Max-Planck-Institut für Physik

Searches for new phenomena with the ATLAS detector

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on behalf of the ATLAS Collaboration

- **overview** of ATLAS **Beyond the Standard Model** searches
- **focus** on analyses performed using **full 13 TeV Run-2** integrated luminosity
  - probing very different **final states**
  - using different **physics objects**
- present **perspectives** for the future at **HL-LHC**
- does this talk cover **all ATLAS BSM searches**?
  - no, that would take quite some time...
  - find more here
    - ATLAS exotics
    - ATLAS higgs and diboson
    - ATLAS results (all)
- recall Yanwen Liu's review talk on 26/8
- see Edoardo Maria Farina's talk on 29/8 about Dark Matter
- see Tadej Novak's talk on 29/8 about lepton+jets final states

Run-2

- **dijet**
  - [ATL-CONF-2019-007](#)
- **dibjet**
  - [EXOT-2019-03](#): soon to be public
- **dilepton**
  - [Phys. Lett. B 796 \(2019\) 68](#)
- **lepton+MET**
  - [EXOT-2018-30](#)
- **diboson**
  - [HDBS-2018-31](#)
- **dihiggs**
  - [ATLAS-CONF-2019-030](#)

HL-LHC

- **dijet**
  - [ATL-PHYS-PUB-2015-004](#)
- **dilepton and lepton+MET**
  - [ATL-PHYS-PUB-2018-044](#)
- **diboson**
  - [ATL-PHYS-PUB-2018-022](#)
- **dihiggs**
  - [ATL-PHYS-PUB-2018-028](#)

Run-2

- search for **localized resonances** in the dijet invariant **mass spectrum**
- benchmark models:
  - **excited quarks**
  - **generic gaussian signals**
- event selection
  - unprescaled single jet trigger
  - jets $p_T > 150$ GeV
  - central jets: $|y^*| < 0.6$
  - $m_{jj} > 1.1$ TeV
- **main background**: QCD
- **data-driven background**
  - **fit function**: $f(x) = p_1(1 - x)^{p_2}x^{p_3+p_4\ln(x)}$
  - sliding window method
- **BumpHunter** test statistic
- most **discrepant** region: 7.1-7.3 TeV
  - p-value = **0.8**
  - **not significant**

- **limits** set at 95% CL using CL_s method
- **excited quarks limits**
  - $m_{q^*} > 6.7 \text{ TeV}$, 139/fb
- **previous** excited quarks limits:
  - $m_{q^*} > 6.0 \text{ TeV}$, 37/fb
- limits set on **generic gaussian signals**
  - allow **re-interpretation** of results
  - signal width: 3-15%
- recall Trine Poulsen's talk on 27/8 about hadronic final states

- search for **localized resonances** in the dibjet invariant **mass spectrum**
- benchmark models:
  - **excited b quarks**, **Z'** (dark matter mediator and SSM), **graviton**, **generic gaussian signals**
- event selection
  - same as for **dijet**
  - 1 or 2 **b-jets**
- **main background**: QCD
- **data-driven** background
  - **fit function**
  - sliding window method
- **BumpHunter** test statistic
- most **discrepant** region: ~ 1.5 TeV
  - p-value = **0.83**
  - **not significant**

- **limits** set at 95% CL using CL_s method
- **excited quarks limits**
  - $m_{Z'(\text{SSM})} > \mathbf{2.7\ TeV}$, 139/fb
- **previous** excited quarks limits:
  - $m_{Z'(\text{SSM})} > 2.0\ \text{TeV}$, 37/fb
- **×1.2-3.7 improvement** factor beyond integrated luminosity increase
  - thanks to improved **b-tagging**

- search for **localized resonances** in the dilepton invariant **mass spectrum**
  - **dimuon** and **dielectron**
- benchmark models:
  - **narrow generic Breit-Wigner signals**
  - **Z'** (ψ , X , SSM), **Heavy Vector Triplet** model
- event selection
  - trigger: dielectron or single muon
  - lepton $p_T > 30$ GeV
  - $m_{ll} > 225$ GeV
- main background: Drell-Yan Z
- **data-driven** background
  - **fit function**
- most **discrepant** regions:
  - combined: 264 GeV, $p_0 = 0.0 \sigma$
  - **none significant**

- **improvements** over previous analysis
  - event reconstruction, detector alignment, $\times 4$ integrated luminosity
- **dominant systematic uncertainties**
  - spurious signals, electron identification, muon quality
- **limits** set at 95% CL using CL_s method
- **Z'_{SSM} limits**
  - $m_{Z'(\ell\ell)} > 5.1 \text{ TeV}$, 139/fb
    - $m_{Z'(\text{ee})} > 4.9 \text{ TeV}$, 139/fb
    - $m_{Z'(\mu\mu)} > 4.5 \text{ TeV}$, 139/fb
- **previous Z'_{SSM} limits:**
  - $m_{Z'(\ell\ell)} > 4.5 \text{ TeV}$, 36/fb
    - $m_{Z'(\text{ee})} > 4.3 \text{ TeV}$, 36/fb
    - $m_{Z'(\mu\mu)} > 4.0 \text{ TeV}$, 36/fb
- see [Deshan Kavishka Abhayasinghe's talk](#) on 29/8 about dilepton final states

- search for **heavy charged bosons**
- **signature**: one charged lepton (e, μ) and **Missing Transverse Energy** (ν)
  - clean channel, low background
  - excess in lepton+MET **transverse mass** distribution
- benchmark models: **W' _{SM}**, generic resonances
- **event selection**
  - unrescaled single lepton (e or μ) trigger
  - exactly one isolated lepton
  - $p_T > 65/55$ GeV (e/ μ)
  - MET > 65/55 GeV (e/ μ)
  - $m_T > 130/110$ GeV (e/ μ)
  - $m_{lv} > 1.1$ TeV
- **main background**: Drell-Yan W
- background **described by MC**
  - high m_T tails fitted
- QCD background data-driven
- **combined fits** of e and μ channels
- **no significant deviations**

- **improvements** over previous analysis
  - event reconstruction, detector alignment, $\times 4$ integrated luminosity
- **dominant systematic uncertainties**
  - lepton reconstruction, identification, momentum scale and resolution
- **limits** set at 95% CL using CL_s method
- **W'_{SSM} limits**
  - $m_{W'}(l\nu) > \mathbf{6.0\ TeV}$, 139/fb
    - $m_{W'}(e\nu) > \mathbf{6.0\ TeV}$, 139/fb
    - $m_{W'}(\mu\nu) > \mathbf{5.1\ TeV}$, 139/fb
- **previous W'_{SSM} limits:**
  - $m_{W'}(l\nu) > 5.2\ TeV$, 36/fb
    - $m_{W'}(e\nu) > 5.1\ TeV$, 36/fb
    - $m_{W'}(\mu\nu) > 4.7\ TeV$, 36/fb

- search for **localized resonances** in the diboson invariant **mass spectrum**
- **benchmark models**: HVT model, graviton
- **signature**: two boosted vector bosons producing large-R jets
  - decays products (qq) highly collimated
  - all hadronic channel has the **largest branching ratio**
- **event selection**
  - unrescaled single jet trigger
  - two large-R jets: $p_T > 500, 200$ GeV
  - $m_{JJ} > 1.3$ TeV
- **main background**: QCD
- **data-driven** background
  - fit function
- **no significant deviations**

- **2.40 TeV** dijet invariant **mass**
  - jet p_T of **1.26 TeV** and **1.15 TeV**
  - jet invariant **mass** of **83.7 GeV** and **73.9 GeV**
- visible **two-pronged** structure of both large-R jets

- **dominant systematic uncertainties**
  - background fit, jet tagging, jet p_T calibration
- **limits** set at 95% CL using CL_s method
- **limits**
  - $m_{\text{HVT}} > 3.5/3.8 \text{ TeV}$, 139/fb
- **previous limits:**
  - $m_{\text{HVT}} > 3.1/3.5 \text{ TeV}$, 37/fb
- recall Yuta Okazaki's poster on diboson search

- search **resonant and not-resonant** di-Higgs production
  - Higgs decaying to two b quarks
- **signature**: 4 b-jets
  - **Vector Bosons Fusion** production: 2 forward jets
- **2016-2018 data, 126/fb**
  - temporary trigger b-tagging inefficiencies in 2016
- **event selection**
  - mix of b-jet triggers
  - 4 b-jets, $p_T > 40$ GeV
  - 2 forward jets, $p_T > 30$ GeV
  - additional requirements on jets combination for HH pair
- **main background**: QCD and tt
- most discrepant region: 550 GeV
  - **not significant**: $p_0 = 1.5 \sigma$

- **dominant systematic uncertainties**
  - QCD background, jet energy scale and resolution
- **limits** set at 95% CL using CL_s method
  - no benchmark model
- **non-resonant** di-Higgs production compatible with **Standard Model** expectations
  - c_{2V}: 4-point coupling (di-Higgs and divector boson)
- recall [Yuta Sano's talk](#) on 27/8 about di-Higgs final states

HL-LHC

we are here

- recall [Francesca Pastore's talk](#) on 26/8 about ATLAS and HL-LHC
- High Luminosity LHC**
  - increased **instantaneous luminosity**: from 2 to $7.5 \times 10^{34} \text{ cm}^{-2}\text{s}^{-1}$
  - increased **pile-up**: from 34 to 200 interactions per bunch crossing
  - increased **radiation** damage ($\times 10$ dose)
  - >10 years** data taking
  - 3/ab** integrated luminosity

- ATLAS Phase-2**

- trigger** rate up to 10 kHz ($\times 10$ increase)
- new **Inner Tracker** (ITk) to replace current Inner Detector
- muon chambers** with higher granularity
- new High Granularity **Timing Detector**
- new **calorimeter readout**
- similar performance** to current detector despite **fiercer conditions**

- MC with **parametrized** detector **response**
- based on **2015** dijet search (3.6/fb)
- q^* **signal injected** into QCD **data-like** background
- integrated luminosity **increased until** signal is **identified** with 5σ
  - tested up to 3/ab
- **signal sensitivity** grows ~ 1 TeV for each order of magnitude of integrated luminosity
- **expected limits** in line with **2018 results** ($m_{q^*} > 6.7$ TeV) however...
- dijet analysis **updates and improvements** since 2015
  - e.g. sliding window instead of global fit

- MC with **parametrized** detector **response**
- 3/ab at **13, 14 and 15 TeV**
- 15/ab at **27 TeV (HE-LHC)**
  - electron channel only (muon spectrometer limitations)
- analysis **strategy** similar to 13 TeV
  - single lepton triggers
  - two leptons
  - $p_T > 25$ GeV
- main **background**: Drell-Yan Z
- search limited by **statistics**
- **discovery** reach similar to limits
  - looking in the m_T **tail**
- **limits**
  - $m_{Z'(\ell\ell)} > \mathbf{6.5\ TeV}$, 3/ab at **14 TeV**
  - $m_{Z'(\ell\ell)} > \mathbf{12.8\ TeV}$, 15/ab at **27 TeV**
- **current** limits:
  - $m_{Z'(\ell\ell)} > 5.1$ TeV, 139/fb at 13 TeV
- **discovery** reach (5σ):
  - $m_{Z'(\ell\ell)} < \mathbf{6.4\ TeV}$, 3/ab at **14 TeV**
  - $m_{Z'(\ell\ell)} < \mathbf{12.8\ TeV}$, 15/ab at **27 TeV**
- ± 1 TeV in **sqrt(s)** can change the results by 0.2-0.3 TeV

- MC with **parametrized** detector **response**
- analysis **strategy** similar to 13 TeV
  - single lepton triggers
  - exactly one lepton (e or μ)
  - $p_T > 65/55$ GeV (e/ μ)
  - MET > 55/65 GeV (e/ μ)
- main **background**: Drell-Yan W
- search limited by **statistics**
  - looking in the m_T **tail**
- limits**
  - $m_{W'}(lv) > 7.9$ TeV, 3/ab at 14 TeV
- current** limits:
  - $m_{W'}(lv) > 6.0$ TeV, 139/fb at 13 TeV
- discovery** reach (5σ):
  - $m_{W'}(lv) < 7.7$ TeV, 3/ab at 14 TeV
  - similar to limits since ~ 0 events in the tails

- MC with **parametrized** detector **response**
- **semileptonic** channel: $WV \rightarrow lvqq$
  - single lepton triggers
  - exactly one lepton (e or μ)
  - two jets or one large-R jet
    - **resolved or merged**
  - MET > 60 GeV
  - **VBF or ggF** production
- main **background**: W+jets
- search limited by **statistics**
  - looking in the m_T **tail**
- **limits**
  - $m_{HVT(WZ)} > 4.3 \text{ TeV}$, 300/fb at 14 TeV
  - $m_{HVT(WZ)} > 4.9 \text{ TeV}$, 3/ab at 14 TeV
- **current limits** ($WV \rightarrow lvqq$):
  - $m_{HVT(WZ)} > 2.8 \text{ TeV}$, 36/fb
- **current limits** ($VV \rightarrow qqqq$):
  - $m_{HVT(WW+WZ)} > 3.5 \text{ TeV}$, 139/fb
- **discovery reach** including tagger **improvements** (TCC jets, $VV \rightarrow qqqq$)

- mix of **scaled** 13 TeV **data**, **MC** and **MC truth** samples
- analysis **strategy** similar to 13 TeV **boosted**
  - large-R jet trigger
  - two large-R jets
  - jet $p_T > 450, 250$ GeV
- main **background**: QCD
- **limits**
  - $m_G > 2.75/2.00$ TeV, 3/ab at 14 TeV
- **current** limits:
  - $m_G > 1.36/\text{NA}$ TeV, 36/fb at 13 TeV

- overview of ATLAS Beyond the Standard Model searches
- focus on full Run-2 analyses
- current results compared to HL-LHC perspectives
  - expect sensible improvements
- plenty of results to come from Run-2
- improvements from combinations
- Run-3 coming next

ATLAS Exotics Searches* - 95% CL Upper Exclusion Limits

Status: May 2019

ATLAS Preliminary

$\int \mathcal{L} dt = (3.2 - 139) \text{ fb}^{-1}$ $\sqrt{s} = 8, 13 \text{ TeV}$

*Only a selection of the available mass limits on new states or phenomena is shown.

[†]Small-radius (large-radius) jets are denoted by the letter j (J).

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thank you