Boosted light Higgs from TeV scale resonance: $h \to \tau\tau$

BOOST 2010, Oxford

Andrey Katz

Work in progress with Minho Son and Brock Tweedie

University of Maryland

June 24, 2010

Outline

1. Motivation
2. $h \to \tau\tau$ channel in Higgs searches
3. Analysis of boosted ditaus
4. Outlook

Discovering Z' and measuring of its couplings

Z' discovery

Usually it is not difficult to discover Z'. If it has leptonic decay modes (which is likely), it will be first discovered in the channels:

$$Z' \to e^+e^-, \quad Z' \to \mu^+\mu^-.$$

What else can we measure? What can we learn about Z'?

Discovering Z' and measuring of its couplings

Z' discovery

Usually it is not difficult to discover Z'. If it has leptonic decay modes (which is likely), it will be first discovered in the channels:

$$Z' \to e^+e^-, \quad Z' \to \mu^+\mu^-.$$

What else can we measure? What can we learn about Z'?

- What is the charge of Higgs under the new symmetry?
- Is this Z' part of a new strong dynamics (e.g. RS, little Higgs...)?

Discovering Z' and measuring of its couplings

Z' discovery

Usually it is not difficult to discover Z'. If it has leptonic decay modes (which is likely), it will be first discovered in the channels:

$$Z' \to e^+e^-, \quad Z' \to \mu^+\mu^-.$$

What else can we measure? What can we learn about Z'?

- What is the charge of Higgs under the new symmetry?
- Is this Z' part of a new strong dynamics (e.g. RS, little Higgs...)?

We can measure *directly* the coupling of Z' to higgs in two channels:

$$Z' \to Z\ h \qquad\qquad Z' \to W^+\ W^-$$

Discovering Z' and measuring of its couplings

Z' discovery

Usually it is not difficult to discover Z'. If it has leptonic decay modes (which is likely), it will be first discovered in the channels:

$$Z' \to e^+e^-, \quad Z' \to \mu^+\mu^-.$$

What else can we measure? What can we learn about Z'?

- What is the charge of Higgs under the new symmetry?
- Is this Z' part of a new strong dynamics (e.g. RS, little Higgs...)?

We can measure *directly* the coupling of Z' to higgs in two channels:

$$Z' \to Z\ h \qquad\qquad Z' \to W^+\ W^-$$

Evidence for compositeness

If Z' is perturbative, these channels are small (typically of order few percents or even less). However in the case of composite Z' (e.g. RS) can be as high as 90%. If we measure that these channels dominate Z' decay modes, it will be a suggestive evidence for composite Z' and higgs.

More detailed decay channels

- $h \to b\bar{b}$ – the most generic and probably the best mode if Z decays leptonically. *(see talk by Minho Son)*
- $h \to WW^*$ – important for heavier Higgs
- $h \to \tau\tau$ – light Higgs

More detailed decay channels

- $h \to b\bar{b}$ – the most generic and probably the best mode if Z decays leptonically. *(see talk by Minho Son)*
- $h \to WW^*$ – important for heavier Higgs
- $h \to \tau\tau$ – light Higgs

Why are we interested in $h \to \tau\tau$

1. BR$\sim$ 7% for light Higgs, but can be even easier than $h \to b\bar{b}$ since it should have smaller backgrounds
2. Extremely sensitive to the mass of higgs. BR quickly drops if Higgs mass is above 120 GeV.

$h \to \tau\tau$ in "ordinary" Higgs searches

In events with taus we always have missing energy. However it is possible to reconstruct the invariant mass of Higgs:

- τ is always boosted, namely neutrino is parallel to the visible τ-decay products
- project MET onto two τ-axes:

$$\vec{p}(\nu_1) = \alpha_1 \ \vec{p}(\tau_1); \quad \vec{p}(\nu_2) = \alpha_2 \ \vec{p}(\tau_2)$$

$h \to \tau\tau$ in "ordinary" Higgs searches

In events with taus we always have missing energy. However it is possible to reconstruct the invariant mass of Higgs:

- τ is always boosted, namely neutrino is parallel to the visible τ-decay products
- project MET onto two τ-axes:

$$\vec{p}(\nu_1) = \alpha_1\ \vec{p}(\tau_1); \quad \vec{p}(\nu_2) = \alpha_2\ \vec{p}(\tau_2)$$

When is it possible?

- if τs are back-to-back, there is just one axis, and the projection is impossible (e.g. direct production of higgs at the LHC in gluon fusion).
- possible if Higgs recoils (WBF)

$h \to \tau\tau$ in "ordinary" Higgs searches

In events with taus we always have missing energy. However it is possible to reconstruct the invariant mass of Higgs:

- τ is always boosted, namely neutrino is parallel to the visible τ-decay products
- project MET onto two τ-axes:

$$\vec{p}(\nu_1) = \alpha_1 \ \vec{p}(\tau_1); \quad \vec{p}(\nu_2) = \alpha_2 \ \vec{p}(\tau_2)$$

When is it possible?

- if τs are back-to-back, there is just one axis, and the projection is impossible (e.g. direct production of higgs at the LHC in gluon fusion).
- possible if Higgs recoils (WBF)

In our case Higgs will be boosted, such that the τs will be close to each other, and the angle between the axes might be small. How far away can we go reconstructing Higgs?

Main questions

Two important goal of our analysis are:

- Reconstruct Higgs from $\tau\tau$ – can be very difficult in the boosted case
- Reconstruct the entire Z' – should be easier

Main questions

Two important goal of our analysis are:

- Reconstruct Higgs from $\tau\tau$ – can be very difficult in the boosted case
- Reconstruct the entire Z' – should be easier

Importance of Z decay modes

We have in principle very convenient channel in this case with $Z \to l^+l^-$, where it is easy to reconstruct Z and the background should be manageable. We will take a closer look on this channel and see how does it work. However the statistics in that channel is too low. Our main hope is: $Z \to jj$, $h \to \tau\tau$, should be easier to control the backgrounds rather in $Z \to jj$, $h \to b\bar{b}$.

$h \to \tau\tau$ in Z' decays

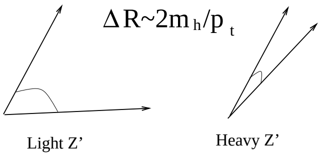
Since we consider Z', which mixes with the Higgs, it is very likely to be heavy (EW precision measurements) $m(Z') \gtrsim 2~\mathrm{TeV}$.

Higgs is likely to be very boosted:

$h \to \tau\tau$ in Z' decays

Since we consider Z', which mixes with the Higgs, it is very likely to be heavy (EW precision measurements) $m(Z') \gtrsim 2\ \mathrm{TeV}$.

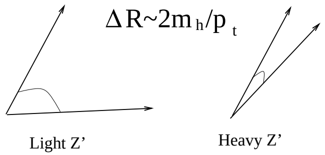
Higgs is likely to be very boosted:



$h \to \tau\tau$ in Z' decays

Since we consider Z', which mixes with the Higgs, it is very likely to be heavy (EW precision measurements) $m(Z') \gtrsim 2\ \mathrm{TeV}$.

Higgs is likely to be very boosted:



- Can we identify (di-)τs when they are spatially not well separated?
- Can we reasonably project missing energy on these axes?

How do we usually identify hadronic τs ?

What is special with τ?

How do we usually identify hadronic τs ?

What is special with τ?

- It is **not a colored state**, it does not shower gluons
- τs are boosted (specially in our case)

How do we usually identify hadronic τs ?

What is special with τ?

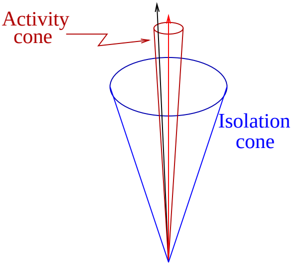
- It is **not a colored state**, it does not shower gluons
- τs are boosted (specially in our case)
- We expect to find decay product in a very narrow cone (1 or 3 prongs $+ \gamma$s). Furthermore, since (secretly) it is a lepton, we impose usual lepton isolation criteria.

How do we usually identify hadronic τs ?

What is special with τ?

- It is **not a colored state**, it does not shower gluons
- τs are boosted (specially in our case)
- We expect to find decay product in a very narrow cone (1 or 3 prongs + γs). Furthermore, since (secretly) it is a lepton, we impose usual lepton isolation criteria.

Demand that the hardest track (red) "is not too far" from the jet vector and allow the activity inside the inner cone. Demand no activity inside the isolation cone



Ditau composition

1. $\sim 12\%$ all leptonic (should not be a problem, but statistics is low)

Ditau composition

1. $\sim 12\%$ all leptonic (should not be a problem, but statistics is low)
2. $\sim 45\%$ semileptonic mode. The lepton will usually fail to pass simple isolation criteria. Can we identify these events properly?

Ditau composition

1. $\sim 12\%$ all leptonic (should not be a problem, but statistics is low)
2. $\sim 45\%$ semileptonic mode. The lepton will usually fail to pass simple isolation criteria. Can we identify these events properly?
3. $\sim 43\%$ all hadronic mode. Expect it to be very hard. Can we do anything with this mode?

Semileptonic ditaus

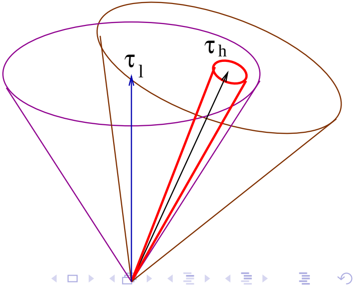
For heavy Z' we expect that the lepton will not pass stringent lepton isolation criteria. However the lepton will fail due to very well-collimated hadronic activity in the vicinity of the lepton, without any other hadronic activity around. This behavior is not characteristic for QCD (when the leptons are produced from heavy flavor decays).

Semileptonic ditaus

For heavy Z' we expect that the lepton will not pass stringent lepton isolation criteria. However the lepton will fail due to very well-collimated hadronic activity in the vicinity of the lepton, without any other hadronic activity around. This behavior is not characteristic for QCD (when the leptons are produced from heavy flavor decays).

Define new objects: mutually isolated lepton and τ.

Find the hardest track in the isolation cone of the lepton. Cut out a small cone around that track and check the lepton for the isolation. If it passes, draw an isolation cone around the "would-be τ" and check this object for isolation. Only if both the small cone of activity and lepton fulfill these requirements, refer them "mutually isolated".



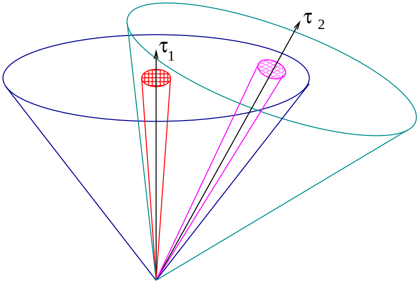
Mutual isolation

Can we use definitions of mutual isolation on all-hadronic ditaus?

Mutual isolation

Can we use definitions of mutual isolation on all-hadronic ditaus?

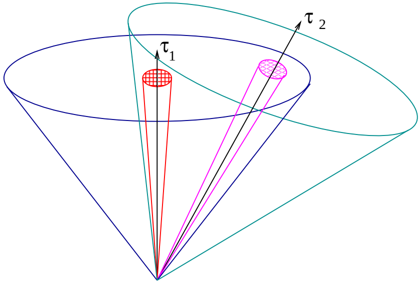
Theoretically this definition is possible. Practically we get reasonable efficiency only if both τs are one-prongs (which is relatively rare).



Mutual isolation

Can we use definitions of mutual isolation on all-hadronic ditaus?

Theoretically this definition is possible. Practically we get reasonable efficiency only if both τs are one-prongs (which is relatively rare).



Exact definitions:

Isolation cone radius: $\Delta R = 0.4$

Inner cone for hadronic τ: $\Delta R = 0.07$

Use only tracks and photons for purposes of isolation cuts

The lepton carries 90% or more of p_T in the isolation cone

Z' reconstruction in $h \to \tau\tau$ channel

In the most optimistic case (RS KK modes) we can get $(m(Z') = 2\ TeV)$

$$\sigma((Z'\ production) \times BR(Z' \to Zh)) \approx 25\ \mathrm{fb}\ .$$

This means approximately 40 events at the end of the run (with $Z \to l^+ l^-$ and $h \to \tau\tau$).

Z' reconstruction in $h \to \tau\tau$ channel

In the most optimistic case (RS KK modes) we can get $(m(Z') = 2\ TeV)$

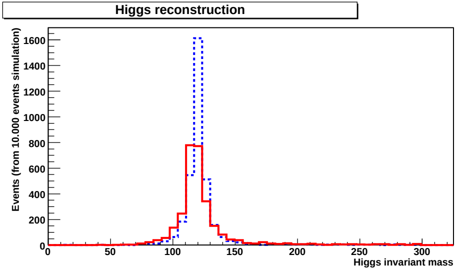
$$\sigma((Z'\ production) \times BR(Z' \to Zh)) \approx 25 \text{ fb} .$$

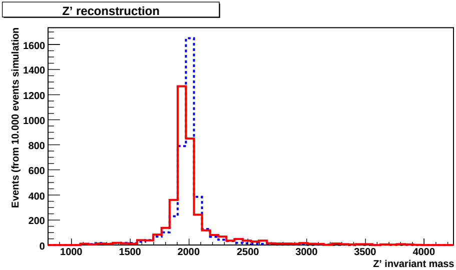
This means approximately 40 events at the end of the run (with $Z \to l^+l^-$ and $h \to \tau\tau$).

How well do we reconstruct these events?

- 85% of all leptonic Zs are reconstructed
- out of these events we properly reconstruct almost all dileptonic Higgses (above 95%).
- around 65% of the semileptonic events are reconstructed properly
- efficiency in all hadronic channel is a problem (less than 20%)

Explicit simulations





- Blue line – ideal measurement of momenta, no MET mismeasurement
- Red line – distributions are smeared (according to CMS TDR formula), MET calculated as a sum of leading reconstructed (and smeared) objects.

Backgrounds

Naive expectation: the most backgrounds should come from pure QCD production, when leptons are produced either from heavy flavor decays or decays-in-flight. The explicitly simulated the background Z+jets applying on it the same criteria, as we did on ditau jets (including mutual isolation) and found them negligible (virtually non-existent) in the relevant kinematic regime.

Backgrounds

Naive expectation: the most backgrounds should come from pure QCD production, when leptons are produced either from heavy flavor decays or decays-in-flight. The explicitly simulated the background Z+jets applying on it the same criteria, as we did on ditau jets (including mutual isolation) and found them negligible (virtually non-existent) in the relevant kinematic regime.

One should still worry about the following channels:

- $ZZ^* \to l^+l^-l^+l^-$+jets (if both Zs are on-shell this background is irrelevant, the pair of leptonic τs almost never reconstructs Z).
- $Z \to l^+l^-$, $W \to l\nu$+jets, might be dangerous for semileptonic channel, however given a very low fake rate and extreme kinematic regime, it is probably not a problem

Conclusions and Outlook

1. Measuring a BR of Z' into $Z\ h$ can give us an important information about the nature Z' and h and shed a light on physics it comes from.
2. If the higgs is light $h \to \tau\tau$ can be a useful channel to perform this measurement.
3. Even the lowest statistics channel ($Z \to l^+l^-$) gives by itself an important information in the most optimistic case, the backgrounds are negligible.
4. The main hope: may be this analysis is possible in the channel $Z \to jj$:
    - the statistics is expected to grow by factor of 10.
    - can have a reasonable result also with smaller cross-section
    - are backgrounds still under control??