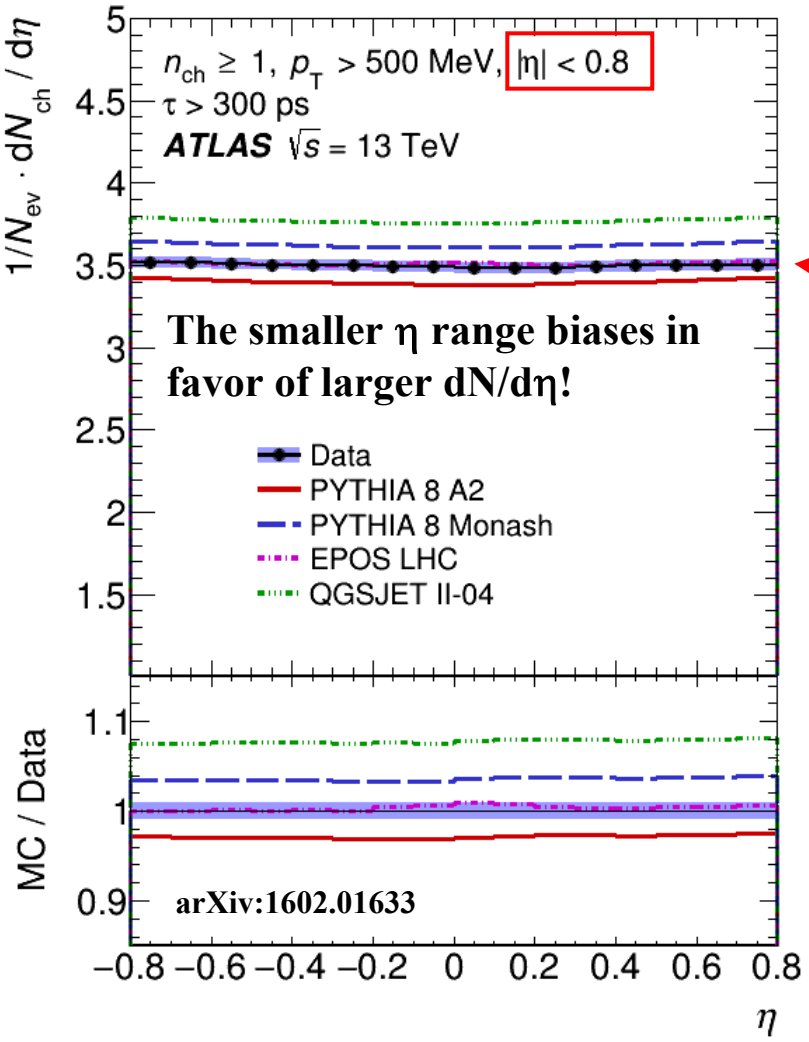




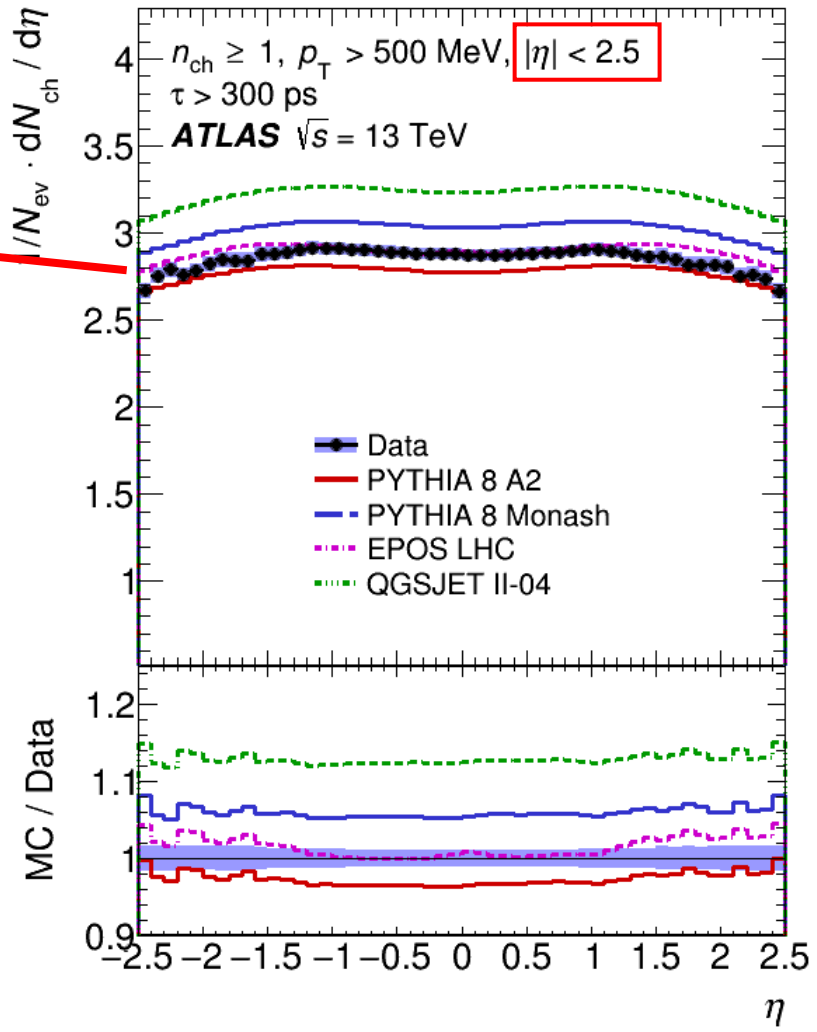
Not exactly the same observable! CMS requires $N_{ch} \geq 1$ in $|\eta| < 2.4$ while ATLAS requires $N_{ch} \geq 1$ in $|\eta| < 2.5$. The smaller η range biases in favor of larger dN/dη!

MB at 13 TeV: dN/dη

13 TeV MB "Common Plot"!

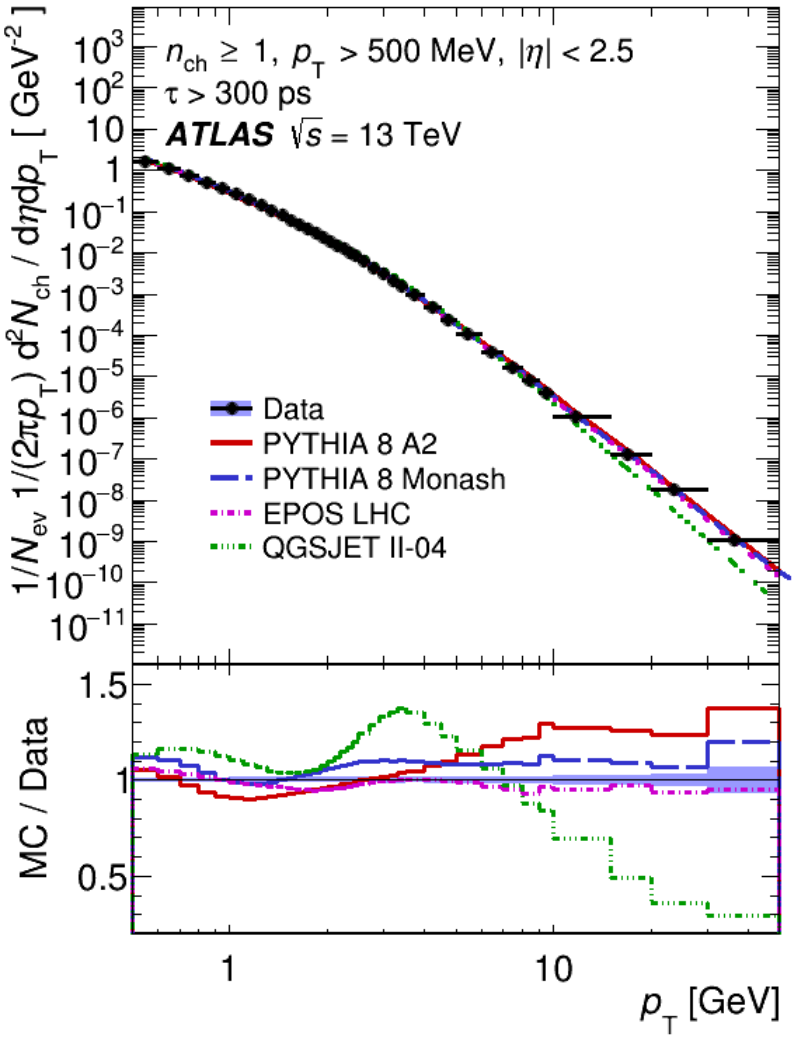


arXiv:1602.01633



MB Distributions at 13 TeV

arXiv:1602.01633



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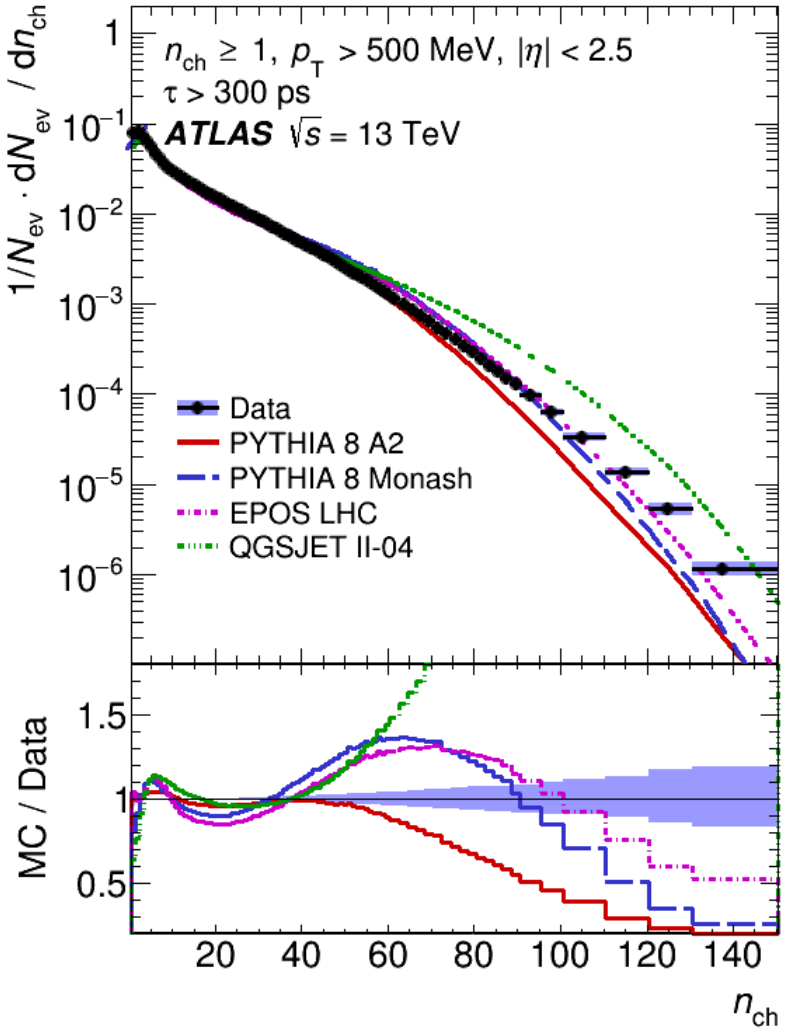
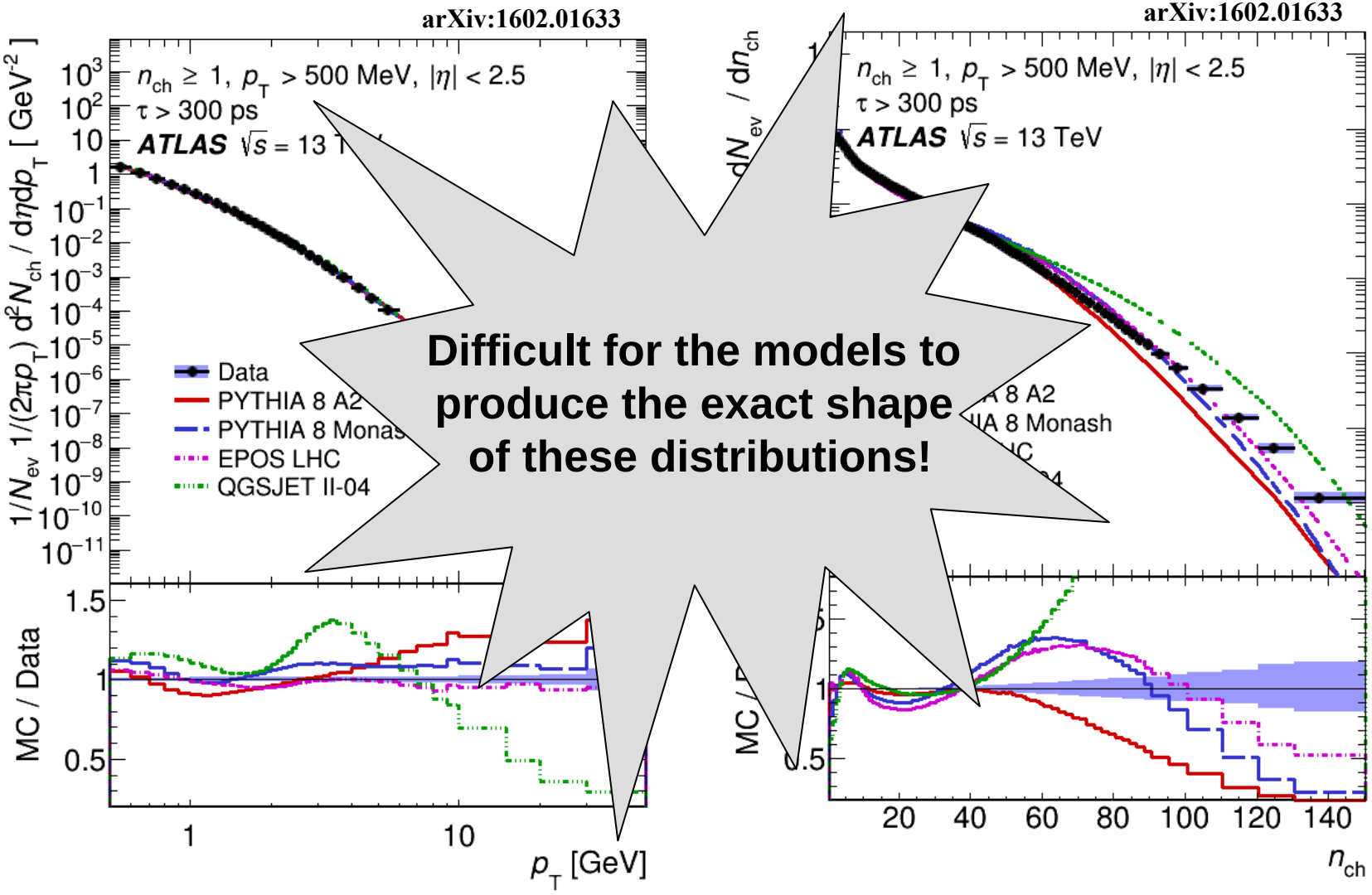
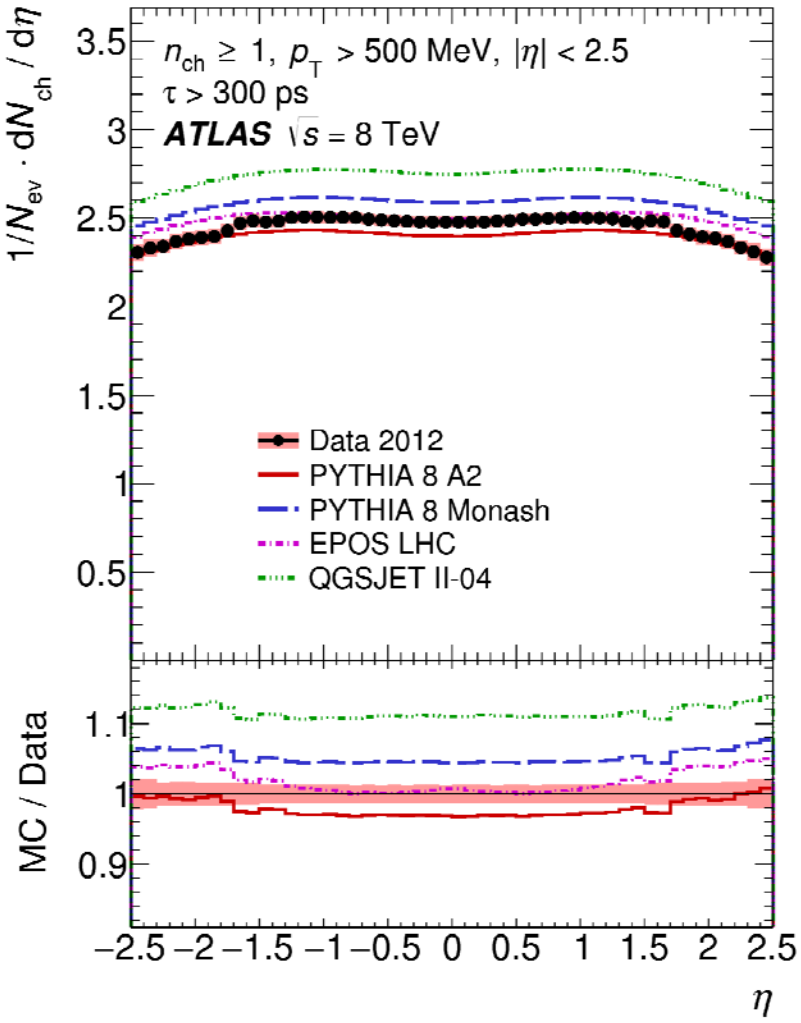


MB Distributions at 13 TeV

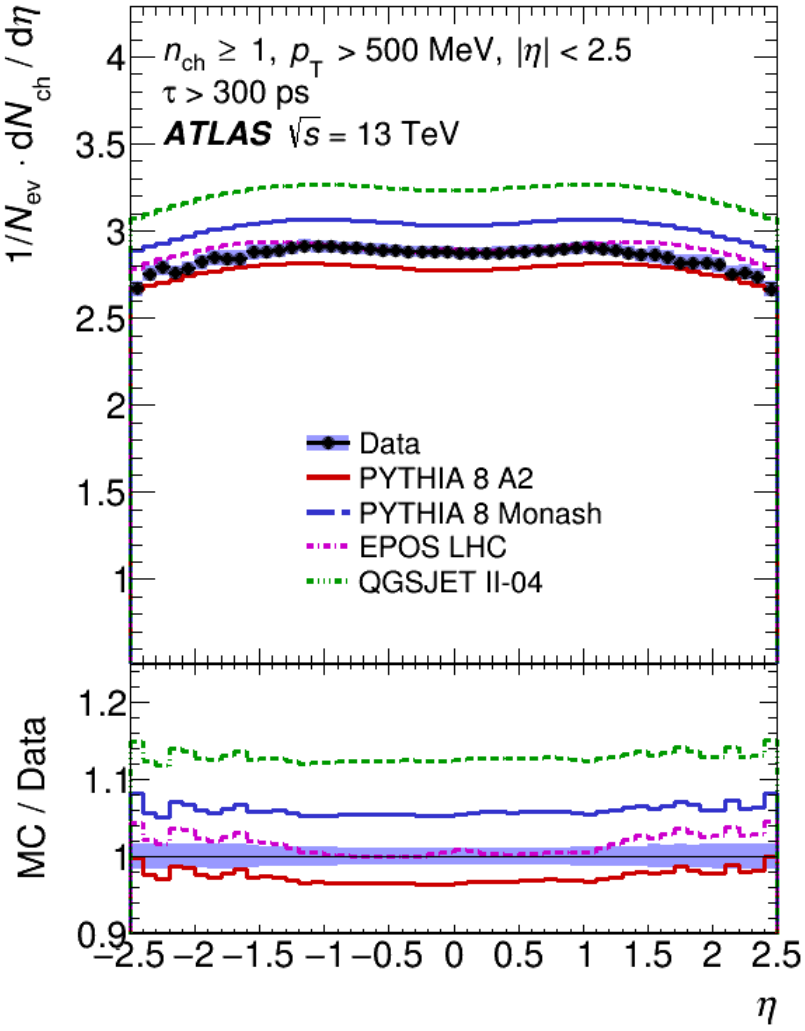


8 TeV versus 13 TeV

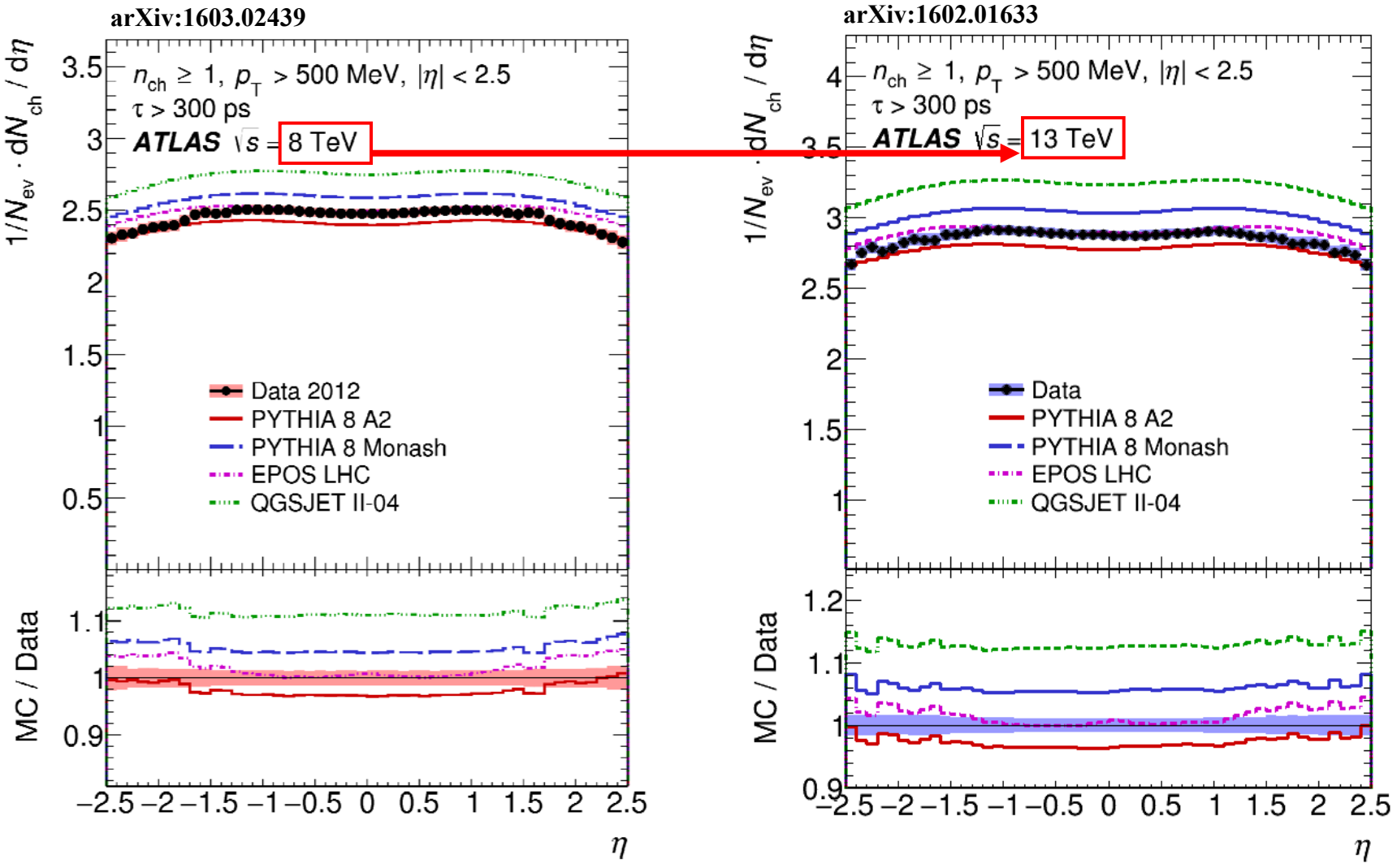
arXiv:1603.02439



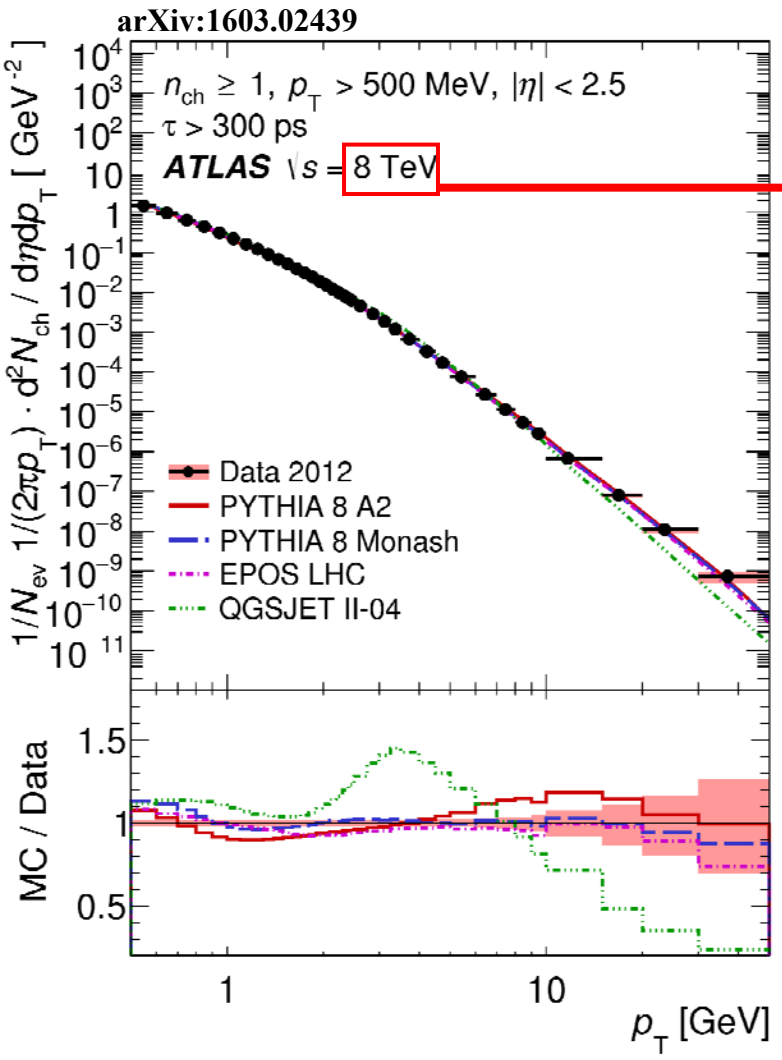
arXiv:1602.01633

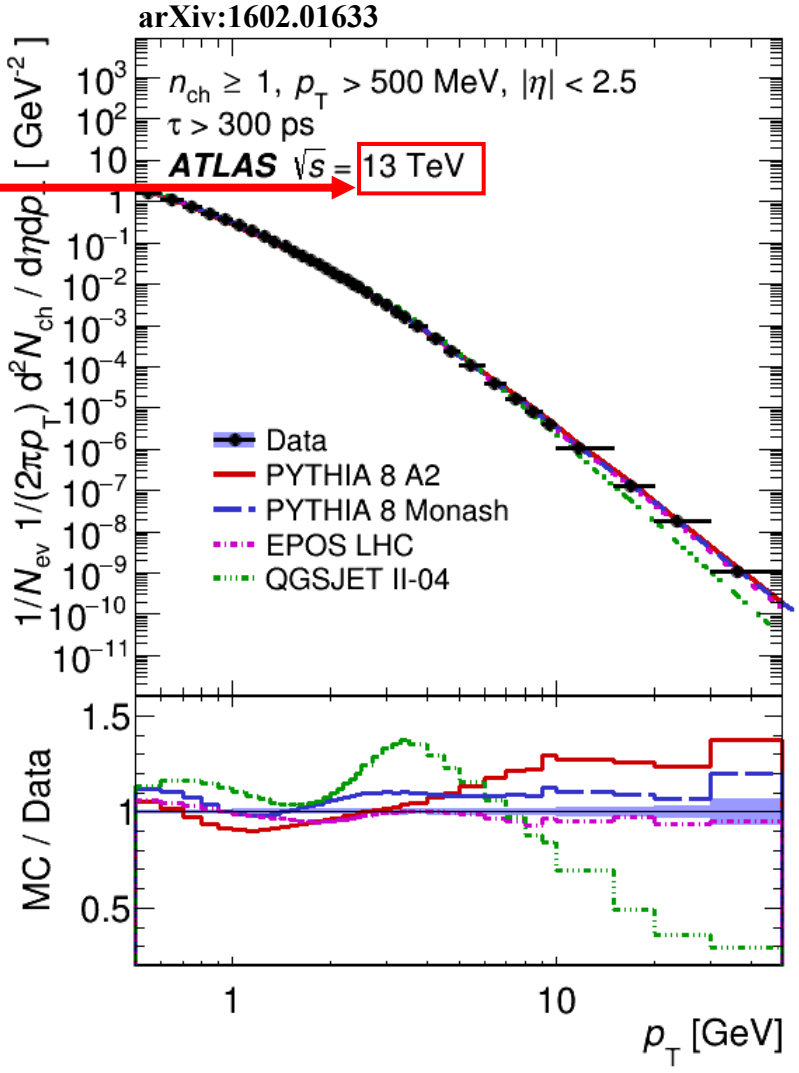


8 TeV versus 13 TeV

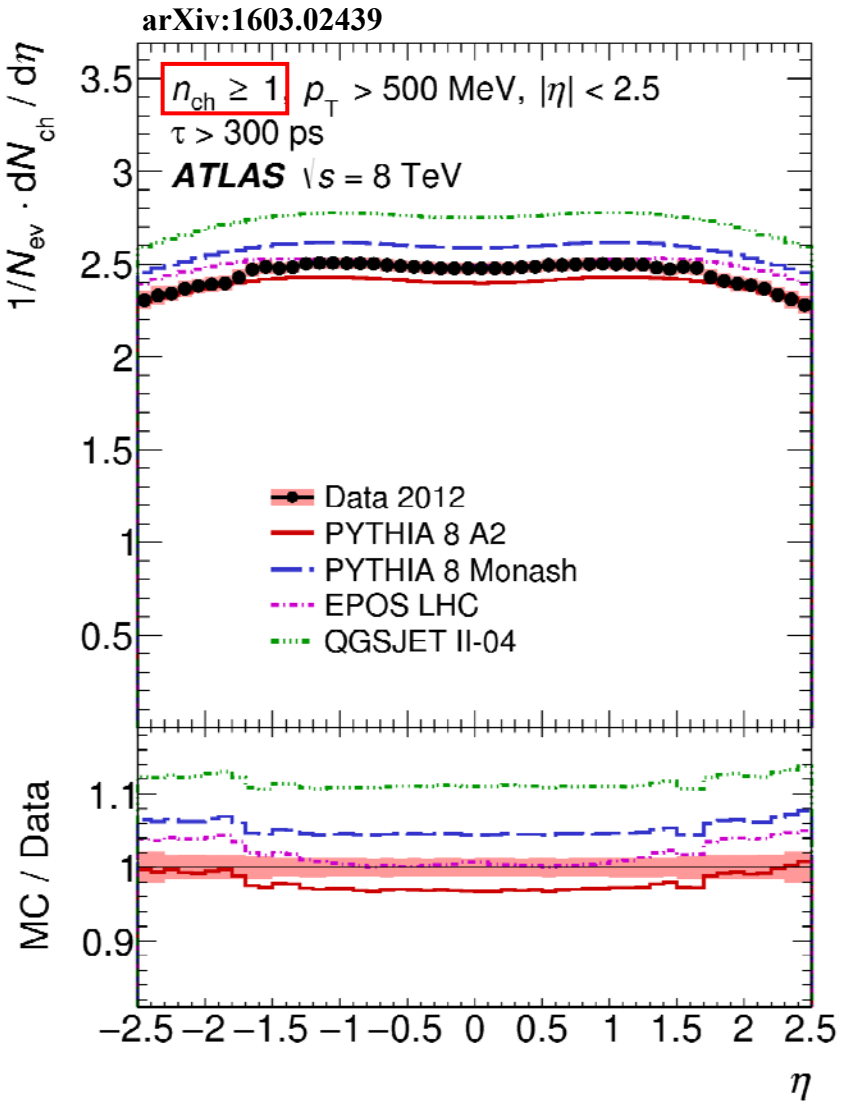


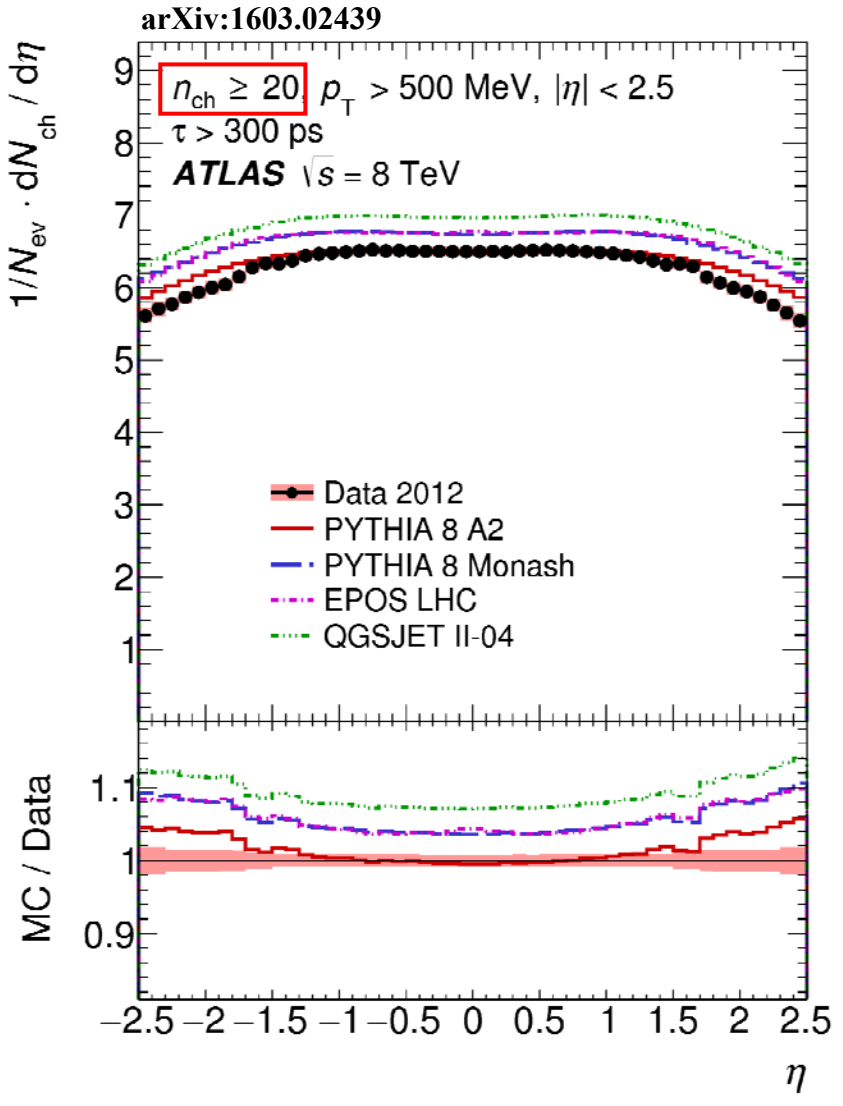
8 TeV versus 13 TeV



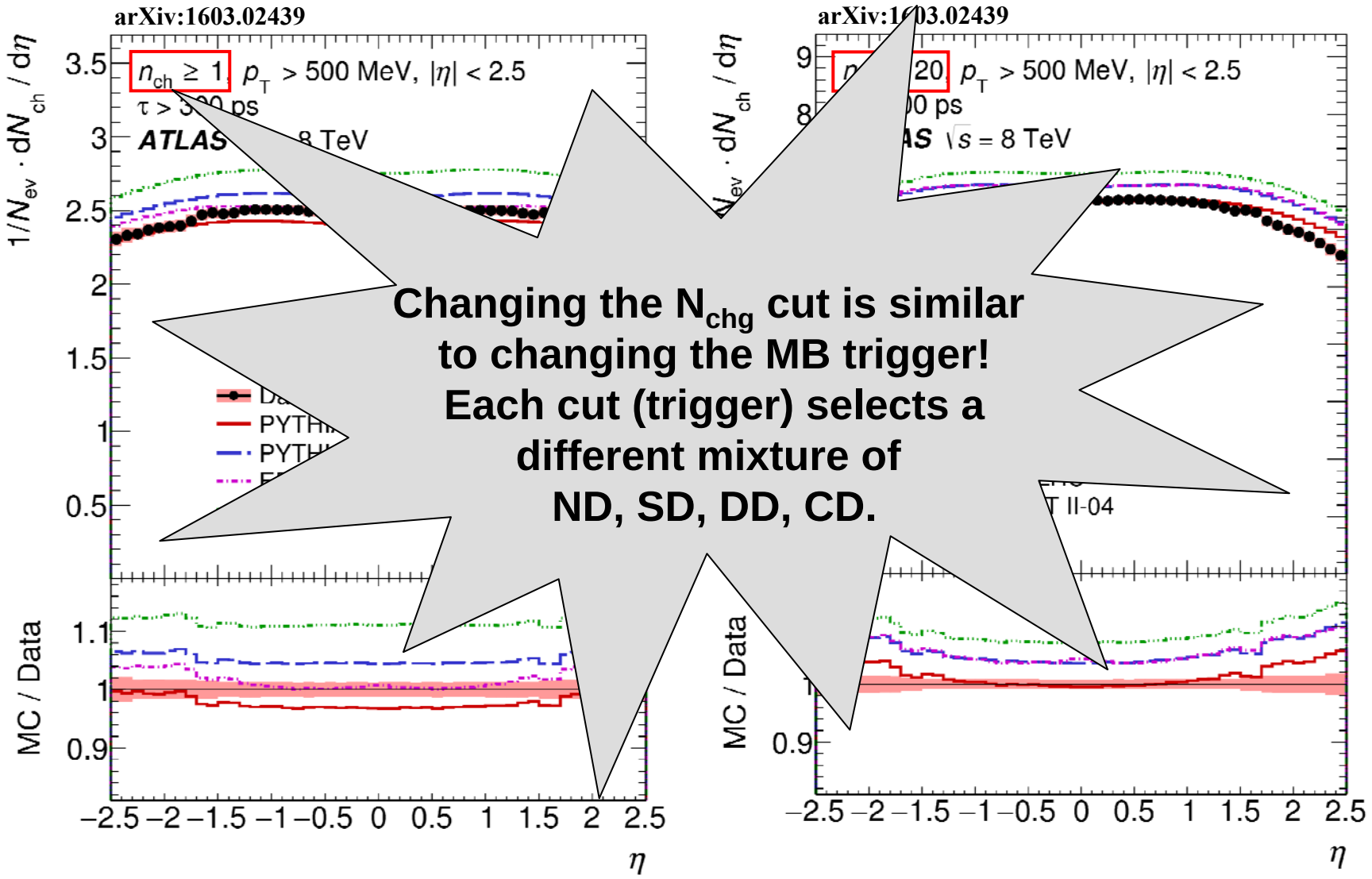


Dependence on N_{chg} Cut



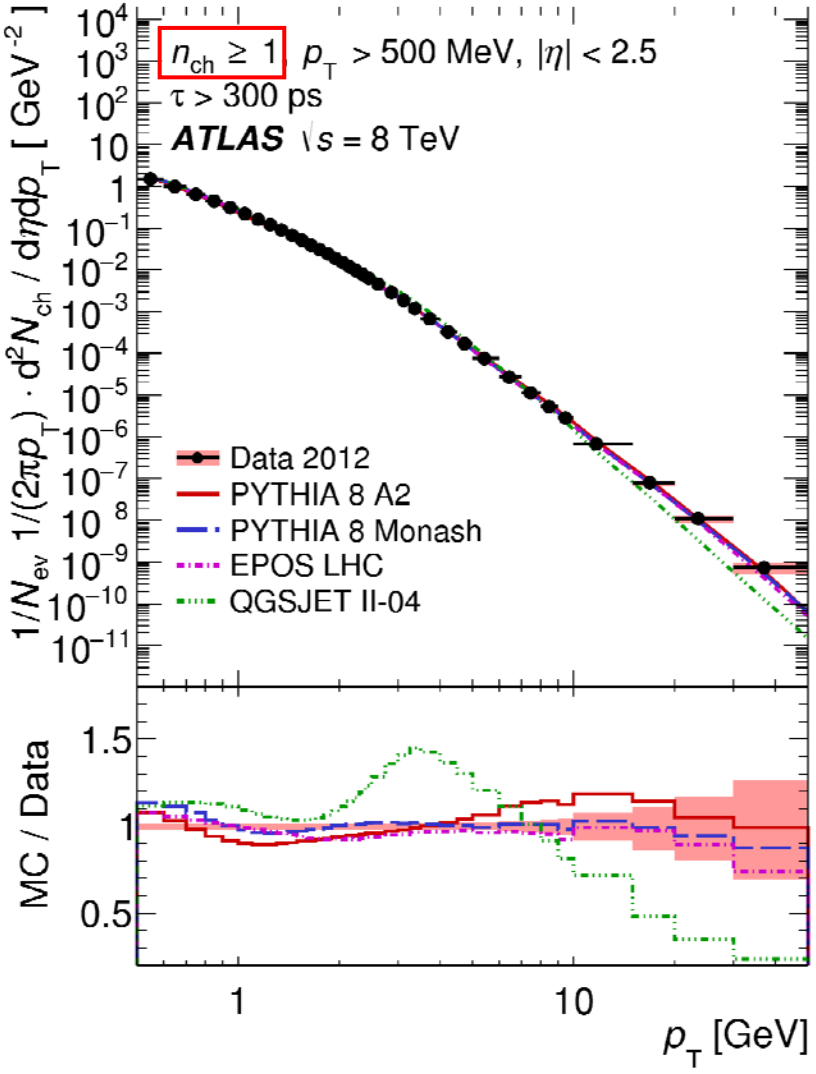


Dependence on N_{chg} Cut



Dependence on Nchg Cut

arXiv:1603.02439



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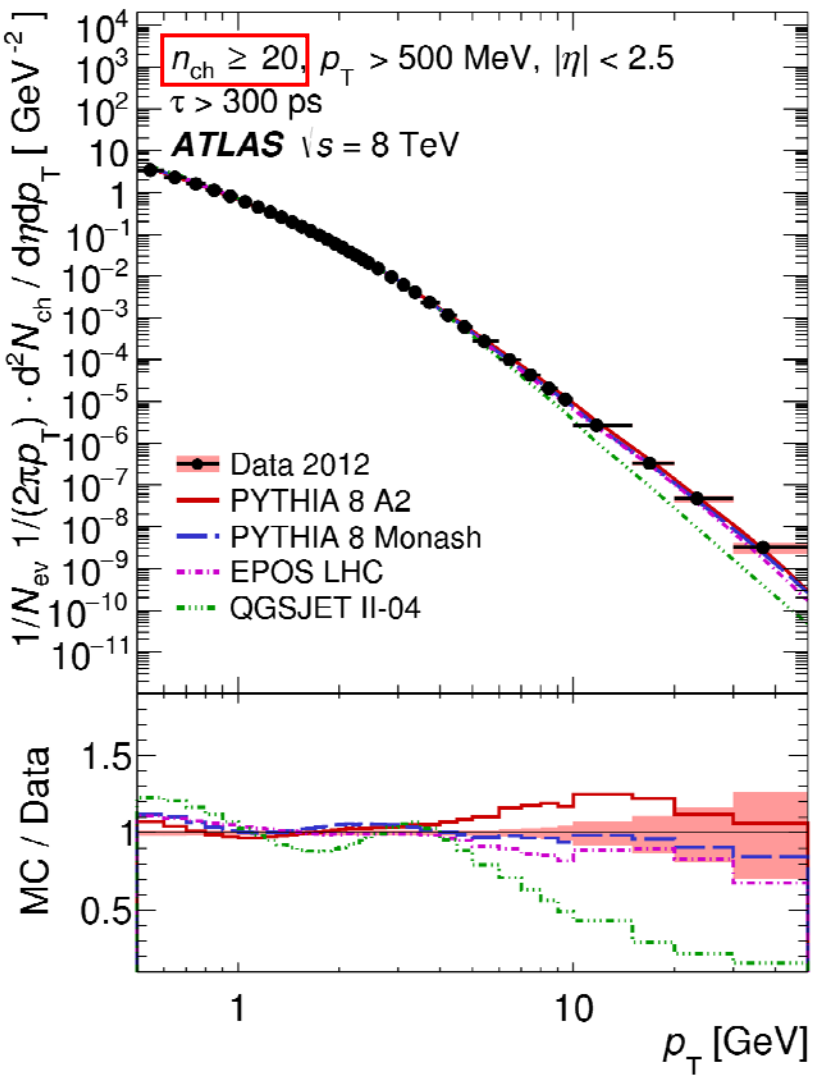
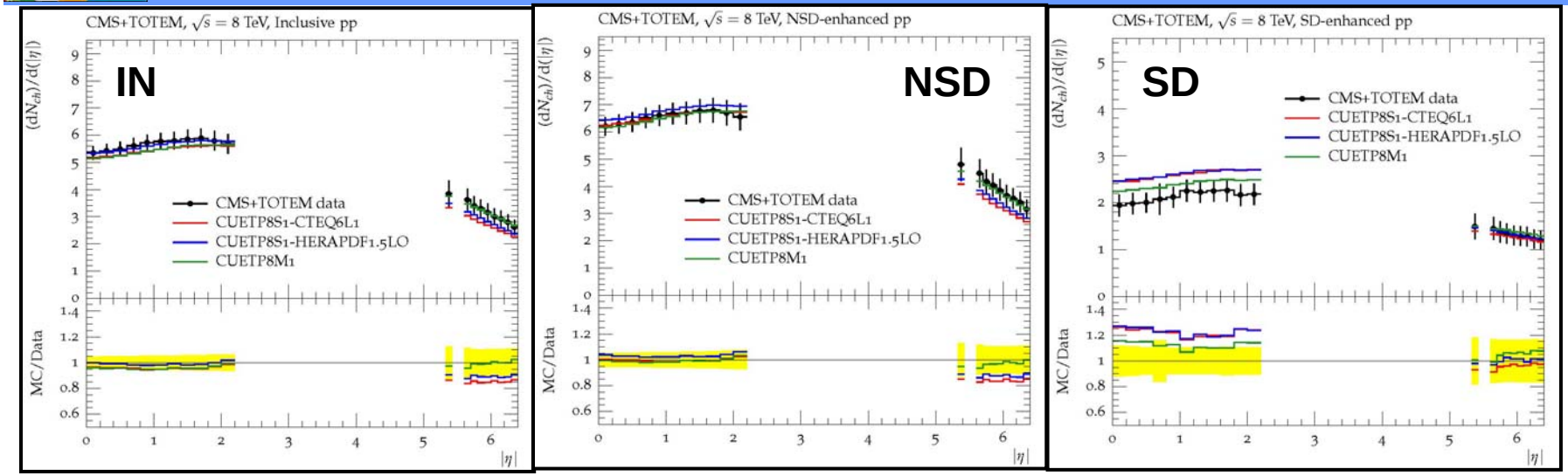


CMS+TOTEM dN/dη



➡ **Compares the CMS CUEP8M1-NNPDF2.3LO tune with the CMS+TOTEM dN/dη data at 8 TeV.**

The CMS UE tunes do a fairly good job (although not perfect) describing the MB data! No need for a separate MB tune.

The CMS UE tune CUEP8M1-NNPDF2.3LO (Mstar) does a better job in the forward region due to the PDF!

From CMS GEN-14-001

Energy Flow

Available on the CERN CDS information server **CMS PAS FSQ-15-006**

CMS Physics Analysis Summary

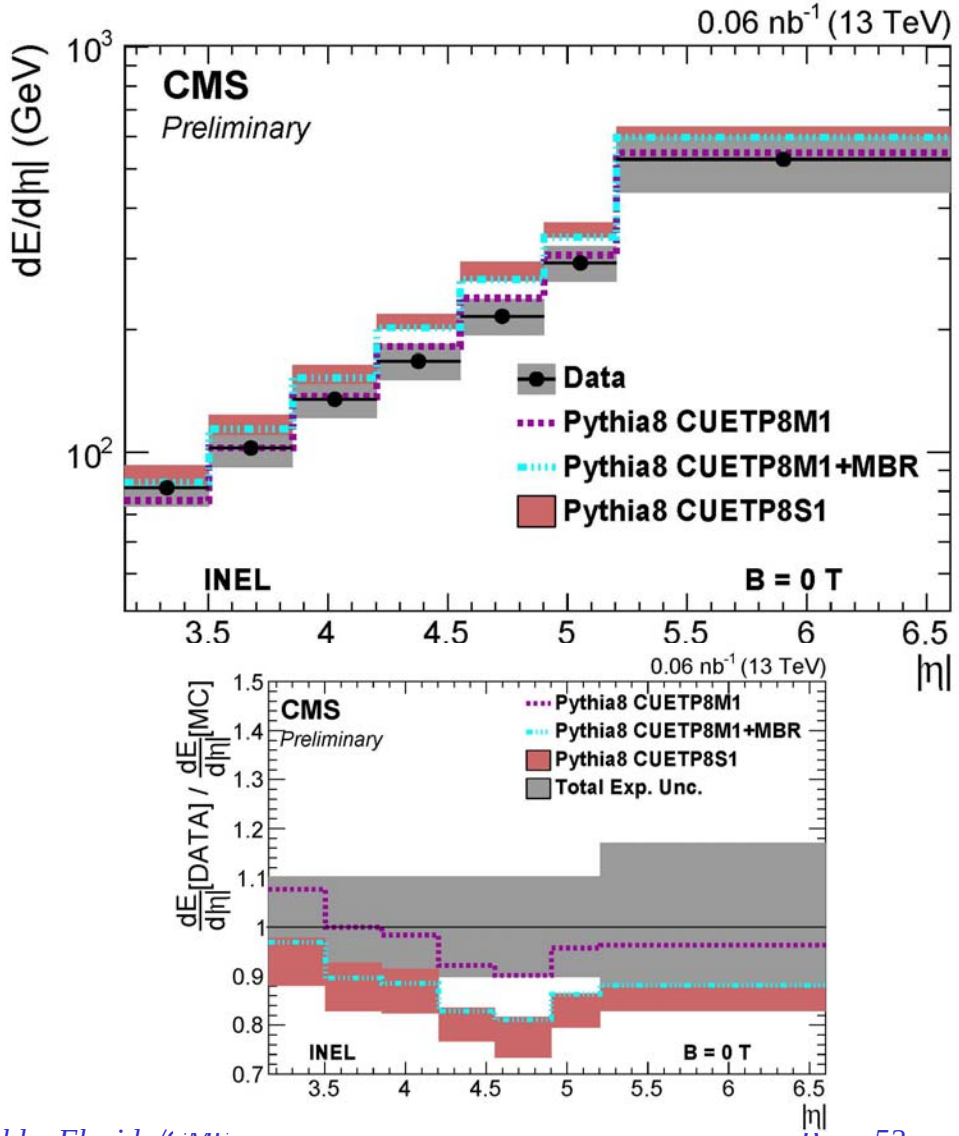
Contact: cms-pag-conveners-fsq@cern.ch 2016/04/14

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

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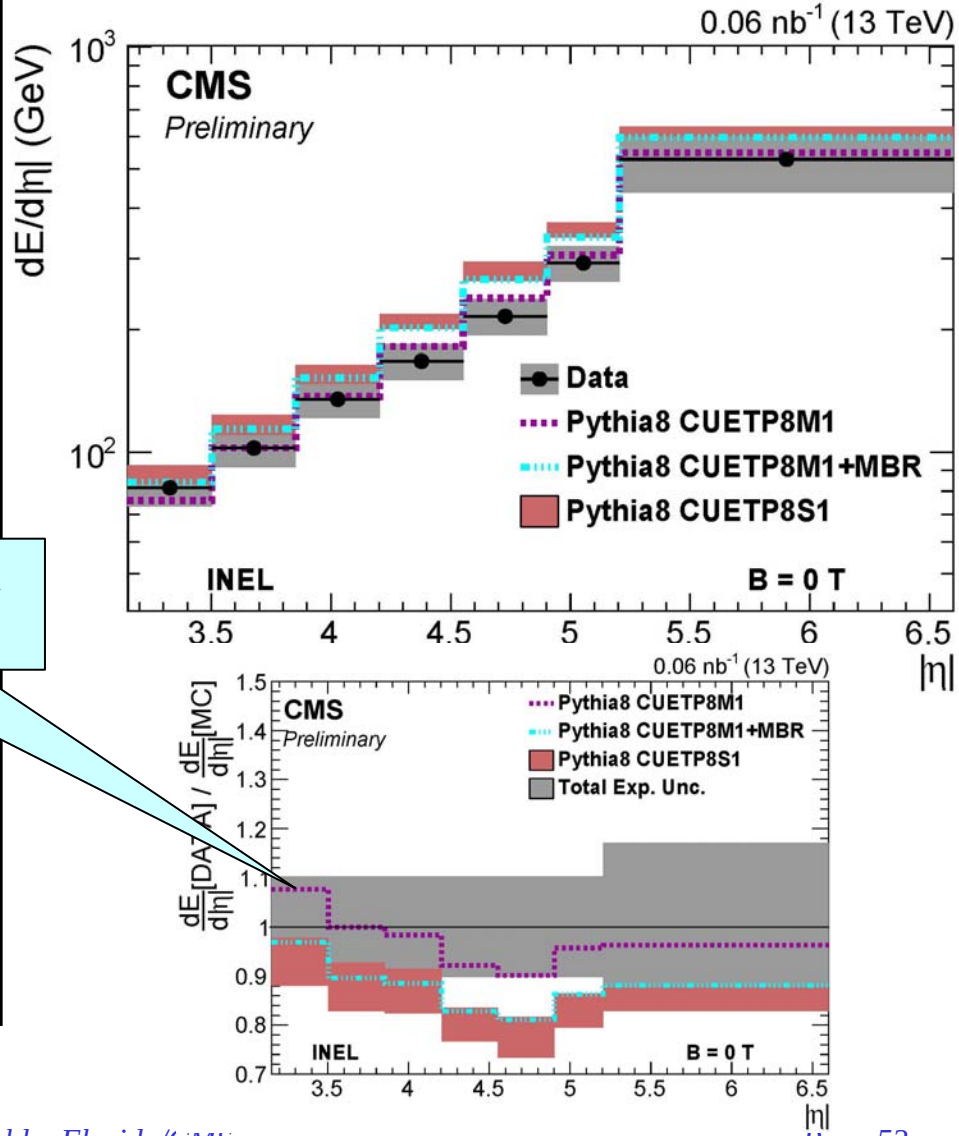
CUETP8M1 does a fairly good job!



Forward Energy Distribution

Available on the CERN CDS information server **CMS PAS FSQ-16-002**

CMS Physics Analysis Summary

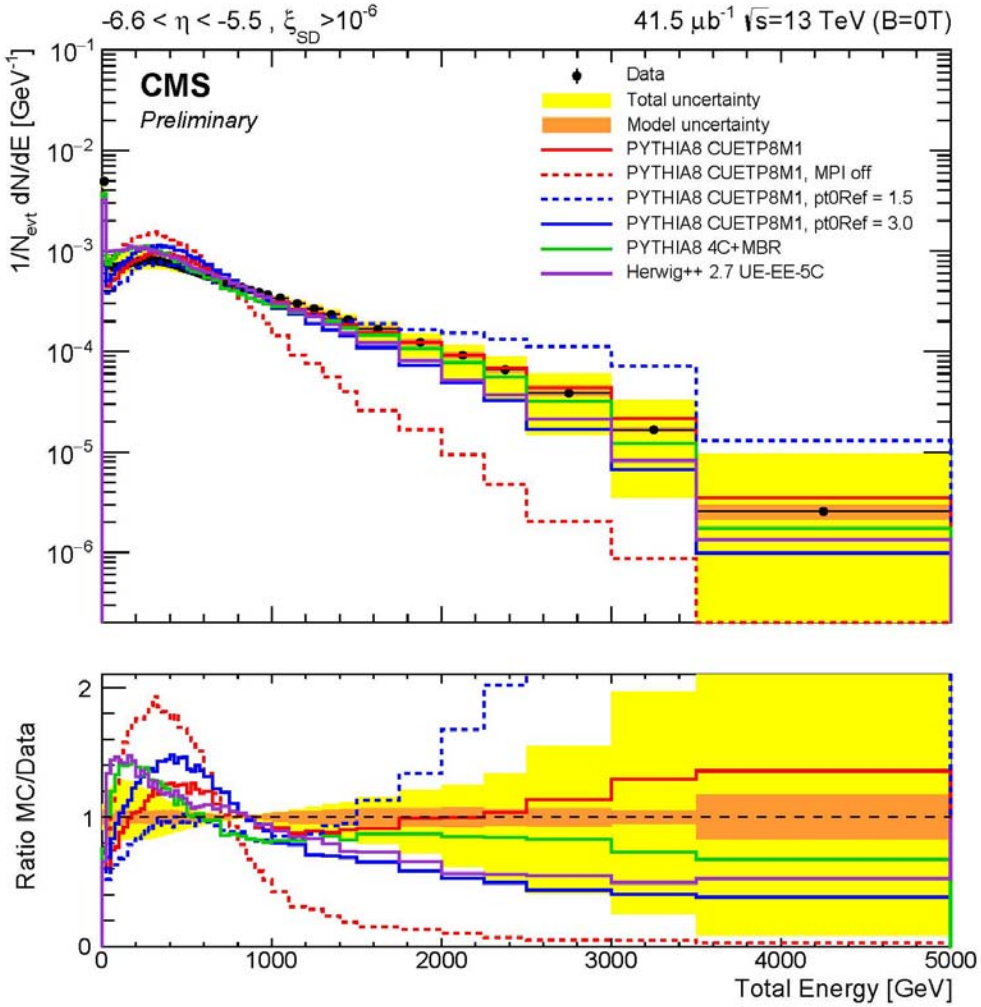
Contact: cms-pag-conveners-fsq@cern.ch 2016/04/11

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-conven /11

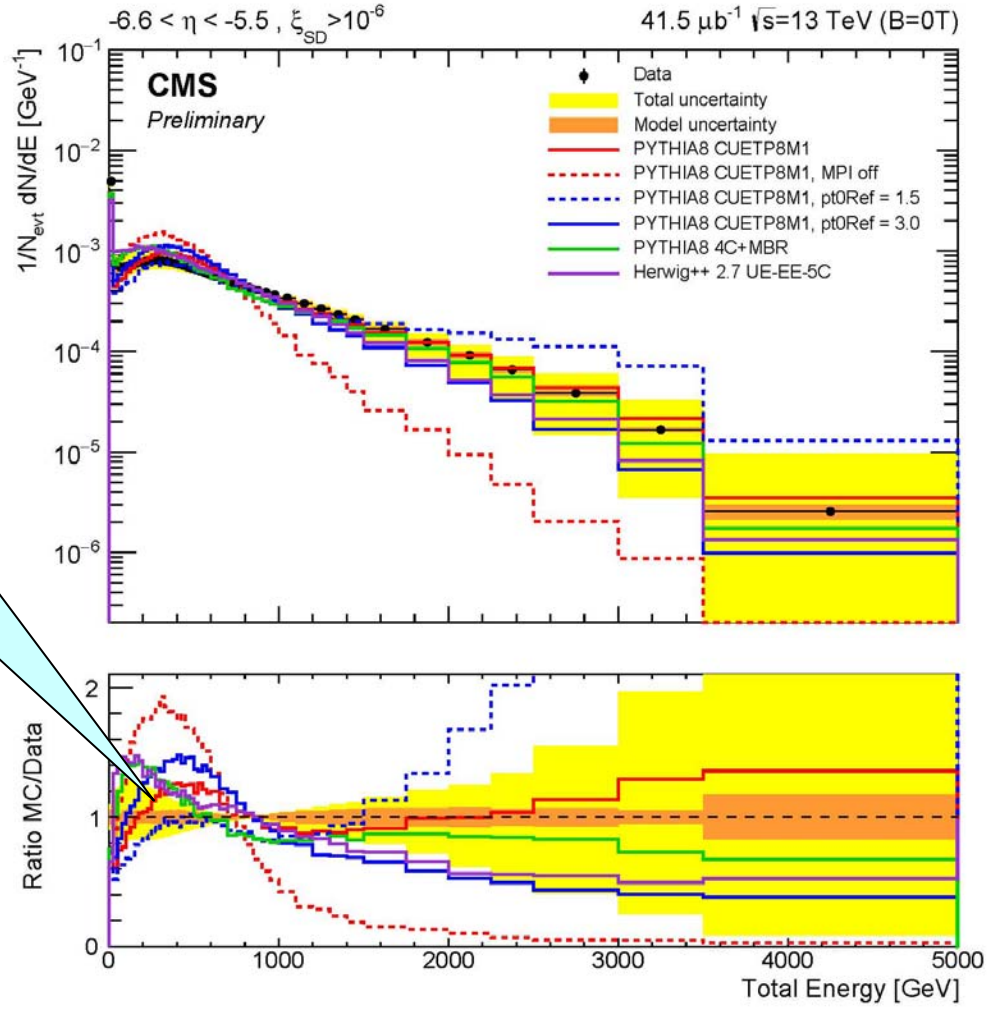
Measurement of the energy distributi very forward direction at 13 TeV with

The CMS Collaboration

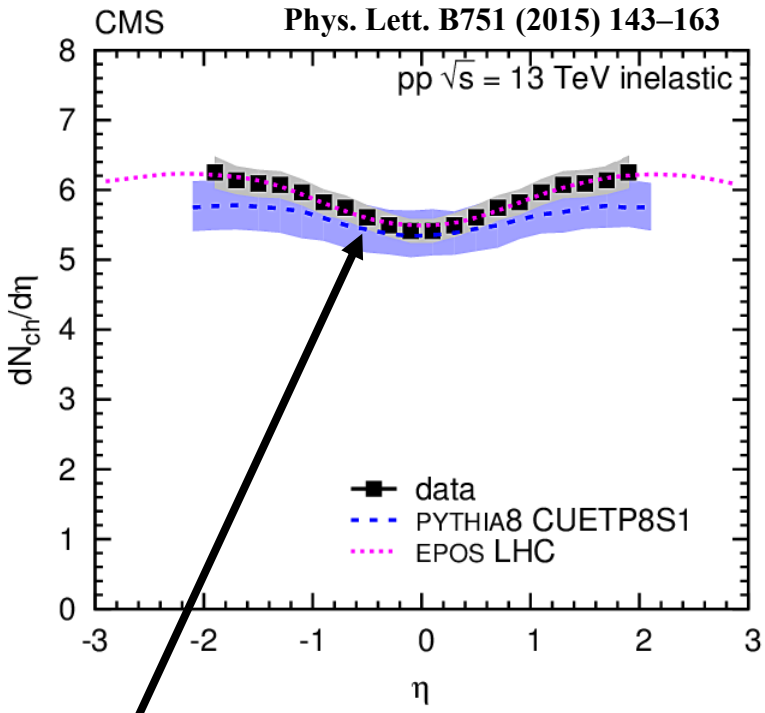
Abstract

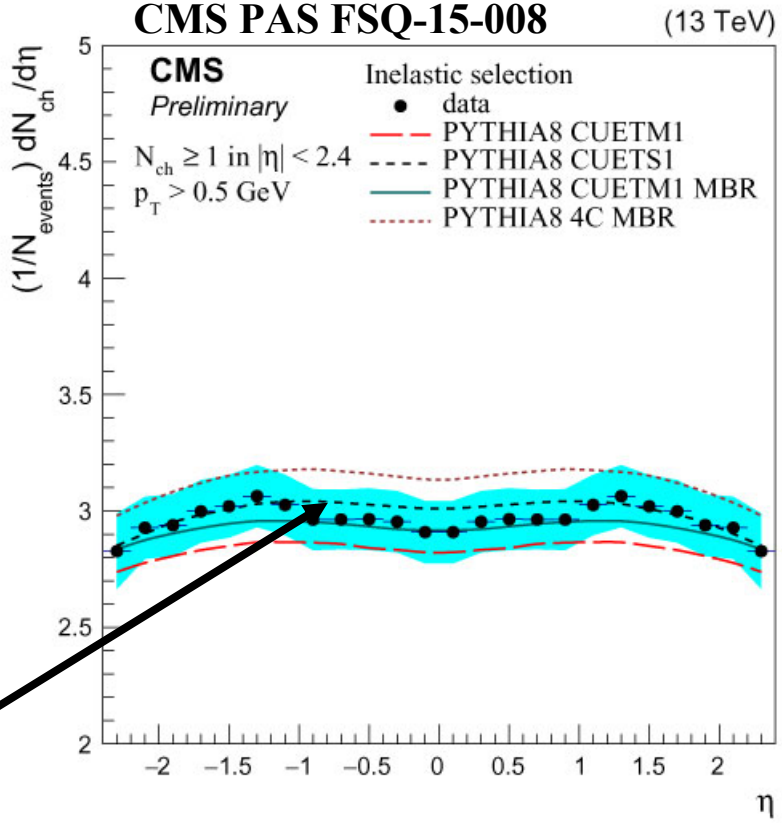
The event-by-event energy deposition into the very forward acceptance, $-6.6 < \eta < -5.2$, of CMS is measured and characterized in proton-proton collisions at 13 TeV. Data from the electromagnetic and hadronic sections of the CASTOR calorimeter are used for this purpose. The results are corrected to 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.

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



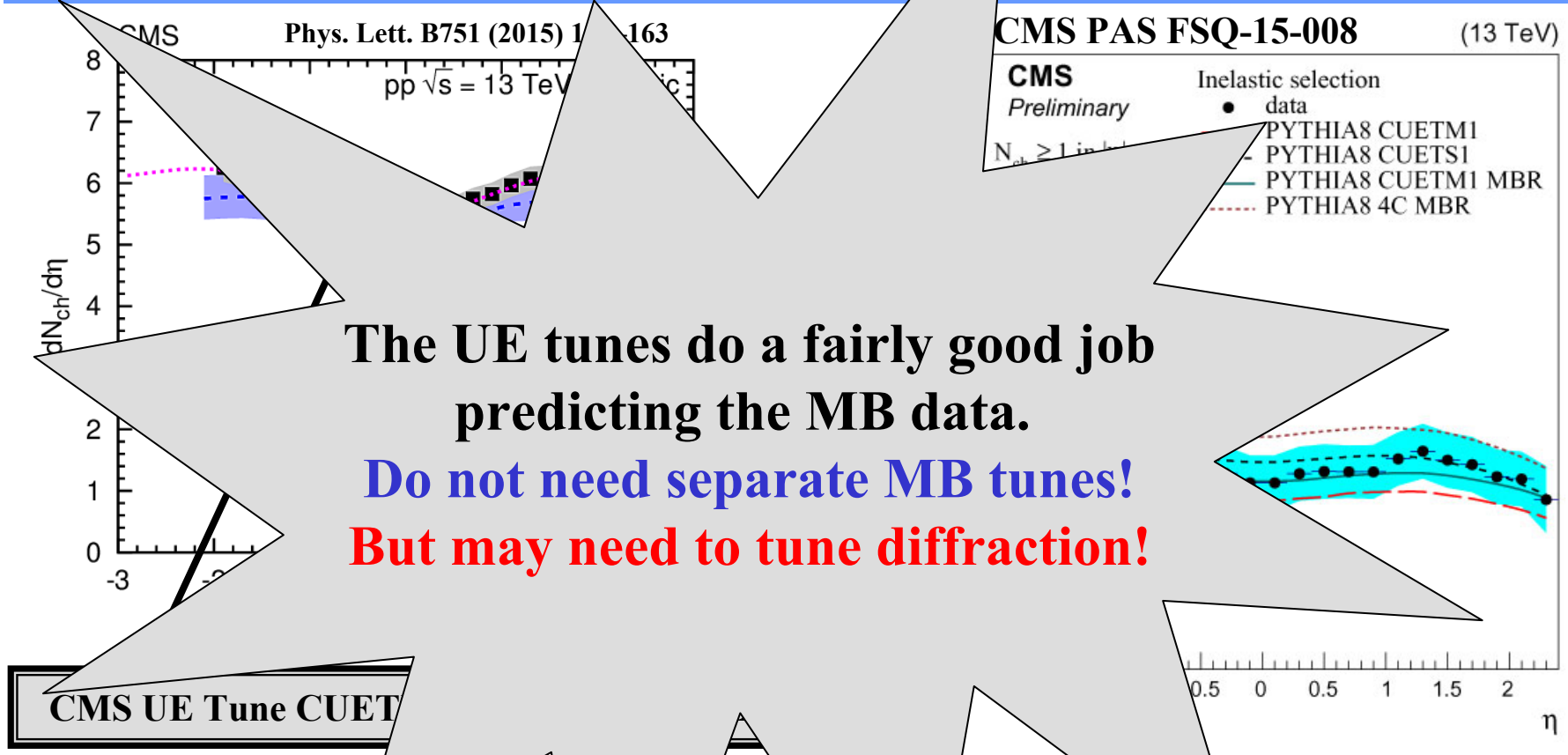
MB at 13 TeV: dN/dη





CMS UE Tune CUETP8S1-HERAPDF1.5LO.

MB at 13 TeV dN/dη



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

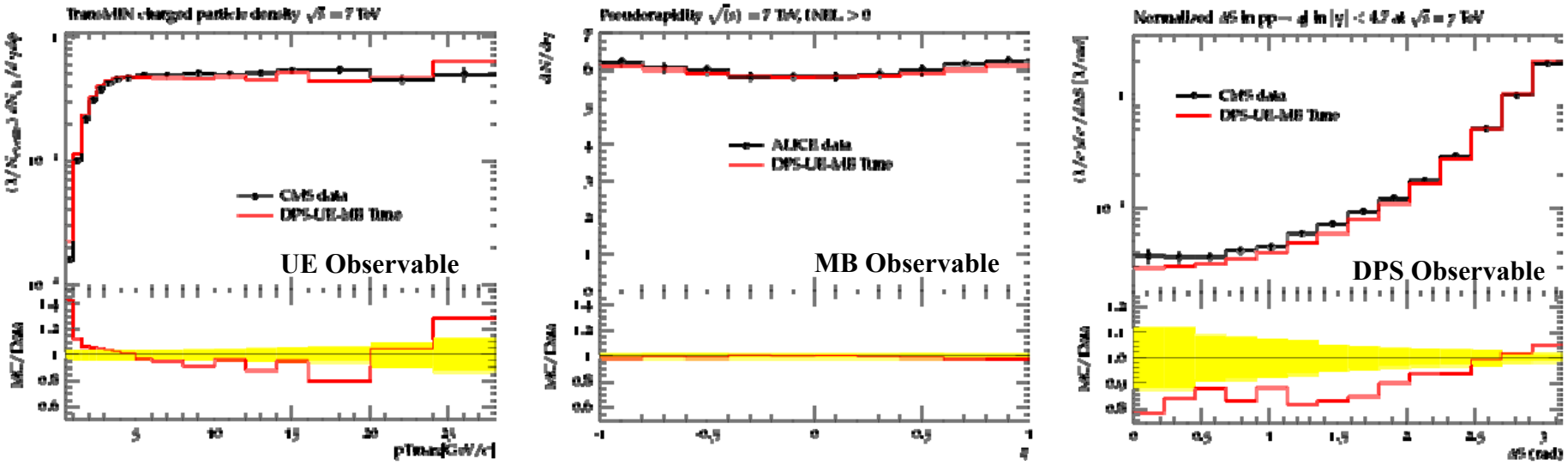
Do not need separate MB tunes!

But may need to tune diffraction!

CMS UE Tune CUET

Simultaneous UE-MB-DPS Tune

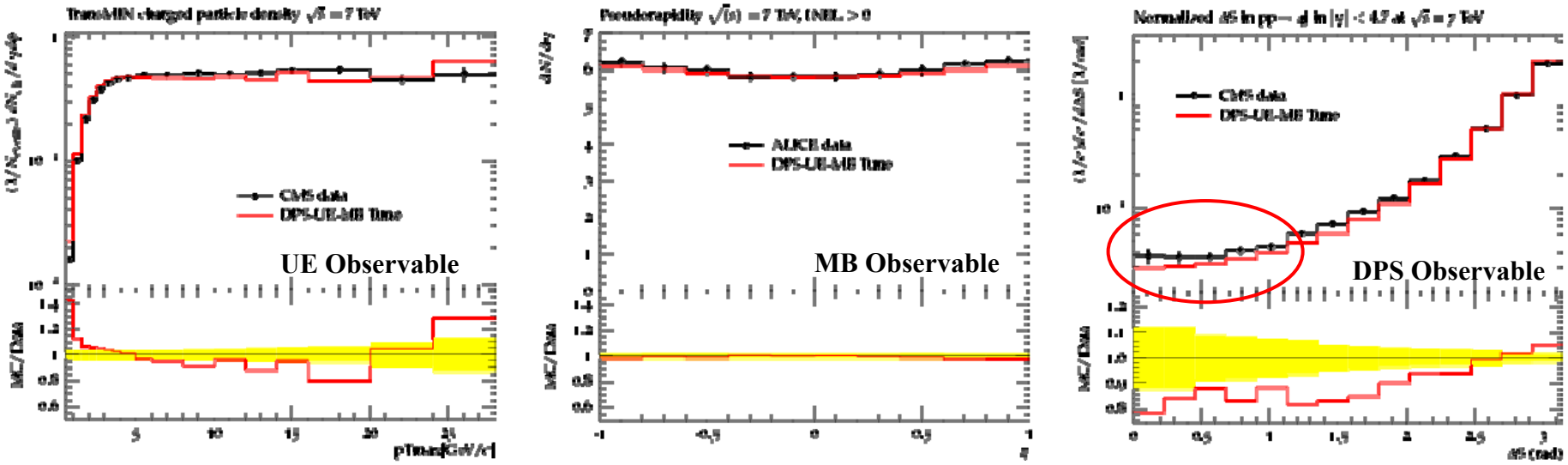
Paolo Gunnellini and the CMS PC&GT Team



➡ **Simultaneous UE-MB-DPS Tune at 7 TeV: Simultaneously fit the CMS PTmax UE data, the ALICE dN/dη data, and the CMS pp→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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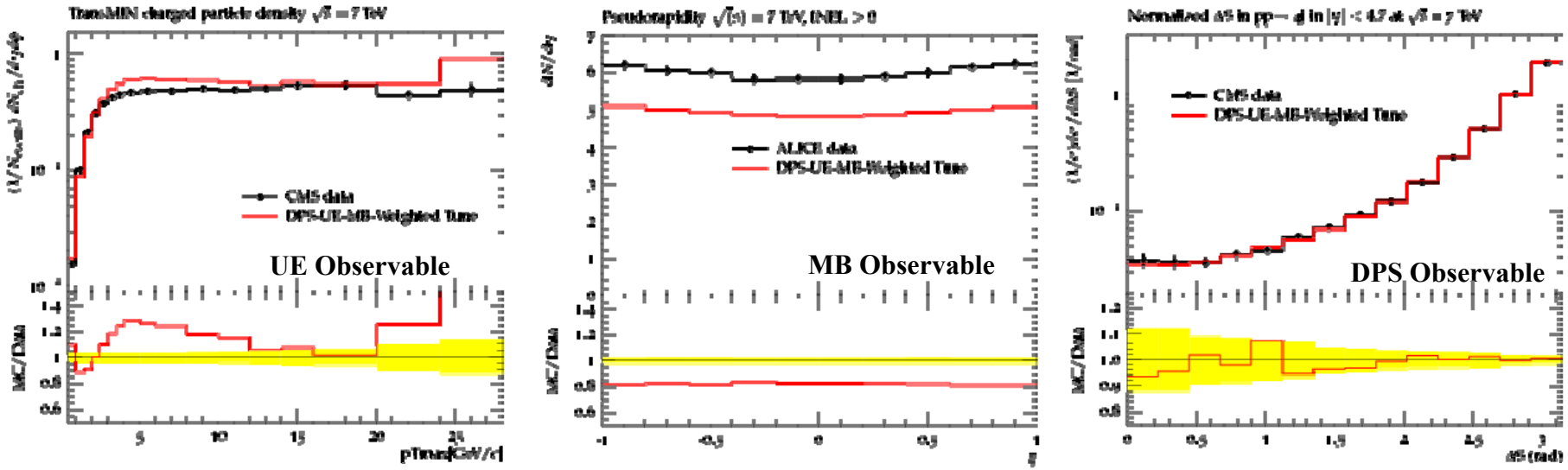
UE and MB are good, but DPS is bad!

Simultaneous UE-MB-DPS Tune

Paolo Gunnellini and the CMS PC&GT Team



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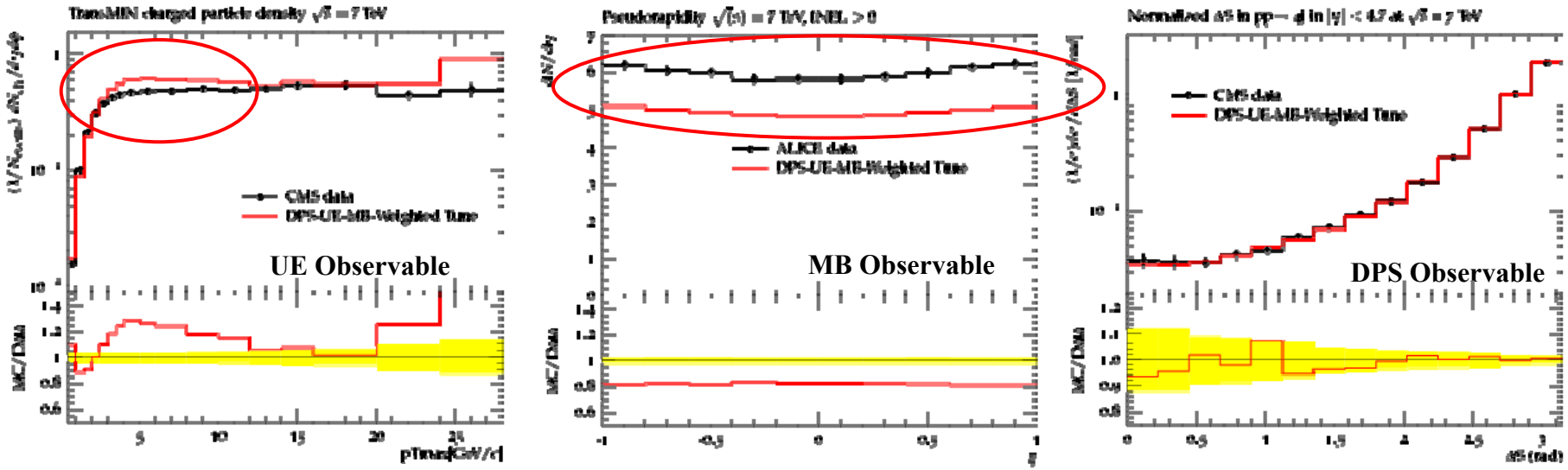
Simultaneous UE-MB-DPS Tune

Paolo Gunnellini and the CMS PC&GT Team



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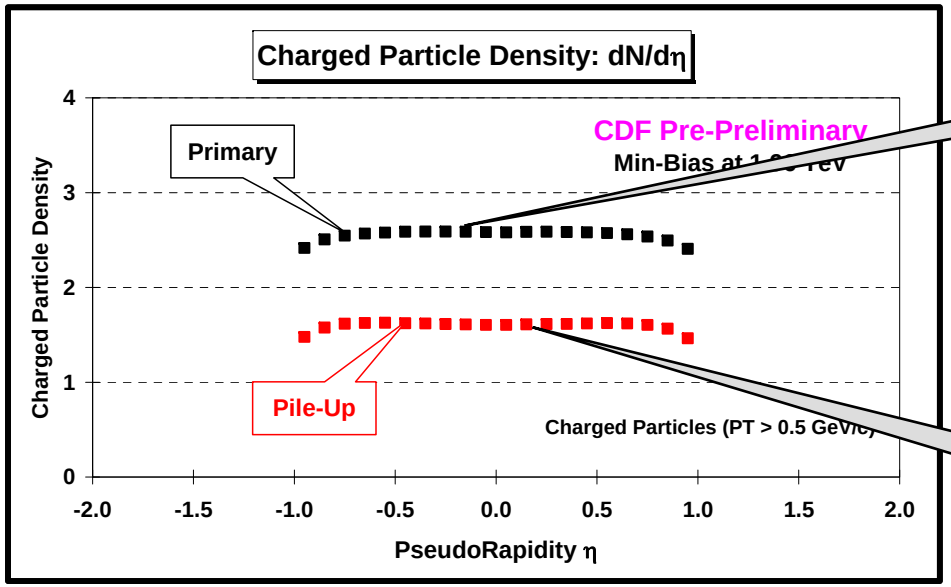
DPS is good, but UE and MB are bad!

Using Pile-Up to Study Min-B

Rick Field C2CR07
February 28, 2007



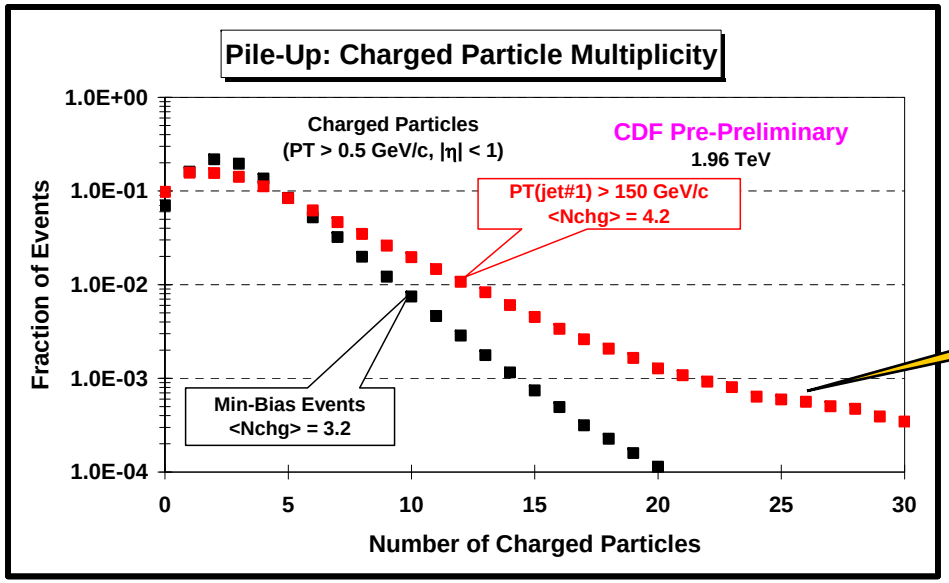
About 2.6 charged particles per unit η at η = 0.

About 1.6 charged particles per unit η at η = 0.

- Shows the the charged particle density, $dN_{chg}/d\eta$, for charged particles ($p_T > 0.5$ GeV/c) pointing to the primary vertex for "Min-Bias" collisions at 1.96 TeV.
- Shows the the charged particle density, $dN_{chg}/d\eta$, for charged particles ($p_T > 0.5$ GeV/c) pointing to the pile-up vertices for "Min-Bias" collisions at 1.96 TeV.
- Clearly the pile-up "min-bias" is biased because there must to be some particles in the central region to form a vertex (*e.g.* elastic scattering does not contribute).

Is the Pile-Up Biased?

Rick Field C2CR07
February 28, 2007



The pile-up is different for Min-bias collisions and high p_T jet production! Amasing!

- **Shows the the charged particle multiplicity distribution for charged particles (p_T > 0.5 GeV/c, |η| <1) pointing to the pile-up vertices for "Min-Bias" collisions at 1.96 TeV.**
- **Shows the the charged particle density, $dN_{chg}/d\eta$, for charged particles (p_T > 0.5 GeV/c, |η| <1) pointing to the pile-up vertices for high p_T jet production (PT(jet#1) > 150 GeV/c) at 1.96 TeV.**

Is the Pile-Up Biased?

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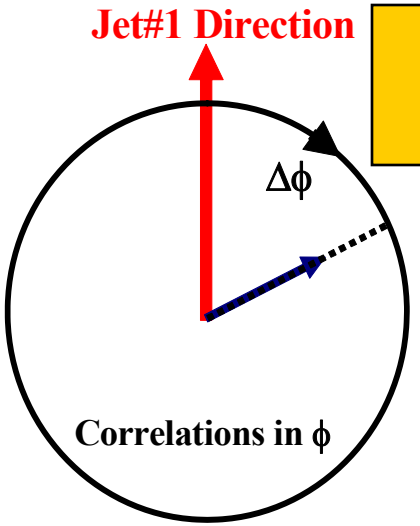
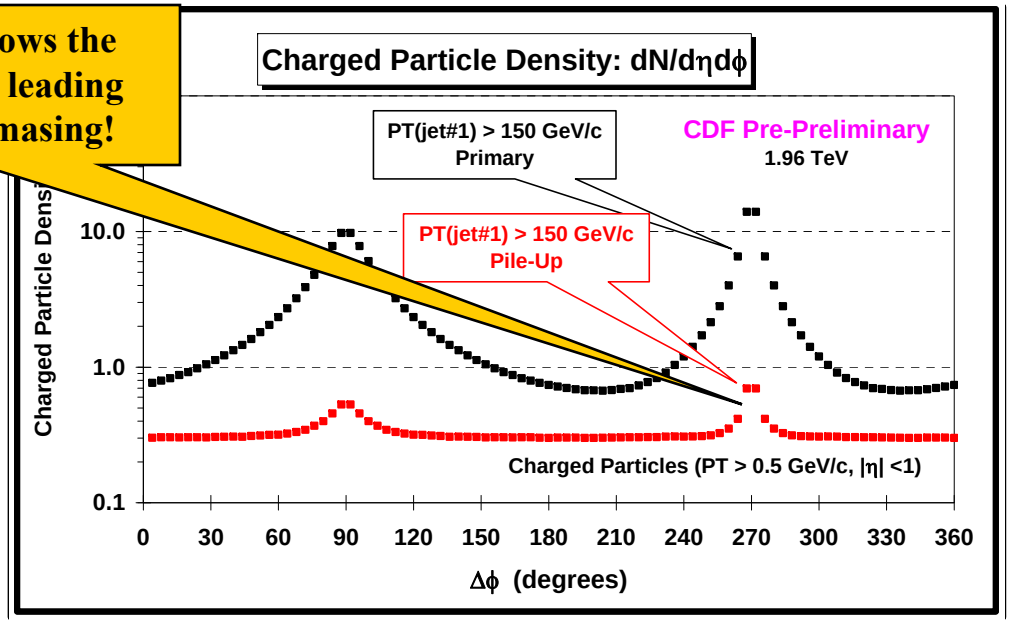
February 28, 2007

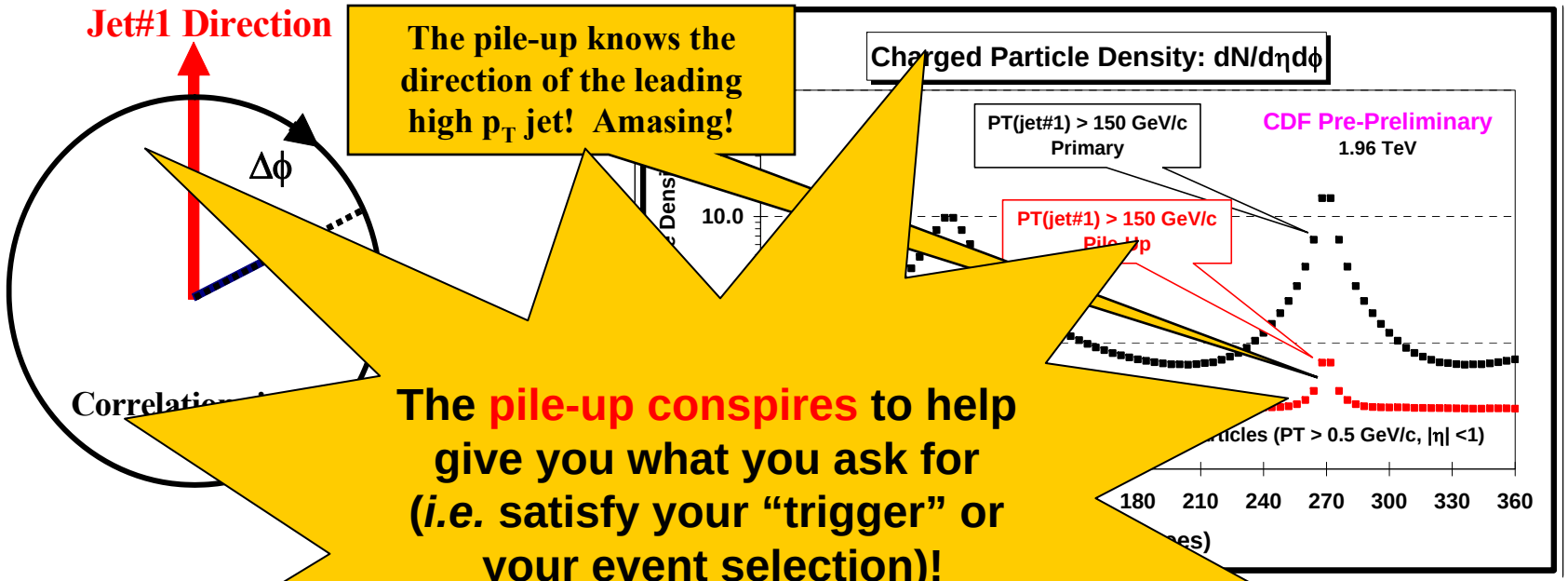


The pile-up knows the direction of the leading high p_T jet! Amasing!



- Shows the data on the Δϕ dependence of the charged particle density, $dN_{chg}/d\eta d\phi$, for charged particles ($p_T > 0.5$ GeV/c, $|\eta| < 1$) pointing to the primary vertex relative to the leading jet (rotated to 270°) for PT(jet#1) > 150 GeV/c $|\eta(\text{jet\#1})| < 2$.
- Shows the data on the Δϕ dependence of the charged particle density, $dN_{chg}/d\eta d\phi$, for charged particles ($p_T > 0.5$ GeV/c, $|\eta| < 1$) pointing to the pile-up vertices relative to the leading jet (rotated to 270°) for PT(jet#1) > 150 GeV/c $|\eta(\text{jet\#1})| < 2$.

Is the Pile-Up Biased?

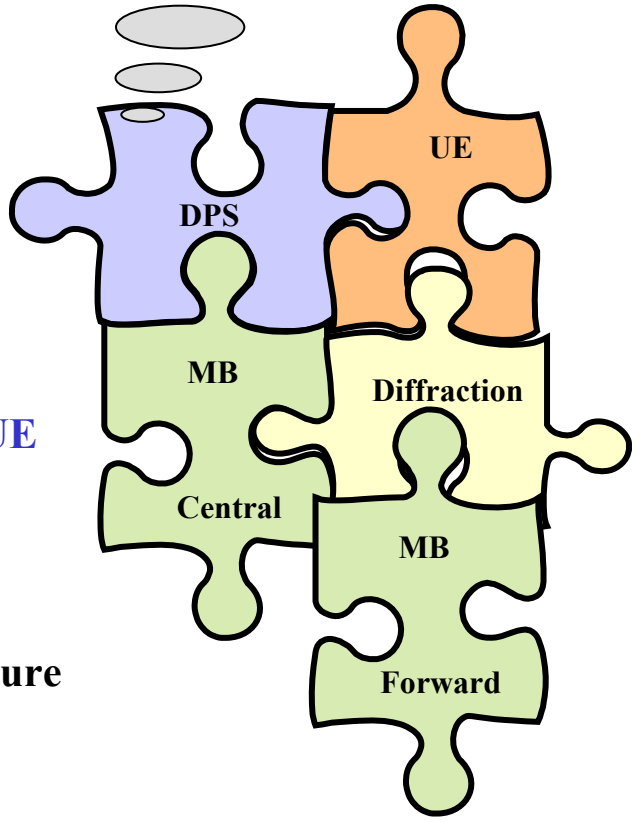


The pile-up knows the direction of the leading high p_T jet! Amasing!

The pile-up conspires to help give you what you ask for (*i.e.* satisfy your "trigger" or your event selection)!

- Shows the da… ensity, $dN_{chg}/d\eta d\phi$, for charged particles (p_T > 0.5… y vertex relative to the leading jet (rotated to 27… > …c |η(j… < 2.
- Shows the data on the Δφ depende… f the cha… particle den…ty, $dN_{chg}/d\eta d\phi$, for charged particles (p_T > 0.5 GeV/c, … < 1) pointi…o the pile-up vertices relative to the leading jet (rotated to 270°) for PT… t#1) > 150 GeV/c |η(jet#1)| < 2.

Summary & Conclusions

- We now have at lot of MB data at several energies and with a variety of trigger and selection criteria. Fantastic!
- 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!
- Tunes that use NPDF2.3LO PDF do a better job in the forward region due to the low-x gluon distribution.
- 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.
- Pile-up is interesting. We need to measure a variety of pile-up observables and compare the QCD Monte-Carlo models. I am sure this is being done.

No model describes all the features of the LHC UE, MB, and DPS data!