Probes of pQCD with vector bosons, photons and jets at ATLAS

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on behalf of the ATLAS collaboration

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Outline

Measurements presented here focus on two topics:

- Heavy Flavor production in association with Z-bosons
  - $Z+\geq 1$ and ≥ 2 $b-$jet cross sections and differential distributions
- Measurement of isolated-photon plus two-jet production
  - Distributions for direct and fragmentation enhanced regions
  - Angular correlations and invariant mass distributions for jj, γj and γjj

Additional measurements presented in other QCD sessions:

- Precision probes of jet substructure
  - see Matt LeBlanc Wed 15:21
- $Z \to \ell^+\ell^-$ cross section and p_T Distribution
  - see Alexis Vallier Mon 15:00

b-Jet production in association with Z bosons

arXiv:2003.11960

- $Z + b$-jet production important test of pQCD
- Calculations to NLO accuracy
- Both 4 and 5 flavor number scheme (FNS) approaches available
  - 5FNS uses initial b-quark PDF: massless b
  - 4FNS b-quarks from gluon splitting: massive b possible
- Benchmark process for testing performance of MC generators
- Important background to many BSM searches
- Compare performance of calculations in both schemes and for different generators
  - Both ≥ 1 and ≥ 2 tagged b-jet selections
  - Unfolded differential distributions for a large number of kinematic variables
- Show only subset of available distributions here

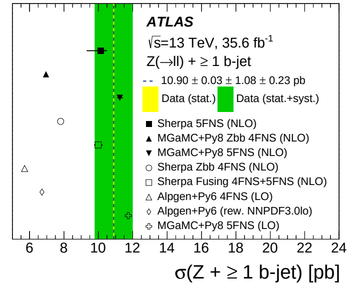
$Z + b$-jet Fiducial Cross Sections

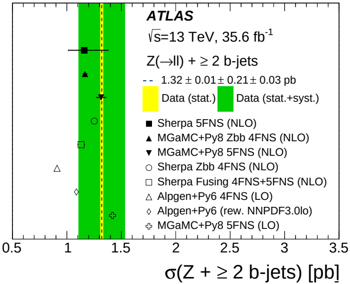
arXiv:2003.11960

- Fiducial region:
  - $p_T^\ell > 27$ GeV
  - $|\eta^\ell| < 2.5$
  - $m_{\ell\ell} = 91 \pm 15$ GeV
  - p_T b-jet > 20 GeV
  - $|y|$ b-jet < 2.5
  - $\Delta(Rb - jet, \ell) > 0.4$
- MC Configurations:

Generator	$N_{max}^{partons}$ NLO	$N_{max}^{partons}$ LO	FNS	PDF set	Parton Shower
Z+jets (including $Z+b$ and $Z+bb$)					
Sherpa 5FNS (NLO)	2	4	5	NNPDF3.0nnlo	Sherpa
Sherpa Fusing 4FNS+5FNS (NLO)	2	3	5 (*)	NNPDF3.0nnlo	Sherpa
Alpgen + Py6 4FNS (LO)	-	5	4	CTEQ6L1	Pythia v6.426
Alpgen + Py6 (rew. NNPDF3.0lo)	-	5	4	NNPDF3.0lo	Pythia v6.426
MGaMC + Py8 5FNS (LO)	-	4	5	NNPDF3.0nlo	Pythia v8.186
MGaMC + Py8 5FNS (NLO)	1	-	5	NNPDF3.0nnlo	Pythia v8.186
$Z+bb$					
Sherpa Zbb 4FNS (NLO)	2	-	4	NNPDF3.0nnlo	Sherpa
MGaMC + Py8 Zbb 4FNS (NLO)	2	-	4	NNPDF3.0nnlo	Pythia v8.186

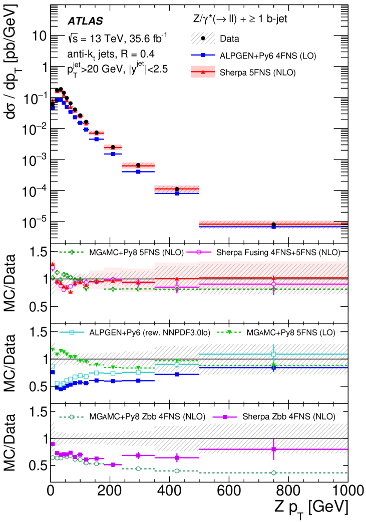
- Observations:
  - 4FNS underestimates $\sigma(Z+ \geq 1b)$ but is consistent with data for $\sigma(Z+ \geq 2b)$
  - 5FNS predicts σ in both regions

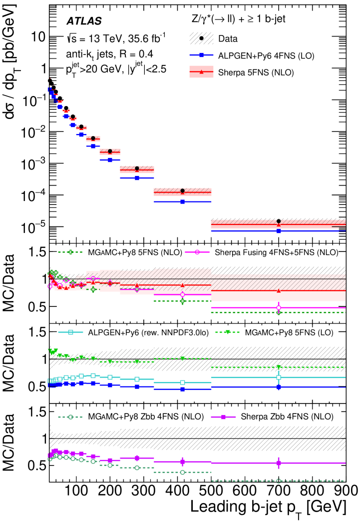




$Z+\geq 1$ b-jet kinematic distributions

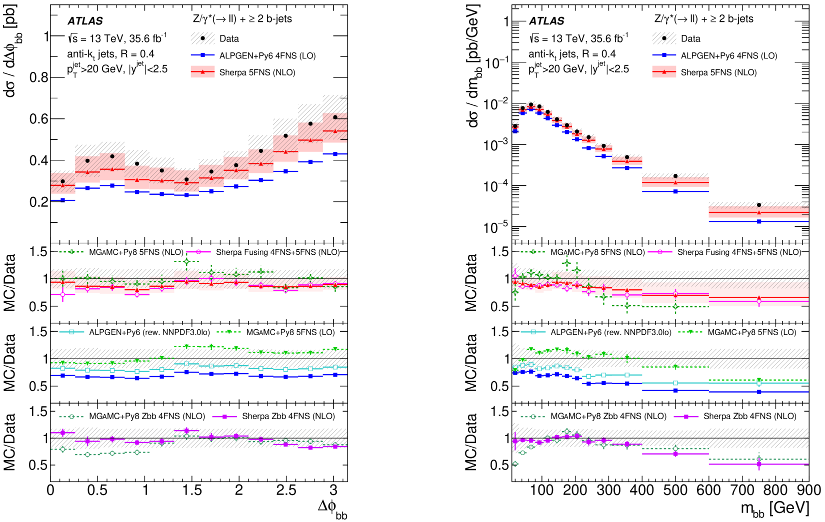
arXiv:2003.11960





$Z+\geq 2$ b-jet kinematic distributions

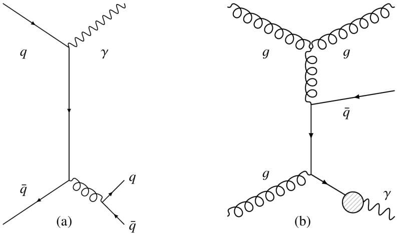
arXiv:2003.11960



$Z + b$-jets: Summary of Observations

- In general, 5FNS NLO calculations predict inclusive cross section, while 4FNS LO underestimate rate
- Multi-leg calculations model region of large p_T^b better than NLO+PS
- SHERPA NLO 5FNS with up to two partons at NLO merged with up to 4 partons at LO describes most differential distributions within experimental uncertainties
- All generators disagree with data at large m_{bb}

Photon+2 jet Production



- Prompt photon + two-jet production a rich system to test pQCD
- Angular correlations between final state objects probe dynamics of hard scattering
- Two production mechanisms at LO (doesn't factorize at NLO)
  - Photons from the hard scatter
  - Photons from fragmentation

$\gamma + 2$-jet definition of fiducial regions

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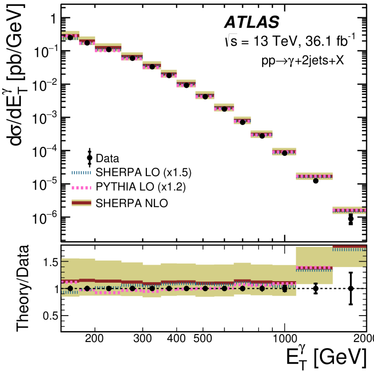
- Fiducial requirements:
  - $E_T^{\gamma} > 150$ GeV
  - $|\eta^{\gamma}| < 2.37$(exclude $(1.3 < |\eta^{\gamma}| < 1.56)$
  - $E_T^{iso} < 0.0042 \cdot E_T^{\gamma} + 10$ GeV
  - $p_T^{jet} > 100$ GeV
  - $y^{jet} < 2.5$
  - $\Delta R^{\gamma-jet} > 0.8$
- Comparison with 3 predictions:
  - Pythia 8.186 (LO) with LO NNPDF2.3 pdf
  - Sherpa 2.1.1 (merged LO; $2 \rightarrow n,\ n = 2-5$ with NLO CT10 pdf
  - Sherpa 2.2.2 (merged $\gamma + (1,2)$-jets at NLO and $\gamma + (3,4)$-jets at LO) with NNLO NNPDF3.0 pdf
- LO calculations displayed with k-factors
- Filled bands: NLO theoretical uncertainty



- Can identify regions where direct and fragmentation contributions are enhanced
- Fragmentation enriched region: $E_T^{\gamma} < E_T^{jet2}$
- Direct enriched region: $E_T^{\gamma} > E_T^{jet1}$

$\gamma + 2$ jets: Photon and Jet Kinematics

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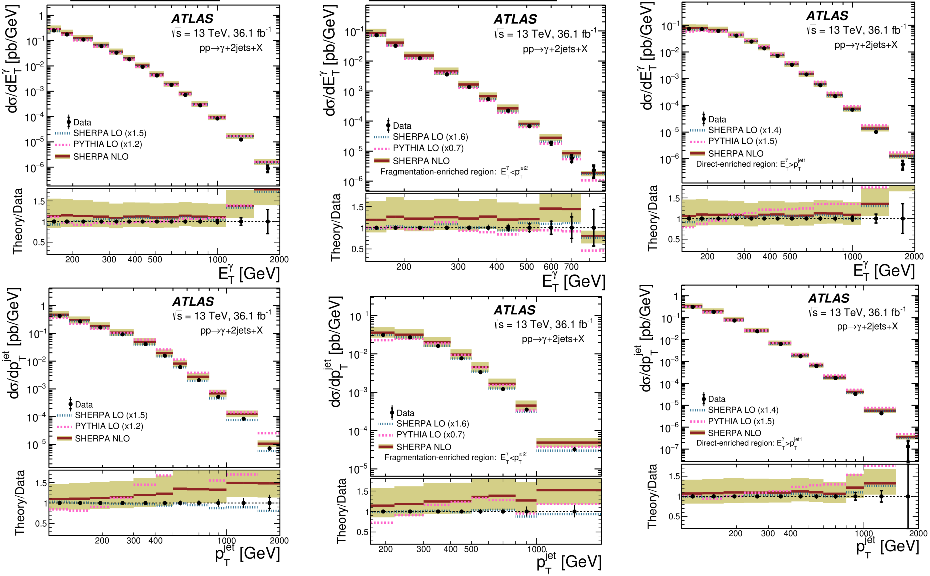
Total Phase Space | Fragmentation Enriched | Direct Enriched



$\gamma + 2$ jets: $\Delta\phi^{jj}$ and Δy^{jj}

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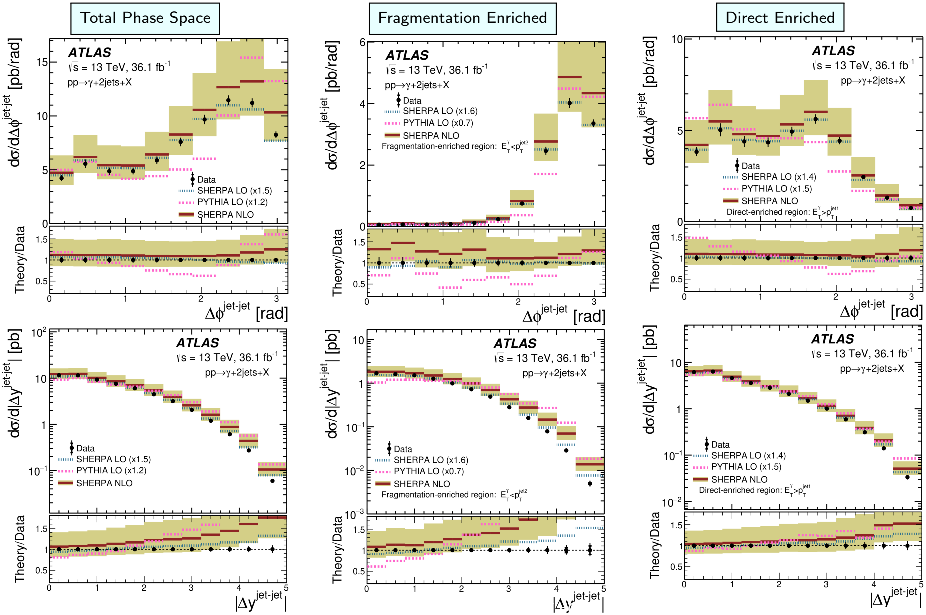

$\gamma + 2$ jets: m^{jj} and $m^{\gamma jj}$

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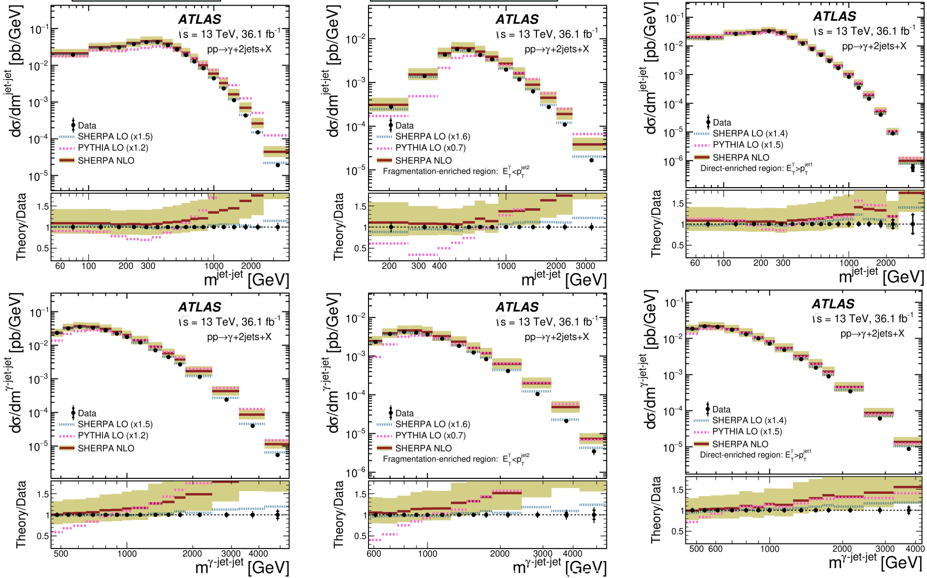
Total Phase Space | Fragmentation Enriched | Direct Enriched



Photon+2 jet Summary of Results

- Measured distributions in direct and fragmentation enhanced regions exhibit features expected from the two underlying processes
- Tree level LO SHERPA gives a good description of shape of data except at high E_T^γ, $|\Delta y^{jj}|$ and $m^{\gamma jj}$
- PYTHIA8 (where sub-leading jet originates from parton shower) does not describe the distributions well
- NLO SHERPA describes data adequately both in shape and normalization except at high E_T^γ, $|\Delta y^{jj}|$ and $m^{\gamma jj}$
  - Although LO SHERPA reproduces the shapes better
- Theoretical uncertainties rather than experimental ones dominate

Conclusions

- Recent ATLAS results on jets, photons and bosons probe pQCD with high precision
- $Z+\geq 1b$-jet and $\geq 2b$-jet kinematic distributions probe sensitivity of prediction to flavor number scheme
- Prompt photon + 2 jet measurements test NLO calculations in regions where direct and fragmenation photons dominate
- Ability of theoretical calculations and MC generators to model complex QCD systems is in general good, but some discrepancies with data remain
- Wide range of observables available to tune MC generators and to explore regions where theoretical calculation are difficult or problematic