Prospects for Searches for New Heavy Quarks with CMS

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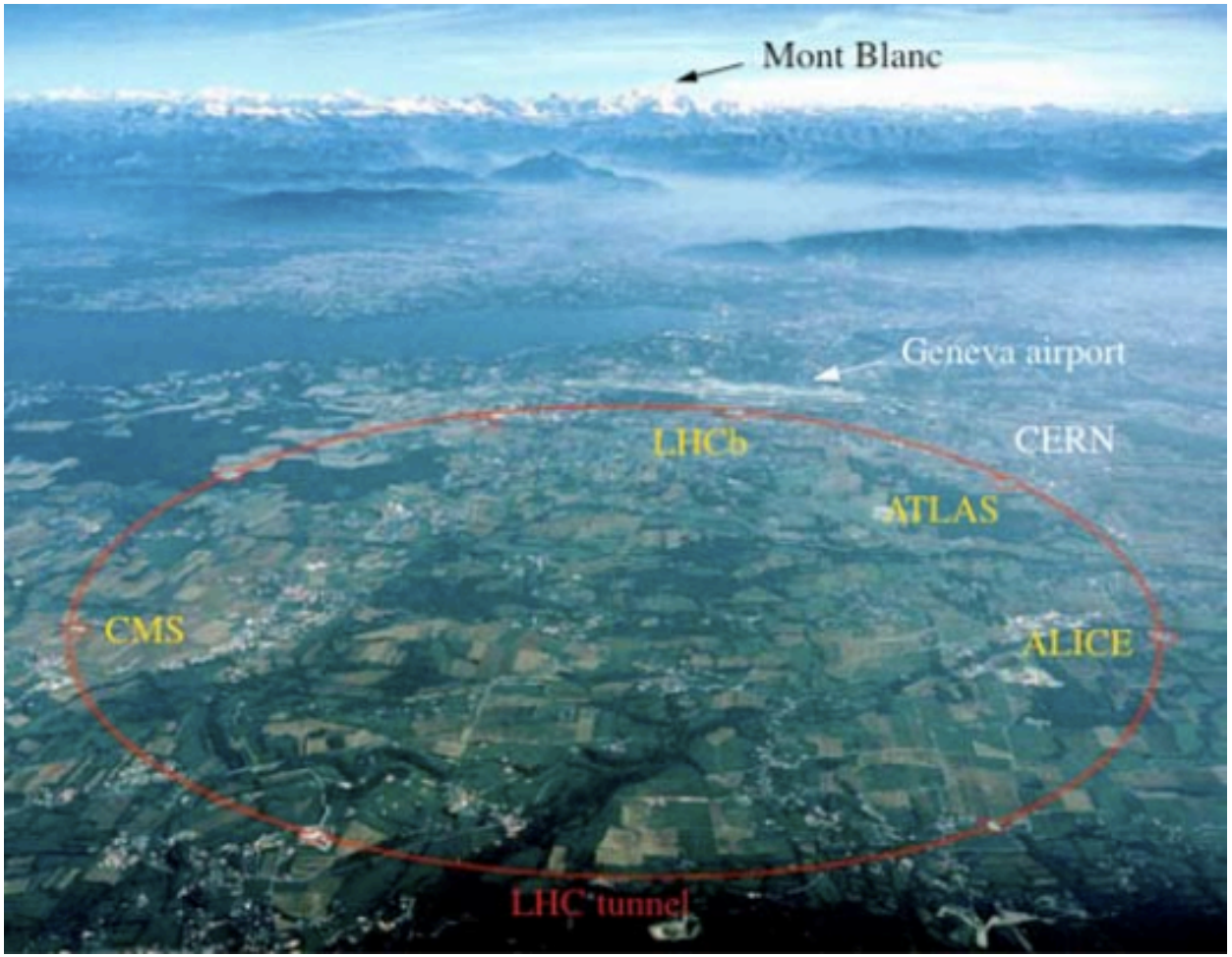
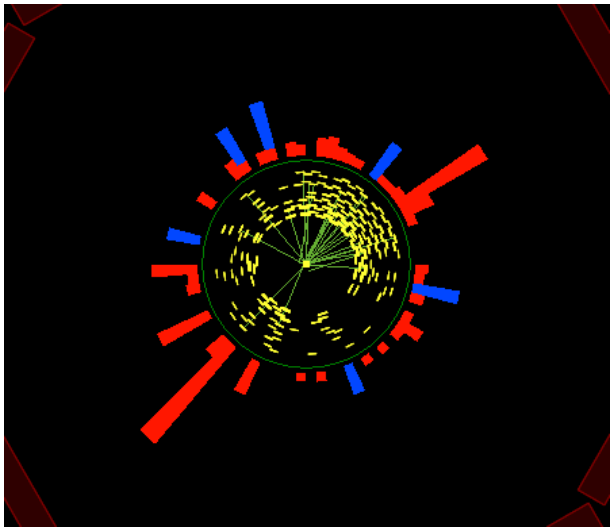
(for the CMS Collaboration)

Jan 14th, 2010
Beyond 3 Generation Standard Model Workshop

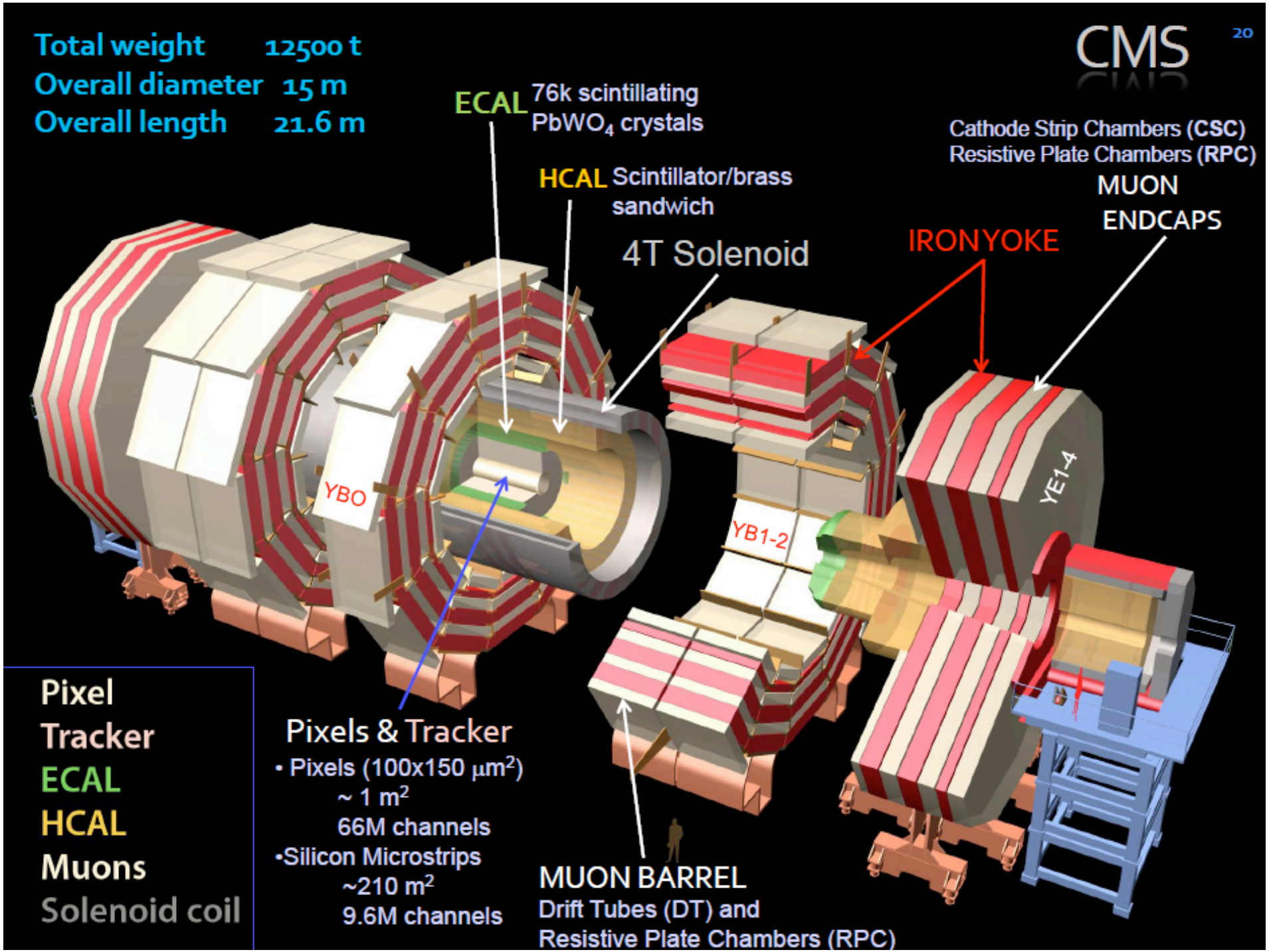
Large Hadron Collider (Re)start



- pp $\sqrt{s}$ =14 TeV
  $L=10^{34}$ cm^{-2} s^{-1} (design)
- 27 km Tunnel in Switzerland & France
- Turn on in ~~Sep 2008~~ Nov. 2009



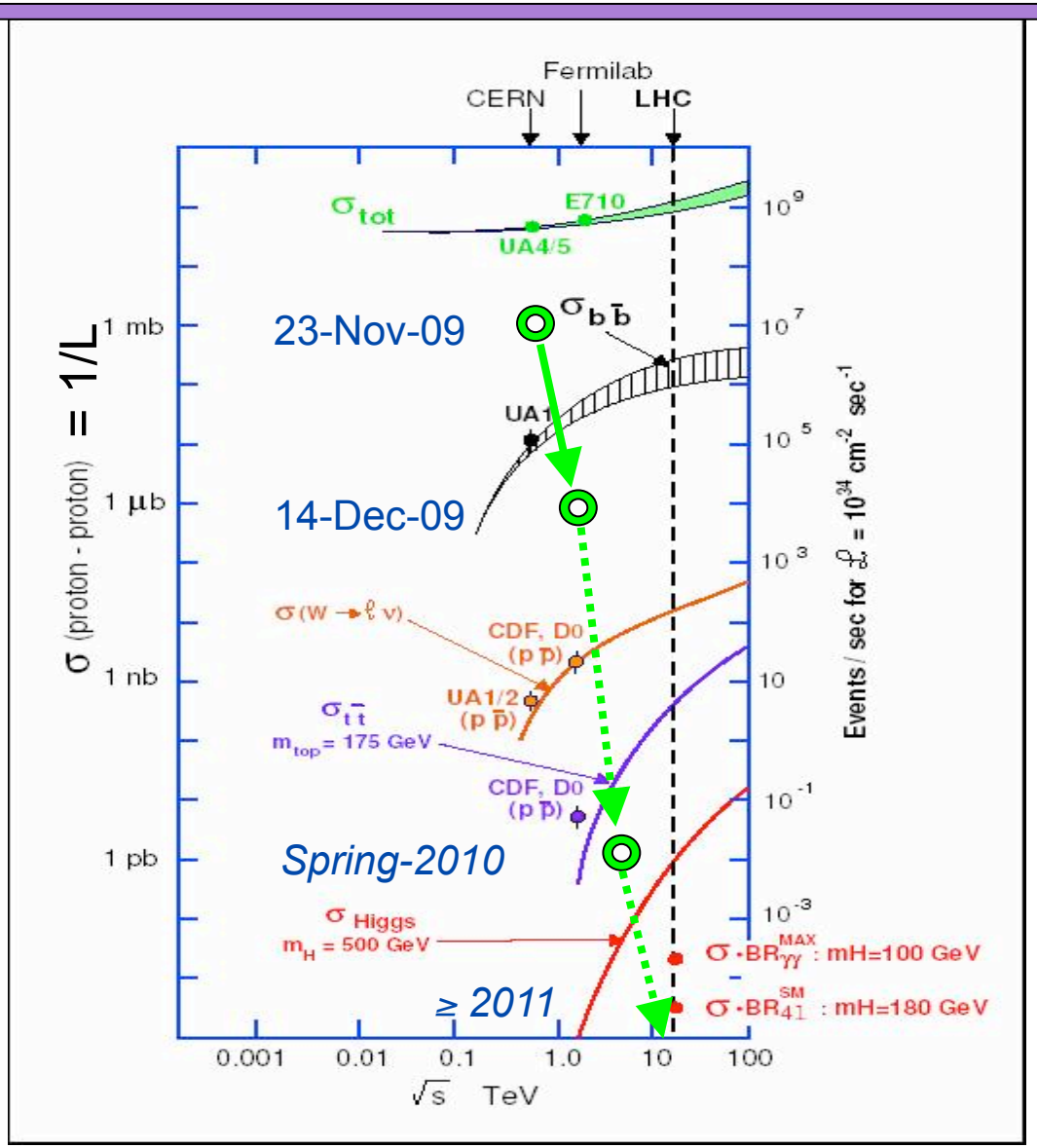
Fall 2009-2010 Expectations: $\sqrt{s}$ =0.9 -- 10 TeV
Long Physics Run: 2010 Int. Luminosity up to 500 pb^{-1}


Total weight 12500 t
Overall diameter 15 m
Overall length 21.6 m
CMS
20
ECAL 76k scintillating PbWO4 crystals
HCAL Scintillator/brass sandwich
4T Solenoid
IRONYOKE
Cathode Strip Chambers (CSC)
Resistive Plate Chambers (RPC)
MUON ENDCAPS
YBO
YB1-2
YE1-4
Pixel
Tracker
ECAL
HCAL
Muons
Solenoid coil
Pixels & Tracker
• Pixels (100x150 μm2)
~ 1 m2
66M channels
•Silicon Microstrips
~210 m2
9.6M channels
MUON BARREL
Drift Tubes (DT) and
Resistive Plate Chambers (RPC)

CMS Detector

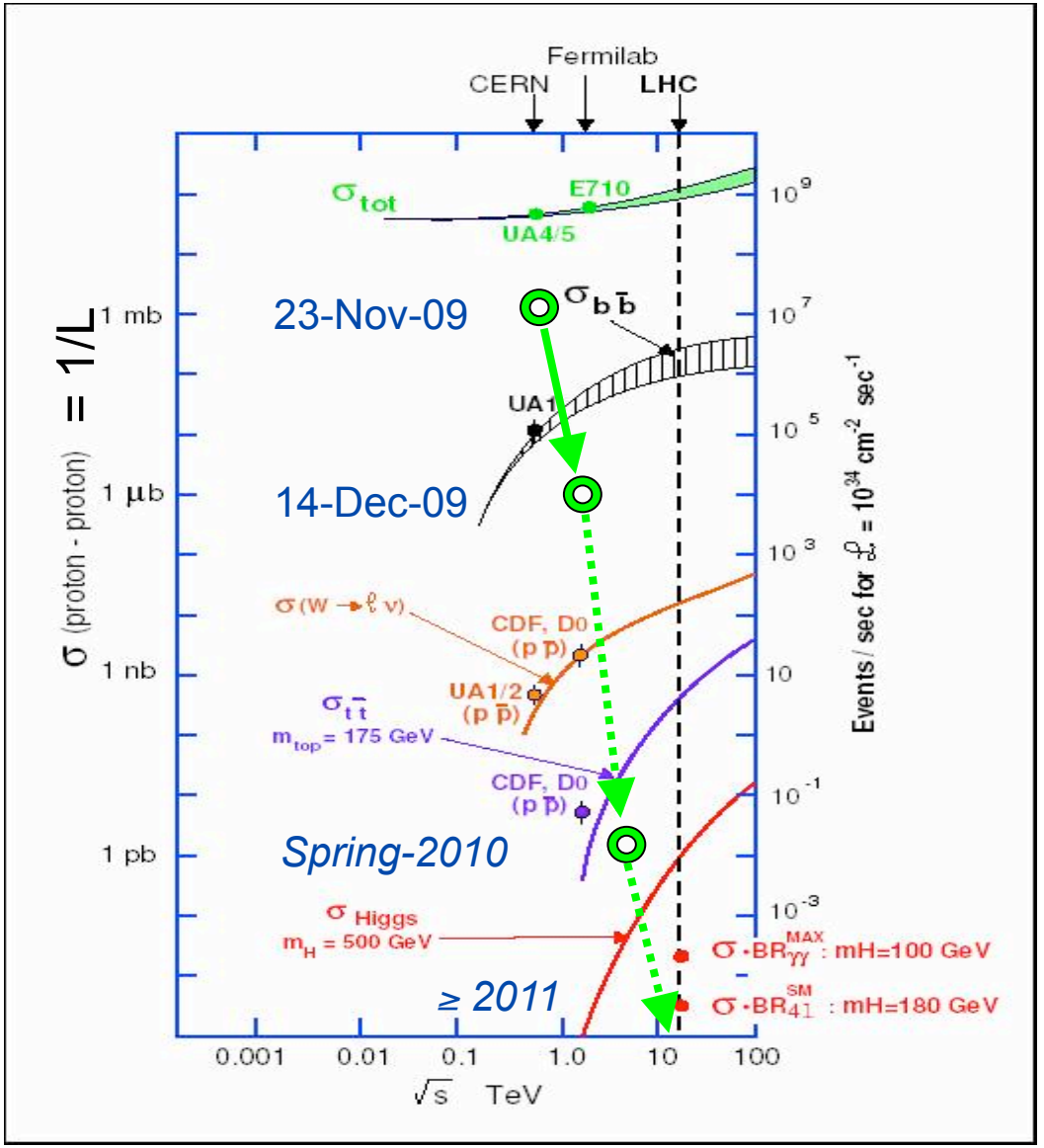
Startup of the LHC Physics Program

- First collisions on Nov.23 at 900 GeV
  - ~0.1 Hz collisions
  - L ~ few 10^{24} $cm^{-2}s^{-1}$
- By mid-December: collisions at 900 and 2236 GeV
  - ~10Hz collisions
  - L ~ few 10^{26} $cm^{-2}s^{-1}$
- Ultimately, the LHC program should take us to:
  - 14 TeV
  - 10^9 Hz collisions
  - L ~ 10^{34} $cm^{-2}s^{-1}$



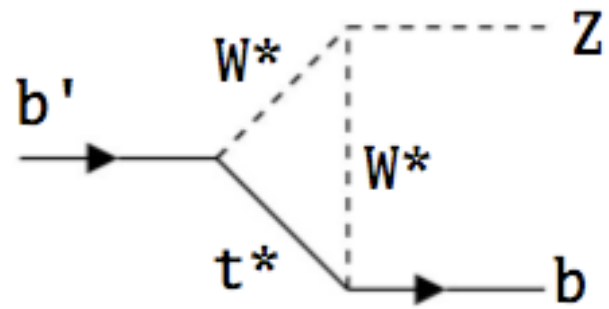
Talk Outline

- In this talk focus on prospects for searches with early data (10 TeV center of mass energy)
  - Expected 2010 integrated luminosity up to 500 pb^{-1}
- 4^{th} generation quarks
- Heavy top and bottom partners
- https://twiki.cern.ch/twiki/bin/view/CMS/PhysicsResults

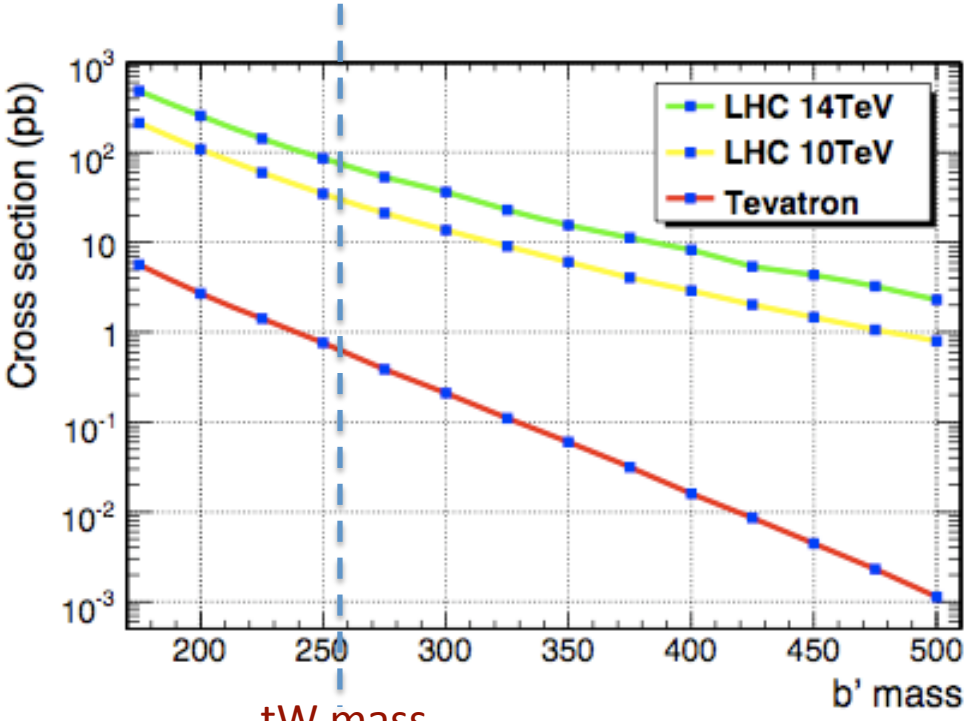


4th generation quarks

- Bottom-like (b') and top-like (t')
  - Light b' scenario
    - b' → cW
    - b' → bZ



Sizable FCNC channel



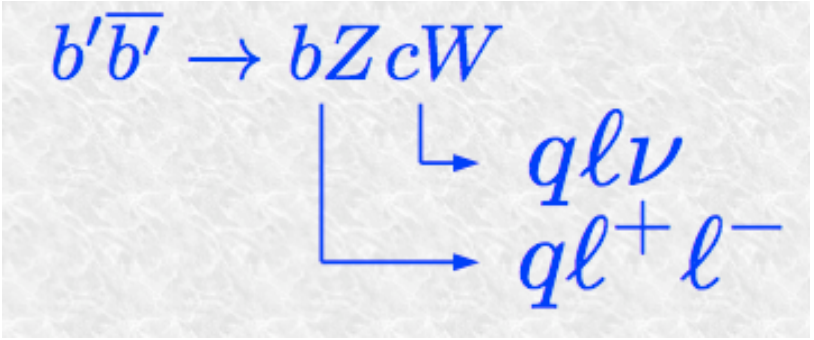
tW mass threshold

Doubly Cabibbo-suppressed process dominates

- Heavy b' scenario
  - b'→tW

Light b'

- Signal: $b'\bar{b}' \rightarrow cWbZ$
  - Assume BR(b'→bZ)=10%, BR(b'→cW)=90%
  - Tri-leptonic final state
    - Signature: 3 leptons (WZ) and 2 jets

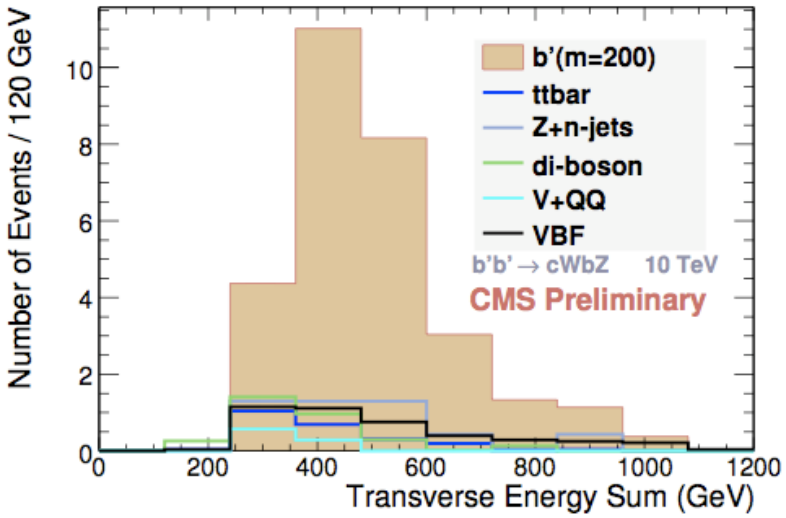


- Background:
  - Z+jets, WZ+jets, $t\bar{t}$
  - Background suppression done by requiring
    - one and only one Z candidate
    - one and only one W (W lepton independent of the Z daughters)

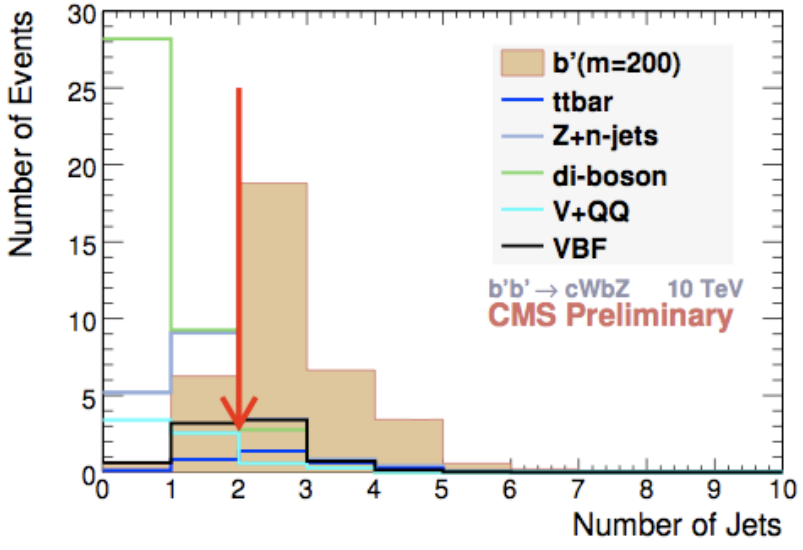
$$M_T = \sqrt{2 \cdot MET \cdot E_T^l (1 - \cos(\Delta\phi))}$$

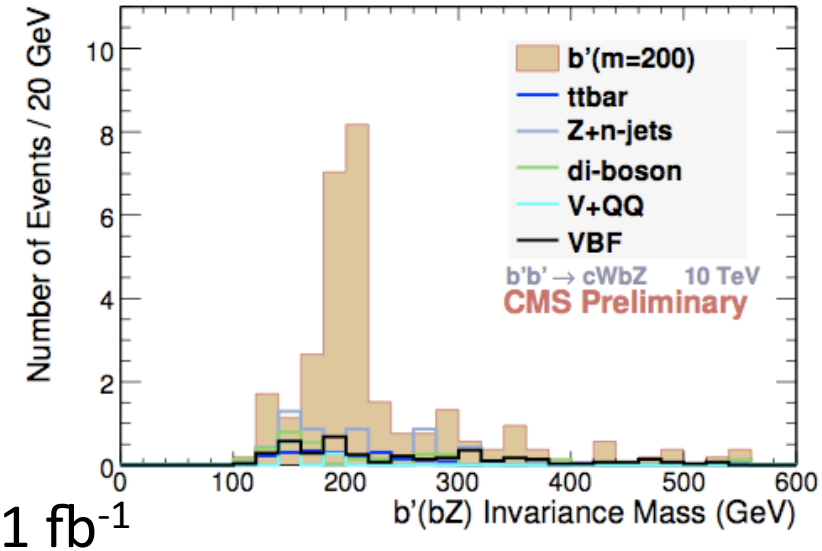
    - two isolated jets from the lepton candidates

Signal Extraction: Observables



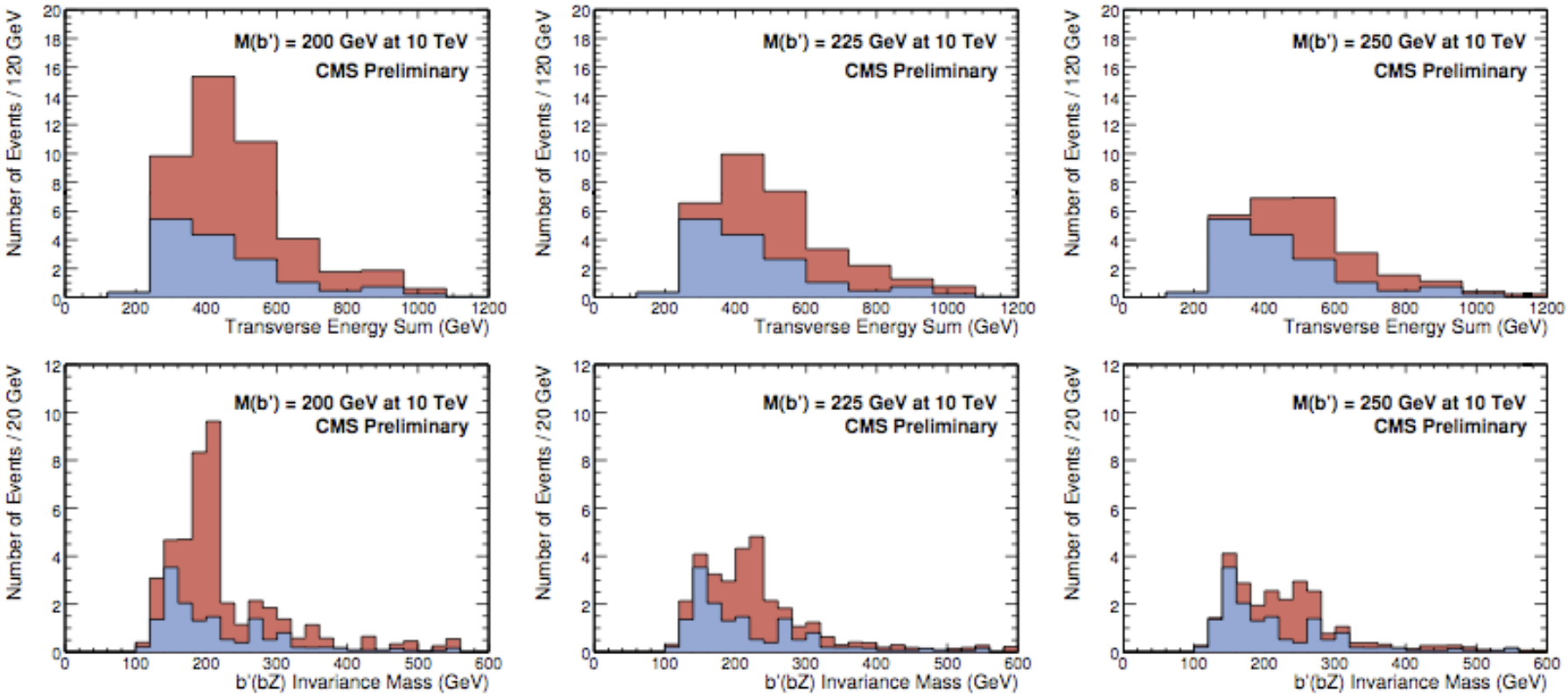
$$H_T = \sum E_T^{jet} + \sum p_T^{trk} + \text{Missing } E_T$$





@ 1 fb^{-1}

Observables



@ 1 fb^{-1}

Background Estimation

- Extract background using data-driven techniques
  - matrix method
- Define two samples
  - "Tight-cut" sample: events passing all cuts
  - "Loose-cut" sample: events passing all the selection cuts, except for the isolation cuts on the W daughter leptons

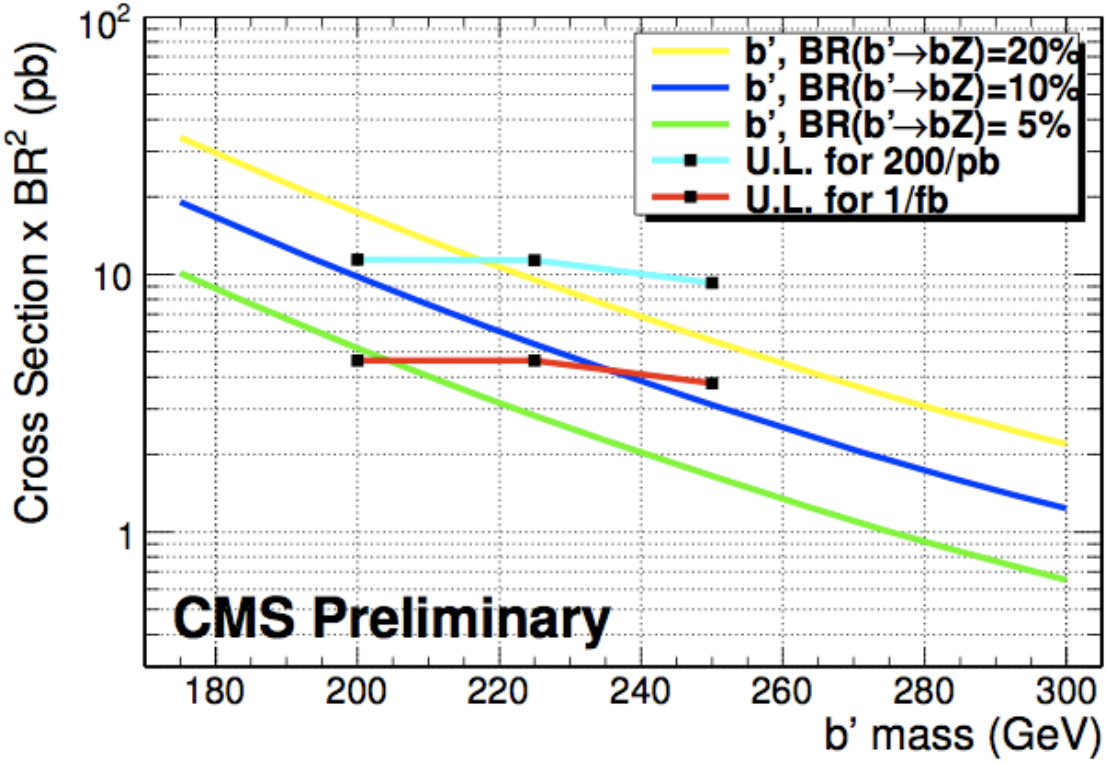
$$N_{loose} = N_{lep} + N_{jet}$$

$$N_{tight} = \varepsilon_{tight} N_{lep} + P_{fake} N_{jet}$$

Will be measured from data

Light b' Results

m(b') @ 1 fb^{-1}	200 GeV	225 GeV	250 GeV
Cross-section	113 pb	65 pb	11 pb
Expected Yields	29.9	16.7	11.4
Background	13.8	13.8	13.8
Significance	3.8 σ	1.9 σ	1.1 σ



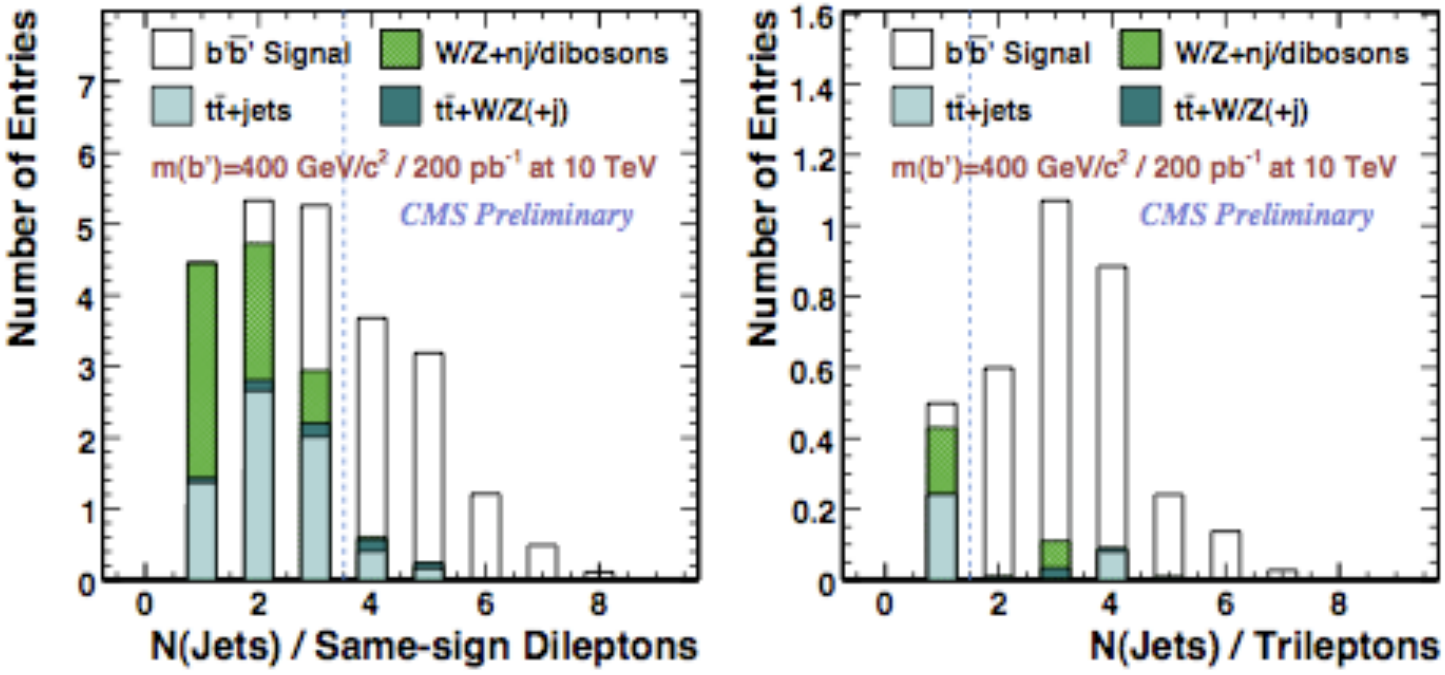
Heavy b’

- Bottom-like quark that decays to tW (mass > 255 GeV)
- Decay chain with 4 W bosons!
  - b’b’→ tW tW → bbW$^+$W$^-$W$^+$W$^-$
- Possible final states:
  - 4 leptons + 2 jets, 3 leptons + 4 jets, 2 leptons + 6 jets, 1 lepton + 8 jets, 0 lepton + 10 jets
  - Concentrate on large, clean modes first
    - (Standard Model background expected to be small for the 2 same-sign lepton final state)

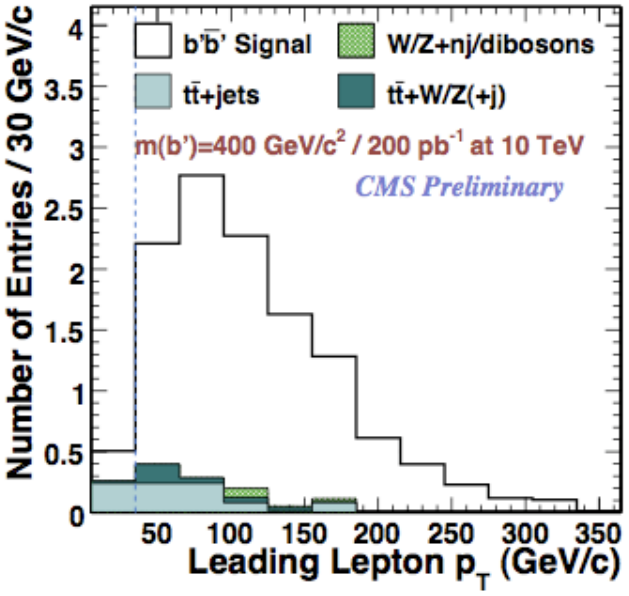
$$b'\overline{b'} \rightarrow tWtW$$
$$\hookrightarrow qqqq\ell^{\pm}\nu\ell^{\pm}\nu$$
$$\hookrightarrow qq\ell^{\pm}\nu\ell^{\mp}\nu\ell^{\pm}\nu$$

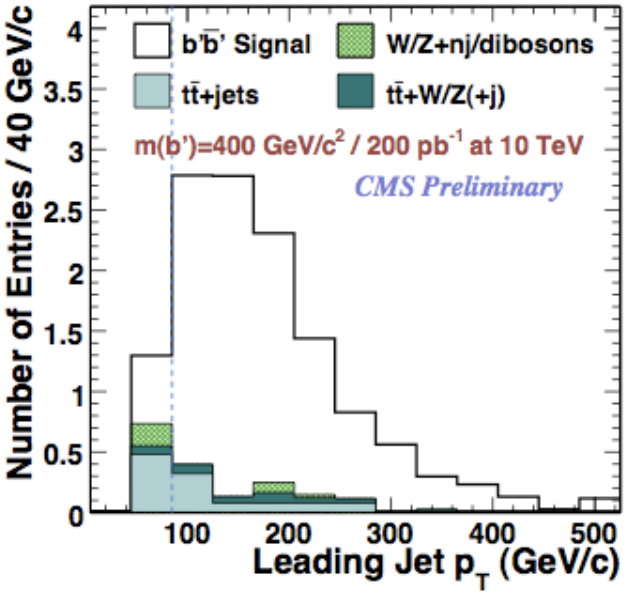
Signal Extraction

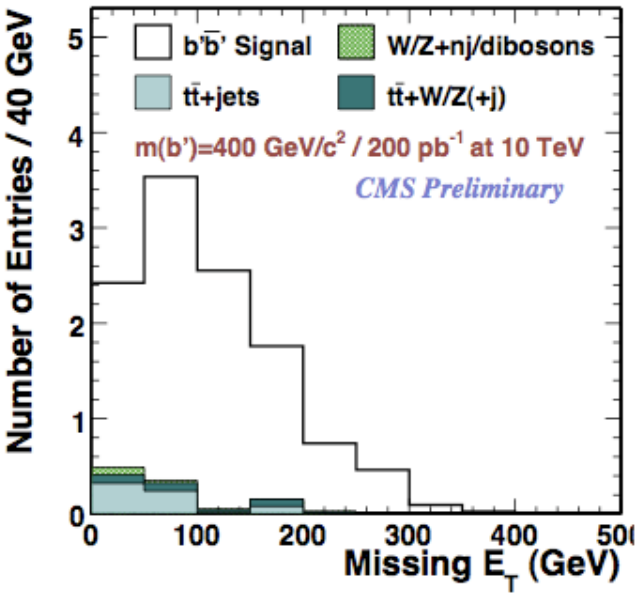
- Background:
  - tt+jets, tt+W/Z+jets, W/Z+jets, di-bosons
- Background suppression done by requiring:
  - Z invariant mass veto
  - lepton-lepton isolation (reject fake electrons from radiated photons)
  - lepton-jet separation (reject additional leptons from jets)

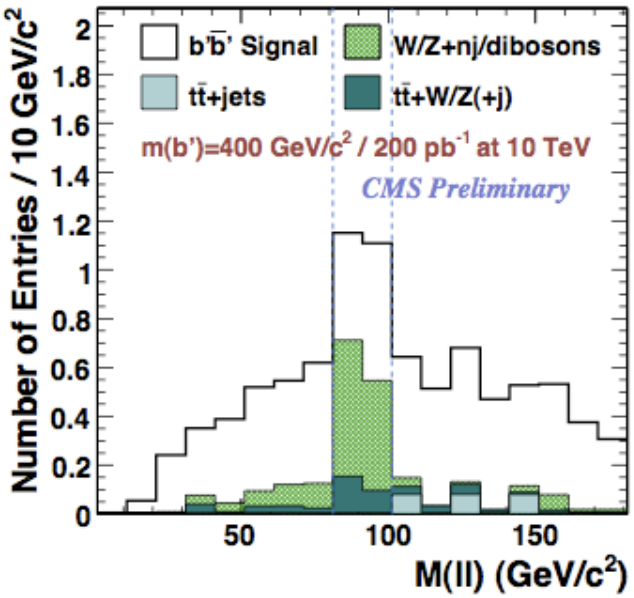


Signal Extraction



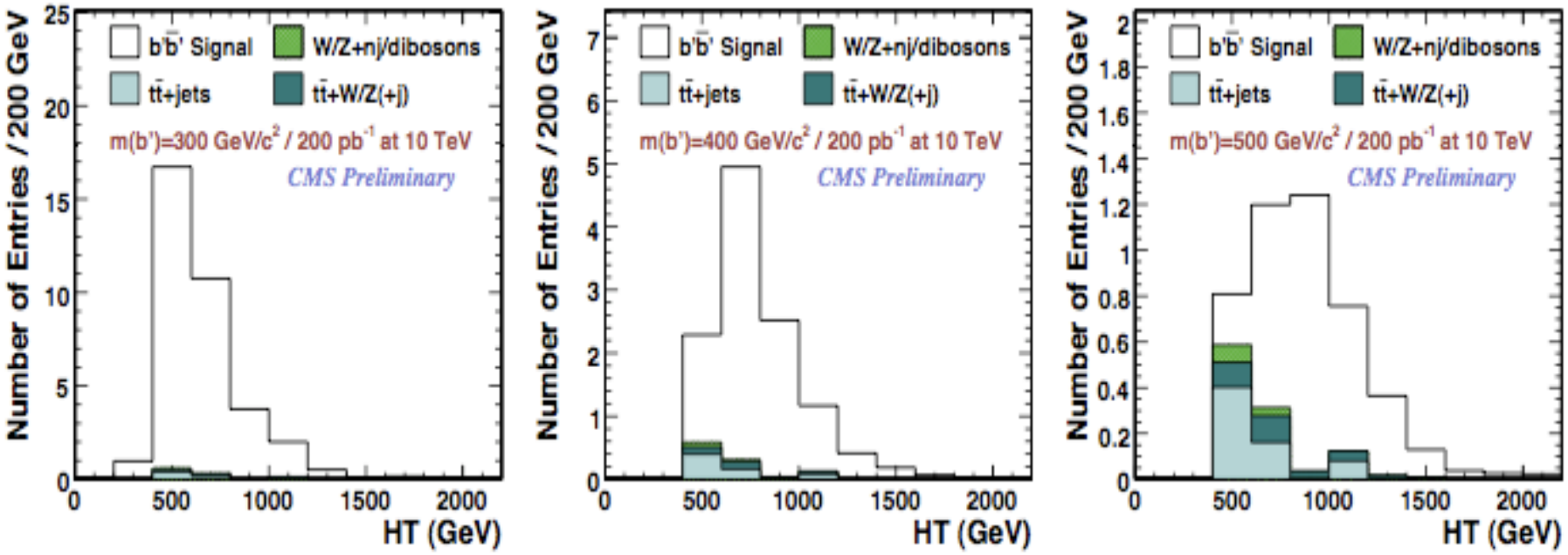






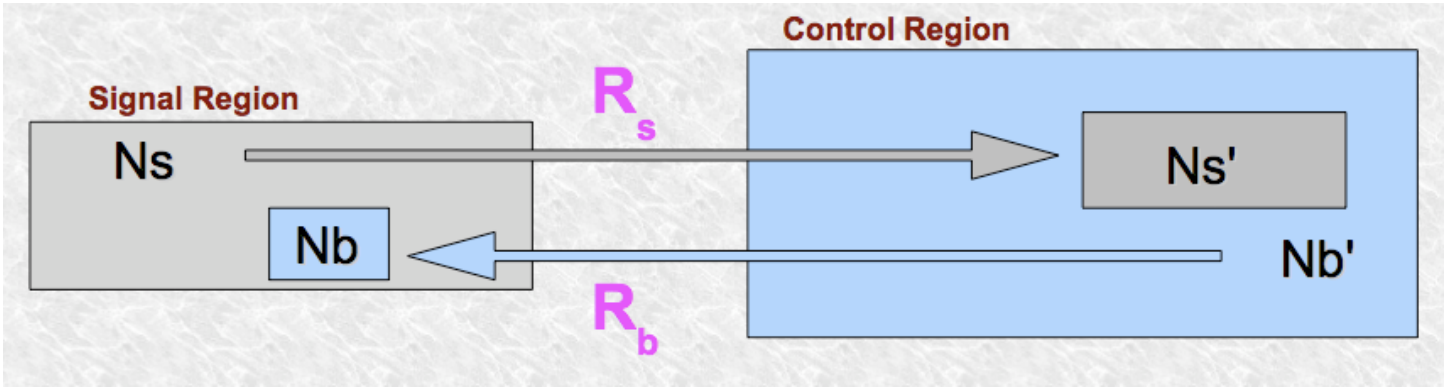
Heavy b’

$$H_T = \sum p_T(\text{jets}) + \sum p_T(\text{leptons}) + \text{MET}$$



Background Estimation

- Use data-driven background estimation techniques
  - Define background rich control samples for normalizing the background contributions
  - Events with two oppositely charged leptons are selected



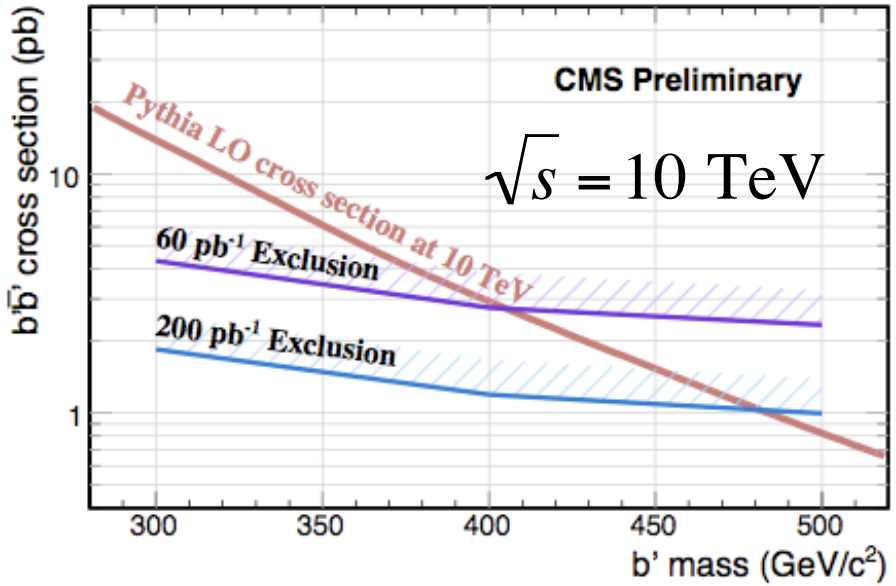
An iterative method is used to extract the signal yield

$$
\begin{aligned}
N_B &= N_B^{\text{control}} \times R_B = (N^{\text{control}} - N_S^{\text{control}}) \times R_B \,, \\
N_S &= N - N_B \,, \\
N_S^{\text{control}} &= N_S / R_S \,,
\end{aligned}
$$

Heavy b' limits

m(b') @ 200pb^{-1}	300 GeV	400 GeV	500 GeV
Cross-section	13.6 pb	2.8 pb	0.78 pb
Expected Yields	34.08	10.58	3.52
Background	1.08	1.08	1.08
Significance	9.0 σ	3.7 σ	1.4 σ

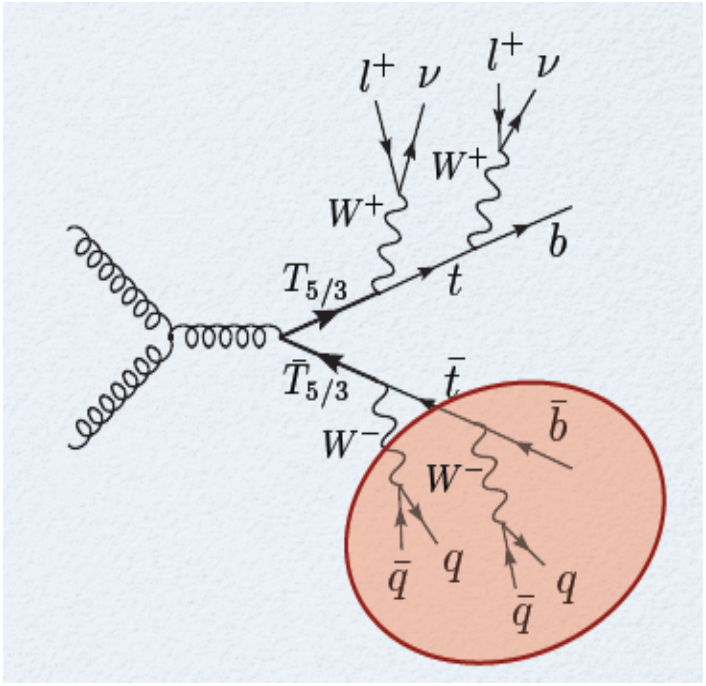
Exclude b' masses less than 485 (405) GeV with 200 (60) pb^{-1}

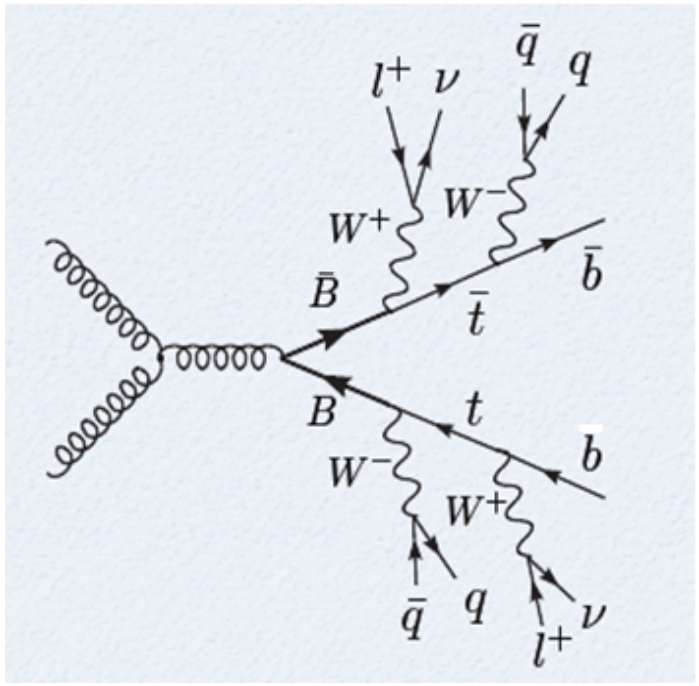


Stringent limits can be set at the LHC with early data

Exotic Top Quark Partner

- Fermionic top partners arise from natural, non-supersymmetric solutions of the hierarchy problem
  - model suggested by Contino and Servant: arXiv:0801.1679 (2008)
  - Pseudo-Goldstone boson Higgs
  - $T_{5/3}$ with Q_e = 5/3 and B with Q_e = -1/3 decay into W and top





- tW invariant mass peak ($T_{5/3}$)

$$l^{\pm}l^{\pm} + n \text{ jets } (\text{n } \geq 5)$$

Signal Extraction

- Backgrounds:

Physics backgrounds

$t\bar{t}W^{\pm}$ + jets

$t\bar{t}W^{+}W^{-}$

$W^{+}W^{-}W^{\pm}$ + jets

$W^{\pm}W^{\pm}$ + jets

Instrumental backgrounds

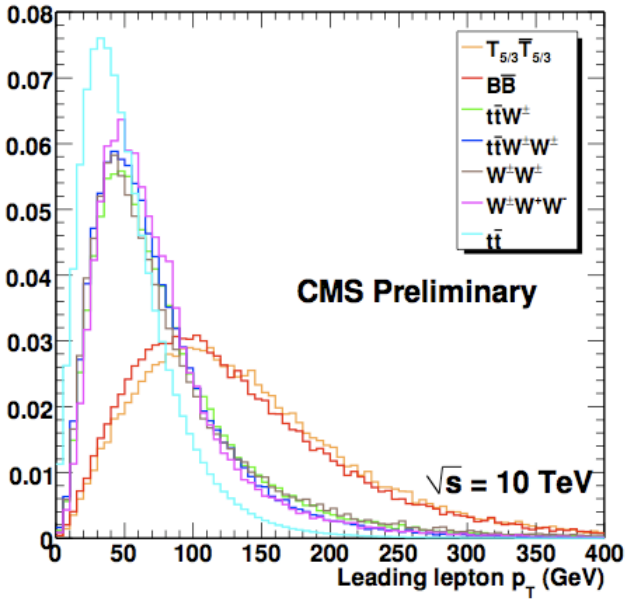
$t\bar{t}$ + jets

$W^{\pm}$ + jets

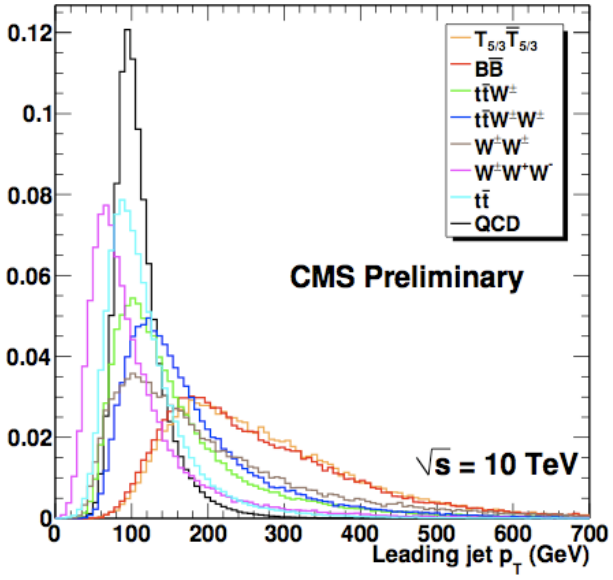
Z + jets

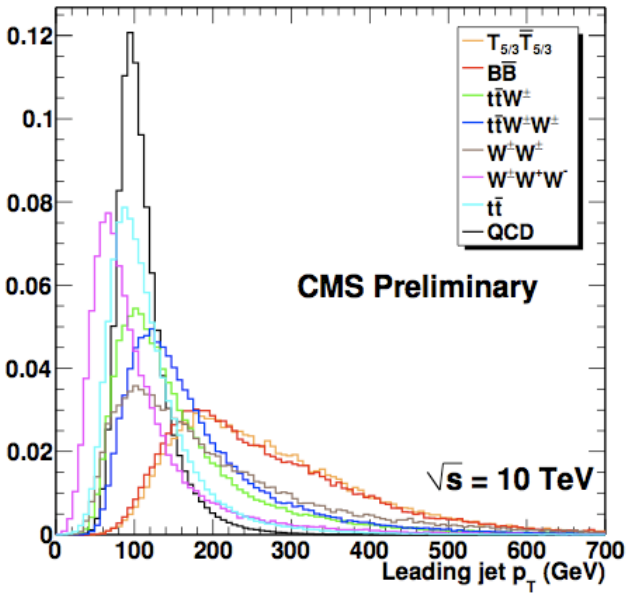
QCD multijets

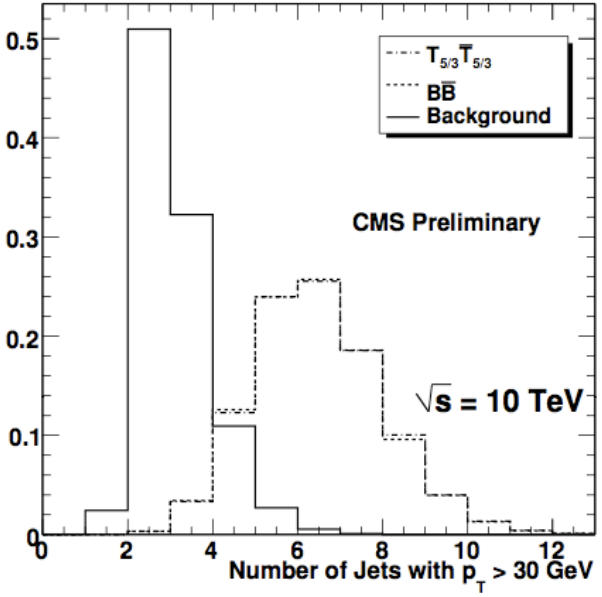
- background suppression done by requiring
  - 2 isolated same-sign leptons
  - at least 5 high pT jets
  - Z invariant mass veto for the “ee” channel

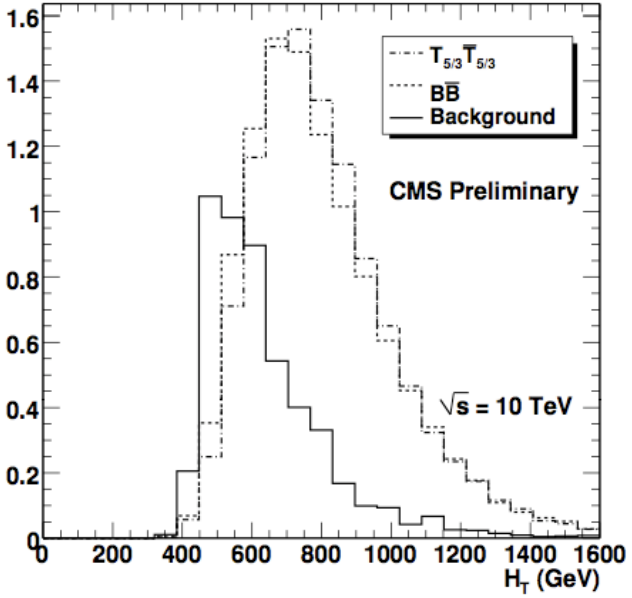


Signal Extraction







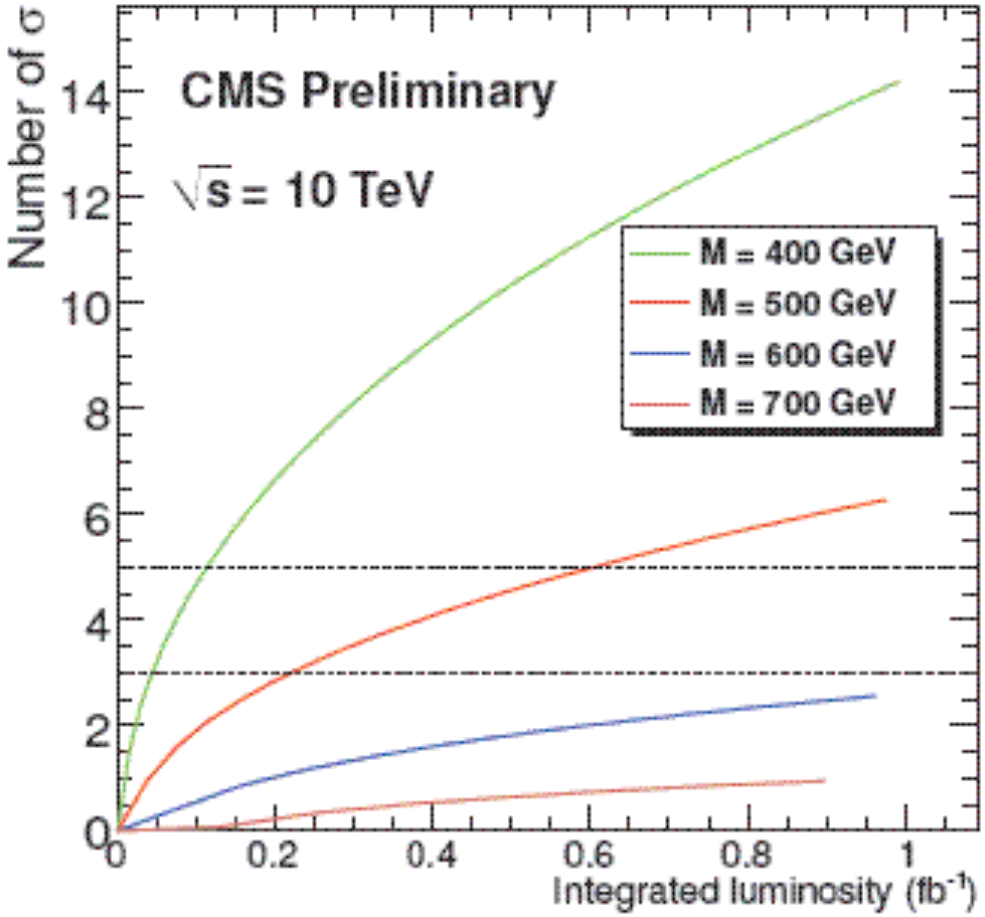


Background Estimation

- $t\bar{t}$ is the largest background
  - From charge misidentification
  - From semi-leptonic decays with b quark contributing the second lepton
- Data-driven estimation - define two samples:
  - N_C: control sample with events which pass all cuts except the same sign requirement
  - N_S: signal sample
- Subtract out the contributions of Z+jets and QCD multi-jet events
  - The remaining events are then due to $t\bar{t}$ with some signal contribution
    - Can lead to overestimate of $t\bar{t}$ in signal sample
- Define:
  - f_{tt} : ratio of same sign to opposite sign events for $t\bar{t}$
  - C_{tt}, S_{tt}: $t\bar{t}$ events in the control sample, signal sample.
- Then $S_{tt} = f_{tt} * C_{tt}$
  - f = 0.026 leading to S = 3.3 events per fb^{-1}

Discovery Potential

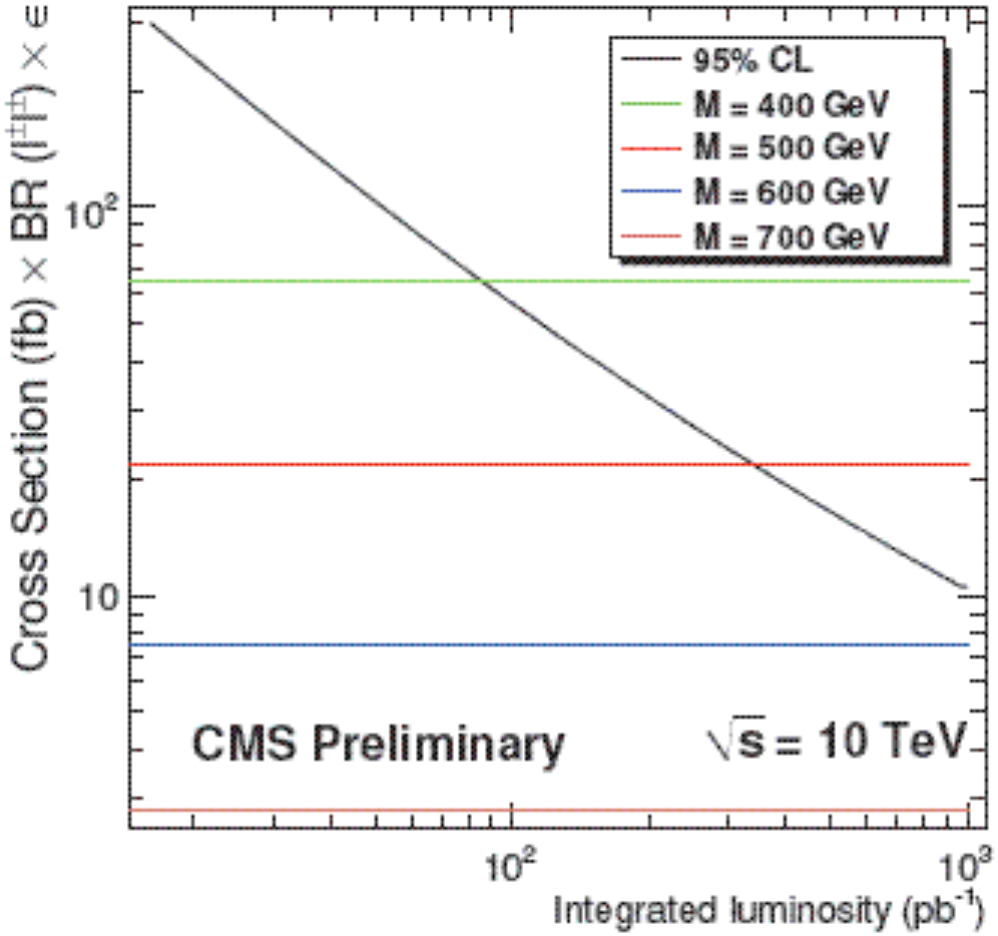
- For M = 400 GeV
  - 3σ at ~50pb^{-1}
  - 5σ at ~115pb^{-1}
- For M = 500 GeV
  - 3σ at ~220pb^{-1}
  - 5σ at ~600pb^{-1}
- Only 150pb^{-1} at 14 TeV for M =500 GeV



Cross section Limits

Stringent limits can be set at the LHC with early data

- Cross-section lines correspond to sum of $T_{5/3}$ and B expectations
- Exclude masses of up to 400 GeV with 80 pb^{-1}, 500 GeV with 340 pb^{-1}



Conclusions

- The LHC is back online!
- Expect a long physics run this year with integrated luminosity up to 500 pb^{-1}
- Many searches for exotic heavy quarks at the LHC offer unusual and/or spectacular signatures
- Early discoveries are possible in many cases
- A very exciting time is ahead of us; we need to keep an open mind and be prepared for the unexpected!