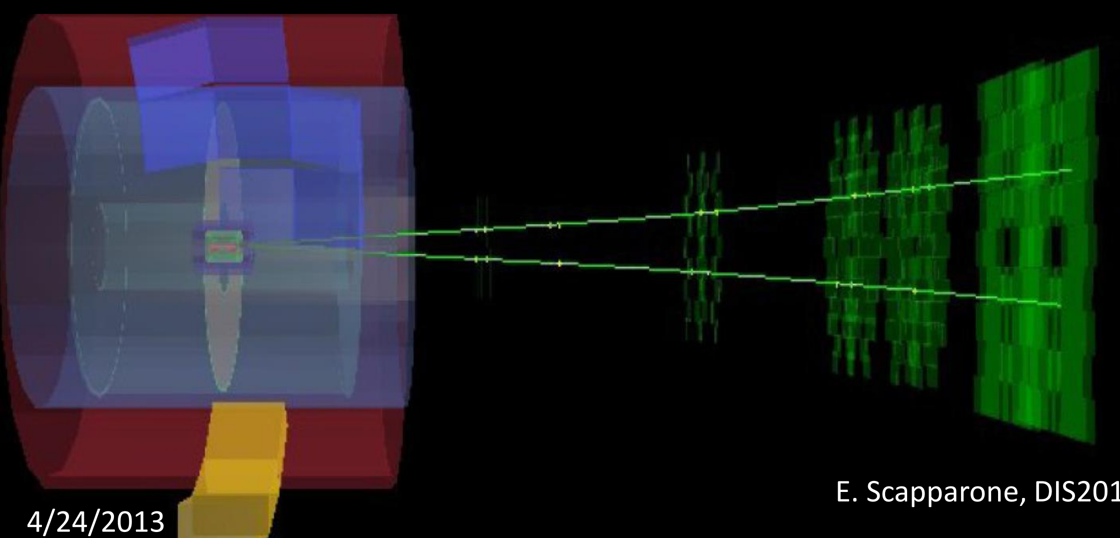
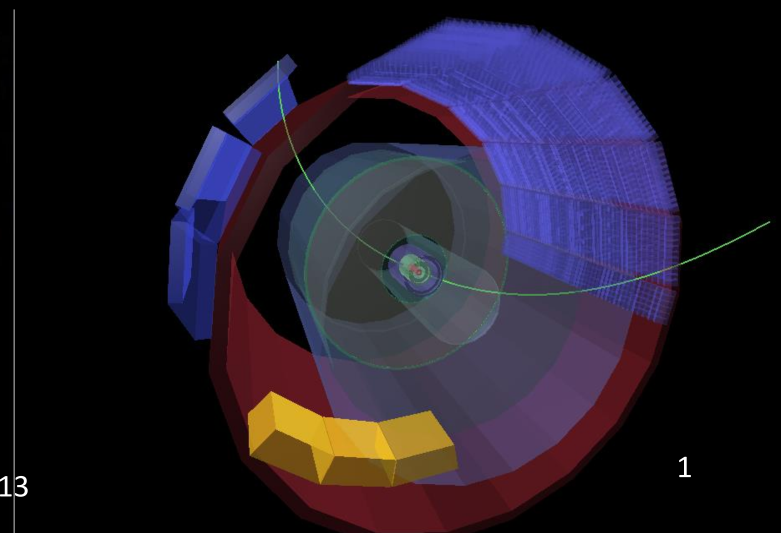
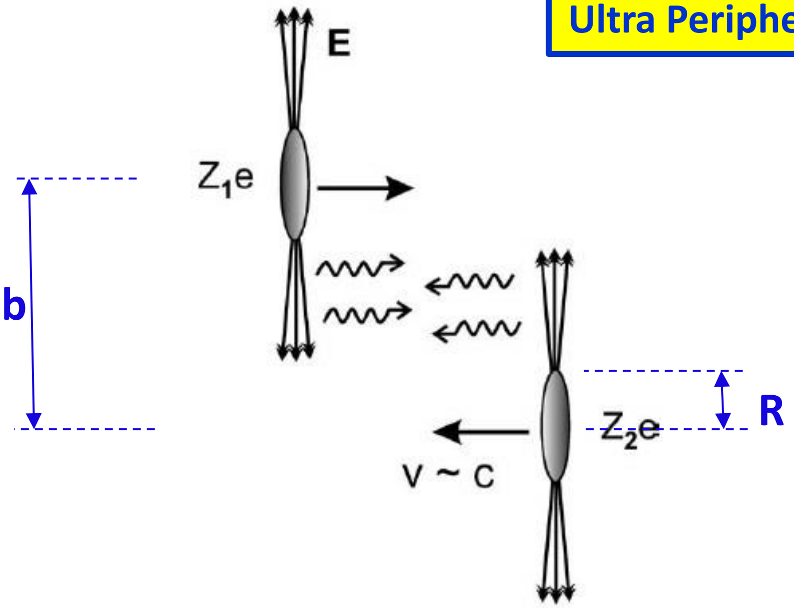
Charmonium and e^+e^- pair photoproduction in Ultra Peripheral Pb-Pb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV

E. Scapparone on behalf
of the ALICE Collaboration,
DIS2013, April 24, 2013

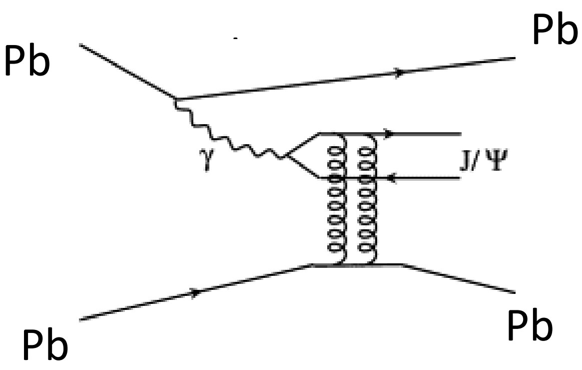


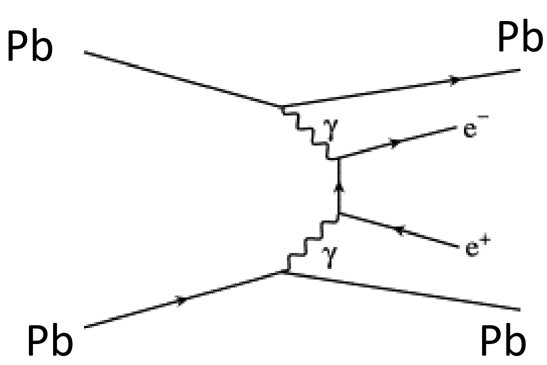


Ultra Peripheral Collisions at LHC



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





Coherent vector meson production:

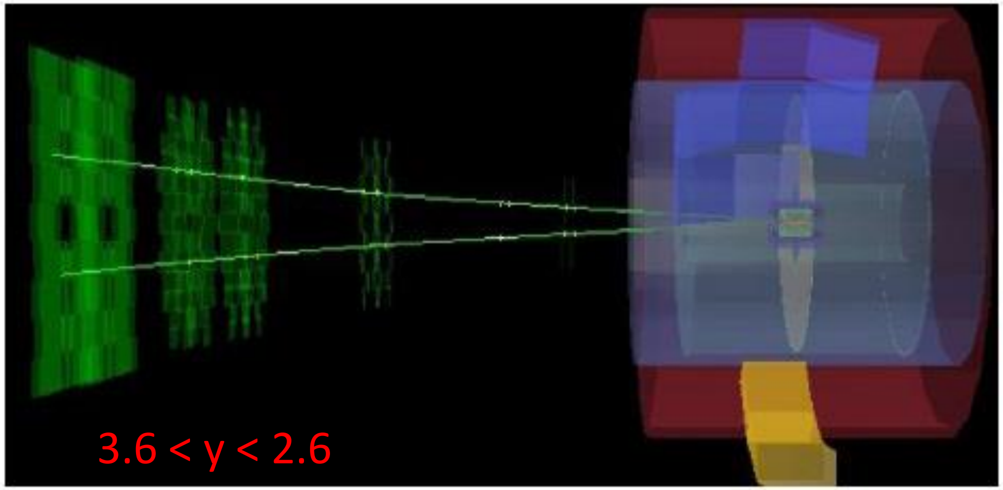
- photon couples coherently to all nucleons
- $\langle p_T \rangle \sim 1/R_{Pb} \sim 60$ MeV/c
- no neutron emission in ~80% of cases

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

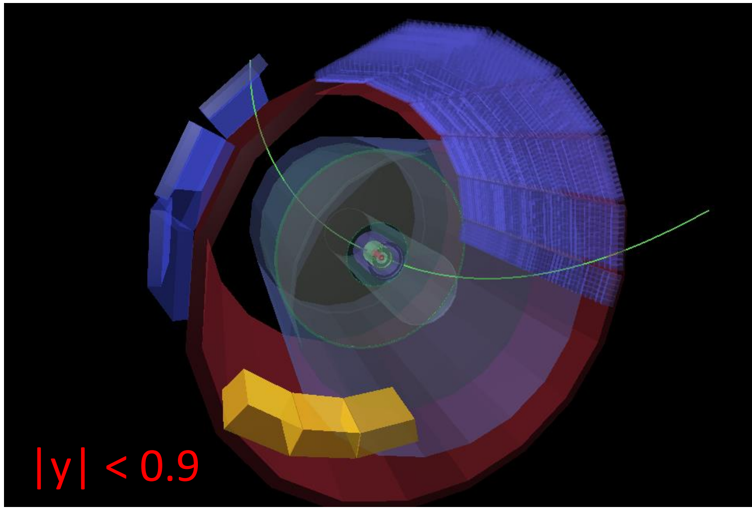
Where can we look at them in ALICE ?

Forward rapidity



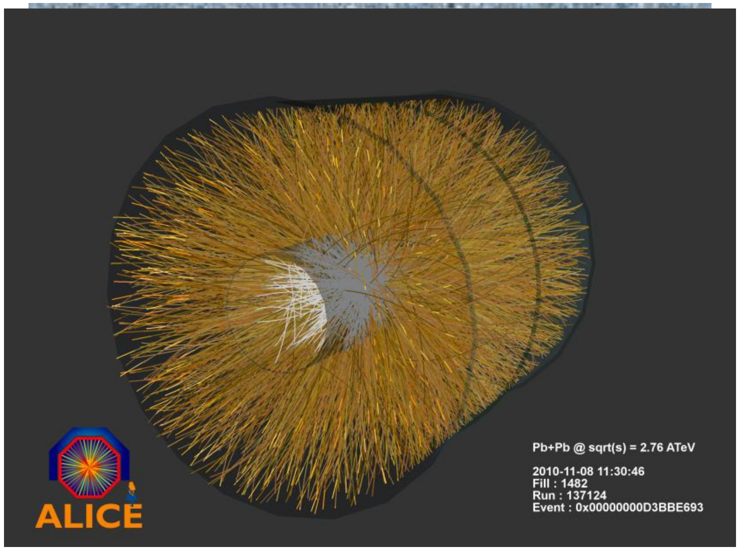
OR

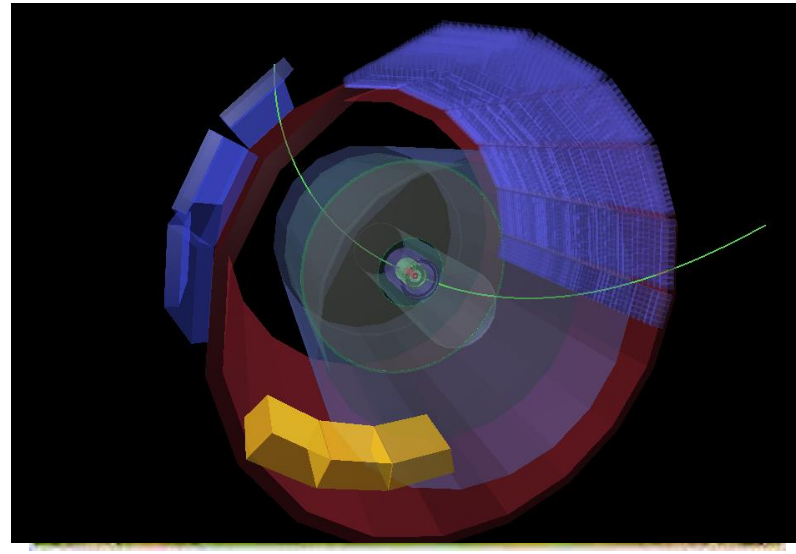
Mid-rapidity



The treasure map

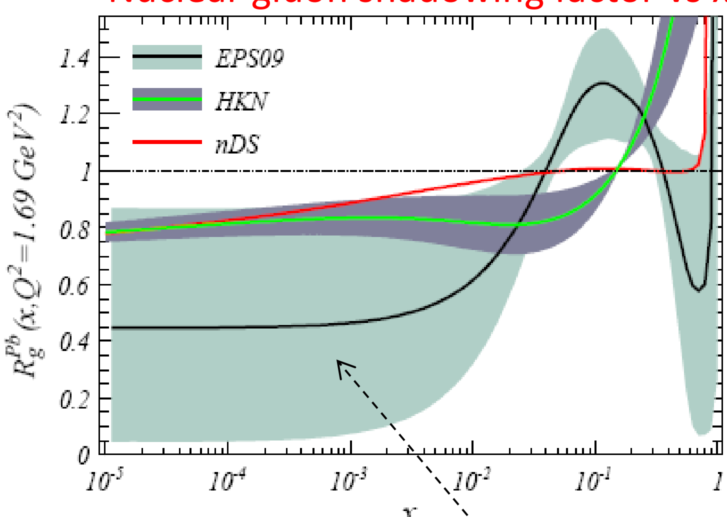
Tastes differ…





…but no doubt UPCs at LHC are a nice physics opportunity

Nuclear gluon shadowing factor vs x



Large uncertainties at small x

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

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

Bjorken x ~ $10^{-2} - 10^{-5}$

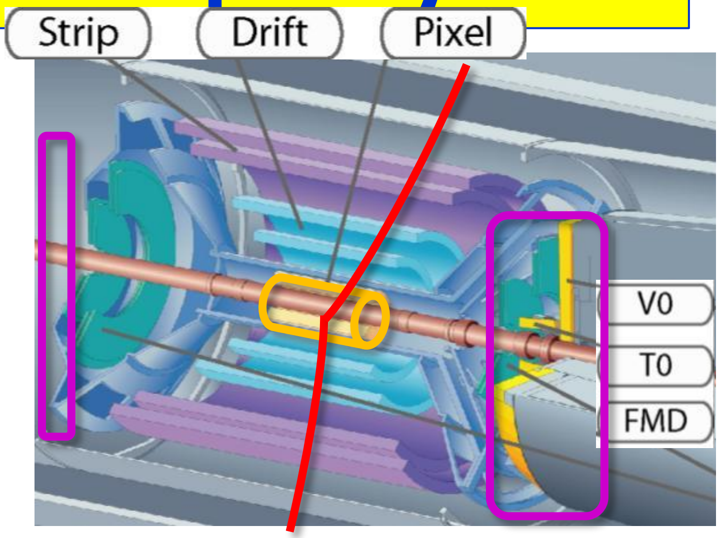
accessible at LHC

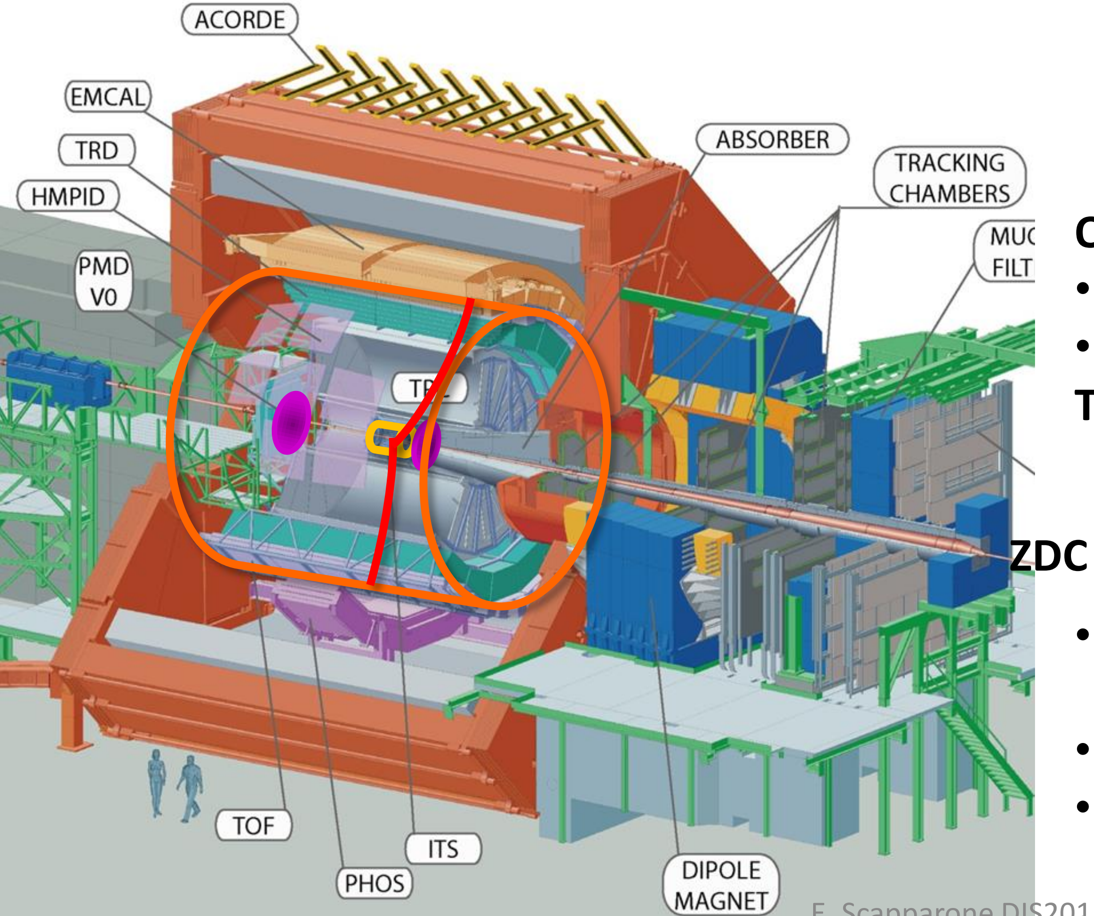
J/Ψ in Pb-Pb UPC is
a direct tool to measure
nuclear gluon shadowing

UPC J/ψ at central rapidity

UPC central barrel trigger:

- 2 ≤ **TOF** hits ≤ 6 (|η| < 0.9)
  + back-to-back topology (150° ≤ φ ≤ 180°)
- ≥2 hits in **SPD** (|η| < 1.5)
- no hits in **VZERO** (C: -3.7 < η < -1.7, A: 2.8 < η < 5.1)





Offline event selection:

- Offline check on VZERO hits
- Hadronic rejection with ZDC

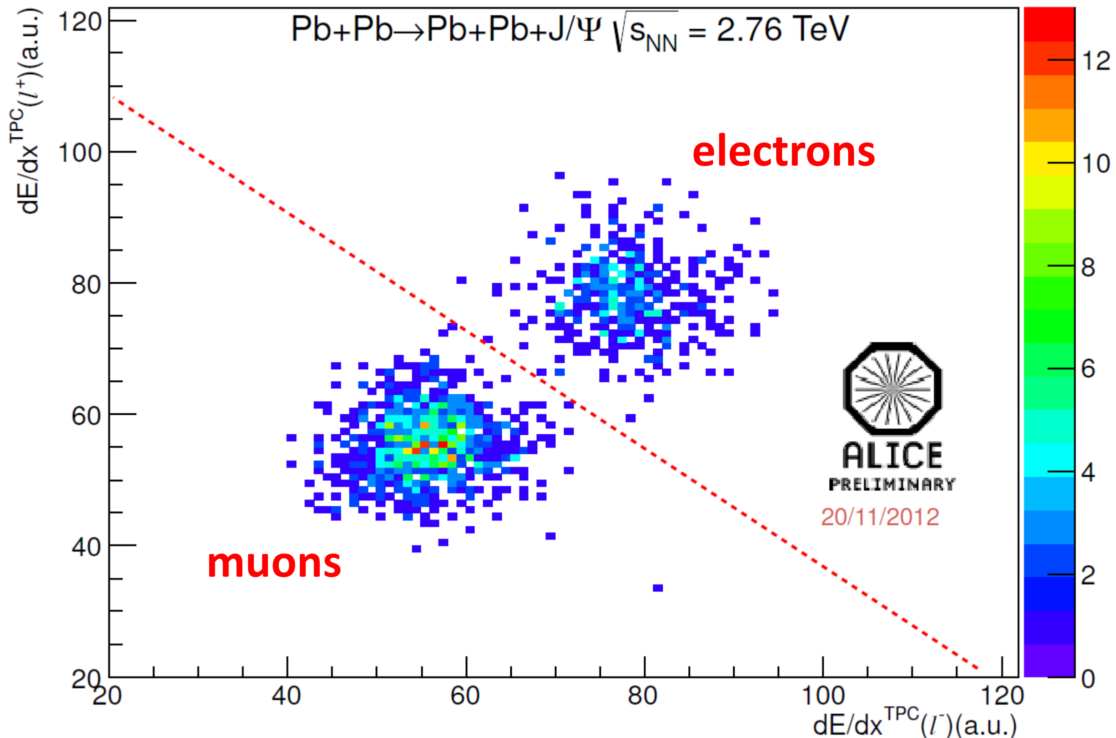
Track selection:

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

- Only two tracks: |η| < 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

Integrated luminosity ~ 23 μb^{-1}

dE/dX selection in TPC



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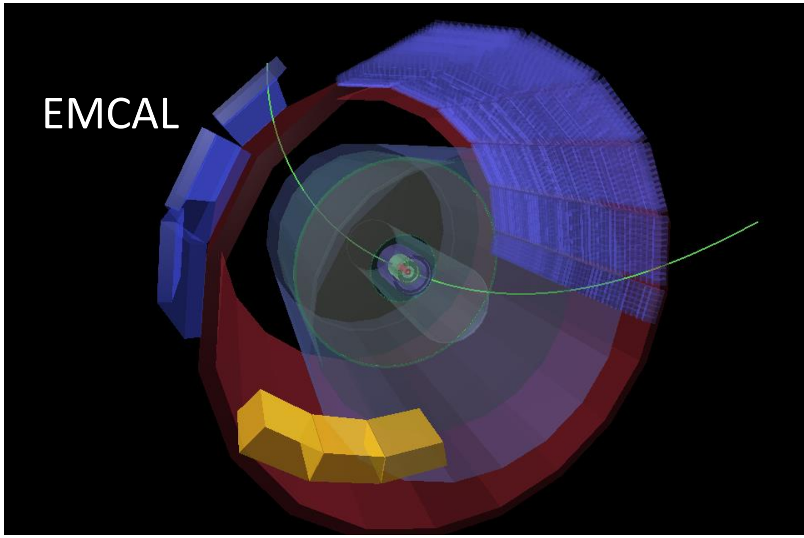
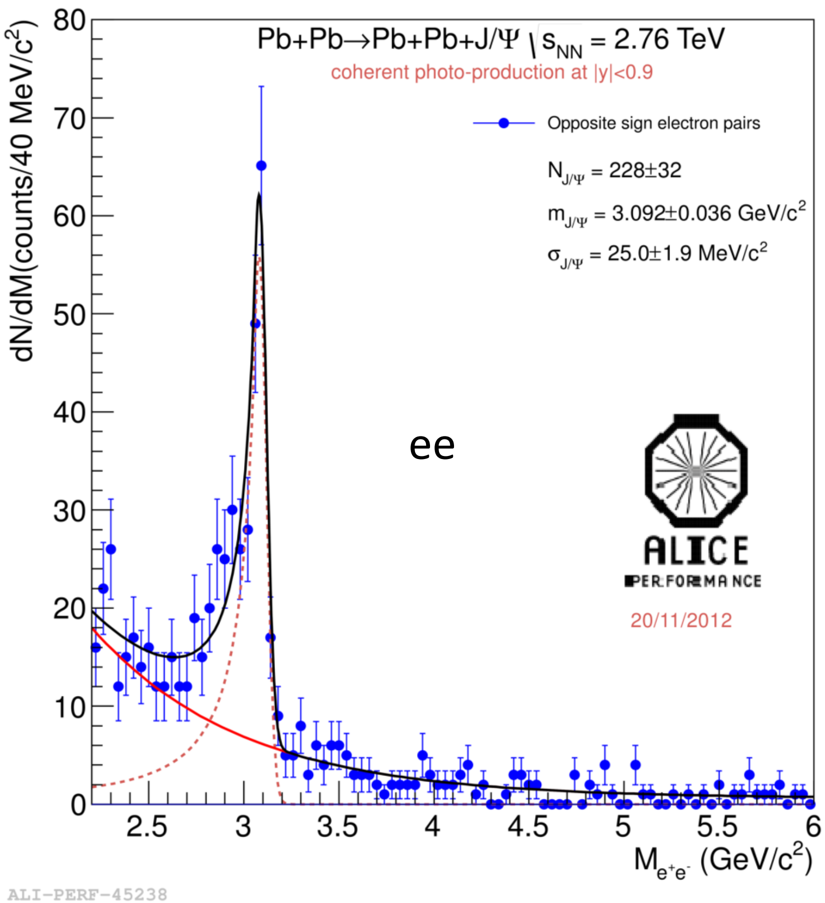
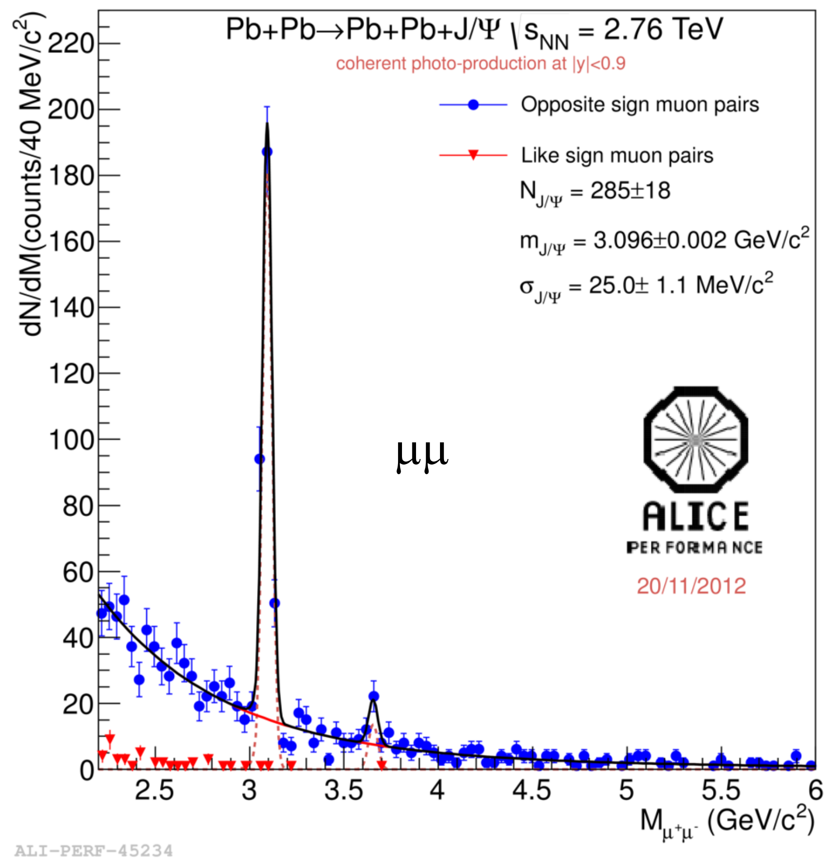


- dE/dx in TPC compatible with e/μ energy loss
- Cross-checked with E/p in EMCAL
- ±2% systematics due to e/μ separation

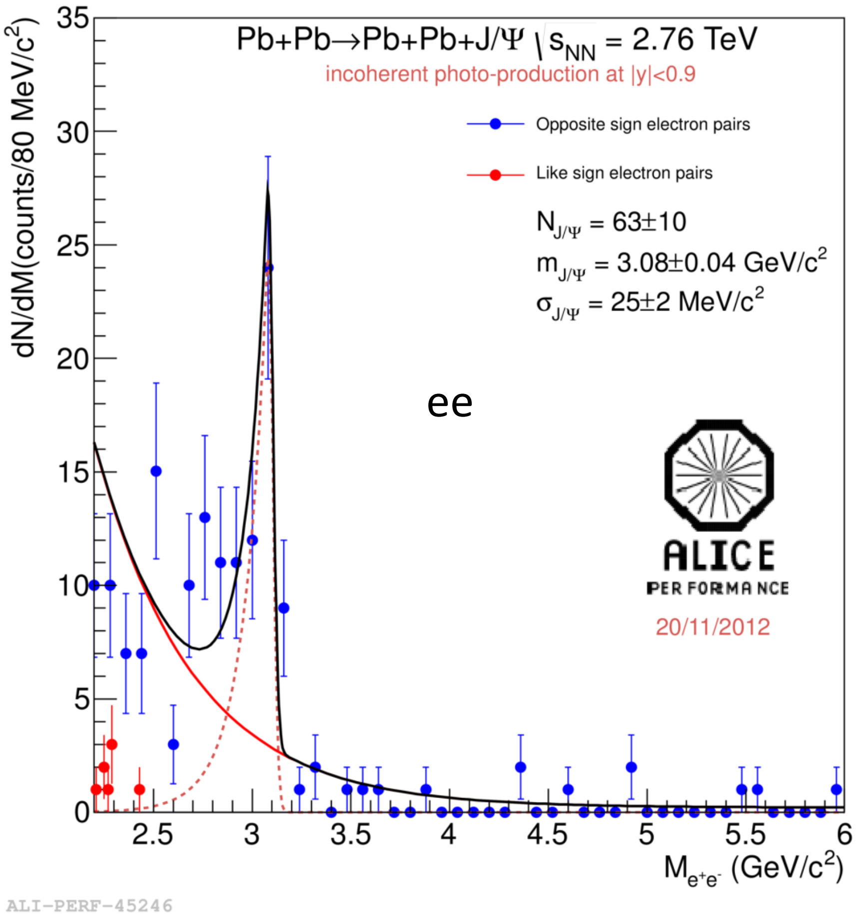
P.S. we cannot distinguish μ from π

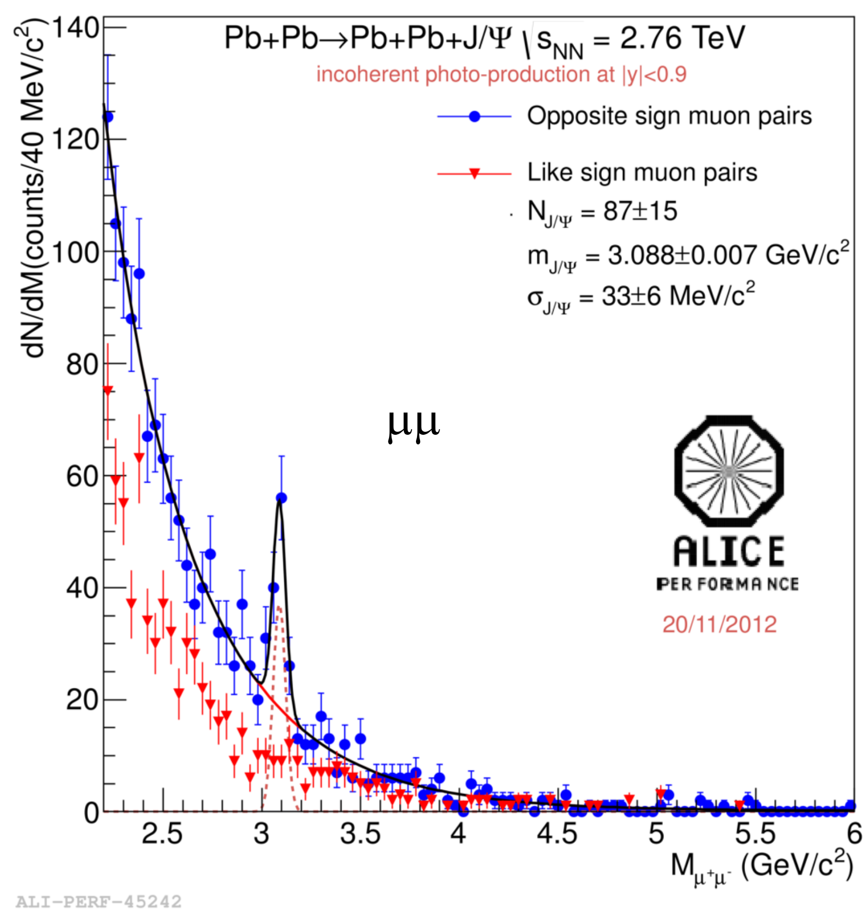
pt < 200 MeV/c for di-muons (300 MeV/c for di-electrons) .and. < 6 neutrons in ZDC
→ Coherent enriched sample





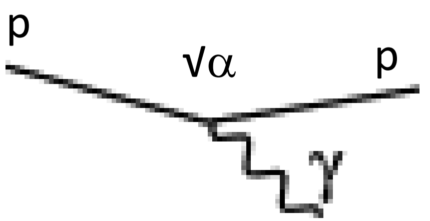
pt > 200 MeV/c for di-muons (300 MeV/c for di-electrons)
→ Incoherent enriched sample

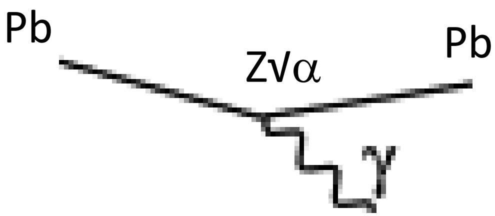




$\gamma\gamma \rightarrow ee$

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 GeV/c^2 < M_{inv} < 2.6 GeV/c^2 and 3.7 GeV/c^2 < M_{inv} < 10 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).

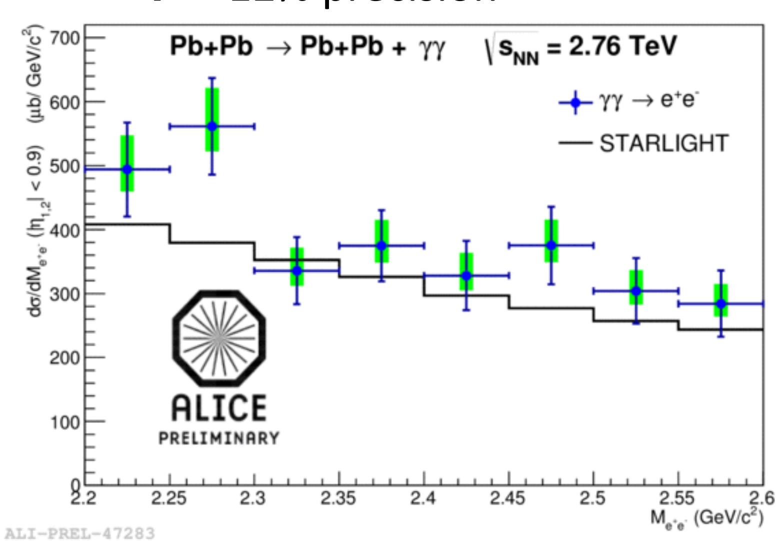
At LHC:

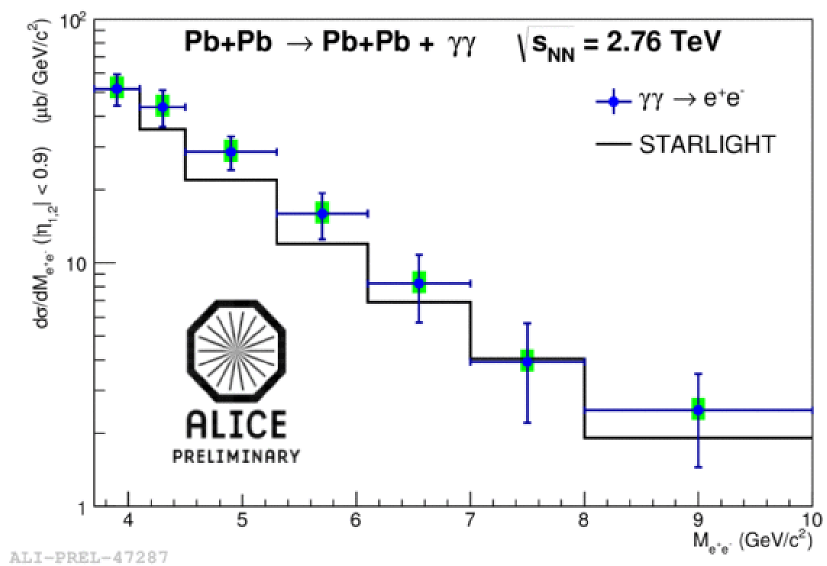
STARLIGHT prediction ($|\eta|<0.9$, $2.2\ GeV/c^2 < M_{inv} < 2.6\ GeV/c^2$):
$\sigma_{\gamma\gamma}=128\ \mu b$

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

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

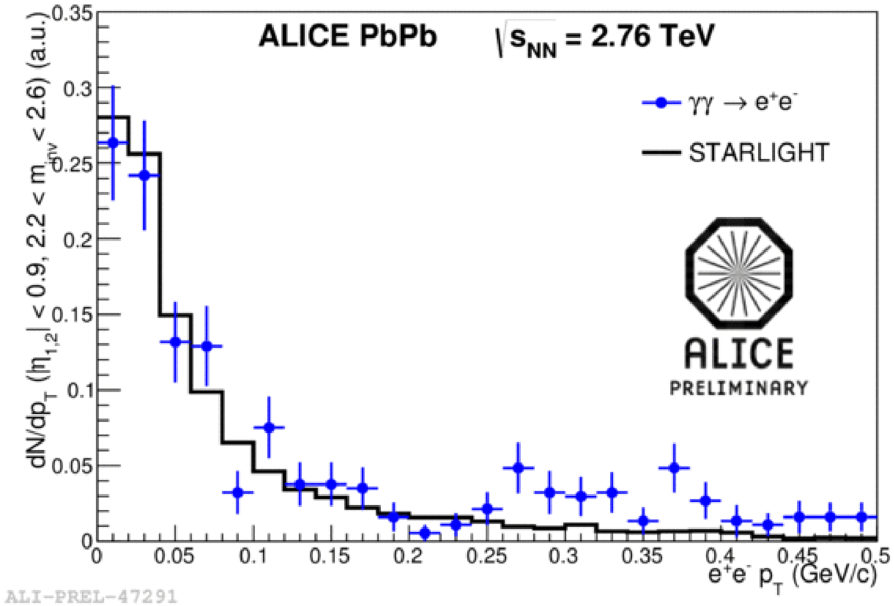
ALICE preliminary result:
$\sigma_{\gamma\gamma}=91 \pm 10(stat)\ ^{+10.9}_{-8.0}(sys)\ \mu b$
→ ~ 16% precision

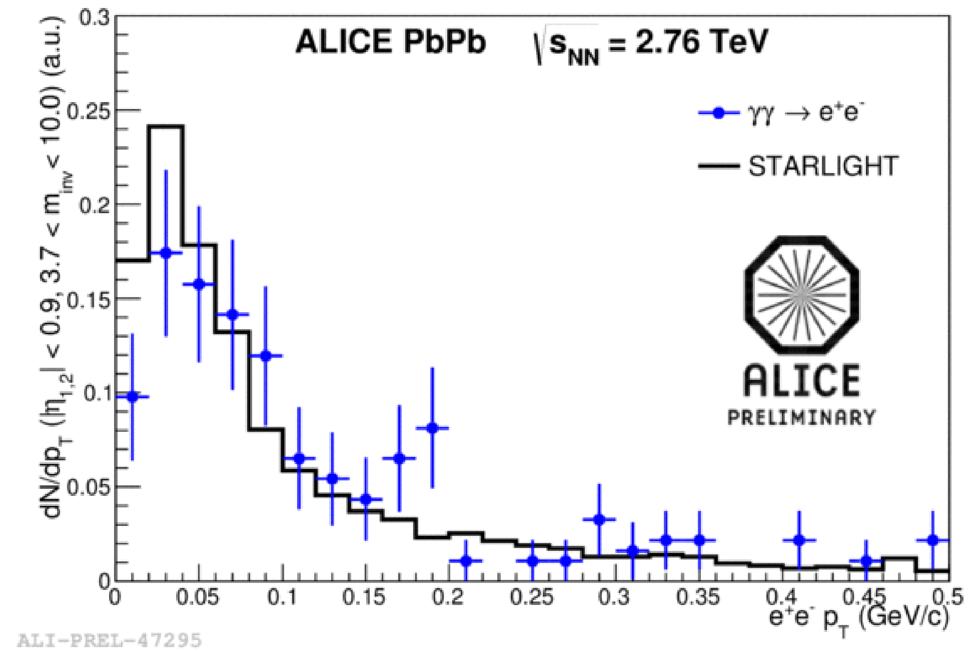




Data 20% above the predictions (compatible within 1 and 1.5 σ). 30% cross section reduction predicted in Phys. Rev. C 80 (2009) 034901 not supported. Consistent with STAR, measurement precision improved.

Moreover....

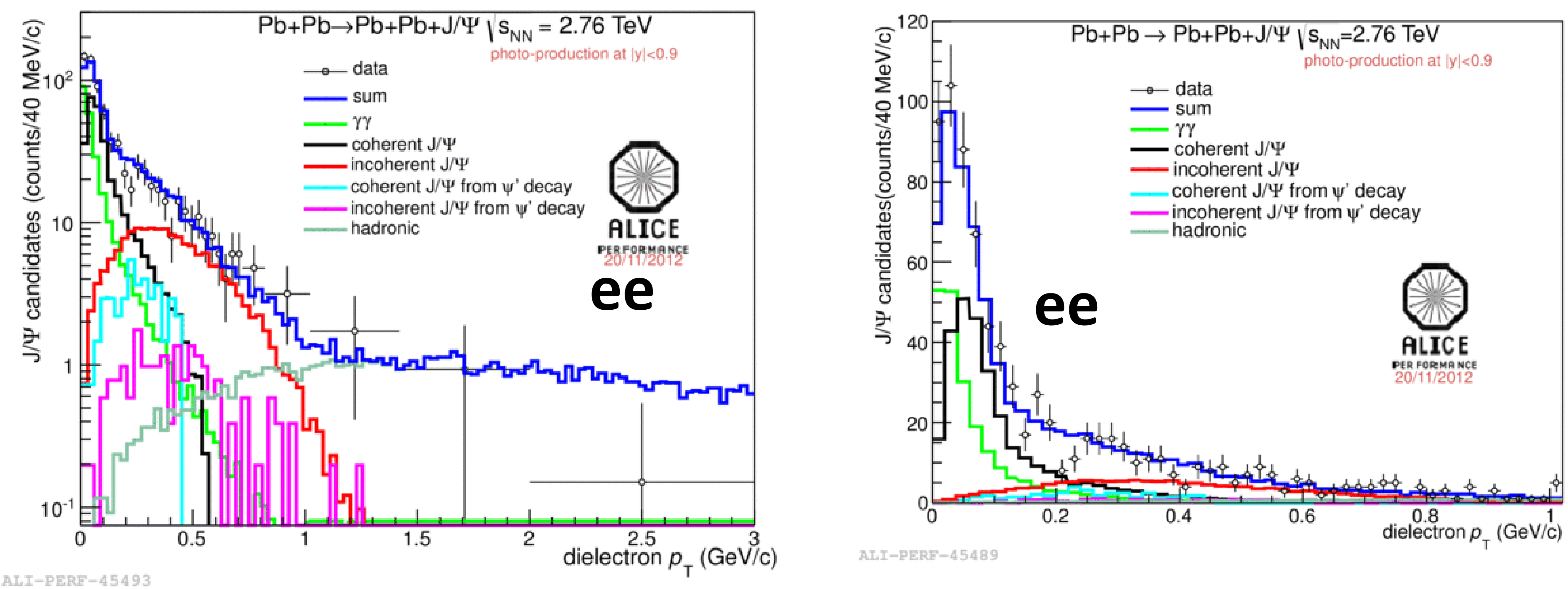




....p_T spectrum properly reproduced

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 a 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;



Detail study of the systematics including:

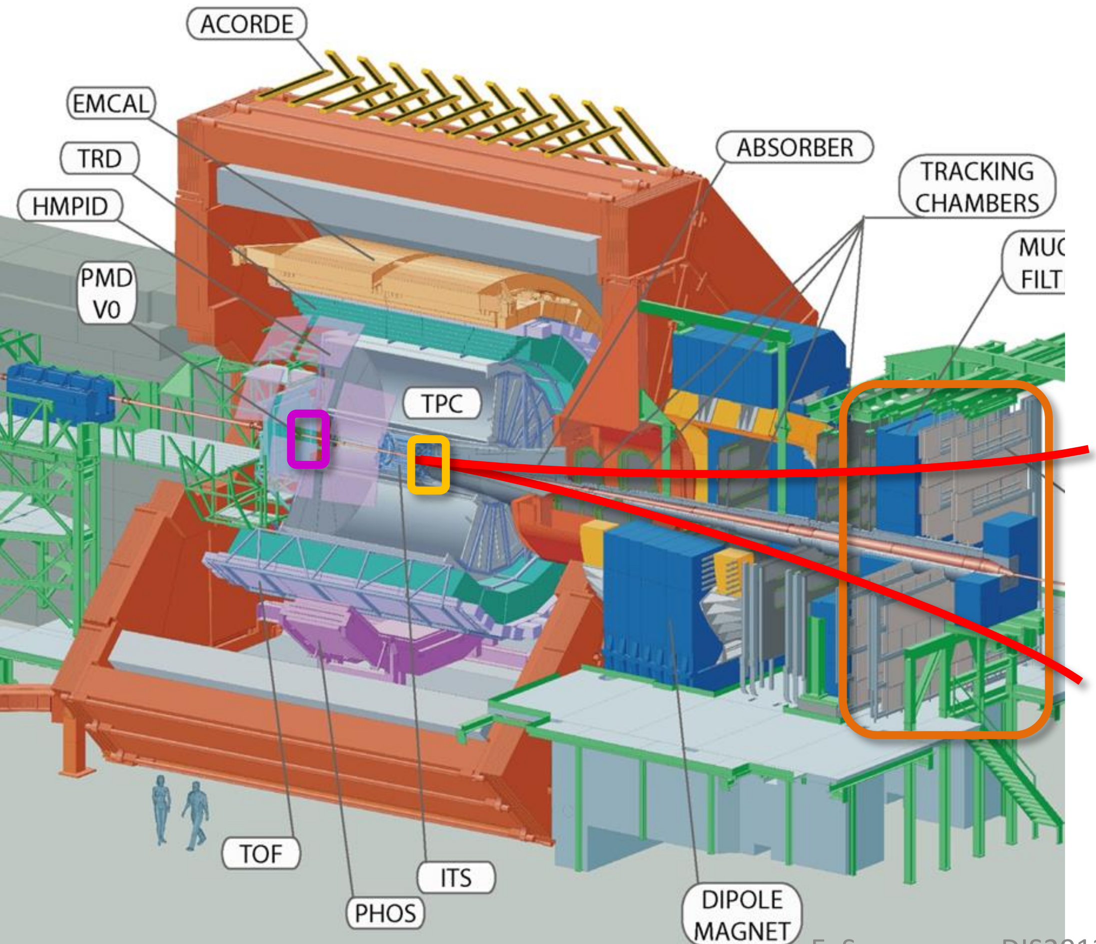
- **Luminosity;**
- **Acc x ε;**
- **Trigger efficiency (random sample);**
- **Trigger dead time;**
- **Signal extraction;**
- **e/μ separation;**
- **γγ→ee in addition to the J/Ψ (from the same or another Pb-Pb pair)**

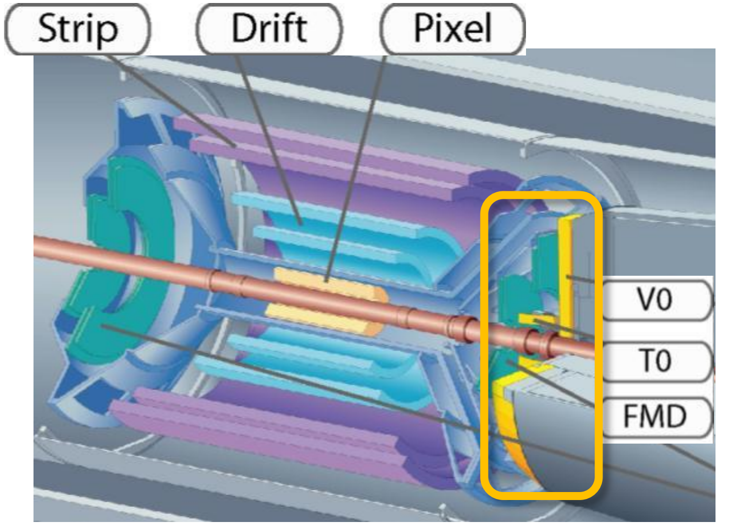
$$N^{\mathrm{coh}}_{\mathrm{J}/\psi} = \frac{N_{\mathrm{yield}}}{1 + f_I + f_D}$$

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

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

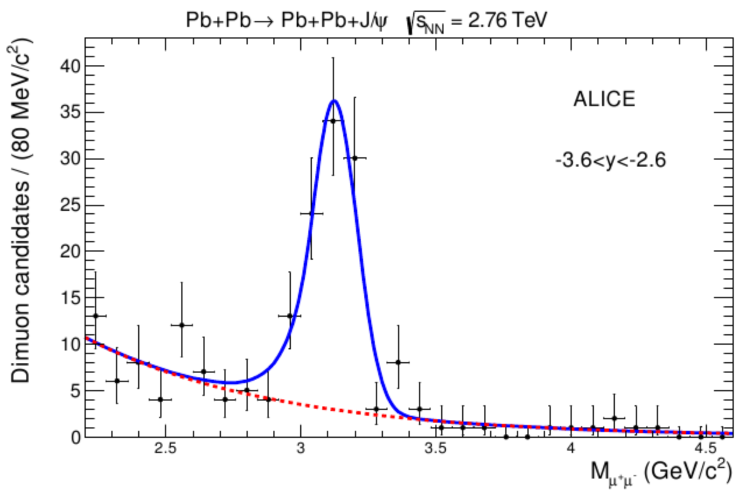


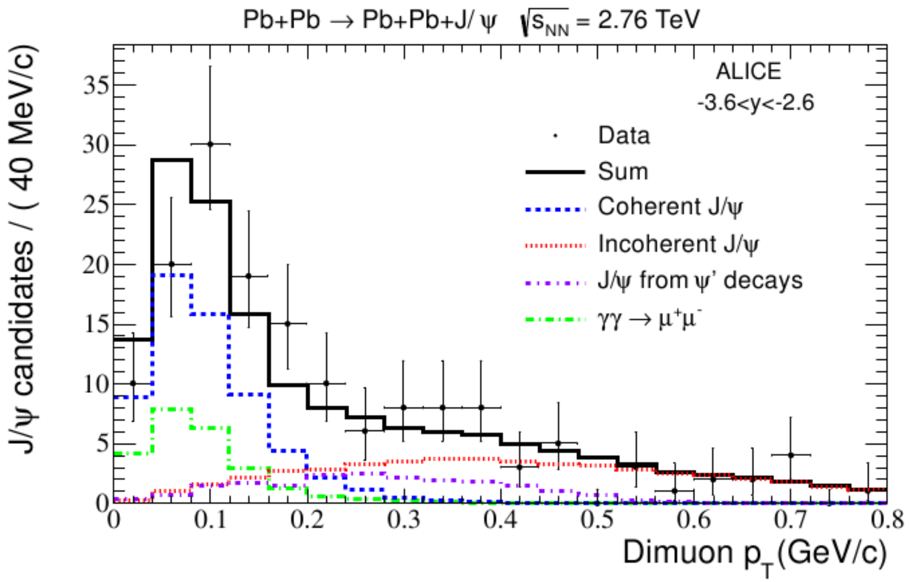


Integrated luminosity ~ 55 μb^{-1}

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
- $\gamma\gamma \rightarrow \mu\mu$

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

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

ALICE: Phys. Lett. B718 (2013) 1273

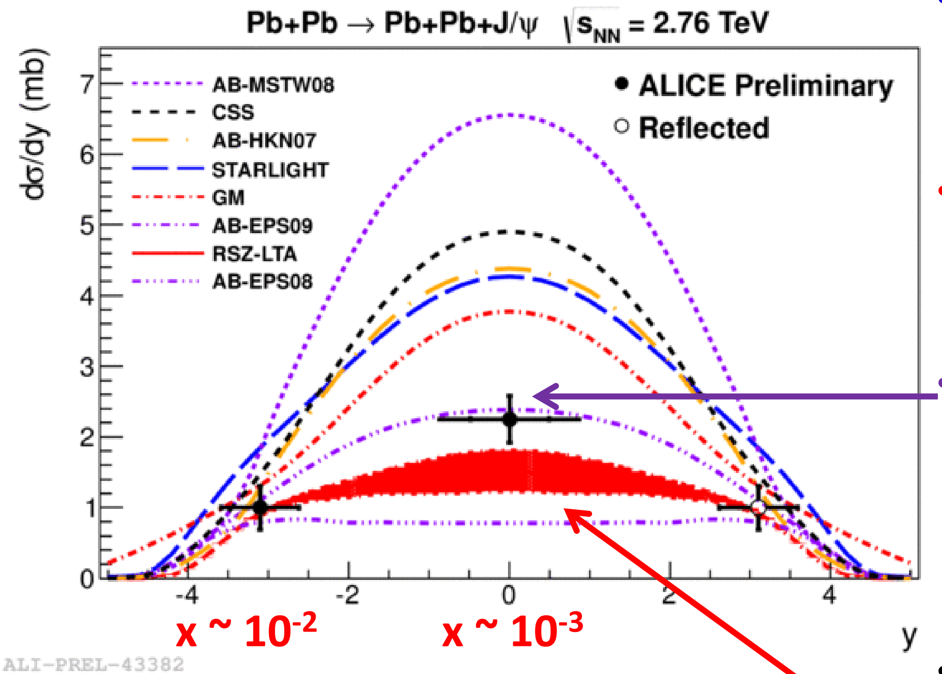
$$\frac{d\sigma_{\rm coh}}{dy} = \frac{1}{BR} \cdot \frac{N_{\rm coh}}{N_{\gamma\gamma}} \cdot \frac{({\rm Acc\ x\ }\epsilon)_{\gamma\gamma}}{({\rm Acc\ x\ }\epsilon)_{\rm coh}} \frac{\sigma_{\gamma\gamma}}{\Delta y}$$

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

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

ALICE: Phys. Lett. B718 (2013) 1273

Coherent J/ψ: comparison to models



- **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

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

Plan to include also:

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

Conclusions and outlook

- 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
- $\sigma_{\gamma\gamma \to ee}$ cross section measured at mid-rapidity: LO implementation gives a satisfactory prediction

- Incoherent J/Ψ at mid-rapidity coming soon;
- ρ vector meson production analysis in progress;
- J/Ψ production in p-Pb and Pb-p interaction in progress