# Photon photon and photon nucleus physics at the LHC


CMS Experiment at LHC, CERN
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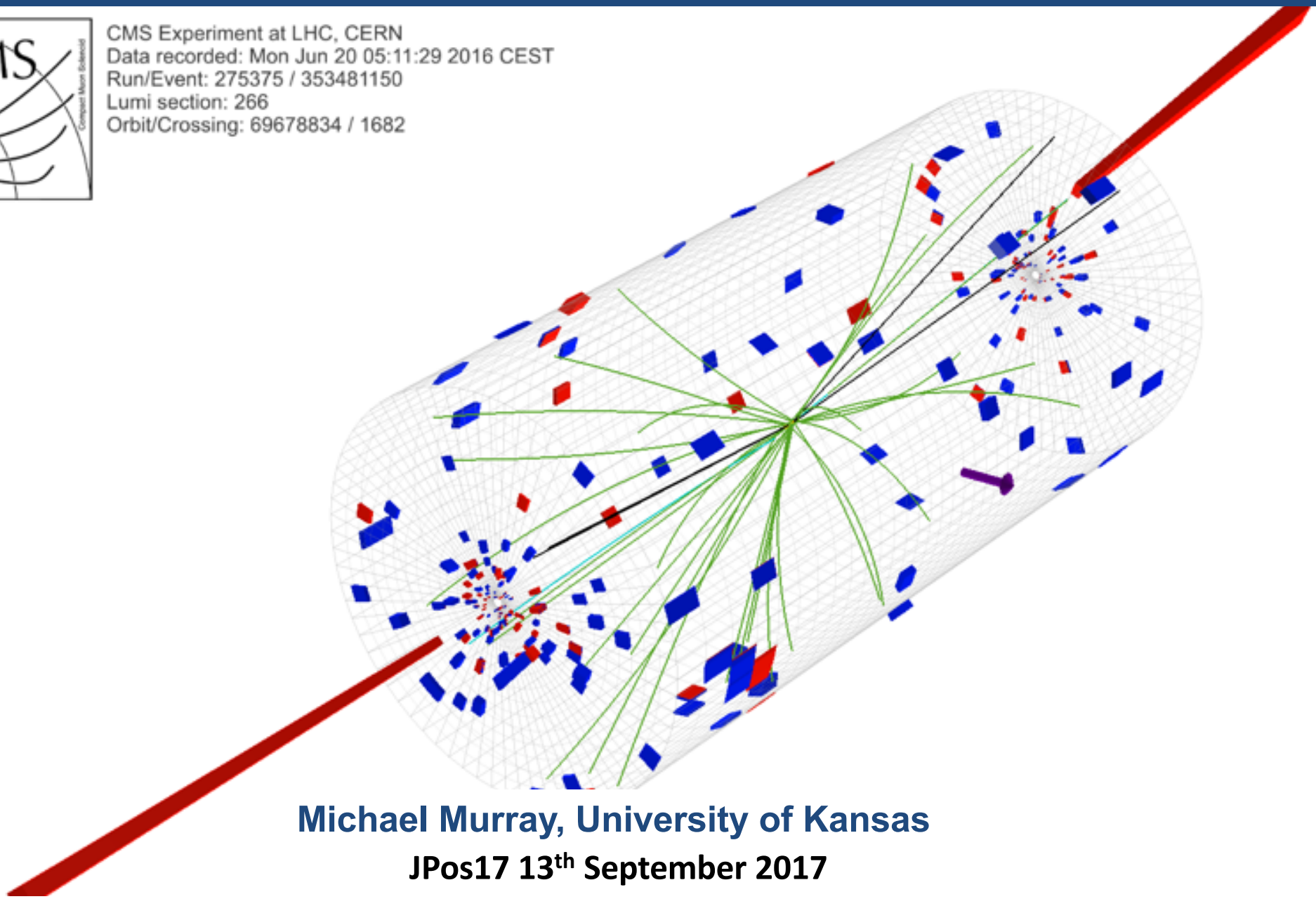


**Michael Murray, University of Kansas**

**JPos17 13th September 2017**

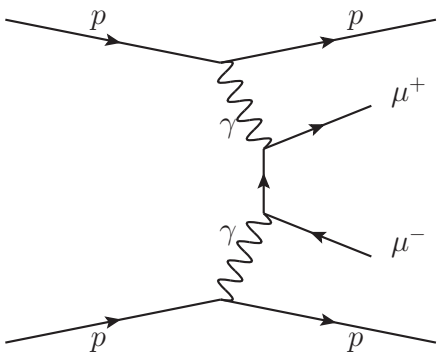
# Photon studies at the LHC

1) Search for new physics from γγ => high mass
   - ATLAS, CMS-TOTEM in pp running
2) Search for gluon saturation i lead via γp=> vector mesons and dijets
   - ALICE, CMS and soon ATLAS
3) Search for gluon saturation in the proton via γp=> vector mesons
   - ALICE, LHCb, CMS and soon ATLAS.
   - This work is very complementary to HERA studies.

In this talk I will discuss the first two points

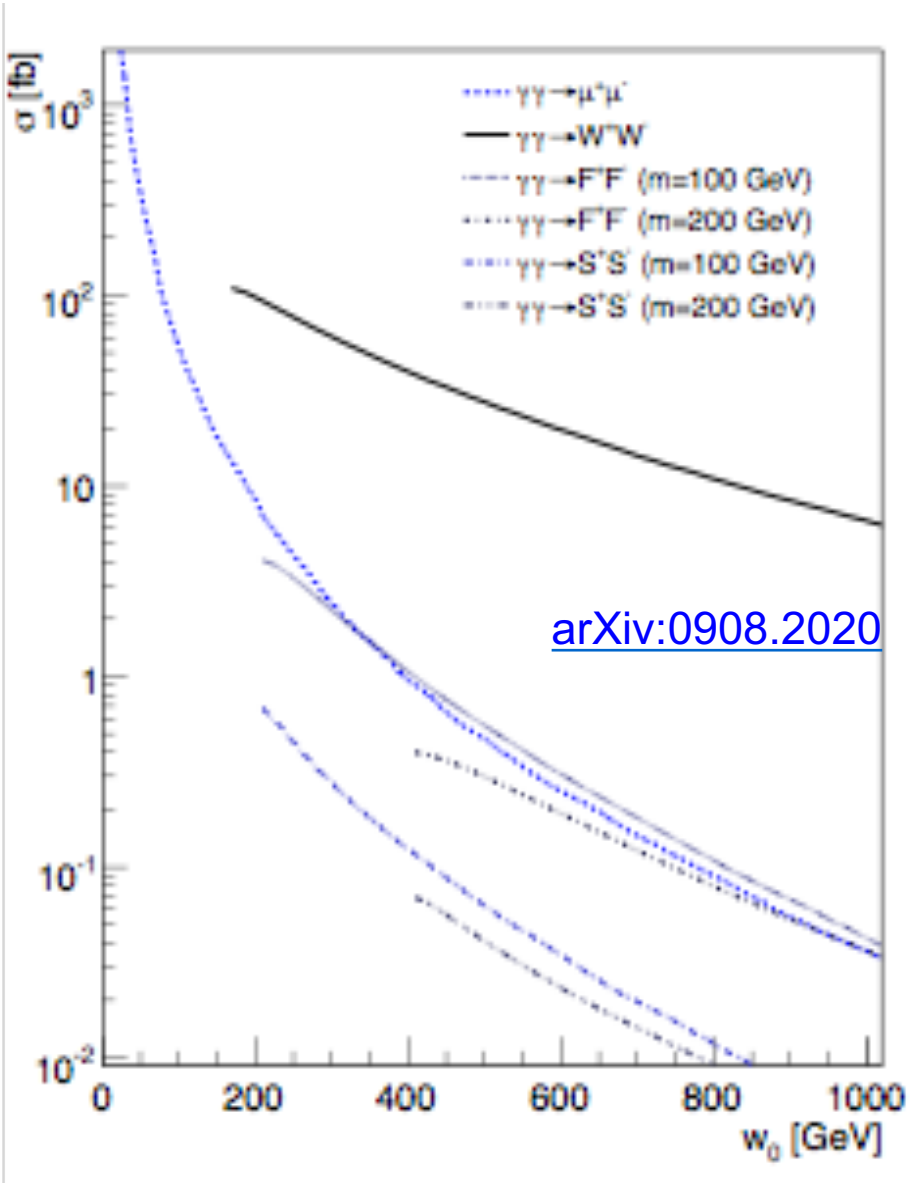
# Photon – Photon => High Mass

- LHC produces huge photon flux



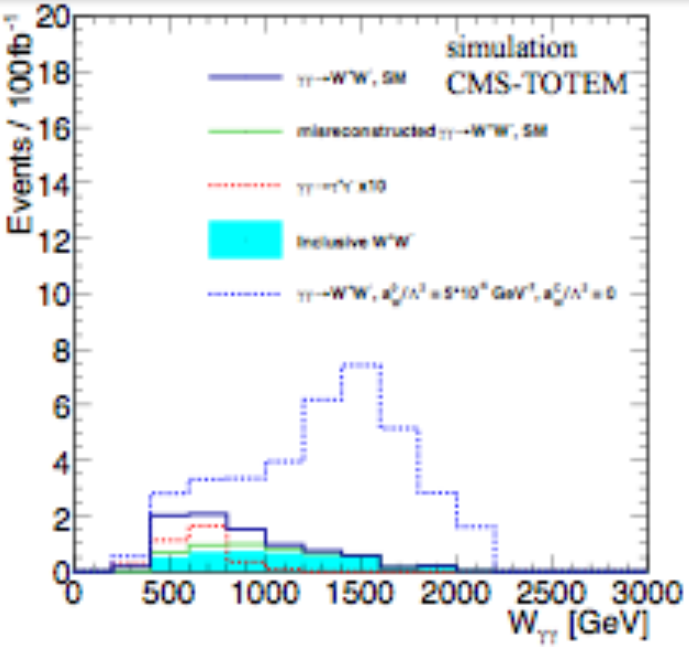

- When forward protons are matched to the central system we get a strong background suppression by matching $\sqrt{s_{\gamma\gamma}}$ and rapidity.

- Theory is much cleaner than for proton dissociation.

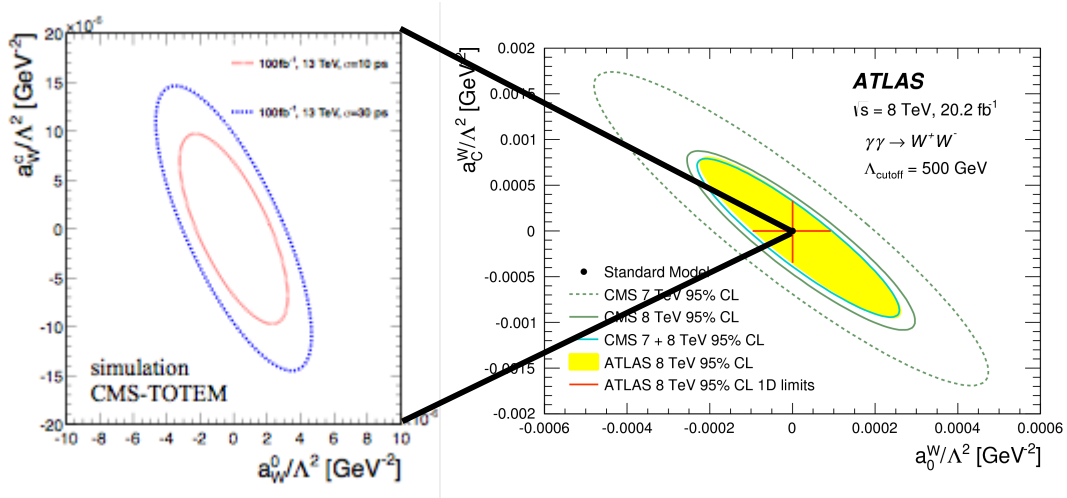


# Physics potential of γγ with proton tags

**Indirect searches, via anomalous couplings, loop-level effects**

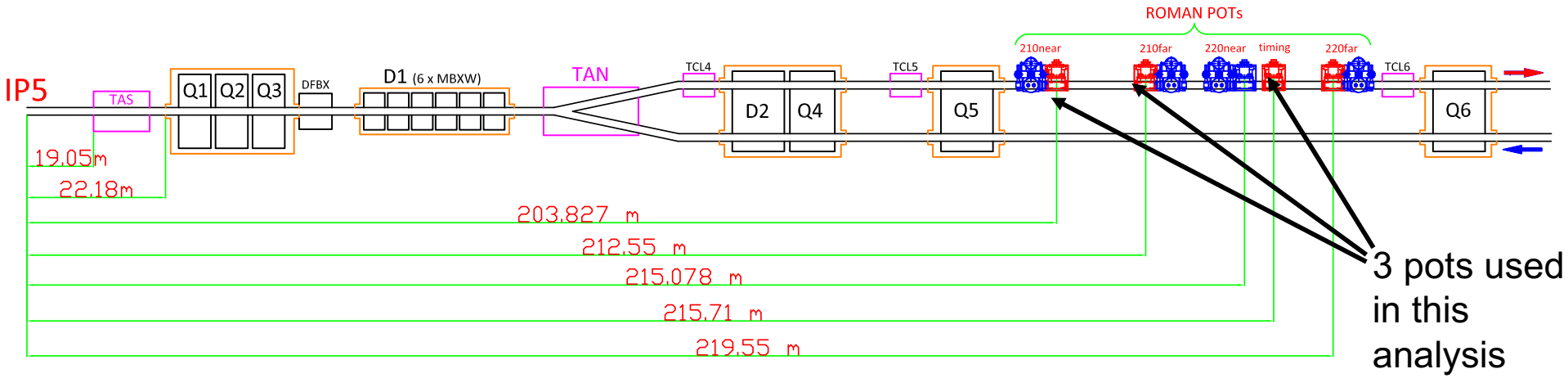


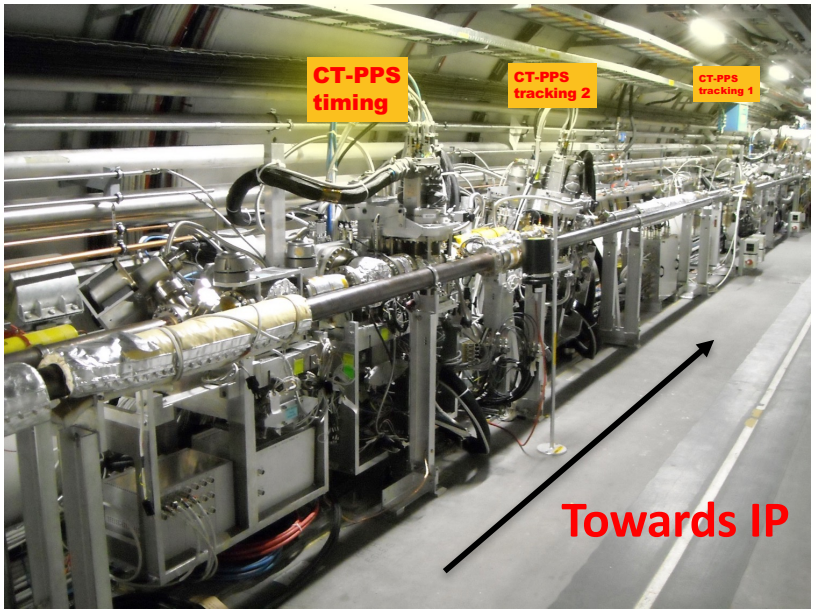

**Direct search for new resonances, exotically charged particles, etc.**




CERN-LHCC-2014-021

# CT-PPS in 2016

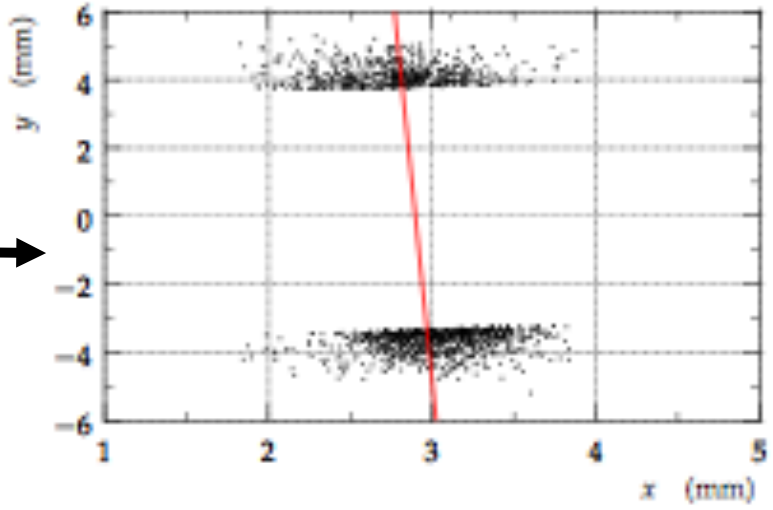


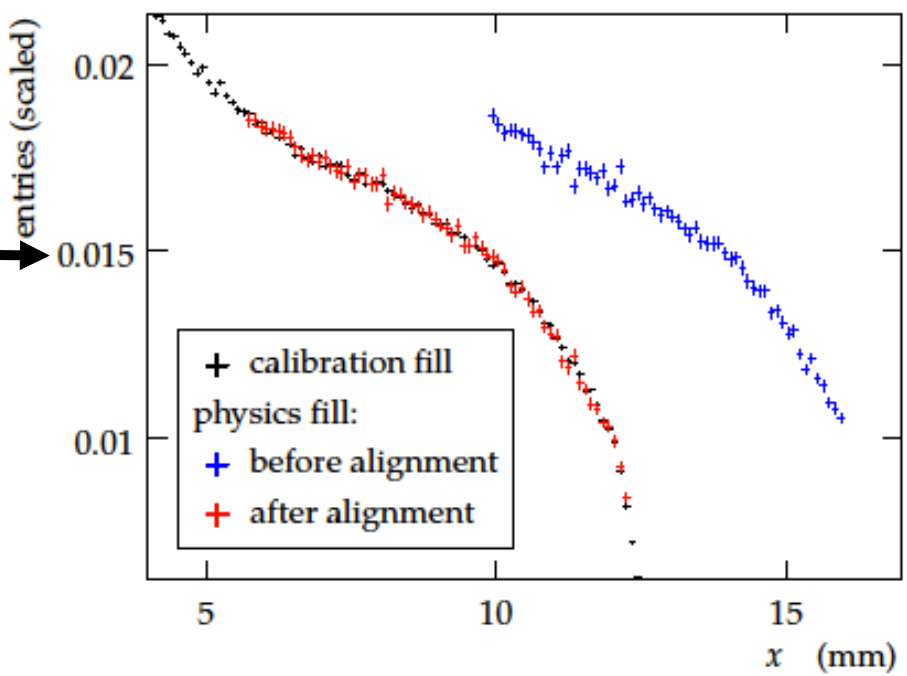

- 2 horizontal Roman Pots , equipped with Si-strips & RF shielding for insertion at high luminosity
- 1 cylindrical RP, equipped with fast-timing diamond detectors

# Alignment

1. Use elastic scattering (pp→pp) events, in special alignment runs where both horizontal and vertical RPs are very close to the beam




2. Use inclusive sample of protons triggered by central CMS detector and then match distribution of proton track positions to that of alignment runs



# Measuring proton momentum loss “ξ”

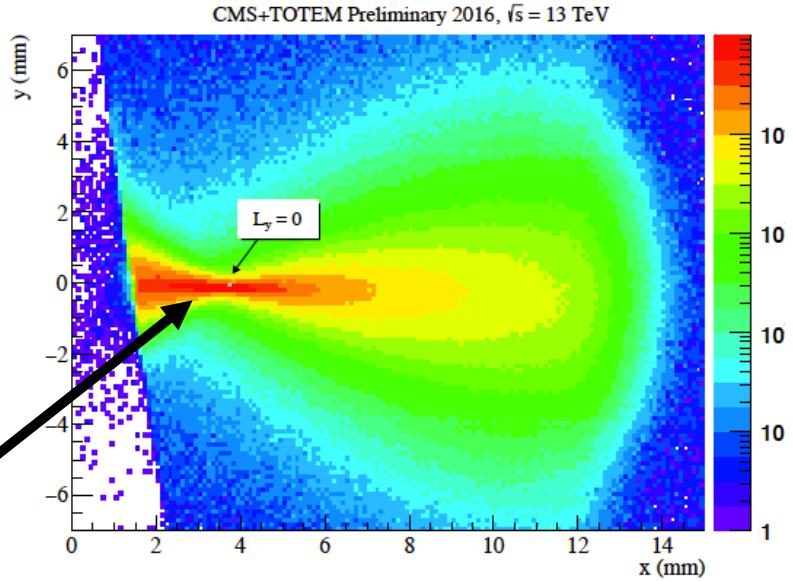
Reconstruction uses track position and knowledge of LHC optics & dispersion.

- Optics matching uses elastic events, quadrupole strengths and positions of RPs and beam position monitors. [New J. Phys. 16 (2014) 103041]

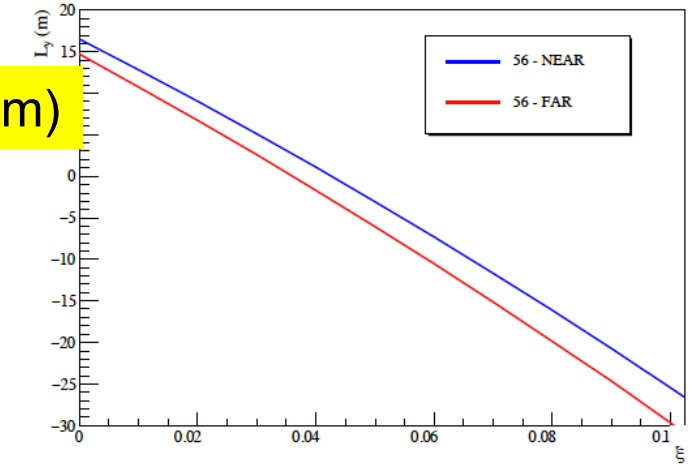
- Dispersion calibration uses the vertical pinch point $L_y(x) = 0$.

- Final result is a (non-linear) calibration of ξ vs. the measured track x position

- Overall ξ resolution = 5.5%

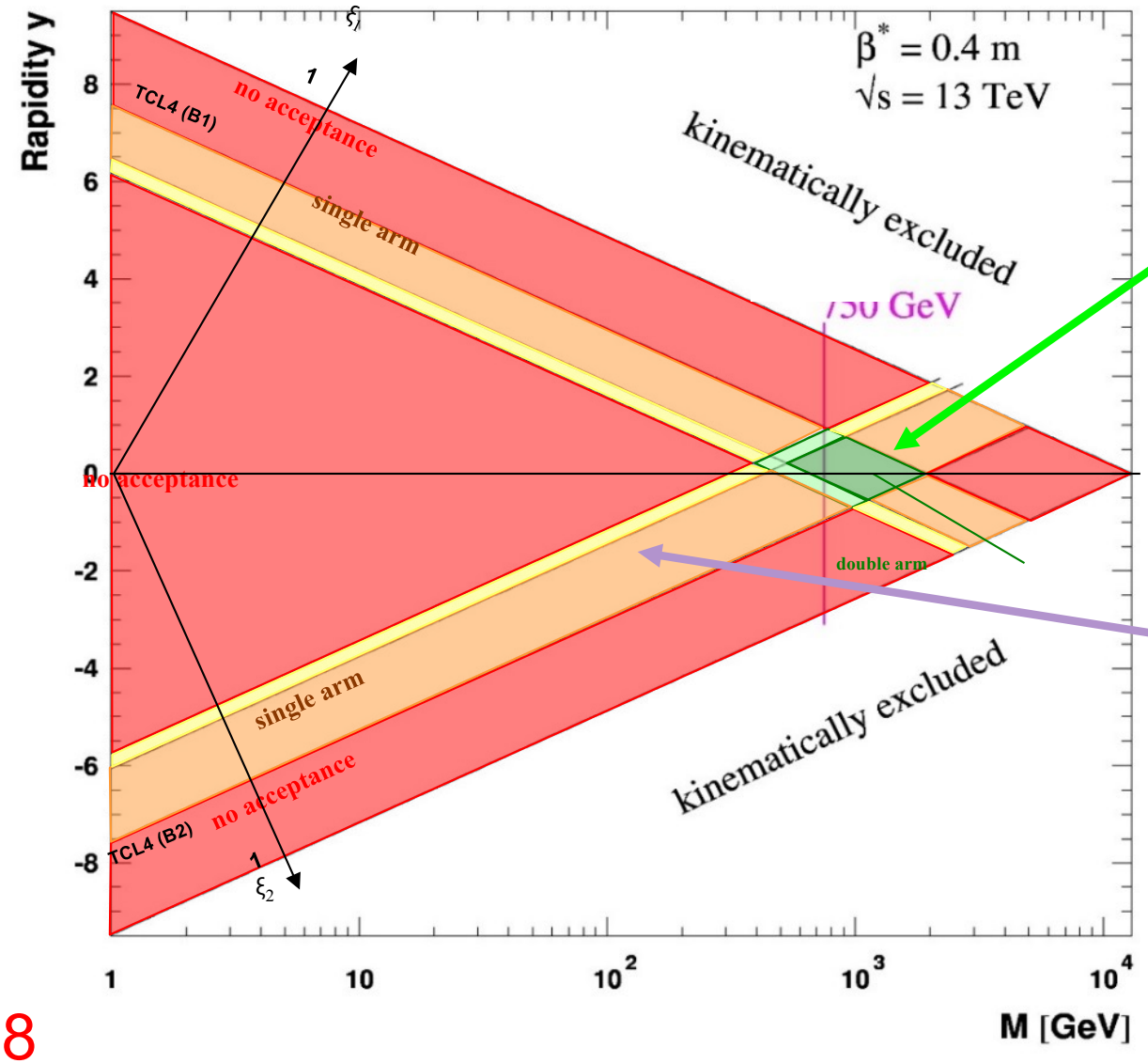



$L_y$ (mm)



# Acceptance, vs Mass and Rapidity

**2016 optics before TS2 (data-calibrated): β* = 0.4 m, $\alpha_X$ = 370 µrad, mild orbit bump, RPs @ 15σ**



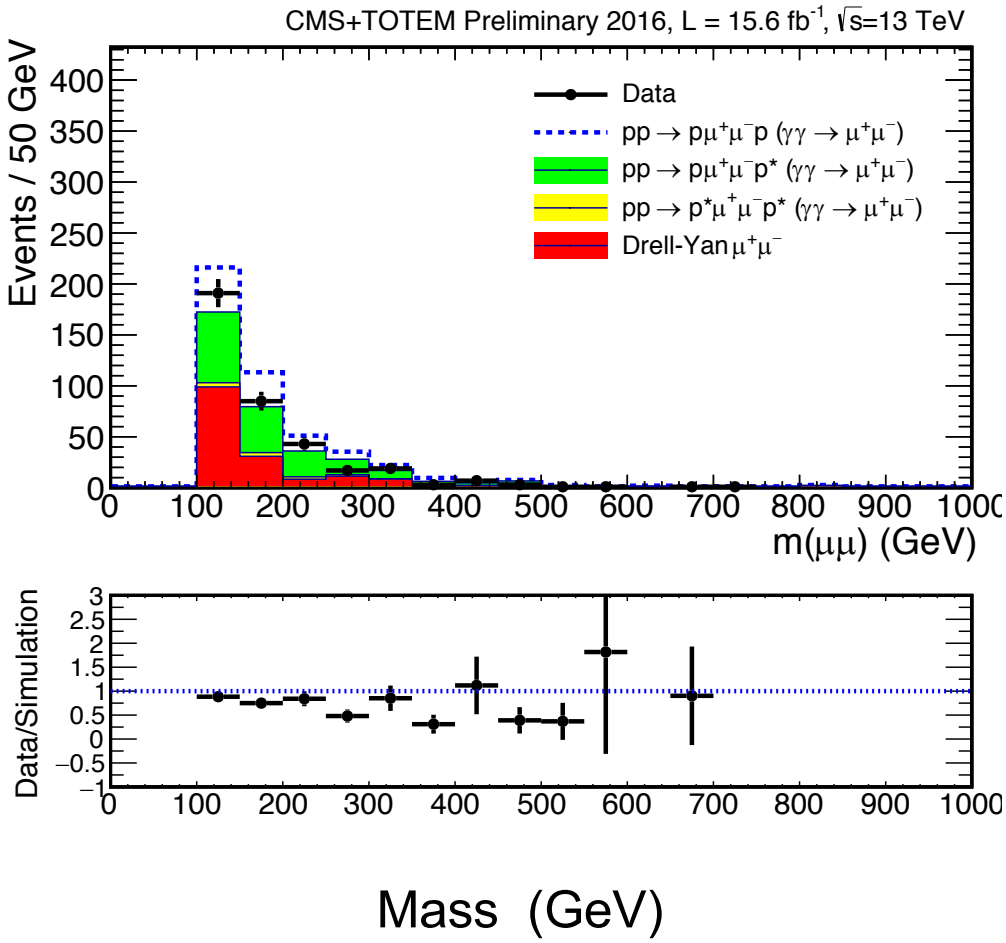

Acceptance for seeing both protons at mid-rapidity and m = 360 - 2000GeV

Acceptance for seeing 1 proton at lower masses and forward rapidity

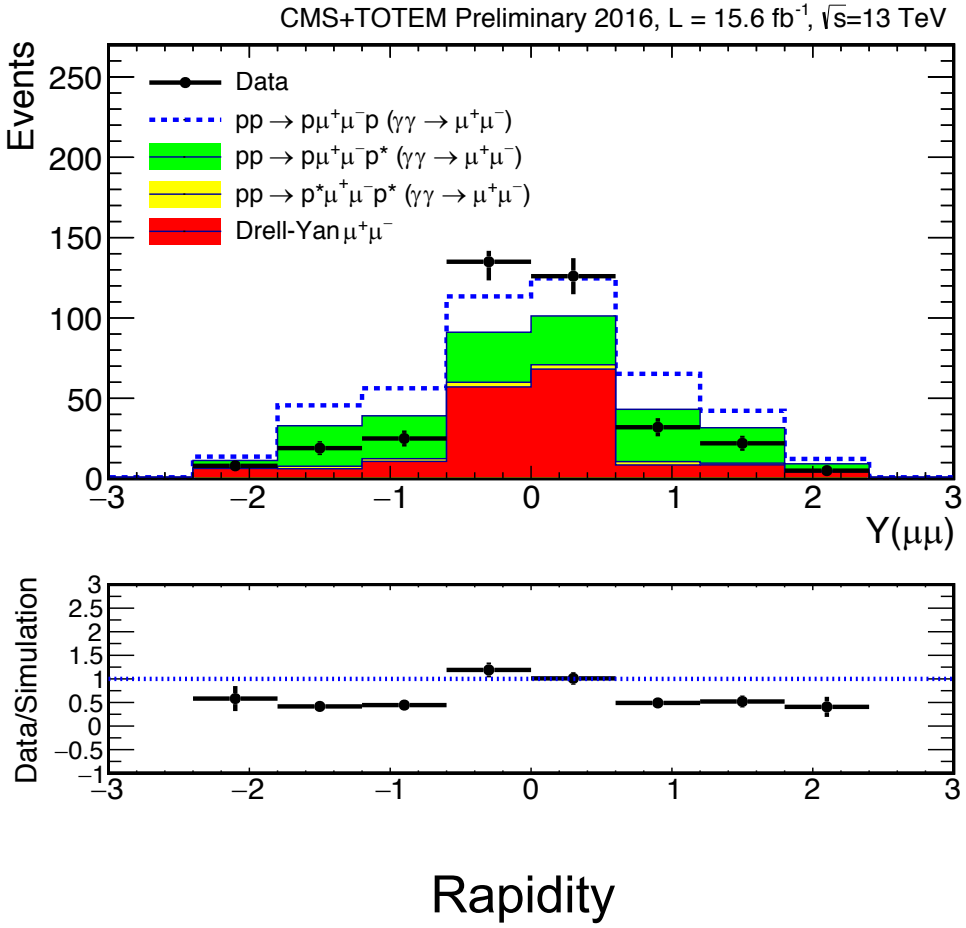
# Event selection and backgrounds

- Integrated luminosity of ~10fb$^{-1}$, with stable optics in 2016
- Require back to back muons with m(μμ)>110GeV, above the *Z*
- Require the μμ vertex be separated from other tracks, and muons be back to back in φ
- Require ξ(μμ) and ξ(RP) to match within 2σ
- "Data-driven" estimate of remaining backgrounds, using inclusive Z→μμ events in coincidence with pileup protons
- Total background estimate: 1.47 ±0.06 (stat.) ±0.52 (syst.)

# Mass and rapidity distributions



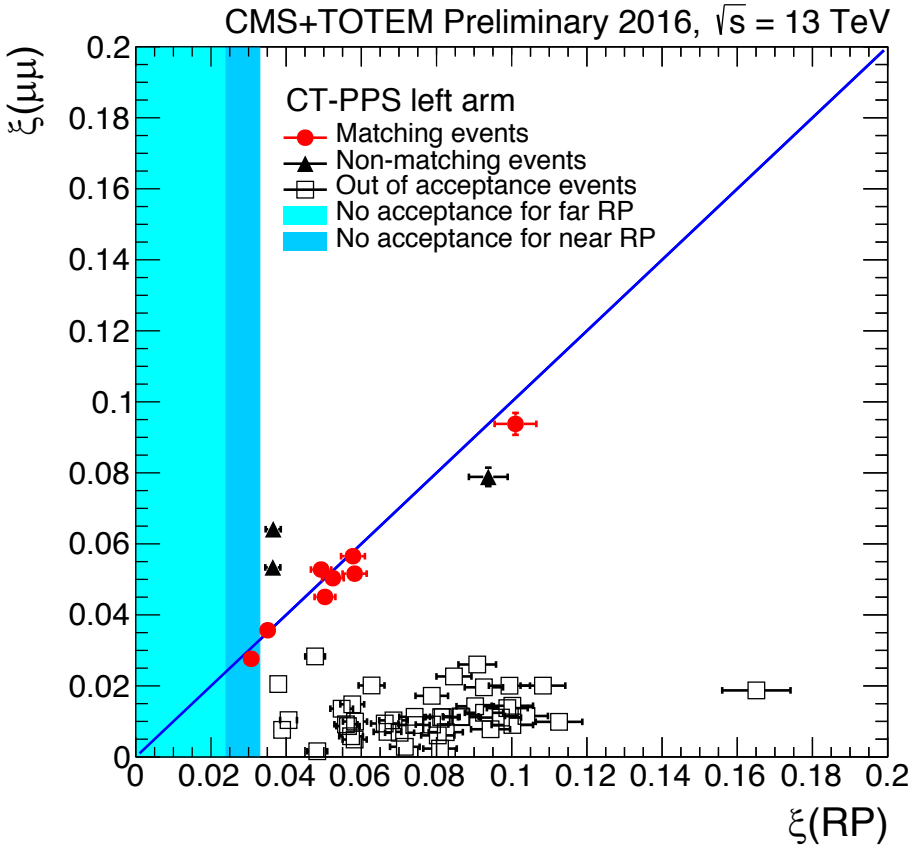

Mass (GeV)



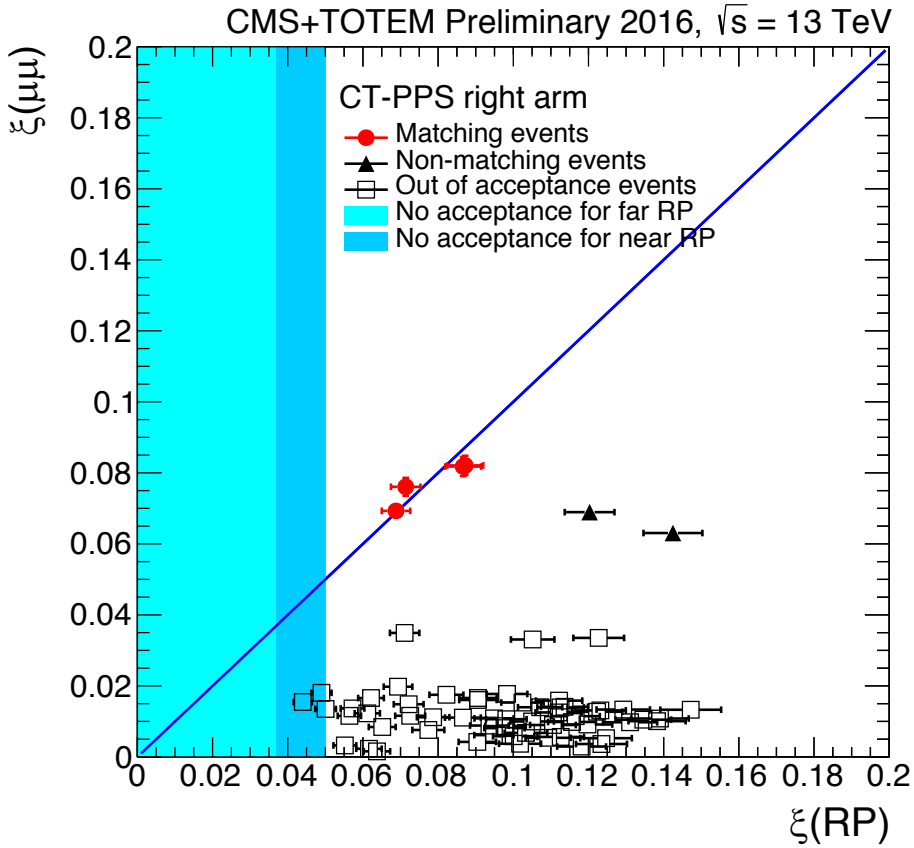

Rapidity

# Observed ξ correlations

Left Arm




Right Arm



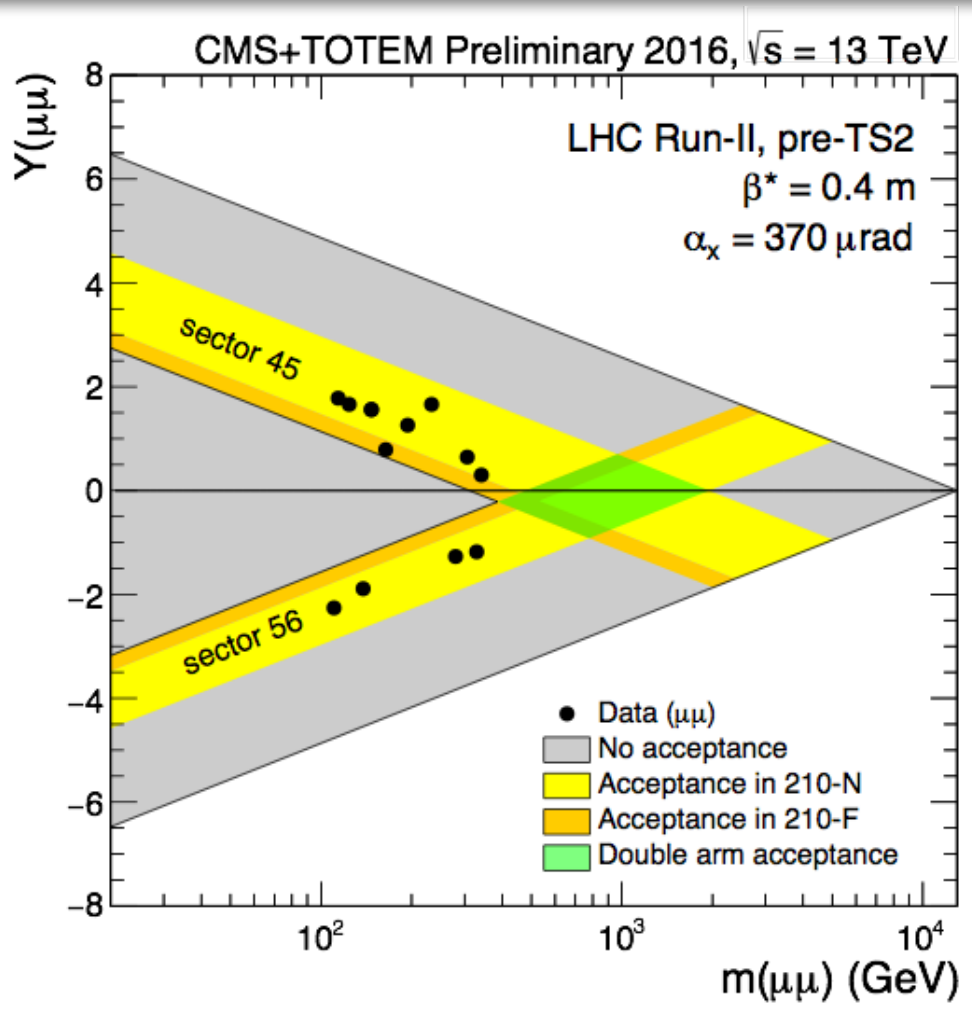

17 events have ξ(μμ) consistent with RP acceptance

12 of these have ξ(μμ) that matches ξ(RP) (red points)

Significance for a background of 1.47±0.06 (stat.)±0.52 (syst.): 4.3σ

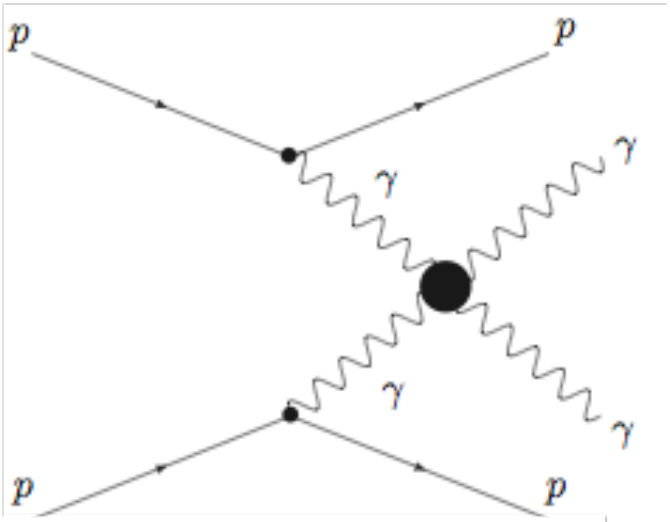
# Distribution in mass and rapidity

- Spectrum extends to m(μμ) = 341 GeV.
- Tagged γγ collisions at the electroweak scale!
- Range is several times beyond previous results with proton tags.
- No double-tagged events observed as expected for SM cross section * efficiency.

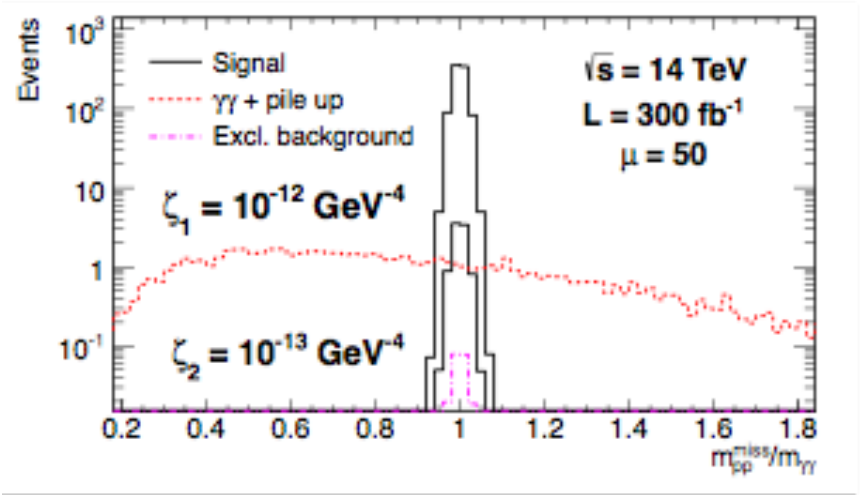


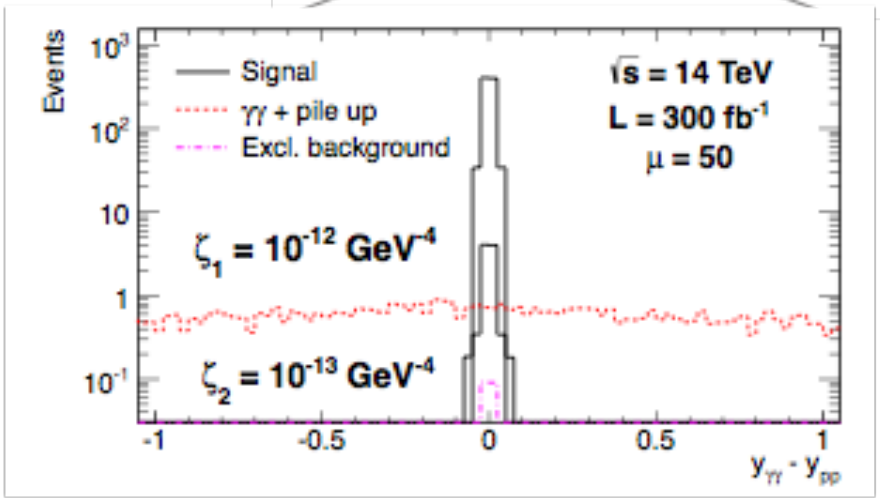
# Ongoing search for γ γ → γ γ

This channel should provide best sensitivity to neutral quartic gauge couplings at LHC **(JHEP 08 (2016) 119**




Later look for γγ→γZ, γγ→ZZ, γγ→WW

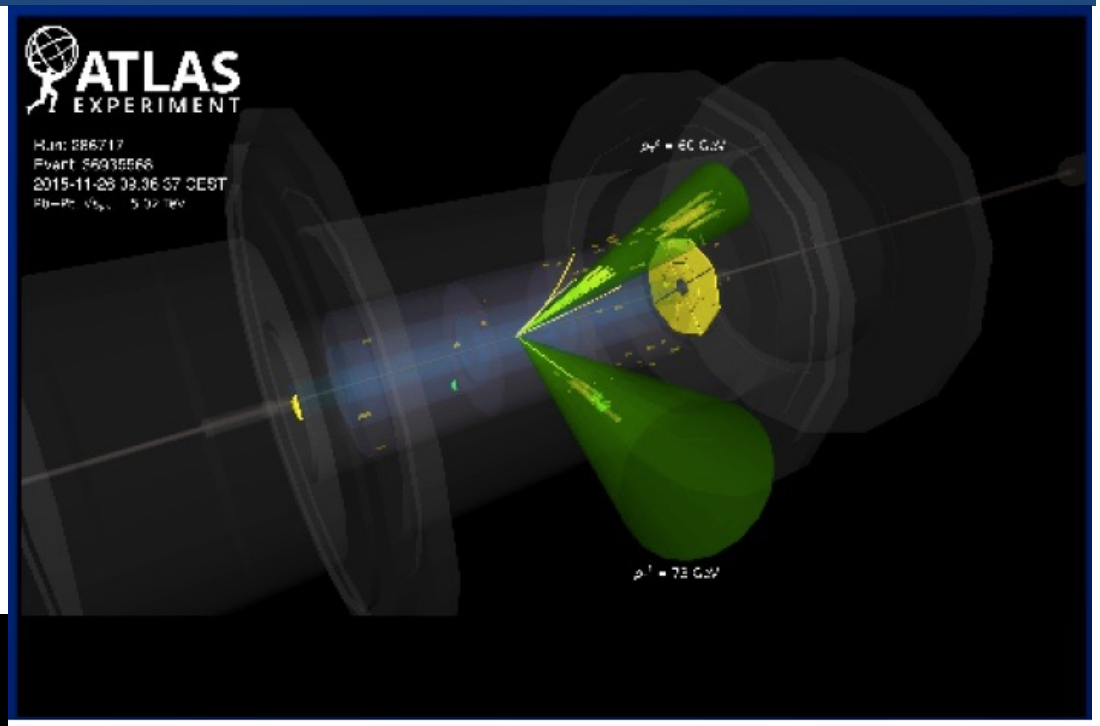


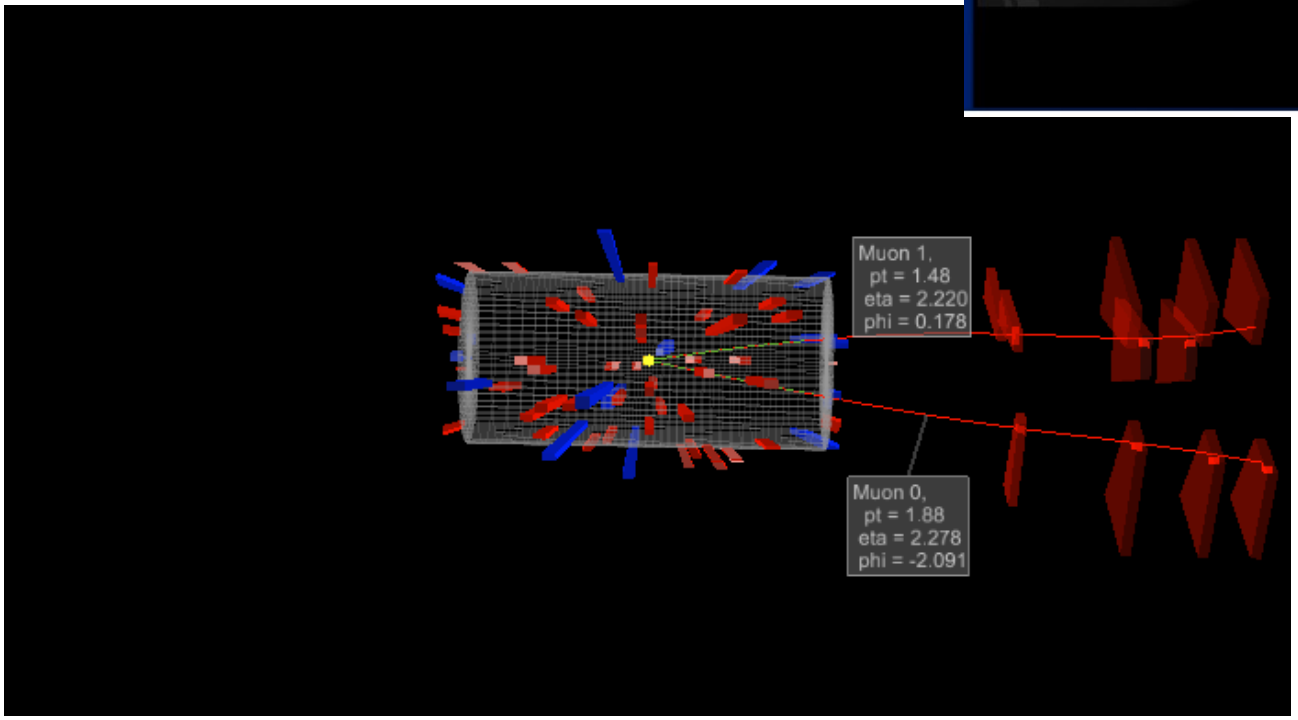




After mass and rapidity matching this is almost a background free measurement

# Search for gluon saturation in lead

Di-Jets from ATLAS

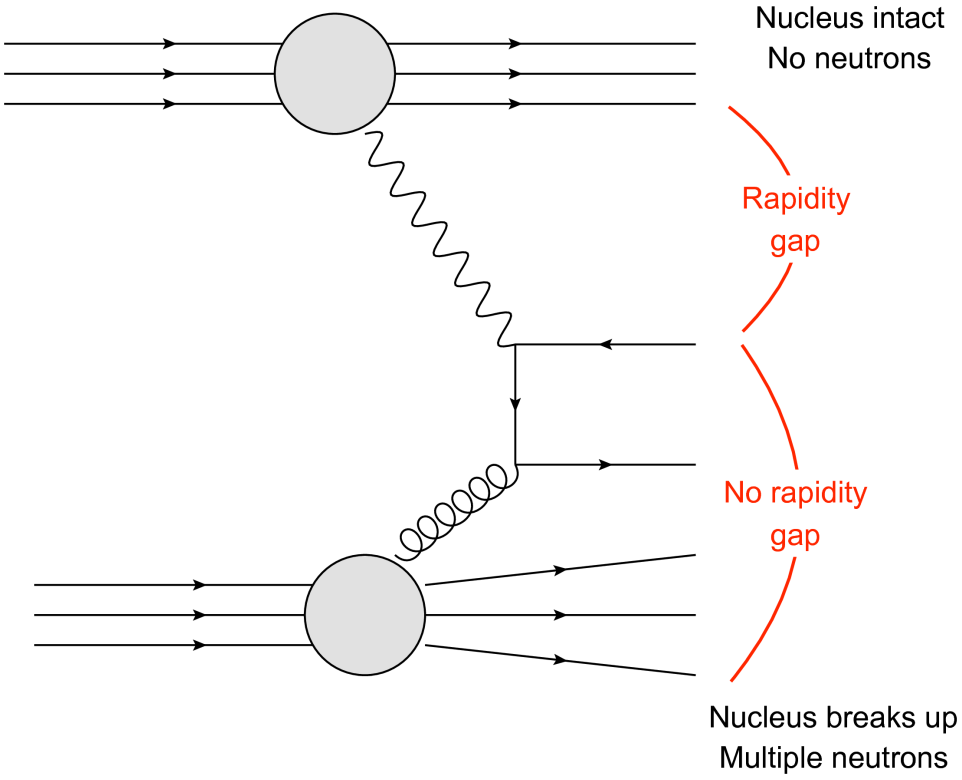


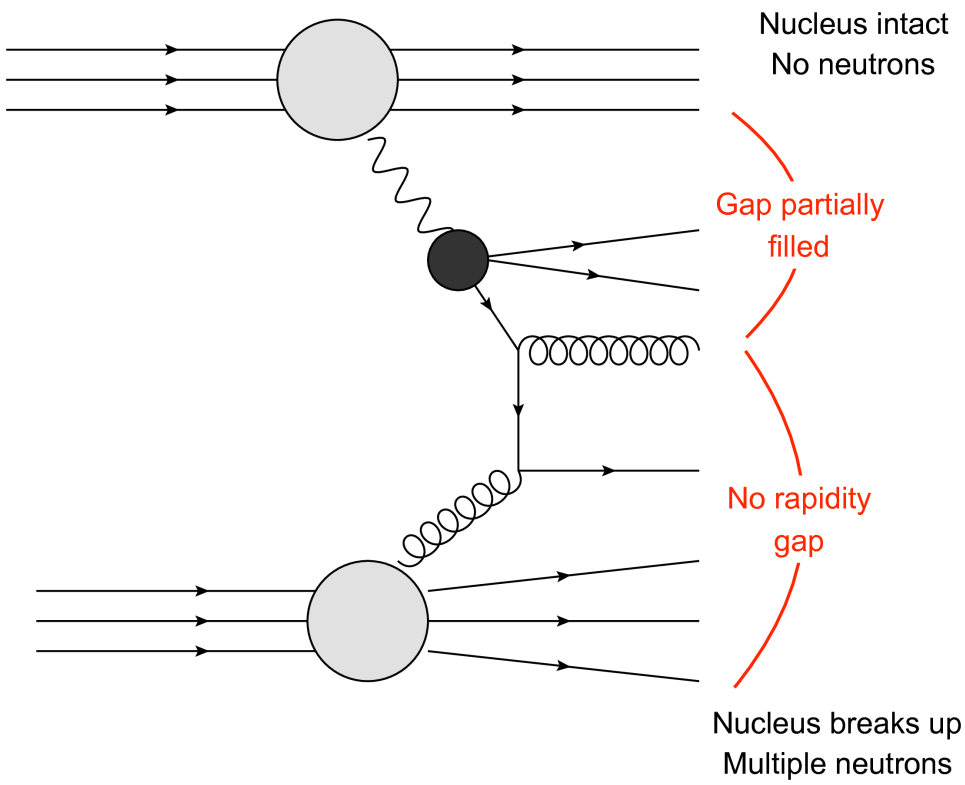

J/ψ from ALICE, CMS

# Photon-lead => dijets in ATLAS

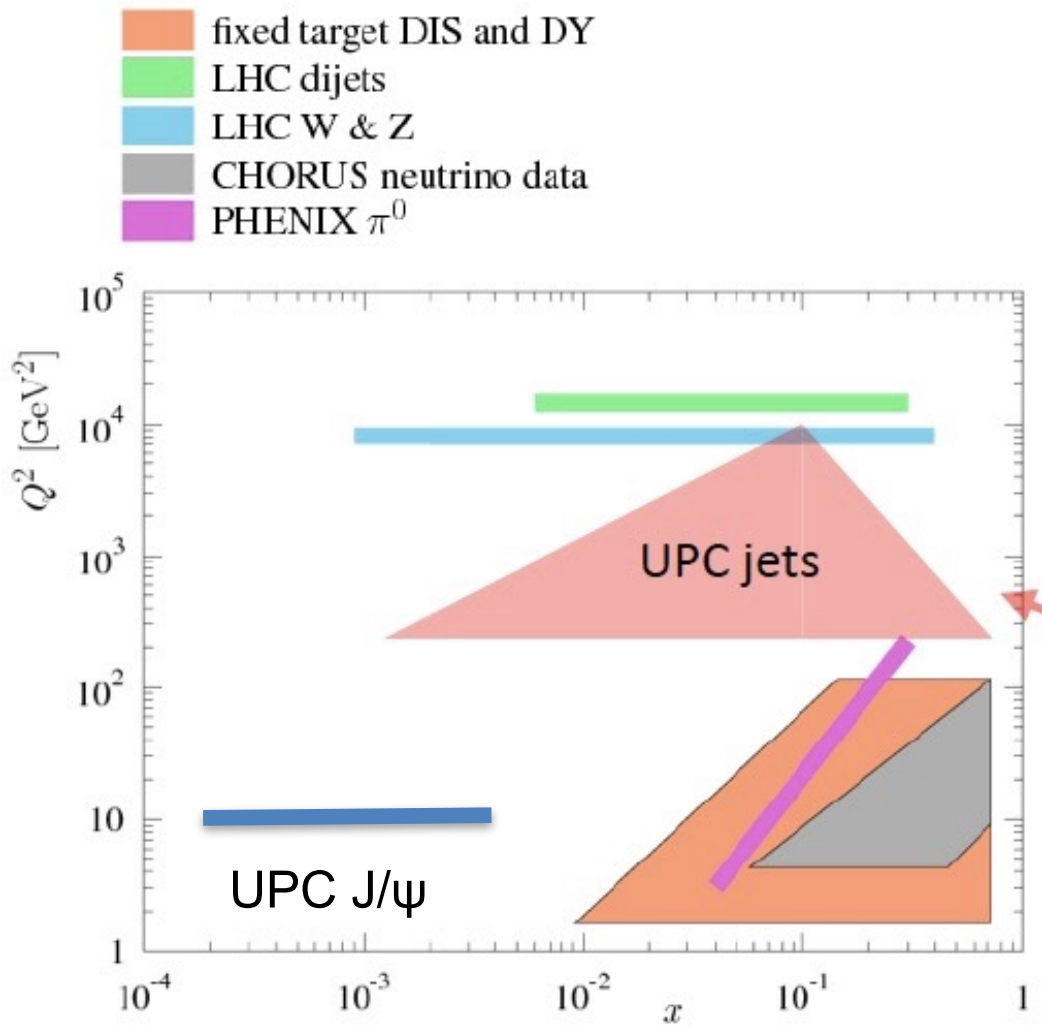
## Photon interacts directly

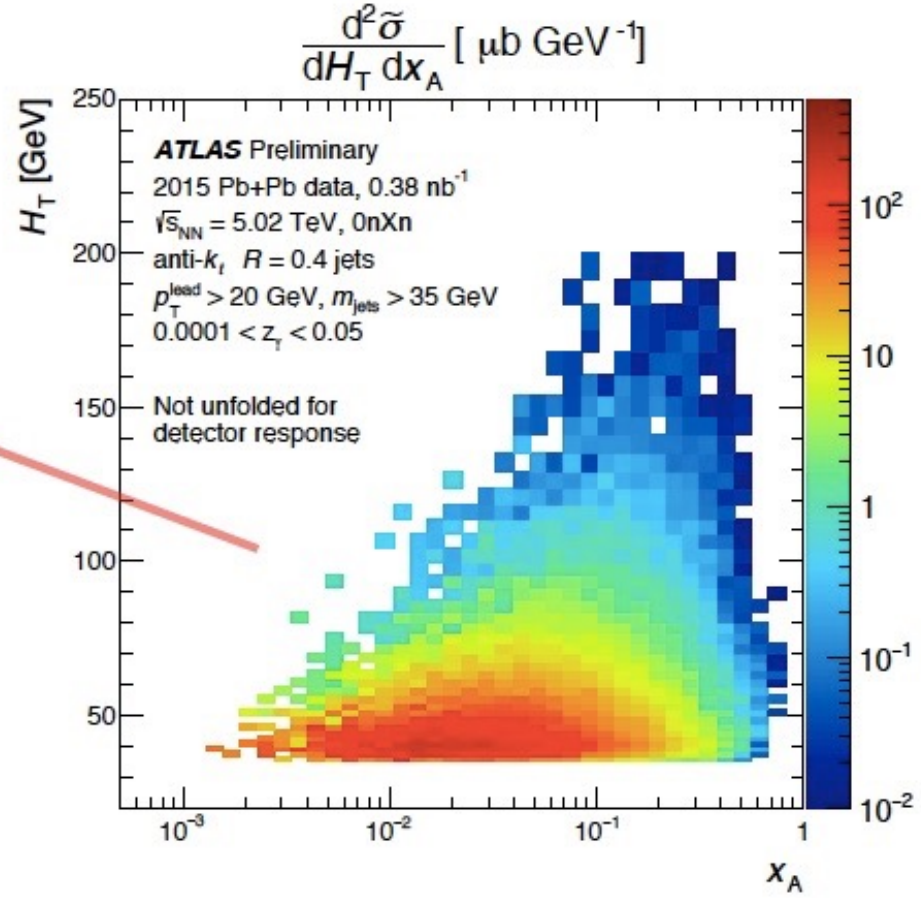



## Photon structure is resolved



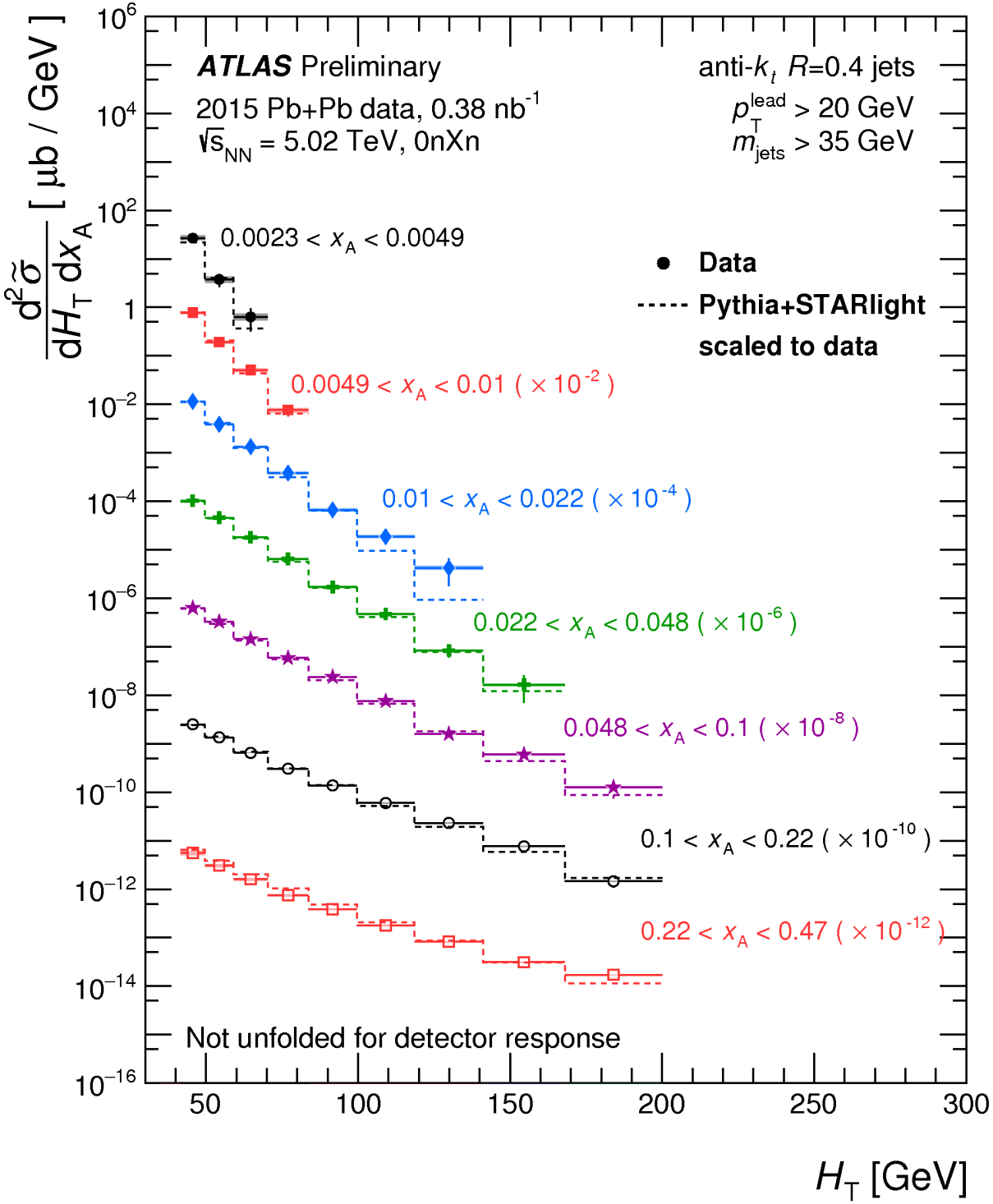
# UPC dijets cover a huge phase-space



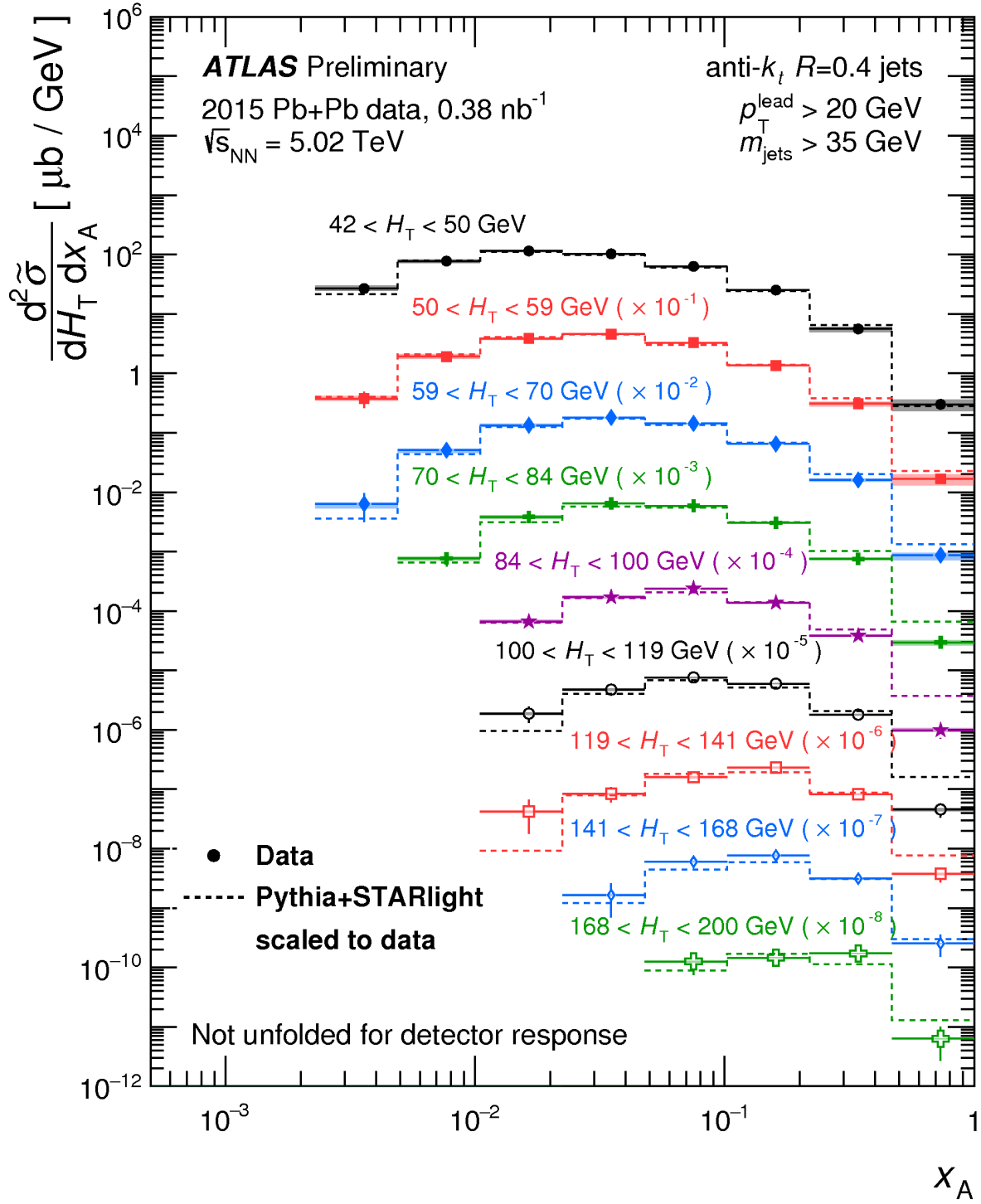
# Spectra vs total dijet $p_T$

**Data compared to a hybrid simulation from STARLIGHT (for photon flux) and Pythia**

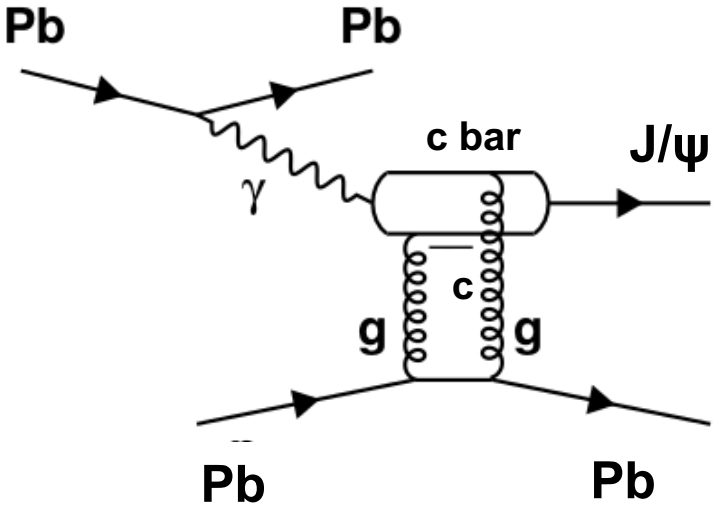


# Spectra vs momentum fraction of parton in the nucleus

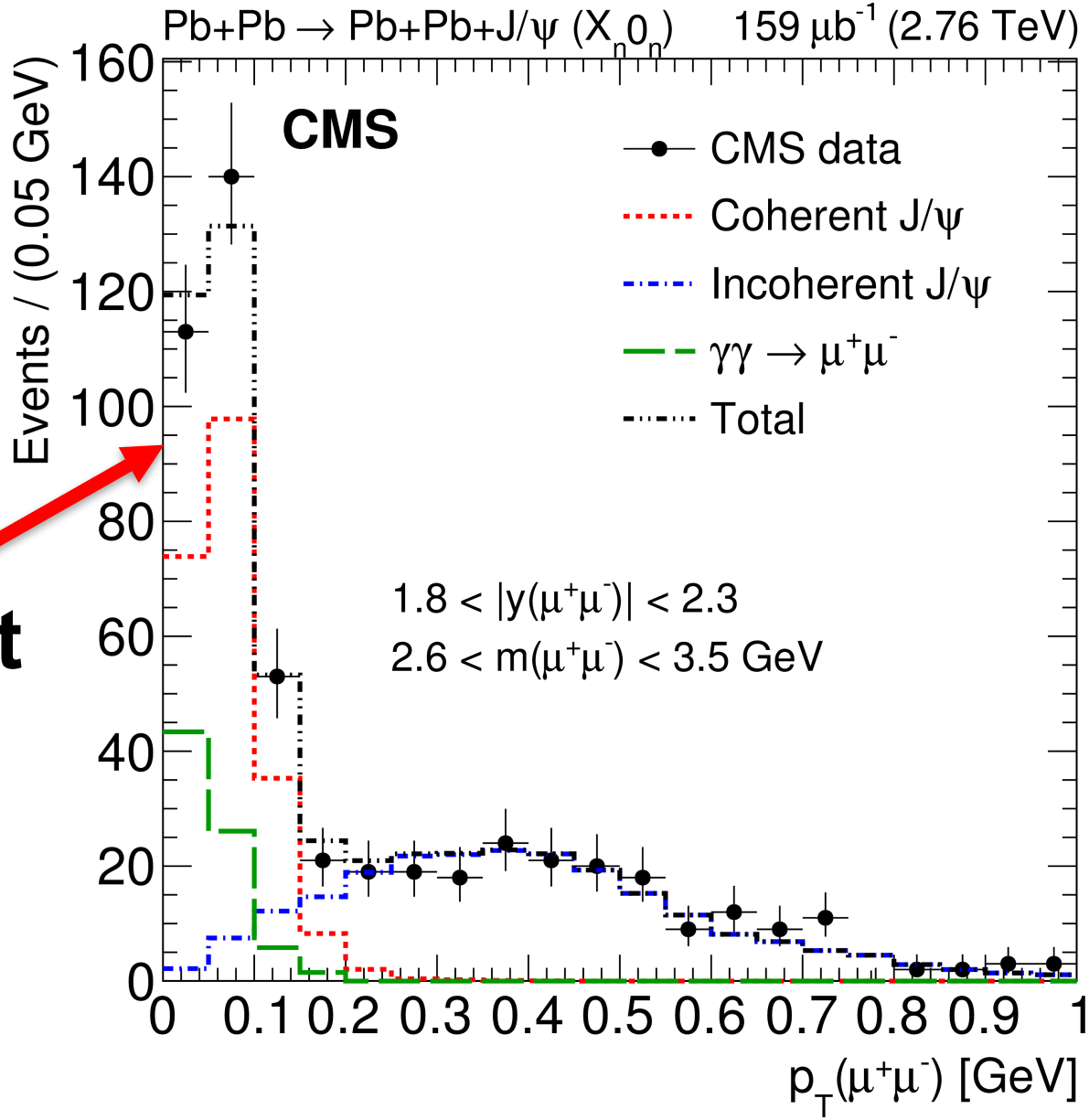
**Data compared to a hybrid simulation from STARLIGHT (for photon flux) and Pythia**



# CMS: Coherent γPb =>J/ψ



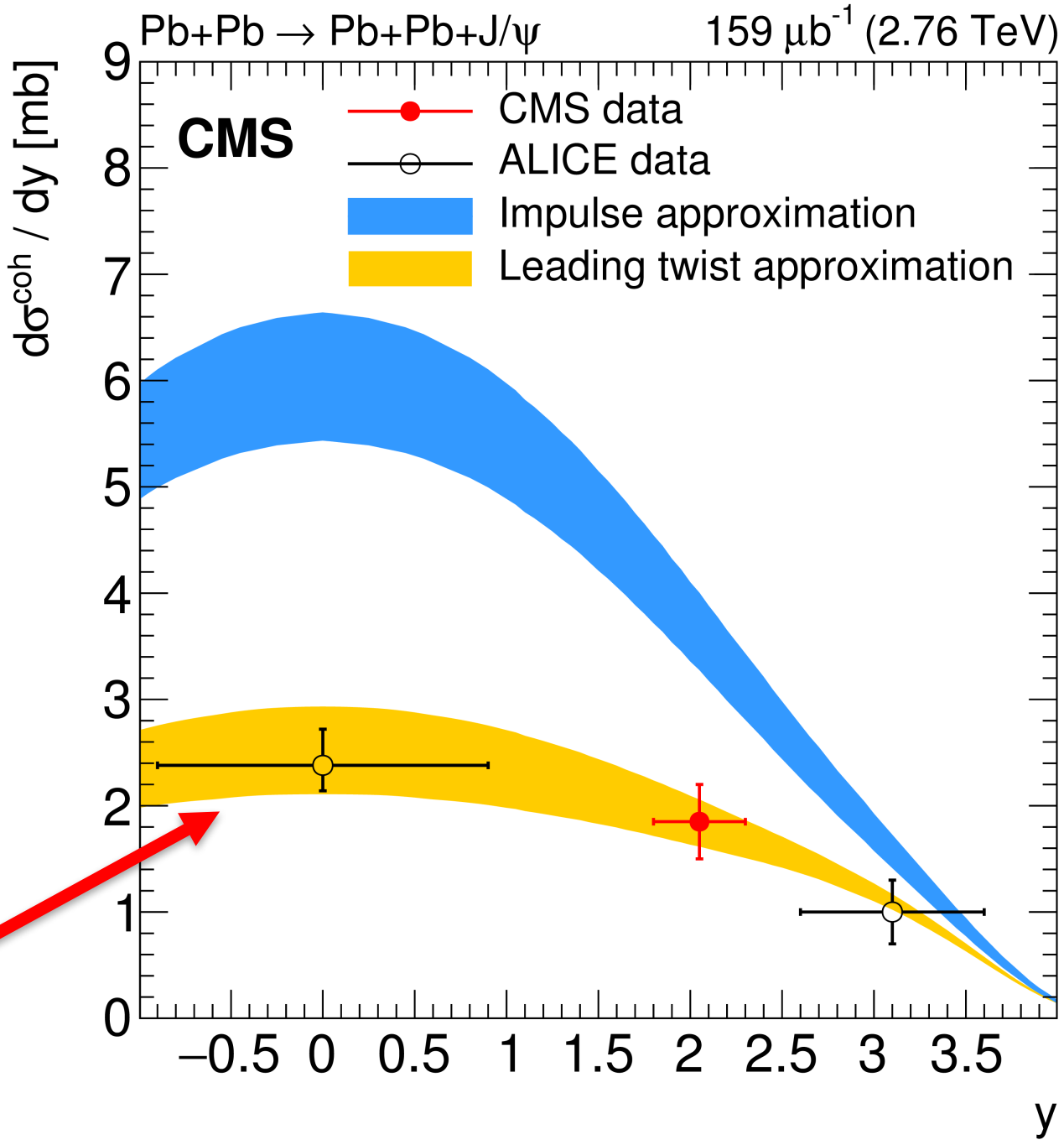

**Spectrum peaks at $p_T$ = hbar/radius**



# Rapidty dependence of coherent γPb =>J/ψ

**Data is significantly suppressed relative to simple extrapolation from pp results**

**Data suggest significant gluon shadowing**



# Summary

- Photon-photon studies are competitive channels in searches for new physics at the LHC.
- Requiring consistency between energy and momentum of central state and diffracted protons gives an almost background free measurement.
- Ultra-peripheral lead-lead collisions allow us to study the lead wave-function over a very phase space
- $\gamma Pb \Rightarrow J/\psi$ suggests gluon shadowing in lead

# Backup

# Summary

- **CT-PPS has proven for the first time the feasibility of operating a near-beam proton spectrometer at a high luminosity hadron collider on a regular basis.**
- **Collected > 15 $fb^{-1}$ of data in high luminosity runs with good physics acceptance, thanks to the LHC machine/optics experts**
- **RP alignment and optics corrections derived from alignment runs + inclusive proton samples, based on methods previously used in TOTEM**
- **First evidence for "standard candle" γγ->μμ process with single proton tagging**Ref: CMS PAS PPS-17-001, TOTEM-NOTE-2017-003
- **4σ signal for single proton-tagged γγ collisions at electroweak scale**

**CT-PPS is taking data & ready for much more physics in 2017**