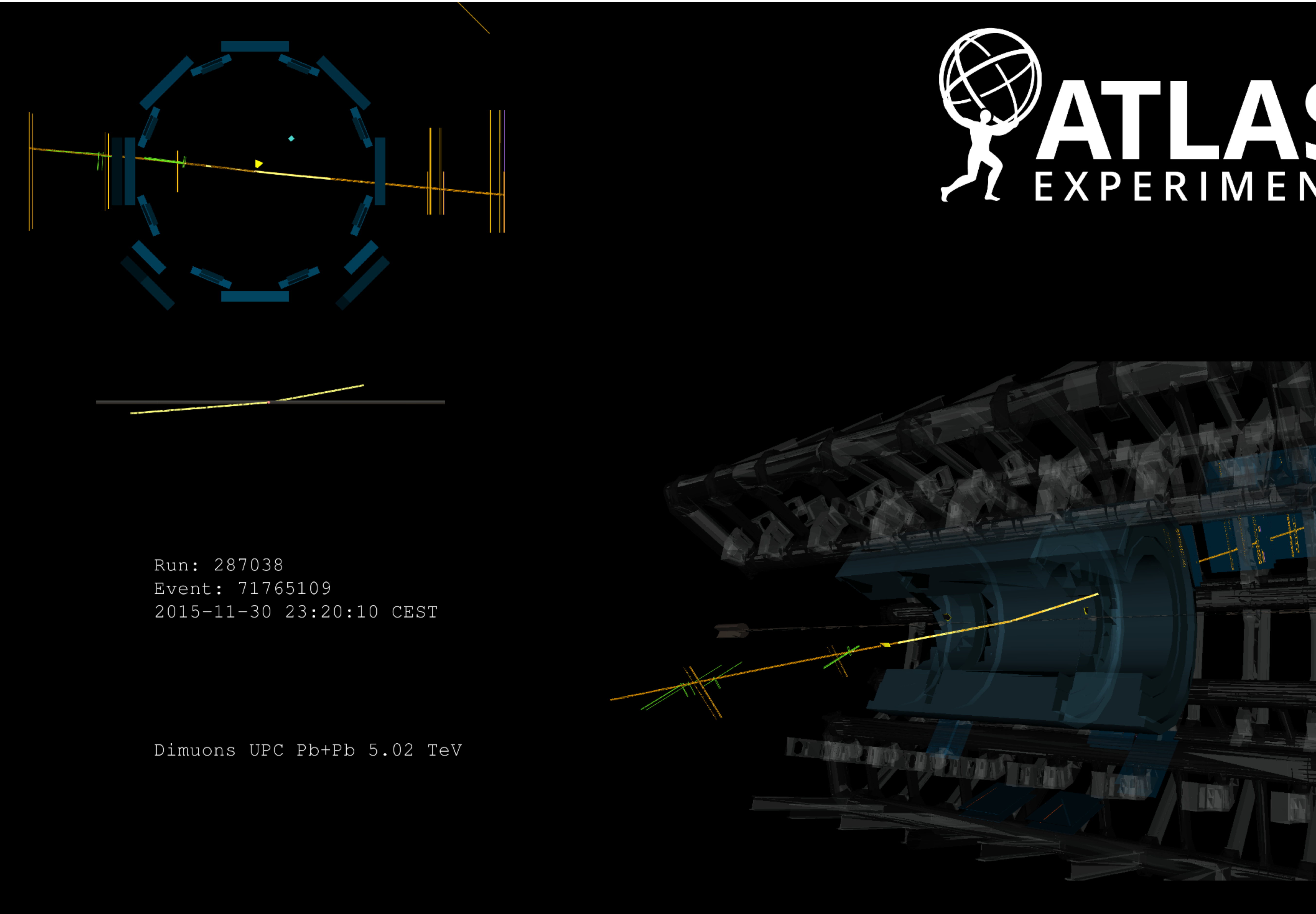
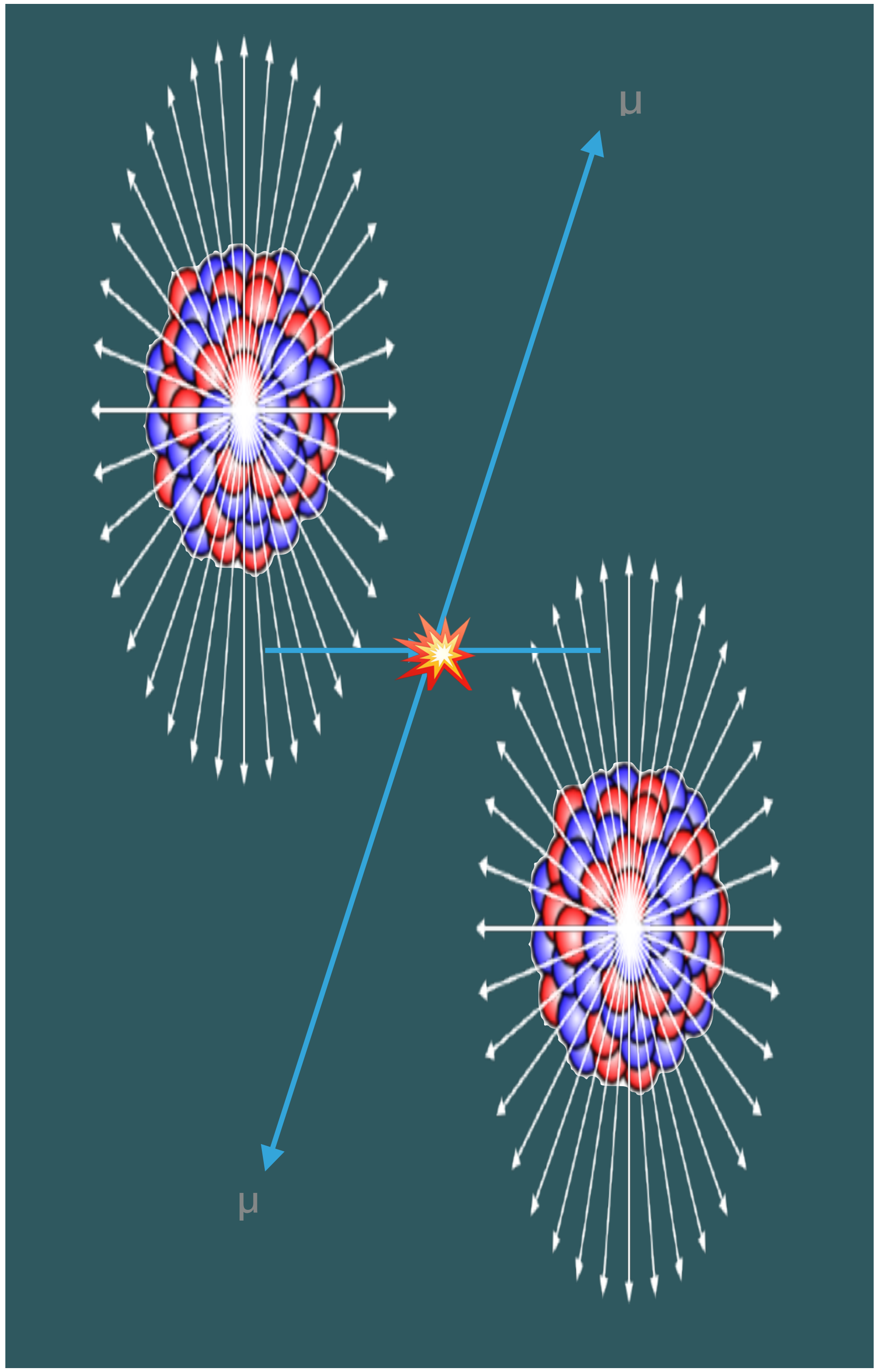
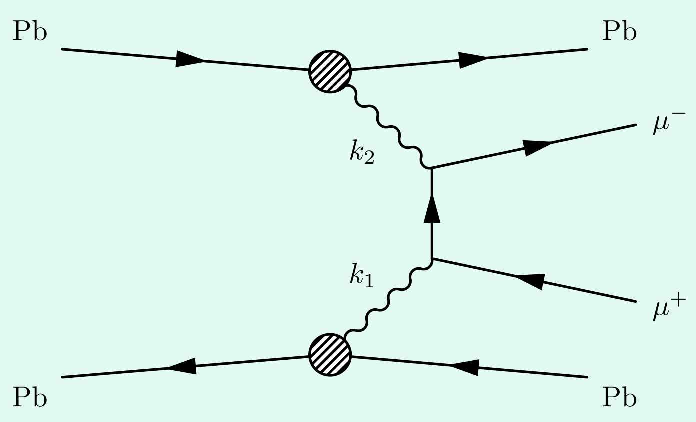
Dimuon production from γ+γ scattering in UPC with the ATLAS detector

Peter Steinberg, BNL / Initial Stages 2021 / 10-15 January 2021

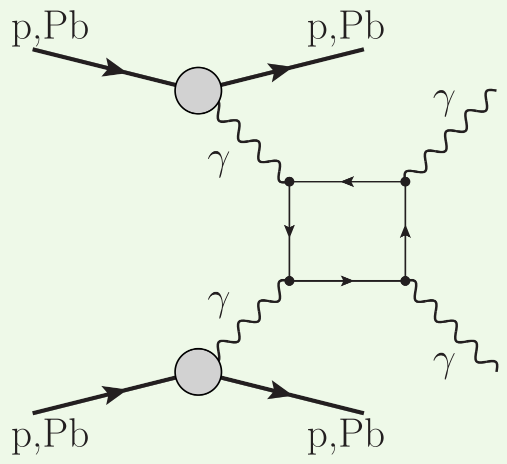

ATLAS
EXPERIMENT
Run: 287038
Event: 71765109
2015-11-30 23:20:10 CEST
Dimuons UPC Pb+Pb 5.02 TeV

Introduction





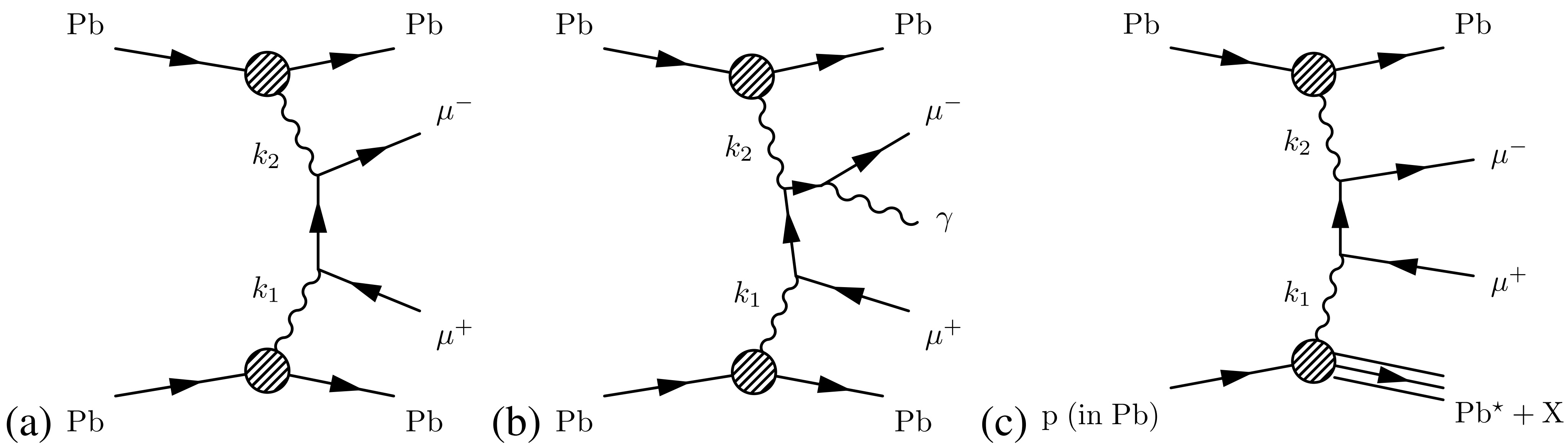
lepton pair production
(Breit-Wheeler formula, Brodsky et al 1971)



photon pair production
(via quark, lepton, W, BSM? loops)

exclusive μμ production is a pure QED process,
one photon from each nucleus

Exclusive processes & dissociation

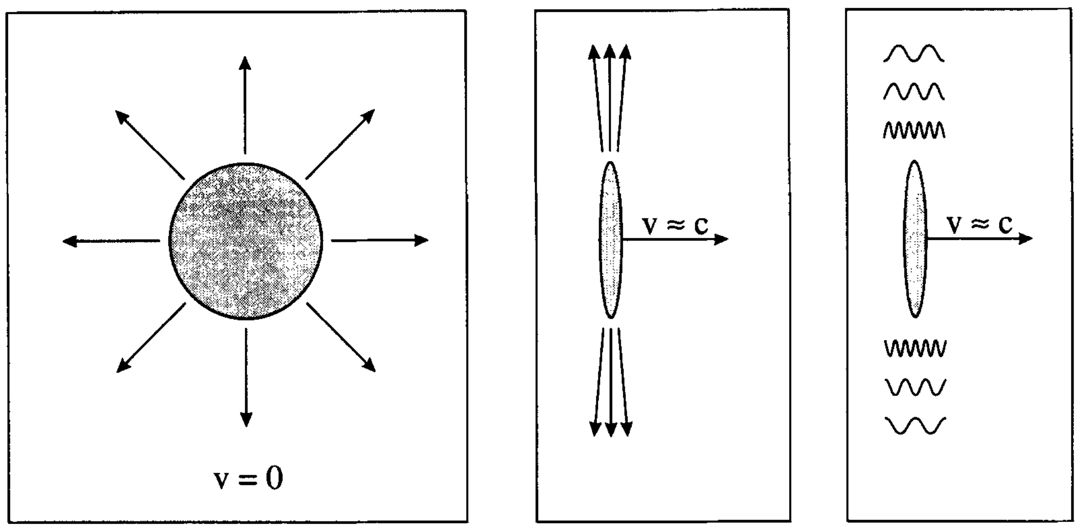


$\mathrm{PbPb}(\gamma\gamma) \to \mu^+\mu^-(\mathrm{Pb}^{(\star)}\mathrm{Pb}^{(\star)})$ is the primary signal Breit-Wheeler process cross section implemented in STARlight, SuperChic, etc.

$\mathrm{PbPb}(\gamma\gamma) \to \mu^+\mu^-\gamma(\mathrm{Pb}^{(\star)}\mathrm{Pb}^{(\star)})$ is a higher order final state, also signal. Not in any existing MC, but now being addressed in calculations, and can be added to final states (e.g. from STARlight) using Pythia8

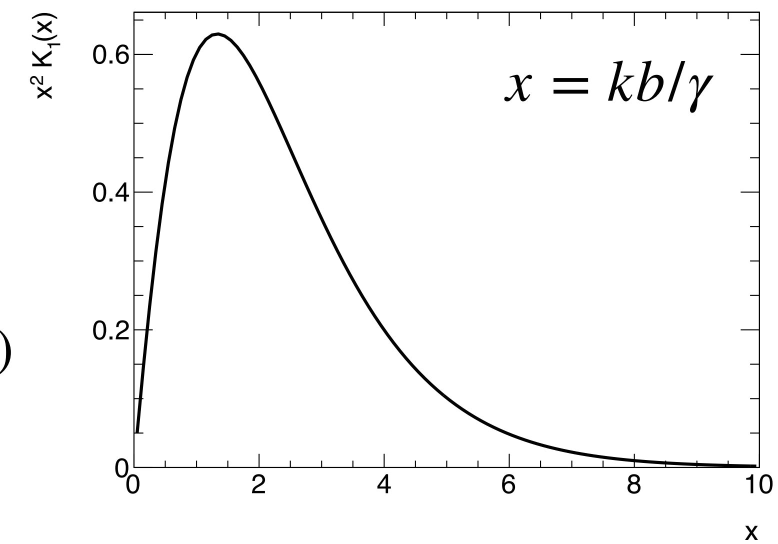
$\mathrm{Pb}+\mathrm{p}/\mathrm{Pb}(\gamma\gamma) \to \mu^+\mu^-X(\mathrm{Pb}^{\star}\mathrm{Pb}^{(\star)})$ is dissociative background (non-EPA) process, including nuclear breakup as well, modeled using LPair.

Theory background



For a point charge:

$$n(k,b) = \frac{d^3N_\gamma}{d^2b\,dk} \propto \frac{\alpha Z^2}{kb^2} f(kb/\gamma)$$



$$\frac{d^2N}{dk_1dk_2} = \int_{b_1>R_1} d^2b_1 \int_{b_2>R_2} d^2b_2 \; n(k_1,b_1)n(k_2,b_2) \; P_{\rm fn}(b) \; (1-P_{\rm H}(b))$$

Radial cutoff to nuclear distributions (or use measured form factors)

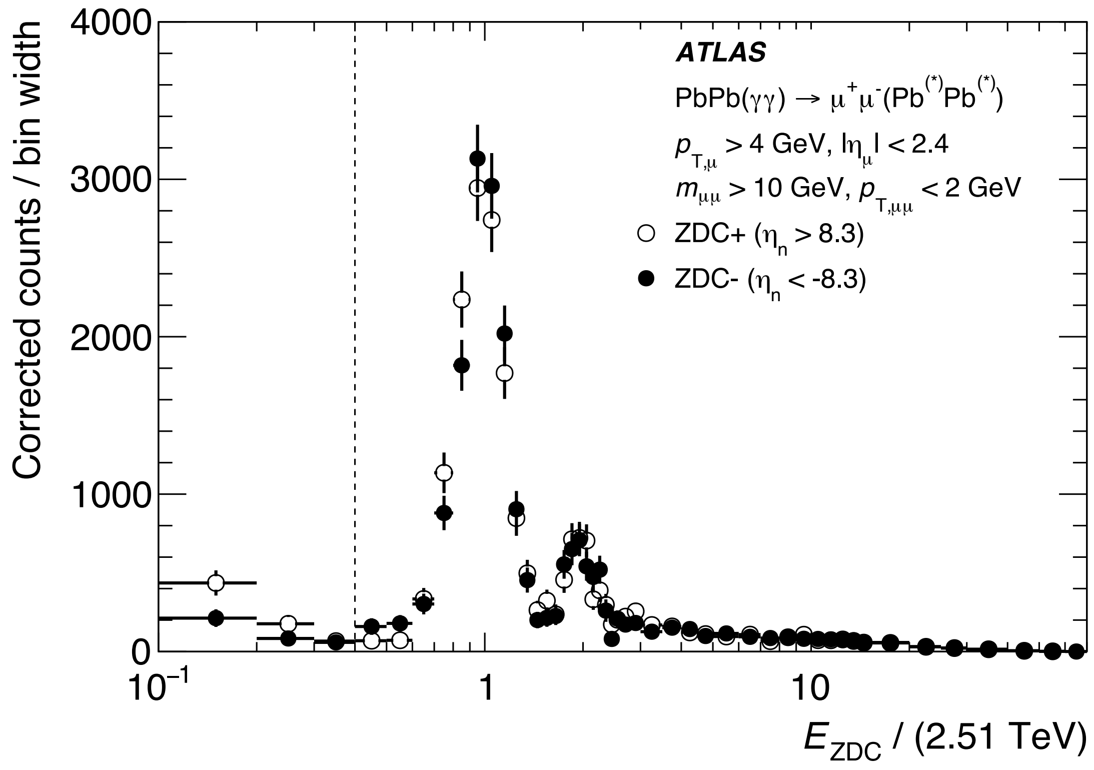
forward neutron topology (from photonuclear processes)

(no) hadronic interaction: Glauber calculation

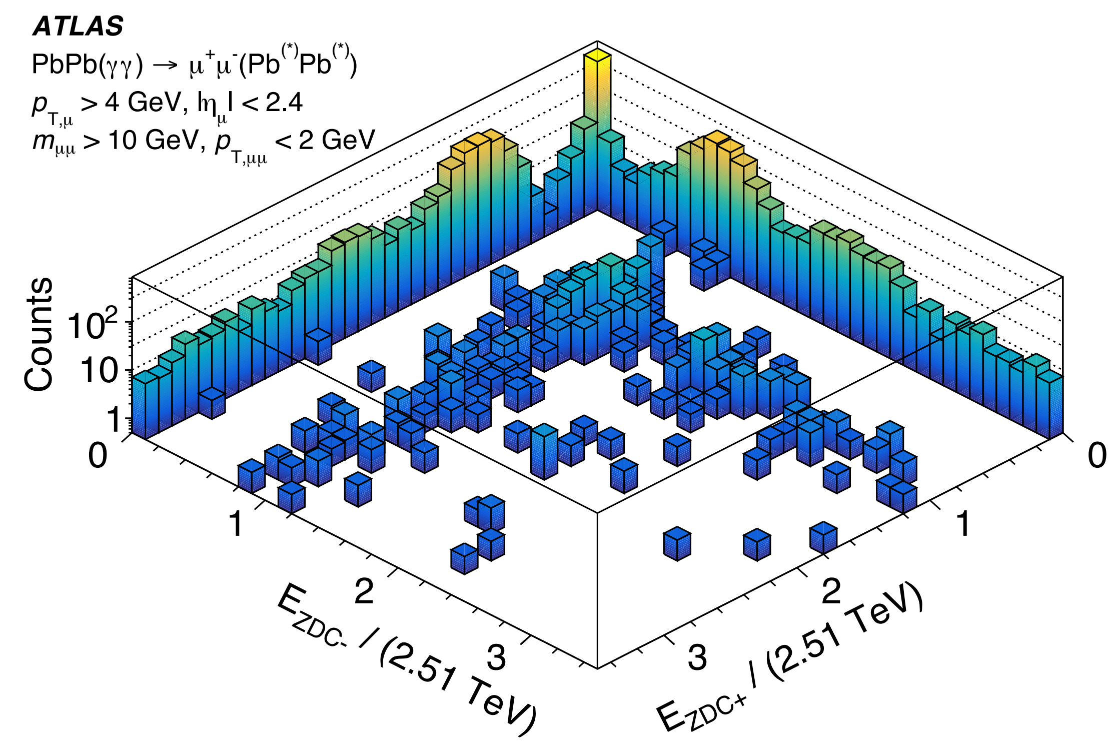
Two photon flux convolves two separate nuclear photon densities, the probability of a hadronic process (violating exclusivity), and the probability (if required) of a specific forward neutron topology

ZDC selections

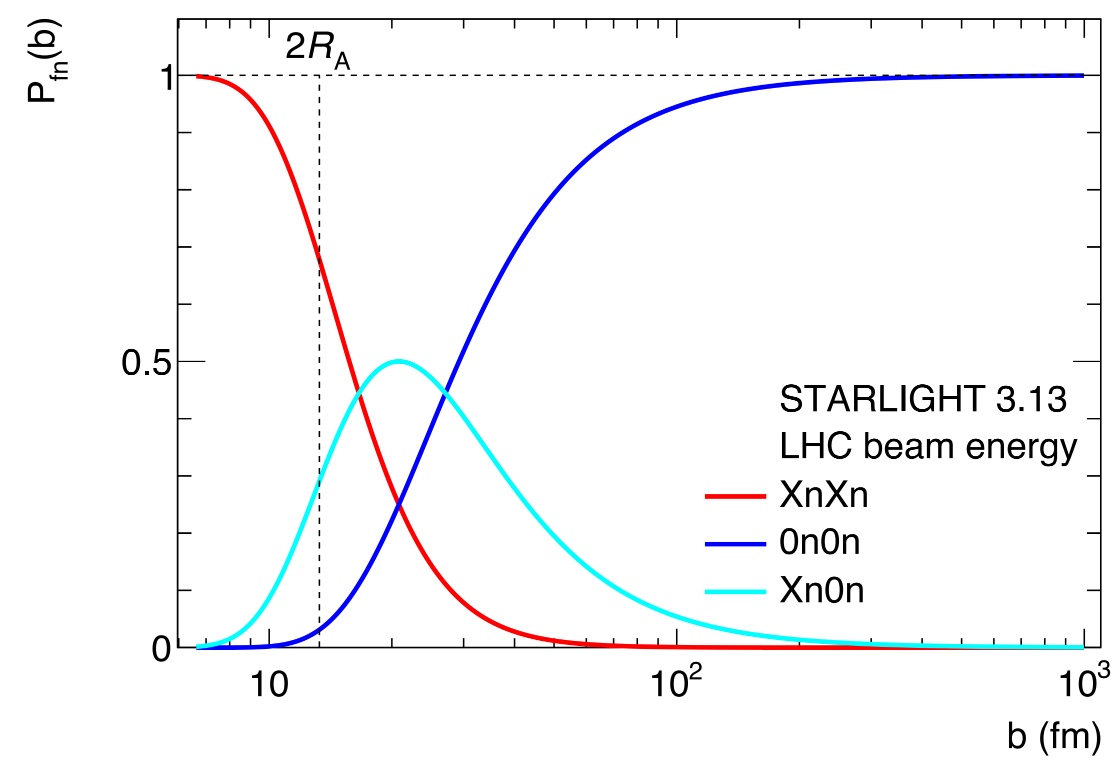
ZDCs can distinguish 0n from 1n, 2n…



and thus classify events according to 0n0n, Xn0n/0nXn, or XnXn



Selection of a specific ZDC topology is also filtering on a range of impact parameters (0-15 fm, 15-40fm, 40+ fm), and so modifies expected incoming photon spectrum

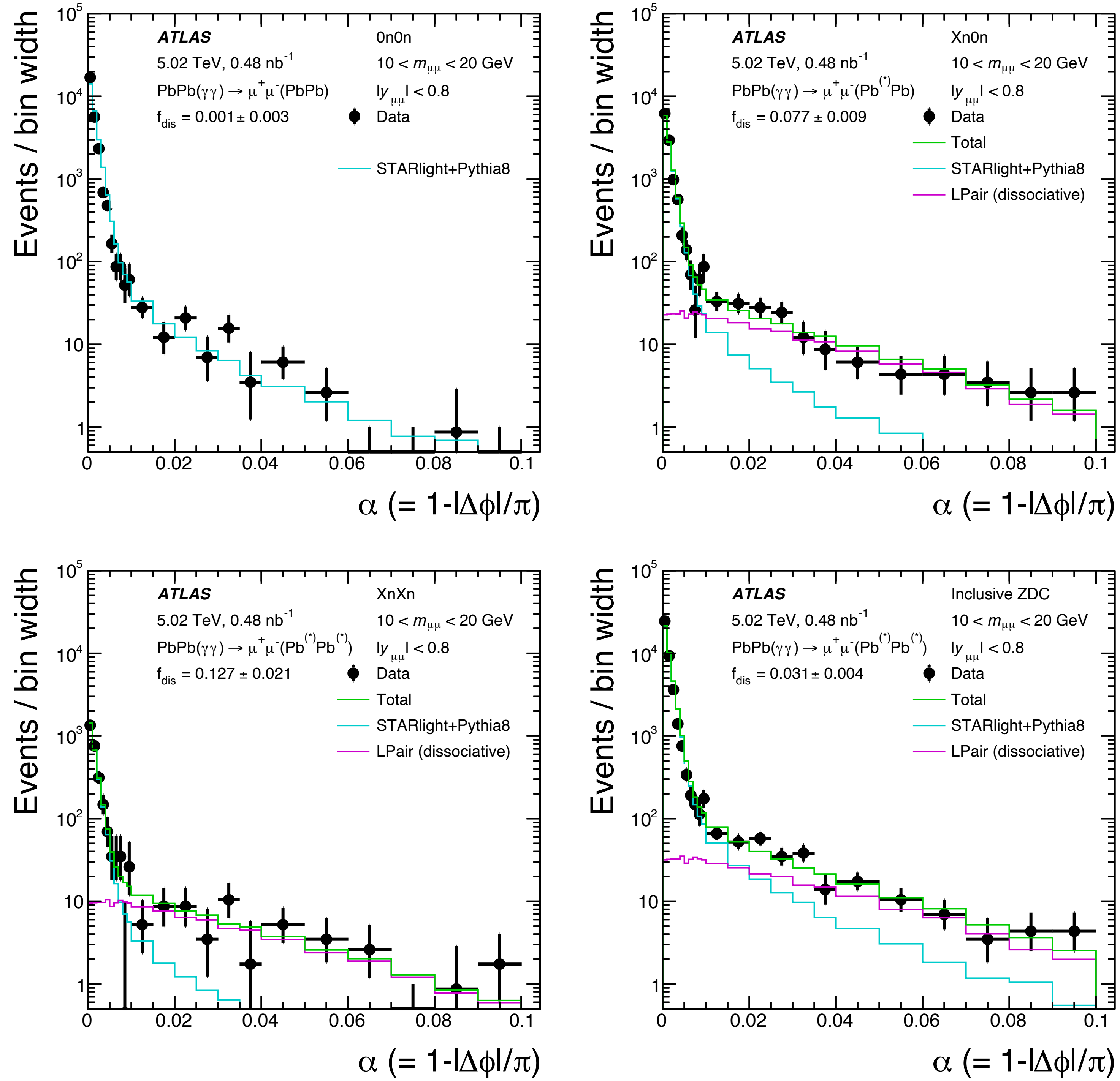


Exclusive dimuon dataset & analysis

- **2015 Pb+Pb dataset, L_{int} = 0.48 nb^{-1}**
- **Event trigger**
  - Muon reconstructed at L1 with no p_T selection
  - Maximum total limited to E_T < 50 GeV to suppress hadronic events
  - At least one track reconstructed with p_T>200 MeV to suppress empty events
  - No ZDC selection in primary trigger
- **Event & fiducial selection**
  - Two good ("tight") muons and no additional tracks
  - Fiducial selection:
    - $p_{T\mu}>4$ *GeV,* $|\eta_\mu|<2.4$, $m_{\mu\mu} > 10$ *GeV,* $p_{T\mu\mu} < 2$ *GeV*
  - (optional) ZDC topology measured using calibrated energies
- **Corrections**
  - Trigger efficiency (measured)
  - Reconstruction efficiencies (MC+data corrections)
  - Dissociative background
  - Bin migration (mainly at edges of $p_{T\mu1}, p_{T\mu2}$ = 4 GeV) - 1-3% effect

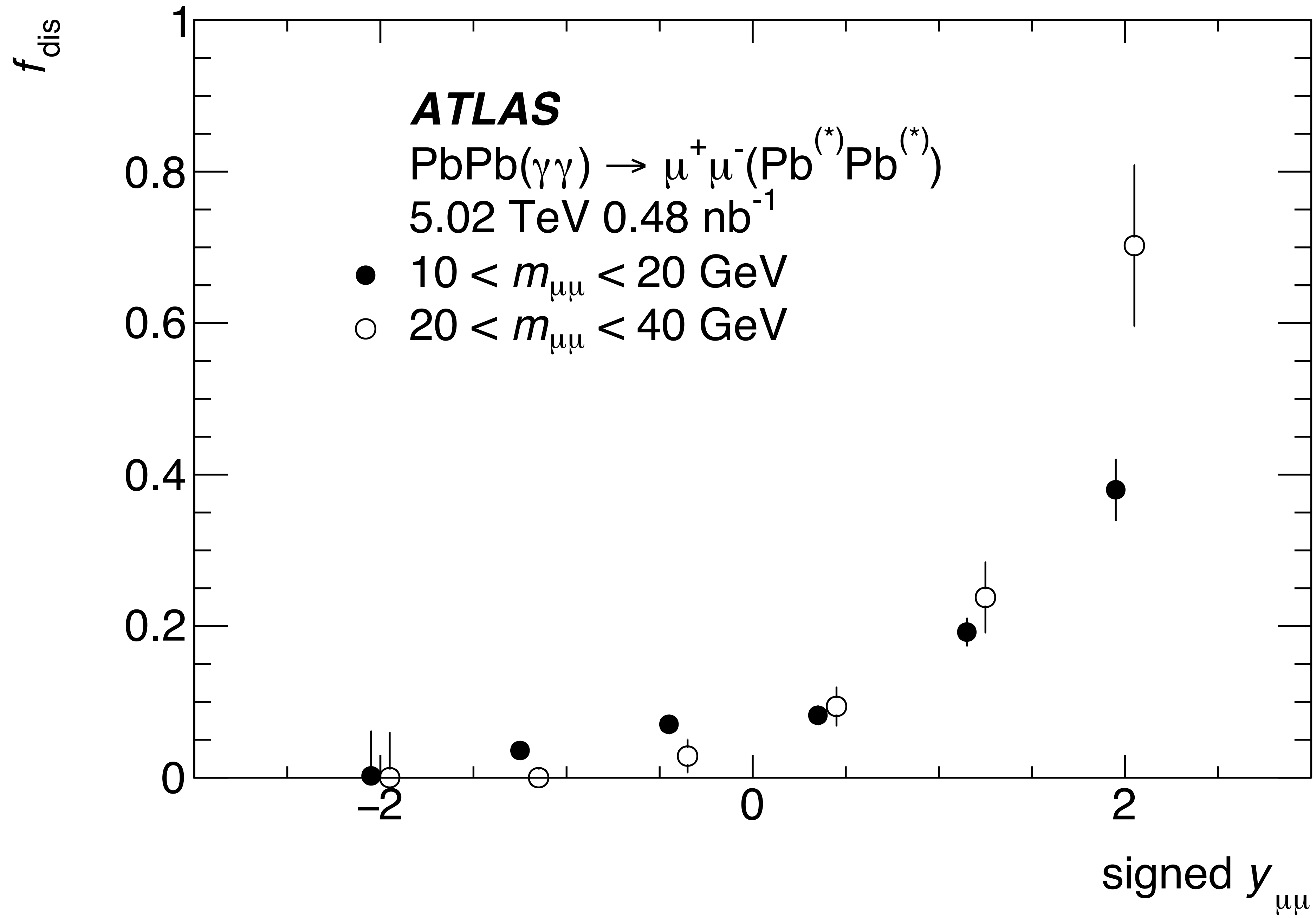
Dissociative contributions

- **Dimuon acoplanarity distributions in coarse $m_{\mu\mu}$ and $y_{\mu\mu}$ bins fit with two templates**
  - STARlight+Pythia8 to include FSR - full description of 0n0n
  - LPair to model dissociative contributions - needed for Xn0n and XnXn



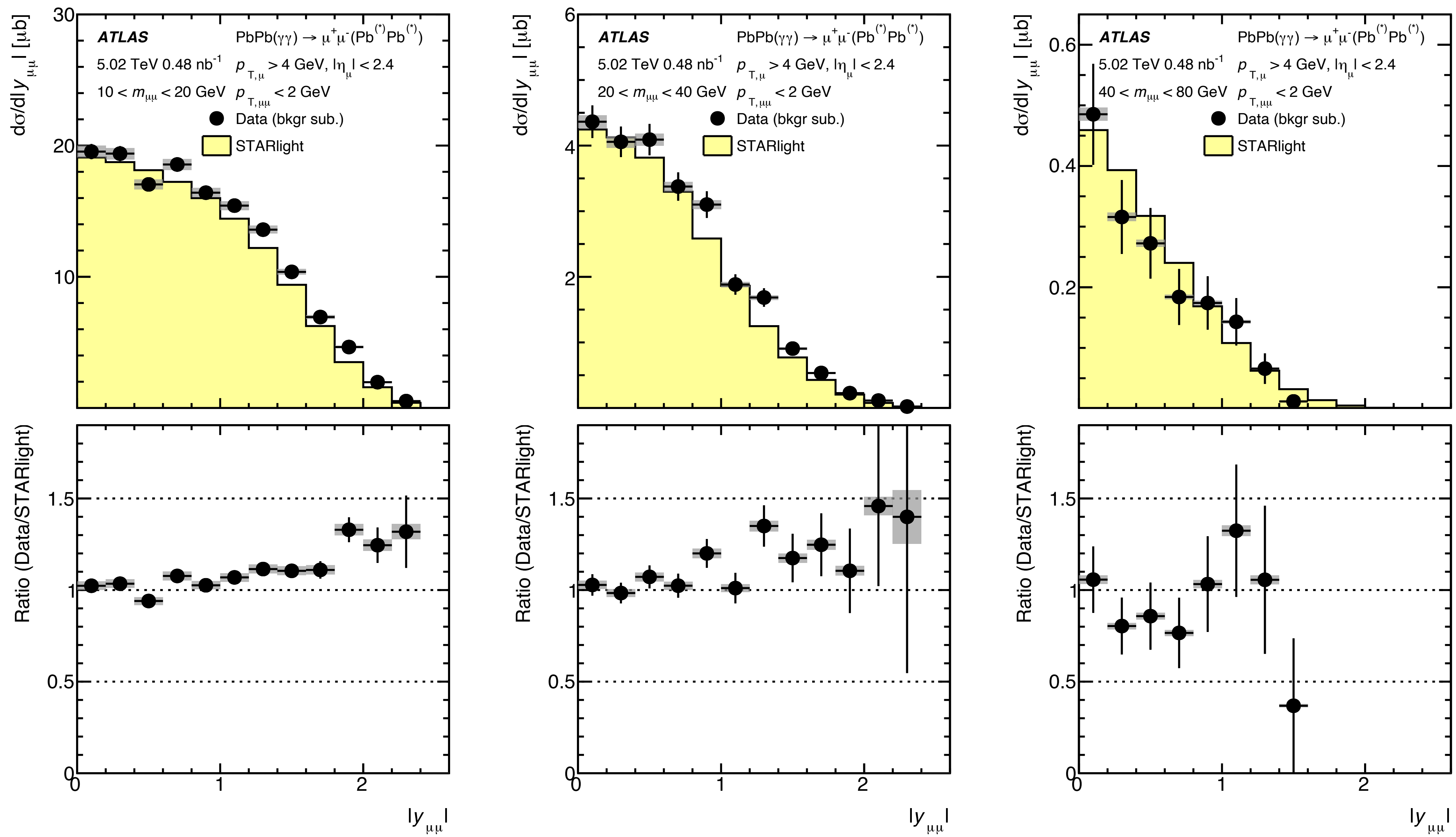
- **Averaged over ZDC topologies, only 3% correction for lower *$m_{\mu\mu}$*, *$y_{\mu\mu}$***

Dissociative fraction in Xn0n



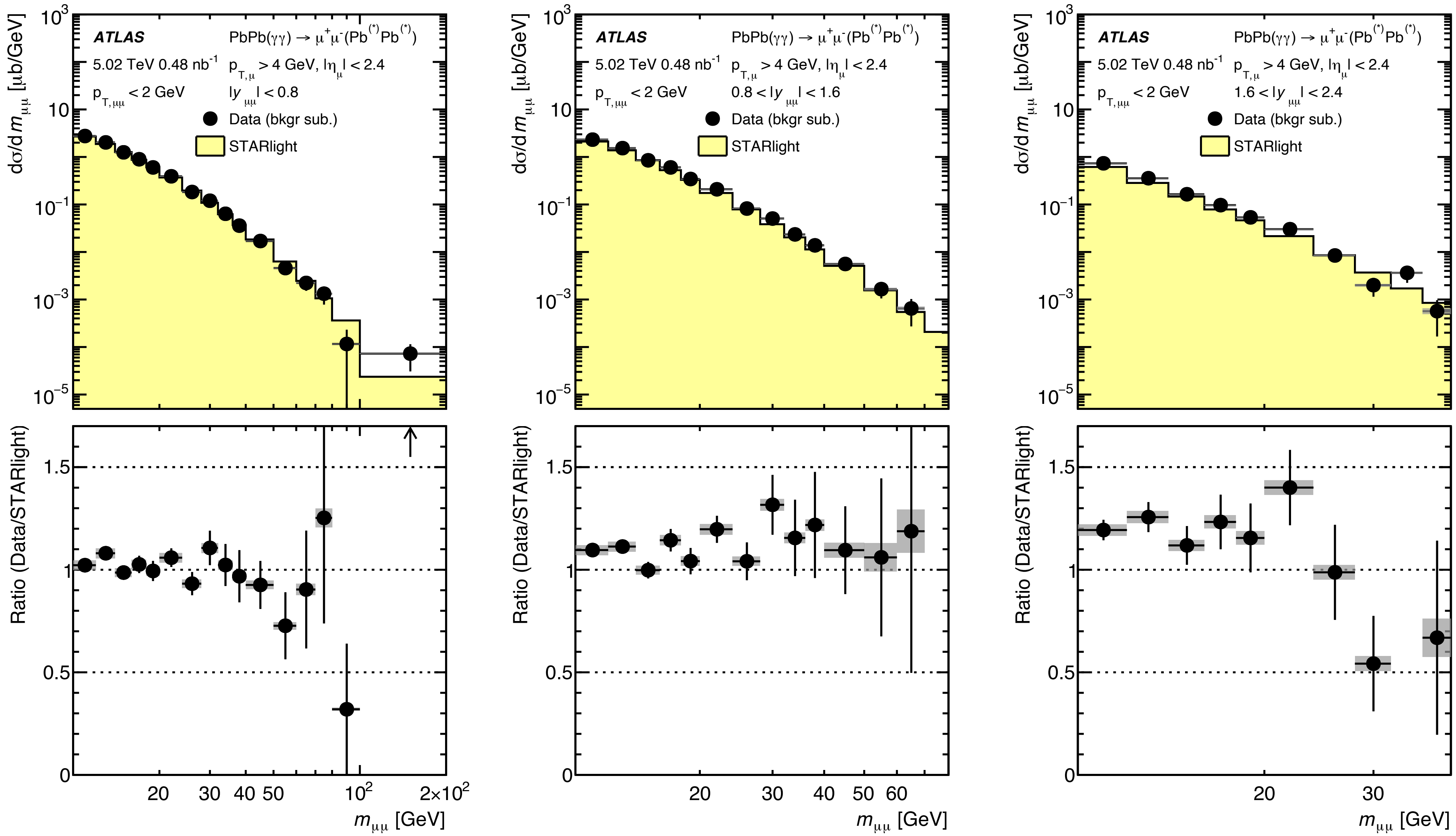
If sign of $y_{\mu\mu}$ is defined to be positive in the direction of the forward neutron, strongly-increased dissociation observed as the pair rapidity increases

Data compared to STARlight: $y_{\mu\mu}$



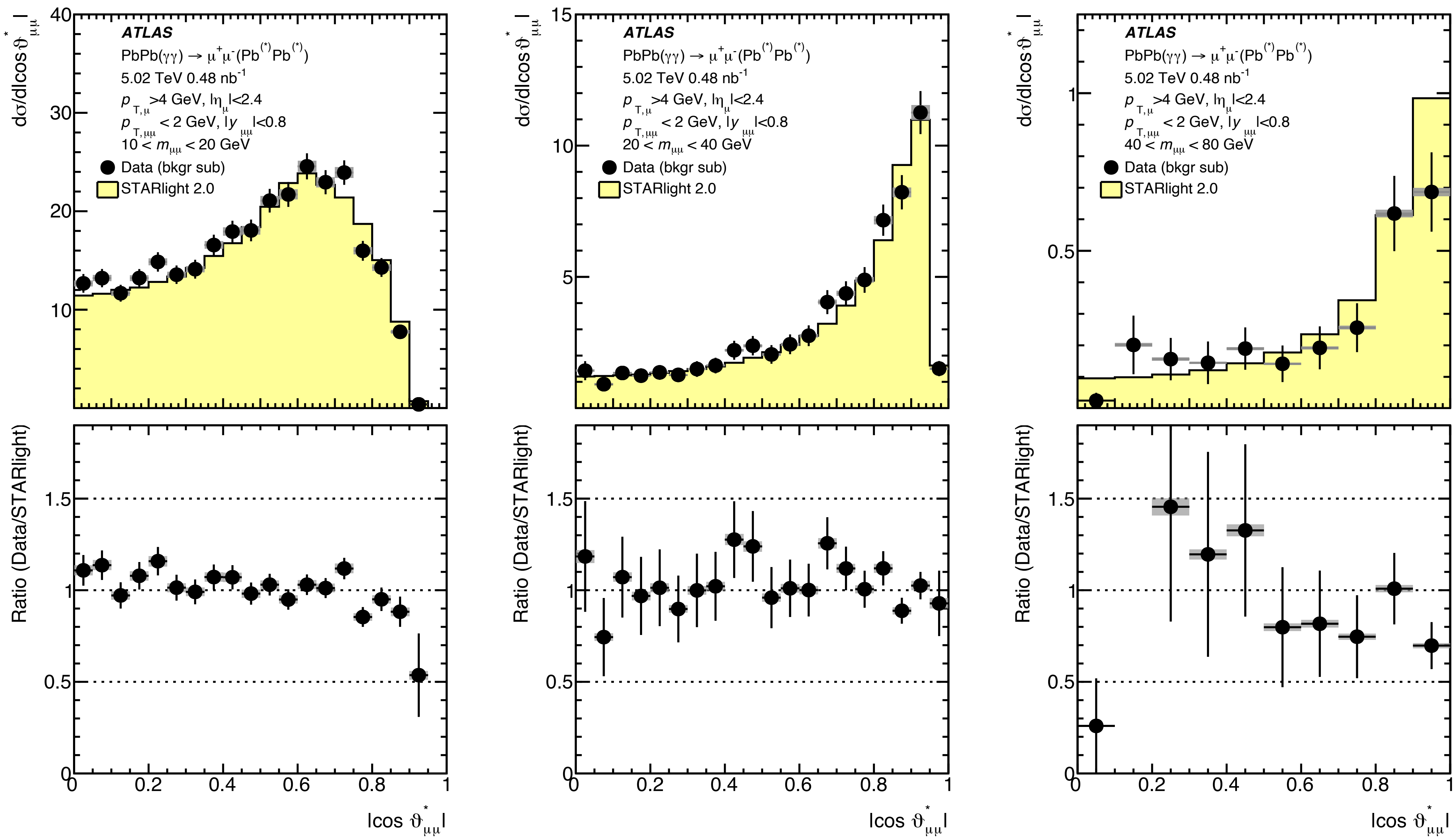
Good agreement with STARlight 2.0, but systematic increase observed at higher $y_{\mu\mu}$

Data compared to STARlight: $m_{\mu\mu}$



Overall increase in mass distribution just reflects increase vs. $y_{\mu\mu}$

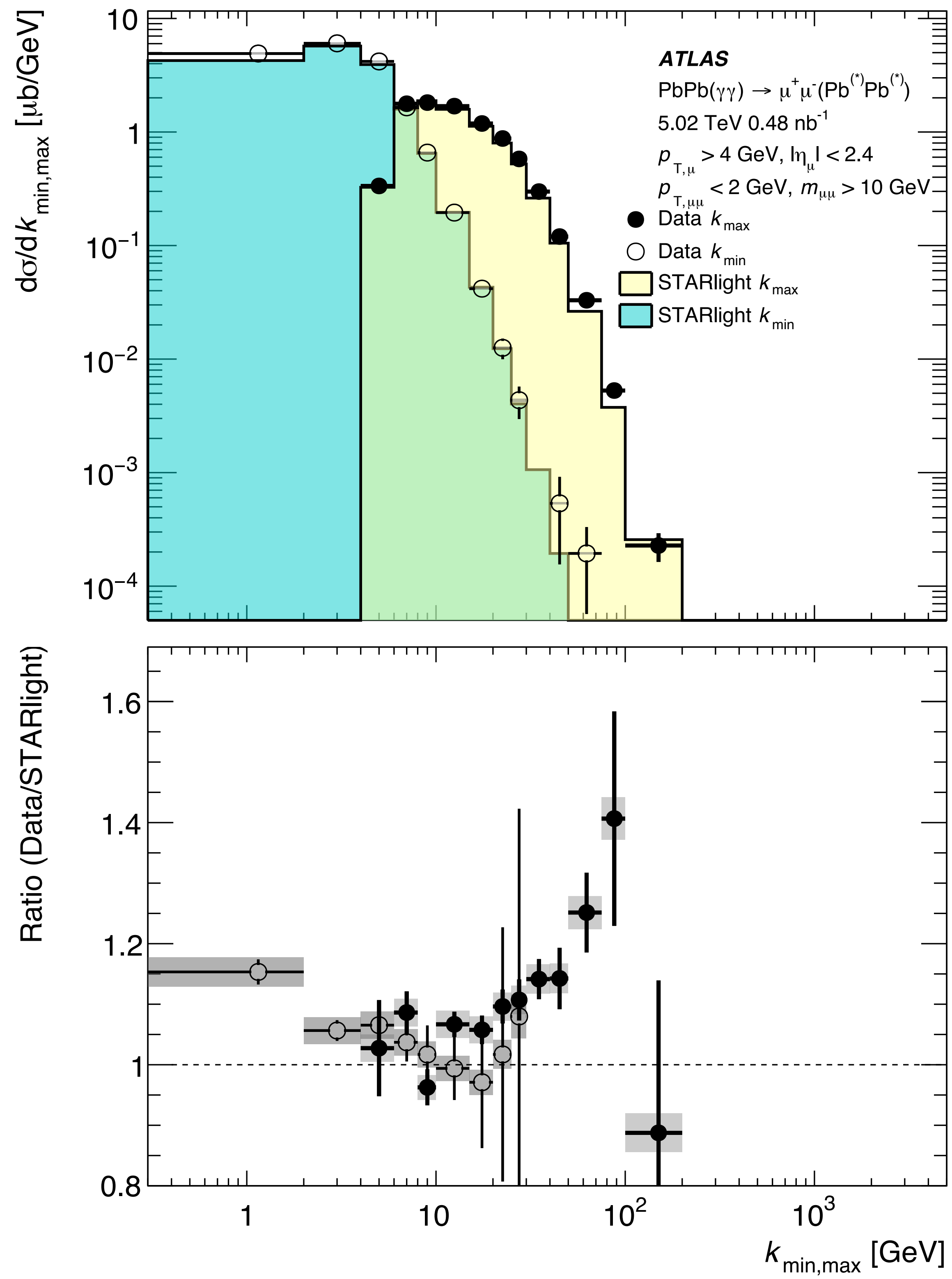
Data compared to STARlight: |cos(*θ**)|



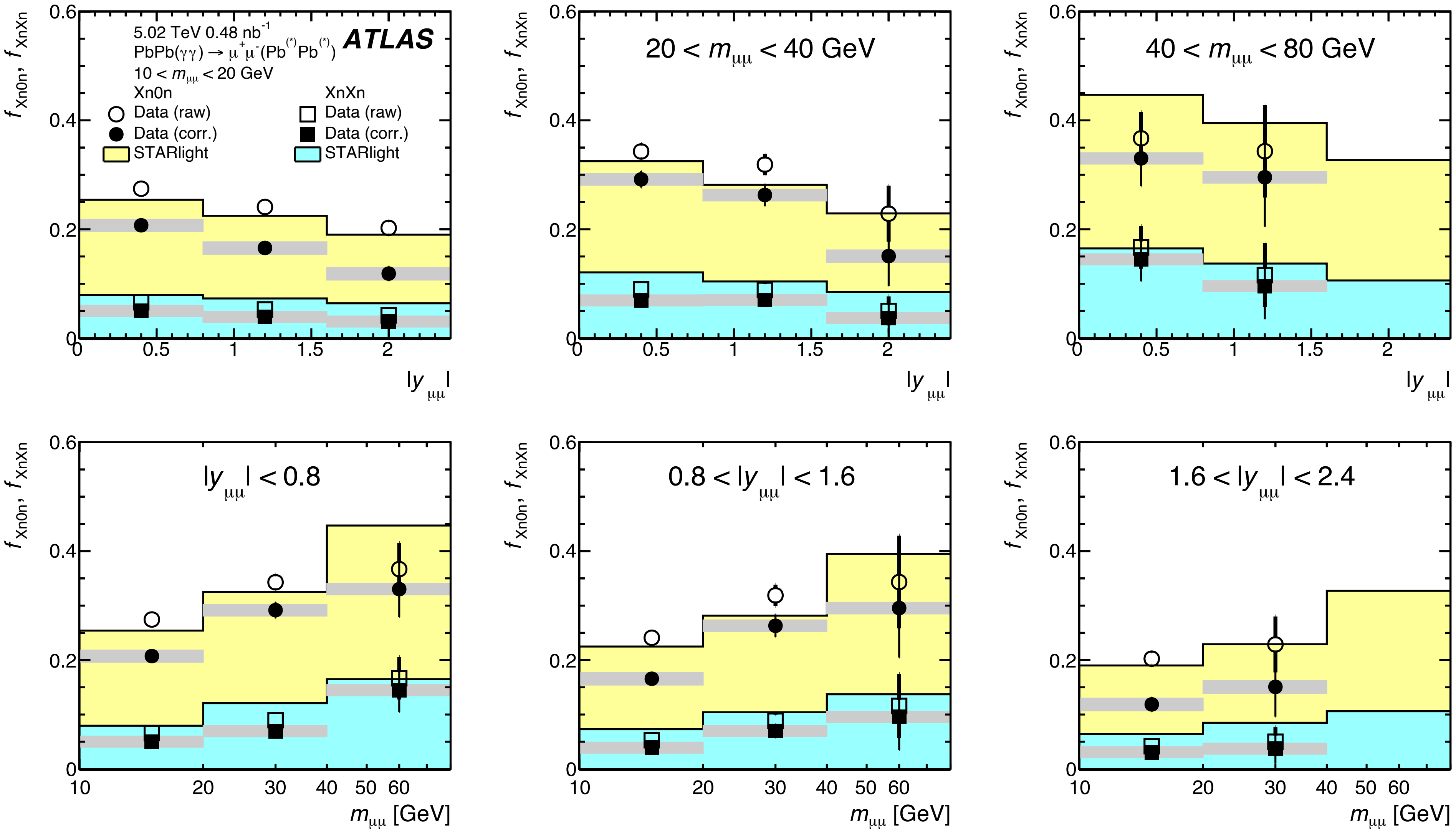
After restricting comparisons to $|y_{\mu\mu}|<0.8$, to avoid differences at larger $|y_{\mu\mu}|$, good agreement in scattering angle (Breit-Wheeler)

Photon energy distributions

- **Incoming photon energies estimated assuming p_T~0**
  - $k_{1,2} = (m_{\mu\mu}/2)\exp(\pm y_{\mu\mu})$
- **Distributions of maximum and minimum k agree well with STARlight**
  - Differences seen at low and high k
- **One obvious issue is requirement of $b > R_{1,2}$ in 2-photon flux**
  - Several authors already questioned this, but need to address systematically
  - Ignoring it completely gives 20% increase in predicted cross section



ZDC fraction vs. $m_{\mu\mu}$ and $y_{\mu\mu}$



Fractions of events with Xn0n, and XnXn corrected for electromagnetic pileup, assuming Xn cross sections from ALICE, extrapolated to 5.02 TeV

Reasonable agreement with STARlight, but MC slightly overestimates nuclear dissociation.

Corrected acoplanarity distributions

Dissociative contributions removed using 0n0n selection

Bin-by-bin corrections performed using fast simulation, verified by full GEANT4 simulations

STARLIGHT & STARlight+Pythia8 scaled down according to measured 0n0n fraction (72%)

STARlight is clearly missing long tail, but reasonable agreement near α~0

STARlight+Pythia8 also shows similar agreement near α~0, and gets shape of high α tails correct

Clearly need better description of initial photon p_T distributions