# UPC results from ALICE

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# Overview

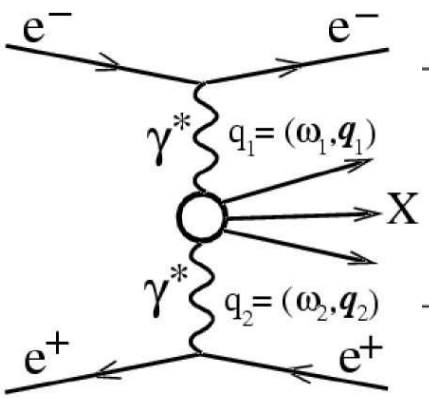
- Introduction
- J/Ψ cross-section measurements in p-Pb
- Ultra-peripheral γγ -> $e^+e^-$ in Pb-Pb

## Motivation

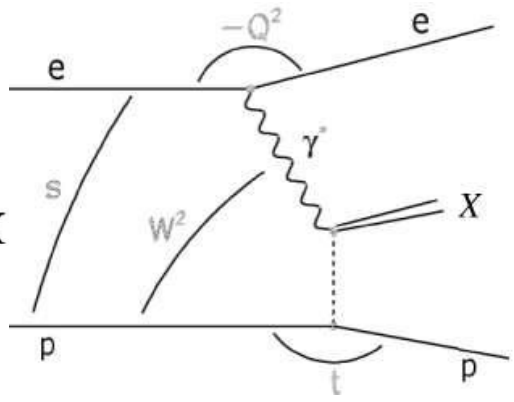
- There is an intense photon field around Pb ions
- This allows one to use the LHC as a γ-Pb and γ-p collider
- The accessible $W_{\gamma p}$ energy range probes part of the $W_{\gamma p}$ energy range foreseen for the LHeC

# e-p vs. UPC p-Pb and Pb-Pb Collisions

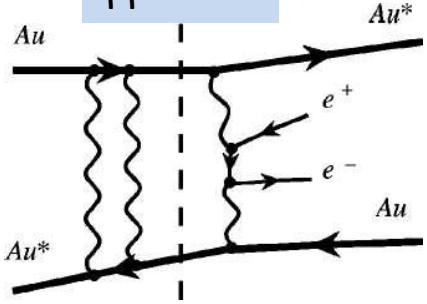
γγ in e+e-



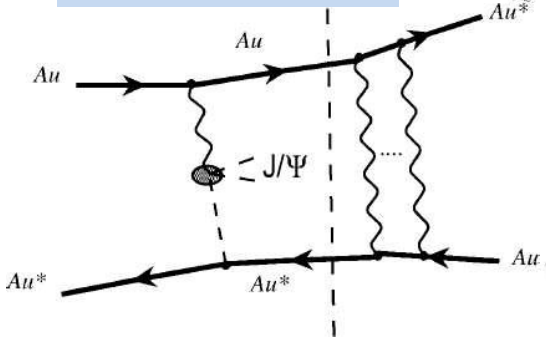

γp in ep

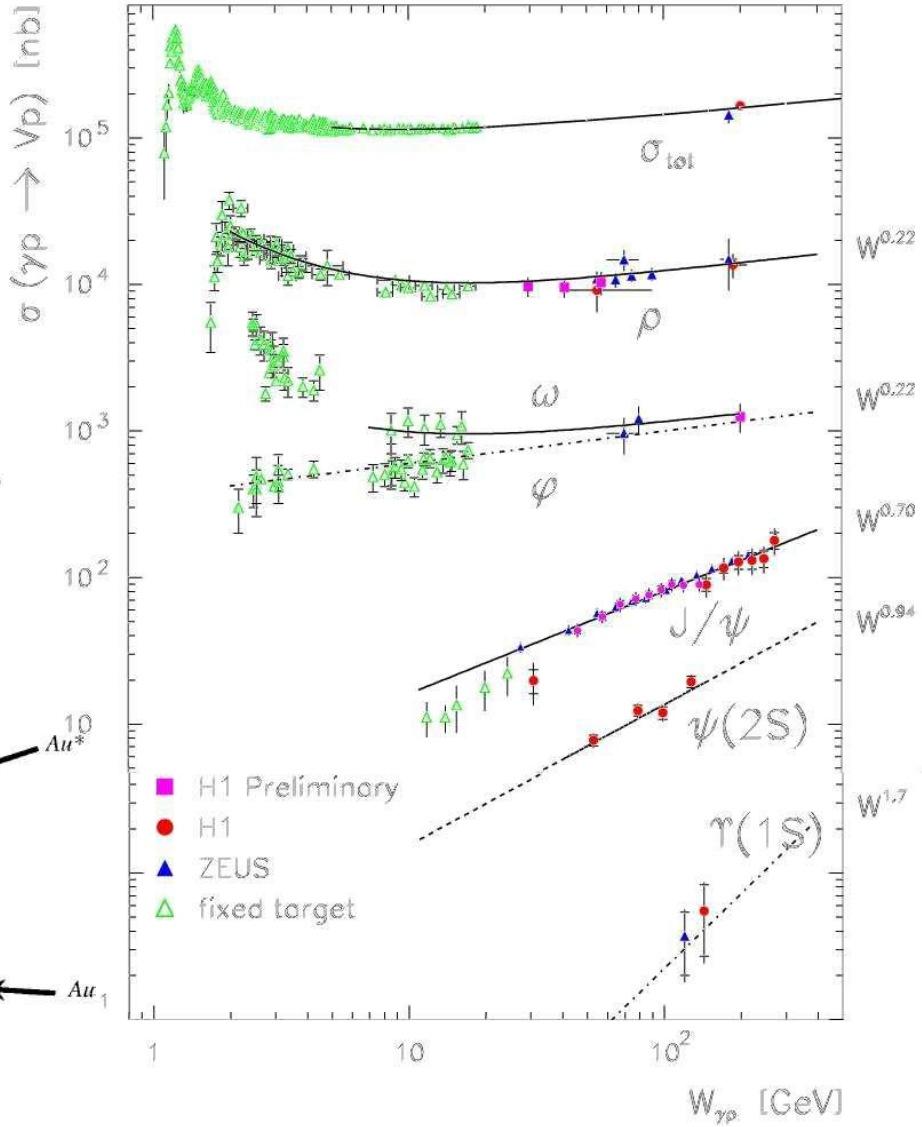



γγ in AA




γ-nucleus in AA



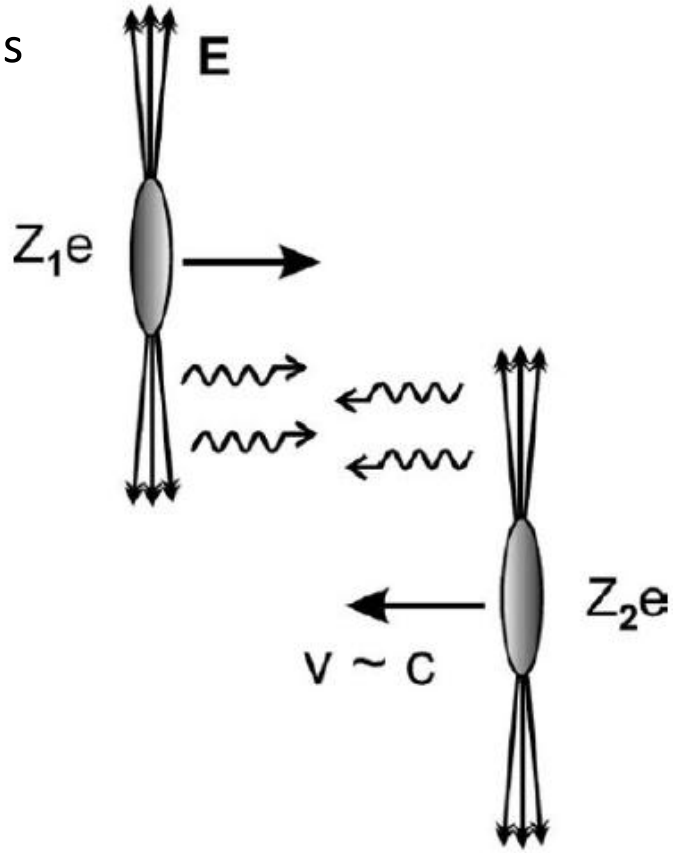



# Ultra-peripheral collisions (pA and AA)

- Ultra-peripheral collisions (UPC): impact parameter $b > R_1+R_2$
  - Hadronic interactions are strongly suppressed
  - Electro-magnetic interactions dominant
- Exclusive UPC interactions:
  - Clean events which allow one to study QCD/QED processes
  - Photon-nucleus/photon-proton: charmonium production, $\rho^0 \rightarrow \pi^+\pi^-$, …
  - Photon-photon: $\gamma\gamma \rightarrow$ lepton pairs
- Strong electro-magnetic field around ions:
  - number of photons $\approx Z^2$ in AA ($\approx Z$ in pA)
- J/Psi: photons probe the color sub-structure of nucleons
  - Allows one to study the gluon-distribution $g(x; q^2)$ in the Pb-Pb system
  - Accessible partonic momentum fractions $x \approx 10^{-3}$–$10^{-5}$
  - Gluon shadowing, saturation
- $\gamma\gamma \rightarrow$ lepton pairs: QED process
  - higher-order corrections are difficult to compute; but can be constrained by measurements

# Ultra-peripheral collisions

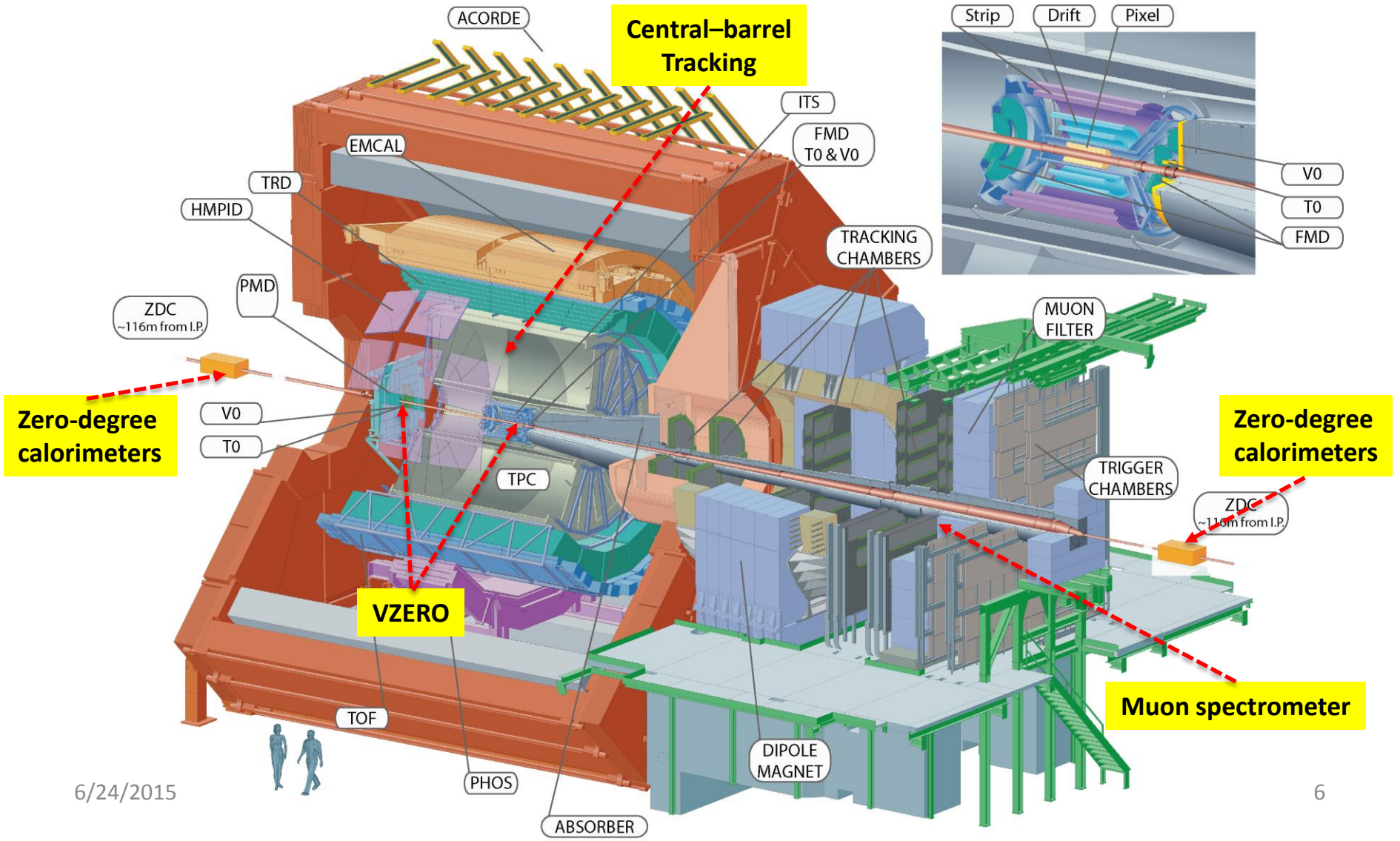
- Coherent
  - Photon couples coherently to all the nucleons
  - $\langle p_T \rangle \approx 60$ MeV/c
  - Target nucleus normally[a] does not break up
- Incoherent
  - Photon couples to a part of the nucleus
  - $\langle p_T \rangle \approx 500$ MeV/c
  - Target nucleus normally[b] does break up
- p-Pb collisions
  - Photon from the Pb ion interacts with p
  - Flux of virtual photons of Pb enhanced by a factor of Z relative to pp






a) Coherent – ≈20% breakup probability
b) Incoherent– ≈80% breakup probability

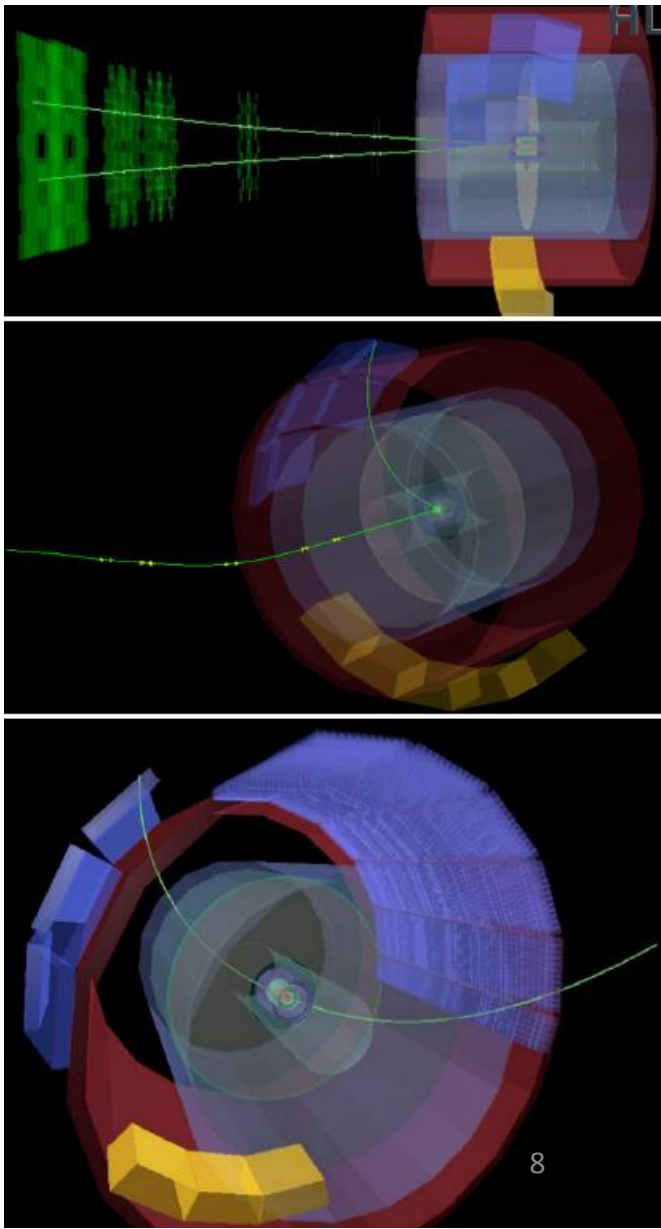
# The ALICE detector



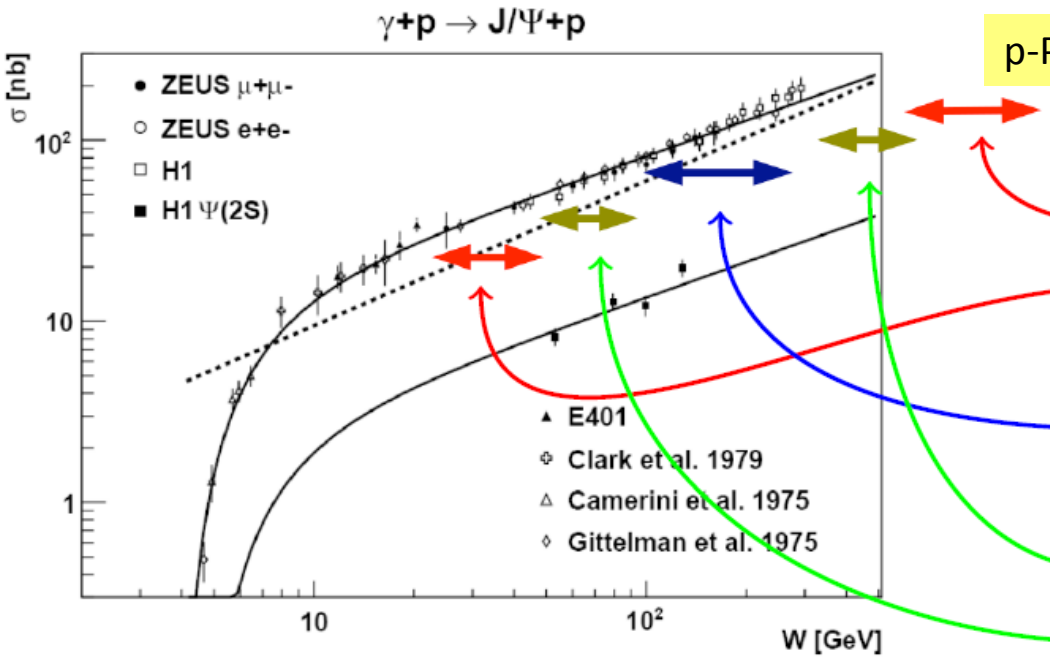
# UPC J/Psi measurements

# ALICE Configurations for UPC J/Ψ measurements

- Forward (Pb-Pb and p-Pb)
  - Two tracks in the muon arm
  - Rapidity of J/Ψ: $2.5 < y < 4$
- Semi-forward (p-Pb)
  - One track in the muon arm, one track in the central barrel
  - Rapidity of J/Ψ : $1.2 < y < 2.7$
- Mid-rapidity (Pb-Pb and p-Pb)
  - Two tracks in the central barrel ($\mu^+\mu^-$ or $e^+e^-$)
  - Rapidity of J/Ψ: $|y| < 0.9$



# J/Ψ measurements in p-Pb




H1: A. Aktas et al. Eur.Phys. J.C46:585-603,2006
ZEUS: S. Chekanov et al., Nucl. Phys. B695 (2004) 3.

p-Pb: **no ambiguity where the photon comes from**

- forward rapidity
  - Pb-p: $577 < W_{\gamma p} < 492$ GeV
  - p-Pb: $21 < W_{\gamma p} < 45$ GeV
- central rapidity
  - p-Pb,Pb-p: $100 < W_{\gamma p} < 250$ GeV
- semi-forward rapidity
  - Pb-p: $287 < W_{\gamma p} < 549$ GeV
  - p-Pb: $41 < W_{\gamma p} < 86$ GeV

- HERA $W_{\gamma p}$ range extended by factor ≈ 3
- Lower energy range of the HERA experiments covered
- A part of the LHeC $W_{\gamma p}$ range is accessible
- **Allows one to study saturation**

# J/Ψ measurements in p-Pb

UPC Trigger in p-Pb (Proton $\rightarrow$ muon arm)

- Two unlike-sign tracks in the muon spectrometer with $p_T > 0.5$ GeV/$c$ $(-4.0 < \eta < -2.7)$
- Empty VZERO-A beam-beam trigger $(2.8 < \eta < 5.1)$

UPC Trigger in Pb-p (Pb $\rightarrow$ muon arm)

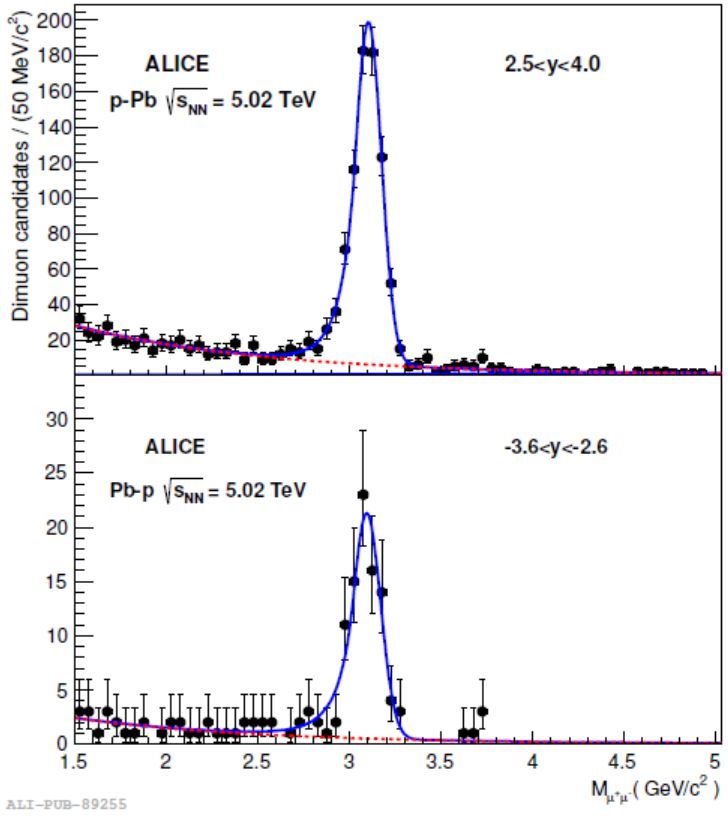
- Two unlike-sign tracks in the muon spectrometer with $p_T > 0.5$ GeV/$c$
- Empty VZERO-A beam-beam and beam-gas trigger
- At least one hit in VZERO-C at beam-beam time $(-3.7 < \eta < -1.7)$

Event Selection

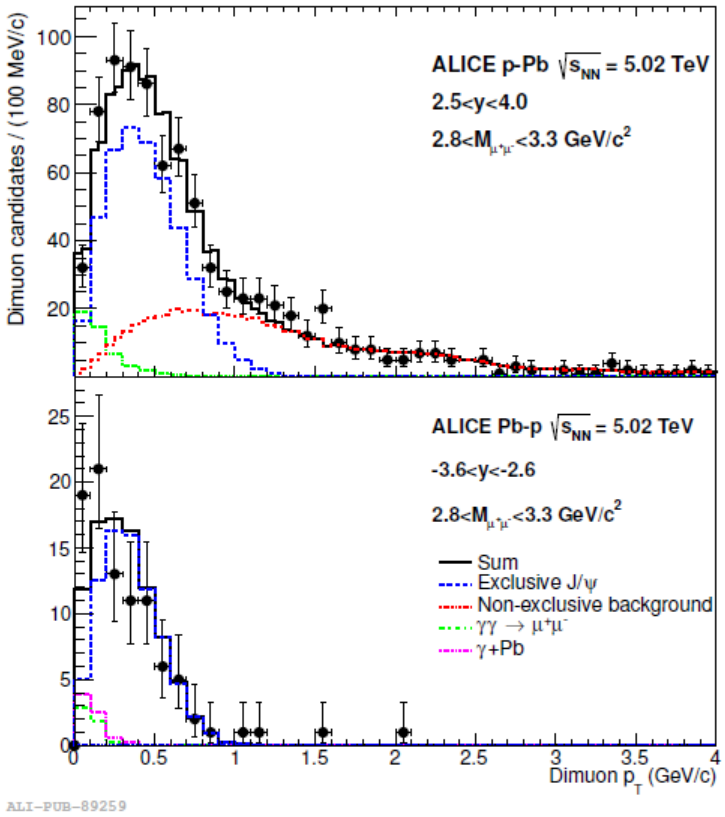
- UPC trigger + offline VZERO timing cut + veto on ZDC (neutron,proton)
- requiring two good unlike-sign muon tracks with $-4.0 < \eta_{1,2} < -2.5$ (p-Pb), $-3.7 < \eta_{1,2} < -2.5$ (Pb-p)
- di-muon rapidity: $2.6 < y < 4.0$ (p-Pb), $-3.6 < y < -2.6$ (Pb-p)

# J/Ψ measurements in p-Pb

Phys. Rev. Lett. 113 (2014) 232504




Phys. Rev. Lett. 113 (2014) 232504




Fit function:
exponential + Crystal-Ball

p-Pb: STARLIGHT slope changed from default
$b = 4.0\ \text{GeV}^{-2}$ to $b = 6.7\ \text{GeV}^{-2}$

Templates fitted to $p_T(\mu^+\mu^-)$:

$\underbrace{\text{excl. J}/\Psi, \gamma\gamma \rightarrow \mu^+\mu^-, \gamma+\text{Pb}}_{\text{STARLIGHT MC, } \gamma\gamma \text{ constr. from data}}, \underbrace{\text{non excl. bkgd}}_{\text{from data}}$

STARLIGHT MC; S.R. Klein, J. Nystrand, Phys. Rev. C 60 (1999) 014903

# γγ -> $\mu^+\mu^-$ in p-Pb

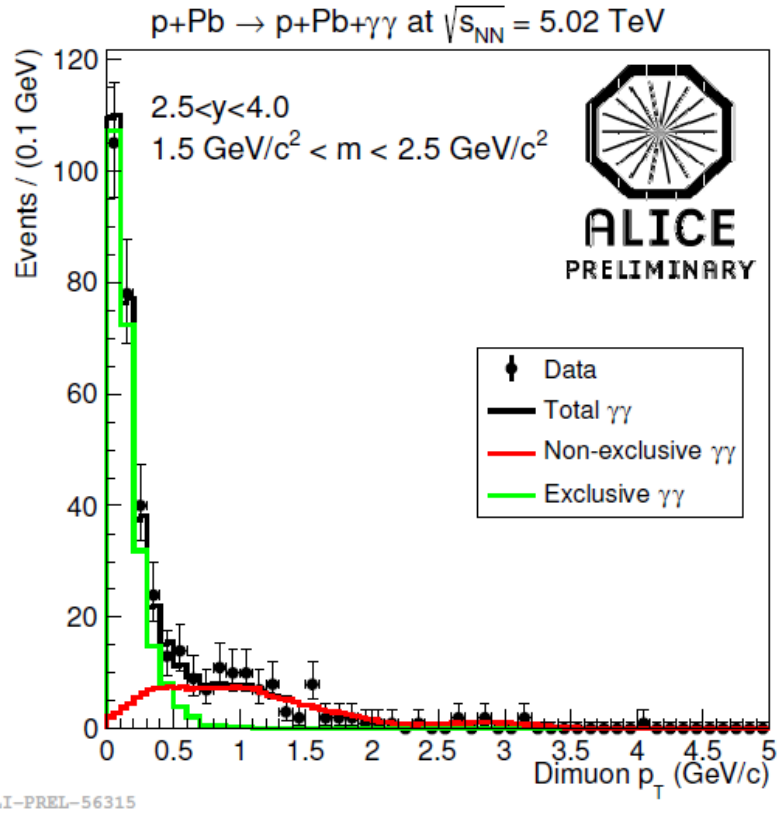
Comparison with STARLIGHT as a cross check

- Same event selection as for J/ψ
- $1.5 < M_{\mu^+\mu^-} < 2.5$
- Templates fitted to $p_T(\mu^+\mu^-)$:
  $\underbrace{\text{excl. } \gamma\gamma \to \mu^+\mu^-}_{\text{STARLIGHTMC}}$, $\underbrace{\text{non excl. bkgd}}_{\text{from data}}$
- measured cross section

$$\sigma(\gamma\gamma \to \mu^+\mu^-) = 1.76 \pm 0.12(\text{stat.})\ ^{+0.16}_{-0.15}(\text{syst.})\ \mu\text{b}$$

- STARLIGHT prediction: 1.8 $\mu$b

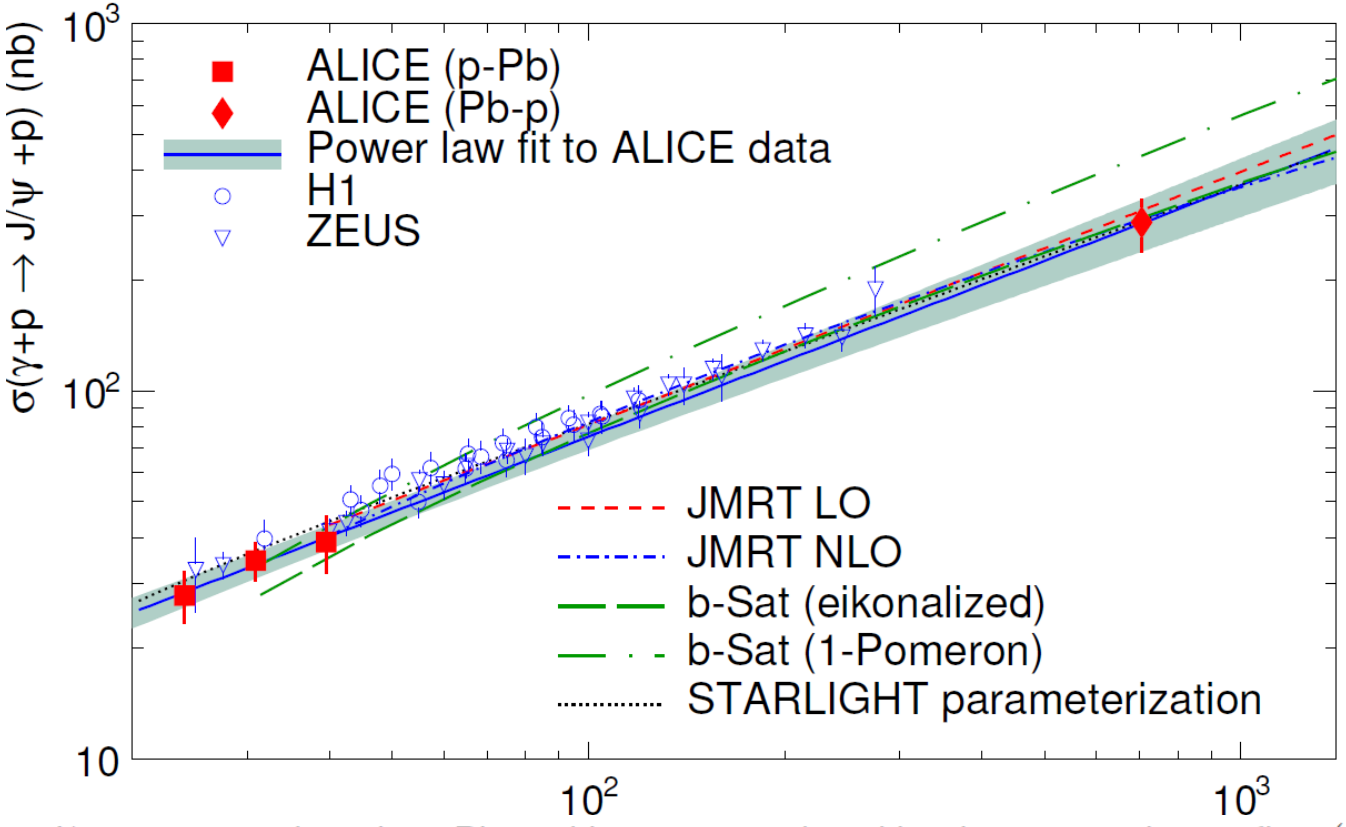
Phys. Rev. Lett. 113 (2014) 232504




The cross section predicted by STARLIGHT agrees with our measurement within statistical errors

# J/Ψ measurements in p-Pb

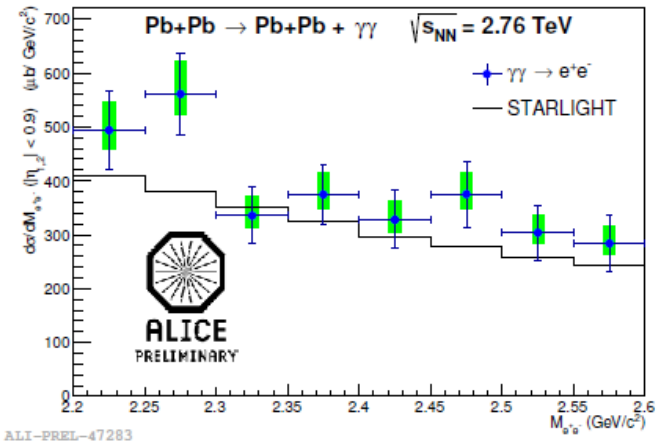
Phys. Rev. Lett. 113 (2014) 232504

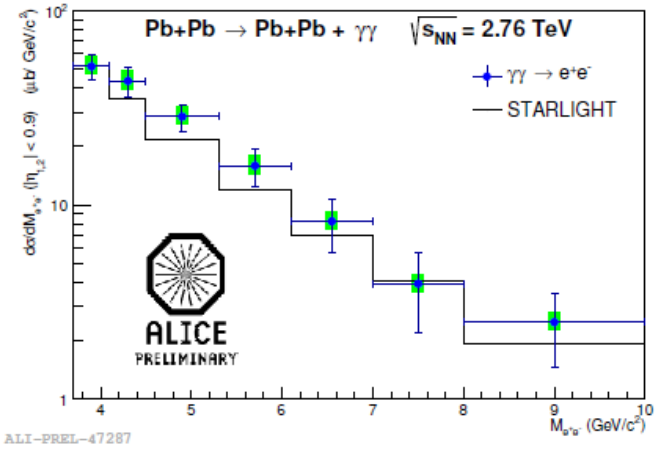


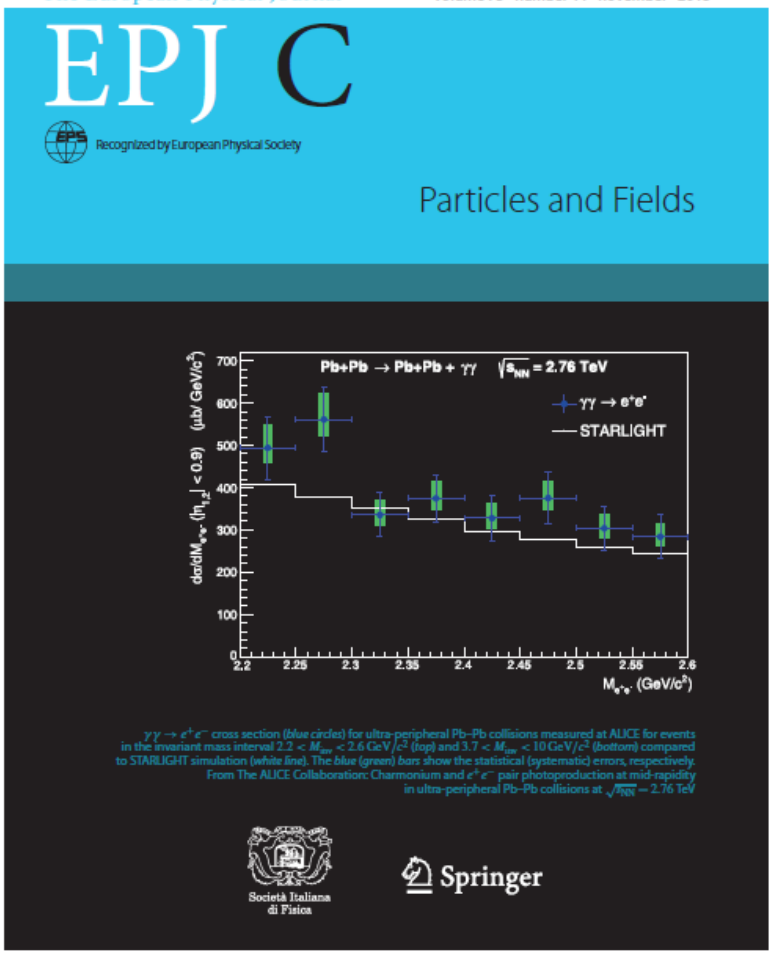

- J/Ψ cross sections in p-Pb and in $\gamma$-p are related by the mean photon flux $\left(\frac{dN}{dk}\right)$:
  $\frac{d\sigma}{dy}(p + Pb \to p + Pb + J/\Psi) = k\frac{dN}{dk}\sigma(\gamma + p \to J/\Psi)$, ($k$ photon energy).
- The weighted average photon flux is taken from STARLIGHT;
  the error is propagated to $\sigma(\gamma + p)$ as an additional theoretical error

# UPC γγ -> e+e- in Pb-Pb

# Two-photon production of electron pairs in Pb-Pb – ALICE 2011 data



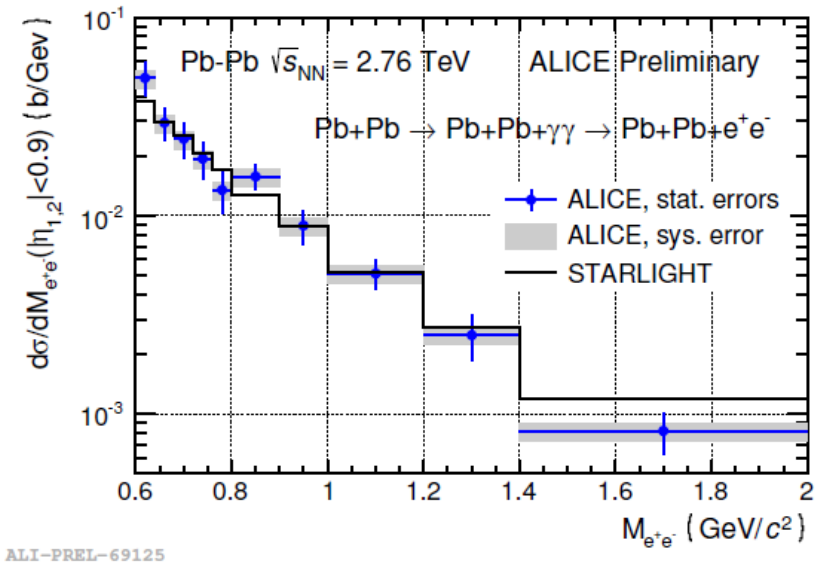

Topology cut in trigger:

$M_{e^+e^-} > 2.2\ \mathrm{GeV}/c^2$

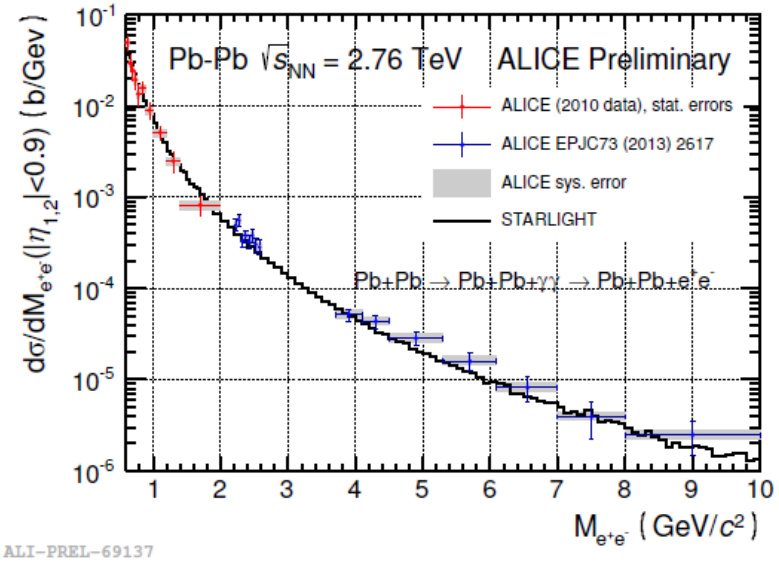
ALICE Collaboration, EPJC 73 (2013) 2617 (Central Barrel).

# Two-photon production of electron pairs in Pb-Pb – ALICE 2010 data

With 2010 data this range can be extended down to 0.6 GeV/$c^2$:



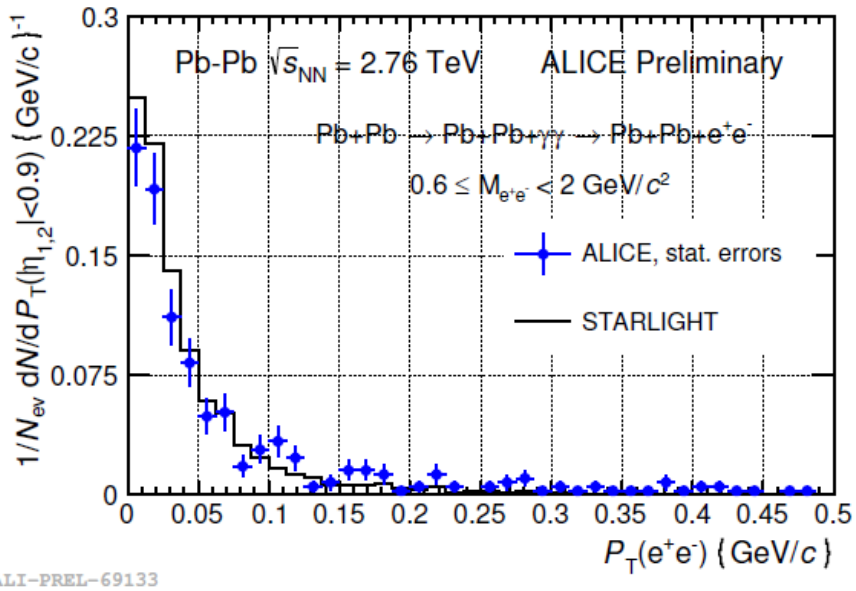

And the results can be combined to cover the range $M_{e^+e^-} \in [0.6, 10]$ GeV/$c^2$:




| | Data | STARLIGHT |
|---|---|---|
| $\sigma\left(M_{e^+e^-} \in [0.6, 2.0]\,\mathrm{GeV}/c^2;\ \lvert\eta_{1,2}\rvert < 0.9\right)$: | $\left(9.8 \pm 0.6(\mathrm{stat.})\,^{+0.9}_{-1.2}(\mathrm{sys.})\right)$ mb | 9.7 mb |
| $\sigma\left(M_{e^+e^-} \in [2.2, 2.6]\,\mathrm{GeV}/c^2;\ \lvert\eta_{1,2}\rvert < 0.9\right)$: | $\left(154 \pm 11(\mathrm{stat.})\,^{+17}_{-11}(\mathrm{sys.})\right)$ mb | 128 $\mu$b |
| $\sigma\left(M_{e^+e^-} \in [3.7, 10.0]\,\mathrm{GeV}/c^2;\ \lvert\eta_{1,2}\rvert < 0.9\right)$: | $\left(91 \pm 10(\mathrm{stat.})\,^{+11}_{-8}(\mathrm{sys.})\right)$ mb | 77 $\mu$b |

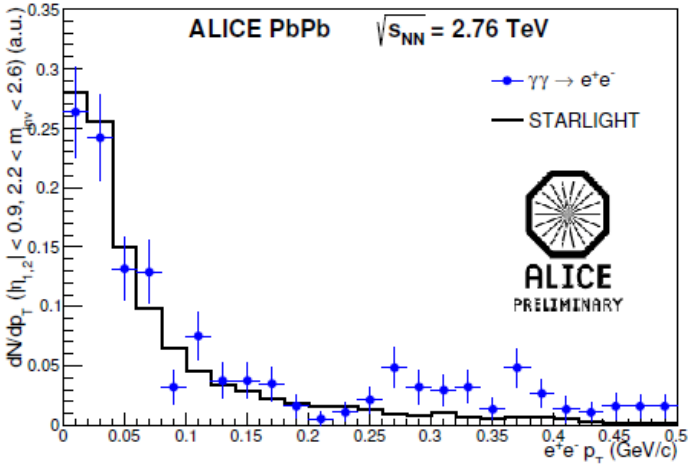
# Two-photon production of electron pairs in Pb-Pb

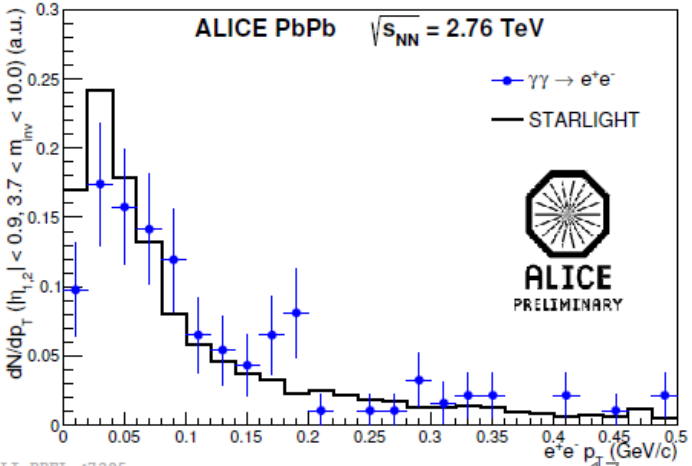
ALICE 2010 data




ALI-PREL-69133

ALICE EPJC 73 (2013) 2617




ALI-PREL-47295

- The transverse-momentum distribution is well -described by the STARLIGHT Monte-Carlo simulation for $0.6 \leq M_{e^+e^-} < 10.0$ GeV/$c^2$.
  - Left: 2010 Pb-Pb data
  - Right: 2011 Pb-Pb data (EPJC paper)
- Broadening of pair-$p_T$ with increasing $M_{e^+e^-}$

# Further ALICE UPC Results

- UPC J/Ψ -> $\mu^+\mu^-$ in Pb-Pb (forward rapidity)

  Physics Lett. B 718, (2013) 1273
- UPC J/Ψ and γγ -> $e^+e^-$ in Pb-Pb (mid-rapidity)

  J Eur. Phys. J. C 73 (2013) 2617
- Coherent $\rho^0$ -> $\pi^+\pi^-$ in Pb-Pb (mid-rapidity)

  http://arxiv.org/abs/1503.09177
- Psi(2s) -> J/Ψ $\pi^+\pi^-$, $e^+e^-$, $\mu^+\mu^-$ in Pb-Pb (mid-rapidity)
  to be published

## Work in progress:

- UPC $f_2$ -> $\pi^+\pi^-$ (γγ-process) in Pb-Pb (mid-rapidity)
- UPC $\rho^0$ and ρ'-production on p-Pb

# LHC Run2 Outlook

ALICE

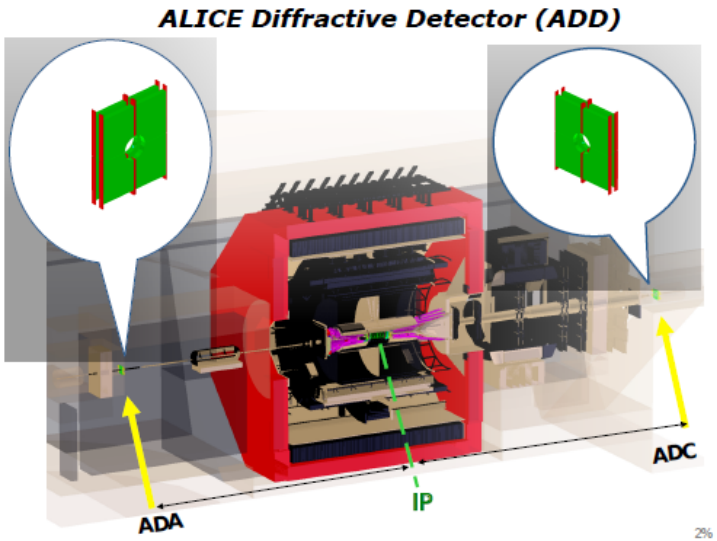
## Pb-Pb in LHC Run 2 ($\mathcal{L}^{\text{int.}} \approx 1\text{nb}^{-1}$):

- We expect $\times 20$–$\times 50$ more UPC events than in Run 1
- High precision measurements of J/$\Psi$, $\Psi(2S)$ photo-production
- Detailed $p_T$ and rapidity distributions
- Exploratory studies of $\Upsilon$ photo-production possible
- Two-photon production of $\eta_c$ appears feasible
- Extended $\gamma$p energy range

| | A-side | C-side |
|---|---|---|
| VZERO | $-3.7 < \eta < -1.7$ | $2.8 < \eta < 5.1$ |
| ADD (approx. $\eta$ range) | $-7.5 < \eta < -5.5$ | $5.5 < \eta < 7.5$ |

## New forward detector ADD

- Two layers of scintillators on each side of the interaction point
- Extension of the veto outside central rapidity
- Reduction of non-exclusive background



# Summary and Conclusions

- ALICE has measured J/Ψ cross-sections in UPC p-Pb collisions
  - Can be related to γp cross sections using the known photon-flux
  - Different combination of ALICE detectors allow to probe a wide range in γp energies, probing part of the range accessible by the LHeC
  - No evidence for saturation found
- UPC γγ -> $e^+e^-$ in Pb-Pb
  - Differential cross section measured from 0.6 – 10 GeV/$c^2$
  - Sets limits for higher-order correction from perturbative QED
- Outlook on LHC RUN2
  - Increased statistics will allow to measure J/Ψ $p_T$ and rapidity dependence
  - The new AD detector is already taking pp data -> extends the rapidity gap
  - Expected new results include:
    UPC phi production, γγ -> $f_2$ -> $\pi^+\pi^-$, UPC Upsilon production, …