Coherent J/ψ photoproduction with forward neutrons

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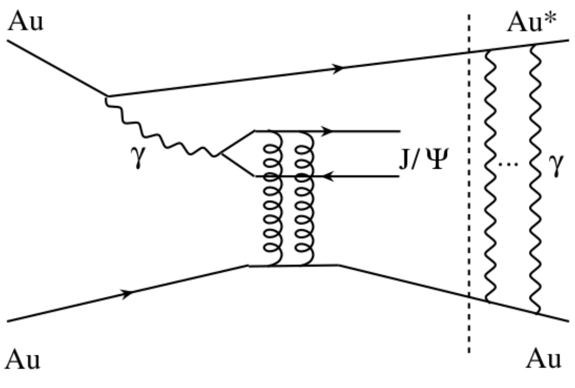
- Nuclear break-up in UPC
- ZDC selection
- Ingredients for cross section
- Cross section

UPC and nuclear break-up

- Relativistic heavy ions are accompanied by high photon fluxes due to their large electric charge and the strongly Lorentz contracted electric fields.
- At impact parameters large enough so that no hadronic interactions occur, the photonuclear interactions can be seen: these are Ultra-Peripheral Collisions (UPCs)
- Because of the high photon flux, the UPC events have a high probability to be accompanied by additional photon exchanges that excite one or both of the ions



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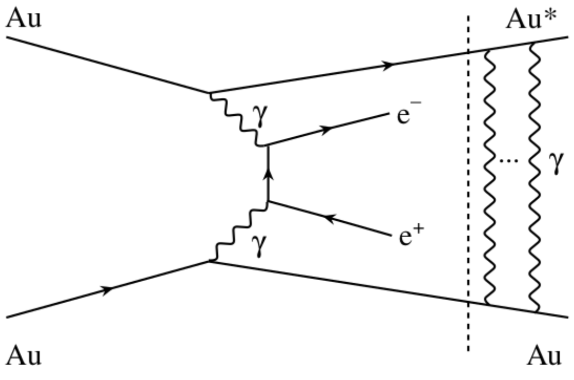
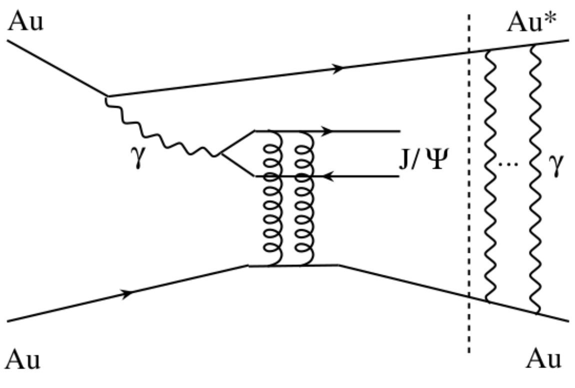


b)

UPC and nuclear break-up

- Experimentally, requiring mutual Coulomb excitation along with VM production may lead to a trigger with a higher purity, allowing more events to be collected than for the VM state by itself
- Neutron-differential studies are considered as a promising tool to decouple low-x and high-x contributions in vector meson photo-production
- STAR and CMS used requirement on forward neutrons in their UPC triggers
- ALICE measured event fractions of various break-up scenarios



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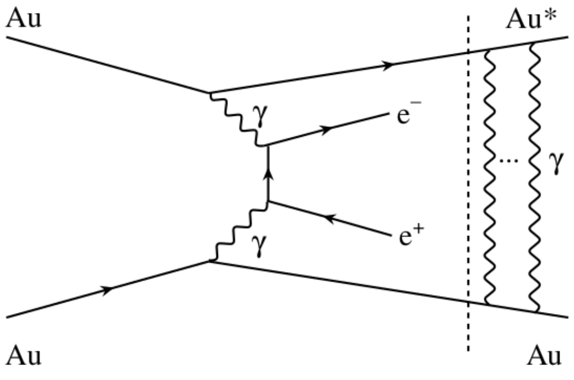


b)

Ambiguity in photon source

- Vector meson cross section in Pb–Pb UPC = sum of two terms
  - Either of the ions can be photon source:

$$\sigma(y) = n(+y)\sigma_{\gamma\mathrm{Pb}}(+y) + n(-y)\sigma_{\gamma\mathrm{Pb}}(-y)$$

- Photoproduction cross sections $\sigma_{\gamma\mathrm{Pb}}(y)$ $\sigma_{\gamma\mathrm{Pb}}(-y)$ are coupled
  - Cannot be extracted from the measured cross section

- Can be decoupled by measuring additional neutron activity

$$\begin{aligned}\sigma_{\mathrm{0N0N}}(y) &= n_{\mathrm{0N0N}}(+y)\sigma_{\gamma\mathrm{Pb}}(+y) + n_{\mathrm{0N0N}}(-y)\sigma_{\gamma\mathrm{Pb}}(-y),\\ \sigma_{\mathrm{0NXN}}(y) &= n_{\mathrm{0NXN}}(+y)\sigma_{\gamma\mathrm{Pb}}(+y) + n_{\mathrm{0NXN}}(-y)\sigma_{\gamma\mathrm{Pb}}(-y),\end{aligned}$$

Analysis details

- This analysis is a follow-up of the midrapidity J/ψ analysis
  - Goal: Extract coherent cross section in neutron emission classes
- 3 emission classes(0n0n, 0nXn, XnXn) and 3 |y| bins
  - Xn±: With neutrons in/in opposite direction of J/ψ
  - 2D analysis with 12 bins
  - But **not** every piece of the analysis is both rapidity and neutron emission dependent (only yield is)
- To enhance the statistics -> Merge the electron and muon channels
  - No PID is used in this analysis
  - Invariant mass and p_T distributions from MC are merged with weights corresponding to efficiency in electron/muon channel
  - $MC_{lepton} = \varepsilon_e * MC_e + \varepsilon_\mu * MC_\mu$

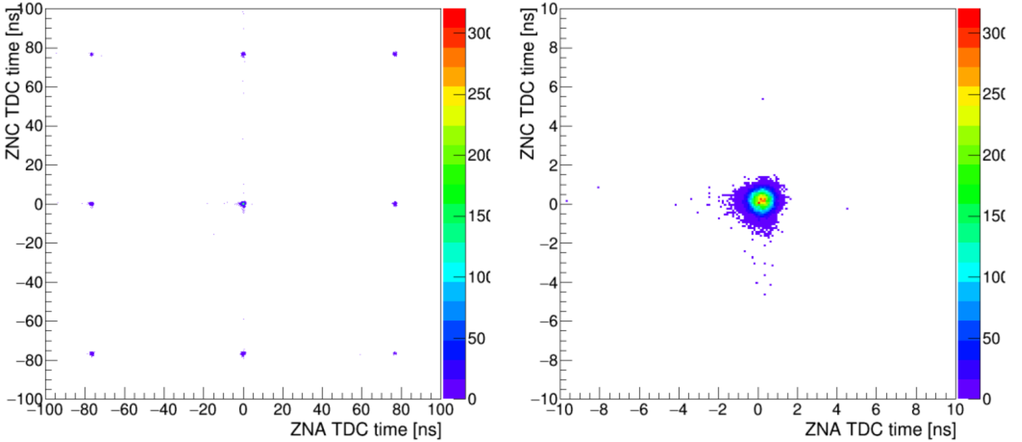
Analysis details

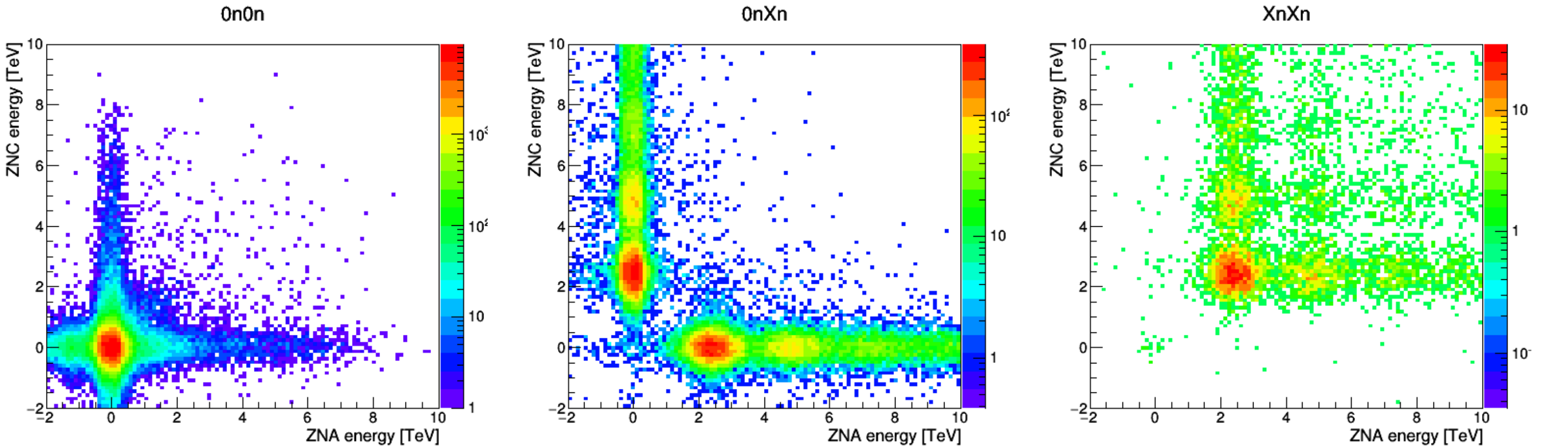
- LHC18q+LHC18r, running on ESDs (train 250)
  - Exactly the same data sample as in the charmonia paper analysis

- Empty offline AD and VZERO veto
- Search for events with exactly two good tracks
- Good track = AliESDtrackCuts::GetStandardITSTPCTrackCuts2011(kFALSE,1) + 2SPD clusters per track
  - Bit 4 equivalent + 2SPD clusters per track
- Matching of SPD clusters to the FO fired chips and re-checking the STG trigger condition with matched FO chips
- Asking both tracks to be in $|\eta|<0.8$
- Cut on additional tracks with GetStandardTPCOnlyTrackCuts()+1SPD cluster and GetStandardITSSATrackCuts2010(kFALSE,kTRUE) has effect of ~1%, not used here

ZDC selection

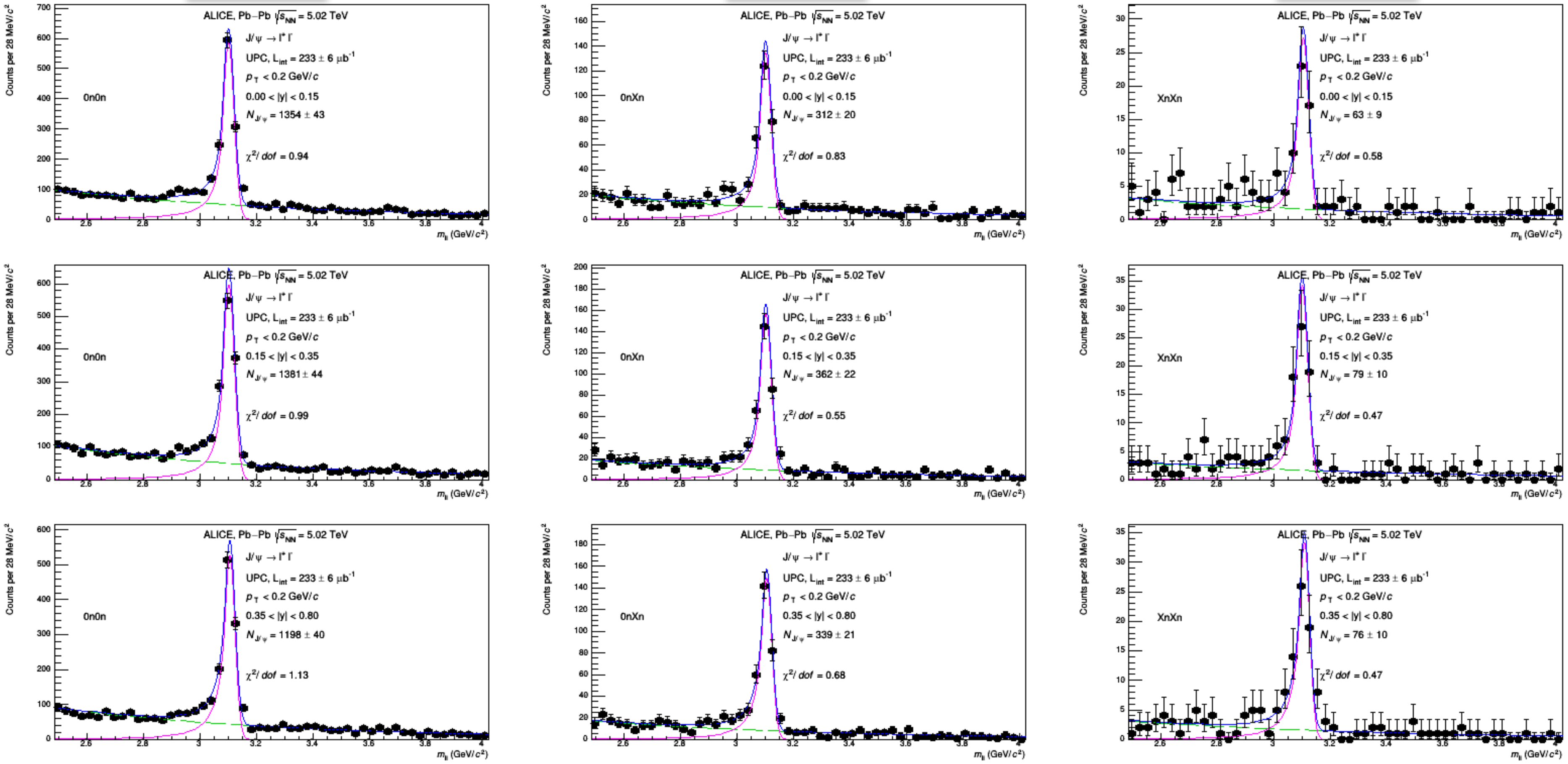
- Neutron emission classes are selected using timing information from ZDC
  - fZNCTDCm[4], fZNATDCm[4]
  - |fTDCm[i]| < 5ns
- Seems to select correctly the 0n…Xn peaks in ZNA/ZNC energy spectra





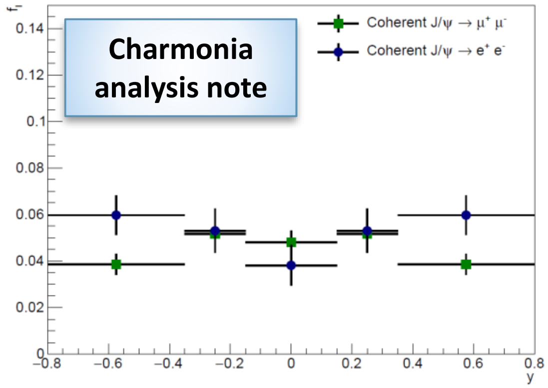
Invariant mass fits

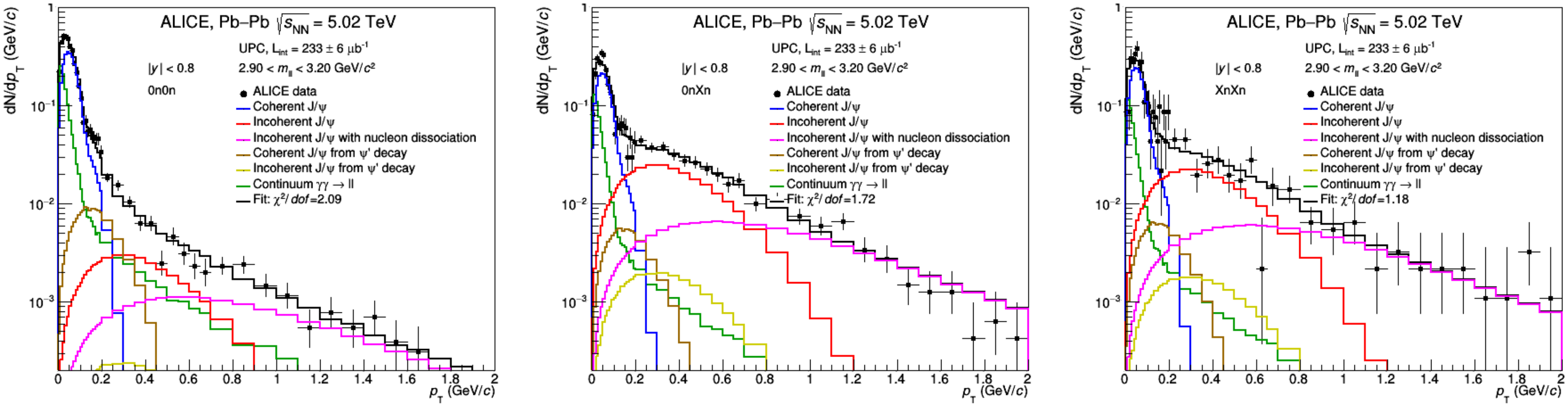
0n0n | **0nXn** | **XnXn**



p_T distribution of J/ψ candidates

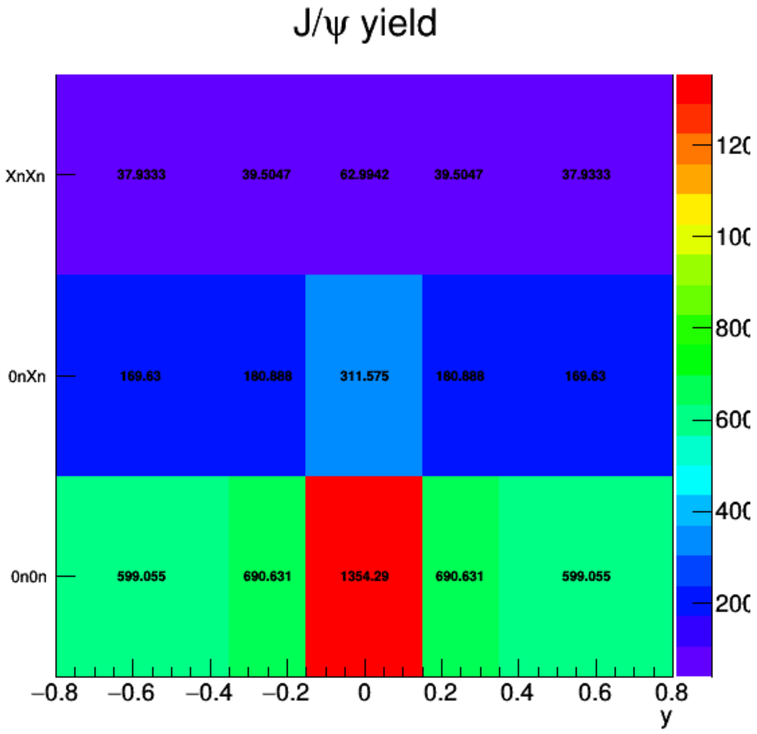
- Incoherent contamination was found to be constant as function of rapidity (within uncertainties)
- Only overall value per channel used in the paper
- In this analysis, f_I evaluated within $|y|<0.8$ and dependent on neutron emission class

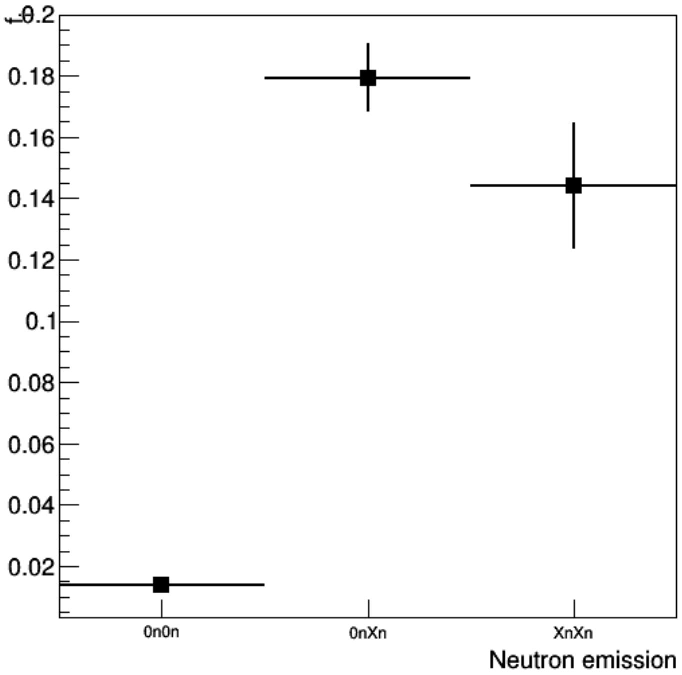




Yield and incoherent contamination

- Yield of ~1300 J/ψ per |y| bin in 0n0n, ~300 0nXn and ~ 60 XnXn



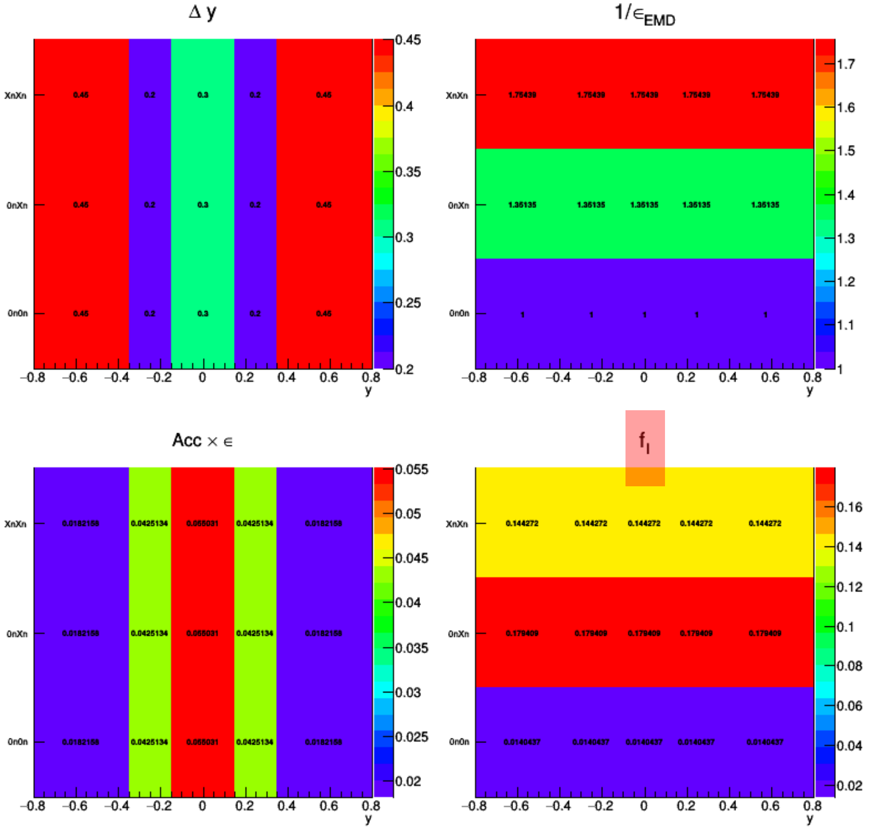


Ingredients for x-section

$$\frac{d\sigma^{coh}_{VM}}{dy} = \frac{N^{coh}_{VM}}{(\mathrm{Acc}\times\varepsilon)_{VM}\cdot\varepsilon^{pileup}_{veto}\cdot\varepsilon^{EMD}_{veto}\cdot \mathrm{BR}(\mathrm{VM}\to\mathrm{X}+\mathrm{Y})\cdot\mathscr{L}_{int}\cdot\Delta y}$$

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

- N_{yield} is differential in |y| and ZDC(previous slide)
- f_I is differential in ZDC and constant in |y|
- f_D (feed down fraction) is constant



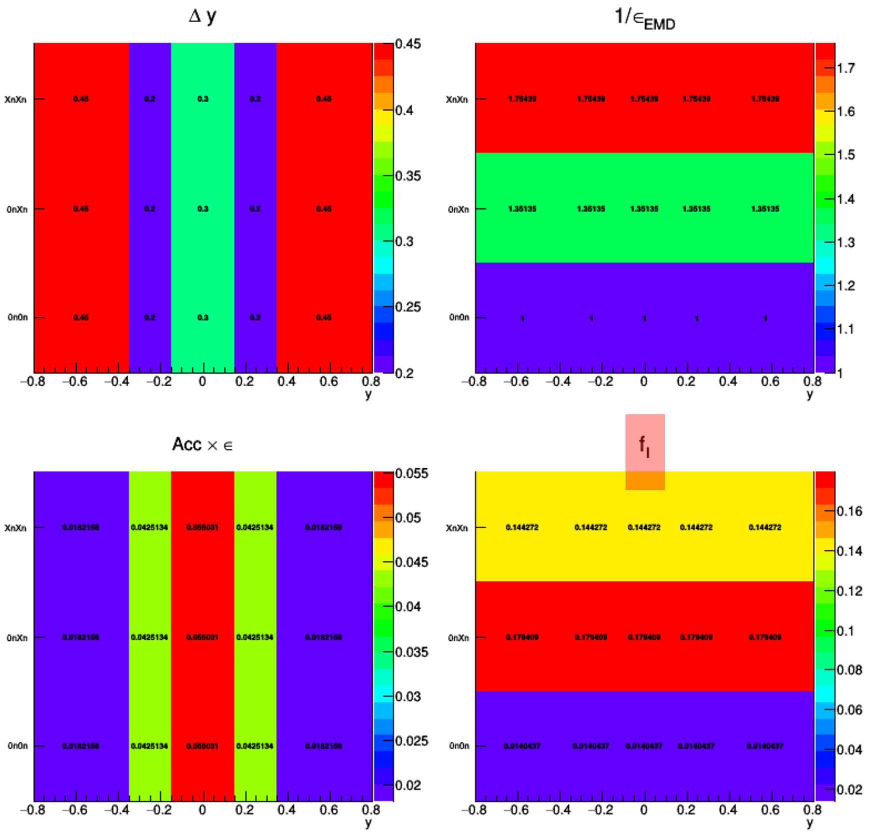
Ingredients for x-section

$$\frac{d\sigma^{coh}_{VM}}{dy} = \frac{N^{coh}_{VM}}{(Acc \times \varepsilon)_{VM} \cdot \varepsilon^{pileup}_{veto} \cdot \varepsilon^{EMD}_{veto} \cdot BR(VM \rightarrow X+Y) \cdot \mathscr{L}_{int} \cdot \Delta y}$$

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

- N_{yield} is differential in |y| and ZDC(previous slide)
- f_I is differential in ZDC and constant in |y|
- f_D (feed down fraction) is constant

Decay	$\lvert y \rvert$	$N_{J/\psi}$	ε	f_D	f_I	$d\sigma^{coh}_{J/\psi}/dy$ (mb)
$\mu^+\mu^-$	(0.00, 0.80)	3120 ± 61	0.037	0.035	0.047 ± 0.003	$4.20 \pm 0.08(stat.) \pm 0.04(syst.)$
e^+e^-	(0.00, 0.80)	2116 ± 65	0.025	0.043	0.050 ± 0.005	$4.12 \pm 0.13(stat.) \pm 0.10(syst.)$

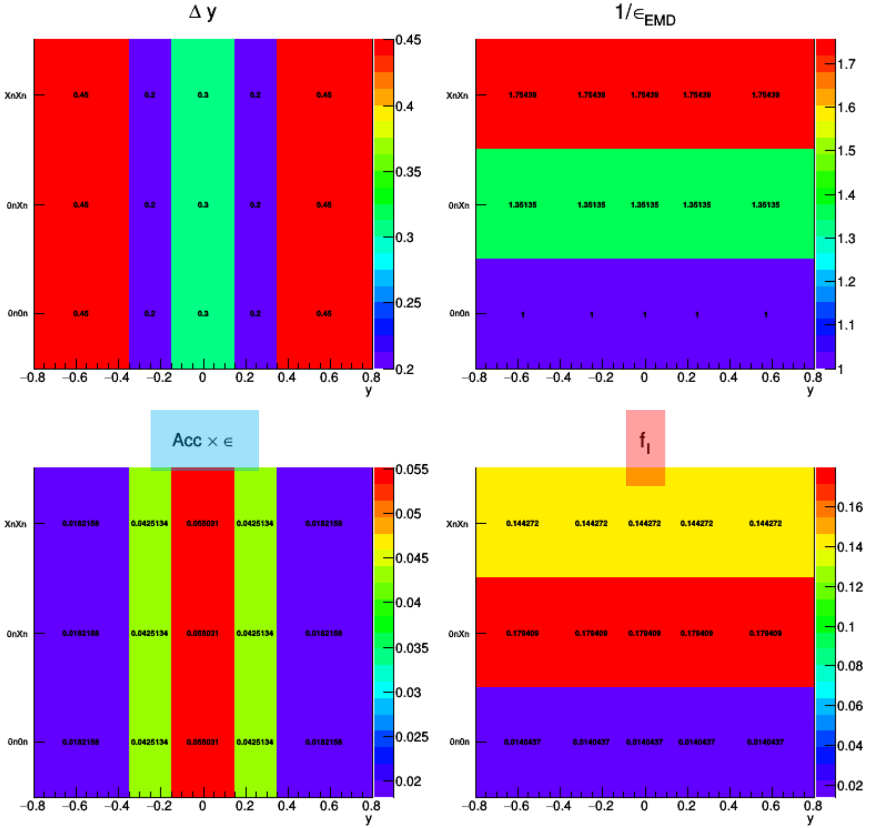


Ingredients for x-section

$$\frac{\mathrm{d}\sigma_{\mathrm{VM}}^{\mathrm{coh}}}{\mathrm{dy}} = \frac{N_{\mathrm{VM}}^{\mathrm{coh}}}{(\mathrm{Acc}\times\varepsilon)_{\mathrm{VM}}\cdot\varepsilon_{\mathrm{veto}}^{\mathrm{pileup}}\cdot\varepsilon_{\mathrm{veto}}^{\mathrm{EMD}}\cdot\mathrm{BR}(\mathrm{VM}\to\mathrm{X}+\mathrm{Y})\cdot\mathscr{L}_{\mathrm{int}}\cdot\Delta\mathrm{y}}$$

$$N_{J/\psi}^{\mathrm{coh}} = \frac{N_{\mathrm{yield}}}{1+f_{\mathrm{I}}+f_{\mathrm{D}}}$$

- N_{yield} is differential in |y| and ZDC(previous slide)
- f_{I} is differential in ZDC and constant in |y|
- f_{D} (feed down fraction) is constant
- Acc*ε is differential in |y| and constant in ZDC



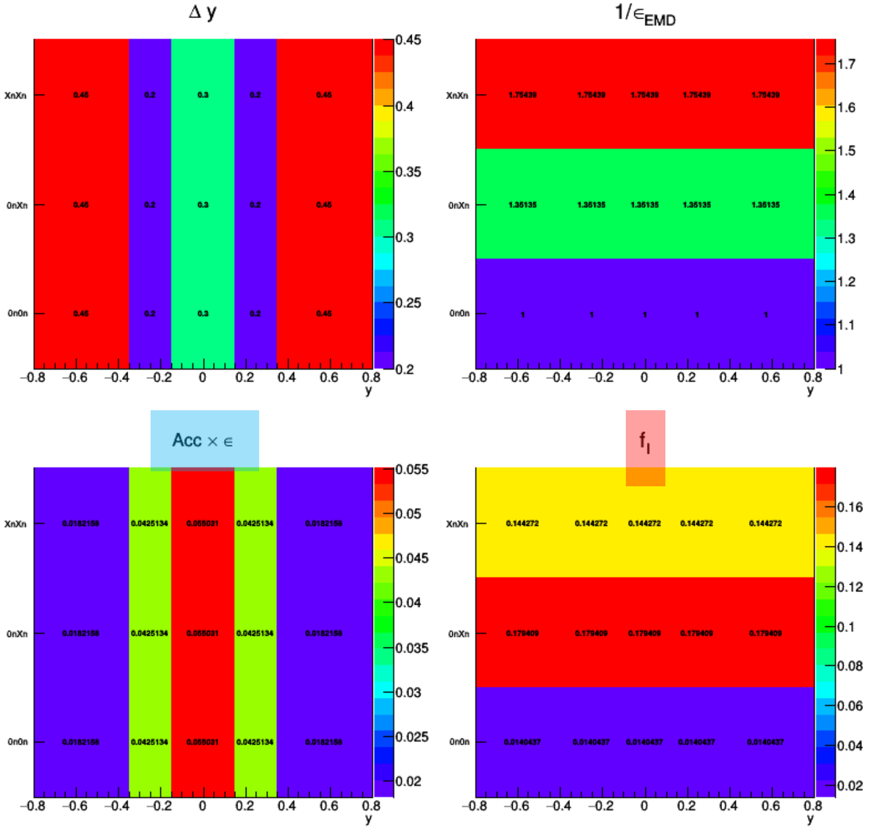
Ingredients for x-section

$$\frac{d\sigma^{coh}_{VM}}{dy} = \frac{N^{coh}_{VM}}{(\mathrm{Acc}\times\varepsilon)_{VM}\cdot\varepsilon^{pileup}_{veto}\cdot\varepsilon^{EMD}_{veto}\cdot \mathrm{BR}(\mathrm{VM}\to \mathrm{X}+\mathrm{Y})\cdot\mathscr{L}_{int}\cdot\Delta y}$$

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

- N_{yield} is differential in |y| and ZDC(previous slide)
- f_I is differential in ZDC and constant in |y|
- f_D (feed down fraction) is constant
- Acc*ε is differential in |y| and constant in ZDC
- Pile-up veto is constant
  - Mostly QED electrons hitting VZERO/AD
  - Evaluated using CTRUE events

$$\varepsilon^{pileup}_{veto} = 0.92 \pm 0.002$$

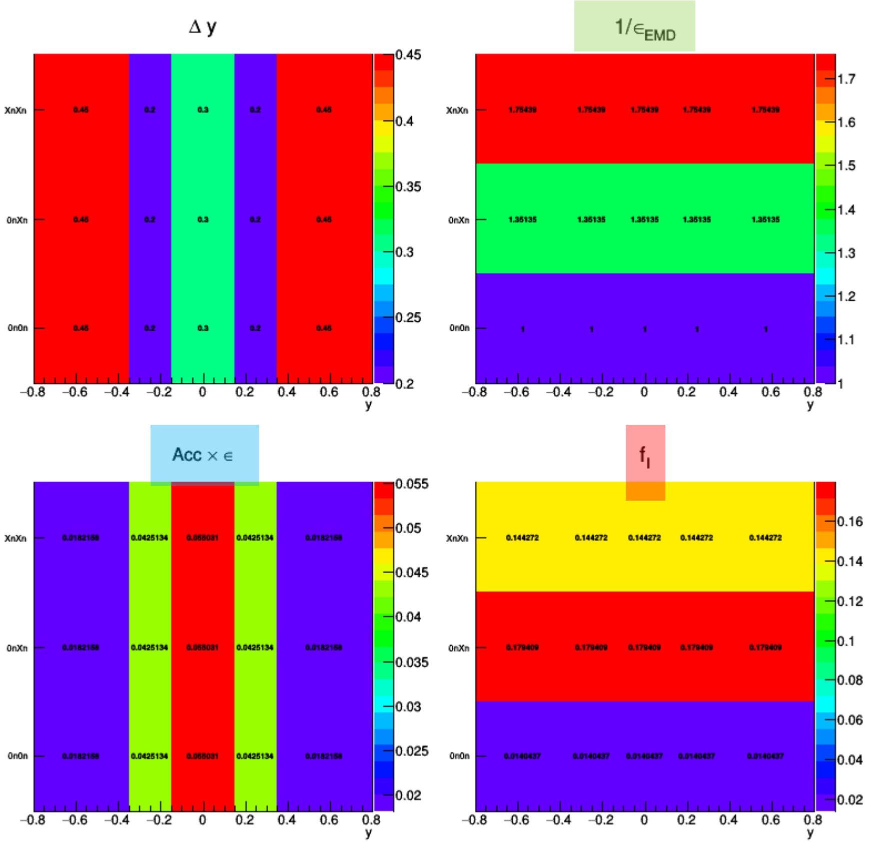


Ingredients for x-section

$$\frac{d\sigma_{VM}^{coh}}{dy} = \frac{N_{VM}^{coh}}{(\mathrm{Acc}\times\varepsilon)_{VM}\cdot\varepsilon_{veto}^{pileup}\cdot\varepsilon_{veto}^{EMD}\cdot \mathrm{BR}(\mathrm{VM}\to \mathrm{X}+\mathrm{Y})\cdot\mathscr{L}_{int}\cdot\Delta y}$$

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

- N_{yield} is differential in |y| and ZDC(previous slide)
- f_I is differential in ZDC and constant in |y|
- f_D (feed down fraction) is constant
- Acc*ε is differential in |y| and constant in ZDC
- Pile-up veto is constant
- EMD veto is differential in ZDC and constant in |y|



Corrections related to electromagnetic dissociation

$$\frac{d\sigma_{VM}^{coh}}{dy} = \frac{N_{VM}^{coh}}{(\mathrm{Acc}\times\varepsilon)_{VM}\cdot\varepsilon_{veto}^{pileup}\cdot\boxed{\varepsilon_{veto}^{EMD}}\cdot \mathrm{BR}(\mathrm{VM}\to\mathrm{X}+\mathrm{Y})\cdot\mathscr{L}_{int}\cdot\Delta y}$$

In some cases, in addition to the neutrons, there may be some pions or other particles produced in the dissociation of the nucleus.

Two types of corrections are needed: to account for events lost at the trigger level due to EMD accompanied by charged particles at AD or V0 rapidities, and to account for migration across forward-neutron classes due to inefficiencies and pile-up in the neutron ZDC. The corrections were evaluated for analysis of coherent photoproduction of the ρ^0 meson, details can be found in [7].

The correction factors we use are $\varepsilon = 26\% \pm 4\%$ for 0nXn and $\varepsilon = 43\% \pm 5\%$ for XnXn class. Corrections are applied as

$$N_{corr} = \frac{N_{raw}}{1-\varepsilon}$$

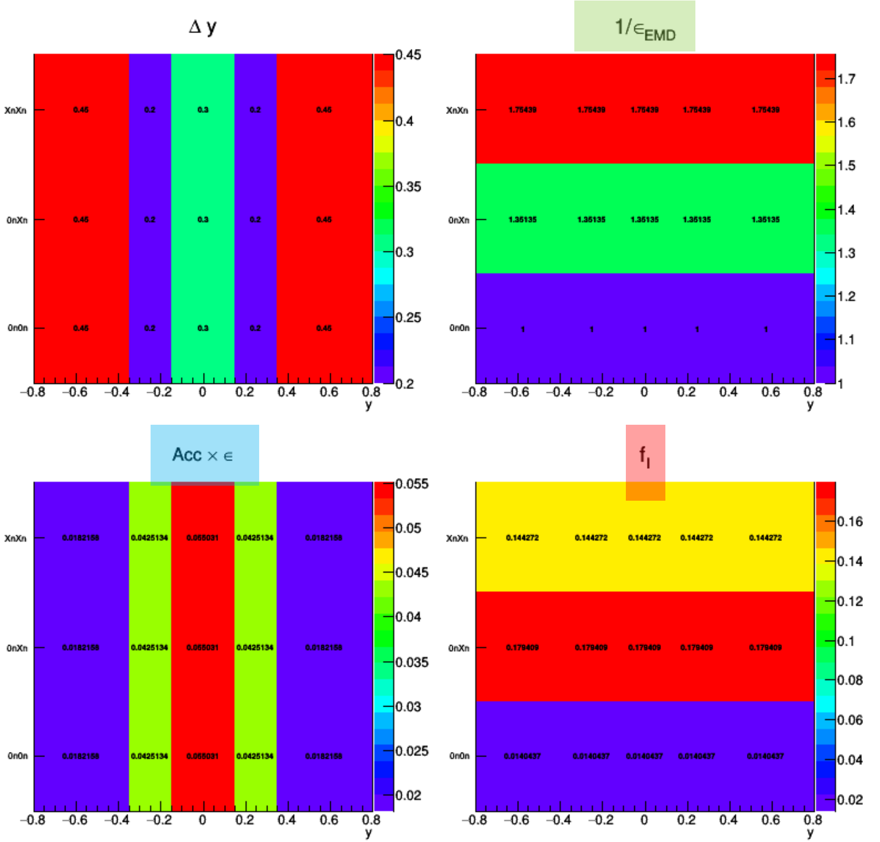
- [7] = ANA1021

Ingredients for x-section

$$\frac{d\sigma^{coh}_{VM}}{dy} = \frac{N^{coh}_{VM}}{(\mathrm{Acc}\times\varepsilon)_{VM}\cdot\varepsilon^{\mathrm{pileup}}_{\mathrm{veto}}\cdot\varepsilon^{\mathrm{EMD}}_{\mathrm{veto}}\cdot \mathrm{BR}(\mathrm{VM}\to X+Y)\cdot\mathscr{L}_{\mathrm{int}}\cdot\Delta y}$$

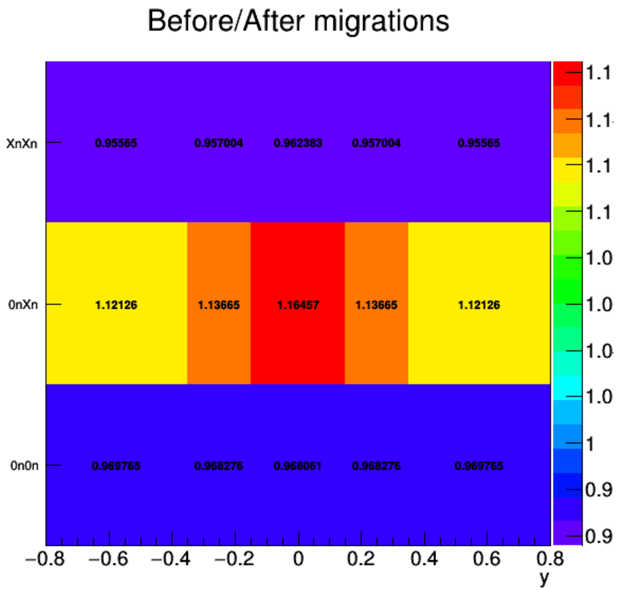
$$N^{coh}_{J/\psi} = \frac{N_{\mathrm{yield}}}{1+f_{\mathrm{I}}+f_{\mathrm{D}}}$$

- N_{yield} is differential in |y| and ZDC(previous slide)
- f_I is differential in ZDC and constant in |y|
- f_D (feed down fraction) is constant
- Acc*ε is differential in |y| and constant in ZDC
- Pile-up veto is constant
- EMD veto is differential in ZDC and constant in |y|
- Lumi and BR are constants
- Δy is the width of the rapidity bin



Migrations in ZDC classes

- Events can be misclassified due
  - ZN inefficiencies
    - 94% ± 1%
  - EMD pile-up in ZN
    - Estimated with CTRUE-B triggers
    - 2.37% ± 0.05% (2.38% ± 0.06%) for A(C) side of neutron ZDC
- Based on ANA1021



Cross section

	$\lvert y \rvert$	$N_{J/\psi}$	ε	$\varepsilon_{\mathrm{EMD}}$	f_{I}	σ_{Raw}	$\mathrm{d}\sigma^{\mathrm{coh}}_{\mathrm{J}/\psi}/\ \mathrm{dy}$ (mb)
0n0n	(0.00, 0.15)	1354 ± 43	0.055	1.00	0.014 ± 0.002	3.04	$3.15 \pm 0.10(\mathrm{stat}) \pm 0.17(\mathrm{syst})$
0n0n	(0.15, 0.35)	1381 ± 44	0.043	1.00	0.014 ± 0.002	3.01	$3.11 \pm 0.10(\mathrm{stat}) \pm 0.17(\mathrm{syst})$
0n0n	(0.35, 0.80)	1198 ± 40	0.018	1.00	0.014 ± 0.002	2.71	$2.80 \pm 0.09(\mathrm{stat}) \pm 0.15(\mathrm{syst})$
0nXn	(0.00, 0.15)	312 ± 20	0.055	0.74	0.179 ± 0.011	0.82	$0.70 \pm 0.05(\mathrm{stat}) \pm 0.06(\mathrm{syst})$
0nXn	(0.15, 0.35)	362 ± 22	0.043	0.74	0.179 ± 0.011	0.92	$0.81 \pm 0.06(\mathrm{stat}) \pm 0.06(\mathrm{syst})$
0nXn	(0.35, 0.80)	339 ± 21	0.018	0.74	0.179 ± 0.011	0.90	$0.80 \pm 0.06(\mathrm{stat}) \pm 0.06(\mathrm{syst})$
XnXn	(0.00, 0.15)	63 ± 9	0.055	0.57	0.144 ± 0.021	0.22	$0.23 \pm 0.03(\mathrm{stat}) \pm 0.02(\mathrm{syst})$
XnXn	(0.15, 0.35)	79 ± 10	0.043	0.57	0.144 ± 0.021	0.27	$0.28 \pm 0.03(\mathrm{stat}) \pm 0.02(\mathrm{syst})$
XnXn	(0.35, 0.80)	76 ± 10	0.018	0.57	0.144 ± 0.021	0.27	$0.28 \pm 0.04(\mathrm{stat}) \pm 0.02(\mathrm{syst})$

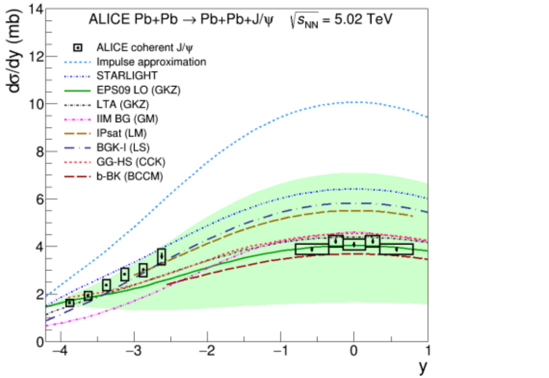
Systematic uncertanties

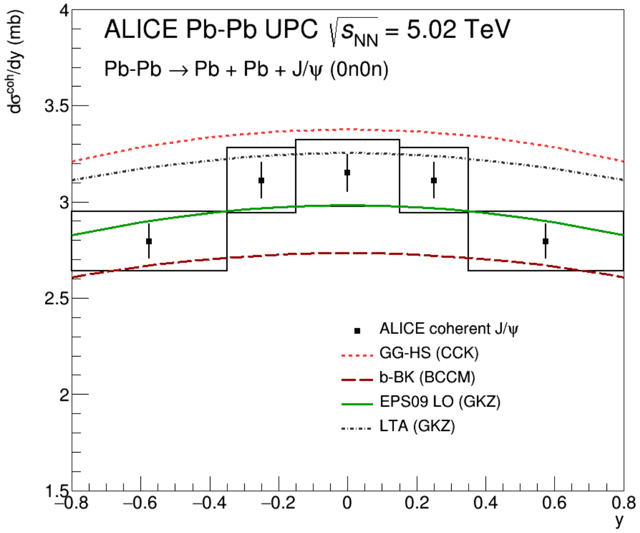
- Most of the uncertianties are addopted from the paper and are the same for all ZDC emmision classes
- Incoherent contamination: propagated uncertianty of the f_I from the p_T fit
- EMD correction: uncertainty of the fraction of vetoed events

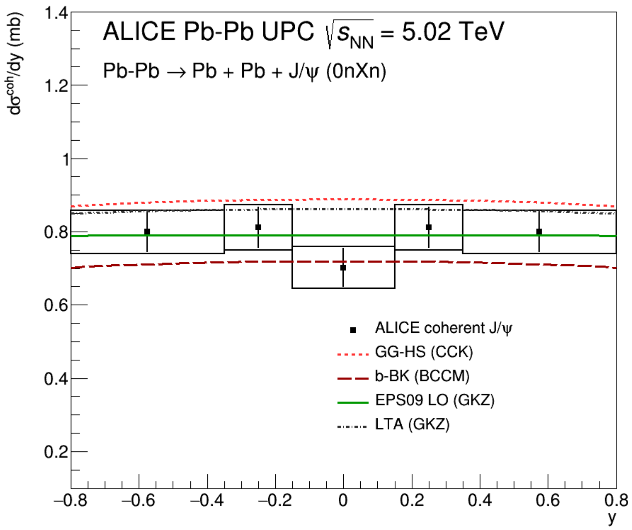
	0n0n	0nXn	XnXn
Signal extraction		1.5	
Branching ratio		0.5	
Incoherent contamination	0.2	1.7	1.4
Luminosity		2.7	
TOF trigger efficiency		0.7	
SPD trigger efficiency		1.0	
Feed down		0.6	
AD and V0 veto		3.0	
ITS-TPC matching		2.8	
EMD correction	0.0	3.2	3.5
Subtotal	5.3	6.4	6.5

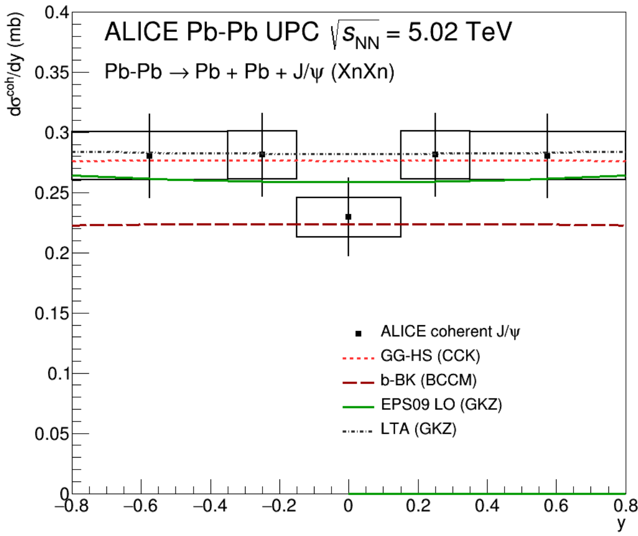
	$\|y\|$	ZDC ε	ZDC pile-up	TOTAL
0n0n	(0.00, 0.15)	±0.2	±1.2	±5.5
0n0n	(0.15, 0.35)	±0.3	±1.2	±5.5
0n0n	(0.35, 0.80)	±0.3	±1.2	±5.5
0nXn	(0.00, 0.15)	±0.4	$^{+4.9}_{-4.7}$	±8.0
0nXn	(0.15, 0.35)	±0.3	$^{+4.1}_{-4.0}$	±7.6
0nXn	(0.35, 0.80)	±0.3	±3.6	±7.4
XnXn	(0.00, 0.15)	±2.1	±1.9	±7.1
XnXn	(0.15, 0.35)	±2.1	±1.8	±7.1
XnXn	(0.35, 0.80)	±2.1	±1.8	±7.1

Cross section



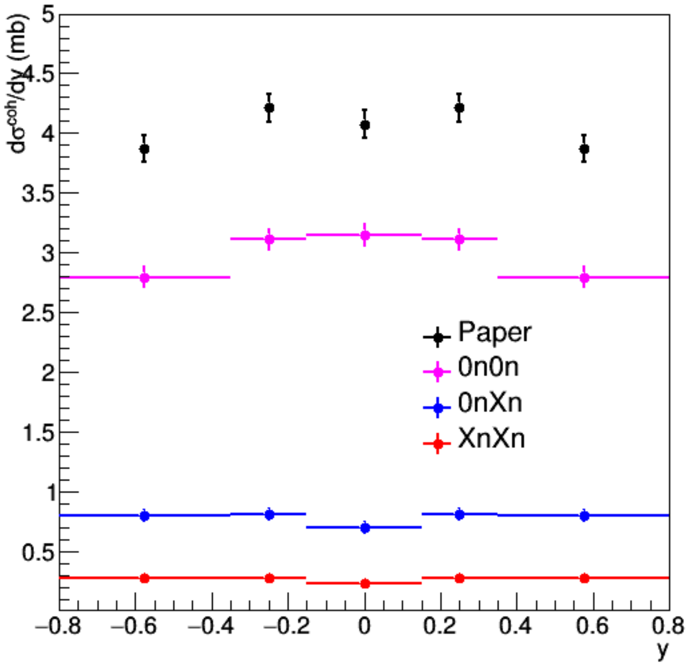


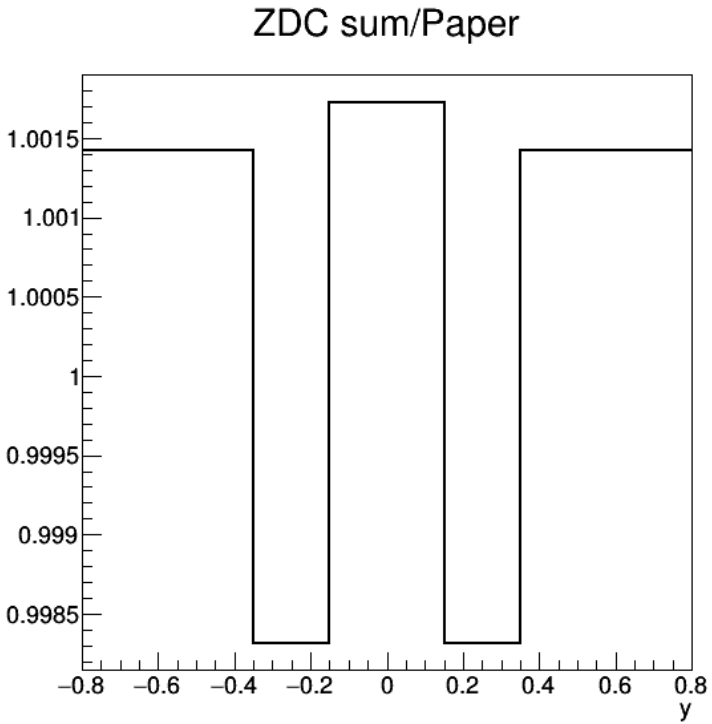




Cross section

- Sum of the cross sections in various ZDC classes agrees with the integrated cross sections evaluated per channel (from paper) within 0.2%





Summary

- Coherent J/ψ photoproduction cross section evaluated differentially in |y| and neutron emission classes, 3*3 bins
- Forward neutrons from electromagnetic dissociation measured in neutron ZDCs, events selected using timing measurements in the calorimeter
- Ingredients for x-section evaluated as function of |y| or neutron class, as needed
- Cross section corrected for event loss due to veto by charged particles from EMD
- Analysis note: [ANA1188]

Backup