CMS Measurements and UHECR

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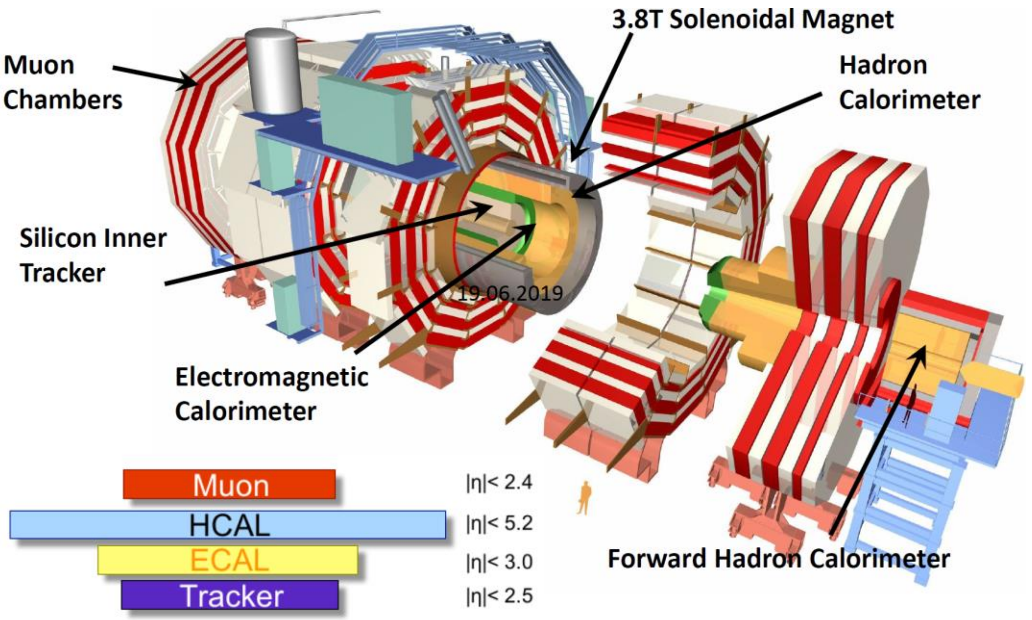
On behalf of CMS

SINP MSU

Introduction

LHC collides p+p, p+Pb and Pb+Pb.
Air nuclei are in between proton and lead in atomic weight, so joint analysis of results of pp and pPb interactions is particular relevant for tuning UHECR generators.
Two generators, EPOS-LHC and QGSJETII-04, are compared here with CMS data on pp and pPb.

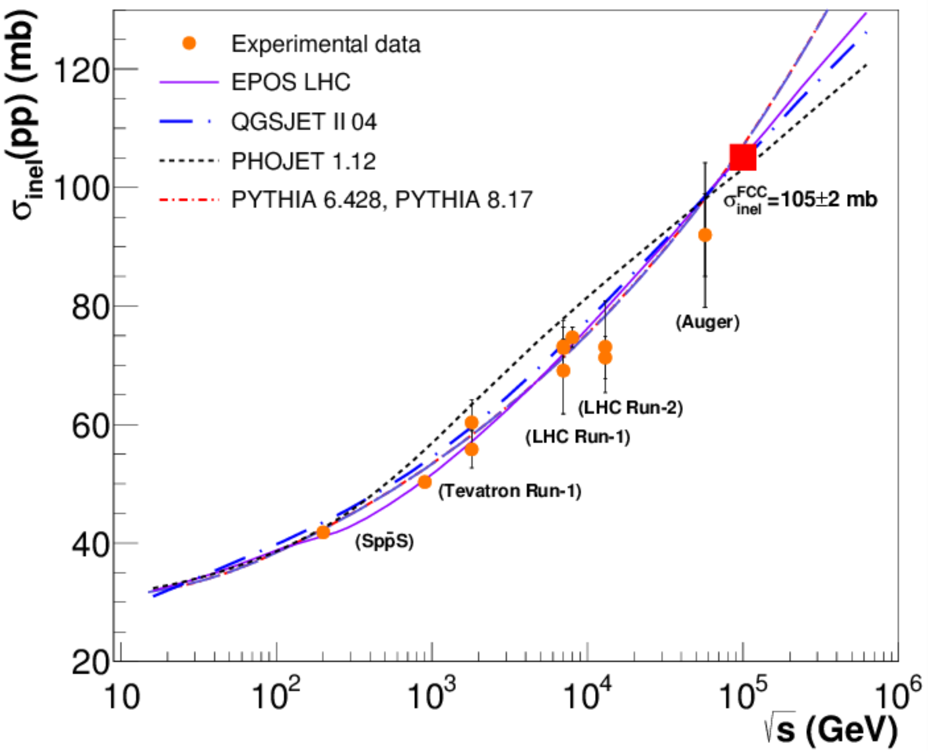
CMS detector



pp: inelastic cross-sections

D. d'Enterria, T. Pierog

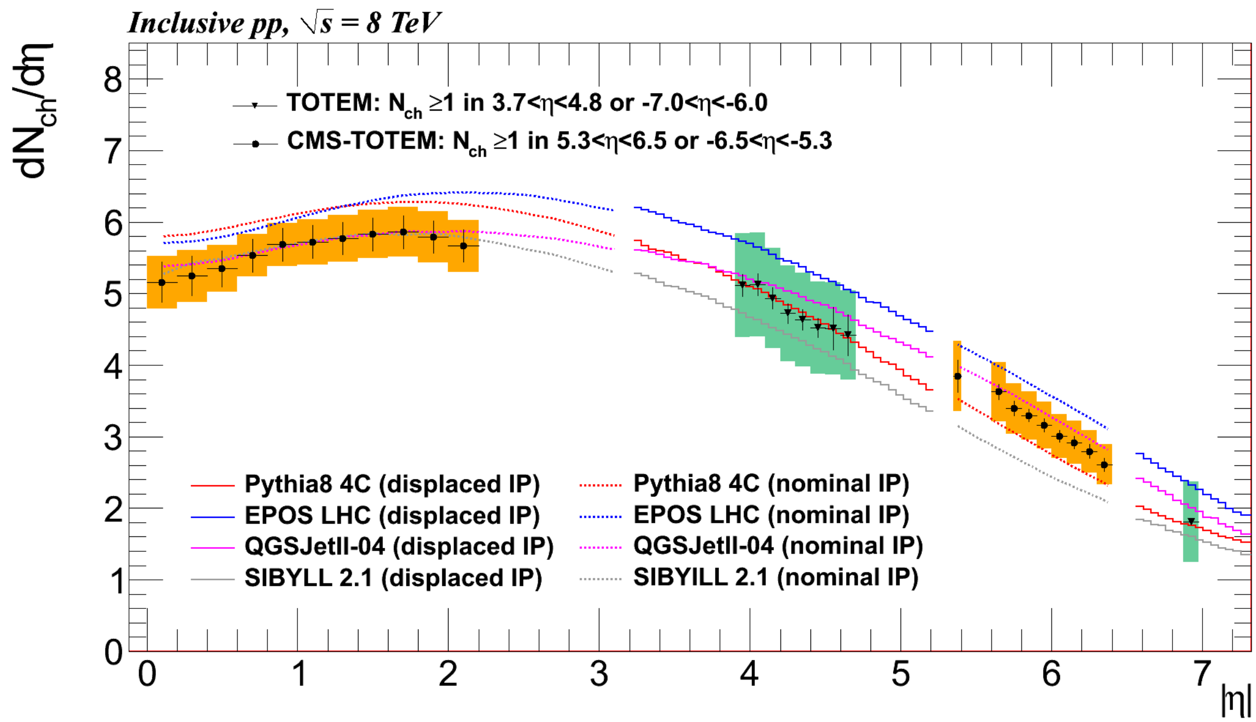
J. High Energ. Phys. **2016**, 170 (2016)



EPOS-LHC and QGSJETII 04 are close to each other in LHC energy range and are compatible with data.

pp 8 TeV: charged particle density

Eur. Phys. J. C 75, 126 (2015).

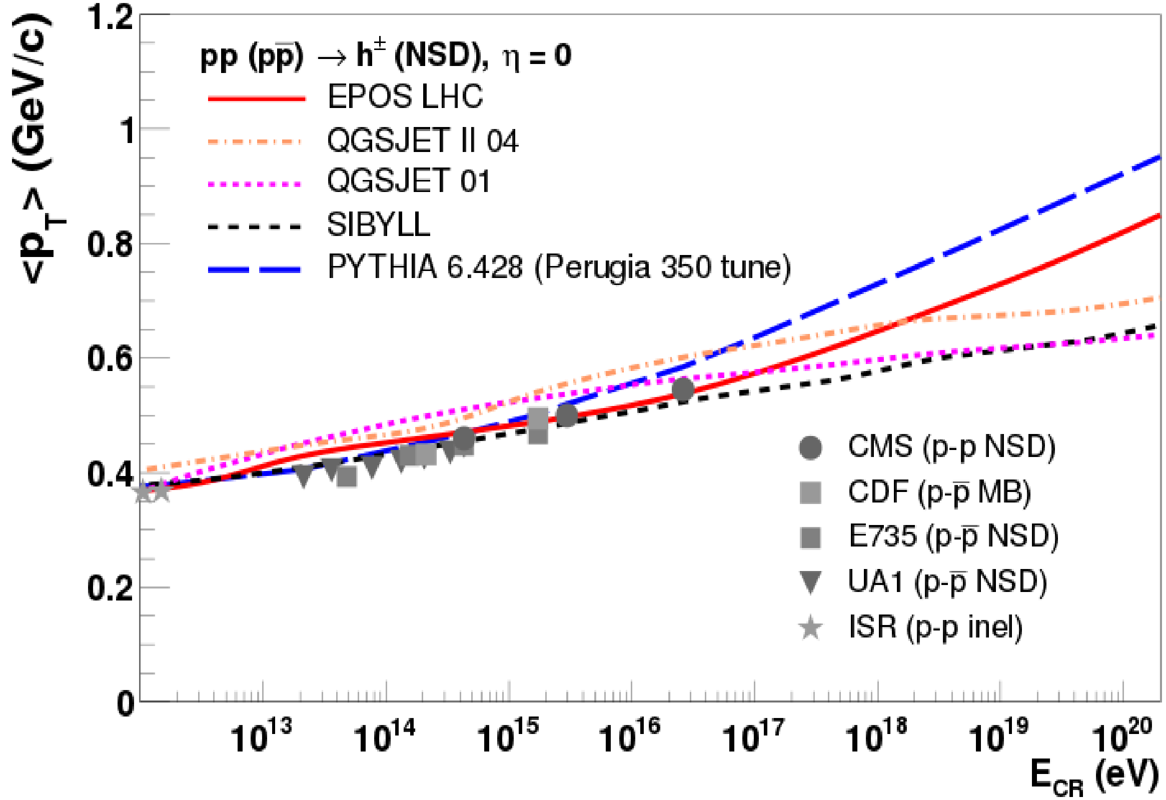


- QGSJETII-04 is close to data
- EPOS-LHC is above data by ~10%.

pp: <p_T> energy dependence

D.d'Enterria, T.Pierog

Astrophys.J. 874 (2019)

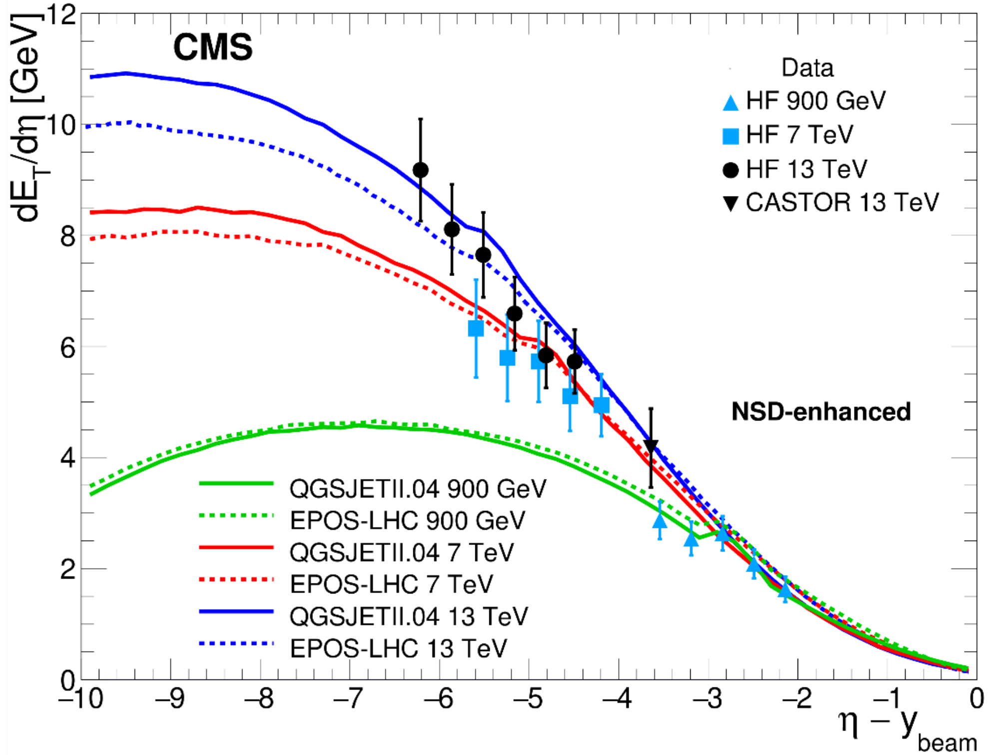


- EPOS-LHC is close to data.
- QGSJET II-04 overestimates <p_T>.

pp: transverse energy

*Eur. Phys. J. C **79**, 391 (2019)*

NSD enhanced selection: at least one charged particles in both sides at 3.9 < |η| < 4.4

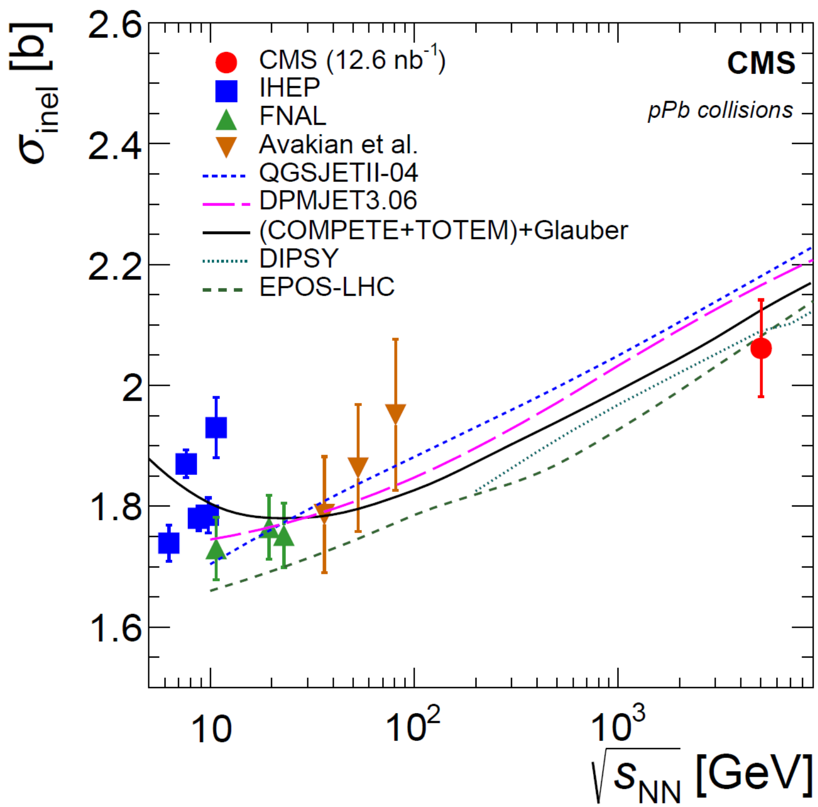


- Both generators agree with data within errors.
- Consistent with hypothesis of limiting fragmentation.

pPb

Inelastic cross-section

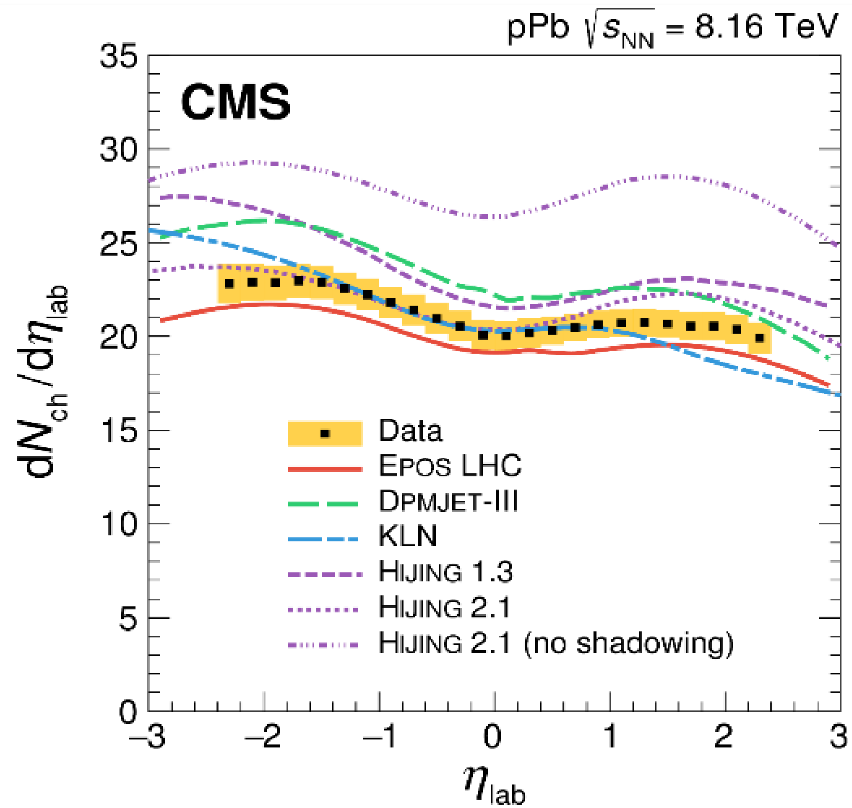
PLB 759 (2016) 641,



- EPOS-LHC fits CMS data.
- QGSJETII-04 is above data by ~5%.

Charged particle density

JHEP 01 (2018) 045



EPOS-LHC is below data by ~7%.

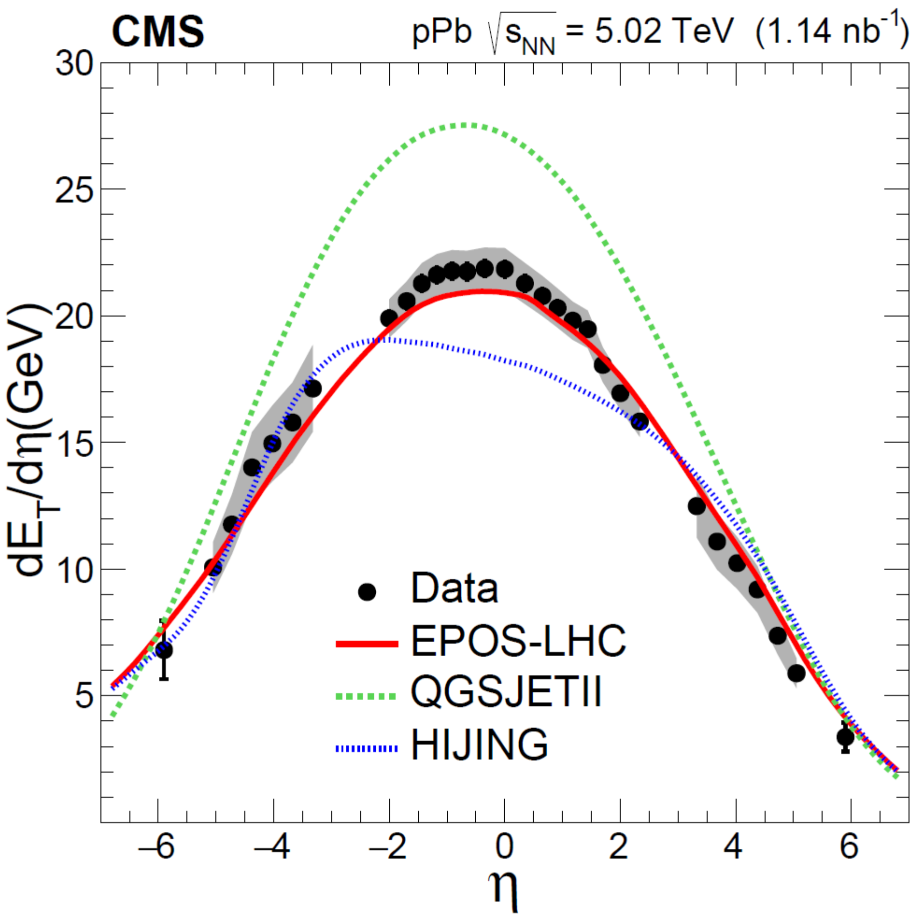
pPb: transverse energy

pPb 5 TeV

Centrality and pseudorapidity dependence of the transverse energy density in pPb collisions at $\sqrt{s_{NN}} = 5.02$ TeV

CMS collaboration *Phys.Rev.C* 100 (2019) 2, 024902

$dE_T/d\eta$ in minimum bias events



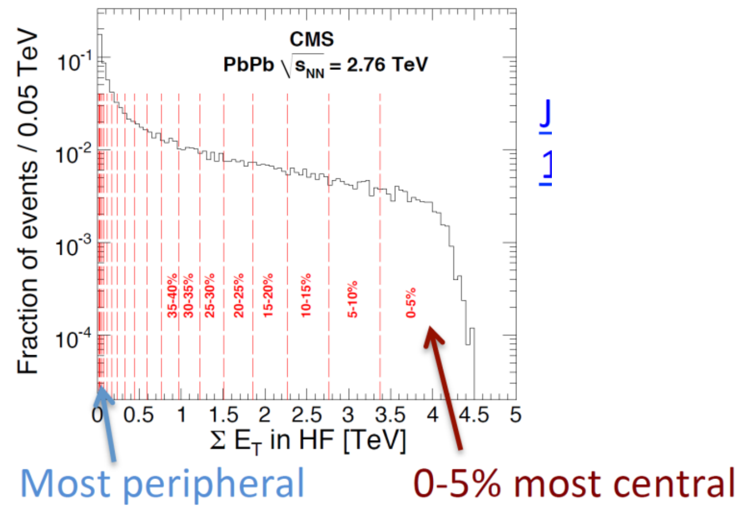
- EPOS-LHC does well
- QGSJETII significantly overestimates production

Centrality

Centrality estimates impact parameter of collision and thus overlap of two nuclei and number of participating nucleons. Since these quantities are not measured directly, centrality in data is defined with use of some strongly correlated with number of participating nucleons measured quantities.

Three such estimators are considered:

JHEP 08 (2011) 141



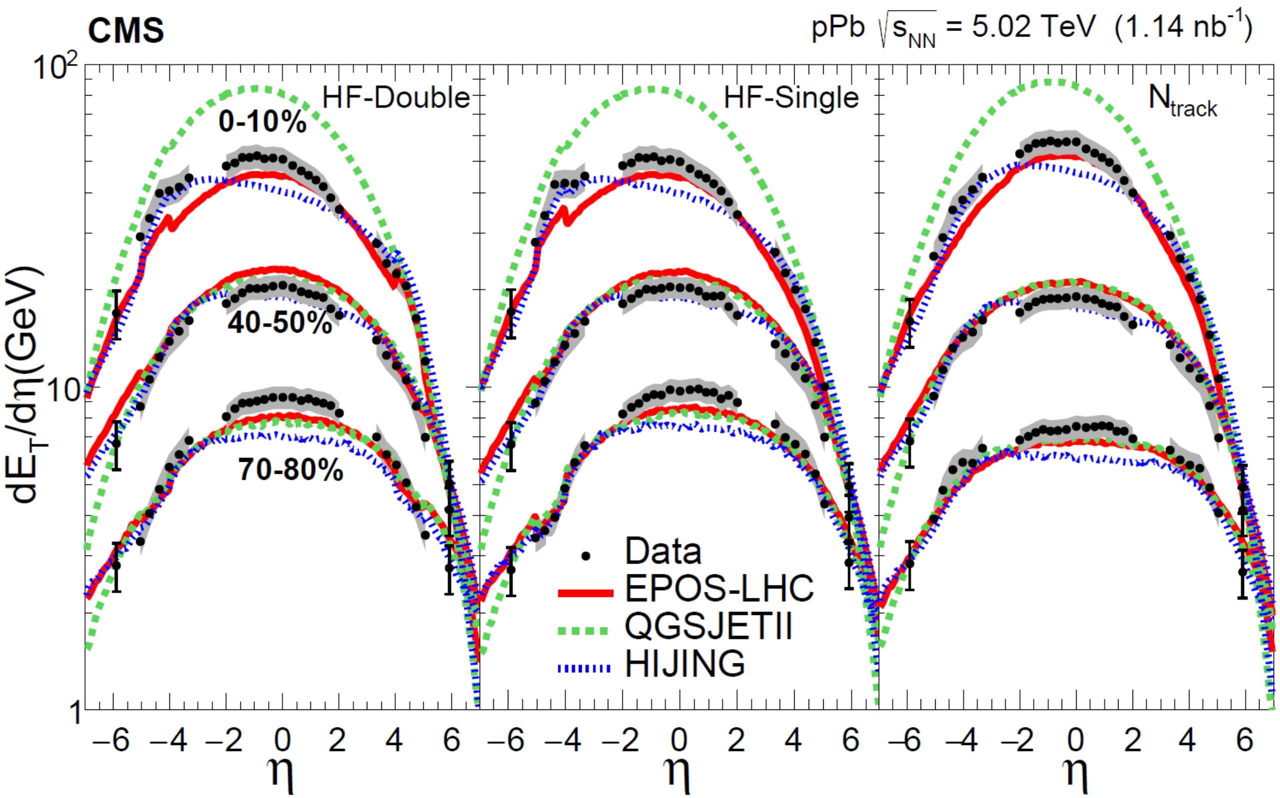
Centrality Name	Definition
HF-Double	E_T within $4 < \|\eta\| < 5$
HF-Single	E_T within $-4 > \eta > -5$
N_{Track}	Tracks within $\|\eta\| < 2.4$

Centrality is defined as percentile of events with values of the estimator within some interval.

Glauber model is used to relate the centrality to N_{part} and impact parameter.

$dE_T/d\eta$ at different centralities

Three centrality estimators



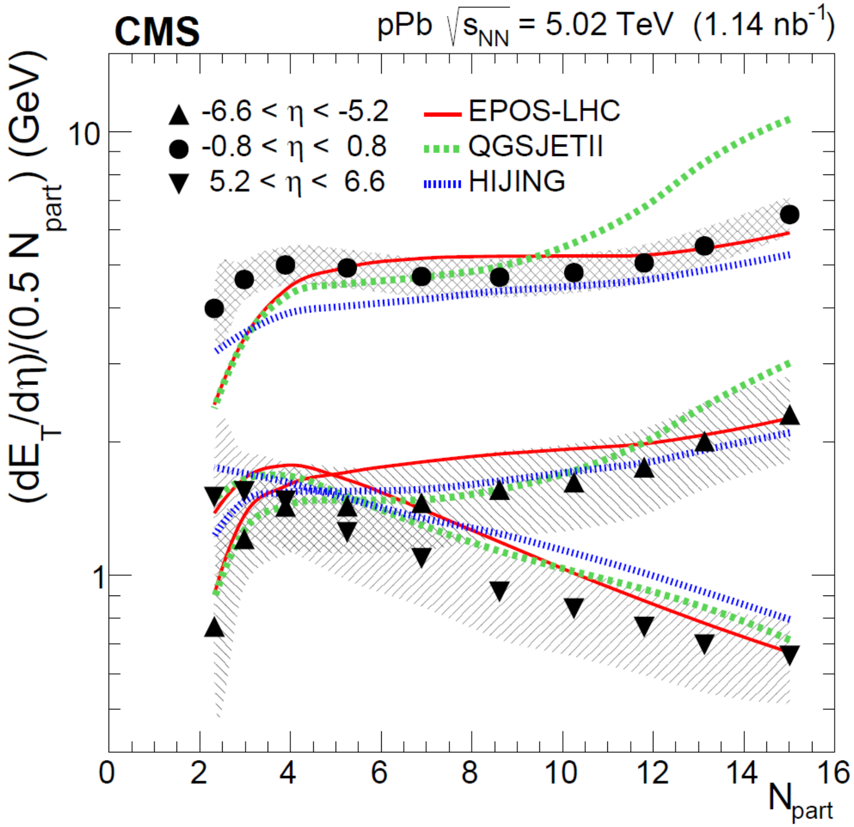
Negative eta -> proton side, positive eta -> lead side

- QGSJETII grossly overestimates production at high centrality
- QGSJETII and EPOS-LHC are close to each other and data at medium and low centrality

$dE_T/d\eta$ divided by participant number

Three η ranges

N_{part} from Glauber model



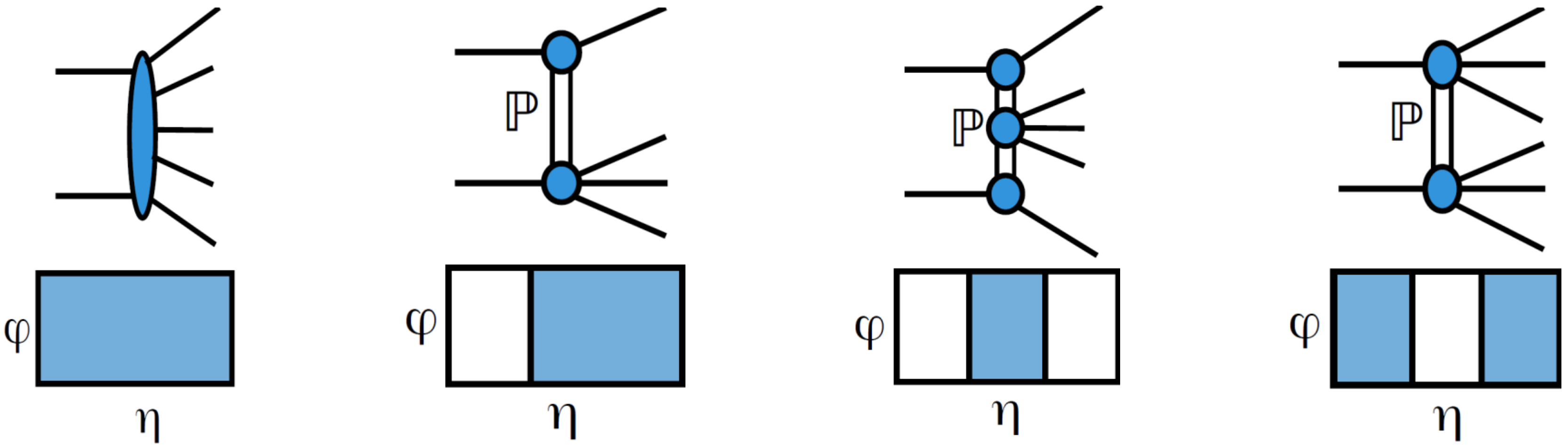
- $dE_T/d\eta$ scales on N_{part} at midrapidity, except for smallest and largest N_{part}
- $dE_T/d\eta$ rises faster than N_{part} in lead fragmentation and slower than N_{part} in proton fragmentation region
- QGSJETII goes up from data for large N_{part} at central η and in lead fragmentation region.
- All generators are close to each other and within errors to data in proton fragmentation region

Problem in QGSJETII at large participant number.

Inelastic diffraction

pp 7 TeV

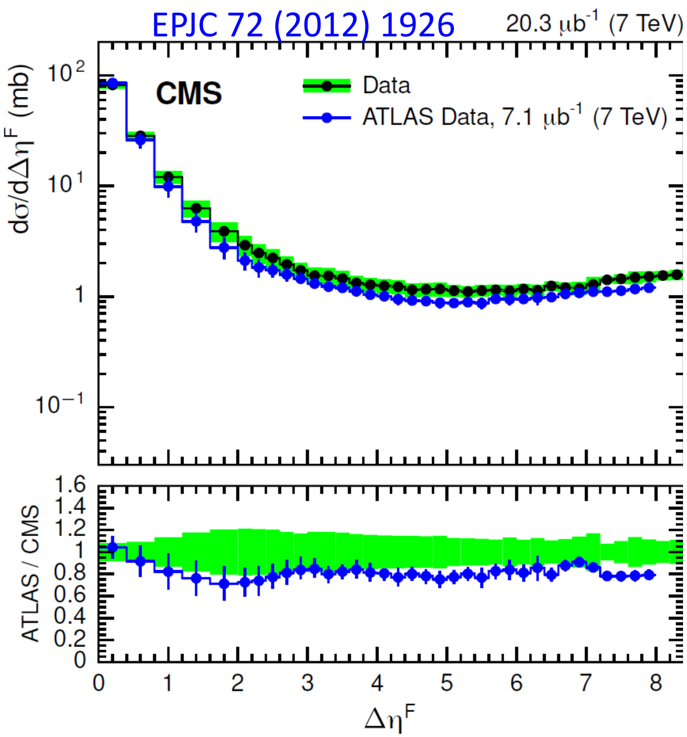
***PhysRevD.92.**012003*



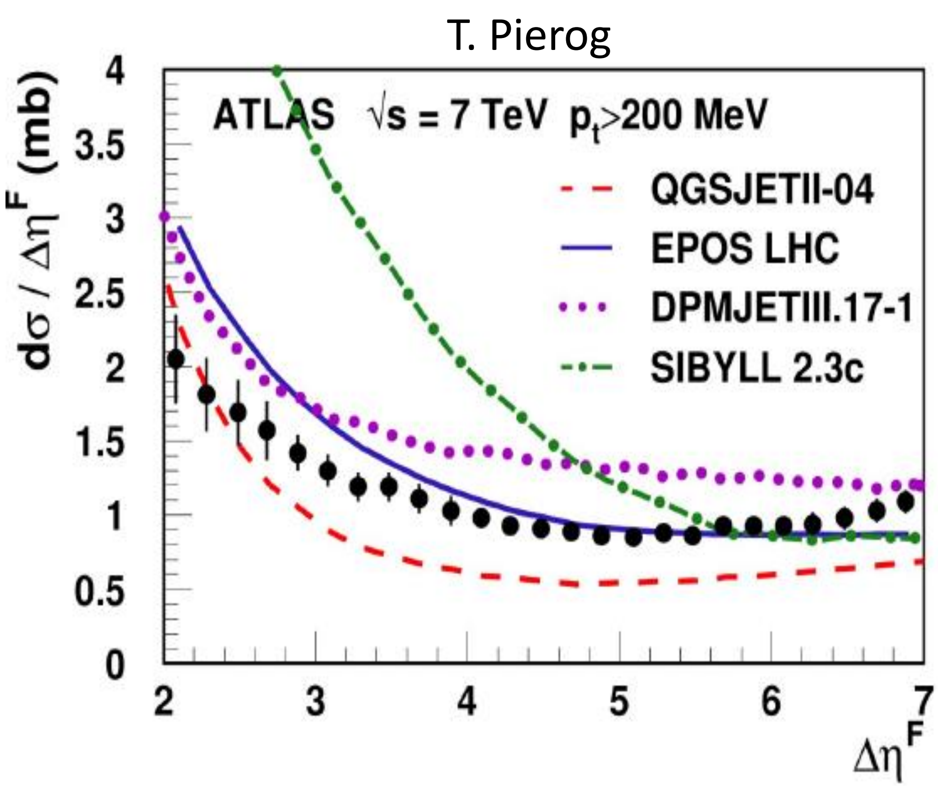
Non-Diffractive | Single Diffraction | Central Diffraction | Double Diffraction

Forward rapidity gaps

"Forward" rapidity gap implies that gap starts at most forward in used acceptance of detector pseudorapidity.



Good agreement of CMS with ATLAS

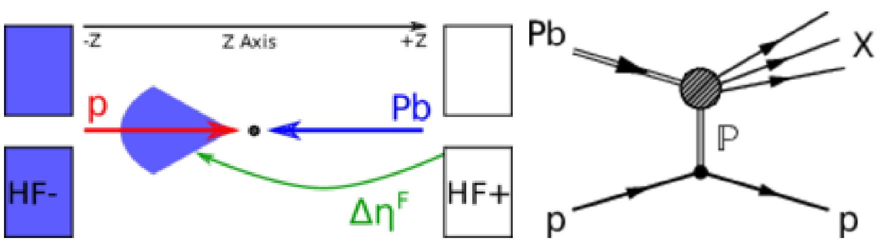


- At large $\Delta\eta^F$, EPOS-LHC close to data.
- QGSJETII-04 is below data by factor ~1.5

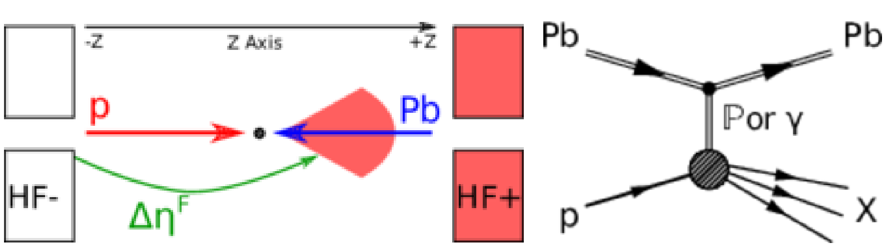
pPb 8.16 TeV/n

CMS, pPb $\sqrt{s_{NN}}$ = 8.16 TeV; 6.4μb^{-1}(2016) ***arXiv: 2301.07630***

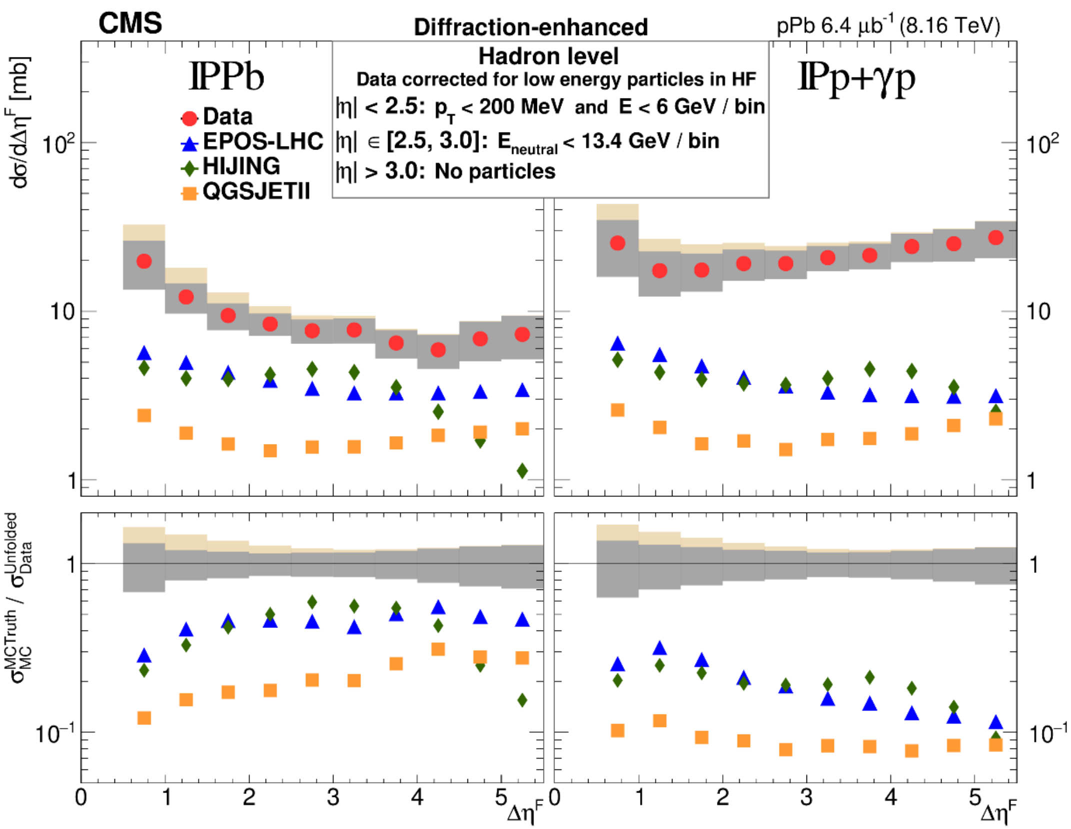
Lead dissociation



Proton dissociation



Forward rapidity gap distribution



At large $\Delta\eta^F$, where contribution of non-diffractive events is small:

- For **IPPb** topology (γ-exchange contribution negligible), EPOS-LHC is about a factor of two below data and QGSJETII-04 is about a factor of three below data.
- Relative difference between two generators is approximately same as in **pp** case, but in **pPb** case, both generators additionally move down from data by a factor of two.
- For **IPp+γp** topology, generators are much more below data than for **IPPb** topology, that implies strong contribution of γp events.

Summary

CMS provides plenty of data valuable for tuning UHECR generators: **inelastic cross-section, particle multiplicity, energy flow, mean p_T, diffraction**. Table shows results of comparison of two generators with data for pp and pPb interactions. Sign ≈ implies closeness with data, +10% means above data by 10%, /2 means less than data by factor 2, etc.

	pp		pPb	
	EPOS-LHC	QGSJETII-04	EPOS-LHC	QGSJETII-04
σ_{inel}	≈	≈	≈	+10%
$dN_{ch}/d\eta$	+10%	≈	-7%	
$dE_T/d\eta$	≈	≈	≈	+25%
$\langle p_T \rangle$	≈	+10%		
σ_{diffr}	≈	/1.5	/2	/3

Strongest effects:

- Big excess of production in QGSJETII-04 in pPb at high centrality/large participant number.
- Big deficit of diffractive cross-sections in QGSJETII-04 relative to data in pp.
- Decrease of diffractive cross-sections in both MC by factor 2 in pPb relative to pp.