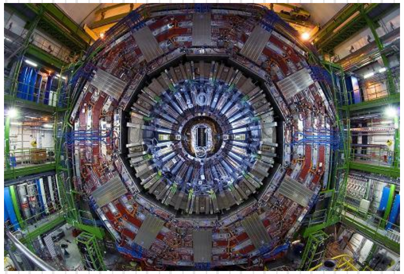
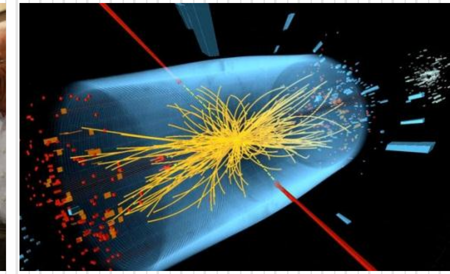
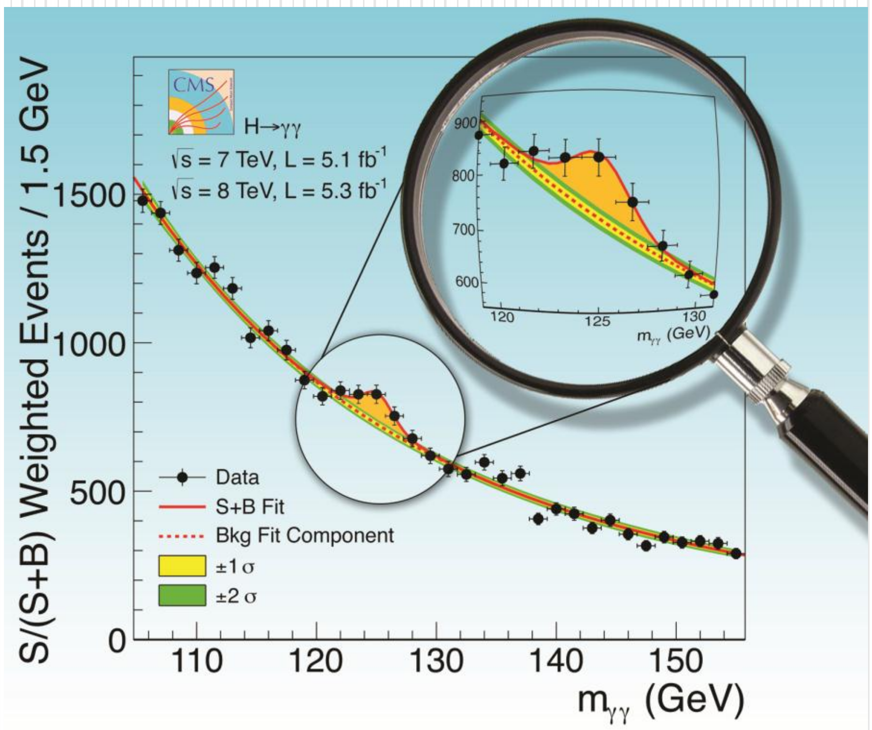


H → bb and Higgs Properties @ CMS



Jim Olsen

Princeton University

KITP Higgs Workshop

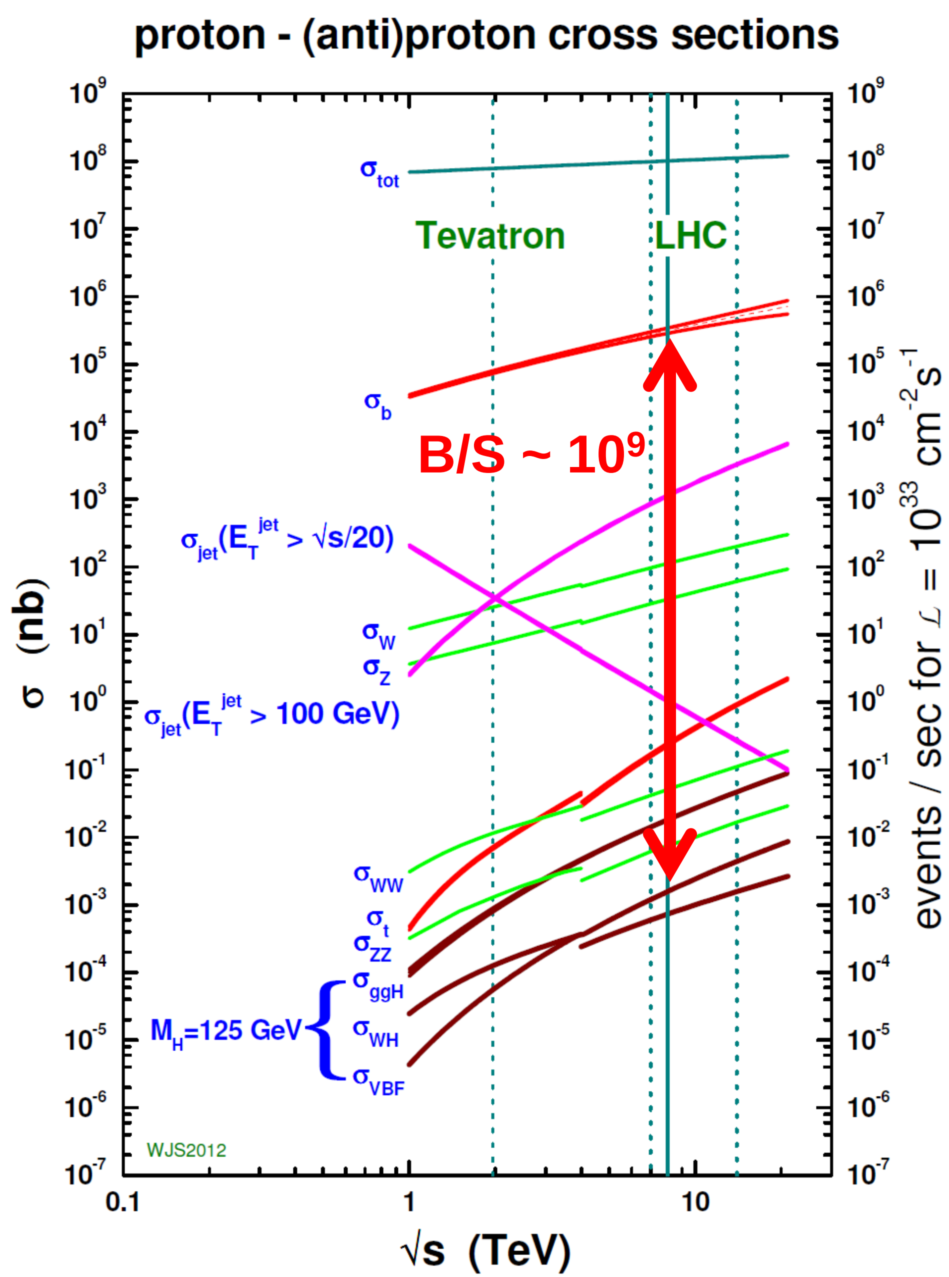
December 18, 2012

Latest results for the SM Higgs:

Channel	m_H range [GeV/c^2]	data set [fb^{-1}]	Data used CMS [fb^{-1}]	m_H resolution
1) $H \rightarrow \gamma\gamma$	110-150	5+5/fb	2011+12	1-2%
2) $H \rightarrow$ tau tau	110-145	5+12/fb	2011+12	15%
3) $H \rightarrow bb$	110-135	5+12/fb	2011+12	~~10%~~ 8-9%
4) $H \rightarrow WW \rightarrow l\nu l\nu$	110-600	5+12/fb	2011+12	20%
5) $H \rightarrow ZZ \rightarrow 4l$	110-1000	5+12/fb	2011+12	1-2%

Updates from ZZ, WW, $\tau\tau$, and bb presented at HCP

Search for VH, $H \rightarrow bb$



Inclusive H → bb?

Overwhelmed by QCD production of bottom-quark jets (B/S ~ 10^9)

Need to find another haystack!

VH to the Rescue!

PRL **100,** 242001 (2008) PHYSICAL REVIEW LETTERS week ending 20 JUNE 2008

Jet Substructure as a New Higgs-Search Channel at the Large Hadron Collider

Jonathan M. Butterworth and Adam R. Davison
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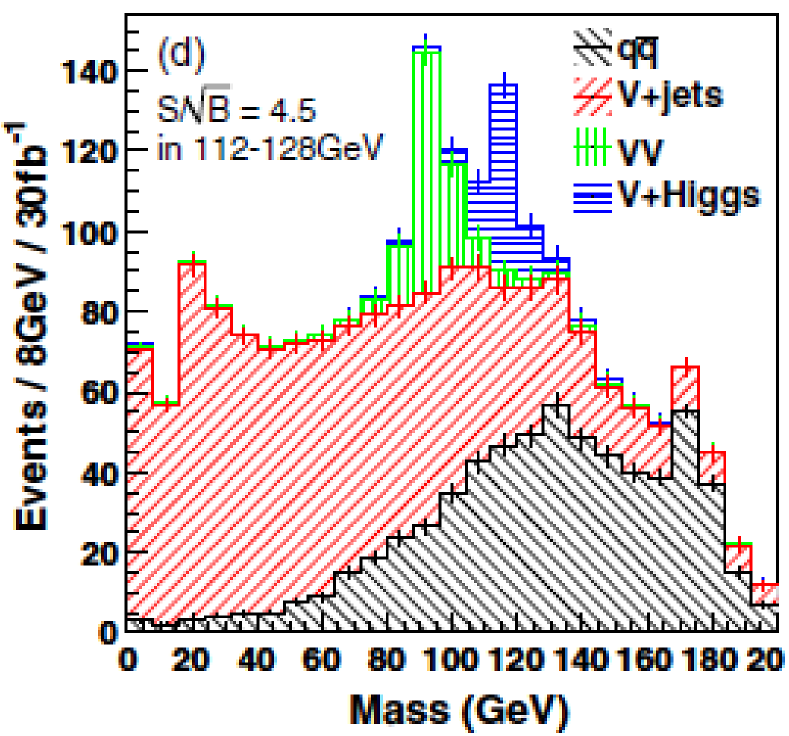
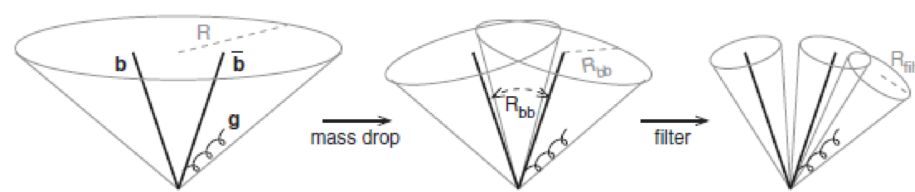
Mathieu Rubin and Gavin P. Salam
LPTHE; UPMC Univ. Paris 6; Univ. Denis Diderot; CNRS UMR 7589; Paris, France
(Received 2 March 2008; published 18 June 2008)



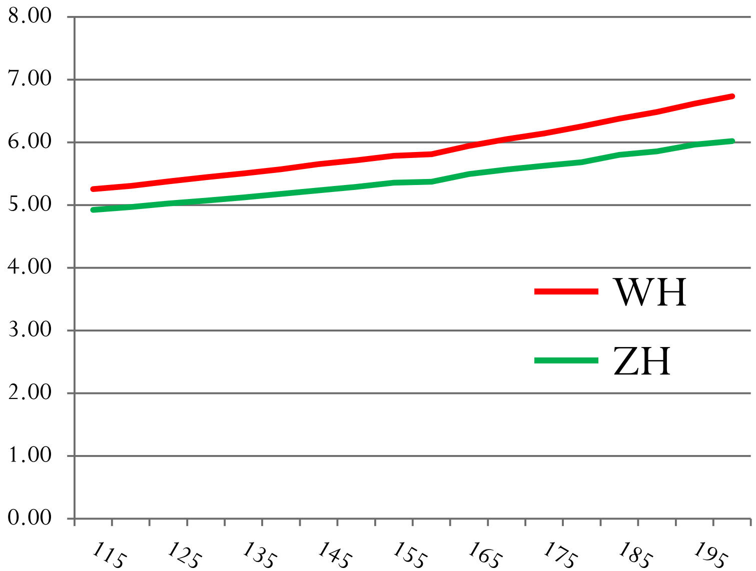
Features:

- V mostly kills QCD and provides an efficient trigger
- Boosting (> 200 GeV) suppresses V+jets and makes Z($\nu\nu$)H visible
- Substructure facilitates boost

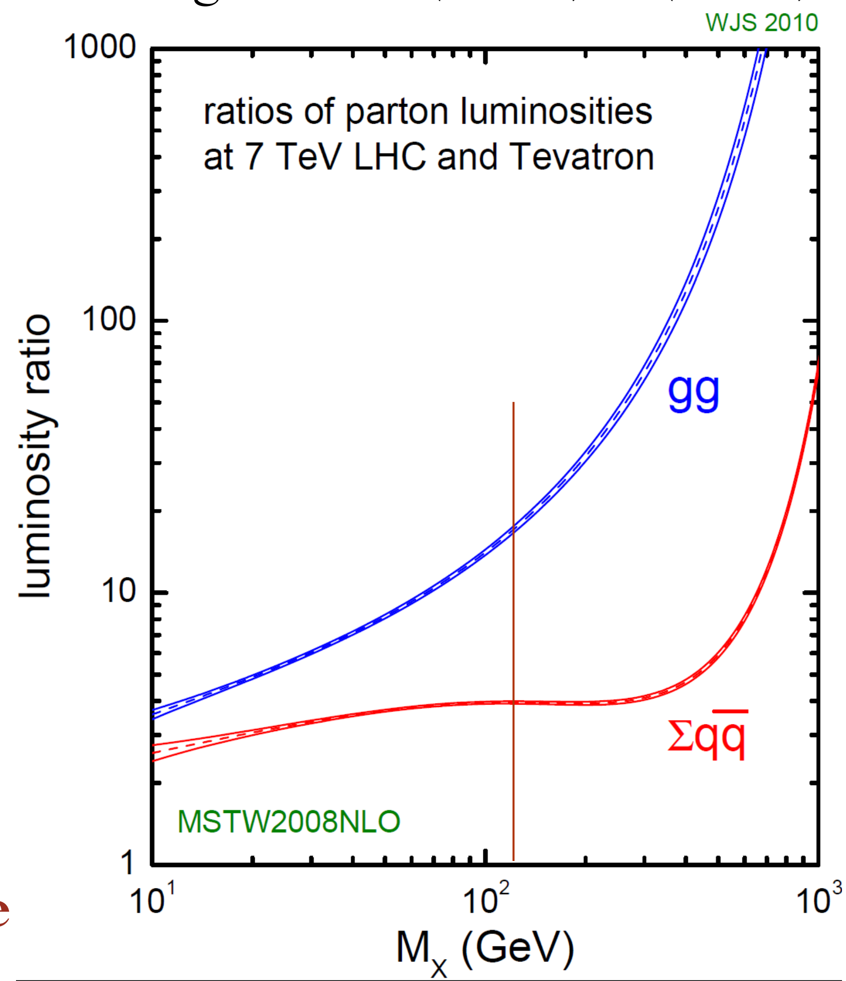


VH Production: LHC vs. Tevatron

Signal: VH(8 TeV)/VH(2TeV)



Background: L(7 TeV)/L(2TeV)

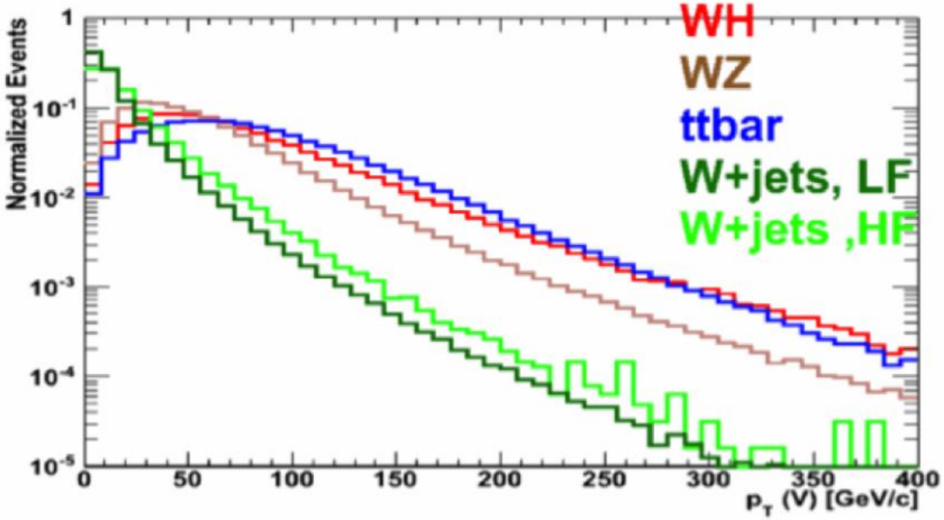


Signal increases ~5x

Gluon-initiated bkg increases > 20x

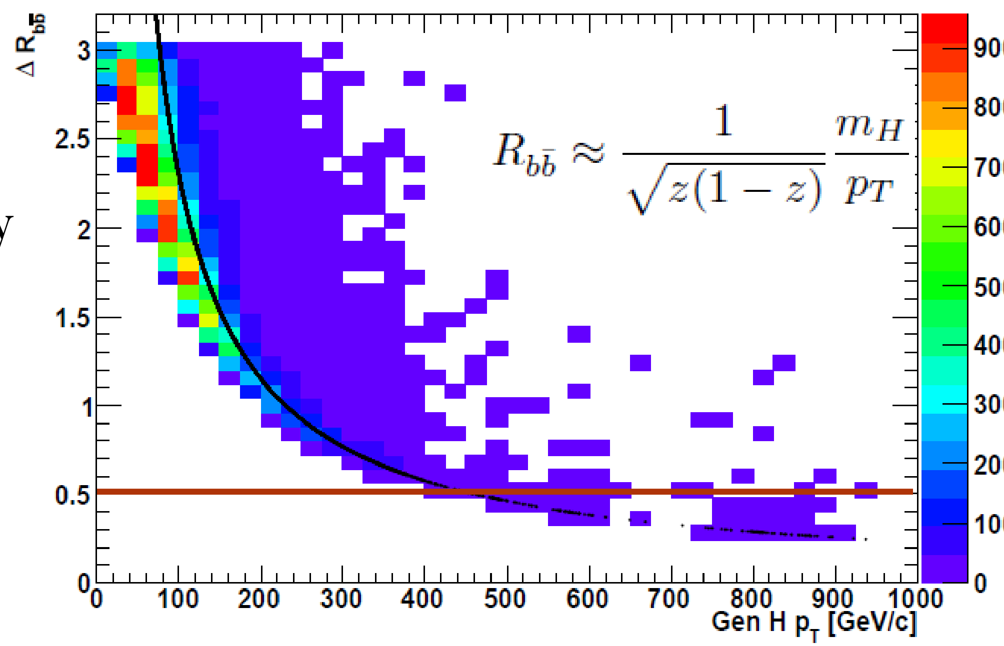
Still challenging at LHC, but more cross section to burn → boost!

Substructure or no substructure?



@ 8 TeV, optimal boost is somewhat lower than 200 GeV, in WH it's more like 150-170 GeV

For AK5 jets with a size parameter 0.5 (CMS), b jets from Higgs decay merge only above 400 GeV:



Substructure not "necessary", and does not seem to gain much over standard jets. But could be different @ 13 TeV

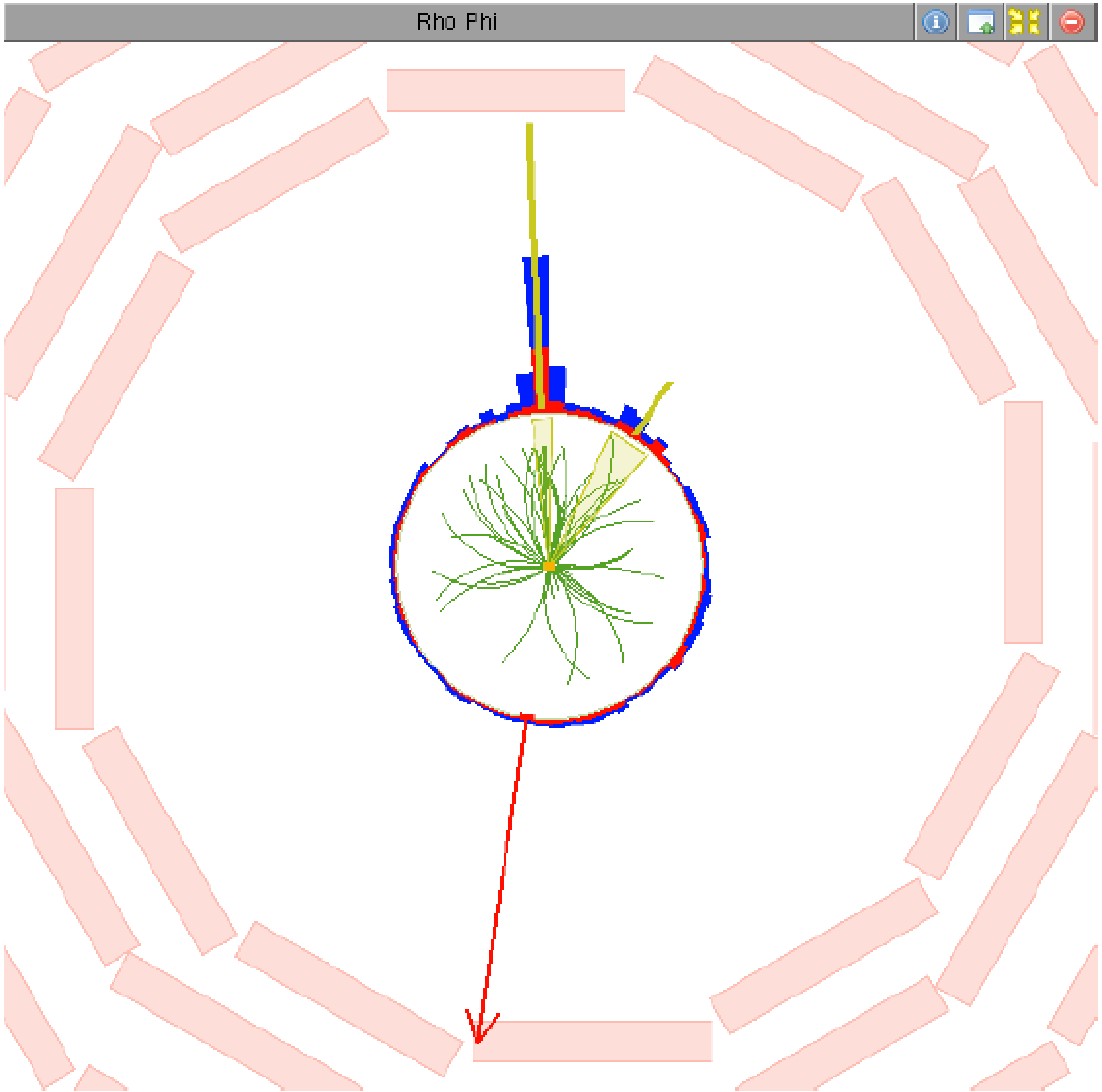
Analysis strategy (I)

- **Five separate channels:** Z(ℓℓ), Z(νν), W(ℓν); ℓ = e,μ
- **Triggers (8 TeV):**
  - Incl μ (24-40 GeV), iso elec (27 GeV), double elec (17/8 GeV)
  - MET (80 GeV) + 2 jets (60/25 GeV) + (Δϕ or MHT)
- **Jet reco and b-tagging:**
  - Two AK5 jets, b-tagged
  - B-tag discriminator used as input to analysis BDT
  - Jet energy regression for improved M(jj) resolution

Analysis strategy (II)

- **Boost and topology discriminants**
  - pT(V), pT(H) optimized separately for each channel
  - Topology: $\Delta\phi$(V,H), ΔR(jj), $\Delta\eta$(jj), N_{jet}, color flow
- **Control Regions**
  - Check shapes in regions kinematically similar to signal
  - Estimate starting parameters for background yields in final fit
- **Shape analysis on BDT output**
  - Fit to BDT shape performed in two bins of pT(V), and (in some channels) to two bins of b-tagging quality
  - Mjj comparison in signal region as a cross-check, in particular for SM diboson production

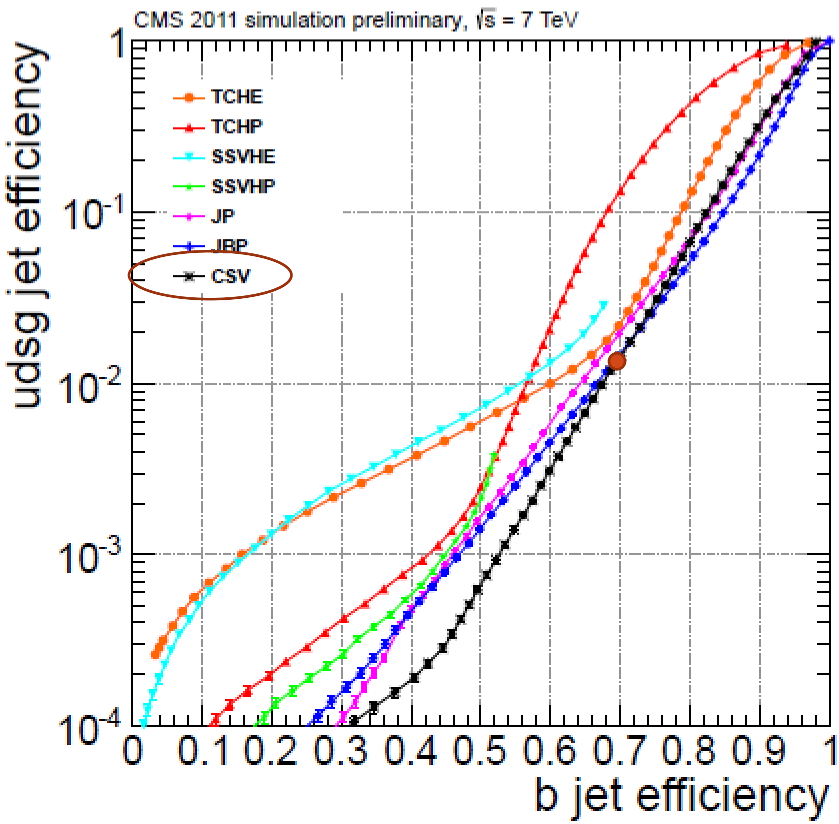
$Z(\nu\bar{\nu})H(b\bar{b})$ candidate



PD: /MET/Run2011B
Run: 177183
Lumi: 183
Event: 305295270

- M(jj) = 120.0 GeV
- p_T(jj) = 248.4 GeV
- Jets:
  - p_T = 209.5 GeV, CSV = 0.889
  - p_T = 46.2 GeV, CSV = 0.957
- MET:
  - 243.2 GeV

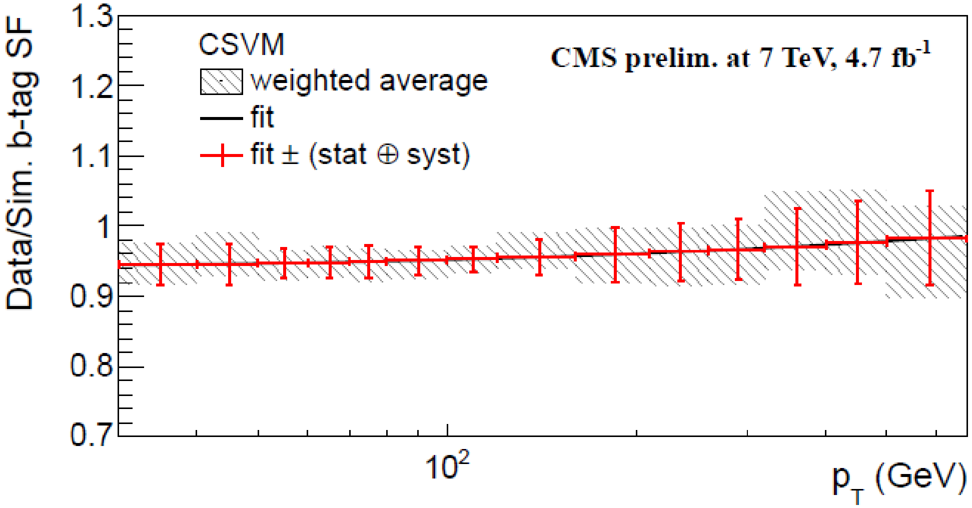
B-tagging: Performance and Validation

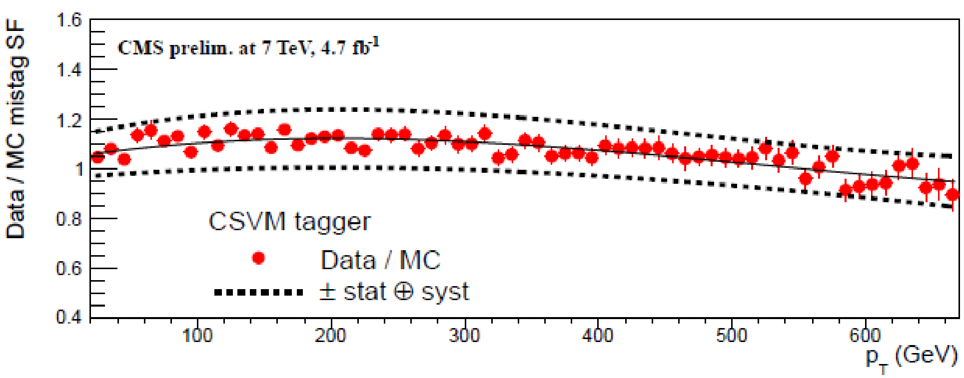


Typical working point:

- **Eff(sig) ~ 70%**
- **Eff(bkg) ~ 1%**

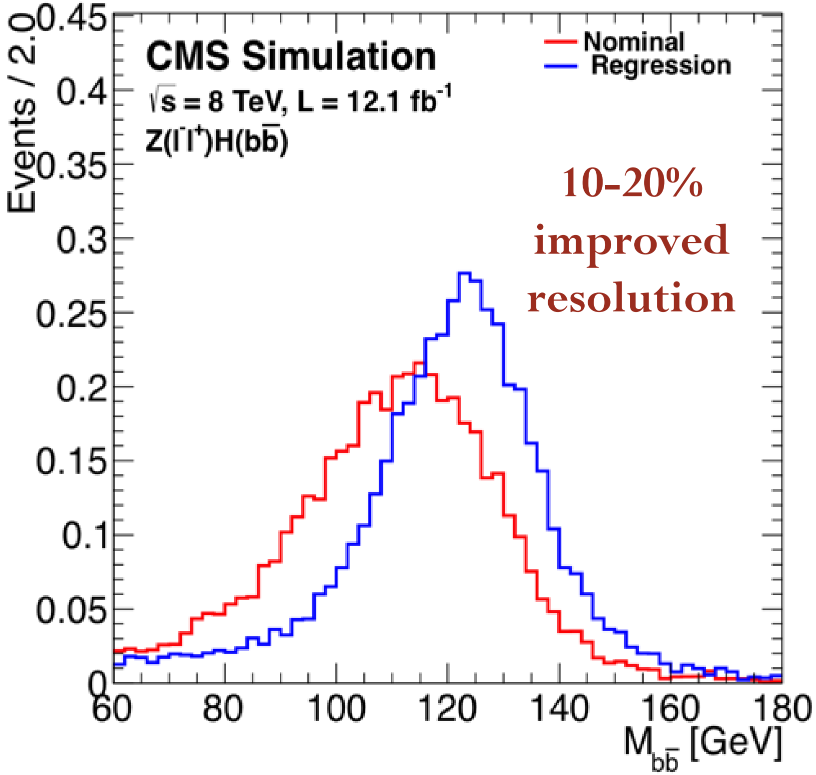
Calibrated on ttbar data up to pT(j) > 600 GeV



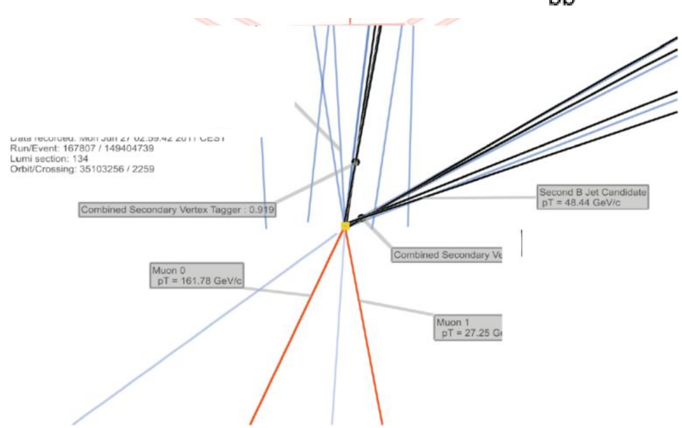


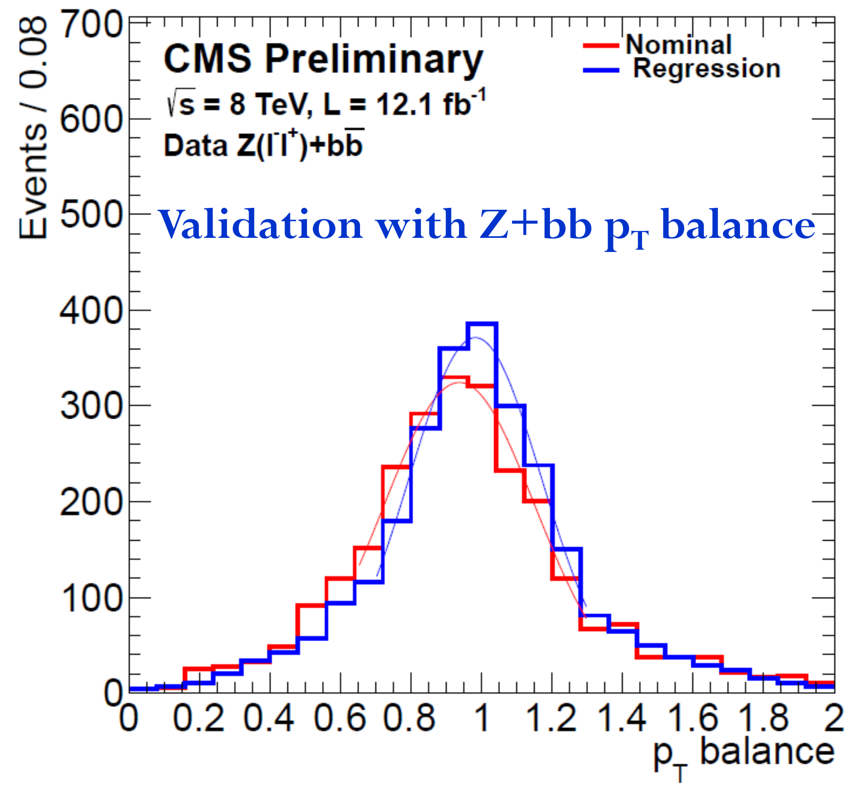
Corrected shapes used as input to BDT

B-jet Energy Regression



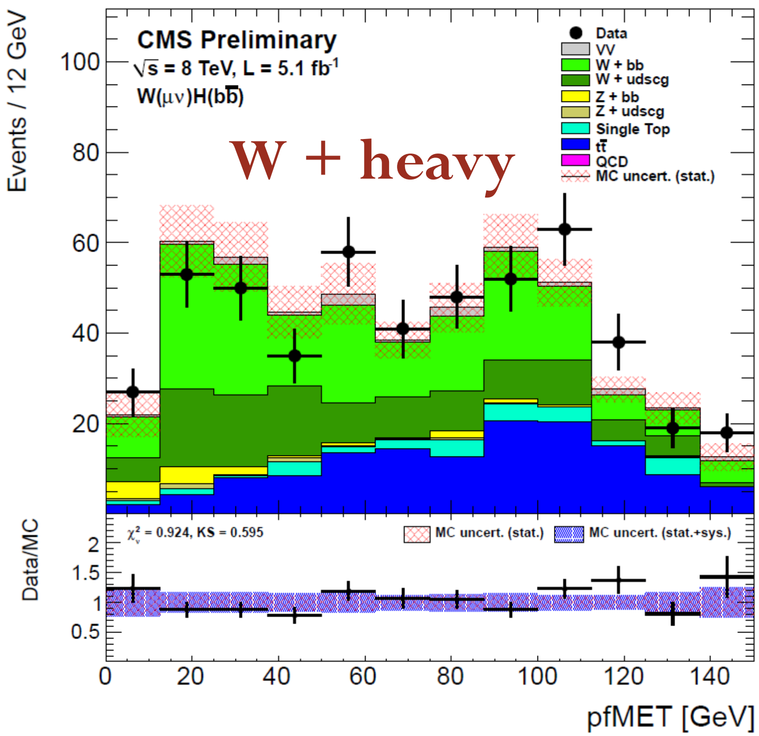
Use information about the jet energy and b-jet characteristics in a BDT regression to improve energy resolution (a la CDF)



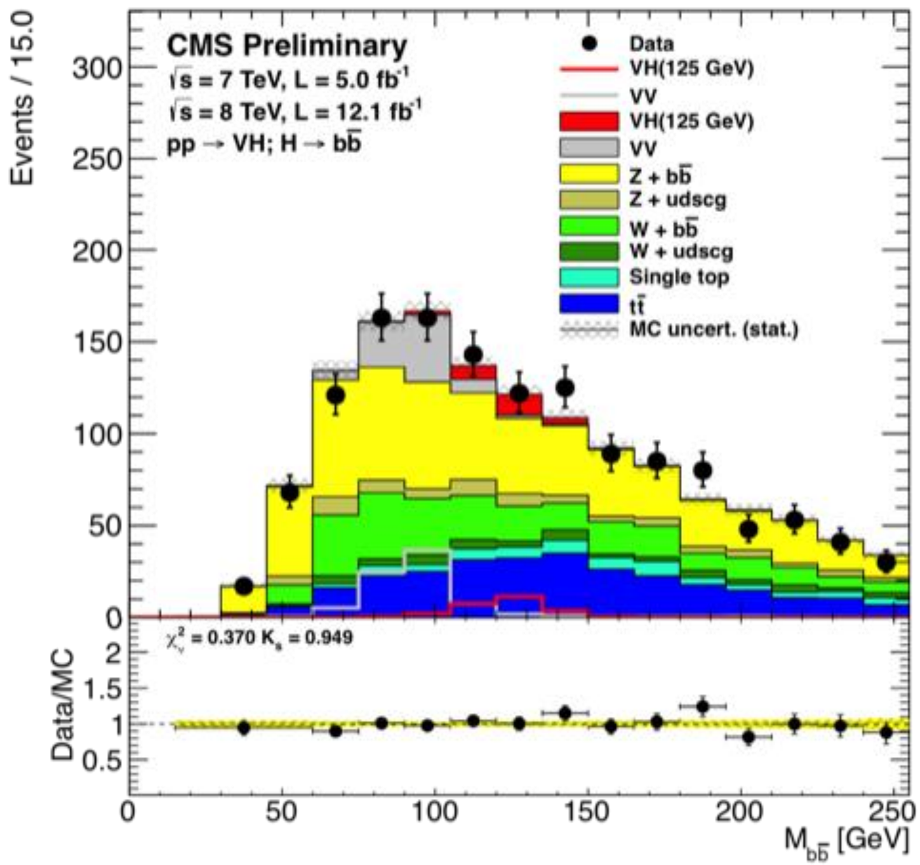


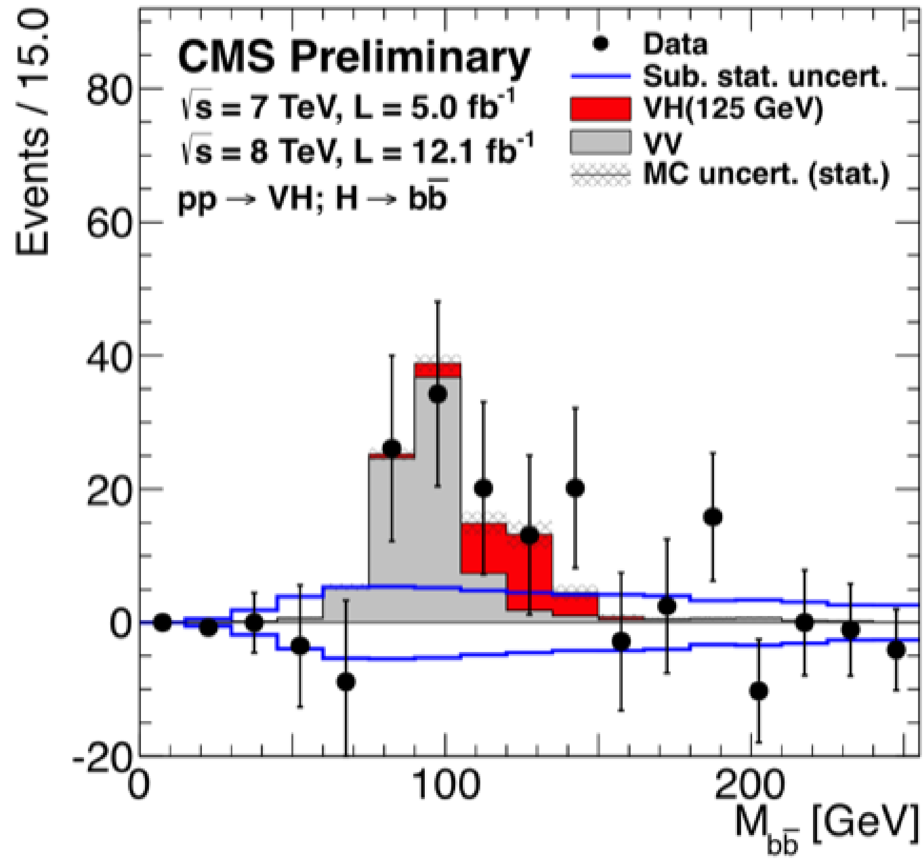
Backgrounds and Control Regions

- **Dominant backgrounds**
  - V+bb, V+udscg, ttbar, single top, VV
- **Control regions**
  - Enhance particular backgrounds
  - As close as possible to the signal region
  - "V+heavy", "V+light", "Top"
  - More plots available on the CMS twiki
- **Extrapolation to signal region**
  - Scale factor starting values obtained from control regions
  - Shape analysis floats these correction factors, final values consistent with starting values



Dijet Invariant Mass: all channels

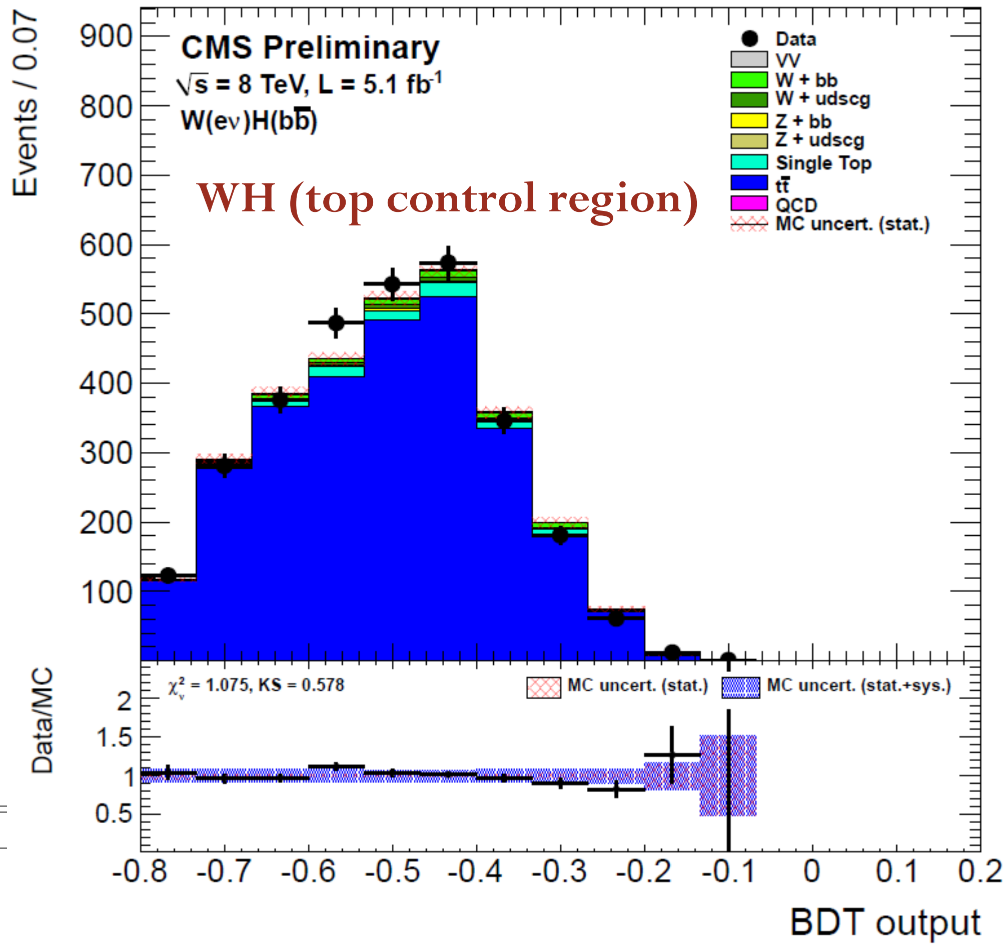




Already from non-optimized M(jj) plot: a clear VV(+VH) peak above SM backgrounds

BDT discriminant

Combine kinematic, topological, b-tagging, and color flow variables into BDT, separately for high and low pT bins

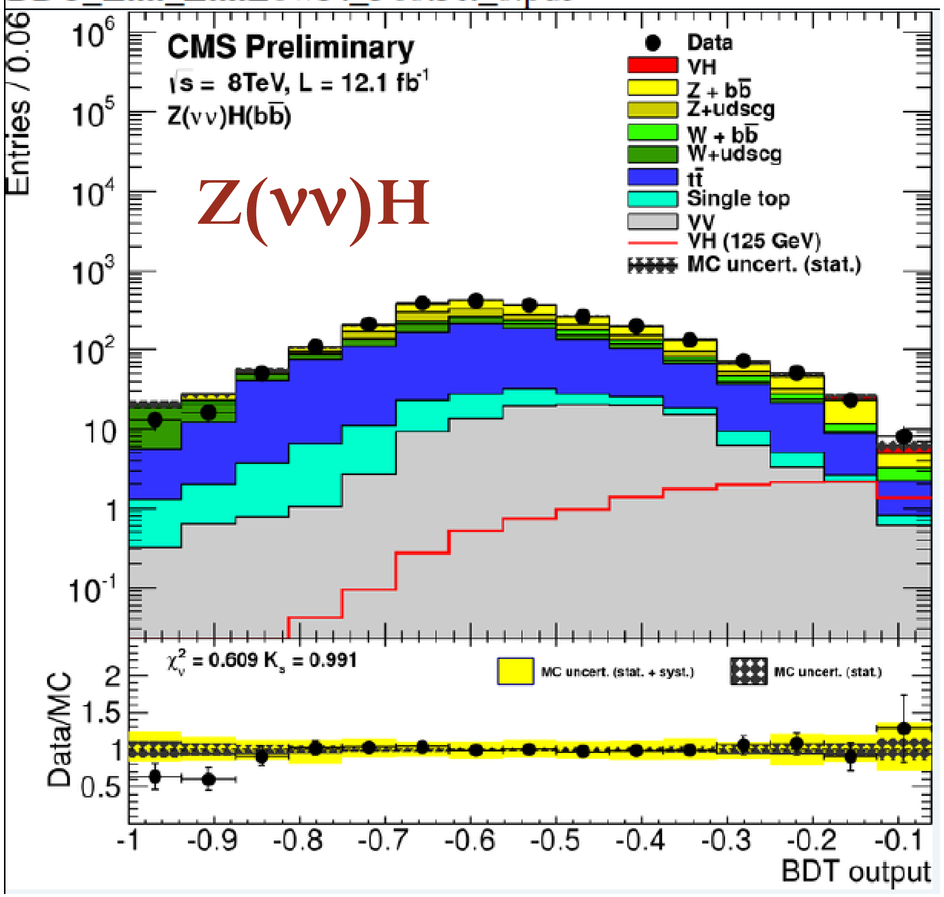


Variable
p_{Tj}: transverse momentum of each Higgs daughter
$m(jj)$: dijet invariant mass
$p_T(jj)$: dijet transverse momentum
$p_T(V)$: vector boson transverse momentum (or pfMET)
CSV_{max}: value of CSV for the b-tagged jet with largest CSV value
CSV_{min}: value of CSV for the b-tagged jet with second largest CSV value
$\Delta\phi(V,H)$: azimuthal angle between V (or E_T^{miss}) and dijet
$\lvert\Delta\eta(jj)\rvert$; difference in η between Higgs daughters
$\Delta R(j1,j2)$; distance in η–ϕ between Higgs daughters (not for $Z(\ell\ell)H$)
N_{aj}: number of additional jets ($p_T > 30\,GeV$, $\lvert\eta\rvert < 4.5$)
$\Delta\phi(E_T^{miss}, jet)$: azimuthal angle between E_T^{miss} and the closest jet (only for $Z(\nu\nu)H$)
$\Delta\theta_{pull}$: color pull angle [62] (not for $Z(\ell\ell)H$)

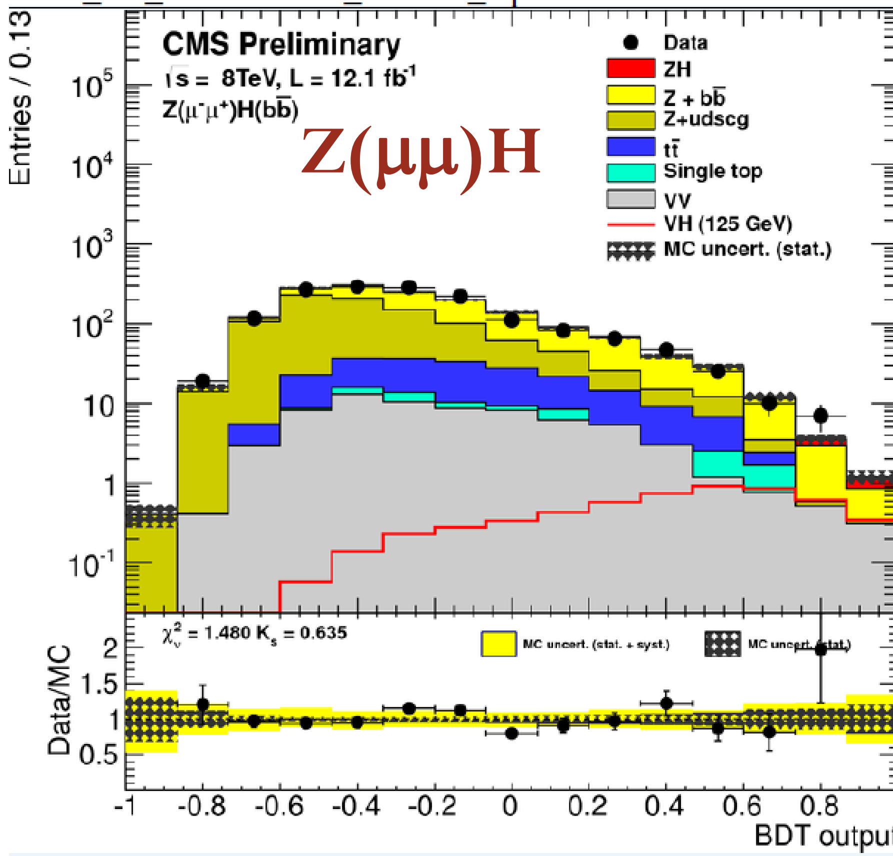
Shapes validated in background control regions, simulation (with shape uncertainties) used for final fit

Example BDT shapes in signal region

BDT_Znn_ZnnLowPt_PostFit_s.pdf



BDT_Zll_ZmmLowPt_PostFit_s.pdf

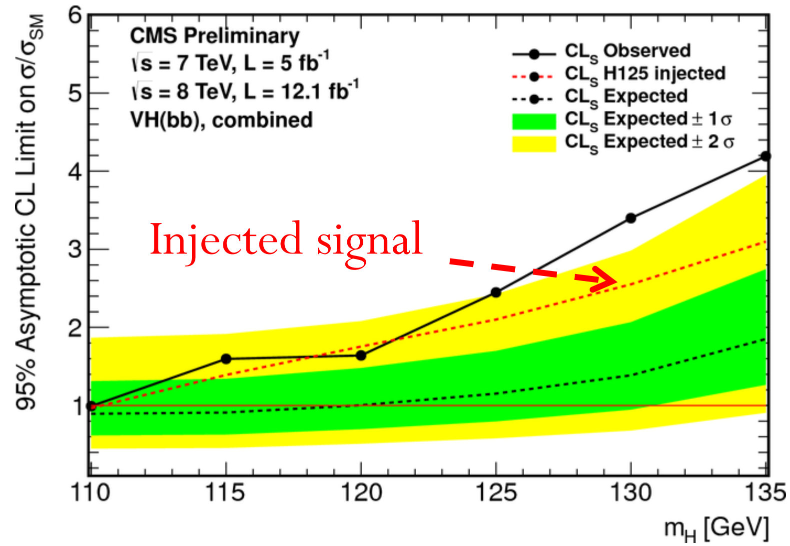


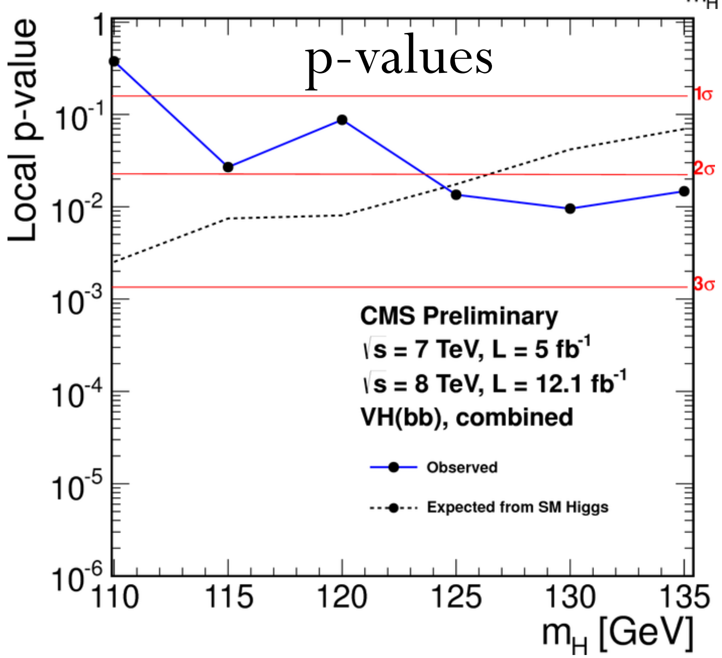
All shape comparisons look good, data consistent with background-only hypothesis

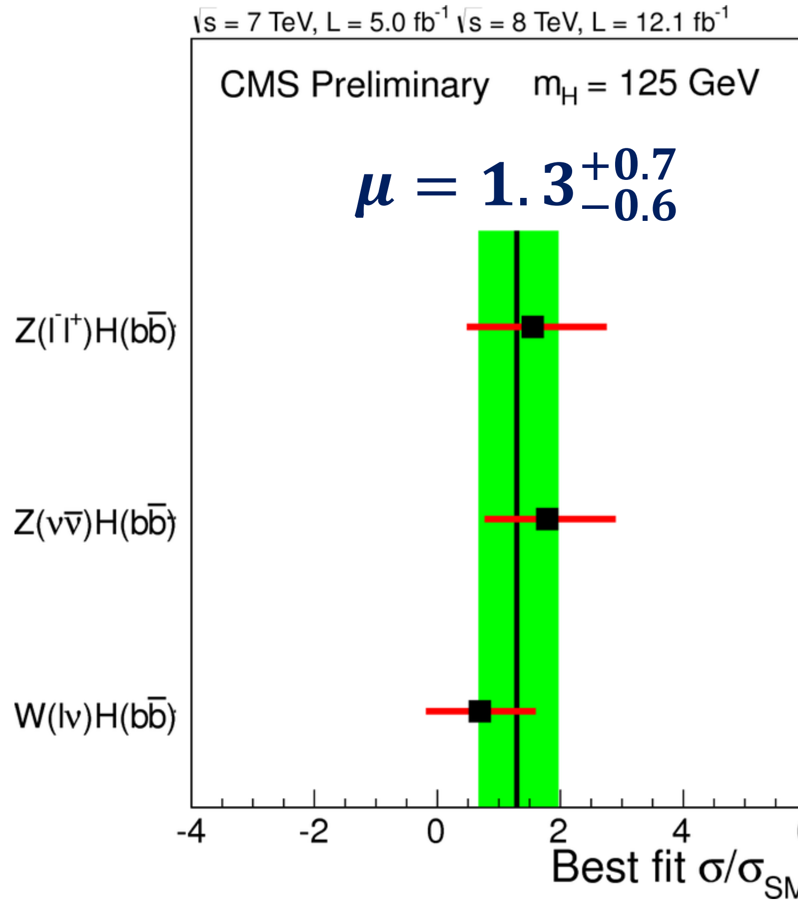
Systematic Uncertainties

Source	Range
Luminosity	2.2-4.4%
Lepton efficiency and trigger (per lepton)	3%
$Z(\nu\nu)H$ triggers	3%
Jet energy scale	2–3%
Jet energy resolution	3–6%
Missing transverse energy	3%
b-tagging	3–15%
Signal cross section (scale and PDF)	4%
Signal cross section (p_T boost, EWK/QCD)	5–10% / 10%
Signal Monte Carlo statistics	1-5%
Backgrounds (data estimate)	$\approx$ 10%
Single-top (simulation estimate)	15–30%
Dibosons (simulation estimate)	30%

Results: 7 + 8 TeV (17/fb)







@125 GeV:

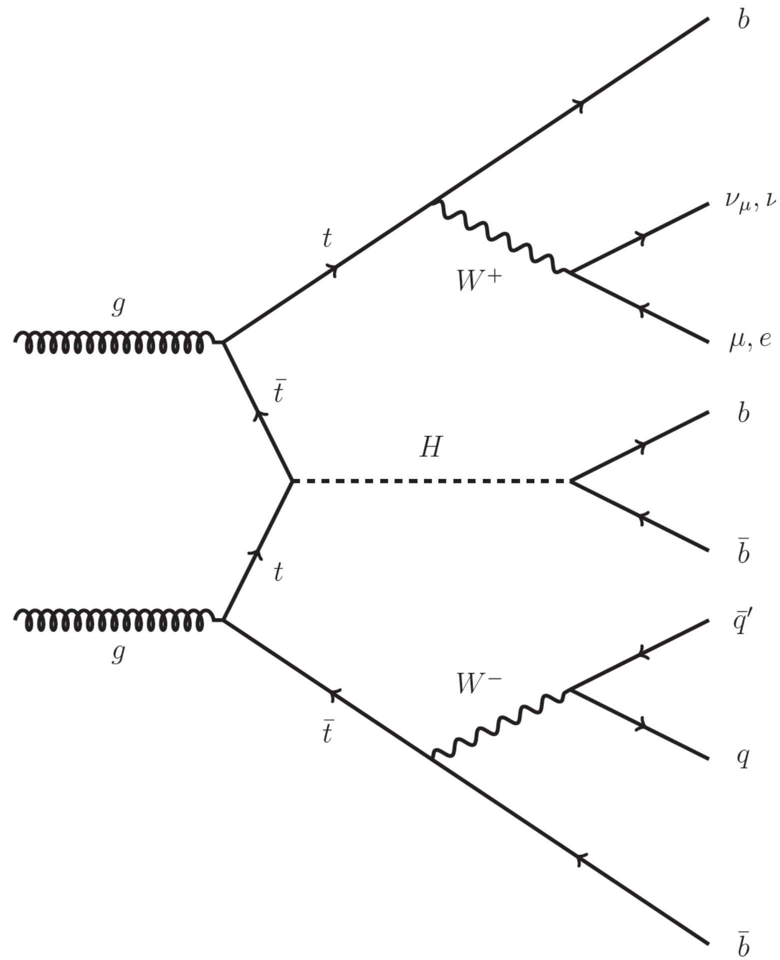
exp (obs) limit = 1.15 (2.45) x SM

exp (obs) significance = 2.1 (2.2) σ

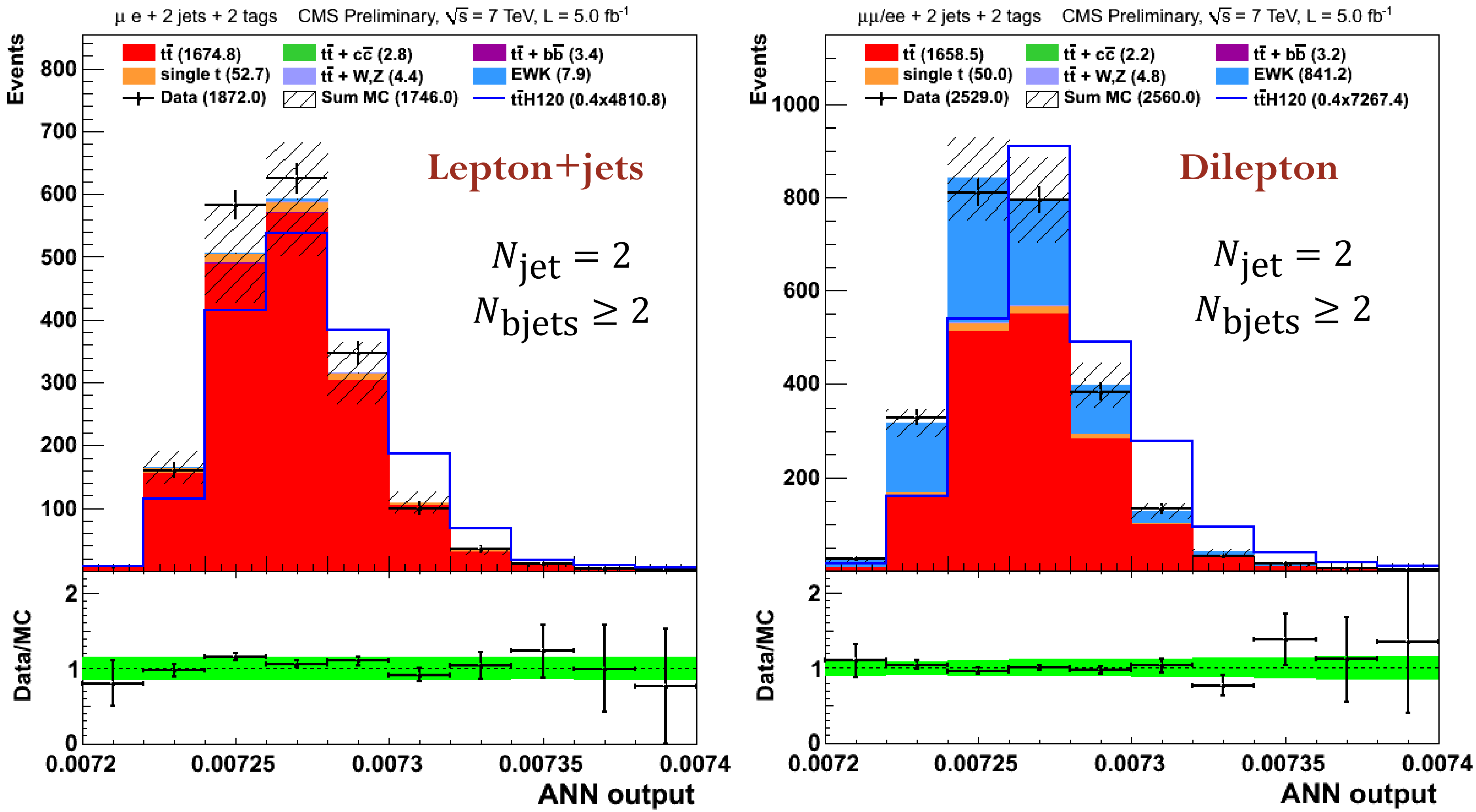
Searching for ttH, H → bb

Overview of ttH(bb)

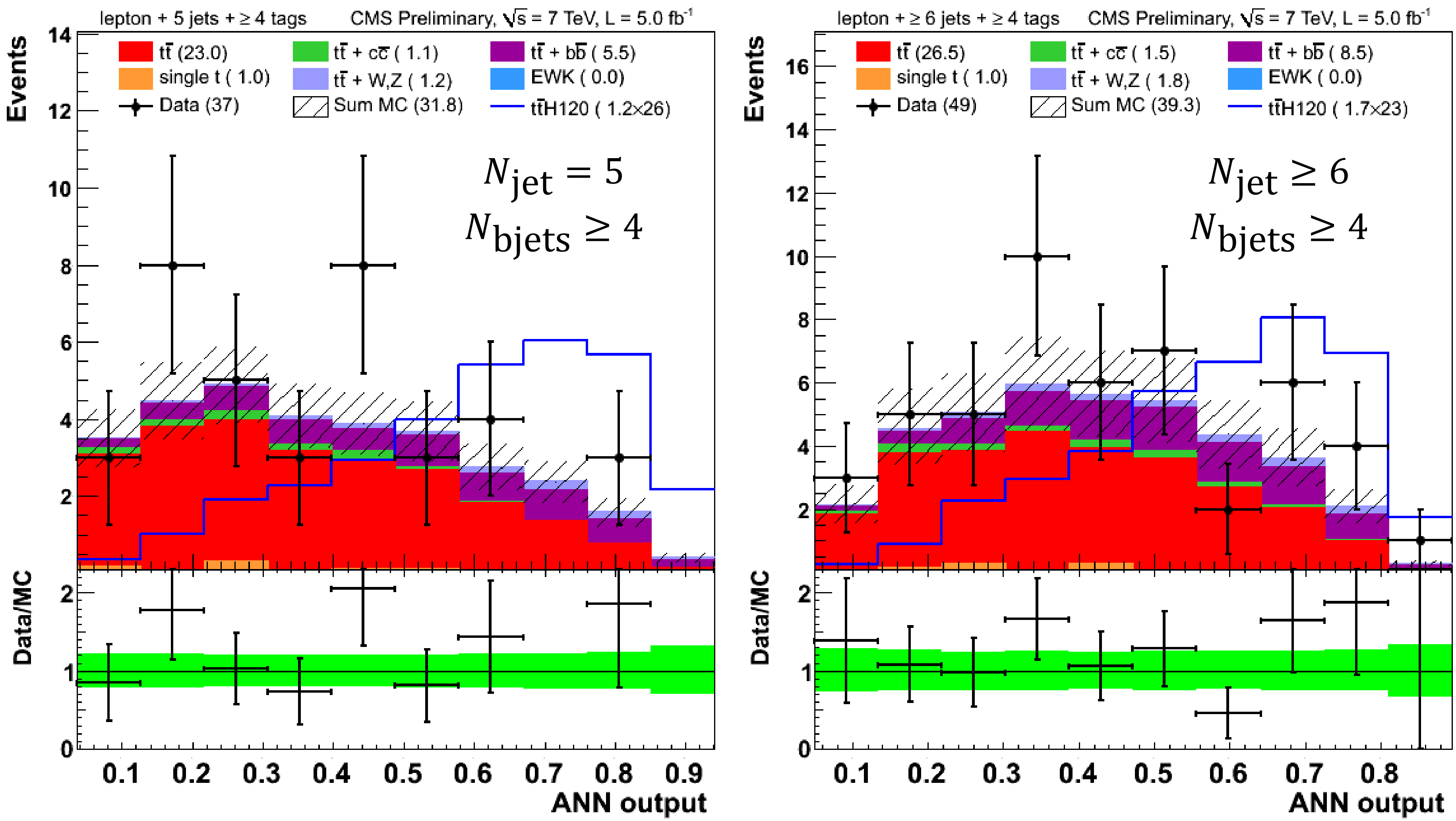
- **Important channel**
  - Doubly sensitive to fermion coupling
  - No connection to vector bosons
  - Busy! Four b-jets plus 4 jets/leptons
- **Issues**
  - Mass is not an effective disc. variable
  - Critical input is estimated background on SM tt+bb production, which is nearly indistinguishable from signal
- **Strategy**
  - Effectively a counting experiment
    - Signal estimated from fits to ANN shape in bins of (Njet, Nbjet)
  - Lepton+jets and Dilepton categories



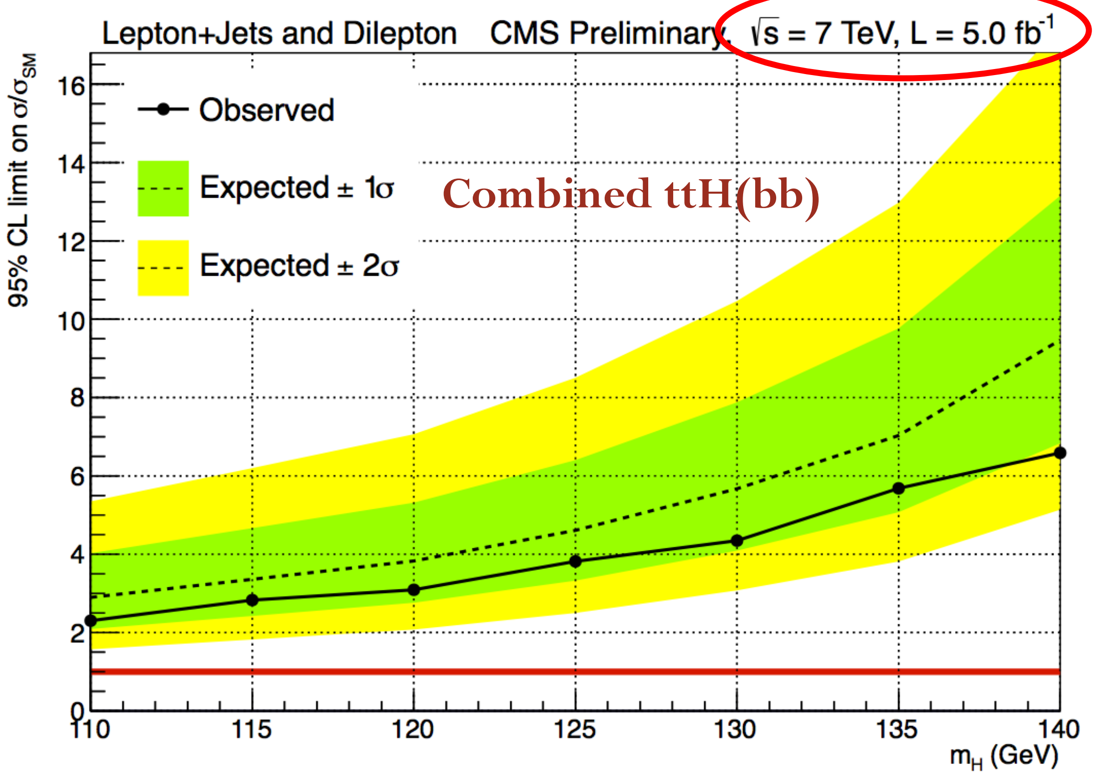
Shape Comparisons: Background

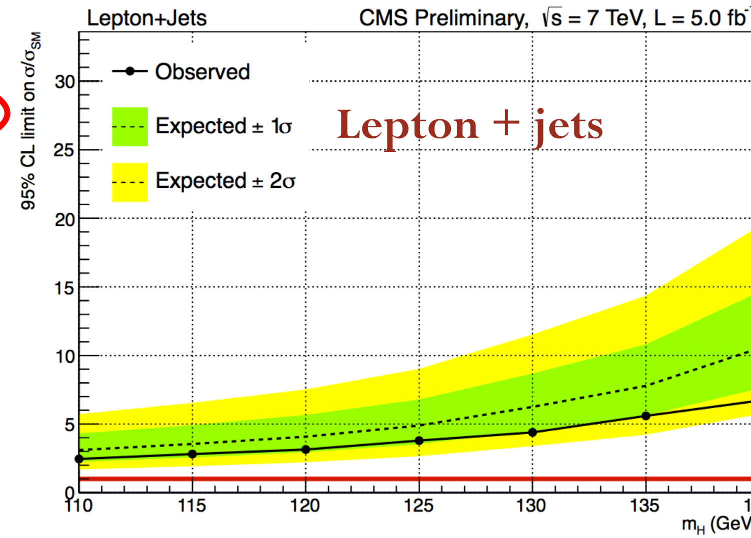


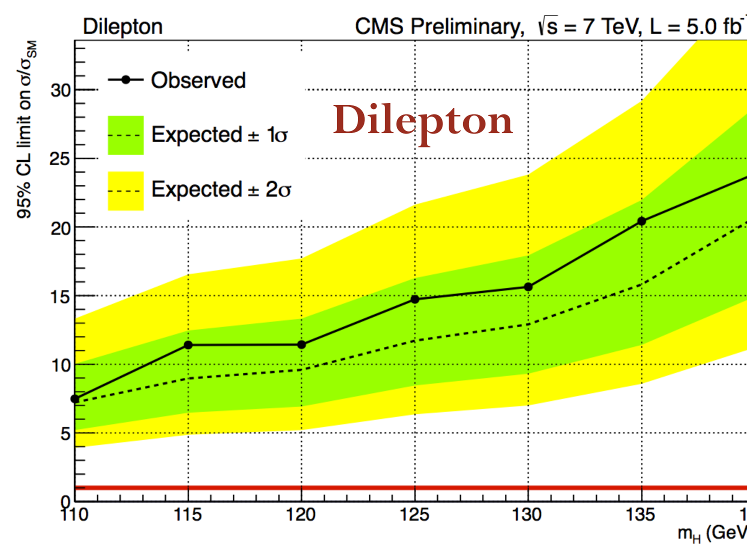
Shape Comparisons: Signal Region



Results





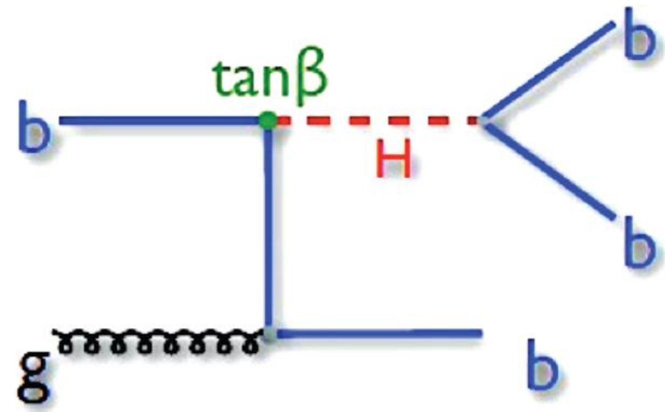


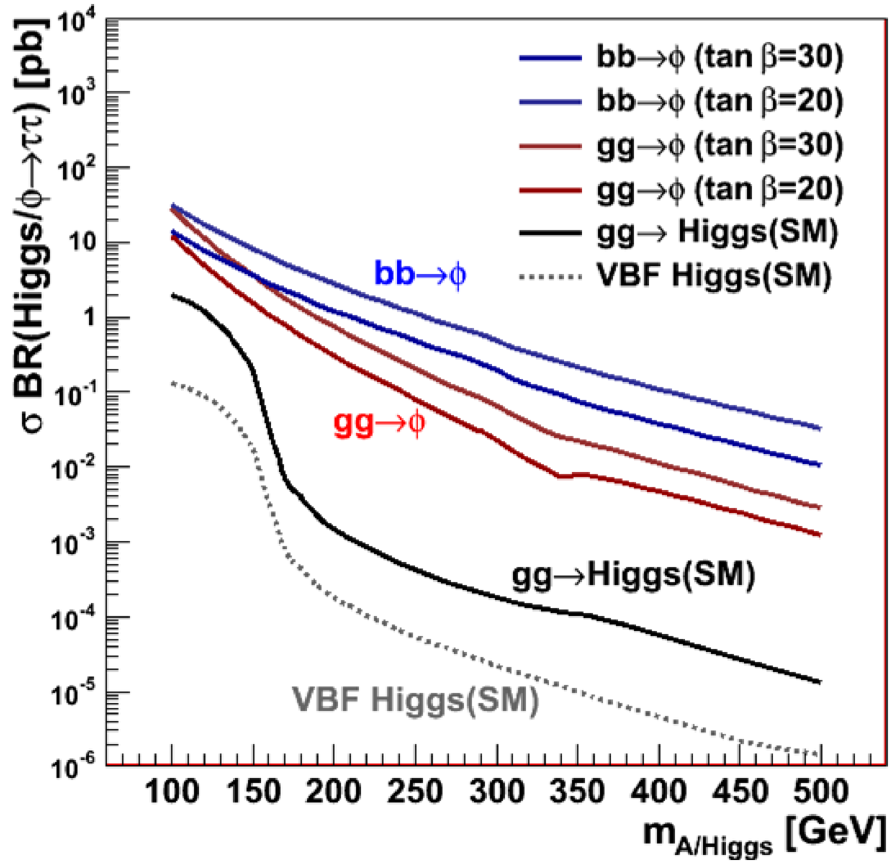
- Lepton+jets dominates, Dilepton adds 5-10%
- Results consistent with background-only hypothesis, limit @ 125 GeV: 4.6 exp, 3.8 obs

One step beyond: Search for MSSM Higgs decaying to bb

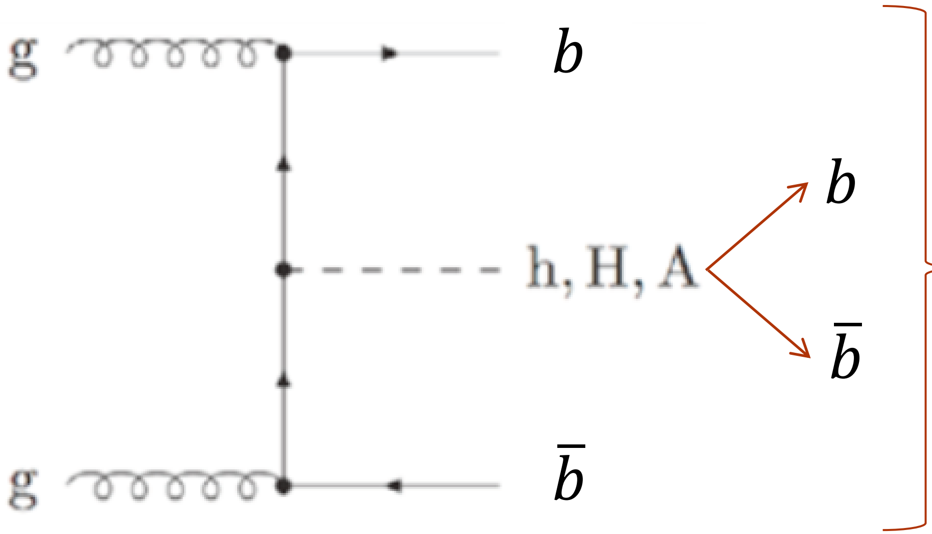
MSSM Higgs

- Two Higgs doublets
  - Five Higgs particles
    - Three neutral (h, H, A)
    - Two charged ($H^{\pm}$)
  - Two free parameters
    - Mass
    - tanβ – ratio of vevs for up and down
- Searches @ CMS
  - Neutral: ττ and bb
  - Charged: look in top decays





Search for MSSM $\phi(h, H, A) \rightarrow bb$

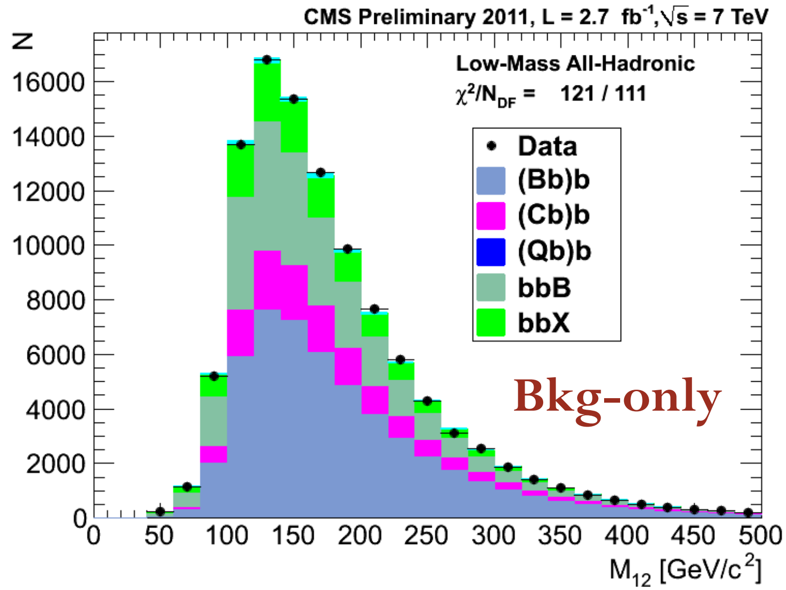


Only b-jets (and radiation) in the final state, trigger is one of the most challenging at LHC

Two complementary approaches:

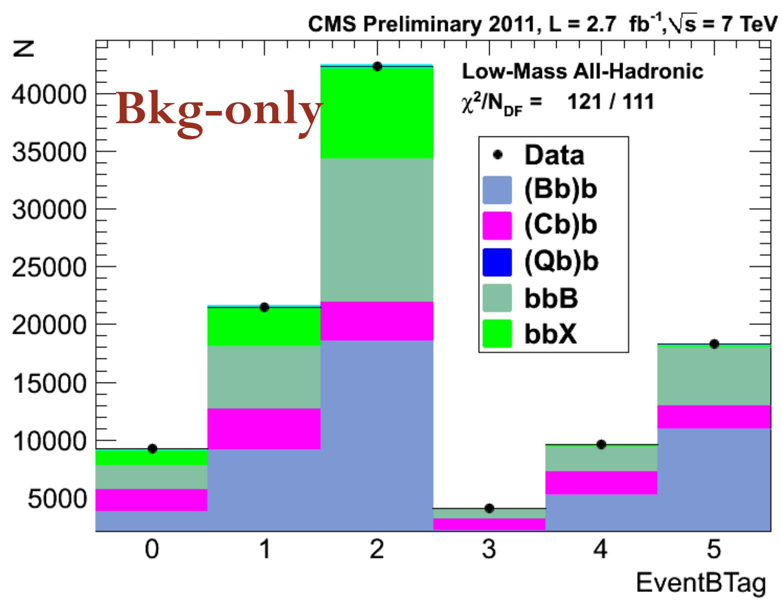
- <u>All-hadronic</u> trigger requiring up to three jets and at least two b-tagged jets (three offline)
- <u>Semileptonic</u> trigger requiring up to three jets, two b-tagged jets (three offline), and one muon from b-hadron decay
- **Essentially independent samples (2-3% overlap)**

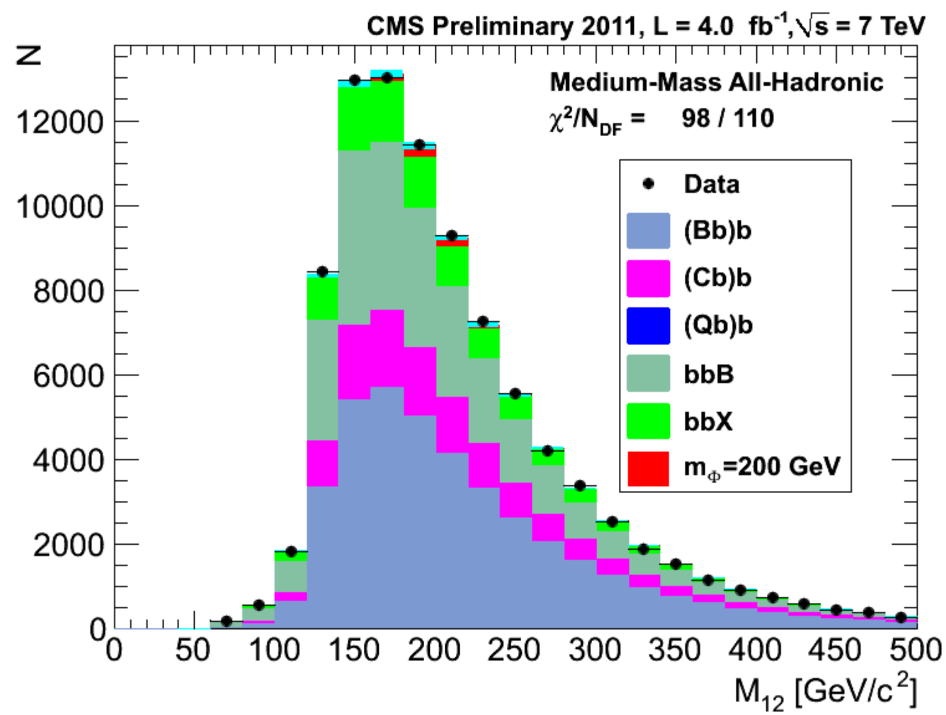
Results: All-hadronic analysis



Background shapes obtained from double-tag sample give excellent agreement when applied to triple-tag sample.

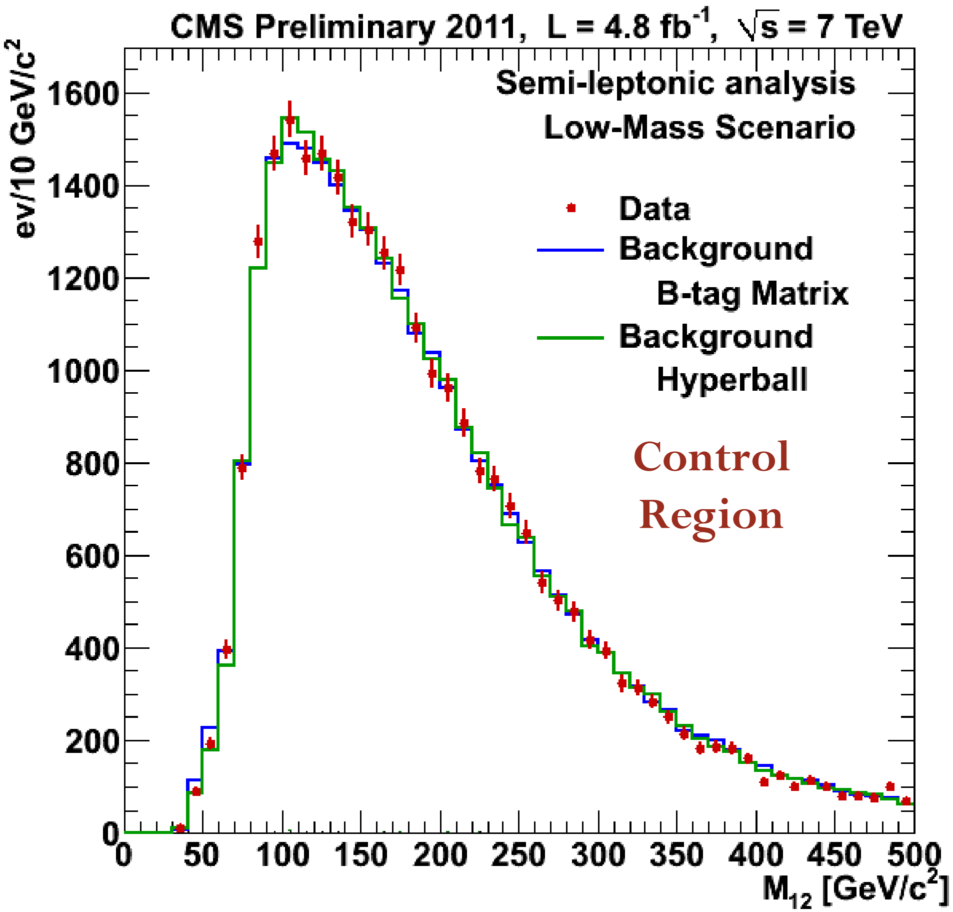
Signal fits scan in mass from 90 to 350 GeV, no significant signal is observed at any mass.

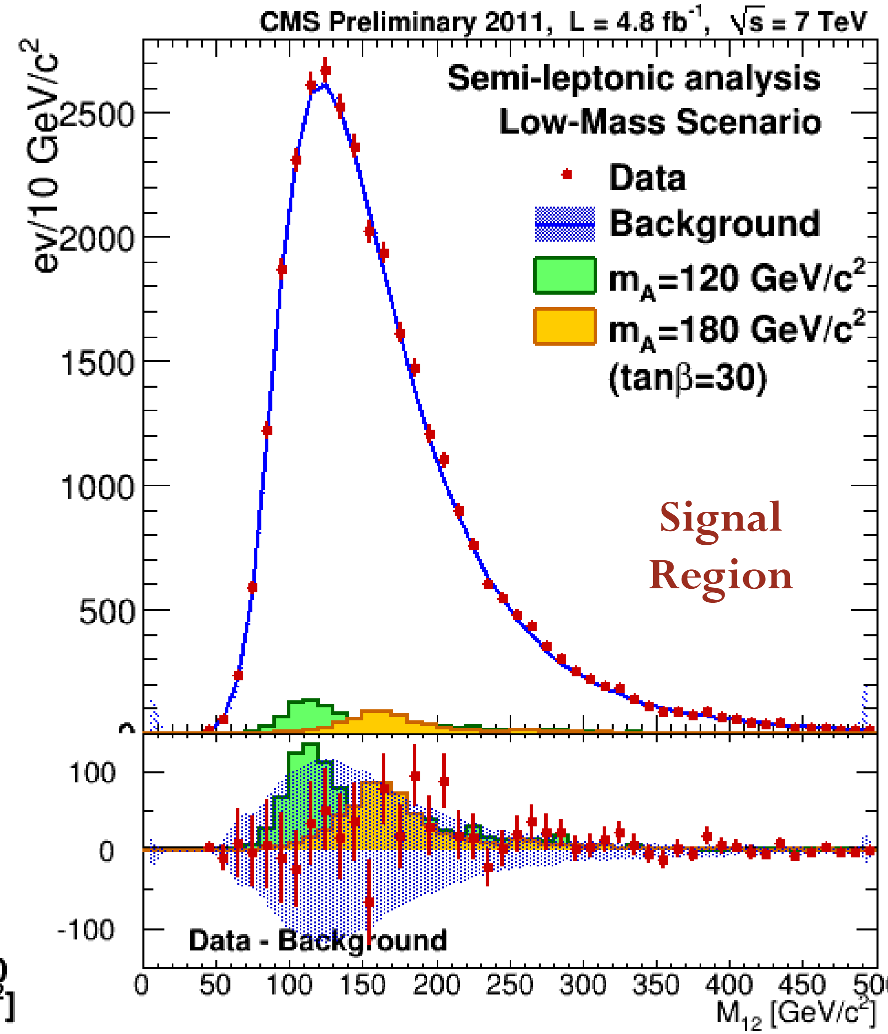




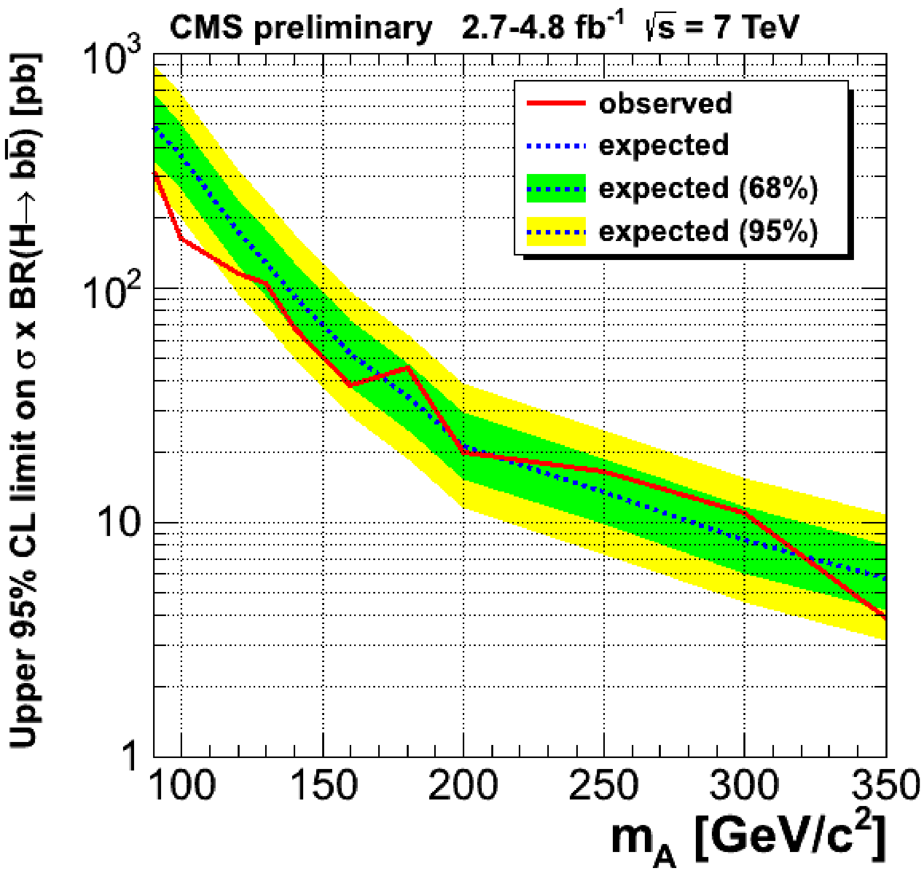
Results: Semileptonic analysis

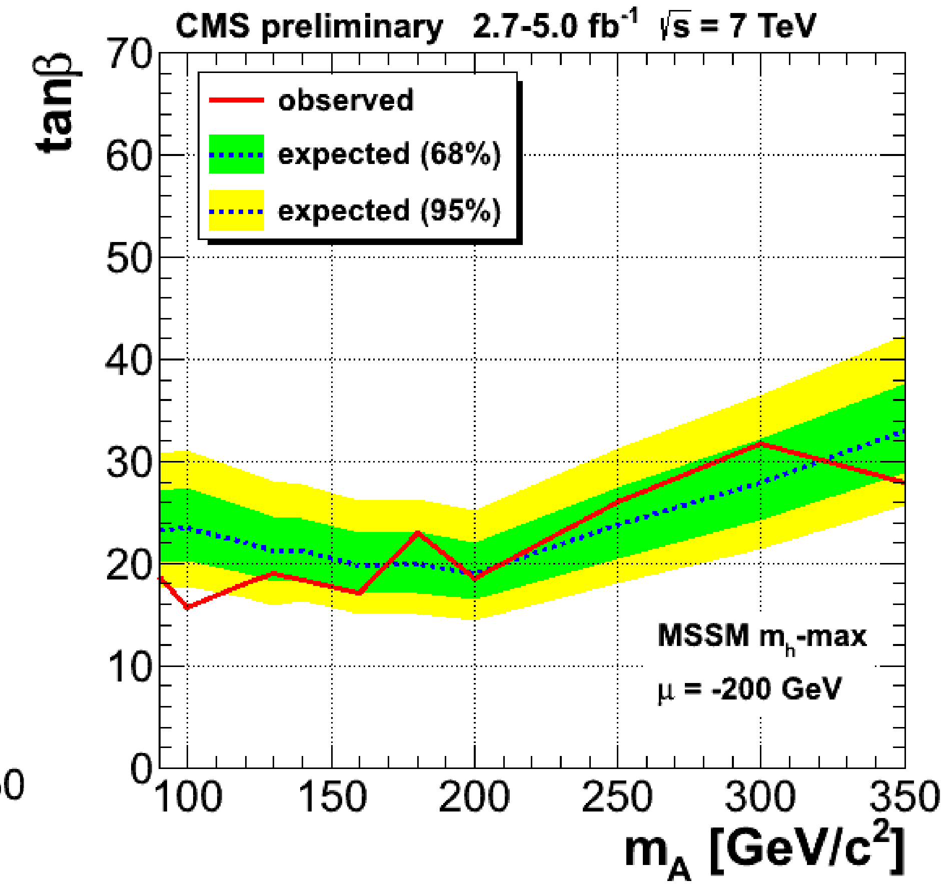
Background shape determined from two independent methods applied to 2- and 1-tag samples





Limits on MSSM $\phi(h, H, A) \rightarrow bb$

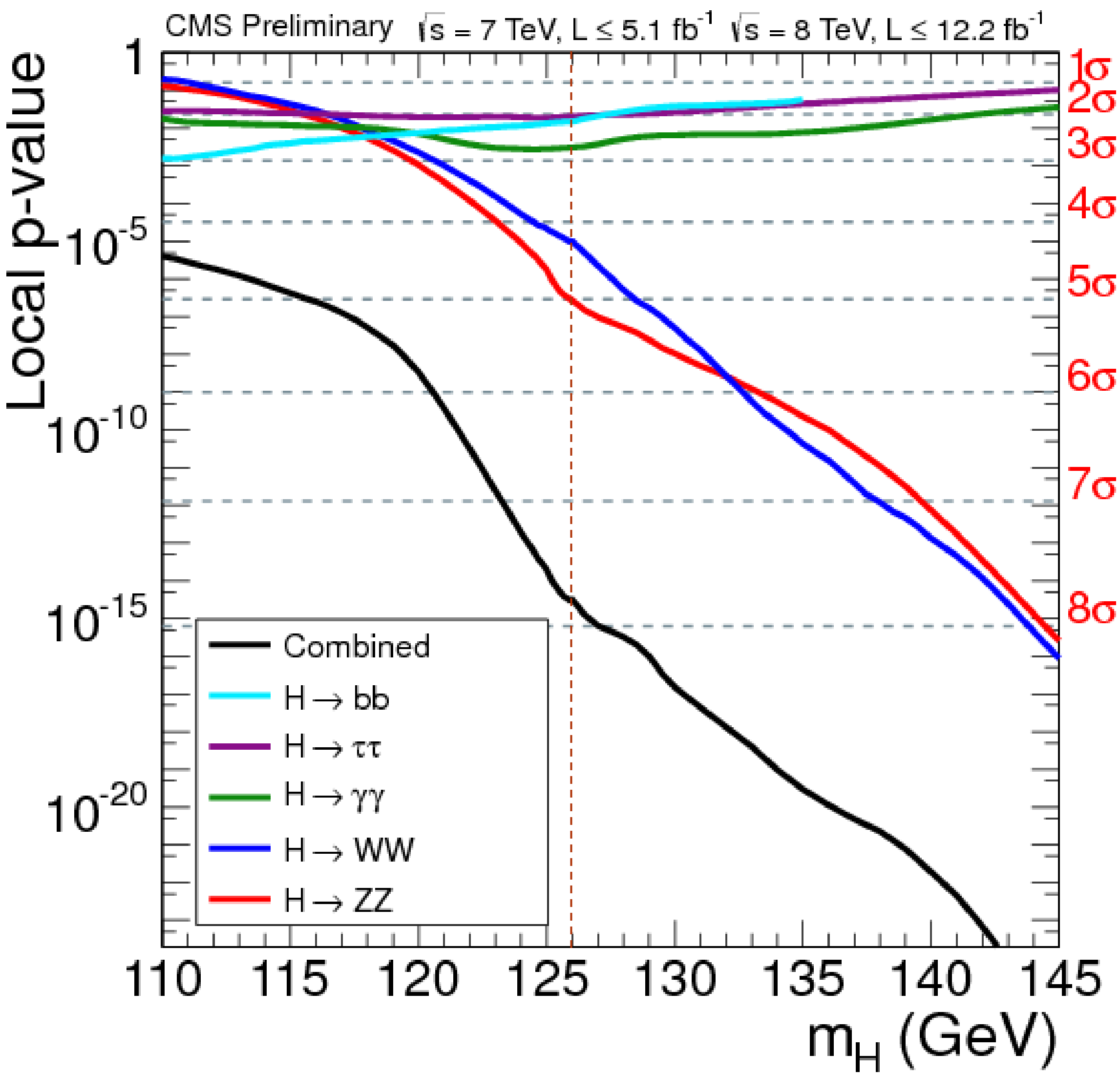




No evidence for CDF 2σ excess at low mass

Updated CMS Combination and Properties of the New Boson

CMS Sensitivity (Nov, 2012)

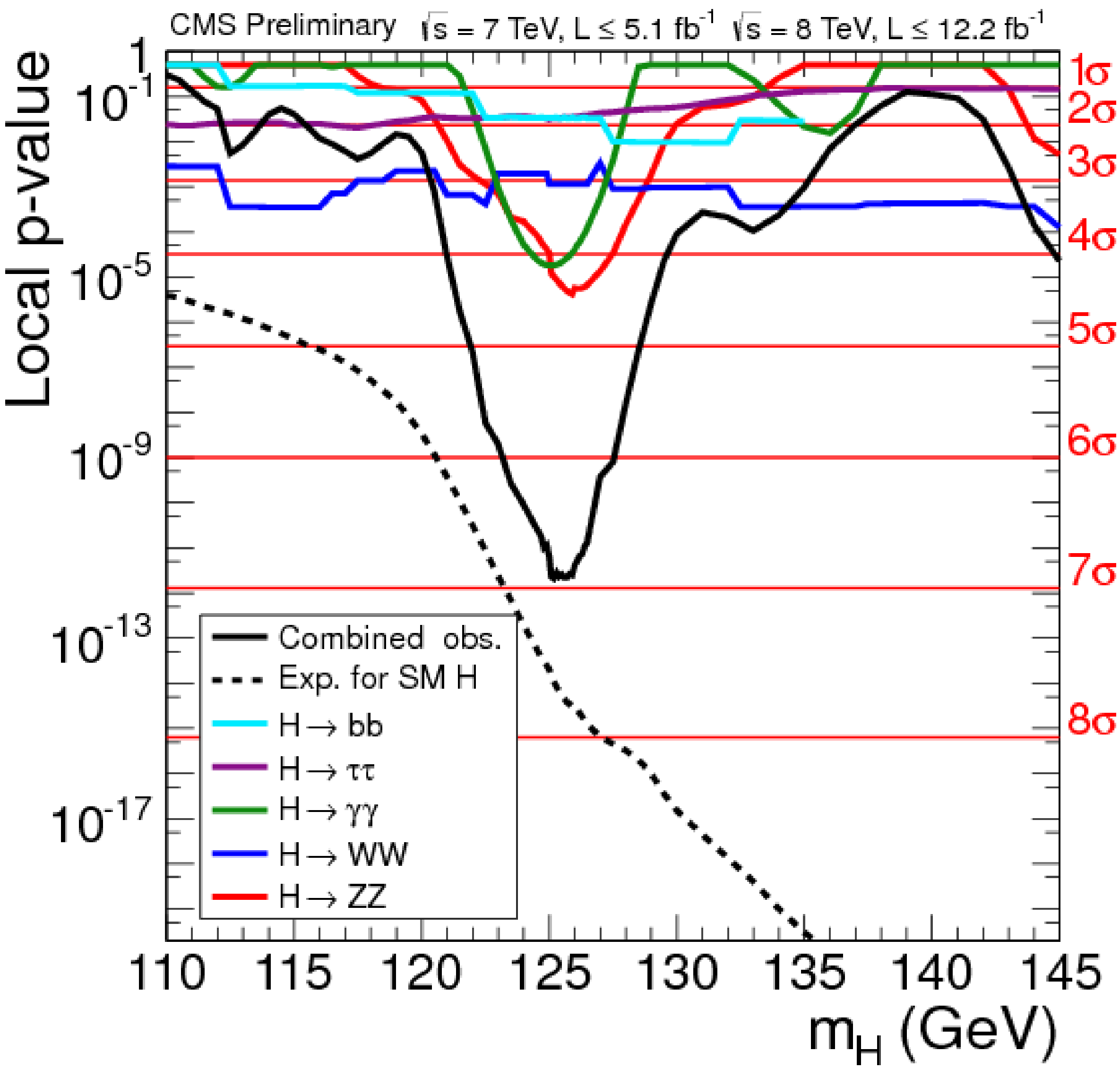


ZZ hits 5σ expected at ~126 GeV

WW close behind (γγ not updated @ HCP)

bb most sensitive channel below 118

Observed p-values



γγ: > 4σ @ 125 GeV

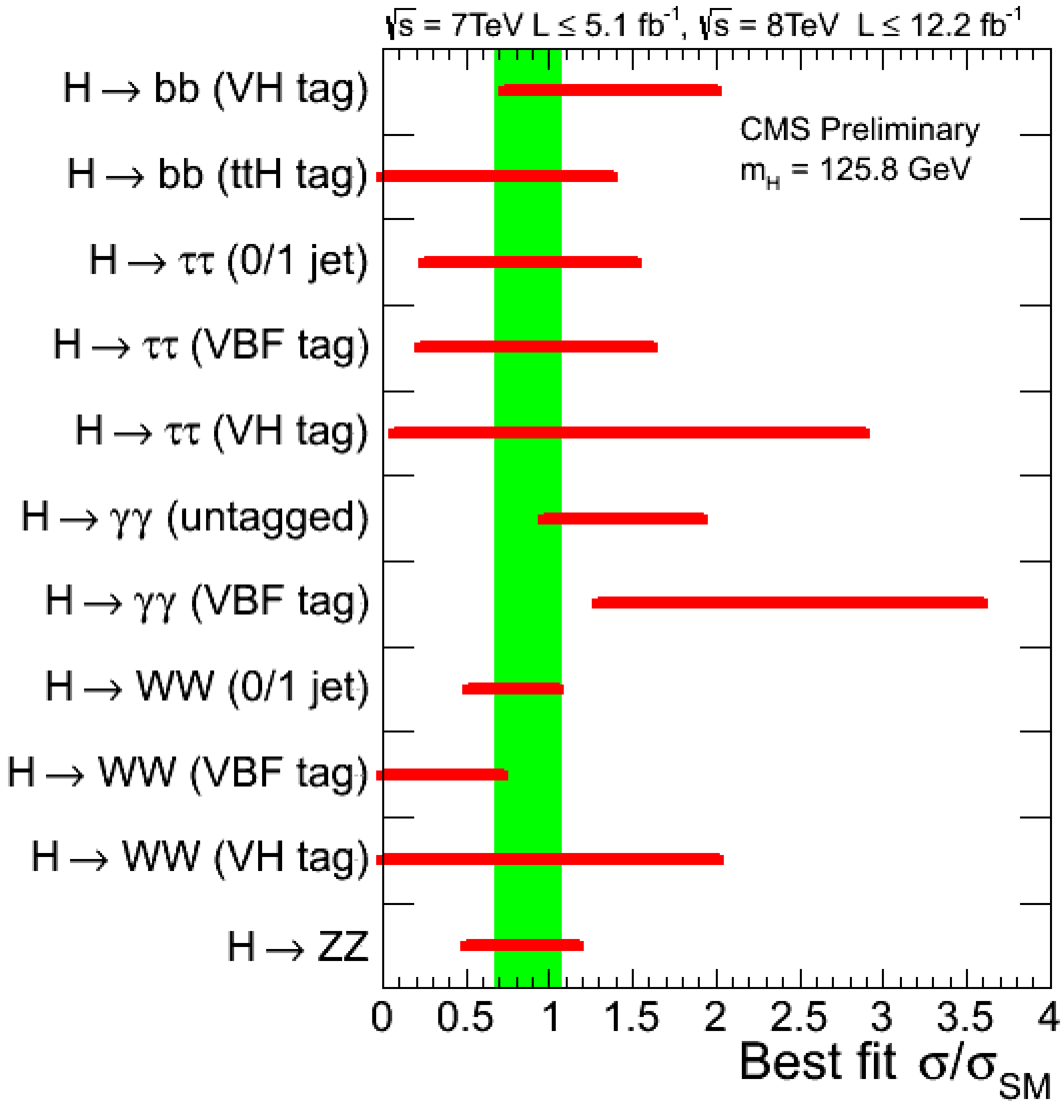
ZZ: > 4σ @ 126 GeV

WW: > 3σ ~everywhere

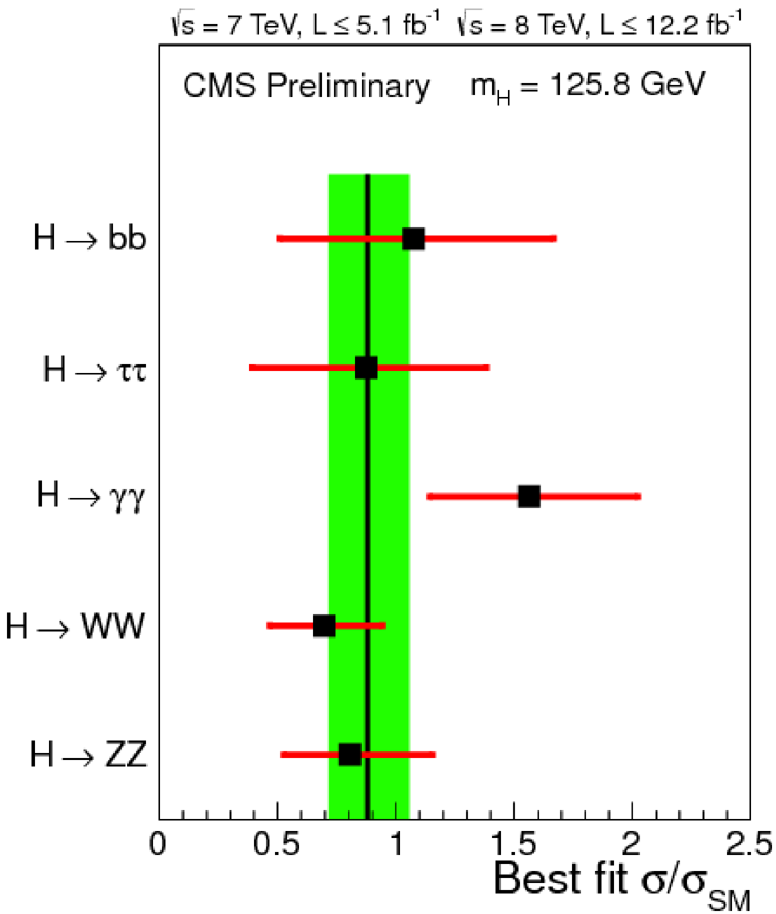
ττ: > 1-2σ ~everywhere

bb: > 2σ @ 125 GeV
(VH production only)

Signal Strength by Decay

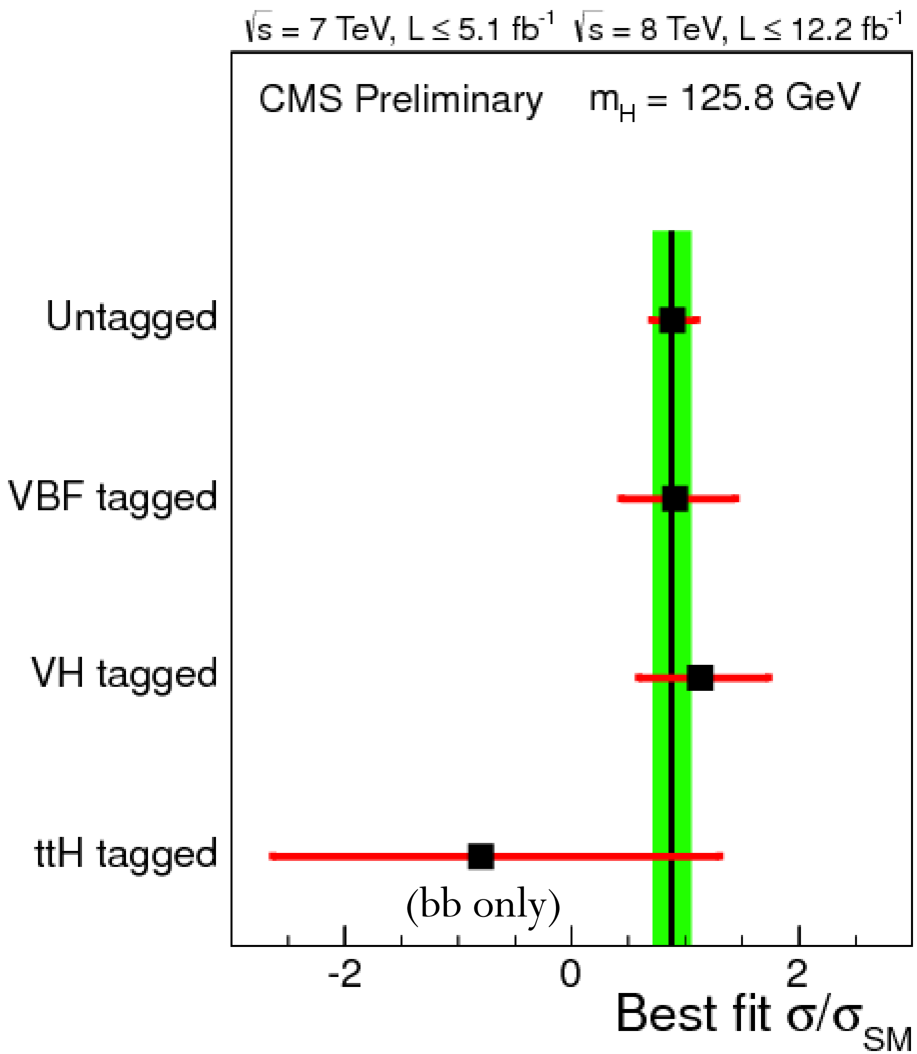


Integrating over production

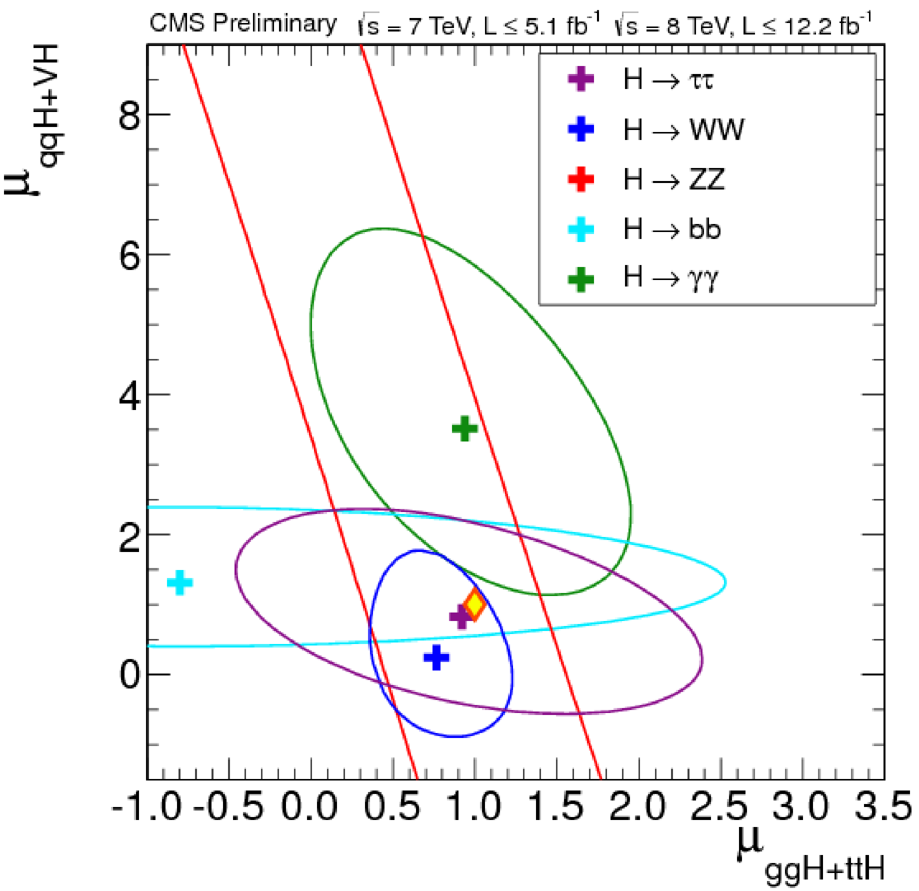


$$\mu = 0.9 \pm 0.2$$

Signal Strength by Production

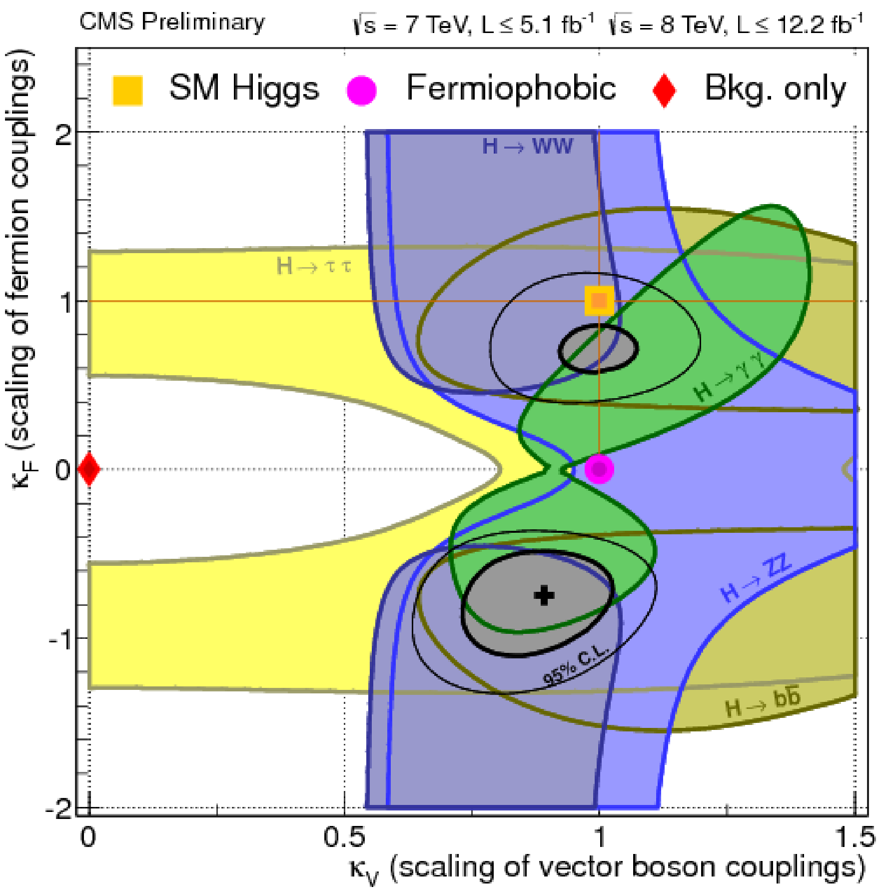


Production: boson vs. fermion

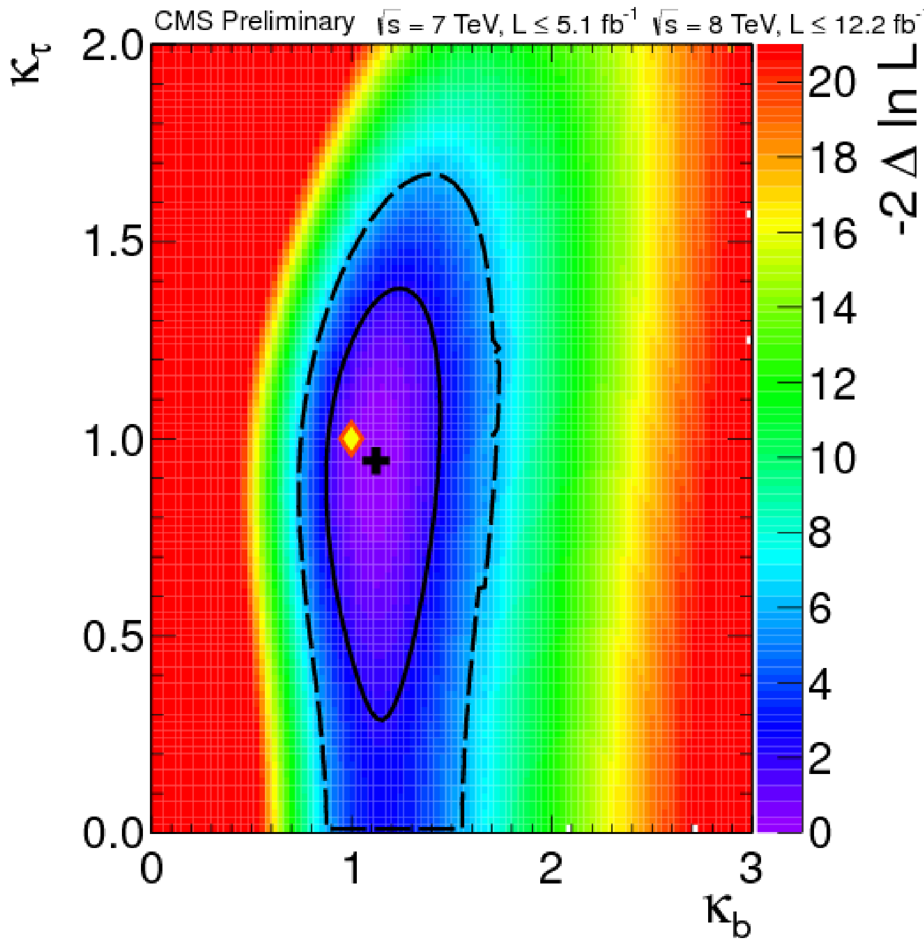


Couplings

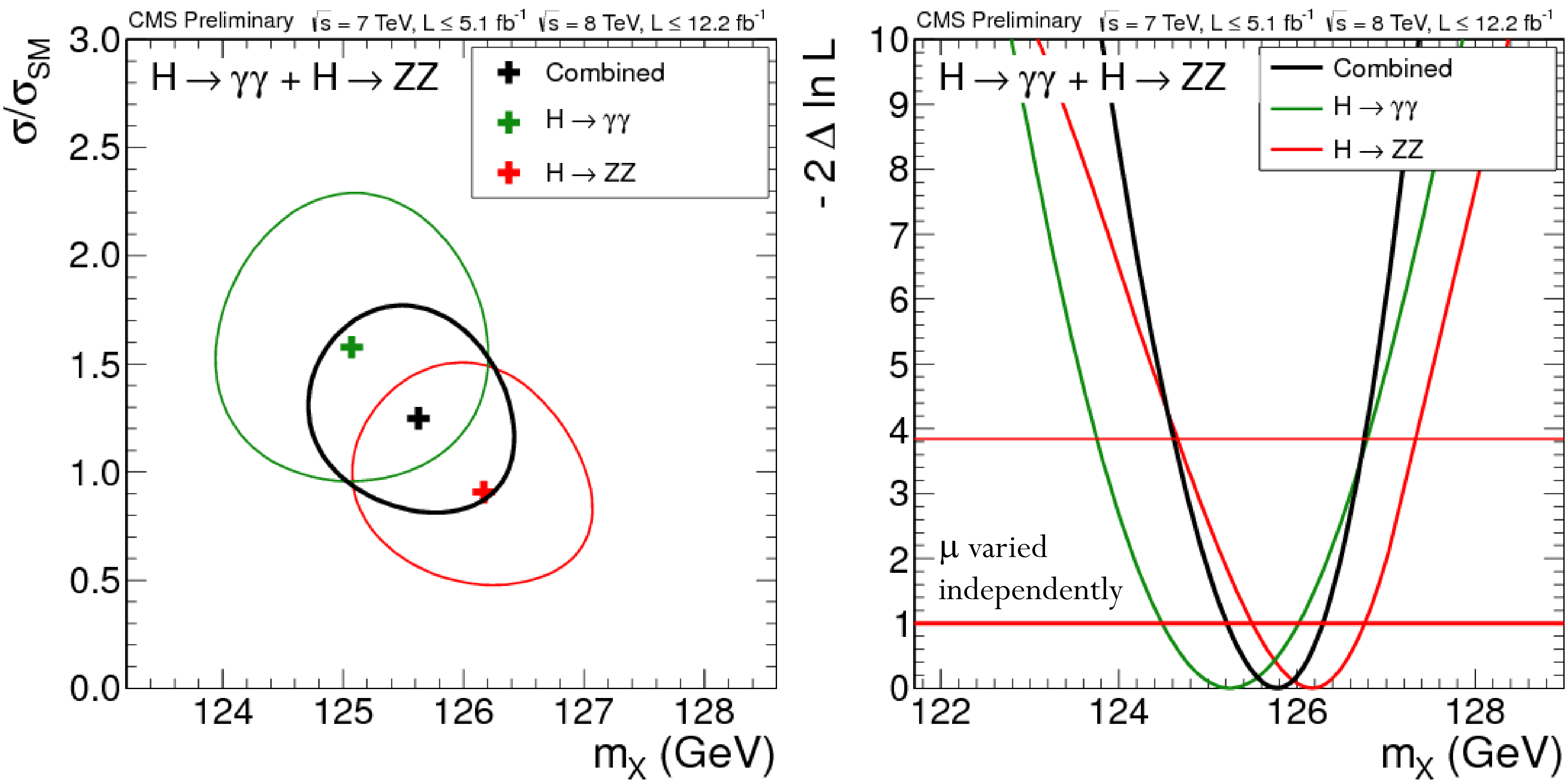
All



Tau vs. Bottom

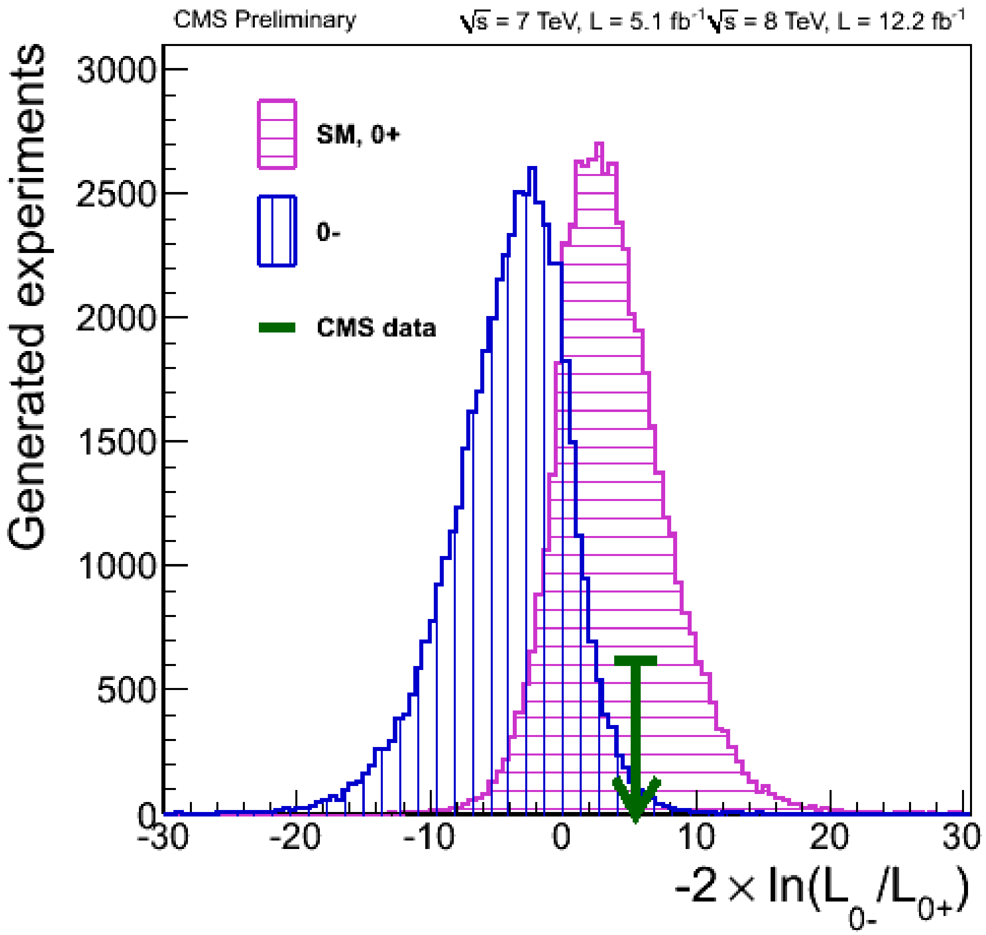


Mass from γγ and ZZ*



$$M_X = 125.8 \pm 0.4\ (\text{stat}) \pm 0.4\ (\text{syst})$$

Parity from ZZ*



From angular analysis (MELA) of the four-lepton final state, can separate scalar from pseudoscalar: exp ~ 2σ

Data consistency with $0^+ = 0.5\sigma$

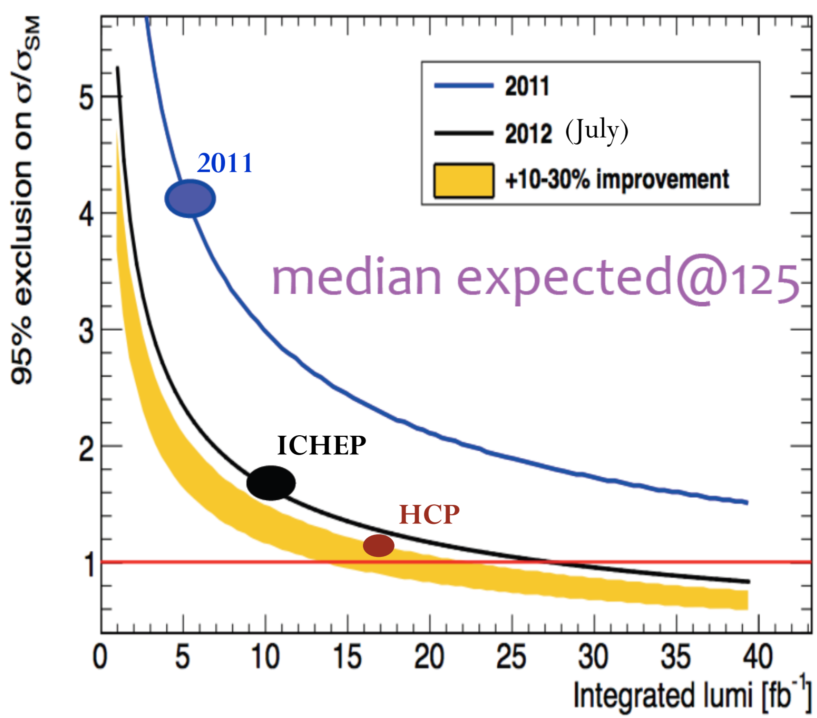
Data consistency with $0^- = 2.4\sigma$

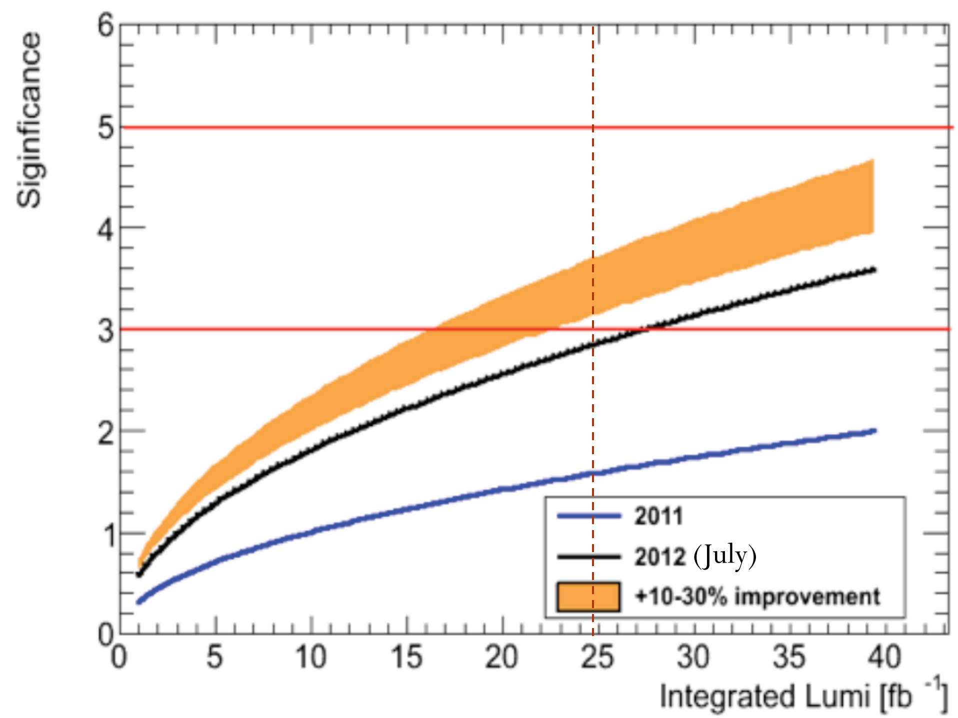
Current data favors SM hypothesis comparing against pseudoscalar alternative

Future Projections

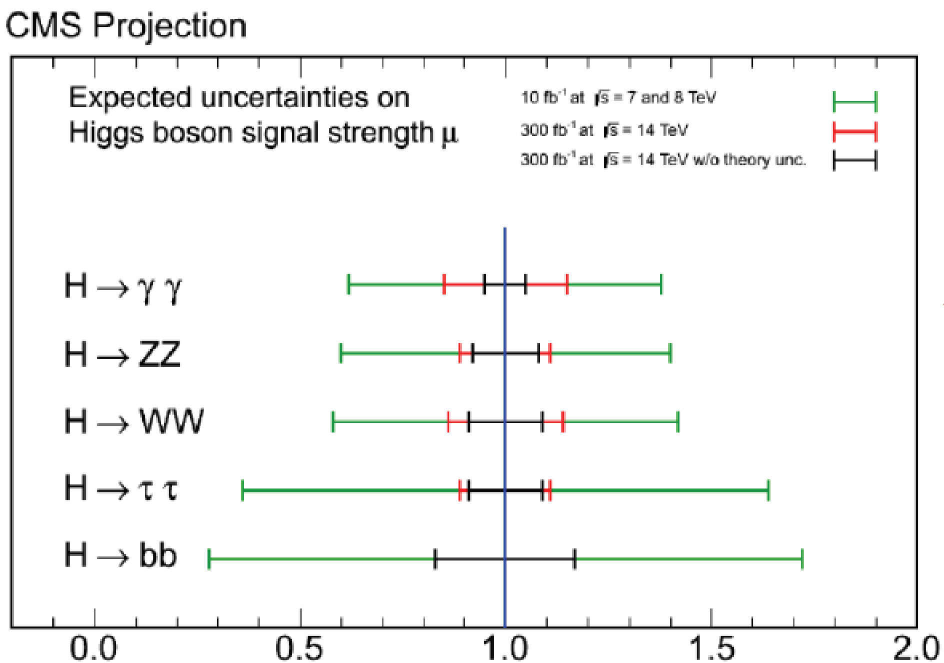
Bottom near future projections…

- VH(bb) ICHEP analysis improved 50% over 2011 analysis
- HCP analysis improved 10% over ICHEP analysis
- Goal: reach expected significance of at least **3σ** with the final 7+8 TeV data set (need another ~20% improvement)





CMS Future Projections



Signal Strengths:

10/fb (ICHEP)

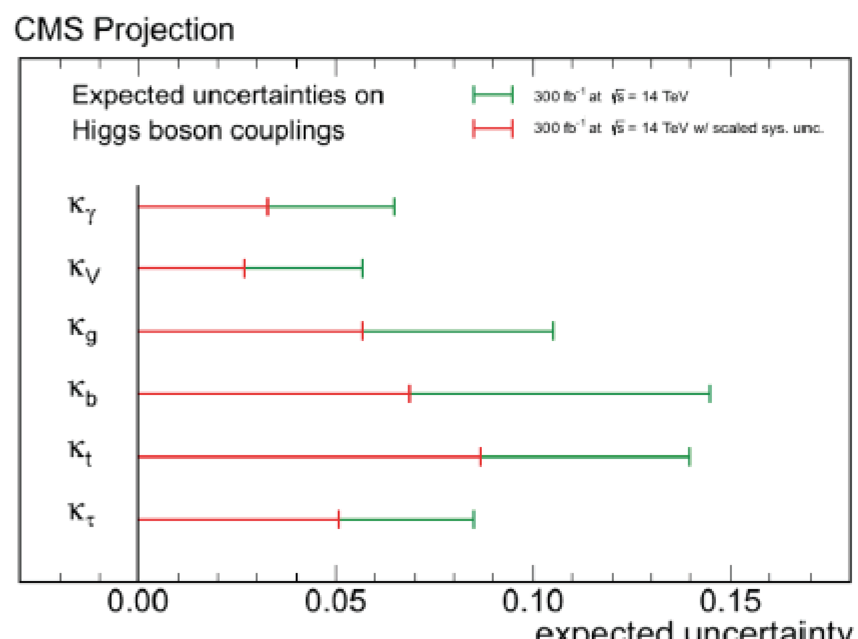
300/fb assuming same systematic uncertainties (exp and thy) as now

Removing theory uncertainties

Couplings:

300/fb with current uncertainties

300/fb with 0.5 x σ_{thy} and exp uncertainties scaled by luminosity



Conclusions

- The new particle @ "125 GeV" is observed to decay to all gauge bosons, mostly in the right proportion ($\gamma\gamma$ a little hot)
- Angular distribution in ZZ disfavors pseudoscalar hypothesis
- New results from CMS not yet conclusive, but moving to SM
  - $H \rightarrow \tau\tau$ observed significance = 1.5 σ
  - $H \rightarrow bb$ observed significance (VH) = 2.2 σ
- New CMS combination shows signal strength and couplings consistent with the SM expectation anyway you slice it
- No sign of (any of) the MSSM Higgs bosons
- **Future projections (30 → 300/fb):**
  - VH(bb) hoping to reach 3σ on the final 7+8 TeV data set
  - 5 – 10% on CMS combined signal strength
  - Few % – 15% on couplings