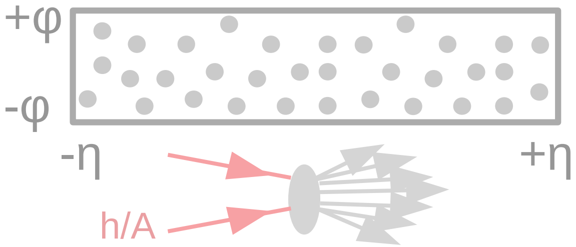
# First measurement of the forward rapidity gap distribution in pPb collisions at 8 TeV

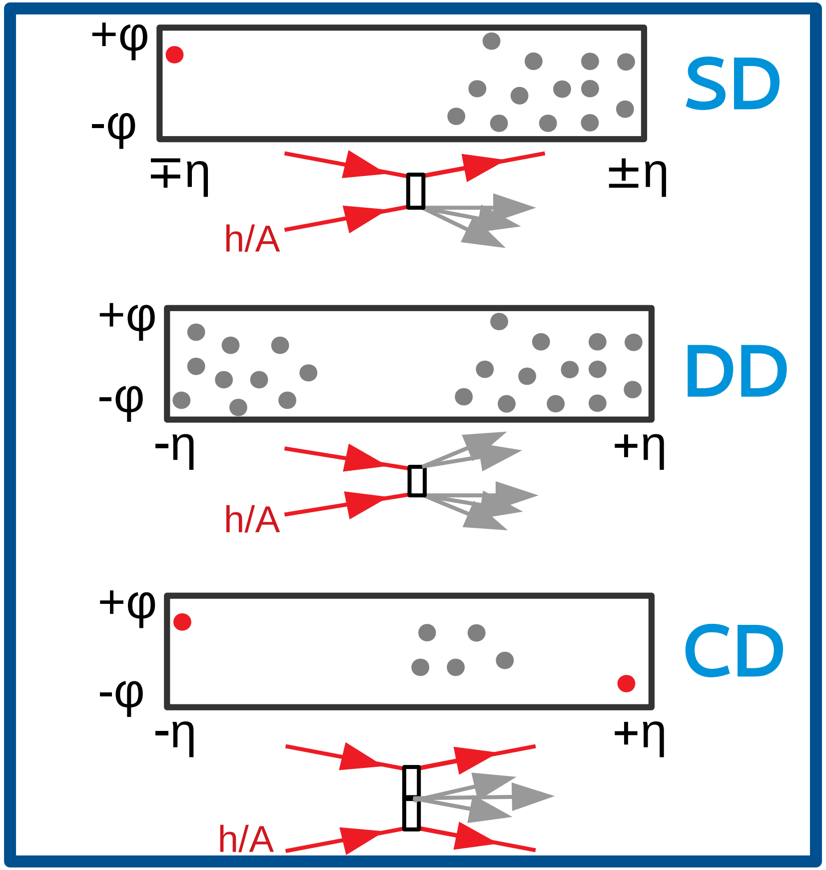
Ekaterina Kuznetsova (PNPI)
on behalf of the CMS collaboration

*IS2021: The VI-th International Conference on the Initial Stages of High-Energy Nuclear Collisions, 10-15 Jan 2021, Weizmann Institute of Science, Rehavot (Israel)*

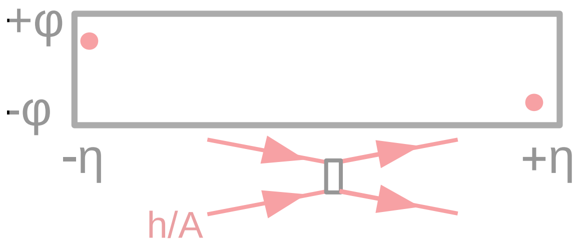
# Events with large rapidity gaps (LRG) in hadronic collisions

Non-diffractive (ND)




Elastic




**Diffractive production (Pomeron exchange in t-channel):**

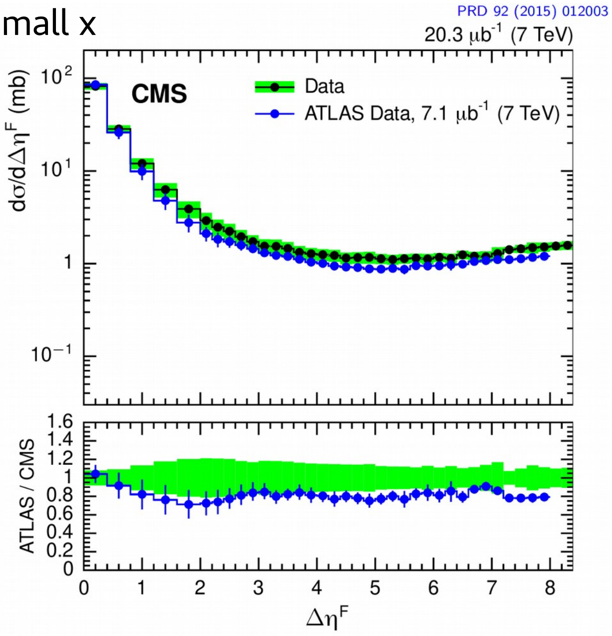
- **SD: single diffractive**
- **DD: double diffractive**
- **CD: central diffractive**

Events with LRG are also contributed by photon exchange processes. **This contribution becomes significant for ions with large Z**

# Motivation

## Inclusive diffractive production in hadronic collisions

- Relatively large contribution to the total cross-section
- Access to the Pomeron nature
- Access to processes at small x




*Differential cross-section of LRG events in 7 TeV pp collisions (CMS and ATLAS measurements)*

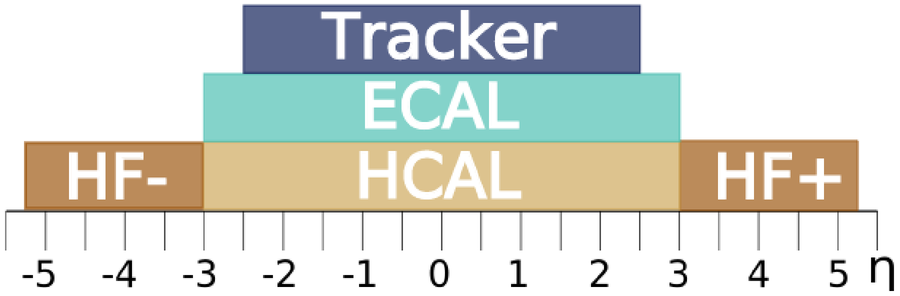
## Inclusive diffractive production in pA collisions

- Cross sections of inelastic diffractive processes are very sensitive to nonlinear saturation effect
- Important information for precise cosmic ray shower modeling
- The most recent results before LHC are obtained by **HELIOS for 27 GeV cme in 1991** (Z. Phys. C 49 (1991) 355)

As for pp collisions, those measurements require good forward instrumentation of a detector

Recently measured at CMS for pPb at $\sqrt{s_{NN}}$ = 8.16 TeV : **CMS-PAS-HIN-18-019**

# CMS detector




**Tracking** $|\eta|<2.4$
Pixel+SiStrip, Muon detectors

**Central calorimeters** $|\eta|<3$
ECAL, HCAL

**Hadronic Forward Calorimeter (HF):**
$2.9<|\eta|<5.2$
in **towers of** $\Delta\eta \times \Delta\varphi \sim$ **0.175 x 175**

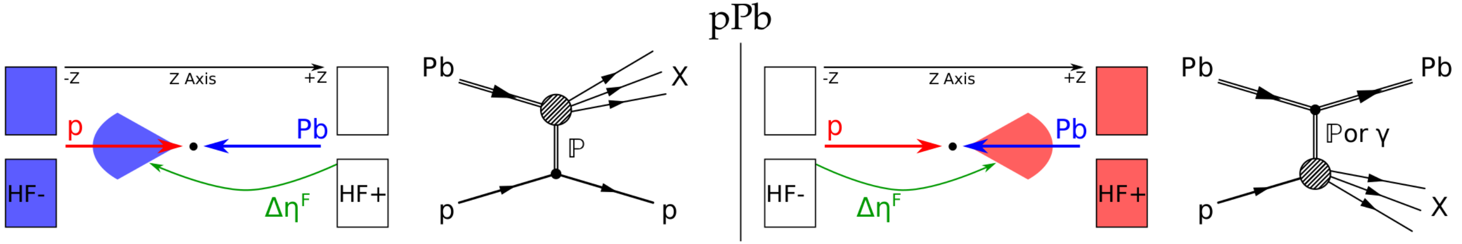
***Calorimetry + tracking*** → **Particle Flow Objects**

+ Forward detectors available for AA/pA collision modes
(but not used in the baseline of our analysis for compatibility with pp results):
Castor $-6.6 < \eta < -5.2$ and Zero Degree Calorimeter (ZDC): $|\eta| > 8.5$

# Data and event topology

pPb/Pbp run 2016: $\mathbf{\sqrt{s_{NN}} = 8.16}$ **TeV**, low mean number of collisions per bunch (~0.15)

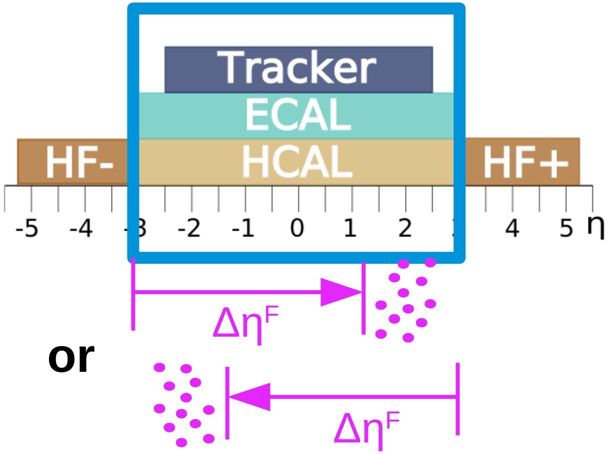
~6.4 $\mu b^{-1}$ in total




**Goal**: to obtain the differential cross section for events with large RG, for the IPPb and (IPp+γp) topologies

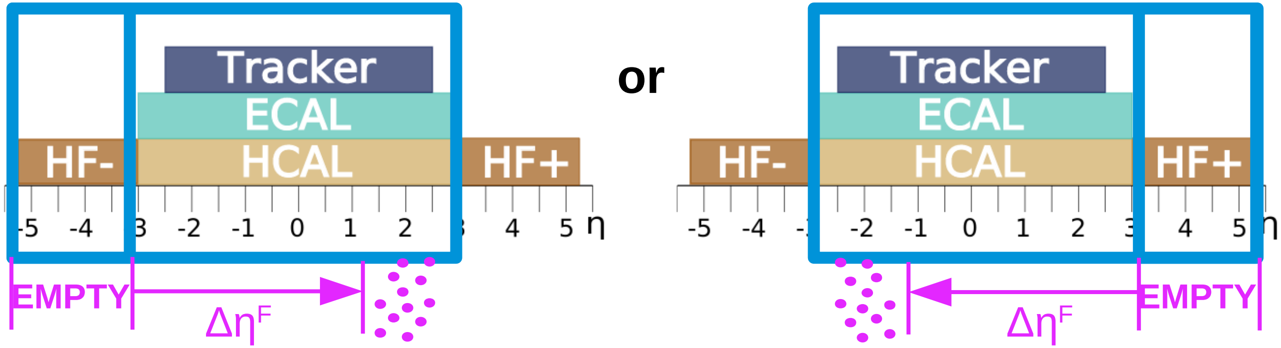
**STEP 1**:

RG in the central detector area




**STEP 2**:

RG in the extended detector area



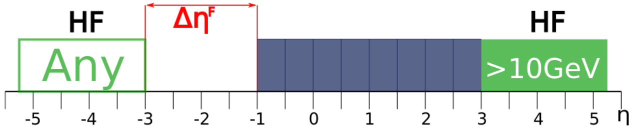

Larger RG – higher sensitivity to the diffractive production

# Event selection

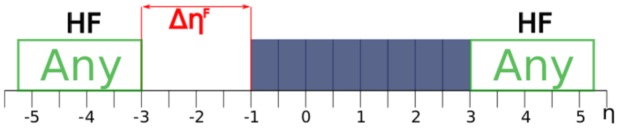
Analysis performed on inclusive Minimum Bias data

+ acceptance corrections are evaluated with Zero Bias data

- HF-based "Minimum Bias" data: require at least one tower of any of HF calorimeters to have at least 10 MeV deposition
  - large statistics, very inclusive but limited to the HF acceptance




- "Zero Bias" events triggered on beams crossing the interaction point, ensure inelastic collisions with a track, correct the tracker acceptance using Monte Carlo
  - total inelastic data set but low statistics



# Rapidity Gap definition (STEP1: $|\eta|<3$)

**Rapidity Gap definition: thresholds depend on detector performance**

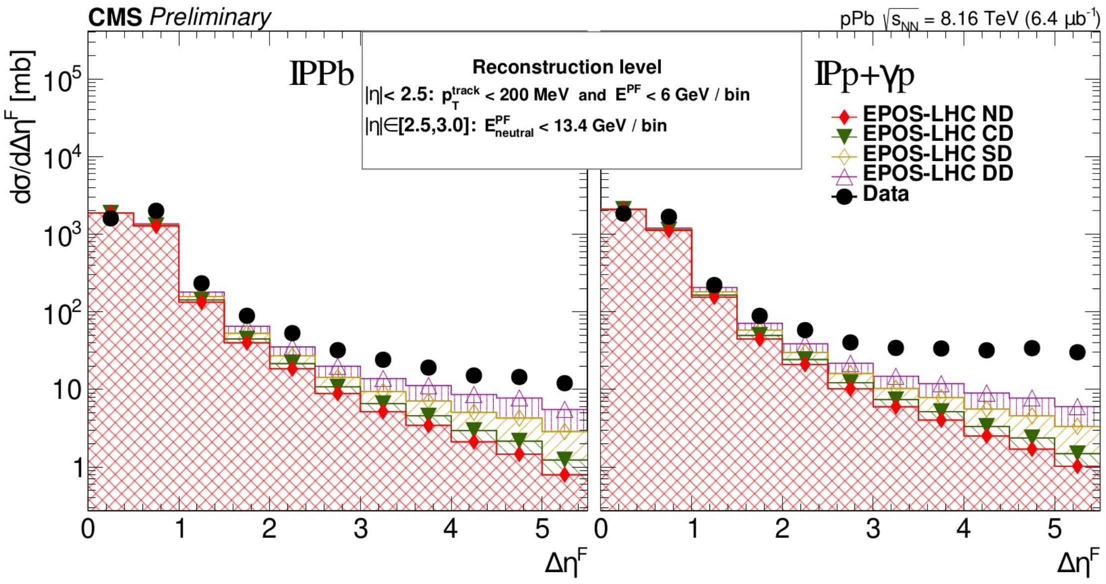
- Theoretically the RG is defined as an acceptance region free of final state particles
- Practically we can not introduce the "zero" threshold due to finite detector sensitivity
- The thresholds should be as low as possible, but well above detector noise

  - RG is defined in bins of $\eta$=0.5. Per every bin:

    for $|\eta|<2.5$:
    - No tracks with $P_T>200$ MeV
    - Total energy of all Particle Flow candidates < 6 GeV

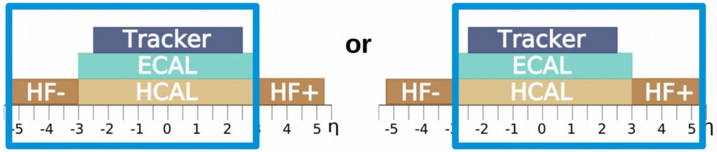
    for $2.5<|\eta|<3$
    - Total energy of all hadronic Particle Flow candidates<13.4 GeV

# Forward RG cross-section at reconstruction level (STEP1: |η|<3)

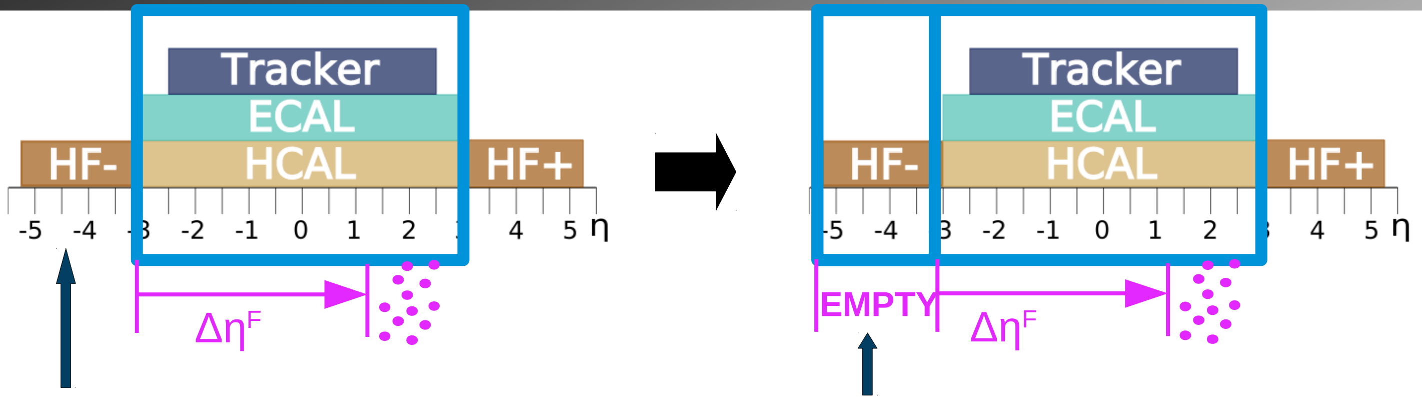




Compared to EPOS MC predictions

- EPOS does not account for the photoproduction contribution
- Larger data-MC deviation for the (IPp+γp) typologies, as expected
- EPOS predicts quite large contribution from non-diffractive events even for large RG
- To suppress the contribution from non-diffractive events, the analysis was extended to the HF acceptance



# Expanding the Forward FG (STEP2)




*We don’t care if there are final state particles in HF acceptance*

*HF- does not have detectable final state particles*

- **Reweighing** according the fraction of events with **no detectable final state particles in the corresponding HF acceptance**.
  The weighting coefficients are found comparing the HF energy spectra obtained for every considered FRG size to the noise spectrum of the corresponding HF.
- **Acceptance correction** for the total inelastic cross section
- **Unfolded** using EPOS MC

The FRG size is still counted from |η|=3, but the distributions correspond to the events with vetoed HF => “**diffraction enhanced**” data sample

# Hadron level RG definition

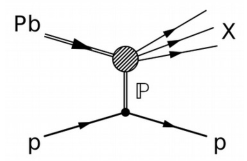
- **RG at the central detector acceptance: the same as at the detector level**
  - RG is defined in bins of η=0.5. Per every bin:

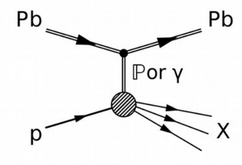
    for |η|<2.5:
    - No tracks with $P_T$>200 MeV
    - Total energy of all Particle Flow candidates < 6 GeV

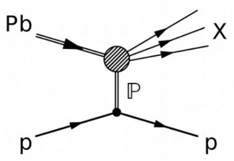
    for 2.5<|η|<3
    - Total energy of all hadronic Particle Flow candidates<13.4 GeV

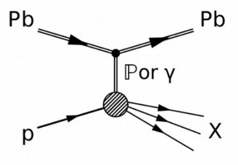
- **RG extension into the HF acceptance (3<|η|<5): no detectable particles**

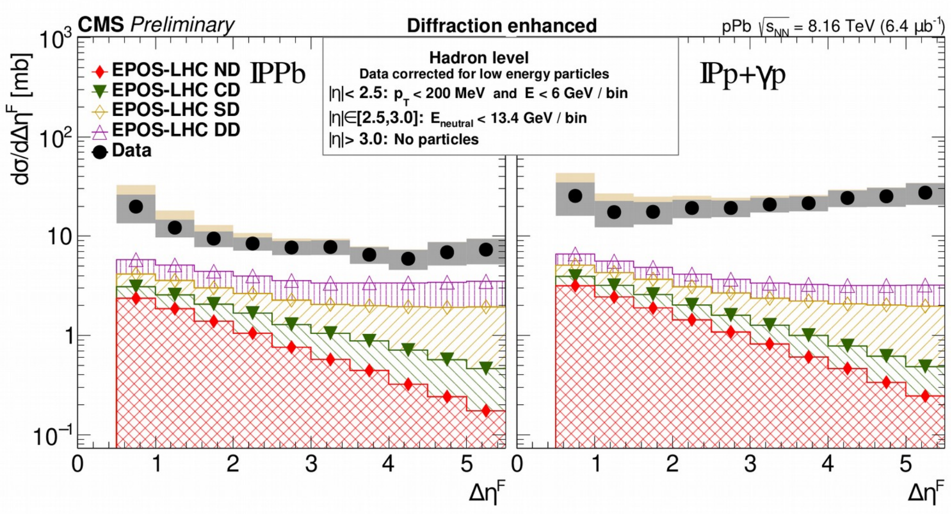
# Diffraction enhanced cross section at hadron level (STEP2)



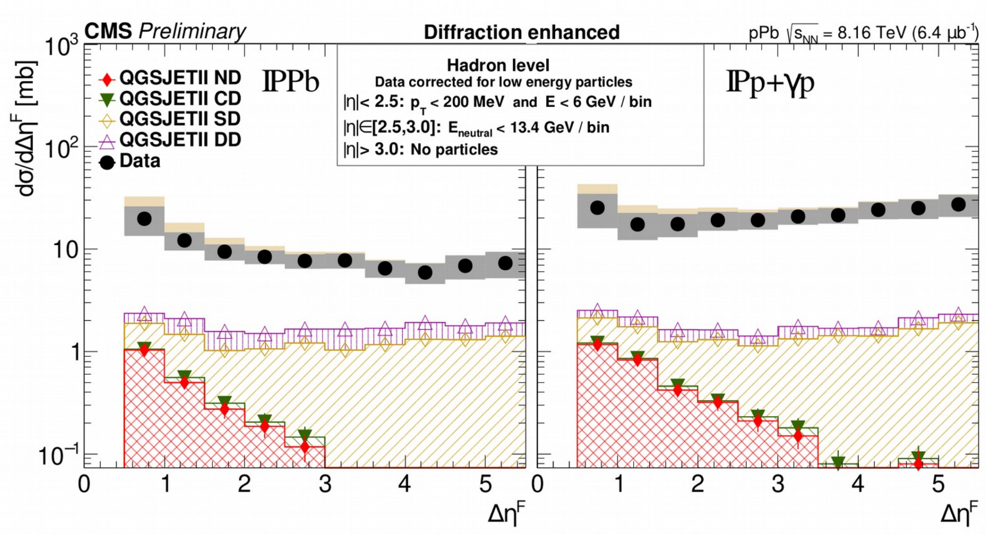



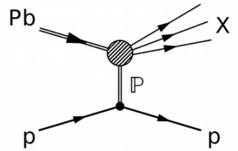

Compared to EPOS MC predictions

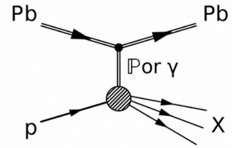


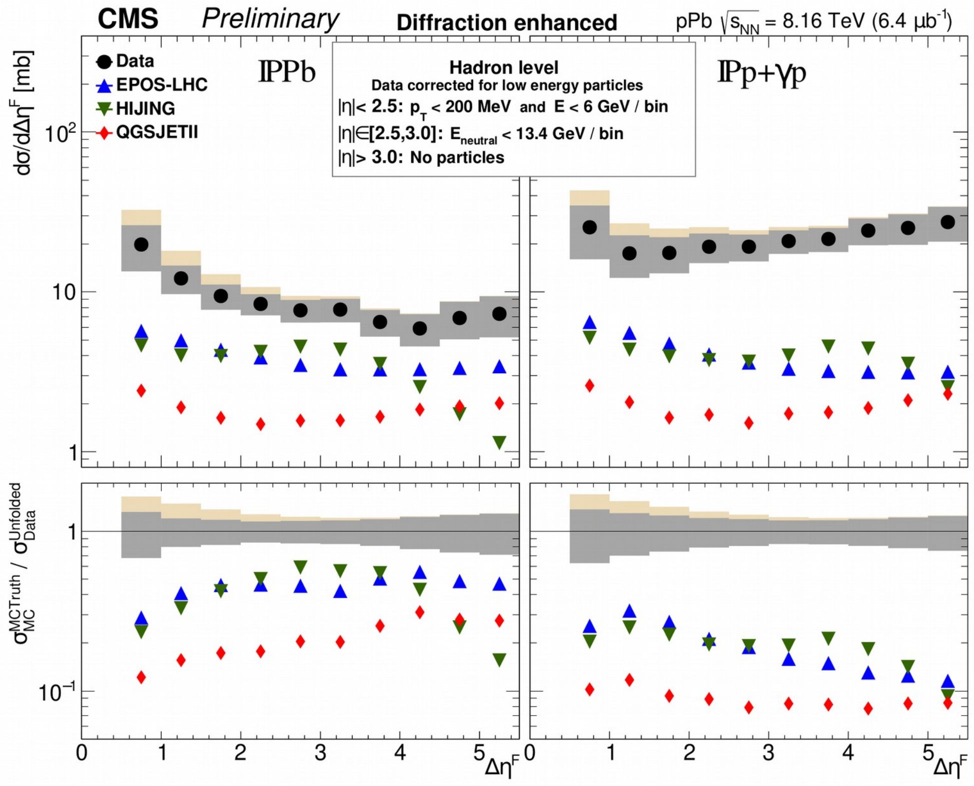

Compared to QGSJET MC predictions

Both MC generators do not account for photon exchange processes

# Diffraction enhanced cross section at hadron level



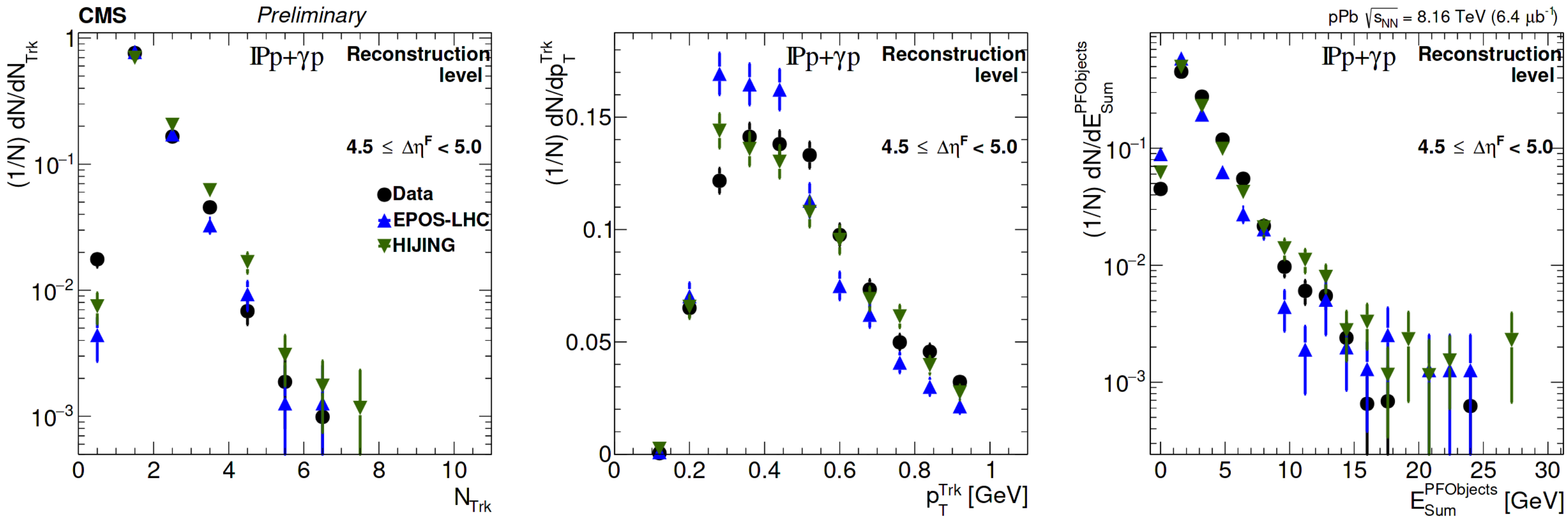




- Data are compared to **EPOS**, **QGSJET** and **HIJING** MC predictions (no contribution from γp)
- Large difference between the data and MC in **IPp+γp** case is defined by the **missing γp contribution in MC**
- **IPPb : EPOS provides the closest prediction**, but still ~2 times lower than the data
- In contrast to the data and other MC, HIJING demonstrates decrease of the differential cross section for large FRG

# Additional studies: particle spectra at the RG edges

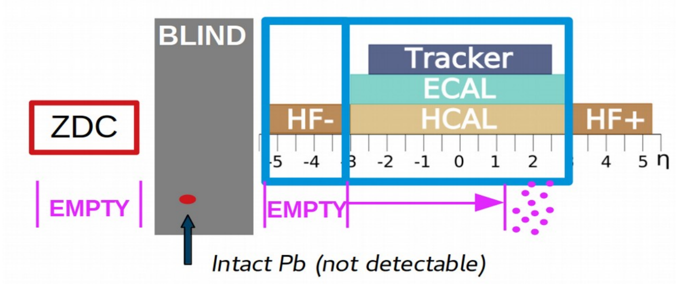
- IPp and γp events are topologically indistinguishable
- They have similar nature due to their “quasi-elasticity” and absence of the color exchange
- Due to lack of earlier experimental data, we do not have MC which can reliably describe inclusive photoproduction
- To use diffractive MC for data unfolding, the spectra of particles defining the RG size were studies

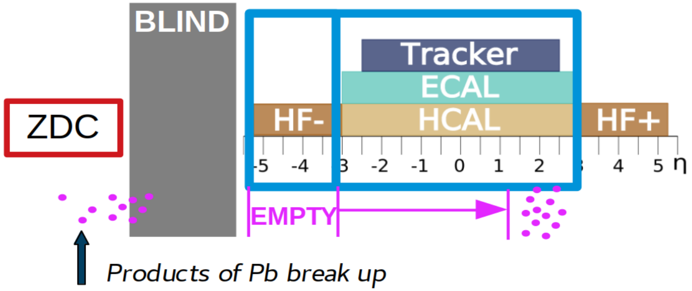


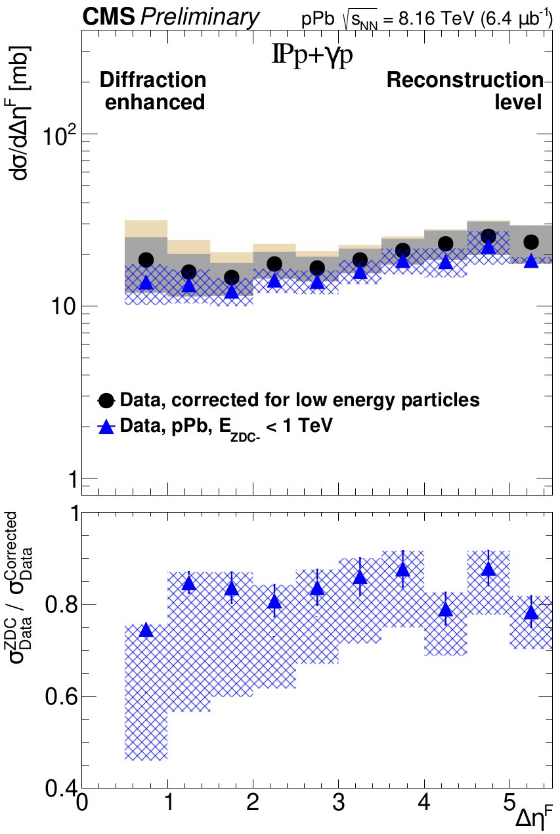

*Number of tracks, their $p_T$ distributions and energy distribution of Particle Flow candidates in the pseudorapidity bin adjacent to the FRG:* ***both HIJING and EPOS describe the data very well even for large FRG with high contribution of γp events***

# Additional studies: intact Pb event fraction in IPp+γp sample

- **Zero Degree Calorimeter**: is located behind the LHC dipole magnets.
- Sensitive to **neutral particles in |η|>8.5** – perfect detector of neutrons originating in Pb break up



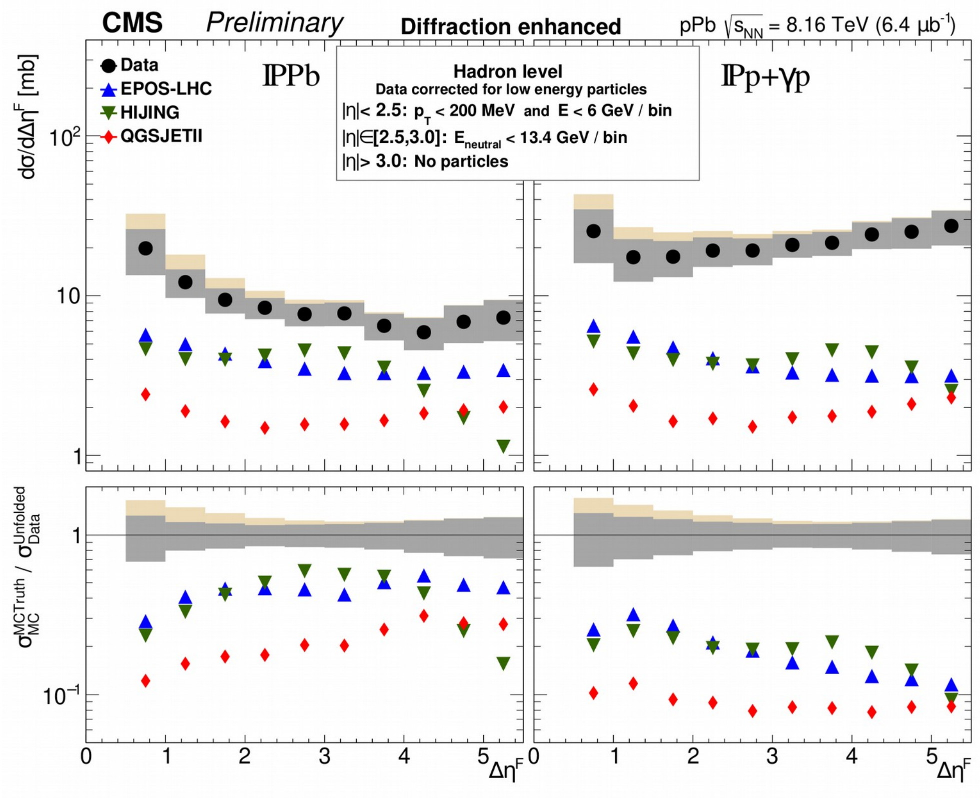




- Though ZDC efficiency is known to be very high, we don't know the precise value
- The fraction of intact Pb events is quite high (~80%) and does not depend on the FRG size

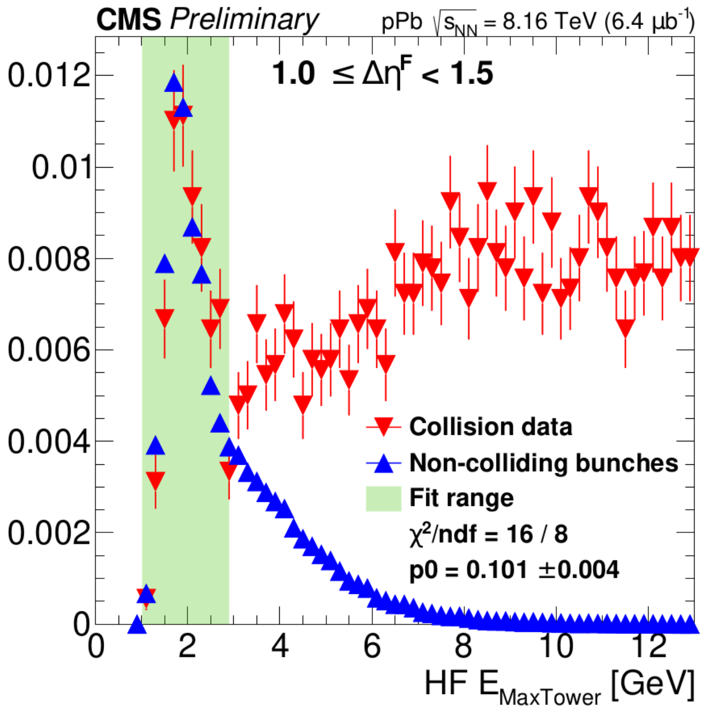
# Summary

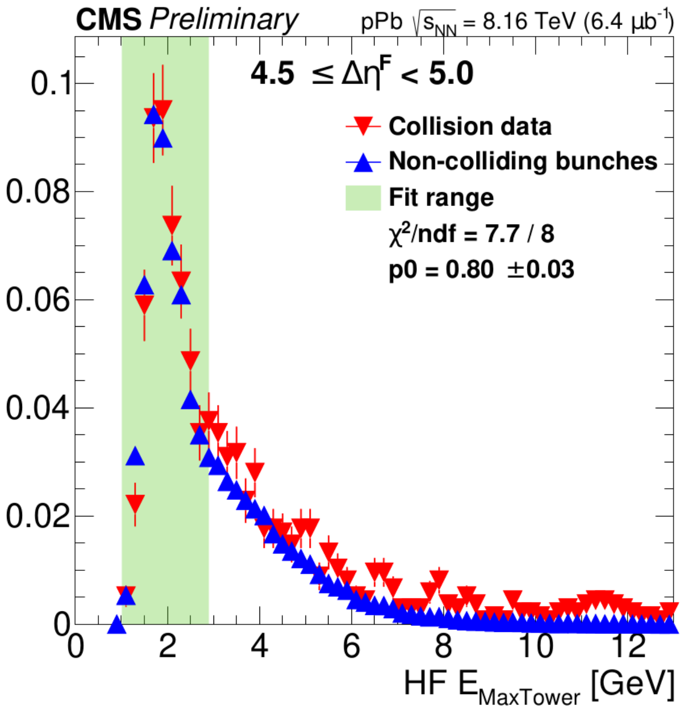
- **Differential FRG cross section has been measured for the first time at the LHC energies for both pomeron-lead and pomeron-proton topologies**
- **Comparison to the EPOS, QGSJET and HIJING MC (IPPb)**:
  - neither of this generators can describe the absolute value of the cross-section
  - EPOS and QGSJET describe the distribution shape quite well
- Pomeron-proton topology events are strongly contributed by the photon exchange events (γp) due to the large lead ion charge. The event signatures are indistinguishable for IPp and γp events
  - Those events (IPp+γp) have large probability to avoid lead break up, and this probability does not depend on the FRG size for large gap sizes
- **The obtained results can be used for further MC generator tuning and improvement of the cosmic ray shower modeling**



# BACKUP

# Weighting procedure



# Additional studies: intact Pb event fraction in IPp+γp sample

- Zero Degree Calorimeter: located behind the LHC dipole magnets and is sensitive to neutral particles in |η| >8.5 – perfect detector of neutrons originating from Pb break up