Search for MSSM Higgs decaying into b quarks with CMS

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On Behalf of the CMS Collaboration

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Outline:

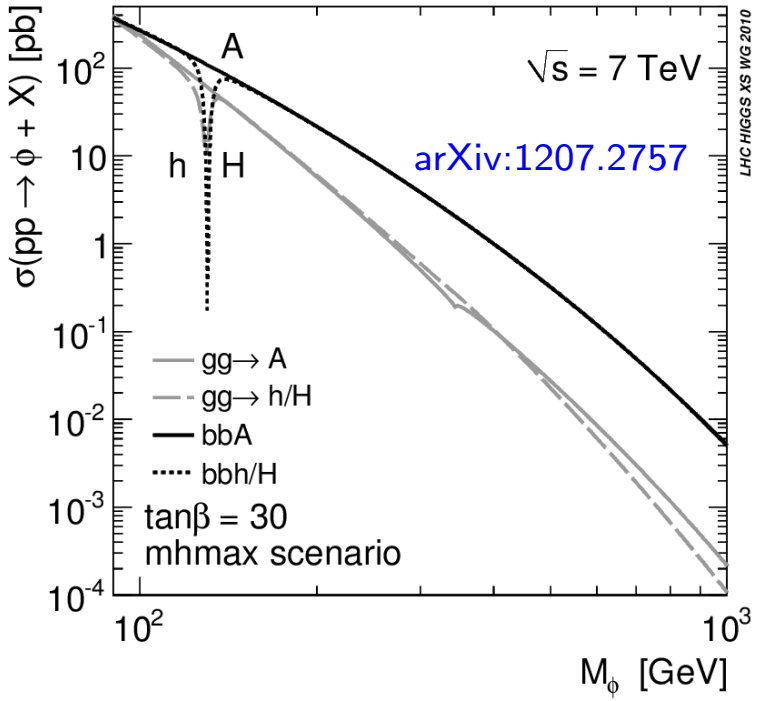
1. Neutral MSSM Higgs boson production
2. The all-hadronic $b\Phi \rightarrow b(bb)$ analysis
3. Background modelling
4. Fits to the data in the signal region
5. Systematic uncertainties and limits
6. Summary

Neutral MSSM Higgs boson production

- Higgs-like boson observed, question now is structure of Higgs sector

Minimal Supersymmetric Standard Model (MSSM)

- Two scalar Higgs doublets, five particles
  - Three neutral (h, H, A)
  - Two charged ($H^{\pm}$)
- Higgs sector defined by
  1. Mass of pseudoscalar Higgs, M_A
  2. Ratio of vacuum expectation values, $\tan\beta$



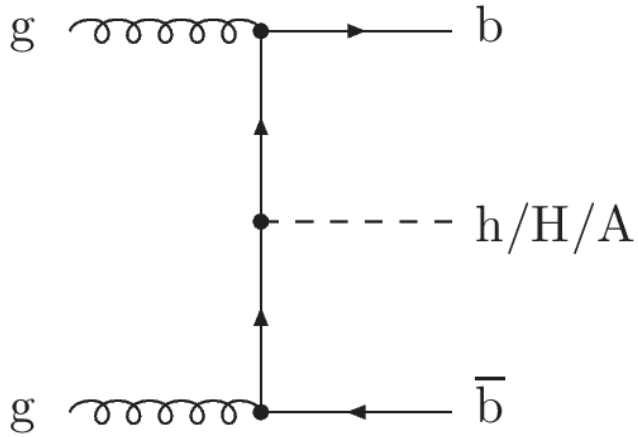
Production at the LHC:

- For relatively large values of $\tan\beta$
  - Higgs couplings to u-type particles suppressed w.r.t. Standard Model
  - Couplings to d-type particles enhanced by $\tan\beta$
  - Mass degeneration within experimental resolution
  - $\rightarrow$ Enhancement of Higgs production in association with b quarks by $\approx 2\tan^2\beta$
  - High branching ratio of $\approx 90\%$ for the decay to b quarks

MSSM $\Phi \to bb$ searches

Signature:

- Search for Higgs decaying to a pair of b quarks + at least one additional b quark
- Signal would show up as a peak in the invariant mass distribution of the two leading jets
- Very large background, dominated by QCD multi-jet events



2011 CDF+D0 results (arXiv:1207.2757):

- $\sim 2\sigma$ excess around $M_\Phi \sim [120, 150]\,\mathrm{GeV}$

Searched for with CMS using two complementary approaches:

1. All-hadronic: Final state characterized purely by jets ←*focus of this talk*
2. Semi-leptonic: Requirement of additional non-isolated muon

All-hadronic $b\Phi \rightarrow b(bb)$ analysis

Challenging trigger due to large hadronic interaction rate:

- Dedicated trigger developed
- Requirement of at least 2 to 3 centrally ($|\eta| < 2.6$) produced jets
- Online b-tagging: Select ≥ 2 b-tagged jets based on the impact parameter significance of 2^{nd} most significant track

Two scenarios for Higgs mass hypothesis:

1. Low mass scenario ($M_\Phi < 180$ GeV): $P_T^{jet1(2,3)} > 46\ (38,\ 20)$ GeV
   $\rightarrow$ integrated luminosity: 2.7 fb^{-1} at $\sqrt{s} = 7$ TeV
2. Medium mass scenario ($M_\Phi \geq 180$ GeV): $P_T^{jet1(2,3)} > 60\ (53,\ 20)$ GeV
   $\rightarrow$ integrated luminosity: 4.0 fb^{-1} at $\sqrt{s} = 7$ TeV

Additional offline cuts:

- $\Delta R > 1$ between two leading jets to suppress background from gluon splitting
- Offline b tagging for selected jets using *"Combined Secondary Vertex"* algorithm

The analysis strategy

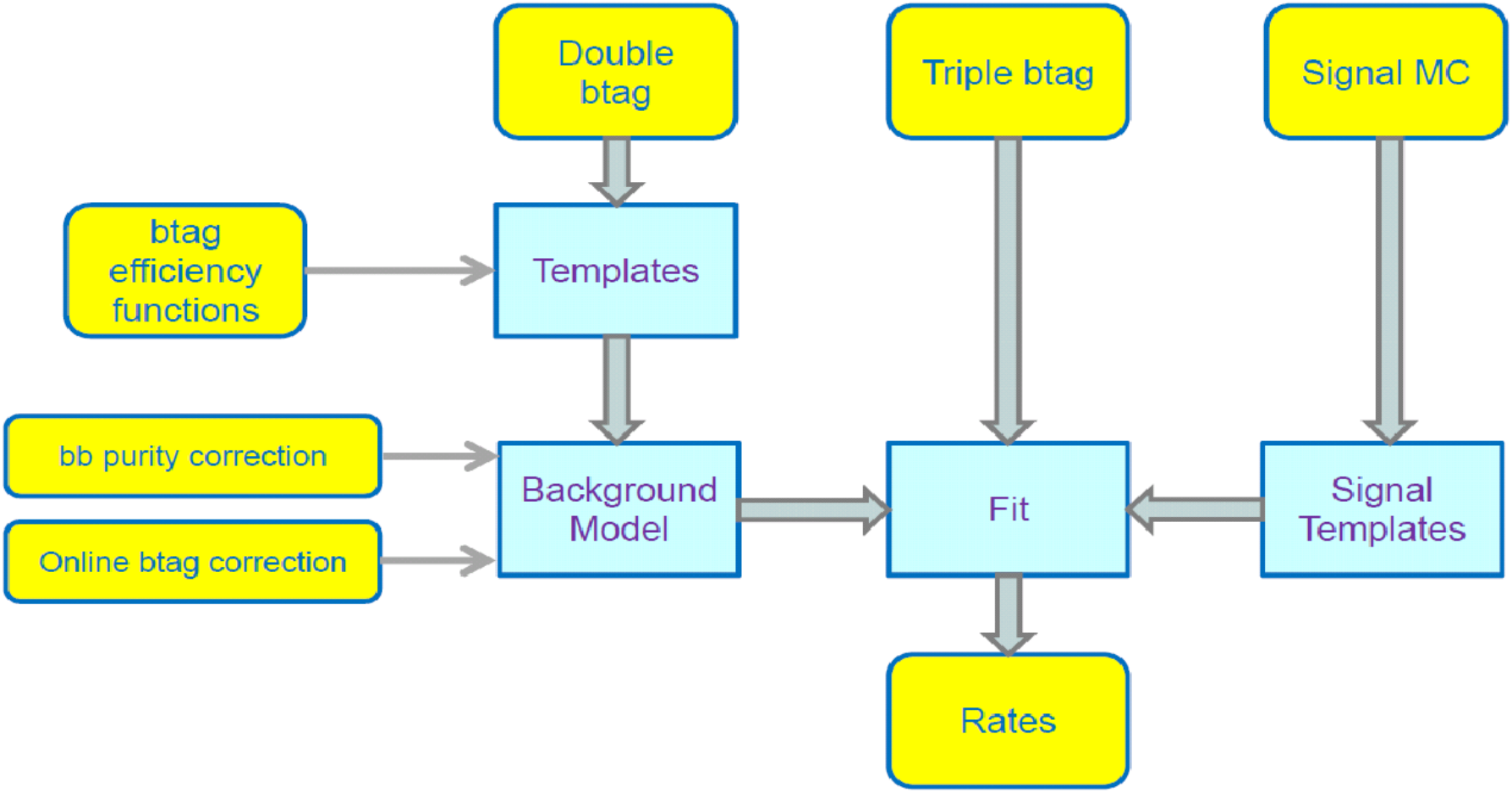
Signature of the signal:

Events with at least three b-tagged jets (Triple b-tag sample)

Background:

- Composed of multi-jet events (mainly from QCD) with three b jets and two b jets + one misidentified c or light-flavour jet
- Other backgrounds such as $t\bar{t}$ and Z + jets found to be small
- Analysis employs a data-driven technique to model the background
  - $\rightarrow$ Construction of background templates using events with two b-tagged jets (Double b-tag sample)

The analysis strategy



Background model in data

Construction of background templates in double b-tag sample:

- Require at least 3 jets (sorted in p_T)
- Assign flavour assumption of b, c, udsg for untagged jet **X**

  → **bbX**, **bXb**, **Xbb**

→ Nine different templates

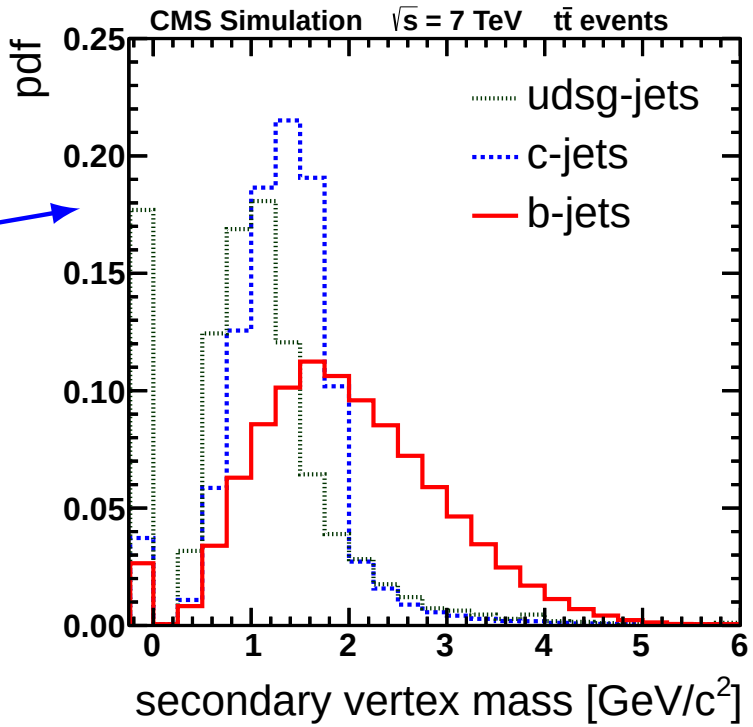
- Apply probability of the assumed flavour to be identified as b jet to the events
  - Probabilities extracted from background MC

- Templates have been constructed for the invariant dijet mass, M_{12}, distribution

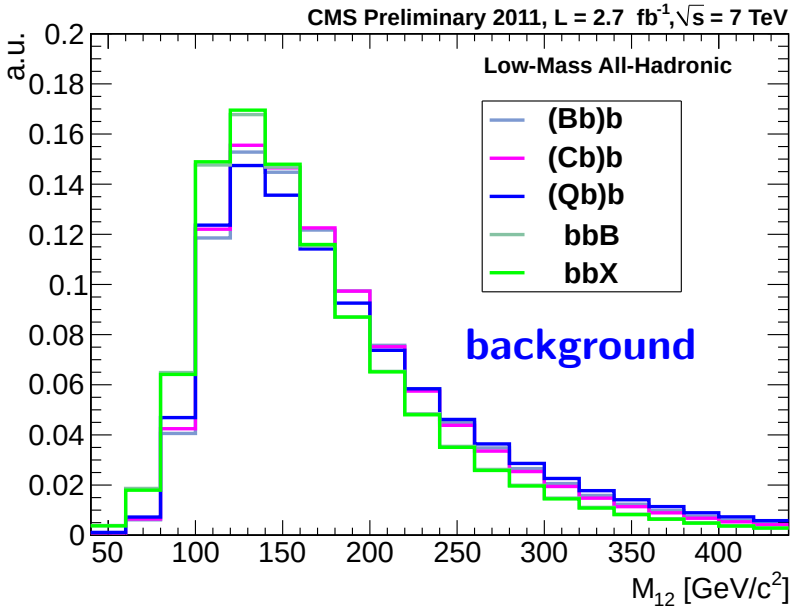
→ Need additional handle on the flavour composition of the events

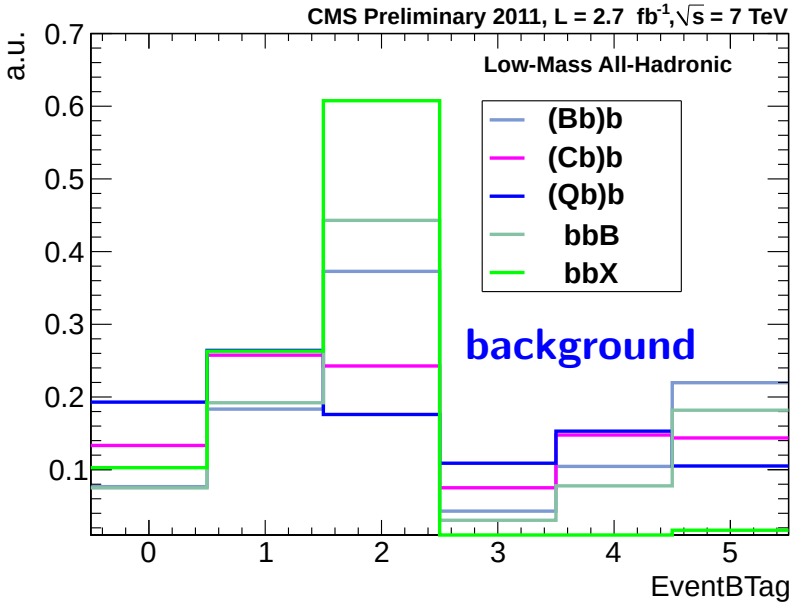
→ Secondary vertex mass sensitive to the flavour of jets

→ Improved distinction between templates shapes by utilising M_{12} and "EventBTag" which is based on the secondary vertex mass of all three considered jets



Background and signal templates



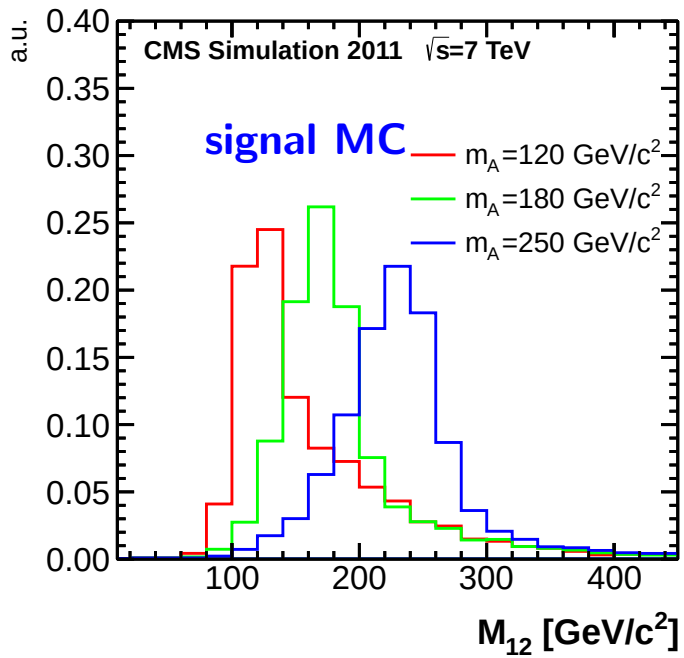


- Similar Background templates are merged :

→ (Qb)b=Qbb+bQb

→ Reduction from 9 to 5 templates!

- "EvtBtag" helps to distinguish e.g. (Bb)b and (Qb)b
- Signal templates extracted from MC



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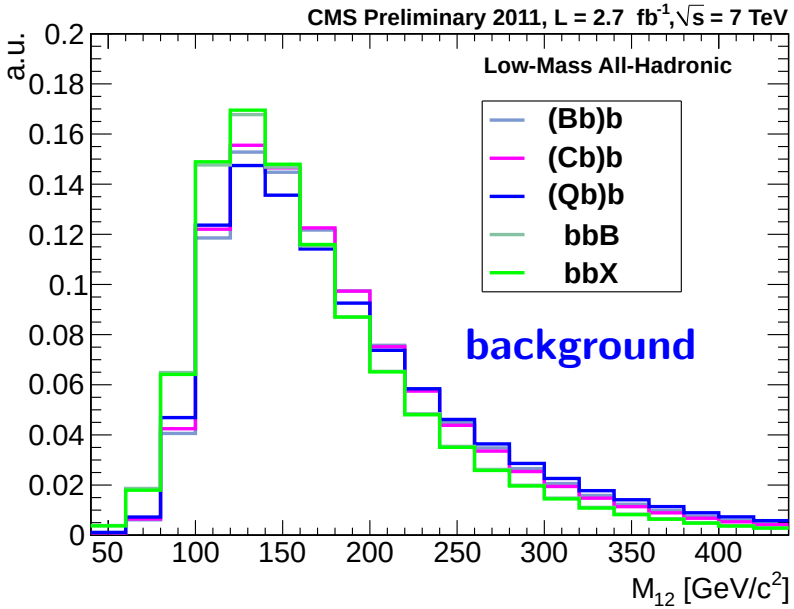

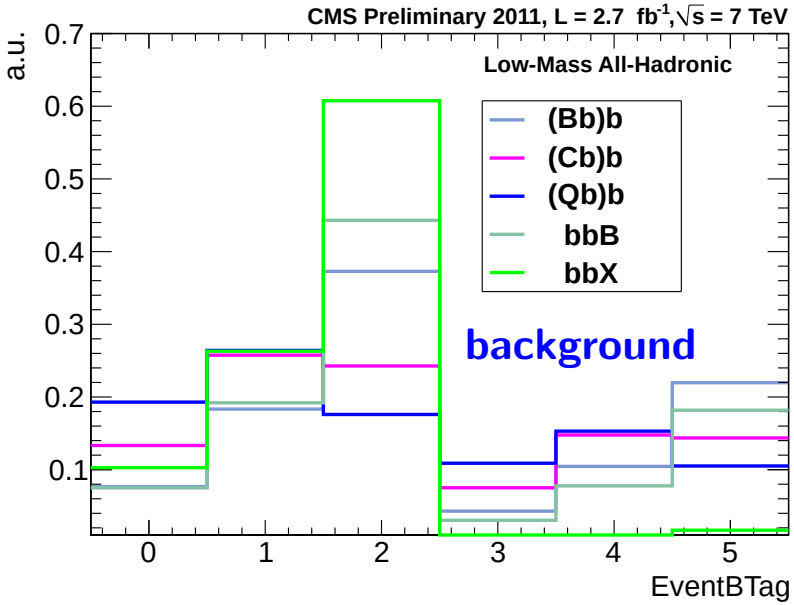

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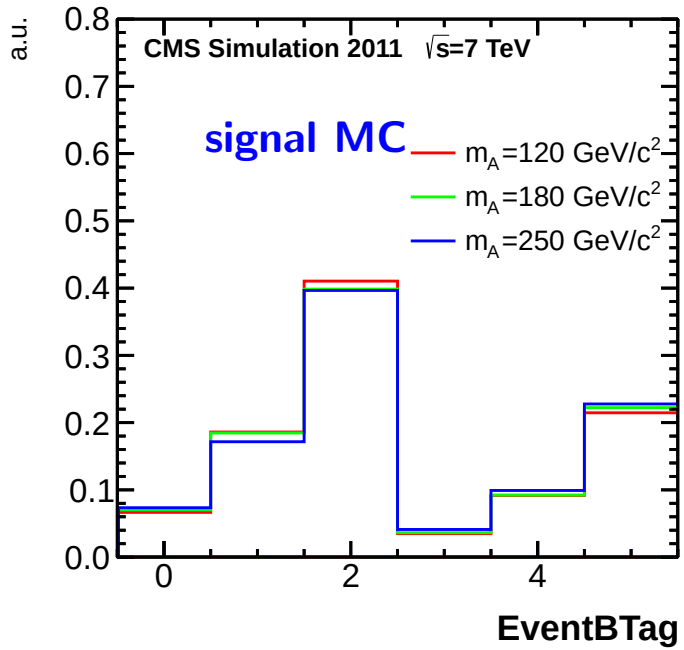
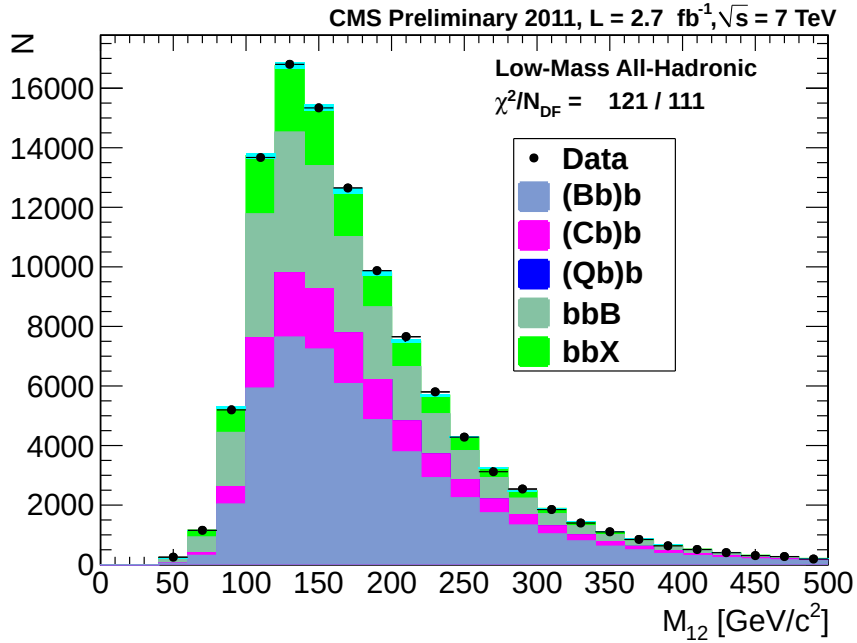
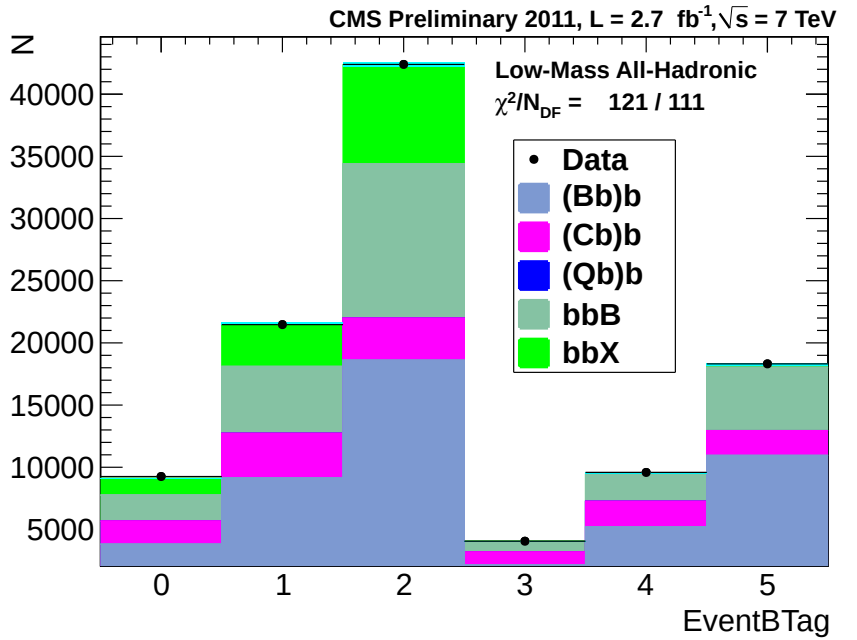


Background-only fit in signal region

Low mass scenario:

- Fit of linear combination of background templates in the signal region (triple b-tag sample)
- Good agreement of fit result with the data
- Background mainly ($\sim 70\%$) composed of three b jets
- No indication of an excess



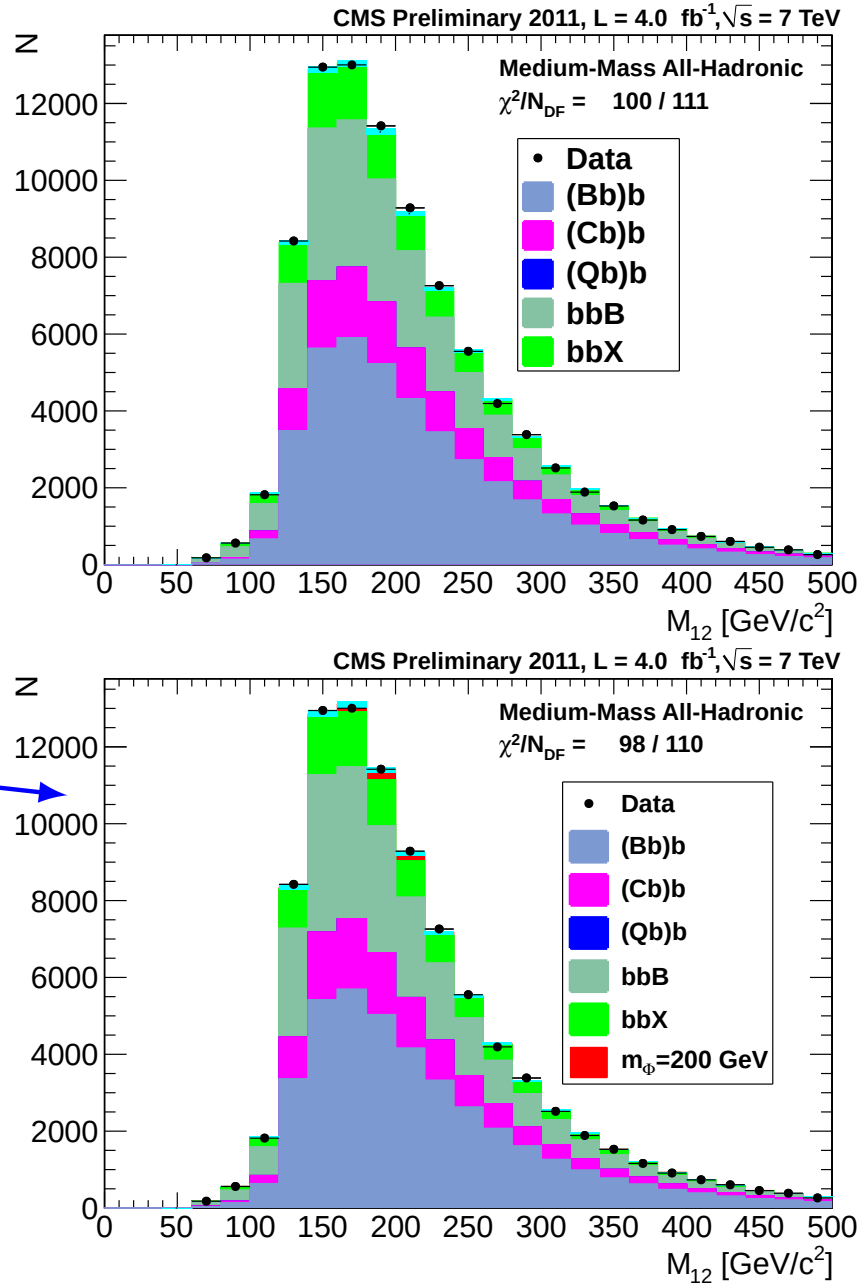


Background+signal fit in signal region

Medium mass scenario:

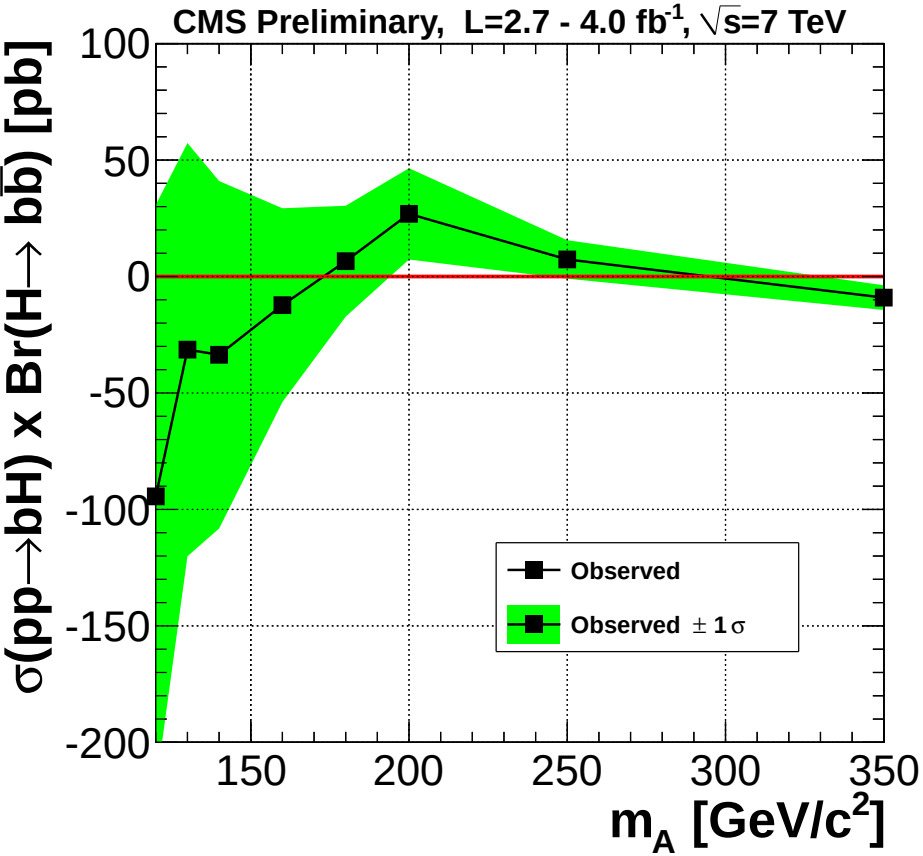
- Fit of linear combination of background + signal templates in the signal region (triple b-tag sample)
- Performed for Higgs masses from 90 to 350 GeV
- Shown: $M_\Phi = 200$ GeV
  - Good fit quality
  - Largest upward fluctuation of the signal: $\sim 1.4\sigma$

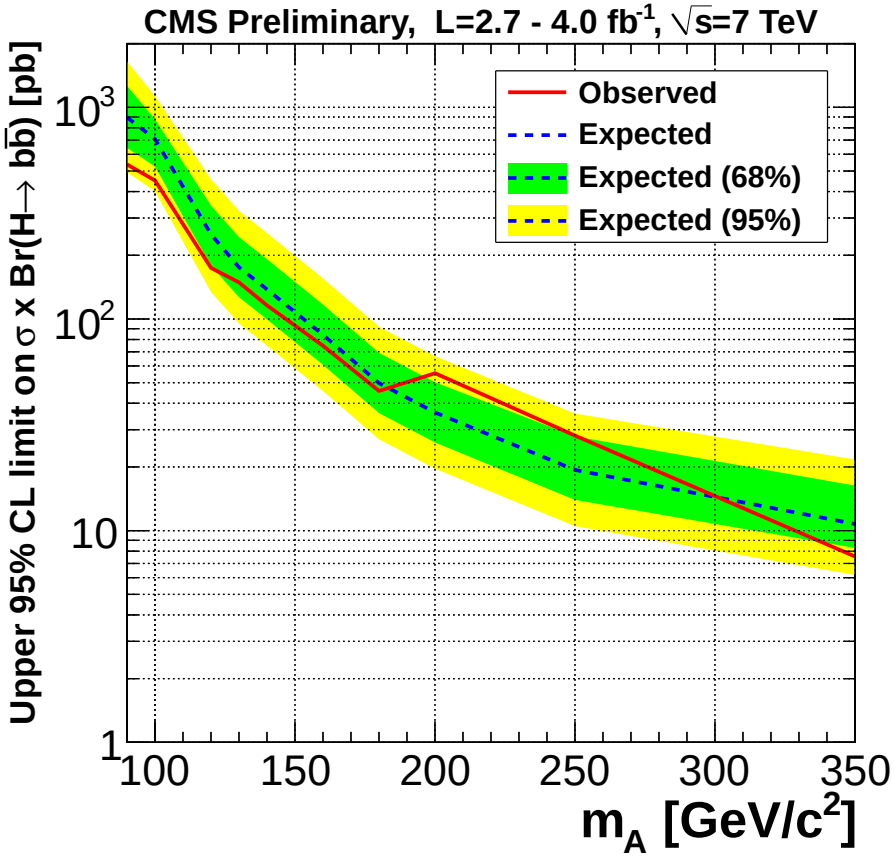
$\rightarrow$ No significant deviation from background observed



Extraction of cross sections × branching ratio and limits

- Extraction of observed cross sections × branching ratio as a function of Higgs mass and limits

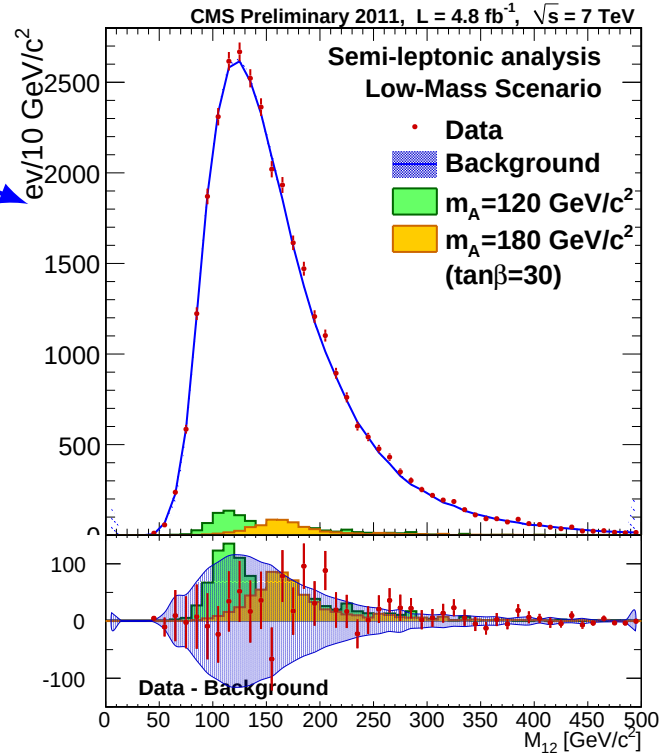




→ **No observation of a Higgs boson!**

Combination and systematic uncertainties

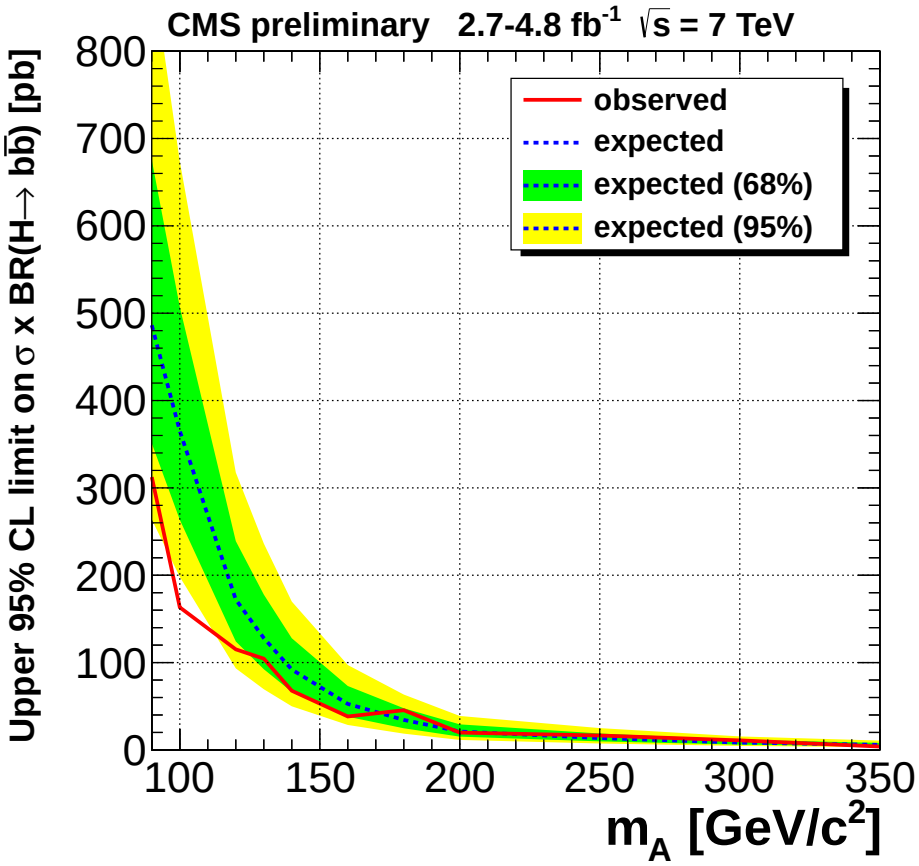
- Combination of results from semi-leptonic and all-hadronic analyses
  - Common events removed from all-hadronic analysis
  - Small statistical overlap of ($\sim 2.5\%$) due to requirement of additional muon and, hence, rather different kinematical selection cuts
  - Statistical and systematic uncertainties and correlations thoroughly treated

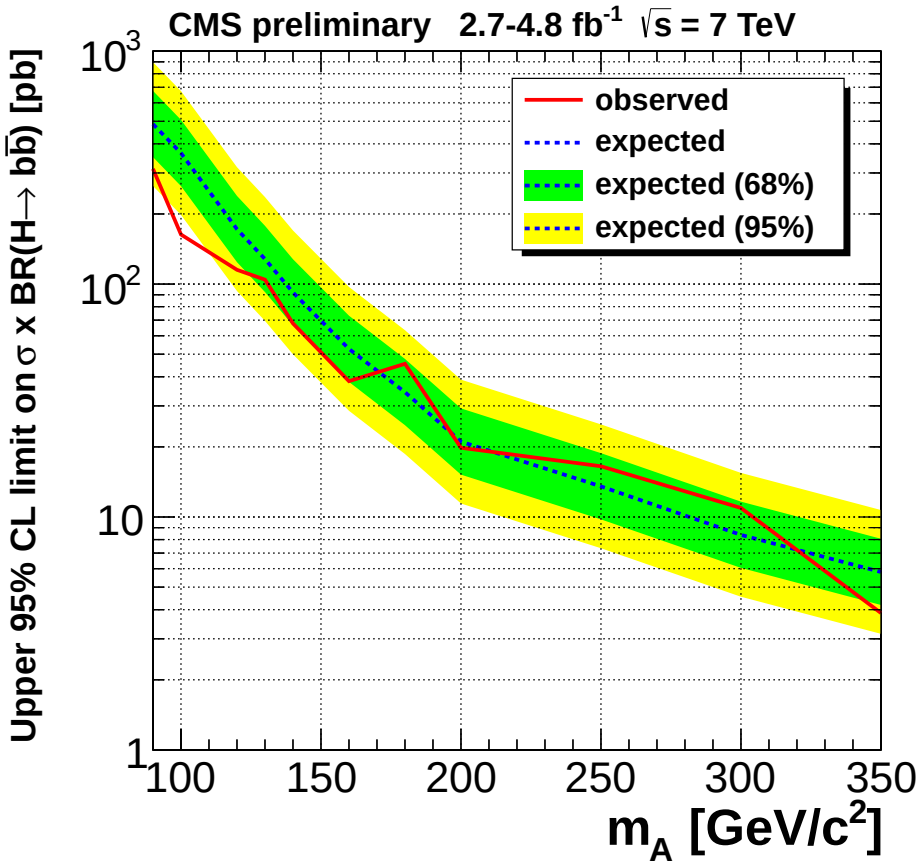


Source	all-hadronic	semi-leptonic	type
Trigger efficiency	10%	$3-5\%$	rate
Online b-tagging efficiency	32%	-	rate
b-tagging efficiency	$10-13\%^{\dagger}$	12%	shape/rate
b-tagging efficiency dependence on topology	6%	-	rate
Jet Energy Scale	$1.4-6.8\%$	$^{+2.5}_{-3.1}\%$	shape/rate
Jet Energy Resolution	$0.6-1.3\%$	1.9%	shape/rate
Muon momentum scale	-	0.2%	rate
Muon momentum resolution	-	0.6%	rate
Signal Monte Carlo statistics	$1.1-2.6\%$		rate
Integrated luminosity	2.2%		rate
PDF and α_s uncertainties*	$3-6\%$	$^{+(2.5-4.7)}_{-(2.7-4.4)}\%$	rate
Renormalisation and fragmentation QCD scale*	$6-28\%$		rate
Underlying event and parton showering*	4%		rate

In all-hadronic analysis shape altering systematic uncertainties are implemented as nuisance parameters in the fit

95% CL upper limits on cross sections × branching ratio



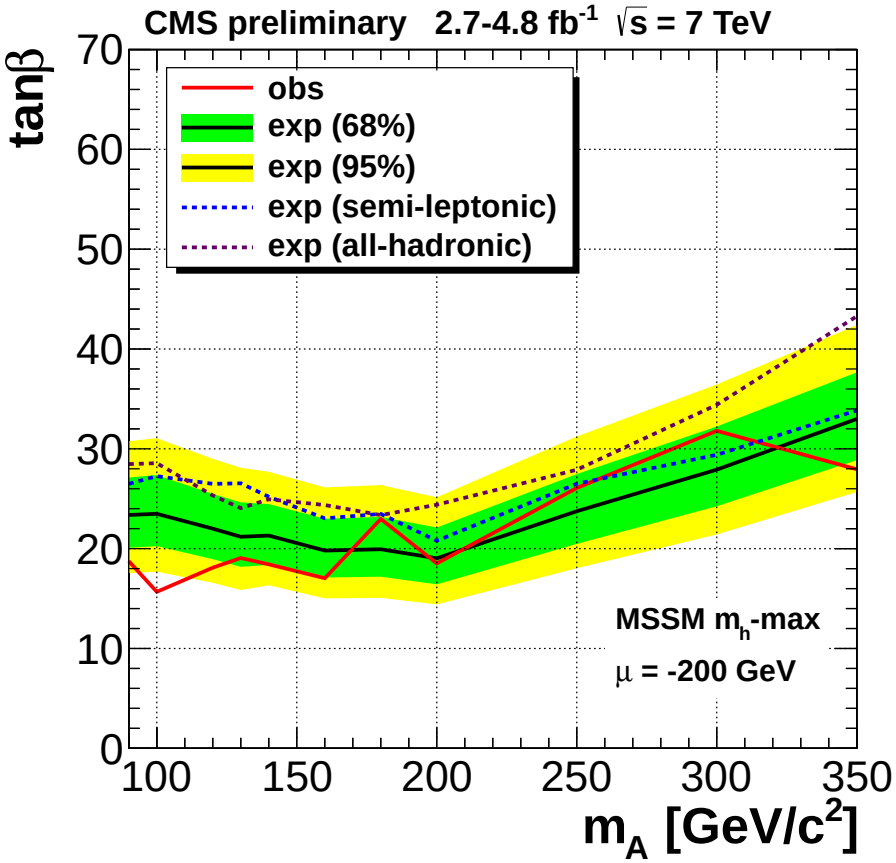


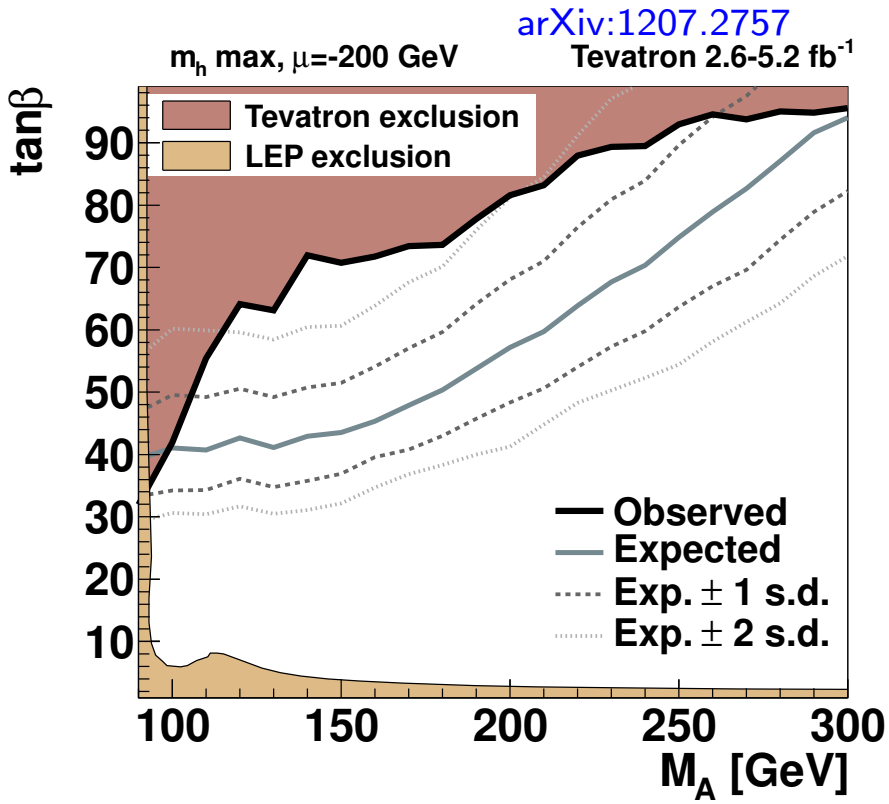
→ Observed combined limits statistically in agreement with expected limits!

→ In particular no excess present at low m_A as seen by CDF/D0

Comparison of MSSM limits with Tevatron results

- Combined result translated to the MSSM framework as functions of the mass of the pseudoscalar Higgs, m_A, and $\tan\beta$





- CMS results more sensitive to MSSM parameter space

Summary

- A search for a MSSM Higgs boson decaying into a pair of b quarks and produced in association with at least one additional b quark was performed[abc]
- Measurement performed for the first time at CMS
  - $\rightarrow$ Currently it is the only measurement at the LHC!
- No evidence for an excess of events was found
- The results from a all-hadronic and semi-leptonic analyses have been combined
- Limits as functions of $\tan\beta$ and m_A have been derived and found to exclude a considerable amount of the MSSM parameter space
- Currently most stringent MSSM Higgs limits in this decay channel

$\rightarrow$ Analysis will be extended to 2012 dataset ($\sqrt{s} = 8\ \mathrm{TeV}$)

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[a] https://twiki.cern.ch/twiki/bin/view/CMSPublic/Hig12027TWiki
[b] https://twiki.cern.ch/twiki/bin/view/CMSPublic/Hig12026TWiki
[c] https://twiki.cern.ch/twiki/bin/view/CMSPublic/Hig12033TWiki

Backup

Background model in data

Construction of background templates in double b-tag sample:

- Require at least 3 jets (sorted in p_T)
- Assign flavour assumption of b, c, udsg for untagged jet **X**

  → **bbX**, **bXb**, **Xbb**

→ Nine different templates

- Apply probability of the assumed flavour to be identified as b jet to the events

- $B_j = 0$ if $M_{\mathrm{SV}} \leq 1\ \mathrm{GeV}$
- $B_j = 1$ if $1 < M_{\mathrm{SV}} \leq 2\ \mathrm{GeV}$
- $B_j = 2$ if $M_{\mathrm{SV}} > 2\ \mathrm{GeV}$

→ EventBTag$= T_{12} + T_3$

- $T_{12} = 0$ if $B_1 + B_2 < 2$
- $T_{12} = 1$ if $2 \leq B_1 + B_2 < 3$
- $T_{12} = 2$ if $B_1 + B_2 \geq 3$
- $T_3 = 0$ if $B_3 < 2$
- $T_3 = 3$ if $B_3 = 2$