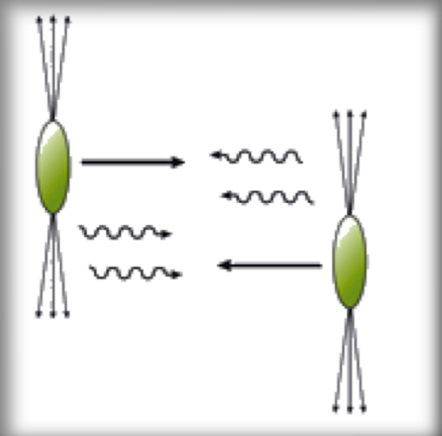
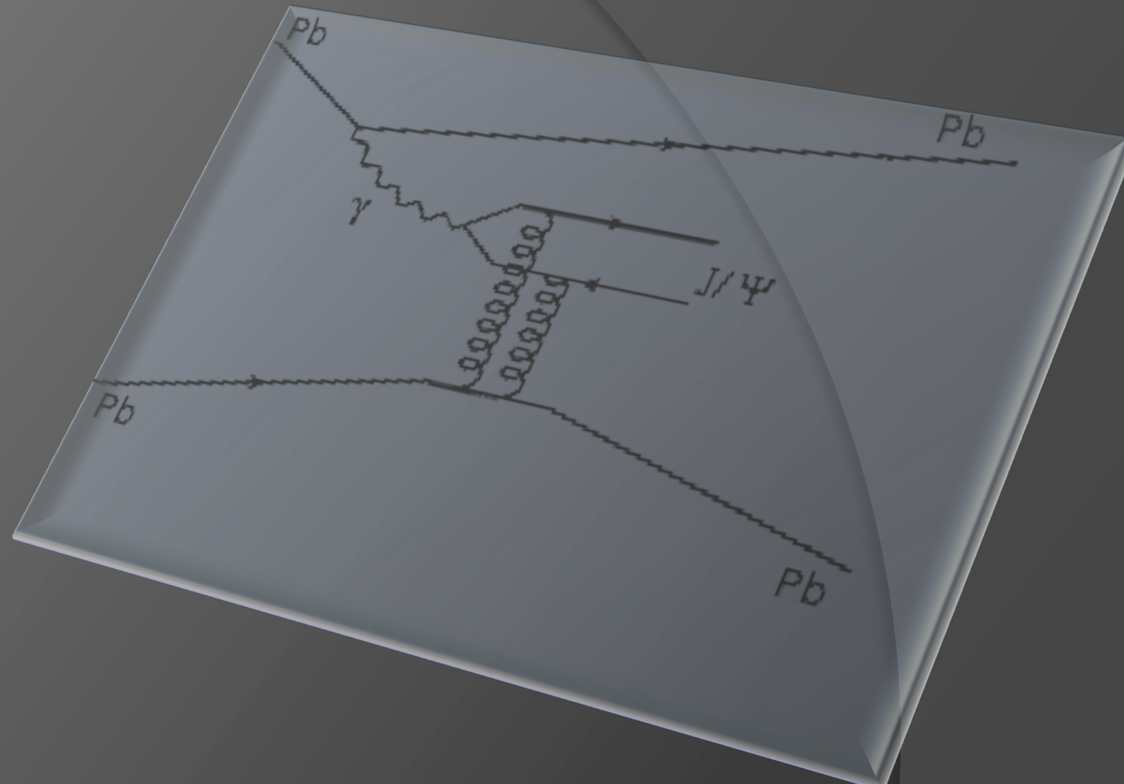




Ultra-peripheral J/ψ production with ALICE at LHC

D. De Gruttola* for ALICE Collaboration

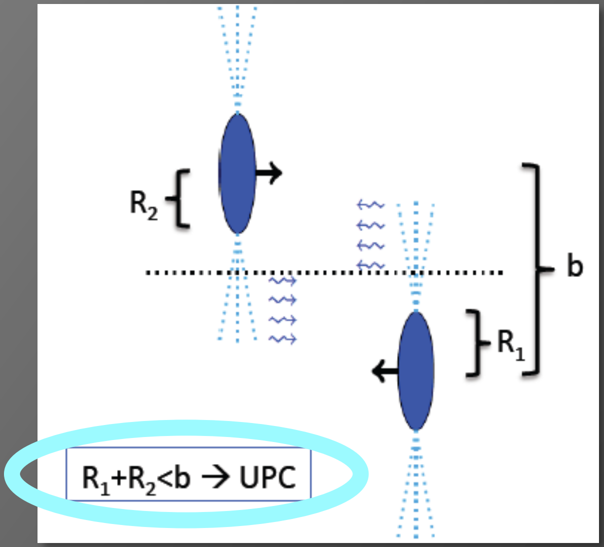
*Centro Fermi Roma and Salerno INFN - Italy

Summary

- ✓LHC as γPb collider (Ultra-peripheral collisions)
- ✓Physics motivation (gluon distribution in the nuclei)
- ✓ALICE and UPCs (detector and trigger description)
- ✓coherent J/ψ measurement (forward and mid-rapidity)
- ✓incoherent J/ψ measurement (mid-rapidity)
- ✓results and comparison with models (gluon shadowing?)
- ✓$\gamma\gamma$ cross section (constraint on QED processes)
- ✓conclusions (achieved results and on going analyses)

LHC as γPb 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
- ✓ high σ for γ-induced reactions e.g. vector meson photoproduction



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

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

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

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

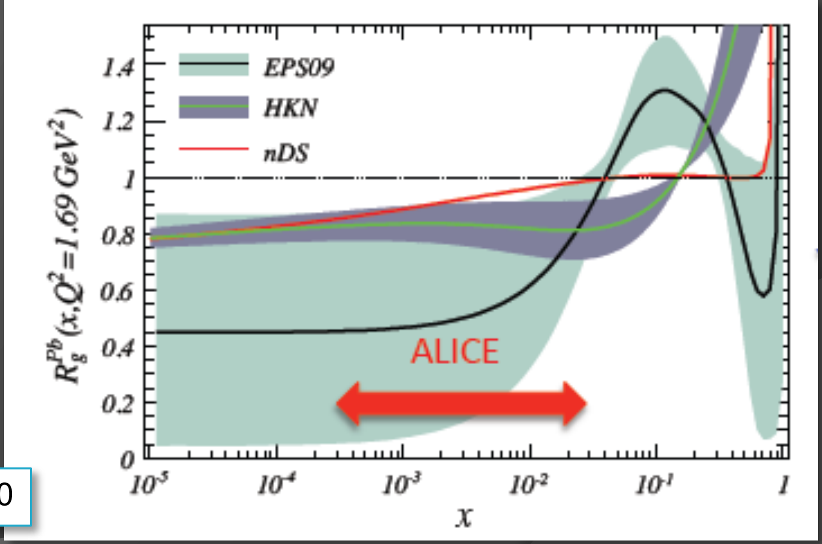
Physics motivation

- ✓ 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

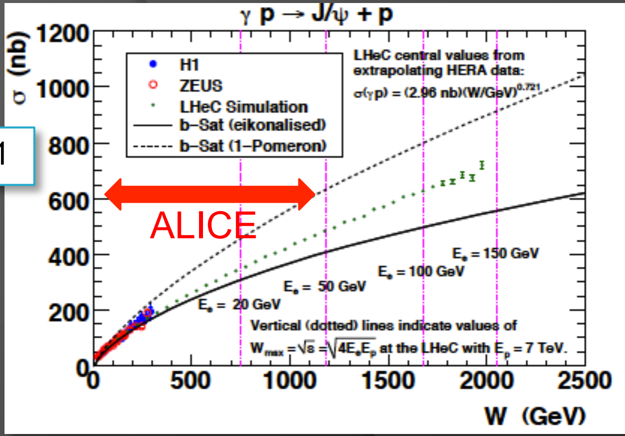
✓ some representative values for γA cms energy $W_{\gamma A}$:

✧ y = 0 → $W_{\gamma A}$~ 90 GeV

✧ y = -3 → $W_{\gamma A}$~ 400 or 20 GeV

(the flux of photons at 400 GeV is ~4% of the flux at 20 GeV)

LHeC Study group ArXiv: 1211.4831

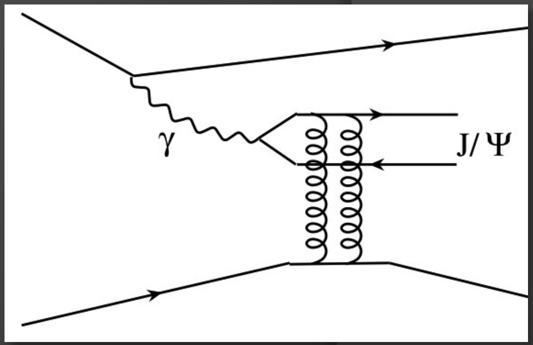


✓ coherent vector meson production:

✧ 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



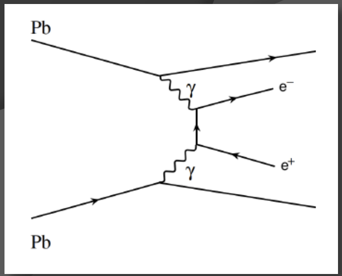
✓ incoherent vector meson production:

✧ photon couples to a single nucleon

✧ $\langle p_T \rangle \sim 1/R_p \sim$ 500 MeV/c

✧ target nucleus normally breaks up

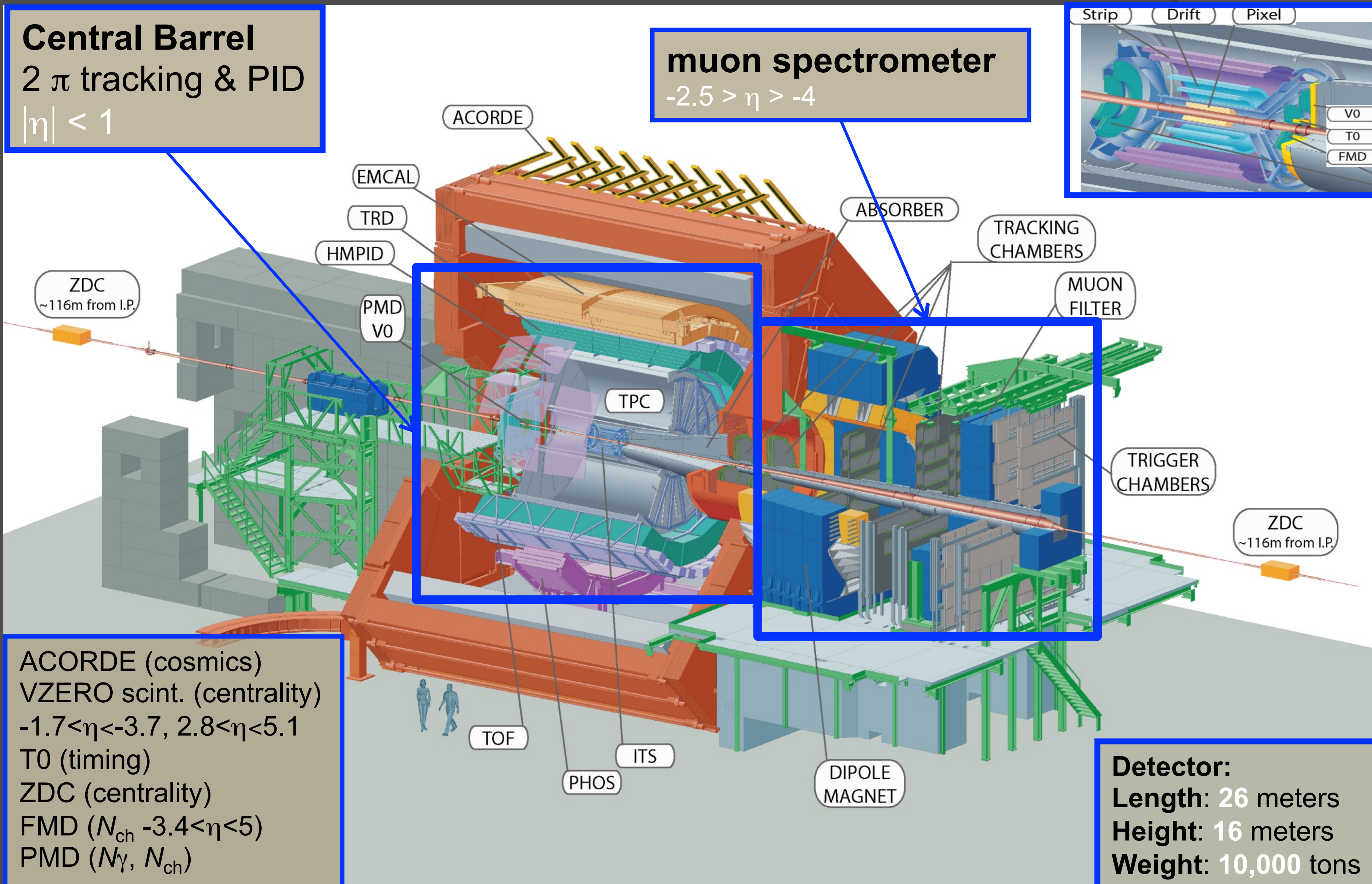
✓ an interesting physics case is also $\gamma\gamma$ interactions to provide informations on QED processes when $\sqrt{\alpha}$ is replaced by $Z\sqrt{\alpha}$



ALICE layout

Central Barrel
2 π tracking & PID
$|\eta| < 1$

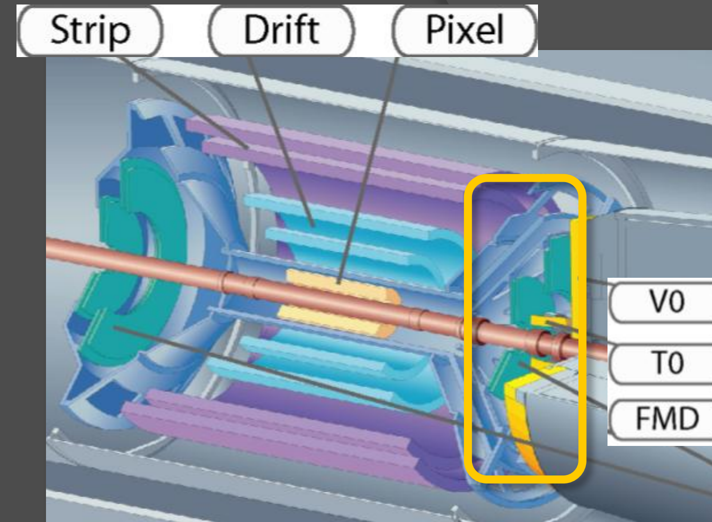
muon spectrometer
$-2.5 > \eta > -4$



ACORDE (cosmics)
VZERO scint. (centrality)
$-1.7<\eta<-3.7$, $2.8<\eta<5.1$
T0 (timing)
ZDC (centrality)
FMD (N_{ch} $-3.4<\eta<5$)
PMD ($N\gamma$, N_{ch})

Detector:
Length: **26** meters
Height: **16** meters
Weight: **10,000** tons

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

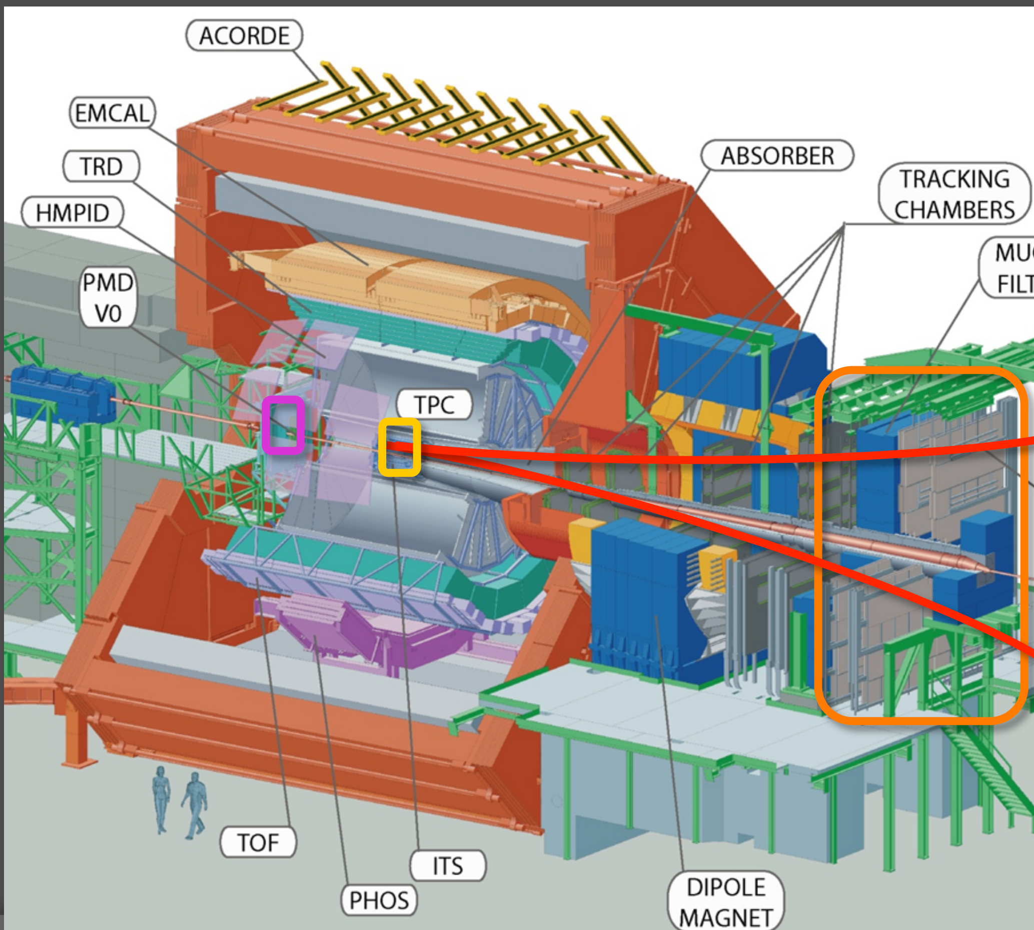


UPC forward trigger:

✧ 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:

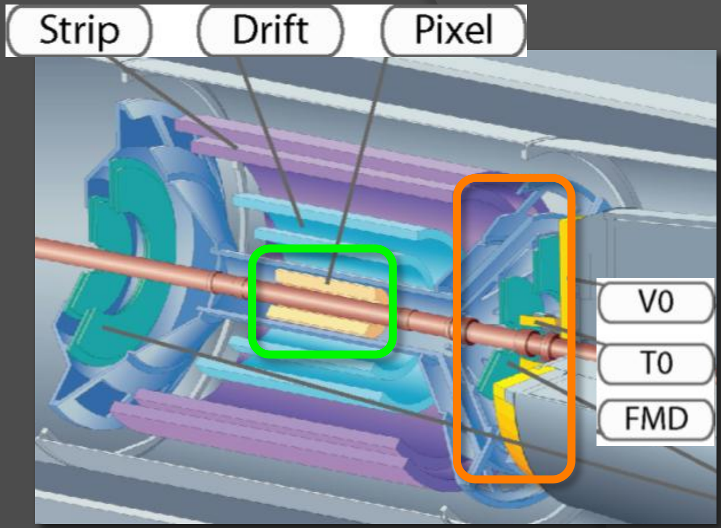
- ✧ beam gas rejection with VZERO
- ✧ hadronic rejection with ZDC and SPD

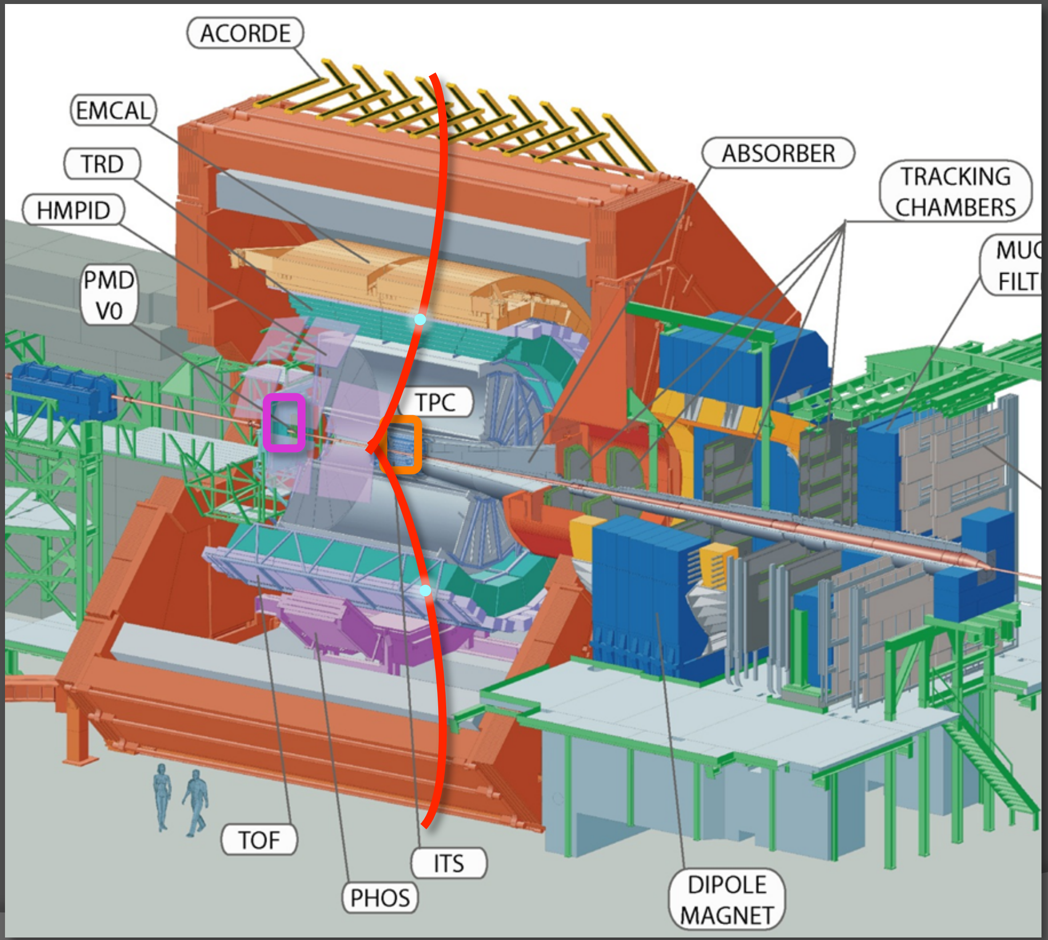
✓ track selection:

- ✧ 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



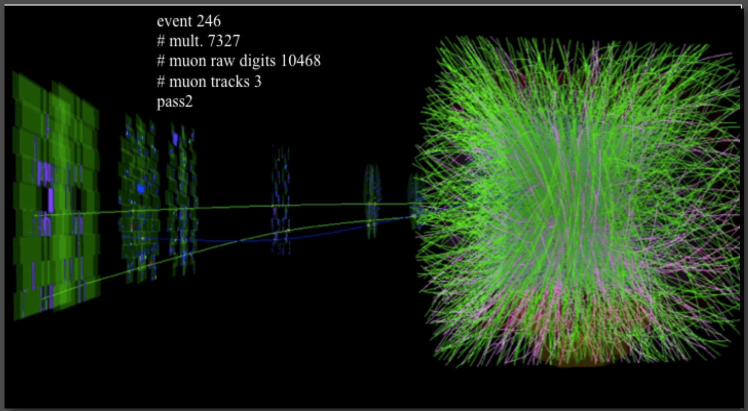


integrated luminosity ~ 23 μb^{-1}

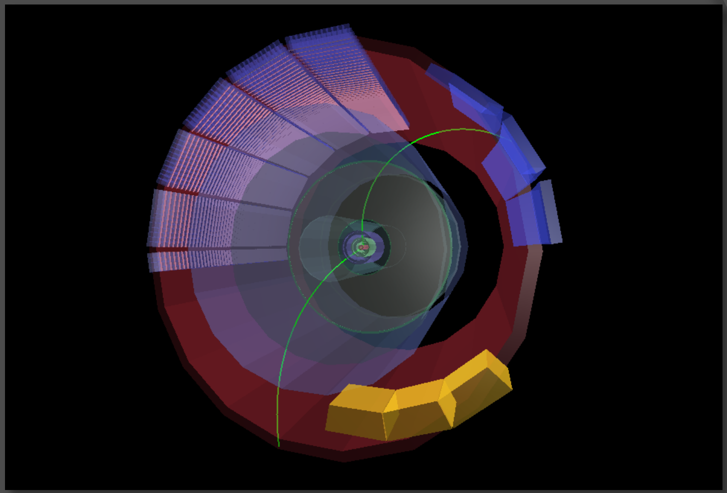
✓ offline event selection:

- ✧ 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

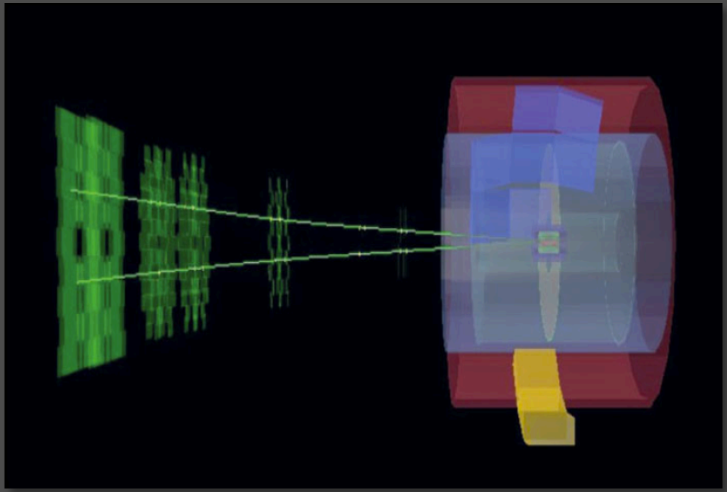
ALICE and UPCs



central Pb-Pb collision



UP Pb-Pb collision at mid-rapidity



two tracks in an otherwise empty detector

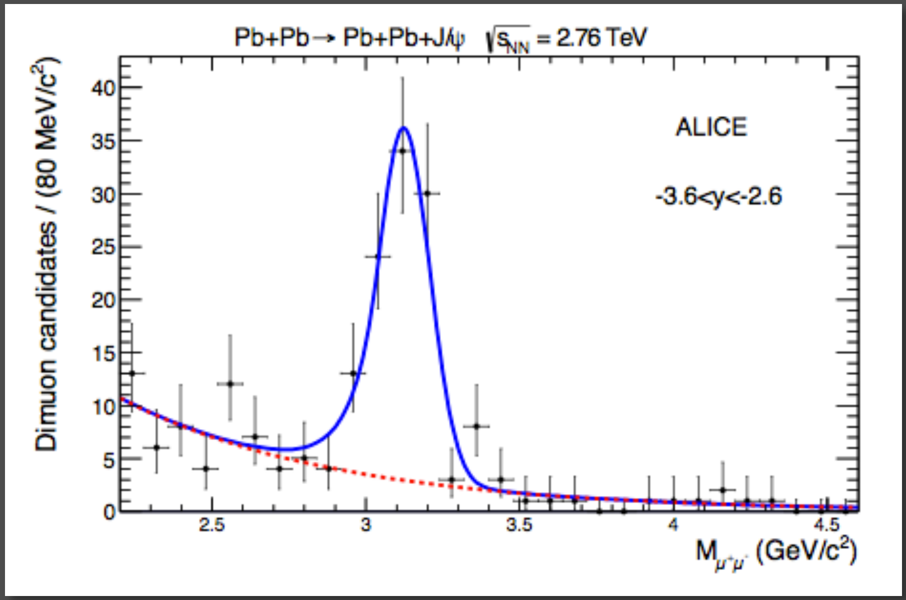
long work done to understand the noise and the emptiness of the detector

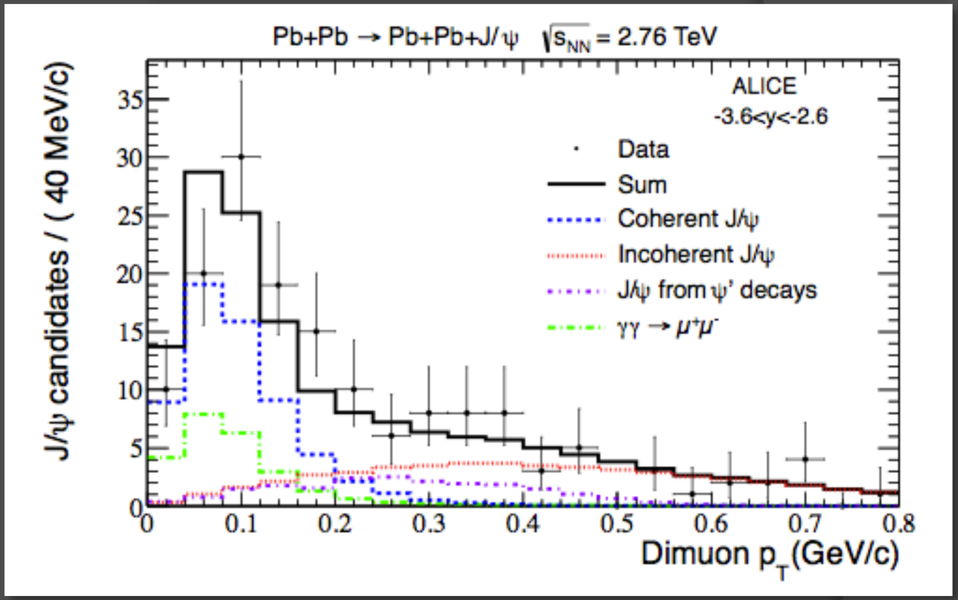
UP Pb-Pb collision at forward rapidity

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
- $\gamma\gamma \to \mu^+\mu^-$

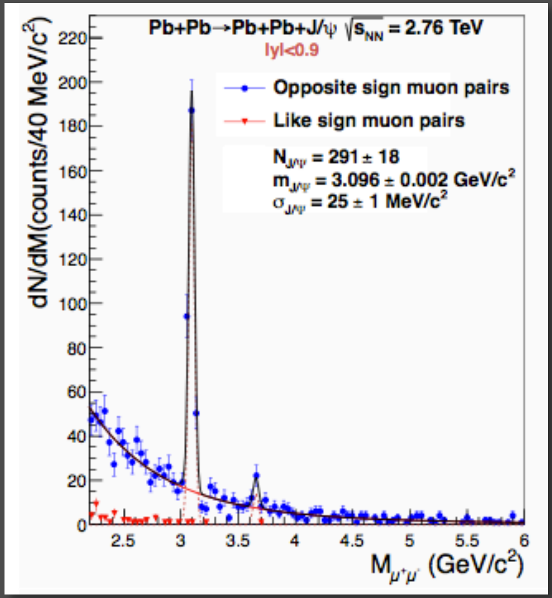
distribution peaked at low momentum as expected from coherent production

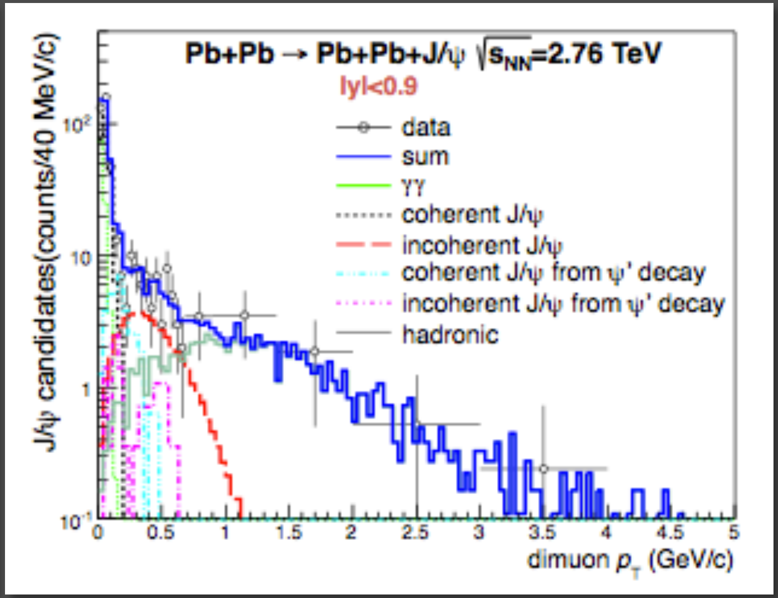
J/ψ photo-production probes the gluon distribution in Pb at $x \sim 10^{-2}$

J/ψ measurements (coherent at mid-rapidity)

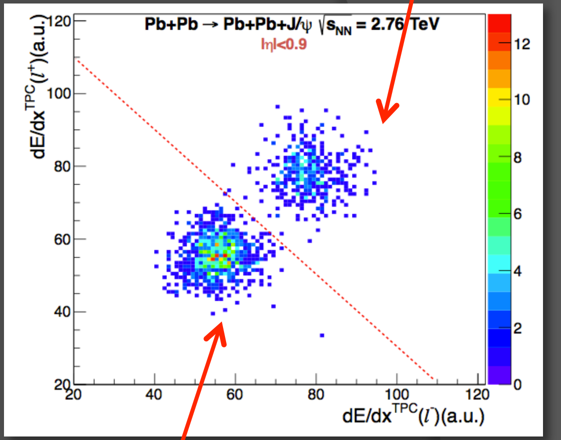
dimuon channel

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

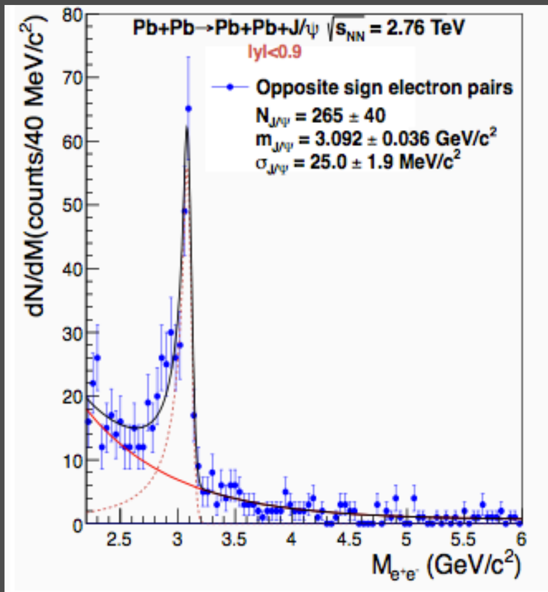
distribution peaked at low momentum as expected from coherent production

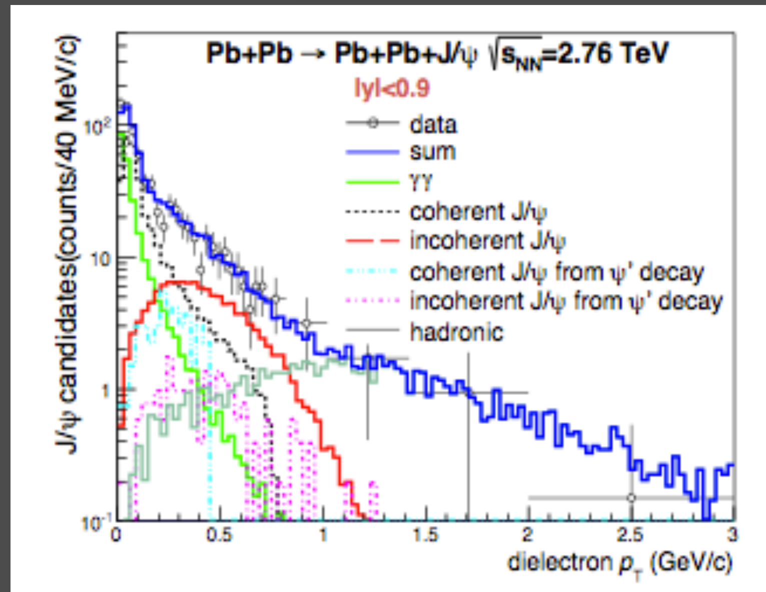
J/ψ photo-production probes the gluon distribution in Pb at $x \sim 10^{-3}$

J/ψ measurements (coherent at mid-rapidity)

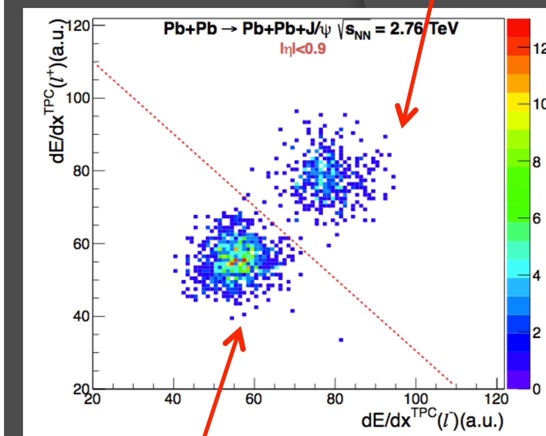
dielectron channel

arXiv:1305.1467 [nucl-ex]





electrons



muons

p_T distribution fitted using MC samples representing several components:

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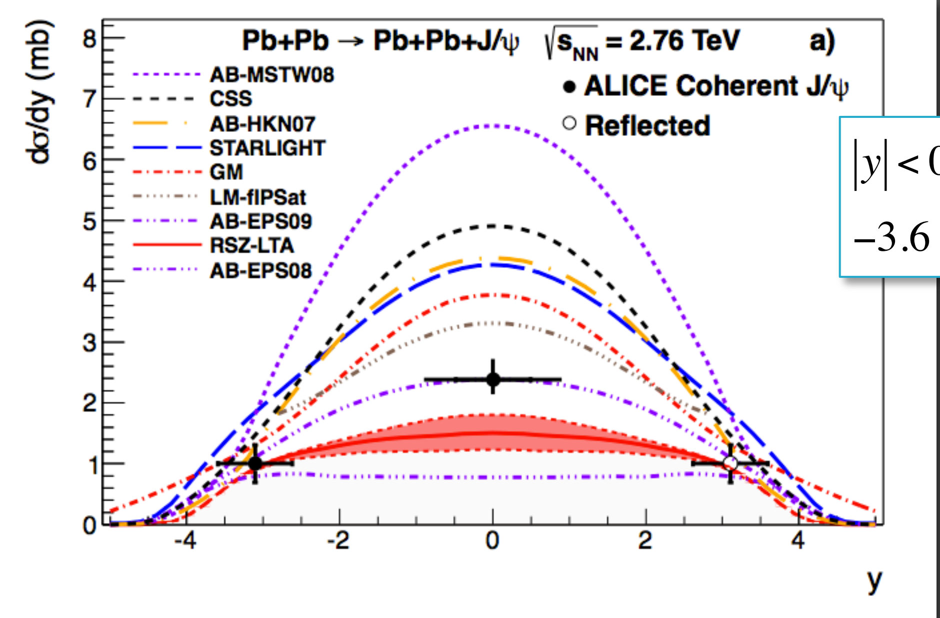
- (coherent and incoherent) ψ' feed down
- $\gamma\gamma \rightarrow e^+e^-$
- hadronic

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



arXiv:1305.1467 [nucl-ex]

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

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

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

✓ 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

data are closer to models incorporating nuclear gluon shadowing

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

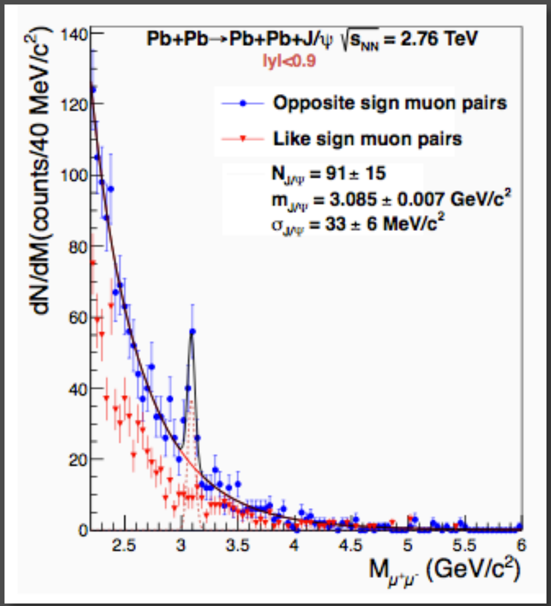
✓ GM: Goncalves, Machado, PRC84 (2011) 011902
color dipole model, where the dipole nucleon cross section is from the IIM saturation model

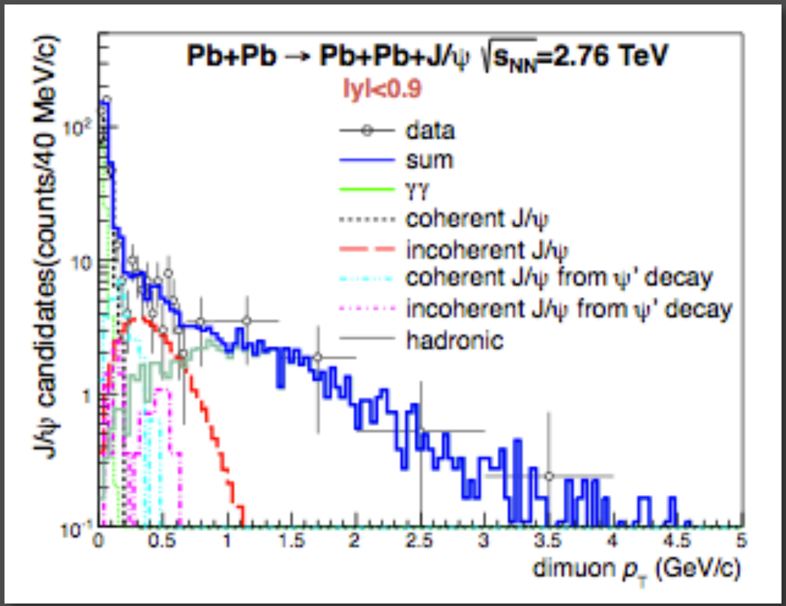
✓ RSZ: Rebyakova, Strikman, Zhalov, PLB 710 (2012) 252
based on LO pQCD amplitude for two gluon exchange where the gluon density incorporates shadowing computed in leading twist approximation

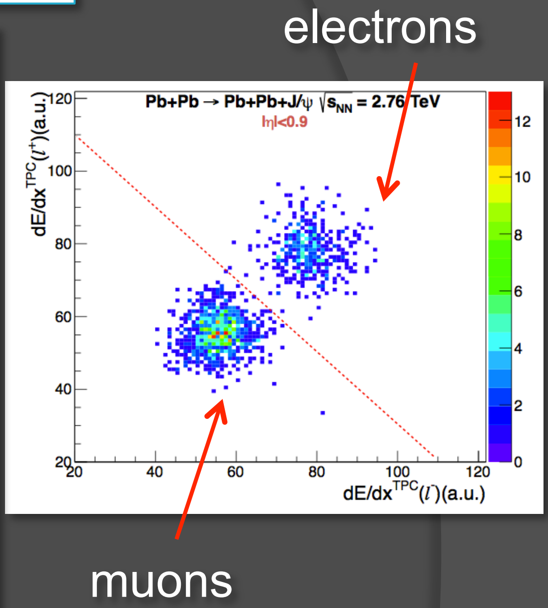
J/ψ measurements (incoherent at mid-rapidity)

dimuon channel

arXiv:1305.1467 [nucl-ex]







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

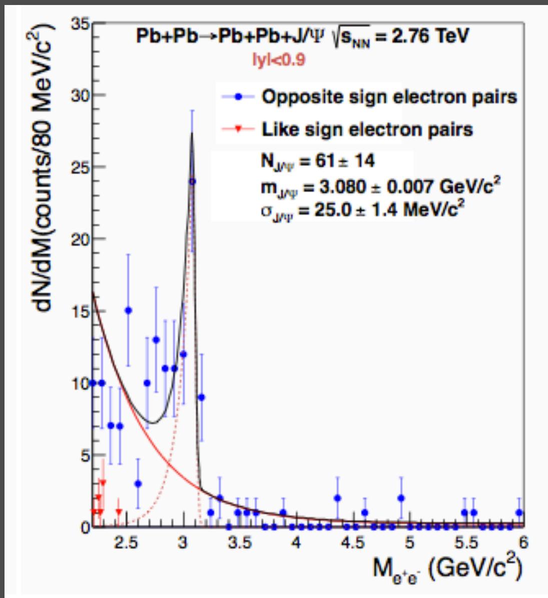
p_T > 200 MeV/c

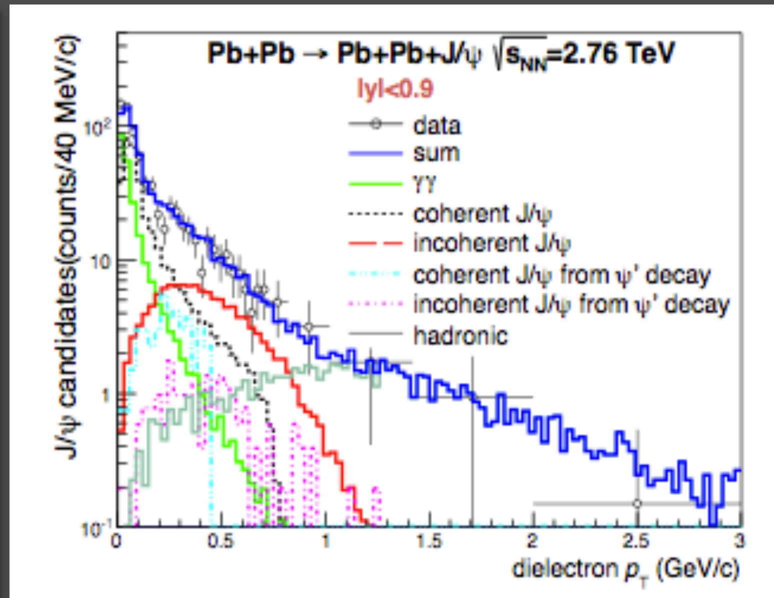
the ratio $\sigma_{inc}/\sigma_{coh}$ provides further constraints on the treatment of the nuclear modifications implemented in the different models

J/ψ measurements (incoherent at mid-rapidity)

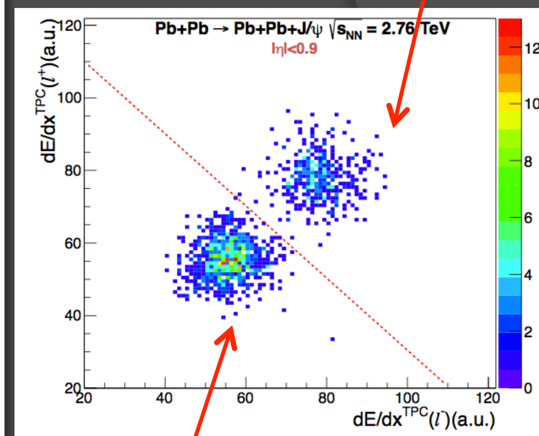
dielectron channel

arXiv:1305.1467 [nucl-ex]





electrons



muons

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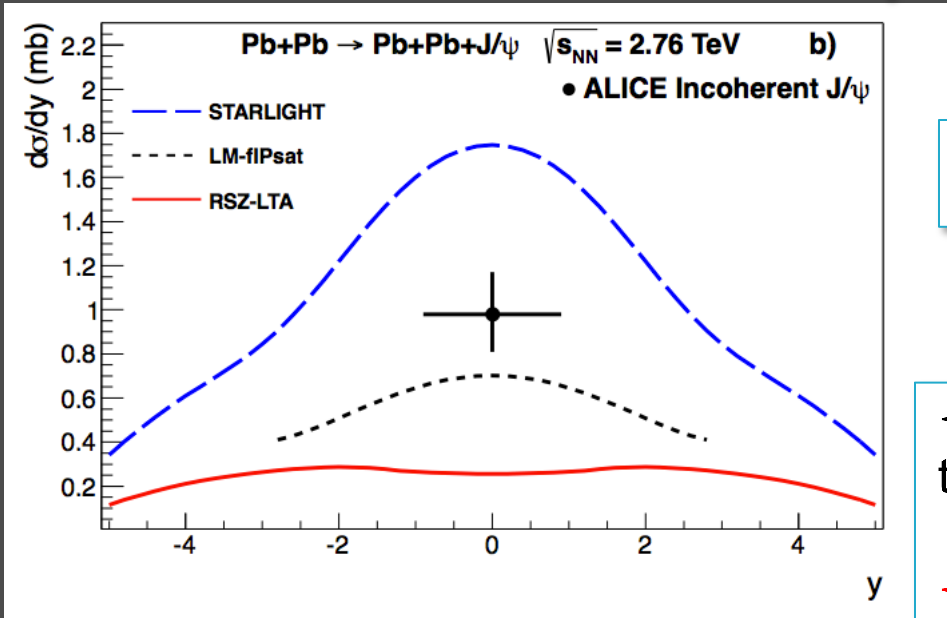
p_T > 300 MeV/c

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

Results and comparison with models



arXiv:1305.1467 [nucl-ex]

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

✧ 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

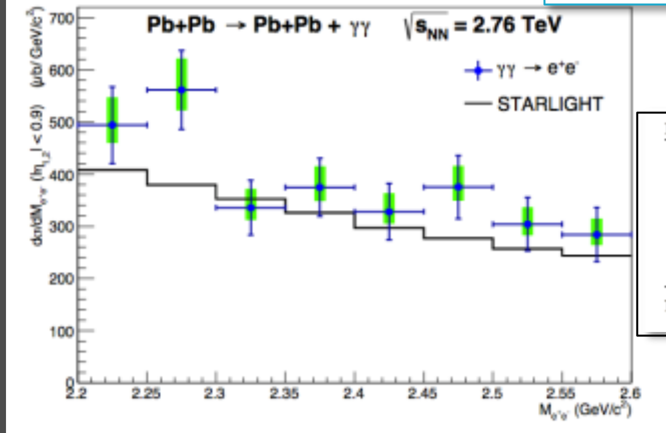
✓ RSZ: Rebyakova, Strikman, Zhalov, PLB 710 (2012) 252
based on LO pQCD amplitude for two gluon exchange where the gluon density incorporates shadowing computed in leading twist approximation

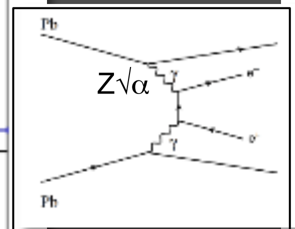
✓ LM: Lappi, Mantysaari, PRC87 (2013) 032201
color dipole model based with Glauber approach and a saturation prescription

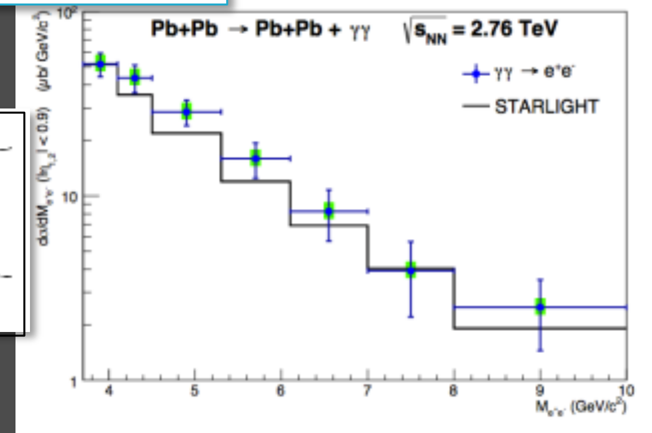
the ratio $\sigma_{inc}/\sigma_{coh}$ provides further constraints on the treatment of the nuclear modifications implemented in the different models

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 → $d\sigma_{\gamma\gamma}^{e^+e^-} = 154 \pm 11(stat)^{+16.6}_{-10.8}(syst)\ \mu\text{b}$ precision 12%
  - ✧ [3.7,10] GeV/c² → $d\sigma_{\gamma\gamma}^{e^+e^-} = 91 \pm 10(stat)^{+10.9}_{-8.0}(syst)\ \mu\text{b}$ 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)

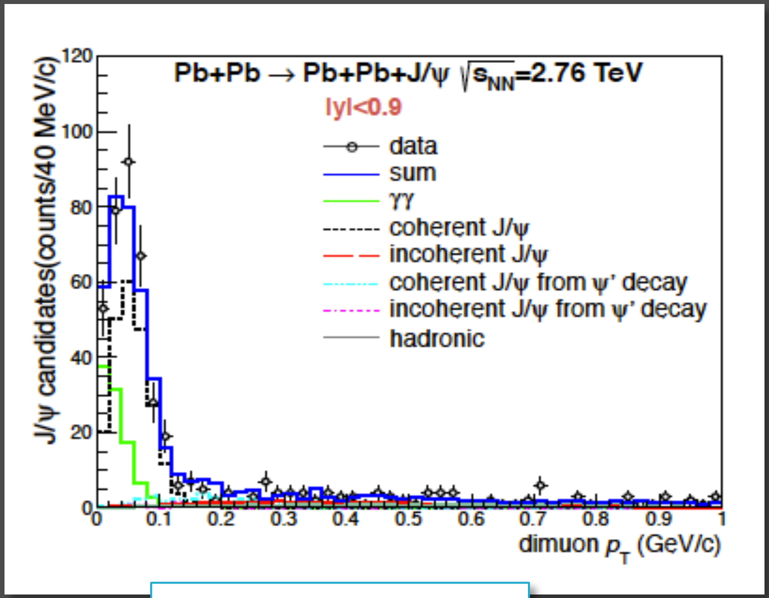
→ the models predicting a strong contribution of higher-order terms (not included in STARLIGHT) are not favored

Conclusions

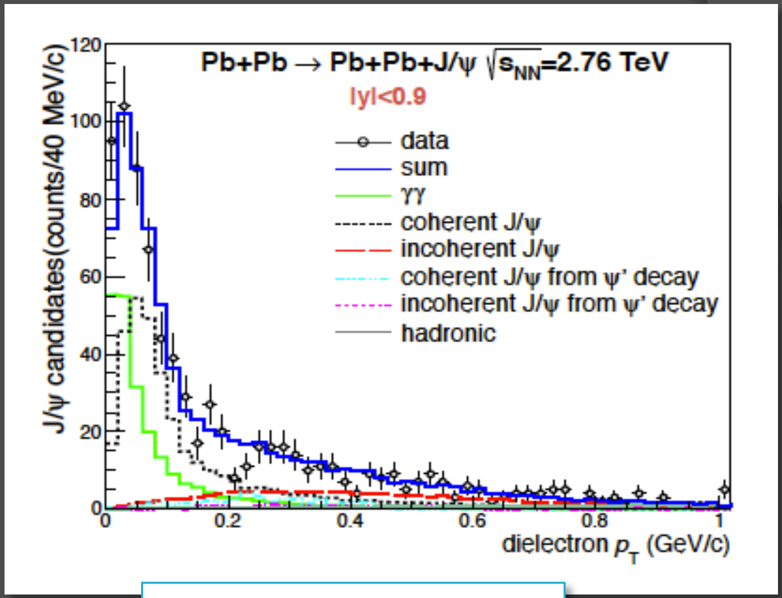
- ✓ LHC as γPb collider to study $\gamma\gamma$ and photo-nuclear processes
- ✓ measurement of exclusive vector meson (J/ψ) cross sections to investigate the gluon distribution in the nuclei
- ✓ results seem to favor models including gluon shadowing
- ✓ $\gamma\gamma$ cross section to set limits on higher order terms in QED processes
- ✓ two papers:
  - ✧ Phys. Lett. B718 (2013) 1273-1283
  - ✧ arXiv:1305.1467 [nucl-ex]
- ✓ on going analyses:
  - ✧ J/ψ cross section in p+Pb and Pb+p collisions for three different topologies (central, forward and semi-central) → this allows J/ψ photo-production measurement in γp in a wide range of center of mass energy ([20,1000] GeV)
  - ✧ ρ^0 cross section in Pb+Pb collisions

back up

p_T distributions (linear scale)



dimuon channel



dielectron channel

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distribution peaked at low momentum as expected from coherent production