Measurements of vector boson production in association with jets with the ATLAS detector

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On behalf of the ATLAS Collaboration

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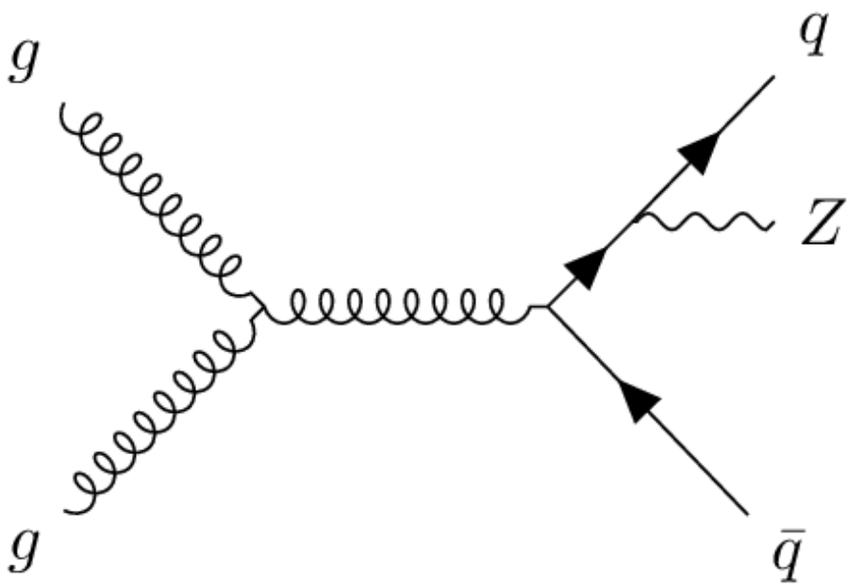
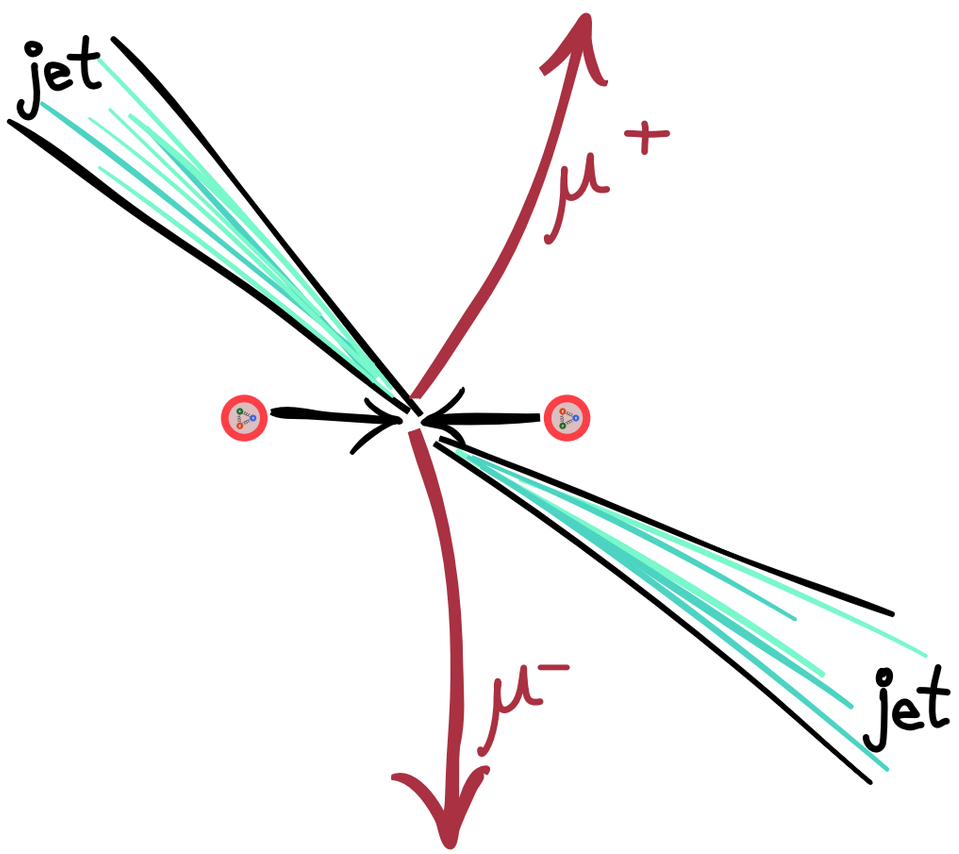
ATLAS EXPERIMENT

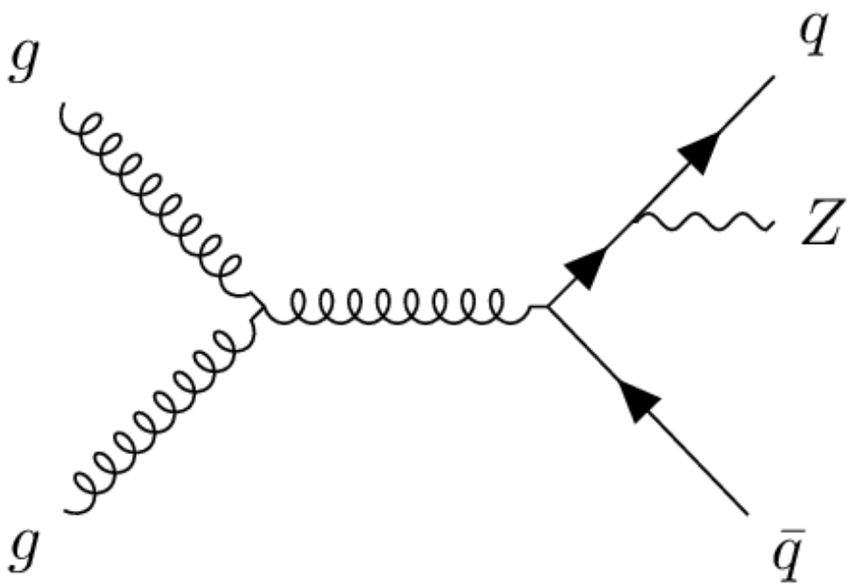
University of Victoria

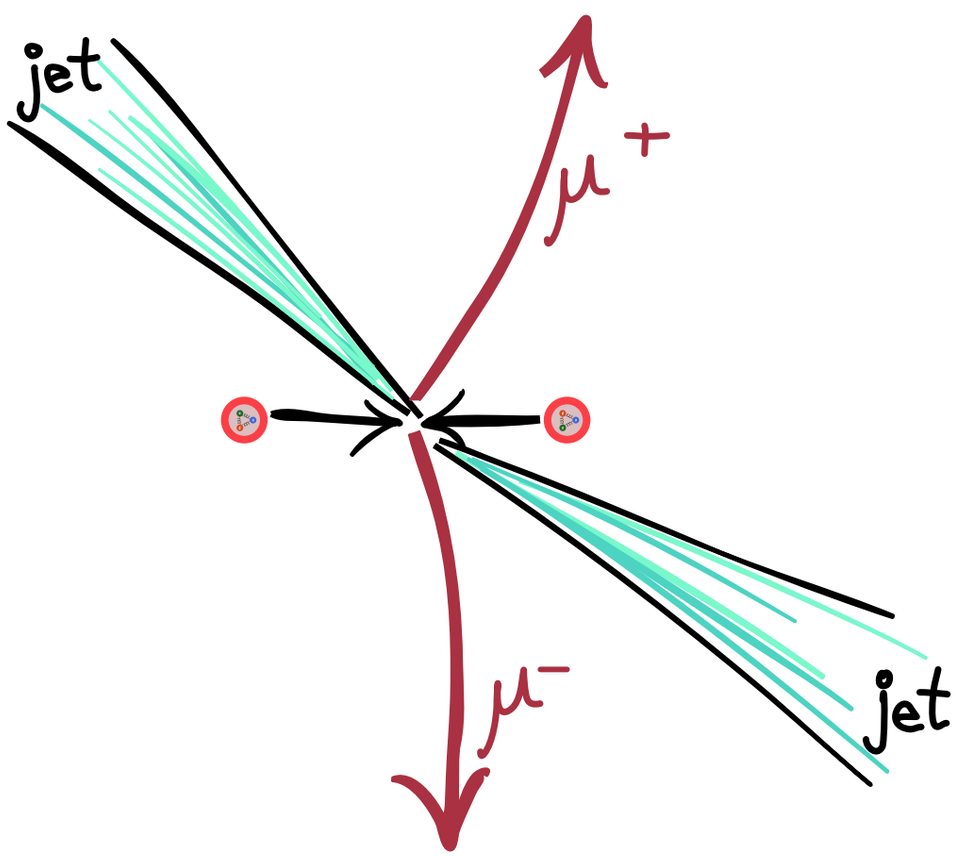
Vector bosons in association with jets

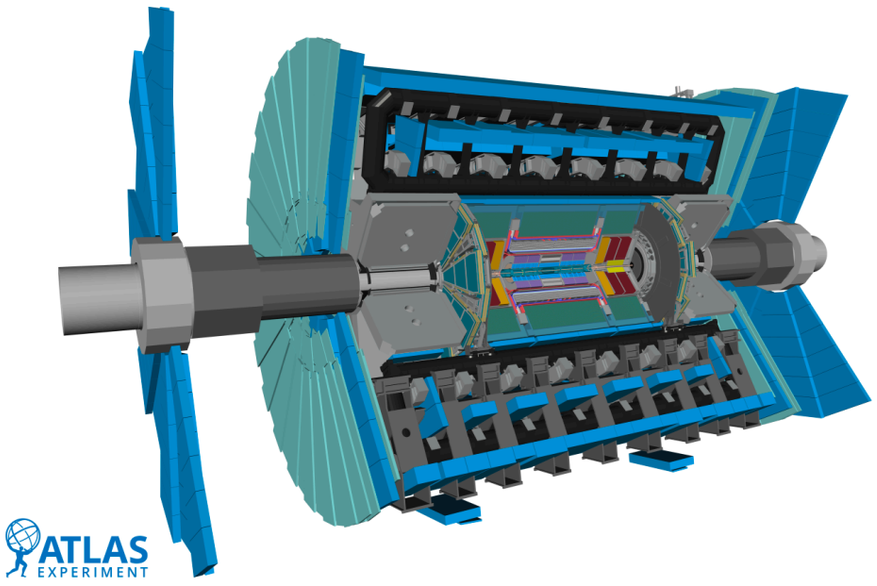




Vector bosons in association with jets



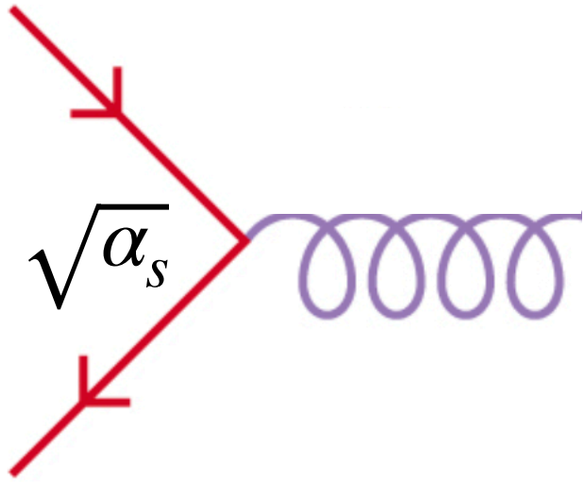




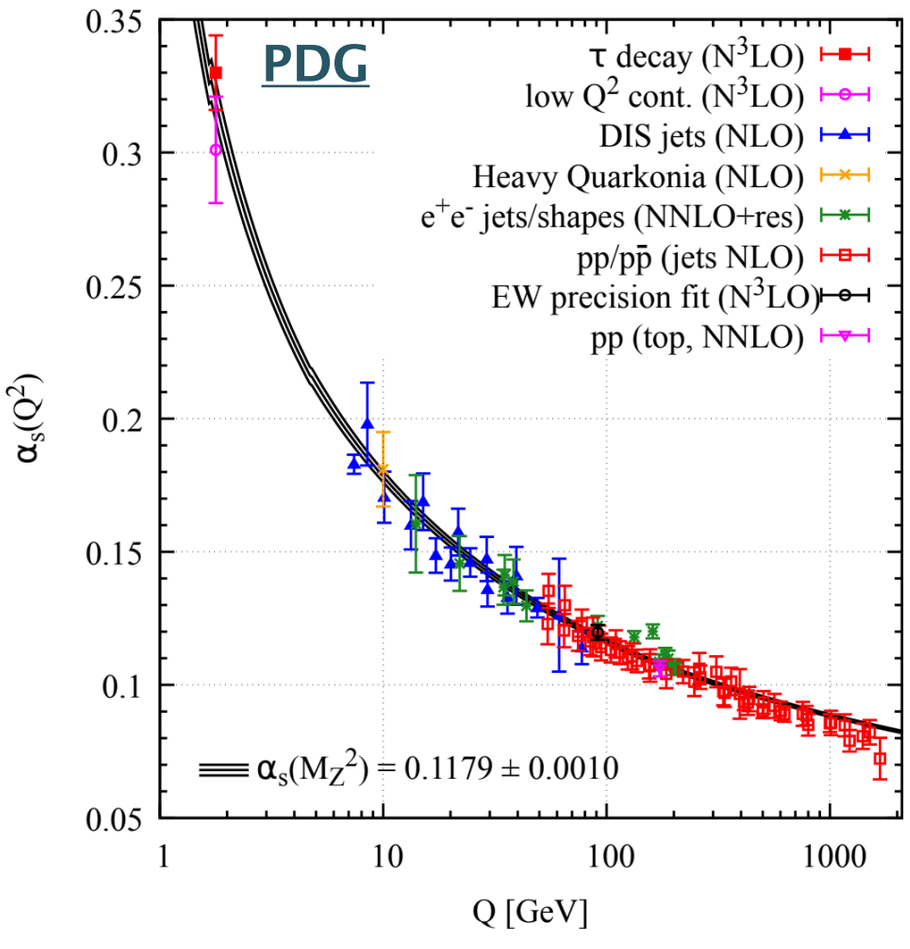
(with the ATLAS detector)

What does measuring these events tell us?

Interactions in quantum chromodynamics (QCD) have a coupling strength α_s:

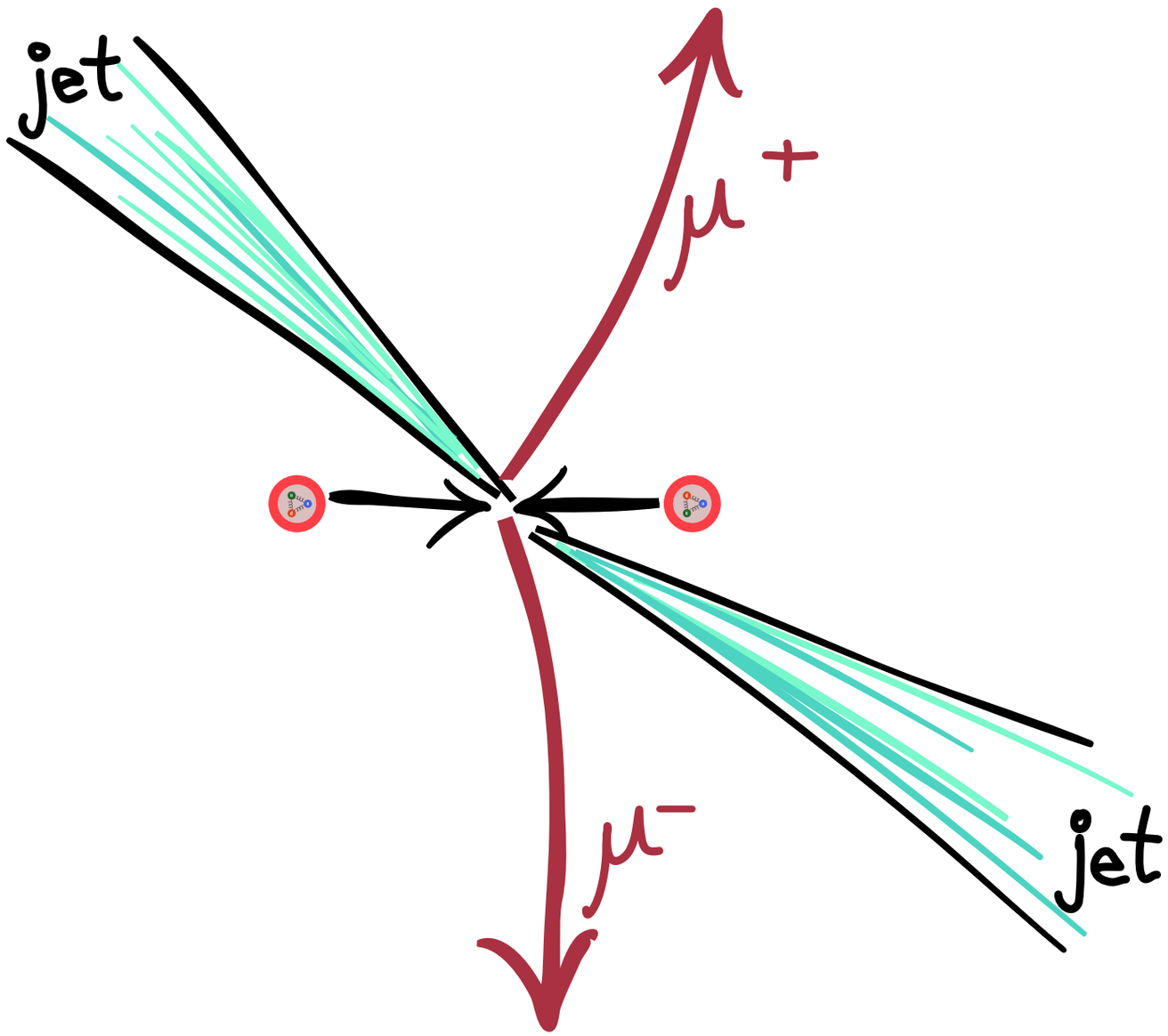


α_s depends on energy:



@ low energy, α_s large (confinement)
⇒ non-perturbative

@ high energy, α_s small (asymptotic freedom)
⇒ **perturbative regime of QCD**



Z + jets

Z boson decaying leptonically ($2e/2\mu$)

Jets with p_T > 100 GeV

High-p_T region:

Jet p_T > 500 GeV

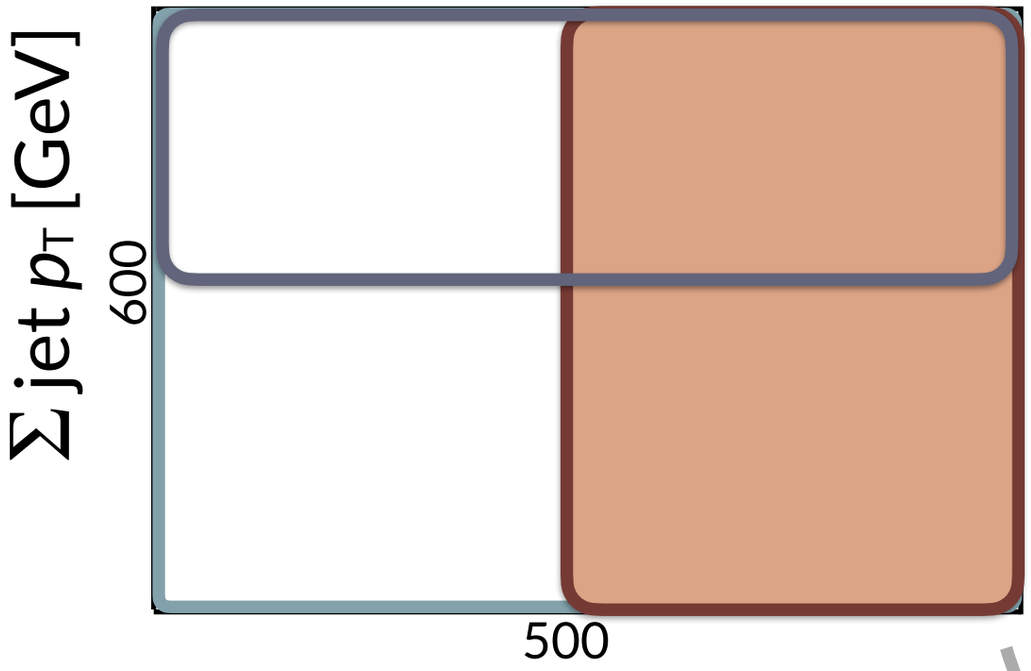
High-S_T region:

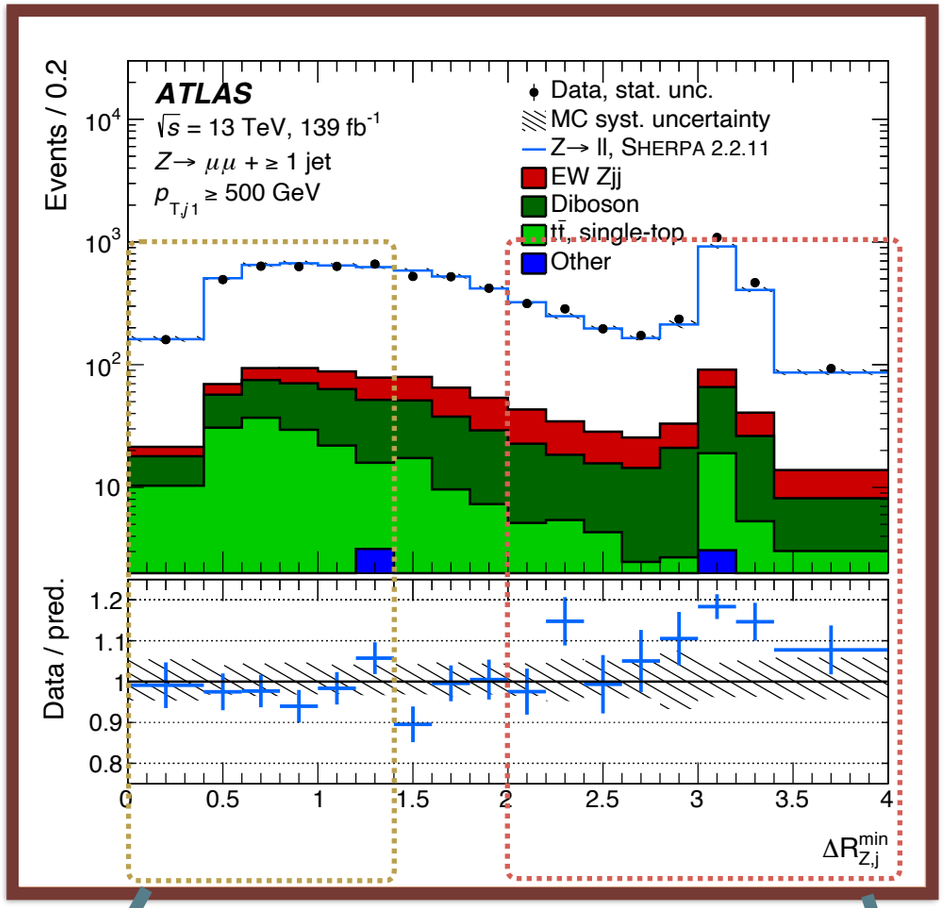
Scalar sum (jet p_T) > 600 GeV

arXiv:2205.02597

Z+jets: Measurement setup

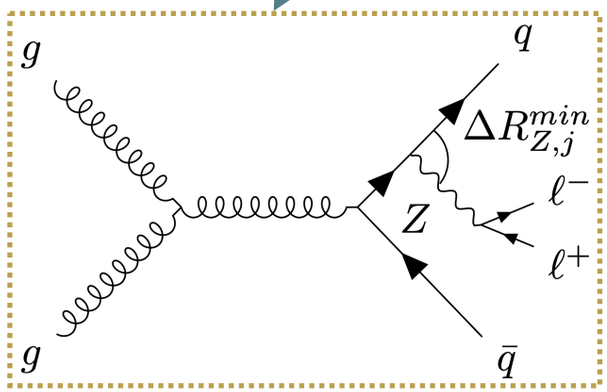
arXiv:2205.02597

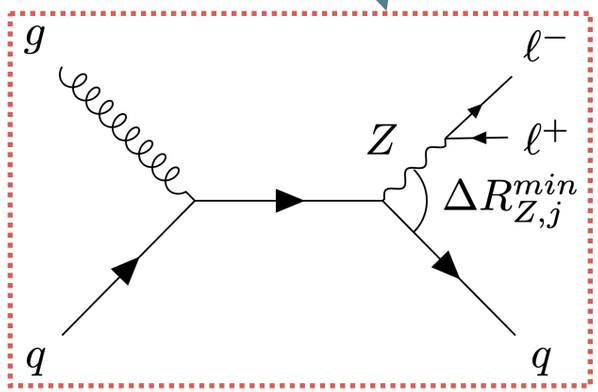




Collinear

Back-to-back





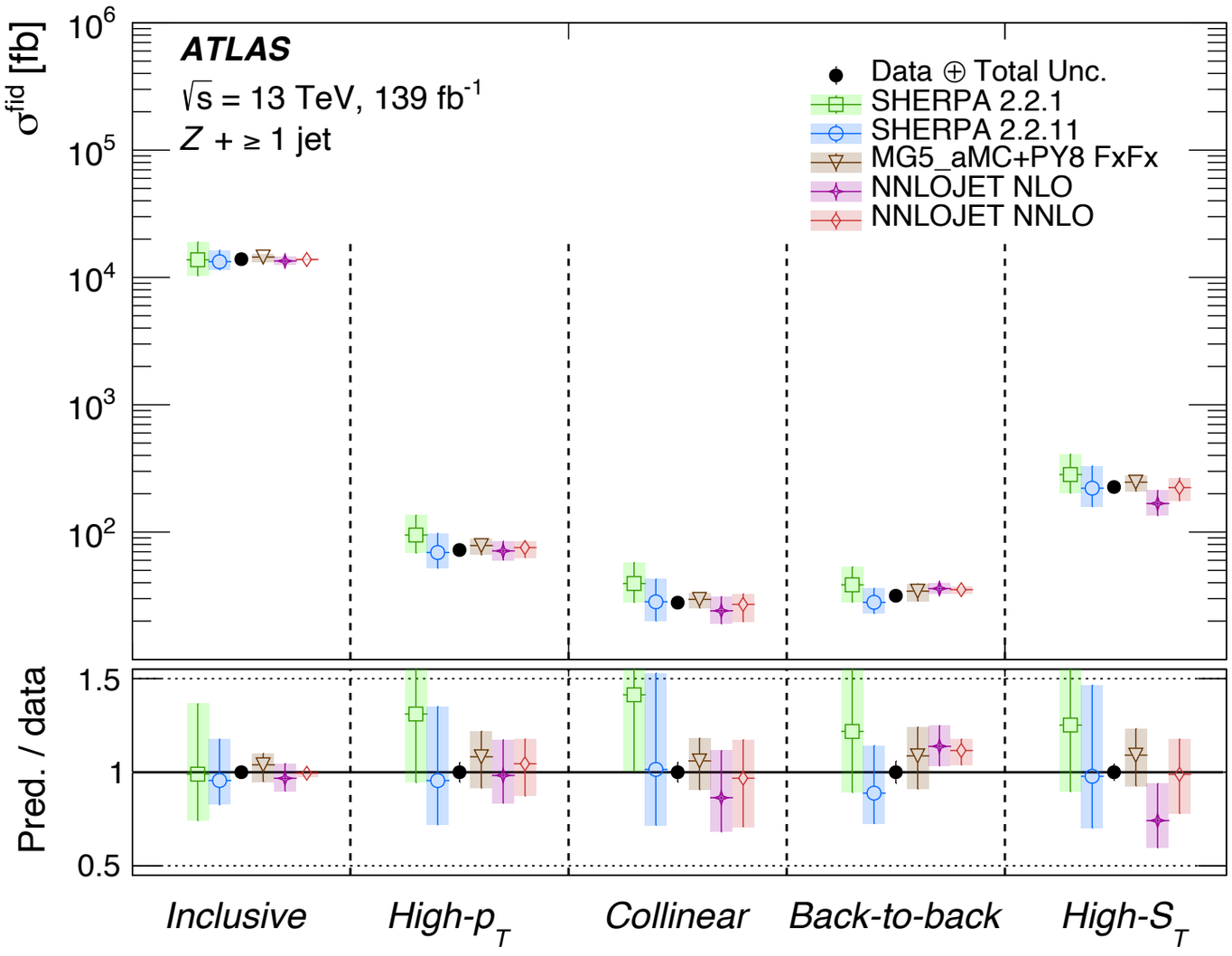
Five analysis regions

Inclusive region

- **High-p_T region**
  - **Collinear region**
  - **Back-to-back region**
- **High S_T region**

Z+jets: results

arXiv:2205.02597



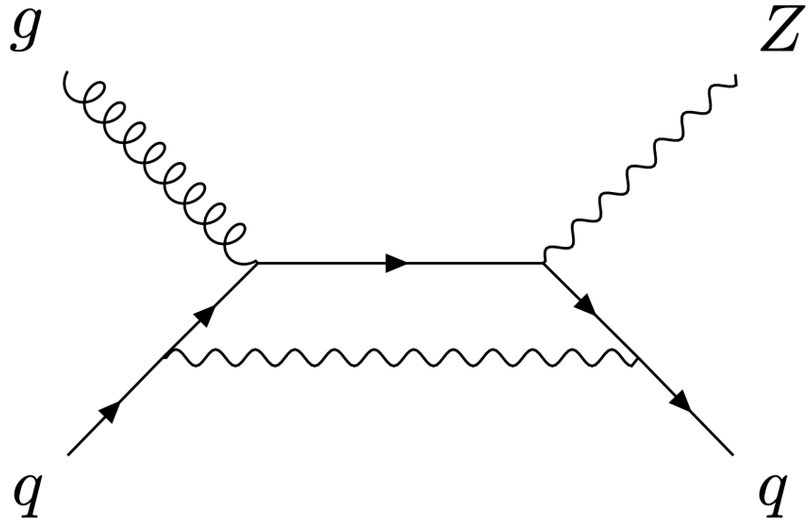
Inclusive cross-sections show good agreement with various MC generators:

MG5_aMC+Py8 FxFx: NLO MadGraph very precise in all regions

Large **Sherpa** uncertainties from theoretical QCD scale uncertainties

Only **Sherpa 2.2.11** includes NLO virtual electroweak corrections

(Largest in the back-to-back region)



Z+jets: results

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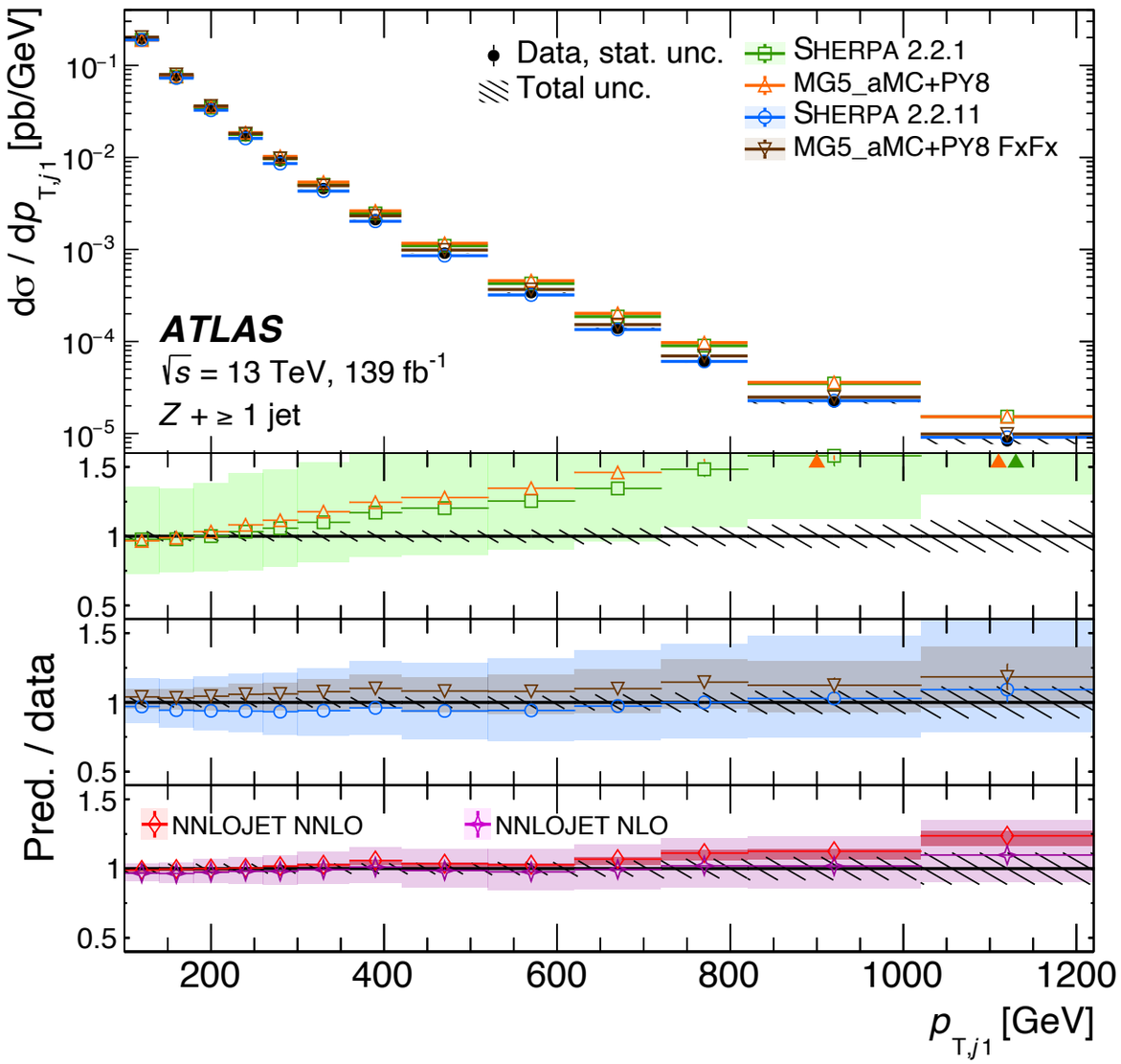
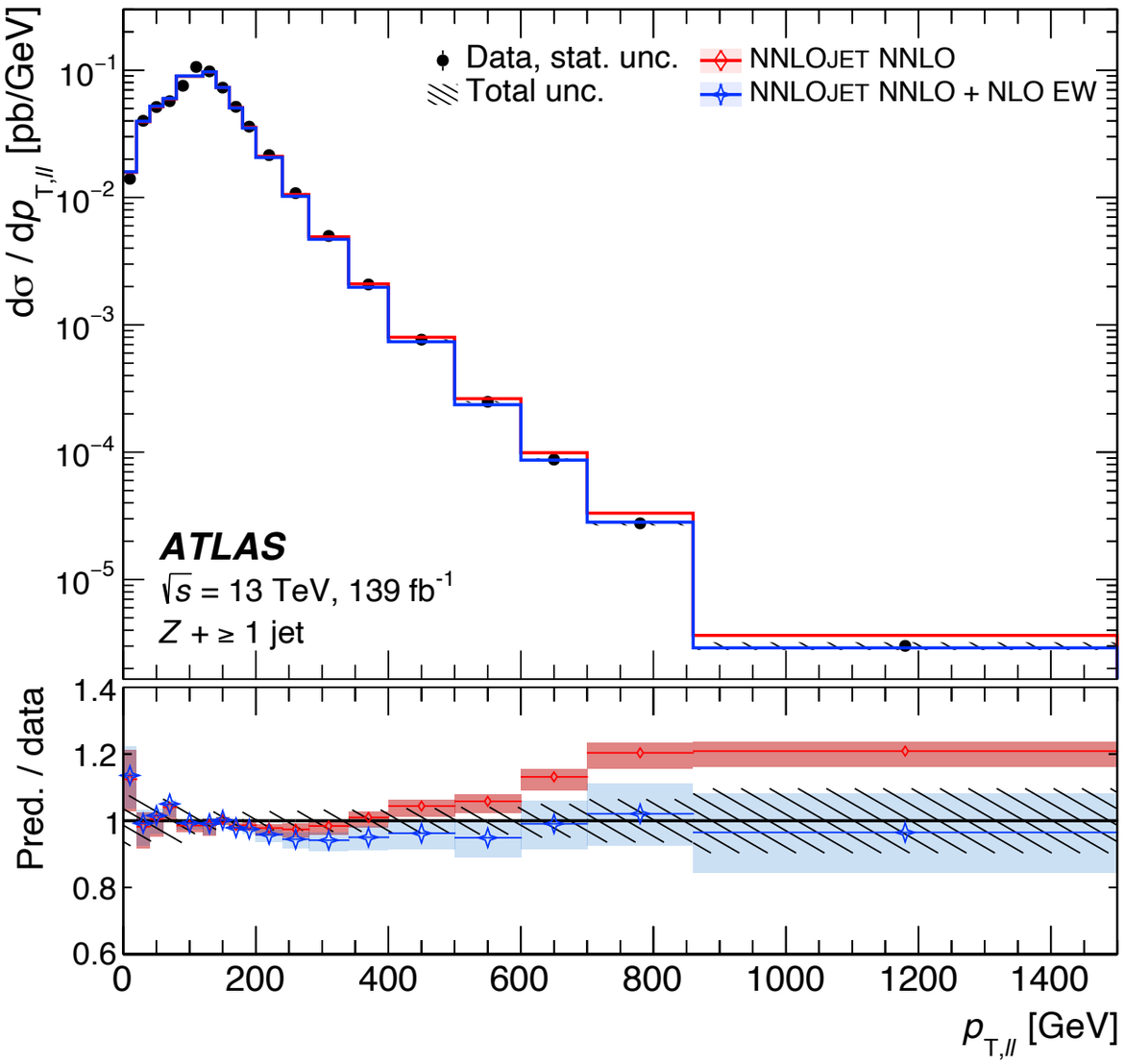
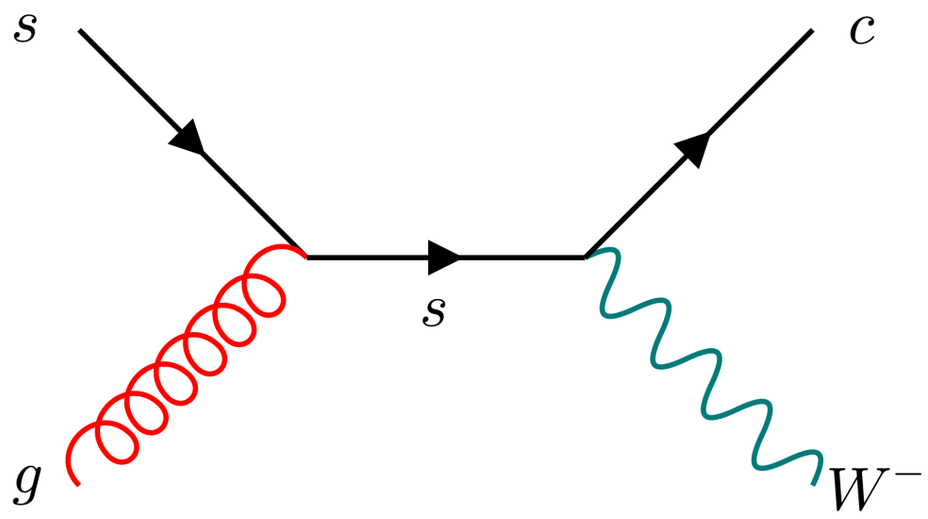


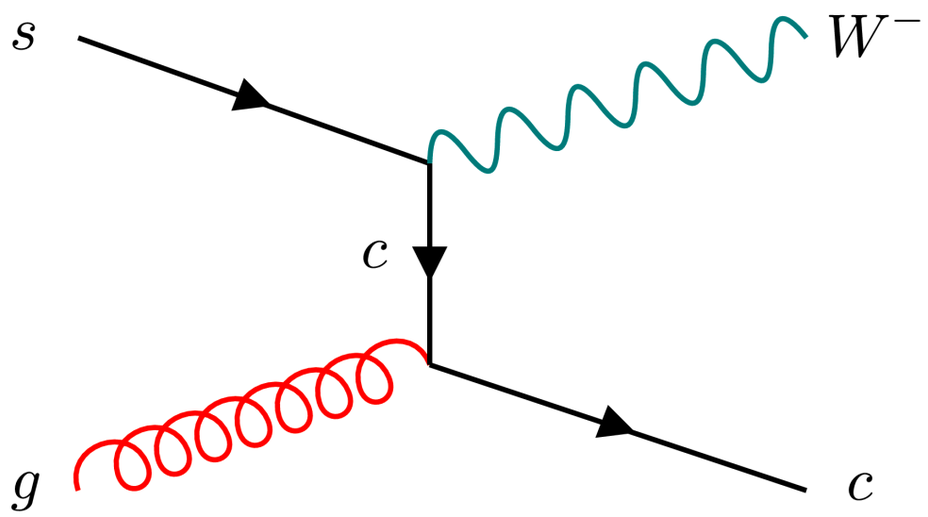
Nice agreement with **NLO** (and higher) predictions



NNLOjet @ NNLO (Z + 1 jet @ NNLO) provides a precise prediction

NLO virtual EW corrections extracted from **Sherpa2.2.11** and supplied to **NNLOjet @ NNLO:** excellent agreement





W + charm

W boson decaying leptonically ($e\nu/\mu\nu$)

$E_T^{miss} > 30$ GeV

$m_T(W) > 60$ GeV

Reconstructed D^+ or D^{*+} meson ($c\bar{d}$) from ID tracks

$D^+ \rightarrow K^-\pi^+\pi^+$

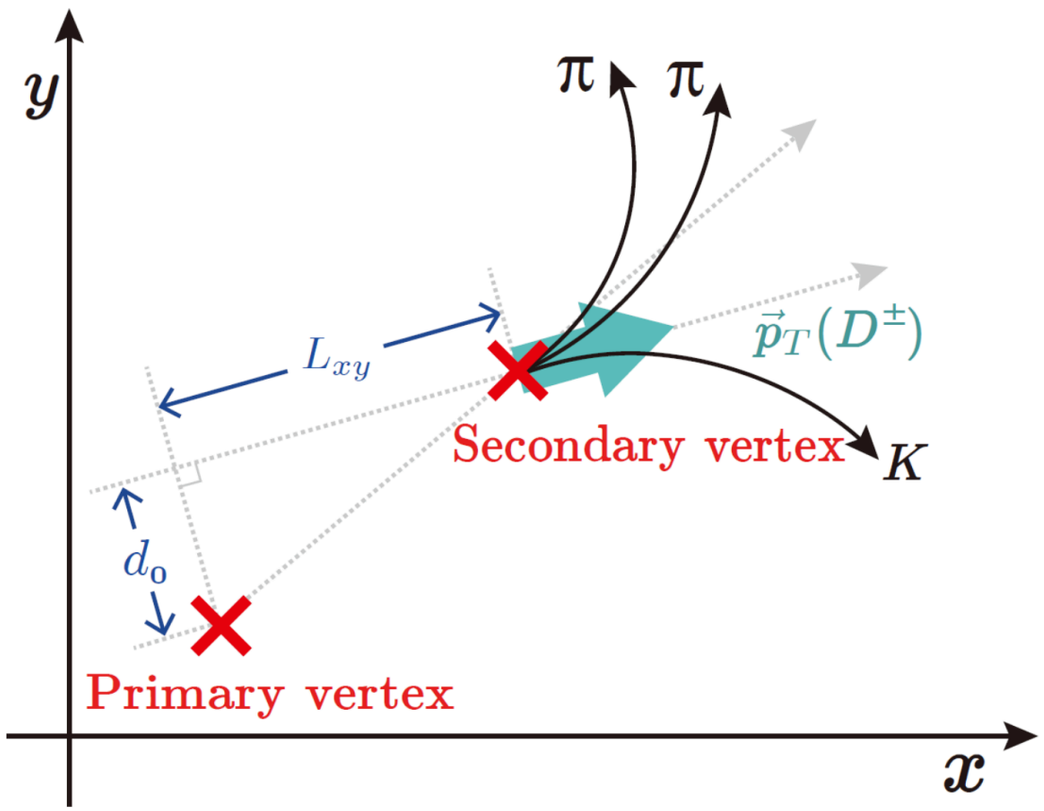
$D^{*+} \rightarrow D^0\pi^+ \rightarrow (K^-\pi^+)\pi^+$

arXiv:2302.00336

W+charm: Reconstructing $D^{+(*)}$ mesons

arXiv:2302.00336

D^+ meson



D^{*+} mesons decay promptly:

1. Reconstruct D^0 meson from $K^-\pi^+$
2. Combine with prompt tracks (π^+ candidates)
3. Check candidates against selection criteria

	D^+	D^{*+}
N_{tracks} @ SV	3	2
SV charge	± 1	0
D^0 selection	–	$\lvert m(K\pi) - m(D^0)\rvert < 40$ MeV
Invariant mass	$1.7 < m(D^+) < 2.2$ GeV	$140 < m(D^{*+} - D^0) < 180$ MeV
$D_s \to \pi\phi$ rejection	$m(K^+K^-) > \lvert m_\phi^{PDG} - 8\rvert$ MeV	–
D^* rejection	$m(K\pi\pi) - m(K\pi) > 160$ MeV	–
Semileptonic $B-$decay rejection	$\Delta R(D^{(*)}, \ell) > 0.3$	

W+charm: Signal extraction

arXiv:2302.00336

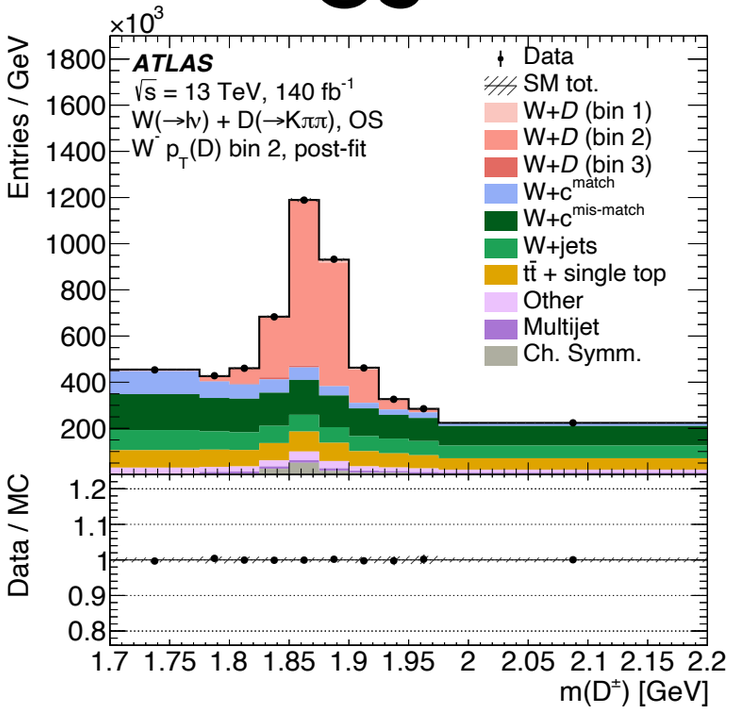
Signal events have an **opposite-sign (OS)** W boson and D meson

Backgrounds are predominantly charge-symmetric: same number of opposite-sign and same-sign (SS) events

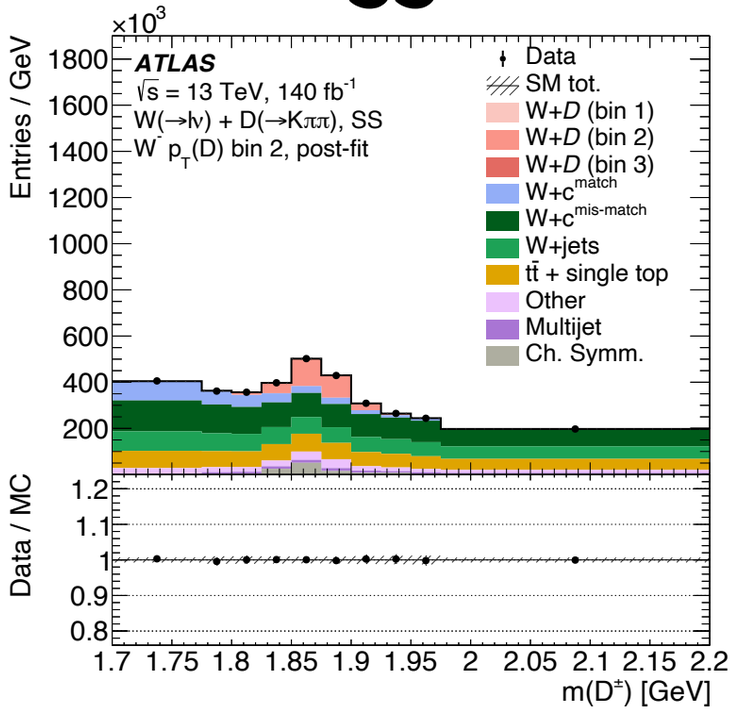
Binned profile likelihood fit of $m(D^{+})$ or $m(D^{*}\text{-}D^{0})$ in bins of pT or eta

Simultaneous fit to **SS and OS** templates; extract signal cross-sections in a background-subtracted OS-SS region

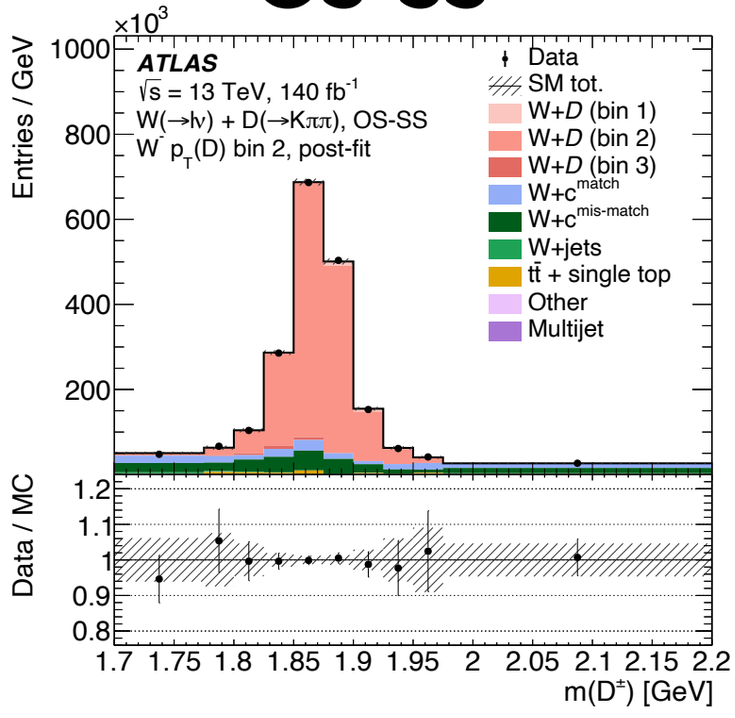
OS



SS

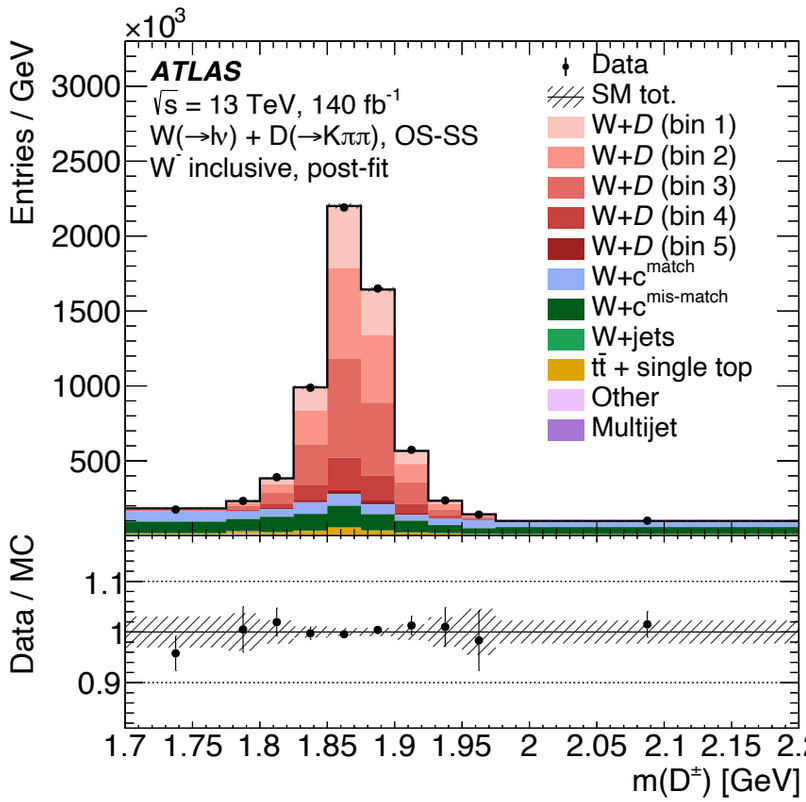


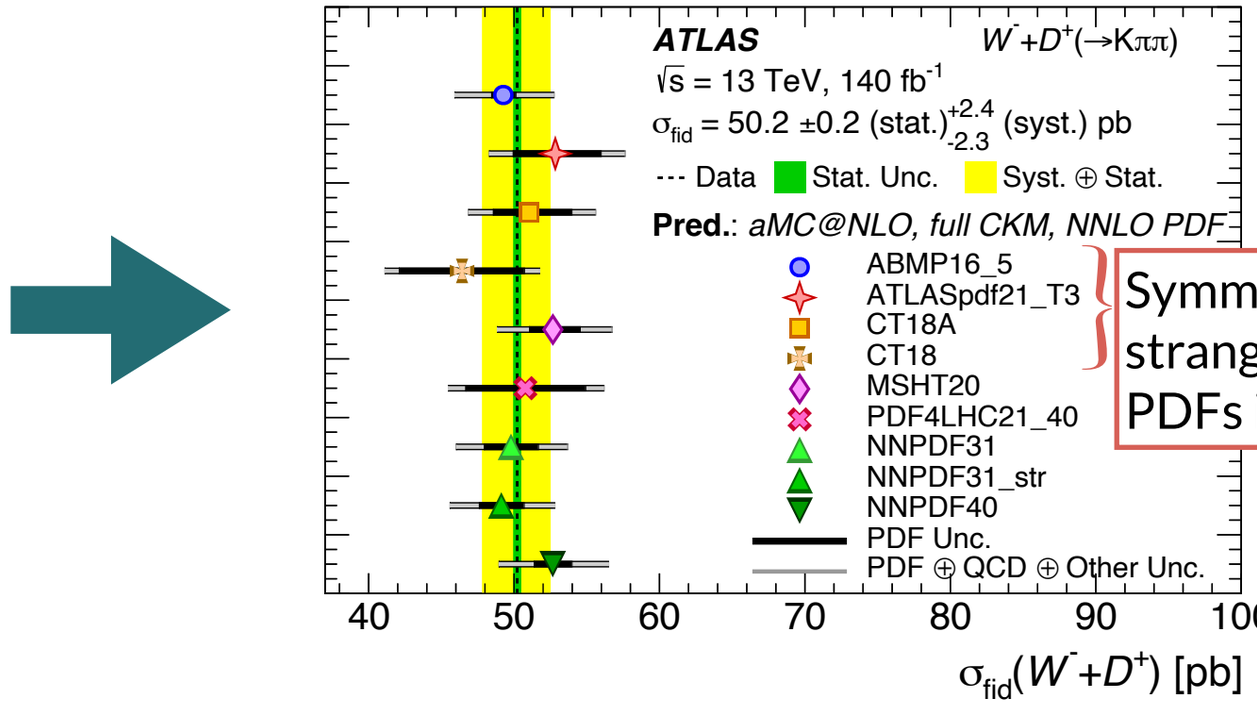
OS-SS



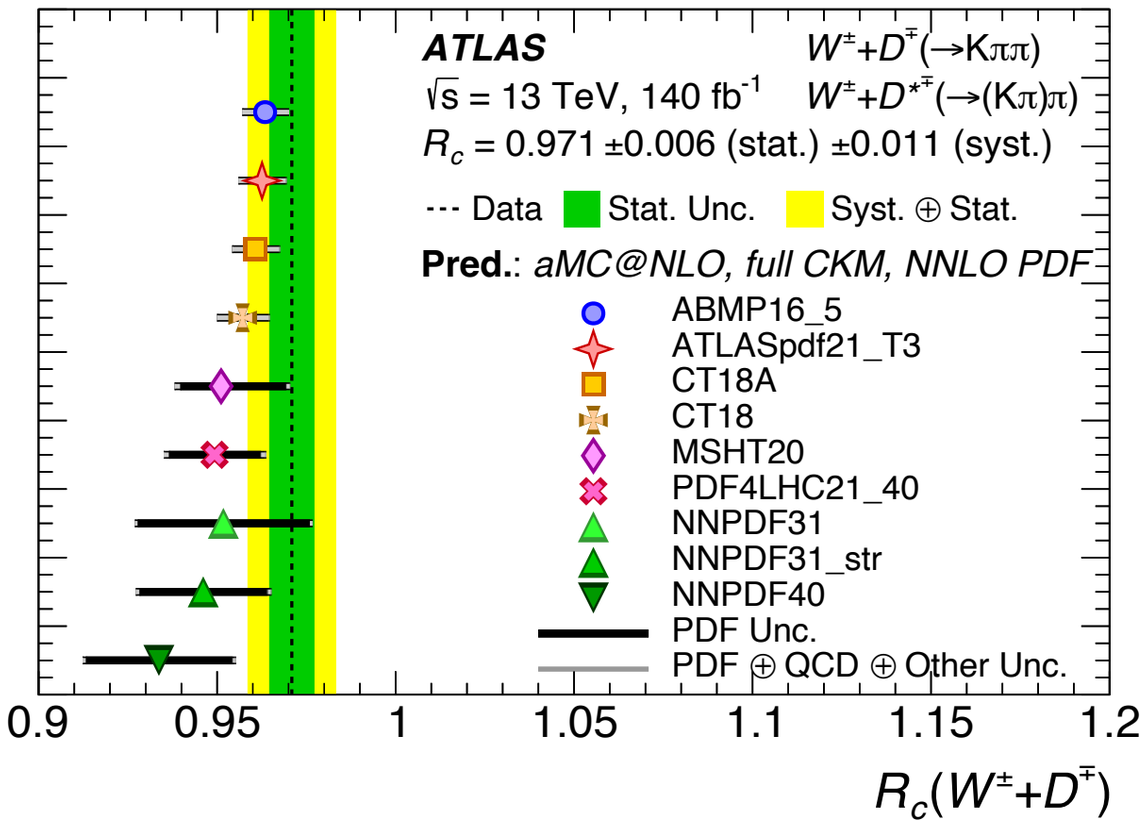
W+charm: Results

arXiv:2302.00336





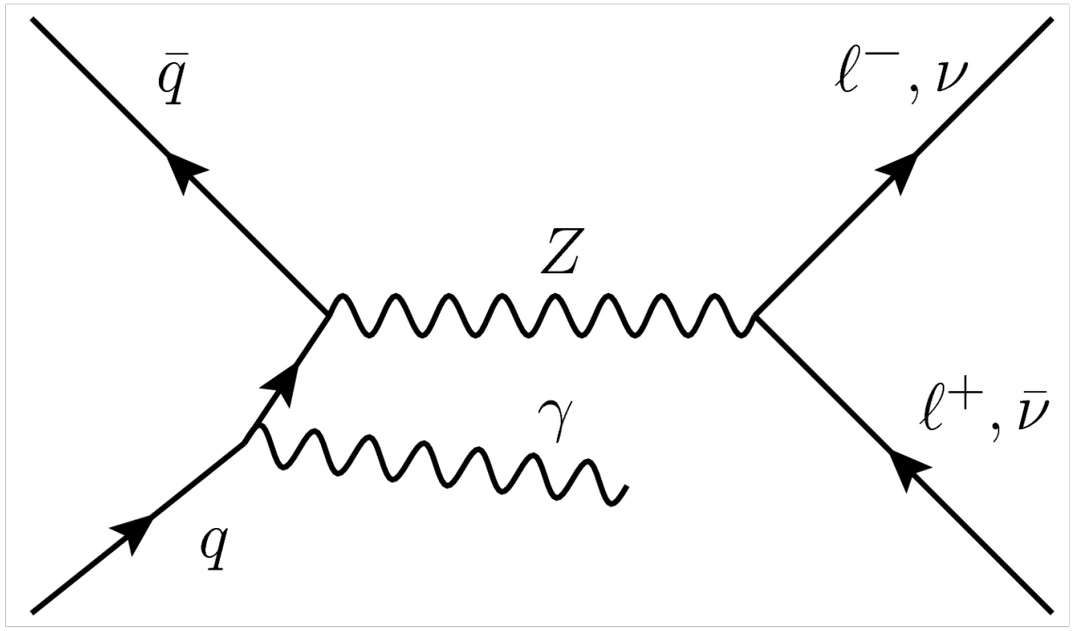
Symmetric strange-sea PDFs imposed



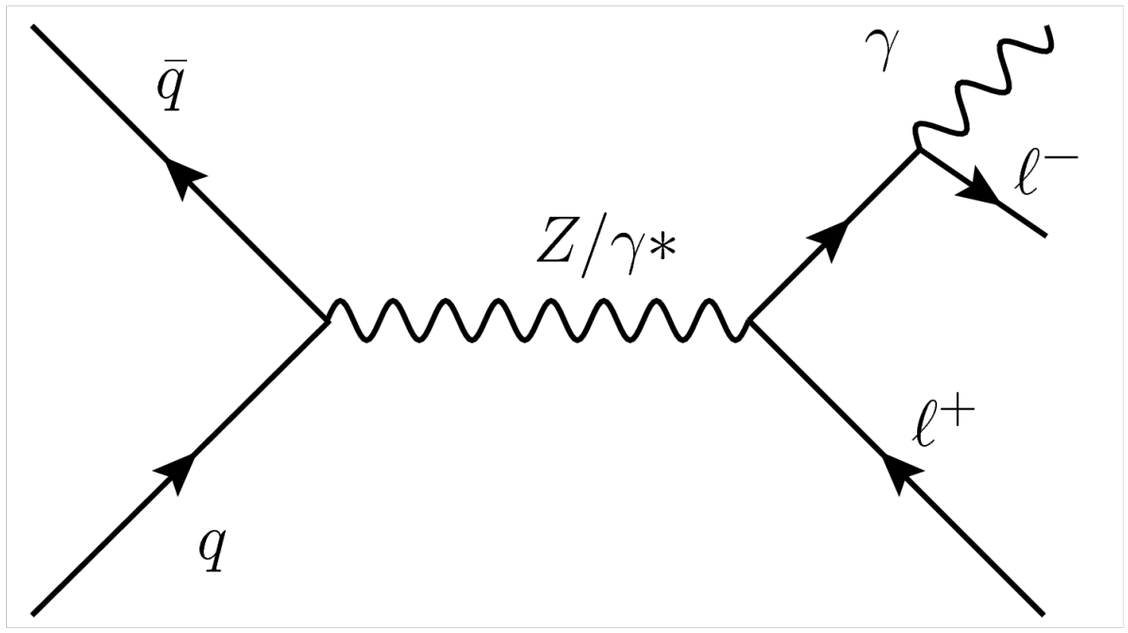
Consistency with strange-sea symmetric PDFs suggests s-s asymmetry is small (in regions probed by this analysis)

Ongoing effort to include these results in the next ATLAS global PDF fit

Initial state radiation:



Final state radiation:



$Z\gamma$ + jets

One Z boson decaying leptonically ($2e/2\mu$)

$m(\ell\ell) > 40$ GeV

One photon **not** from final state radiation:

$m(\ell\ell) + m(\ell\ell\gamma) > 182$ GeV

Jets:

$p_T > 20$ GeV if within ID

$p_T > 50$ GeV if outside ID

arXiv:2212.07184

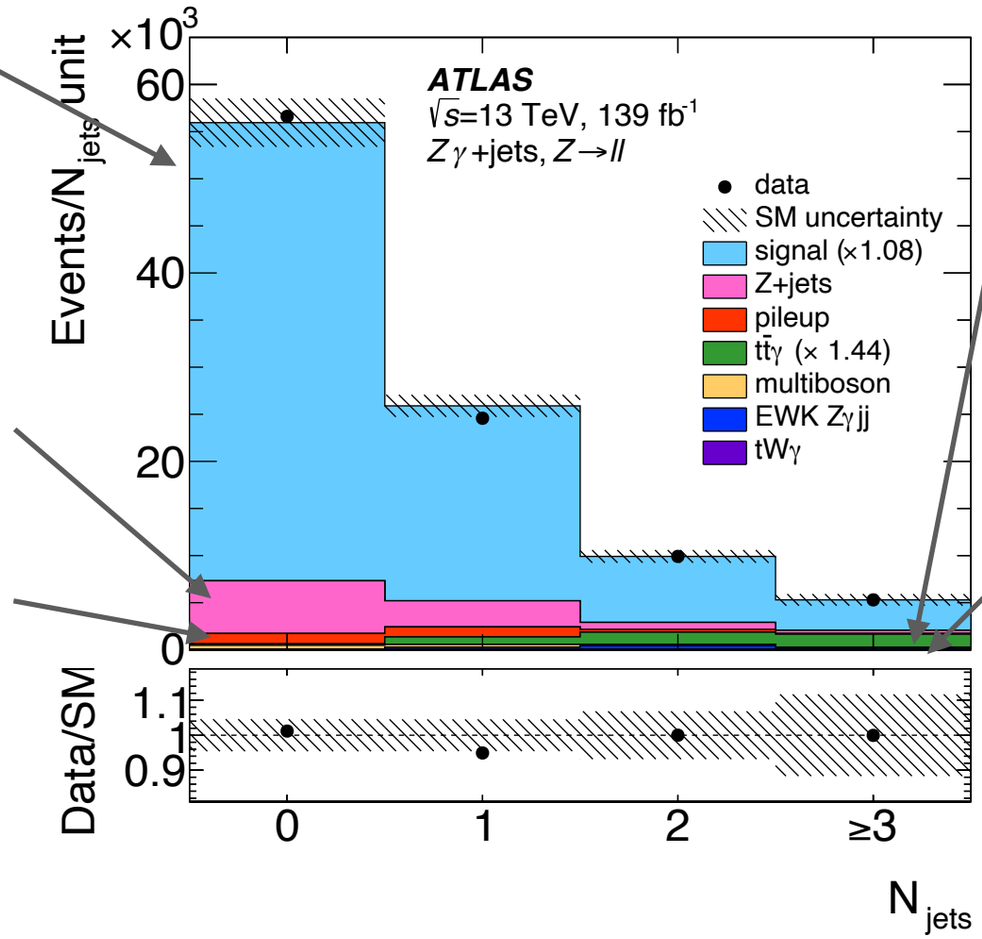
$Z\gamma$ + jets: background determination

arXiv:2212.07184

Very little background

Hadronic-sourced "fake" photons e.g. $\pi^0 \to \gamma\gamma$ or misreconstructed jets

Photon comes from a different p-p interaction (pileup)



Two $t \to W(\ell\nu)b$ decays with same-flavour leptons

Tiny "real" background from other processes

- Z+jets background determined by studying photons in data control regions where "jet like" photons are selected
- $tt\gamma$ background is normalised in an opposite-flavour control region

$Z\gamma$ + jets: results

arXiv:2212.07184

Two categories of variables for unfolding:

Hard variables

Sensitive to the scale of the hard scatter

Non-zero at leading order

$$m(Z\gamma), p_T^Z + p_T^\gamma, H_T, p_T^\gamma/\sqrt{H_T},$$
$$\Delta R(\ell\ell), p_T^Z, \cos(\theta_{CS}), \phi_{CS}$$

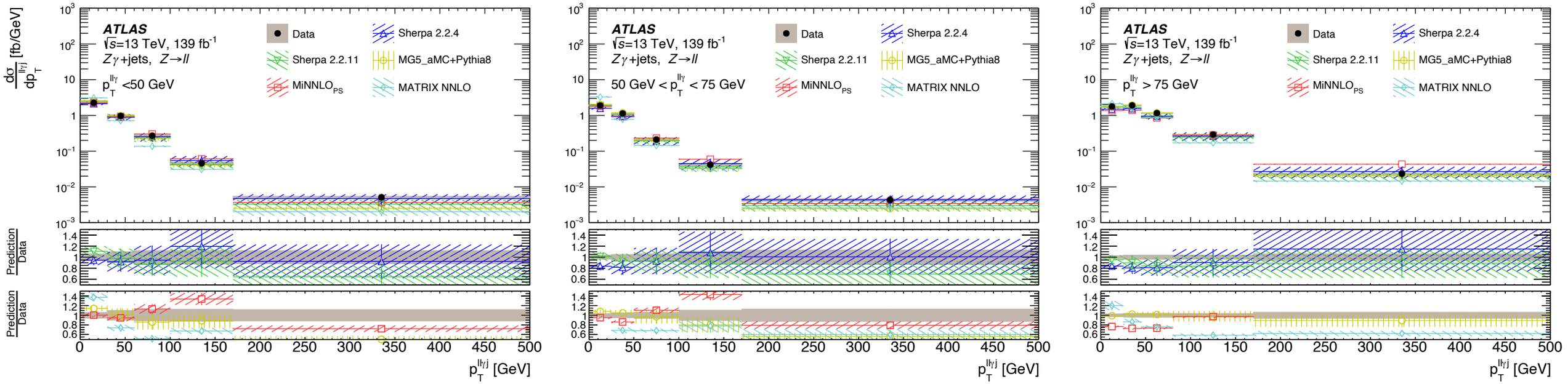
Resolution variables

Sensitive to additional soft QCD radiation

Only non-zero beyond leading order

$$p_T^{Z\gamma}/m_{Z\gamma}, p_T^Z - p_T^\gamma, p_T^{Z\gamma j}, N_{jets},$$
$$m_{jj}, \Delta\Phi(j,\gamma), p_T^{j1}, p_T^{j2}, p_T^{j1}/p_T^{j2}$$

QCD effects probed by unfolding a **hard variable** as a function of a **resolution variable**, e.g.:



Sherpa and Madgraph model data well, but MiNNLO$_{PS}$ underestimates at high p_T and MATRIX has a much softer spectrum

Conclusions

Precision measurements with the full run 2 dataset provide a rich environment to probe QCD

- Measurements to provide valuable feedback for generator and PDF development
- MC generators are in general describing data well
- Some processes/areas of phase space where theory predictions are much less precise than measurements
- Some processes/areas of phase space with questionable agreement