FNSPE CTU in Prague

Charmonium photoproduction at the LHC

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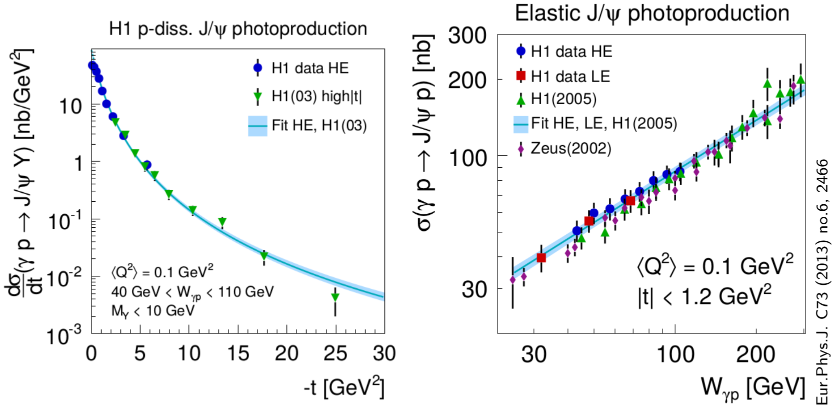
Content

Introduction

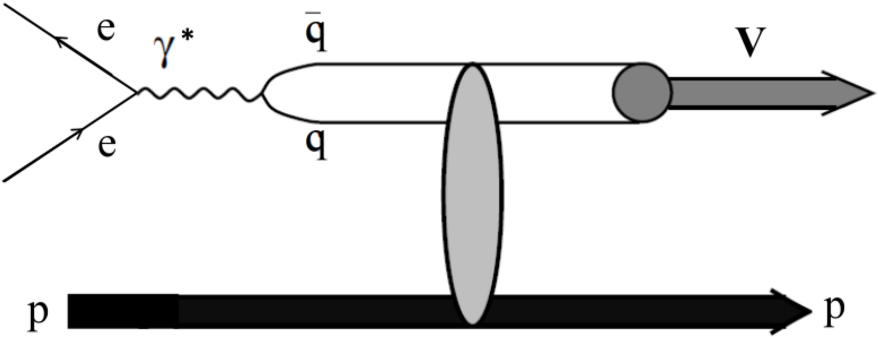
Why and how...

Published results - ep collisions at HERA



- High precision data covering a large part of the phase space is available from HERA.

Process used at HERA - exclusive electro-production

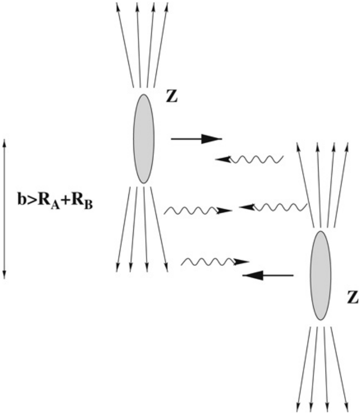


Eur.Phys.J. C73 (2013) no.6, 2466

- Electron emits virtual photon which fluctuates into quark-antiquark.
- Quark-antiquark pair interacts with proton and creates vector meson.

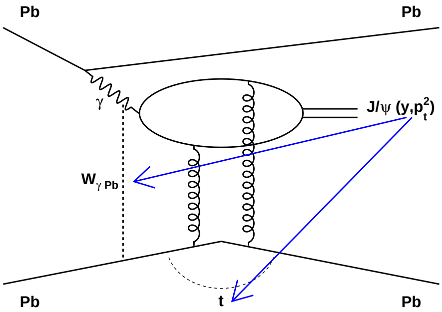
Available tools now - Ultra-peripheral collisions

- Collisions with impact parameter $b > R_A + R_B$.
  - Strong interaction suppressed.
  - EM interaction remains.
- EM field of ultra-relativistic electrically charged particle $\sim$ flux of photons.
  - Interaction intensity increasing with Z^2.



Phys.Rept. 458 (2008) 1-171

Process used at LHC - coherent photo-production



- Lead emits (quasi-)real photon which fluctuates into quark-antiquark.
- Quark-antiquark pair interacts with lead and creates vector meson.

Measurement

It has several parts...

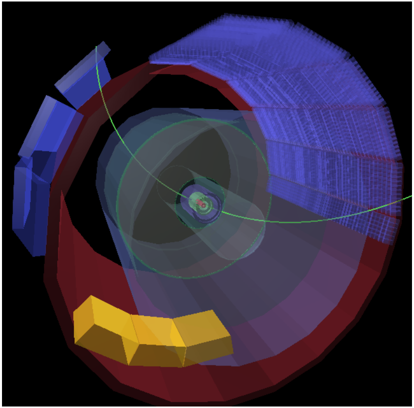
Cross section measurement

$$\frac{\mathrm{d}\sigma^{coh}_{J/\psi}}{\mathrm{d}y} = \frac{N^{coh}_{J/\psi}}{(Acc \times \epsilon)^{coh}_{J/\psi} \cdot \mathrm{BR}(J/\psi \to l^+l^-) \cdot \mathscr{L}_{int} \cdot \Delta y}$$

- $N^{coh}_{J/\psi}$ - number of coherently produced J/ψ
- $(Acc \times \epsilon)^{coh}_{J/\psi}$ - correction on acceptance and detector efficiencies
- $BR(J/\psi \to l^+l^-)$ - branching ratio
- $\mathscr{L}_{int}$ - integrated luminosity of UPC triggers
- Δy - rapidity region

How to pick our data

- We look for a clear signal where:
  - there are 2 leptons,
  - these are back-to-back,
  - these are in central rapidity,
- 2 level selection:
  - Online:
    - triggers collision recording,
    - few μs to decide,
    - has to be simple
    - and not to restrictive.
  - Offline:
    - detail look into data,
    - can be complex.



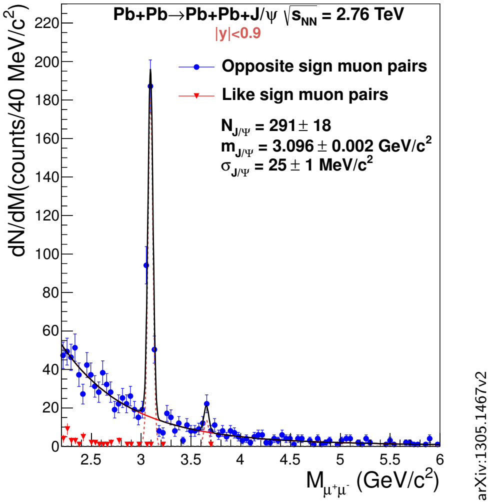
2011 UPC trigger

- CCUP4:
  - should see $\gamma\gamma \rightarrow l^+ l^-$
  - and PbPb$\rightarrow$ PbPb (VM$\rightarrow$ $l^+ l^-$).
- Detailed selections:
  - at least 2 hits in the SPD detector,
  - fired pads in TOF $\in$(2,6) while at least 2 of them $\in(150°, 180°)$,
  - no hit in VZERO-A and VZERO-C detectors.
- this triggered the event recording in $\sim$ 6 600 000 cases

Selection criteria

Selection	Events
Trigger CCUP4	6 610 590
N_{trk} $\in$(1,10)	2 311 056
Primary vertex	1 972 231
2 reconstructed good tracks	436 720
max(p_t^1,p_t^2)$>$ 1 GeV/c	46 324
VZERO offline	46 183
Lepton PID	45 518
Opposite charge	31 529
Mass $\in$ (2.2;6.0) GeV/c^2	4 542

Yield calculation



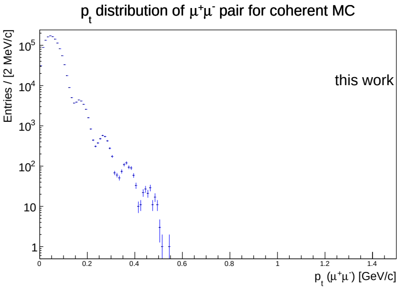
- Crystal Ball fit + exponential background.

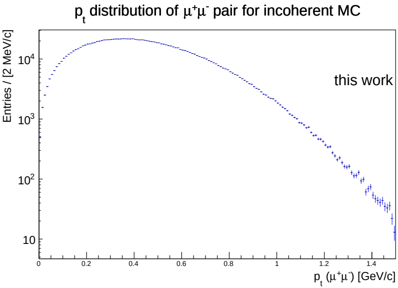
Yield corrections

$$N^{\text{coh}}_{J/\psi} = \frac{N^{\text{yield}}}{1 + f_I + f_D}$$

- f_I:
  - incoherently produced J/ψ,
  - $\sim 4.5\%$.
- f_D :
  - called feed-down,
  - $\psi(2S)$ decay to J/ψ + anything which is missed by detector,
  - $\sim 10\%$.

Coherent vs. Incoherent

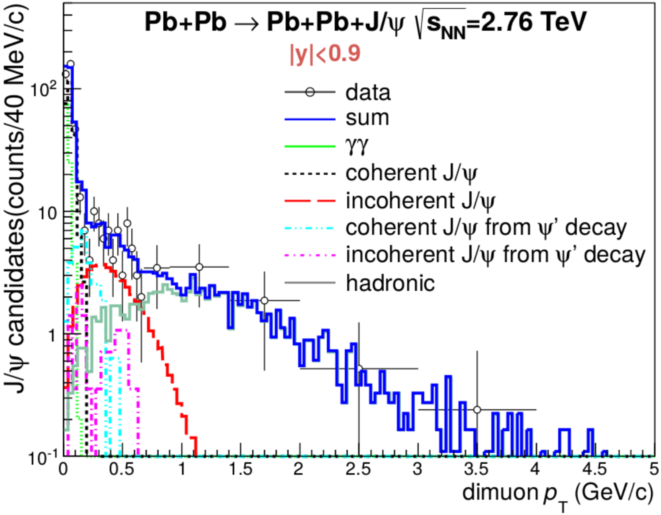




arXiv:1305.1467v2

- Coherent:
  - interaction with a whole nucleus,
  - diffractive pattern,
  - low transversal momentum.
- Incoherent:
  - interaction with a part of a nucleus,
  - no diffractive pattern,
  - high transversal momentum.

Incoherent correction - MC p_t fit



arXiv:1305.1467v2

Incoherent, feed-down correction - MC direct calculation

- Derived from the cross section measurement equation.

$$f_I = \frac{{}_{\mathrm{meas}}N^{\mathrm{inc}}_{\mathrm{J}/\psi}}{{}_{\mathrm{meas}}N^{\mathrm{coh}}_{\mathrm{J}/\psi}} \overset{\text{data to MC}}{=} \frac{{}_{\mathrm{rec}}N^{\mathrm{inc}}_{\mathrm{J}/\psi}}{{}_{\mathrm{rec}}N^{\mathrm{coh}}_{\mathrm{J}/\psi}} = \frac{\sigma^{\mathrm{inc}}}{\sigma^{\mathrm{coh}}} \cdot \frac{(\mathrm{Acc} \times \epsilon)^{\mathrm{inc}}_{\mathrm{J}/\psi}}{(\mathrm{Acc} \times \epsilon)^{\mathrm{coh}}_{\mathrm{J}/\psi}}.$$

$$f_D = \frac{\sigma^{\mathrm{coh}}_{\psi(2\mathrm{S})}}{\sigma^{\mathrm{coh}}_{\mathrm{J}/\psi}} \cdot \frac{(\mathrm{Acc} \times \epsilon)^{\mathrm{coh}}_{\psi(2\mathrm{S})}}{(\mathrm{Acc} \times \epsilon)^{\mathrm{coh}}_{\mathrm{J}/\psi}} \cdot \mathrm{BR}(\psi(2\mathrm{S}) \to \mathrm{J}/\psi + \text{anything}).$$

Acceptance × efficiency

- Easy.
- Take the correct Monte Carlo.
- Apply our cuts on reconstructed events.
- Add cut on p_t to restrict yourself on coherent.
- Divide no. of rec events with generated events.
- Result from the paper is 4.57(2.71)% for $\mu^+\mu^-(e^+e^-)$.

Luminosity

- In theory.

$$\mathscr{L}_{int} = \frac{R}{\sigma}$$

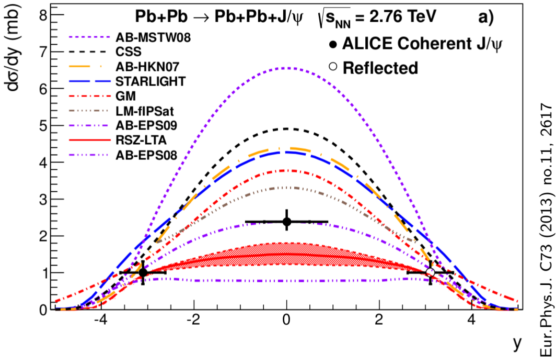
- In ALICE (real) world.

$$\mathscr{L}_{UPC} = \frac{R^B_{REF}}{\sigma_{REF}} F(\mu_{REF}) \frac{R^A_{UPC}}{R^B_{UPC}}$$

$\mathscr{L}_{int}$ - integrated luminosity of UPC triggers
σ_{REF} - corresponding reference cross section
R - number of reference and UPC triggers (A)fter/(B)efore CTP veto.

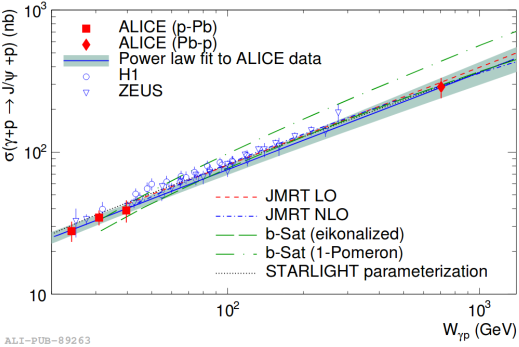
- σ_{REF} taken from Van der Meer scan.
- This gives total recorded luminosity.
- Needs to be corrected for the size of analysed sample.

Published results - Pb-Pb collisions at ALICE



- Forward and central rapidity region.
- Large difference between of measurement and no nuclear shadowing models.

Published results - p-Pb/Pb-p collisions at ALICE



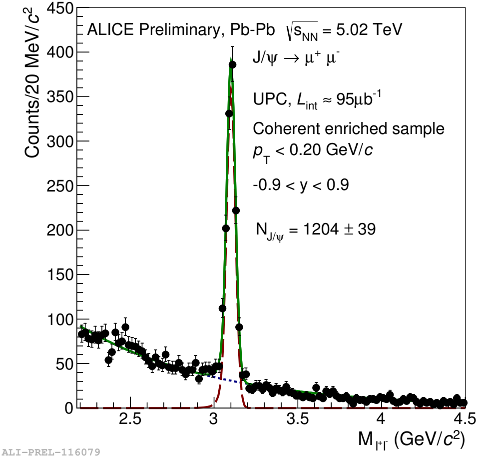
Nucl.Part.Phys.Proc. 273-275 (2016) 2599-2601

- Consistency with HERA results and its extention by factor of 2.
- Recent collisions at higher energies will allow to reach over 1 TeV.

Extension

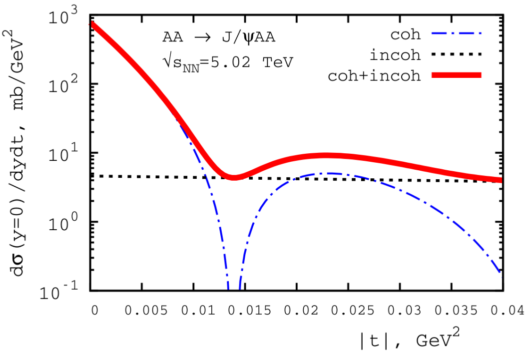
What can follow up...

Extensions - more data



- More data collected in 2015.
- Even more data is incoming in Autumn 2018.

Extensions - $|t|$-dependence



Phys. Rev. C 95, 025204 (2017)

- Nuclear shadowing effects, gluon saturation, distribution functions...
- Cross section t-dependence.

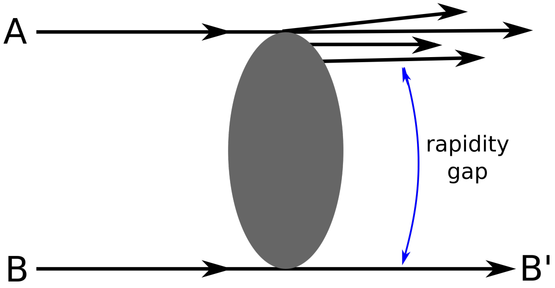
$$\frac{\mathrm{d}\sigma}{\mathrm{d}t} = \left.\frac{\mathrm{d}\sigma}{\mathrm{d}t}\right|_{t=0} |F(t)|^2$$

Summary

- We have tools to follow up research at H1 experiment.
- Some results were already published.
- We learnt the analysis flow.
- We learnt that more is coming!!!

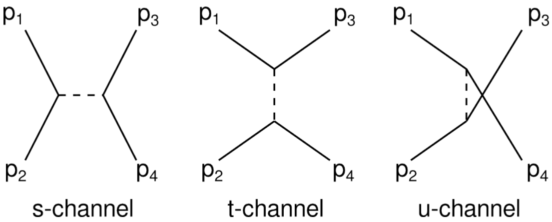
BACK UP

Diffractive physics - definition



- No quantum number exchange.
- High energy.
- Rapidity gap.

Diffractive physics - kinematics



- t - transferred momentum (Mandentelstam variable).

$$t = (\mathrm{p}_1 - \mathrm{p}_3)^2 = (\mathrm{p}_2 - \mathrm{p}_4)^2$$

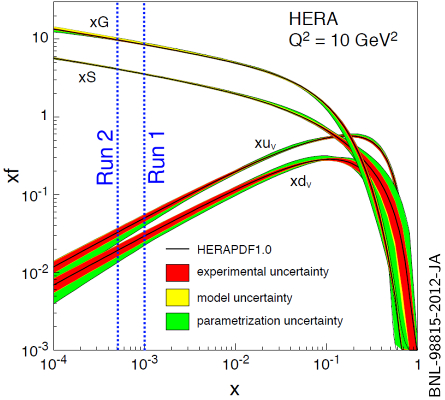
- y - rapidity.

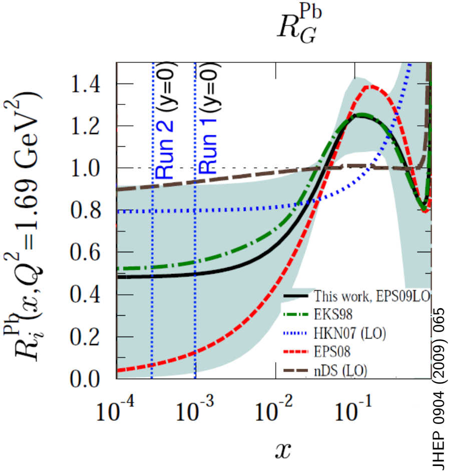
$$y = \frac{1}{2} \ln \frac{E + p_z}{E - p_z}$$

Ultra-peripheral collisions at ALICE

Where is QCD now

- Proton is mainly gluons at Bjorken $x \sim 10^{-3}$ (HERA).
- LHC provides possibility to study lead nuclei at small Bjorken x.





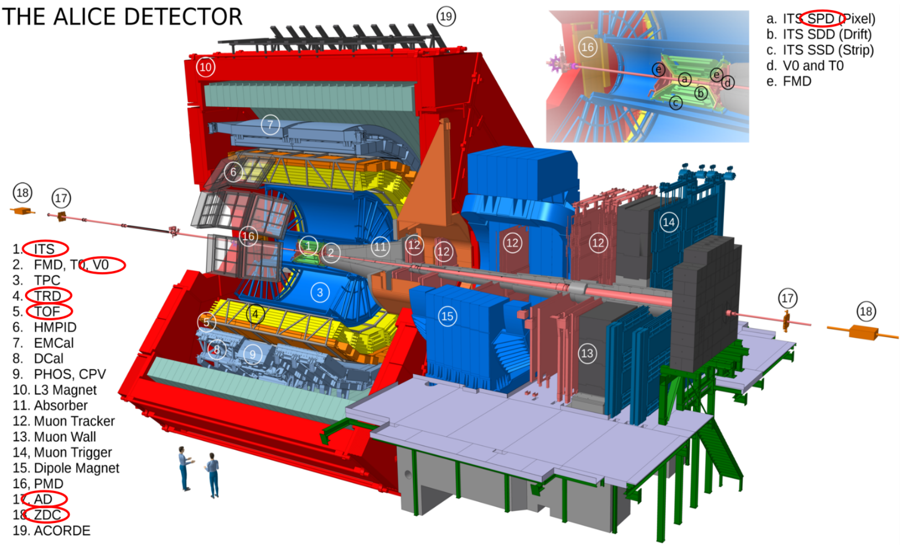
What we are going to study

- Coherent production of J/ψ in Pb-Pb UPC at mid rapidity at ALICE.
  - Run 1: $x \sim 10^{-3}$; Run 2: $x \sim 0.5 \cdot 10^{-3}$.
- t-Dependence of the cross section.
- Sensitive to the gluon distribution of the target in the impact parameter plane.

Measurement

Experiment

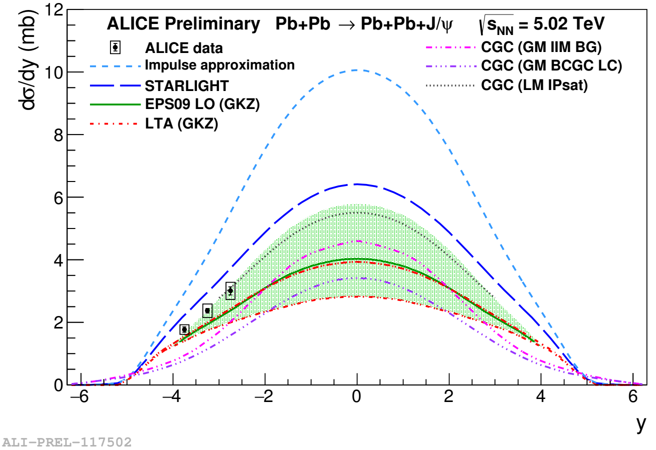
ALICE detector



Measurement

Analysis

Preliminary results - Pb-Pb collisions at ALICE of Run 2



- Forward region.

Template title

- Template item.