Search for Standard Model Higgs Decaying to $b\bar{b}$

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on behalf of the CMS Collaboration

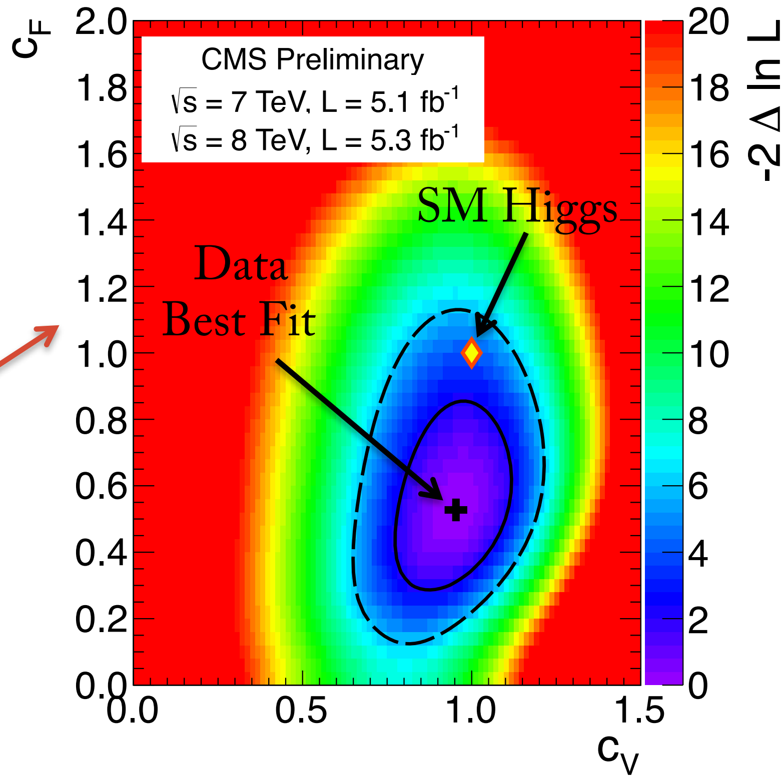
ETH Zurich

Higgs Hunting – Orsay – July 2012

Motivations

Higgs -> $b\bar{b}$

- A new resonance with mass near 125 GeV/c^2 has been observed in Higgs searches
- Properties of this resonance still unclear
- Combination of all CMS analyses shows fermion couplings (C_F) slightly suppressed
- H->bb key channel in the next future to characterize the new resonance



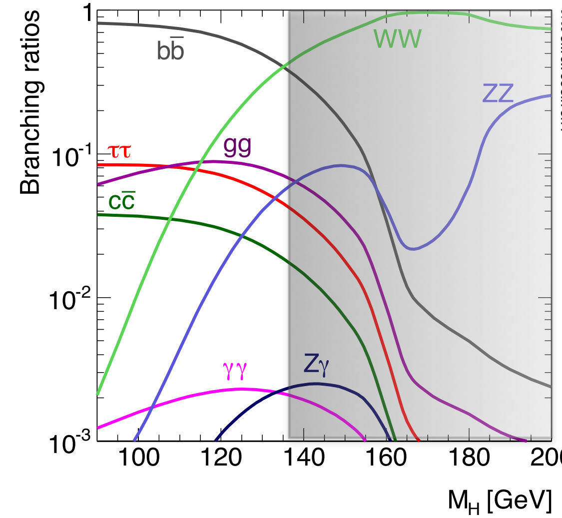
The solid and dashed contours show the 68% and 95% CL ranges

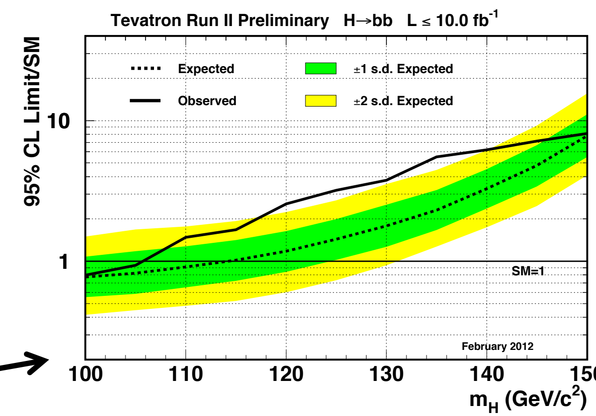
Pierluigi Bortignon – Higgs Hunting – 18th July 2012 – Orsay

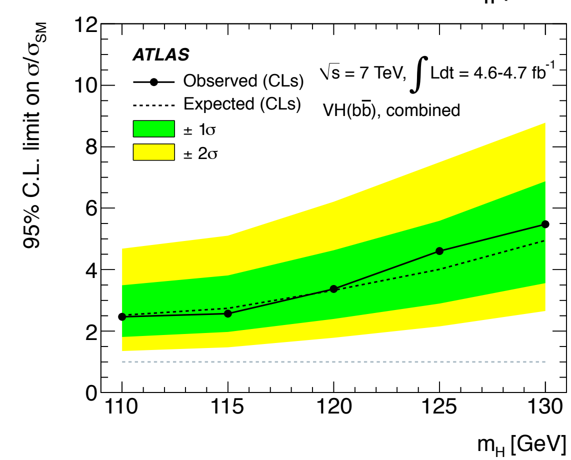
Introduction

Higgs -> $b\bar{b}$ Status

- @ 125 GeV/c^2 $b\bar{b}$ highest branching ratio
- At hadron colliders
  - ✗ Gluon fusion (huge QCD background)
  - ✓ Associated production with vector boson
- Analysis performed by 4 experiments
  - Tevatron (D0, CDF)
  - LHC (ATLAS, CMS)
  - None yet sensitive to SM cross section for m_H = 125GeV/c^2



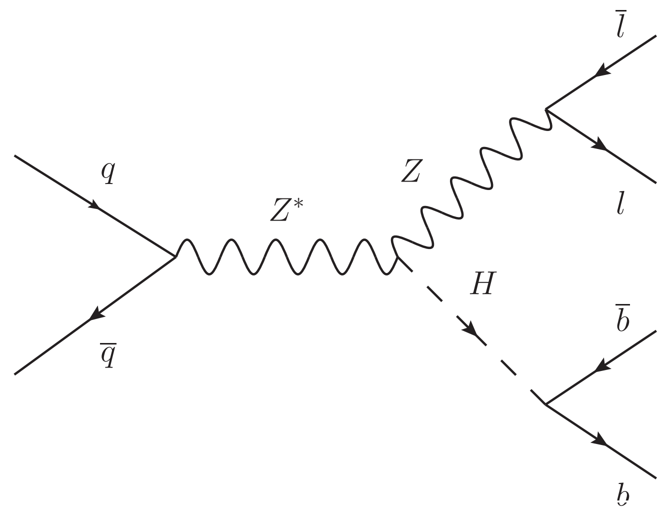


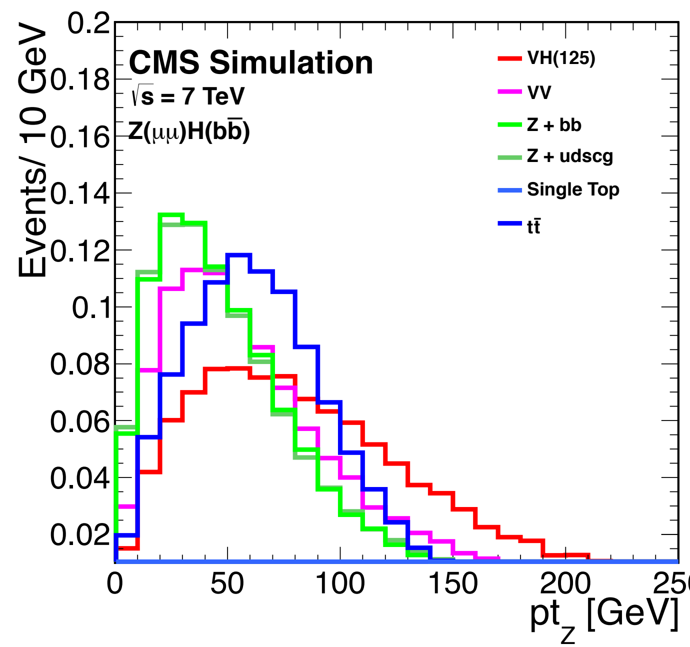


Analysis Strategy

Channels

- Five channels with different vector boson
  - W ($l\nu_l$) H($b\bar{b}$), l = Electron, Muon
  - Z (ll) H($b\bar{b}$), l = Electron, Muon, Neutrino
- Large boost on the vector boson important to suppress background





Vector Boson Selection

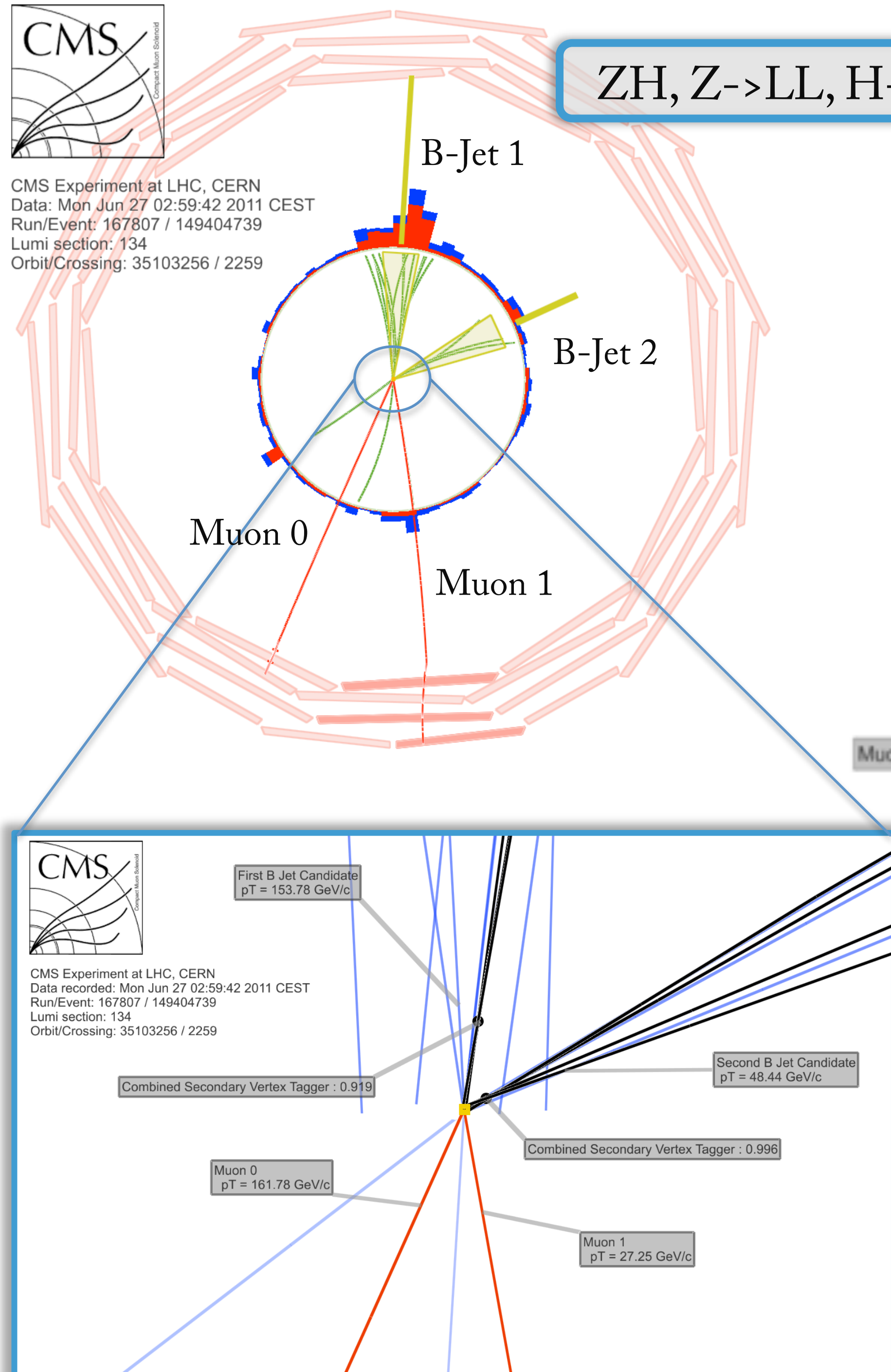
- Isolated lepton(s)
- Transverse Missing Energy

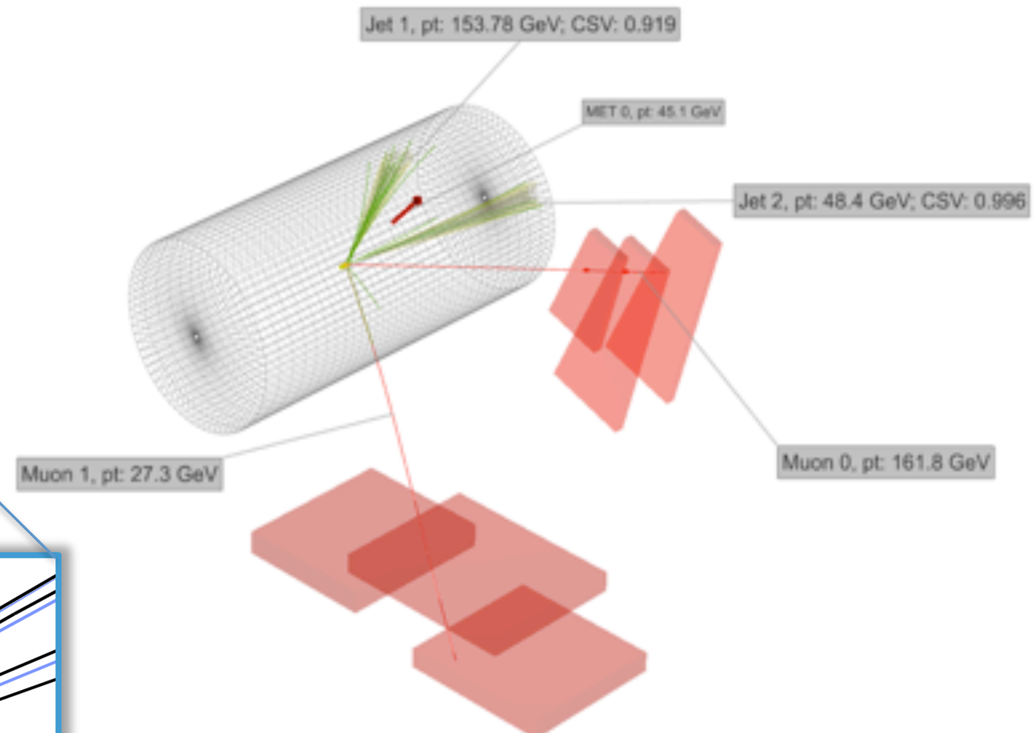
Higgs Candidate

- Two jets identified as B-Jets using dedicated likelihood discriminant

Event display

ZH, Z->LL, H->bb





$M_{bb} = 128\ \mathrm{GeV}/c^2$
$M_{LL} = 91\ \mathrm{GeV}/c^2$
$p_{T\,LL} = 185\ \mathrm{GeV}/c$

Analysis Improvements

	7 TeV	Combined 7 – 8 TeV	Improvement
Background Normalisation	Scale factors form solution of analytic system	Simultaneous fit using full shapes	Better confidence of background normalisation
Di-Jet Mass Resolution	Standard CMS Jet Energy Correction	Multivariate Jet Energy Regression in addition	~ 20% better mass resolution
Phase-Space Analyzed	Single bin in vector p_T	Add a lower vector p_T bin to recover signal efficiency	~ 10% Higher sensitivity
Signal Extraction	Cut and Count on BDT discriminator output	Use of full shape information of BDT discriminator	~ 20% Higher sensitivity

Results (I)

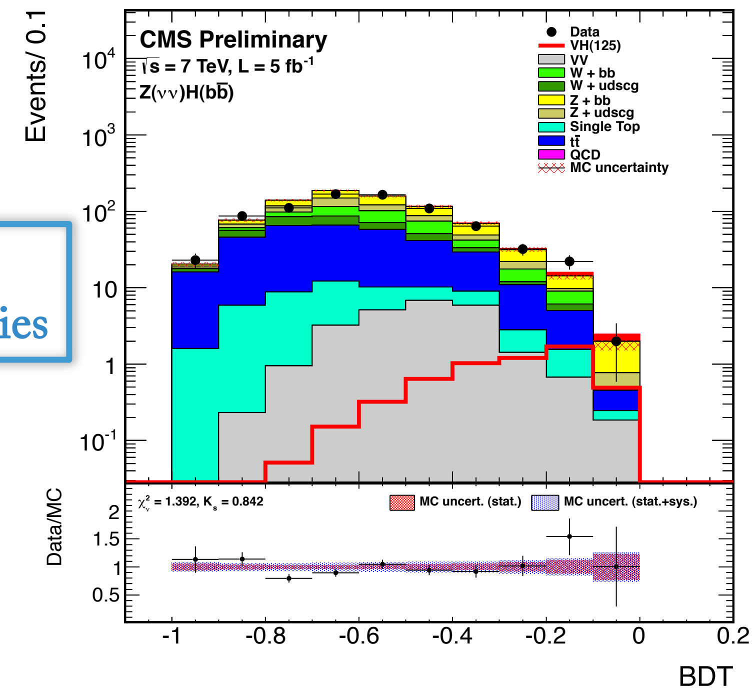
Multivariate Analysis

- Combination of all 5 channels
- 7 TeV and 8 TeV data. $5 fb^{-1}$ each
- Two vector p_T categories

20 categories

- MVA techniques (BDT) to classify signal against background
- BDT validated in control regions
- Fit on the shape of the BDT output distribution

Example of BDT discriminant output

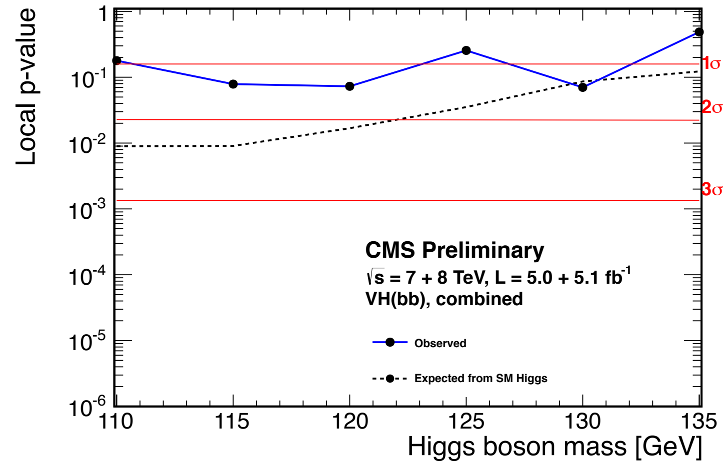


Background-like

Signal-like

Results (II)

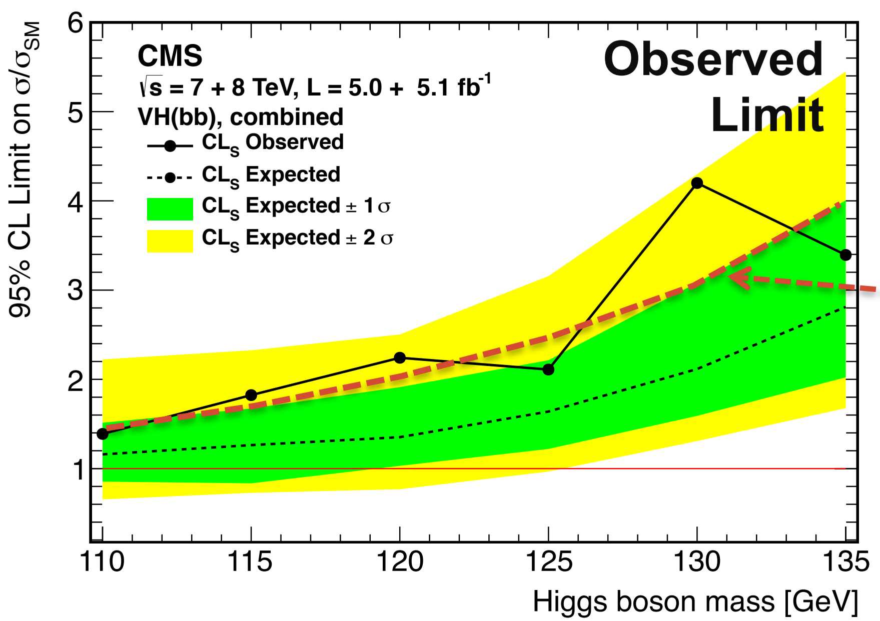
- ~ 50% improvements on the analysis since 2011 published results
- CMS is the most sensitive experiment for this channel by now
- About a factor 2.5 in integrated luminosity needed to be sensitive at m_H = 125 GeV/c^2

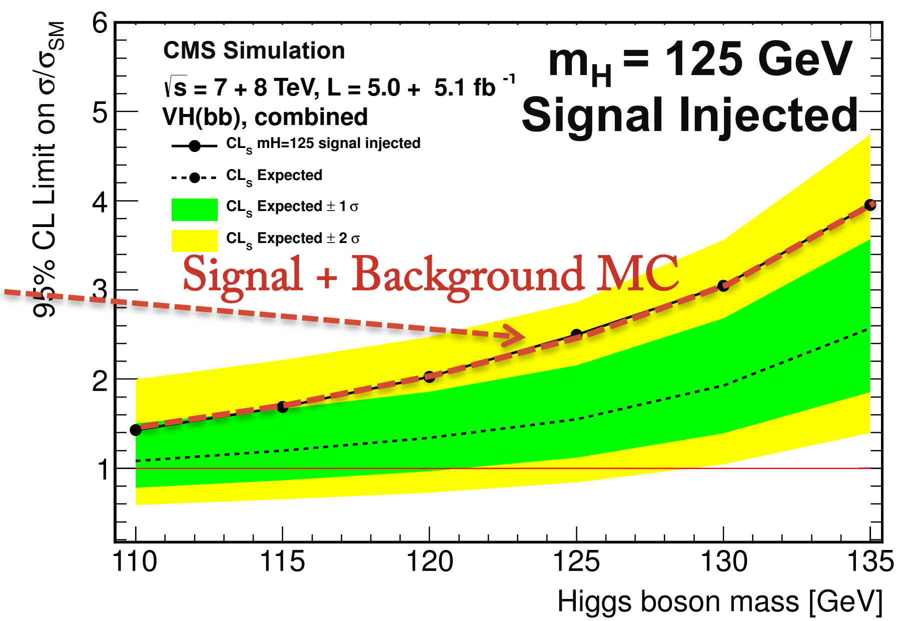


Higgs mass resolution ~ 8%

=> Excess compatible with γγ and ZZ

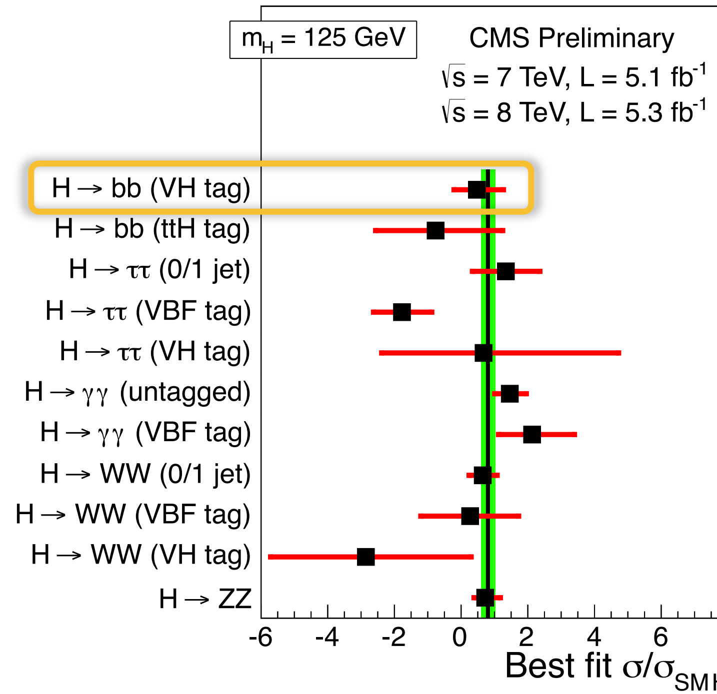
Higgs observation at 126 GeV/c^2

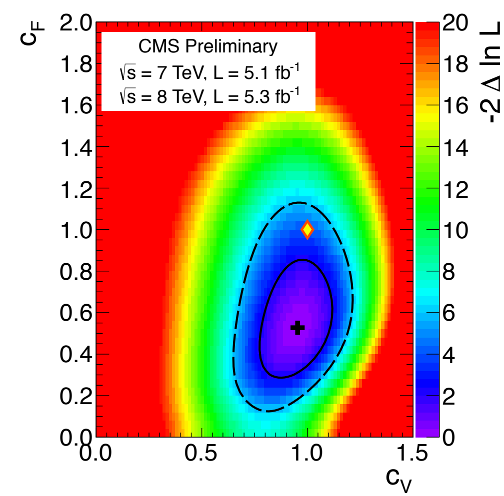




Conclusions

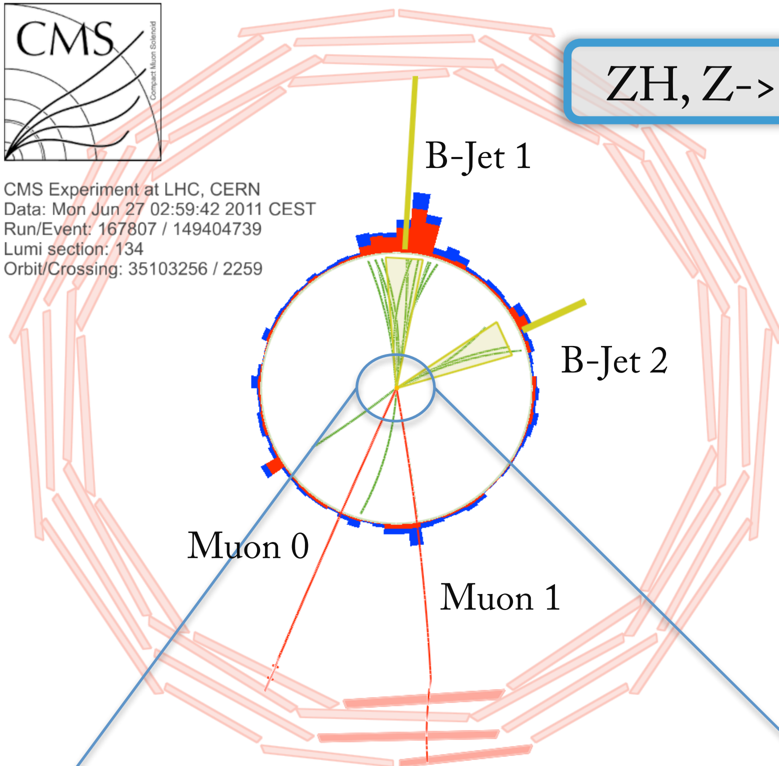
- Higgs to $b\bar{b}$ results are in the official Higgs combination of CMS
- Essential channel to characterize the observation in $\gamma\gamma$ and ZZ channels
- Important to measure Higgs couplings
- LHC is expected to provide about 20 fb^{-1} before the next long shut-down
- Improved analysis will be sensitive to SM Higgs with full LHC dataset

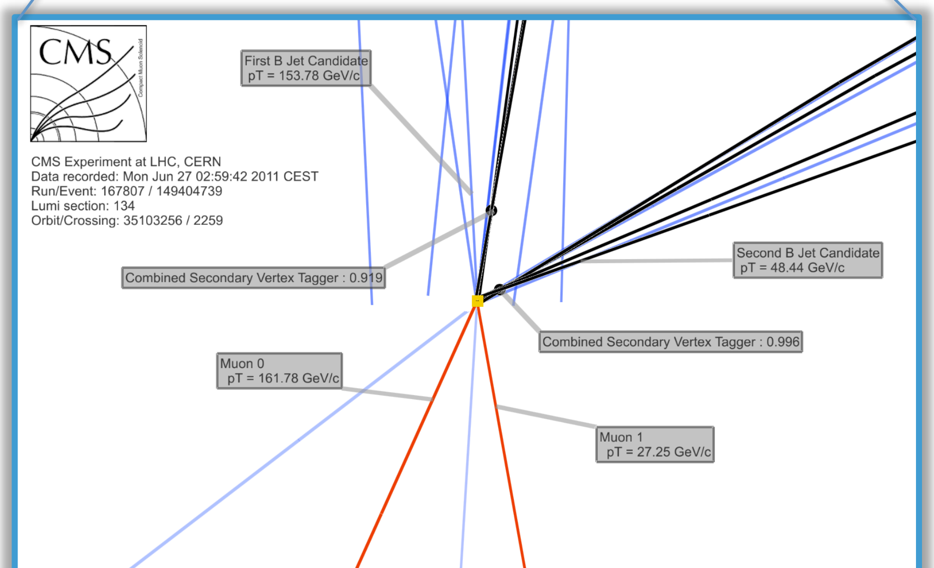


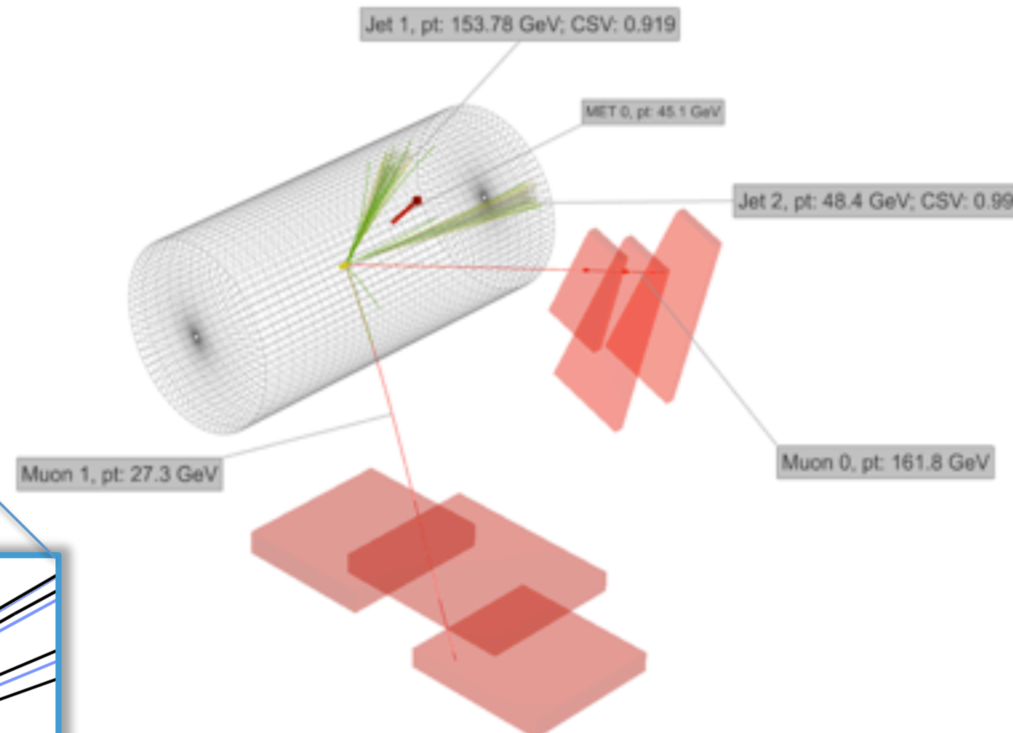


Thank you

ZH, Z->LL, H->bb







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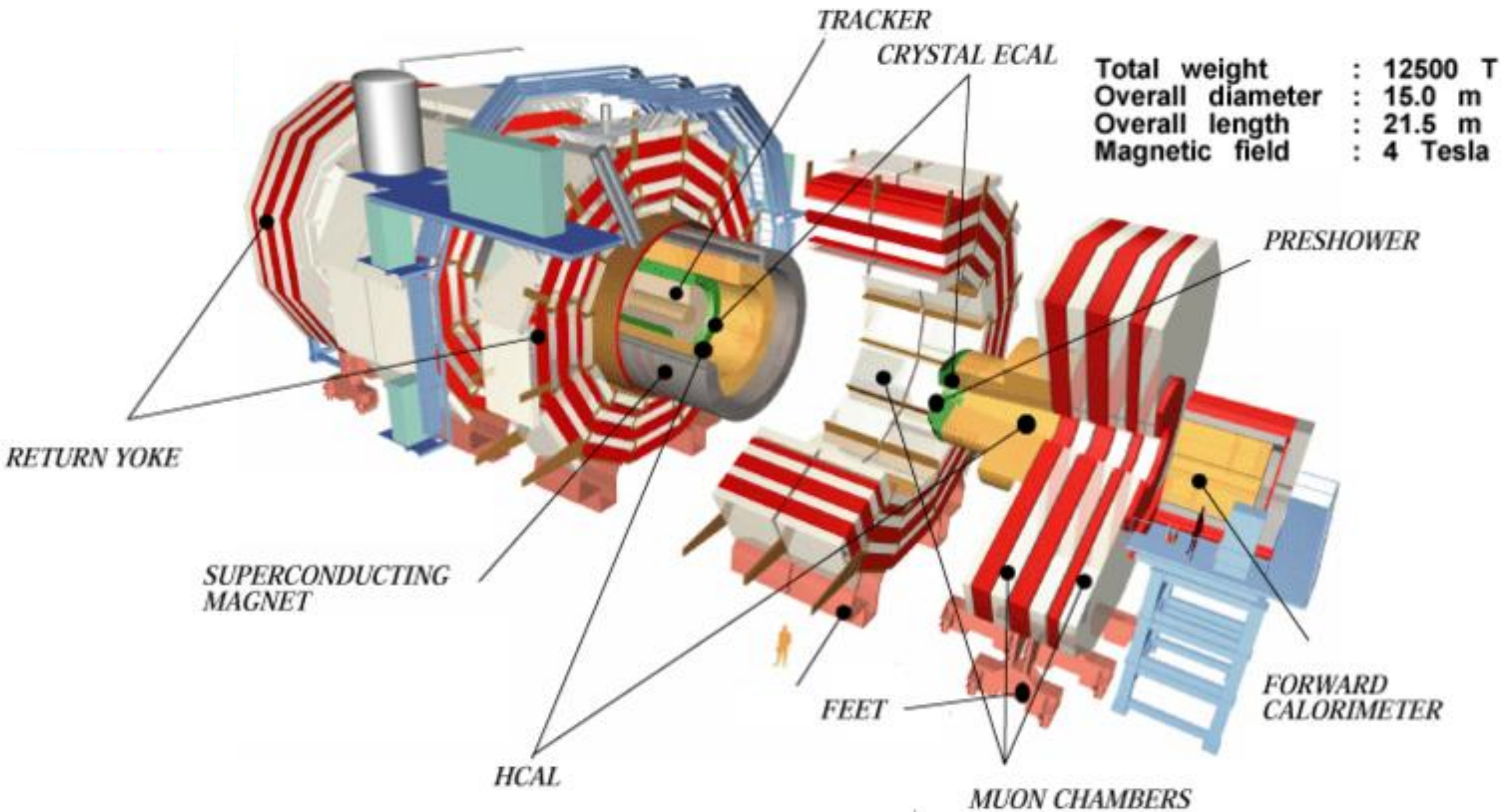
References

1. CMS Collaboration, “Search for the standard model Higgs boson decaying to bottom quarks in pp collisions at”, *Physics Letters B* **710** (2012), no. 2, 284, doi:10.1016/j.physletb.2012.02.085.

2. CMS Collaboration, “Search for the standard model Higgs boson produced in association with W or Z bosons, and decaying to bottom quarks for ICHEP 2012”, CMS-PAS-HIG-12-019, http://cdsweb.cern.ch/record/1460692?ln=en

CMS

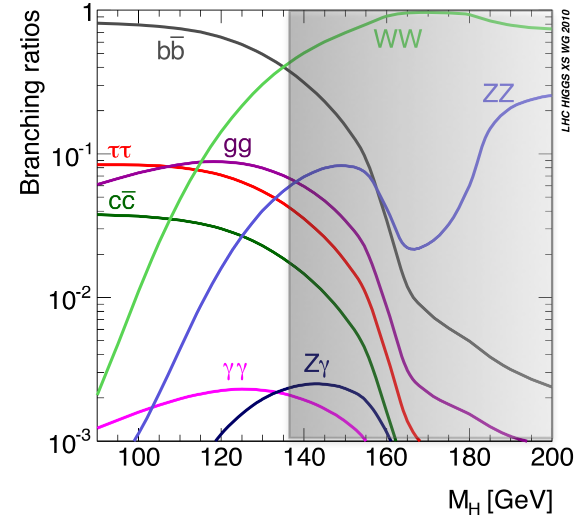


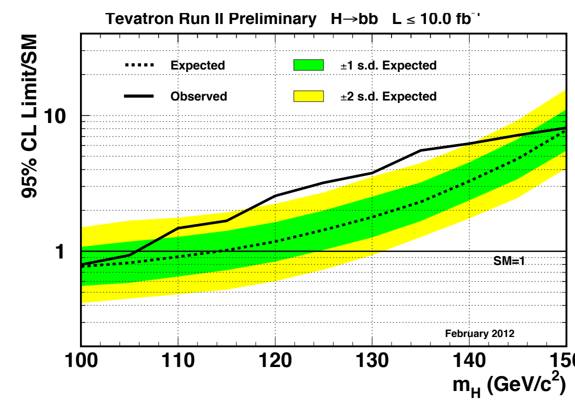
Pierluigi Bortignon SPS 2012 - ETH Zurich

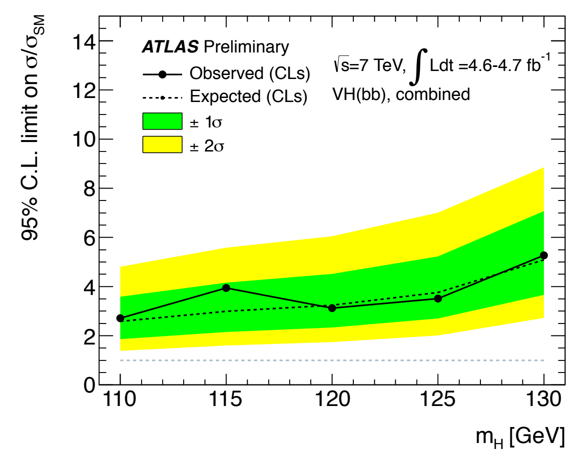
Introduction

Higgs -> $b\bar{b}$ Status

- For low SM Higgs mass hypothesis bb decay channel has the highest branching ratio
- At hadron colliders very difficult to suppress QCD background if looking at gluon fusion production
  - Way out : require associated production with a vector boson
- Phenomenology paper shows the importance of vectors boson p_T at LHC for this channel
  - [Phys. Rev. Lett. 100 (2008) 242001]
- Tevatron not sensitive to SM Higgs at 125 GeV/c^2
- ATLAS has published 2011 results only

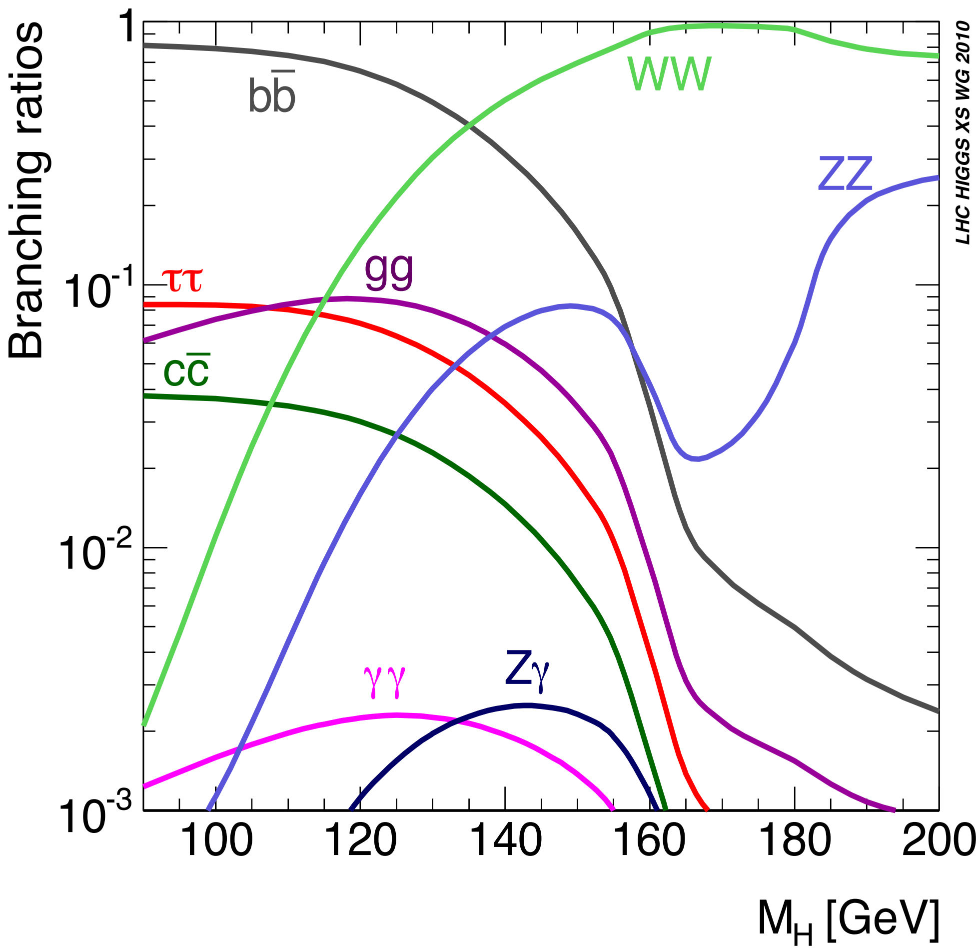






Introduction

Higgs Branching Ratios



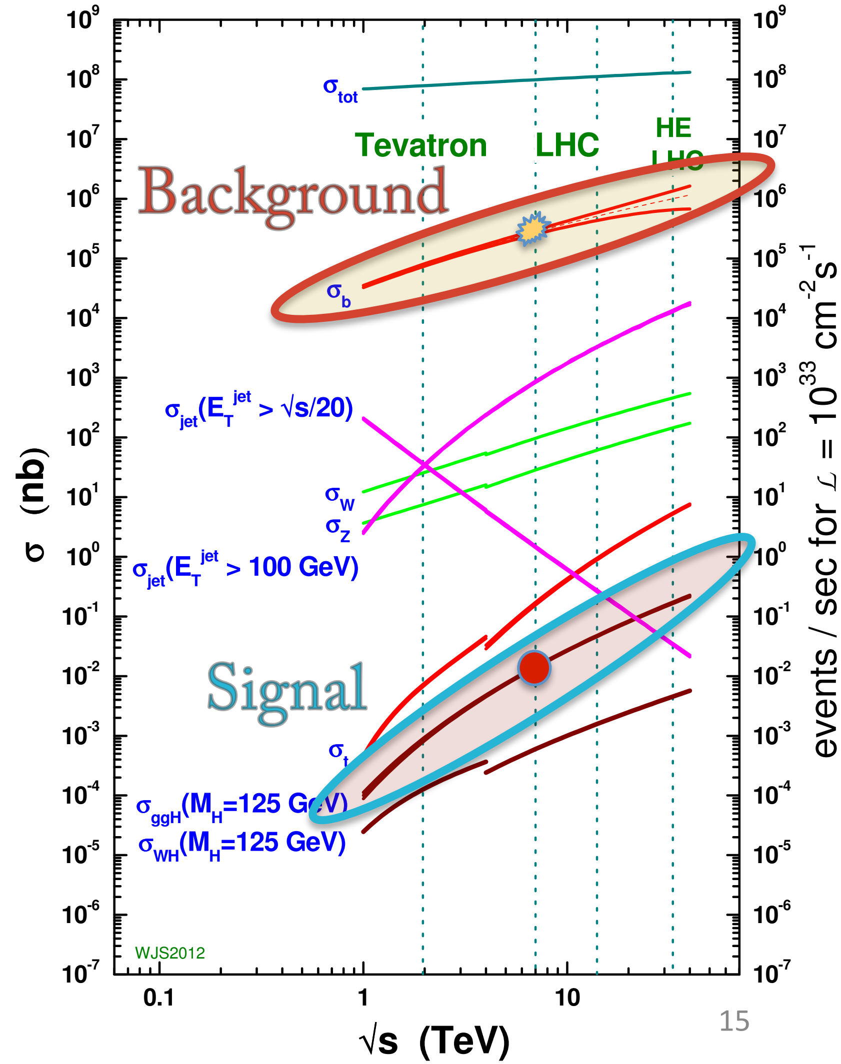
Low Mass Higgs at LHC

Gluon fusion production combined with $b\bar{b}$ decay is extremely challenging at hadron colliders

- B hadron production cross section is huge compared to the Higgs one
- QCD B hadron production is a mostly irreducible background
- B Jet energy resolution not optimal to look for a peak on the m_{BB} distribution
- Difficult to design an efficient trigger for this topology

Signal / Background ~ 10^{-7}

Hadron Colliders Cross Sections



Low Mass Higgs at LHC

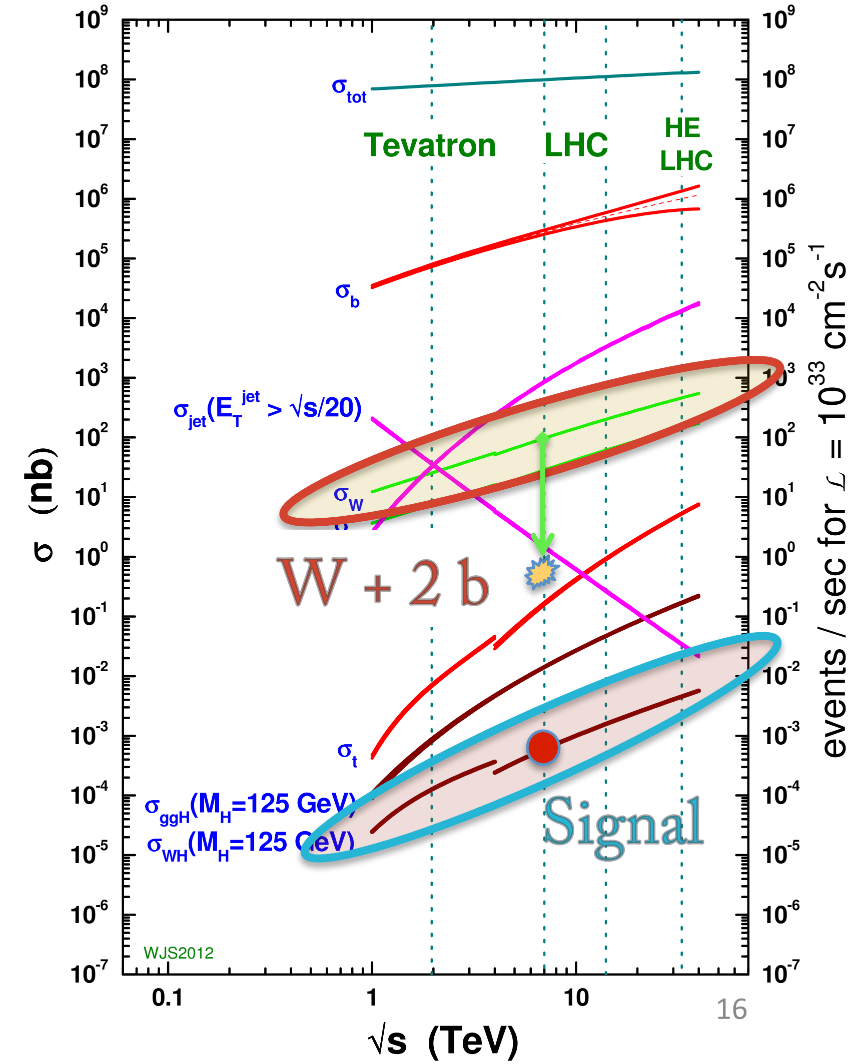
Associated production combined with $b\bar{b}$ decay is a better analysis strategy

- Main background V+2 b
- S/B increases by ~ 4 orders of magnitude
- Partially reducible background using vector boson momentum
- Easier to trigger using isolated leptons or high transverse missing energy

Signal / Background ~ 10^{-3}

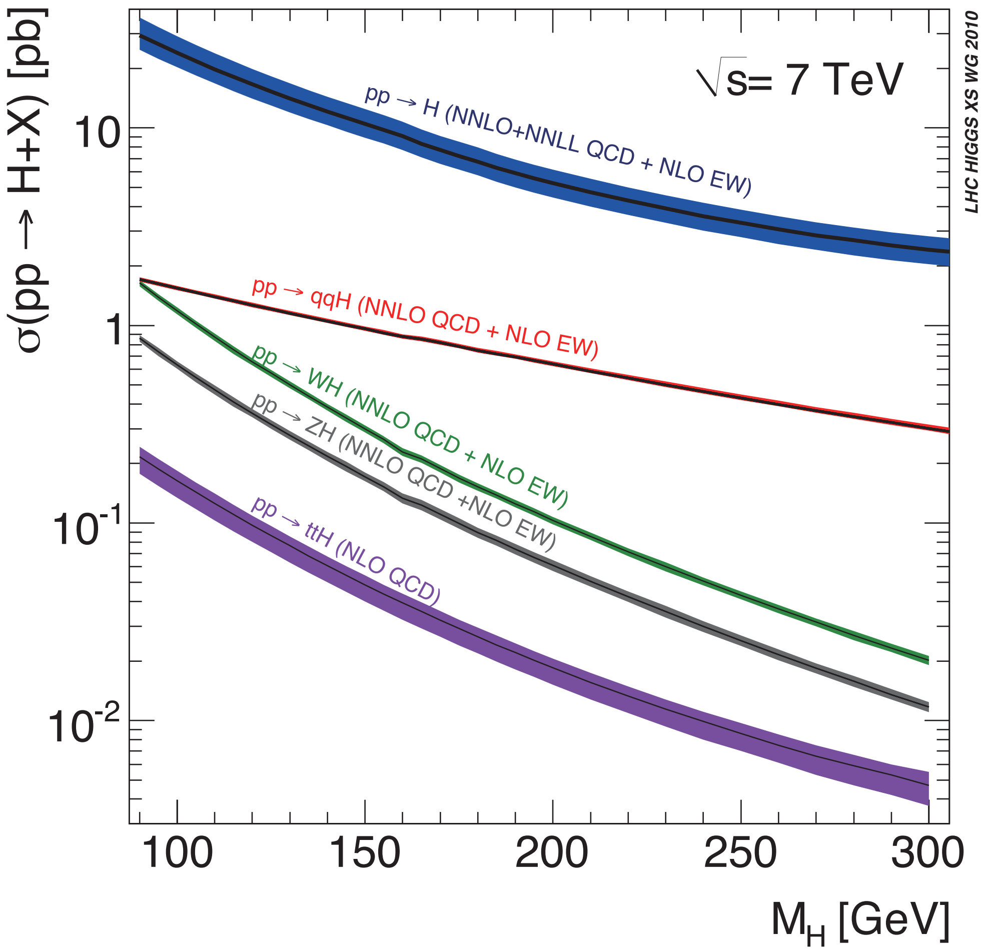
Signal / Background ~ 10^{-7}

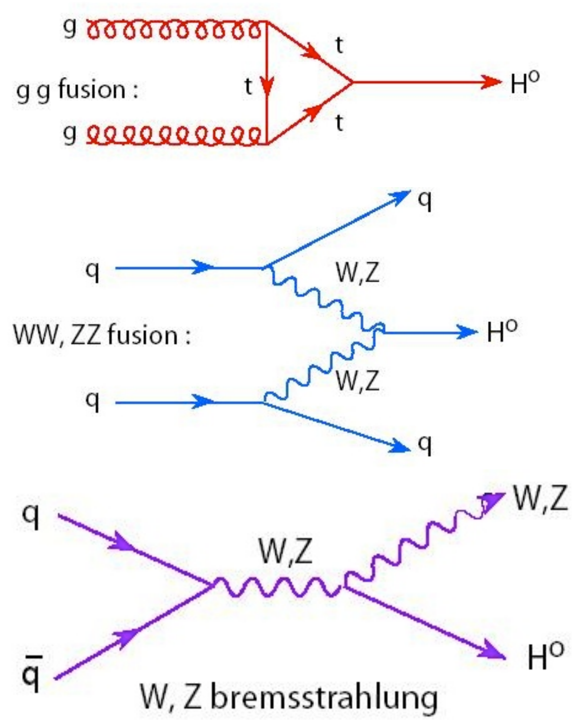
Hadron Colliders Cross Sections



Low Mass Higgs at LHC

Higgs Production Cross Sections



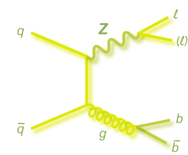


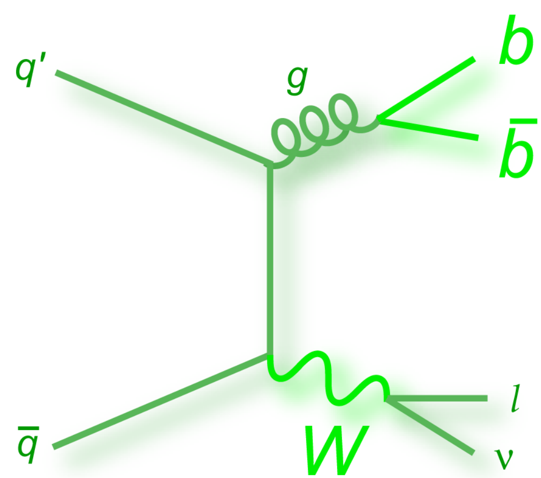
Analysis strategy

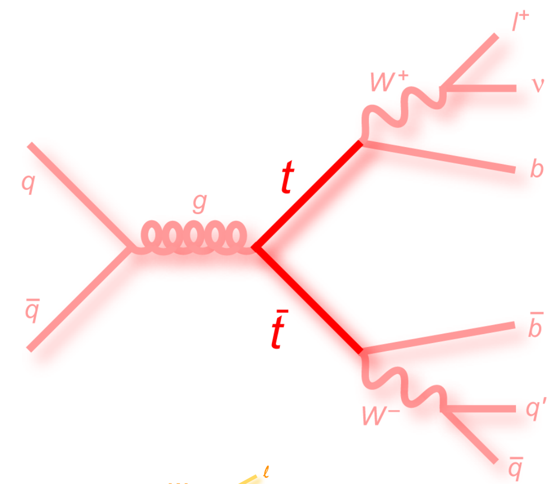
Channels

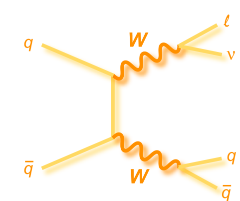
- Five different channels
  - W (EleNu) H(bb)
  - W (MuNu) H(bb)
  - Z(EleEle) H(bb)
  - Z(MuMu) H(bb)
  - Z(NuNu) H(bb)
- Different channels have different background composition

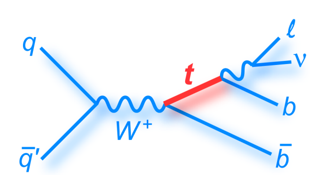
Backgrounds











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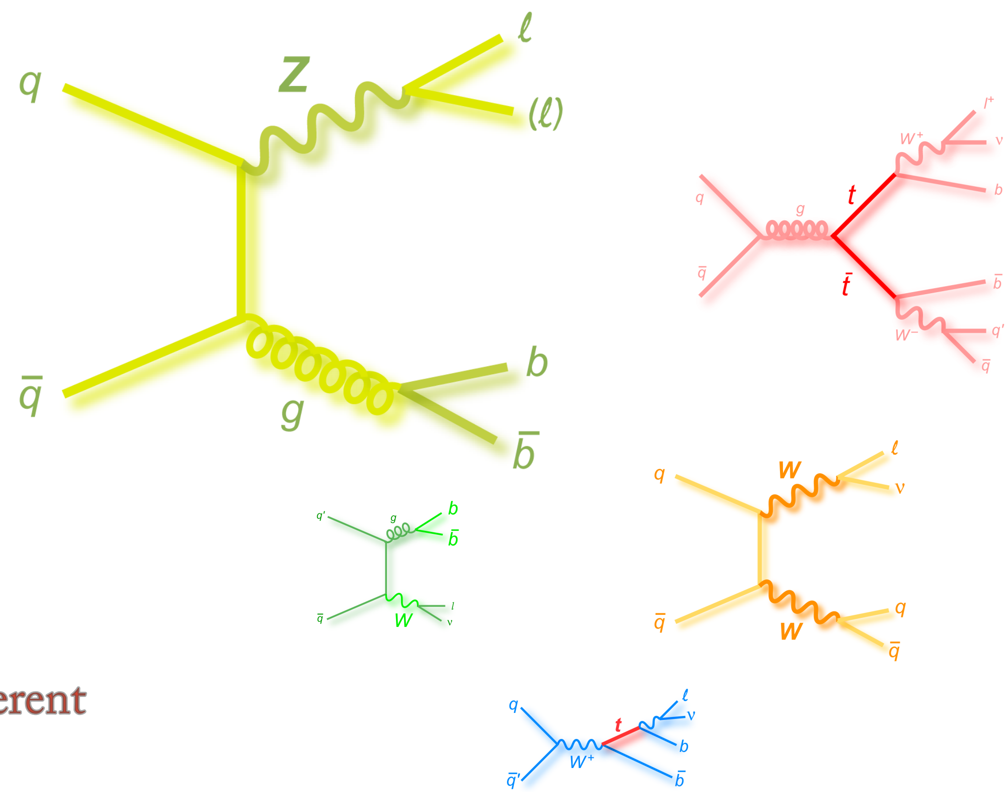

Analysis strategy

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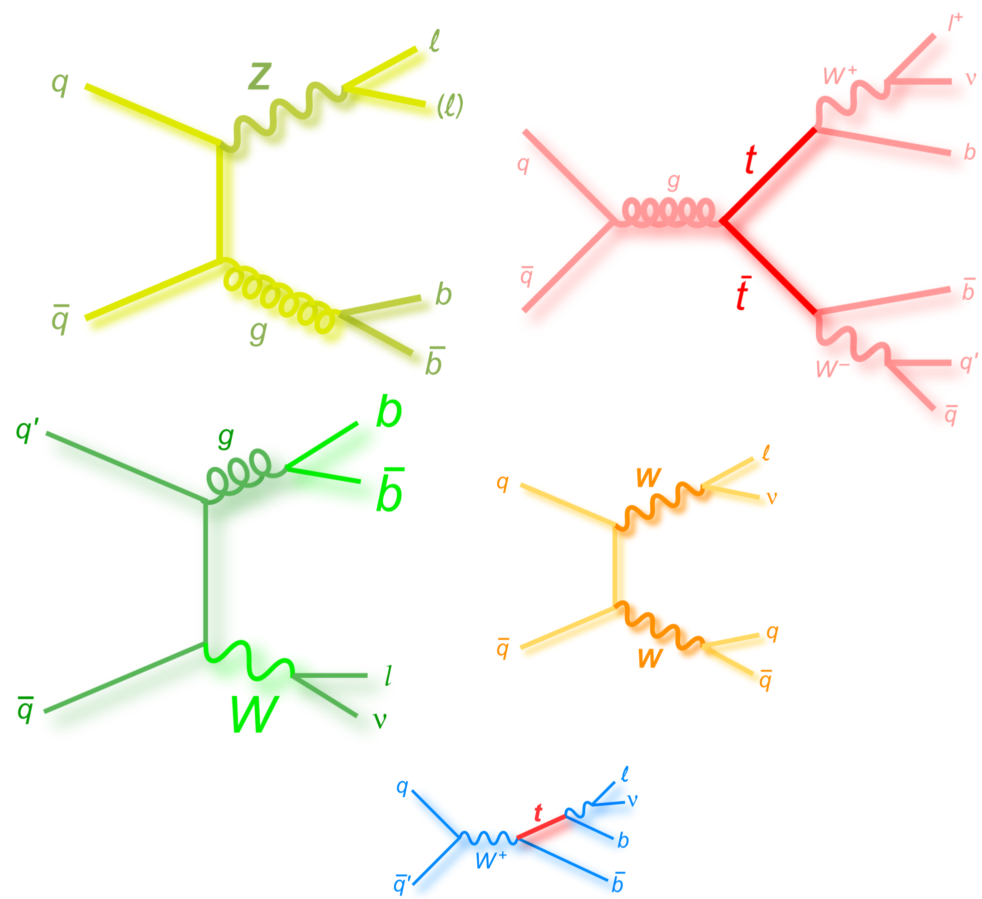
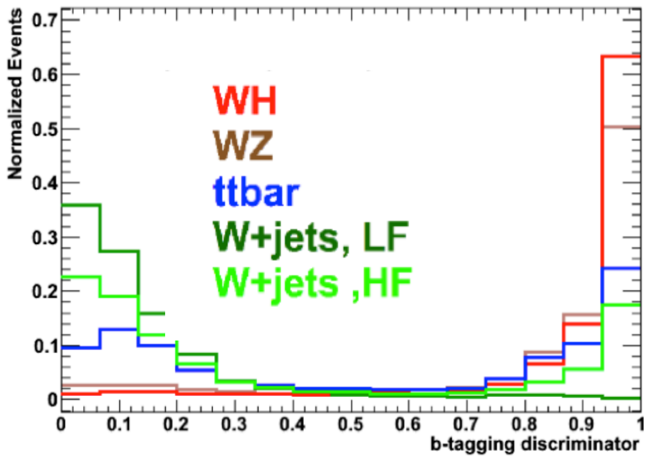
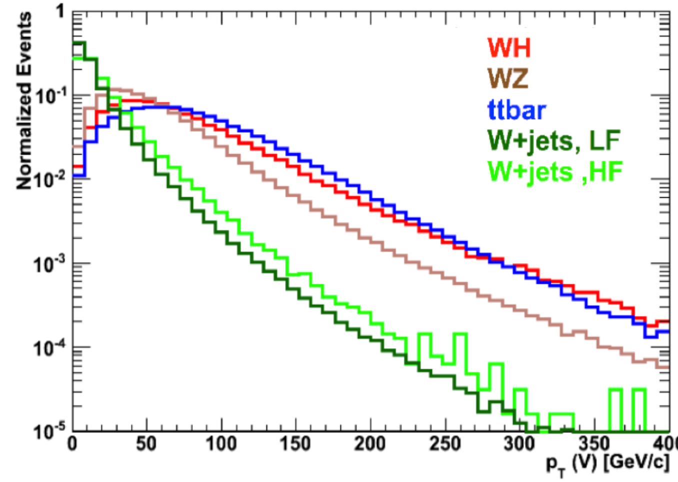
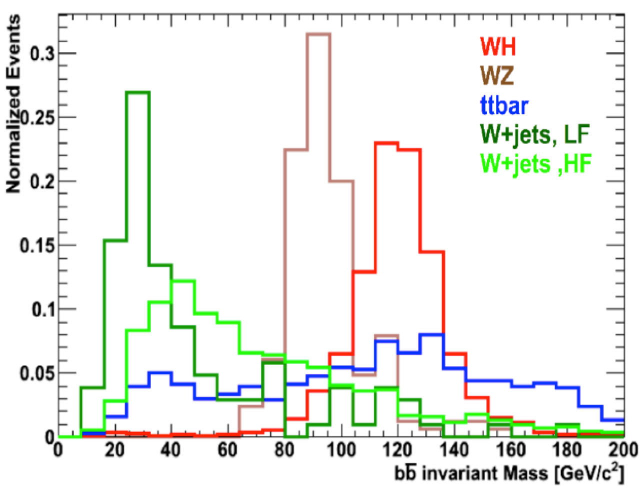


Most Discriminating Variables

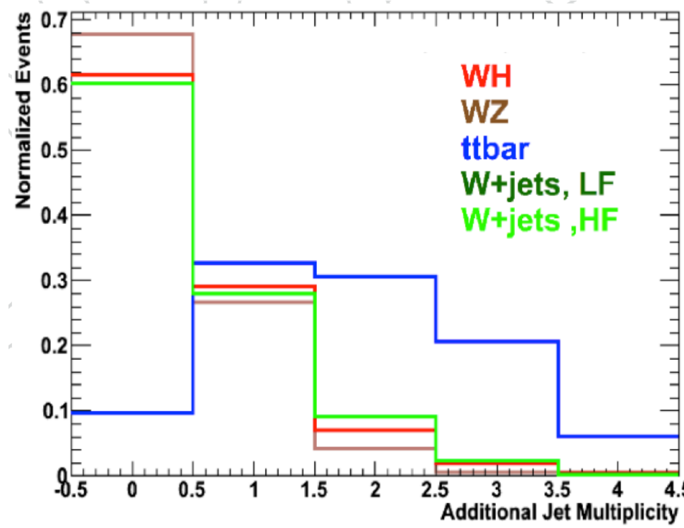


B-Tag working point efficiency ~ 50%





Invariant mass resolution ~ 10%



Analysis strategy

Boosted Decision Tree Variables

Variable
$p_{\mathrm{T}j}$: transverse momentum of each Higgs daughter
$m(\mathrm{jj})$: dijet invariant mass
$p_{\mathrm{T}}(\mathrm{jj})$: dijet transverse momentum
$p_{\mathrm{T}}(\mathrm{V})$: vector boson transverse momentum (or pfMET)
$\mathrm{CSV_{max}}$: value of CSV for the b-tagged jet with largest CSV value
$\mathrm{CSV_{min}}$: value of CSV for the b-tagged jet with second largest CSV value
$\Delta\phi(\mathrm{V,H})$: azimuthal angle between V (or $E_{\mathrm{T}}^{\mathrm{miss}}$) 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 ($p_{\mathrm{T}} > 30\,\mathrm{GeV}$, $\lvert\eta\rvert < 4.5$)
$\Delta\phi(\mathrm{E_T^{miss}},\mathrm{jet})$: azimuthal angle between $E_{\mathrm{T}}^{\mathrm{miss}}$ and the closest jet (only for $\mathrm{Z}(\nu\nu)\mathrm{H}$)
$\Delta\theta_{\mathrm{pull}}$: color pull angle [62] (not for $\mathrm{Z}(\ell\ell)\mathrm{H}$)

Preselection

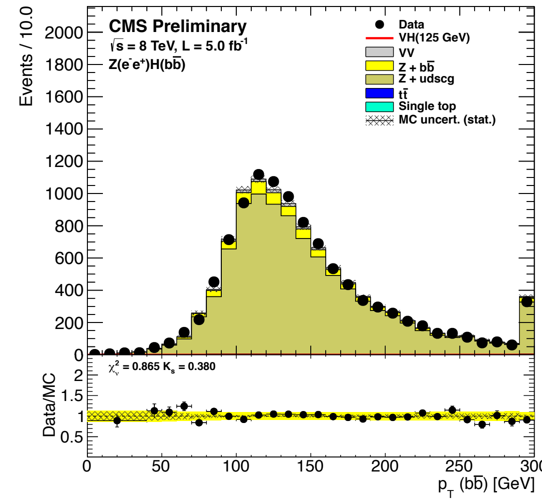
Variable	$\mathrm{W}(\ell\nu)\mathrm{H}$	$\mathrm{Z}(\ell\ell)\mathrm{H}$	$\mathrm{Z}(\nu\nu)\mathrm{H}$
$m_{\ell\ell}$	–	$75 < m_{\ell\ell} < 105$	–
$p_{\mathrm{T}}(j_1)$	> 30	> 20	> 80
$p_{\mathrm{T}}(j_2)$	> 30	> 20	> 20
$p_{\mathrm{T}}(\mathrm{jj})$	> 120	–	$120 - 160\ (> 160)$
$m(\mathrm{jj})$	< 250	$80 < m(\mathrm{jj}) < 150$ (–)	< 250
$p_{\mathrm{T}}(\mathrm{V})$	$120 - 170\ (> 170)$	$50 - 100\ (> 100)$	–
$\mathrm{CSV_{max}}$	> 0.40	0.50 (0.244)	> 0.50
$\mathrm{CSV_{min}}$	> 0.40	0.244	> 0.50
N_{al}	$= 0$	–	$= 0$
$\Delta\phi(\mathrm{E_T^{miss}},\mathrm{jet})$	–	–	> 0.5
$E_{\mathrm{T}}^{\mathrm{miss}}$	> 35 (elec)	–	$120 - 160\ (> 160)$
BDT	full distribution	full distribution	full distribution

Background Normalisation

Main backgrounds are taken from the data. Simulation only used to extrapolate to the signal region.
The control regions are defined as close as possible to the signal region to minimize the extrapolation.

Good agreement with theory predictions

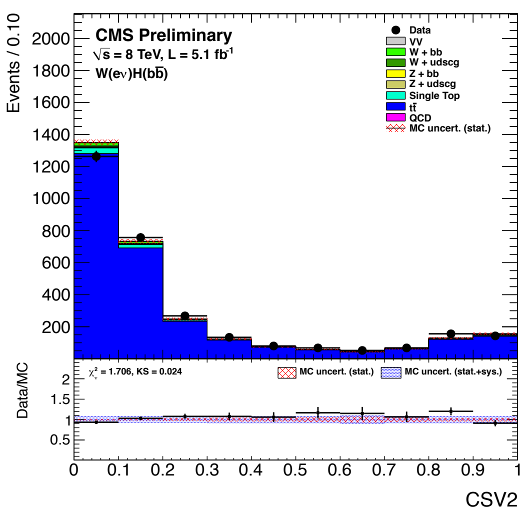
Z + Light Jets



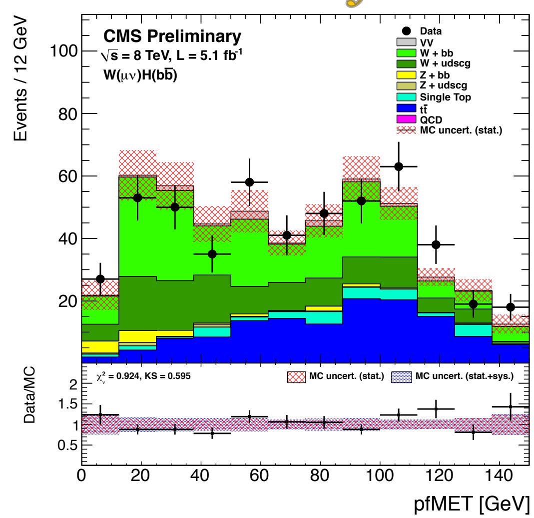
Data/MC Scale Factors

Process	WH	$Z(\ell\ell)$H	$Z(\nu\nu)$H
Low p_T			
W + udscg	0.88 ± 0.01 ± 0.03	–	0.89 ± 0.01 ± 0.03
Wbb̄	1.91 ± 0.14 ± 0.31	–	1.36 ± 0.10 ± 0.15
Z + udscg	–	1.11 ± 0.03 ± 0.11	0.87 ± 0.01 ± 0.03
Zbb̄	–	0.98 ± 0.05 ± 0.12	0.96 ± 0.02 ± 0.03
tt̄	0.93 ± 0.02 ± 0.05	1.03 ± 0.04 ± 0.11	0.97 ± 0.02 ± 0.04
High p_T			
W + udscg	0.79 ± 0.01 ± 0.02	–	0.78 ± 0.02 ± 0.03
Wbb̄	1.49 ± 0.14 ± 0.19	–	1.48 ± 0.15 ± 0.20
Z + udscg	–	1.11 ± 0.03 ± 0.11	0.97 ± 0.02 ± 0.04
Zbb̄	–	0.98 ± 0.05 ± 0.12	1.08 ± 0.09 ± 0.06
tt̄	0.84 ± 0.02 ± 0.03	1.03 ± 0.04 ± 0.11	0.97 ± 0.02 ± 0.04

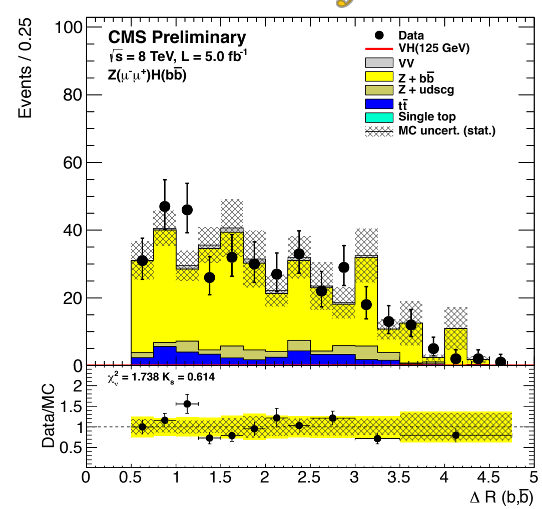
TTbar



W + B Jets



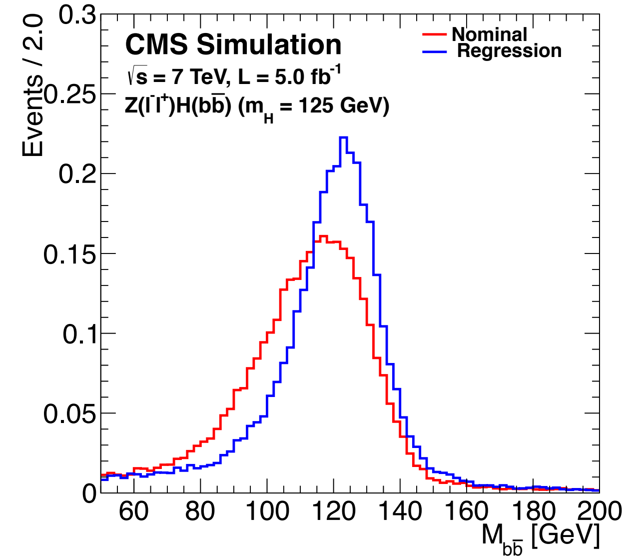
Z + B Jets

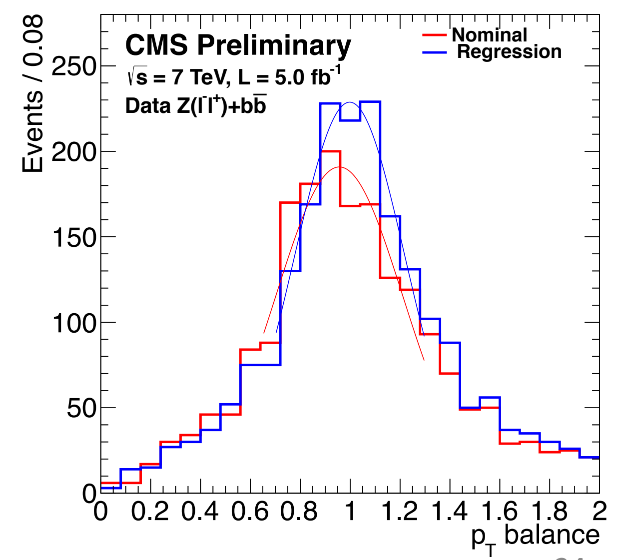


Jet Energy Regression

Di-Jet Mass Resolution improvement

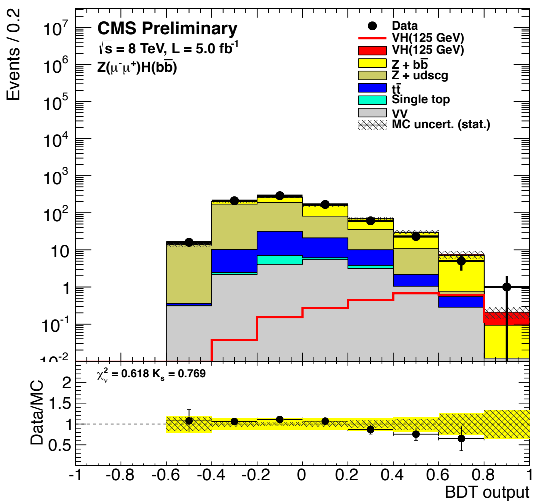
- Specialized b jet energy regression similar to CDF http://arxiv.org/pdf/1107.3026.pdf
  - => improve dijet invariant mass (and MET)
- Use MVA regression trained with b quark jets discriminant, properties of a secondary vertex, track information, charged constituents, variables related to the energy reconstruction of the jet etc.
- Attempts to **recover the true b-jet energy**.
  - Validated in MC and in data using p_T balance in Z + 2 Jets events
- Upshot
  - **15-20% improved mass resolution**
  - m_{bb} distribution becomes **more consistent with true generated mass** spectrum

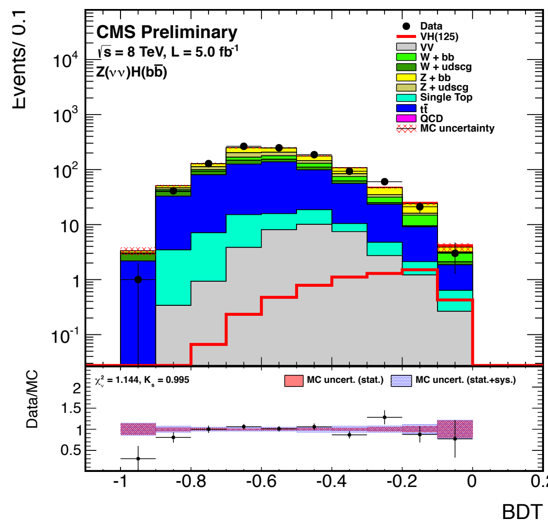


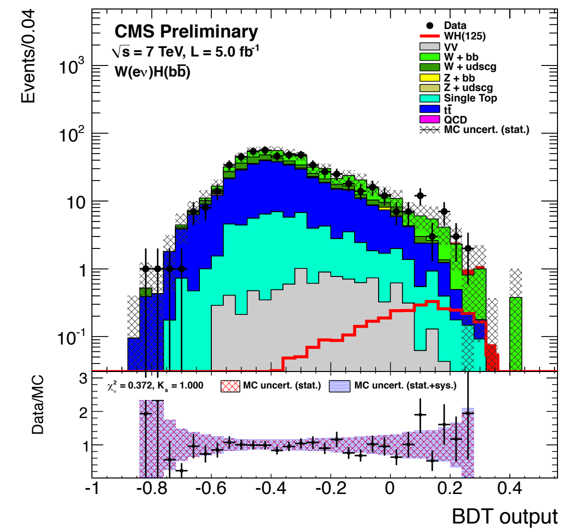


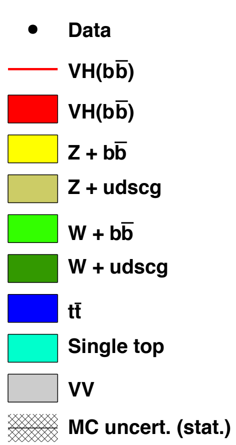
Results

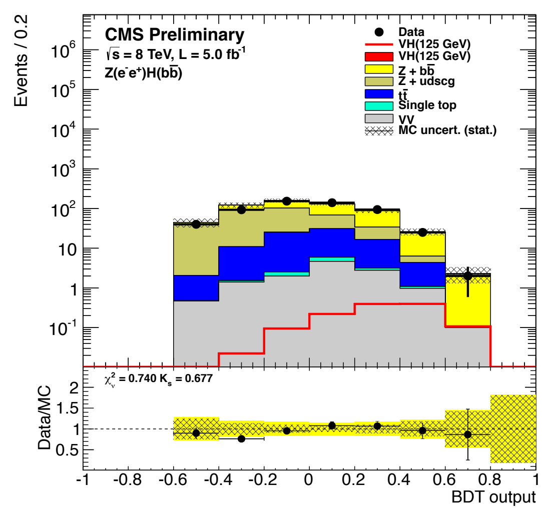
Shape Fit of the BDT Output

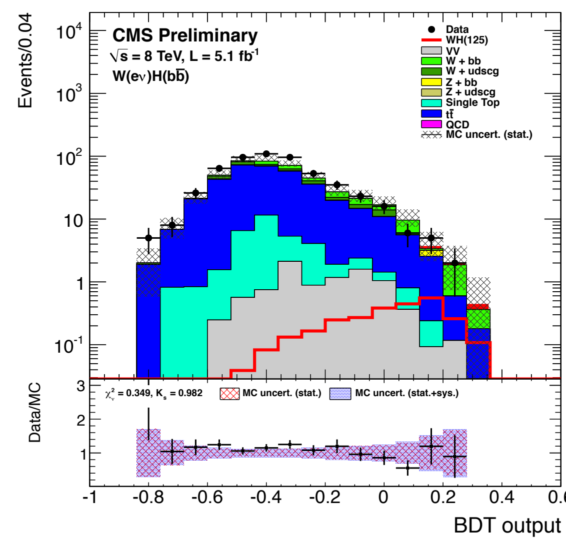












Results

m_H(GeV)	110	115	120	125	130	135
Exp.	1.16	1.26	1.35	1.64	2.12	2.81
Obs.	1.39	1.82	2.24	2.11	4.20	3.39