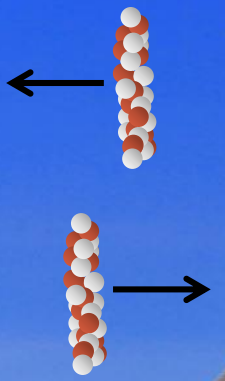
Ultraperipheral Collisions Summary



Janet Seger

Creighton University

HARD PROBES 2018

Oct. 1-5, 2018
Aix-les-Bains

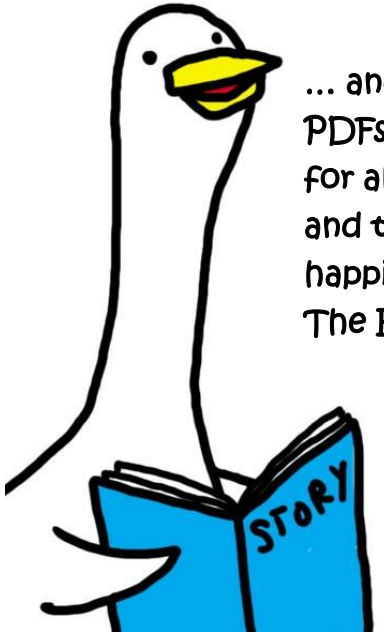
Creighton UNIVERSITY

U.S. DEPARTMENT OF ENERGY

Office of Science

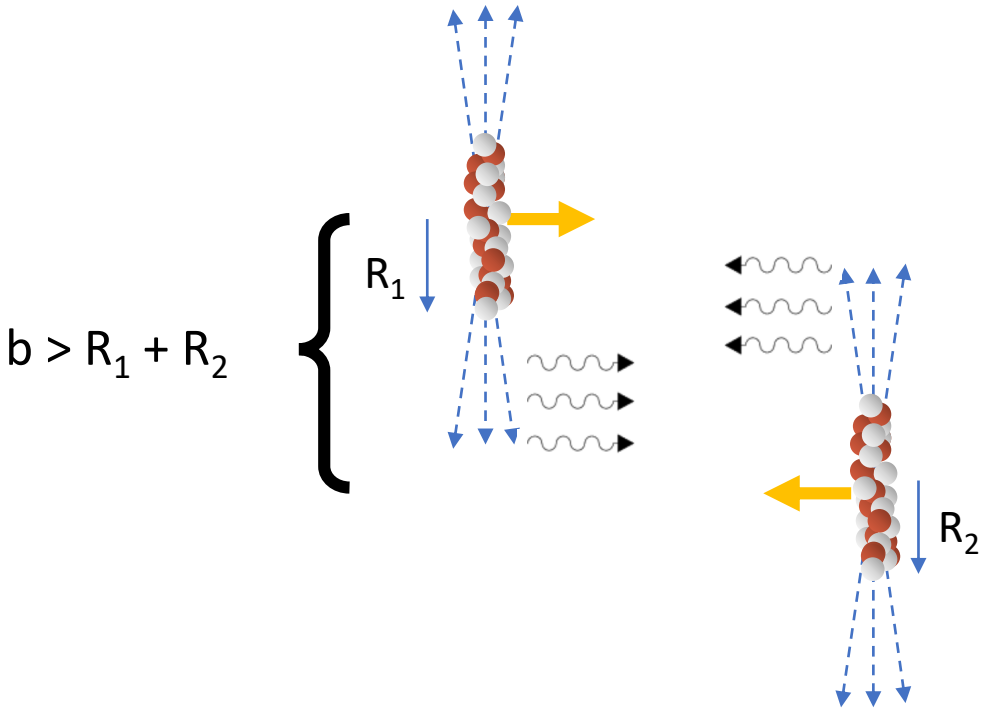
My story line

- Heavy Ions collisions produce intense photon beams
- Photons from the two nuclei can interact with each other – tests QED $\gamma+\gamma$
- Photon from one nucleus can interact with other nucleus – probes nucleus, nPDFs $\gamma+N$
- Some interesting results in peripheral collisions may be explained by these same photon-induced processes – nuclear medium effects? $\gamma+N$**?**



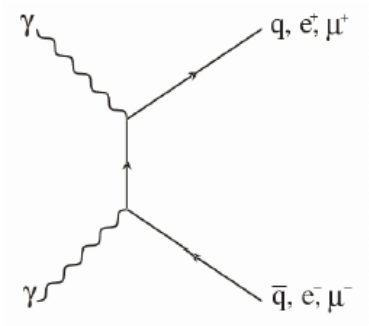
... and the gluon PDFs were known for all values of x, and they all lived happily ever after. The End.

Ultraperipheral Collisions



- Large impact parameter($b > R_1 + R_2$) → no nuclear overlap → no "collision" → electromagnetic interactions dominate
- Relativistic heavy ions are intense source of quasi real photons
  - Q ~ 1/R ~ 0.06 GeV (Pb) or 0.28 GeV (p)
  - Photon flux ~ Z^2 from each nucleus
  - Experimentally: very low multiplicity events with small momentum transfer, rapidity gaps

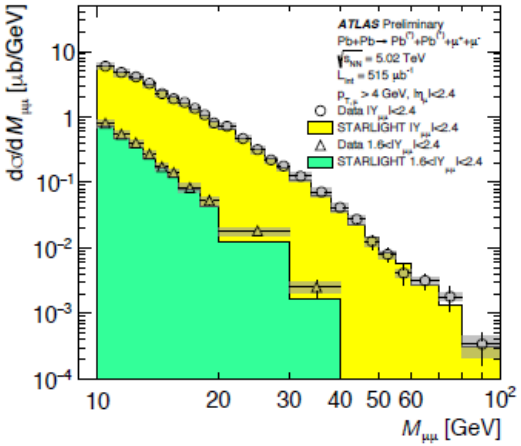
γ+γ Lepton Pair Production

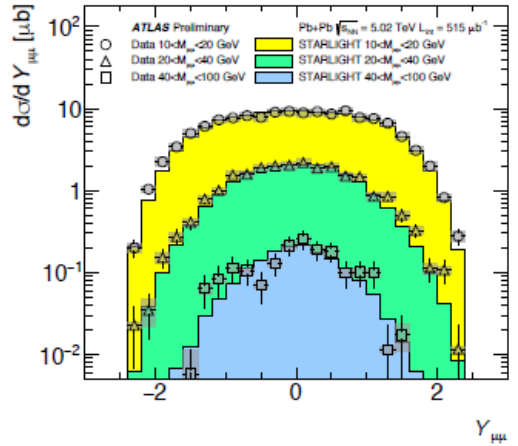


- Basic QED process
  - allows validation of EPA approach
  - Flux amplified by Z^4 over pp
  - Background for other measurements (quarkonia, light-by-light)
  - Provides baseline for more central collisions
- Kinematic distributions and overall rates generally well described by Starlight generator

(S. R. Klein, J. Nystrand, S. Seger, Y. Gorbunov, J. Butterworth, Comp. Phys. Comm, 212 (2017)258.)

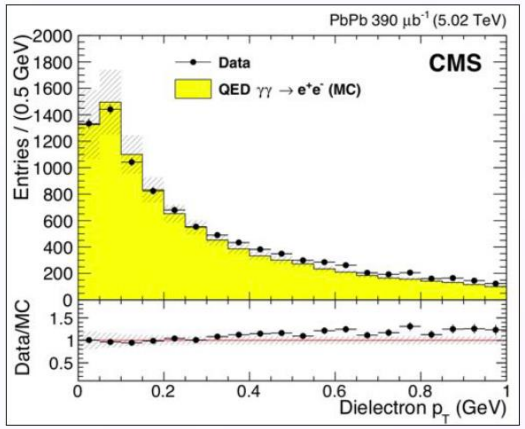
ATLAS γγ→ μμ ATLAS-CONF-2016-025

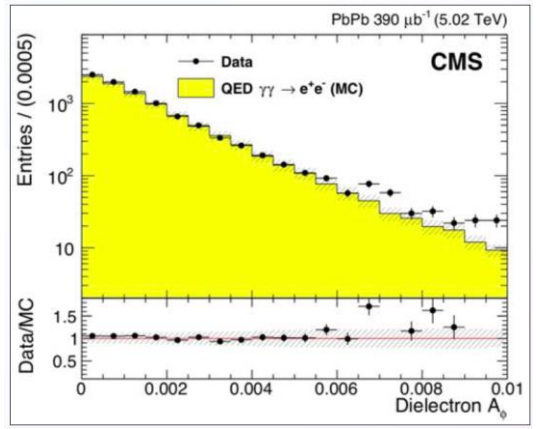




See talk by Steinberg

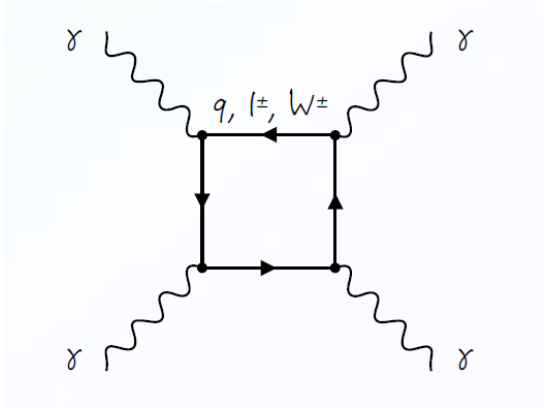
CMS γγ→ ee





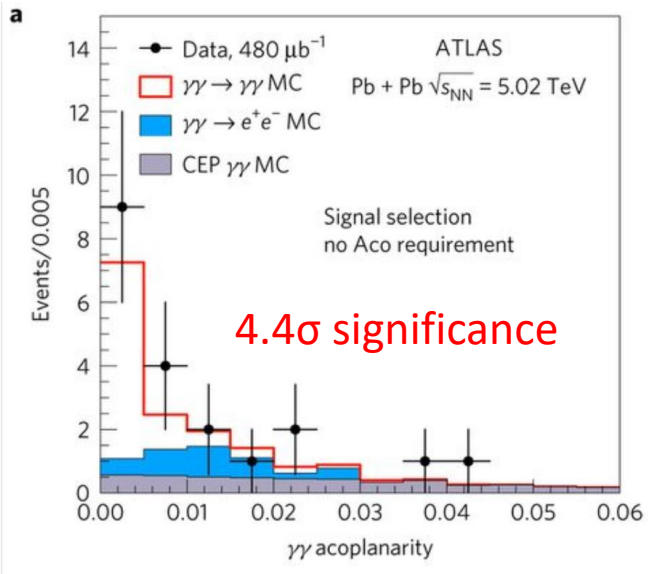
See talk by Niedziela

γ+γ Light by Light scattering



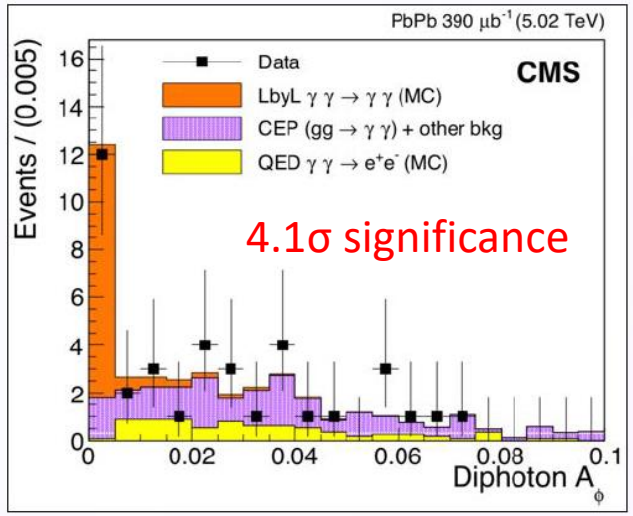
Textbook quantum physics that had nevertheless not been directly observed

ATLAS discovery (https://doi.org/10.1038/NPHYS4208)



See talk by Steinberg

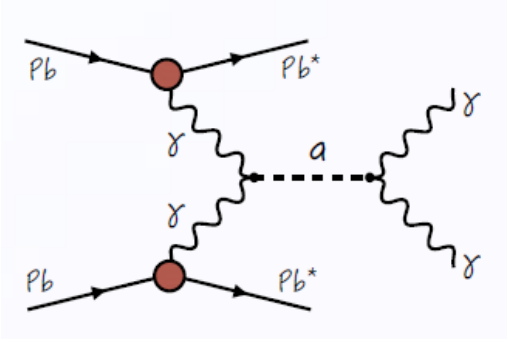
Confirmation from CMS



See talk by Niedziela

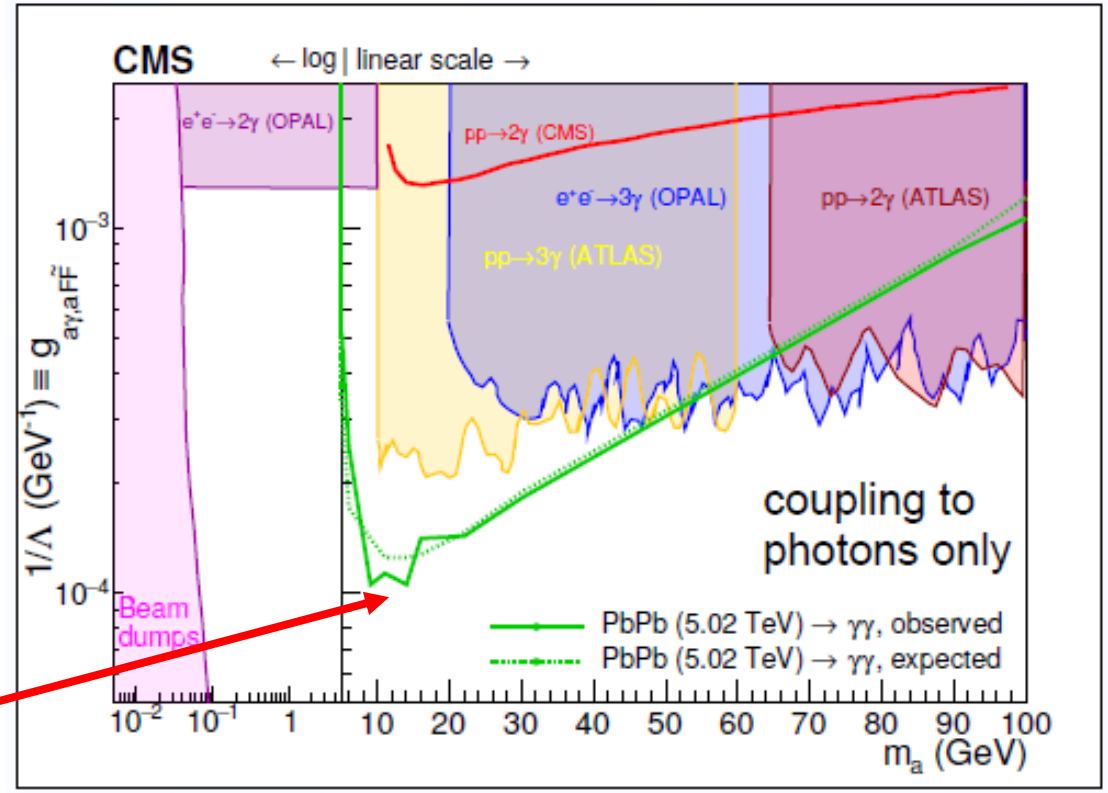
Cross sections and distributions consistent with SM expectations

γ+γ CMS: Axion-like particle search – dark matter candidate



- Exclusive diphoton final-state from resonant CP-odd axion-like particles
  - LbyL, QED and CEP considered as background in this analysis,
- No evidence for this in the 2-photon signal

→ place new limits on the coupling constant



See talk by Niedziela

γ+N

Photoproduction of vector mesons

- Has been extensively studied at HERA, RHIC, LHC
- Factorize into
  - photon emission and
  - interactions with nuclear target
- Allows probe of nucleus via QCD to learn about shadowing, saturation effects, nPDFs

γ+N

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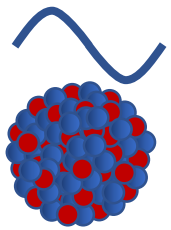
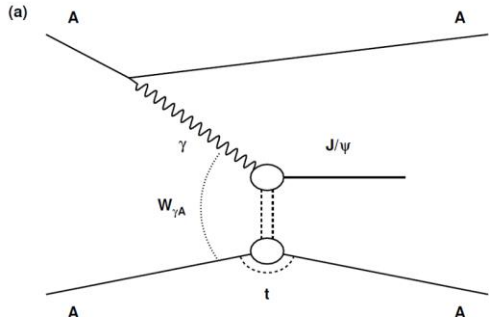
- Coherent interaction: Photon interacts with entire nucleus
  - Nucleus generally remains intact
  - Small momentum transfer: $p_T \sim \hbar/R_A \sim 15$ MeV
  - Max Photon energy $\sim \gamma\hbar/R_A \sim 3$ GeV at RHIC, 80 GeV at LHC





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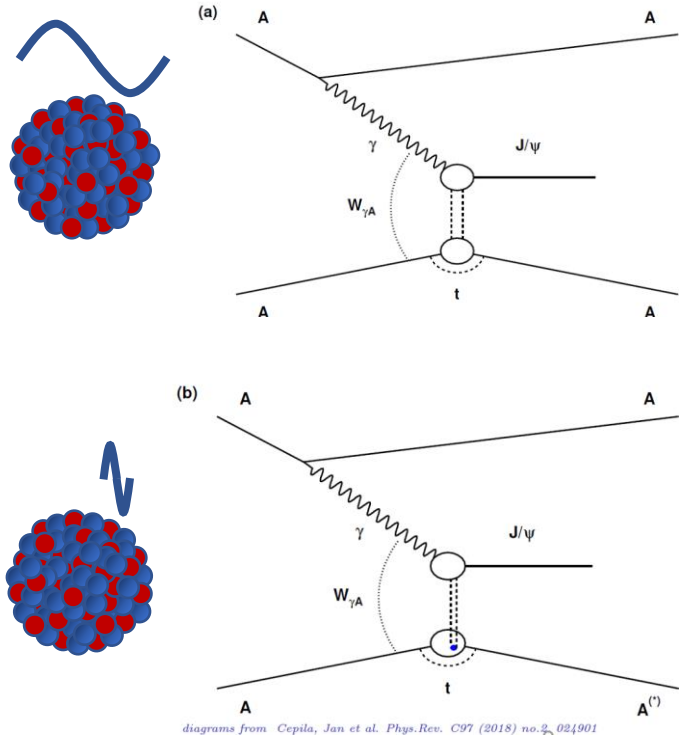
- Coherent interaction: Photon interacts with entire nucleus
  - Nucleus generally remains intact
  - Small momentum transfer: $p_T \sim \hbar/R_A \sim 15$ MeV
  - Max Photon energy ~ $\gamma\hbar/R_A \sim 3$ GeV at RHIC, 80 GeV at LHC
- Incoherent interaction: Photon can interact with individual nucleons
  - Nucleus generally breaks
  - Momentum transfer is biggerL $p_T \sim \hbar/R_A \sim 100$ MeV
  - Max Photon energy ~ $\gamma\hbar/R_A \sim 20$ GeV at RHIC, 2.5 TeV at LHC

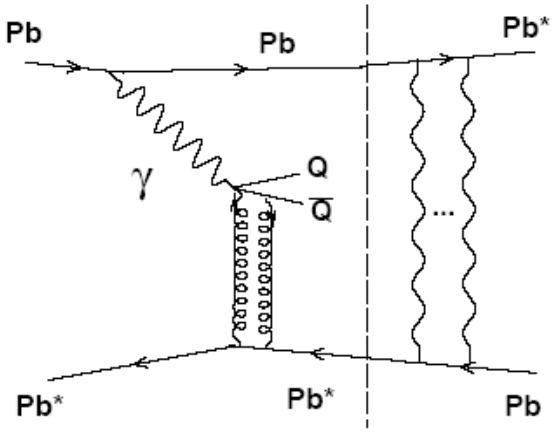


diagrams from Cepila, Jan et al. Phys.Rev. C97 (2018) no.2, 024901

γ+N

Heavy Vector Mesons: J/ψ, Υ

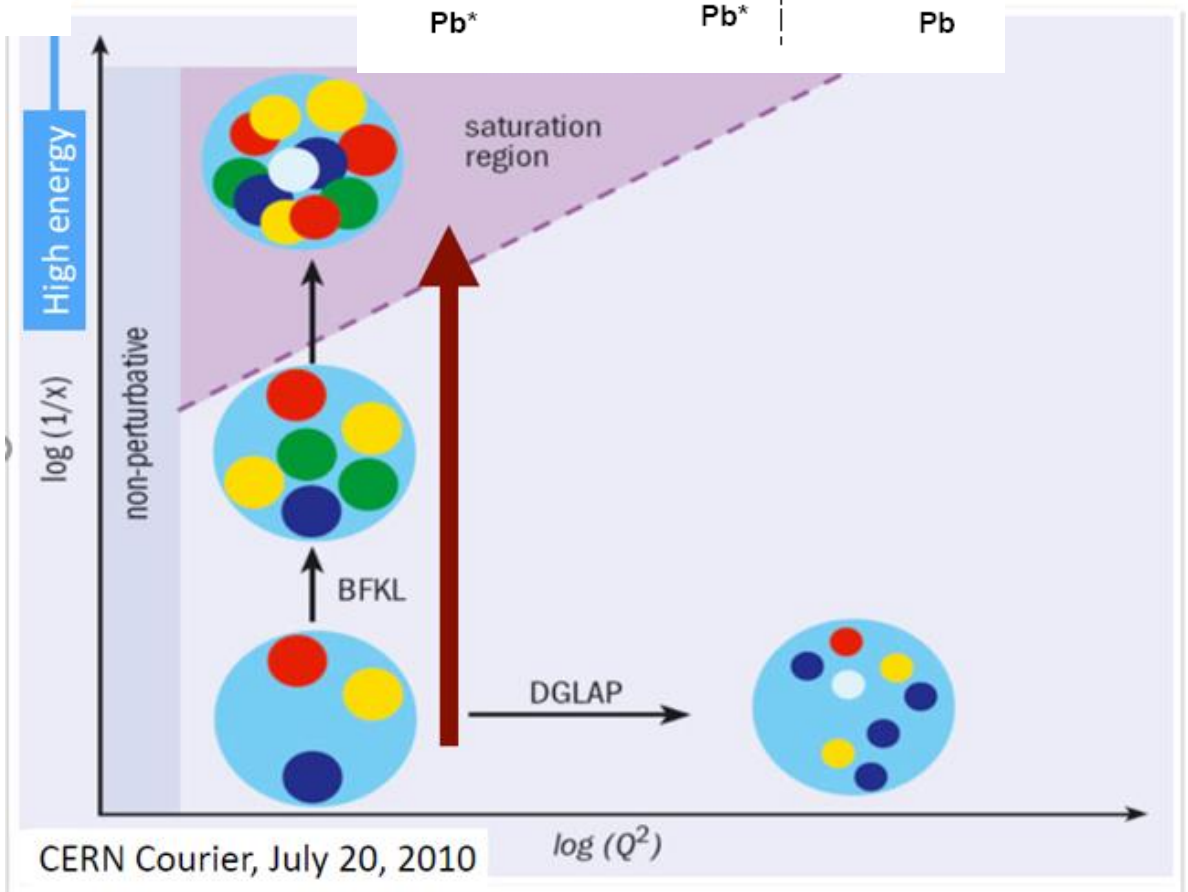
$$\frac{\mathrm{d}\sigma^{\gamma^\star \mathrm{A}\to J/\psi\,\mathrm{A}}}{\mathrm{d}t} \propto \left(xG_{\mathrm{A}}(x,Q^2)\right)^2$$



- 2-gluon exchange
- Sensitive probe of gluon GPDs
- For vector mesons,

$$x \simeq \frac{m_{J/\psi} e^{-y}}{\sqrt{s}}$$

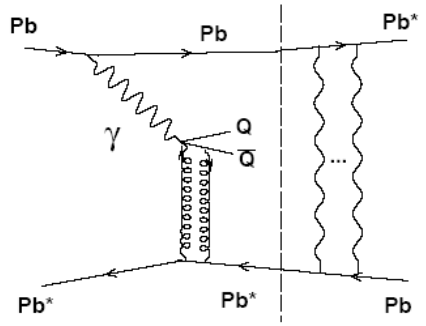
- Measurements at different rapidities sample different values of x

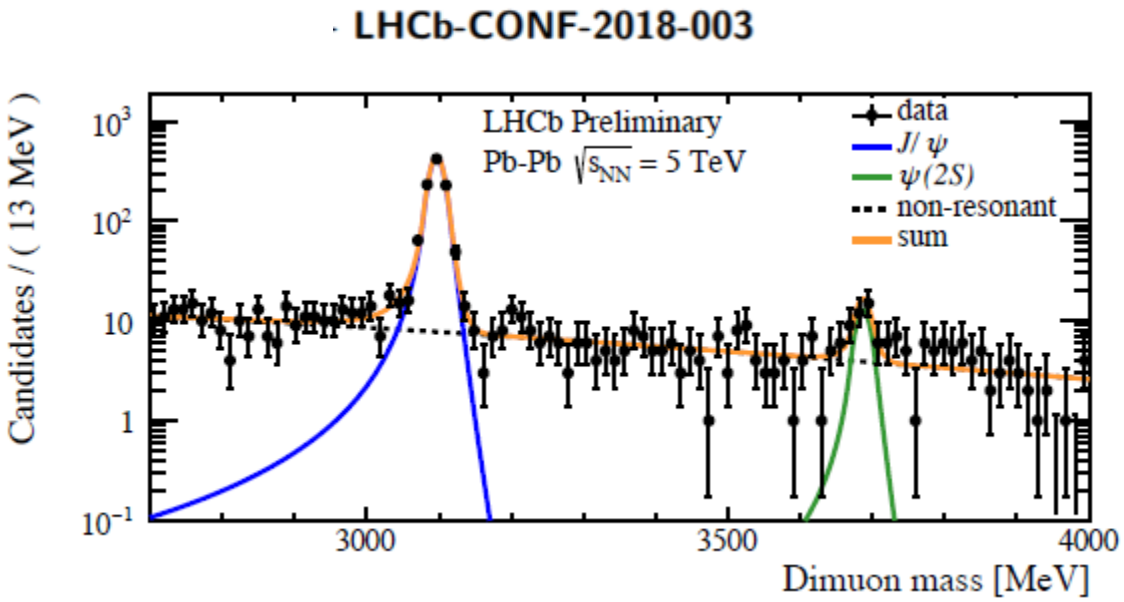


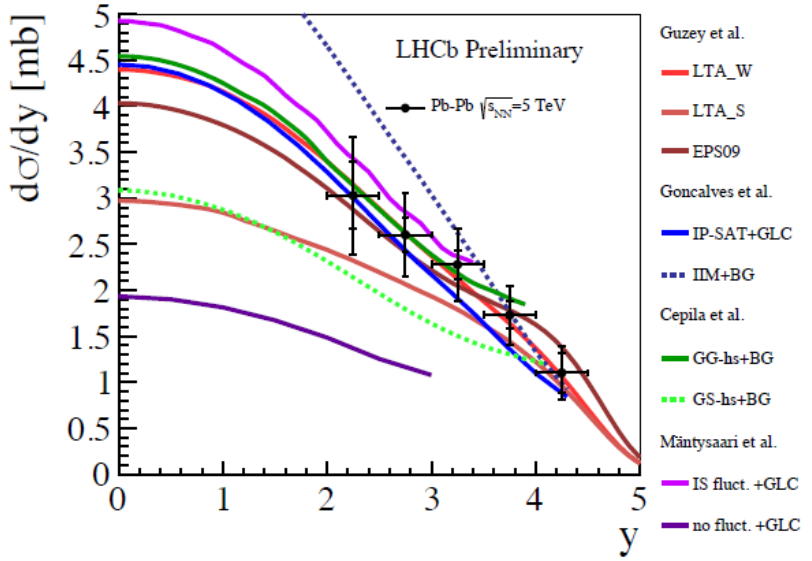
γ+N

LHCb: J/Psi – first PbPb UPC measurement

- Forward detector → reach to lower x
- Cross sections consistent with ALICE in overlap

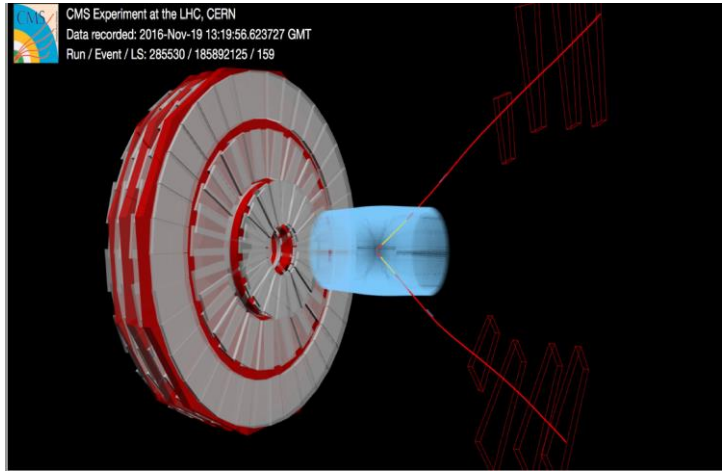




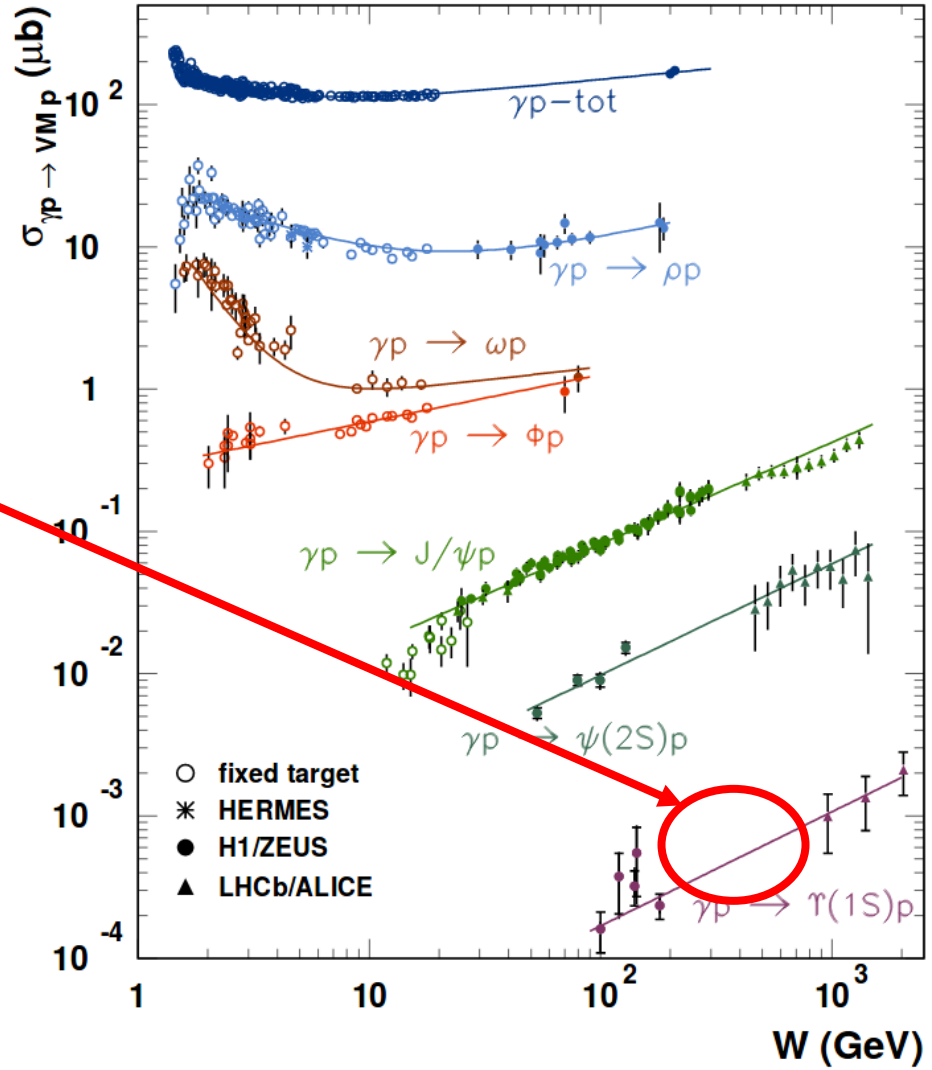


See talk by S. Belin

γ+N CMS: Upsilon in p+Pb at 5 TeV



- Measure cross section in W range not covered at HERA



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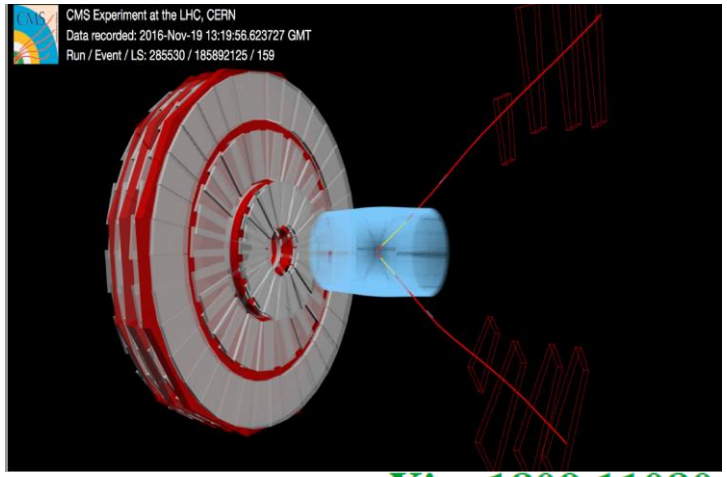
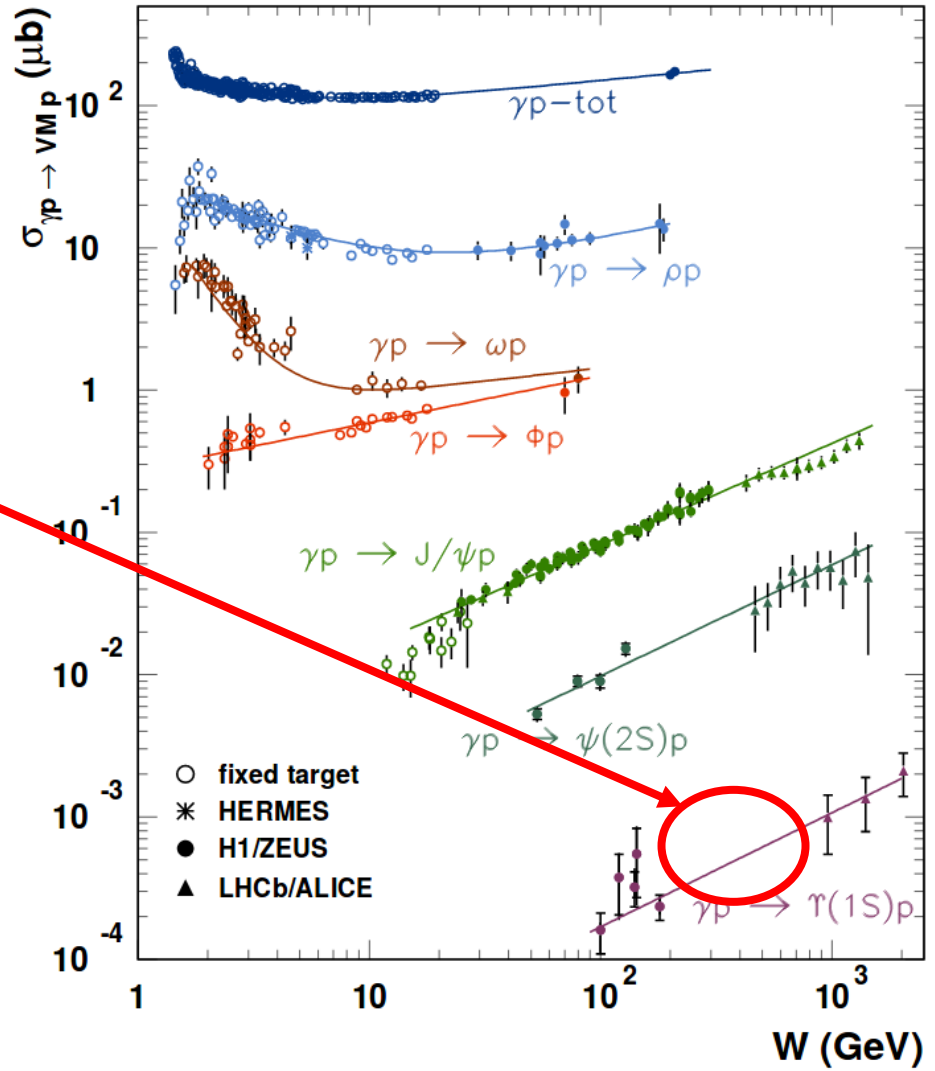
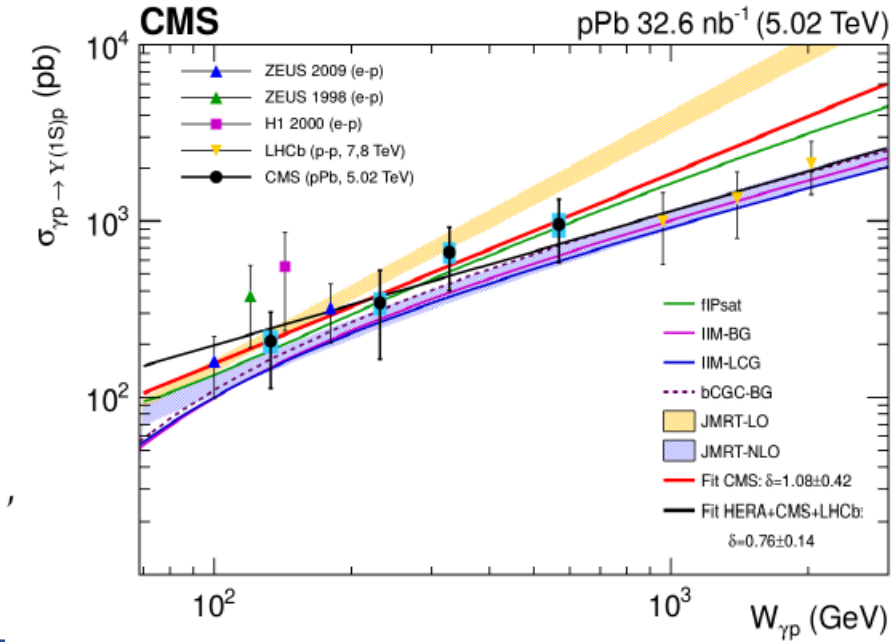


arXiv: 1809.11080

- Measure cross section in W range not covered at HERA

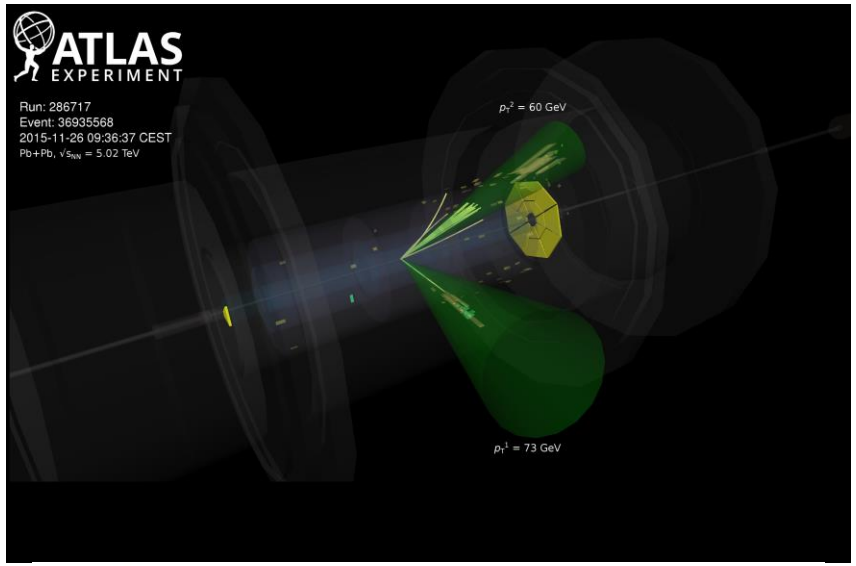


See talk by Naskar



Fit parameters of power-law dependent cross section consistent with HERA results, disfavors LO calc

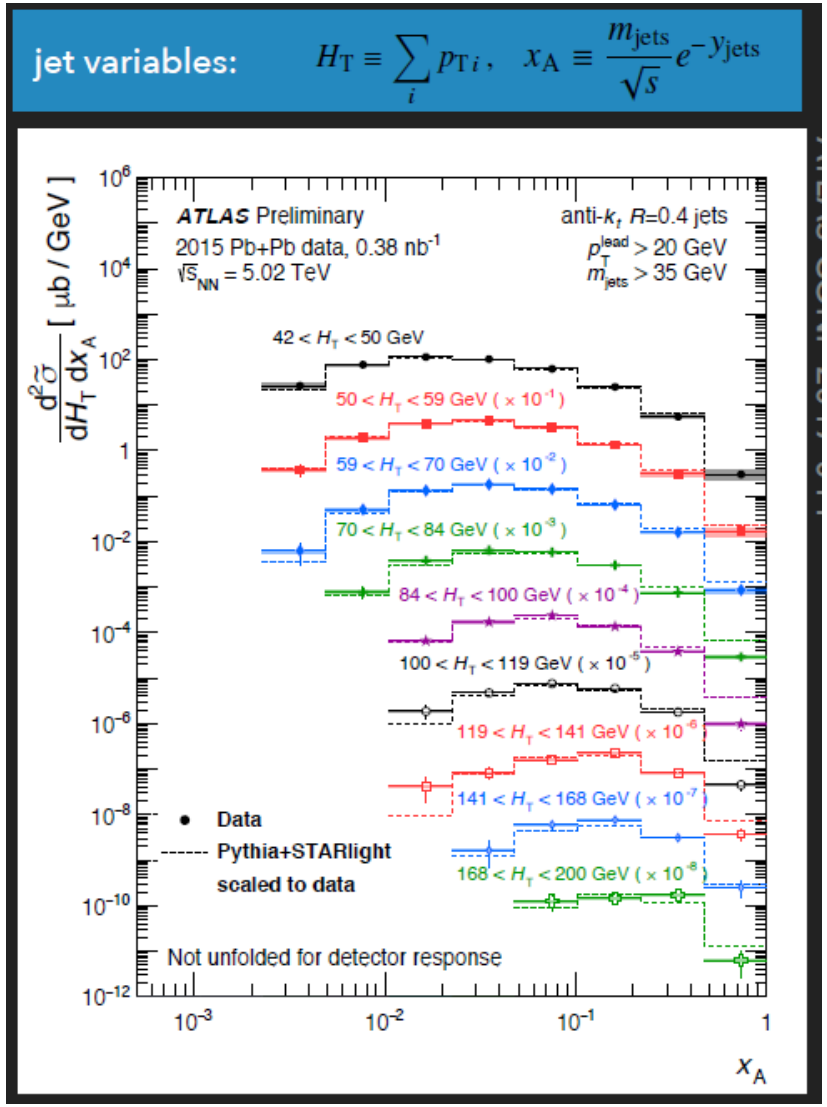
γ+N ATLAS: Photonuclear di-jets in 5.02 TeV PbPb



See talk by Steinberg

- Jet selection:
  - Anti-k_T, $R = 0.4$, $|\eta| < 4.4$
  - $p_T^{lead} > 20$ GeV, $p_T^{jets} > 15$ GeV

- Shape qualitatively described by Pythia 6 with photon flux scaled via Starlight
- Samples PDFs directly, but will need to do the detector unfolding



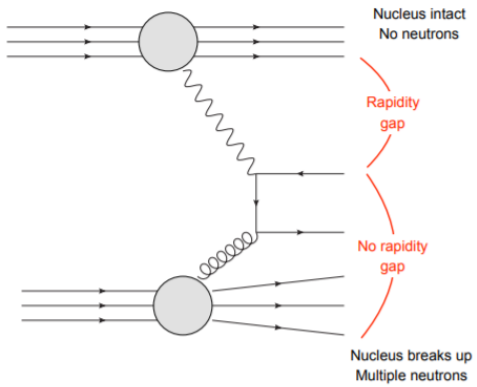
ATLAS-CONF-2017-011

γ+N

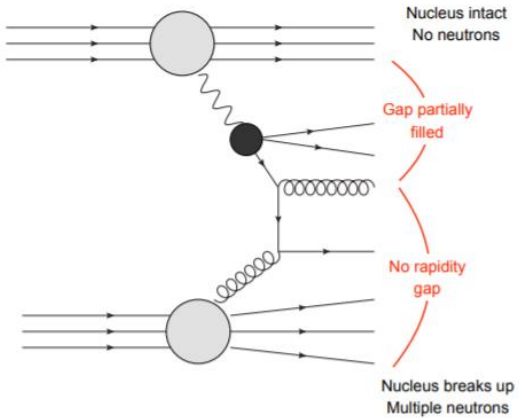
Pythia 8 has Photoproduction Framework

- Can be used to model photonuclear di-jets
- Automatically mixes direct and resolved jets

"direct" jet: photon participates directly



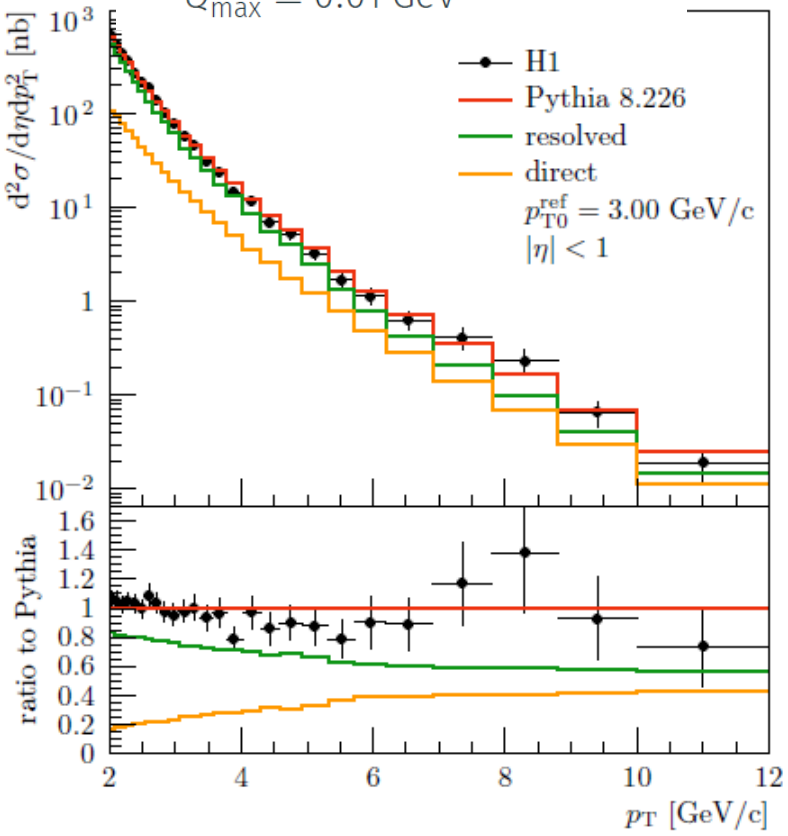
"resolved" jet: virtual photon excitation to qqbar, etc. Depends on photon PDF as well as nPDF



Figures from ATLAS-CONF-2017-011

H1 measurement

- $E_p = 820$ GeV, $E_e = 27.5$ GeV
- $< W_{\gamma p} > \approx 200$ GeV
- $Q^2_{max} = 0.01$ GeV^2



See talk by Helenius

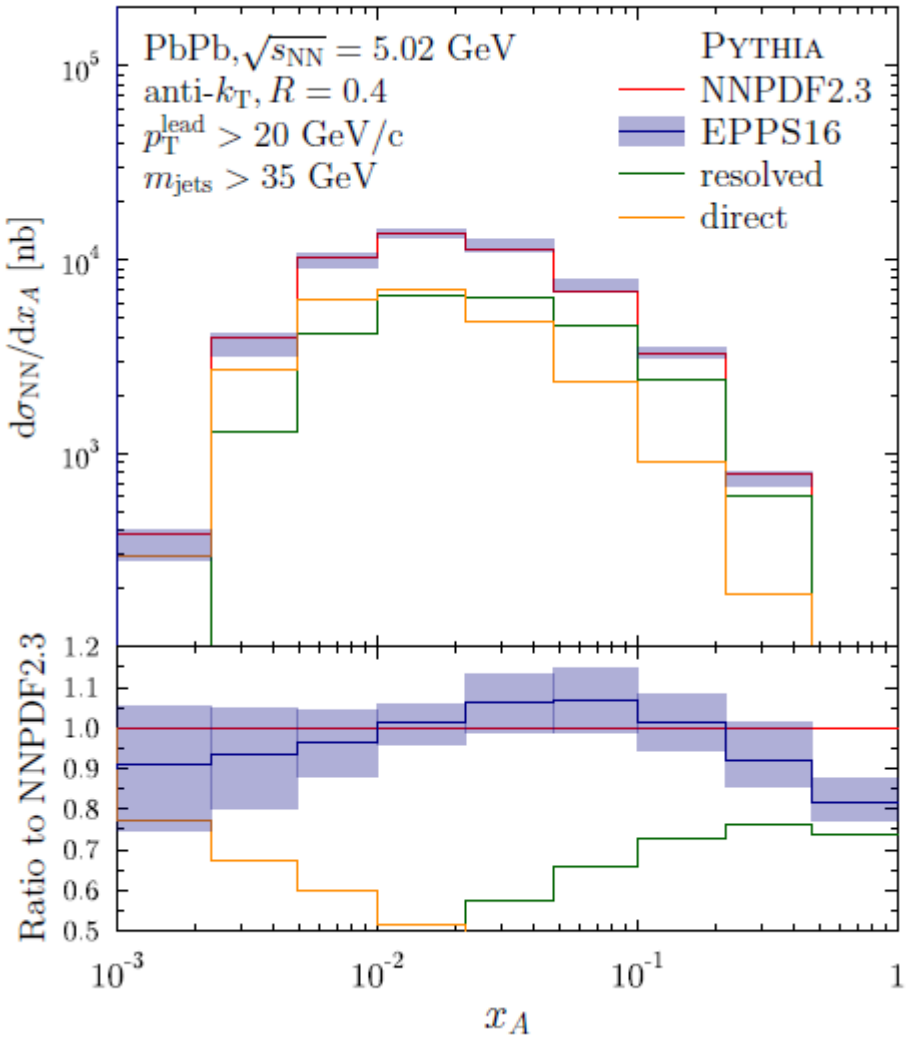
[H1: Eur.Phys.J. C10 (1999) 363-372]

- Fits HERA data well
  - Only one parameter re-tuned from pp

γ+N

Photonuclear di-jets in Pythia 8

- *b*-integrated photon flux
- Nuclear PDFs for hard scattering
- Identical jet selection as used in ATLAS study
- Direct processes dominate for $x_A < 10^{-2}$
- Sensitive to nuclear PDF modifications

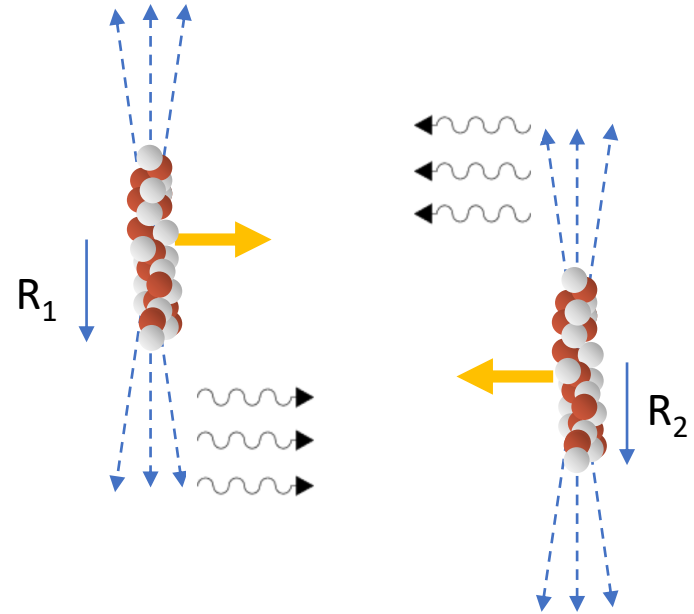


See talk by Helenius

γ+N?

Some interesting results in peripheral collisions may be explained by these same photon-induced processes

- Here hadronic interactions dominate

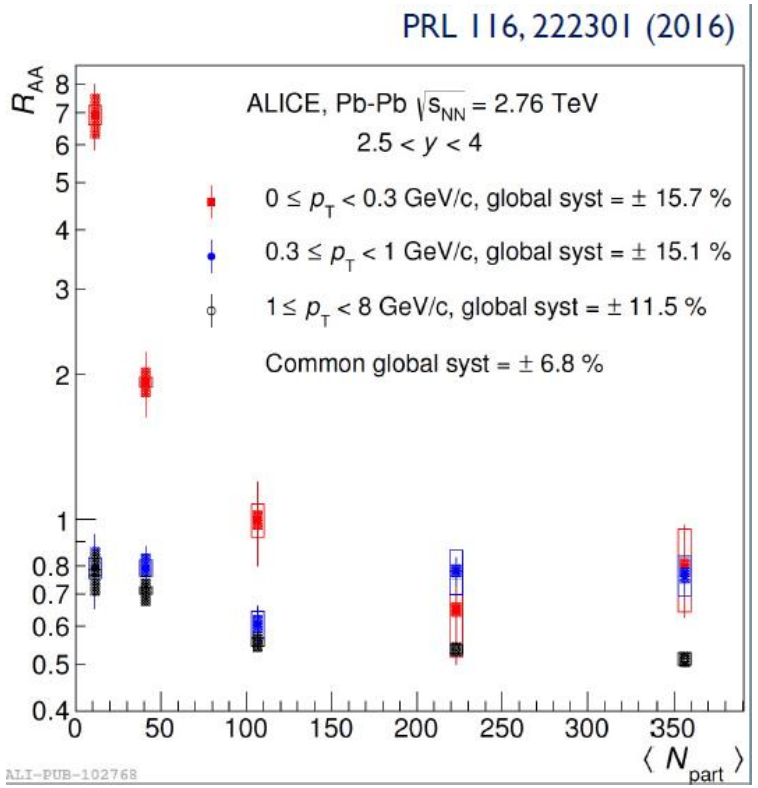


γ+N?

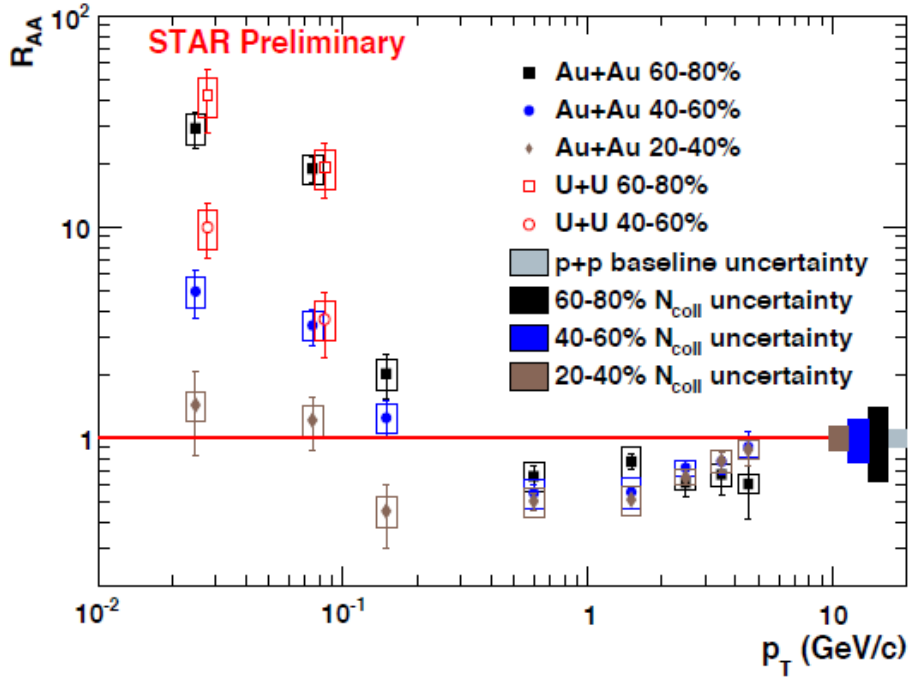
BUT: Anomalous low-p_T enhancement in J/ψ in peripheral PbPb collisions

- Not explained by hadronic interactions
- Consistent with coherent photonuclear photoproduction

See talk by Massacrier



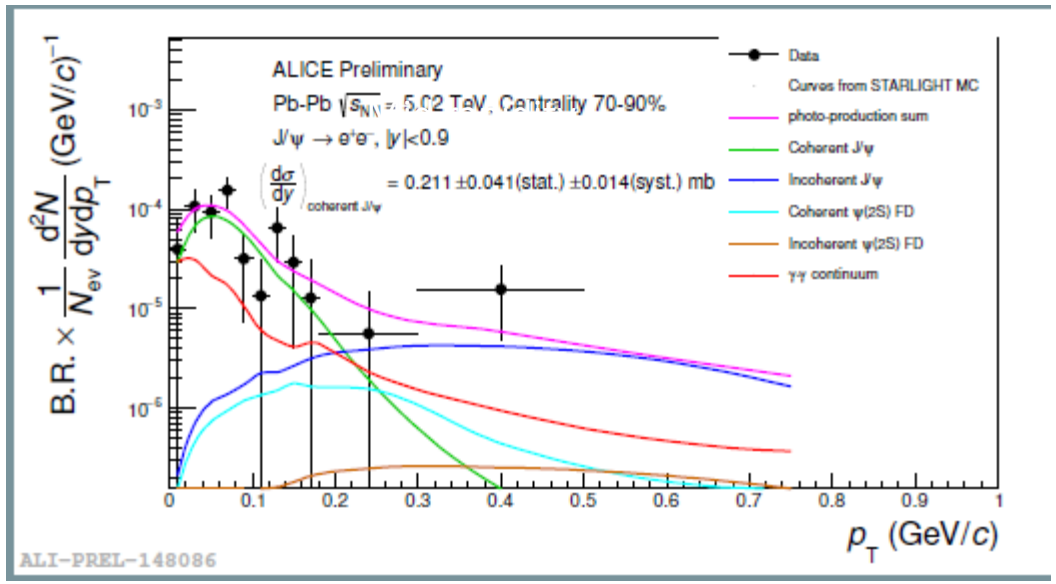
J/Psi in peripheral AuAu and UU collisions



See talk by Yang

γ+N? Confirmed by ALICE at higher energy

See talk by Massacrier

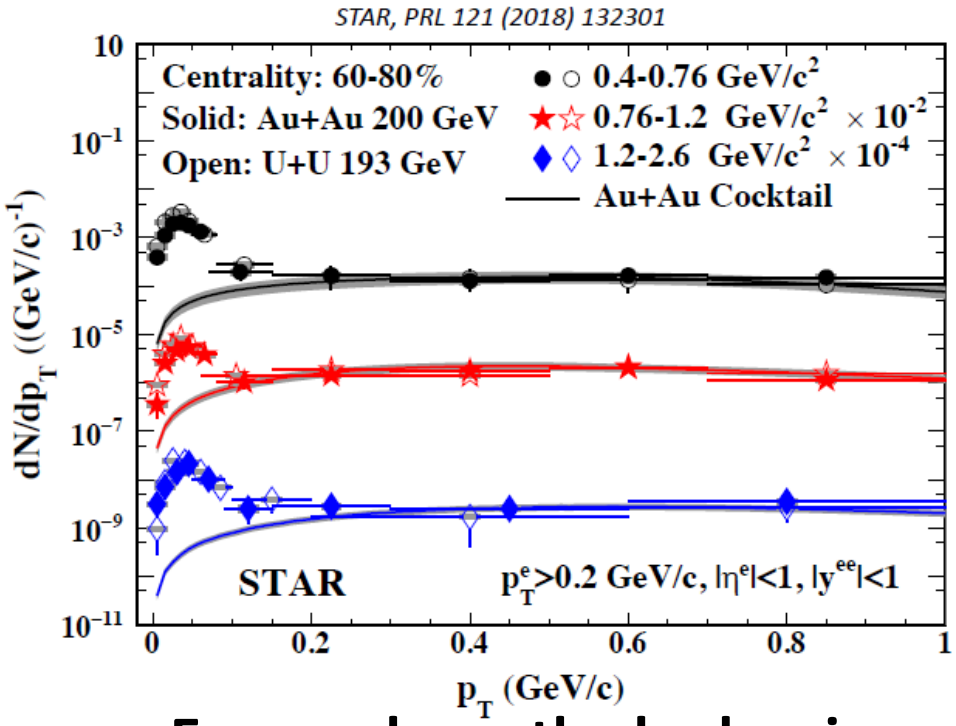


Shape of low p_T excess matches that expected from photonuclear production – can be fit with the same Starlight template as used for UPCs

γ+N?

Excess also seen in di-lepton pairs

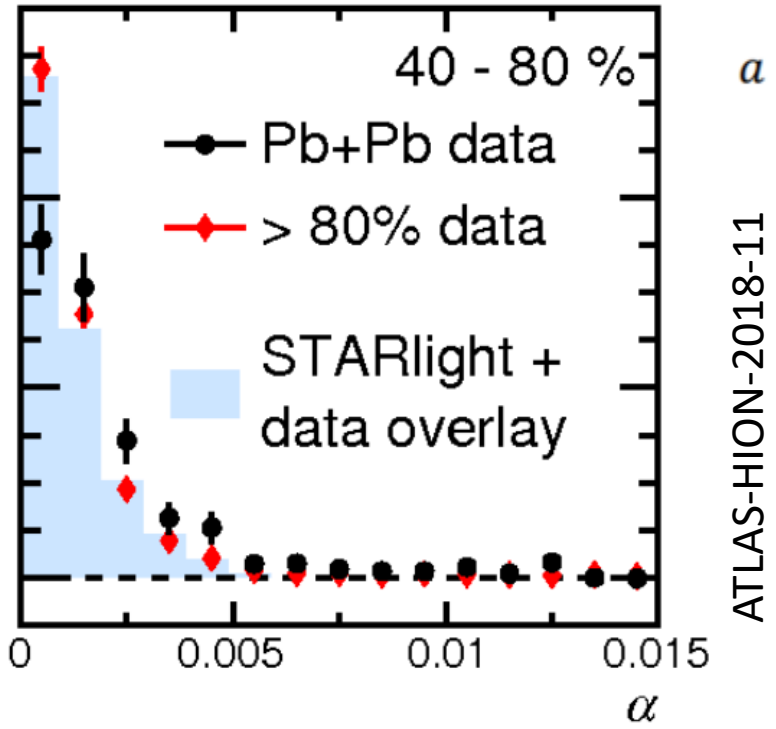
STAR: ee in peripheral AuAu and UU collisions



Excess above the hadronic cocktail at very low p_T

See talk by Yang

ATLAS: μμ in peripheral PbPB collisions



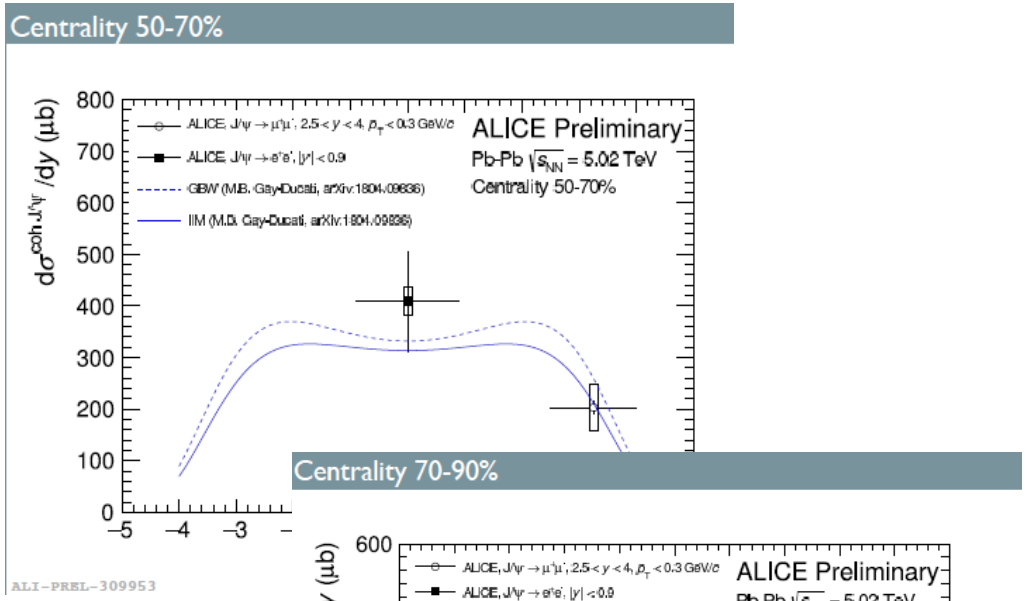
$$a = 1 - \frac{|\varphi^+ - \varphi^-|}{\pi}$$

80% centrality matches UPC

See talk by Steinberg

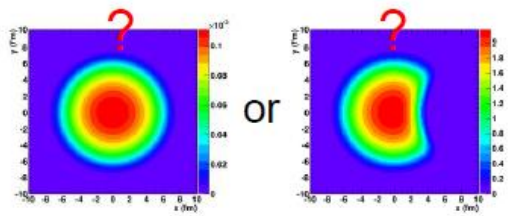
γ+N?

Models used to describe UPC data and modified to account for nuclear overlap region qualitatively reproduce the J/ψ data

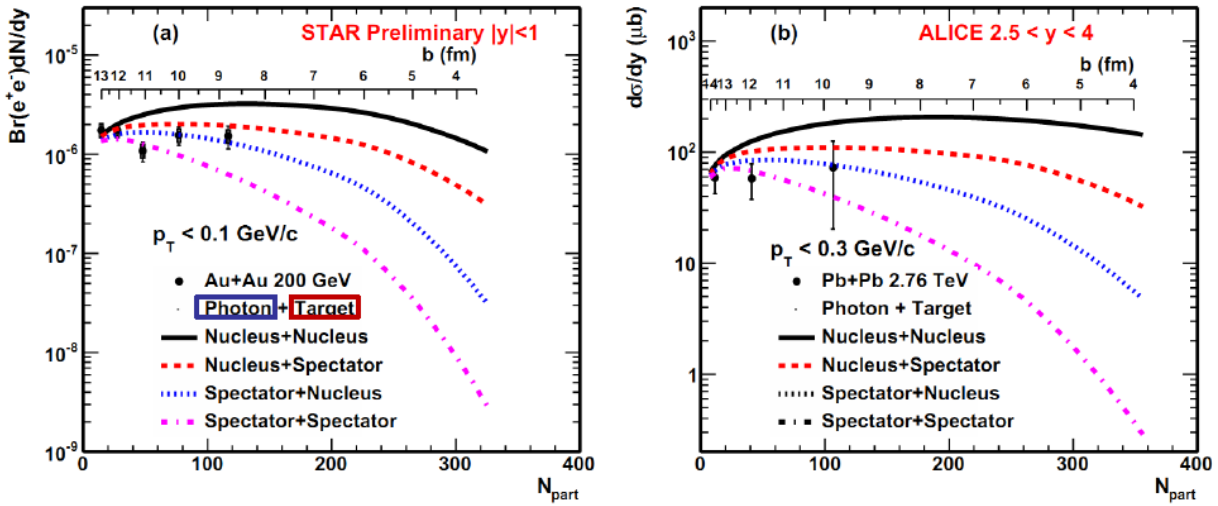


Photon emitter:

Pomeron emitter:



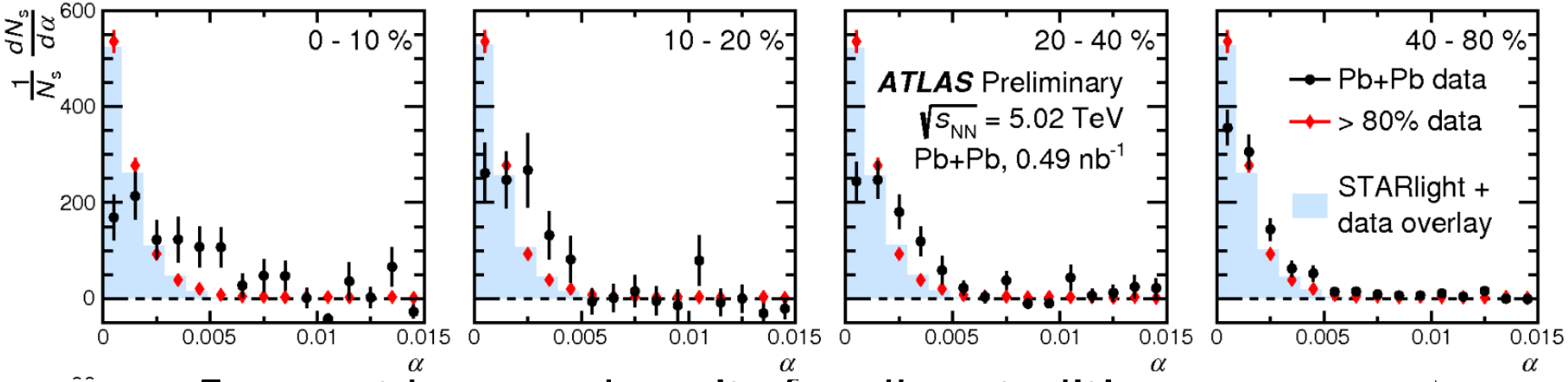
W. Zha etal., PRC **97** (2018) 044910



γ+N?

BUT there's more…

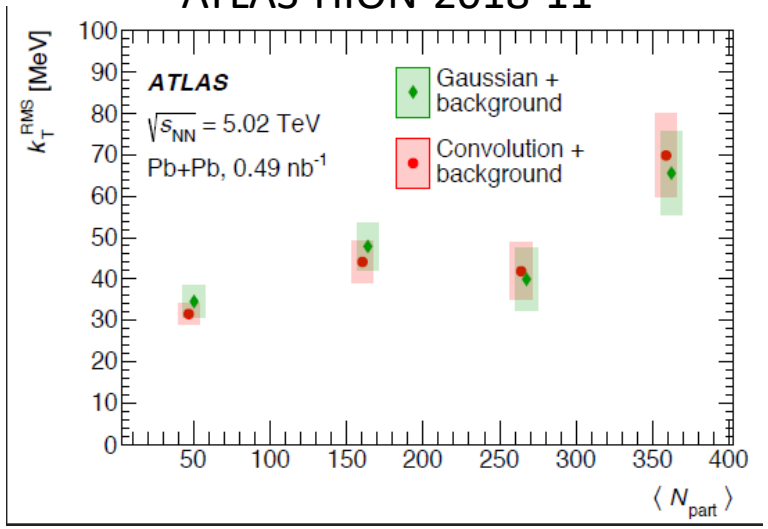
ATLAS-HION-2018-11



$$a = 1 - \frac{|\varphi^+ - \varphi^-|}{\pi}$$

- Excess at low acoplanarity for all centralities
- Peak broadens for more central collisions
- Additional $\mu^+\mu^-$ k_T over in UPCs is extracted from broadening of acoplanarity peak
- Modifications qualitatively consistent with re-scattering of the muons passing through hot matter produced in the collision

ATLAS-HION-2018-11



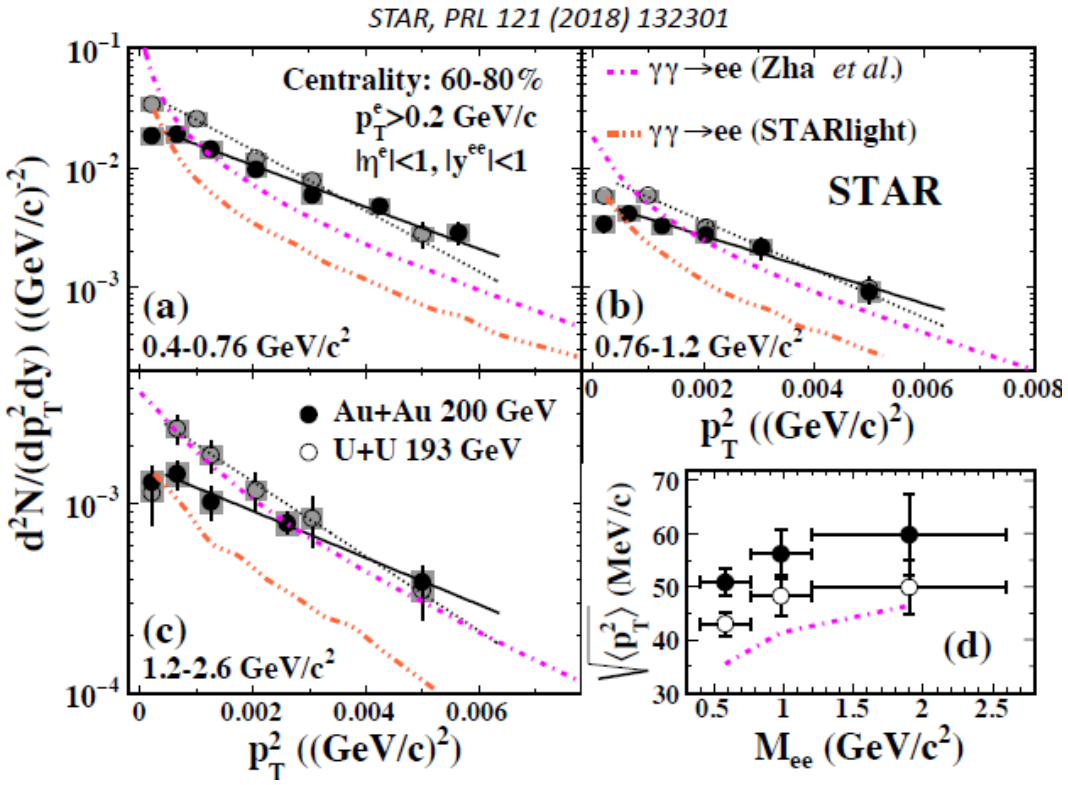
See talk by Steinberg

γ+N?

And there's more…

STAR:

- e^+e^- p_T^2 not well matched by Starlight
- Calculation by Zha, et al., does somewhat better but both underpredict $\langle p_T^2 \rangle$

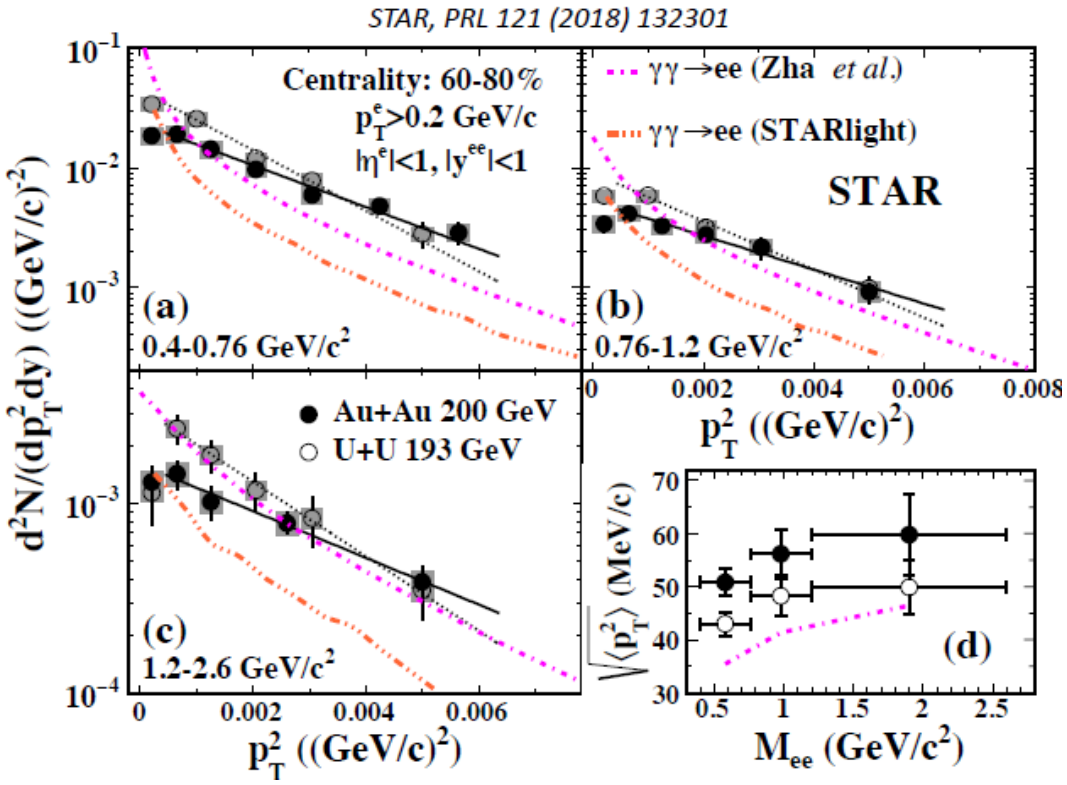


γ+N?

And there's more…

STAR:

- e^+e^- p_T^2 not well matched by Starlight
- Calculation by Zha, et al., does somewhat better but both underpredict $\langle p_T^2 \rangle$
- Add a kick due to pair interacting with residual magnetic field

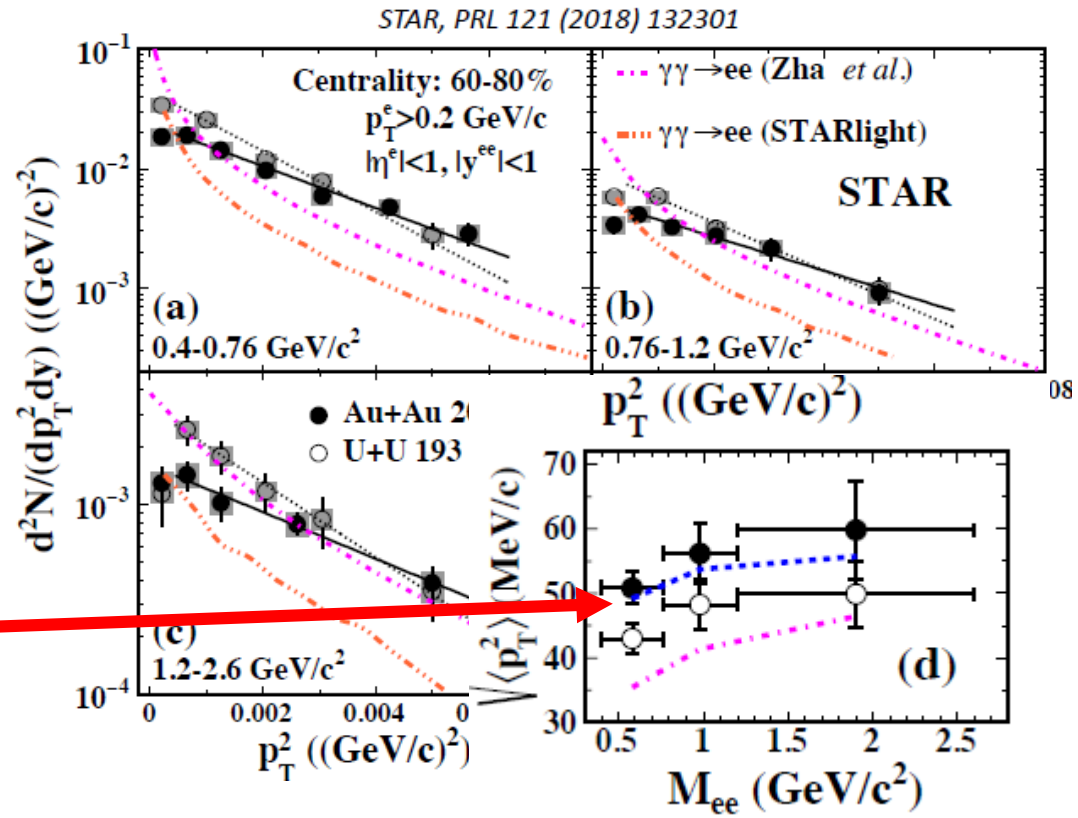


γ+N?

And there's more…

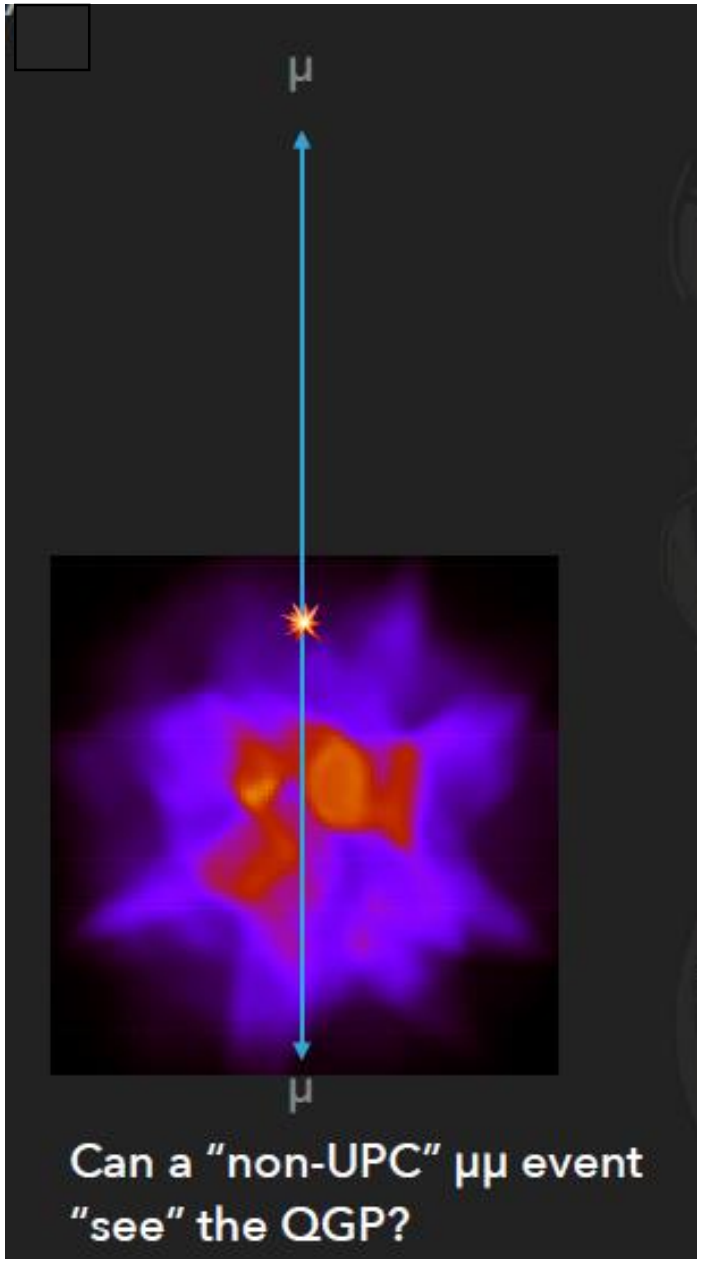
STAR:

- e^+e^- p_T^2 not well matched by Starlight
- Calculation by Zha, et al., does somewhat better but both underpredict $\langle p_T^2 \rangle$
- Add a kick due to pair interacting with residual magnetic field



γ+N? What does it mean?

- How can there be coherent emission in a hadronic collision?
- Is the photon source smaller than the entire nucleus (hot spots, spectators)?
- Do the leptons traverse the nuclear medium?
- Can they be a novel probe of the QGP?



See talk by Steinberg

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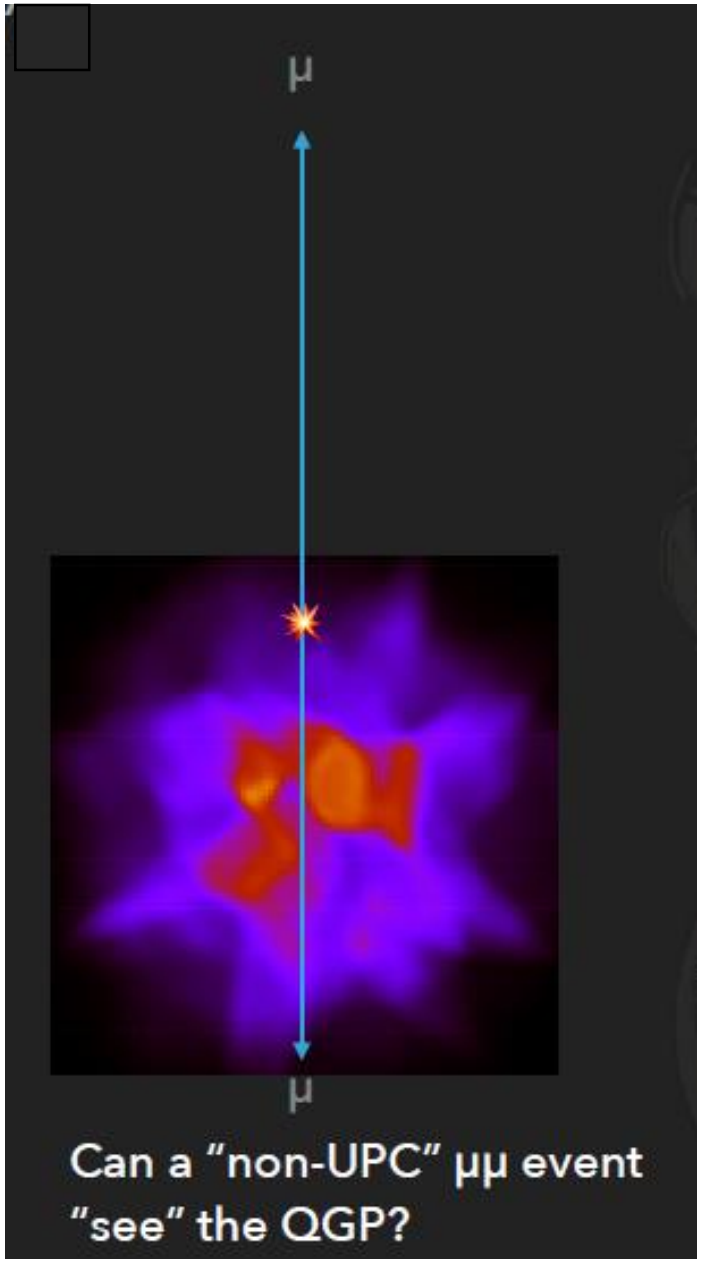
Won't it be interesting to find out?!



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What is coming up?

- 10x more data from 2018 heavy ion run at LHC
  - Many of these statistics-limited analyses will be much improved
- dAu and Rb/ZR isotope data at RHIC
- Hopefully more theoretical guidance particularly regarding coherent interactions in peripheral collisions
- People are already thinking about observing UPCs at FCC, AFTER…

Thank you for your attention