Probing low-x structure of nuclei with J/ψ photoproduction in Ultra-peripheral Pb+Pb collisions

Daniel Tapia Takaki

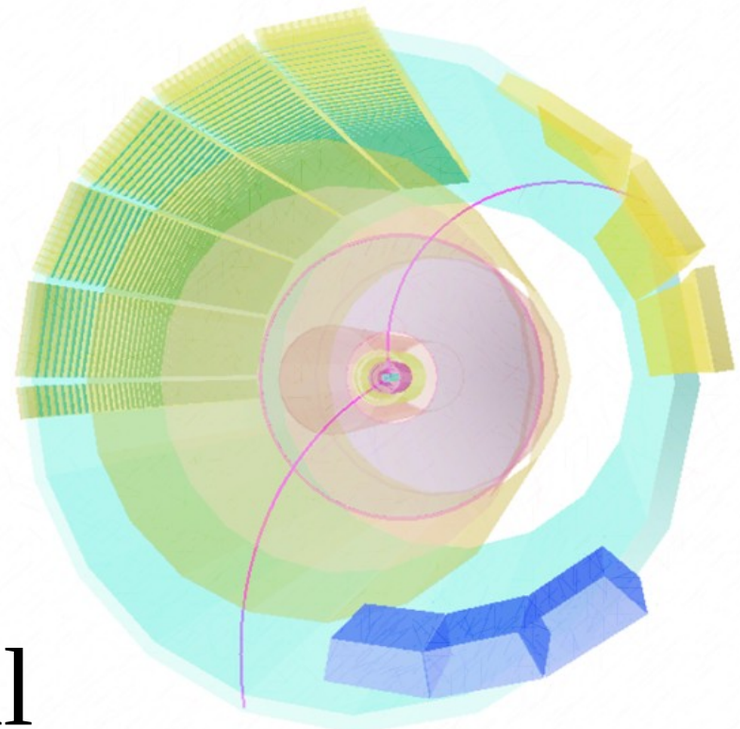
IPN Orsay – Université Paris-sud

Reunion LHC France

Annecy, 5 April 2013

Plan of this talk

- **Ultra-Peripheral (heavy-ion) Collisions**
  - What are UPC
  - Why at the LHC
  - Why at ALICE



Recent ALICE results

- Coherent J/ψ production, central and forward rapidity in Pb-Pb
- First look at p-Pb

Outlook

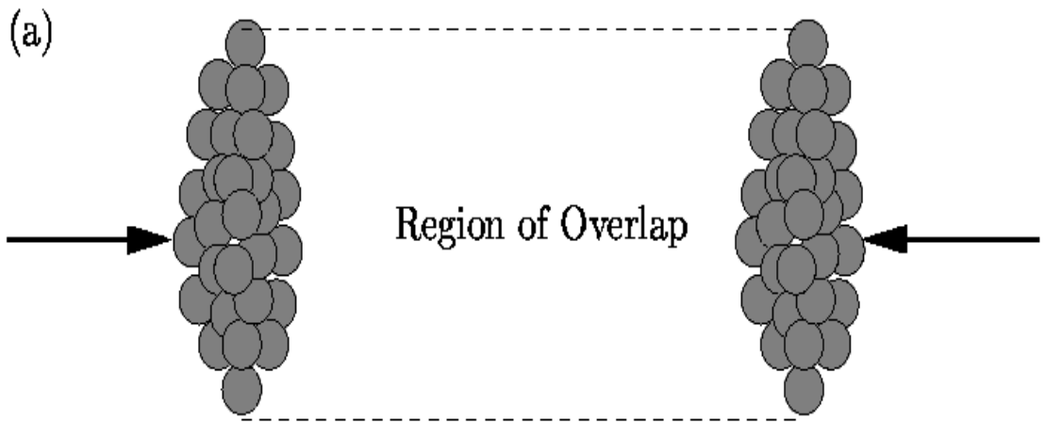
Using the LHC as a γγ, γPb, γp collider

The most powerful collider not only for pp and Pb-Pb collisions, but also for photon-photon and photon-hadron interactions

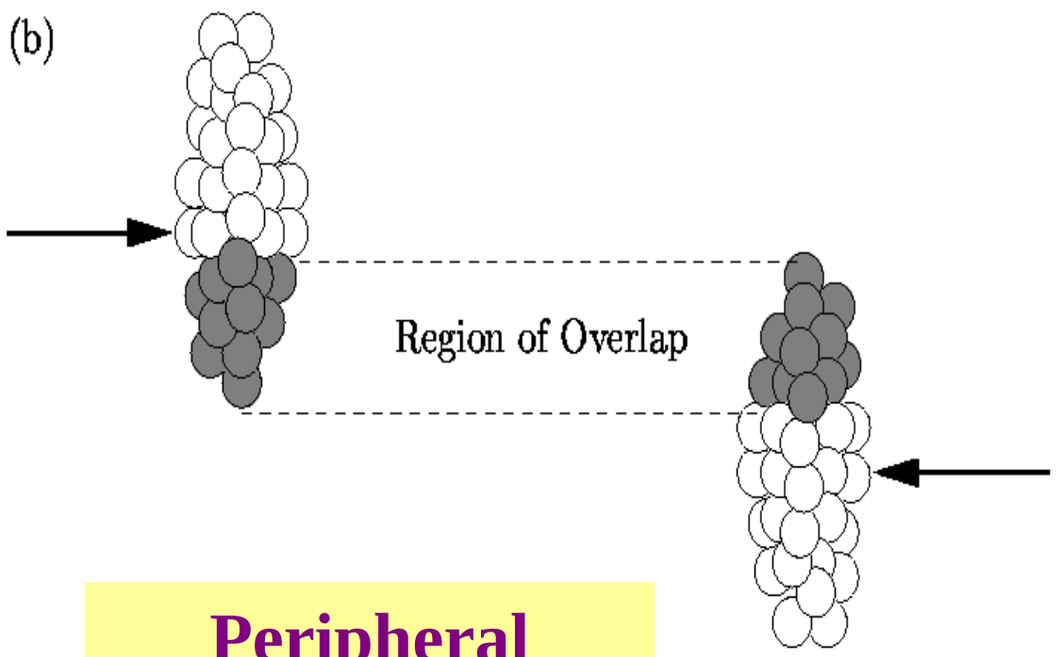
Using the LHC as a γγ, γPb, γp collider

UPCs in Pb-Pb

Terminology in heavy-ion collisions



Central collision



Peripheral collision

Collision Centrality

- Describes the overlap of two incoming ions at the point at which they collide
- The more central the collision, the greater number of participating nucleons (N_{part} or N_{wound})
- Energy of system increases with collision centrality

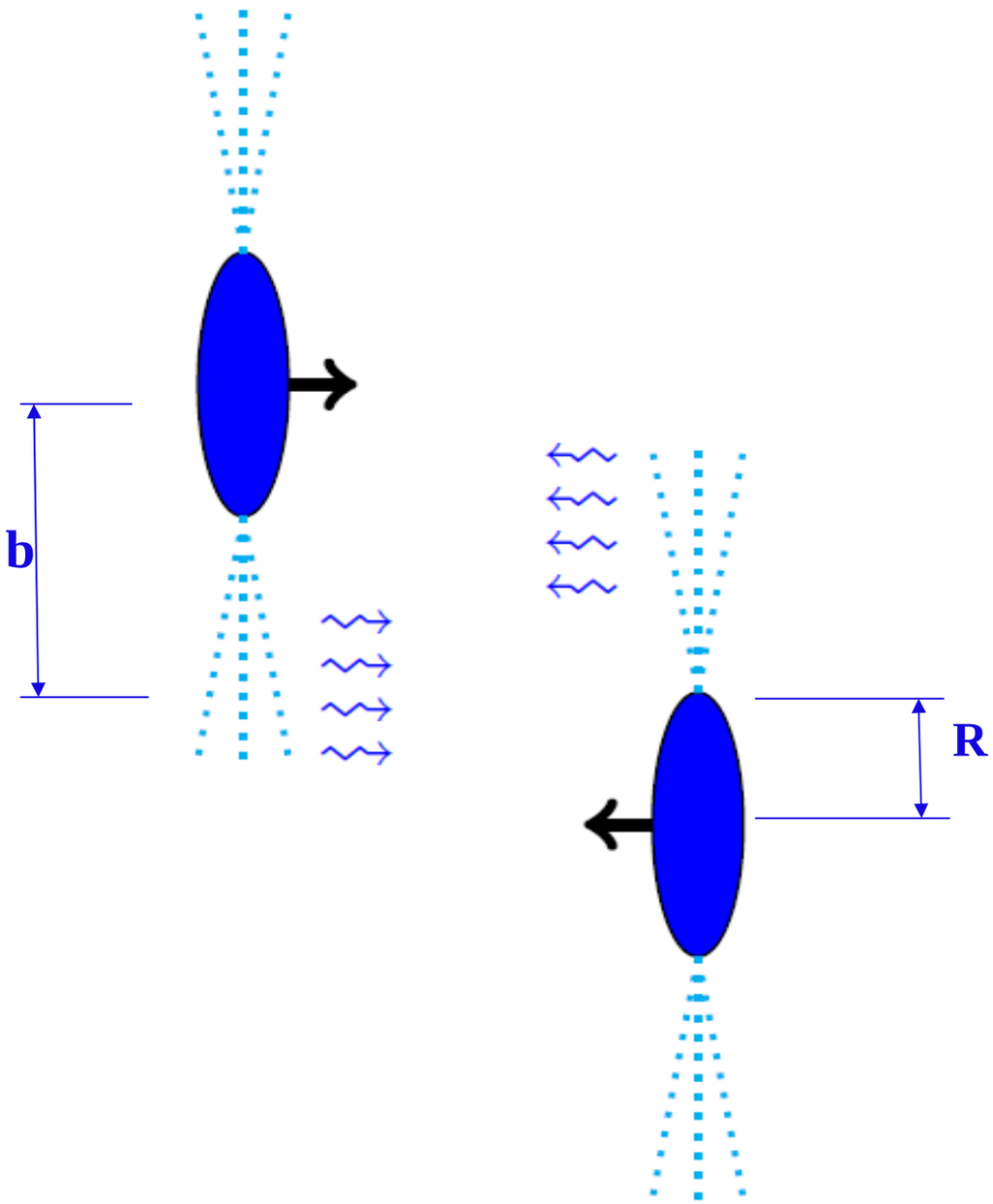
Multiplicity

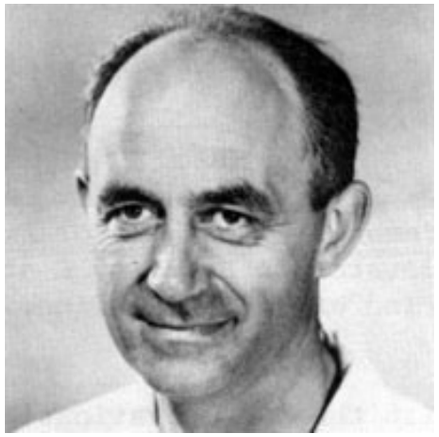
- Number of charged particles produced in the collision

If this is a peripheral collision ....

Here is a sort of ultra-peripheral ...

Why Ultra-Peripheral collisions



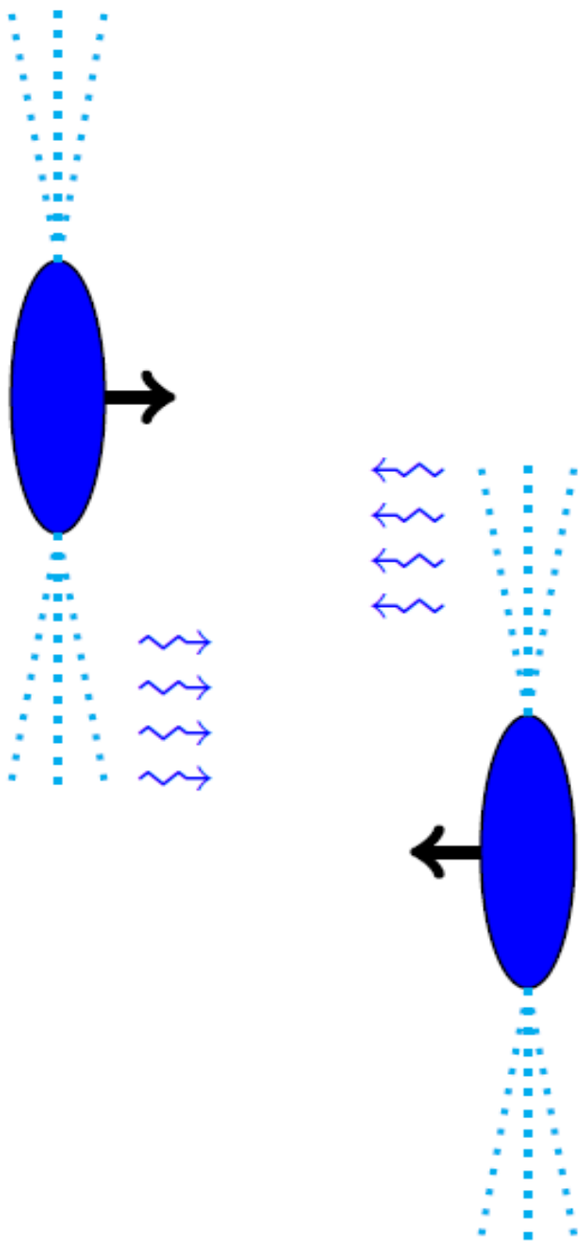


Enrico FERMI

The electromagnetic field surrounding these protons/ions can be treated as a beam of quasi real photons

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

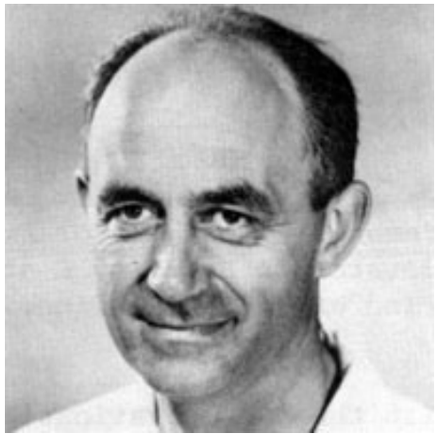
Why Ultra-Peripheral collisions



Nuovo Cim.,2:143-158,1925

http://arxiv.org/abs/hep-th/0205086

Therefore, we consider that when a charged particle passes near a point, it produces, at that point, a variable electric field. If we decompose this field, via a Fourier transform, into its harmonic components we find that it is equivalent to the electric field at the same point if it were struck by light with an appropriate continuous distribution of frequencies.



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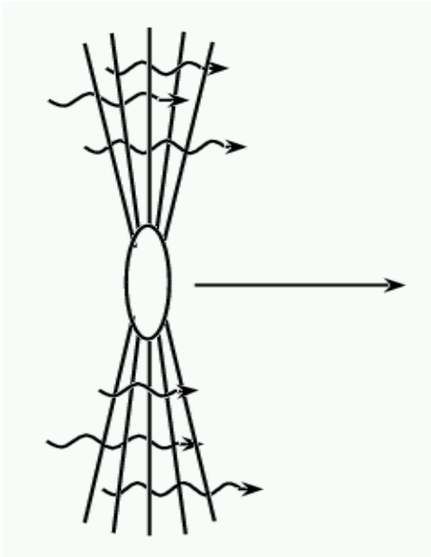
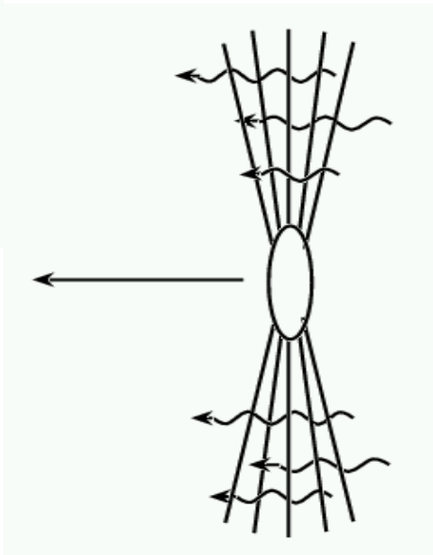
The electromagnetic field surrounding these protons/ions can be treated as a beam of quasi real photons

High photon flux ~ Z^2
→ well described by the Weizsäcker-Williams approximation

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

Why ultra-peripheral heavy-ion collisions



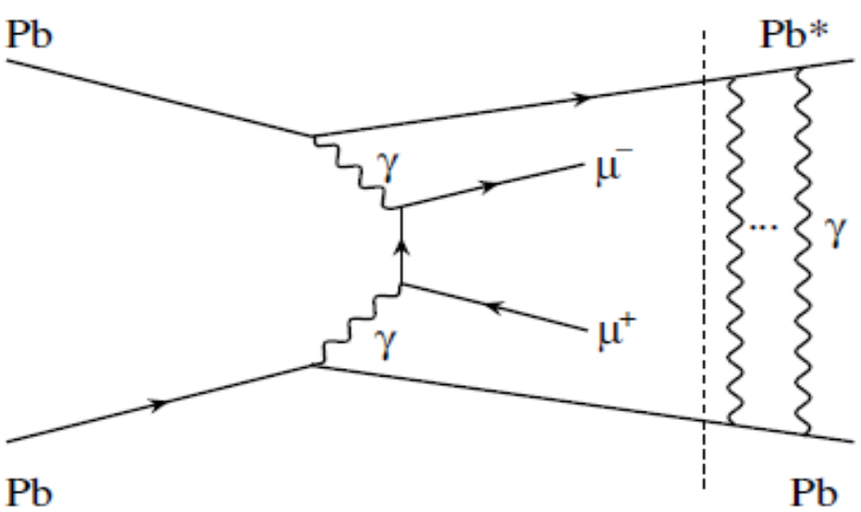


Two ions (or protons) pass by each other with impact parameters b > 2R. **Hadronic interactions are strongly suppressed**

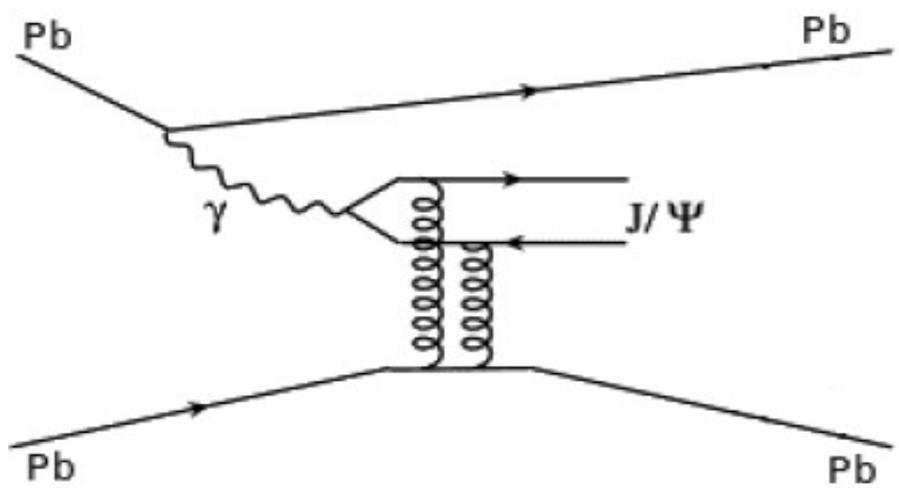
Number of photons scales like Z^2 for a single source ⇒ exclusive particle production in heavy-ion collisions dominated by electromagnetic interactions.

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

Photon-induced reactions



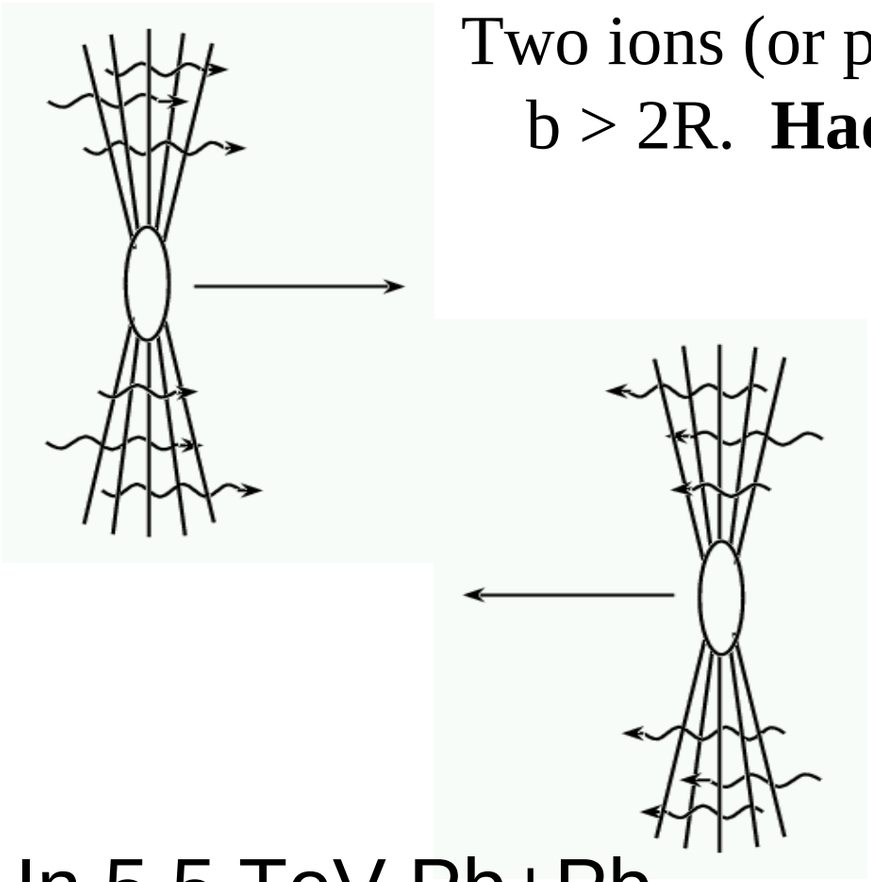
Two-photon production



γ + p → J/ψ + p

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

Why ultra-peripheral heavy-ion collisions



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In 5.5 TeV Pb+Pb

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

σ(hadronic) ~ 8b; σ(e^+e^-) ~ 281 b

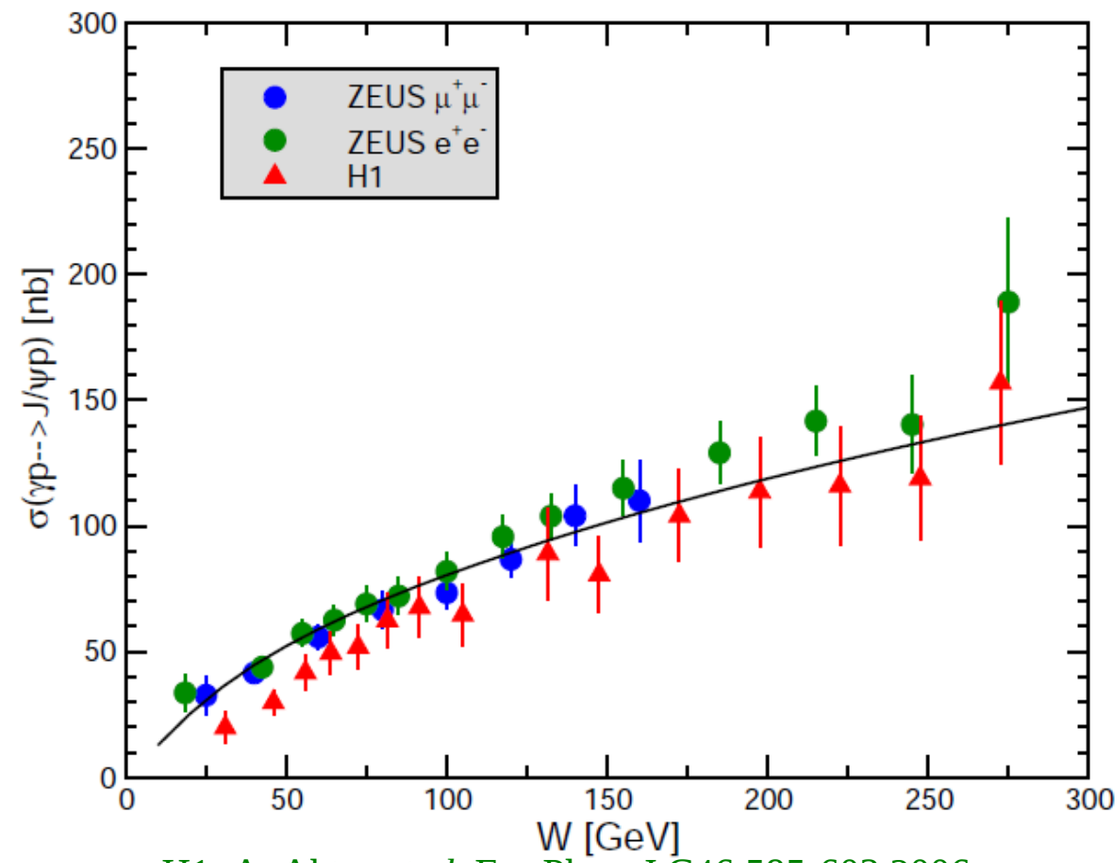
σ(EMD) ~ 226 b

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

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...

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

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

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

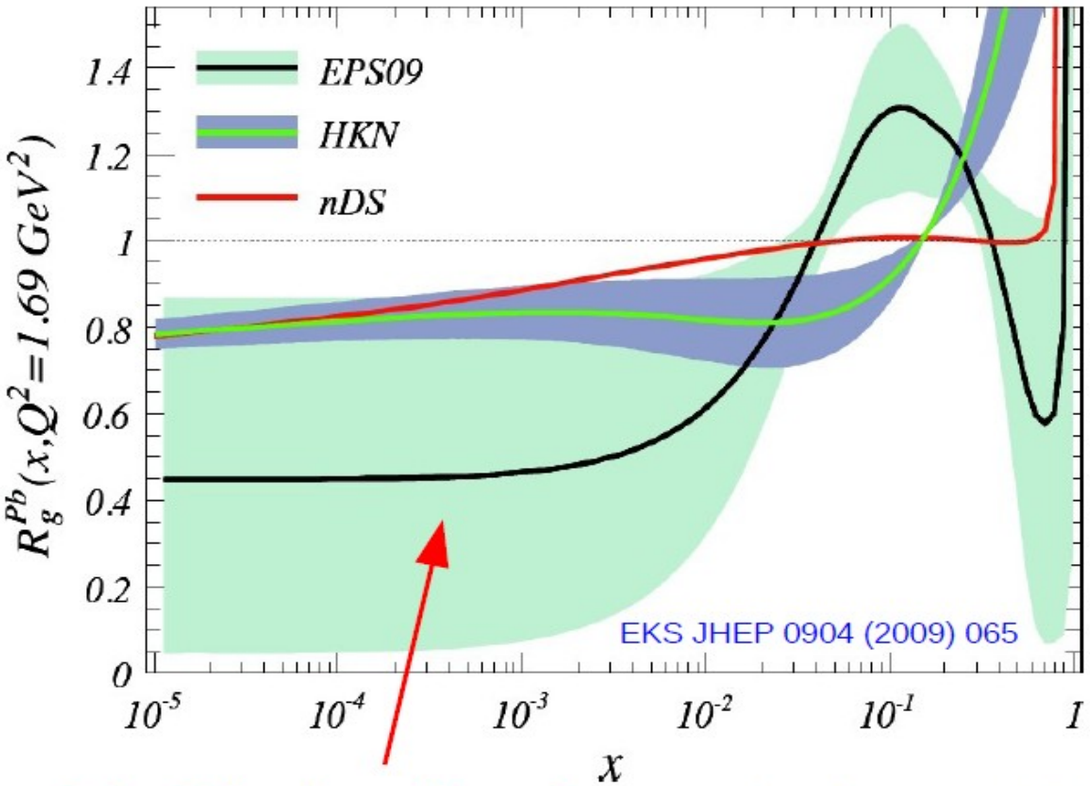
Ryskin 1993

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

Also a more recent calculation

T. Lappi, H. Mäntysaari
http://arxiv.org/abs/1301.4095

Nuclear gluon density: huge uncertainties



$xG(x,Q^2)$ virtually unknown below $x \sim 10^{-2}$!

Is a proton inside a nucleus = a free proton?

No, nuclear effects

Nuclear effects will change the probability of finding partons of a given x $x = E_{\text{constituent}}/E_{\text{hadron}}$

There are some models that provide the ratio between the PDFs in a <u>proton of a nucleus of mass number A</u> an in a <u>free proton</u>

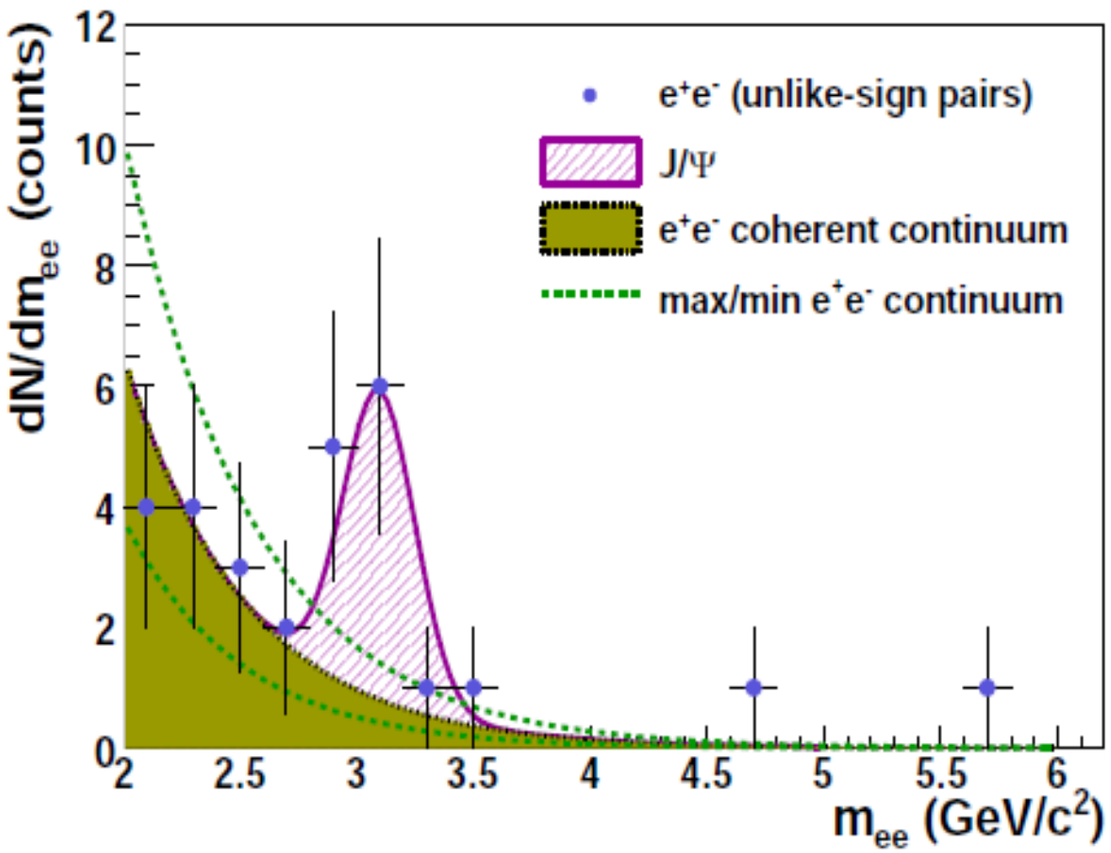
Shadowing → some of the partons are obscured by virtue of having another parton in front of them → Low-x effect

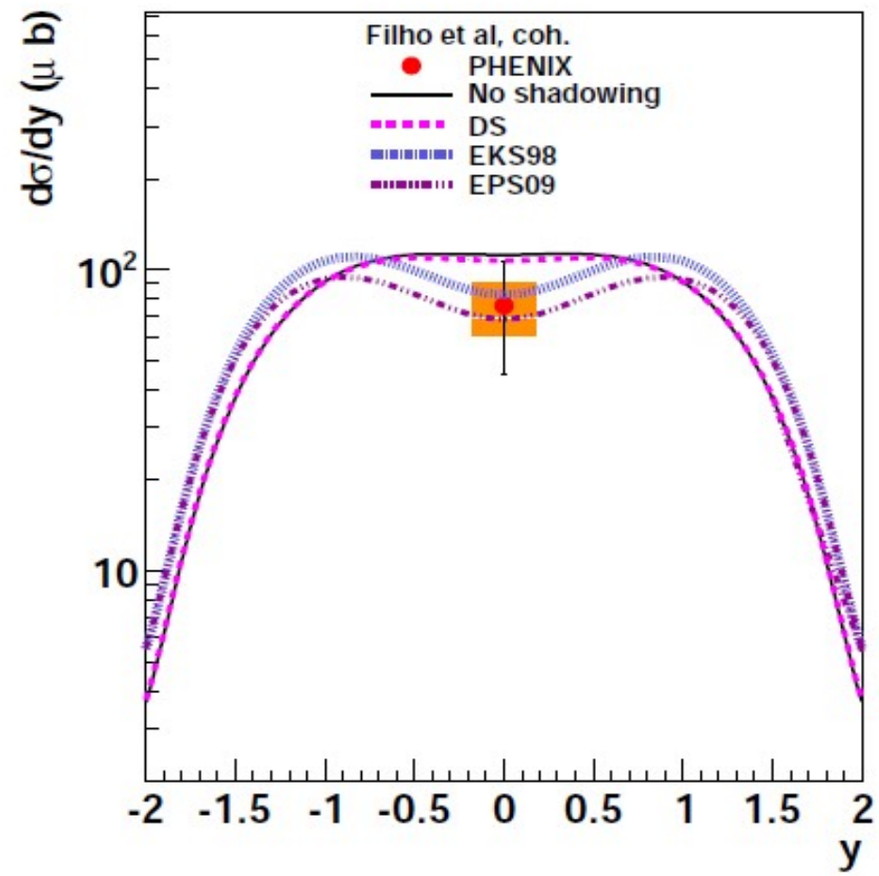
Parton's density inside the nucleus, for a given kinematics range

$$\left.\frac{d\sigma(\gamma p \to V p)}{dt}\right|_{t=0} = \frac{\alpha_s^2 \Gamma_{ee}}{3\alpha M_V^5} 16\pi^3 \left[xG(x,Q^2)\right]^2, \text{ with } Q^2 = M_V^2/4$$

$$x = M_V^2/W_{\gamma p}^2$$

RHIC results by PHENIX





Au+Au collisions at 200 GeV

PHENIX study:

PLB Vol 679, issue 4, p. 321-333

Coherent production:

Photon couples coherently to all nucleons

$\langle p_T \rangle$~60MeV/*c;* target nucleus does not break up, in most cases

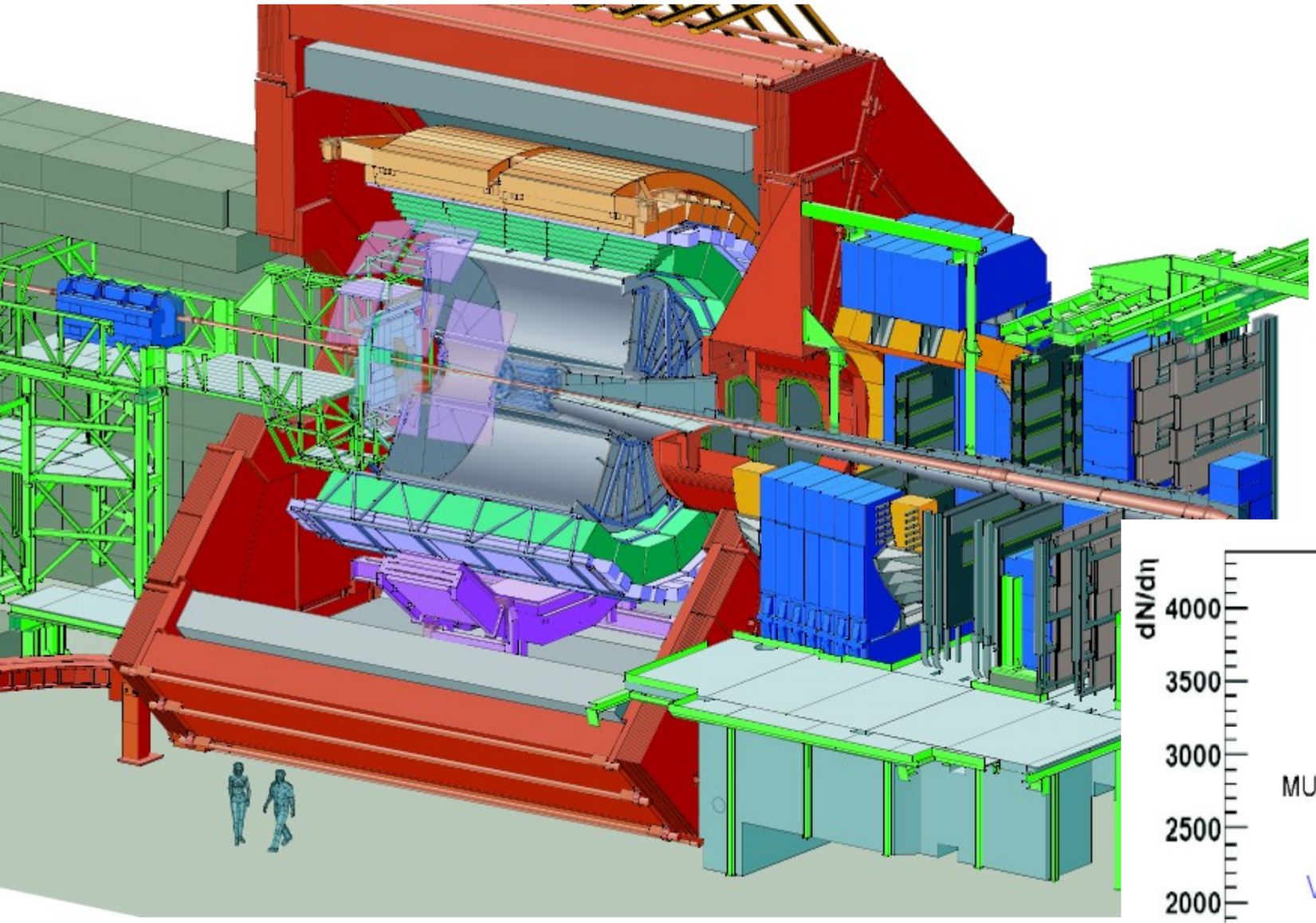
Incoherent production

Photon couples to a single nucleon

Quasi-elastic scattering off a single nucleon

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

The ALICE experiment at LHC



Central rapidity

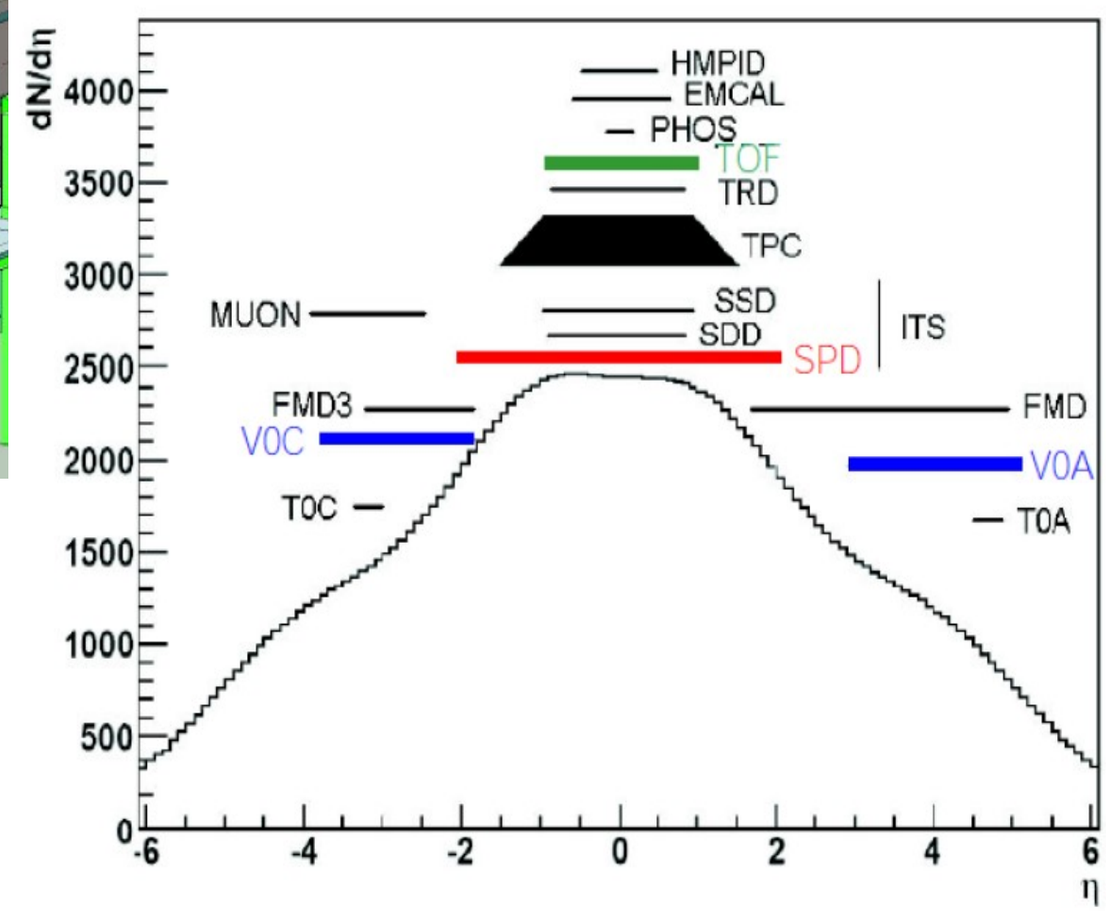
Inner Tracking (ITS), Time Projection Chamber (TPC), Time-of-Flight, TRD, EMCAL

$|\eta| < 0.9$

Forward rapidity

Muon Spectrometer

$-4 < \eta < -2.5$



ALICE can measure J/ψ mesons down to zero p_T

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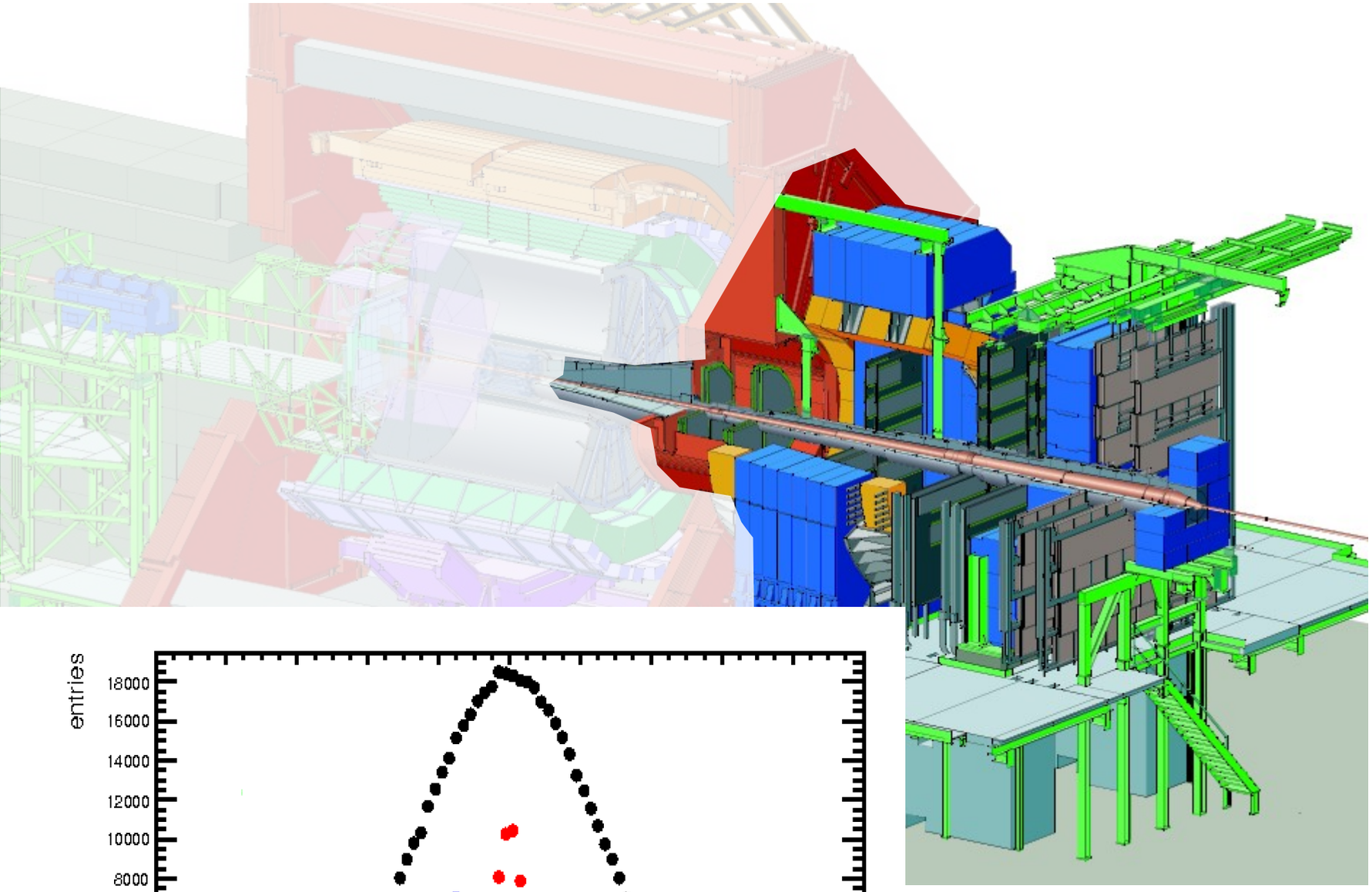
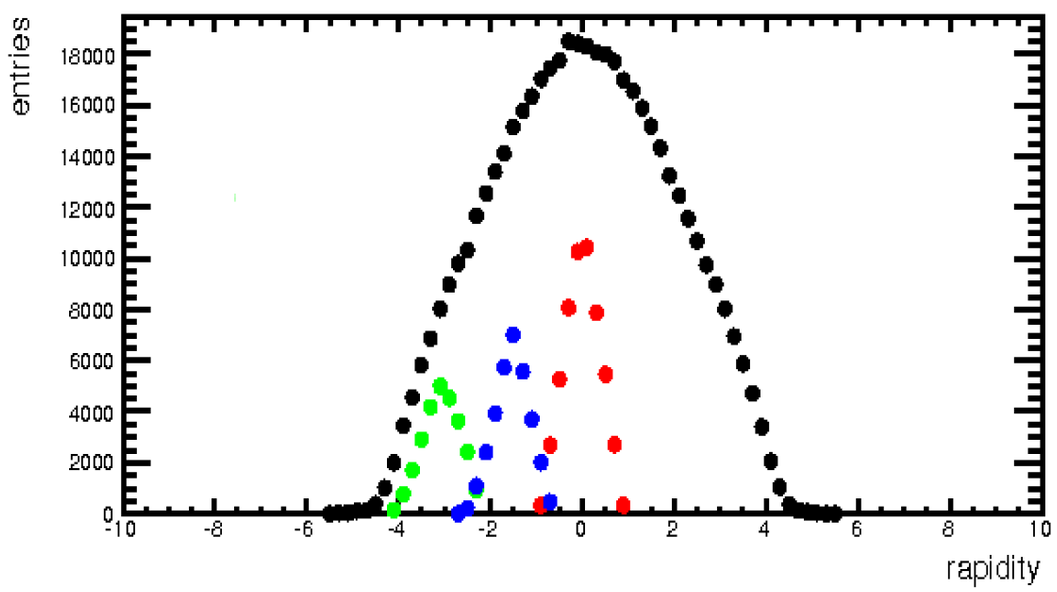
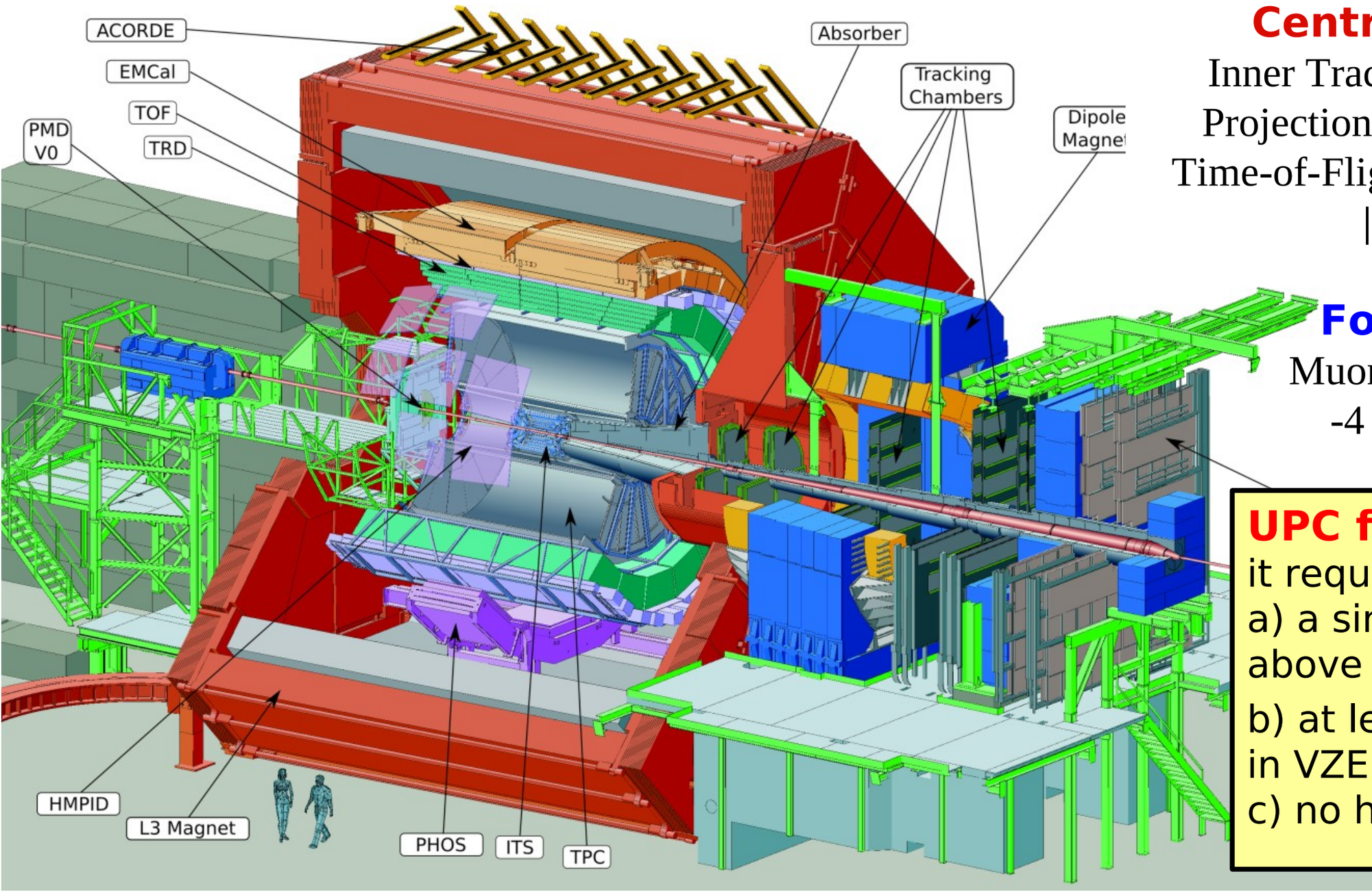




Quarkonia measurements at ALICE



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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

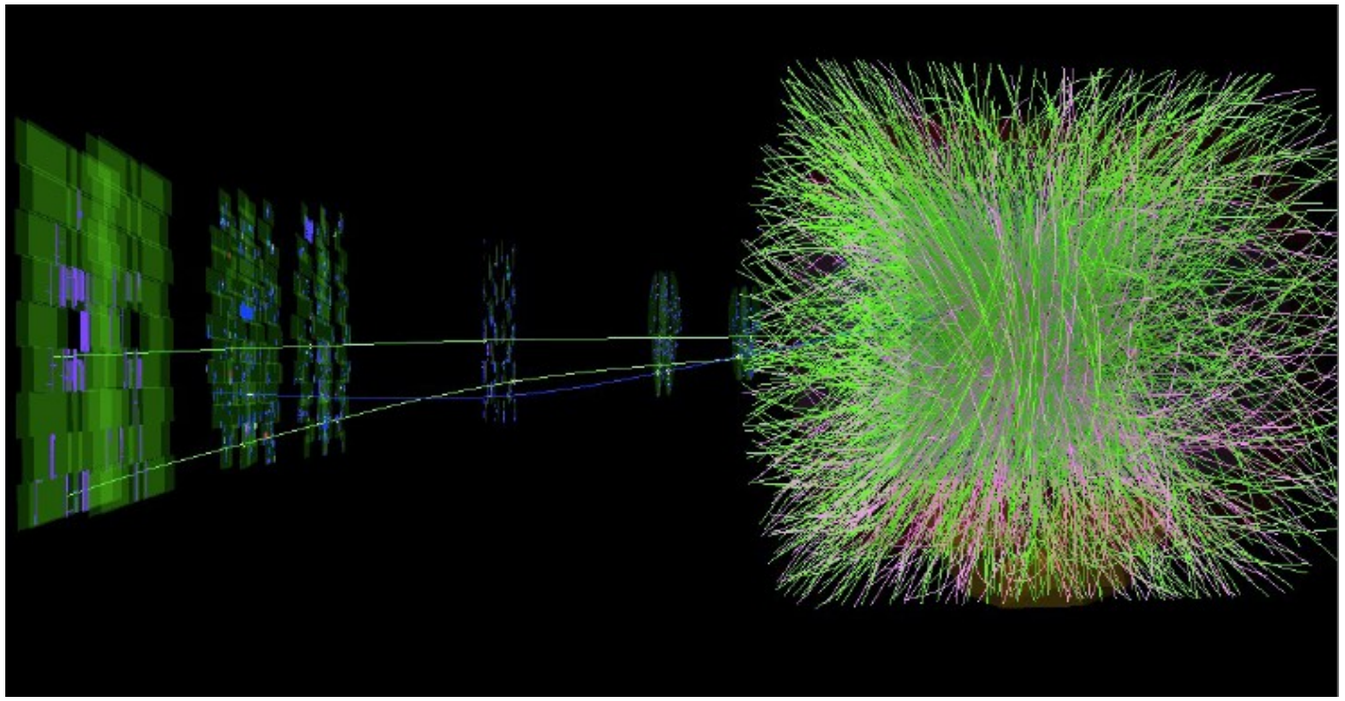
Forward detectors used in this analysis:

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

ZDC: 116 m on either side of the IP

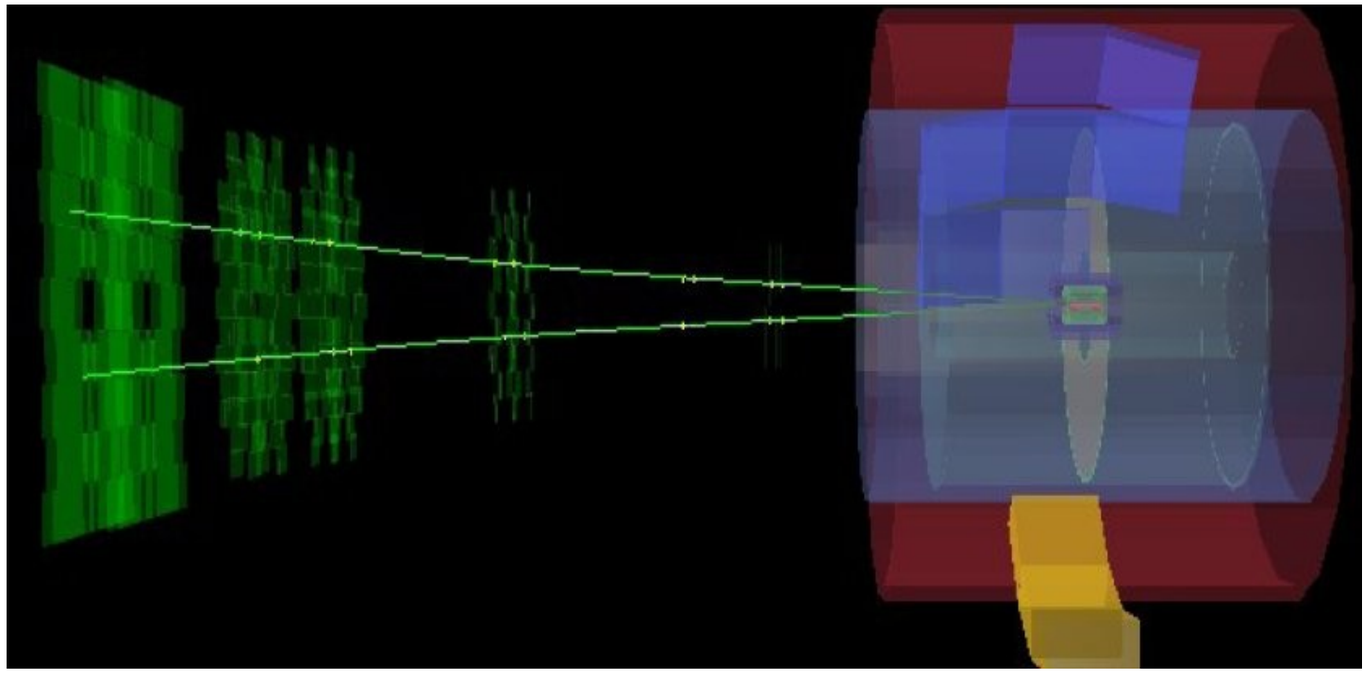
ALICE can measure J/ψ mesons down to zero p_T

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



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

….to an exclusive J/ψ candidate



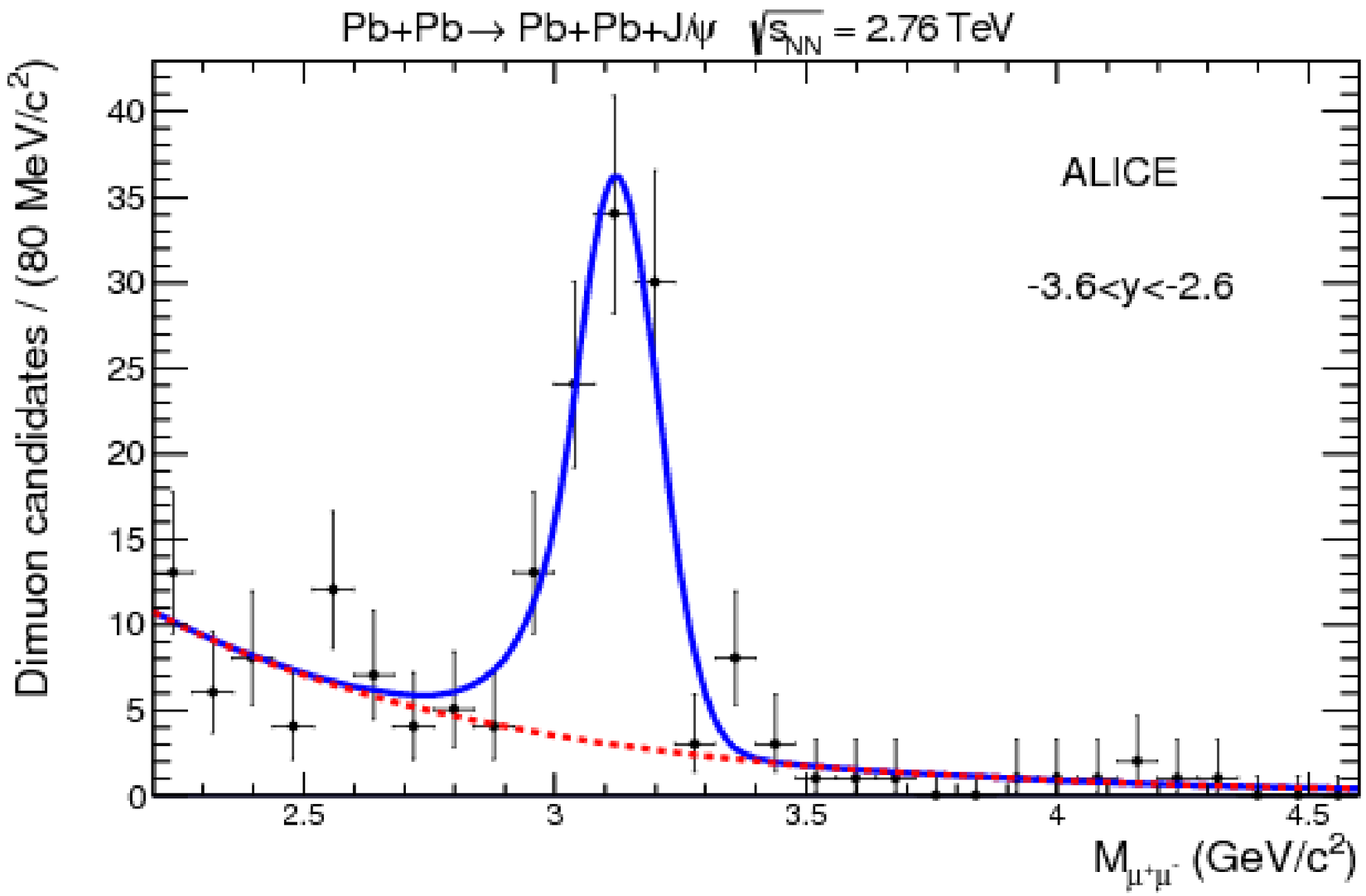
First UPC measurement at LHC carried out by ALICE

Phys.Lett. B718 (2013) 1273-1283

CERN Courier; Nov issue

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

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

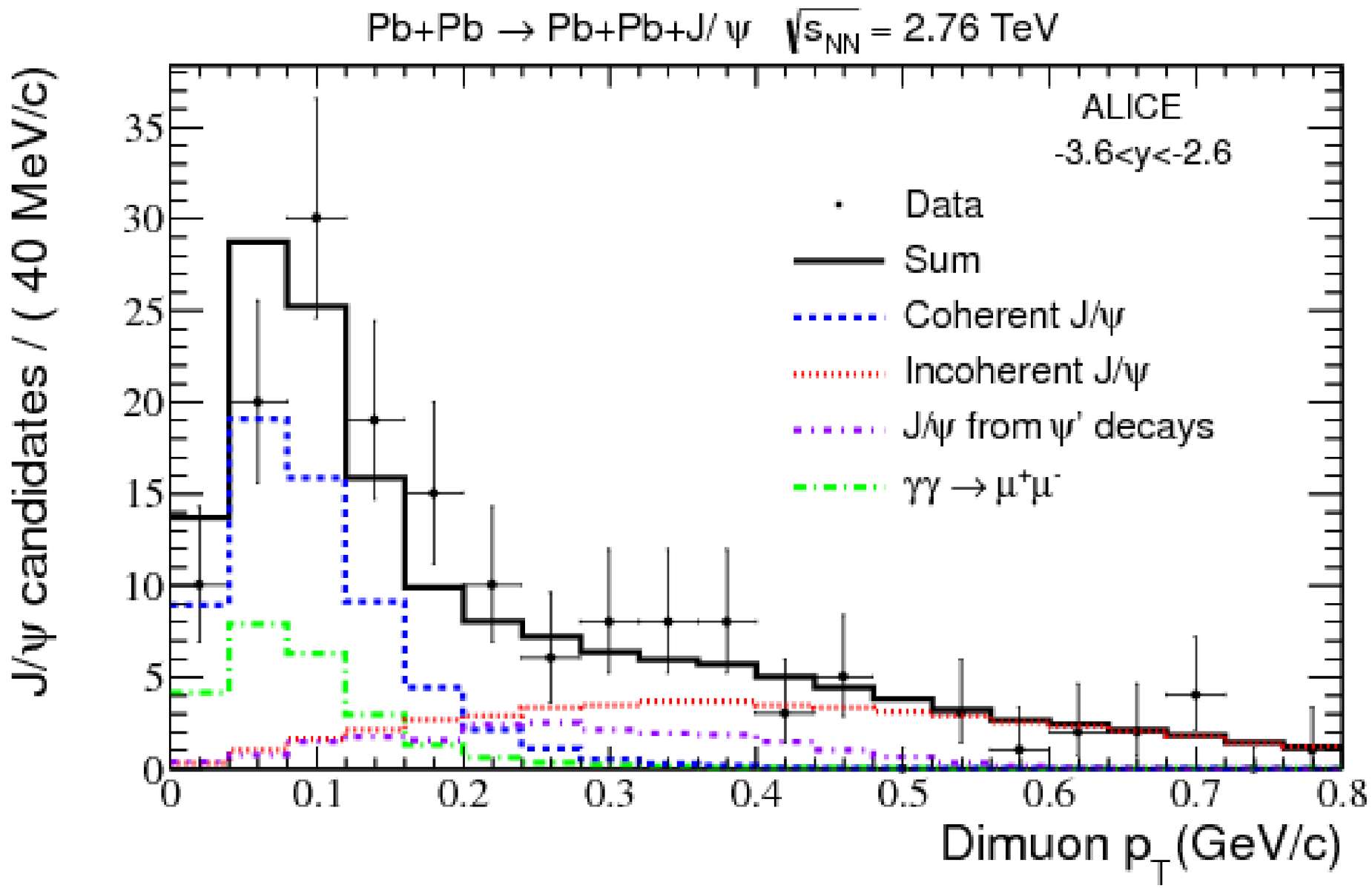
Exponential slope parameter

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

MC($\gamma\gamma \rightarrow \mu^+\mu^-$): -1.39 +/- 0.01 $\text{GeV}^{-1}\text{c}^2$

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

p_T distribution for J/ψ candidates



The coherent J/ψ signal is clearly visible

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

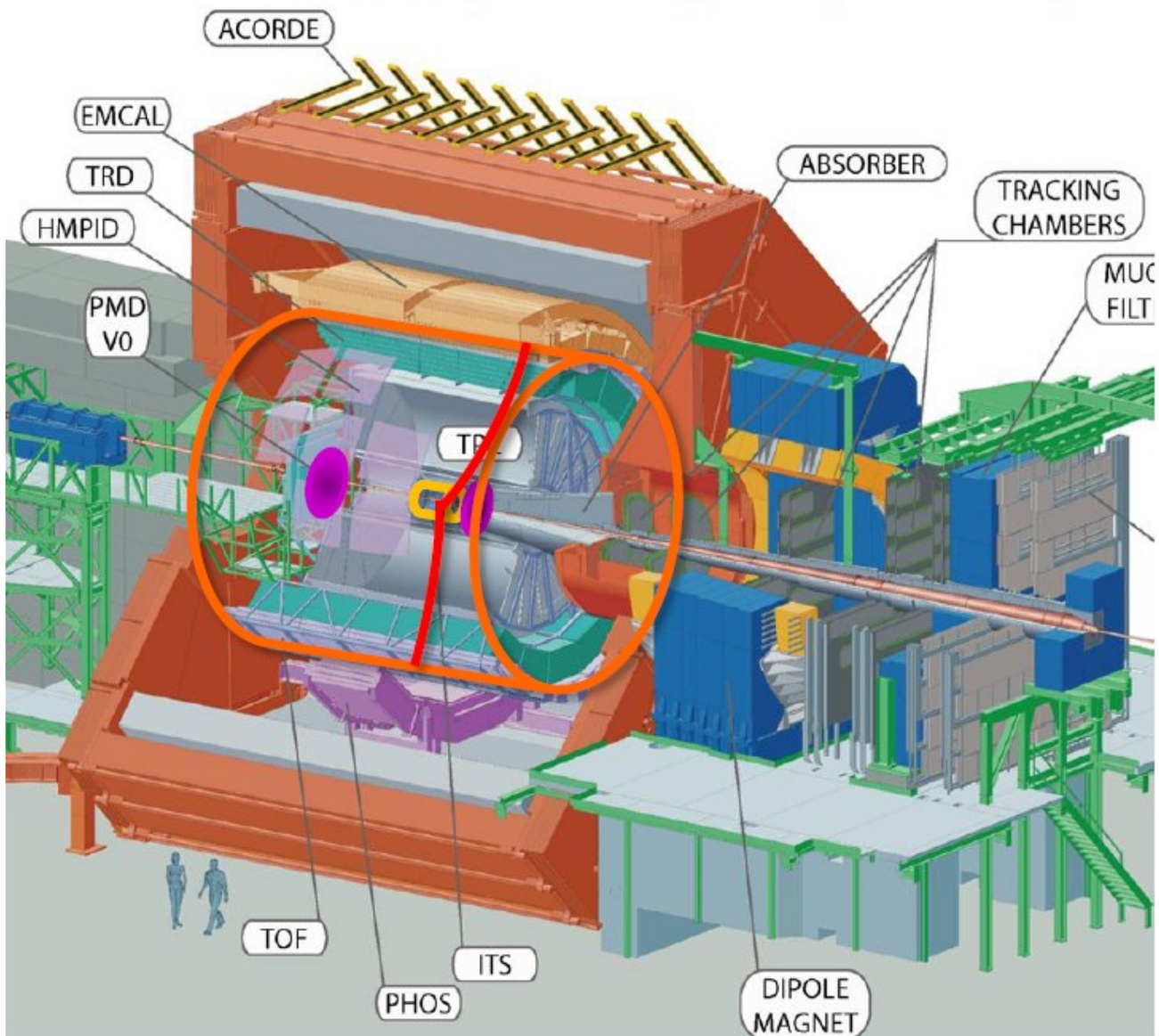
Four physics processes:

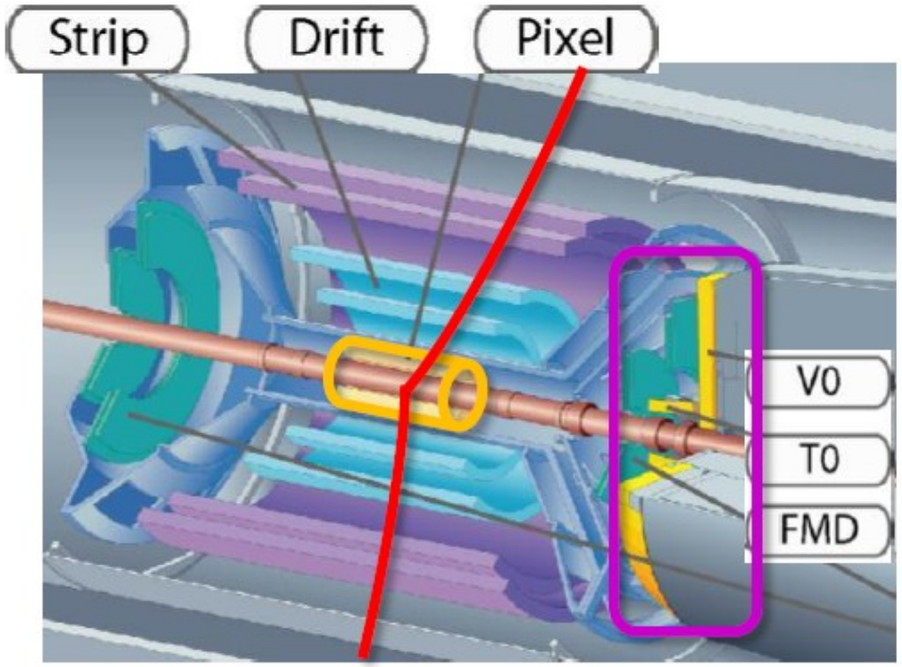
- Coherent J/ψ
- Incoherent J/ψ
- J/ψ from ψ' decays
- γγ → μ+μ-

Central barrel measurements

UPC central barrel trigger:

- $2 \leq$ **TOF** hits ≤ 6 ($|\eta| < 0.9$)
  + back-to-back topology ($150° \leq \varphi \leq 180°$)
- ≥ 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}

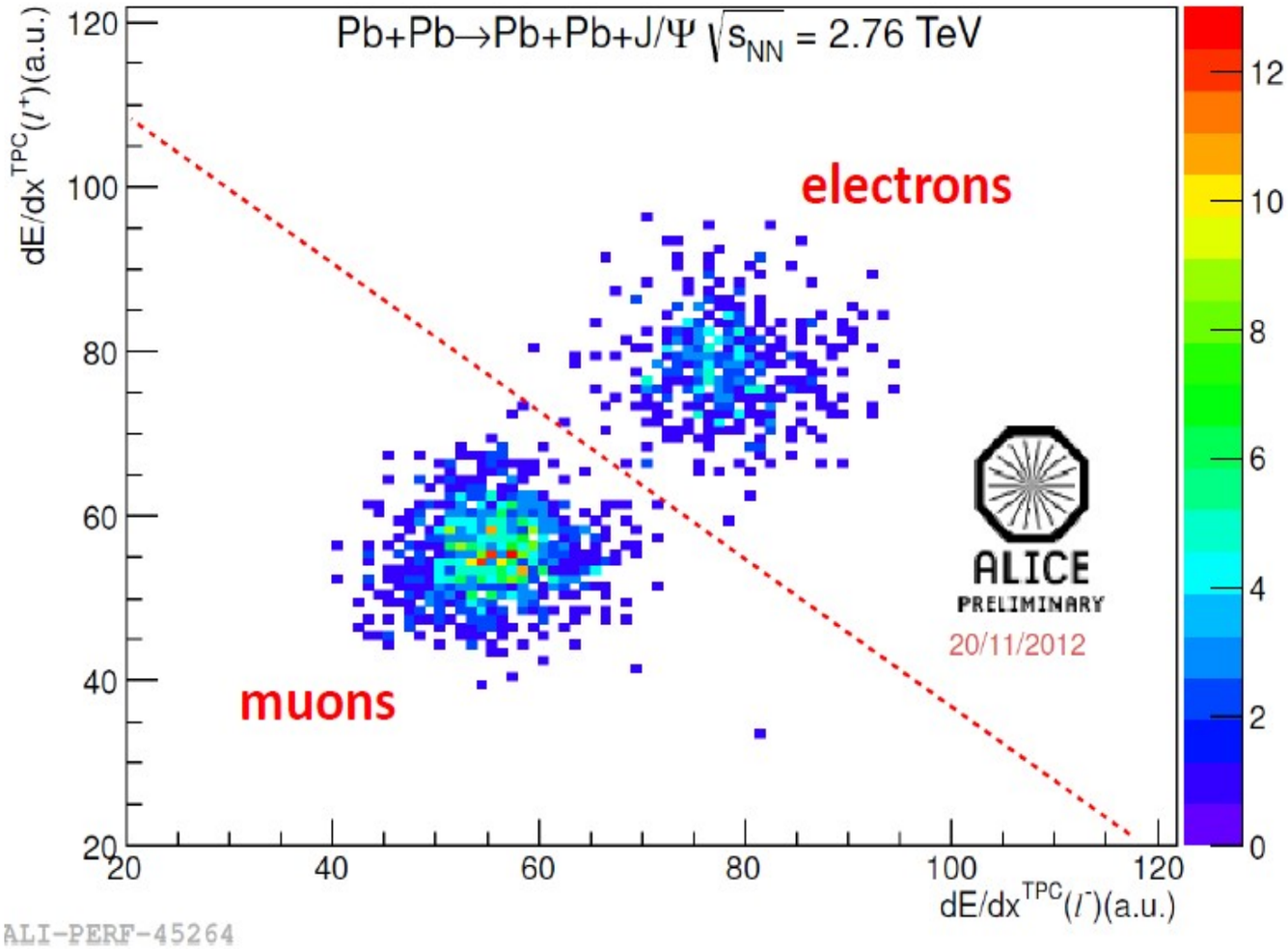
Offline event selection:

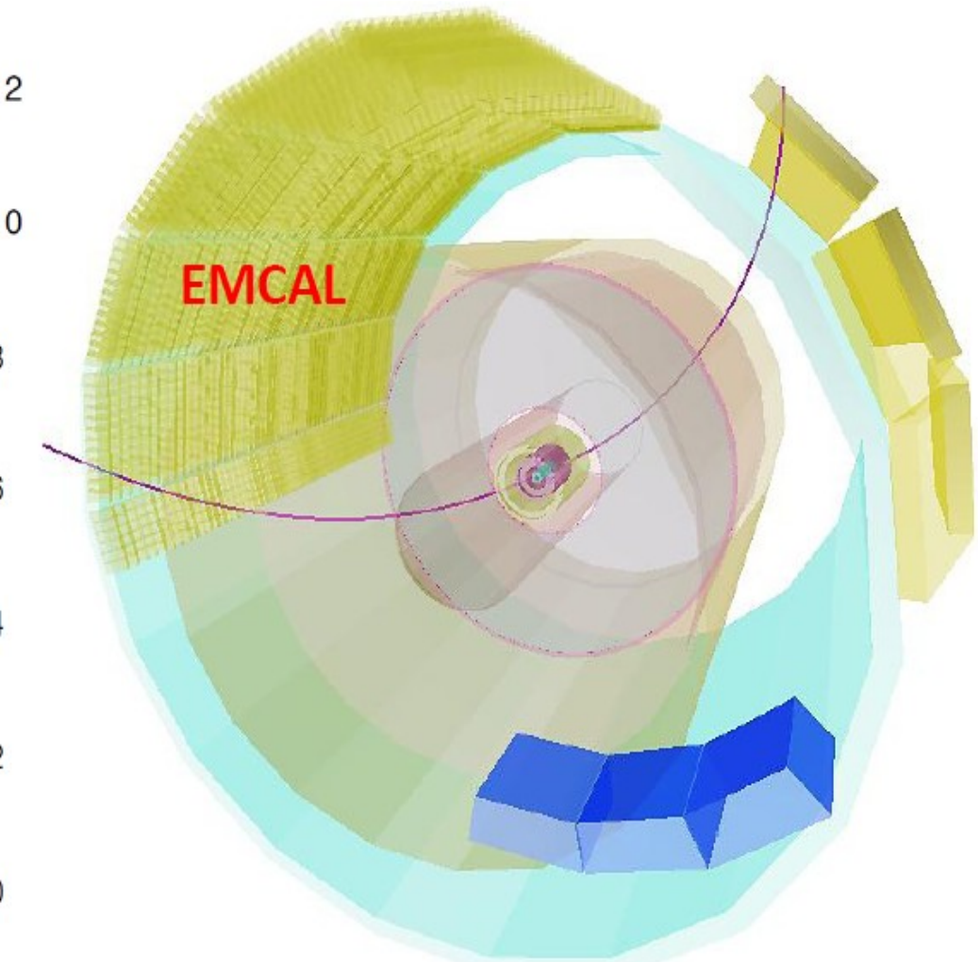
- Offline check on VZERO timing
- Hadronic rejection with ZDC

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

Central barrel measurements

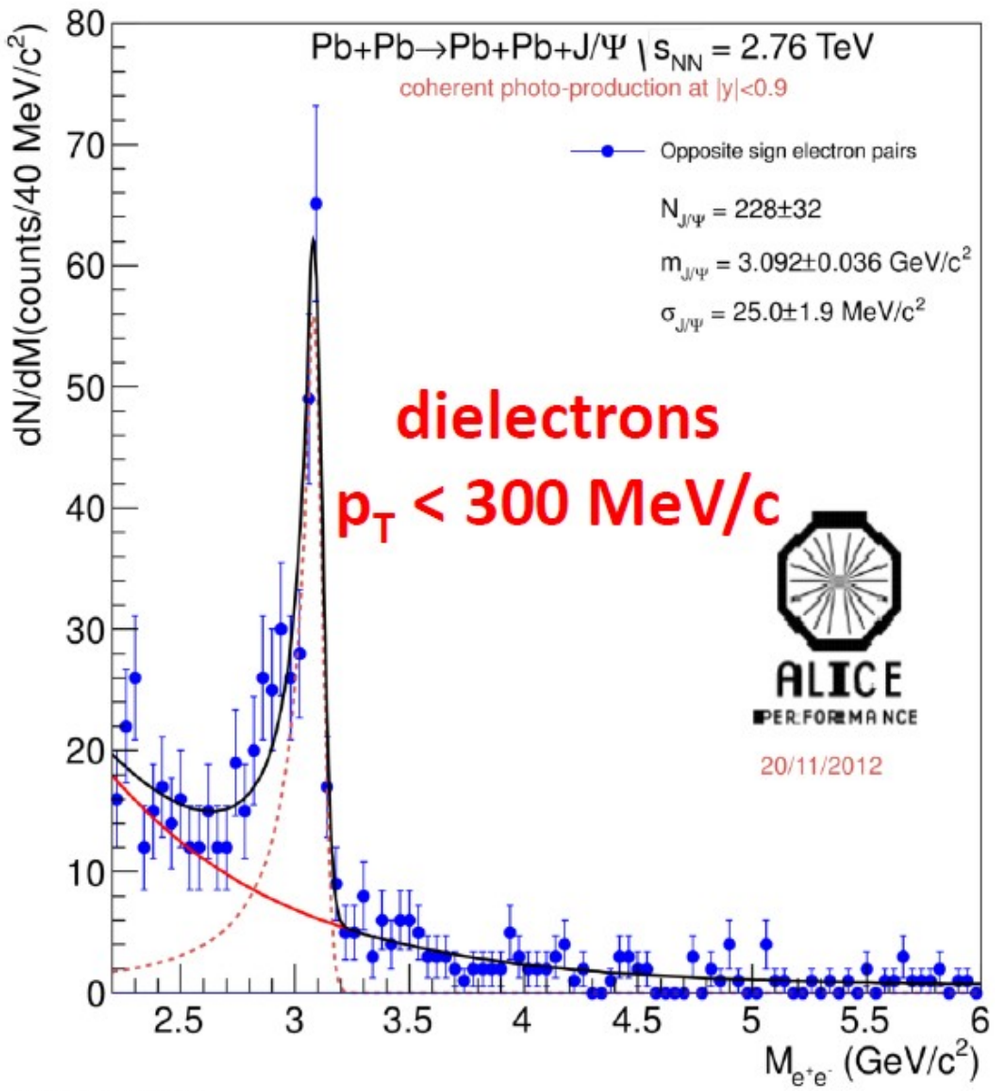


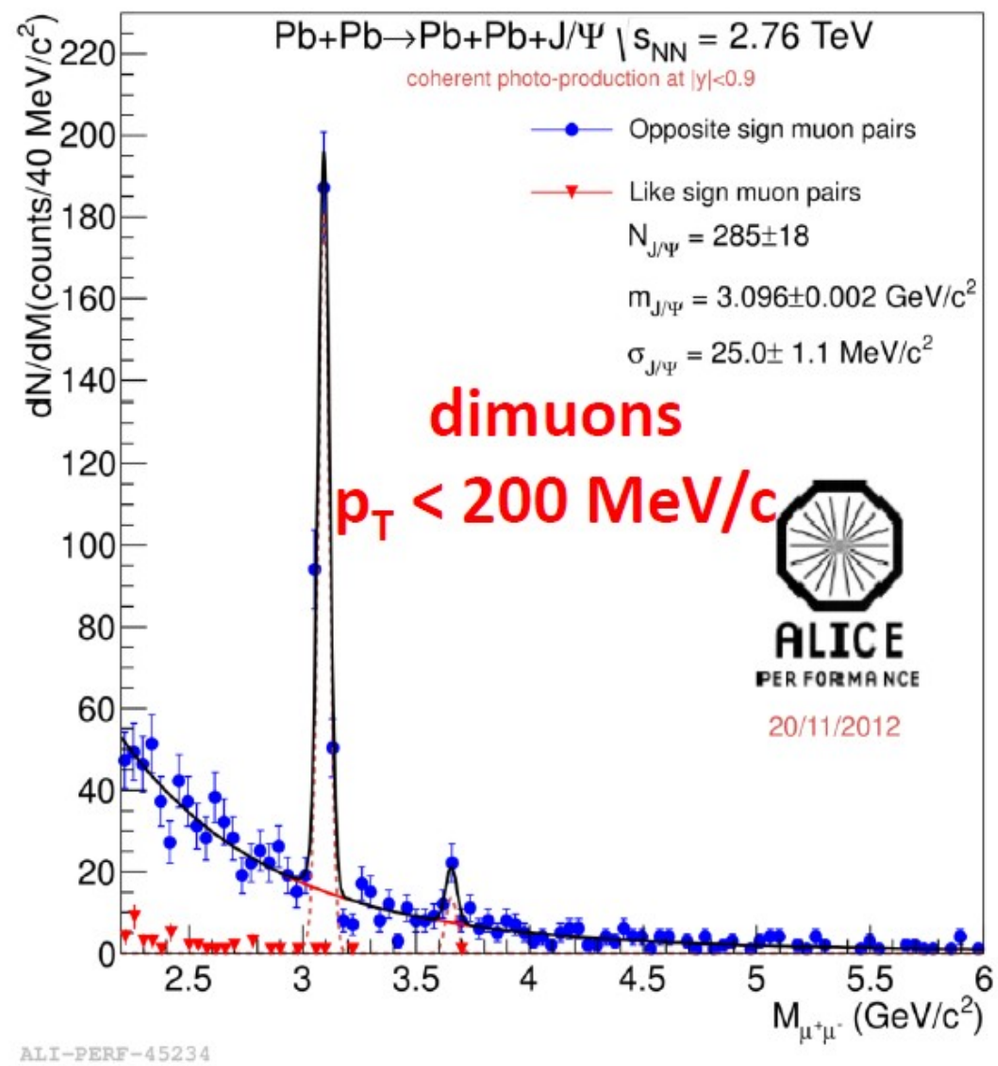


- dE/dx in TPC compatible with e/μ energy loss
- Cross-checked with E/p in EMCAL
- ±2% systematics due to e/μ separation

Central barrel measurements

coherent enriched sample





Theoretical predictions

1. AB-MSTW08 - No nuclear effects
All nucleons contribute to the scattering $d\sigma/dt$ 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 *and* theoretical predictions

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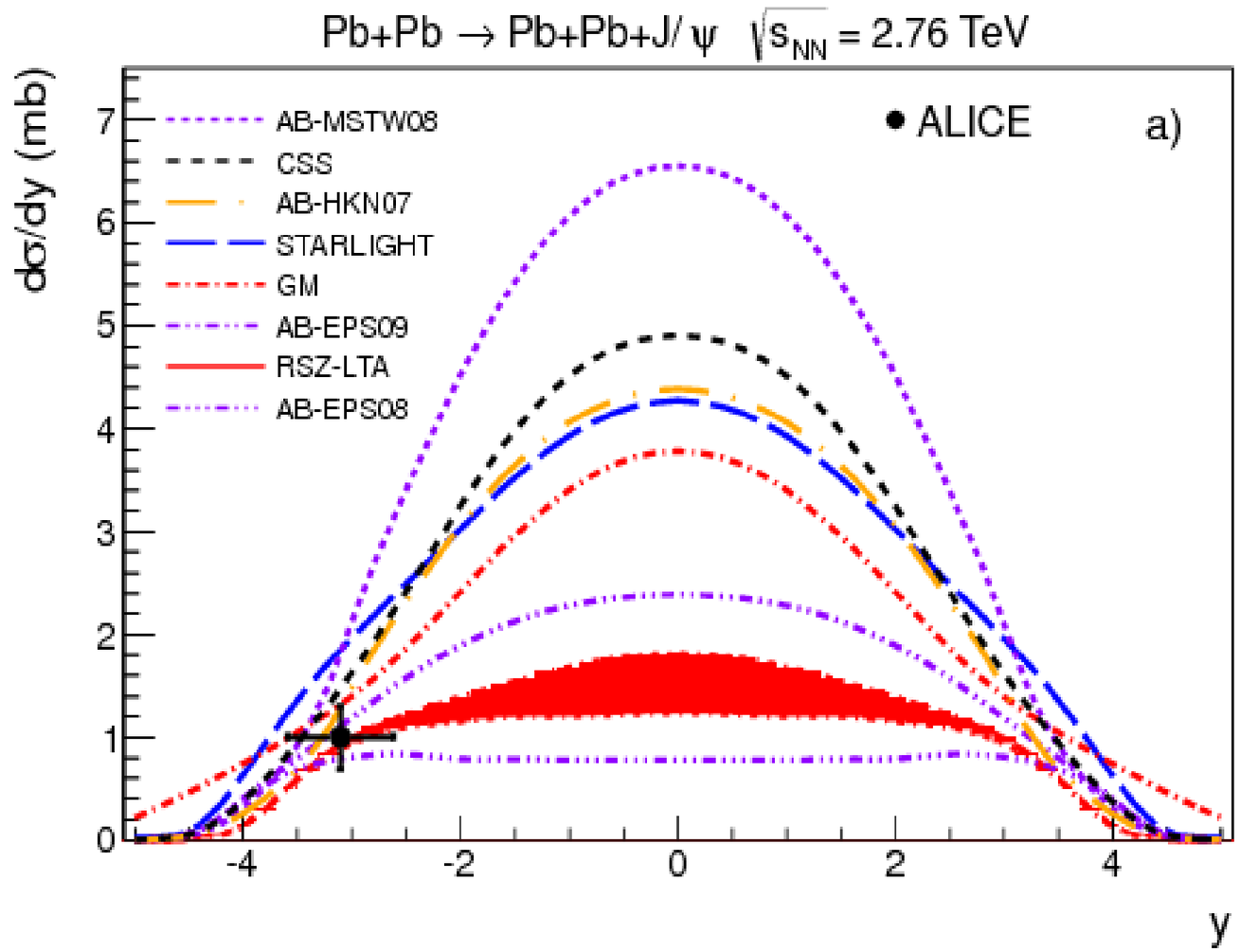


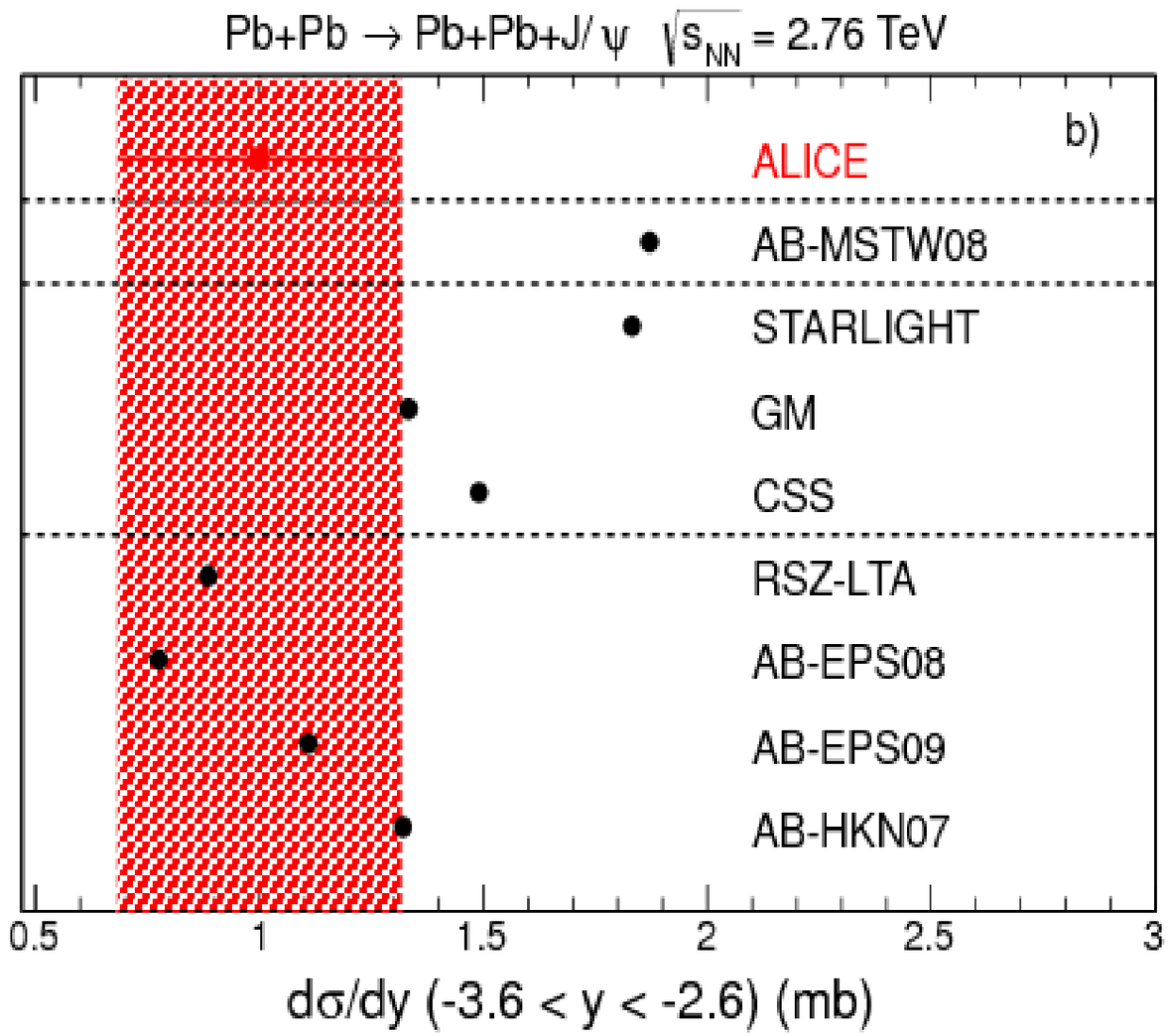
Most forward J/ψs in UPC Pb-Pb at LHC are from low photon-proton c.m.s. energy

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

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

Data *and* theoretical predictions

Integrated cross section

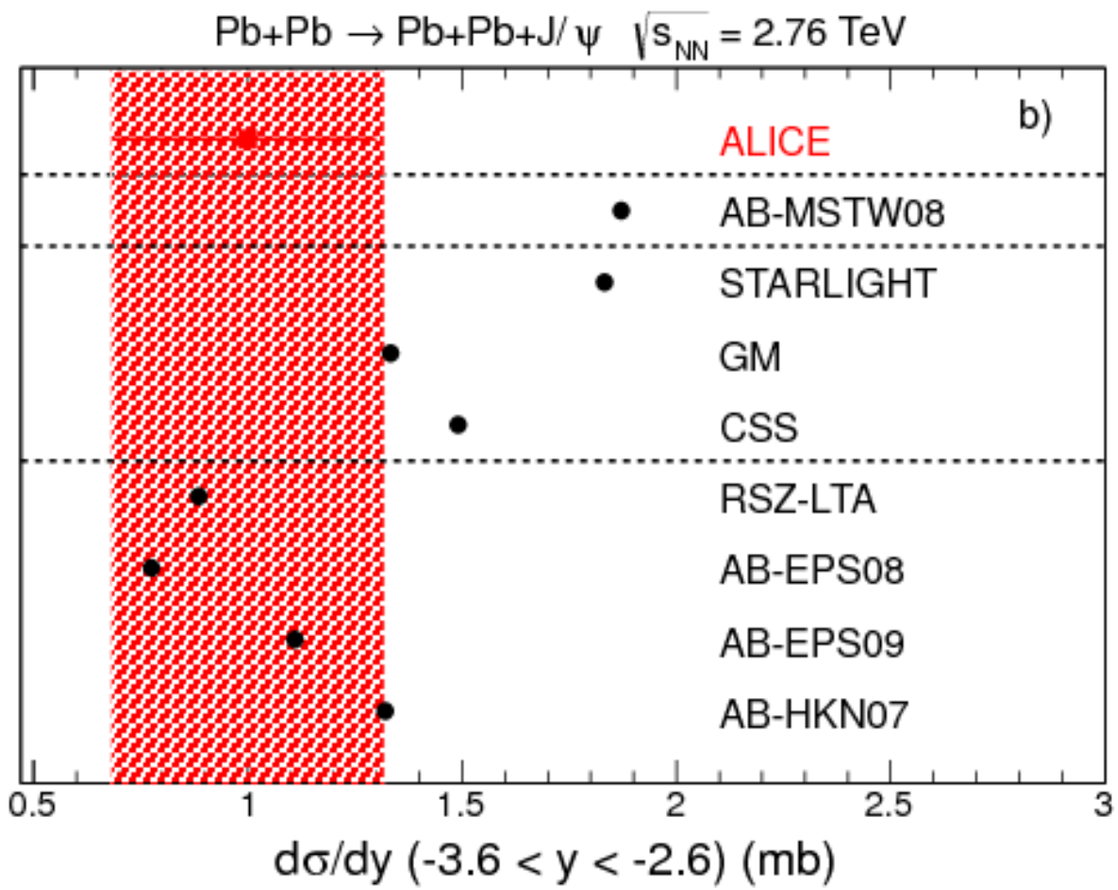


Largest deviations (3σ):
STARLIGHT and AB-MSTW08

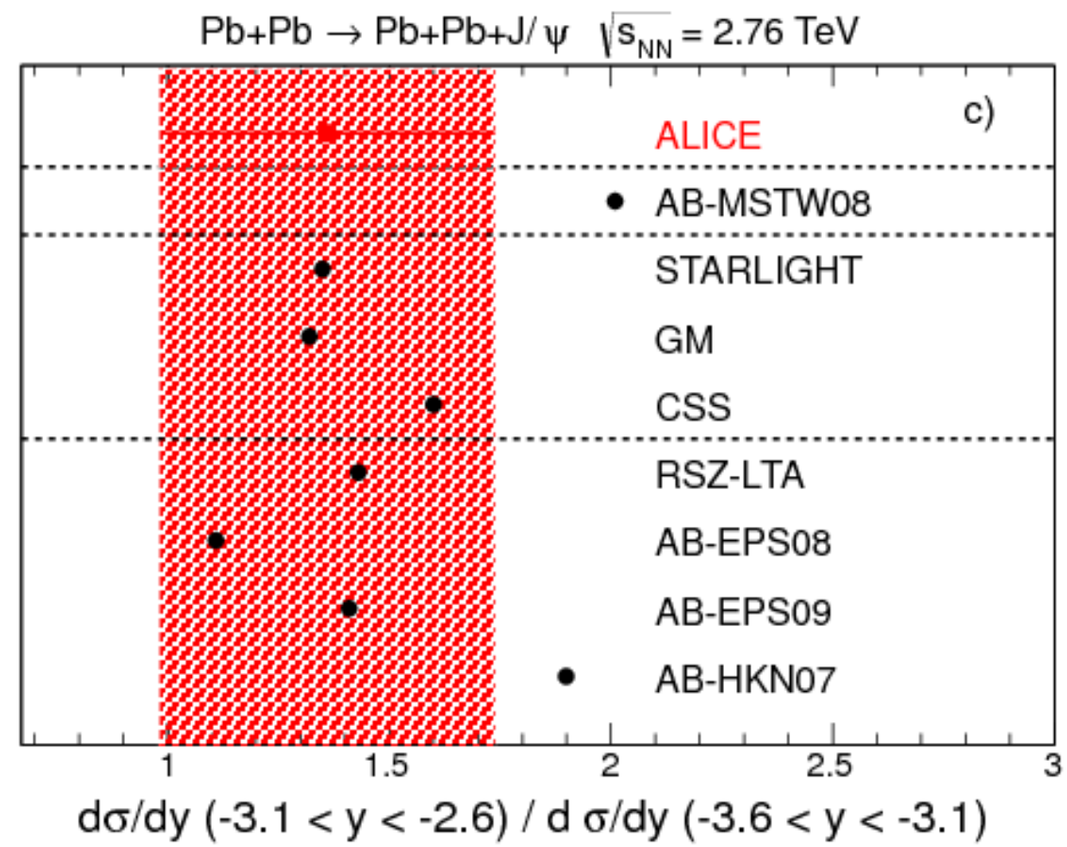
Best agreement (1σ):
RSZ-LTA, AB-EPS08 and AB-EPS09

Data *and* theoretical predictions

Integrated cross section



Ratio of dσ/d*y*



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

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

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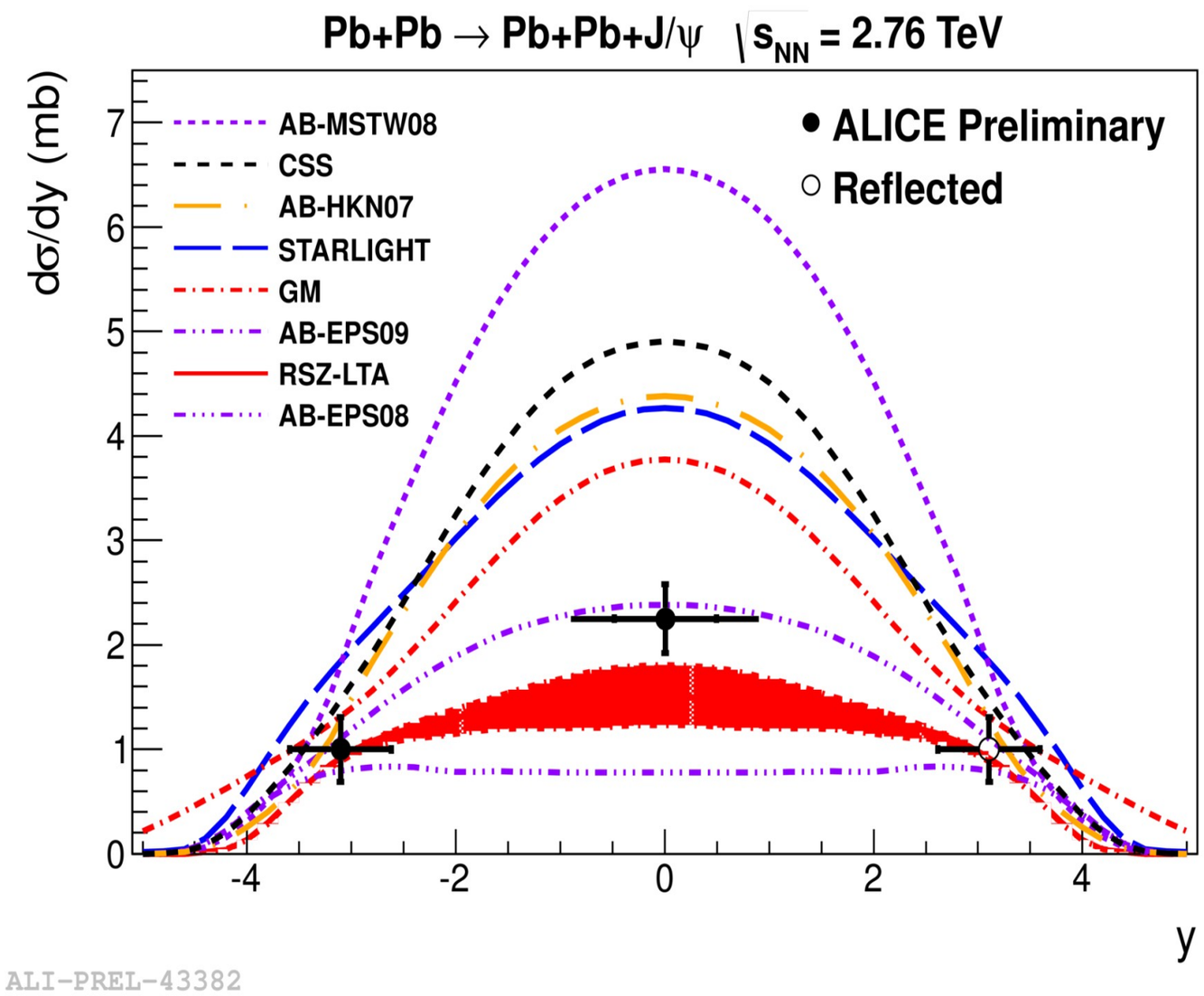


Published forward J/ψ measurement
Preliminary central J/ψ measurement

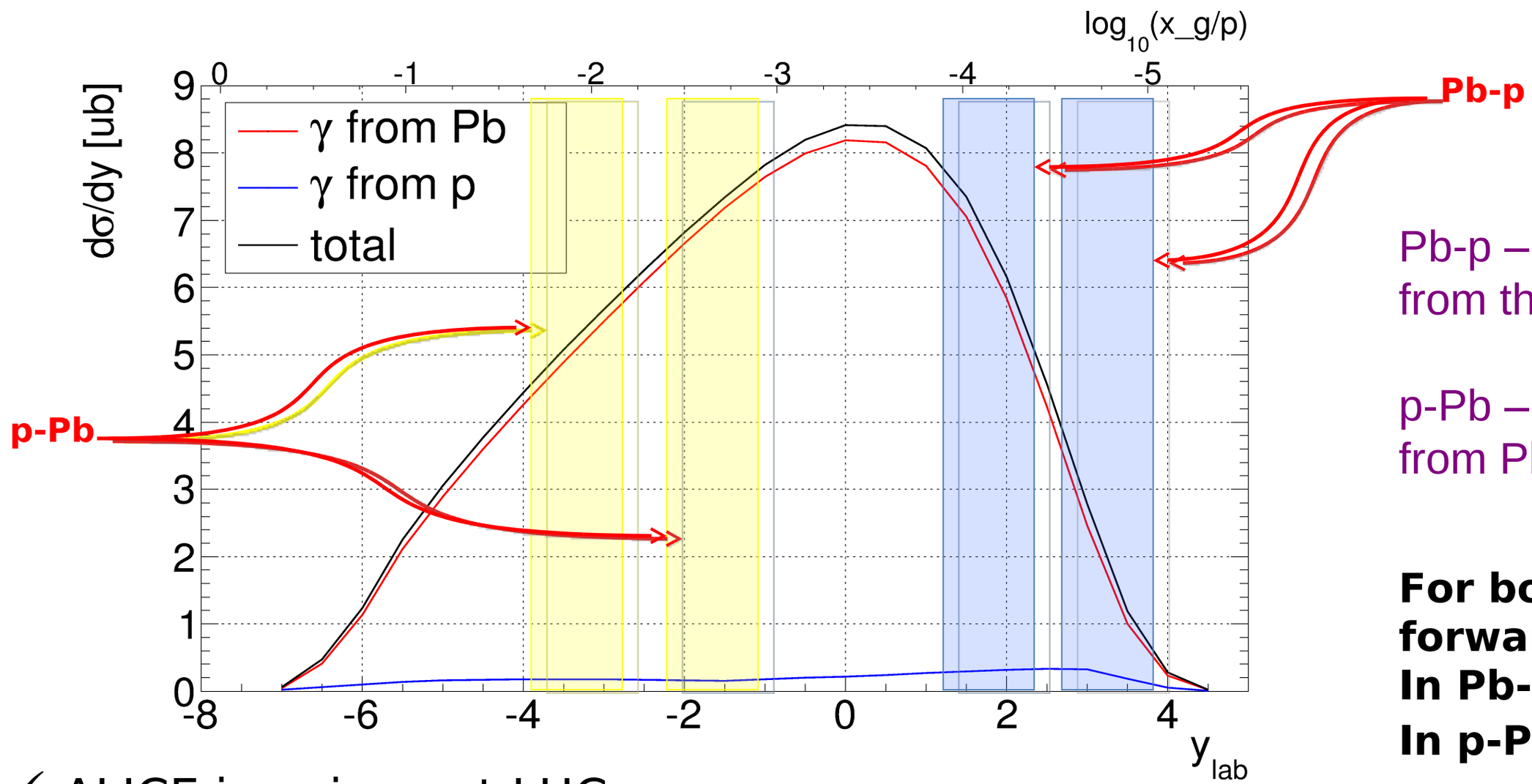
Best agreement with EPS09 shadowing

One more thing…

UPC J/ψ in pPb

Rapidity coverage using MUON

σ_{tot} (5030 GeV) = 55 μb



Pb-p – low-x gluons from the proton

p-Pb – low-x gluons from Pb

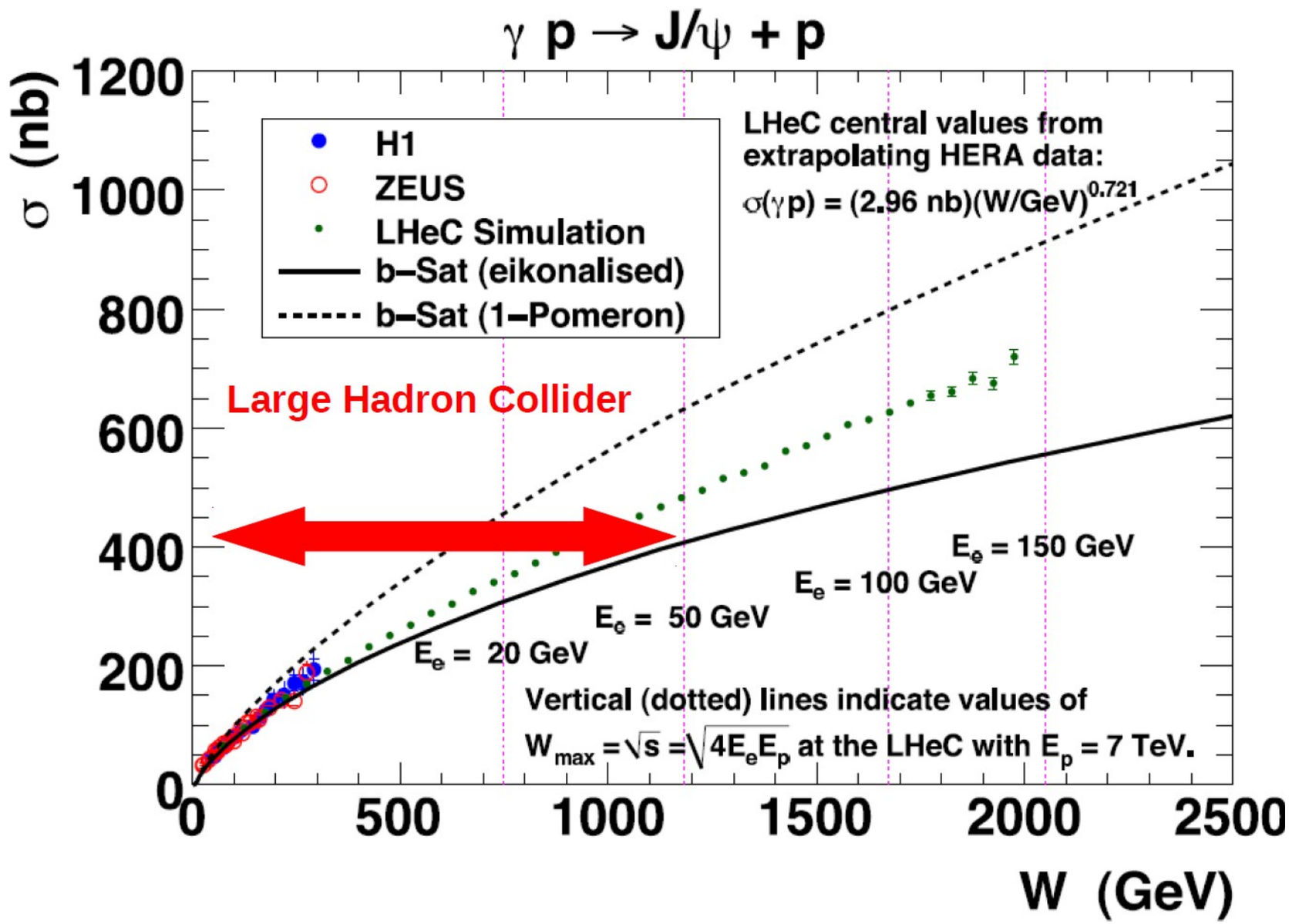
For both muons forward
In Pb-p ->x_p~10^{-5}
In p-Pb ->x_p~10^{-2}

For semi-forward

In Pb-p ->x_p~10^{-4}
In p-Pb ->x_p~10^{-3}

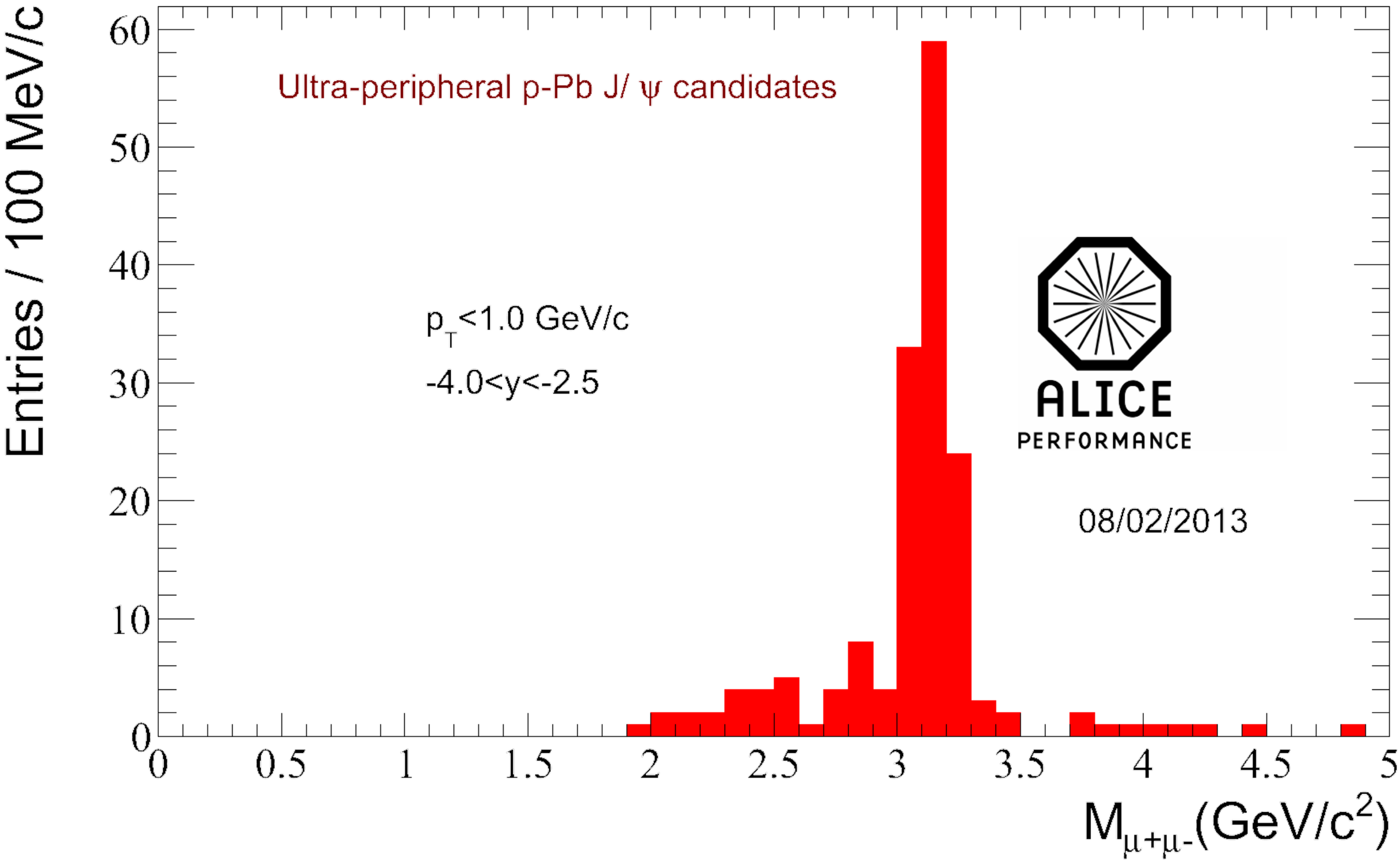
- ✓ ALICE is unique at LHC
- ✓ Unexplored kinematic regime

J/ψ photoproduction in γ+p



T. Toll and T. Ullrich
Phys. Rev. C 87, 024913 (2013)

UPC J/ψ candidates in p-Pb



Summary on UPC analyses at ALICE

UPC Pb-Pb

- Coherent J/ψ at forward rapidity → **Phys.Lett. B718 (2013) 1273-1283**
- Preliminary coherent J/ψ at mid-rapidity
- Other ongoing analyses
  - Incoherent J/ψ photoproduction
  - ρ^0 photoproduction at mid-rapidity

More studies with higher energy (√sNN = 5.5 TeV) and increased statistics

UPC Ppb and pPb

- Data collected in in early 2013