ATLAS at the dawn of Run2

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LHCC Meeting Open Session
23.9.2015 CERN
# LHC Timeline

## very eventful period

LHC Timeline

<table>
<thead>
<tr>
<th>Week</th>
<th>April</th>
<th>May</th>
<th>June</th>
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<tbody>
<tr>
<td>Mo</td>
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<td>Su</td>
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**Big thanks to the LHC!!**

<table>
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<tr>
<th>Week</th>
<th>July</th>
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<td>TS2</td>
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<td>32</td>
<td>LHCP</td>
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<td>Su</td>
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<td>33</td>
<td>Jeune G</td>
</tr>
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</table>

**Lepton**

**Photon**

**Special run for 25 ns operation**

**Machine checkout**

**Injector TS**

**Recommissioning with beam**

**LHCP**

**EPS**

**Intensity ramp-up with 50 ns beam**

**Intensity ramp-up with 25 ns beam**

**VDM**

**TS2**

**VAT**

**EPS**

**LHCP**

**Jeune G**
• $\mu$ values still similar to Run1 values

• EPS and LHCP datasets ~100 pb each

• early lumi systematics from LHCf run ... 9%
**Inner Detector**

- **Pixel/IBL operational since Week1**
- **IBL significantly improves the performance of the Pixel**
- **operational stability thanks to firmware upgrades and mainly before 25 ns runs (3 order of magnitude less errors)**

**IBL** = the 4\textsuperscript{th} and innermost Pixel layer installed in LS1

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**average fraction of modules with synchronisation errors**

- **SCT and TRT are operating smoothly and are preparing for high \( \mu \) runs**

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**ATLAS** Preliminary

\( \sqrt{s} = 13 \text{ TeV}, 2015 \)
transverse impact parameter resolution
in 2015 (+IBL) and 2012

- large gain in resolution through IBL
- generally good agreement between data and MC
very smooth operations for 50 and 25ns

**LAr:**
- noise burst flagging running @ HLT level (very energetic with high Q factor over a few μs, looked up in a 100ms sliding window)
- LAr Phase-I trigger upgrade demonstrator boards (1.767 < φ < 2.160, |η| < 1.4, super cells record data) installed

**Tile:**
- no LVPS trips (unlike in Run1), 2 dead modules
- Using all calibration systems to preserve the scale
- new MBTS counters were inter-calibrated based on the minimum bias current measurements from Tile
Muons

- alignment performed with toroid magnet off
  - 30M muon tracks collected (target resolution of 10% @ 1 TeV)
  - initial alignment from July available

- overall performance of the muon systems is very good, operational teams are focusing on troubleshooting of small issues
  - TGC deployed the inner coincidence (reduction of muon trigger rates in the ECs.)
  - additional Tile-muon coincidence under commissioning

\[
\begin{align*}
\text{Inst. Luminosity} \quad [10^{33} \text{ cm}^{-2} \text{s}^{-1}] \\
\text{Level 1 Muon Rate (p_c > 20 GeV)} \quad [\text{kHz}]
\end{align*}
\]
ALFA - will be used in the special $\beta^*=90\text{m}$ run; elastic and diffractive physics

LUCID - newly installed, very well performing and providing online and offline luminosity for ATLAS

ZDC - test beam (SPS) showed need for refurbishment of EM modules; will take part in the next LHC Heavy Ion run (installation during TS3) - centrality measurement

AFP - Roman Pot installation approved by LMC on August 26th. Aiming to install infrastructures and possibly two stations in the Year End Technical Stop 2015/2016, soft QCD, hard diffraction
Grid utilisation at full

MC simulation:
- 2.8B simulated events produced
- 5B events reconstructed for 50 ns & 25 ns conditions

No issue with data transfer and data processing

Parts of 2015 data have been reprocessed twice

Major software update for summer 2016 only.

New analysis model: group data format
DxAOD made using a train model
- Production of 83 DxAOD species on the grid via 17 trains
- Within 24h after data reconstruction at Tier-0

Successful and popular
Trigger Performance

- L1 trigger menu ~500 items, HLT ~2000 items
- pedestal correction minimising pile up effects and linearising trigger rate for the L1Calo MET > 35 GeV trigger shows dramatic improvement for the rate

**Single-γ-trig** with $E_T > 25/35$ GeV measured with L1_EM7

$\int = 13$ TeV, $\sqrt{s} = 13$ TeV, $L dt = 15.7$ pb$^{-1}$

$|\eta| < 1.37$, $1.52 < |\eta| < 2.37$

- HLT_g25_loose
- HLT_g35_loose

online-offline resolution for HLT $E_T > 24$ GeV trigger, medium ID applied
Object performance

- Prepared so-called ‘pre-recommendations’ for physics object calibrations based on MC and Run-1 data. These pre-recommendations, verified with early 13 TeV data, were used in initial physics analyses presented at EPS-HEP in July.

- Since then, data driven recommendations were determined for electron and muon identification efficiencies and calibrations, as well as jet calibrations (in-situ corrections). The calibrations of the other physics objects are ongoing.

Electrons and Photons

- Data/MC disagreement in Electron ID is due to (known) GEANT mis-modelling of shower shapes
- quite flat as a function of in-time pile up
- scale factors from data applied to MC
Muon reconstruction

- based on 50 ns data (85 pb\(^{-1}\))
- improved acceptance (1.0 \(< |\eta| < 1.4\)) and reconstruction algorithm

Efficiencies of the combined track-based and calorimeter-based isolation for the Gradient working point

efficient data/MC agreement for reconstruction efficiency, but large \(\delta_{\text{stat}}\)
Jets

- jet cleaning defined – selection of good jets based on calorimeter criteria (beam background, noise, cosmics)
- JES and JER preliminary recommendations (based on simulations) delivered for early analyses, AntiKt4TopoEM, validated on data
- good shape agreement in data/MC -> validated inputs to more sophisticated methods (GSC, substructure...)

\[ \frac{1}{\sqrt{s}} = 13 \text{ TeV}, 25 \text{ ns} \]
\[ \eta = 0.0 \]

25ns JES uncertainties

25ns JES uncertainties

\[
\begin{align*}
\sqrt{s} & = 13 \text{ TeV}, 25 \text{ ns} \\
\text{anti-}k, \text{ EM+JES} + \text{ in situ }, R = 0.4 \\
\eta & = 0.0
\end{align*}
\]
Flavour Tagging

- Several enhancements between Run-1 and 2 will impact flavour tagging
  - Improved tracking (including IBL) and flavour tagging algorithms
  - Significant improvement predicted in both light-flavour (factor ~4!) and c-jet rejection (~1.6)

ATL-PHYS-PUB-2015-022

ATL-PHYS-PUB-2015-039

- Flavour tagging MVA output shows good data-MC agreement
- Full data-based calibration underway
Missing $E_T$

- New techniques developed during LS1, use tracking information
- TST (track soft term), Track MET
- Reduces pile up sensitivity
- Systematics derived from MC, will be updated soon
- Validated against data in ATL-PHYS-PUB-2015-027

Performance plot from mono-jet search
Physics - Measurements and Searches

First Stable Beams at 13 TeV

\[ m_{jj} = 5.2 \text{ TeV} \]

\[ m_{jj} = 6.9 \text{ TeV} \]

\[ J/\Psi \text{ candidate} \]
Inelastic pp Cross Section

- MBTS triggers (counting experiment, highly efficient) runs taken in June
- fiducial volume: $2.08 < |\eta| < 3.86 \rightarrow M_x > 13 \text{ GeV} \rightarrow$ extrapolation
- $\sigma_{\text{inel}} = \sigma_{\text{SingleDiff}} + \sigma_{\text{DoubleDiss}} + \sigma_{\text{CentralDiff}} + \sigma_{\text{NonDiff}}$

Constraints on diffractive dissociative component through single sided event vs inclusive selection (25-30% depending on model)

$\sigma_{\text{fid}} = 65.2 \pm 0.8 \text{ (exp.)} \pm 5.9 \text{ (lum.)} \text{ mb}$

$\sigma_{\text{tot}} = 73.1 \pm 0.9 \text{ (exp.)} \pm 6.6 \text{ (lum.)} \pm 3.8 \text{ (extr.)} \text{ mb}$
Charged Particle spectra and UE

- Measurement of unfolded spectra of charge particle multiplicity, also differentially in $\eta$ and $p_T$
- Comparison to model prediction
- Allowed to validate the tune (Pythia A2) used for the pileup modelling in the 13 TeV MC that was derived from Run-1 data
- 'Leading track underlying event' analysis (ATL-PHYS-PUB-2015-019) has allowed to validate the underlying event tune (Pythia A14) used in the simulation of hard scattering processes, also derived from Run-1 data
**The Ridge**
Observation of long-range elliptic anisotropies in pp collisions

[Image of a graph showing ridge modulation and correlation]

low $N_{ch}$ template ($\sim \sin(\Delta \Phi)$)

- first ATLAS Run2 paper!
- long range correlations at high $\Delta \eta$ and $\Delta \Phi=0$ measured at two $\sqrt{s}$ points - 2.76 TeV (Run1 - 4pb$^{-1}$) and 13 TeV (Run2 - 14nb$^{-1}$)
- at large $N_{ch}$, quantifiable through $Y$

ATLAS
$\sqrt{s}=13$ TeV

- ridge modulation factorises (shows global modulation of per-event single particle distributions)
- $\sim$independent of $\sqrt{s}$ and $N_{ch}$, only of $p_T$

This paper is arXiv:1509.04776
Inclusive jet measurement

- lowest $p_T$ unprescaled trigger ($346 < p_T < 838$ GeV) in central region $|y| < 0.5$
- cross section compared to fixed order NLO (NLOJET++) with several PDFs - CT10, NNPDF3, MMHT

Relative uncertainty of 9% in the integrated luminosity not included

Good agreement with pQCD calculation

$\frac{d^2\sigma}{dp_T dy}$ in pb/GeV

$\frac{\sigma_{\text{NLO pQCD}}(\text{CT10})}{\sigma_{\text{NLOJET++}}}$
W/Z Boson Cross Sections

- 50 ns run, \( L = 85 \text{pb}^{-1} \)

- Single lepton triggers with \( p_T > 24 \) (20) GeV for \( e (\mu) \to \) final selection \( p_T^{\text{lep}} > 25 \) GeV

- \( W: \text{MET} > 25 \text{ GeV}, m_T > 50 \text{ GeV} \sim 1 \text{ M evts} \)

- \( Z: 66 < m_{ll} < 116 \text{ GeV} \sim 80K \text{ evts} \)

- Dominant systematics:
  - luminosity
  - lepton efficiencies
  - backgrounds
  - JES
**W/Z Boson Cross Sections**

**ATLAS** Preliminary
13 TeV, 85 pb⁻¹

- lumi ± exp. uncertainty
- exp. uncertainty
- ▲ ABM12LHC
- ▼ CT10nnlo
- ▼ NNPDF3.0
- ● MMHT14nnlo68CL
  (inner uncert.: PDF only)

### W±

- 15000
- 20000

### Z

- 1300
- 1400
- 1500
- 1600
- 1700
- 1800
- 1900
- 2000
- 2100
- 2200

**ATLAS-CONF-2015-039**

**W/Z Boson Cross Sections**

- ▲ ABM12LHC
- ▼ CT10nnlo
- ▼ NNPDF3.0
- ● MMHT14nnlo68CL

### Z fid σ / W fid σ

- 1500
- 1400
- 1500
- 1600
- 1700
- 1800
- 1900
- 2000
- 2100
- 2200

### W/Z σ / Z fid σ

- 15000
- 20000

**ATLAS-CONF-2015-041**

Z+j XS measured in ATLAS-CONF-2015-041

**good agreement with SM**
single lepton triggers > 25 GeV
exactly 2 leptons with opposite charge
60 < m_{ll} < 81 GeV \| m_{ll} > 101 GeV; MET > 30 GeV
exactly one or two b-Tagged jets (MV2c20 70%)

pure in top
good agreement with SM backgrounds
agreement within uncertainties

\[ \sigma_{tt} = 829 \pm 50 \text{ (stat)} \pm 56 \text{ (syst)} \pm 83 \text{ (lumi)} \text{ pb.} \]

\[ R_{tt/Z} = 0.445 \pm 0.027 \text{ (stat)} \pm 0.028 \text{ (syst)} = 0.445 \pm 0.039 \]
Dijet searches

- High-\(p_T\) searches do not use July data due to a trigger problem
- Central production, highest \(p_T\) (\(> 360\,\text{GeV}\))
- Di-jet invariant mass spectrum (\(> 1.1\,\text{TeV}\))
- Quantum Black Holes models

\(\sqrt{s} = 13\,\text{TeV}, 80\,\text{pb}^{-1}\)

\text{ATLAS Preliminary}

- \(\chi \sim \text{difference in rapidities}\)
- No significant deviations observed, limit extended to 6.5 TeV (+1 TeV wrt Run1)
**Multijet searches**

**ATLAS-CONF-2015-043**

- at least 3 jets, $H_T > 1$ TeV
- Control (fitted) -> Validation -> Signal region
- models with additional space-time dimensions

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Lepton+jet searches - **ATLAS-CONF-2015-046** - show also consistency with SM

Limits are significantly extended wrt Run1, yet no evidence for deviations from SM was observed
Brief selection of latest Run1 Highlights

ATLAS-CONF-2015-047

- 8 TeV analysis (20.3 fb^{-1}), single lepton triggers
- Single top s-channel production, leptonic W decays, Matrix element method

Run1 ATLAS+CMS coupling combinations

- H\rightarrow ZZ, WW, \gamma\gamma, \tau\tau, bb & \mu\mu
- \mu = 1.09^{+0.11}_{-0.10}

Significance (VBF) = 5.4\sigma
Significance (H\rightarrow\tau\tau) = 5.5\sigma

ATLAS-CONF-2015-044
CMS-PAS-HIG-15-002

\sigma=4.8^{+2.5}_{-2.2} \text{ pb}

SUSY Run1 summary on phenomenological MSSM (19 parameters)

22 ATLAS searches considered (Inclusive, 3rd generation of squarks, EW produced,...)

arXiv:1508.06608
Into the future...

- 3 Scoping Scenarios for $\mu=200$ and $L=3ab$:
  - **275MCHF** - “Reference”
    - ITk up to $|\eta| = 4.0$, sFCAL, timing detectors...
  - **235MCHF** - “Middle”
    - ITk up to $|\eta| = 3.2$, central region degradation
  - **200MCHF** - “Low”
    - ITk up to $|\eta| = 2.7$, significant central region degradation

### HWW VBF, ~100% degradation from Ref->Low

<table>
<thead>
<tr>
<th>Scoping Scenario</th>
<th>without Theo. Unc. $\Delta \mu/\mu$</th>
<th>$Z_0$-value ($\sigma$)</th>
<th>with Theo. Unc. $\Delta \mu/\mu$</th>
<th>$Z_0$-value ($\sigma$)</th>
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<tbody>
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<td>0.14</td>
<td>8.0</td>
<td>0.20</td>
<td>5.7</td>
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<td>0.20</td>
<td>5.4</td>
<td>0.25</td>
<td>4.4</td>
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<tr>
<td>Low</td>
<td>0.30</td>
<td>3.5</td>
<td>0.39</td>
<td>2.7</td>
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</tbody>
</table>

- Distribution of pile up jets (> 30 GeV) and effect of PU mitigation in the tracker range

- Low scenario dramatically reduces potential for SUSY searches
Summary

- Huge thanks to the LHC team for the good start and rapidly increasing luminosity!
- ATLAS has restarted successfully
  - Detector is in good shape and running quite smoothly
  - recorded now 0.8 fb\(^{-1}\) with a data-taking efficiency of 91%
- Detailed performance studies ongoing, demonstrating already a good understanding of the 2015 data
- Exploring the landscape of physics at 13 TeV with measurements of inclusive, jet, W, Z and top production processes
- Sensitivity to beyond-the-SM physics starts to extend beyond Run-1
- Eagerly awaiting more data in 2015!

Full list of 13 TeV results can be found [here](#)
backup
Run1 Searches for new heavy bosons

ATLAS-CONF-2015-045

- lvl'l', llqq, lvqq and JJ final states
- J ... CA R=1.2 jets -> groomed (mass drop)
- Extended Gauge Model (EGM, W')
- bulk-Randall-Sundrum (RS, G*)

bRS min. mass limit = 790 (810) GeV exp (obs)

EGW min. mass limit = 1.81 TeV (exp = obs)
# ATLAS Status

## ATLAS pp run: June-August 2015

| Inner Tracker | Calorimeters | Muon Spectrometer | Magnets |  |
|---------------|--------------|-------------------|---------|
| Pixel         | SCT          | TRT               | LAr     | Tile    | MDT   | RPC   | CSC   | TGC | Solenoid | Toroid |
| 98.5          | 99.7         | 100               | 99.1    | 100     | 100   | 99.3  | 100   | 100 | 100       | 99.6   |

Luminosity weighted relative detector uptime (in percent) and good quality data delivery during the stable beams in pp collisions at 13 TeV between June-August 2015, corresponding to 173 pb\(^{-1}\) recorded luminosity.

<table>
<thead>
<tr>
<th>period</th>
<th>date</th>
<th>bunch spacing</th>
<th>(\mu)(_{\text{Max}})</th>
<th>(L_{\text{peak}}) ([10^{32}\text{cm}^{-2}\text{s}^{-1}])</th>
<th>(L_{\text{recorded}}) ([\text{pb}^{-1}])</th>
<th>(L_{\text{total}}) ([\text{pb}^{-1}])</th>
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<td>3.6.-14.6.</td>
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<td>27.6</td>
<td>1.4</td>
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<td>25ns</td>
<td>29.4</td>
<td>10.5</td>
<td>105</td>
<td>214</td>
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*EPS dataset*

*LHCP dataset*
Inner Detector (II)

- **SCT** - Noise, gain and operating voltage comparable to Run1 conditions, Excellent data taking efficiency
  - SCT vetoing signals from “previous” BX causes inefficiencies during 25 ns running (negligible effect on the data)

- **TRT** operates smoothly and provides high DQ, preparing HW and SW tools to run with high $\mu$ and 25ns
  - HV Protection system against overshoot at the beam dump implemented.
  - No discharges in the detector since
  - Significant ROD repair effort and ROD FW upgrade made. (10% spares, able to operate @ 100kHz)
    - due to leaks in exit pipes (50-70l/day, no new ones in Run2), Ar is used in parts of the detector instead of Xe, Kr is under testing
Muons

- alignment performed in July and August runs with toroid magnet off

- resolution of 10% @ 1 TeV needs resolution 20-80µm (10^{-6} scale!), ~30M muon tracks ~collected

- overall performance of the muon systems is very good, operational teams are focusing on troubleshooting of small issues

- **CSC** - two planes OFF, 5 reduced HV

- **MDT** - noise burst study ongoing (origin in one chamber)

- **RPC** - new chambers installed in LS1 and equipped with electronics in LS1; still need some development and commissioning work

- **TGC** are ready to deploy the inner coincidence (reduction of muon trigger rates in the ECs.); timing verified (scan), Tile-muon coincidence under commissioning
Tracking

transverse impact parameter in 2015 (+IBL) and 2012

• huge gain through IBL

• generally good agreement between data and MC

very well modelled alignment & #IBL hits
Muon reconstruction

- based on 50 ns data (85 pb\(^{-1}\))
- improved acceptance (1.0 < |\(\eta|\) < 1.4) and reco algorithm

Efficiencies of the combined track-based and calorimeter-based isolation for the Gradient working point

Excellent agreement, but large \(\delta_{\text{stat}}\) mass resolution:
- J/\(\Psi\): 35-60 MeV
- Z: 1.5-2.0 GeV
- identification based on BDT
- data samples: low $\mu$ runs (MBTS trigger) and high $\mu$ ($e, \mu$ and $\tau$ triggers)

**minimum bias**

**W(\rightarrow \mu\nu)+jets**

**enriched $Z\rightarrow\tau\tau$ sample**

- good modelling by MC and understanding of the detector
Jets (I)

- Jet cleaning – selection of good jets based on calorimeter criteria (beam background, noise, cosmics)
- Criteria for analyses defined
- JES and JER preliminary recommendations (based on simulations) delivered for early analyses, AntiKt4TopoEM

**Energy Response**

- **ATLAS Simulation Preliminary**
  - Pythia Dijet $\sqrt{s} = 13$ TeV
  - Anti-$k_t$, EM jets $R = 0.4$
  - $E_{\text{true}} > 20$ GeV

**MC JES correction**

**25ns uncertainties**

- $\sqrt{s} = 13$ TeV, 25 ns
- anti-$k_t$, EM+JES + in situ, $R = 0.4$
- $\eta = 0.0$

**Total uncertainty**
- Total uncertainty, 2012
- Absolute in situ JES (2012)
- Relative in situ JES (scaled 2012)

**Flav. composition**
- Flav. response
- Pileup, predicted 2015 conditions
- Punch-through, predicted 2015 conditions
- 2012 to 2015 extrapolation uncertainty
Jets (II)

- preliminarily calibrated jets
- MC normalized to data
- good shape agreement -> validated inputs to more sophisticated methods (GSC, substructure...)

**ATLAS** Preliminary

\[ \sqrt{s} = 13 \text{ TeV}, 0.22 \text{ nb}^{-1} \]

- anti-\( k_t \), \( R = 0.4 \)
- \( |y_{\text{jet}}| < 4.5, p_T > 25 \text{ GeV} \)

**ATLAS** Simulation Preliminary

- anti-\( k_t \), \( R = 1.0 \) jets
- Trimmed (\( f_{\text{cut}} = 0.05, R_{\text{sub}} = 0.2 \))
- Double b-tagged @ 70% WP

**Higgs(\rightarrow bb) Tagger, large R jets**
**The Ridge**

Observation of long-range elliptic anisotropies in pp collisions

\[ Y^{\text{templ}}(\Delta \phi) = F Y^{\text{periph}}(\Delta \phi) + Y^{\text{ridge}}(\Delta \phi), \]

\[ Y^{\text{ridge}}(\Delta \phi) = G (1 + 2v_{2,2} \cos(2\Delta \phi)), \]

\[ v_2(p_T) = v_{2,2}(p_T^1, p_T^2) / \sqrt{v_{2,2}(p_T^1, p_T^2)}, \]
Pile up jets in Run1 vs HL-LHC

- pile up jet multiplicity in Run1 and HL-LHC conditions:
  - $\langle \mu \rangle = 20$ for $p_{Tj} > 30$ GeV ... $\langle n_{j^{PU}} \rangle \sim 0.04$
  - $\langle \mu \rangle = 200$ for $p_{T} > 30$ GeV ... $\langle n_{j^{PU}} \rangle \sim 7.4$
Lepton+jet searches

- single lepton trigger $p_T > 50$ GeV
- SRs: $p_{Tl} > 100$ GeV + additional l/j with $p_T > 100$ GeV, $\sum p_T > 2$ TeV/3TeV
- bkg: W+j, Z+j, ttbar -> CRs

no evidence for deviations from SM was observed