Exploring tau lepton pairs from Higgs at the LHC

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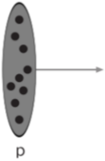
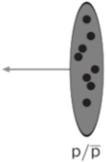
Motivation

- We have just celebrated the 4th birth day of Higgs.
- Now the main priority is to study the properties of it.
- Higgs decays to tau leptons abundantly which gives us the opportunity to study different aspects like spin, coupling structure, CP properties.
- Determination of these properties requires the full reconstruction of tau pair events.
- Reconstruction of these semi-invisible tau events at LHC is challenging.

Why it is challenging?





$$p_1 = E(x_1, 0, 0, x_1) \qquad\qquad p_2 = E(x_2, 0, 0, -x_2)$$

- Incoming parton momenta unknown.
- CM energy of collision unknown.
- Boost along the beam direction unknown.
- At least two neutrinos in the final state goes undetected.

Reconstruction methods

◇ Collinear approximation: Assumes the decay tau decay products are collinear with tau-lepton.

- The neutrino momenta $\vec{q}_i = \vec{p}_{\tau_i} - \vec{p}_i = (\frac{1}{f_i} - 1)\vec{p}_i$. Where f_i is the fraction of momenta carried by the visible decay products.

- Unknowns for the full reconstruction of the event: f_i.

- Constraints: missing transverse momenta, $\vec{\not{p}}_T = \sum_i (\frac{1}{f_i} - 1)\vec{p}_{iT}$.

R.K. Ellis and I. Hinchliffe and M. Soldate and J.J. Van Der Bij, Nuclear Physics B,297(2):221, 1988

Reconstruction methods

◇ MAOS: A M_{T2} based reconstruction method.

$$M_{T2}(\tilde{m}_\nu) = \min_{\substack{\vec{q}_{1T},\vec{q}_{2T} \\ \{\vec{q}_{1T}+\vec{q}_{2T}=\vec{P}\!\!\!/_T\}}} \left[\max\{M_T^{(1)}(\tilde{m}_\nu), M_T^{(2)}(\tilde{m}_\nu)\}\right]$$

with

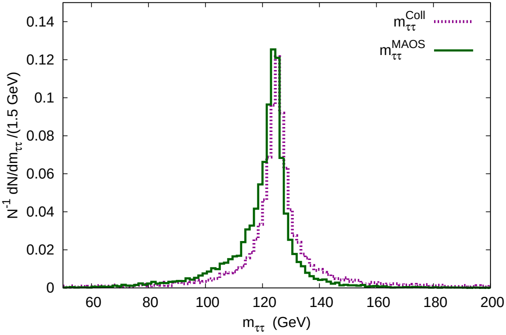
$$M_T^{(i)} = m_{v_i}^2 + \tilde{m}_\nu^2 + 2(E_T^{vis(i)} E_T^{inv(i)} - \vec{p}_{iT}.\vec{q}_{iT}).$$

- q_{iT}^{MAOS}: momenta from the minimization of M_{T2}.
- q_{iz}^{MAOS}: momenta after solving the tau mass shell constraints.

W.S. Cho, K. Choi, Y.G. Kim, and C.B. Park, Phys.Rev., D79:031701, 2009

Reconstruction methods

◦ Higgs mass using Collinear approximation and MAOS method.



Reconstruction method : *M2Cons*

◇ *M2Cons*: A (1+3) dimensional constrained variable based on M_2.

$$M_2(\tilde{m}_\nu) = \min_{\substack{\vec{q}_1, \vec{q}_2 \\ \{\vec{q}_{1T} + \vec{q}_{2T} = \vec{P}\!\!\!/_T\}}} [\max\{M^{(1)}(\tilde{m}_\nu), M^{(2)}(\tilde{m}_\nu)\}]$$

with

$$M^{(i)} = m_{v_i}^2 + \tilde{m}_\nu^2 + 2(E^{vis(i)} E^{inv(i)} - \vec{p}_i.\vec{q}_i).$$

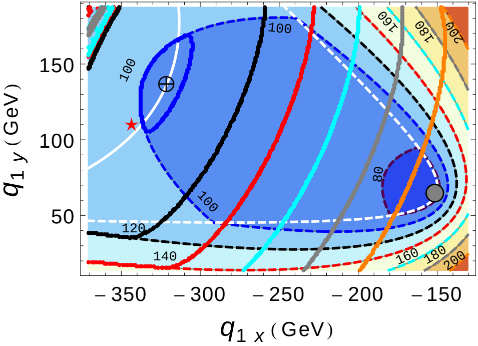
$$M_{2Cons}(\tilde{m}_\nu) = M_2(\tilde{m}_\nu) + \text{ Additional cons. : } (p_1 + p_2 + q_1 + q_2)^2 = m_h^2$$

Partha Konar and Abhaya Swain, Phys. Rev., D93:015021, 2016

Reconstruction method : *M2Cons*

$$M_{2Cons}(\tilde{m}_\nu) = M_2(\tilde{m}_\nu) + \text{ Additional cons. : } (p_1 + p_2 + q_1 + q_2)^2 = m_h^2$$

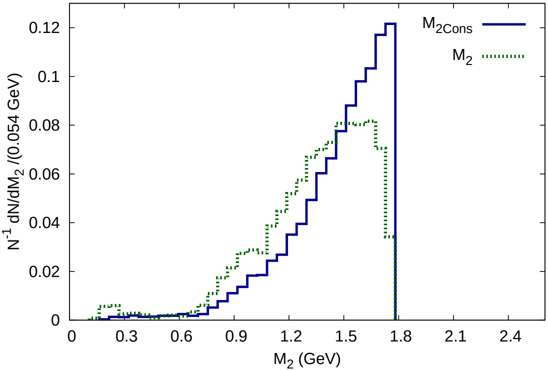
◇ Consequence of additional constraint:



Partha Konar and Abhaya Swain, Phys. Rev., D93:015021, 2016

Reconstruction method : *M2Cons*

M_2 and M_{2Cons}:

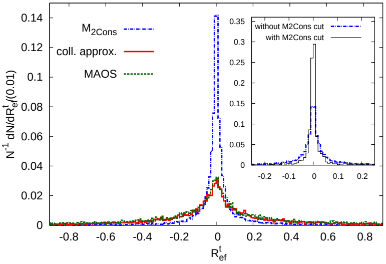


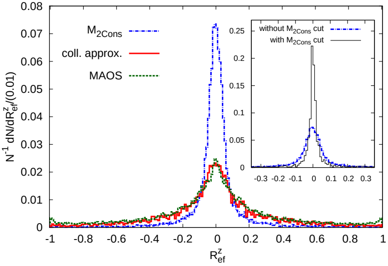
Abhaya Swain and Partha Konar, Phys.Lett.B757, 211 (2016)

Reconstruction efficiency

$$R^t_{ef} = \frac{\Delta q_t}{|q_t^{True}|} = \frac{q_t^{Reco} - q_t^{True}}{|q_t^{True}|},$$

$$R^z_{ef} = \frac{\Delta q_z}{|q_z^{True}|} = \frac{q_z^{Reco} - q_z^{True}}{|q_z^{True}|}.$$





Abhaya Swain and Partha Konar, Phys.Lett.B757, 211 (2016)

CP property

⋆ process: $pp \to h \to \tau\tau \to \pi^{\pm}\nu_{\tau}\pi^{\mp}\nu_{\tau}$.

⋆ T-odd correlation observables constructed in Higgs rest frame:

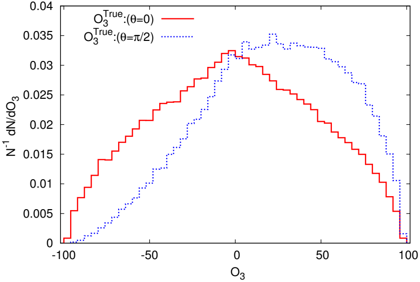
Observable name	Definition
O_3	$(p_{\nu^-} - p_{\nu^+}).(p_{\pi^-} \times p_{\pi^+})$
O_{10}	$\frac{((p_{\nu^-} - p_{\nu^+}).(p_{\pi^-} - p_{\pi^+}))}{m_h^2} * O_1$
O_{11}	$(p_{\nu^-} \times p_{\nu^+}).(p_{\pi^-} \times p_{\pi^+})$
$O_{13(x/y/z)}$	$(p_{\nu^-} - p_{\nu^+}) \times (p_{\pi^-} + p_{\pi^+})$
$O_{14(x/y/z)}$	$(p_{\nu^-} + p_{\nu^+}) \times (p_{\pi^-} - p_{\pi^+})$
$O_{15(x/y/z)}$	$(p_{\nu^-} - p_{\nu^+}) \times (p_{\pi^-} - p_{\pi^+})$

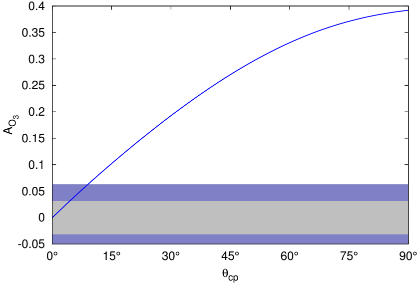
Partha Konar, Pankaj Sharma and Abhaya Swain, arXiv:1607.XXXXX

CP property

$$O_3 \equiv (p_{\nu^-} - p_{\nu^+}).(p_{\pi^-} \times p_{\pi^+})$$

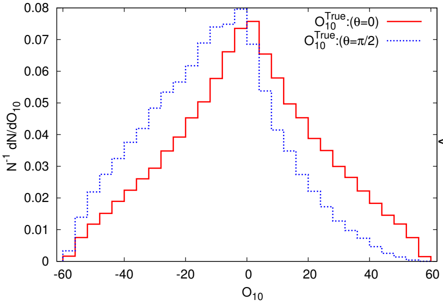
$$A_{O_3} \equiv \frac{N(O_3>0)-N(O_3<0)}{N(O_3>0)+N(O_3<0)}$$

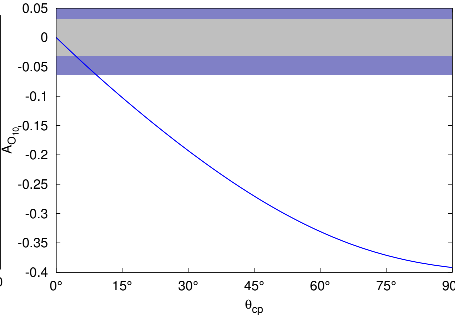




CP property

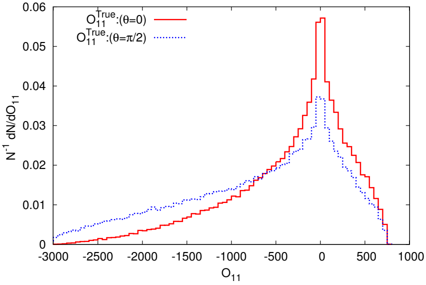
$$O_{10} \equiv \frac{((p_{\nu^-} - p_{\nu^+}).(p_{\pi^-} - p_{\pi^+}))}{m_h^2} * O_1 \qquad A_{O_{10}} \equiv \frac{N(O_{10}>0) - N(O_{10}<0)}{N(O_{10}>0) + N(O_{10}<0)}$$

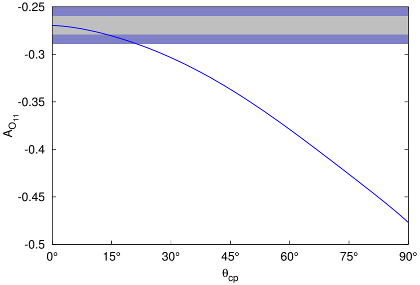




CP property

$$O_{11} \equiv (p_{\nu^-} \times p_{\nu^+}).(p_{\pi^-} \times p_{\pi^+}) \qquad A_{O_{11}} \equiv \frac{N(O_{11}>0)-N(O_{11}<0)}{N(O_{11}>0)+N(O_{11}<0)}$$

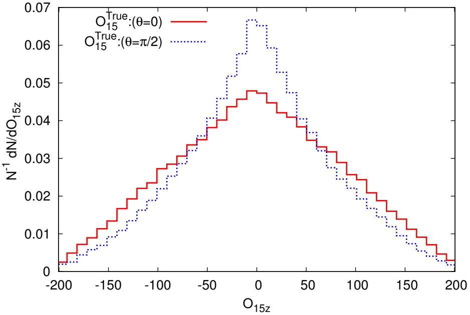




Partha Konar, Pankaj Sharma and Abhaya Swain, arXiv:1607.XXXXX

CP property

$$O_{15(x/y/z)} \equiv (p_{\nu^-} - p_{\nu^+}) \times (p_{\pi^-} - p_{\pi^+})$$



Summary

- We discuss a new reconstruction method using M_{2Cons} which can be used for tau pair reconstruction.
- The reconstructed momenta are unique and well correlated with the true momenta.
- This reconstruction method is very efficient compared to other methods.
- We have also discussed various CP sensitive observables and constructed their asymmetries.

Summary

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Thank You