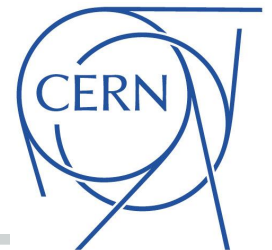

Small-x QCD and forward physics results from CMS

Gabor Veres (CERN)
on behalf of the CMS Collaboration

EPS HEP 2015 Conference, Vienna, Austria
July 23, 2015

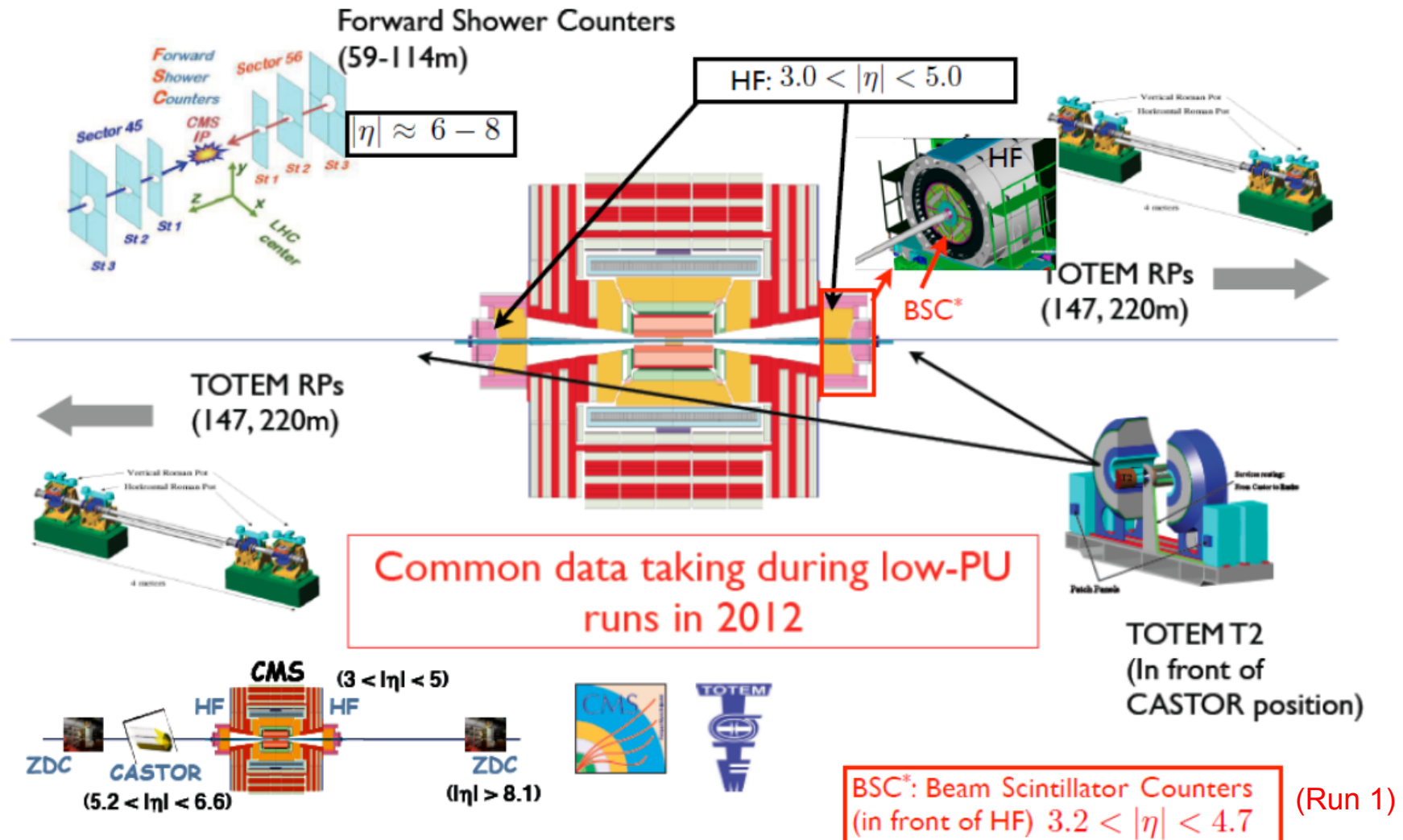


Outline

- CMS: forward instrumentation
- Various aspects of soft, diffractive QCD and EWK (in the order of increasing “hardness”):
 - Bose-Einstein Correlations, emission source size
 - soft single- and double- diffraction
 - Double Parton Scattering
 - 2 light and 2 b-jets
 - γ + 3 jets
 - Underlying event at 2.76 TeV with a hard scale
 - Exclusive WW and Anomalous QGC
- New: $dN/d\eta$ of charged hadrons at 13 TeV

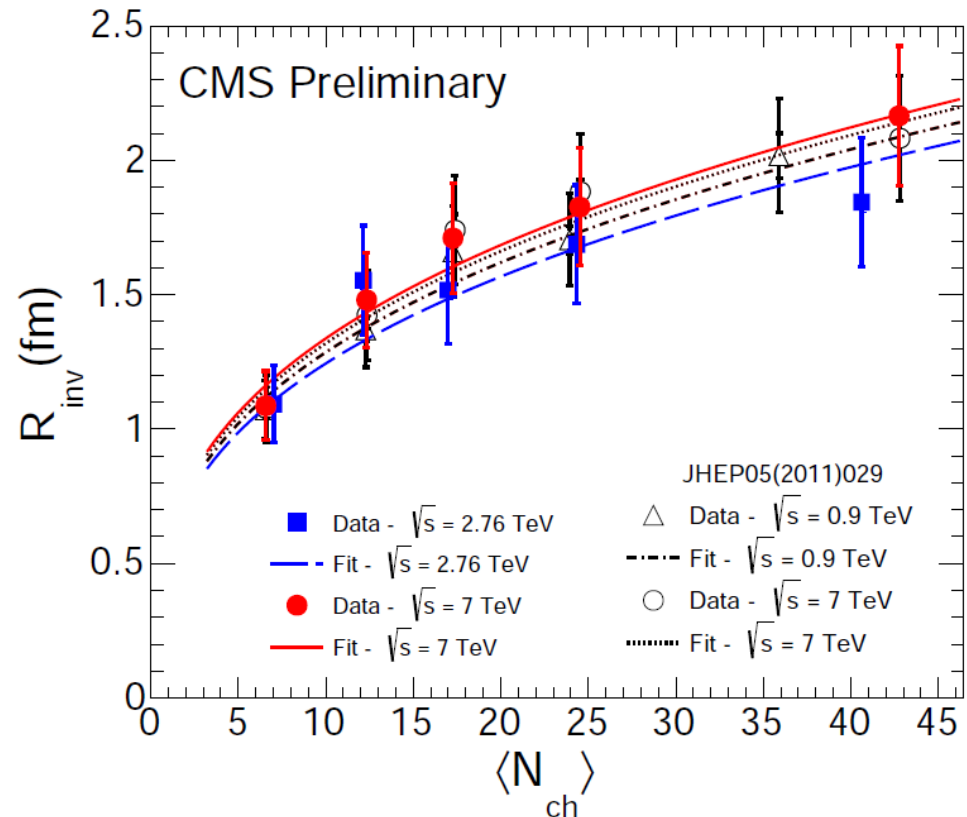
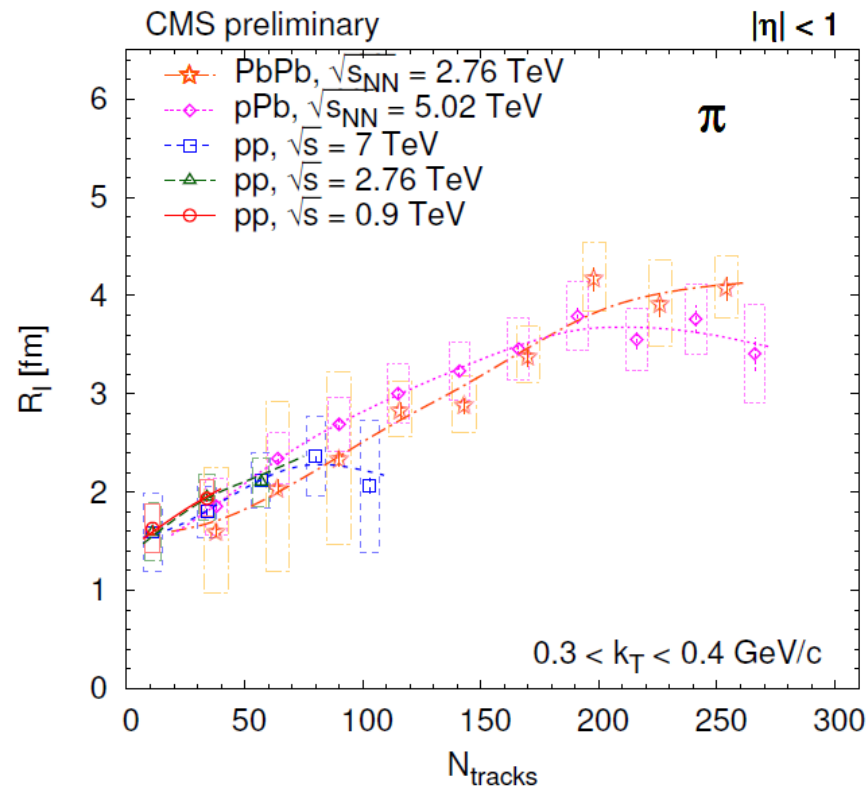
CMS Experiment

- Excellent instrumentation at high η (“forward”)



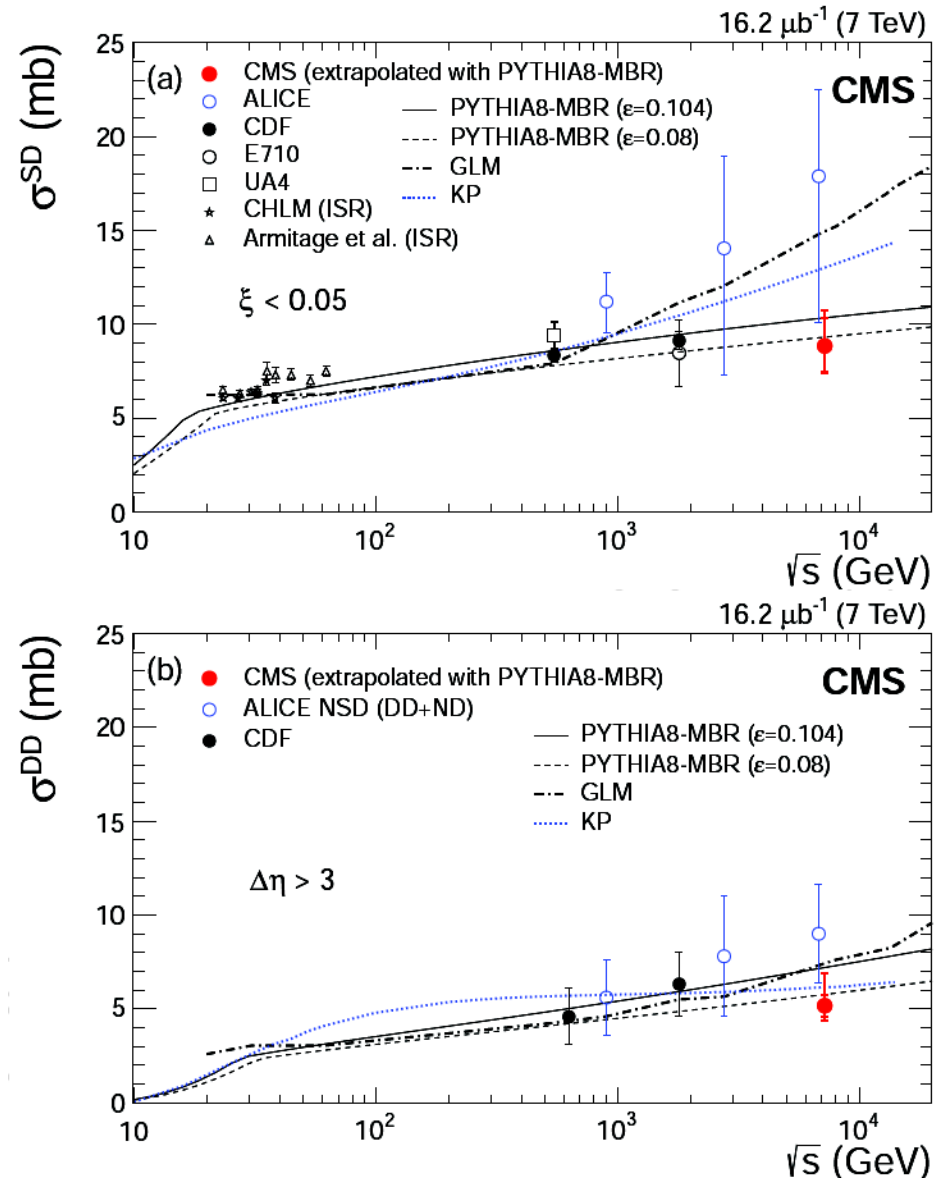
Bose-Einstein Correlations

- Identical boson-boson correlations can be used to determine the effective size of the emission source
- Identified particles, multi-dimensional analysis
- Scaling and similarity between pp, pPb, PbPb vs N_{ch}



Soft diffraction at 7 TeV

- Diffraction studied using the M_X , M_Y masses of subevents separated by the largest rapidity gap
- Measurements extrapolated to total single (SD) and double (DD) diffractive cross sections:
 - using PYTHIA 8 MBR
 - extrapolation around a factor of 2
- This measurement was made possible by the **CASTOR** detector



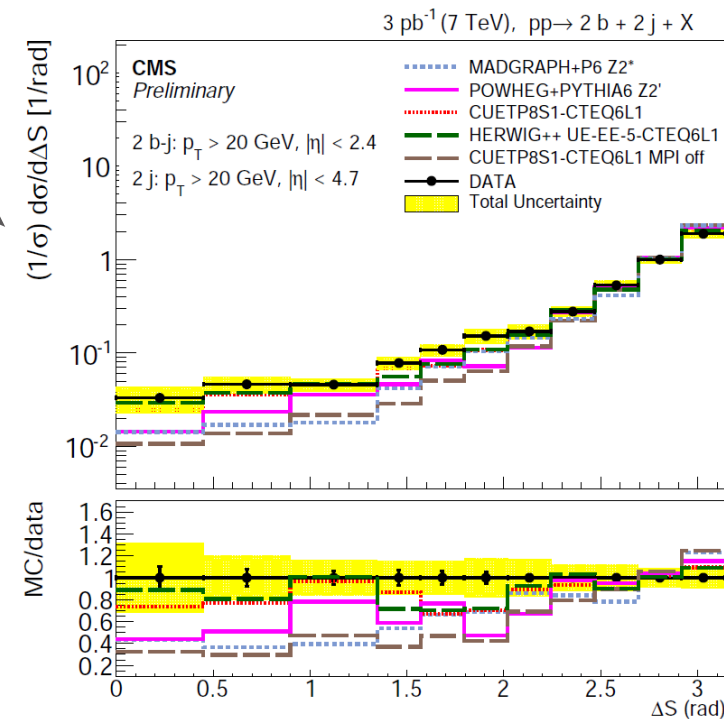
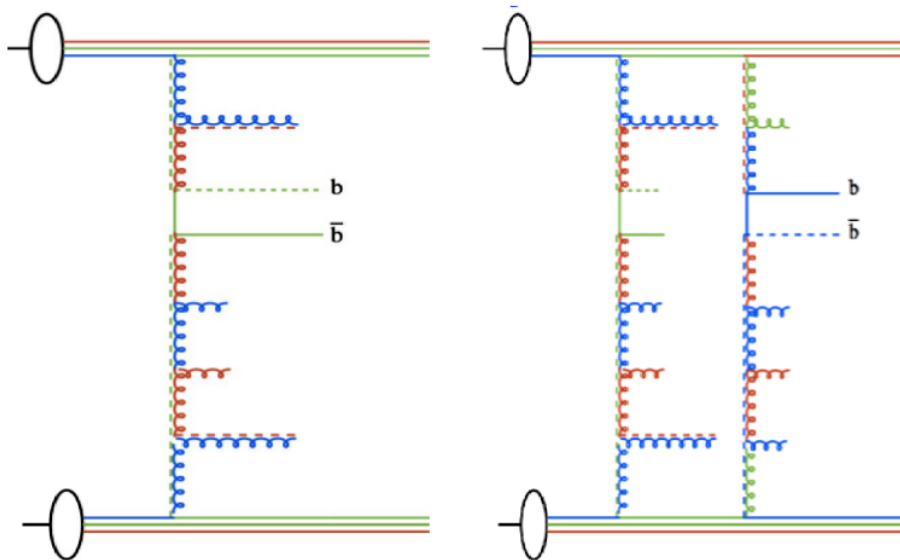
DPS in 2 jets and 2 b-jets

- QCD evolution with heavy flavour
- How to separate single and double chain processes?
- at least 4 jets with $p_T > 20$ GeV
- Correlation observables depend on the DPS contribution

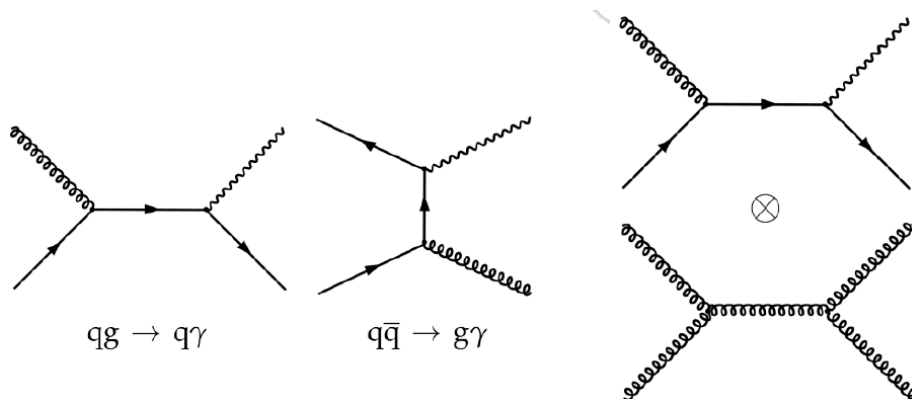
$$\Delta\phi(j_i, j_k) = |\phi_i - \phi_k|$$

$$\Delta S = \arccos \left(\frac{\vec{p}_T^b \cdot \vec{p}_T^l}{|\vec{p}_T^b| \cdot |\vec{p}_T^l|} \right)$$

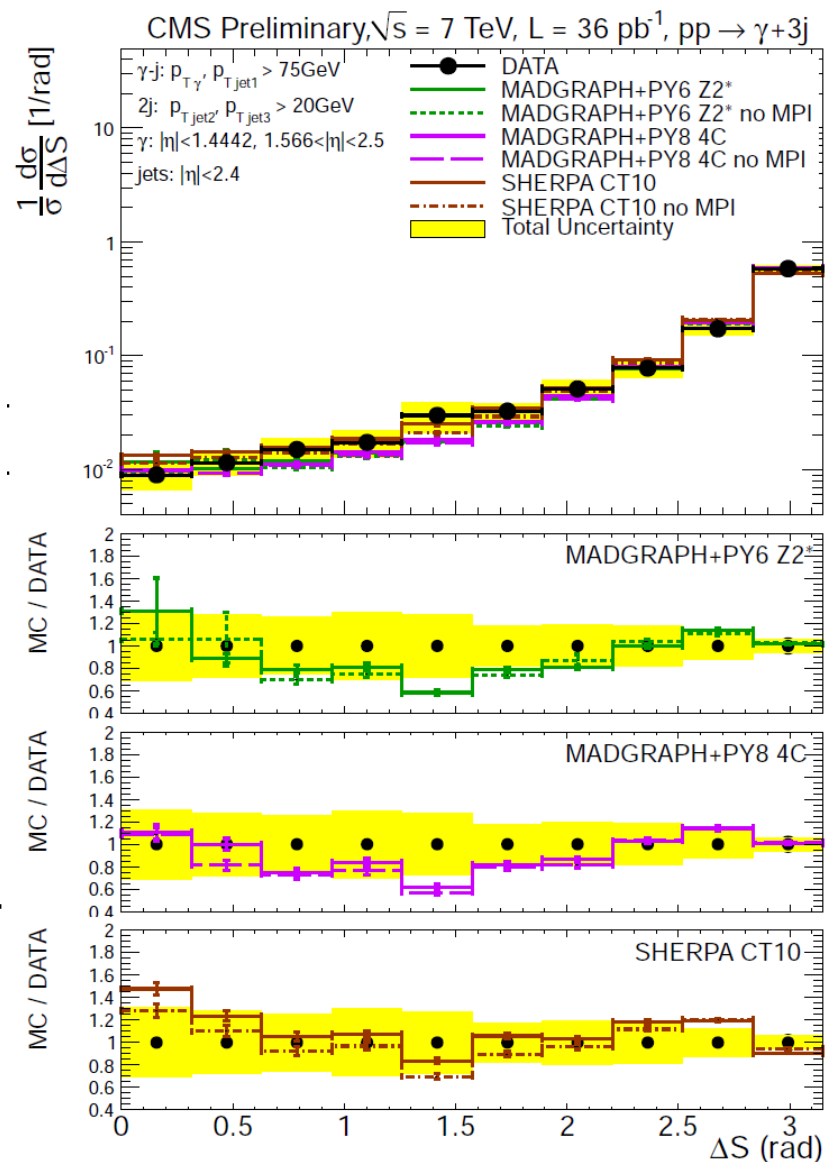
$$\Delta_{pair}^{rel} p_T = \frac{|p_T(j_i, j_k)|}{|p_T(j_i)| + |p_T(j_k)|}$$



DPS in $\gamma+3$ jets

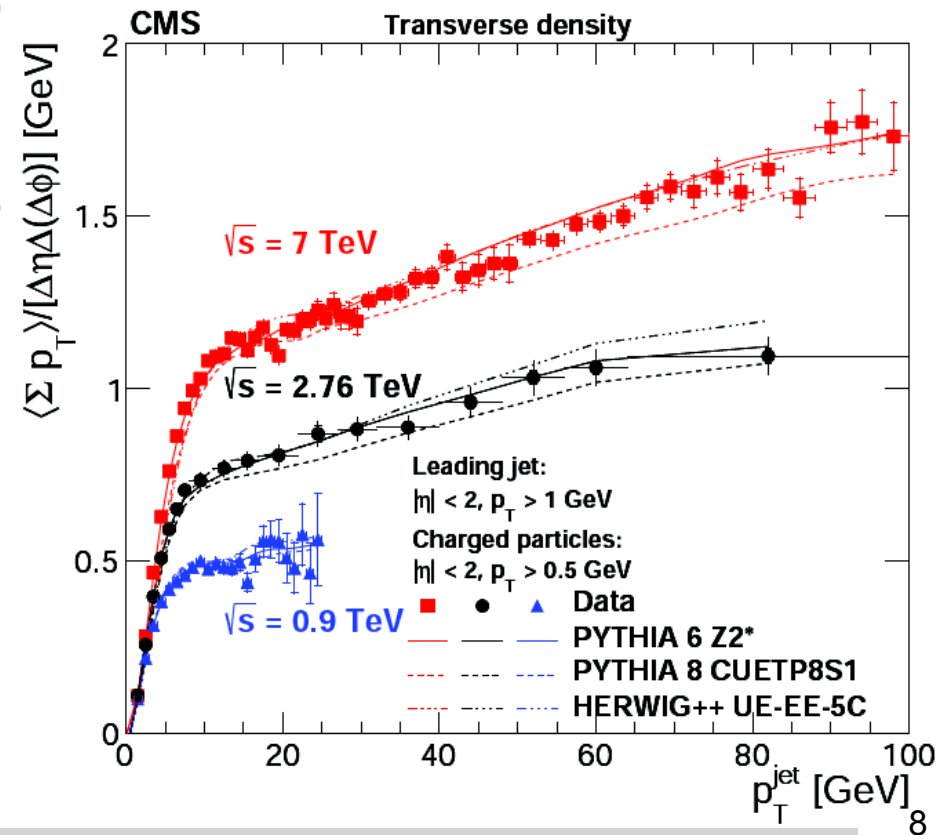
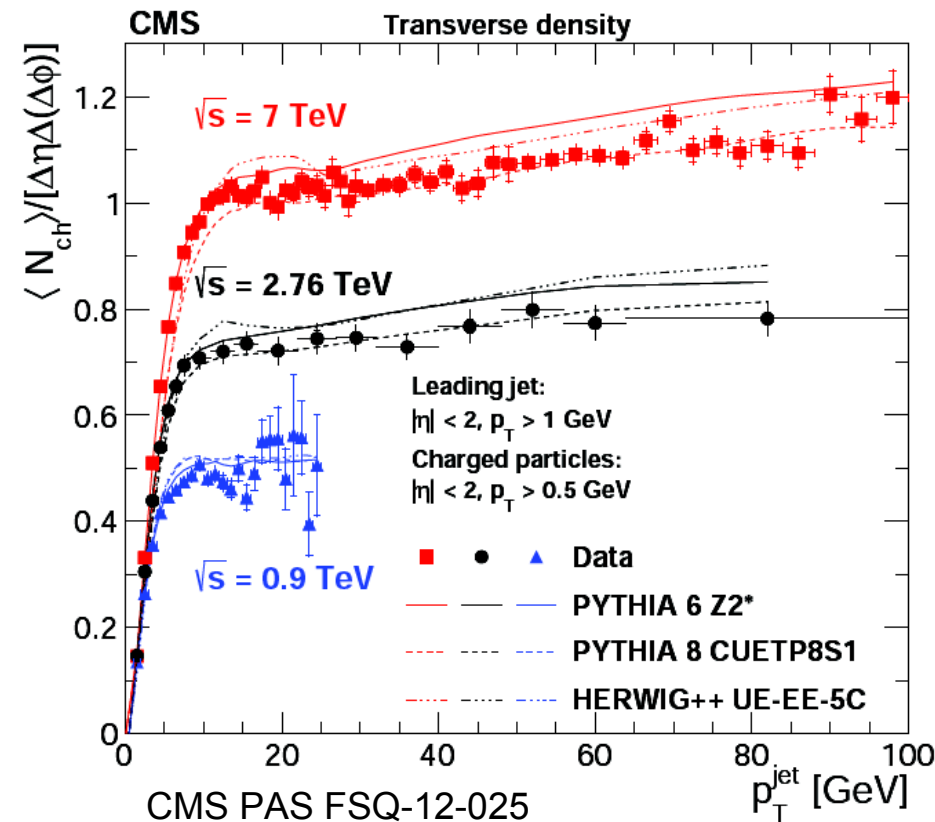


- Contributions: 3 jets + ...
 - direct photon
 - fragmentation photon
 - misidentified photon
- Selections:
 - gamma and one jet in the central region with $p_T > 75$ GeV
 - two jets with $p_T > 20$ GeV and $|\eta| < 2.4$
- MC describes the data well
 - measurement not very sensitive to MPI with these high p_T cuts



Underlying Event: new result at 2.76 TeV

- Charged particle density and Σp_T density in the region transverse to the highest p_T track-jet
- Good description by PYTHIA and HERWIG, well tuned
- collision energy dependence well reproduced

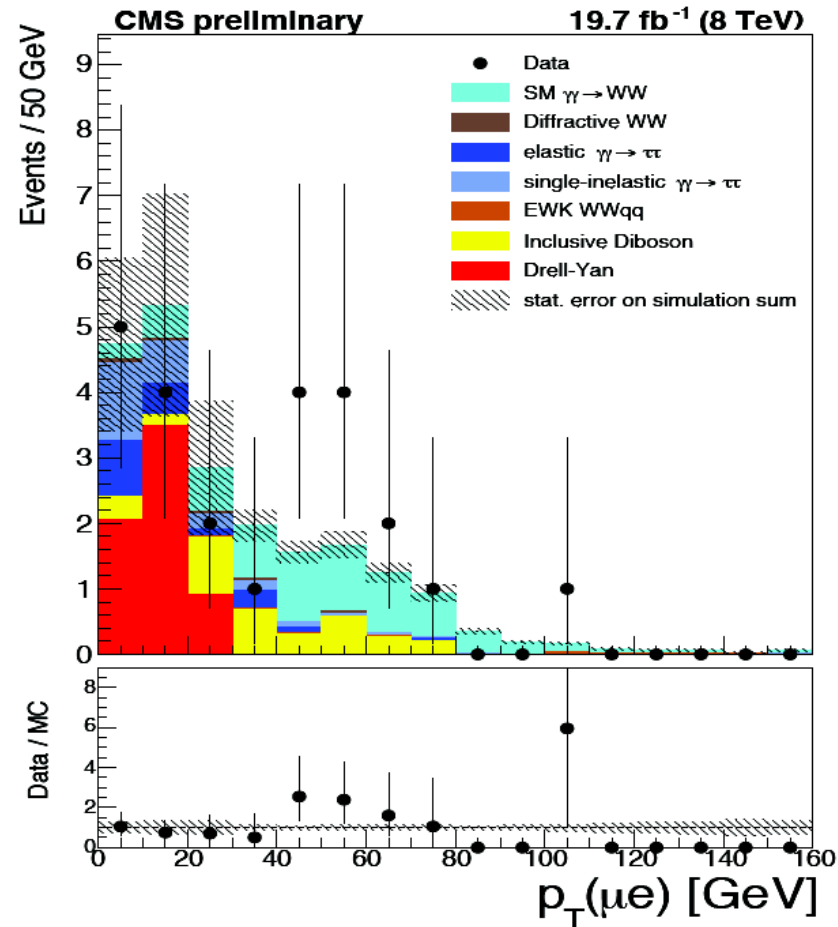
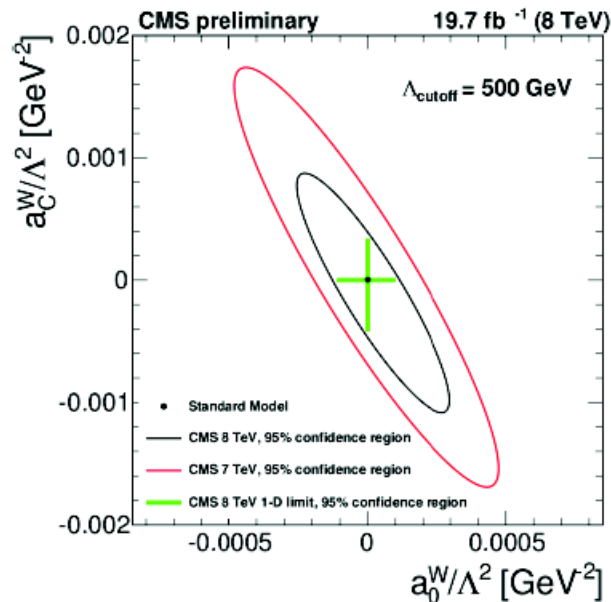
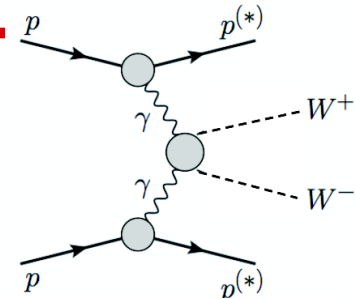


Exclusive W^+W^- and AQGC limits

- SM xsec not measured before, excess indicates new physics
- Using $WW \rightarrow \mu e$ channel to beat the QCD and DY bg
- veto on additional tracks (reducing the inclusive diboson bg)
- require high $p_T(e\mu)$
- 13 data events, 5.3 ± 0.1 signal, 3.5 ± 0.5 background

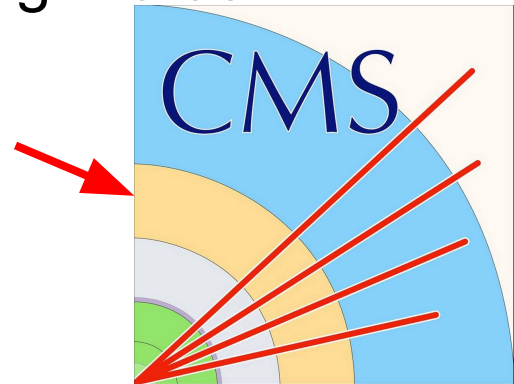
$$\sigma(pp \rightarrow p^{(*)}W^+W^-p^{(*)} \rightarrow p^{(*)}\mu^+e^-p^{(*)}) = 12.3^{+5.5}_{-4.4} \text{ fb}$$

- New AQGC limits:



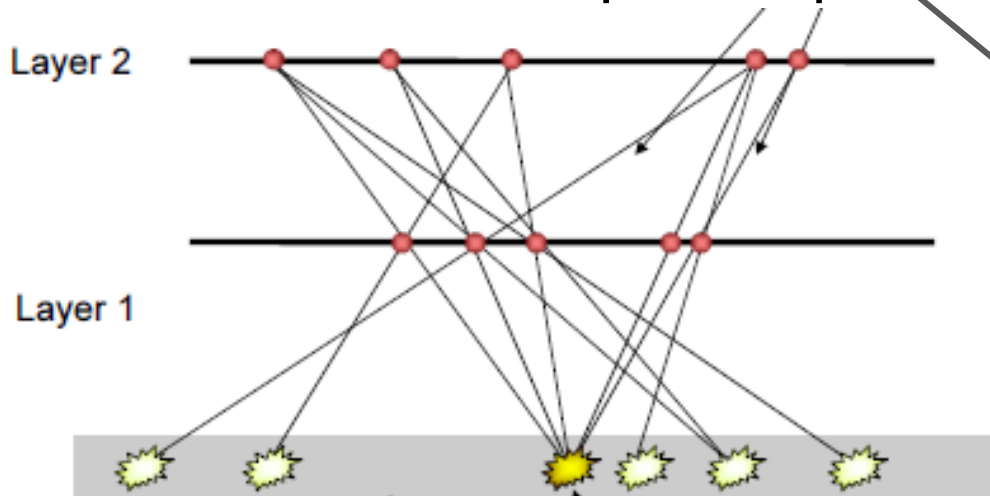
dN/d η of charged hadrons at 13 TeV

- Several methods employed
 - tracking, tracklets, pixel counting
- Trigger:
 - zero bias, PU = 0.05, ~170k collisions in a special run
- Definition of a 'collision':
 - inelastic (leads to a few % MC dependence)
- Datasets:
 - data taken June 7, 2015
 - number of collisions per bunch crossing: ~0.05
 - CMS tracker and pixel detectors ON
 - CMS magnet off, B=0 (straight tracks)
- First LHC publication at 13 TeV

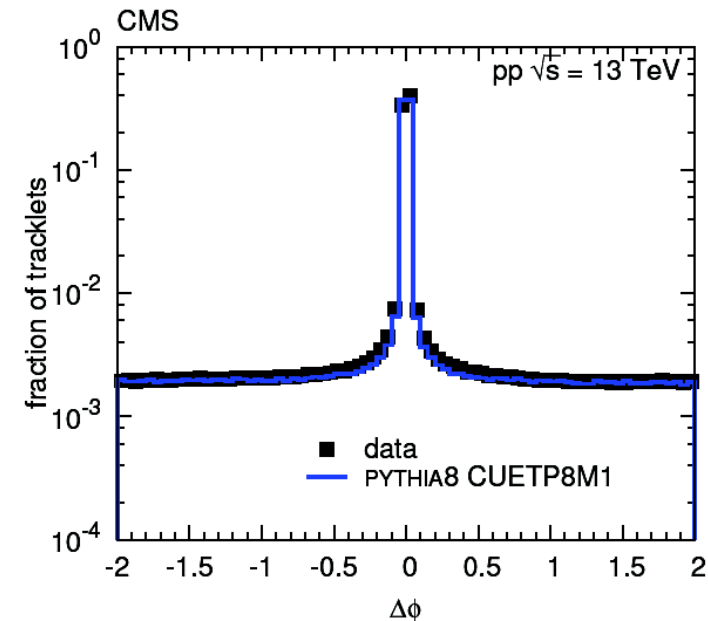
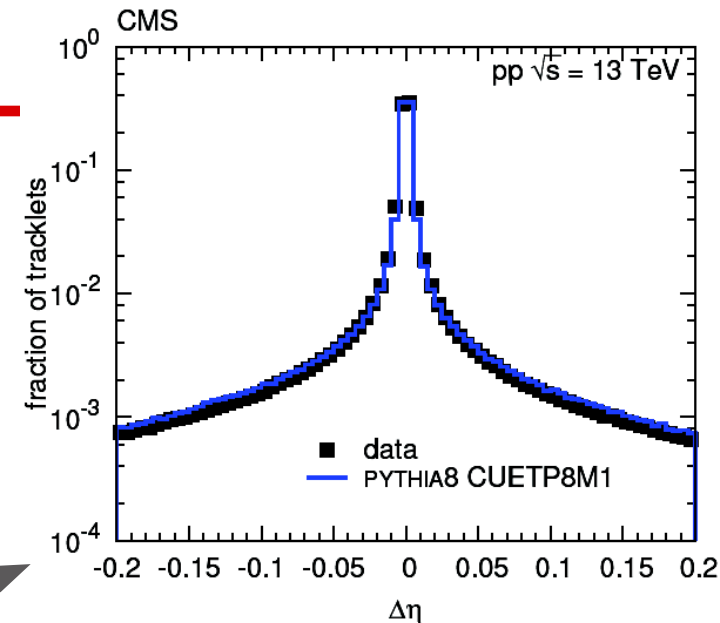


dN/d η : tracklets

- Using pairs of pixel barrel layers (3 combinations)
- Insensitive to alignment, very robust
- Has its own vertexing (extremely efficient)
- straight tracklets, sharp correlations in $\Delta\eta$ and $\Delta\phi$

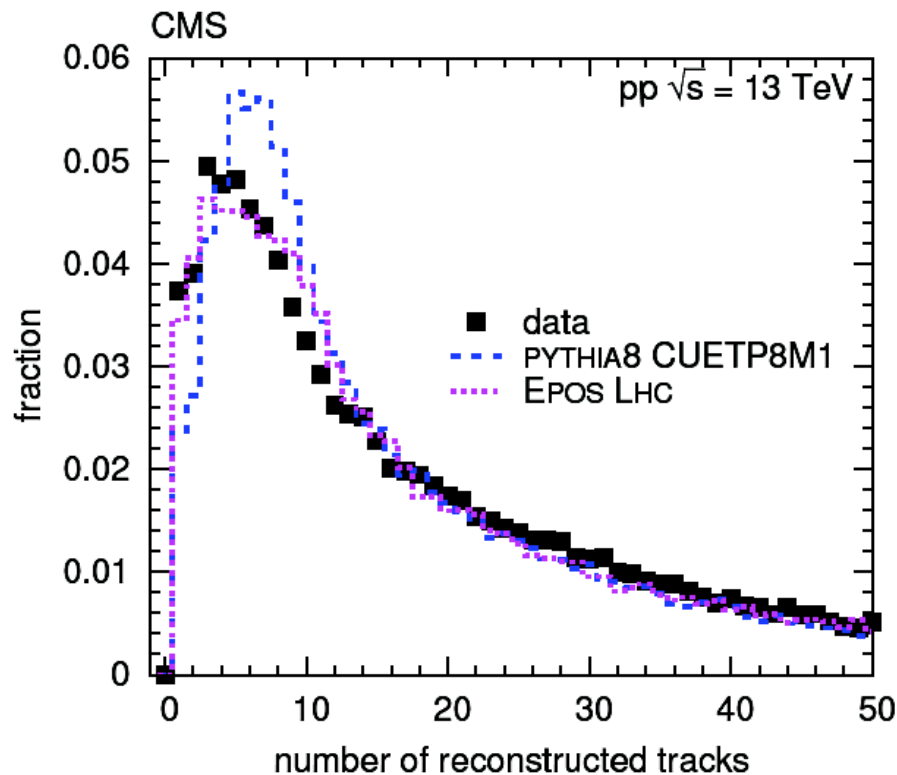


<http://arxiv.org/abs/1507.05915>

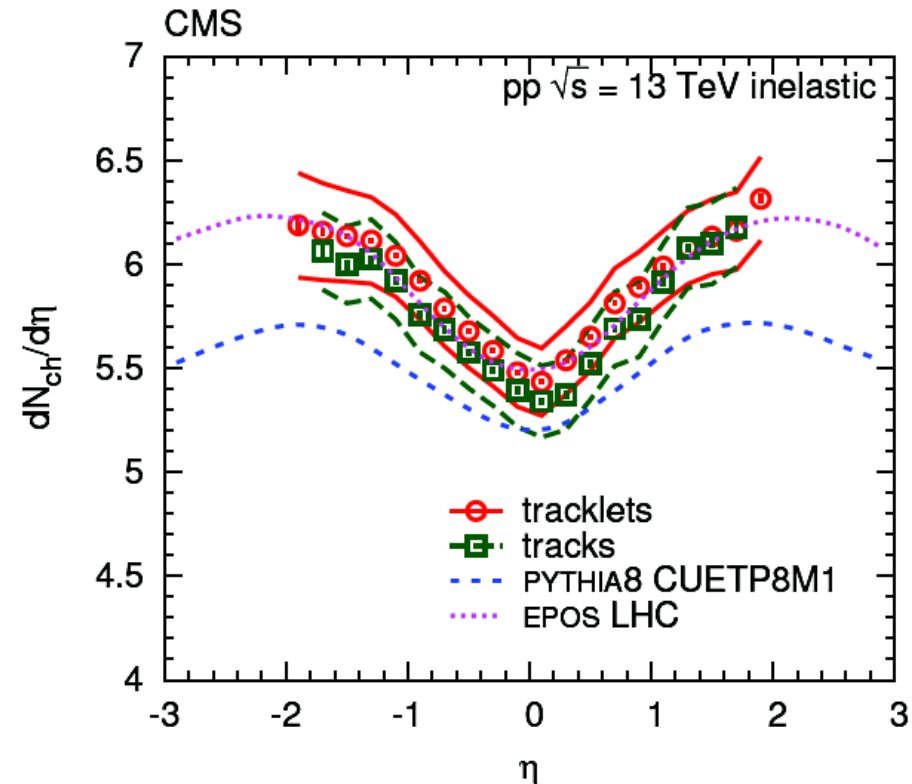


$dN/d\eta$: tracks

- Multiplicity distribution of reconstructed tracks



- Comparison of corrected $dN/d\eta$ results: tracks and tracklets

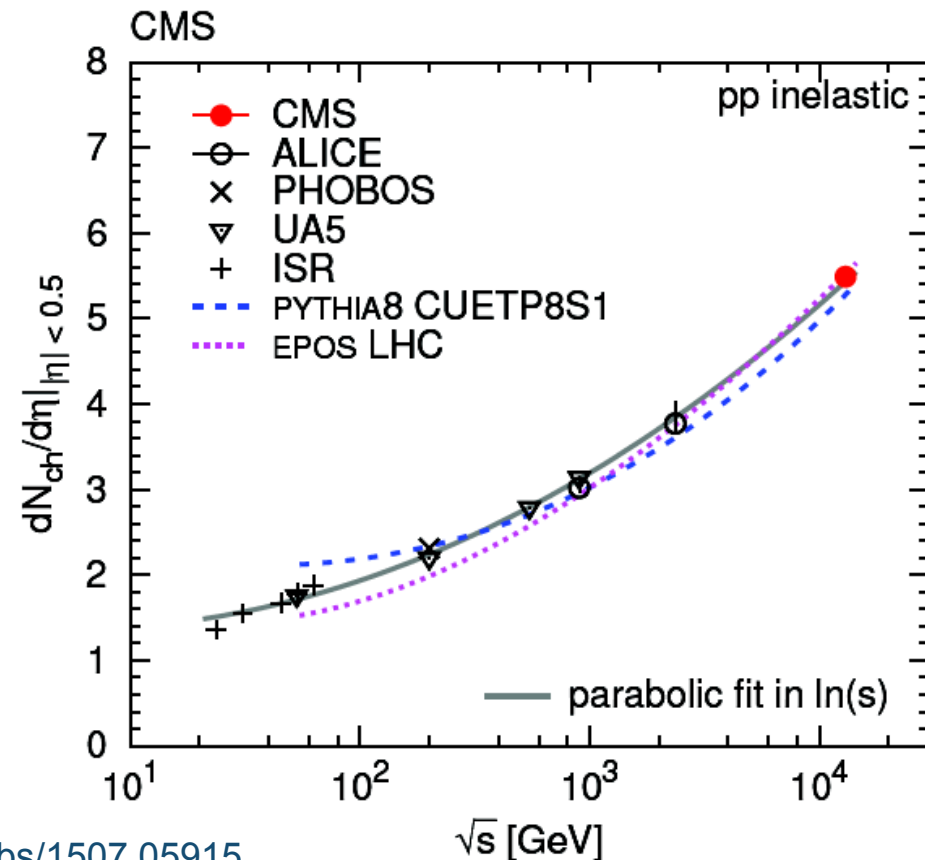
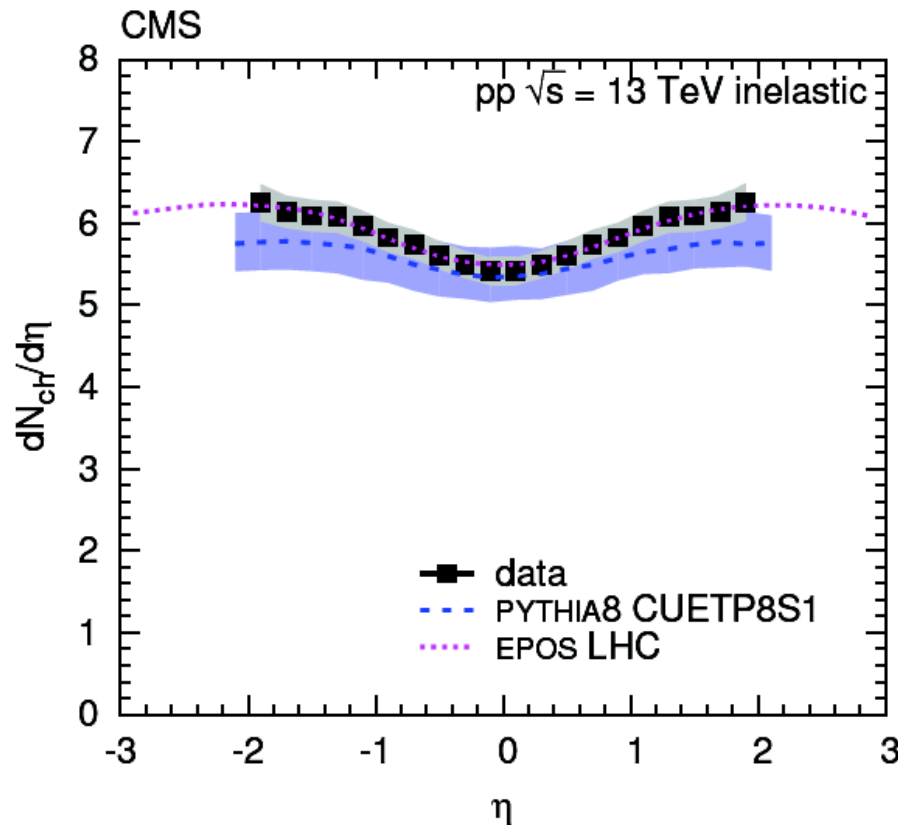


- In both cases, agreement is better with EPOS LHC

$dN/d\eta$ of charged hadrons at 13 TeV

- Averaged main $dN/d\eta$ result for *inelastic* events

- Collision energy dependence
- Central value:
 $5.49 \pm 0.01(\text{stat}) \pm 0.17(\text{syst})$



Summary

- CMS has a **versatile** forward, diffractive, exclusive, soft QCD, MPI and low-x physics program
- CMS **forward instrumentation** is unique, especially complemented by the TOTEM experiment
 - a joint physics program and data taking is underway
 - **CT-PPS** will take off next year: tagging diffraction and CEP at high luminosity
- **BEC**: scaling between pp, pPb, PbPb
- **SD and DD** cross sections measured at 7 TeV, CASTOR
- **DPS** studied with 2 jets + 2 b-jets, and γ +3 jets
- New: **Underlying Event** at 2.76 TeV agrees well with models
- New limits on **AQGC** and measured xsec of **exclusive WW**
- The **first LHC paper** at 13 TeV: $dN/d\eta$ of charged hadrons

Results that did not fit in this talk...:

- Identified particle spectra
 - Eur. Phys. J. C 72 (2012) 2164
- EWK production of Z + fwd/bckwd jets,
 - Eur. Phys. J. C 75 (2015) 66
- Mueller-Navelet dijet decorrelations,
 - CMS PAS FSQ-12-002
- forward-central jet correlations,
 - CMS PAS FSQ-12-008
- Drell-Yan cross section with jets,
 - CMS PAS FSQ-13-003
- ...

Please see the full collection at:

<https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsFSQ>

Results that did not fit in this talk...:

Please see the following *related CMS* talks:

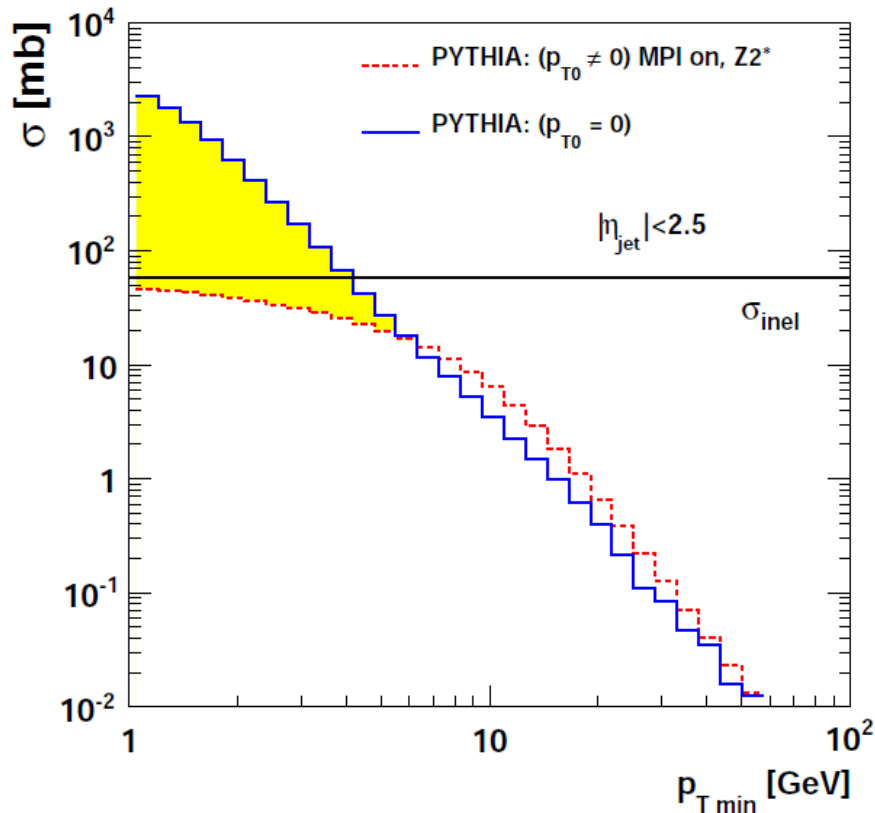
- Manfred Jeitler: exclusive WW and AQGC
 - today 12:24, HS31
- Hans Jozef H Van Haeevermaet: jets and diffraction
 - today 15:15, HS32
- Ankita Mehta: Double Parton Scattering
 - today 17:45, HS32
- Manfred Jeitler: inelastic cross section
 - poster session

THANK YOU FOR YOUR ATTENTION!

END

Leading charged particle (jets)

- How is the p_T -integrated cross section of $2 \rightarrow 2$ processes tamed?



$$\sigma_{\text{int}}(p_{T,\min}) = \int_{p_{T,\min}} dp_T \frac{d\sigma}{dp_T}$$

$$\sigma_{\text{int}}(p_{T,\min}) \propto \frac{1}{p_{T\min}^2} \text{ for } p_{T,\min} \rightarrow 0$$

In PYTHIA:

$$\sigma \rightarrow \sigma \times \frac{\alpha_s^2(p_{T0}^2 + p_T^2)}{\alpha_s^2(p_T^2)} \frac{p_T^4}{(p_{T0}^2 + p_T^2)^2}$$

What do the data say?

Leading charged particle (jets)

- How is the p_T -integrated cross section of $2 \rightarrow 2$ processes tamed?

$$r(p_T^{\min}) = \frac{1}{N_{\text{evt}}} \sum_{p_T^{\text{lead}} > p_T^{\min}} \Delta p_T^{\text{lead}} \left(\frac{\Delta N}{\Delta p_T^{\text{lead}}} \right)$$

normalized at 15 GeV

- Shape of the distribution is not well described in general
- EPOS gives the best (and excellent) description of the data

