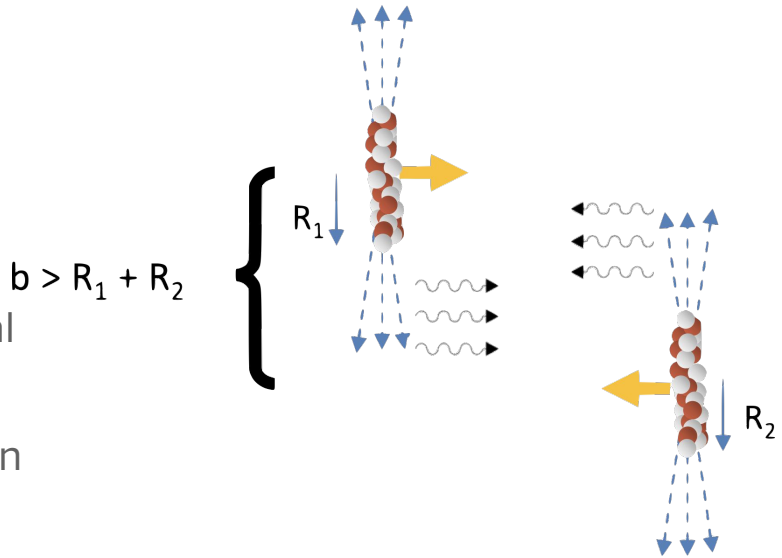
MEASUREMENTS FOR HADRON STRUCTURE IN ULTRA-PERIPHERAL COLLISIONS

GDR QCD WG1

Aude Glaenzer & Michael Winn, 23rd of June

Ultra-peripheral collisions

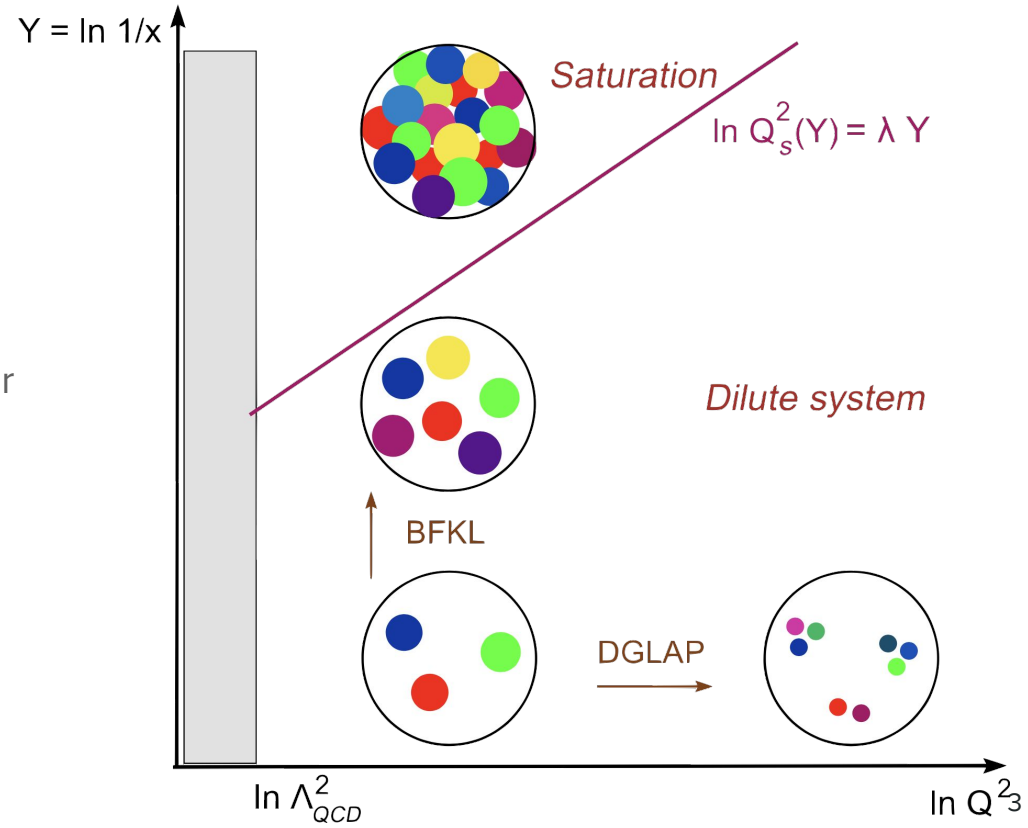
- Ultrarelativistic system
- Large impact parameter (b > R1 + R2[OBJ])
- No nuclear overlap - no "collision"
- Photon induced reactions dominate
- The intensity of the photon beam is proportional to Z^2
- In p-Pb Ultra-peripheral collisions (UPC): lead-ion is most likely (~95%) the photon source



Why UPC at the LHC for low-x?

Collider mode

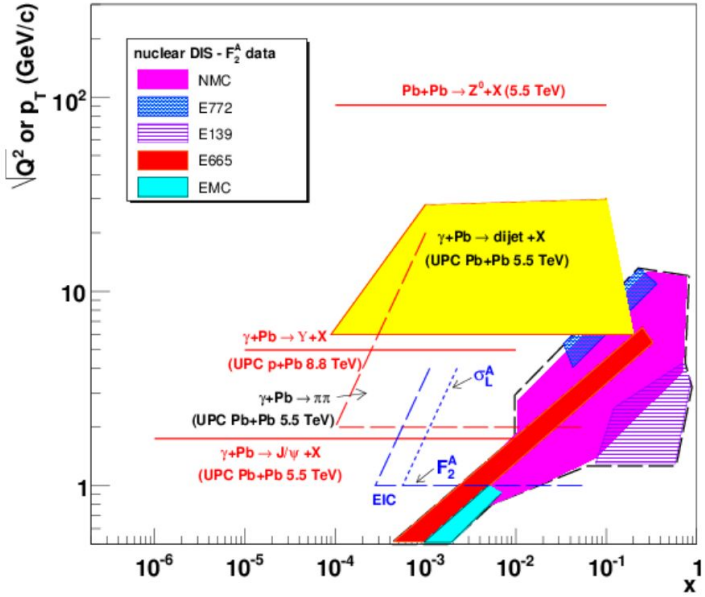
- x = mT/sqrt(s) * exp(-y)
- low-x reach beyond EIC and HERA
- very interesting to test limits of collinear factorisation, important input for initial state of heavy-ion collisions



Why UPC at the LHC for low-x?

Collider mode

- kinematic reach for UPC compared to nuclear targets



https://cds.cern.ch/record/2650176/files/1812.06772.pdf early version by N. Armesto from HL-LHC YR WG 5 for nuclear targets, see later for proton targets for Jpsi example. .
Statistics on dijet and vector meson production statistics available contained in YR.

Why UPC at the LHC in addition to inelastic production?

Collider mode

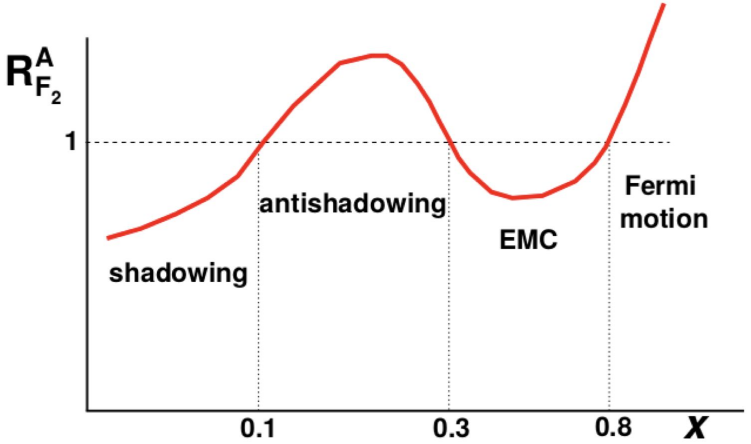
- Avoid color-dense environment in final state factorisation in inelastic collisions discussed in heavy-ion community:
  - hadronisation modifications
  - ‘collective’ effects
  - energy loss

- Exclusive photo-production measurements (experimentally so far mainly exploited) probing not the same non-perturbative hadron structure observables as inelastic ones: GPD vs. PDF

- Ideally: develop a self-consistent picture with the help of different observables from photo and gluo-production

Why UPC at the LHC for nuclear structure?

Collider mode



- Proton and nuclear targets:
  not available at HERA in collider mode
- Interesting for saturation phenomenology:
  saturation scale boost as at EIC with Au nucleus
- Nuclei different from superposition of constituents nucleons
- Nuclear structure function per nucleon divided by the nucleon structure function $R_{F2}^{A}(x,Q^2) = F_2^{A}(x,Q^2) / F_2^{nucleon}(x, Q^2)$
- For low x values: the γ*-nuclei interaction cross section lower than the scaled up γ*-nucleon interaction cross section.
- ‘Shadowing’ interpretation: 'multiple scattering' of hadronic components of virtual photon (arXiv:hep-ph/0604108v2)

Why UPC at the LHC now?

Collider mode

- Luminosity increase for heavy-ion related beams by a factor 5-10 in Run 3 w.r.t. Run 2
- Many UPC measurements in Run 1 and 2 largely statistically limited
    - EIC: future high-luminosity precision machine
    - LHC: frontier machine for low-x dynamics

Why UPC at the LHC for hadron structure?

Fixed target mode

- Very special kinematics: large boost
- Access far-backward rapidity with LHC detectors
  - at EIC at similar sqrt(s): the photoproduction hadrons at this high-x ‘squeezed’ in hadron endcap
  - zoom in large x-domain of target at comparatively large sqrt(s)

- Large luminosities reachable

- Target flexibility

- several studies, summarised in Hadjidakis et al.: https://arxiv.org/pdf/1807.00603.pdf
  - interesting example: single transverse spin asymmetry with a future polarised target at the LHC: Massacrier et al. https://arxiv.org/pdf/1709.09044.pdf

not covered further: lack of time and expertise

Challenges

- Typically not full kinematics reconstructed:

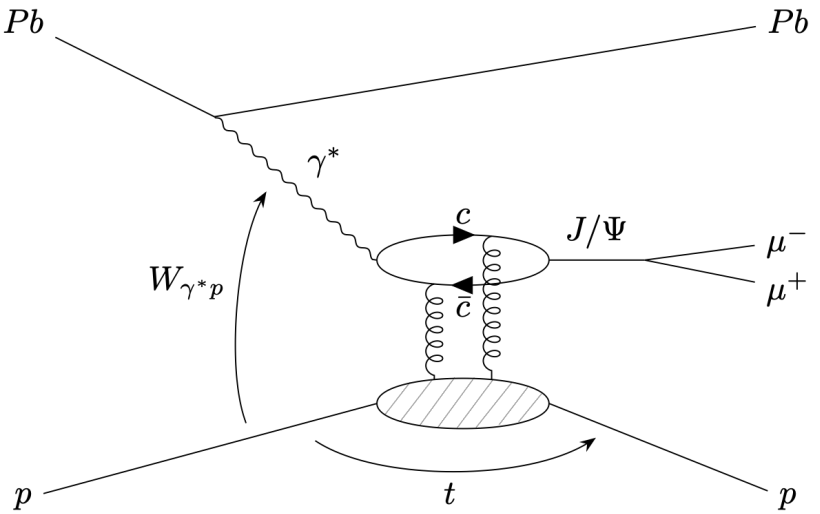
  exception CMS/ATLAS pp running with roman pots (but quite limited in x-Q^2 plane);

  - exclusivity control via neutron emission (nucleus fragile object) and vetos
  - reconstruct kinematic variables with hadronic part of final state

- Luminosities comparatively limited: Run 3 change factor 5-10 for ions beams more
- Production measurements for Inclusive photoproduction: only preliminary so far, only exclusive production published
- Inclusive photoproduction often more difficult to distinguish cleanly with inelastic collisions:
  - However, ATLAS claiming to control this very well: https://arxiv.org/abs/2101.10771

An example: Exclusive vector meson production in UPC proton case - Benchmark with HERA & lowest available x

- The virtual photon fluctuates in a dipole
- The virtual photon interacts with the proton and probes its internal structure via the exchange of 2 gluons
- From this interaction a vector meson (here J/ψ) is produced

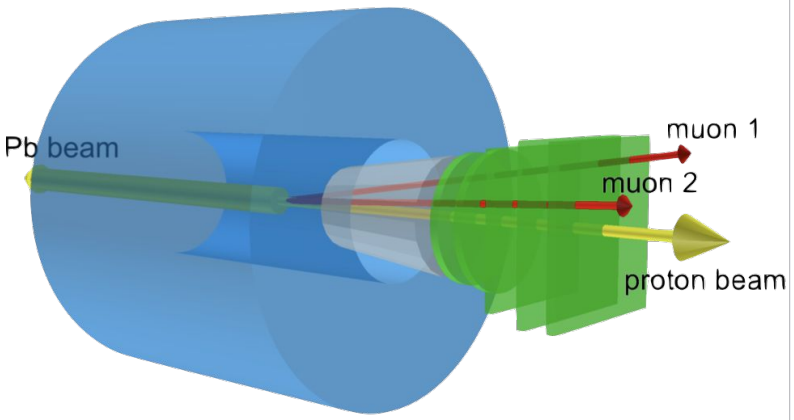


Kinematics for vector meson production for asymmetric p-Pb and forward spectrometer in ALICE

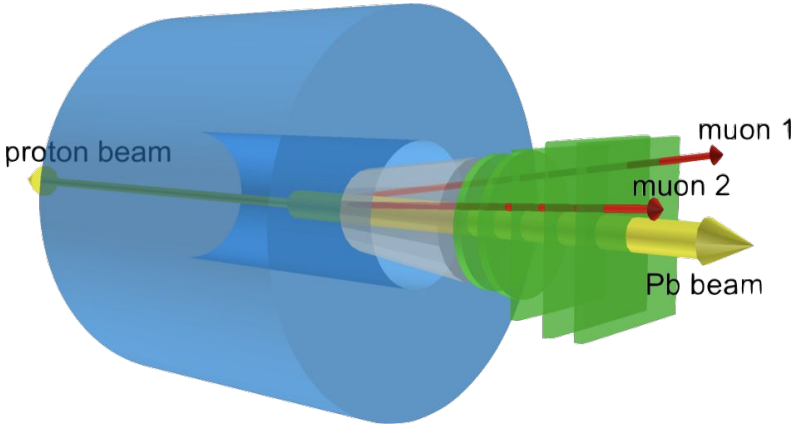
2 ENERGY CONFIGURATIONS depending on beam direction

p-γ* center-of-mass energy given by $W_{\gamma^* p} = 2E_p M_{J/\psi} e^{-y}$ where y is the rapidity of the J/ψ defined according to the proton beam

The J/Ψ goes in the direction of the proton:
$27\ \text{GeV} < W_{\gamma^* p} < 58\ \text{GeV}$



The J/Ψ goes in the direction of the Pb ion:
$702\ \text{GeV} < W_{\gamma^* p} < 1486\ \text{GeV}$

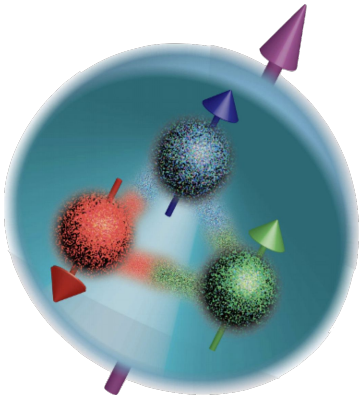


Kinematics for vector meson production for asymmetric p-Pb and forward spectrometer in ALICE

2 ENERGY CONFIGURATIONS depending on beam direction

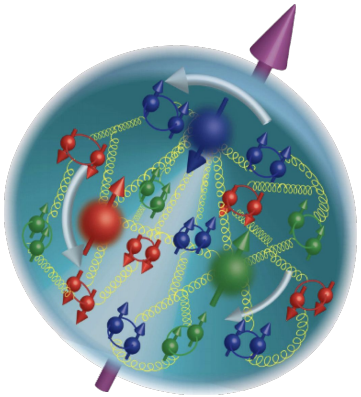
The target is probed at the longitudinal momentum fraction (analogous to the Bjorken-x of DIS): $x_P = 2\ M_{J/\Psi}^2 / W_{\gamma^* p}^2$

The J/Ψ goes in the direction of the proton:
$27\ \text{GeV} < W_{\gamma^* p} < 58\ \text{GeV}$



$5 \times 10^{-3} < x < 2 \times 10^{-2}$

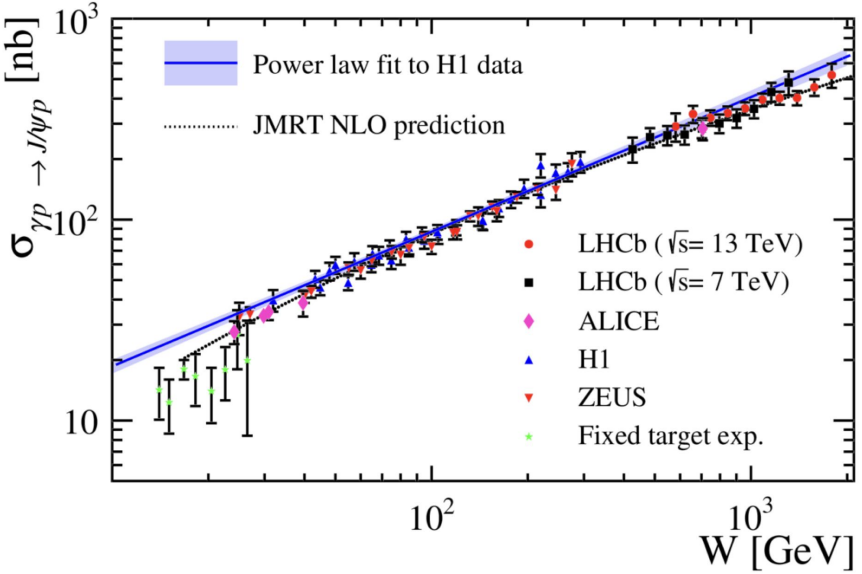
The J/Ψ goes in the direction of the Pb ion:
$702\ \text{GeV} < W_{\gamma^* p} < 1486\ \text{GeV}$



$8 \times 10^{-6} < x < 3 \times 10^{-5}$

Exclusive vector meson production in UPC - proton case

- Power-law fit $\sigma \sim W_{\gamma^* p}^{\delta}$
- Fit to ALICE data (Run 1) alone: $\delta = 0.68 \pm 0.06$ ➔ no deviation from a power law is observed up to about 700 GeV
- (ZEUS: $\delta = 0.69 \pm 0.02$ (stat) ± 0.03 (syst), H1: $\delta = 0.67 \pm 0.03$ (stat + syst))
- LHCb studied the same process in p-p collisions (symmetric system : photon emitter identified via HERA data)
- HERA: H1 and ZEUS have measured the cross section of J/ψ photoproduction at energies from 20 to 305 GeV
- No change in the behavior of the gluon PDF in the proton is observed between HERA and LHC energies



Exclusive vector meson production in UPC - proton case

pPb: done by ALICE Run 1 (J/ψ), CMS (Y)

pp: (photon emitter ambiguity, removed by HERA fit) LHCb (J/ψ, Y, ψ(2s))

What could be interesting and should be feasible:

- φ only in LHCb at low t
- Y with precision in pA: more luminosity
- t-dependence: with more luminosity
- dissociative production ➔ Aude's thesis (ALICE)
- continuum: Bethe-Heitler + TCS ➔ ongoing work by Charlotte Van Hulse (LHCb)

Exclusive vector meson production in UPC - proton case

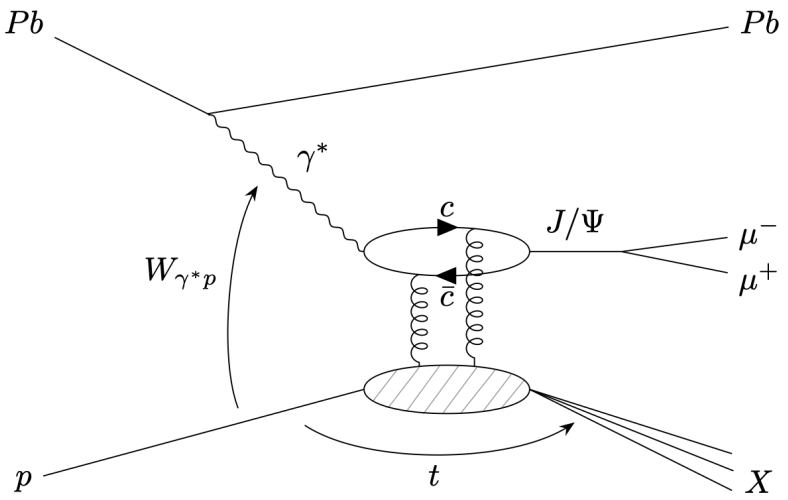
pPb - lead shine, γp								
Meson	σ	All Total	Ctl. 1 Total	Ctl. 2 Total	FW 1 Total	FW 2 Toal	BW 1 Total	BW 2 Total
$\rho \to \pi^+\pi^-$	35 mb	70 B	3.9 B	15 B	2.0 B	5.5 B	850 M	2.0 B
$\phi \to \mathrm{K}^+\mathrm{K}^-$	870 μb	1.7 B	65 M	290 M	22 M	120 M	9.7 M	52 M
$\mathrm{J}/\psi \to \mu^+\mu^-$	6.2 μb	12 M	1.0 M	5.2 M	260 K	800 K	180 K	430 K
$\psi(2\mathrm{S}) \to \mu^+\mu^-$	134 nb	270 K	22 K	110 K	6.0 K	18 K	3.2 K	7.7 K
$\Upsilon(1\mathrm{S}) \to \mu^+\mu^-$	5.74 nb	11 K	1.1 K	5.4 K	310	880	41	100

Working group 5 Yellow Report, total Run 3-4 lumi for pPb (2 /pb), prepared by Spencer Klein. only angular acceptance for ALICE, ATLAS/CMS, ALICE fw., LHCb fw assuming same ('full') luminosity for all detectors
https://cds.cern.ch/record/2650176/files/1812.06772.pdf

Never done so far:
Dissociative vector meson production in UPC - proton case

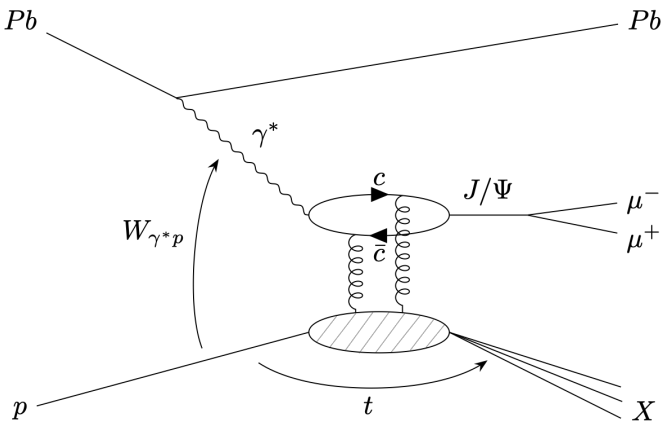
- Has been measured at HERA but not at the LHC

- Ongoing analysis in ALICE for $W_{\gamma^* p}$ ~ 27 - 58 GeV (in the future 700 - 1500 GeV)



Dissociative J/Ψ photoproduction - the proton case

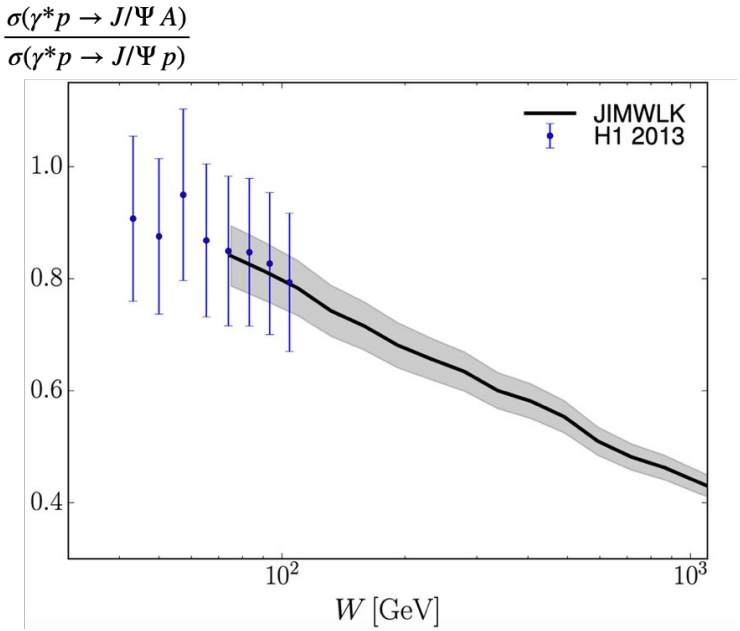
- In Good-Waker formalism (Heikki Mäntysaari 2020 Rep. Prog. Phys. 83 082201): initial and final states are required to be different
- Physically: we measure the fluctuations of the configurations of the proton
- The gluon parton density increases with decreasing momentum fraction x
- More sensitive to saturation than exclusive production, since fluctuations in asymptotic limit of high energies expected to be suppressed (black disc limit) as well as (more generically) higher t and hence smaller impact parameter and hence higher density



Diffractive J/Ψ photoproduction - the proton case

One example prediction for a model including saturation effects

Cross section ratio between dissociative and exclusive production decreases strongly as function of W

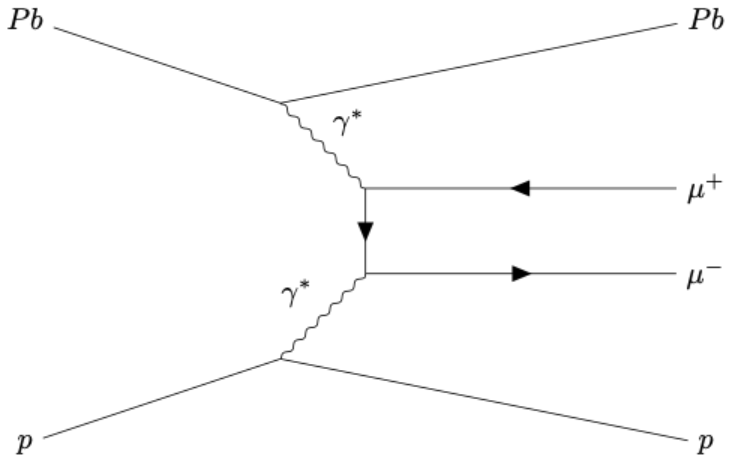


source : arXiv:2001.10705v1
H.M, B. Schenke, 1806.06783

The continuum: only early measurements so far in γ-p QED benchmark and potentially time-like compton scattering (TCS) - proton case

The continuum

- TCS - the brother of DVCS - now measured for first time at JLAB, see presentation by Pierre Chatagnon
- Integrated continuum cross section work ongoing in ALICE
- see e.g. https://arxiv.org/pdf/1207.2301.pdf
- Independent of TCS feasibility: important to confirm good understanding of QED side of diagrams

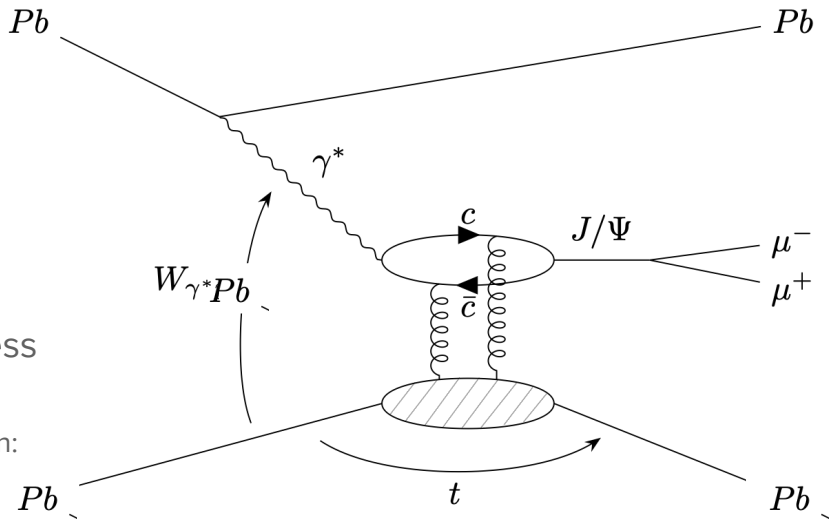


Bethe-Heitler diagram for UPC pPb

Exclusive vector meson production in UPC - nuclear case

Extensively studied at RHIC and LHC

- Large cross sections
- Often interpreted in the context of leading twist gluon shadowing à la EPS without reference to GPDs
- Complication as in pp for production at y unequal 0: symmetric system: photon emitter not resolved



- 2 proposals to resolve this ambiguity by varying process and photon fluxes:
  - measure production with different number of neutron emission: Guzey, Strikman, Zhalov: https://arxiv.org/abs/1312.6486
  - measure in peripheral collisions: Contreras: https://arxiv.org/abs/1610.03350 , published in PRC

Exclusive vector meson production in UPC - nuclear case

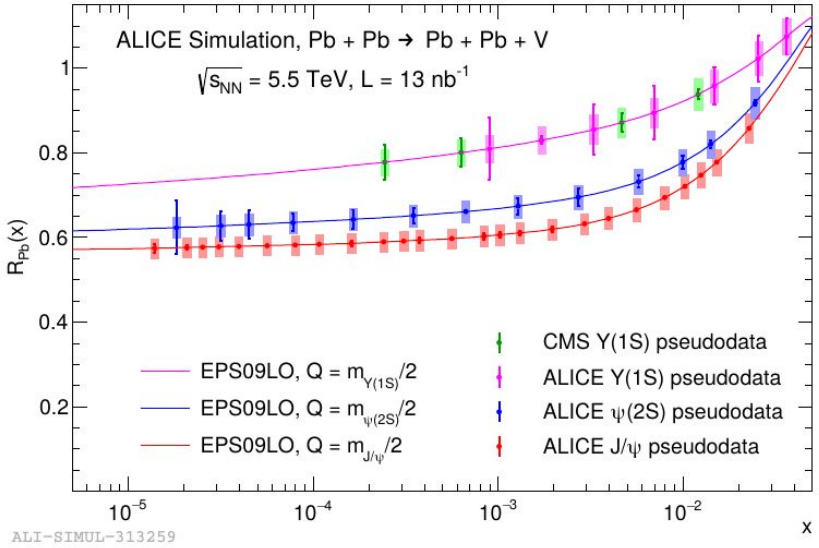


Fig. 79: Pseudodata projections for the nuclear suppression factor by ALICE and CMS measured with the photoproduction of three heavy vector mesons in Pb–Pb ultra-peripheral collisions are shown. The pseudodata points are derived from EPS09-based photoproduction cross section projections following the method described in Ref. [817].

https://cds.cern.ch/record/2650176/files/1812.06772.pdf

Inclusive dijet photoproduction - the nuclear case

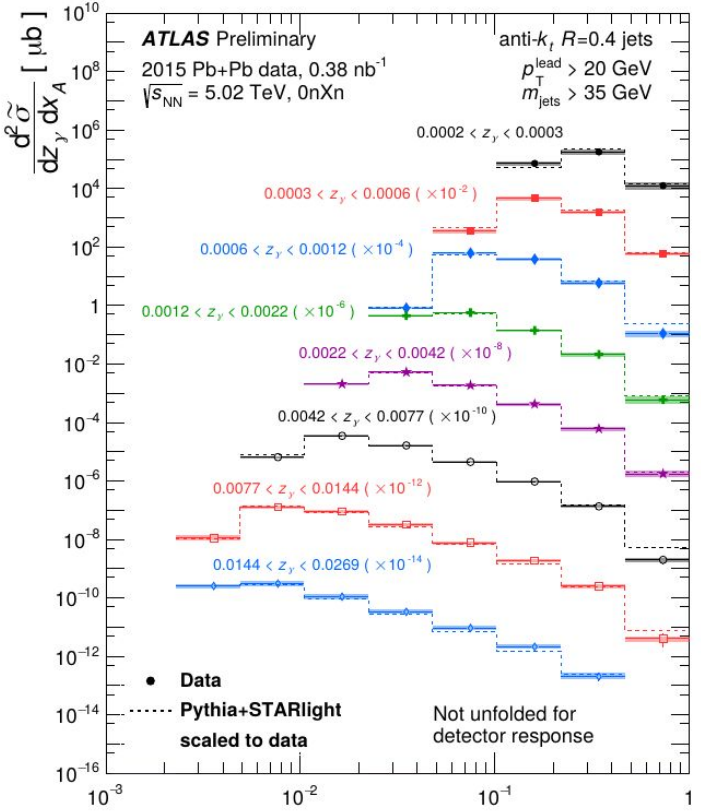
Preliminary measurement by ATLAS
- direct access to gluon pdfs in nucleus

Publication in preparation with 2015+2018
- not aware of pPb measurement so far

Measurement by ATLAS on di-hadron production
in inclusive nuclear photoproduction
https://arxiv.org/abs/2101.10771
see collectivity context in presentation by Maxime

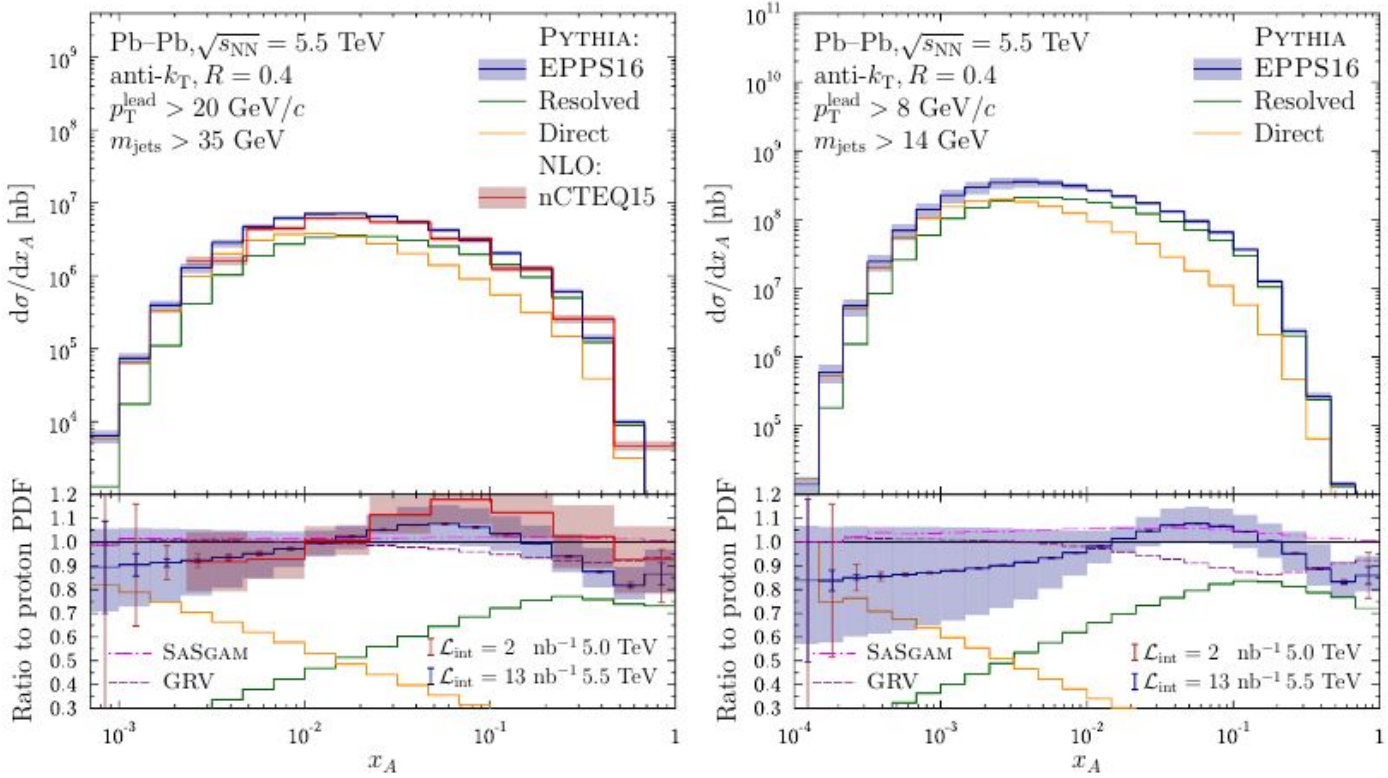
Future:
- interesting in Run 4 with extended tracker coverage with ATLAS/CMS
- interesting also with LHCb for extreme kinematics
- charm production potential with ALICE upgrades to be investigated

Theory input welcome to make use of those events beyond cross section!!



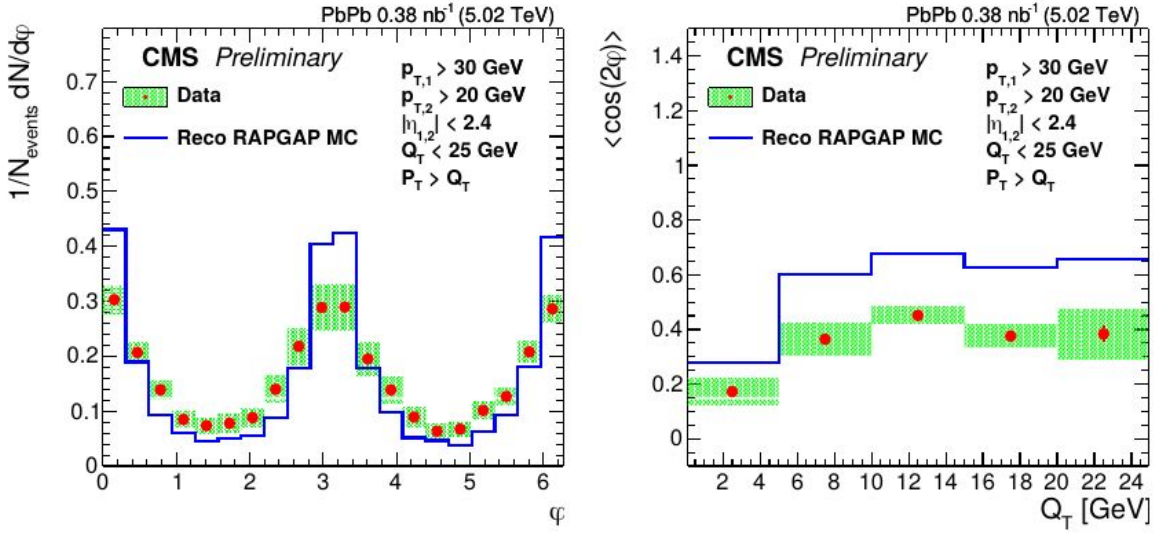
https://cds.cern.ch/record/2244822/files/ATLAS-CONF-2017-011.pdf

Inclusive dijet production: available theory



Pythia LO implementation (Helenius et al.) and NLO calculation (Guzey&Klasen) of inclusive photonuclear dijet production with statistical errors according to full Run ¾ data set in PbPb

Exclusive diffractive dijet production by CMS in nucleus-nucleus collisions



phi defined as difference of momentum sum and the momentum difference of the dijet

https://inspirehep.net/literature/1809346

Conclusion

High beam energies at the LHC:

- unique chance for extreme kinematics hadron structure studies
- in particular important for heavy-ion physics
- interesting for saturation (collider) & backward physics (fixed-target)

Luminosity increase in Run 3-6:

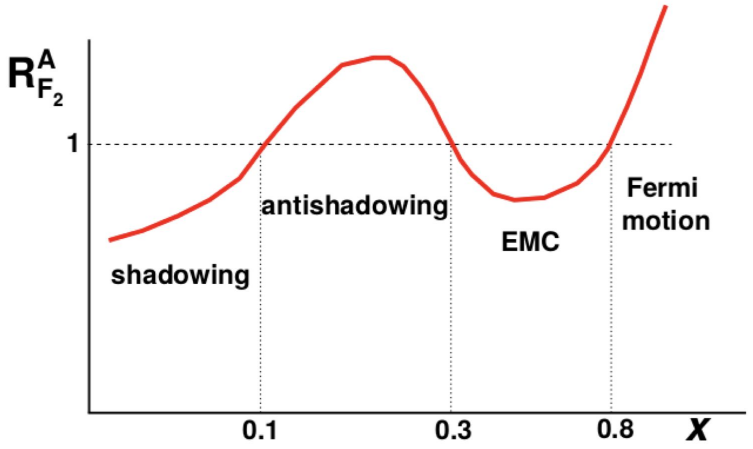
- improve precision
- extend kinematic reach and observable scope of programme
- both already ongoing

Interesting experimental opportunities requiring theory support for full exploitation

Why UPC at the LHC for hadron structure?

- Nuclear and proton structure in one collider at same rigidity
- Can compare quite directly results Pb and p
- Could do ratios gamma p w.r..t gamma Pb
- Nuclear structure functions in nuclei are different from the superposition
- of those of their constituents nucleons
- The nuclear ratio is defined as the nuclear structure function per nucleon divided by the nucleon structure function

$R_{F2}^{A}(x,Q^2) = F_2^{A}(x,Q^2) / F_2^{nucleon}(x, Q^2)$

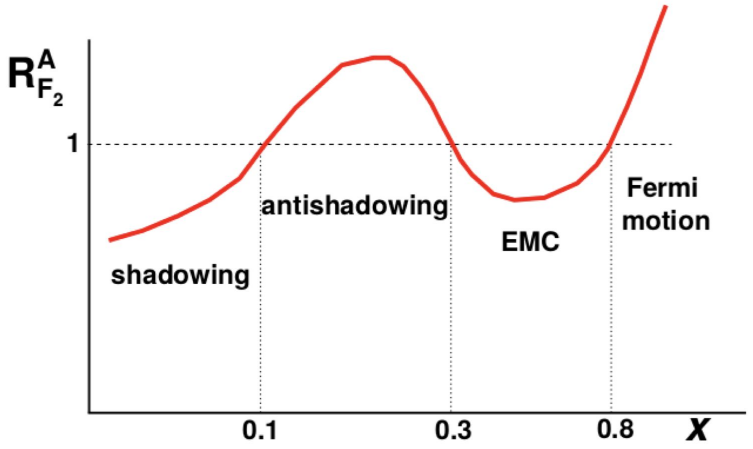


Why UPC at the LHC for hadron structure?

Nuclear and proton structure in one collider at same rigidity

can compare quite directly results Pb and p

could do ratios gamma p w.r..t gamma Pb



Why UPC at the LHC for hadron structure?

Extreme kinematic in collider mode

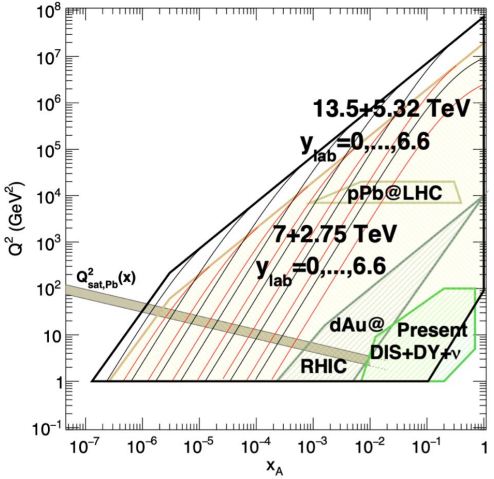
low-x beyond EIC and HERA

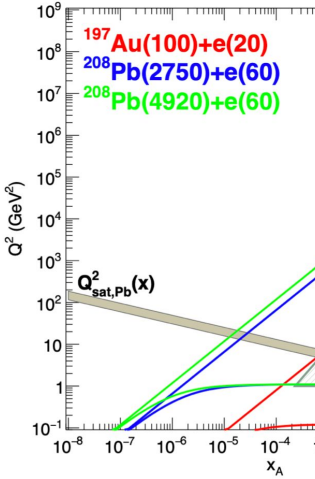
Copy x-Q^2 plane from Yellow Report ➔ this one?

Question to be answered to us before we do the talk to address fixed target mode:

what is special about fixed-target mode w.r.t. other kinematics

I think that it is not so interesting in terms of x, however you can test high-x at higher Q2 (i.e. such that charm production is already available to use it to probe gluons or intrinsic charm), so it can test DGLAP for GPD for example, we should read a bit, if there is something else: https://arxiv.org/pdf/1807.00603.pdf





Commentaires de Michael

I think that we should be a bit more humble:

- I would say like this (a bit different from what I said)
-very general (thisis what I prepared) for collider and fixed target: I changed this a bit already and put the slides in some logic, if you have time, you maybe able to transfer this to the other slide
- then some challenges (this is already there)

I would say that there I can talk, if you want.

one part on vector mesons: this I think that you can prepare: what has been done, what we are planning (including incoherent production/dissociative)

Then, I would say:
- what has been started or are only weak precision so far in exclusive channels: continuum (you can point to ATLAS or ALICE as examples), TCS (point to some theory paper: Bernard Pire wrote about this), phi (point to White paper of EIC, even if it is photoproduction, it has its interest and point that this is feasible in ALICE), Upsilon: you can show the plot for nuclear data or the table from the YR and the link to the ATLAS measurement in pPb (I think that it is the only one so far done)
(maybe you could do this?)

Then, what one should try to say what could be done as well

- inclusive photoproduction jet measurements: ATLAS measurements (preliminary)
(This I can do ...)

as well as measurements that one would like to do do. (This I can do as well)

ABSTRACT

We would like to discuss current activities and future possibilities in photon-induced (ultra-)peripheral collisions at the LHC. The very high-beam energies at the LHC offer unique opportunities that are complementary in terms of kinematic reach and type of reconstructable objects to dedicated accelerator facilities as JLAB and EIC or the compass programme and warrant further attention.

At the moment, the measurements are mainly limited to exclusive vector meson production, but the increase in luminosity by about a factor 5-10 in the next years in pPb and PbPb data takings as well as improved instrumentation and/or trigger capabilities should allow to gain precision and to add diffractive and inclusive photo-production measurements and potentially measurements in fixed-target mode. The French community is well placed in terms of detector expertise to contribute and it could be leading on these aspects making also use of the experimental and theoretical expertise on lepton-hadron scattering measurements.

The presentation will make a tour of current related activities in the local and global community and present a selection of possible future directions.