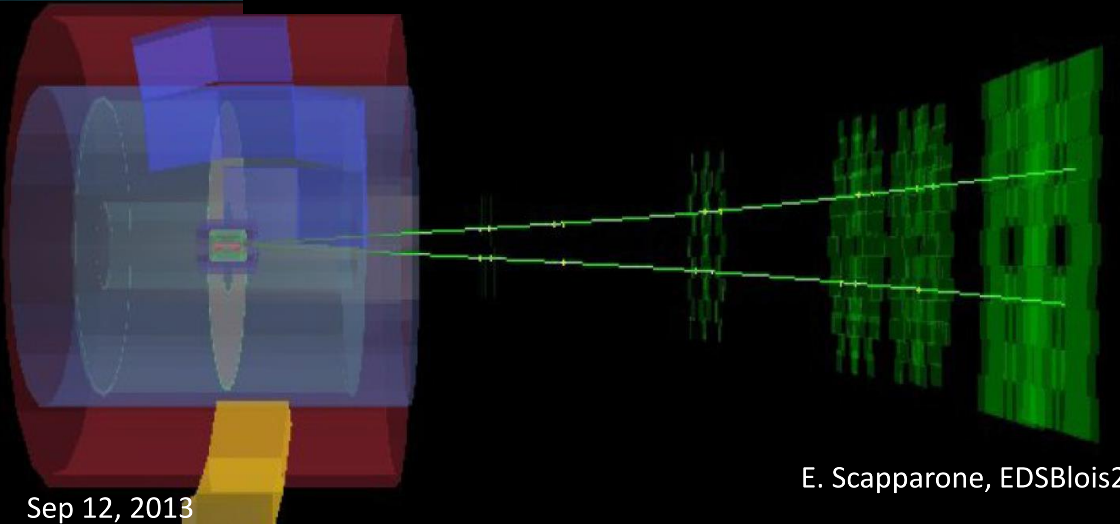
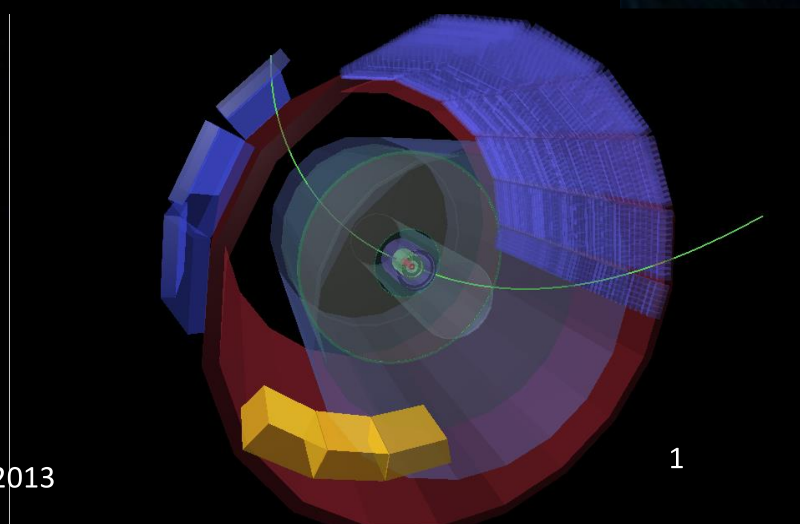
Results on ultra-peripheral interactions in Pb-Pb and p-Pb collisions in ALICE

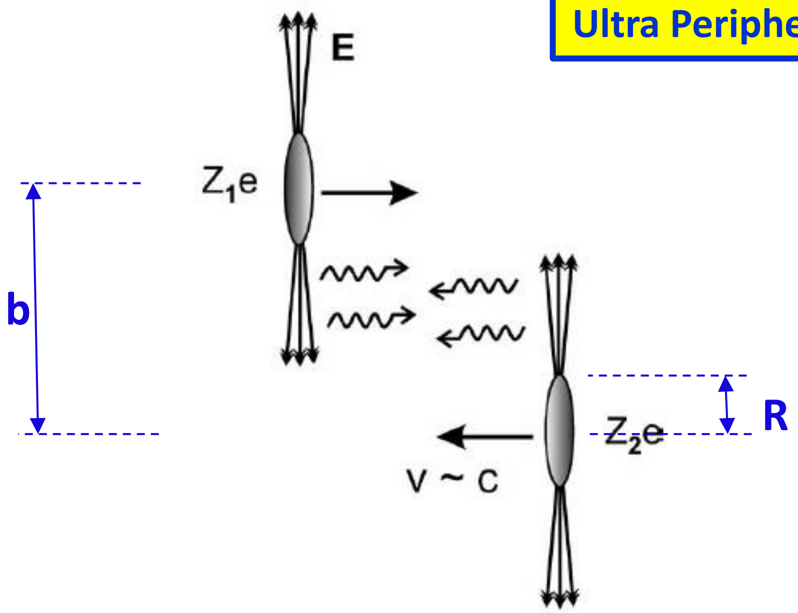
E. Scapparone on behalf of the ALICE Collaboration, EDSBlois2013, Sep 10, 2013

Light provides outstanding performance both here and at CERN …





Ultra Peripheral Collisions at LHC



EM field → photon flux
When hadronic cross section becomes negligible
(b>2R) photons can give:

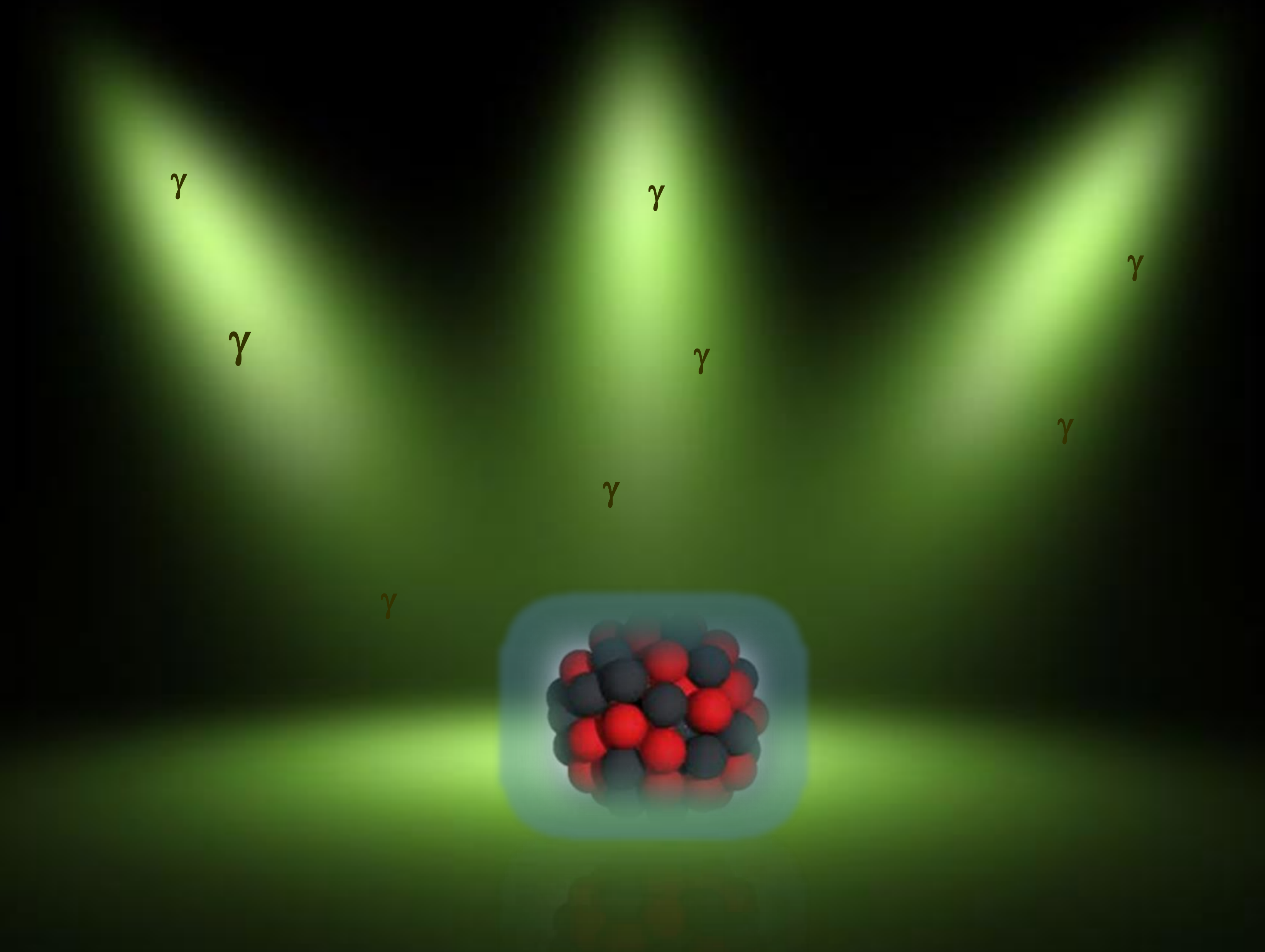
Coherent vector meson production:

- photon couples coherently to all nucleons
- $\langle p_T \rangle \sim 1/R_{Pb} \sim 60$ MeV/c
- no neutron emission in ~80% of cases

Incoherent vector meson production:

- photon couples to a single nucleon
- $\langle p_T \rangle \sim 1/R_p \sim 500$ MeV/c
- target nucleus normally breaks up

Pb-Pb collisions: shedding light on the nucleus



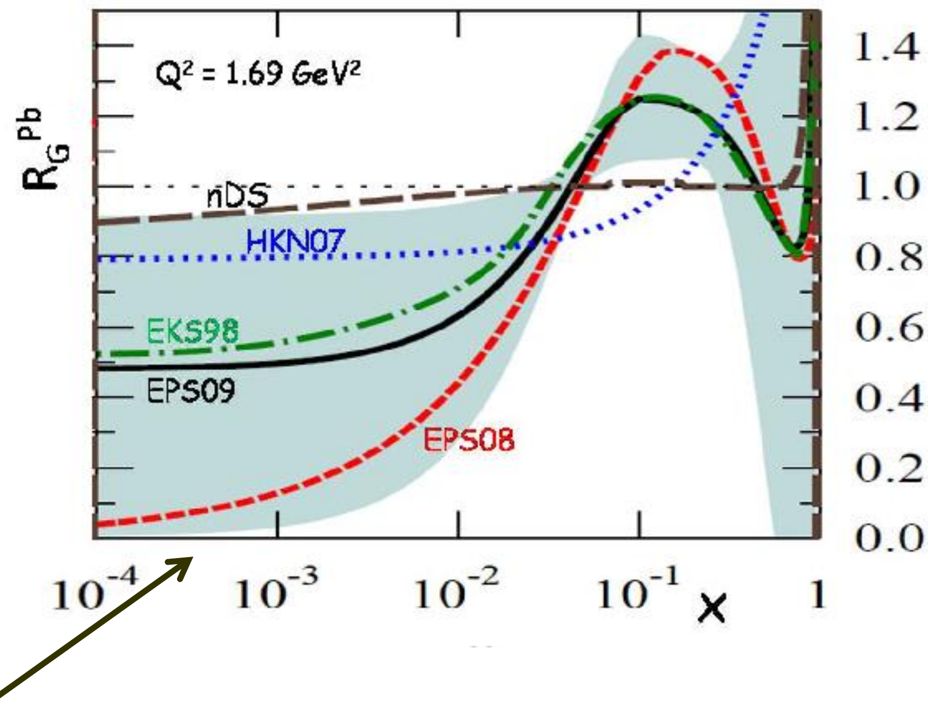
What do we expect to see ?

The main reason to shed light on the nucleus is to understand the nuclear gluon structure function.
It's not expected to behave as a simple superposition of the nucleon PDF.

$$R_g^{Pb}(x,Q^2) = \frac{G_{Pb}(x,Q^2)}{G_p(x,Q^2)}$$

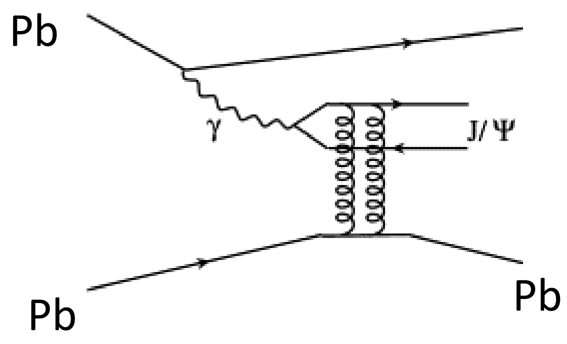
Bjorken $x \sim 10^{-2} - 10^{-5}$

accessible at LHC



Large uncertainties at small x

Why a nucleus, being hit by a γ, would unveil its gluon PDF ?



$$\frac{d\sigma_{\gamma\mathrm{Pb}\to J/\psi\mathrm{Pb}}(t=0)}{dt} = \frac{16\,\Gamma_{ee}\pi^3}{3\alpha_{em}M^5_{J/\psi}}\left[\alpha_s(Q^2)xG_{\mathrm{Pb}}(x,Q^2)\right]^2$$

$$R_g^{Pb}(x,Q^2) = \frac{G_{Pb}(x,Q^2)}{G_p\,(x,Q^2)}$$

Bjorken $x \sim 10^{-2} - 10^{-5}$

accessible at LHC

J/Ψ in Pb-Pb UPC is
a direct tool to measure
nuclear gluon shadowing

…clearly UPCs at LHC are a nice physics opportunity

This was realized time ago by several people (you may find a lot of UPC reviews in the last 10 years), but bringing it from a suggestion to a results is not trivial….

STAR gave the golden definition…..“Two tracks in an otherwise empty detector”.

→ But “2-tracks” means triggering on few hits, fighting with noise, pile-up and so on.

You can select a part of the cross section triggering on events in which the nuclei got excited (ZDC), but taking the full cross section is another business.

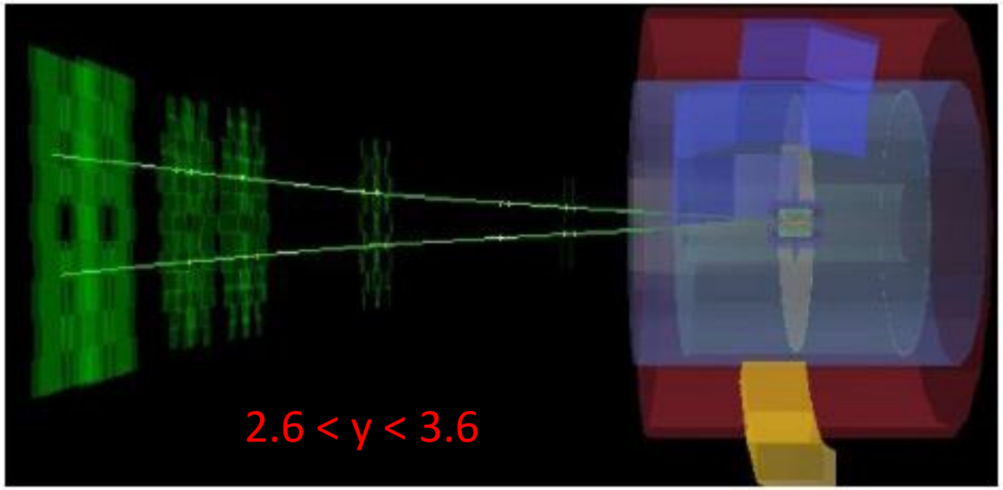
Leptons from J/Ψ decay, are soft e,μ (few GeV), usually below calorimeter threshold

ALICE is a light detector (barrel has < 1 rad length), nevertheless this is a non trivial analysis (….and you have ≤ 2 hits/layer).

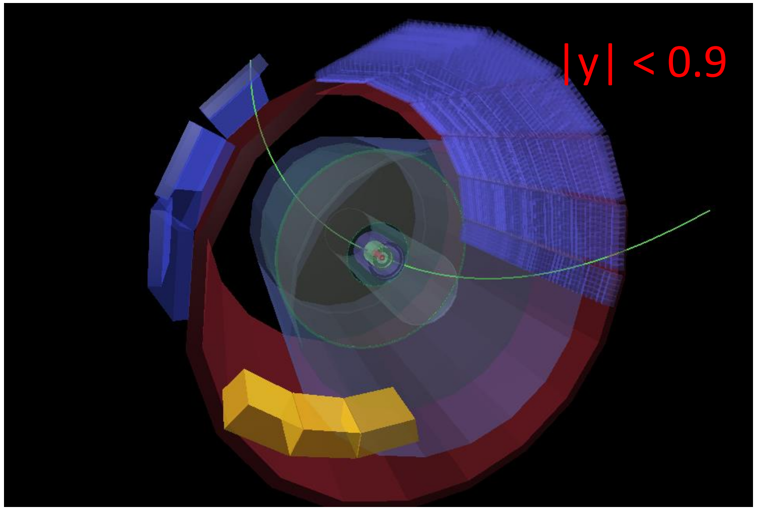
A 10^{-4} smaller (cross section x branching) wrt the hadronic cross section

Where can we look at them in ALICE ?

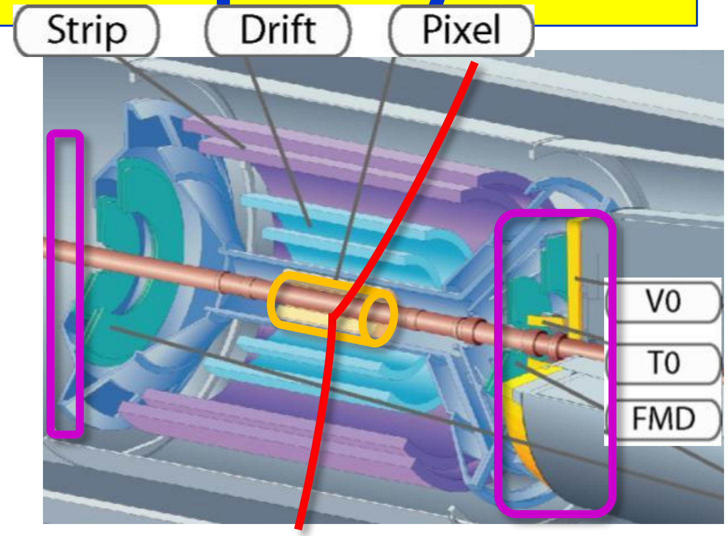
Forward rapidity



Mid-rapidity

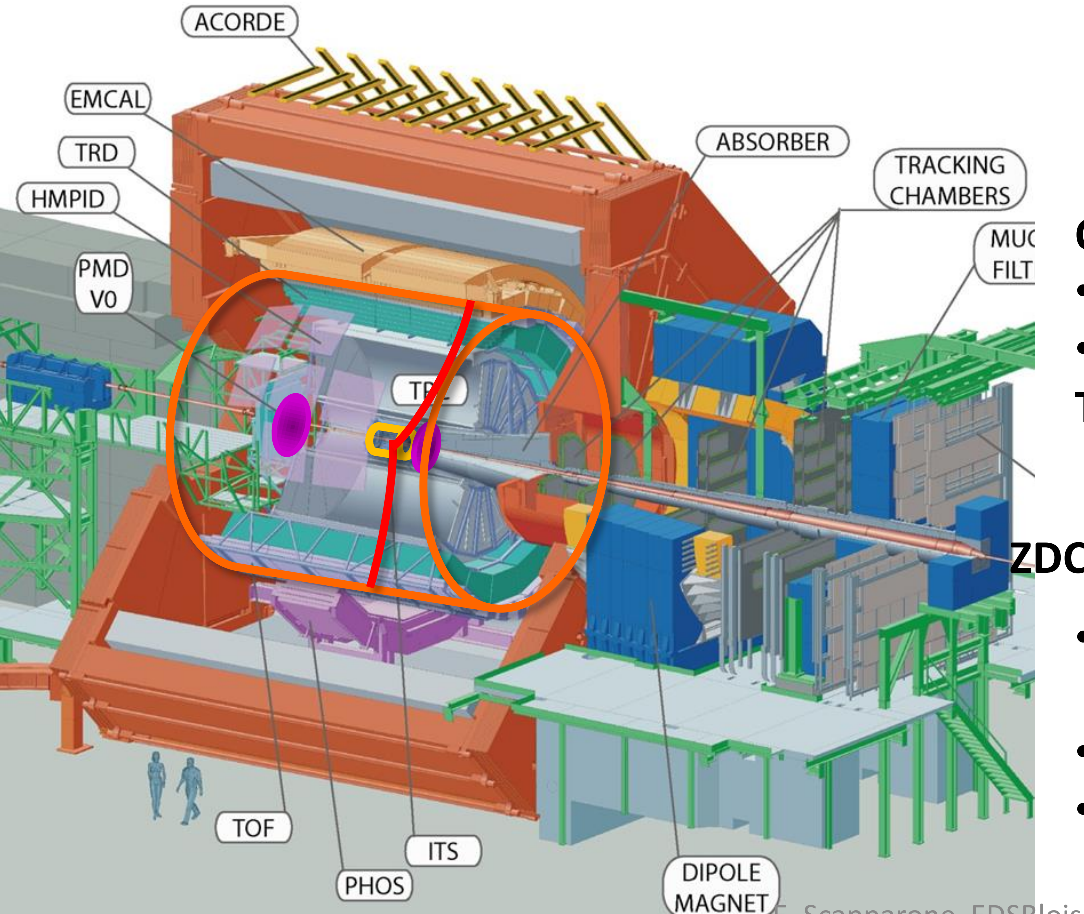


UPC J/ψ at central rapidity



UPC central barrel trigger:

- $2 \leq$ **TOF** hits ≤ 6 ($|\eta| < 0.9$)
  + back-to-back topology ($150° \leq \varphi \leq 180°$)
- ≥ 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}

Offline event selection:

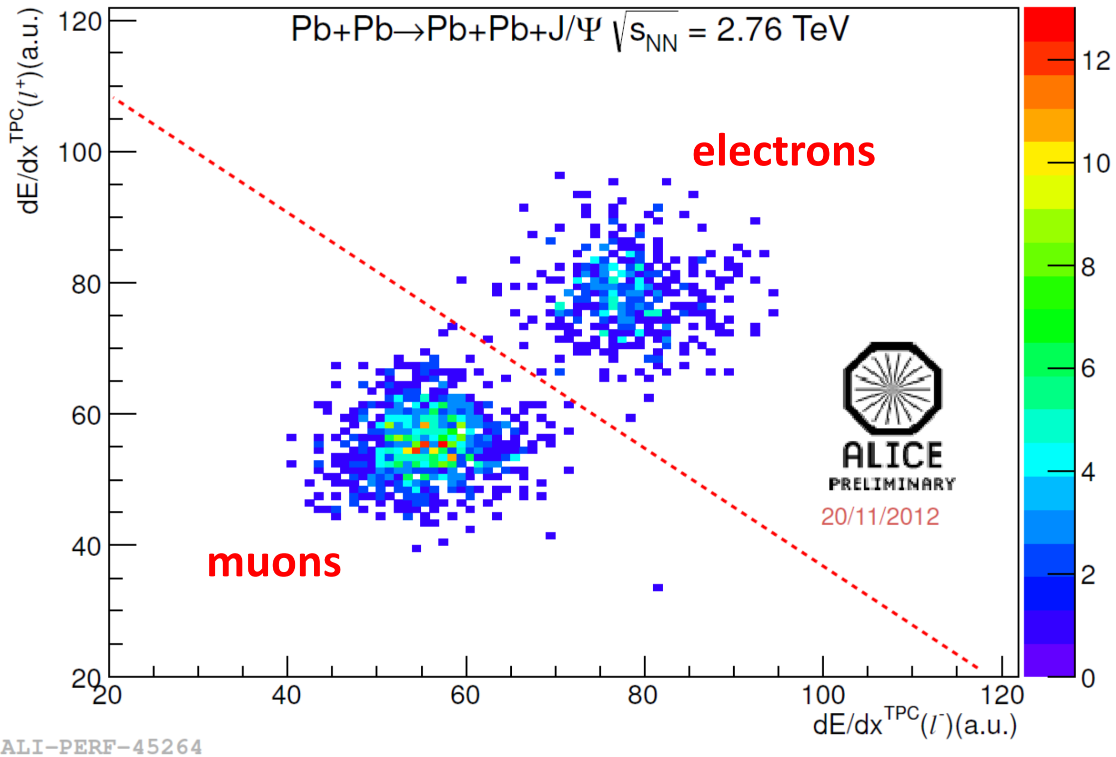
- Offline check on VZERO hits
- Hadronic rejection with ZDC

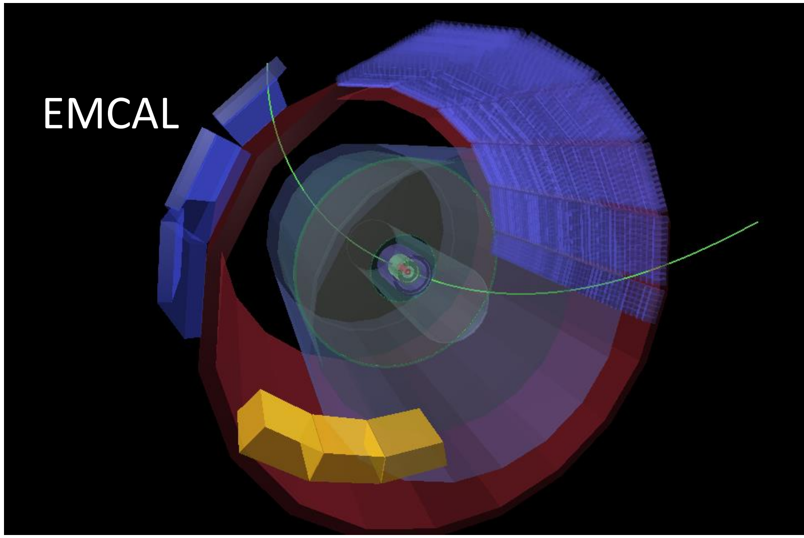
Track selection:

< 10 tracks with loose requirements ($|\eta| < 0.9$, > 50% findable TPC clusters and > 20 TPC clusters)

- Only two tracks: $|\eta| < 0.9$, with ≥ 70 TPC clusters, ≥ 1 SPD clusters
- p_T dependent DCA cut
- opposite sign dilepton
  $|y| < 0.9$, $2.2 < M_{inv} < 6$ GeV/c^2
- dE/dx in TPC compatible with e/μ

dE/dx selection in TPC

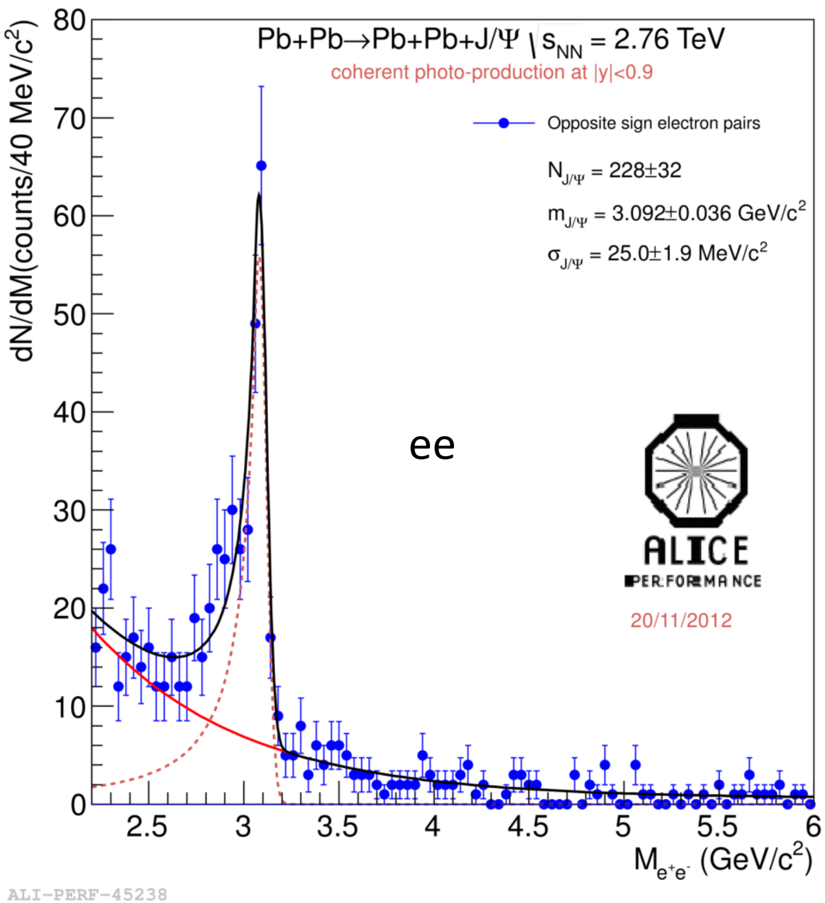


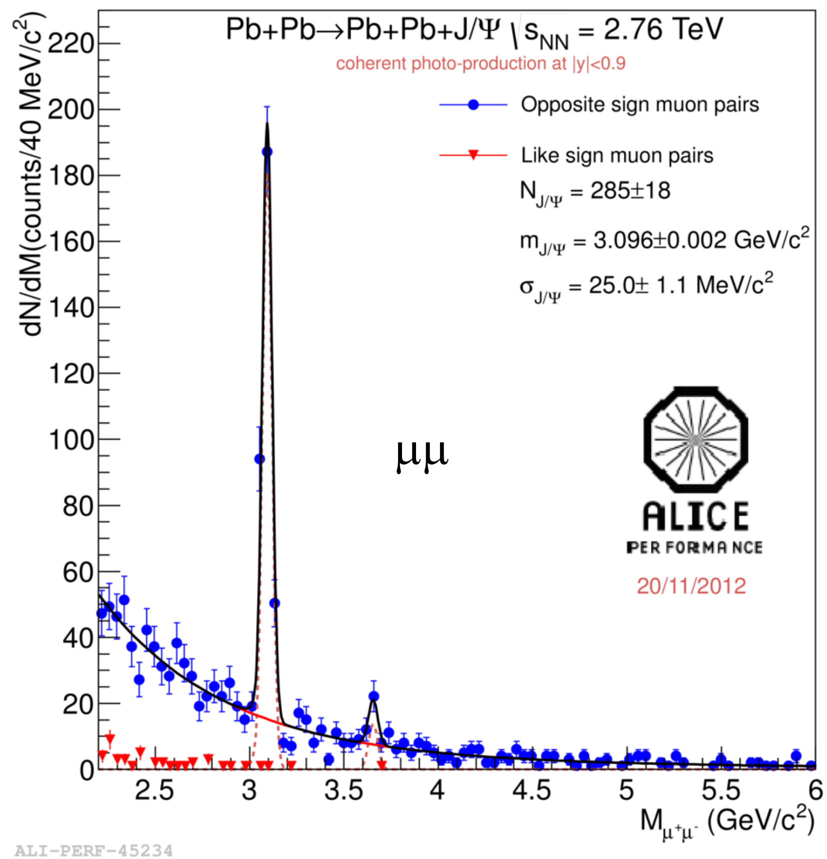


- dE/dx in TPC compatible with e/μ energy loss
- Cross-checked with E/p in EMCAL
- ±2% systematics due to e/μ separation

P.S. we cannot distinguish μ from π

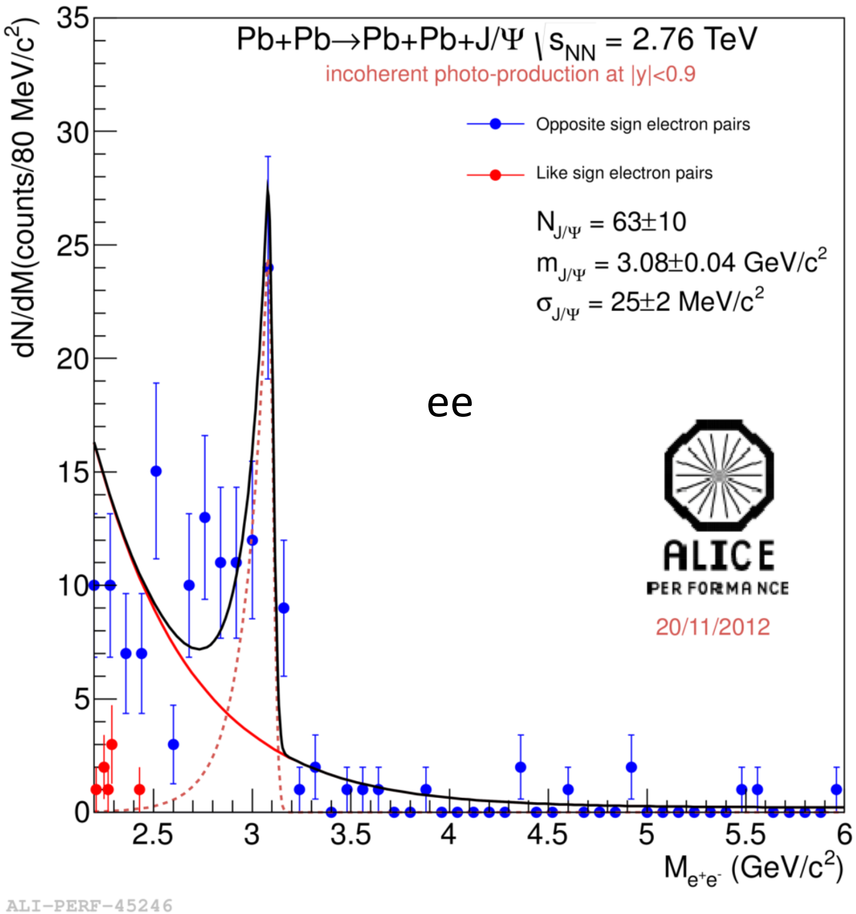
p_T < 200 MeV/c for di-muons (300 MeV/c for di-electrons) .and. < 6 neutrons in ZDC
→ Coherent enriched sample

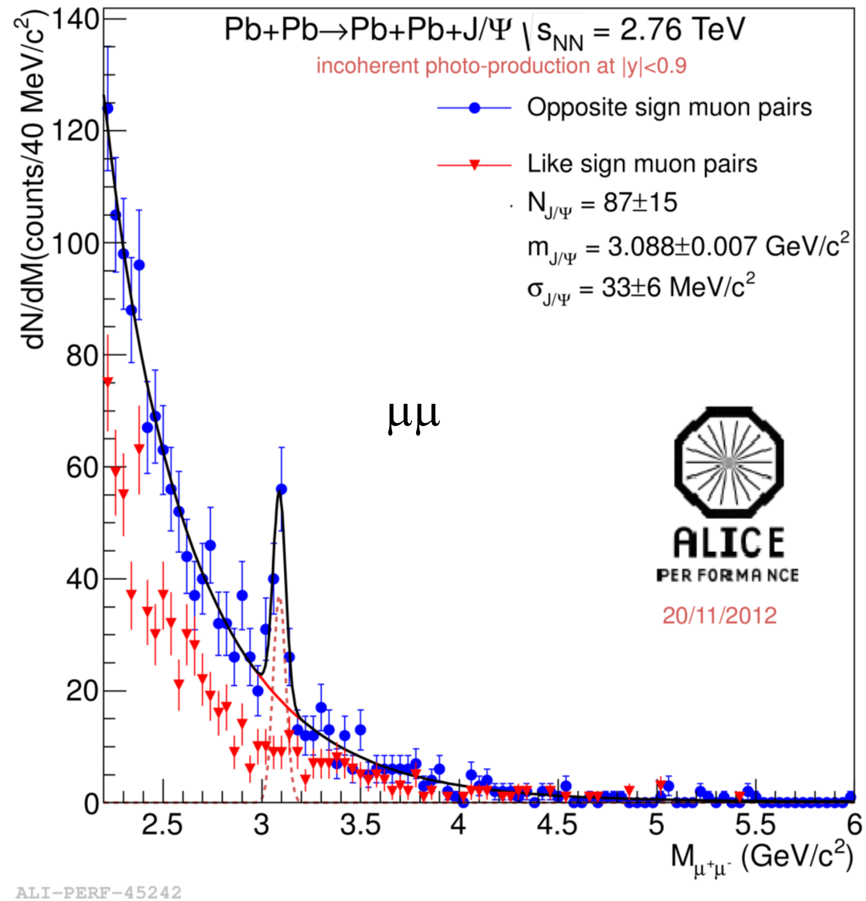




p_T > 200 MeV/c for di-muons (300 MeV/c for di-electrons)

→ Incoherent enriched sample

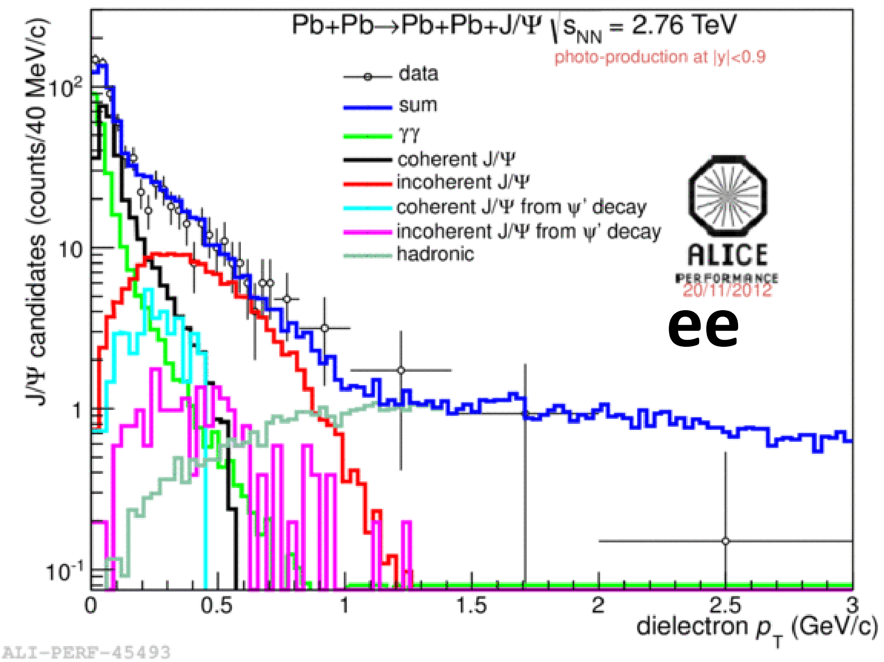


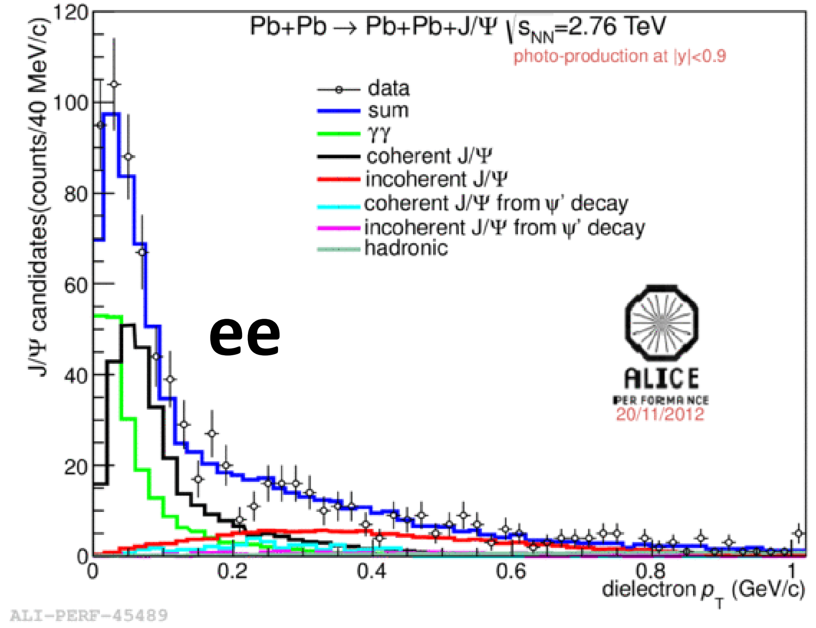


The J/Ψ peak region: 2.2 GeV/c^2 < M_{inv} < 3.2 GeV/c^2 for electron and 3.0 GeV/c^2 < M_{inv} < 3.2 GeV/c^2 for muons

Used templates:

- Ψ' contribution to (in)coherent J/Ψ → f_D;
- Incoherent J/Ψ contribution to coherent J/Ψ (and vice-versa) → f_I
- γγ → $\ell^+\ell^-$ contribution to coherent J/Ψ
- Hadronic J/Ψ;





Detailed study of the systematics including:

- **Luminosity;**
- **Acc x ε;**
- **Trigger efficiency (random sample);**
- **Trigger dead time;**
- **Signal extraction;**
- **e/μ separation;**
- **$\gamma\gamma \rightarrow$ee in addition to the J/Ψ (from the same or another Pb-Pb pair)**

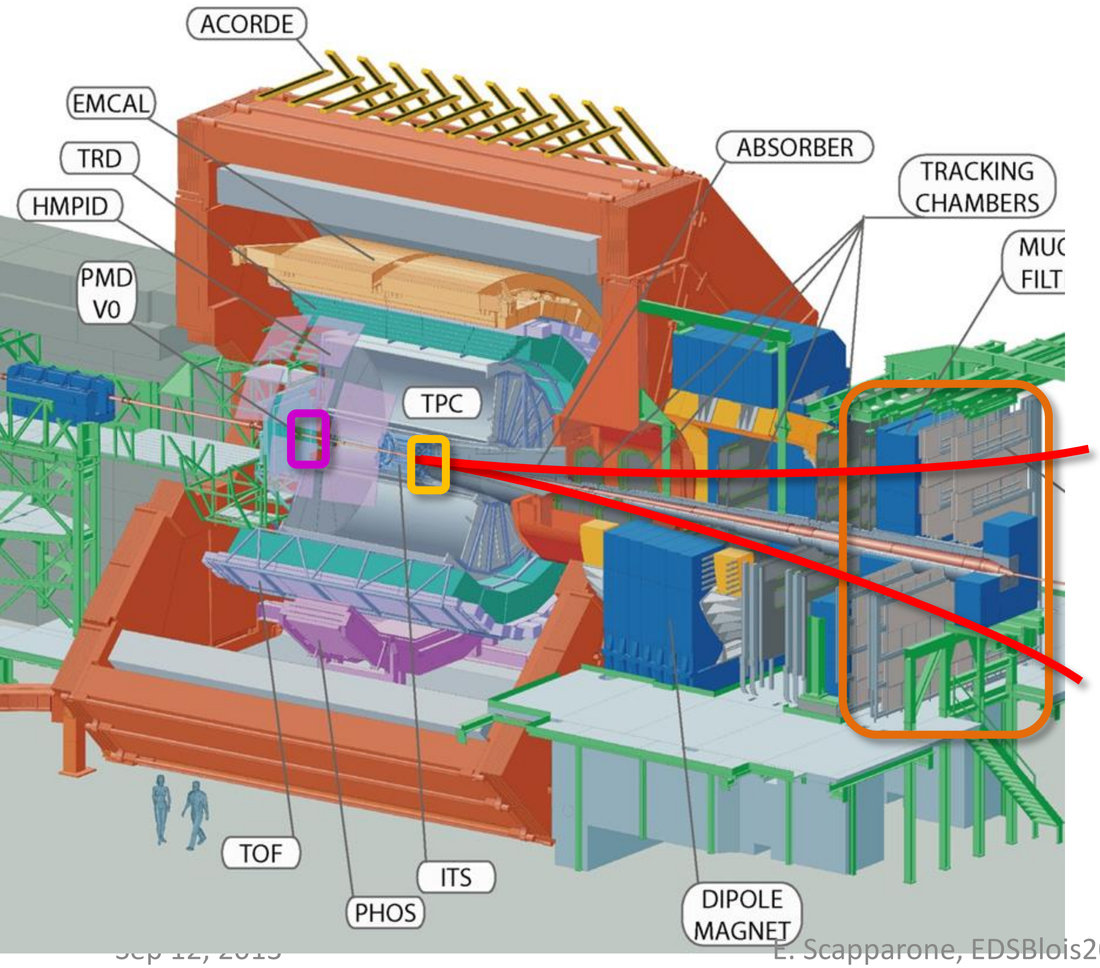
$$N_{\mathrm{J}/\psi}^{\mathrm{coh}} = \frac{N_{\mathrm{yield}}}{1 + f_I + f_D}$$

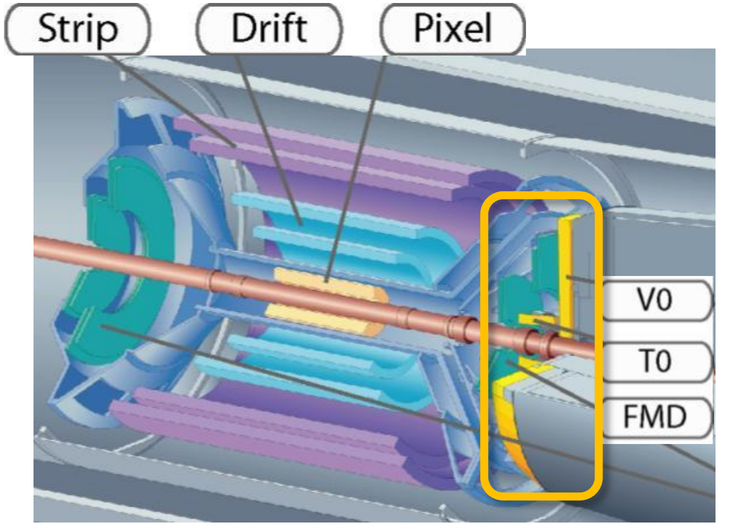
$$\frac{\mathrm{d}\sigma_{\mathrm{J}/\psi}^{\mathrm{coh}}}{\mathrm{d}y} = \frac{N_{\mathrm{J}/\psi}^{\mathrm{coh}}}{(\mathrm{Acc} \times \varepsilon)_{\mathrm{J}/\psi} \cdot BR(\mathrm{J}/\psi \rightarrow l^+l^-) \cdot \mathcal{L}_{\mathrm{int}} \cdot \Delta y}$$

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** ($2.8 < \eta < 5.1$)





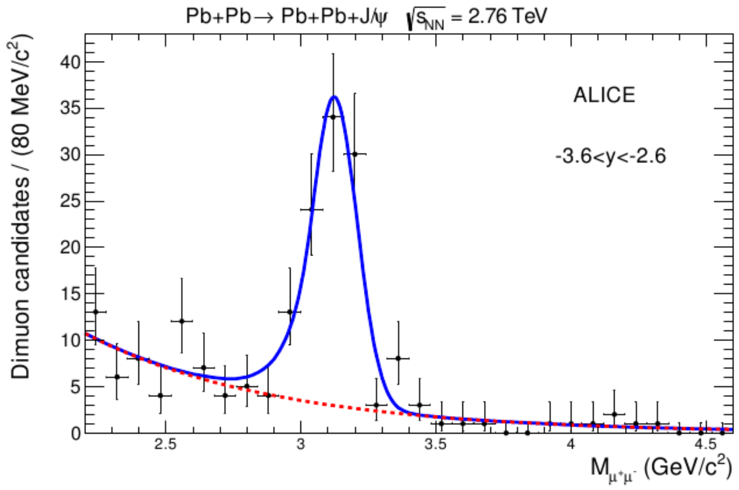
Integrated luminosity ~ 55 μb^{-1}

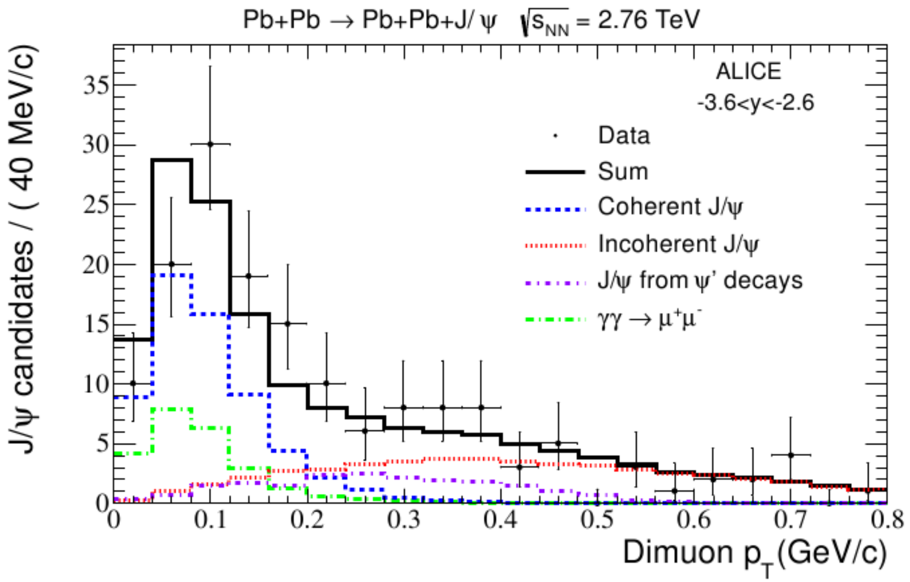
Offline event selection:

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

Track selection:

- muon tracks: $-3.7 < \eta < -2.5$
- matching with tracks in the muon 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: $-3.6 < y < -2.6$





Invariant mass distribution:

- Dimuon p_T< 0.3 GeV/*c*
- Clean spectrum: only 2 like-sign events
- Signal shape fitted to a Crystal Ball shape
- Background fitted to an exponential
- Exponential shape compatible with expectations from $\gamma\gamma \rightarrow \mu\mu$ process

Four contributions in the p_T spectrum:

- Coherent J/ψ
- Incoherent J/ψ
- J/ψ from ψ' decays
- $\gamma\gamma \rightarrow \mu\mu$

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

$$N^{\rm coh}_{J/\psi} = 78 \pm 10({\rm stat})^{+7}_{-11}({\rm syst})$$

ALICE: Phys. Lett. B718 (2013) 1273

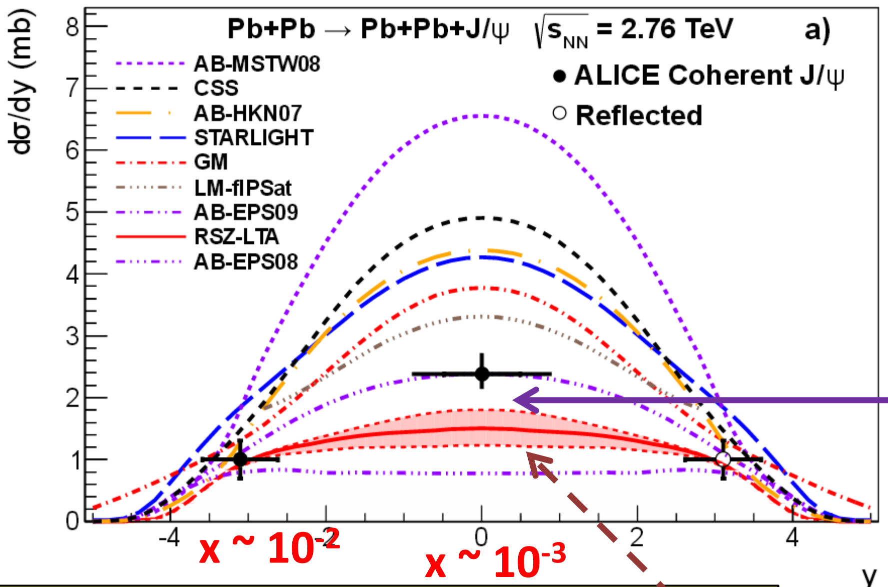
$$\frac{d\sigma_{\rm coh}}{dy} = \frac{1}{BR} \cdot \frac{N_{\rm coh}}{N_{\gamma\gamma}} \cdot \frac{(\mathrm{Acc\ x}\ \epsilon)_{\gamma\gamma}}{(\mathrm{Acc\ x}\ \epsilon)_{\rm coh}} \frac{\sigma_{\gamma\gamma}}{\Delta y}$$

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	$^{+24}_{-26}$%

$$\mathrm{d}\sigma^{\rm coh}_{J/\psi}/\mathrm{dy} = 1.00 \pm 0.18(\mathrm{stat})^{+0.24}_{-0.26}(\mathrm{syst})\ \mathrm{mb}$$

ALICE: Phys. Lett. B718 (2013) 1273

Coherent J/ψ: comparison to models



arXiv:1305.1467 - submitted to EPJC

Good agreement with models which include nuclear gluon shadowing.
Best agreement with EPS09 shadowing

$$|y| < 0.9 \rightarrow d\sigma^{coh}_{J/\psi}/dy = 2.38^{+0.34}_{-0.24}(stat+syst)\ \text{mb}$$

$$-3.6 < y < -2.6 \rightarrow d\sigma^{coh}_{J/\psi}/dy = 1.00 \pm 0.18(stat)^{+0.24}_{-0.26}(syst)\ \text{mb}$$

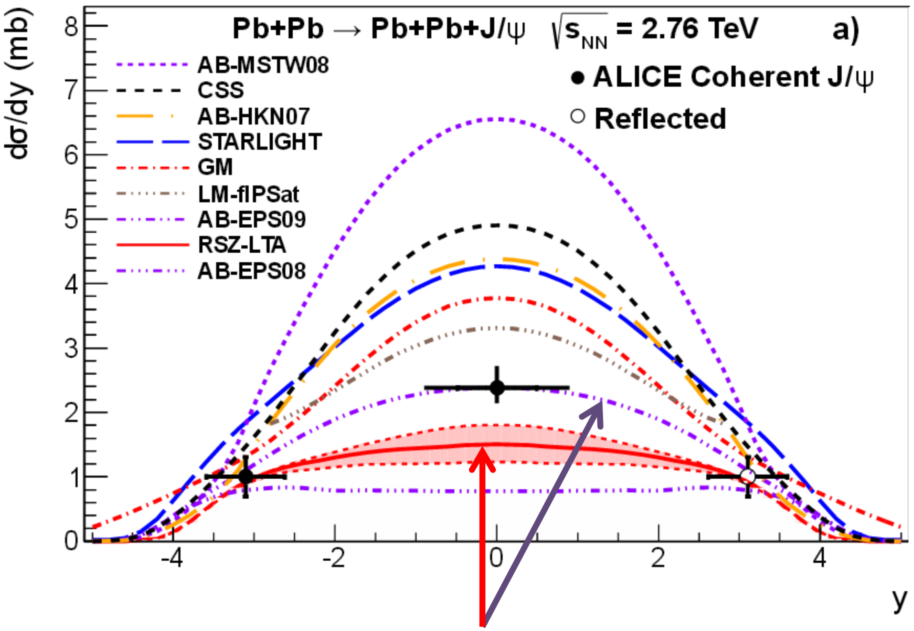
→ Yes, gluon shadowing is there…

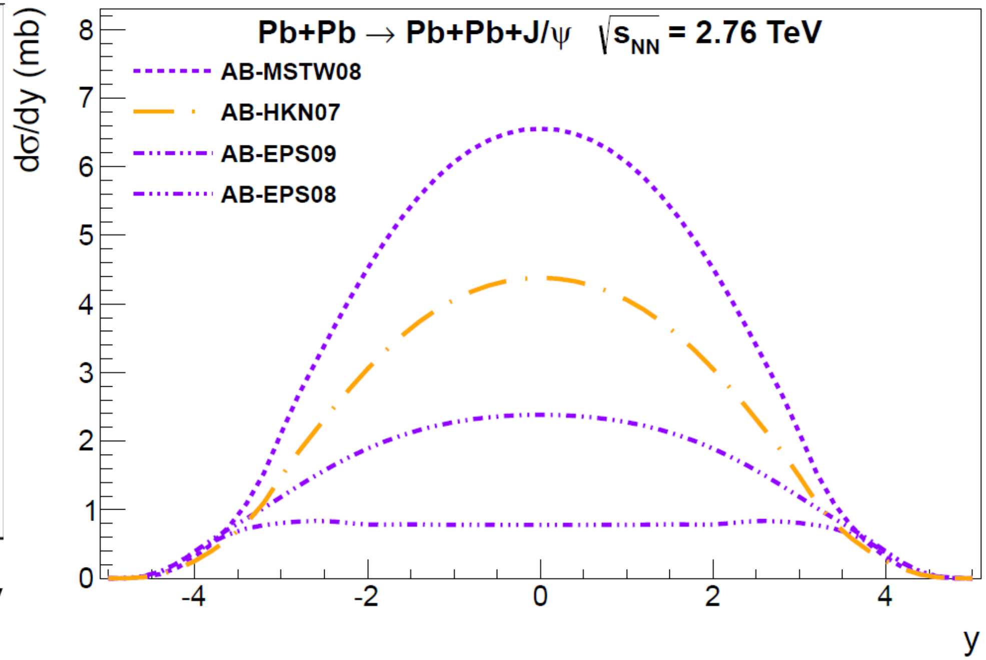
- **STARLIGHT: Klein, Nystrand, PRC60 (1999) 014903** VDM + Glauber approach where J/ψ+p cross section is obtained from a parameterization of HERA data
- **GM: Gonçalves, Machado, PRC84 (2011) 011902** color dipole model, dipole nucleon cross section taken from the IIM saturation model
- **AB: Adeluyi 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

Plan to include also:

- **Lappi, Mäntysaari, hep-th/1301.4095**

Disentagling the gluon shadowing



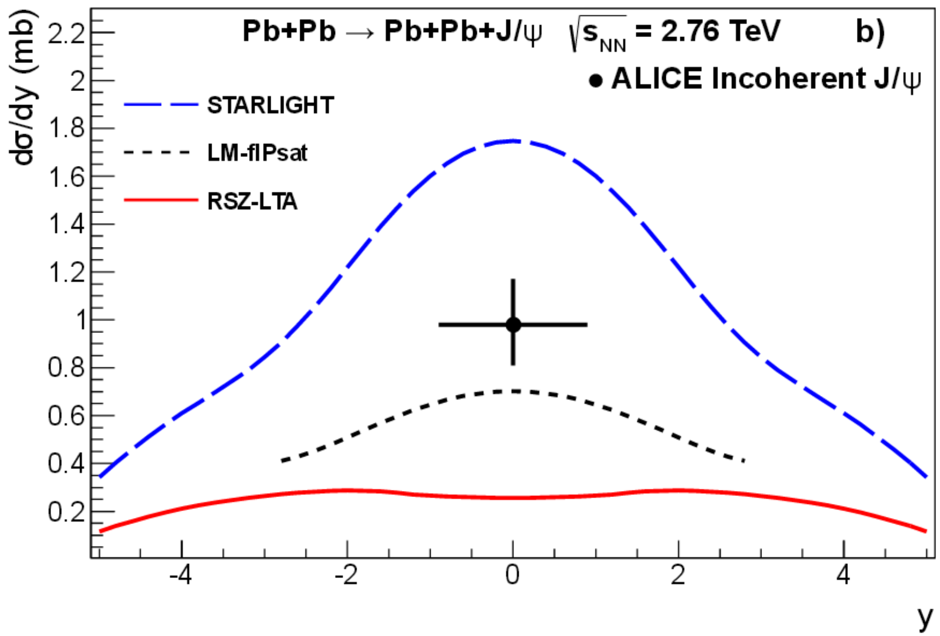


Similar amount of gluon shadowing, different models

Same model, different gluon shadowing fits

→ Nuclear gluon shadowing required to reproduce data

Incoherent J/ψ: comparison to models



arXiv:1305.1467
Sent to EPJC

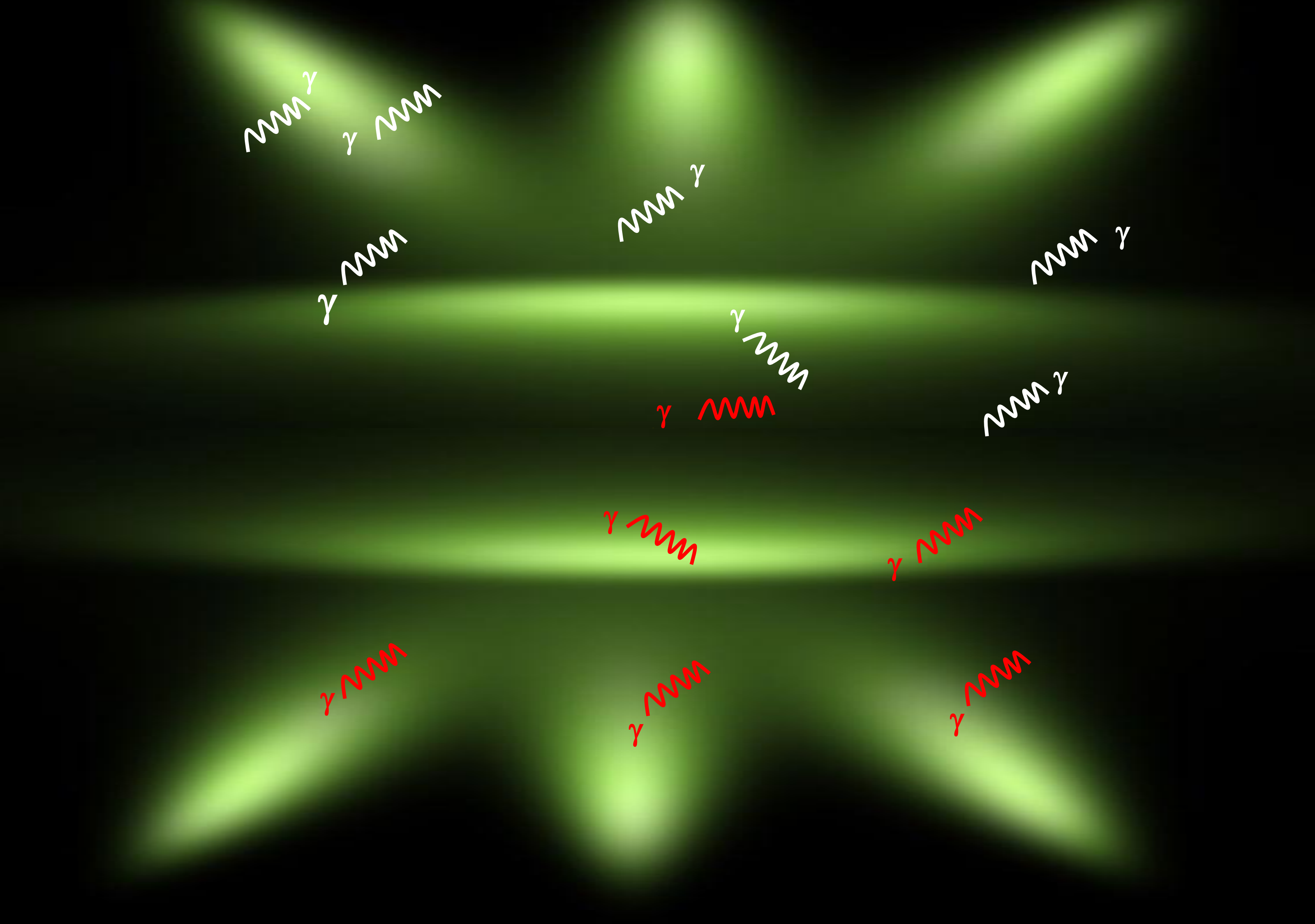
More model predictions welcome…

The ratio $\sigma_{inc}/\sigma_{coh}$ provides further constraints on the treatment of the nuclear modifications implemented in the different model. Starlight prediction 0.41

ALICE result: $\sigma_{inc}/\sigma_{coh} \pm = 0.41^{+0.10}_{-0.08}$ (stat+syst)

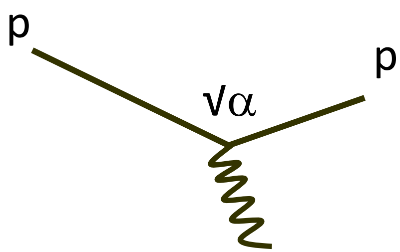
…and one more thing

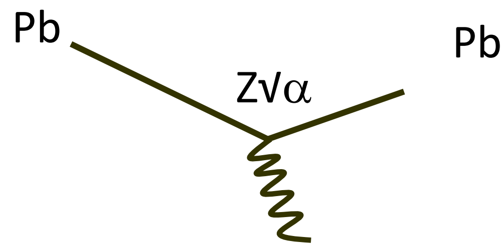
Pb-Pb collisions: shedding light on ...light



$\gamma\gamma \rightarrow ee$

Outside the J/Ψ peak opportunity to study $\gamma\gamma \rightarrow ee$





Higher orders could be not negligible. Few models predicted a cross section reduction up to 30% (J. Baltz, Phys. Rev. C 80 (2009) 034901).

STARLIGHT(S.R. Klein and J. Nystrand) implements the above cross section at LO.

Data analysis performed in the invariant mass intervals $2.2\ \mathrm{GeV/c^2} < M_{inv} < 2.6\ \mathrm{GeV/c^2}$ and $3.7\ \mathrm{GeV/c^2} < M_{inv} < 10\ \mathrm{GeV/c^2}$

Previous $\gamma\gamma \rightarrow ee$ measurement by STAR at RHIC: results compatible with STARLIGHT within 2 σ, measurement precision 22.5% (stat+sys).

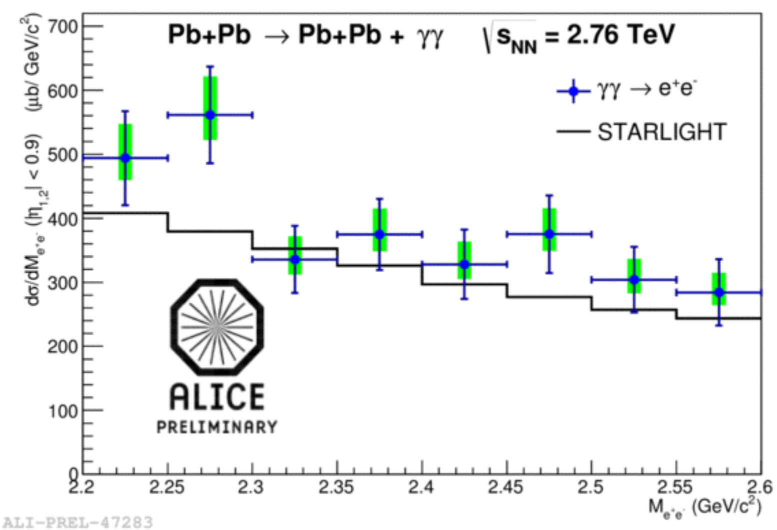
At LHC:

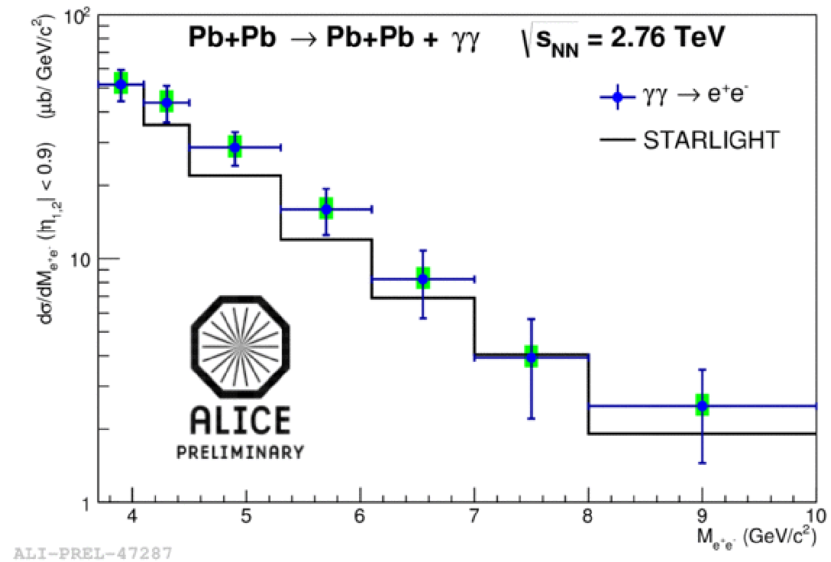
STARLIGHT prediction ($|\eta|<0.9$, 2.2 GeV/c^2 < M_{inv} < 2.6 GeV/c^2):
$\sigma_{\gamma\gamma}$=128 μb

ALICE preliminary result:
$\sigma_{\gamma\gamma}=154 \pm 11(stat)\ ^{+16.6}_{-10.8}(sys)\ \mu b$
→ ~ 12% precision

STARLIGHT prediction ($|\eta|<0.9$, 3.7 GeV/c^2 < M_{inv} < 10 GeV/c^2):
$\sigma_{\gamma\gamma}$=77 μb

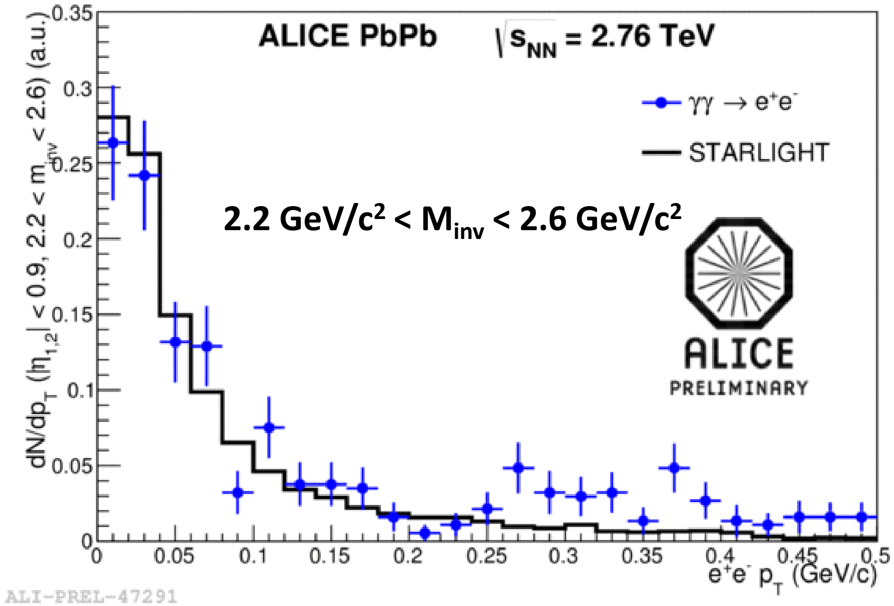
ALICE preliminary result:
$\sigma_{\gamma\gamma}=91 \pm 10(stat)\ ^{+10.9}_{-8.0}(sys)\ \mu b$
→ ~ 16% precision

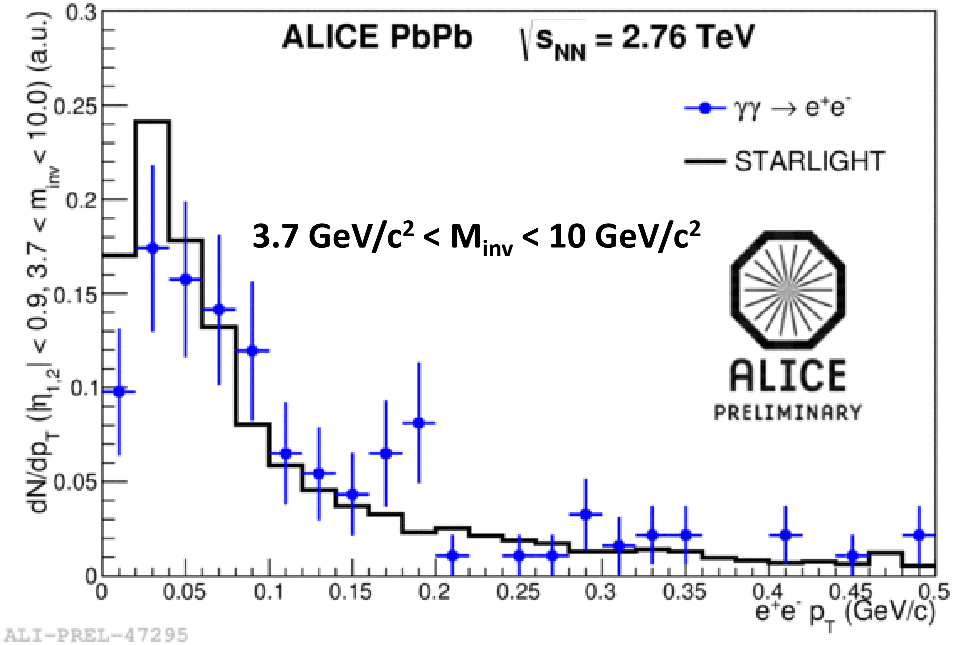




Data 20% above the predictions (compatible within 1 and 1.5 σ). 30% cross section reduction predicted in Phys. Rev. C 80 (2009) 034901 not supported. Consistent with STAR, measurement precision improved.

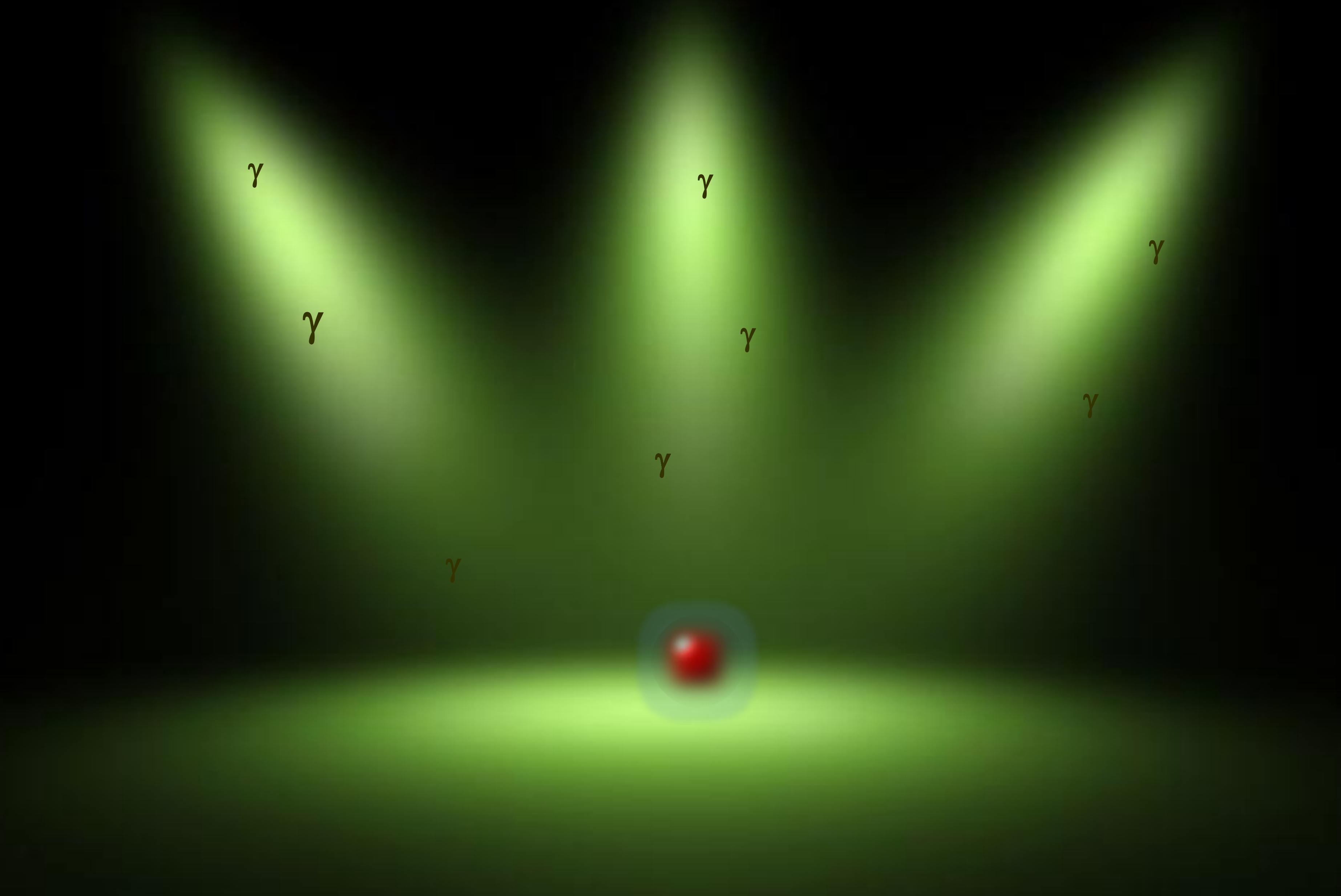
Moreover....





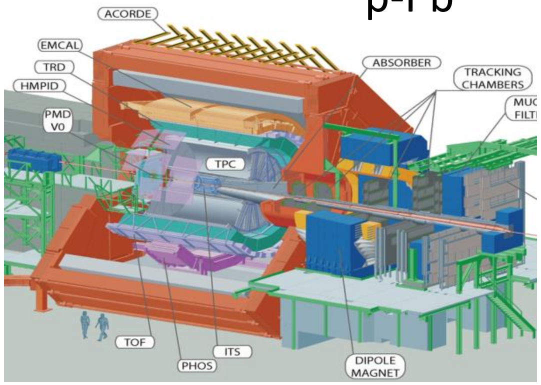
....p_T spectrum properly reproduced

p-Pb collisions: shedding light on the proton



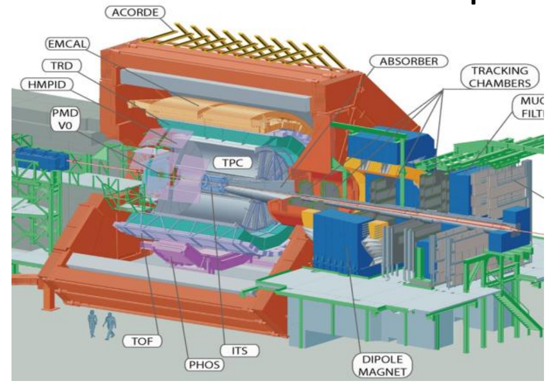
Two different configurations:

p-Pb



p

Pb-p



p

$\sqrt{s}$=5.02 TeV

- J/Ψ decay product in the forward muon arm:

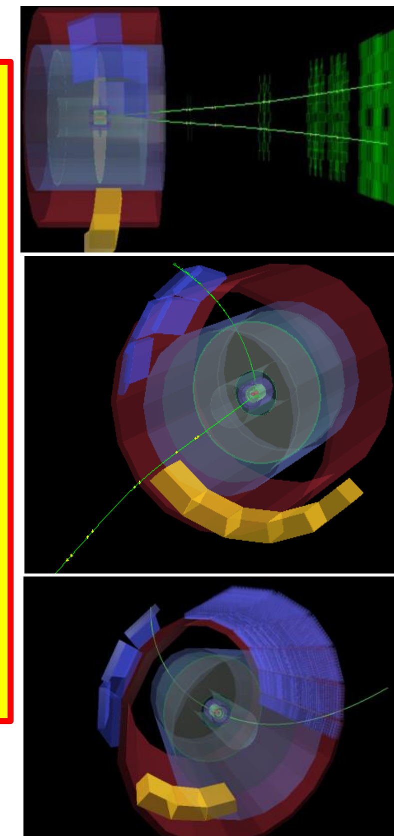
  21 GeV ≤ $W_{\gamma p}$ ≤ 45 GeV **550 GeV ≤ $W_{\gamma p}$ ≤ 1160 GeV**

- J/Ψ decay product (1 μ in the barrel + 1 μ in the muon arm)

  45 GeV ≤ $W_{\gamma p}$ ≤ 82 **300 GeV ≤ $W_{\gamma p}$ ≤ 550 GeV**

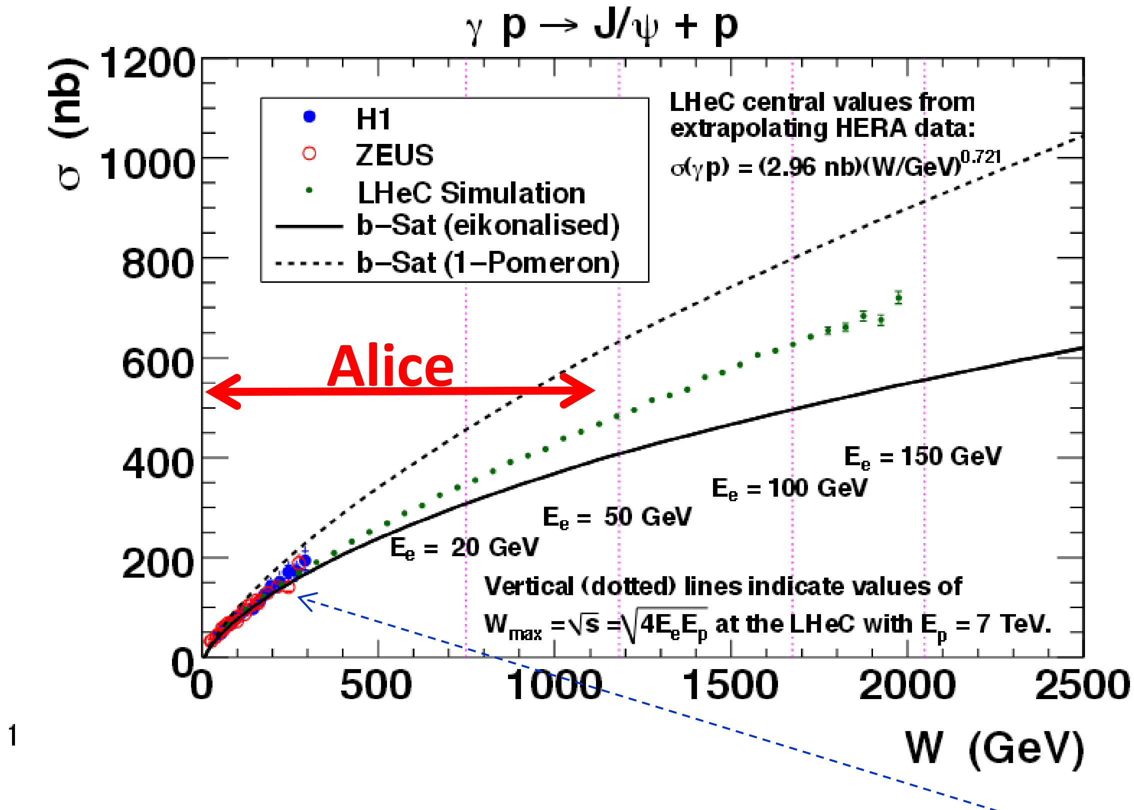
- J/Ψ in the Barrel:

  100 GeV ≤ $W_{\gamma p}$ ≤ 250 GeV



Access to a wide energy interval: $W_{\gamma p}$ varies by a factor 50

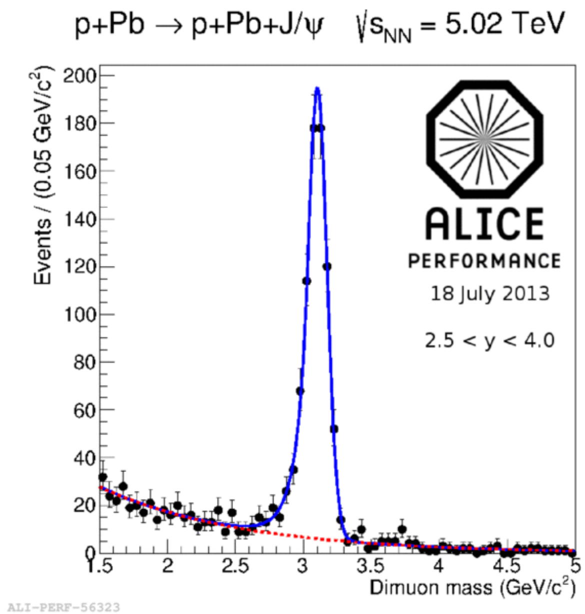
The present .....

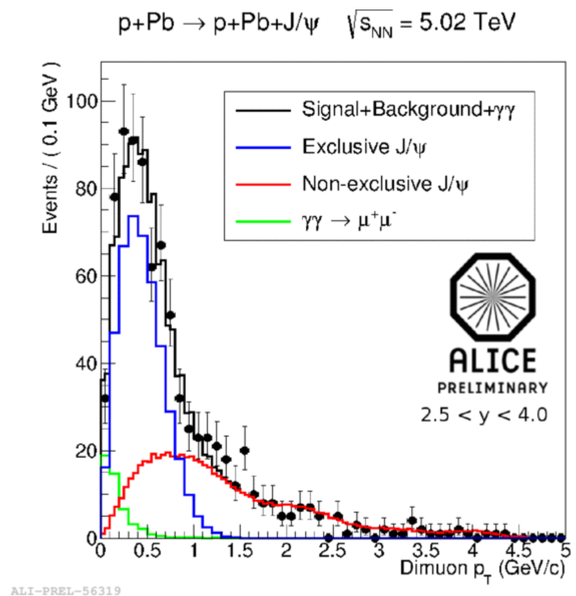


Strategy: start from the region where already existing data and ALICE overlap to check for consistency

p-Pb analysis

Analysis with the forward muon arm (lowest $W_{\gamma p}$). Non exclusive J/Ψ contribution estimated by data (events with ≥ 3 hits in the VZERO detector)

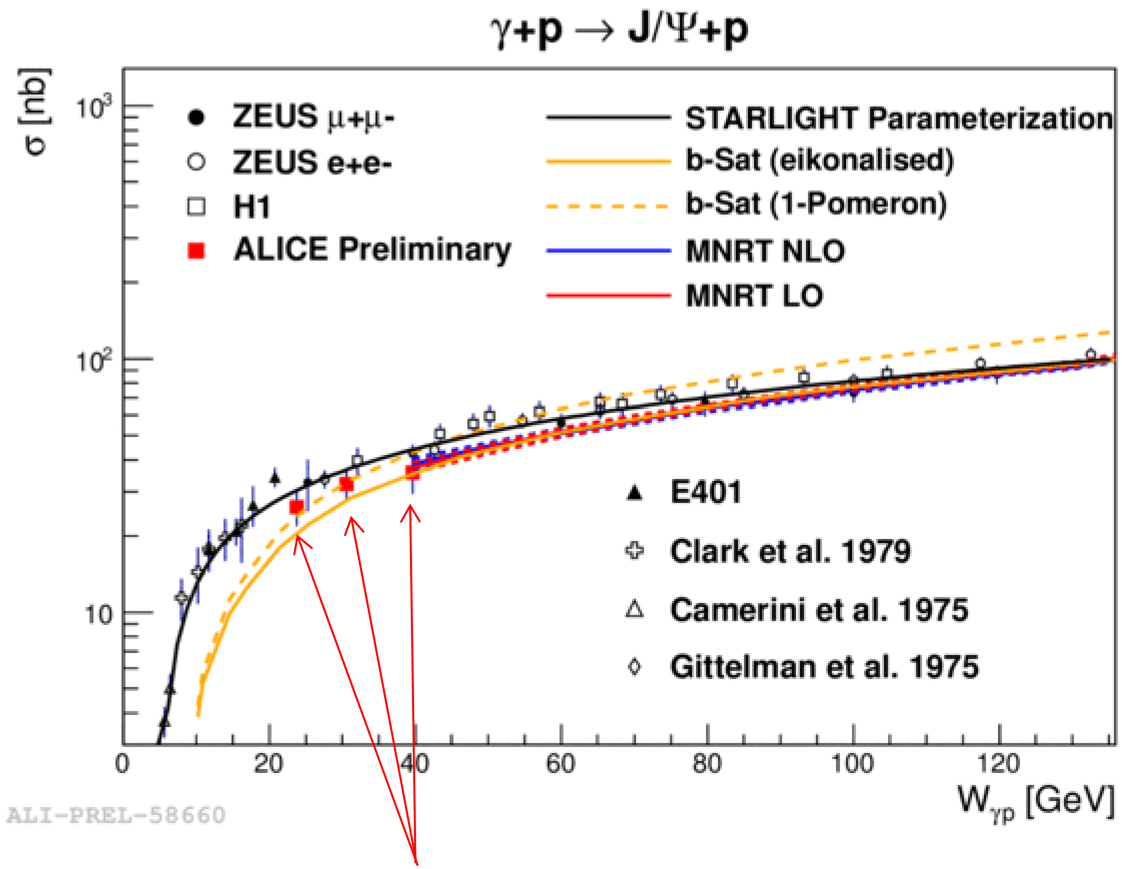




rapidity	$d\sigma(p-Pb \to p-Pb+J/\psi)/dy(\mu b)$
-4.0 < y < -2.5	6.18 ± 0.42 (stat) ± 0.56 (sys)
-4.0 < y < -3.5	5.50 ± 0.72 (stat) ± 0.52 (sys)
-3.5 < y < -3.0	6.26 ± 0.55 (stat) ± 0.57 (sys)
-3.0 < y < -2.5	6.39 ± 0.94 (stat) ± 0.59 (sys)

Alice preliminary

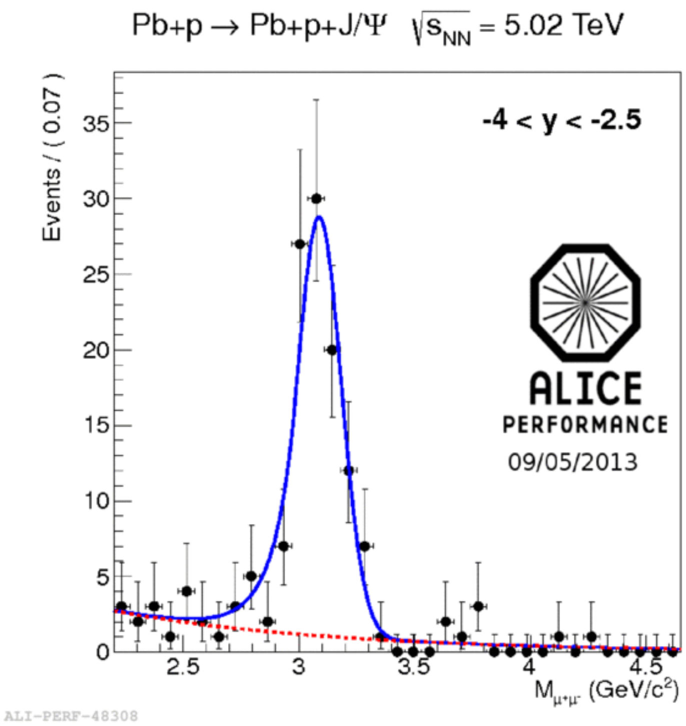
Once the photon spectrum n(γ) is calculated, the cross section for γ+p→ J/Ψ + p can be obtained



→ ALICE is consistent with previous experiment: go ahead to higher $W_{\gamma p}$

Pb-p: the unexplored region:

Analysis with the forward muon arm (highest $W_{\gamma p}$).



Preliminary results coming soon.....

Conclusions and outlook

Done:

- The J/Ψ coherent cross section was successfully measured in ALICE both at mid-rapidity and at forward rapidity;
- Models including nuclear gluon shadowing are favoured;
- The J/Ψ incoherent was measured at mid-rapidity too: more models please !
- $\sigma_{\gamma\gamma \rightarrow ee}$ cross section measured at mid-rapidity: LO implementation gives a satisfactory prediction

In progress:

- Pb-Pb ρ vector meson production analysis;
  γ+p$\rightarrow$ J/Ψ+p cross section at W > 1000 GeV (and not only) in progress.

The future:

- Υ measurement could be feasible: strong theoretical motivation would be important;
- Any idea to understand the origin of the nuclear gluon shadowing (saturation) ?

$\rightarrow$ Hints from theoreticians crucial to define the UPC program in the next years.