Searching for a New Z' Vector Boson in 4μ Events with the ATLAS Experiment

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Physics Motivation

- A new gauge boson Z' is predicted by well-motivated gauged $L_\mu - L_\tau$ models [1], which extends the Standard Model (SM) with an additional $U(1)_{L_\mu - L_\tau}$ symmetry to address the observed muon anomalous magnetic dipole moment $(g-2)$ [2-5] and the B meson decay anomalies [6-9]. These models also aim to probe outstanding questions related to the dark matter and neutrino mass.
- In the $L_\mu - L_\tau$ model, the Z' couples to the 2nd and 3rd generation left-handed lepton doublets (μ, τ and neutrinos) and right-handed μ and τ singlets.
- At the LHC, the Z' could be produced in the final-state radiation of muon or tau leptons.
- Four-muon (4μ) final state is used to search for the new gauge boson Z' from radiative Drell-Yan production around Z pole energy with the ATLAS experiment.

Data and MC

Data

- Collected by ATLAS at LHC in pp collisions at $\sqrt{s}$=13 TeV, with total integrated luminosity of 139 fb^{-1}

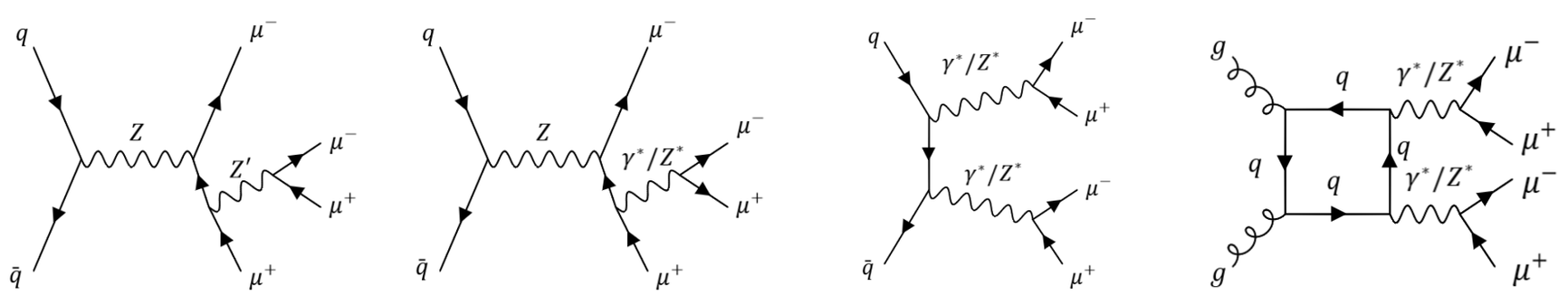
Signal MC samples

- Leading Order (LO) Universal Feynman rules Output (UFO) model with MadGraph + Pythia8
- 25 mass points from 5 to 75 GeV

Background MC samples

- >95% background from SM single resonant $Z \to 4\mu$ (s-channel)
- ~4% background from SM t-channel ZZ* production from $q\bar{q}$
- $gg \to ZZ$: negligible under the Z peak. ~6% level in Z off-shell region

Feynman Diagrams



Z' Production via Drell-Yan process

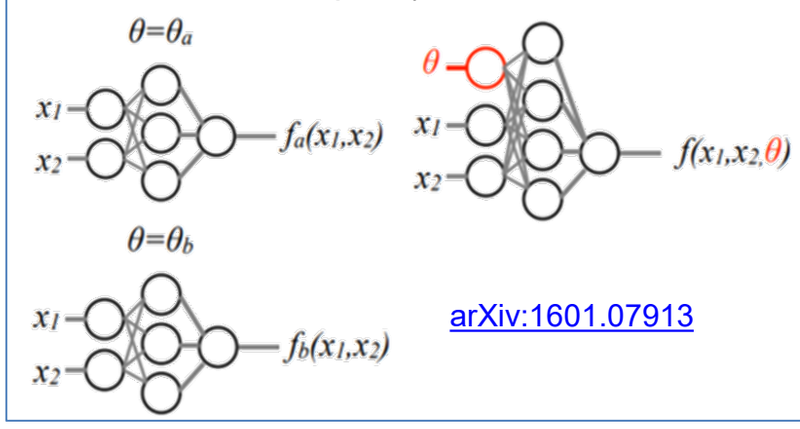
SM background processes

4μ event selection

- Numb. of identified muons ≥4
- $p_T^{\mu,i}$ (i=1,4) > 20, 15, 8, 3 GeV
- μ isolated with impact parameter significance $\frac{d_0}{\sigma_{d0}} < 3$
- Angular separation $\Delta R(\mu_i, \mu_j) > 0.2$
- 2 pairs of $\mu^+\mu^-$ are selected: Z_1 has the smallest mass difference compared to Z mass; Z_2 is selected from remaining pair.
- $m_{4\mu}$ inside mass window [80, 110] or [130, 180] GeV

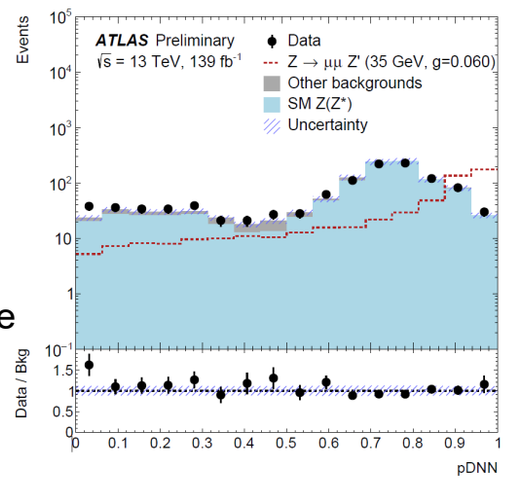
Parameterized deep neural network (pDNN)

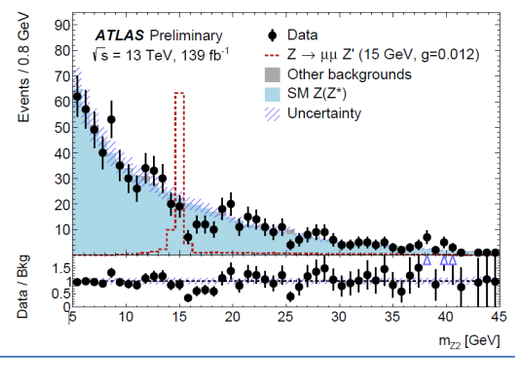
- Parameterized deep neural network (pDNN) is used to classify 4μ events to either signal or background categories at different Z' hypothesis mass points
- The training make use of basic kinematic distributions as the input features
- The model is optimized using the Bayesian method to optimized the hyperparameters automatically to gain the optimal performance
- (g represents the coupling strength of the Z' to muons in the plots)



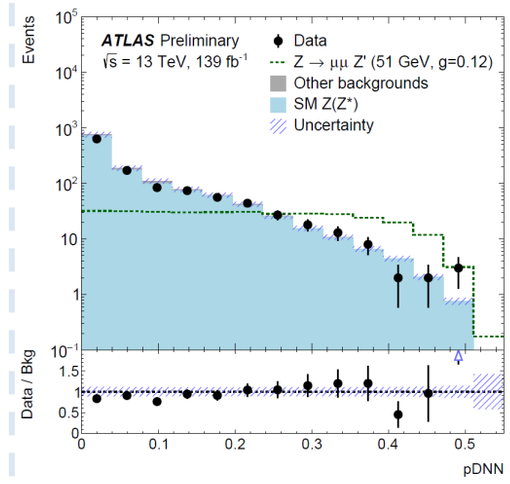
arXiv:1601.07913

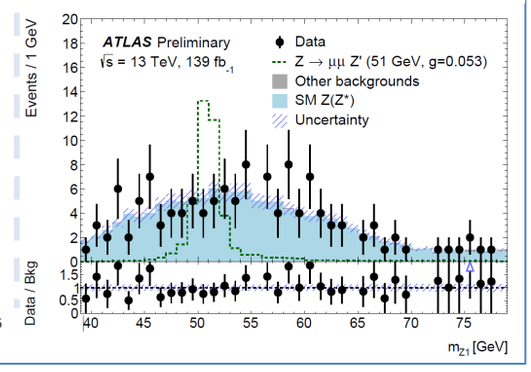
$m_{Z'} \leq 42$ GeV





$m_{Z'} \geq 42$ GeV





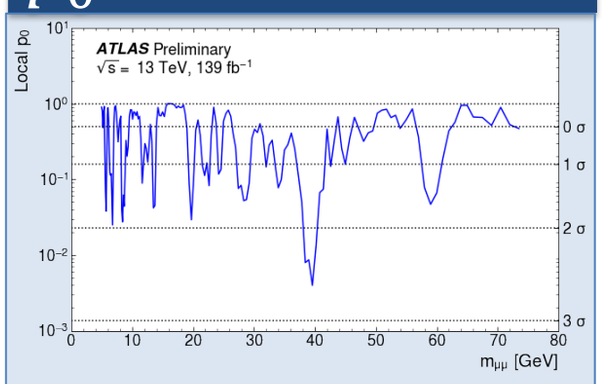
Yields summary

Data - 1131

Total background - 1148 ± 70

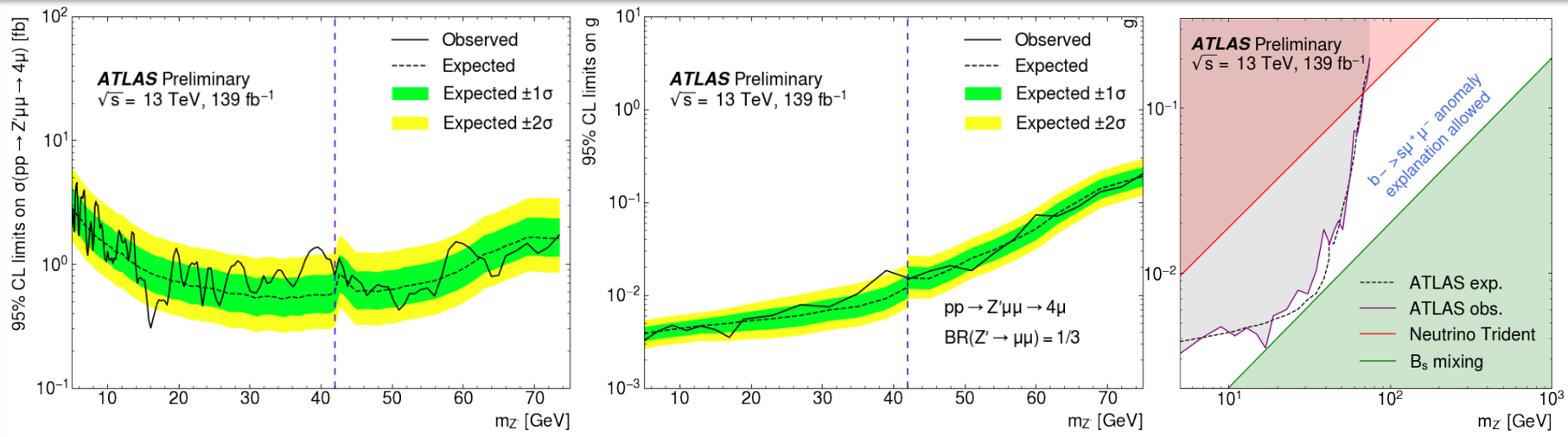
- $qq \to ZZ^*$ - 1065^{+70}_{-69}
- $gg \to ZZ^*$ - 15.6 ± 2.5
- $ttV + VVV + H$ - 6.2 ± 2.9
- fake - $61.1^{+9.1}_{-8.3}$ estimated from data

p_0 scan



- The smallest p_0 values @ 39.6 GeV, corresponding to 2.6 σ deviation (b-only model)
- The global deviation 0.52 σ
- No significant data excess

Upper limits



- Limits are extracted by fitting data to the Z_1 and Z_2 mass spectra, which are obtained with pDNN classifier
- Coupling strength g of the Z' to muons are excluded from **0.003 to 0.2**, depending on the Z' mass
- Excludes an interesting part of the $m_{Z'} - g$ parameter space, which was allowed to explain the B decay anomalies and not excluded by B_s mixing measurements and Neutrino Trident experiments

References

[1] X.-G. He, G. C. Joshi, H. Lew and R. R. Volkas, Phys. Rev. D 44 (7 1991)
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[5] Muon g-2, Phys. Rev. D 73 (7 2006)
[6] LHCb, Nat. Phys. 18 (2022) 277
[7] LHCb, Phys. Rev. Lett. 111 (2013)
[8] LHCb, Phys. Rev. Lett. 113 (2014)
[9] LHCb, Phys. Rev. Lett. 125 (1 2020)