Higgs measurements in the $H\to ZZ^* \to 4l$ channel in the ATLAS detector using the KLFitter tool

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Overview: $H \rightarrow ZZ^* \rightarrow 4l$ channel
H→ZZ*→4l channel in the ATLAS detector

• Good sensitivity: $S/B \sim 2$ (120 GeV < $m_{4l}$ < 130 GeV).
• Excellent mass resolution in the four final states: 1.6 GeV to 2.2 GeV.
• Backgrounds:
  - ZZ (QCD ZZ production).
  - Z+jets and $t\bar{t}$.
• The final states are divided into four categories: $\mu\mu\mu\mu$, $eeee$ (4e), $\mu\mu e$ (2$\mu2e$) and $ee\mu\mu$ (2e2$\mu$).
• Event selection:
  - Two opposite sign and same flavour dilepton pair in an event.
  - Z mass constraint was applied.
• Higgs measurements:
H→ZZ*→4l mass measurement

- 2D likelihood fit method (m_{4l}, BDT_{ZZ})
  BDT_{ZZ} input: p_T, \eta and matrix-element kinematic discriminant.
  reduced expected statistical uncertainty by 8% w.r.t 1D.

\[ m_H = 124.51 \pm 0.52 \text{ (stat)} \pm 0.06 \text{ (syst)} \text{ GeV} \]
\[ = 124.51 \pm 0.52 \text{ GeV} \]

Previous result:
\[ m_H = 124.3 \pm 0.6(-0.5) \text{ (stat)} \pm 0.5(-0.3) \text{ (syst)} \text{ GeV} \]
\[ \mu = 1.43 \pm 0.40(-0.38) \]

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- Systematic uncertainty: almost negligible due to improvement on the electron and photon energy uncertainty.
- Cross checks with 1D likelihood and a method utilising per-event lepton resolution without the Z-mass constraint. All consistent with 2D method.
Z mass constraint in Run I
Higgs mass resolution can be improved by constraining the 4-momenta of the leptons that comes from the physical (on-shell) Z boson in such a way that the dilepton mass is equal to the mass of the Z boson in that event. This procedure is called the Z mass constraint.

The Z boson has a natural width which is comparable with the detector resolution.
If there is enough energy for both Z bosons to be on-shell, as in the case of a high mass Higgs, then the Z mass constraint is also applied to the second pair of leptons.

The likelihood is maximised to obtain $m_Z^{\text{fit}}$. This is combined with the off-shell leptons to obtain $m_{4l}$.

Z mass constraint improvement $\sim 15\%$ (using signal MC).

Improvements that could help: Take into account each possible assignment of leptons to off-shell and on-shell Z bosons. Additional leptons and jets can be considered in the event.
Kinematic Likelihood Fitter Tool (1)

- The kinematic likelihood Fitter (KLFitter) is a general tool for kinematic fits.
- The tool is independent of the physics process (KLFitter tool is used in top quark single lepton analyses).
- The KLFitter maximises the likelihood function with respect to given parameters and constraints. The parameters are usually the energies of jets and charged leptons, which are varied in the fit. Constraints are typically given by distributions around the invariant mass of a decay vertex (for example the invariant mass of the Z boson decaying into two leptons).
Kinematic Likelihood Fitter Tool (2)

- In the case of the Z boson decaying into two leptons, the tool allows it to consider all possible permutations of assigning the leptons to the Z boson. Also, additional leptons and jets can be considered in the event.

- The KLFitter provides probability weights for each combination.

We are studying the feasibility of using this tool for the Higgs ZZ analyses.
Results

- In a first stage, our study was to validate the KLFitter tool against the standard tool used in run I.
- Both tools were implemented in a Run I analysis code.
- A MC sample with $m_H = 125$ GeV with 10000 events was used.
- Only default pairing of leptons was considered.
KLFitter uses Minuit as the minimisation method.

Values are consistent with one. See ratio plots.

The maximum differences are of the order of 50 MeV and of 10 MeV for $m_{Z1}$ and $m_{4l}$.

Resolution is improved a bit in the $m_{4l}$ distribution.
Conclusions

❖ The standard Z mass constraint is a powerful tool to improve the resolution of the $m_{4l}$ distribution.

❖ However, more information can be added to the fit to improve this even more.

❖ We are capable of reproduce the standard Z mass constraint results using KLFitter.

❖ The fitter holds promise for improvements in Run 2 (maybe Run I) for Higgs mass measurements.
Backup
Same minimisation method

- Same minimisation method was used for both constraints (Minimisation of the log likelihood by slicing the likelihood 400 times).
- No differences between both methods (standard: blue, klfitter: red), ratio is consistent with one.
- We are capable of reproduce the Z mass constraint standard with KLFitter tool.