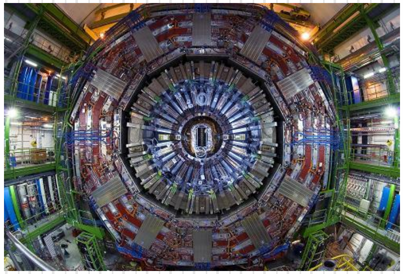
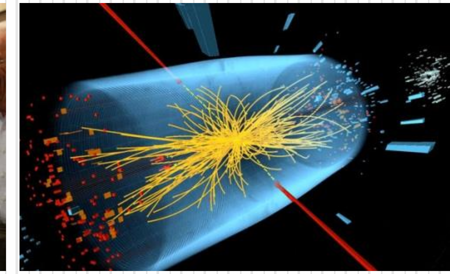
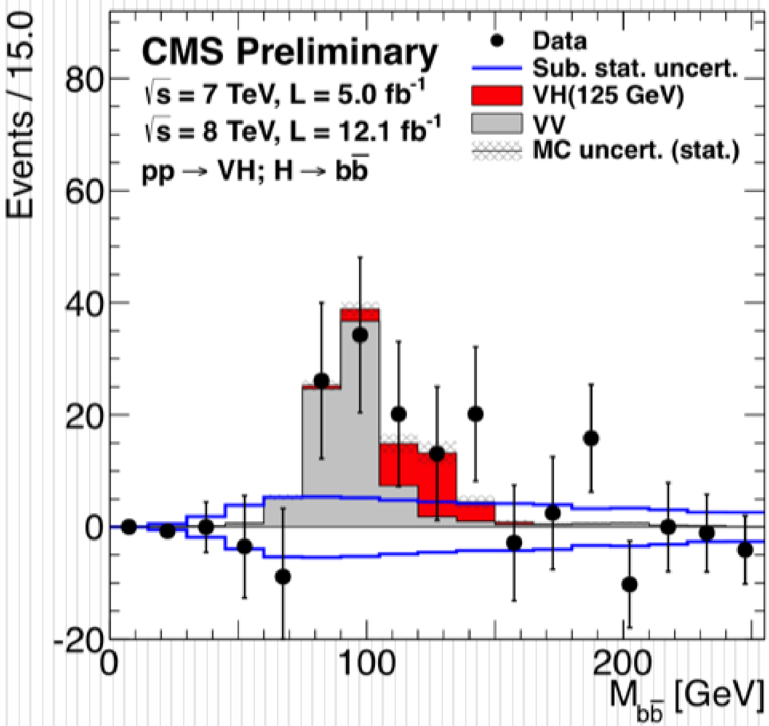


H → bb status and future @ CMS



Jim Olsen

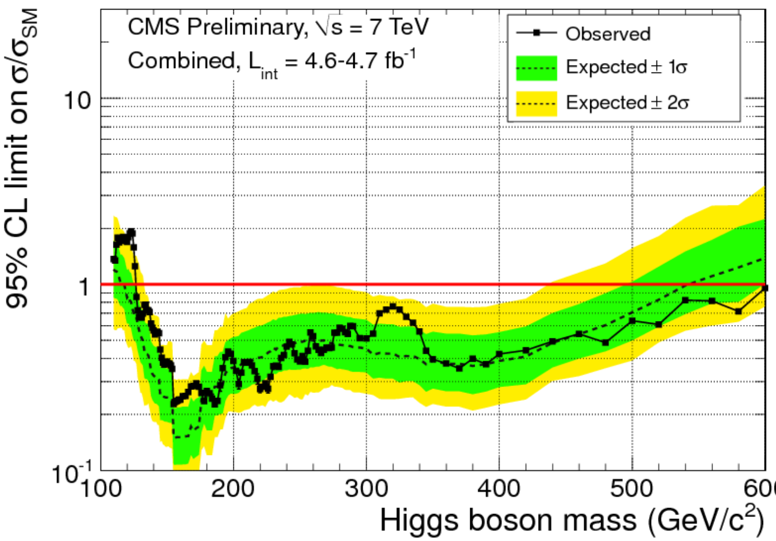
Princeton University

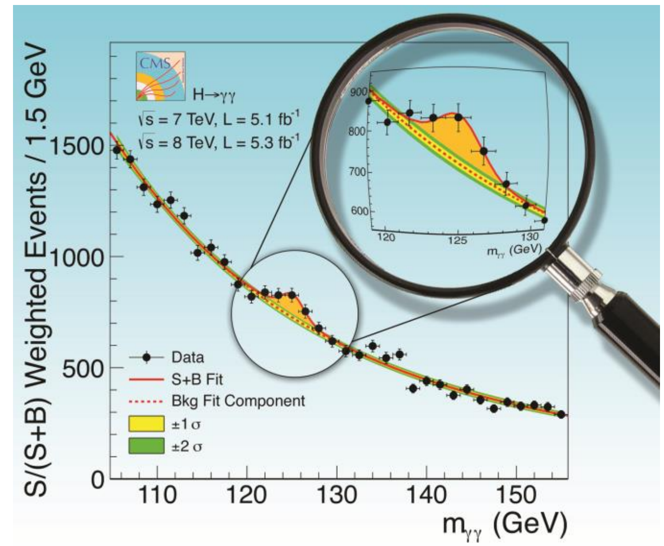
PCTS Workshop:
"Higgs Physics after Discovery"

April 25, 2013

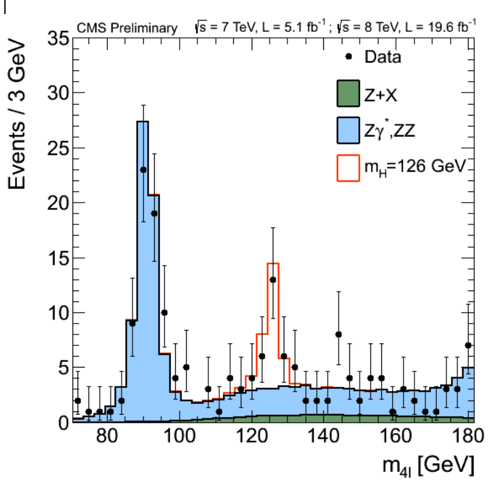
Higgs Discovery Timeline

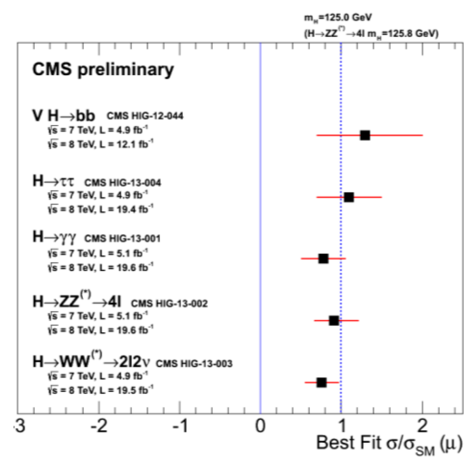
From drops in a bucket (Dec. 2011), to discovery of a "Higgs-like particle" (July 2012),

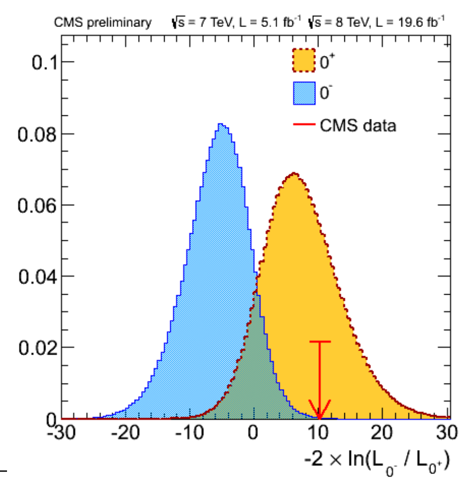


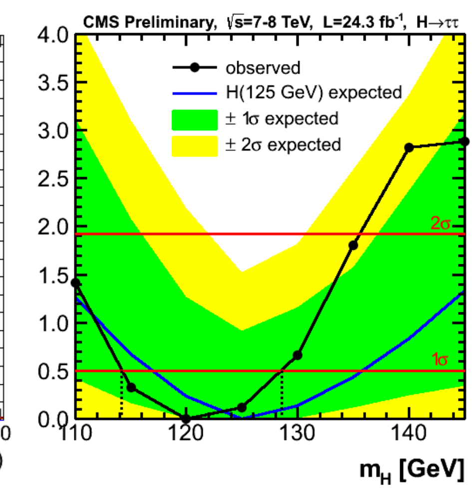


to confirmation of "a Higgs boson" (March, 2013):

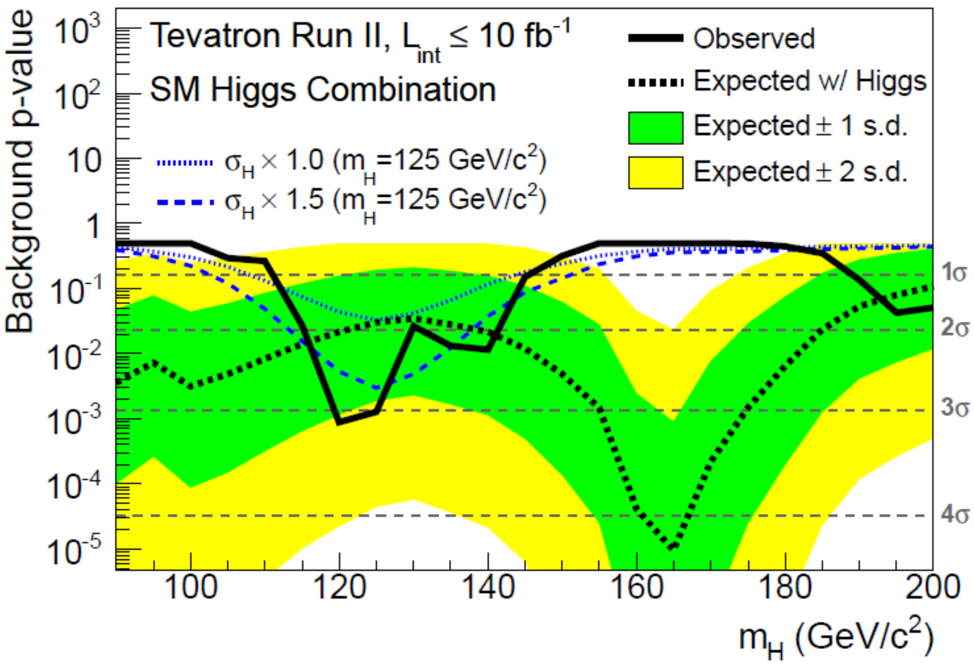


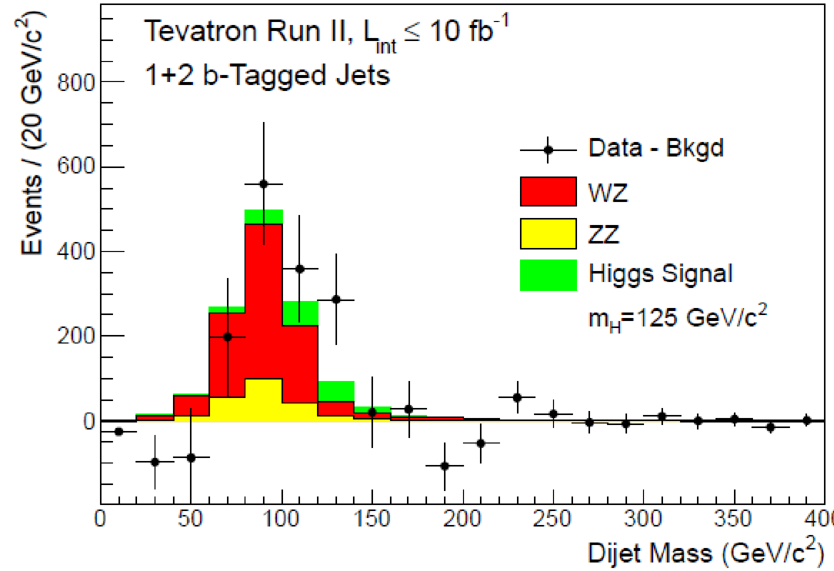




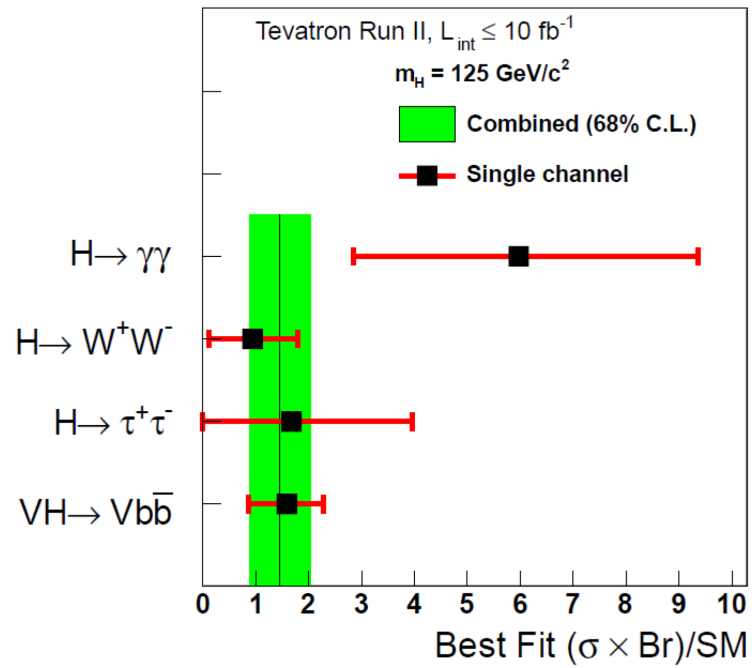


Higgs at the Tevatron





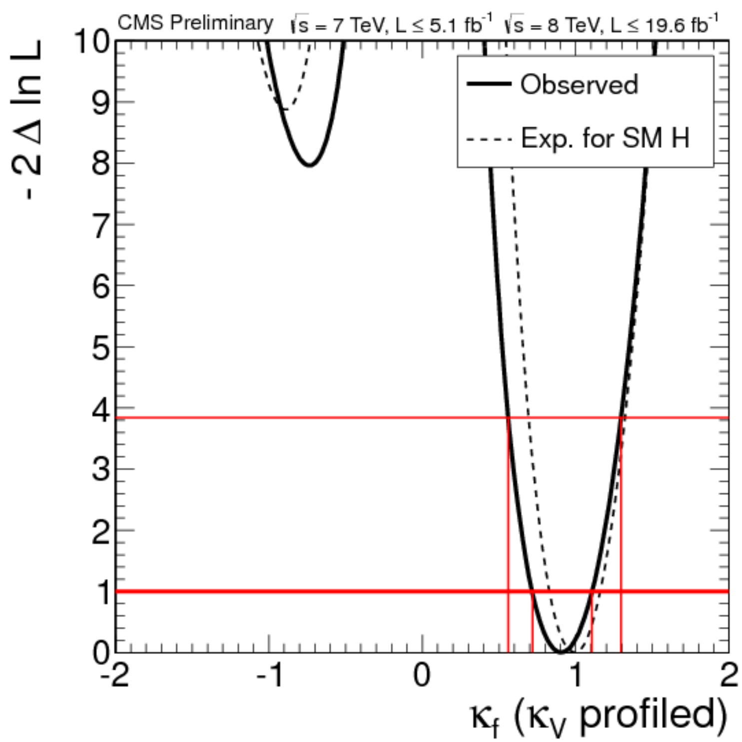
@ mH = 125 GeV, 3.1σ evidence (for bb alone: μ/μ_{SM} = 1.6, came down significantly since last summer)

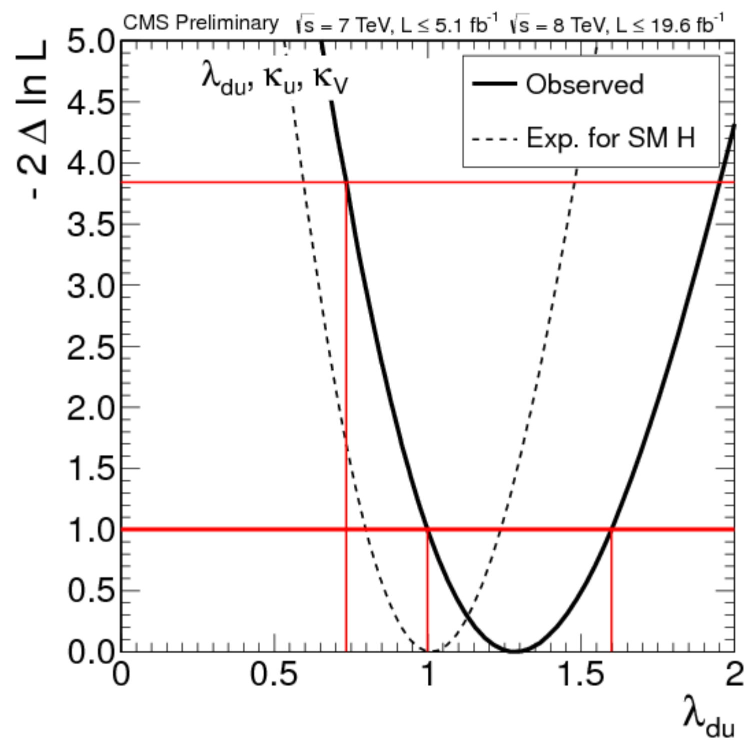


Fermions at CMS: current status

	Significance (m_H = 125.7 GeV)		
Combination	Expected (pre-fit)	Expected (post-fit)	Observed
H ZZ	7.1	7.1	6.7
H	4.2	3.9	3.2
H WW	5.6	5.3	3.9
H bb	2.1	2.2	2.0
H	2.7	2.6	2.8
H→ ττ and H bb	3.5	3.4	3.4

2.8σ in ττ alone, 3.4σ combining fermions





VHbb @ LHC

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

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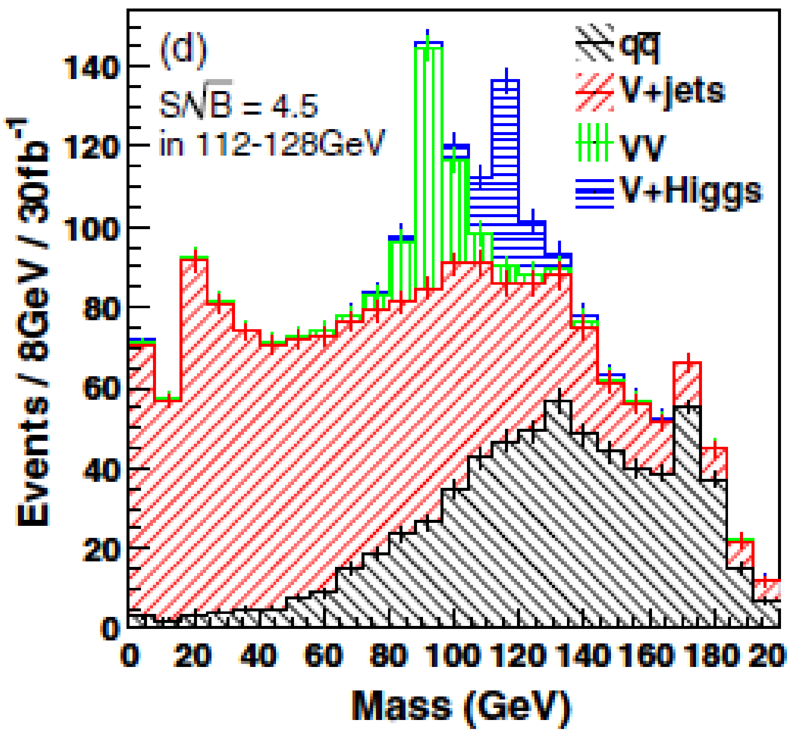
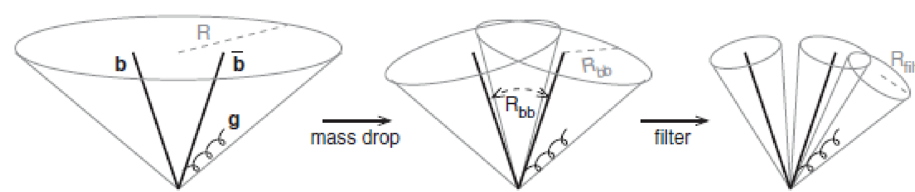
LPTHE; UPMC Univ. Paris 6; Univ. Denis Diderot; CNRS UMR 7589; Paris, France

(Received 2 March 2008; published 18 June 2008)



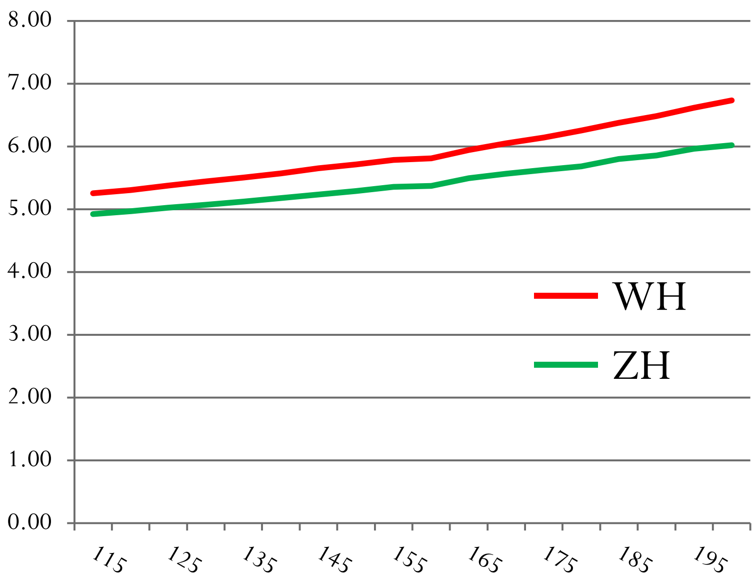
Features:

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

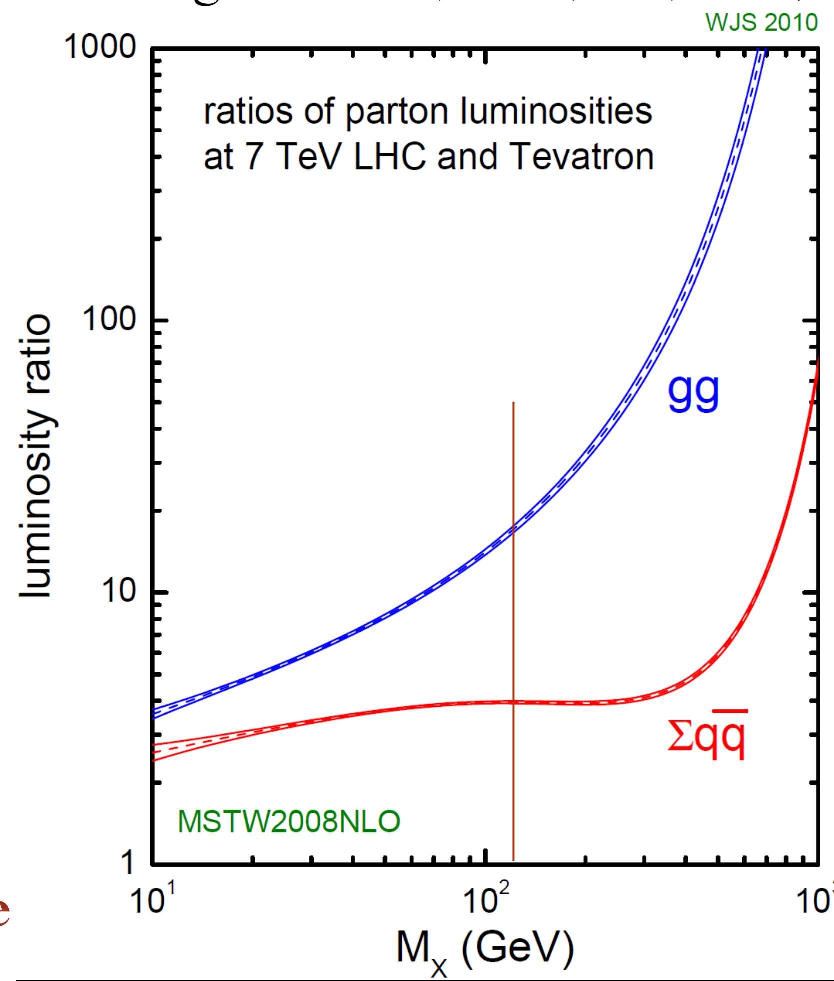


VH Production: LHC vs. Tevatron

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



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

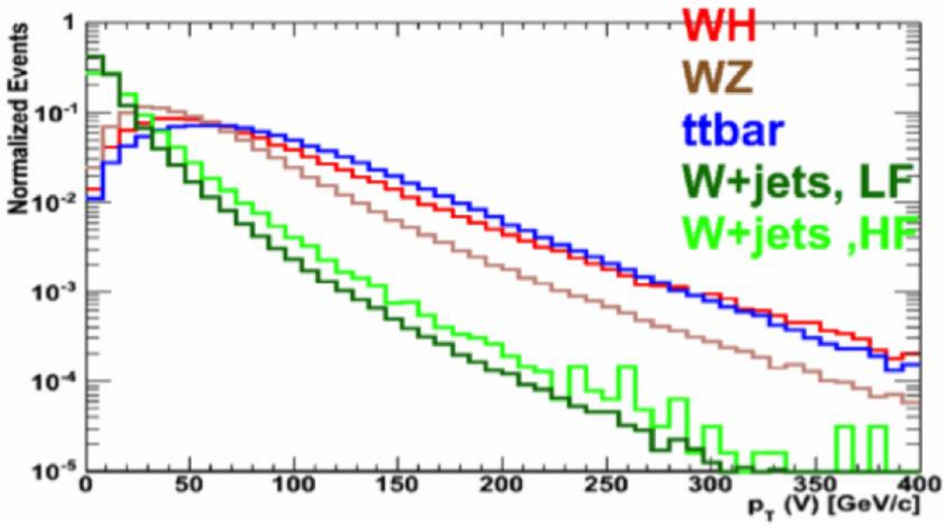


Signal increases ~5x

Gluon-initiated bkg increases >~ 20x

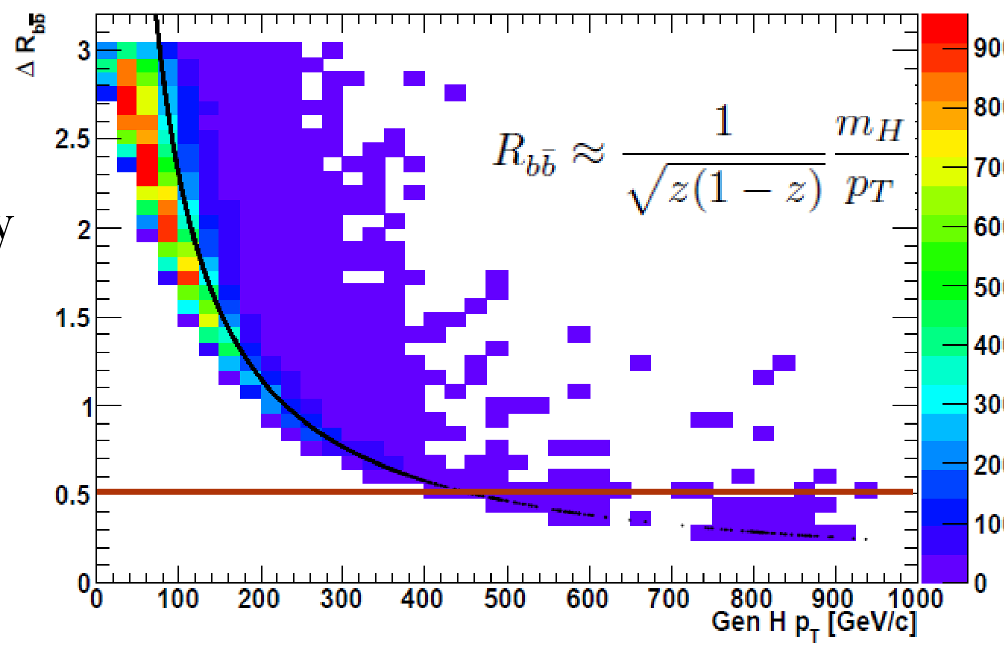
Still challenging at LHC, but more cross section to burn → boost

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 @ 14 TeV

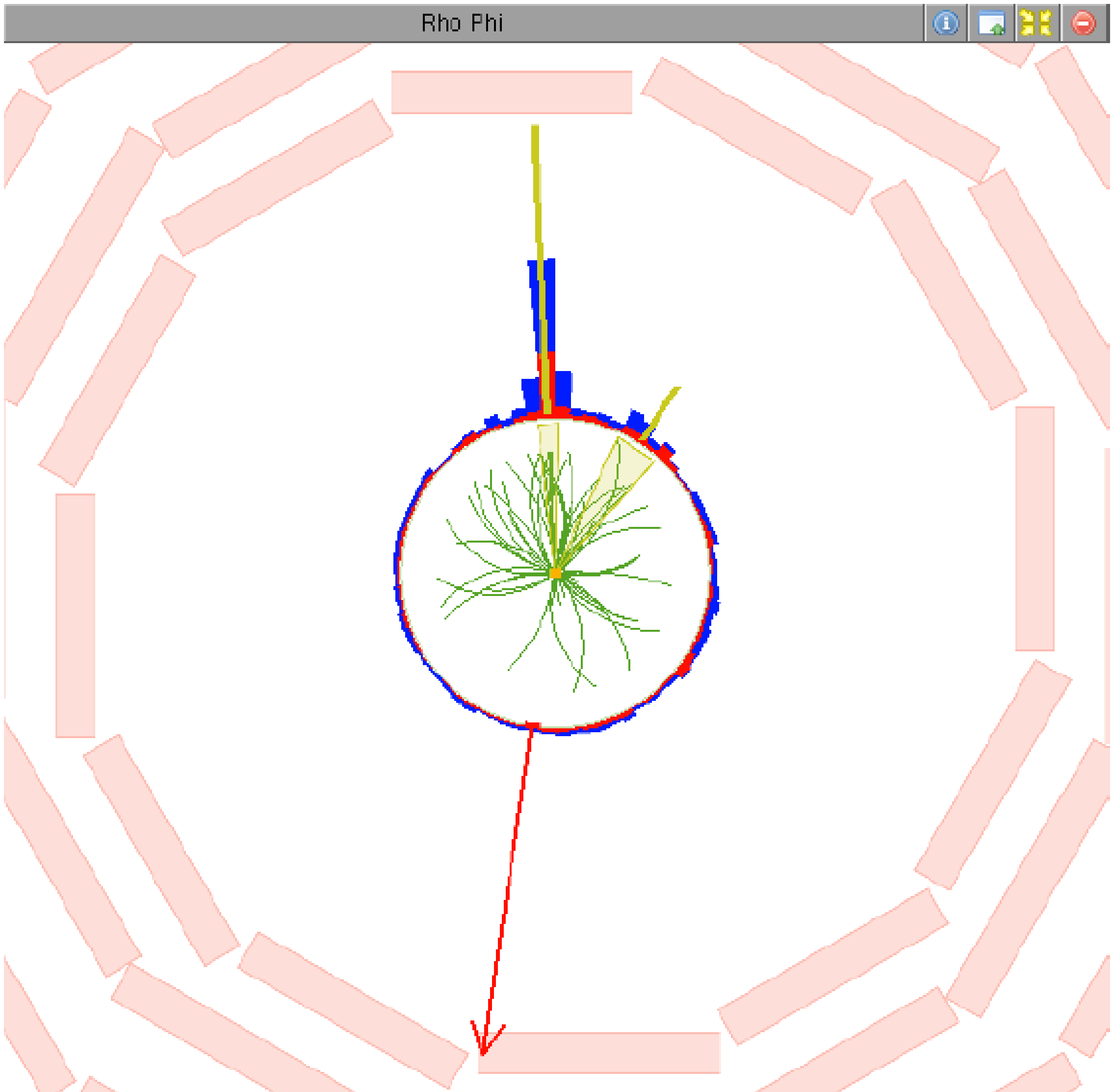
Analysis strategy @ CMS (I)

- **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)
  - **All primary triggers remained unprescaled in 2012**
- **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 @ CMS (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

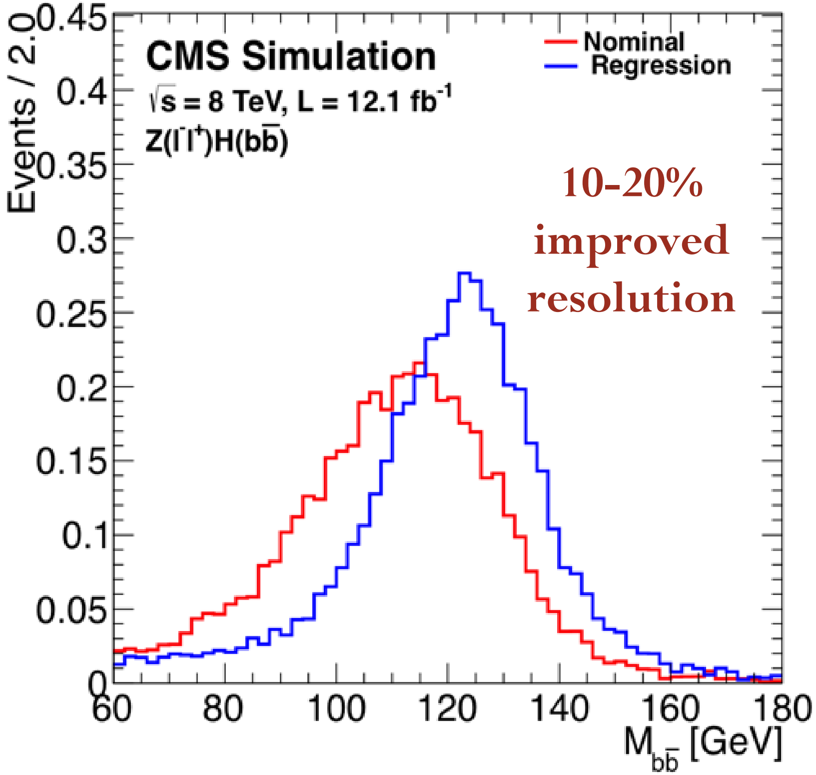
$Z(\nu\bar{\nu})H(b\bar{b})$ candidate

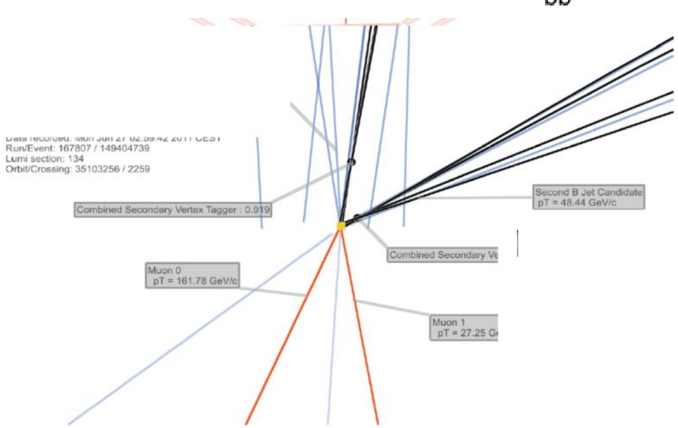


PD: /MET/Run2011B
Run: 177183
Lumi: 183
Event: 305295270

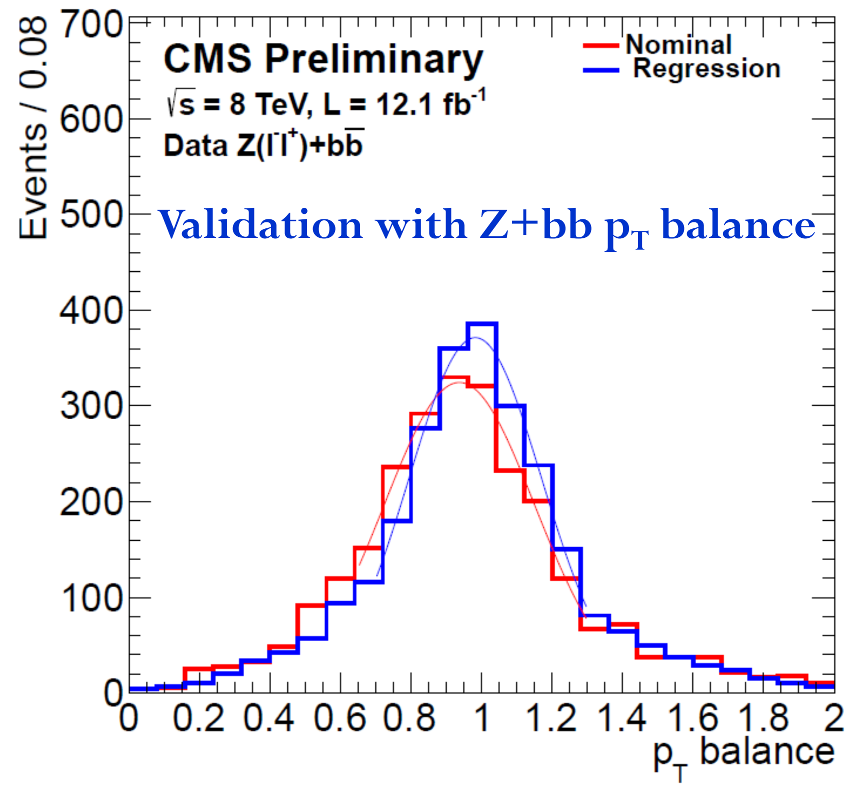
- M(jj) = 120.0 GeV
- p_T(jj) = 248.4 GeV
- Jets:
  - p_T = 209.5 GeV, CSV = 0.889
  - p_T = 46.2 GeV, CSV = 0.957
- MET:
  - 243.2 GeV

B-jet Energy Regression

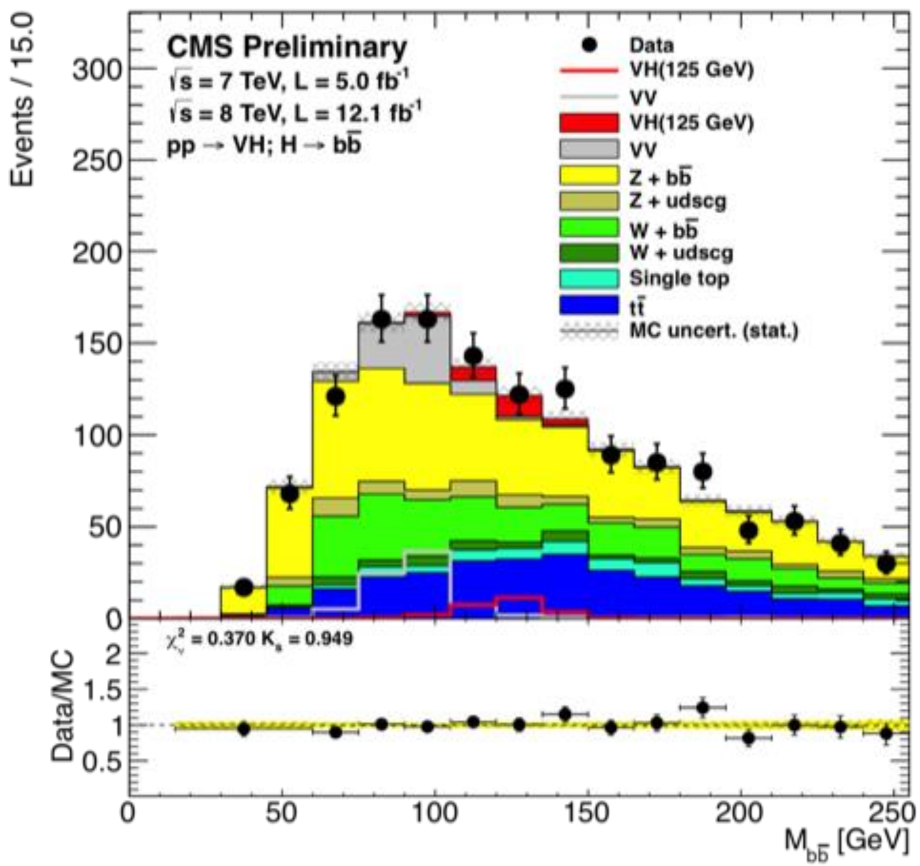


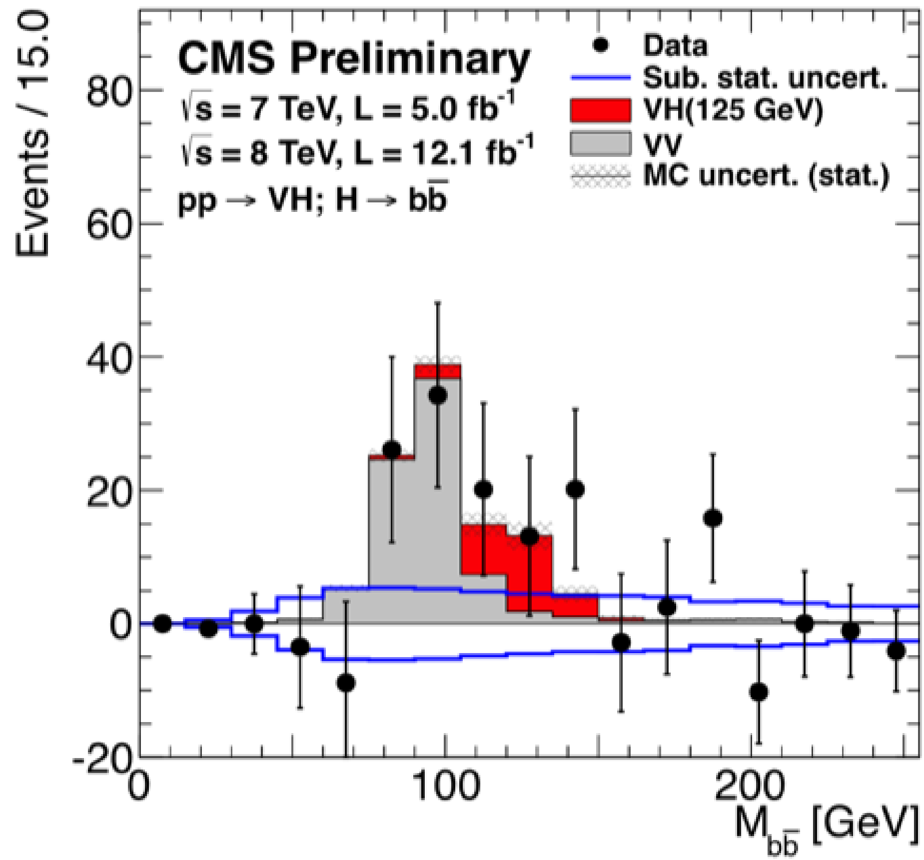


Use information about the jet energy and b-jet characteristics in a BDT regression to improve energy resolution (a la CDF)



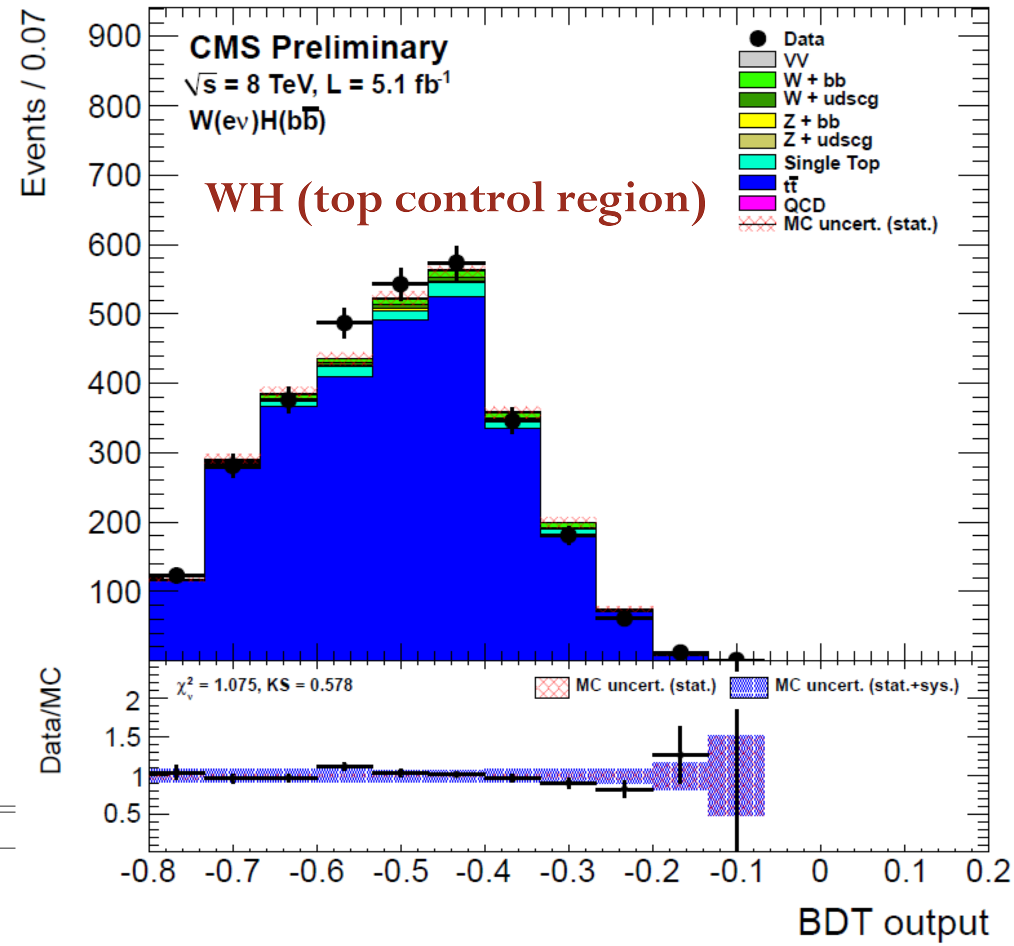
Standard Model Boosted VV Signal





Already from non-optimized M(jj) plot: a clear VV(+VH) peak above SM backgrounds. Optimized analysis in progress (exp > 6σ)

BDT discriminant

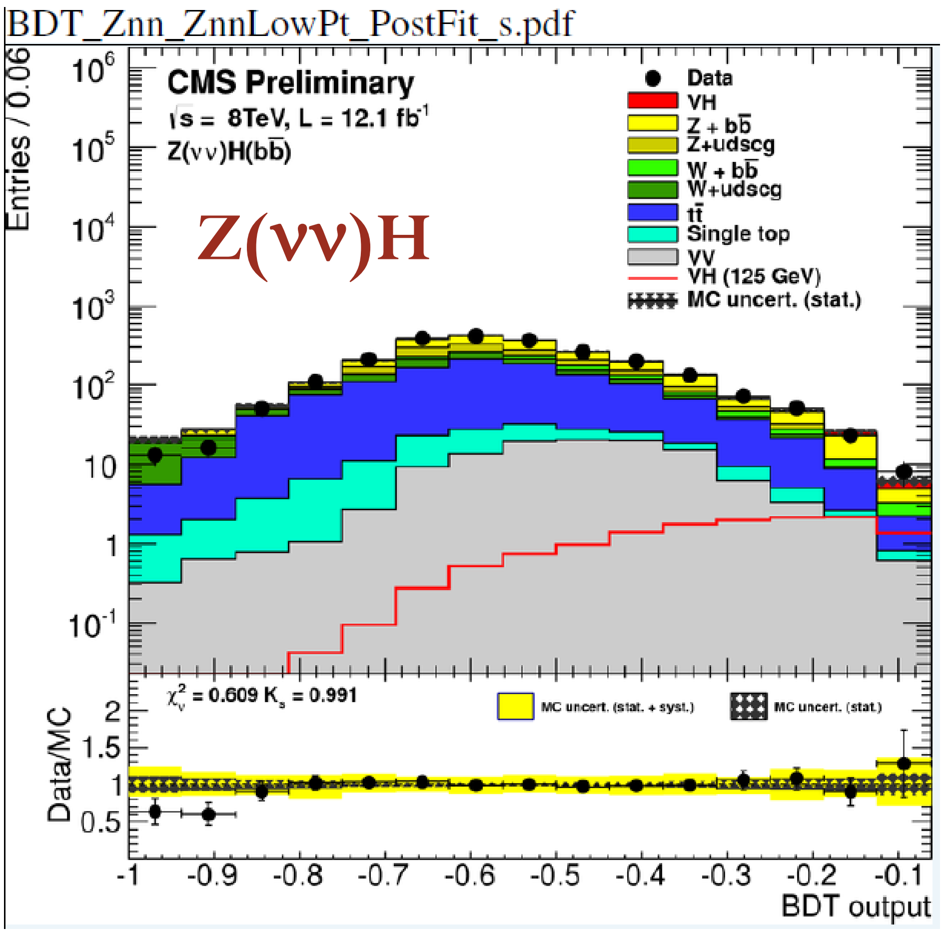


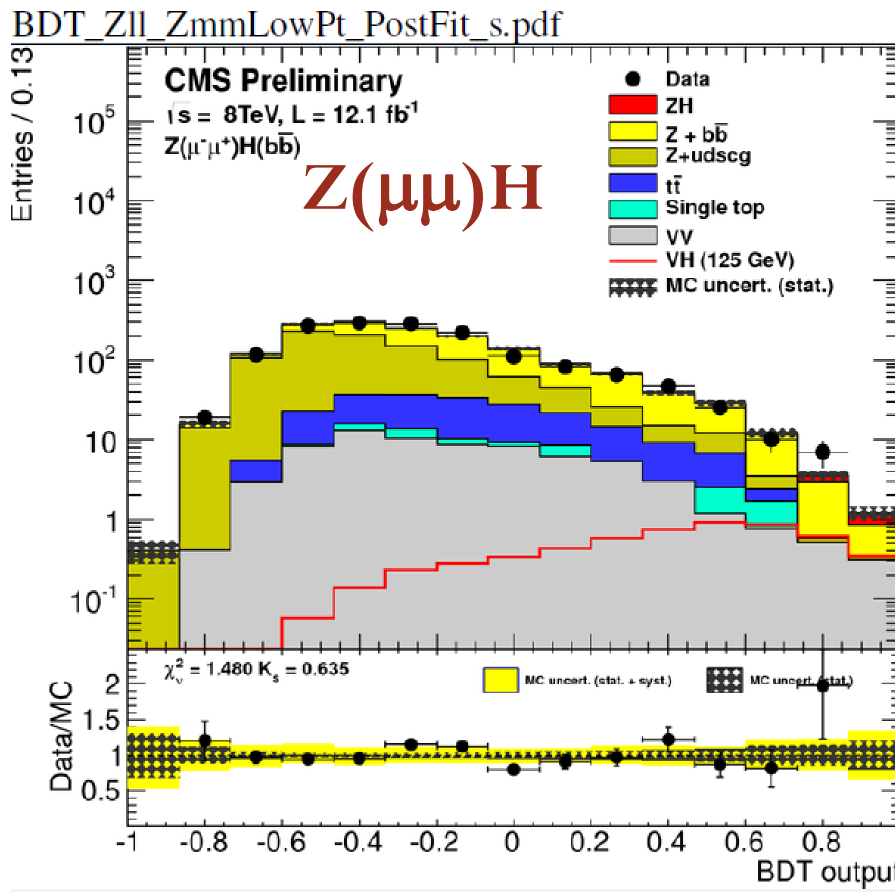
Combine kinematic, topological, b-tagging, and color flow variables into BDT, separately for high and low pT bins

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

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

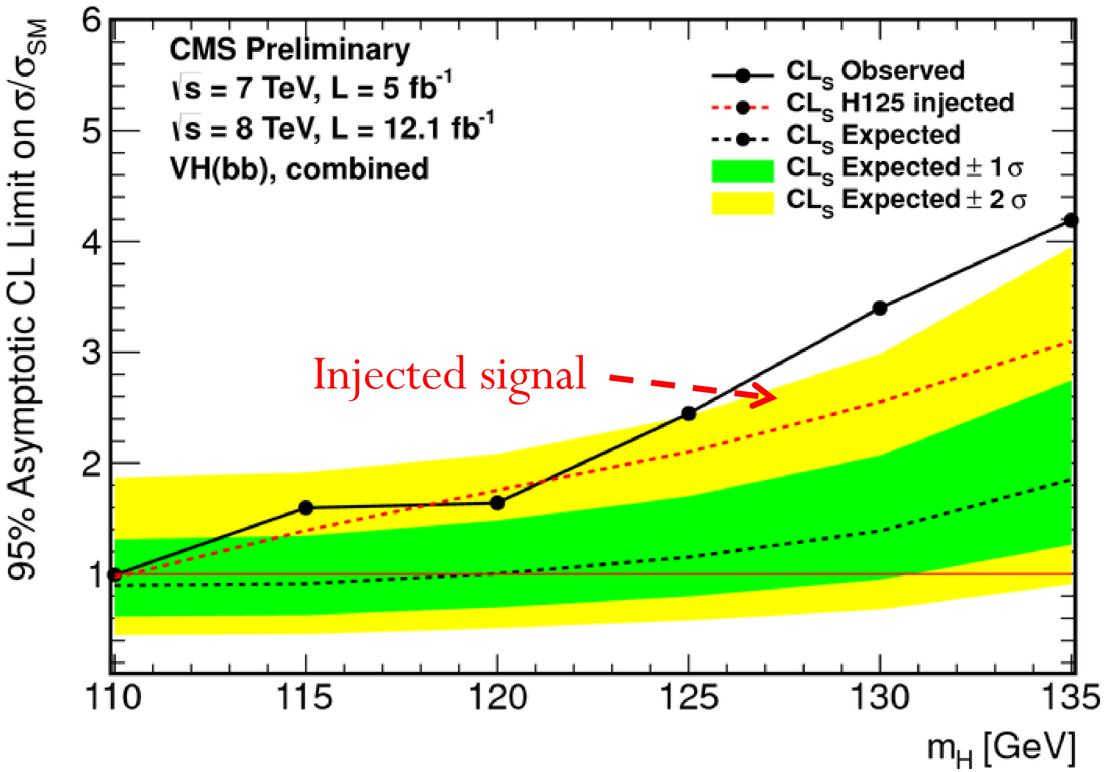
Example BDT shapes in signal region

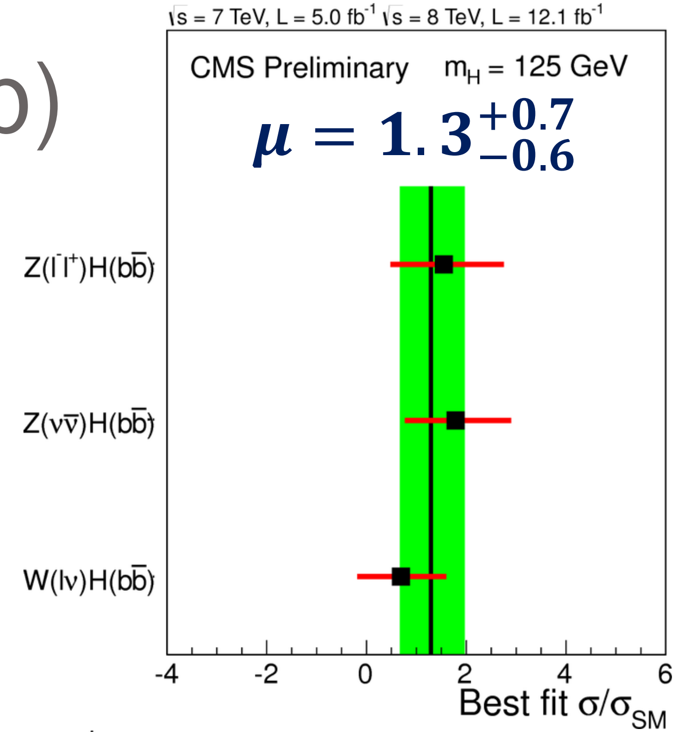


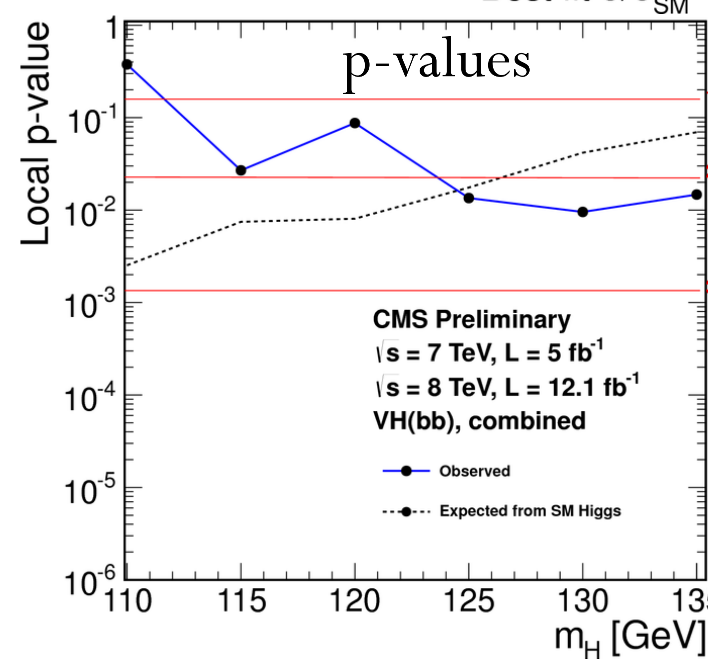


All shape comparisons look good, data consistent with background-only hypothesis

Results: 7 + 8 TeV (17/fb)







@125 GeV:

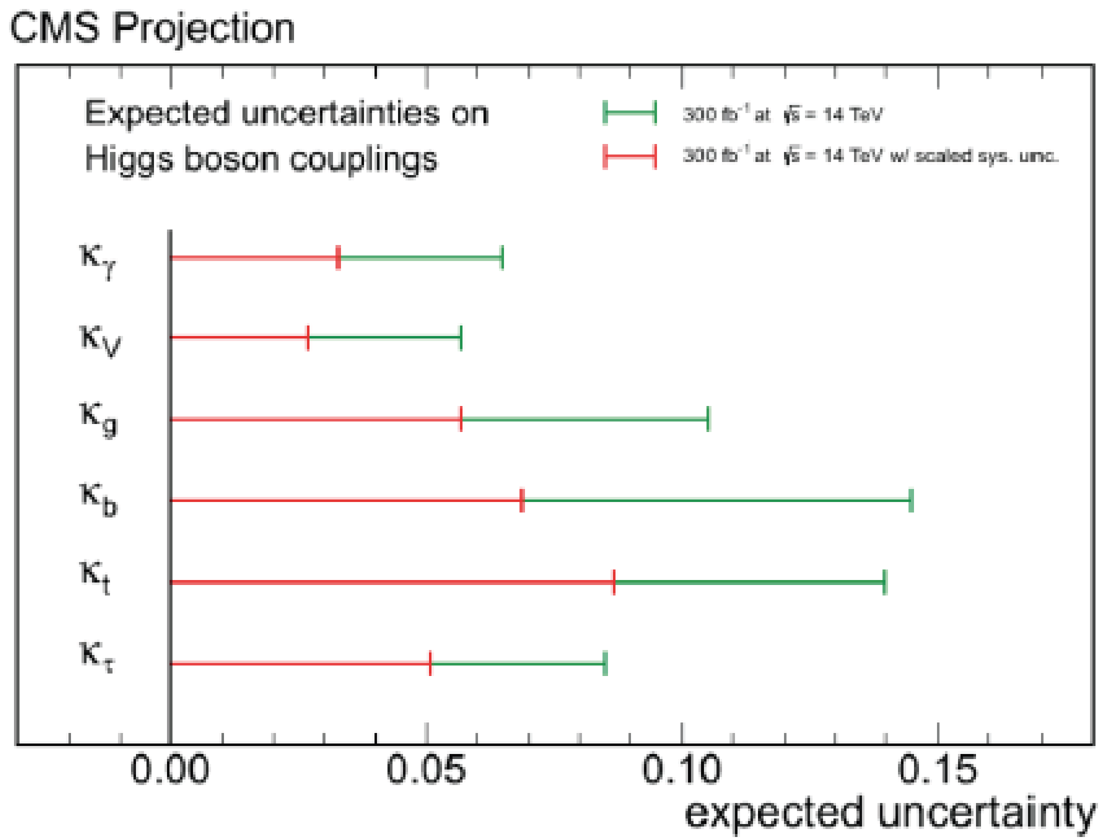
exp (obs) limit = 1.15 (2.45) x SM

exp (obs) significance = 2.1 (2.2) σ

CMS Future Projections (ESPG report)

Phase 1:

- 14 TeV
- 300/fb



Two scenarios:

1) With current systematic uncertainties [$\sigma(\kappa_b) = 15\%$]

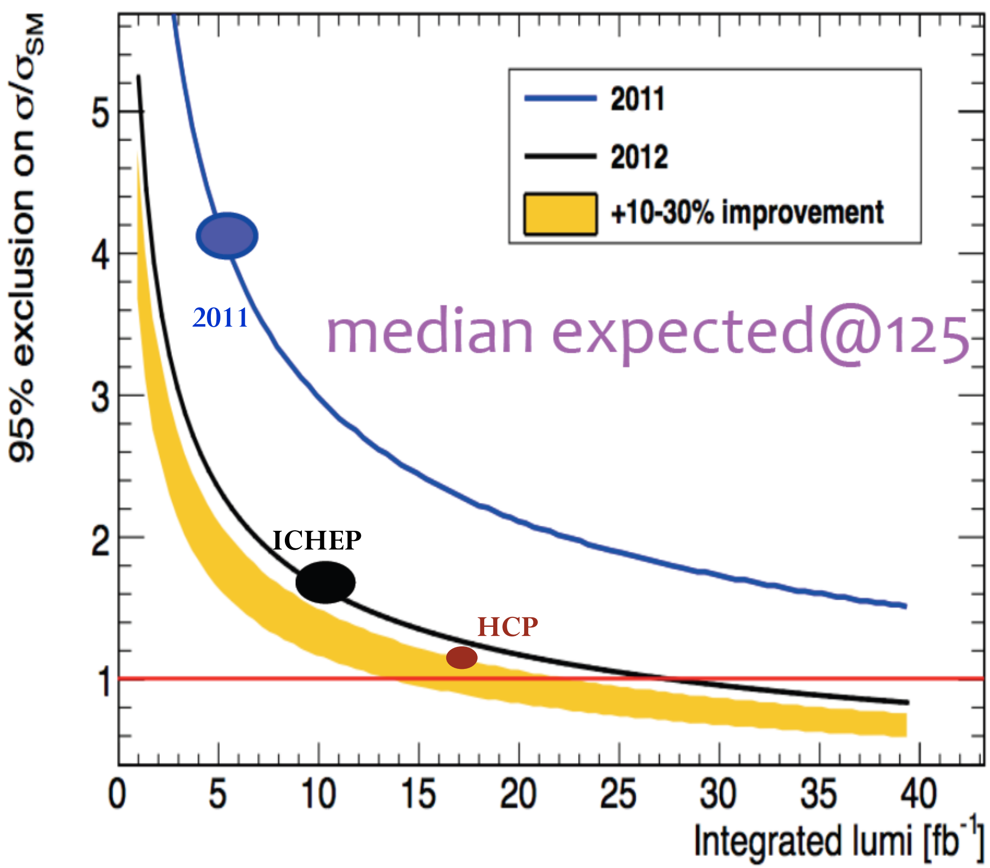
2) 300/fb with 0.5 x σ_{thy} and exp unc $\propto 1/\sqrt{L}$ [$\sigma(\kappa_b) = 6.9\%$]

How reasonable is Scenario 2 for VH(bb)?

Will start to be limited by knowledge of Γ_{bb} (~3%)

Evolution of VHbb Results

- VH(bb) ICHEP analysis improved 50% over 2011 analysis
- HCP analysis improved 10% over ICHEP analysis



Significant gains in analysis sensitivity **even as PU increased by 2x (~10 → ~20)**

Critical charged lepton triggers remained stable and unprescaled through 2012

Higher energy could enable additional analysis gains that might offset higher PU (to be studied)

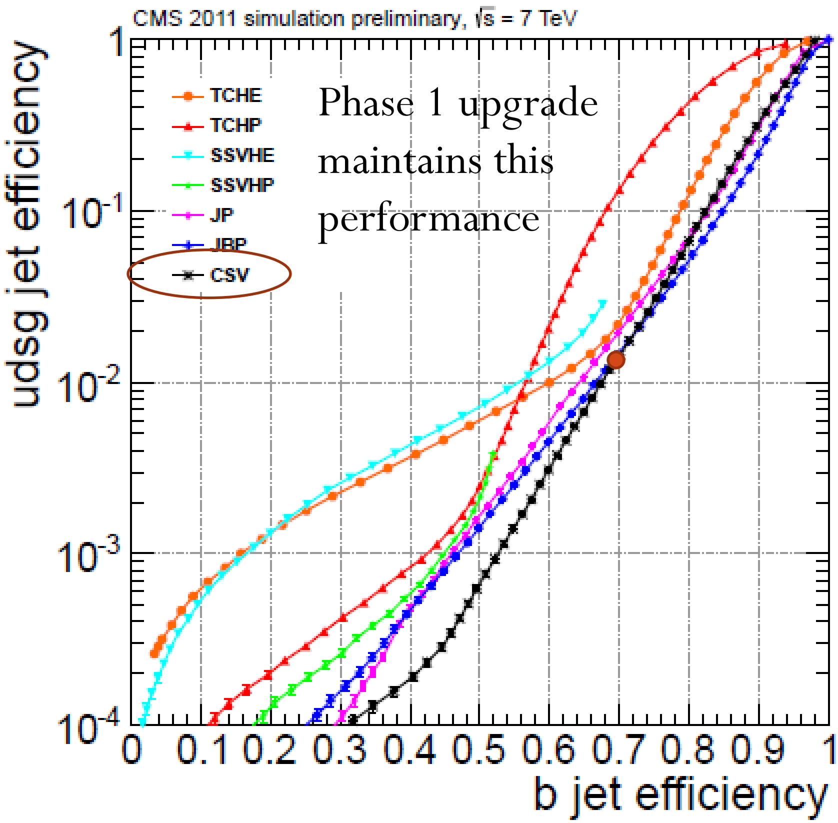
Current VH(bb) Systematic Uncertainties

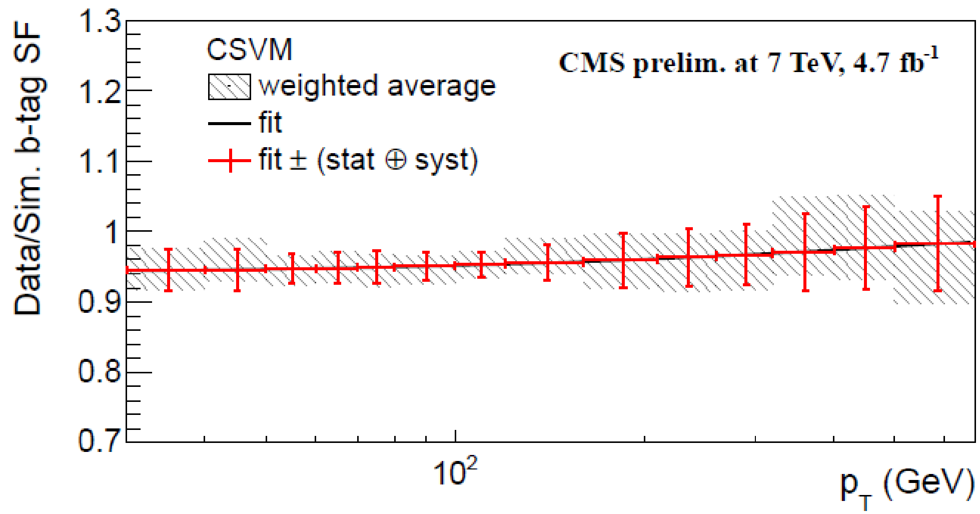
Source	Range
Luminosity	2.2-4.4%
Lepton efficiency and trigger (per lepton)	3%
$Z(\nu\nu)H$ triggers	3%
Jet energy scale	2–3%
Jet energy resolution	3–6%
Missing transverse energy	3%
b-tagging	3–15%
Signal cross section (scale and PDF)	4%
Signal cross section (p_T boost, EWK/QCD)	5–10% / 10%
Signal Monte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

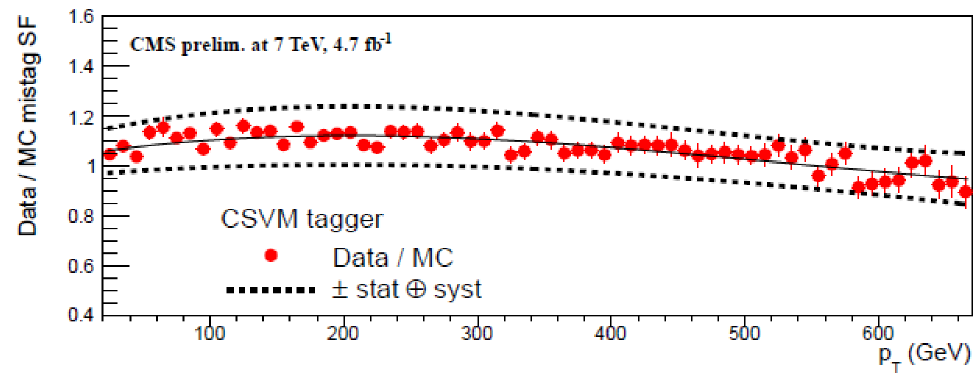
- Dominant systematics: b-tagging and background estimates
  - Driven by data sample size, should scale with luminosity (next slides)
  - Single top and VV will also eventually be taken from LHC measurements
  - More data → improved design of control regions, better understanding of bkgs
- Dominant theoretical uncertainty comes from pT spectrum

Ex: B-tagging Calibration from Data

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





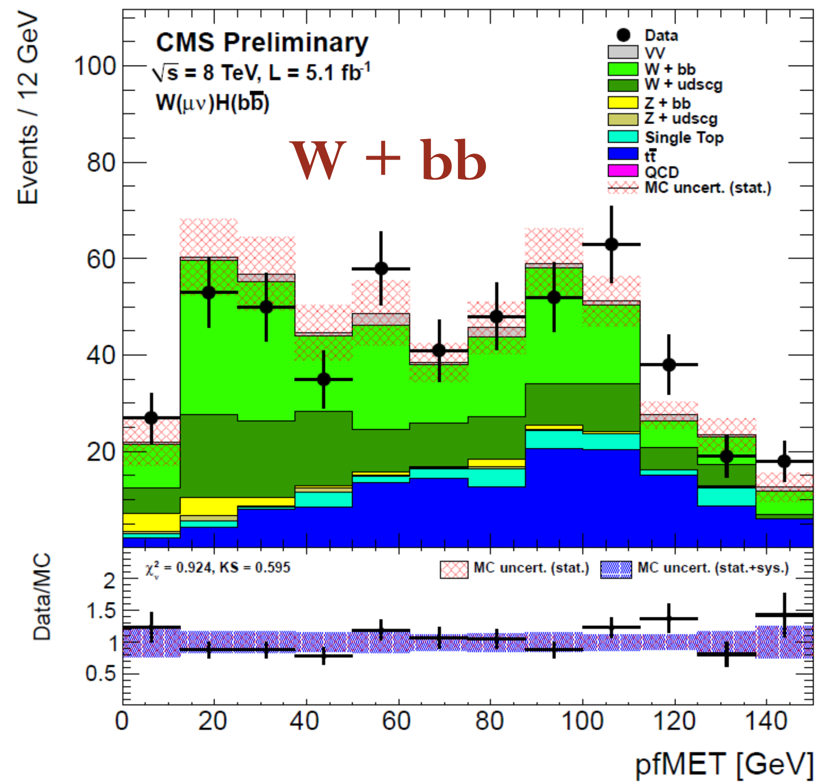


Systematic uncertainty from spread in data/MC

More data allows for higher precision and finer binning (reduced syst)

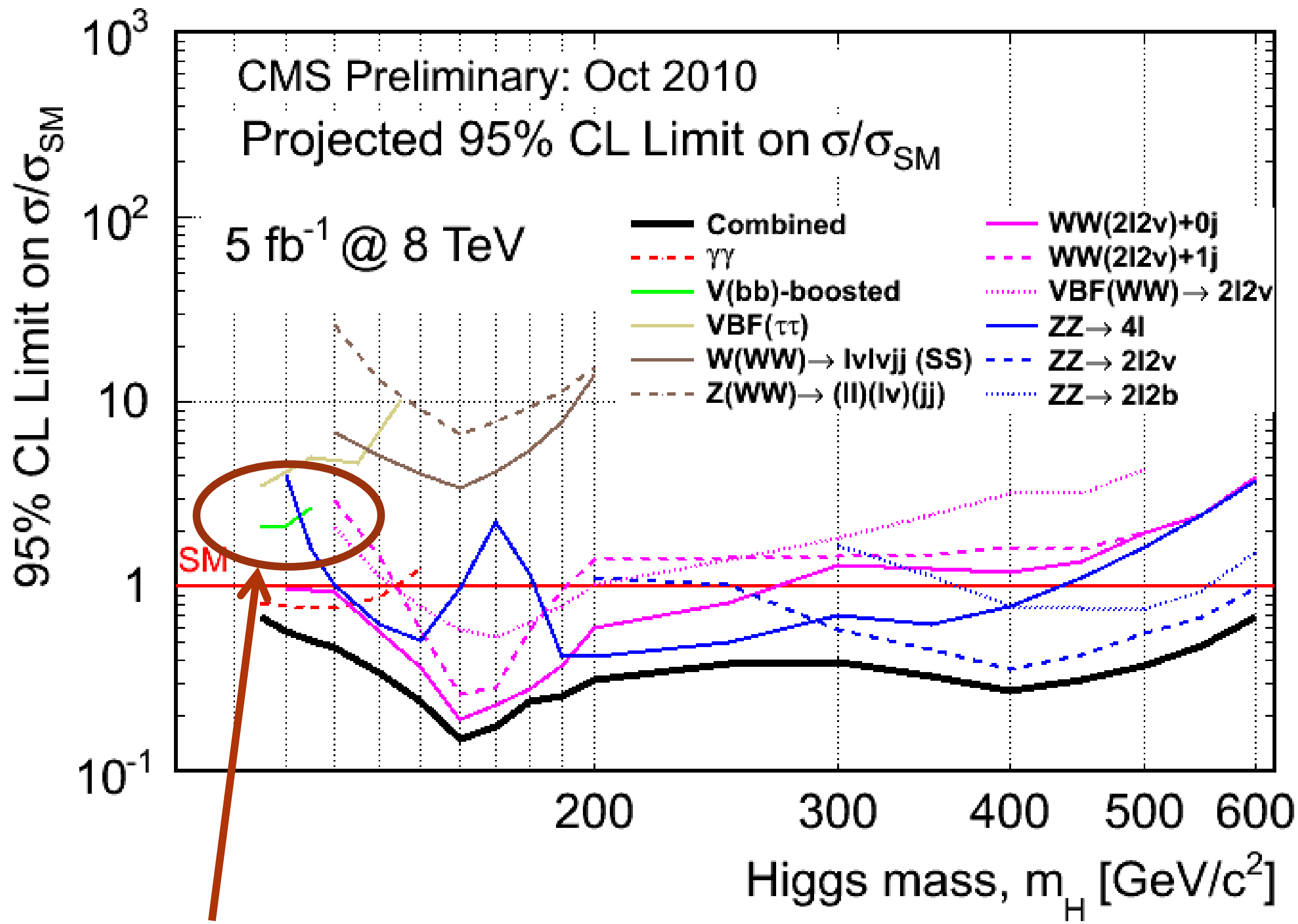
Ex: Background calibration from data

- **Dominant backgrounds**
  - V+bb, V+udscg, ttbar, single top, VV
- **Control regions**
  - Enhance particular backgrounds
  - As close as possible to the signal region
- **Extrapolation to signal region**
  - Scale factor starting values obtained from control regions, varied in final fit
  - Including systematics for extrapolation from control region to signal region



- **Scaling with lumi already demonstrated**
  - **Uncertainties reduced from ~30% to ~15% for dominant backgrounds over course of Run 1 (5/fb → ~20/fb)**

Looking Back: MC projections (2010)



VHbb scaled almost perfectly from 2010 simulation

Summary

- Evidence for fermionic decays of h(125) at LHC and Tevatron
  - Updated result in VHbb on full dataset in progress (coming ~soon)
- Precision (~5%) measurement of κ_b is an important future goal
  - Sets the scale for all absolute partial width measurements
  - Constrains new physics models
- Experimental considerations
  - Analysis improvements needed to maintain lumi scaling
    - Unlike the stock market, past gains should indicate future profits
  - Dominant experimental systematic uncertainties driven by data
- Theoretical considerations
  - Knowledge of Higgs pT spectrum will be key
  - Theory uncertainty on the bb partial width also important