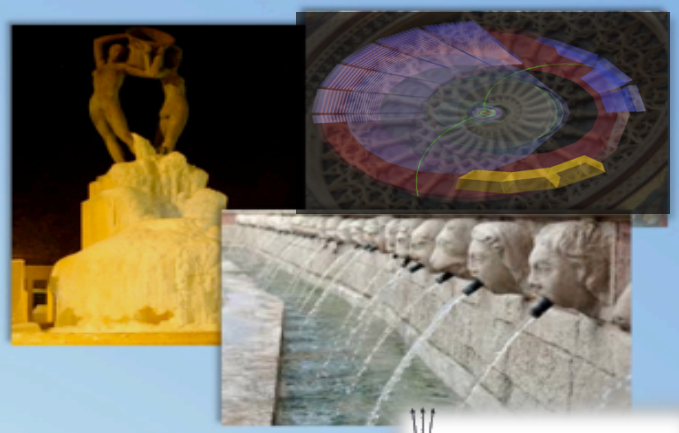
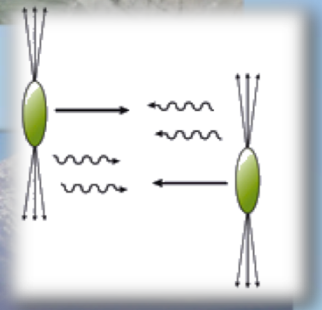
LABORATORI NAZIONALI DEL GRAN SASSO
GRAN SASSO SCIENCE INSTITUTE
9-11 APRILE 2014

IFAE

INCONTRI DI FISICA DELLE ALTE ENERGIE

2014





Physics of Ultra-peripheral collisions with ALICE at LHC

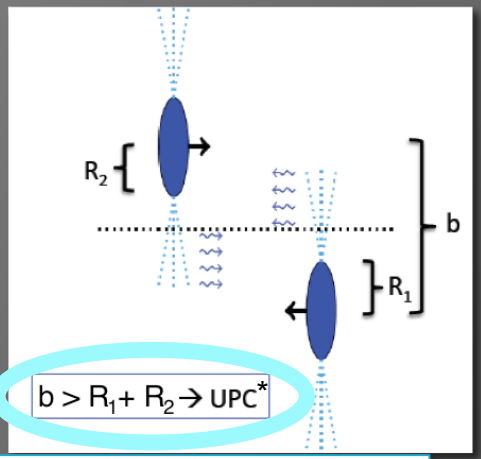
D. De Gruttola* on behalf of the ALICE Collaboration

*Centro Fermi Roma and Salerno INFN and University - Italy

LHC as γPb and γp collider

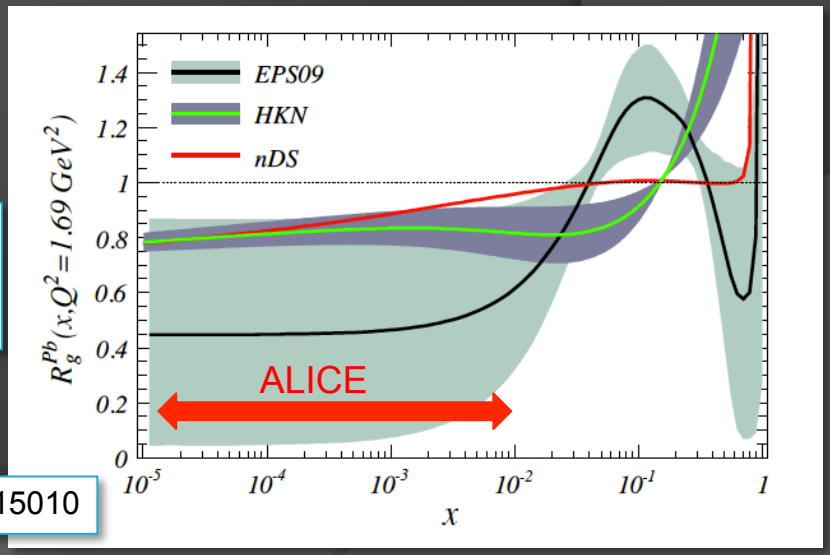
- ✓ heavy ions accelerated at ultra relativistic energies → electromagnetic field that can be viewed as a flux of quasi-real photons
- ✓ hadronic processes strongly suppressed when $b > R_1+R_2$
- ✓ high σ for γ-induced reactions e.g. vector meson photoproduction
- ✓ quarkonia photo-production proportional to the gluon density $G(x,Q^2)$ in Pb
- ✓ 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



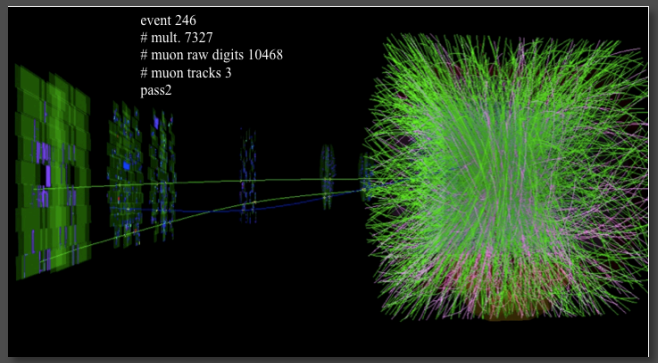
*UPC = Ultra-Peripheral Collisions

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

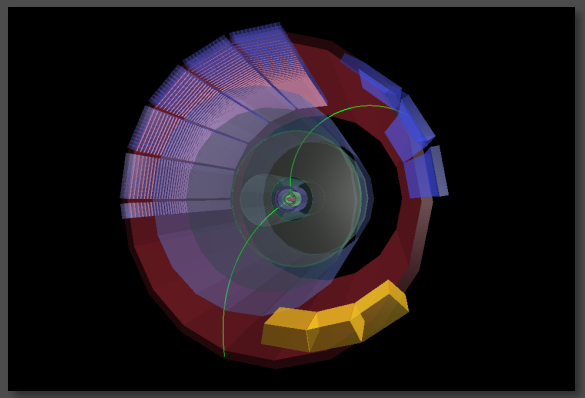


C A Salgado *et al* 2012 *J. Phys. G.: Nucl. Part. Phys.* **39** 015010

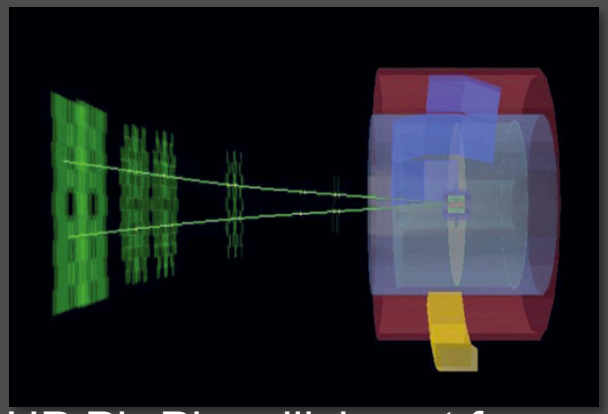
ALICE and Ultra-Peripheral (UP) Collisions



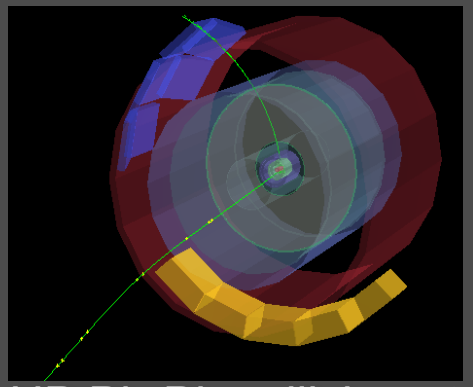
central Pb-Pb collision



UP Pb-Pb collision at mid-rapidity



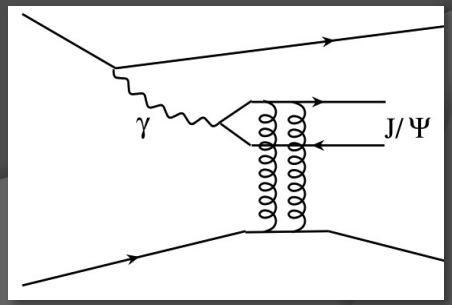
UP Pb-Pb collision at forward rapidity



UP Pb-Pb collision at semi-forward rapidity

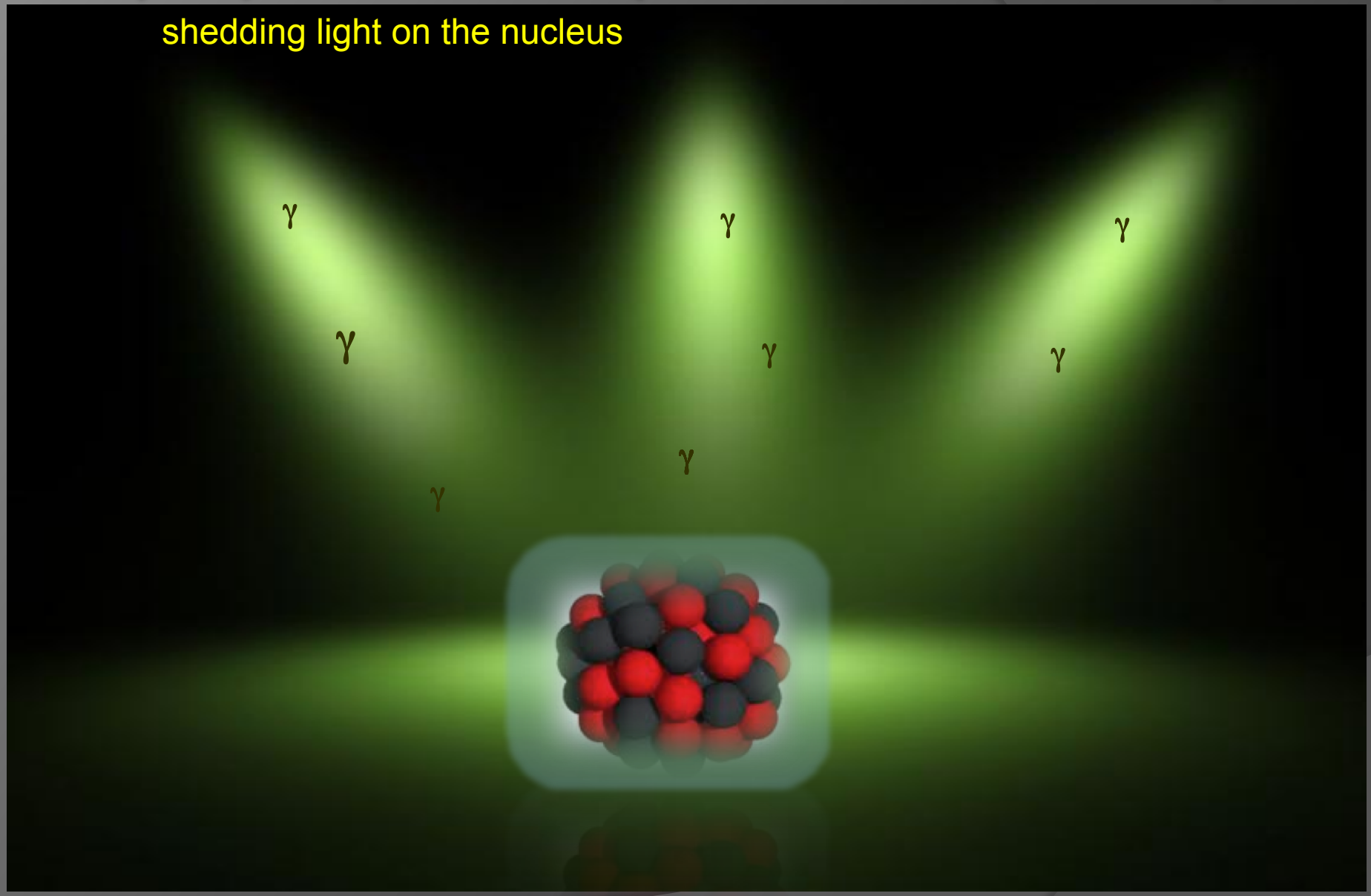
two tracks in an otherwise empty detector*

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



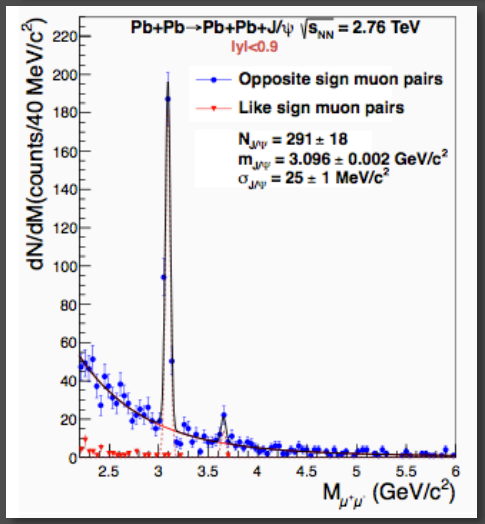
*definition from STAR

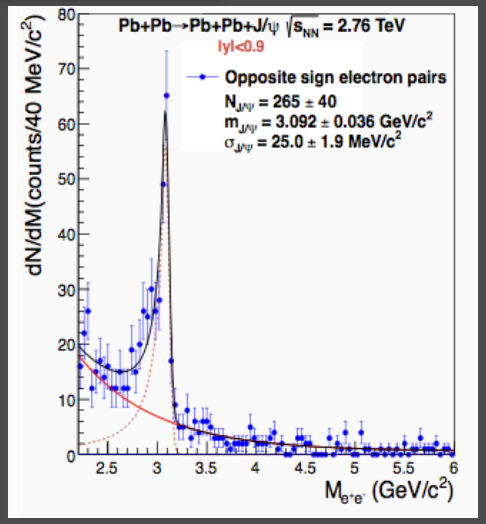
γN processes (Pb-Pb collisions)

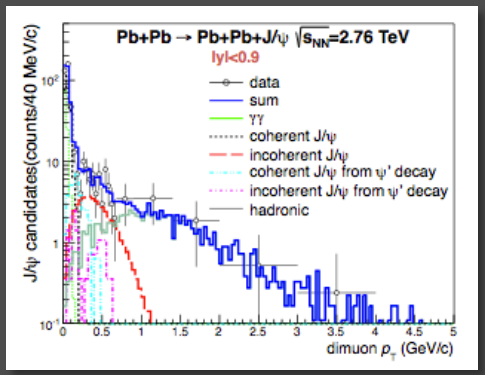


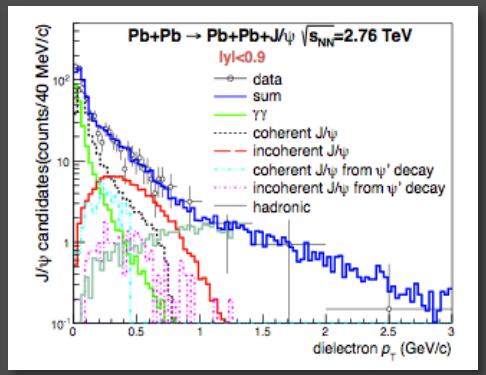
J/ψ measurements at mid-rapidity

Eur. J. Phys. C73, 2617 (2013)







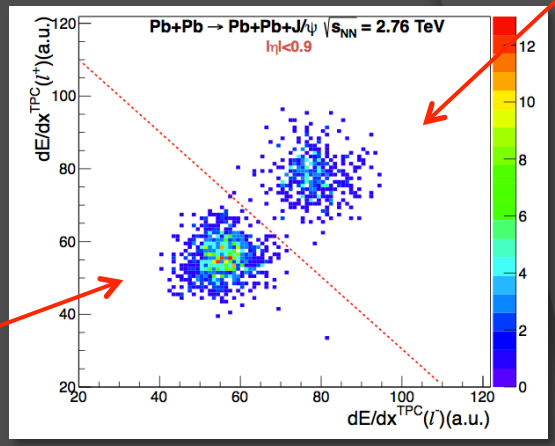


- coherent and incoherent J/ψ
- (coherent and incoherent) ψ' feed down
- $\gamma\gamma \rightarrow \mu^+\mu^-(e^+e^-)$
- hadronic

(more details in the backup)

electrons

muons



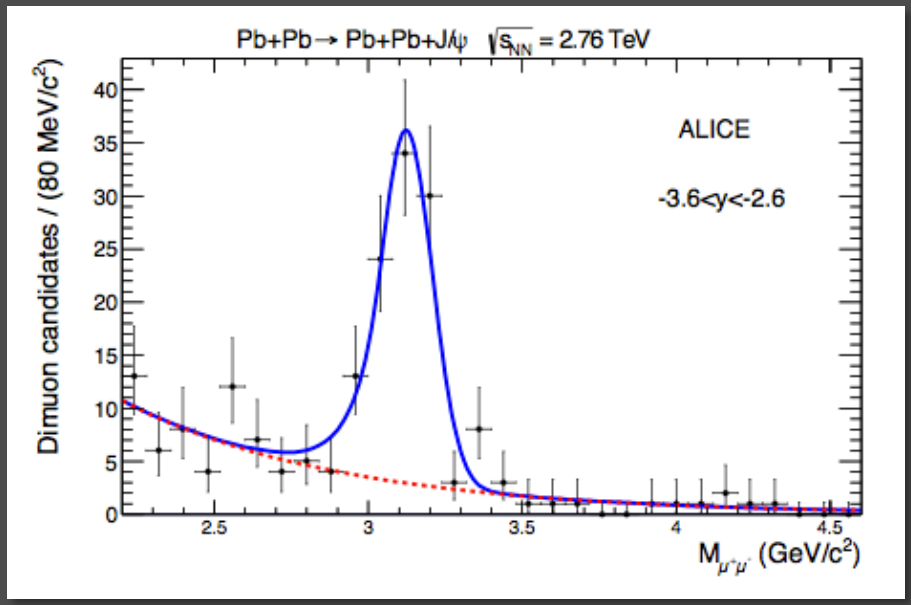
- ✓ coherent vector meson production:
  - ✧ photon couples coherently to all nucleons
  - ✧ $\langle p_T \rangle \sim 1/R_{Pb} \sim 60$ MeV/c
  - ✧ no neutron emission in ~80% of cases
- ✓ incoherent vector meson production:
  - ✧ photon couples to a single nucleon
  - ✧ $\langle p_T \rangle \sim 1/R_p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

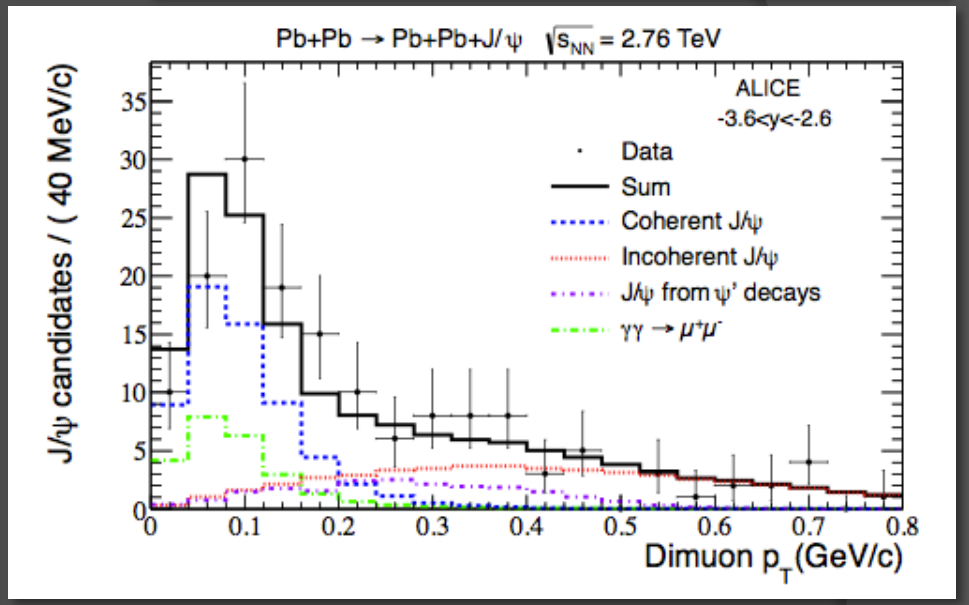
p_T < 200 (300) MeV/c and < 6 neutrons emitted by nuclei to separate coherent from incoherent samples

J/ψ measurements (coherent at forward rapidity)

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

Phys. Lett. B718 (2013) 1273 -1283





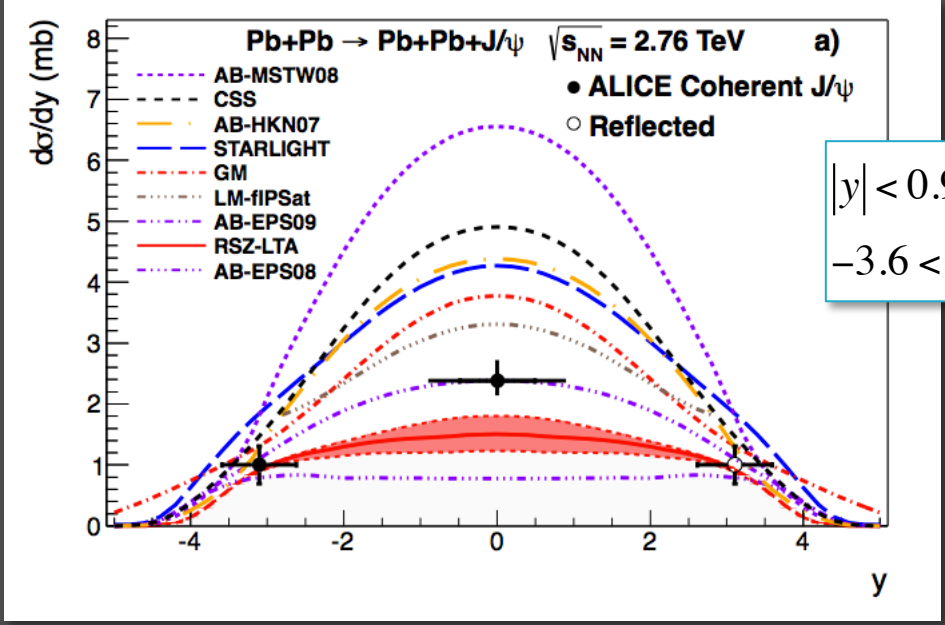
p_T distribution fitted using MC samples representing several components:

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

distribution peaked at low momentum as expected from coherent production

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

Results and comparison with models



Phys. Lett. B718 (2013) 1273 -1283

Eur. J. Phys. C73, 2617 (2013)

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

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

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

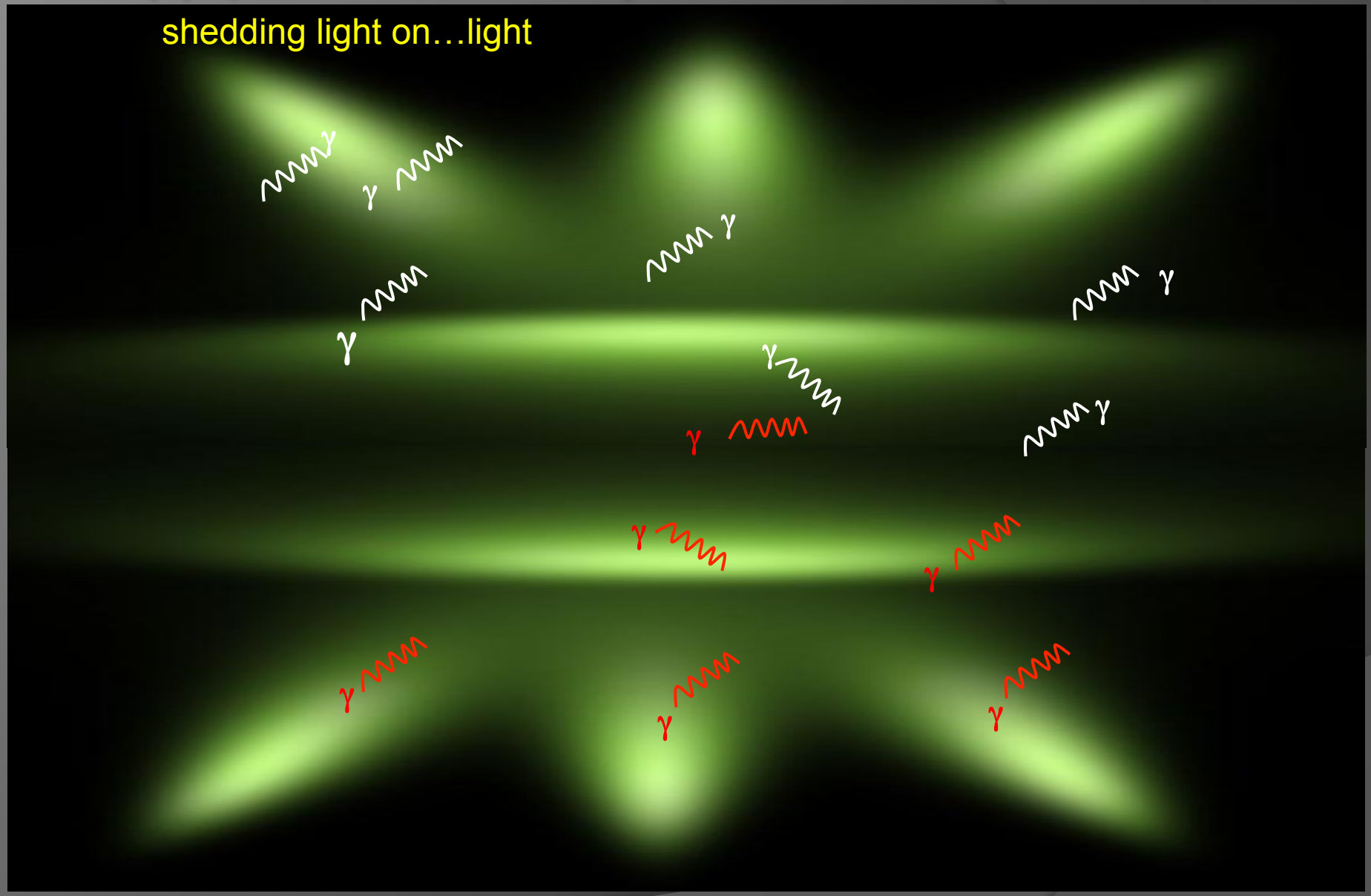
measured cross section in good agreement with the calculation using the EPS09 nuclear gluon fit

✓ 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

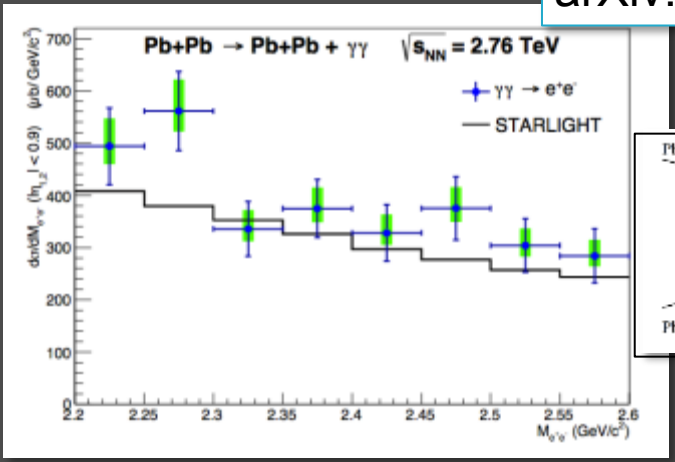
✓ RSZ: Rebyakova, Strikman, Zhalov, PLB 710 (2012) 252
based on LO pQCD amplitude for two gluon exchange where the gluon density incorporates shadowing computed in leading twist approximation

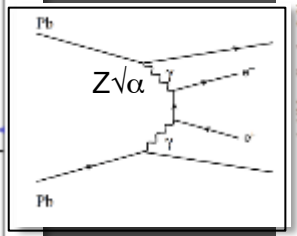
γγ processes (Pb-Pb collisions)

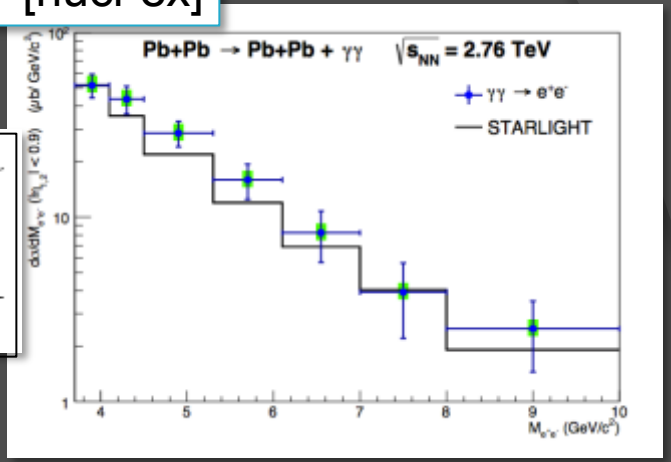


γγ cross section

arXiv:1305.1467 [nucl-ex]





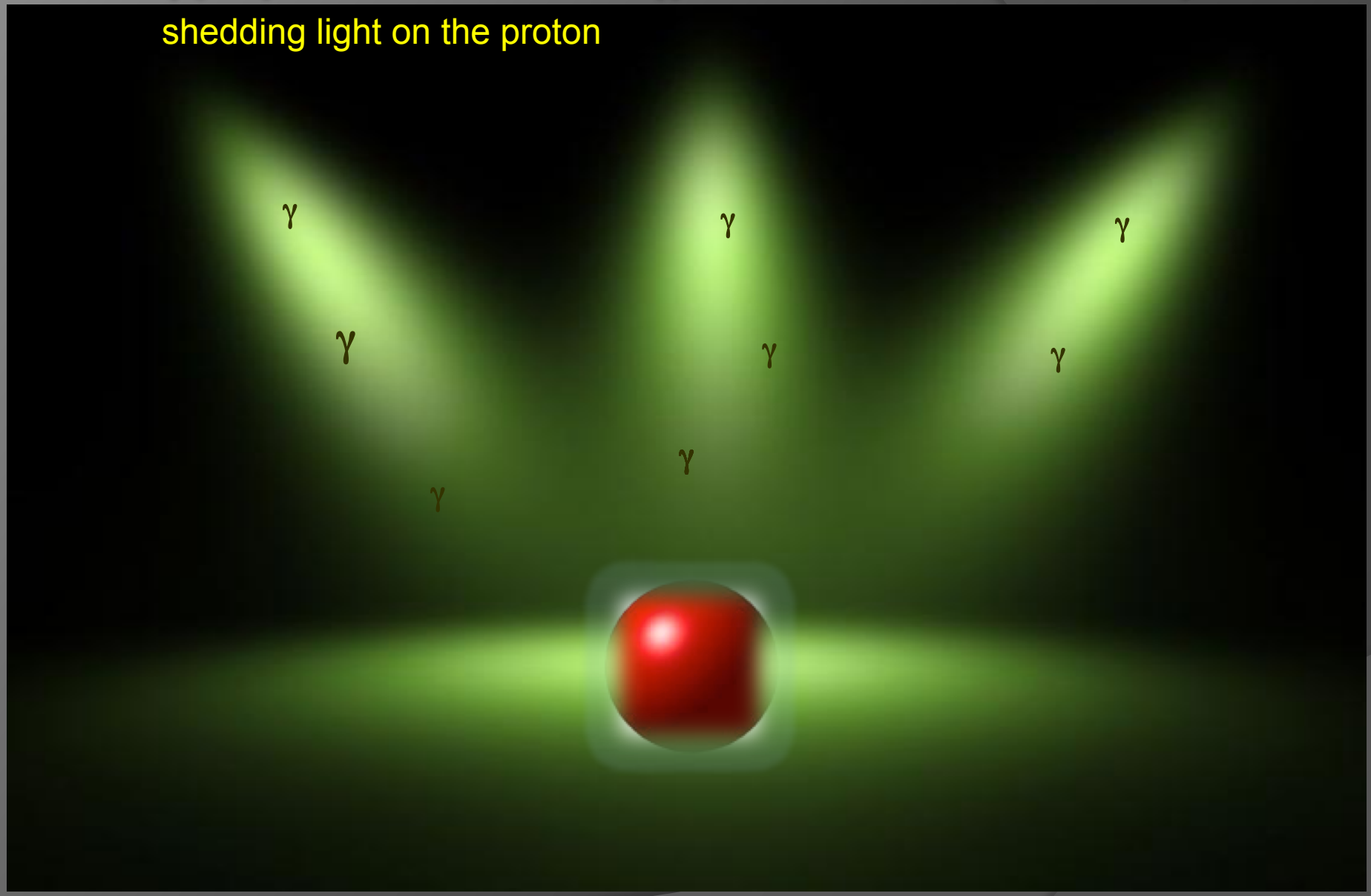


- ✓ the γγ cross section measurement provides important constraints on QED calculations when the vertex $\sqrt{\alpha}$ has to be replaced by $Z\sqrt{\alpha}$
- ✓ due to the large Pb charge, giving $Z\sqrt{\alpha} \sim 0.6$, the inclusion of higher order terms is not straightforward → the models* including 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*

γp processes (p-Pb collisions)



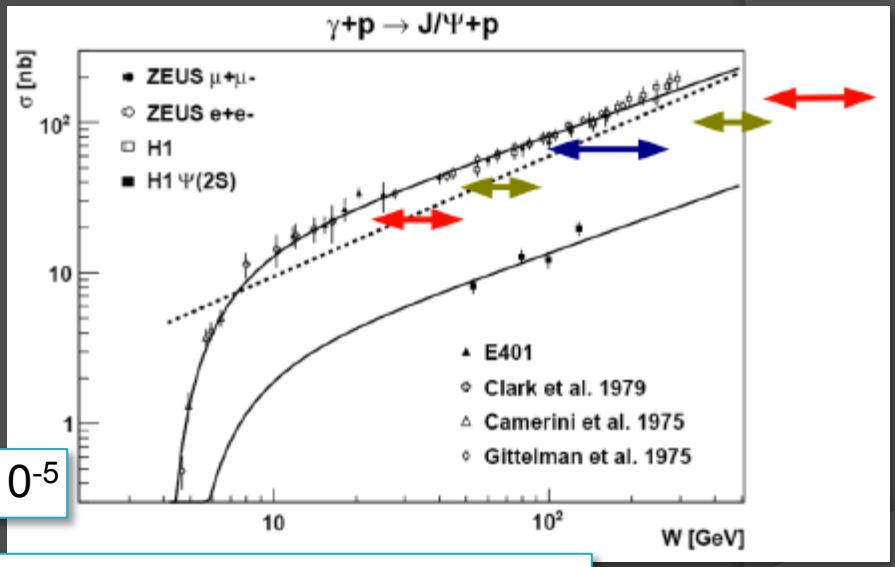
ALICE Physics potential in p-A

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:

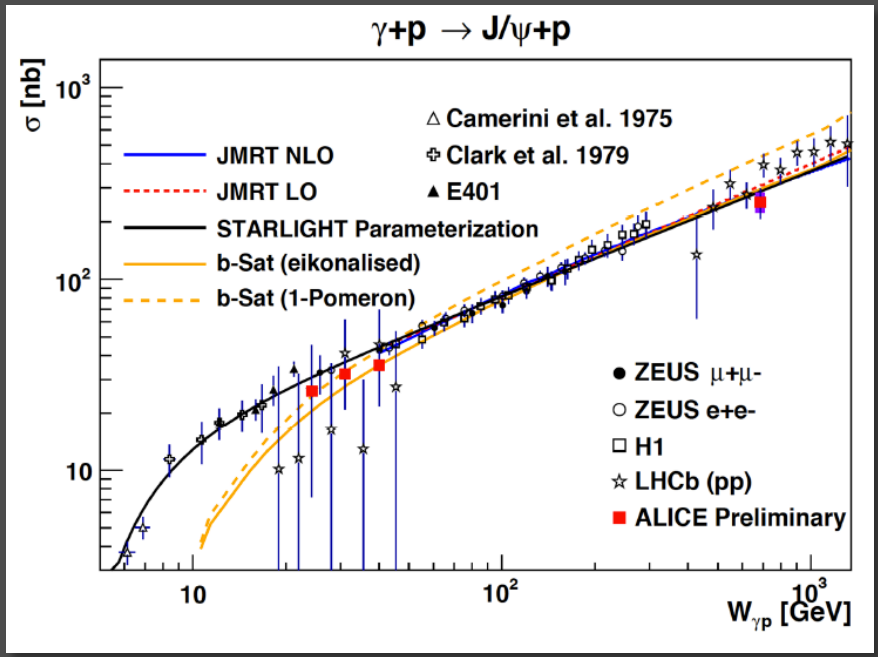
p-Pb forward	$21<W_{\gamma p}<45$ GeV
p-Pb semi-forward	$45<W_{\gamma p}<82$ GeV
mid-rapidity	$100<W_{\gamma p}<250$ GeV
Pb-p semi-forward	$300<W_{\gamma p}<550$ GeV
Pb-p forward	$550<W_{\gamma p}<1160$ GeV



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

Measured γp cross sections in p-Pb



- ✓ 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
- ✓ measured σ(p-Pb) to σ (γ+p) through the photon spectrum $n_\gamma(y)$:

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

power law fits (not shown)
$\sigma \sim (W_{\gamma p}/ 90GeV)^{\delta}$

- ✓ ALICE data compatible with a power law with δ=0.67 ±0.06
- ✓ exponent compatible with H1 (δ=0.67±0.03) and ZEUS (δ=0.69 ±0.02±0.03)
- ✓ exponent from LHCb: δ=0.92 ±0.15 (J. Phys. G40 (2013) 045001, waiting for update)
- ✓ it would be interesting to reach higher energy in the future LHC runs in order to investigate the possible occurence of saturation

Conclusions

LHC as γPb, γp and $\gamma\gamma$ collider to study:

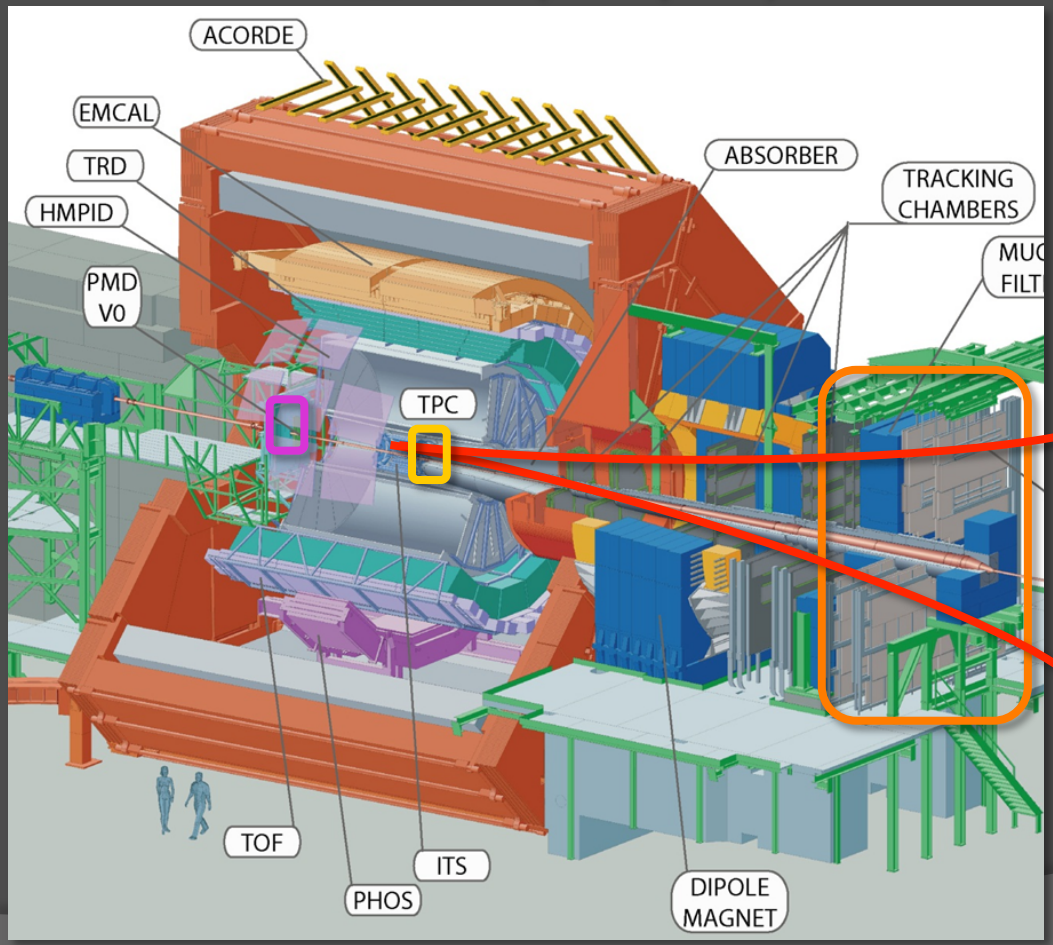
- ✓ (Pb-Pb) measurement of exclusive vector meson (J/ψ) cross sections to investigate the gluon distribution in the nuclei
- ✓ (Pb-Pb) results agree with EPS09 gluon distribution, favoring the presence of gluon shadowing
- ✓ (Pb-Pb) $\gamma\gamma$ cross section to set limits on higher order terms in QED processes
- ✓ (p-Pb) good agreement on J/ψ photoproduction from previous experiments at <W> ~ 30 GeV
- ✓ (p-Pb) J/ψ+p cross section at W > 1000 GeV (and not only) in progress
- ✓ (Pb-Pb) ρ vector meson photoproduction analysis ongoing
- ✓ (Pb-Pb) ψ' vector meson photoproduction analysis ongoing

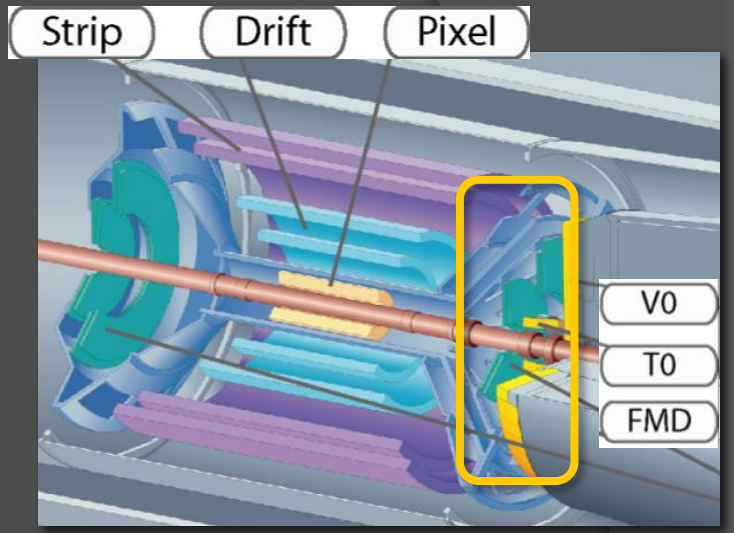
Back up

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

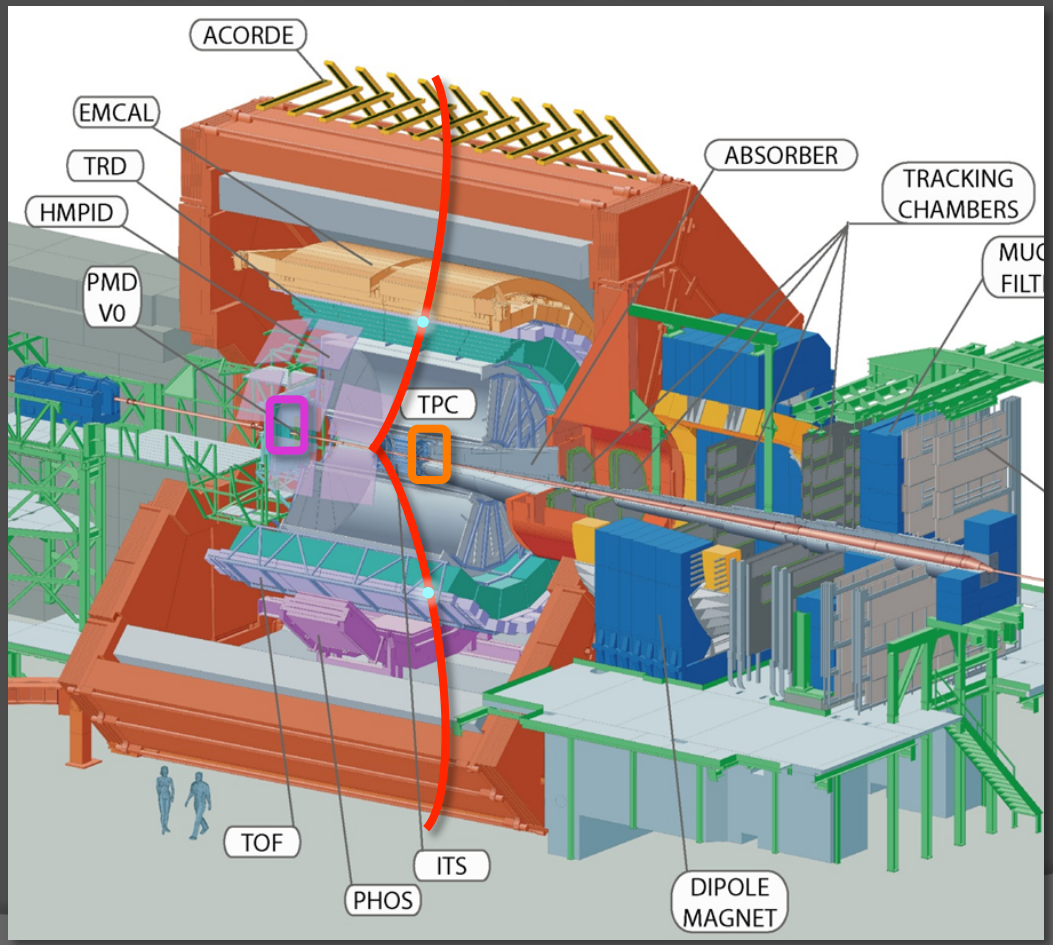
✓ track selection:

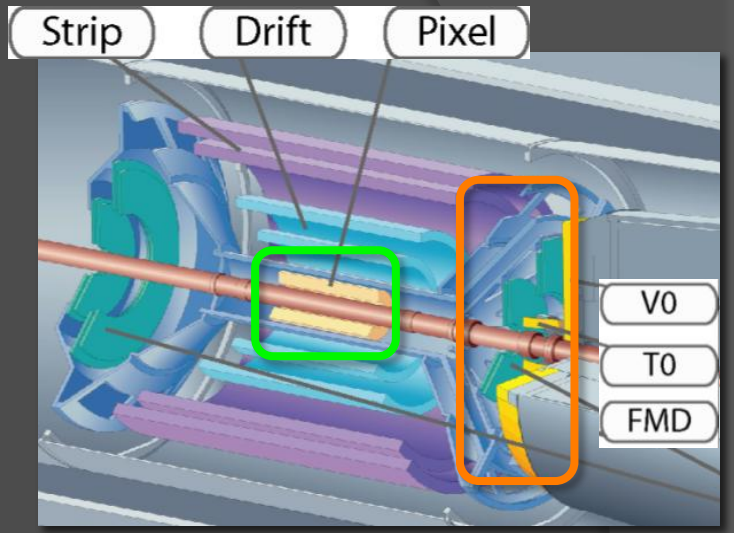
- ✧ muon tracks: $-3.7 < \eta < -2.5$
- ✧ matching with the trigger
- ✧ radial position for muons at the end of absorber: $17.5 < R_{abs} < 89.5$ cm
- ✧ p_T dependent DCA cut
- ✧ opposite sign dimuon: $-3.6 < y < -2.6$

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





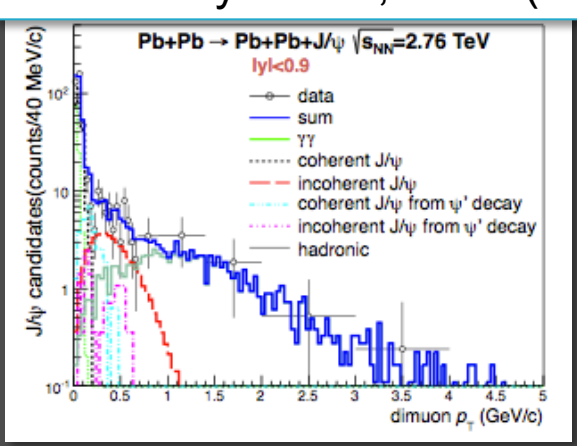
integrated luminosity ~ 23 μb^{-1}

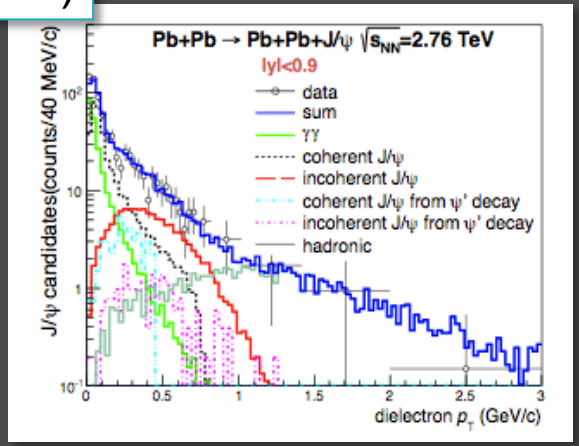
✓ offline event selection:

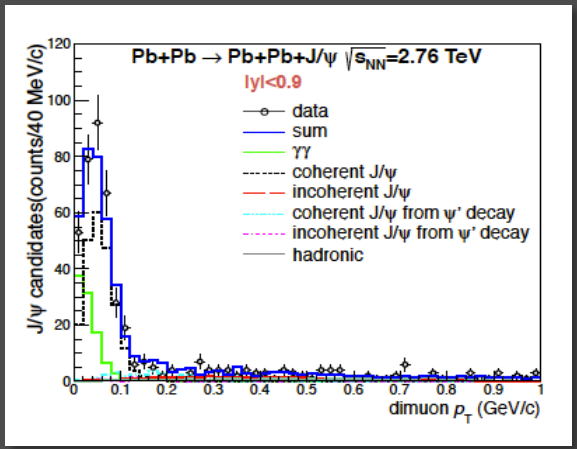
- rejection with VZERO and FMD
- primary vertex
- max (p_{T1}, p_{T2}) > 1 GeV/c
- dE/dx consistent with e/μ
- opposite sign tracks
- ZDC cut on number of neutrons emitted in coherent events

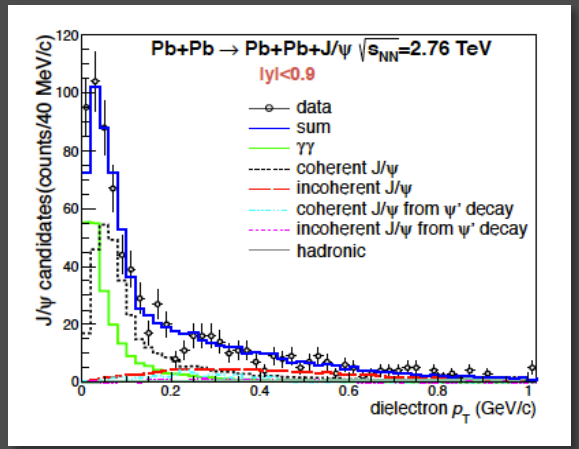
J/ψ measurements at mid-rapidity

Eur. J. Phys. C73, 2617 (2013)









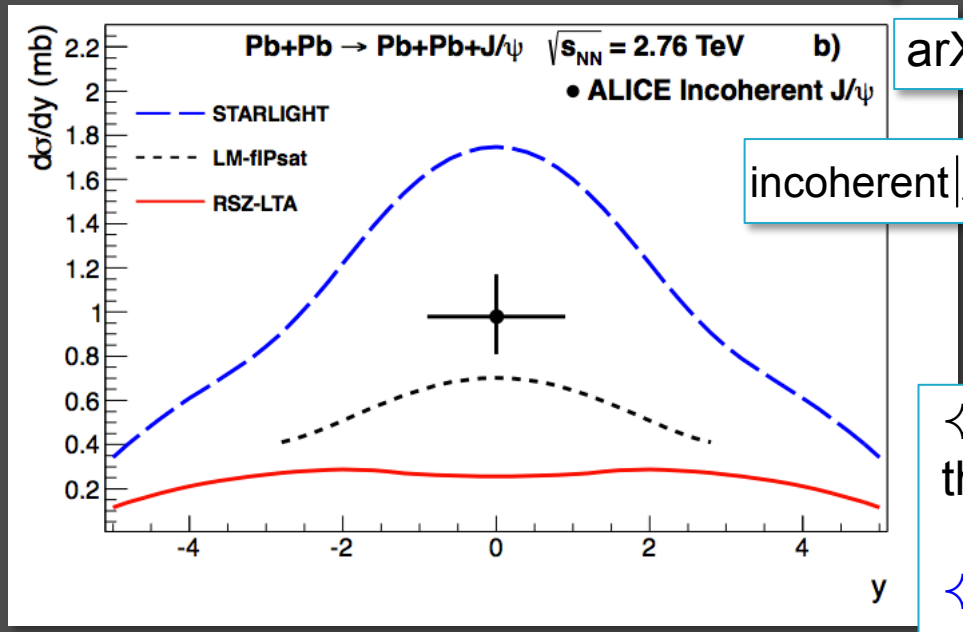
fit of p_T distribution to estimate the different components of the signal:

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

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

- ✓ shapes for the first five fitting functions provided by STARLIGHT
- ✓ hadronic component extracted from data at higher centralities
- ✓ relative normalization left free for coherent and incoherent photoproduction
- ✓ feed down constrained to the theory
- ✓ two-photon contribution determined from the fit to the continuum of inv mass distributions
- ✓ hadronic component constrained by the fit to the region $p_T > 1.1$ GeV/c, where the ultra-peripheral J/ψ contribution is negligible

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