Measurements of prompt photon and Z boson production in association with jets at ATLAS

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on behalf of the ATLAS Collaboration

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Photon and Z boson

Good coupling to quarks	+	Clean experimental signature Measured / reconstructed very precisely	=	Excellent QCD probe tool

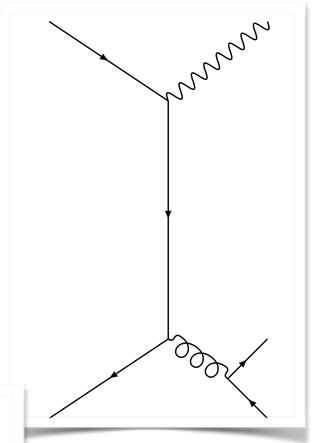
- Test resummation, perturbative QCD, PDF…
- Improve MC background description for BSM searches

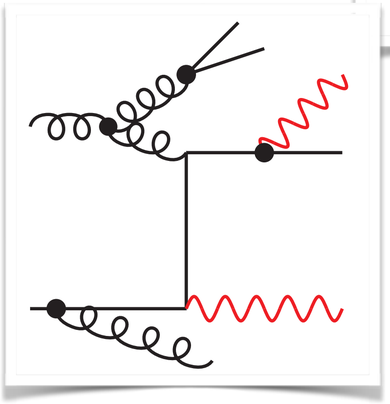
Isolated photon measurements

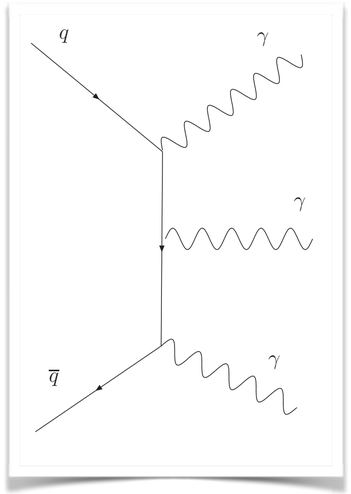
- γ+2jets at 13 TeV (JHEP 03 (2020) 179)
  - $p_T^{\gamma} > 150$ GeV, $p_T^{jet} > 100$ GeV
  - Differential cross section vs. multiple observables in 3 regions: Inclusive, fragmentation enriched $p_T^{\gamma} < p_T^{jet2}$ and direct enriched $p_T^{\gamma} > p_T^{jet1}$

- $\gamma\gamma$ at 13 TeV (arXiv:2107.09330)
  - $p_T^{\gamma 1} > 40$ GeV, $p_T^{\gamma 2} > 30$ GeV
  - Inclusive differential cross section vs. multiple observables

- Predictions for 3γ and 4γ, at 8 and 13 TeV (ATL-PHYS-PUB-2021-001)
  - Compared to 8 TeV 3γ measurement







Background estimation for γ analyses

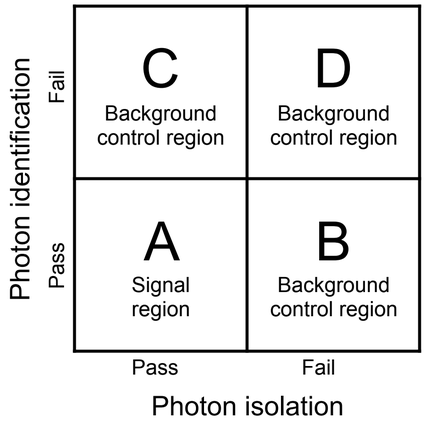
- Sample purity:
  - For γ+2jets ($p_T^\gamma > 150$ GeV): ≳95%
  - For $\gamma\gamma$ ($p_T^\gamma > 30$ GeV): 35%–80%

- Main background: Jets:
  Energetic neutral hadrons within jets decaying to collimated γ-pairs → misidentified as single γ

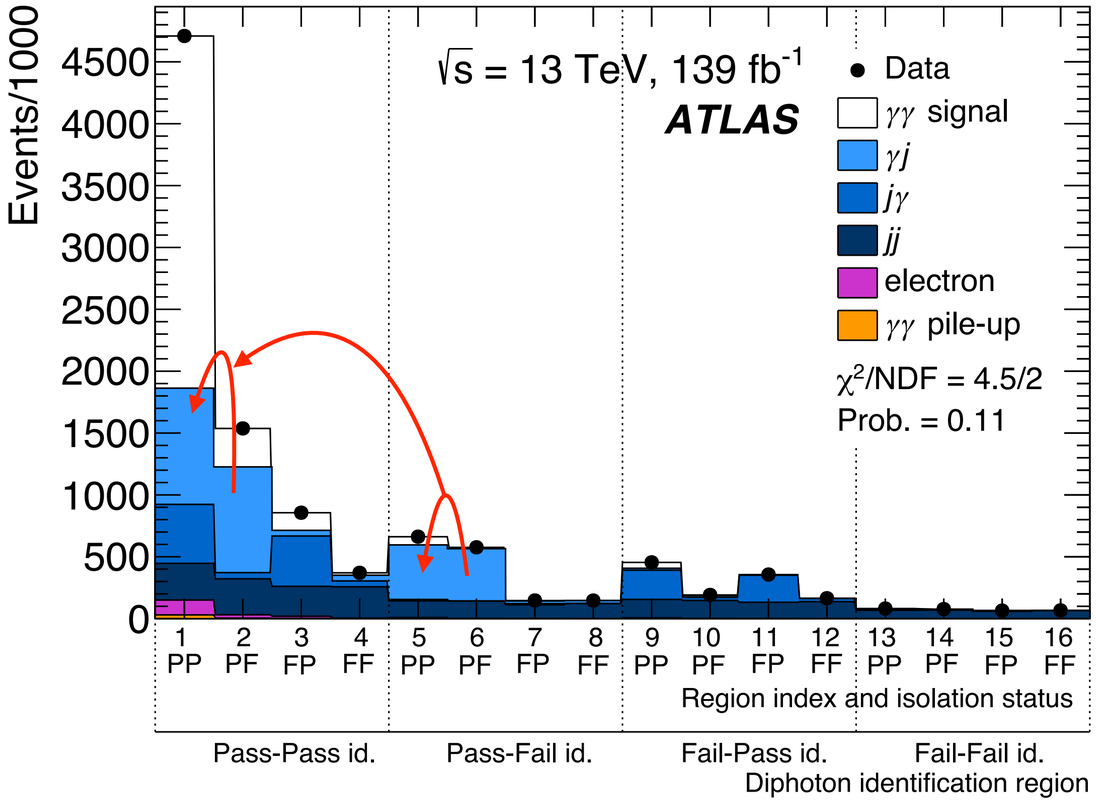
  Estimation based on non-correlation between EM shower shape and the isolation energy

- New source of background for $\gamma\gamma$:
  Pileup of 2 γ+jet events,
  0.6% inclusively, up to 6% differentially
  Estimated with track-info from $\gamma \to e^+e^-$ conversions

ABCD method for single γ

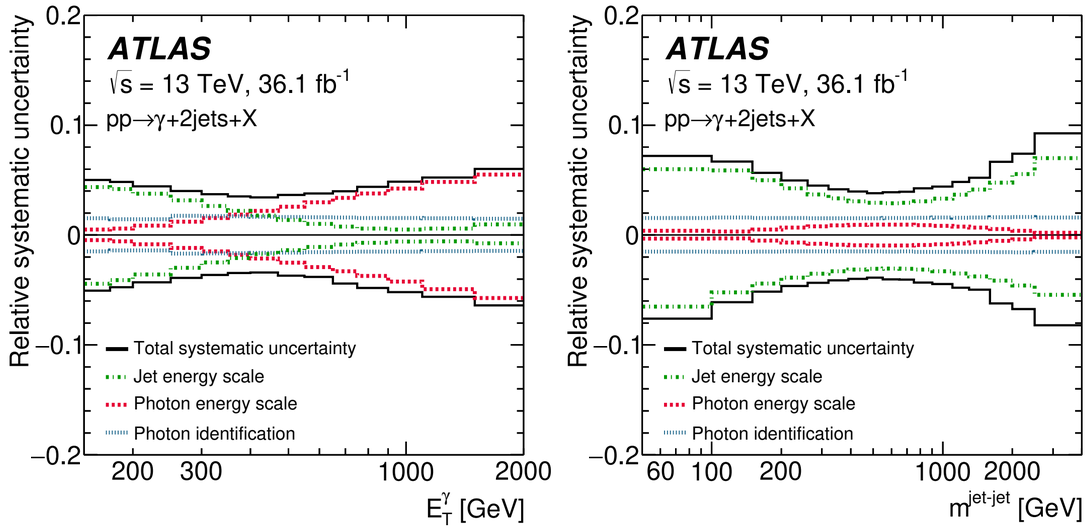


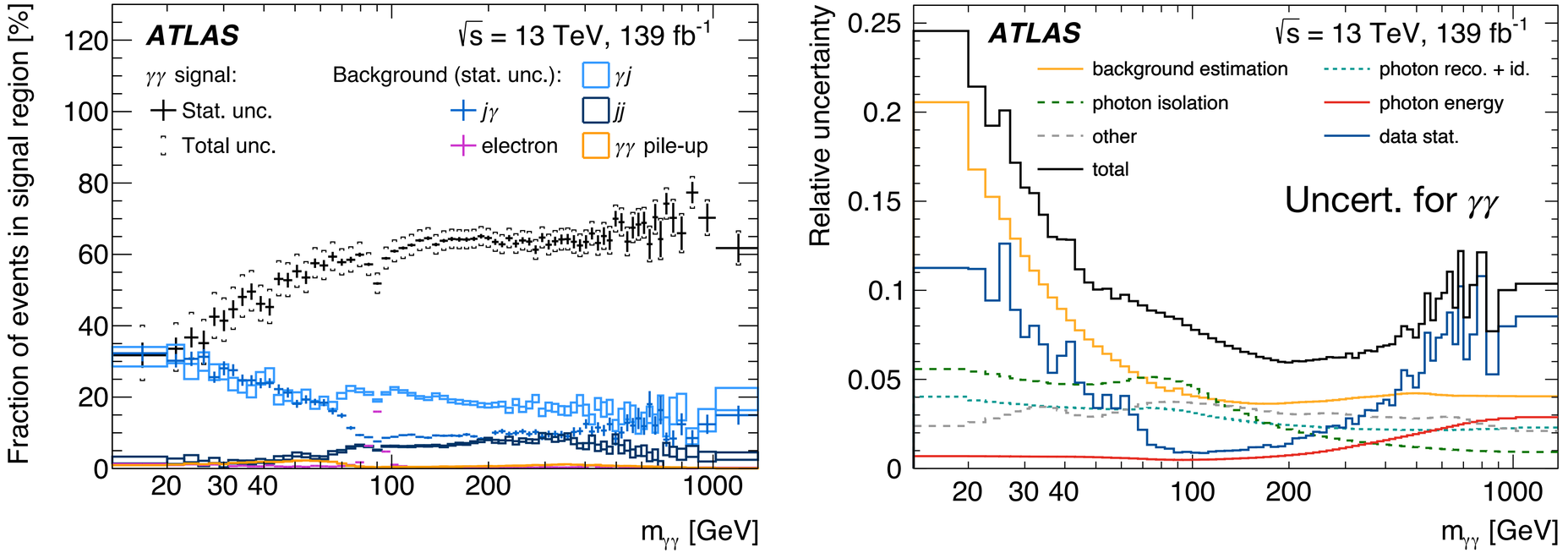
For $\gamma\gamma$: ABCD extension to 2γ case



Leading uncertainties

- For γ+2jets: γ and jet energy scale
- For $\gamma\gamma$: Background and isolation-requirement efficiency

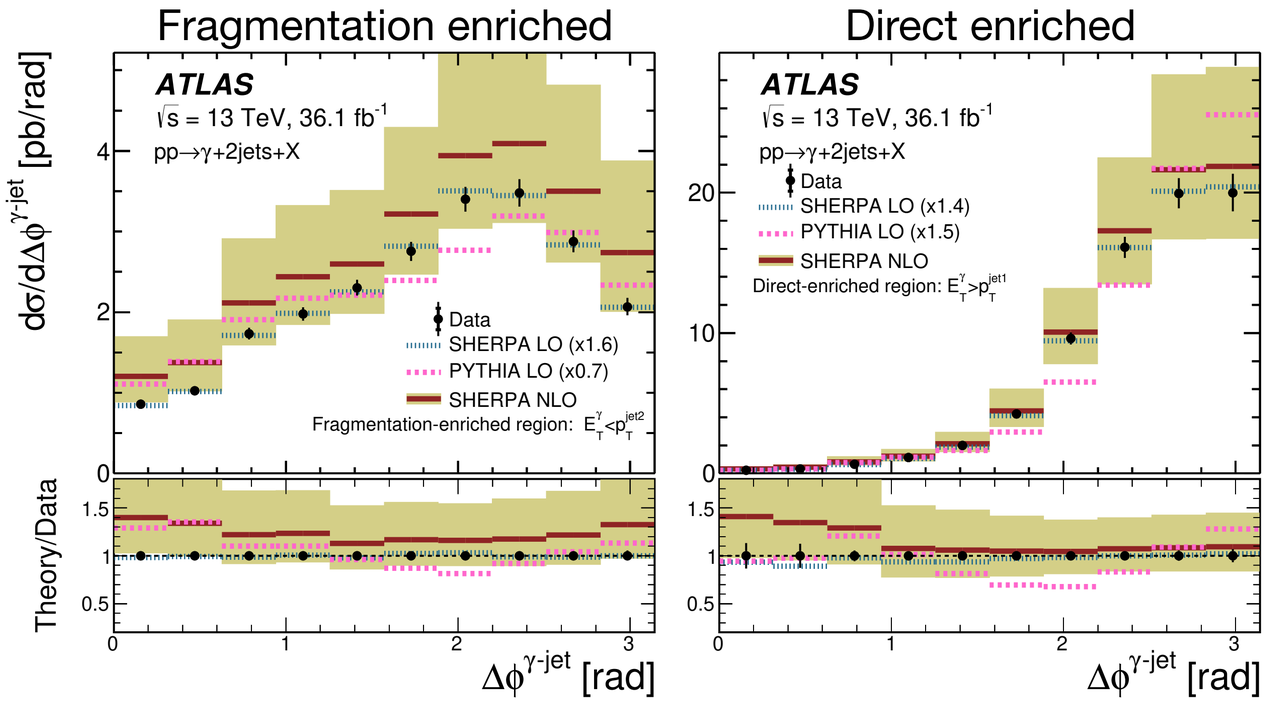


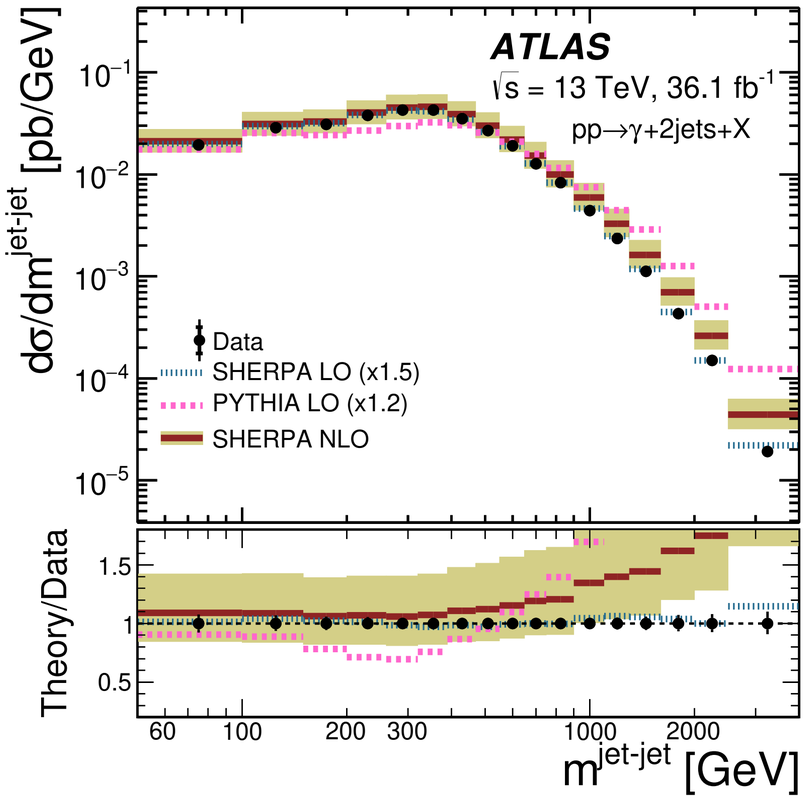


Results for γ+2jets

Sherpa NLO predictions:

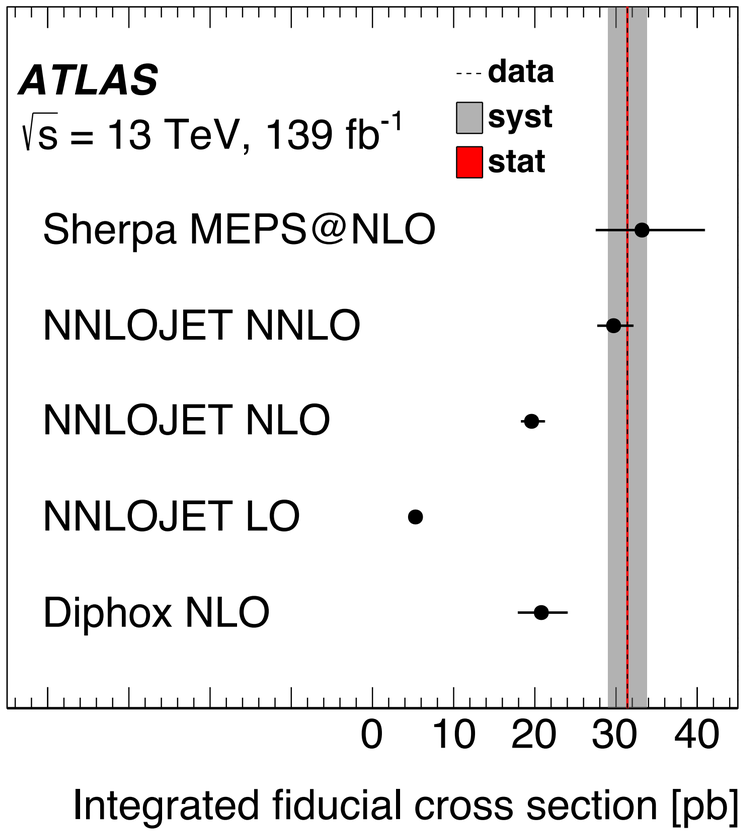
- $\Delta\phi(\gamma\text{-jet})$ well described
- High m_{jj} mismodelling (similar to Z+jets) – phase space important for Vector Boson Fusion and Scattering studies





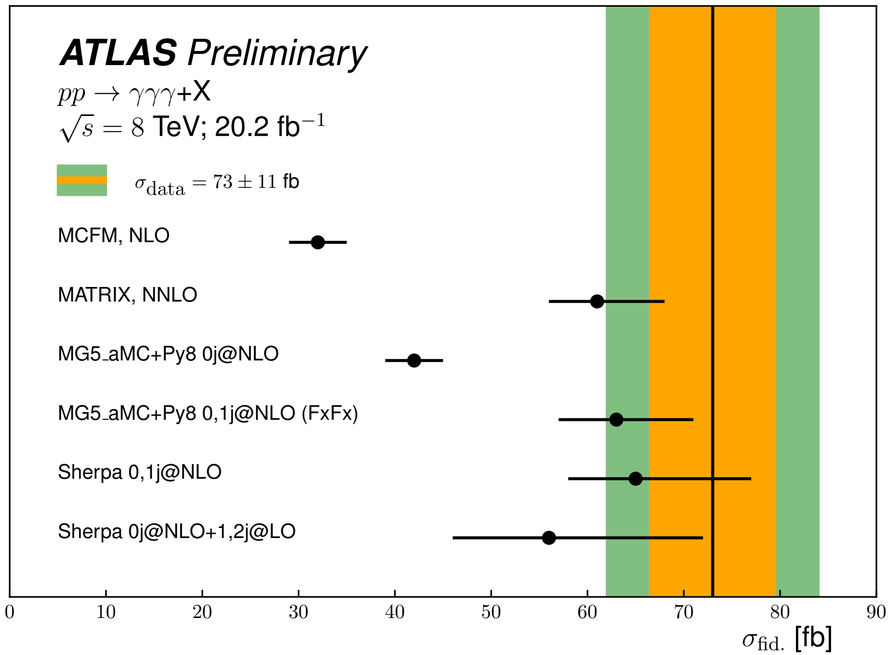
Integrated fiducial cross section for $\gamma\gamma$ and $\gamma\gamma\gamma$

Result for $\gamma\gamma$



Impressive impact from perturbative QCD on the event rate for these processes

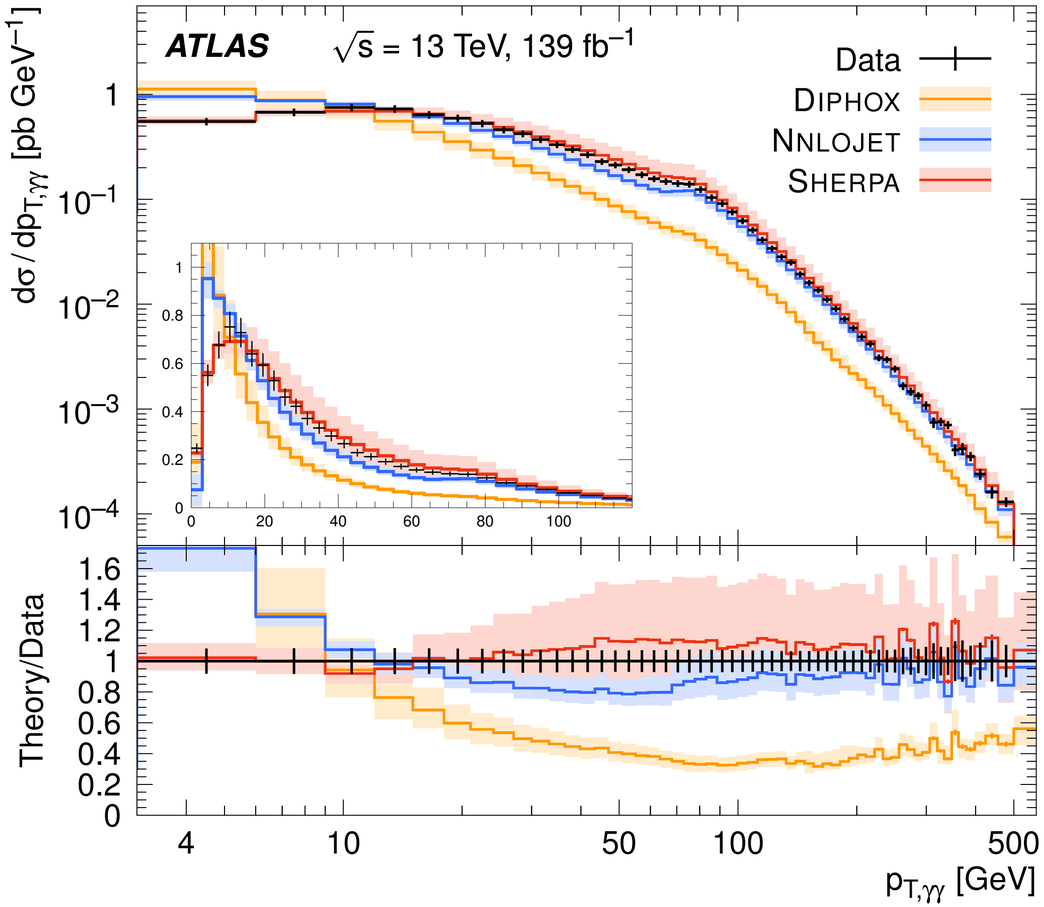
Result for 3γ

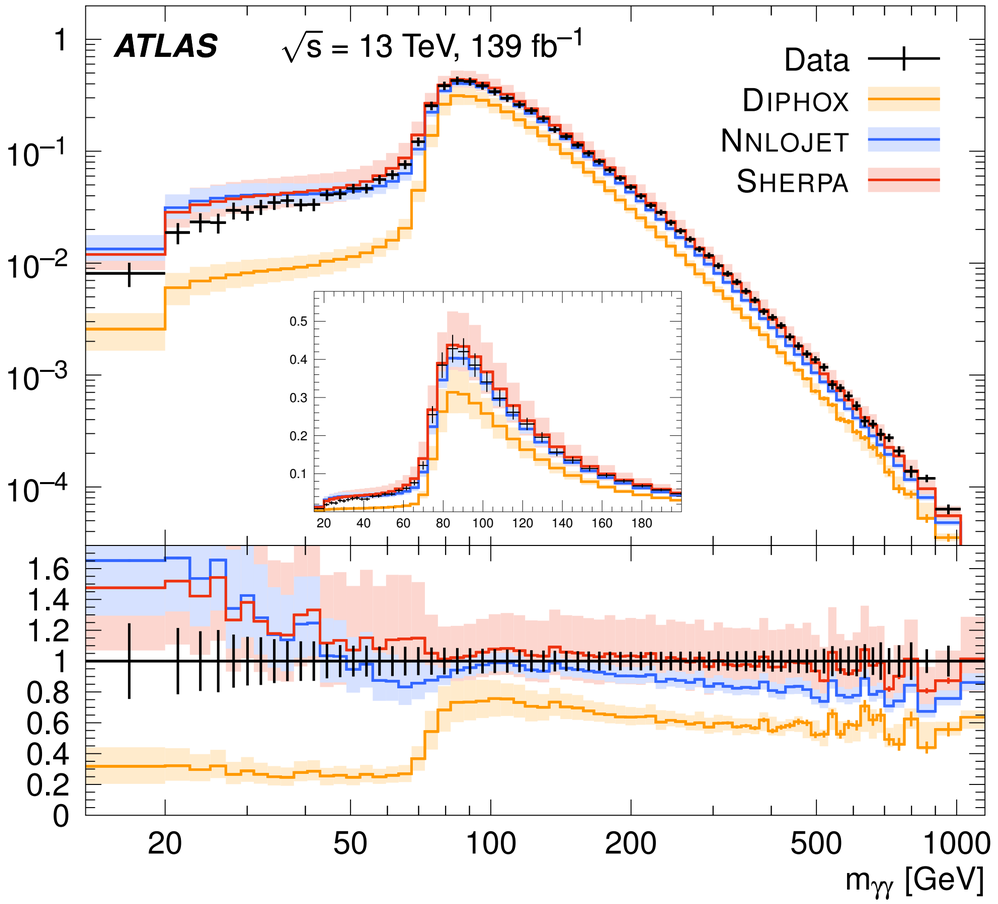


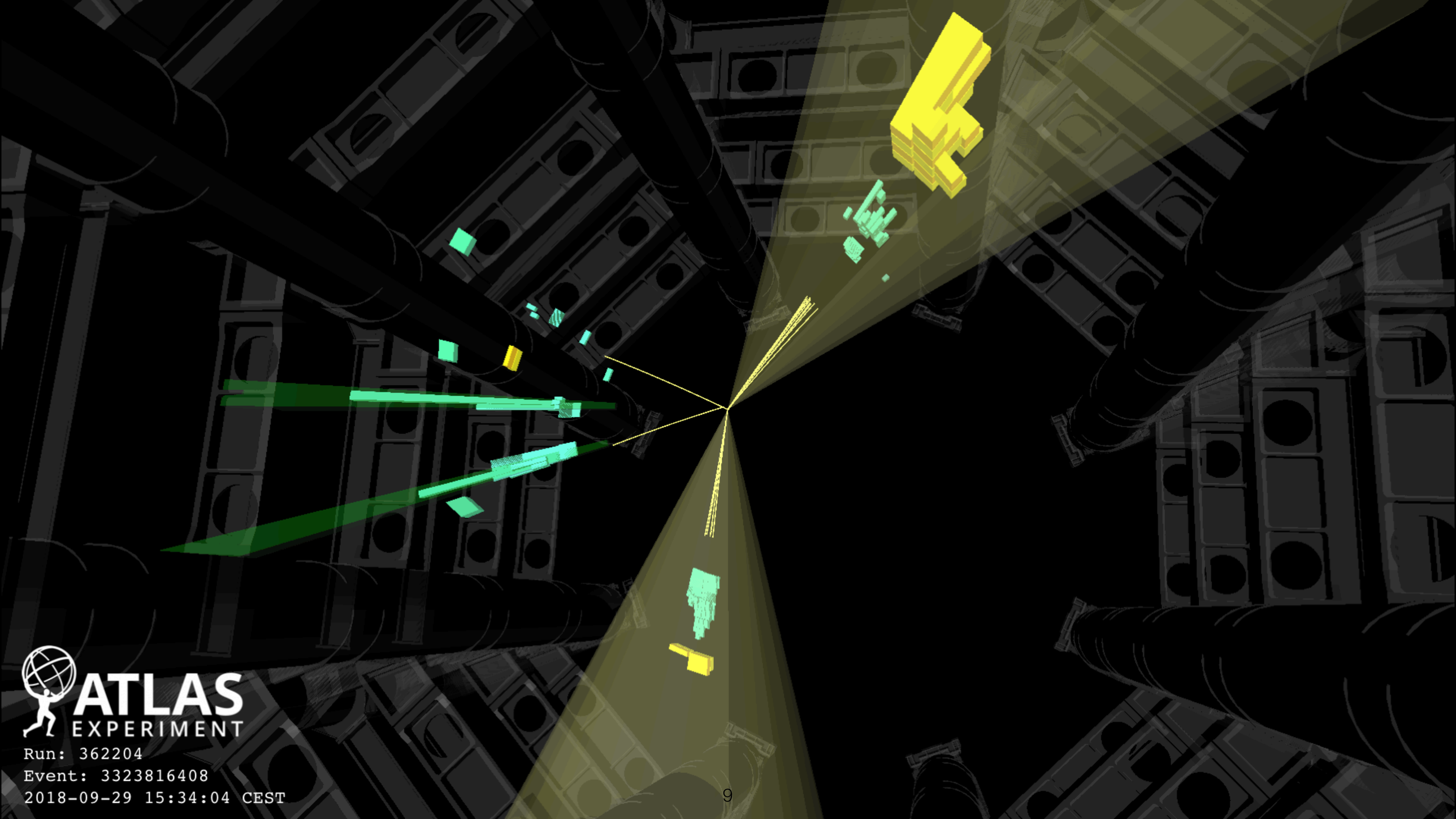
Results for $\gamma\gamma$

- Generally good modelling of perturbative regions by NNLO and multi-leg merged NLO predictions
- Soft QCD also described well by Sherpa NLO

(Theory prediction uncert. dominated by QCD scale variations)



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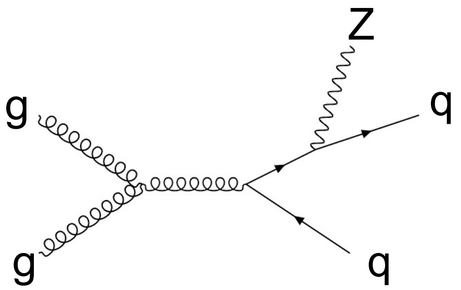
Z + jets measurements

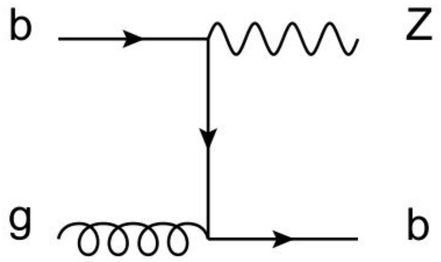


Using Z → ee/$\mu\mu$ decays

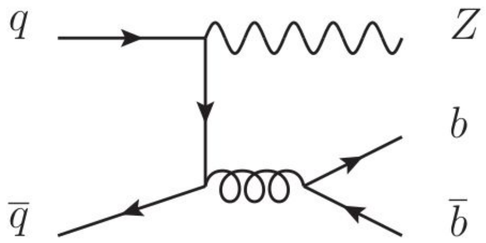
- Collinear Z + jets (ATLAS-CONF-2021-033)

  Measure and study collinear emission of a Z boson from a high p_T jet

NEW! for EPS



- Z + 1 or 2 b-jets (JHEP 07 (2020) 44)
  - Testing different flavor schemes of initial-state partons
  - Sensitive to gluon splitting



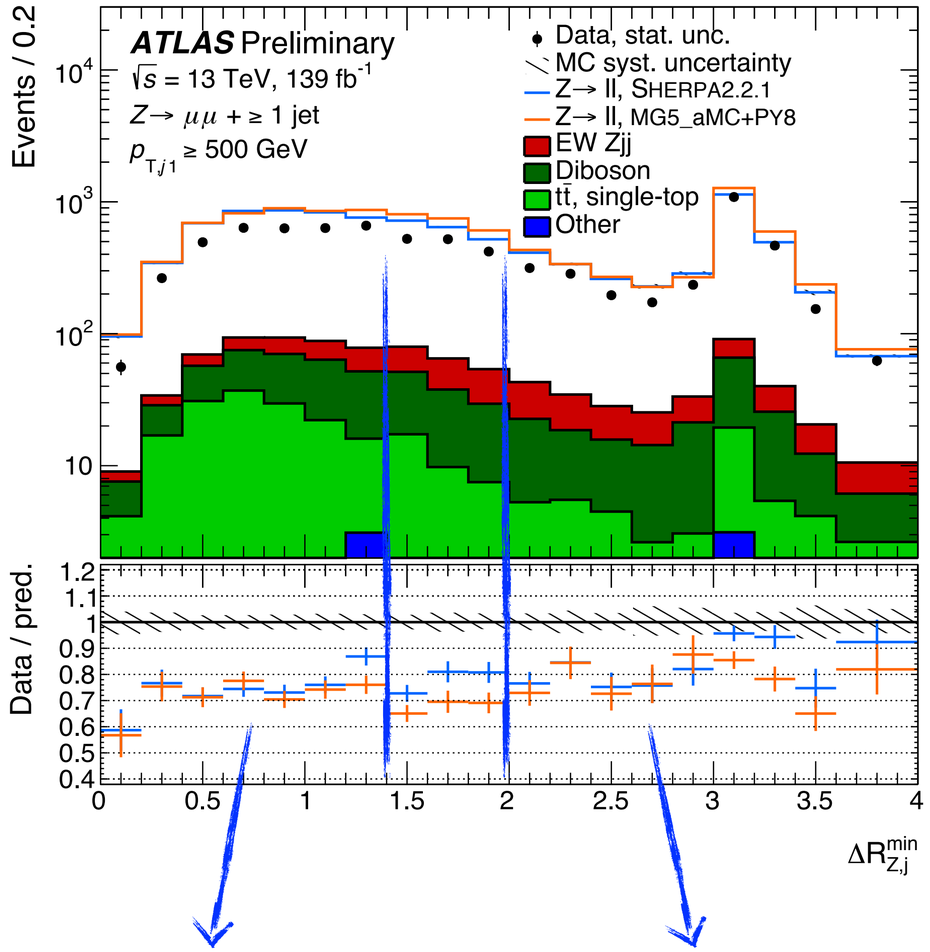
Collinear Z + jets

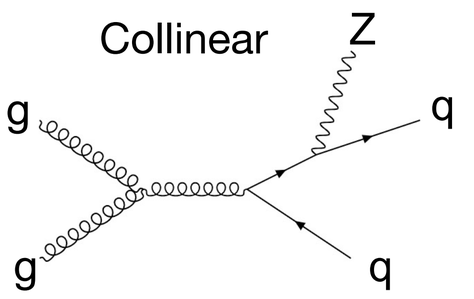
- Splitting in 5 regions:
  - Inclusive (p_T^{jet} > 100 GeV),
  - High p_T (p_T^{jet1} > 500 GeV),
  - Collinear (high p_T + min(ΔR) < 1.4),
  - Back-to-back (high p_T + min(ΔR) > 2.0),
  - High S_T (Scalar sum(p_T^{jet}) > 600 GeV)

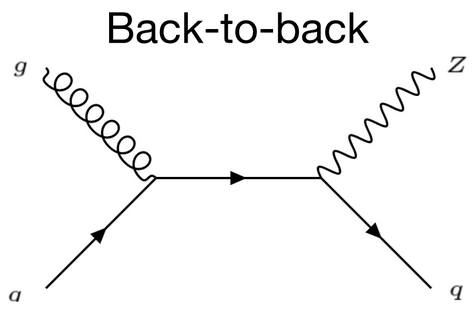
- Main backgrounds:
  - ttbar: 2-7% (data driven estimation)
  - Diboson: 2-6%
  - EW Zjj: 1-3%

- Main uncertainties: Jet energy scale and resolution, unfolding (MC modelling and sample statistics)

NEW! for EPS





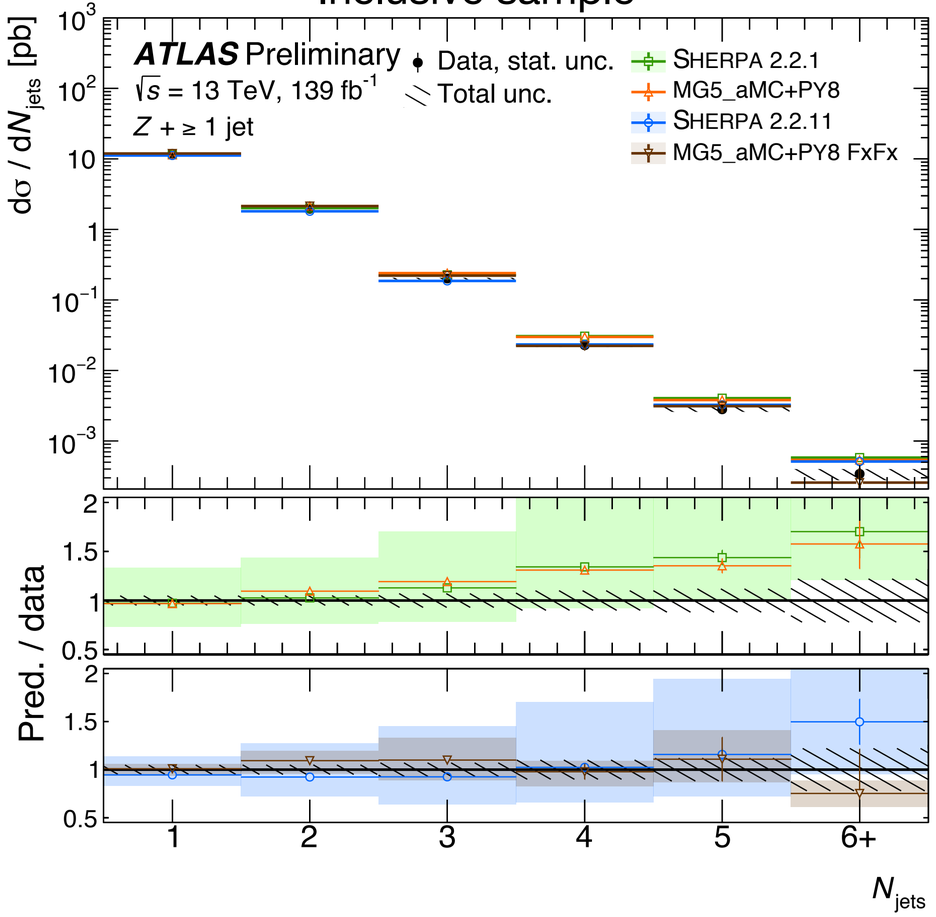


Results for collinear Z + jets

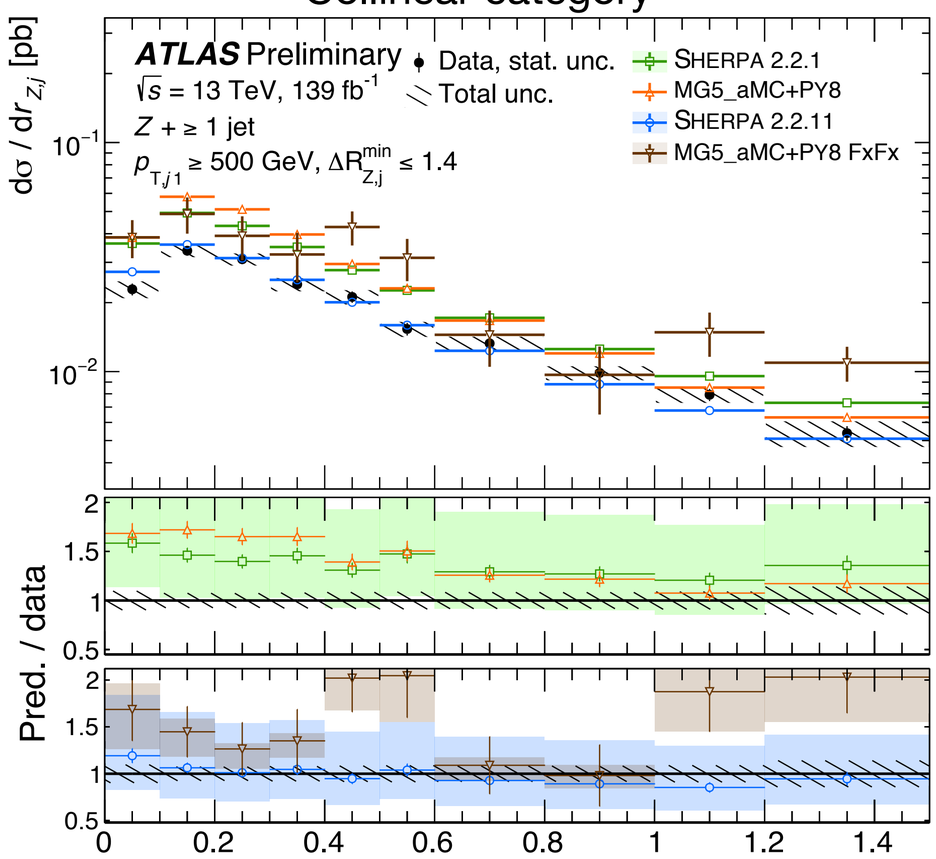
- Sherpa 2.2.11 (0-2p NLO, 3-5 LO) and MGPy8 FxFx (0-3p NLO) describe well N_{jets}
- Good modelling of $p_T(Z)/p_T(jet)$ by Sherpa
- Syst. uncert. on predictions dominated scale uncert.

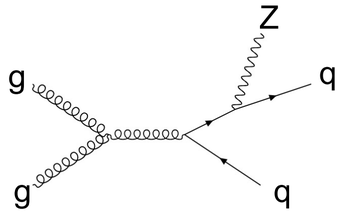
NEW! for EPS

Inclusive sample



Collinear category



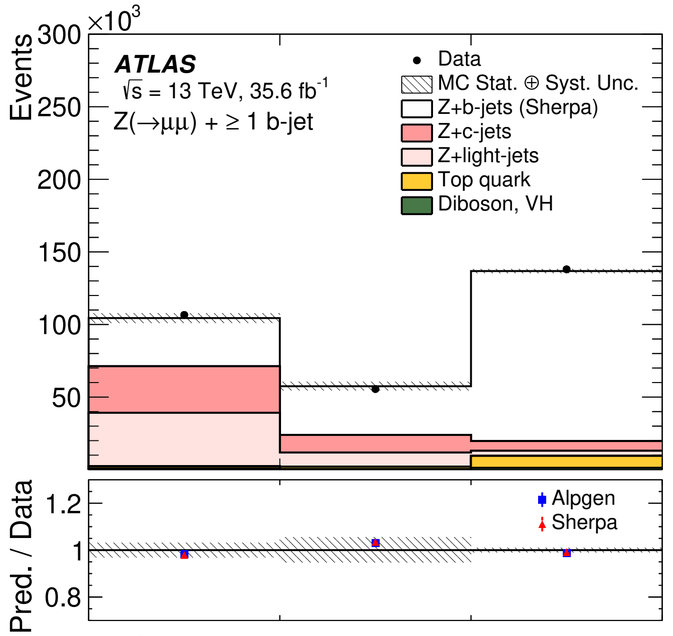


$\longrightarrow \frac{p_T(Z)}{p_T(\text{jet})}$

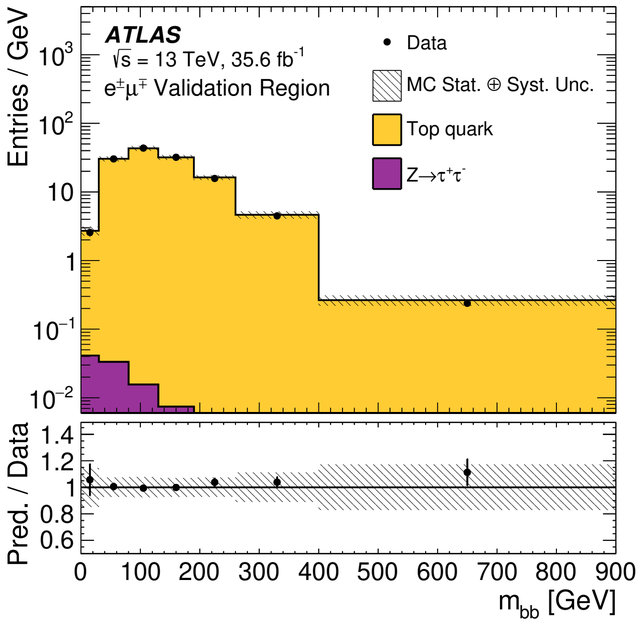
Z + 1 or 2 b-jets

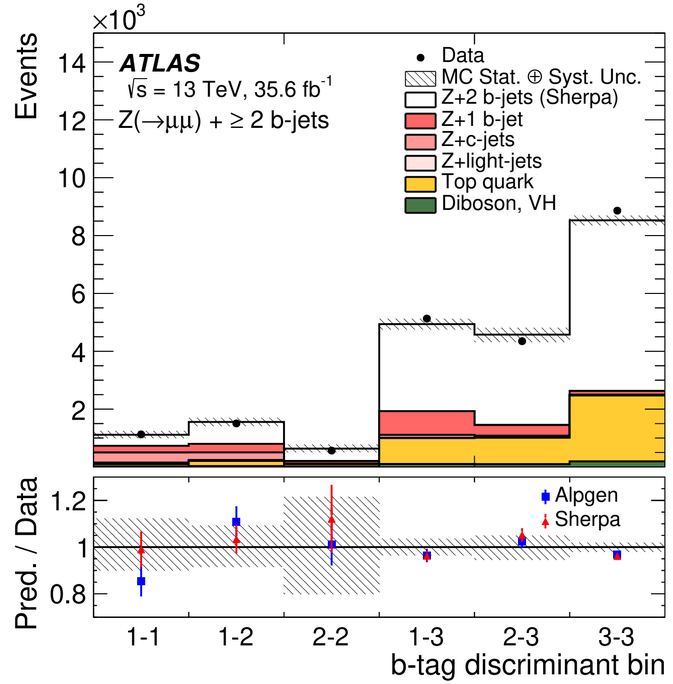
- Z + at least 1 or 2 b-jets ($p_T^{b\text{-jet}} > 20$ GeV)
- Main backgrounds: Z+jets for 1b-jet cat., and ttbar for 2b-jet cat.
- Main uncertainties: b-tagging efficiency and mis-tag rate

Z+jets estimation fitting flavor discriminant distribution



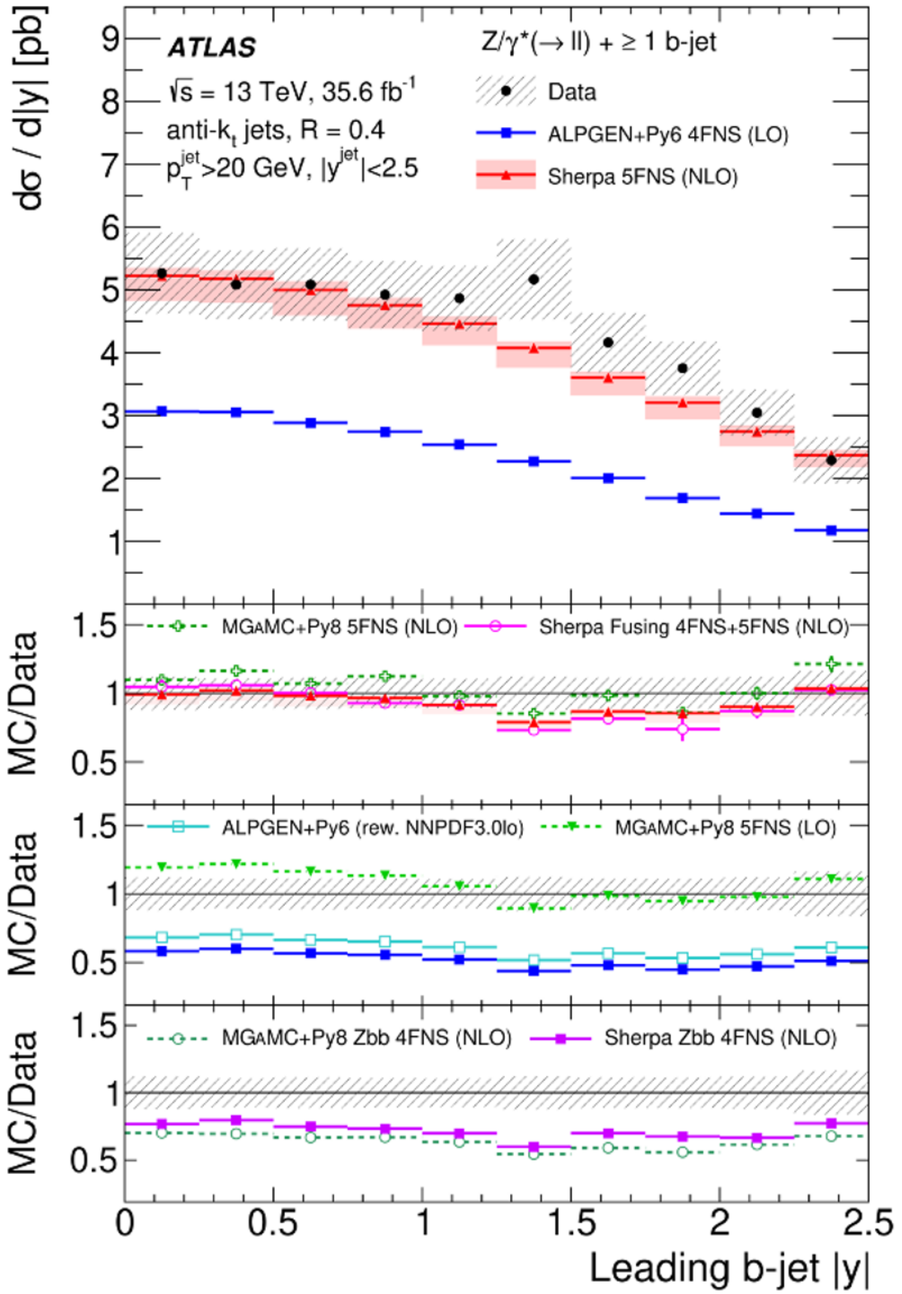
ttbar estimated with MC + data validation region



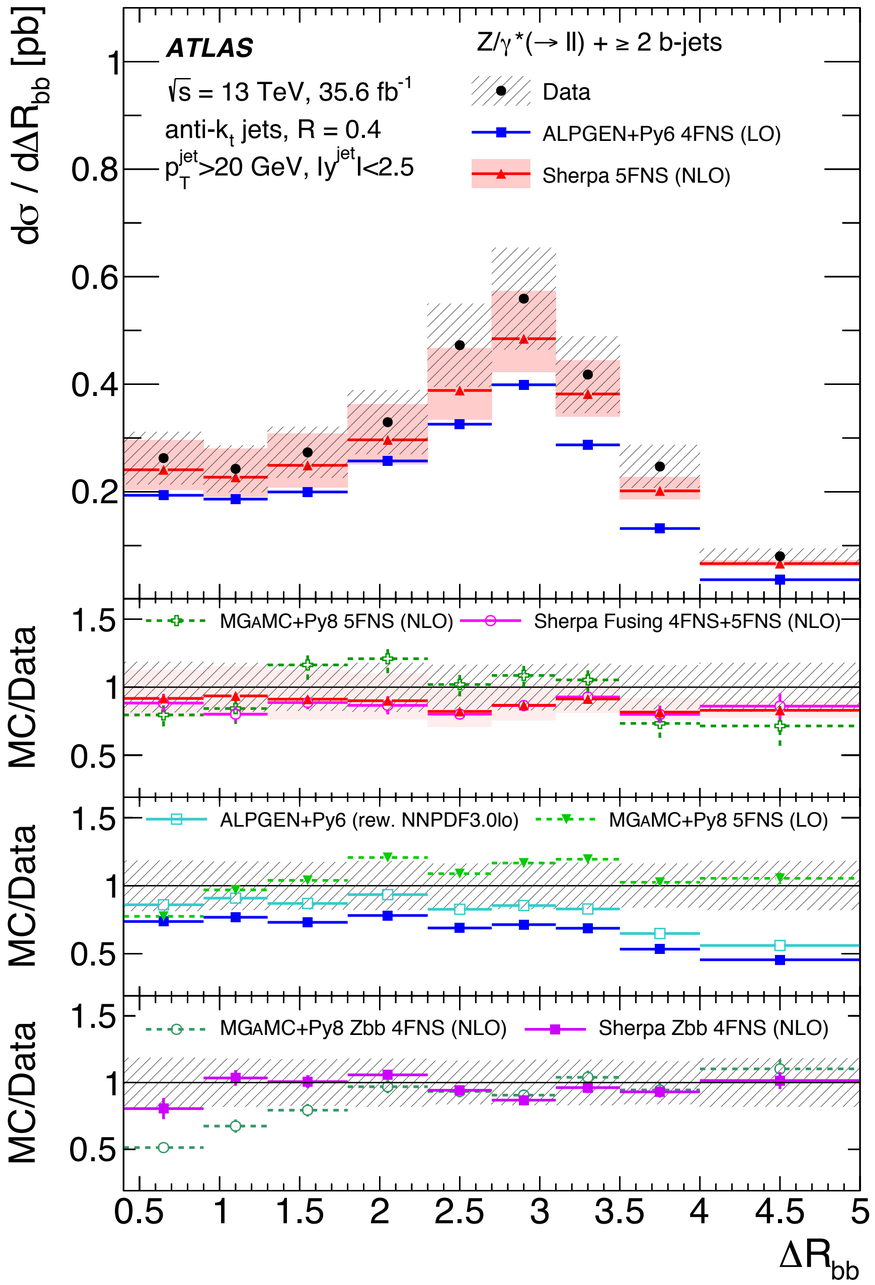


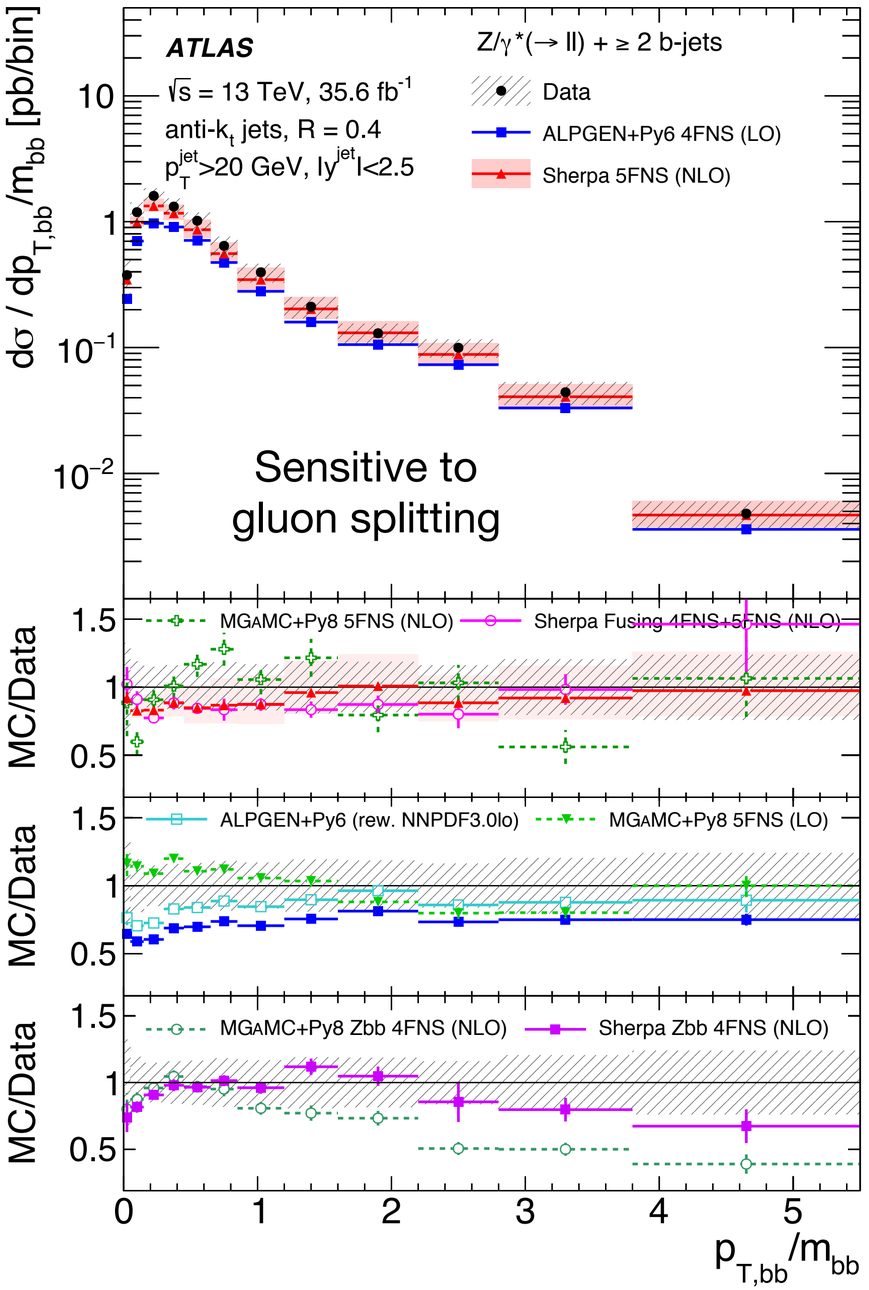
Z + 1 b-jet

- Shows the need
  for 5-flavor number scheme



Z+2 b-jets





Sherpa shows significant improvement at low ΔR_{bb} compared to previous comparisons

Conclusion

Showed our recent progress on understanding QCD
both from theory and experimental perspectives,
using photons and Z bosons as tool
in ATLAS