Heavy ions and small-x at CMS

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QCD midsummer school

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Outline

1.- Introduction

2.- Present key current measurements which probe low-x physics:

 2.1.- Forward Jets in pPb at CMS

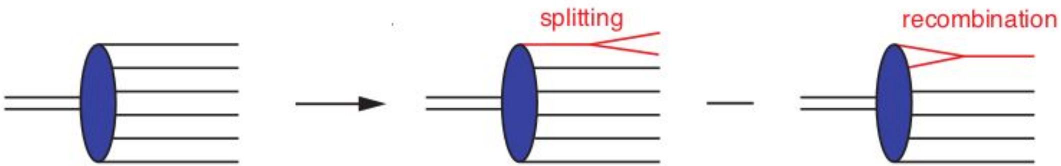
 2.2.- Constraining gluon distributions in nuclei: pp + Pb dijets

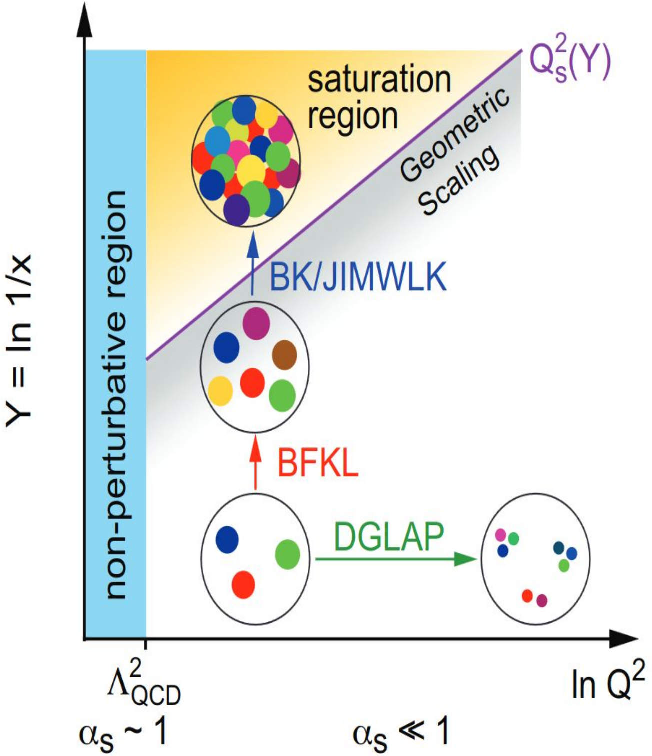
 2.3.- Dijet azimuthal correlations

3.- Diffractive Dijet Photoproduction in pPb (ongoing)

4.- Summary

Small-x physics





- At first approximation, the small-x evolution of the proton/nuclear wave function is dominated by gluon splitting: g-> g g . This contribution incorporated in DGLAP equations.
- At high gluon density expected to have recombination contributions. gg->g
- Energy at splitting and recombination mechanisms in balance = Saturation scale.
- Saturation effects expected to be universal.
- **Saturation scale in heavy ion larger than single nucleon.**

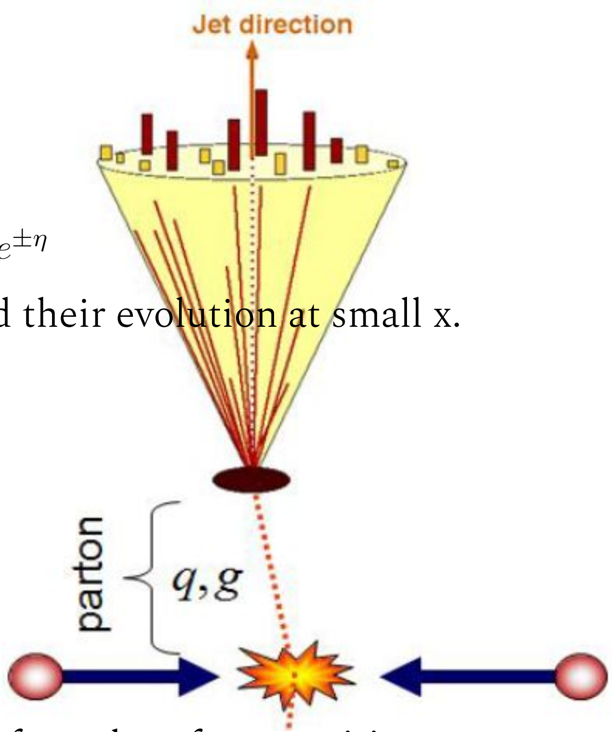
- Q^2 increases as $A^{1/3}$.   For lead ~ factor 6 with respect to proton
- **More accessible experimentally.**

Forward Jets in pA at CMS

- Low x gluon density poorly known

- Very forward jets allow to probe the low-x domain region $x \approx \frac{p_T}{\sqrt{s}} e^{\pm\eta}$

- forward jets with low p_T offer insights into the parton densities and their evolution at small x.



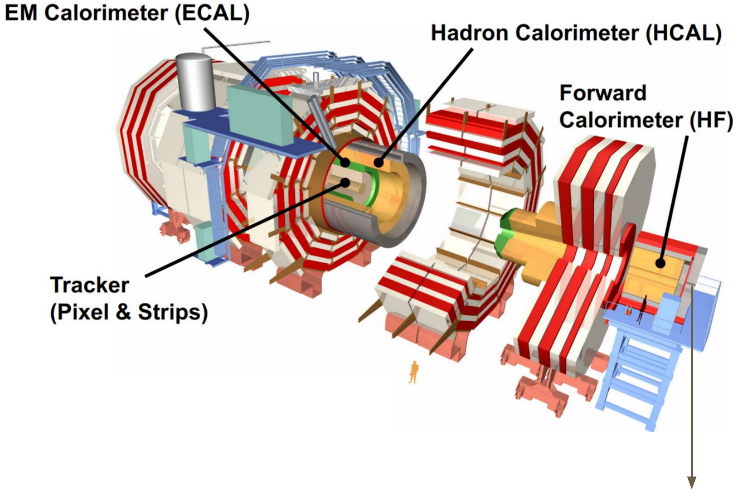
- sensitive to non-linear QCD effects
  - Constrain low-x gluon PDFs
  - Saturation scale in heavy ion larger than single nucleon.
  - Q^2 increases as $A^{1/3}$; for lead ~ factor 6 with respect to proton.

- Jets in the p+Pb data probe the ion parton density at low values of x → therefore sensitive to possible enhanced saturation effects in nuclei.

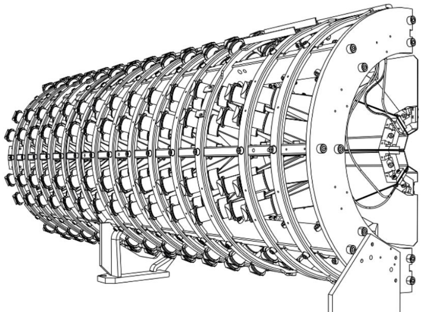
Forward Calorimeter at CMS

- CASTOR EM-hadronic calorimeter at CMS:
  $-6.6 \leq \eta \leq -5.2$
  - Forward calorimeter at 14 m from interaction point

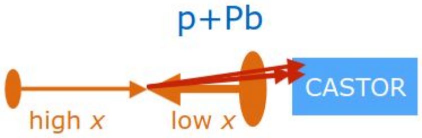
- CASTOR has no η segmentation. Present energy spectra instead of pt

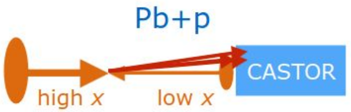


CASTOR



14 modules





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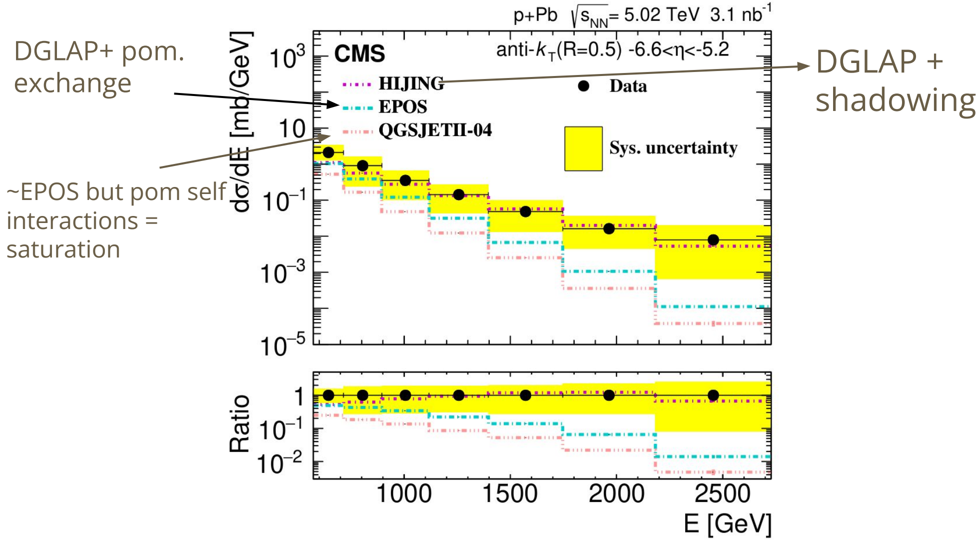
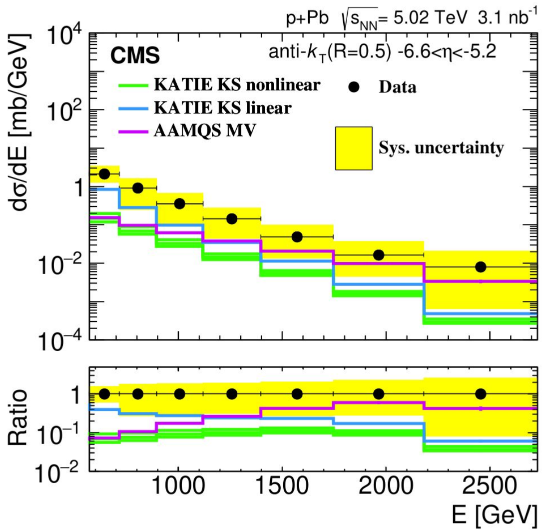
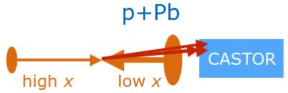
p+Pb differential jet cross section as a function of jet energy



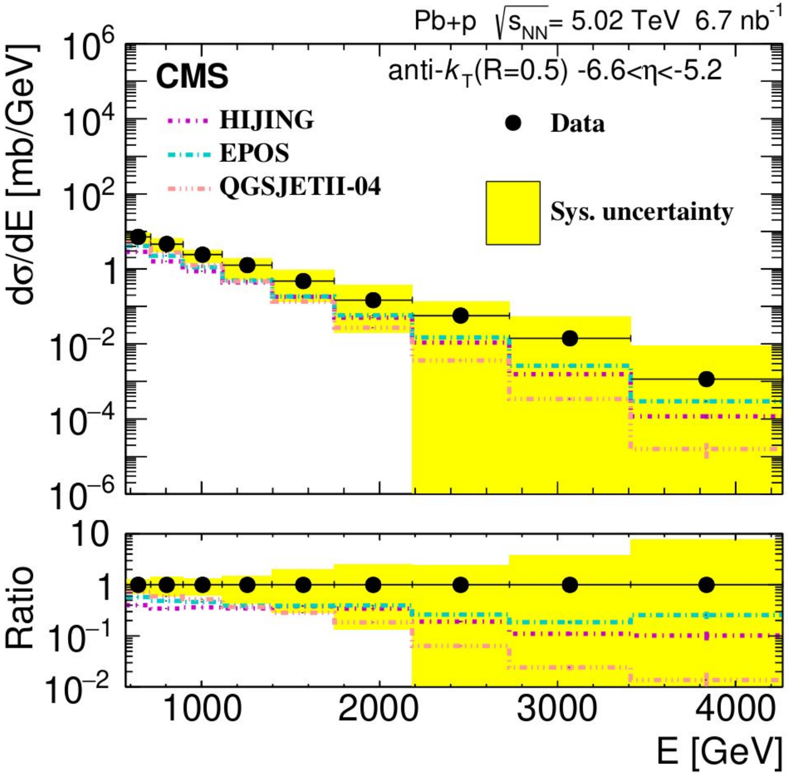


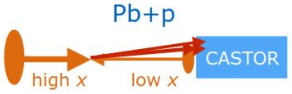


JHEP 05 (2019) 043

- The predictions of the EPOS-LHC and QGSJETII-04 model differ by more than two orders of magnitude at E = 2.5 TeV.
  - both yield an energy spectrum that is too soft and underestimate the data at high energy.
- HIJING model describes the measured distributions best.
- KATIE-KS predictions differ by an order of magnitude in the low energy region, while converging for the high energies.
- The AAMQS model underestimates the data also in the region most affected by saturation.

Pb+p differential jet cross section as a function of jet energy



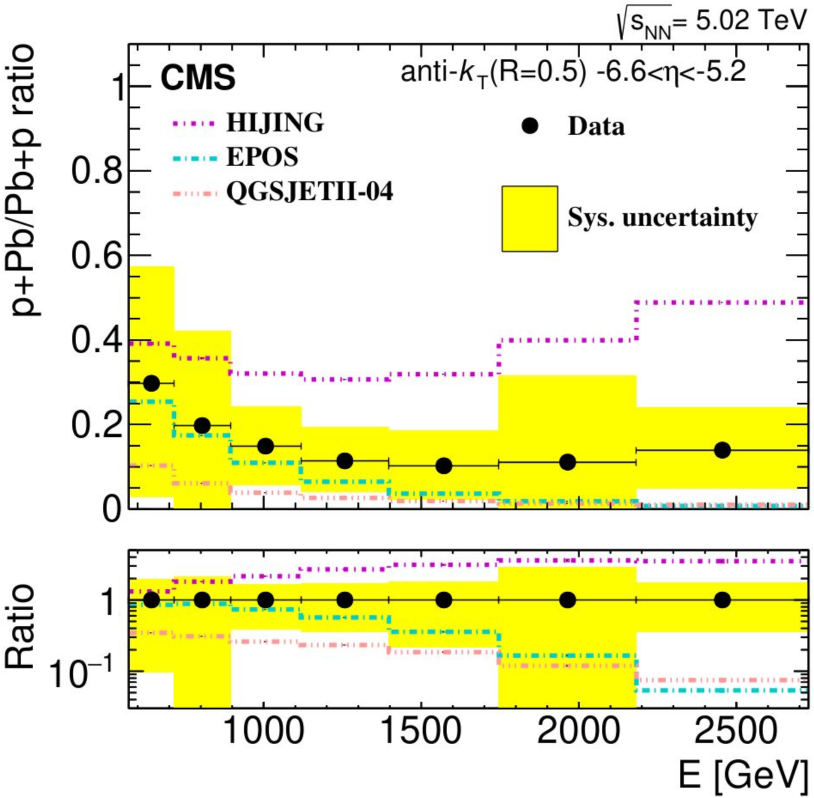


- <u>All models</u> underestimate the data for a few lower energy bins.
- From ~ 1.2 TeV onwards, all models are in agreement with the data within the systematic uncertainty.

JHEP 05 (2019) 043

Ratio of the p+Pb to Pb+p cross sections

JHEP 05 (2019) 043

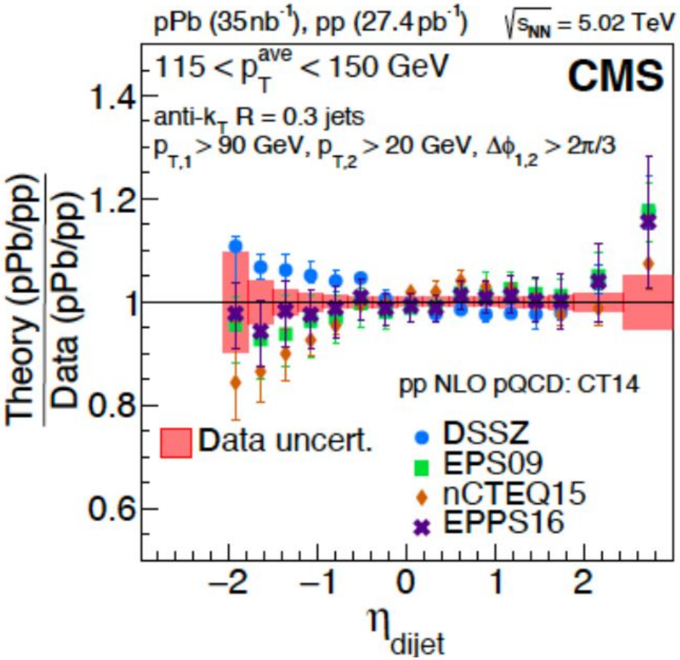


- p+Pb cross section order of magnitude smaller than Pb+p.
- Ratio is quite flat, substantial uncertainty cancelation occurs.
  → Ratio opportune observable
- HIJING describes shape well but an overall factor ≈ 2 off, due to poor Pb+p description.
- EPOS-LHC model describes the lower energy part of the ratio spectrum well, but fails to describe the shape at high energies.
- QGSJETII-04 underestimates both the shape and normalization of the ratio, which can also be attributed to the poor description of the p+Pb spectrum.

-No clear sign for saturation yet

Constraining gluon distributions in nuclei: pp + pPb dijets

Phys. Rev. Lett. 121, 062002 (2018)

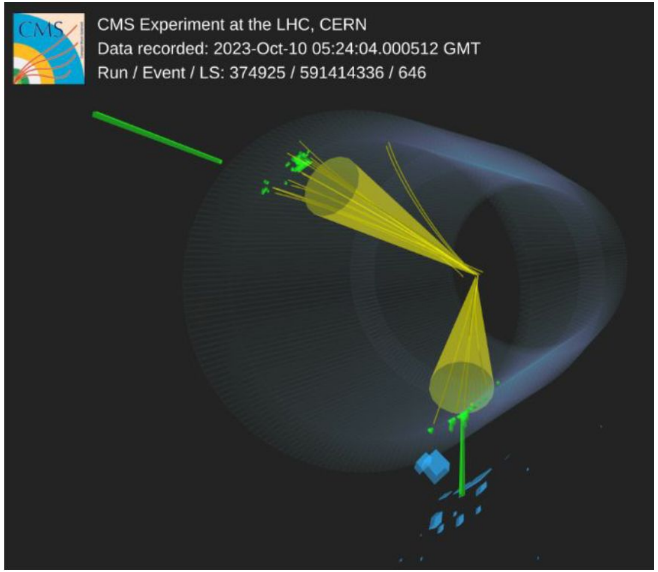


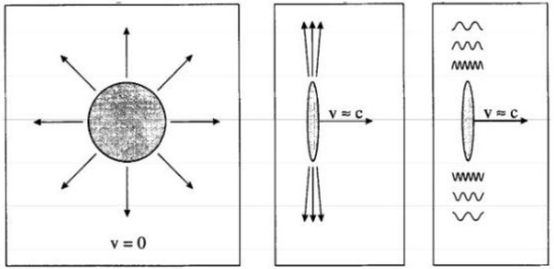
Good study to constraint nPDFs

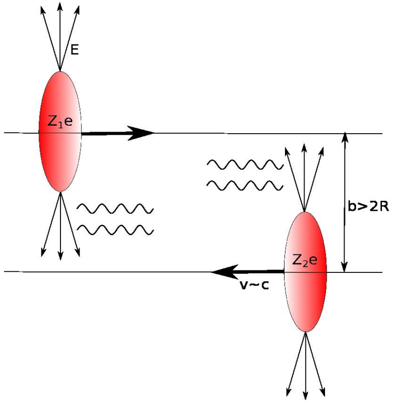
DSSZ without gluon EMC effect: disfavored
EPS09: EMC implementation compatible with data
nCTEQ15: overshoots EMC and anti-shadowing effects
EPPS16 similar to EPS09 w/ relaxed constraints; larger nPDF uncertainties

With Ultraperipheral heavy-ion collisions...

- Impact parameter is a bit bigger than the sum of the radii.
- Boosted charged particles are an intense source of photons.
- Strong interaction effects are suppressed.



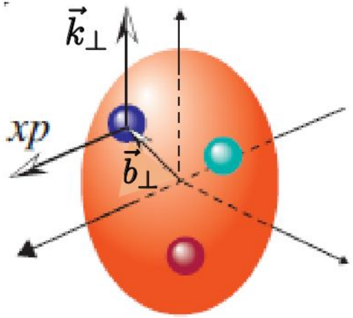




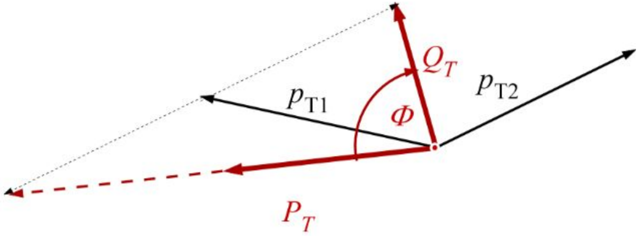
CMS dijet azimuthal correlations PbPb

Sensitive to the Wigner gluon distribution. Phys. Rev. Lett. 116, 202301 (2016)

How?



Partons also have transverse momentum $\vec{k}_\perp$ and are spread in impact parameter space $\vec{b}_\perp$



predicted non-trivial angular correlations of the gluon Wigner distributions.

Depend on impact parameter and gluon transverse momentum.

$$P_T = \frac{(p_{T1} - p_{T2})}{2}$$

$$Q_T = (p_{T1} + p_{T2})$$

$$P_T \cdot Q_T = |P_T||Q_T|\cos\Phi$$

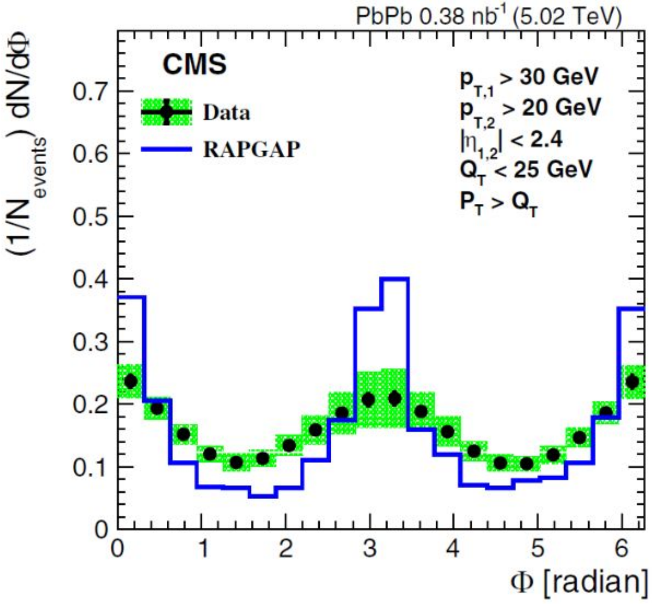
The magnitude of the spatial momentum anisotropy is measured by the second Fourier harmonic of the azimuthal distribution

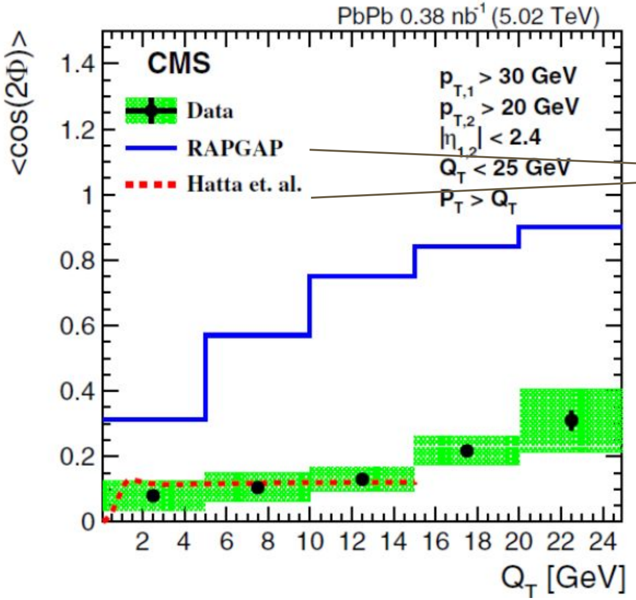
$$v_2 = \langle \cos(2\phi) \rangle,$$

CMS-PAS-HIN-18-011

Phys. Rev. Lett. 131 (2023) 051901

Φ distribution





ignore the effect of elliptically polarized gluons

- Similar trend between data and RAPGAP

-<cos(2Φ)> rises with Q_T and effect is overestimated by RAPGAP.

- This increase in azimuthal asymmetry has been associated with soft gluon emissions and leading order color-glass-condensate calculations. **Phys. Rev. Lett. 126, 142001**

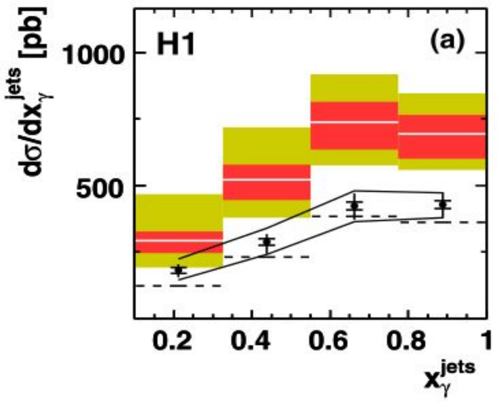
Exclusive diffractive dijet photoproduction in UPC pPb

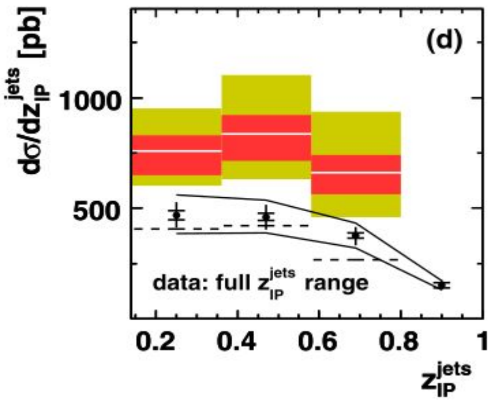
[diffractive dijet photoproduction in ep at Hera](#)
Eur. Phys. J. C 70, 15–37 (2010)

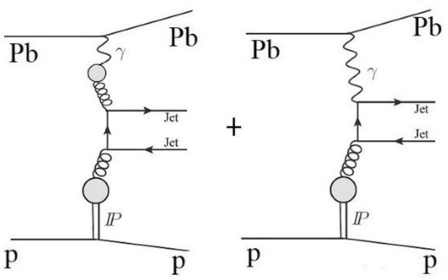
- we study the exclusive dijet photoproduction in ultra-peripheral pPb, with γ+ℙ→Pb+jet+jet+p
- Rapidity gap method

- Exclusive dijet photoproduction is of great interest since it is a good probe to study nPDF.

- currently not studies in pPb.
- Main observables of interest , momentum fractions: x_gamma , x_pomeron







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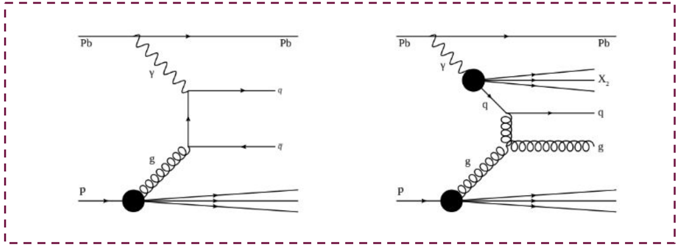
Experimental strategy for diffractive photoproduction

Background

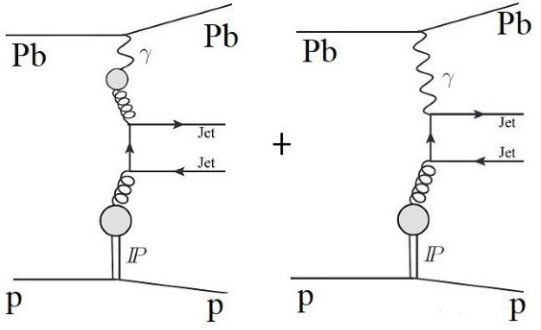


- UPC Photonuclear interaction

- Contamination from **hadronic** events.
- Could have 0n0x signature

- Double Diffractive events

Signal



Resolved photon   Direct photon

- Unbroken nuclei
- Exchanging pomeron.

pPb dataset of 2016 at 8.16TeV.

Detectors:
-Hadronic Forward calorimeters to determine rapidity gaps.
-Zero Degree Calorimeter -> lead dissociation

Forward Rapidity Gap (FRG)

Following HIN-18-08 , HIN-18-019

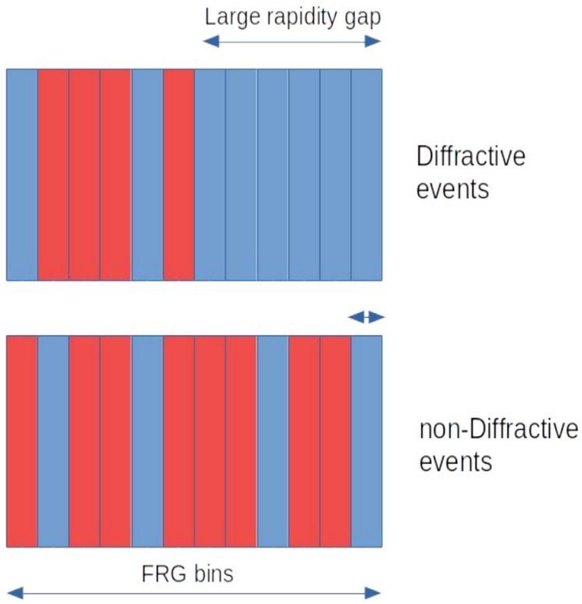
- 20 bins to be defined in |η| < 5 of 0.5 units of width.
- Empty bins are defined by :

a) |η| < 2.5 a bin is empty if no high purity track with pt > 200 MeV and total energy of PF candidates < 6 GeV .

b) 2.5 < |eta| < 3 a bin is empty if energy of all neutral hadronic PF candidates < 13.14 GeV .

c) 3 < |eta| < 5 energy of PF candidates < 13.4GeV

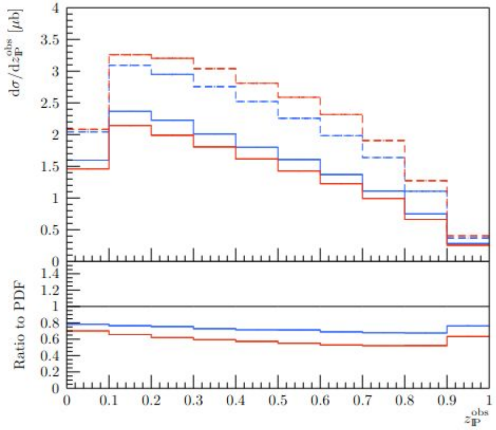
FRG is the number of empty bins from η= -5 to the lower edge of the first non-empty η bin

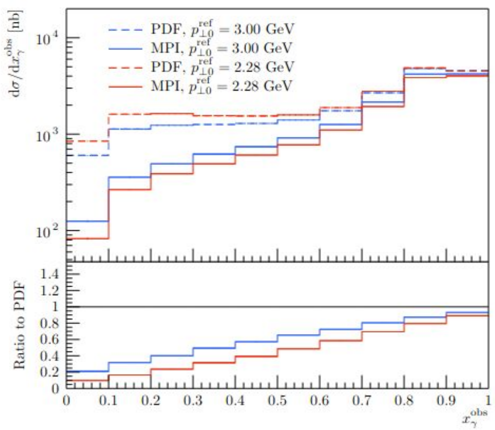


MC Simulations:

- MC set up with Pythia8, simulating photon-gluon and photon-pomeron interaction.
- Ion photon-flux implemented in p-p configuration.

Motivated by:





Helenius, I., Rasmussen, C.O
Eur. Phys. J. C **79**, 413 (2019)

Summary

- Saturation effects expected at small-x.
- Saturation scale in heavy ion larger than single nucleon
- Measurements of the differential inclusive forward jet cross sections in proton-lead collisions at 5.02 TeV have been discussed .
  - Major challenge: energy scale uncertainty
  - No clear sign for saturation yet
- Jet studies good tool to constraint nPDFs.
- Jets in UPCs are a promising new probe for low-x studies.

- Diffractive photoproduction in pPb in UPCs 

Thank you!