Measurement of diffraction in pPb collisions at 8.16 TeV with the CMS experiment

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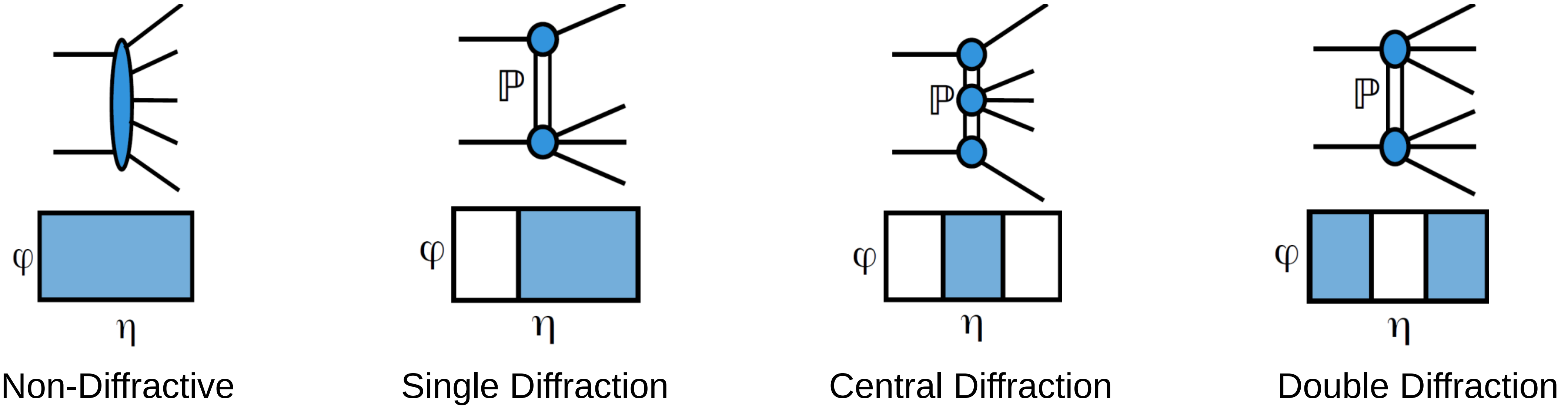
On Behalf of the CMS Collaboration

SINP MSU

Physics relevance

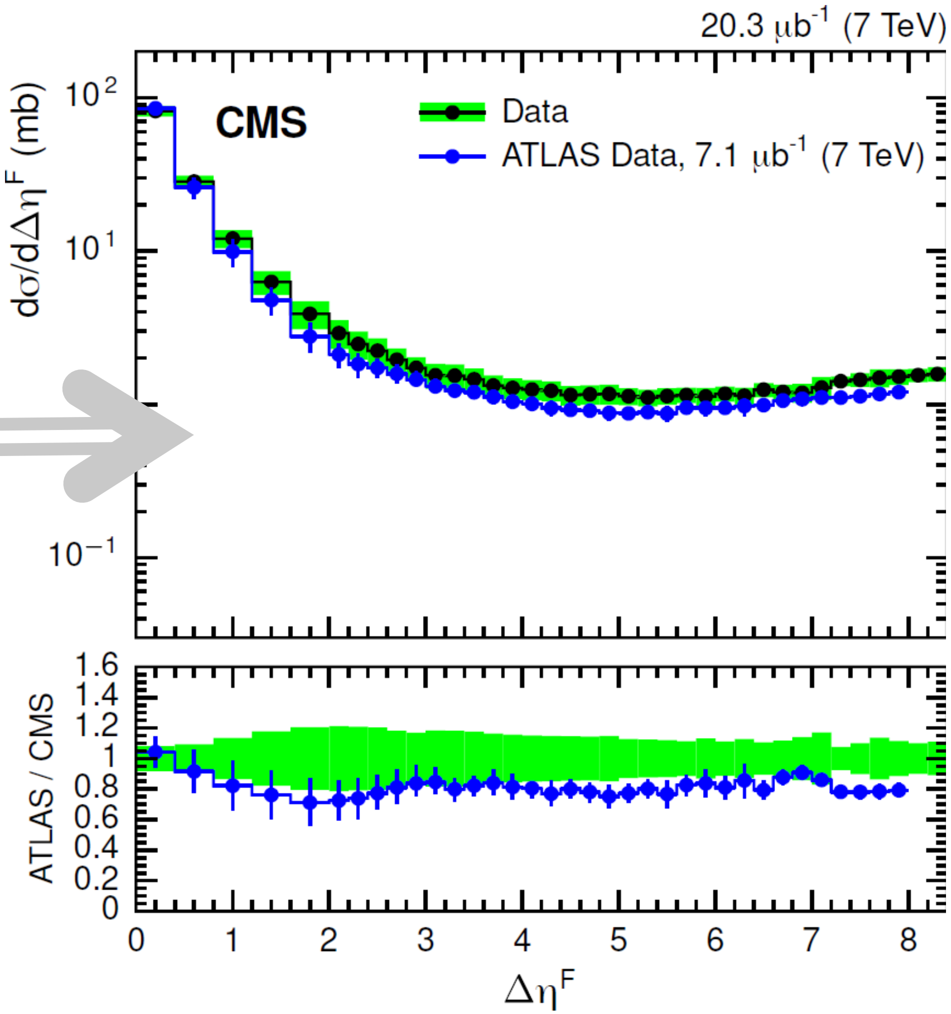


- ❑ Most important problems of QCD which can be studied with diffraction:
  - Nature of the pomeron
  - Small-x & saturation
- ❑ Non-linear effects (saturation) are enlarged in collisions with nuclei
- ❑ Diffraction of hadrons on nuclear targets at high energies is highly relevant to cosmic-ray physics.

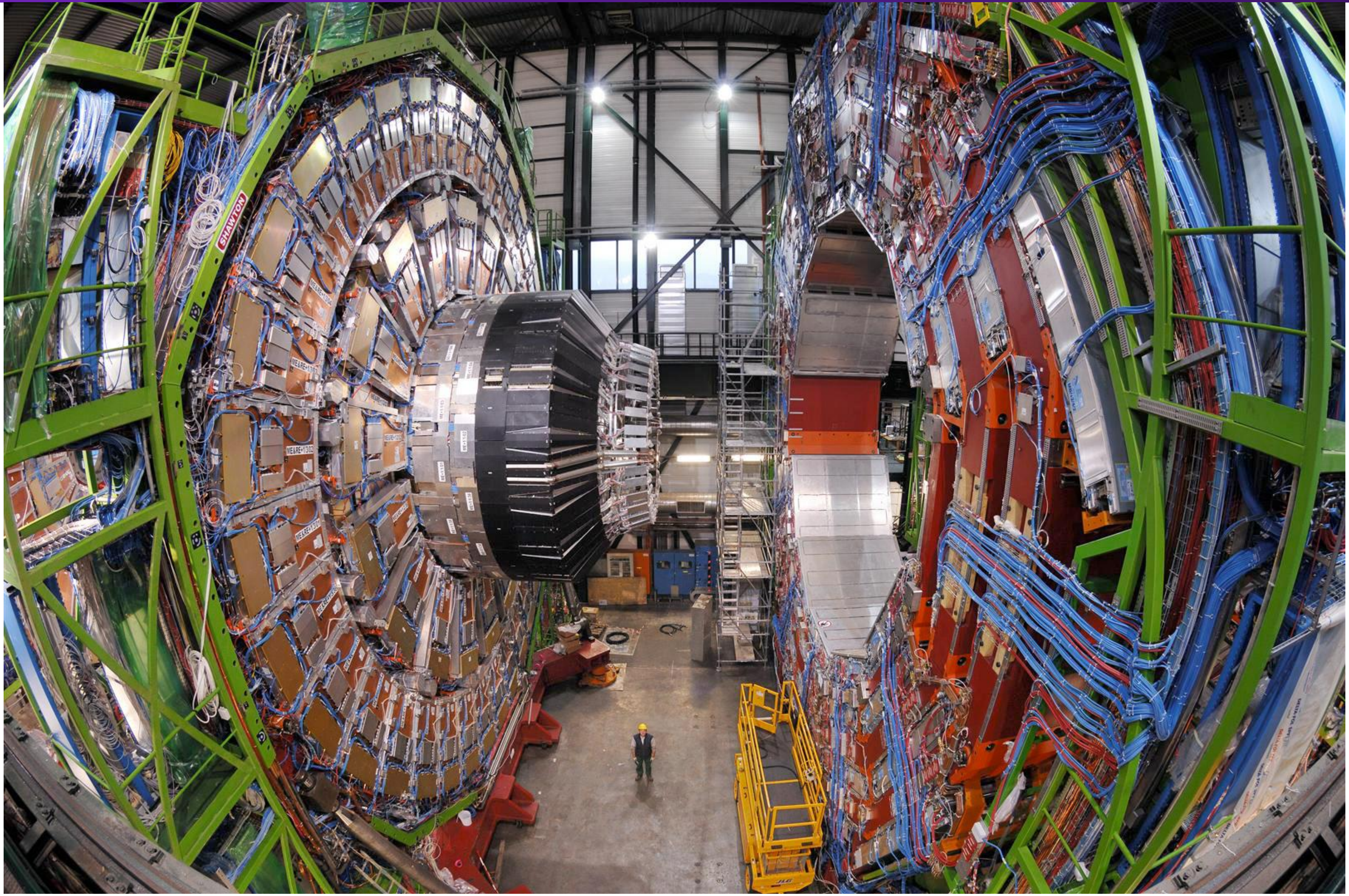
Previous measurements

Latest measurements on diffraction in pA were done by HELIOS collaboration at $\sqrt{s_{NN}} = 27$ GeV
Z. Phys. C 49 (1991) 355

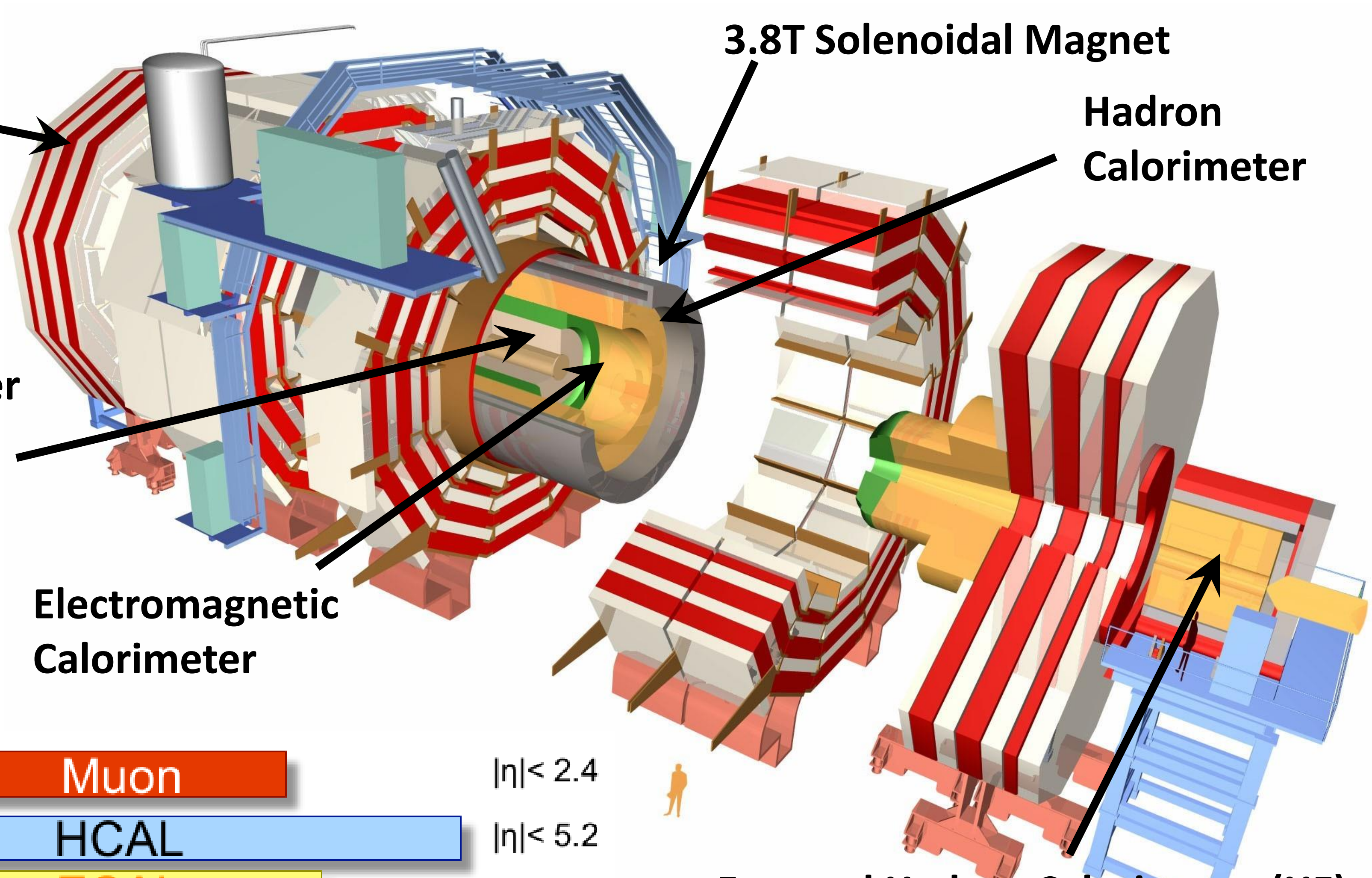
At LHC, forward rapidity gaps (see definition below) have been studied in pp collisions at $\sqrt{s} = 7$ TeV
by ATLAS EPJC 72 (2012) 1926
and CMS PRD 92 (2015) 012003

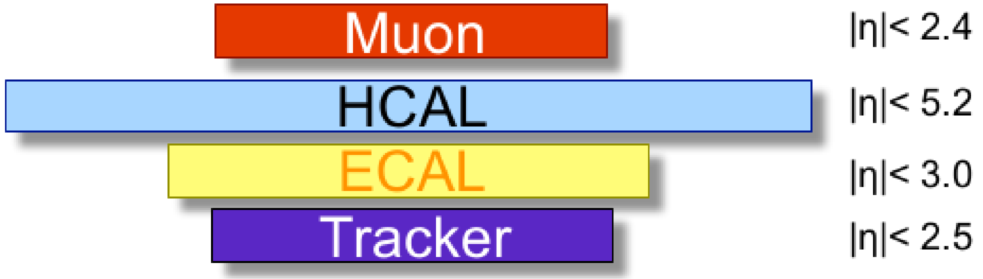


Inside CMS



The CMS detector

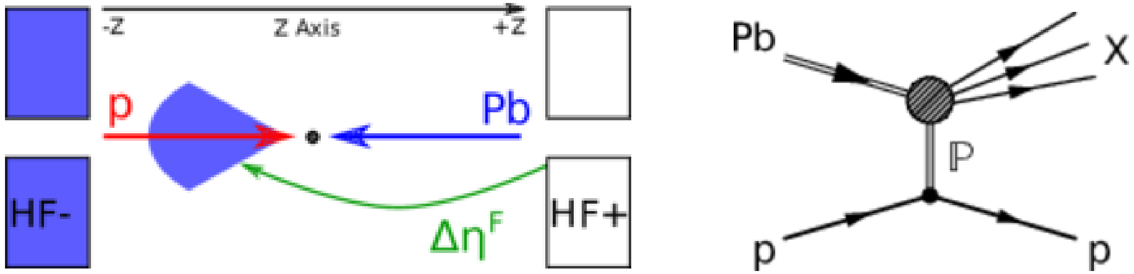




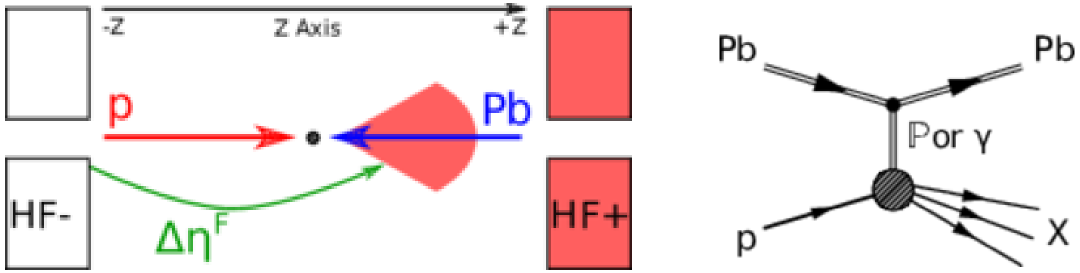
HF is segmented in η, φ into 432 towers

Data, event topology

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



Lead dissociation



Proton dissociation

"Rapidity gap" (RG) is interval in pseudorapidity devoid of activity (either on detector or hadron level). We study forward rapidity gap (FRG) distribution. By forward is meant that gap starts at the most forward in used acceptance of detector rapidity. In practice, usually studied are not rapidity but pseudorapidity distributions.

Measurements are done in two steps

- measurement of rapidity gap distribution in central part of detector at $-3<\eta<3$
- adding up HF calorimeters to acceptance at $-5.2<\eta<-3$, $3<\eta<5.2$

Two-step procedure is caused by different treatment of "emptiness" of η intervals in central detector and HF.

Monte Carlo

Monte-Carlo
HIJING v2.1: hard parton scatterings: perturbative QCD, soft interactions, string excitations
EPOS-LHC: Gribov-Regge theory for the parton interactions, phenomenological implementation of gluon saturation
QGSJET II-04: Gribov-Regge theory for the parton interactions, gluon saturation via higher order pomeron-pomeron interactions

Those generators do not include photon exchange processes.

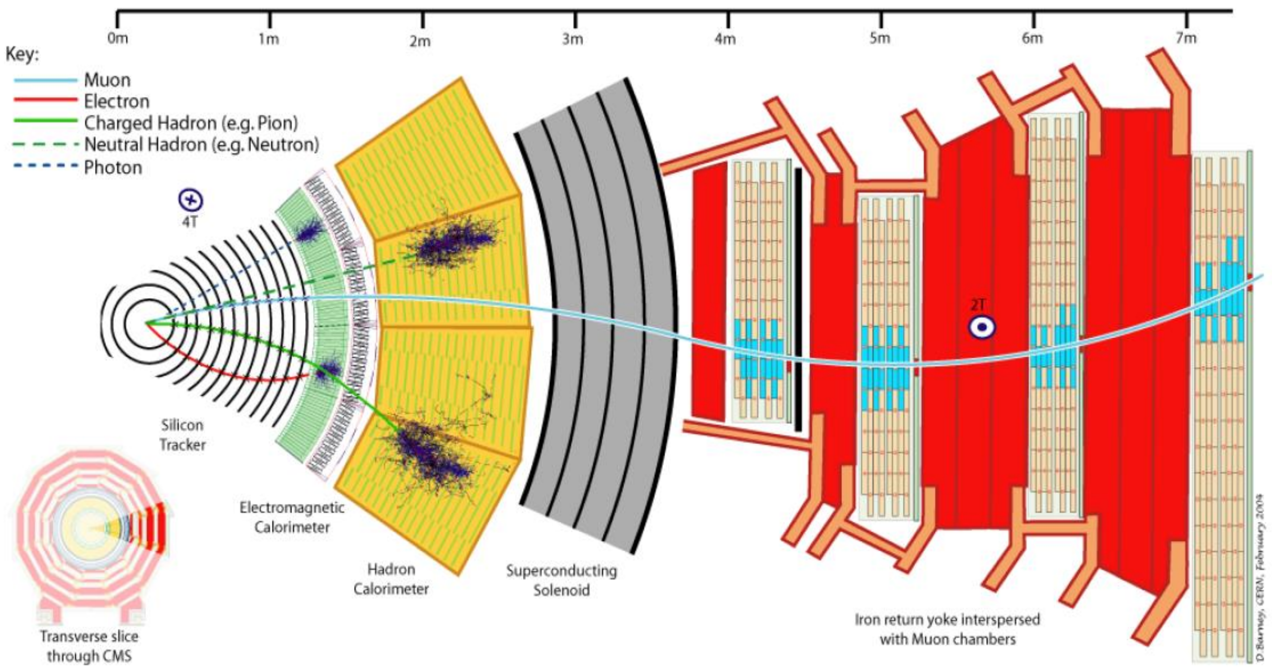
Particle flow algorithm

In central region, at |η|<3, particle flow (PF) algorithm is used.

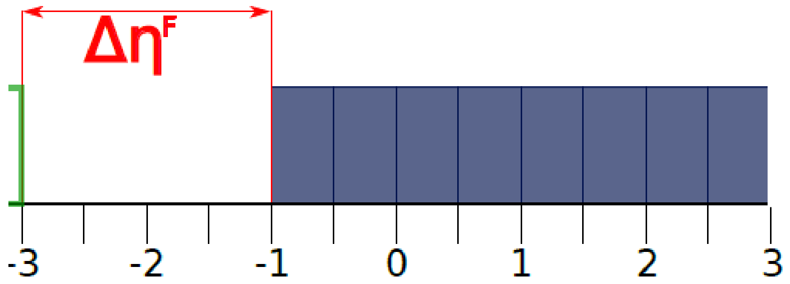
The algorithm combines tracker (at |η|<2.5), calorimeter and muon detector information to assign all signals to one of 5 particle types:

1. **Muons**
2. **Electrons**
3. **Charged Hadrons**
4. **Neutral Hadrons**
5. **Photons**

- **Calorimeters signals associated with a track are removed and the energy is estimated from the track momentum**
- **Calorimeter energy is only used for the neutral hadrons and photons**



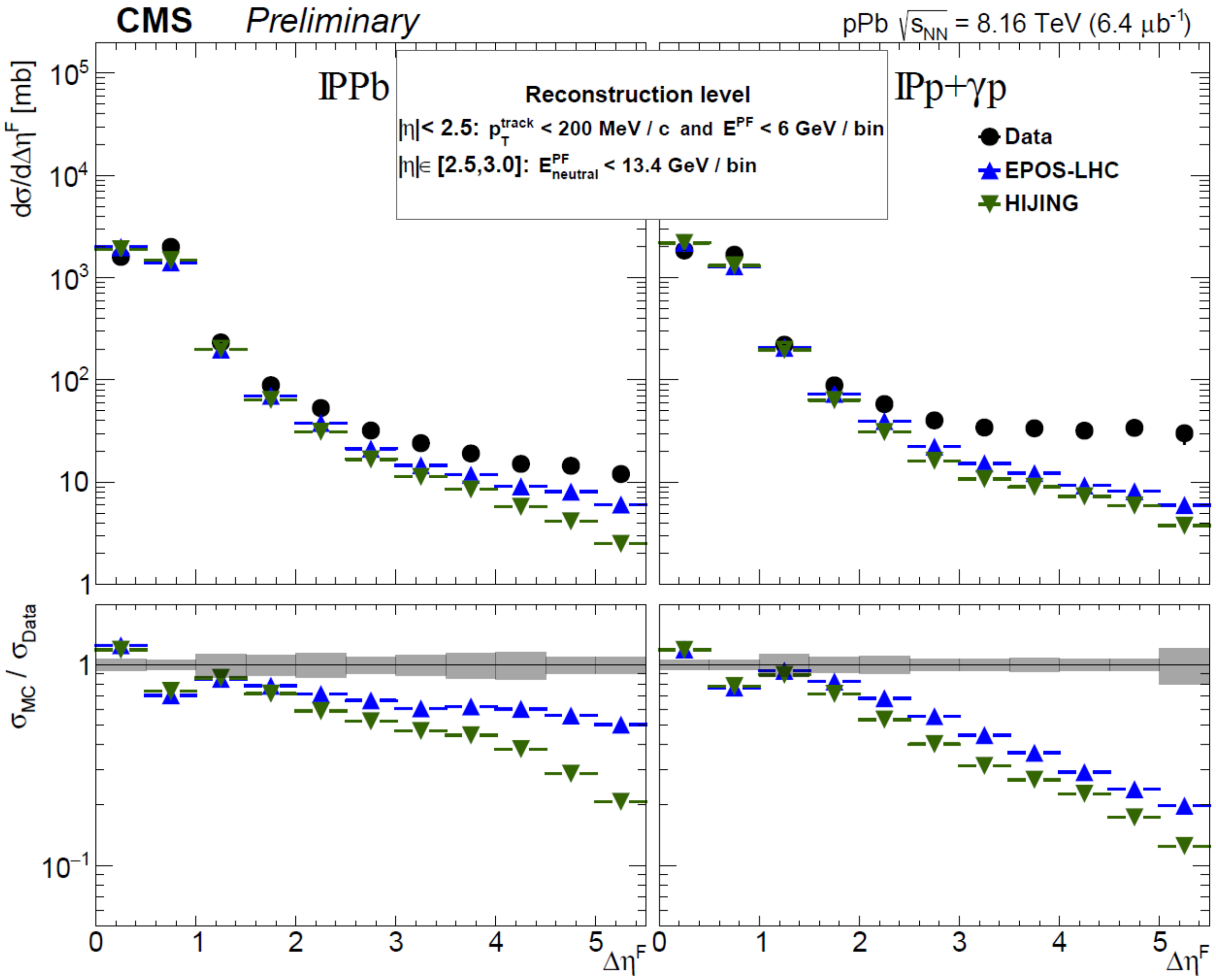
Rapidity gaps in central detector



12 bins in pseudorapidity of size 0.5

- For $|\eta| < 2.5$:
  - No track with $p_T > 200$ MeV
  - Total energy of all PF objects < 6 GeV
- For $2.5 < |\eta| < 3.0$:
  - Total energy of all PF hadronic objects < 13.4 GeV

Rapidity gap in central detector

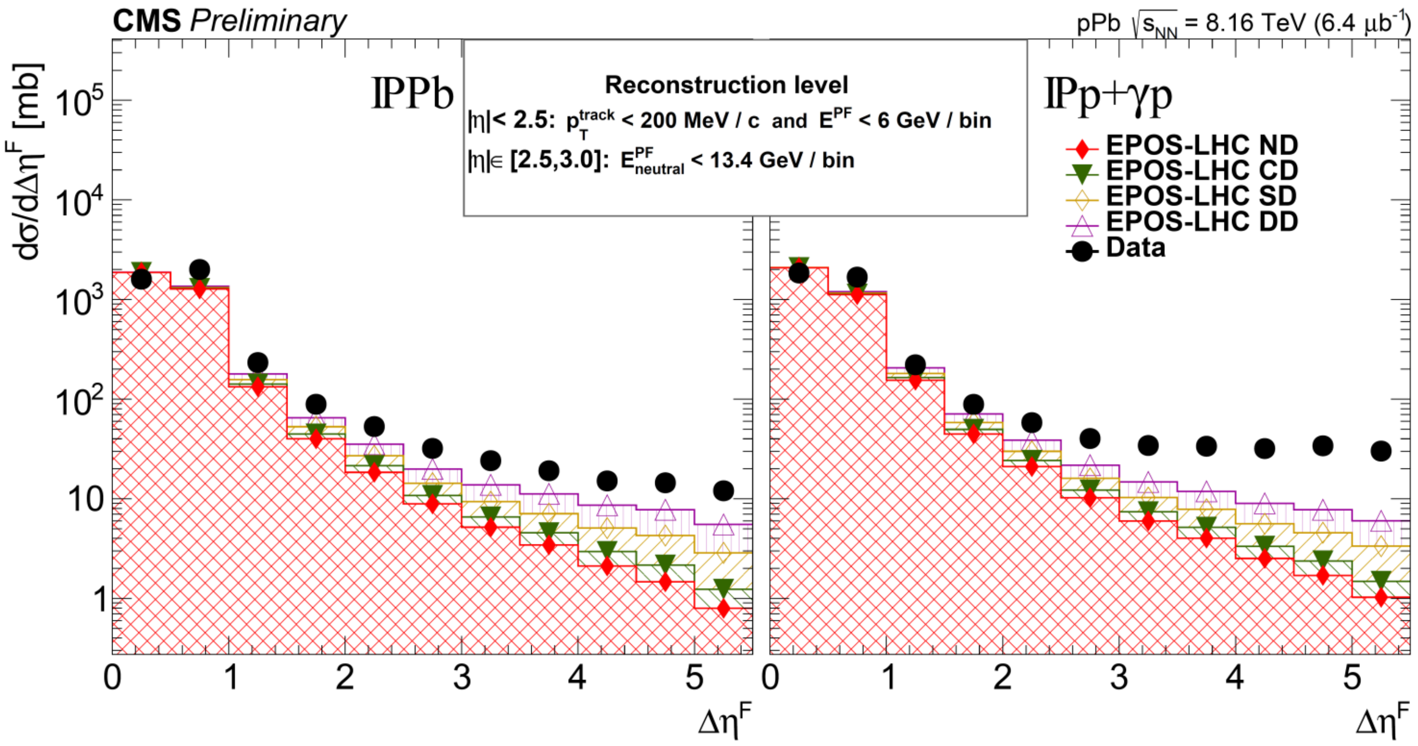


The Monte Carlo spectra are normalized to the total visible cross-section of the data.

- For both topologies, IPPb and IPp (IP stands for pomeron), MC are close to data at small $\Delta\eta^F$.
- At large $\Delta\eta^F$, for IPPb topology, i.e. dissociation of lead, data above EPOS-LHC by factor two and more above HIJING
- At large $\Delta\eta^F$, for IPp topology, i.e. dissociation of proton, data get much above MC due to contribution of γp events

Contribution of different processes

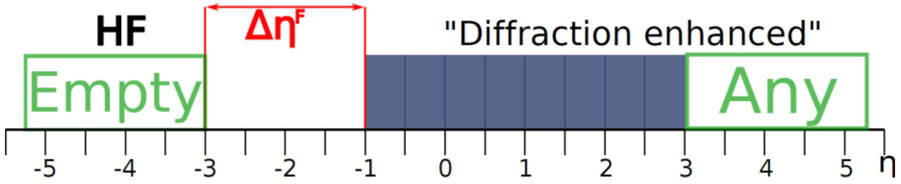
Stacked distributions



- At small $\Delta\eta^F$, non-diffractive processes dominate.
- Significant excess of diffraction over non-diffractive contribution appears only at large $\Delta\eta^F$.

Extension of acceptance with HF

HF calorimeters are placed at two sides of CMS at $-5.2 < \eta < -3$ and $3 < \eta < 5.2$. Each calorimeter contains 432 towers



We employed data only driven method to define probability of HF to have no signal. We assumed that low energy part of the maximal tower energy distribution produced by noise in HF in used data sample and in sample from no-collision events agrees in shape. We normalized no-collision distribution to used data distribution in the low energy range. Integral of that distribution provided us with estimate of the number of events with empty HF. The fraction of these was weighted with rapidity gap distribution in the central detector.

We present thus obtained results in same pseudorapidity bins as before. Since adding up HF allows to much enhance diffractive processes contribution these results are titled "**diffraction enhanced**". It is implied that to compare with e.g. pp results one should add $\Delta\eta=2.2$ to the presented $\Delta\eta^F$.

Unfolding to hadron level

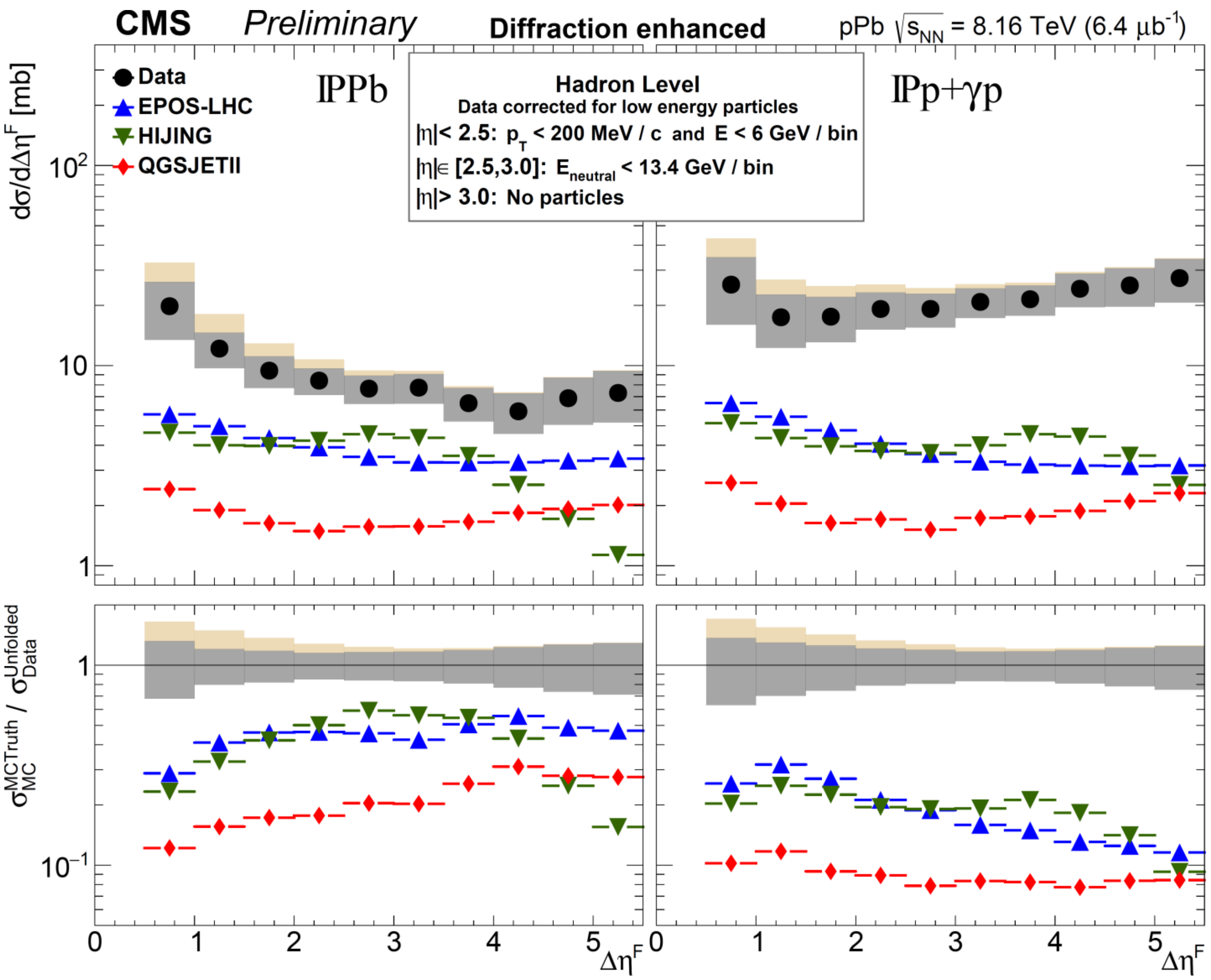
Rapidity gap at the hadron level

- ❖ η=[-2.5,2.5] in bins of η=0.5
  - no charged particles with p_T > 200 MeV
  - total energy in the bin E < 6 GeV
- ❖ Edge bins 2.5<|η|<3
  total energy in the bin: E < 13.4 GeV
- ❖ HF acceptance
  no detectable particles

Unfolding is done with iterative Bayesian method

$$x_j^{ITER+1} = x_j^{ITER} \sum_i \frac{A_{ij}}{\varepsilon_j} \frac{y_i^{data}}{\sum_k A_{ik} x_k^{ITER}}$$

Final results



For **IPPb** topology case (γ-exchange contribution negligible):

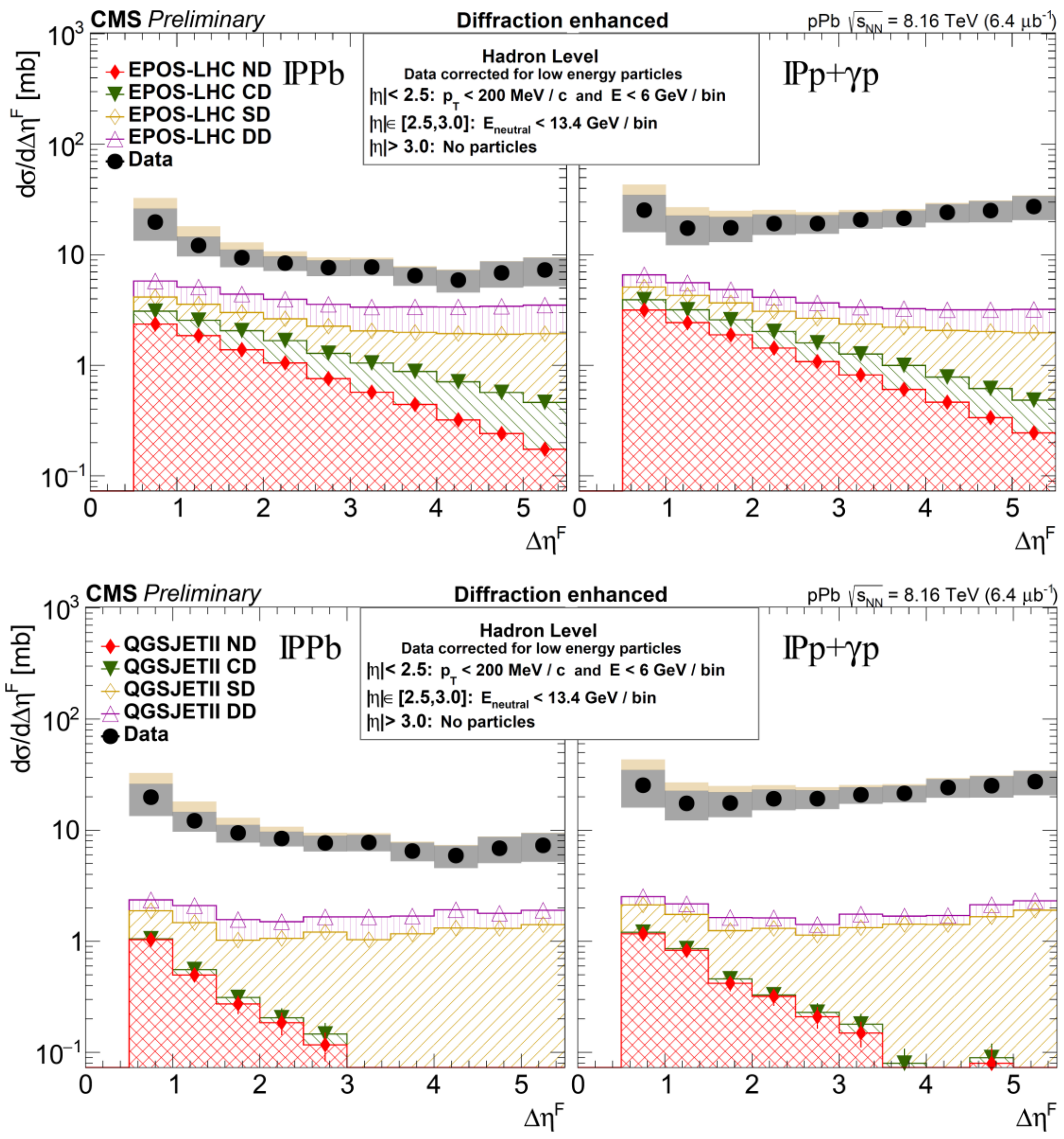
- At large $\Delta\eta^F$, EPOS-LHC is about a factor of 2 and QGSJETII-04 is about a factor of 4 below data.
- HIJING demonstrates sharp decline at large $\Delta\eta^F$, which is a consequence of deficit of low-mass diffraction in the generator.
- Some rise of spectrum at large $\Delta\eta^F$ should be noted in data as well as in cosmic ray MC.
- At small $\Delta\eta^F$, excess of data over MC gets larger.

For **IPp** topology, all generators are significantly below data. This suggests very strong contribution from γp events non-simulated in considered generators.

- QGSJETII-04 is much below two other generators.
- EPOS-LHC and QGSJETII-04 are noticably different in shape, QGSJETII-04 being closer in shape to data.
- Systematic falling off of data to smaller $\Delta\eta^F$ t, i.e. to higher masses, could be explained by decrease of cross-section of high mass production in γp.

Contribution of different processes

Stacked distributions for two generators



- Non-diffraction noticeably contributes only at smallest gaps, resulting in rise of total distribution.
- This contribution is larger in EPOS-LHC, moving MC predictions closer to data than that of QGSJETII-04 and providing difference in shape of distributions between two generators.
- Cross-section of diffraction in QGSJETII-04 is about two times smaller that in EPOS-LHC, which is most certain at large $\Delta\eta^F$, where non-diffractive contribution is small.

Summary

Diffraction in pPb collisions at 8.16 TeV with the CMS experiment has been measured.

- For the **IPPb** topology where γ-exchange contribution is negligible:
  - At large $\Delta\eta^F$, cross-sections of EPOS-LHC is about a factor of 2 and of QGSJETII-04 is about a factor of 4 below data.
  - HIJING demonstrates sharp decline at large $\Delta\eta^F$, which is a consequence of deficit of low-mass diffraction in the generator.
  - Some rise of spectrum at large $\Delta\eta^F$ should be noted in data as well as in cosmic ray MC.
  - At small $\Delta\eta^F$, excess of data over MC gets larger.

- For the **IPp** topology, all generators are much more below data. This suggests very strong contribution from γp events non-simulated in considered generators:
  - QGSJETII-04 is much below two other generators.
  - EPOS-LHC and QGSJETII-04 are noticeably different in shape, QGSJETII-04 being closer in shape to data.
  - Systematic falling off of data with decrease of $\Delta\eta^F$, i.e. with increase of mass, could be explained by decrease of cross-section of high mass production in γp.