Recent Soft QCD Results from the LHC

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on behalf of the ATLAS, CMS, ALICE, and LHCb collaborations

List of Results Discussed in These Slides

ATLAS results

https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CONFNOTES/ATLAS-CONF-2015-038/
https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PUBNOTES/ATL-PHYS-PUB-2015-019/
https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CONFNOTES/ATLAS-CONF-2015-038/
https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CONFNOTES/ATLAS-CONF-2015-058/

CMS results

http://cms-results.web.cern.ch/cms-results/public-results/publications/FSQ-13-006/index.html
http://cms-results.web.cern.ch/cms-results/public-results/publications/GEN-14-001/index.html
http://cms-results.web.cern.ch/cms-results/public-results/publications/FSQ-12-025/index.html
http://cms-results.web.cern.ch/cms-results/public-results/publications/FSQ-15-001/index.html
http://journals.aps.org/prd/abstract/10.1103/PhysRevD.92.112001

LHCb results

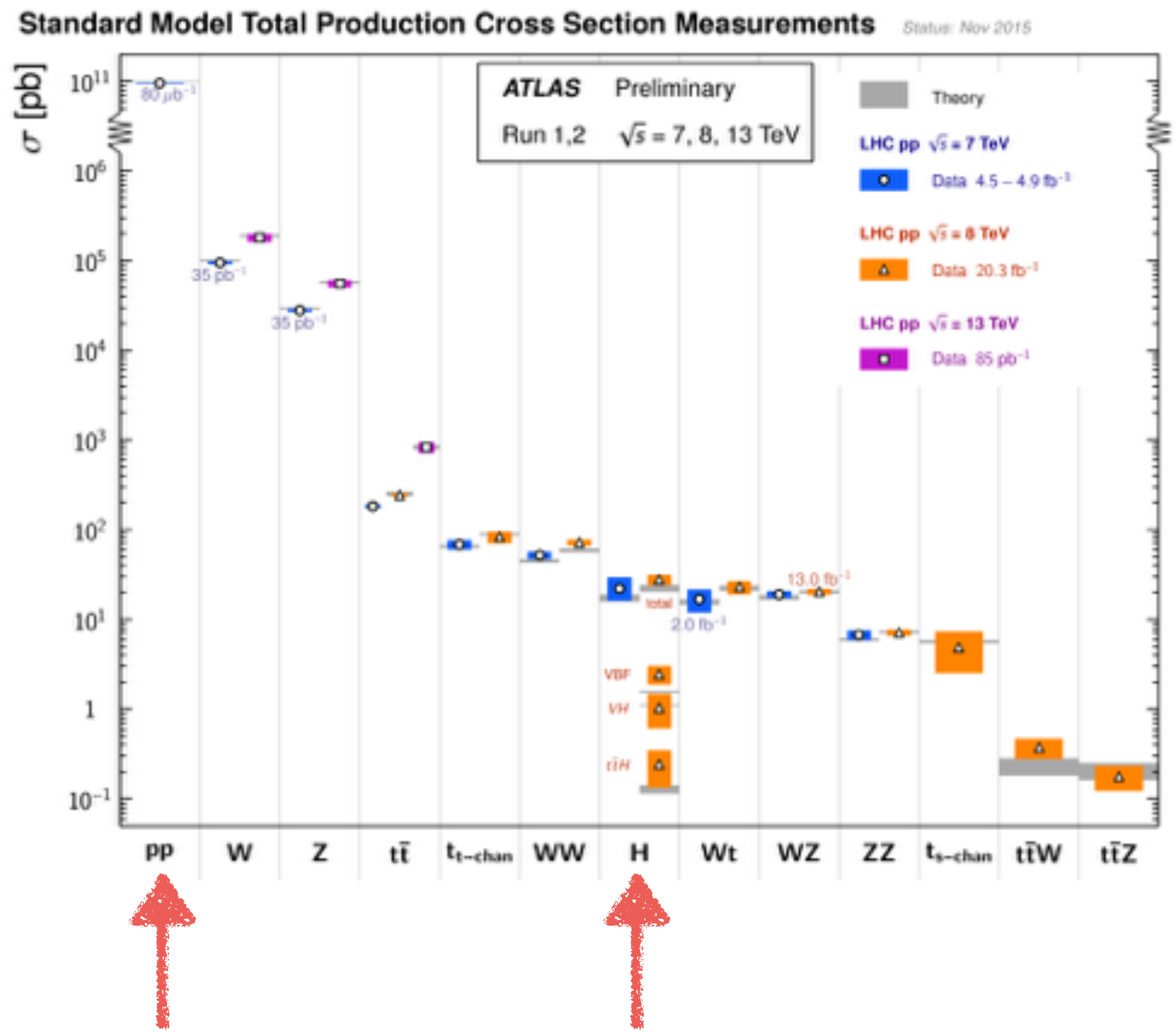
http://lhcbproject.web.cern.ch/lhcbproject/Publications/LHCbProjectPublic/LHCb-PAPER-2015-037.html

ALICE results

1509.08734v1

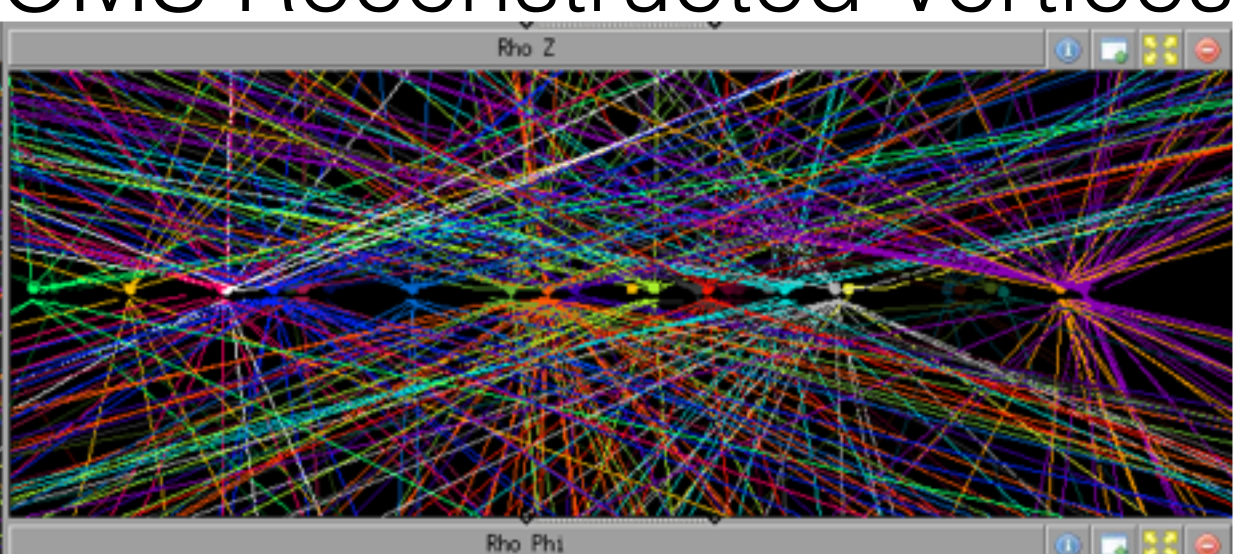
Why Study Soft QCD?

- We care about EWK, Higgs, and SUSY production right?
- pp collisions very rarely produce Higgs (10^{-9}events)
- **Pileup**: Average number of collisions per bunch crossing is 13.6 at 25 ns in 2015
    - Expected to increase to 50 or more over the next 2 yrs
- **Underlying event modeling:** remaining parton constituents from a hard collision



$\sim 10^9$ difference between σ_{pp} and σ_H

CMS Reconstructed Vertices



Why Study Soft QCD?

- We care about EWK, Higgs, and SUSY production right?
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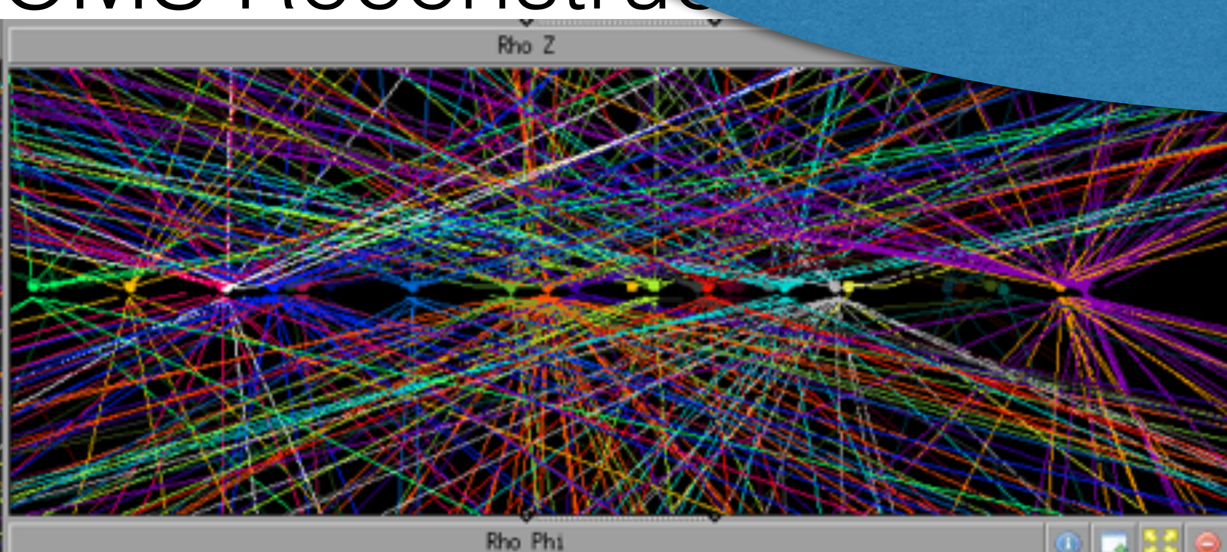
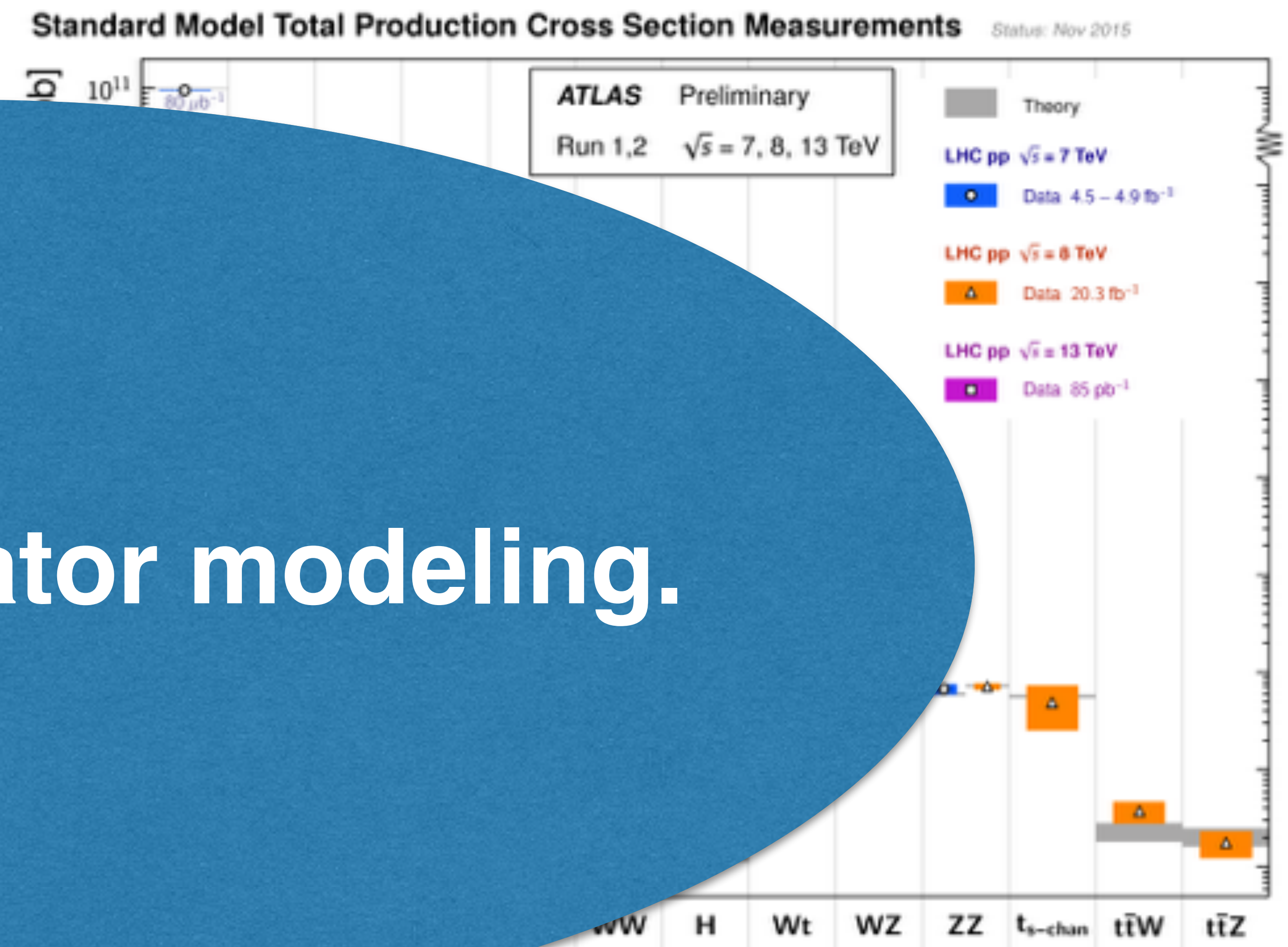
- **Pileup**: A... crossin...
  - Ex... ne...
- **Underly...** constituent...

CMS Reconstru...



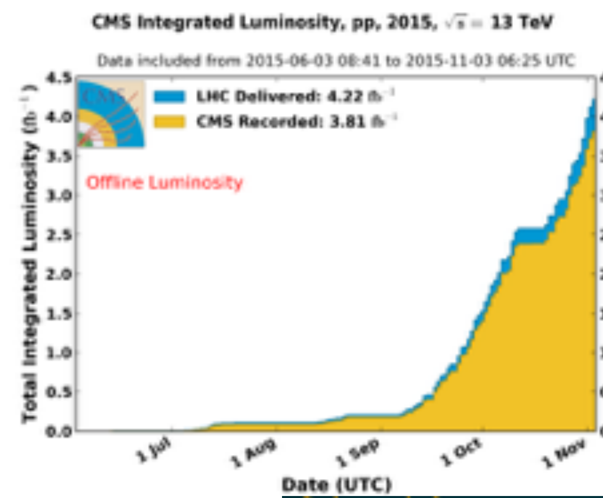
Improve generator modeling.

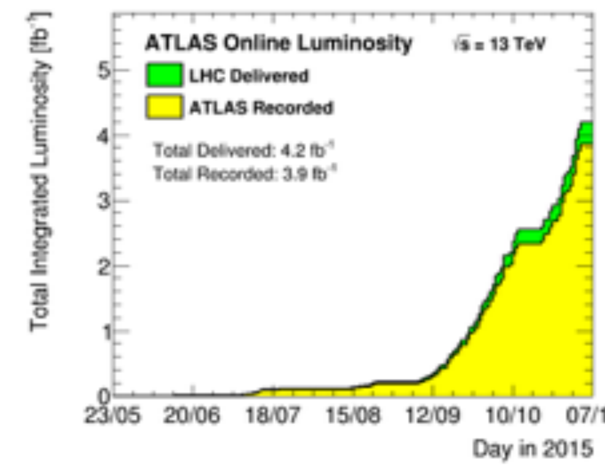


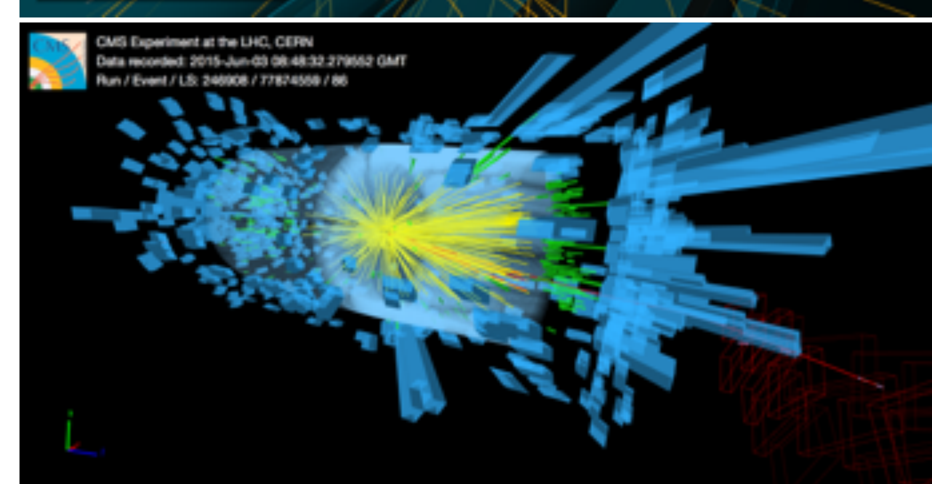
~10^9 difference between σ_{pp} and σ_H

Introduction

- ATLAS, CMS, ALICE & LHCb collected data with high efficiency during 2015 at 13 TeV center of mass energy
- Talk focuses on special low pileup (μ<0.007) runs with up to 170 ub^{-1} and 50ns bunch spacing
- Collected around 4-13 million events depending on the analysis
    - Underlying Event (UE) modeling including multiple parton interactions
    - Minimum Bias (MB) Modeling
- Track reconstruction performance
- Newer results from Heavy Ion runs, and 7 and 8 TeV LHC runs are also shown

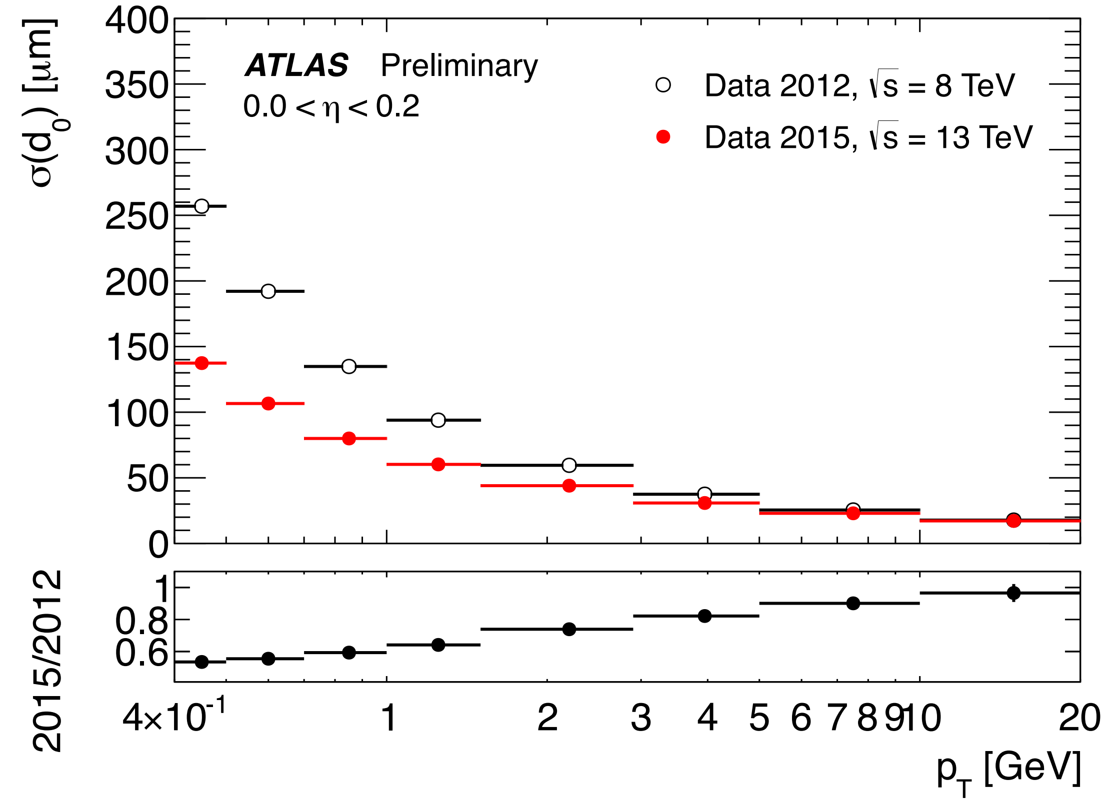


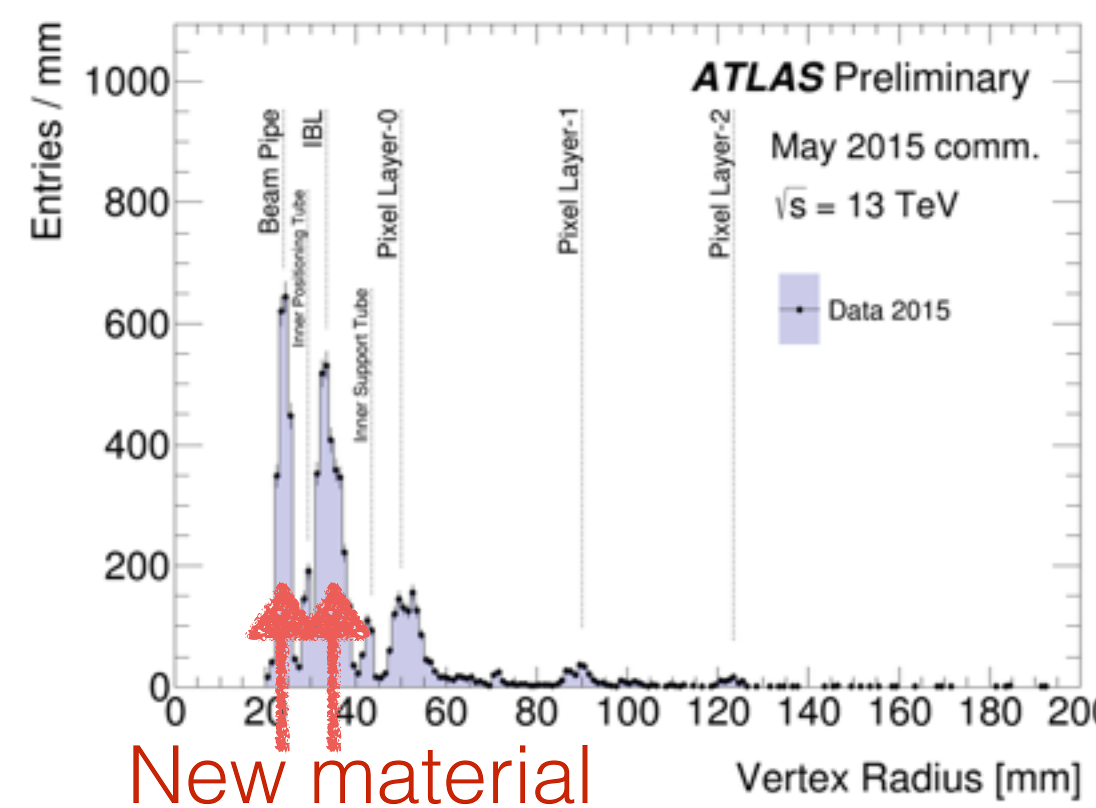




Detector Changes

- First measurements like Min. Bias analyses are important for mapping the detector material distributions
- During the shutdown, ATLAS installed the insertable b-layer along with a new beam pipe
    - Adds an extra tracking layer inside the pixel b-layer
    - Improves the track impact parameter resolution but also adds material
- Material is measured by reconstructing hadronic interaction vertices (also photon conversions)
- CMS added upgrades to their data acquisition system
- CMS had zero magnetic field for the 2015 min bias data, so they could only measure the dN/dη initially with no p_T selection
    - Detailed plan for cleaning and repairing the cryo system is scheduled for early 2016





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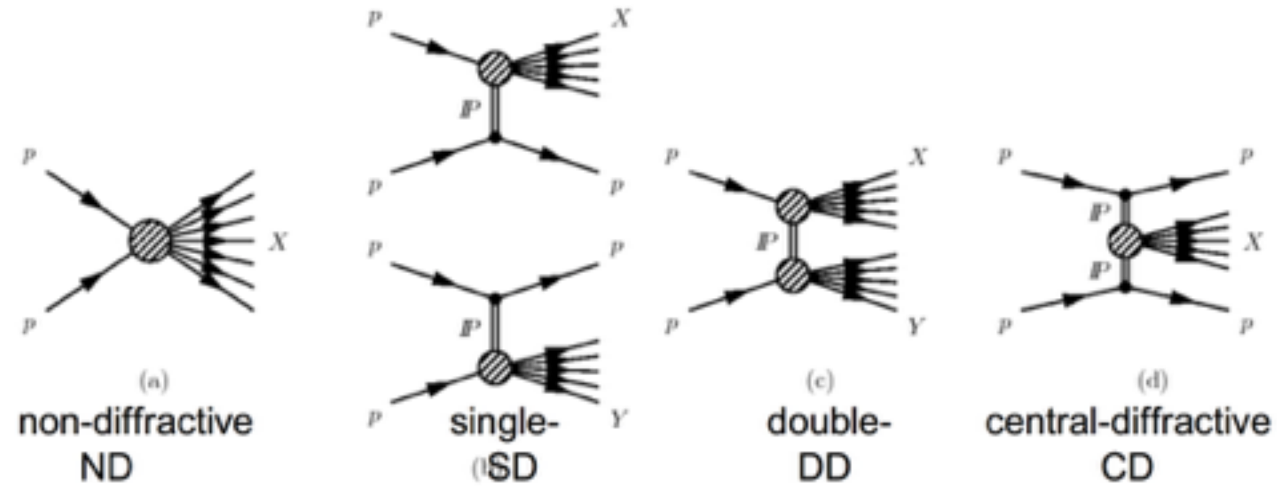
Minimum Bias Collisions

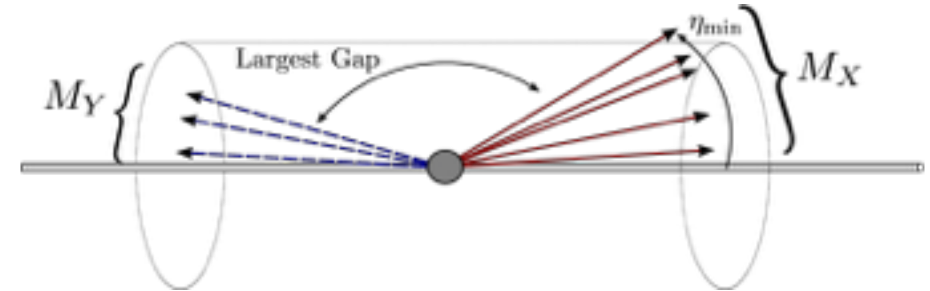


$$\sigma_{inel} = \sigma_{ND} + \sigma_{SD} + \sigma_{DD} + \sigma_{CD}$$

- Total pp collision cross-section is an important property for colliders, but it cannot be calculated from first principles
- Elastic collisions are around 20% of the total pp collisions at 13 TeV LHC collisions
- Inelastic pp collisions consist of 4 processes:
  - **Non-diffractive:** t-channel gluon dominated & has the largest cross-section
  - **Diffractive:** color singlet dominated
    - *single (SD)*: one initial hadron remain intact
    - *double (DD)*: both initial hadrons dissociate
    - central *(CD)*: both initial hadrons remain intact (negligible)

ATLAS Total Inelastic Cross-section

$$\sigma_{\text{inel}}(\tilde{\xi} > 10^{-6}) = \frac{N - N_{\text{BG}}}{\epsilon_{\text{trig}} \times L} \times \frac{1 - f_{\tilde{\xi}<10^{-6}}}{\epsilon_{\text{sel}}},$$



- Total pp inelastic XS is measured with 63ub^{-1} of 13 TeV ATLAS data
- Require M_X>13 GeV
- Corrections are made for:
  - Non-collision beam bkg
  - Trigger Efficiencies
  - Selection Efficiencies
- Observed XS agrees with the phenomenological predictions

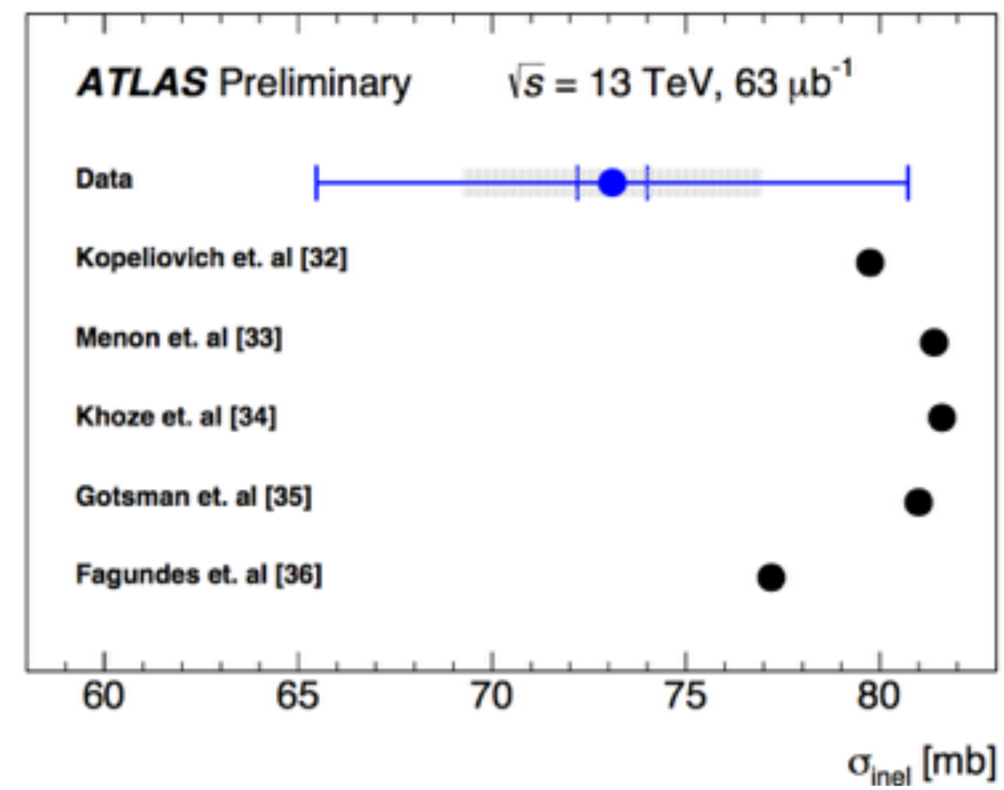
Factor	Value	Rel. unc.
Number of selected events (N)	4159074	–
Number of background events (N_{BG})	43512	±100 %
Luminosity [μb^{-1}] (L)	62.9	±9 %
Trigger efficiency (ϵ_{trig})	99.7%	±0.1 %
MC Correction factor ($(1 - f_{\tilde{\xi}<10^{-6}})/\epsilon_{\text{sel}}$)	0.993	±0.5 %

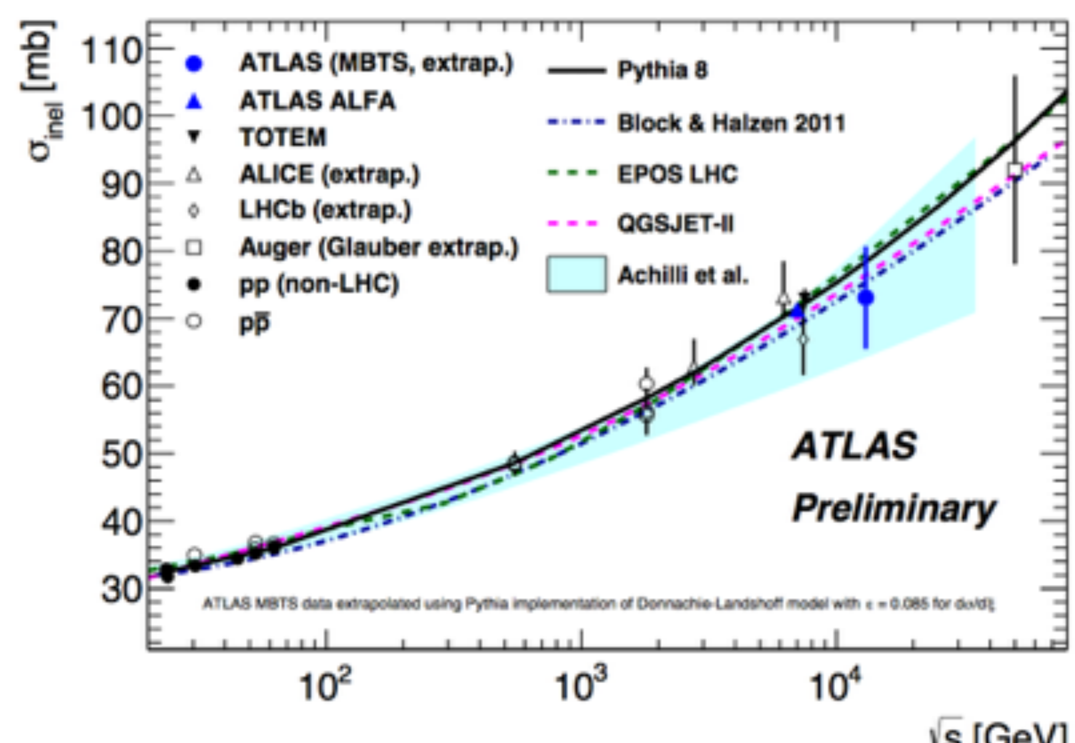
- σ_{inel}=73.1±0.9(exp)±6.6(lumi) ±3.8(extra.)mb
- Measured the ratio of events with trigger hits on both sides of detector to those with only 1 side
  - Constrained the sum of SD and DD to be between 25-32% of σ_{inel} for Pythia

ATLAS-CONF-2015-038

Total Inelastic Cross-section

- Measured cross-section agrees with the theoretical prediction
  - Uncertainty is dominated by the luminosity
- Cross-section over different center-of-mass energy collisions with the LHC and Auger measurements
  - CMS measured σ_{inel} at 7 TeV by counting calorimeter deposits and interaction vertices
  - LHCb measured σ_{inel} at 7 TeV based upon charged tracks
  - Will be interesting when ALFA, which very precisely measured the XS at 7 TeV, is done at 13 TeV. Used optical theorem and elastic XS measurements from Roman pot detectors





Pierre Auger experiment measured p-air XS at sqrt(s)=57 TeV and extrapolated to pp-collisions using the Glauber model

ATLAS-CONF-2015-038

ATLAS Track Efficiency for Unfolding Charged Particle Distributions

$$\varepsilon_{\mathrm{trk}}(p_{\mathrm{T}}, \eta) = \frac{N_{\mathrm{rec}}^{\mathrm{matched}}(p_{\mathrm{T}}, \eta)}{N_{\mathrm{gen}}(p_{\mathrm{T}}, \eta)},$$

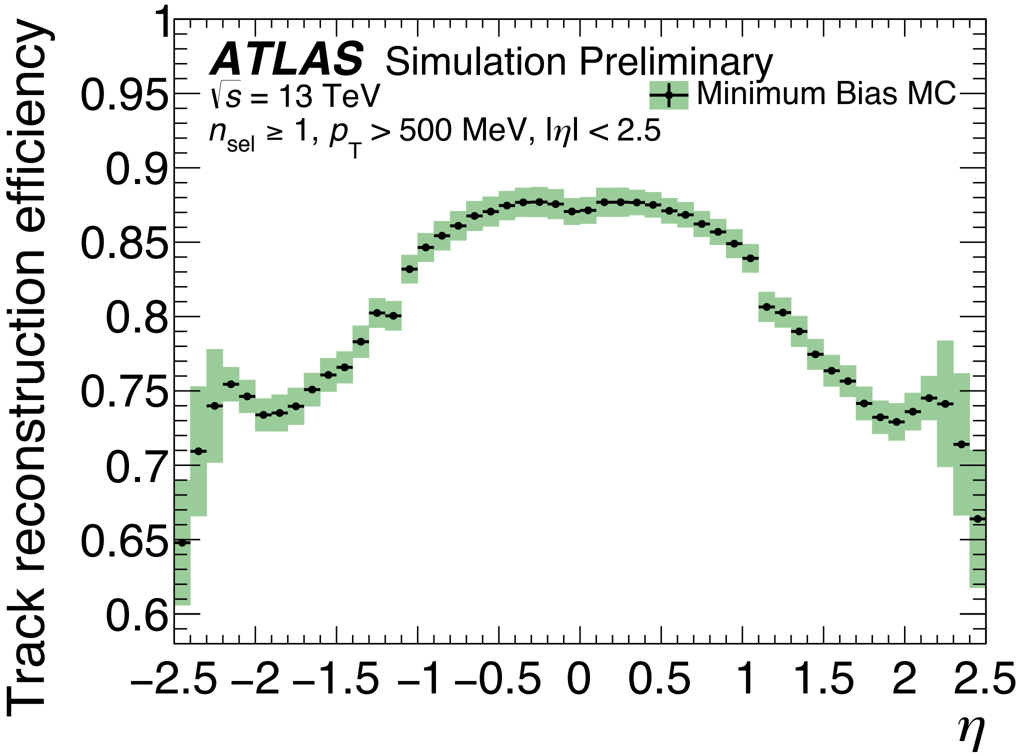
- Track efficiency is parameterized as a function of track p_T and η
- Tracks are matched if the weighted fraction of hits exceeds 50%

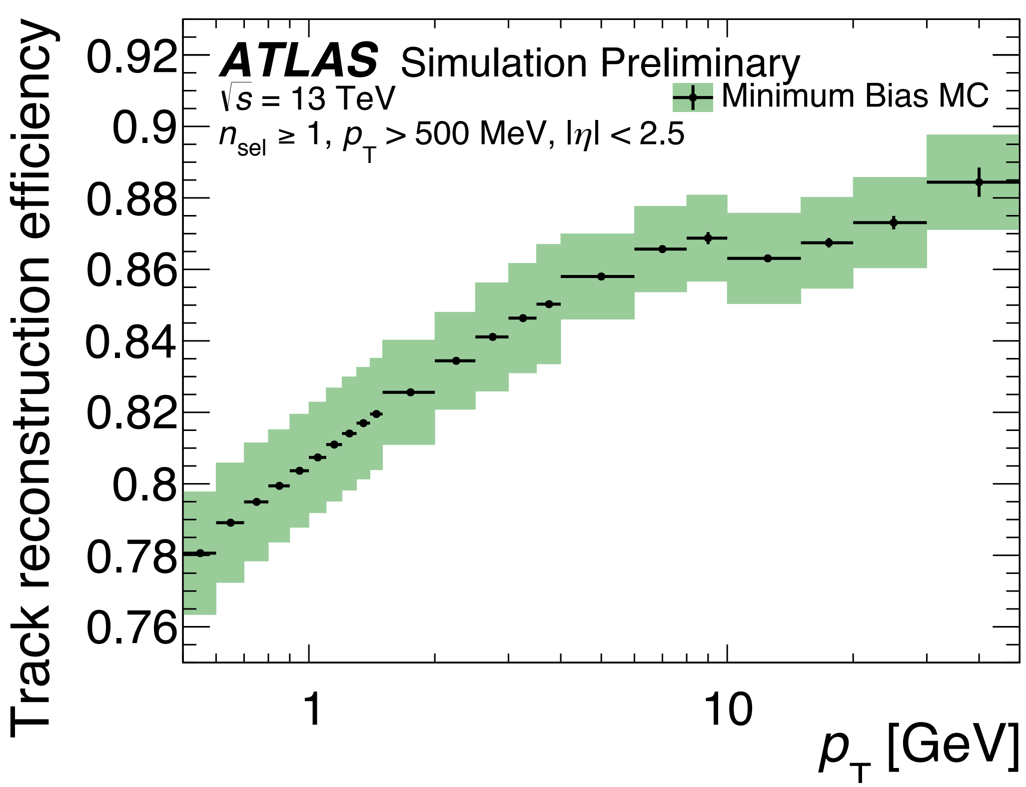
$$w_{\mathrm{trk}}(p_{\mathrm{T}}, \eta) = \frac{1}{\varepsilon_{\mathrm{trk}}(p_{\mathrm{T}}, \eta)} \cdot (1 - f_{\mathrm{sec}}(p_{\mathrm{T}}, \eta) - f_{\mathrm{sb}}(p_{\mathrm{T}}) - f_{\mathrm{okr}}(p_{\mathrm{T}}, \eta)),$$

- Events are reweighed to correct for
  - $\boldsymbol{\varepsilon}_{\mathbf{trk}}$: the trigger & vertex efficiency
  - $\mathbf{f}_{\mathbf{sec}}$: secondary interaction charged particles
  - $\mathbf{f}_{\mathbf{sb}}$: long lived strange baryon particles
  - $\mathbf{f}_{\mathbf{okr}}$: fraction of truth particles following outside the detector acceptance. Estimated from simulation

ATLAS-CONF-2015-028

Track Efficiency

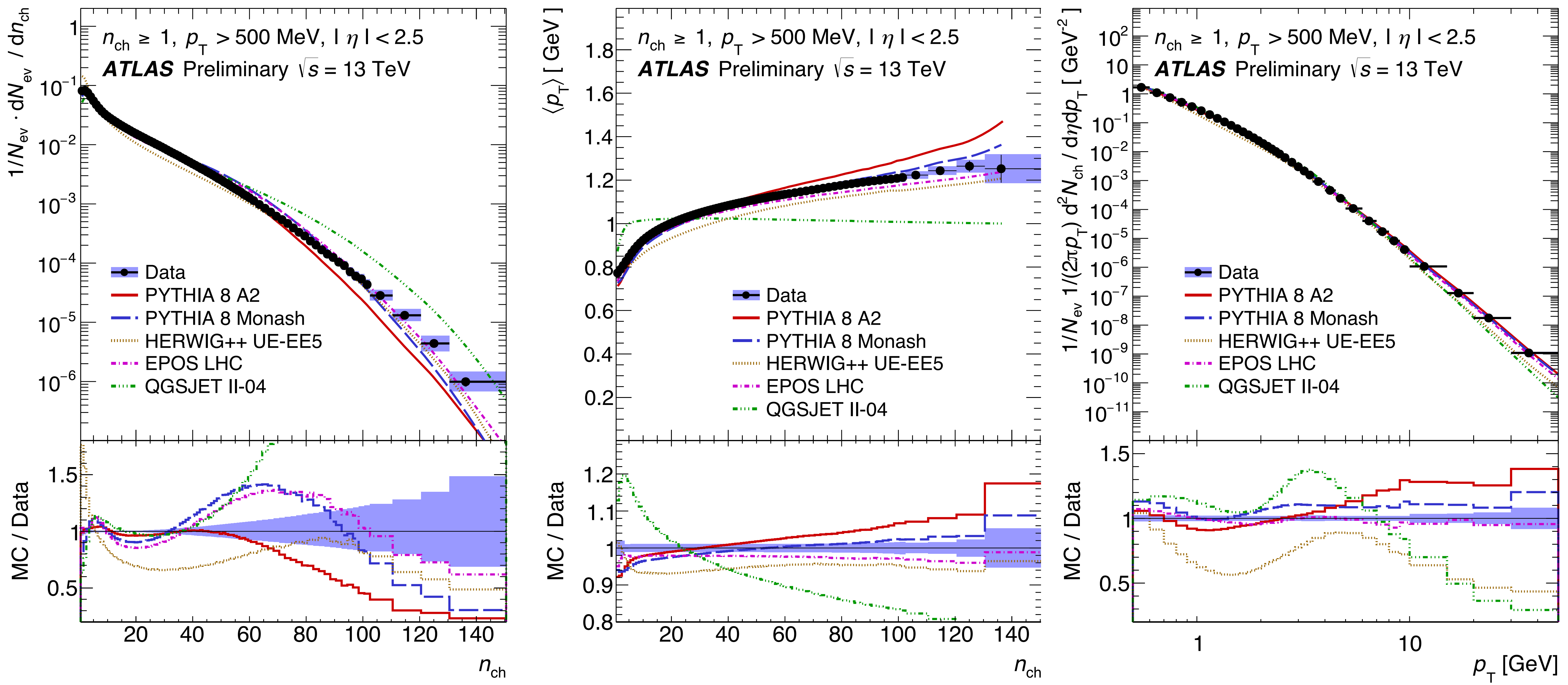




- **Dominant uncertainties come from material modeling**
- **Amount of material is estimated with the following procedures:**
  - Secondary vertices from photon conversions
  - Vertex mass and radii of hadronic interactions
  - A comparison between data and simulation of the efficiency to extend a track reconstructed in the pixel detector into the SCT
- Run-1 constrained the material to within 5%. New IBL and beam pipe material uncertainties are larger especially in the forward region

ATLAS-CONF-2015-028

Min Bias Distributions

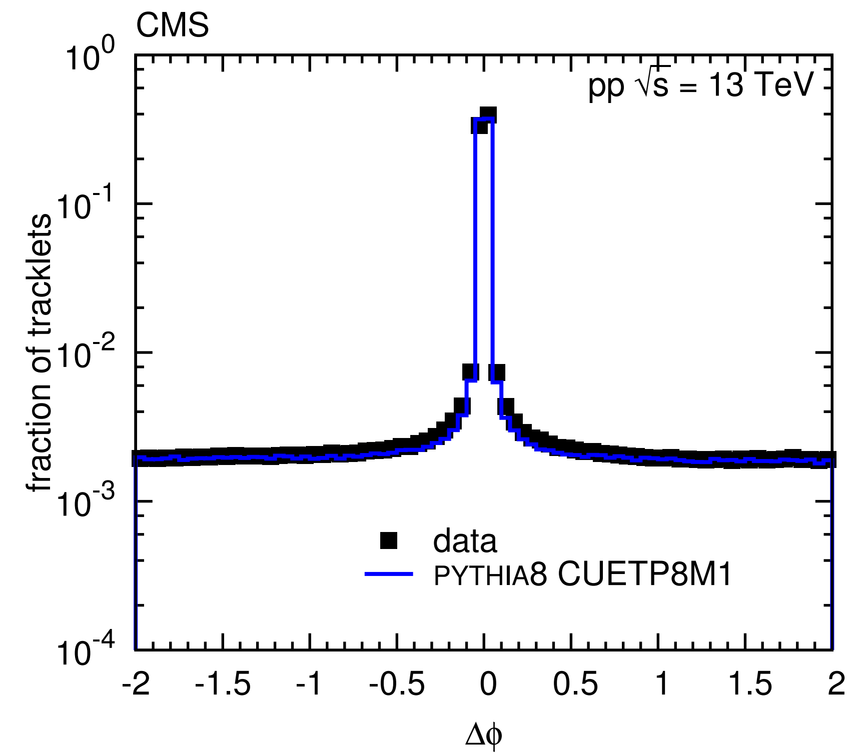


- EPOS predicts the pT distribution of charged particles well
- Pythia A2 tune is the default on ATLAS and performs reasonably well on the distributions

ATLAS-CONF-2015-028

CMS 13 TeV Min. Bias

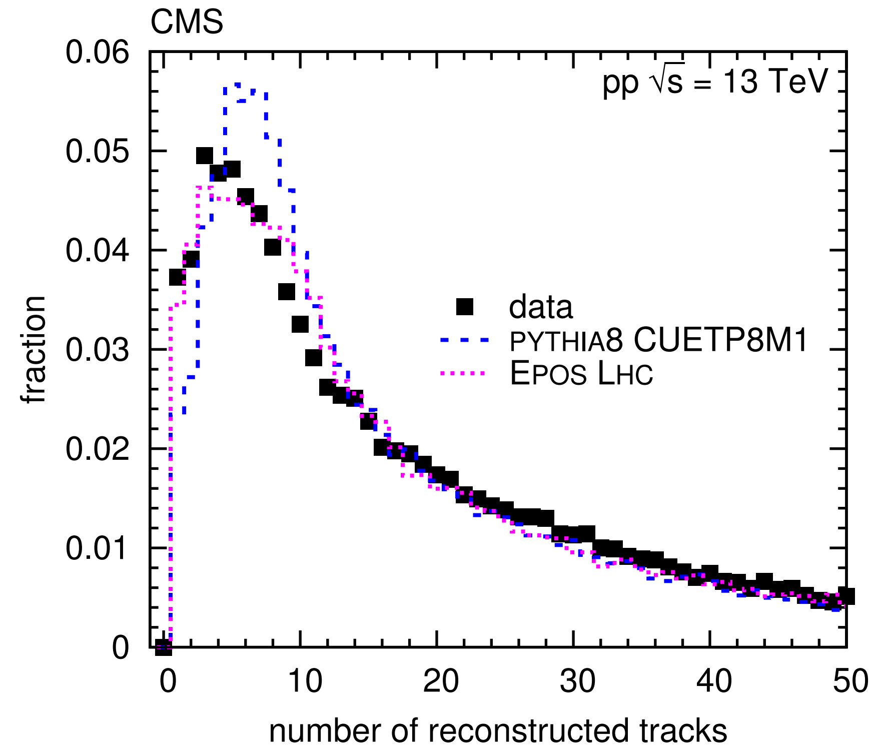
- Trigger by requiring beam in both Beam Pickup Timing Devices (BPTX)
    - Zero magnetic field on the 11.5 million events collected.
- Offline at least 1 vertex from tracklet or track vertex reconstruction is required
    - These requirements keep the non-collision beam bkg and cavern bkg below $5x10^{-5}$
    - Tracks with $|\eta|<2.0$ & $p_T>0.05$ GeV
    - Low pileup results in ~1.5% of triggered events with a vertex
- Vertex reconstruction eff. was compared between EPOS and Pythia. Differences are assigned as a 2% systematic uncertainty
- Measure $dN/d\eta$ for particles with $c\tau>1$cm

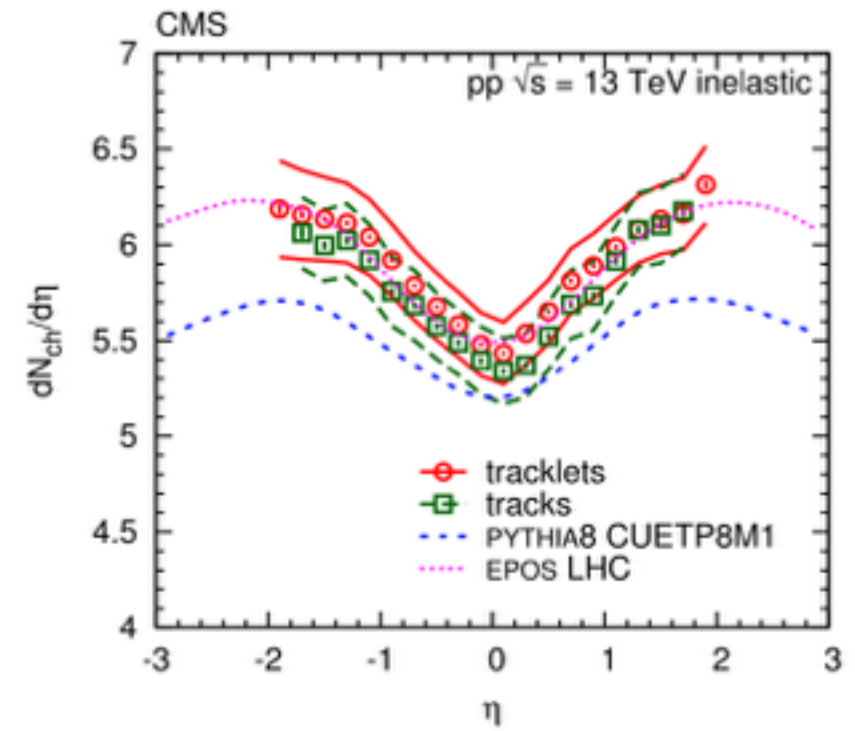


Tracklet: reconstruction finds hit pairs with $|\Delta\phi|<1$ & $\Delta\eta<0.1$ and then subtracts combinatorial background using a data control sample of $1<|\Delta\phi|<2$
Track: reconstruction minimizes background by requiring 3 collinear hits in the detector

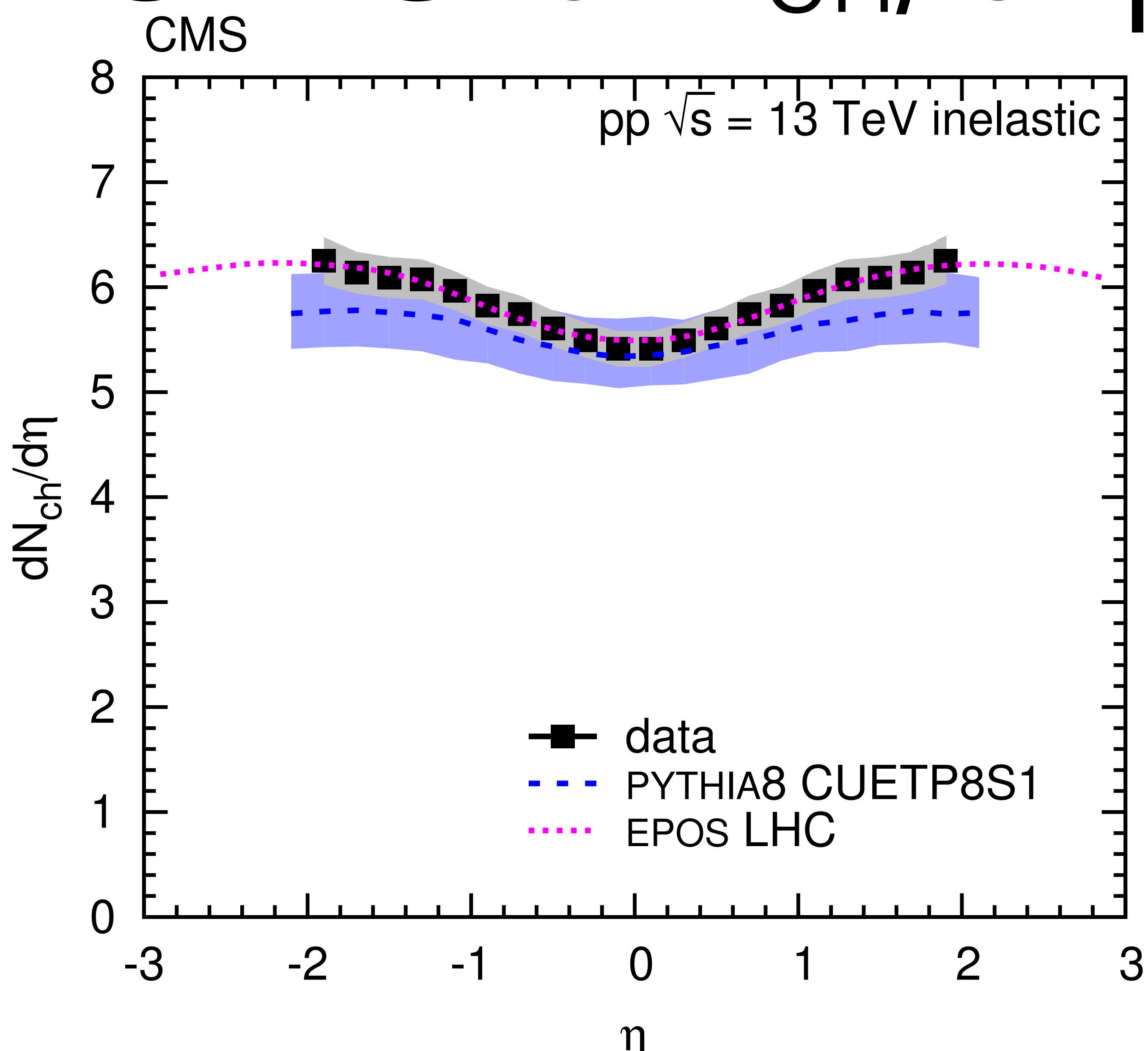
CMS Charge Particle Multiplicities

- Data and simulation agree for larger track multiplicities
- Number of charged particles is unfolded versus η taking into account the following systematic uncertainties:
  - 3% on unseen tracks
  - **Tracklet method** has 1-3% from pixel noise and 2-3% from modeling of tracklet to hadron correction
  - **Track method** missed particles from the 3 hit requirement is 1.8% & 2-3% comparison of corrections between the 2 generators
- Both have similar 3-4% uncertainties and they agree within 2% in the central region and 3% in the forward region





CMS $dN_{ch}/d\eta$

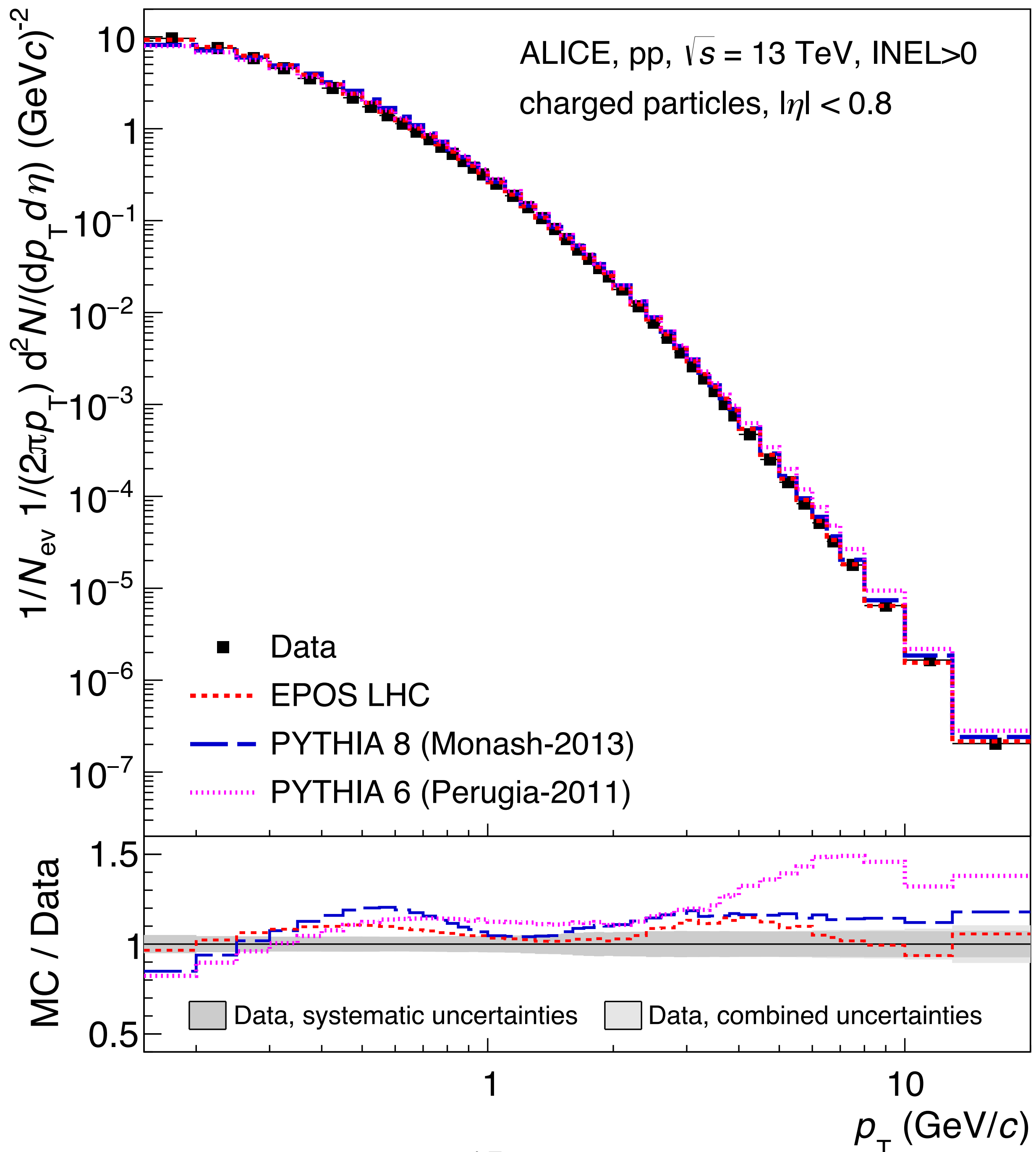


- Central values of the Track & Tracklet methods are averaged and the systematic uncertainties, which are mostly correlated, are averaged as well
- The η dependence of $dN_{ch}/d\eta$ agrees within the uncertainties on the tuning parameter settings for Pythia8 but EPOS agrees better

FSQ-15-001

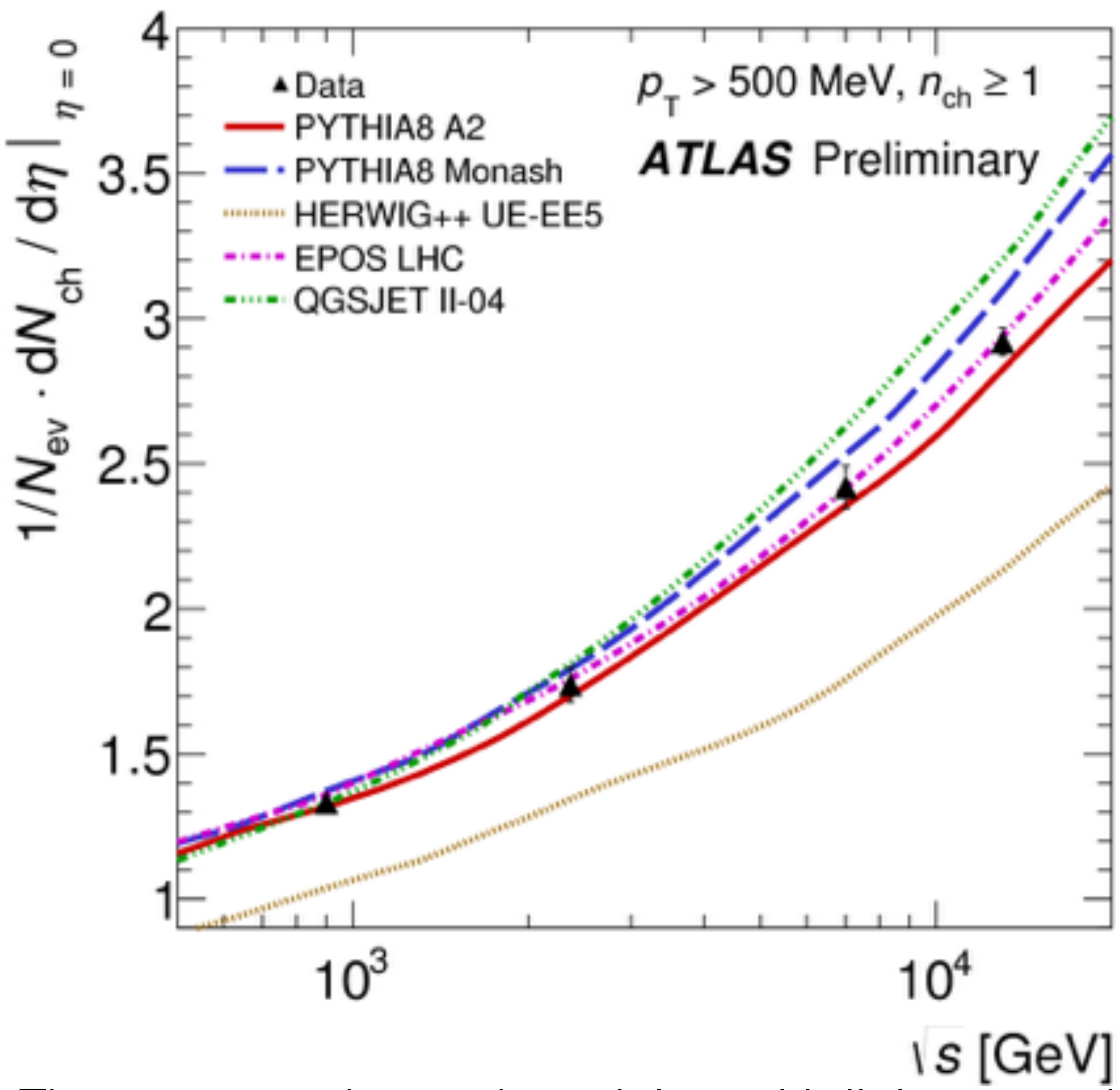
ALICE 13 TeV Min Bias Results

- Selected Tracks:
    - |η|<0.8
    - $0.15<p_T<20$ GeV
- Unfolded the charged particle pT spectrum
    - EPOS models the track pT distribution a little better than the Pythia8 Monash and Pythia6 Perugia generators



arXiv:1509.08734v1

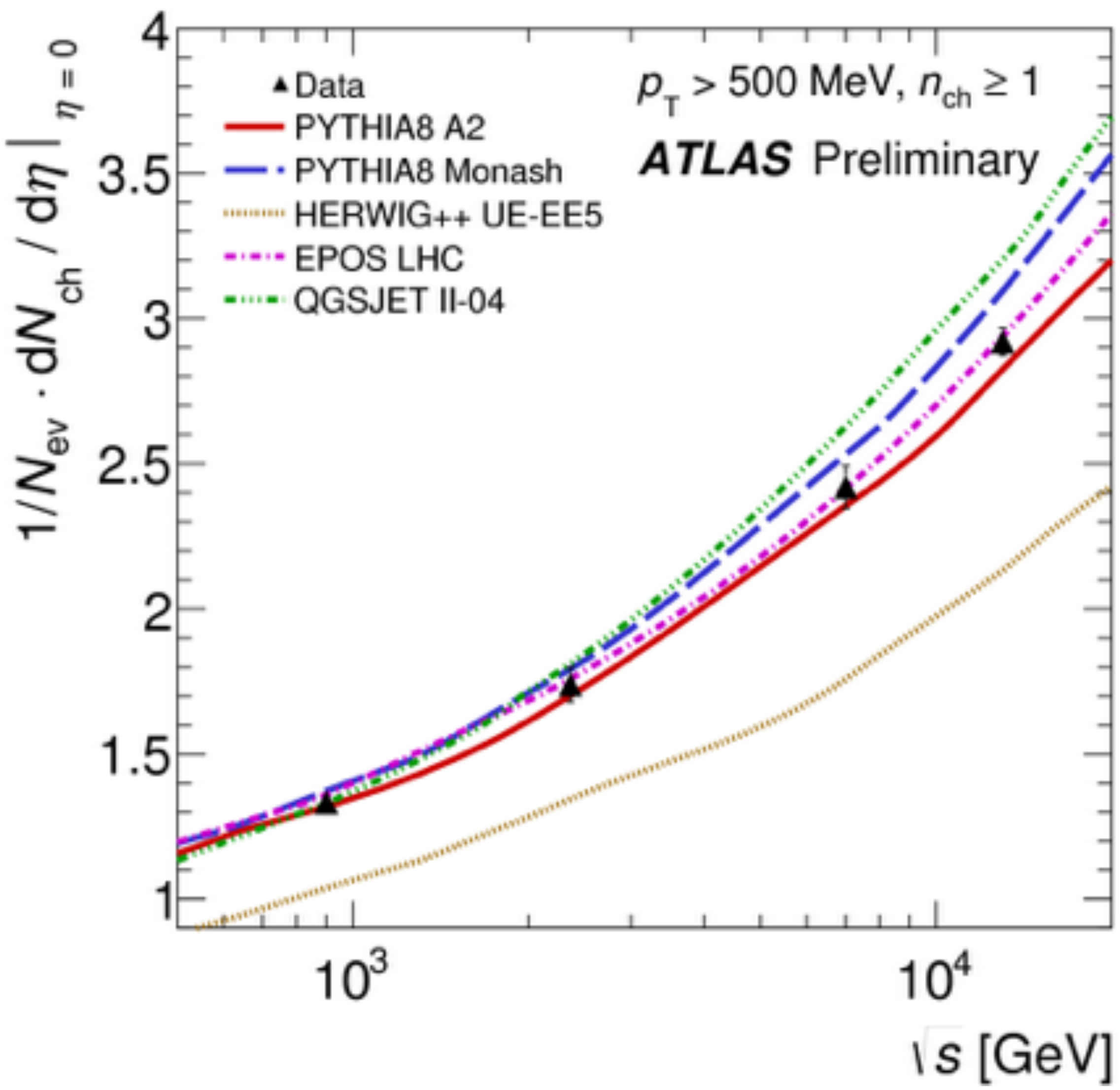
Charged Particle Multiplicity

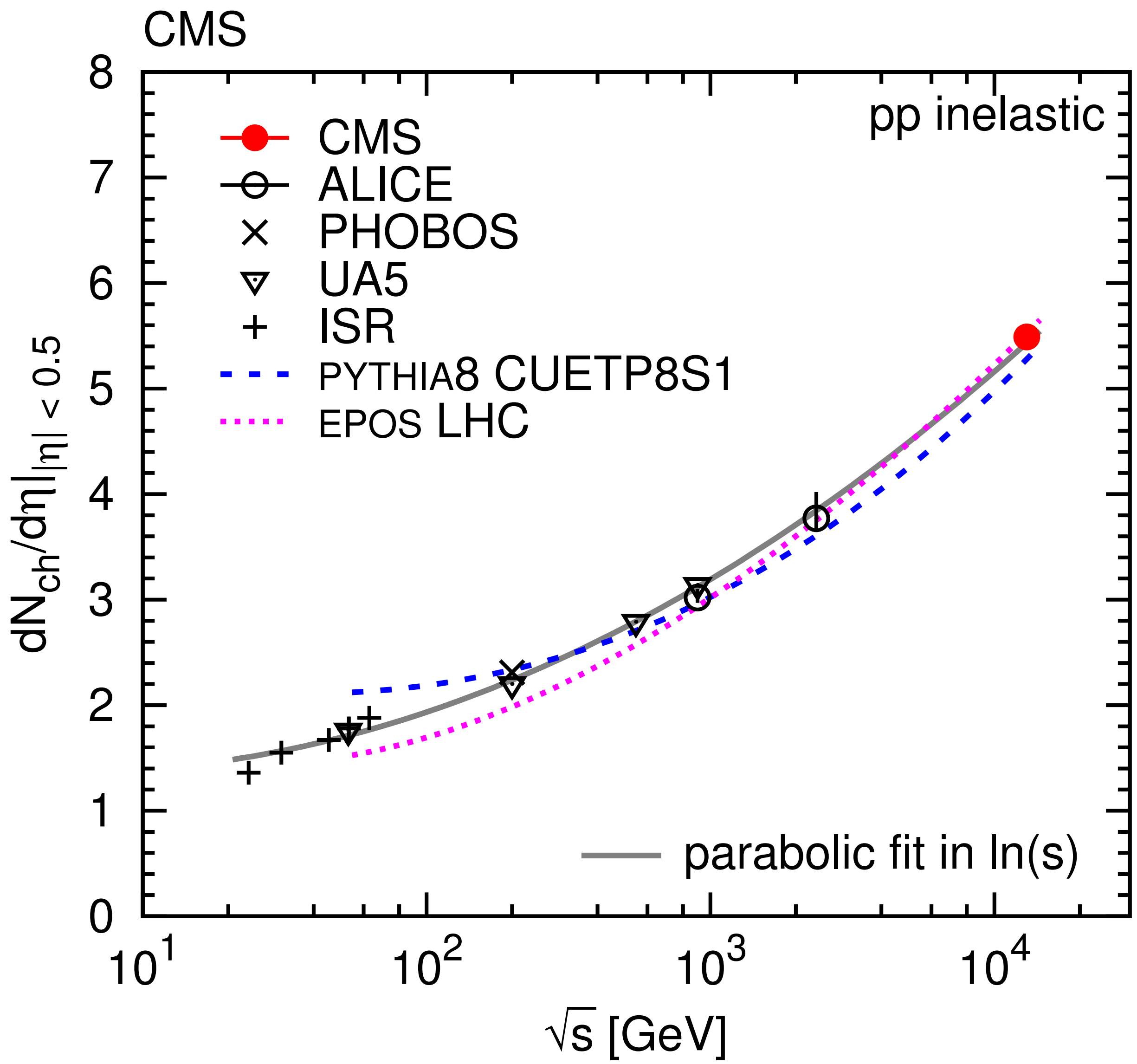


- The average charged-particle multiplicity per unit of rapidity for η = 0 as a function of the centre-of-mass energy.
  - The definition of charged-particle includes charged strange baryons.
  - The data are compared to various particle level MC predictions.
  - The vertical error bars on the data represent the total uncertainty.

ATLAS-CONF-2015-028

Charged Particle Multiplicity

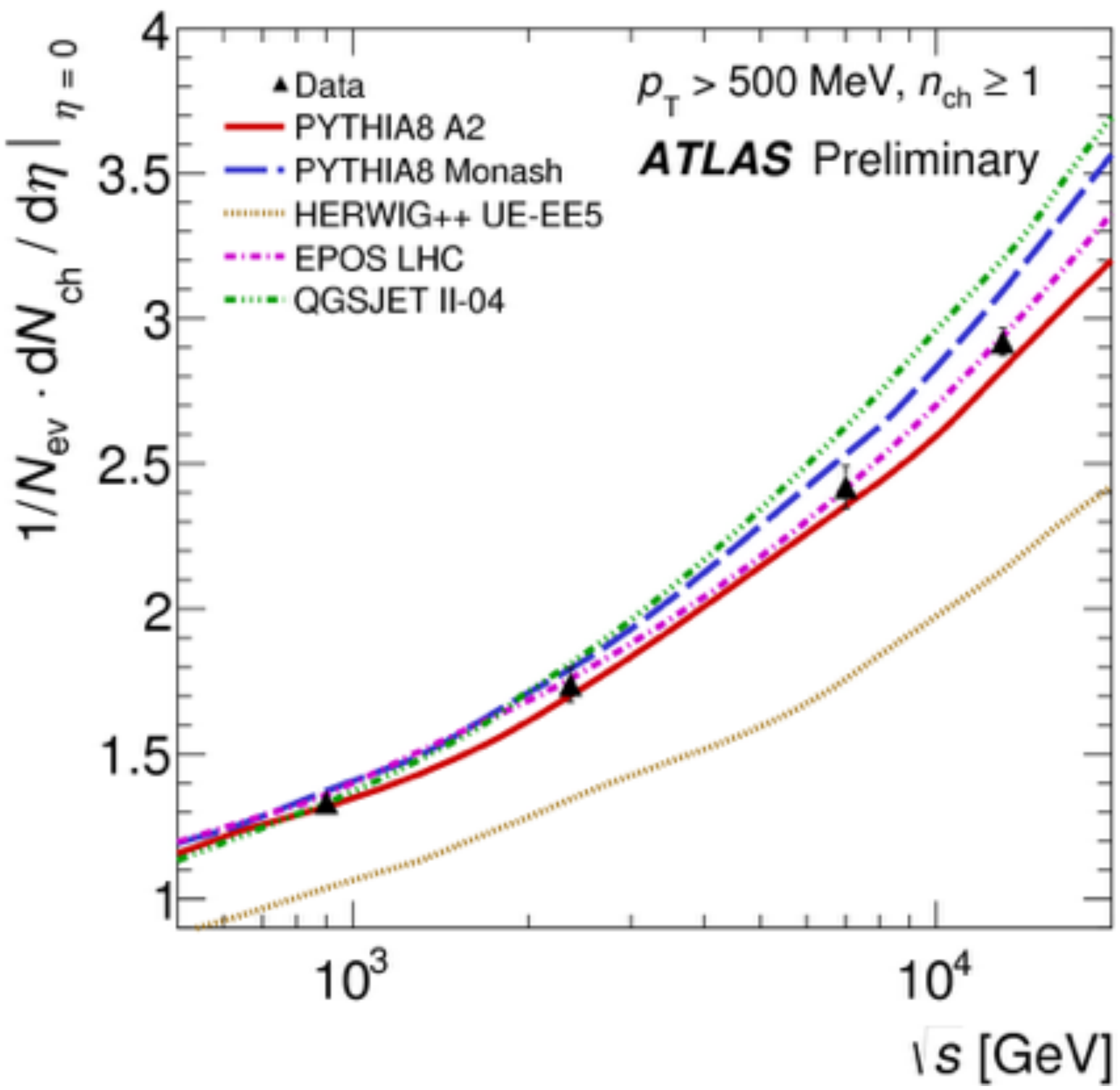


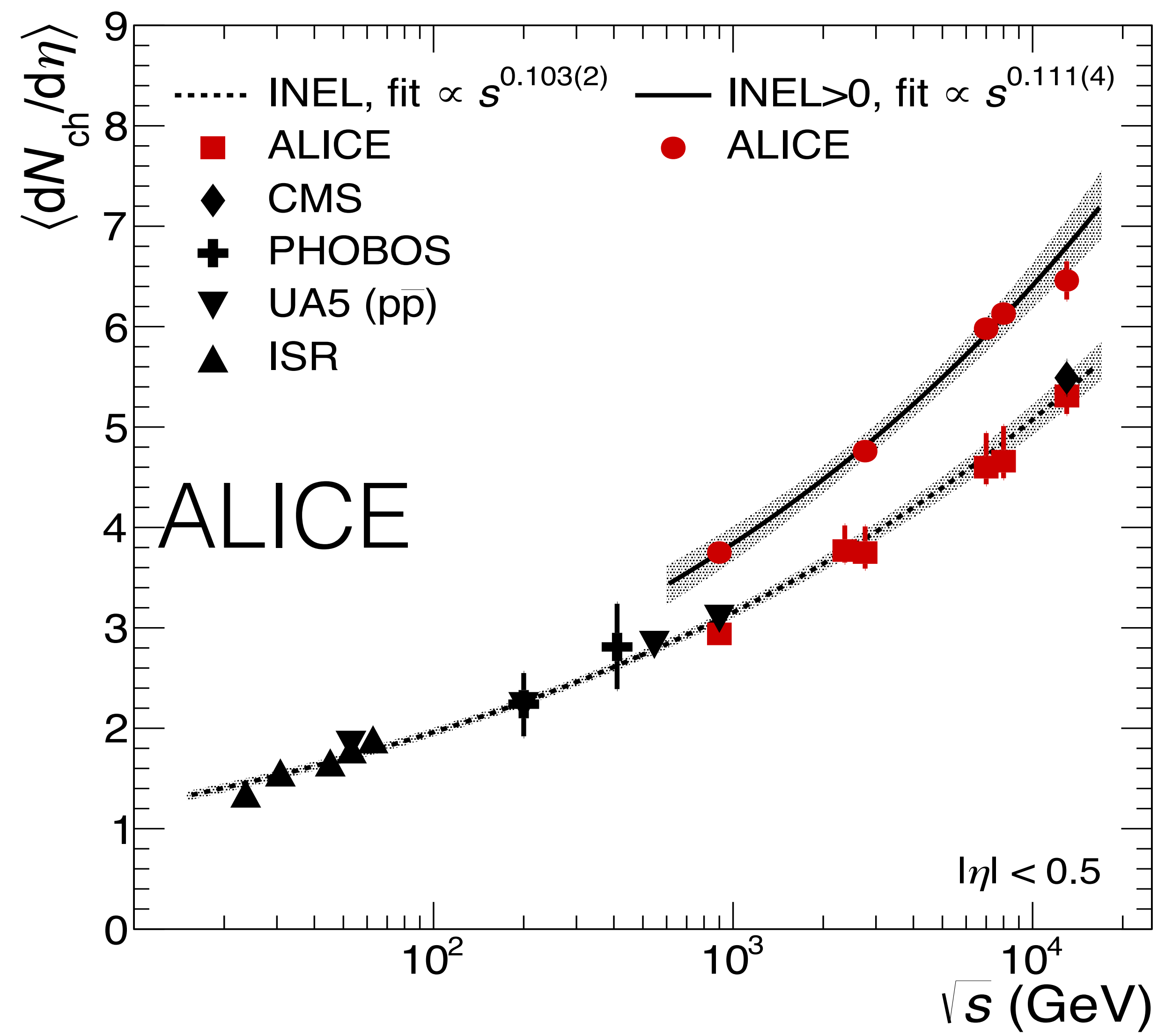


- CMS selects all inelastic collisions with a charged particle having |η| <0.5 & no charged particle p_T selection
  - Results in a larger yield than observed for ATLAS

ATLAS-CONF-2015-028 & FSQ-15-001

Charged Particle Multiplicity

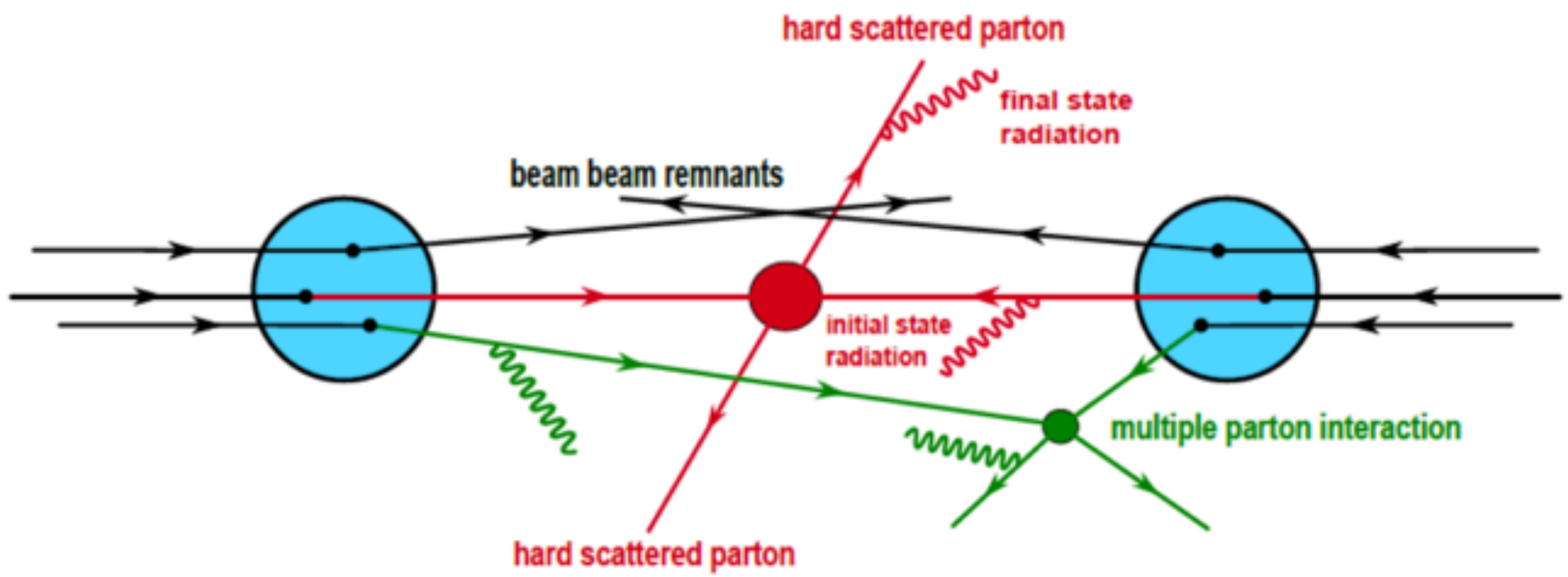




- ALICE selects two subsets
  - **INEL**: All inelastic events
  - **INEL>0**: Events with a charged particle having |η|<0.5 (matches CMS)

ATLAS-CONF-2015-028 & arXiv:1509.08734v1

Underlying Event



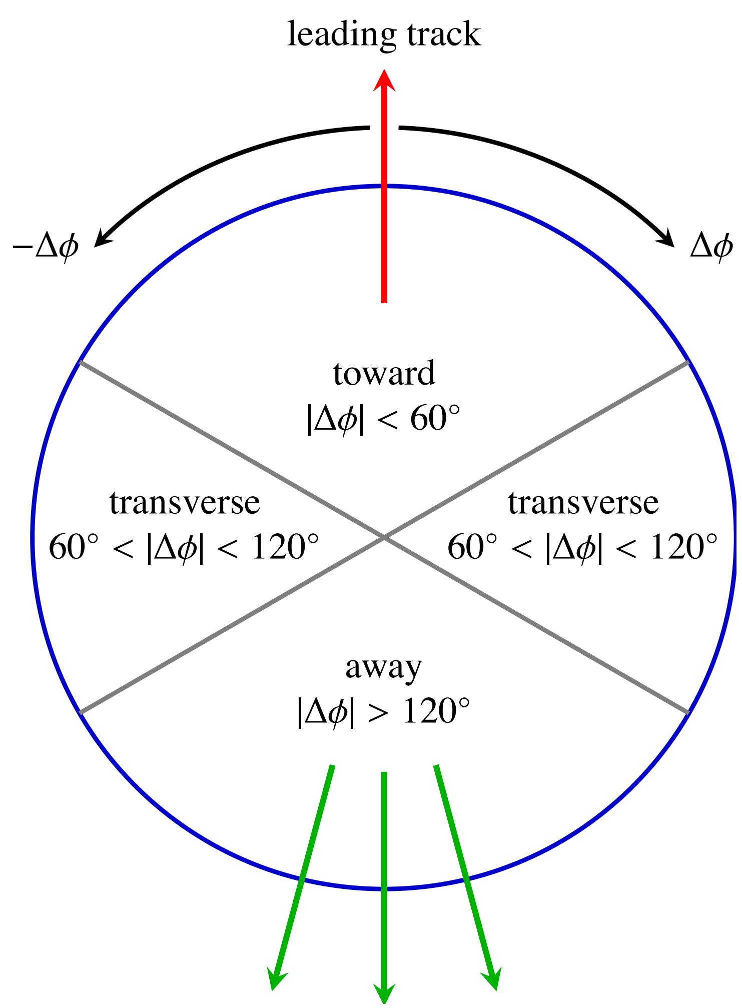
- Modeling of charged particle characteristics in the Underlying Event (UE) are assessed on ATLAS and CMS including the following physics interactions:
    - **Multiple parton interactions (MPI)**: additional scatterings from the same proton pair
    - **Beam remnant**: remaining partons from the hard scatter
    - Initial and final state gluon radiation

FSQ-15-007 & ATL-PHYS-PUB-2015-019

Modeling Underlying Event

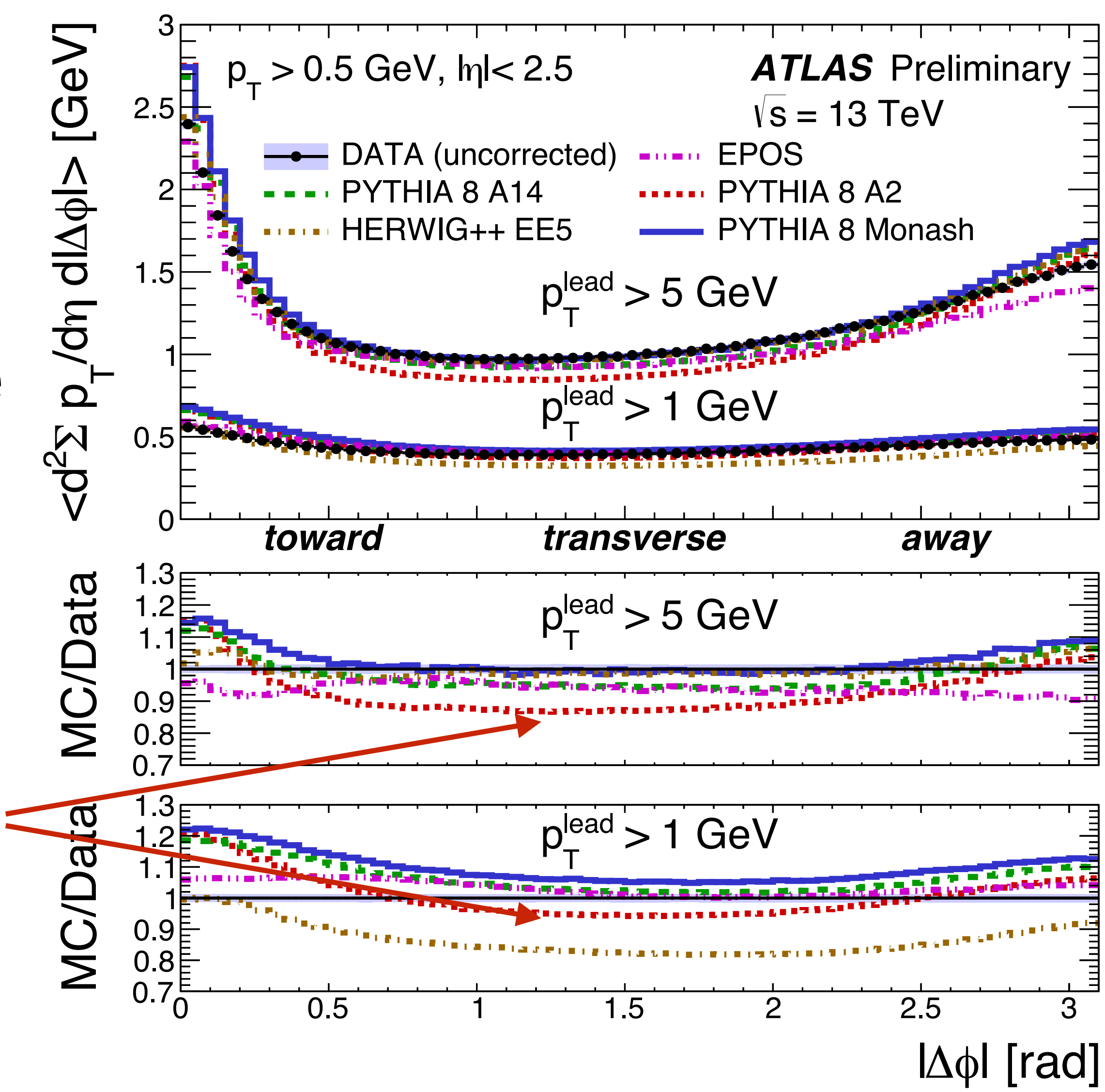
- Divide ηxϕ regions according to the highest energy flow in the event (Highest track p_T>1 GeV track)
- Transverse region of Δϕ is sensitive to the UE as it is perpendicular to the hard scatter
- ATLAS selected events with a lead track p_T>1 and 5 GeV

- UE Tunes (Herwig++, etc) are better for lead p_T>5 GeV
- MB Tunes (Pythia8 A2) are better for lead p_T>1 GeV
- All generator+parton shower are modeling the data within ~20%



Sensitive to UE

MB Tune

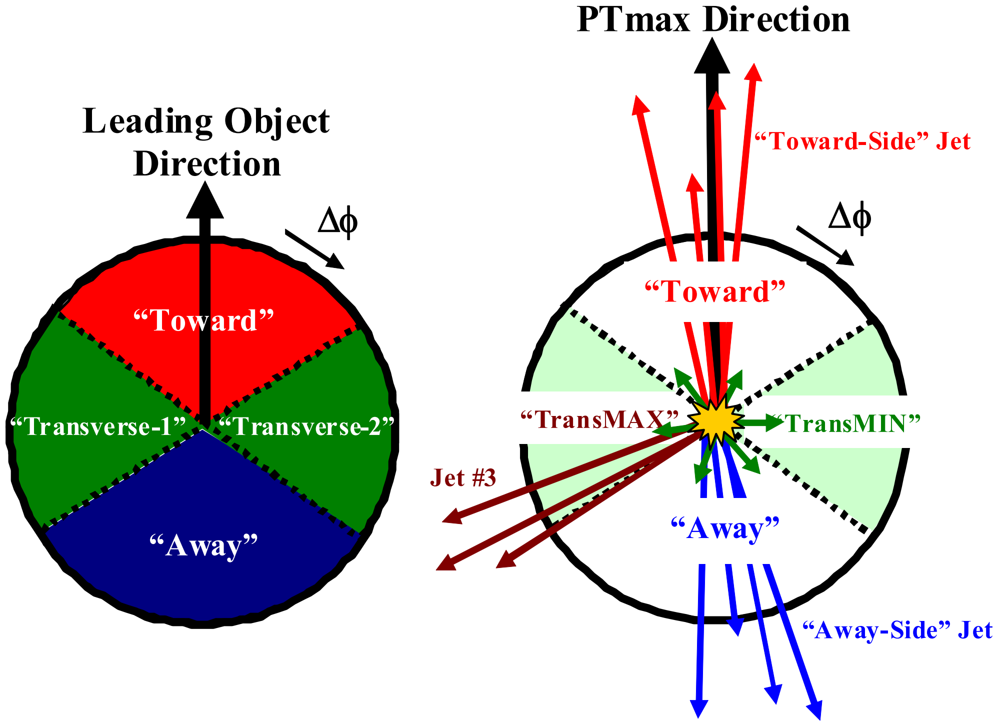


ATL-PHYS-PUB-2015-019

CMS Underlying Event

Extracting UE Information

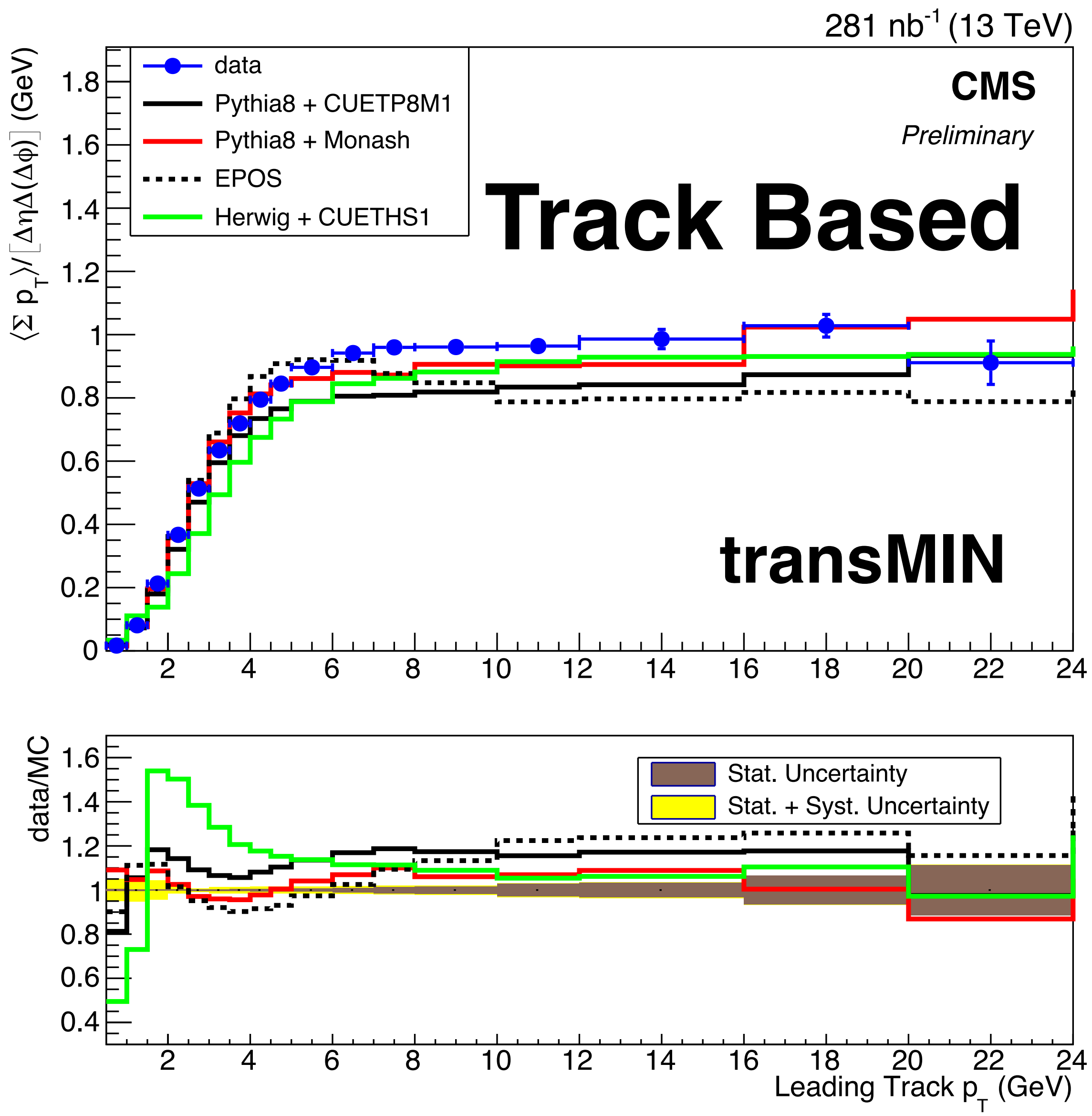
- **Leading object:** either track or jet
- Compare the modeling in each of the 4 regions
- Extract the following distributions for tracks with p_T>0.5 GeV & $|\eta|$<2:
  - $\Sigma p_T/d\eta d\phi$: Sum track p_T
  - N_{chg}: Number of charged particles
- Study the changes for different collision energies

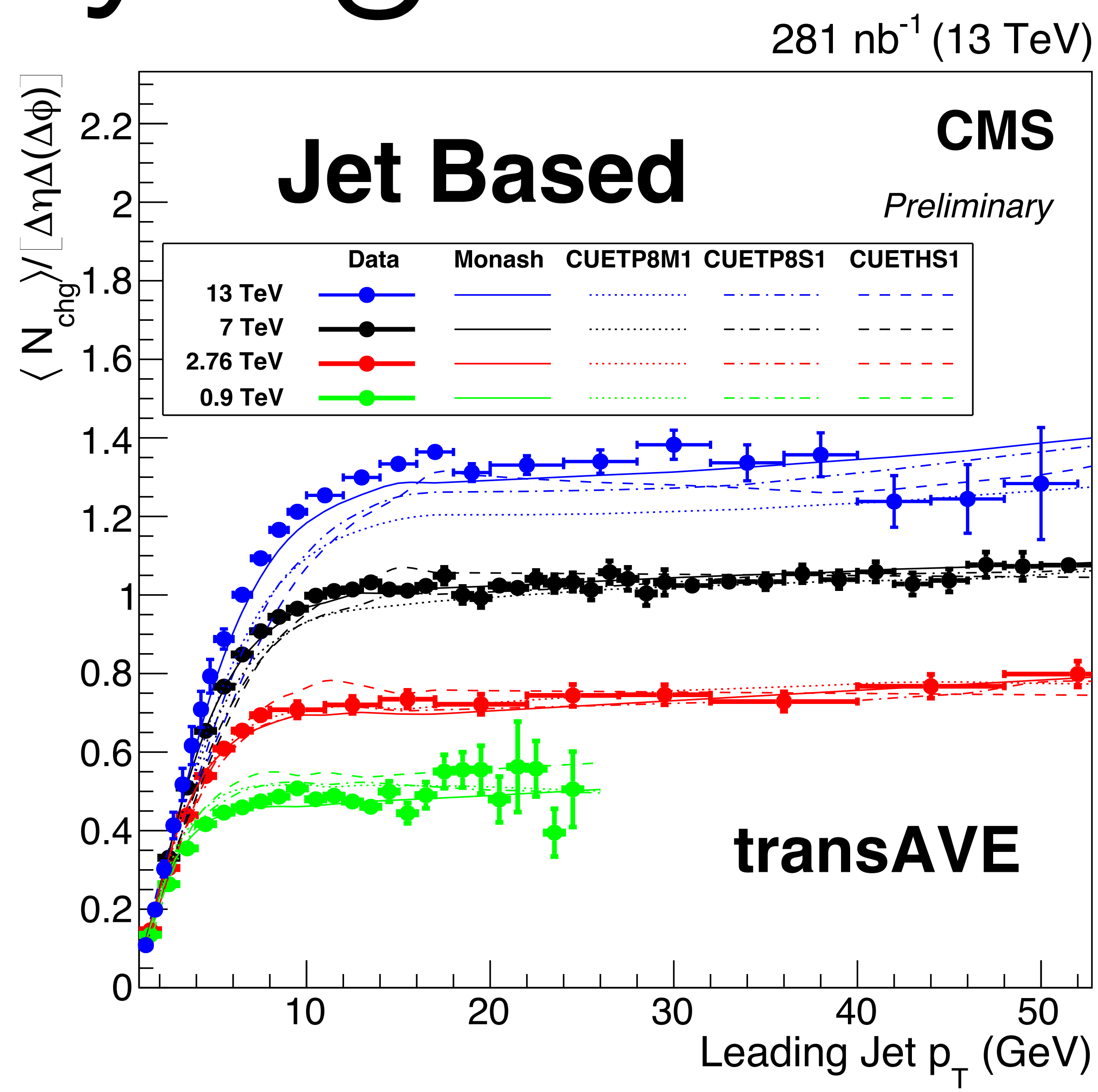


TransMax: Max density, sensitive to MPI
TransMin: Min density
TransAVE: Average of TransMax and TransMin
TransDIF: sensitive to ISR, FSR

FSQ-15-007

CMS Underlying Event





- Herwig: UE tuned, does not model low leading track p_T as well
- Pythia: Monash Tune for min bias

- N_{chg} increases with collision energy
- Monash models the N_{chg} full distribution the best

FSQ-15-007

CMS Event Generator Tunes

- Recent detailed studies done by CMS on the 7 TeV & 13 TeV data
  - Include CDF data at 0.3, 0.9, and 1.96 TeV
- Fit for UE and Double Parton Scattering (DPS) parameters in tunes using the above datasets
- Pythia6, Pythia8, and Herwig++ are compared with different tunings
  - Selected samples: Drell-Yan, MB, and multi-jet
  - Focus on Pythia8 tunings (used by CMS)
- Check consistency of tunes on UE and Min Bias samples
- Show results of the extrapolated tunes to 13 TeV CMS data

Compatibility of UE and DPS Tunes

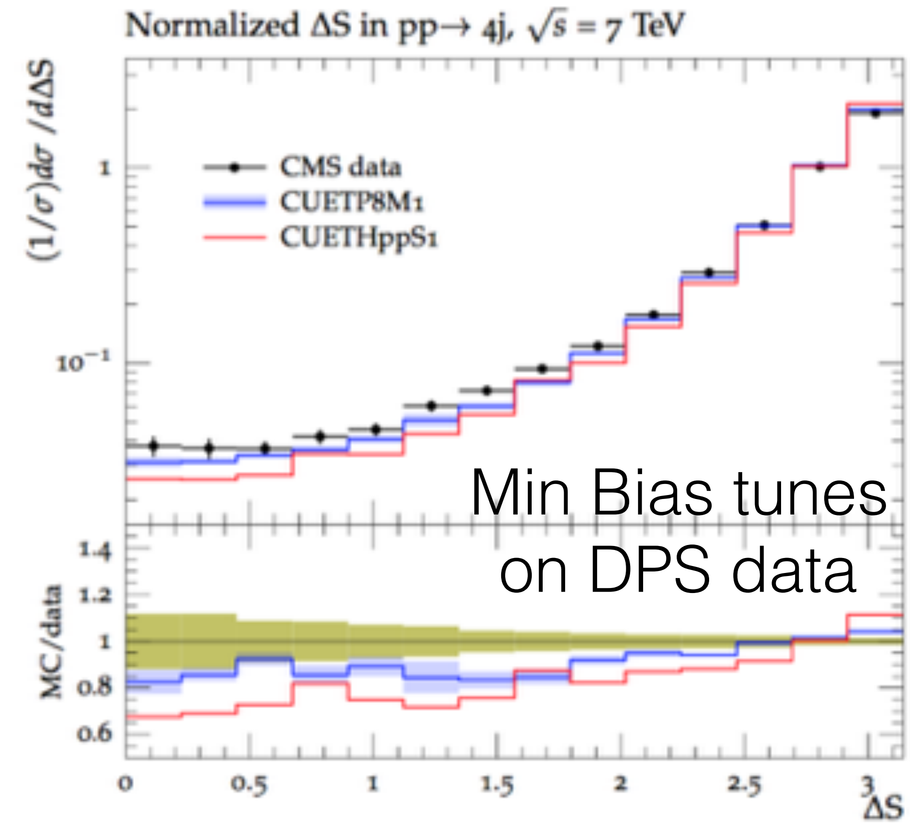
- Compare the cross-section for DPS (σ_{eff}) from the UE and DPS tunes
  - Resulting value is not as important as the quality of fit.
  - Simultaneous fit to UE and DPS observables results in a poor fit quality
- Description of MB and DPS tunes are checked on each other's observables (plots on the right)

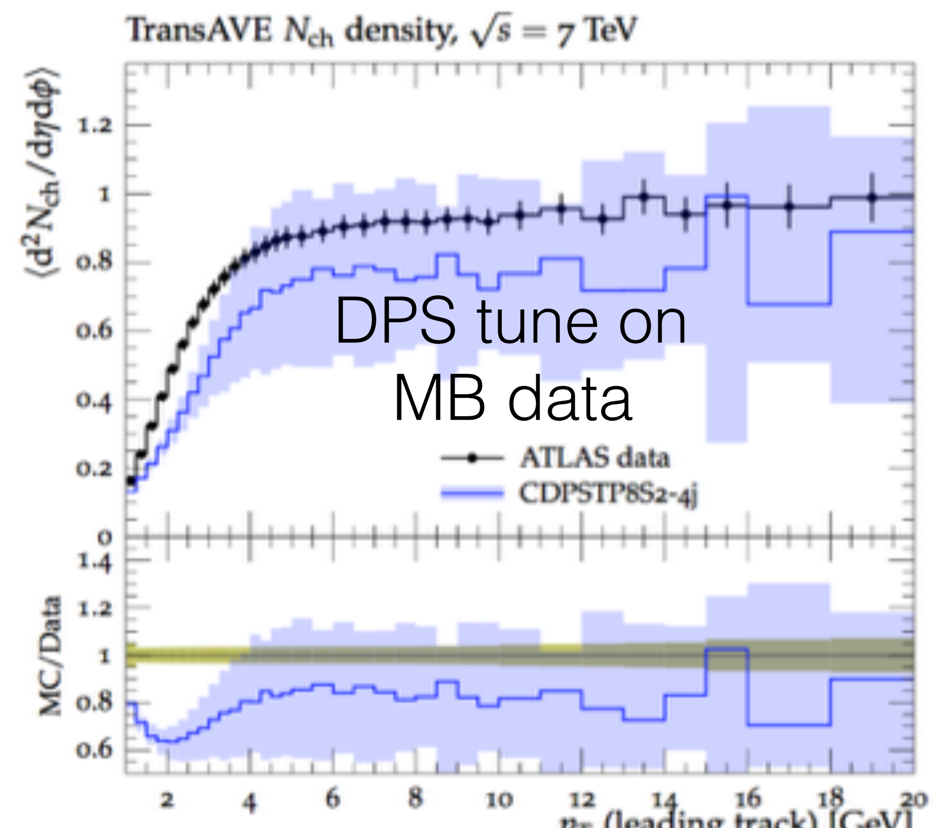
Observable	Fit	Fit quality
UE	UE	Good
	DPS	Poor
DPS	UE	OK
	DPS	Good

$$\Delta S = \arccos\left(\frac{\vec{p}_T(\text{object}_1)\cdot\vec{p}_T(\text{object}_2)}{|\vec{p}_T(\text{object}_1)|\times|\vec{p}_T(\text{object}_2)|}\right)$$

CMS Tune	σ_{eff}(mb) at 7 TeV	σ_{eff}(mb) at 13 TeV
CUETP8S1-CTEQ6L1	$27.8^{+1.2}_{-1.3}$	$29.9^{+1.6}_{-2.8}$
CUETP8S1-HERAPDF1.5LO	$29.1^{+2.2}_{-2.0}$	$31.0^{+3.8}_{-2.6}$
CUETP8M1	$26.0^{+0.6}_{-0.2}$	$27.9^{+0.7}_{-0.4}$
CUETHppS1	$15.2^{+0.5}_{-0.6}$	$15.2^{+0.5}_{-0.6}$
CDPSTP8S1-4j	$21.3^{+1.2}_{-1.6}$	$21.8^{+1.0}_{-0.7}$
CDPSTP8S2-4j	$19.0^{+4.7}_{-3.0}$	$22.7^{+10.0}_{-5.2}$

arXiv:1507.07229v2



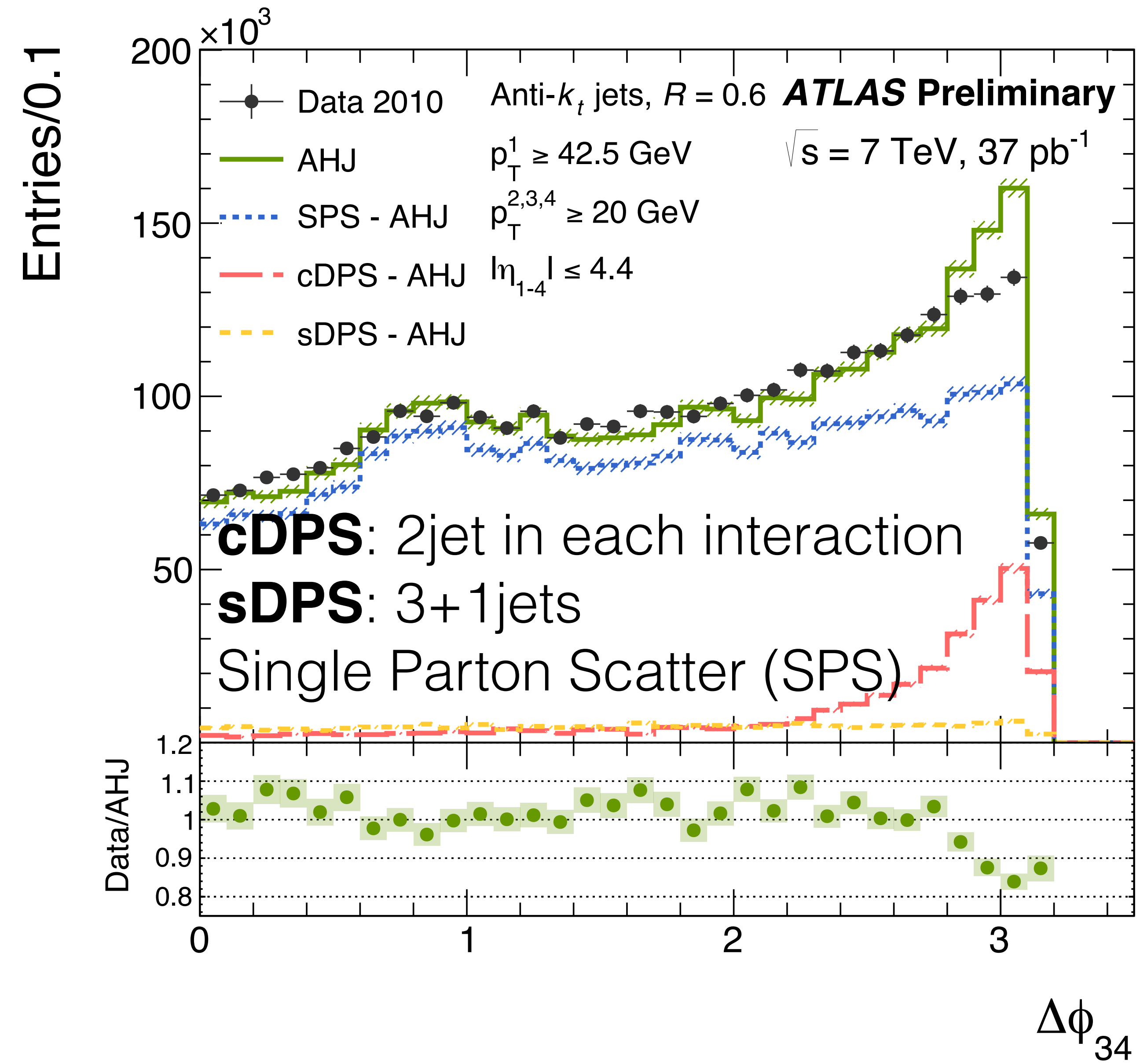


ATLAS Double Parton Scattering

- 7 TeV data with 4-jet inclusive events with $p_T \geq 20$ GeV with 37/pb
- NN analysis is used to separate single parton scattering
- Measured σ_{eff}

$$\sigma_{\rm eff} = 16.1\ ^{+2.0}_{-1.5}\ ({\rm stat.})\ ^{+6.1}_{-6.8}\ ({\rm syst.})\ {\rm mb}$$

- Fraction of the inelastic XS is 8.4±5% in 4-jet events

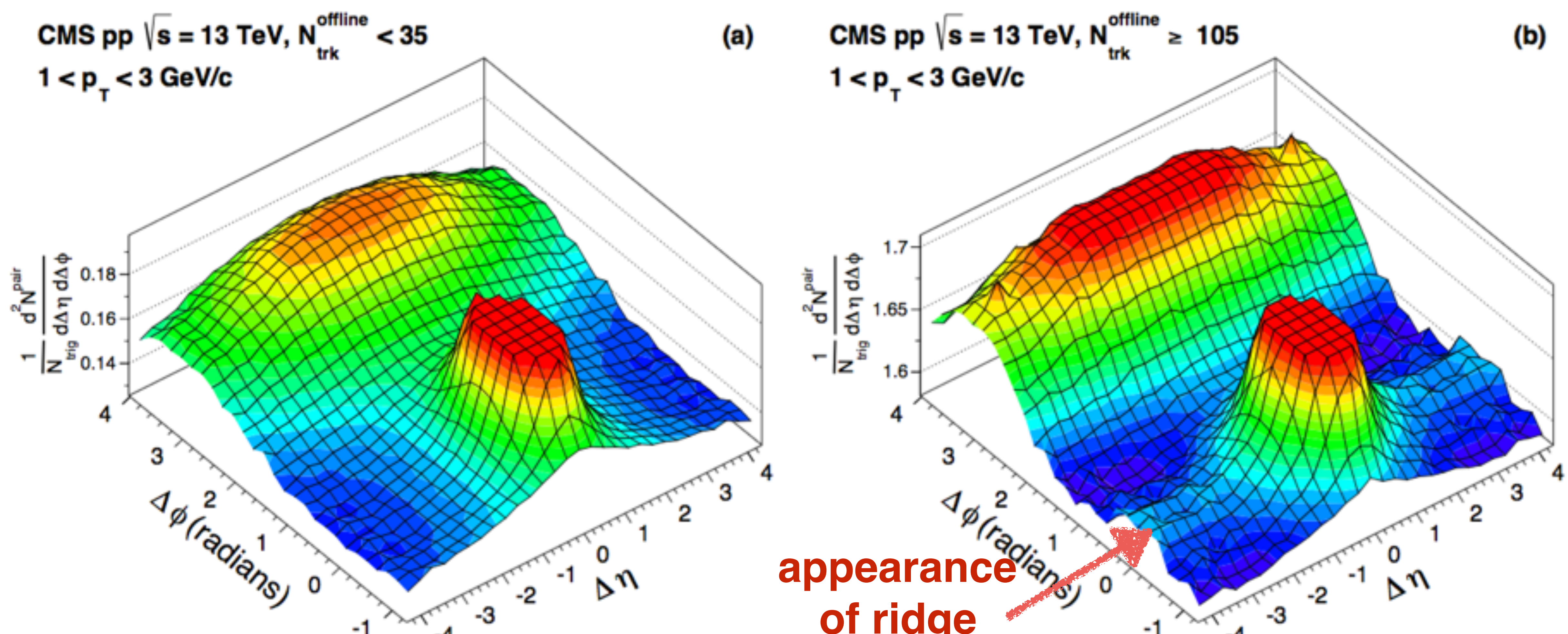


DPS: Two jet pairs should be more balanced in ϕ resulting in a peak in $\Delta\phi_{34} = \pi$

ATLAS-CONF-2015-058

CMS Measurements of Long Range Correlations

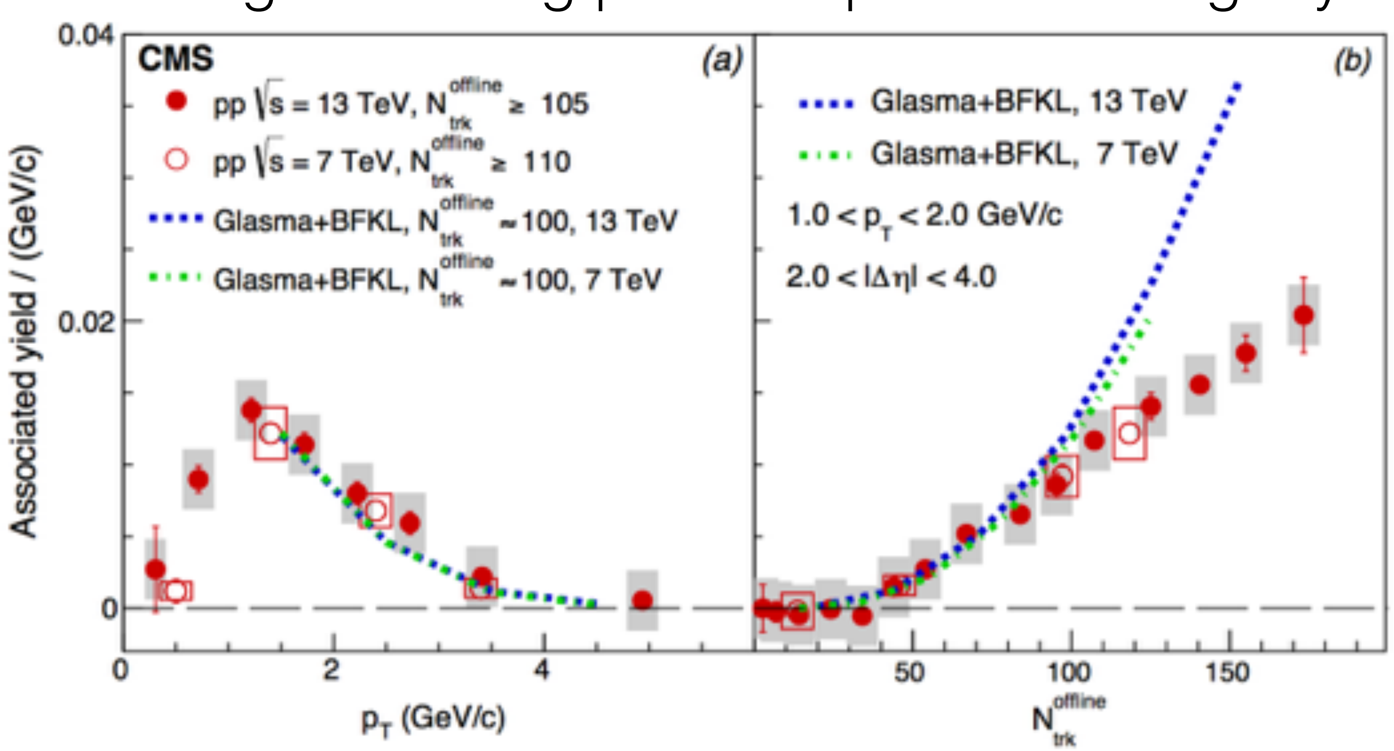
- Two particle correlations were first observed in 7 TeV data with a pronounced peak at $\Delta\eta=0$ and $\Delta\phi=0$
- With larger numbers of tracks a “ridge” structure appears at $\Delta\phi=0$
    - Confirmed in the 13 TeV data & no such correlation is predicted by Pythia simulation
- LHCb (arXiv:1512.00439v1) also confirmed the ridge with tracking acceptance from $2.0<|\eta|<4.9$ using 5T4V pPb and Pb+p collisions

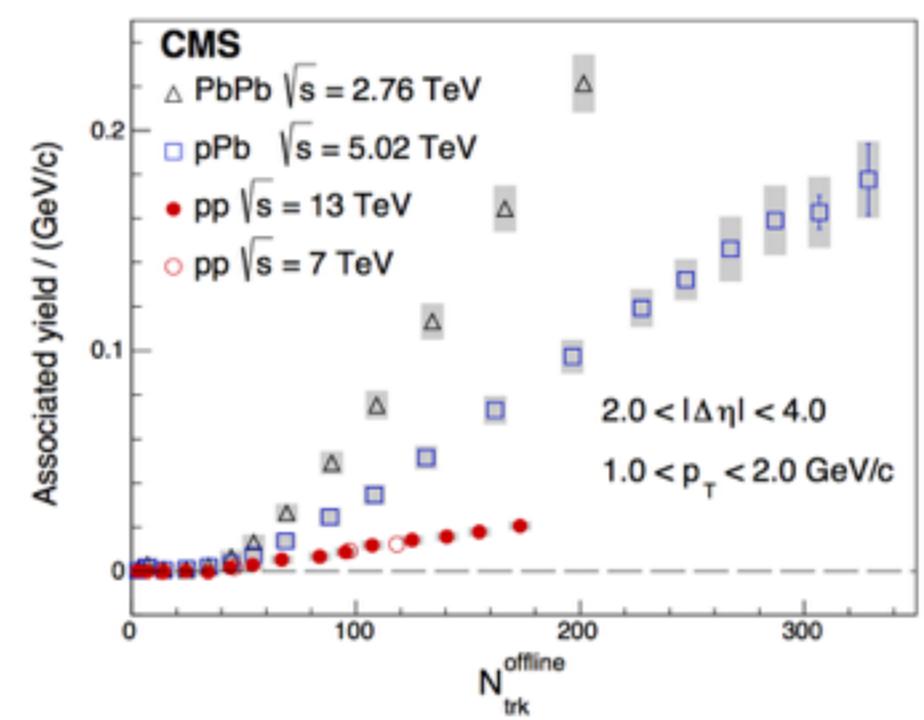


arXiv:1510.03068v1

CMS Long Range Correlations

- Track p_T and N_{trk} are compared for events in the “ridge”
    - Similar yields are found for 7 and 13 TeV
    - Gluon saturation models qualitatively fit the data; though the multiplicity increase is slower than predicted
- Observed long range track multiplicities are seen in PbPb, pPb, and pp collisions
    - Larger colliding particles produce a larger yield in the “ridge”

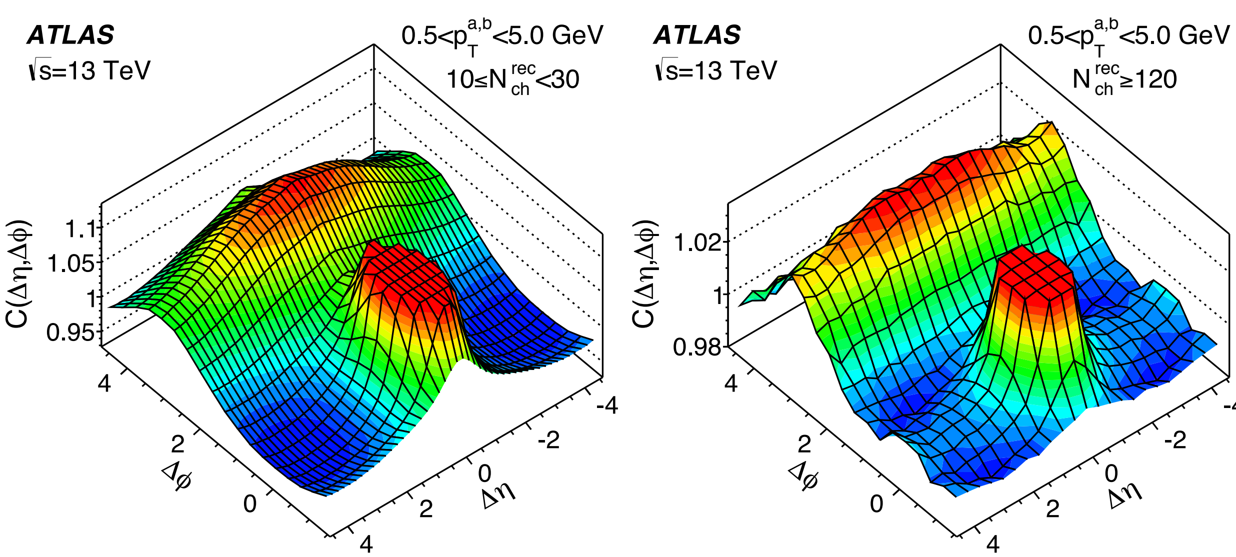


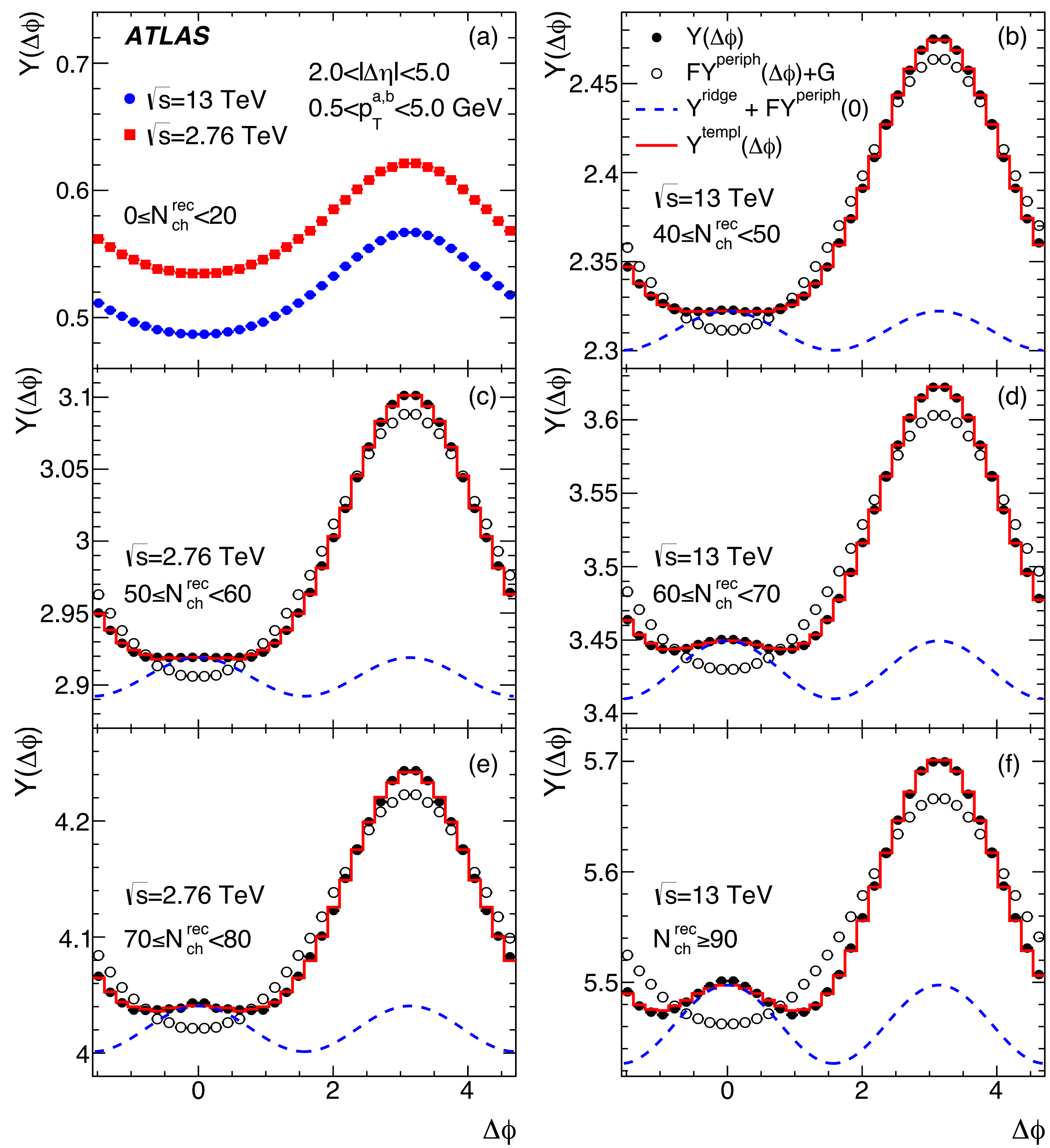


arXiv:1510.03068v1

ATLAS Results

- Touch on this briefly as it was discussed in Marumi's talk on Monday
- Y(Δϕ): Per trigger particle yields
    - Fits well to Y(Δϕ)+cos(2Δϕ)term
- Shapes are similar in 13 & 2.76 TeV
- “Ridge” increases with particle multiplicity





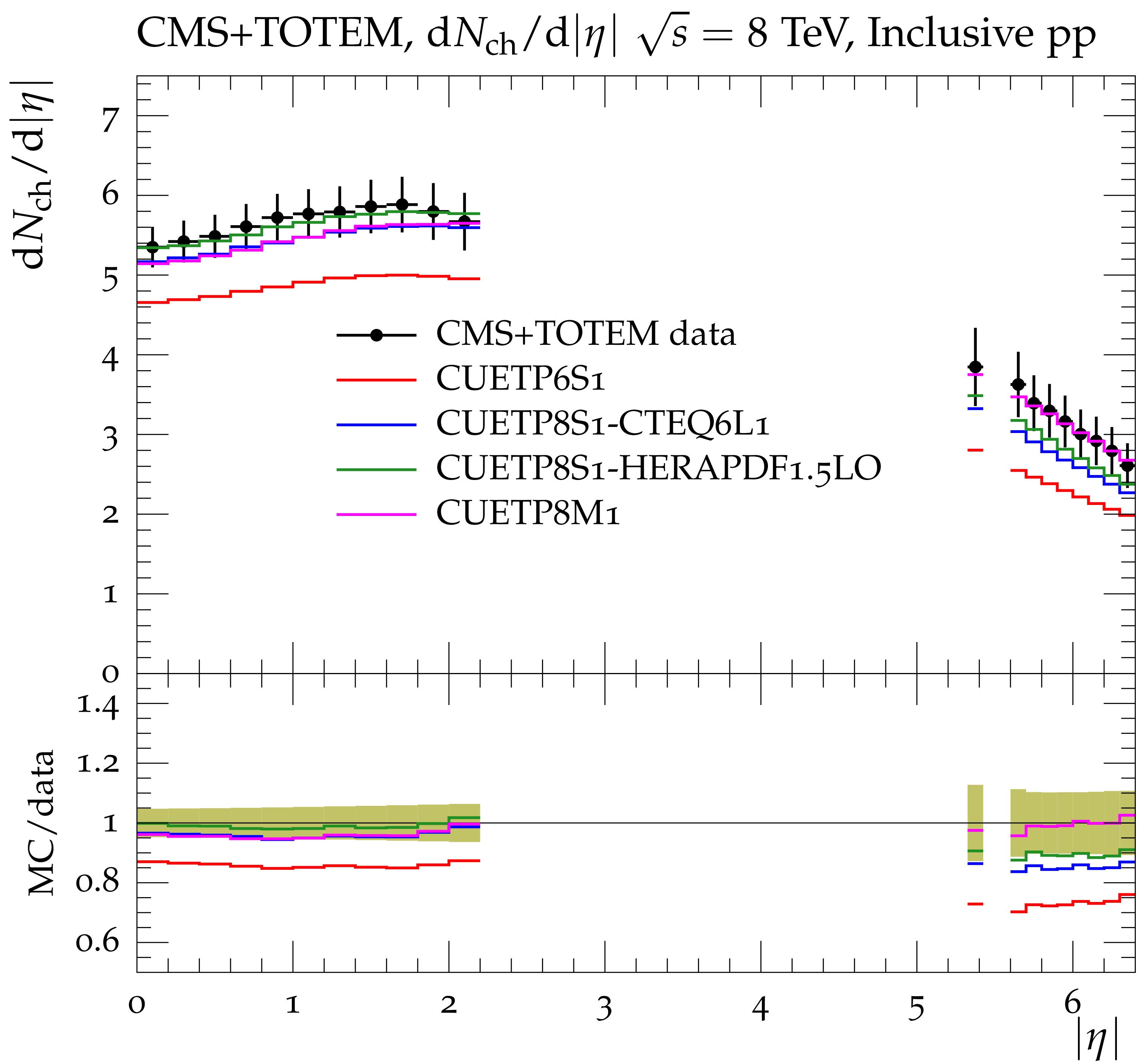
arXiv:1509.04776

Conclusions

- Material descriptions of the ATLAS & CMS are well described
- Minimum Bias (MB) track multiplicity and leading track p_T properties are compared to simulation models by CMS & ATLAS
- MB cross-section was measured by ATLAS
- Underlying Event (UE) and Double Parton Scattering (DPS) tunes are studied by CMS using CDF and CMS data from 0.3-13 TeV
    - Consistent predictions for 13 TeV are observed, but the UE and DPS could not be described well by the current parameters
- Low range two particle correlations are confirmed at 13 TeV by CMS and in pPb by LHCb

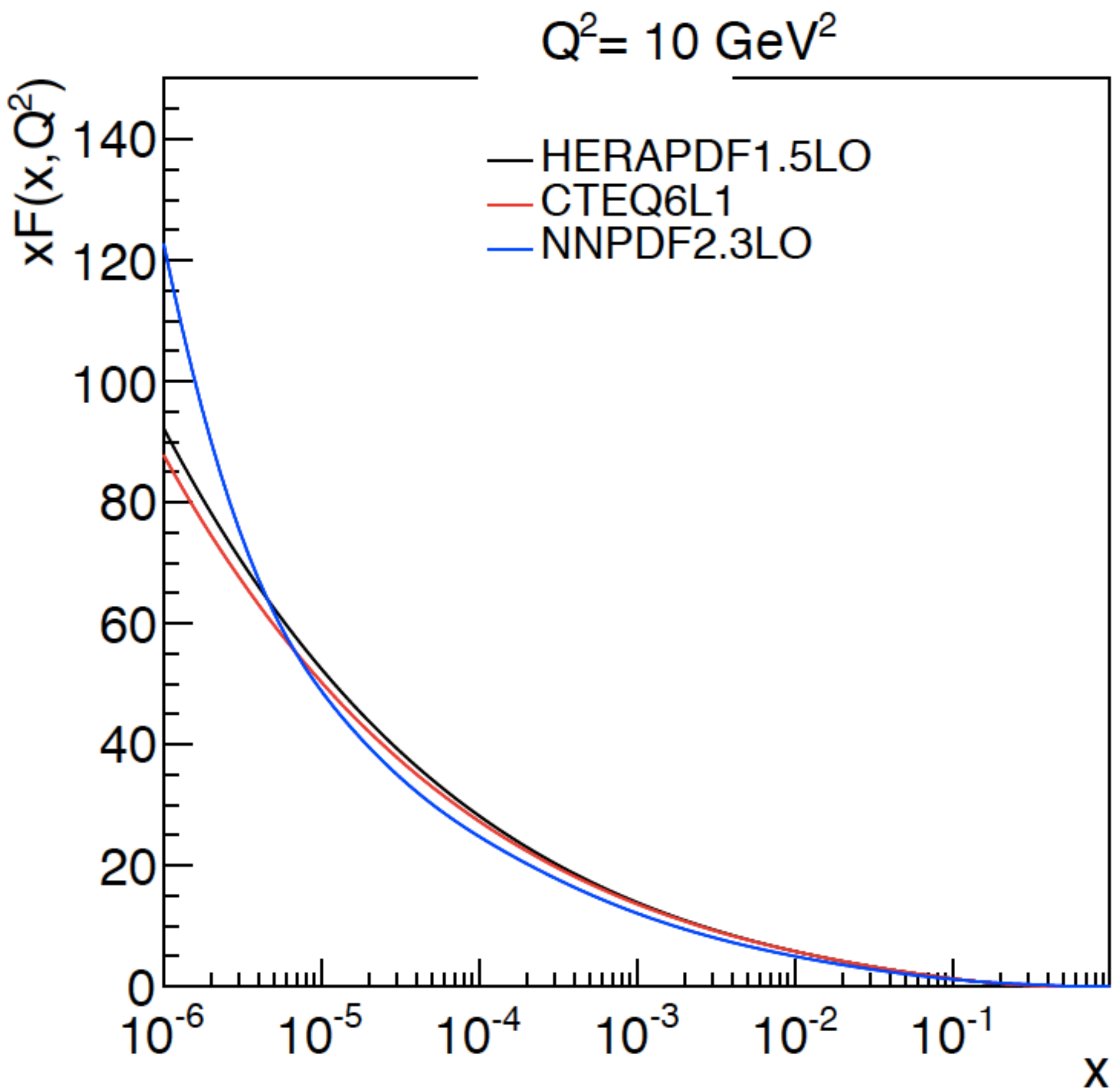
Backup

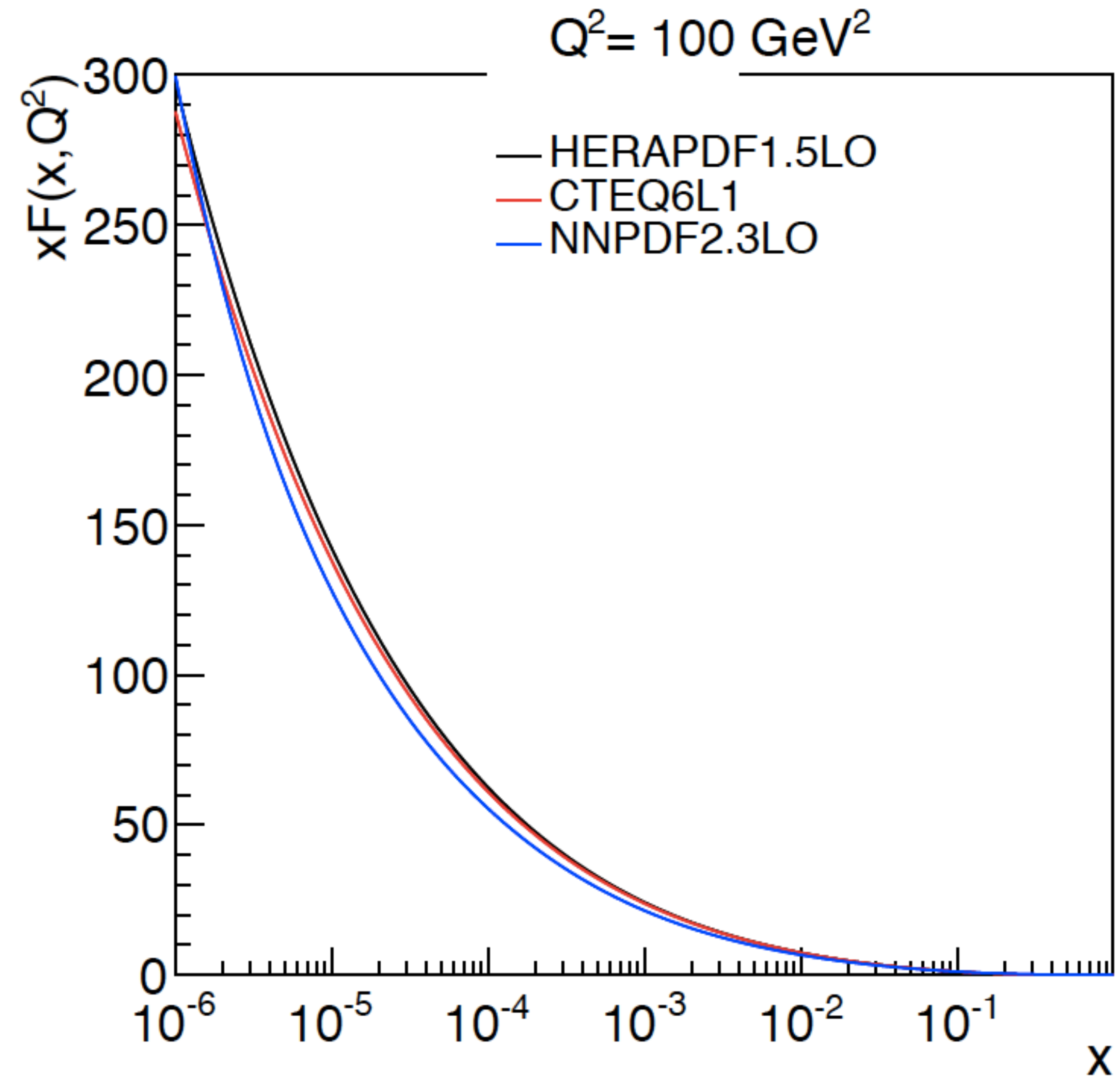
Totem



CMS+TOTEM, $dN_{ch}/d|\eta|$ $\sqrt{s} = 8$ TeV, Inclusive pp
$dN_{ch}/d|\eta|$
7
6
5
4
3
2
1
0
CMS+TOTEM data
CUETP6S1
CUETP8S1-CTEQ6L1
CUETP8S1-HERAPDF1.5LO
CUETP8M1
MC/data
1.4
1.2
1
0.8
0.6
0
1
2
3
4
5
6
$|\eta|$

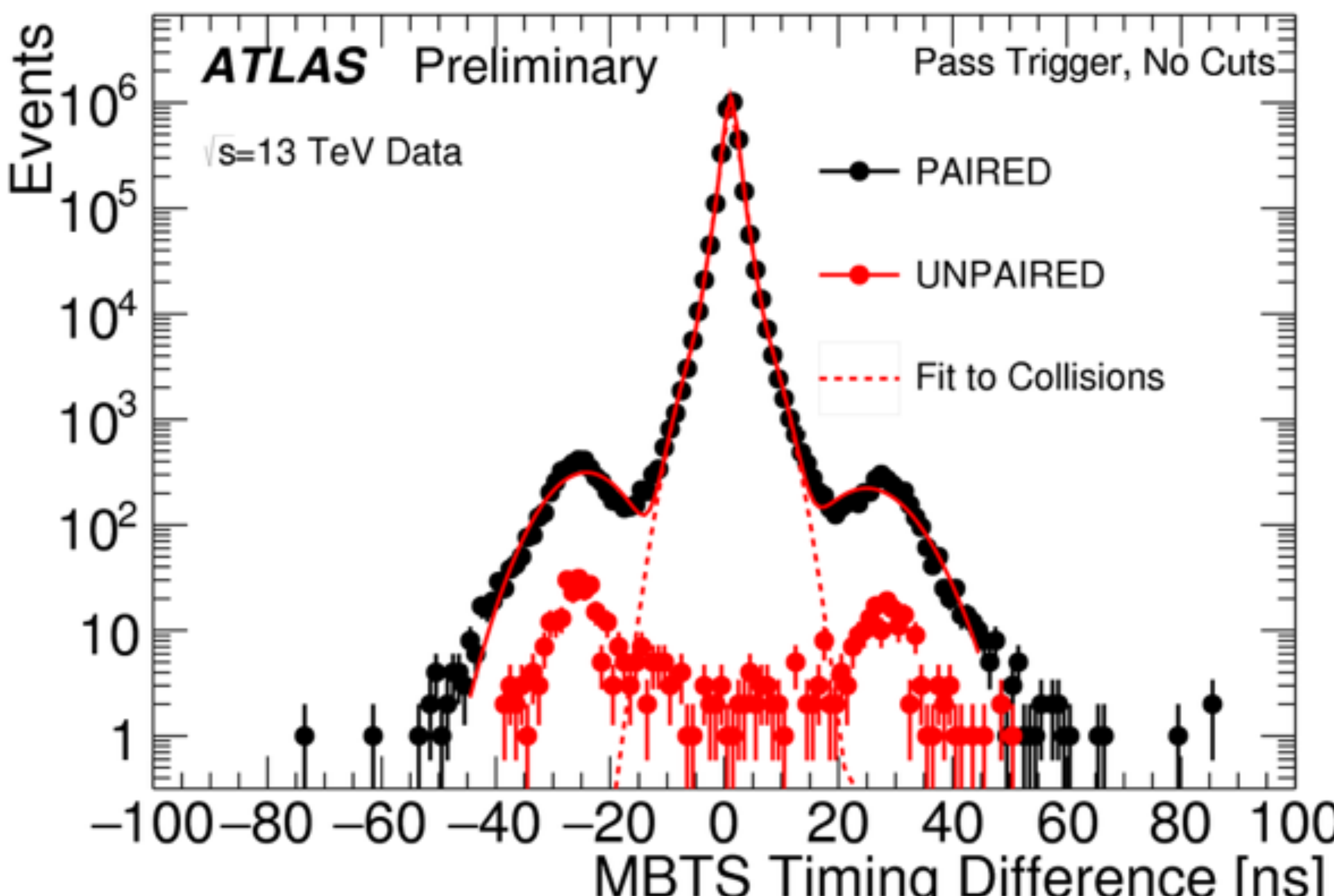
PDFs


Q^2= 10 GeV^2
HERAPDF1.5LO
CTEQ6L1
NNPDF2.3LO
xF(x,Q^2)
0
20
40
60
80
100
120
140
10^{-6}
10^{-5}
10^{-4}
10^{-3}
10^{-2}
10^{-1}
x


Q^2= 100 GeV^2
HERAPDF1.5LO
CTEQ6L1
NNPDF2.3LO
xF(x,Q^2)
0
50
100
150
200
250
300
10^{-6}
10^{-5}
10^{-4}
10^{-3}
10^{-2}
10^{-1}
x

Beam Background

- The difference in the time of the MBTS hits on each side of the detector. Events triggered on UNPAIRED beams (only one of the two beams present at the detector collision point) are shown in red. Events triggered in PAIRED beams (both beams present at the detector collision point) are shown in black. The large central peak in the PAIRED distribution comes from collisions, and the smaller peaks away from 0 ns are caused by non-collision beam background.

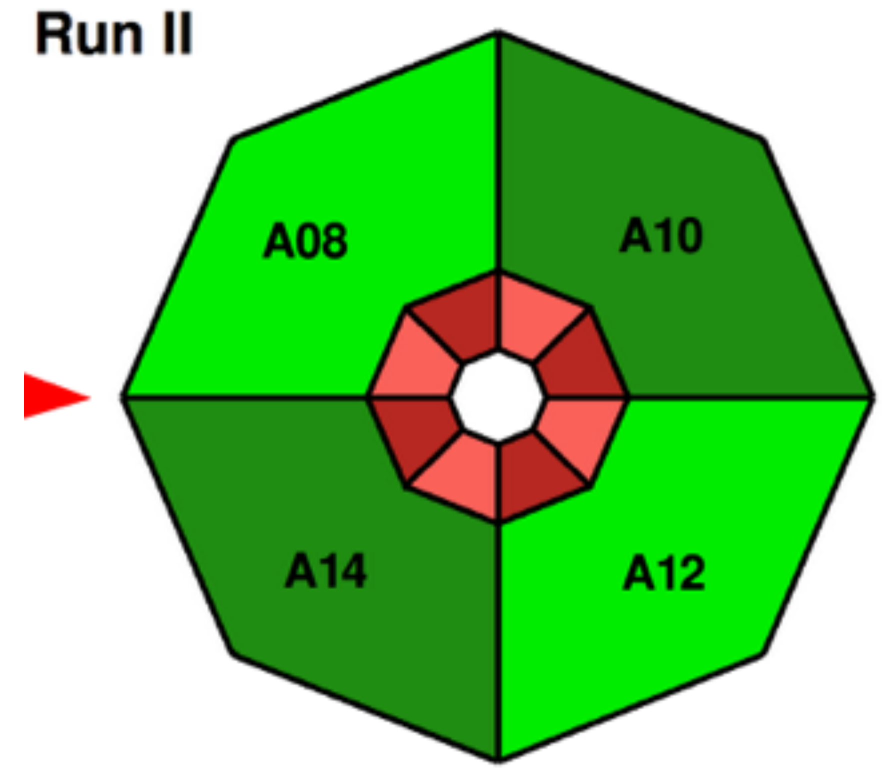


Normalized the UNPAIRED trigger to the PAIRED

Negligible <0.01% of events

Trigger Definitions

- **L1 triggers (L1_MBTS_X)**
  - Use the MBTS disks (described on right)
  - L1_MBTS_1 requires 1 or more hits
  - *L1_MBTS_2 requires 2 or more hits*
- **HLT triggers**
  - *HLT_mb_mbts_L1MBTS_2 (requires at least 1 track with pT>4 GeV)*
  - HLT_noalg_L1MBTS_1 (physics)
  - *HLT_mb_sptrk (supporting pT>200 MeV track)*



MBTS Disk

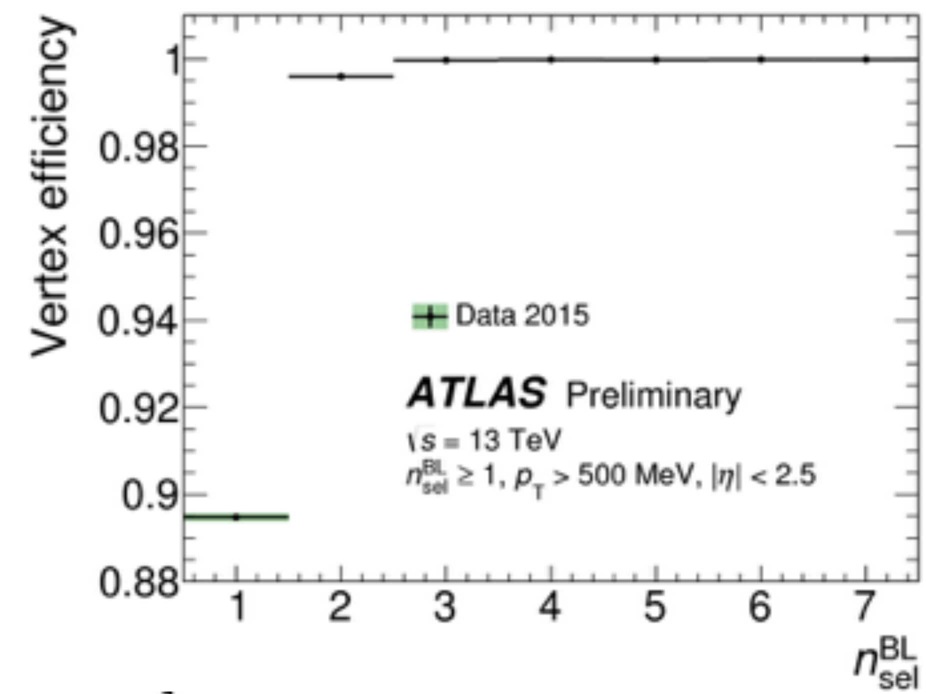
- 4+8 scintillators on each side at z=±3560 mm
- PMT light is readout by the TileCal
- MBTS hit is signal above 60mV

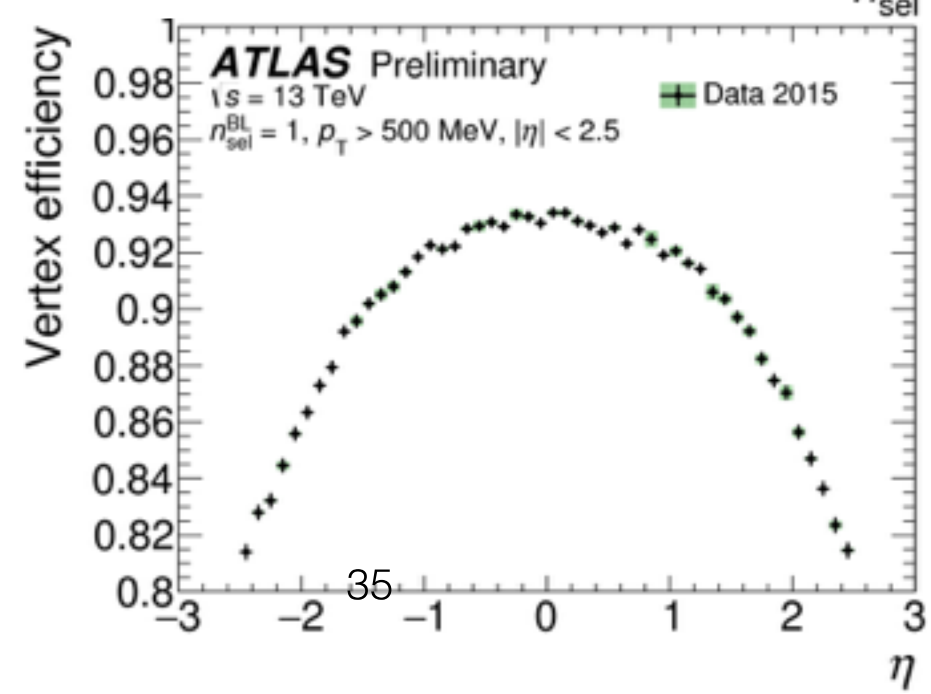
Black are physics triggers

Vertex Efficiency

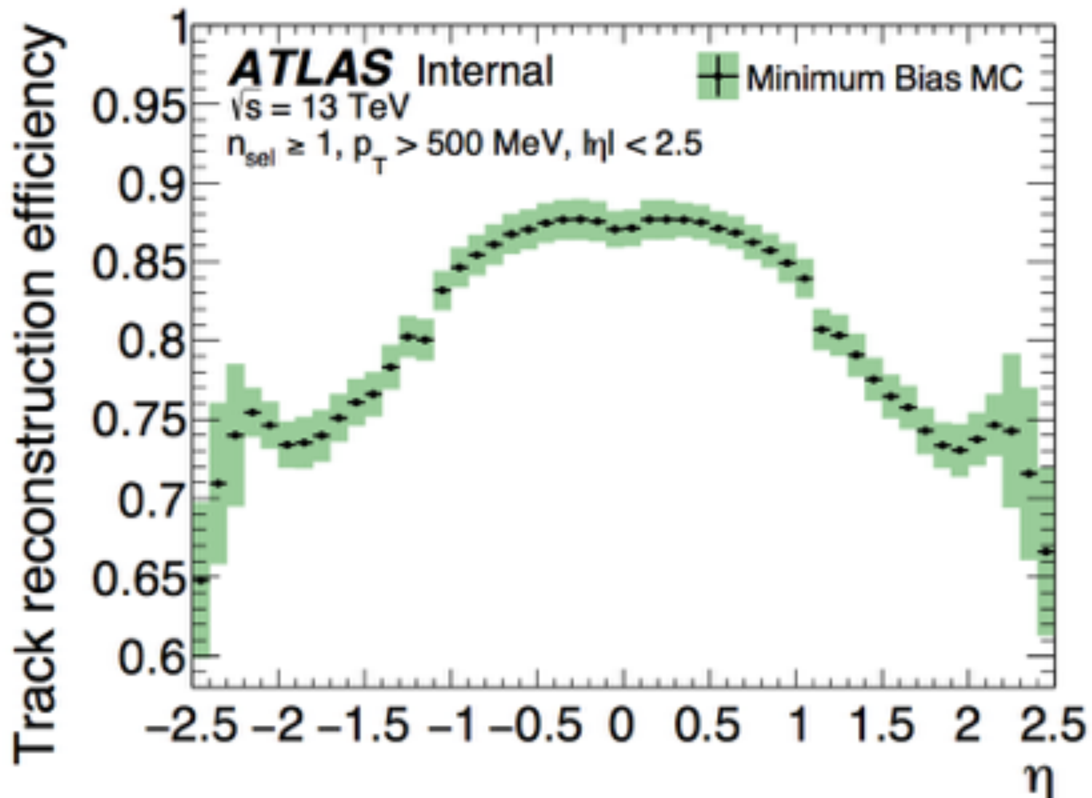
$$\epsilon_{vtx} = \frac{\text{events passing MBTS\_1 with } n_{sel}^{BL} \geq 1 \text{ and having a reconstructed vertex}}{\text{events passing MBTS\_1 with } n_{sel}^{BL} \geq 1}$$

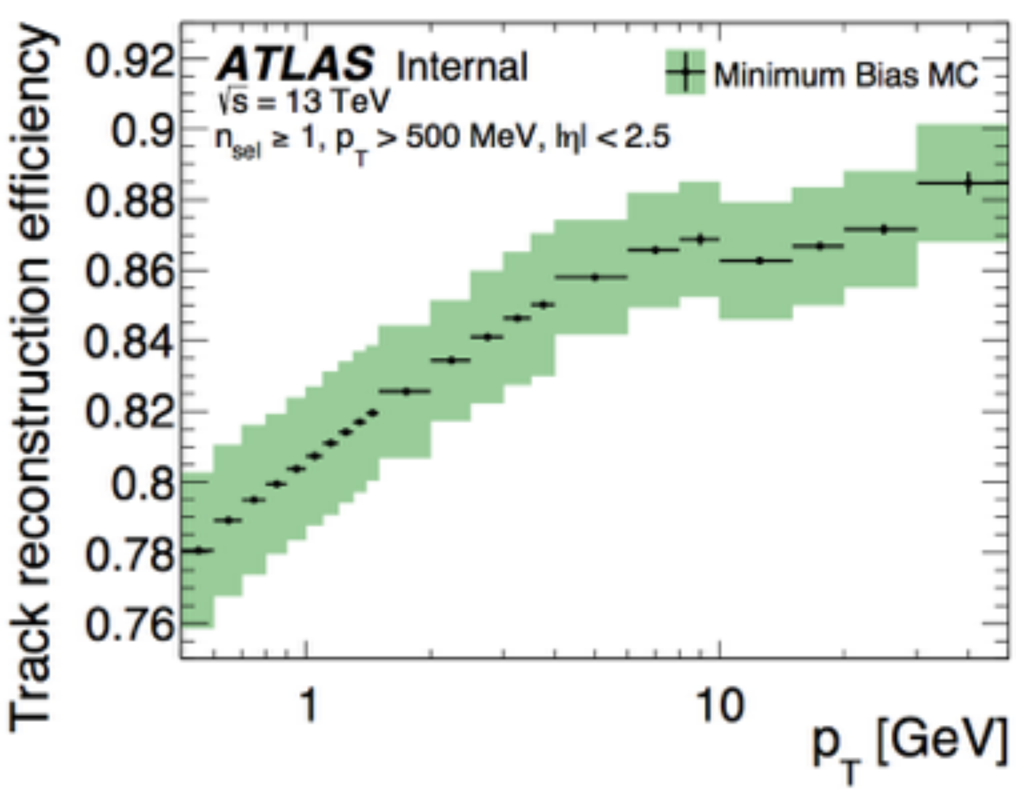
- Vertex efficiency as a function of the number of tracks
    - z_0 cut is loosened to <1000 mm
- Non-collision beam background is subtracted, and the full subtraction is shown in the green bands
- Vertex efficiency is done separately for data and MC
- Parameterized h in the n_{sel}=1 bin
- Uncertainties are small and are neglected





Track Efficiency





<u>Systematics uncertainties</u>

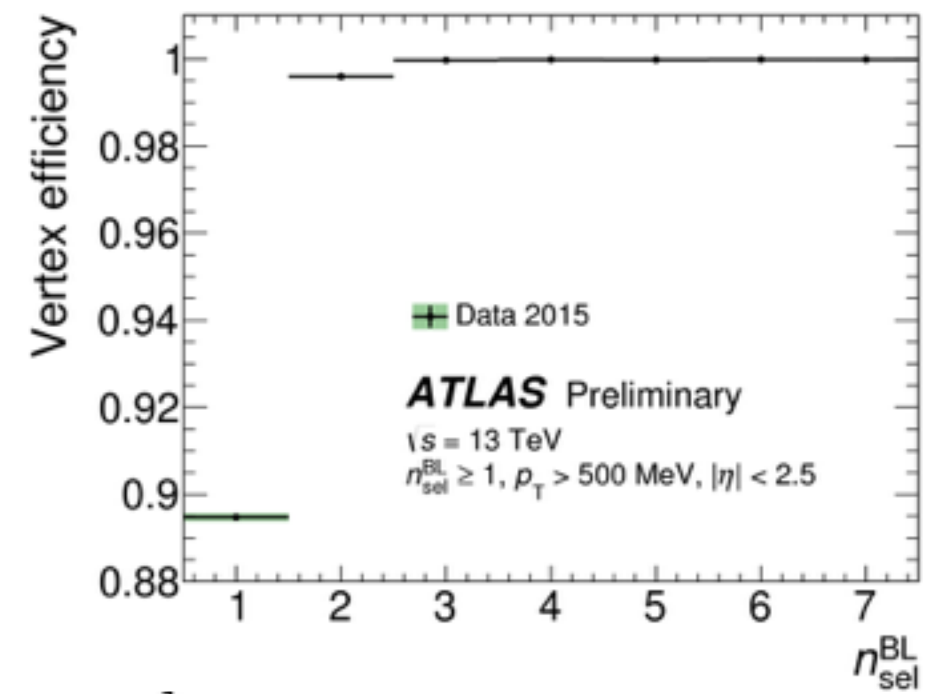
1. N-1 cut efficiencies (MC versus data) for the number of hit requirements: 0.5% systematic
2. N-1 cut efficiency for χ^2 prob. Cut: 0.5% systematic for $p_T > 10$ GeV
3. Material description [dominant] combine the following three *linearly*:
   a) material constrained to ±5% from Run 1 → 1% (1.5%) systematic in the central (forward) region
   b) Studies of conversions and secondary vertices from hadronic interactions indicate missing material in the IBL leading to ~1% systematic
   c) SCT extension efficiency indicates possible missing material in the region $|\eta| > 2.2$ → 5% syst.

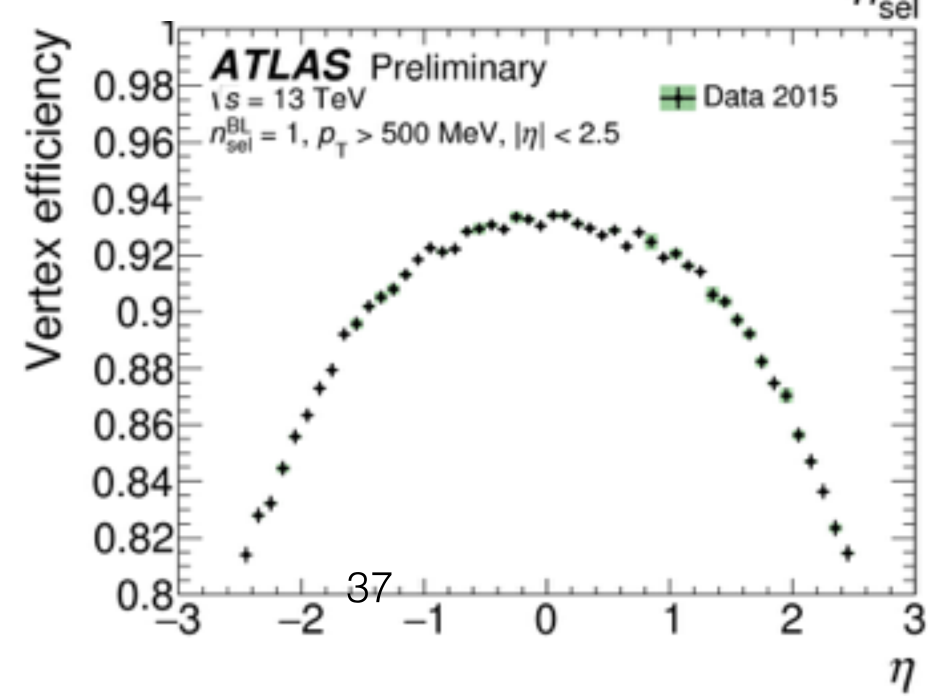
b+c are added linearly and a is added in quadrature

Vertex Efficiency

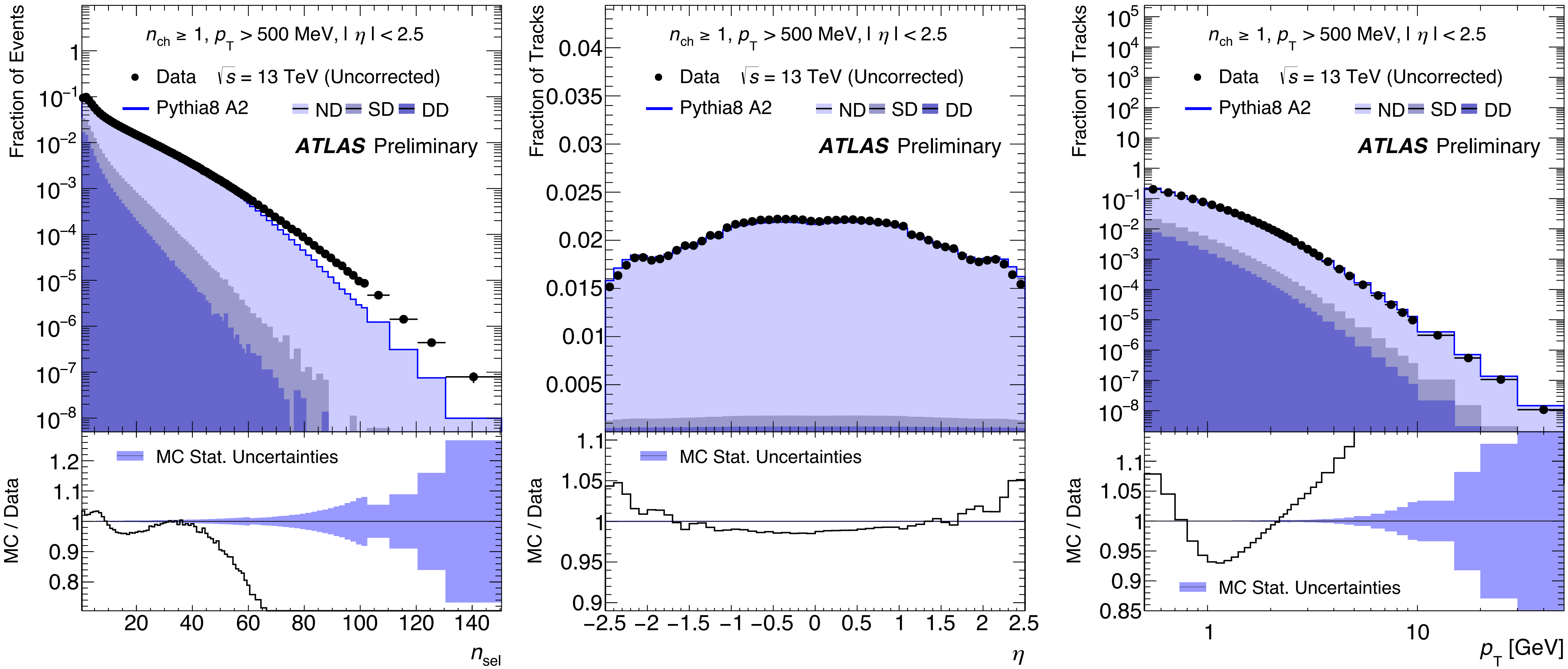
$$\epsilon_{\text{vtx}} = \frac{\text{events passing MBTS\_1 with } n_{\text{sel}}^{\text{BL}} \geq 1 \text{ and having a reconstructed vertex}}{\text{events passing MBTS\_1 with } n_{\text{sel}}^{\text{BL}} \geq 1}$$

- Vertex efficiency as a function of the number of tracks
    - z_0 cut is loosened to <1000 mm
- Non-collision beam background is subtracted, and the full subtraction is shown in the green bands
- Vertex efficiency is done separately for data and MC
- Parameterized h in the n_{sel}=1 bin
- Uncertainties are small and are neglected

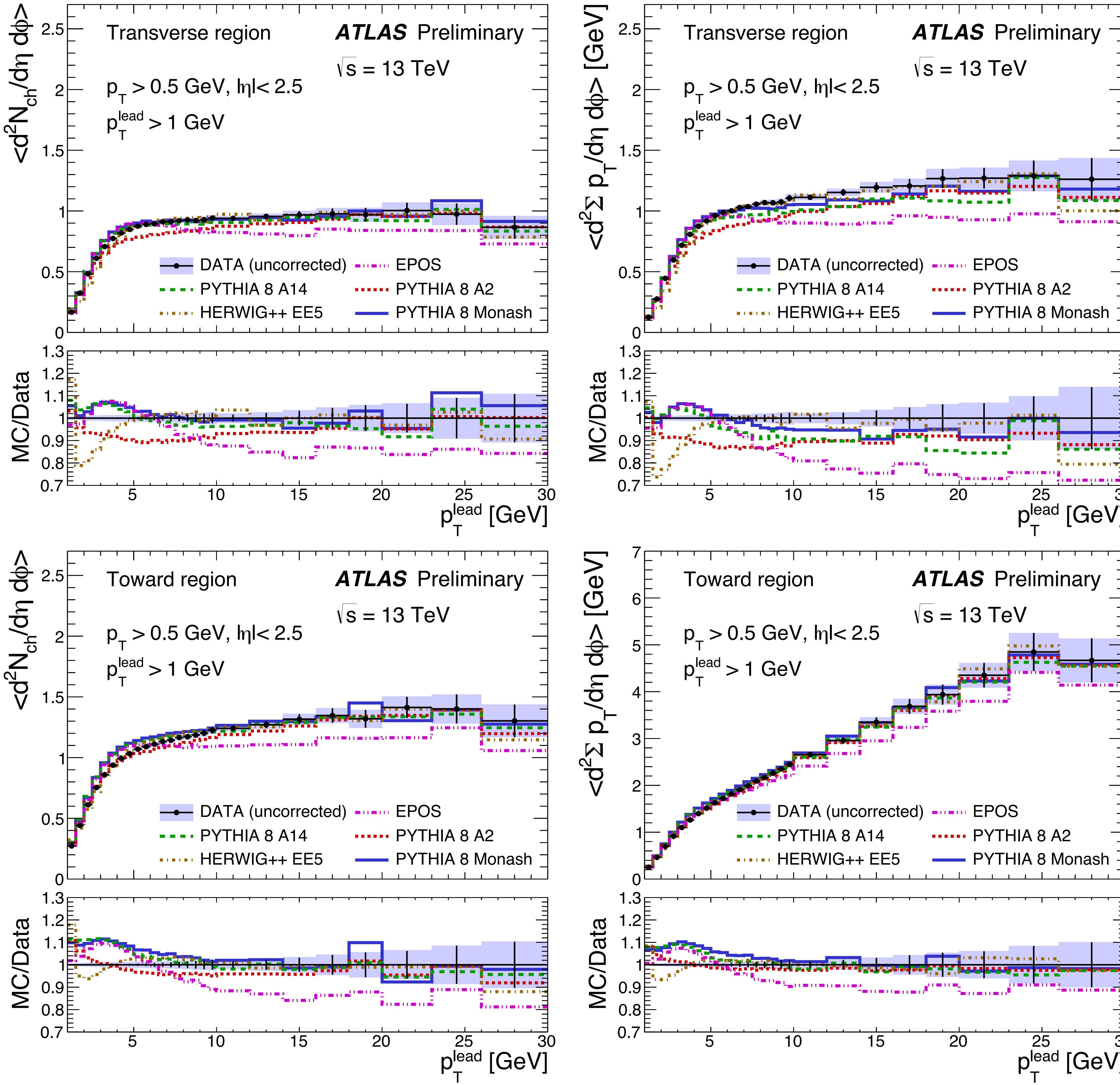




MB MC Modeling

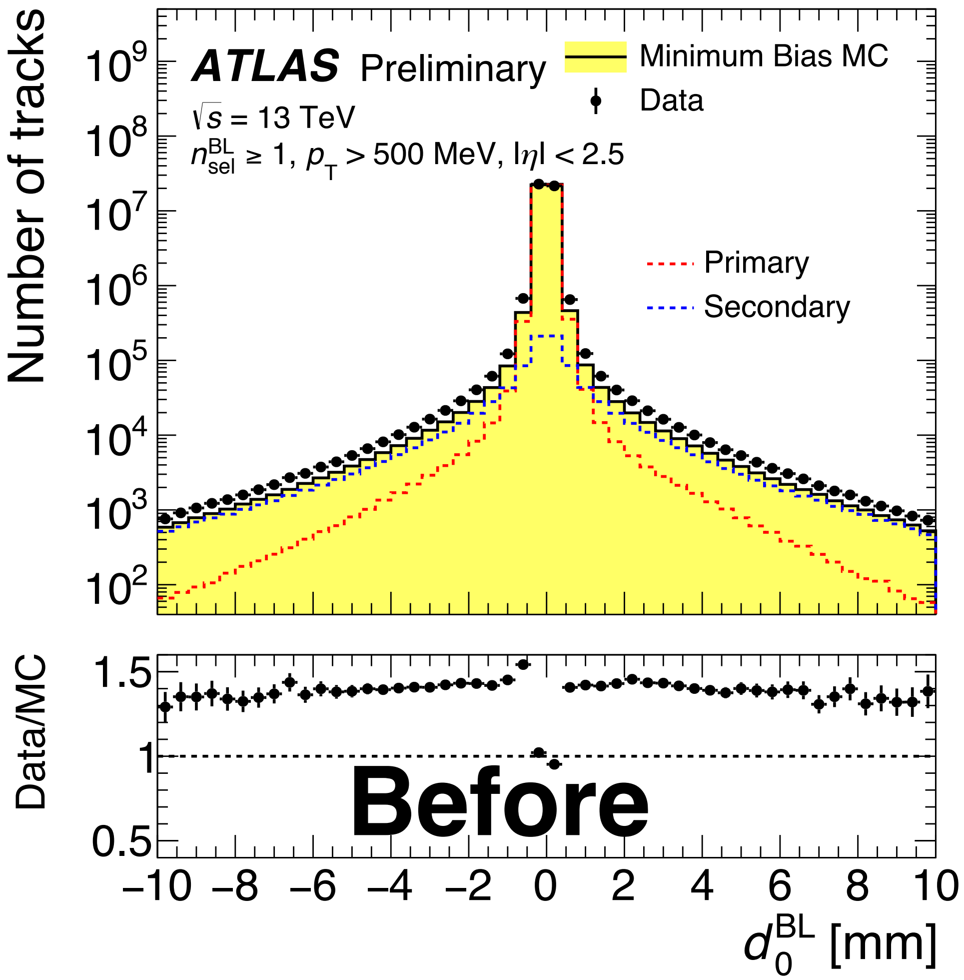


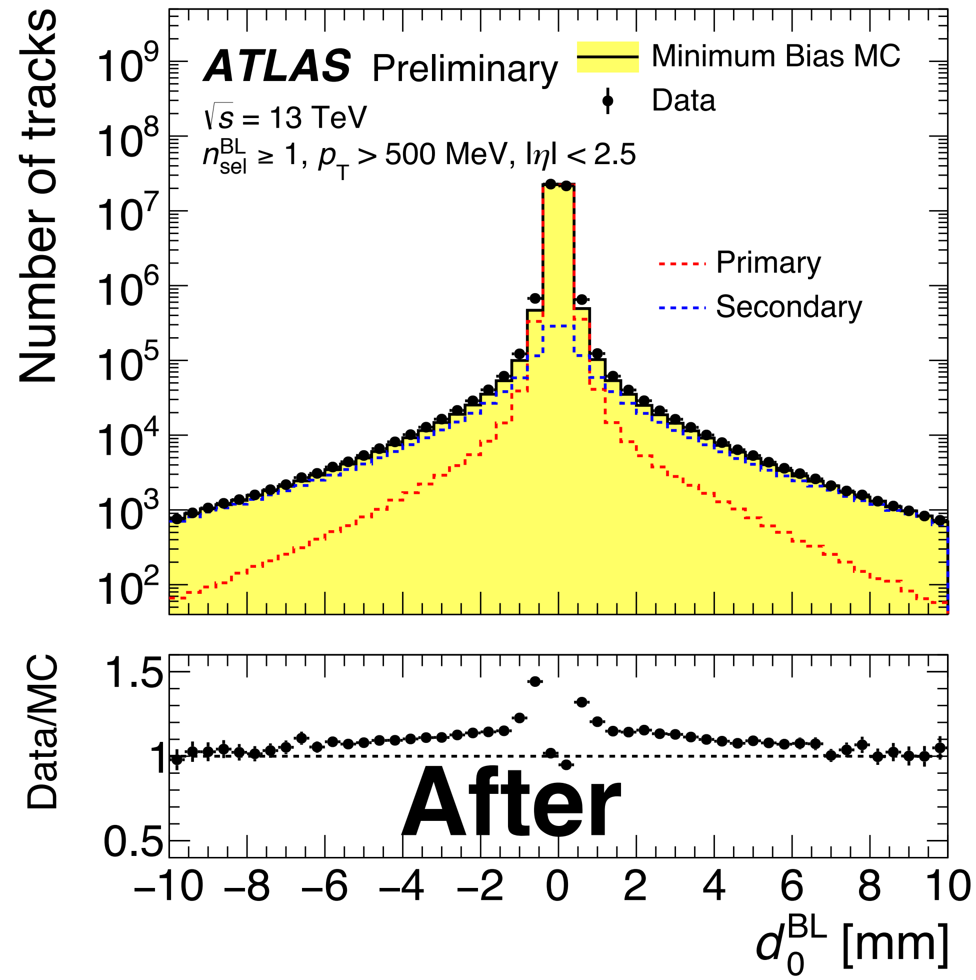
UE Modeling



Transverse region
ATLAS Preliminary
√s = 13 TeV
p_T > 0.5 GeV, |η|< 2.5
p_T^lead > 1 GeV
<d²N_ch/dη dφ>
<d²Σ p_T/dη dφ> [GeV]
Toward region
DATA (uncorrected)
EPOS
PYTHIA 8 A14
PYTHIA 8 A2
HERWIG++ EE5
PYTHIA 8 Monash
MC/Data
p_T^lead [GeV]

Secondary Interactions

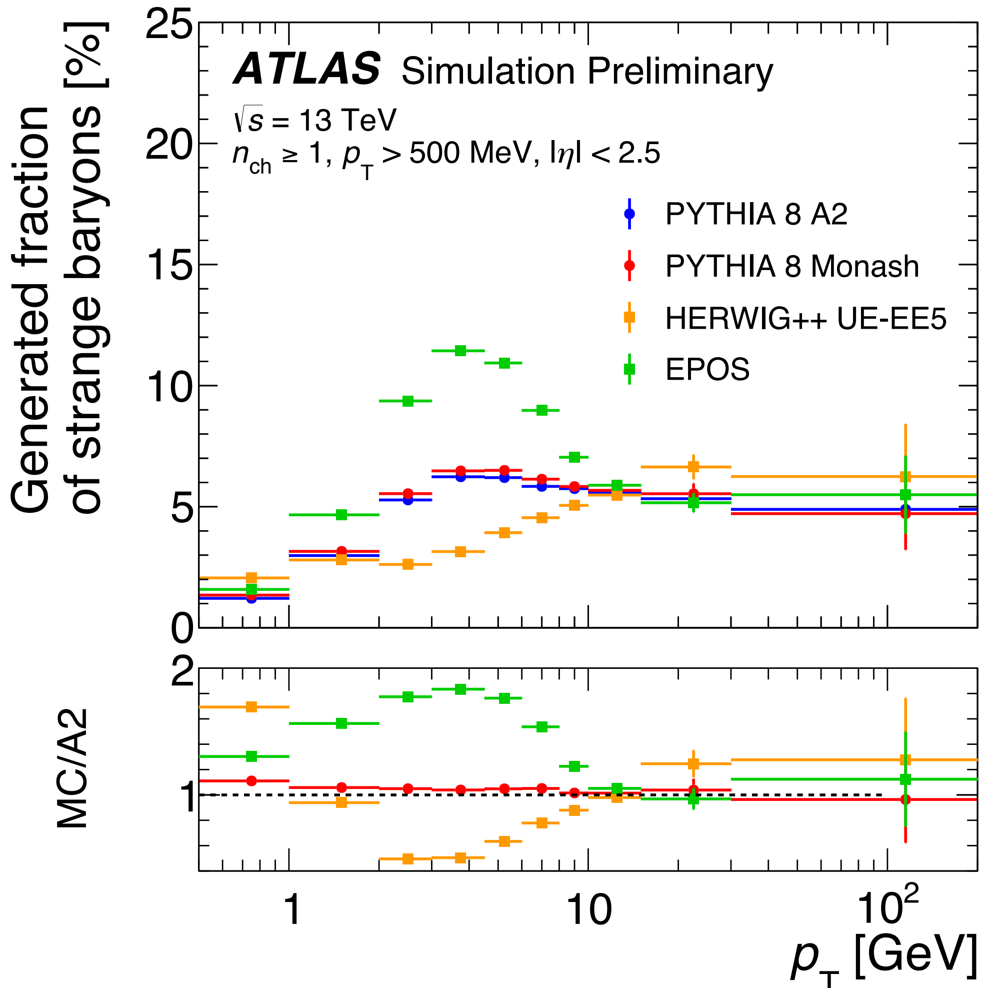


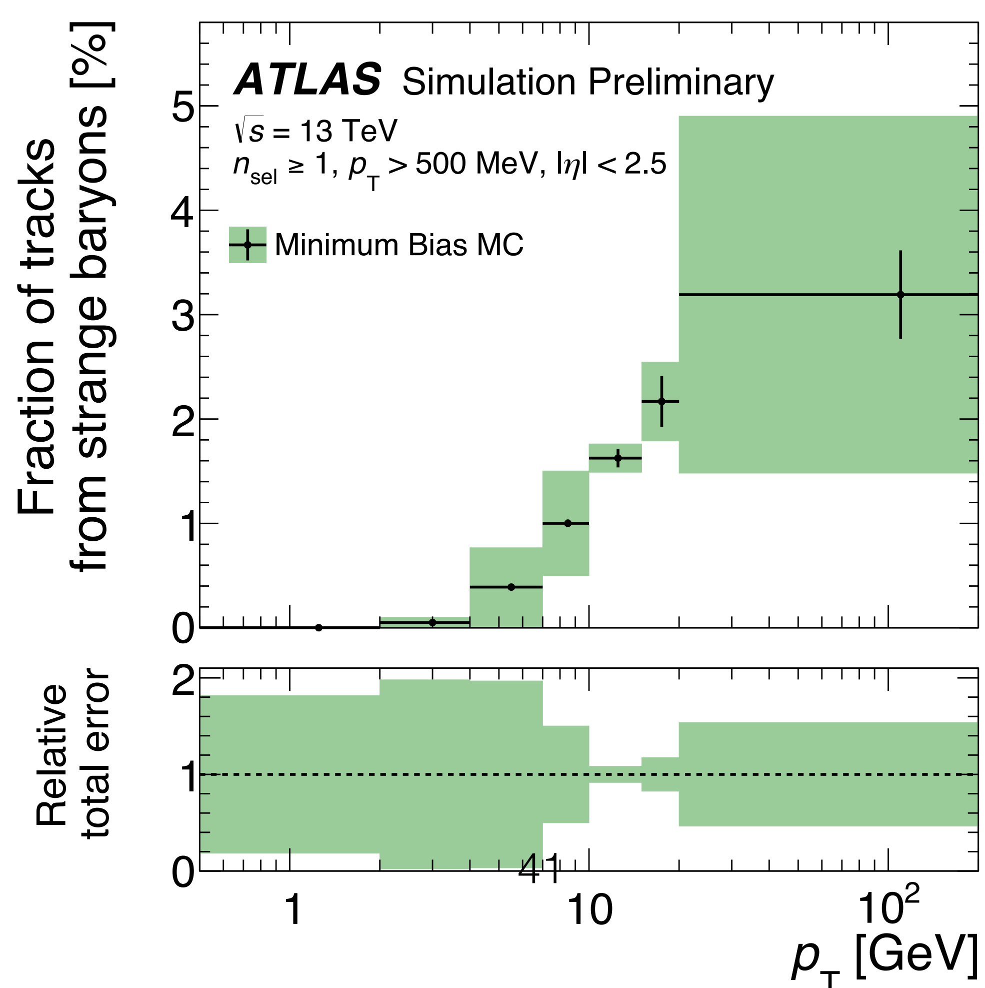


- Tails in the transverse distance from the beam line d_0 come mostly from photon conversions, hadronic interactions, and long lived particles
- Fit the distribution to extract the normalization of secondaries in the range of 5-9.5 mm to avoid mismodeling of the d0 distribution of the primary particles with d0<1.5
- Result is 2.2±0.6% of particles within the signal region (|d0|<1.5 mm) are secondary track particles

Strange Baryons

- Charged strange baryons ($0.3 \times 10^{-10} < \tau < 3 \times 10^{-10}$ s) are excluded from the primary particle definition
    - These decay in the inner detector and have lower reconstruction efficiency
- Remaining tracks from strange baryons: contributions take from Pythia8 A2, systematic uncertainties from the maximum differences between the generators
- Correction is 0.007±0.0006% on average and 3±2% for p_T>20 GeV





Generators

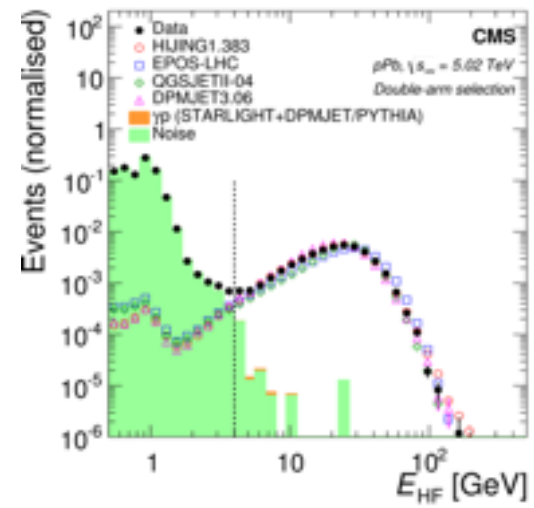
- Various generators and tunes were considered
  - Tunes comes from various data with only the most important ones shown

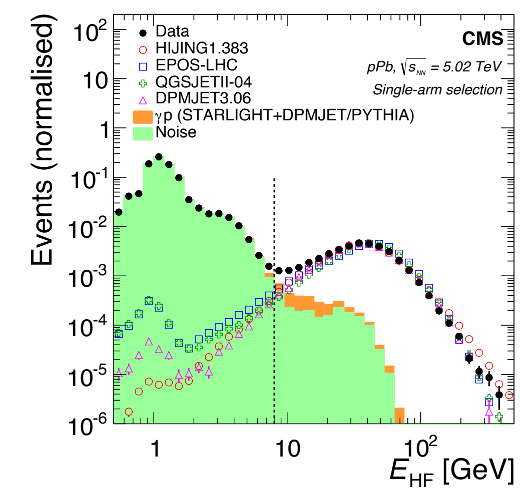
Generator	Version	Tune	PDF	Focus
Pythia8	8.186	A2	MSTW2008LO	MB
Pythia8	8.186	Monash	NNPDF2.3LO	MB/UE
Pythia8	8.186	A14	NNPDF2.3LO	UE/Shower
Herwig++	2.7.1	UEEE5	CTEQ6L1	UE
EPOS	3.1	LHC	N/A	MB
QSJET	II-04	LHC	N/A	MB

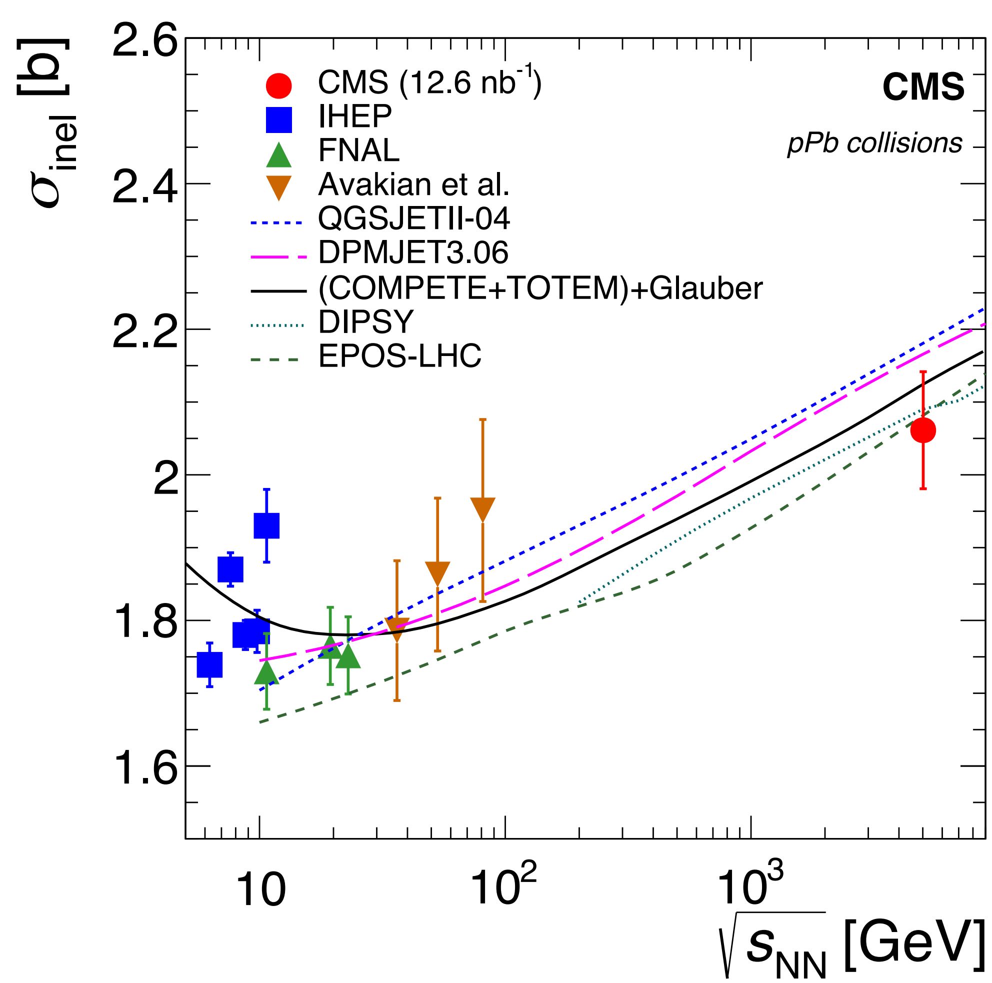
Developed to model cosmic rays in the atmosphere

Measurement of the inelastic cross section in proton-lead collisions at 5.02 TeV

- In summary, the measurement of the cross sections in pPb collisions presented here is the first such fully corrected measurement at multi-TeV energies and, thus, provides important constraints on hadronic interaction models commonly used in high-energy heavy ion and cosmic ray physics.







http://cms-results.web.cern.ch/cms-results/public-results/publications/FSQ-13-006/index.html

CMS UE Tunes

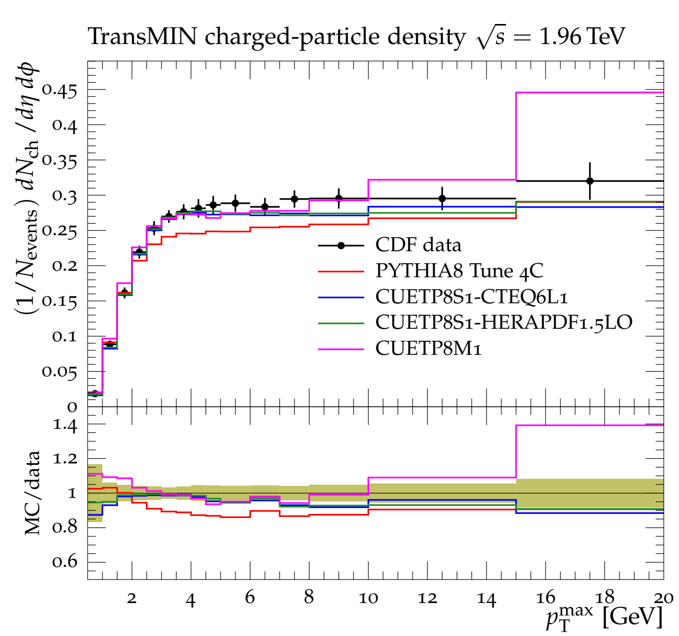
- Two tunes developed for Pythia8
  - Start with reference tune 4C
  - χ^2 fit of TransMax and TransMin 0.9 and1.96 TeV CDF and 7TeV CMS data for $\mathbf{N_{ch}}$ and $\mathbf{\Sigma p_T}$ density
- Parameters are varied in fit
  - Exponential falling matter overlap between the colliding protons
  - MPI interaction term
  - Prob. of color reconnection (CR)
- CR has the largest difference between Hera and CTEQ PDF's due to differences in shape at low x
- Fits are independently performed with the Monash Tune

PYTHIA8 Parameter	Tuning Range	Tune 4C	CUETP8S1	CUETP8S1
PDF	—	CTEQ6L1	CTEQ6L1	HERAPDF1.5LO
MultipartonInteractions:pT0Ref [GeV]	1.0–3.0	2.085	2.101	2.000
MultipartonInteractions:ecmPow	0.0–0.4	0.19	0.211	0.250
MultipartonInteractions:expPow	0.4–10.0	2.0	1.609	1.691
ColourReconnection:range	0.0–9.0	1.5	3.313	6.096
MultipartonInteractions:ecmRef [GeV]	—	1800	1800*	1800*
χ^2/dof	—	—	0.952	1.13

* Fixed at Tune 4C value.

PYTHIA8 Parameter	Tuning Range	Monash	CUETP8M1
PDF	—	NNPDF2.3LO	NNPDF2.3LO
MultipartonInteractions:pT0Ref [GeV]	1.0–3.0	2.280	2.402
MultipartonInteractions:ecmPow	0.0–0.4	0.215	0.252
MultipartonInteractions:expPow	—	1.85	1.6*
ColourReconnection:range	—	1.80	1.80**
MultipartonInteractions:ecmRef [GeV]	—	7000	7000**
χ^2/dof	—	—	1.54

* Fixed at CUETP8S1-CTEQ6L1 value.
** Fixed at Monash Tune value.



New tunes improve over 4C

Monash does not model well at low and high pTmax

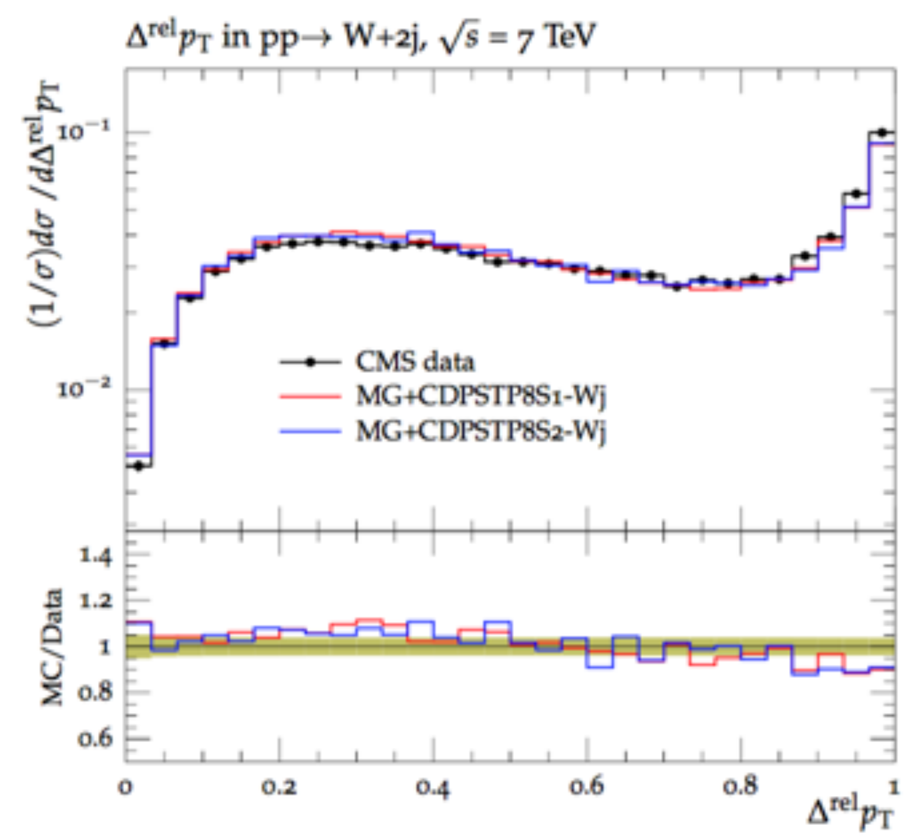
0.3 TeV CDF data is excluded

CMS Double Parton Showering Tunes

- σ_{eff} is determined by fitting for DPS in W+2jet and 4-jet using 2 tunes
  - first with only the exponential matter parameter
  - second with all 4 MPI parameters
- σ_{eff} is computed from the terms modifying the non-diffractive XS, which are the MPI parameters
  - Two tunes provide compatible σ_{eff}

Fits use the kinematics of the softer 2 jets

$$\Delta^{\mathrm{rel}} p_{\mathrm{T}} = \frac{|\vec{p}_{\mathrm{T}}^{\,\mathrm{jet}_1} + \vec{p}_{\mathrm{T}}^{\,\mathrm{jet}_2}|}{|\vec{p}_{\mathrm{T}}^{\,\mathrm{jet}_1}| + |\vec{p}_{\mathrm{T}}^{\,\mathrm{jet}_2}|},$$



PYTHIA8 Parameter	Tuning Range	Tune 4C	CDPSTP8S1-Wj	CDPSTP8S2-Wj
PDF		CTEQ6L1	CTEQ6L1	CTEQ6L1
MultipartonInteractions:pT0Ref [GeV]	1.0–3.0	2.085	2.085*	2.501
MultipartonInteractions:ecmPow	0.0–0.4	0.19	0.19*	0.179
MultipartonInteractions:expPow	0.4–10.0	2.0	1.523	1.120
ColourReconnection:range	0.0–9.0	1.5	1.5*	2.586
MultipartonInteractions:ecmRef [GeV]	—	1800	1800*	1800*
χ^2/dof	—	—	0.118	0.09
Predicted σ_{eff} (in mb)	—	30.3	$25.9^{+2.4}_{-2.9}$	$25.8^{+8.2}_{-4.2}$

* Fixed at Tune 4C value.

1507.07229v2