Precision measurements with single Z and WZ production at LHC

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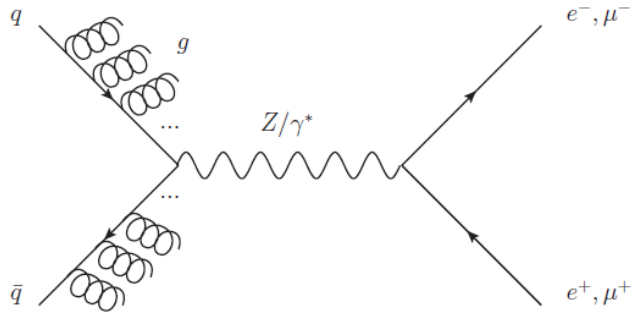
COPIN-IN2P3 workshop Kracow - 20 November 2023

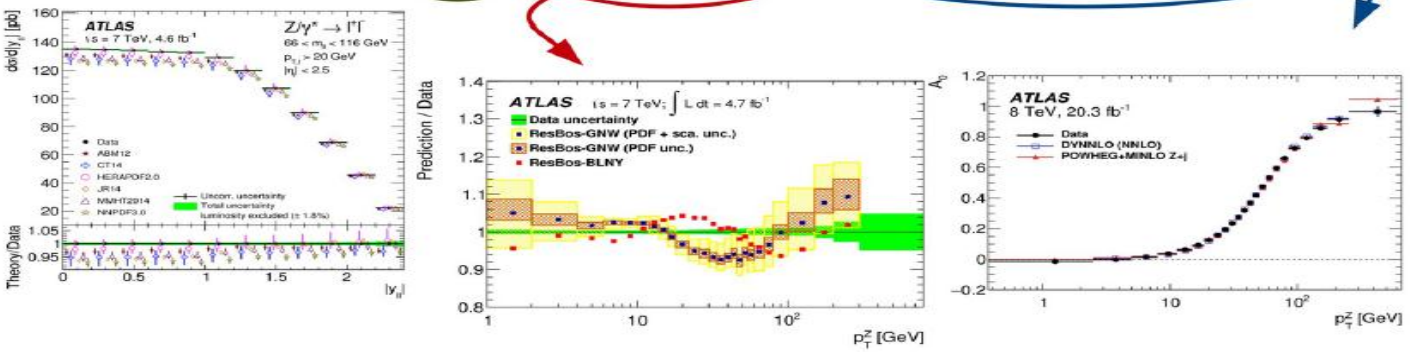
EN11-142 : Determination of Z boson double-differential cross-sect. ATLAS Collaboration, arXiv:2309.09118

Motivation

- Full-lepton phase space cross sections are needed for precise rapidity measurements interpretation (PDF fits)
- pT-y-Ai measurement based on factorisation ansatz



$$\frac{d\sigma}{dp_1\,dp_2} = \left[\frac{d\sigma(m)}{dm}\right]\left[\frac{d\sigma(y)}{dy}\right]\left[\frac{d\sigma(p_T, y)}{dp_T\,dy}\left(\frac{d\sigma(y)}{dy}\right)^{-1}\right]\left[(1+\cos^2\theta) + \sum_{i=0}^{7} A_i(p_T, y)P_i(\cos\theta, \phi)\right]$$



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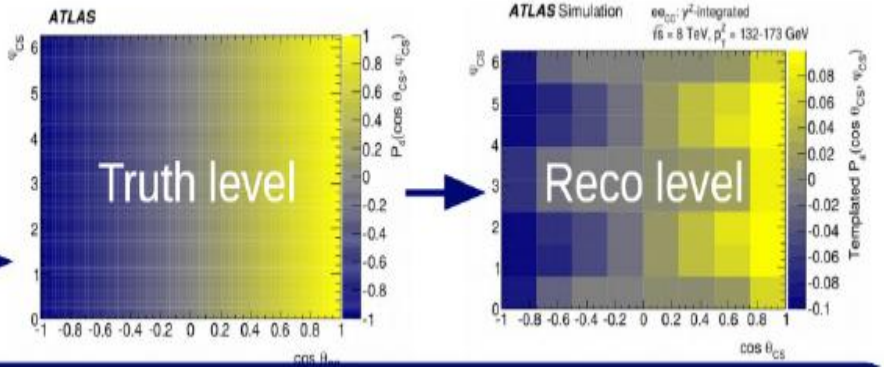
Methodology

- Measurement of the unpolarised cross section based on the angular momentum decomposition
- Extrapolation to full-lepton phase space through analytic continuation of spherical

$$\frac{d\sigma}{dp_T^Z\, dy^Z\, dm^Z\, d\cos\theta\, d\phi} = \frac{3}{16\pi}\frac{d\sigma^{U+L}}{dp_T^Z\, dy^Z\, dm^Z}\Big\{(1+\cos^2\theta) + \frac{1}{2}A_0(1-3\cos^2\theta) + A_1 \sin 2\theta \cos\phi + \frac{1}{2}A_2 \sin^2\theta \cos 2\phi + A_3 \sin\theta \cos\phi + A_4 \cos\theta + A_5 \sin^2\theta \sin 2\phi + A_6 \sin 2\theta \sin\phi + A_7 \sin\theta \sin\phi\Big\}$$



Expected Yield

Reco (p_T^Z, y^Z, m^Z, cosθ, ϕ) bin

$$N_{\text{exp}}^{n}(A,\sigma,\theta) = \left\{\sum_{j=1}^{N_{\text{bins}}^{ana}} \mathcal{L}\sigma_j \left[t_{8j}^{n}(\beta) + \sum_{i=0}^{7} A_{ij}\, t_{ij}^{n}(\beta)\right]\right\}\gamma^n + \sum_{B}^{\text{bkgs}} T_B^n(\beta)$$

Cross section — Background template

Truth (p_T^Z, y^Z, m^Z) bin — Angular coefficient — Templated polynomial

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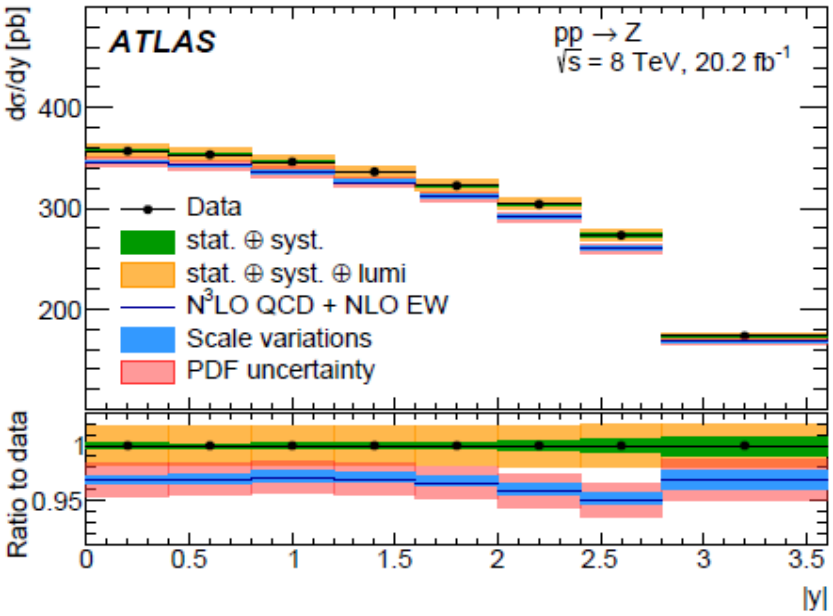
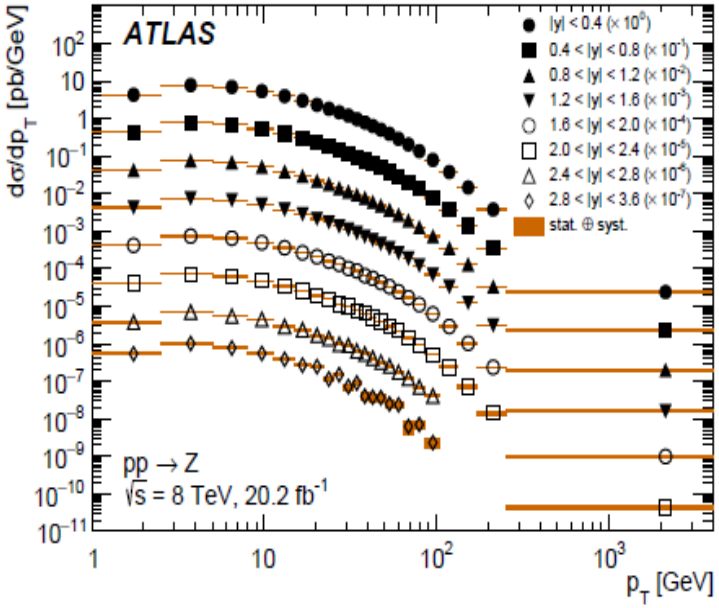
Results

- Total uncertainties for the rapidity shape at the level of 0.2-1%, plus 1.8% of luminosity uncertainty
- Agreement with N4LLa resummation at a few percent in dσ/dpT





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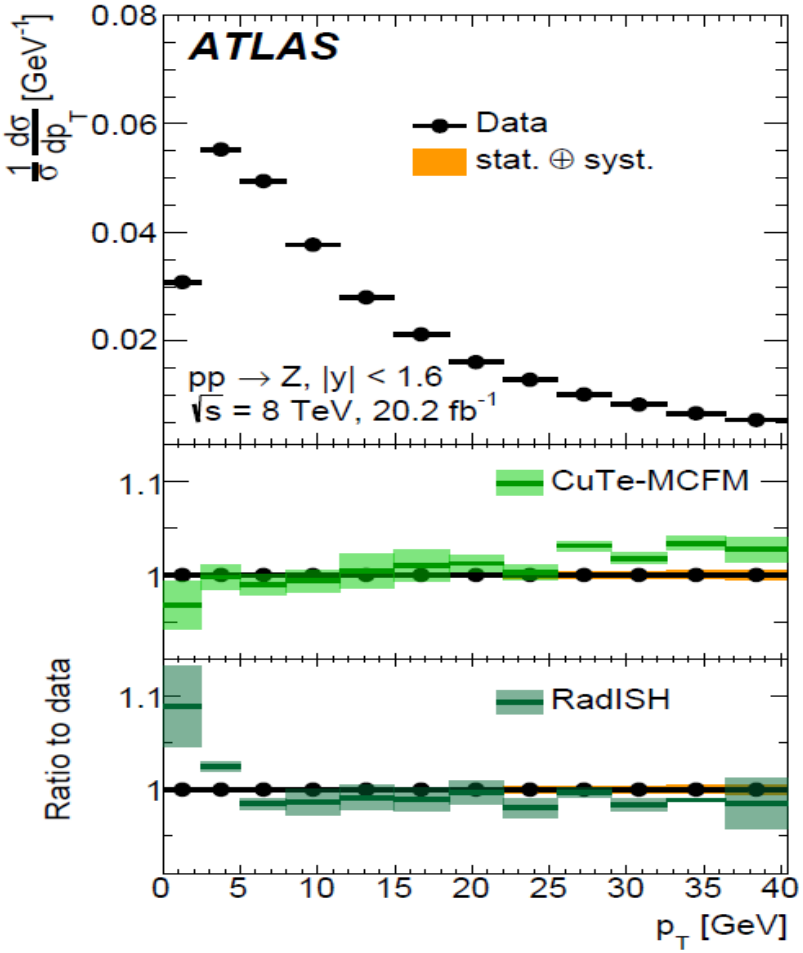
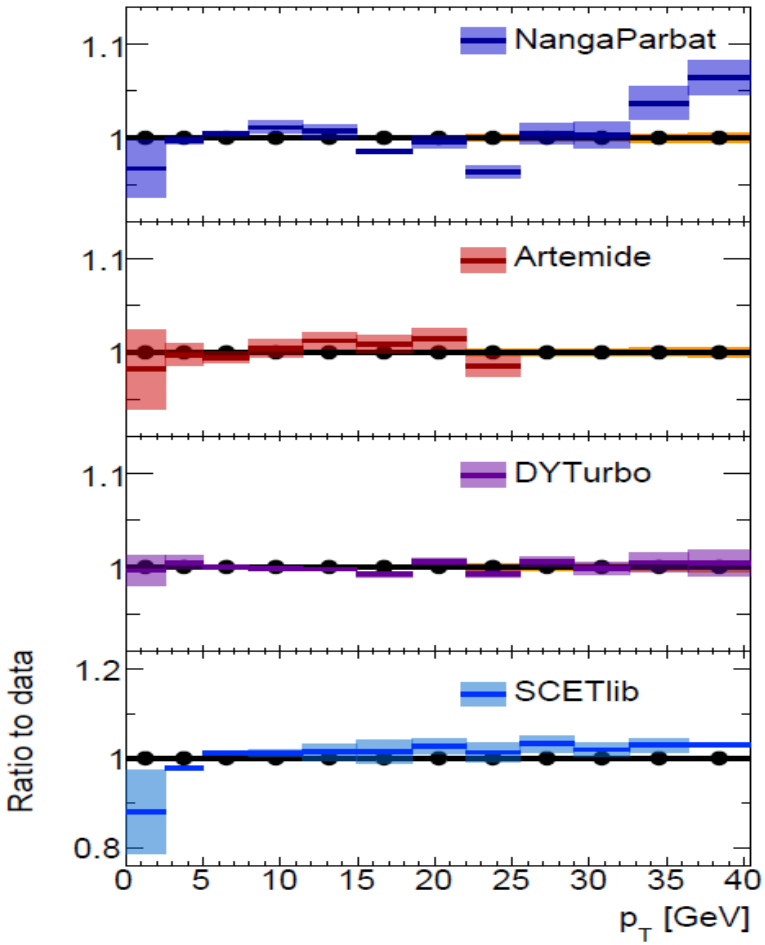
Results

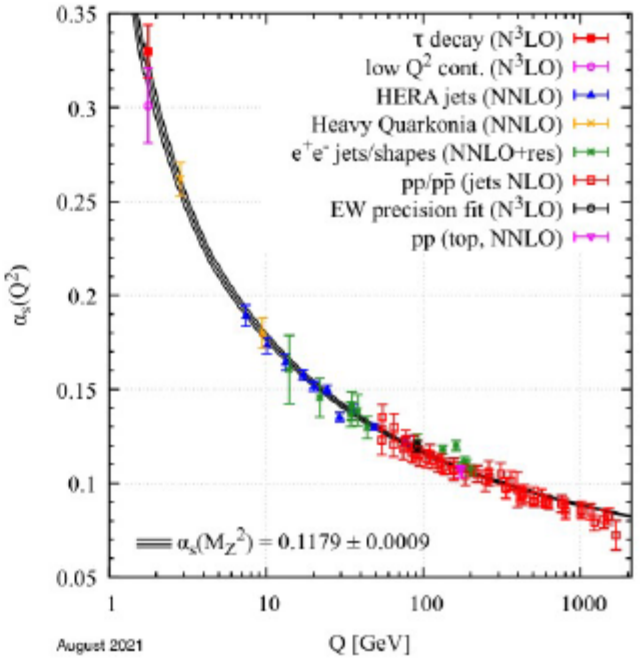




EN11-142 : Precise determination of α_S from the recoil of Z-boson ATLAS Collaboration, arXiv:2309.12986

Motivation

- Single free parameter of QCD in the $m_q \rightarrow 0$ limit
- Conventionally determined at the reference scale $Q = m_Z$
- Decreases ("runs") as $\alpha_s \sim \ln(Q^2/\Lambda^2)^{-1}$



- World average dominated by lattice QCD and tau decays, few N3LO determinations (tau decays, Z hadronic width)

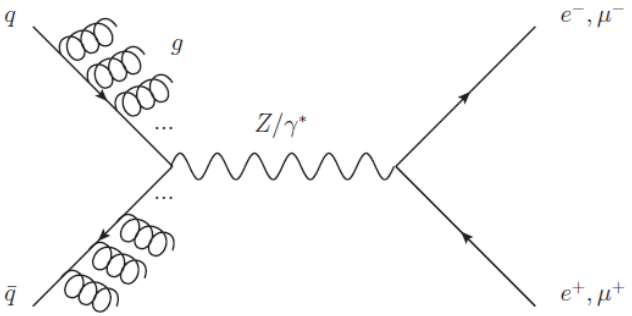
EN11-142 : Precise determination of α_S from the recoil of Z-boson ATLAS Collaboration, arXiv:2309.12986

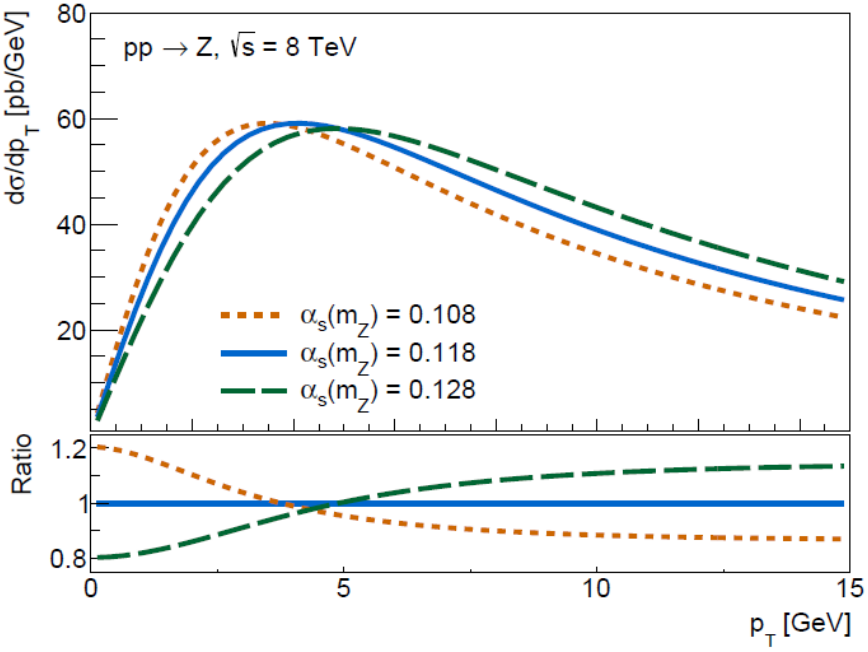
Metodology

- Double-differential $ds/dp_T/dy$ cross sections in full-lepton phase space
- Theory predictions at N4LLa+N3LO

The recoil of Z bosons is sensitive to the value of the strong- coupling

- Clear experimental signature
- High-order theory predictions
- Precise $\alpha_s(m_Z)$

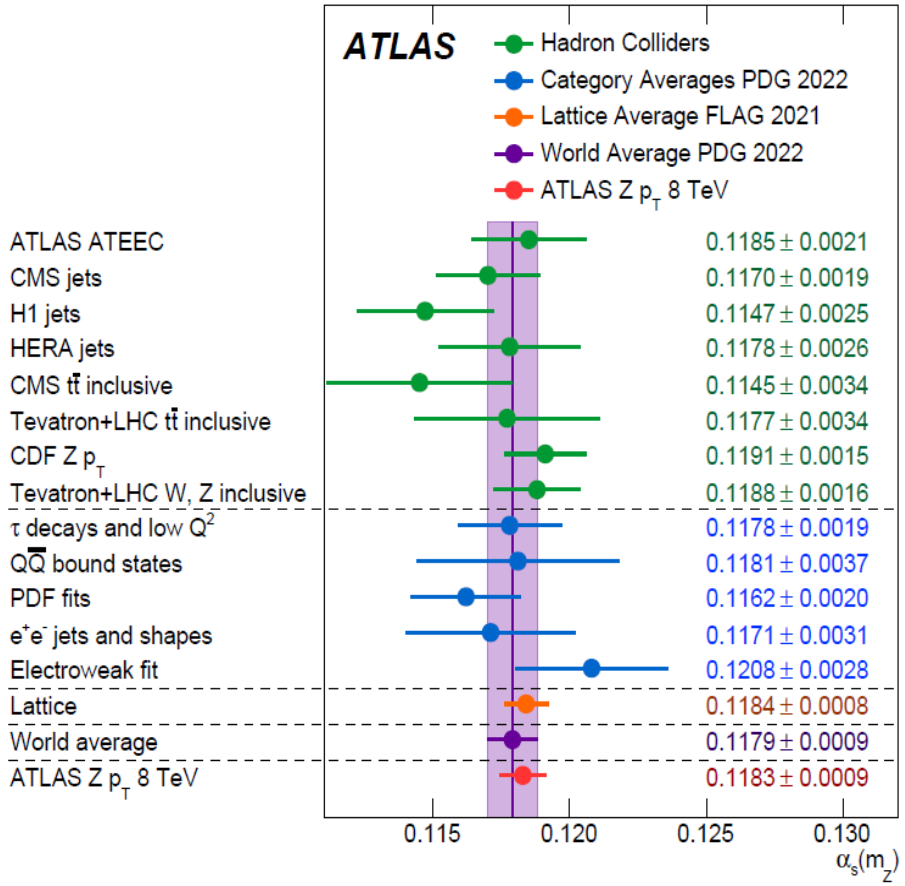




EN11-142 : Precise determination of α_S from the recoil of Z-boson
ATLAS Collaboration, arXiv:2309.12986

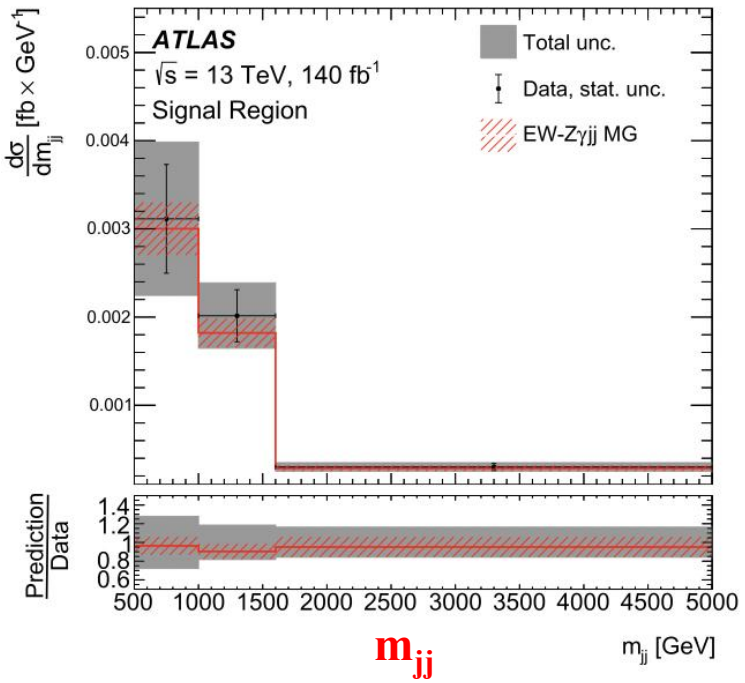
Results

- Comprehensive list of theoretical systematic uncertainties considered
- Total uncertainty inflated by sqrt(χ^2/dof)
- Most precise single-measurement experimental determination of $\alpha_s(m_Z)$, with total uncertainty at the level of 0.7%
- As precise as and in agreement with the world and lattice QCD averages

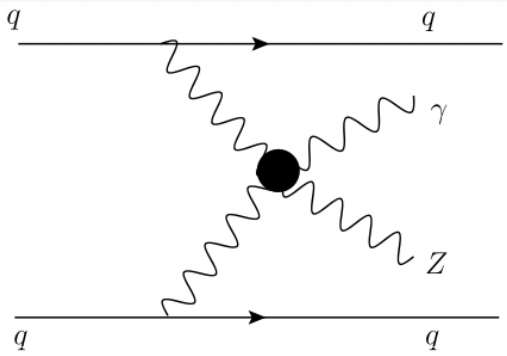


EN10-138 : Cross section measurements of pp->Z γ jj events

- Published Phys. Lett. B 846 (2023)



m_{jj}



- Thesis of Gitangeli Poddar

Contents lists available at ScienceDirect

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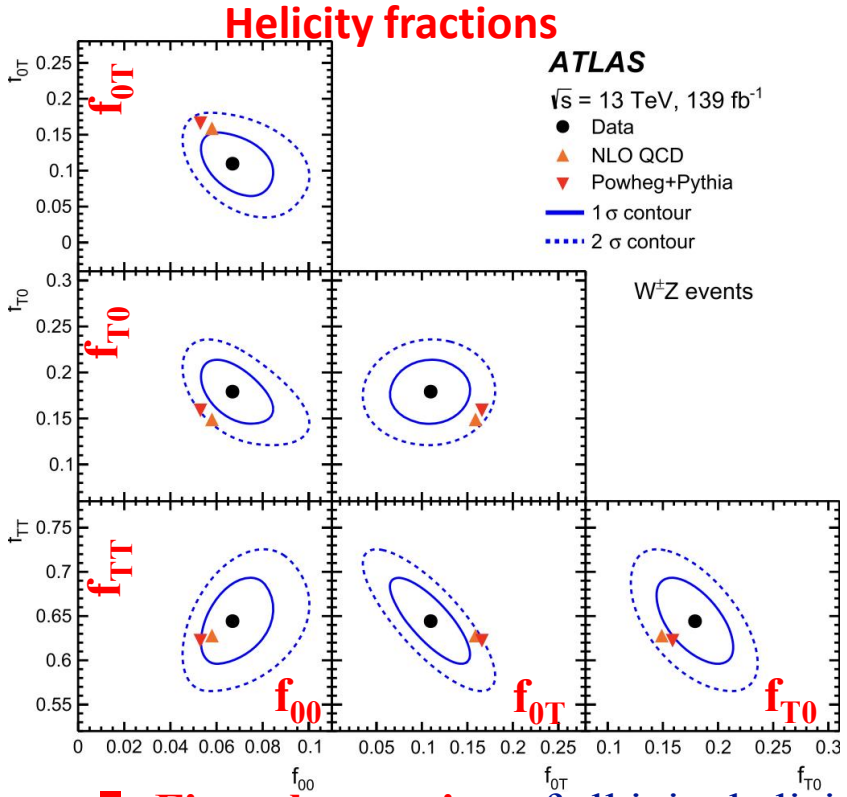
Measurement of the cross-sections of the electroweak and total production of a $Z\gamma$ pair in association with two jets in pp collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector

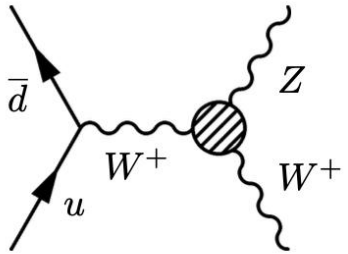
The ATLAS Collaboration *

- EW production of a Zγ pair probes the **neutral quartic gauge couplings**, which are forbidden at the lowest order in the SM → sensitive test of BSM effects
- Results consistent with the SM predictions
- Dominant systematics: photon treatment
  → Theoretical photon treatment, expertise of colleagues from IFJ PAN

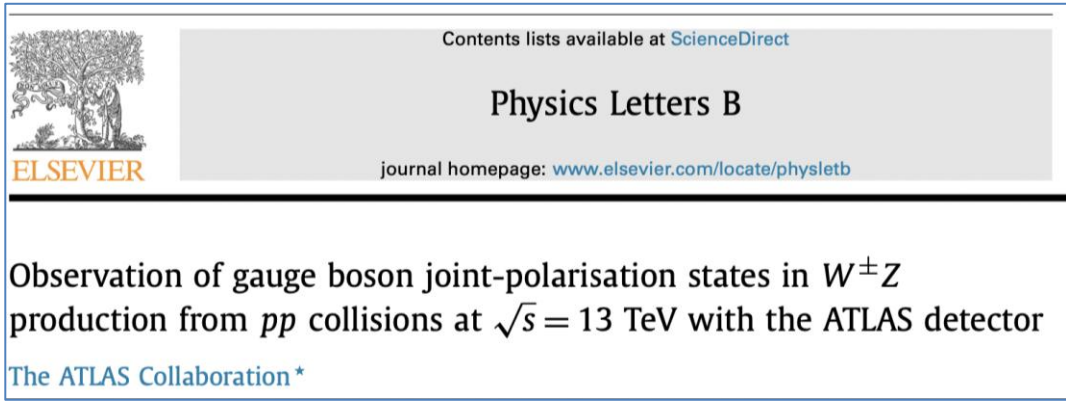
EN11-142 : Joint polarisation of boson pairs in pp->WZ X events

- Published in Phys. Lett. B 843 (2023)





- Thesis of **Luka Selem** (E. Richter Was in the thesis defence jury)
- Polarisation: expertise of colleagues from IF UJ

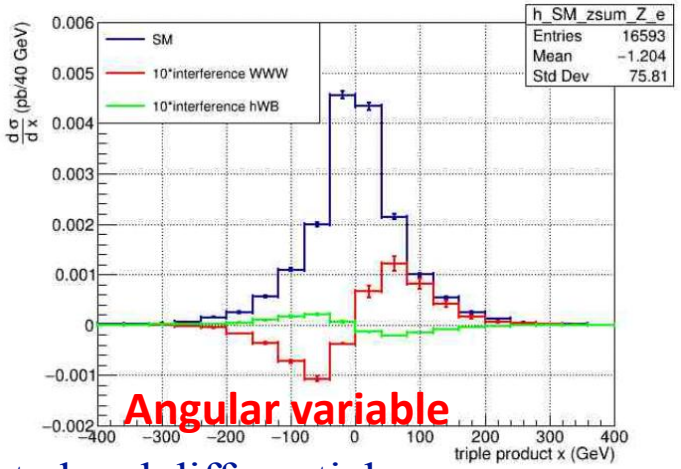


- **First observation** of all joint helicity fractions f_{00}, f_{0T}, f_{TL}, f_{TT} (consistent with the SM)
- The longitudinal degree of freedom of W & Z is related to the mechanism of the EWSB

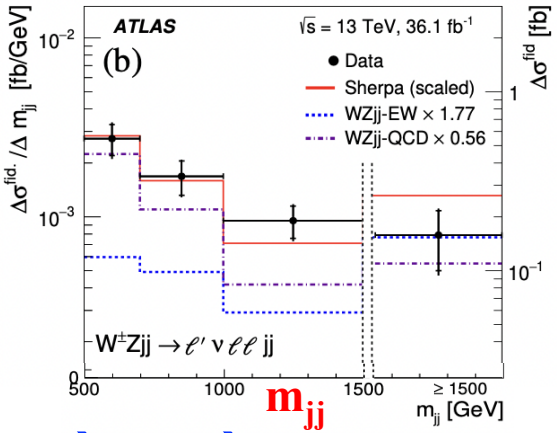
→ First step for the measurements that uniquely probe the EWSB mechanism at high transferred momentum

EN 10-138 and EN11-142 : plans for 2024

- **pp-> WZ X**: conclude the measurements of several differential distributions and extract limits on the Wilson coefficients of an Effective Field Theory to search for BSM effects.
  Focus on CP-violating effects less studied so far.
  Use of angular variables (more sensitive)



- **pp-> WZ jj X** : conclude the measurements of the integrated and differential cross sections of the W and Z scattering process of W and Z with **full Run 2 data** (4 times more events in a measurement statistically dominated)



- First observation by the LAPP group in 2019
- Fiducial cross-section for WZ electroweak production found to be larger than the LO SM predictions
- **Key measurement @ HL-LHC** for the understanding of the EWSB

- **pp→ HH → bbγγ** : **key measurement @ HL-LHC** for the understanding of the EWSB
  → need photons treatment expertise