Charged Higgs search @ CDF

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On behalf of the CDF collaboration

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Outline

- Introduction
  - Search Strategy
    - Previous charged Higgs search
    - $H^+ \to c\bar{s}$ in decays of top
  - Fermilab, Tevatron, and CDF II detector
- $t \to bH^+(\to c\bar{s})$ Analysis
  - Event Selection & Reconstruction
  - Study on the H^+ mass
  - Extracting br($t \to H^+b$)
  - Systematic Uncertainty
- Result from 2.2 fb^{-1}
- Summary

Introduction

- Search strategy

  Previous charged Higgs search

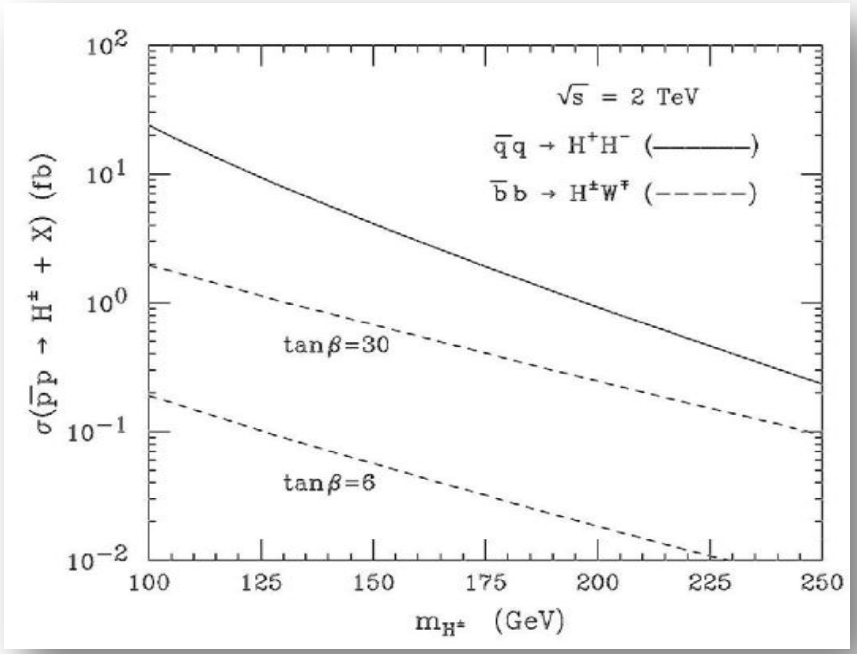
  $H^+ \rightarrow c\bar{s}$ in decays of top

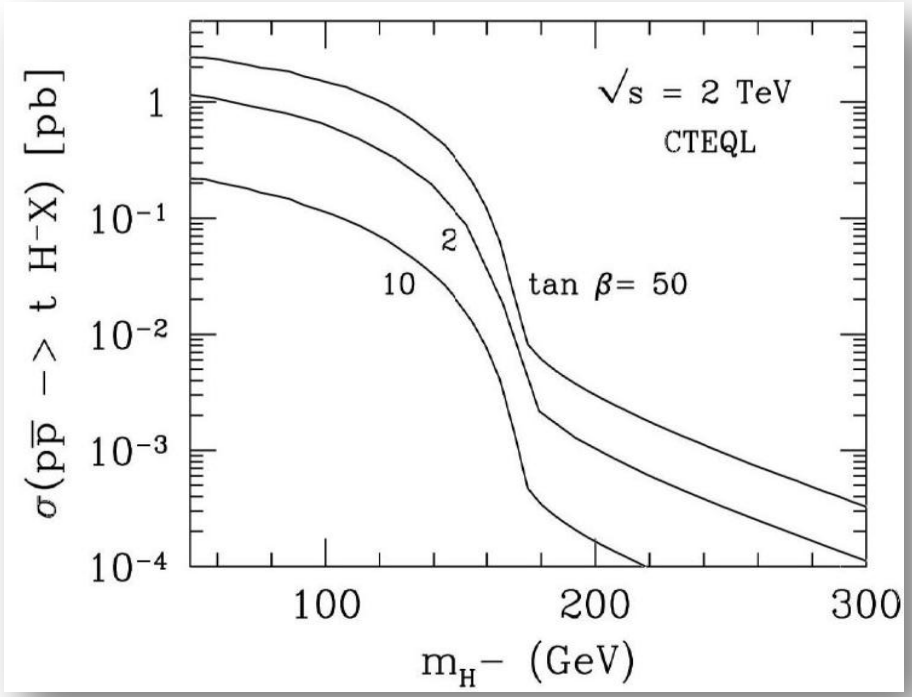
  Fermilab, Tevatron, and CDF II detector

Production of charged Higgs @ Tevatron

Prog.Part.Nucl.Phys.50:63-152,2003

- Direct production cross-section
  - ~ fb level.
  - ~1/1000 of top pair production





- Indirect production associated with top
  - Light Higgs: M(H^+)<M(t)
  - Heavy Higgs: M(H^+)>M(t)

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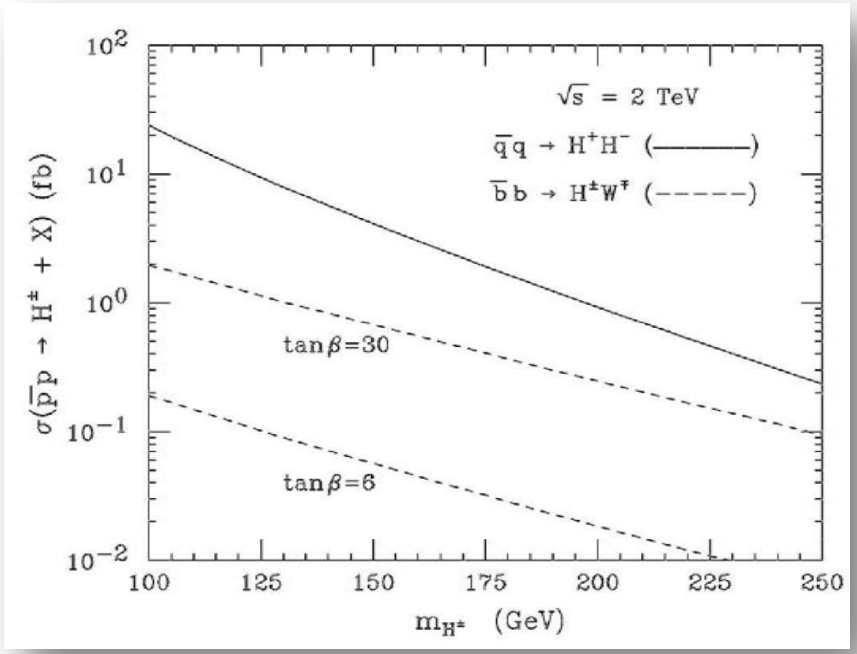

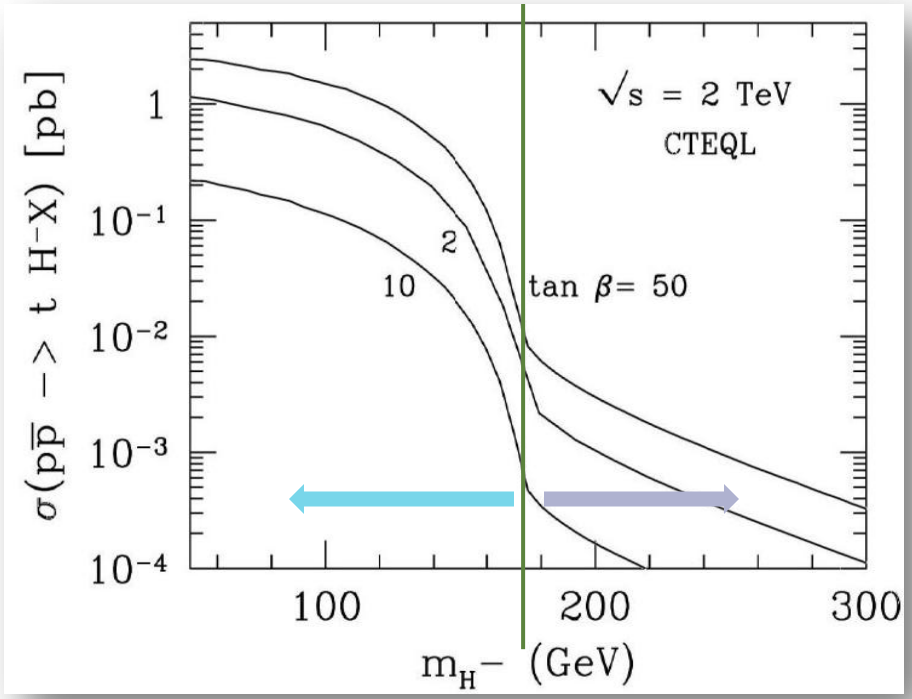

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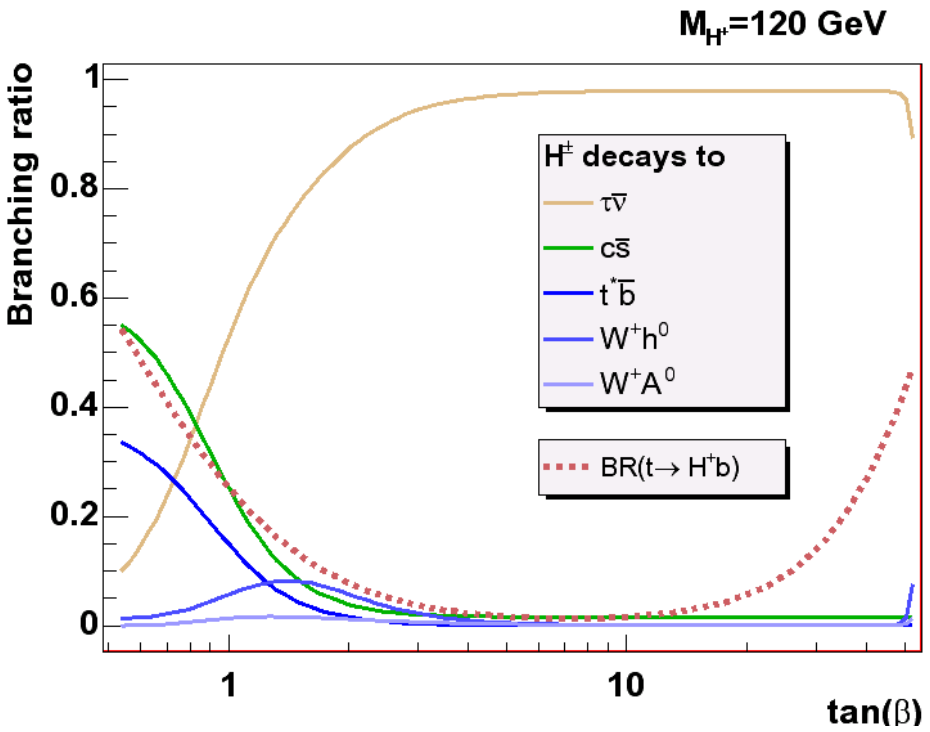
Charged Higgs in top decays

- Charged Higgs viable in high and low tan β
- For tan $\bar{\beta}$ > 7,
  - $H^- \rightarrow \tau\bar{\nu}$ dominant
  - Difficult to identify τ
- In low tan $\bar{\beta}$~1,
  - $H^+ \rightarrow c\bar{s}$ dominant for Higgs mass ≤130 GeV
  - can be fully reconstructed



Made by R. Eusebi using CPsuperH together with br(t→H^+b) calculation

Introduction

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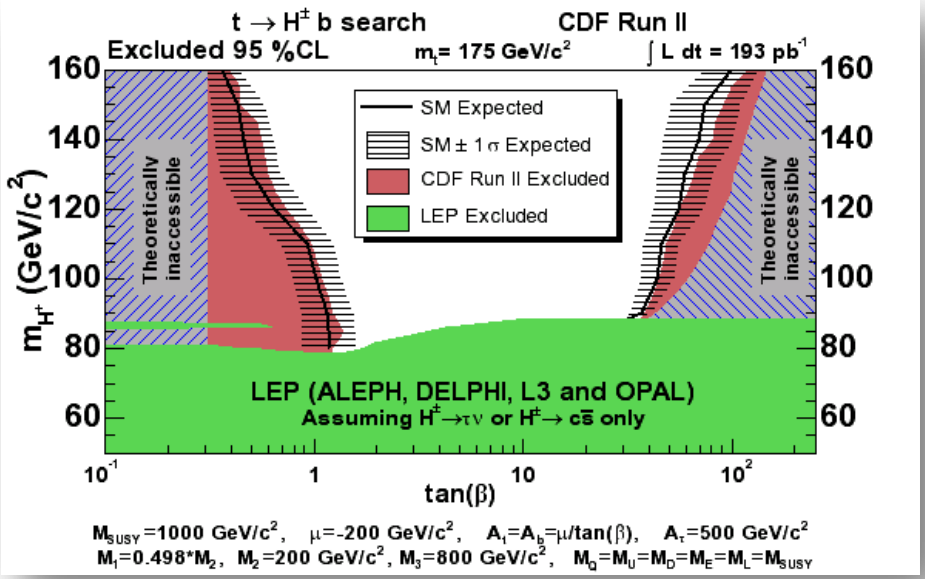
Previous charged Higgs search in top

R. Eusebi *et. al.*, Phys. Rev. Lett. 96, 042003 (2006)

- Look at the relative rates of events between different $t\bar{t}$ decay channel using cross-section measurements.
  - Consider 5 different final state of top quark:
    - $t \rightarrow bW^+$, $bH^+(\rightarrow c\bar{s}, \tau\nu, h^0(\rightarrow b\bar{b})W+, t^*b)$
  - Get br(t→H+b) limits comparing the cross-section of top in each category:
    - Lepton+jets, Lepton+hadronic τ, Dilepton
- Do the same search assuming br($H^+ \rightarrow \tau\nu$) = 100%
  : tauonic Higgs model
  - Good approximation at large tan β
- Scan over all Higgs branching ratio combinations and take worst limits of br($t \rightarrow H^+b$) as a upper limits.

Result 1 : MSSM parameter plane

Minimum stop mixing scenario



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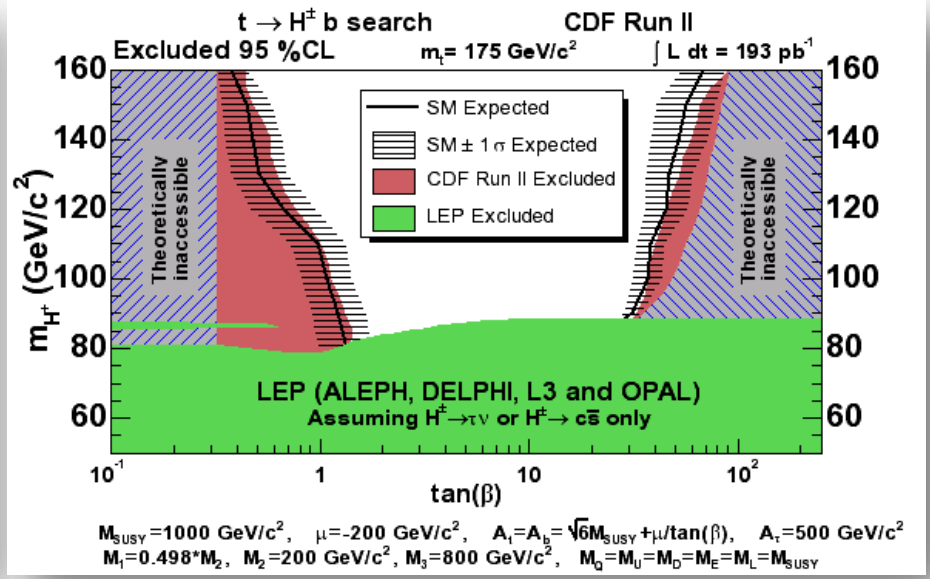
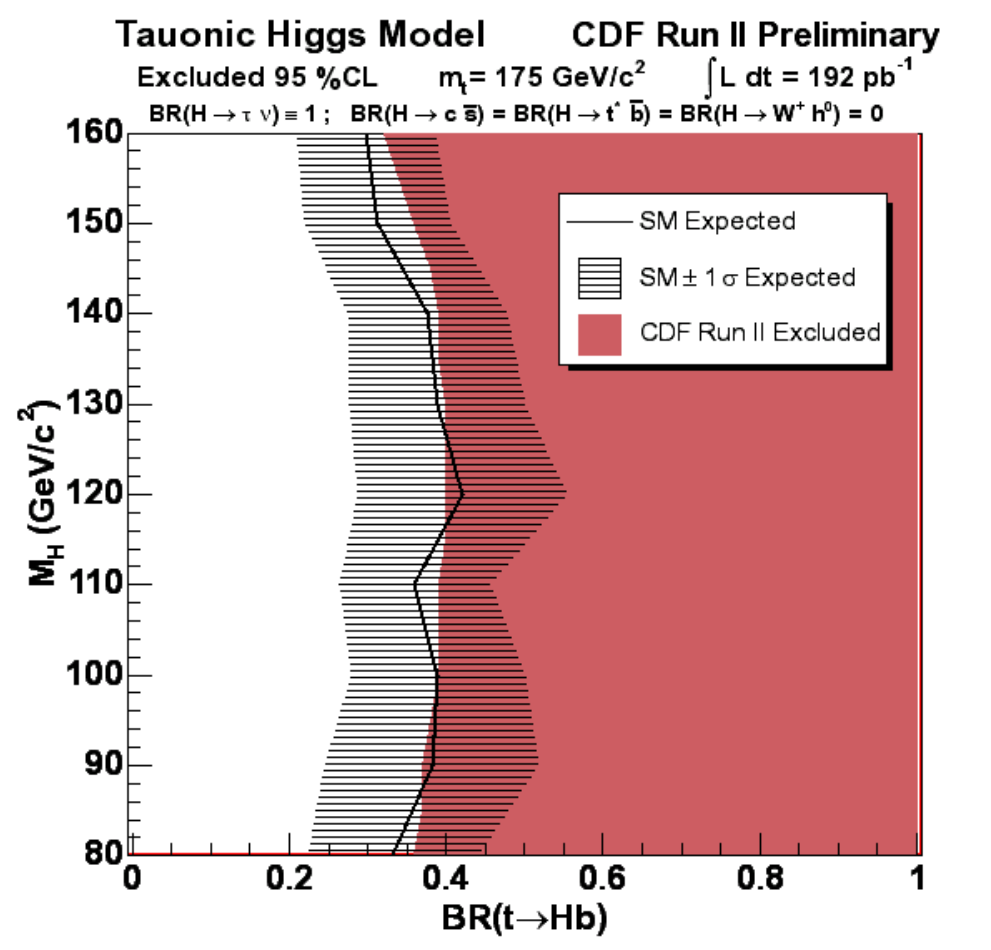


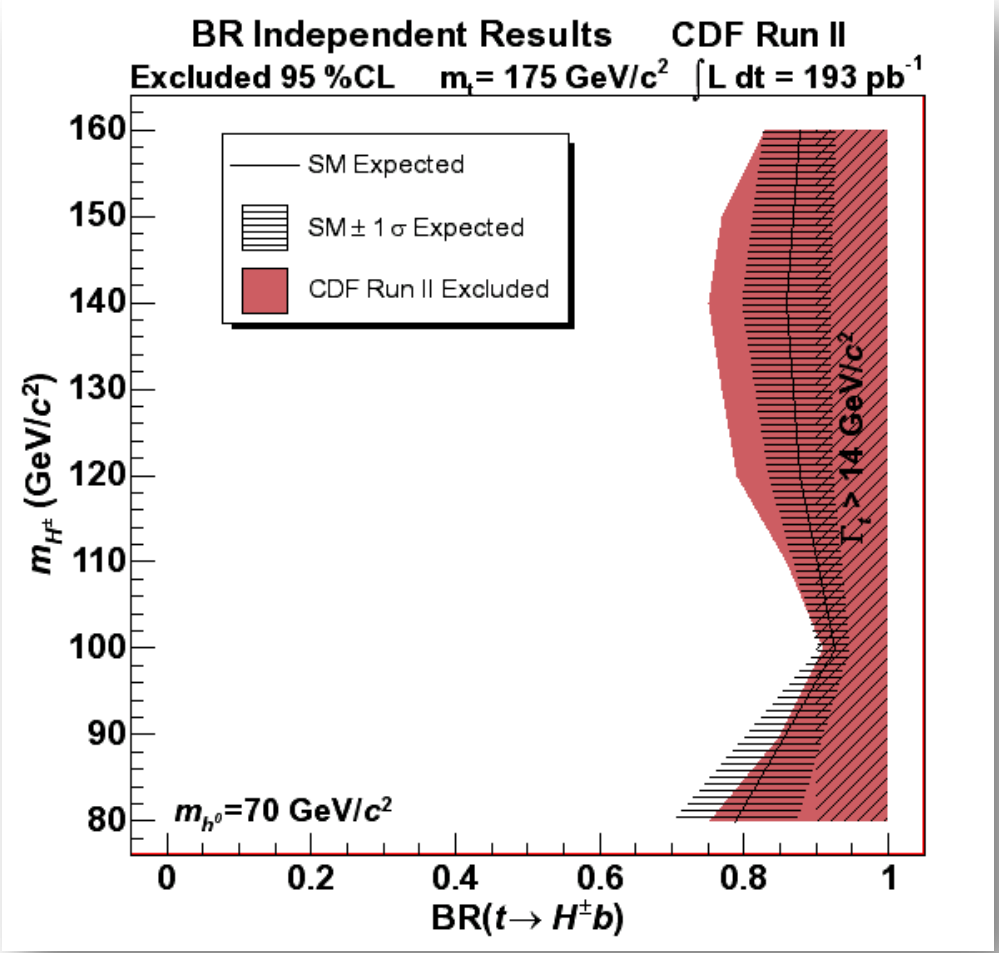
Result 2 : Tauonic model



Br(t→H+b) <0.4 @ 95% C.L.
for 80 GeV < m(H^+) < 160 GeV

Result 3 : Higgs BR independent upper limits

Br(t→H+b) <0.83 @ 95% C.L.
for 80 GeV < m(H⁺) < 160 GeV



H^+ search in $c\bar{s}$ from top decays

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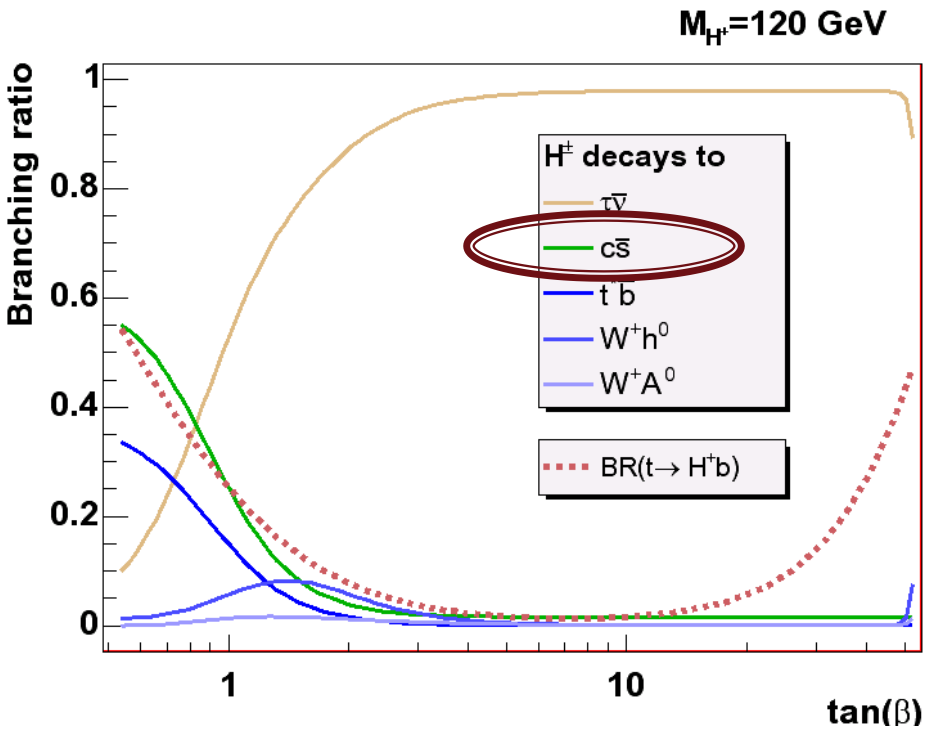

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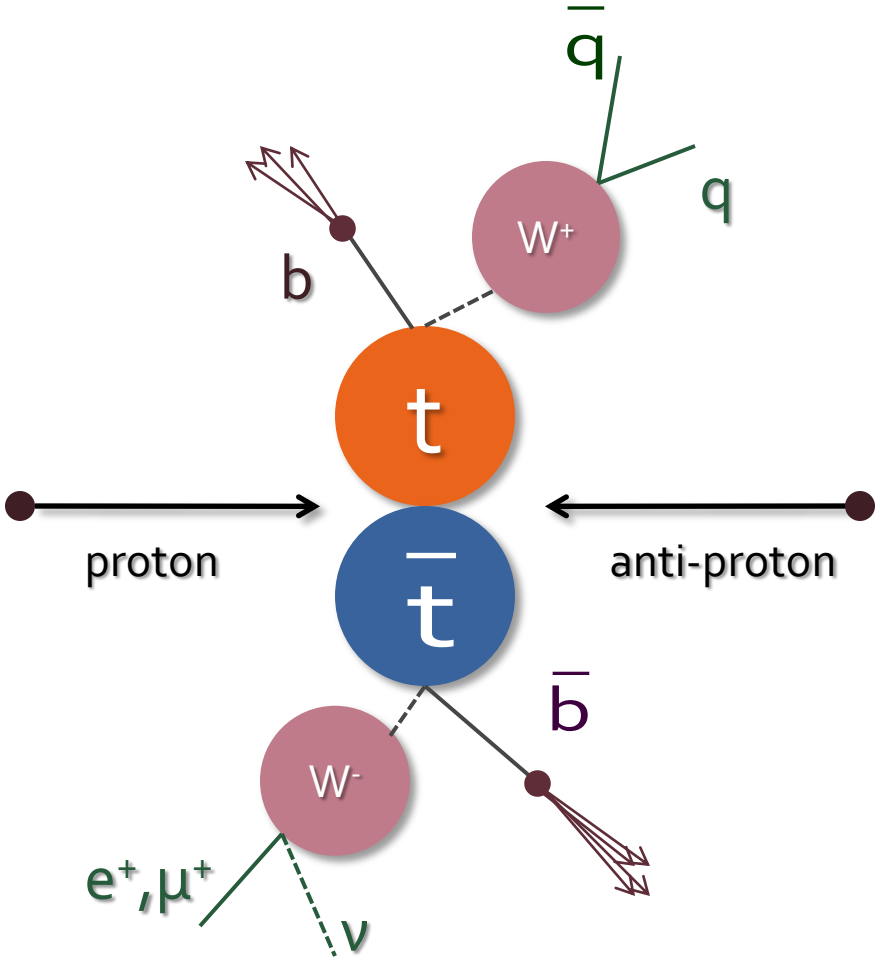
  - $H^+ \to c\bar{s}$ in decays of top
- Fermilab, Tevatron, and CDF II detector

$t\bar{t}$ lepton+jets channel

- Top quark is mainly produced in pairs from proton-antiproton collision.
- Top analysis is categorized by W boson sub-decays.
  - $W^+W^- \rightarrow l^+l^-\nu\nu$ (~5%)
  - $W^+W^- \rightarrow l\nu jj$ (~29%)
  - $W^+W^- \rightarrow jjjj$ (~ 46%)
- In lepton+jets channel, the charged Higgs($H^+ \rightarrow c\bar{s}$) can be reconstructed by di-jet.



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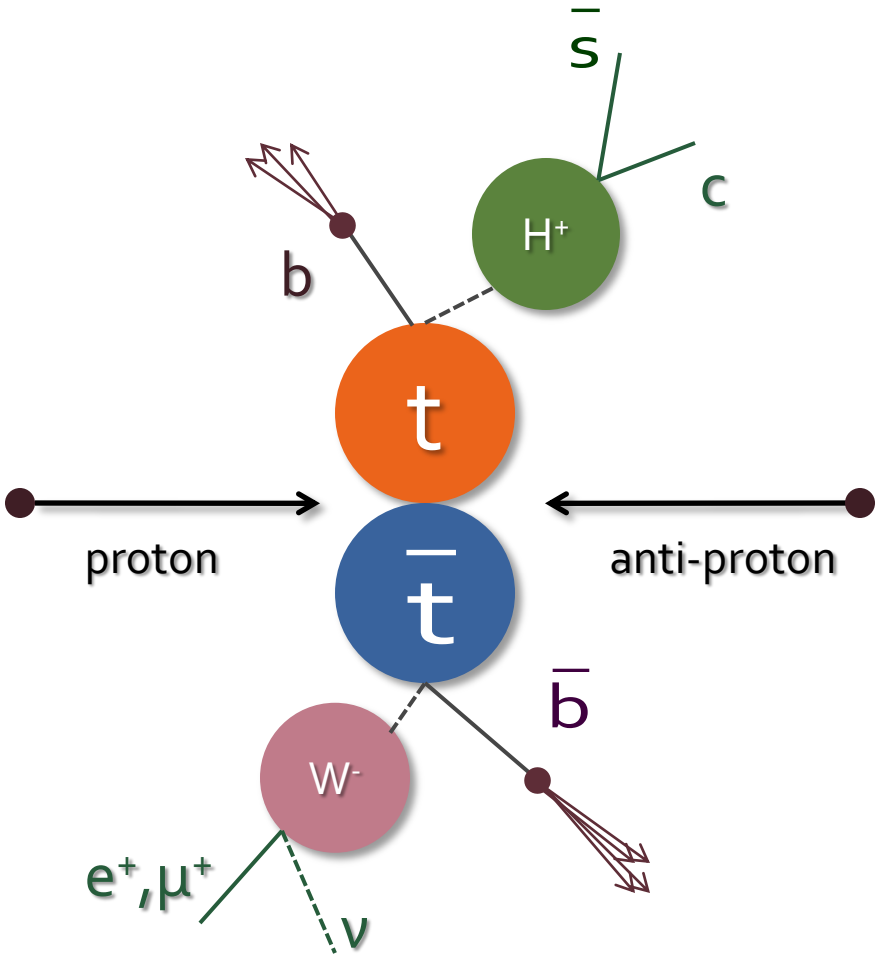

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Fermilab

- Located 30 miles west from Chicago

Tevatron

- World's most powerful collider for 25 years
- Provides $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV
- Two colliding points,
  - CDF & DZero

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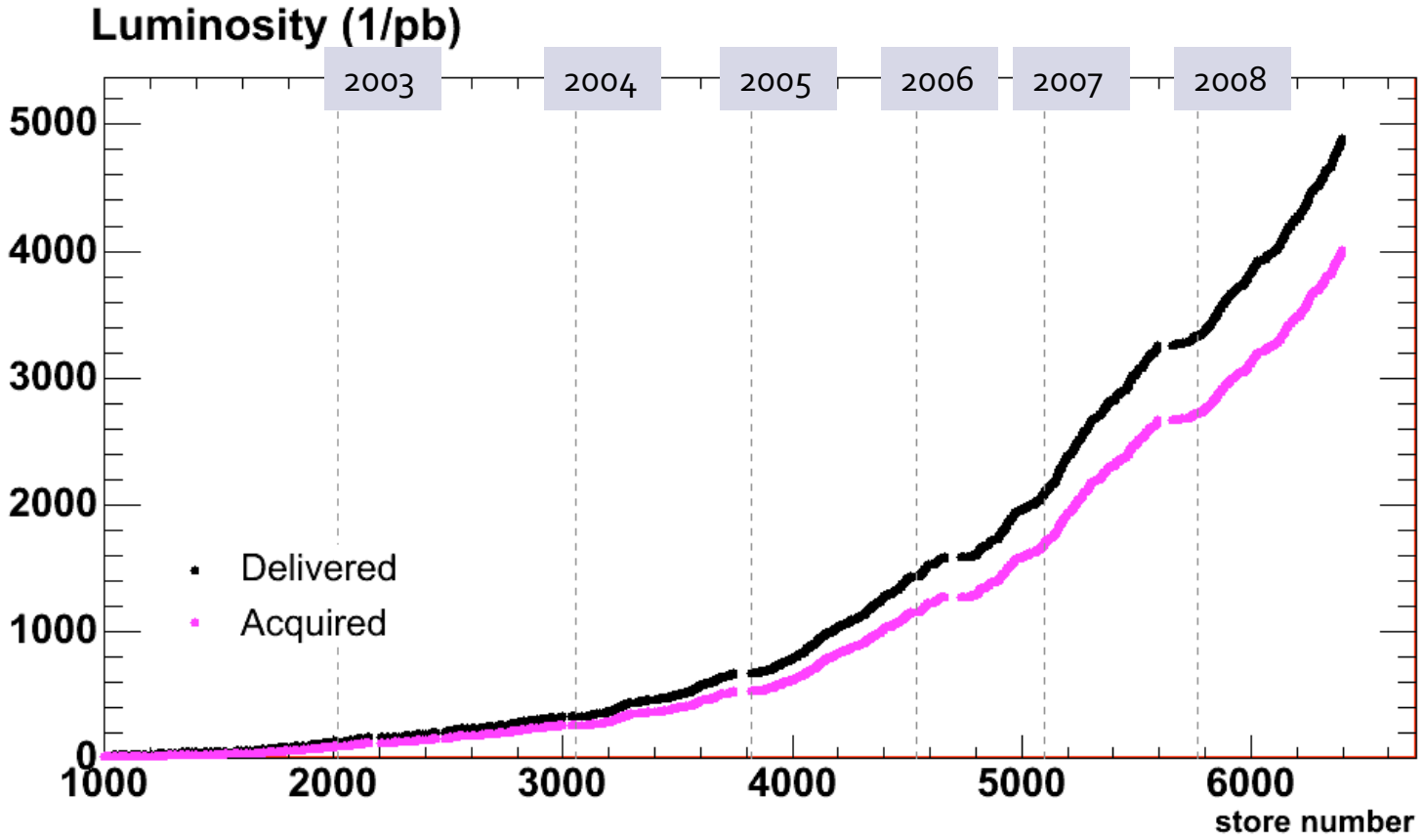
Integrated Luminosity



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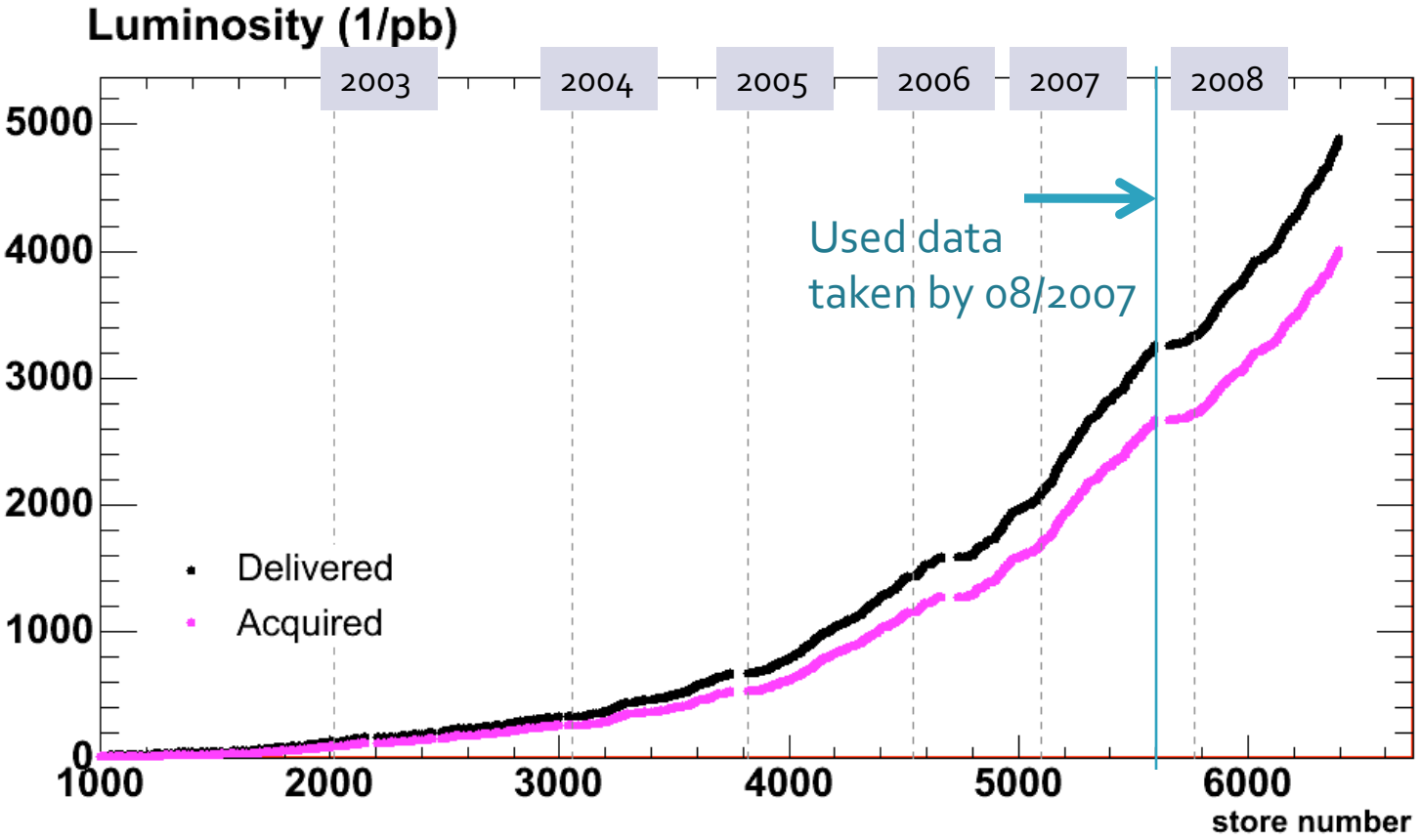

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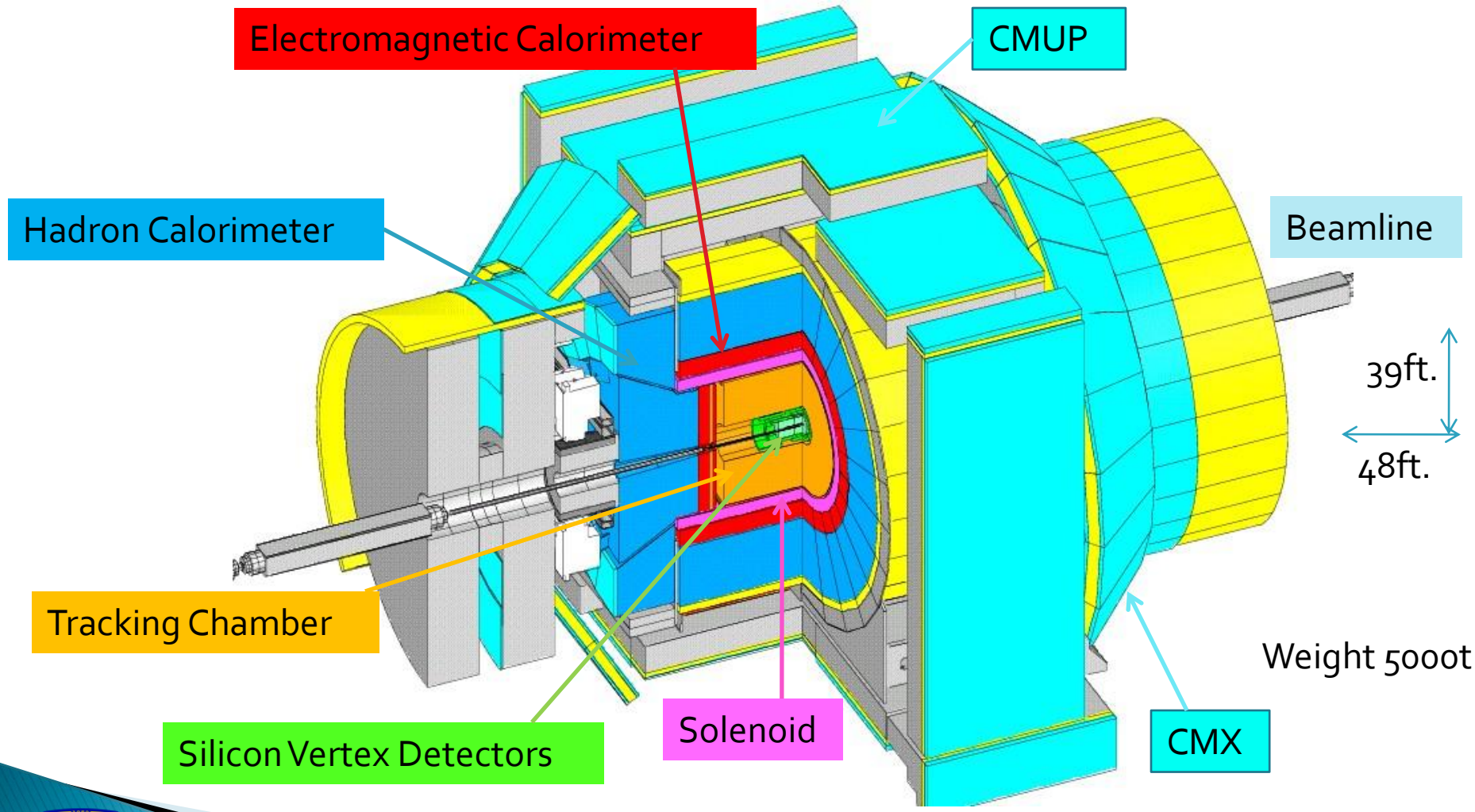
Collider Detector at Fermilab



$t \to bH^+(\to c\bar{s})$ Analysis

- Event Selection & Reconstruction

  Study on the H^+ mass

  Extracting br($t \to H^+b$)

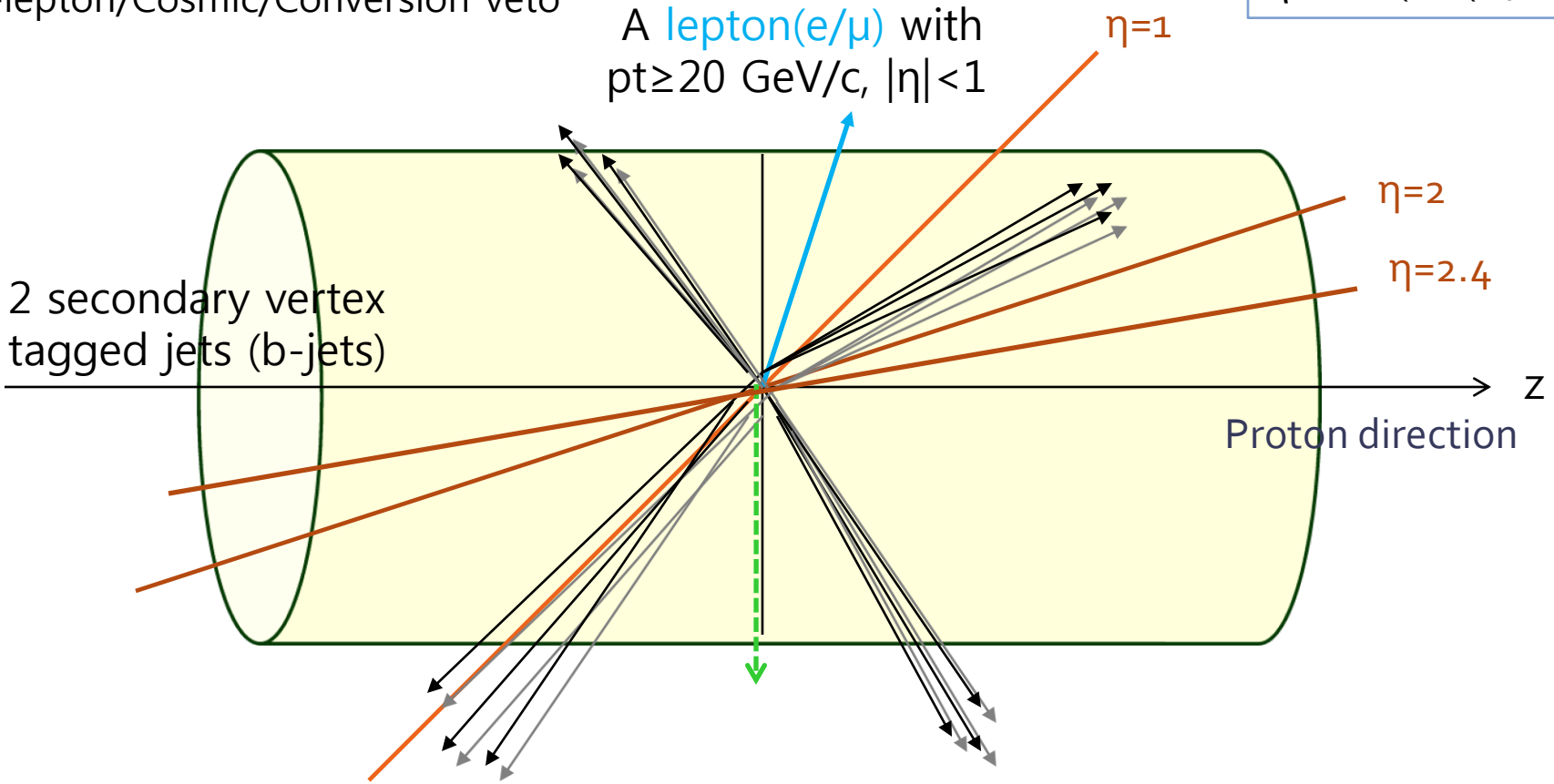
  Systematic Uncertainties

$t\bar{t}$ Event Selection

Detector in x-y plane

Z/Di-lepton/Cosmic/Conversion veto

Pseudo rapidity
$\eta = -\ln(\tan(\theta / 2))$



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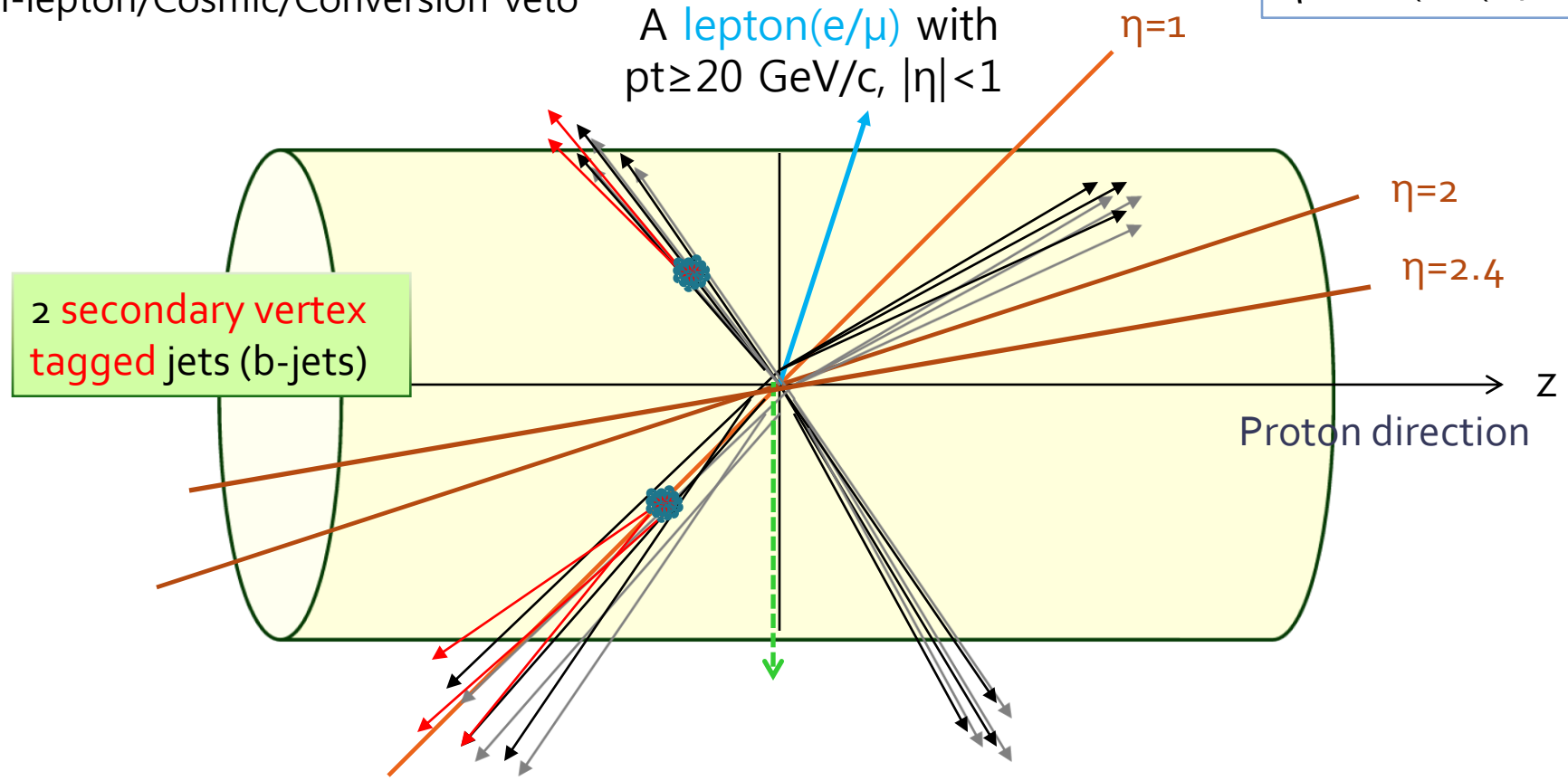

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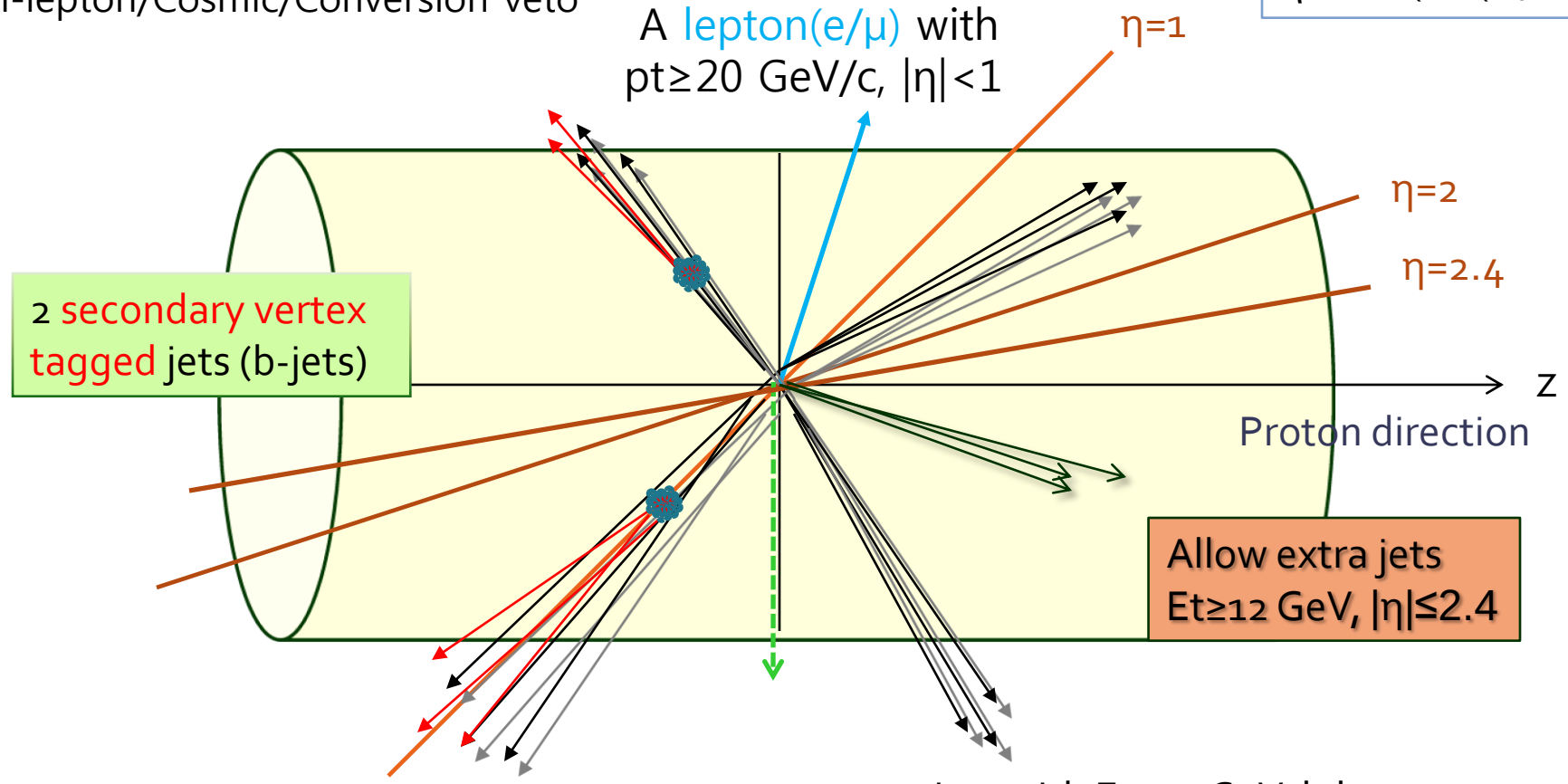
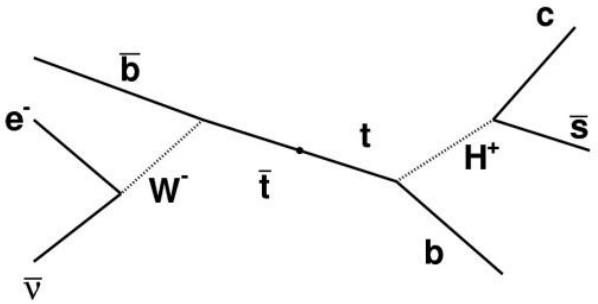


Top Event Reconstruction

- Matching final state objects to the partons in kinematic χ^2 fitter:
  - Leading 4 jets (b-jets to b-parton)
  - Lepton
  - Un-clustered energy for missing Et calculation
- Constrain top and leptonic W mass
- Vary energies within 1σ in the fitter



$$\chi^2 = \sum_{i=l,4\ jets} \frac{(p_T^{i,fit} - p_T^{i,meas})^2}{\sigma_i^2} + \sum_{j=x,y} \frac{(p_T^{UE,fit} - p_T^{UE,meas})^2}{\sigma_j^2}$$

$$+ \frac{(m_{l\nu} - m_W)^2}{\Gamma_W^2} + \frac{(m_{bjj} - m_t)^2}{\Gamma_t^2} + \frac{(m_{bl\nu} - m_t)^2}{\Gamma_t^2}$$

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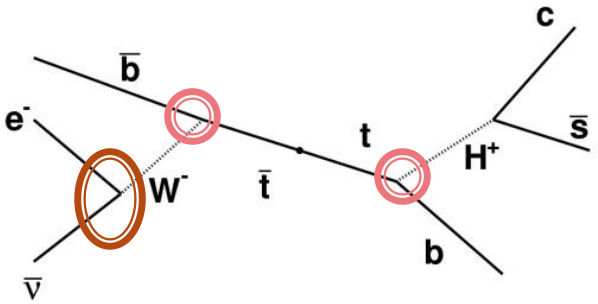

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M_W=80GeV

M_t=175GeV

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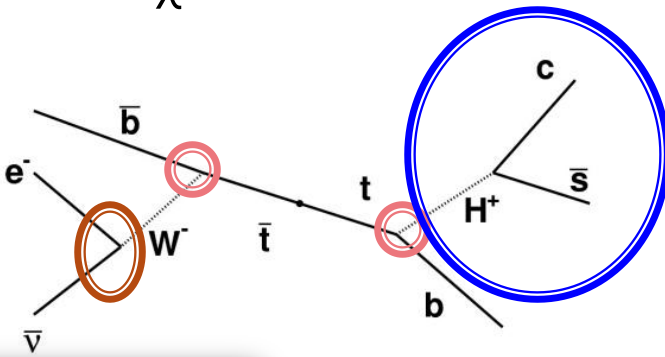

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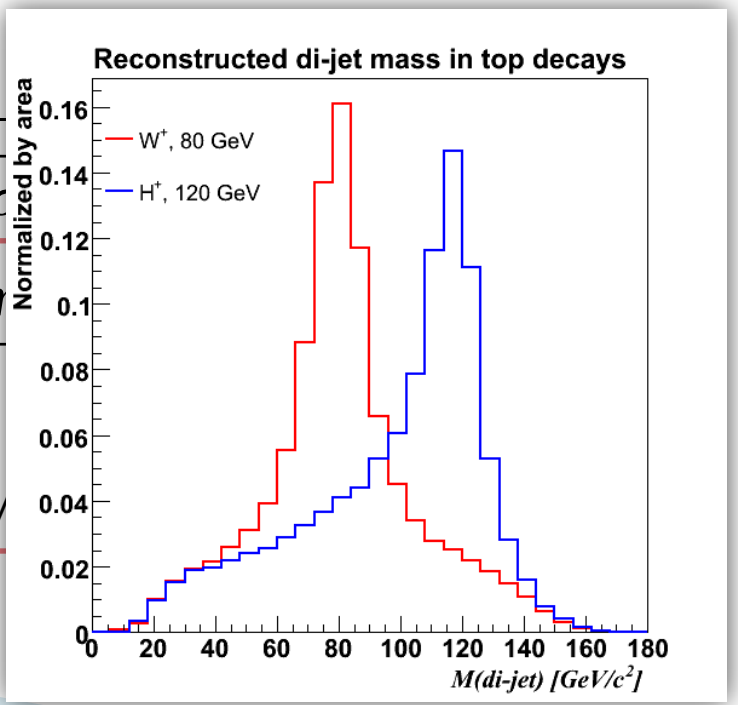


$t \to bH^+(\to c\bar{s})$ Analysis

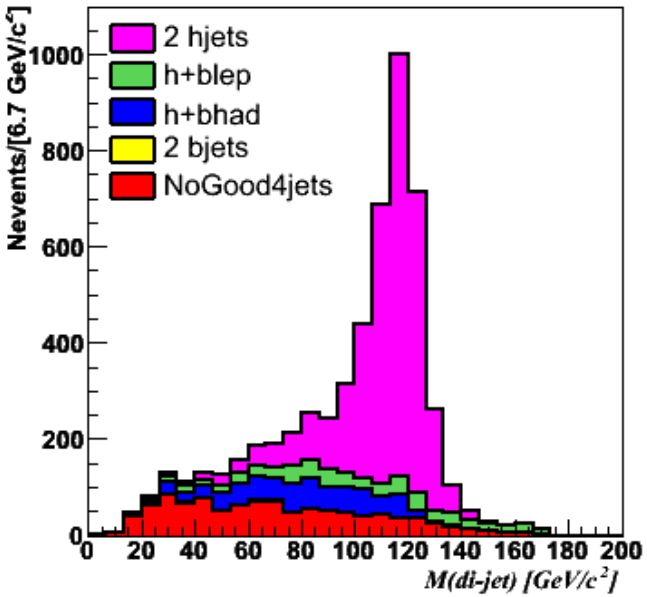
- Event Selection & Reconstruction
- Study on the H^+ mass
- Extracting br($t \to H^+b$)
- Systematic Uncertainties

Di-jet Mass vs. Number of Jets

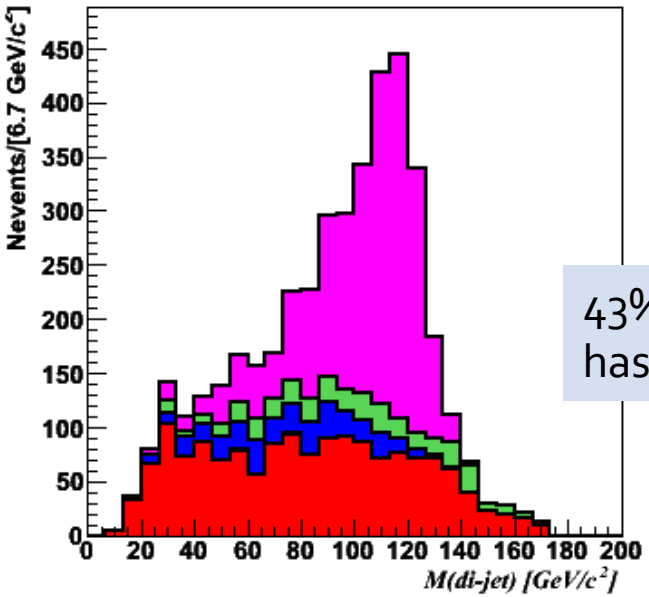
In 120 GeV Higgs Monte Carlo

Good Higgs combination
Others bad combination

Number of jets = 4



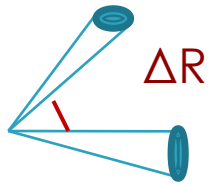
Number of jets ≥5

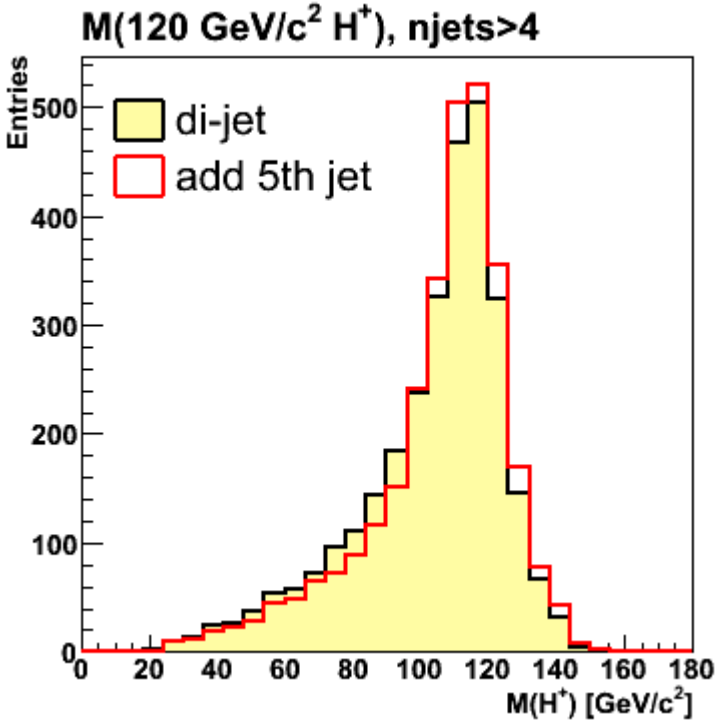


43% of events has > 4 jets

- Worse Higgs di-jet mass resolution with extra jets in $t\bar{t}$
- Energy loss by final state radiation from the Higgs particle

Improvement on Di-jet Mass





- Merge most energetic extra jet to the closest leading jet if ΔR<1.0
  - Jet cone size : 0.4
  - 5^{th} jet = the most energetic extra jet
- Mean of histogram close to the true mass
  - 103.3±21.8 GeV → 105.7±20.8 GeV
- Among 5^{th} jets added to the Higgs, about ¾ are turned out a real FSR from Higgs.
- No effect on W^+ and non-$t\bar{t}$ backgrounds

Reconstruct di-jet mass after merging nearby 5^{th} jet

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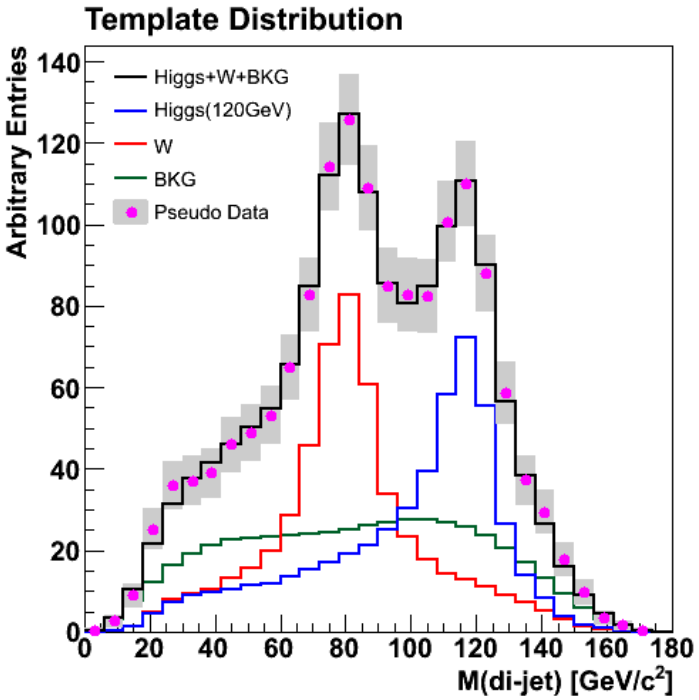
Extracting br(t→H⁺b)

- The binned likelihood function is constructed using:
  - Poisson probability
  - Gaussian constraints on number of non-$t\bar{t}$ background
- Di-jet mass distribution is fitted with the template :
  - H^+,W^+, and non-$t\bar{t}$ shape
- Likelihood fitter returns
  - br(t→H^+b) assuming br(H^+→$c\bar{s}$)=100%, br(t→H+b)+br(t→W+b) = 1
  - Number of non-$t\bar{t}$ background
- Templates for Higgs mass of
  - 90 GeV, 100 GeV, …, 150 GeV

$$LH = \prod \frac{\nu_i^{n_i} \times e^{-\nu_i}}{n_i!} \bigotimes G(N_{bkg}, \sigma_{bkg})$$



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Systematic Uncertainty

- Check systematic that can affect mass distribution
- Jet Energy Scale
  - Jet energy is corrected after reconstructing energy from calorimeter
  - Absolute, out of cone, detector response, multiple interactions, etc.
  - Change the overall correction scale $\pm 1\sigma$
- Monte Carlo generator
  - W^+ distribution from Pythia vs. Herwig
- Initial/Final state radiation
  - Generate Monte Carlo with more/less radiation jets tuning in Pythia
- Q^2 scale on W+jets background
  - Generate W+jets background with different momentum transfer

Systematic Uncertainties

- Take output br(t→H^+b) shifts due to 1σ systematic changes.
- Square-root-sum of each uncertainty is symmetrized and used to Gaussian smearing of the likelihood shape.

M(H^+)	JES	MC-gen	ISR	FSR	Q^2, W+jets
90 GeV	0.063	0.047	0.015	0.003	0.008
100 GeV	0.026	0.021	0.013	0.003	0.003
110 GeV	0.011	0.020	0.011	0.003	0.003
120 GeV	0.010	0.021	0.009	0.003	0.002
130 GeV	0.005	0.018	0.007	0.003	0.001
140 GeV	0.003	0.014	0.005	0.004	0.001
150 GeV	0.002	0.020	0.003	0.004	0.002

@ br(t→H^+b) =0

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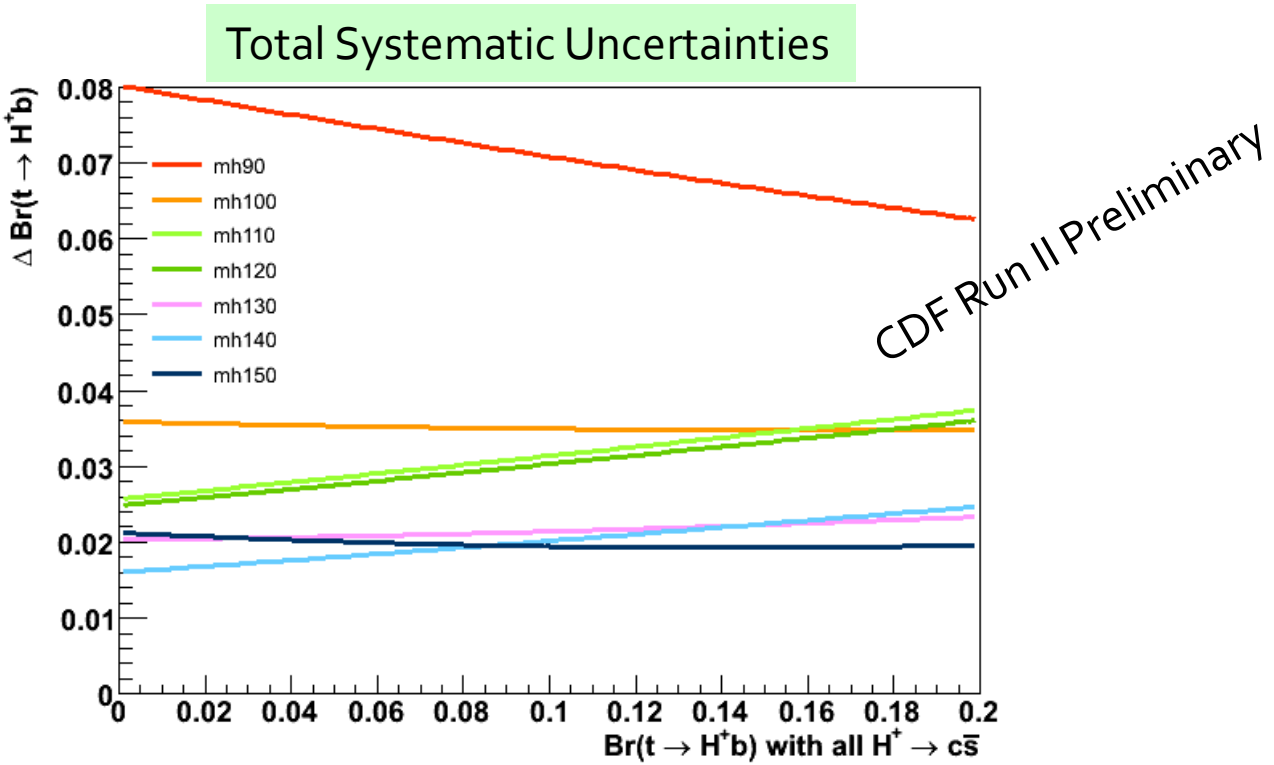
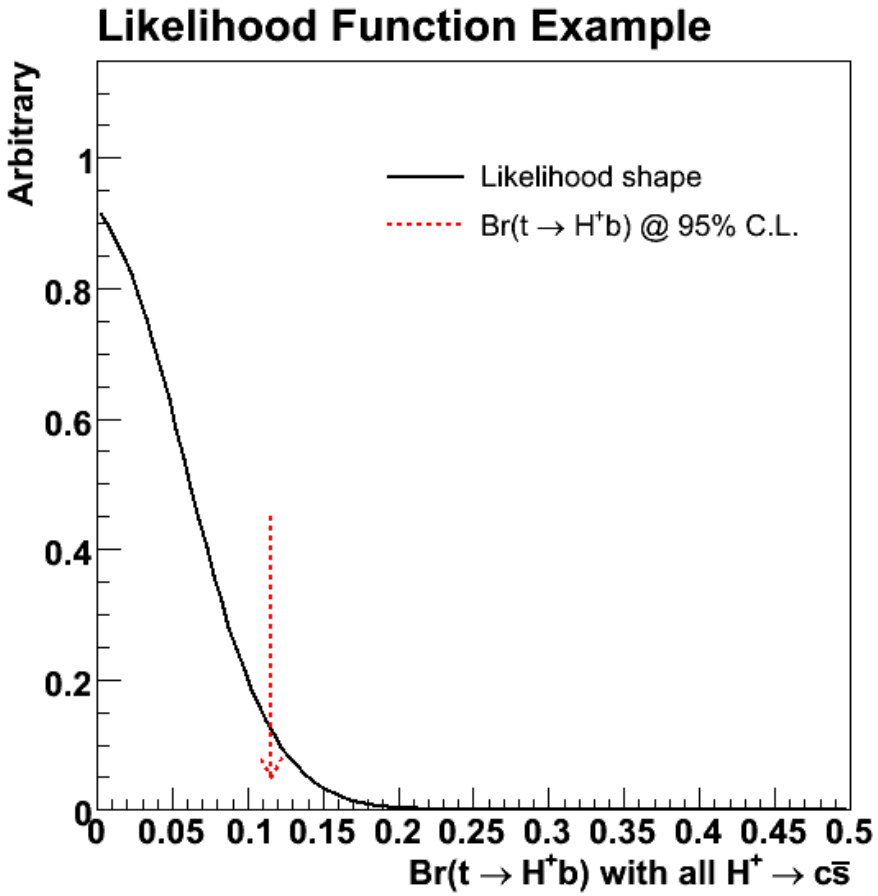
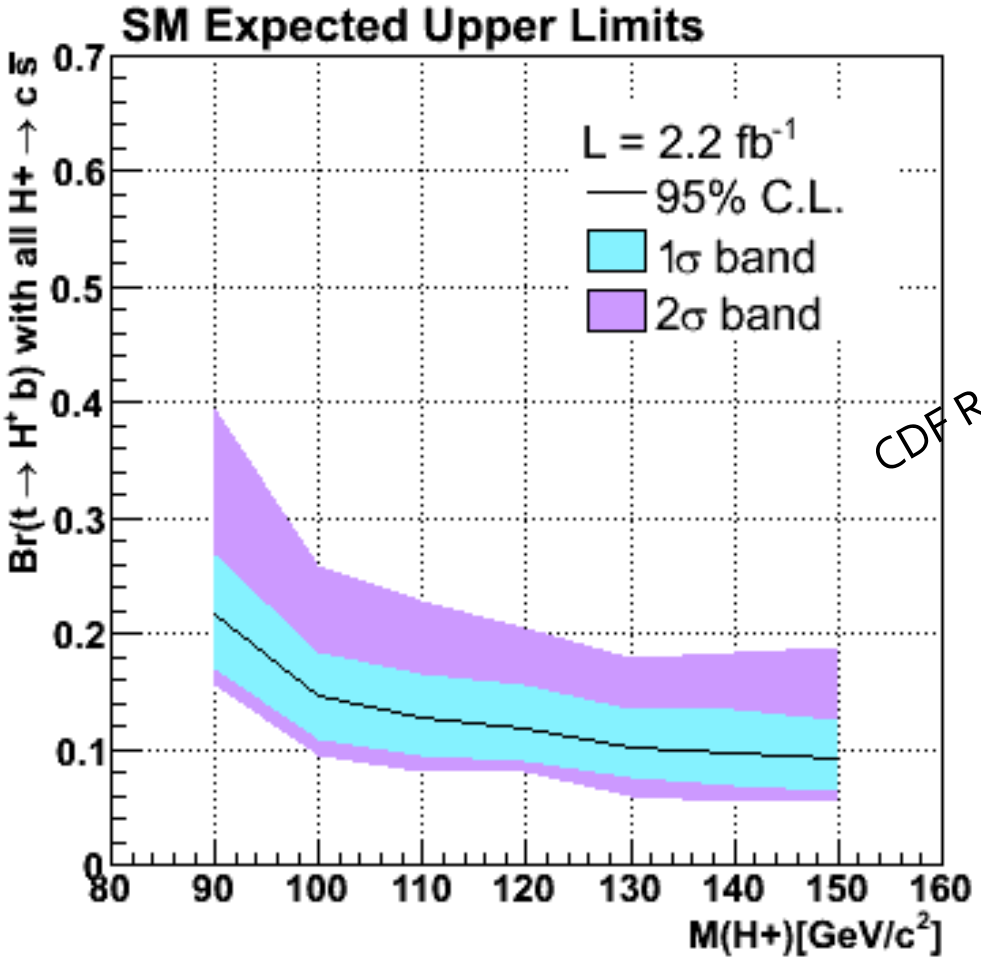


Upper Limit on Br(t→H⁺b)

- Upper limit on the br(t→H⁺b) is calculated by
  - Integration of the likelihood function up to 95% of positive (physical) branching ratio area
  - Projection onto x-axis is the upper limit on the branching ratio at 95% C.L.



SM Expected Limit on Br(t→H⁺b)

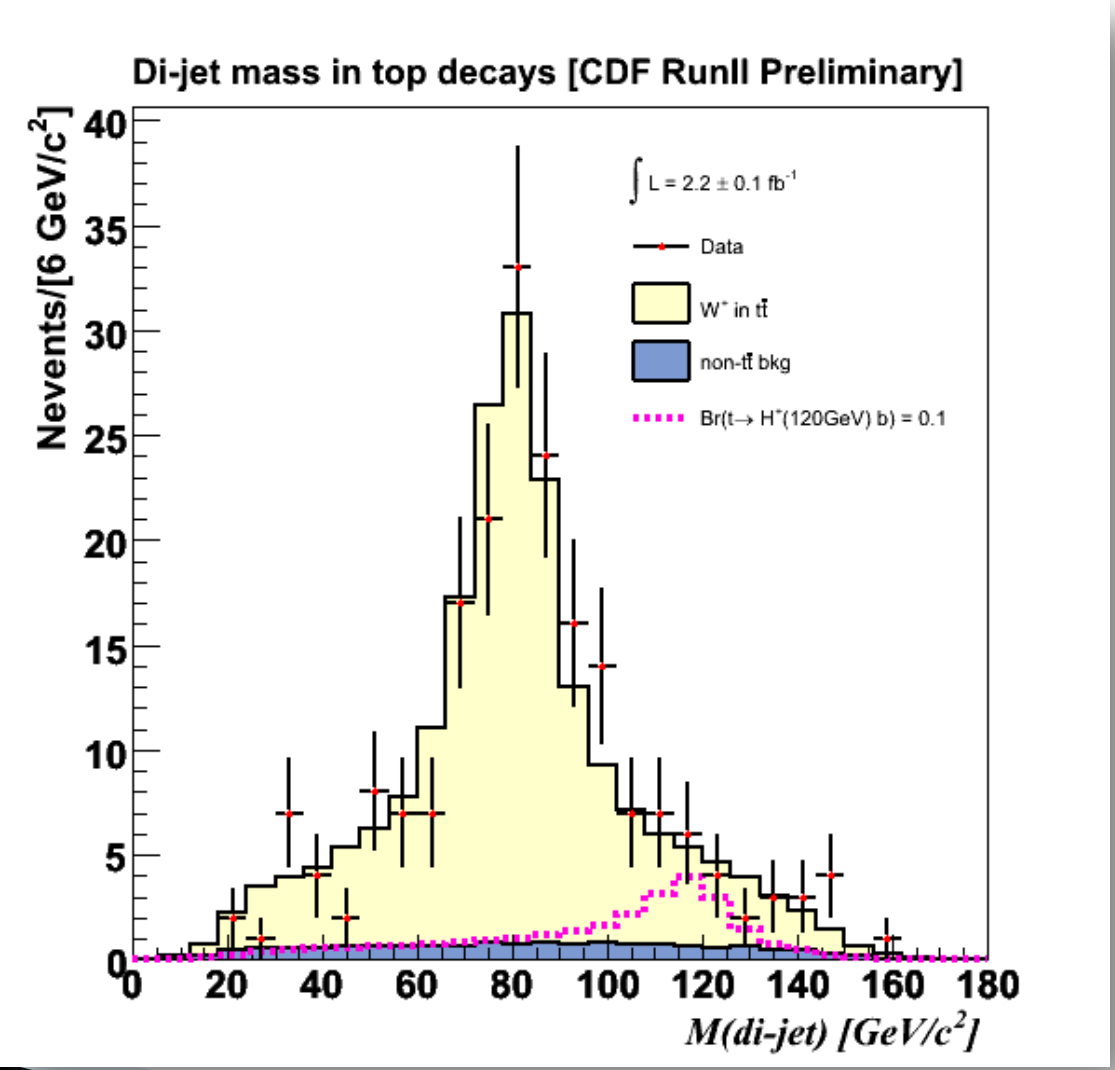


CDF Run II Preliminary

Results

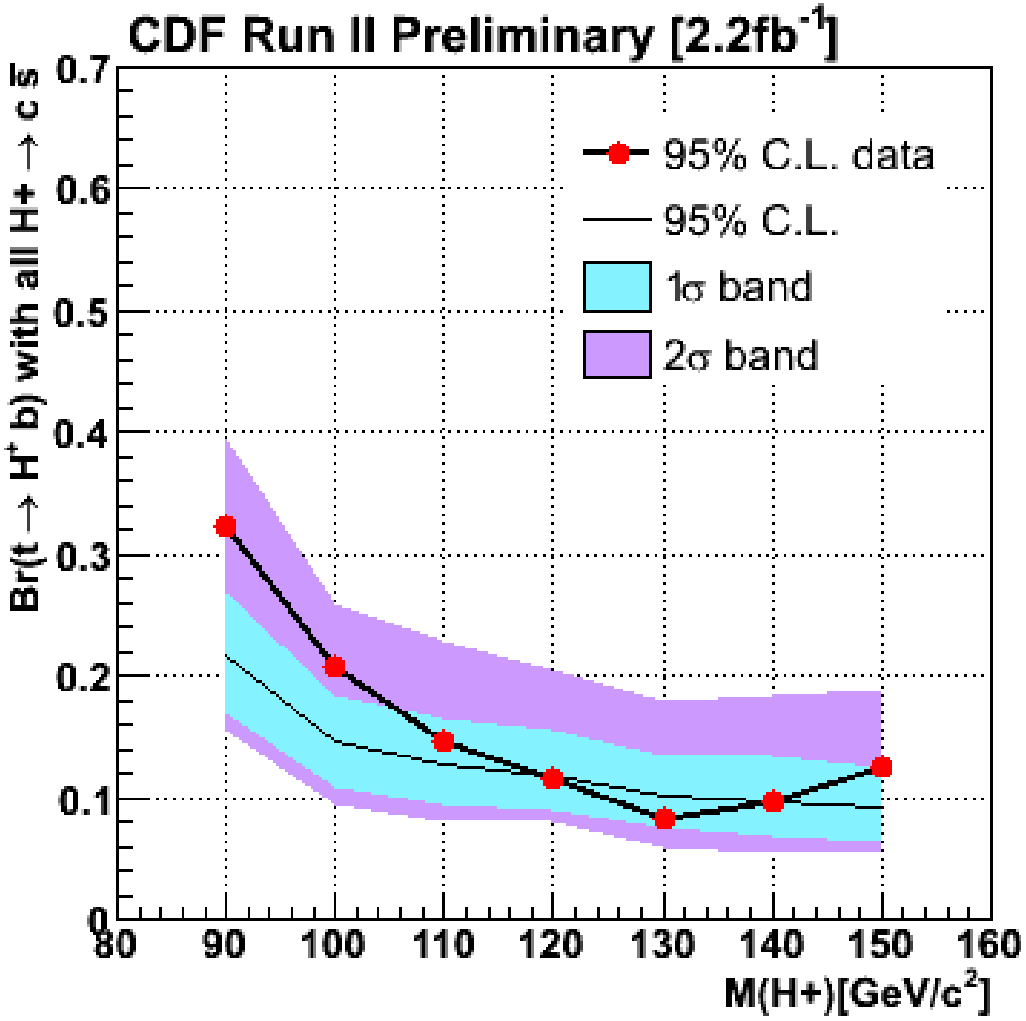
» from 2.2 fb^{-1}

Di-jet Mass in 2.2 fb^{-1} Top Decays



Upper Limit Br(t→H⁺b) @ 95% C.L.

Br(t→H⁺b) < 0.1~0.3
for 90 GeV < M(H⁺) < 150 GeV



Summary

Summary

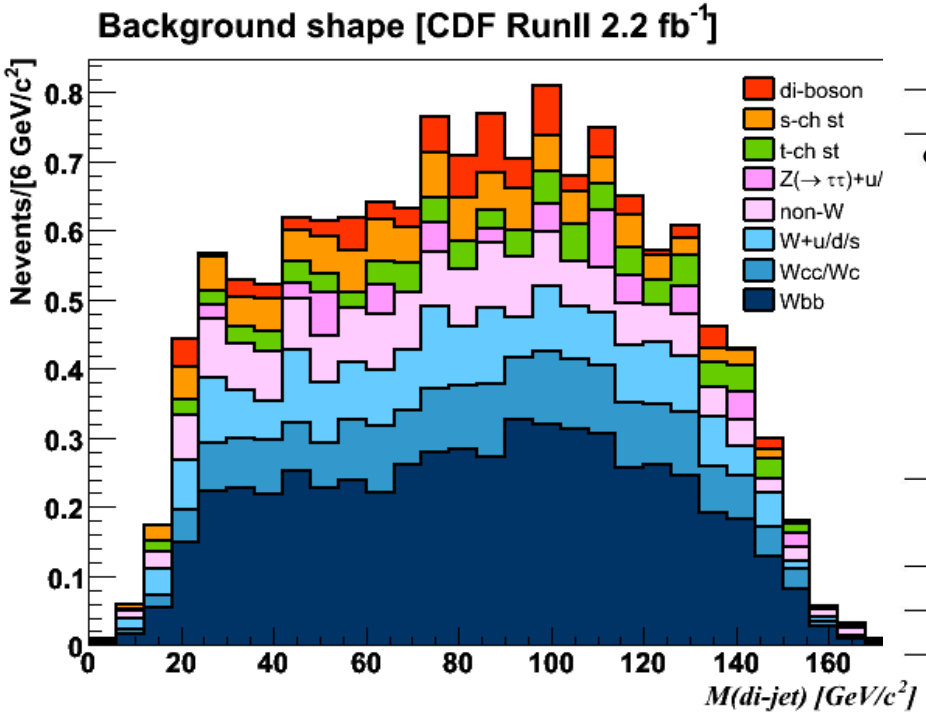
- Charged Higgs search in decays of top in 2.2 fb^{-1} of CDF Run II data
  - Fully reconstructed di-jet invariant mass for $H^+ \rightarrow c\bar{s}$
  - Viable at small tan β in the MSSM parameter
  - Improved result on the br(t→H^+b) upper limits
    - In 2.2 fb^{-1}: br(t→$H^+(c\bar{s})$b) < 0.1~0.3 for 90GeV < M(H^+) < 150 GeV
    - In 192 pb^{-1}: br(t→$H^+(\tau^+\nu)$b) < 0.4 for 80 GeV < M(H^+) < 160 GeV
  - Can be Interpreted as an independent search of top quark property
    - br(t→W^+b)>0.7~0.9 for 90 GeV <M(H^+)<150 GeV
- New era of charged HIGGS coming soon @ LHC?!

Thank you
Tack så mycket

Previous Charged Higgs searches @ CDF

- **Search for Charged Higgs Bosons from Top Quark Decays in p anti-p Collisions at s**(1/2)= 1.96 TeV**
  - Phys. Rev. Lett. 96, 042003 (2006)
- **Search for the Charged Higgs Boson in the Decays of Top Quark Pairs in the e tau and mu tau Channels at s**(1/2) = 1.8 TeV**
  - Phys. Rev. D62, 012004 (2000)
- **Search for Charged Higgs Boson Decays of the Top Quark using Hadronic Decays of the Tau Lepton**
  - Phys. Rev. Lett. 79, 357 (1999)
- **Search for Charged Higgs Boson Decays of the Top Quark Using Hadronic Tau Decays**
  - Phys. Rev. D54, 735 (1996).
- **Search for the Top Quark Decaying to a Charged Higgs Boson in p anti-p Collisions at s**(1/2)=1.8 TeV**
  - Phys. Rev. Lett. **72**, 1977 (1994)

Non-ttbar background composition



CDF Run II Preliminary (2.2 fb^{-1})

Process	$\geq$ 4 tight jets	fraction(%)
di-boson(WW/ZZ/WZ)	0.7 $\pm$ 0.1	0.4
s-channel single Top	1.0 $\pm$ 0.1	0.5
t-channel single Top	0.8 $\pm$ 0.1	0.5
Z+lf	0.5 $\pm$ 0.1	0.3
W+bb	5.6 $\pm$ 2.3	3.4
W+cc/W+c	1.9 $\pm$ 0.8	1.1
W+lf	1.9 $\pm$ 0.6	1.1
non-W	1.6 $\pm$ 3.3	0.9
non-$t\bar{t}$	13.9 $\pm$ 7.5	8.4
$t\bar{t}$ (6.7pb)	152.6 $\pm$ 25.0	91.6
Total Prediction	166.5 $\pm$ 32.4	100
Observed	200	