Vector Meson production in Ultra-Peripheral Collisions at the ALICE experiment

O. Villalobos Baillie for the ALICE Collaboration

The University of Birmingham

James Stirling Memorial Conference
Durham September 18th 2019

Plan of Talk

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

Durham Connection

- ALICE members invited by James Stirling as from about 2003 for meetings in Durham on different physics topics that could be of mutual interest.
  - Centred on pp physics on the whole.
- J/ψ production and $\gamma\gamma \rightarrow l^+l^-$ figured early. In particular we were asked to think about the γγ process.

Durham Connection

- Invited by James Stirling as from about 2003 for meetings in Durham on different physics topics that could be of mutual interest.
  - Centred on pp physics on the whole.
- J/
  p
  p

Date: Wed, 15 Sep 2004 10:44:07 +0100 (BST)
From: James Stirling <W.J.Stirling@durham.ac.uk>
To: o.villalobos@bham.ac.uk, d.evans@bham.ac.uk
Subject: j/psi in ALICE

Hi Orlando

Remember you were up at IPPP last year and we talked about
J/psi (and Drell-Yan) in pp collisions at ALICE?

This triggered a study by Misha Ryskin, Alan Martin, Valery Khoze and
myself on calculating the total j/psi (and upsilon) cross section
in hadron-hadron collisions. Our analysis in nearing completion,
and in it we compare our results with existing measurements
(fixed-target, Tevatron etc). We will also include a prediction
for LHC energies, and of course a reference to ALICE (since I believe only

Durham Connection

- Invited by James Stirling as from about 2003 for
  ysics topics that
  early. In
  bout the γγ

Eur. Phys. J. C 19, 313–322 (2001)
Digital Object Identifier (DOI) 10.1007/s100520100616

THE EUROPEAN PHYSICAL JOURNAL C

Luminosity measuring processes at the LHC

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Received: 18 October 2000 / Revised version: 9 February 2001 /
Published online: 15 March 2001 – © Springer-Verlag 2001

Abstract. We study the theoretical accuracy of various methods that have been proposed to measure the luminosity of the LHC pp collider, as well as for Run II of the Tevatron $p\bar{p}$ collider. In particular we consider methods based on (i) the total and forward elastic data, (ii) lepton-pair production and (iii) W and Z production.

1 Introduction

The Large Hadron Collider (LHC) being constructed at CERN, will generate proton-proton collisions with total c.m. energy of 14 TeV with a design luminosity $\mathcal{L} = 10^{34}$ cm^{-2} s^{-1}. The experiments at this new facility will have a high potential to discover New Physics and to make var-

Two types of processes stand out as examples of the second possibility to measure the luminosity. First there is exclusive lepton-pair production via photon-photon fusion

$$p \overset{(-)}{p} \to p + l^+ l^- + \overset{(-)}{p} \qquad (1)$$

where $l = e$ or μ. To the best of our knowledge this pro-

V.A. Khoze et al., Eur. Phys. J **C19** 313

PHYSICS PERFORMANCE STUDIES FOR THE ALICE EXPERIMENT AT THE CERN LHC

J. Daniel Tapia Takaki

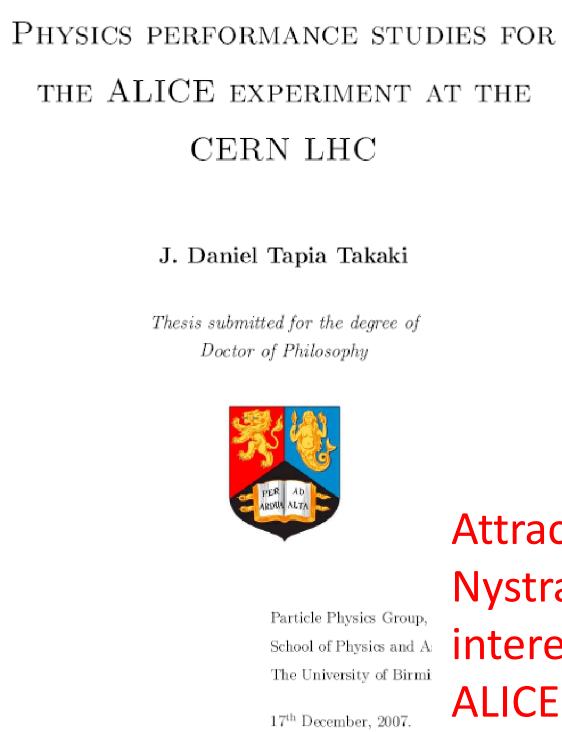
Thesis submitted for the degree of Doctor of Philosophy

Particle Physics Group,
School of Physics and Astronomy,
The University of Birmingham.

17th December, 2007.

xv

Study in Birmingham thesis of feasibility of making such studies in ALICE, undertaken before LHC startup



Physics performance studies for the ALICE experiment at the CERN LHC

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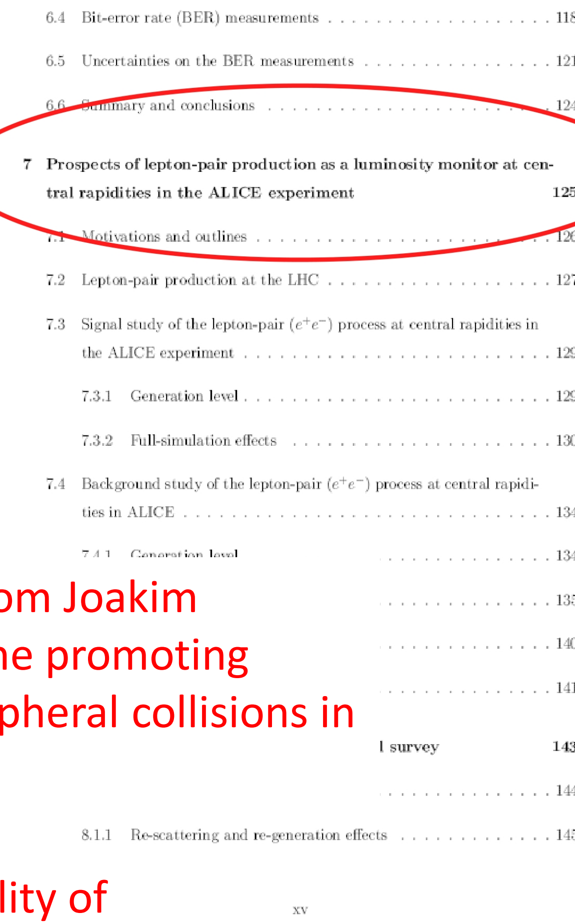

xv

Attracted interest from Joakim Nystrand, at that time promoting interest in ultra-peripheral collisions in ALICE.

Study in Birmingham thesis of feasibility of making such studies in ALICE, undertaken before LHC startup

Physics performance studies for the ALICE experiment at the CERN LHC

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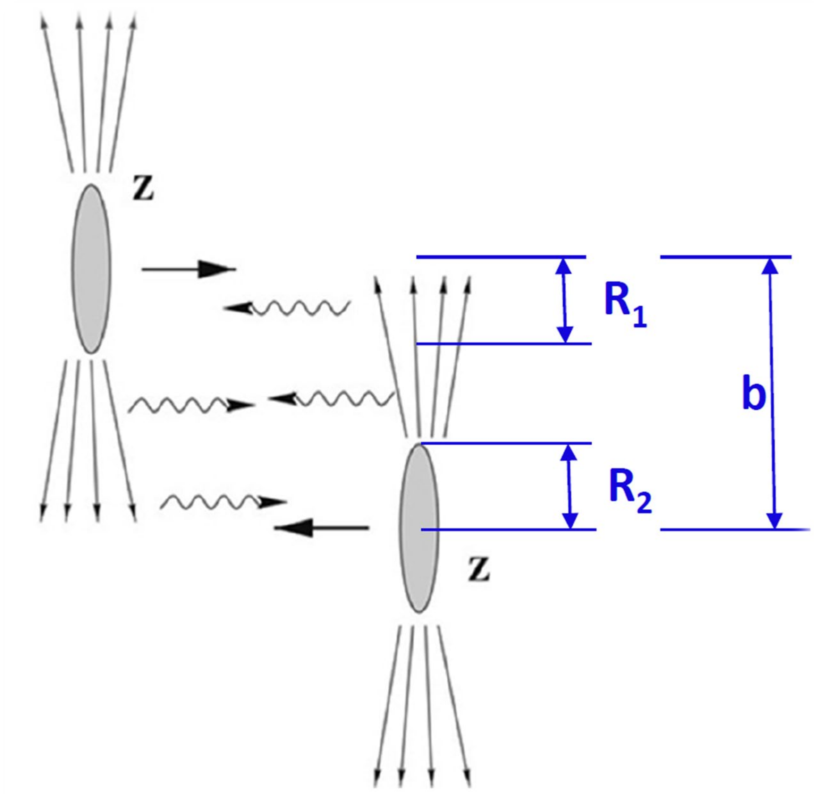
Thesis submitted for the degree of Doctor of Philosophy

Proposed trigger was shown to be highly effective at rejecting hadronic events. Based on earlier ideas in study presented by A. Kirk and OVB in 1998 (ALICE-INT 98-45). Used for photon-photon, photon-Pomeron and Pomeron-Pomeron studies in ALICE. There have been a number of enhancements of the original idea

17th December, 2007.

xv

Ultra-Peripheral Production



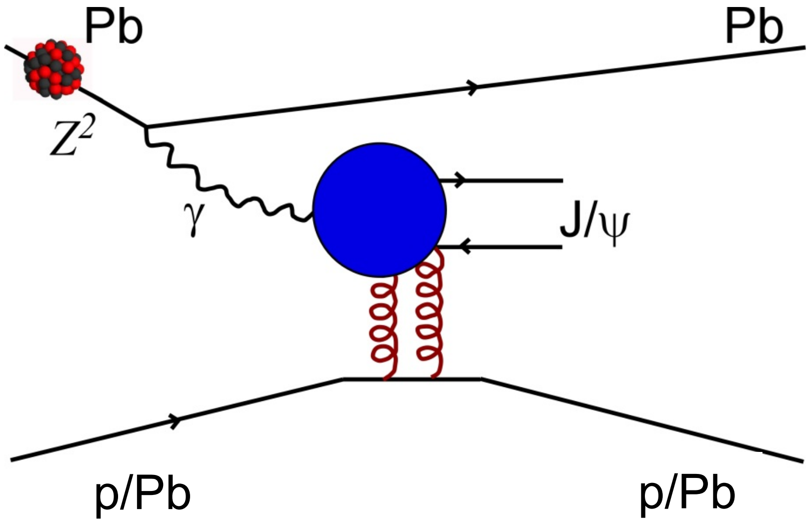
- In Ultra-Peripheral Collisions (UPC), the projectiles (Pb-Pb, p-Pb or pp) are at large impact parameters, $b > R_1 + R_2$, and so hadronic processes are greatly suppressed
- Photon flux $\propto Z^2$
- Photon virtuality $Q^2 = (\hbar c/R)^2$

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

J/ψ Ultra-Peripheral Production

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

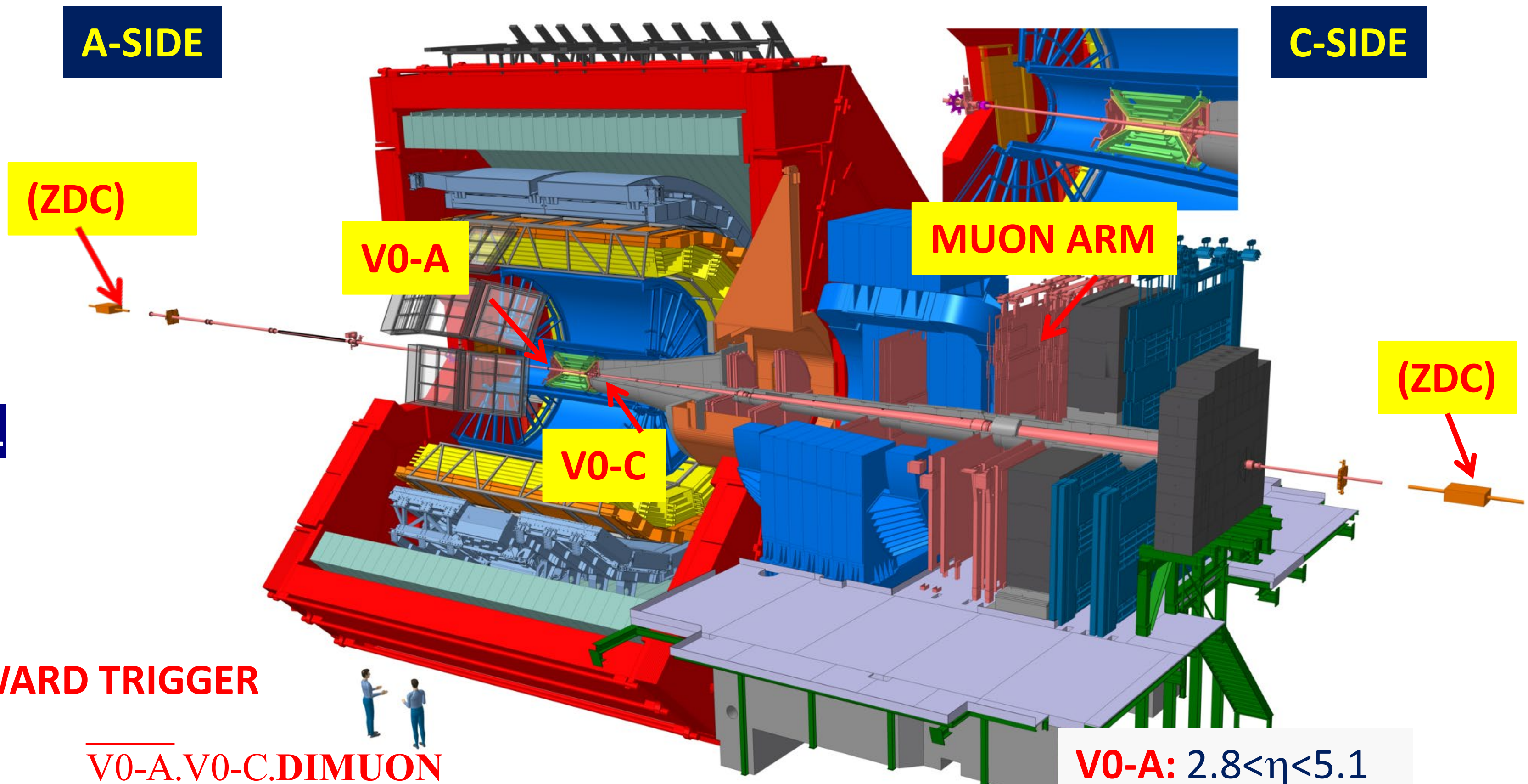
LEADING ORDER



- 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 $Q^2 \sim (M_{J/\psi}{}^2/4) \sim 2.5\ GeV^2$
  - Model dependence for lighter particles (e.g. ρ)

Exclusive process: we go to very *low* multiplicities

ALICE Apparatus



RUN 1

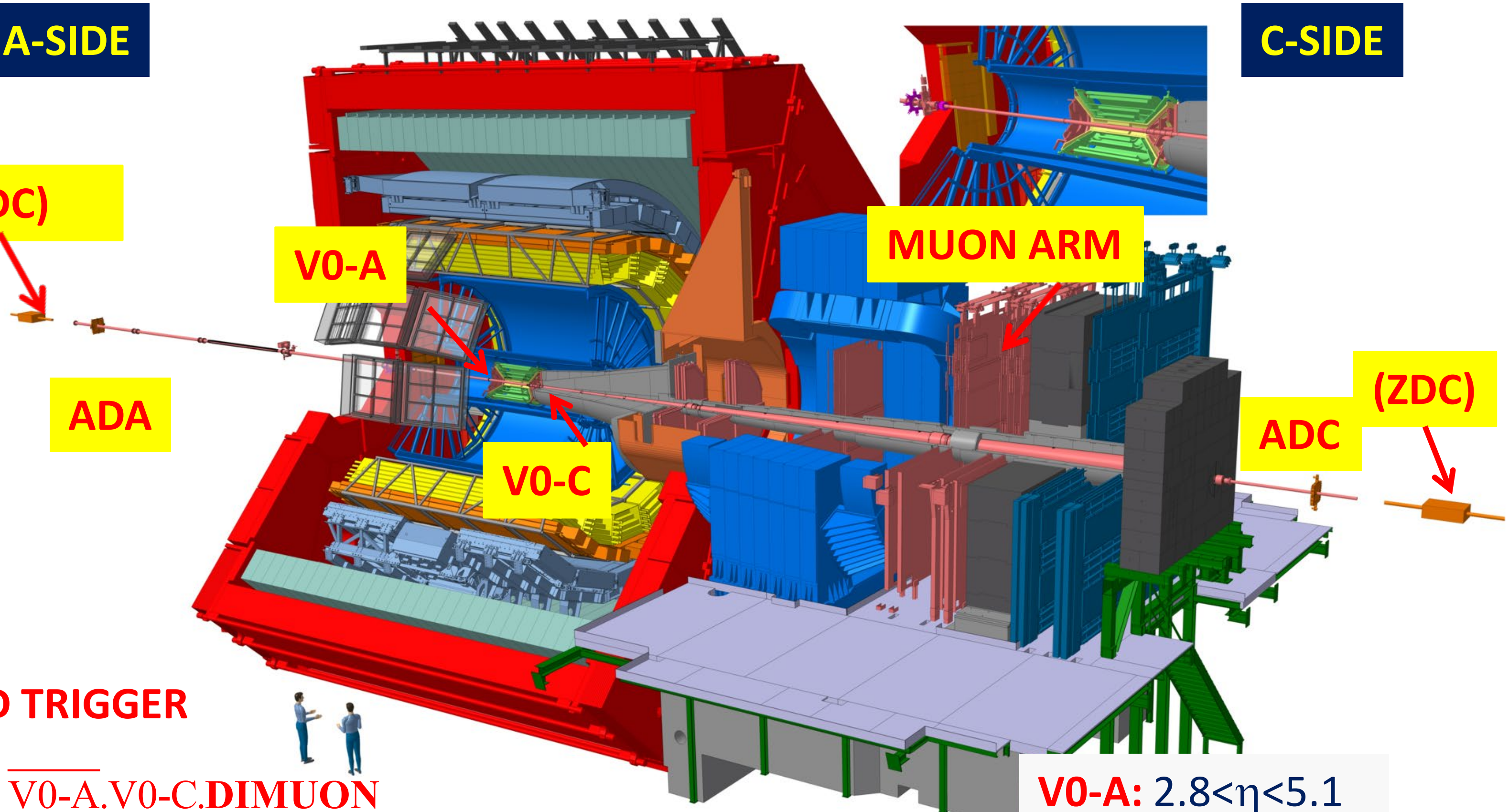
FORWARD TRIGGER

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

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

V0-C: $-3.7<\eta<-2.7$

ALICE Apparatus



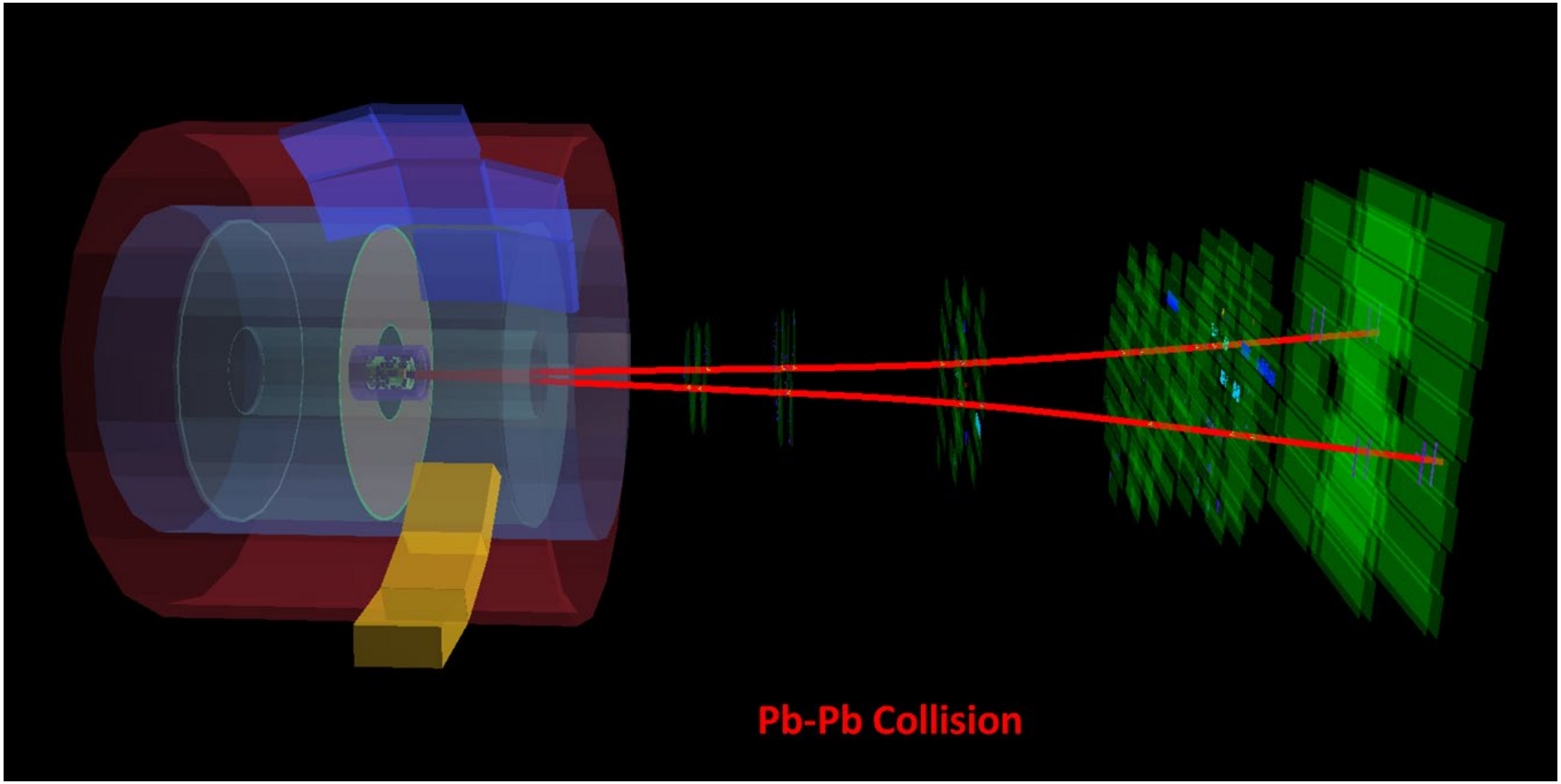
FORWARD TRIGGER

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

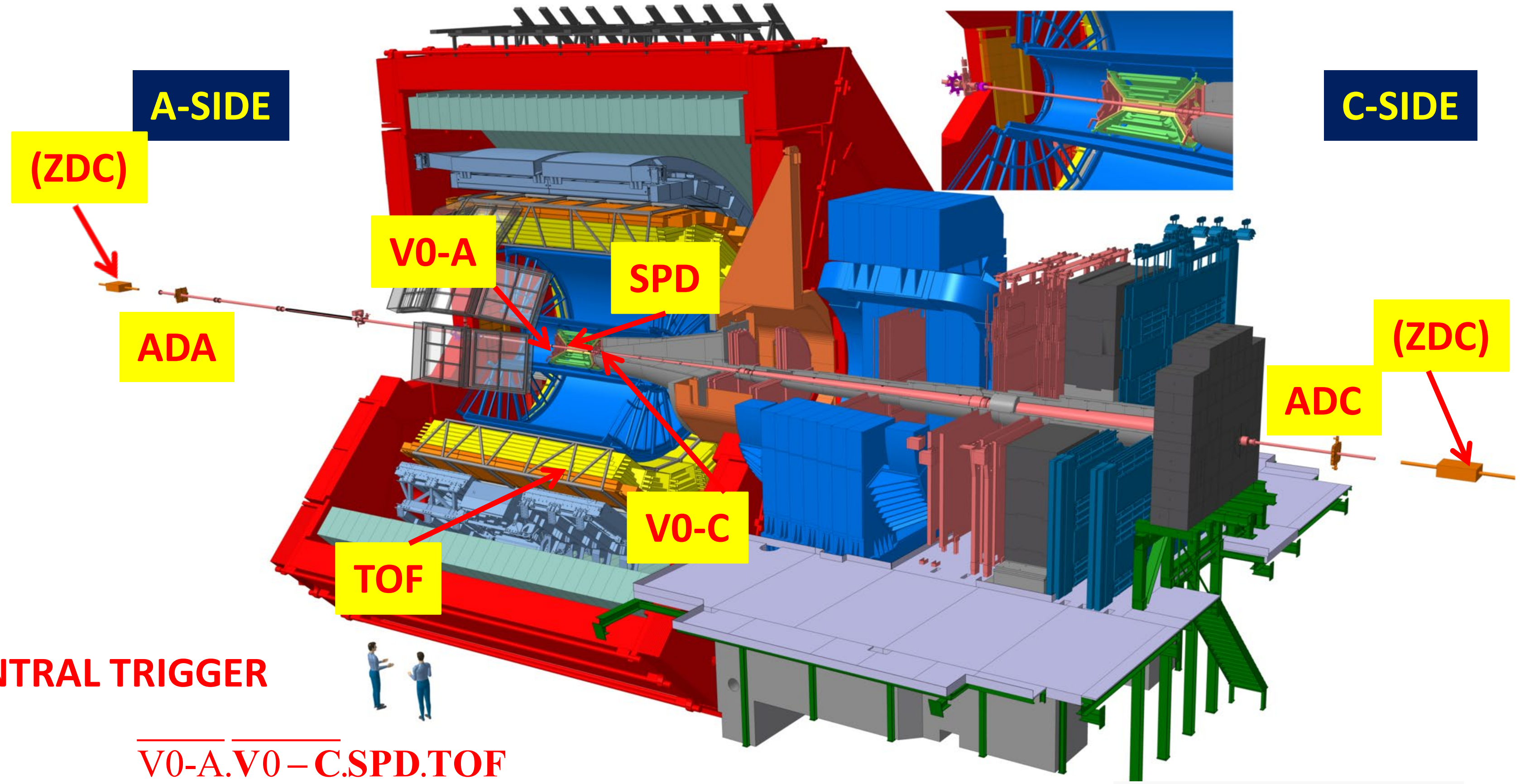
V0-A: $2.8<\eta<5.1$
V0-C: $-3.7<\eta<-2.7$

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

Forward



ALICE Apparatus



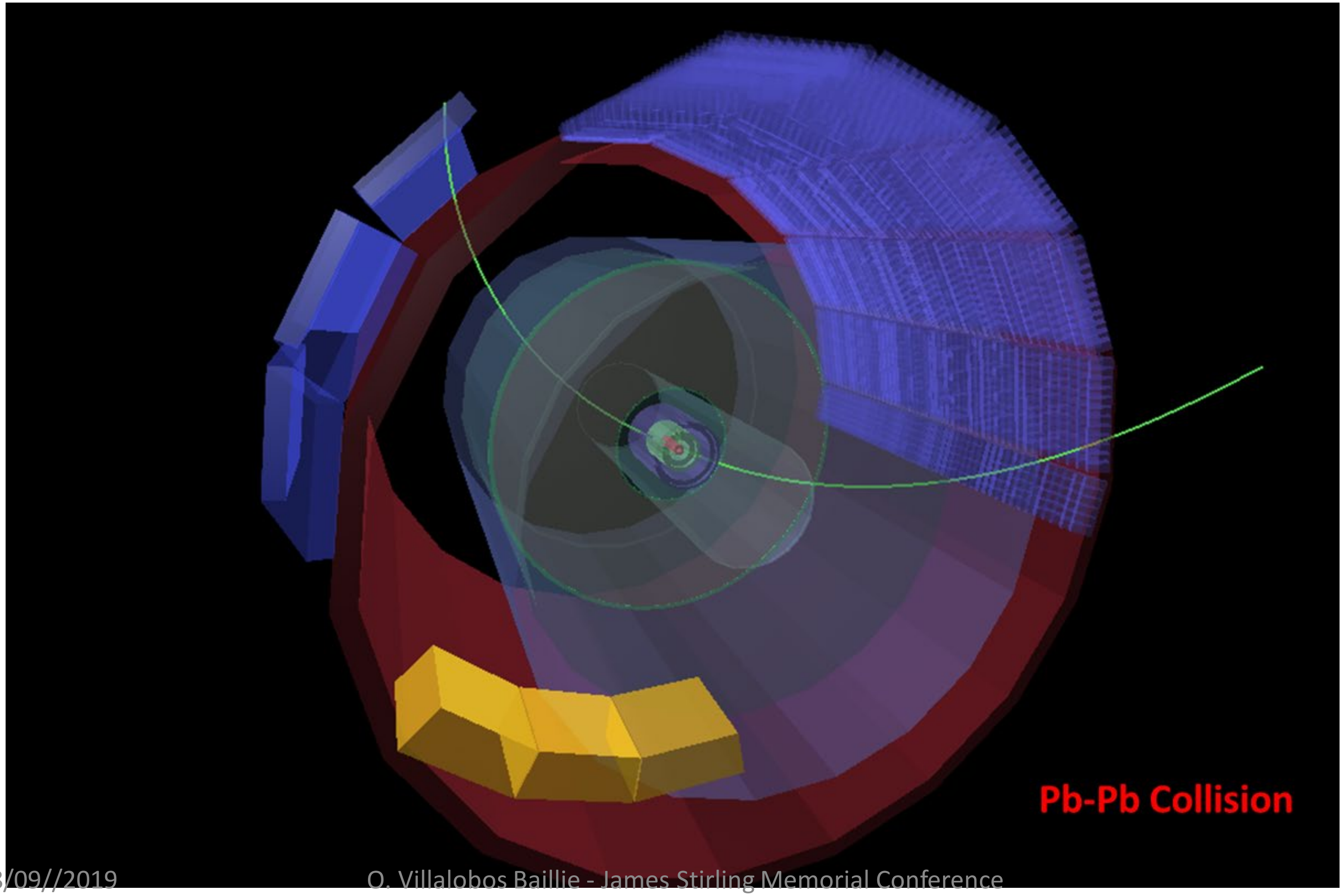
CENTRAL TRIGGER

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

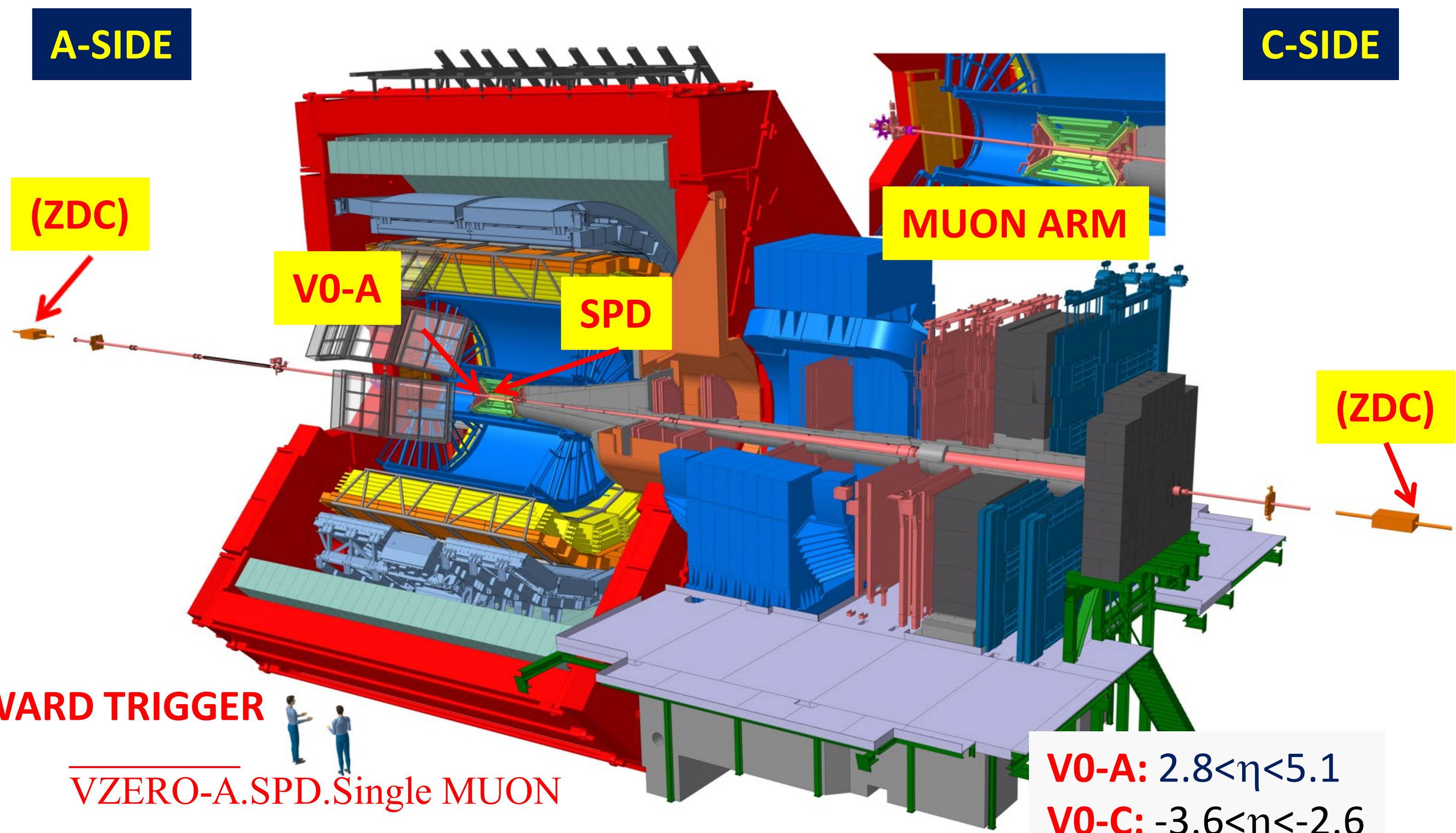
Also **AD** veto counters in Run 2

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

Central



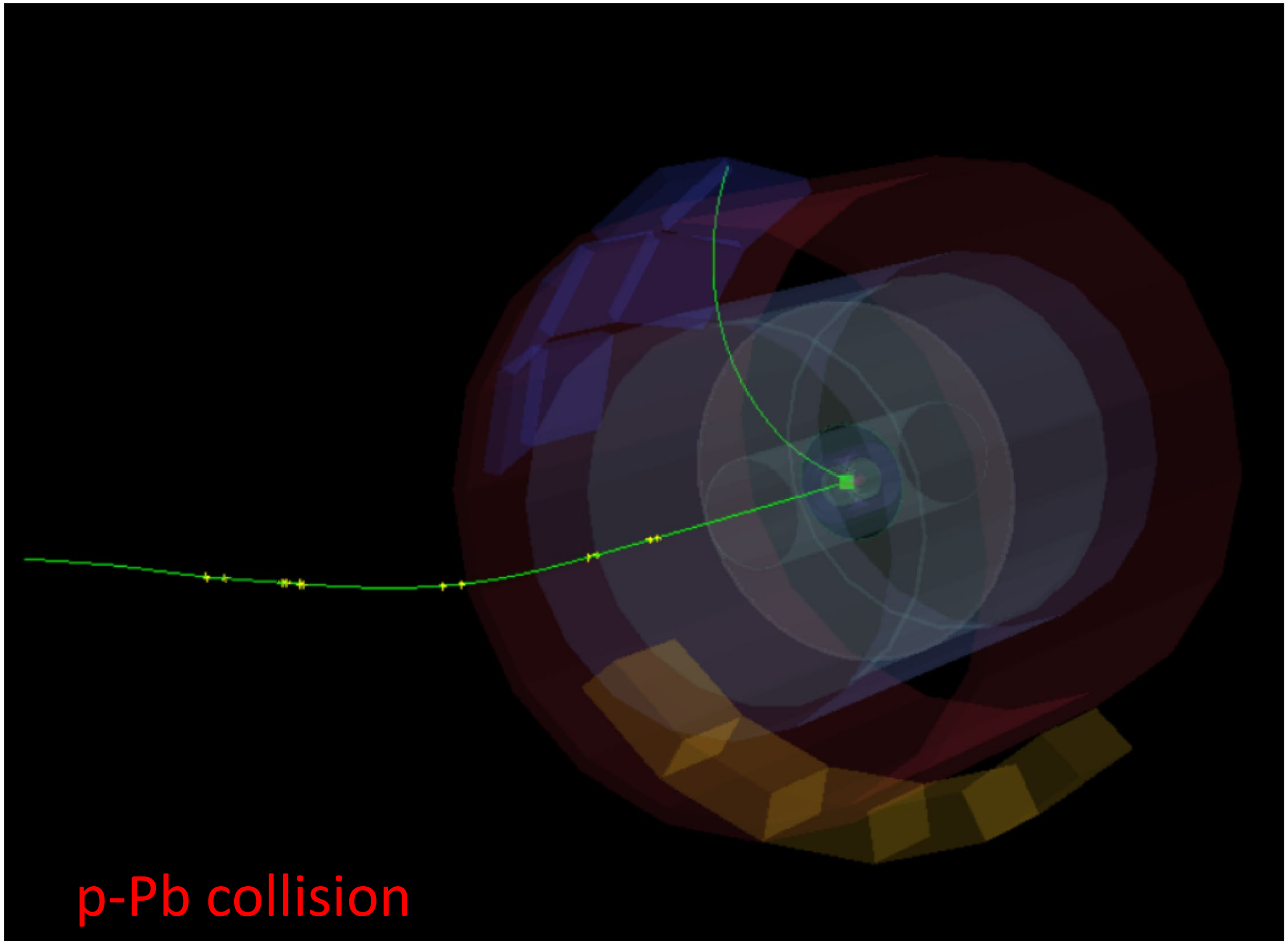
ALICE Apparatus



SEMI-FORWARD TRIGGER

$\overline{\text{VZERO-A}}$.SPD.Single MUON

Semi-Forward



Run 1

Publications Run 1

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
J/ψ forward (*)	J. Adam et al., Phys.Rev.Lett. 116 (2016) no.22, 222301

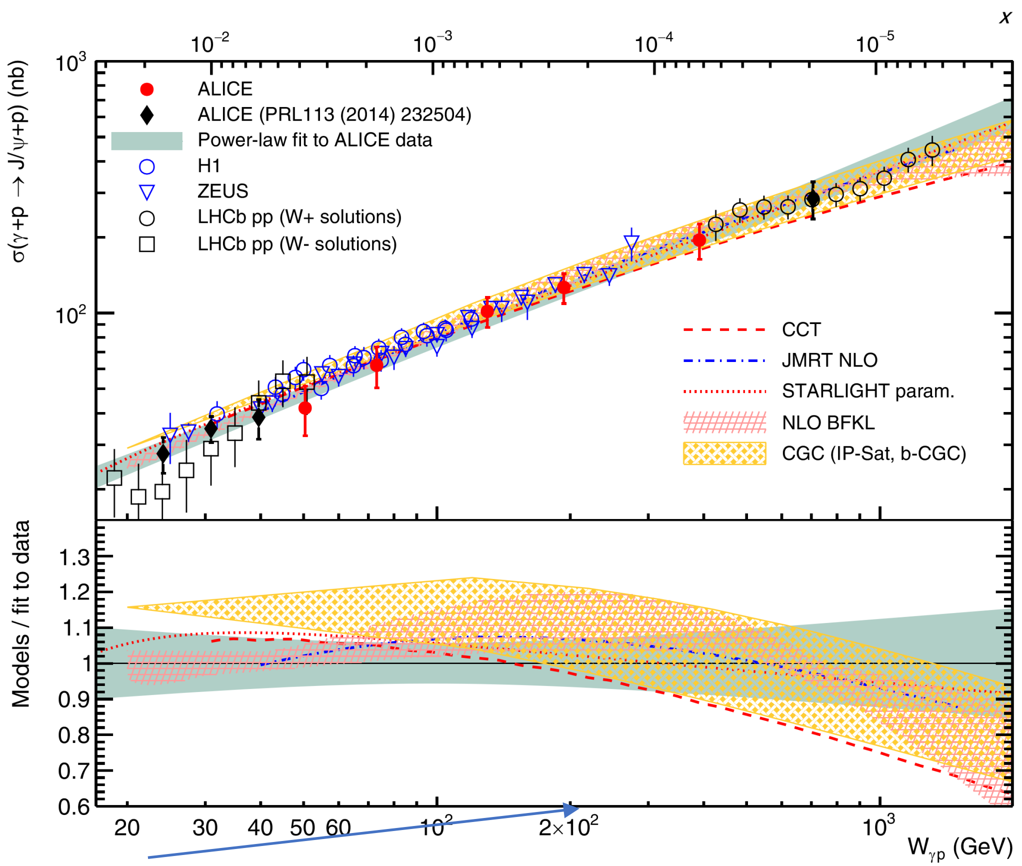
p-Pb 5.02 TeV per nucleon

J/ψ forward	B.B. Abelev et al., Phys. Rev. Lett. **113** (2014) 23250
J/ψ central/s.-fwd	S. Acharya et al. Eur. Phys. Journal **C79** (2019) 402

* Peripheral

J/ψ pPb with new points

Eur. Phys. J. C79 (2019) 402



ArXiv:1809.03235v1

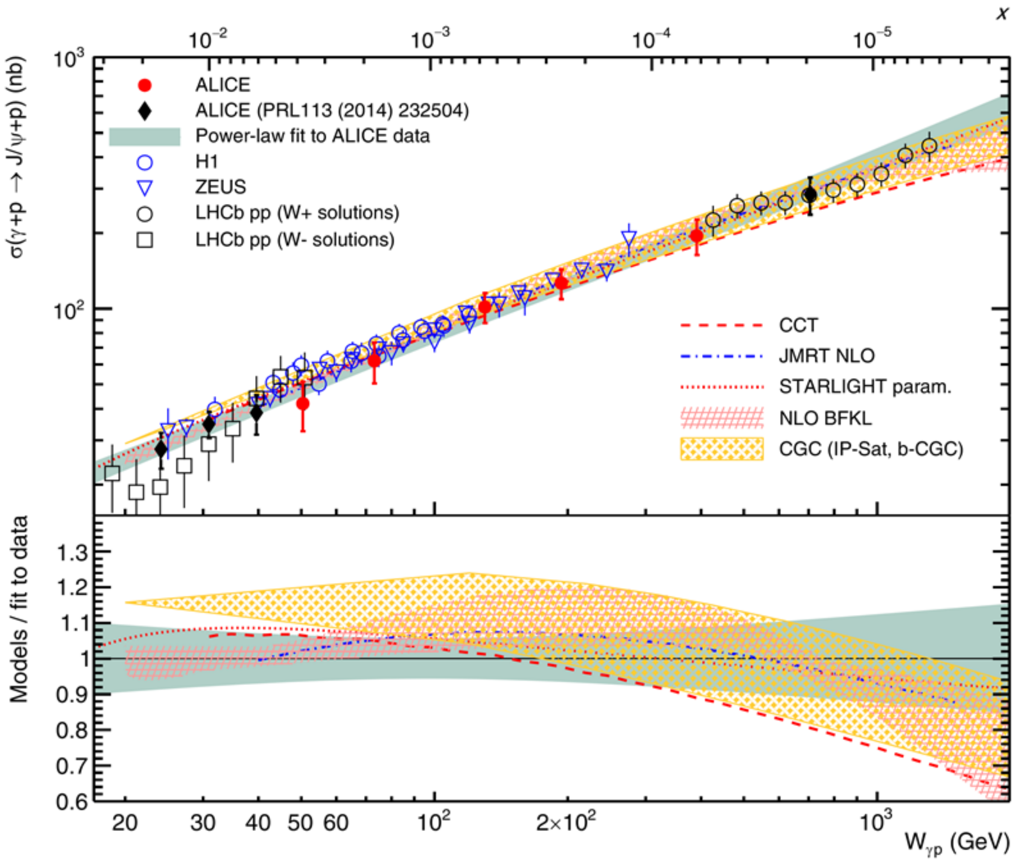
- Central and semi-forward points added
- New configurations confirm original forward spectrometer results
- Power law fit ($\sigma(W) \sim W^{\delta}$) to ALICE data points gives $\delta = 0.70 \pm 0.05$.
- All models considered agree with data.

Combines forward, central and semi-forward configurations

Range covered: from ~20 to 700 GeV

J/ψ pPb with new points

Eur. Phys. J. C79 (2019) 402



ArXiv:1809.03235v1

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

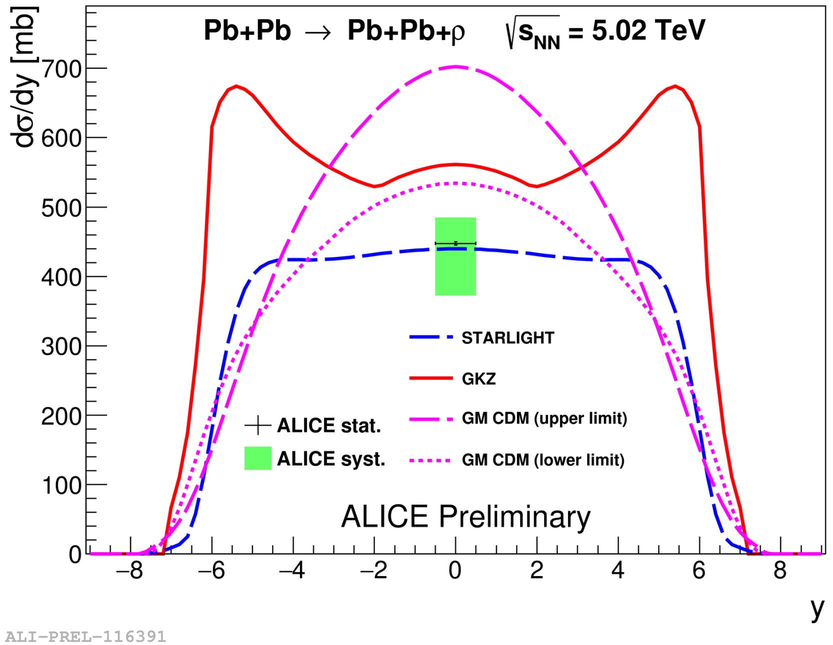
Run 2 benefits from:-

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

Results in/out of the pipeline

- We expect to release results on central J/ψ, ψ(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 in 2018 in 5.02 TeV Pb-Pb provide much higher statistics at forward rapidity than previously. Allows more differential studies.

ρ^0 cross section at 5.02 TeV



- STARLIGHT: VDM + Glauber. S.R. Klein & J. Nystrand, Phys. Rev. **C60** (1999) 014903
- 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

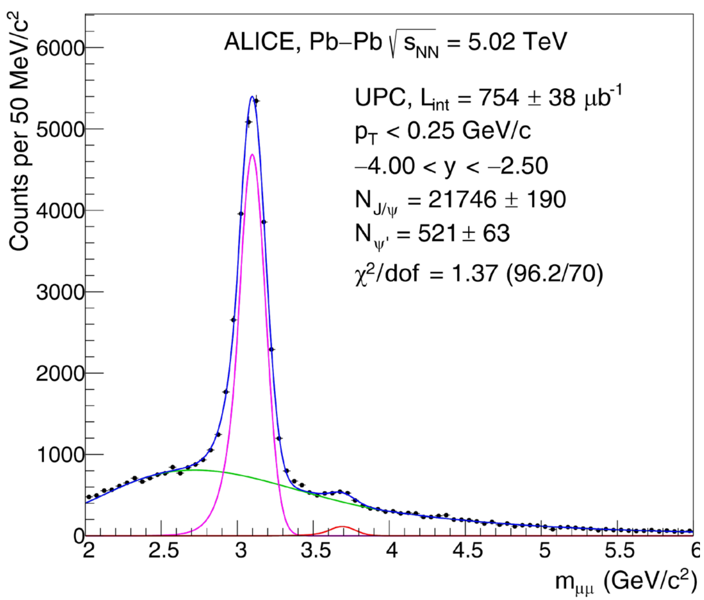
Publications Run 2

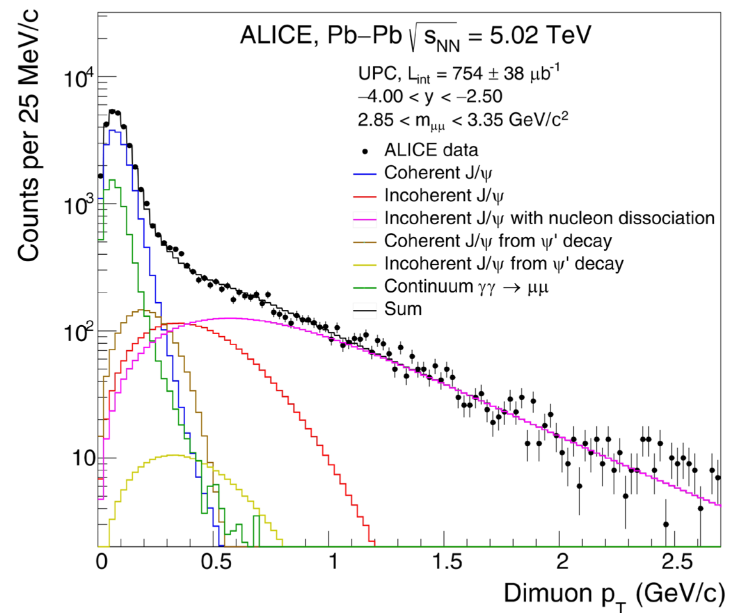
Pb-Pb 5.02 TeV per nucleon

J/ψ forward S. Acharya et al., Physics Letters **B798** (2019) 134926

NEW

Forward J/ψ

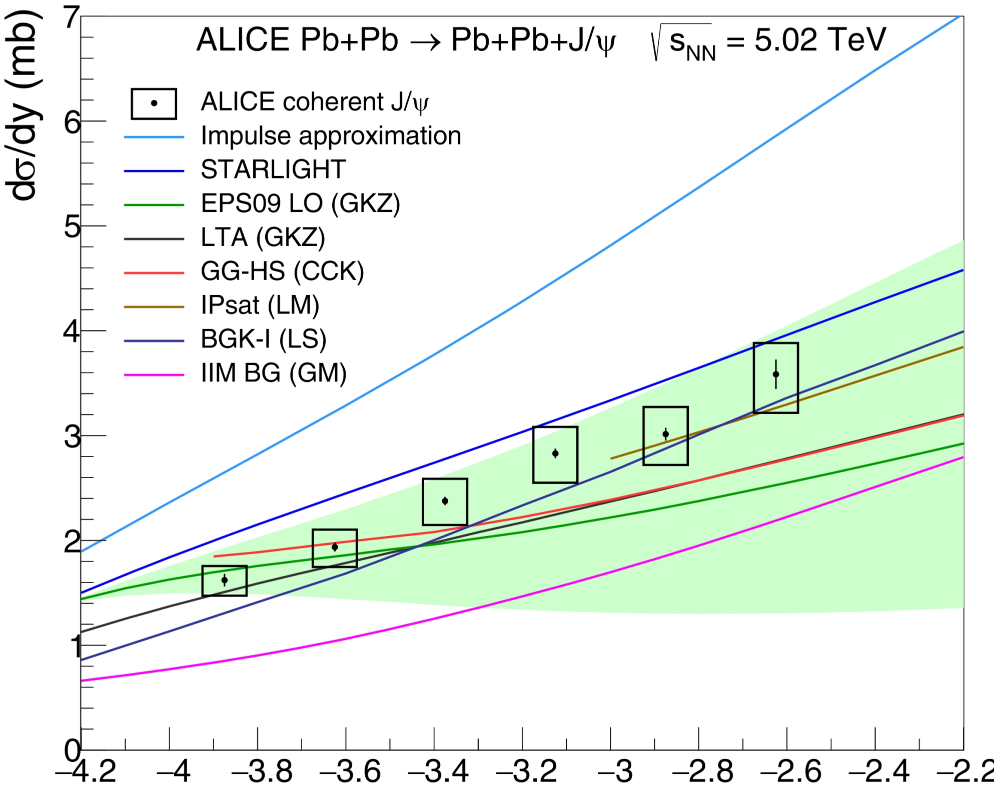




- Both J/ψ and ψ’ can be seen in $\mu^+\mu^-$ spectrum.
    - Fully corrected ratio

$$R = \frac{\sigma(J/\psi)}{\sigma(\psi')} = 0.150 \pm 0.15\ (\text{stat.}) \pm 0.021\ (\text{syst.}) \pm 0.007\ (\text{BR})$$

Forward J/ψ



ArXiv:1904.06272v1

- Run 2 PbPb 2015 + 2018: ~**170** × run 1 statistics!
- Data consistent with moderate nuclear shadowing

- James Stirling M

- 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)
- CCK GGS Energy dependent hot-spot model in Glauber-Gribov formalism

  (Cepila, Contreras, Krelina, PL B766 (2017) 186)
- IPsat LM: Color dipole model + IPSat

  (Lappi, Mantysaari, PRC **83** (2011)065202; **87** (2013) 032201)
- BGK-I Colour Dipole with Glauber-Gribov model

  (Luszczak Schafer, arXiv:1901.07989)
- IIM BG (Gonçalves, Machado et al.) PR C90 (2014) 015203, JPG **42** (2015) 105001)

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

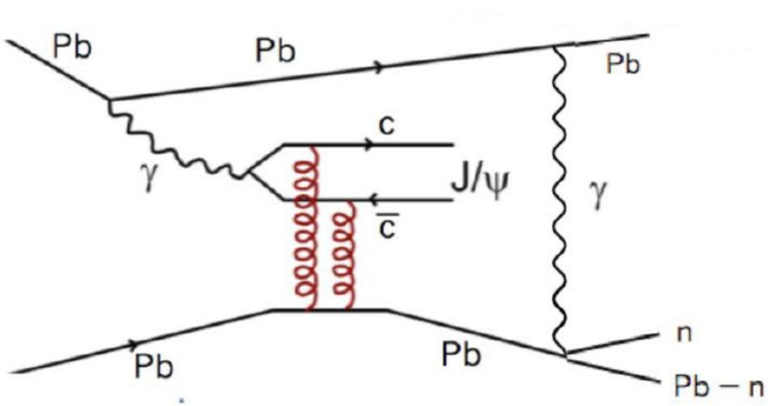
- Kinematics provides dσ/d*y*, but this is not uniquely linked to dσ/d*x*

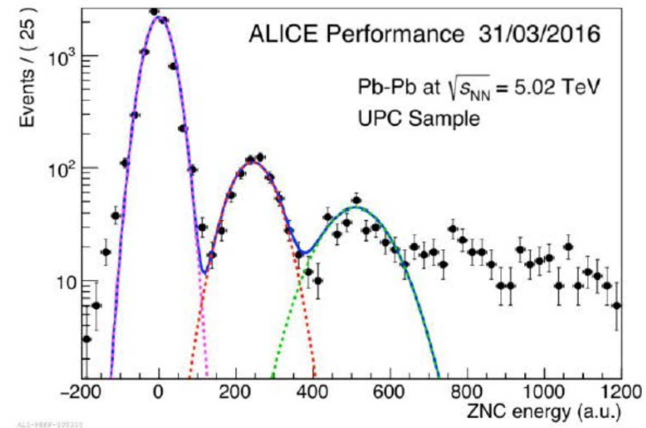
$$\frac{d\sigma}{dy} = n(y)\frac{d\sigma_{\gamma Pb}}{dy}\bigg|_{+y} + n(-y)\frac{d\sigma_{\gamma Pb}}{dy}\bigg|_{-y}$$

High-*x* Low-*x*

- Flux factors *n*(±*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

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

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

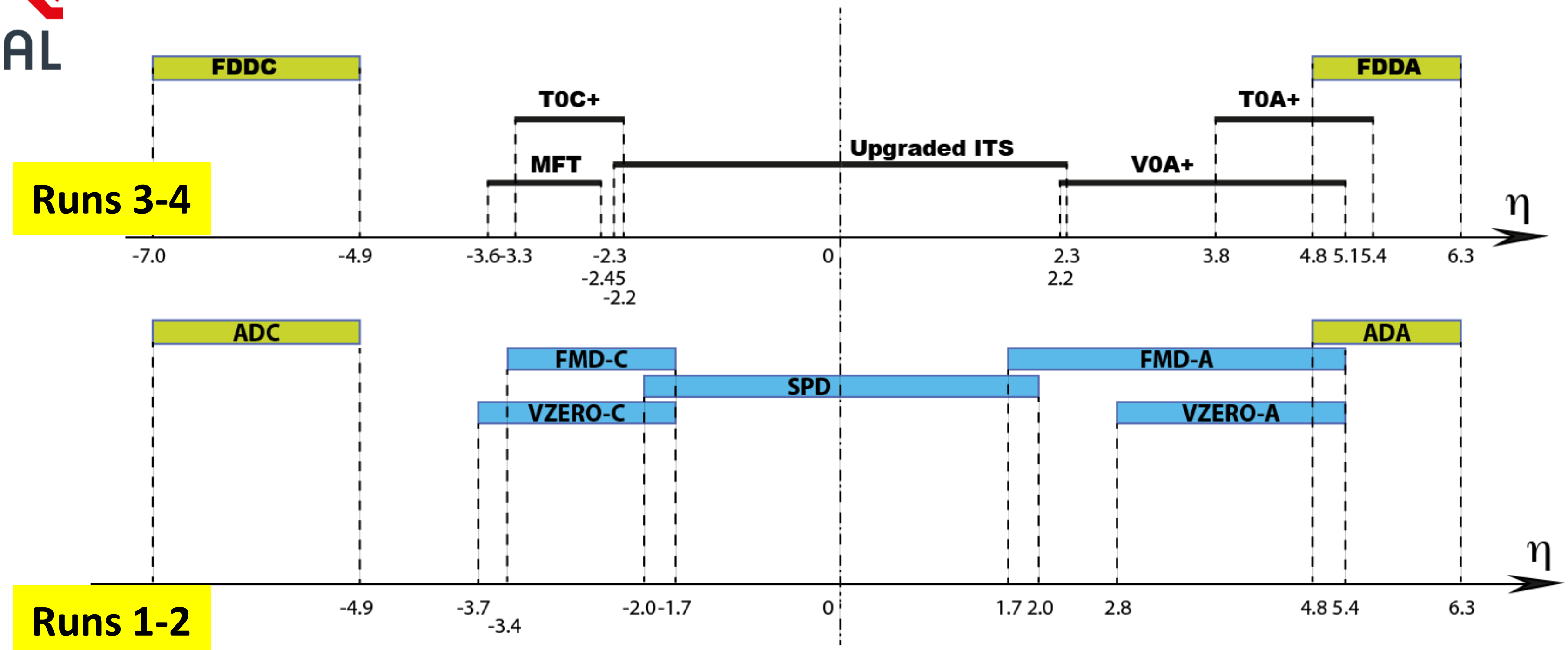
2 equations
2 unkowns
OK

Run 3/4

New readout and detectors

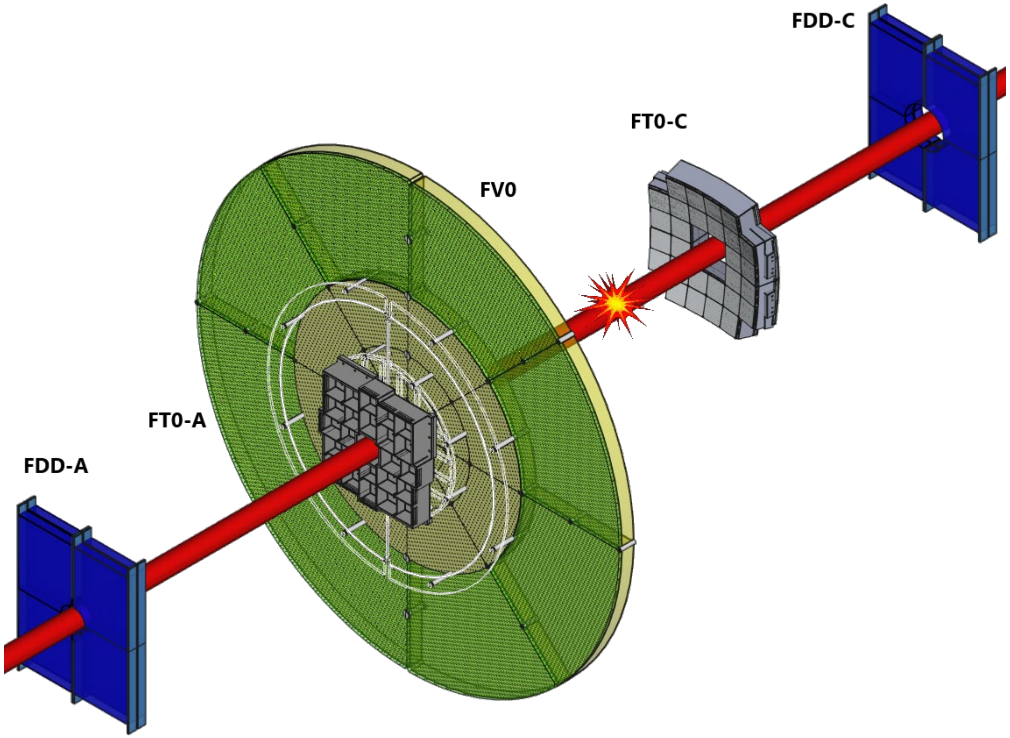
- To cope with the increased collision rate for Run 3 we will have a major upgrade in LS2, in which detectors will prepare for *continuous readout*.
- Most ALICE signatures are complex and are embedded in very high multiplicity events: not suitable for conventional triggers.
- Instead, in continuous 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)

Fast Interaction Trigger Detector



- Main design aims:
  - Accurate Timing of interaction (σ ~ 30ps) (T0+A/C)
  - Measurement of forward multiplicity density (V0+)
  - High Trigger efficiency.

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.
- Muon Forward Tracker (MFT) placed in front of absorber, gives a measured point inside the ALICE solenoid, and will improve track measurement accuracy (and therefore mass resolution) significantly.
- 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 20K J/ψ events in the “Forward 1” interval (PbPb 2015+2018)

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 already giving 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

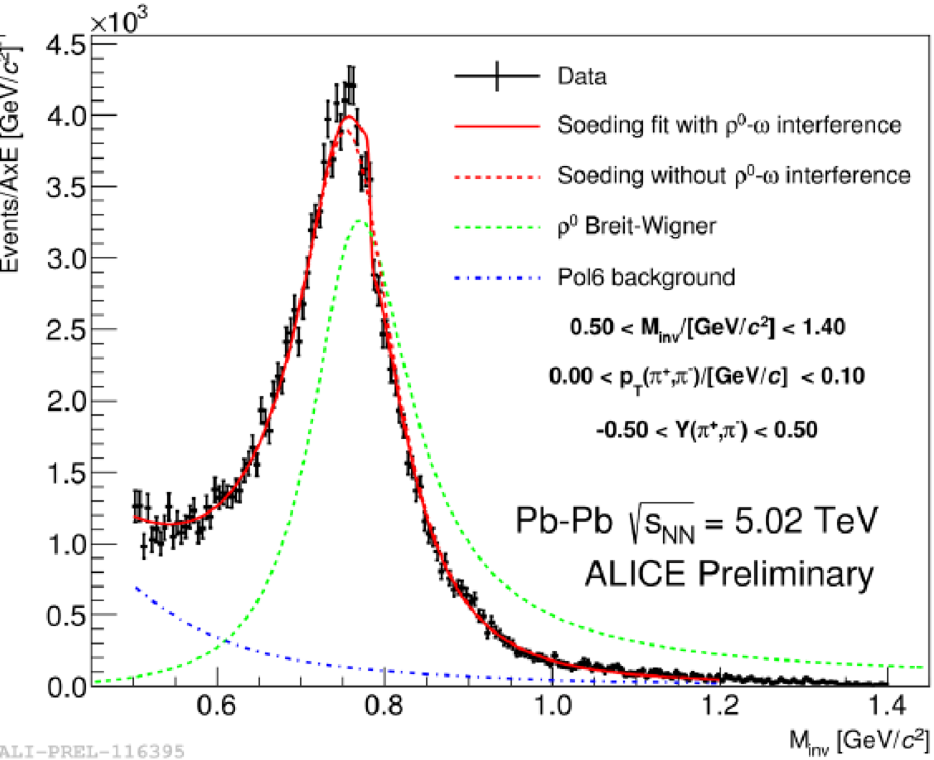
J/ψ Photoproduction

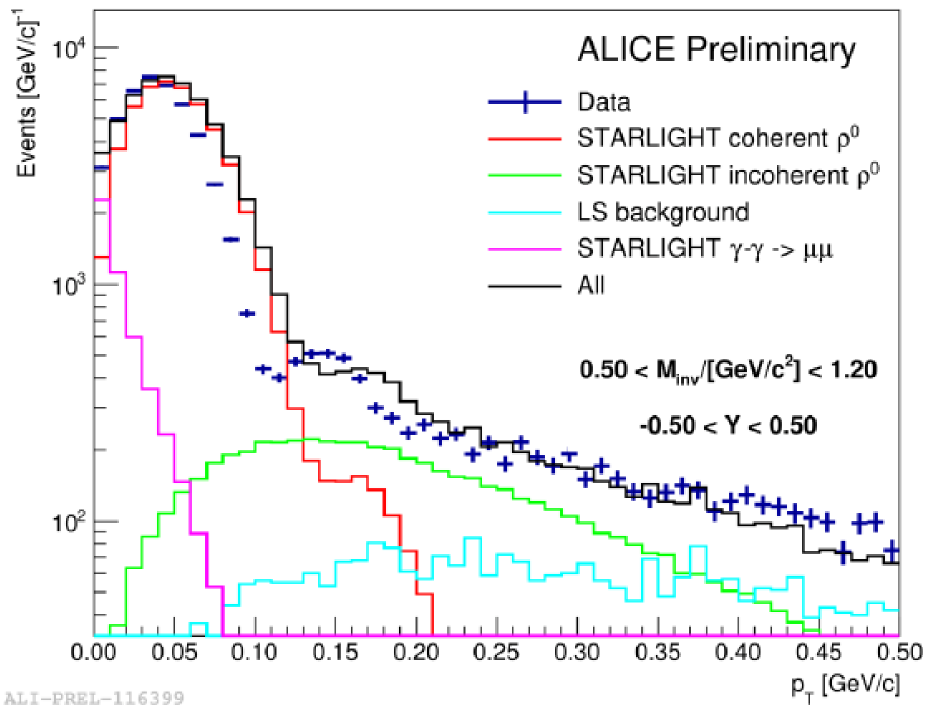
- In principle, there is an ambiguity in the energy $W_{\gamma p/Pb}$ of the measurement, according to whether the photon is emitted from one projectile or the other.
  - For a J/ψ produced with rapidity y, the two solutions are of the form

$$x = \left(M_{J/\psi} / \sqrt{s_{NN}} \right) \exp(\pm y)$$

- Two solutions coincide for $y=0$, but forward rapidity and identical beams an *ansatz* is needed to weight the two solutions.
- Ambiguity *lifted* for pPb, as the Z^2 factor means that the Pb ion is almost certain to be the photon emitter.

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))

E. Kryshen *Baldin Seminar* Dubna September 2018

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
$\rho \to \pi^+\pi^-$	531 μb	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