Probing ZZ diboson polarization with four-lepton events in ATLAS

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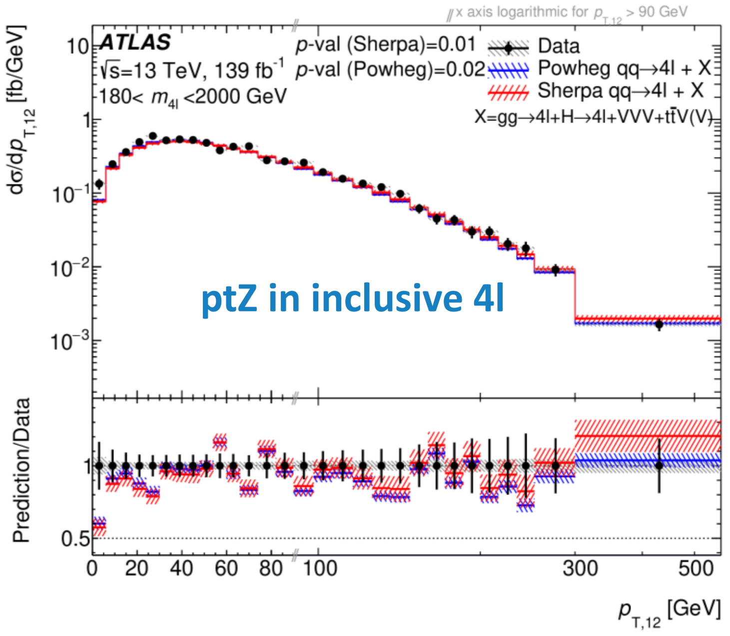
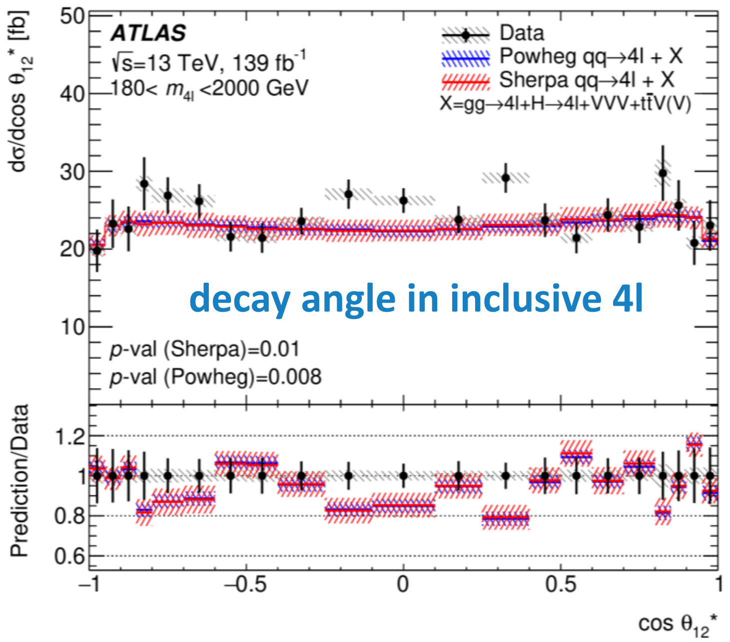
Introduction

- **Motivation**

  - Diboson polarization: a good probe for SM test and New Physics search:
    - **Longitudinal-longitudinal (LL)** version of VBS
      - test Higgs mechanism of EWSB in SM
    - Polarized differential cross-sections
      - constrain EFT operators

  - pp→4l differential cross-sections measured as a function of **many observables** with **high precision** in ATLAS



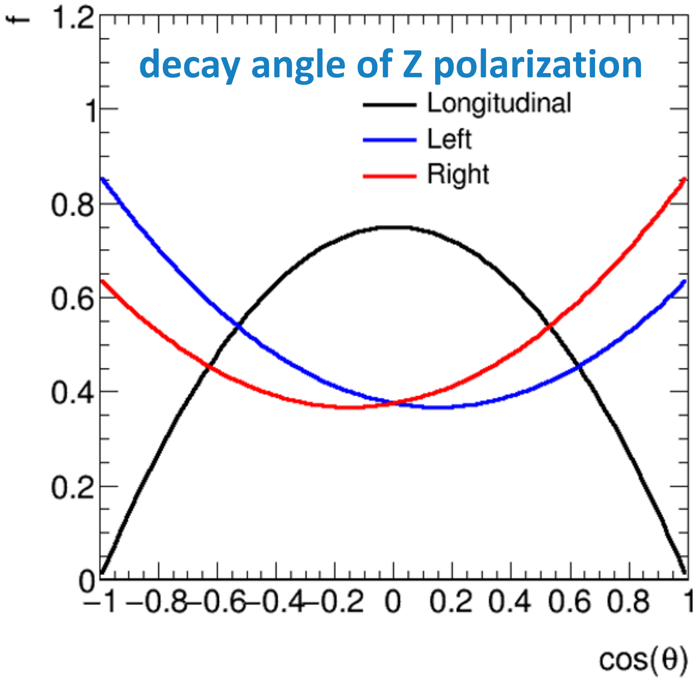


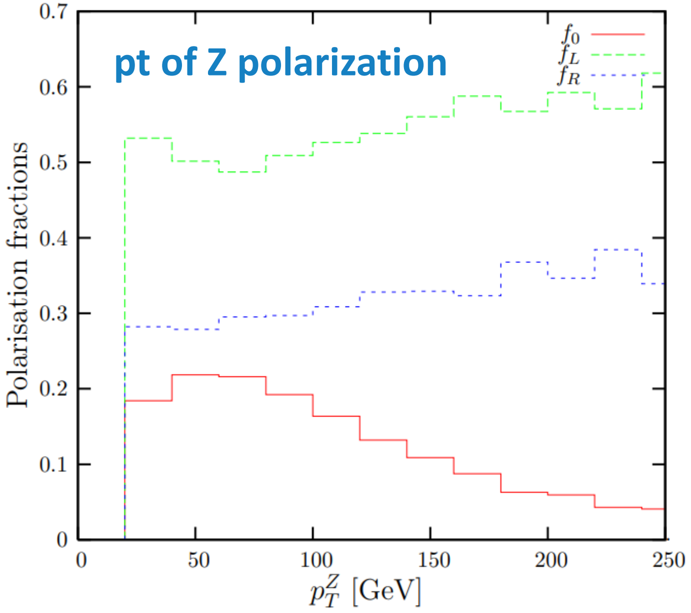
Introduction

➢ **Motivation**

- Kinematic observables behaving differently in ZZ(4l) according to polarization states (TT, TL, LL)

- Trying to measure ZZ polarization based on **angular observables**, and other observables if possible





Selection and observables

- **Selection**
  - **On-shell ZZ region** with loose lepton selection

	Lepton Selection
Muon	Dressed, $p_\mathrm{T} > 5$ GeV, $\lvert\eta\rvert < 2.7$
Electron	Dressed, $p_\mathrm{T} > 7$ GeV, $\lvert\eta\rvert < 2.47$
	Event Selection
Leptons	At least 4 leptons (e, μ)
Lepton flavor	At least 2 Same-Flavor Opposite-Sign (SFOS) lepton pairs
Lepton p_T	$p_\mathrm{T} > 20/10$ GeV for leading two leptons
Lepton separation	$\Delta R_{ij} > 0.05$ for any two leptons
J/Ψ veto	$m_{ij} > 5$ GeV for all SFOS pairs
On-shell ZZ region	$m_{4\ell} > 180$ GeV for the quadruplet
On-shell Z	$\lvert m_{ij} - m_Z\rvert < 10$ GeV for both SFOS pairs in the quadruplet

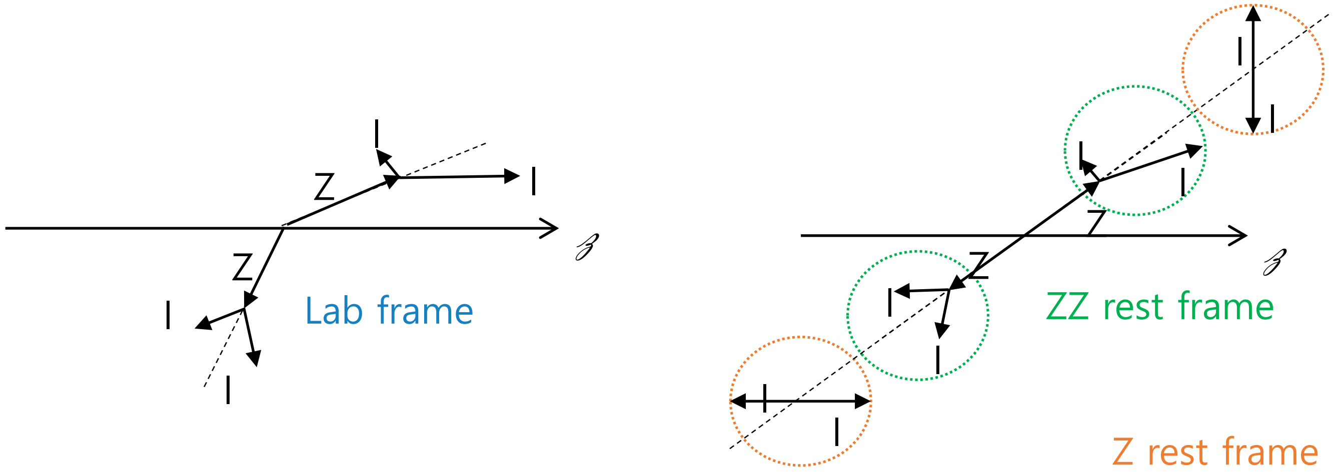
  - LL component appearing with a fraction of **~6%**

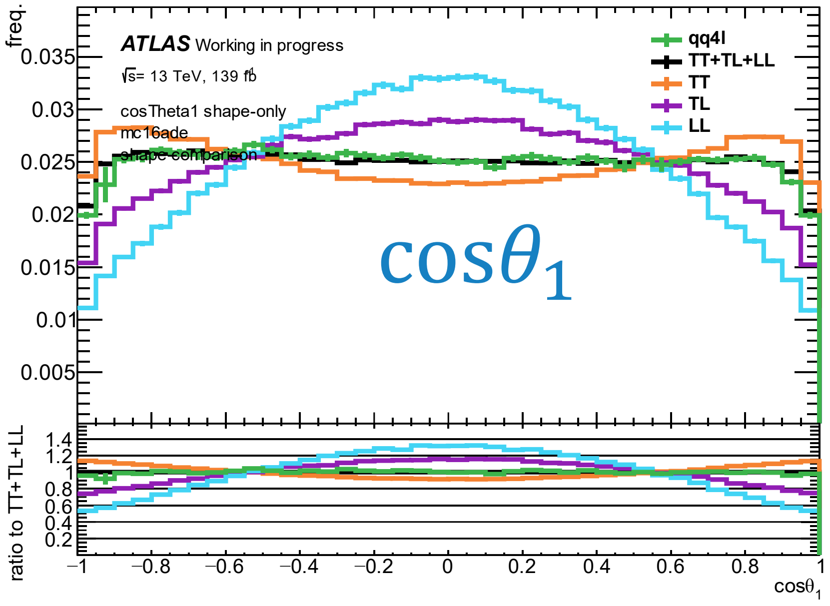
Category	X-section (fb)	Total PS yield	Ratio to Sum. (tot.)	FV yield	Ratio to Sum. (fid.)	Cut eff.
TT	24.00118	3335.3285	68.27%	1169.2565	68.62%	35.06%
TL	9.08615	1262.6586	25.84%	436.93006	25.64%	34.60%
LL	**2.070862**	**287.77773**	**5.89%**	**97.694777**	**5.73%**	**33.95%**
TT+TL+LL	35.158192	4885.7648	100%	1703.8813	100%	34.87%

  - kinematic differences suppressed with low LL fraction

Selection and observables

- **Observables**
  - Observables defined based on different reference frames





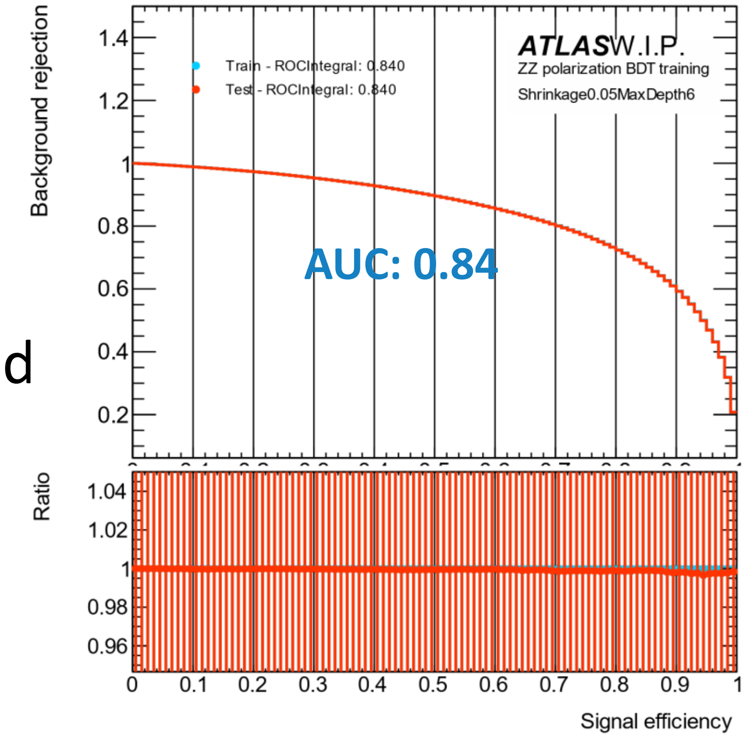
  - Each of observables compared, the definition being able to enhance LL significance chosen
  - Most of the optimized observables defined in ZZ rest frame
  - Considering to combine the separation power in all observables

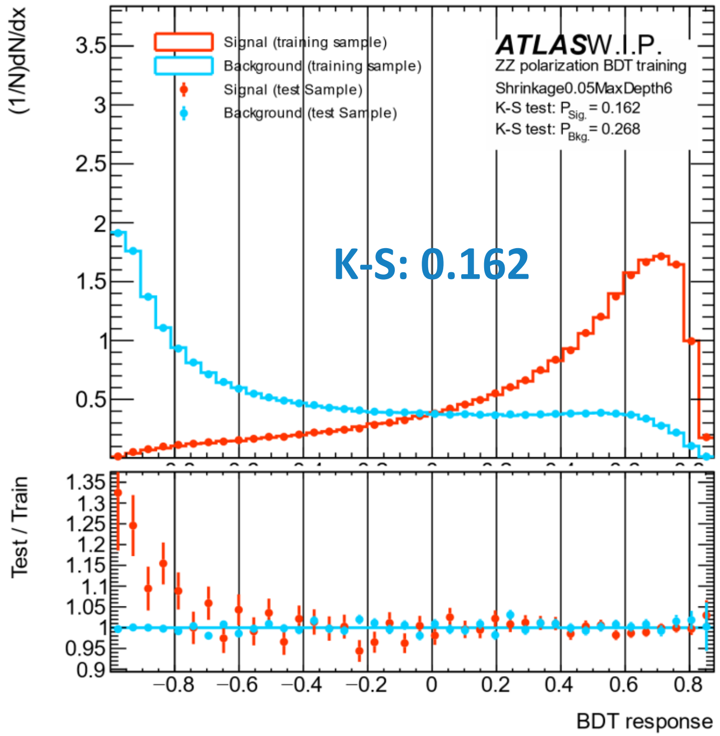
MVA method and LL significance

- MVA method to extract, condense the differences of 3 polarization states and classify them

- Boost Decision Tree (BDT) is used and achieve very nice performance with detailed tuning

- Optimized input observables:
  - $p_{T,4\ell}^{\mathrm{LAB}},\ y_{4\ell}^{\mathrm{LAB}},\ \Delta\phi_{pairs}^{\mathrm{LAB}}, \cos\theta_1^{\mathrm{ZZREST}},\ \cos\theta_2^{\mathrm{ZZRSET}}, \cos\theta_{Z1}^{*,\mathrm{ZZREST}},$
  - $\Delta\mathrm{R}_{\ell1\ell2}^{\mathrm{ZZREST}}, \Delta\mathrm{R}_{\ell3\ell4}^{\mathrm{ZZREST}}, \Delta\phi_{\ell1\ell2}^{\mathrm{ZZREST}}, p_{T,Z1}^{\mathrm{ZZREST}}, y_{Z1}^{\mathrm{ZZREST}}$





MVA method and LL significance

- LL significance fit including only statistical uncertainty
- BDT giving LL significance of **4.52σ** with statistic-only fit, while the best result of fit on individual observables yielding **2.95σ**
- Polarization of ZZ can be measured with largely improved significance using MVA method