



Large rapidity gap events in proton-nucleus collisions at LHC energies

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Diffraction collisions are defined as special inelastic collisions in which no quantum numbers are exchanged between colliding particles

Diffraction process markers (**observables**):

- **Fast particle** ($\frac{E_{fin}}{E_{in}} = x \geq 0.9$) and slow particle(s) ($x \leq 0.9$)
- **Rapidity gap** ($\Delta\eta$) – the rapidity region free of final state particles (between slow and fast particles)

Diffraction scattering in proton-nucleus collisions:

- Sensitive to collective effects in nucleus: $\sigma_{diff} = f(A)$
- Diffraction of hadrons on nuclear targets at very high energies are valuable input, for example, for modelling of extensive cosmic ray shower

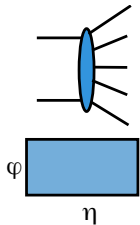


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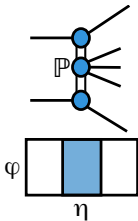
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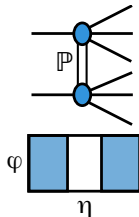
Non-Diffractive



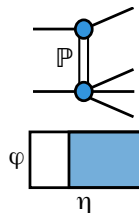
Central Diffraction



Double Diffraction



Single Diffraction



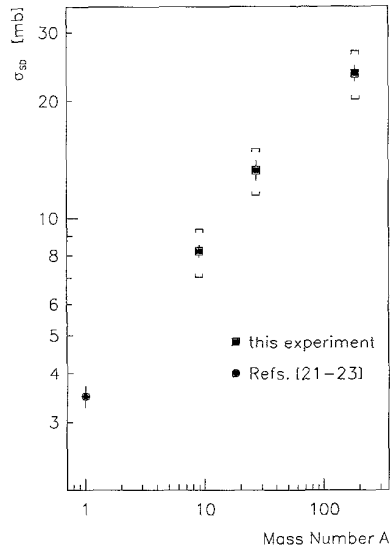
Fast: $x \geq 0.9$

Slow: $x \leq 0.1$



Main HELIOS results

- The latest (before LHC) measurements on diffraction in pA were done by HELIOS with $\sqrt{s} = 27$ GeV Z. Phys. C 49 (1991) 355
- The cross-section of single diffraction is proportional to the nuclear radius, $\sigma_{SD} = \sigma_0 \cdot A^\alpha$, $\alpha = 0.35$
This suggests that diffractive dissociation of nuclei is a peripheral process, predominantly involving nucleons on the rim of the nucleus.





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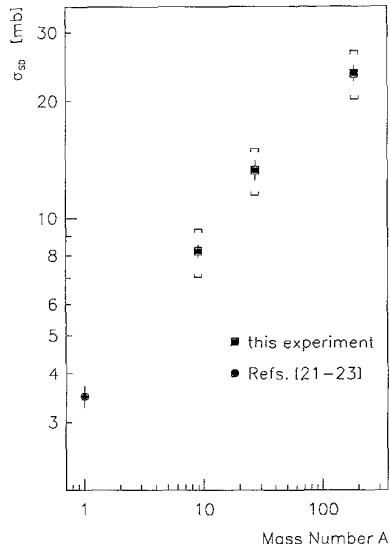
SPS vs LHC energies for pA:

$$\sqrt{s} = 27 \text{ GeV}$$

$$\sqrt{s} = 8000 \text{ GeV}$$

Center-of-mass system: 300 times

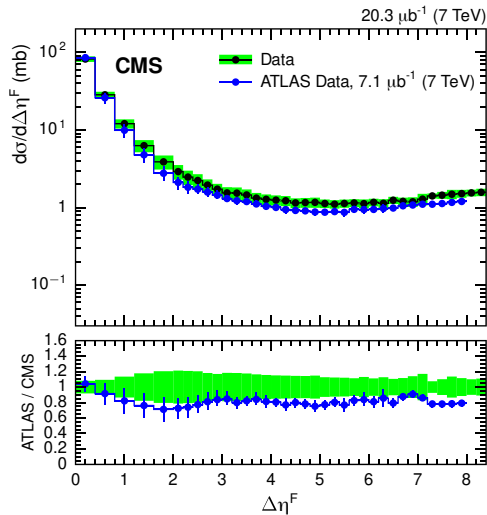
Laboratory system: 80000 times





- As a consequence of the color-less nature of pomeron, the diffractive processes are characterized by a Rapidity Gap
- Rapidity Gap ($\Delta\eta$) – the rapidity region free of final state particles

rapidity gap was studied with **pp** collisions data by
ATLAS EPJC 72 (2012) 1926, CMS PRD 92 (2015) 012003





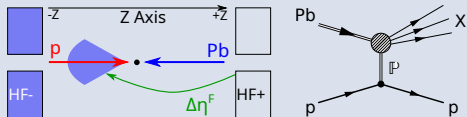
Event topologies for pPb collisions

CMS analysis

CMS collaboration, "First measurement of the forward rapidity gap distribution in pPb collisions at $\sqrt{s_{NN}} = 8.16$ TeV",
[Phys.Rev.D 108 \(2023\) 092004](#)

Event topologies

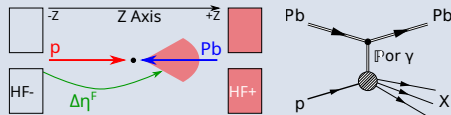
Named as "PPb + γ Pb topology"



Lead dissociation

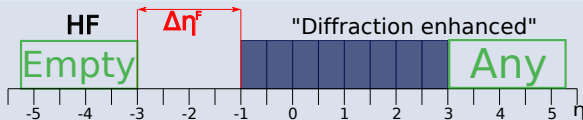
The photon flux from the Pb is enhanced by a factor of Z_{Pb}^2 compared to that of protons

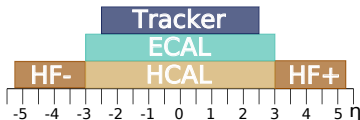
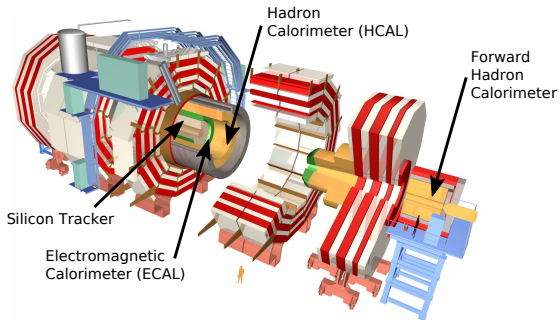
Named as "Pp + γ p topology"



Proton dissociation

Rapidity gap selection



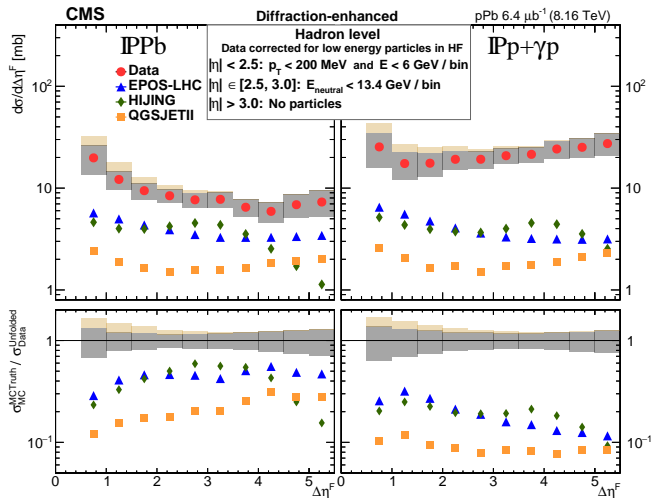


Calorimetry + tracking = Particle Flow (PF) objects

- Silicon tracker: $|\eta| < 2.5$
- ECAL and HCAL: $|\eta| < 3.0$
- Forward Hadron Calorimeter (HF):
 $3.0 < |\eta| < 5.2$
has fine segmentation by η and ϕ into 432 HF Towers
- Zero Degree Calorimeter (ZDC): $|\eta| > 8.5$



Hadron-level pPb rapidity gap results



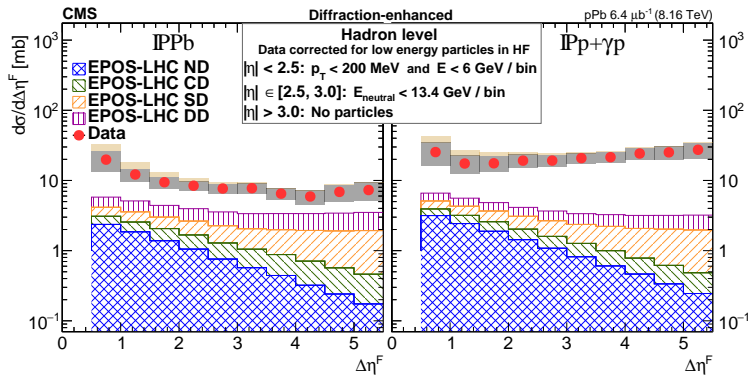
(\mathbb{P}/γ)-p topology

- The generators are more than a factor of 5 below the data

(\mathbb{P}/γ)-Pb topology

- Predictions of EPOS-LHC and QGSJET II are about a factor of 2 and 4 below the data
- The rapidity spectrum from the HIJING generator falls at large $\Delta\eta^F$ in contradiction to the data

Used generators includes **only** pomeron exchange events



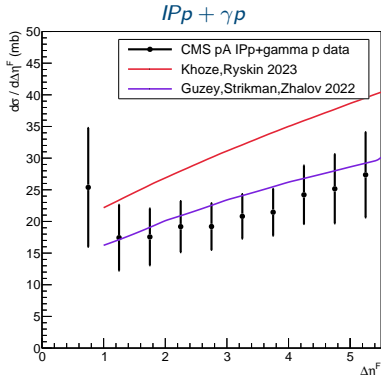
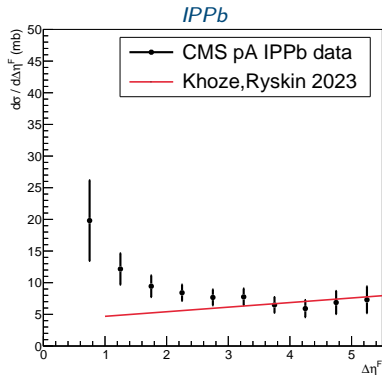
Stacked distributions:

- ND: Non-Diffractive
- CD: Central Diffractive
- SD: Single Diffractive
- DD: Double Diffractive

For the pomeron exchange events, diffractive events dominates at high rapidity gap sizes



Hadron-level pPb rapidity gap results: (\mathbb{P}/γ)-p topology



- V. Guzey, M. Strikman, M. Zhalov, *Phys.Rev.C.* 106 (2022) L021901
- Khoze V. A., Ryskin M. G., *EPJC* 83 (2023) 11, 991

The difference between generator predictions and CMS data can be described by γp events!



Summary

- Forward rapidity gap distribution $\frac{d\sigma}{d\Delta\eta^F}$ from p-A collisions at the LHC ($\sqrt{s_{NN}} = 8.16$ TeV) have been measured for the first time for both (IP/ γ)-A and (IP/ γ)-proton topologies
- The performed measurements at \sqrt{s} are about 300 times larger than the previous measurements (80000 in lab system).
- For (IP/ γ)-A topology, the predictions of event generators (EPOS-LHC, QGSJET II) are about a factor of 2-4 below the data, but the shapes of the spectrum are similar to that of the data
- For (IP/ γ)-p topology, the all used generators yield the cross section values a factor of 5 smaller than the data due to the contribution from γp events (not implemented in the used event generators)
- This measurement changes relation between the common diffraction process markers: fast particle observable and rapidity gap observable
- Rapidity gap observable in p-A measured by CMS shows that electromagnetic contribution exceeds strong interaction diffraction
- These data may be of significant help in modeling ultrahigh-energy cosmic ray air showers

Thank you!