Workshop on results and prospects of forward physics at the LHC

Ultra-peripheral collisions with ALICE

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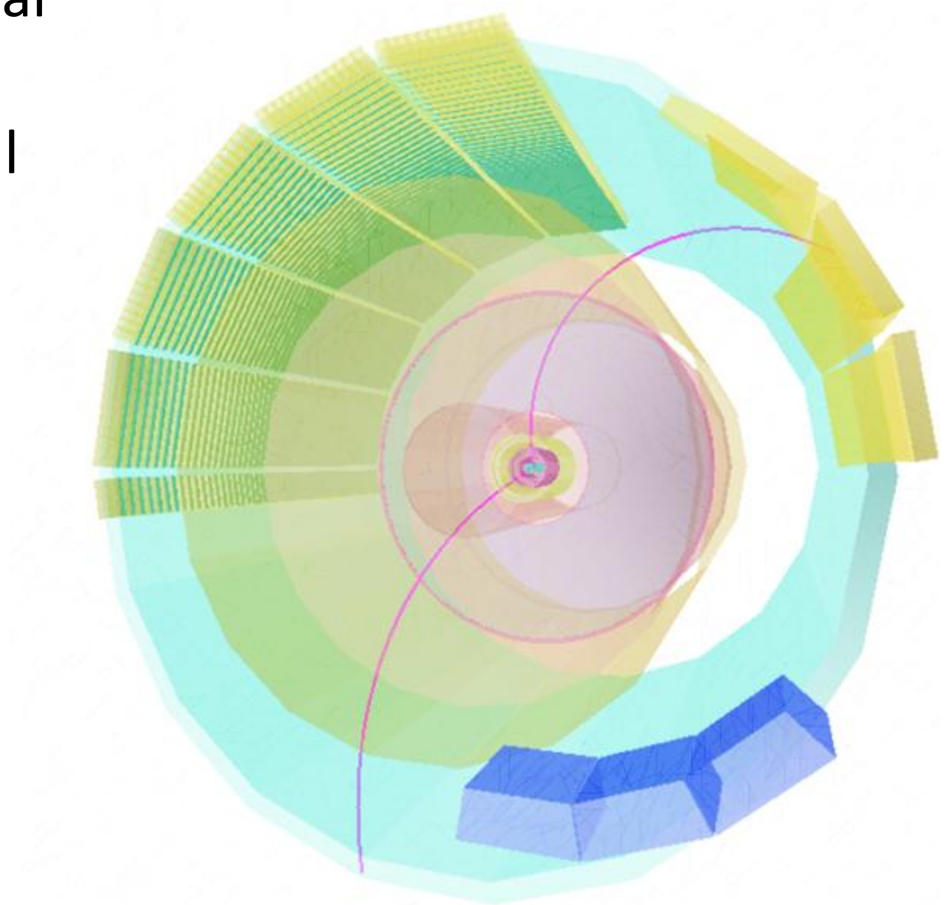
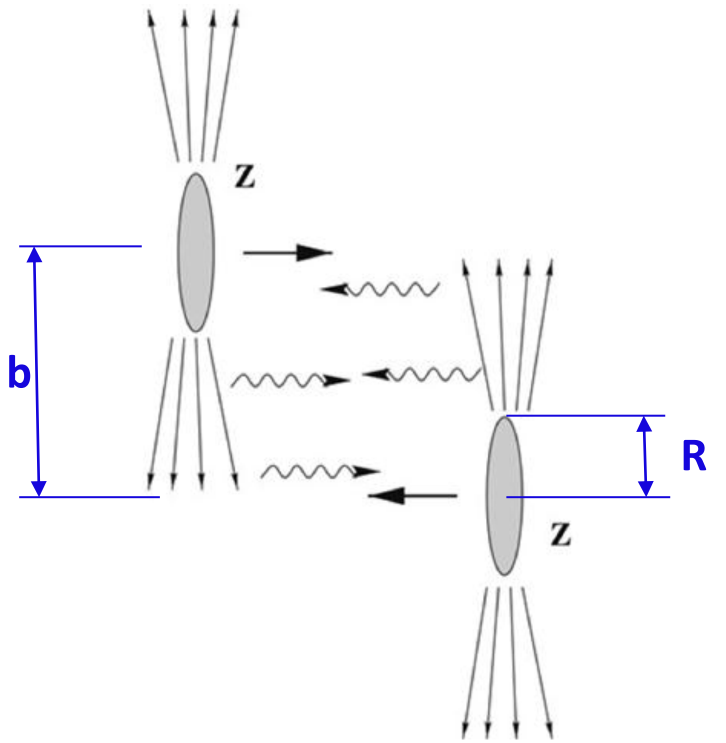
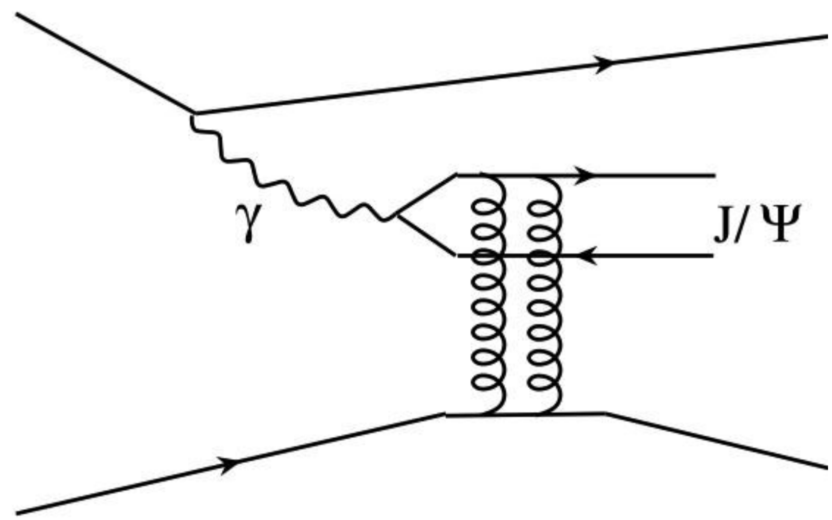
  - ρ^0 at central rapidity
- Prospects of pA UPC
- Summary



LHC as a γPb collider





- **Ultra-peripheral (UPC) collisions: b > 2R**
  → hadronic interactions strongly suppressed

- **High photon flux** ~ Z^2
  → well described in Weizsäcker-Williams approximation
  → high σ for γ-induced reactions
  e.g. exclusive vector meson production

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
- $\langle p_T \rangle \sim 1/R_p \sim$ 450 MeV/c
- target nucleus normally breaks up

Recent review on UPC physics: Phys. Rept. 458 (2008) 1-171

Why UPC in ALICE?

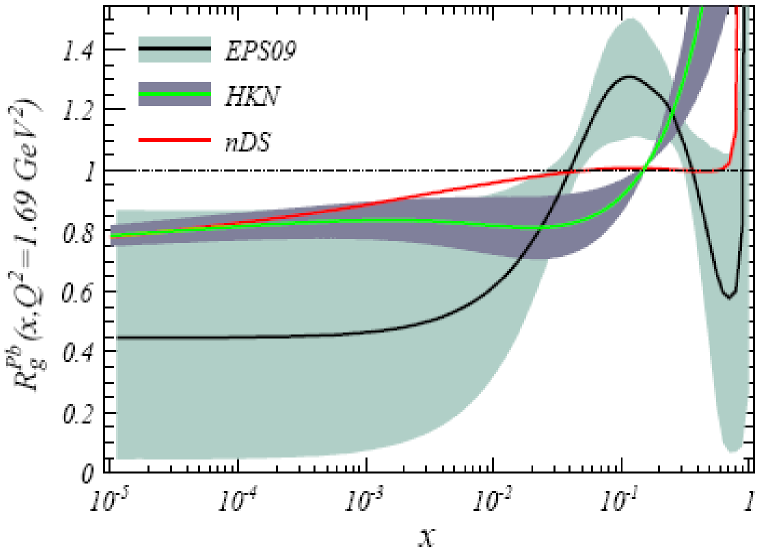
Why UPC?

- Quarkonia photoproduction allows to study the gluon density $G(x; Q^2)$ in Pb
- LO pQCD: forward coherent photoproduction cross section is proportional to the squared gluon density:

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

$$Q^2 \sim \frac{M_{J/\psi}^2}{4} \sim 2.5\ \mathrm{GeV}^2$$

Nuclear gluon shadowing factor vs x



- Bjorken $x \sim 10^{-2} - 10^{-5}$ accessible at LHC
- Quarkonium photoproduction in UPC is a direct tool to measure nuclear gluon shadowing!

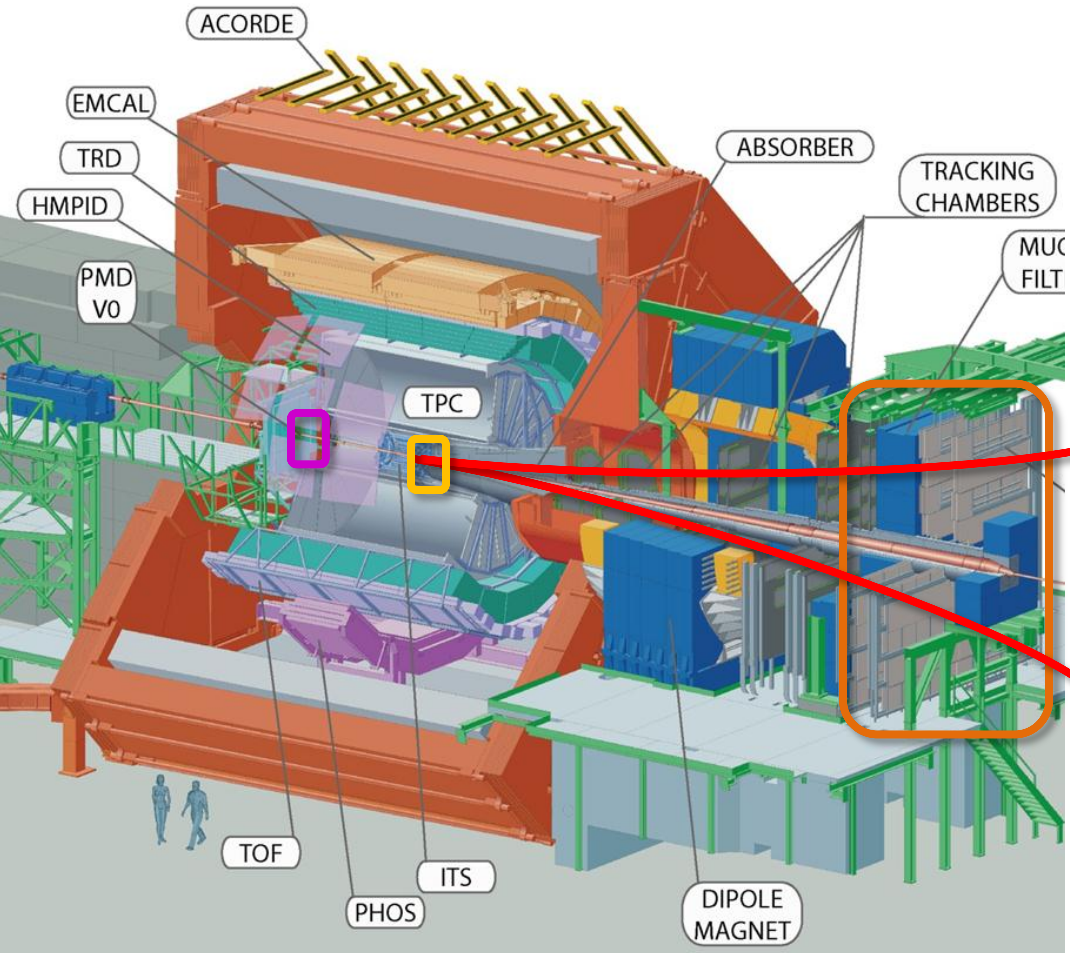
Why ALICE?

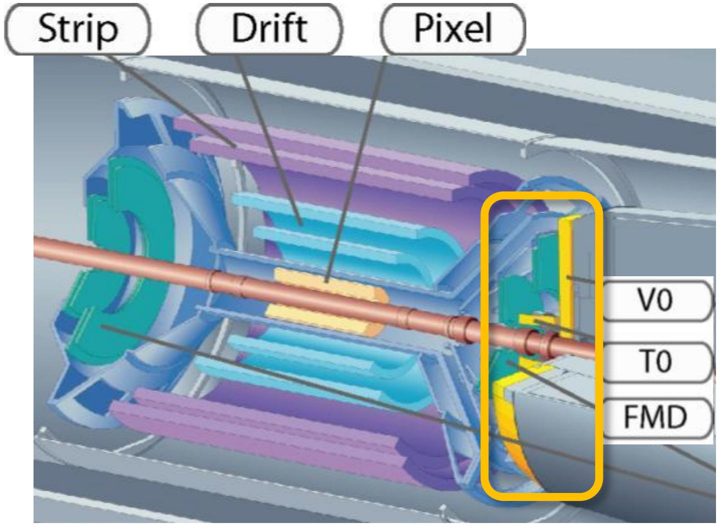
- Large pseudorapidity coverage: $-4.0 < \eta < 5.1$ + ZDC calorimetry
- Trigger on J/ψ with p_T down to 0 MeV/c both at forward and central rapidity
- Low pile-up

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}

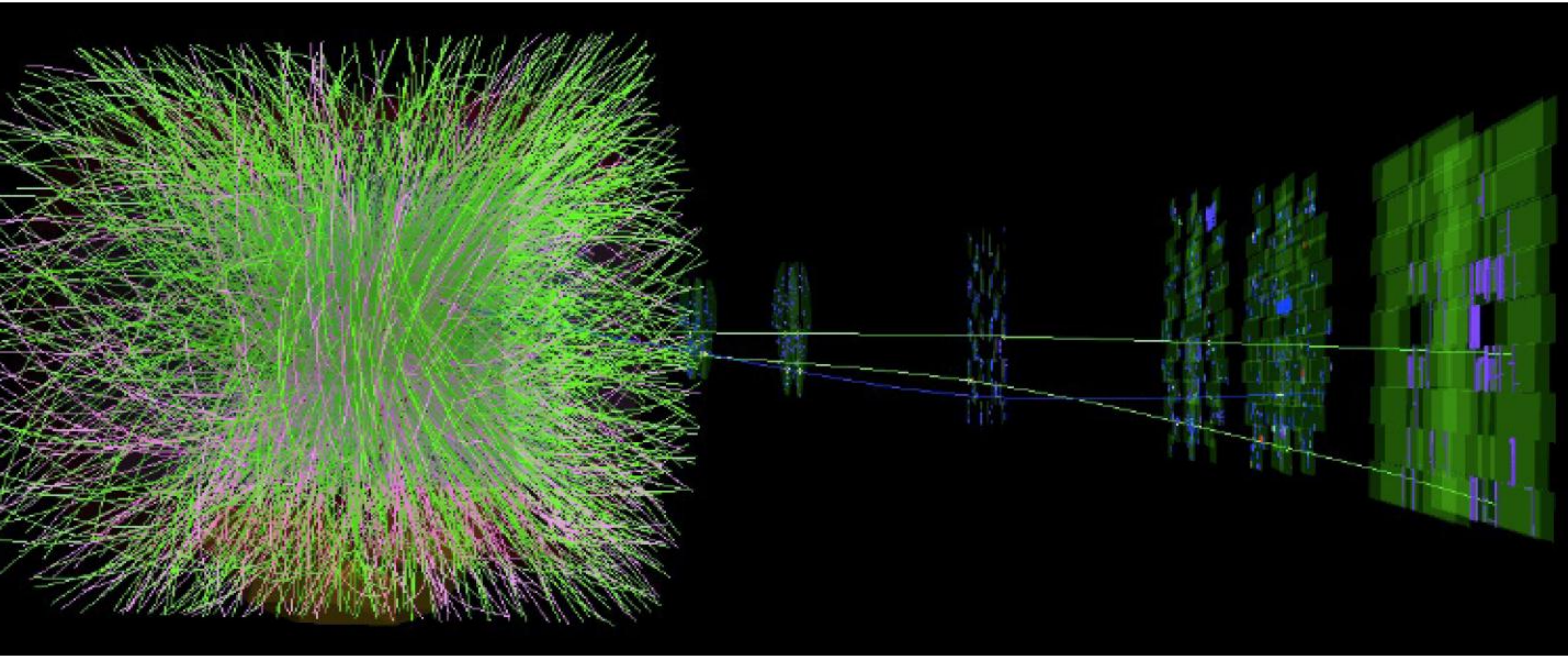
Offline event selection:

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

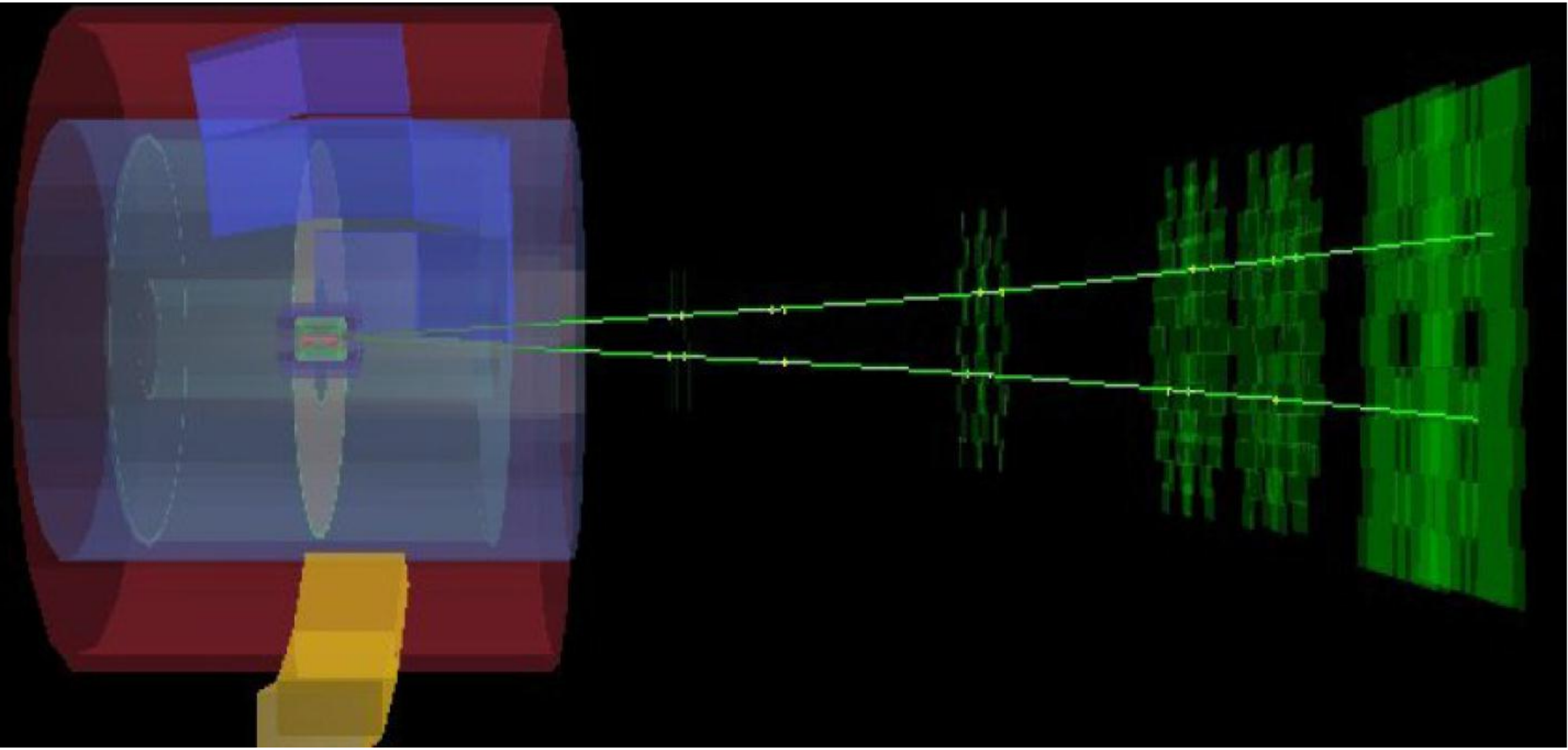
Track selection:

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

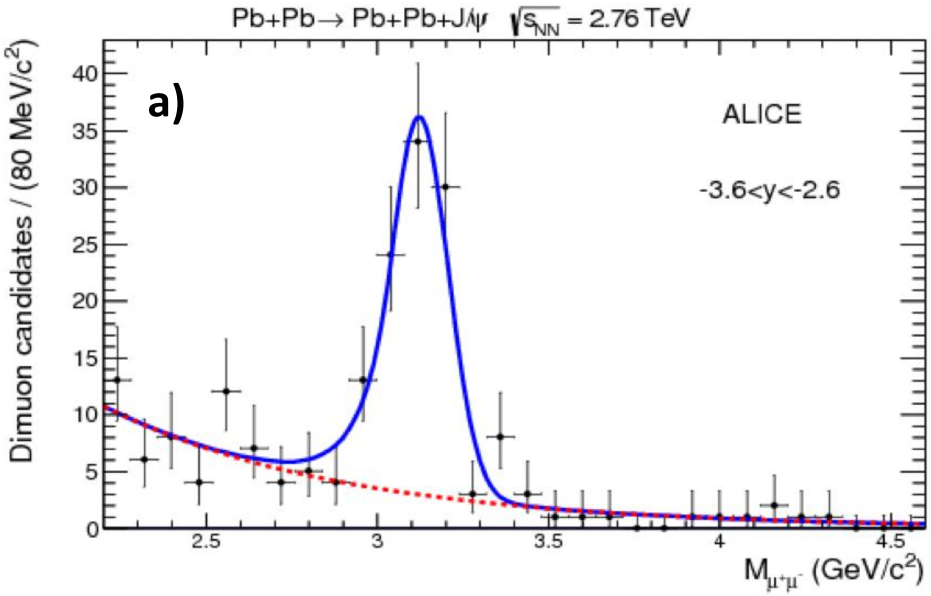
From typical hadronic PbPb collision…

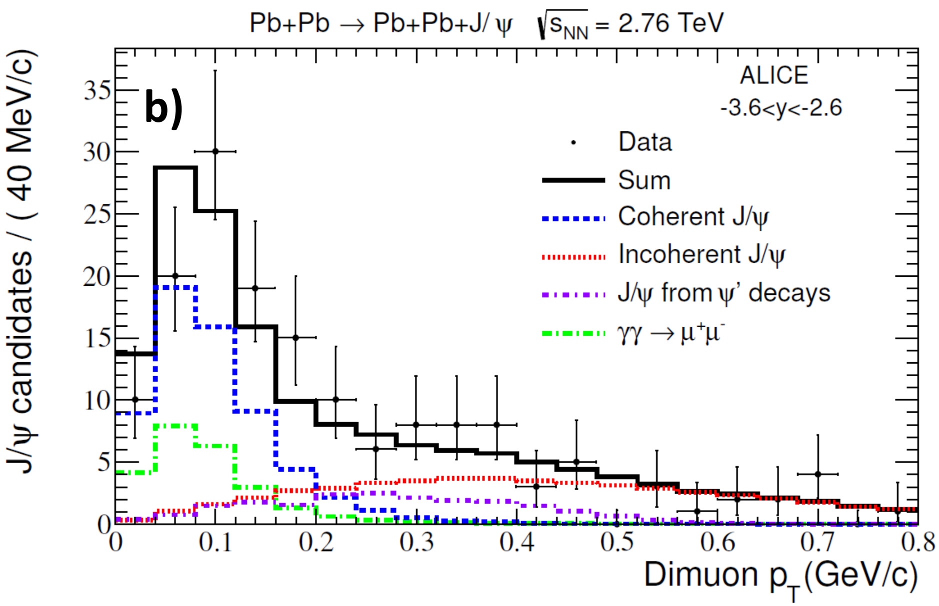


… to exclusive J/ψ



Invariant mass and p_T distributions





Invariant mass distribution:

- $p_T < 0.3$ 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
- $\gamma\gamma \rightarrow \mu\mu$

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

$f_I = 0.12^{+0.14}_{-0.04}$ - fraction of incoherent J/ψ in fig a.

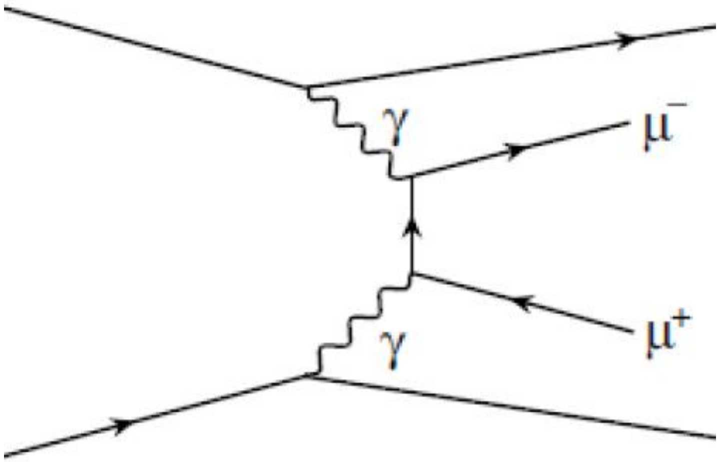
$f_D = 0.11 \pm 0.06$ - fraction of J/ψ from ψ' decays in fig a.

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

Coherent J/ψ cross section at forward rapidity

- QED continuum pair production used for normalization:

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



Standard QED … but:

- Uncertainty in higher order terms due to coupling $Z\sqrt{\alpha}$
- Uncertainty on minimum momentum transfer and nuclear form factor
- Previous experimental results from RHIC also have large uncertainties and cannot constraint the theory
- 20% systematics

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

$-3.6 < y < -2.6$

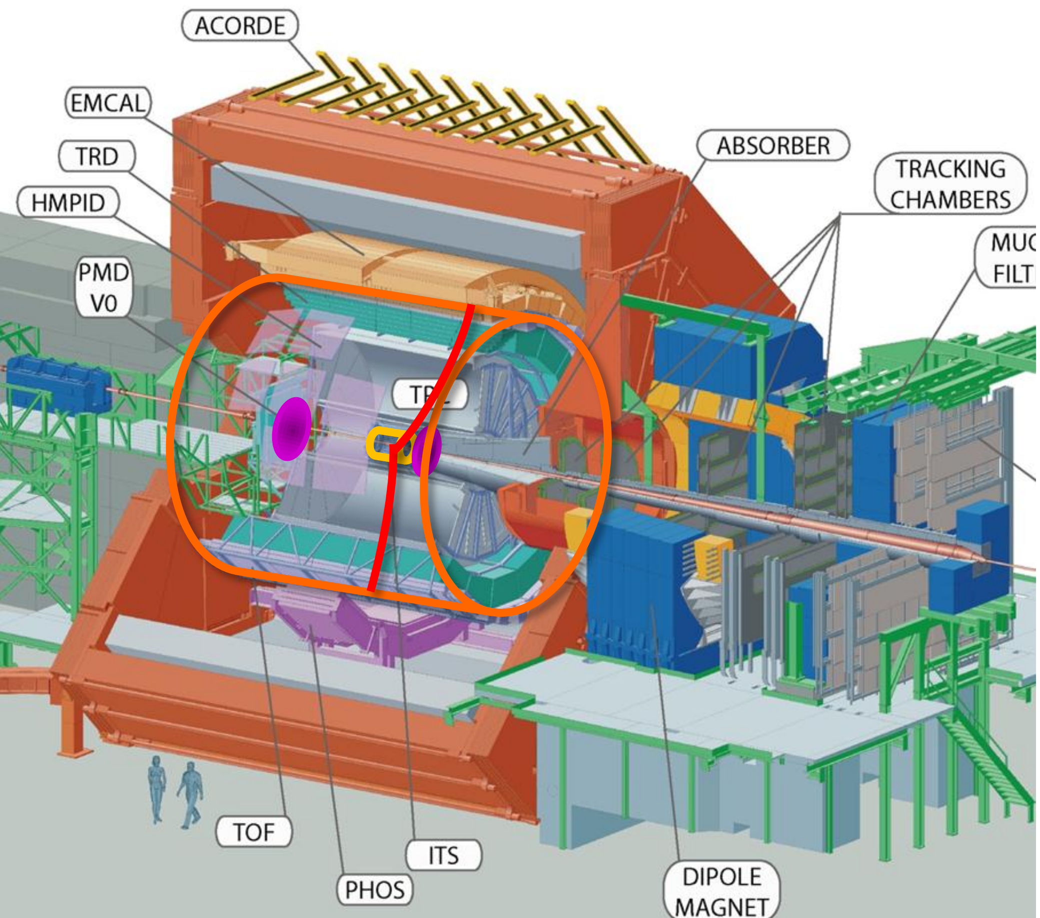
$$\frac{d\sigma_{\rm coh}}{dy} = 1.00 \pm 0.18\ ({\rm stat})\ ^{+0.24}_{-0.26}\ ({\rm sys})\ \ {\rm mb}$$

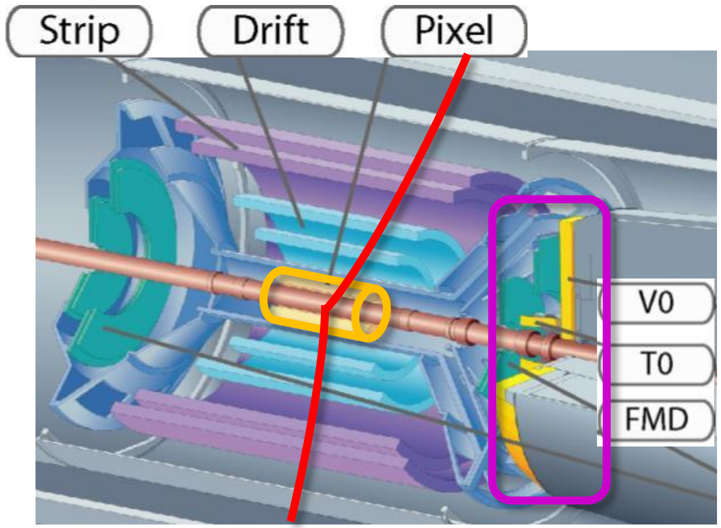
ALICE collaboration. Phys. Lett. B718 (2013) 1273

UPC J/ψ at central rapidity

UPC central barrel trigger:

- $2 \leq$ **TOF** hits ≤ 6 ($|\eta| < 0.9$)
  + back-to-back topology ($150^\circ \leq \varphi \leq 180^\circ$)
- ≥ 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 ~ 20 μb^{-1}

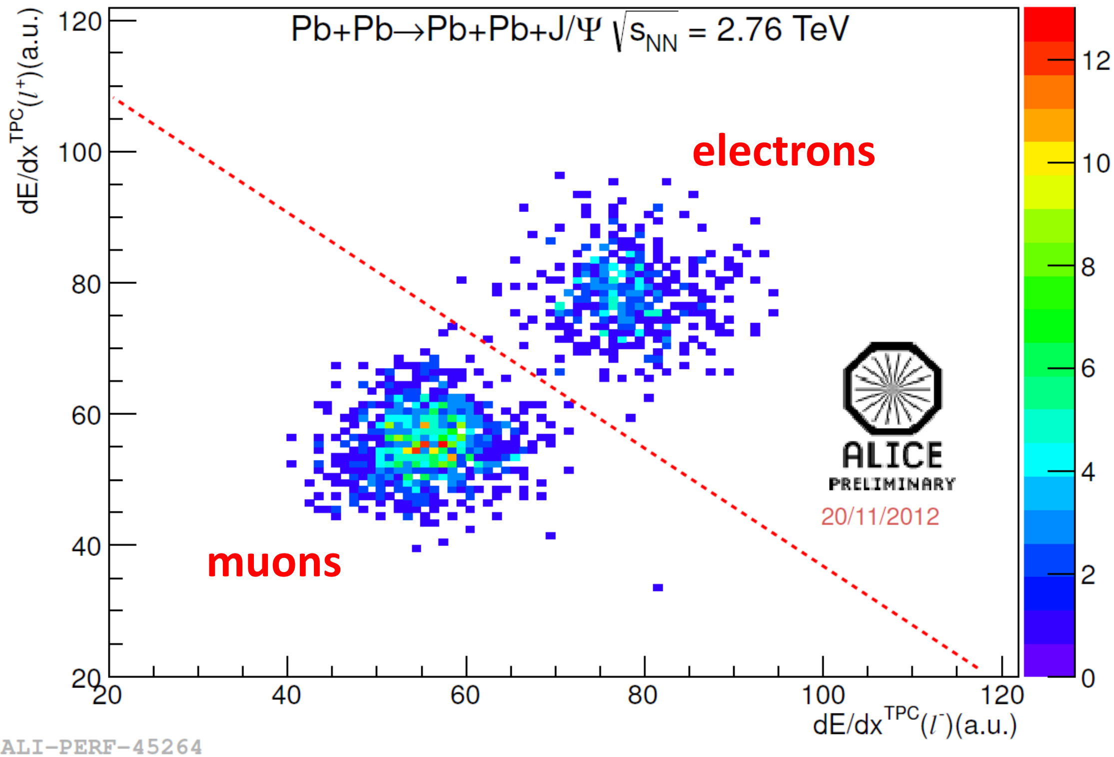
Offline event selection:

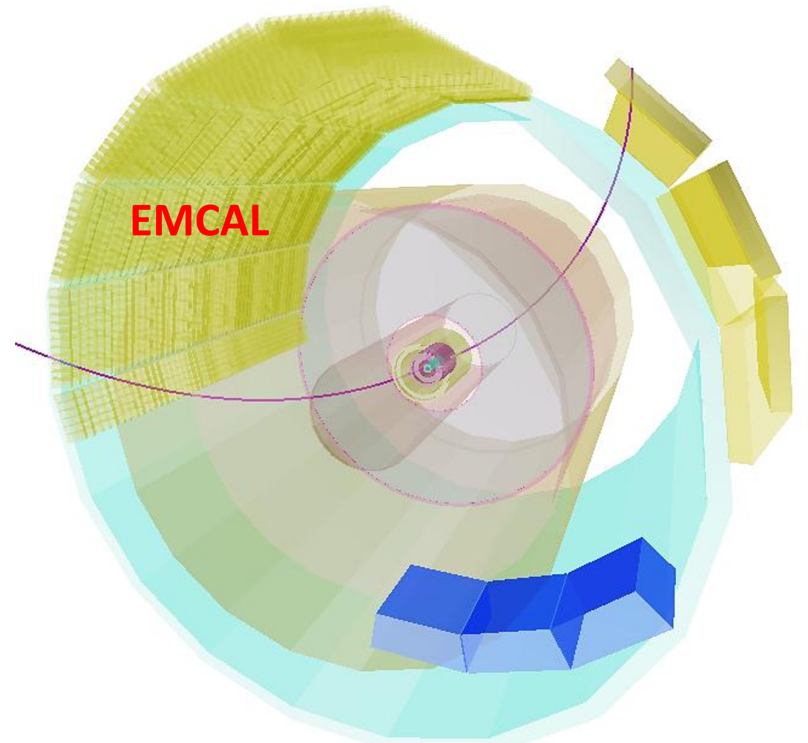
- Offline check on VZERO timing
- Hadronic rejection with ZDC

Track selection:

- Two tracks: $|\eta| < 0.9$
- ≥ 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

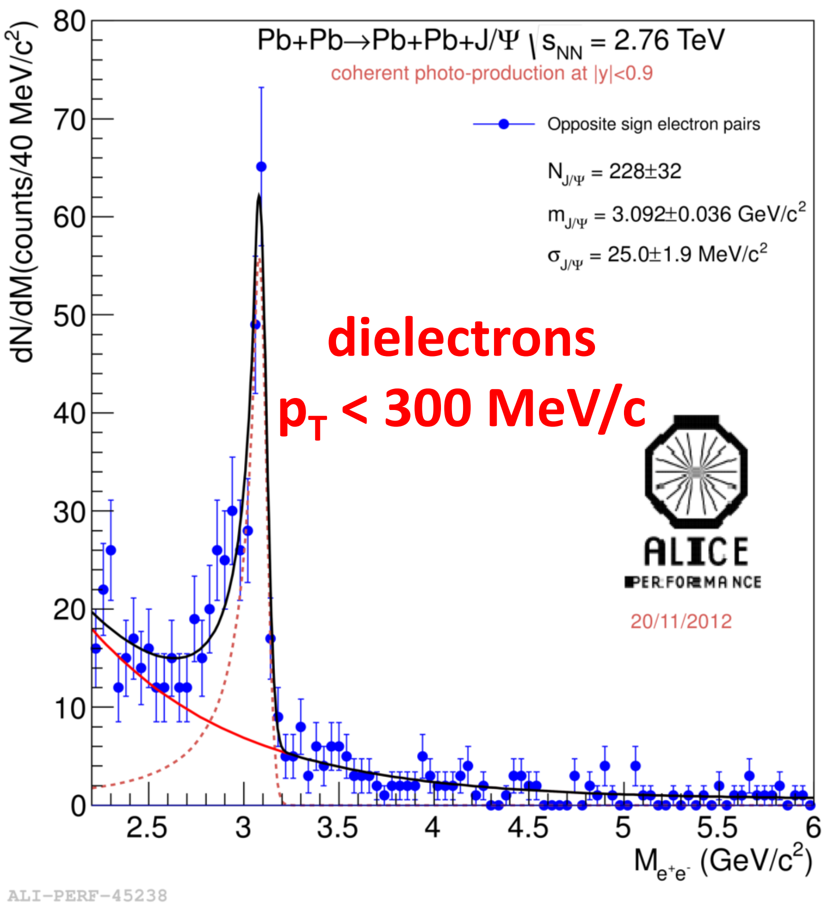


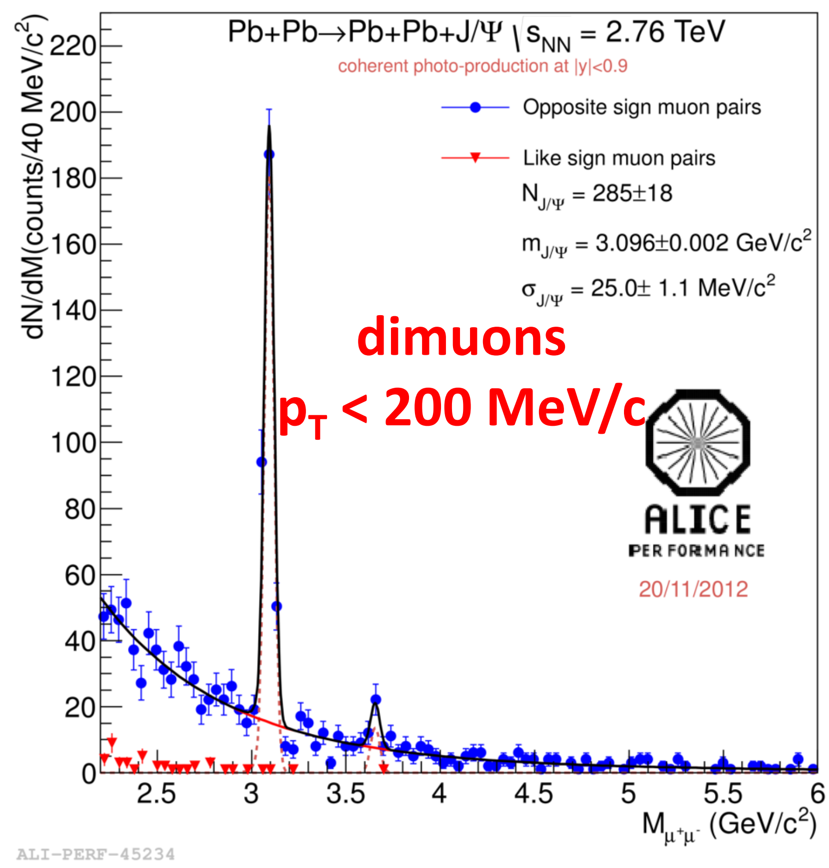


- dE/dx in TPC compatible with e/μ energy loss
- Cross-checked with E/p in EMCAL
- ±2% systematics due to e/μ separation

Coherent J/ψ

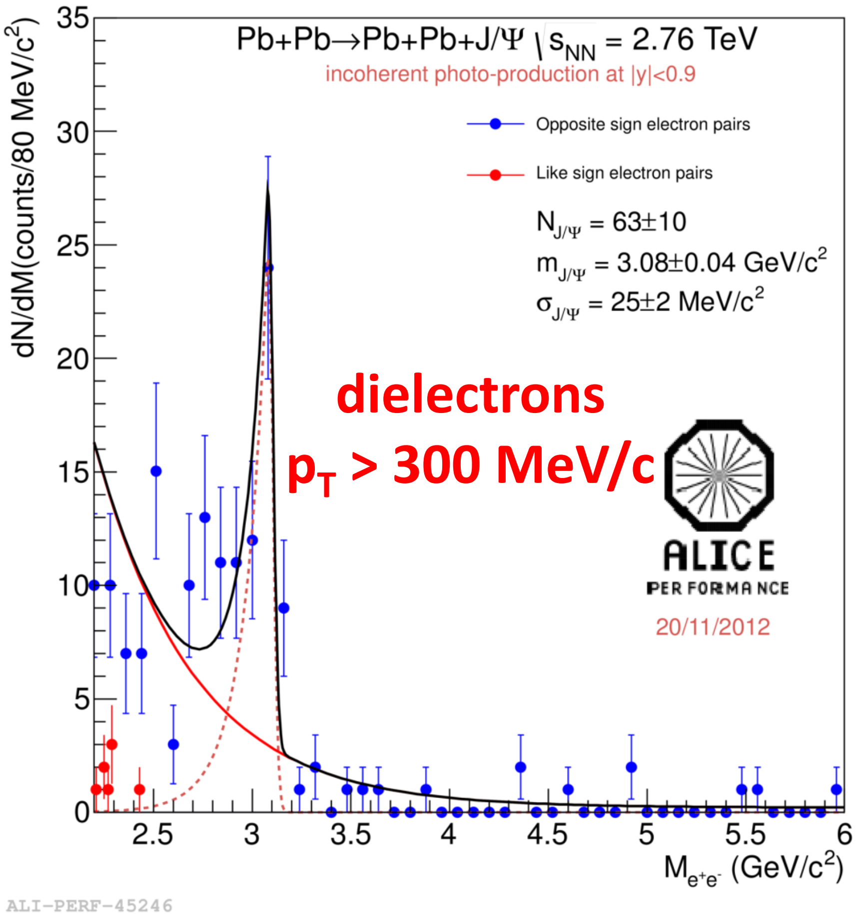
coherent enriched sample

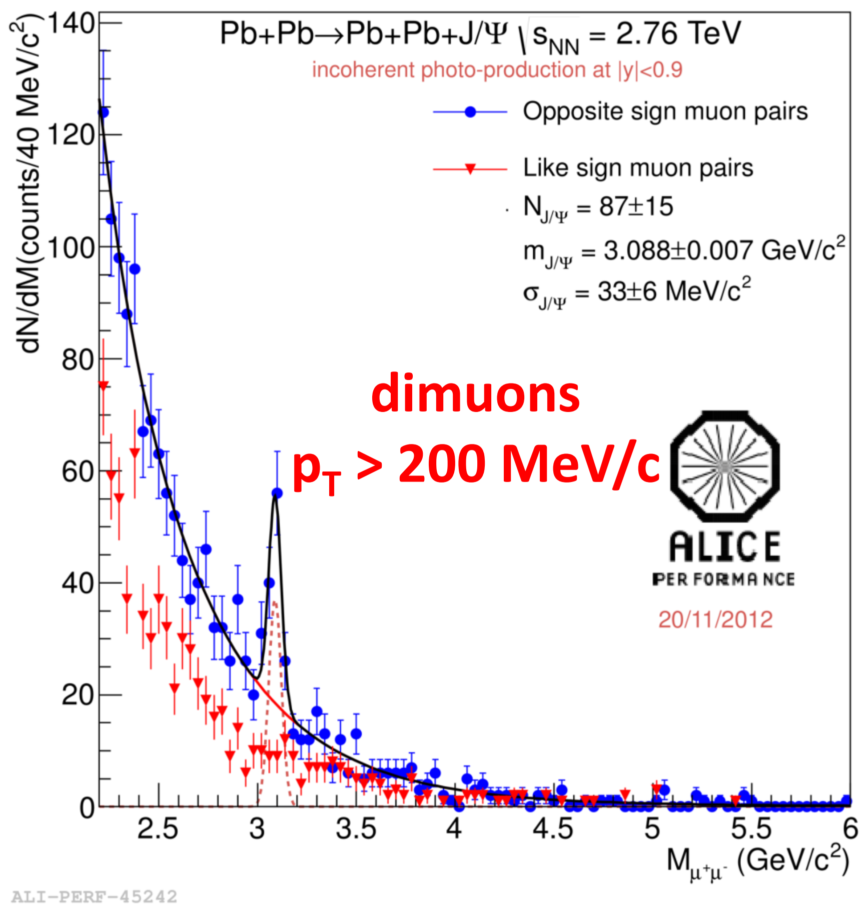




Incoherent J/ψ

incoherent enriched sample





p_T distributions

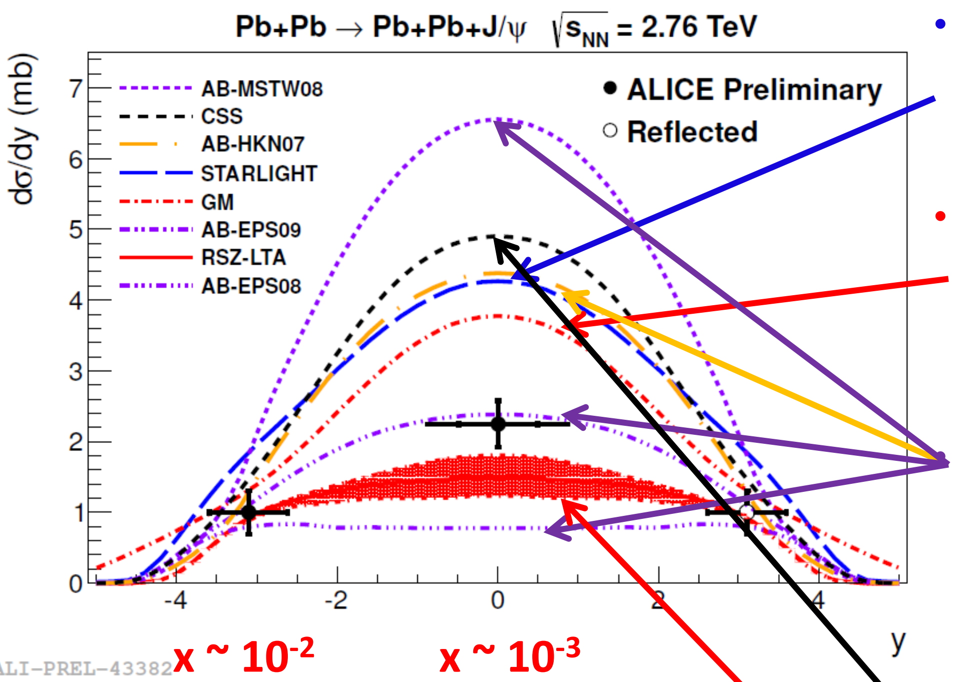
6 components in the dilepton p_T spectrum:

- coherent J/ψ
- incoherent J/ψ: f_I
- feed-down from coherent and incoherent ψ': f_D
- continuum γγ →ee(μμ) from the fit to invariant mass
- hadronic J/ψ events constrained for p_T> 1.1 GeV/c

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

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

Coherent J/ψ: comparison to models



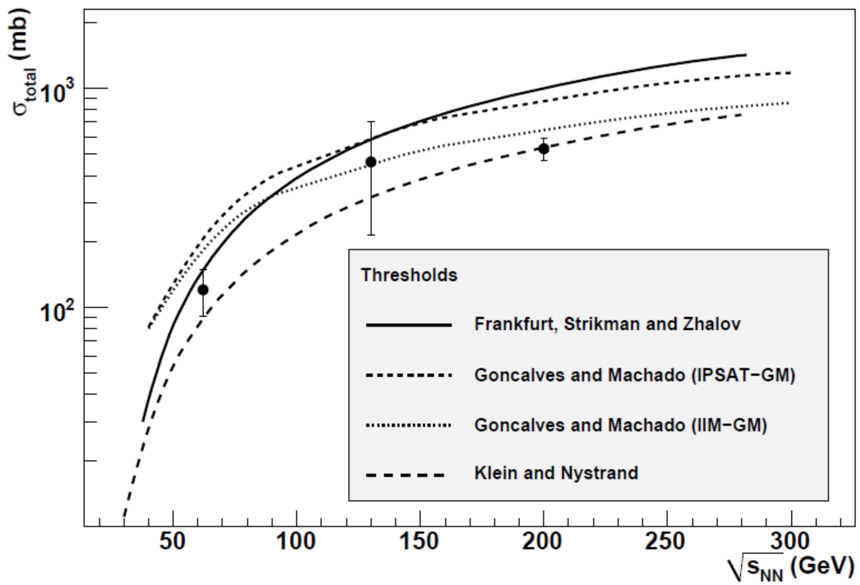
Good agreement with models which include nuclear gluon shadowing.
Best agreement with EPS09 shadowing
(shadowing factor ~0.6 at $x \sim 10^{-3}$, $Q^2 = 2.5$ GeV^2)

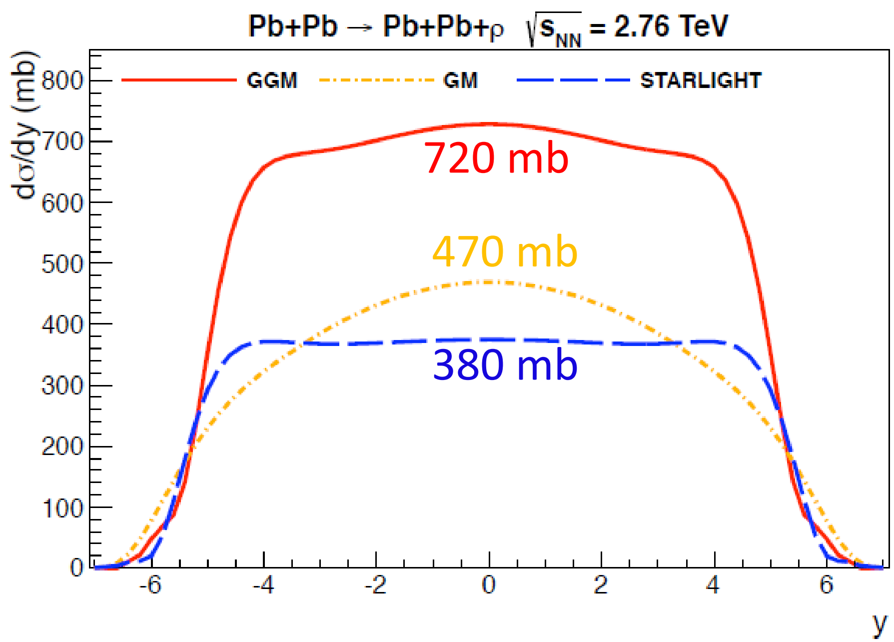
- **STARLIGHT: Klein, Nystrand, PRC60 (1999) 014903** VDM + Glauber approach where J/ψ+p cross section is obtained from a parameterization of HERA data
- **GM: Gonçalves, Machado, PRC84 (2011) 011902** color dipole model, where the scattering amplitude depends on the nuclear profile and the dipole nucleon 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
- **Lappi, Mäntysaari, hep-th/1301.4095** (postprediction, not shown yet): color dipole model + saturation

+ incoherent J/ψ cross section and σ(γγ→μμ) … **will be published soon…**

ρ^0 photoproduction in PbPb

STAR: Phys. Rev. C85 (2012) 014910





GGM: Frankfurt, Strikman, Zhalov, Phys. Lett. B 537 (2002) 51; Phys. Rev. C 67(2003) 034901

- Generalized Vector Meson Dominance Model in the Gribov-Glauber approach.
- Includes nondiagonal transitions $\gamma \to \rho' \to \rho$
- $\sigma_{\rho N}$ from Donnachie-Landshoff model, in agreement with HERA and lower energy data.

GM: Gonçalves, Machado, Phys. Rev. C 84 (2011) 011902

- Based on the color dipole model in combination with saturation from a CGC model.

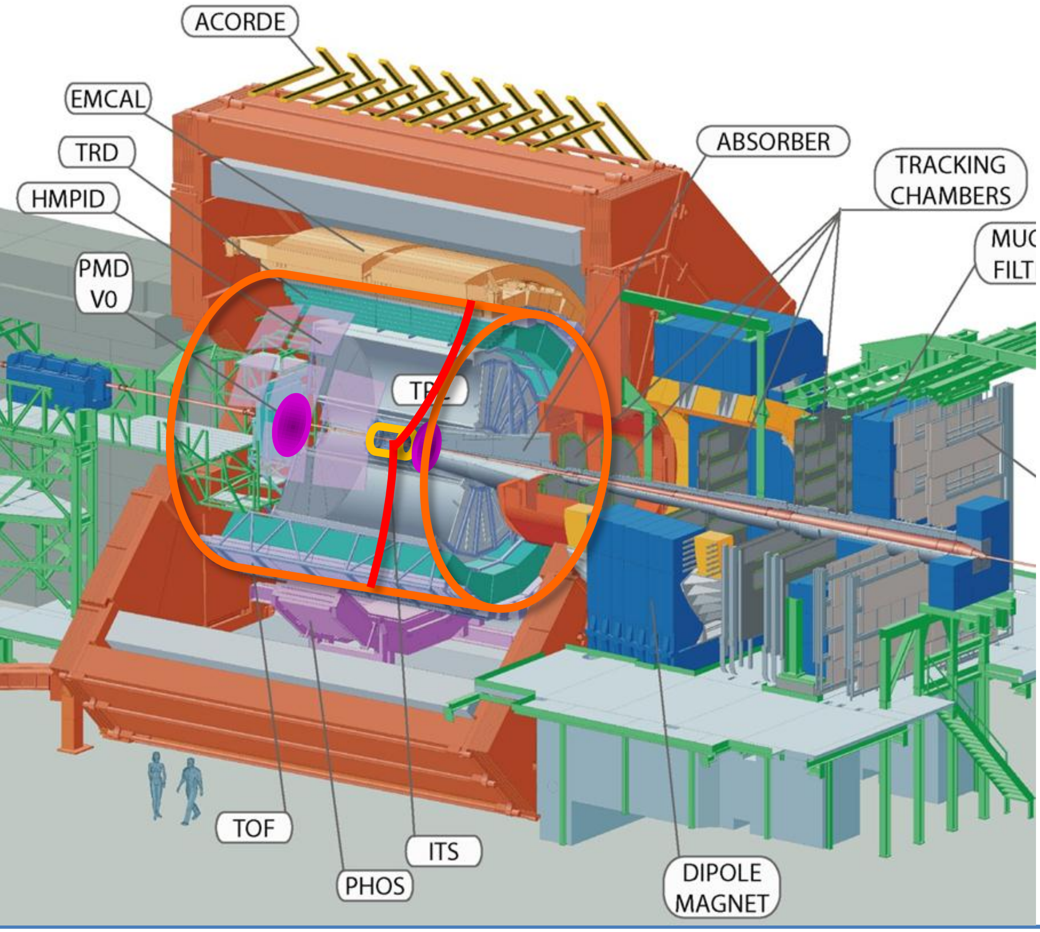
STARLIGHT: Klein, Nystrand, Phys. Rev. C 60 (1999) 014903, http://starlight.hepforge.org/

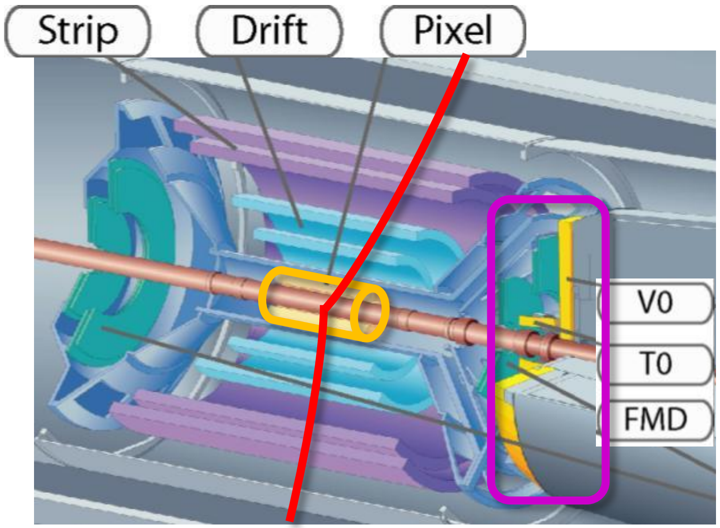
- Uses experimental data on $\sigma_{\rho N}$ cross section.
- Glauber model neglecting the elastic part of total cross section.

$\rho^0 \rightarrow \pi^+\pi^-$ at central rapidity

UPC central barrel trigger:

- $\geq$2 hits in **TOF** ($|\eta| < 0.9$)
- $\geq$2 hits in **SPD** ($|\eta| < 1.5$)
- no hits in **VZERO** (C: $-3.7 < \eta < -1.7$, A: $2.8 < \eta < 5.1$)





Integrated luminosity (2010 data) ~ 0.2 μb^{-1}

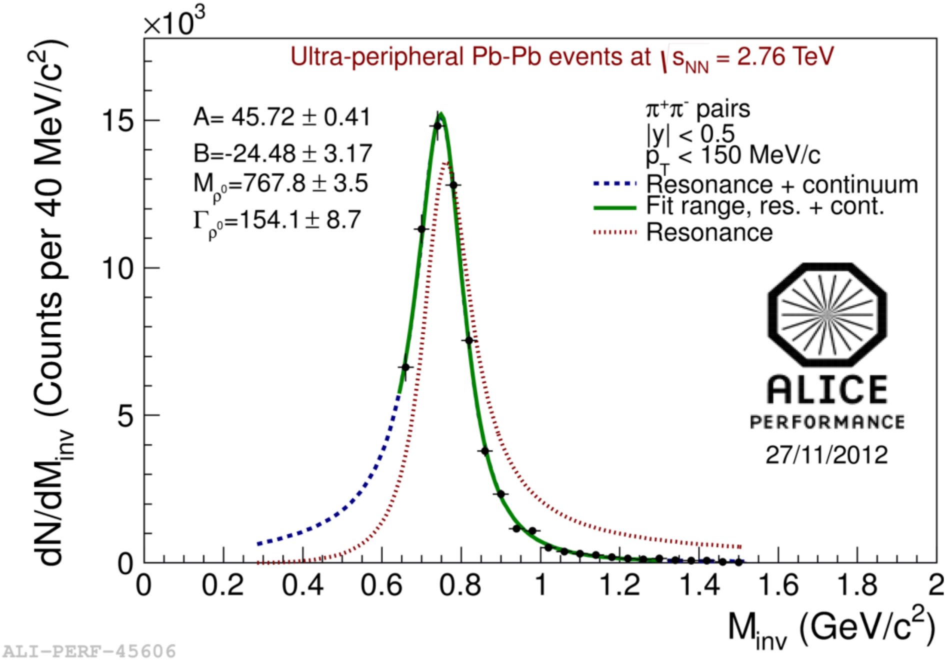
Offline event selection:

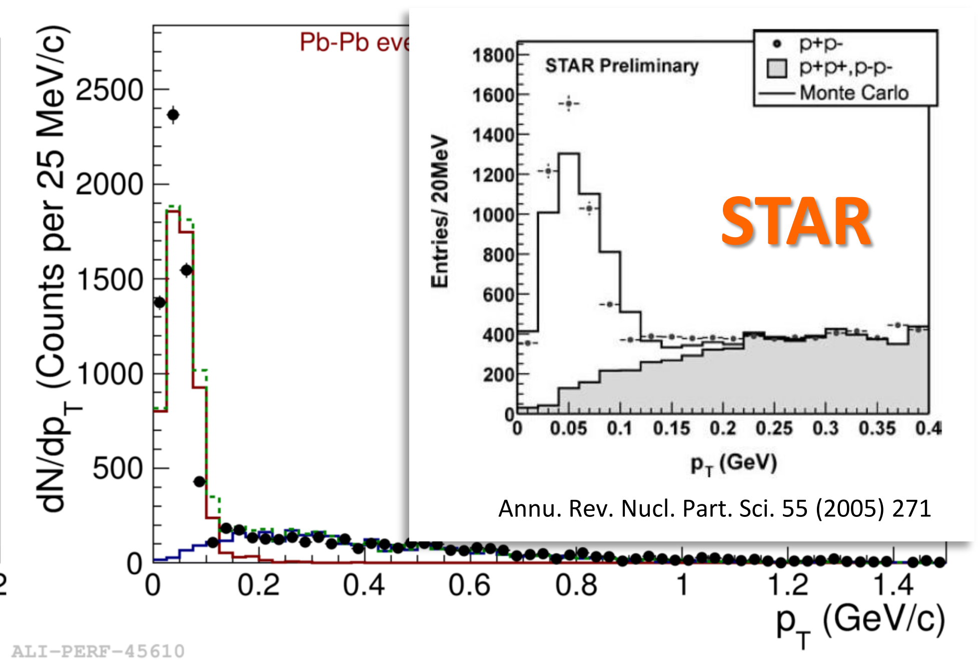
- Offline check on VZERO timing
- Hadronic rejection with ZDC

Track selection:

- Track quality cuts
- Vertex $|v_z| < 10$ cm
- opposite sign $\pi\pi$ pair:
  - $|y| < 0.5$
  - $p_T < 150$ MeV/c
- dE/dx in TPC compatible with π

Invariant mass and p_T spectra





$$\frac{d\sigma}{dm_{\pi\pi}} = \left| A \frac{\sqrt{m_{\pi\pi} M_{\rho^0} \Gamma(m_{\pi\pi})}}{m_{\pi\pi}^2 - M_{\rho^0}^2 + i M_{\rho^0} \Gamma(m_{\pi\pi})} + B \right|^2$$

A - amplitude of the Breit-Wigner function

B - amplitude of the non-resonant ππ production

$$\Gamma(m_{\pi\pi}) = \Gamma_{\rho^0} \frac{M_{\rho^0}}{m_{\pi\pi}} \left(\frac{m_{\pi\pi}^2 - 4m_\pi^2}{M_{\rho^0}^2 - 4m_\pi^2} \right)^{3/2}$$

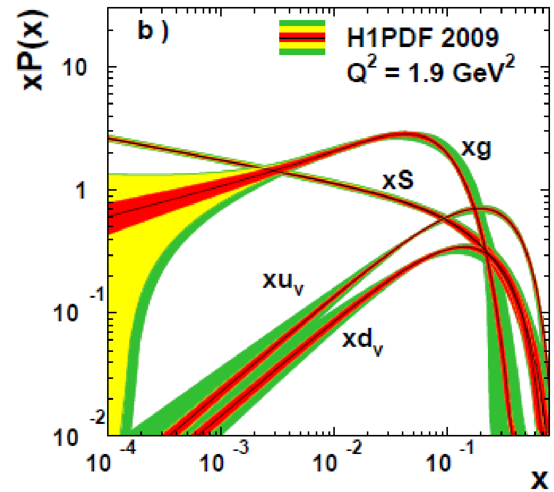
- coherent/incoherent template-pair-p_T distributions from STARLIGHT
- 7 % contribution from incoherent events with pair-p_T < 150 MeV/c
- p_T distribution in Starlight broader than in data (similar trend in STAR)

The absolute cross section will be released soon

pA UPC potential

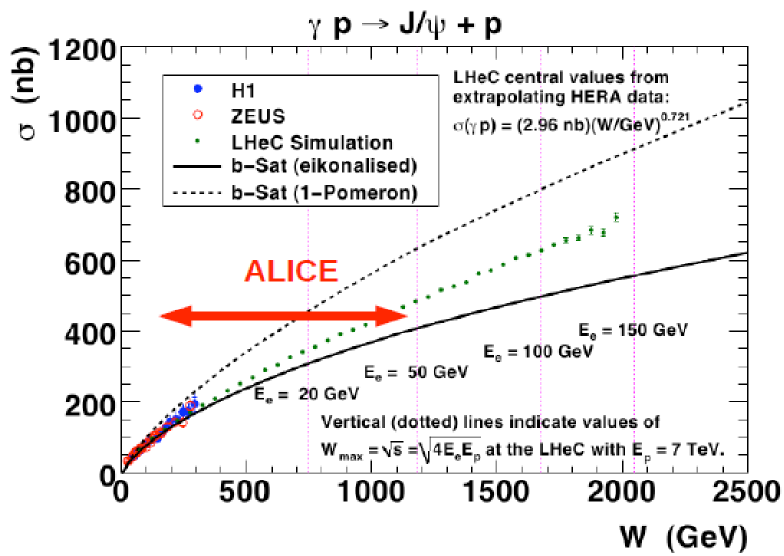
- High flux from Pb
- Quarkonium photoproduction on p
- Allows to study gluon PDFs in proton up to very small x ($\sim 10^{-5}$):

$$\frac{d\sigma_{\gamma p \to pJ/\psi}}{dt} = \frac{\Gamma_{ee} M_{J/\psi}^3 \pi^3}{48\alpha_{em}} \cdot \frac{\alpha_S^2(\bar{Q}^2)}{\bar{Q}^8} \left[x g_N(x, \bar{Q}^2)\right]^2 \exp[B_{J/\psi}(s)t]$$



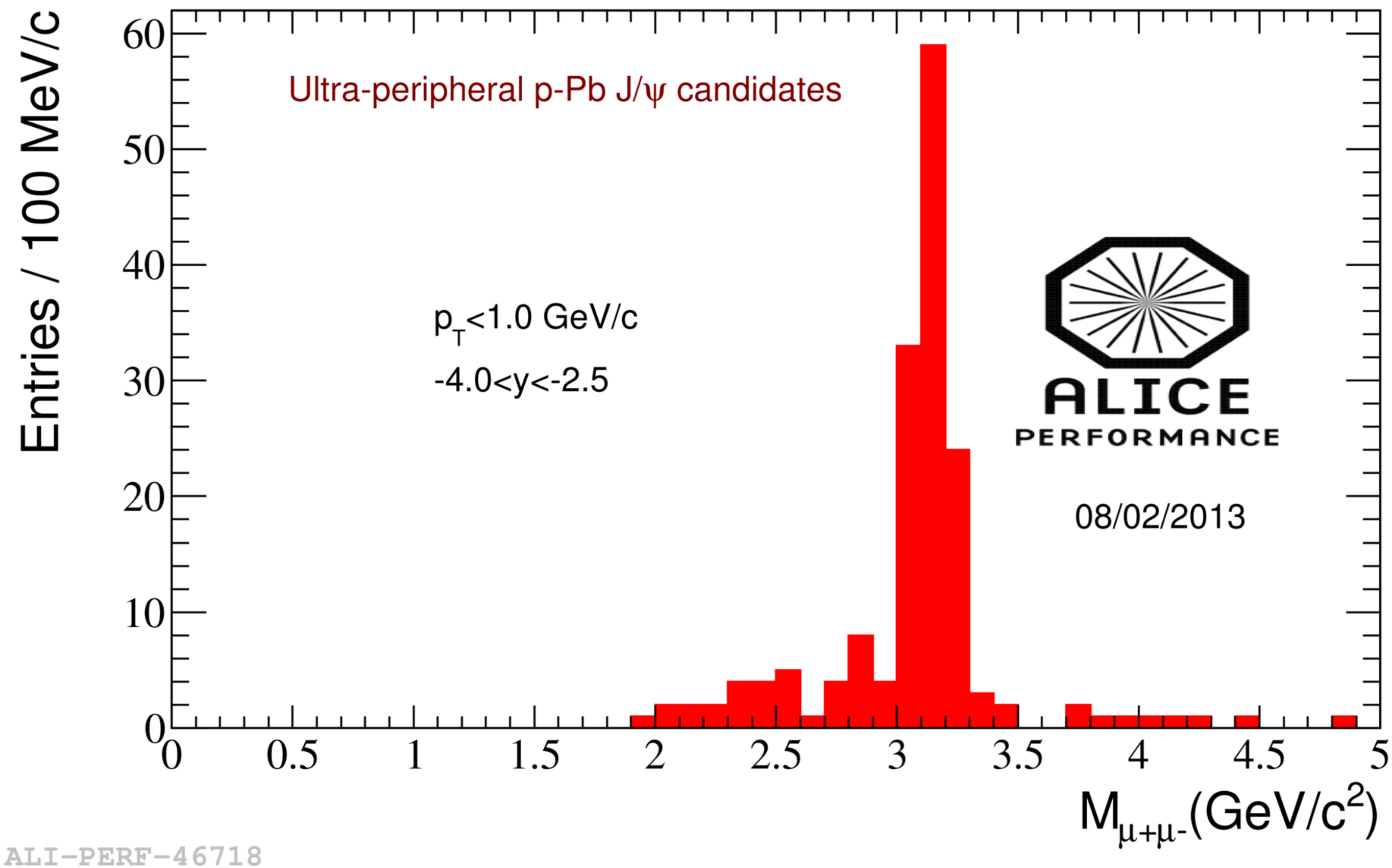
- Gluon PDF up to $x \sim 10^{-4}$ from J/ψ photoproduction at HERA.
- UPC J/ψ production measured in CDF at midrapidity ($x \sim 10^{-3}$)
- LHCb: exclusive J/ψ in pp @ 7 TeV at forward rapidity (hep-ex/1301.7084). Sensitive to $x \sim 10^{-5}$

- No two fold ambiguity: small contribution from J/ψ produced on Pb can be removed by p_T cut
- 3 options in ALICE:
  Forward: both muons in the muon arm
  Central: Both muons/electrons in the barrel
  Semi-forward: one muon in the muon arm, second in the barrel
- Wide x coverage with ALICE: 10^{-2} - 10^{-5}



LheC Study Group, A Large Hadron Electron Collider at CERN, arxiv:1211.4831

pA appetizer



Conclusions and outlook

- The LHC is an effective γA (and γp) collider
- Quarkonium photoproduction in UPC is the most promising tool to measure gluon shadowing effects. Bjorken x up to 10^{-5} accessible
- ALICE measured J/ψ photoproduction in ultra-peripheral Pb-Pb collisions @ 2.76 TeV both at forward and central rapidities
  → Coherent cross section in good agreement with EPS09 parameterization
- $\rho^0 \rightarrow \pi^+\pi^-$ measured in PbPb UPC at central rapidity. Cross section will be released soon
- Measurement of J/ψ photoproduction up to TeV scale in pA UPC is under way

Backup

ALICE pseudorapidity coverage