Heavy quarkonium production in UPC/Diffractive reactions

Daniel Tapia Takaki

For SaporeGravis

1st SaporeGravis day - Research European network

Joliot-Curie Auditorium, Orsay, France, 23 November 2012

Plan of this talk

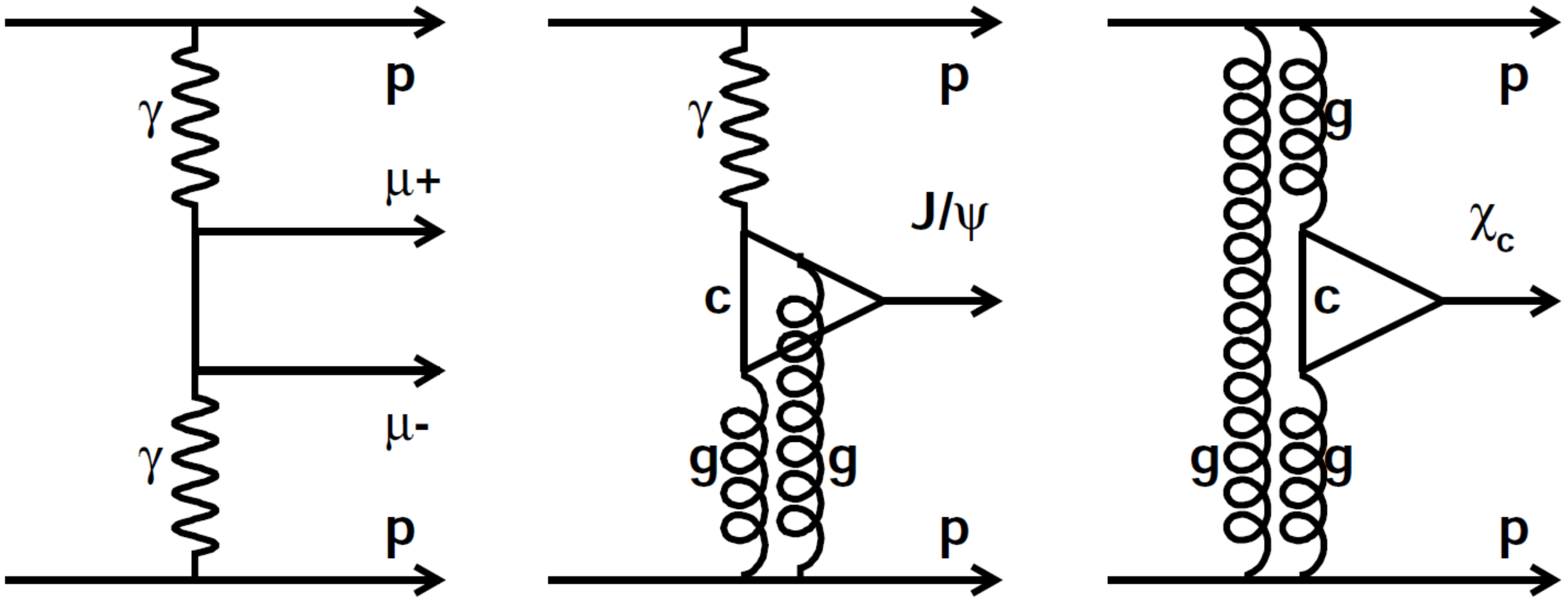
Colliding systems

- proton-proton
- lead-lead
- proton-lead

Summary

Proton-proton collisions

Feynman diagram; exclusive dimuon final states



Diphoton production

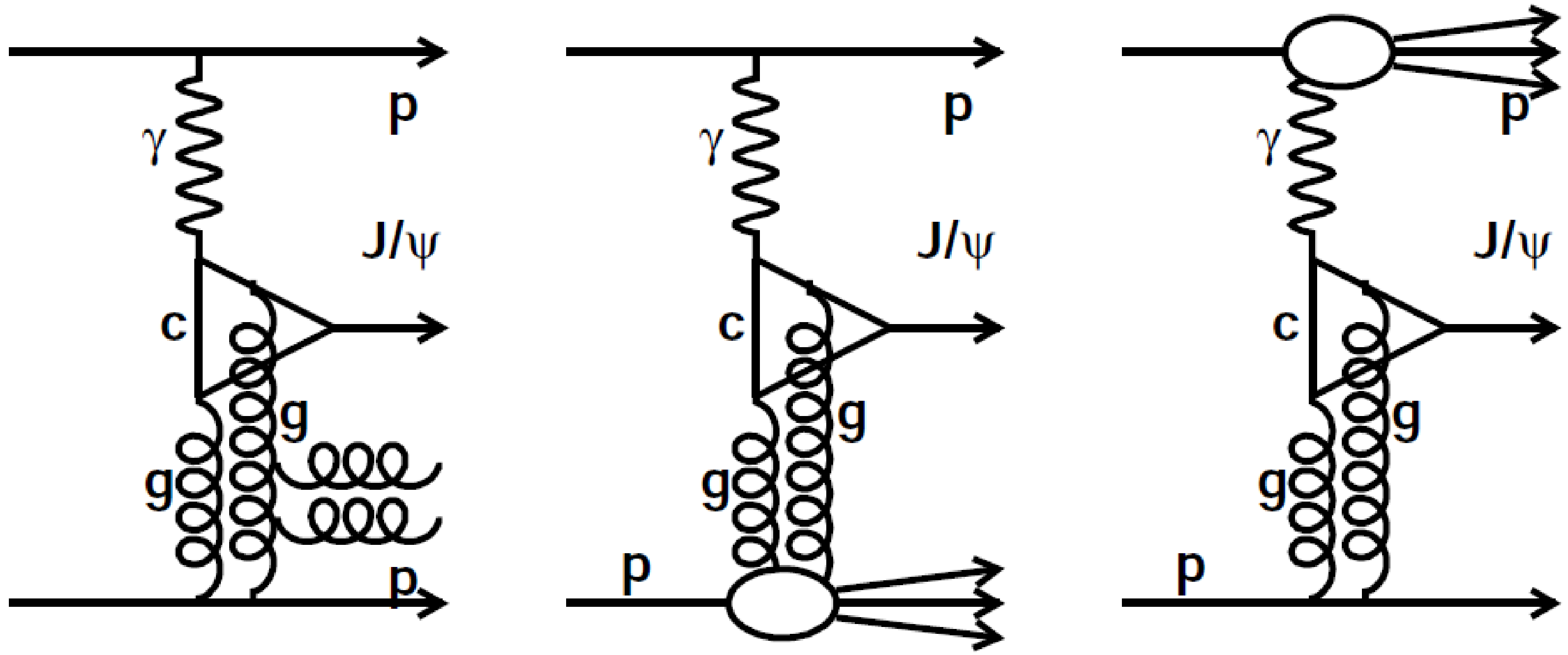
Photon-pomeron fussion

Double pomeron exchange

p+p → p + X + p

First LHC studies by LHCb-CONF-2011-022

Non-exclusive J/ψ

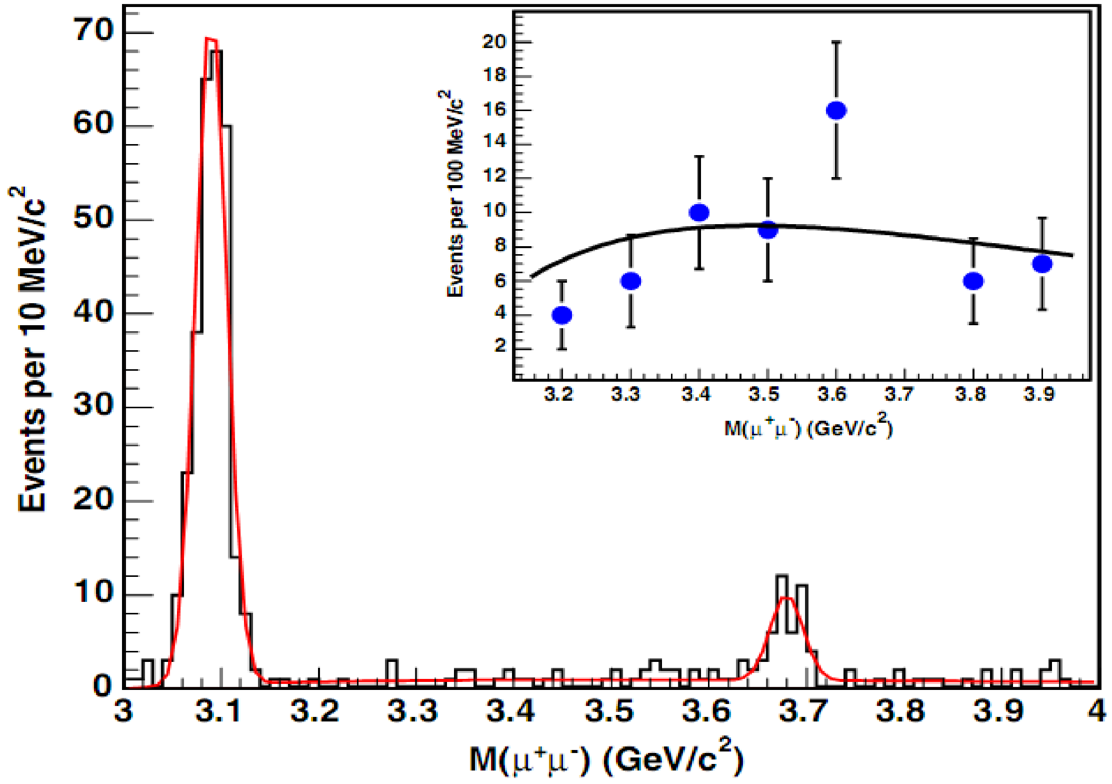


Additional final states particles due to proton dissociations or additional gluon radiations

CDF results

CDF - Phys. Rev. Lett. 102, 242001 (2009)

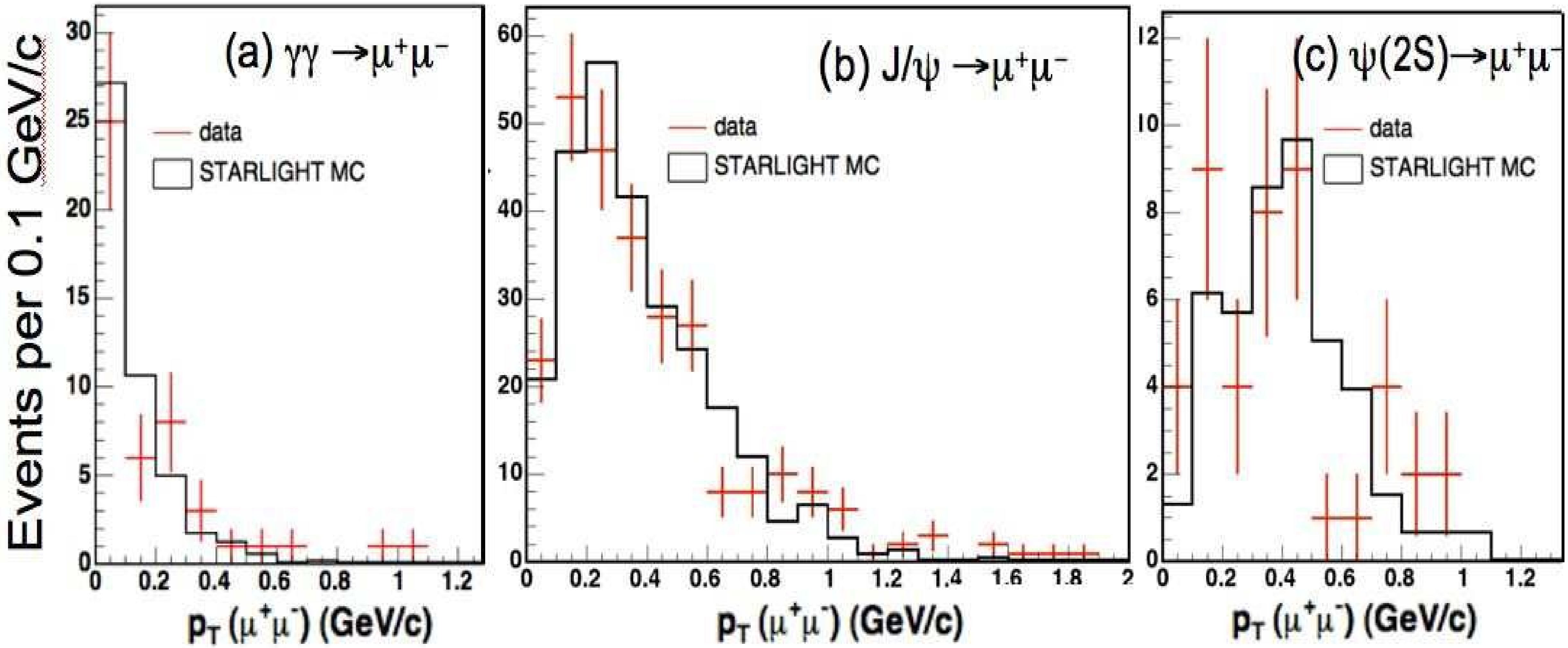
- Integrated luminosity: 1.48 fb^{-1}
- Total μμ events: 402
- μμ in the barrel (y=0): |η|<0.6
- η coverage:
  - |η|<3.6 - EM calorimeter
  - 3.6<|η|<5.2 – lead liquid scintillator calorimeter
  - 3.4<|η|<4.7 – Cherenkov counters
  - |η|<7.4 – Beam shower scintillator counters
- Good η coverage allowed to reject background contributions.
- Good calorimetry allowed to separate χ_{c0} contribution
- y=0 → x~10^{-3} – consistent with HERA results
-
- γ + p ~ 100 GeV



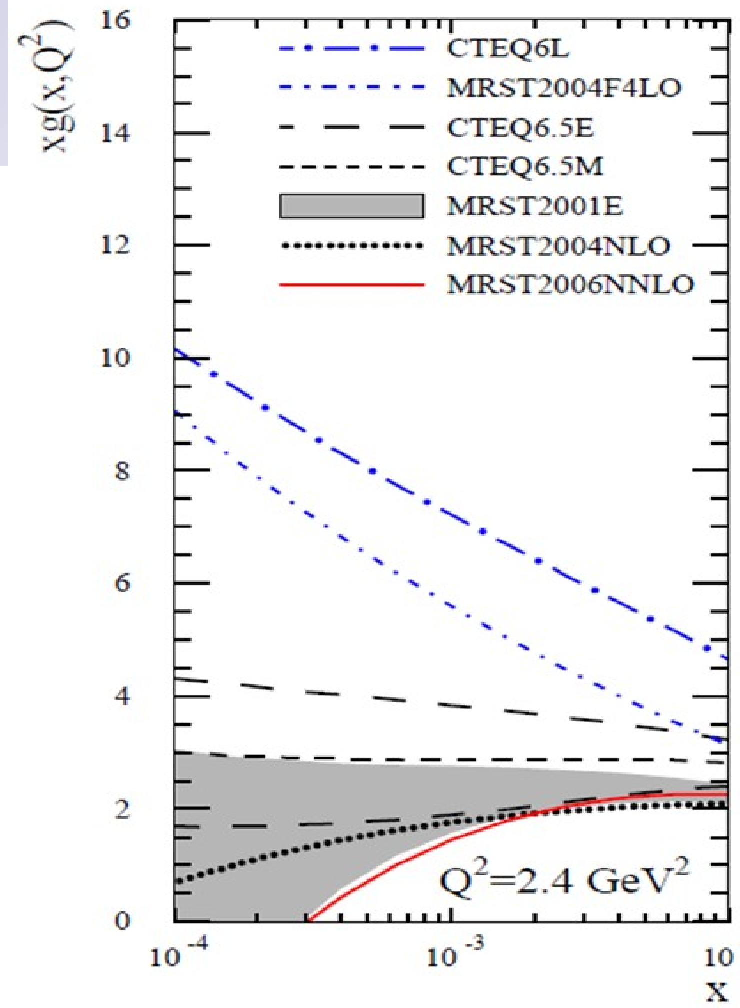
Channel	# Events	dσ/dy (y=0), nb
J/ψ	286	3.92 ± 0.25 ± 0.52
ψ’	39	0.53 ± 0.09 ± 0.10
χ_{c0}	65	76 ± 10 ± 10

CDF results

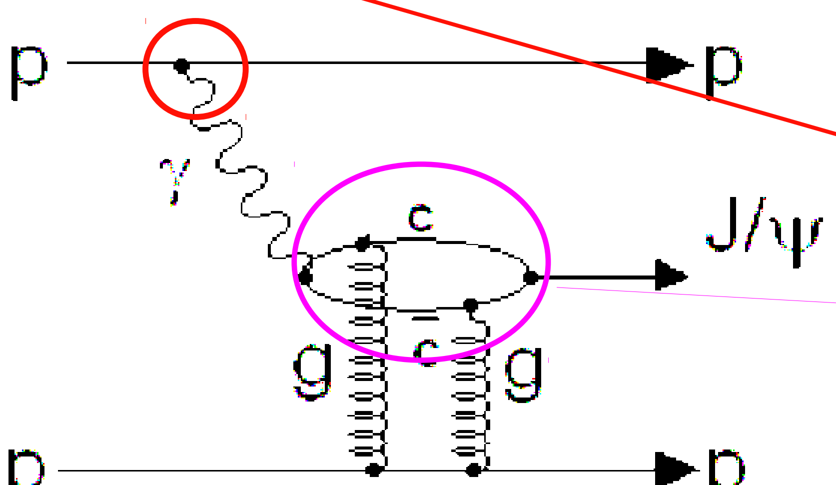
CDF - Phys. Rev. Lett. 102, 242001 (2009)



Small x gluon physics



- V. Rebyakova, M. Strikman and M. Zhalov. *LHC potential for study of the small x gluon physics in ultraperipheral collisions of 3.5 TeV protons*, Phys. Rev. D81, 031501(R) (2010)
- Coherent J/ψ production: pp → ppJ/ψ:



$$\frac{d\sigma_{pp\to ppJ/\psi}}{dtdy} = \frac{dN_{\gamma/p}(y)}{dy}\cdot\frac{d\sigma_{\gamma p\to ppJ/\psi}(y,t)}{dt} + \frac{dN_{\gamma/p}(-y)}{dy}\cdot\frac{d\sigma_{\gamma p\to ppJ/\psi}(-y,t)}{dt}$$

- Extraction of gluon density up to $x \sim 10^{-5}$.
  In the leading order:

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

Predicted J/ψ cross-section: σ_{tot} = 65.5 nb.

σ(-4<y<-2.5) = 8.5 nb.

LHCb - Exclusive χ_c

	$\sigma(pp \to pp(J/\psi + \gamma))$ LHCb (pb)	SuperCHIC prediction (pb)
χ_{c0}	9.3 ± 4.5	14
χ_{c1}	16.4 ± 7.1	10
χ_{c2}	28 ± 12.3	3

[2] See LHL, V. A. Khoze, M. G. Ryskin, W. J. Stirling, Eur. Phys. J. **C69** (2010) 179-199.
[3] LHCb-CONF-2011-022

L.A. Harland-Lang (University of Cambridge) 4 / 19

CDF - Phys. Rev. Lett. 102, 242001 (2009)

Our observation of exclusive χ_{c0} production implies that exclusive Higgs boson production should occur at the LHC [9] and imposes constraints on the $p+p \to p+H+p$ cross section.

***Challenging measurement at the LHC**

***Large theoretical errors**

***Could be used as a standard central diffraction candle, useful for exclusive Higgs production**

Odderon production

Exclusive J/Ψ and Υ hadroproduction

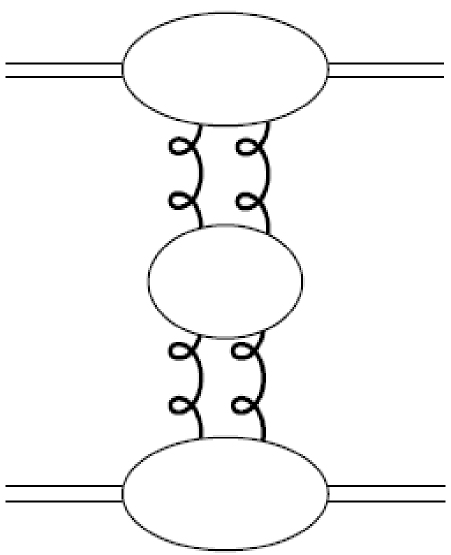
and the QCD odderon

Lech Szymanowski

Ecole Polytechnique, Palaiseau,

Soltan Inst. for Nucl. Studies, Warsaw

Lech et al.
Phys Rev D. 75. 094023



16 July 2011

- Puzzle:

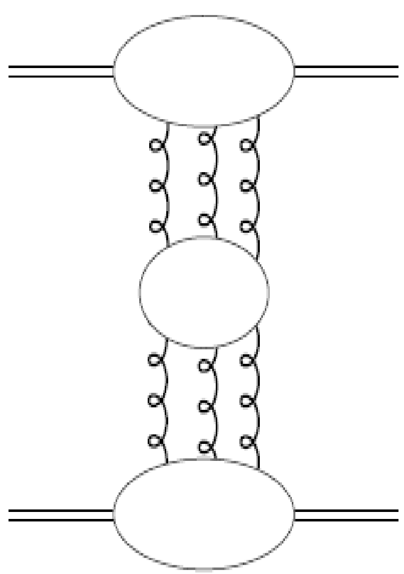
QCD $\rightarrow$

TWO colour singlet reggeons with intercepts around 1:

POMERON $(C = 1)$ $\sigma_{AB} + \sigma_{\bar{A}B}$

ODDERON $(C = -1)$ $\sigma_{AB} - \sigma_{\bar{A}B}$

which still escapes experimental verification



Odderon was introduced more than 30 years ago

L. Lukaszuk and B. Nicolescu, Lett. Nuovo Cim. **8** (1973) 405

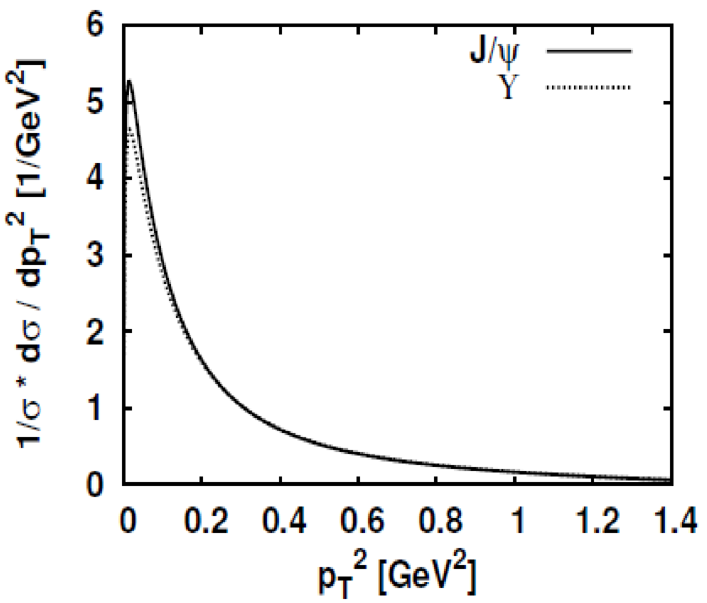
it was often considered as a "heretic and doubtful concept"

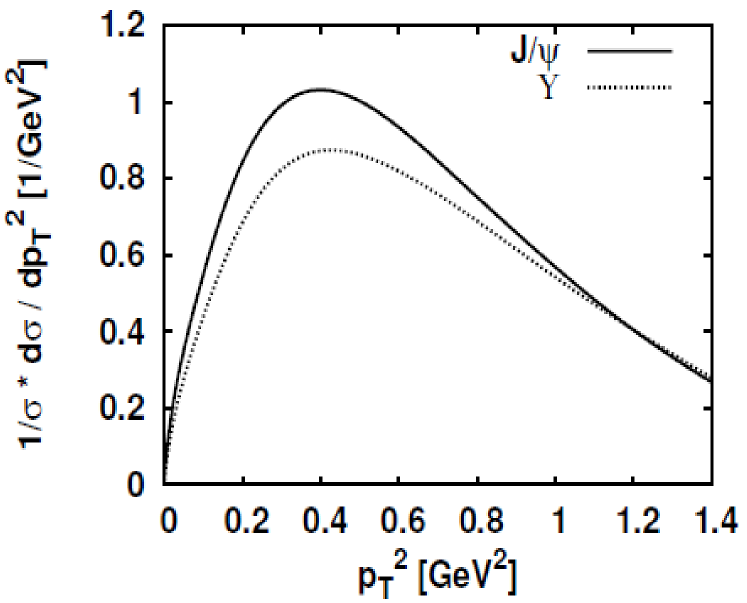
C. Ewerz

naive Pomeranchuk thm: $\Delta\sigma = \sigma_T^{\bar{p}p} - \sigma_T^{pp} \rightarrow 0$, for $s \rightarrow \infty$

too strong assumptions in the proof (no odderon)

Odderon production





Lech et al.
Phys Rev D. 75. 094023

$\left.\frac{d\sigma}{dy d\mathbf{p}^2}\right|_{norm}$ for $p\bar{p} \to p\bar{p}V$ and $pp \to ppV$.

$d\sigma^{corr}/dy$	J/ψ		Υ	
	odderon	photon	odderon	photon
Tevatron	0.3–1.3–5 nb	0.8–5–9 nb	0.7–4–15 pb	0.8–5–9 pb
LHC	0.3–0.9–4 nb	2.4–15–27 nb	1.7–5–21 pb	5–31–55 pb

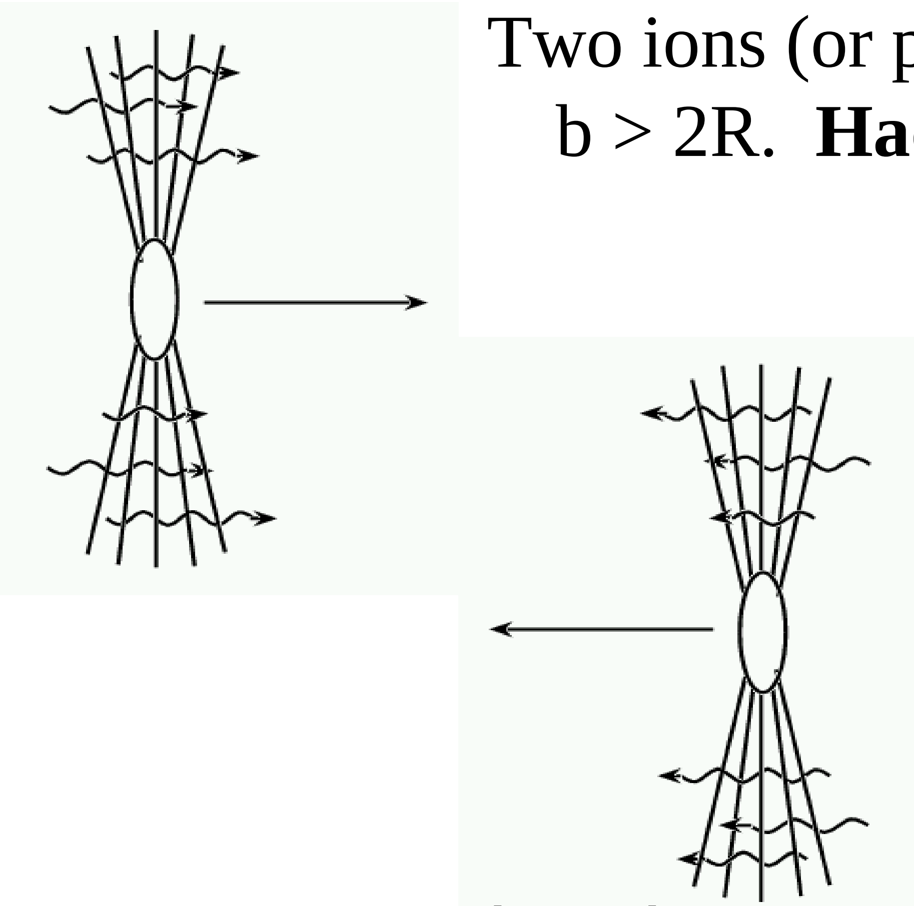
- γ-P and P-O ampl. do not interfere in our approx. → they can be treated independently

CDF - Phys. Rev. Lett. 102, 242001 (2009)

If the J/ψ and $\psi(2S)$ cross sections were larger than expected for photoproduction, it would be evidence for odderon exchange. If we assume a theoretical value of $\frac{d\sigma}{dy}|_{y=0}(J/\psi) = 3.0 \pm 0.3$ nb for photoproduction ($\gamma I\!P \to J/\psi$), compatible with the predictions, we can place a 95% C.L. upper limit $\frac{d\sigma}{dy}|_{y=0}(J/\psi) < 2.3$ nb for odderon exchange ($O I\!P \to J/\psi$).

UPC Pb-Pb

Why ultra-peripheral heavy-ion collisions



Two ions (or protons) pass by each other with impact parameters b > 2R. **Hadronic interactions are strongly suppressed**

Number of photons scales like Z^2 for a single source ⇒ exclusive particle production in heavy-ion collisions dominated by electromagnetic interactions.

The virtuality of the photons → 1/R ~ 30 MeV/*c*

In 5.5 TeV Pb+Pb

R. Bruce et al., Phys.Rev. 12 071002 (2009)

σ(hadronic) ~ 8b; σ(e^+e^-) ~ 281 b

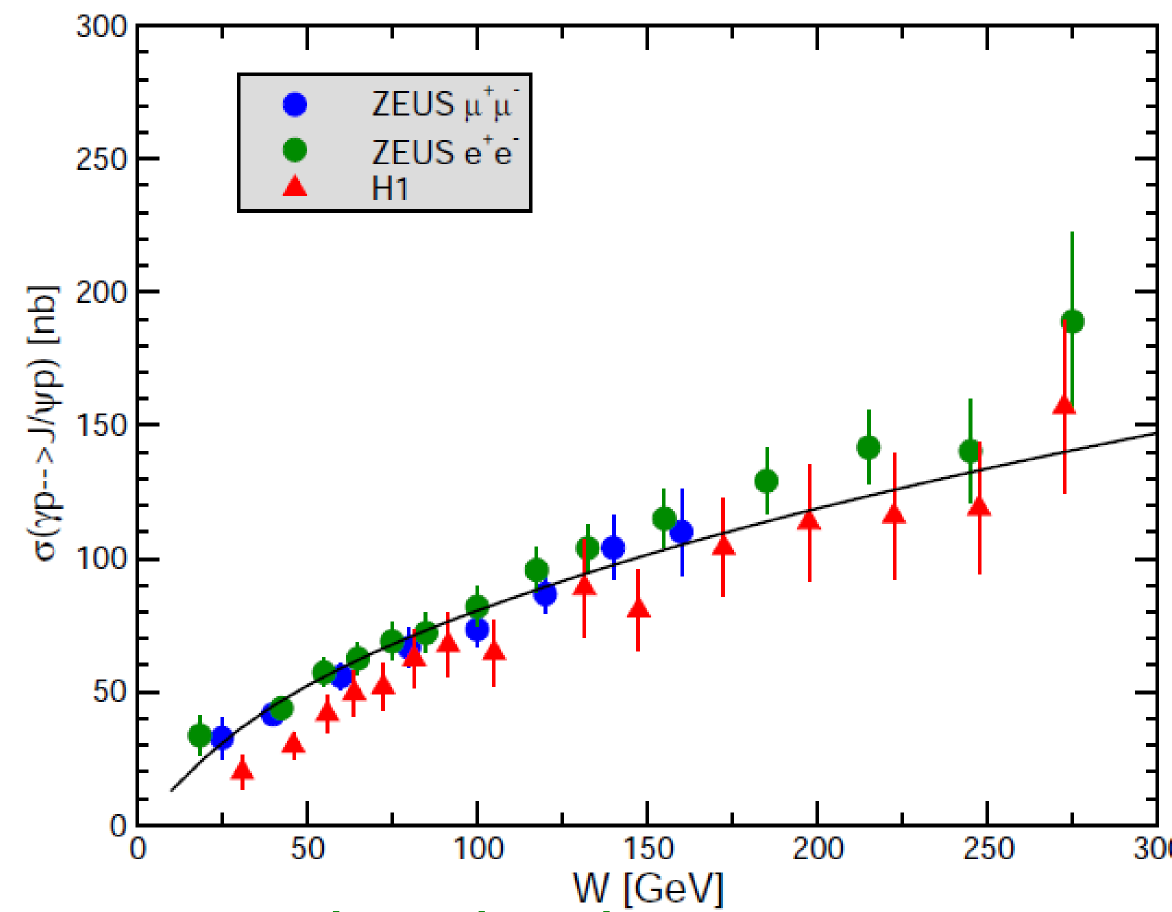
σ(EMD) ~ 226 b

A big jump in energy …

RHIC: $W_{\gamma N,max}$ ~ 34 GeV

HERA: $W_{\gamma N,max}$ ~ 300 GeV

LHC: $W_{\gamma N,max}$ reaches up to 950 GeV !



H1: A. Aktas *et al.* Eur.Phys. J.C46:585-603,2006
ZEUS:S. Chekanov et al., Nucl. Phys. B695 (2004) 3.
A. Martin et al. Phys.Lett. B 662:252-258, 2008

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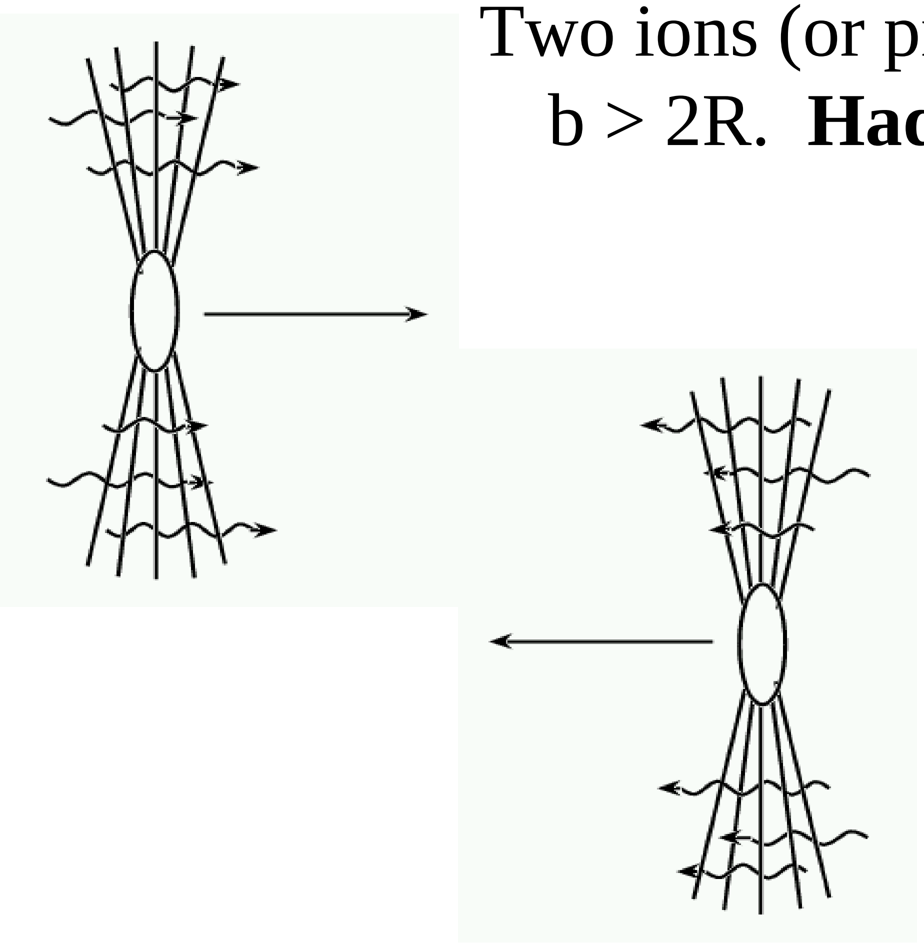

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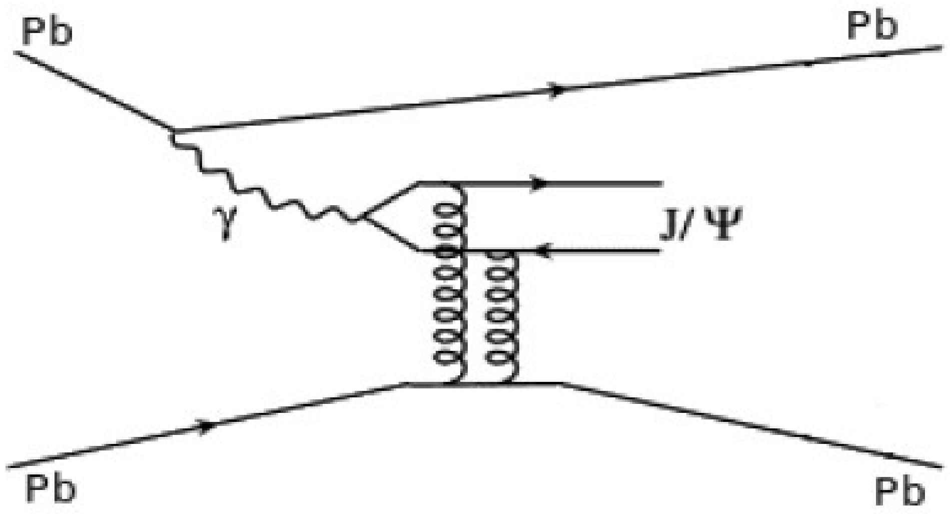

Coherent production:

Photon couples coherently to all nucleons

$\langle p_T \rangle \sim 60$MeV/*c*; target nucleus normally does not break up

Incoherent production

Photon couples to a single nucleon

Quasi-elastic scattering off a single nucleon

$\langle p_T \rangle \sim 500$ MeV/*c*

γ + p → J/ψ + p

modelled in pQCD: exchange of two gluons with no net-colour transfer

Why J/ψ photo-production at LHC

Total J/ψ cross section: 23 mb (STARLIGHT) *vs* 10.3 mb Rebyakova, Strikman and Zhalov

Models differ by the way photo-nuclear interaction is treated...

Five model predictions available
– published in the last two years-

STARLIGHT
http://starlight.hepforge.org

Adeluyi and Bertulani (AB)
Phys. ReV. C 85 (2012) 044904

Goncalves and Machado (GM)
Phys. ReV C 84 (2011) 011902

Cisek, Szczurek, Schafer (CSC)
Phys. ReV. C 86 (2012) 014905

Rebyakova, Strikman and Zhalov (RSZ)
Phys. Lett. B 710 (2012) 252

$$\frac{d\sigma}{dt}\Big|_{t=0} = \frac{\alpha_s^2 \Gamma_{ee}}{3\alpha M_V^5} 16\pi^3 \left[xg\left(x, \frac{M_V^2}{4}\right)\right]^2$$

Ryskin 1993

$$\frac{\frac{d\sigma(\gamma A \to VA)}{dt}\Big|_{t=0}}{\frac{d\sigma(\gamma N \to VN)}{dt}\Big|_{t=0}} = \left[\frac{G_A(x, M_V^2/4)}{G_N(x, M_V^2/4)}\right]^2$$

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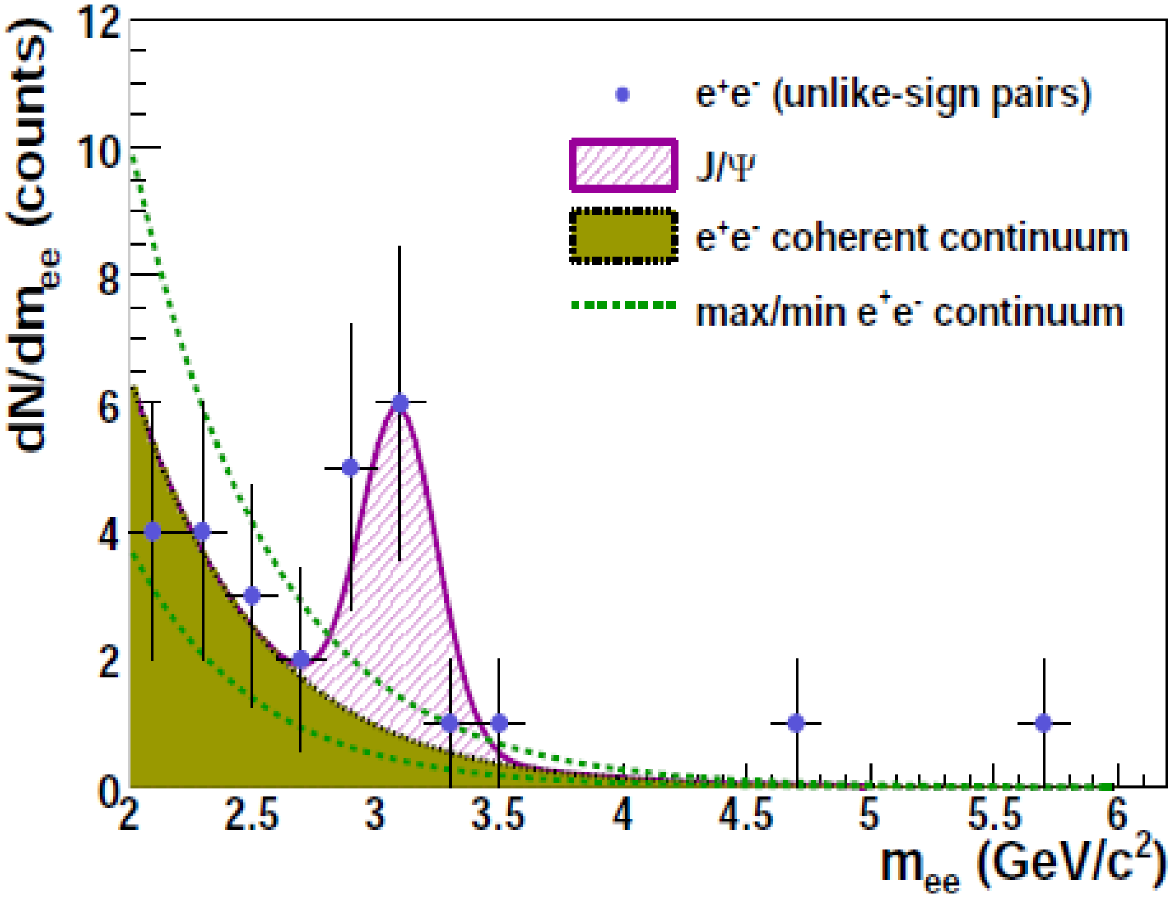
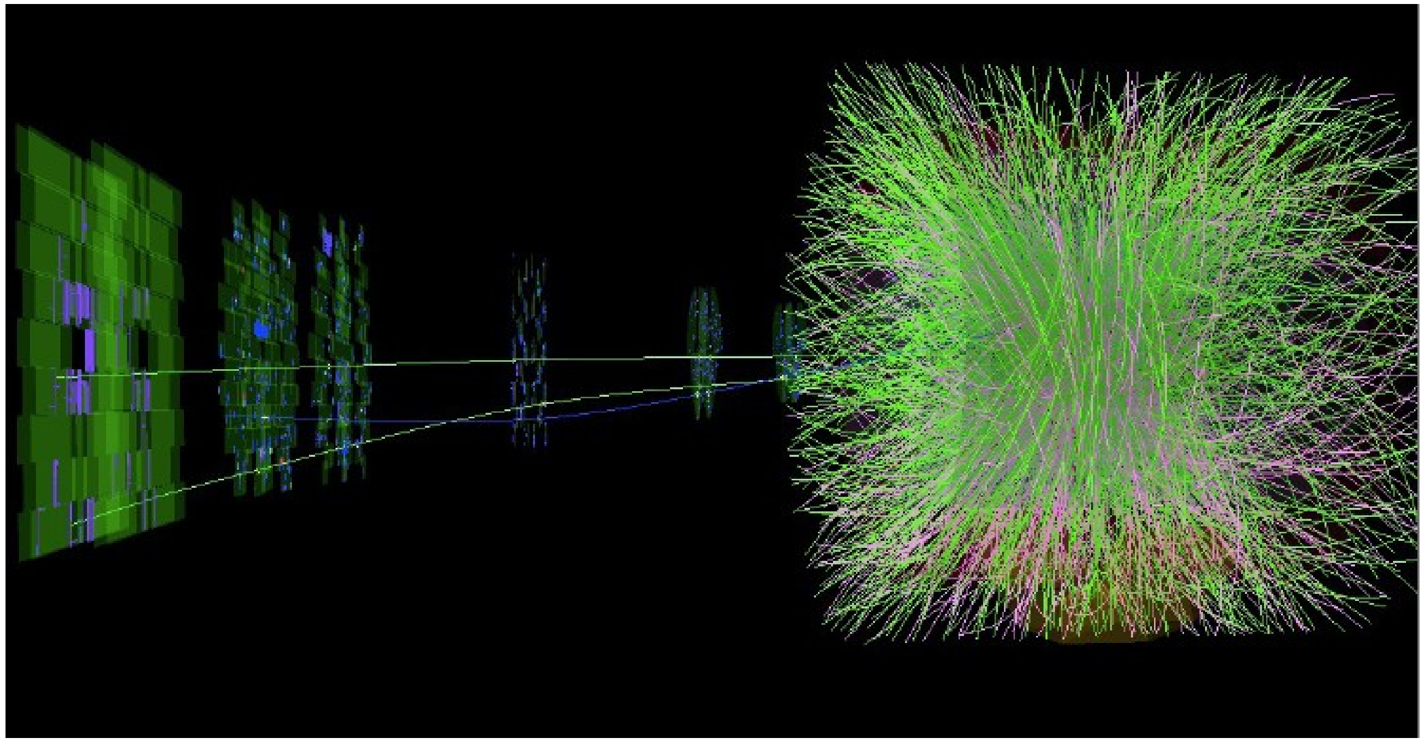


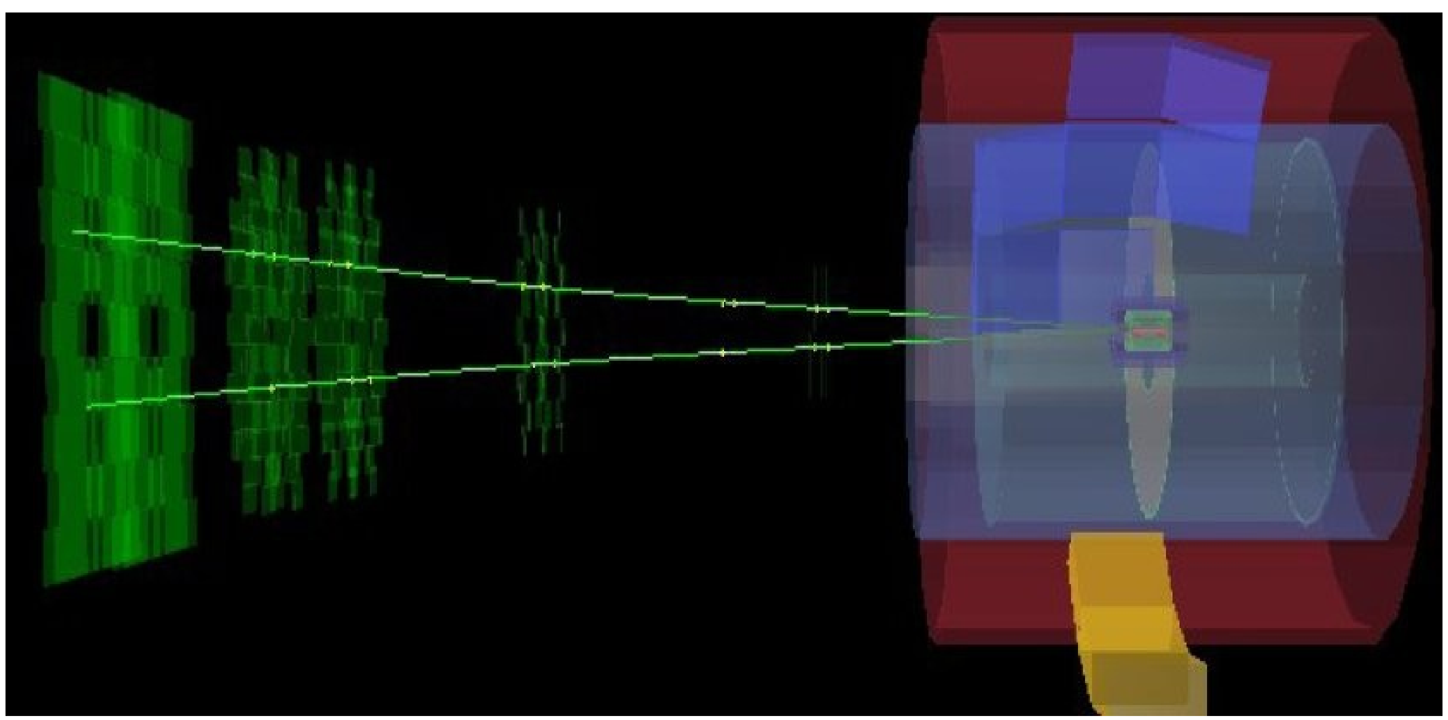
Au+Au collisions at 200 GeV
PHENIX study:
PLB Vol 679, issue 4, p. 321-333

Exclusive J/ψ analysis at **forward rapidity**



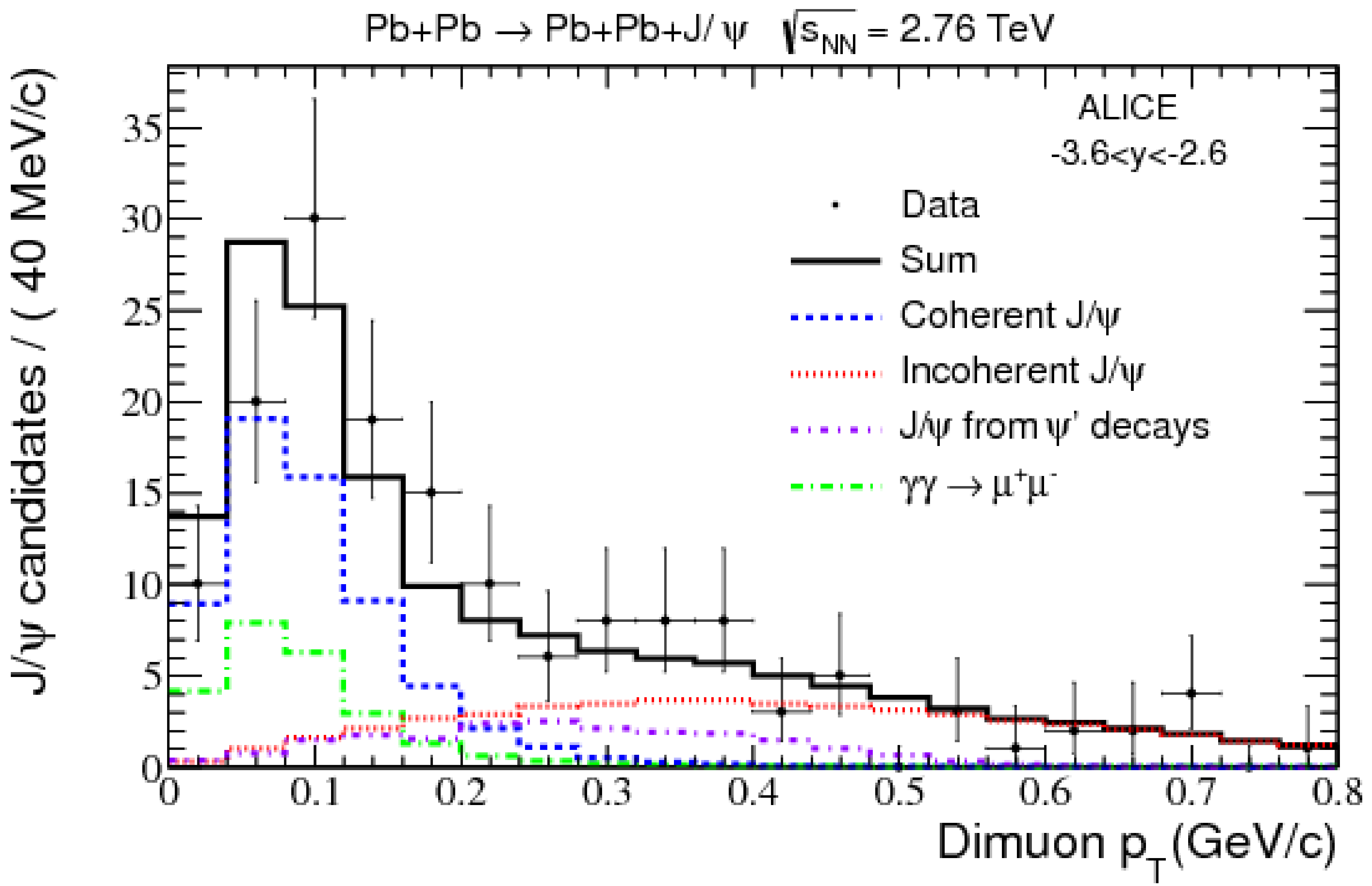
From a typical inclusive J/ψ candidate in Pb-Pb collisions…

….to an exclusive J/ψ candidate



First UPC measurement at LHC carried out by ALICE
arXiv:1209.3715 [nucl-ex]
17 Septembre 2012
Submitted to PLB
CERN Courier; Nov issue

p_T distribution for J/ψ candidates



Four physics processes:

- Coherent J/ψ
- Incoherent J/ψ
- J/ψ from ψ' decays
- $\gamma\gamma \rightarrow \mu^+\mu^-$

The coherent J/ψ signal is clearly visible

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

Theoretical predictions

1. AB-MSTW08 - No nuclear effects
All nucleons contribute to the scattering dσ/dt at t=0 scales with A^2

2. STARLIGHT, CM and CSS Glauber approach to calculate the number of nucleons contributing to the scattering. Dependence on total J/ψ-nucleon cross section

3. Partonic models (AB-EPS08, AB-EPS09, AB-HKN07, RSZ-LTA)
Cross section proportional to the nuclear gluon distribution squared

Data *vs* theoretical predictions

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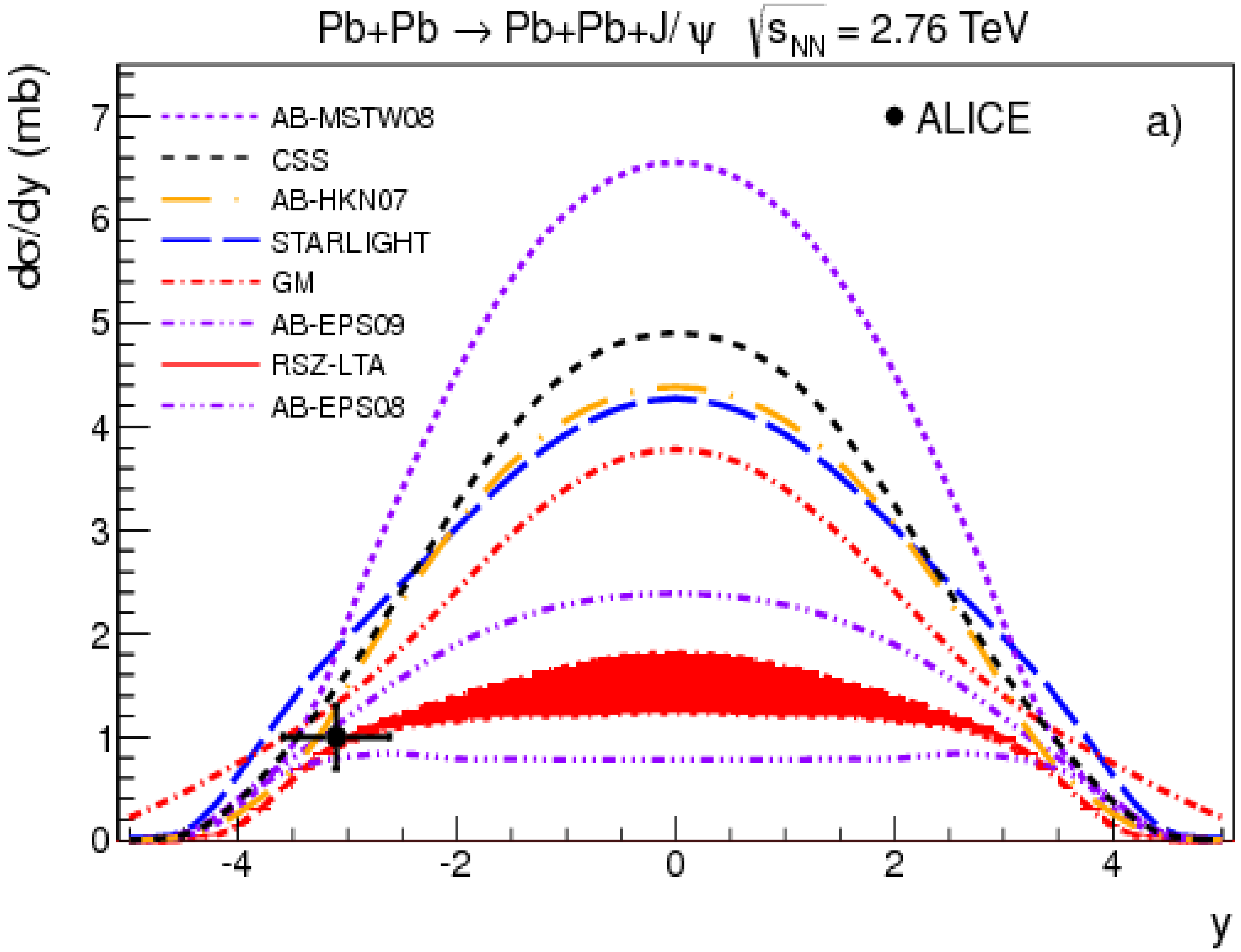


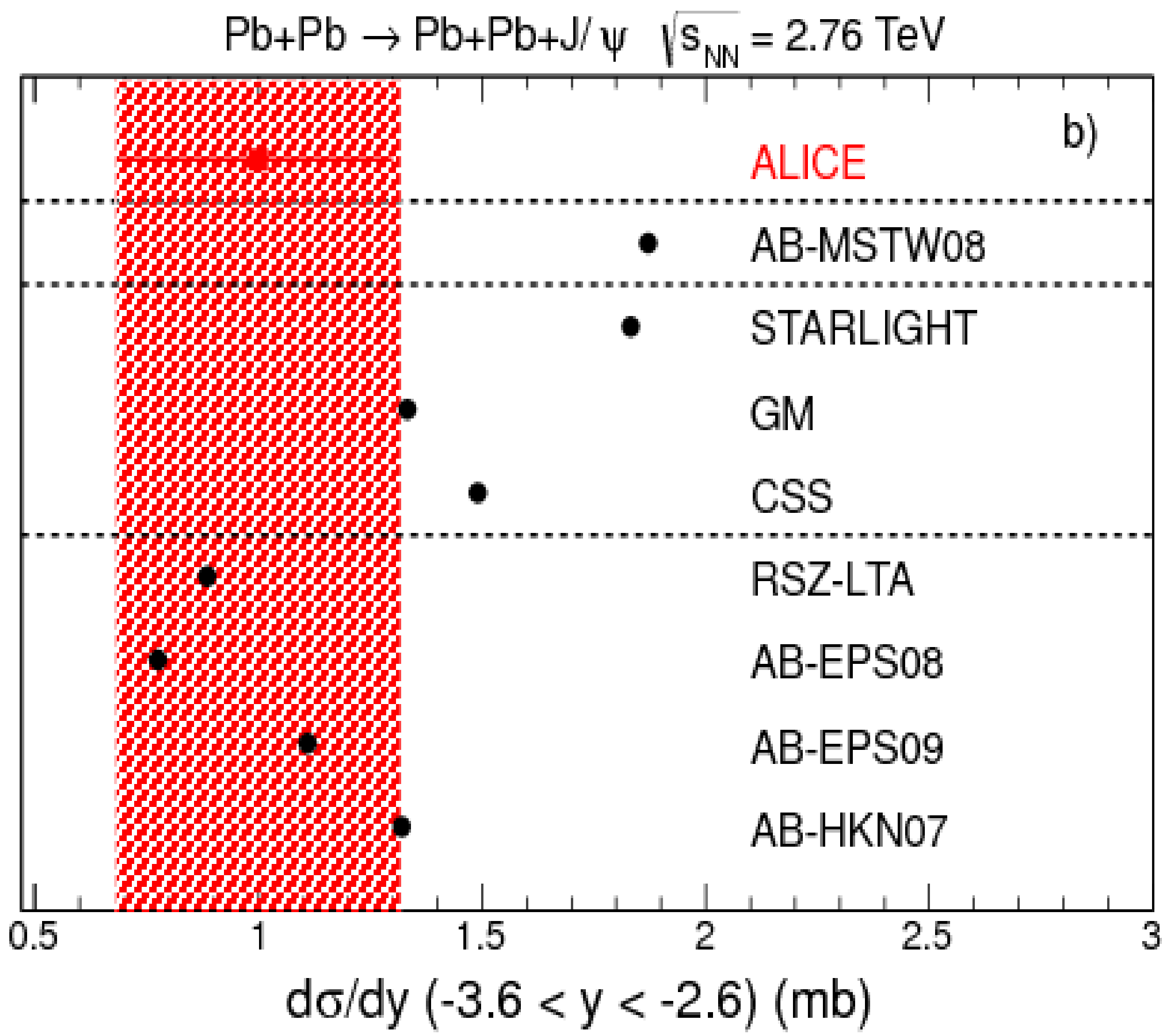
Most forward J/ψs in UPC Pb-Pb at LHC are from low photon-proton c.m.s. energy

Either nucleus can serve as photon emitter or photon target, at forward rapidity (-3.6<y<-2.6), $x \sim 10^{-2}$ and $x \sim 10^{-5}$

The error is the quadratic sum of the statistical and systematic errors

Data *vs* theoretical predictions

Integrated cross section

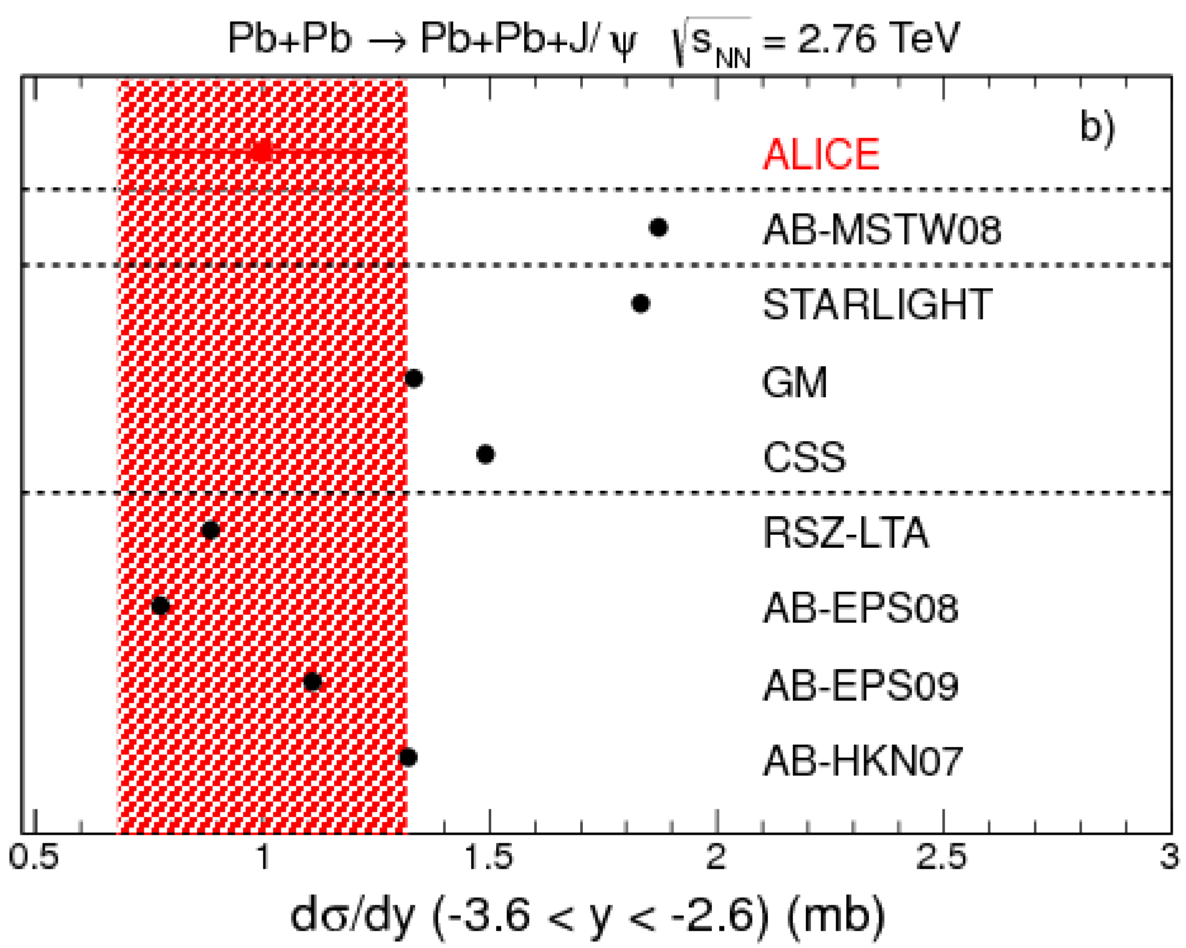


Largest deviations (3σ):
STARLIGHT and AB-MSTW08

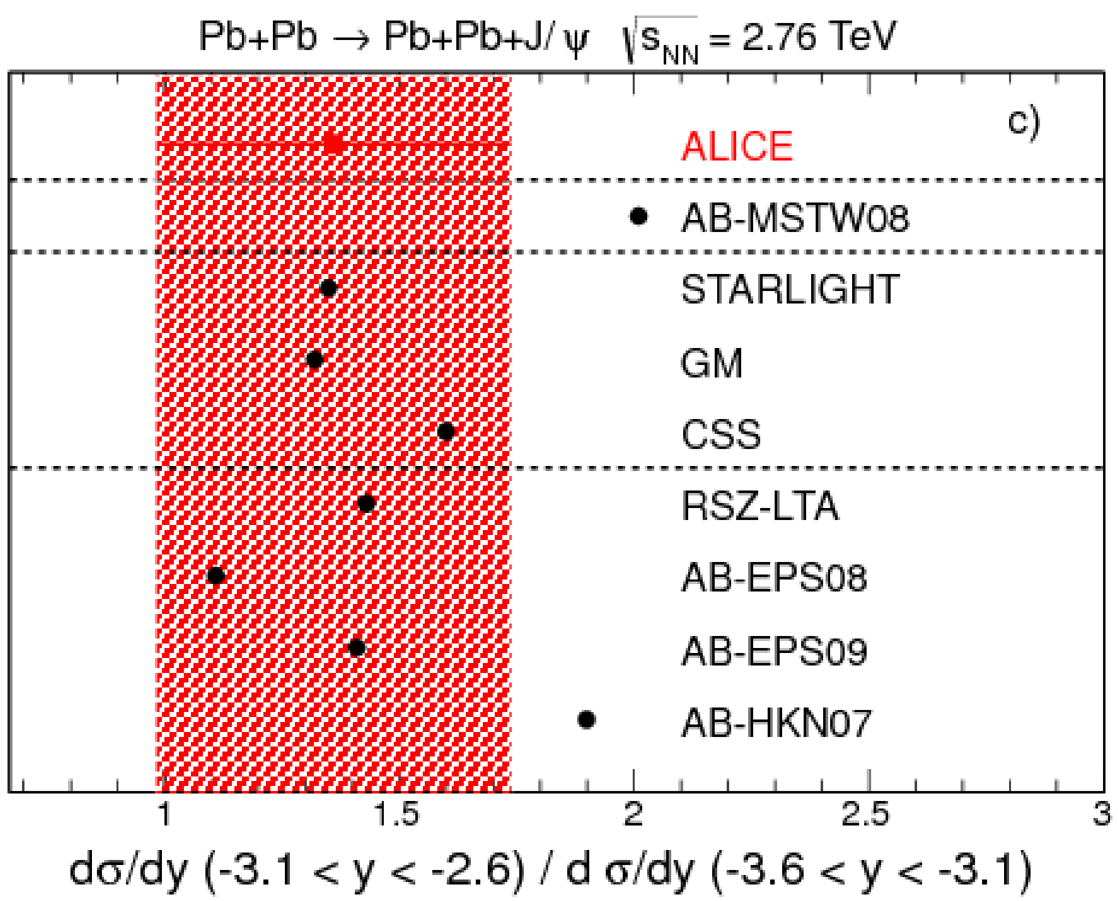
Best agreement (1σ):
RSZ-LTA, AB-EPS08 and AB-EPS09

Data *vs* theoretical predictions

Integrated cross section



Ratio of dσ/d*y*



$$R = \sigma(-3.1 < y < -2.6)/\sigma(-3.6 < y < -3.1) = 1.36 \pm 0.36(\mathrm{stat}) \pm 0.19(\mathrm{syst})$$

Largest deviations (3σ):
STARLIGHT and AB-MSTW08

Best agreement (1σ):
RSZ-LTA, AB-EPS08 and AB-EPS09

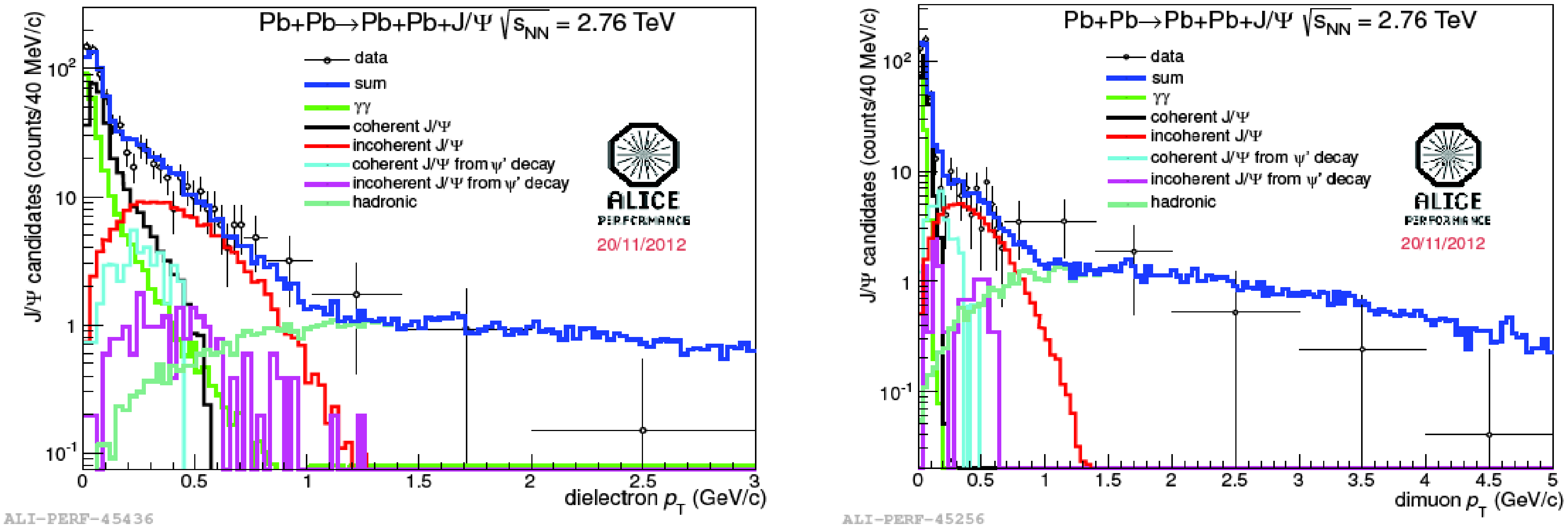
More than 1.5σ deviations:
AB-MSTW08 and AB-HKN07

J/Ψ photo-production in Pb-Pb

Central Rapidity - pair-p_T

C. Mayer
LHC on the March, Protvino 2012

ALICE



Left: di-electron channel, Right: dimuon channel.

6 Components:

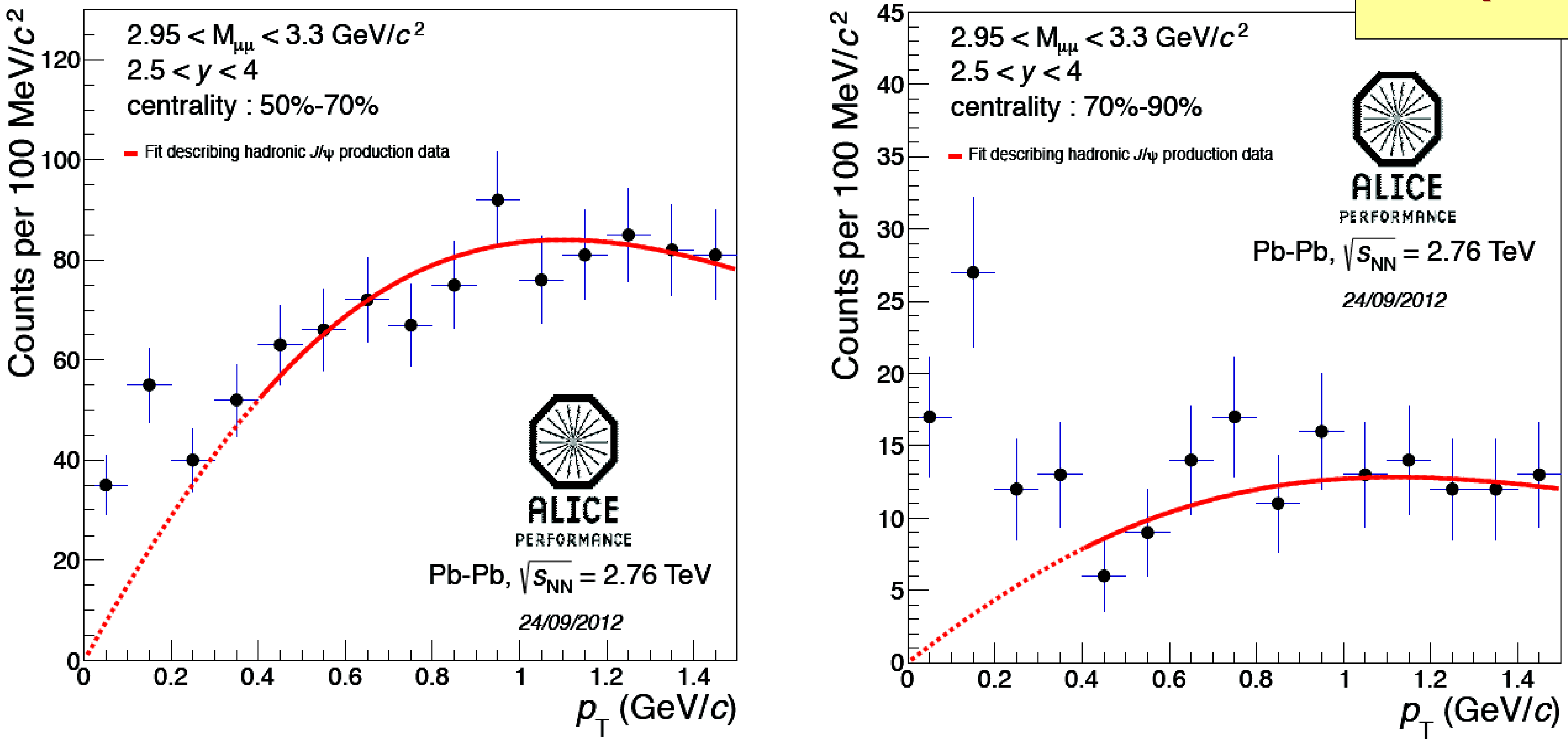
- coherent+incoherent J/Ψ
- feed-down from coherent+incoherent Ψ′-decay
- hadronic J/Ψ events, and continuum $\gamma\gamma \to e^+e^-(\mu^+\mu^-)$

One more thing in Pb-Pb…

Low p_T J/Ψ excess in nuclear collisions

A. Lardeux
Hot Quarks 2012

Dimuon p_T distribution ($M_{\mu\mu}$ within $M_{J/\Psi} \pm 3\sigma$)



Compared to expected shape from J/Ψ hadro-production, an excess of *J/Ψ* is clearly visible at low p_T in semi-peripheral and peripheral collisions

→ *J/Ψ* photo-production could be at the origin

<u>Caveat:</u> At the moment a counting technique is used to extract the *J/Ψ* (quite reasonable approach, given the S/B). However, we plan to perform a more detailed study, evaluating the *J/Ψ* yield after the background subtraction.

UPC in pPb and Pbp

*Photon emission from Pb is dominant, but photons emitted from the proton that interacts with the nucleus is also possible

*Rapidity gaps between the nucleus and the produced particles

For a detailed review, See talk by D. D'enterria CERN, 17/10/2011

Photon flux scale $\rightarrow Z^2$ Targer scale $\rightarrow A^{2/3}$

Then, flux/target scale ~200

J/ψ photoproduction - Ppb and Pbp

Recent calculations by E. Kryshen and M. Zhalov, private communication

Pb-p – low-x gluons from the proton (up to 10^{-5})

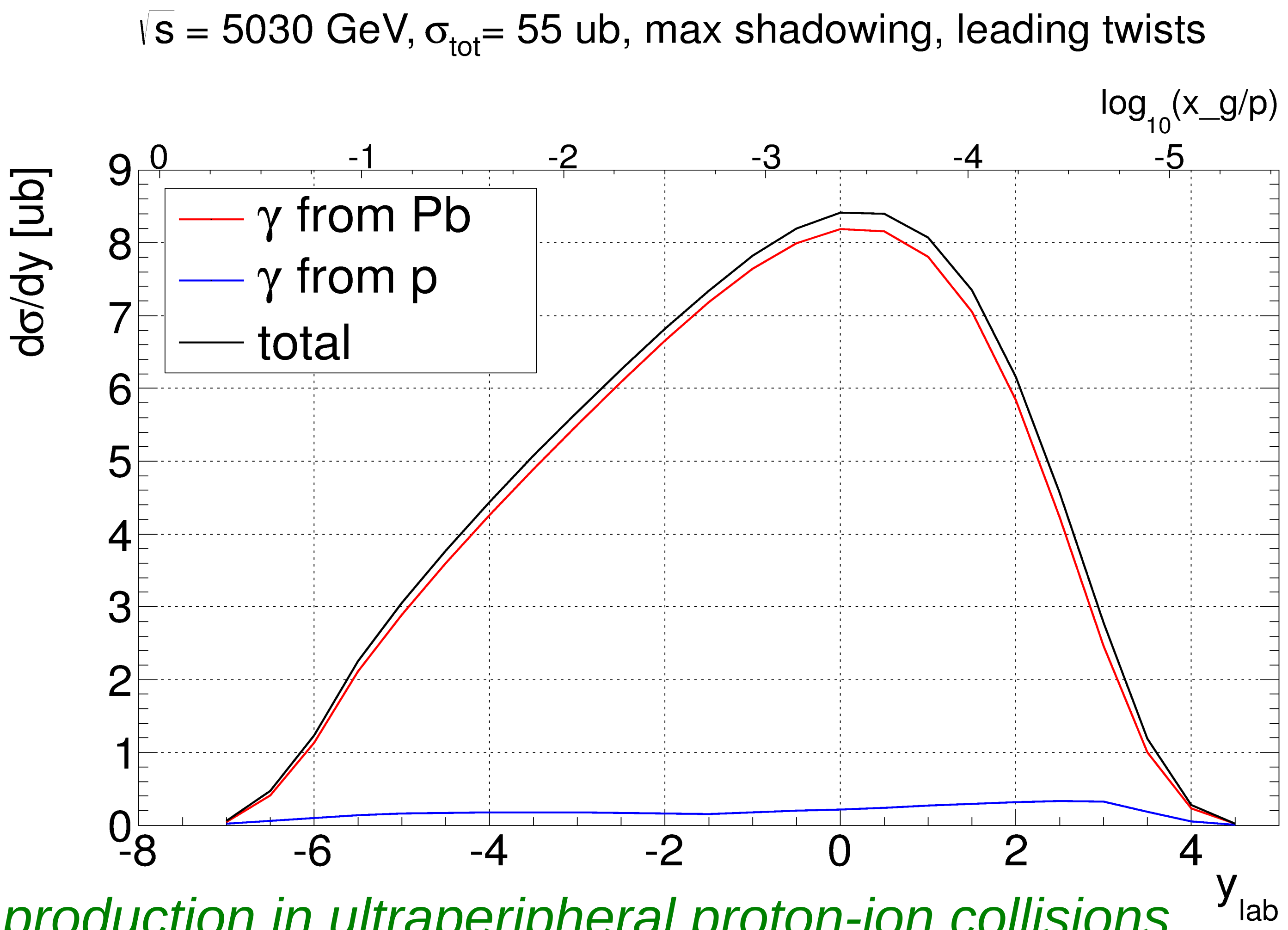
p-Pb – low-x gluons from Pb (up to 10^{-5})

σ_{tot}(5030 GeV) = 55 ub

For ALICE/LHCb forward rapidities

In Pb-p -> $x_p \sim 10^{-5}$

In p-Pb -> $x_p \sim 10^{-2}$



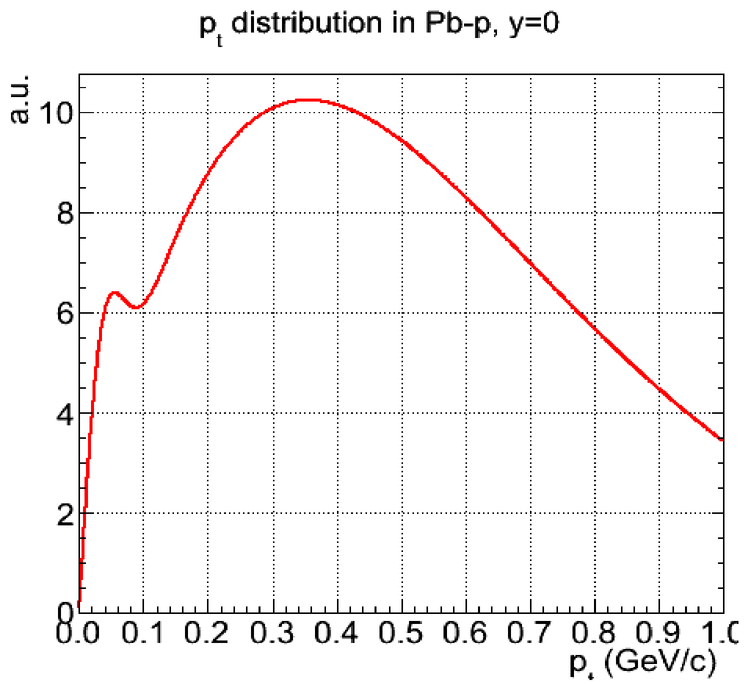
Frankfurt, Strikman, Zhalov,
Elastic and large t rapidity gap vector meson production in ultraperipheral proton-ion collisions
Phys. Lett. B640, 162, 2006;

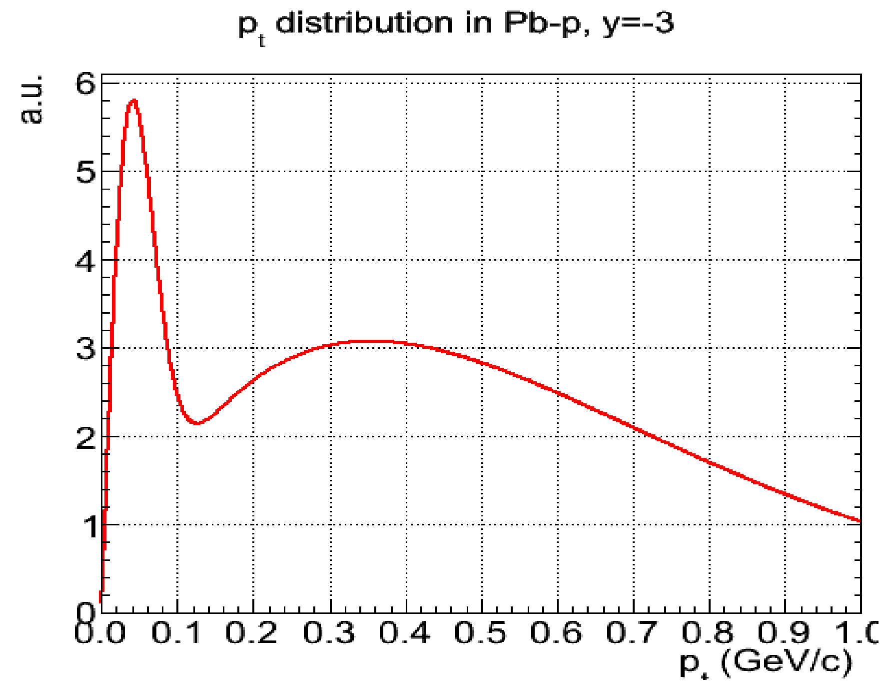
Frankfurt, Strikman, Zhalov,
Large t diffractive J/psi photoproduction with proton dissociation in ultraperipheral pA collisions at LHC.
Phys. Lett. B 670, 32, 2008.

J/ψ photoproduction - p_T

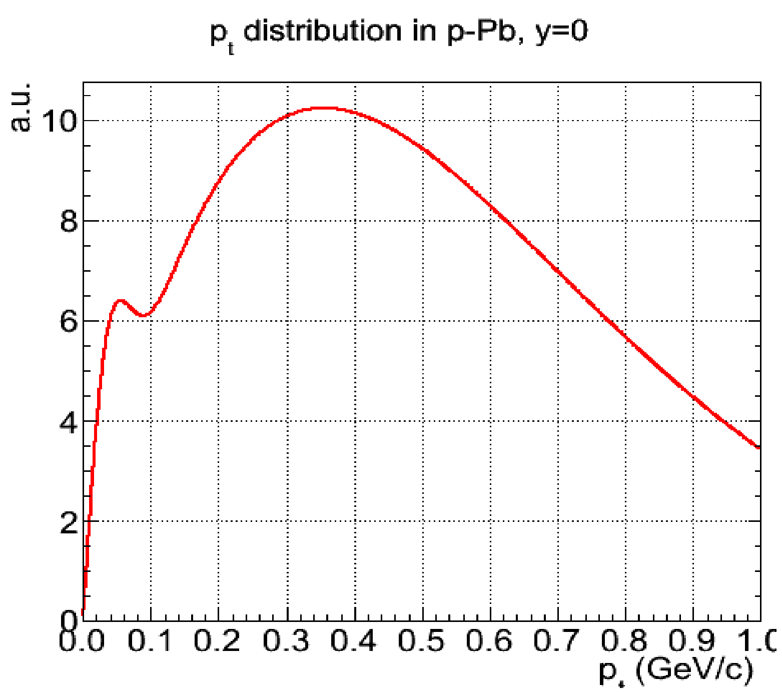
Pb-p **Central** **Forward**

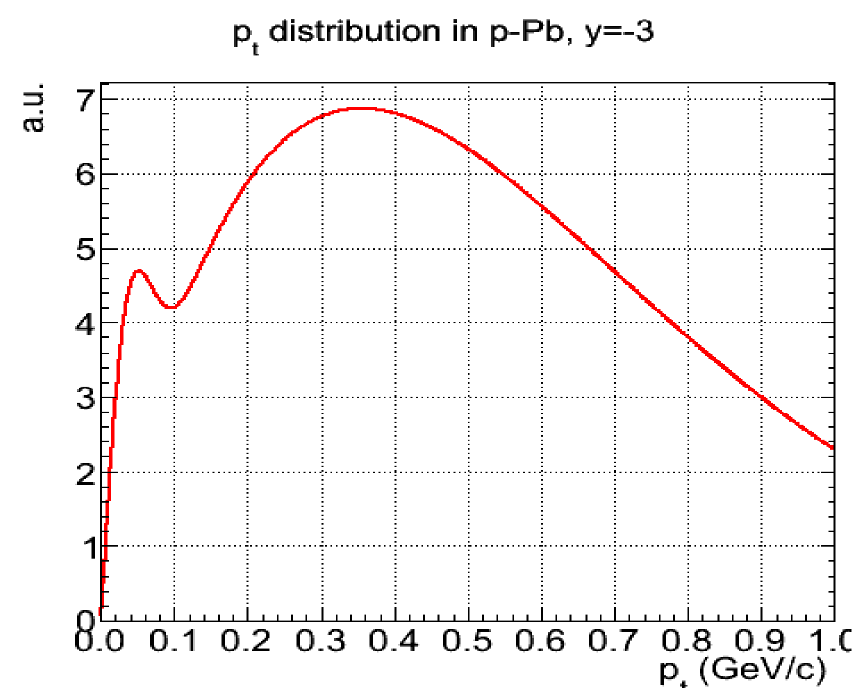
Recent Calculations by E. Kryshen and M. Zhalov, private communication





p-Pb





Upsilon photoproduction

$\gamma + p \rightarrow \Upsilon + p$: possible thanks to strong photon flux of the proton hitting the Pb nuclues

Very limited statistics from HERA (H1 and ZEUS) ~ 100 candidates

Uncertainty in measured cross section larger than a factor 3

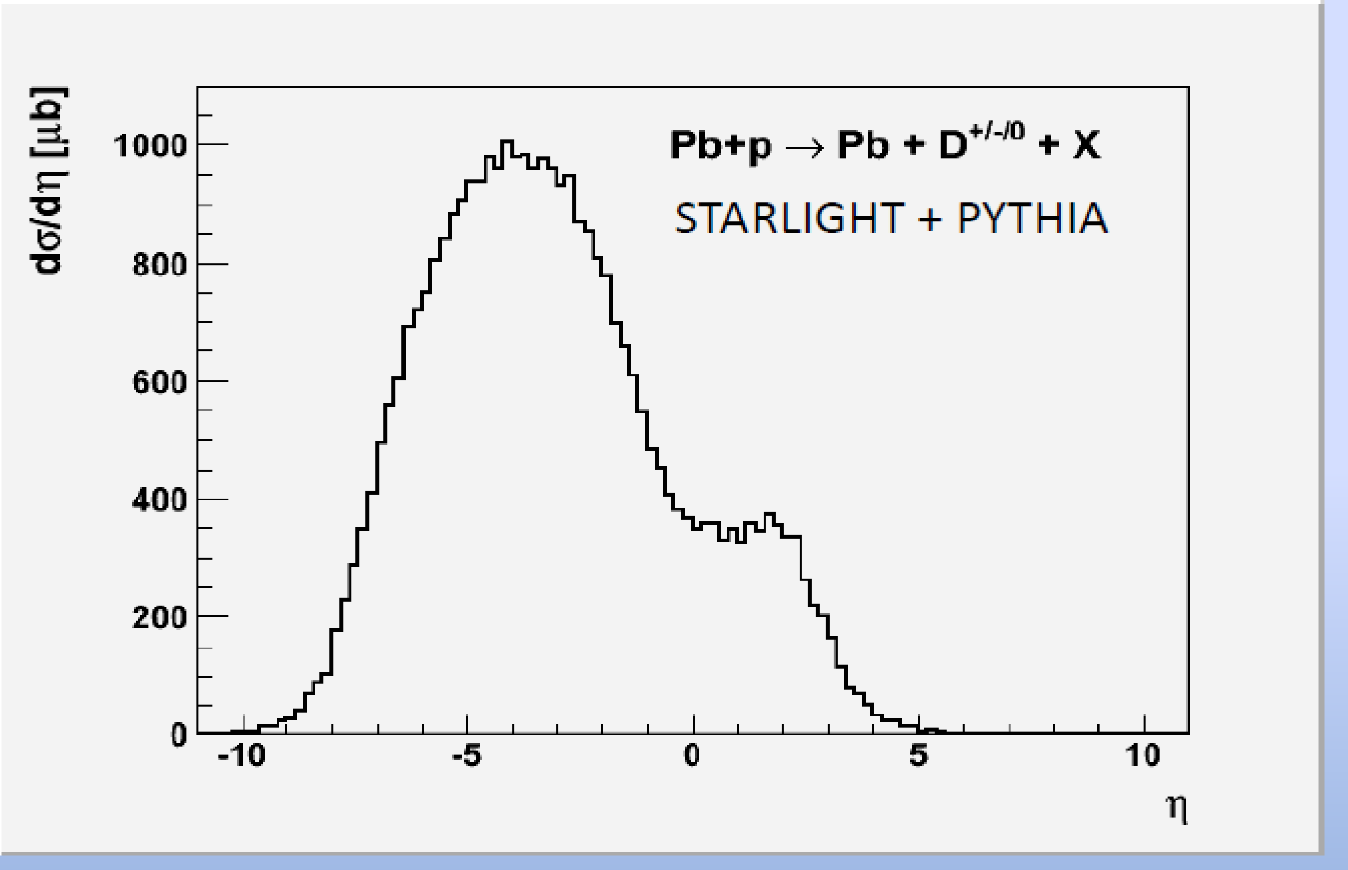
Ideal way to measure this process at LHC

Needed to have a baseline for

$\gamma + Pb \rightarrow \Upsilon + Pb$

Ultra-Peripheral Collisions – Proton-nucleus collisions

Example: photoproduction of open charm in p+Pb collisions.



- Cross section for photoproducing D mesons around mid-rapidity dσ/dy ≈ 400 μb.
- Plateau in forward direction from γ fluctuating to a ccbar-pair.

EDS Blois Workshop, Qui Nhon, Vietnam, 2011 Joakim Nystrand, University of Bergen

Summary

Heavy quarkonium production in UPC → interesting in its own right, many observables/physics to look at

At LHC, the following analysis can be done

- Energy dependence
- Rapidity dependence
- Collidying systems (pp, PbPb, pPb, Pbp)

J/ψ, ψ, Υ, χ_c and the two-photon production, and other channels not discussed here.

Additional slides

Coherent production?!

Four physics processes:

- Coherent J/ψ
- Incoherent J/ψ
- J/ψ from ψ' decays
- $\gamma\gamma \rightarrow \mu^+\mu^-$

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

Feed-down (f_D):
for example, ψ' decays to J/ψ $\pi^+\pi^-$

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

Three polarisation scenarios for ψ' decays were considered:

- No polarisation (NP)
- Full longitudinal polarisation (L)
- Full transverse polarisation (T)

According to STARLIGHT

$$f_D^{NP} = 11.9\%,\ f_D^T = 9.3\%,\ f_D^L = 16.8\%$$

According to RSZ

$$f_D^{NP} = 5.5\%,\ f_D^T = 4.3\%,\ f_D^L = 7.9\%$$

Thus, we took as the best estimate

f_D=(11±6)%

J/ψ Incoherent fraction (f_I)

According to STARLIGHT

$$f_I = 0.12$$

According to RSZ

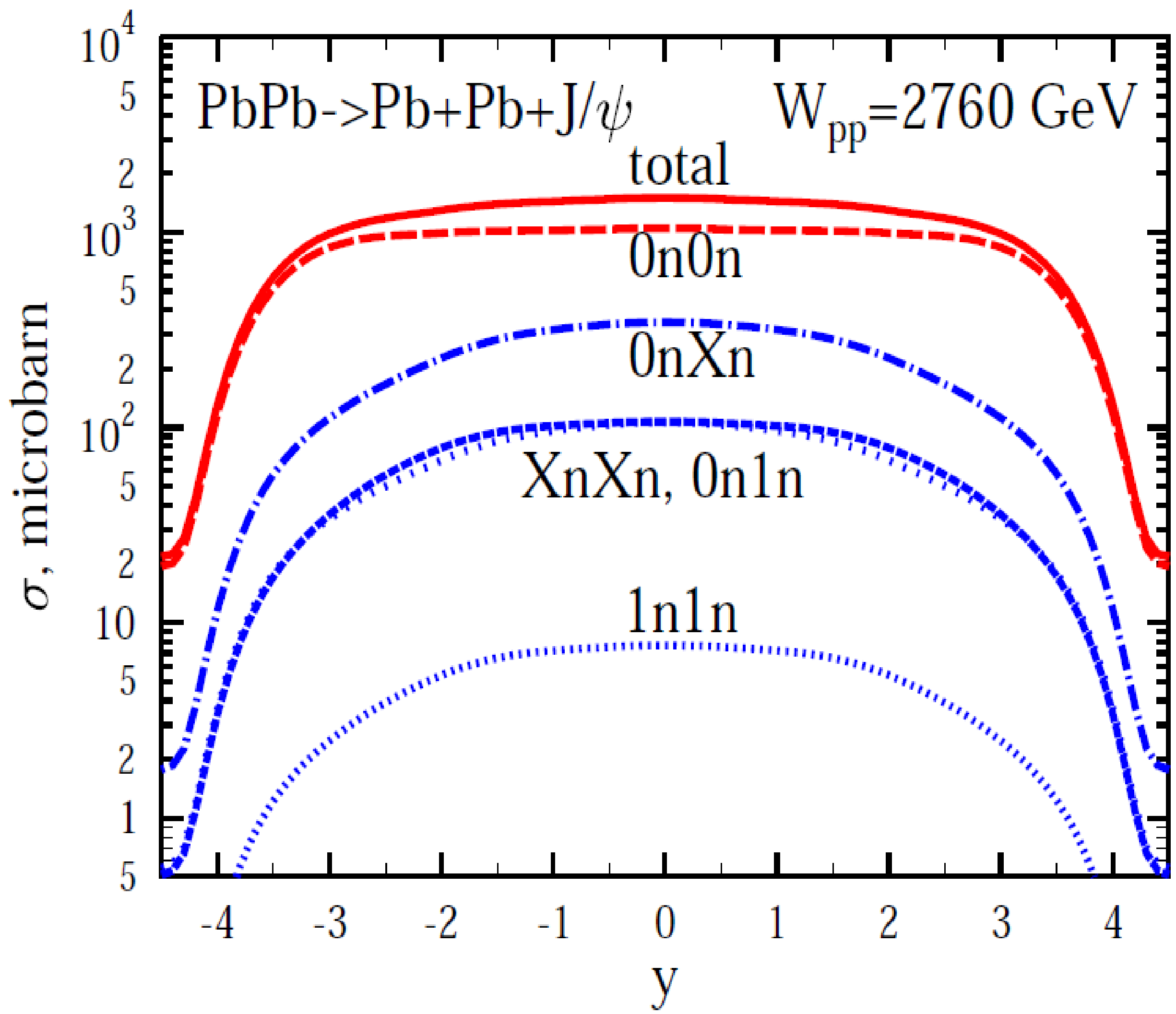
$$f_I = 0.08$$

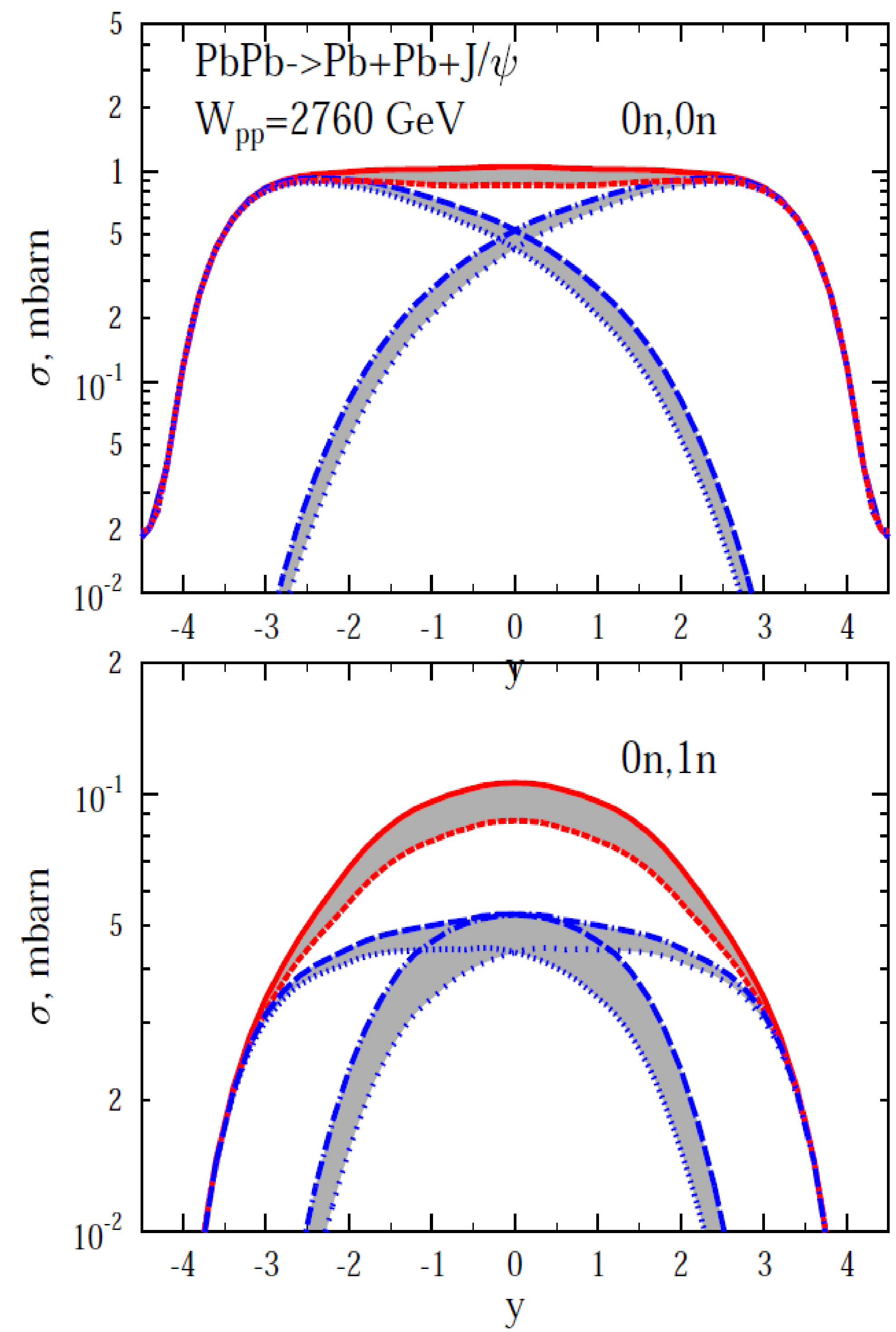
Using data …

$$f_I = 0.26 \pm 0.05 \Rightarrow f_I = 0.12^{+0.14}_{-0.04}$$

New at the LHC: Dependence on neutron emission

Using Zero Degree Calorimeters (ZDC) it is possible to select coherent production with ion excitation, where neutrons are emitted from at least one of the nuclei





Different configurations:

1n1n: one neutron emission by each ion;

XnXn: emission of several neutrons;

0n1n and 0nXn: excitation and decay of one of the ions, and

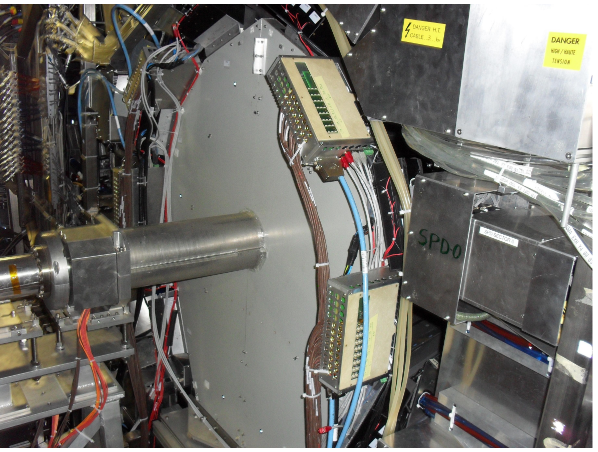
0n0n: no neutron emission

Rebyakova, Strikman and Zhalov
Phys. Lett. B 710 (2012) 252

Shaded area: Uncertainty on nuclear gluon shadowing

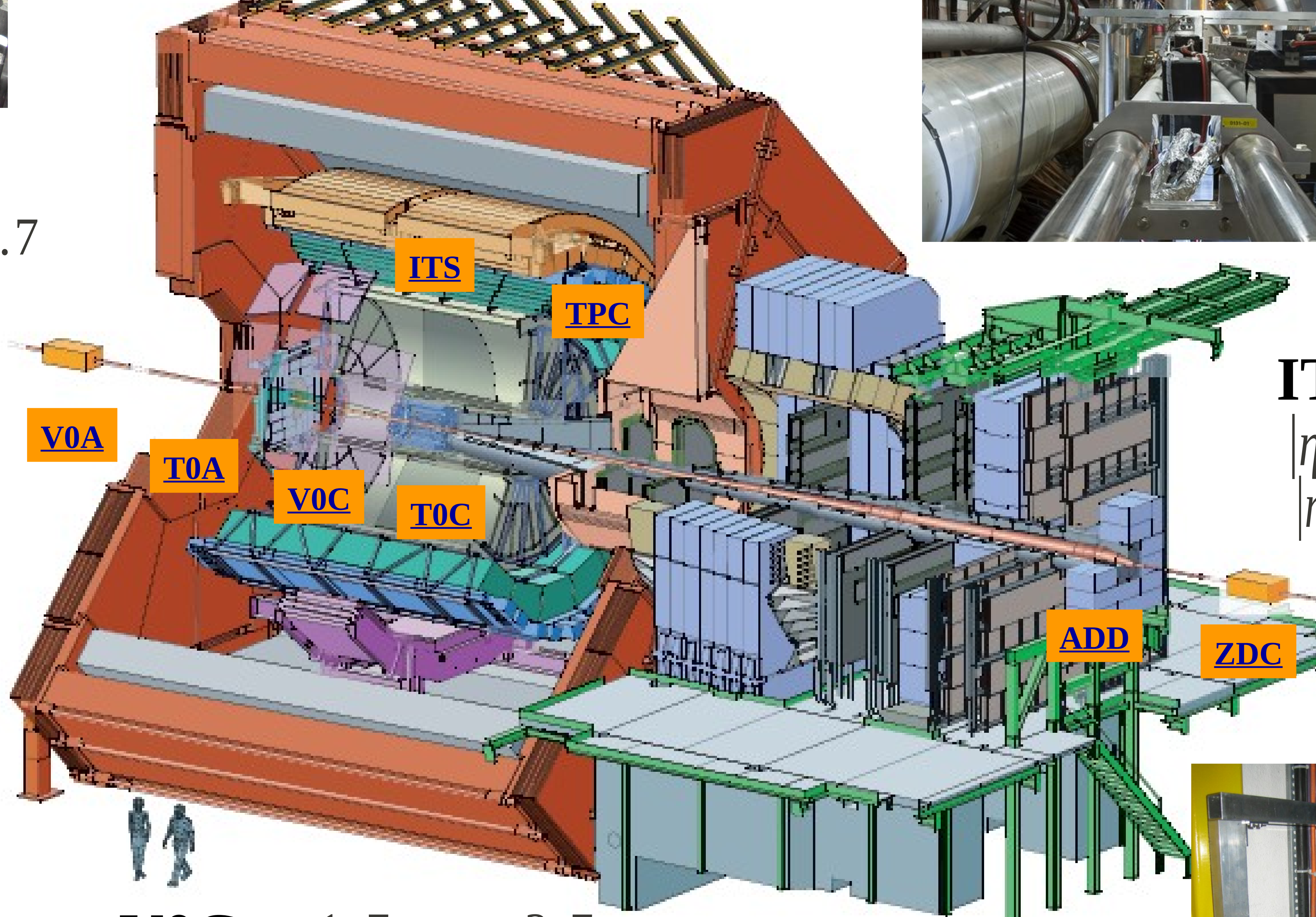
Diffractive Physics Today

V0A $2.8 < \eta < 5.1$



ZN $|\eta| > 8.7$ **ZP** $|\eta| > 8.4$

TPC $|\eta| < 0.9$

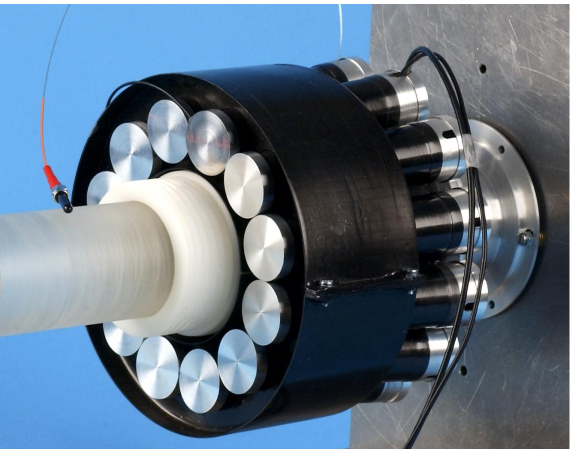


ZEM $4.8 < \eta < 5.7$

ITS
$|\eta| < 1.4$
$|\eta| < 2.0$

T0A $4.5 < \eta < 5.0$

T0C
$-2.9 < \eta < -3.3$



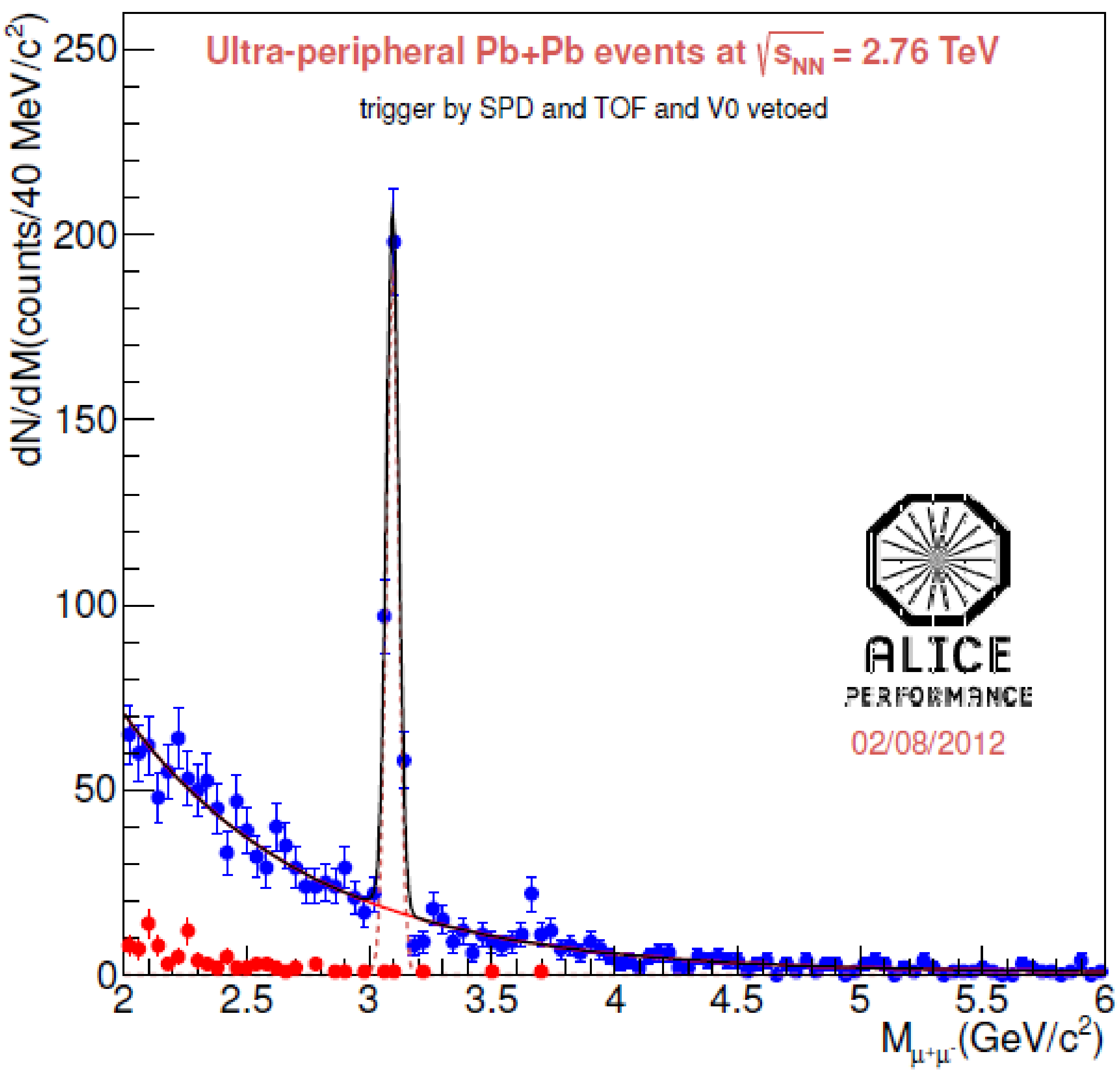
V0C $-1.7 < \eta < -3.7$

FMD $1.7 < \eta < 5.0$ $-3.4 < \eta < -1.7$

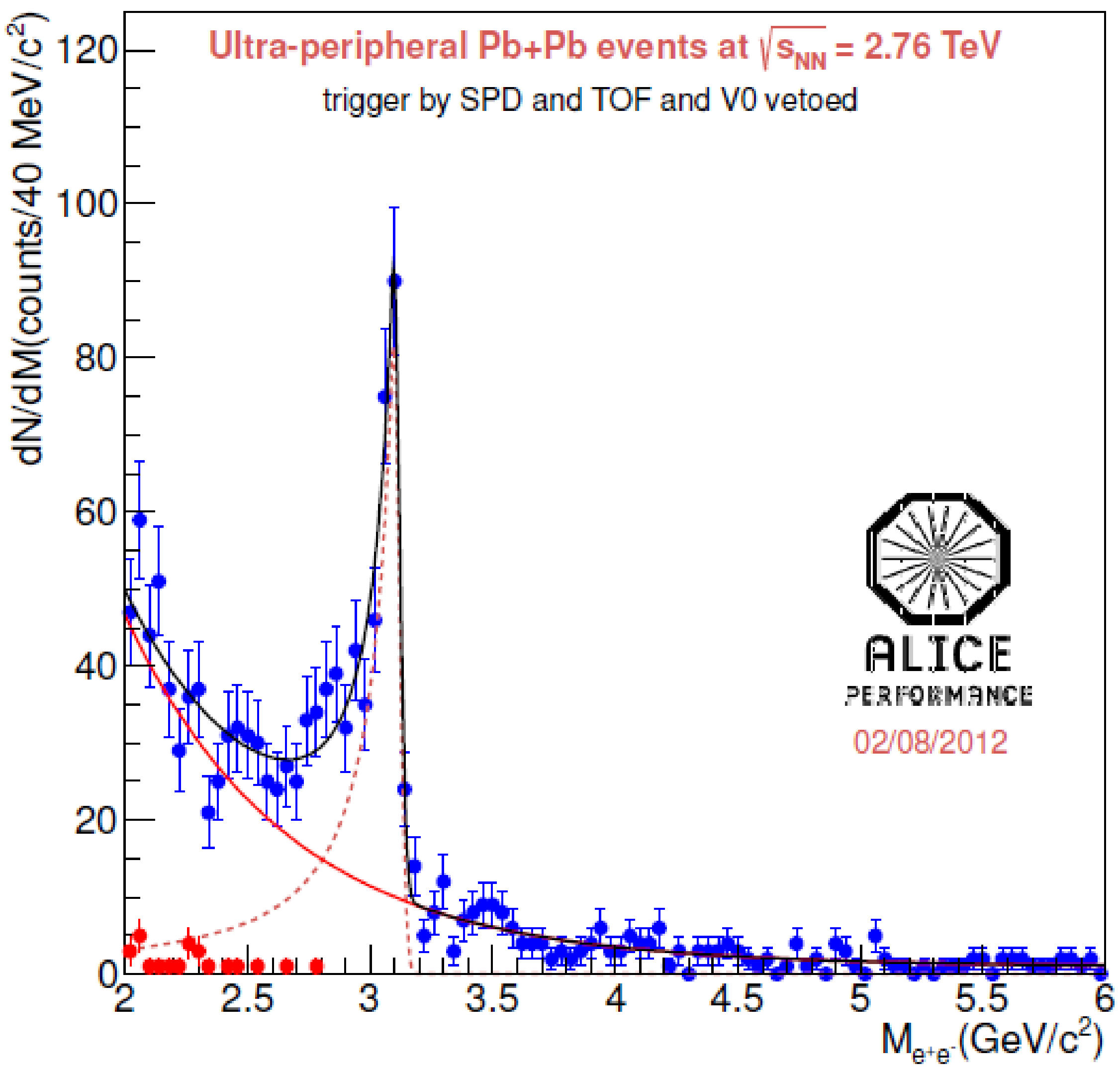
ADD $-4.9 < \eta < -6.0$

J/ψ photo-production at **central rapidity**

Analysis ongoing – 2011 Pb-Pb data



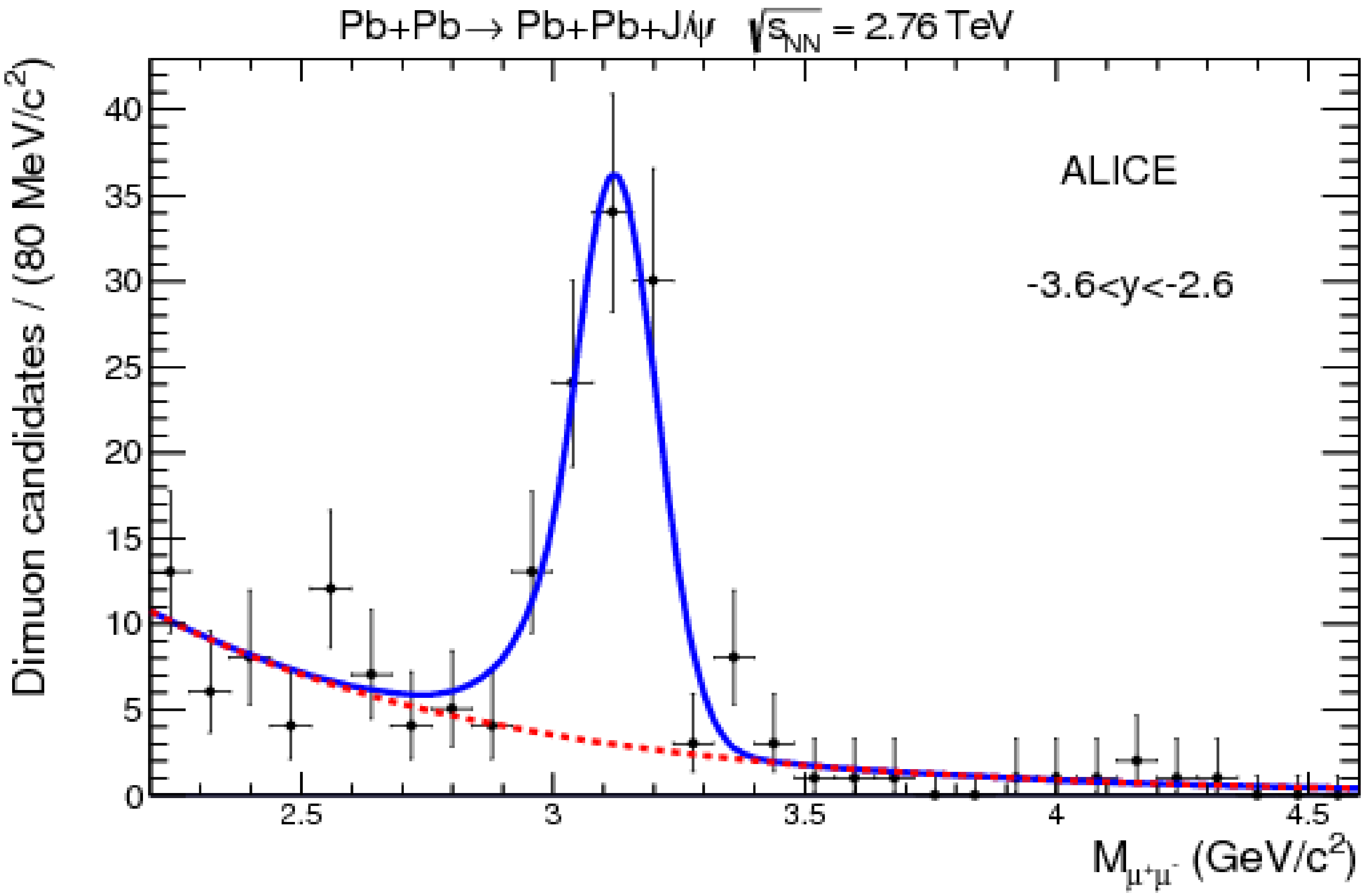
Dimuon channel



Dielectron channel

Signal yield extraction

Exactly two oppositely charged muons



Only two like-sign pairs → Combinatorial background <2% at 90% CL around J/ψ mass

Fitting functions: Crystal Ball and exponential

$$N_{\mathrm{yield}} = 96 \pm 12(\mathrm{stat}) \pm 6(\mathrm{syst})$$

Exponential slope parameter

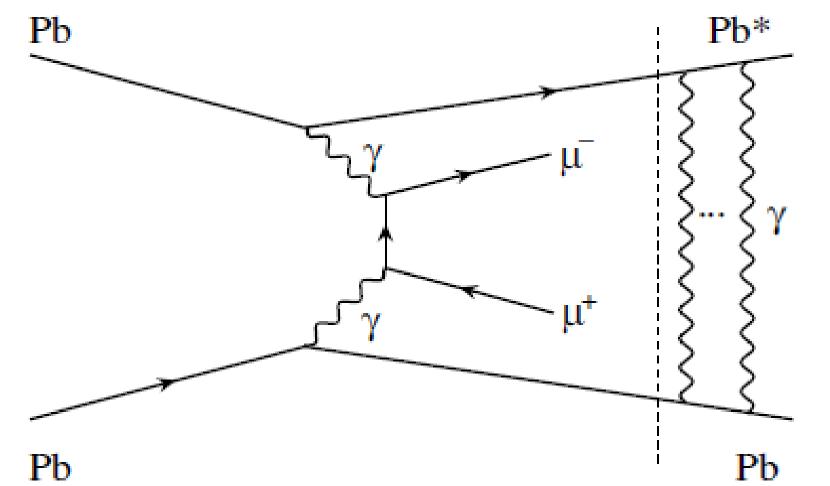
Data: -1.40 +/- 0.20 $GeV^{-1}c^2$

MC(γγ → $\mu^+\mu^-$): -1.39 +/- 0.01 $GeV^{-1}c^2$

→ An additional indication that background is under control in this kinematic region

Coherent J/ψ differential cross section

We use the QED continuum pair production ($\gamma+\gamma \rightarrow \mu^+\mu^-$) for normalisation



$$\frac{d\sigma^{coh}_{J/\psi}}{dy} = \frac{1}{BR(J/\psi \rightarrow \mu^+\mu^-)} \cdot \frac{N^{coh}_{J/\psi}}{N_{\gamma\gamma}} \cdot \frac{(Acc \times \varepsilon)_{\gamma\gamma}}{(Acc \times \varepsilon)_{J/\psi}} \cdot \frac{\sigma_{\gamma\gamma}}{\Delta y}$$

Standard QED process,but there are some caveats...

1. Uncertainty from higher order terms :

Photon coupling to the nuclei is $Z\alpha^{1/2}$ rather than $\alpha^{1/2}$. Here Z=82
Either negligible effect or a 16% reduction in the $\gamma+\gamma$ cross section

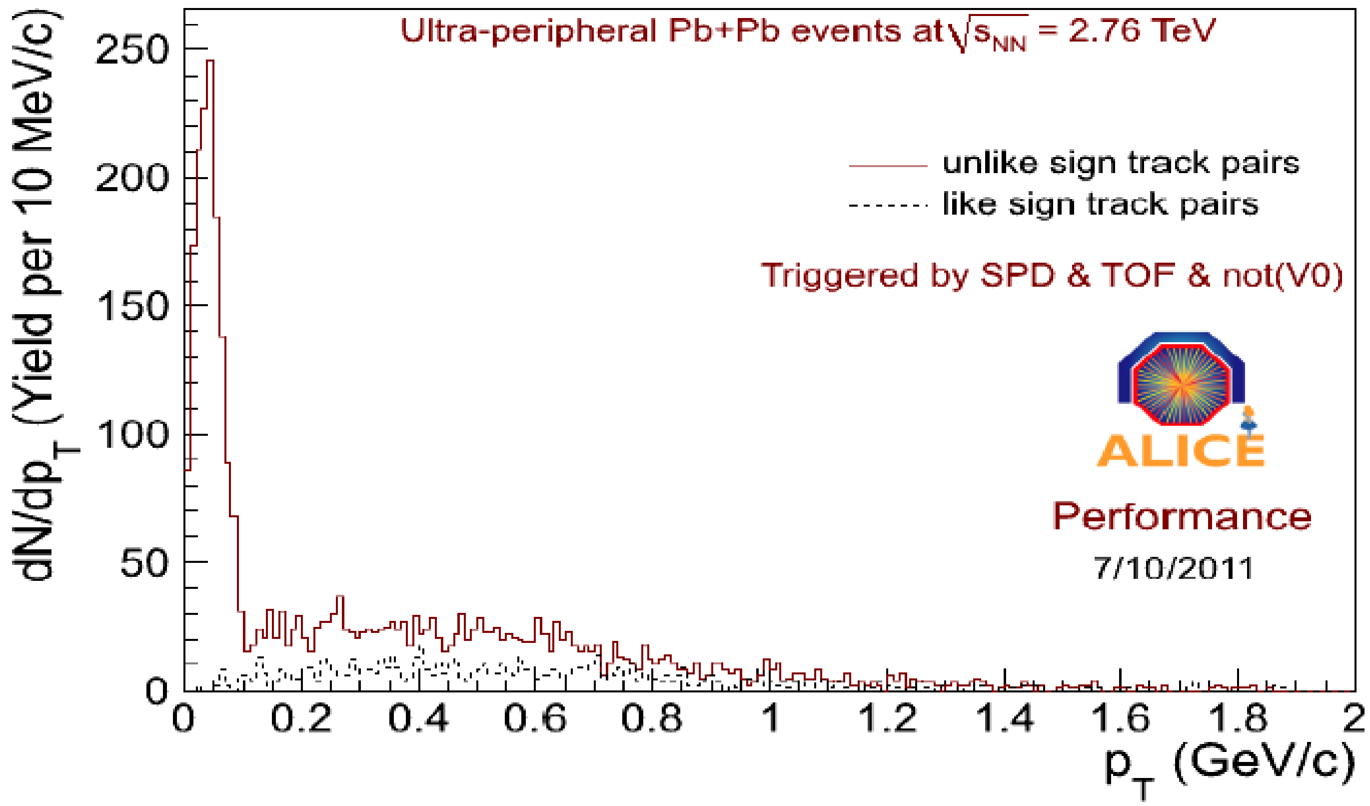
2. Uncertainty on minimum momentum transfer and nuclear form factor

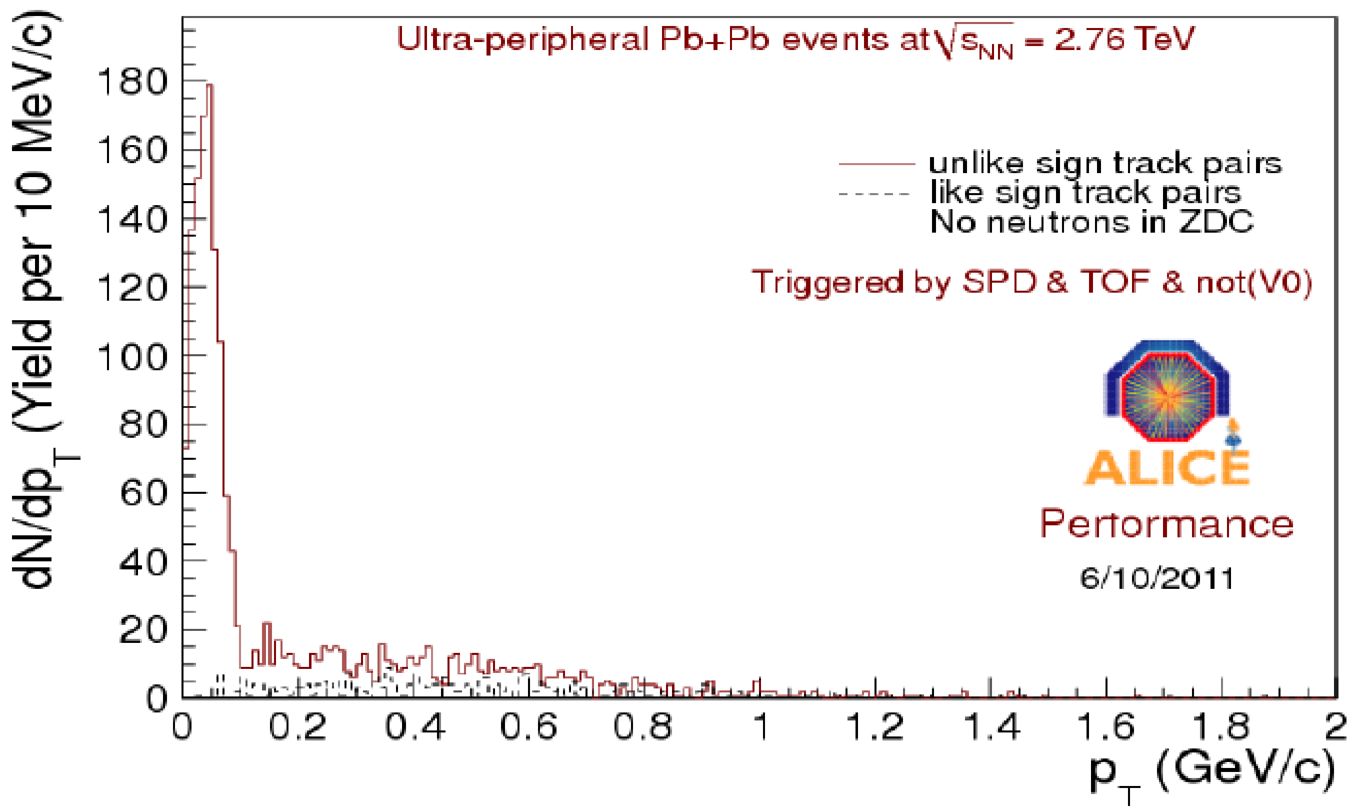
3. Previous experimental results:

STARLIGHT predictions in good agreement to STAR/PHENIX measurements, but their experimental results have uncertainties between 20-30%

Theoretical uncertainty on $\gamma+\gamma \rightarrow \mu^+\mu^-$ is 20%

ρ^0 photo-production at central rapidity – 2010 data



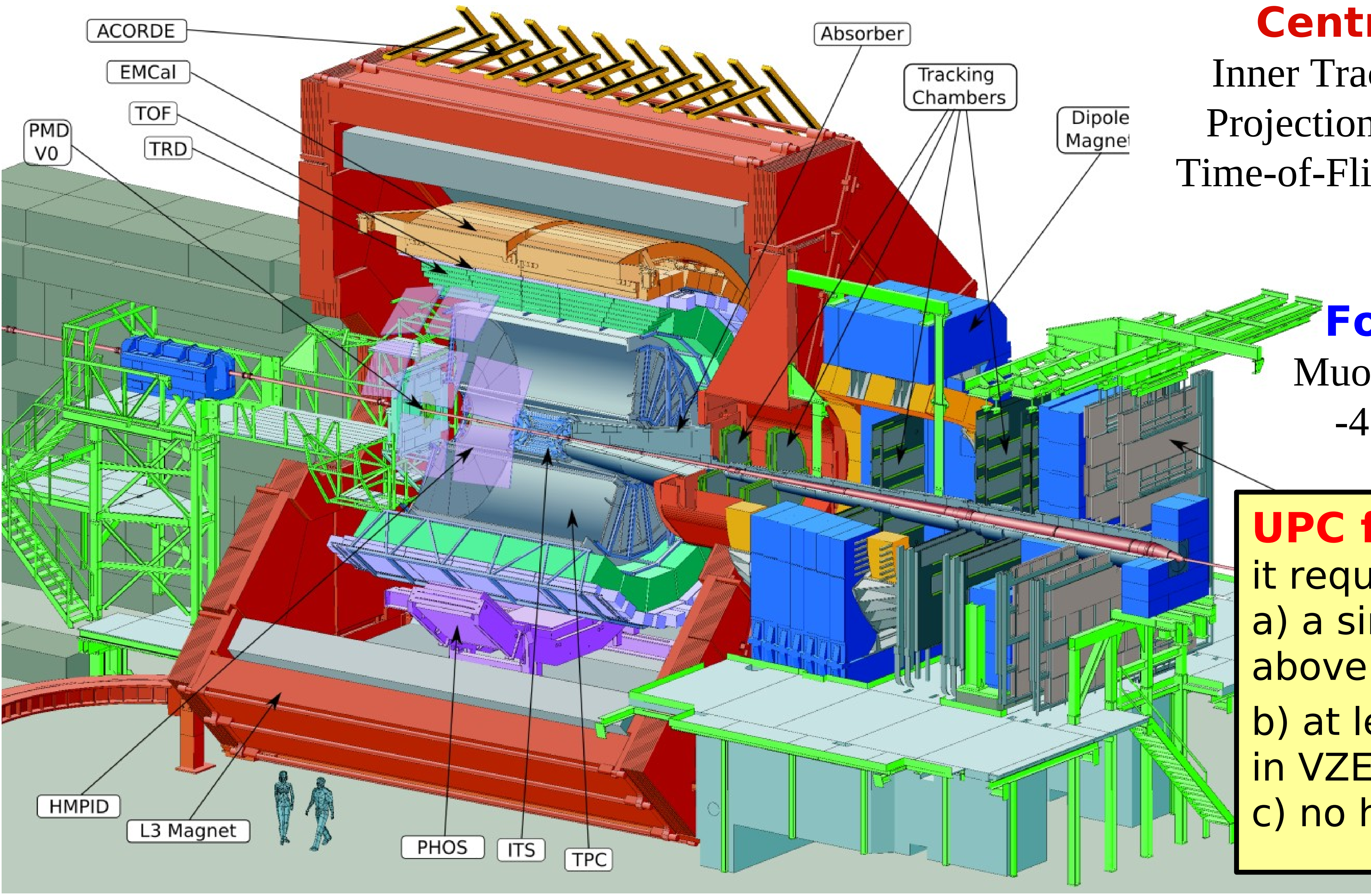


- Coherent production characterised by low transverse momentum of the final state, determined by the nuclear form factor, $p_T < \approx 100$ MeV/c.

- Results after requiring no neutron emission using ZDCs, *i.e.* No neutron break-up

- Next step: Determine ρ^0 photoproduction cross section

Quarkonia measurements at ALICE



Central rapidity

Inner Tracking (ITS), Time Projection Chamber (TPC), Time-of-Flight, TRD, EMCAL

$|\eta| < 0.9$

Forward rapidity

Muon Spectrometer

$-4 < \eta < -2.5$

UPC forward trigger

it requires

a) a single muon trigger above 1 GeV/c p_T

b) at least one hit in VZERO-C

c) no hits in VZERO-A

Forward detectors used in this analysis:

VZERO-A: $2.8<\eta<5.1$; VZERO-C: $-3.7<\eta<-1.7$

ZDC: 116 m on either side of the IP

ALICE can measure J/ψ mesons down to zero p_T

Summary and conclusions

- **ALICE** has made the first LHC measurement on J/ψ photoproduction in ultra-peripheral Pb-Pb collisions at 2.76 TeV, per nucleon pair

- **Coherent J/ψ differential cross section**

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

-3.6<y<-2.6
p_T<0.3 GeV/*c*

- AB-MSTW08 is strongly disfavoured. It assumes that the forward scatting cross section scales with the number of nucleons squared. STARLIGHT cross section is also disfavoured

arXiv:1209.3715 [nucl-ex]
17 Septembre 2012
Submitted to PLB

- Best agreement is found with models that include nuclear gluon shadowing (RST-LTA, AB-EPS08, AB-EPS09)