Analysis Framework for $H \to Za$ analysis

Abdualazem Fadol

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HZZ Analysis Framework

- Several analyses use the HZZAnalRun2Code:
  - HZZ (inclusive, cross-section)
  - HZZ off-shell ($ZZ \to 4\ell$, $ZZ \to 2\ell 2\nu$)
  - $X4\ell\mathrm{MET}$ analysis
- It's maintained to the CDI recommendations;
- The code works with HIGG2D1 derivation;
- But it's updated to DAOD_PHYS now.
- Mini-trees production:
  - nominal
  - Systematic: e/μ/jet & normalisation
- So we can adapt the code to HZa analysis.

Table 2: Summary of the event selection requirements. The two lepton pairs are denoted as m_{12} and m_{34}.

Physics Objects	
Electrons	
Loose Likelihood quality electrons with hit in innermost layer, $E_{\mathrm{T}} > 7$ GeV and $\lvert\eta\rvert < 2.47$	
Interaction point constraint: $\lvert z_0 \cdot \sin\theta\rvert < 0.5$ mm (if ID track is available)	
Muons	
Loose identification with $p_{\mathrm{T}} > 5$ GeV and $\lvert\eta\rvert < 2.7$	
Calo-tagged muons with $p_{\mathrm{T}} > 15$ GeV and $\lvert\eta\rvert < 0.1$, segment-tagged muons with $\lvert\eta\rvert < 0.1$	
Stand-alone and silicon-associated forward restricted to the $2.5 < \lvert\eta\rvert < 2.7$ region	
Combined, stand-alone (with ID hits if available) and segment-tagged muons with $p_{\mathrm{T}} > 5$ GeV	
Interaction point constraint: $\lvert d_0\rvert < 1$ mm and $\lvert z_0 \cdot \sin\theta\rvert < 0.5$ mm (if ID track is available)	
Jets	
anti-k_T jets with *bad-loose* identification, $p_{\mathrm{T}} > 30$ GeV and $\lvert\eta\rvert < 4.5$	
Overlap removal	
Jets within $\Delta R < 0.2$ of an electron or $\Delta R < 0.1$ of a muon are removed	
Vertex	
At least one collision vertex with at least two associated track	
Primary vertex	
Vertex with the largest p_T^2 sum	
Event Selection	
Quadruplet Selection	- Require at least one quadruplet of leptons consisting of two pairs of same-flavour opposite-charge leptons fulfilling the following requirements: - p_{T} thresholds for three leading leptons in the quadruplet: 20, 15 and 10 GeV - Maximum one calo-tagged or stand-alone muon or silicon-associated forward per quadruplet - Leading di-lepton mass requirement: $50 < m_{12} < 106$ GeV - Sub-leading di-lepton mass requirement: $m_{\mathrm{threshold}} < m_{34} < 115$ GeV - $\Delta R(\ell, \ell') > 0.10$ for all leptons in the quadruplet - Remove quadruplet if alternative same-flavour opposite-charge di-lepton gives $m_{\ell\ell} < 5$ GeV - Keep all quadruplets passing the above selection
Isolation	- Contribution from the other leptons of the quadruplet is subtracted - FixedCutPFlowLoose WP for all leptons
Impact Parameter Significance	- Apply impact parameter significance cut to all leptons of the quadruplet - For electrons: $d_0/\sigma_{d_0} < 5$ - For muons: $d_0/\sigma_{d_0} < 3$
Best Quadruplet	- If more than one quadruplet has been selected, choose the quadruplet with highest Higgs decay ME according to channel: 4μ, $2e2\mu$, $2\mu2e$ and $4e$
Vertex Selection	- Require a common vertex for the leptons: - $\chi^2/\mathrm{ndof} < 5$ for 4μ and < 9 for others decay channels

Running the default code

m_a [GeV]	$H \to Z(\to \ell\ell)a(\to ee)$	$H \to Z(\to \ell\ell)a(\to \mu\mu)$	$H \to Z(\to \ell\ell)a(\to bb)$
5	601431	601442	-
6	601432	601443	-
8	601433	601444	-
10/11	601434	601445	601424
12	601435	601446	601425
15	601436	601447	601426
25	601437	601448	601427
35	601438	601449	601428
45	601439	601450	601429
55	601440	601451	601430

- These are all the samples we have generated so far with p5440 p-tag.
- mc20a, mc20d and mc20e with r13167, r13144 and r13145 tags, respectively.
- I'll run the default code with only mc20a without change anything.

Cut-flow for the preselection

$H \to Z(\to \ell\ell)a(\to ee)$ with $m_a = 5$ GeV

	4mu	4e	2mu2e	2e2mu	4l
allEvents	80000	80000	80000	80000	80000
preselection	0	26545	26729	0	79689
lepton	0	3385	4568	0	8313
SFOS	0	3309	4433	0	7878
kinematics	0	3116	4183	0	7379
Z1Mass	0	3097	4156	0	7280
Z2Mass	0	32	26	0	59
massWindow	0	0	0	0	0
JPsiVeto	0	22	26	0	48
dR	0	22	25	0	47
Iso	0	6	3	0	9
d0Sig	0	6	3	0	9
vertex	0	6	3	0	9
trigger	0	6	3	0	9
final	0	6	3	0	9

Cut-flow for the preselection

$H \to Z(\to \ell\ell)a(\to \mu\mu)$ with $m_a = 5$ GeV

	4mu	4e	2mu2e	2e2mu	4l
allEvents	80000	80000	80000	80000	80000
preselection	0	0	0	0	79736
lepton	0	0	0	0	17481
SFOS	0	0	0	0	16868
kinematics	0	0	0	0	15161
Z1Mass	0	0	0	0	14955
Z2Mass	0	0	0	0	202
massWindow	0	0	0	0	0
JPsiVeto	0	0	0	0	164
dR	0	0	0	0	163
Iso	0	0	0	0	41
d0Sig	0	0	0	0	31
vertex	0	0	0	0	31
trigger	0	0	0	0	31
final	0	0	0	0	31

Cut-flow for the preselection

$H \to Z(\to \ell\ell)a(\to bb)$ with $m_a = 11$ GeV

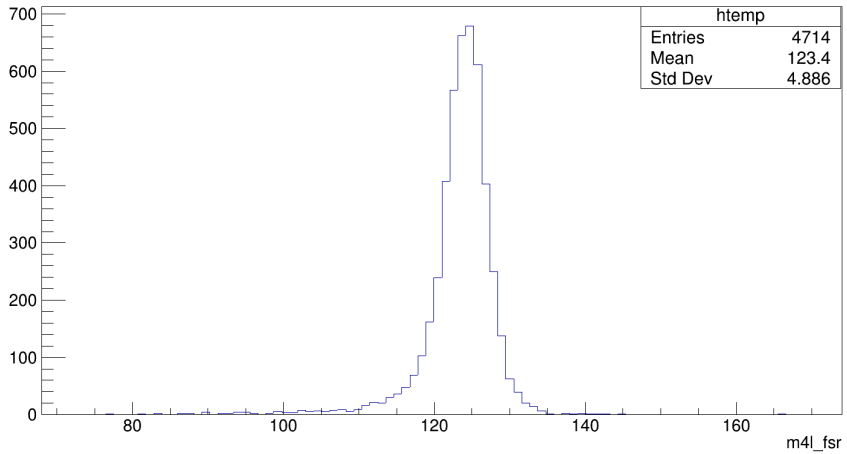
	4mu	4e	2mu2e	2e2mu	4l
allEvents	80000	80000	80000	80000	80000
preselection	0	16709	0	0	79712
lepton	0	1	0	0	109
SFOS	0	1	0	0	58
kinematics	0	0	0	0	26
Z1Mass	0	0	0	0	26
Z2Mass	0	0	0	0	4
massWindow	0	0	0	0	0
JPsiVeto	0	0	0	0	4
dR	0	0	0	0	4
Iso	0	0	0	0	0
d0Sig	0	0	0	0	0
vertex	0	0	0	0	0
trigger	0	0	0	0	0
final	0	0	0	0	0

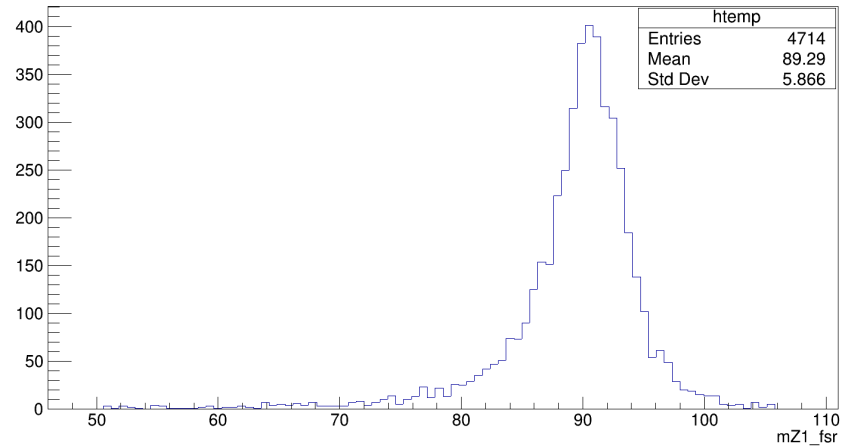
Modifying the HZZ Analysis Framework

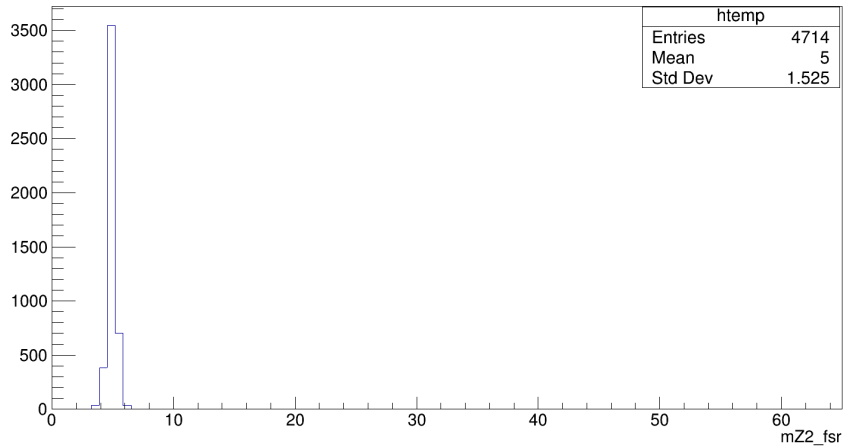
	4mu	4e	2mu2e	2e2mu	4l
allEvents	80000	80000	80000	80000	80000
preselection	0	25957	26729	0	79689
lepton	0	3300	4568	0	8313
SFOS	0	3225	4433	0	7878
kinematics	0	3036	4183	0	7379
Z1Mass	0	3018	4156	0	7280
Z2Mass	0	3018	4156	0	7280
massWindow	0	0	0	0	0
JPsiVeto	0	2973	4156	0	7232
dR	0	2967	4126	0	7196
Iso	0	2018	2824	0	4915
d0Sig	0	2003	2790	0	4860
vertex	0	2002	2787	0	4856
trigger	0	1981	2667	0	4714
final	0	1981	2667	0	4714

- Removing the $m_{\text{threshold}} < m_{Z_2} < 119$ cut brings up more events.
- Cut-flow for the $H \to Z(\to \ell\ell)a(\to ee)$ with $m_a = 5$ GeV.
- But we still need to figure out the combination of the quadruplets.

Modifying the HZZ Analysis Framework

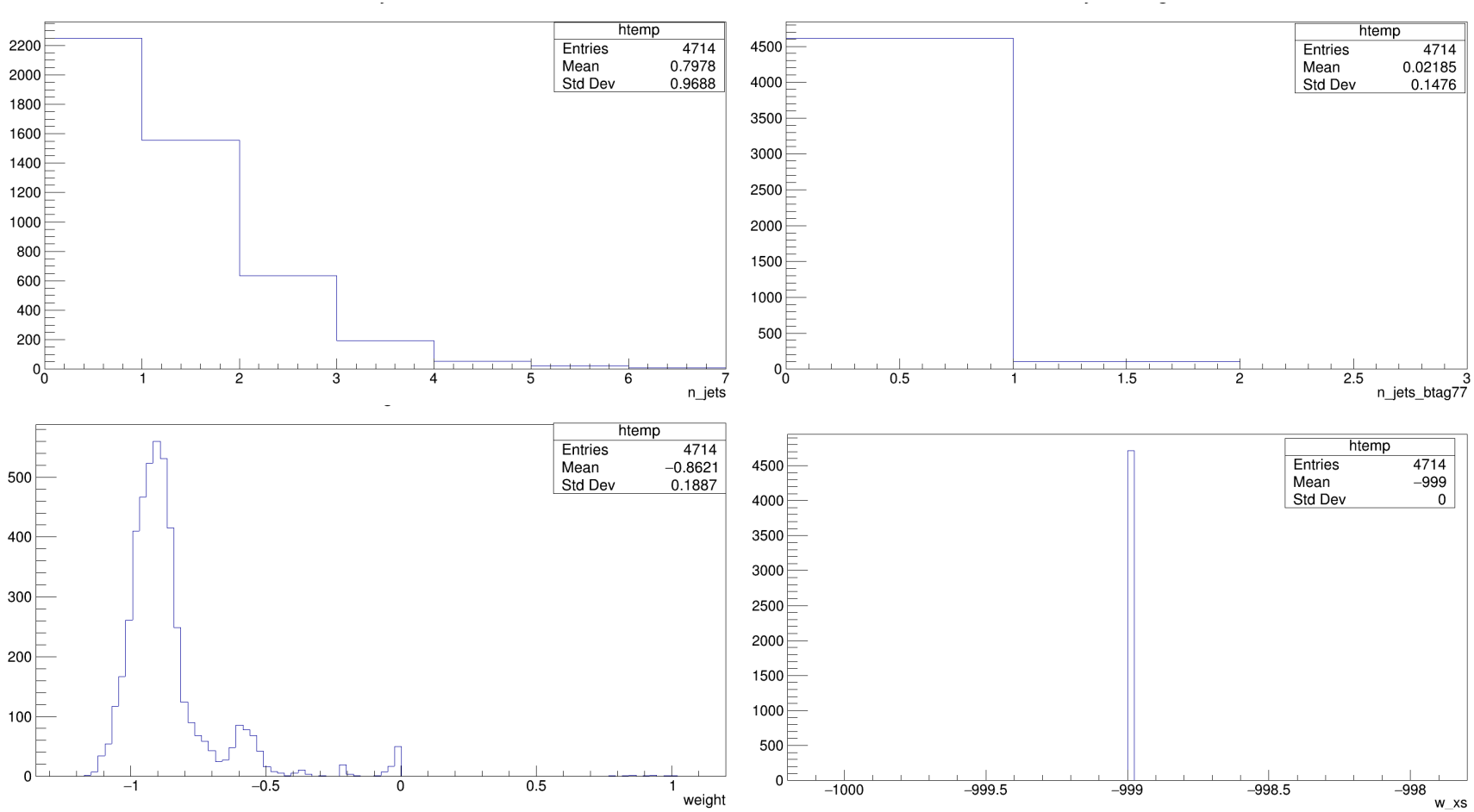






- Cut-flow for the $H \to Z(\to \ell\ell)a(\to ee)$ with $m_a = 5$ GeV for 4ℓ channel.

Modifying the HZZ Analysis Framework



- Cut-flow for the $H \to Z(\to \ell\ell)a(\to ee)$ with $m_a = 5$ GeV for 4ℓ channel.