

SEARCH for Heavy 4th generation quarks at CMS

Ricardo Vásquez Sierra



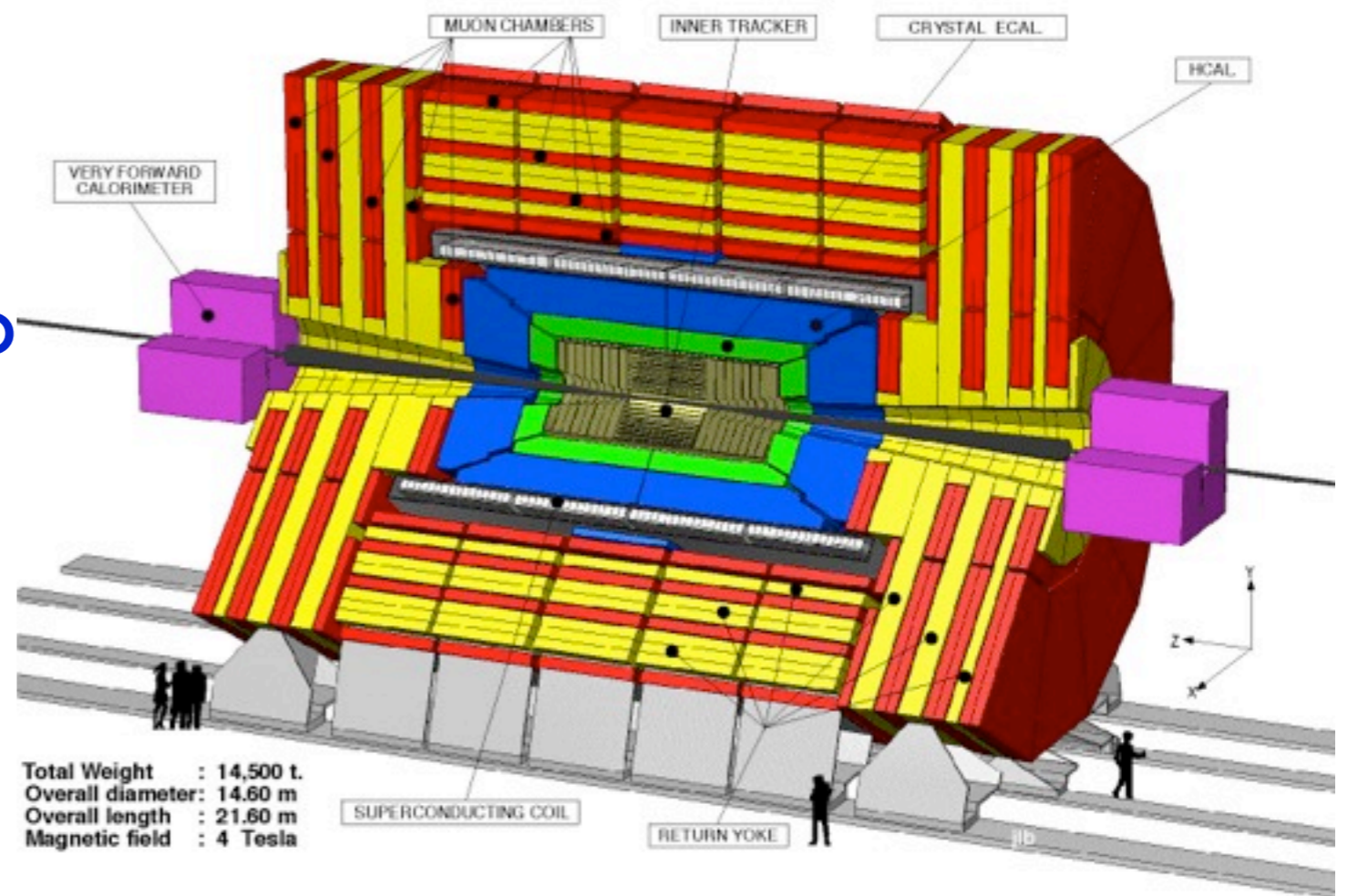
On behalf of the CMS Collaboration
SEARCH 2012 Workshop
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Outline

- Particle flow introduction
 - ▶ All analyses use this event description
- CMS 4th generation searches
 - ▶ t' pair search in the dilepton channel
 - ▶ b' search in the trilepton and same sign dilepton channel
 - ▶ Inclusive t' and b' search
 - ▶ t' pair search in the lepton+jets channel
- Conclusion

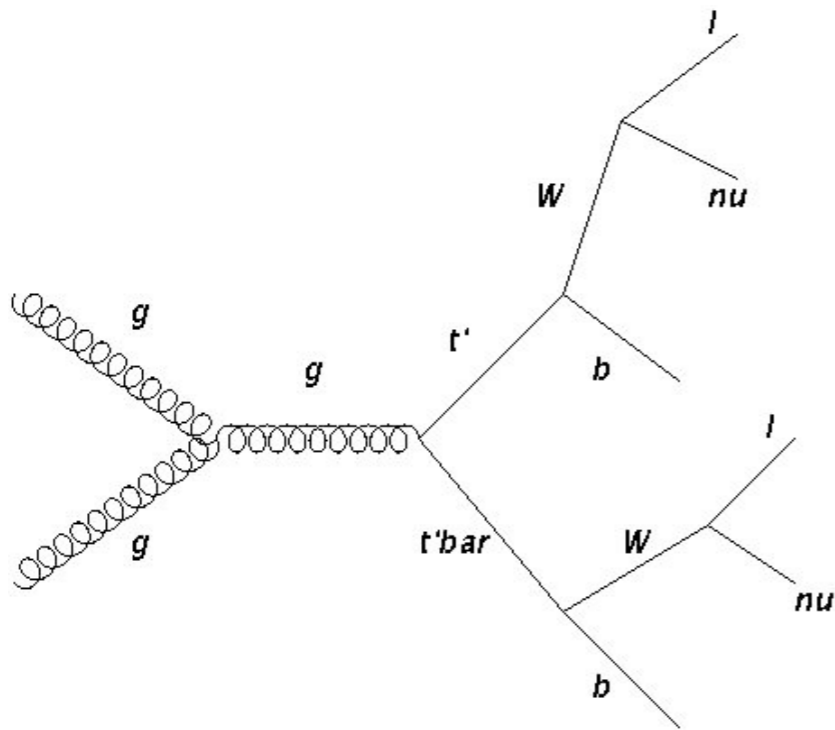
Particle Flow Algorithm

- Provides a list of observable particles that describe the event
 - ▶ muons, electrons, photon, charged and neutral hadrons
- It combines the information from all CMS sub-detectors to achieve this
- This list is used to reconstruct higher level objects like jets, MET



Search for $t' \rightarrow bW$ (dilepton)

4.7 fb⁻¹



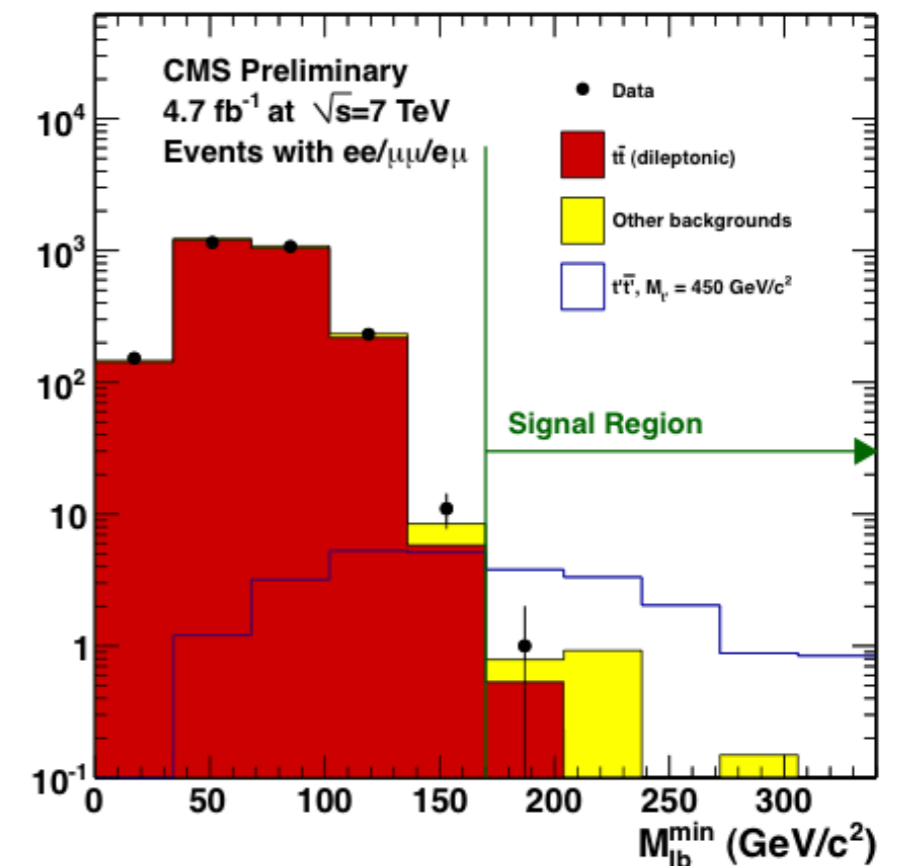
- ▶ Opposite sign leptons+jets
- ▶ 2 jets b-tagged
- ▶ Missing E_T

$$t' \bar{t}' \rightarrow W^+ b W^- \bar{b} \rightarrow l^+ \nu b l^- \bar{\nu} \bar{b}$$

EXO-11-050

Analysis Strategy

- Preselect a region $t\bar{t}$ and $t'\bar{t}'$ rich
- Define a signal region separate from the $t\bar{t}$
- Estimate residual backgrounds using data driven methods whenever possible on the background rich region



Selection

- Two opposite sign leptons ($ee, e\mu, \mu\mu$) with $p_T > 20 \text{ GeV}/c$ and $|\eta| < 2.5$ (2.4) for $e(\mu)$
- At least two jets with $p_T > 30 \text{ GeV}/c$ and $|\eta| < 2.5$
- Two b-tagged jets
- Missing $E_T > 50 \text{ GeV}$
- $Z \rightarrow ee/\mu\mu$ and $\Upsilon \rightarrow ee/\mu\mu$ veto

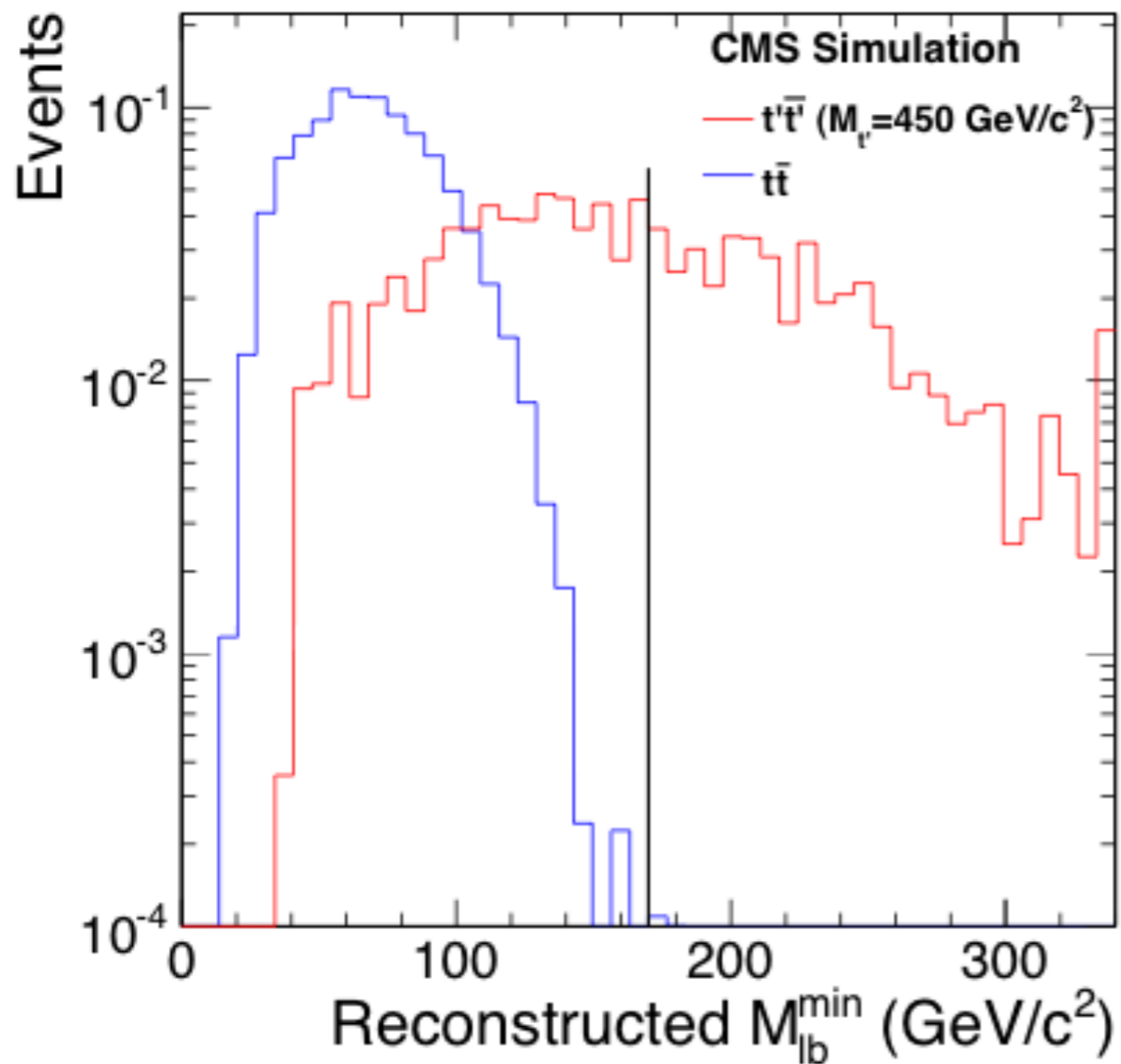
Discriminating variable

- We attempt to look at the invariant mass of the lepton and the b-tagged jet from the t/t' and $t\text{bar}/t'\text{bar}$ decays:

$$M_{lb} = \sqrt{(E_l + E_b)^2 - |\vec{p}_l + \vec{p}_b|^2}$$

- There are two ways to combine the two leptons and two b-tagged jets in each event giving four possible values of M_{lb} so we choose the combination with the minimum $\rightarrow M_{lb}^{min}$

M_{lb}^{min}



- For our selection $t\bar{t}$:

$$M_{lb}^2 < M_t^2 - M_W^2$$

- Defining signal region:

$$M_{lb}^{min} > 170 \text{ GeV}/c^2$$

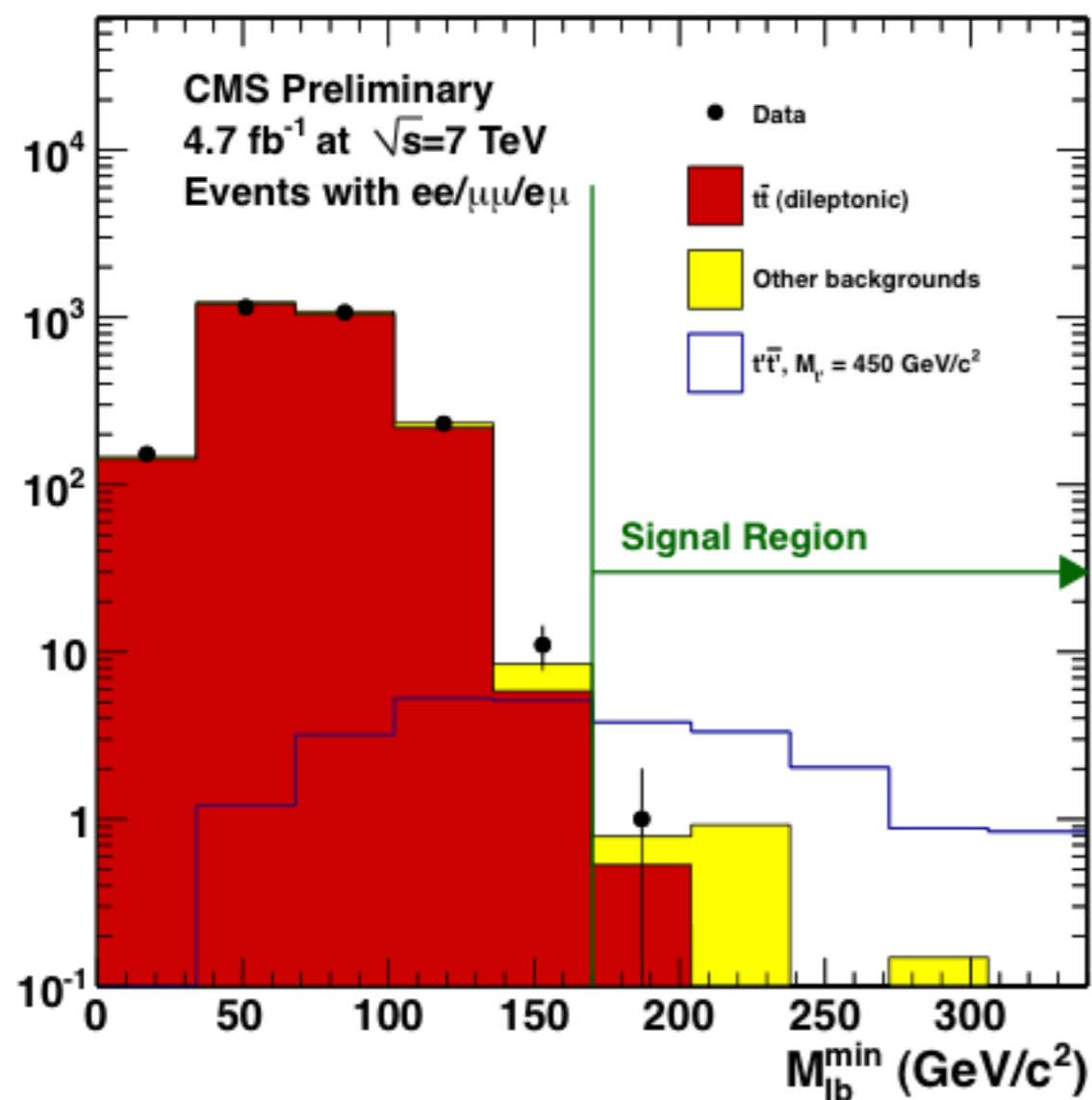
Background estimation

Four sources of background were identified:

- Category I - Events with b-mistagged jet(s) and real leptons
- Category II - Events with fake lepton(s) and real b-tagged jet(s)
- Category III - Events with 2 real b-tagged jets and 2 real leptons obtained from MC
- Category IV - Events with b-mistagged jet(s) and fake lepton(s) which turns out to be negligible

Data driven estimations for Categories I, II and IV and most of it coming for $t\bar{t}b\bar{a}$ events

Final distribution

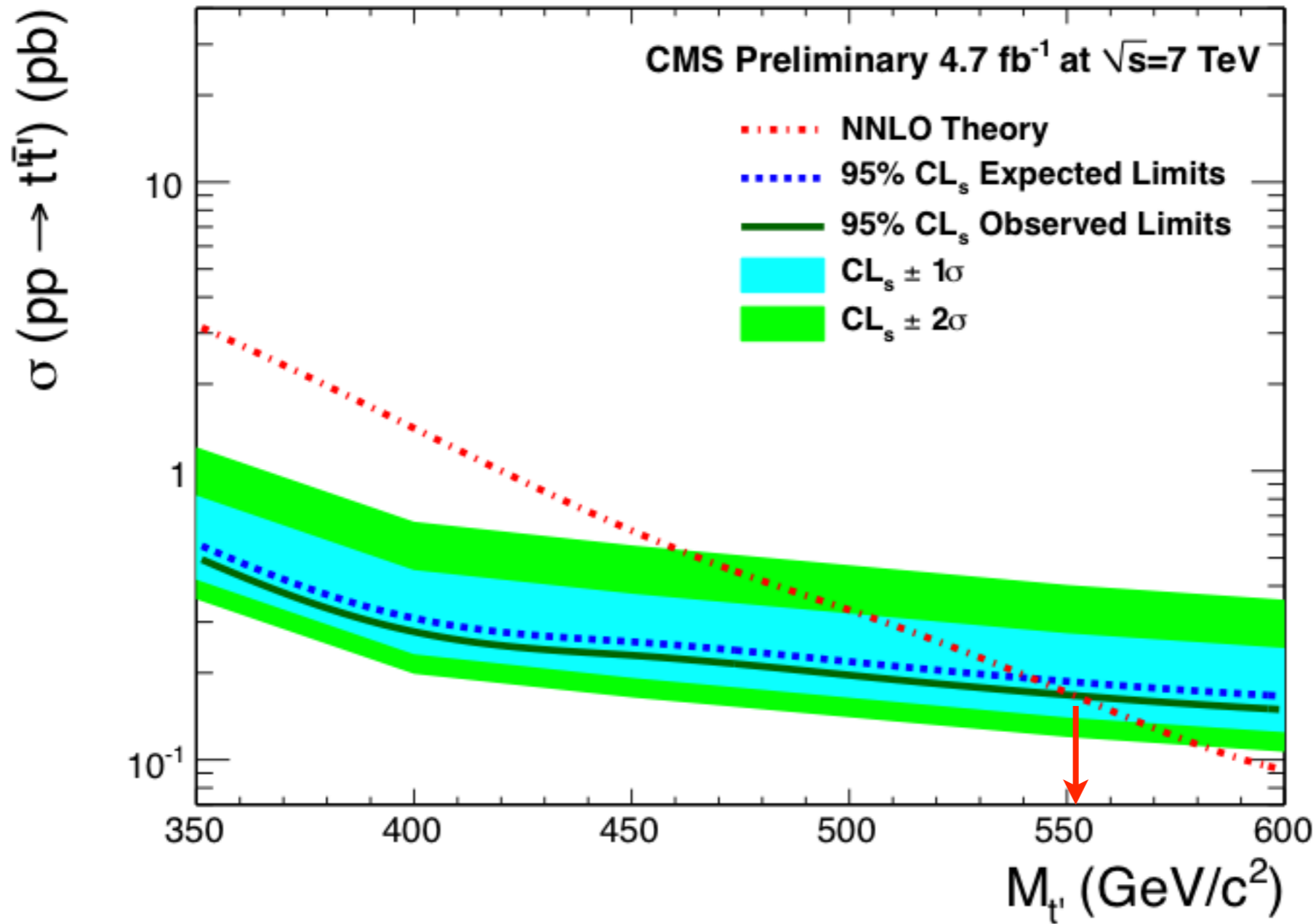


Counting experiment

Sample	Yield
Category I (data-driven)	0.74 ± 0.79
Category II (data-driven)	$0_{-0.0}^{+0.4}$
Category III (simulated)	0.99 ± 0.69
Total prediction	1.73 ± 1.12
Data	1

In the absence of signal, perform 95 % C.L.
upper limit on the production cross section

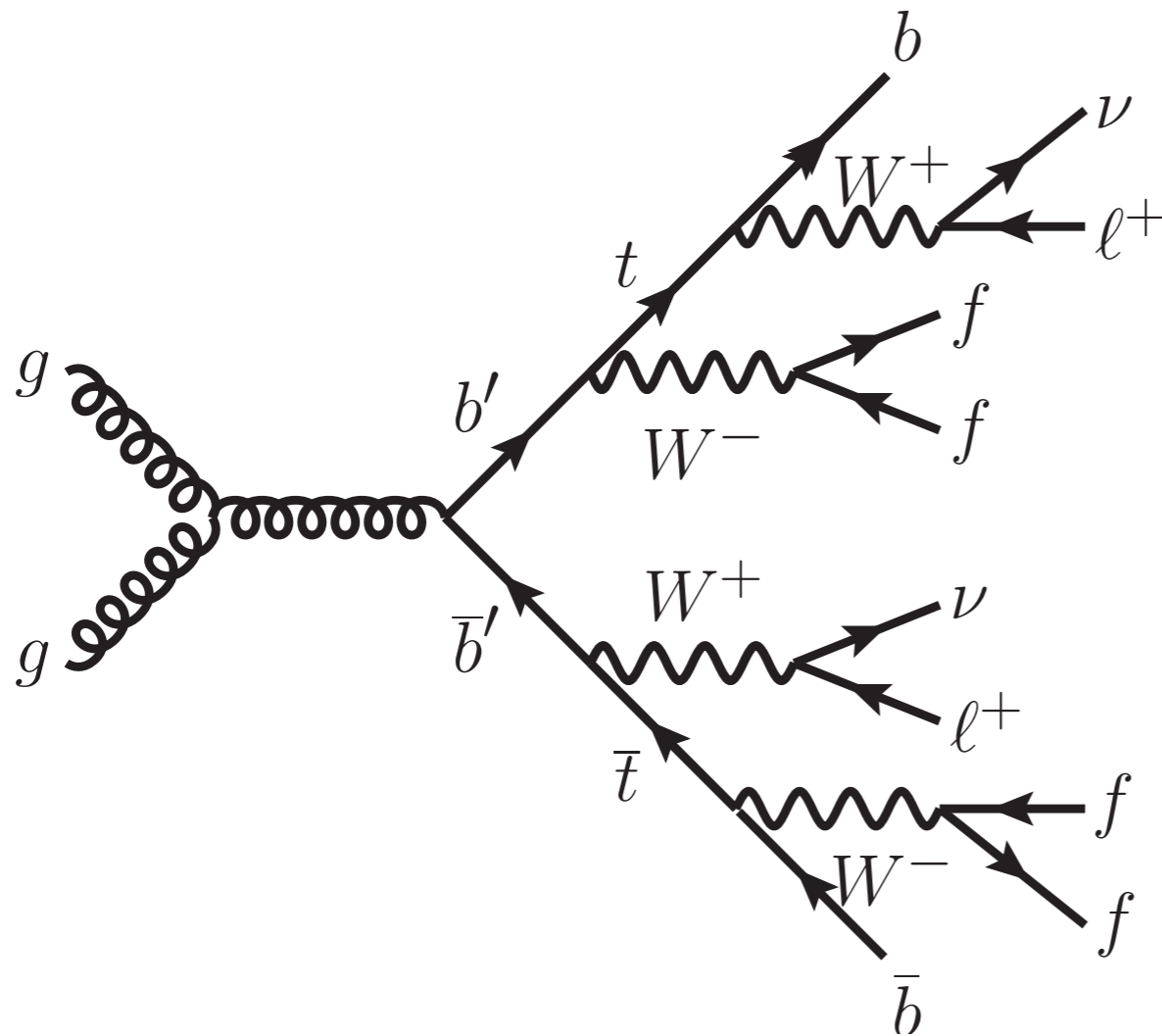
Results



- Observed t' lower mass limit of 552 GeV/c²

Search for $b' \rightarrow tW$

4.6 fb⁻¹



- Two channels are studied
 - ▶ Same-sign dilepton + jets
 - ▶ Trilepton + jets

The jet multiplicity is higher than the $t\bar{t}$ case

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Selection

- Leptons(e/μ) with $p_T > 20$ GeV and $|\eta| < 2.4$

(dilepton)

- 2 same sign leptons
- At least 4 jets

(trilepton)

- 3 leptons (charge ++- or +--)
- At least 2 jets

$$S_T = |E_T^{miss}| + \sum |p_T^l| + \sum |p_T^{jet}|$$

- One b-tagged jet
- $S_T > 500$ GeV

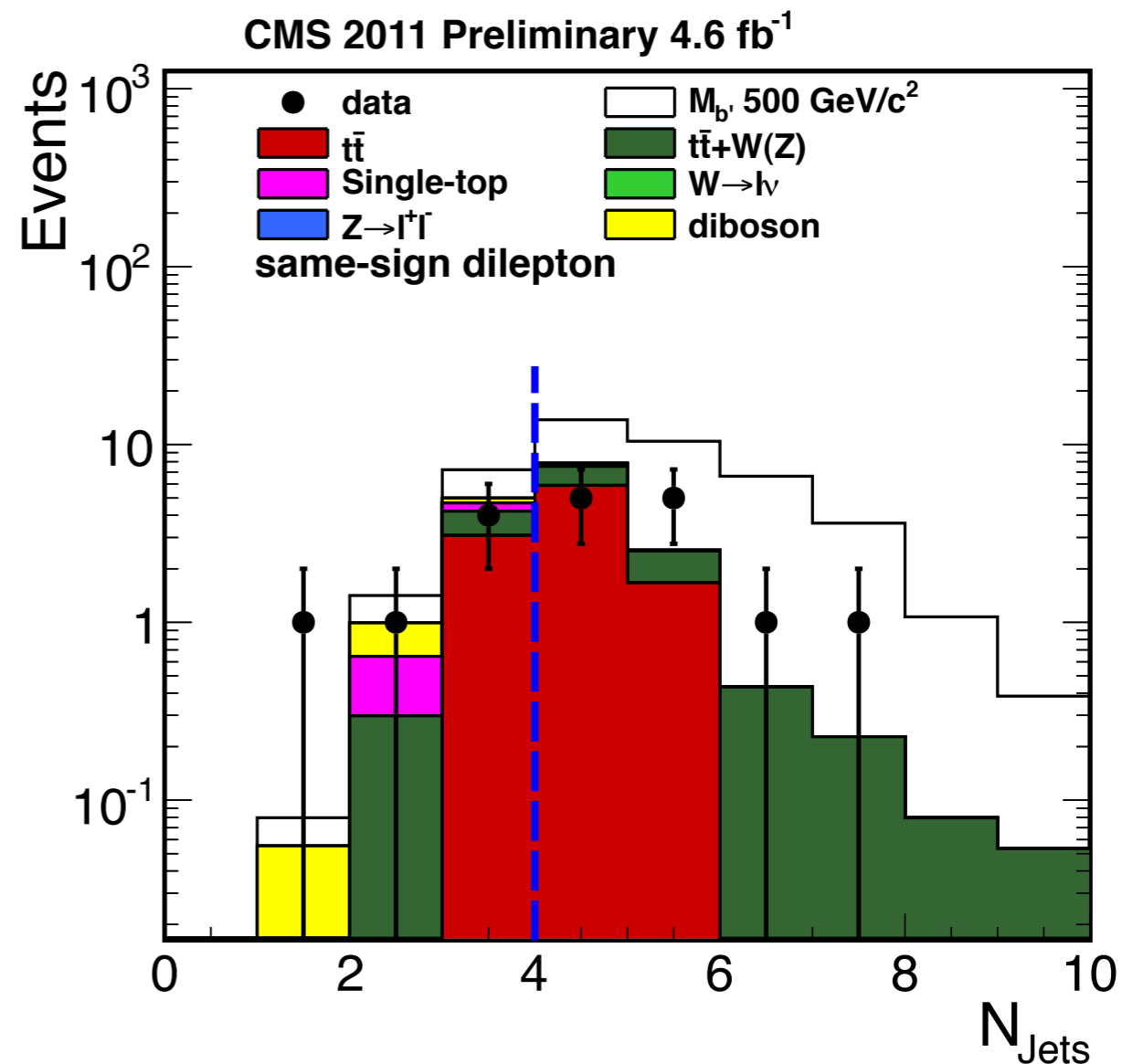
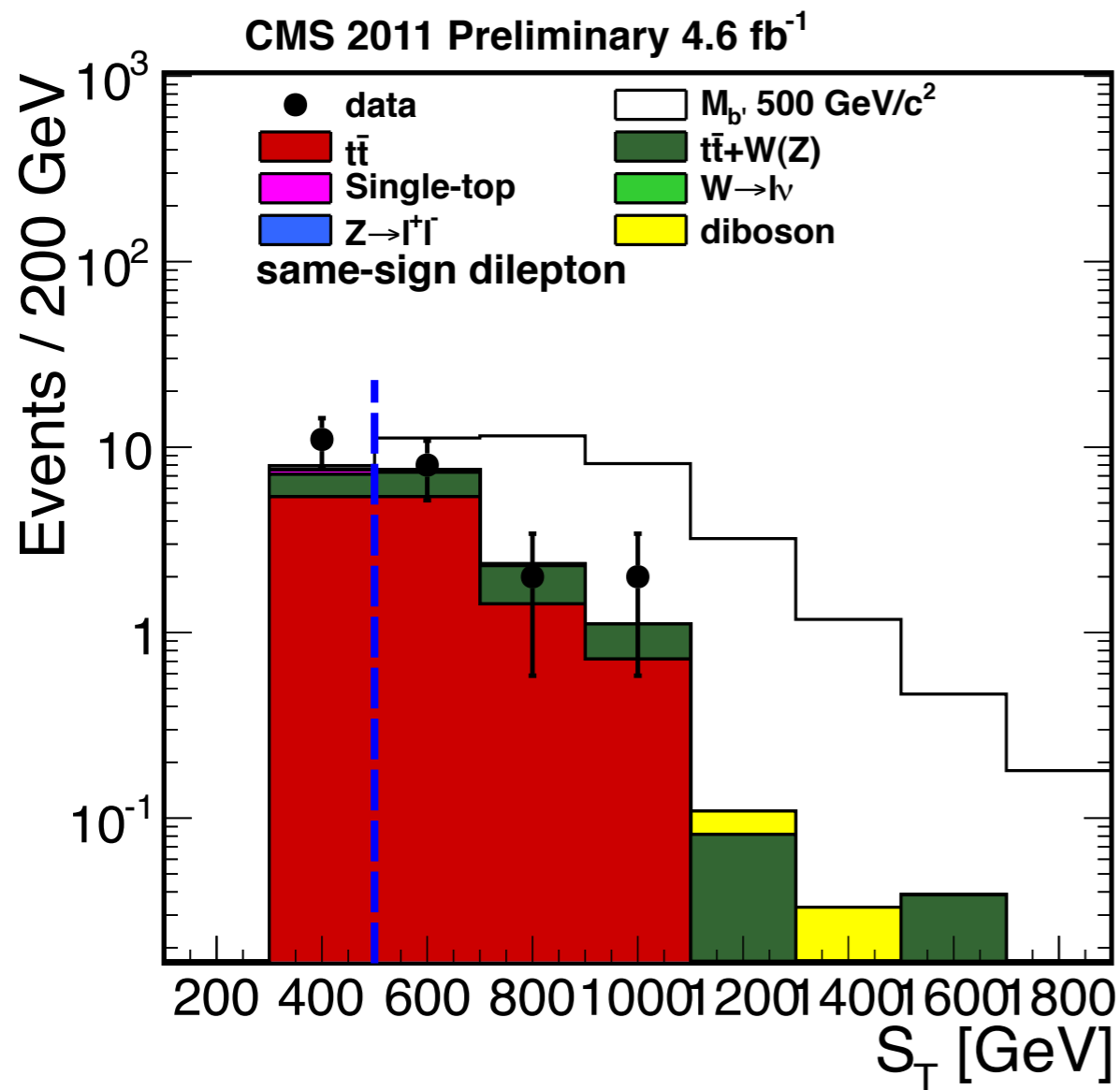
Background Estimation

- Sources for same sign dilepton channel
 - ▶ Type I (data driven) -- Fake lepton
 - ▶ Type II (data driven)-- Charge Misidentification
 - ▶ Type III (from MC) -- Prompt dileptons
- Sources for trilepton channel
 - ▶ Dominated by 3 prompt leptons events (ttW)

Most backgrounds coming from ttbar events

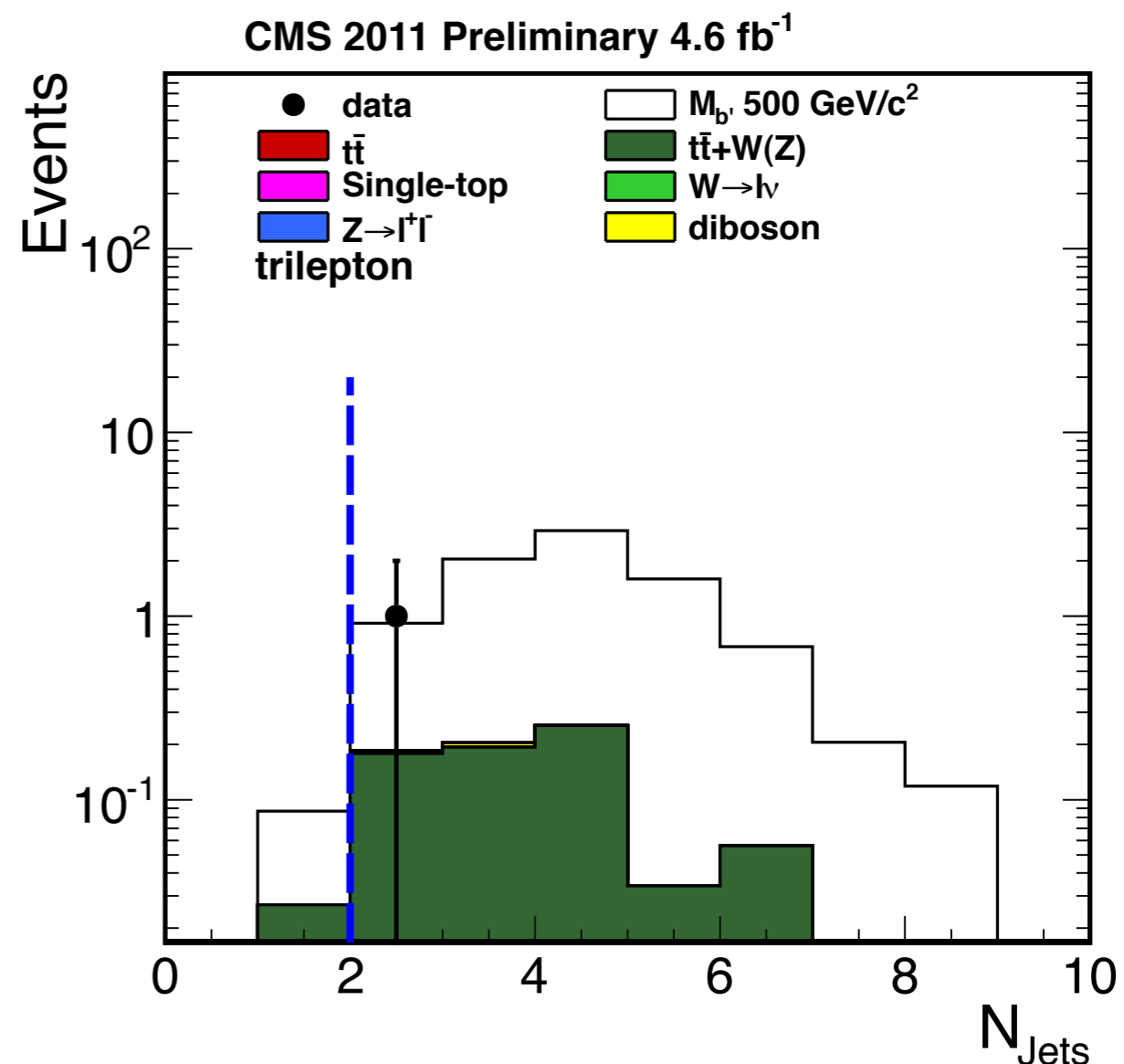
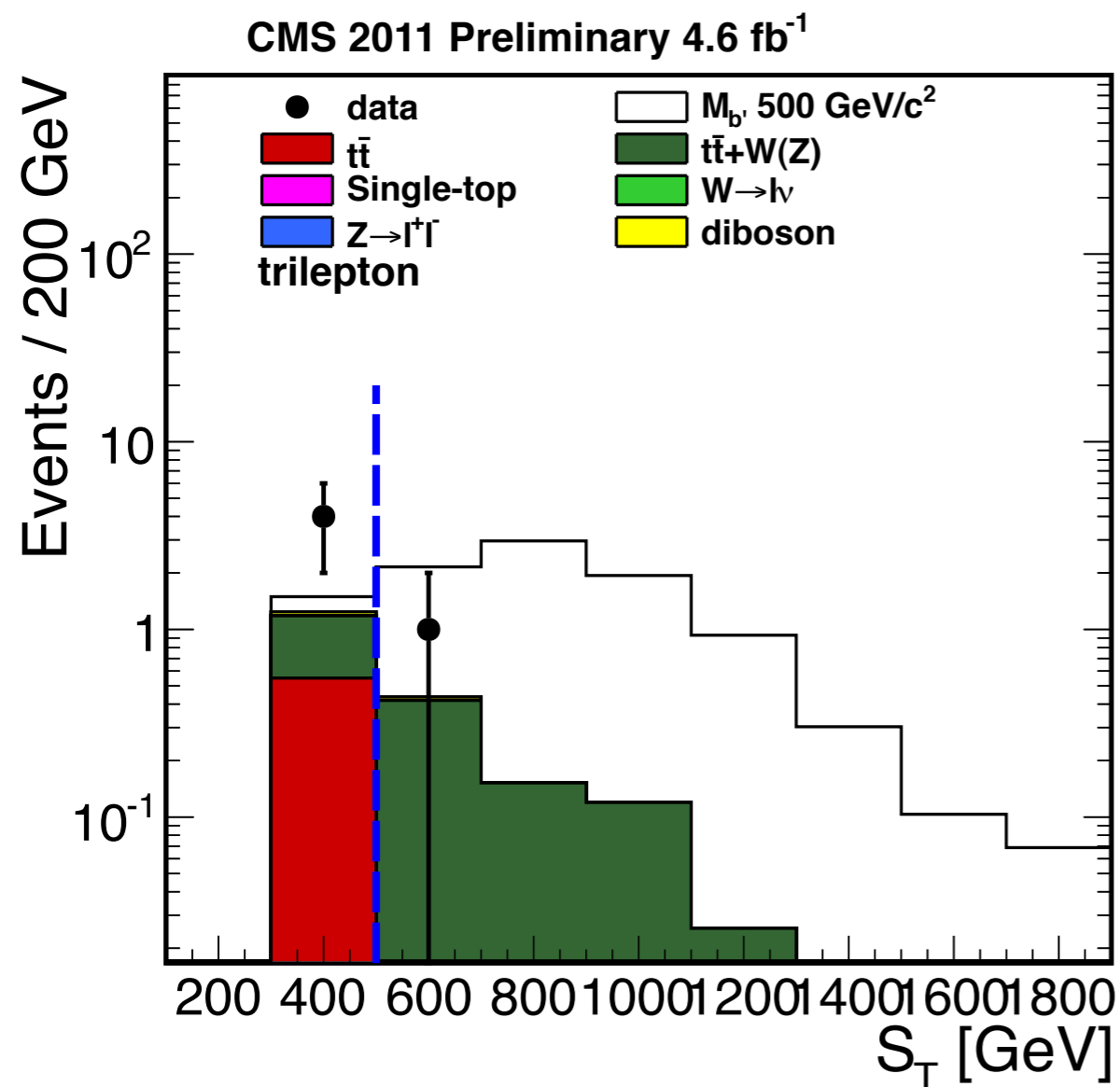
Same sign dileptons

$b\bar{b}$ dilepton
trilepton



- Very pure signal almost no SM background

Trilepton channel

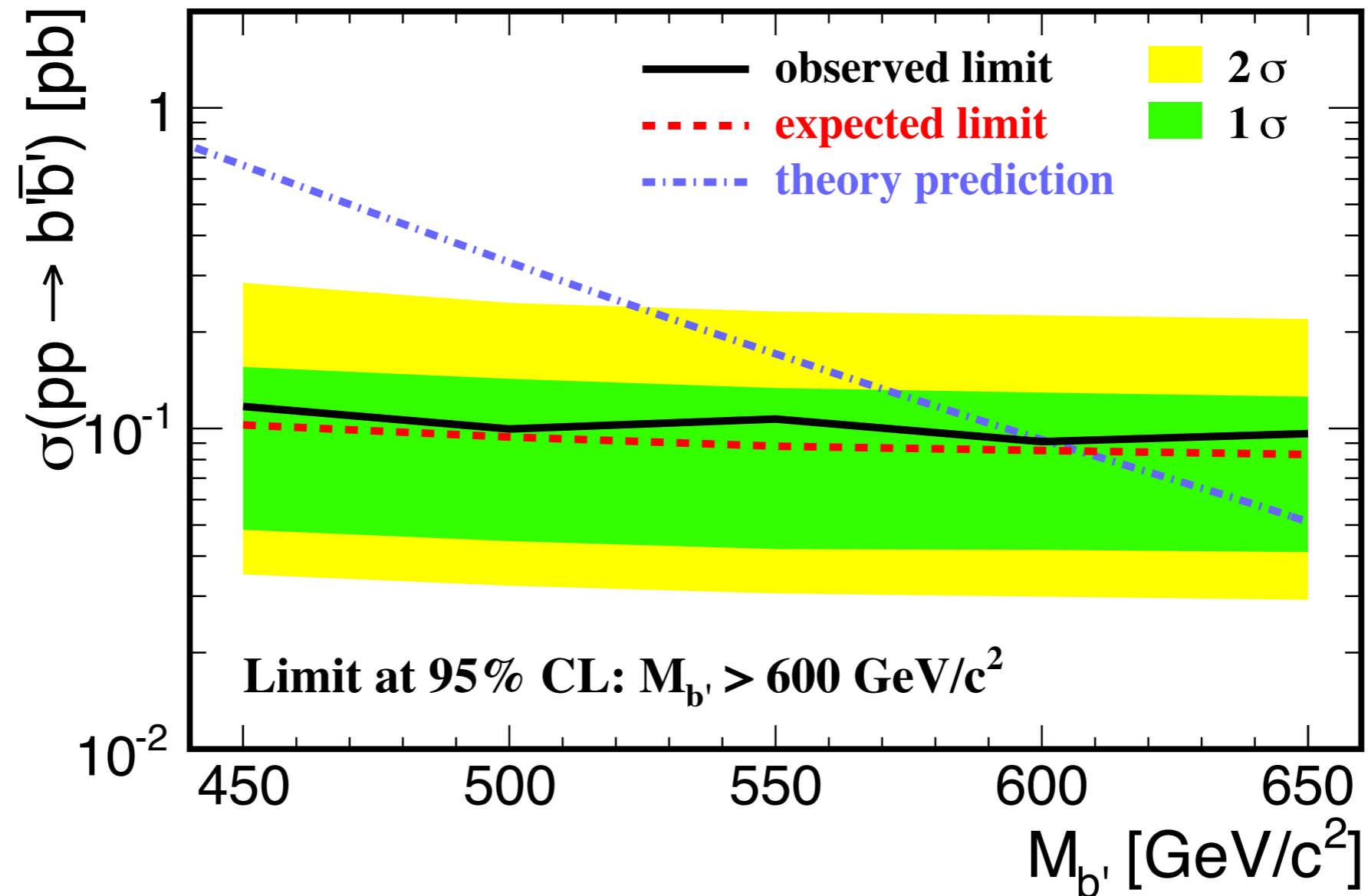


- Simple counting experiment with exclusion limits obtained using the Bayesian method

Results

CMS 2011 Preliminary

$4.6 \text{ fb}^{-1} \sqrt{s} = 7 \text{ TeV}$



- The strong pair production is excluded at 95% confidence level for b' quark masses below 600 GeV

Inclusive search for b' or t' production

1.1 fb⁻¹

- Why not look for b'/t' at the same time?
- What about single productions?
- Assuming degenerate states: $m_{t'} = m_{b'} = m_{q'}$
- By simplifying the V_{CKM4} with one free parameter:

$$\begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & \sqrt{A} & \sqrt{1-A} \\ 0 & 0 & \sqrt{1-A} & \sqrt{A} \end{pmatrix}$$

- Assuming the branching fractions to be $\sim 100\%$

$$\begin{aligned} b' &\rightarrow tW \\ t' &\rightarrow bW \end{aligned}$$

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Final states

b' and t'

- These produce the following processes

$$t' b \rightarrow b W b$$

$$b' t \rightarrow t W b W \rightarrow b W W b W$$

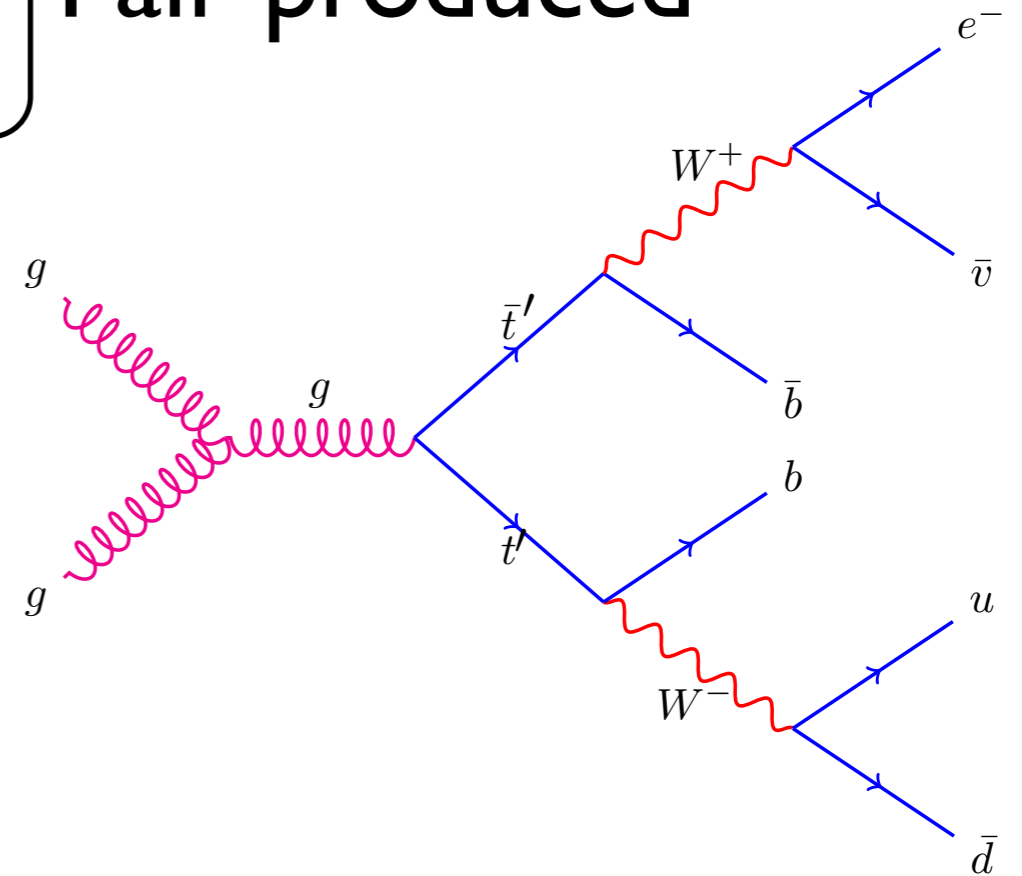
Singly produced

$$t' \bar{t}' \rightarrow b W b W$$

$$b' \bar{b}' \rightarrow t W t W \rightarrow b W W b W W$$

Pair produced

- Require one W boson to decay leptonically
- With 2 b quarks and at least one to four W bosons



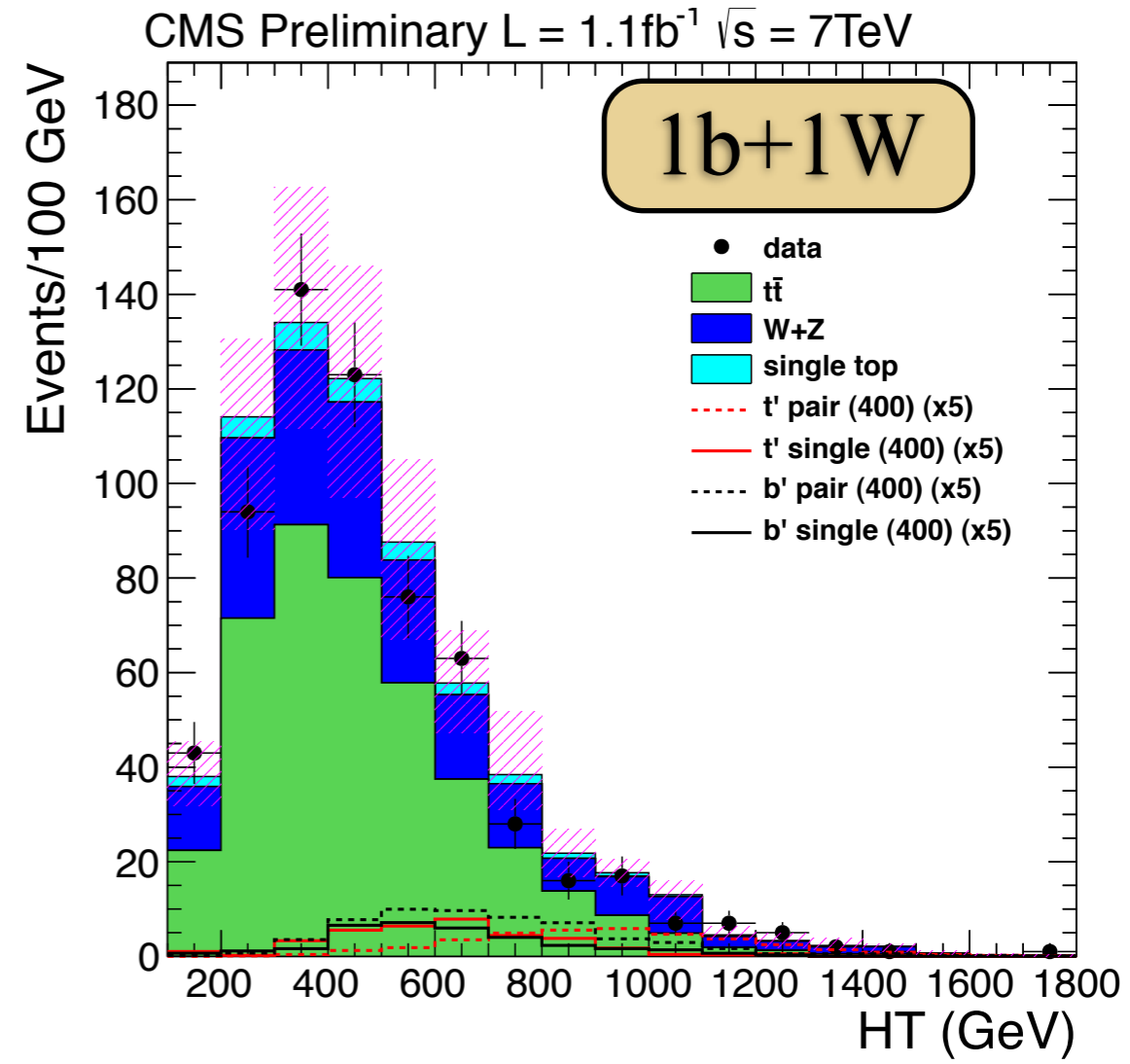
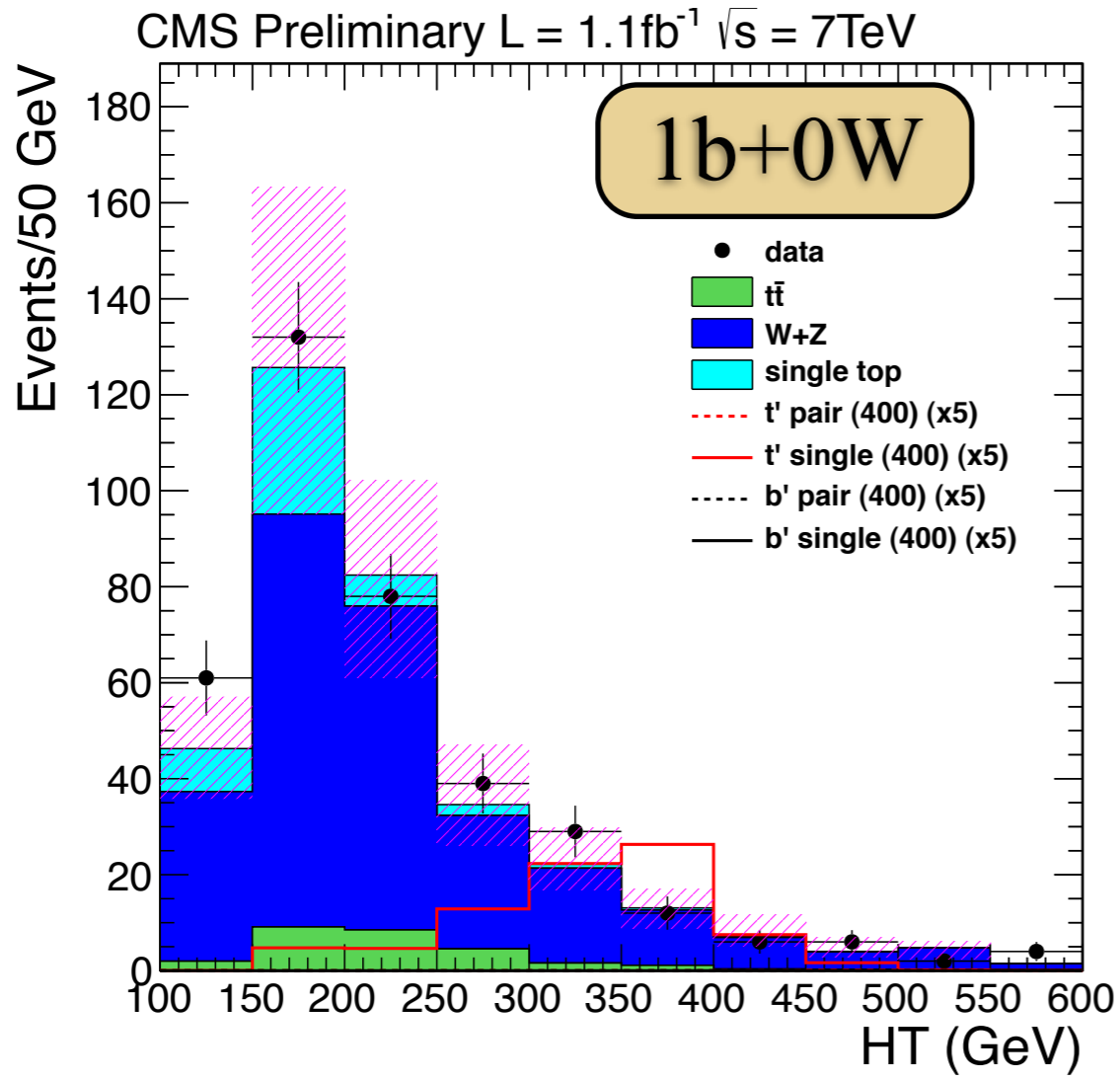
Selection and classification

- One μ with $p_T > 40$ GeV/c and $|\eta| < 2.1$
- At least one jet $p_T > 30$ GeV/c and $|\eta| < 2.4$ and at least one b-tagged
- Missing Transverse $E_T > 40$ GeV

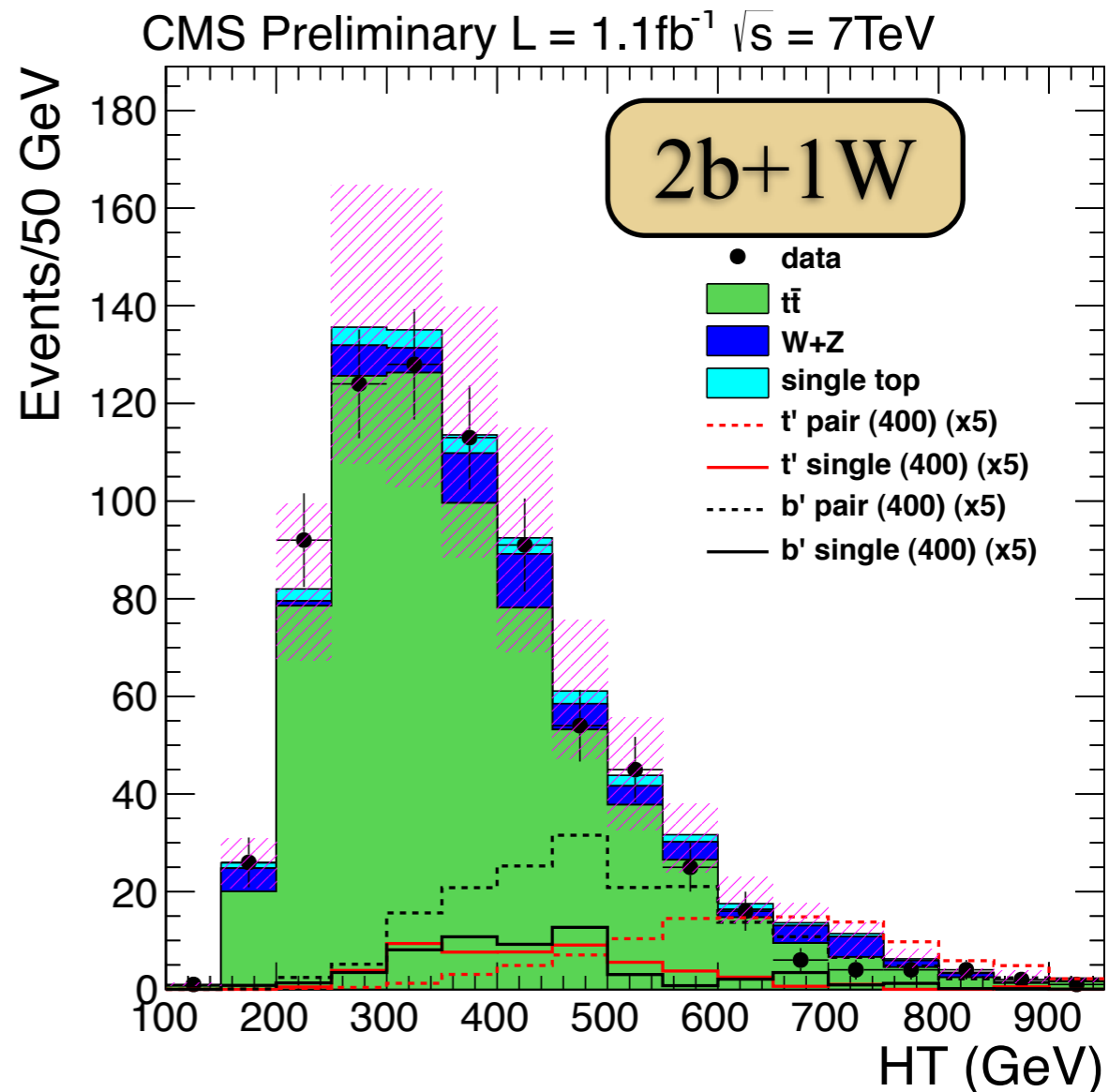
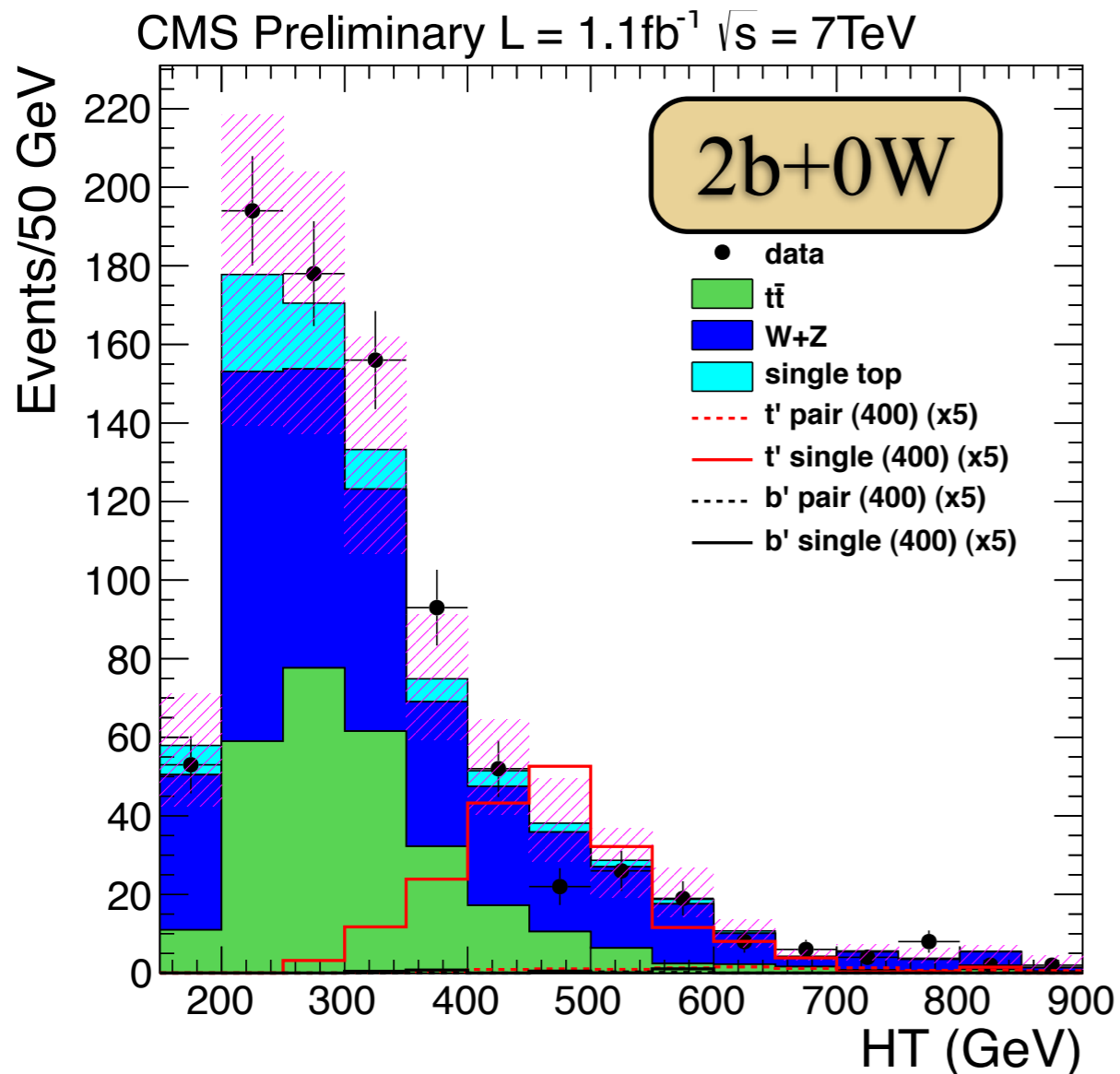
Events are classified according to # of b-tags and # hadronic W bosons

Discriminating variable

$$H_T = p_T^l + \sum p_T^{jet} + E_T^{miss}$$



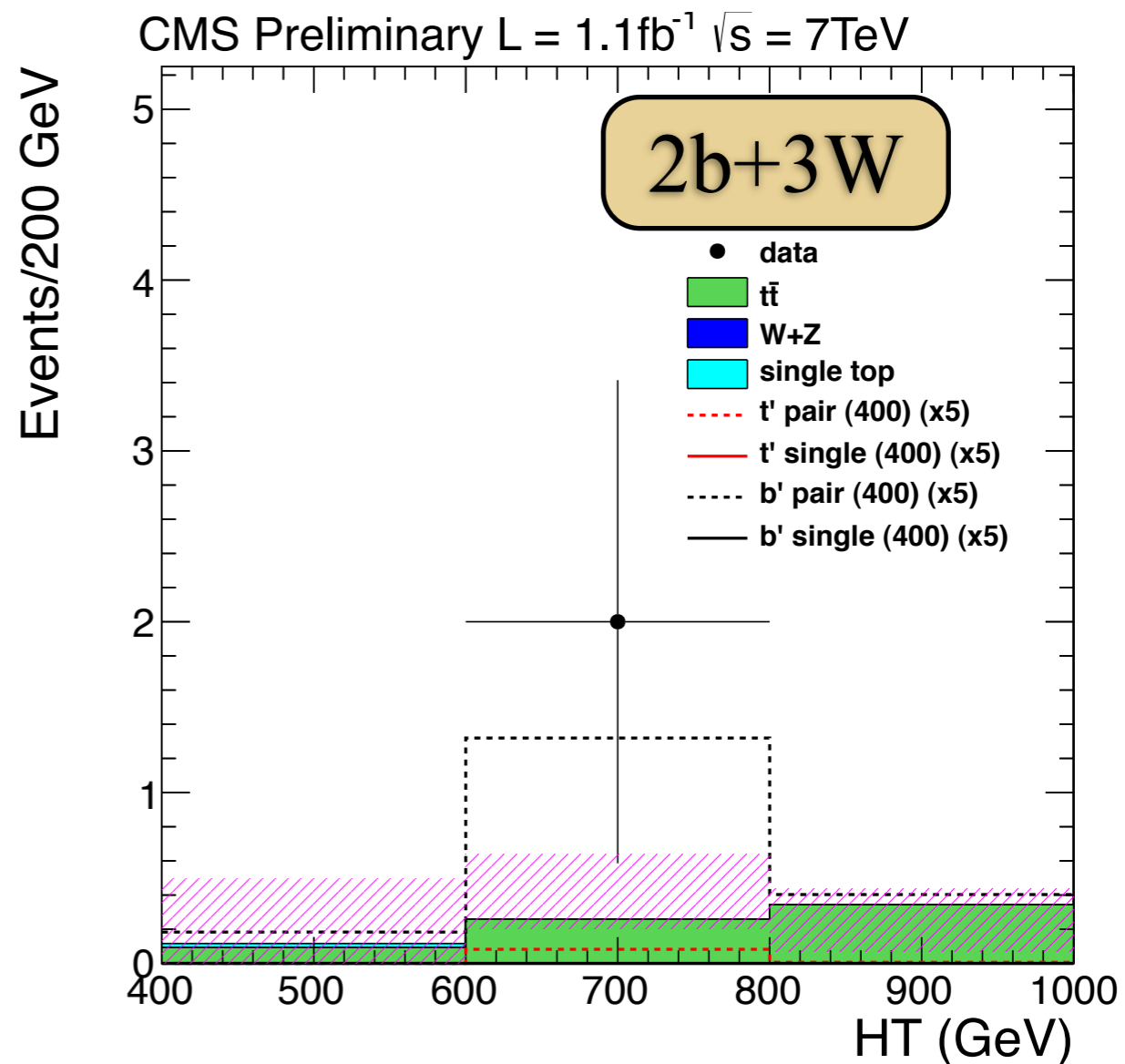
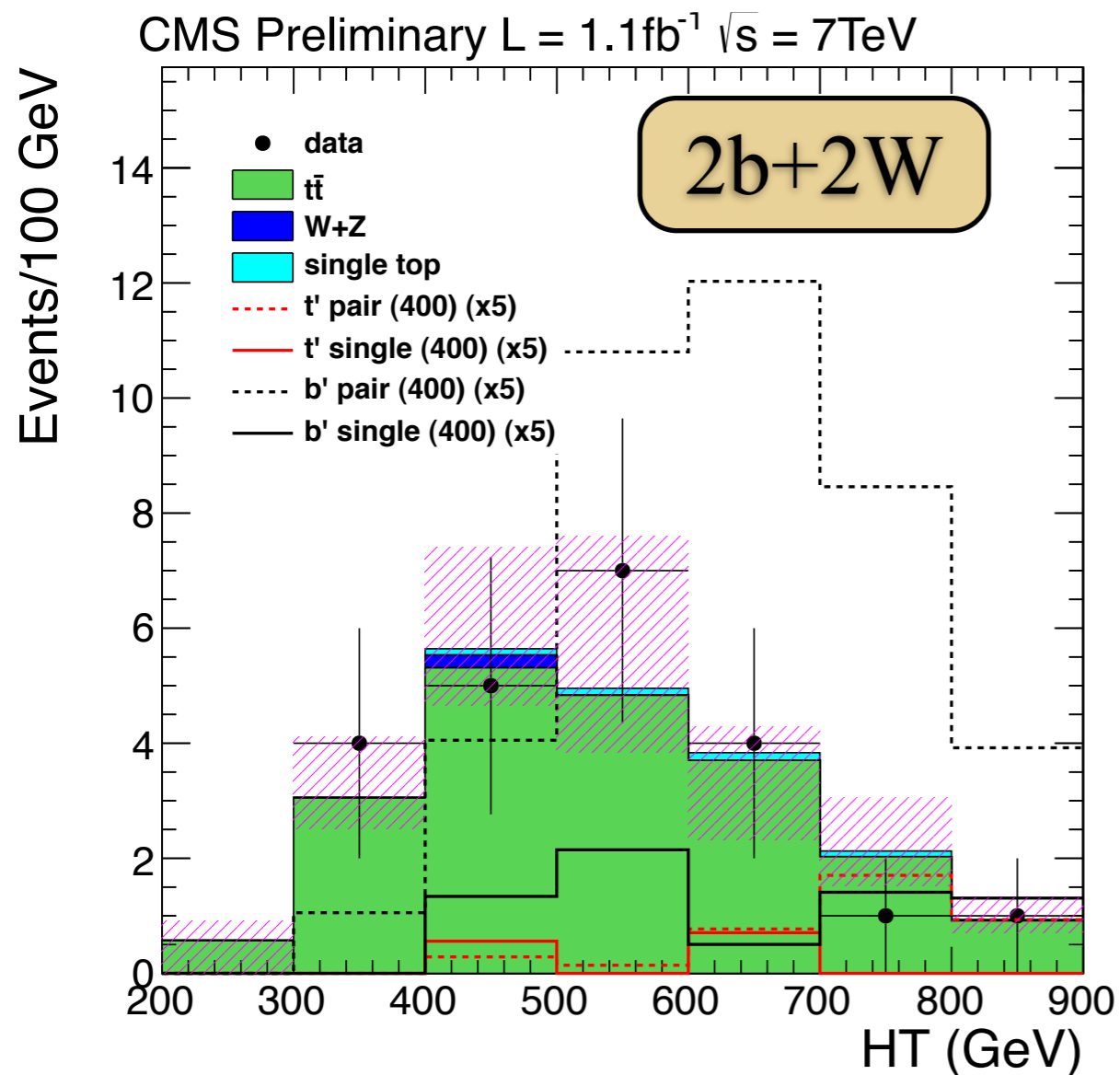
Discriminating variable



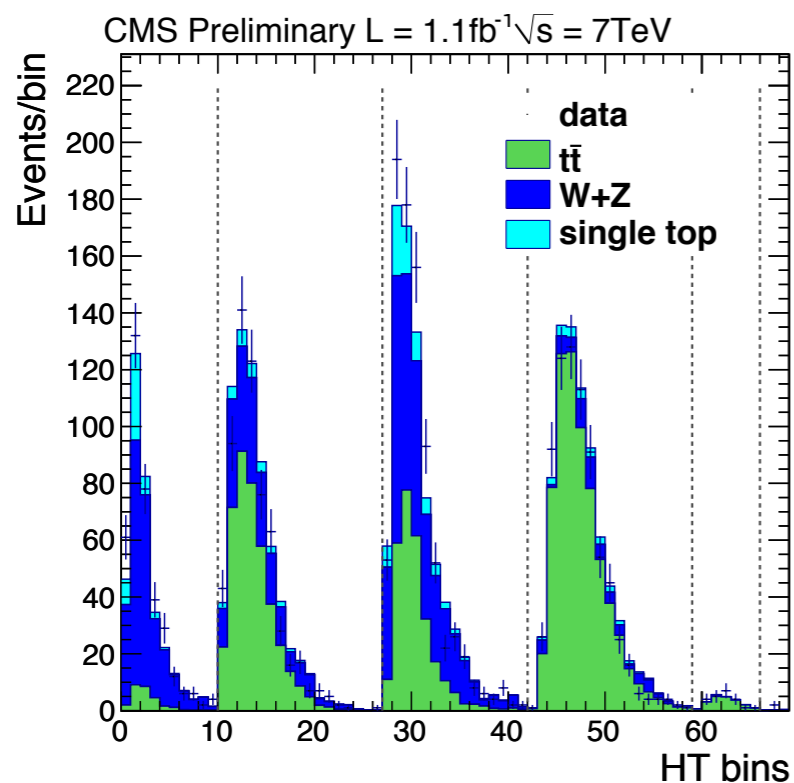
- 2b+0W suitable for the t' singly produce for example

Discriminating variable

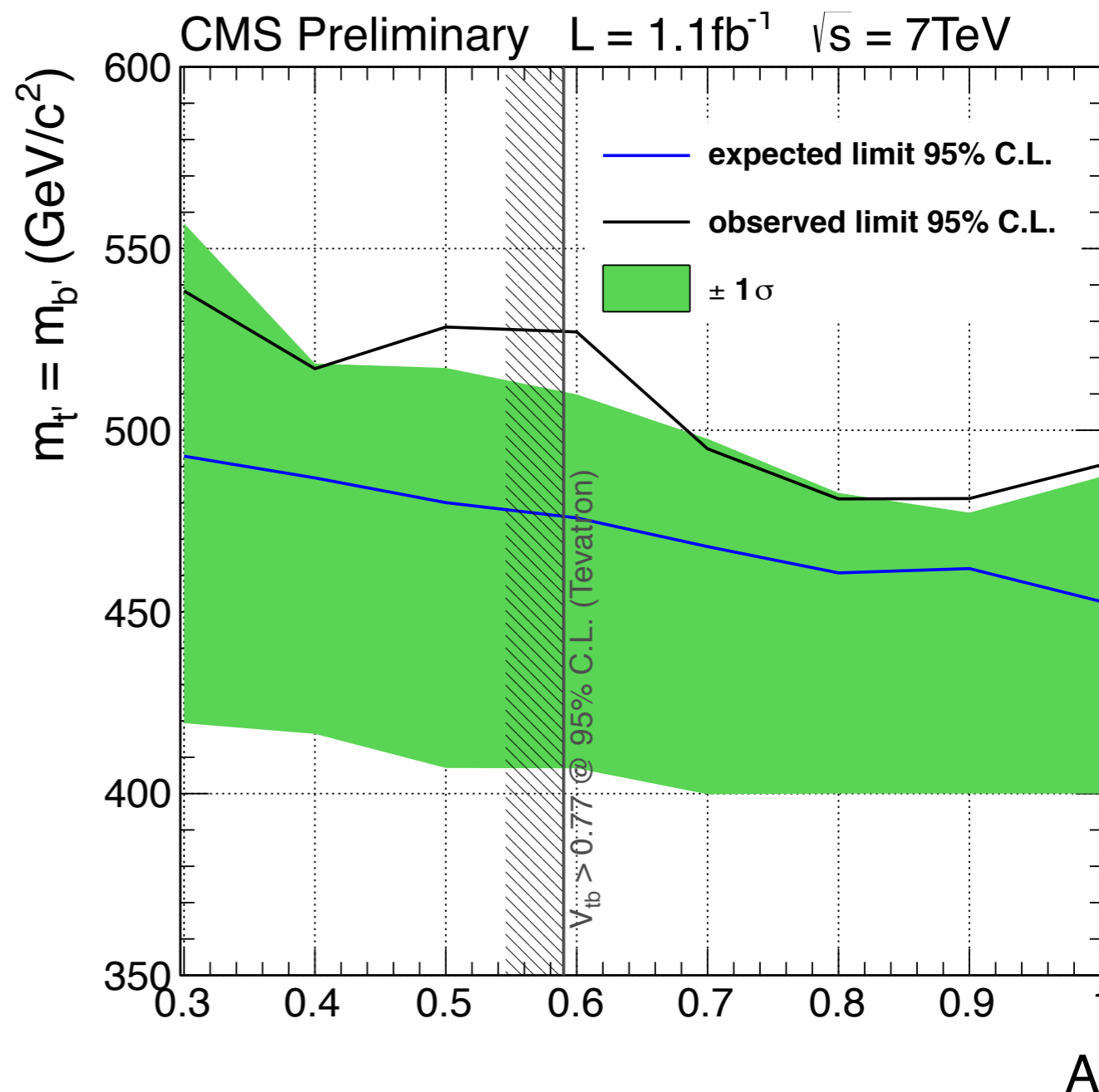
- These categories are particularly suitable for b' pair production search



Results



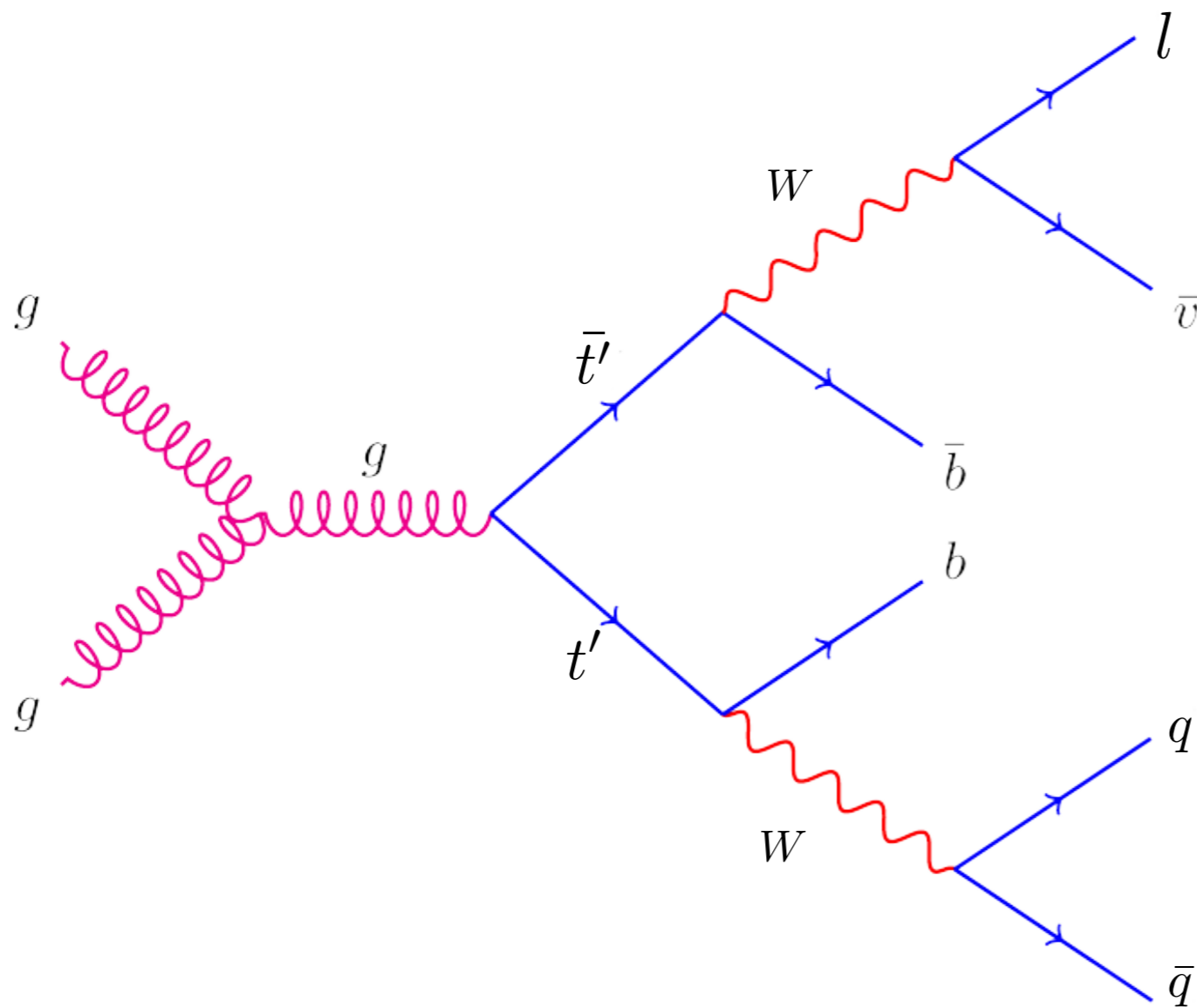
- Fit the binned HT template
- Scanned the mass limit as a function of A



For $m(b') = m(t')$ and $A = |V_{tb}|^2 = |V_{t'b'}|^2 \sim 1$
 $M > 490 \text{ GeV}$

Search for $t' \rightarrow bW$ (lepton+jets)

4.6 fb⁻¹



- Reconstruct a “Heavy Top” pair in the lepton+jets channel

EXO-11-099

Selection and Strategy

- Select events with one electron or a muon
- ≥ 4 high p_T jets at least one of them b-tagged
- Missing transverse momentum

Apply kinematic fit for mass reconstruction

Strategy

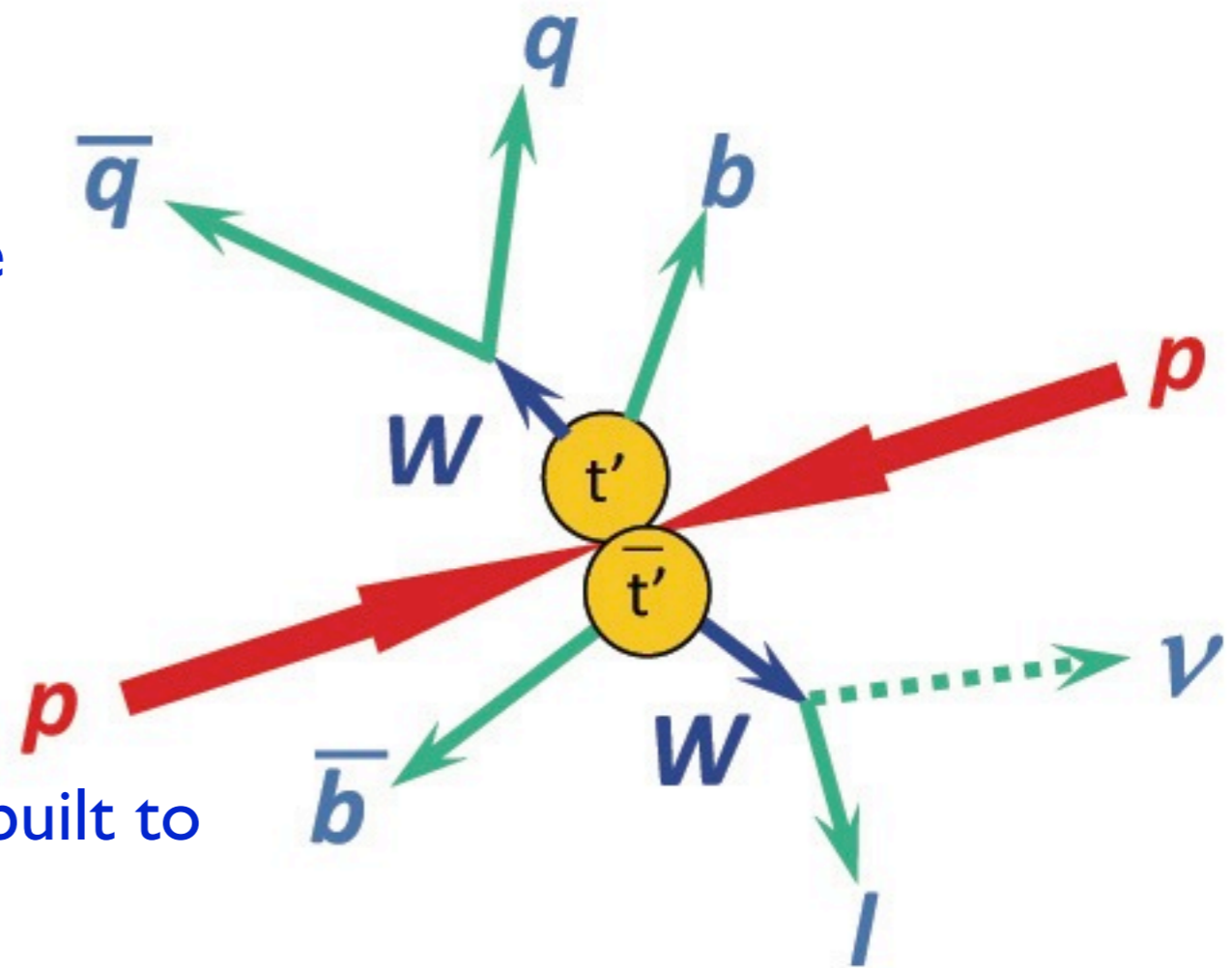
- Look in the H_T and reconstructed mass tails for signs of a massive quark decay

$$H_T = p_T^{lepton} + p_T^{miss} + \sum p_T^{jets}$$

Mass reconstruction

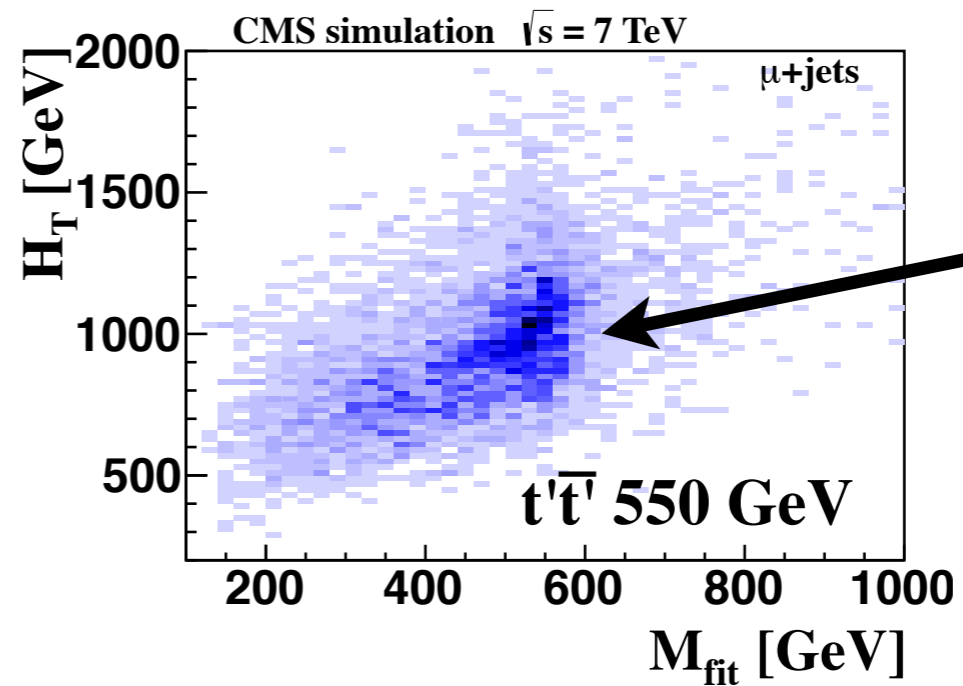
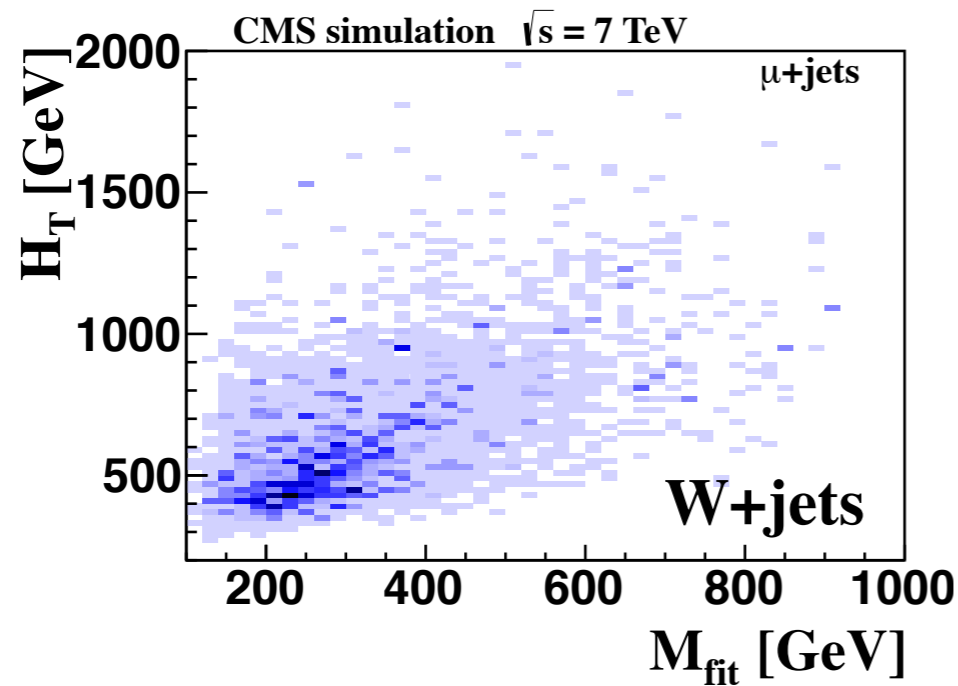
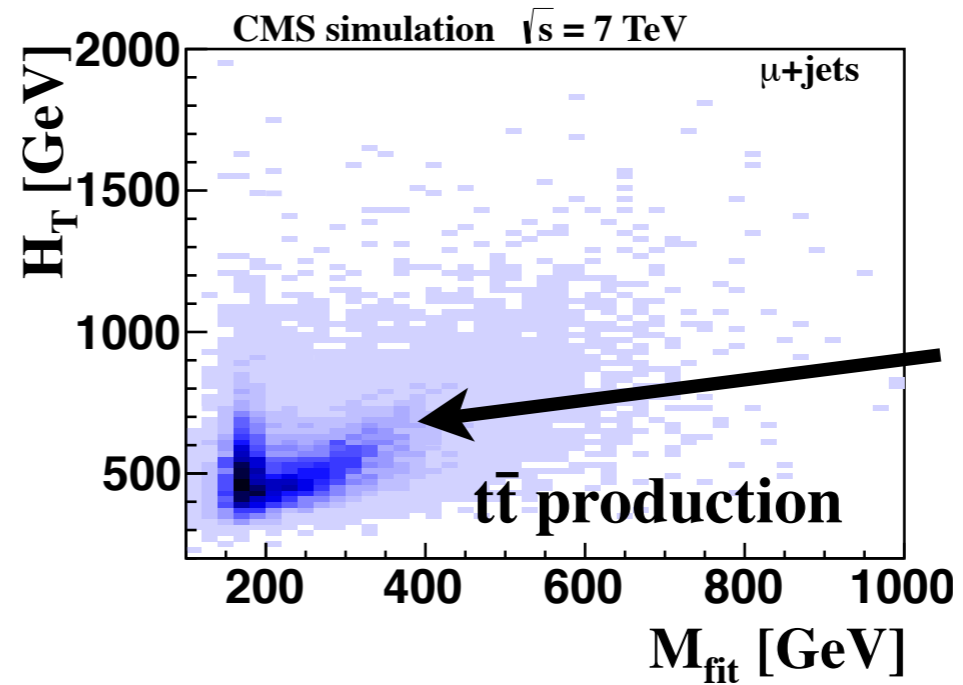
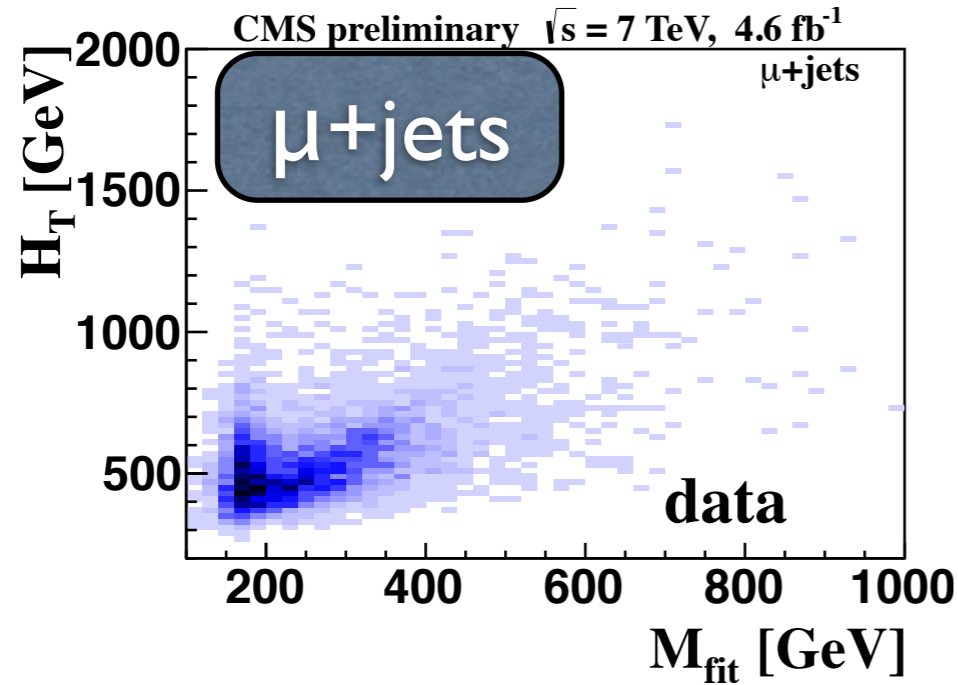
t' lepton+jets

- From the experiment we get:
 - ▶ lepton momentum
 - ▶ neutrino p_T (as missing E_T)
 - ▶ jet momenta
- One unknown - z-component of the neutrino momentum
- Constraints
 - ▶ $m(l\nu) = m(qq) = MW$
 - ▶ $m(lvb) = m(qqb)$
- Two-constraint fit \rightarrow minimize a χ^2 built to test our hypothesis for each jet combination
- We take the combination with the minimum



Discriminating variables

τ^- lepton+jets



Electron templates look very similar

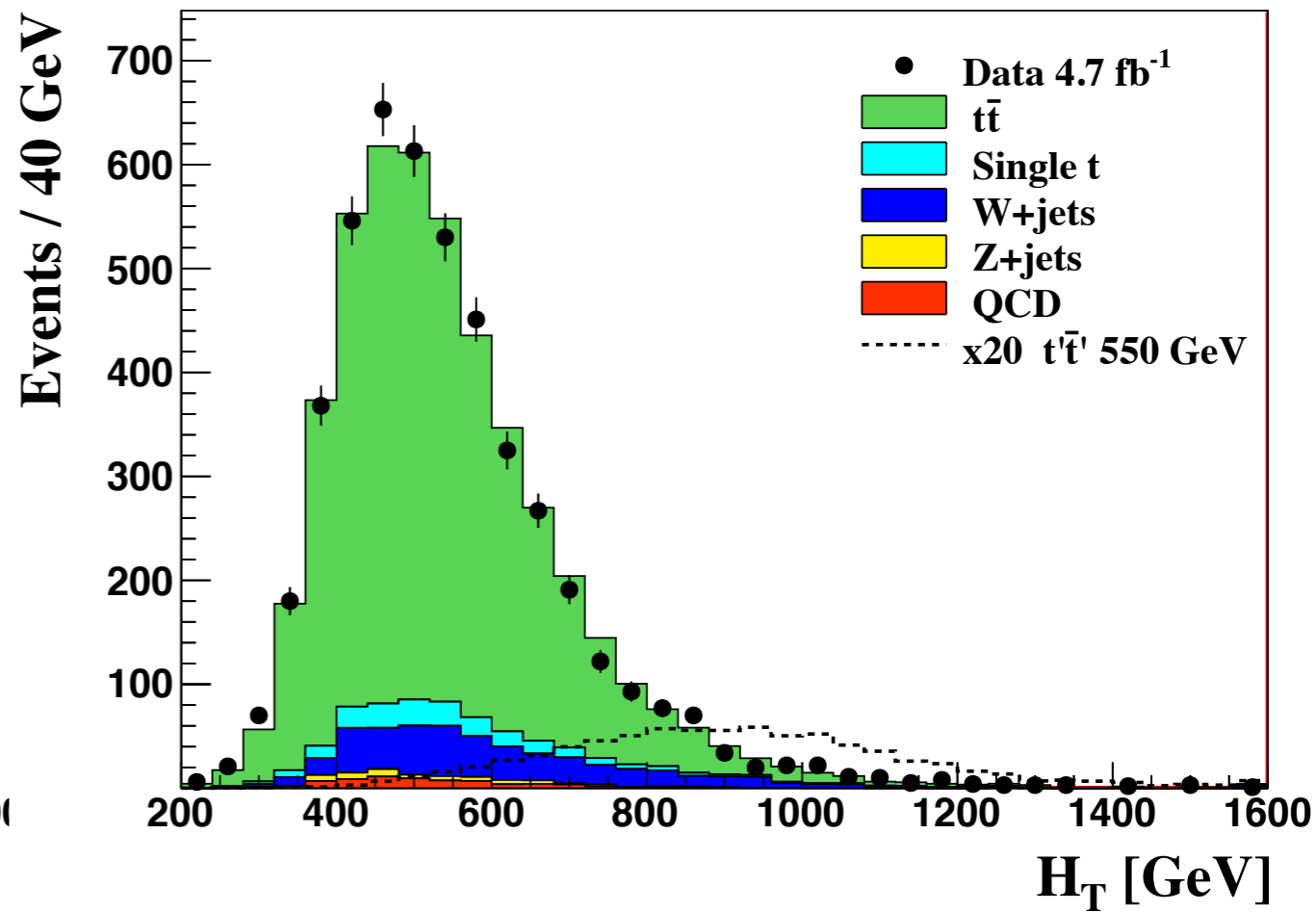
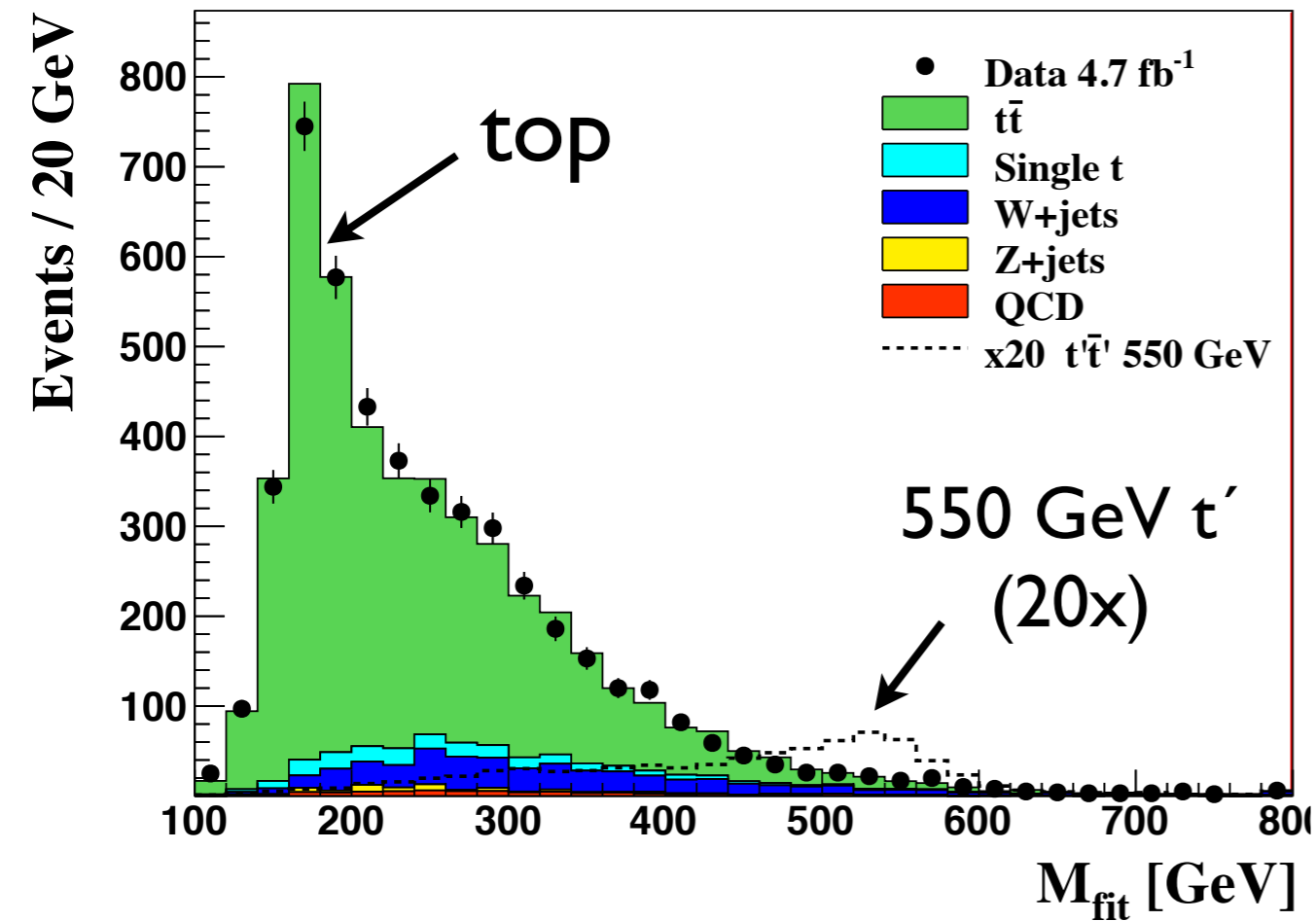
ID projections

τ^- lepton+jets

e+jets

CMS Preliminary $\sqrt{s} = 7$ TeV e+jets

CMS Preliminary $\sqrt{s} = 7$ TeV e+jets



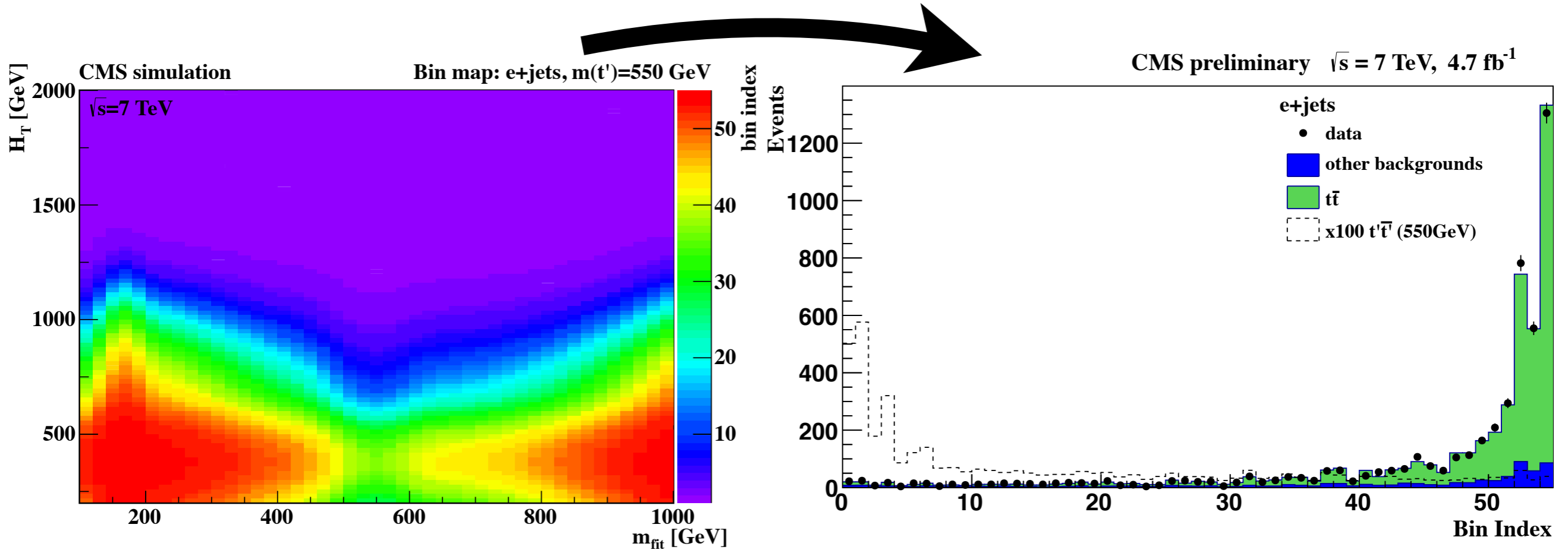
$$M(bqq) = M(bl\nu) = M_{fit}$$

$$H_T = p_T^{lepton} + p_T^{miss} + \sum p_T^{jets}$$

Rebinning 2D histograms

- HT vs Mfit histograms have many empty or low occupancy bins
- This could lead to incorrect statistical inferences, so the histograms are rebinned to extract the final information
- The rebinning algorithm briefly can be described as follows:
 - ▶ We project the simulated signal and background 2D histograms into a 1D by ordering the bins in descending S/B ratio
 - ▶ We then proceed to merge neighboring bins in the 1D histogram by requiring a minimum precision in the expected number of background and signal events

2D \rightarrow 1D Rebinning



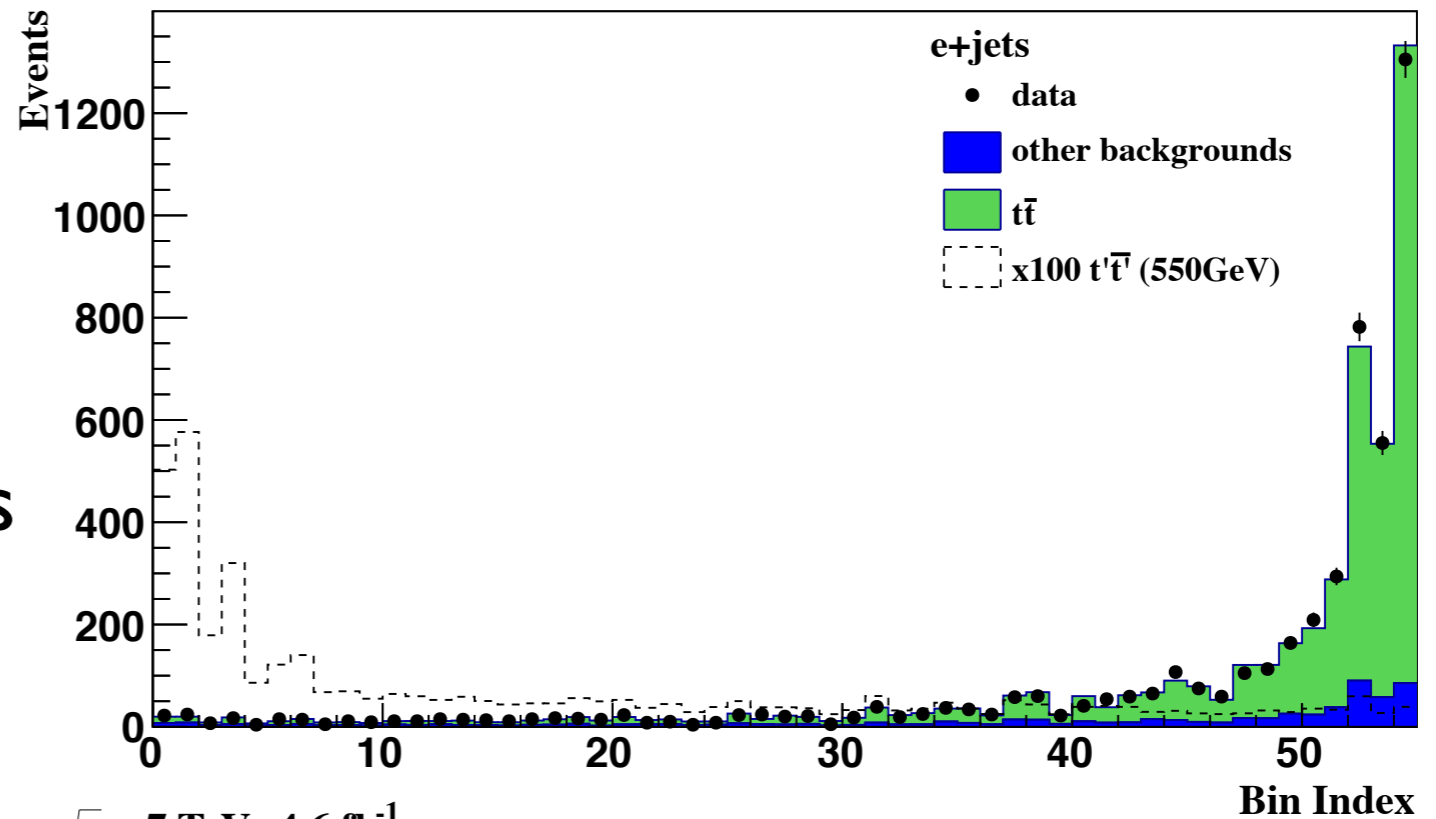
- Each color becomes a single bin in the 1D template
- This procedure is done for every simulated t' mass point on these plots we have 550 GeV/c²

Final merged templates

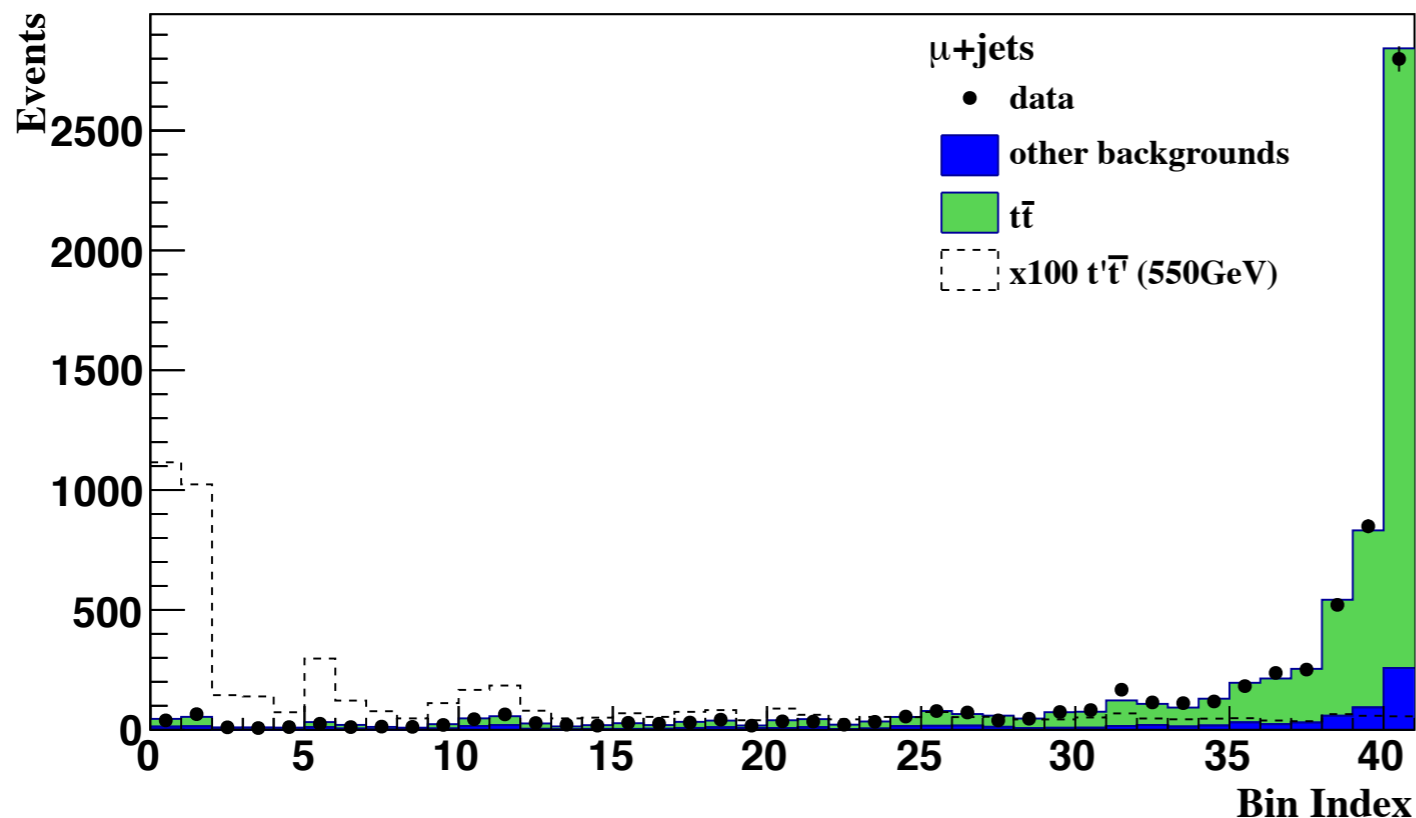
t' lepton+jets

CMS preliminary $\sqrt{s} = 7$ TeV, 4.7 fb^{-1}

These distributions are used to estimate the upper limit for the production cross section (there is a distribution for every t' mass point simulated)



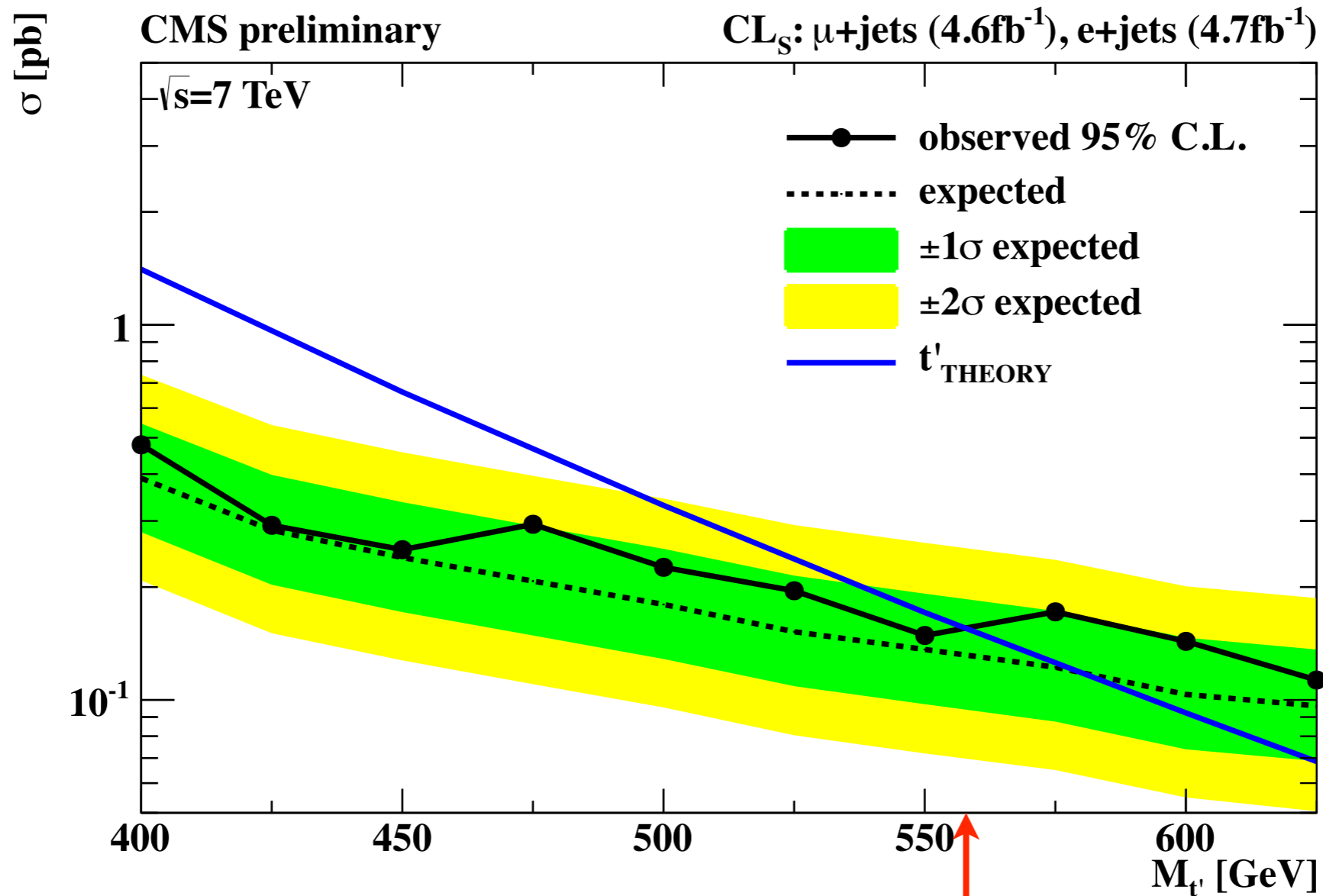
CMS preliminary $\sqrt{s} = 7$ TeV, 4.6 fb^{-1}



No hint of signal found in 2011 data

Result

t' lepton+jets



- The strong pair production is excluded at 95% confidence level for t' -quark masses below 560 GeV/c^2

Conclusions

- CMS has searched for 4th G Quarks, in a nutshell
 - ▶ $t' \rightarrow bW$ pair in dileptons excludes $m_{t'} < 552 \text{ GeV}/c^2$
 - ▶ $t' \rightarrow bW$ pair in lepton+jets excludes $m_{t'} < 560 \text{ GeV}/c^2$
 - ▶ $b' \rightarrow tW$ pair in trilepton & same-sign dilepton excludes $m_{b'} < 600 \text{ GeV}/c^2$
 - ▶ b'/t' inclusive search $m_{t'}=m_{b'} < 490 \text{ GeV}/c^2$
- The existence of sequential 4th generation quark is reaching unprecedented exclusions limits
- We have reached the critical mass of $550 \text{ GeV}/c^2$ at which fermion's weak interactions become non-perturbative

M.S. Chanowitz, M.A. Furman, I. Hinchlie, Phys. Lett.B78, 285 (1978)

Shall we still bet on it?

The end

Backup