Charged Higgs Analysis in CMS

XXX Reunión Anual de la División de Partículas
y Campos de la SMF

Jan Eysermans & Isabel Pedraza
Benemérita Universidad Autónoma de Puebla (BUAP)

May 23-15, 2015

Outline

- Theory of Charged Higgs
- Production modes
- Decay modes
- 8 TeV results
- $H^{\pm} \rightarrow \tau\nu$ and $H^{\pm} \rightarrow tb$ decay modes
- Other decay modes
- Charged Higgs @ BUAP

Theory of Charged Higgs

- Standard Model: W and Z gauge bosons acquire mass through symmetry breaking of a Higgs doublet field ϕ in a Mexican hat shaped potential:

$$\phi = \frac{1}{\sqrt{2}} \begin{pmatrix} \phi^+ \\ \phi^0 \end{pmatrix} \qquad V(\phi) = \mu^2 \phi^\dagger \phi - \lambda (\phi^\dagger \phi)^2$$

  Expand V(ϕ) around vacuum results in one massive neutral scalar particle: the (SM) Higgs boson

- Simple extension (2DHM): add second Higgs doublet ϕ_1, ϕ_2

  Expanding V(ϕ_1, ϕ_2) around vacuum expectation values (ν_1, ν_2) results in 5 physical Higgs bosons:

  - Two neutral CP-even scalars: h (SM Higgs) and H (“heavy Higgs”)
  - **Two charged Higgs bosons $H^\pm$**
  - One neutral CP-odd pseudoscalar A

Theory of Charged Higgs

- Free parameters of the model:
  - Mass of the other Higgs bosons (H, $H^{\pm}$, or A)
  - Value of $\tan(\beta) = \nu_2/\nu_1$ (ratio of VEVs)
- Different types of 2DHM according to Yukawa fermion coupling:

Model	Type I	Type II	Lepton-specific	Flipped
Φ_1	–	d, ℓ	ℓ	d
Φ_2	u, d, ℓ	u	u, d	u, ℓ

MSSM

u ~ cot(β)

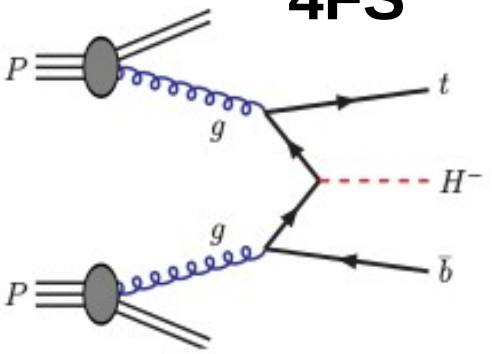
d, l ~ tan(β)

- MSSM (minimal supersymmetric SM) is Type 2 2DHM

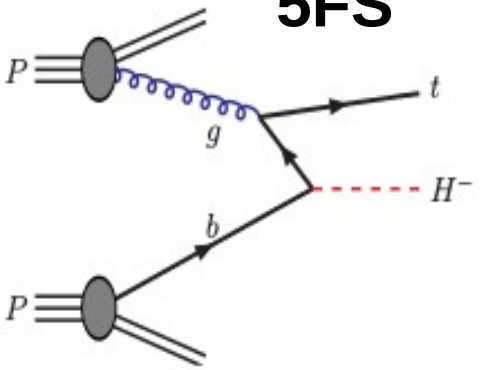
$H^{\pm}$ Production modes (pp)

- Production mode depends on mass of the charged Higgs
- “Light” charged Higgs $m_H < m_t$: production via top decay in $t\bar{t}$ production
- “Heavy” charged Higgs $m_H > m_t$: fusion of bottom-top quarks (4FS or 5FS)

4FS



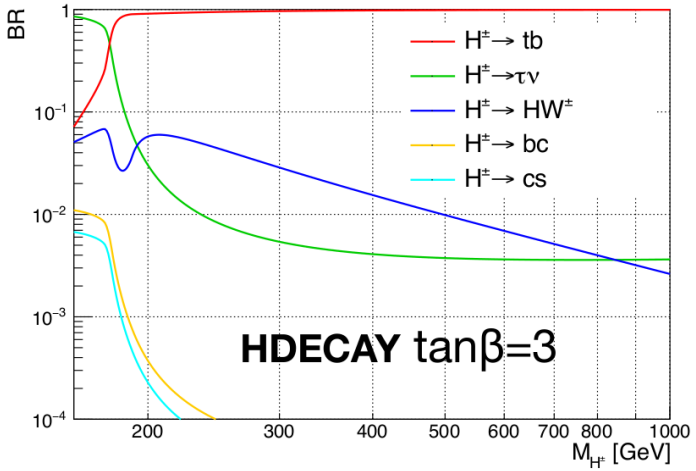
5FS

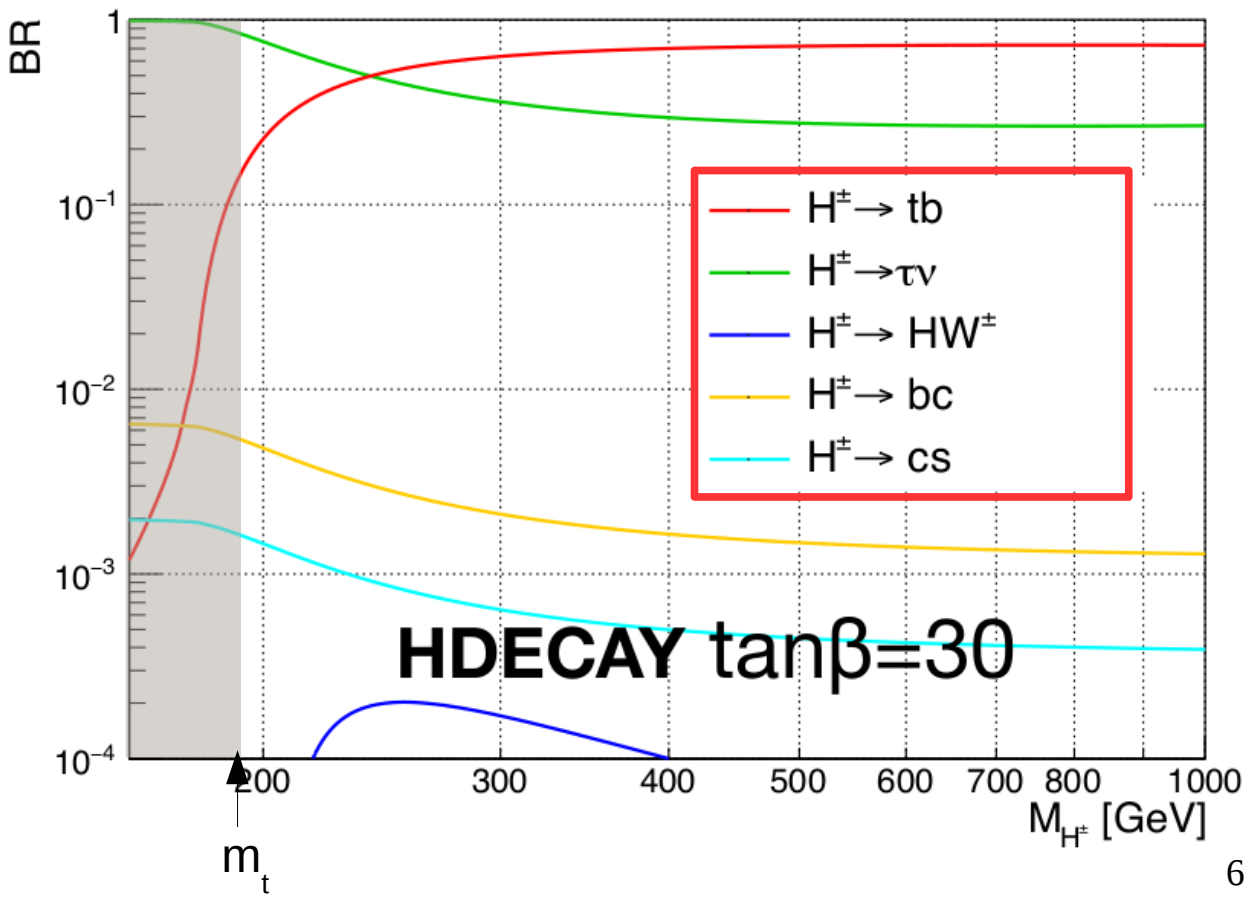


- We mainly focus on “heavy” Higgs searches exceeding top mass

Decay modes

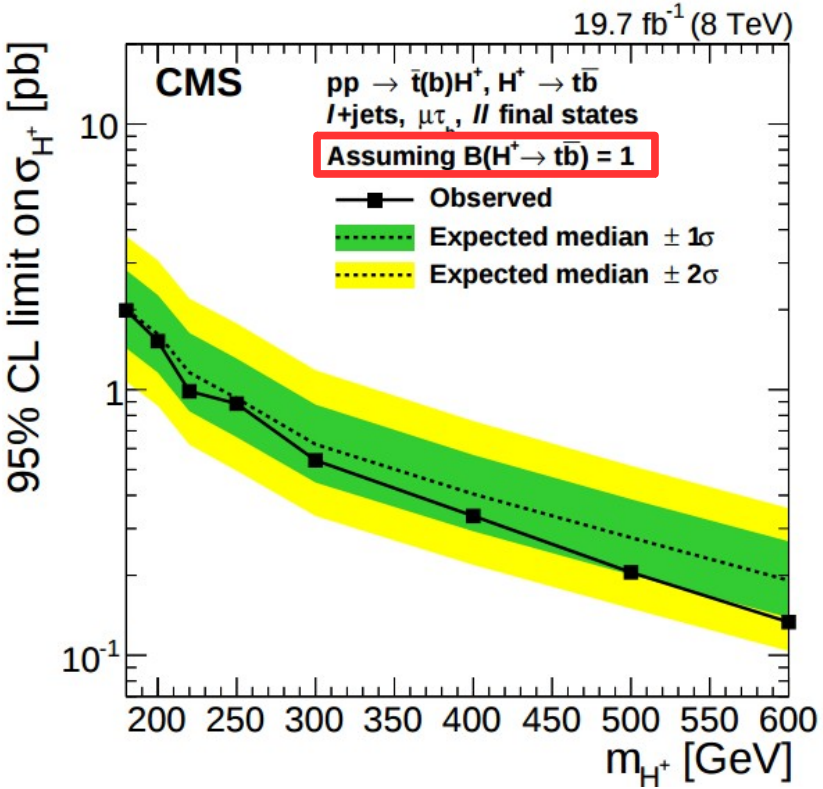
- Decay modes depends mainly on $H^{\pm}$ mass, to a lesser extent on the parameter tan(β)
- $H^{\pm} \rightarrow tb$ dominant in high-mass region, $H^{\pm} \rightarrow \tau\nu$ also contributing
- SUSY channels (?)





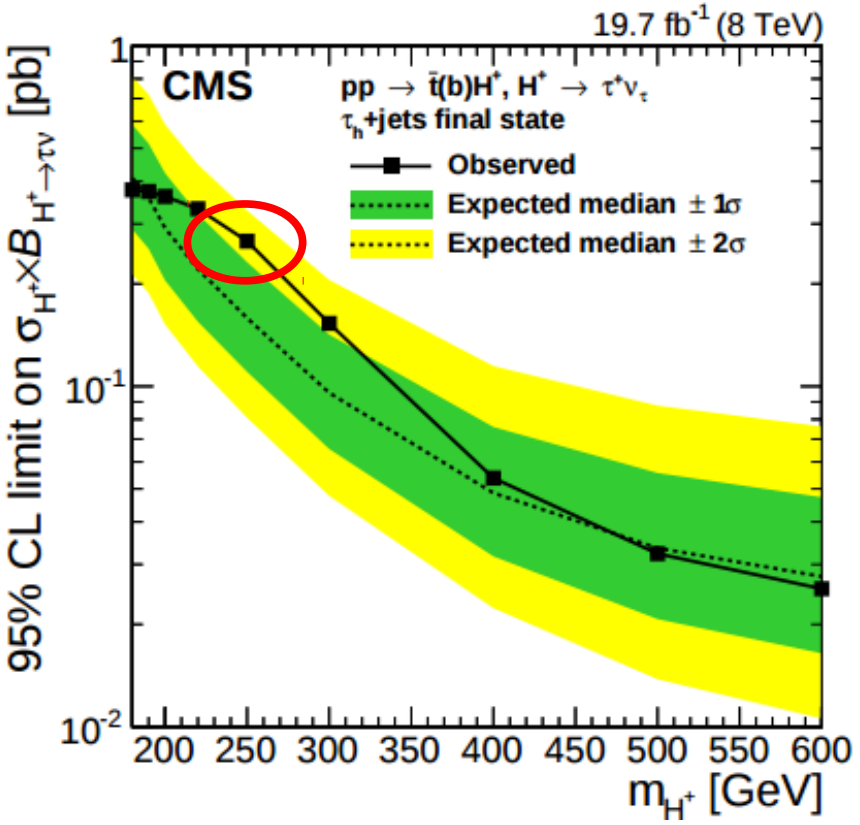
8 TeV results

- 8 TeV results on arXiv:1508.07774
- Recorded data: 19.7 fb^{-1}
- Analysis sensitive for $H^{\pm} \rightarrow tb$ and $H^{\pm} \rightarrow \tau\nu$
- No signal observed in 95% confidence level → upper limits on σ



- Results σ(pp → t(b)$H^{\pm}$)
- Assumption: BR($H^{\pm} \rightarrow tb$) = 1
- Upper limit tb: σ = 2.0–0.13 pb in mass region 180–600 GeV

8 TeV results

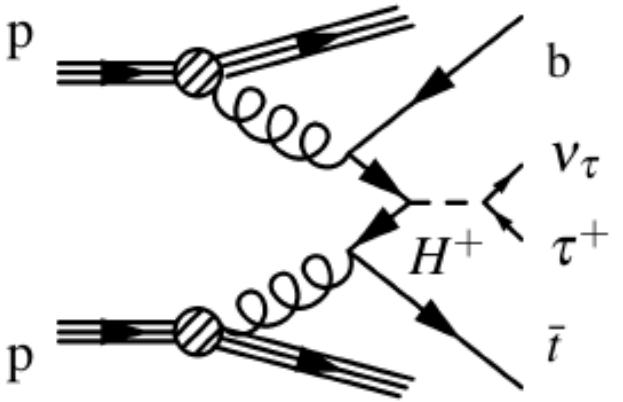


- Results $\sigma(pp \to t(b)H^{\pm})BR(H^{\pm} \to \tau\nu)$
- Model independent
- Upper limit: σ = 0.38–0.025 pb in mass region 180–600 GeV
- Local excess of data around m_H = 250 GeV
- Significance 1.7σ, p-value 0.046

- ATLAS results (arXiv:1412.6663), 8 TeV, 19.7 fb^{-1}
- Upper limit $\sigma(pp \to t(b)H^{\pm})BR(H^{\pm} \to \tau\nu)$ = 0.8–0.004 pb in mass range 180-1000 GeV

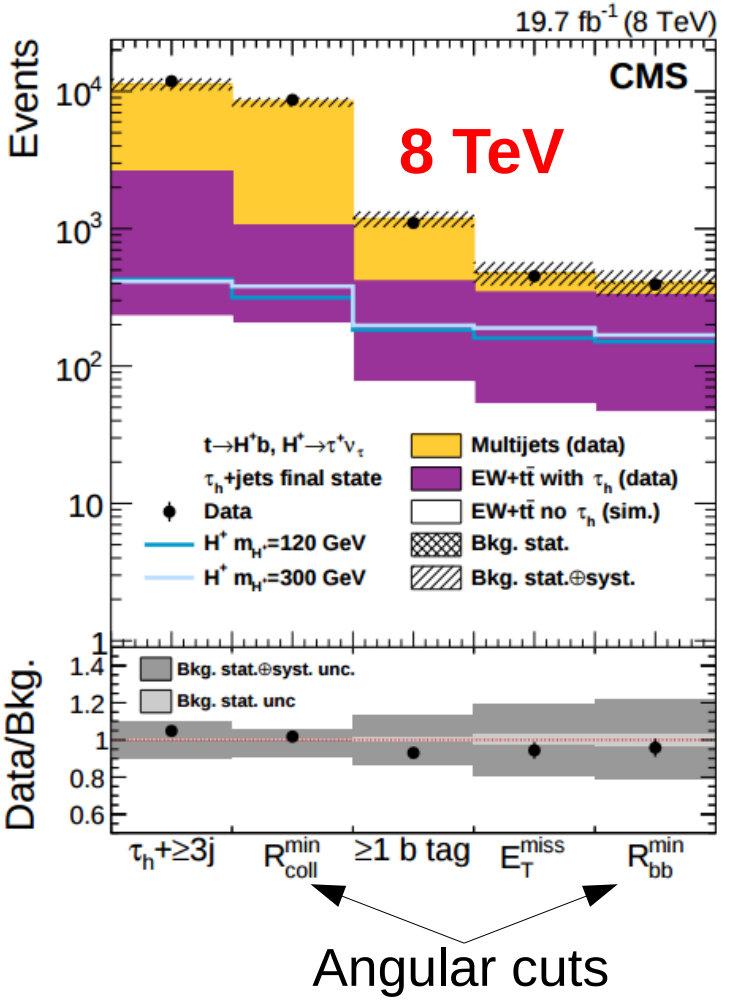
$H^{\pm} \rightarrow \tau\nu$ overview

- $pp \rightarrow \bar{t}(b)H^{+} \rightarrow \bar{t}(b)\tau\nu$
- Top decays to W and b
- Different final states possible:
  - τ_h + jets (τ and W decays hadronically)
  - $\mu\tau_h$ (τ hadronically, W leptonically)
  - Dilepton ee/eμ/$\mu\mu$ (τ and W decays leptonically)
- Main backgrounds: EWK (ZZ, WZ, WW, W+jets), QCD, Top
- If fully hadronic state (τ_h+jets): all MET neutrinos from H^{+} decay:
  - Construct transverse mass $m_T(\tau_h$,MET)
  - Shape analysis on transverse mass distribution



$H^{\pm} \rightarrow \tau\nu$ event selection

- Analysis strategy based on 8 TeV experience
- Event selection: cut flow analysis
  - Trigger: 1 τ + MET (> 50-120 GeV)
  - 1 τ, decaying hadronically, p_T > 50 GeV
  - No isolated leptons
  - Large MET
  - At least 3 jets, where at least one b-jet
  - Angular cuts for multijet suppression
- Optimize cuts:
  - w.r.t. S/sqrt(B) ratio
  - Categorization of events (e.g. b-jets)

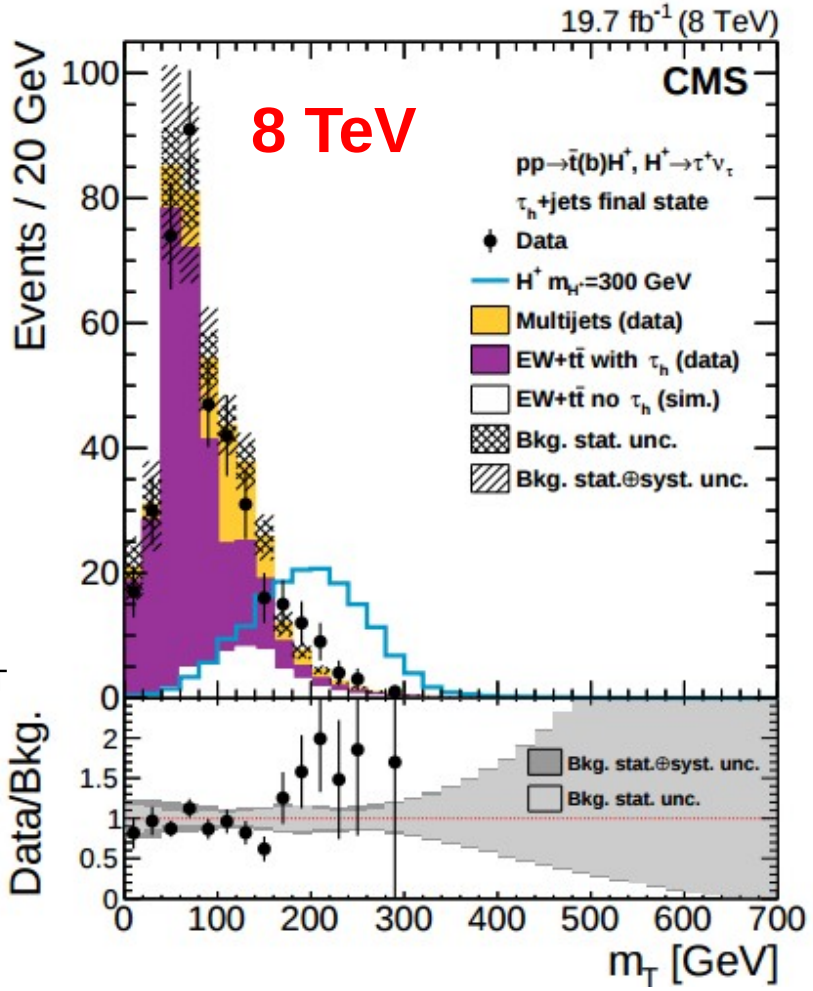


$H^{\pm} \rightarrow \tau\nu$ m_T distribution

- After cut: calculate m_T on remaining events based on leading τ (highest p_T) and MET:

$$m_{\mathrm{T}} = \sqrt{2 p_{\mathrm{T}}^{\tau_{\mathrm{h}}} E_{\mathrm{T}}^{\mathrm{miss}} (1 - \cos \Delta\phi(\vec{p}_{\mathrm{T}}^{\,\tau_{\mathrm{h}}}, \vec{p}_{\mathrm{T}}^{\,\mathrm{miss}}))}$$

- Background measurements
  - QCD (multijet background): τ_h mis-identification rate technique in binned τ_h p_T
  - EWK+tt (τ_h): embedded technique
  - EWK+tt (no τ_h): from simulation

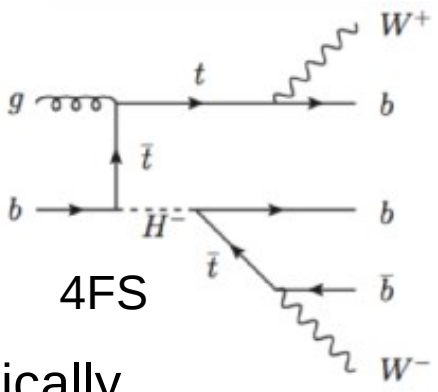


$H^{\pm} \rightarrow \tau\nu$ next steps...

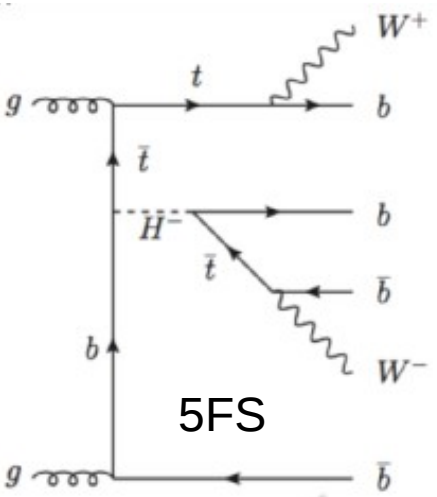
- Continuing analysis on 2015 data
- Event selection optimization: categorization of events based on e.g. b-jets
- Preparing for 2016 data run (port to CMSSW 8.X)
- Generating (centrally) MC samples 500–1000 GeV mass range
- Other search strategies based on MVA analysis
- Systematics analysis

$H^{\pm} \rightarrow tb$ overview

- Semi-final state: tt(b)b
- Final states:
  - At least 3 b-jets
  - 2 W bosons, each decaying leptonically (lν) or hadronically ($q\bar{q}$)



4FS

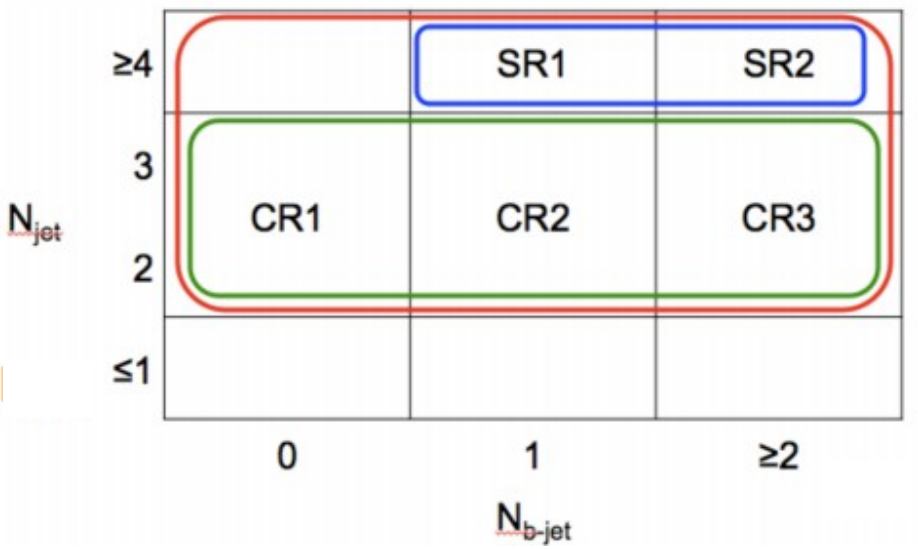


5FS

- Distinguish between single lepton and dilepton final states
- Main backgrounds (grouped, important):
  - EWK: W+jets, Z+jets, γ*+jets, dibosons (ZZ, WZ, WW)
  - TOP: $t\bar{t}$, single t, $t\bar{t}$+W/Z (neglected)
  - QCD
- Shape analysis on jet and b-jet multiplicity (higher than SM processes) or with H_T distribution

$H^{\pm} \rightarrow tb$ event selection

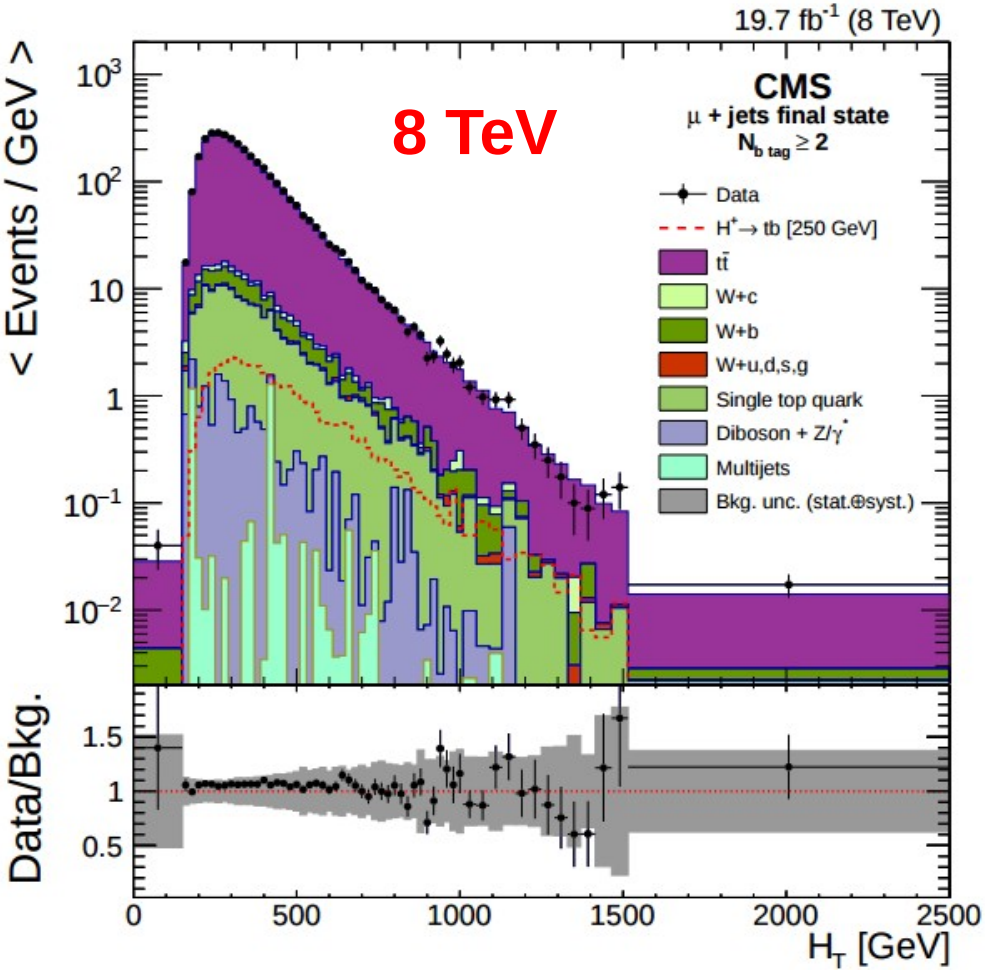
- Single lepton event selection:
  - Trigger: single electron, single muon
  - P_T lepton > 40 GeV, $|\eta| < 2.5$
  - MET > 60 GeV
  - 3 jets, each p_T > 30 GeV, $|\eta| < 2.4$



- Selection regions (both e and μ):
  - Control region (# jet <= 3): used for background normalization from data
  - Signal region (# jet > 3, # b-jet >= 1): used to make discovery or to set limits
- Optimization of cuts: permutations of cut boundaries: P_T(lep), MET, P_T(j1), P_T(j2), P_T(j3), # jets
- For each permutation, calculate expected limits on cross section based on H_T distribution

$H^{\pm} \rightarrow tb$ H_T distribution

- After cut selection, plot H_T histogram in signal region
- All background samples from MC, but normalized:
  - $t\bar{t}$, W+jets (dominant): normalization obtained with MC+data fit to obtain best yields in control and signal regions
  - Others: normalizations directly from MC
  - Normalizations carried out for electron/muons separately
- Can be modified for 13 TeV

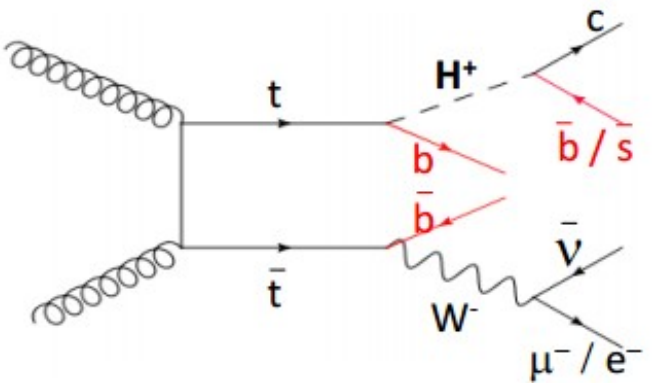


$H^{\pm} \rightarrow tb$ next steps...

- Continuing analysis on 2015 data based on experience 8 TeV analysis
- Event selection optimization: refine permutations on cuts
- Preparing for 2016 data run (port to CMSSW 8.X)
- Generating (centrally) MC samples for entire mass range
- Systematics analysis

$H^{\pm} \rightarrow$ other

- $H^{\pm} \rightarrow$ cs, cb
  - Important for light charged Higgs ($m_H < m_t$)
  - Charged Higgs production via tt production
  - Dominant background: tt
  - Signal: look for secondary peak in the W decay kinematic fit



- $H^{\pm} \rightarrow hW^{\pm}$
  - Higgs reconstruction: h → bb → jets (BR = 58 %)
  - W reconstruction: W → qq' → jets (BR = 67 %)
  - Charged Higgs reconstruction based on reconstruction h and W
  - Complicated final state: lot of jets → combinatorics
- $H^{\pm} \rightarrow$ SUSY: can become dominant for heavy charged Higgs

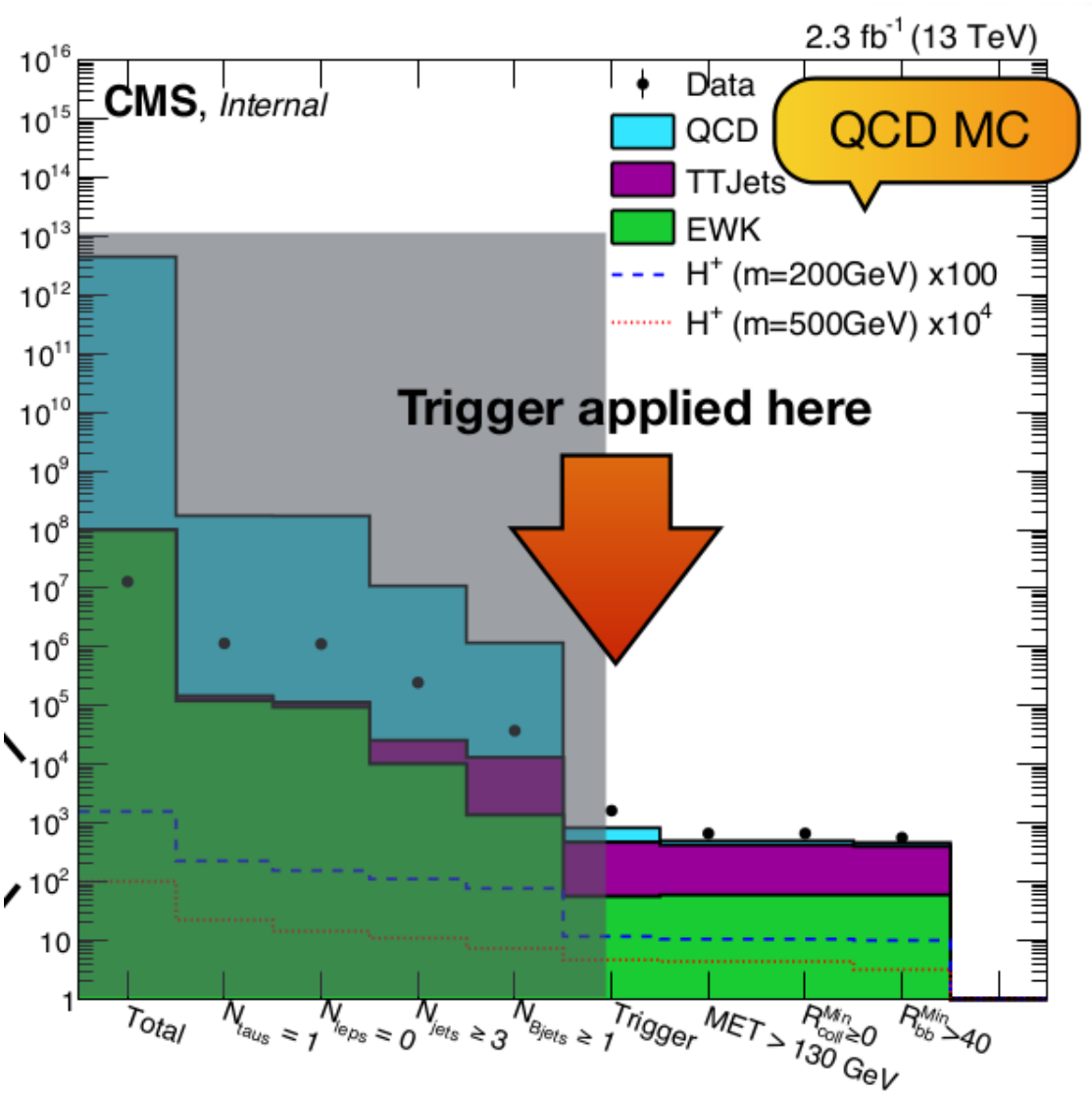
Charged Higgs @ BUAP

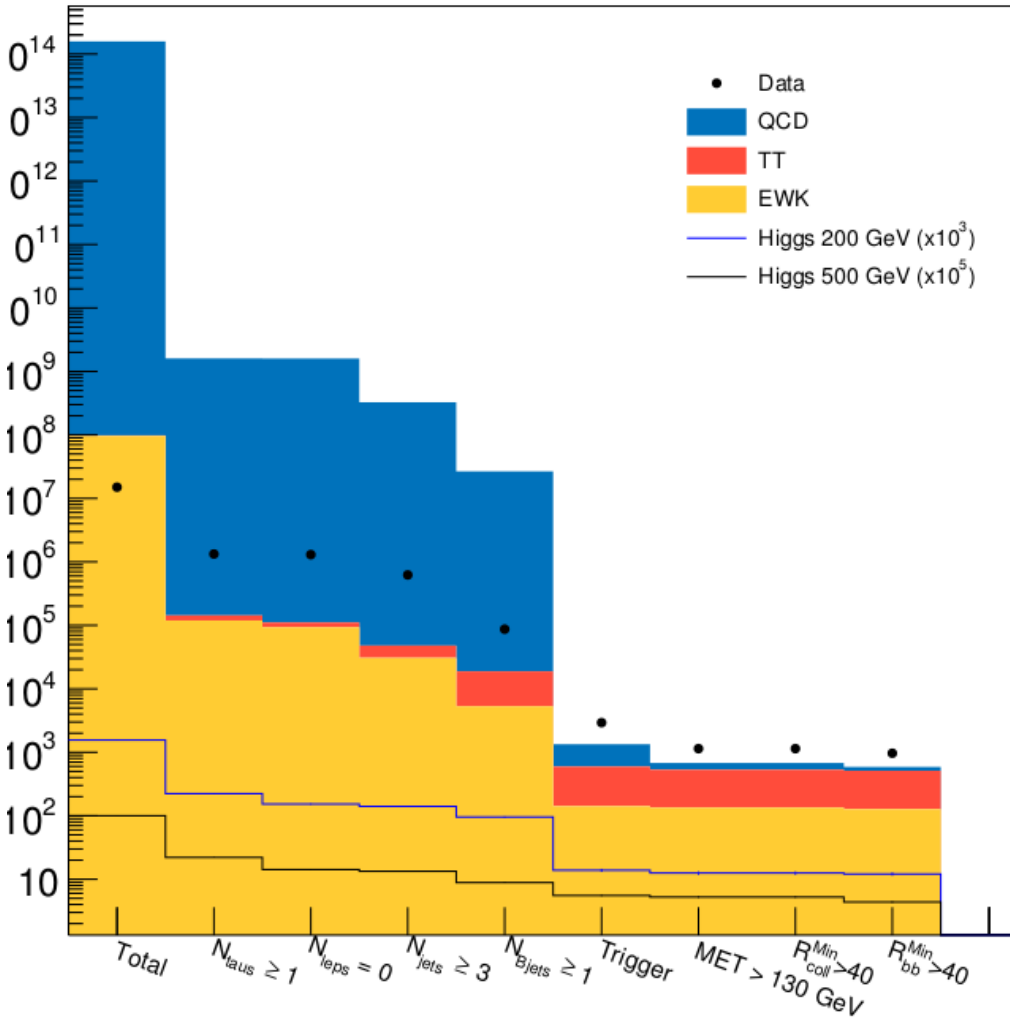
- We will concentrate on the tb channel
- In collaboration with MIT group
- Single or dilepton final state → to be decided yet
- Do the analysis for the 2015 data
- Start preparation for the 2016 data
- MC sample production requested in mass range 100-1000 GeV

Others...

- Added 2015 data to analysis
- Tried to scale the cutflow histogram to be in accordance with results of Andrea
- Scaled Higgs signals with factors:
  - 100 (200 GeV) 1000 (500 GeV) → the same factor as applied by Andrea
  - 2.3 → according to 2.3 fb-1 data taking
  - 1000 → conversion pb ↔ fb
- Higgs signals almost in exact agreement with Andrea's plots
- Scaled other signals too: small(er) differences → working on it

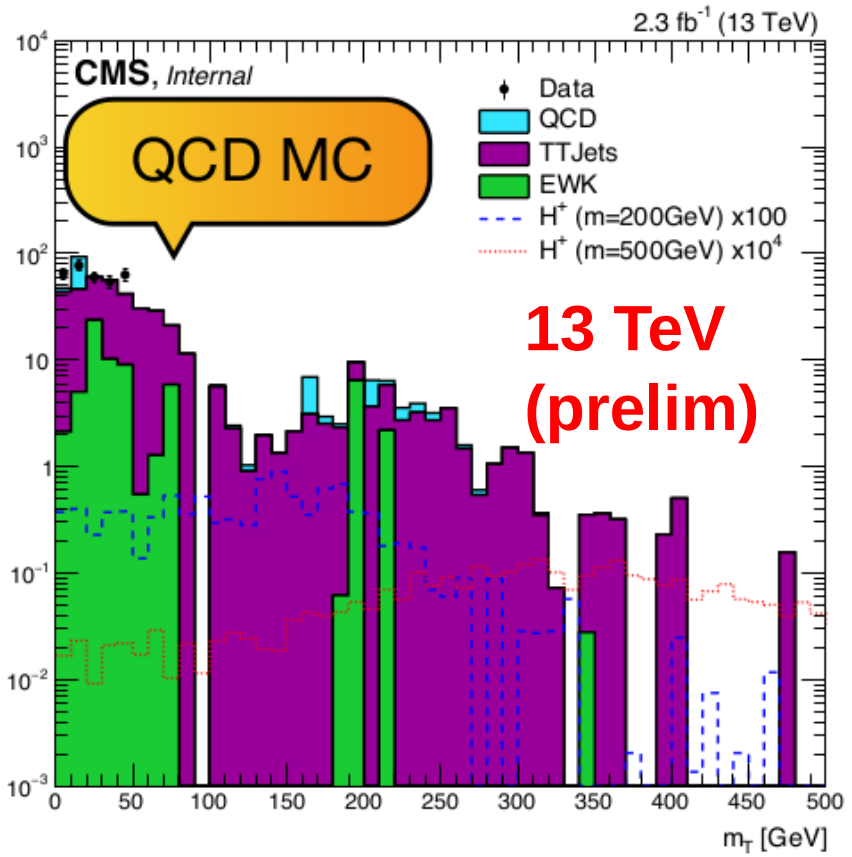
Others...

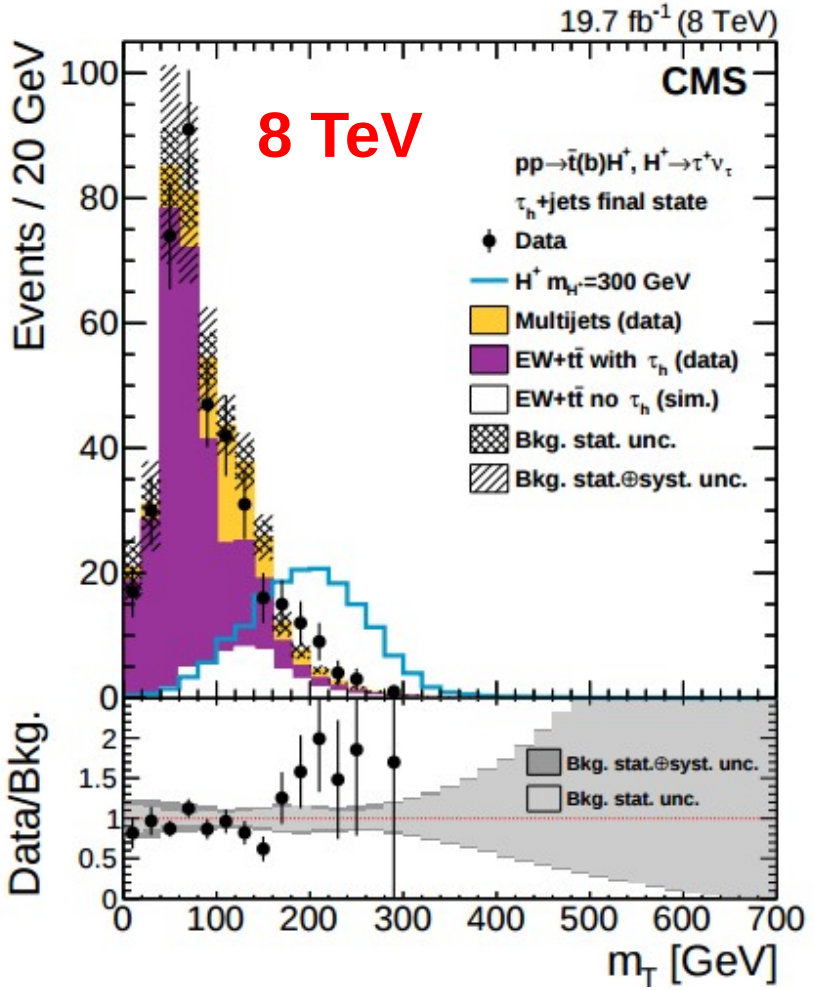

2.3 fb-1 (13 TeV)
CMS, Internal
Data
QCD
TTJets
EWK
H+ (m=200GeV) x100
H+ (m=500GeV) x10^4
QCD MC
Trigger applied here
Total
Ntaus = 1
Nleps = 0
Njets ≥ 3
NBjets ≥ 1
Trigger
MET > 130 GeV
RMincoll≥0
RMinbb >40


Data
QCD
TT
EWK
Higgs 200 GeV (x10^3)
Higgs 500 GeV (x10^5)
Total
Ntaus ≥ 1
Nleps = 0
Njets ≥ 3
NBjets ≥ 1
Trigger
MET > 130 GeV
RMincoll>40
RMinbb >40

$H^{\pm} \rightarrow \tau\nu$ m_T distribution

- MC scaled to fit with data
- Remaining events after cut procedure: calculate m_T on leading τ (highest p_T) and MET: $m_T(\tau_h$,MET)



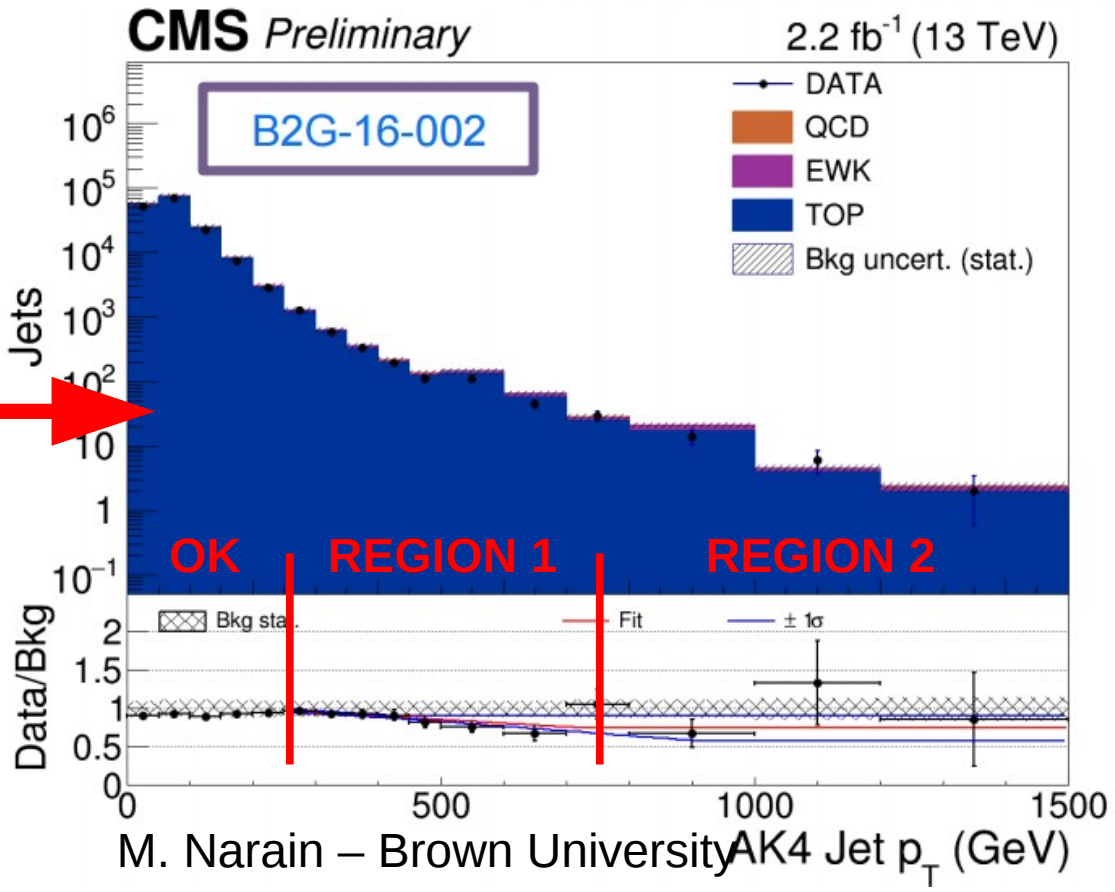


$H^{\pm} \rightarrow tb$ jet discrepancies

- Data/MC discrepancies observed at high p_T
- Correction factors must be applied
- Obtain correction factors by fitting data/MC on sample
  - Single lepton, 3 low pT jets
  - Low MET
  - M_T(lep, MET) = 50–150 GeV
  - 0 b-tag (no tt) and
  - 2+ b-tag fitting (tt + signal)
- Fitting piecewise linear function over p_T spectrum

$$\mathrm{SF}_{\mathrm{jet}} = p_0 + p_1 p_T$$

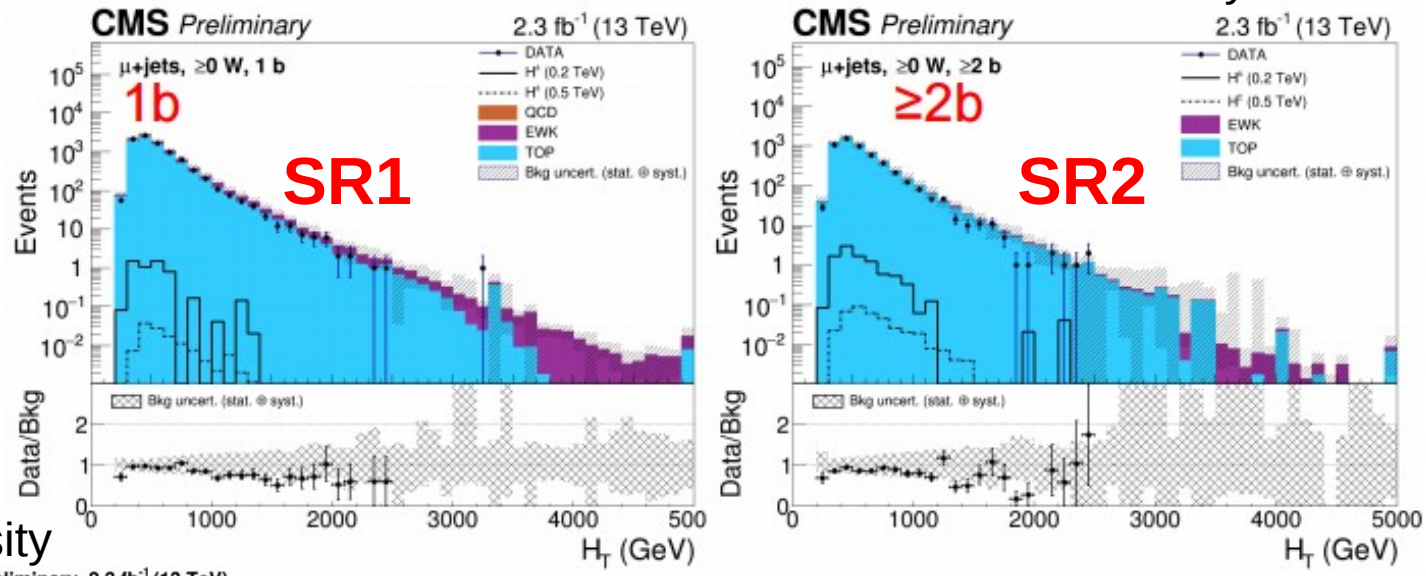
$$w = \prod_{\mathrm{jets}} \mathrm{SF}_{\mathrm{jet}}$$



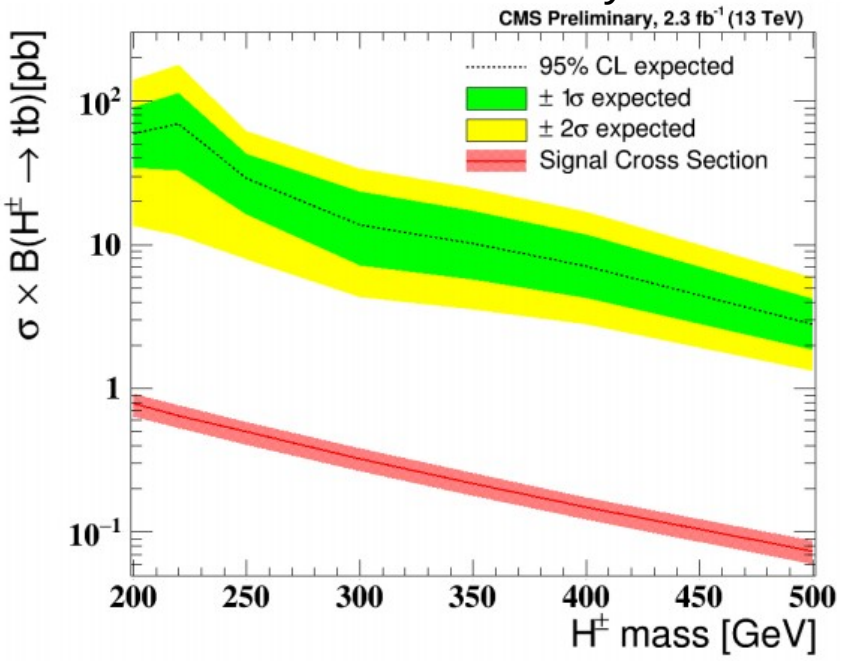
$H^{\pm} \rightarrow tb$ preliminary results

M. Narain – Brown University

- Example: muon final state
- Plotted H_T in two signal regions
- Reweighting not yet applied!



M. Narain – Brown University



- From H_T distributions, calculate limits
- Reweighting not yet applied!
- Systematic uncertainties included (but more work needed)