Vector Bosons Polarisation in VBF Higgs measurements

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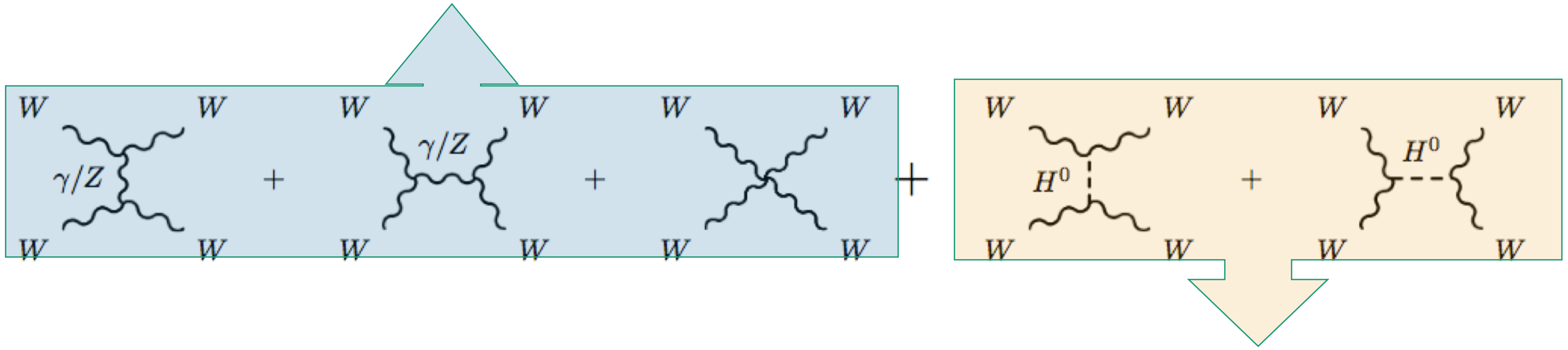
[VBS Polarization Workshop LLR, Palaiseau]

Why measure polarisation-dependent HVV couplings?

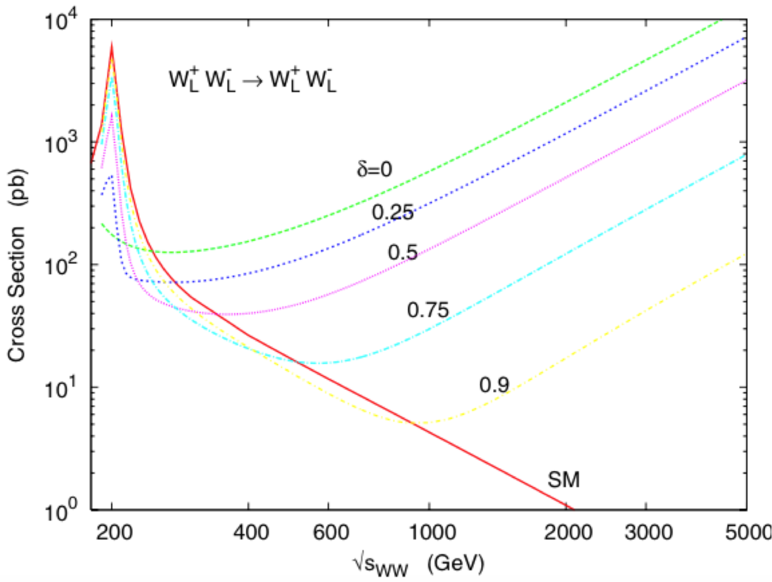
- To test the SM EW symmetry breaking
- The Higgs mechanism introduces masses of gauge bosons and their longitudinal polarisations

$$e^{\mu}_{\pm} = \frac{1}{\sqrt{2}}(0, 1, \pm i, 0), \quad e^{\mu}_{L} = \frac{\sqrt{s}}{2M_W}(\beta, 0, 0, 1)$$

  - $W_L W_L$ scattering amplitude diverges with O(s)



- Higgs diagrams subtract O(s) if $g_{HVV}=g_V\, m_{VV}$ (gauge invariance requirement)
- At infinitely large momenta the transverse parts of V bosons correspond to the "proper" gauge bosons, whereas the longitudinal parts arise from the eaten Goldstone bosons.
- HVV couplings are sensitive to new physics in EWSB: extended Higs sectors, Higgs as a composite pseudo-Goldstone boson (SILH, MCHM), ...



[Cheung, Chiang, Yuan, 2008]

Parametrisation of anomalous couplings

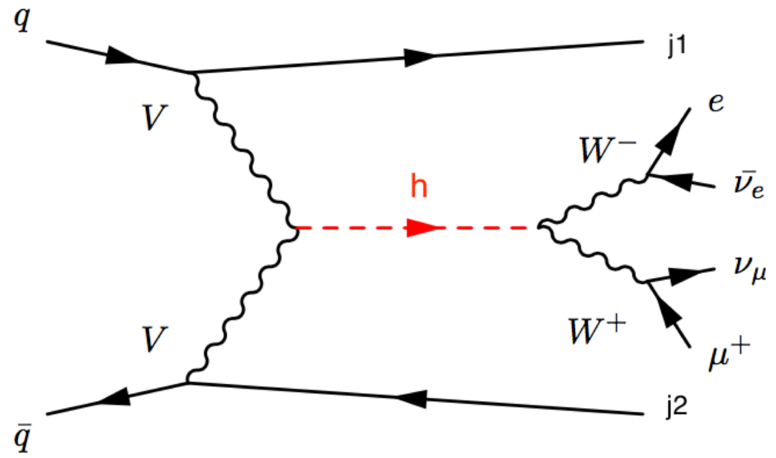
- Agnostic approach: No new gauge interactions or particles assumed, just scalar rescaling of the couplings:

$$a_L = g_{HVLVL}/g_{HVV}\ ,\ a_T = g_{HVTVT}/g_{HVV}$$

- a_L and a_T are defined in the Higgs rest frame so that only HV_LV_L and HV_TV_T coupling combinations are present
- $HW_LW_L \sim HZ_LZ_L$ and $HW_TW_T \sim HZ_TZ_T$

This parametrisation is not Lorentz invariant

- sum rules not conserved → expected effects in normalisation
- kinematical selection restricted to the s-channel Higgs resonance
  - ✓ the bulk of the W_LW_L scattering cross-section
  - ✓ separated from effects of anomalous triple and quartic gauge couplings



Events generation setup

- Polarisation-dependent processes cannot be obtained out-of-the-box from MC generators.
- I used matrix elements generated with Madgraph5_aMC@NLO at LO
- HVV couplings modified using prescription from PHYS. REV.D 90, 054023 (2014):
    - in the ME boost all V's momenta to the Higgs rest frame
    - modify helicity amplitudes in DHELAS independently for HV_LV_L and HV_TV_T
    - boost all momenta back to the LAB frame
- VBF s-channel Higgs production only

Mapping to other parametrisations

in the limit of momenta of incoming W bosons, q_1, q_2 → 0

- SMEFT

$$a_T = 1 + \frac{v^2 F_\phi}{2} + F_{\phi W} q_1 \cdot q_2 \,,$$
$$a_L = 1 + \frac{v^2 F_\phi}{2} + F_{\phi W} \frac{q_1^2 q_2^2}{q_1 \cdot q_2} \,.$$

$$\mathcal{L}_{SM} = (\mathbf{D}_\mu \phi)^\dagger \mathbf{D}^\mu \phi$$
$$\mathcal{L}_{\phi W} = -\frac{g^2 F_{\phi W}}{4} \left(\phi^\dagger \phi - \frac{v^2}{2}\right) \mathrm{tr}\left[\mathbf{W}_{\mu\nu} \mathbf{W}^{\mu\nu}\right] \,,$$
$$\mathcal{L}_\phi = F_{HD} \left(\phi^\dagger \phi - \frac{v^2}{2}\right) \left((\mathbf{D}_\mu \phi)^\dagger \mathbf{D}^\mu \phi\right) \,.$$

New Lorentz structures, not just couplings rescaling

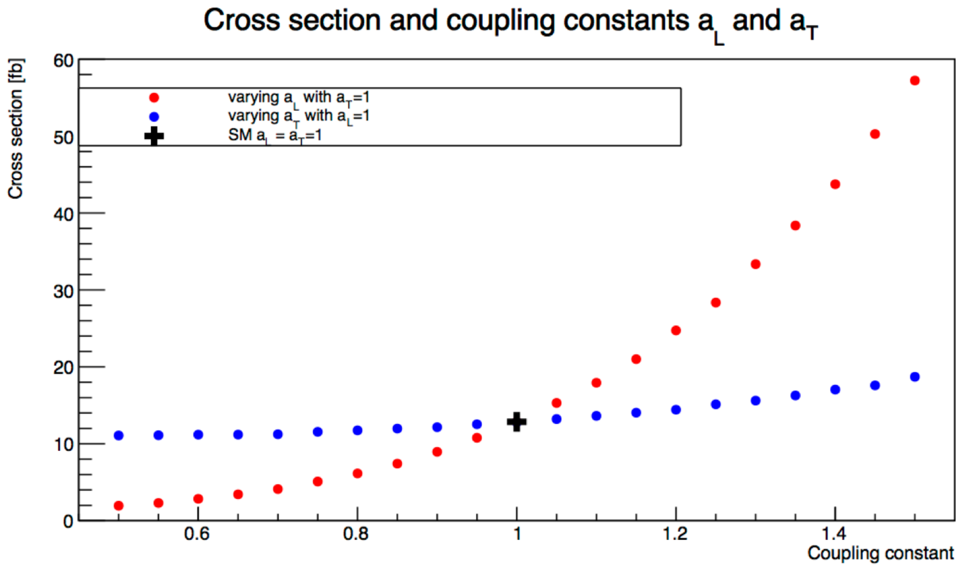
EFT kinematics can be reproduced fitting a_L and a_T (see 1404.5951)

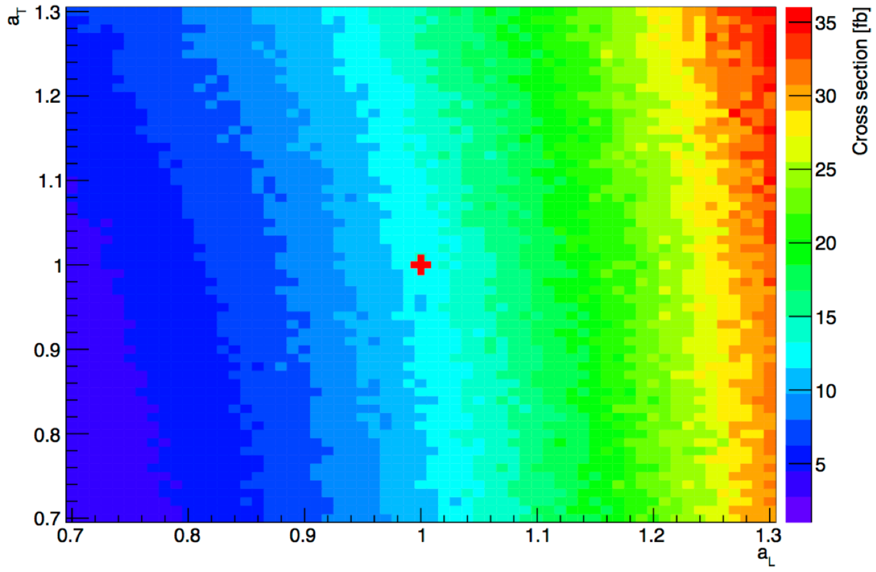
- on-shell and off-shell Pseudo Observables

$$a_L = \kappa_{VV} + \Delta_L(q_1, q_2)\epsilon_{VV}, \quad a_T = \kappa_{VV} + \Delta_T(q_1, q_2)\epsilon_{VV}$$

$$\Delta_L(q_1, q_2) \to 0, \quad \Delta_T(q_1, q_2) \to \frac{m_H^2}{2m_V^2}$$

Kinematical effects of coupling modifications

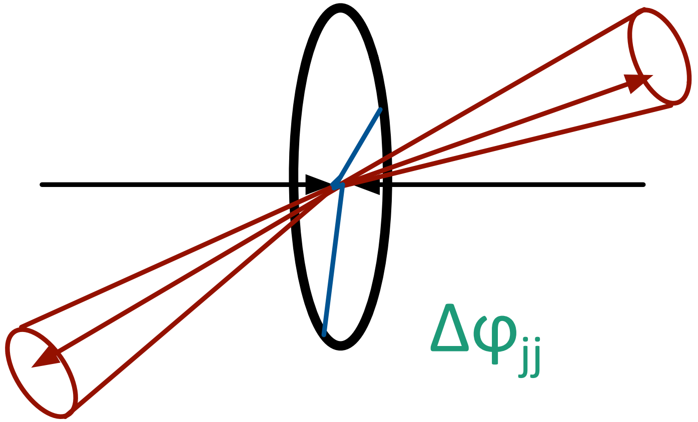


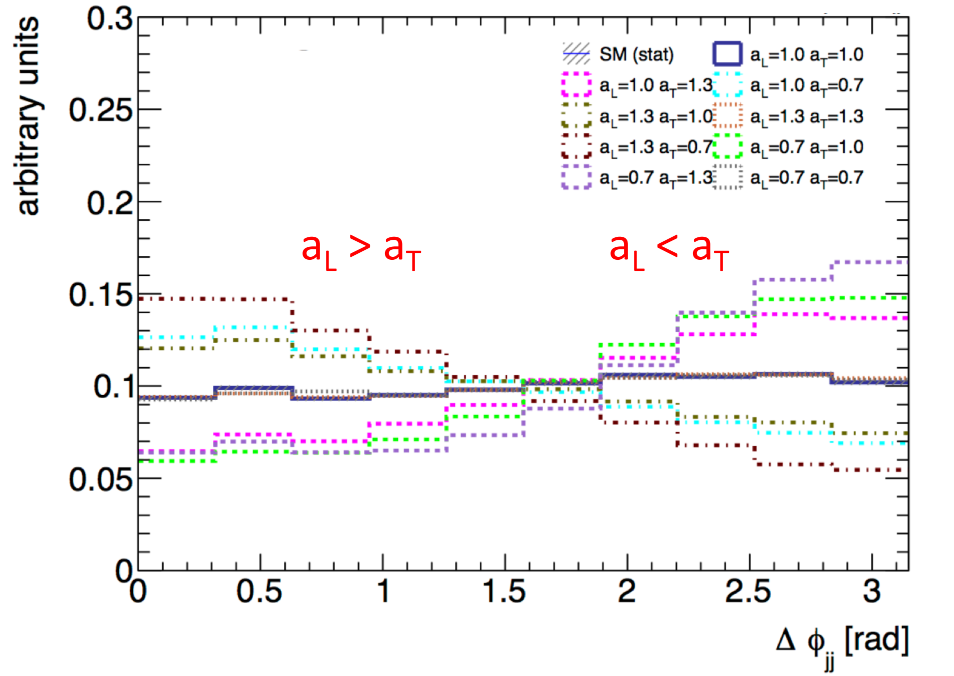


- Cross-sections w/o VBF cuts
- Total rates more sensitive to a_L as the dominant contribution to VBF comes from longitudinal Vs
- Normalisation effects from two Higgs vertices

Effects of coupling modifications in production and decay

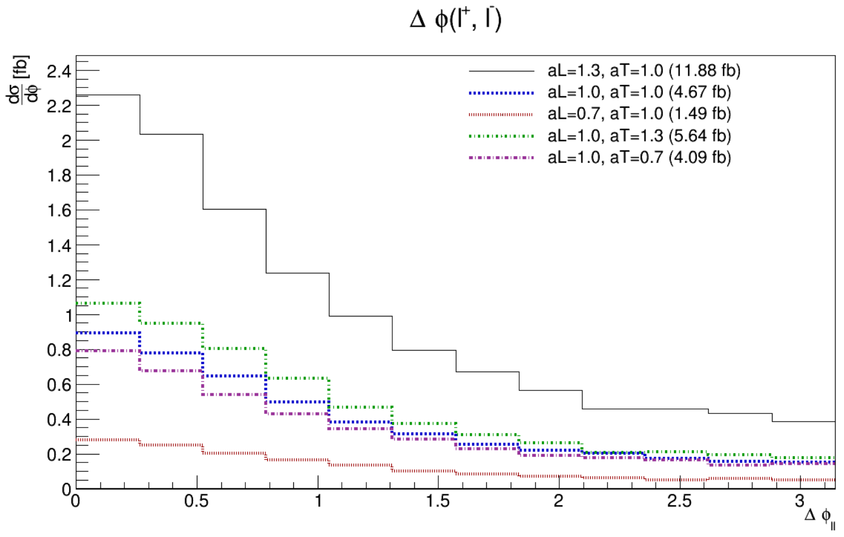
- In the production the shape of $\Delta\varphi_{jj}$ is sensitive to $a_L - a_T$

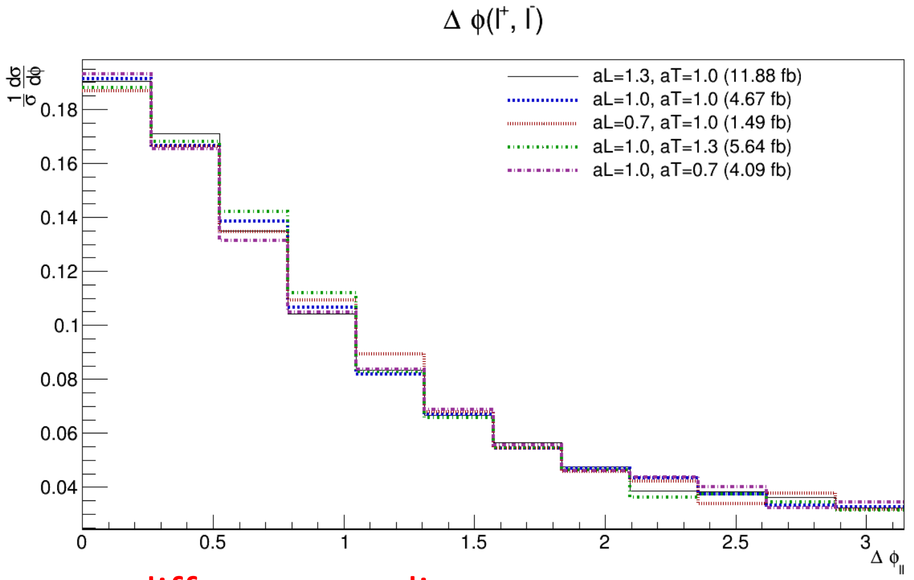




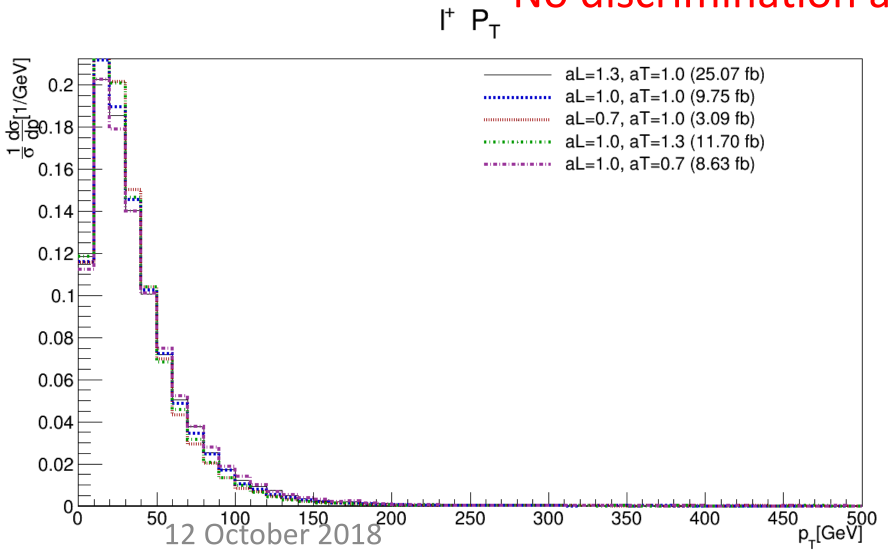
- In the decay leptonic correlations could be related to W polarisation

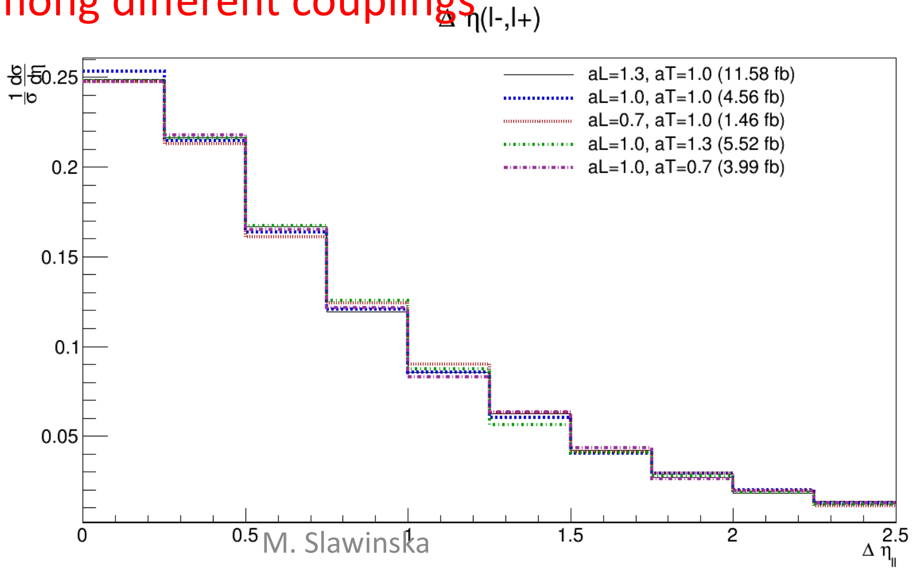
Lepton variables in the LAB frame





No discrimination among different couplings



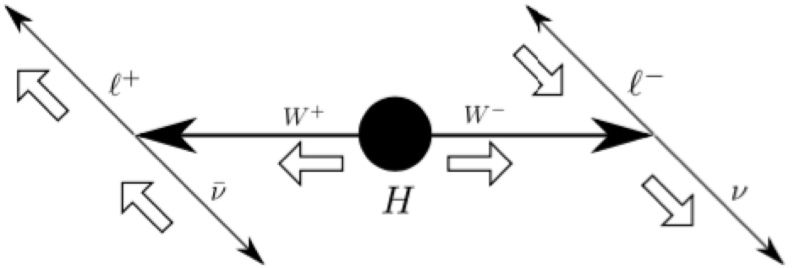


VBF cuts:

$p_T^{\text{leading } l} > 15$ GeV,
$p_{Tsub}^{\text{leading } l} > 10$ GeV
$p_T^{jet} > 45$ GeV
$m_{jj} > 300$ GeV,
$m_{ll} < 60$ GeV
$m_T < 125$ GeV
$\Delta\eta_{jj} > 3$

Spin-momentum correlations in the W decays

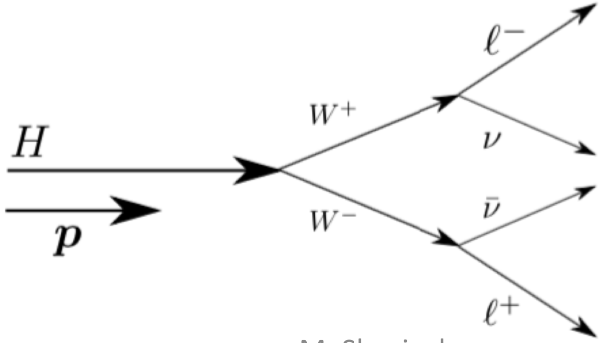
Higgs rest frame



- spin and momentum conservation in the W decays
- neutrinos have only one handedness → charged leptons spins are (anti-)aligned with W bosons
- the Higgs is scalar → correlations among spins the two W bosons

LAB frame

- W's not on-shell → W are not back-to-back and their spins are decorrelated



Approximate reconstruction of the Higgs four momentum

Tune the algorithm for the Higgs frame reconstruction in ggF H→WW
R. Aben,PhD thesis CERN-THESIS-2015-034

$$p_h^2 = (E_{ll} + E_{\nu\nu})^2 - (\vec{p}_{ll} + \vec{p}_{\nu\nu})^2$$

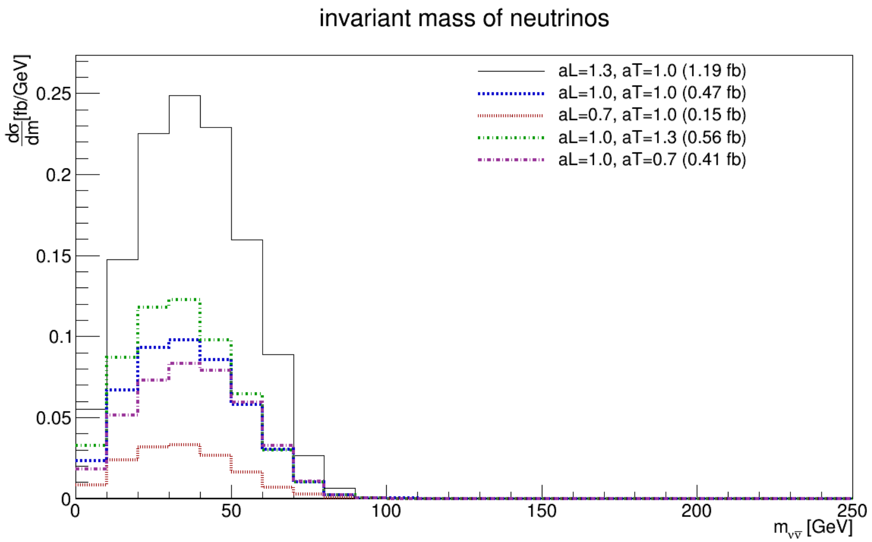
- The experimentally available information about the Higgs kinematics comes from
  - charged leptons
  - missing transverse energy

→ transverse momentum available

- Finding p_h^z requires solving quadratic equation for $p_{\nu\nu}^z$.
- Assuming the Higgs is on-shell

$$p_h^2 = M_h^2 = (E_{ll} + E_{\nu\nu})^2 - (\vec{p}_{ll} + \vec{p}_{\nu\nu})^2$$

- Assume $M_{\nu\nu} = 30$ GeV



truth $M_{\nu\nu}$

Obtaining the best solution

$$[(p_{ll}^z)^2 - (E_{ll})^2](p_{\nu\nu}^z)^2 + M_{fix}^2 p_{ll}^z p_{\nu\nu}^z + \frac{1}{4} M_{fix}^4 - E_{ll}^2[(E_T^{miss})^2 + M_{\nu\nu}^2] = 0,$$

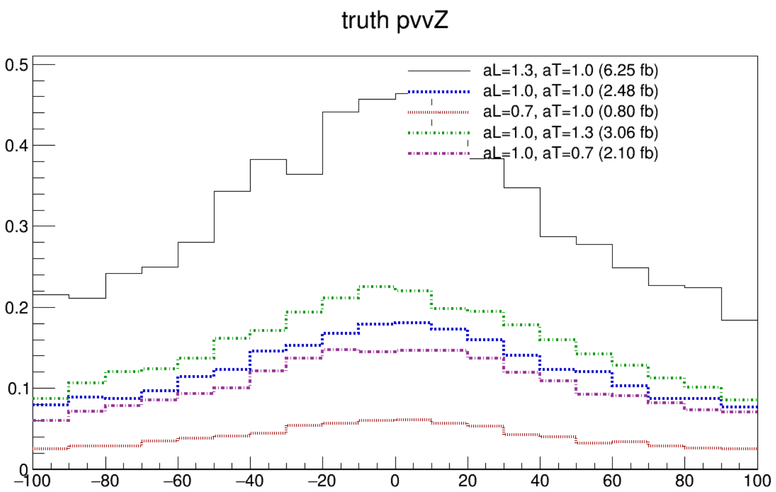
where

$$M_{fix}^2 = M_h^2 - M_{ll}^2 - M_{\nu\nu}^2 + 2p_{ll}^x (E^{miss})^x + 2p_{ll}^y (E^{miss})^y$$

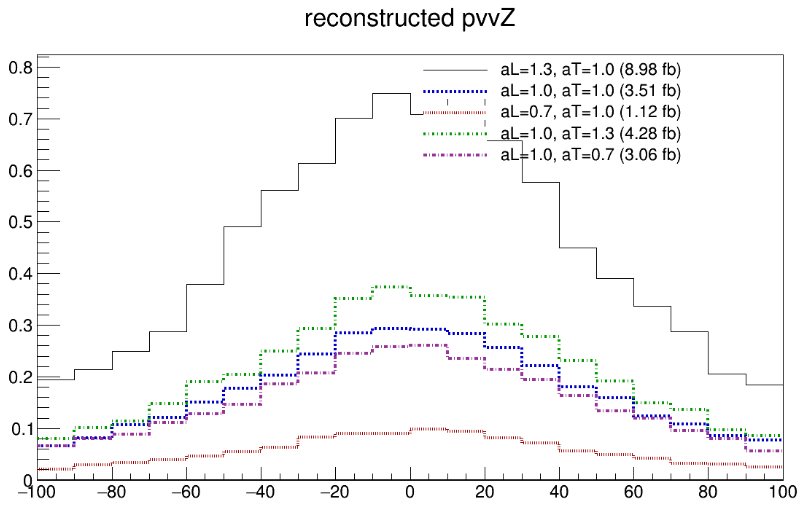
- The determinant of the quadratic equation is negative in ~10% of events
- In this case obtain a real solution setting $M_{\nu\nu}$ =0 (~ 10% events not reconstructed)
- If determinant is positive, select the best solution
  - as the smallest $|p_{ll}^Z|$ (at present)
  - minimise the angles between neutrinos in the Higgs rest frame (not tried yet)

Quality of the reconstruction algorithm

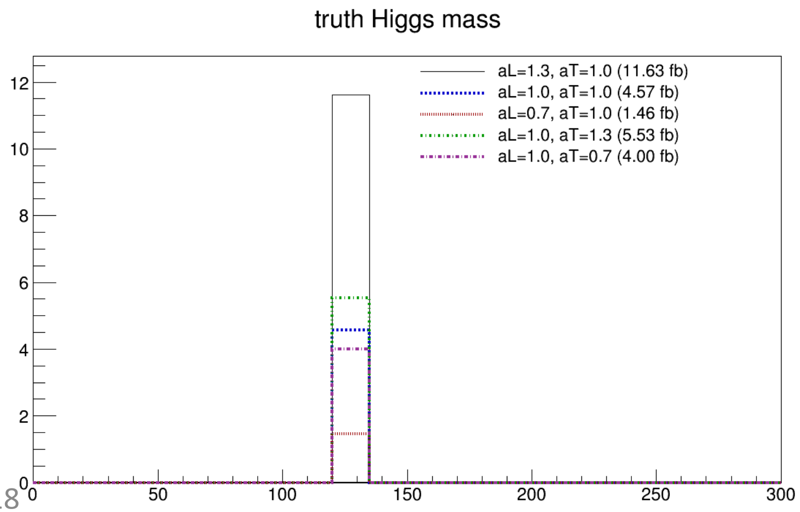
- truth $p_{\nu\nu}^{Z}$



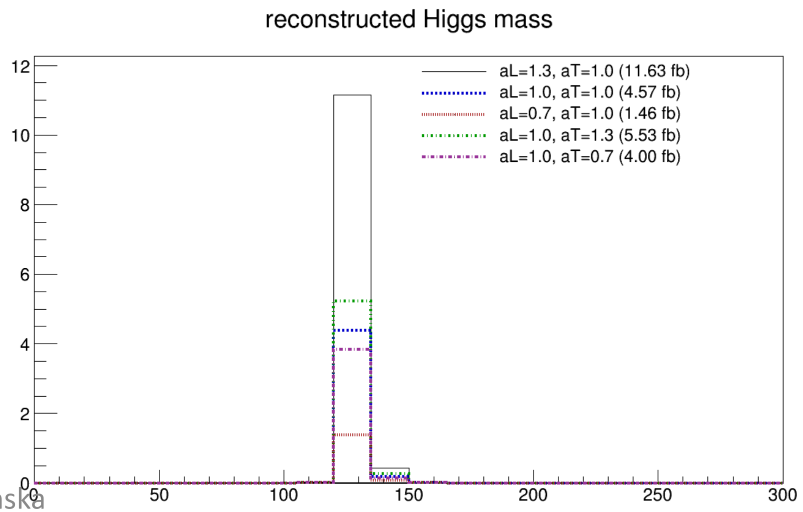
reco $p_{\nu\nu}^{Z}$



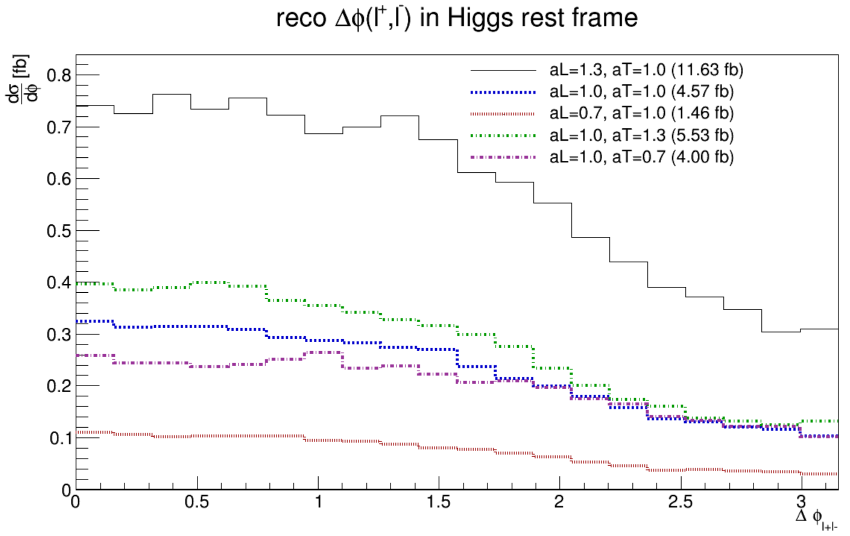
truth M_h

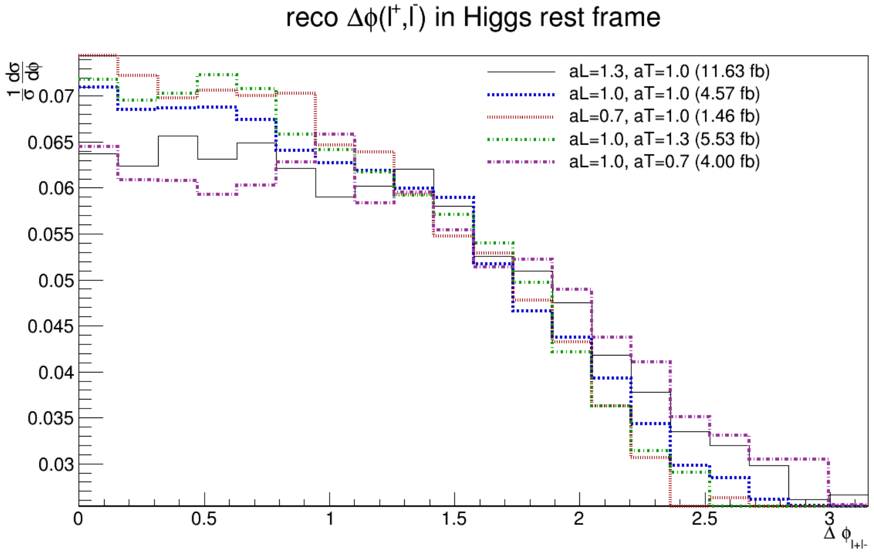


reco M_h



$\Delta\varphi_{ll}$ in the Higgs rest frame





Better discrimination in the Higgs rest frame!

Outlook

- Results of the reconstruction algorithm very preliminary
- Test the performance of the with a different choice of the single solution
- Apply the algorithm to te reconstruct pure HV_LV_L and HV_TV_T components (tagging polarisations?)
- The quality of the reconstruction algorithm depends on the quality of measuring missing transverse energy, test in real experimental environment necessary!