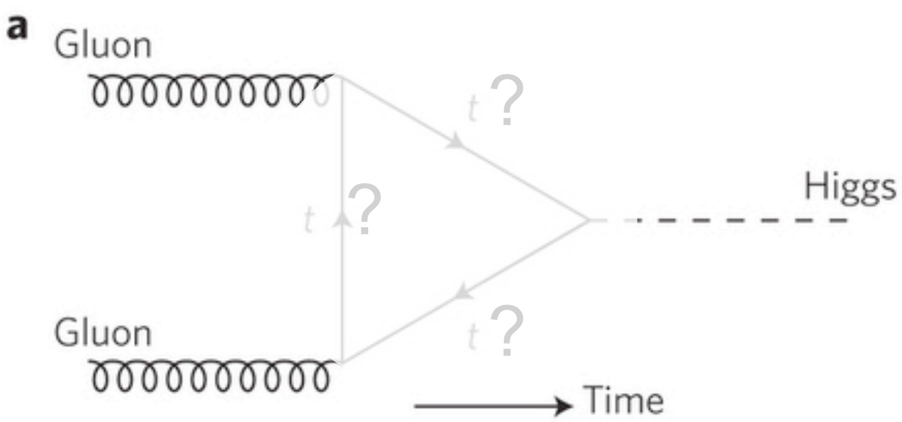
The search for top-antitop-Higgs production at CMS

Fabrizio Margaroli (Sapienza and INFN)
on behalf of the CMS collaboration

HIGGS AND FERMIONS

- We know there is a Higgs boson in LHC data



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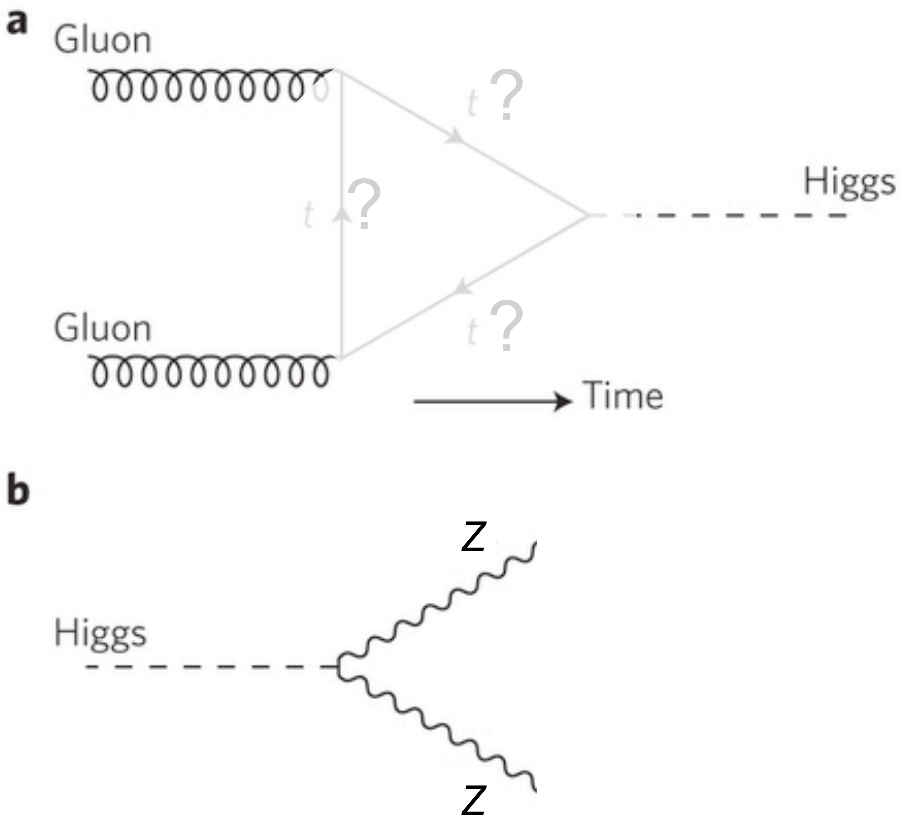

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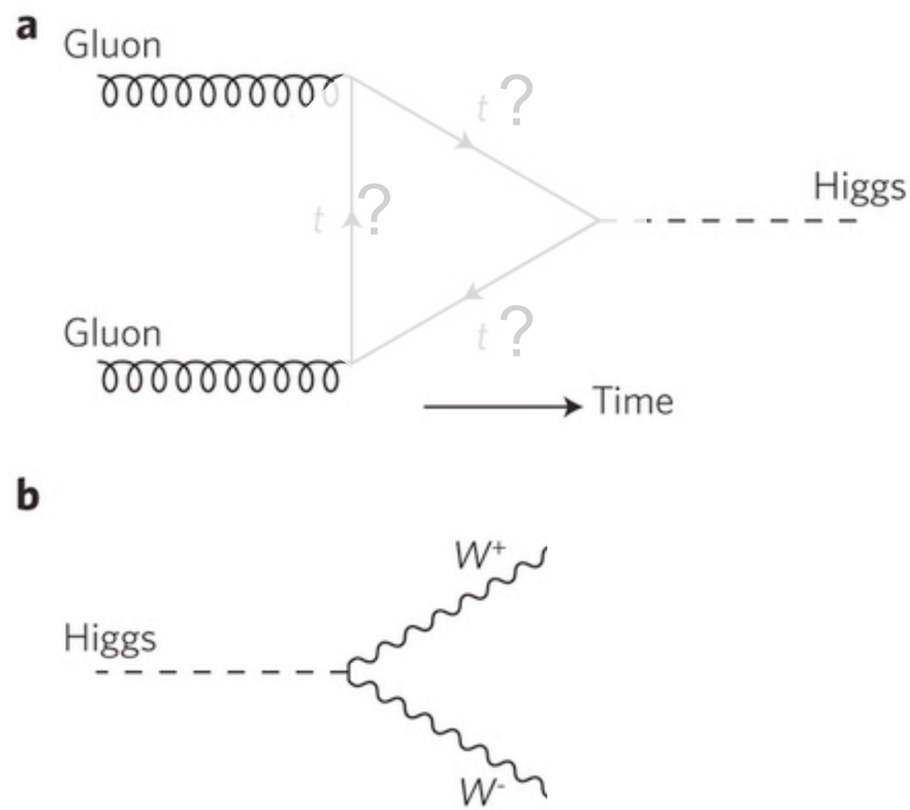
See morning session talks



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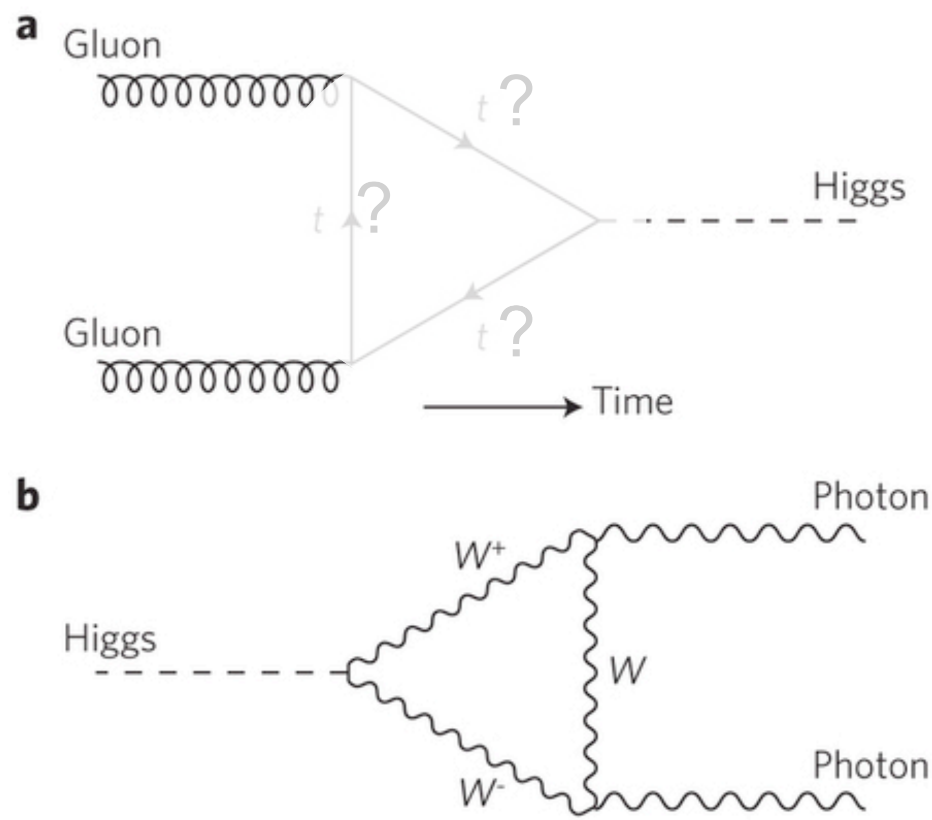

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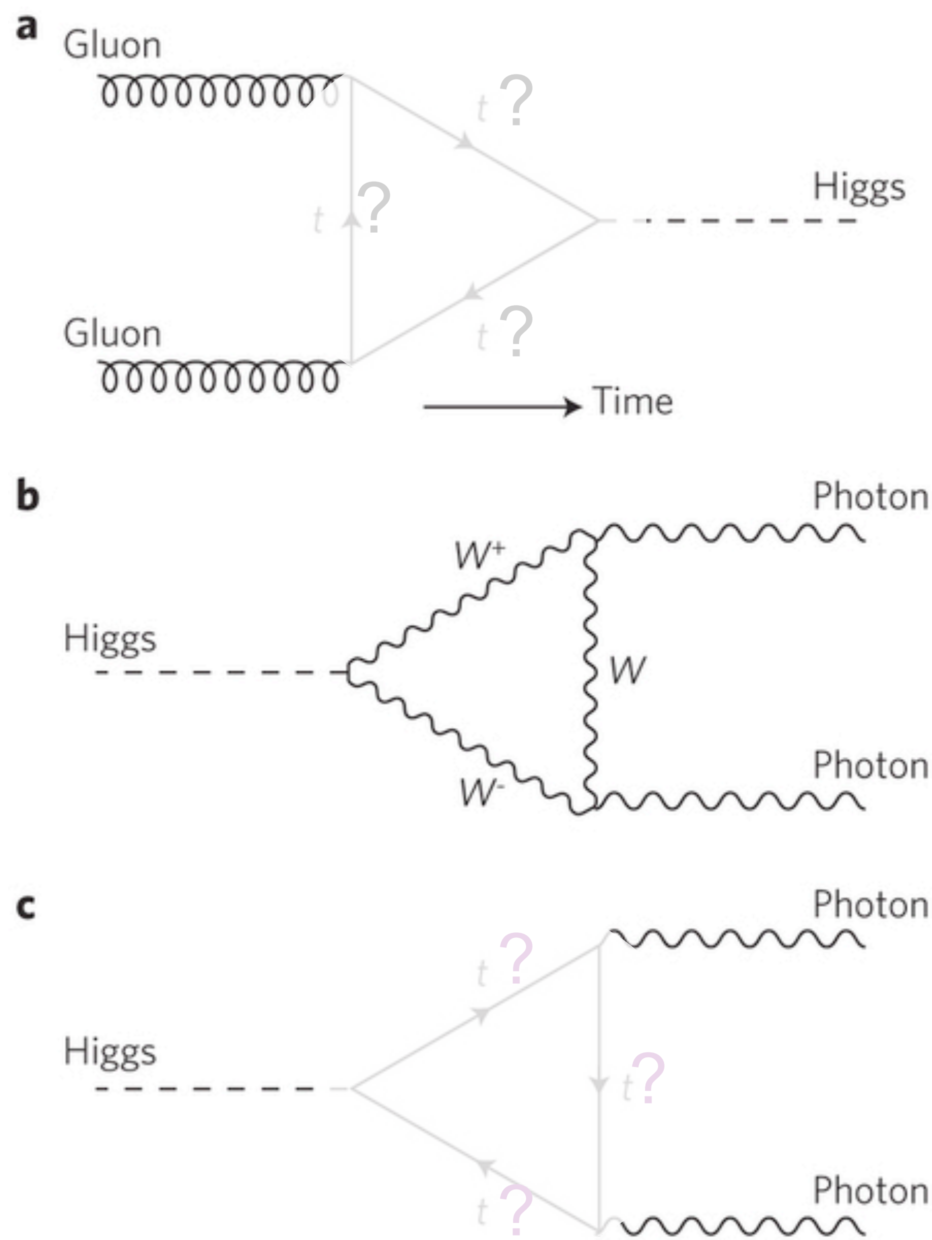

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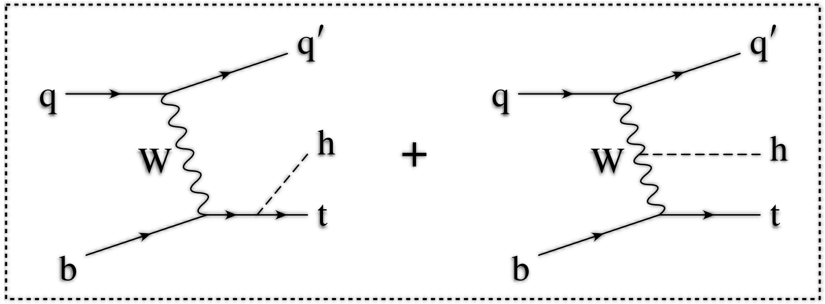
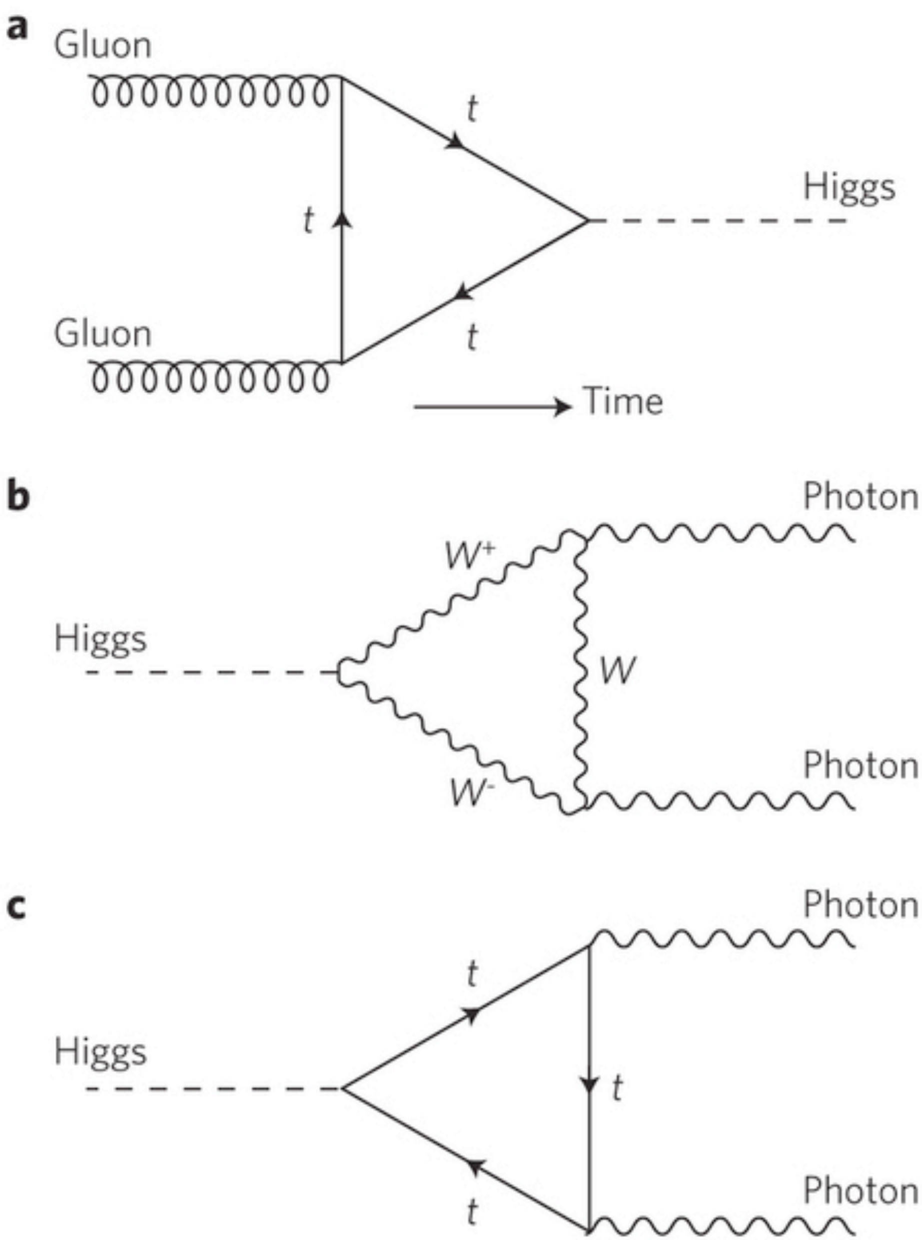
See Biswas's at the poster session

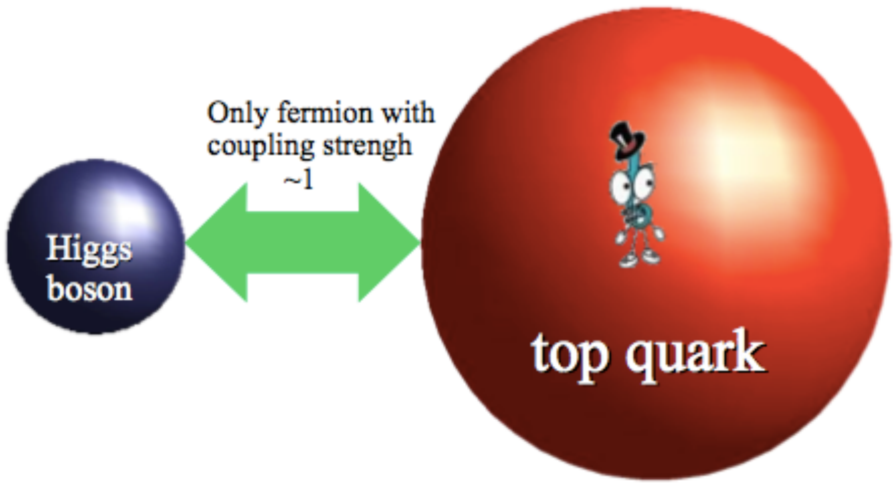


S.Biswas et al. JHEP 01 (2013) 088
M.Farina et al. JHEP 05 (2013) 022
S.Biswas et al. JHEP 07 (2013) 073



A SPECIAL RELATIONSHIP

- Higgs coupling to fermions proceeds via a different lagrangian - interesting!
  - but also very hard to measure   See H to bb/tautau talks in this session
- Observing ttH is the only way to directly measure the magnitude of top-Higgs coupling, i.e. Yt
- Our current indirect knowledge: $Y_t = \sqrt{2}M_t/vev = 0.996 \pm 0.005$ using latest Tevatron and/or LHC Mtop

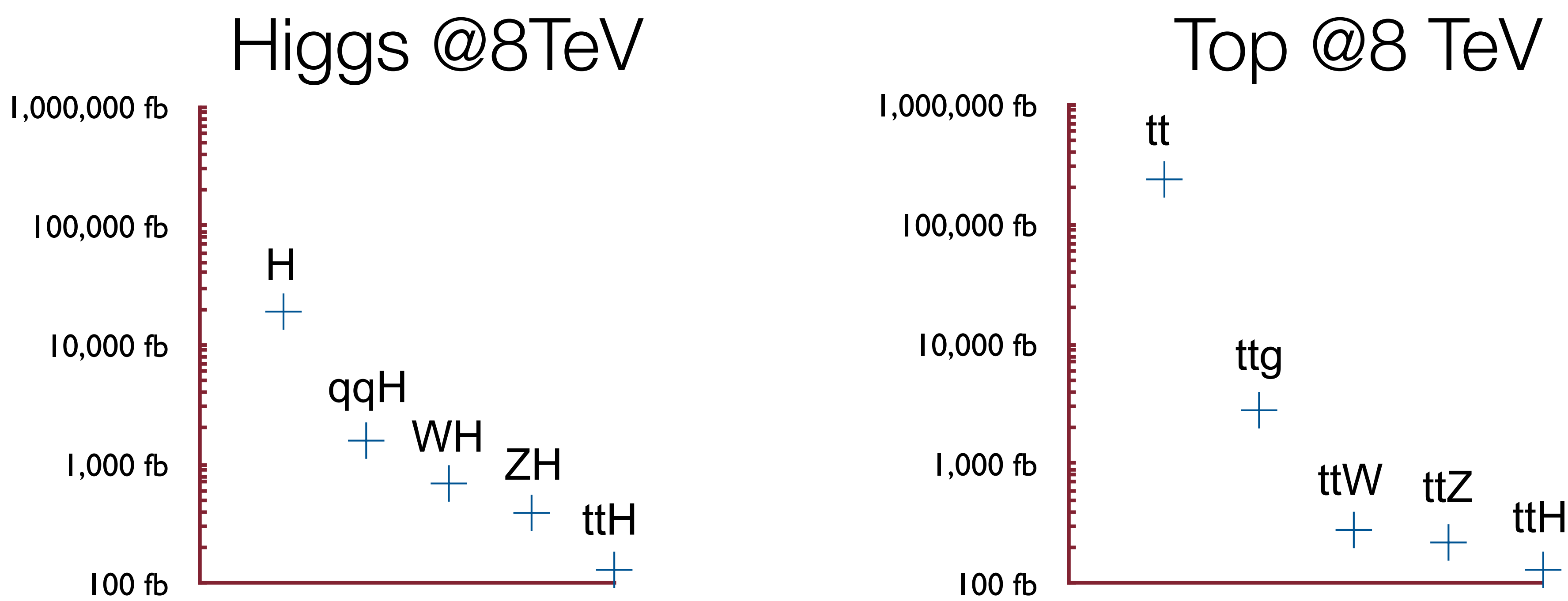


- Does Y_t=1 mean a special role of the top quark in EWSB?
- ttH sensitive to several natural new physics scenarios (little Higgs, composite Higgs, Extra Dimensions) where new vector-like quarks decay to top and Higgs: ttH+more
  - <u>early ttH discovery could signal new physics!</u>

See Devdatta, Antonella's talks

DIG DEEPER INTO THE LHC GOLD

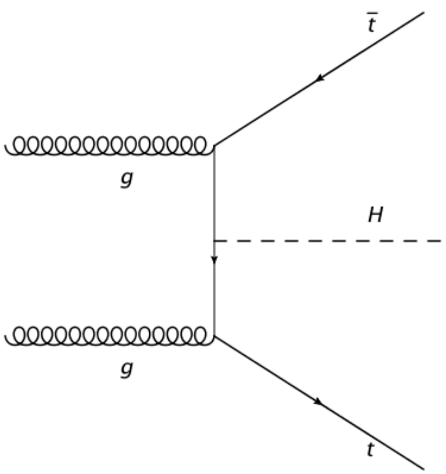
Higgs and top cross sections at 8 TeV pp collisions



ttH is the next goal in Higgs physics, <u>and</u> in top physics

A *VERY* COMPLEX FINAL STATE

- Cross section is only ~1/200 of the inclusive Higgs production cross section
- Large multiplicity of objects in the final state (signature is dominated by the t/tbar decays)
- Need to find the best combination of top and Higgs decays to isolate the small signal (130fb)



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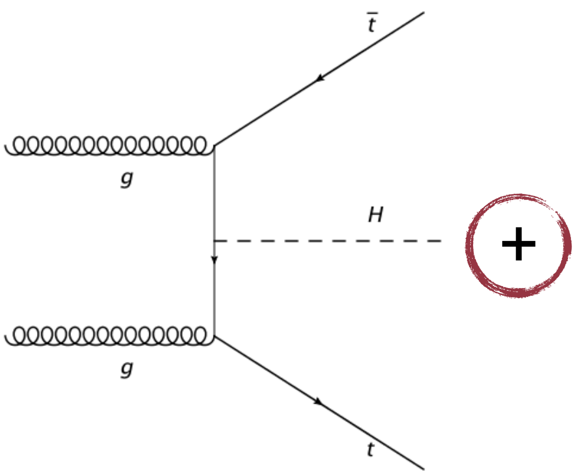

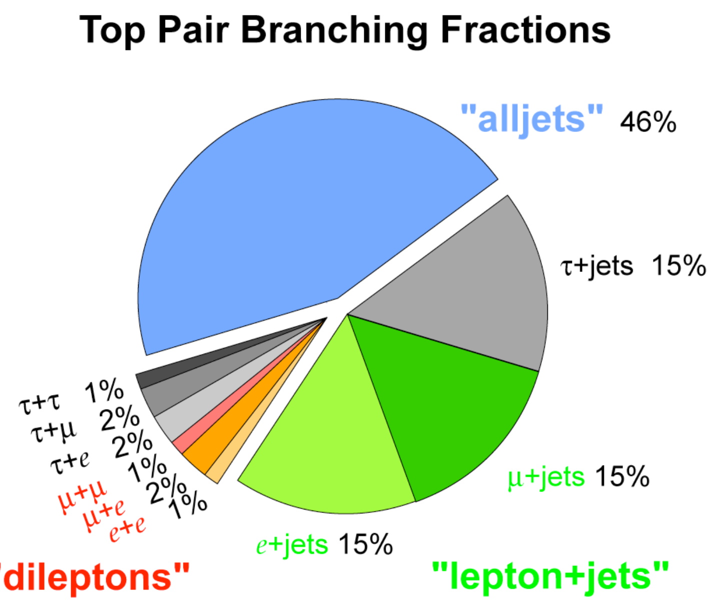

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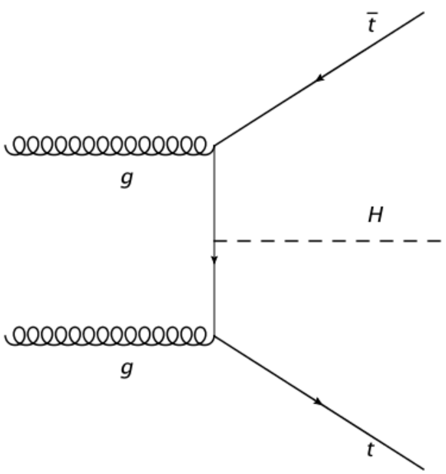

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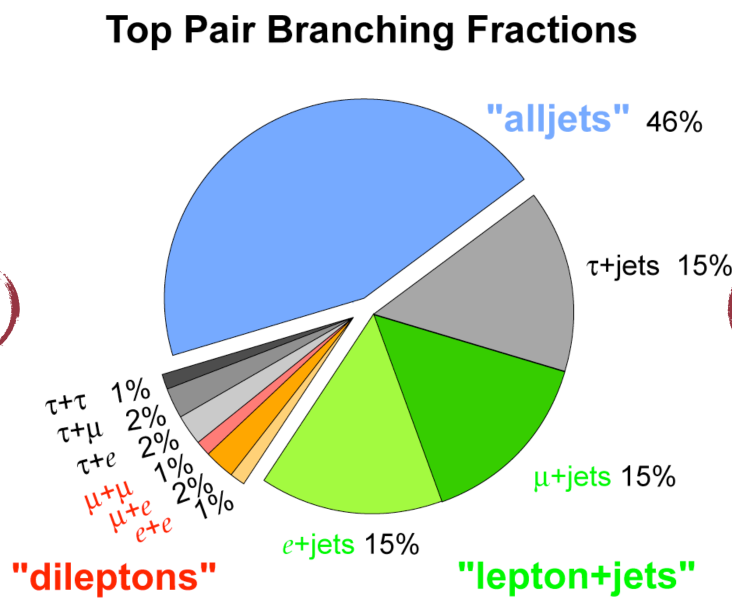

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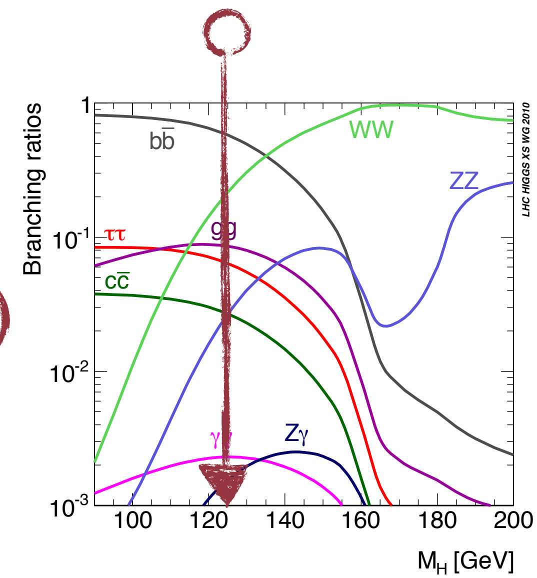

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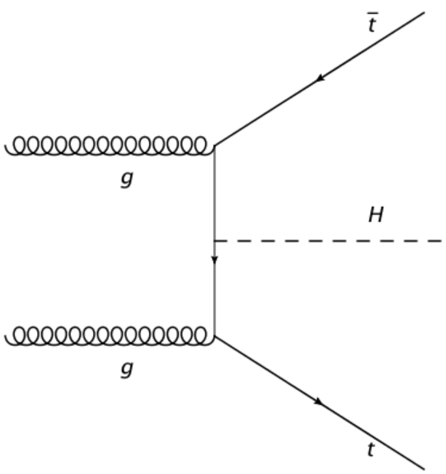
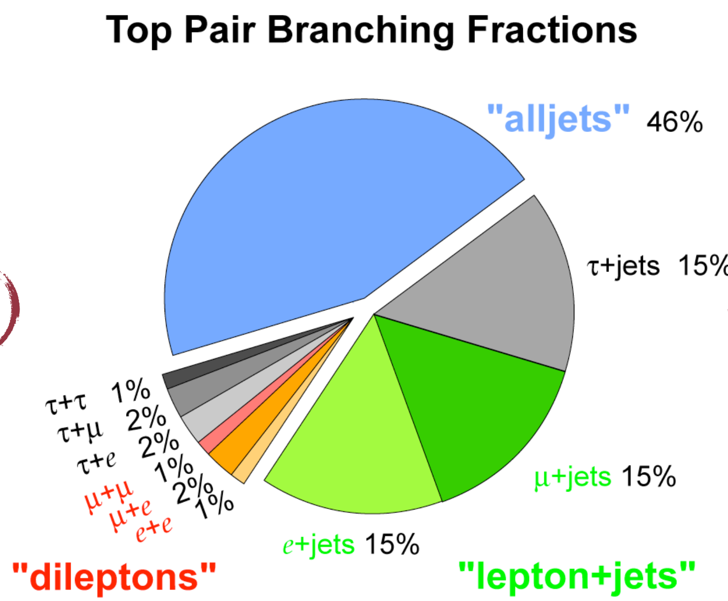
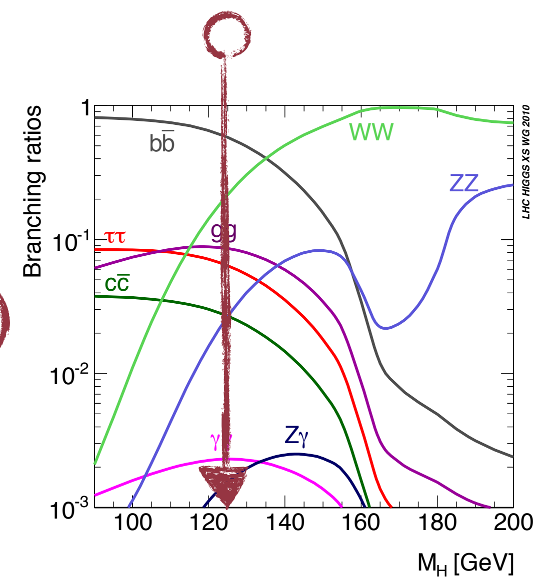




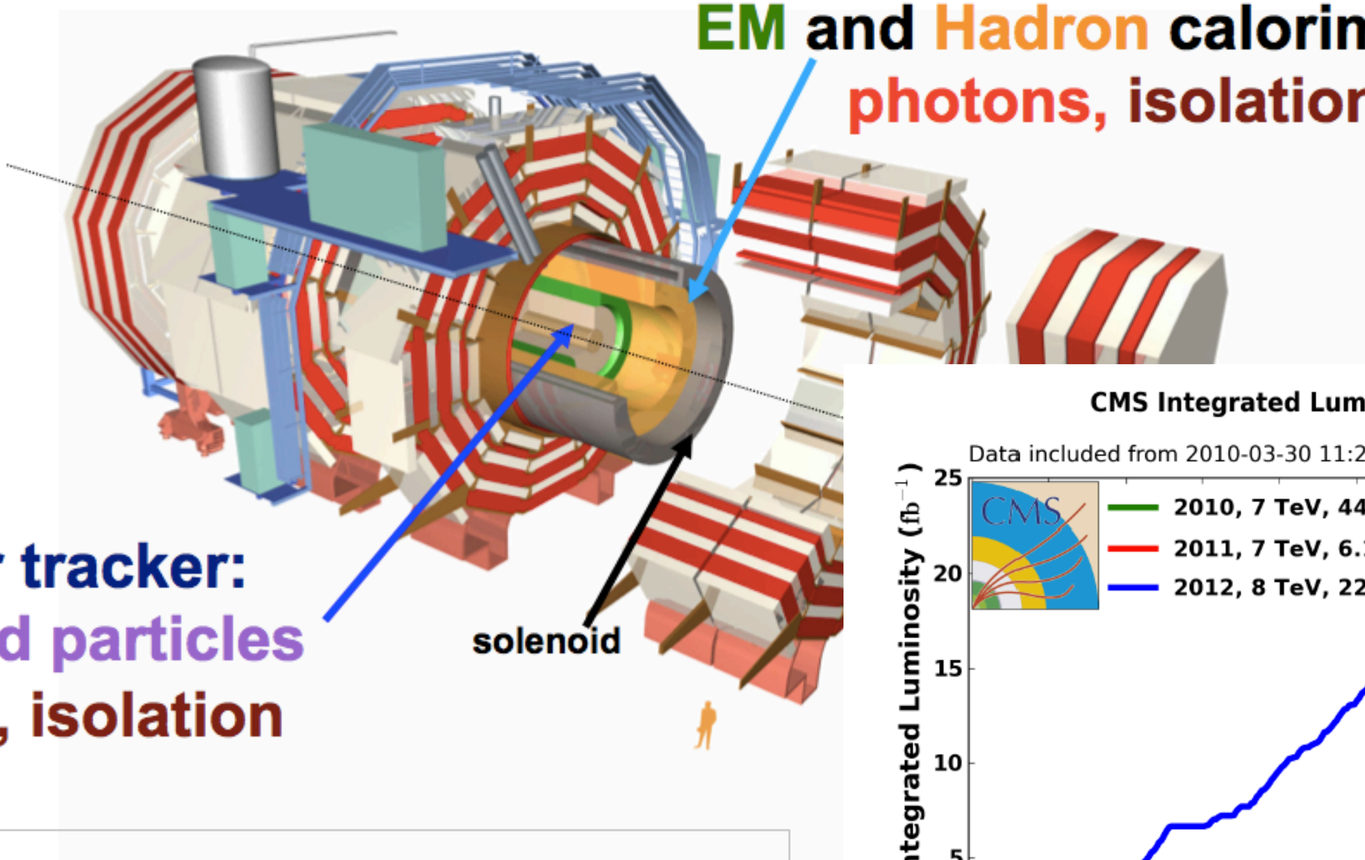


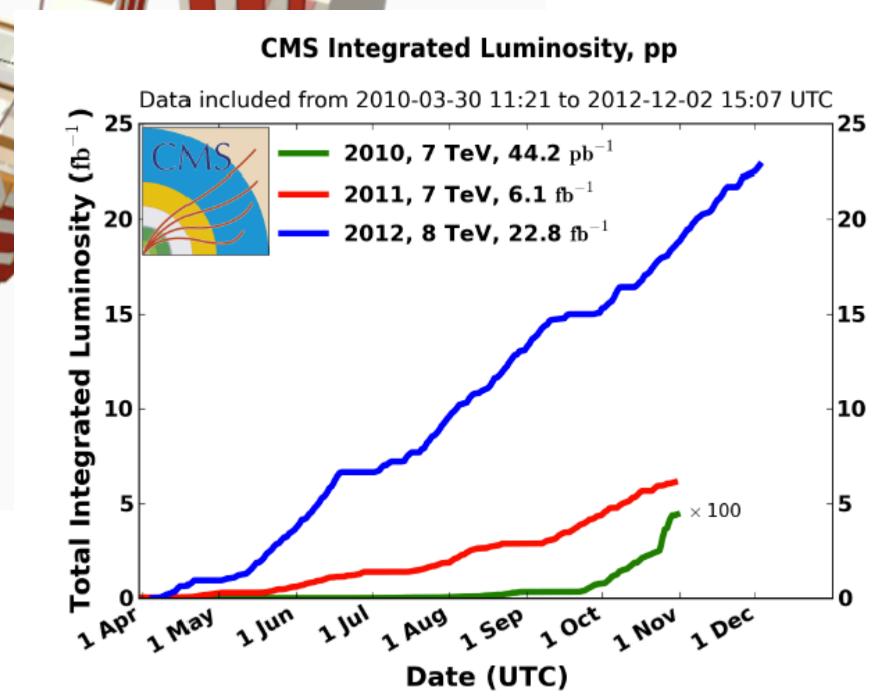
- In the following, will show CMS results on several ttH decay modes:
  - ttH, H → bb, ttbar → lepton+jets and dilepton
  - ttH, H → tautau, ttbar → lepton+jets
  - ttH, H → gammagamma, ttbar → all decay modes

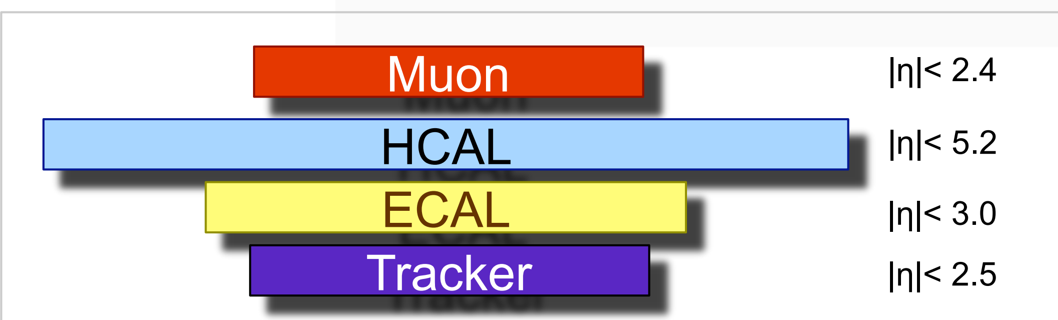
The CMS detector

EM and Hadron calorimeters
photons, isolation

Inner tracker:
charged particles
vertex, isolation





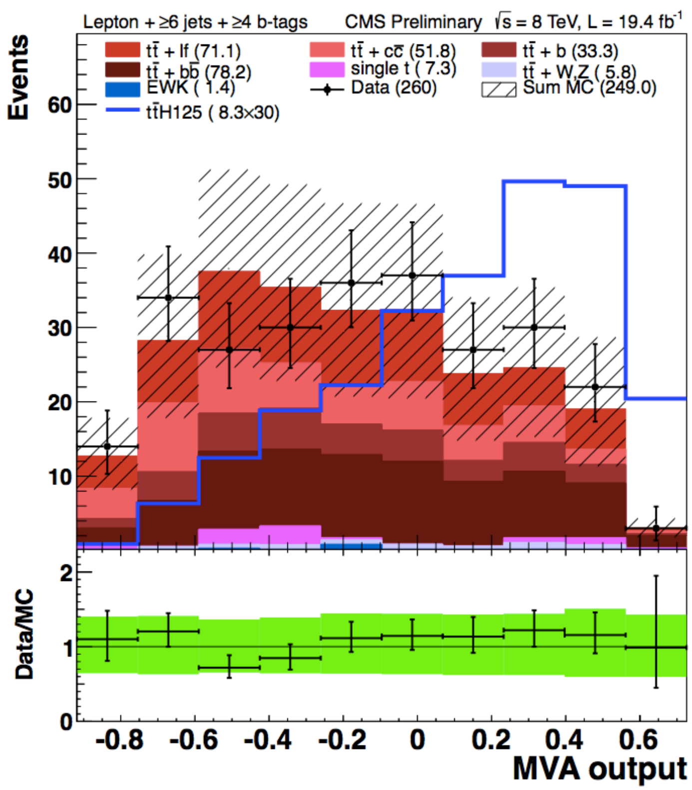


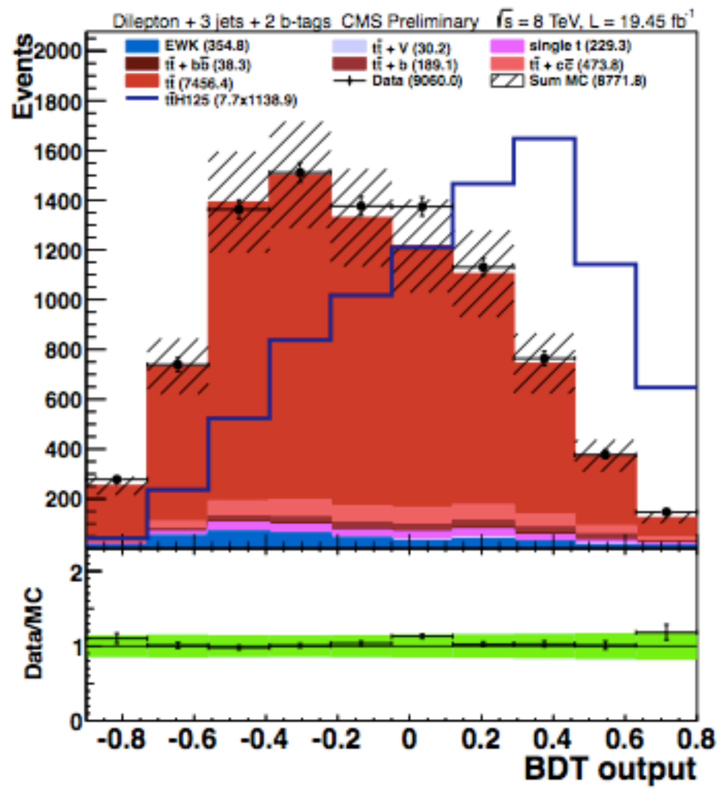
The search for ttH requires all subdetectors!

H → BB, TT → LJETS OR DILEPTON

CMS-HIG-13-019

- Identify tops and Higgs via multiple b-tagged jets, leptons (ele/muons) and light flavor jets
- Split into Njet/Nbtag categories to further increase sensitivity
- For each category, use machine learning techniques to discriminate signal from dominant tt +bb/cc/b backgrounds





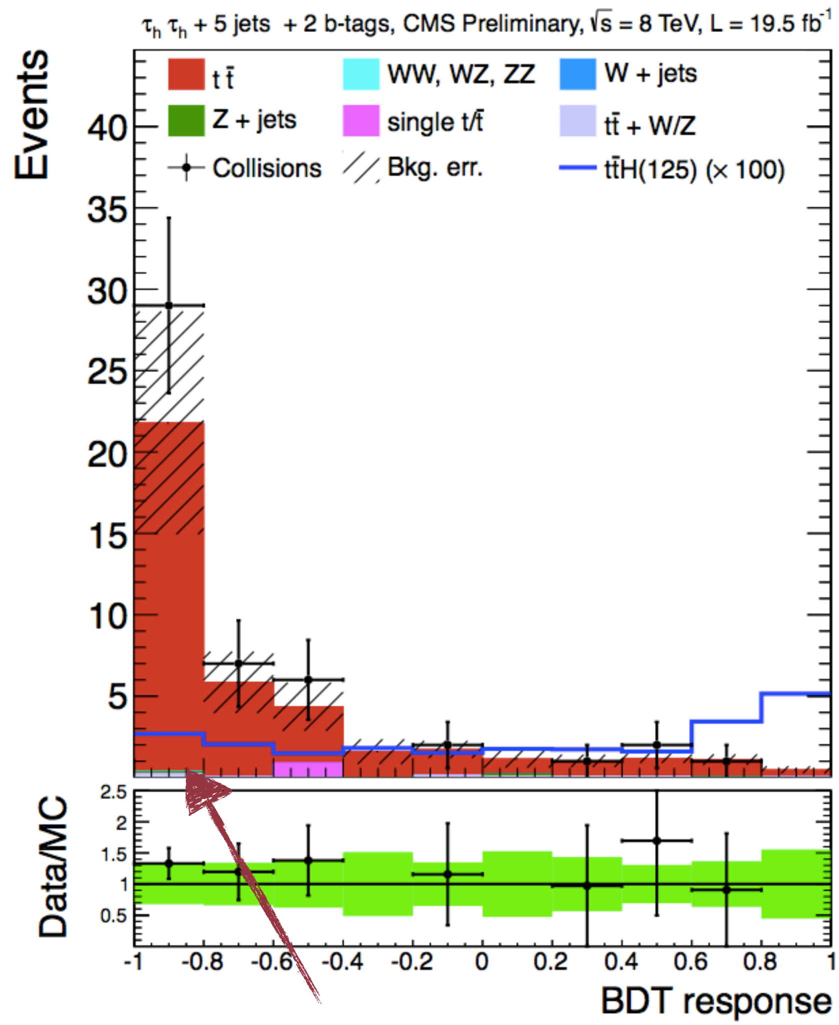
- Fit over resulting shapes, systematics modify relative normalization and shapes themselves
  - largest systematic is on the poorly known tt+bb/cc/b background

TTH, H → TAUTAU

CMS-HIG-13-019

- Select hadronically decaying taus, coming from the Higgs decay, reconstructed via a Particle Flow algorithm
- Select additional b-jets, leptons, light flavor jets consistent with ttbar decays, split into Njets and Nbtags categories

	4 jets 1 b-tag	5 jets 1 b-tag	≥6 jets 1 b-tag	4 jets 2 b-tags	5 jets 2 b-tags	≥6 jets 2 b-tags
$t\bar{t}H(125)$	0.4 ± 0.1	0.6 ± 0.1	0.6 ± 0.2	0.1 ± 0.0	0.2 ± 0.1	0.4 ± 0.1
$t\bar{t}$	225 ± 69	119 ± 38	64 ± 22	48 ± 15	38 ± 12	27.0 ± 9.1
$t\bar{t}V$	1.1 ± 0.3	1.3 ± 0.3	1.4 ± 0.4	0.4 ± 0.1	0.6 ± 0.2	1.1 ± 0.3
Single t	11.2 ± 4.0	3.0 ± 1.4	1.1 ± 1.0	1.9 ± 1.1	0.9 ± 0.6	0.6 ± 0.7
V+jets	33 ± 17	11.7 ± 6.8	3.8 ± 2.8	1.4 ± 0.9	0.4 ± 0.3	0.5 ± 0.6
Diboson	0.9 ± 0.2	0.7 ± 0.2	0.1 ± 0.0	0.0 ± 0.0	0.1 ± 0.0	0.1 ± 0.1
Total bkg	271 ± 82	135 ± 41	71 ± 24	52 ± 16	40 ± 12	29.2 ± 9.4
Data	292	171	92	41	48	35



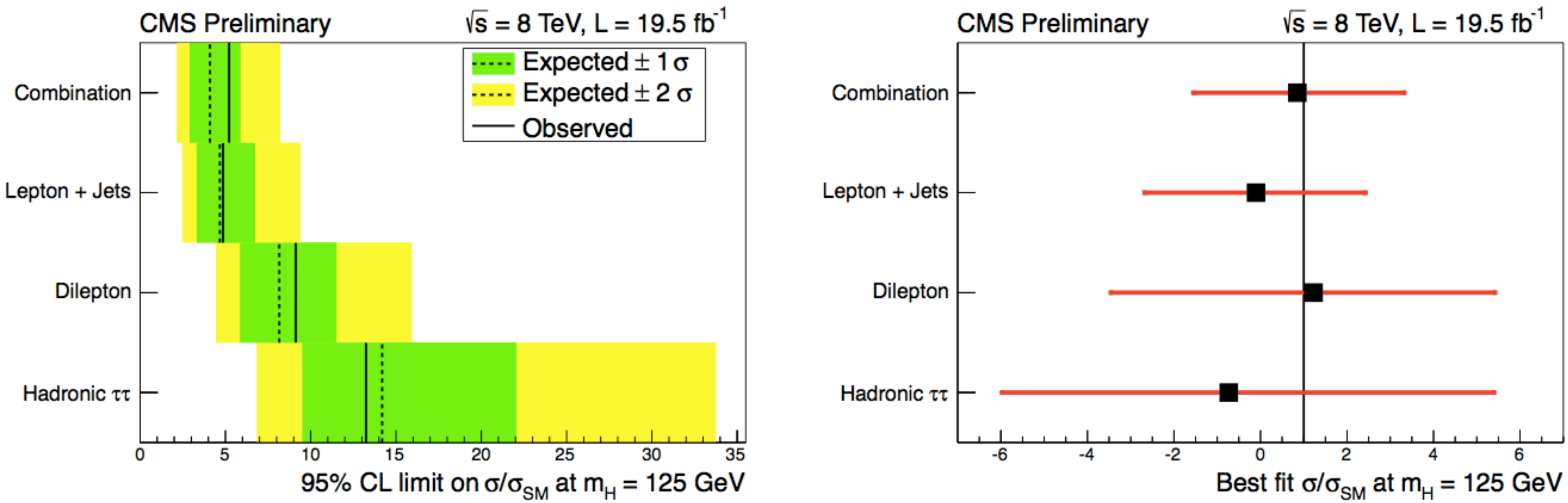
Non H→tautau ttH component

- Here tt+jets is again dominant background
  - multivariate discriminants exploit mostly tau-related informations
- Total Ns~2.5 evts
  - x10 (H → bb, ttbar → dilepton)
  - x100 (H → bb, ttbar → l+jets)

A PARTIAL COMBINATION

CMS-HIG-13-019

- No statistically significant excess over background predictions
- ttH, H → bb and H → tautau have been combined to produce statements on sensitivity to this production mode



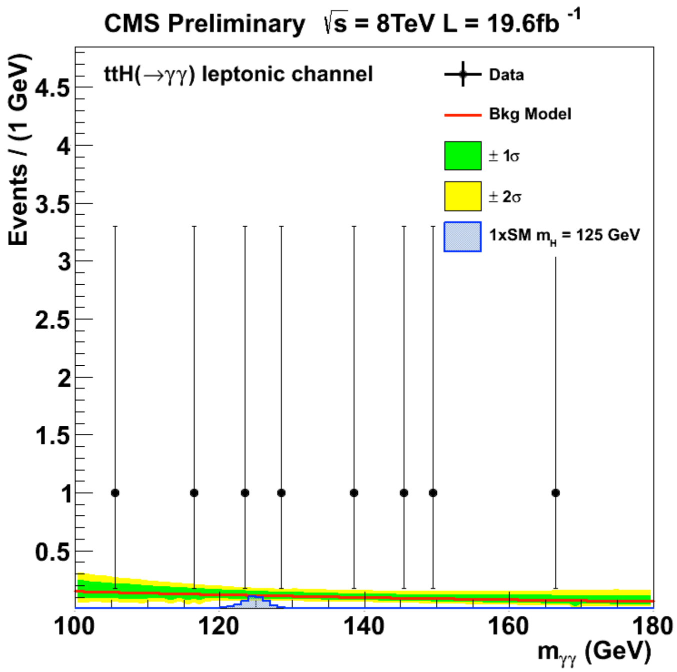
ttH decay mode	Exp	Ob
H→bb, tt→lepton+jets	4.7	4.9
H→bb,. tt→dilepton	8.2	9.1
H→tautau, tt→ljets or dilepton	14.2	13.2
Combination	4.1	5.2

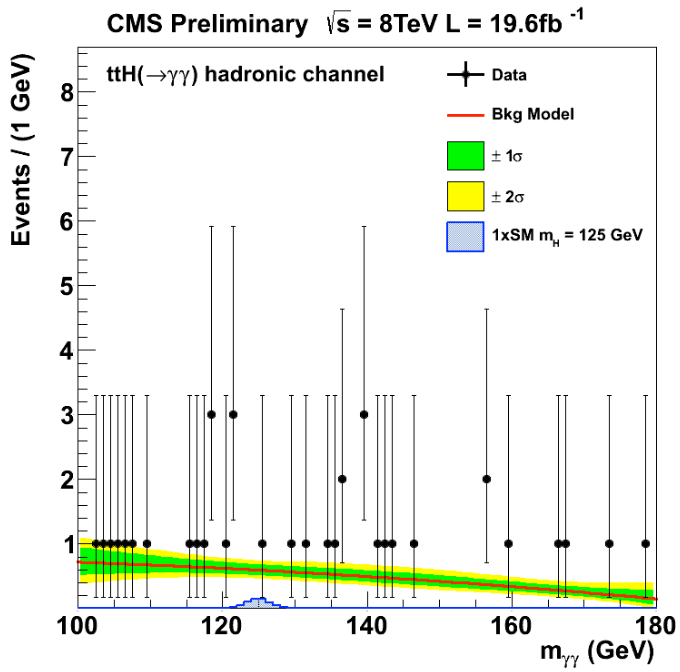
Systematics already taking a hit on the most sensitive channels

HIGGS TO GAMMA GAMMA

CMS-HIG-13-015

- Very low rate, but distinctive signature of the Higgs peak. Backgrounds are coming from top(s) +photon(s), or photons+(b)jets, latter poorly known at theoretical level
- Split into events with leptons and few jets (leptonic) or no leptons and many jets (hadronic)





Event selection minimizes contamination from other Higgs sources

Process	Hadronic Channel	Leptonic Channel
$t\bar{t}H$	0.567 (87%)	0.429 (97%)
$gg \to H$	0.059 (9%)	0 (0%)
VBF H	0.006 (1%)	0 (0%)
WH/ZH	0.019 (3%)	0.013 (3%)
Total signal	0.65	0.44

- fitting the diphoton peak greatly reduce sensitivity to background systematics

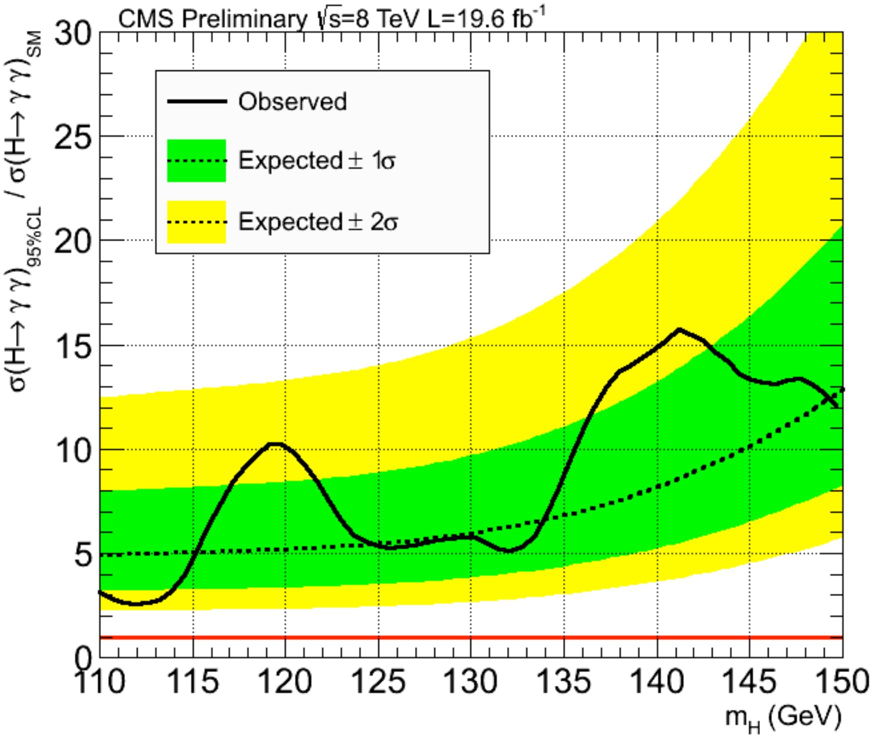
HIGGS TO GAMMA GAMMA RESULTS

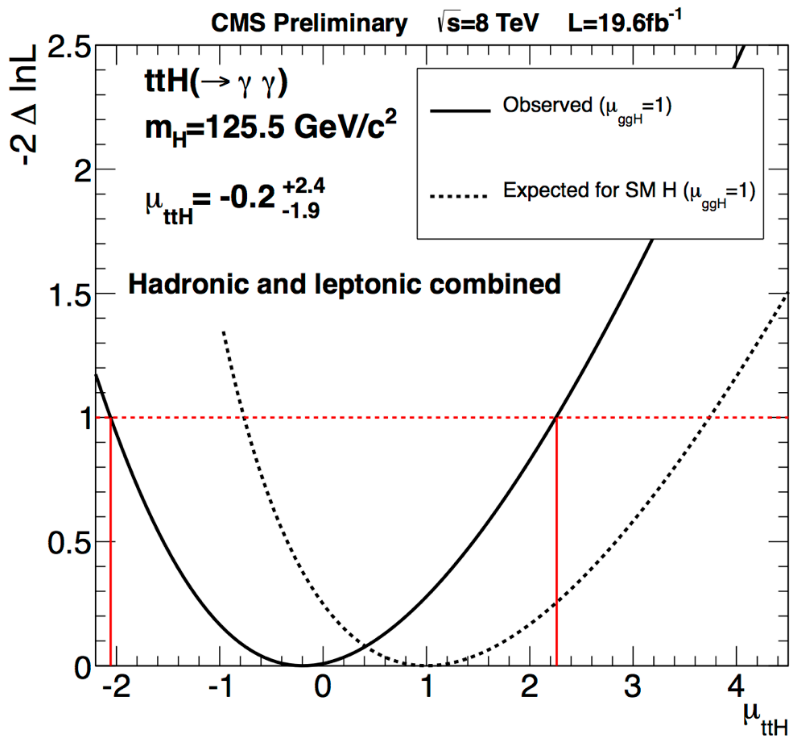
CMS-HIG-13-015

- No significant excess found, combine the two (statistically independent) channels to increase sensitivity

	Observed	Expected	Expected (No Syst.)
Hadronic Channel	6.8	9.2	8.8
Leptonic Channel	10.7	8.0	7.7
Combined	5.4	5.3	5.1

- Extract upper limits on ttH cross section





- Interpret the data as a cross section measurement
  - keep in mind that precision on Yt is *twice better* than on sigma(ttH)!

CONCLUSIONS

- Measurement of Higgs coupling to top quarks especially interesting
- Deviations of top-Higgs coupling from SM, are very possible as our current knowledge comes only from loop-induced diagrams
- Increasing our sensitivity to ttH by combining multiple channels

ttH decay mode	Exp	Obs
H→bb, tt→lepton+jets	4.7	4.9
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H→gamma gamma, tt→all jets	9.2	6.8
H→gamma gamma, tt→leptons	8.0	10.7

Here MH = 125 GeV

  - already beating benchmark extrapolations for top-Higgs coupling
  - still lots can be said before LHC run at higher energies

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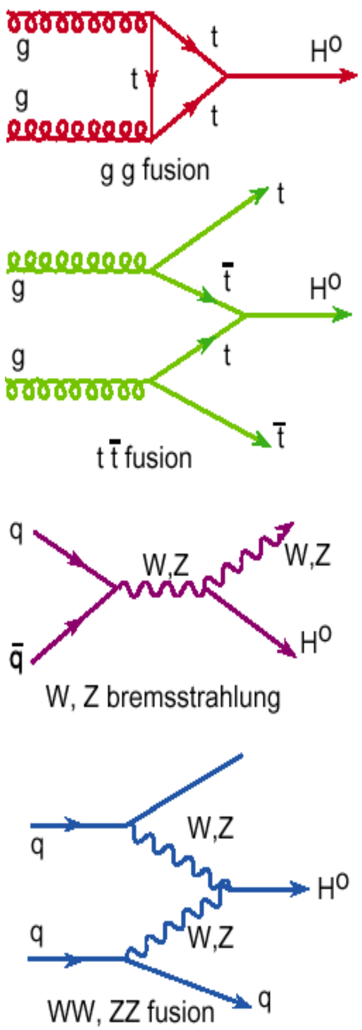
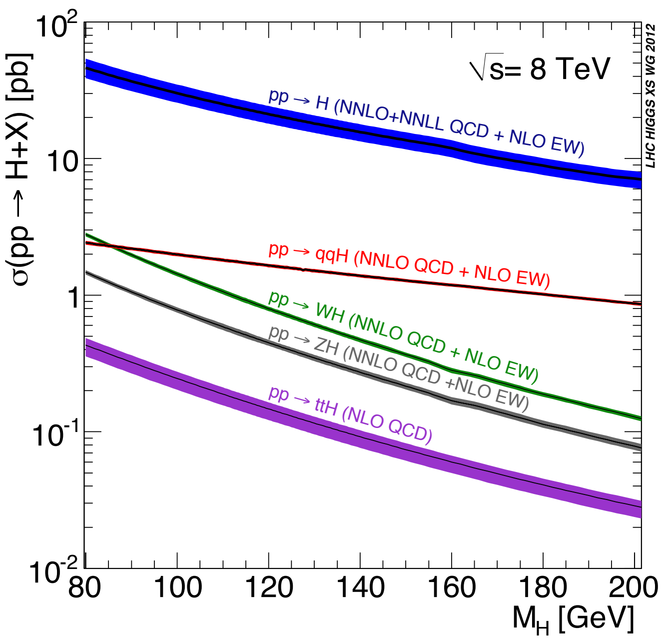
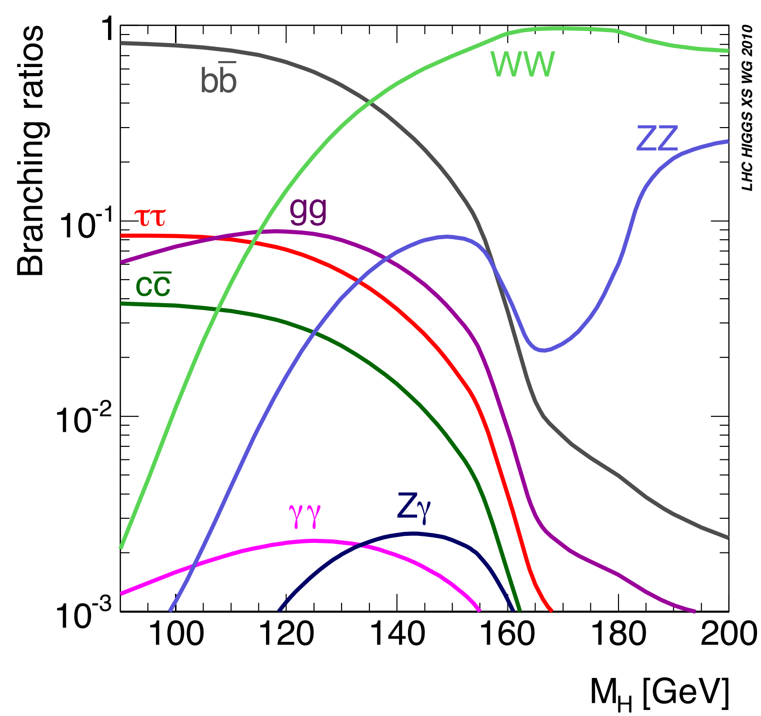
Exploring top-Higgs relation at 360 degrees: stay tuned!

BACKUP

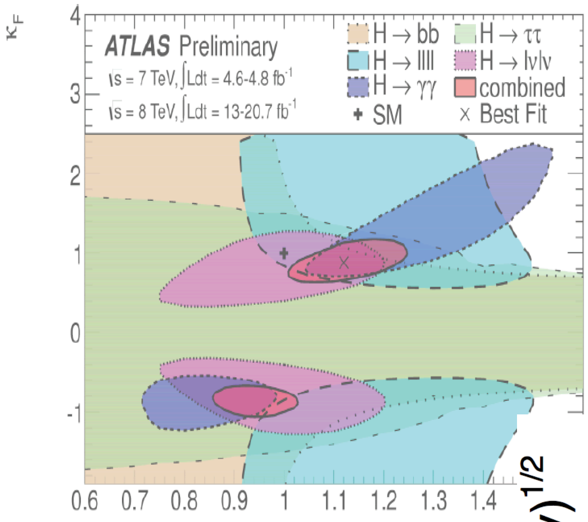
HIGGS PRODUCTION AND DECAY

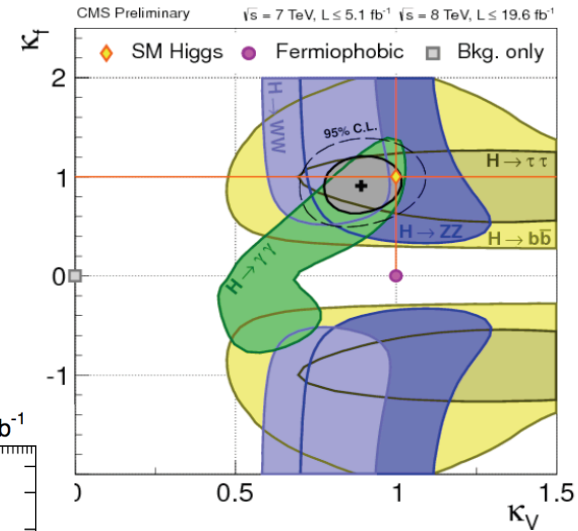


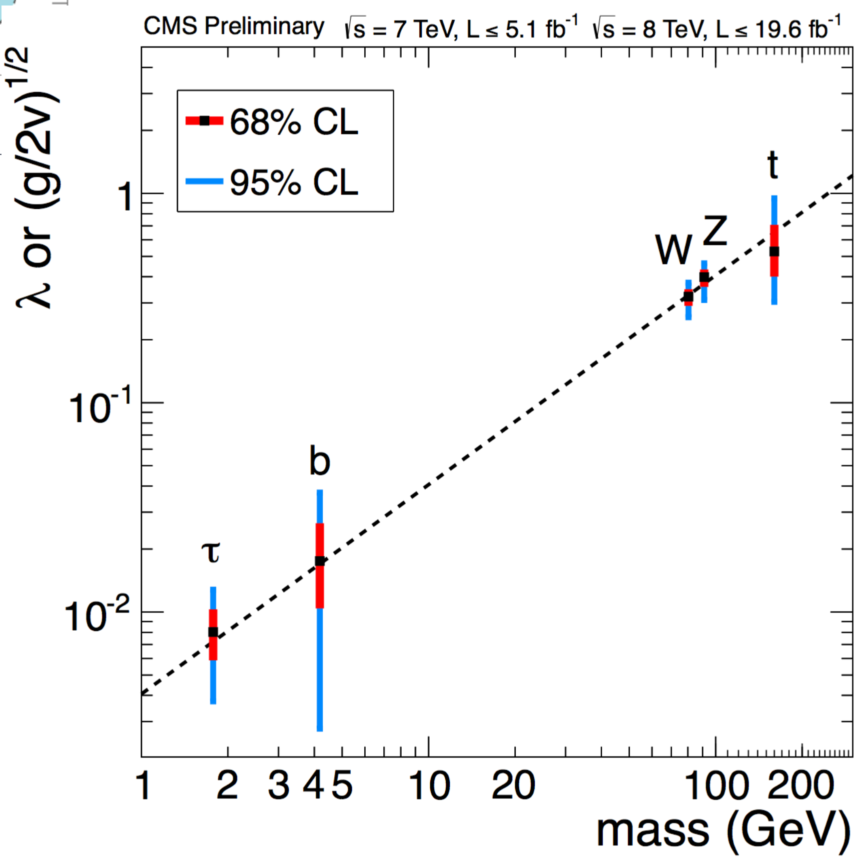




HIGGS AND FERMIONS

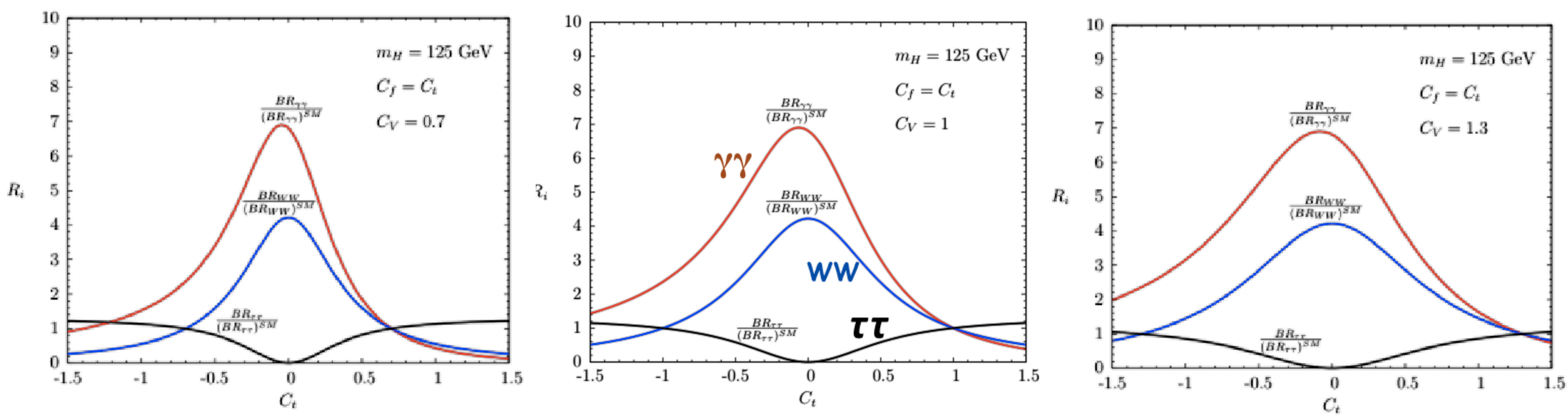






HIGGS BRANCHING RATIOS

- It is interesting to interpret ttH results on the Ct, Cv plane.
- sigma(ttH) proportional to Yt^2 → Ct^2
- Higgs decays have a complex dependence on Ct and Cv
- The different decay modes explored here probe different regions of the Ct and Cv plane

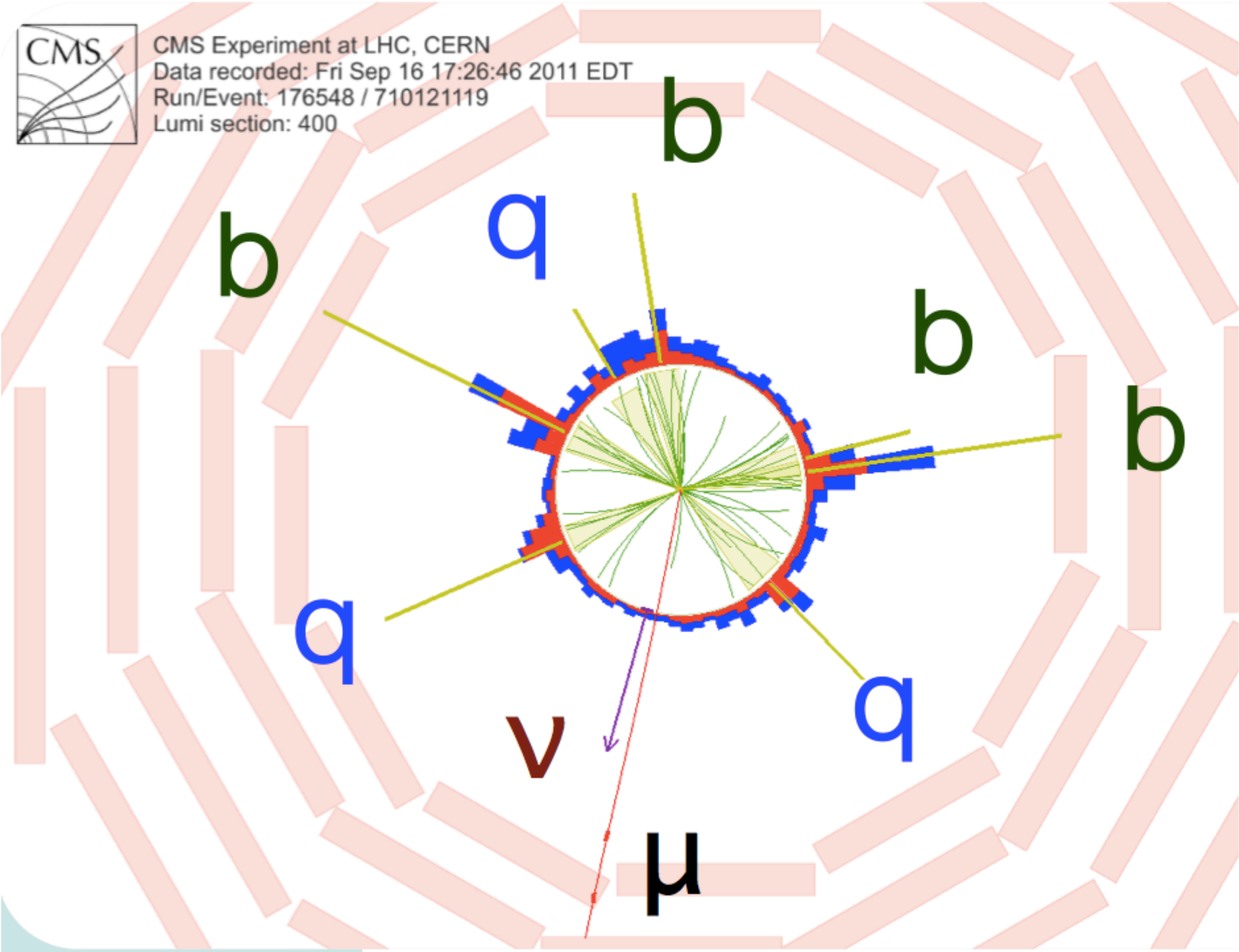


Taken from S.Biswas et al, compatible results from HDECAY

SYSTEMATICS ON TTH, H→BB

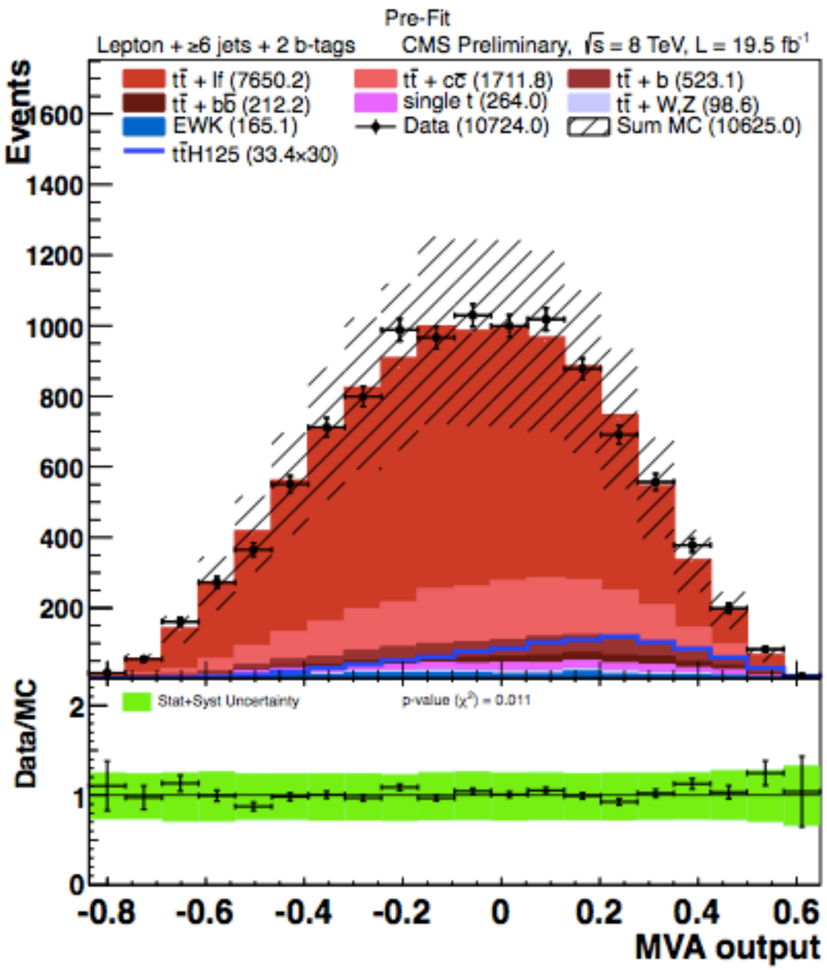
Uncertainties on the sum of $t\bar{t}$+lf, $t\bar{t}$+b, $t\bar{t}+b\bar{b}$, and $t\bar{t}+c\bar{c}$ events with ≥ 6 jets and ≥ 4 b-tags		
Source	Rate	Shape?
QCD Scale (all $t\bar{t}$+hf)	35%	No
QCD Scale ($t\bar{t}+b\bar{b}$)	17%	No
b-Tag hf contamination	17%	Yes
QCD Scale ($t\bar{t}+c\bar{c}$)	11%	No
Jet Energy Scale	11%	Yes
b-Tag lf contamination	9.6%	Yes
b-Tag hf stats (linear)	9.1%	Yes
QCD Scale ($t\bar{t}$+b)	7.1%	No
Madgraph Q^2 Scale ($t\bar{t}+b\bar{b}$)	6.8%	Yes
b-Tag Charm Uncertainty (quadratic)	6.7%	Yes
Top Pt Correction	6.7%	Yes
b-Tag hf stats (quadratic)	6.4%	Yes
b-Tag lf stats (linear)	6.4%	Yes
Madgraph Q^2 Scale($t\bar{t}+2$ partons)	4.8%	Yes
b-Tag lf stats (quadratic)	4.8%	Yes
Luminosity	4.4%	No
Madgraph Q^2 Scale ($t\bar{t}+c\bar{c}$)	4.3%	Yes
Madgraph Q^2 Scale ($t\bar{t}$+b)	2.6%	Yes
Lepton ID/Trig	1.4 (2.8)%	No
QCD Scale ($t\bar{t}$)	3%	No
pdf (gg)	2.6%	No
Jet Energy Resolution	1.5%	No
Pileup	1%	No
b-Tag Charm Uncertainty (linear)	0.6%	Yes

EVENT DISPLAY H→BB

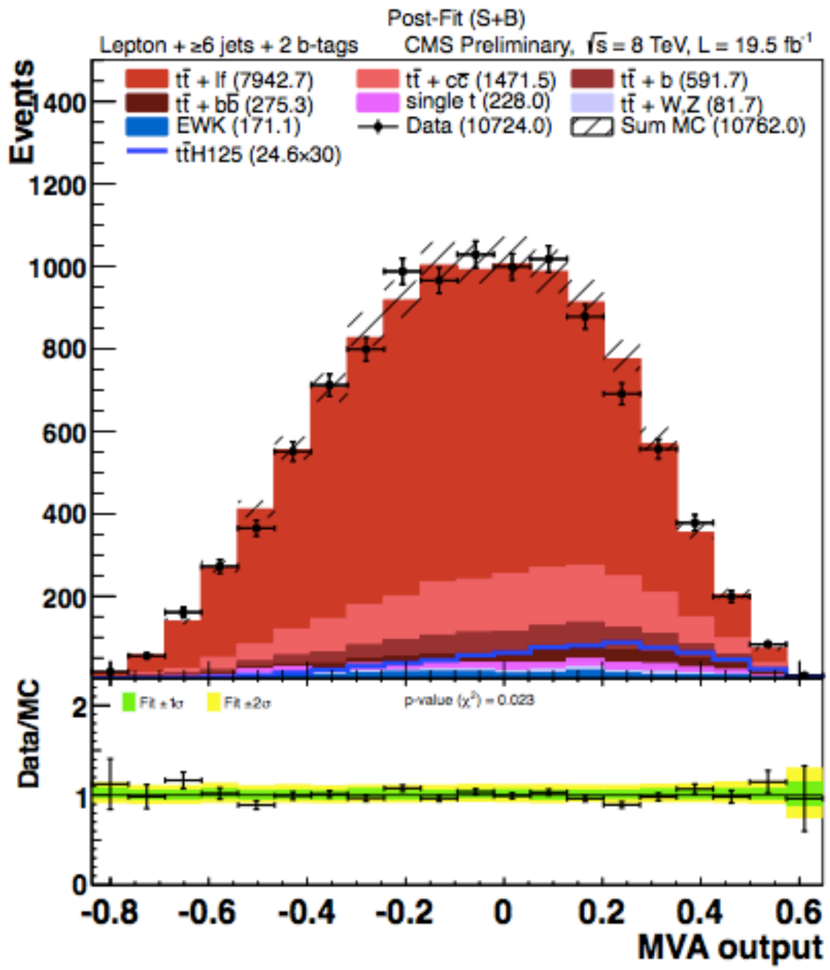


PRE AND POST FIT

Pre-fit

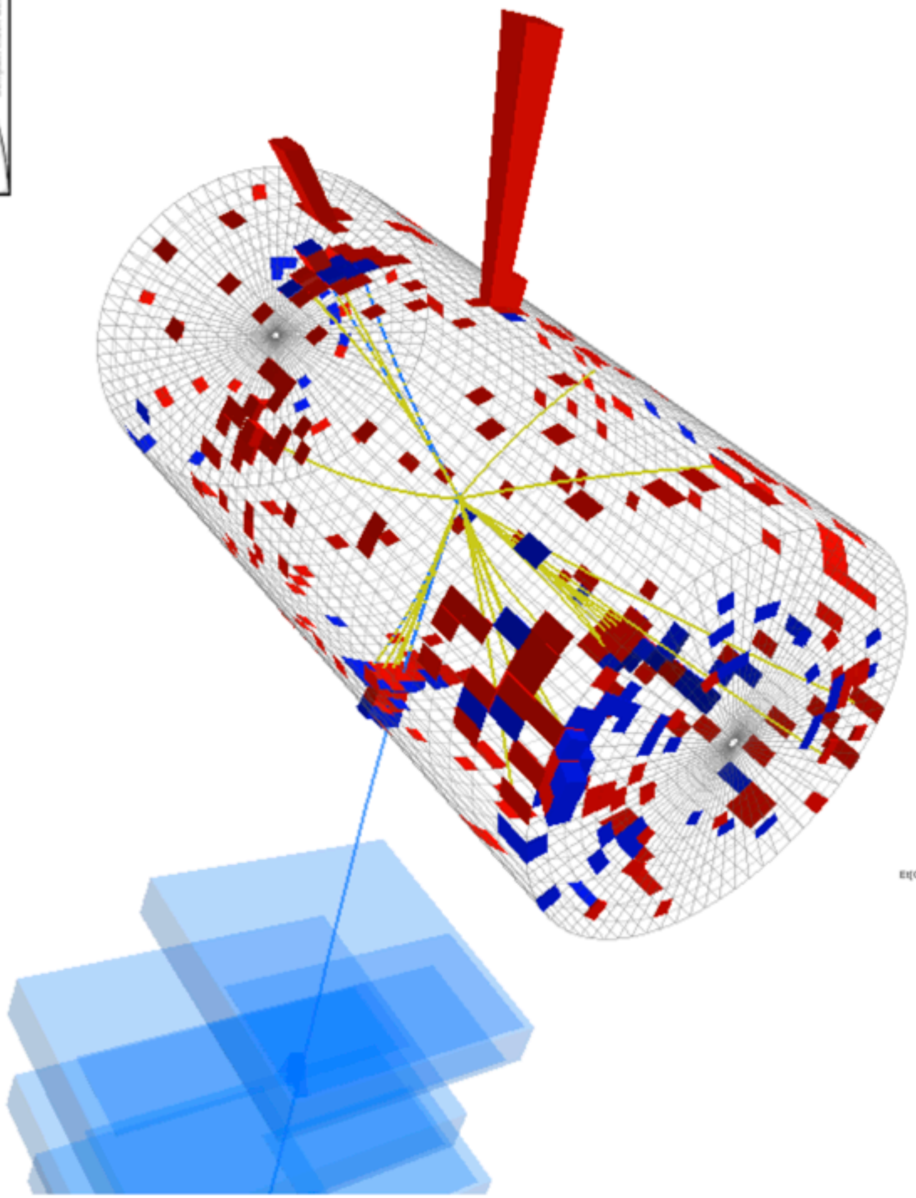


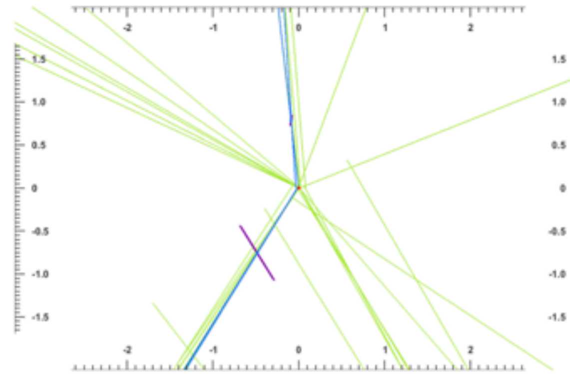
Post-fit

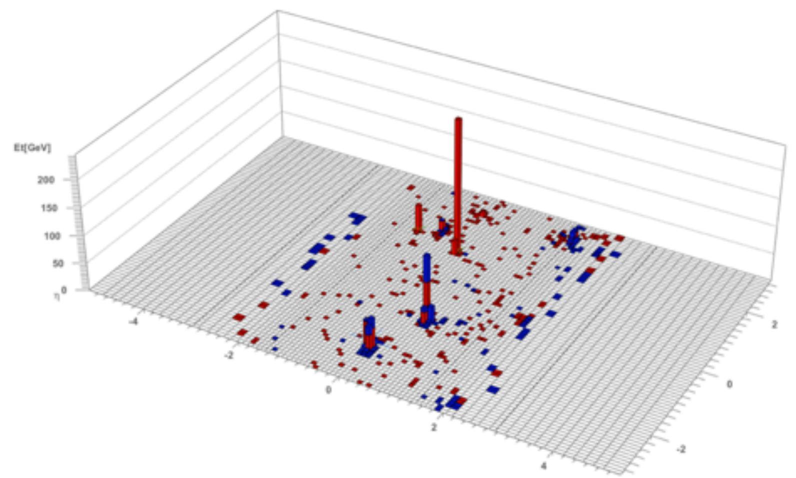


EVENT DISPLAY H→PHOTONS

CMS Experiment at LHC, CERN
Data recorded: Sat Nov 24 19:16:36 2012 CEST
Run/Event: 207889 / 771018991
Lumi section: 783







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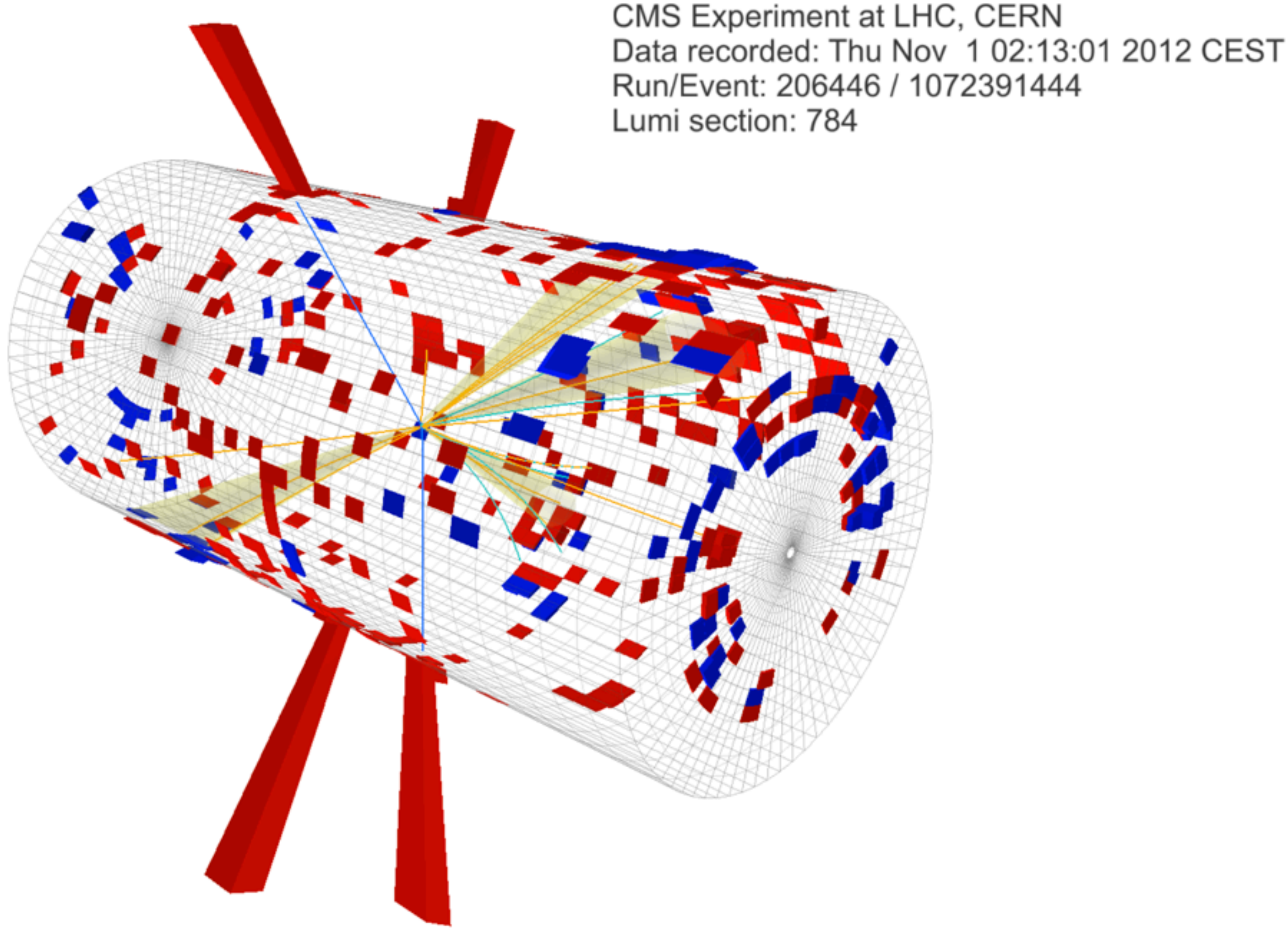

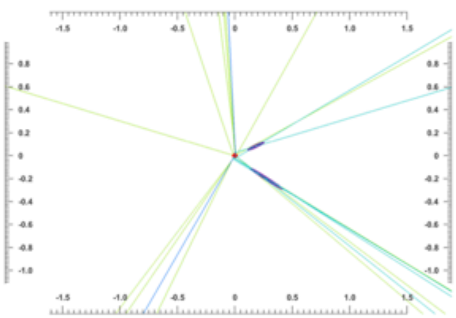

TECHNICALITIES

Signal and background modeling

- ttH, WW, WZ, ZZ Pythia
- ttW/ttZ/ttgamma/ttgammagamma/gamma+jets/gammagamma+jets MadGraph
- tq/tW Powheg

Triggers used:

- Diphoton trigger
- Electron trigger
- Muon trigger
- ee/emu/mumu triggers

btagging

- Combined secondary vertex, medium OP
- H->bb also uses full CSV spectrum