Heavy New Physics and Boosted Techniques in CMS

UCDAVIS
UNIVERSITY OF CALIFORNIA

Ricardo Vásquez Sierra

Implications of LHC results for TeV-scale physics: WG3 meeting
8-9 December 2011 CERN

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Z' to ttbar search

Mass of top quark pair (GeV/c²)
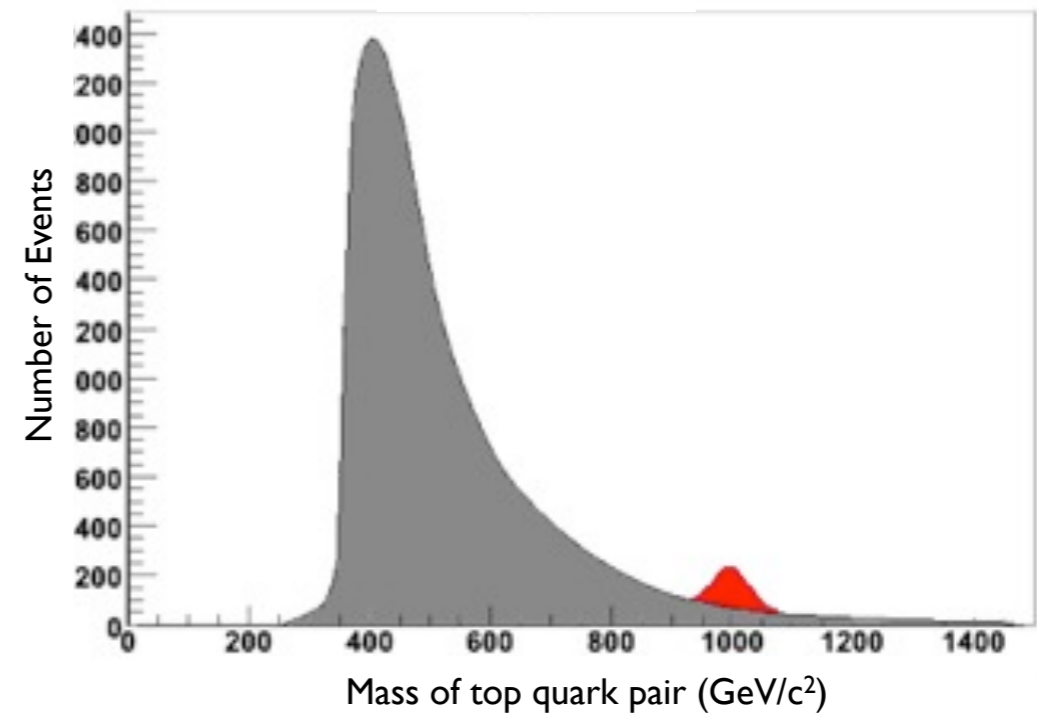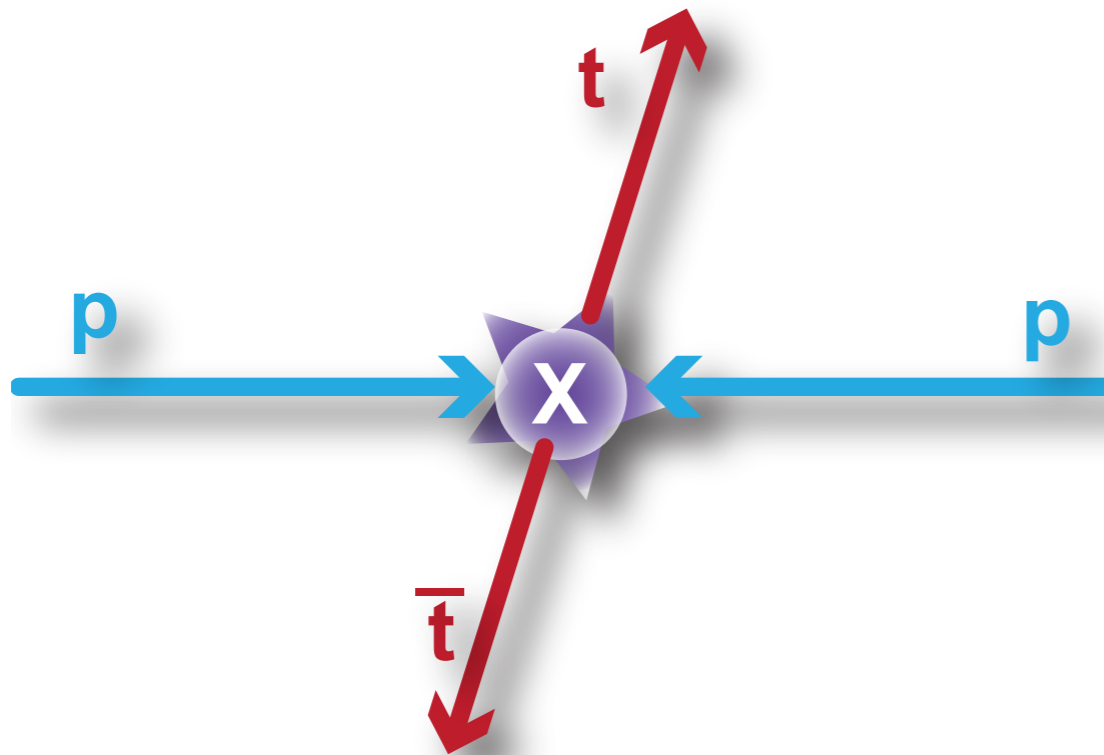
- Searches for Z' or KK resonances decaying to top pairs in the all hadronic and semi-leptonic final state

# All hadronic
Using jet substructure
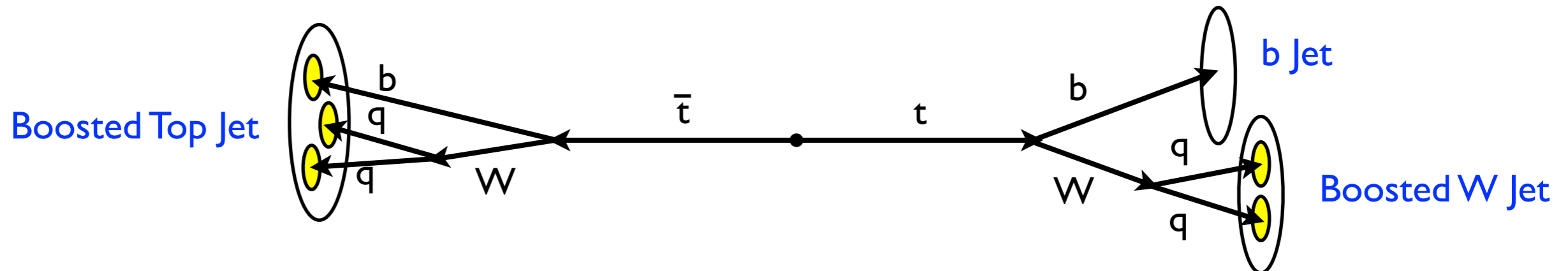
- Cluster the list of particles from particle flow using Cambridge-Aachen (C-A algortihm)

- Attempt to find substructure in the last iterations of the clustering sequence, that would map to the partons from a top quark or a W boson hadronic decay

CMS-PAS-JME-10-013

Boosted top signatures

- tt produced from a high mass resonance X→tt

- Decay products can be reconstructed within 1-2 jets

- Jets have unique characteristics which can help identify them
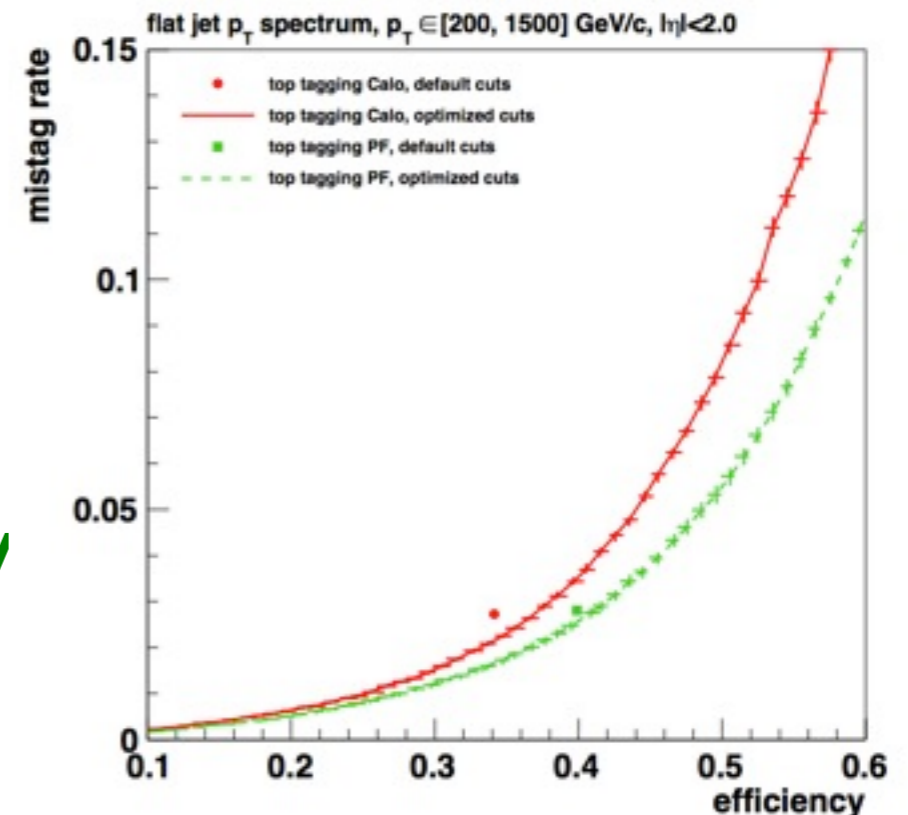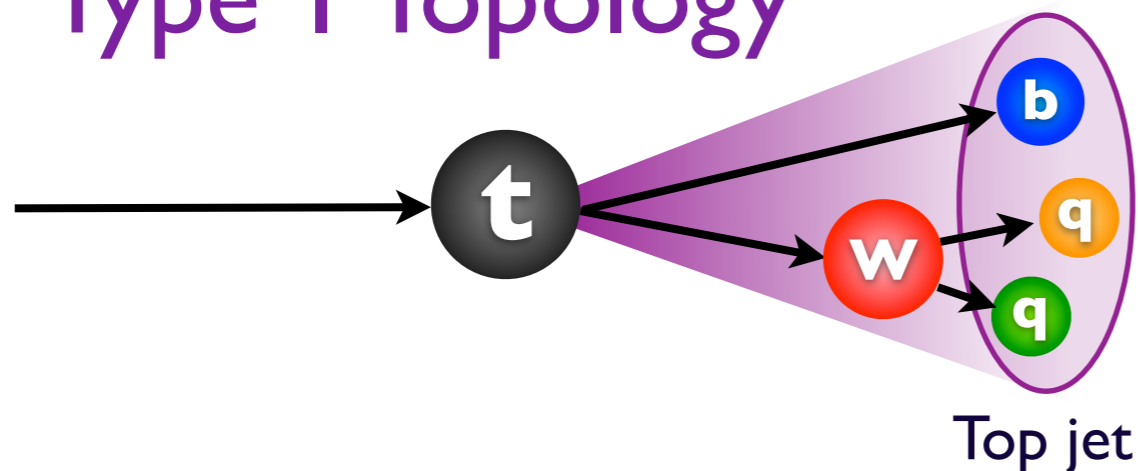
  ▸ Number of subjets, W mass, top mass

Type 1 Topology

Top jet

Type 2 Topology

W jet
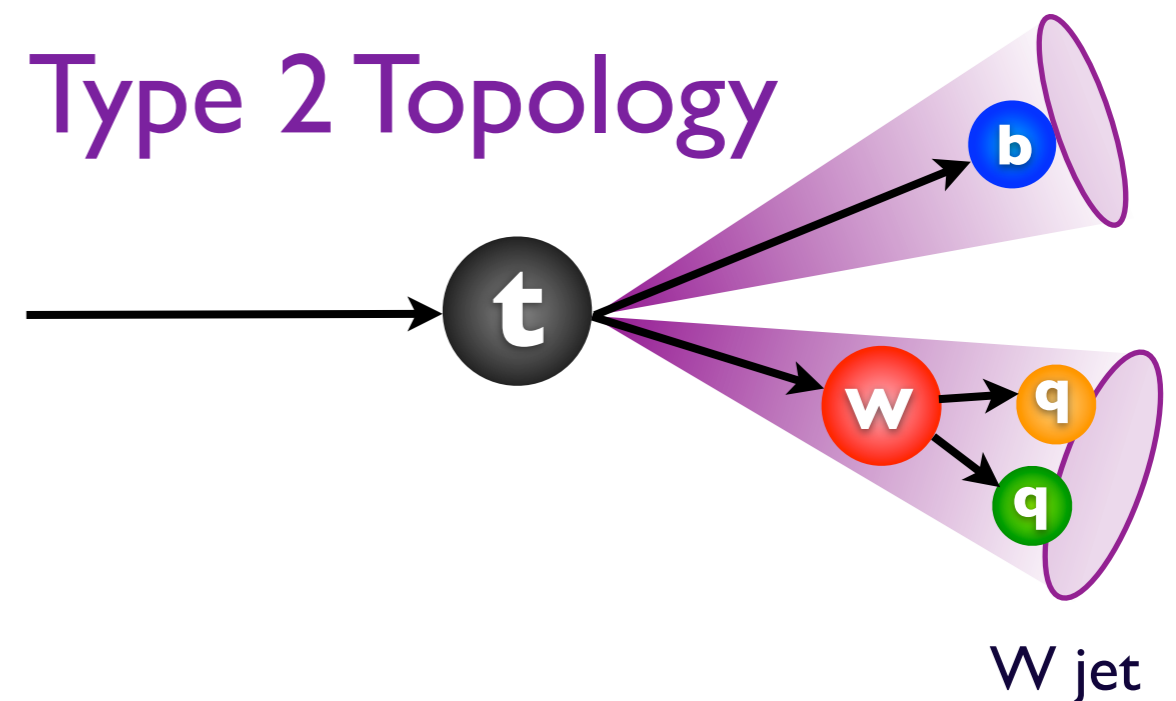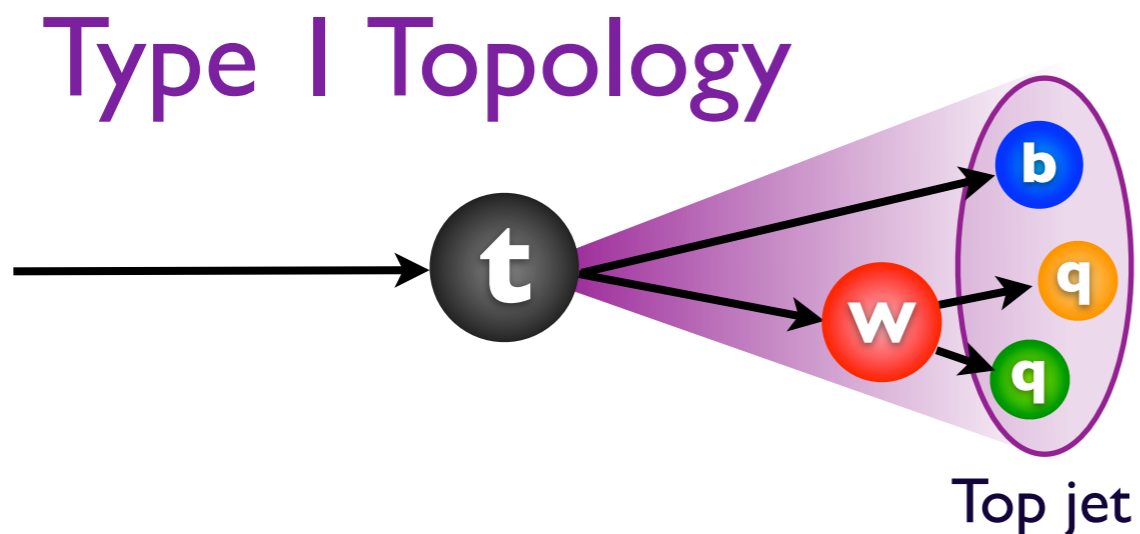
CMS-PAS-JME-10-013

Top Tagging

- **Tagging variables**

  ▸ $140 < \text{mass}_{jet} < 250$ GeV

  ▸ $n_{subjets} >= 3$

  ▸ minMass(jet1,jet2) > 50 GeV

  Type 1 Topology

Top jet

flat jet p_T spectrum, $p_T \in [200, 1500]$ GeV/c, $|\eta|<2.0$

- top tagging Calo, default cuts
- top tagging Calo, optimized cuts
- top tagging PF, default cuts
- top tagging PF, optimized cuts

mistag rate vs efficiency
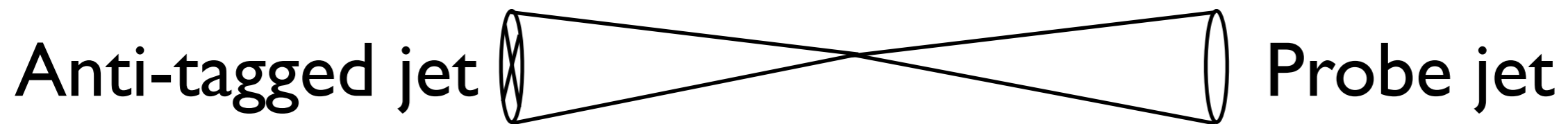
based on arXiv: 0806.0848

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Top Tagging/mistag rate

- Using dijet type events, we measure the mistag rate from data:

Anti-tagged jet   Probe jet

$m_{jet} <$ 140 GeV or
$m_{jet} >$ 250 GeV or
minMass < 50 GeV or
$n_{subjets} <$ 3

$$\text{Mistag Rate} = \frac{\text{Number of probe jets that are tagged}}{\text{Number of probe jets}}$$

CMS Preliminary, 886 pb^{-1} at $\sqrt{s}$ = 7 TeV

Mistag Rate

- Type 1+1
- Type 1+2

Jet p_T (GeV/c)
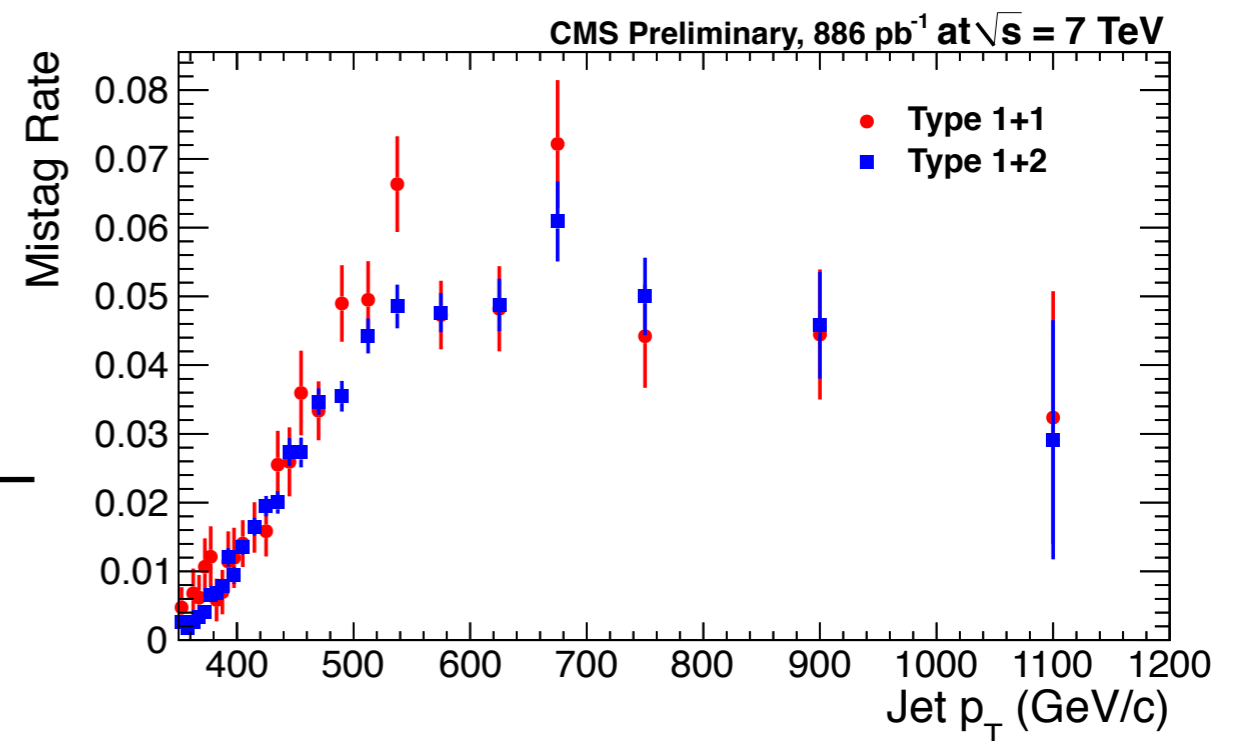
W tagging

- We tag Ws using pruned jets (based on Ellis et al. arXiv:0903.5081)

  ▸ $60 < m_{jet} < 100$ GeV/c2

  ▸ 2 subjets

  ▸ Mass drop : $\mu = \dfrac{mass_{subjet}}{mass_{jet}}$

By looking into semileptonic events we get the subjet energy scale
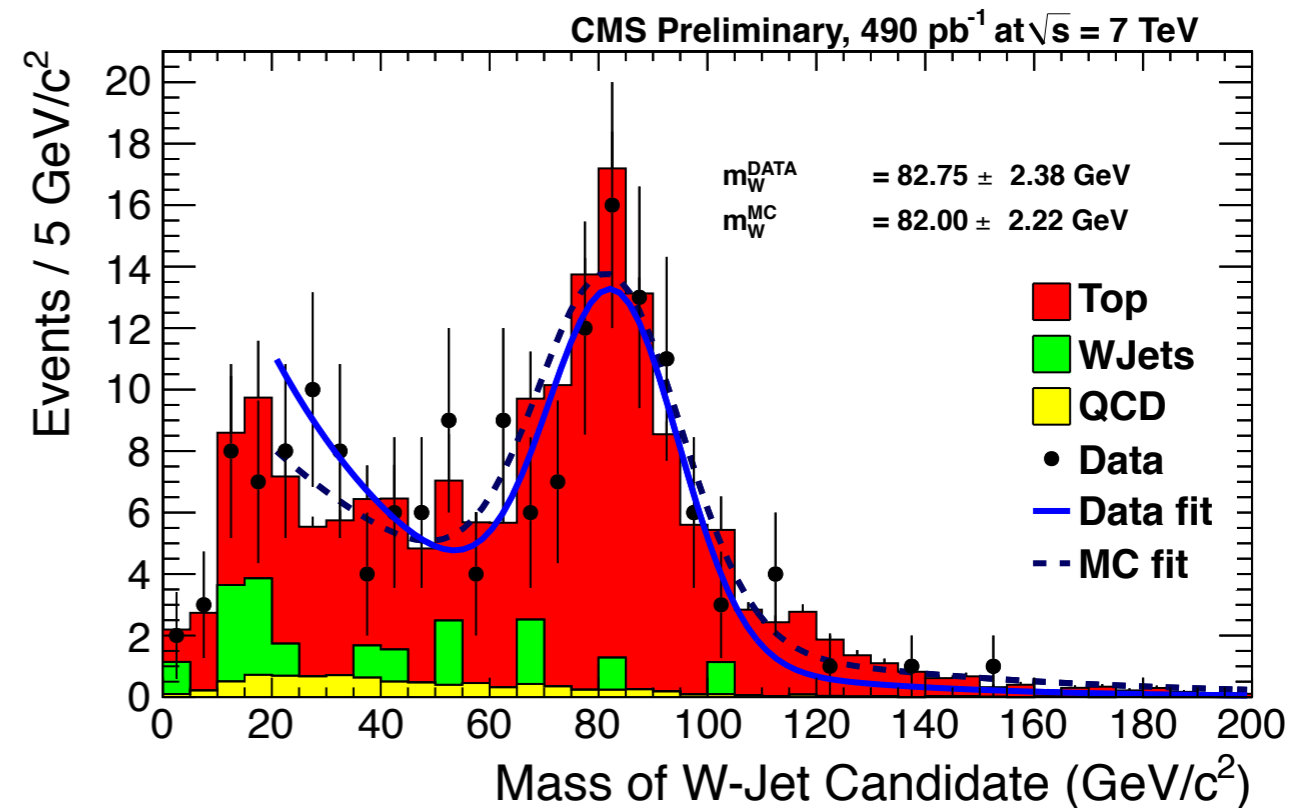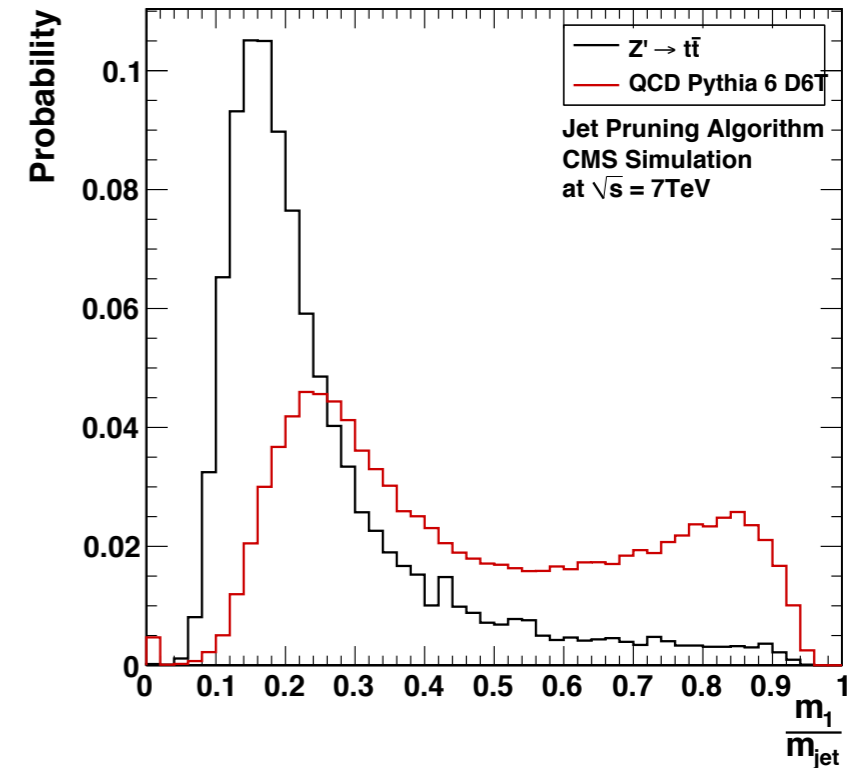
All-hadronic Search strategy

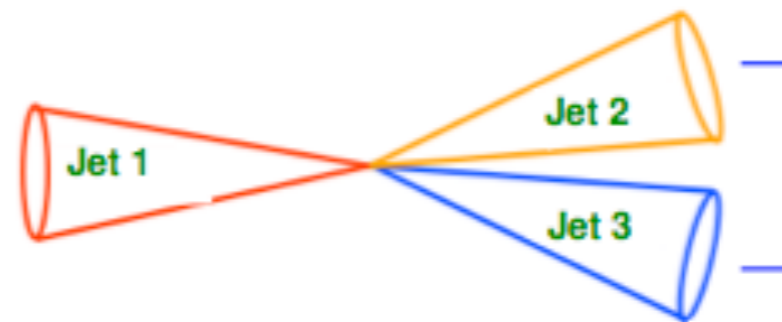- Type 1 : Fully merged jets using top tagging

- Type 2 : Partially merged using W tagging

Type 1 + Type 1

Jet 1   Jet 2

Type 1 + Type 2

Jet 1   Jet 2

Jet 3

- 2 jets, $p_T > 350$ GeV
- Both jets are "top tagged"
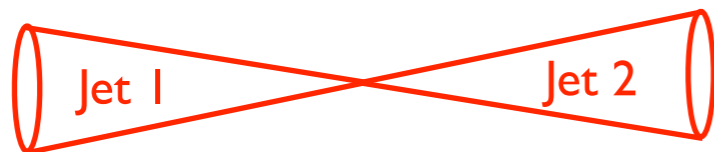
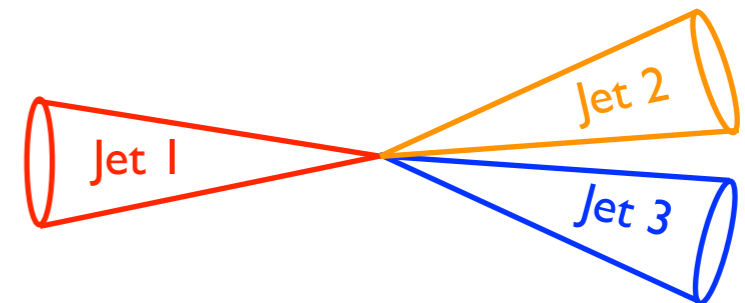- Not type 1 + 1
- Jet 1 pT > 350 GeV, top tagged
- Jet 2 pT > 200 GeV, W tagged
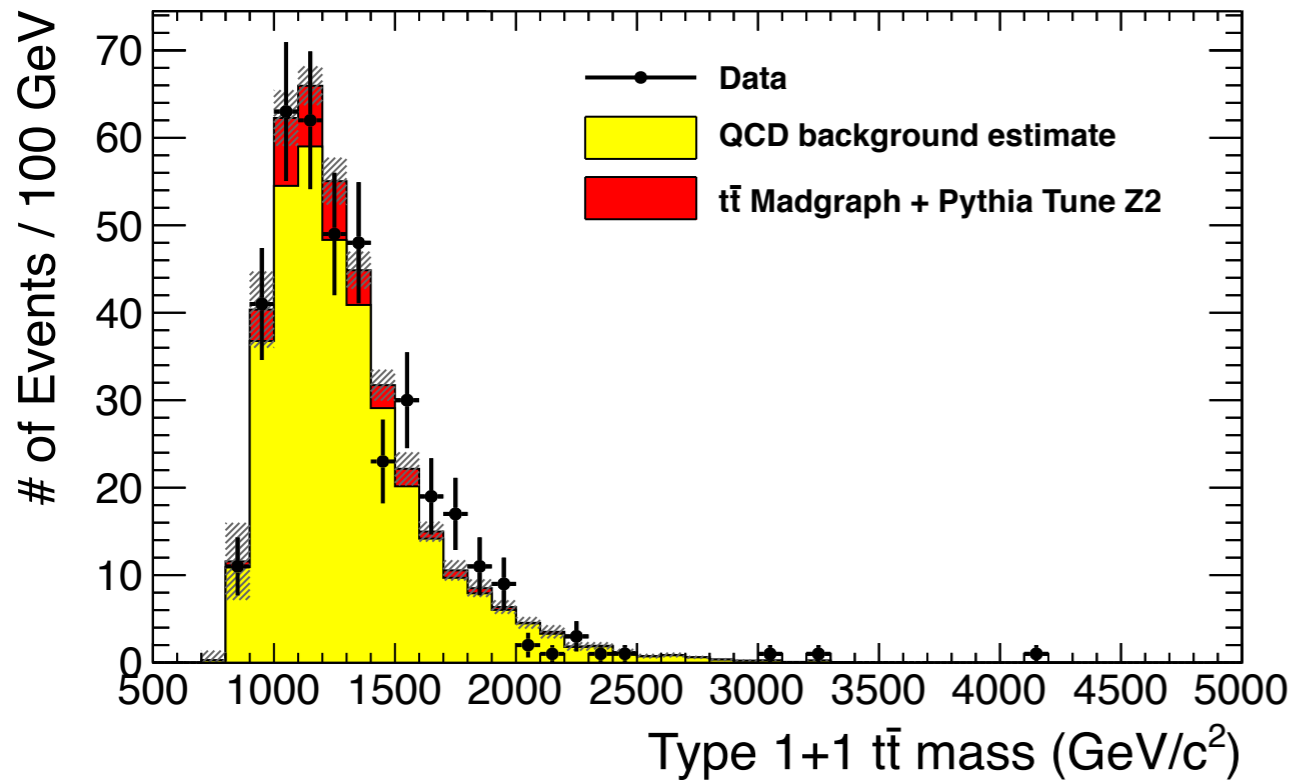- Jet 3 pT > 30 GeV, form top mass with jet 2

Mtt data + bkg distributions

Search results

CMS Preliminary, 886 pb^{-1} at $\sqrt{s}$ = 7 TeV

Combined type 1+1 & 1+2
- Observed (95% CL)
- Expected (95% CL)
- $\pm 1\sigma$ Expected
- $\pm 2\sigma$ Expected
- KK Gluon, Agashe et al
- Topcolor Z', 3.0% width, Harris et al
- Topcolor Z', 1.2% width, Harris et al

Upper Limit $\sigma_{Z'} \times BR(Z' \to t\bar{t})$ (pb)

$t\bar{t}$ Invariant Mass (TeV/c^2)
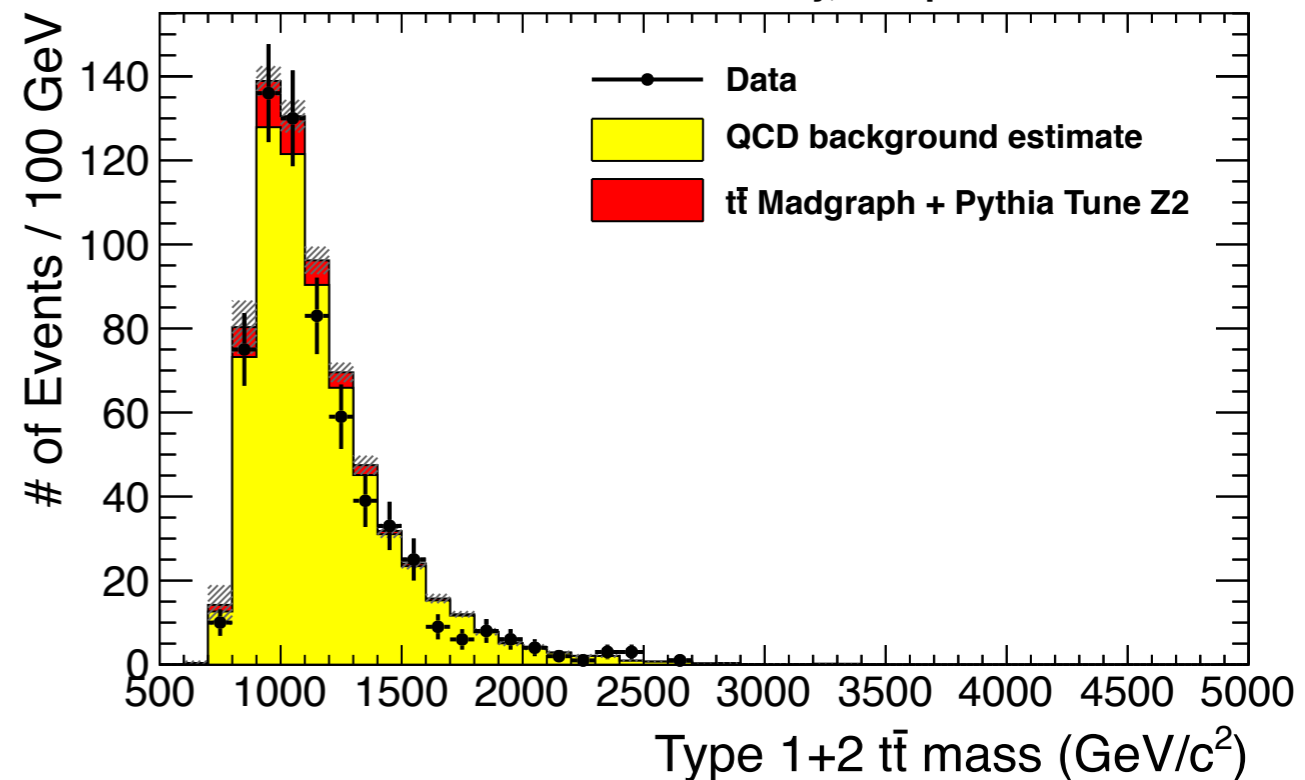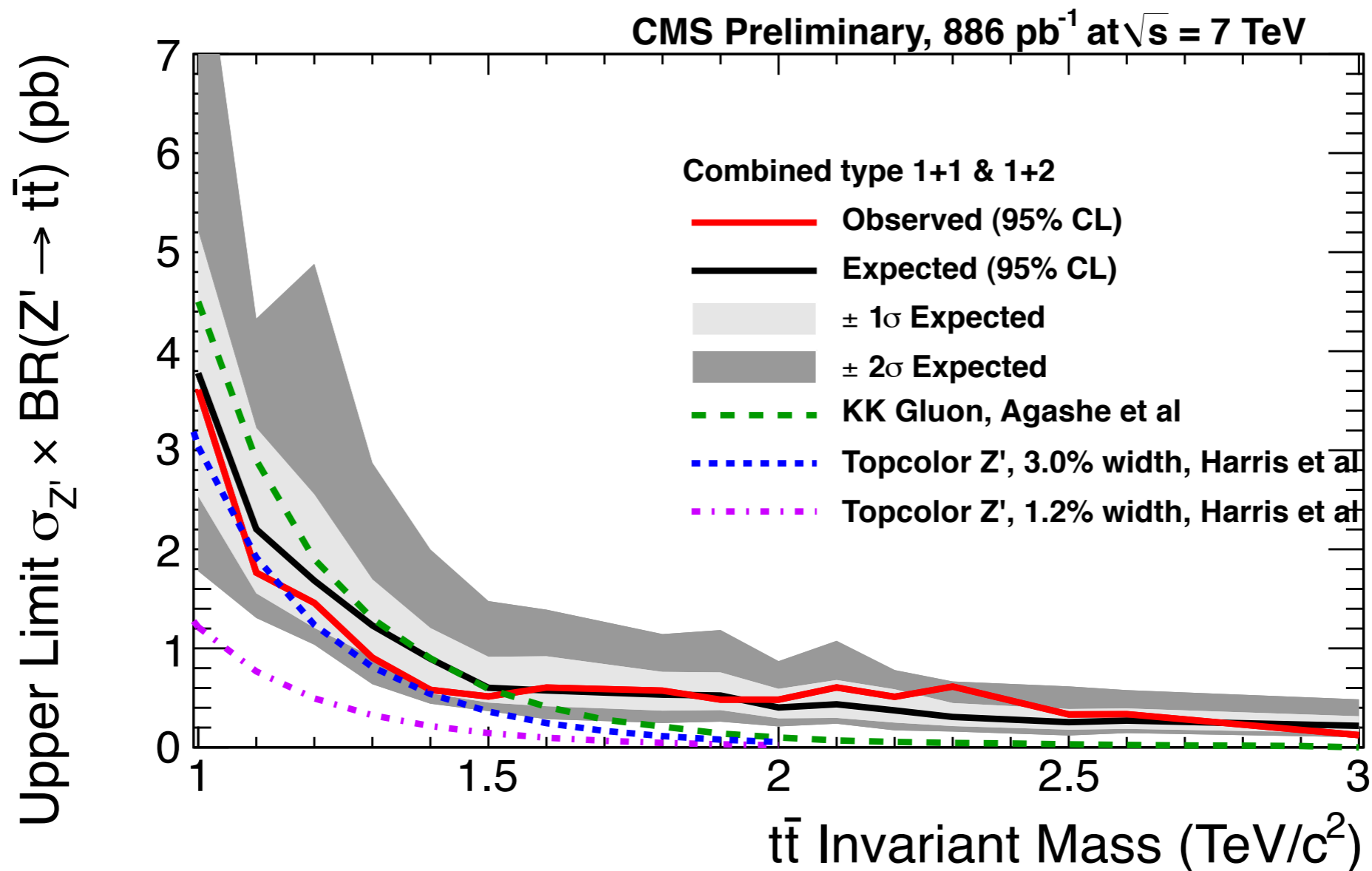
- Perform counting experiment in signal windows then interpolate

- Exclude KK gluons with mass in range 1.0-1.5 TeV

- Set subpicobarn limits on $\sigma_{Z'} x BR(Z' \to tt)$ Topcolor Z'

CMS PAS EXO-11-006

μ+jets search

- A similar search but now with one top decaying hadronically and the other leptonically

- Focuses on heavy resonances resulting in energetic top quarks whose decay products are collimated.
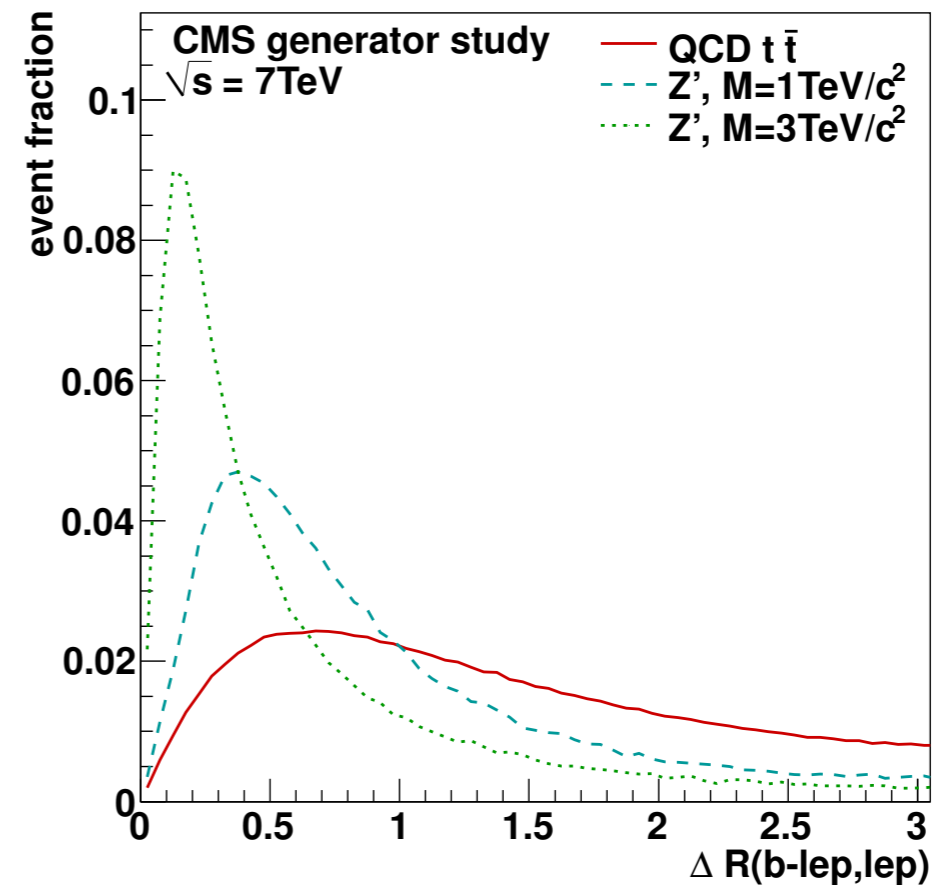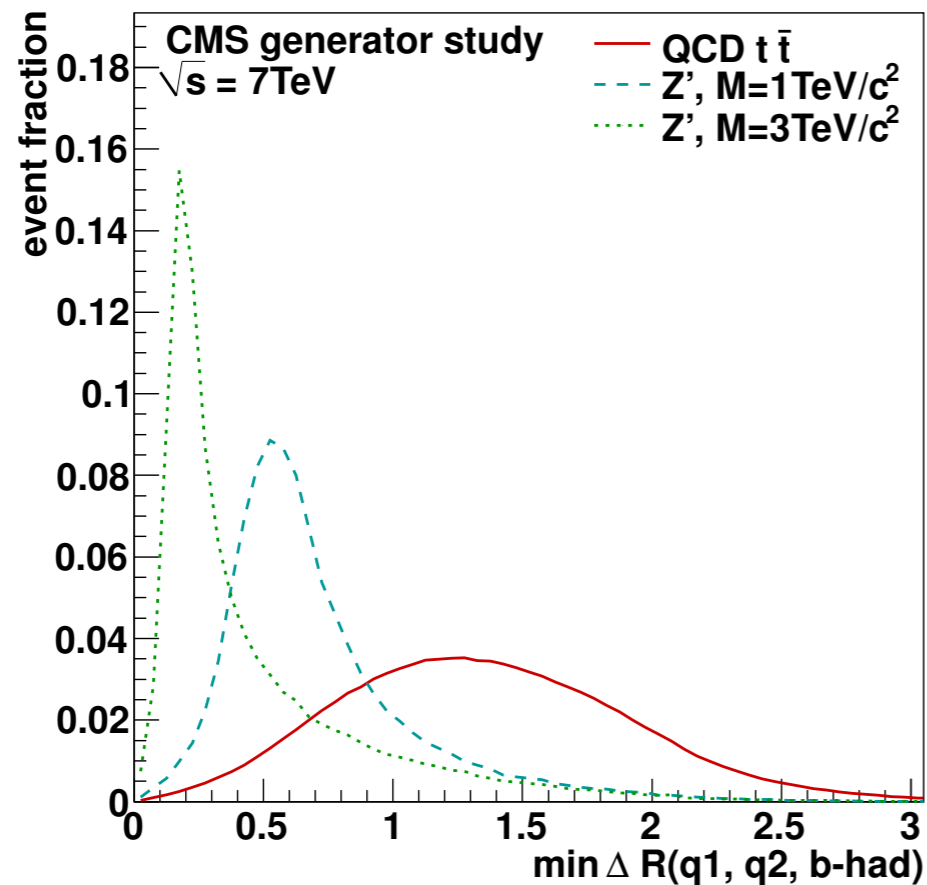
μ+jets search strategy

- Muon isolation: 2D-cut (ΔR or pTrel)
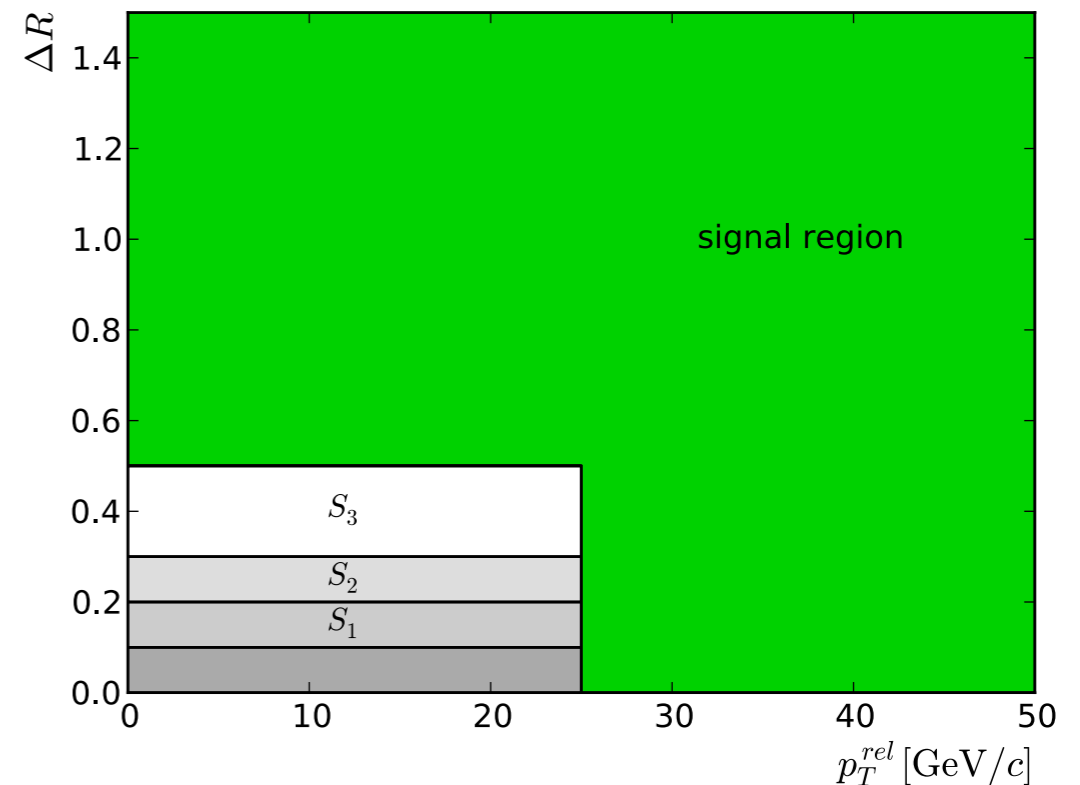
- We test a list of different jet-to-quark assignments and possible neutrino p_z values

- Keep the one that minimizes

$$\Delta R_{\mathrm{sum}} = \Delta R(b_\mu, t_\mu) + \Delta R(\nu, t_\mu) + \Delta R(\mu, t_\mu)$$

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Results

- Mtt distributions used for the search

- We used Z' samples for masses 0.75, 1.0, 1.25, 1.5, 2.0 and 3.0 TeV/c2 to derive the limits.

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Search Results

CMS preliminary, $\sqrt{s} = 7$ TeV

$L = 1.14$ fb^{-1}

- median expected limit
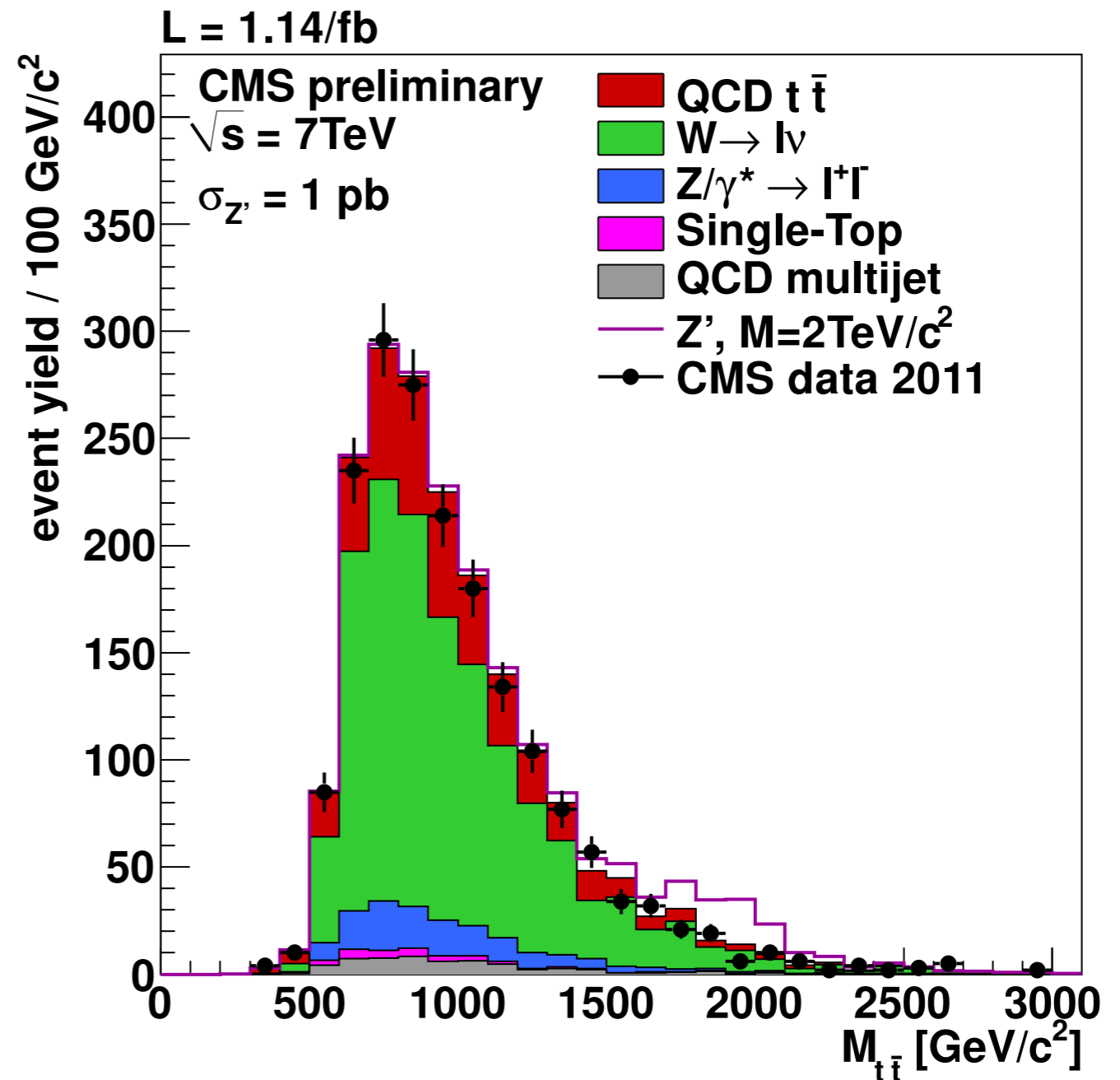- observed limit (95% C.L.)
- central 1σ expected limit
- central 2σ expected limit
- Topcolor Z', 3.0% width, Harris et al.
- Topcolor Z', 1.2% width, Harris et al.

y-axis: limit on $\sigma(pp \to Z' \to t\bar{t})$ [pb]

x-axis: $M_{Z'}$ [GeV/c^2]
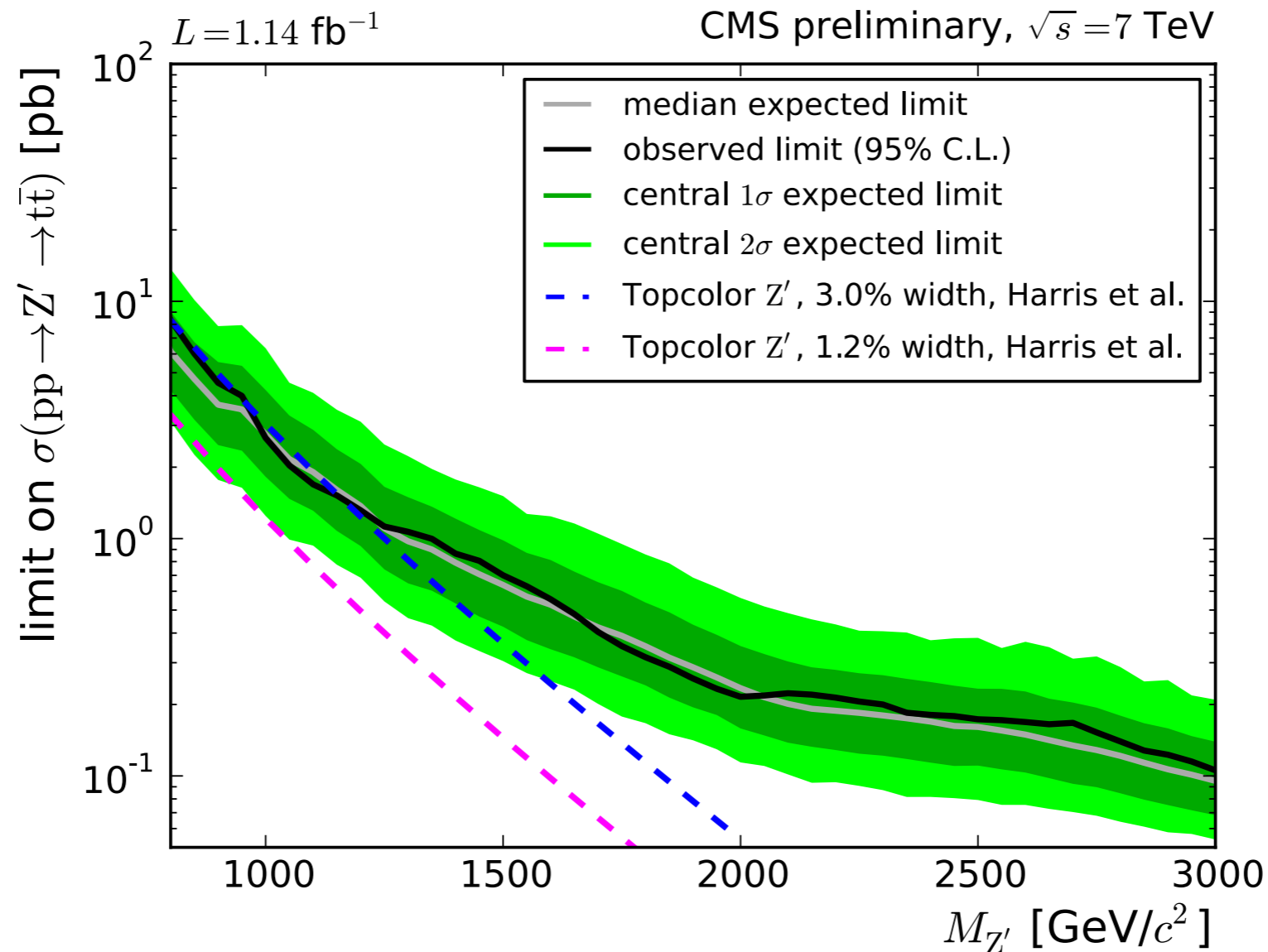
- Expected and observed exclusion limits, excluding Z' with 3% width in the mass regions 805 < mZ' < 935 GeV/c2 and 960 < mZ' < 1060 GeV/c2

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CMS PAS EXO-11-055

Inclusive search for a fourth generation of quarks

- A fourth generation of quarks is possible but constrained by electroweak precision measurements.

- This can be potentially the simplest extension of the standard model.

- An inclusive b' and t' search is proposed assuming degenerate masses for up and down-type quarks, hence $m_{t'} = m_{b'} = m_{q'}$

- And mass splitting $|m_{b'} - m_{t'}| < m_W$

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An inclusive search

- If we assume the branching fractions for the fourth generation quarks to be 100%

$$t' \to bW \qquad b' \to tW$$

- We end up with 4 final state topologies

$$t'\overline{b} \to bWbW$$
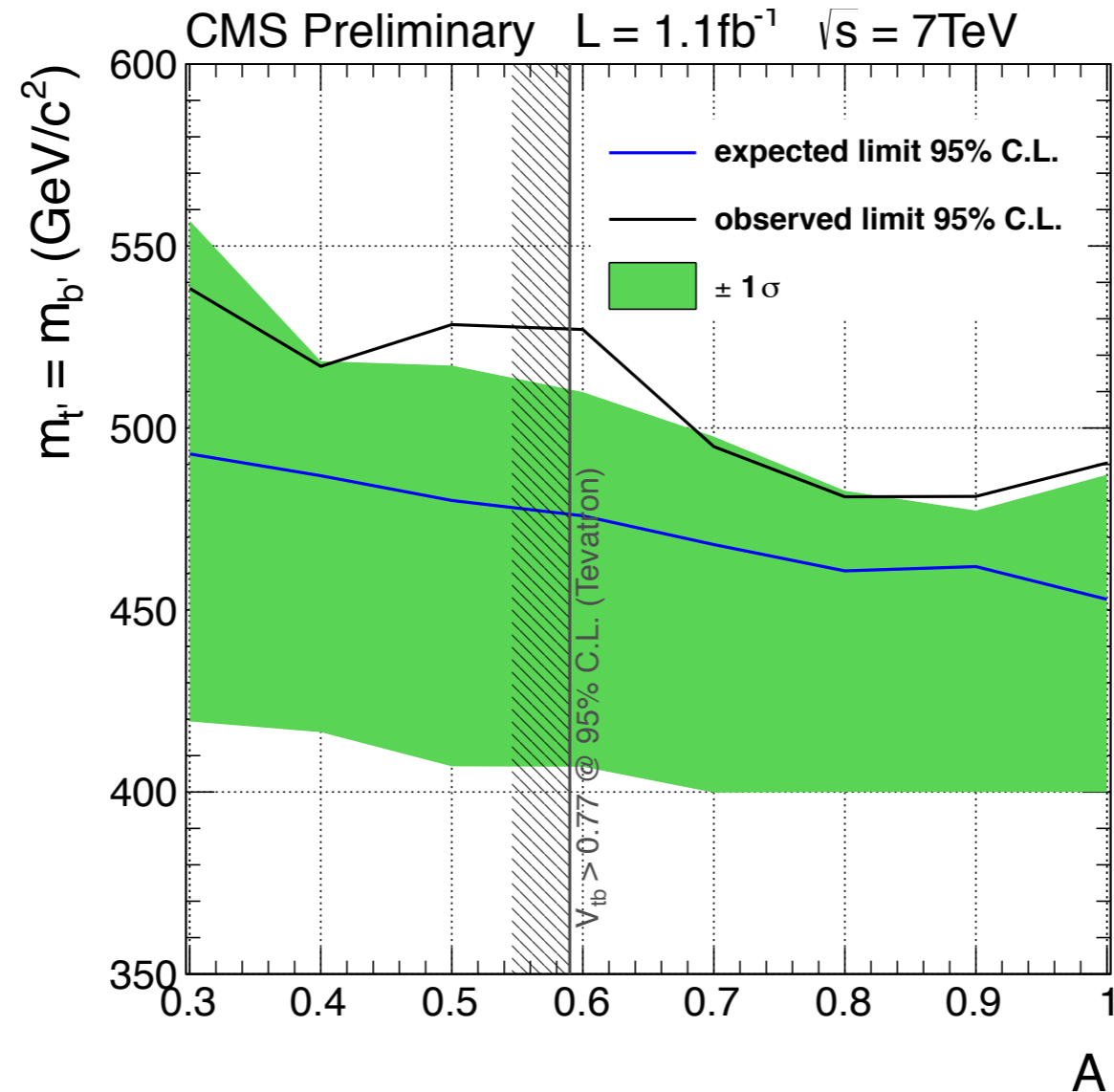$$b'\overline{t} \to tWbW \to bWWbW$$
$$t'\overline{t}' \to bWbW$$
$$b'\overline{b}' \to tWtW \to bWWbWW$$

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Results

CMS PAS
EXO-11-054

CMS Preliminary   L = 1.1fb^{-1} $\sqrt{s}$ = 7TeV

- expected limit 95% C.L.
- observed limit 95% C.L.
- $\pm 1\sigma$

m$_{t'}$ = m$_{b'}$ (GeV/c^2)

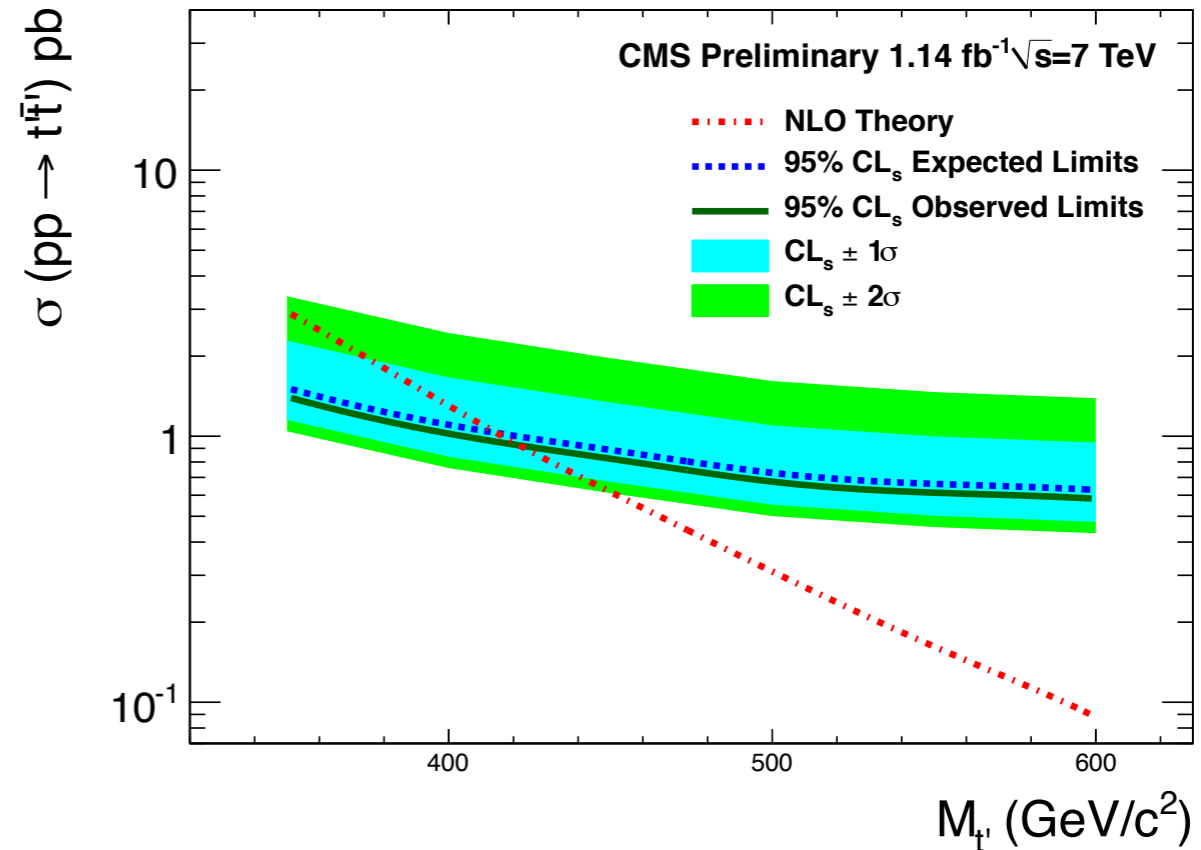V$_{tb}$ > 0.77 @ 95% C.L. (Tevatron)

A

- **Limits as a function of CKM4 parameter**
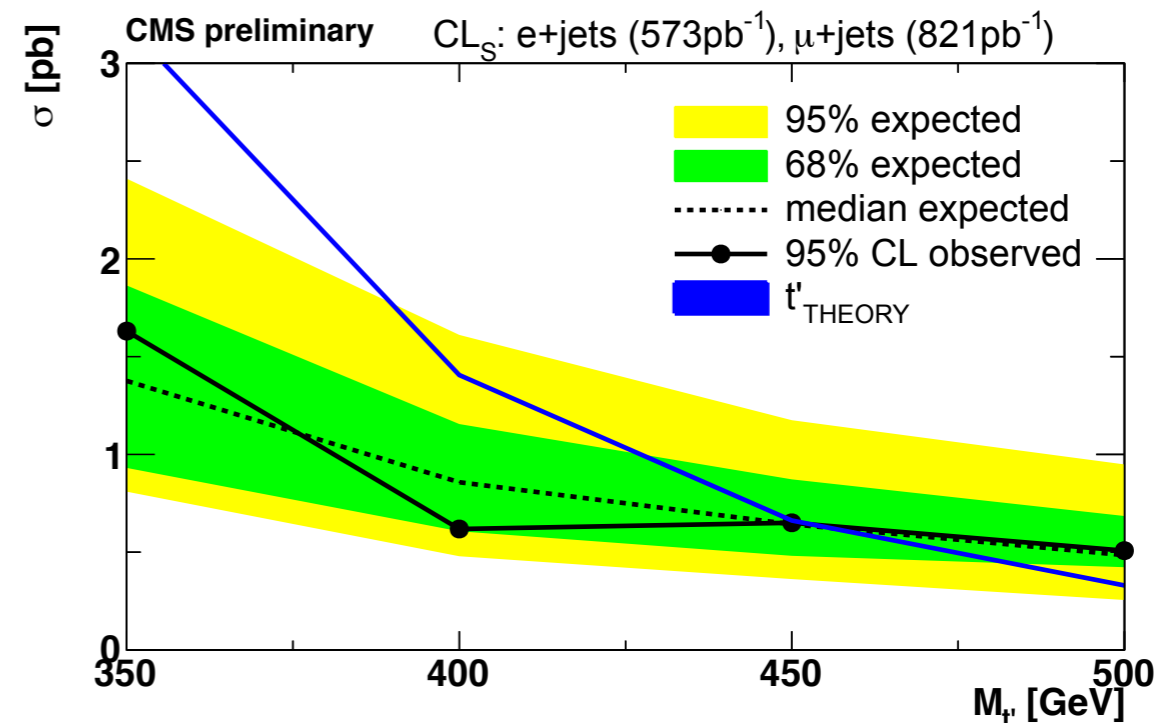
$$A = V_{tb}^2 = V_{t'b'}^2 = 1 - V_{t'b}^2 = 1 - V_{tb'}^2$$

Parameter values below the solid black line are excluded

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4th Generation t'
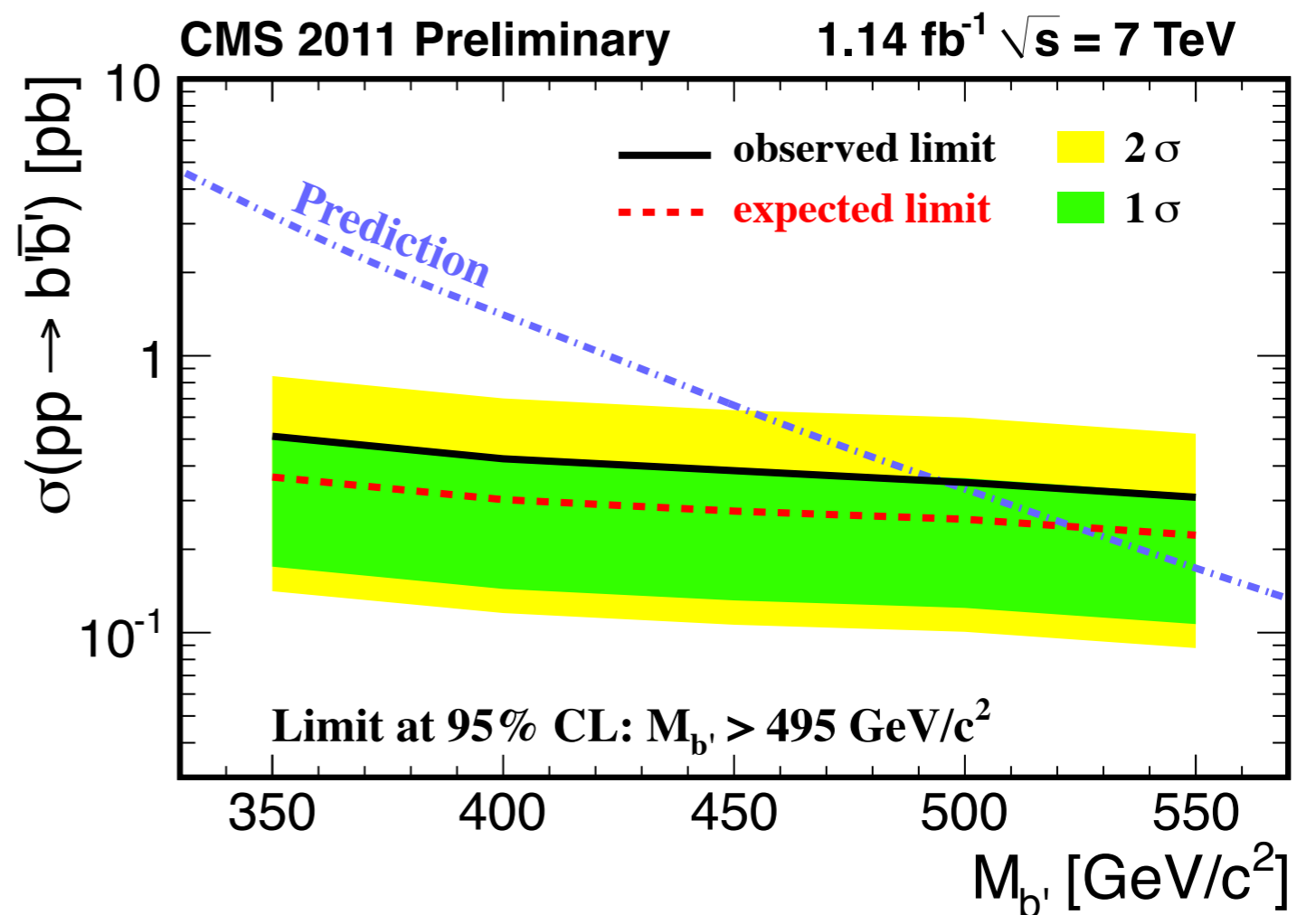
- **dileptons excluding up-type quark mass < 422 GeV/c2**

CMS Preliminary 1.14 fb^{-1} $\sqrt{s}$=7 TeV

- NLO Theory
- 95% CL$_s$ Expected Limits
- 95% CL$_s$ Observed Limits
- CL$_s$ ± 1σ
- CL$_s$ ± 2σ

σ (pp → t$\bar{\text{t}}$') pb

M$_{t'}$ (GeV/c^2)

- **lepton+jets excluding up-type quark mass < 450 GeV/c2**

CMS preliminary   CL$_S$: e+jets (573pb^{-1}), μ+jets (821pb^{-1})

- 95% expected
- 68% expected
- median expected
- 95% CL observed
- t'$_{THEORY}$

σ [pb]

M$_{t'}$ [GeV]

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4th Generation b'

- Excluded down-type quark massb'<495 GeV with 95% CL

CMS 2011 Preliminary   1.14 fb^{-1} $\sqrt{s}$ = 7 TeV

$\sigma(pp \rightarrow b'\bar{b}')$ [pb]

observed limit — 2σ
expected limit — 1σ

Prediction

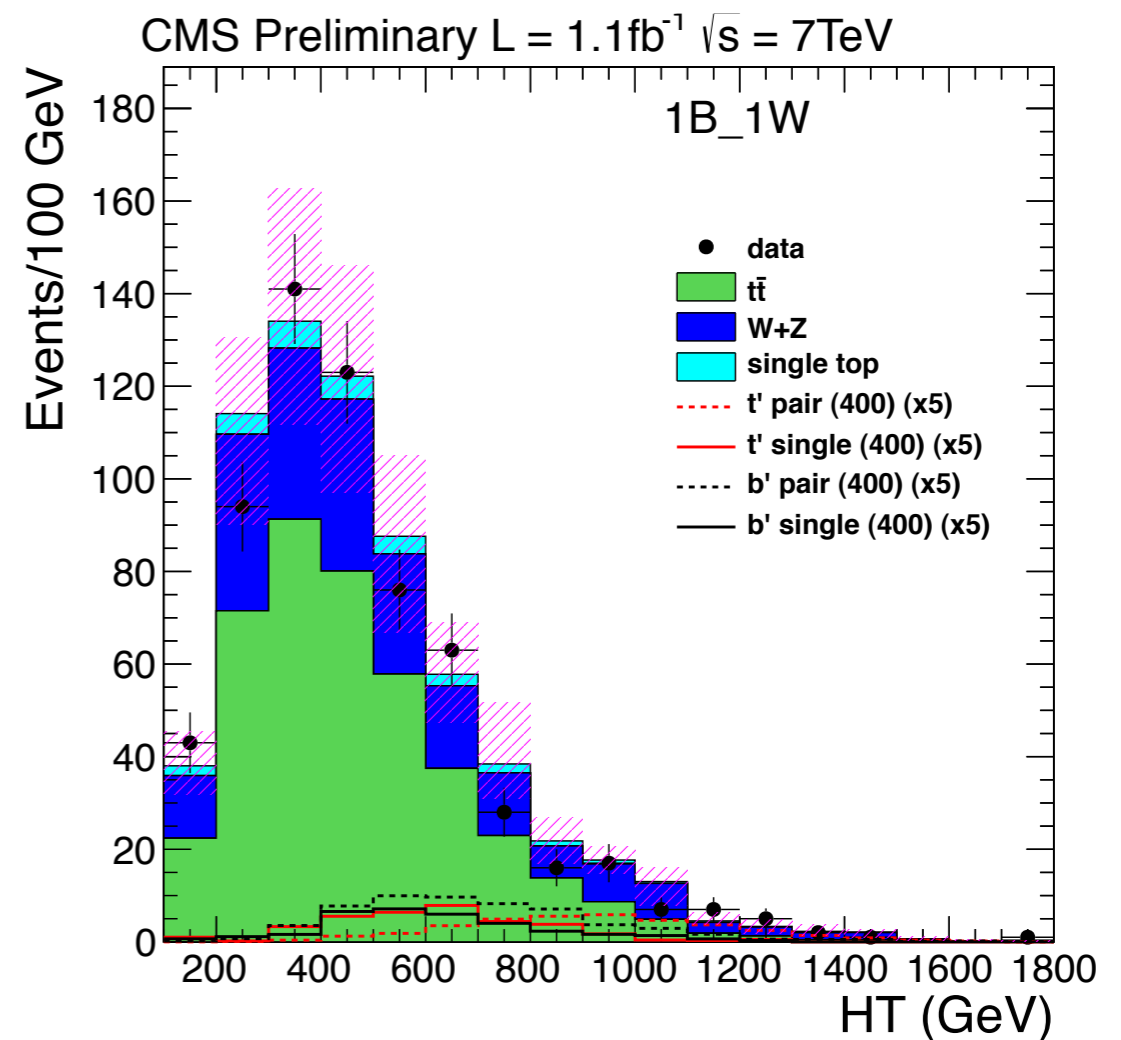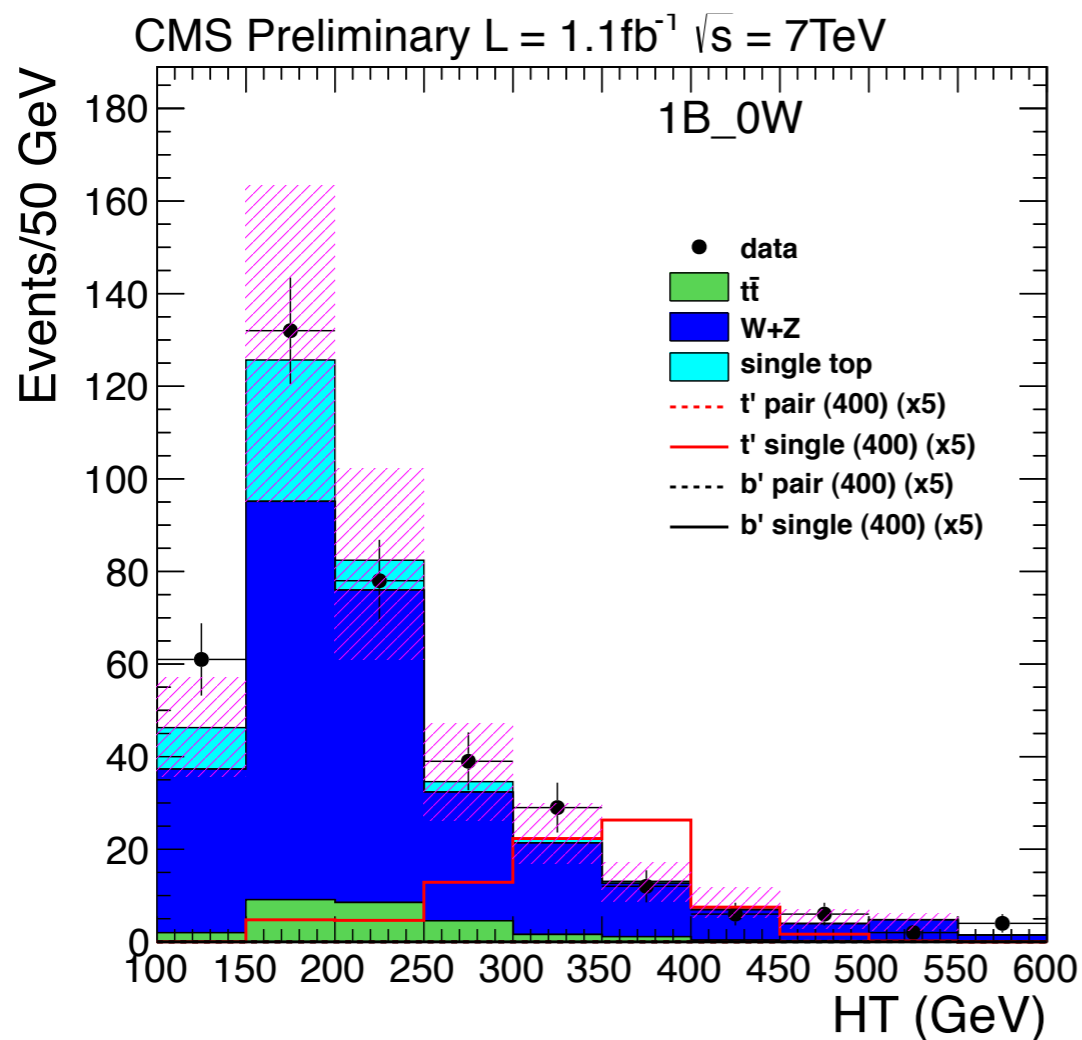Limit at 95% CL: $M_{b'}$ > 495 GeV/c^2

$M_{b'}$ [GeV/c^2]

Conclusions

- The exclusion of Z' reached already the TeV-scale

- The exclusion of fourth generation quark masses has not reached the TeV scale

- There is certainly plenty of activity on these subjects, the search is still on going.

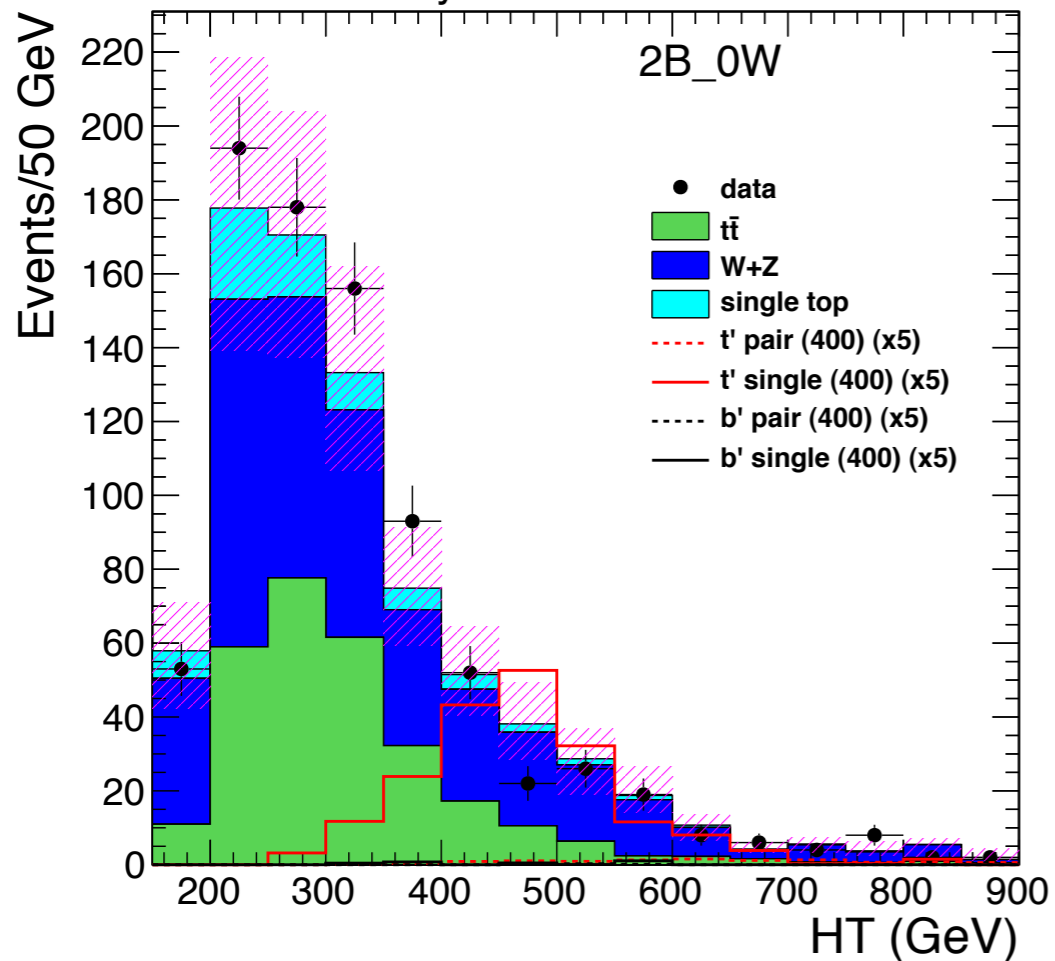- Analyses including the full 2011 are on their way, don't miss the news.

Backup slides

Divided into 6 samples

- The search is done dividing the sample into 6 different samples, like 6 analysis in one depending on the number of b jets and Ws

Thursday, December 8, 2011