CMS Results on Ultra-Peripheral Heavy-Ion Collisions

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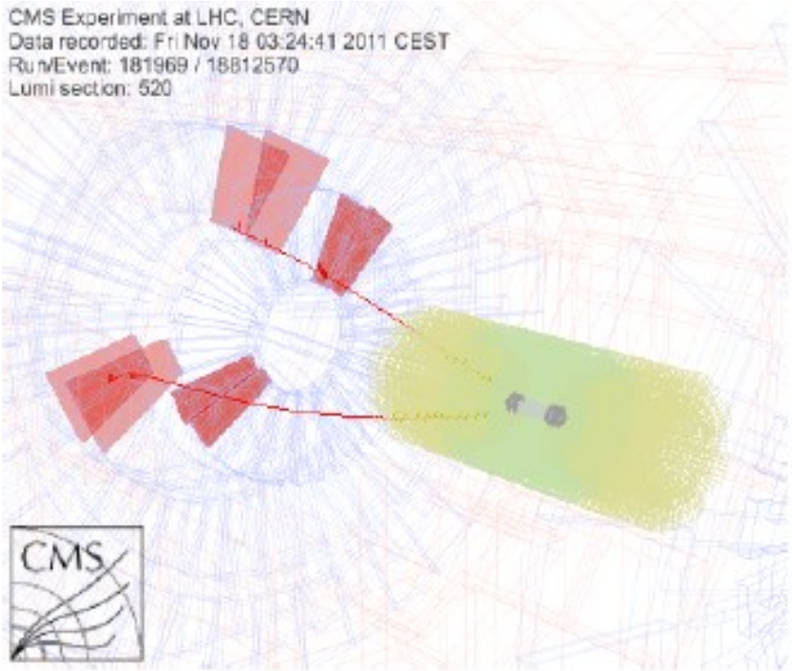
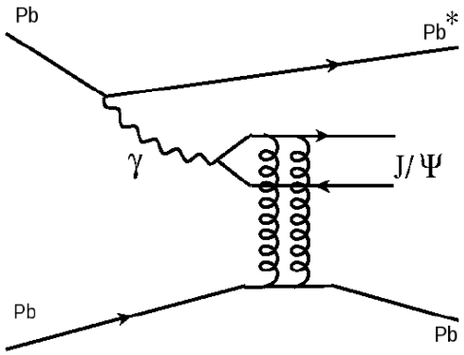
Overview of CMS Results on Ultra-Peripheral Collisions

- **Introduction to UPC physics**
- **Detector description**
- **Measurement of coherent J/ψ cross section**
- **Future prospects**

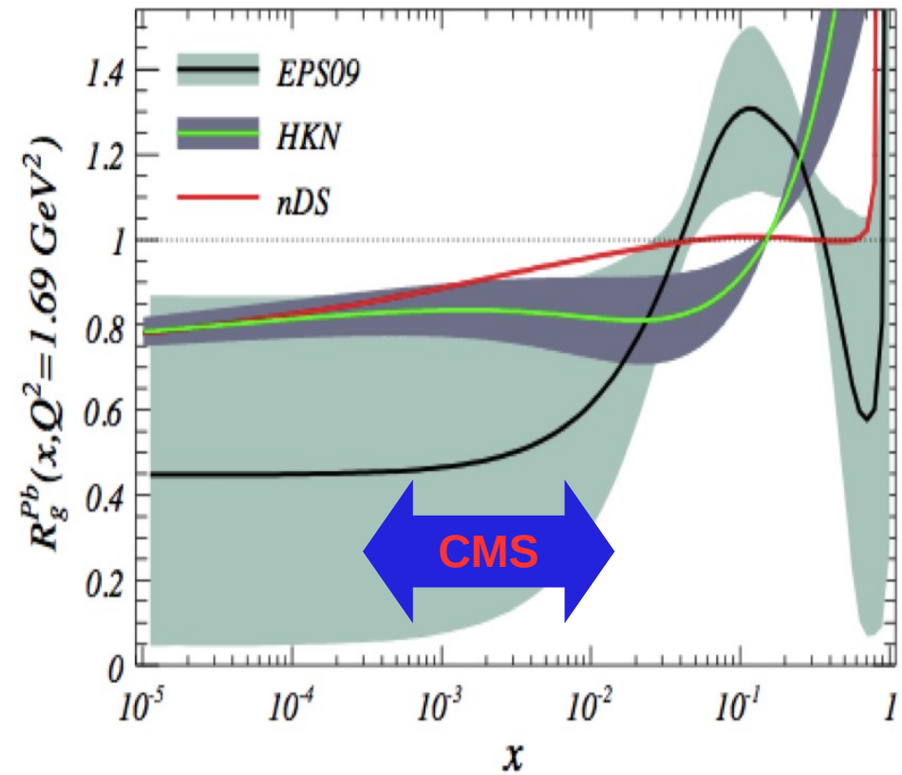


UPC Quarkonia Probe Nuclear Glue



$$\left.\frac{d\sigma_{\gamma A\to J/\Psi A}}{dt}\right|_{t=0} = \xi_{J/\Psi}\left(\frac{16\pi^3\alpha_s^2\Gamma_{l^+l^-}}{3\alpha M_{J/\Psi}^5}\right)\boxed{[xG_A(x,\mu^2)]^2}$$

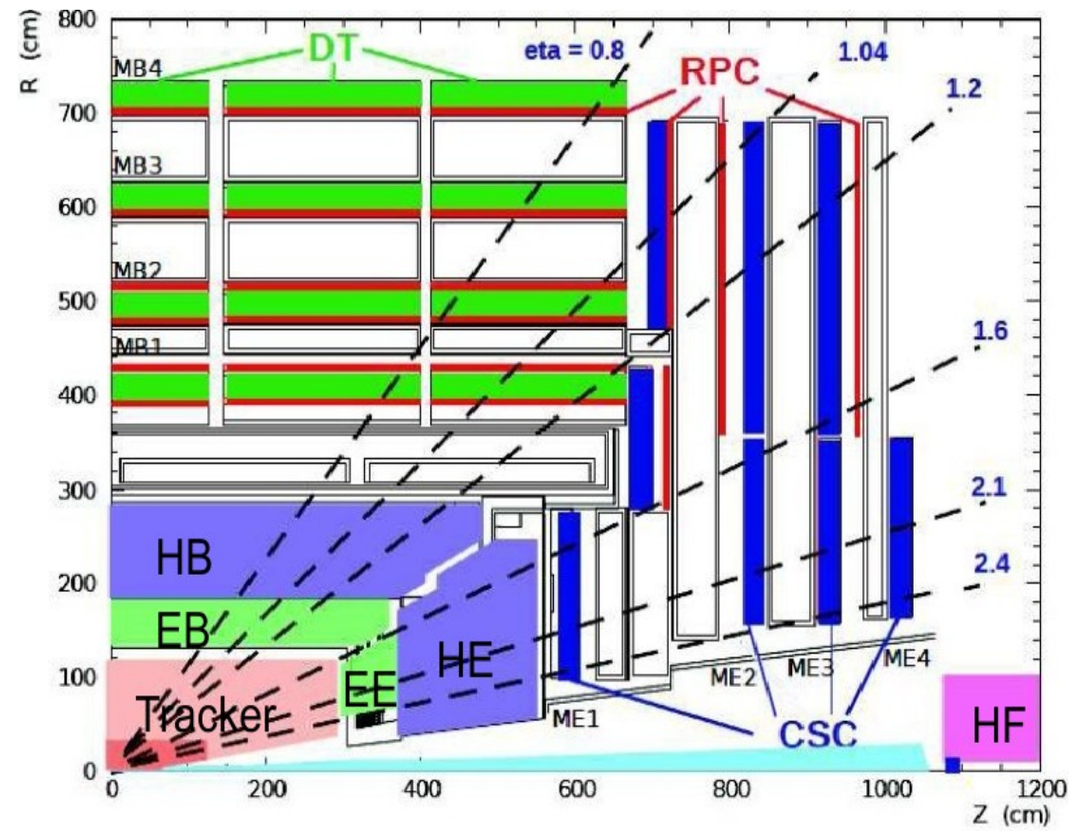
The ultra-peripheral coherent J/ψ photoproduction cross section depends on the **nuclear gluon density squared**



C. A. Salgado et al 2012 J. Phys . G : Nucl. Part. Phys . 39 015010

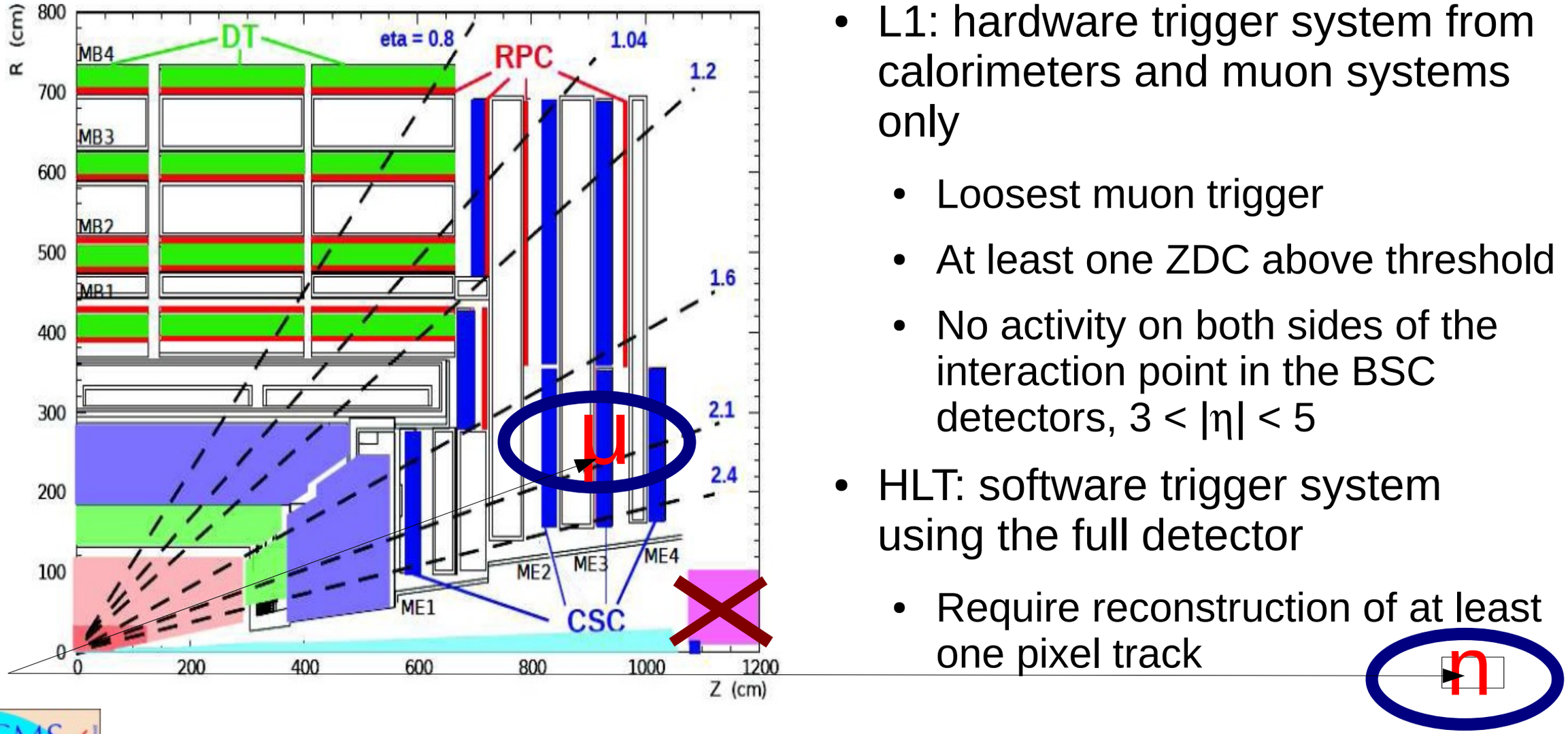
The Compact Muon Solenoid

- Calorimeter coverage extending to $|\eta| = 5$ helping to ensure exclusivity
- Muon coverage up to $|\eta| = 2.4$ for triggering and id
- Track p_T resolution of 1-2%
- Efficient triggering collecting about 95% of the delivered PbPb luminosity



Wide muon coverage allows for acceptance of zero p_T J/ψ mesons near $|y| = 2$

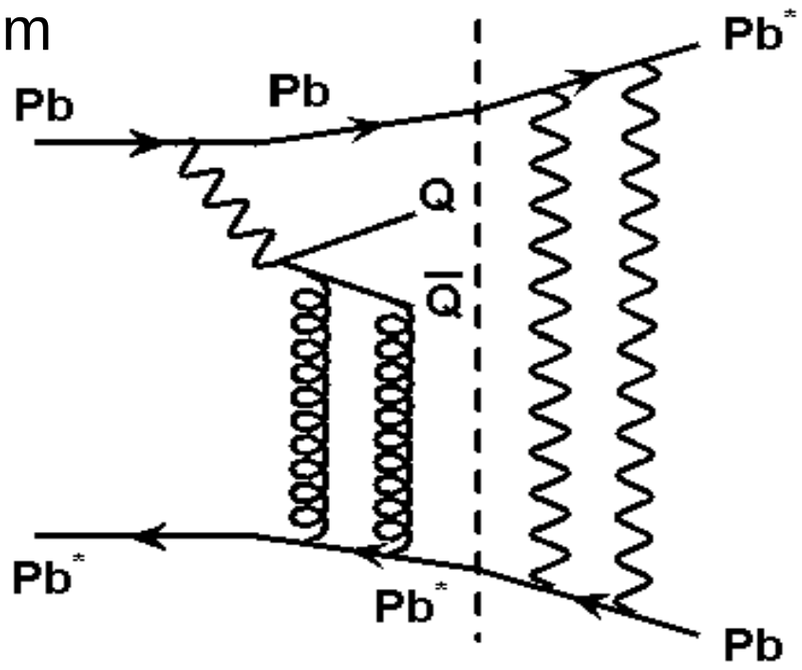
2011 PbPb UPC Trigger for J/ψ Analysis

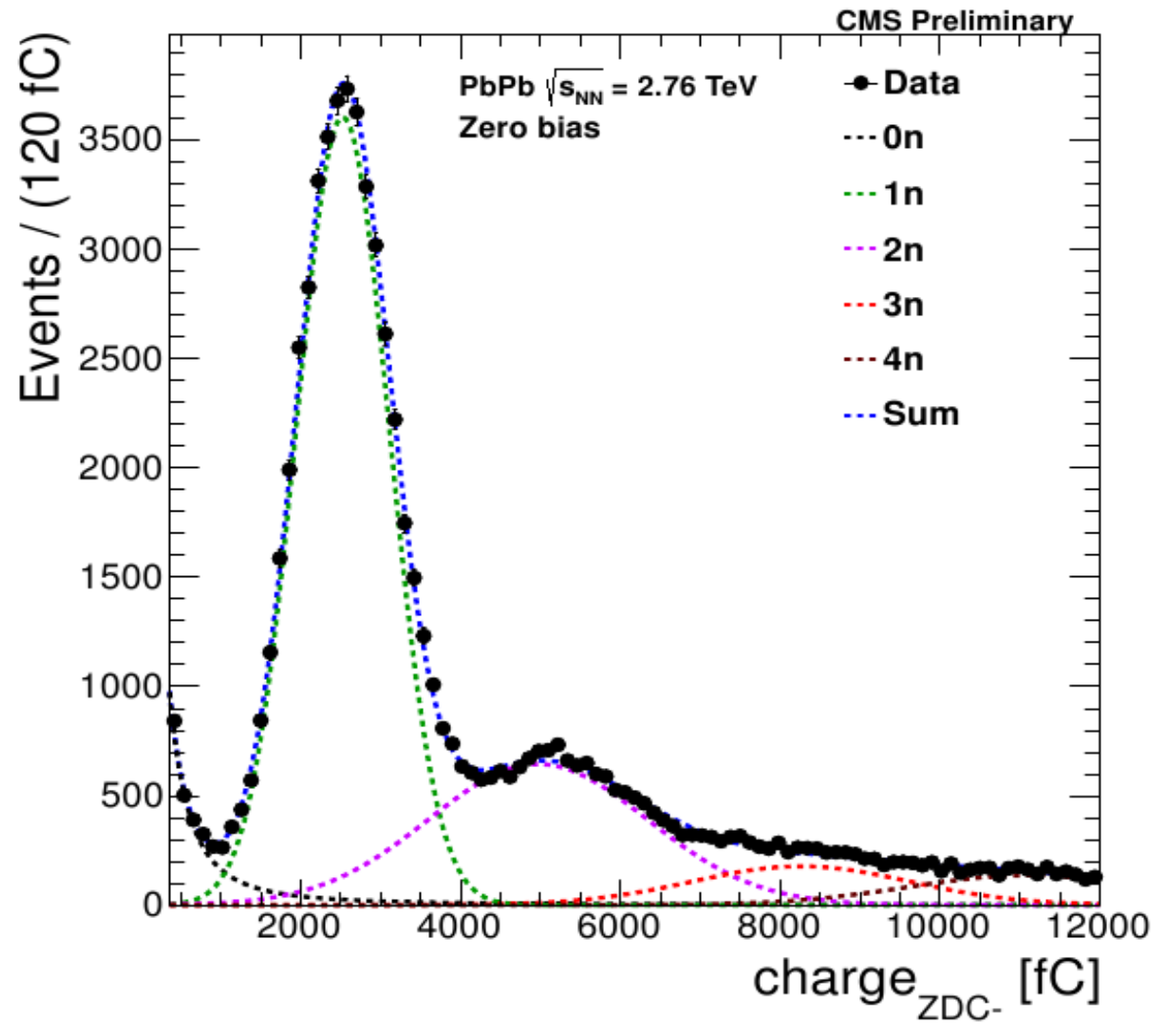


- L1: hardware trigger system from calorimeters and muon systems only
  - Loosest muon trigger
  - At least one ZDC above threshold
  - No activity on both sides of the interaction point in the BSC detectors, $3 < |\eta| < 5$
- HLT: software trigger system using the full detector
  - Require reconstruction of at least one pixel track

Neutron Tagging

- Neutron emission can occur through multiple photon exchange in coherent production
- Detected by the ZDCs covering |η| > 8.3
- Thresholds for one and more neutrons are set from the fits to the zero bias spectrum





Event Selection for UPC J/ψ

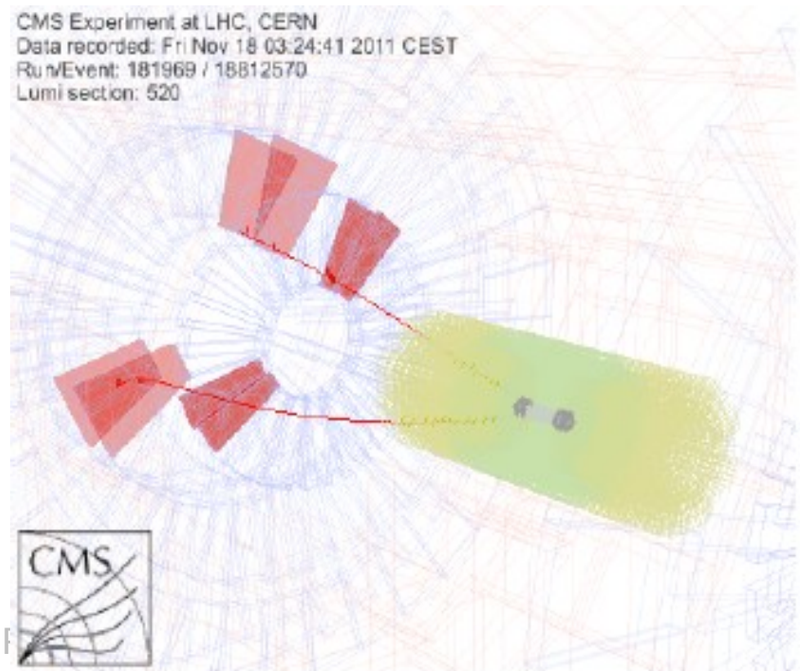
Beam background rejection: pixel cluster shapes are consistent with the vertex position, timing of hits in the BSCs are consistent with a collisions, and vertex within 25 cm of the nominal interaction point in the beam direction and 2 cm in transverse direction

Hadronic rejection: HF calorimeters, $3 < |\eta| < 5$, are empty, a neutron signal in the ZDCs on only one side of the interaction point, and only two reconstructed tracks in the tracker

Muon quality: muon track χ^2 per degree of freedom < 3, at least 5 hits in the tracker, and matches within 3σ of hit in muon systems

Restrict reconstructed muons to $1.2 < p_T < 1.8$ GeV/c and $1.2 < |\eta| < 2.4$ to match muon trigger efficiency measurements

517 candidate events with p_T below 1 GeV/c and $1.8 < |y| < 2.3$ after event selection



Extraction of the Coherent J/ψ Signal

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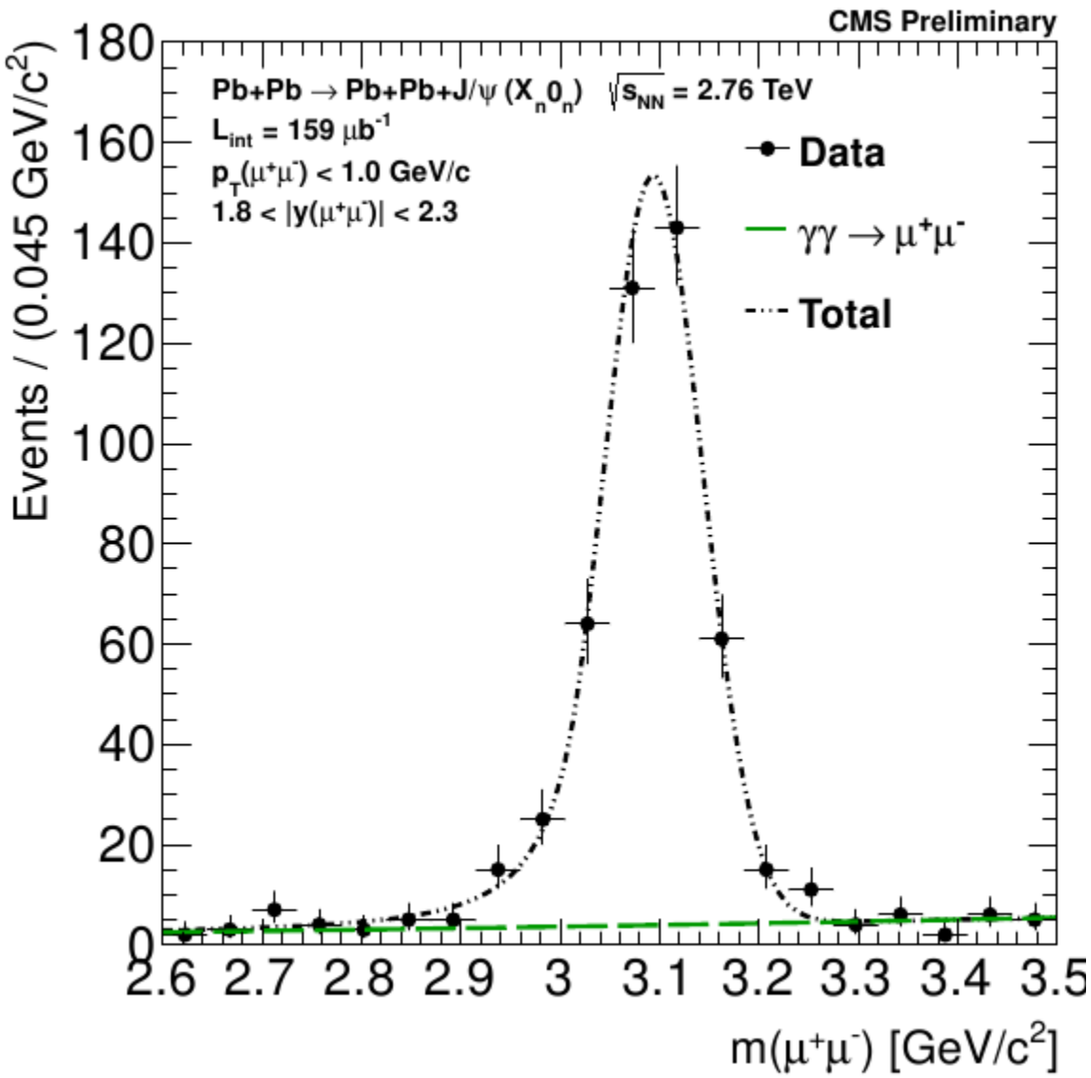
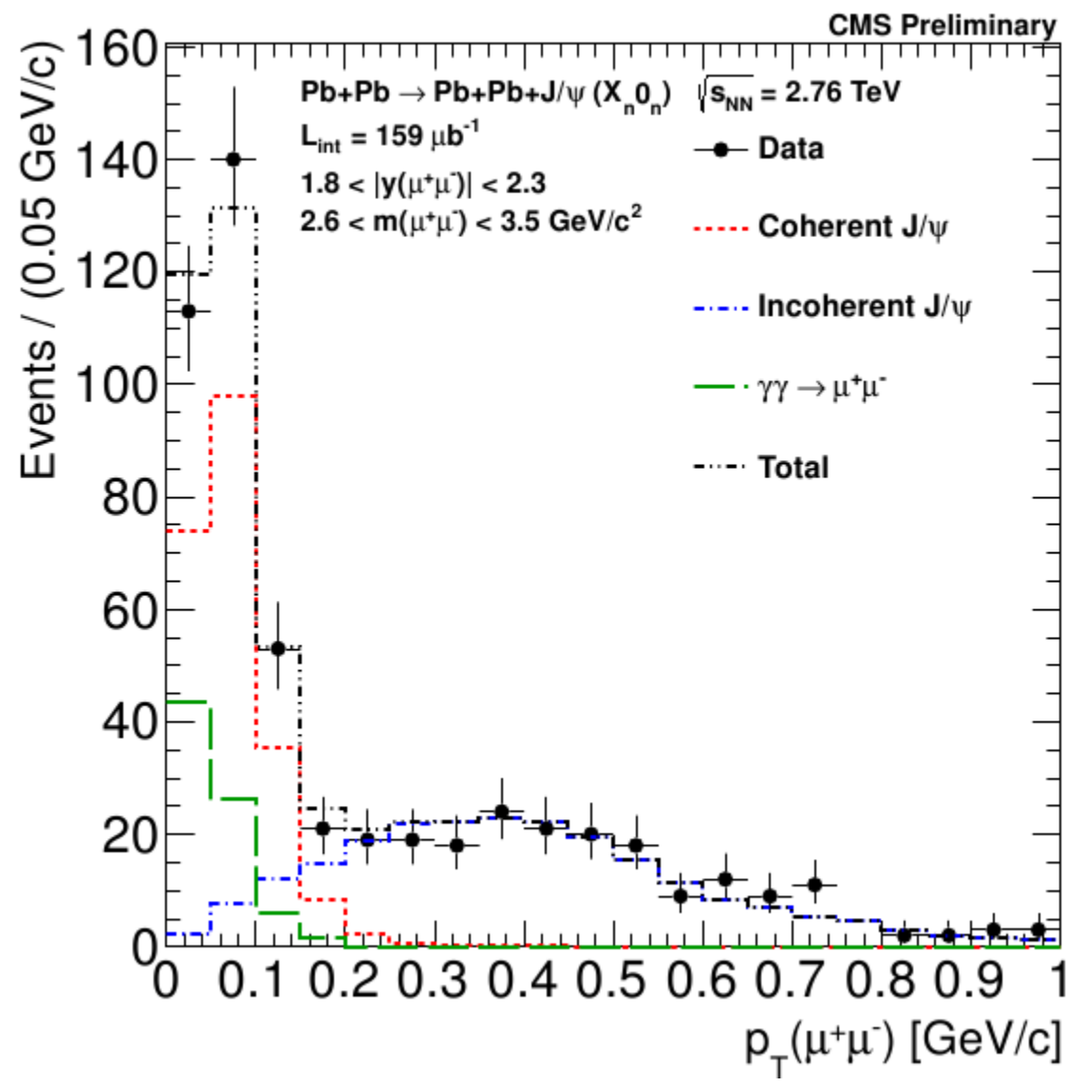




207 +/- 18 Coherent candidates with p_T below 0.15 GeV/c from the simultaneous mass and p_T fit

Acceptance and Efficiency Corrections

$$\frac{d\sigma^{coh}_{X_n 0_n}}{dy}(J/\psi) = \frac{N^{J/\psi}_{coh}}{BR(J/\psi \to \mu^+\mu^-) \cdot \mathcal{L}_{int} \cdot \Delta y \cdot (A \times \varepsilon)^{J/\psi}}$$

- The combined total correction factor $(A x \varepsilon)^{J/\psi} = 6\%$
- The acceptance and reconstruction efficiency are estimated from MC and found to be 12%
- The trigger efficiency is measured from data and found to be 50%

Systematic Uncertainties on J/ψ Cross Section

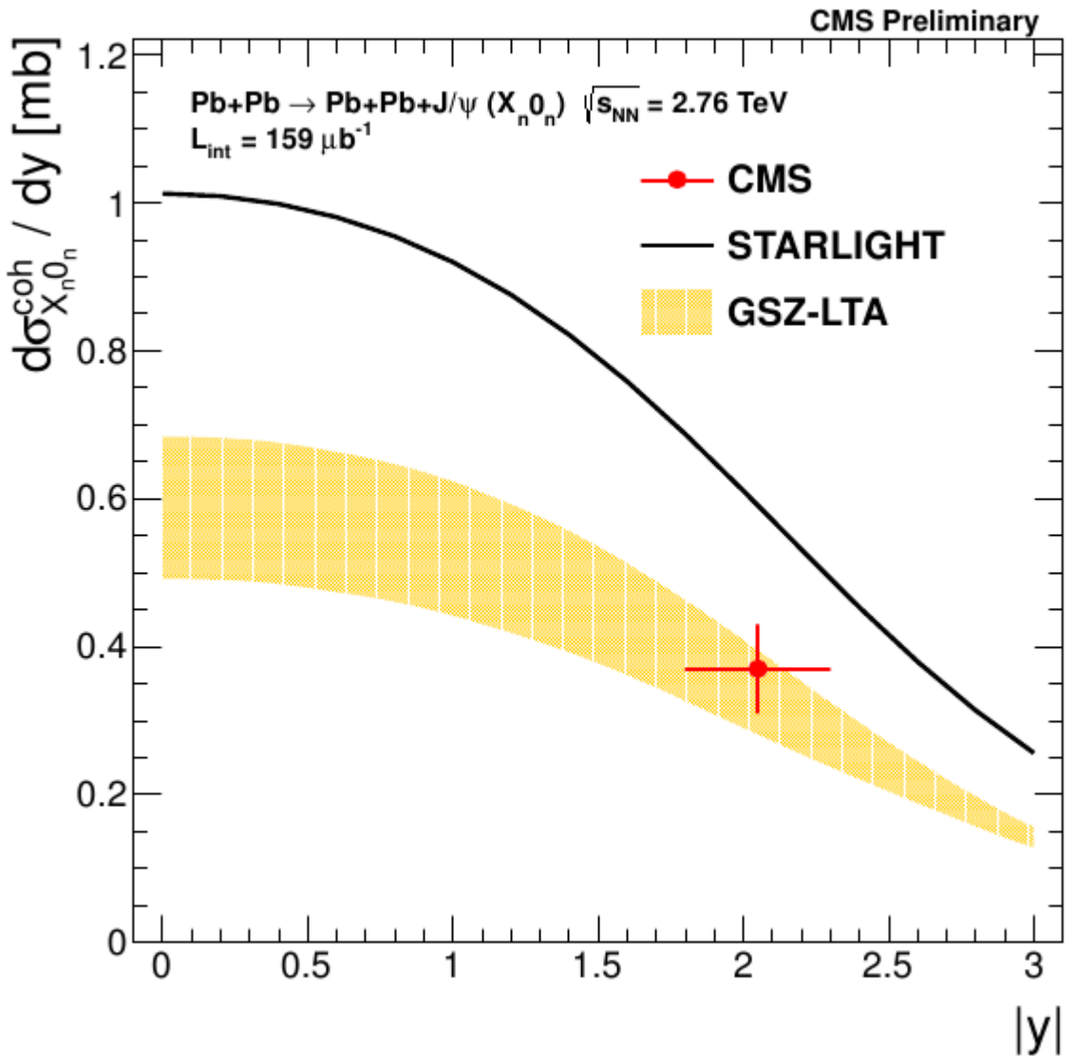
Table 1: Summary of systematic uncertainties.

	Uncertainty
(1) Neutron tagging	6%
(2) HF energy cut	1%
(3) signal extraction	5%
(4) MC input	1%
(5) ZDC efficiency estimation	3%
(6) Tracking reconstruction	4%
(7) Luminosity determination	5%
(8) Branching ratio	1%
Total	11%

- Neutron tagging is the leading systematic uncertainty
  - Several methods are used to define the ZDCs signal and corresponding thresholds
- The sub-leading systematic uncertainty comes from signal extraction
  - The invariant mass fit functions were varied as well as the mass range, which was extended to 8 GeV/c^2

Coherent J/ψ Cross Section in PbPb UPC

NEW



- Cross section measured for events with single sided neutron emission, the Xn0n break-up mode
- X_n0_n is the largest cross section available given ZDC trigger requirement

$d\sigma/dy(coh/X_n0_n) = 0.37 \pm 0.04(stat) \pm 0.04(syst)mb$

NEW

Break-up Modes Ratios

J/ψ with p_T <0.15 GeV/c	X_nX_n/X_n0_n	$1_n0_n/X_n0_n$	$1_n1_n/X_n0_n$
Data	0.36±0.04	0.26±0.03	0.03±0.01
STARLIGHT	0.37	N/A	0.02
GSZ	0.32	0.30	0.02

First measurement of break-up ratios for UPC J/ψ

X_n0_n single-sided neutron emission with any number of neutrons

X_nX_n double-sided neutron emission with any number of neutrons

1_n0_n single-sided neutron emission with only one neutron

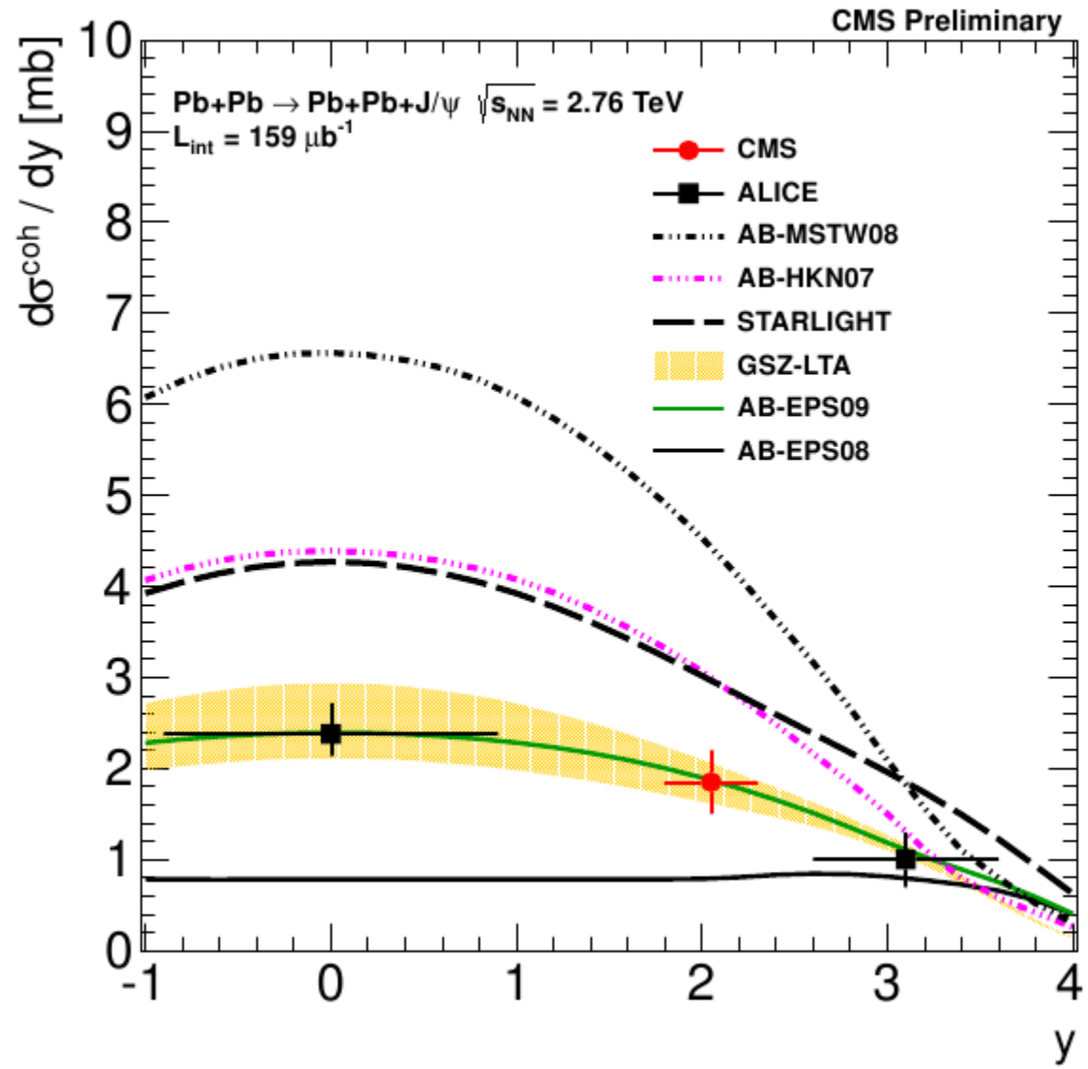
1_n1_n double-sided neutron emission with only one neutron on each side

The multiple photon-exchange model of nuclear break-up in coherent interactions describes the data reasonably well

Coherent J/ψ Cross Section in PbPb UPC

NEW

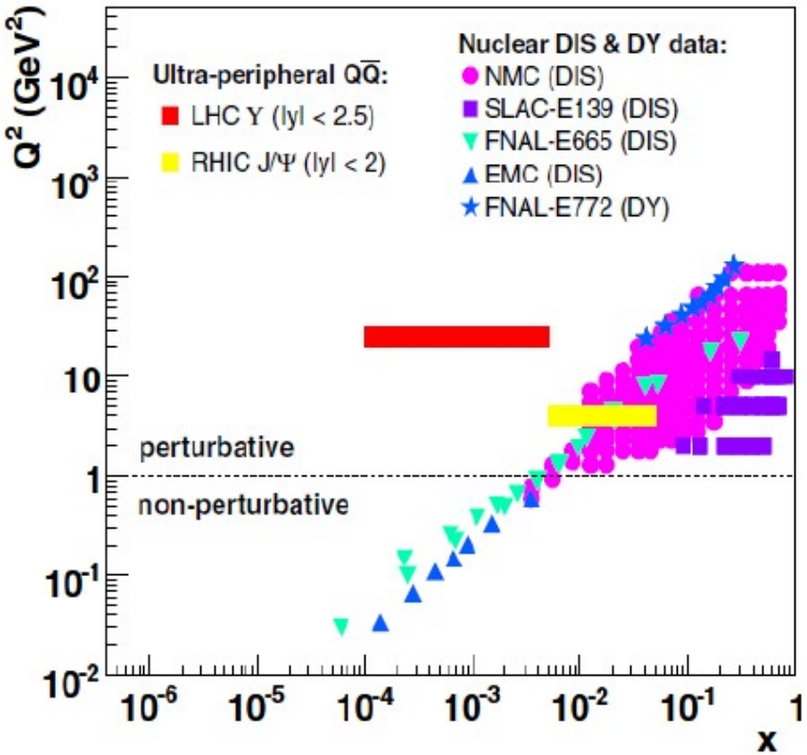
- Cross section for X_n0_n is scaled up to the total cross section using STARLIGHT
- CMS and ALICE results favor the same theoretical models
- ALICE and CMS measurements favor models containing moderate gluon shadowing

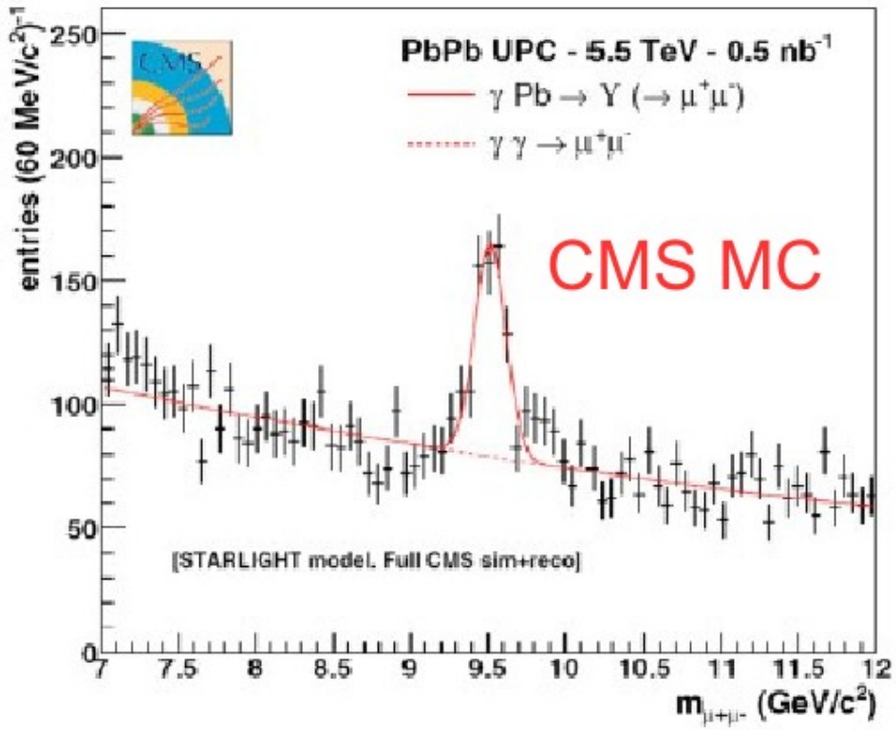


CMS: HIN-12-009: http://cds.cern.ch/record/1971267

ALICE: Eur.Phys.J. C73 (2013) 2617 Phys.Lett. B 718 (2013) 1273-1283

Prospect for 2015





2011: 150 μb^{-1}

at $\sqrt{s_{NN}}$ = 2.76 TeV

2015: 0.5-1.5 nb^{-1}

at $\sqrt{s_{NN}}$ = 5.1 TeV

Nuclear Physics B 179–180 (2008) 150–155

- Increase in luminosity of a factor of 5-10
- Increase in cross section for coherent Υ of 4 due to increase in energy
- Between 200-1000 Υ candidates expected

Summary

- UPC quarkonia studies offer a clean probe of the initial state, in particular the nuclear gluon density
- Recent preliminary results from CMS measuring the coherent J/ψ cross section made public HIN-12-009: http://cds.cern.ch/record/1971267
  - Favor same theoretical models as previous ALICE results
  - Cover a new rapidity region
  - Favor theoretical models including nuclear gluon shadowing
  - Break-up ratios are consistent with theoretical models using multiple photon exchange
- The higher energies and luminosities in 2015 PbPb collisions will offer the opportunity to study Υ in UPC events and potentially new objects like dijets

Backup

Coherent J/ψ Cross Section in PbPb UPC

- Triggering: dedicated UPC triggers rejecting hadronic
- Event selection: rejection of beam background, hadronic interactions, and muon quality requirements
- Neutron tagging: neutron threshold definitions to define break-up modes
- Signal extraction: mass and p_T fits to extract the coherent yield
- Systematic uncertainties: list of systematic uncertainties
- Results: coherent J/ψ cross section and ratios between break up modes

UPC Triggers in pp, PbPb, and pPb

- L1 trigger: hardware based trigger using the calorimeters and muon systems
  - PbPb: single muon trigger with no p_T threshold, require empty scintillation counters in the forward region, and activity in the zero degree calorimeters
  - pPb: single muon trigger with no p_T threshold
- HLT trigger: software trigger using the full detector
  - PbPb: at least on reconstructed pixel track
  - pPb: between 1 and 6 reconstructed online tracks

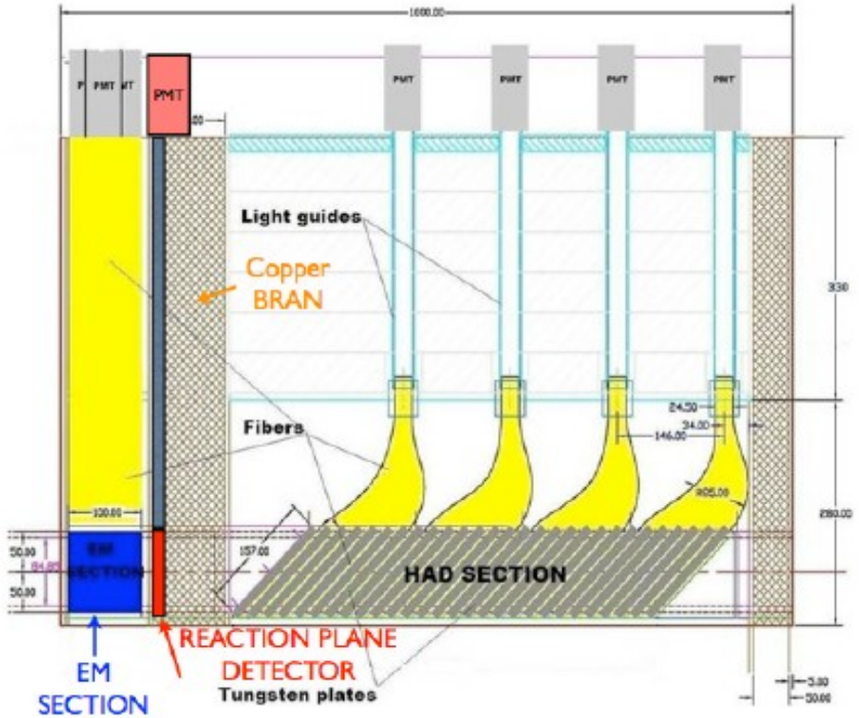
CMS UPC Analyses

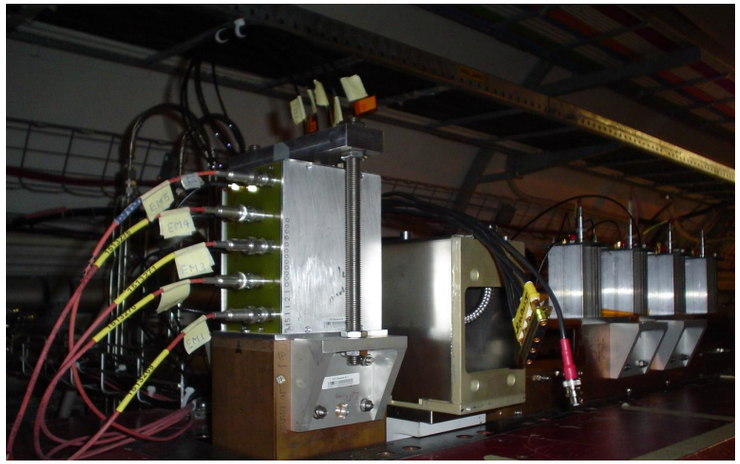
- Preliminary results on coherent J/ψ production made public recently HIN-12-009: http://cds.cern.ch/record/1971267
- Analysis of exclusive Υ in pp is underway
- Analysis of J/ψ and Υ underway in pPb
  - Potential to look at γ-p and γ-Pb interactions for J/ψ

Studies of photoproduction of vector mesons in pp, pPb, PbPb can probe both the proton and nuclear gluon densities

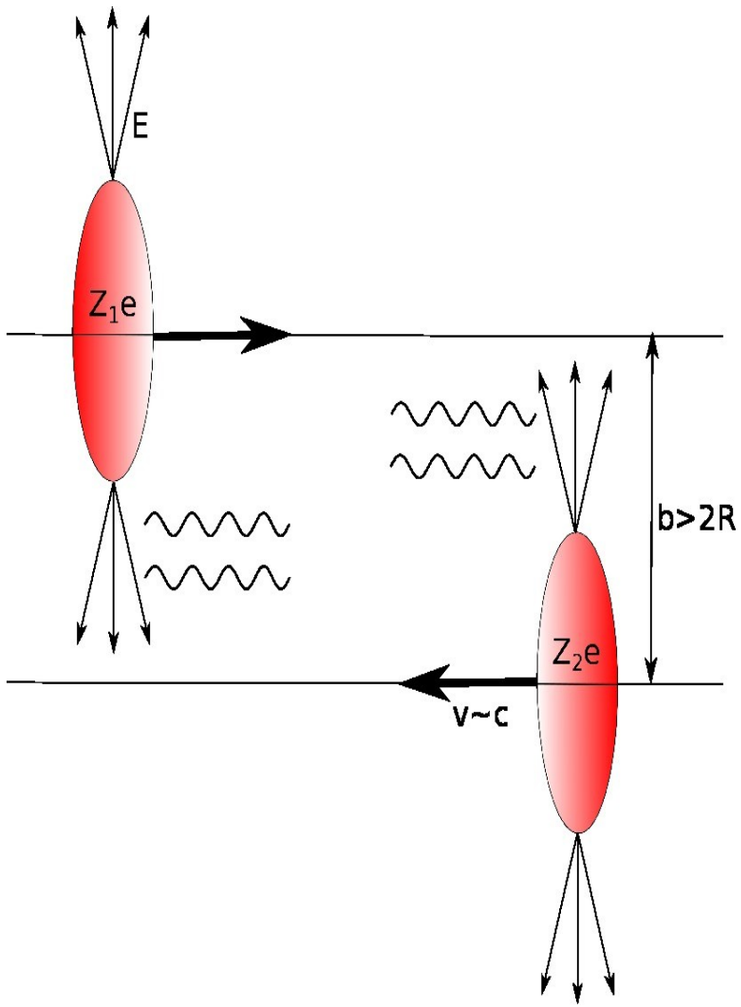
The Zero Degree Calorimeters

- Quartz fibers and tungsten absorber Cherenkov detectors
- 140 meters from interaction point on either side
- Total of 18 channels
  - 5 electromagnetic sections each segmented transverse to the beam
  - 4 hadronic sections segmented longitudinally
  - Detects neutral particles $|\eta| > 8.3$





Physics Processes in Ultra-Peripheral Collisions



Coherent photoproduction: the photon couples to the nucleus as a whole

Incoherent photoproduction: the photon couples to the nucleons inside

Photon-photon interaction: photons from the two nuclei can interact with each other