Direct Searches for 4th Generation Quarks at CMS

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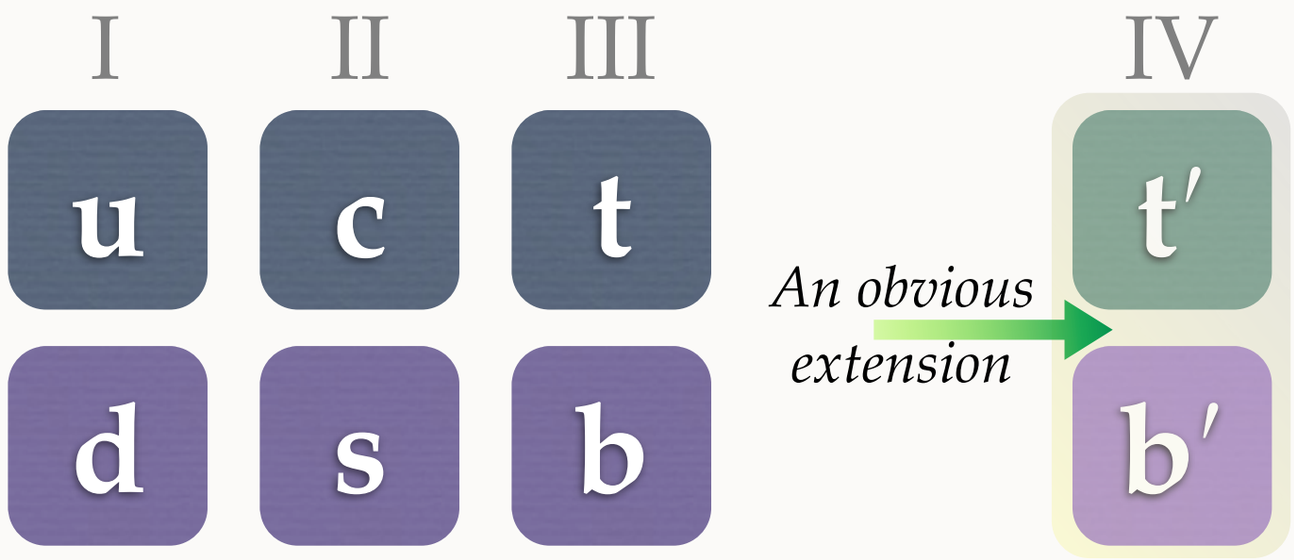
4TH GENERATIONS: MOTIVATION



- The possibility of 4th generation is not really excluded by the electroweak precision data.
- Large impact to the Higgs sector, if the 4th generation exists.
- May resolve some potential problems in a low cost way.
- LHC is an ideal place to do a carpet searching –

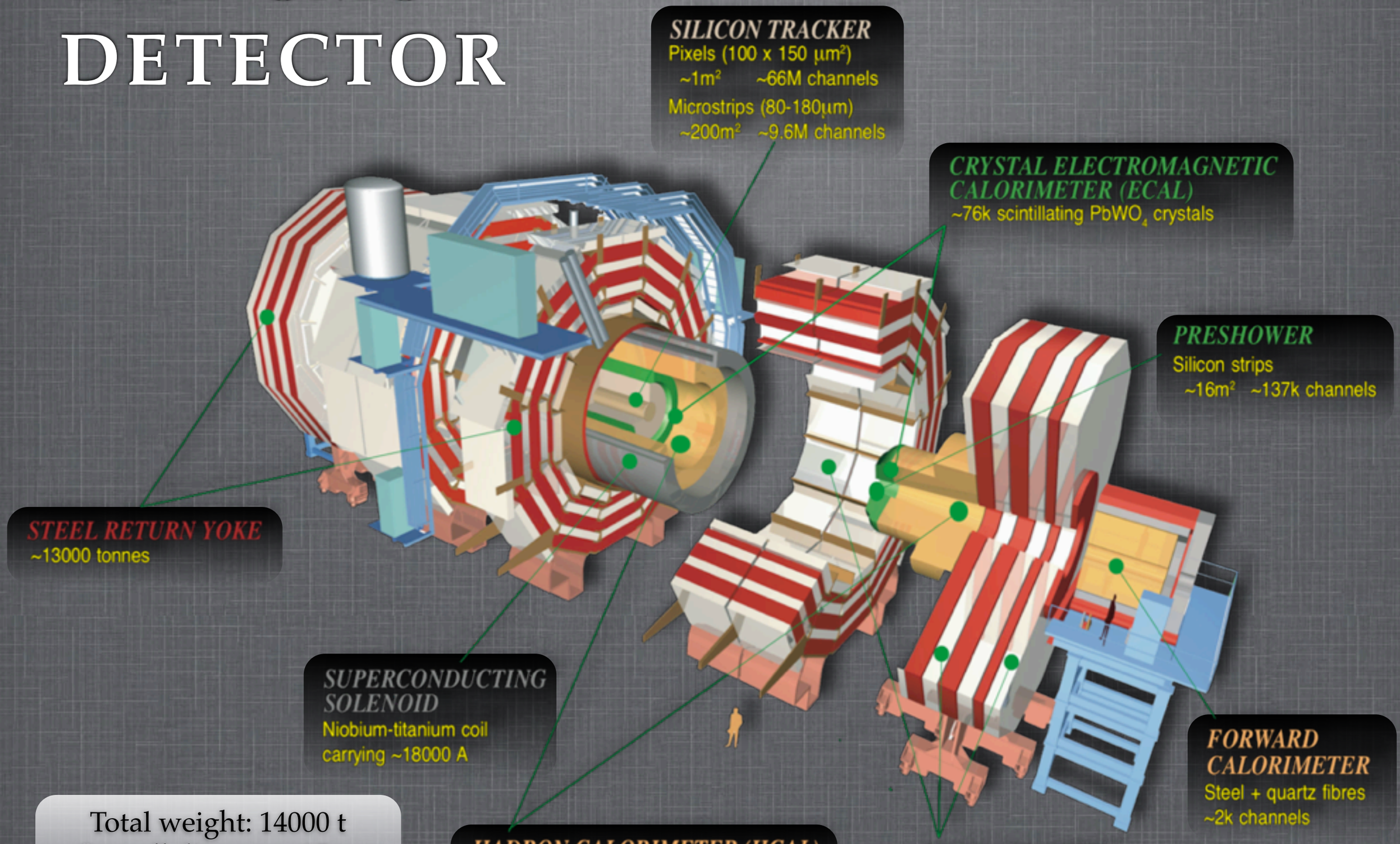
find them, or *exclude* them!

THE CMS COLLABORATION

← ¼ of collaboration

3170 scientists and engineers
(including ~800 students)
from 169 institutes in 39 countries.

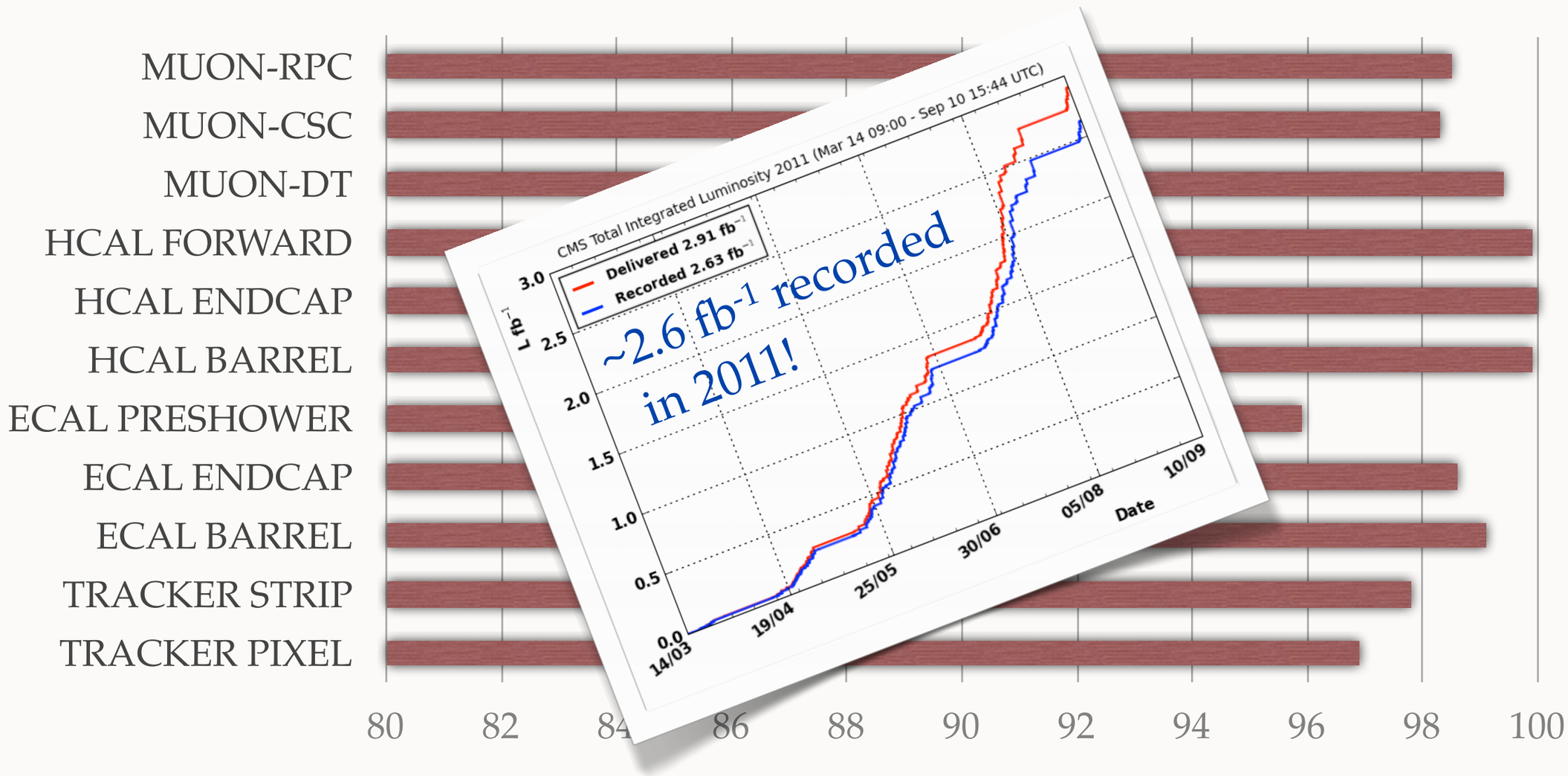
THE CMS DETECTOR



Total weight: 14000 t
Overall diameter: 15 m
Overall length: 28.7 m
Magnetic field: 3.8 Tesla

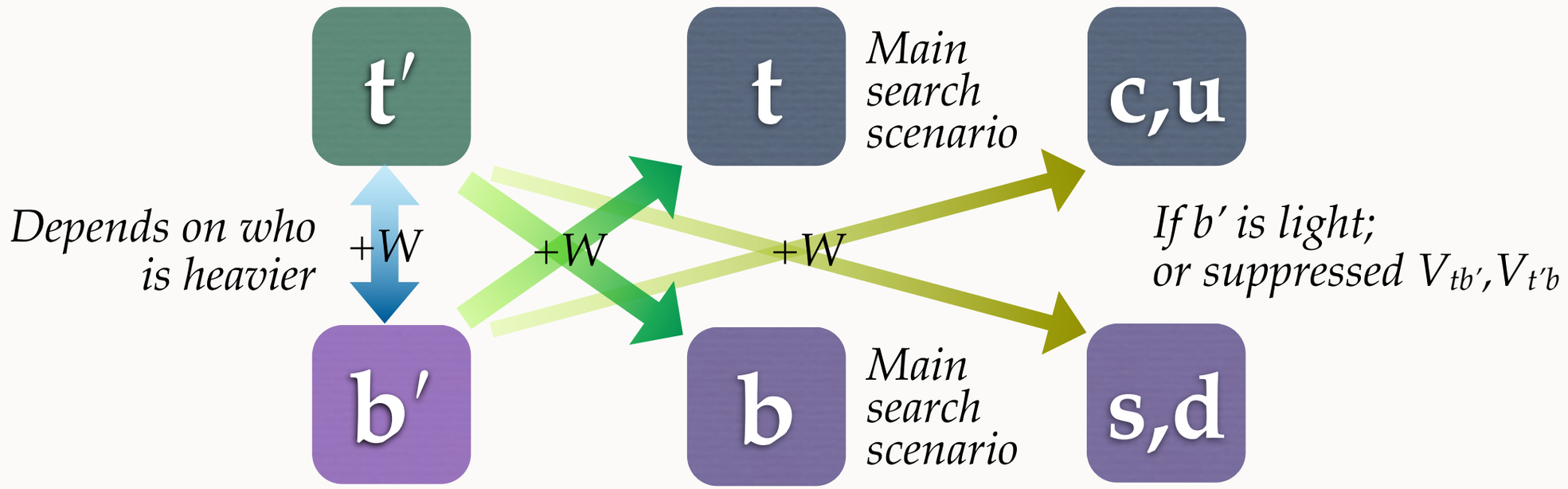
EXCELLENT DETECTOR OPERATIONS

Average fraction of operational channels per subsystem >98% operational



In this talk: **0.2 ~ 1.1 fb^{-1}** used for 4th generation searches

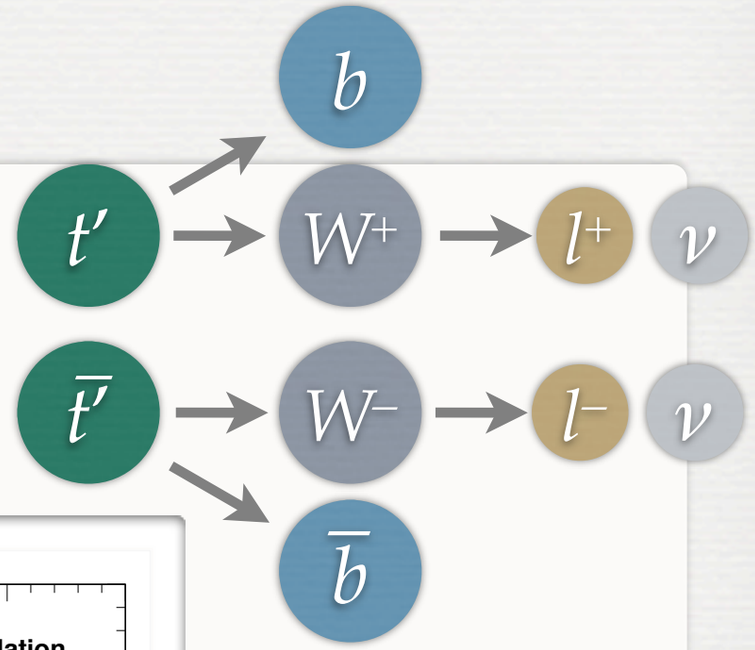
SIGNATURES OF 4TH GENERATIONS



Main decay signatures for direct searches:

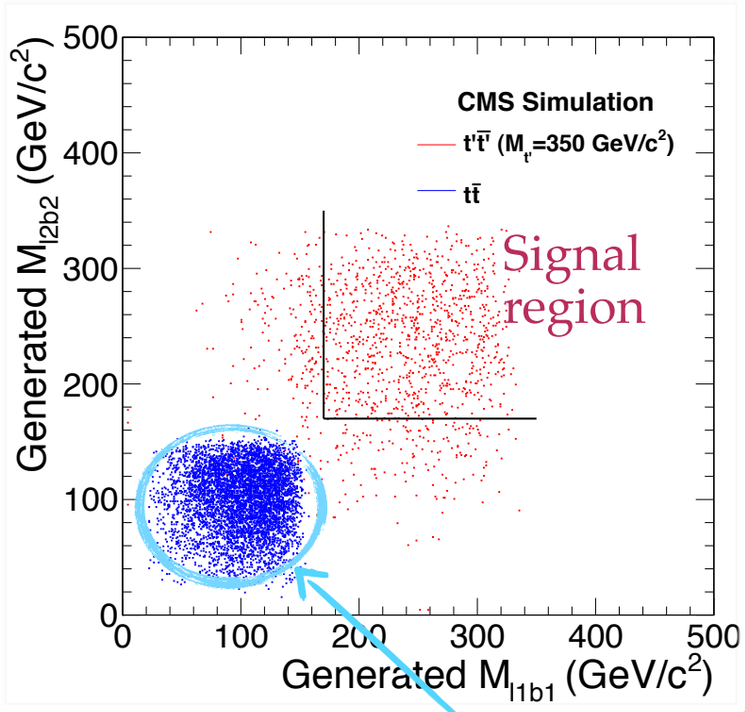
- **t′ → bW**, **t′ → qW** : not really different from a heavy top.
- **b′ → tW(→ bWW)** : complex signature, **b′ → qW** : heavy top.
- **t′ → b′W & b′ → t′W** : should be seen after the above two.

SEARCHES FOR t′→bW
(dilepton)

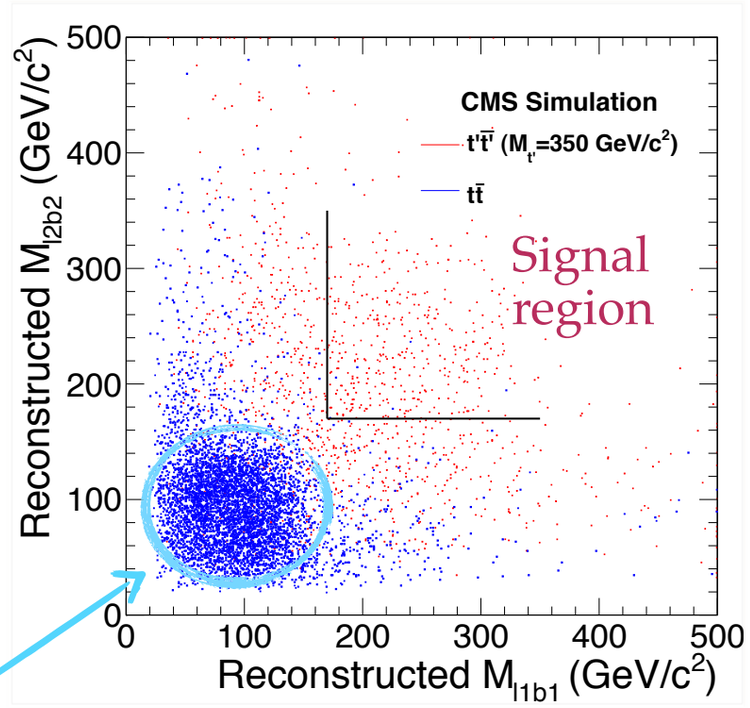


- Look for **dilepton events** + jets.
- Reconstruct two "b-jet+lepton" masses:

Generator level



Reconstruction level



Signal lost due to the resolution, but it (still) keeps the background away.

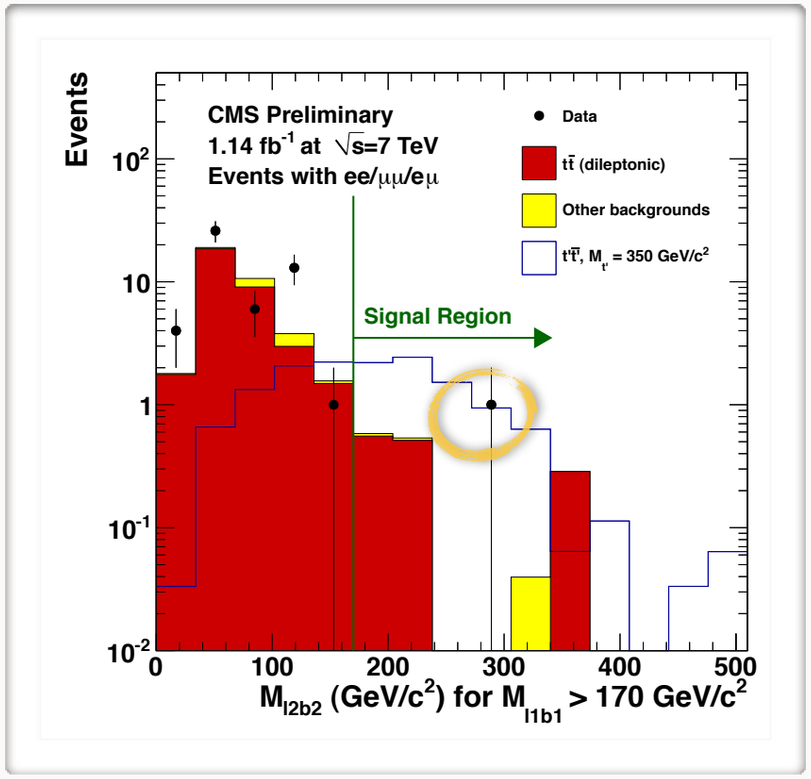
Optimize the b-lepton pairing to keep top background outside of the signal region

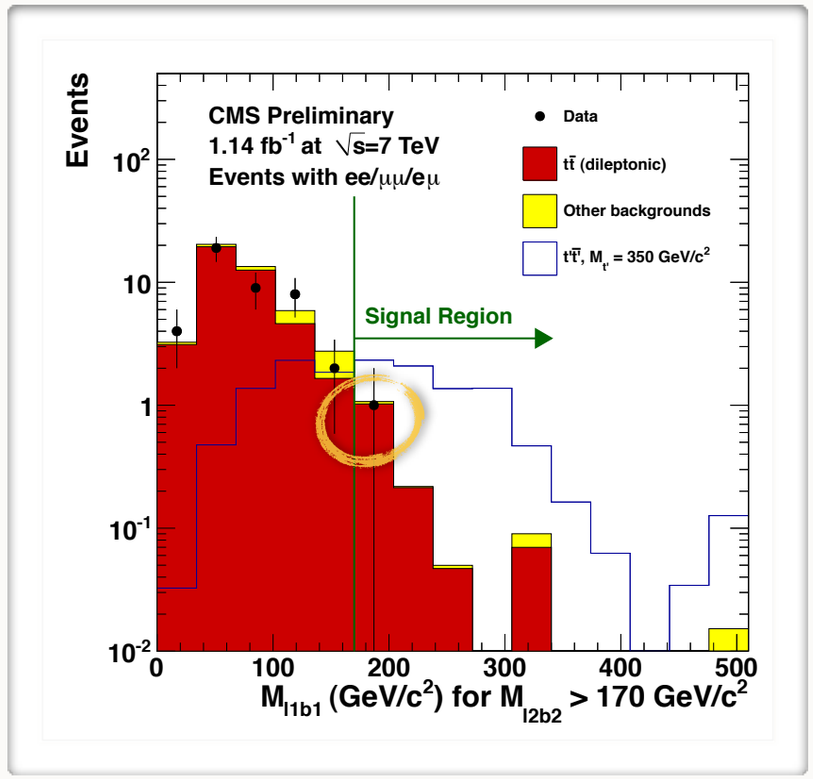
SEARCHES FOR t′→bW
(dilepton)

- Preselection:
  dilepton + 2 tagged b-jets:
  (just dilepton tops!)

channel	ee	μμ	eμ	all
t′t′(350 GeV/c²)	2.51	2.92	6.33	11.8
MC background	176±6	184±6	458±9	818±13
data	184	182	512	878

- Signal region: M(lepton+b) > 170 GeV/c²

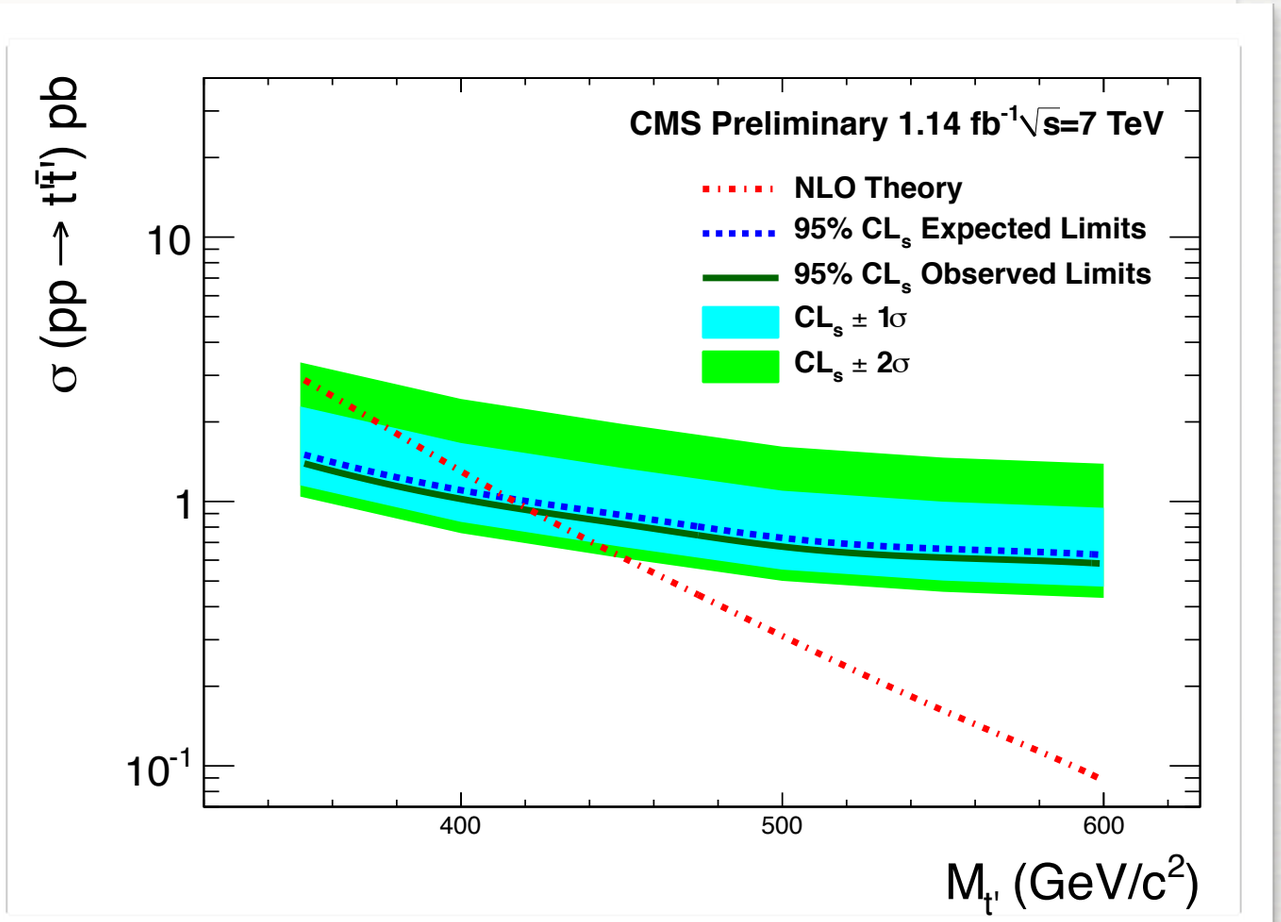




SEARCHES FOR t′→bW
(dilepton)

- Simple counting analysis.
- Data-driven background estimation.
- Exclusion limit is obtained with the CLs method.

	Yield
t′t′(350 GeV/c^2)	11.8
Estimated background	$1.62^{+0.80}_{-0.70}$
data	1

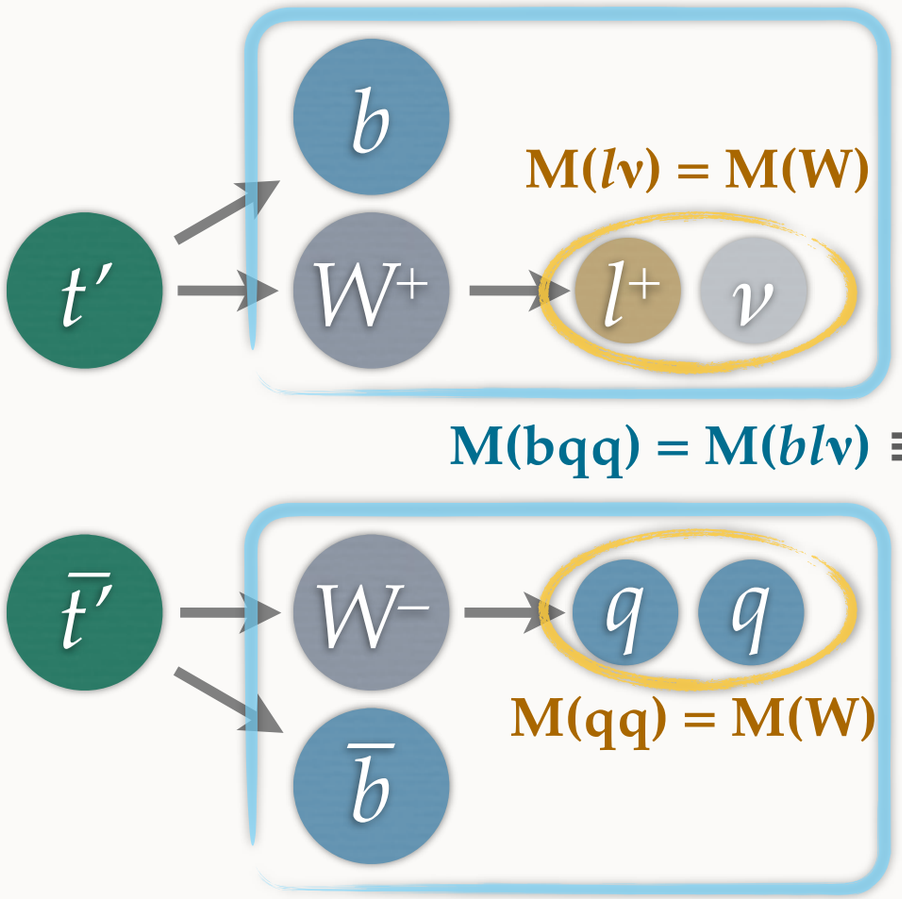


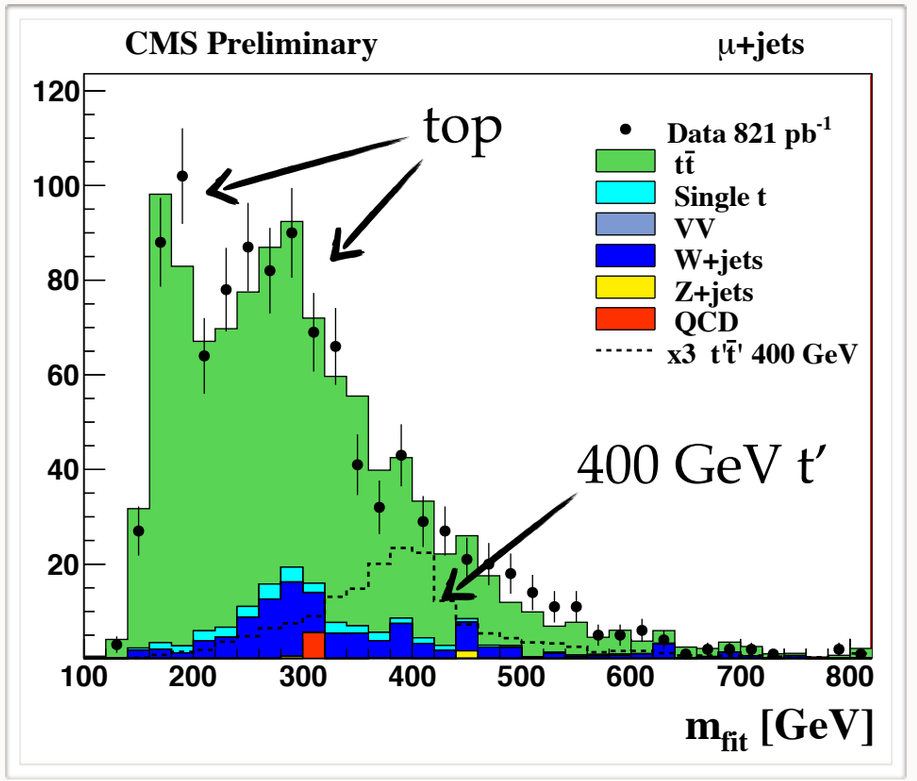
Ref: CMS-EXO-11-050

For **t′→bW** decays,
M(t′) > 422 GeV at 95% C.L.

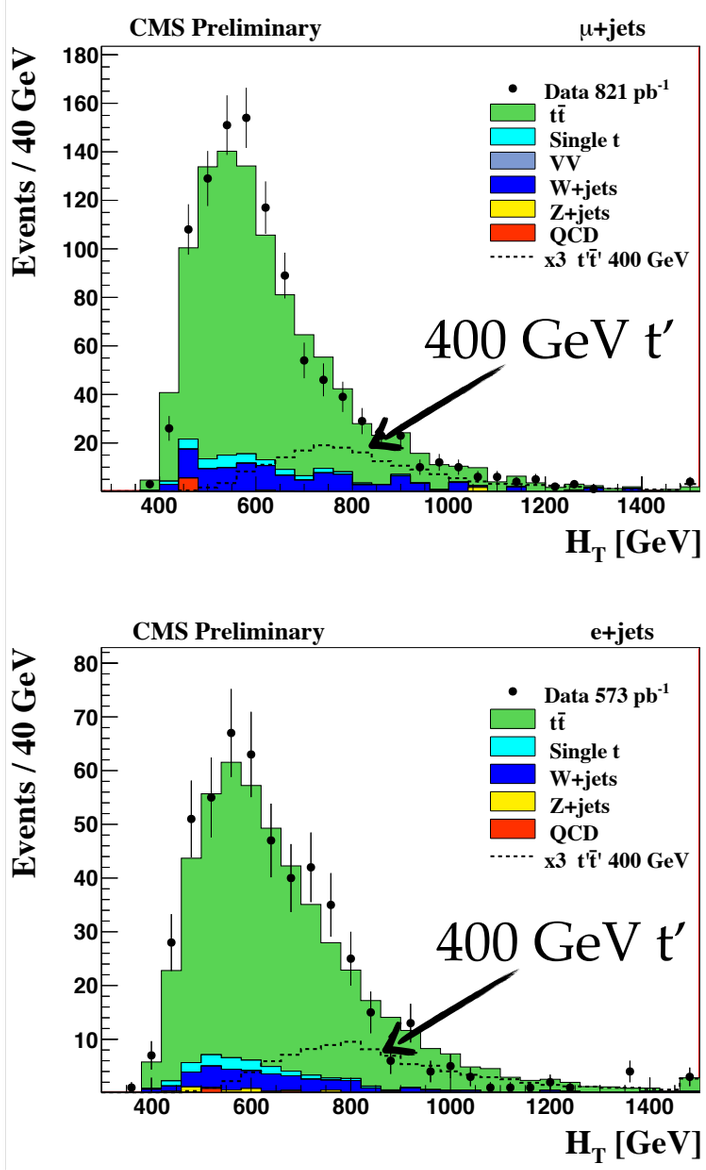
SEARCHES FOR t′→bW
(lepton+jets)

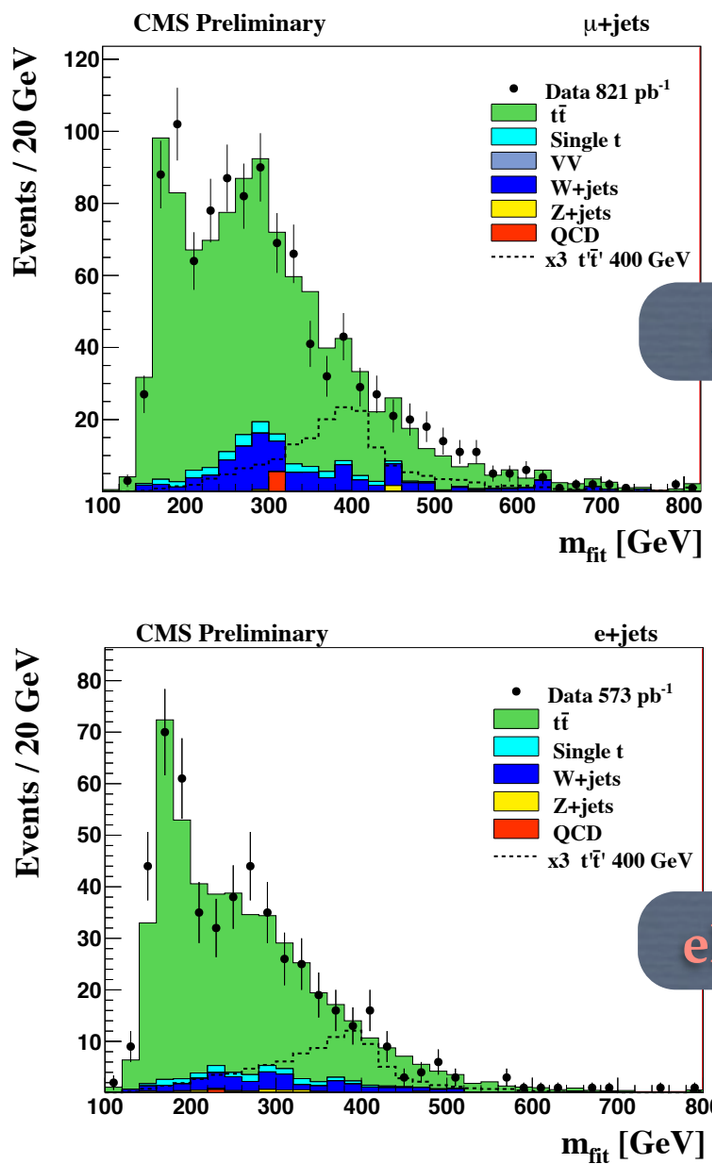
- Reconstruct a pair of "Heavy Top" in lepton+jets channel.
- Select an electron or a muon, ≥ 4 high p_T jets, missing energy, at last one b-tagged jet.
- Kinematic fit applied for the mass reconstruction:





SEARCHES FOR t′→bW
(lepton+jets)





muon+jets

M_{fit} and **H_T** are both reconstructed.

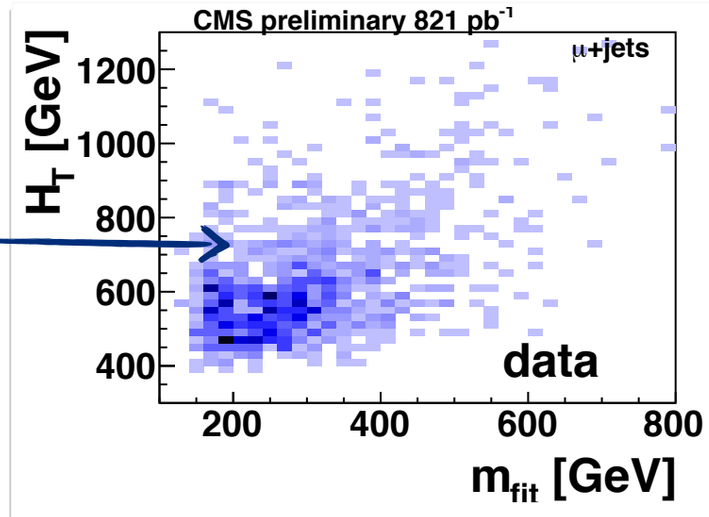
$H_T = \sum p_T(\text{jets}) + \sum p_T(\text{leptons}) + \text{MET}$

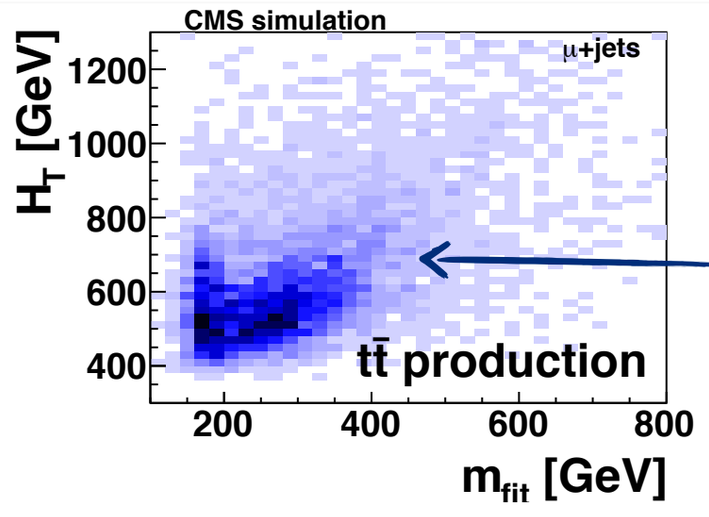
electron+jets

SEARCHES FOR t′→bW
(lepton+jets)

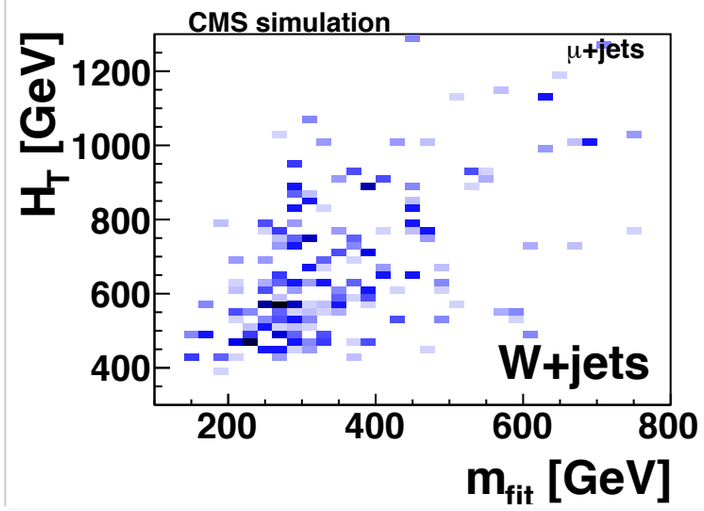
- Limit are extracted by 2D fits to H_T and M_{fit} including the correlations:

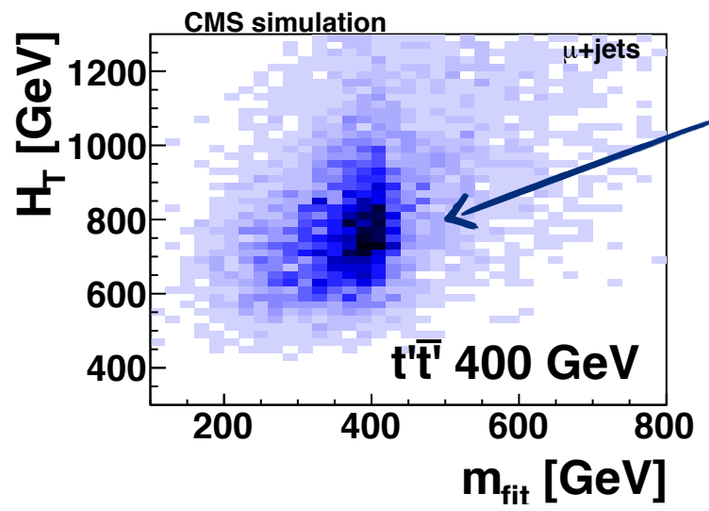
2D fit to data





Top:
Lower H_T, M_{fit}



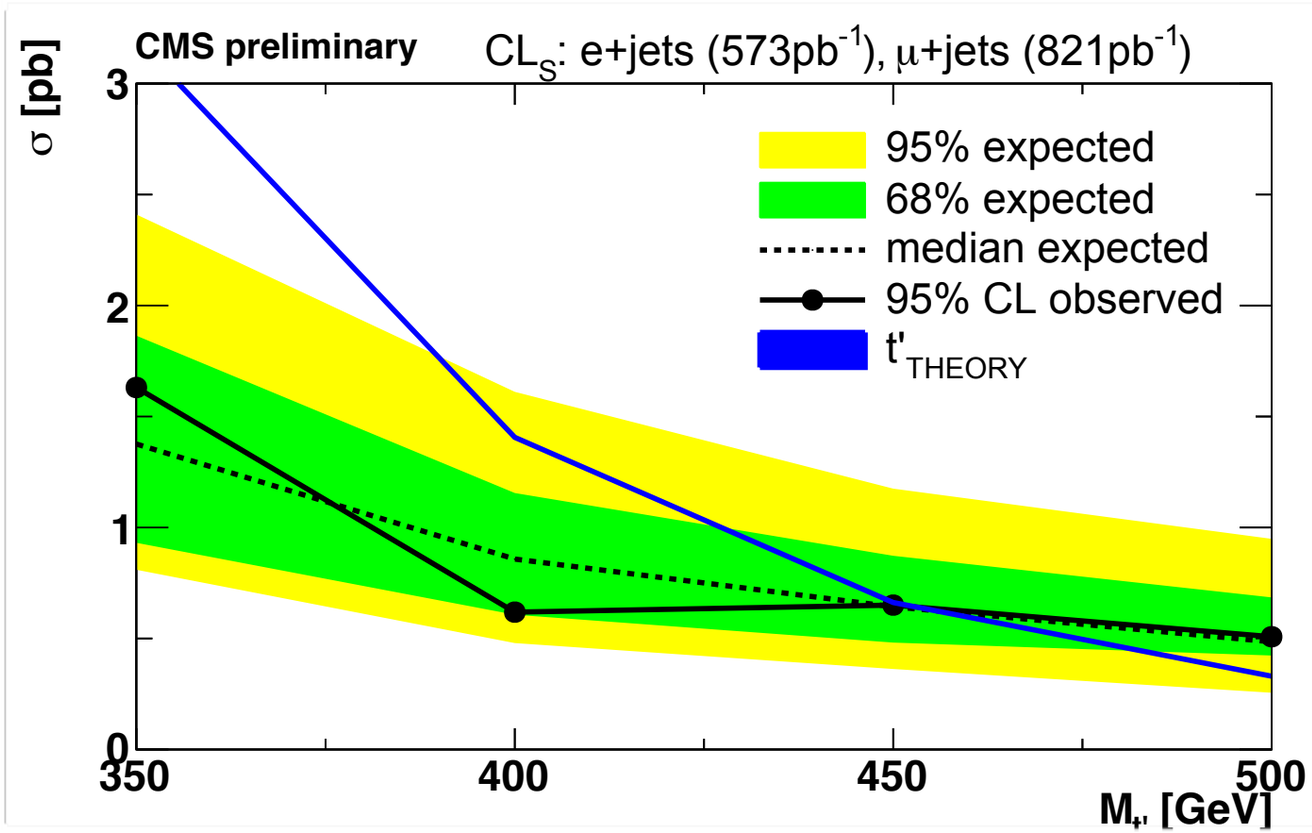


Signal:
Higher H_T, M_{fit}

SEARCHES FOR t′→bW
(lepton+jets)

- No excess found above the SM background.
- The combined limit is determined with the CLs method.

Channel	e+jets	μ+jets
Luminosity	573 pb^{-1}	821 pb^{-1}
Total background	510 ± 103	1054 ± 145
Data	520	1054

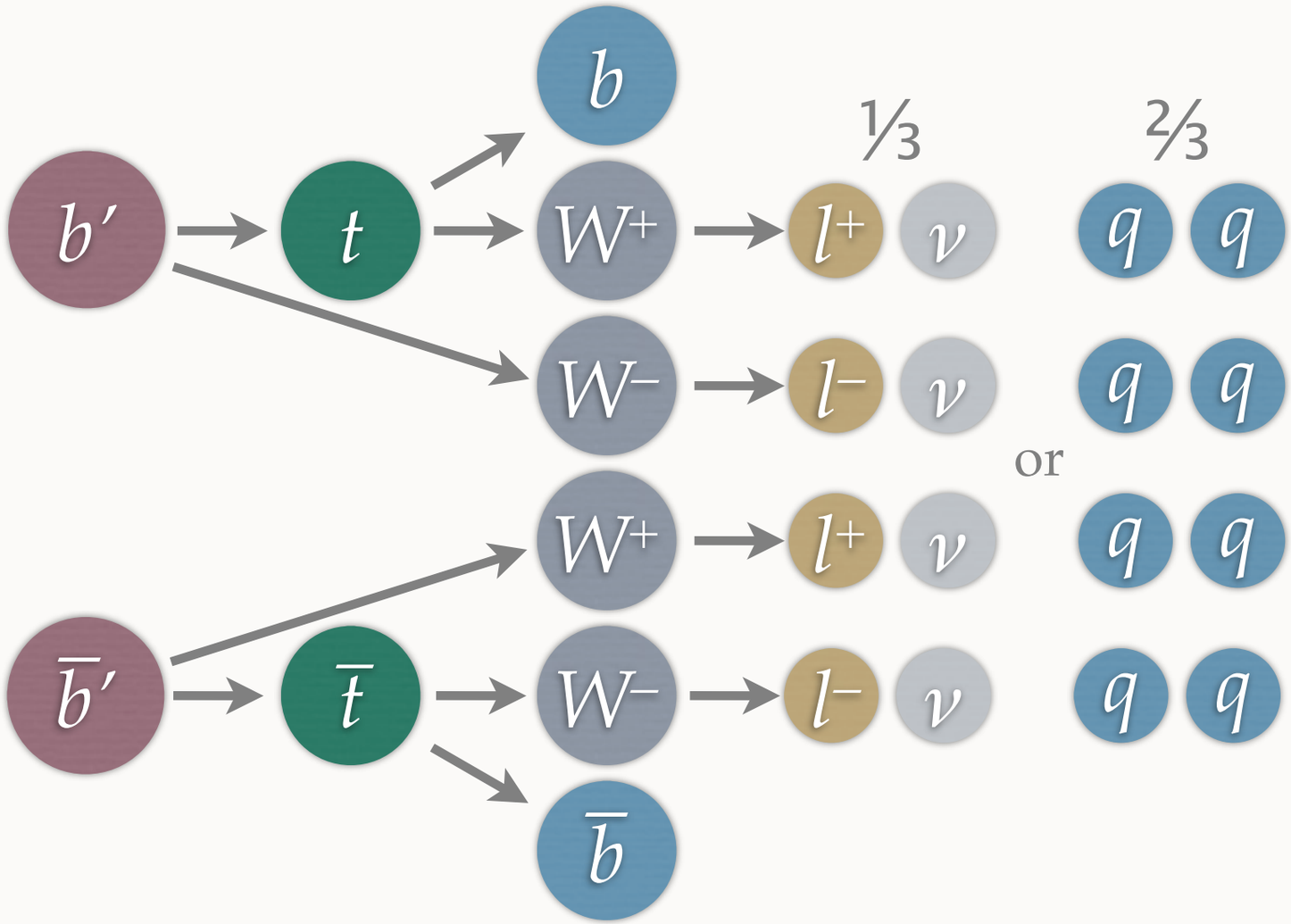


Ref: CMS-EXO-11-051

For **t′→bW**,
M(t′) > 450 GeV at 95% C.L.

SEARCHES FOR b′→tW

The full decay chain: $b'b' \to tWtW \to bbW^+W^-W^+W^-$ (4 W-bosons + 2 b-jets)



Possible final states:

L: Lepton, **J**: Jet,
MET: Missing Energy

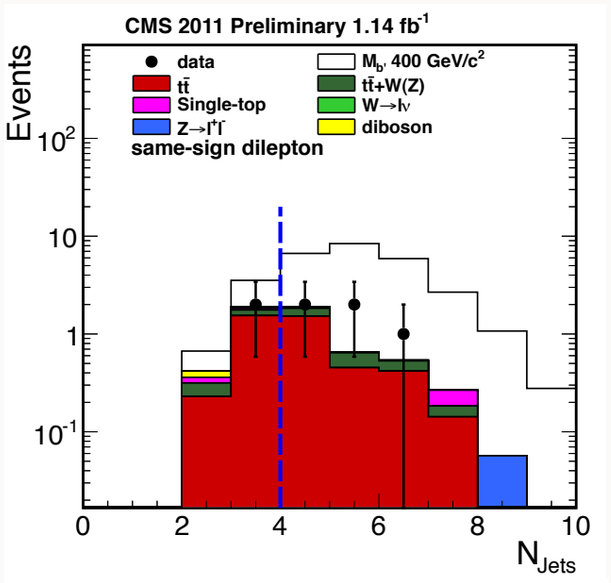
0L+10J
1L+8J+MET ←
2L+6J+MET ←
3L+4J+MET ←
4L+2J+MET

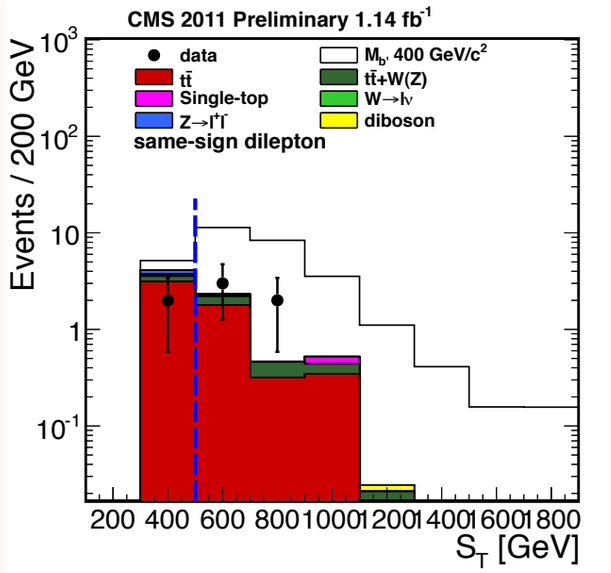
5 possibilities in total

Look for clean signatures: **trilepton** and **same-sign dilepton** events.

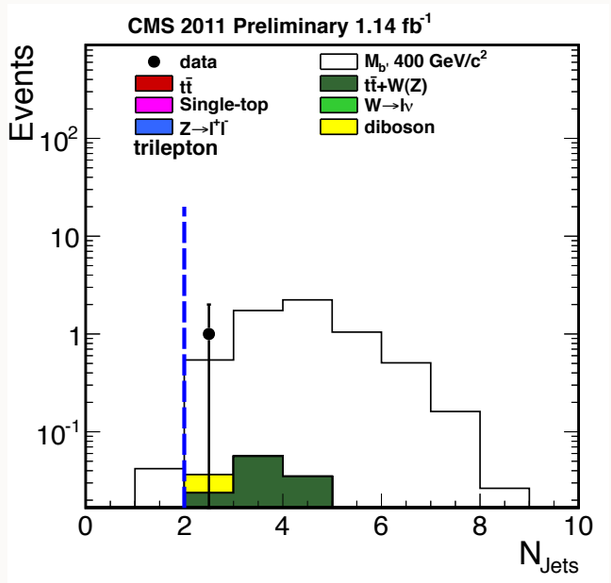
CMS SEARCH FOR b′→tW

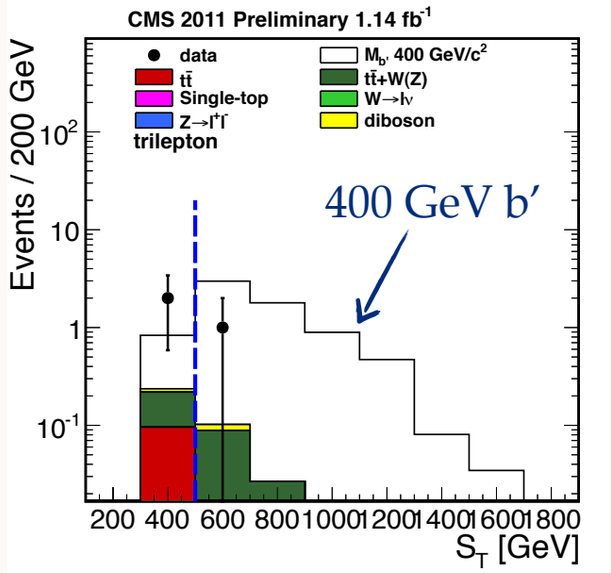
same-sign 2L + ≥4 jets





3L + ≥2 jets





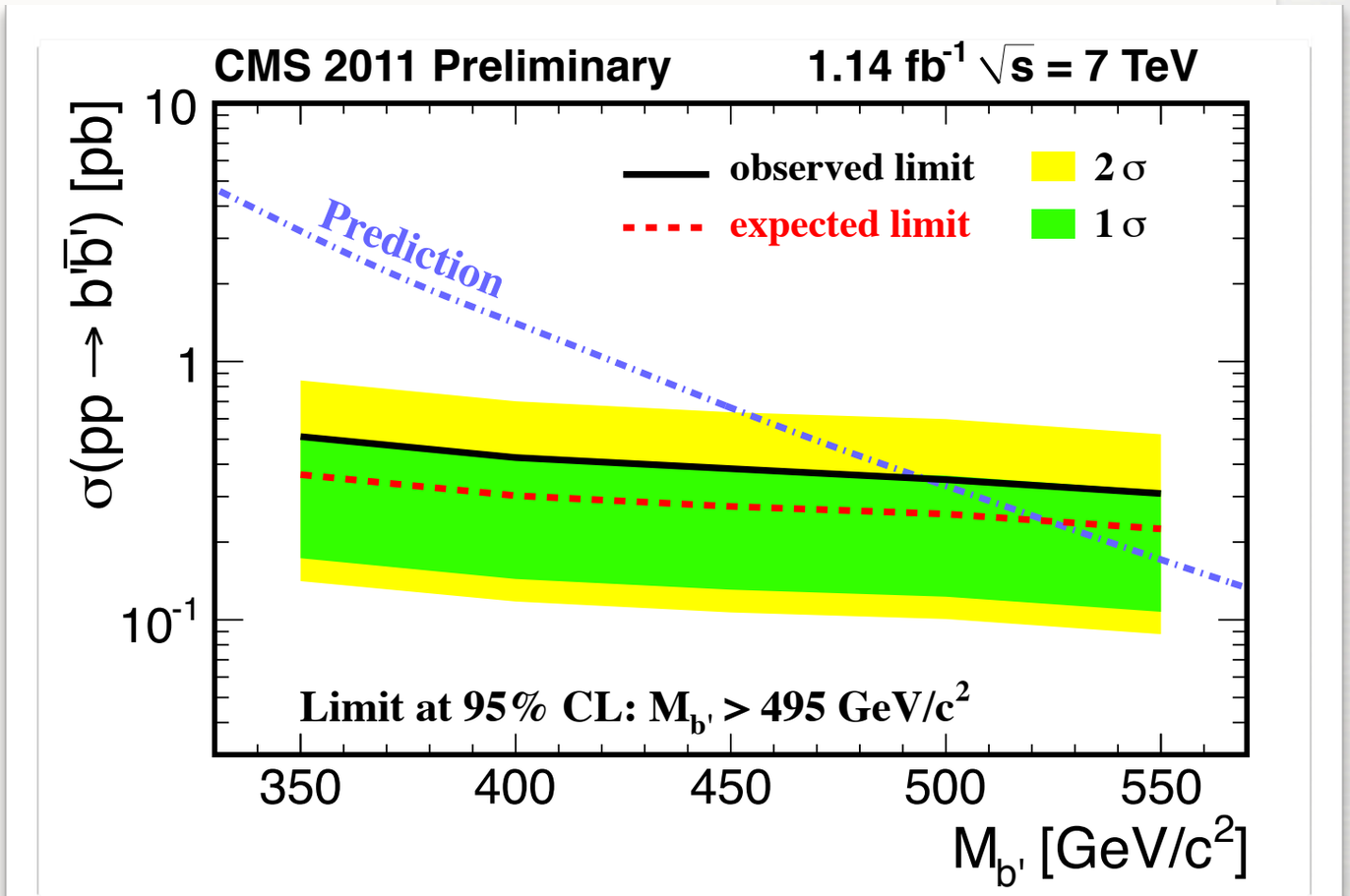
- Select “trilepton + jets” & “same-sign dilepton + jets” events.
- At least 1 b-jet.
- Very clean signature; almost no SM background.
- Reconstruct S_T:

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

CMS SEARCH FOR b′→tW

- Simple counting analysis.
- Exclusion limit is obtained with a Bayesian method.

Channel	SS2L	3L
b'(400 GeV / c^2)	22	6.7
Estimated background	4.4 ± 1.4	0.16 ± 0.09
Data	5	1

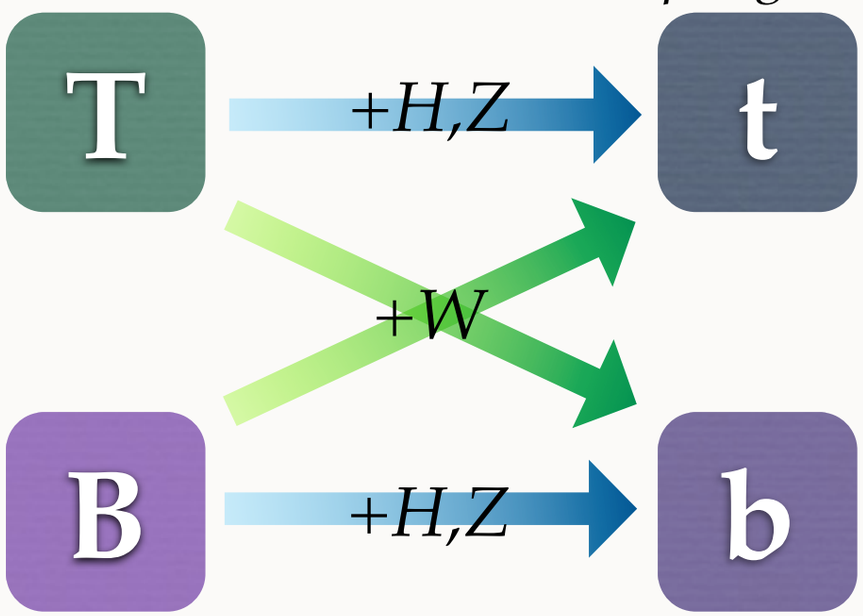


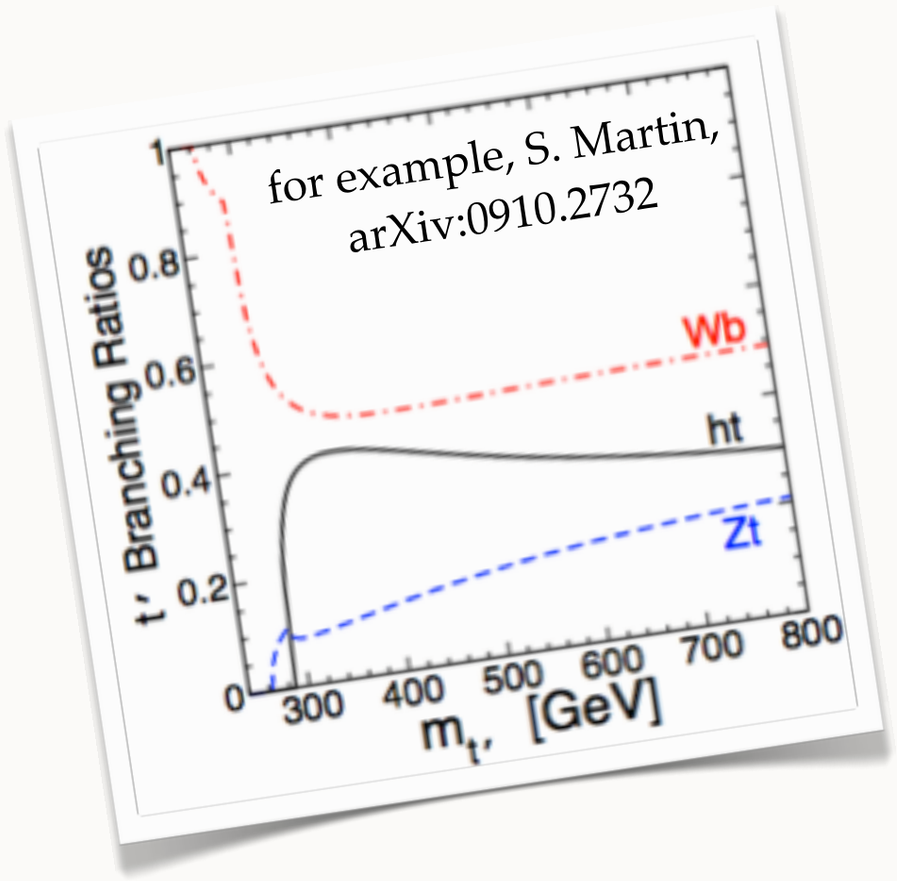
Ref: CMS-EXO-11-036

For **b′→tW** decays,
M(b′) > 495 GeV at 95% C.L.

SIGNATURES OF VECTOR-LIKE QUARKS

FCNC or vector-like quark with H/Z tree-level coupling



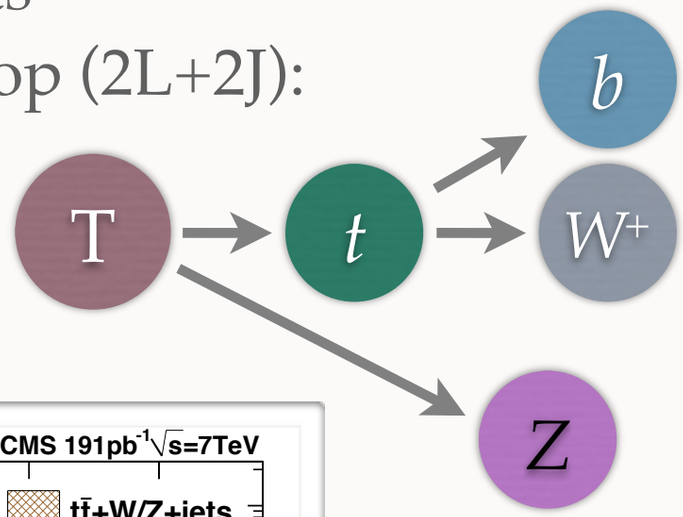


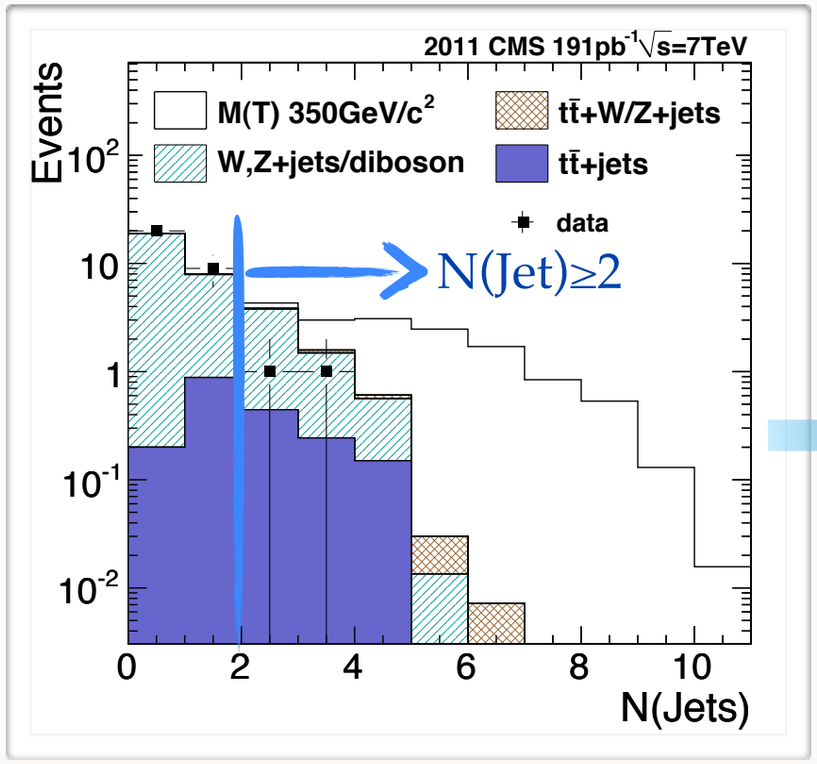
Decay signatures for direct searches:

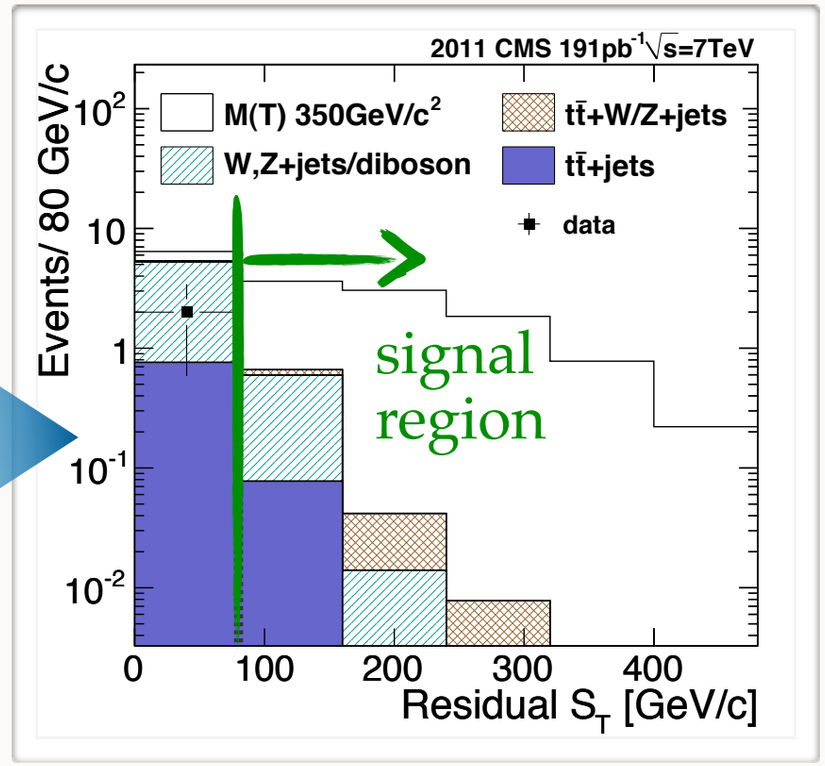
- **T/B → bW, tW** :
  not really different from the sequential 4th gen quark searches.
- **T → tH, tZ / B → bH, bZ** : FCNC decays from sequential 4G quarks, or vector-like quark with enhanced branching fractions.

CMS SEARCH FOR VECTOR-LIKE QUARK

- Tag a $Z(\rightarrow l^+l^-)$ + another isolated lepton + 2 jets
- Reconstruct a special variable to concentrate top (2L+2J):
  "Residual S_T" = $\sum p_T$(jets, expt. leading 2) +
  $\sum p_T$(leptons, expt. leading 2)

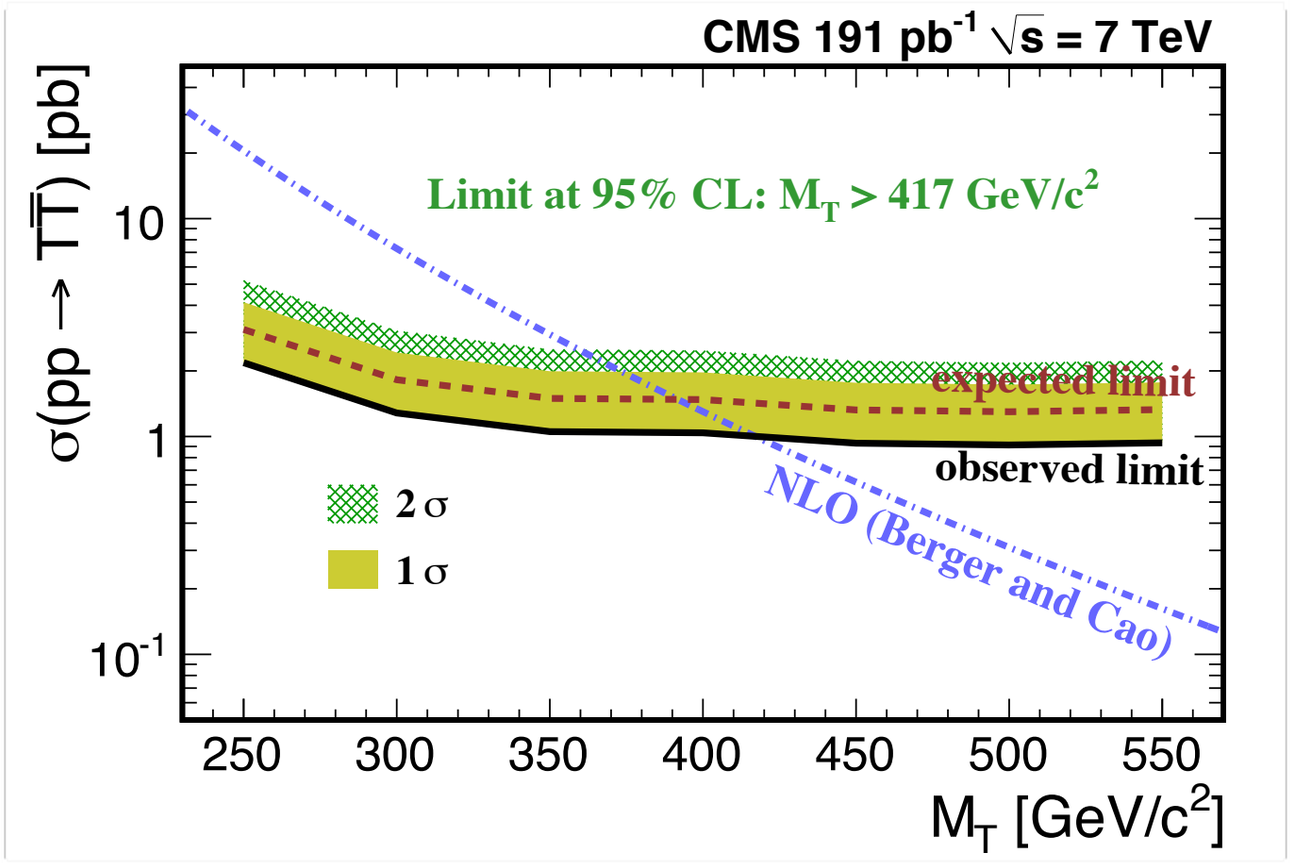






keep top background close to lower residual S_T.

CMS SEARCH FOR VECTOR-LIKE QUARK



- No event observed.
- Limited determined by the Bayesian approach assuming a 100% branching fraction.

	Yield
T(350 GeV / c^2)	8.99
Estimated background	0.73 ± 0.31
Data	0

For **T→tZ** decays,
M(T) > 417 GeV at 95% C.L.

Ref: CMS-EXO-11-005

SUMMARY

- Adding 4th generation fermion is one of the straightforward extensions to the Standard Model:
  - Big impact to the Higgs sector.
  - May resolve some known potential problems in a low cost way.
- Many searches have been carried out at CMS:
  - The strongest limits to date on b′ / t′:
    M(t′→bW) > 450 GeV/c^2;
    M(b′→tW) > 495 GeV/c^2.
    } **Already close to unitarity bound!**
  - Exotic top partner / vector-like quarks searches started; no hit at this moment.
- Prospects for LHC end of year data, 5 fb^{-1} scenario:
  - Push sequential 4G limit by another 50~80 GeV if no hint.
  - More direct searches are coming soon.