Some Searches for New Physics with the Higgs

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Higgs Physics After Discovery
PCTS
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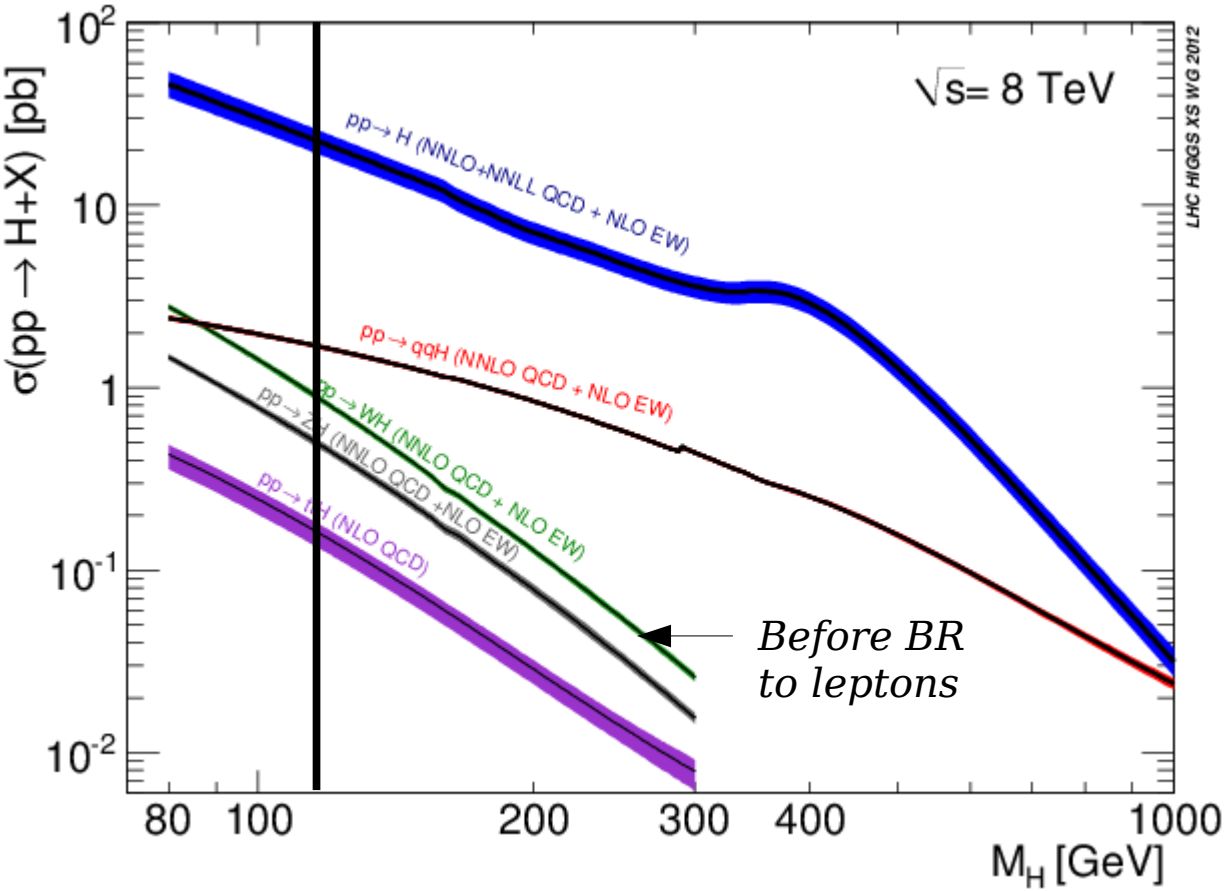
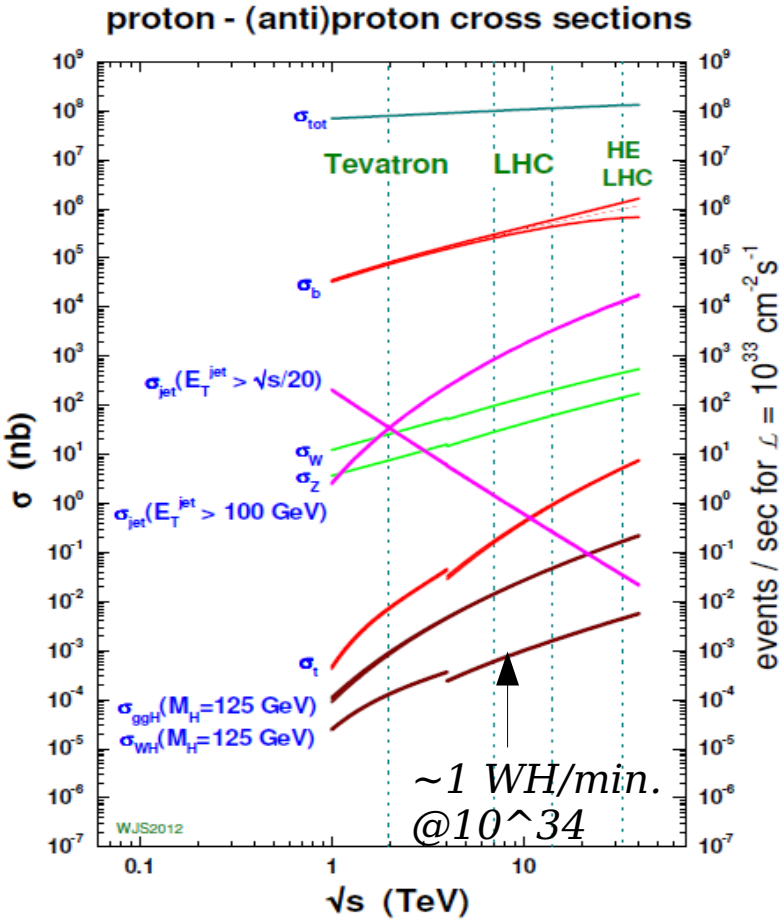
SM Higgs Production at the LHC

- LHC has mainly measured the gg→H production
  - ~3σ evidence for VBF from ATLAS
- Going forward we can start to study the rarer production modes

(New grad students won't see plots vs. m_H anymore?!)





Higgs (→γγ) + X

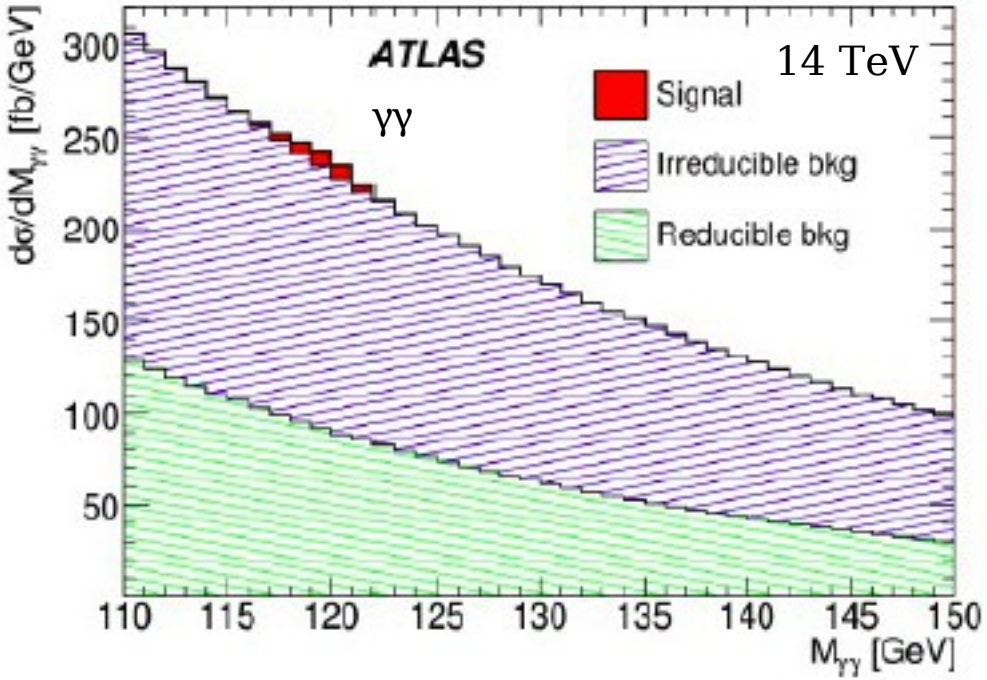
- With 26/fb, can start to see modes with smaller cross-sections!
  - WH(→γγ) : lepton + MET + γγ *(hadronic decay channels dirtier…)*
  - ttH(→γγ) : lepton + MET + b(b) + γγ
  - ZH(→γγ) : 2-lepton + γγ, MET + γγ

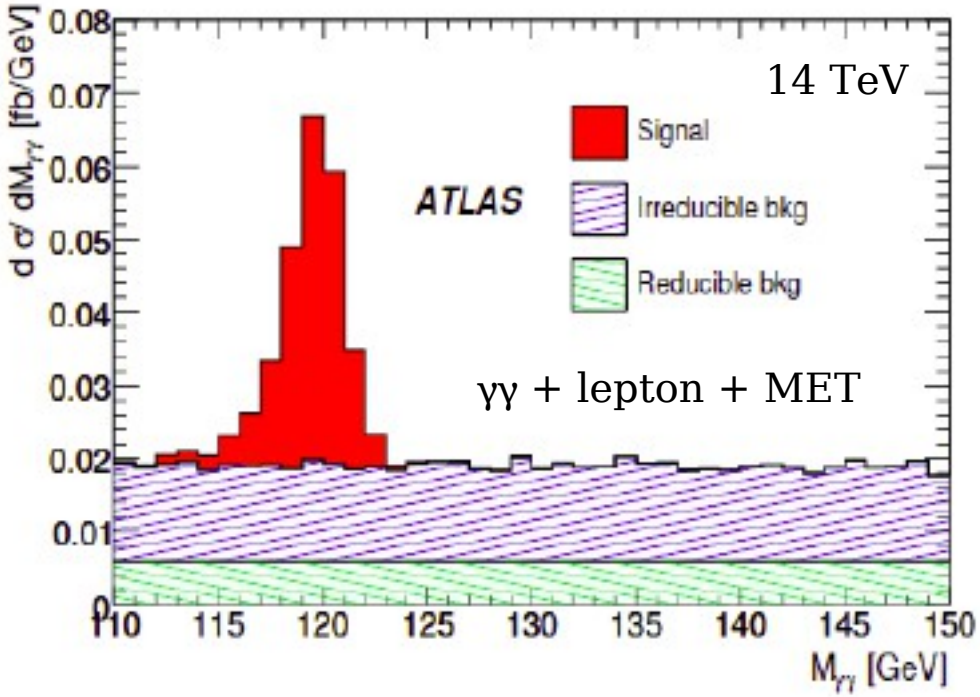
- If BR(H→γγ) is enhanced, these channels may be enhanced
  - Important to measure many production channels to know whether enhancement is due to production rate or decay BR
  - Measure Higgs couplings to W/Z/t in orthogonal channel

- Sensitive to new physics directly – low SM "Higgs background" !
  - SUSY can produce Higgs in decay chains, associated with leptons and/or MET and/or b-jets (and countless other models of new physics)
  - Keep selections as inclusive as possible!
  - Important to have BSM benchmarks in these channels

W + Higgs (→γγ)

- **Clean!**
  - S/B = ~2 compared to ~0.02 for inclusive analysis
- But low rate (in SM)
  - Events of WH(→γγ) in 30/fb:
    ~0.8pb * 30/fb * (20% * 0.5) * (0.25% * 0.6) * (80% * 0.7) = **~2 events**
    lepton*eff H → γγ * eff MET * eff
  - See 4, expect 1.5 bkgd. events → ~2σ expected sensitivity to SM WH





This would have been nice

- Large BR $x_2^0 \rightarrow h\, x_1^0$: "Could discover Higgs in SUSY decays"
- Unfortunately, it didn't turn out this way…
- But, the corollary is still true: "Could discover SUSY using Higgs decays" !
- Still possible that ~10% (?) of Higgs production is through SUSY production and decay!

Particle	Point 1
$\tilde{g}$	1004
$\tilde{\chi}_1^\pm$	325
$\tilde{\chi}_2^\pm$	764
$\tilde{\chi}_1^0$	168
$\tilde{\chi}_2^0$	326
$\tilde{\chi}_3^0$	750
$\tilde{\chi}_4^0$	766
$\tilde{u}_L$	957
$\tilde{u}_R$	925
$\tilde{d}_L$	959
$\tilde{d}_R$	921
$\tilde{t}_1$	643
$\tilde{t}_2$	924
$\tilde{b}_1$	854
$\tilde{b}_2$	922
$\tilde{e}_L$	490
$\tilde{e}_R$	430
$\tilde{\nu}_e$	486
$\tilde{\tau}_1$	430
$\tilde{\tau}_2$	490
$\tilde{\nu}_\tau$	486
h	95
H	1046
A	1044
$H^\pm$	1046

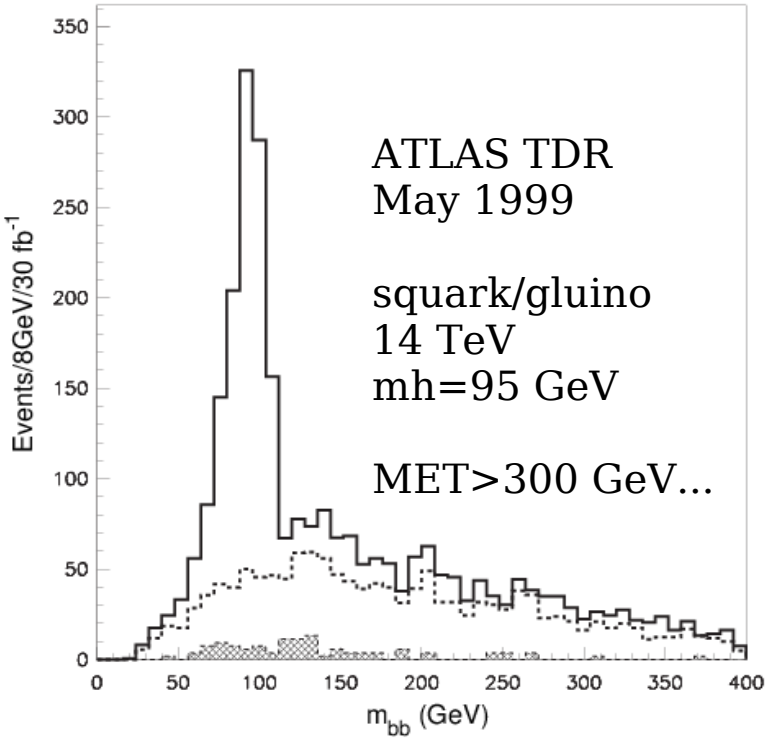


Figure 20-23 Mass distribution for two tagged b-jets at Point 1 for 30fb^{-1}. The dotted curve is the SUSY background, and the shaded histogram is the sum of all Standard Model backgrounds.

New Physics in the "WH" channel

- Could also have additional non-SM production !
- $pp \rightarrow x_1^+ x_2^0 (\rightarrow G\ W^+\ G\ h)$ could be ~1 pb @ 8TeV
  - **comparable to SM WH rate!**
- $pp \rightarrow x_1^+ x_2^0 (\rightarrow x_1^0\ W^+\ x_1^0\ h)$
  - dominant x_2^0 BR for the Bino LSP case with heavy SUSY scalars

"Mini-split", Craig, Domopolos, arXiv:1210.0555

- Could also have softer lepton, less MET, lower mT(MET, lepton), etc. from new physics, e.g. $m(x_1^+) - m(x_1^0) < m(W^+)$
  - Study "lepton + MET + $H(\rightarrow \gamma\gamma)$" : keep cuts as inclusive as possible!
- Generally expect more MET and larger mT compared to WH
- Will study "grid" of $m(x_2^0)$=$m(x_1^+)$, $m(x_1^0)$

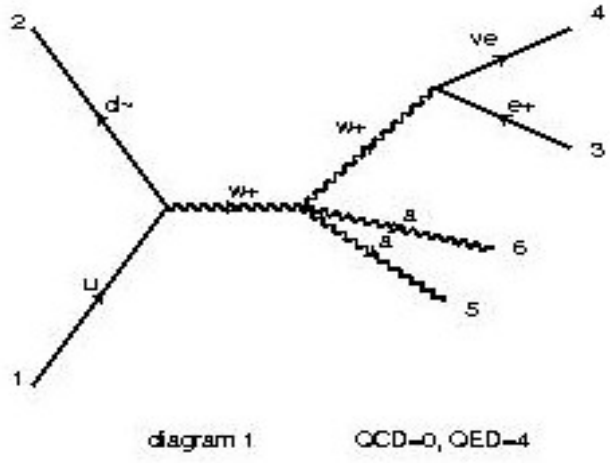
W + Higgs (→γγ) analysis

- Standard γγ selections, as in inclusive analysis
- 1 Tight electron within acceptance, pT>15 GeV
  or
  1 Tight muon within acceptance, pT>10 GeV
  (separate channel for >1 lepton events!)
- Calorimeter and track isolation (corrected for pileup)
- MET>40 GeV (not a lot of MET these days!)
  - Sensitive to primary vertex, calibrations, and pileup suppression!
    - Use same primary vertex for photon pT as pileup corrections and lepton
    - Same photon and lepton object energy corrections in MET calculation
- Remove events with m(eγ) near m(Z), remove Zγ→eeγ, e→γ fake
  - some additional photon selections to reduce e → γ fake (conversions)

- Not cutting on mT(l,MET)!
- Using minimal cut on pT and MET needed to reduce background…
  - Would cut harder to optimize SM WH sensitivity

W + Higgs (→γγ) analysis

- Interesting (non-Higgs) SM backgrounds
  - Irreducible W+γγ (ISR)
  - W+γ (+FSR γ from lepton)
  - W (+FSR γ from lepton + fake γ)
  - Ditto for ttbar
  - Z/Zγ (+e→γ fake or FSR γ from lepton + fake MET)
  - (γγ, real or fake) * fake lepton * fake MET
    - Measure in data low-MET region, scale to MET>40 GeV region determined from non-isolated leptons
    - Turns out to be small!



- Total of just ~6 events expected in m(γγ) signal region (120-130 GeV)
- ~2 events expected from SM WH, up to ~12 events expected from SUSY!

- Also include MET>150 GeV category:
  ~0.1 SM background, ~0.1 events from SM WH, ~1 event from SUSY

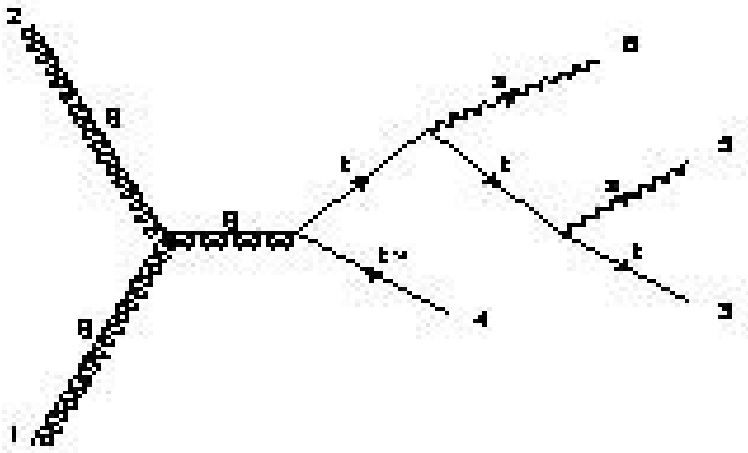
tt + Higgs (→γγ)

- Baseline analysis is lepton + MET + b-jet(s) + γγ
  (“WH analysis + b-jet(s)”)
  - Also studying all-hadronic channel
  - Di-lepton channel is ~9x smaller

- ttH cross-section is ~4x smaller than WH
  - Expect ~0.5 SM ttH(→γγ), lepton+MET+b+γγ, events

- Backgrounds also small from ttbar and W,
  just ~0.5 events expected
  in m(γγ) signal region (120-130 GeV)

- Not very sensitive to SM ttH yet,
  but great place to look for new physics…



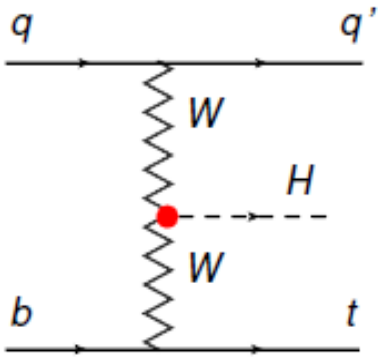
New Physics in the "ttH" channel

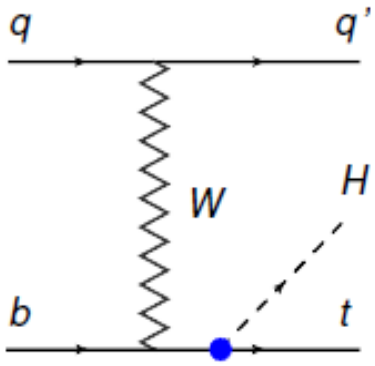
- FCNC t → ch

  ttbar → tch → Wbch → lepton+MET+b+c+h(→γγ)

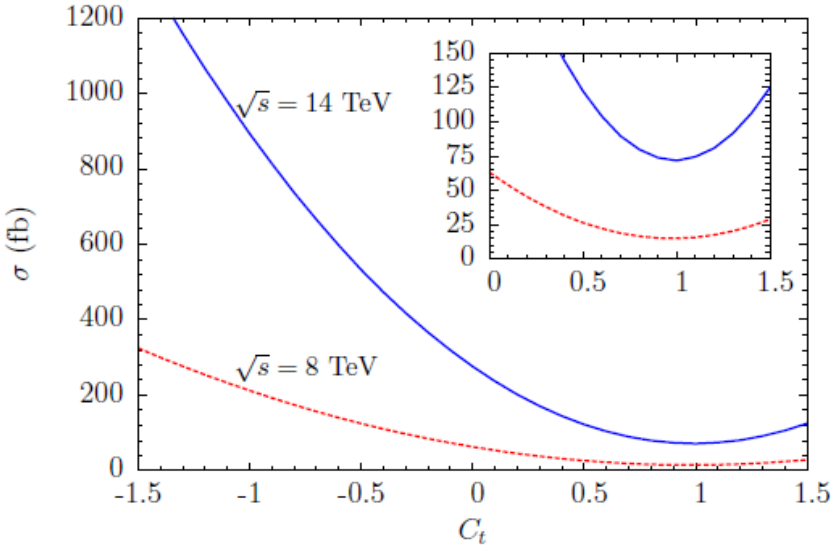
  BR(t → ch)~1% is consistent with current limits
  - Gives ~10 events expected in lepton+MET+b+γγ channel!

- thj, enhanced by 15x by negative th coupling
  - Gives ~2 events expected in lepton+MET+b+γγ channel!



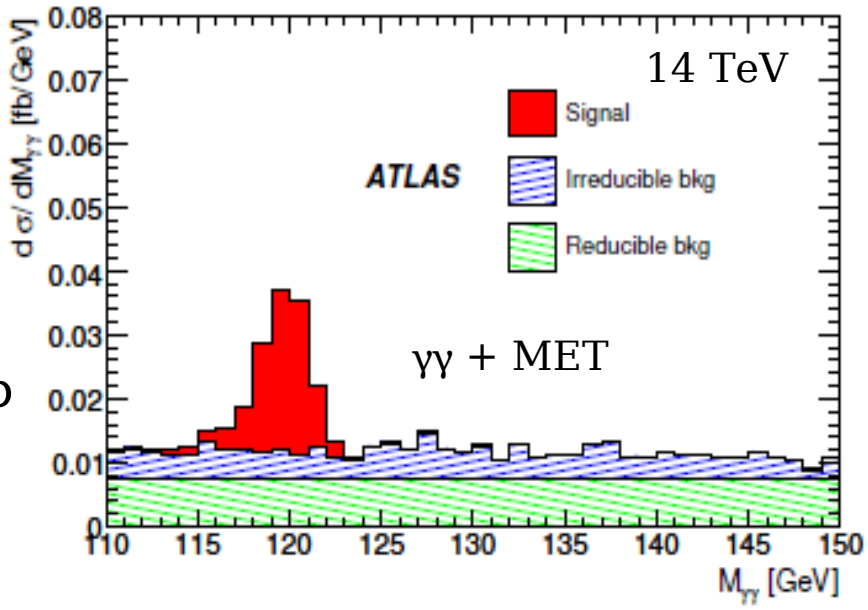


arXiv:1211.3736



Z + Higgs (→γγ)

- MET + γγ
  - For SM ZH, require MET>80 GeV
  - Almost as clean as WH(→γγ)
  - Rate about 2x smaller:
    just ~1 SM ZH event expected in 30/fb



- 2-lepton + γγ
  - SM ZH lives in low-MET, ee/μμ, near mZ
  - Just ~0.2 ZH events expected, and 2 events of (Z) background!
  - But interesting BSM-sensitive channels:
    - med/high MET
    - eμ
    - off Z peak
      - Include m(llγ)~m(Z) veto to kill FSR

New Physics in the "ZH" channels

- Off Z-peak signals?
  - ~1 background event expected (mainly from Z/DY) (and no SM H)
  - Off-shell Z* decays ($x_3^0 \rightarrow Z^* x_2^0$) ?
  - $Z' \rightarrow Z^* h$ decays ?

- eμ is very clean!
  - Just ~0.01 of SM ttH and ttbar background total expected
  - Great place to look for new physics signals…

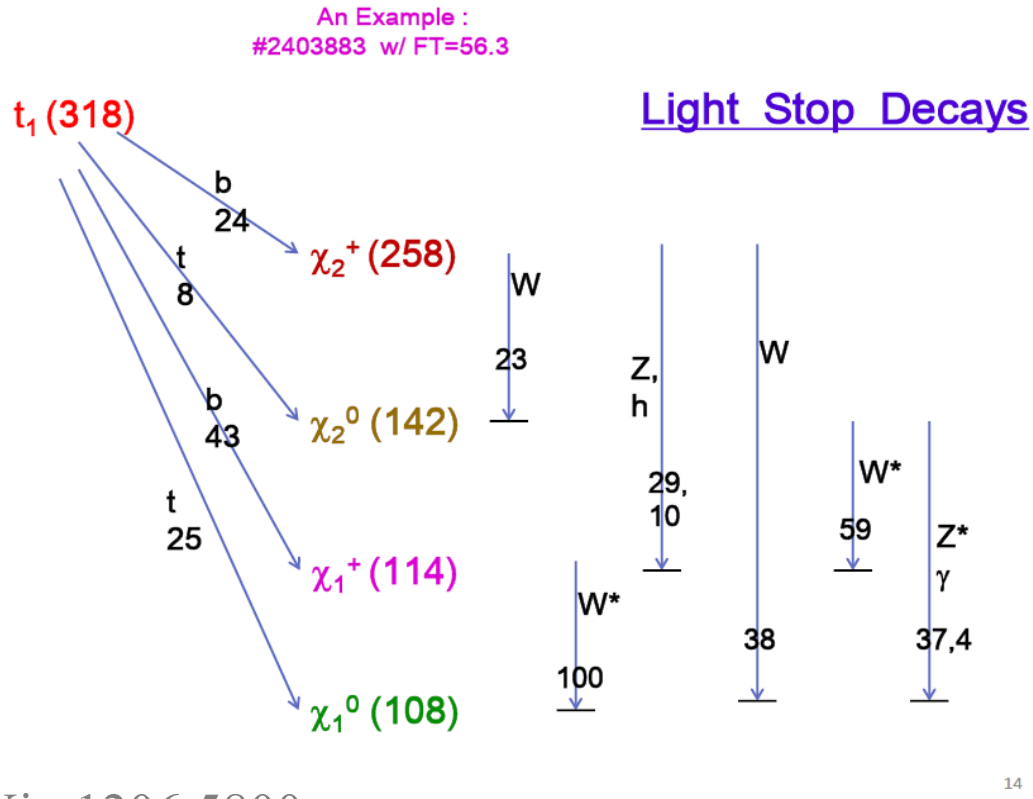
hh production

- Double Higgs production is very small in the SM
- Makes it hard to measure the Higgs self-coupling (sLHC)
- Look on the bright side: very low di-Higgs background to BSM! :)
  - Can be strongly enhanced by new physics arXiv:1208.1542
    - h(→bb) + h(→γγ)
    - Look for bump in m(bb) ? And m(bbγγ)?
  - Backgrounds with 2 b-jets are not so large
    - About ~5 events expected in m(γγ) signal region for 30/fb, pT(b)>20 GeV

- Best channel / selections to see hh?
  - Maybe h(→WW) + h(→WW) → tri-lepton?
- Benchmark model : H → hh, mH=260 GeV (2HDM), 3.6pb@8TeV
  - Gives 20 events in l+MET+γγ channel!
  - Gives 0.5 events in the eμ+MET+γγ channel, with just 0.01 SM background (tt and ttH)

Less minimal new physics in h+X channels

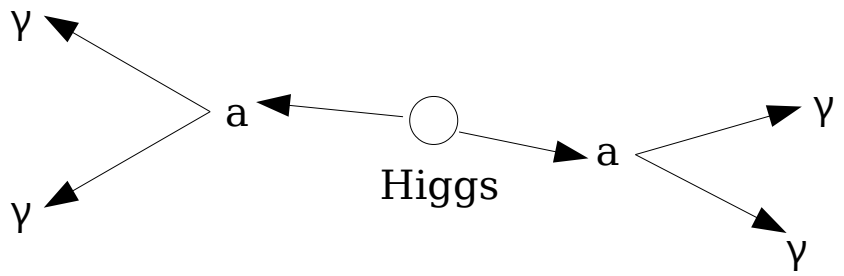
- In general can have a more complicated spectrum / decays
  - ~t ~t → b x_2^+ t x_1^0 → b h W^* x_1^0 t x_1^0 → b h(→γγ) + lepton + jets + MET
  - Rate could be ~1pb*.24*0.1*2 = 50fb*0.25% *eff ~ **2 events in 30/fb**
    - Or larger if BR h(→γγ) is enhanced or ~t is lighter!



arXiv:1206.5800

off-shell Z* decays
on-shell Z decays
3rd photon
high pT lepton
soft lepton
large MET
...

Non-SM Higgs Production / Decay



- $H \rightarrow a\,a \rightarrow \gamma\gamma\,\gamma\gamma$
  - For m(a)<~400 MeV, photons not isolated (ATLAS-CONF-2012-079)
  - Study range from 400 MeV < m(H)/2, **≥3 <u>isolated</u> photons**

- Final-state with ≥3 photons not previously studied?!

- Commissioned new 3-photon trigger (pT=15,15,15 GeV) for 2012
  - ~50% more efficient than standard pT=24,22 GeV trigger (pT=20,20 GeV was unprescaled in 2011…)

Non-SM Higgs Production / Decay

- Offline require ≥3 tight, isolated photons, pT>15 GeV (or trig. thresh.)
- Look for excess rate, and/or invariant mass bumps

- Working on data-driven understanding of fake-photon rate
  - Loose → tight rate in di-photon data/MC
  - Isolation studies in data/MC

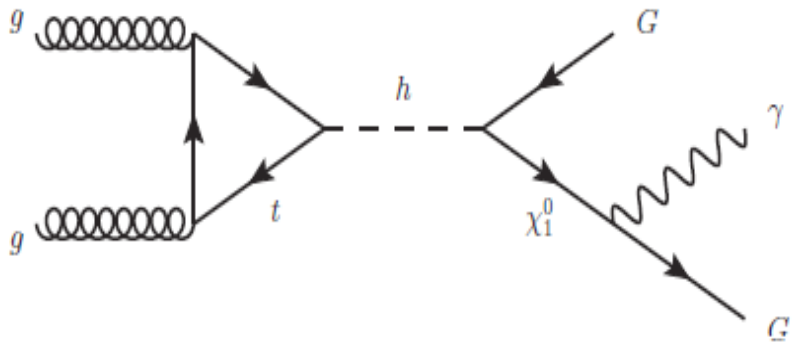
Rough numbers for 3 photons in 0.5/fb:

Ph-Jet	4.22 +- 1.08
Ph-Ph	2.08 +- 0.49
DY	3.10 +- 0.51
Zee+Ph	1.71 +- 0.41
3ph	1.42 +- 0.01
D-D 2Ph-1Jet	1.33 +- 0.90
B_tot	13.85 +- 1.63

- ~600 background events in 30/fb with 3 photons
- Just ~1 background event in 30/fb with ≥4 photons

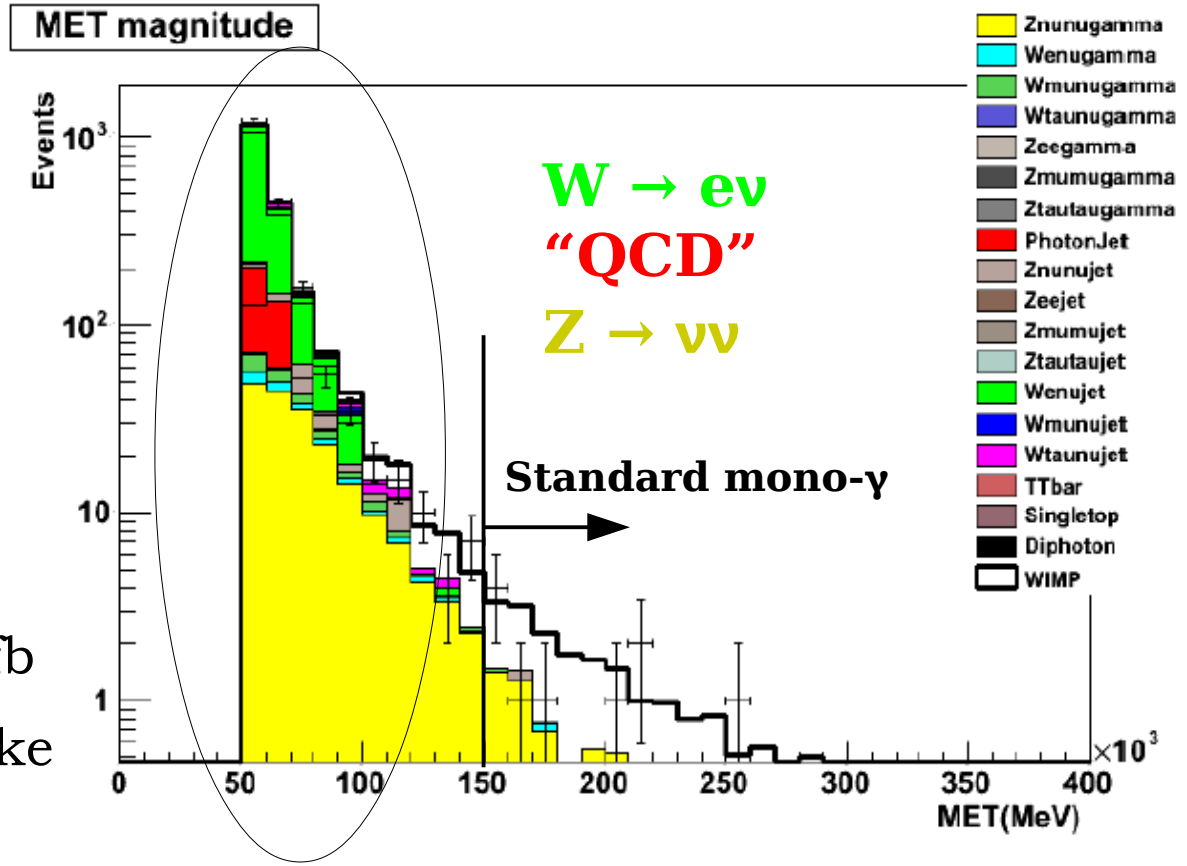
Non-SM Higgs Production / Decay

- Higgs ($\rightarrow G\ x_1^0 \rightarrow G\ \gamma G$)
  - $m(H)/2 < m(x^0) < m(H)$
  - Could be ~10% of Higgs decays? ~25,000 events in 30/fb ?! arXiv:1203.4563



- Mono-photon + MET
  - pT(γ) ~ 40 GeV
  - Use γ+MET trigger with 40+60 threshold

- Large background from W → e → γ-fake
  - ~100,000 events in 30/fb
  - Need specialized e→γ-fake rejection algorithm!



Conclusions

- H(→γγ) is a good channel for studying "W/Z/tt" + H production
  - Low backgrounds, reasonable BR (maybe larger), and *no inherent MET*
- With 30/fb, can start to see:
  - Worst case: evidence for SM production / measure couplings directly
  - Even better: see evidence for extra production from BSM physics!

- Sensitive to many new Higgs signals
  - x_2^0 (→x_1^0 h), t → ch, thj (C_t=-1), Z' → Z* h, …
- And non-SM Higgs decay modes:
  - hh, h(→4γ), h(→γ+MET), …

- Many channels to cover – and first time such analyses attempted!
- Hope for results later this year…

- With 100/fb @13 TeV, these channels become even more important!

Backup

SM Higgs Decays

- Measure bb, ττ, WW, ZZ, γγ (and later Zγ and μμ?) at the LHC

- γγ has reasonable rate (no BR to leptons), good mass resolution, decent S/B, *and no MET*

BR(H→γγ) = 0.25%