Recent ALICE results on Pb-Pb and p-Pb ultraperipheral collisions

Evgeny Kryshen (CERN)
on behalf of the ALICE collaboration

LHC seminar, CERN
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- **Ultra-peripheral physics potential**
- **Ultra-peripheral Pb-Pb collisions:**
  – Results on coherent J/ψ photoproduction at forward and mid-rapidity
  – Constraints on nuclear gluon shadowing from ALICE measurements
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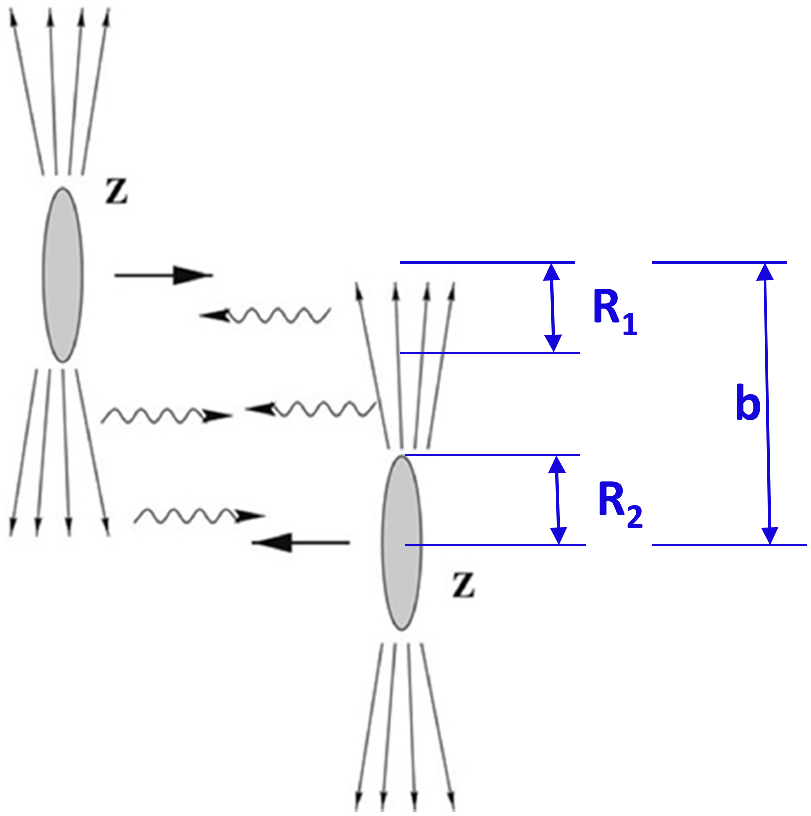
  – Results on dielectron continuum production
- **Preliminary results on J/ ψ photoproduction in ultra-peripheral p-Pb collisions**
- **Summary and outlook**

LHC as a γPb and γp collider



Ultra-peripheral (UPC) collisions: $b > R_1+R_2$

$\rightarrow$ hadronic interactions strongly suppressed

High photon flux

$\rightarrow$ well described in Weizsäcker-Williams approximation (quasi-real photons)

$\rightarrow$ flux proportional to Z^2

$\rightarrow$ high cross section for γ-induced reactions

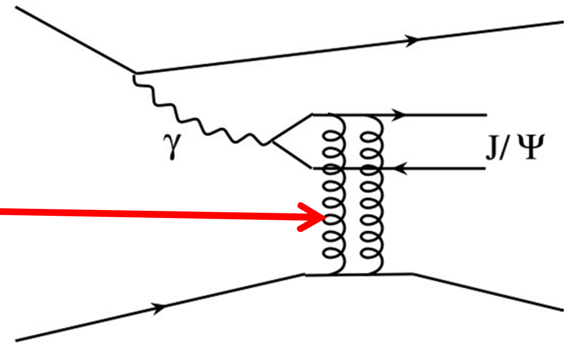
Pb-Pb and p-Pb UPC at LHC can be used to study γ-Pb, γp and $\gamma\gamma$ interactions at higher center-of-mass energies than ever before

Recent review on UPC physics: Phys. Rept. 458 (2008) 1-171

J/ψ photoproduction in UPC

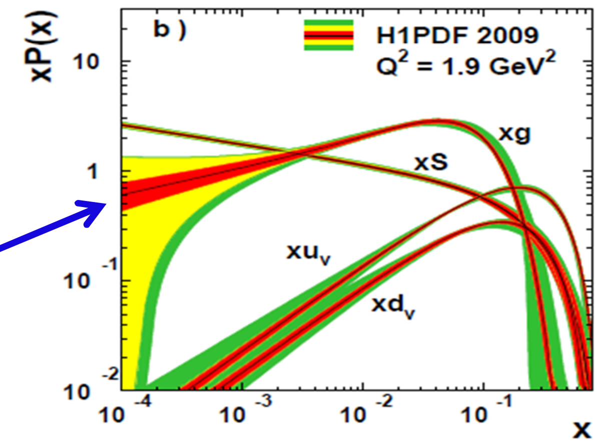
- LO pQCD: coherent J/ψ photoproduction cross section is proportional to the **square of the gluon density in the target**:

$$\left.\frac{d\sigma_{\gamma A \to J/\psi A}}{dt}\right|_{t=0} = \frac{M^3_{J/\psi}\Gamma_{ee}\pi^3\alpha_s^2(Q^2)}{48\alpha_{\rm em}Q^8}\left[xG_A(x,Q^2)\right]^2$$



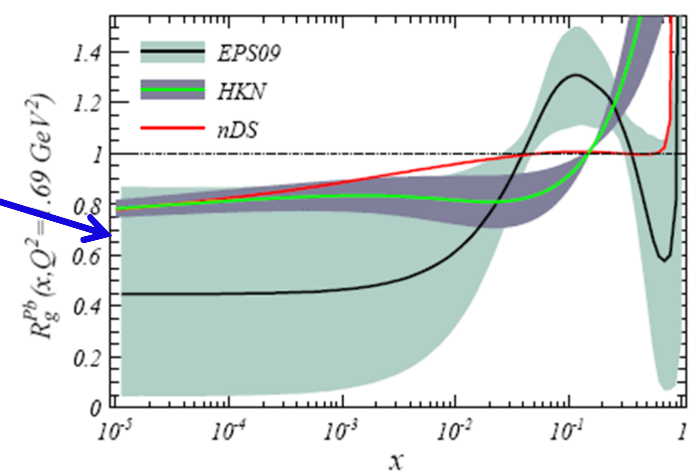
- Mass of J/ψ serves as a hard scale: $Q^2 \sim \frac{M^2_{J/\psi}}{4} \sim 2.5\ \mathrm{GeV}^2$

- Bjorken x ~ 10^{-2} – 10^{-5} accessible at LHC: $x = \frac{M^2_{J/\psi}}{W^2_{\gamma p}}$



- J/ψ photoproduction in p-Pb UPC (proton target) allows one to probe poorly known **gluon distribution in the proton at low x** and search for **saturation effects**

- J/ψ photoproduction in Pb-Pb UPC (lead target) provides information on **gluon shadowing in nuclei at low x** which is essentially unconstrained by existing data



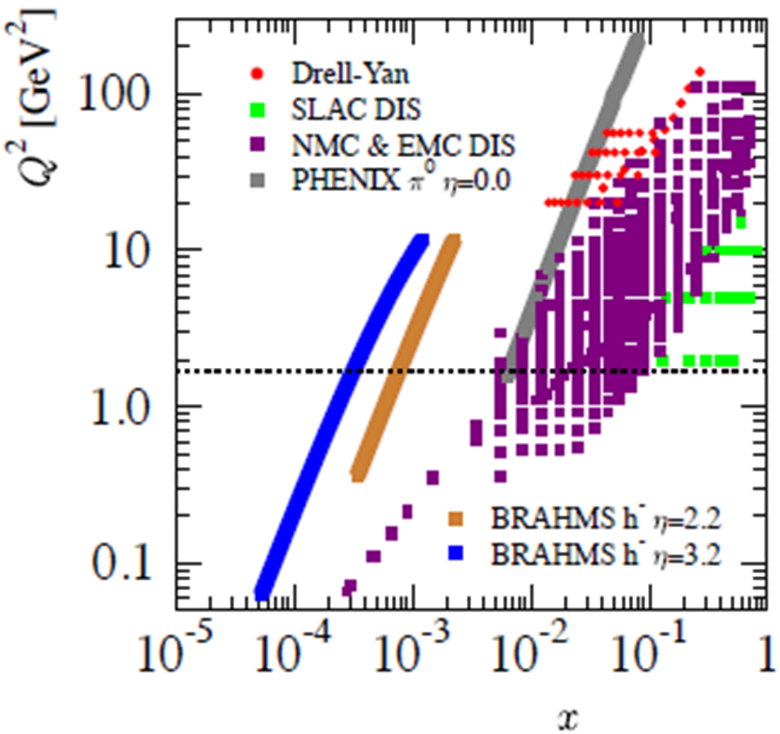
$$R_g^A(x,Q^2) = \frac{G_A(x,Q^2)}{AG_p(x,Q^2)}$$ – gluon shadowing factor

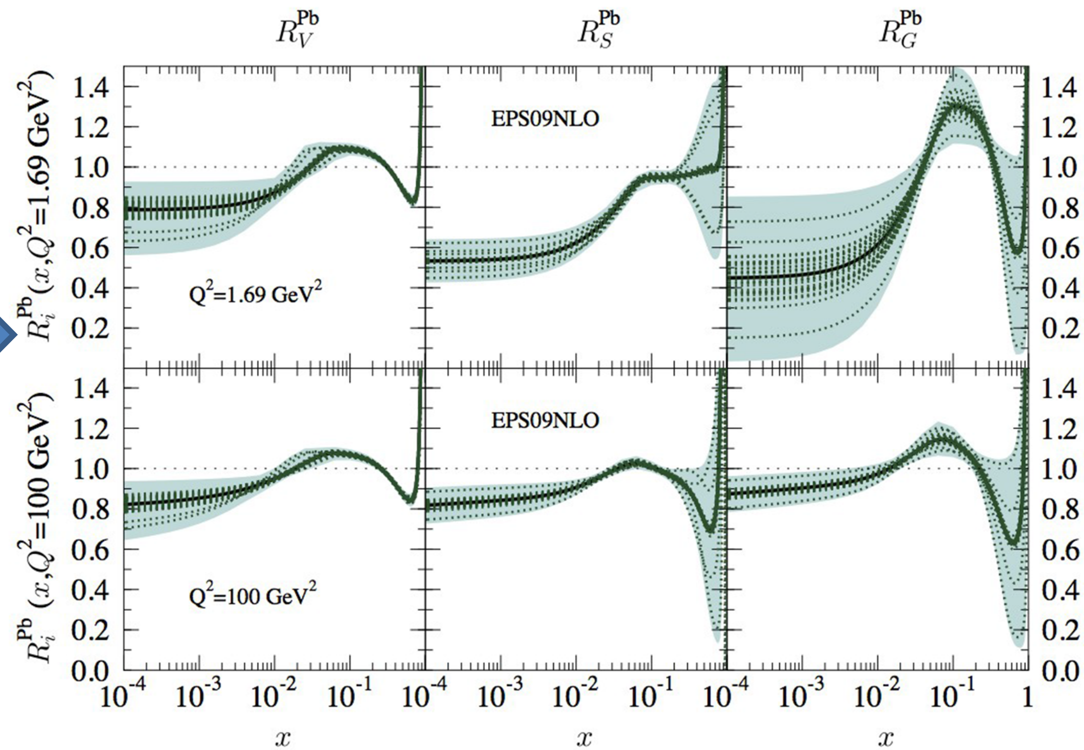
Parton distributions in nuclei (nPDFs)

nPDFs are fundamental QCD quantities for the description of DIS, pA, AA collisions
- determine initial state in heavy ion collisions (main motivation for p-Pb runs)
- required for quantitative estimates for the onset of saturation

Determination of nPDFs:

C. Salgado et al. JHEP 0904:065,2009





Resulting nPDFs have rather **large uncertainties, especially for small-x gluons** due to:
- Limited kinematics
- Indirect extraction of gluons via Q^2 evolution

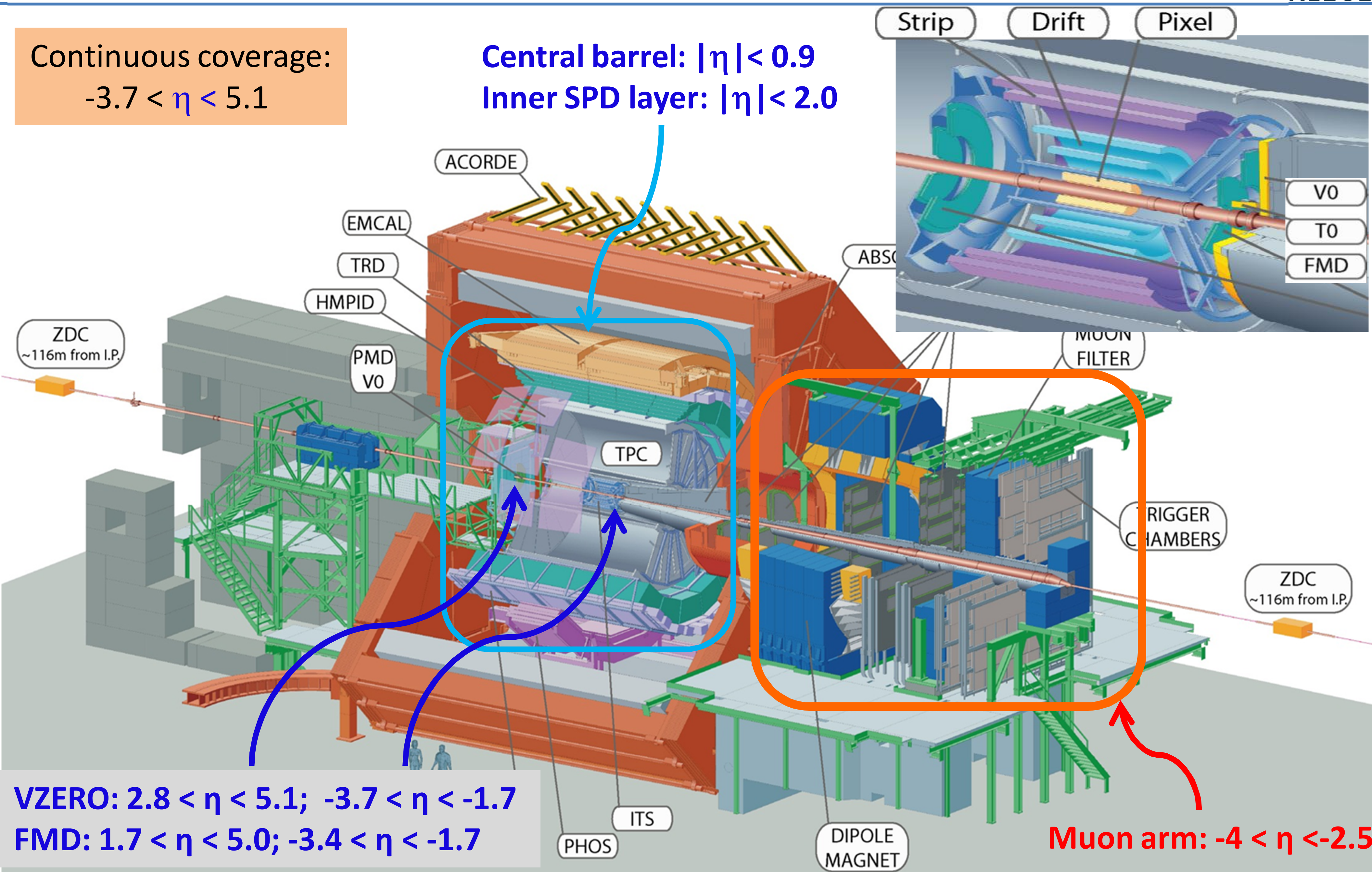
ALICE results on ultraperipheral PbPb collisions from 2011 data

Forward rapidity: Phys. Lett. B718 (2013) 1273

Midrapidity: Eur. Phys. J. C73 (2013) 2617

Looking for two tracks in an otherwise empty detector…

Continuous coverage:
-3.7 < η < 5.1



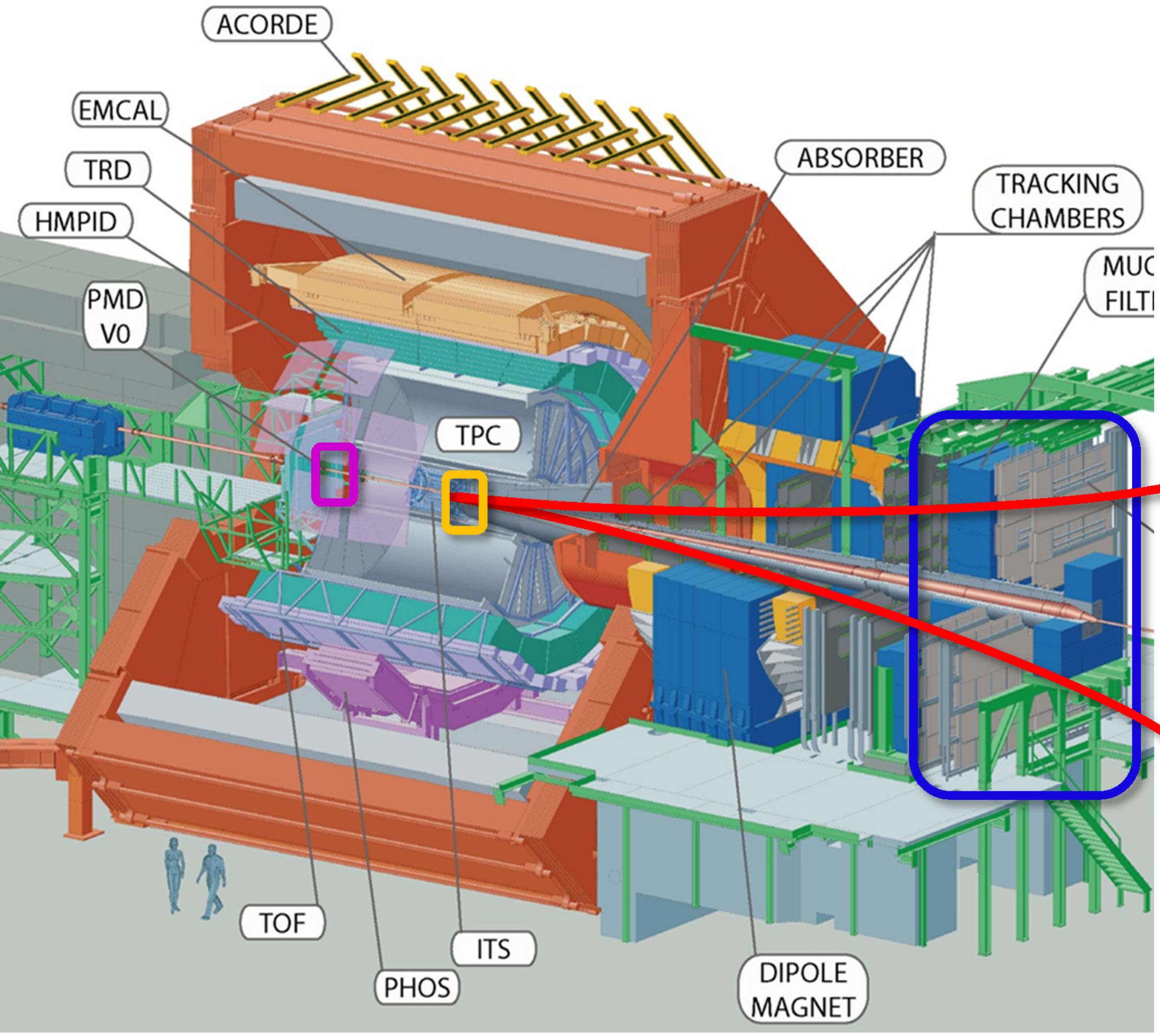
VZERO: 2.8 < η < 5.1; -3.7 < η < -1.7
FMD: 1.7 < η < 5.0; -3.4 < η < -1.7

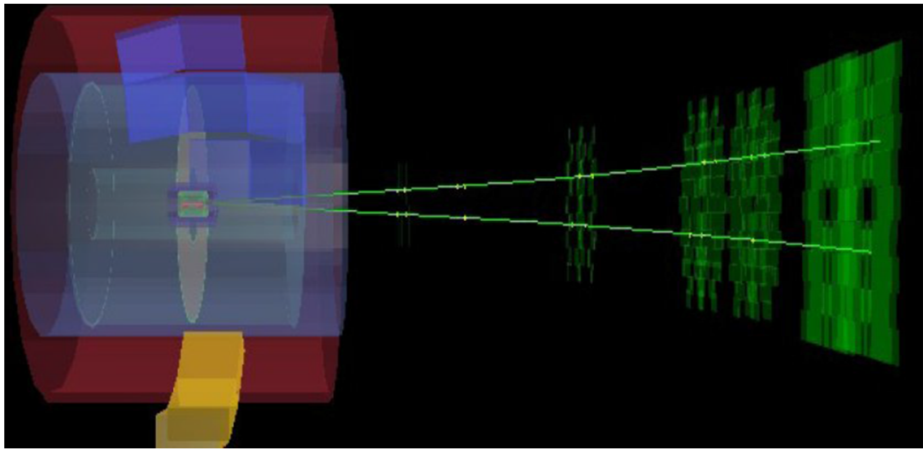
Muon arm: -4 < η <-2.5

UPC J/ψ at forward rapidity

UPC forward trigger:

- single **muon trigger** with $p_T > 1$ GeV/c ($-4 < \eta < -2.5$)
- hit in **VZERO-C** ($-3.7 < \eta < -1.7$)
- no hits in **VZERO-A** ($2.8 < \eta < 5.1$)





Integrated luminosity ~ 55 μb^{-1}

Offline event selection:

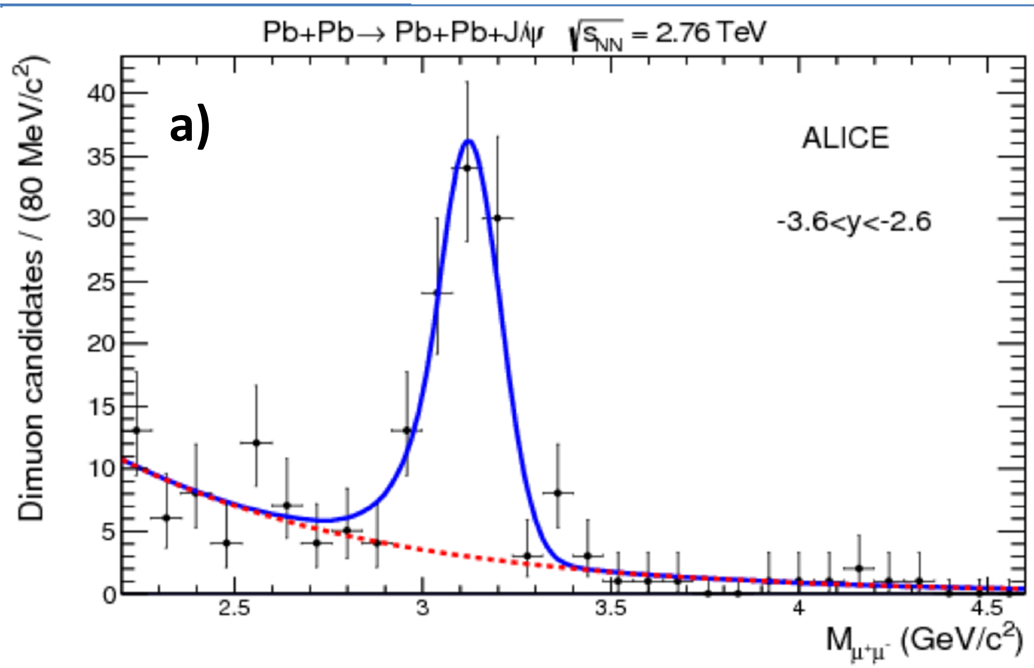
- Beam gas rejection with VZERO
- Hadronic rejection with ZDC and SPD

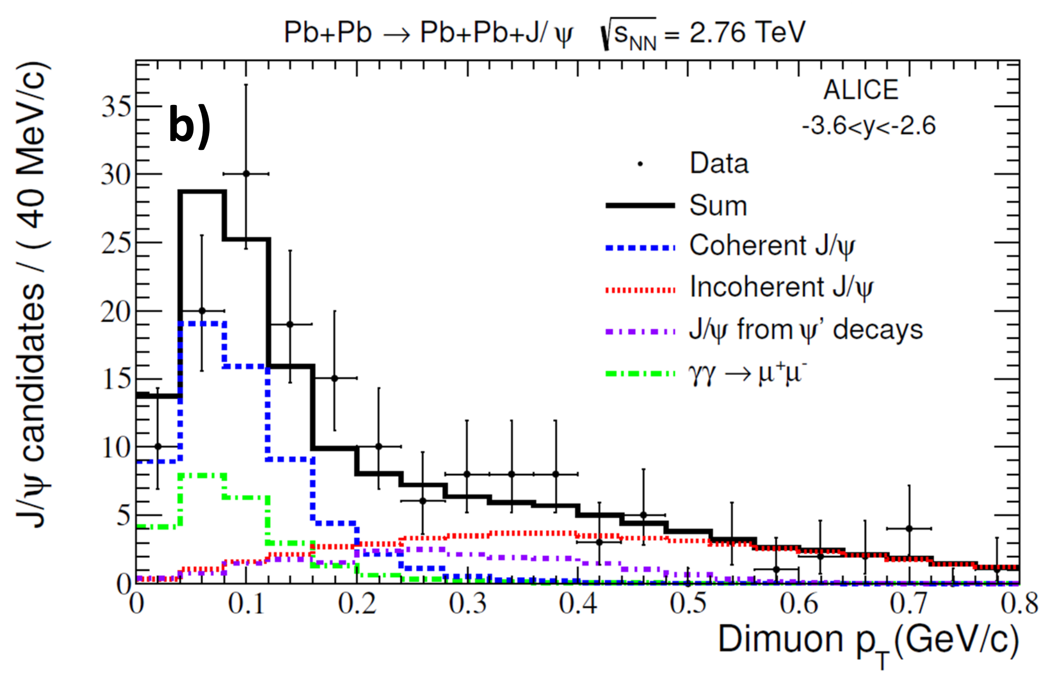
Track selection:

- muon tracks: $-3.7 < \eta < -2.5$
- matching with the trigger
- radial position for muons at the end of absorber: $17.5 < R_{abs} < 89.5$ cm
- p_T dependent DCA cut
- opposite sign dimuon: $-3.6 < y < -2.6$

Phys. Lett. B718 (2013) 1273

J/ψ at forward rapidity





Invariant mass distribution:

- Dimuon p_T< 0.3 GeV/*c*
- Signal fitted to a Crystal Ball shape
- Background well described by exponential shape compatible with expectations from γγ →μμ process

Four contributions in the p_T spectrum:

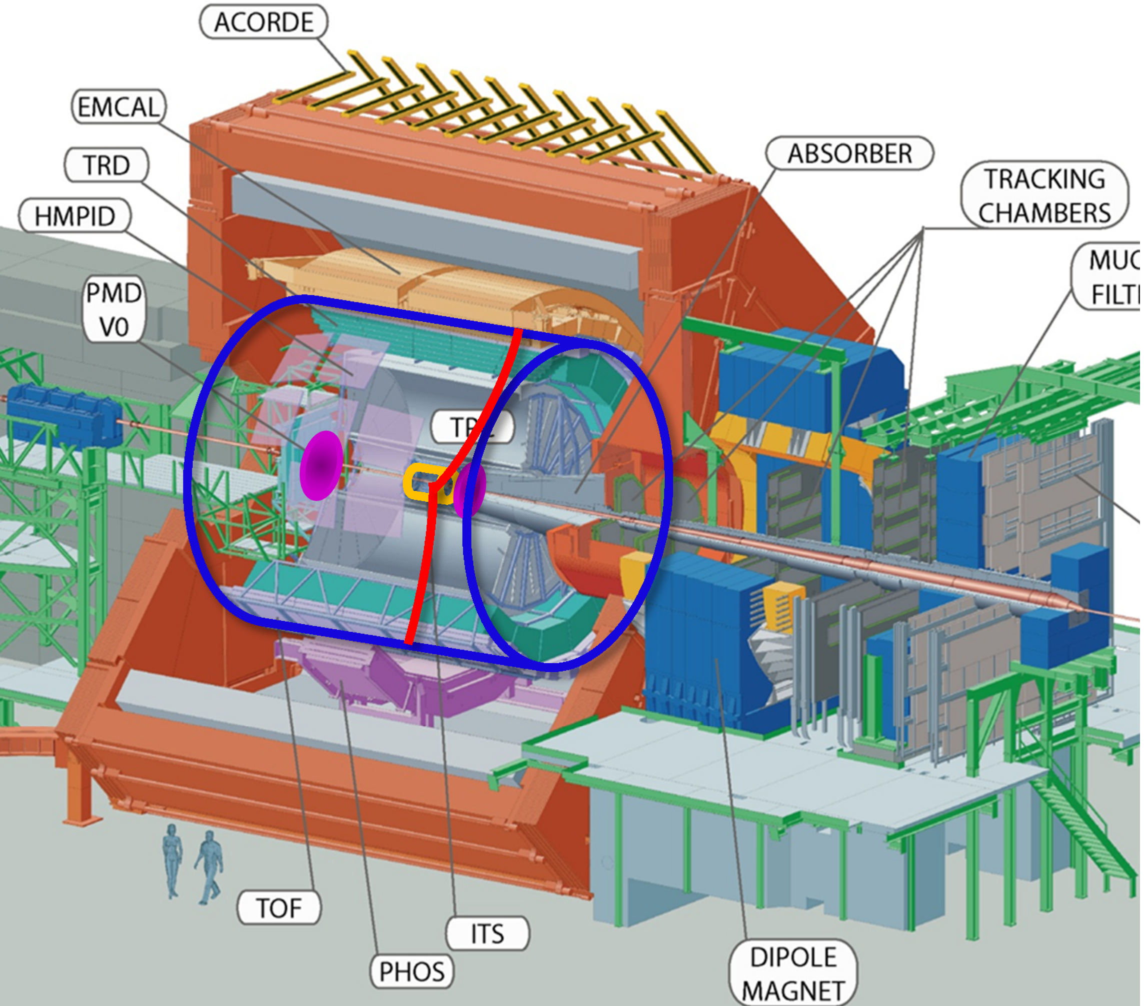
- **Coherent J/ψ:**
  - photon couples coherently to all nucleons
  - ⟨p_T⟩ ~ 1/R_{Pb} ~ 60 MeV/c
  - no neutron emission in ~80% of cases
- **Incoherent J/ψ:**
  - photon couples to a single nucleon
  - ⟨p_T⟩ ~ 1/R_p ~ 450 MeV/c
  - target nucleus normally breaks up
- **J/ψ from ψ' decays**
- **γγ →μμ**

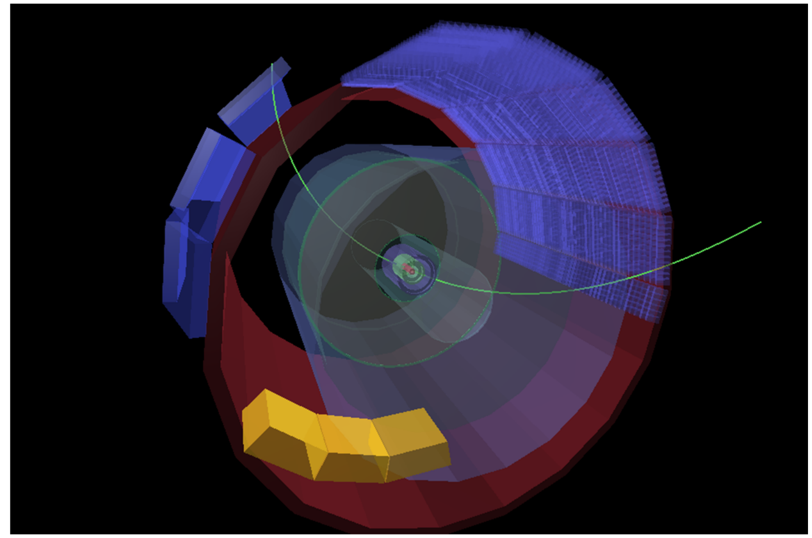
ALICE: Phys. Lett. B718 (2013) 1273

UPC J/ψ at central rapidity

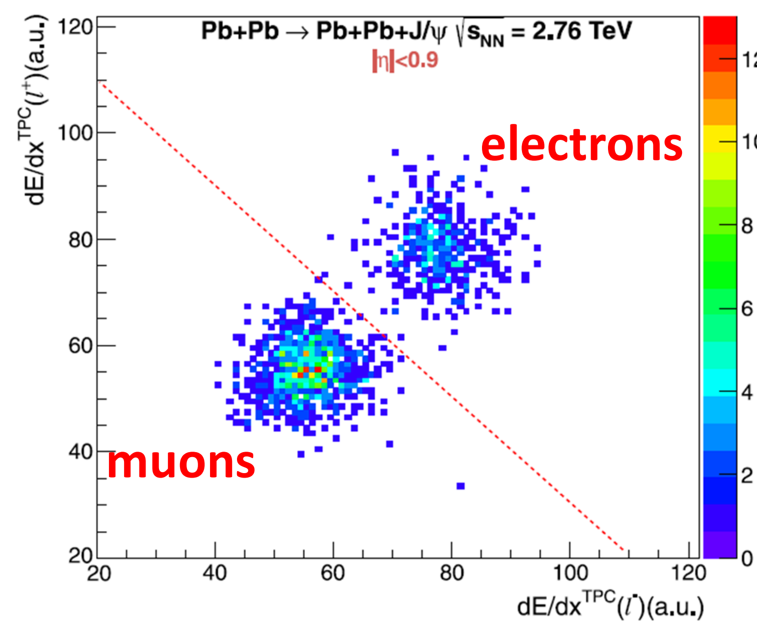
UPC central barrel trigger:

- $2 \leq$ **TOF** hits ≤ 6 ($|\eta| < 0.9$)
  + back-to-back topology ($150^\circ \leq \varphi \leq 180^\circ$)
- ≥ 2 hits in **SPD** ($|\eta| < 1.5$)
- no hits in **VZERO** (C: $-3.7 < \eta < -1.7$, A: $2.8 < \eta < 5.1$)





Integrated luminosity ~ 23 μb^{-1}



Eur. Phys. J. C73 (2013) 2617

Coherent J/ψ at central rapidity

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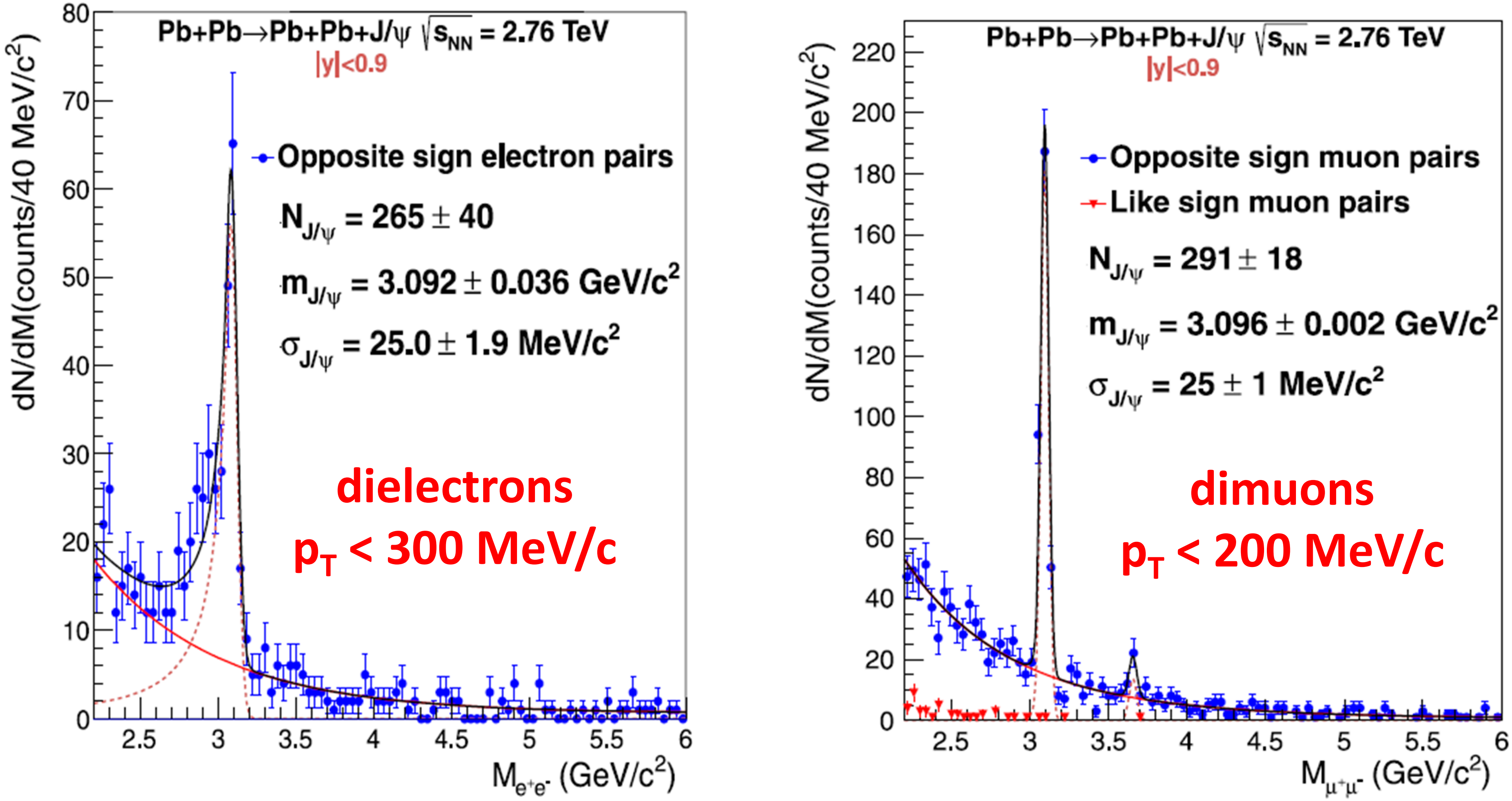
- Measured both in dielectron and dimuon channels
- Coherent J/ψ enriched with p_T cut



p_T distributions for J/ψ in central barrel

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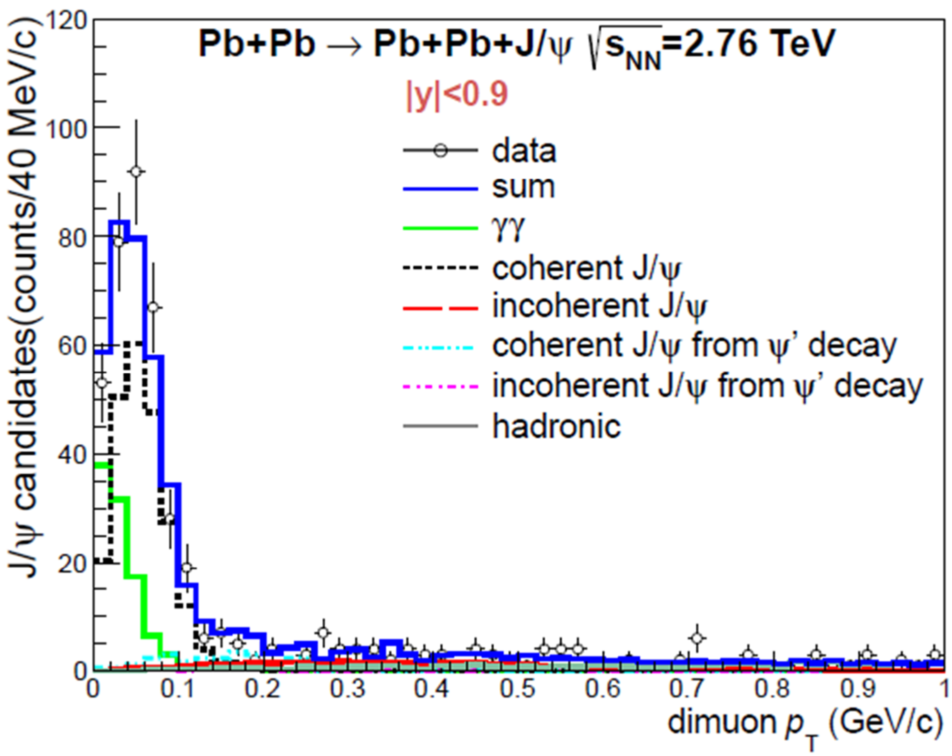
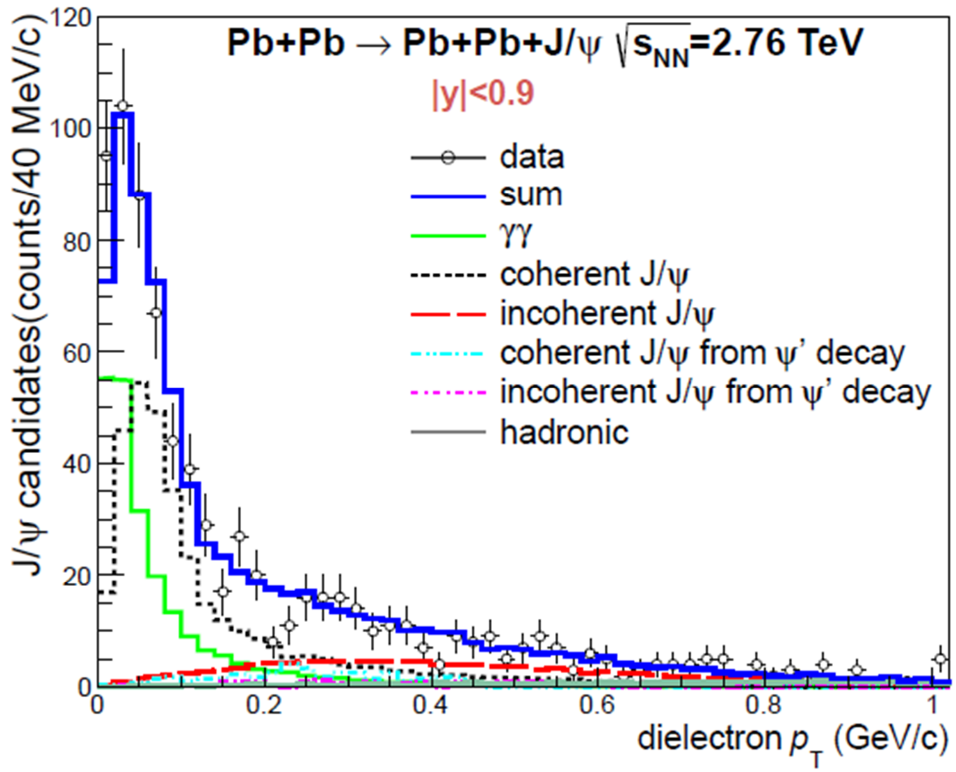




- Clear coherent peak from J/ψ and continuum $\gamma\gamma \to l^+ l^-$
- Full spectrum explained by, in addition, incoherent J/ψ, J/ ψ from ψ' feed down and some hadronic contribution at high p_T

Determination of cross section and systematics

Forward rapidity:

- Cross section determined with respect to $\gamma\gamma \rightarrow \mu\mu$ cross section:

$$\frac{d\sigma_{\rm coh}}{dy} = \frac{1}{BR} \cdot \frac{N_{\rm coh}}{N_{\gamma\gamma}} \cdot \frac{({\rm Acc\ x\ }\epsilon)_{\gamma\gamma}}{({\rm Acc\ x\ }\epsilon)_{\rm coh}} \frac{\sigma_{\gamma\gamma}}{\Delta y}$$

Main source of systematics comes from theoretical uncertainty on $\sigma_{\gamma\gamma}$ and signal extraction

Source	Value
Theoretical uncertainty in $\sigma_{\gamma\gamma}$	20%
Coherent signal extraction	$^{+9}_{-14}\%$
Reconstruction efficiency	6%
RPC trigger efficiency	5%
J/ψ acceptance calculation	3%
two-photon $e^+ e^-$ background	2%
Branching ratio	1%
Total	$^{+24}_{-26}\%$

Mid-rapidiy:

- Cross section:

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

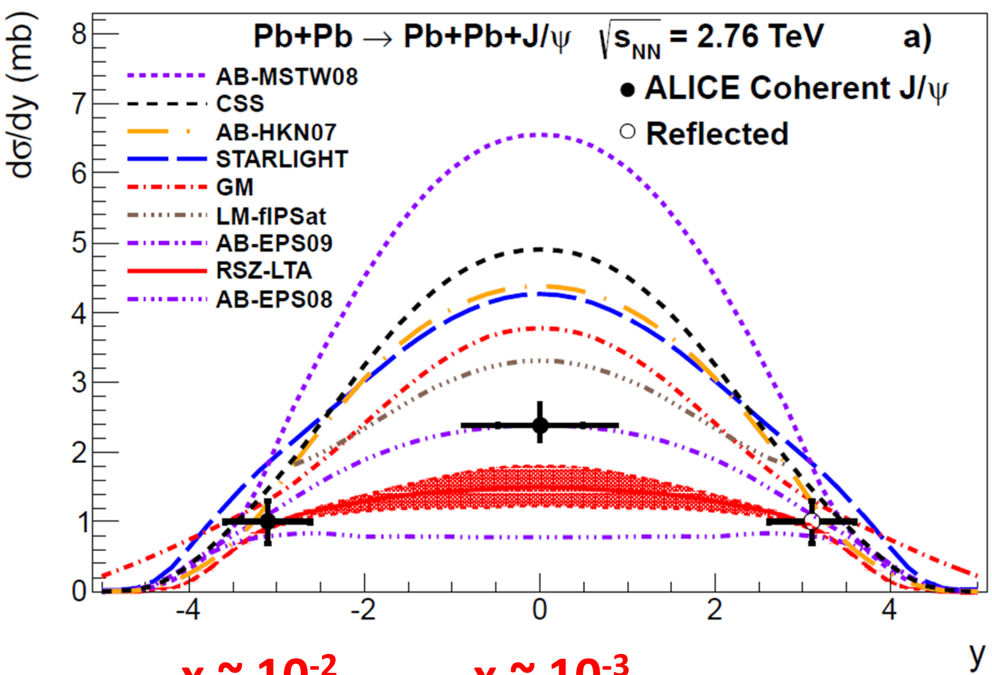
Main sources of systematics:

- signal extraction

- trigger efficiency

Source	Coherent	Incoherent
Luminosity	$^{+5\%}_{-3\%}$	$^{+5\%}_{-3\%}$
Trigger dead time	$\pm 2.5\%$	$\pm 2.5\%$
Signal extraction	$^{+7\%}_{-6\%} \left(^{+6\%}_{-5\%}\right)$	$^{+26.5\%}_{-12.5\%} \left(^{+9\%}_{-8\%}\right)$
Trigger efficiency	$^{+3.8\%}_{-9.0\%}$	$^{+3.8\%}_{-9.0\%}$
$({\rm Acc} \times \varepsilon)$	$\pm 2.5\% \ (\pm 1\%)$	$\pm 6.5(\pm 3.5)\%$
$\gamma\gamma \rightarrow e^+e^-$ background	$^{+4\%}_{-0\%}$	$^{+4\%}_{-0\%}$
e/μ separation	$\pm 2\%$	$\pm 2\%$
Branching ratio	$\pm 1\%$	$\pm 1\%$
Neutron number cut	$^{+2.5\%}_{-0\%}$	-
Hadronic J/ψ	-	$^{+0\%}_{-5\%} \left(^{+0\%}_{-3\%}\right)$
Total	$^{+14.0\%}_{-9.6\%} \left(^{+13.4\%}_{-8.8\%}\right)$	$^{+29.4\%}_{-16.6\%} \left(^{+14.5\%}_{-11.7\%}\right)$

Coherent J/ψ: comparison to models



x ~ 10^{-2} **x ~ 10^{-3}**

Good agreement with models which include nuclear gluon shadowing.
Best agreement with EPS09 shadowing
(shadowing factor ~0.6 at x ~ 10^{-3}, Q^2 = 2.4 GeV^2)

Phys. Lett. B718 (2013) 1273
Eur. Phys. J. C73 (2013) 2617

- **STARLIGHT: Klein, Nystrand, PRC60 (1999) 014903** VDM + Glauber approach where J/ψ+p cross section is obtained from a parameterization of HERA data
- **GM: Gonçalves, Machado, PRC84 (2011) 011902** color dipole model, dipole nucleon cross section taken from the IIM saturation model
- **AB: Adeluyi and Bertulani, PRC85 (2012) 044904** LO pQCD calculations: AB-MSTW08 assumes no nuclear effects for the gluon distribution, other AB models incorporate gluon shadowing effects according to the EPS08, EPS09 or HKN07 parameterizations
- **CSS: Cisek, Szczurek, Schäfer, PRC86 (2012) 014905** Glauber approach accounting $c\bar{c}g$ intermediate states
- **RSZ: Rebyakova, Strikman, Zhalov, PLB 710 (2012) 252** LO pQCD calculations with nuclear gluon shadowing computed in the leading twist approximation
- **Lappi, Mäntysaari, PRC87 (2013) 032201**: color dipole model + saturation

Nuclear gluon shadowing from ALICE data

V. Guzei, E. Kryshen, M. Strikman, M. Zhalov. Phys. Lett. B726 (2013) 290

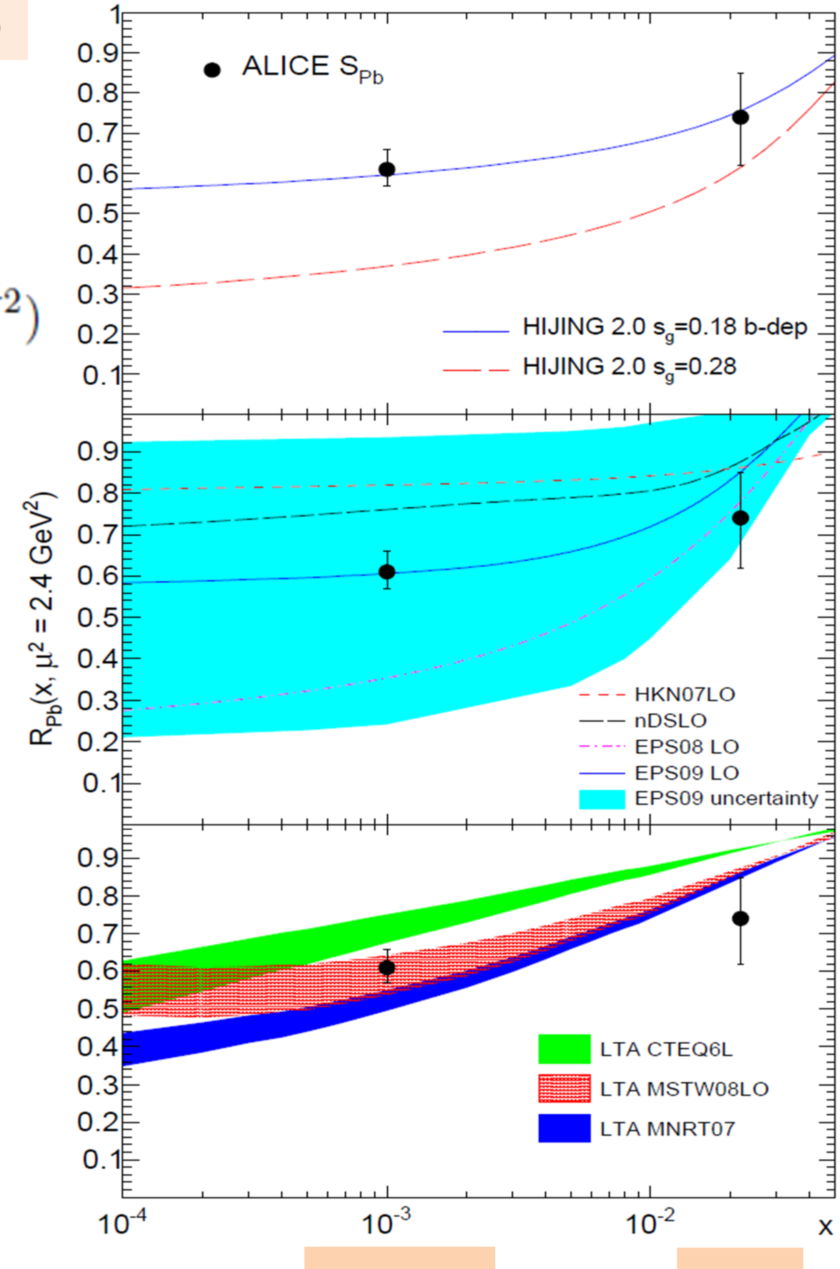
Nuclear suppression factor in J/ψ photoproduction:

ALICE data corrected for photon flux

$$S(W_{\gamma p}) \equiv \left[\frac{\sigma^{\rm exp}_{\gamma {\rm Pb}\to J/\psi {\rm Pb}}(W_{\gamma p})}{\sigma^{\rm IA}_{\gamma {\rm Pb}\to J/\psi {\rm Pb}}(W_{\gamma p})}\right]^{1/2} \Rightarrow R(x, \mu^2 = 2.4\ {\rm GeV}^2)$$

Impulse Approximation: J/ψ photoproduction cross section from HERA corrected for the integral over squared Pb form-factor

- **Hijing:** scale-independent gluon shadowing, characterized by parameter s_g
- **Shadowing parametrizations (EPS,nDS,HKN07)** use DIS and Drell-Yan data + π^0 data from RHIC (EPS) – gluon shadowing essentially unconstrained at low x
- **Leading twist approximation:** propagation of color dipoles in nuclei via intermediate diffractive states (Gribov-Glauber shadowing theory). Incorporates diffractive parton distributions in proton (from HERA)

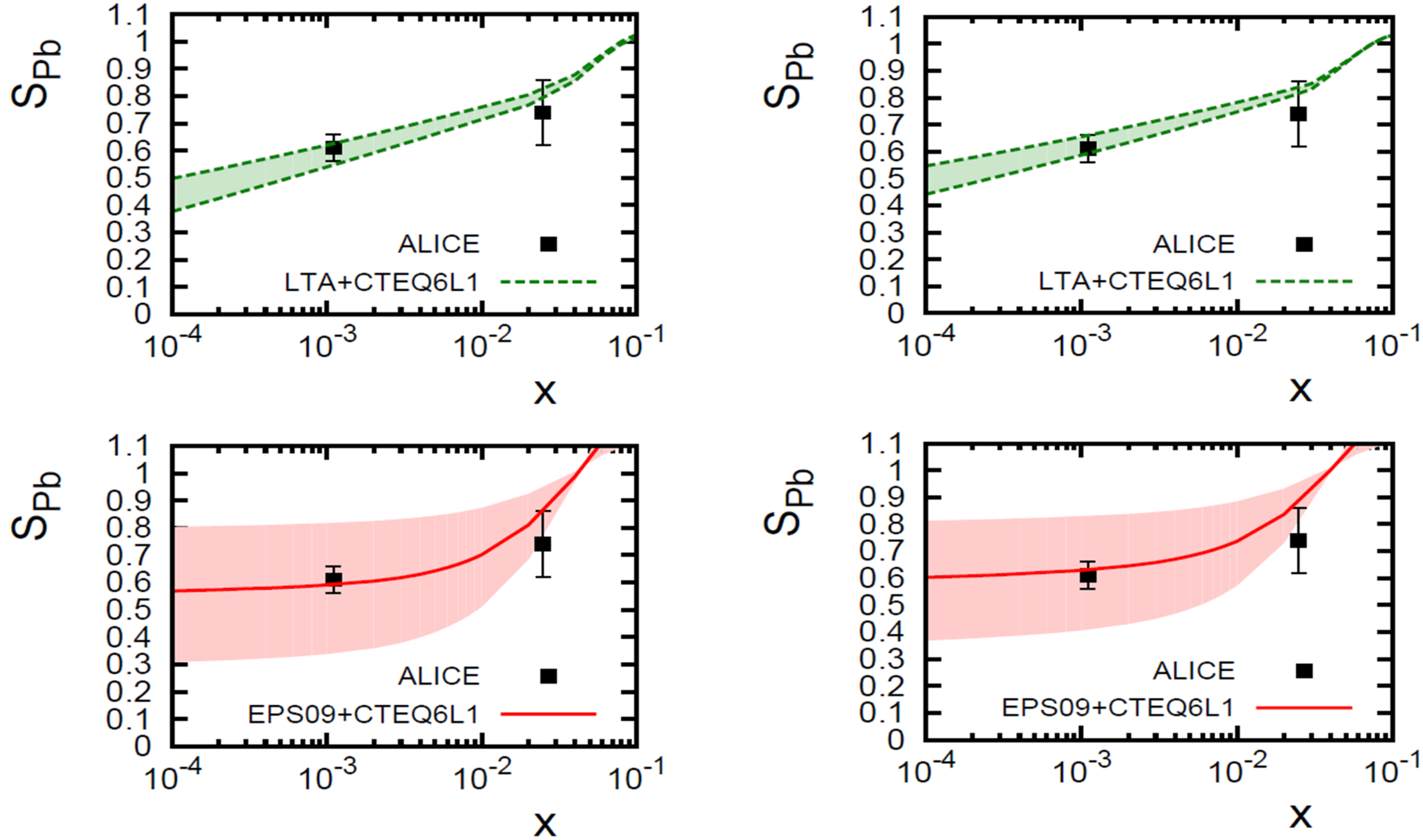


ranges of x probed by ALICE

Scale dependence

- Studied in detail in Guzey, Zhalov: JHEP 1310 (2013) 207.
- Scale of 3 GeV^2 found to be most appropriate for the description of J/ψ photoproduction data

2.4 GeV^2 3 GeV^2



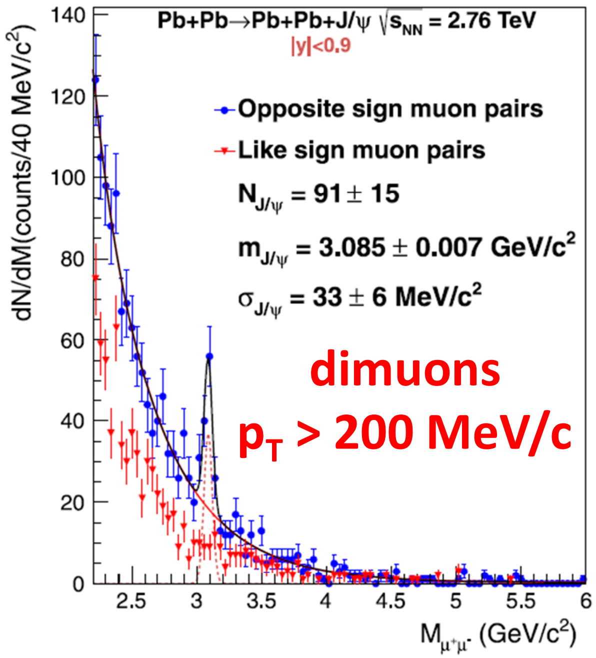
EPS09, variation of scale by factor 4:

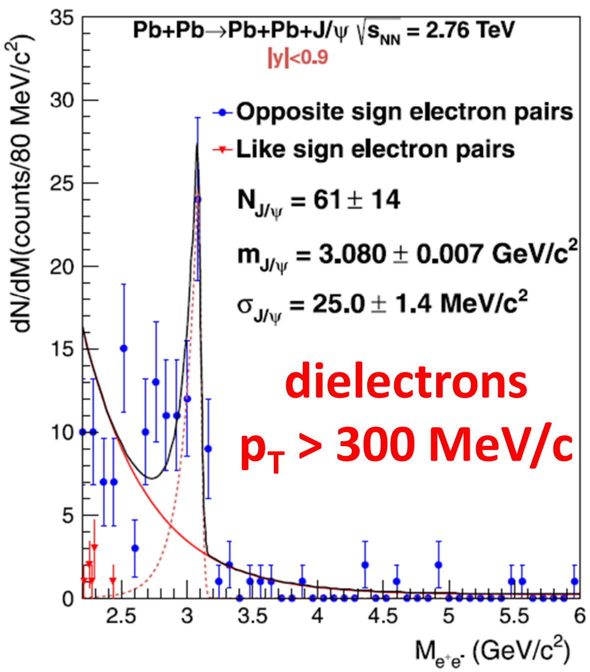
$R(x=0.011, Q^2 = 2.4\ GeV^2) = 0.569$

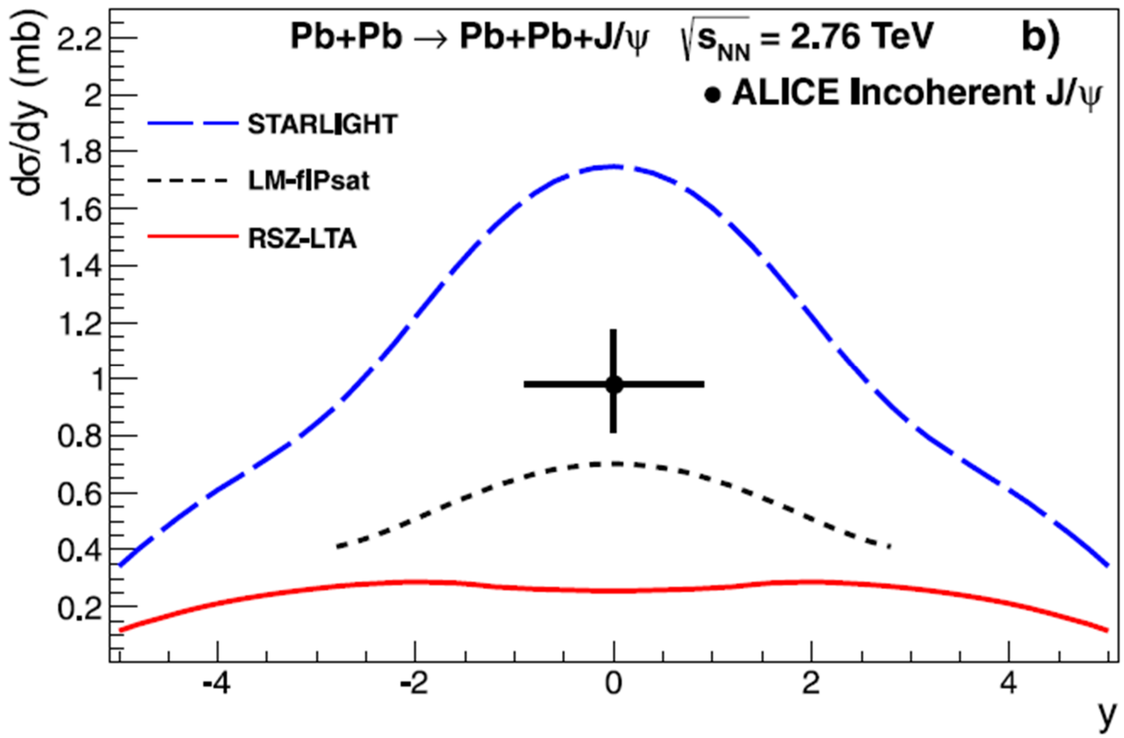
$R(x=0.011, Q^2 = 9.6\ GeV^2) = 0.671$

Future measurements of heavier vector mesons (ψ‘, ϒ) will further elucidate the importance of the scale

Incoherent J/ψ at central rapidity







- Almost one order of magnitude difference in the predicted cross sections
- ALICE sets strong constraints

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$\gamma\gamma \rightarrow e^+e^-$ in central barrel

- Huge cross section: O(100) kb

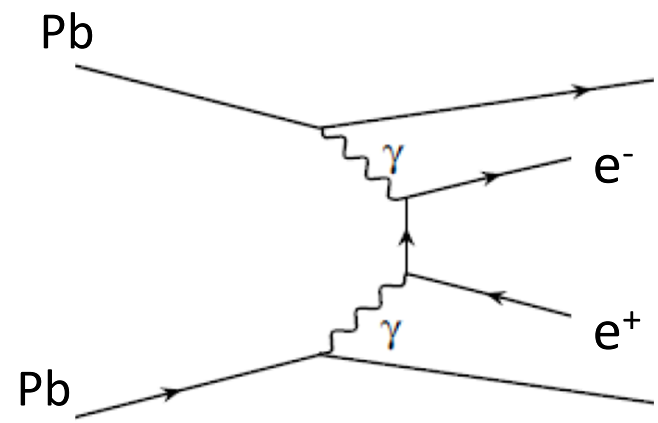
Standard QED:

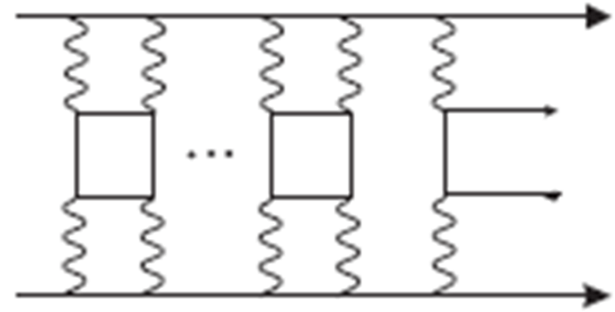
- Born cross sections obtained by Landau & Lifshitz in 1934

But caveats due to

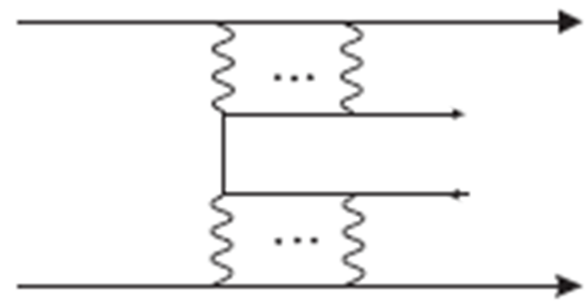
- Uncertainty in higher order terms due to coupling $Z\sqrt{\alpha}$
- Uncertainty on minimum momentum transfer and nuclear form factor

Different models predict a reduction of the LO cross section up to 30% (see e.g. Phys. Rev. C80 (2009)034901; Phys. Rev. Lett. 100 (2008) 062302)





Unitarity correction



Coulomb correction

$\gamma\gamma \rightarrow e^+e^-$ in central barrel

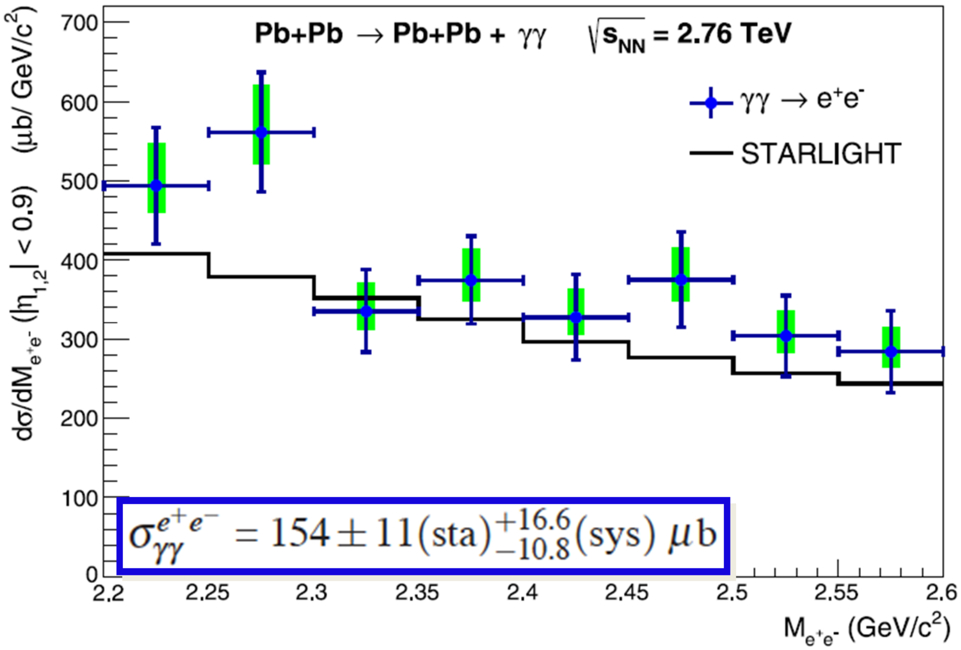
STARLIGHT, PRC60 (1999) 014903:

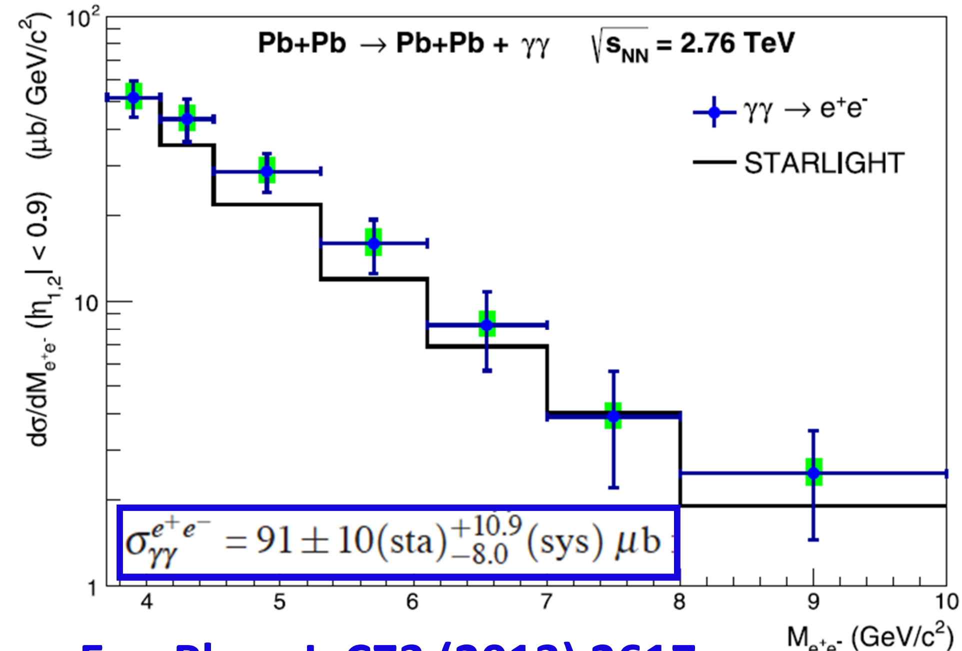
(LO prediction, $|\eta|<0.9$):

- 2.2 GeV/c^2 < M_{inv} < 2.6 GeV/c^2: $\sigma_{\gamma\gamma}$=128 μb
- 3.7 GeV/c^2 < M_{inv} < 10 GeV/c^2 : $\sigma_{\gamma\gamma}$=77 μb

ALICE:

- Data slightly above LO prediction
- 12% and 16% precision in two mass ranges
- ALICE data sets stringent limits on the contribution from high order terms





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$\gamma\gamma\rightarrow$(

STARLIGHT, PRC60 (1999) 0

(LO prediction, |η|<0.9):

- 2.2 GeV/c² < M_{inv} < 2.6 G
- 3.7 GeV/c² < M_{inv} < 10 G

ALICE:

- Data slightly above LO p
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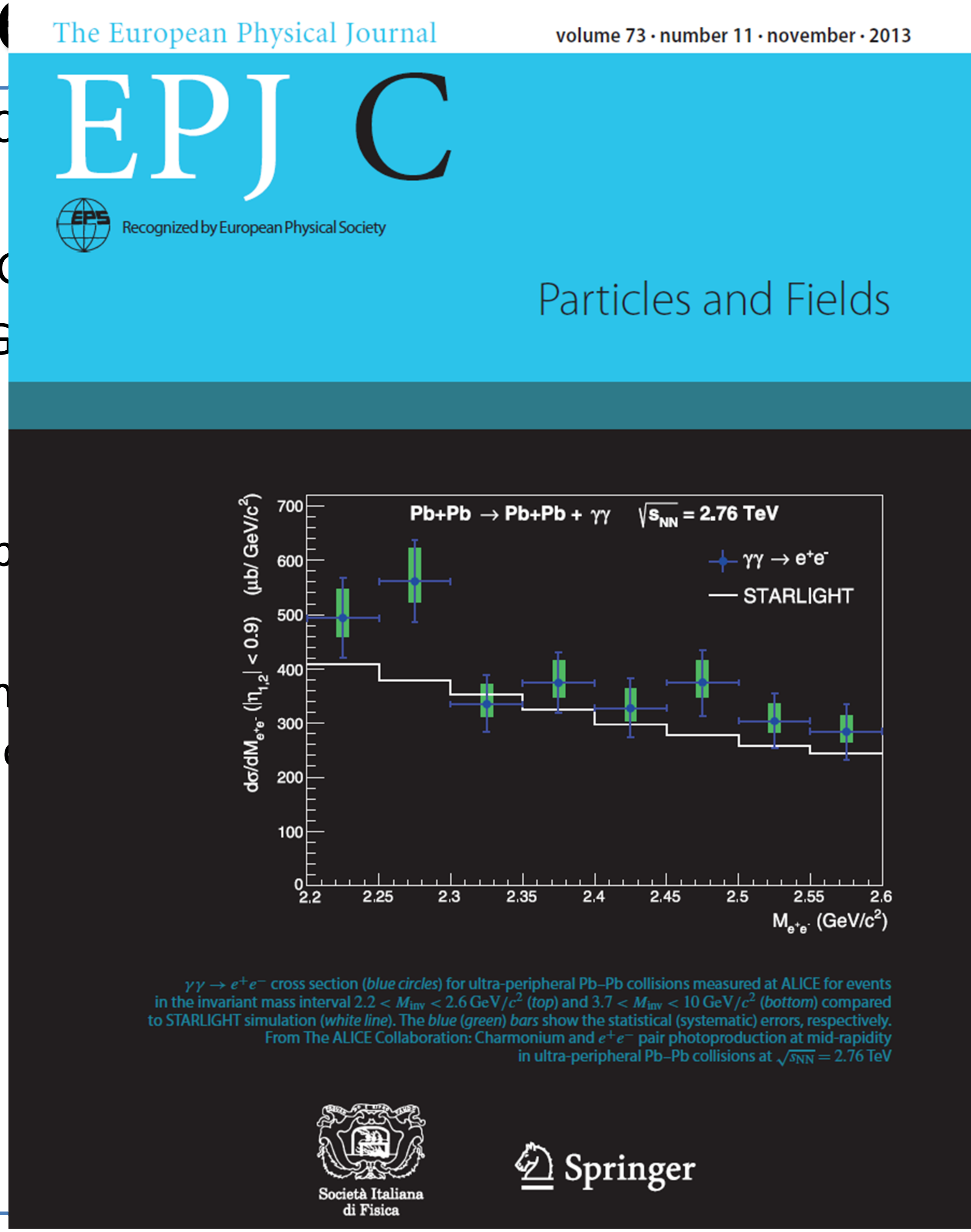
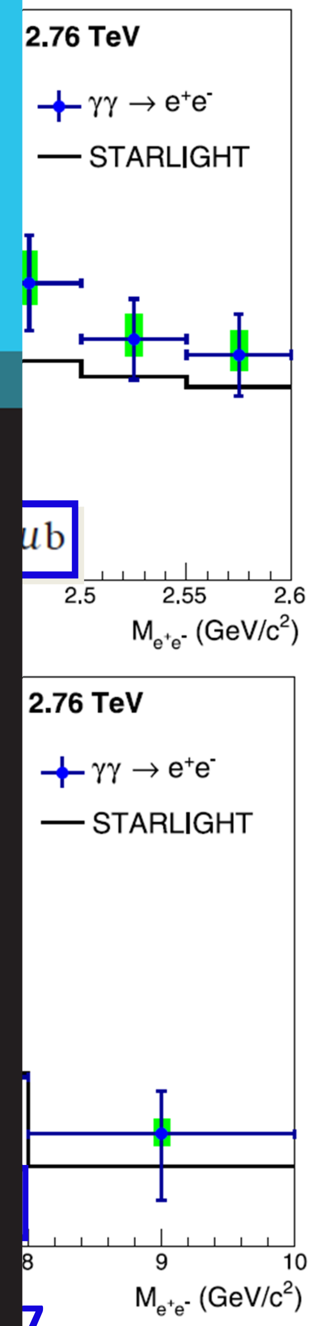




J/ψ in ultraperipheral p-Pb collisions

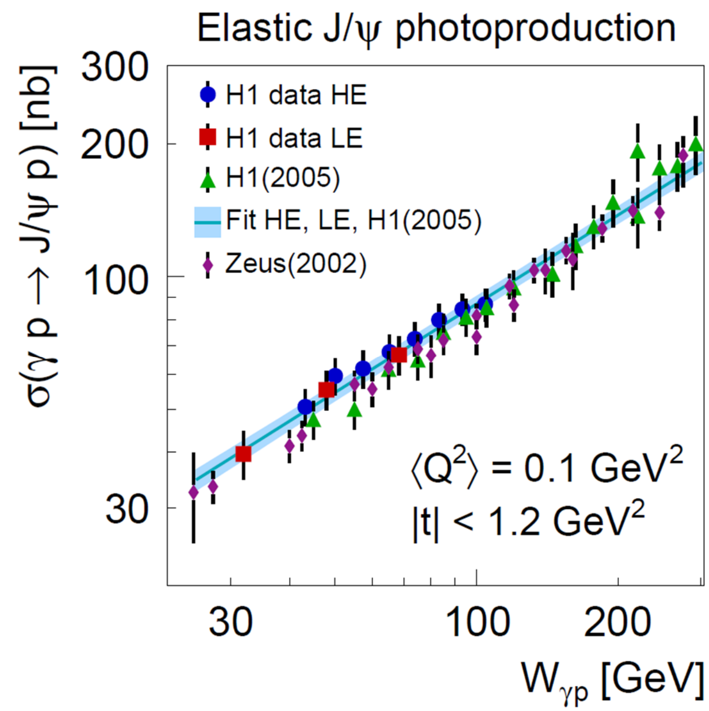
J/ψ photoproduction on proton

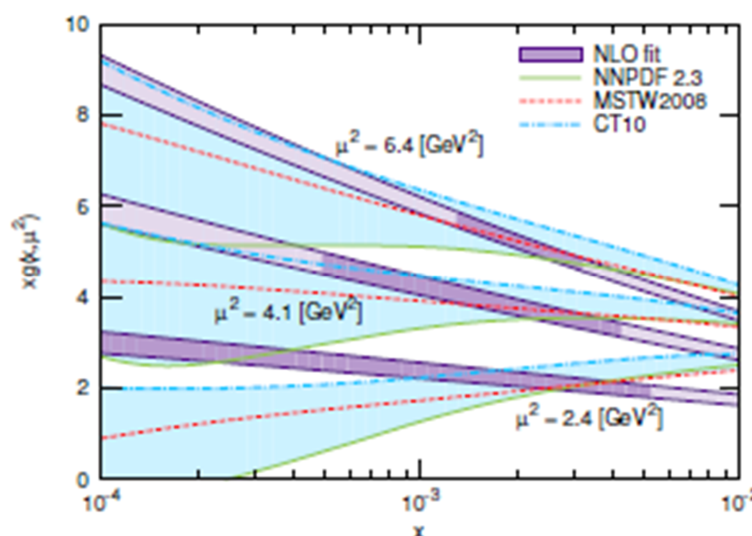
- HERA:
  - J/ψ photoproduction in *ep* (x up to 10^{-4})
  - Latest: H1, Eur. Phys. J. C73 (2013) 2466
  - Results well described with the power law (no hint for saturation)
  - Data was used to extract gluon PDFs:

    MNRT (Martin et al), Phys. Lett. B 662 (2008) 252

    JMRT(Jones et al), JHEP11 (2013) 085

- CDF: exclusive J/ψ in $p\bar{p}$ @ 2 TeV at midrapidity ($x \sim 10^{-3}$), PRL 102, 242001 (2009)
  - compatible with HERA (W~100 GeV)
  - Set upper limit for odderon-pomeron contribution





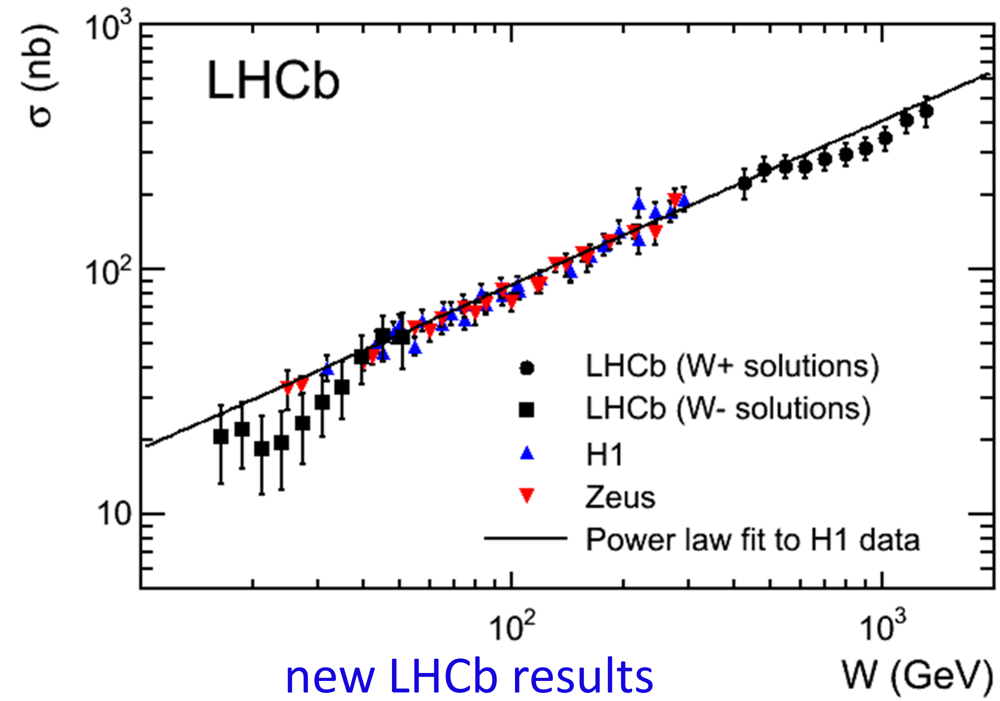
JHEP11 (2013) 085

J/ψ photoproduction at LHC

$$\frac{d\sigma}{dy}_{pp\to pVp} = r(y)\left[k_+ \frac{dn}{dk_+}\sigma_{\gamma p\to Vp}(W_+) + k_- \frac{dn}{dk_-}\sigma_{\gamma p\to Vp}(W_-)\right]$$

LHCb: exclusive J/ψ in pp @ 7 TeV
at forward rapidity ($x \sim 10^{-2}$ + $x \sim 10^{-5}$):

2010 data: 36 pb^{-1}
LHCb, J. Phys. G40 (2013) 045001
2011 data: 930 pb^{-1}
First shown at SaporeGravis Workshop (Nantes) two weeks ago. To be published soon (LHCb-PAPER-2013-059)



new LHCb results

- Large fraction of J/ψ from χ_c decays
- photon emitter is unknown
- assume power law to separate low and high-energy contributions

Advantage of p-Pb collisions wrt pp:

- Large photon flux from Pb
- The photon source is known
  $\rightarrow$ no assumption required to separate low and high energy contributions
- Hadronic contribution can be strongly suppressed by ensuring Pb nuclei are intact (no signal in ZDC)
- Contamination from central exclusive χ_c production negligible

Three UPC trigger options in ALICE

Data collected in 2013:

p-Pb: p towards muon spectrometer

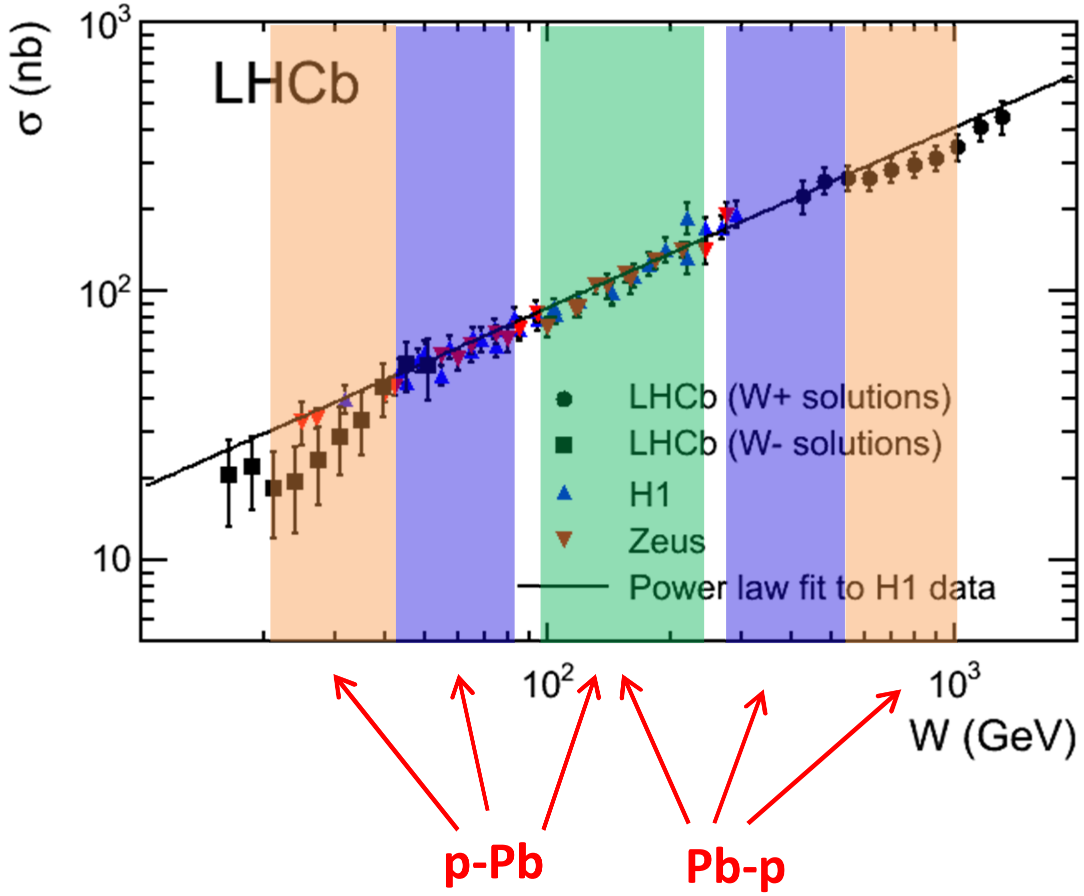
Pb-p: Pb towards muon spectrometer

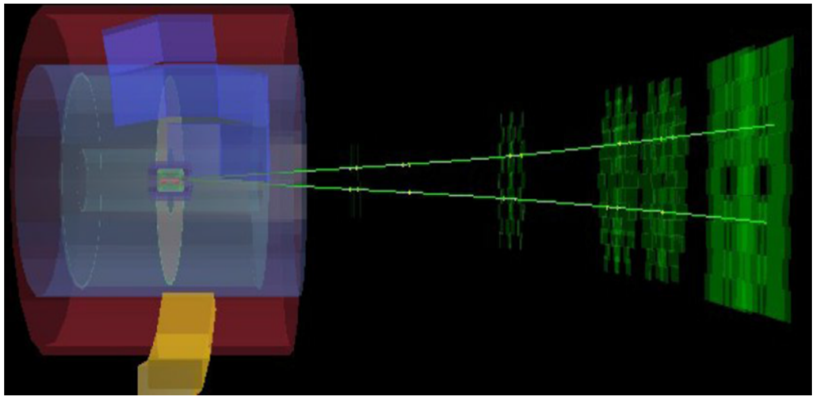
Three UPC trigger options in ALICE:

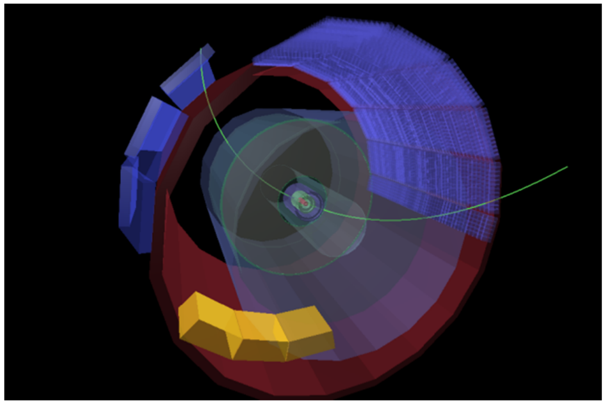
- Forward: both muons in the muon arm
- Central: both leptons in the barrel
- Semi-forward: one muon in the muon arm, second in the barrel

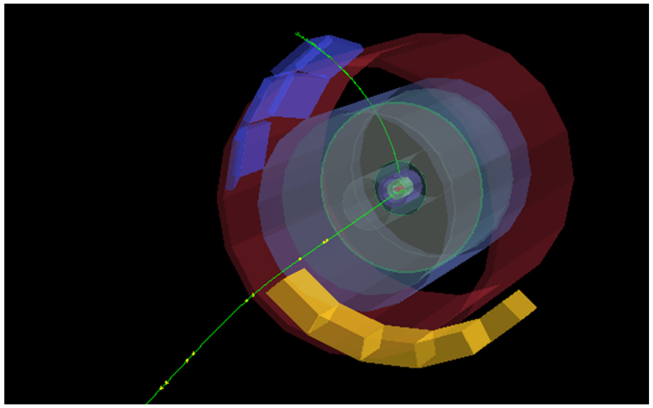
→ wide gamma-proton CM energy coverage up to W ~ 1 TeV!

→ wide x coverage: 10^{-2} - 10^{-5}









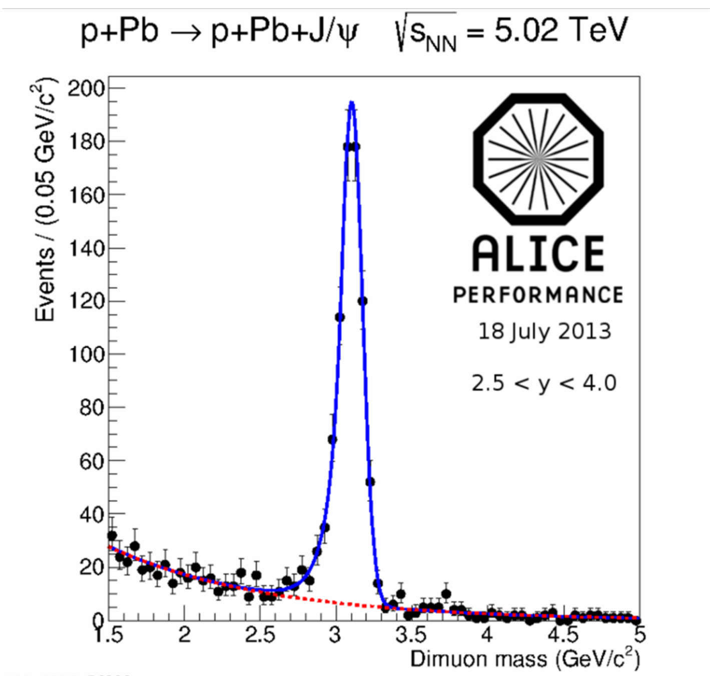
Preliminary results in forward pA

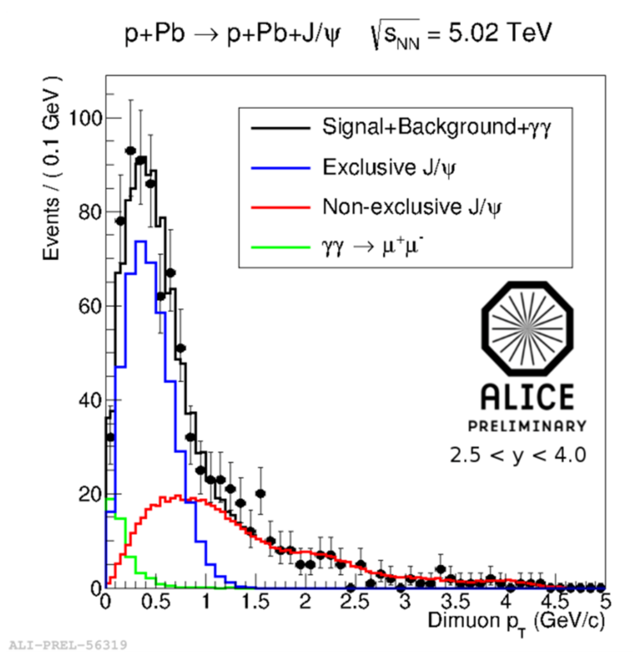
p-Pp (low gamma-proton energy):

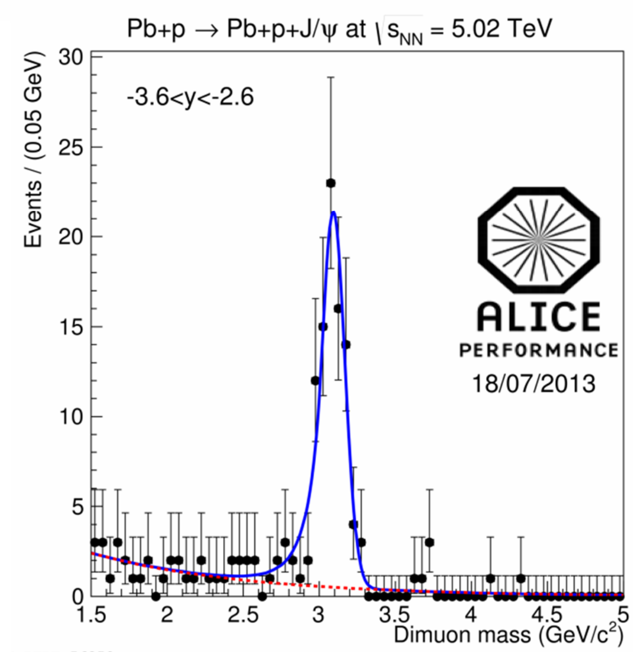
- Exclusive J/ψ production measured in 3 rapidity bins (2.5 < y < 4)
- Background (mainly proton dissociative J/ψ production) estimated with p_T templates
- Same method applied to obtain the $\sigma(\gamma\gamma\rightarrow\mu\mu)$ in 1.5< M_{inv} <2.5 GeV/c^2. Results compatible with QED predictions from STARLIGHT.

Pb-p (high gamma-proton energy):

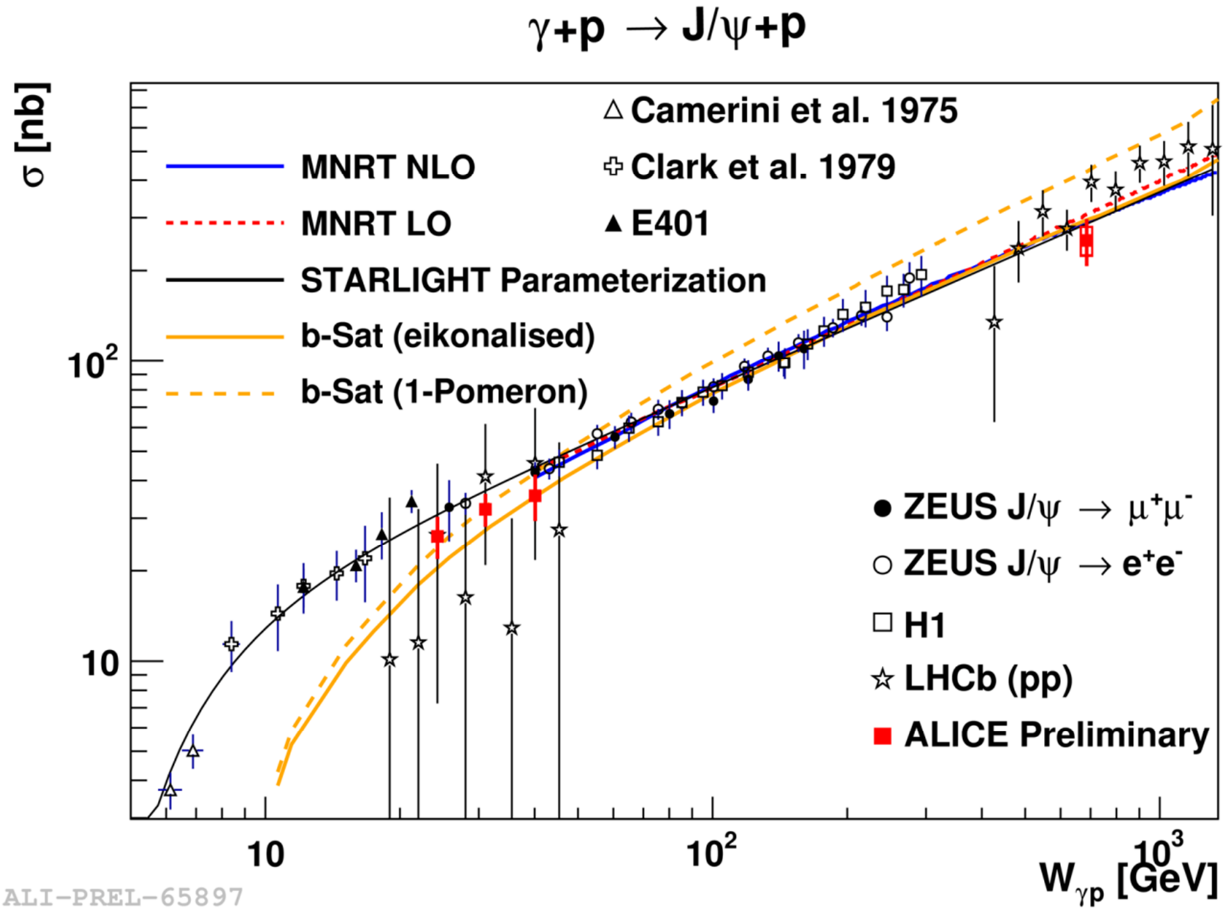
- Reduced rapidity range (-3.6 < y < -2.6) due to requirement of VZERO-C in the trigger
- Less statistics. Exclusive J/ψ production measured in one rapidity bin







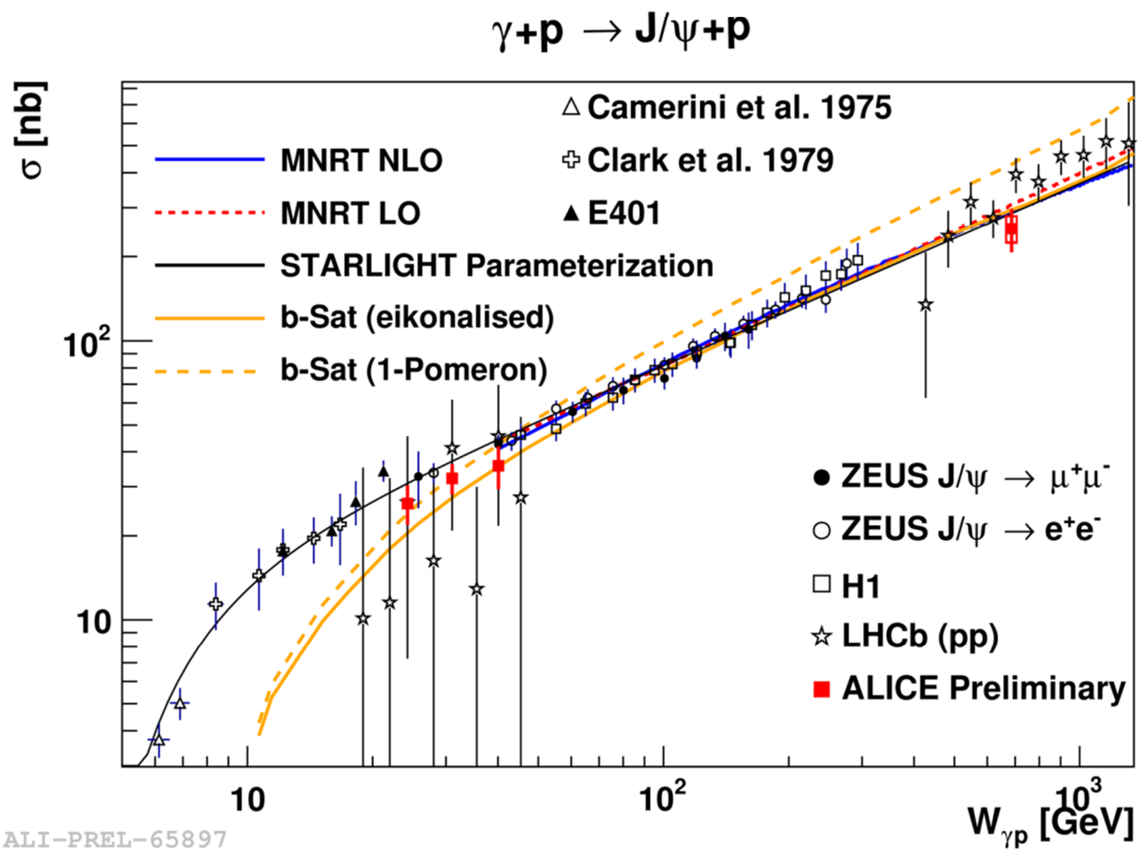
Tests of power law dependence



- Photoproduction cross section $\sigma(W_{\gamma p})$ obtained from ALICE $d\sigma/dy$ divided by photon flux from STARLIGHT.
- 12% flux uncertainty at high energy
- Power law fits (not shown): $\sigma \sim (W_{\gamma p}/ 90\ \mathrm{GeV})^{\delta}$

- ALICE data alone compatible with a power law with $\delta = 0.67 \pm 0.06$
- Exponent compatible with H1 ($\delta = 0.67 \pm 0.03$) and ZEUS ($\delta = 0.69 \pm 0.02 \pm 0.03$)
- Exponent from LHCb: $\delta = 0.92 \pm 0.15$ (J. Phys. G40 (2013) 045001, waiting for update)
- Relative normalization of ~1σ between different HERA sets. ALICE normalization is also ~1σ away wrt HERA

Comparison with models



JMRT (arXiv1307.7099):

LO (gluon distributions follow power law)
NLO (includes expected main NLO contributions)

- fits to HERA photoproduction data set + refit of LHCb data
- give very similar predictions in the considered energy and Q^2 range
- 1 sigma above ALICE measurement

b-sat model (hep-ph/0606272, acc-ph/1206.2913):

- includes b-dependent saturation effects based on a CGC inspired model
- parameters determined by fitting HERA data on the proton structure function F_2 for x<0.01
- 1 sigma above ALICE high energy point

Summary and outlook

Summary:

- J/ψ and dielectron continuum photoproduction measured in UPC Pb-Pb
- ALICE data consistent with gluon shadowing from EPS09 central set
- First results on forward J/ψ photoproduction in p-Pb available

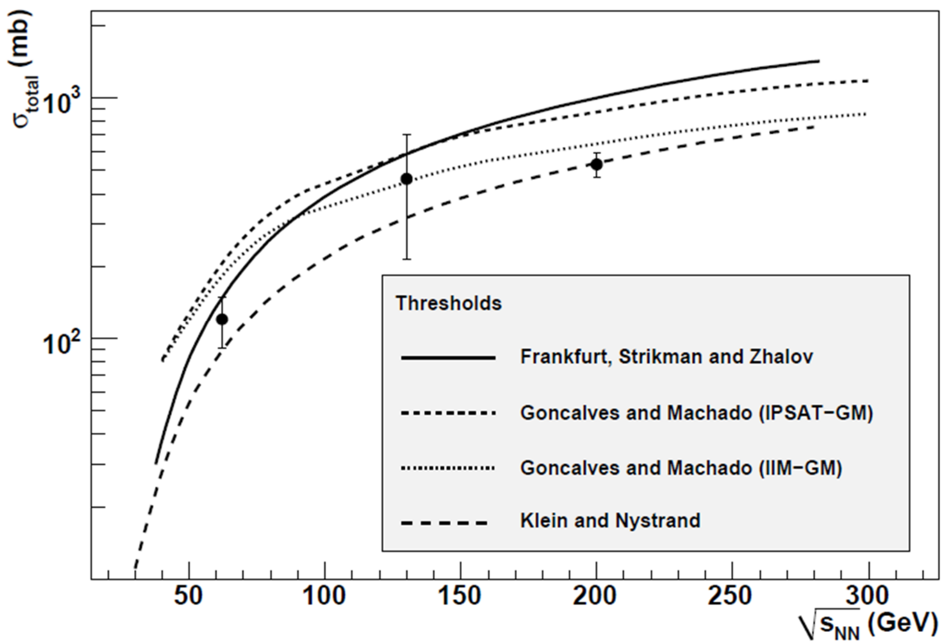
Prospects:

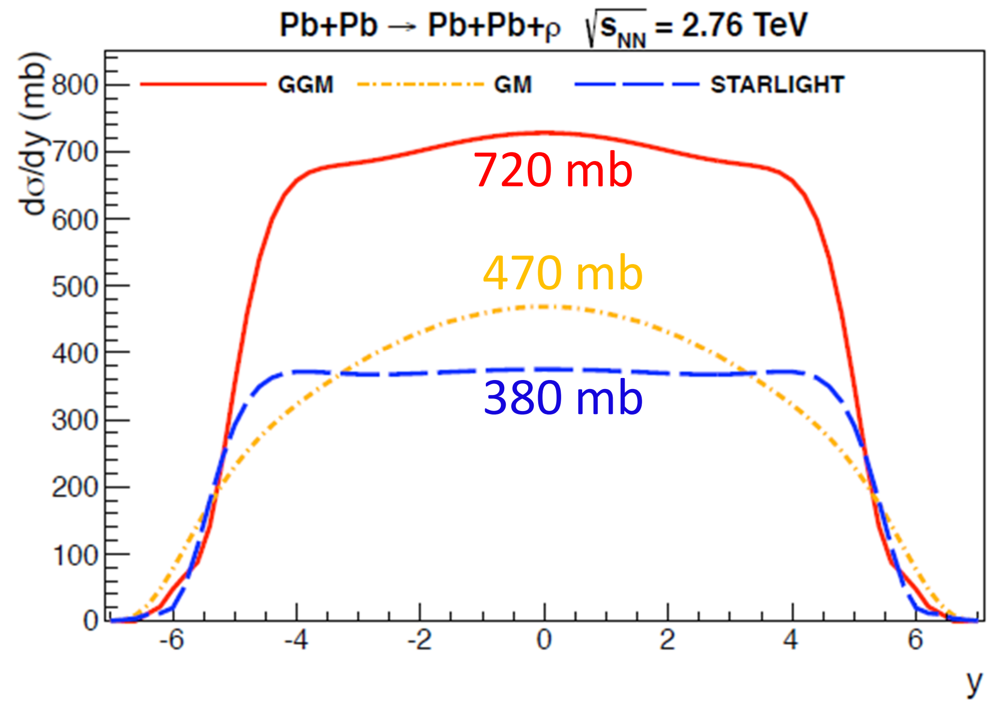
- Finish analysis on J/ψ in p-Pb including central-barrel and semiforward UPC
- Study the production of other vector mesons (ρ, ψ') in existing Pb-Pb data
- Collect new data at higher beam energy (x2) and increased luminosity (Pb-Pb goal: ~ 1 nb^{-1} in 2015-2017 and ~ 10 nb^{-1} until mid 2020's)
- Take advantage of new forward ADA and ADC detectors to improve the exclusivity condition and the trigger purity
- Explore new vector mesons (Υ) and perform multi-differential studies (e.g. explore neutron emission pattern)

Backup

ρ^0 photoproduction in PbPb

STAR: Phys. Rev. C85 (2012) 014910





GGM: Frankfurt, Strikman, Zhalov, Phys. Lett. B 537 (2002) 51; Phys. Rev. C 67(2003) 034901

- Generalized Vector Meson Dominance Model in the Gribov-Glauber approach.
- Includes nondiagonal transitions $\gamma \rightarrow \rho' \rightarrow \rho$
- $\sigma_{\rho N}$ from Donnachie-Landshoff model, in agreement with HERA and lower energy data.

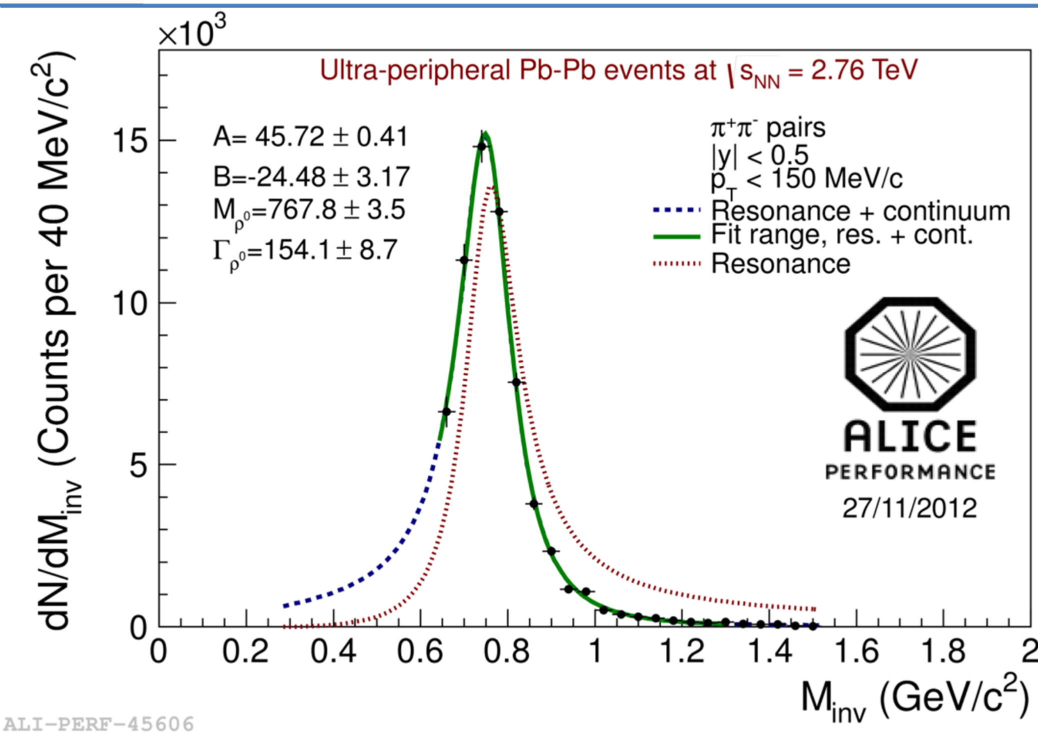
GM: Gonçalves, Machado, Phys. Rev. C 84 (2011) 011902

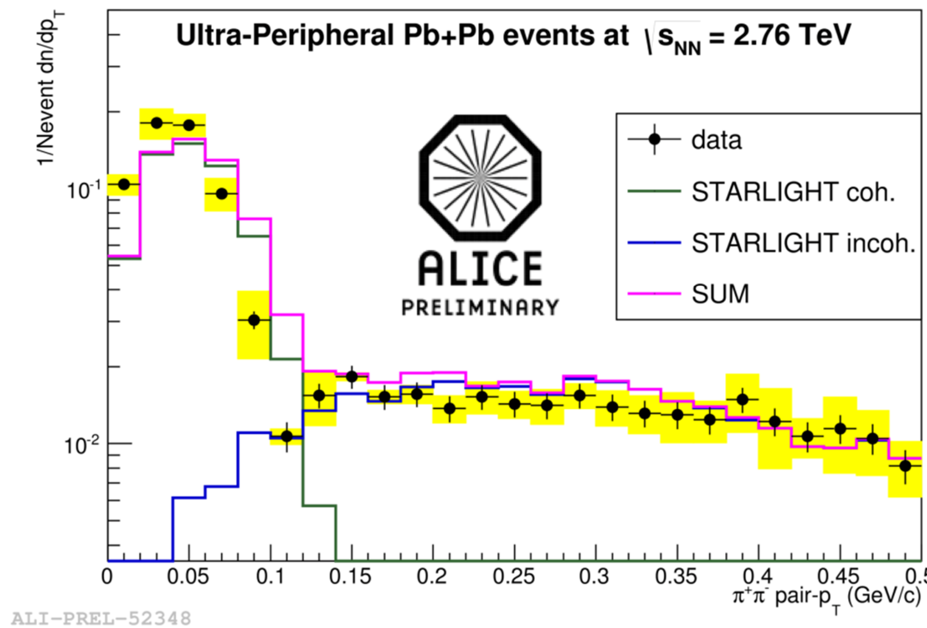
- Based on the color dipole model in combination with saturation from a CGC-IIM model.

STARLIGHT: Klein, Nystrand, Phys. Rev. C 60 (1999) 014903, http://starlight.hepforge.org/

- Uses experimental data on $\sigma_{\rho N}$ cross section.
- Glauber model neglecting the elastic part of total cross section.

ρ^0 invariant mass and p_T spectra





$$\frac{d\sigma}{dm_{\pi\pi}} = \left| A \frac{\sqrt{m_{\pi\pi} M_{\rho^0} \Gamma(m_{\pi\pi})}}{m_{\pi\pi}^2 - M_{\rho^0}^2 + i M_{\rho^0} \Gamma(m_{\pi\pi})} + B \right|^2$$

A - amplitude of the Breit-Wigner function

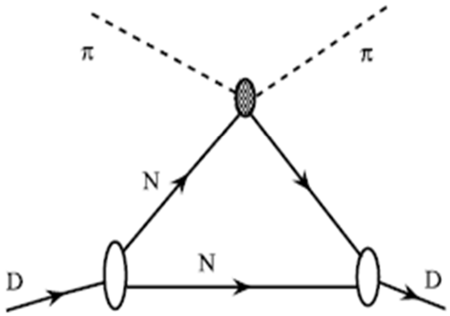
B - amplitude of the non-resonant $\pi\pi$ production

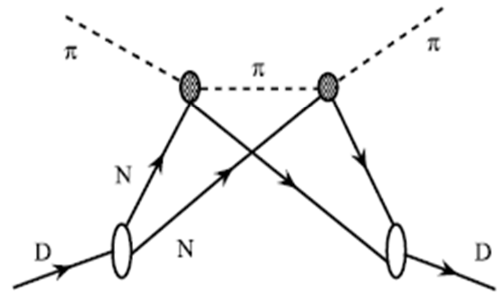
$$\Gamma(m_{\pi\pi}) = \Gamma_{\rho^0} \frac{M_{\rho^0}}{m_{\pi\pi}} \left(\frac{m_{\pi\pi}^2 - 4m_\pi^2}{M_{\rho^0}^2 - 4m_\pi^2} \right)^{3/2}$$

- coherent/incoherent template-pair-p_T distributions from STARLIGHT
- 7 % contribution from incoherent events with pair-p_T < 150 MeV/c
- p_T distribution in Starlight broader than in data (similar trend in STAR)

On nuclear shadowing

Glauber shadowing (modeling of several consequent interactions):

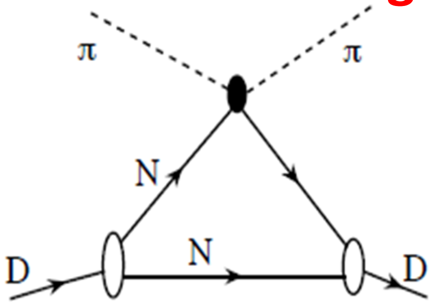


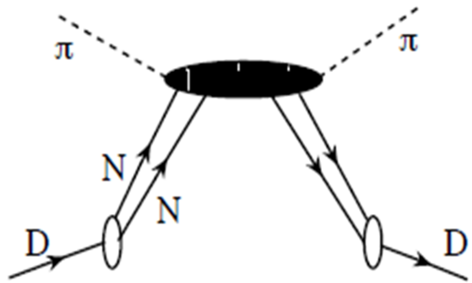


$$\sigma_{\rm tot}^{\pi D} = 2\,\sigma_{\rm tot}^{\pi N} - \frac{(\sigma_{\rm tot}^{\pi N})^2}{4\pi}\left\langle \frac{1}{r^2} \right\rangle_D$$

shadowing = destructive interference between single and multiple interactions

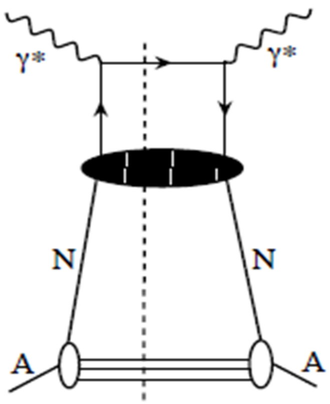
Gribov shadowing (coherent interaction via intermediate diffractive states):

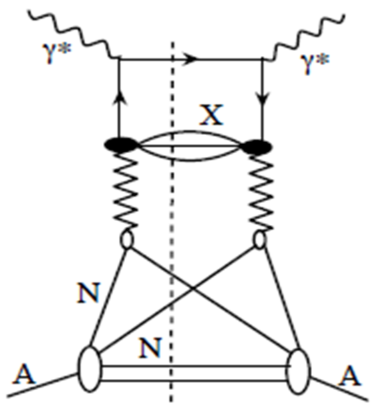




$$\sigma_{\rm tot}^{\pi D} = 2\sigma_{\rm tot}^{\pi N} - 2\int d\vec{k}^2 \rho\left(4\vec{k}^2\right)\frac{d\sigma_{\rm diff}^{\pi N}(\vec{k})}{d\vec{k}^2}$$

Leading twist shadowing (generalization of Gribov shadowing to the parton level):

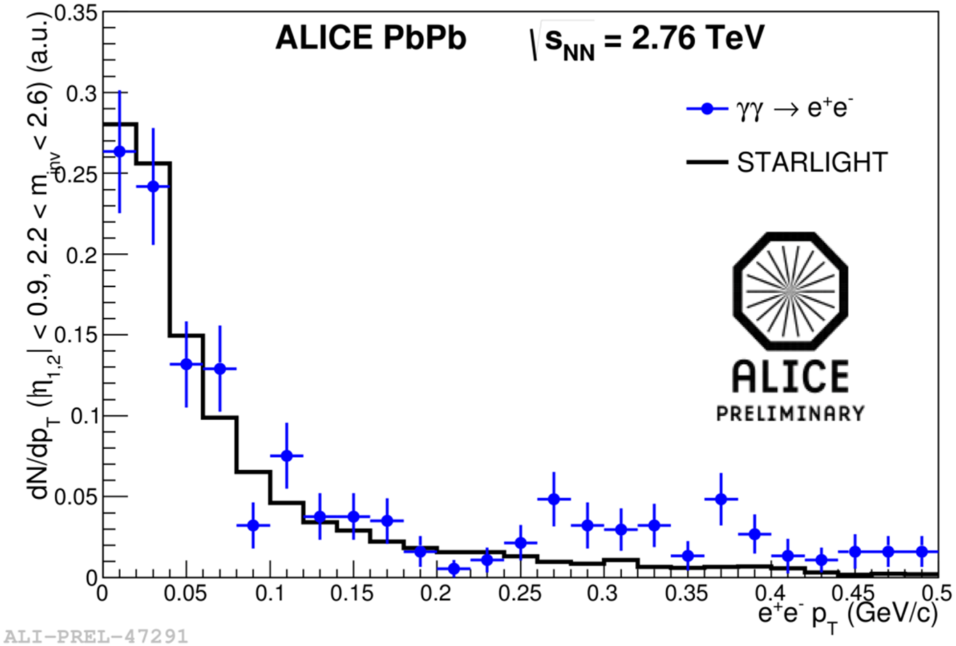


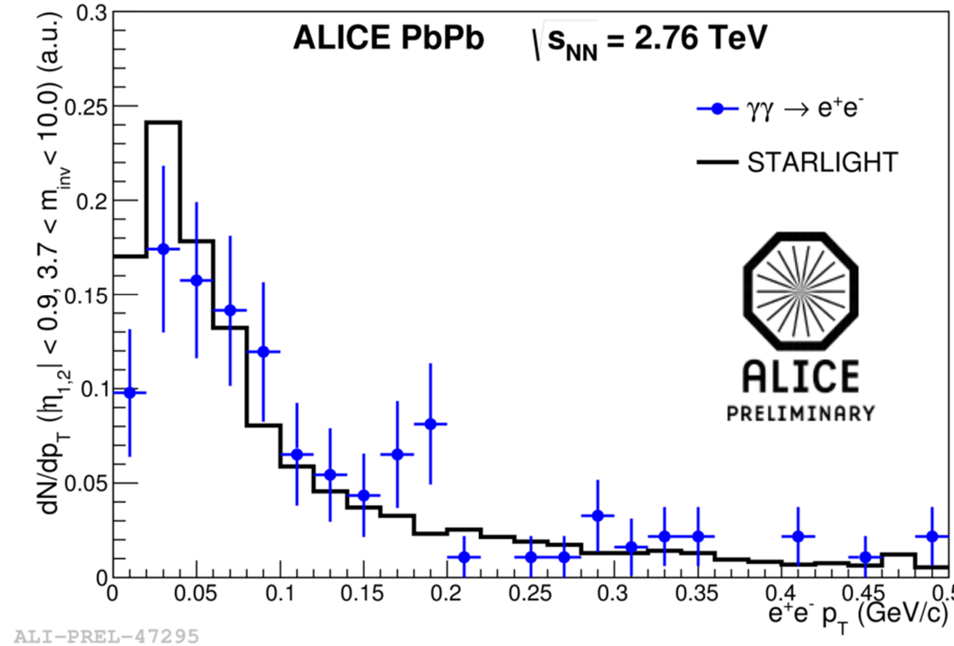


$$xf_{j/A}^{(b)}(x,Q^2) = -8\pi A(A-1)\Re e\frac{(1-i\eta)^2}{1+\eta^2}\int_x^{0.1} dx_{\mathbb{P}}\beta f_j^{D(4)}(\beta,Q^2,x_{\mathbb{P}},t_{\min})$$
$$\times \int d^2\vec{b}\int_{-\infty}^{\infty} dz_1 \int_{z_1}^{\infty} dz_2\, \rho_A(\vec{b},z_1)\rho_A(\vec{b},z_2)e^{i(z_1-z_2)x_{\mathbb{P}}m_N}.$$

shadowing is expressed via diffractive PDFs

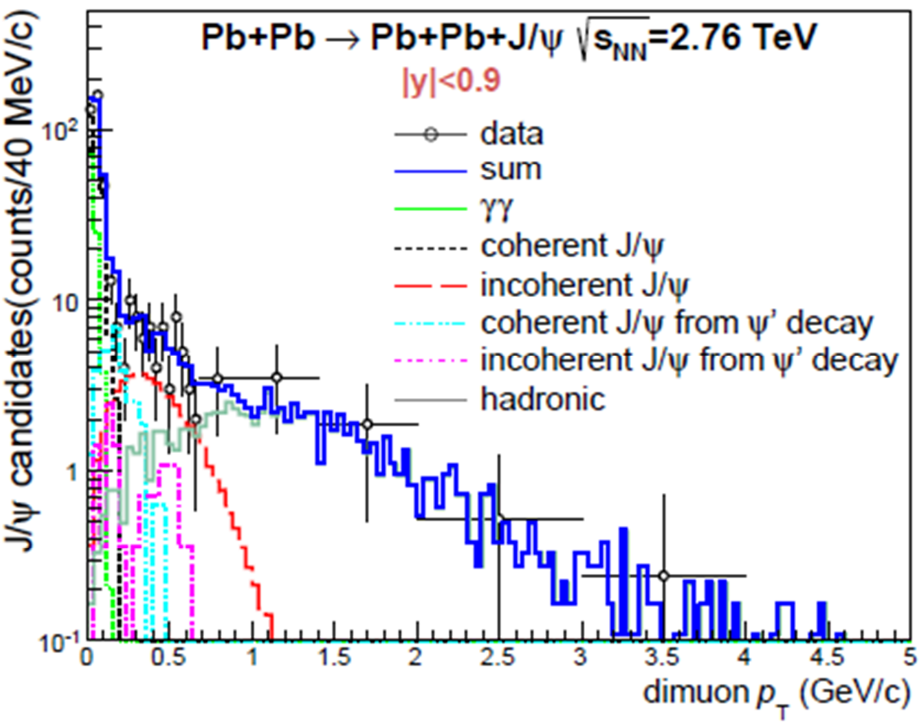
$\gamma\gamma \to e^+e^-$: p_T distributions

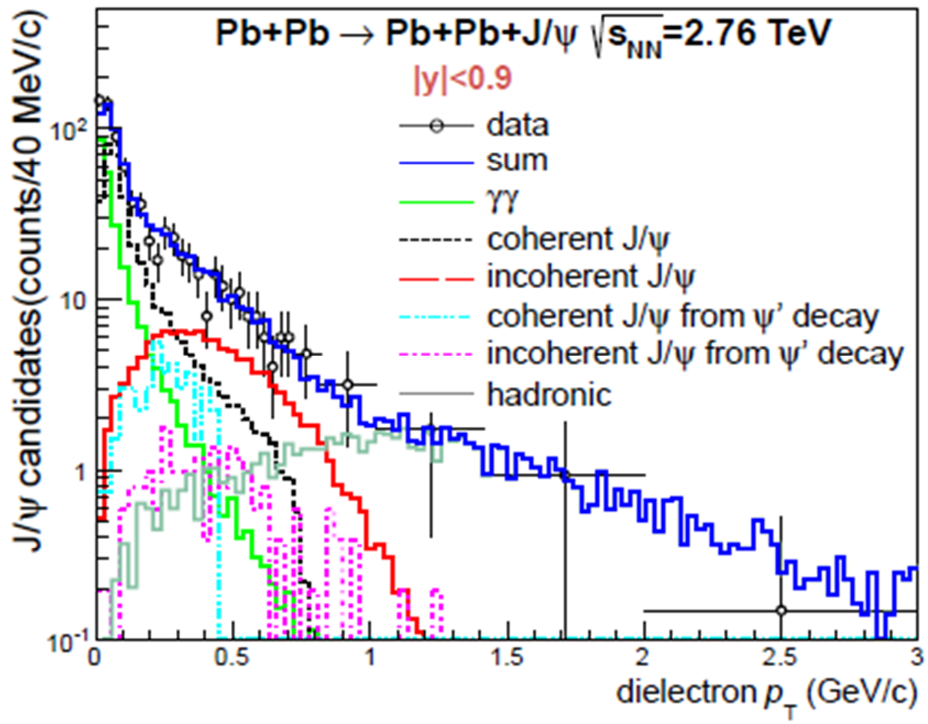




p_T distributions for J/ψ in central barrel: log scale

Eur. Phys. J. C73 (2013) 2617





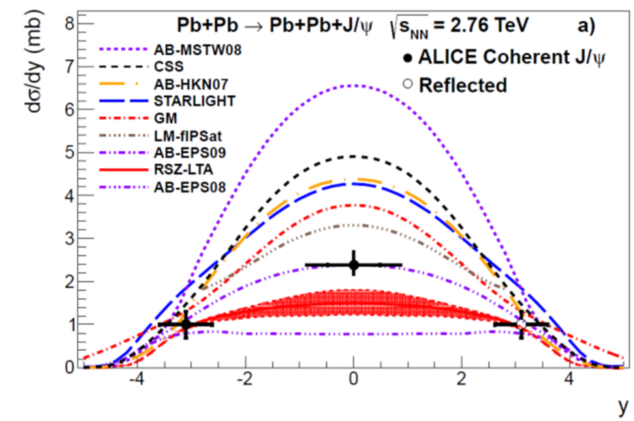
Photoproduction cross-section from ALICE data

V. Guzei, E. Kryshen, M. Strikman, M. Zhalov. Phys. Lett. B726 (2013) 290

ALICE measurement:

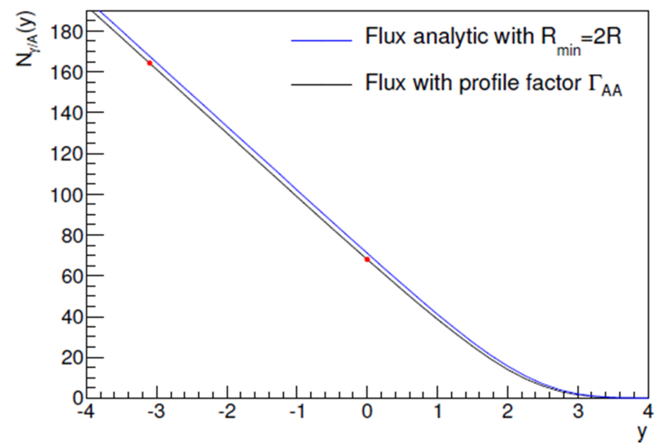
$$\frac{\sigma_{AA\to AAJ/\psi}(|y|<0.9)}{\Delta y} = 2.33 \pm 0.13(\mathrm{stat}) \pm 0.23(\mathrm{syst})\ \mathrm{mb}$$

$$\frac{\sigma_{AA\to AAJ/\psi}(-3.6<y<-2.6)}{\Delta y} = 1.00 \pm 0.18(\mathrm{stat})^{+0.23}_{-0.26}(\mathrm{syst})\ \mathrm{mb}$$



Photon flux:

$$N_{\gamma/Pb}(y=-3.1) = 163.9 \pm 8.2$$
$$N_{\gamma/Pb}(y=0) = 67.7 \pm 3.4$$



J/ψ photoproduction cross section from ALICE data:

$$\sigma_{\gamma Pb\to PbJ/\psi}(W_{\gamma p}=19.6\,\mathrm{GeV}) = 6.1^{+1.8}_{-2.0}\ \mu\mathrm{b}$$
$$\sigma_{\gamma Pb\to PbJ/\psi}(W_{\gamma p}=92.4\,\mathrm{GeV}) = 17.2 \pm 2.1\ \mu\mathrm{b}$$

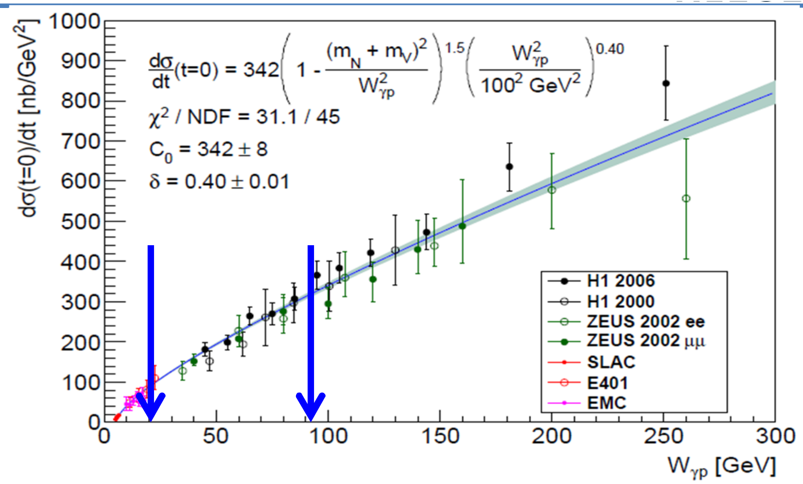
Photoproduction cross-section in the Impulse Approximation

V. Guzei, E. Kryshen, M. Strikman, M. Zhalov. Phys. Lett. B726 (2013) 290

Forward J/psi photoproduction cross section:

$$\frac{d\sigma_{\gamma p\to J/\psi p}(19.6\ \mathrm{GeV}, t=0)}{dt} = 86.9 \pm 1.8\ \mathrm{nb/GeV^2}$$

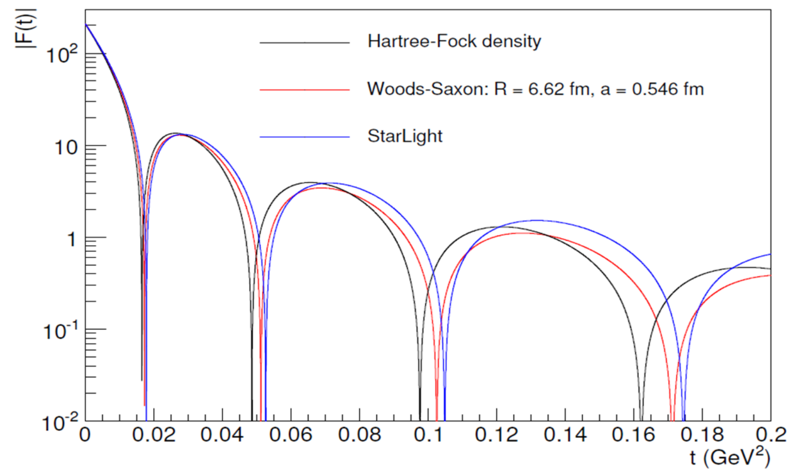
$$\frac{d\sigma_{\gamma p\to J/\psi p}(92.4\ \mathrm{GeV}, t=0)}{dt} = 319.8 \pm 7.1\ \mathrm{nb/GeV^2}$$



Integral over squared form factor:

$$\Phi_{WS}(W_{\gamma p} = 19.6\ \mathrm{GeV}) = 127.2\ \mathrm{GeV}^2$$

$$\Phi_{WS}(W_{\gamma p} = 92.4\ \mathrm{GeV}) = 149.2\ \mathrm{GeV}^2$$



$$\Phi(t_{min}) = \int_{t_{min}}^{\infty} dt\,|F_A(t)|^2$$

J/psi photoproduction on nucleus in Impulse Approximation:

$$\sigma^{IA}_{\gamma Pb\to PbJ/\psi}(W_{\gamma p} = 19.6\,\mathrm{GeV}) = 11.1 \pm 0.6\ \mu\mathrm{b}$$

$$\sigma^{IA}_{\gamma Pb\to PbJ/\psi}(W_{\gamma p} = 92.4\,\mathrm{GeV}) = 47.7 \pm 2.6\ \mu\mathrm{b}$$

Estimation of the nuclear suppression factor

V. Guzei, E. Kryshen, M. Strikman, M. Zhalov. Phys. Lett. B726 (2013) 290

- J/psi photoproduction cross section measured by ALICE:

$$\sigma_{\gamma Pb \to PbJ/\psi}(W_{\gamma p} = 19.6\,\mathrm{GeV}) = 6.1^{+1.8}_{-2.0}\ \mu\mathrm{b}$$
$$\sigma_{\gamma Pb \to PbJ/\psi}(W_{\gamma p} = 92.4\,\mathrm{GeV}) = 17.2 \pm 2.1\ \mu\mathrm{b}$$

$$\div$$

- J/psi photoproduction cross section in the Impulse Approximation:

$$\sigma^{\mathrm{IA}}_{\gamma Pb \to PbJ/\psi}(W_{\gamma p} = 19.6\,\mathrm{GeV}) = 11.1 \pm 0.6\ \mu\mathrm{b}$$
$$\sigma^{\mathrm{IA}}_{\gamma Pb \to PbJ/\psi}(W_{\gamma p} = 92.4\,\mathrm{GeV}) = 47.7 \pm 2.6\ \mu\mathrm{b}$$

- Nuclear suppression factor:

$$S(W_{\gamma p}) \equiv \left[\frac{\sigma_{\gamma \mathrm{Pb} \to J/\psi \mathrm{Pb}}(W_{\gamma p})}{\sigma^{\mathrm{IA}}_{\gamma \mathrm{Pb} \to J/\psi \mathrm{Pb}}(W_{\gamma p})} \right]^{1/2}$$

$$S(W_{\gamma p} = 19.6\ \mathrm{GeV}) = 0.74^{+0.11}_{-0.12}$$
$$S(W_{\gamma p} = 92.4\ \mathrm{GeV}) = 0.61^{+0.05}_{-0.04}$$