News from the Pb-Pb run and future prospects for UPC from ALICE

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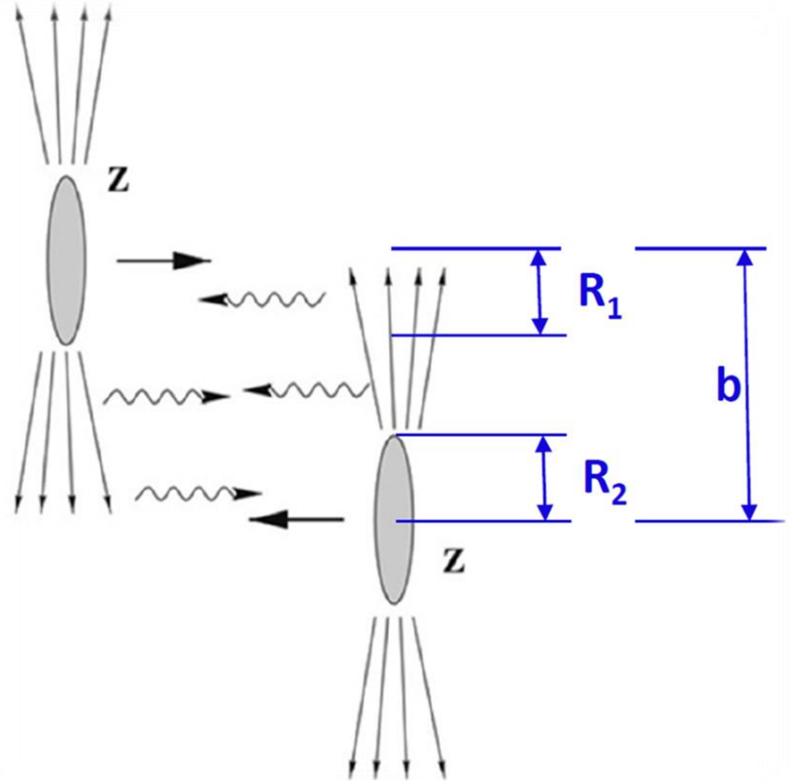
The University of Birmingham

LHC Forward Physics Meeting
CERN December 18th 2018

Plan of Talk

- Introduction
- The ALICE experiment
  - Trigger configurations
- Run 1 results
- Run 2 results and prospects
- Run 3-4 prospects
- Summary

Ultra-Peripheral Production



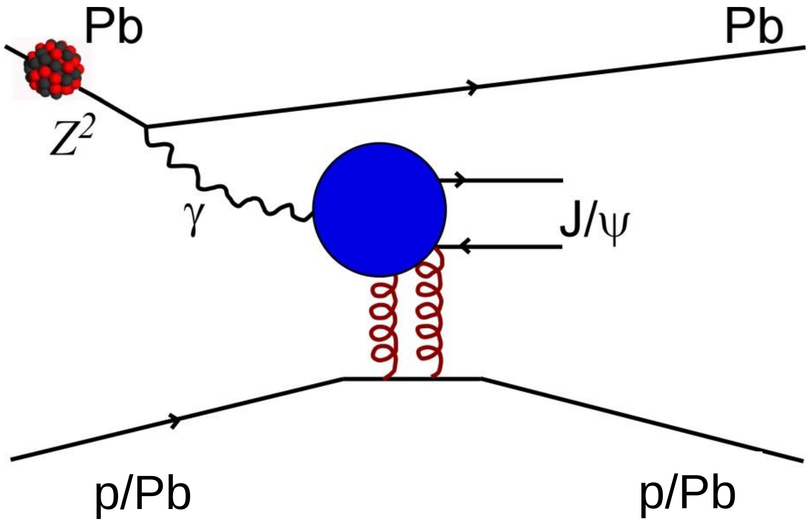
- In Ultra-Peripheral Collisions (UPC), the projectiles (Pb-Pb, p-Pb or pp) are at large impact parameters, $b > R_1 + R_2$, and so hadronic processes are greatly suppressed
- Photon flux $\propto Z^2$
- Photon virtuality $Q^2 = (\hbar c/R)^2$

  $\approx (35\ \text{MeV})^2$ for γ from Pb

J/ψ Ultra-Peripheral Production

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

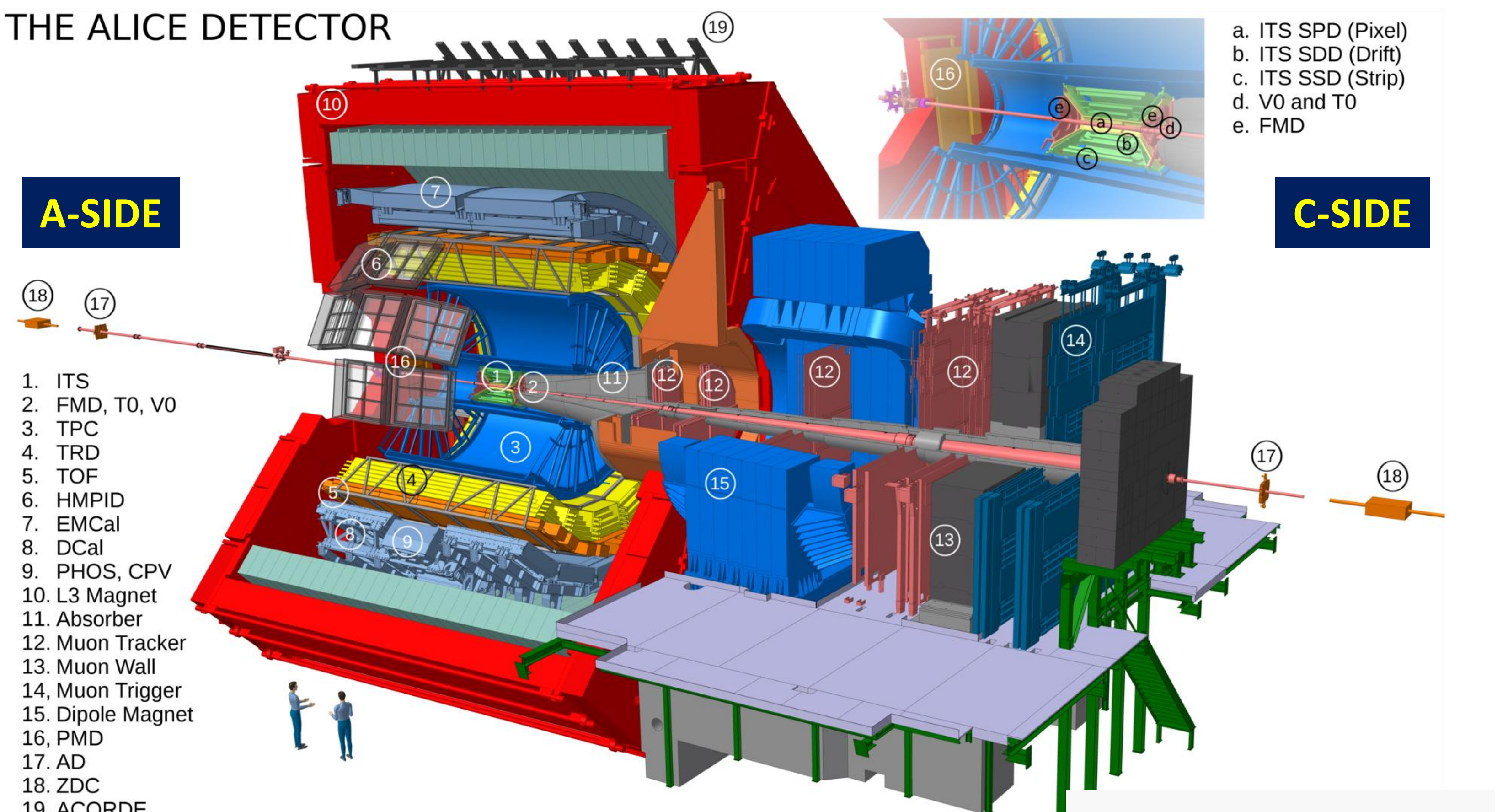
LEADING ORDER



- Essentially the same process as ep, except that the photon is emitted by a proton or *a nucleus.*
- The photon emitted by one nucleus couples to a vector meson
- At LO, the cross-section is proportional to the gluon PDF squared
- Hard scale for the J/ψ of $Q^2 \sim (M_{J/\psi}{}^2/4) \sim 2.5\ \mathrm{GeV}^2$
  - Model dependence for lighter particles (e.g. ρ)

Exclusive process: we go to very *low* multiplicities

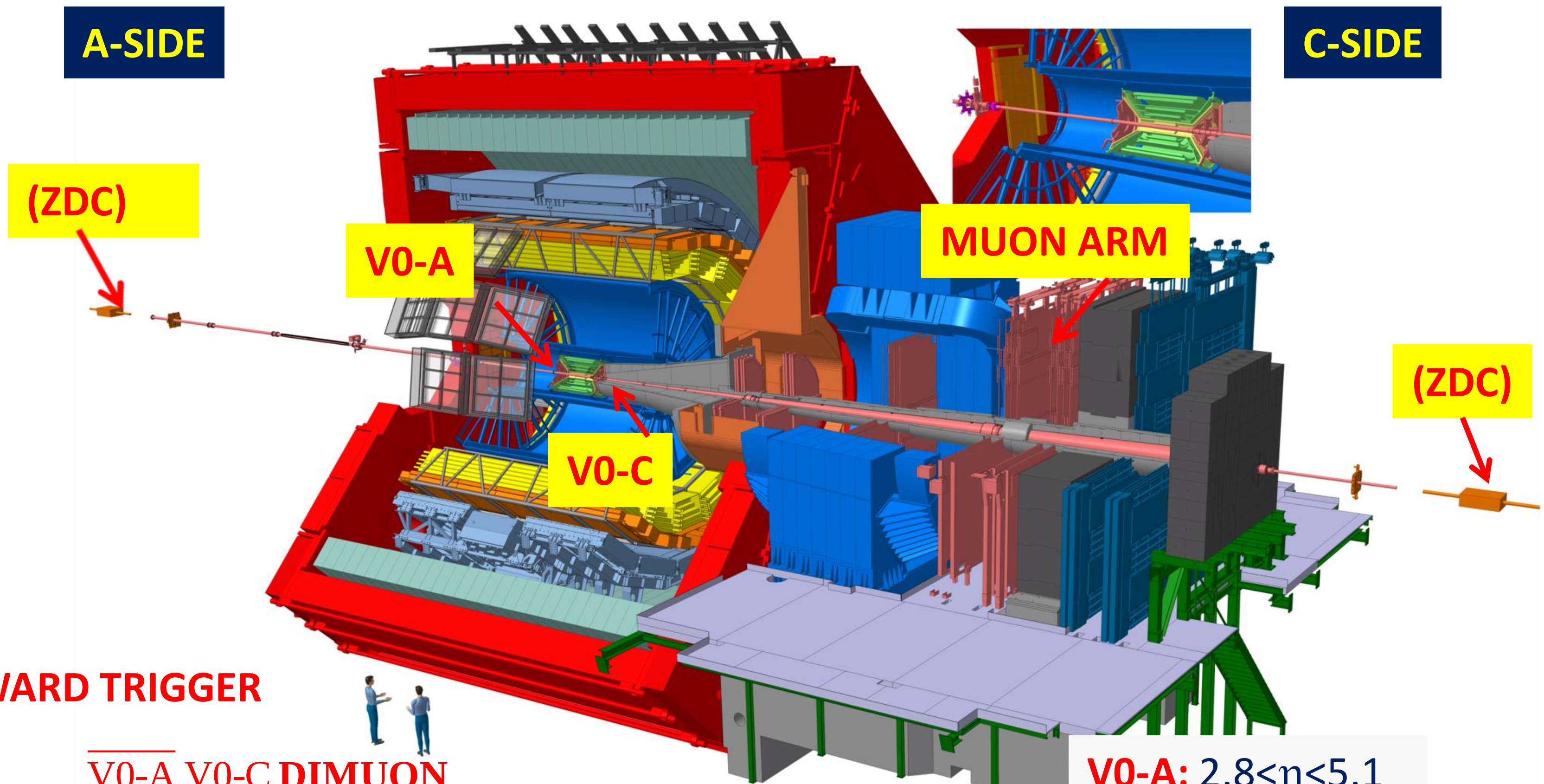
ALICE Apparatus



VZERO-A: $2.8<\eta<5.1$

VZERO-C: $-3.7<\eta<-2.7$

ALICE Apparatus



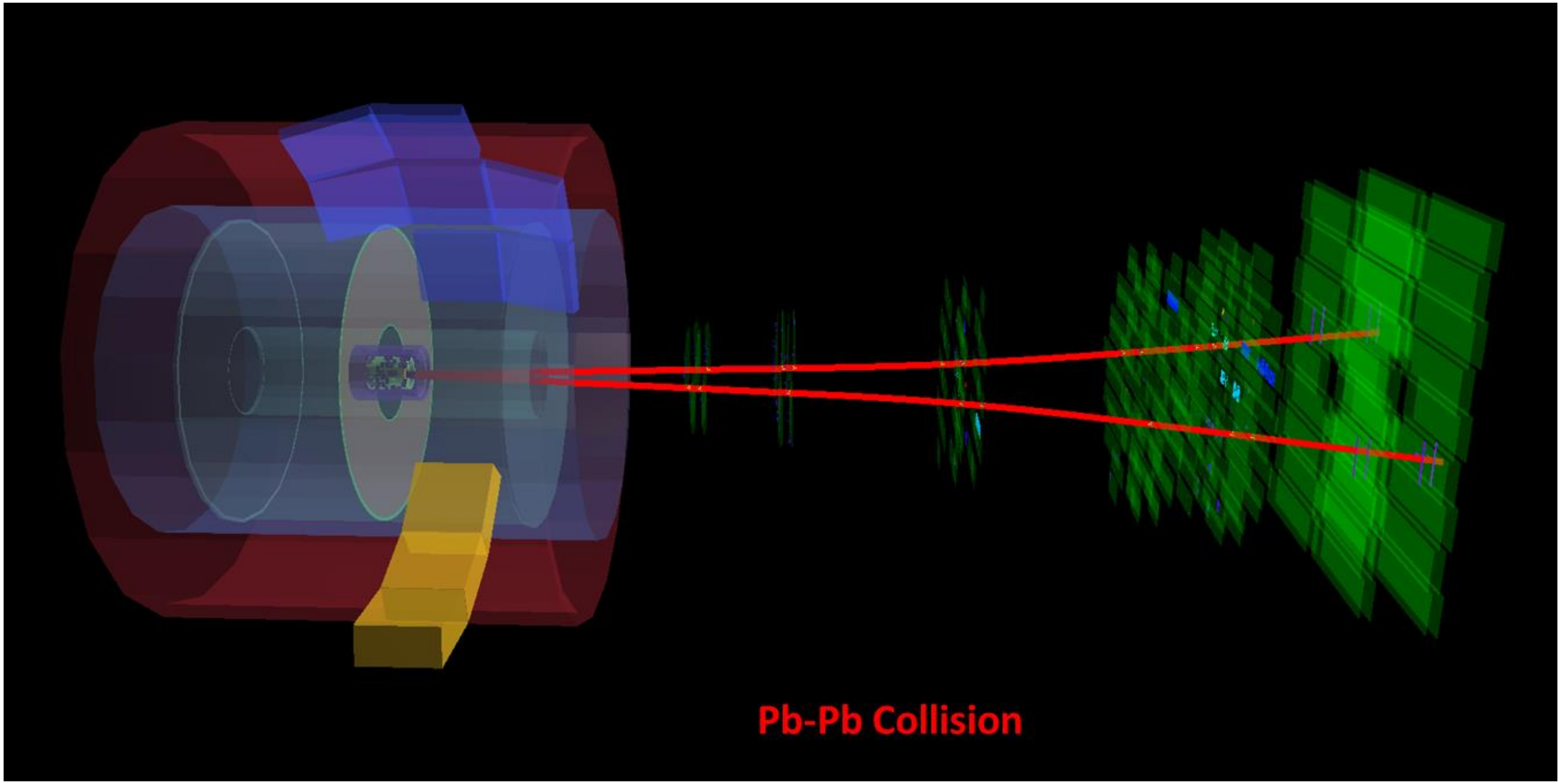
FORWARD TRIGGER

$\overline{\text{V0-A}}$.V0-C.**DIMUON**

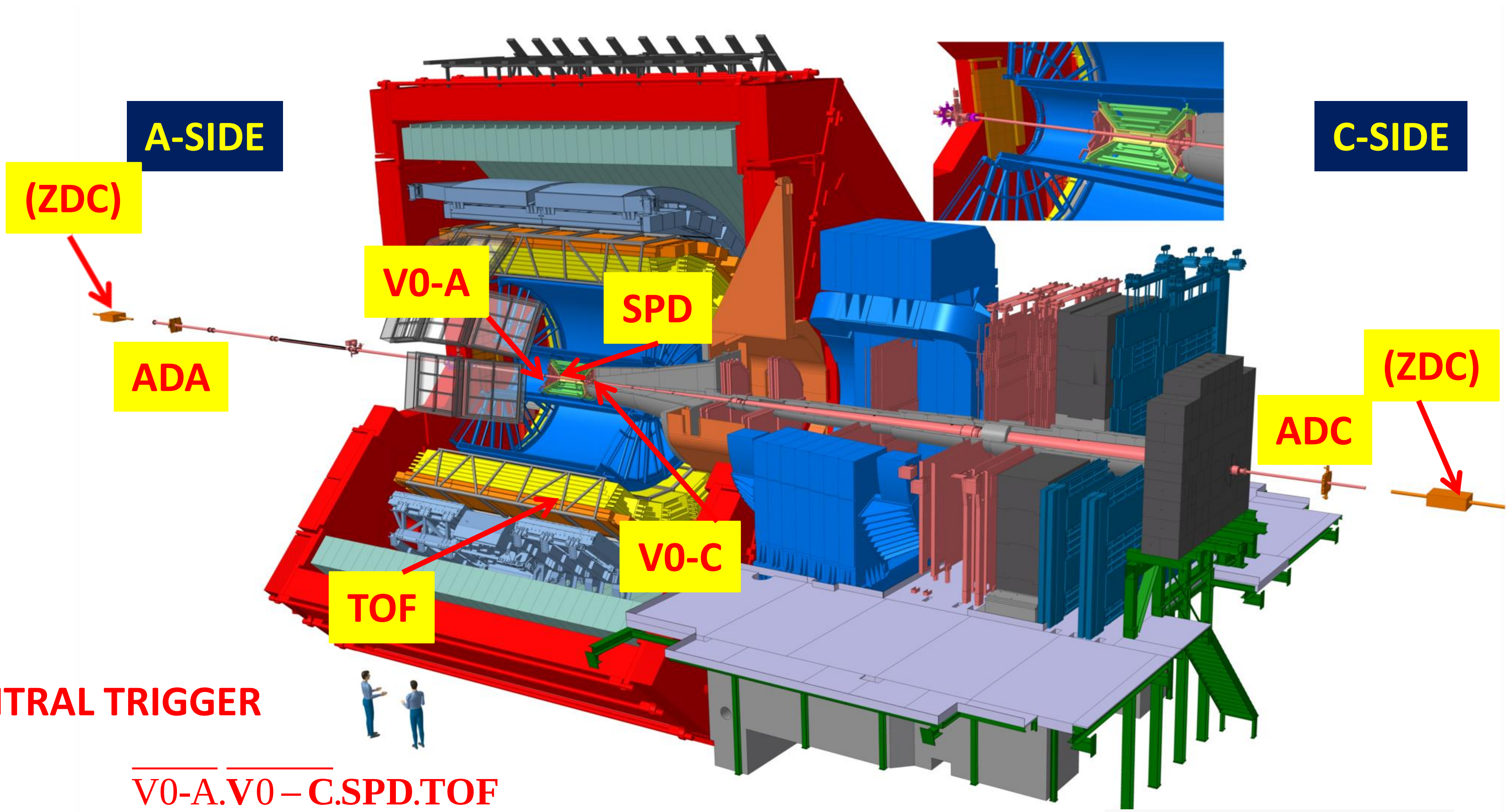
V0-A: $2.8<\eta<5.1$
V0-C: $-3.7<\eta<-2.7$

Also **AD** veto counters in Run 2, extending veto to **η~7**

Forward



ALICE Apparatus



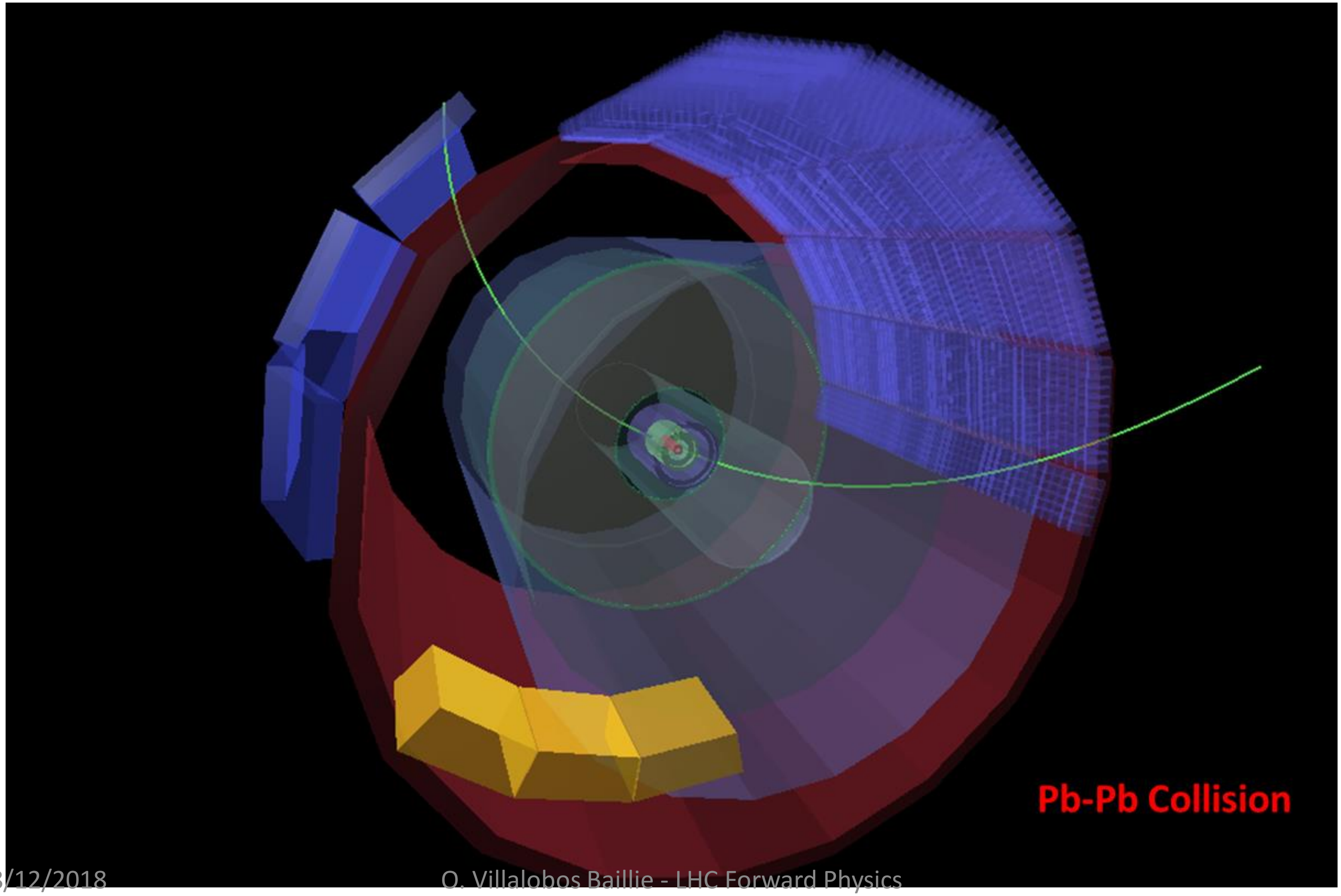
CENTRAL TRIGGER

$$\overline{\text{V0-A}}.\overline{\text{V0}-\text{C}}.\text{SPD}.\text{TOF}$$

Also **AD** veto counters in Run 2

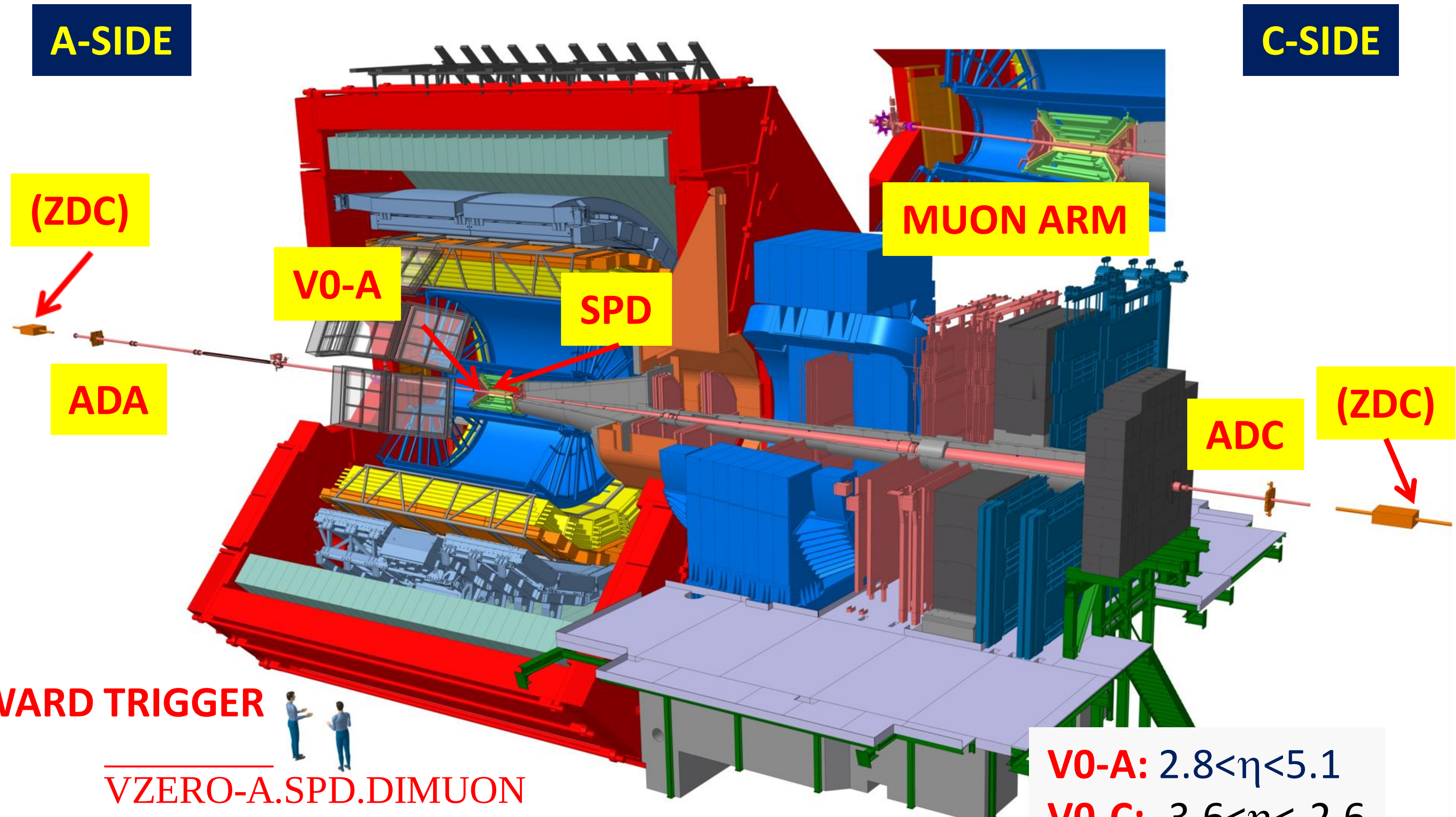
V0-A: $2.8<\eta<5.1$
V0-C: $-3.7<\eta<-2.7$

Central



ALICE Apparatus

NEW - More Later



SEMI-FORWARD TRIGGER

VZERO-A.SPD.DIMUON

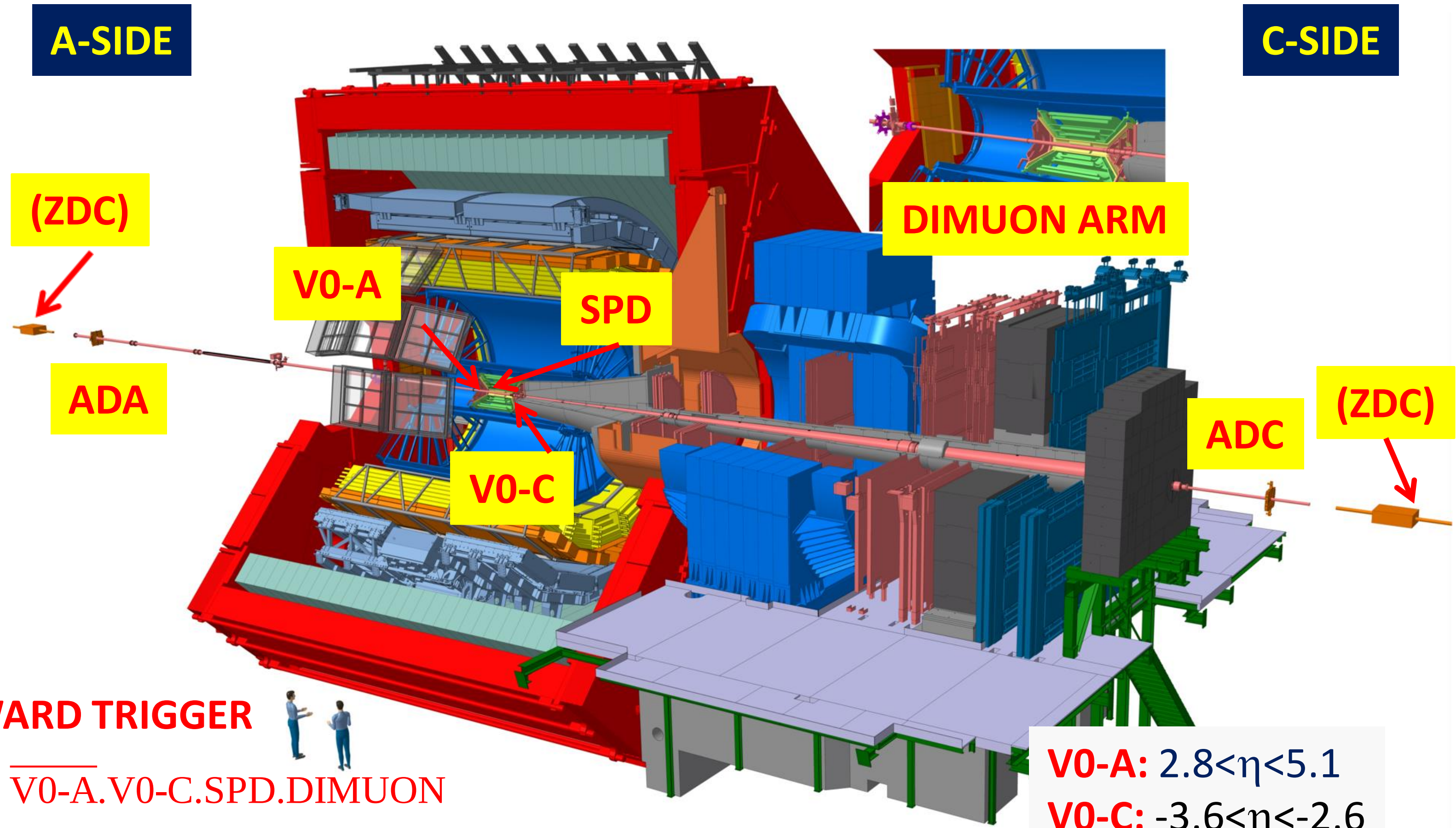
V0-A: $2.8<\eta<5.1$

V0-C: $-3.6<\eta<-2.6$

Also **AD** veto counters in Run 2

ALICE Apparatus

NEW - More Later



SEMI-FORWARD TRIGGER

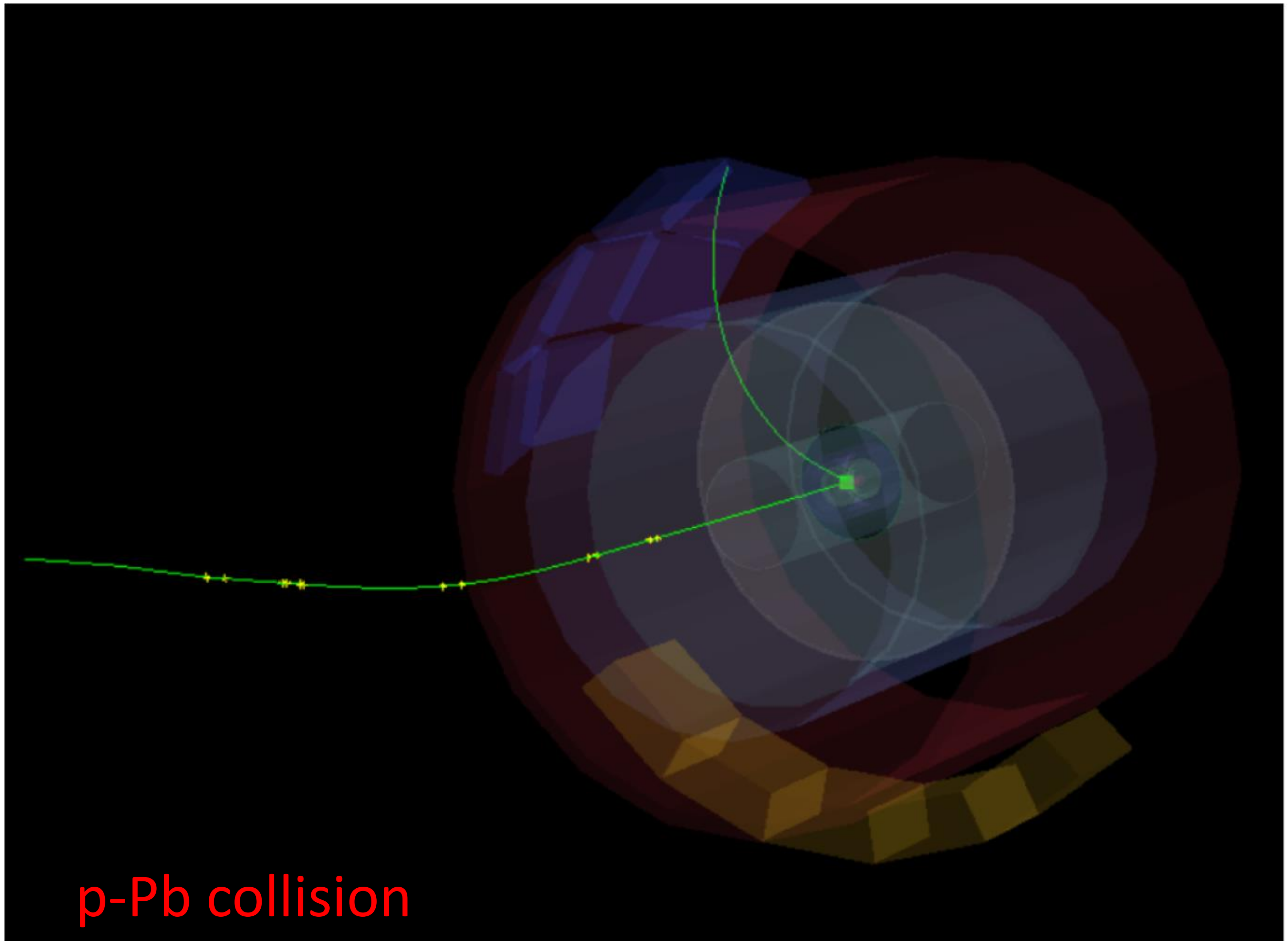
$\overline{\text{V0-A}}$.V0-C.SPD.DIMUON

V0-A: $2.8<\eta<5.1$

V0-C: $-3.6<\eta<-2.6$

Also **AD** veto counters in Run 2

Semi-Forward



Run 1 Summary

Publications

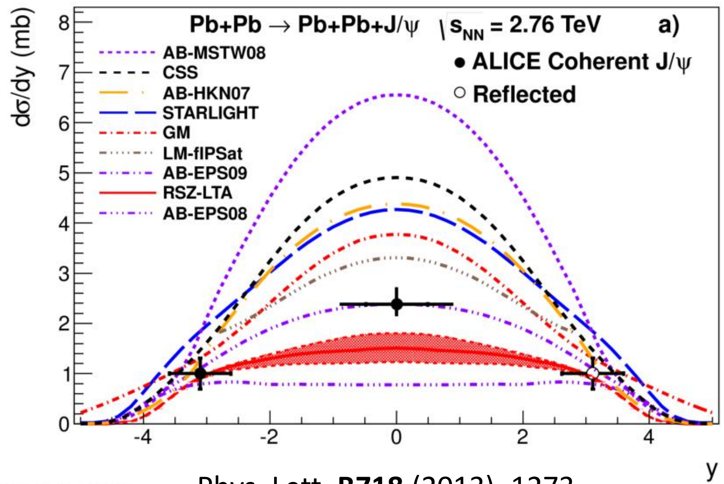
Pb-Pb 2.76 TeV per nucleon

J/ψ forward	B. Abelev et al., Phys. Lett. **B718** (2013) 1273
J/ψ central	E. Abbas et al., Eur. Phys Journal **C73** (2013) 2617
ψ(2S) central	J. Adam et al., Phys.Lett. **B751** (2015) 358
ρ^0 central	J. Adam et al., JHEP **09** (2015) 095

p-Pb 5.02 TeV per nucleon

J/ψ forward	B.B. Abelev et al., Phys. Rev. Lett. **113** (2014) 23250
J/ψ central/s.-fwd	S. Acharya et al. ArXiv:1809.03235v1

J/ψ Production-Pb-Pb



Phys. Lett. **B718** (2013) 1273
Eur. Phys Journal **C73** (2013) 2617

COHERENT

Agreement is best for models incorporating nuclear gluon shadowing.

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**
colour dipole model, dipole nucleon cross section taken from the IIM saturation model

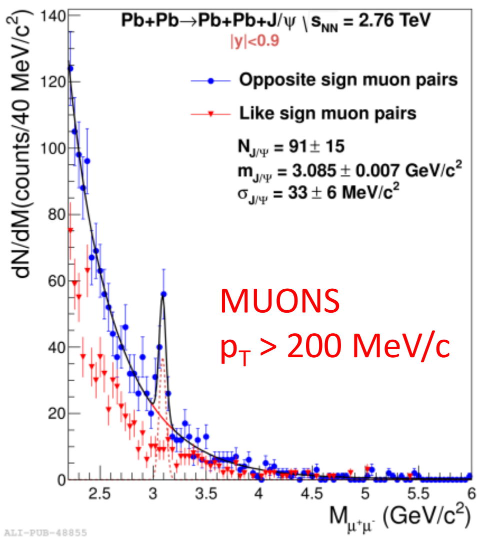
- **AB: Adeluyi and Bertulani, PRC85 (2012) 044904**
LO pQCD calculations: AB-MSTW08 assumes no nuclear effects for the gluon distribution, other AB models incorporate gluon shadowing effects according to the EPS08, EPS09 or HKN07 parameterizations

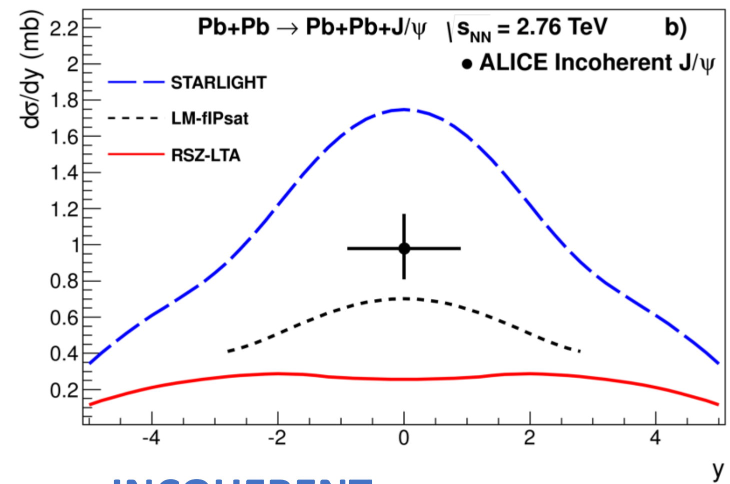
- **CSS: Cisek, Szczurek, Schäfer, PRC86 (2012) 014905**
Glauber approach accounting $c\bar{c}g$ intermediate states

- **RSZ: Rebyakova, Strikman, Zhalov, PLB 710 (2012) 252**
LO pQCD calculations with nuclear gluon shadowing computed in the leading twist approximation

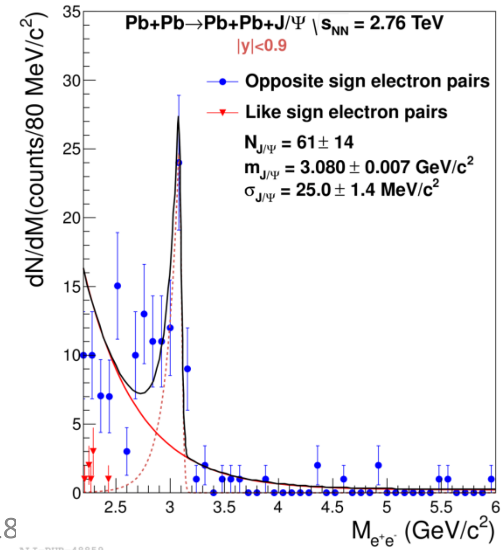
- **LM: Lappi, Mäntysaari, PRC87 (2013) 032201**
colour dipole model + saturation

J/ψ Production-Pb-Pb



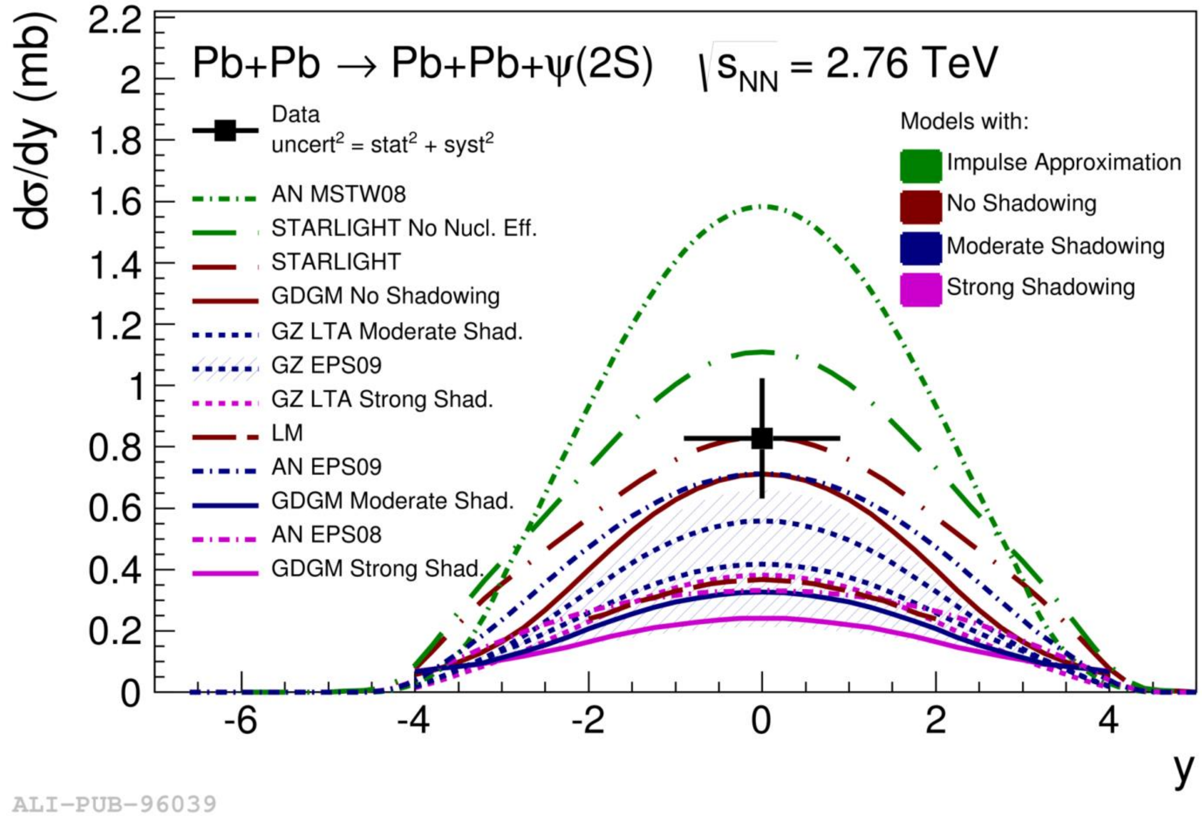


INCOHERENT Eur. Phys Journal **C73** (2013) 2617



- First measurement in Pb-Pb. Helps to constrain models
- Note photon flux cancels between coherent and incoherent measurements, so *ratio* coherent/incoherent is also a useful parameter.
- STARLIGHT overshoots both but gets ratio right.

ψ(2S) Production Pb-Pb



Several channels used:

$\psi(2S) \to \mu^+\mu^-$

$\psi(2S) \to e^+e^-$

$\psi(2S) \to J/\psi\pi^+\pi^-$; $J/\psi \to \mu^+\mu^-$

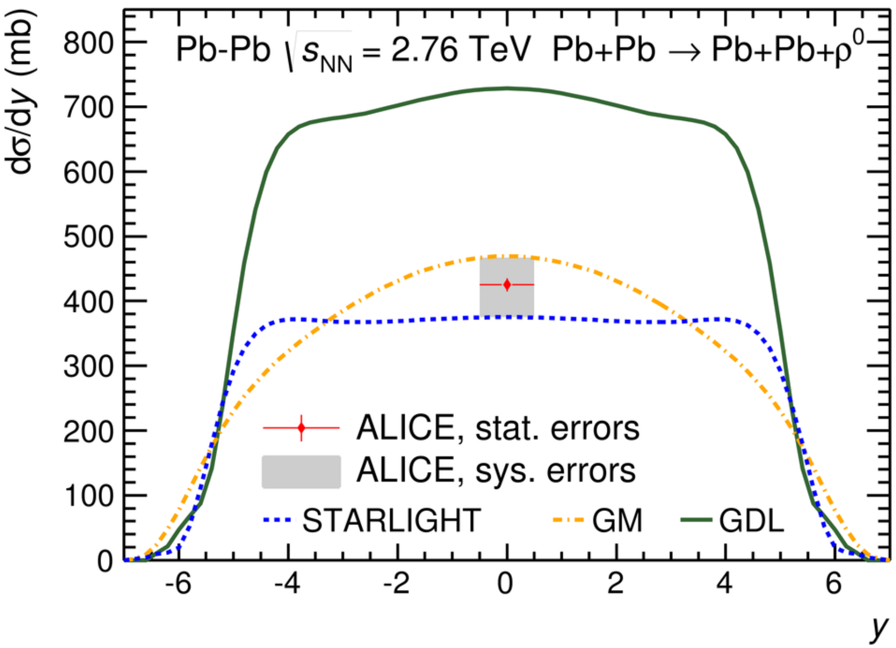
$\psi(2S) \to J/\psi\pi^+\pi^-$; $J/\psi \to e^+e^-$

Phys.Lett. **B751** (2015) 358

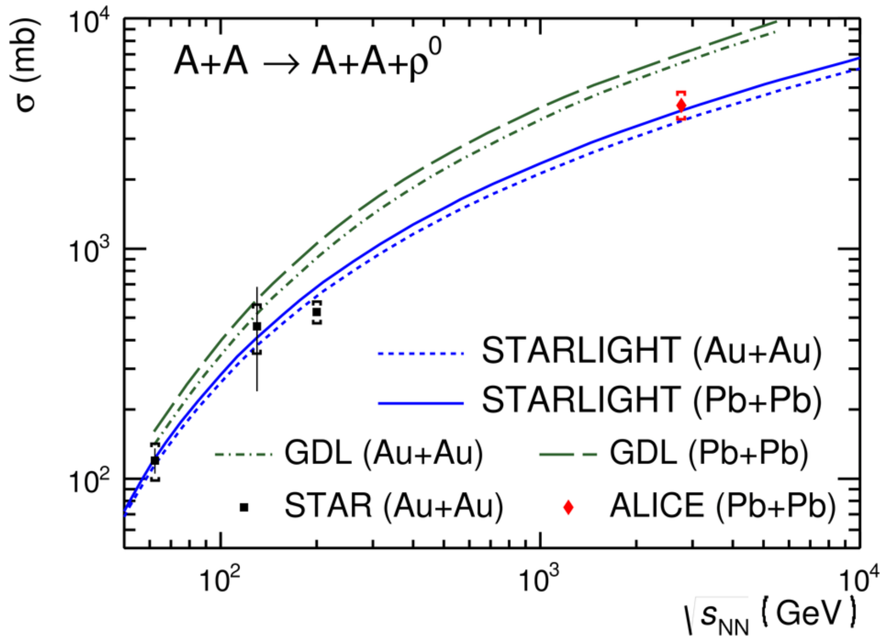
First measurement of ψ(2S) production at LHC energies

Models with moderate shadowing favoured.

ρ^0 Production   Pb-Pb

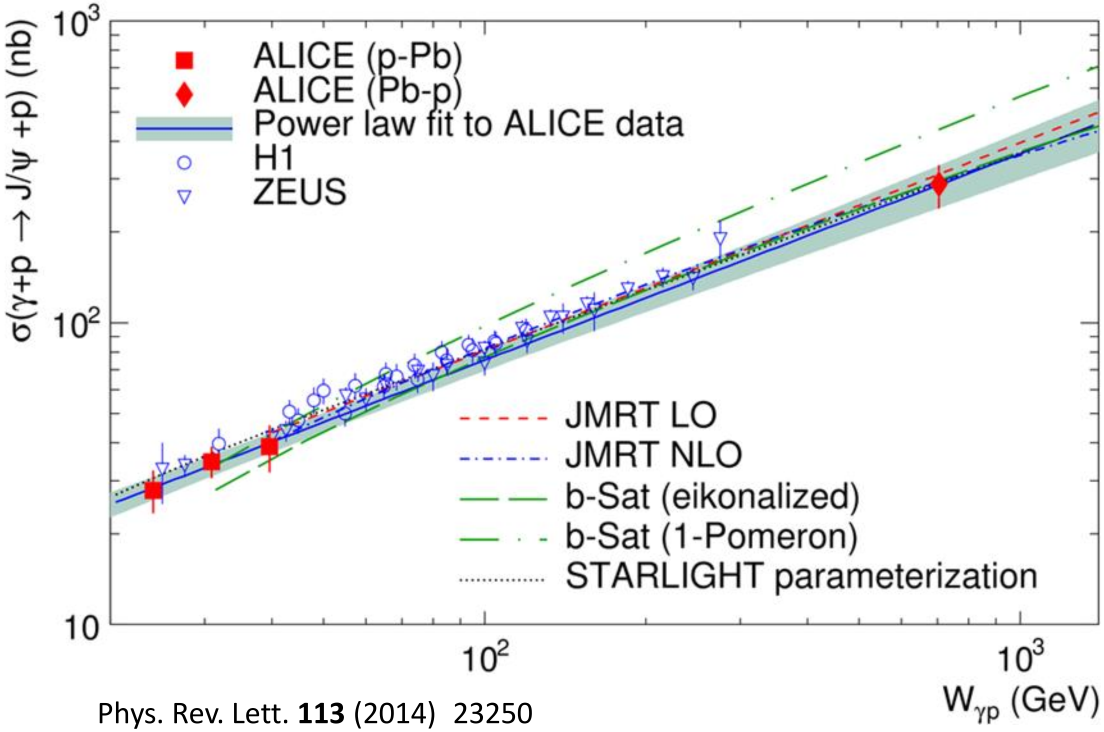


JHEP **09** (2015) 095



- First measurement of mid-rapidity d*N*/d*y* at LHC (consistent with GM (colour dipole) and STARLIGHT)
- Energy dependence consistent with STARLIGHT

J/ψ pPb

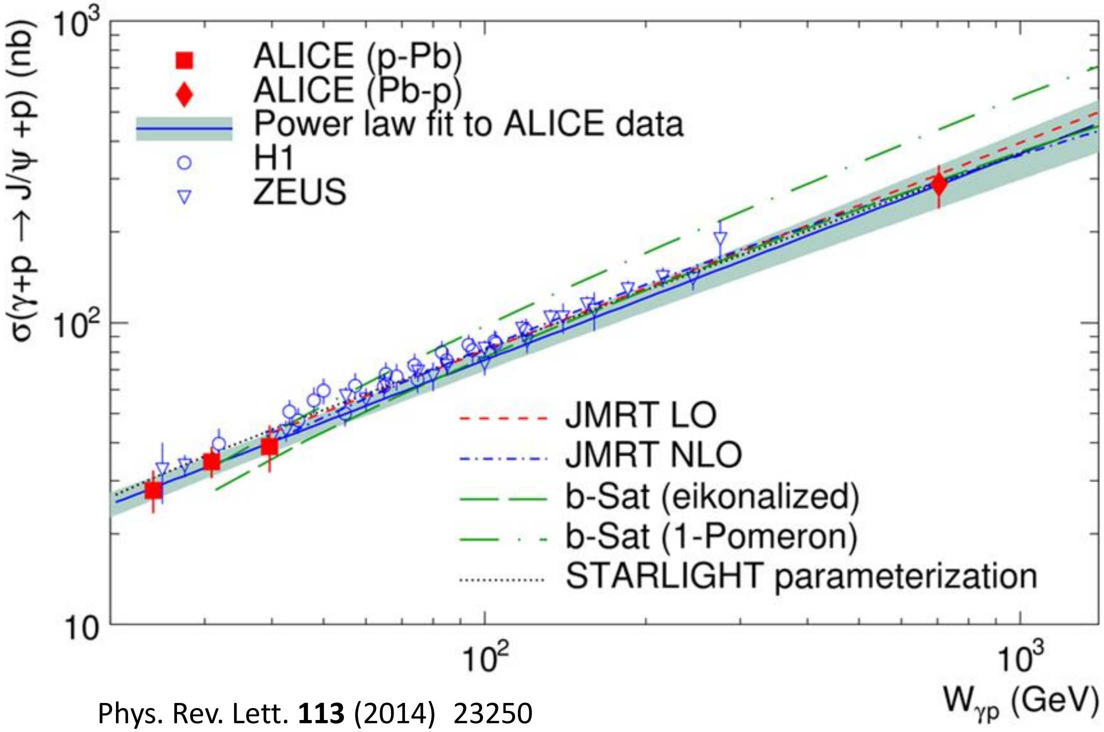


Phys. Rev. Lett. **113** (2014) 23250

- Our knowledge of the photon emitter allows us to solve for $\sigma(W_{\gamma p})$ using the measured $d\sigma/dy$
- A power law fit ($\sigma(W) \sim W^{\delta}$) to ALICE data points gives $\delta=0.67\pm0.06$.

$$\frac{d\sigma}{dy}\left(p+Pb \rightarrow p+Pb+J/\psi\right) = k\frac{dn}{dk}\sigma\left(W_{\gamma p}\right)$$

J/ψ pPb



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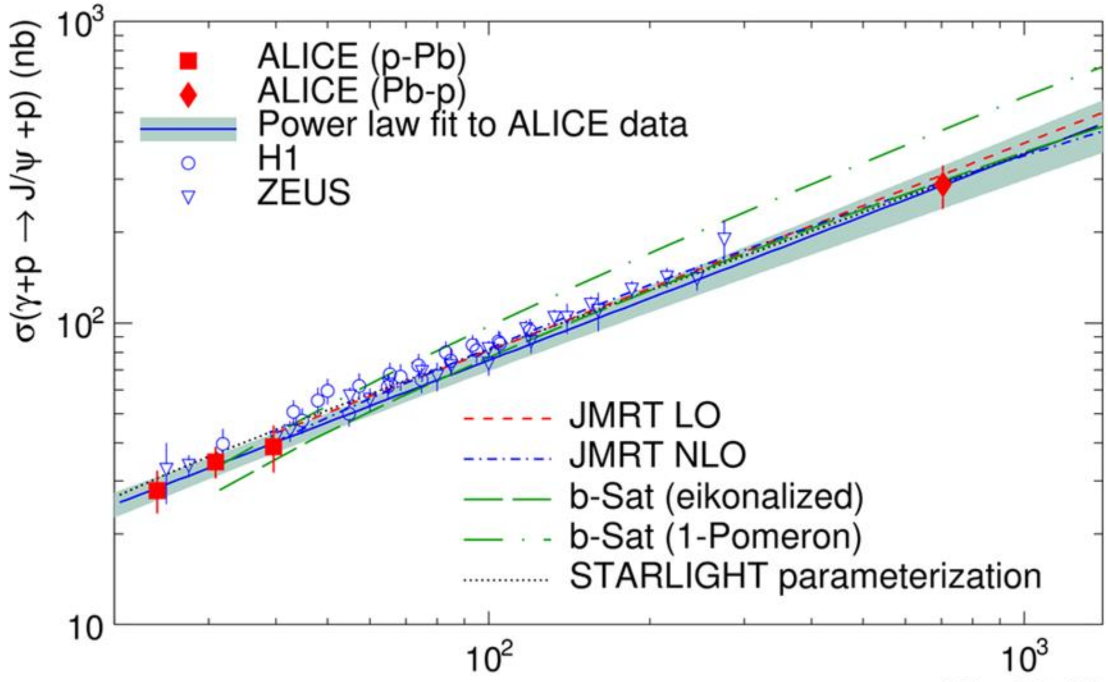
$$\frac{d\sigma}{dy}\left(p + Pb \rightarrow p + Pb + J/\psi\right) =$$

HERA Measurements

H1	δ=0.67±0.03
ZEUS	δ=0.69±0.02

J/ψ pPb



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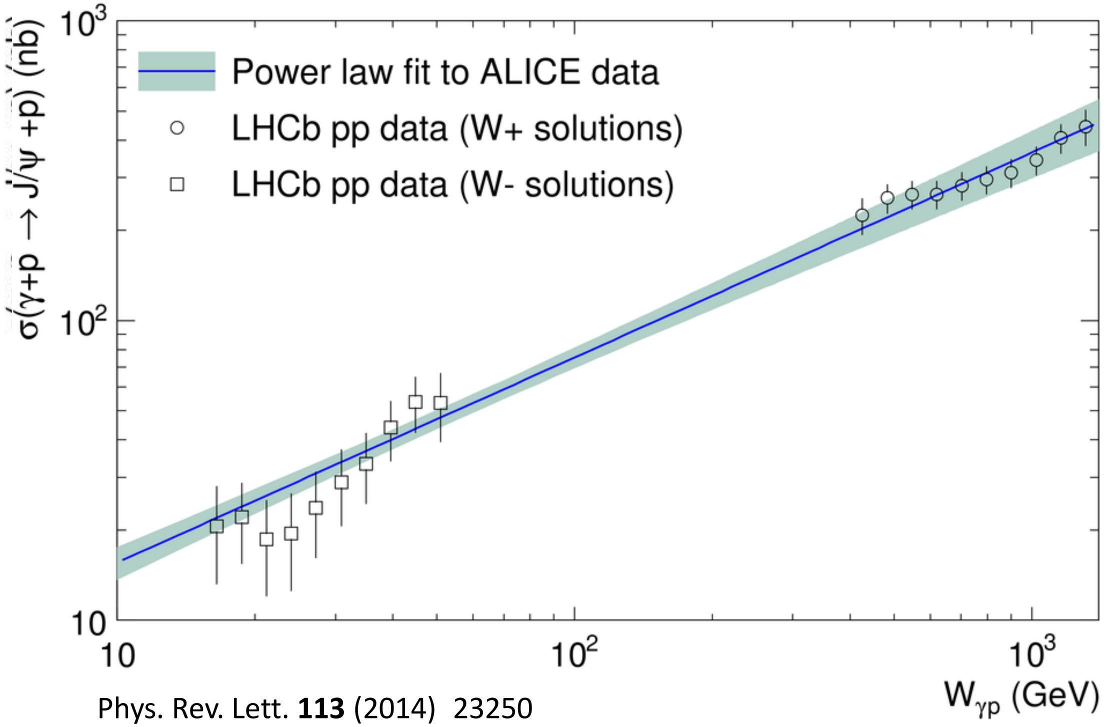
JMRT	S.P. Jones et al., JHEP **1311** (2013) 085
b-Sat	H. Kowalski, L. Motyka and G. Watt. PRD **74** 074016
LHCb	A. Aaij et al. J. Phys. G **41** 055002

J/ψ pPb



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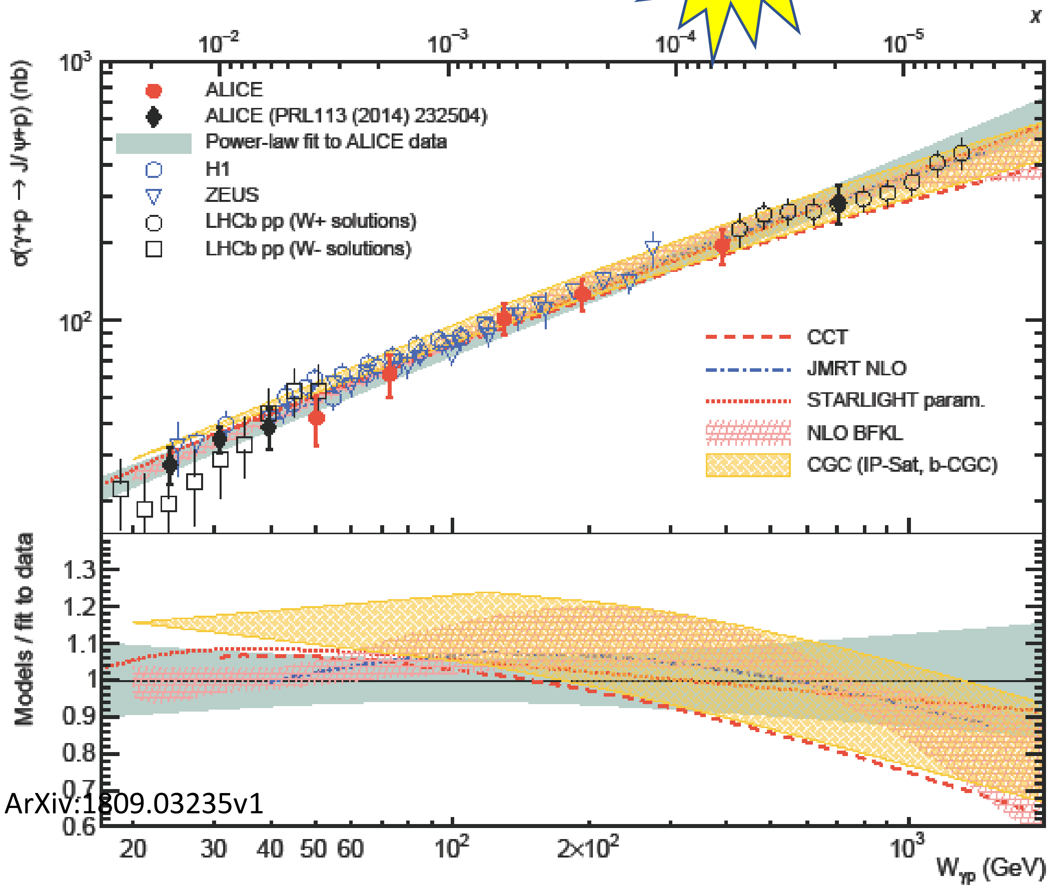
LHCb	A. Aaij et al. J. Phys. G **41** 055002

J/ψ pPb with new points

NEW

arXiv:1809.03235



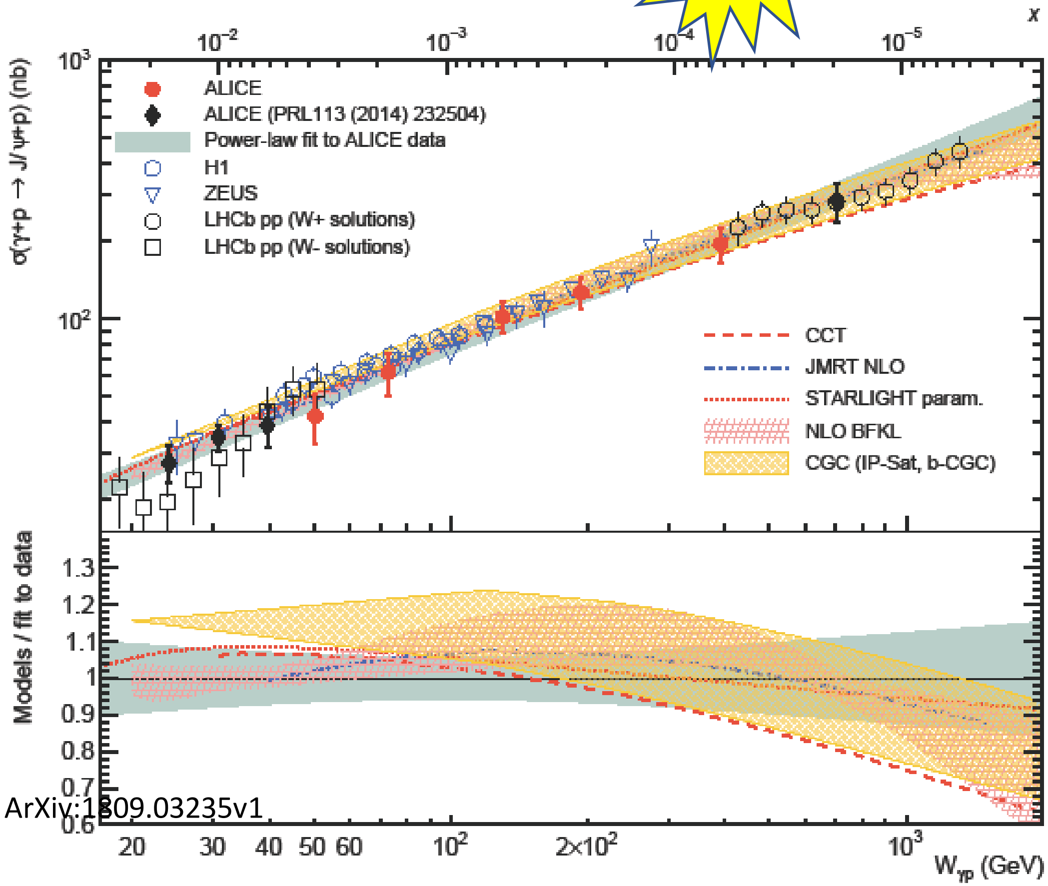
- Central and semi-forward points added
- New configurations confirm original forward spectrometer results
- Power law fit ($\sigma(W) \sim W^{\delta}$) to ALICE data points gives $\delta=0.70\pm0.05$.
- All models considered agree with data.

Combines forward, central and semi-forward configurations

J/ψ pPb with new points

NEW

arXiv:1809.03235



Combines forward, central and semi-forward configurations

CCT:
- Includes saturation in an energy dependent hot spot model.
- PLB766(2017) 186

JMRT NLO
- DGLAP formalism with main NLO contributions included.
- EPJC76 (2016) 633

Starlight:
- Parameterisation of HERA and fixed target data.
- CPhC 212 (2017) 258

NLO BFKL
- Proton impact factor from F2 HERA data.
- PRD94 (2016) 054002

CGC
- CGC models with saturation.
- PRD90 (2014) 054003

Run 2

Run2 Luminosity

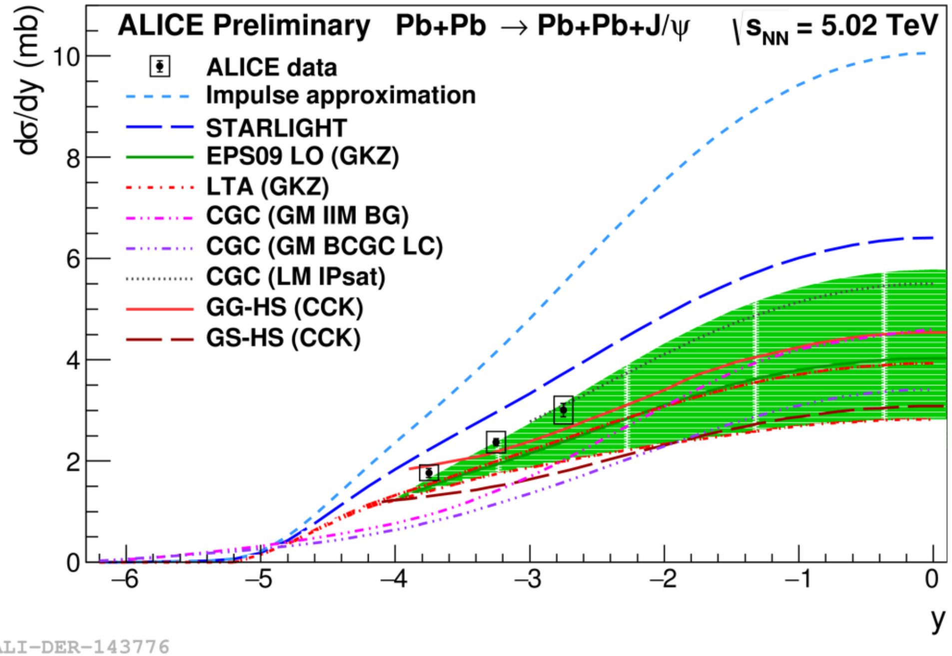
Pb Pb		Run 2	
	Run 1	2015	2018
√s	2.76	5.02	5.02
	μb^{-1}	μb^{-1}	μb^{-1}
mid-rapidity	23	94.6	250
Forward	55	216.8	546

pPb				
		Run 1	Run 2	
√s		5.02	5.02	8.16
		nb^{-1}	nb^{-1}	nb^{-1}
mid-rapidity		6.92		2.7
Forward	pPb	3.7	3.2	7.9
	Pbp	4.5		11.9

Run 2 benefits from:-

- (mostly) increased luminosity
- Higher cross section
- More effective triggers
- New Forward Detector (AD)

Forward J/ψ



- Run 2 PbPb2015: ~50 × run 1 statistics!
- Data consistent with moderate nuclear shadowing

- Impulse approximation: No nuclear effects
- STARLIGHT: VDM + Glauber

  (Klein, Nystrand *et al* Comput. Phys. Commun. **212** (2017) 258)
- EPS09 L0: EPS09 shadowing

  (Guzey, Kryshen, Zhalov, PRC **93** (2016) 055206)
- LTA: Leading Twist Approximation

  (Guzey, Kryshen, Zhalov, PRC **93** (2016) 055206)
- CGC GM: color dipole model + IIM/BCGC (Goncalves, Machado *et al*, PRC **90** (2014) 015203, JPG **42** (2015) 105001)
- CGC LM: Color dipole model + IPSat

  (Lappi, Mantysaari, PRC **83** (2011)065202; **87** (2013) 032201)
- GG-HS: hot spots with Glauber-Gribov

  (Cepila, Contreras and Krelina, PRC **97** (2018) 024901)
- GS-HS: hot spots with geometrical scaling

  (Cepila, Contreras and Krelina, *ibid.)*

Extraction of low *x* and high *x* contributions

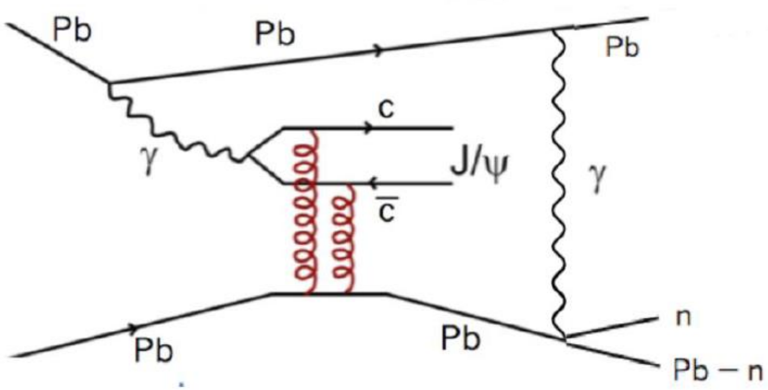
- Kinematics provides dσ/dy, but this is not uniquely linked to dσ/dx

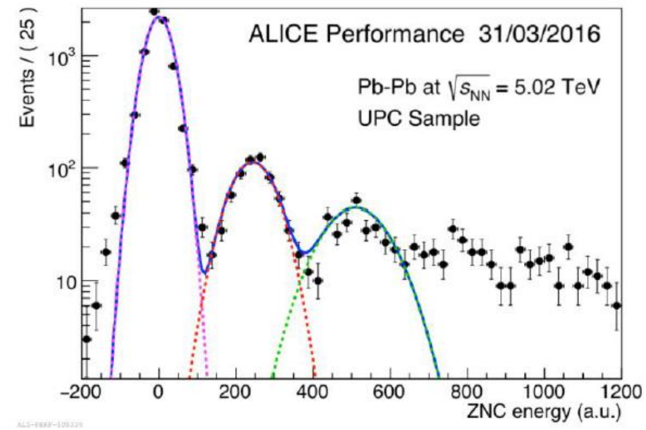
$$\frac{\mathrm{d}\sigma}{\mathrm{d}y} = n(y)\frac{\mathrm{d}\sigma_{\gamma\mathrm{Pb}}}{\mathrm{d}y}\bigg|_{+y} + n(-y)\frac{\mathrm{d}\sigma_{\gamma\mathrm{Pb}}}{\mathrm{d}y}\bigg|_{-y}$$

High-*x* Low-*x*

- Flux factors $n(\pm y)$ can be precisely calculated, but still leaves two unknown cross sections.
- However, ZDC can help resolve the ambiguity. Look at neutron emission to decouple contributions

Decoupling of *x*-contributions





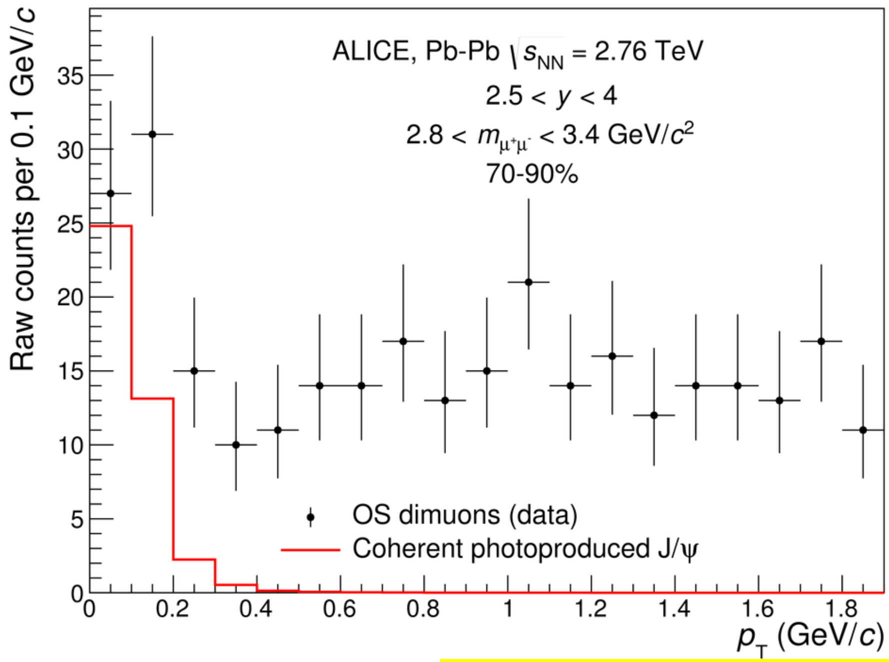
- Fluxes including neutron emission can be calculated precisely. So, in notation where 0N0N means no emission and (e.g.) 0NXN means one sided neutron emission, we have

$$\frac{d\sigma_{0N0N}}{dy} = n_{0N0N}(y)\left.\frac{d\sigma_{\gamma\mathrm{Pb}}}{dy}\right|_{+y} + n_{0N0N}(-y)\left.\frac{d\sigma_{\gamma\mathrm{Pb}}}{dy}\right|_{-y}$$

$$\frac{d\sigma_{0NXN}}{dy} = n_{0NXN}(y)\left.\frac{d\sigma_{\gamma\mathrm{Pb}}}{dy}\right|_{+y} + n_{0NXN}(-y)\left.\frac{d\sigma_{\gamma\mathrm{Pb}}}{dy}\right|_{-y}$$

2 equations
2 unkowns
OK

Peripheral collisions



ALICE PRL 116 (2016) 222301

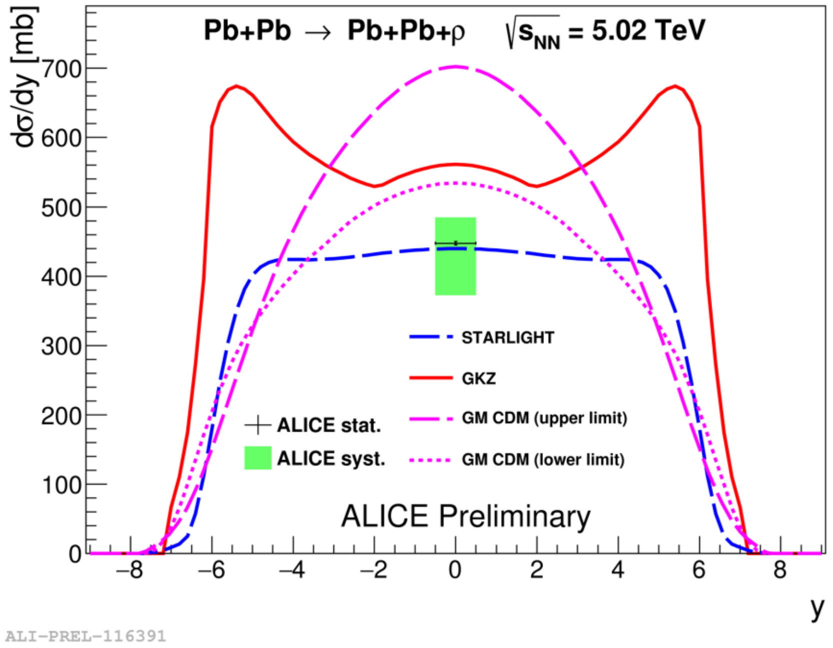
$$\left.\frac{\mathrm{d}\sigma_{\gamma \mathrm{Pb}}}{\mathrm{d}y}\right|_{-y} = \left(n_\gamma^{\mathrm{P}}(y)\frac{\mathrm{d}\sigma^{\mathrm{U}}_{\mathrm{PbPb}}}{\mathrm{d}y} - n_\gamma^{\mathrm{U}}(y)\frac{\mathrm{d}\sigma^{\mathrm{P}}_{\mathrm{PbPb}}}{\mathrm{d}y} \right) / F(y)$$

$$\left.\frac{\mathrm{d}\sigma_{\gamma \mathrm{Pb}}}{\mathrm{d}y}\right|_{y} = \left(n_\gamma^{\mathrm{U}}(-y)\frac{\mathrm{d}\sigma^{\mathrm{P}}_{\mathrm{PbPb}}}{\mathrm{d}y} - n_\gamma^{\mathrm{P}}(-y)\frac{\mathrm{d}\sigma^{\mathrm{U}}_{\mathrm{PbPb}}}{\mathrm{d}y} \right) / F(y)$$

J.G. Contreras PRC 96 (2017) 015203

- In *peripheral* Pb-Pb collisions, $b<R_1+R_2$, and hadronic interactions occur. However, the strong fields are still there, so photonuclear interactions can also still take place.
- The very sharp low p_T peak in the peripheral p_T spectrum indicates this is happening.
- The hadronic activity gives an indication of the impact parameter, and again gives us additional flux equations to disentangle the low-*x* and high-*x* contributions

ρ^0 cross section at 5.02 TeV



- STARLIGHT: VDM + Glauber. Klein, Nystrand et al: Comput. Phys. Commun. 212 (2017) 258
- GKZ: Gribov-Glauber shadowing. Guzey et al, PLB752 (2016) 51, PRC93 (2016) 055206
- GM CDM. Gonçalves, Machado et al, PRC80 (2009), 054901, PRC91 (2015) 025203

ρ photoproduction cross section compatible with STARLIGHT but Gribov-Glauber shadowing predictions are still above data

Other results in the pipeline

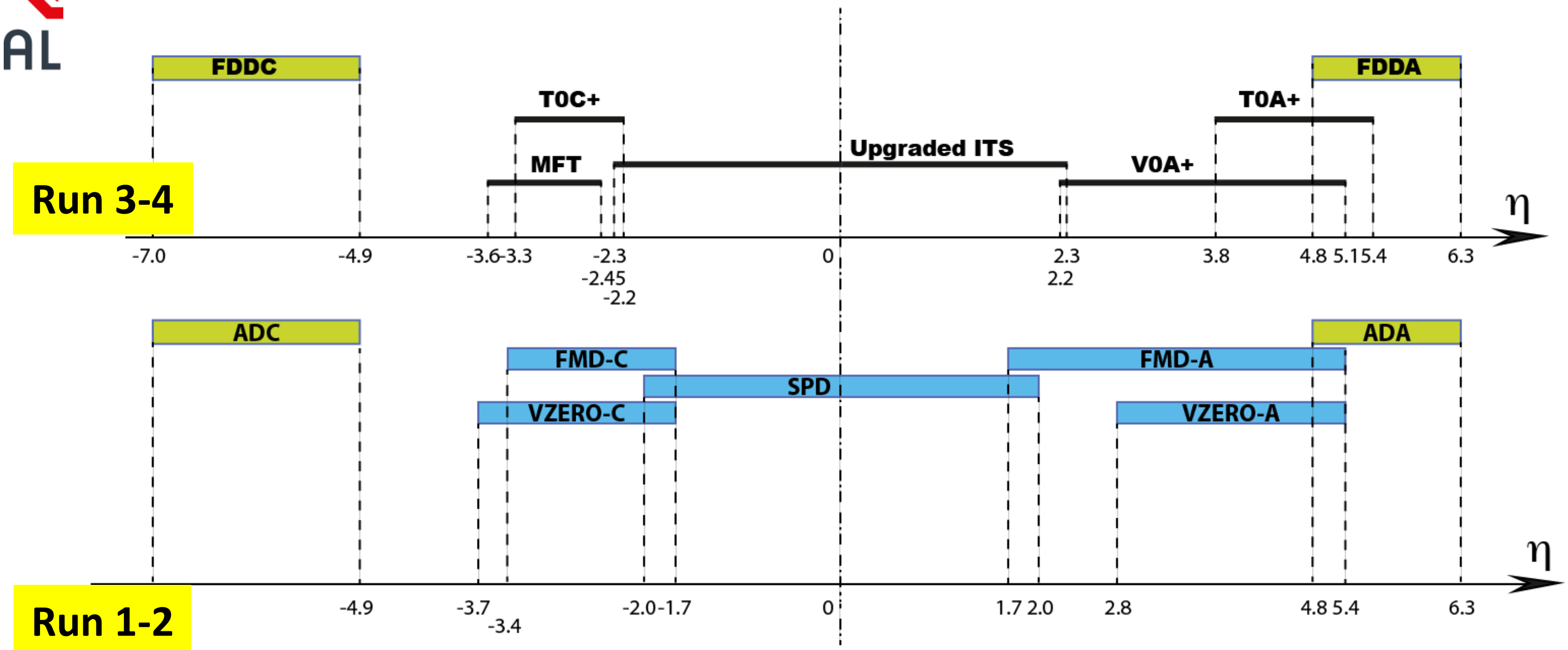
- We expect to release results on central J/ψ, $\psi(2S)$ and ρ^0 shortly
- We are analysing (in particular) the Pb-p 8.16 TeV forward J/ψ data, which will allow us to measure the γp energy spectrum up to higher than 1 TeV.
- Study of ρ^0 production in 5.44 TeV Xe-Xe collisions well underway. New handle on system size dependence.
- Data just taken (2018) in 5.02 TeV Pb-Pb promise higher statistics at forward rapidity than 2015 data. Allows more differential studies.

Run 3/4

New readout and detectors

- To cope with the increased collision rate for Run 3 we will have a major upgrade in LS2, in which detectors will prepare for *continuous readout*.
- Most ALICE signatures are complex and are embedded in very high multiplicity events: not suitable for conventional triggers.
- Instead, in continuous readout, all data are read out and analysed by a huge processor farm, allowing selections to be made on fully processed events.
  - Pb-Pb. Record everything
  - pp, pPb (?) filter in HLT before recording.
- Triggering limited to flagging bunch crossings in which "something happened" as pointers for reconstruction.
- In principle challenging for UPC, as here the minimum bias trigger *does not fire*.

Layout



- In runs 1 and 2, VZERO, FMD and SPD were so arranged as to provide continuous rapidity cover in -3.7 < y < 5.4.
- They will be replaced by a new ITS, and a new Fast Interaction Trigger (FIT) consisting of upgraded V0 and T0 elements, adapted for continuous readout.
- This allows us to tag or veto dissociative production in p-Pb, and improve the purity of the exclusive J/ψ sample in Pb-Pb
- There are predictions that dissociative photoproduction might be sensitive to gluon saturation in the proton (Cepila, Contreras and Tapia Takaki, PL **B766** (2017) 186)

UPC events in Run 3

- Look in time intervals with primary vertex formed from two tracks, and follow them to TOF to look for associated hit, which gives bunch crossing of collision. Require at least one match.
- Verify that vetoes are satisfied for specified bunch crossing.
- ADVANTAGE – Reduced trigger efficiency losses
- ADVANTAGE – No competition with other signatures of interest for bandwidth. We collect everything.

Potential for measurement

- In ALICE, the yields are to be calculated on an expected run 3-4 integrated luminosity of

  13 nb^{-1} (Pb-Pb); 1 pb^{-1} p-Pb; 6 pb^{-1} (pp 5.5 TeV); 200 pb^{-1} (pp 14 TeV)

  (latest figures)
- All signatures for heavy vector mesons (forward, central, semi-forward).
- Next slides show potential yields estimated using STARlight, adjusted for nuclear shadowing
  - No correction for acceptance or reconstruction efficiency beyond enforcing rapidity coverage.
  - Branching ratios taken into account

Expected yields – Pb-Pb

Central 1: |y|<0.9; Central 2: |y|<2.4; Forward 1: 2.5<y<4.0; Forward 2: 2<y<5

PbPb						
Meson	σ	All Total	Central 1 Total	Central 2 Total	Forward 1 Total 1	Forward 2 Total
$\rho \to \pi^+\pi^-$	5.2b	68 B	5.5 B	21B	4.9 B	13 B
$\rho' \to \pi^+\pi^-\pi^+\pi^-$	730 mb	9.5 B	210 M	2.5 B	190 M	1.2 B
$\phi \to K^+K^-$	0.22b	2.9 B	82 M	490 M	15 M	330 M
$J/\psi \to \mu^+\mu^-$	1.0 mb	14 M	1.1 M	5.7 M	600 K	1.6 M
$\psi(2S) \to \mu^+\mu^-$	30μb	400 K	35 K	180 K	19 K	47 K
$Y(1S) \to \mu^+\mu^-$	2.0 μb	26 K	2.8 K	14 K	880	2.0 K

CERN-LPCC-2018-07

13 pb^{-1} Pb-Pb

For comparison, in run 2 we collected about 6K J/ψ events in the "Forward 1" interval (PbPb2015)

Expected yields – pPb

Central 1: |y|<0.9; Central 2: |y|<2.4; Forward 1: 2.5<y<4.0; Forward 2: 2<y<5

pPb - lead shine, γp

Meson	σ	All Total	Ctl. 1 Total	Ctl. 2 Total	FW 1 Total	FW 2 Toal	BW 1 Total	BW 2 Total
$\rho \to \pi^+\pi^-$	35 mb	70 B	3.9 B	15 B	2.0 B	5.5 B	850 M	2.0 B
$\phi \to K^+K^-$	870 μb	1.7 B	65 M	290 M	22 M	120 M	9.7 M	52 M
$J/\psi \to \mu^+\mu^-$	6.2 μb	12 M	1.0 M	5.2 M	260 K	800 K	180 K	430 K
$\psi(2S) \to \mu^+\mu^-$	134 nb	270 K	22 K	110 K	6.0 K	18 K	3.2 K	7.7 K
$\Upsilon(1S) \to \mu^+\mu^-$	5.74 nb	11 K	1.1 K	5.4 K	310	880	41	100

Lead Emits photon

pPb - proton shine, γA

Meson	σ	All Total	Ctl. 1 Total	Ctl. 2 Total	FW 1 Total	FW 2 Total	BW 1 Total	BW 2 Total
$\rho \to \pi^+\pi^-$	531μb	1.1 B	83 M	360 M	20 M	44 M	56 M	150 M
$\phi \to K^+K^-$	23 μb	46 M	1.3 M	8.0 M	120 K	1.7 M	210 K	3.9 M
$J/\psi \to \mu^+\mu^-$	333 nb	670 K	55 K	290 K	14K	36 K	15 K	41 K
$\psi(2S) \to \mu^+\mu^-$	8.9 nb	18 K	1.5 K	7.9 K	380	990	380	1.0 K
$\Upsilon(1S) \to \mu^+\mu^-$	0.43 nb	860	93	460	14	34	14	30

Proton Emits Photon ≤ 10%

CERN-LPCC-2018-07

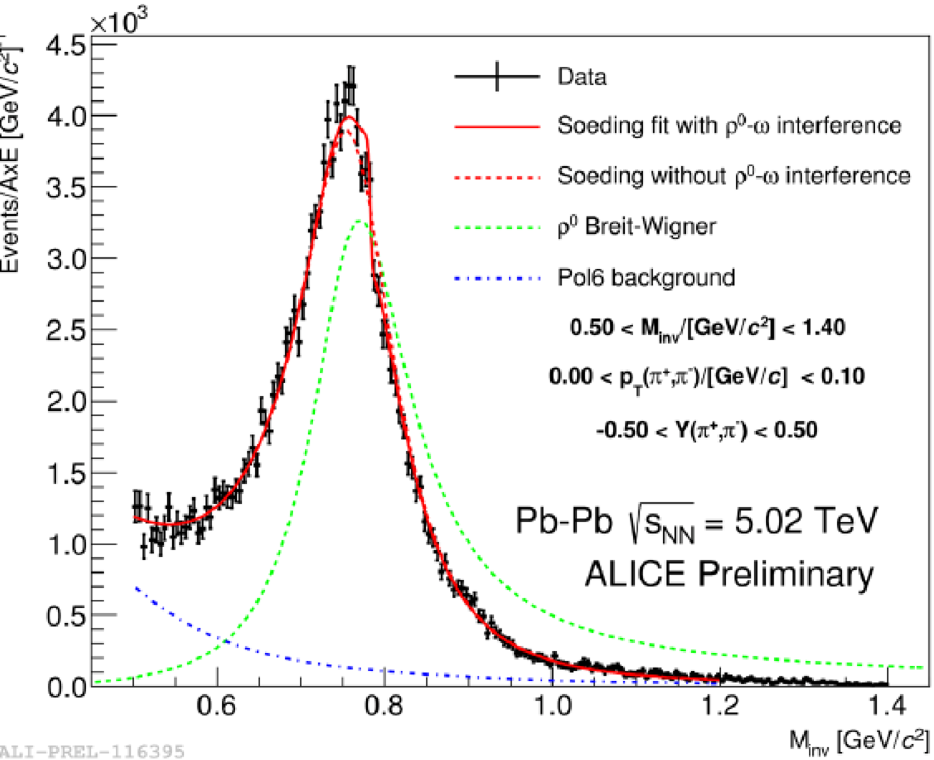
1 pb^{-1} pPb

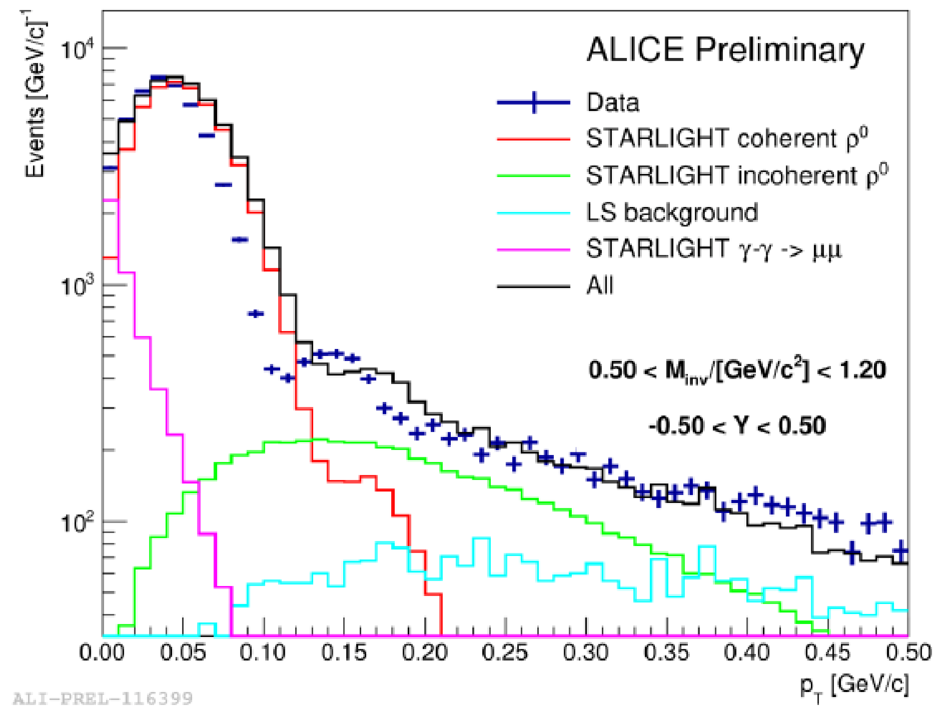
Summary

- Run 1 harvest of results shows the potential of UPC in heavy ion collisions to study photonuclear processes.
  - Exclusive vector meson production the main route for ALICE
- Run 2 already yields considerably higher statistics. Studies now nearing completion will give more detailed information on production.
- Massive increase in statistics in runs 3 and 4 should allow very detailed differential distributions.
  - Detailed access to low-*x* region in gluon pdf for protons
  - Big improvement in understanding of nuclear shadowing from A-A collisions.
  - In pPb large sample allows separation of "lead-shine" (dominant) and "proton shine" components, where *proton-shine* allows new access to low-*x* Pb-Pb at $x \sim 10^{-5}$.

Backup

ρ^0 photoproduction in Pb-Pb @ 5 TeV





$$\frac{d\sigma}{dm_{\pi\pi}} = |A \cdot BW + B + C \cdot e^{i\phi} \cdot BW|^2 + N \cdot \text{pol6}$$

- Second diffractive peak clearly visible
- Coherent p_T distribution from STARLIGHT significantly wider than data
  => access impact-parameter dependent shadowing effects (e.g. Guzey, Strikman, Zhalov: PRC 95, 025204 (2017))

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