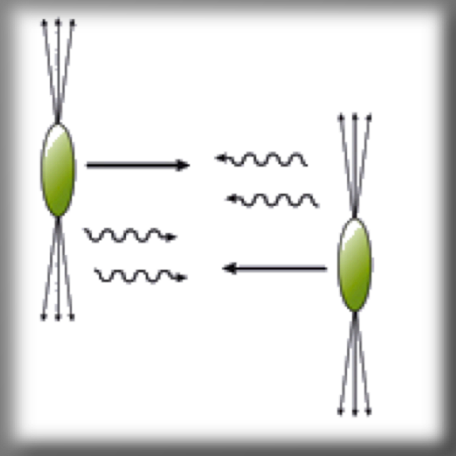
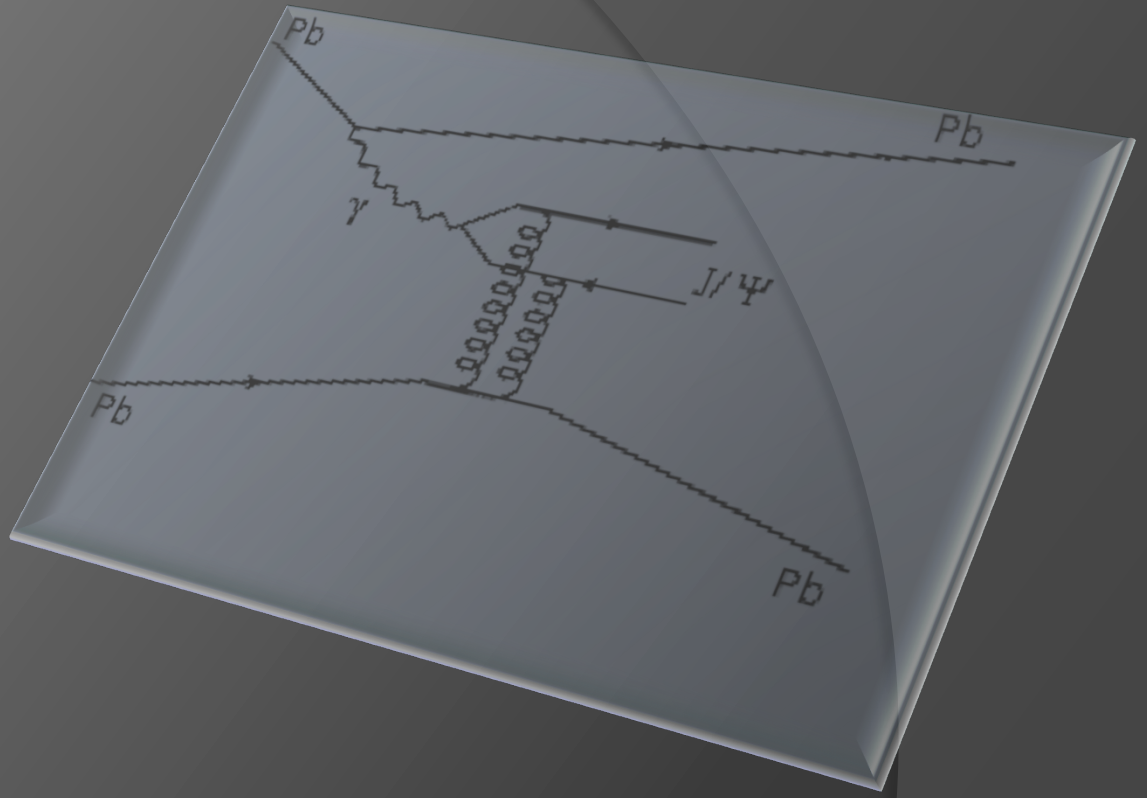




J/ψ photoproduction in Pb-Pb and p-Pb ultra-peripheral collisions with ALICE at LHC

D. De Gruttola* for the ALICE Collaboration

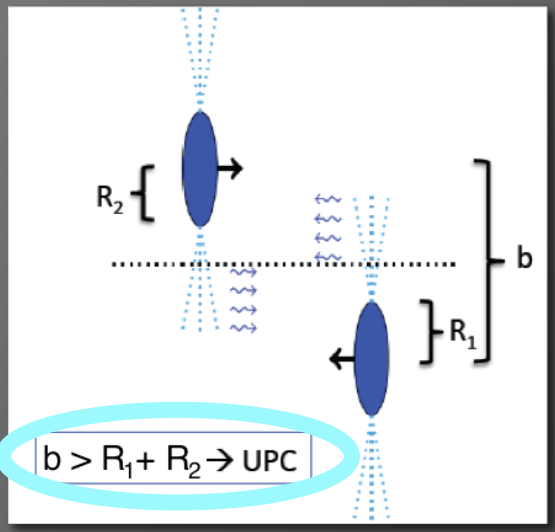
*Centro Fermi Roma and Salerno INFN - Italy

Overview

- ✓LHC as γPb and γp collider (Ultra-peripheral collisions)
- ✓Physics motivation (gluon distribution in nuclei and nucleons)
- ✓ALICE and UPCs (detector and trigger description)
- ✓J/ψ cross section (forward and mid-rapidity)
- ✓results and comparison with models (gluon shadowing)
- ✓$\gamma\gamma$ cross section (constraint on QED processes)
- ✓first results in pA (proton as a target)
- ✓conclusions (achieved results and on going analyses)

LHC as γPb and γp collider

- ✓ at the LHC heavy ions are accelerated towards each other at ultra relativistic energies
- ✓ being charged particles, they are accompanied by an electromagnetic field
- ✓ the EM field can be viewed as a flux of quasi-real photons
- ✓ intensity of the photon beam proportional to Z^2
- ✓ photon flux well described in Fermi-Weizsäcker-Williams approximation
- ✓ hadronic processes strongly suppressed when $b > R_1+R_2$
- ✓ high σ for γ-induced reactions e.g. vector meson photoproduction



- ✓ virtuality of the photon dependent on the radius of the emitting particle:

$$Q^2 \approx \left(\frac{\hbar c}{R}\right)^2$$

$$\gamma \text{ from p} \rightarrow Q^2 \approx (250\,MeV)^2$$

$$\gamma \text{ from Pb} \rightarrow Q^2 \approx (30\,MeV)^2$$

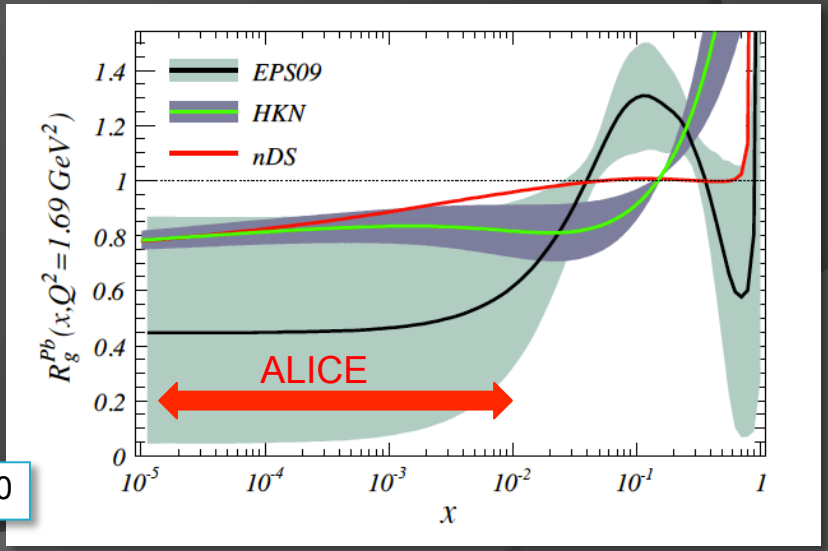
Physics motivation

- ✓ possibility to study non linear effects at low x in the gluon distribution of the target
- ✓ quarkonia photo-production allows to study the gluon density $G(x,Q^2)$ in Pb

$$\left.\frac{d\sigma(\gamma N \to VN)}{dt}\right|_{t=0} \approx \frac{\alpha_s \Gamma_{ee}}{3\alpha_e M_V^5} 16\pi^3 \left(xG(x,Q^2)\right)^2$$

- ✓ Bjorken-*x* accessible at LHC $x = (M_V/\sqrt{s_{NN}})\exp(\pm y) \sim 10^{-2} - 10^{-5}$
- ✓ vector meson photo-production as tool to measure nuclear gluon shadowing and saturation

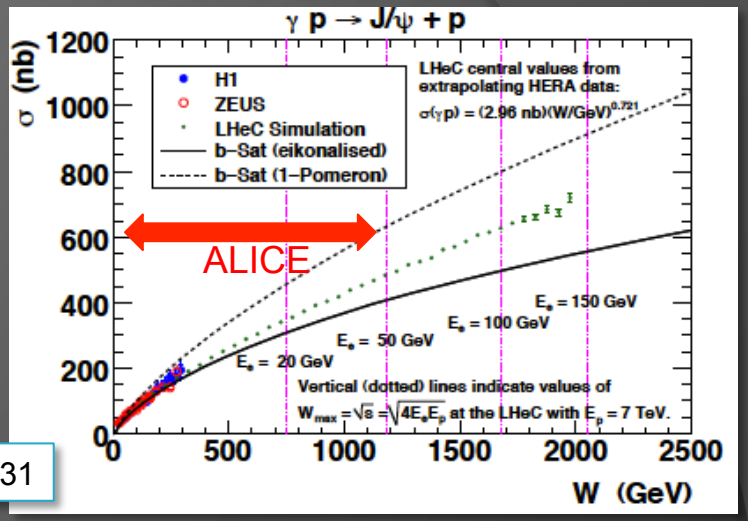
$$R_g^A(x,Q^2) = \frac{G_A(x,Q^2)}{G_p(x,Q^2)}$$



C A Salgado *et al* 2012 *J. Phys. G.: Nucl. Part. Phys.* **39** 015010

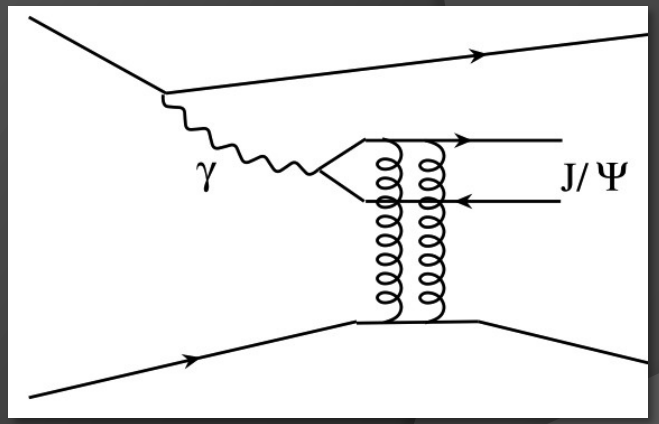
Physics motivation

- ✓ γp cms energy $W_{\gamma p}$

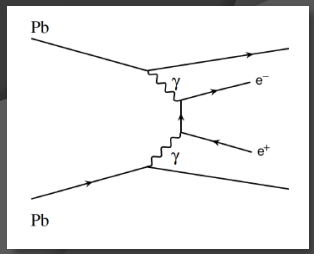


LHeC Study group ArXiv: 1211.4831

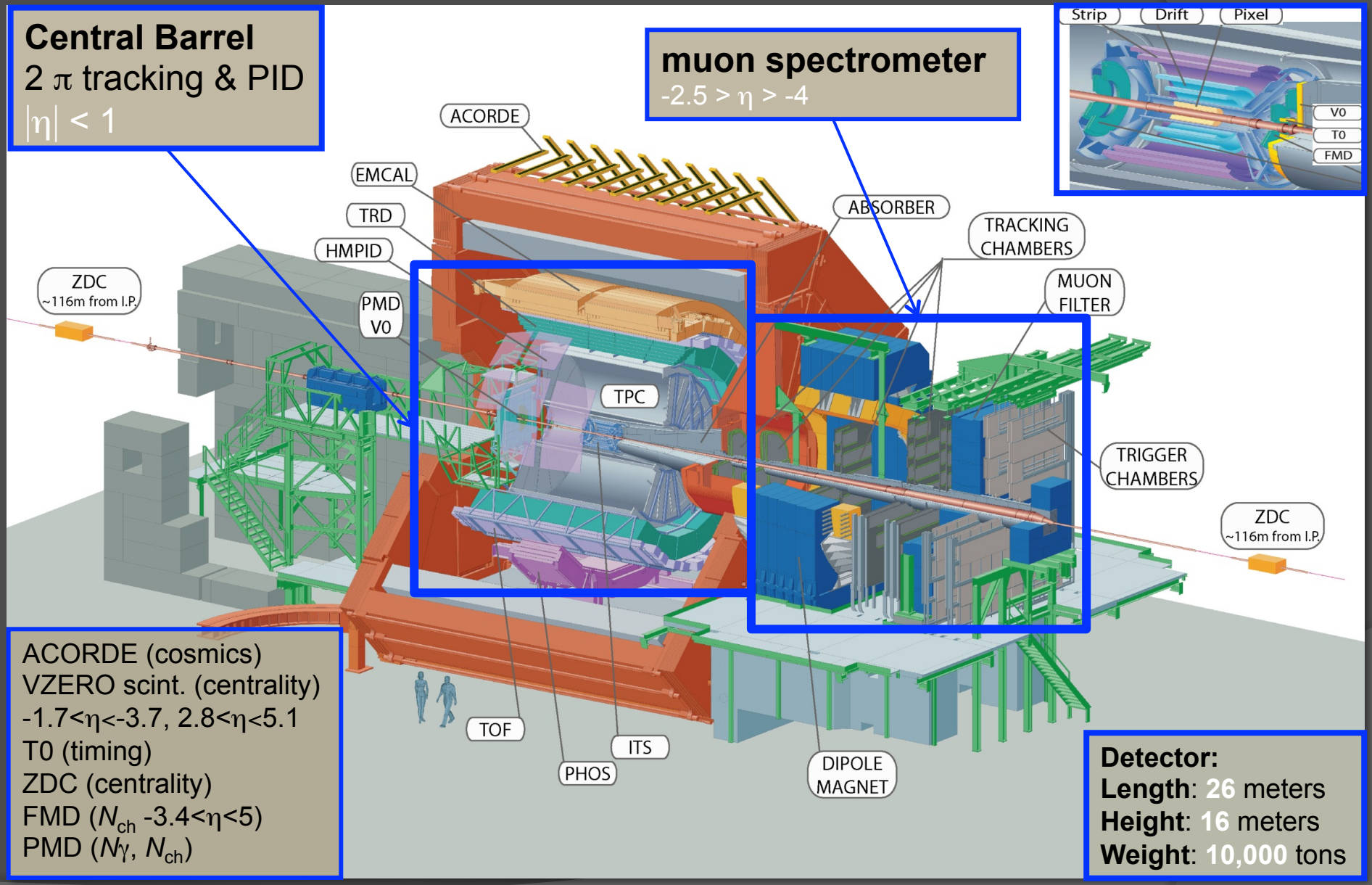
- ✓ coherent vector meson production:
  - ✧ photon couples coherently to all nucleons
  - ✧ $\langle p_T \rangle \sim 1/R_{Pb} \sim 60$ MeV/c
  - ✧ no neutron emission in ~80% of cases
- ✓ incoherent vector meson production:
  - ✧ photon couples to a single nucleon
  - ✧ $\langle p_T \rangle \sim 1/R_p \sim 500$ MeV/c
  - ✧ target nucleus normally breaks up



- ✓ an interesting physics case is also $\gamma\gamma$ interactions to provide informations on QED processes when the vertex $\sqrt{\alpha}$ is replaced by $Z\sqrt{\alpha}$



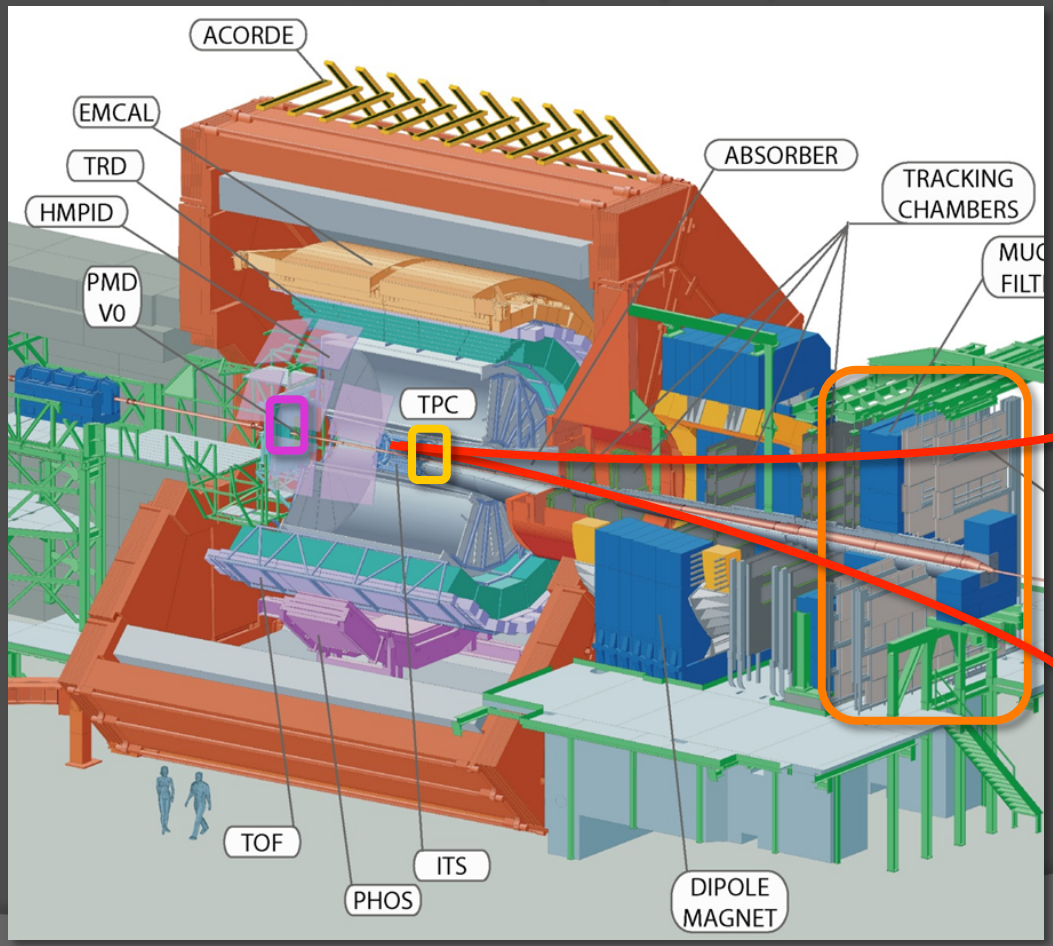
ALICE layout

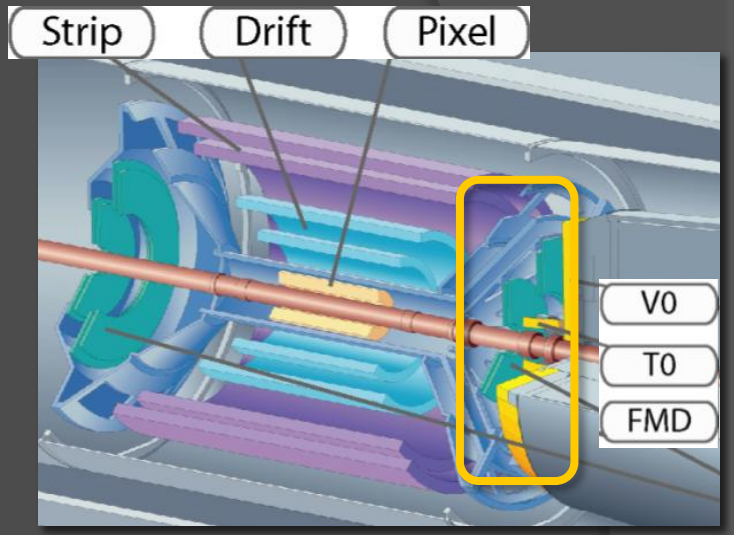


ALICE and UPCs ($J/\psi \rightarrow \mu^+\mu^-$)

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

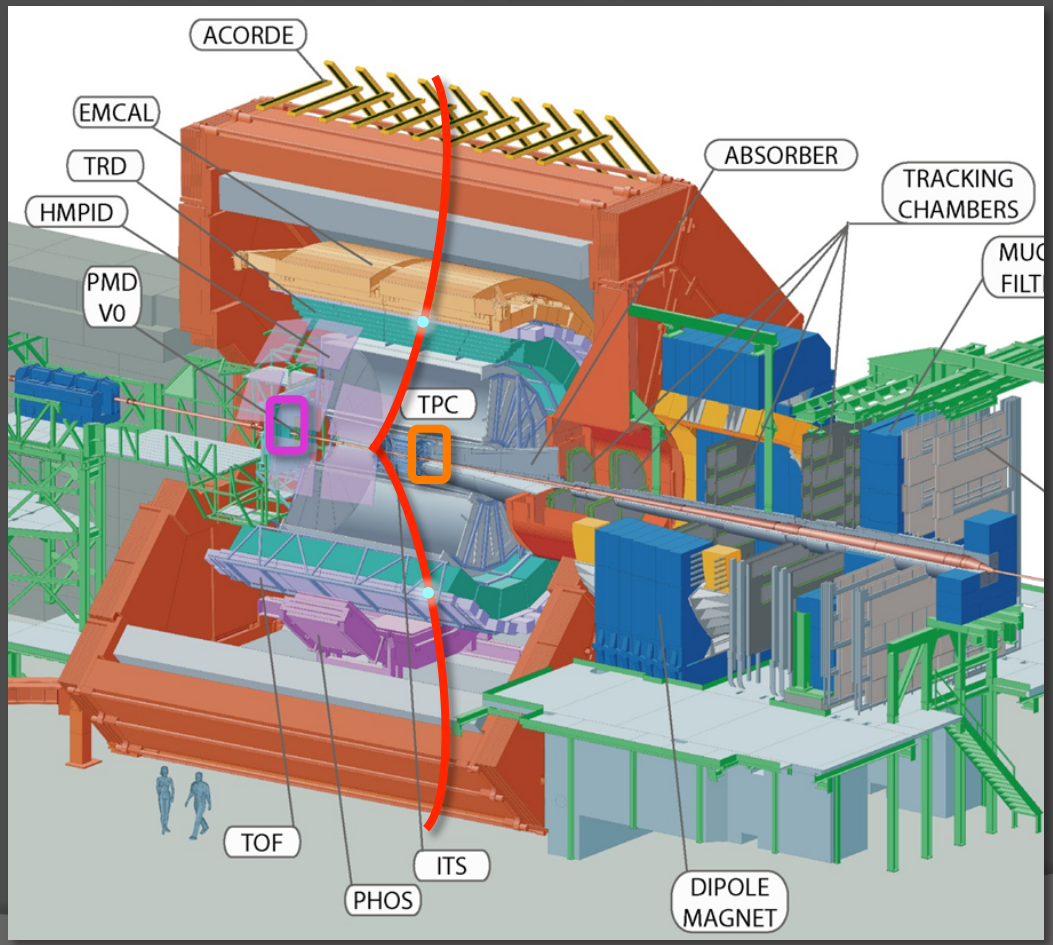
✓ track selection:

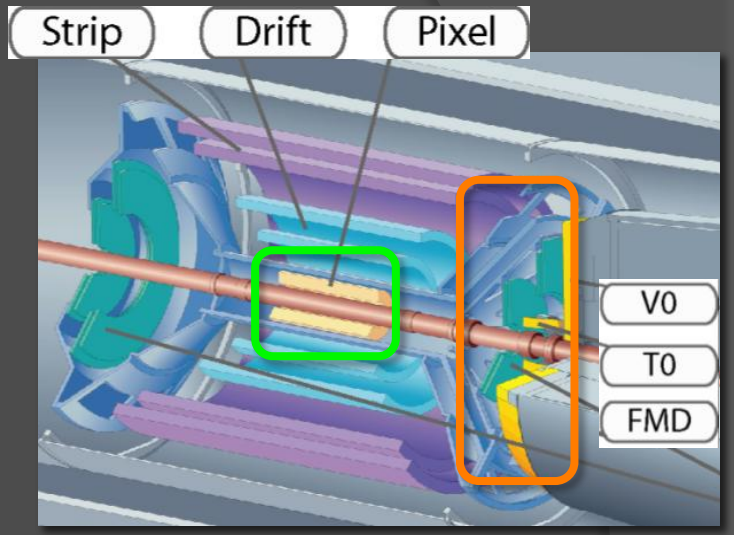
- ✧ muon tracks: $-3.7 < \eta < -2.5$
- ✧ matching with the trigger
- ✧ radial position for muons at the end of absorber: $17.5 < R_{abs} < 89.5$ cm
- ✧ p_T dependent DCA cut
- ✧ opposite sign dimuon: $-3.6 < y < -2.6$

ALICE and UPCs ($J/\psi \to \mu^+\mu^-$ and $J/\psi \to e^+e^-$)

UPC mid-rapidity trigger

- ≥ 2 hits in SPD
- 2≤ TOF hits ≤6 and back-to-back topology
- veto on VZERO-C and VZERO-A



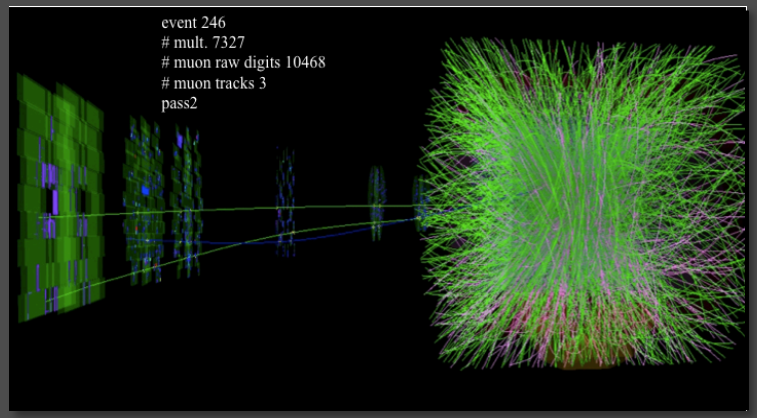


integrated luminosity ~ 23 μb^{-1}

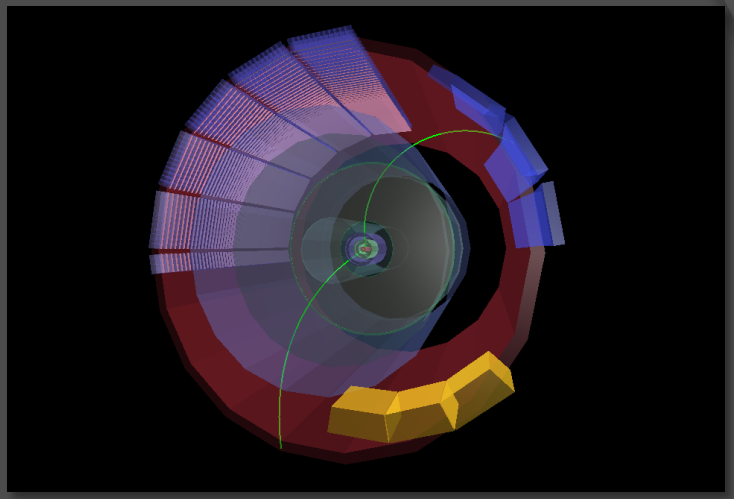
✓ offline event selection:

- rejection with VZERO and FMD
- primary vertex
- max (p_{T1}, p_{T2}) > 1 GeV/c
- dE/dx consistent with e/μ
- opposite sign tracks
- ZDC cut on number of neutrons emitted in coherent events

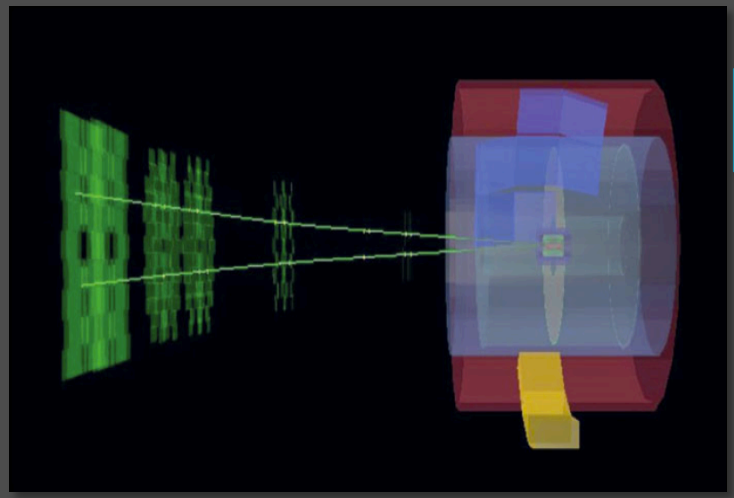
ALICE and UPCs



central Pb-Pb collision



UP Pb-Pb collision at mid-rapidity



UP Pb-Pb collision at forward rapidity

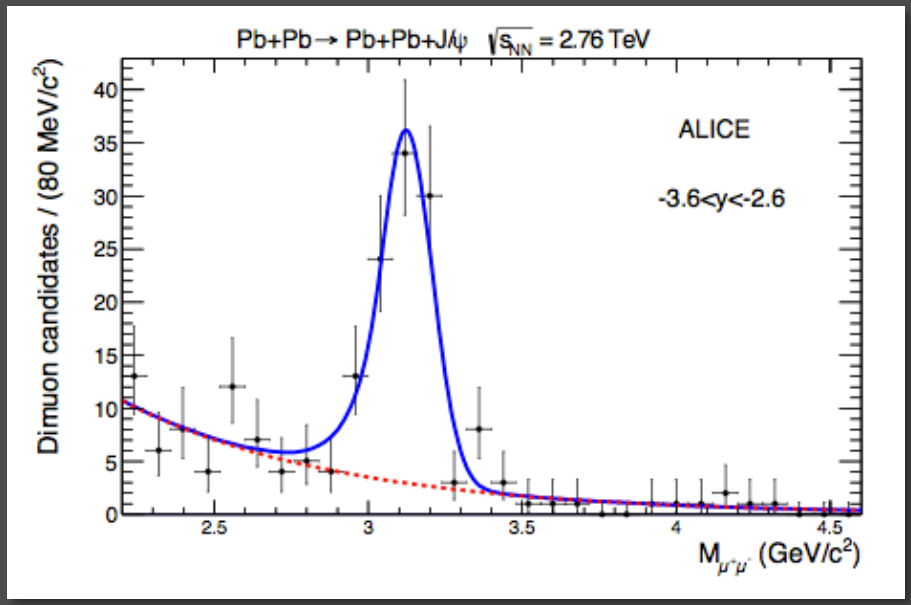
two tracks in an otherwise empty detector

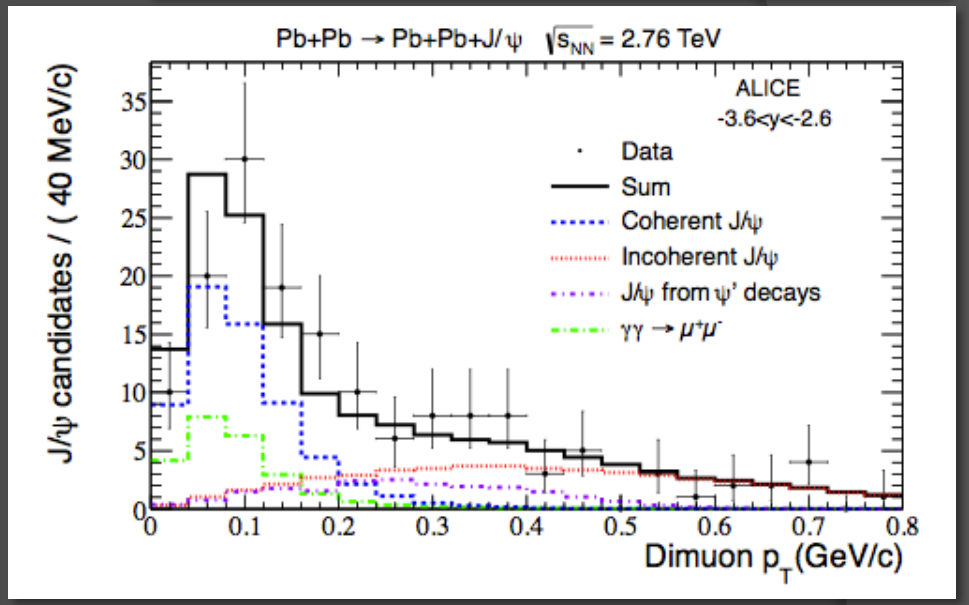
detailed studies done to understand the noise and the emptiness of the detector

J/ψ measurements (coherent at forward rapidity)

first measurement of J/ψ photo-production done at LHC

Phys. Lett. B718 (2013) 1273 -1283





p_T distribution fitted using MC samples representing several components:

- ✧ coherent and incoherent J/ψ
- ✧ ψ' feed down
- ✧ γγ → $\mu^+\mu^-$

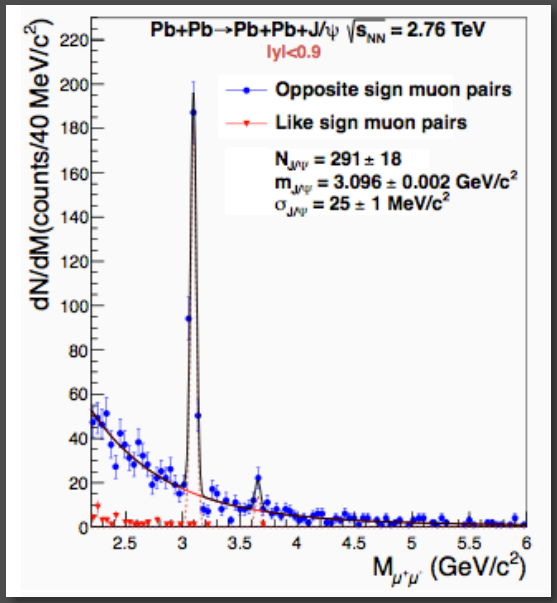
distribution peaked at low momentum as expected from coherent production

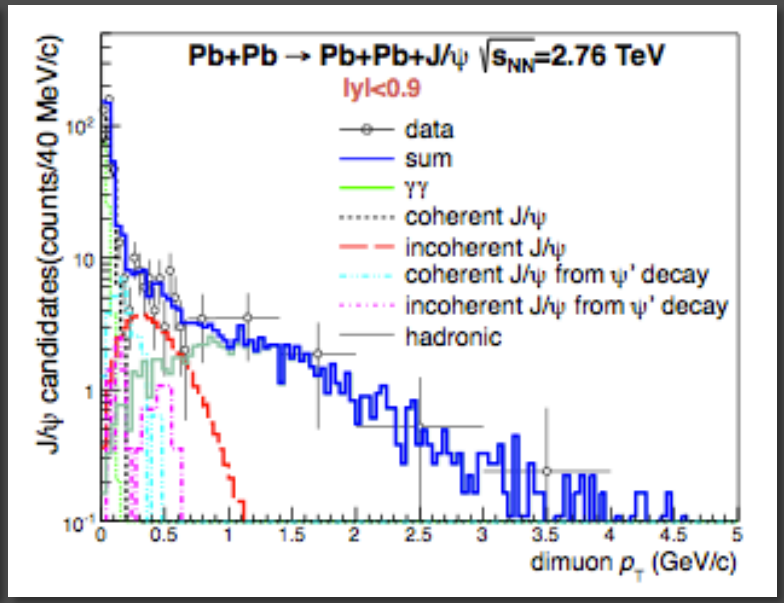
J/ψ photo-production probes the gluon distribution in Pb at x~10^{-2}

J/ψ measurements (coherent at mid-rapidity)

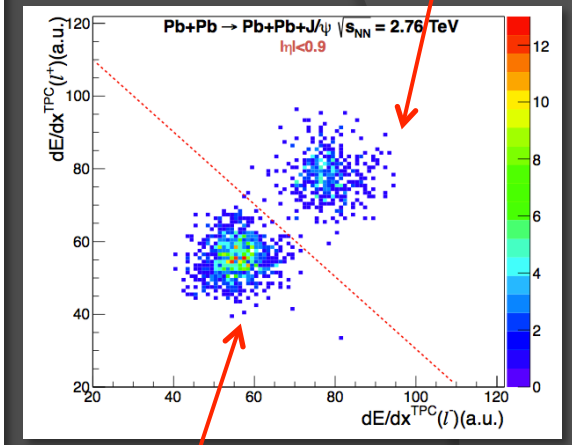
dimuon channel

arXiv:1305.1467 [nucl-ex] submitted to EPJ-C





electrons



muons

p_T distribution fitted using MC samples representing several components:

- coherent and incoherent J/ψ
- (coherent and incoherent) ψ' feed down
- $\gamma\gamma \rightarrow \mu^+\mu^-$
- hadronic

p_T < 200 MeV/c and < 6 neutrons emitted by nuclei

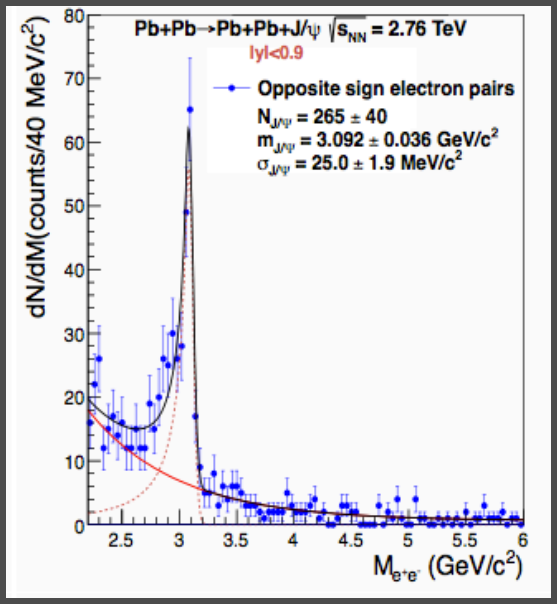
distribution peaked at low momentum as expected from coherent production

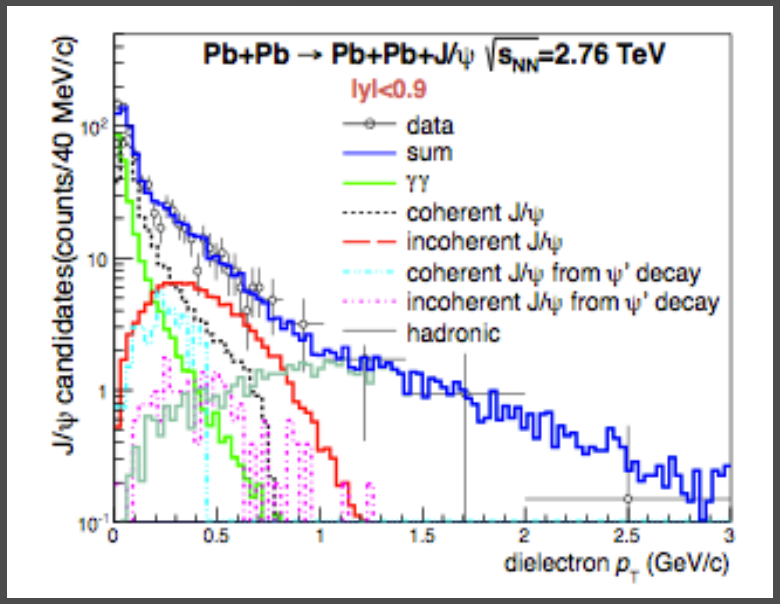
J/ψ photo-production probes the gluon distribution in Pb at $x \sim 10^{-3}$

J/ψ measurements (coherent at mid-rapidity)

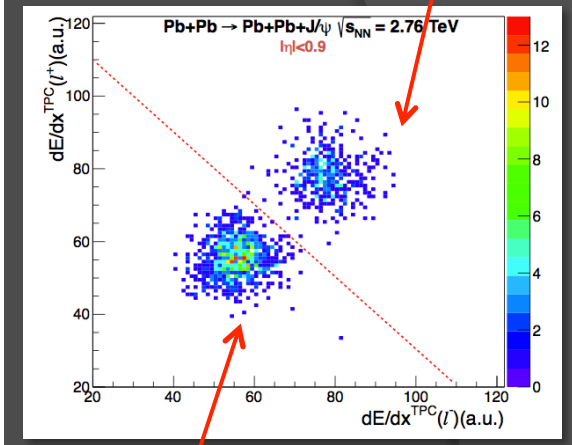
dielectron channel

arXiv:1305.1467 [nucl-ex] submitted to EPJ-C





electrons



muons

p_T distribution fitted using MC samples representing several components:

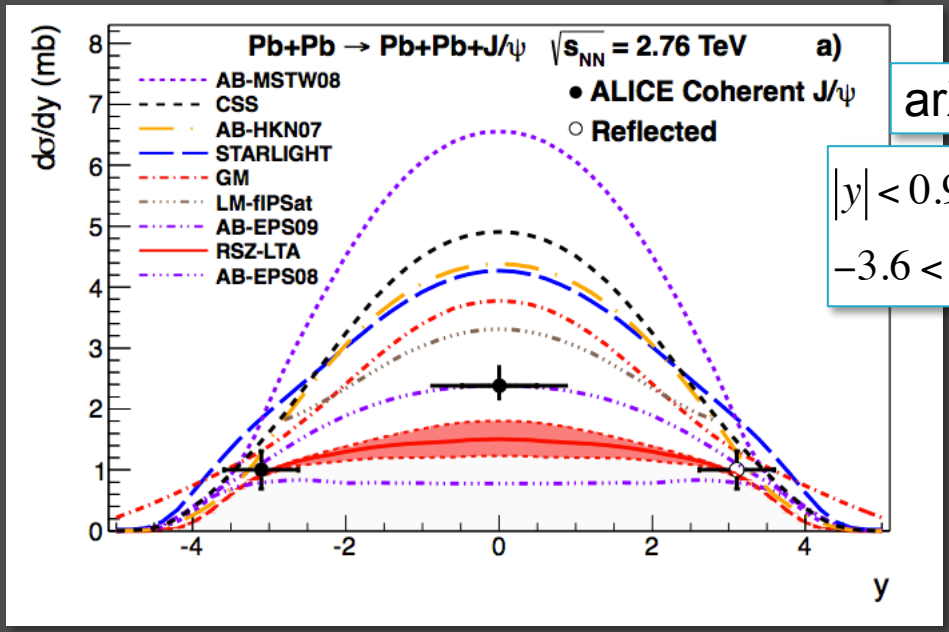
- coherent and incoherent J/ψ
- (coherent and incoherent) ψ' feed down
- $\gamma\gamma \rightarrow e^+e^-$
- hadronic

p_T < 300 MeV/c and < 6 neutrons emitted by nuclei

distribution peaked at low momentum as expected from coherent production

J/ψ photo-production probes the gluon distribution in Pb at $x \sim 10^{-3}$

Results and comparison with models



Phys. Lett. B718 (2013) 1273 -1283

arXiv:1305.1467 [nucl-ex] submitted to EPJ-C

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

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

data are closer to models incorporating nuclear gluon shadowing

✓ AB: Adeluyi and Bertulani, PRC85 (2012) 044904
these models use LO pQCD scaled by an effective constant to correct for missing contributions
MSTW08 assumes no nuclear effects, EPS08/09 incorporate nuclear effects according to different parametrizations

✓ CSS: Cisek, Szczurek, Sch.fer PRC86 (2012) 014905
color dipole model based on unintegrated gluon distribution of the proton

measured cross section in good agreement with the calculation using the EPS09 nuclear gluon prediction

✓ STARLIGHT: Klein, Nystrand PRC60 (1999) 01493
GVDM coupled to a Glauber approach and using HERA data to fix the γp cross section

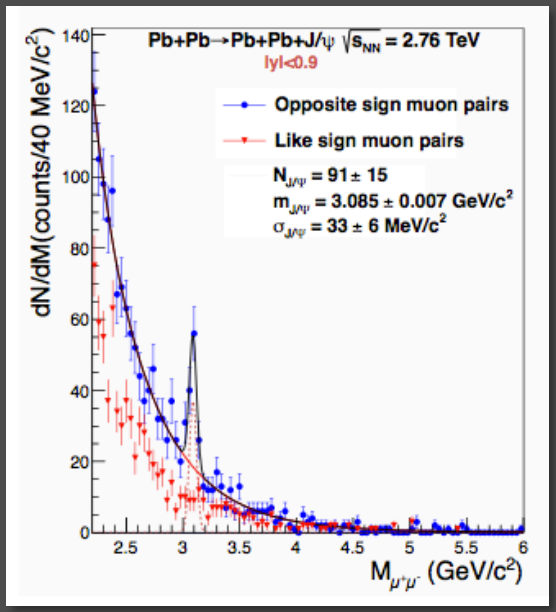
✓ GM: Goncalves, Machado, PRC84 (2011) 011902
color dipole model, where the dipole nucleon cross section is from the IIM saturation model

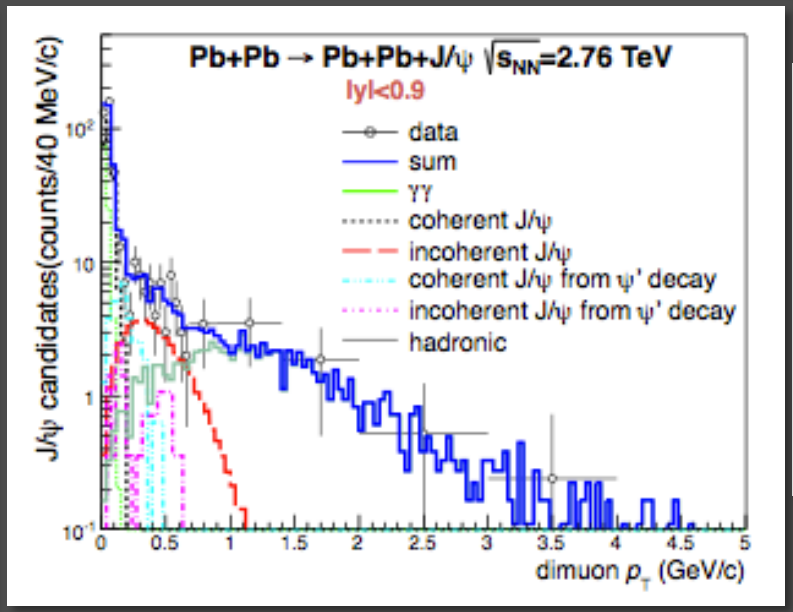
✓ RSZ: Rebyakova, Strikman, Zhalov, PLB 710 (2012) 252
based on LO pQCD amplitude for two gluon exchange where the gluon density incorporates shadowing computed in leading twist approximation

J/ψ measurements (incoherent at mid-rapidity)

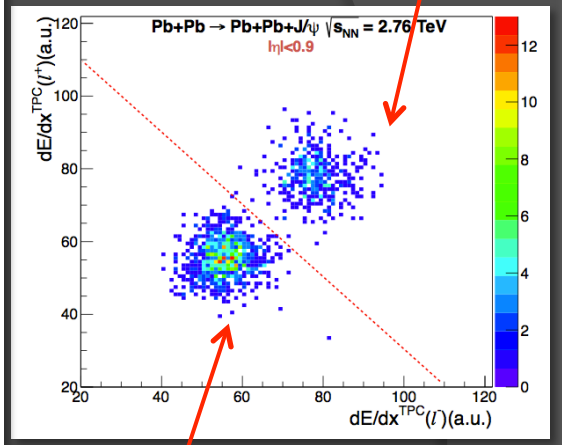
dimuon channel

arXiv:1305.1467 [nucl-ex] submitted to EPJ-C





electrons



muons

p_T distribution fitted using MC samples representing several components:

- coherent and incoherent J/ψ
- (coherent and incoherent) ψ' feed down
- $\gamma\gamma \rightarrow \mu^+\mu^-$
- hadronic

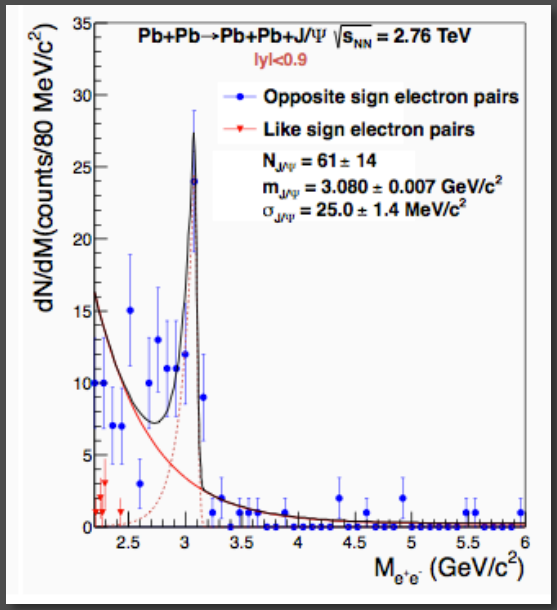
$p_T > 200$ MeV/c

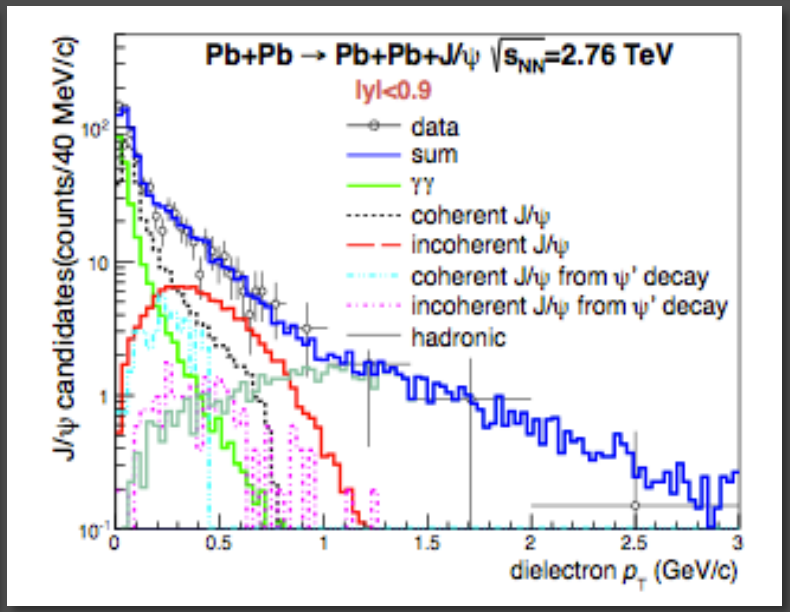
the ratio $\sigma_{inc}/\sigma_{coh}$ provides further constraints on the treatment of the nuclear modifications implemented in the different models

J/ψ measurements (incoherent at mid-rapidity)

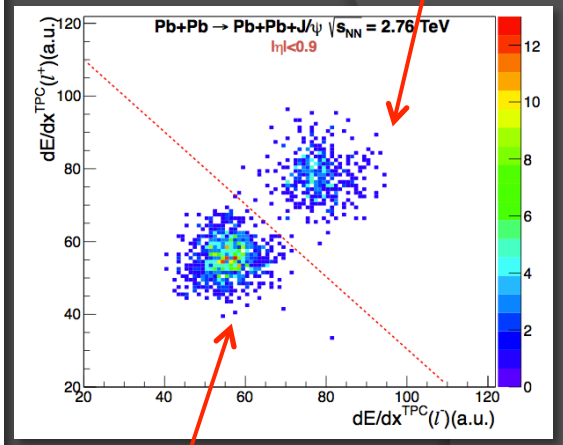
dielectron channel

arXiv:1305.1467 [nucl-ex] submitted to EPJ-C





electrons



muons

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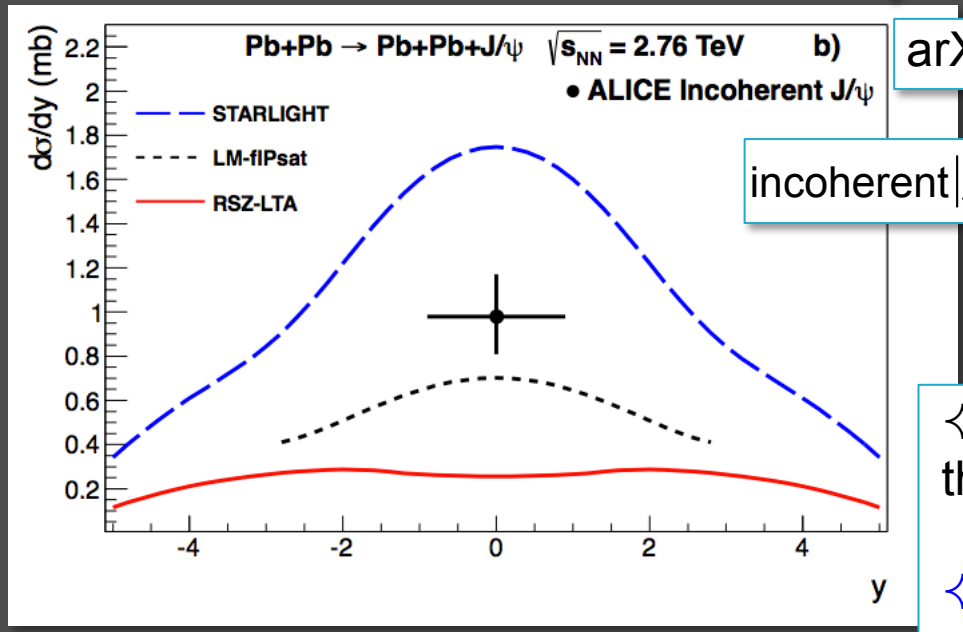
Results and comparison with models



arXiv:1305.1467 [nucl-ex] submitted to EPJ-C

incoherent $|y| < 0.9 \rightarrow d\sigma^{inc}_{J/\psi}/dy = 0.98^{+0.19}_{-0.17}(stat+syst)$ mb

✧ none of the three existing models predicts the incoherent cross section correctly

✧ STARLIGHT predicts a correct incoherent-to-coherent ratio (0.41)

✧ ALICE measurement $0.41^{+0.10}_{-0.08}(stat+syst)$

✓ STARLIGHT: Klein, Nystrand PRC60 (1999) 01493
GVDM coupled to a Glauber approach and using HERA data to fix the γp cross section

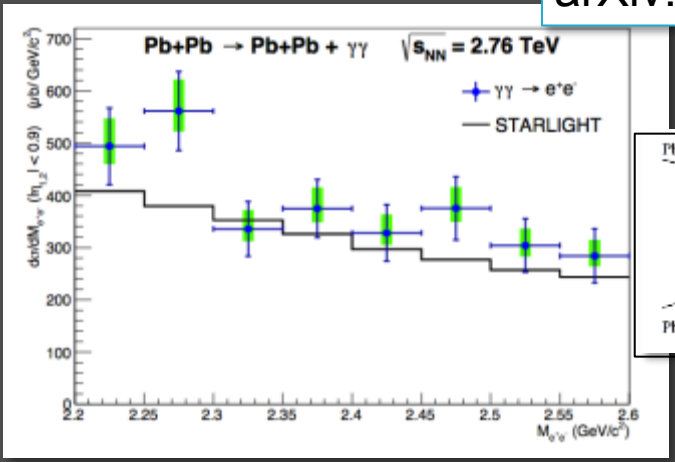
✓ RSZ: Rebyakova, Strikman, Zhalov, PLB 710 (2012) 252
based on LO pQCD amplitude for two gluon exchange where the gluon density incorporates shadowing computed in leading twist approximation

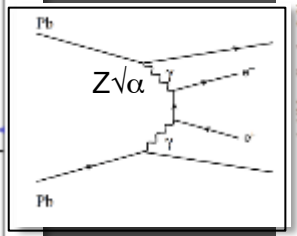
✓ LM: Lappi, Mantysaari, PRC87 (2013) 032201
color dipole model based with Glauber approach and a saturation prescription

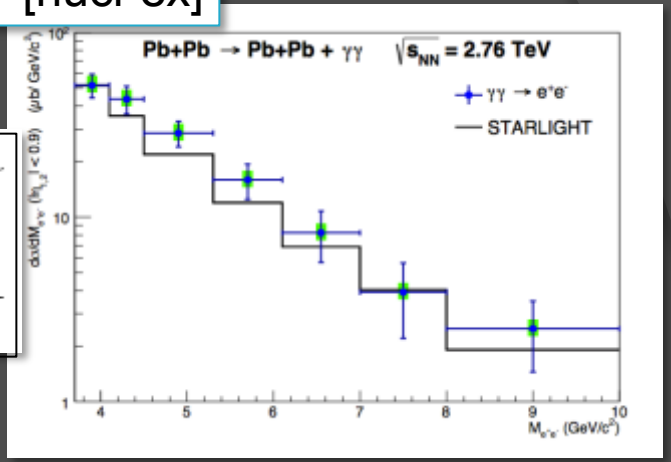
the ratio $\sigma_{inc}/\sigma_{coh}$ provides further constraints on the treatment of the nuclear modifications implemented in the different models

γγ cross section

arXiv:1305.1467 [nucl-ex]





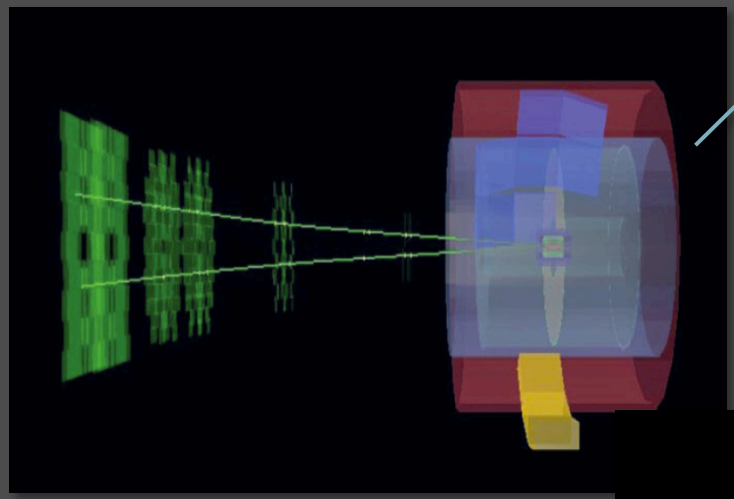


- ✓ the γγ cross section measurement provides important constraints on QED calculations when the vertex $\sqrt{\alpha}$ has to be replaced by $Z\sqrt{\alpha}$
- ✓ due to the large Pb charge, giving $Z\sqrt{\alpha} \sim 0.6$, the inclusion of higher order terms is not straightforward → the models* including higher order terms predict a reduction of the cross section up to 30%
  - ✧ [2.2,2.6] GeV/c² → $\sigma_{\gamma\gamma}^{e^+e^-} = 154 \pm 11(stat)^{+16.6}_{-10.8}(syst)\ \mu b$ precision 12%
  - ✧ [3.7,10] GeV/c² → $\sigma_{\gamma\gamma}^{e^+e^-} = 91 \pm 10(stat)^{+10.9}_{-8.0}(syst)\ \mu b$ precision 16%
- ✓ the measured values for the γγ cross sections are 20% above but fully compatible within 1.0 σ and 1.5 σ with the STARLIGHT (LO) prediction for the low and high invariant mass intervals (128 μb and 77 μb)

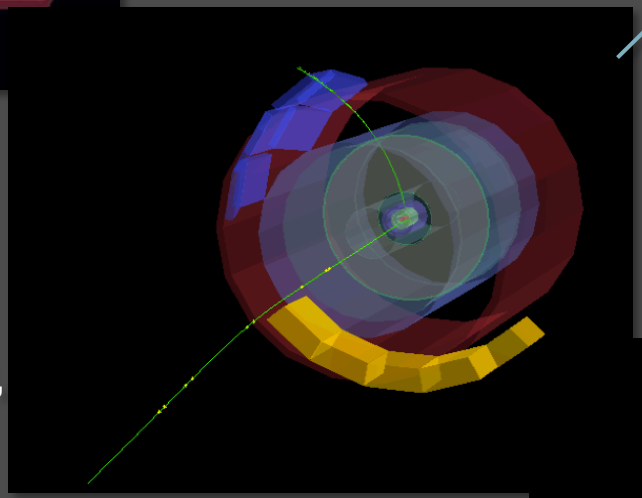
→ the models predicting a strong contribution of higher-order terms (not included in STARLIGHT) are not favored

*Baltz P*hys. Review 80 2009 034-901*

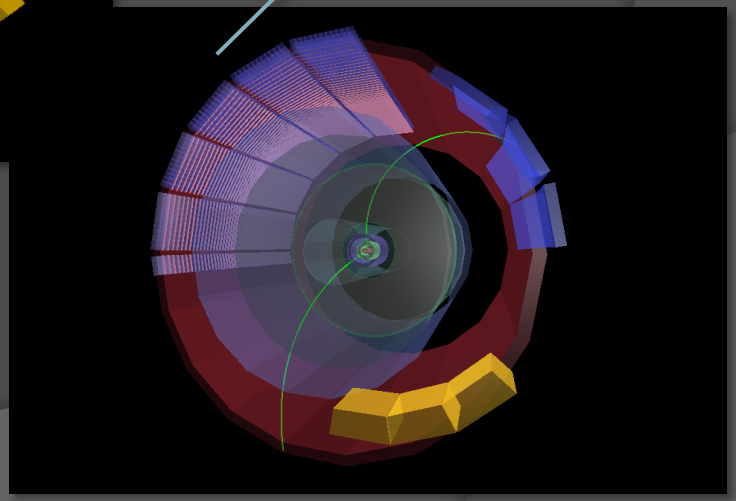
UPCs in pA



forward rapidity ($J/\psi \rightarrow \mu^+\mu^-$)



semi-forward rapidity ($J/\psi \rightarrow \mu^+\mu^-$)



mid-rapidity ($J/\psi \rightarrow \mu^+\mu^-$ and $J/\psi \rightarrow e^+e^-$)

trigger logic:

- ✓ similar to Pb+Pb case for forward and mid-rapidities, but improved purity
- ✓ semi-forward
  - ✧ V0A and V0C (≥5 cells) vetoed
  - ✧ SPD multiplicity (≥ 7 outer chips) vetoed
  - ✧ single muon with p_T>0.5GeV/c
  - ✧ SPD (≥ 1 chips)

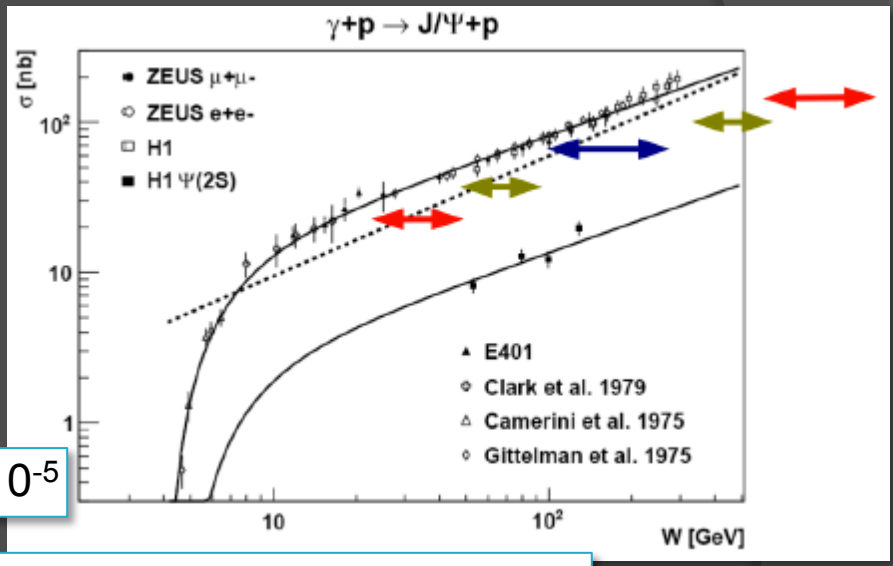
ALICE Physics potential in pA

J/ψ photoproduction dominated by γ+p process

p-Pb: proton moves towards the muon arm
Pb-p: Pb-nucleus moves towards the muon arm

accessible kinematics regions:

p+Pb forward	$21<W_{\gamma p}<45$ GeV
p+Pb semi-forward	$45<W_{\gamma p}<82$ GeV
mid-rapidity	$100<W_{\gamma p}<250$ GeV
Pb+p semi-forward	$300<W_{\gamma p<}550$ GeV
Pb+p forward	$550<W_{\gamma p}<1160$ GeV



possibility to study gluon PDFs in proton up to $x\sim10^{-5}$

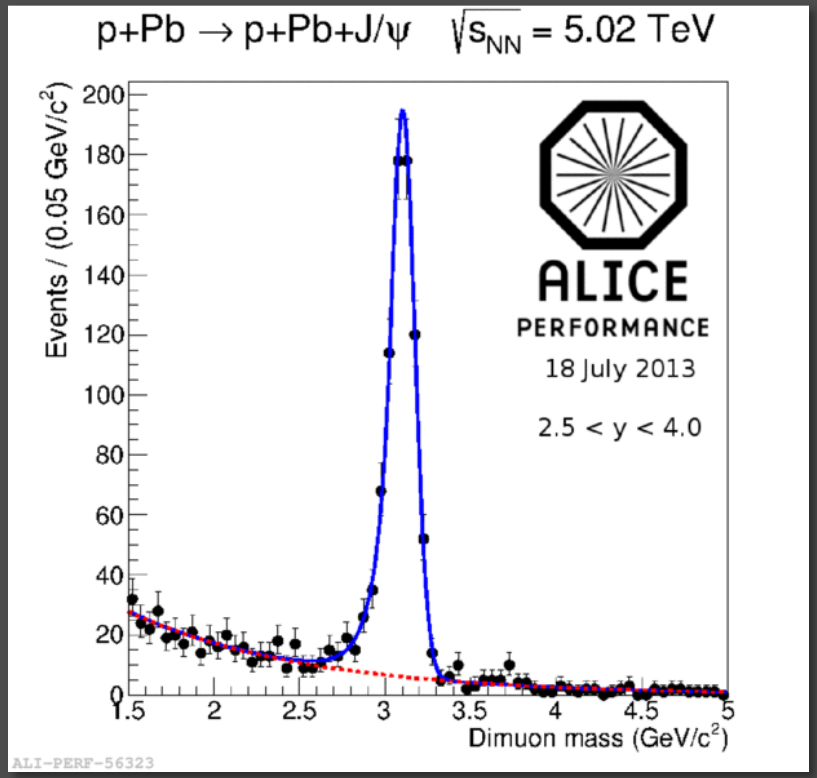
H1: A. Aktas et al. Eur.Phys. J.C46:585-603,2006 ZEUS: S. Chekanov et al., Nucl. Phys. B695 (2004) 3

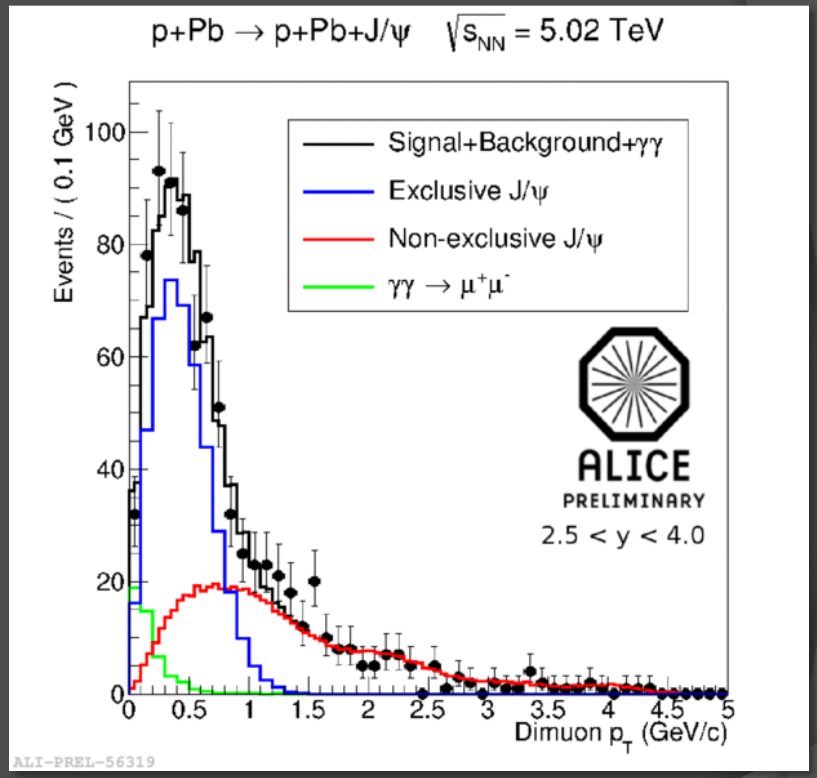
- ✓ HERA energy range extended by factor of ~ 3
- ✓ lower energy of the HERA experiments covered

- ✓ preliminary results at forward rapidity
- ✓ analysis ongoing for central and semi-forward samples

Exclusive J/ψ production in p-Pb

- ✓ forward rapidity p-Pb (p → muon arm side)
- ✓ γ-proton CM energies: 21<W<45 GeV, <W> = 29.8 GeV

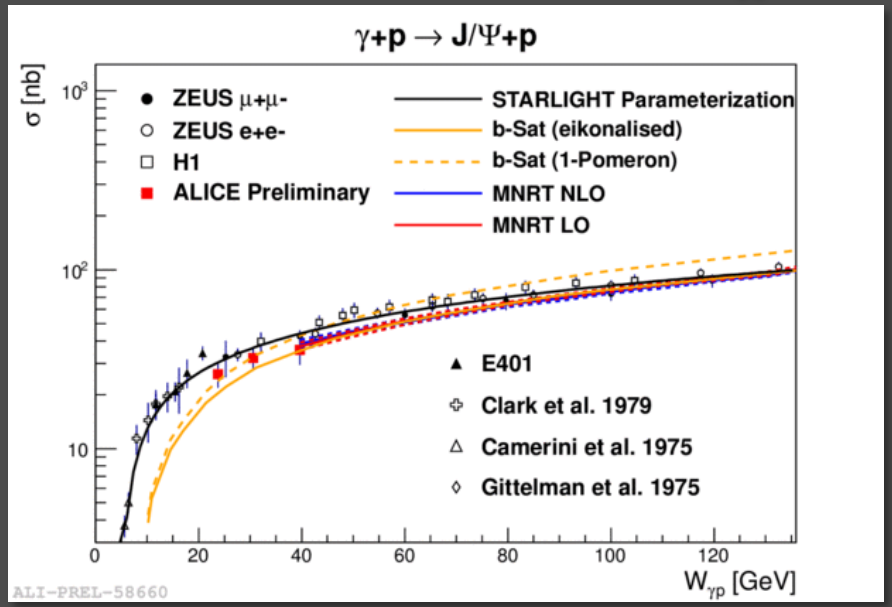




- ✓ contribution from events where the proton breaks up (dissociation)
- ✓ shape of non-exclusive J/ψ p_T distribution estimated from data by considering events with more than 2 hits in V0-C

*rapidity indicated in the plots are in the lab frame

Measured cross sections in p-Pb (preliminary)



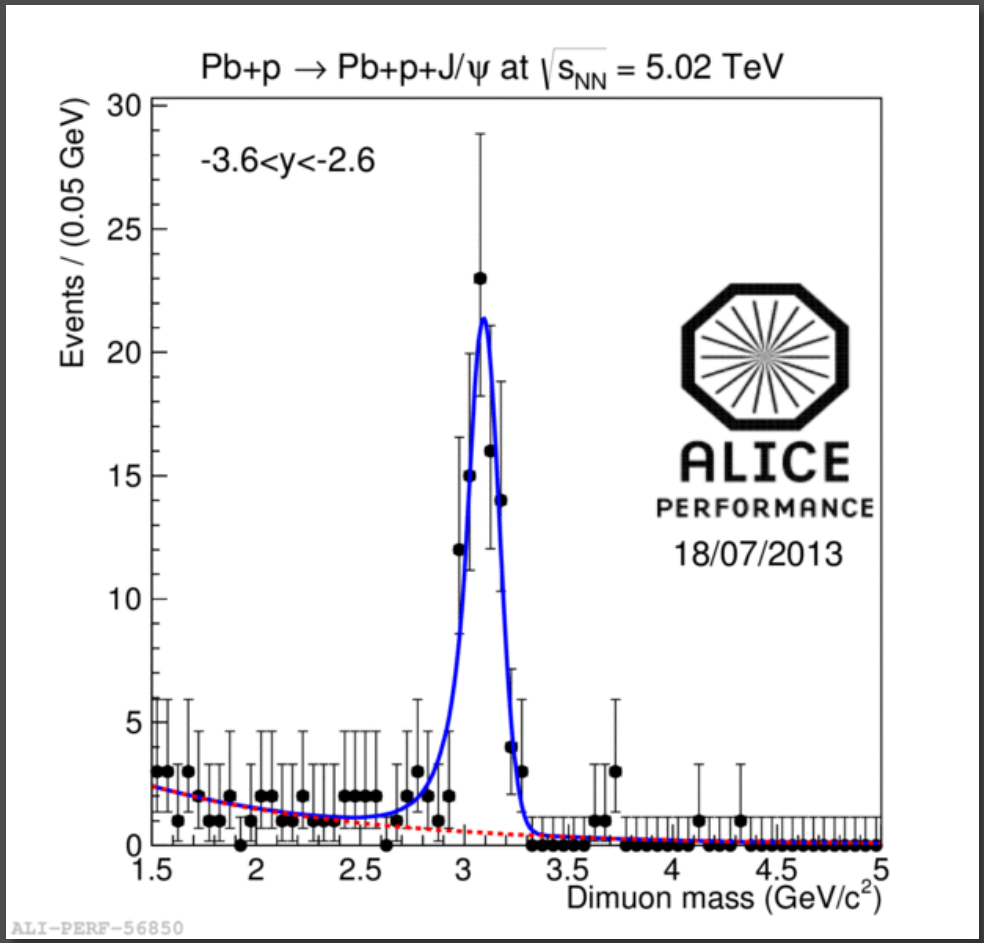
- ✓ ALICE cross section as a function of rapidity in the lab frame
- ✓ comparison with fixed-target experiments and model calculations
- ✓ consistency between ALICE and HERA exclusive cross section
- ✓ correction for feed down from ψ'
- ✓ measured σ(p-Pb) to σ (γ+p) through the photon spectrum $n_\gamma(y)$:

$$d\sigma(p+Pb \rightarrow p+Pb+J/\psi)/dy = n_\gamma(y)\ \sigma(\gamma+p \rightarrow J/\psi+p)$$

rapidity	$d\sigma(p-Pb \rightarrow p-Pb+J/\psi)/dy(\mu b)$
-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)

Exclusive J/ψ production in Pb-p

✓ forward rapidity Pb-p (Pb → muon arm side)



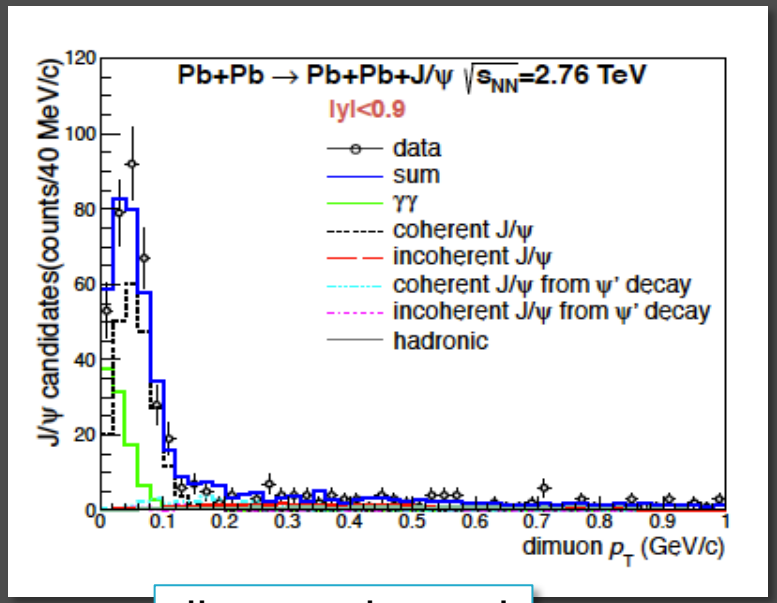
✓ analysis on going (as for mid and semi forward rapidities)

Conclusions

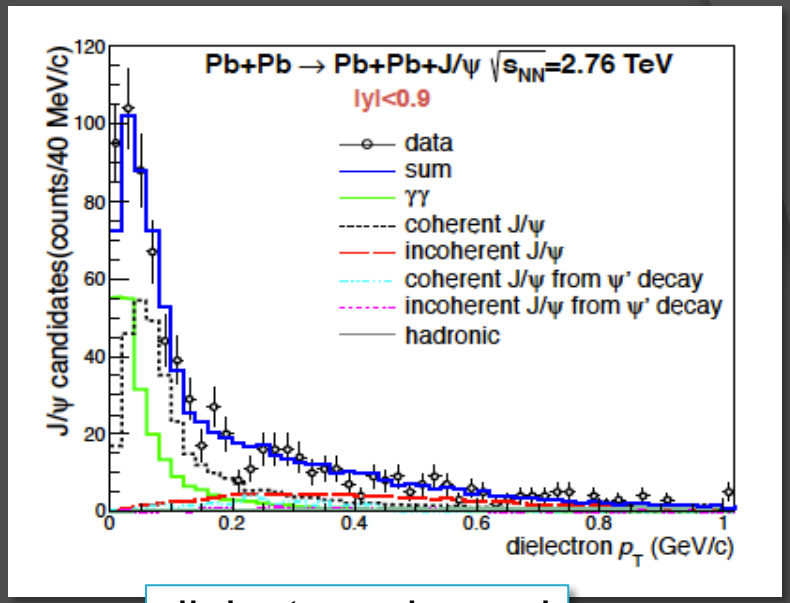
- ✓ LHC as γPb and γp collider to study $\gamma\gamma$, photo-nuclear and γp processes
- ✓ measurement of exclusive vector meson (J/ψ) cross sections to investigate the gluon distribution in the nuclei
- ✓ results agree with EPS09 gluon distribution, confirming the presence of gluon shadowing
- ✓ $\gamma\gamma$ cross section to set limits on higher order terms in QED processes
- ✓ two ALICE papers:
  - ✧ Phys. Lett. B718 (2013) 1273-1283
  - ✧ arXiv:1305.1467 [nucl-ex]
- ✓ p-Pb: good agreement on J/ψ photoproduction from previous experiments at $\langle W \rangle \sim 30$ GeV
  - ✧ first results on exclusive J/ψ in γp
  - ✧ results at higher energies $578 < W_{\gamma p} < 972$ GeV soon

back up

p_T distributions (linear scale)



dimuon channel



dielectron channel

p_T distribution fitted using MC samples representing several components:

- coherent and incoherent J/ψ
- (coherent and incoherent) ψ' feed down
- $\gamma\gamma \rightarrow \mu^+\mu^-$
- hadronic

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

distribution peaked at low momentum as expected from coherent production

Feed down ($\psi' \rightarrow J/\Psi$ + anything)

- ✓ fraction f_D of J/Ψ coming from the decay of $\psi' \rightarrow J/\Psi$ + anything estimated by simulating a sample of coherently produced ψ' with STARLIGHT, using PYTHIA to simulate their decay into J/Ψ

- ✓ contribution from incoherent ψ' expected to be negligible for the enriched coherent J/Ψ samples → not considered

- ✓ ψ' polarization can be shared between J/Ψ and the other daughters → ψ' decay simulated assuming no polarization, full transverse and full longitudinal polarization for the J/Ψ

for a given polarization P:

$$f_D^P = \frac{\sigma_{\psi'} \cdot BR(\psi' \rightarrow J/\psi + \text{anything}) \cdot (\text{Acc} \times \varepsilon)^P_{\psi' \rightarrow J/\psi}}{\sigma_{J/\psi} \cdot (\text{Acc} \times \varepsilon)_{J/\psi}}$$

see table in the next slide for the results

Feed down ($\psi' \rightarrow J/\Psi$ + anything)

alternatively the ratio ψ' over J/Ψ, used to compute the feed-down f_D, can be extracted from the data

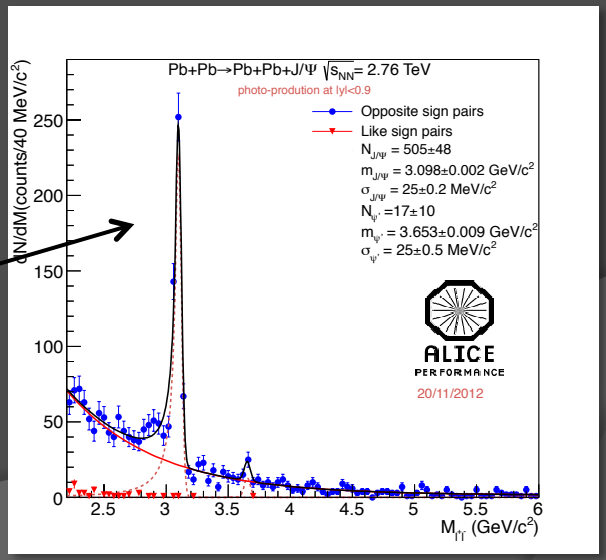
due to the limited statistics the two decay channels were combined:

$N_{\psi'}$ = 17±10 and $N_{J/\psi}$ = 505±48

$$f_D^P = \frac{N_{\psi'} \cdot BR(J/\psi \rightarrow l^+l^-) \cdot BR(\psi' \rightarrow J/\psi + \text{anything}) \cdot (\text{Acc} \times \varepsilon)^P_{\psi' \rightarrow J/\psi}}{N_{J/\psi} \cdot BR(\psi' \rightarrow l^+l^-)(\text{Acc} \times \varepsilon)^P_{\psi' \rightarrow l^+l^-}}$$

→ f_D ranges from 11.0±6.5% for transverse ψ' polarization to 15±9% for longitudinal ψ' polarization

the average of these estimates is $f_D = 0.10^{+0.05}_{-0.06}$



invariant mass distribution for combined dimuon and dielectron channels

Fit procedure

- ✓ exponential for underlying continuum (systematics evaluated using polynomial)
- ✓ Crystall Ball (exp+gauss) to extract the J/Ψ signal
- ✓ tail CB parameters (α and n) left free for the coherent sample (systematics evaluated fixing the paramters) and fixed to MC values for the incoherent one
- ✓ incoherent dimuons fitted also using a polynomial to take into account the combinatorial background, as constrained to the LS pair spectrum
- ✓ fit also constrained to a MC cocktail (J/Ψ + $\gamma\gamma$)