# *Photo-production of vector mesons in 2.76 TeV ultra-peripheral Pb+Pb collisions at ALICE*

**Daniel Tapia Takaki**

*On behalf of the ALICE Collaboration*

Rencontres du Viet Nam: **14th Workshop on Elastic and Diffractive Scattering** (EDS Blois Workshop)
Frontiers of QCD: From Puzzles to Discoveries
Qui Nhon, Vietnam, 15-21 December 2011

# Plan of this talk

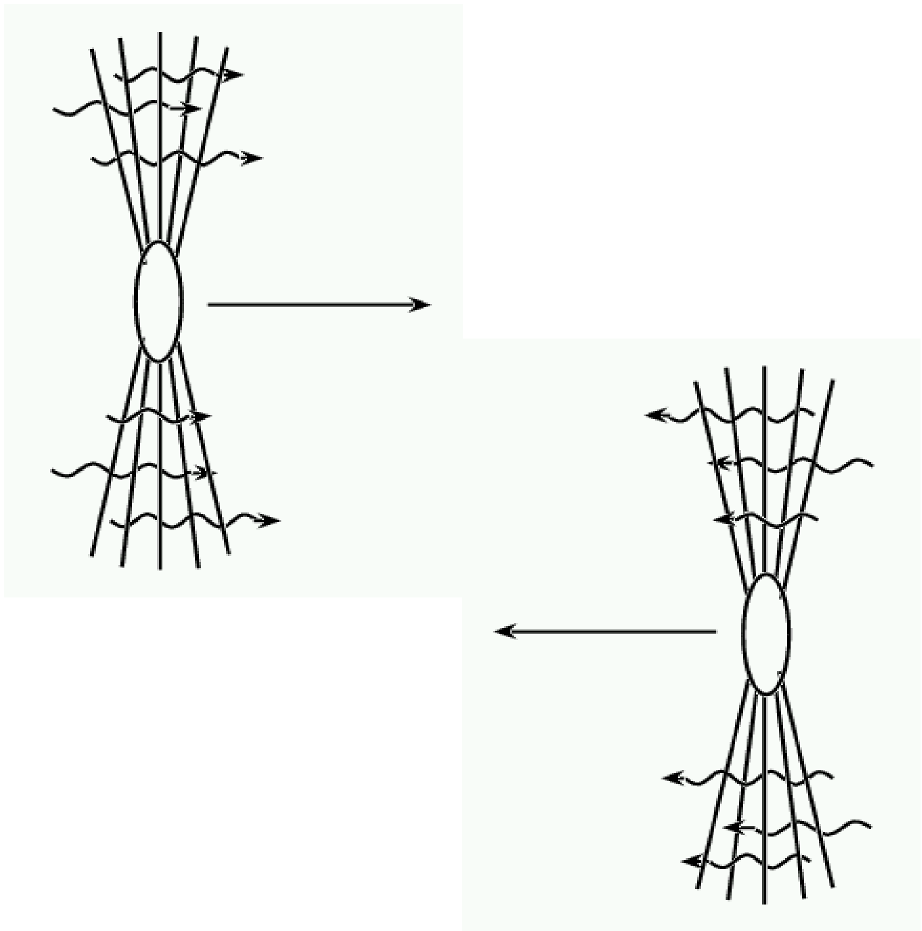
- **Ultra-Peripheral (heavy-ion) Collisions**
  - What are UPC
  - Why at the LHC
  - Why at ALICE

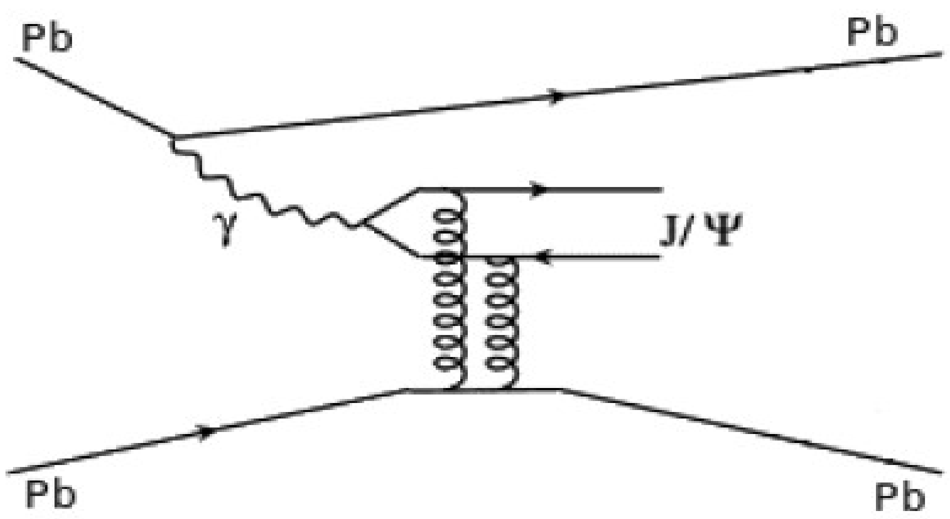
**Performance results by ALICE**

- Trigger strategy
- Evidence of vector meson photo-production in UPC
- Distinguishing different production components

**Outlook**

# Why ultra-peripheral heavy-ion collisions






Two ions (or protons) pass by each other with impact parameters b > 2R

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

In Pb+Pb collisions at 5.5 TeV

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

σ(hadronic) ~ 8b

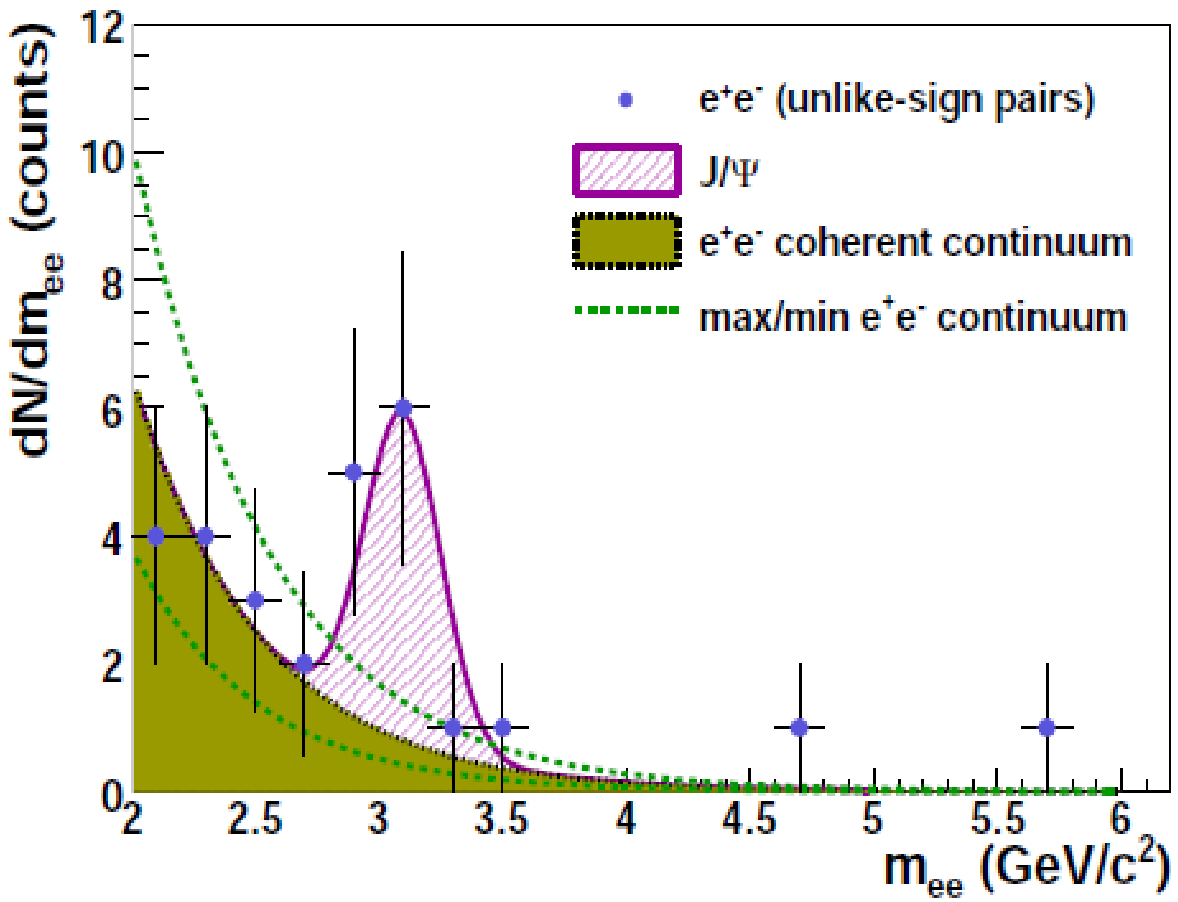
σ($e^+e^-$) ~ 281 b

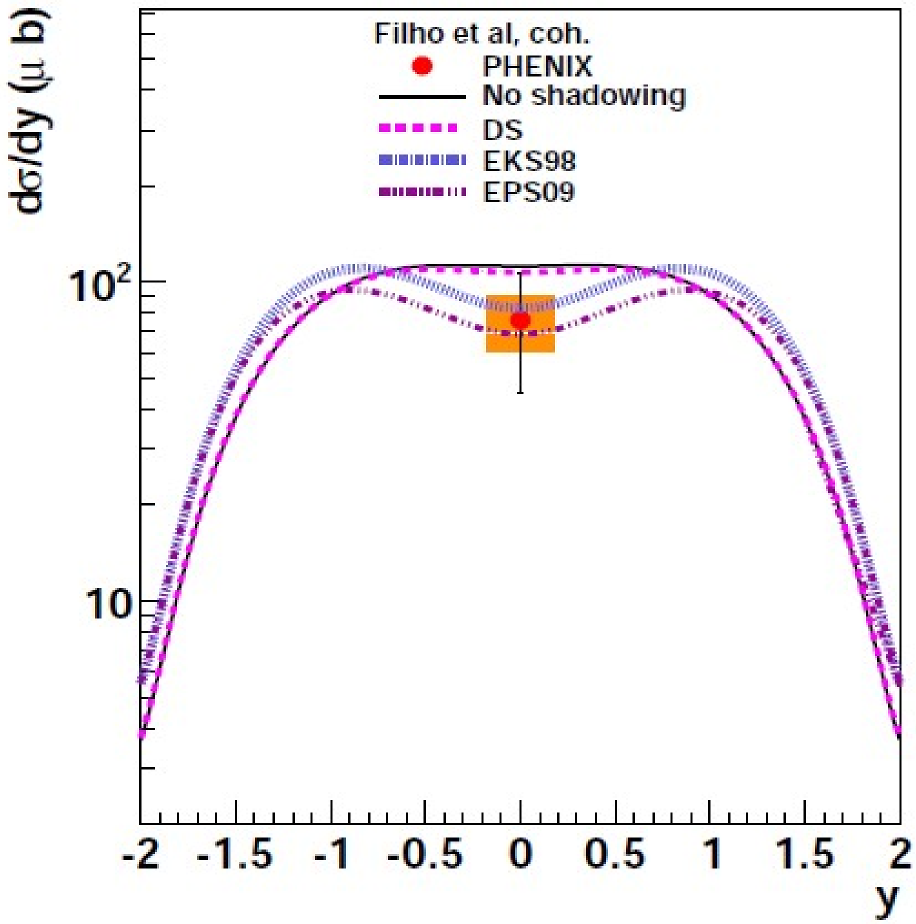
σ(EMD) ~ 226 b

Similar studies can be done for p-Pb

See talk by D. D'enterria CERN, 17/10/2011

# RHIC results by PHENIX



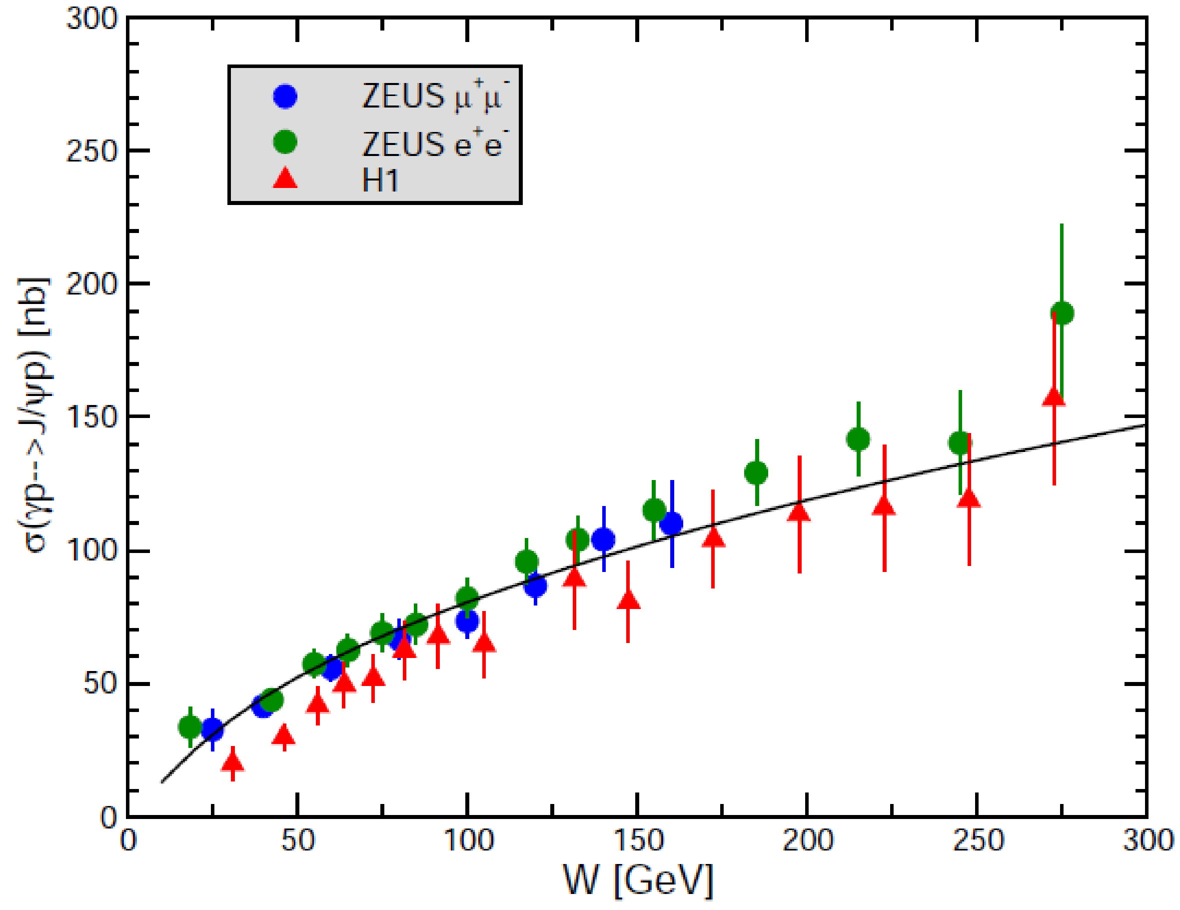

*Au+Au collisions at 200 GeV*

*PHENIX study:*

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

- **Two processes**
  - **Coherent:** $\gamma + A \rightarrow J/\psi + A$
  - **Incoherent:** $\gamma + A \rightarrow J/\psi + X$, dominated by $\gamma + N \rightarrow J/\psi + N$
- **Predicted cross sections**
  - Models differ by the way shadowing is taken into account

# Energy dependence



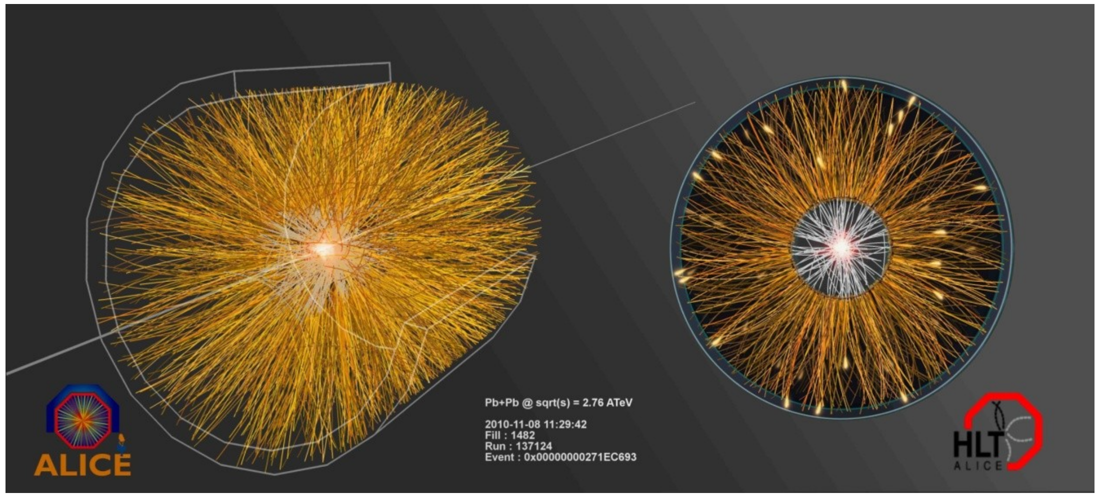

H1: A. Aktas *et al.* Eur.Phys. J.C46:585-603,2006
ZEUS:S. Chekanov et al., Nucl. Phys. B695 (2004) 3.
A. Martin et al. Phys.Lett. B 662:252-258, 2008

**A big jump in energy …**

At RHIC:
W,max ~ 34 GeV

At HERA:
W,max ~ 300 GeV

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



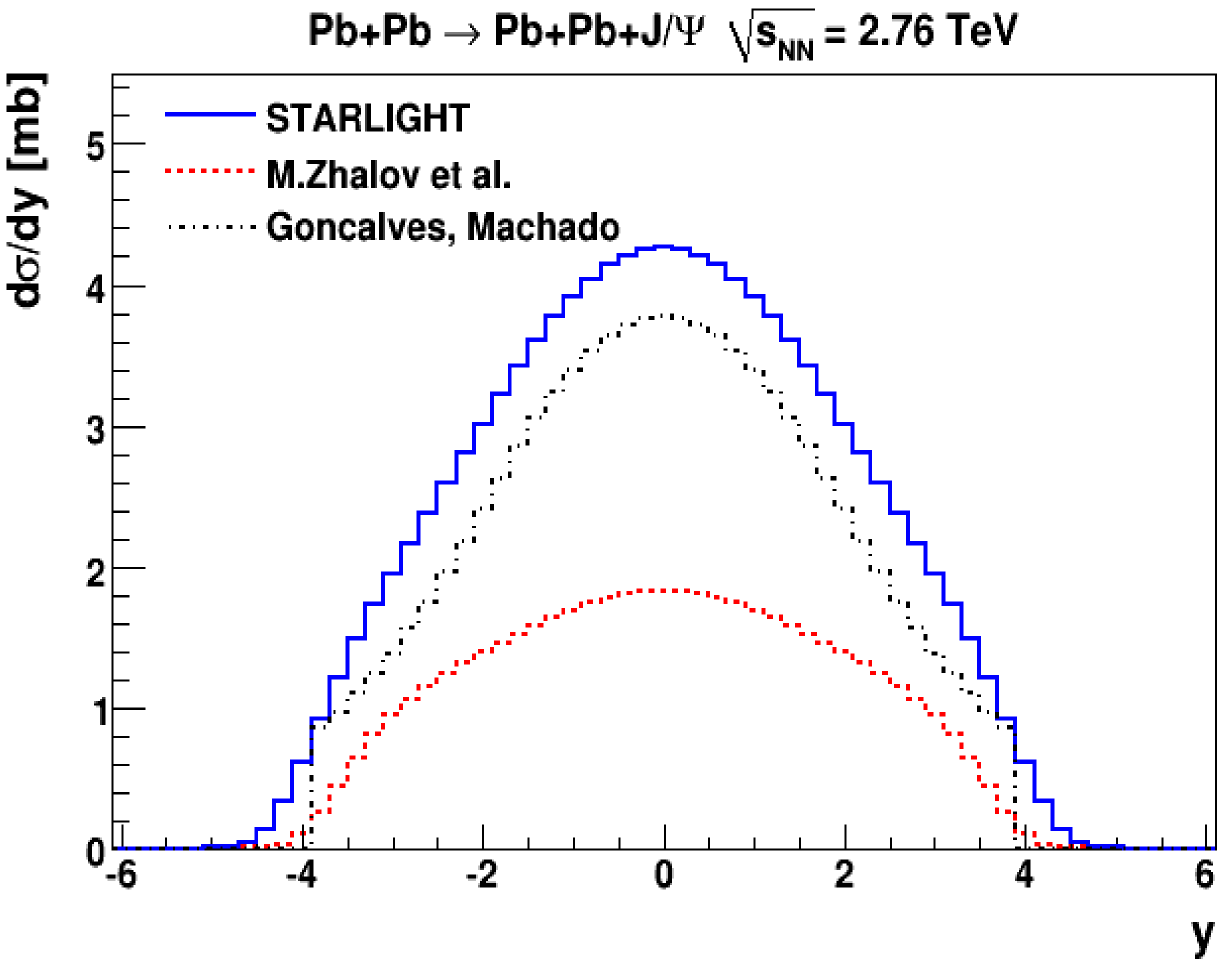
# Why J/ψ photoproduction at LHC

Probe the gluon distribution of the nuclei

Total J/ψ cross section: 23 mb (STARLIGHT) *v* 10.3 mb Strikman, Zhalov, et al.

$$\frac{d\sigma_{\gamma T \to J/\psi T}(t=0)}{dt} = \frac{16\Gamma_{ee}\pi^3}{3\alpha_{em}M^5_{J/\psi}}\left[\alpha_s(\mu^2)xG_T(x,\mu^2)\right]^2$$

At leading order perturbative QCD, it depends quadratically on the gluon distribution

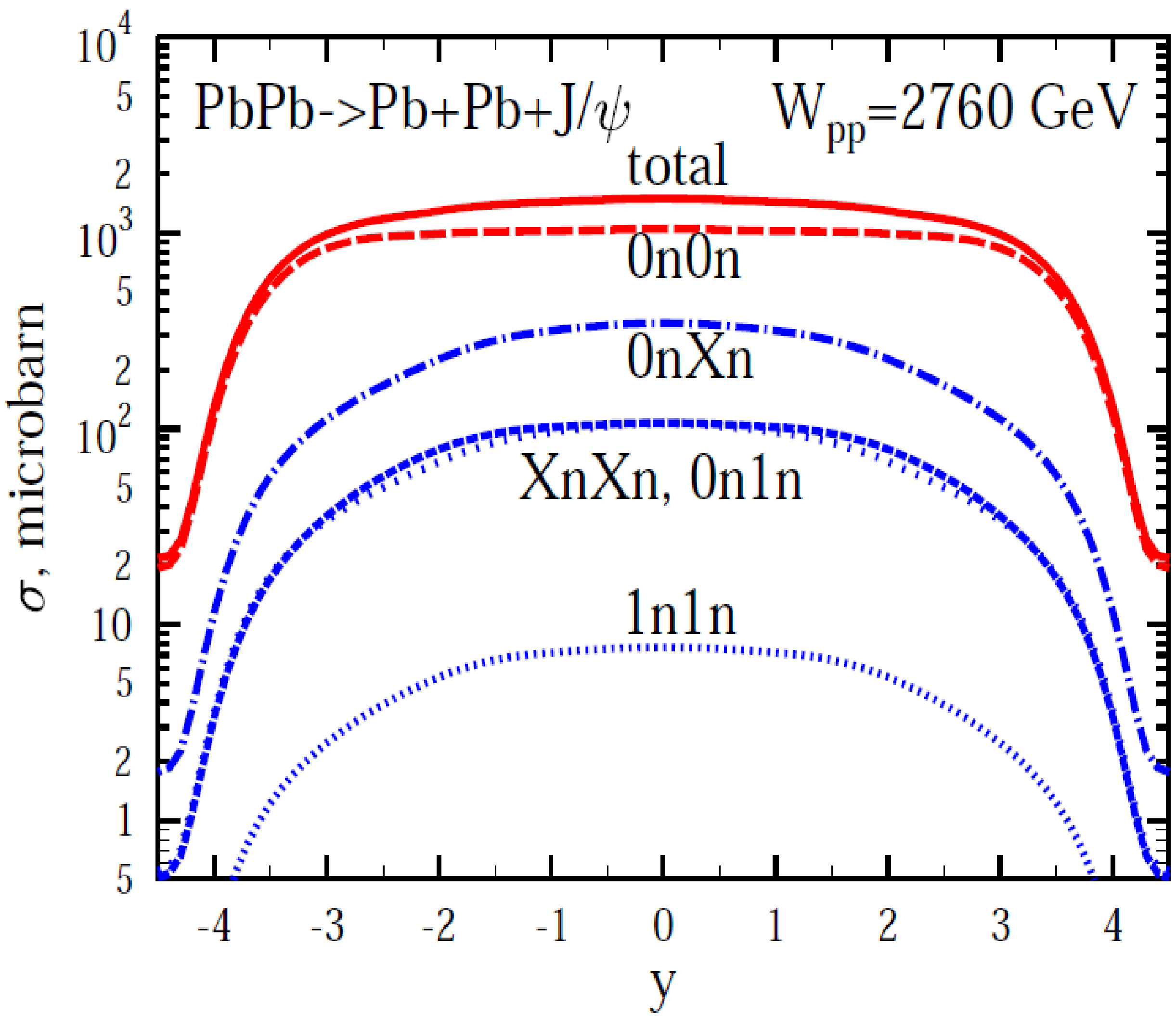


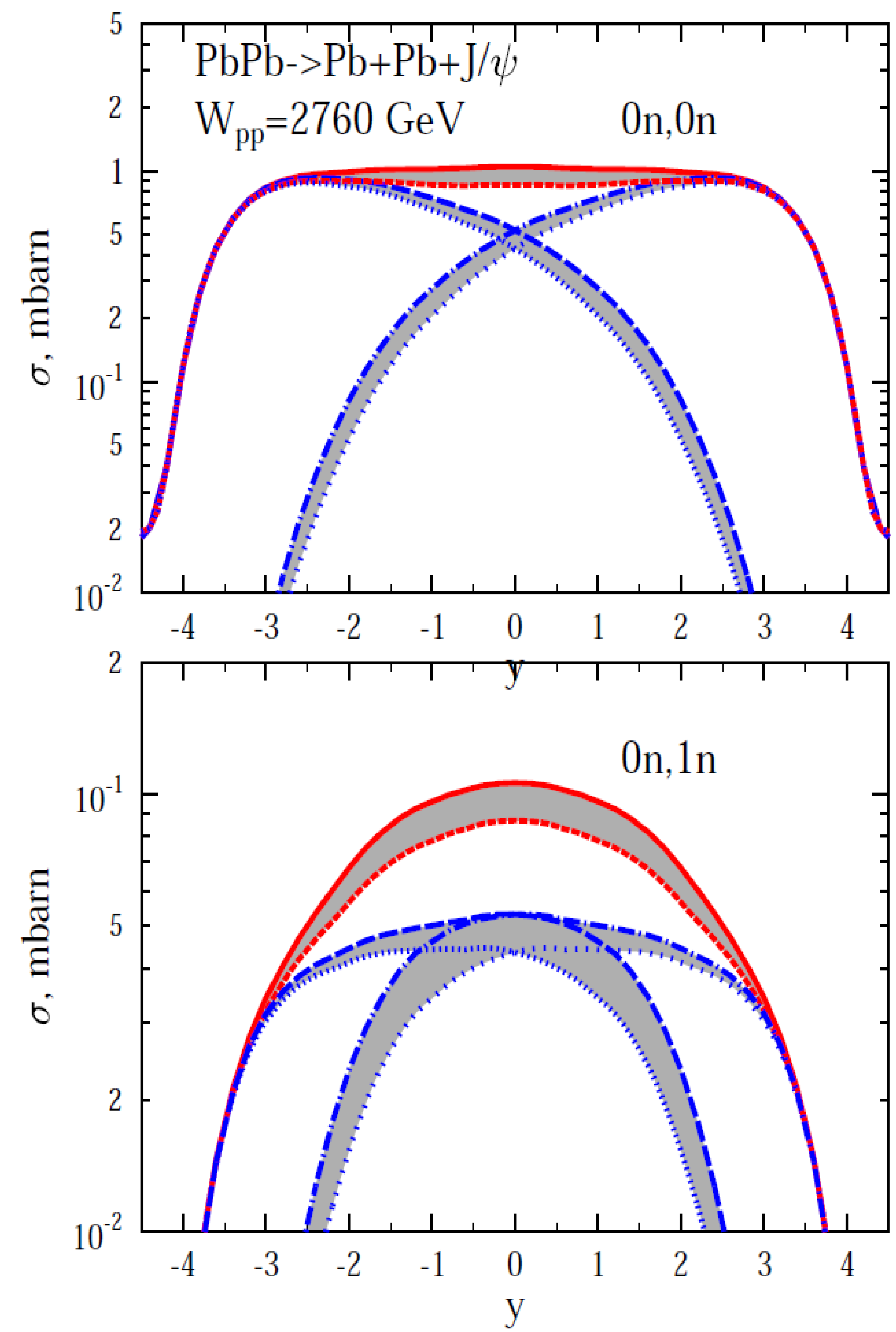

Should provide a measure of the nuclear gluon shadowing

*STARLIGHT: S.R.Klein, J.Nystrand*
*Phys. Rev. C 60 (1999) 014903.*
*L. Frankfurt, M. Strikman, M. Zhalov*
*Phys. Lett. B 626 (2005) 72.*
*V.P. Goncalves, M.V.T. Machado*
*Phys. Rev. C 84 (2011) 011902.*

# 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;

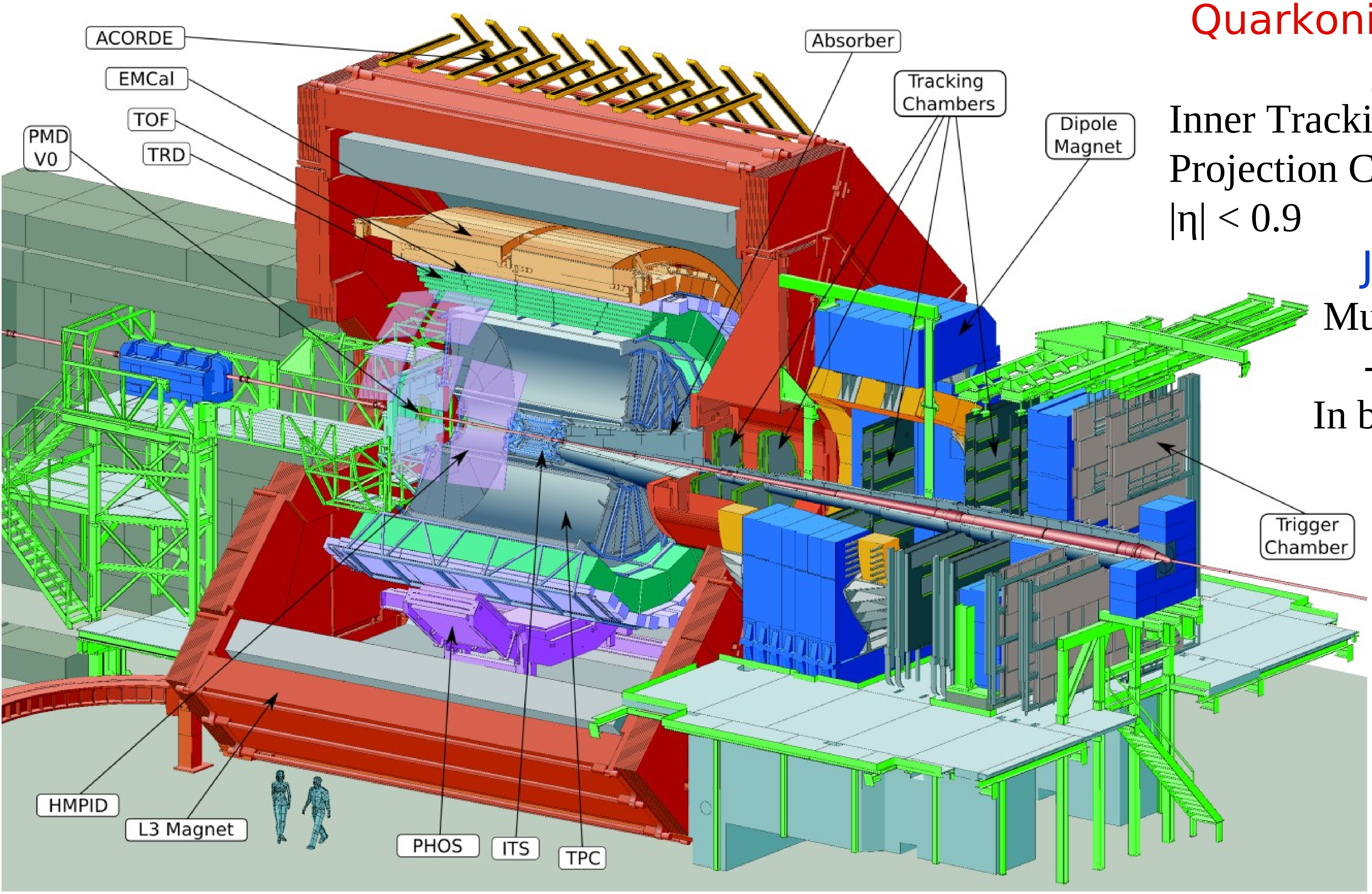
**0n1n and 0nXn:** excitation and decay of one of the ions, and

**0n0n:** no neutron emission

***V. Rebyakova, M. Strikman and M. Zhalov***
**ArXiv:1109.0737, Sept 2011**

Shaded area: Uncertainty on nuclear gluon shadowing

# Quarkonia measurements at ALICE




Quarkonia measurements

$J/\psi \rightarrow e^+e^-$

Inner Tracking (ITS), Time Projection Chamber (TPC)
$|\eta| < 0.9$

$J/\psi \rightarrow \mu^+\mu^-$

Muon Spectrometer
$-4 < \eta < -2.5$

In both case, down to zero $p_T$

# 2010 analysis

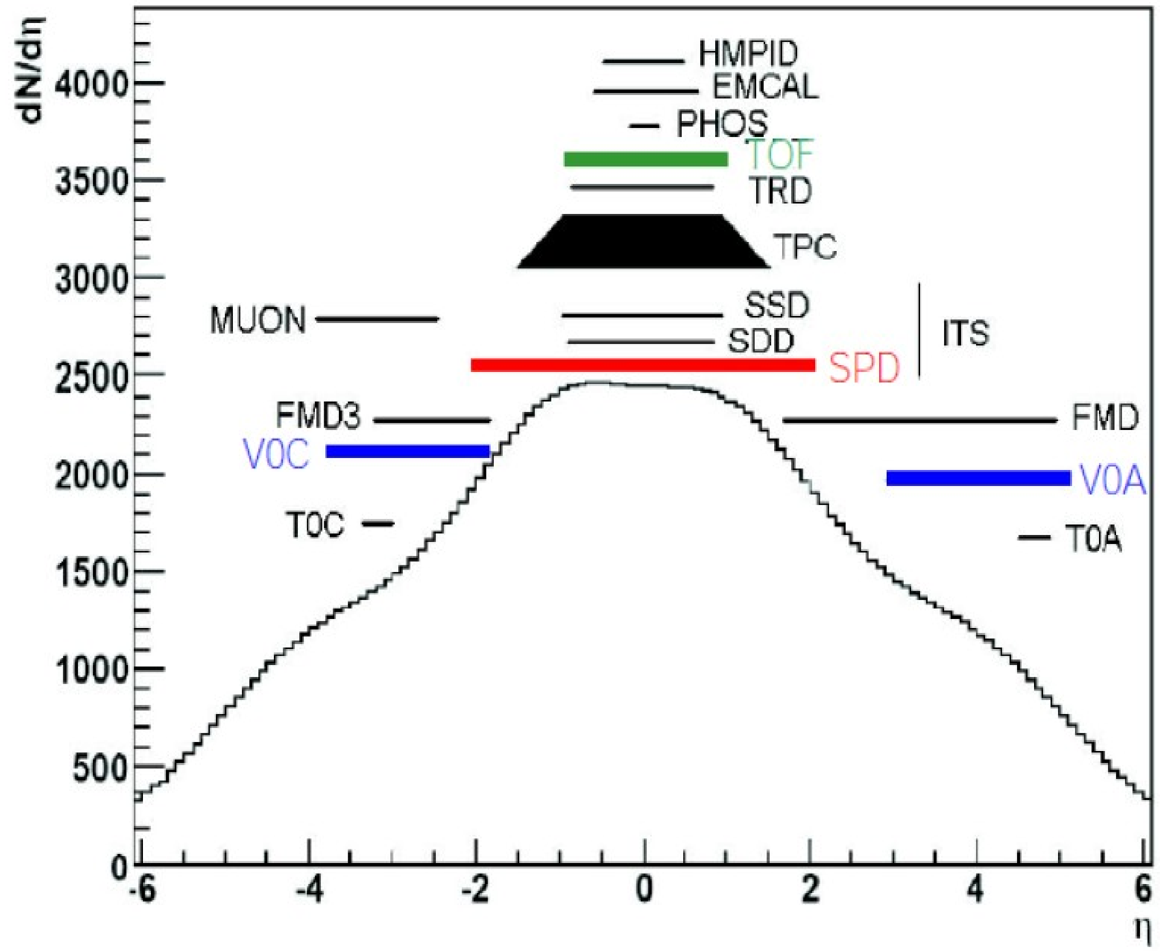
# ALICE triggers in 2010 Pb running

***3 UPC triggers were active in 2010:***

**1.** TOF-only trigger >= 2 hits in TOF

**2.** TOF + SPD + VZERO trigger:
>= 2 hits in TOF + >= 2 hits in SPD
+ veto on both VZERO detectors

**3.** Muon arm + VZERO trigger:
at least one muon candidate +
veto on VZERO-A

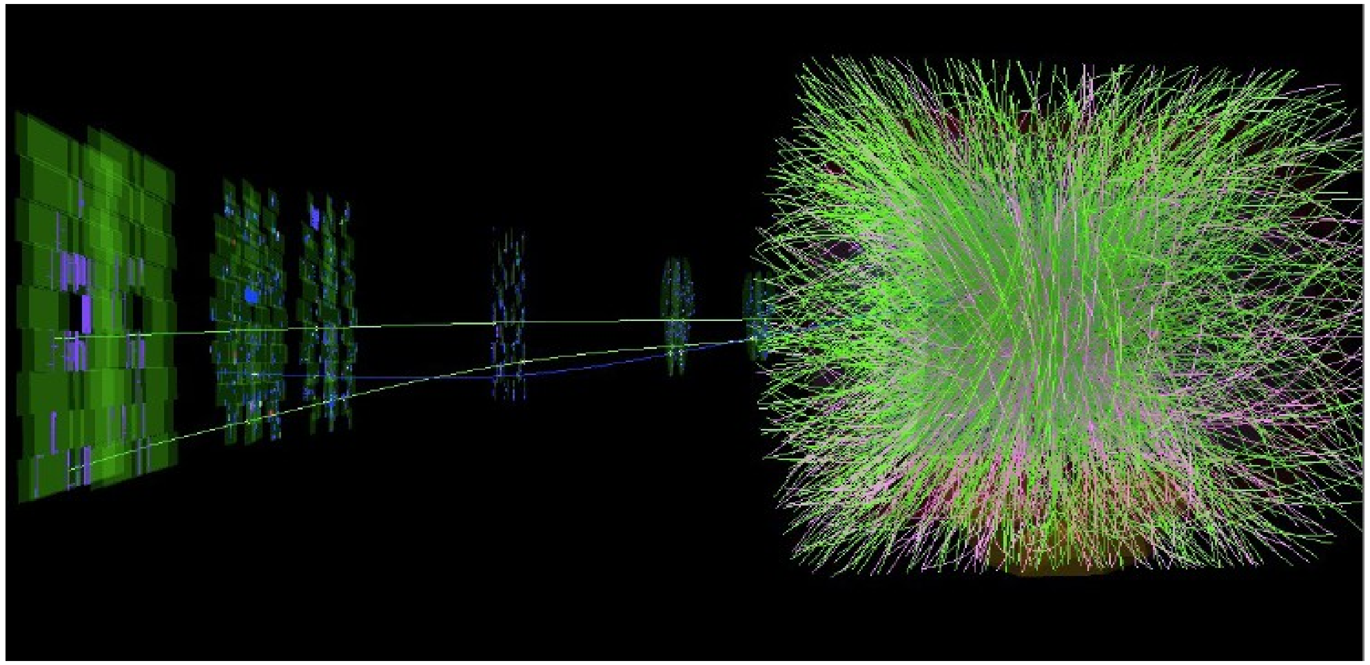



Exclusivity by vetoing on ALICE detectors at several rapidities
~ 8 units of rapidity → both online and offline selections

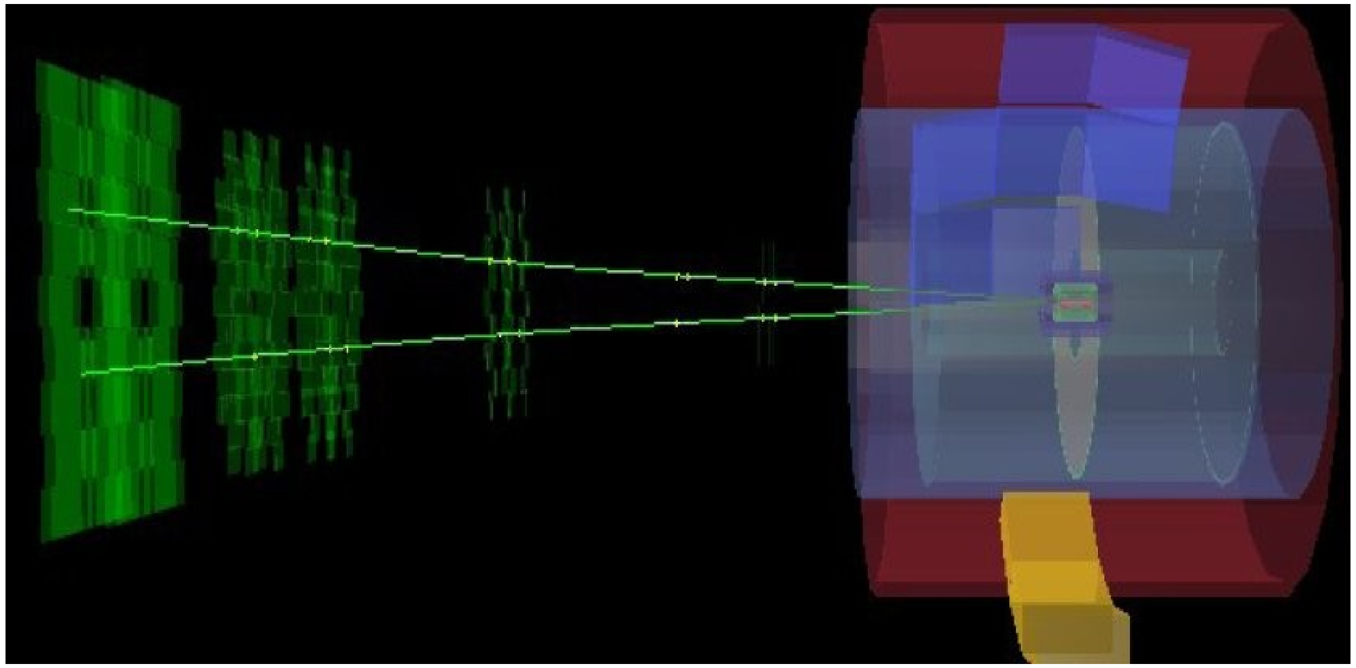
The UPC triggers sensitive to a variety of final states:

$\gamma\gamma \to e^+e^-$, $\gamma\gamma \to \mu^+\mu^-$, $\gamma\gamma \to f_2(1270) \to \pi^+\pi^-$,
$\gamma IP \to J/\Psi \to e^+e^-$ etc.

# Exclusive J/ψ candidates at ALICE



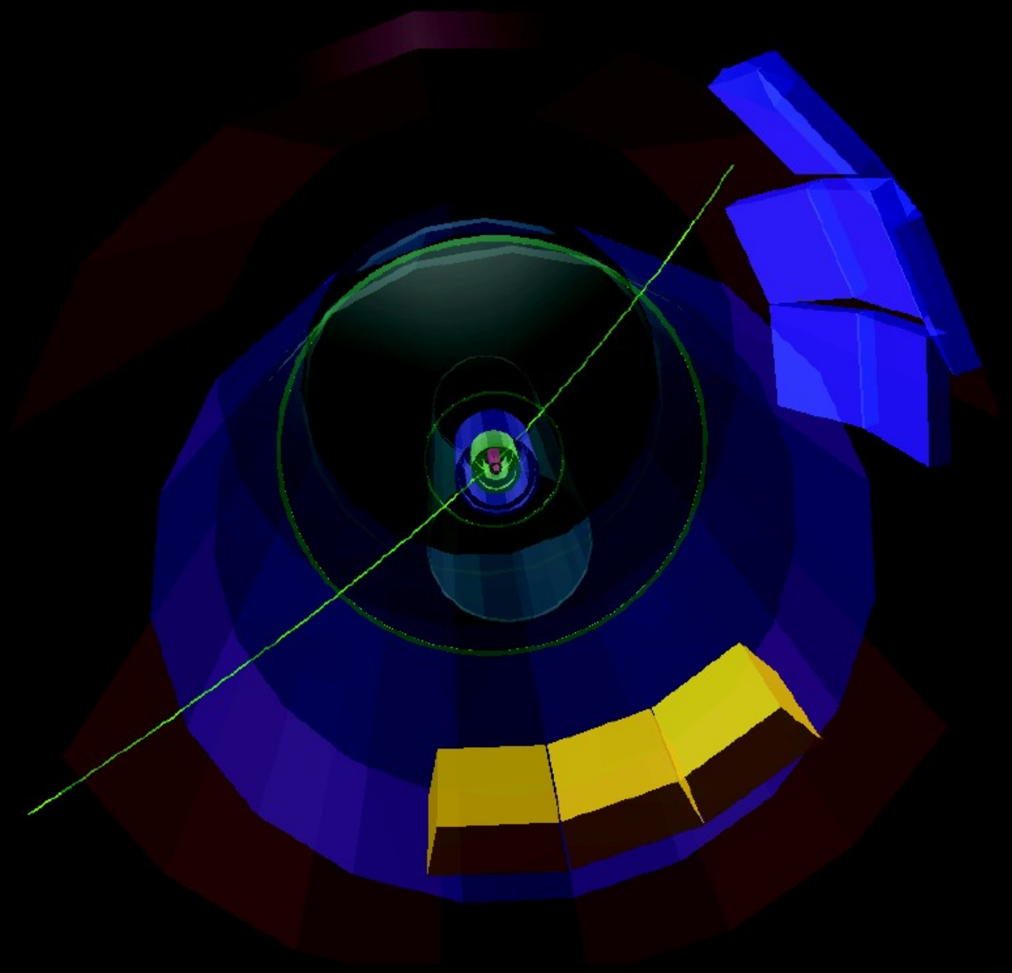
**Inclusive reaction in Pb+Pb collisions at 2.76 TeV**

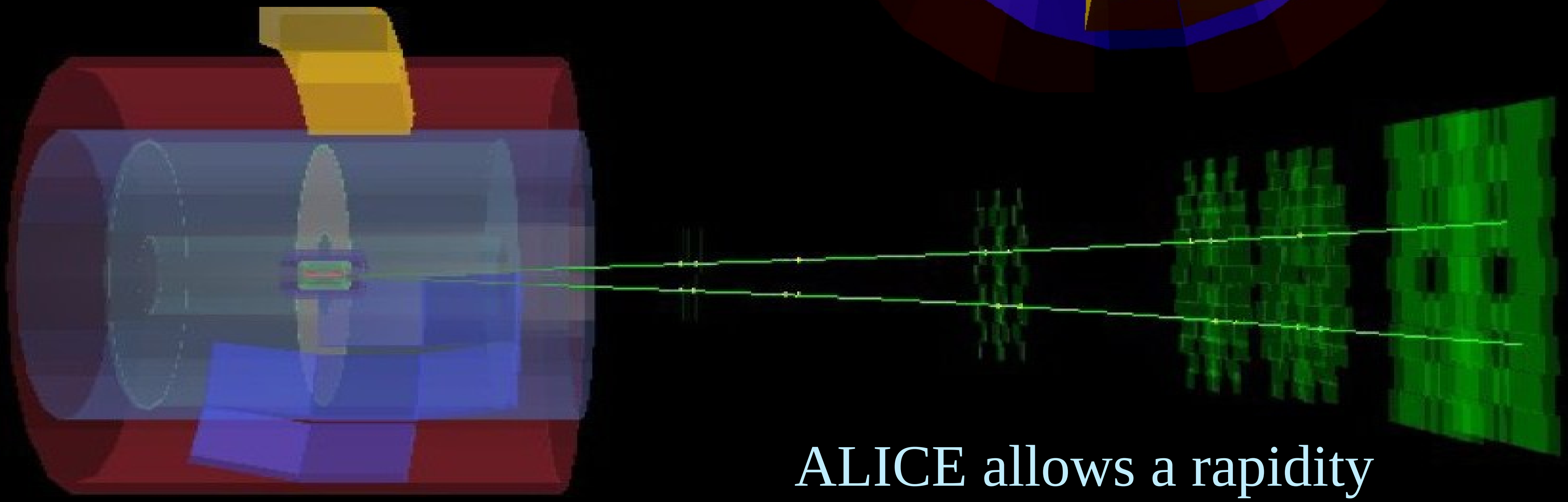


**Exclusive reaction in UPC Pb+Pb collisions at 2.76 TeV**

# Exclusive J/ψ production

**Two tracks in otherwise an empty detector**

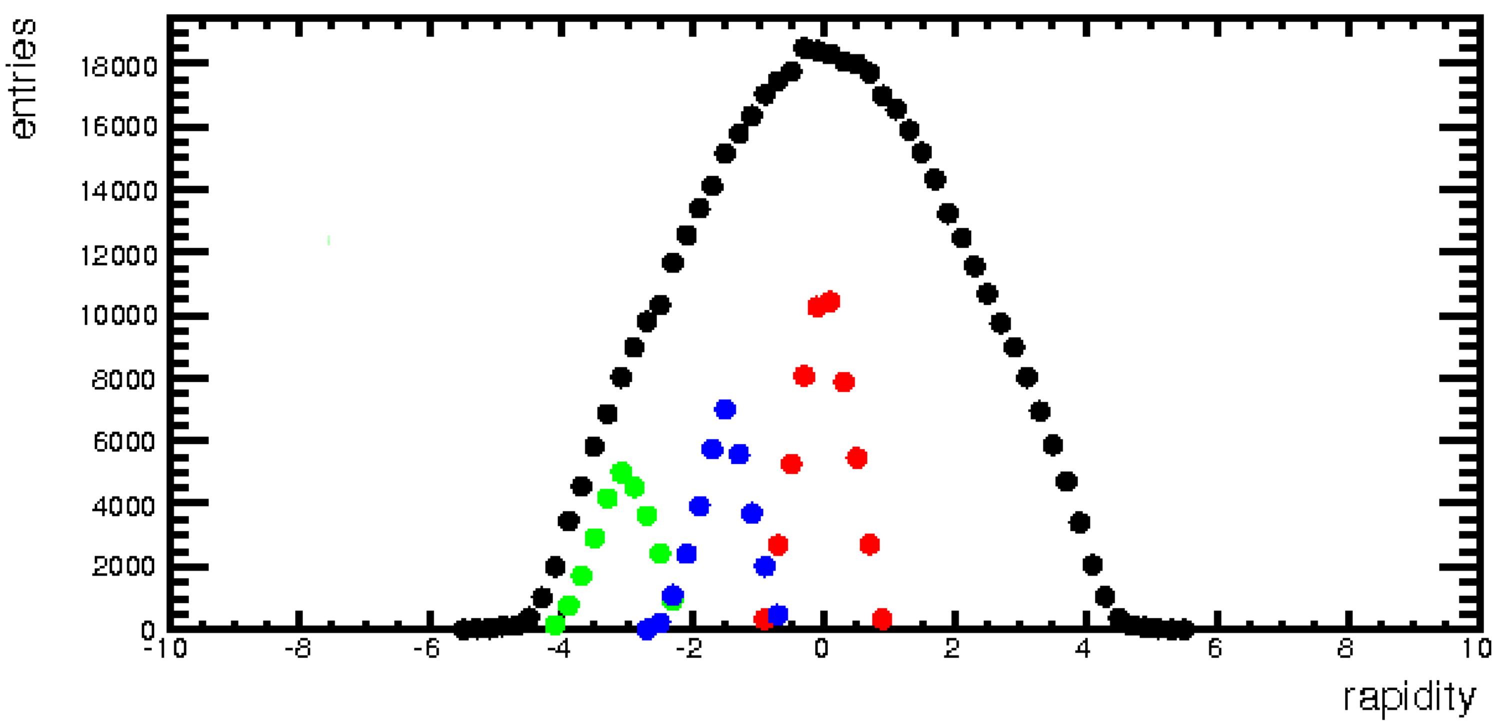




ALICE allows a rapidity dependence study!

# Rapidity dependence

**STARLIGHT simulations for coherent J/ψ**



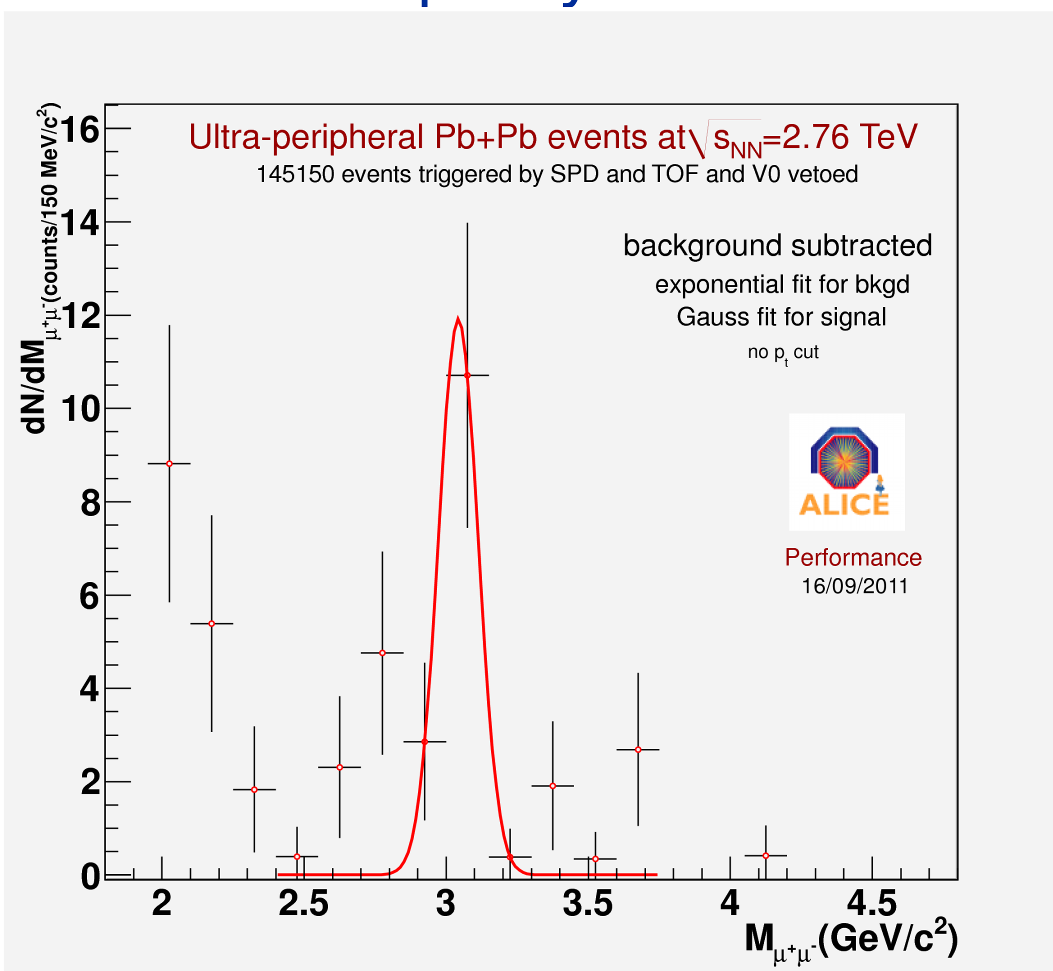

**Three J/ψ analyses are possible at ALICE:**

1. **Both dileptons (muons or electrons) at central rapidity, -0.9<y<0.9**
2. **Both muons at forward rapidity, -4.0 <y< -2.5**
3. **One forward muon and the other at mid-rapidity**

J/ψ can be reconstructed down to zero $P_t$

# Performance results – 2010 Pb+Pb data

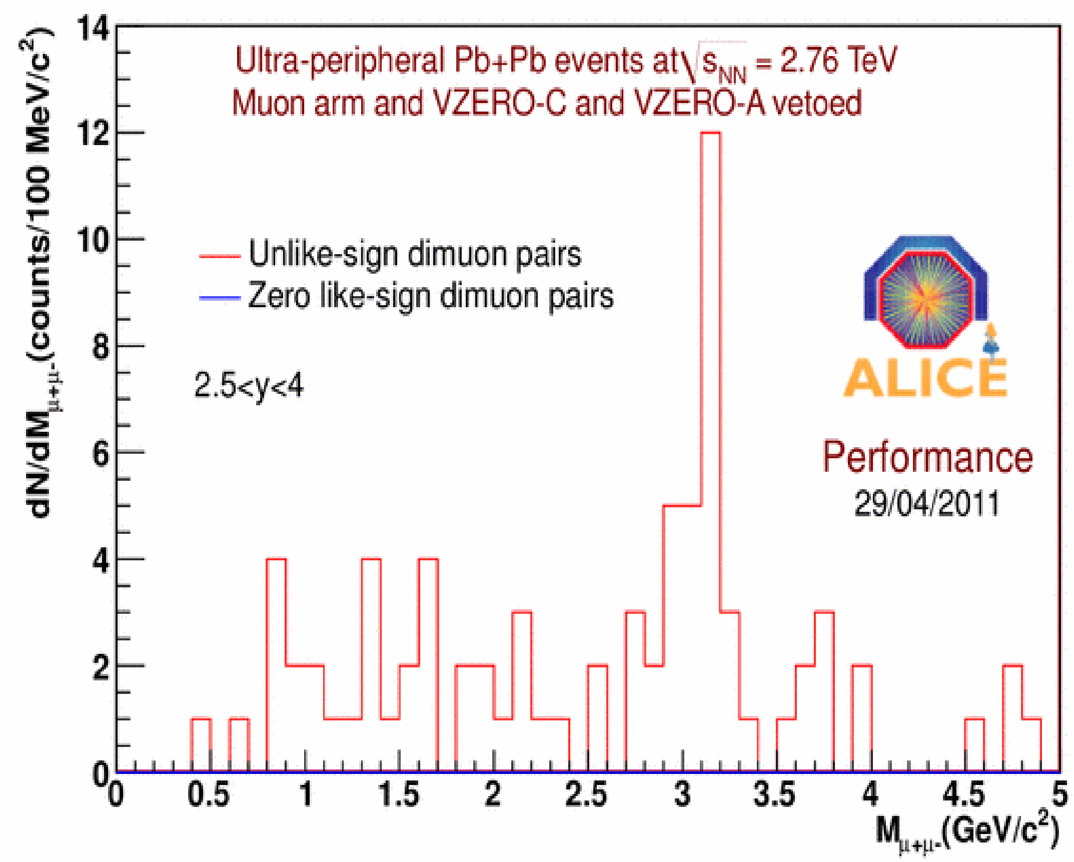
## Central rapidity




After background subtraction
No particle ID was applied

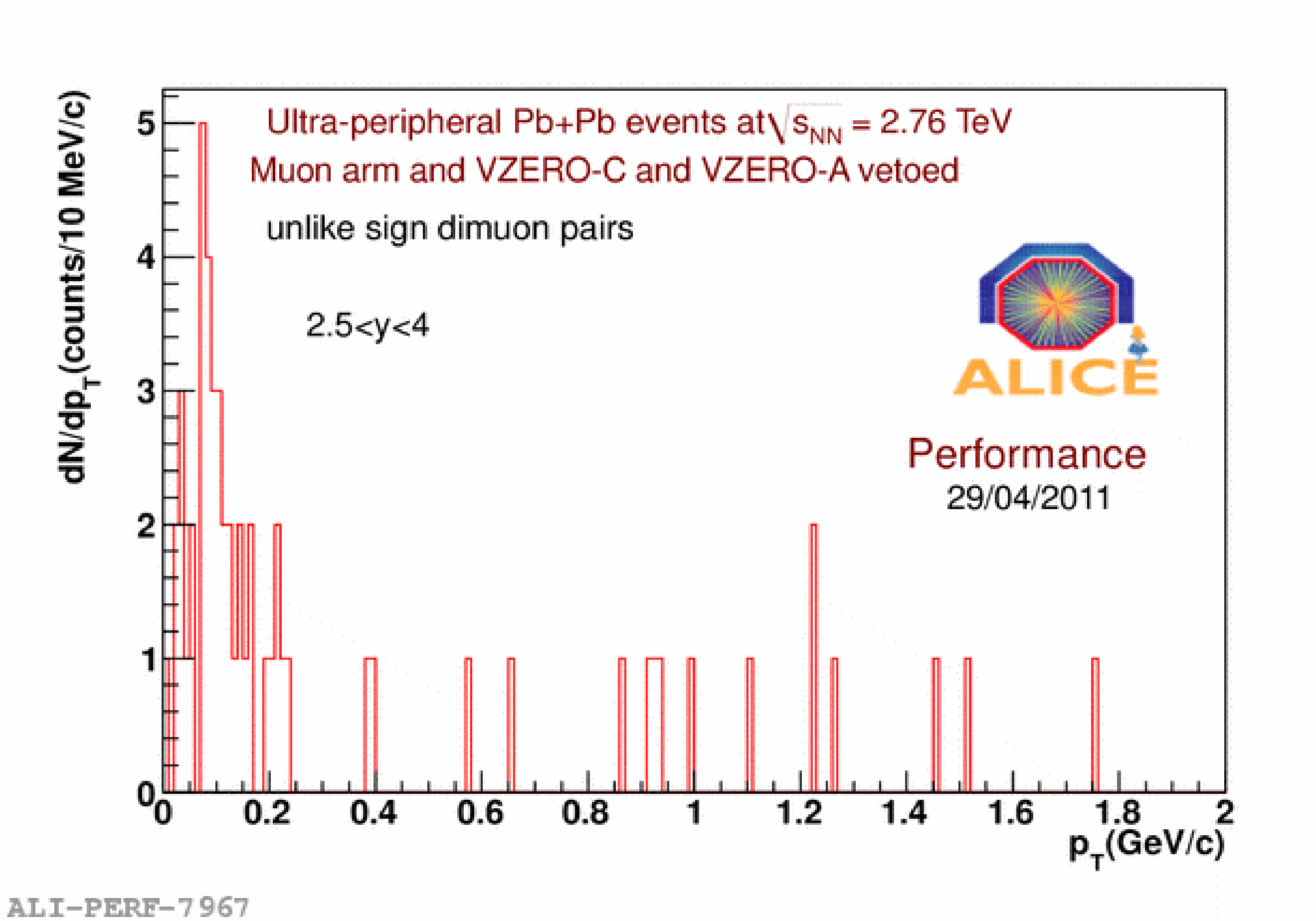
## Forward rapidity

trigger on Muon in coincidence with VZERO-C,
but VZERO-A is vetoed
offline veto on TPC, ITS, FMD

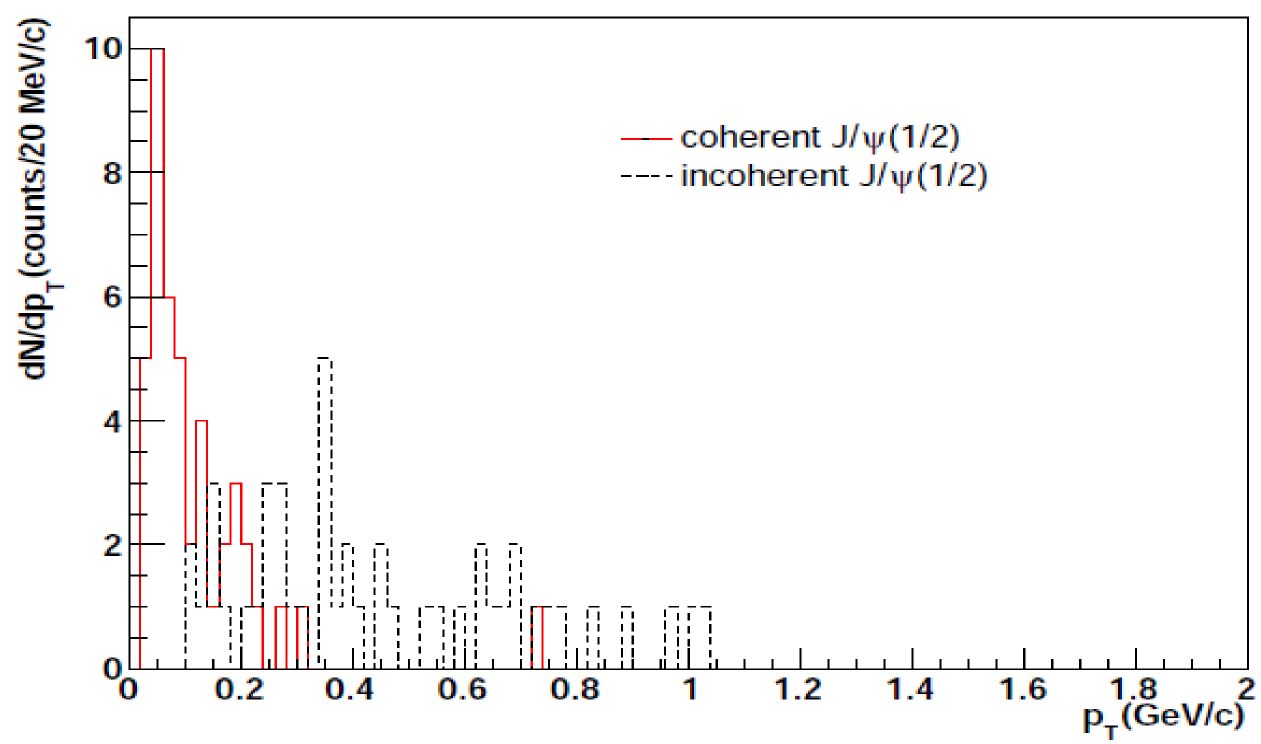


# Coherent production?!

STARLIGHT gives for coherent σ = 23 mb, and σ = 11 mb for incoherent. So, roughly 2/3 for coherent and 1/3 for incoherent. The rapidity distribution is wider for the incoherent part, so in the muon arm the fraction of incoherent should be a bit larger.




STARLIGHT: full simulations

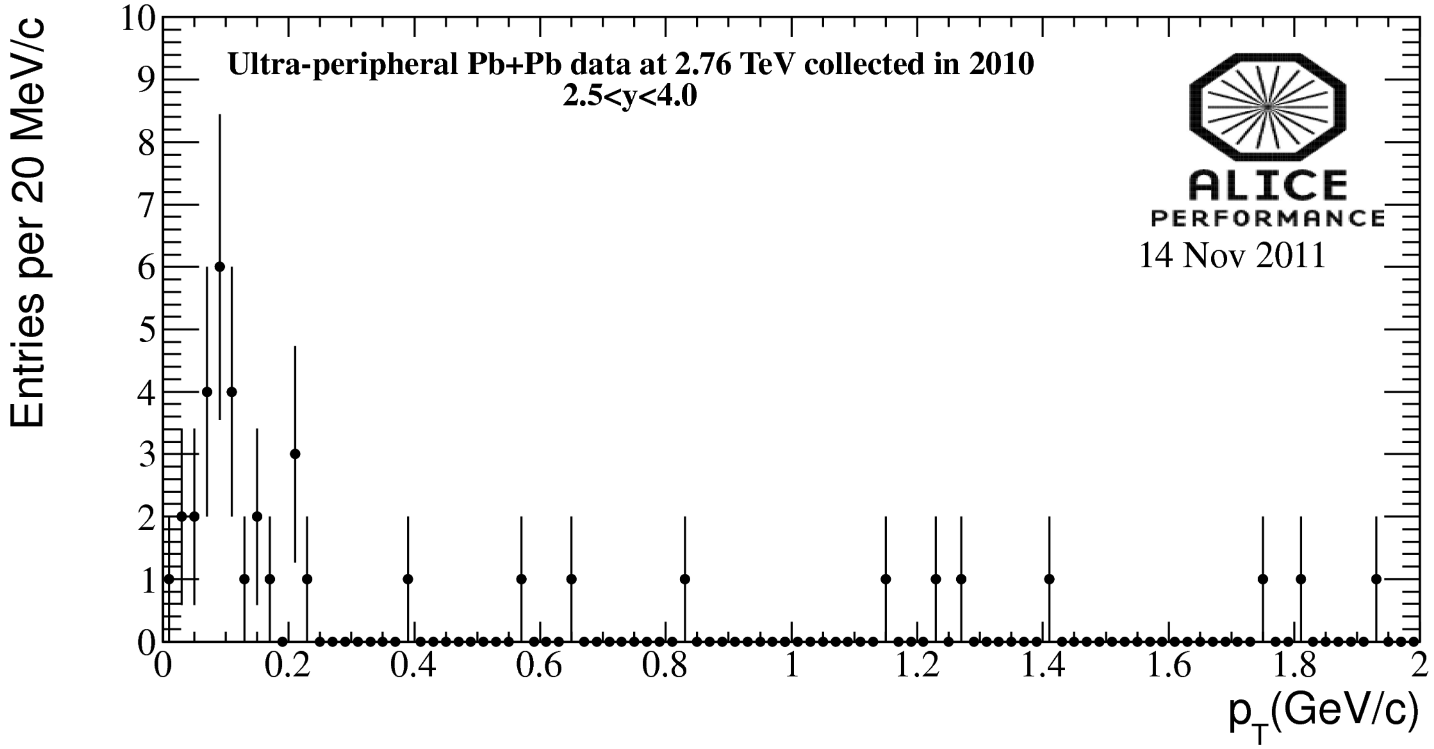



*Strikman, Tverskoy, Zhalov (PLB 626 (2005) 72)* found that 85% of the incoherent J/ψ should have a signal in one of the ZDCs. For coherent J/ψ it is only about 28%

To be confirmed by ZDC analysis ...

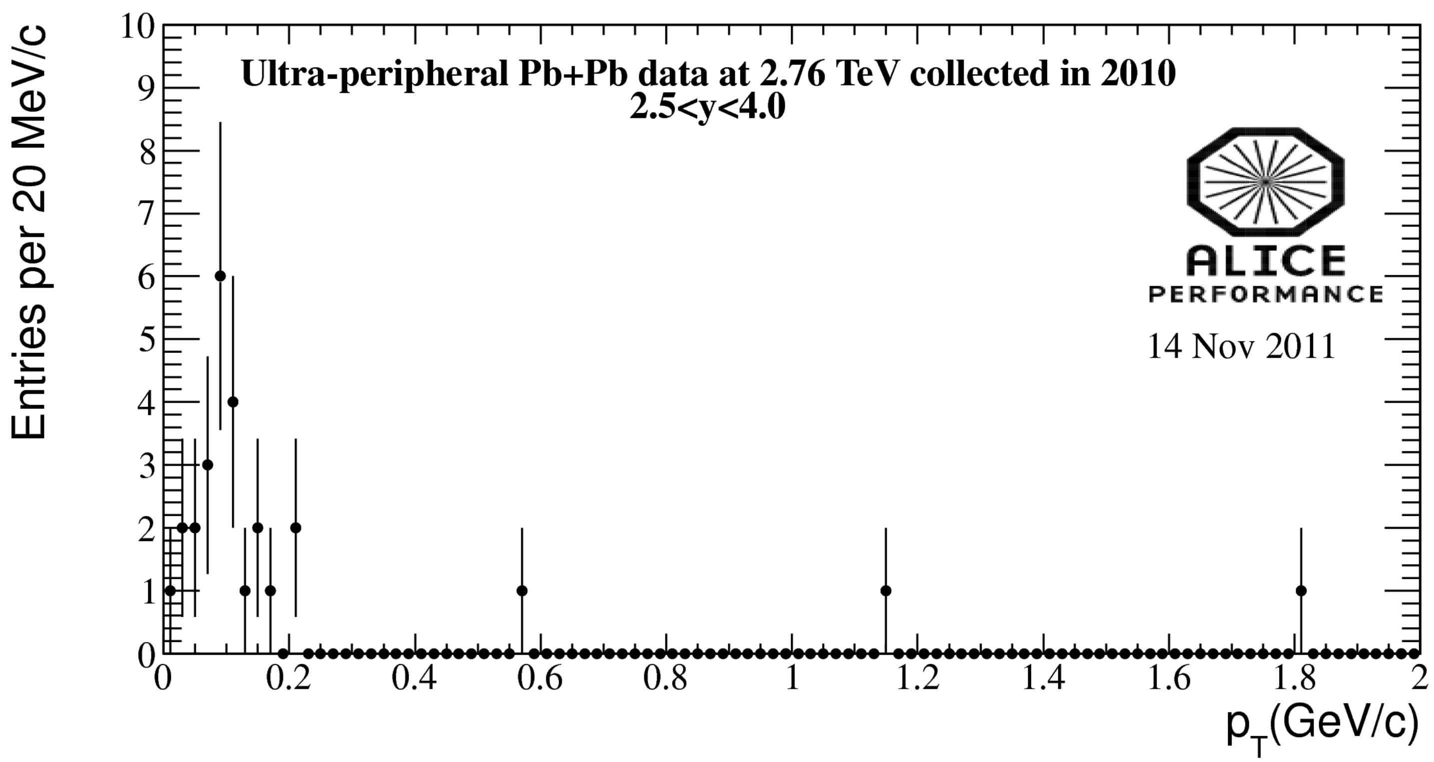
# Neutron emission – 2010 Pb+Pb data

**Coherent + incoherent production**




**ALICE can distinguish between coherent and incoherent components**

**Coherent-enhanced sample**




**Obtained after requiring no neutron emission measured by ZDC**

# 2011 analysis

# ALICE triggers in 2011 Pb running

2 ***UPC triggers were active in 2011:***

**Central rapidity:** TOF trigger requiring a hit multiplicity to be between 2 and 6, vetoing signals from both VZERO detectors, and with at least 2 hits in SPD. In addition, at least one of the triggered tracks by TOF has the angular correlation $150 < \Delta\phi < 180$ degrees

~8 M central barrel UPC triggers collected in 2011

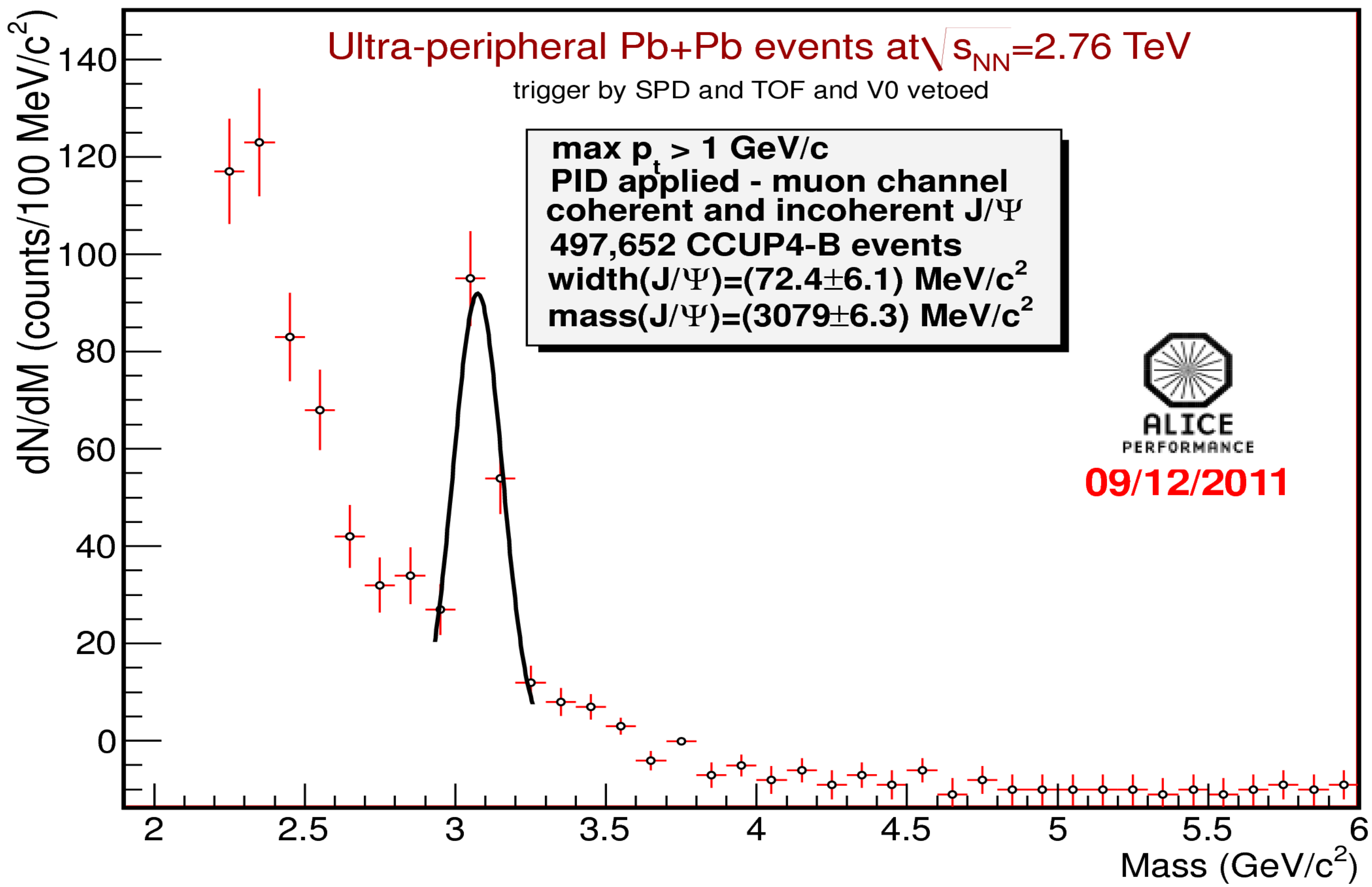
**Forward rapidity:** Same as in 2010. Muon arm + VZERO trigger: at least one muon candidate + veto on VZERO-A.

~ 3.4 M muon UPC triggers collected in 2011

**Collected statistics:**

**an order of magnitude larger than in 2010**

# J/ψ at central rapidity – 2011 Pb+Pb data

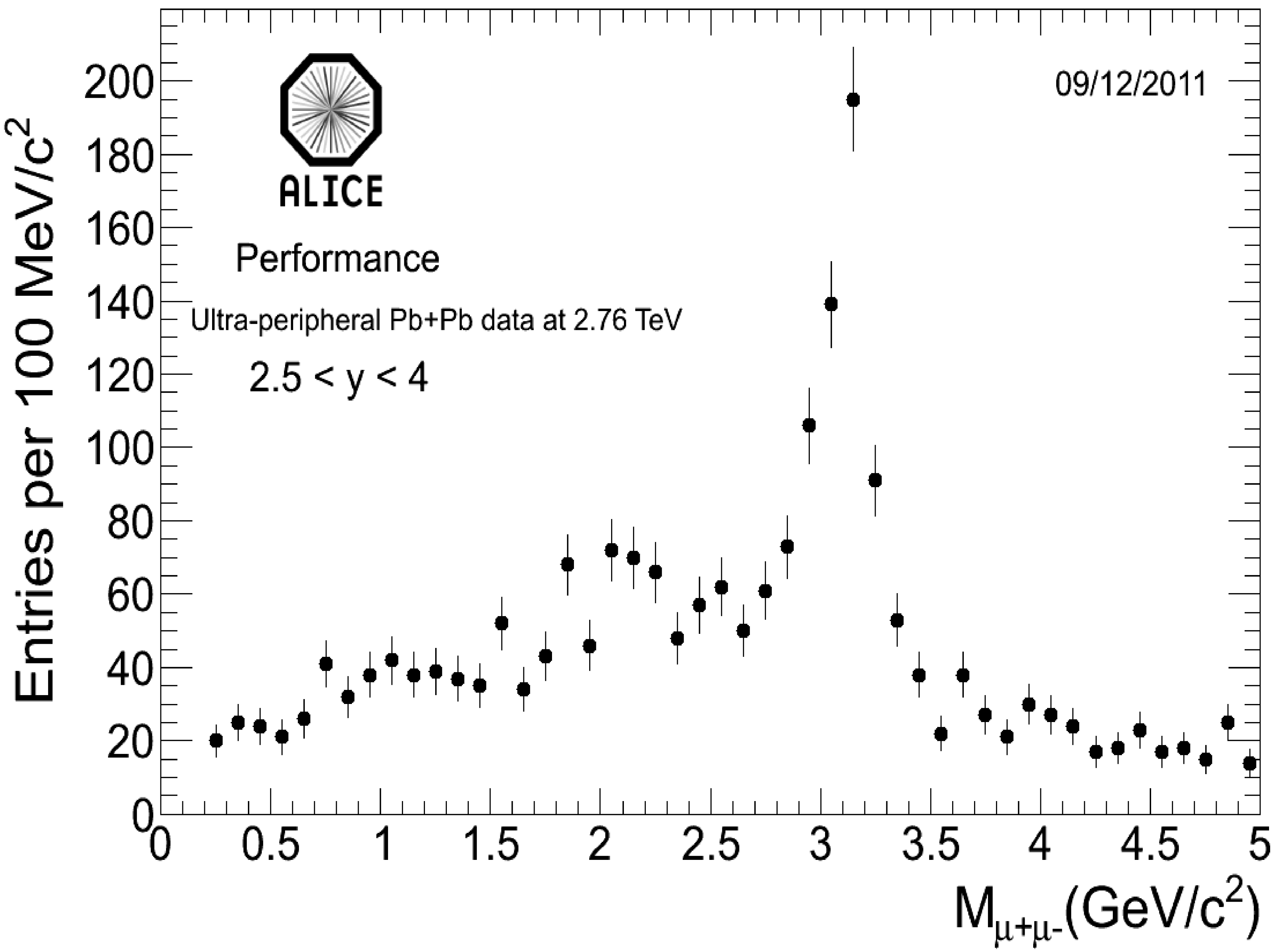



Particle ID by TPC, for muons

Gaussian fit

At least one track has a $P_t$ larger than 1 GeV/*c*

# J/ψ at forward rapidity – 2011 Pb+Pb data




**MUON in coincidence with VZERO-C, but VZERO-A vetoed**

For the moment, no veto at central rapidity

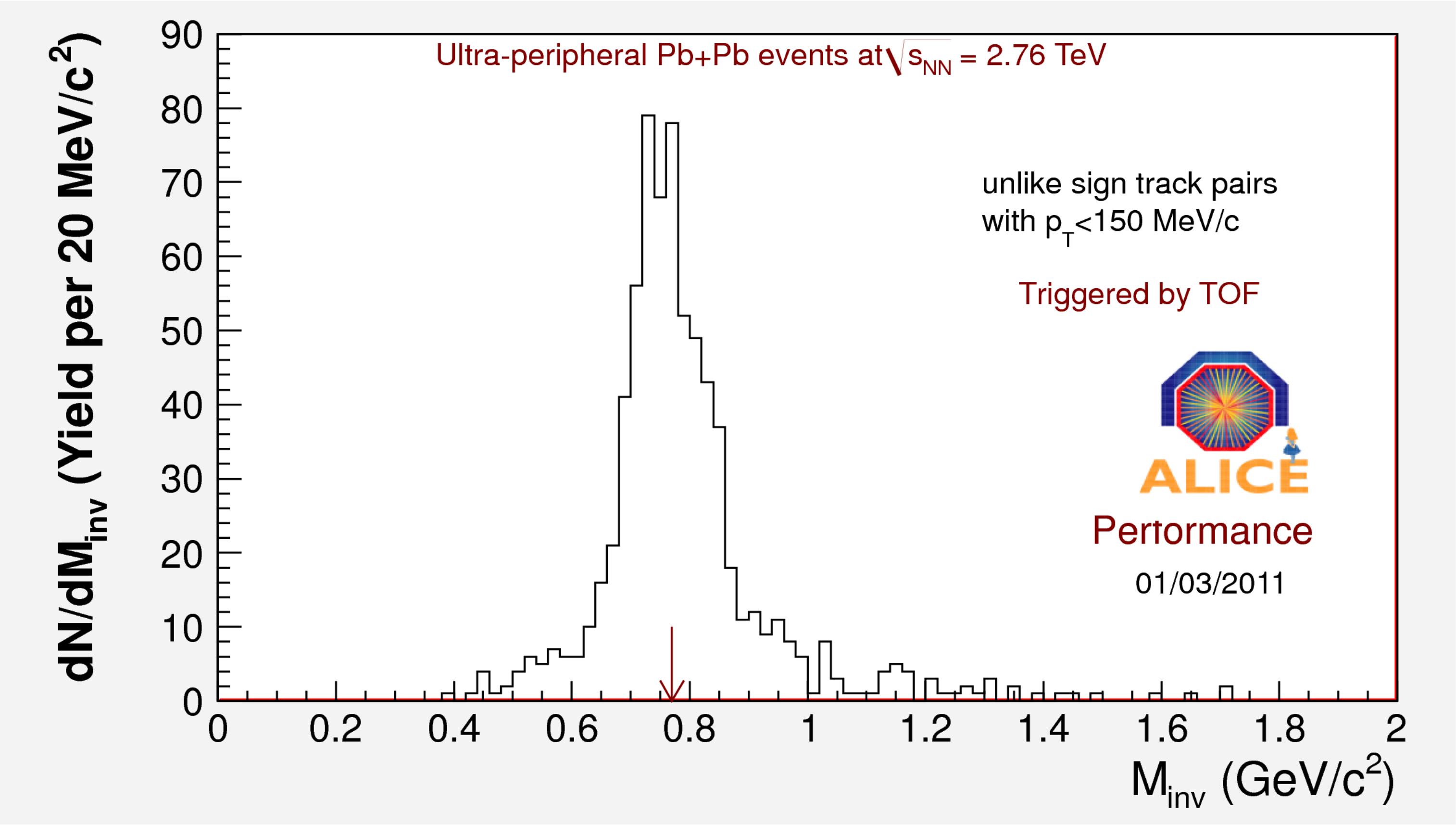
Veto activity on VZERO-C outside muon acceptance
Exactly two good tracks in the muon acceptance
Both tracks match the trigger
At least one track has a $P_t >$ 1 GeV/*c*

# One more thing ...

# $\rho^0$ production at central rapidity – 2010 data

Exclusive photoproduction of $\rho^0 \rightarrow \pi^+\pi^-$ is the dominant channel
Total cross section: 3.9 b.
S.R. Klein, J. Nystrand Phys. Rev. C 60 (1999) 014903

ALICE Acceptance: ≈ 9%.



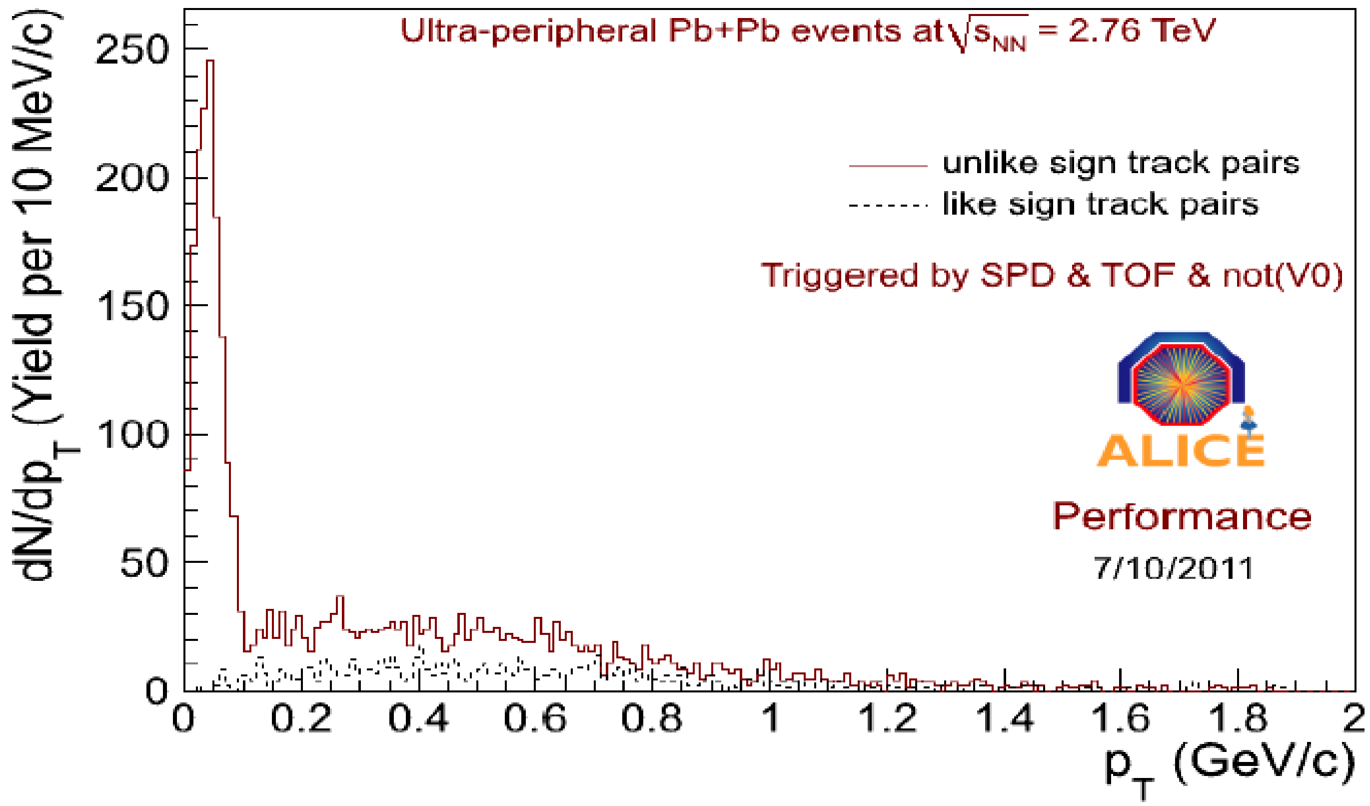

Uncorrected $M_{inv}$ distribution of events in the low $p_T$ peak indicates $\rho^0$ production.

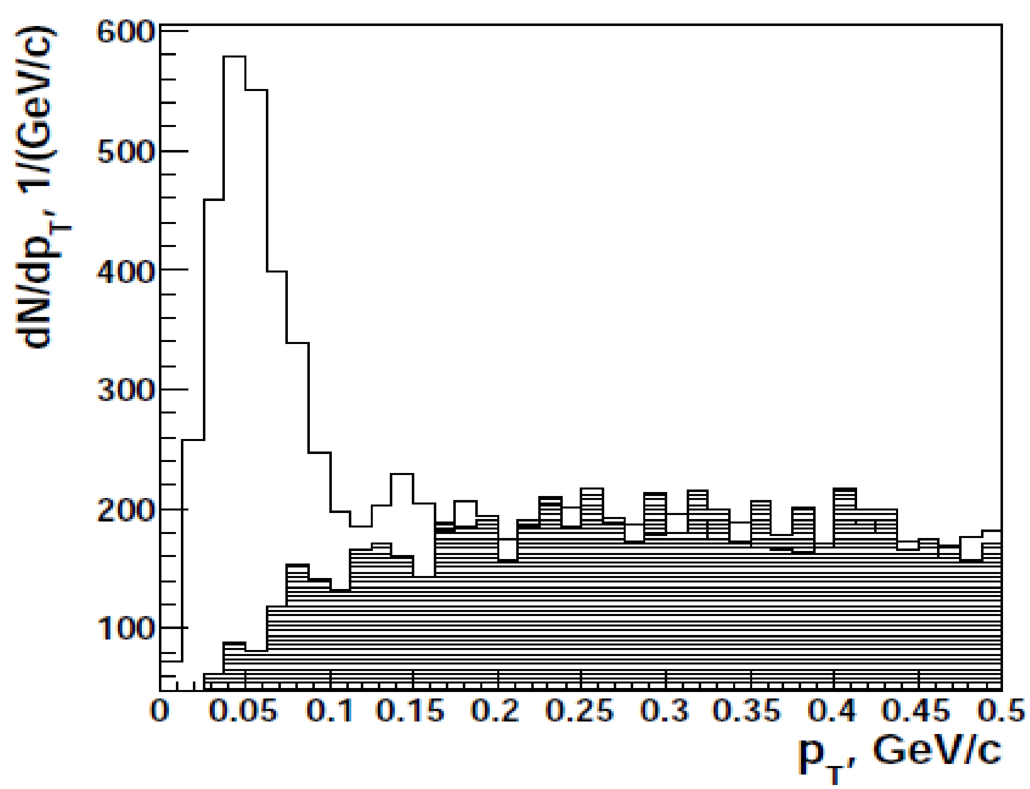
Both invariant mass and transverse momentum are described by STARLIGHT simulations

Mid-rapidity ↔ γ-nucleon CM energy
$W_{\gamma p}$ = 45 GeV

Earlier measurements with fixed target electron beams $W_{\gamma p}$ = 3 – 4 GeV and by STAR at RHIC $W_{\gamma p}$ = 12.5 GeV.

# $\rho^0$ photo-production at central rapidity – 2010 data

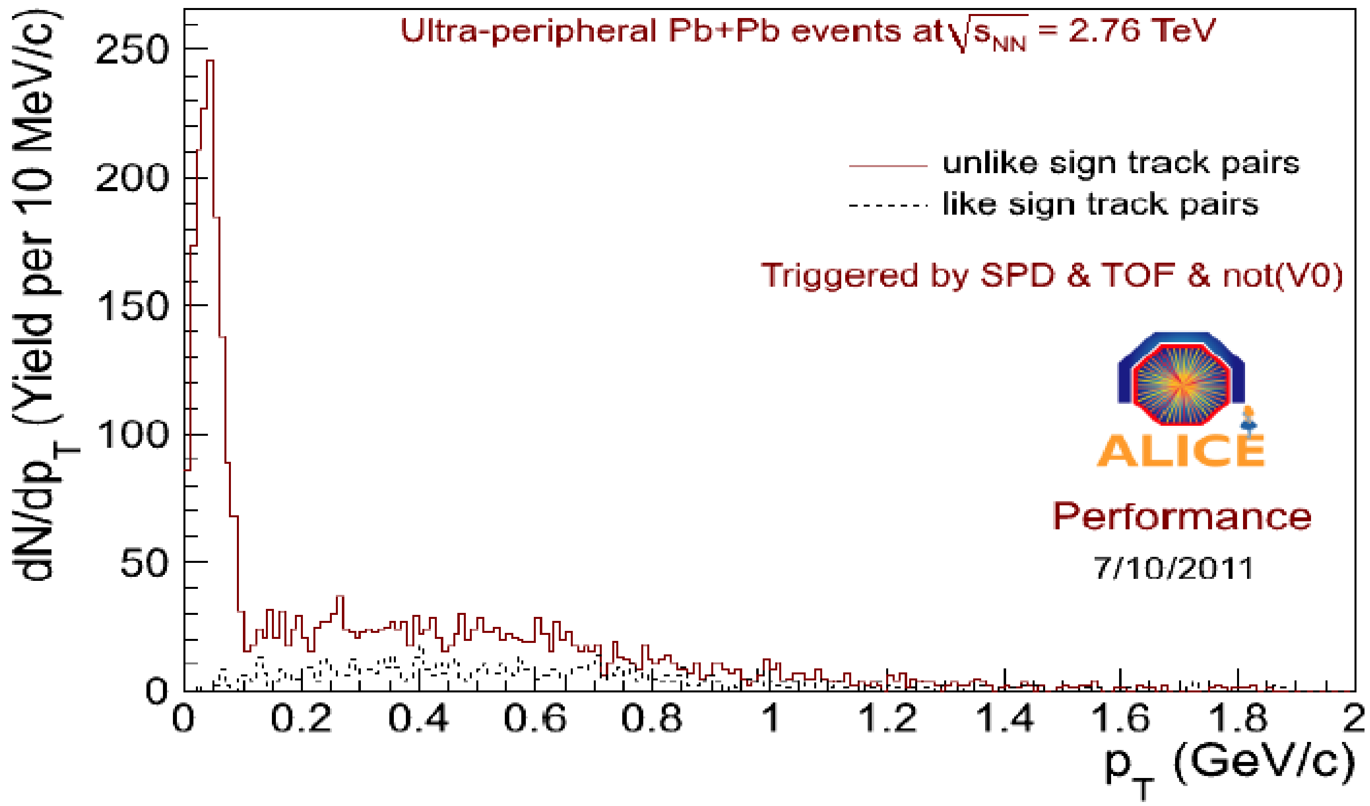



- Coherent production characterised by low transverse momentum of the final state, determined by the nuclear form factor, $p_T < \approx 100$ MeV/c.

- STAR results: arXiv:1107.4630 [nucl-ex] Jul 2011

# $\rho^0$ photo-production at central rapidity – 2010 data

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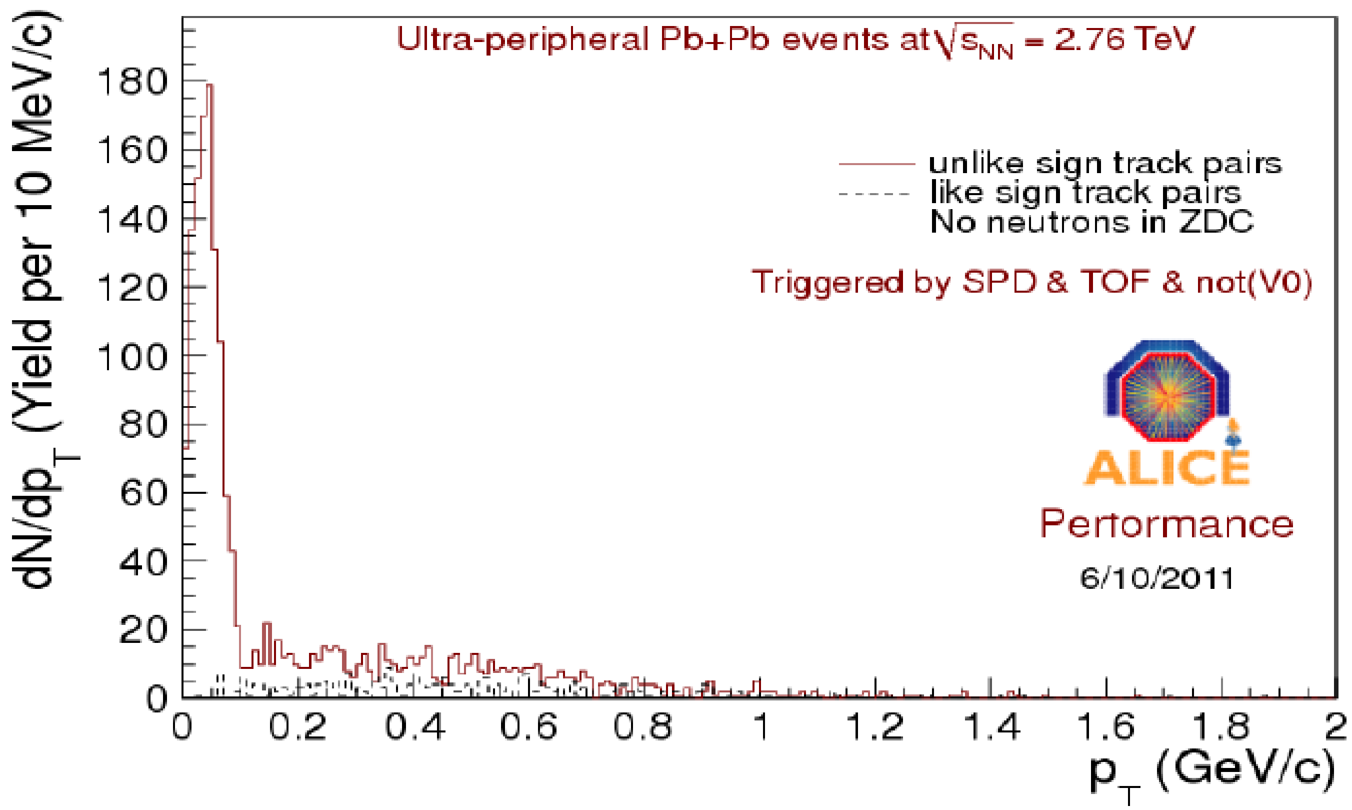



- Results after requiring no neutron emission using ZDCs, *i.e.* No neutron break-up

- Next step: Determine $\rho^0$ photoproduction cross section

# Summary

The ALICE experiment allows the study of vector meson photoproduction in ultra-peripheral nucleus-nucleus collisions. Large rapidity gaps can be defined. $\rho^0$, J/Ψ were already observed.

Exclusive J/Ψ is being studied by ALICE at both central and forward rapidity ---> access to info on gluon density

2011 statistics: a order of magnitude larger than in 2010.

## Outlook

Measurements of absolute and differential cross sections

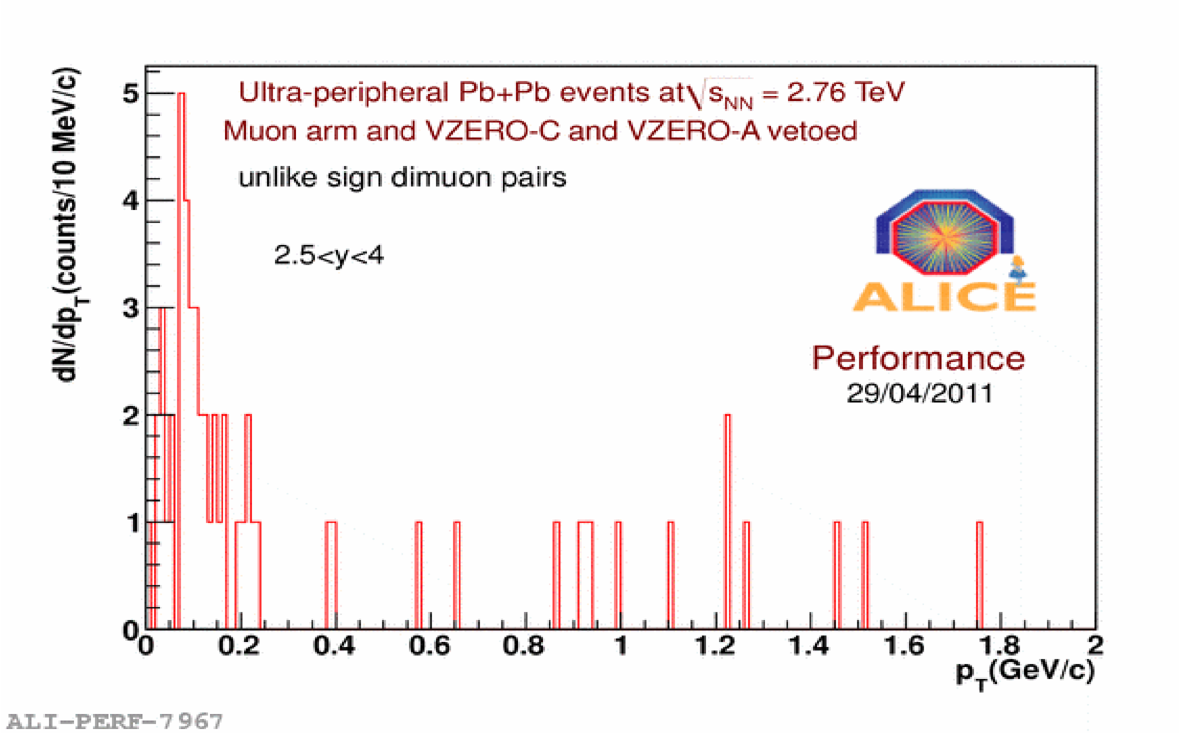
Study of $\rho^0$, J/Ψ as a function of neutron emission

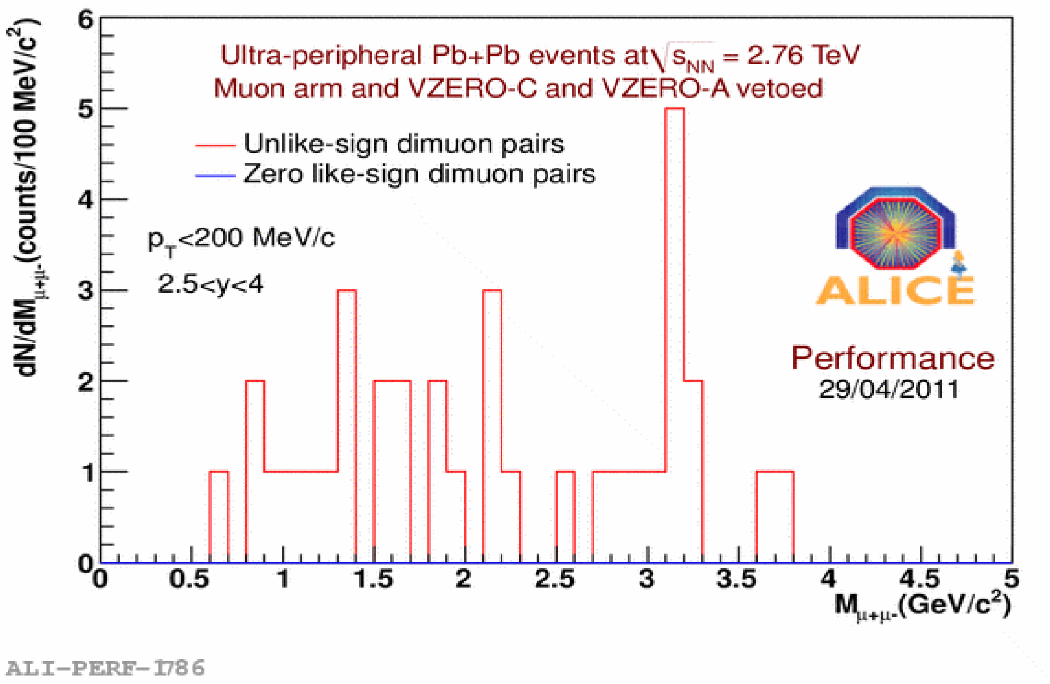
Similar studies in proton-proton collisions are also ongoing

# Additional slides

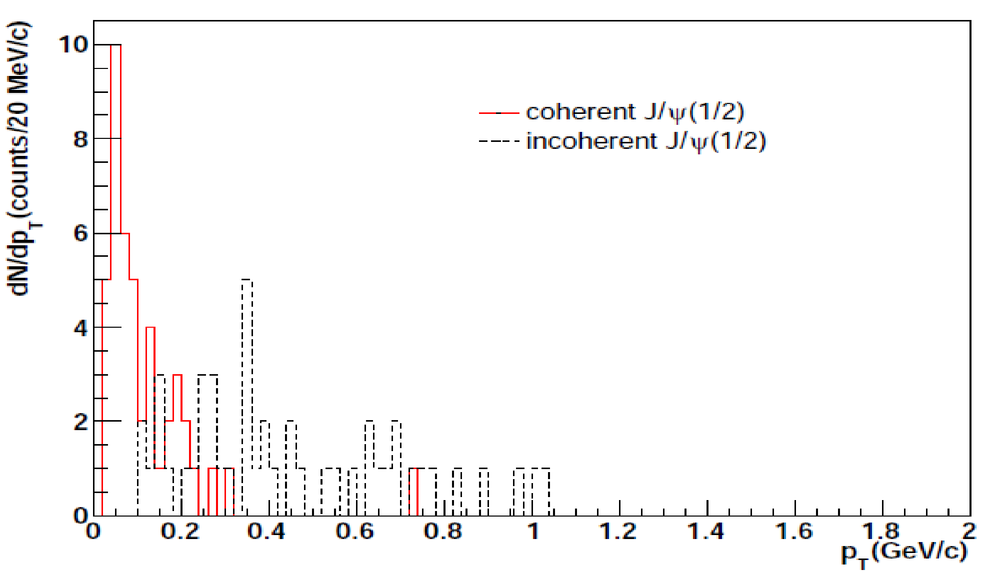
# Coherent production?!

STARLIGHT gives for coherent σ = 23 mb, and σ = 11 mb for incoherent. So, roughly 2/3 for coherent and 1/3 for incoherent. The rapidity distribution is wider for the incoherent part, so in the muon arm the fraction of incoherent should be a bit larger.




STARLIGHT



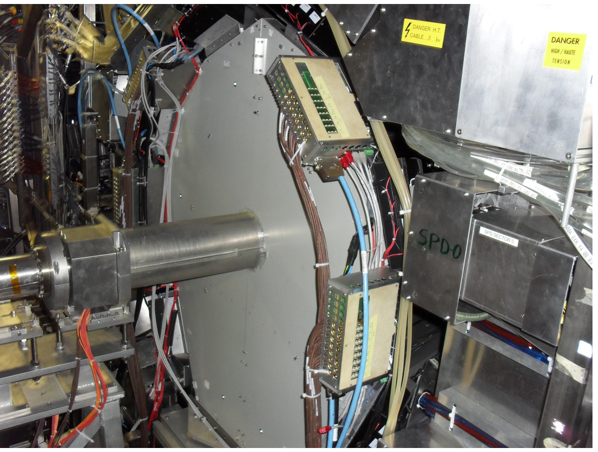

Further discrimination between coherent and incoherent production can be obtained by using the ZDCs.

*Strikman, Tverskoy, Zhalov (PLB 626 (2005) 72)* found that 85% of the incoherent J/ψ should have a signal in one of the ZDCs. For coherent J/ψ it is only about 28%

To be confirmed by ZDC analysis ...

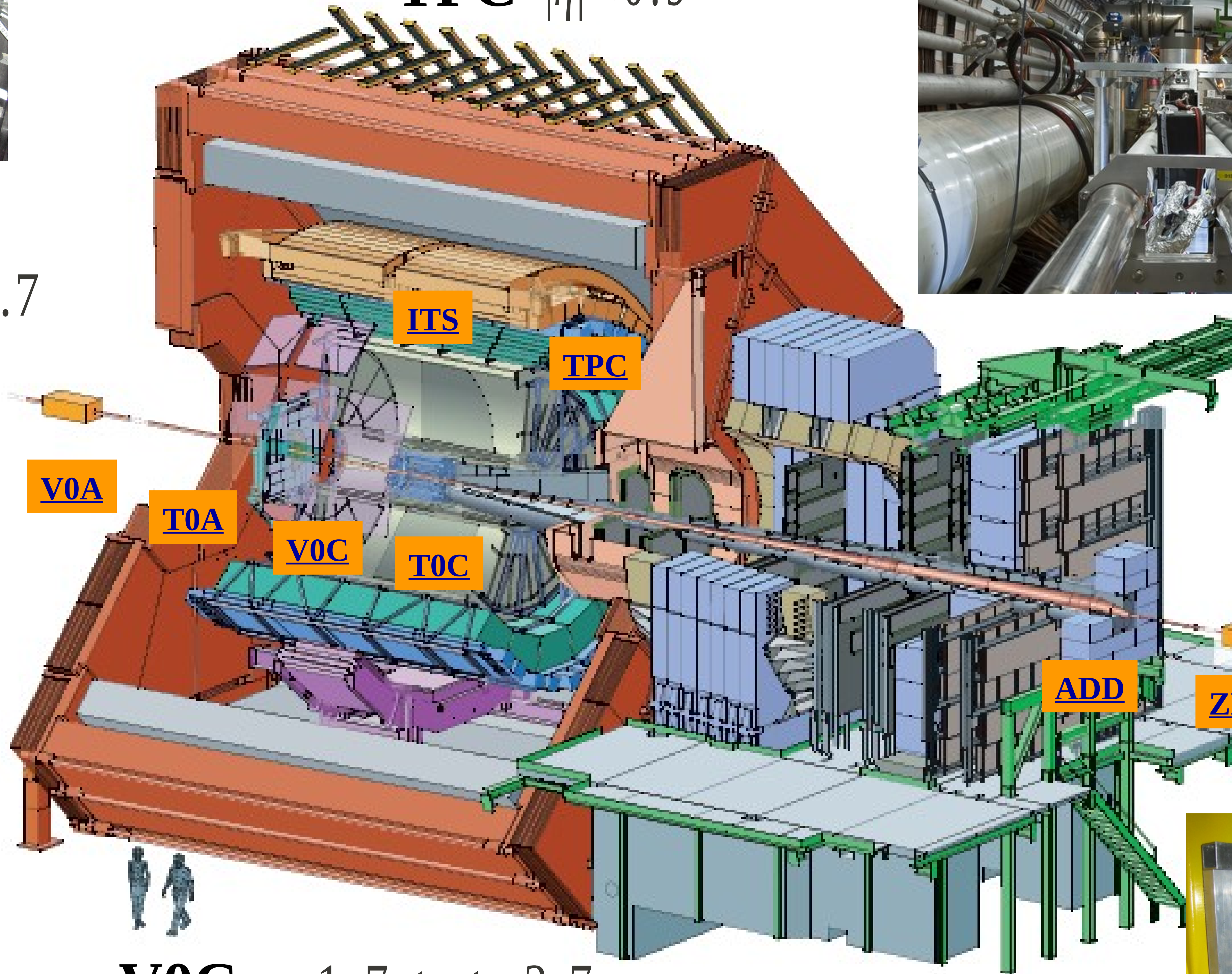
# Diffractive Physics Today

**V0A** $2.8<\eta<5.1$



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

**TPC** $|\eta|<0.9$

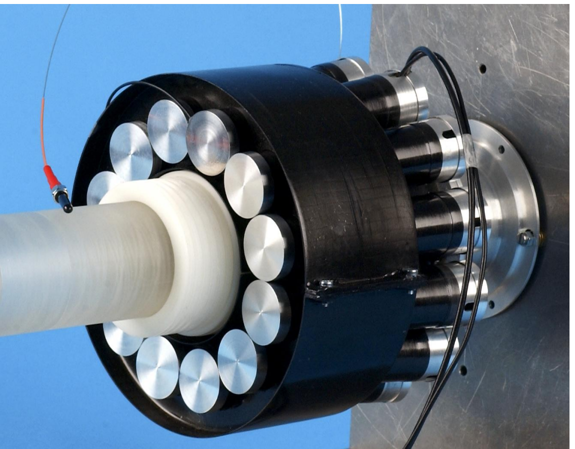



**ZEM** $4.8<\eta<5.7$

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

**T0A** $4.5<\eta<5.0$

**T0C** $-2.9<\eta<-3.3$



**V0C** $-1.7<\eta<-3.7$

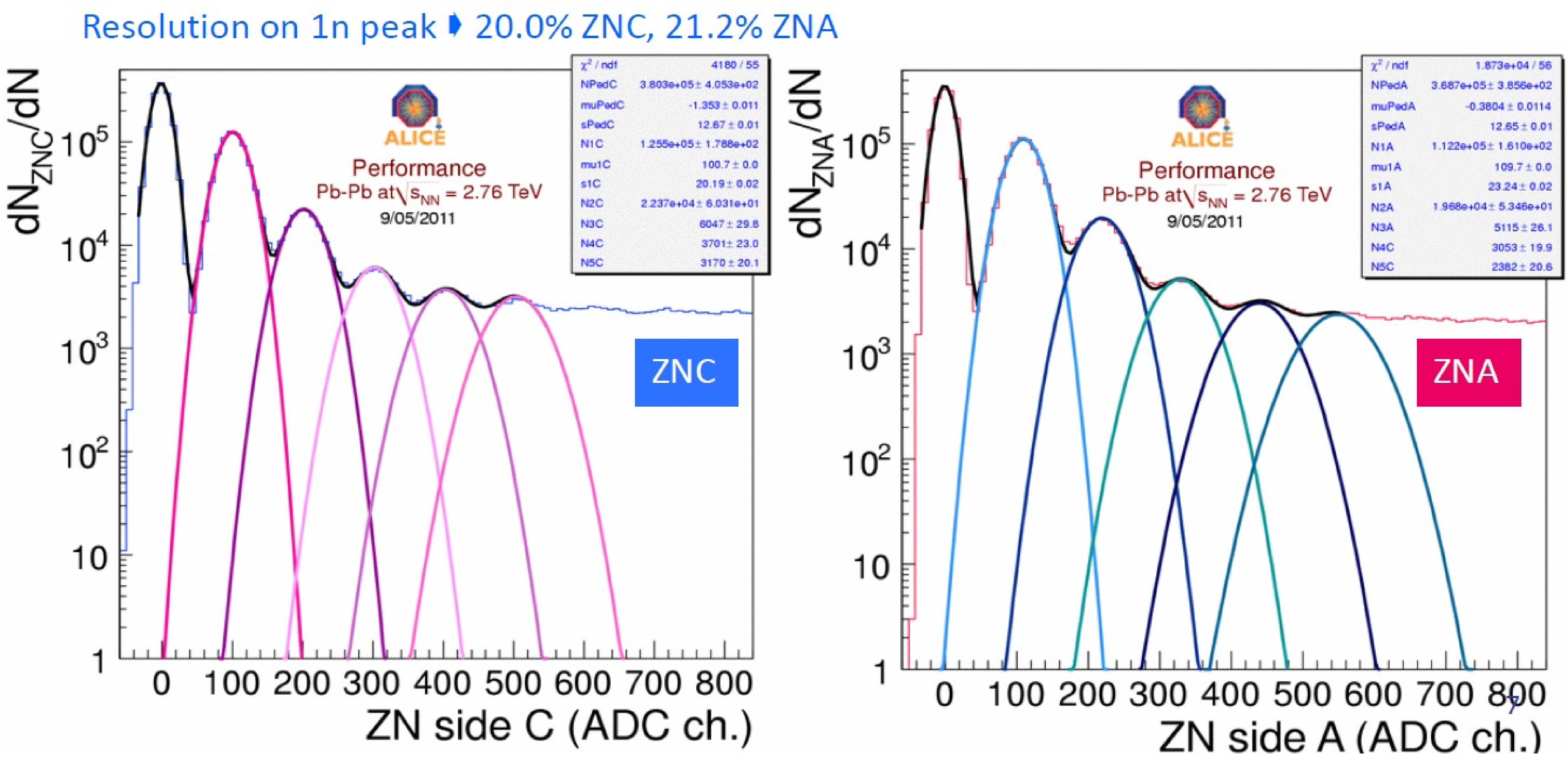
**FMD** $1.7<\eta<5.0$ $-3.4<\eta<-1.7$

**ADD** $-4.9<\eta<-6.0$

# ZDC analysis

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

→ *See C. Oppedisano's talk at Quark Matter 2011, Annecy, France*




Plots for single electromagnetic dissociation

INSTITUT DE PHYSIQUE NUCLÉAIRE ORSAY

# J/ψ vector meson cross section in UPC

Daniel Tapia Takaki

At leading order perturbative QCD

$$\frac{d\sigma_{\gamma T \rightarrow J/\psi T}(t=0)}{dt} = \frac{16\Gamma_{ee}\pi^3}{3\alpha_{em} M^5_{J/\psi}} \left[\alpha_s(\mu^2) x G_T(x,\mu^2)\right]^2$$

- $F_{ee}$ = width of the leptonic decay
- $G_T(x, m^2)$ is the gluon density
- $x = M^2(J/\psi) / s_{\gamma T}$
- $\mu^2 = M^2(J/\psi) / 4$

Note that it depends quadratically on the gluon distribution

# J/ψ vector meson cross section in UPC

*Daniel Tapia Takaki*

For the J/ψ photoproduction off the nuclei

$$\sigma_{\gamma A\to VA}(\omega)=\frac{d\sigma_{\gamma N\to VN}(\omega,t_{min})}{dt}\left[\frac{G_A(\frac{M_V^2}{s},Q^2)}{G_N(\frac{M_V^2}{s},Q^2)}\right]^2\int_{-\infty}^{t_{min}}dt\left|\int d^2b\,dz\,e^{i\vec{q}_\perp\cdot\vec{b}}e^{-q_\parallel z}\rho(\vec{b},z)\right|^2.$$

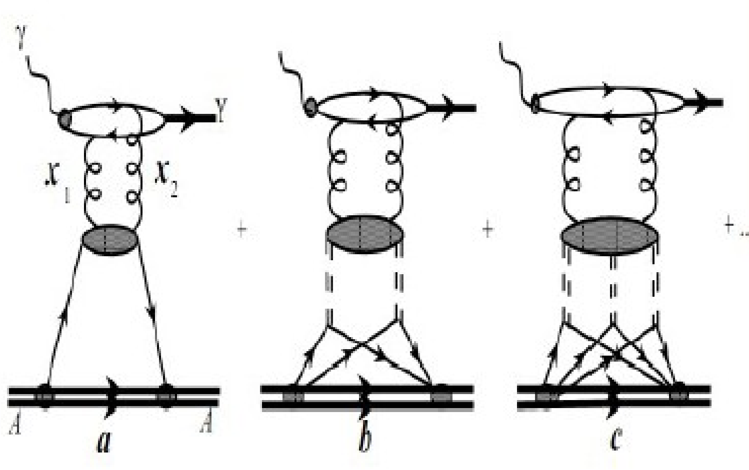
Photoproduction on nucleons

Nuclear gluon density

Nuclear form factor

Leading twist

*JHEP 0308 (2003) 043*

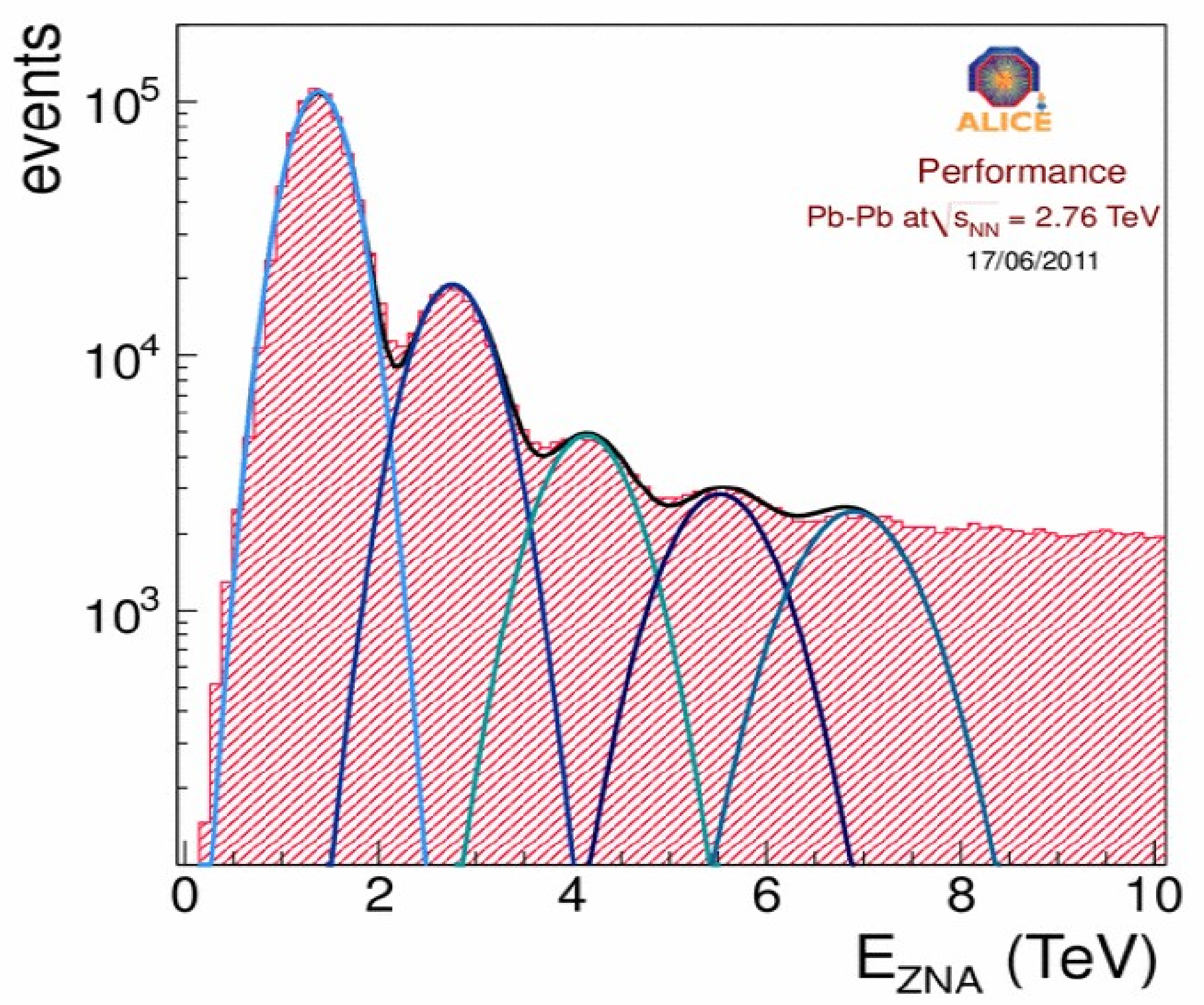



$G_A/G_N$ can be calculated within the theory of leading twist nuclear shadowing

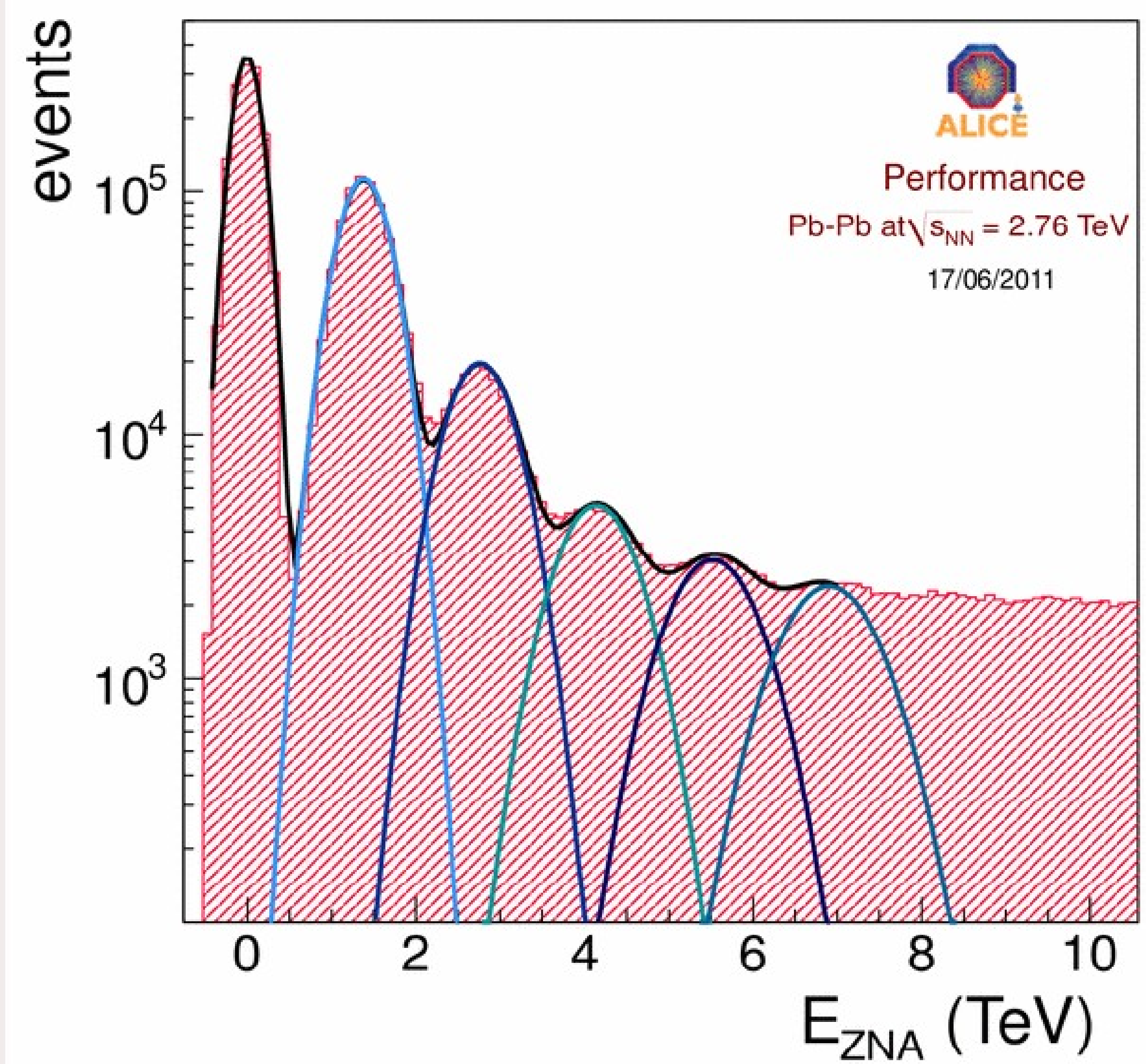
Main ingredients:

- Collin's factorisation theorem for hard diffraction
- DGLAP evolution equations
- Nucleon diffractive PDFs from HERA give a reasonable energy dependence. PDFs are available for both LO and NLO

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
→ *See Chiara Oppedisano's talk at Quark Matter 2011, Annecy, France*




ALI-PERF-9395




ALI-PERF-9391

Fitting: sum of 6 Gaussian functions: pedestal (1 free parameter, mean and normalisation fixed to zero) + 1n peak (3 free parameters) + xn peak (free normalisation, mean value = x*1n Gaussian mean, sigma)

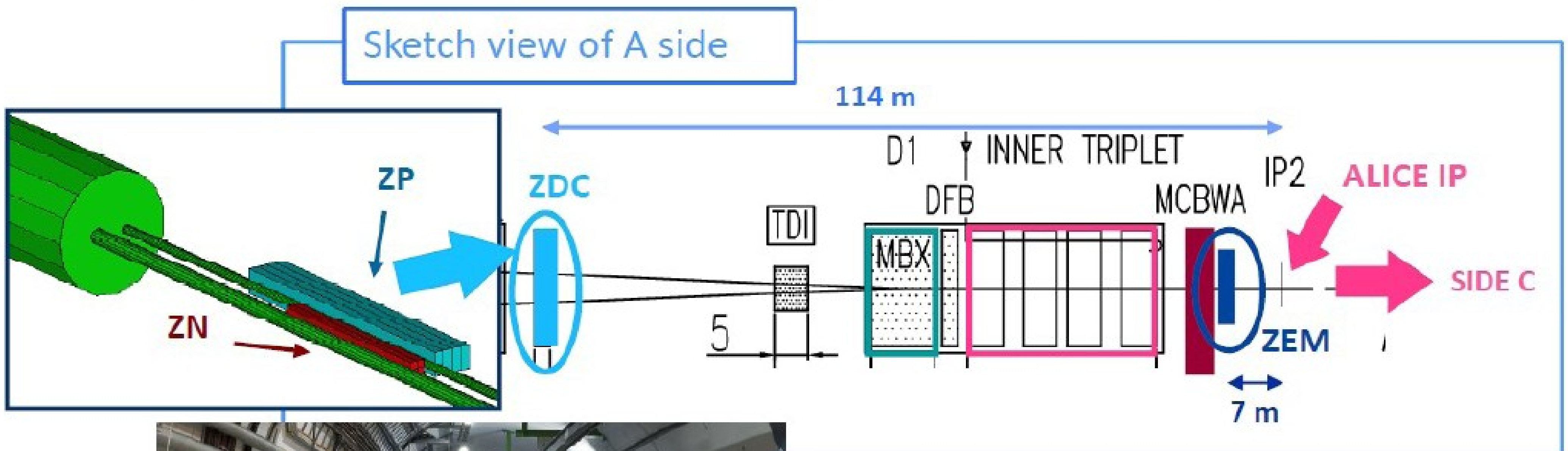
# ALICE ZDCs

ALICE neutron ZDCs (ZNs) ➡ placed at 0° w.r.t LHC axis, ~114 m far from IP on both sides (ZNC on C side, ZNA on A side), ''spaghetti'' calorimeters, dimensions (7x7x100) $cm^3$

The ZDC system is completed by:

- 2 proton calorimeters placed at ~114 m from the IP external to the beam pipe
- 2 small (7x7x21) $cm^3$ EM calorimeters (ZEM1, ZEM2) placed at ~7.5 m from the IP, at ±8 cm from LHC axis, only on A side covering the range $4.8<\eta<5.7$

ZN acceptance for neutrons emitted in EMD of Pb nuclei at $\sqrt{s}$ = 2.76 A TeV ➧ 99 %




# DATA

Sample ➧ dedicated RUN, $2.8 \cdot 10^6$ events collected

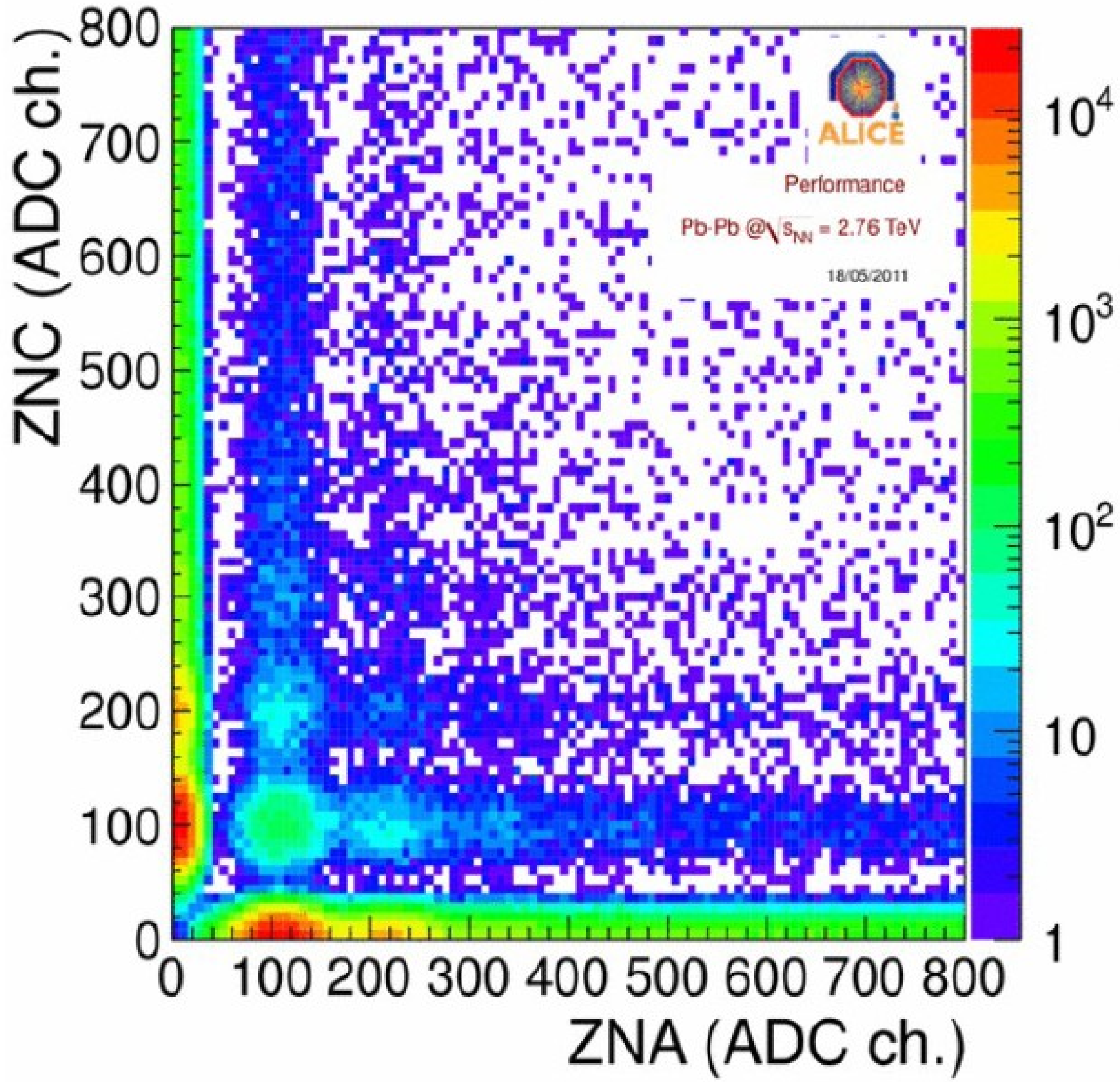
Trigger ➧ OR of the ZNs ➧ same input sent to Van der Meer scan scalers

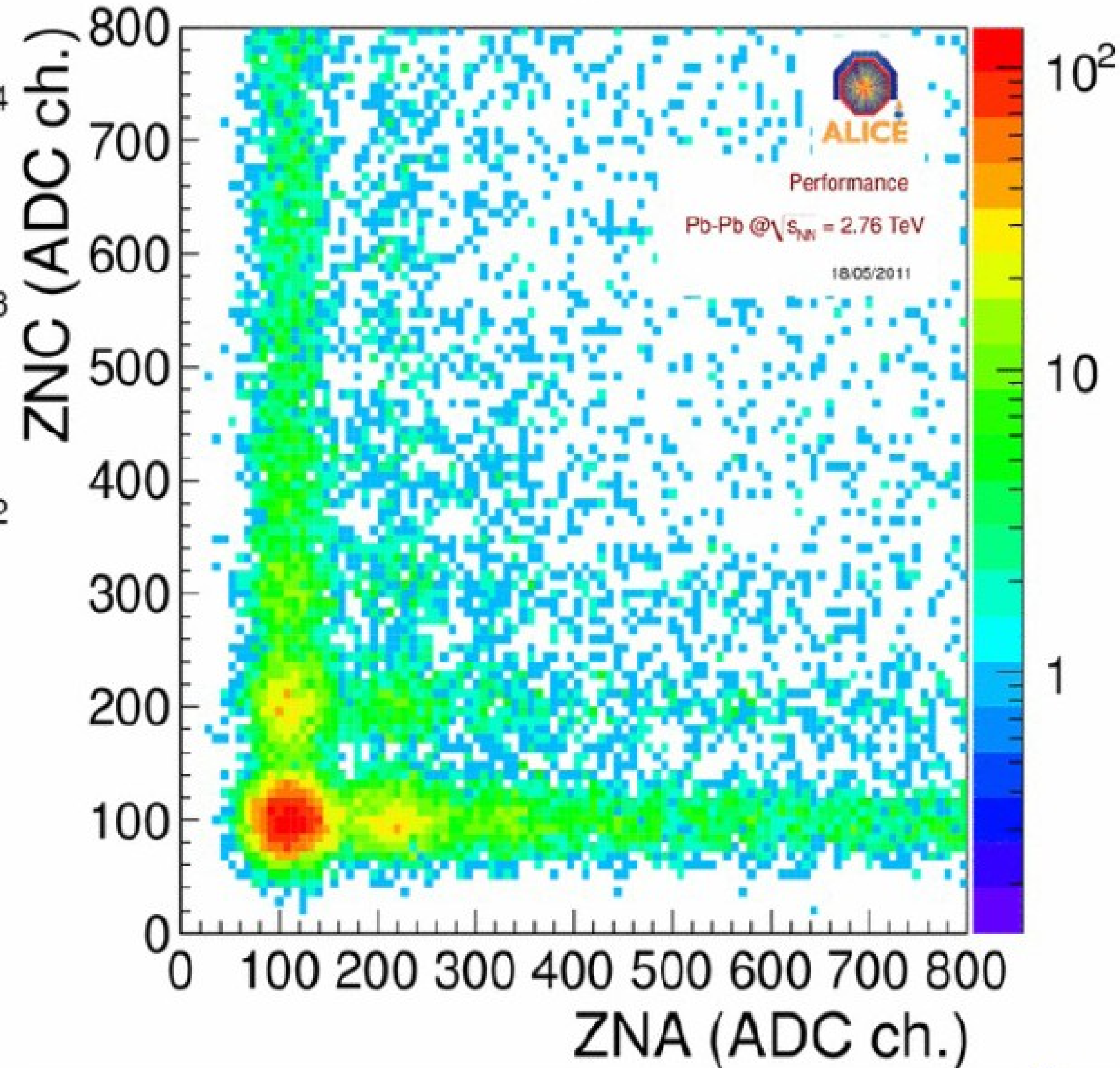
Energy thresholds ➧ ZNC~500 GeV, ZNA~450 GeV ($3\sigma$ below 1n mean value)

➡ ZNC vs. ZNA signal

➧ single EMD processes

➧ mutual EMD processes

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