# Photon-hadron and photon-photon collisions in ALICE

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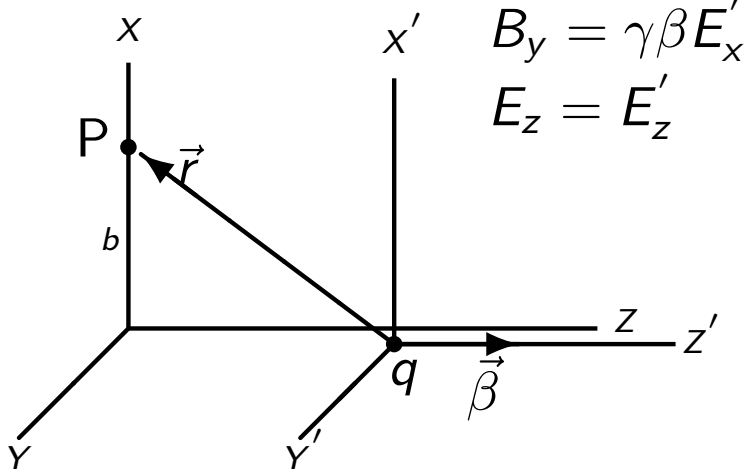
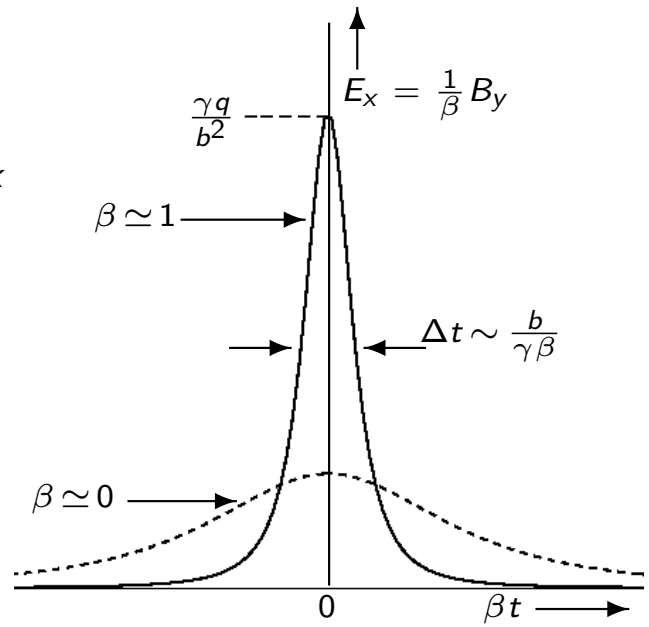
# The electromagnetic field of a moving charge

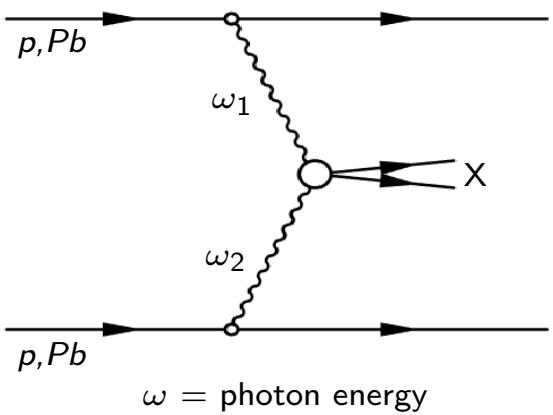
$$E_x = \gamma E_x'$$
$$B_y = \gamma\beta E_x' = \beta E_x$$
$$E_z = E_z'$$

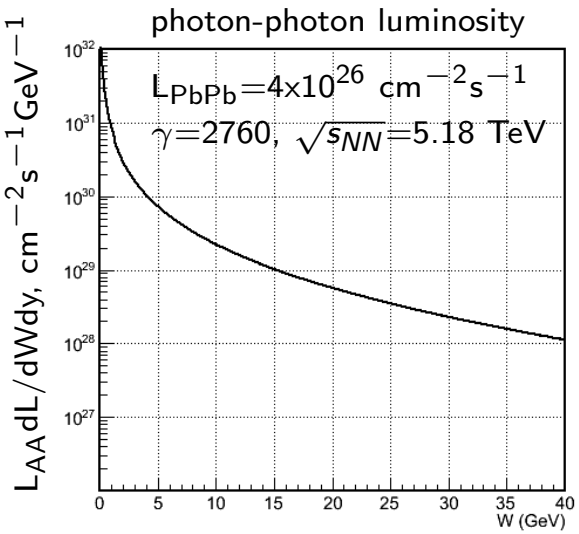



- Fields represent plane polarized radiation moving in z-direction
- Equivalent Photon Approximation (EPA)
  - E. Fermi (1924)
  - C.F. Weizsäcker, E.J. Williams (1934)
- $dn_\gamma(\omega, b) = \frac{Z_1^2\alpha}{\pi^2}\frac{d\omega}{\omega}\frac{d^2b}{b^2}$ (lead. log approx.)

# Photon-photon cross sections



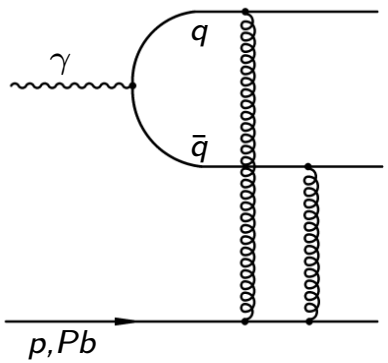

- hadron induced photon-photon processes in EPA-formalism
  - $\sigma^{EPA}_{pp\to pp\,X} = \int\int dn^1_\gamma\; dn^2_\gamma\; \sigma_{\gamma\gamma\to x}(\omega_1\,\omega_2)$
  - $\sigma^{EPA}_{PbPb\to PbPb\,X} = \int\int dn^1_\gamma\; dn^2_\gamma\; \sigma_{\gamma\gamma\to x}(\omega_1\,\omega_2)$
- photon-photon luminosity in EPA formalism

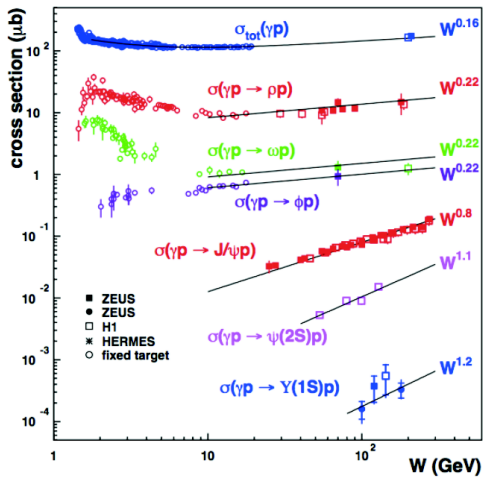
$$\frac{dL}{dWdy}=\frac{2}{W}\frac{dL}{d\omega_1 d\omega_2}=\frac{2}{W}\frac{dn(\omega_1)}{d\omega_1}\frac{dn(\omega_2)}{d\omega_2}=\frac{4Z^4\alpha^2}{\pi^2(\omega_1\omega_2)^{3/2}}\log(\frac{\gamma}{R\omega_1})\log(\frac{\gamma}{R\omega_2})$$

  - W = invariant mass of two-photon system $= 2\sqrt{\omega_1\omega_2}$
  - y = rapidity of two-photon system $= \frac{1}{2}\log(\frac{\omega_1}{\omega_2})$

# Photon-hadron cross sections

- Photon of electromagnetic field of one nucleus interacts with nucleus of the other beam




- cross sections for exclusive vector meson production show energy dependence of hadronic cross sections

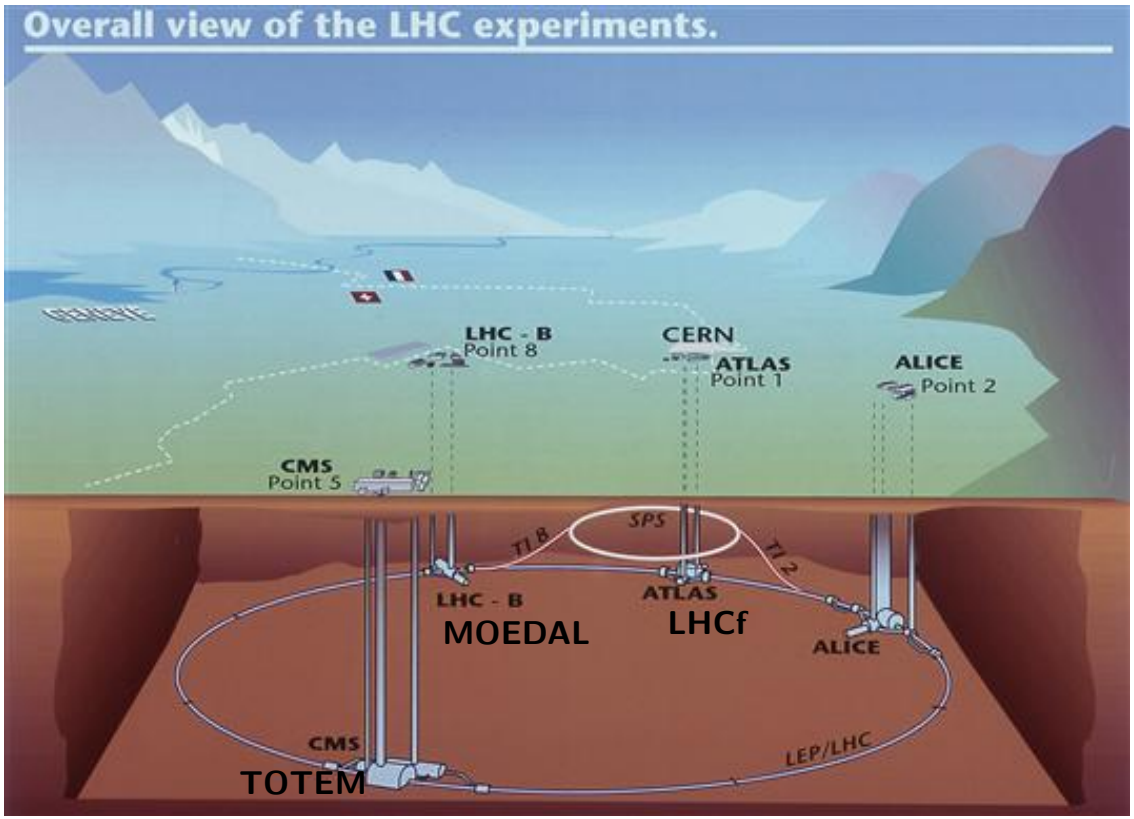
$$\left.\frac{\mathrm{d}\sigma}{\mathrm{d}t}\left(\gamma^* p \to J/\psi\, p\right)\right|_{t=0} = \frac{\Gamma_{ee} M_{J/\psi}^3 \pi^3}{48\alpha}\left[\frac{\alpha_s(\bar{Q}^2)}{\bar{Q}^4} x g(x,\bar{Q}^2)\right]^2 \left(1+\frac{Q^2}{M_{J/\psi}^2}\right)$$

$$\bar{Q}^2 = (Q^2 + M_{J/\psi}^2)/4, \qquad x = (Q^2 + M_{J/\psi}^2)/(W^2 + M_{J/\psi}^2)$$

cross section proportional to (gluon dens.)$^2$, $\sigma \sim (xg)^2$, hence $\sigma \sim x^{\lambda}$

- A.D.Martin, C.Nockles, M.Ryskin, T.Teubner, Small x gluon from exclusive $J/\Psi$ production, *Phys. Lett.*, B662, (2008) 252, arXiv:0709.4406

# The LHC collider - 7 experiments

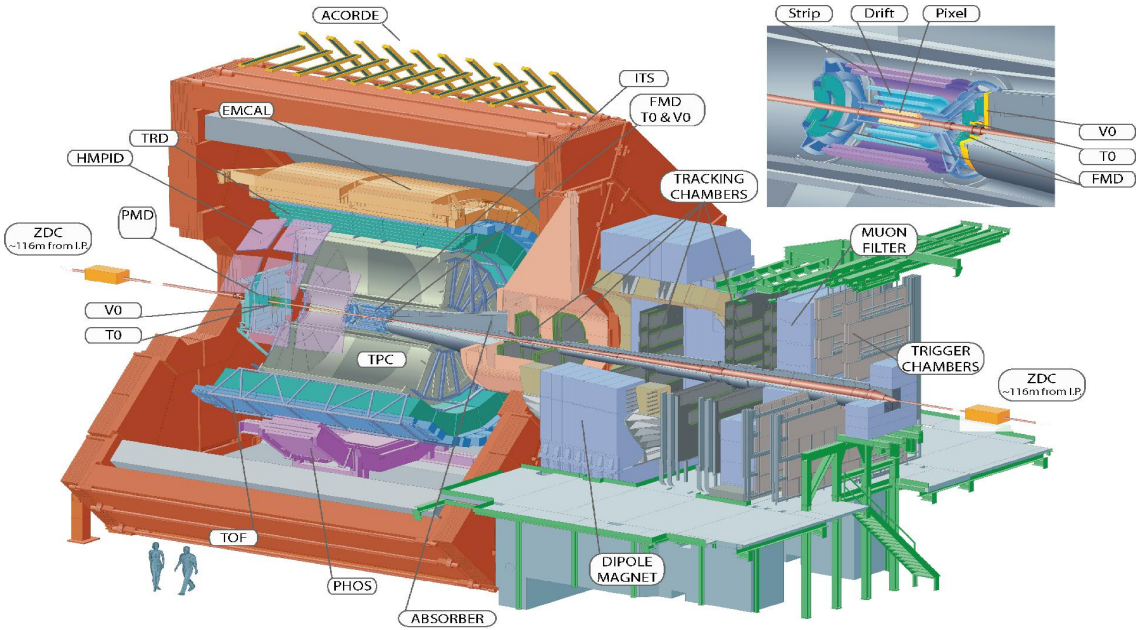



- LHC Run I 2010-2013:

| year | syst. | $\sqrt{s}$ | int. lumi. |
|---|---|---|---|
| 2010 | p-p | 7 TeV | 45 pb$^{-1}$ |
| 2011 | p-p | 7 TeV | 6 fb$^{-1}$ |
| 2012 | p-p | 8 TeV | 23 fb$^{-1}$ |

| year | syst | $\sqrt{s_{NN}}$ | int. lumi. |
|---|---|---|---|
| 2010 | Pb-Pb | 2.76 TeV | $\sim$ 10 $\mu b^{-1}$ |
| 2011 | Pb-Pb | 2.76 TeV | $\sim$ 0.15 nb$^{-1}$ |
| 2013 | p-Pb | 5.02 TeV | $\sim$ 30 nb$^{-1}$ |

# The ALICE experiment

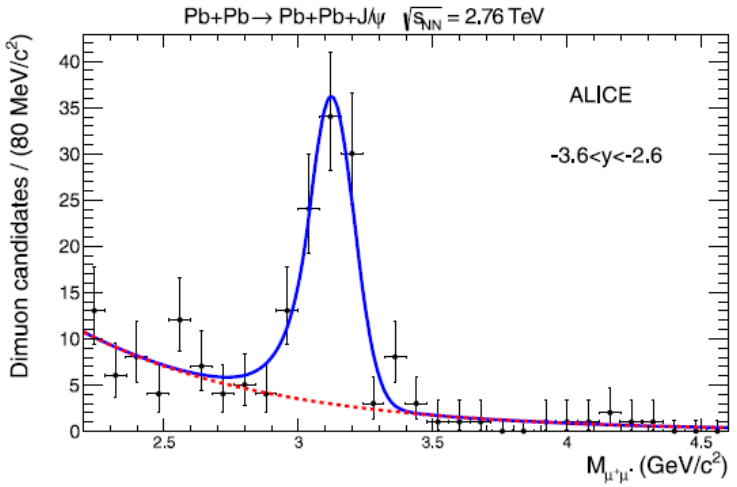



- Central Barrel
  - $|\eta| < 0.9$
  - tracking: ITS+TPC
  - trigger detectors: SPD, TRD, TOF
- Muon spectrometer
  - -4.0 $< \eta <$ -2.5
  - tracking
  - trigger chambers

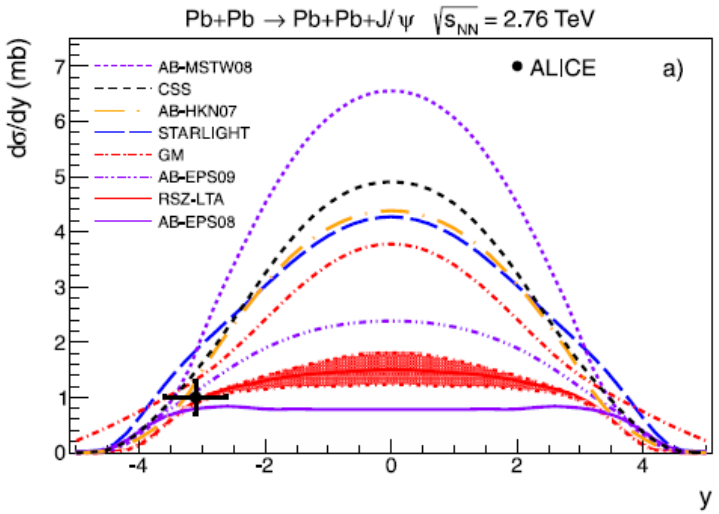
- Scintillator arrays:
  - VZERO-A: 2.8 $< \eta <$ 5.1, segmented in $\Delta\eta \sim 0.5$, $\Delta\phi = 45^0$
  - VZERO-C: -3.7 $< \eta <$ -1.7, segmentation as VZERO-A
- Zero Degree Calorimeter for detecting forward neutrons

# $J/\Psi$ production at forward rapidity in PbPb-collisions

- ALICE Collaboration,
  Phys. Lett. B718 (2013) 1273
  - measurement $J/\psi$ production at forward rapidity
  - $J/\Psi$ in $\mu^+\mu^-$ channel



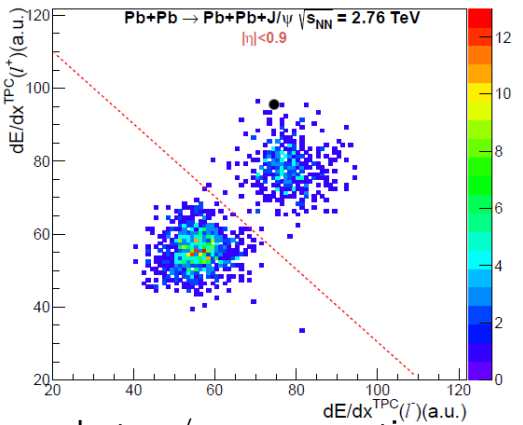

- trigger:
  - single muon trigger $p_T > 1$ GeV/c
  - at least one hit in VZERO-C
  - no hits in VZERO-A



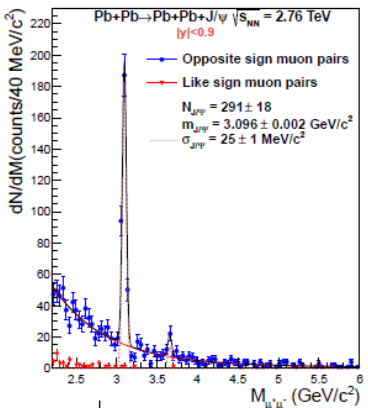

- not much discriminating power of models at this rapidity, models without nuclear gluon shadowing disfavored

# $J/\psi$ production at midrapidity in PbPb-collisions

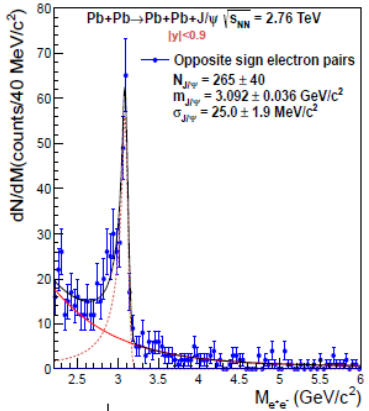
- ALICE Collaboration,
  Eur. Phys. J. C73 (2013) 2617
  - ALICE measurement $J/\psi$, $\psi(2S)$ photoproduction at midrapidity
  - $J/\Psi$ identified in $e^+e^-$ and $\mu^+\mu^-$ channels
- trigger:
  - at least 2 hits in SPD
  - number of TOF hits: $2 \leq N^{TOF} \leq 6$ (2 hits back-to-back)
  - no hits in VZERO-A, VZERO-C
- coherent production $<p_T^{J/\Psi}> \approx 60$ MeV/c
- incoherent production $<p_T^{J/\Psi}> \approx 500$ MeV/c



electron/muon separation based on dE/dx in TPC



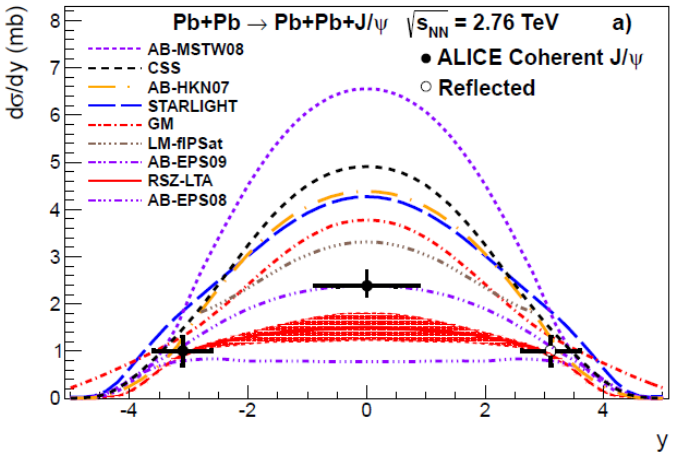
$\mu^+\mu^-$ inv. mass (coherent prod.)



$e^+e^-$ inv. mass (coherent prod.)

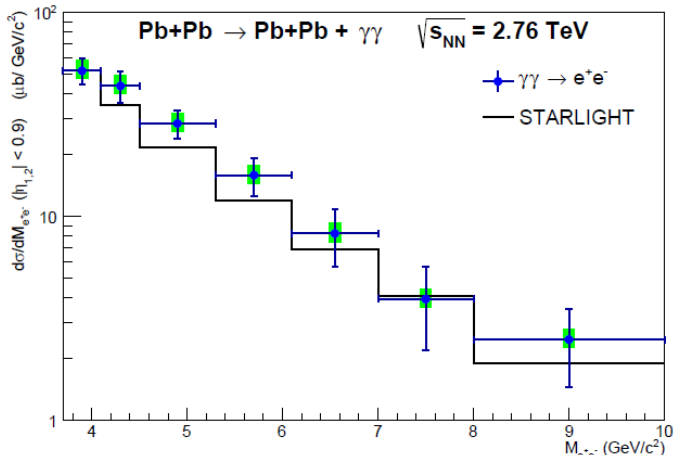
# $J/\psi$ production at midrapidity in PbPb-collisions

- Analysis $J/\psi$ cross section
- coherent/incoherent cross section within rapidity $|y| < 0.9$
- data sample of 23 $\mu b^{-1}$
- $\frac{d\sigma^{coh}_{J/\psi}}{dy} = 2.38^{+0.34}_{-0.24}$ (stat+sys) mb
- $\frac{d\sigma^{inc}_{J/\psi}}{dy} = 0.98^{+0.19}_{-0.17}$ (stat+sys) mb




- models without gluon shadowing inconsistent with measured cross section
- models with EPS09 gluon shadowing agree well with measurements

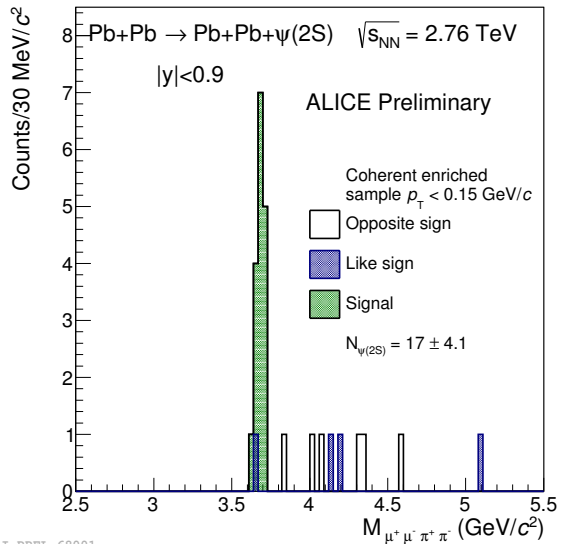
- Analysis $\gamma\gamma \rightarrow e^+e^-$
- cross section $\gamma\gamma \rightarrow e^+e^-$ ($m_{e^+e^-} > m_{J/\psi}$) analyzed within rapidity -0.9 < y < 0.9
- good agreement with STARLIGHT event generator

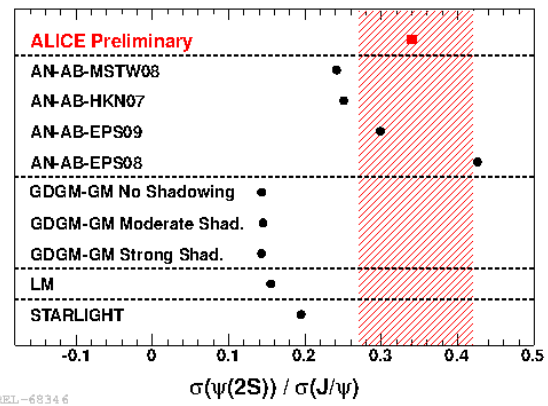



$e^+e^-$-inv. mass, $3.7 < m_{inv} < 10$ GeV/$c^2$

# $\psi$(2S) production at midrapidity in PbPb-collisions

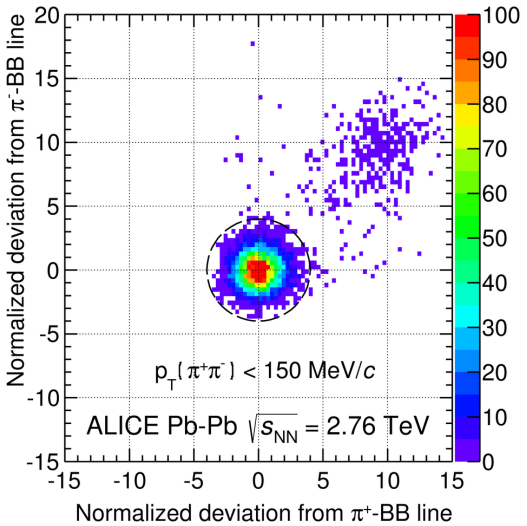
- Analysis $\psi$(2S) cross section
- coherent cross section within rapidity $|y| < 0.9$
- data sample of 23 $\mu b^{-1}$
- identification: $\psi(2S) \to l^+l^-$ and $\psi(2S) \to \pi^+\pi^- l^+l^-$
- $\frac{d\sigma^{coh}_{\psi(2S)}}{dy} = 0.83 \pm 0.19\,(\text{stat+sys})\,\text{mb}$
- mass spectrum shown for $\psi(2S) \to \pi^+\pi^-\mu^+\mu^-$
- similar spectrum for $\psi(2S) \to \pi^+\pi^- e^+e^-$
- cross section ratio $\psi$(2S) / J/$\psi$
- node in $\psi$(2S) radial wave function, smaller $\psi$(2S) cross section expected
- GDGM-GM, STARLIGHT models underpredict ratio $\psi$(2S) to J/$\psi$



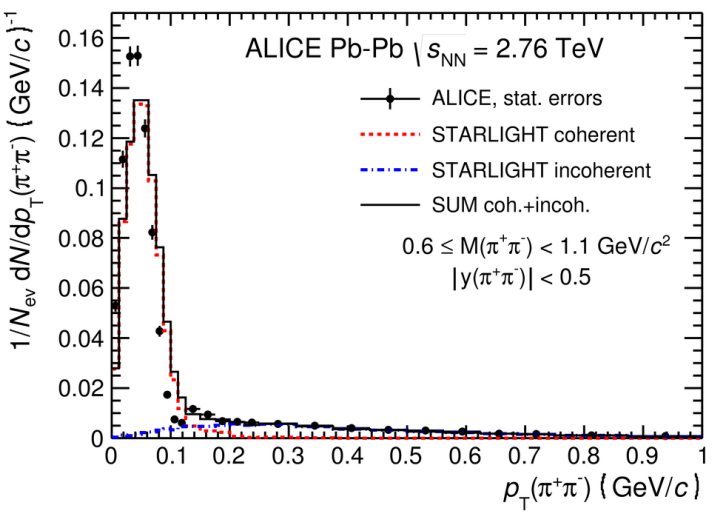



# $\rho^0$ production at midrapidity in PbPb-collisions

- ALICE Collaboration, arXiv:1503.09177
  - coherent $\rho^0$ photoproduction at midrapidity
  - $\rho^0$ identified in $\pi^+\pi^-$ channel within rapidity $|y| < 0.5$
- trigger low-lumi runs 2010:
  - number of TOF hits: $N^{TOF} \geq 2$
- trigger higher lumi runs:
  - number of TOF hits: $N^{TOF} \geq 2$
  - at least 2 hits in SPD
  - no hits in VZERO-A, VZERO-C



pion/electron separation based on dE/dx in TPC



# $\rho^0$ production at midrapidity in PbPb-collisions

- $\pi^+\pi^-$-mass spectrum fitted by:

  in blue: Söding parameterization

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

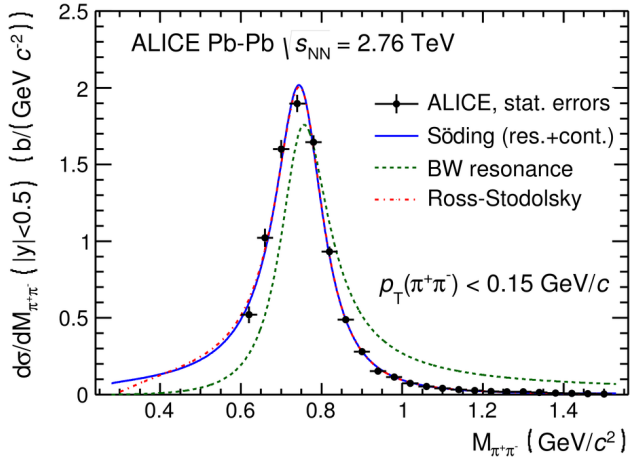
  A=Breit-Wigner / B=non-resonant $\pi^+\pi^-$ ampl.

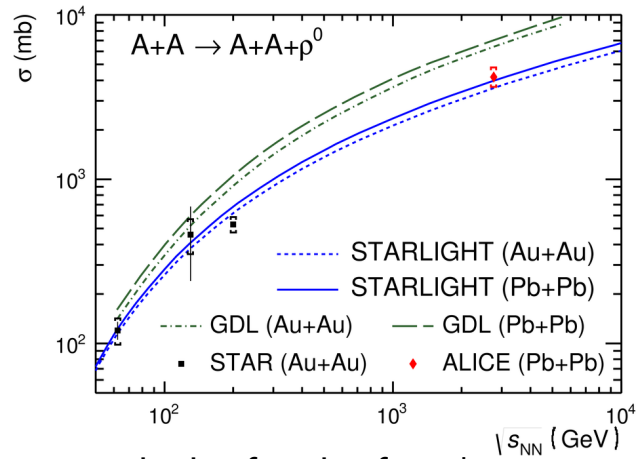
  in green: BW-contr. of Söding fit

  in red: Ross-Stodolsky parametr.

  $$\frac{d\sigma}{dM_{\pi\pi}} = A \left| \frac{\sqrt{M_{\pi\pi} M_{\rho 0} \Gamma(M_{\pi\pi})}}{M^2_{\pi\pi} - M^2_{\rho 0} + i M_{\rho 0} \Gamma(M_{\pi\pi})} \right|^2 \left( \frac{M_{\rho 0}}{M_{\pi\pi}} \right)^k$$

- comparison to models
  - GDL (Glauber-Donnachie-Landshoff):
    DL model for $\rho N$ cross sect.
  - STARLIGHT (Nystrand):
    $\sigma(\rho N) = 5.0\ W^{0.20}_{\gamma N} + 26.0\ W^{-1.23}_{\gamma N}\ \mu$b

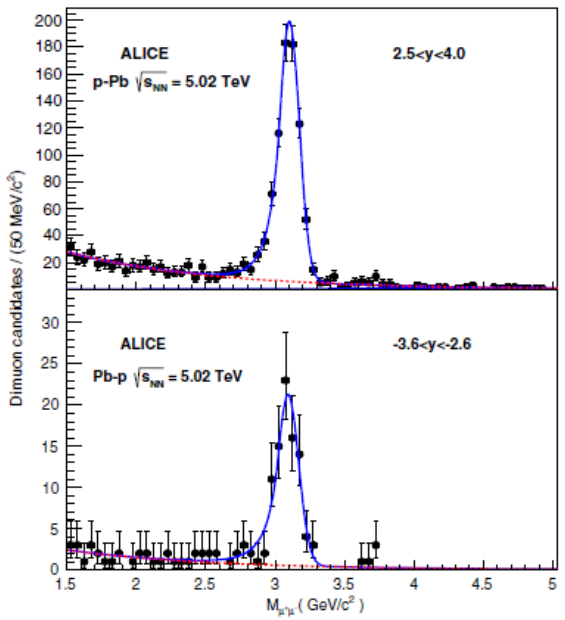


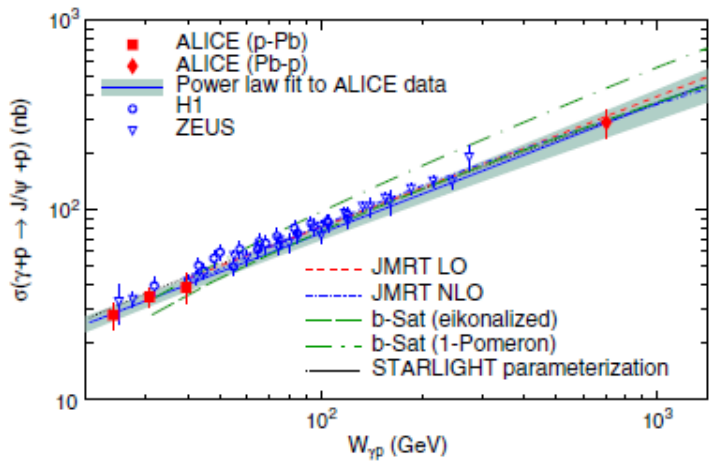




excitation function for coherent and exclusive $\rho^0$ production

# $J/\Psi$ production at forward rapidity in pPb-collisions

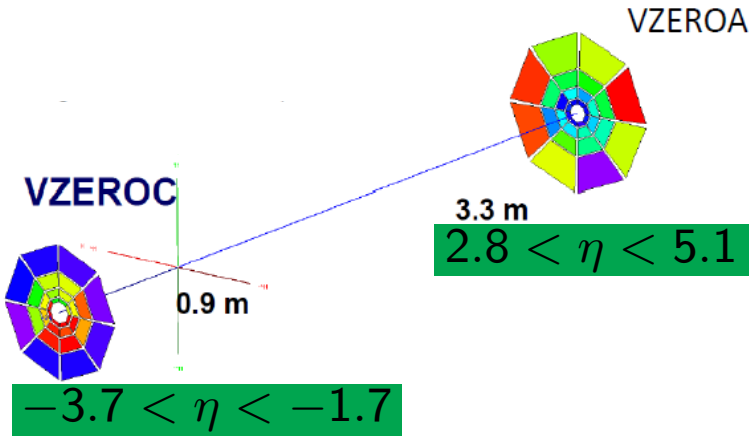
- ALICE Collaboration,
  Phys.Rev.Lett. 113 (2014) 232504
  - measurement of $J/\psi$ production at forward/backward rapidity
  - $J/\Psi$ in $\mu^+\mu^-$ channel
- $J/\Psi$ measured in p-Pb
  - $2.5 < y < 4.0$, $21 < W_{\gamma p} < 45$ GeV
- $J/\Psi$ measured in Pb-p
  - $-3.6 < y < -2.6$, $577 < W_{\gamma p} < 952$ GeV
- ALICE measurement:
  - cross section compatible with power-law dependence up to $W_{\gamma p} \sim 700$ GeV ($x \sim 2 \times 10^{-5}$)
  - no change of gluon PDF between HERA and LHC energy



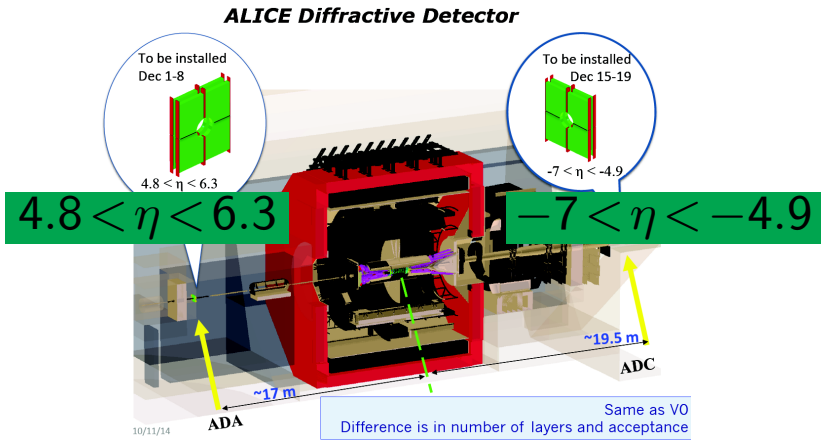



# New detectors for Run II

- Run I veto detectors VZERO

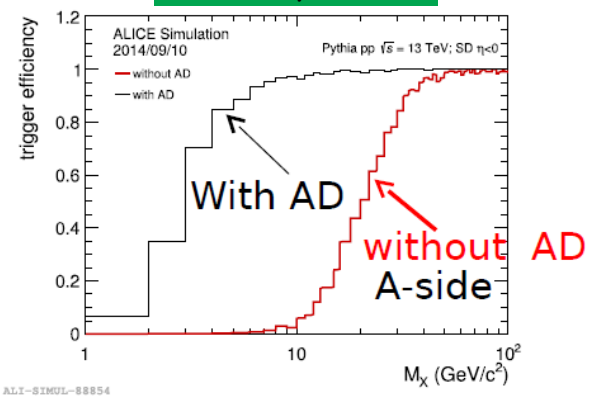



- Run II new detectors ADA, ADC: (in addition to VZERO)




- Scintillation det. ADA

$4.8 < \eta < 6.3$




accept. diffr. masses $M_X$

- Detectors ADC, ADC:
  - extend accept. to lower masses in single/double diffractive dissociation in pp-collisions
  - improve exclusivity condition in pPb and PbPb collisions
  - rejection of beam-gas events
  - ADA/ADC det. taking data

# Plans for Run II

- Run II has officially started !
  First stable proton beams at $\sqrt{s} = 13$ TeV declared on June 3.
- Run II expectations:
  - pp-collisions at $\sqrt{s} = 13$ TeV ( maybe higher later in the run), 75-100 fb$^{-1}$ delivered to ATLAS and CMS
  - Pb-Pb at $\sqrt{s} = 5.1$ TeV, 1 nb$^{-1}$
  - p-Pb, $\sqrt{s}$ under discussion:
    - 5.1 TeV (same $\sqrt{s}$ as in PbPb)
    - $\sim$ 8 TeV ( max. $\sqrt{s}$ available)

# Summary and outlook

- a wealth of Run I data available from ALICE collaboration
  - photon-hadron collisions
    - $J/\psi$ production in PbPb collisions at midrapidity
    - $\psi$(2S) production in PbPb collisions at midrapidity
    - $\rho$ production in PbPb collisions at midrapidity
    - $J/\psi$ production in PbPb collisions at forward rapidity
    - $J/\psi$ production in pPb collisions at forward rapidity
  - photon-photon collisions
    - $\gamma\gamma \rightarrow e^+e^-$ in PbPb at midrapidity
- new detector system ADA, ADC for improved pseudorapidity coverage in Run II