$Z' \to Zh \to \ell\ell bb$ Preliminary studies

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Intro

One possible search for new physics at 13 TeV is the search for a Z' in the decay channel $Z' \to Zh \to \ell\ell bb$
I will cover some preliminary study on relevance, feasibility, and comparison with similar searches.
All is very, very preliminary.

- Physics motivation;
- Current and published searches;
- Back-of-the-envelope comparisons.

Physics motivations

- There a large number of thoeretical model where a Z' is present.
- In general the Z' mass is a free parameter, and can be in the range 1-10 TeV.
  - Examples are GUT with gauge simmetry group with dimension > 5
    - ★ A.Leike, "The Phenomenology of Extra Neutral Gauge Bosons",arXiv:hep-ph/9805494 or
    - ★ G.Rizzo, "Z' Phenomenology and the LHC", arXiv:hep-ph/0610104
  - Or composite-higgs, which have also more scalars in the menu;
  - Or Little-Higgs;
  - Heavy Vector Triplet model generalizes this class of model, with an heavy V' with variable coupling to SM V and f.
    - ★ *al. et* A.Wulzer, "Heavy Vector Triplets: Bridging Theory and Data", arXiv:1402.4431
- Models in general have both Z' and W'.
- Good news is that in some scenarios, apparently the $V' \to f\bar{f}$ and $V' \to VV$ are suppressed.
  - so $Z' \to ee/\mu\mu$ and $Z' \to WW$ do not cover all parameters space.

Current analysis

$Z' \to Zh \to qq\tau\tau$

Search for narrow resonances decaying to ZH in the final state with two τ leptons and a merged jet pair,
CMS Paper EXO-13-007 (CWR ended. No PAS, directly to Paper)
AN-14-063: Perugia, CERN, Zurich, Rochster, SPRACE, IFT

- Search for $M'_Z \in [0.8, 2.5]$ TeV;
- Boosted regime for for $Z \to qq$ and $h \to \tau\tau$;
- Trigger: SingleJet320 o HT650: fully efficient wrt analysis;
- $Z \to qq$ as a single jet (CA8) with substructures and components; $p_T > 400$ GeV
- All τ decays: τ_e, τ_μ, τ_h. Six channels in total.
- $p_T(\mu/e) > 10 GeV$, τ_h from AK5-jets with hadrons-plus-strips: $p_T(\tau_h) > 20$ GeV
- τ reco*ID efficiency: $\sim 20 - 40\%$ depending on channel.

Current analysis

$W' \to Wh \to \ell\nu bb$

Search for massive WH resonances decaying to the $\ell\nu b\bar{b}$ final state in the boosted regime at $\sqrt{s} = 8$ TeV ,

CMS Paper EXO-14-010 (GoingToPreapproval)

AN-14-121: Zurich, Peking

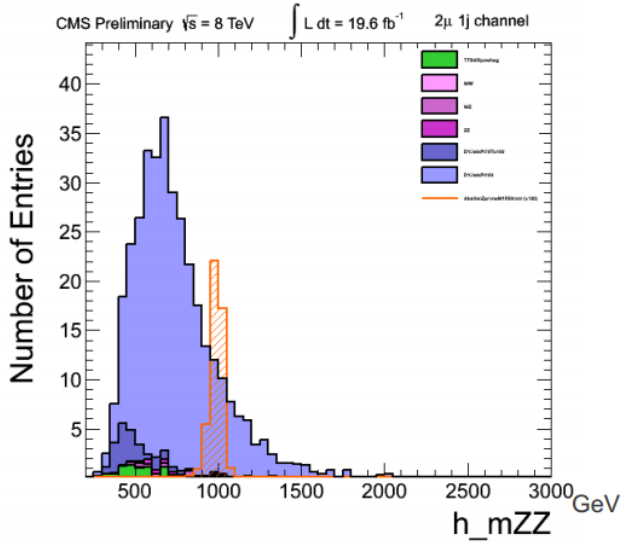
- First search for this channel; closely related to $WW \to \ell\nu qq$ (arXiv:1405.3447)
- Search for $M'_W > 0.8$ TeV;
- Trigger: SingleMu40, SingleEle80
- $W \to \ell\nu$ standard; $h \to bb$ next slide;
- $p_T(W, h) > 200$ GeV, $\Delta R(Wh) > \pi/2$
- top-veto if additional AK5 jets m_{top}^{reco} not close to m_{top}
  - $m_{top}^{leptonic}$ ($MET + \ell$+AK5-jet)
  - $m_{top}^{hadronic}$ (CA08-jet+AK5-jet)

$h \rightarrow bb$ recostruction

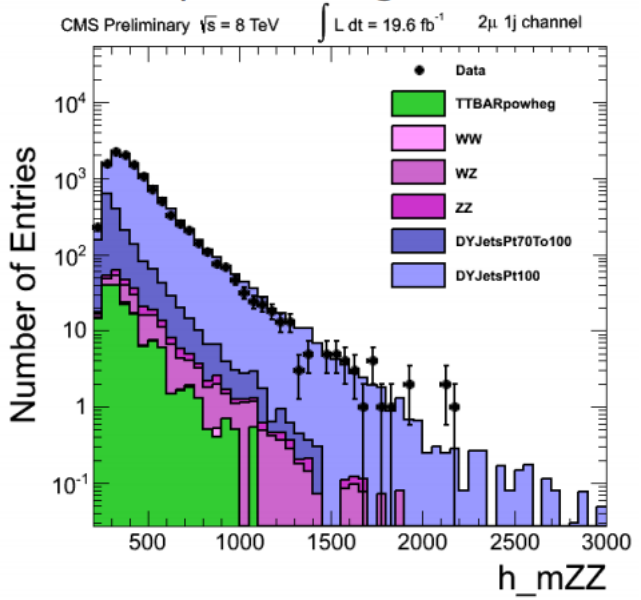
- recostructed as a single, massive CA08 $p_T > 30$ *GeV*
- ID uses both reconstructed bb mass and b-tagging
- N-subjettiness (τ_{12}) does not increase sensitivity;
- CA08 plus *jet pruning*
  - reduce pile-up by removing soft or large angle stuff from jet;
  - standard choice for many/all boosted jets study in CMS;
- compute pruned m_{jet} and select $110 < m_{jet} < 135$ *GeV*
  - m_{jet} performance checked in $W \rightarrow qq'$ decay from semileptonic $t\bar{t}$ events;
  - b-quark fragmentatin model checked with m_{top} recostruction in same events;
  - total syst $\sim 5\%$
- b-tagging:
  - if CA08 jet is splitted in two sub-jets with $\Delta R > 0.3$, use CSV (loose-loose) on subjets
  - otherwise use CSV (loose) directly on CA08
  - BTagPog recipe
  - b-tagging efficiency for signal is $\epsilon \sim 70\%$

NOT active analysis on $Z' \to Zh \to \ell\ell J$

- Two presentations by A.Mauri (Pisa) (plus A.Bonato & J-R.Vlimant (CERN)) 21/8/2013 30/10/2013
- Note $h \to Jet$, so including also $h \to cc/ss$
- Based on bulkGraviton$\to ZZ$ (AN-13-040)
- Preliminary, but apparently in good shape
  - some signals available (with problems), studied at parton level;
  - selections: $m_h \in [110, 130]$ GeV, $p_T(Z/h) > 80$ GeV, $\tau_{12} < 0.75$;
  - study on cut optimization (mostly subjettiness)
  - considering also $h \to WW/ZZ$ full hadronic as signal
  - background estimate from fit of m_{ZH}
  - signal template as Crystal Ball



Data sidebands (pure background)



Back-on-the-envelope calculation

What can we do in $Z' \to Zh \to \ell\ell bb$ channel?

- Comparing this channel with $Z' \to Zh \to qq\tau\tau$;
- Brancing Ratios $\times$ Efficiencies

$Z \to \ell\ell$ from $A \to Zh \to \ell\ell bb$

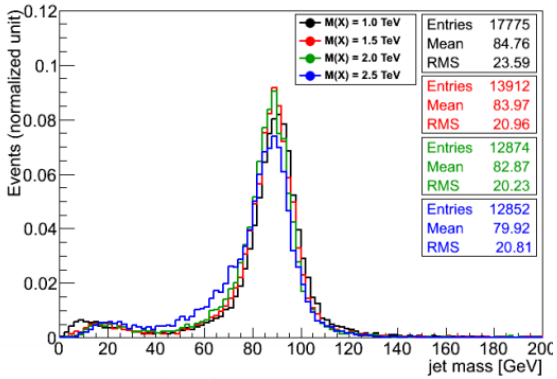
$h \to bb$ from $W' \to Wh \to \ell\nu bb$

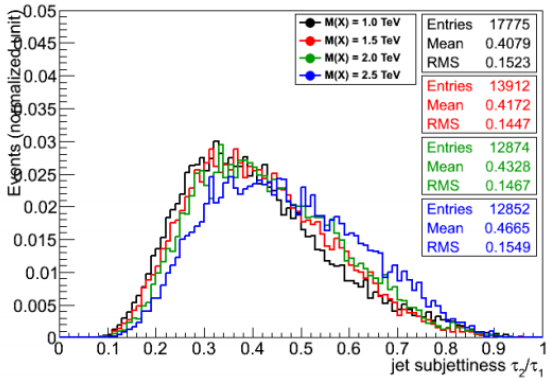
$Zh \to qq\tau\tau$ from PAS/AN

- $\mathcal{B}(Zh \to qq\tau\tau) = (.7 \times 0.064) = 0.045$
- $\mathcal{B}(Zh \to \ell\ell bb) = (.066 \times 0.58) = 0.038$
  - BR are not so different
  - You gain with $h \to bb$ what you lose in $Z \to \ell\ell$
  - $\mathcal{B}(Zh \to qqbb) = .7 \times 0.58 = .40$ x10! Doable? hmmm...

What about efficiencies?

- Trigger efficiency is 100% in both channel (large boost)
- $\epsilon(Z \to qq) \approx 80\%$ (my estimate)
  - $70 < M_{jet} < 110$ and $\tau_{12} < 0.75$
- $\epsilon(h \to \tau\tau)$ 30%
  - taking into proper account all (six) τ decay channels BR and individual efficiencies;
- $\mathcal{B} \times \epsilon(Zh \to qq\tau\tau) \approx 0.045 \times 0.8 \cdot 0.3 = 0.011$
- $\epsilon(Z \to \ell\ell) \approx 0.9^2 = 80\%$
  - Can be lower wrt $Z \to \ell\ell$ due to large boost of the Z;
- $\epsilon(h \to bb)$ 70%
- $\mathcal{B} \times \epsilon(Zh \to \ell\ell bb) \approx 0.038 \times 0.8 \cdot 0.7 = 0.021$



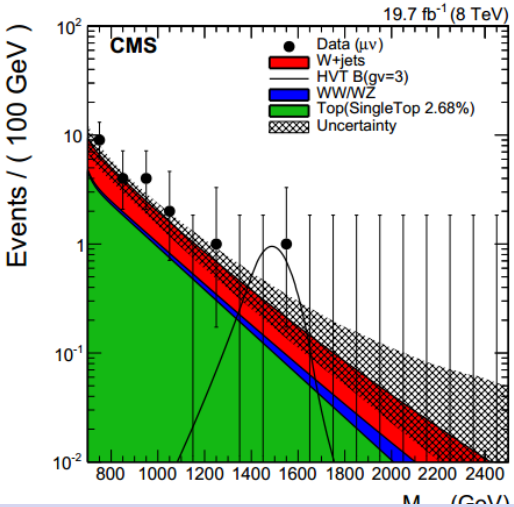


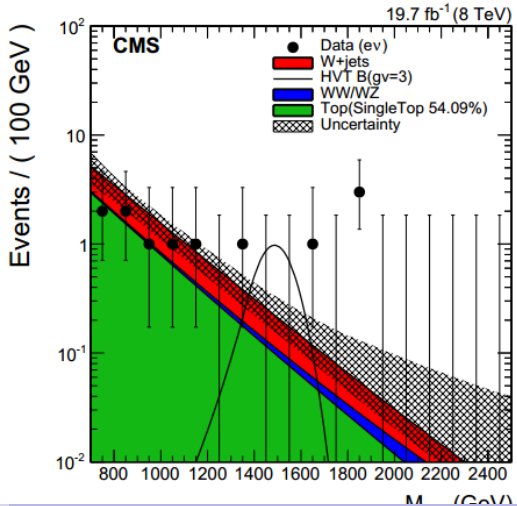
What about background?

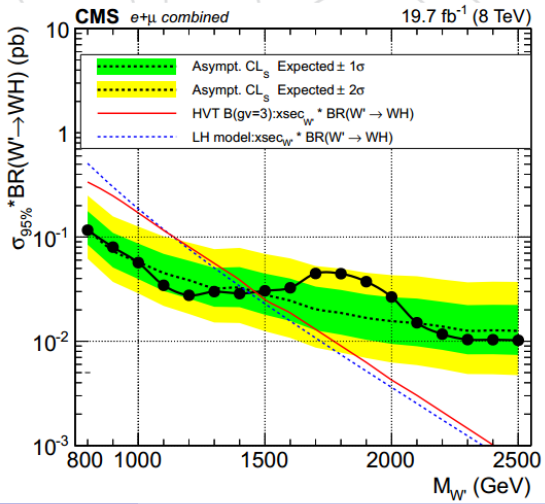
- For $Z' \to Zh \to qq\tau\tau$ is moslty Z+jets and ttbar, plus some VV;
- For $W' \to Wh \to \ell\nu bb$ is the same: W+jets, ttbar, some WW/WZ;
- In both cases the final selection has very little events left $\mathcal{O}(1)$
- $Z' \to Zh \to \ell\ell Jet$ shows more background $\mathcal{O}(10)$ (but w/o b-tagging);
- Final search is in Zh/Wh invariant mass.

Summary

- The physical case is there;
- The reach of this channel seems better than the analogous $Z' \to Zh \to qq\tau\tau$;
- The tools are already available and used by several analysis;
- I send a mail to D.Dal Re asking why the 8TeV analysis is not active: waiting for reply;
- I was not able to find anything on the subject published by ATLAS.
- btw: W' finds a 2.5σ excess at 1.8 TeV...







From Daniele Dal Re

- about $Z' \to Zh \to \ell\ell Jet$ at 8 TeV:
  - Student produced his master thesis (not PhD!) and left Tesi.pdf
- Di certo non e' un canale per lo startup.
- Alternatives with simial final state:
  - Heavy Majorana Nu and $WR \to m(eejj)$ bump search (ripetendo circa quello che e' gia' stato fatto per verificare il bump a 2 TeV);
  - 1st gen LQ eejj and evjj (qui cercando di migliorare o eventualmente rivoluzionare la strategia di analisi);
  - $W' \to Wh \to \ell\nu + Hjet$

Addendum

Q: why would be W' better than Z'?

- First reason is the BR:
  if we consider $W' \to Wh \to \ell\nu bb$ wrt to $Z' \to Zh \to \ell\ell bb$, the BR advantage in for W is about 10/3=BR($W \to \ell\nu$)/BR($Z \to \ell\ell$).
- Second reason is production rate:
  if W' and Z' belogs to the same triplet, their coupling to fermions is the same, and then the production rate depends on the abundance of correct quarks in the colliding protons, namely on PDF.
  In general, we can expect W' to be produced from qq', while Z' from $q\bar{q}$, as for SM W and Z.
  So, we can expect the same ratio (about 10) of W'/Z' production.
  Of course, if the Z' belongs to a singlet, this reasoning is not valid anymore.
- a presentation about this issue Presentation from Jennifer Ngadiuba