Search for a low-mass charged Higgs boson ($H^+ \to c\bar{s}$) in $t\bar{t}$ events with CMS

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Outline

- ✓ Introduction
- ✓ Signal and Backgrounds
- ✓ CMS Detector
- ✓ Trigger and Datasets
- ✓ Object Identification
- ✓ Event Selection
- ✓ Control Plots
- ✓ $t\bar{t}$ Event Reconstruction
- ✓ Results and Summary

Introduction

- In 2012, ATLAS and CMS discovered a new particle with mass ~125 GeV
- Within expt. uncertainties, this particle seems to be compatible with the standard model (SM) Higgs boson
- Still we know that the SM cannot be the full story having several missing links, such as dark matter and matter-antimatter asymmetry

⇓

Motivation for physics beyond the standard model (BSM)

- Many extensions to SM have been proposed to answer these questions
- MSSM (or 2HDM) is one such model that consists of two Higgs doublets resulting five scalars : three neutral and two charged Higgs ($H^{\pm}$) bosons
- Finding more higgs will be a definitive signal for new physics

Chasing the charged Higgs at LHC

- Production and decay rates at the tree level depend only on two parameters:
  1) Ratio of vacuum expectation values between two Higgs doublets ($\tan\beta$)
  2) Mass of the CP-odd neutral Higgs boson (m_A)

- Two possible production mechanisms at LHC:

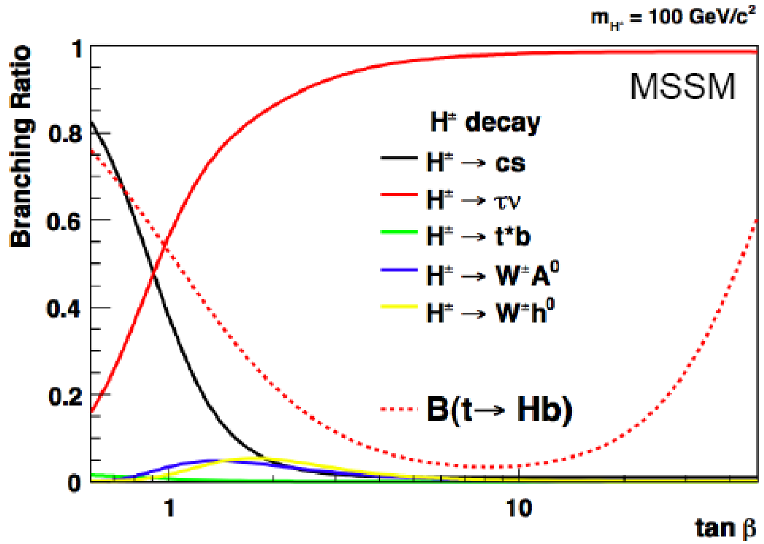
For $m_{H^+} < m_t$:

$pp \to t\bar{t} \to bH^{\pm}\bar{b}W^{\mp}$ with $t \to bH^+$

For $m_{H^+} \geq m_t$: $pp \to tbH^{\pm}$

- Our focus is on the low-mass charged Higgs boson ($m_{H^+} < m_t$)

- For a small value of $\tan\beta$ (< 1), the dominant decay channel is $H^+ \to c\bar{s}$

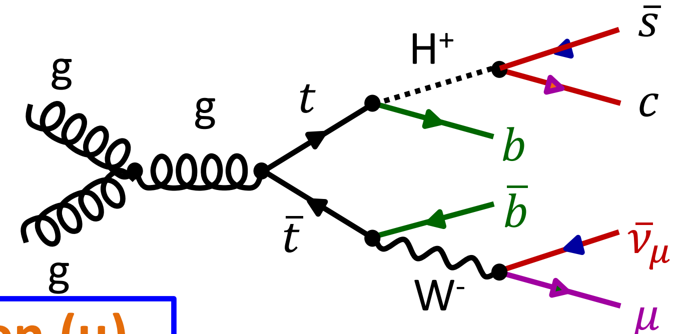


D0 Note 5715-CONF

Signal vs Backgrounds

Signal:

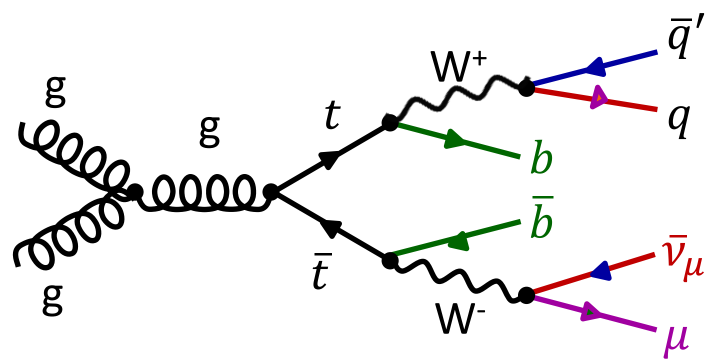
$t\bar{t} \rightarrow bH^{+}\bar{b}W^{-}$ with $H^{+} \rightarrow c\bar{s}$



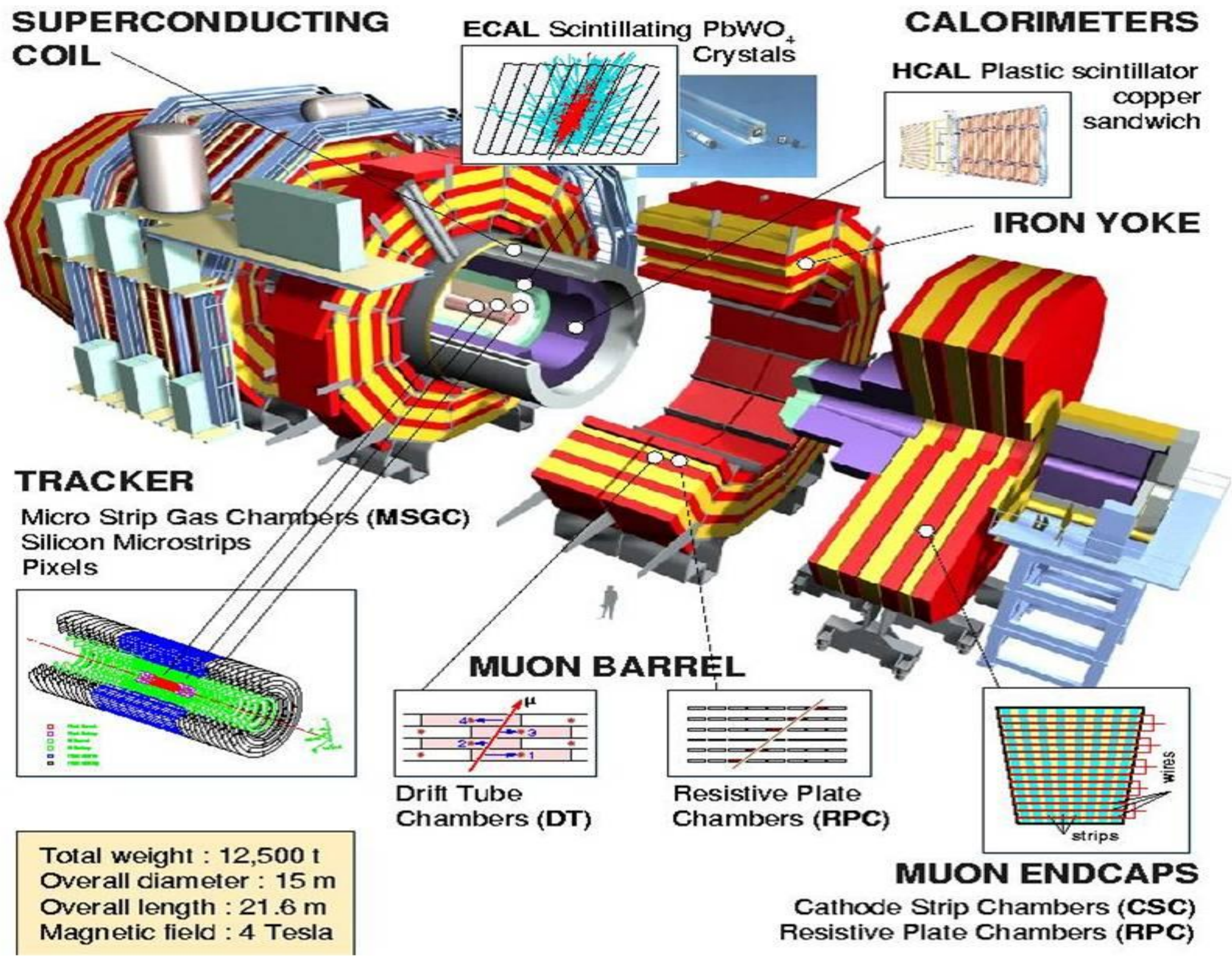
Final state comprises an isolated high p_T lepton (μ), MET due to missing neutrino from the W decay and four or more jets (at least two are b-tagged)

Backgrounds :

- Irreducible SM $t\bar{t} \rightarrow bWbW \rightarrow b\ell\nu bq\bar{q}'$
- Other major backgrounds: single top and W+jets
- Minor contributions from Z+jets and dibosons (WW, WZ, ZZ)



CMS Detector



Data and MC Samples

- Total data in proton-proton collisions @ 8 TeV correspond to an integrated luminosity of 19.7 fb^{-1}
- Event triggered with a single muon with $p_T > 24$ GeV and $|\eta| < 2.1$
- Signal sample is generated with PYTHIA 6.4 and normalized using the same production cross-section as SM $t\bar{t}$
- Background modeling:
  ⇨ $t\bar{t}$, W+jets and Z+jets are generated with MADGRAPH interfaced with PYTHIA 6.4
  ⇨ UE tuning Z2* and CTEQ6M PDFs are used
  ⇨ Single top samples generated with POWHEG

Object Identification

- ✓ Objects are reconstructed using information from various CMS sub-detectors with the particle flow (PF) algorithm
- ✓ Muons are reconstructed by combining information from the tracker and the muon detector
- ✓ Electrons are identified by matching energy deposits in the electro-magnetic calorimeter with tracks in the tracker
- ✓ Missing transverse energy (MET) is calculated as the negative vector sum of the transverse momenta of all PF objects
- ✓ Jets are reconstructed based on PF candidates using the anti-k_T algorithm with a radius parameter of 0.5

Event Selection

Analysis Flow

1 tight and isolated Muon → At least 4 jets → Missing Transverse Energy → Two b-tagged Jets

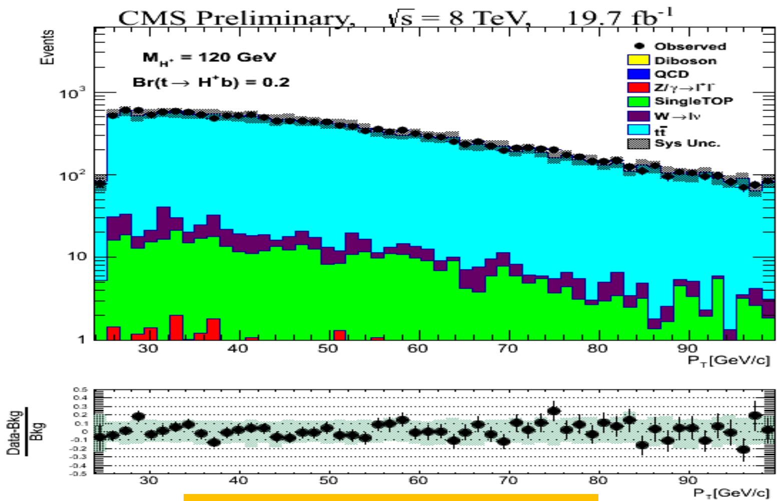
- **1 tight and isolated muon**
- **Relative isolation < 0.12**
- **p_T > 25 GeV, $|\eta|$ < 2.1**
- **Veto the 2nd lepton with p_T > 10 GeV, $|\eta|$ < 2.5 and relative isolation < 0.3**

    - **Jet p_T > 30 GeV and $|\eta|$ < 2.5**
    - **MET (PF) > 20 GeV**

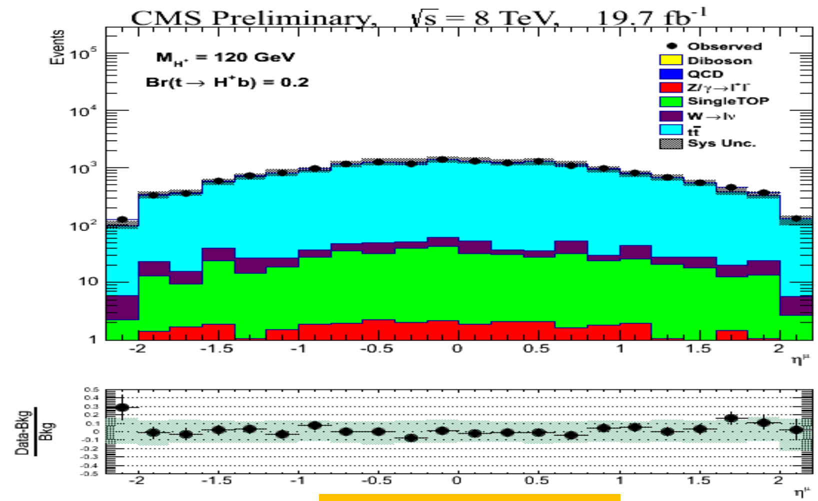
        - **At least 2 b-tagged jets [discriminator > 0.679 (CombinedSecondaryVertexMedium) WP]**

Data-MC Comparisons-I

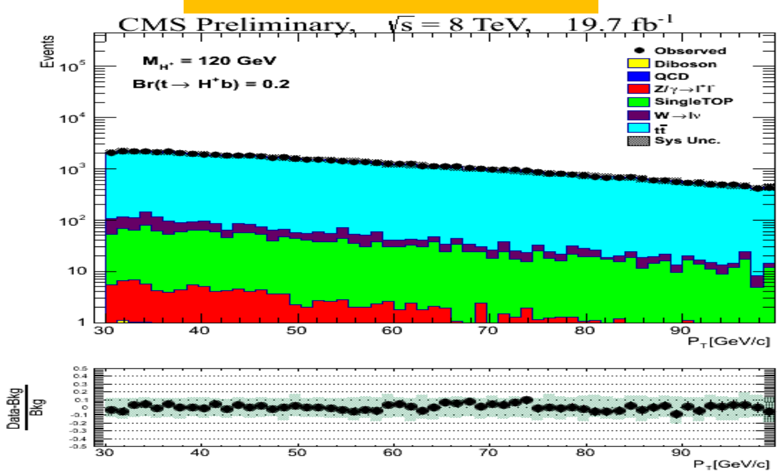
Muon transverse momentum



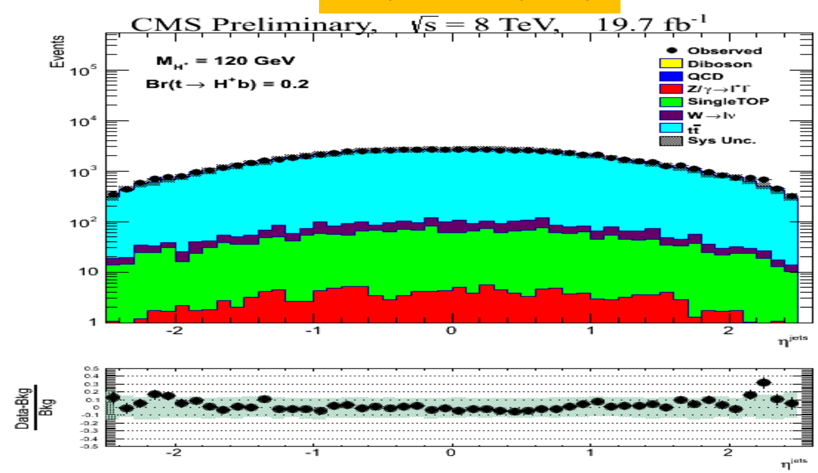
Muon pseudorapidity



Jet transverse momentum

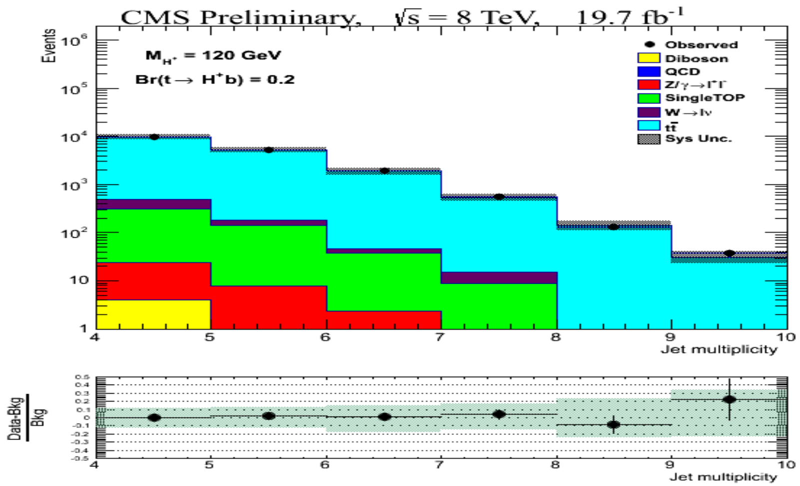


Jet pseudorapidity

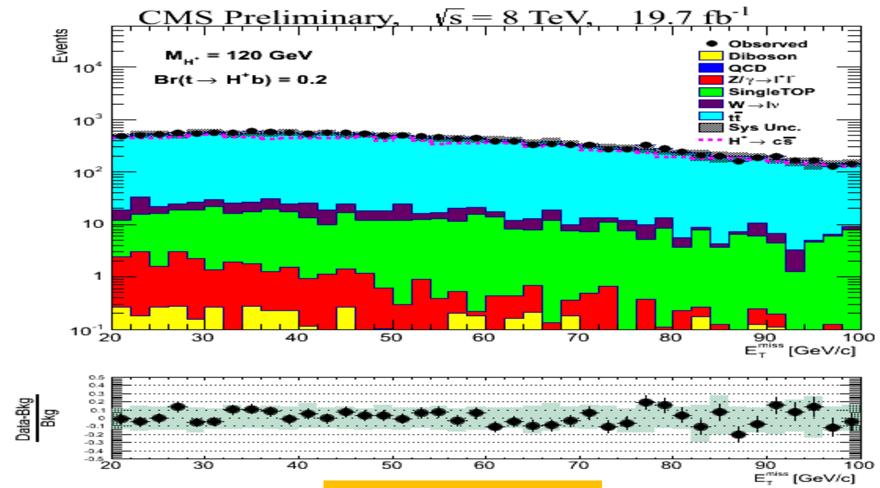


Data-MC Comparisons-II

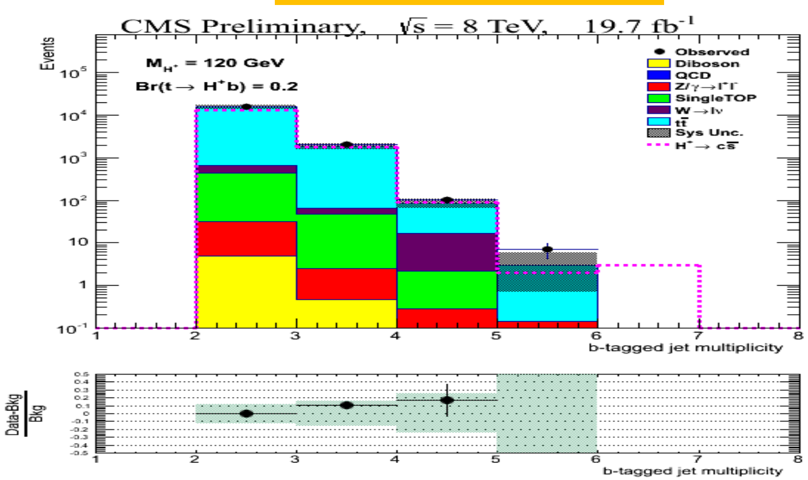
Jet multiplicity



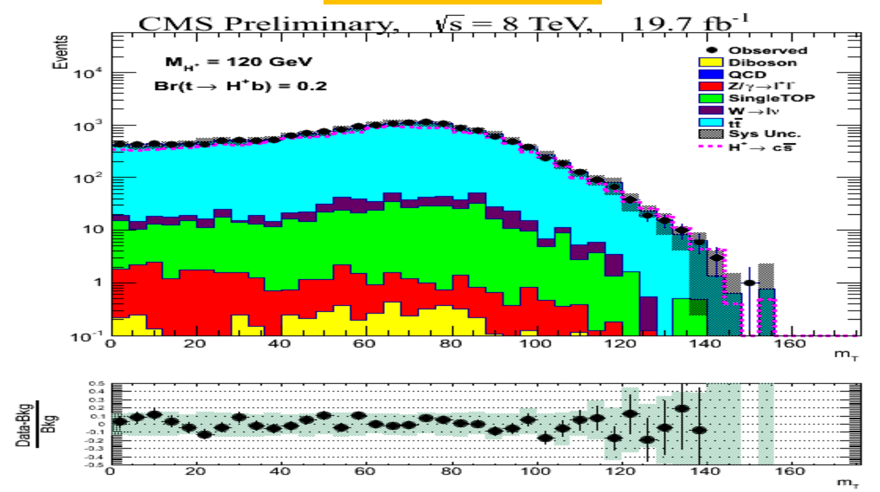
Missing transverse energy



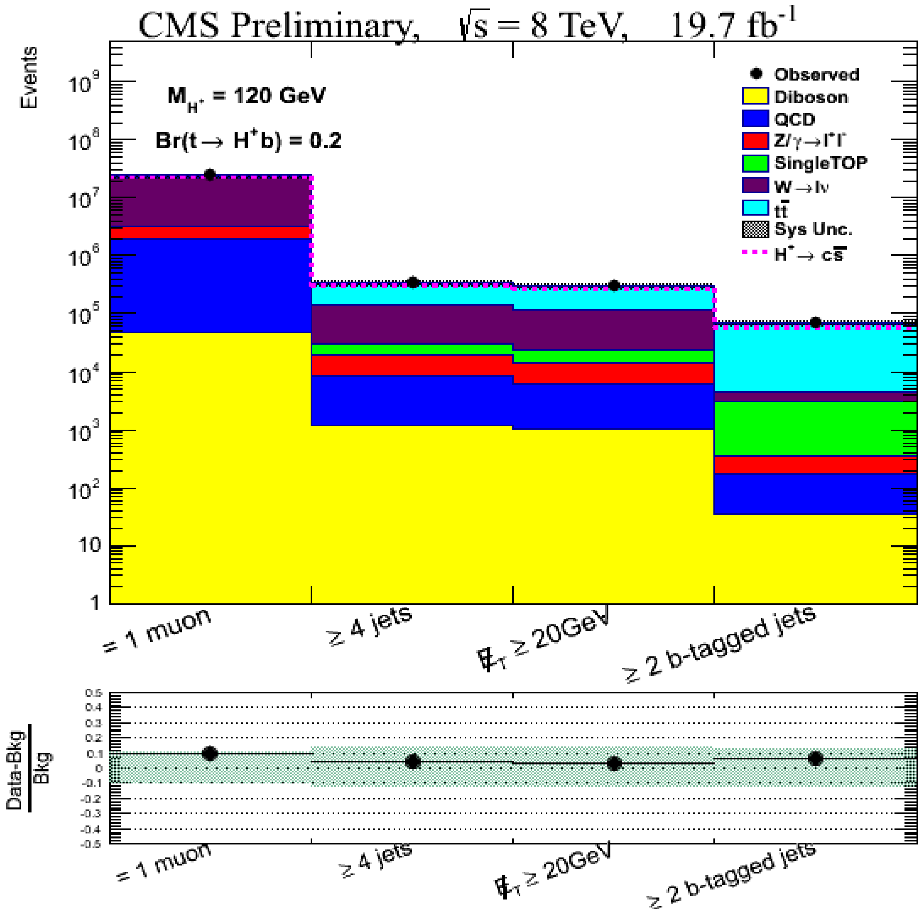
b-tagged jet multiplicity



Transverse mass



Cutflow Plot



Stat ⊕ Syst on MC

The dotted line corresponds to the total BSM event yield

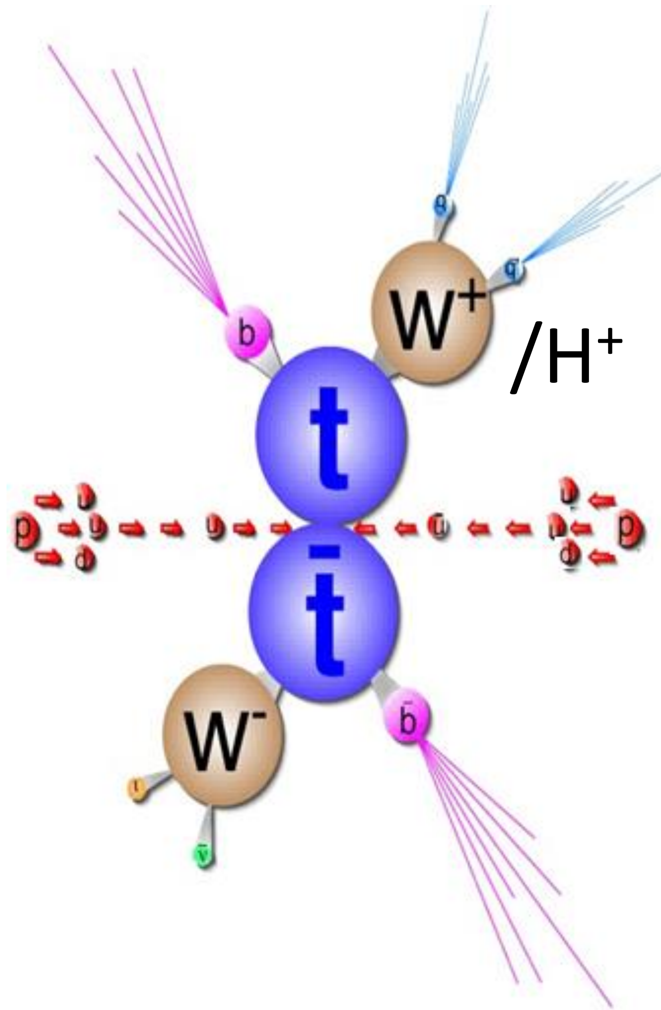
x = BR($t \rightarrow bH^{+}$) = 0.2

$$N^{\mathrm{BSM}}_{\mathrm{total}} = (1-x)^2 \times N_{t\bar{t}\rightarrow bW^{\pm}\bar{b}W^{\mp}} + 2 \times x \times (1-x) \times N_{t\bar{t}\rightarrow bW^{\pm}\bar{b}H^{\mp}} + N_{\mathrm{other}},$$

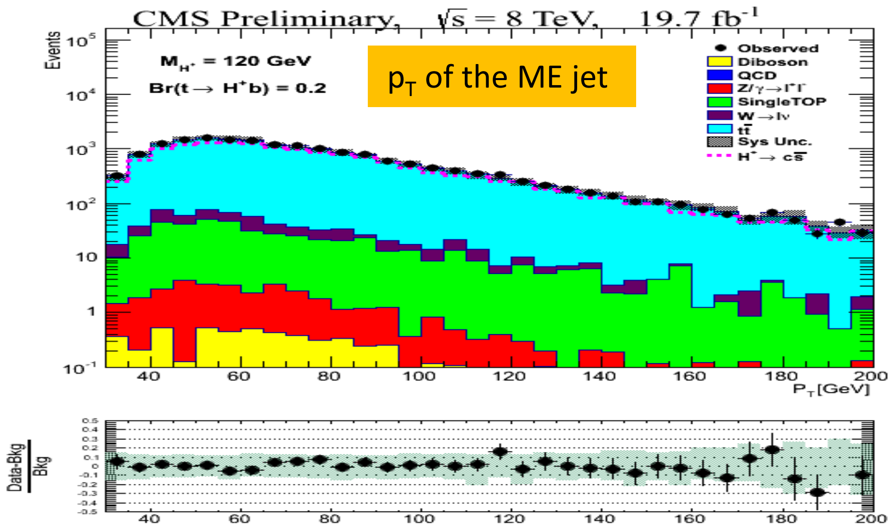
W/H Mass Reconstruction

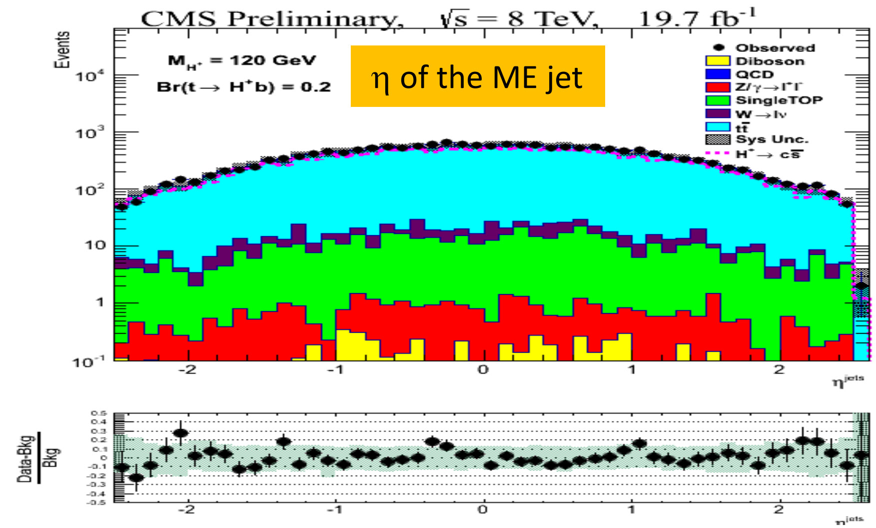
Using a kinematic fit with both top mass constraint to reconstruct the dijet mass for the W/H^{+} boson

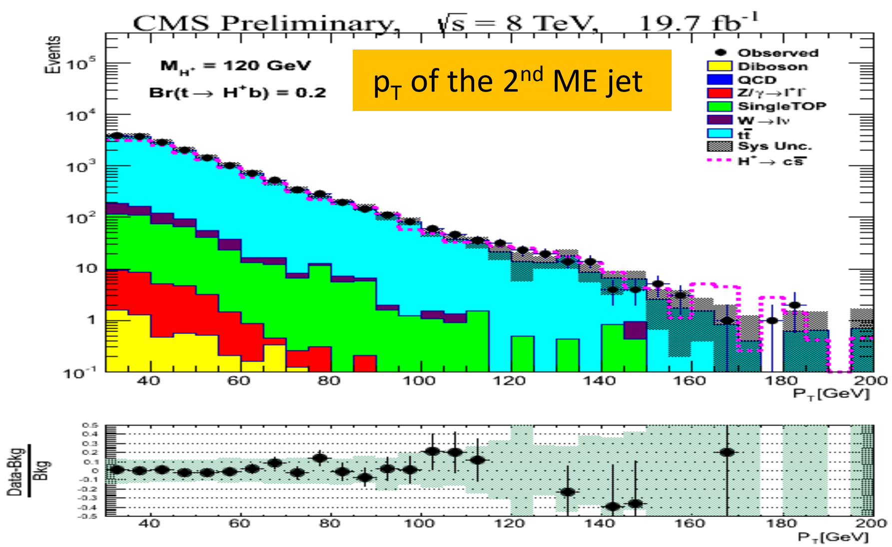
- ✓ Fit inputs: muon, all jets passing jet selection, MET and the corresponding resolutions
- ✓ In the kinematic fit, b-jets are required to be b-tagged with the CSVM working point
- ✓ We constrain the mass of both hadronic and leptonic decaying top quarks
- ✓ No constraint is applied on the W mass as we expect H^{+} in the dijet mass distribution

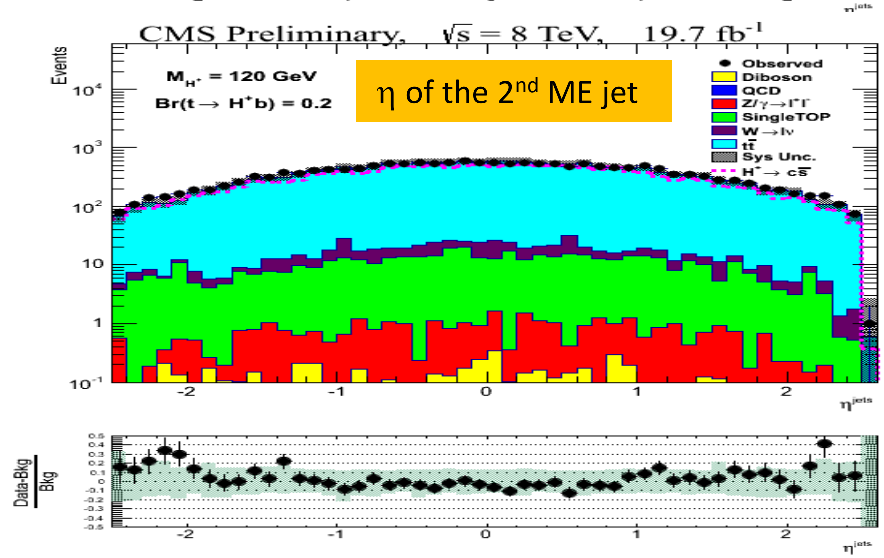


Jet distributions after the kinematic fit









Systematic Uncertainties

- **JES uncertainty:**
  Jet energy scale uncertainty, evaluated as function of jet p_T and η, used as a shape uncertainty to the exclusion limit
- **JER uncertainty:**
  Jet energy resolution in data is known to be worse than simulations, jets in MC samples are smeared according to:
  $$p_T(\mathrm{rec}) \rightarrow \max[0.0,\ p_T(\mathrm{gen}) - c \times (p_T(\mathrm{rec}) - p_T(\mathrm{gen}))]$$
- **b-tagging uncertainty:**
  Data/MC scale factor for b-tagging efficiency and mis-tag rates used to rescale MC and the corresponding uncertainty is propagated
- **Muon trigger, identification and isolation efficiency:**
  2% total using a tag and probe method
- **Uncertainty due to top p_T re-weighting is used**
- **$t\bar{t}$ shape modeling uncertainties due to the variation of renormalization and factorization scales are used**
- **Uncertainties due to MadGraph-PYTHIA matching are also used**

Systematic Uncertainties & Events Yield

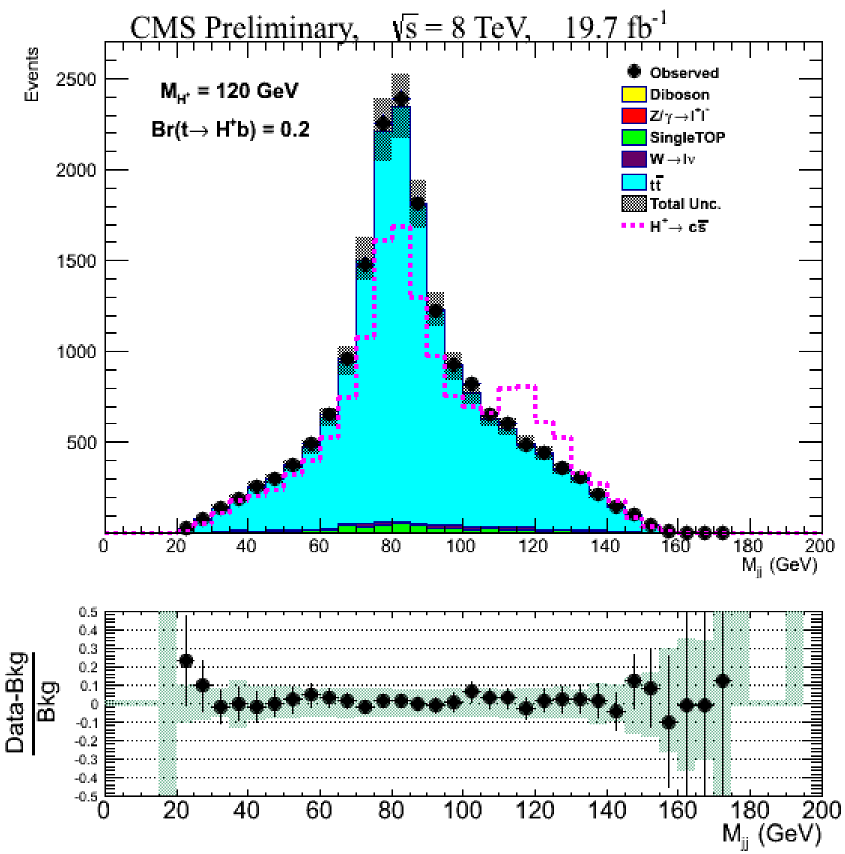
	WH	$t\bar{t}_{\mu+\text{jets}}$	W+jets	Z+jets	Single top	Dibosons
JES+JER+MET	7.8	6.5	18.5	14.2	6.9	15.8
b-jet tagging	4.2	4.6	-	-	4.2	-
Jet→b mis-id	-	-	5.8	6.5	-	8.6
Lepton selections	2.0	2.0	2.0	2.0	2.0	2.0
Cross-section	6.0	6.0	5.0	4.0	6.0	10.0
MC Statistics	3.1	0.7	7.8	6.0	3.8	10.1
Top-Pt reweighting	1.8	1.9	-	-	-	-
Luminosity	2.6	2.6	2.6	2.6	2.6	2.6

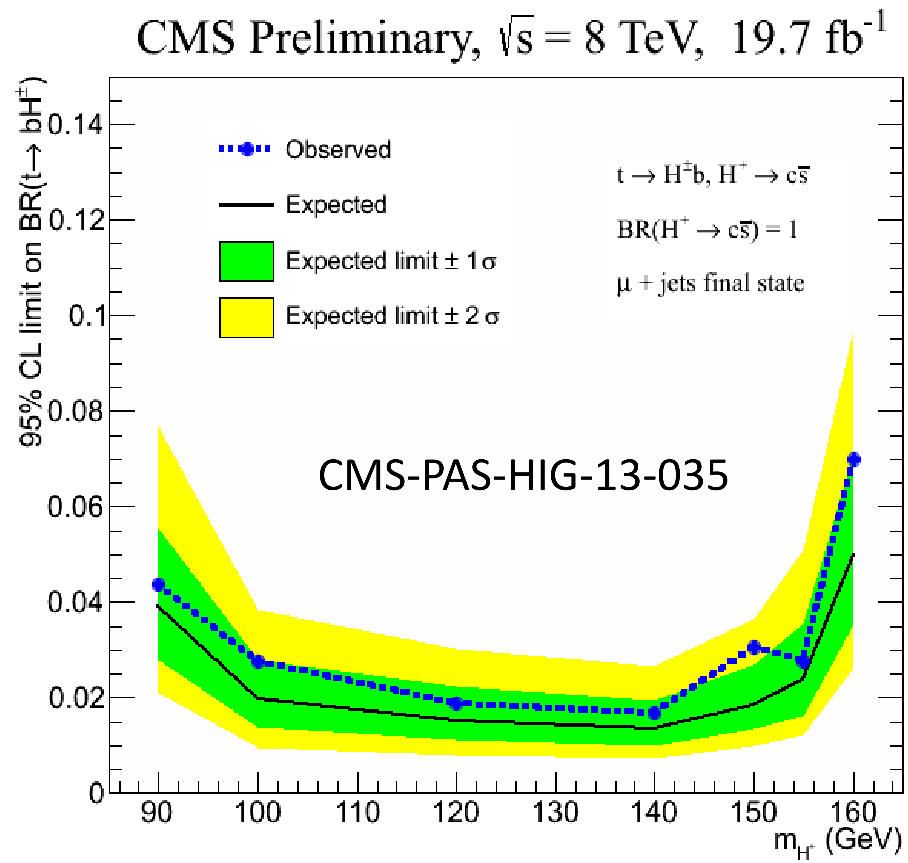
Source	$\mathrm{N_{events}} \pm$ Uncertainty
HW, $M_H = 120\ GeV, \mathcal{B}(t \to bH^+) = 0.2$	3670 ± 503
SM $t\bar{t}$	16911 ± 2163
W+Jets	242 ± 52
Z+Jets	29 ± 5
SingleTop	463 ± 50
Dibosons	5 ± 1
Total Bkg	17651 ± 2164
Data	17759

Final Discriminator and Limit

$$\Delta N = N_{t\bar{t}}^{BSM} - N_{t\bar{t}}^{SM} = 2x(1-x)N^{WH} + [(1-x)^2 - 1]N_{t\bar{t}}^{SM}$$

Exclusion limit is computed using the LHC-type CLs method





Summary

- A search has been performed for the light charged Higgs boson produced in a top-quark decay and subsequently decaying to $c\bar{s}$
- Analyzed 19.7 fb^{-1} of 8 TeV data in the muon+jet channel
- Control plots match well with the SM background expectations
- No excess or deficit of events, so put an upper limit on BR($t \rightarrow bH^{+}$)
- The expected limit is 2-5% and observed limit is 2-7% for a Higgs mass between 90 to 160 GeV
- We are working on the journal publication with additional improvement and inclusion of the electron channel

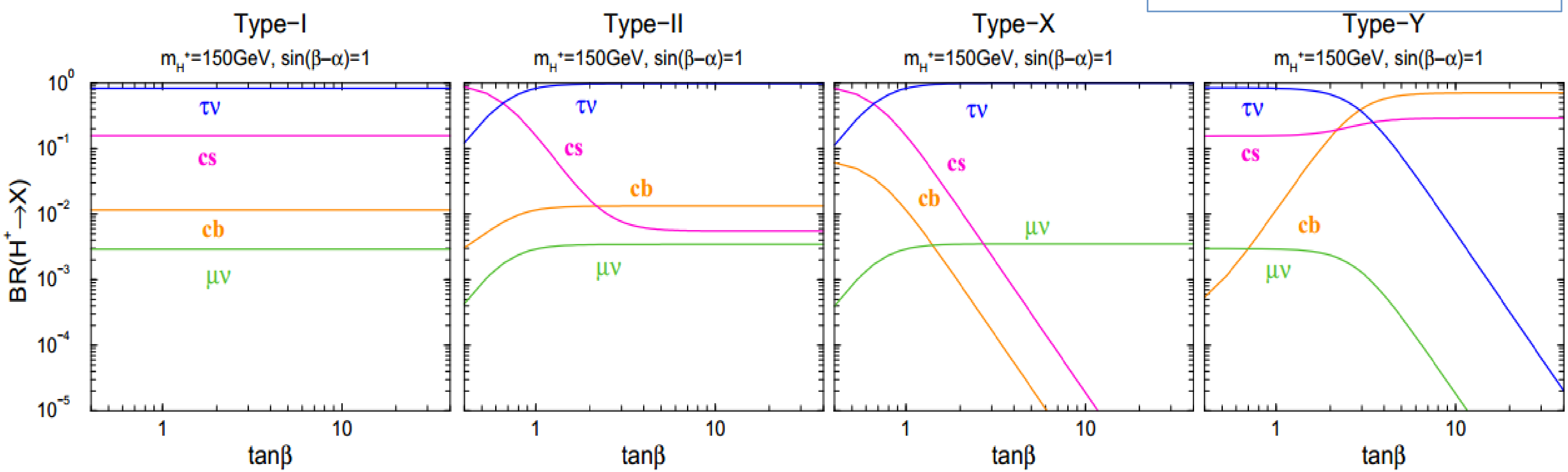
CMS is going to restart data taking in 2015 with higher center-of-mass energy $\sqrt{s} = 13\ TeV$

Stay tuned!

Backup Slide

Different types of 2HDM

PRD 80, 015017 (2009)



Type-I and Type-Y:

BR($H^+ \rightarrow c\bar{s}$) is greater than 10 % for all values of tan β

Type-II and Type-X:

BR($H^+ \rightarrow c\bar{s}$) is close to 100 % for tan β < 1.0