SM activity in the DESY ATLAS group

L. Aperio Bella on behalf of many

Jour fixe – 30th August 23

New publication since last 6 months

- Measurements of Zγ+ jets differential cross sections in pp collisions at √s=13 TeV with the ATLAS detector - https://arxiv.org/abs/2212.07184 Accepted by JHEP .
- Observation of WZγ production in pp collisions at √s=13 TeV with the ATLAS detector -STDM-2019-17 (DESY News: New ATLAS observation: Three different bosons at once - Deutsches Elektronen-Synchrotron DESY) Accepted by PRL

DESY + Freiburg almost exclusive effort

- Z boson transverse momentum and rapidity measurement in full phase space at 8 TeV + α_s determination using Z boson transverse momentum at 8 TeV - ATLAS-CONF-2023-015 and ATLAS-CONF-2023-013 - paper in preparation (Briefing ATLAS measures the strength of the strong force)
- Precise measurements of W and Z transverse momentum spectra with the ATLAS detector at √s = 5.02 TeV and 13 TeV paper in preparation ATLAS-CONF-2023-028 / (Briefing WZ-properties-milestone)

Single-Boson final state

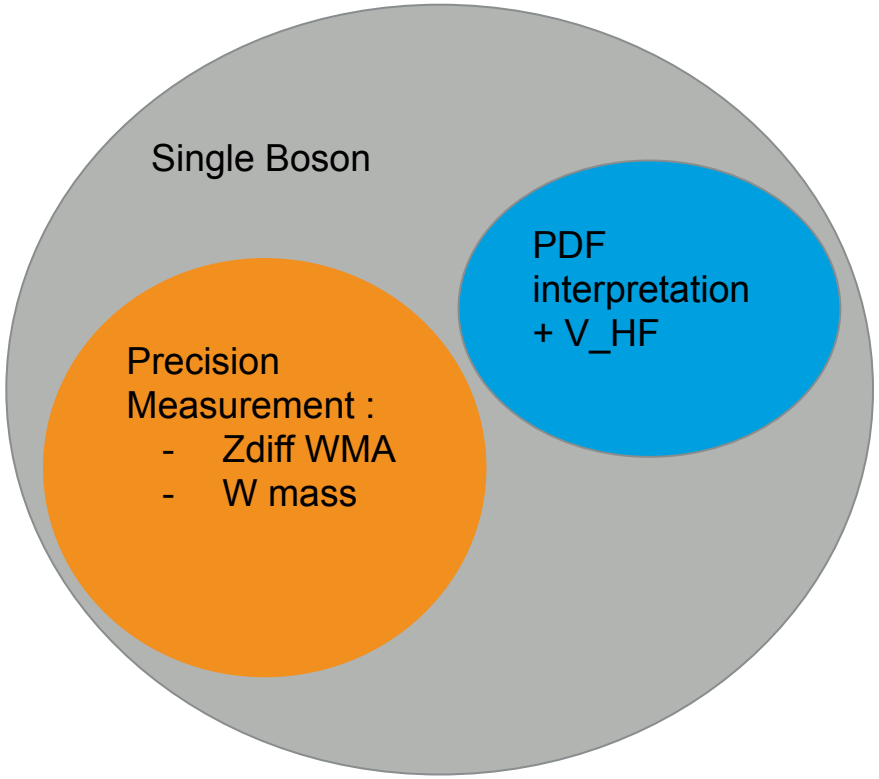
- PROS: very outstanding results, unpresented precision reached
- CONS: Usual time-scale for a precision SM analysis (unfortunately) > 3,4 years bunch of publication now of efforts started several years ago …

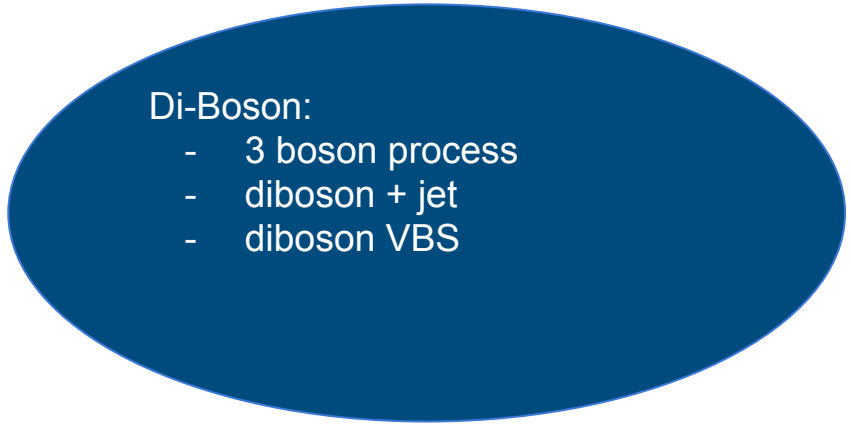
- Measurement of tt and Z cross-sections and their ratio using pp collisions at s√=13.6 TeV with the ATLAS detector paper in preparation (ATLAS-CONF-2023-006)
- Compatibility and combination of world W-boson mass measurements (https://arxiv.org/abs/2308.09417)

SM/Top + W-Mass (LHC/Tevatron)

DESY SM group

Group composition in the near past

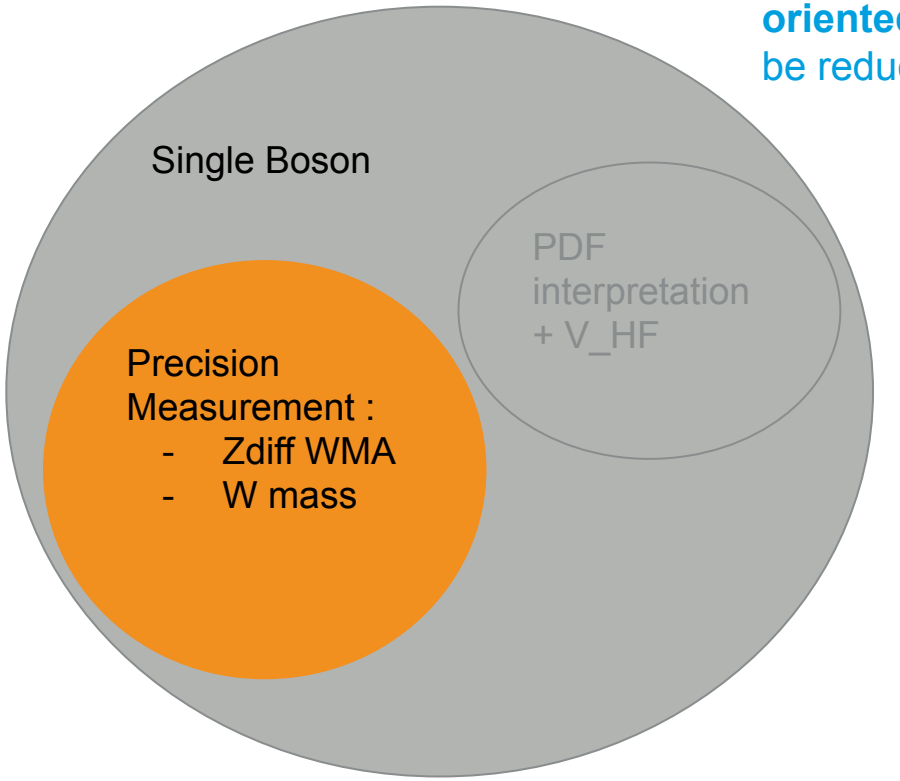




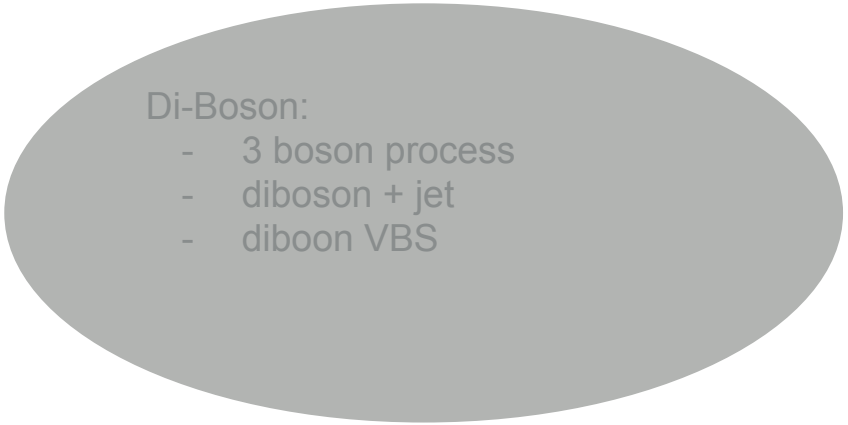
DESY SM group

Group composition - now

PDF interpretation and PDF oriented analysis expected to be reduced in the future



Multi-Boson final state:
Dibsoon activity in DESY SM group expected to be reduced in the future



- People involved:
  - 2 staff: Ludovica Aperio Bella (egamma convener), James Ferrando (Data preparation coordinator ***left August*** 23), *Sarah Heim (limited involvement)*
  - 2 fellows: Filip Nechansky, Filippo Dattola
  - 3 students: Alberto Rescia, Craig Wells *(Last year of PhD)*, Lukas Bayer (**new** 1st May) , Joshua Newell (**new** DESY/Liverpool 1st Oct)

Focus of the group activity (the way forward)

Main part of the group focus on: **single Boson** (W,Z) (LAB)

- PDF:
  - **Low-mass DY** [analysis close to publication] **(James)**
  - Z+HF **Z+bb analysis focusing on jet substructure observables (James + Alberto + LAB)**
- Precision measurements:
  - **Z fourfold cross-section measurement, angular coefficient , extraction of sin2θW @13TeV (LAB + Filip + Craig + Lukas)**
  - **W mass with low-mu data (LAB + Filippo + Josh)**
  - **W polarization low-mu data (LAB)**

Other activities (Sarah)

- Search for $\gamma\gamma$VBS (Sarah, still very preliminary stage, plan: ALPS interpretation)
- $\gamma\gamma$WW measurement *(Filip limited involvement)*

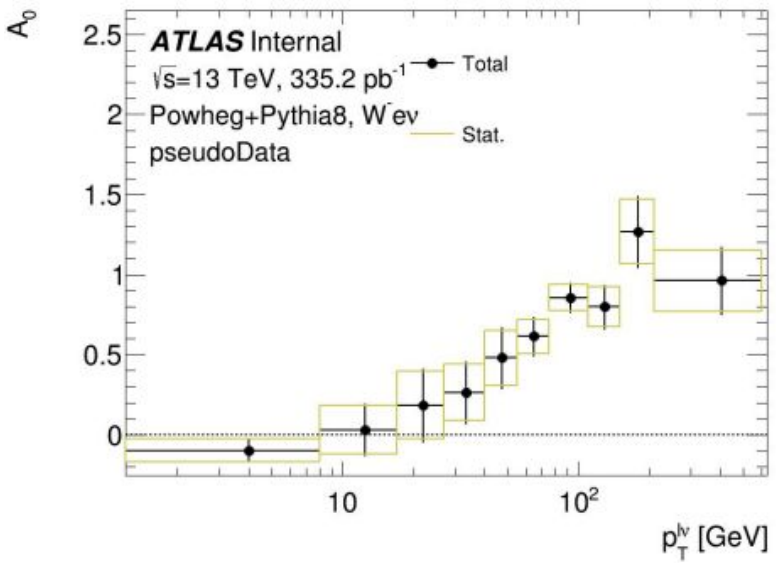
Current Analysis details

Ongoing

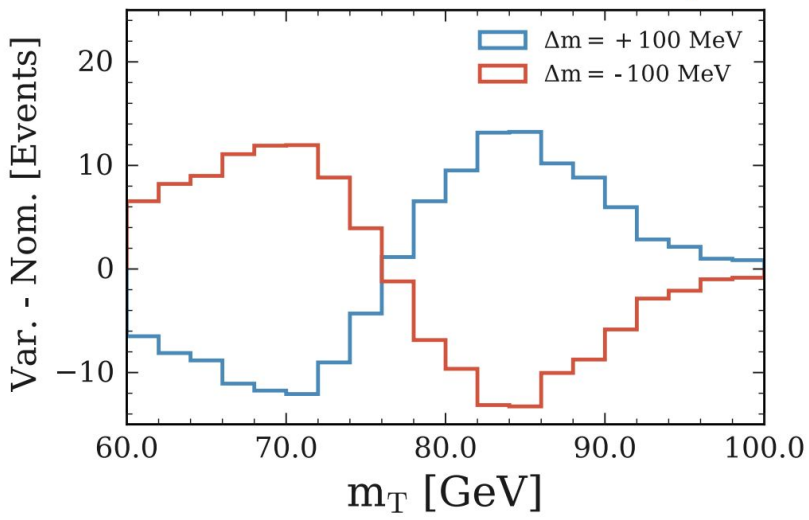
W-Boson Precision Measurements with low-mu data

Precision test of QCD and EW sector of SM

- First ever measurement of **W polarization** using 13 TeV low-mu data
  - This analysis was ideated and initiated by LAB (DESY contribution from Ruth Jacob, Craig Wells)
- **W mass measurement** with better precision
  - DESY focus: implement a simplified Gaussian model for template fits to extract the mW
  - Use improved PDF and pT modelling from ongoing analyses.
    - Outlook: Collaboration with DESY theory department to improve the theory model to NP N3LL accuracy



Variations coupled with $\mu = \alpha_{m_W}$



Four-fold Z measurement @13TeV

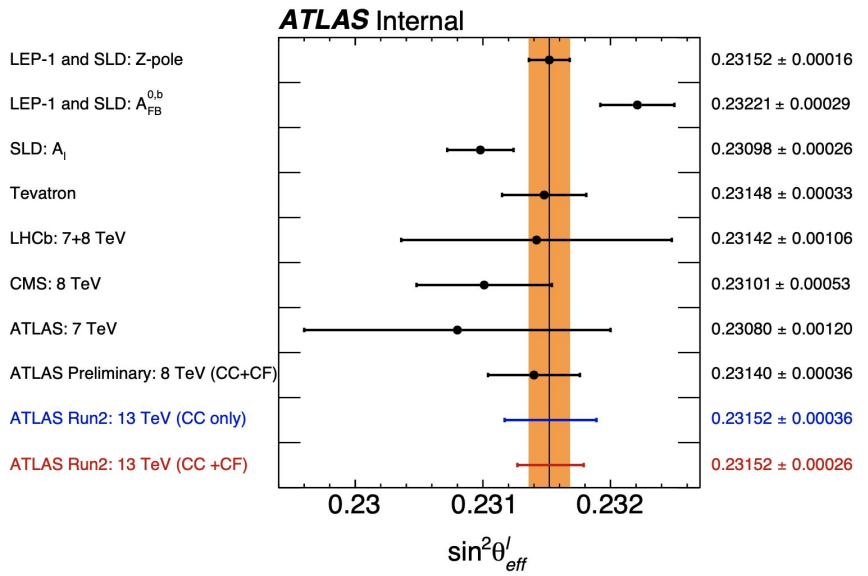
Ongoing fully DESY driven analysis

Precision test of QCD and EW sector of SM

- The data statistics collected in the full Run-2 gives an **unprecedented opportunity** to measure the complete decomposition of the Drell-Yan cross section in [m_{ll} : y_{ll} : p_{Tll} : cosθ*] bins.
- **Ongoing analysis using the full Run-2 dataset:**
  - Z angular coefficients (Ai) and DY differential cross-section $d\sigma+Ai/dp_T^Z dy^Z$ measurement [eeCC + μμCC channel]
  - Below % precision expected also at very high transverse momentum
  - Work on eeCC almost finished and compatibility studies with muon channel being performed

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

- **Addition of central-forward** ($|\eta_e|$>2.5) **channel: Ai + $d\sigma/dp_T^Z dy^Z$ towards $\sin^2\theta^{eff}$ extraction (CC+eeCF)**
  - optimal sensitivity and minimal theory uncertainties: $dp_T^Z dy^Z$ measured from data in 3 mass bin (m_{ll}).
  - Calibration of forward electrons
    - expect an improvement of up to 15% in sensitivity in A4 through forward electron calibration
  - expected weak mixing angle sensitivity $\delta\sin^2\theta^{eff} \sim 26\times10^{-5}$



Vector Boson + HF Measurements

Ongoing

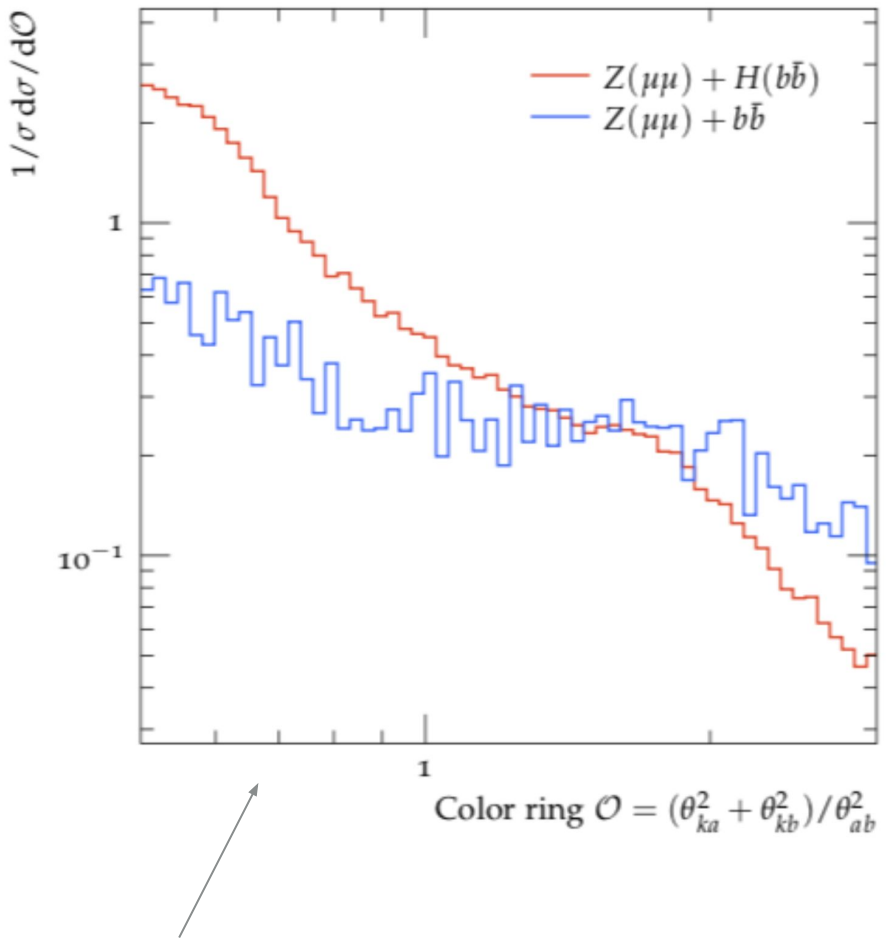
Precision tests of QCD in a rich experimental environment

Vector Boson+HF:

- Measurements of Vector boson production in association with heavy flavour quarks can act as a direct probe of heavy flavour PDFs
- Working on a **full Run 2 measurement of Z+bb production**, including very high PT production
  - Want to study jet substructure in this final state:
    - e.g Lund plane can be used to discriminate H->bb from bb in association with Z (see arXiv:2112.09650)

Status:

- Proceeding with the analysis, completed a list of substructure variables to the list of observables to measure including: Lund-plane, $D_2^{(\alpha)}$, jet colour-ring (new)

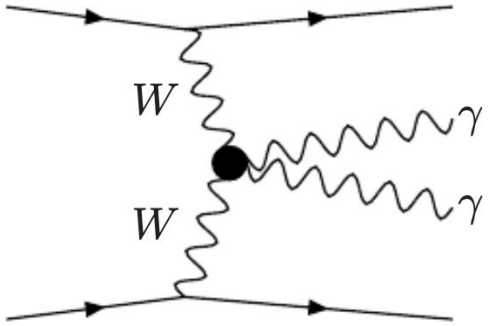


Jet colour ring example figure from arXiv:2110.12918

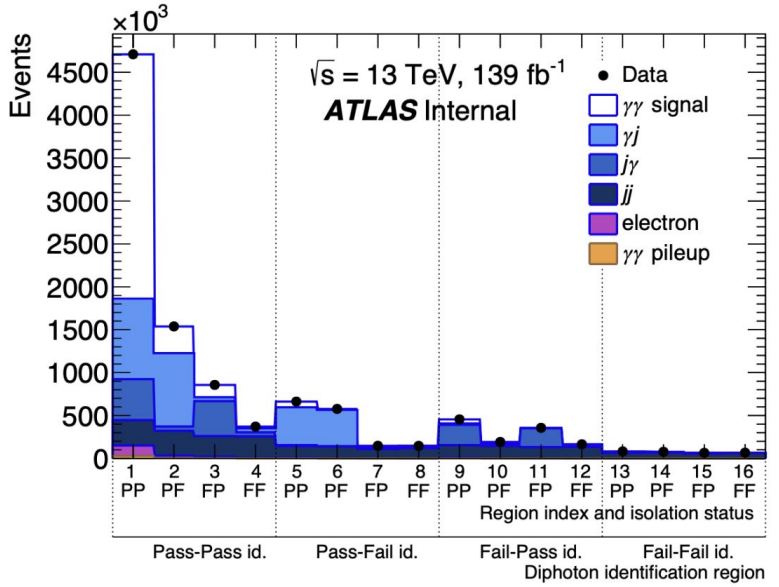
New effort

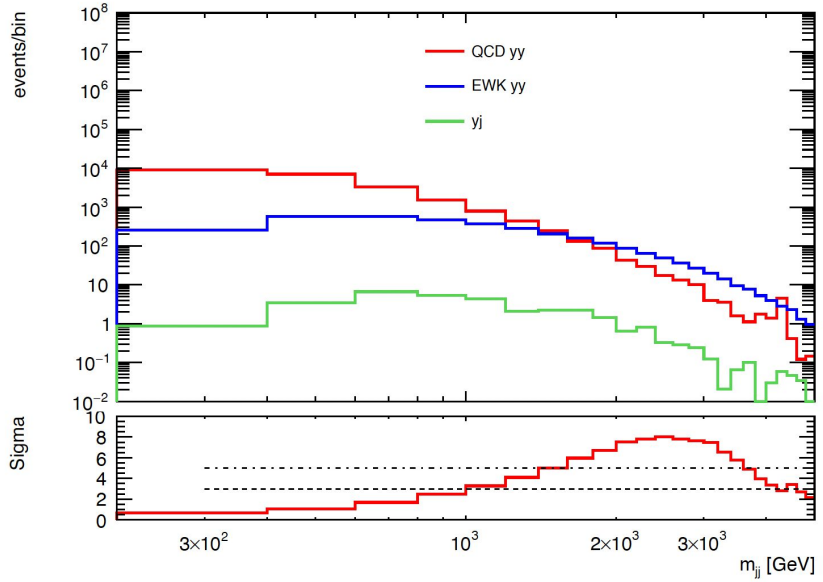
Measurement of γγ VBS

Measurements of EWK production of $\gamma\gamma$



- Purely electroweak process not yet observed
- Sensitive to $\gamma\gamma$WW coupling
- $\gamma\gamma$jj important background to h→$\gamma\gamma$
- Plan to measure the inclusive cross section
  - QCD and EWK contribution together
  - Extract EWK contribution alone if statistic is enough
- Effort recently started full Run2 data set .
- From preliminary estimates, we should be able to observe it!





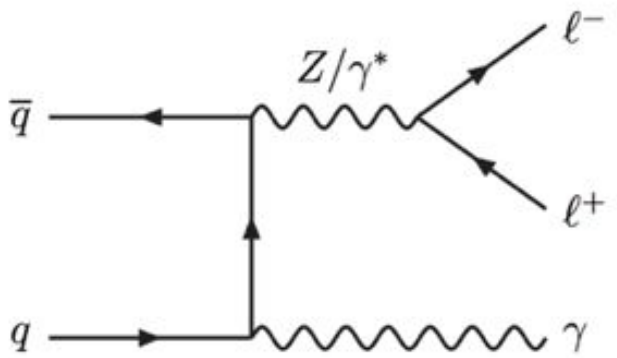
Published results

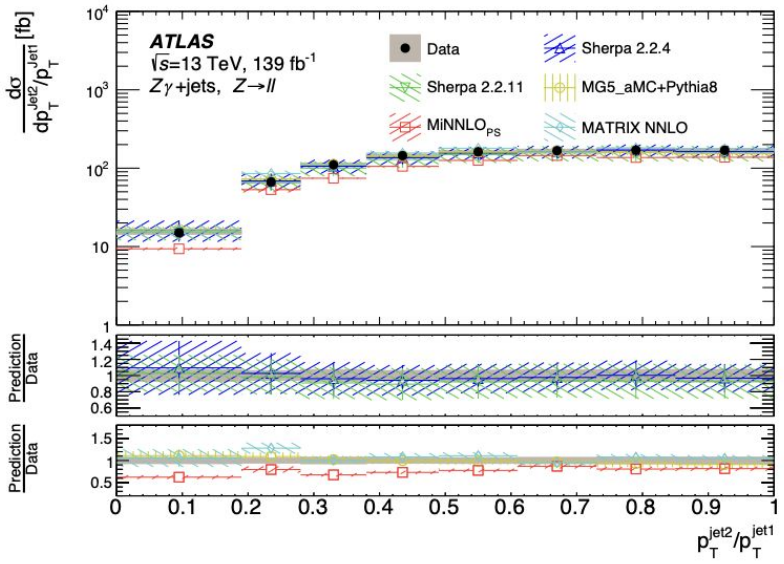
Differential cross section for Zγ+ jet

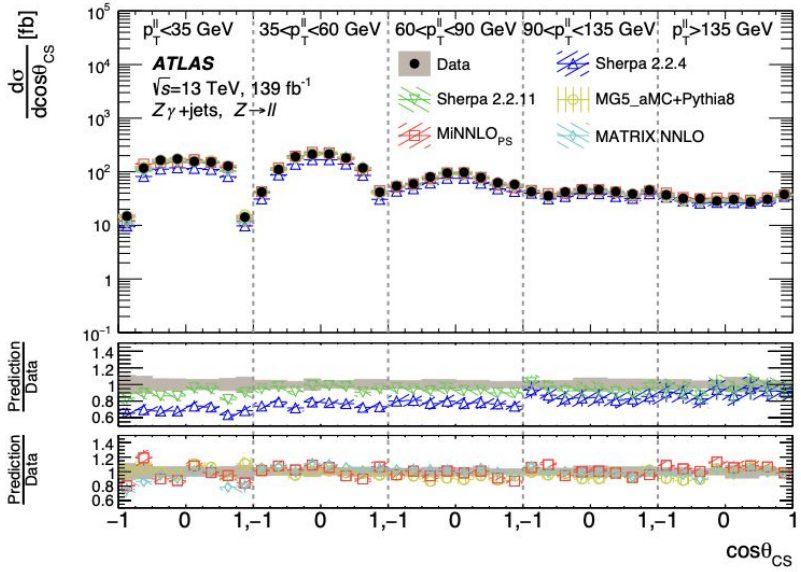
New public results: submitted to JHEP
arXiv:2212.07184

Measurements of QCD radiation in diboson process

- Good statistic and low background → Good candle for SM measurements
  - Use this measurement for test of QCD radiation modelling (resummation, parton shower)
  - Important background for Higgs searches
- Compare results with fixed order calculation (MATRIX) and other PS MC (Sherpa, MiNNLOPS)
- Use two dimensional unfolding
- Results use full Run2 dataset. Published as CONF Note for ICHEP 2022. Paper accepted by JHEP (arXiv:2212.07184)







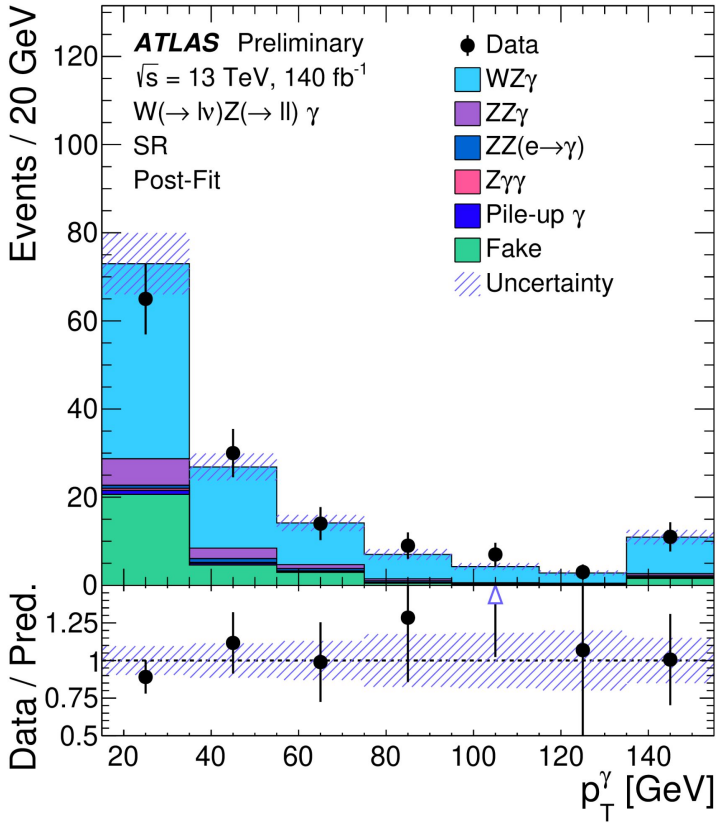
Search for WZγ production

NEW public results atlas-conf-2023-014 PAPER in preparation

First Observation of another rare decay !

- Multiboson production is important for gauge coupling investigation and complimentary to VBS
- WZγ production observed for the **first time** with **6.3 s.d. significance**

Process	SR	$ZZ\gamma$ CR	$ZZ(e \to \gamma)$ CR
$WZ\gamma$	92 ± 15	0.21 ± 0.07	0.56 ± 0.14
$ZZ\gamma$	10.7 ± 2.3	23 ± 5	1.8 ± 0.4
$ZZ(e \to \gamma)$	3.0 ± 0.6	0.028 ± 0.020	30 ± 6
$Z\gamma\gamma$	1.05 ± 0.32	0.15 ± 0.06	0.29 ± 0.10
Non-prompt background	30 ± 6	-	-
Pile-up γ	1.9 ± 0.7	-	-
Total prediction	139 ± 12	23 ± 5	33 ± 6
Data	139	23	33



$$\sigma^{\text{fid}}_{\text{exp}} = 1.50 \pm 0.01\,(\text{stat}) \pm 0.02\,(\text{PDF} + \alpha_S) \pm 0.07\,(\text{scale})\ \text{fb}$$ @ NLO (QCD) + LO (EW)

$$\sigma^{\text{fid}}_{\text{obs}} = 2.01 \pm 0.30\,(\text{stat}) \pm 0.16\,(\text{syst})\ \text{fb}$$

Full-lepton phase space Drell-Yann cross sections at 8TeV

NEW public results ATLAS-CONF-2023-015 and ATLAS-CONF-2023-013 **PAPER in preparation**

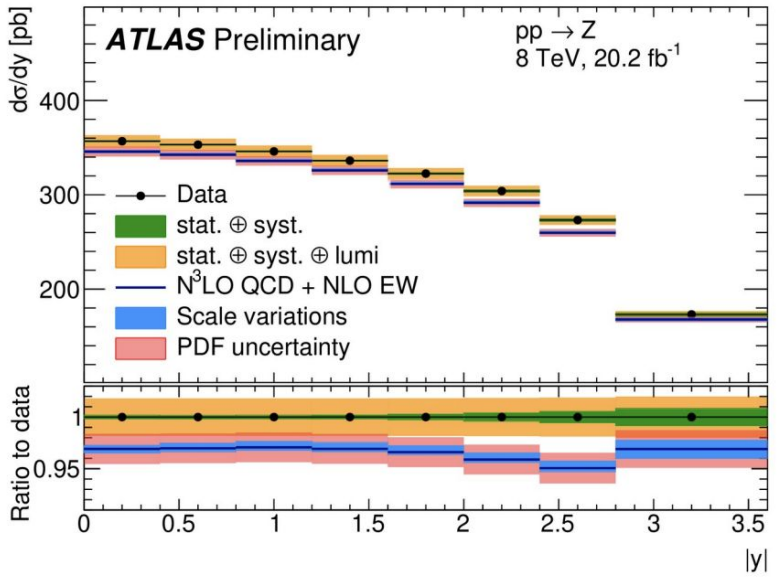
ATLAS measures the strength of the strong force

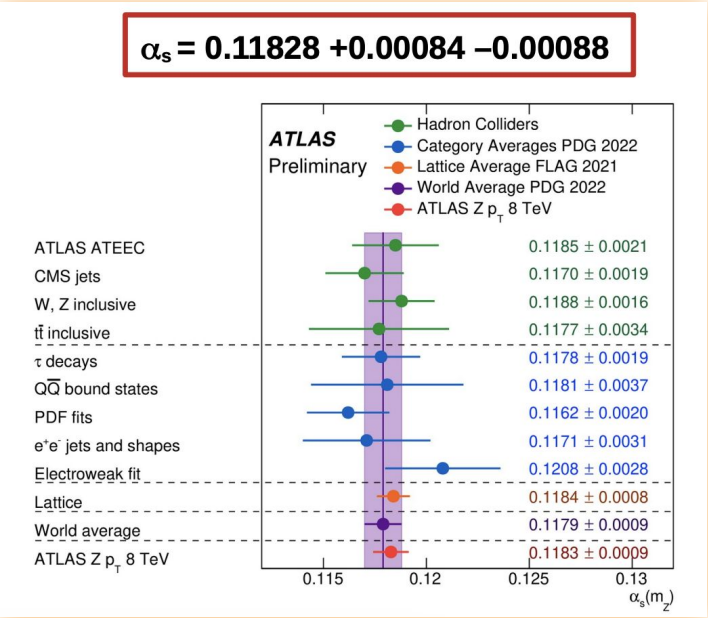
A convenient way of expressing the DY cross section is through the factorisation of the production dynamic and the decay kinematic properties of the dilepton system

$$\frac{d\sigma}{dpdq} = \frac{d^3\sigma^{U+L}}{dp_T dydm}\left(1 + \cos^2\theta + \sum_{i=0}^{7} A_i(p_T, y, m) \cdot P_i(\cos\theta, \phi)\right)$$

- Simultaneous determination of angular coefficient and cross-sections
  - Analytical propagation of fit results to full-lepton phase space
  - Negligible theory uncertainties: cross sections are parameters of the fit, and not the result of an extrapolation
- Statistically dominated measurement ‰ level in the central region % uncertainties up to |y| < 3.6
- First comparison to N3LO QCD predictions

Very powerful: avoids theoretical extrapolation of fiducial lepton cuts to full phase space and thereby opens the door to a rich field of precise interpretations





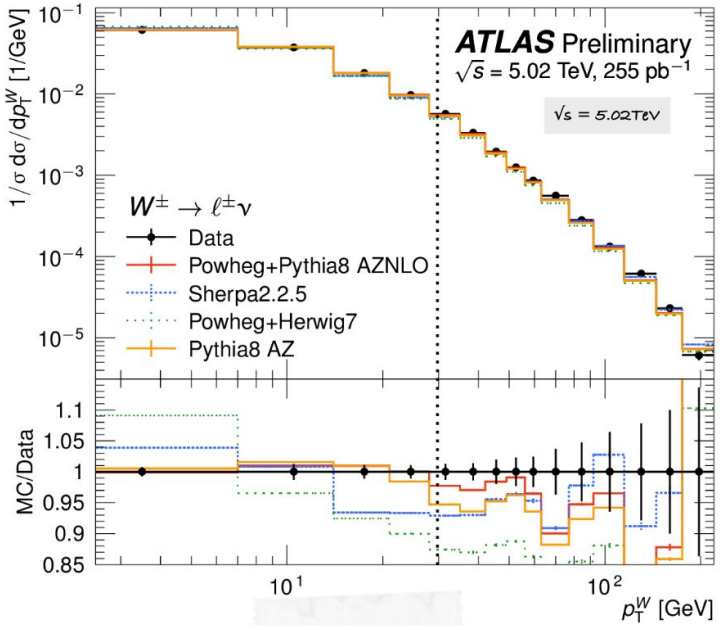
NEW public results ATLAS-CONF-2023-028
PAPER in preparation

W and Z boson pT measurements

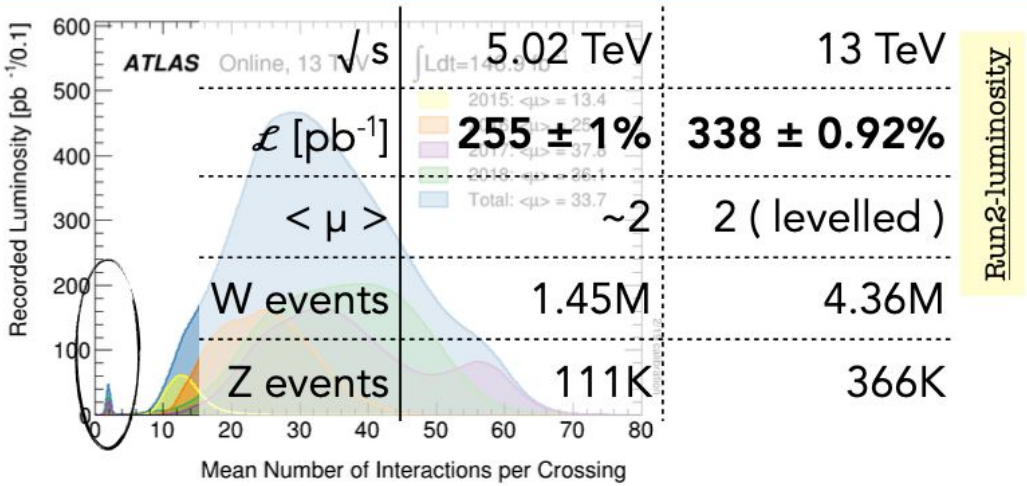
first low mu data result!

Measurements using low-mu data (5 TeV and 13 TeV)

- Measurement of the Z/W p_T ratio - reduce the p_T W modelling uncertainty in m_W measurement



W mass pTW physics modelling [Powheg+Pythia 8 AZNLO; Pythia 8 AZ] describe well the data in the low-pT region @5TeV



Most precise integrated fiducial measurement of the W± and Z boson @ 5.02 and 13 TeV:

Process	Cross section at $\sqrt{s} = 5.02$ TeV [pb]	Cross section at $\sqrt{s} = 13$ TeV [pb]
$W^- \to \ell\nu$	1385 ± 2 (stat.) ± 5 (sys.) ± 15 (lumi.)	3486 ± 3 (stat.) ± 18 (sys.) ± 34 (lumi.)
$W^+ \to \ell\nu$	2228 ± 3 (stat.) ± 8 (sys.) ± 23 (lumi.)	4571 ± 3 (stat.) ± 21 (sys.) ± 44 (lumi.)
$Z \to \ell\ell$	333.0 ± 1.2 (stat.) ± 2.2 (sys.) ± 3.3 (lumi.)	780.3 ± 2.6 (stat.) ± 7.1 (sys.) ± 7.1 (lumi.)

experimental accuracy 0.4 - 0.5 % with 1% lumi
factor of 2 (3.5) better then previous W X-section at 5.02 (13TeV)
good agreement with DYTURBO [NNLO+NNLL] prediction with 3 different PDF sets