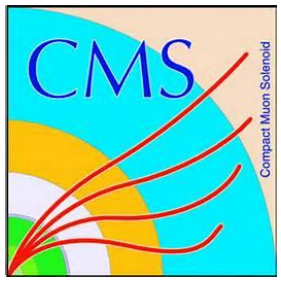


New Physics Seaches with HL-HLC Upgrade

Sadia Khalil
(on behalf of CMS Collaboration)

ECFA Preparatory Meeting

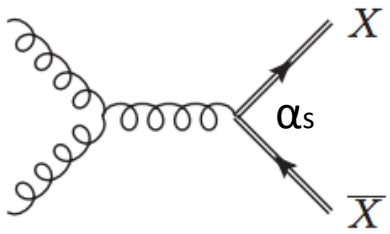
Sep 15th, 2016

Introduction

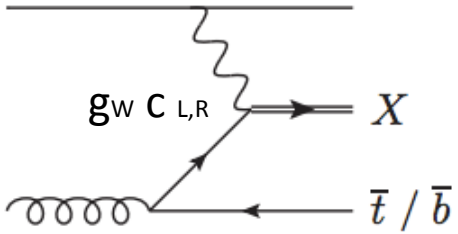
- Pair and single production of vector-like quarks (non-chiral matter)
  - Both left and right couplings to electroweak bosons
  - Preference of left or right couplings depend on the quark multiplet

arXiv:1306.0572

Singlets	Doublets	Triplets
$(T)(B)$	$\begin{pmatrix} X \\ T \end{pmatrix}\begin{pmatrix} T \\ B \end{pmatrix}\begin{pmatrix} B \\ Y \end{pmatrix}$	$\begin{pmatrix} X \\ T \\ B \end{pmatrix}\begin{pmatrix} T \\ B \\ Y \end{pmatrix}$
Left	Right	Left



Strong production, $\sigma = \sigma(M_X)$



Electroweak production, $\sigma = \sigma(M_X, c)$

  - Expected Limits on VLQ x-section vs mass (Pair), couplings vs mass (Single)

- Projections of heavy new resoances of W´ → tb and Z´ → tt from 13 TeV to 14 TeV
  - W´: $m(v_R) > m(W')$, $m(v_R) << m(W')$
  - Z´ : Narrow Z´ (1% width), Wide Z´ (RS Gluon)

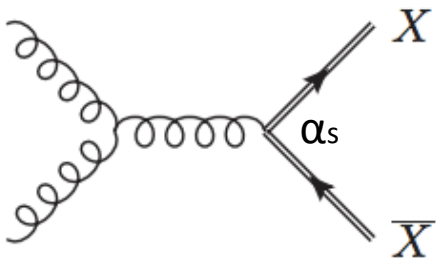
Pair Production of Vector-like $T_{2/3}$ quark

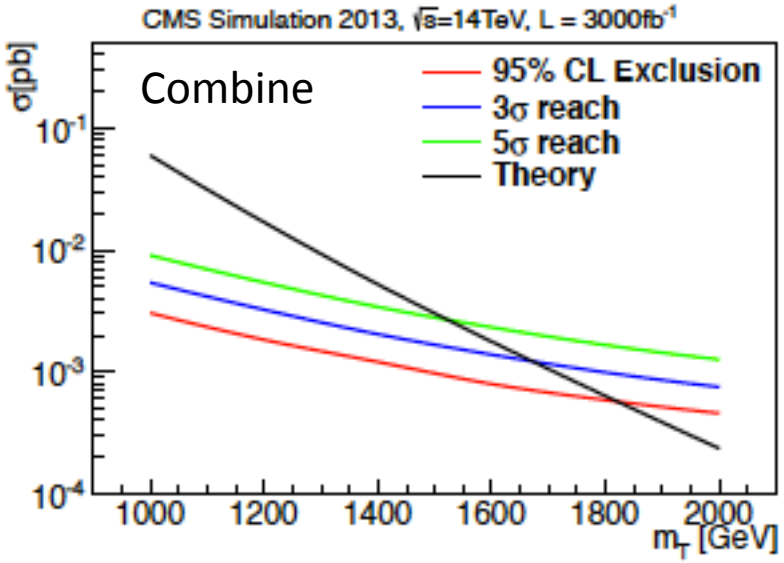
Final state

L+jets: {e/μ} ν + nJets => 8 categories:
1 lep+(0, ≥1) Wjet + (0, 1, 2, ≥3) b-jets

Multileptons+jets: => 12 categories:
(ee, eμ, μμ) on/off Z + (μμμ, eeμ, eee)+nJets

$T_{2/3} \rightarrow bW, tZ, tH$



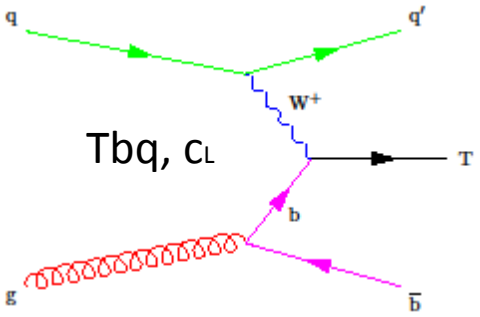


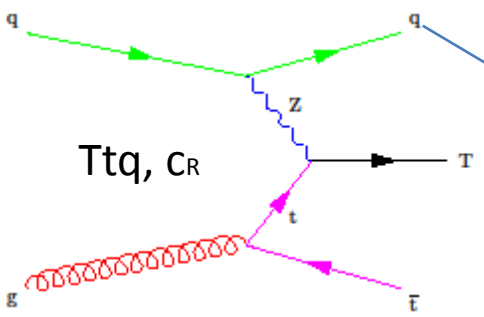
Results: Considering the benchmark point with BR of bW, tZ, tH = 50 : 25 : 25 %

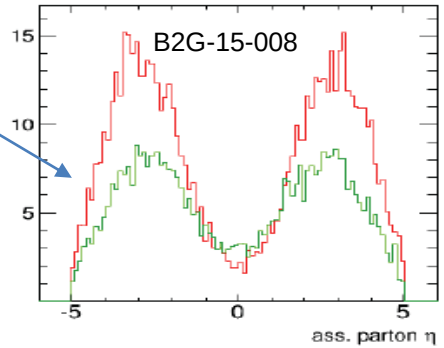
- 3 σ reach: 1.65 TeV, 5 σ reach: 1.48 TeV
- The 95% C.L. exclusion reach is expected to be around 1.85 TeV

New

Single Vector-Like Production





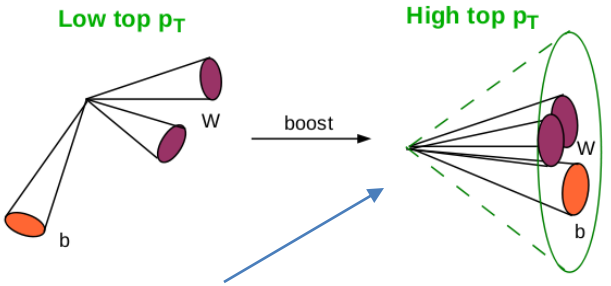


- The dominant production is through t-channel via W or Z exchange
- Production cross section is proportional to square of the coupling => mixing angle

- **Signal samples** are produced using MadGraph+Pythia up to 1 extra parton and with narrow width approximation, and are simulated using Delphes FastSim package (new CMS tracker geometry with $|\eta| < 4$ and PU = 200)
- M (T) : 1, 1.5, 2, 2.5, and 3 TeV; **Decay:** $T \rightarrow t\,H \rightarrow (\iota\nu b)\,(bb)$

Single VLQ: T → t H (l+jets channel)

- Backgrounds:
  - tt+jets, V+jets (normalized to NNLO x-sections)
  - single top, diboson (normalized to NLO x-sections)

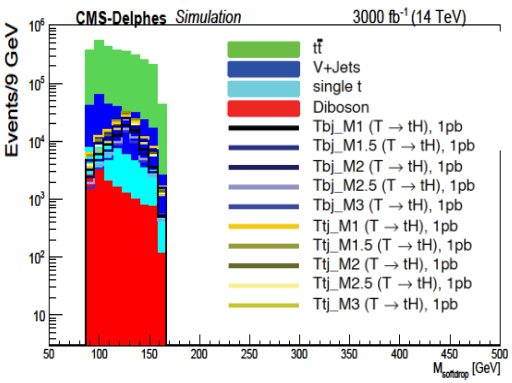


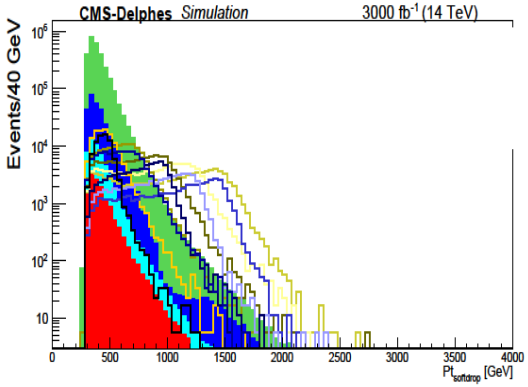
- Event Selection:
  - one tight lepton (e/mu) with pt > 30 GeV, |η| < 4.0
    - No isolation, since leptons are close to b-jets in semileptonic top decays
  - Using PUPPI jet: Jet overlap removal: dR(l,j) > 0.4 and $\Delta p_{T,rel}$ > 40 GeV
    - $\Delta p_{T,rel}$ is the relative p_T of lepton w.r.t the closest jet
  - ≥ 1 forward jet: 2.4 < |η| < 5.0, jet p_T > 30 GeV
  - ≥ 3 central jets: |η| < 2.4; leading (sub-leading) jet p_T > 200 (80) GeV
  - ≥ 1 b-jet with 70% tagging efficiency
  - Missing transverse momentum > 20 GeV (PUPPI MET)

Will check it against QCD MC

T Mass Reconstruction

- Constrain lepton + MET four-momentum to W mass and solve for the neutrino p_z
- Higgs Tagging:
  - AK8 jets $p_T > 300$ GeV, $|\eta| < 2.4$
  - N Subjettiness: $\tau_2/\tau_1 < 0.6$
  - 2 hard softdrop subjets
  - $90 < M_{softdrop} < 160$ GeV
  - $\Delta R(l, ak8jet) > 1.0$

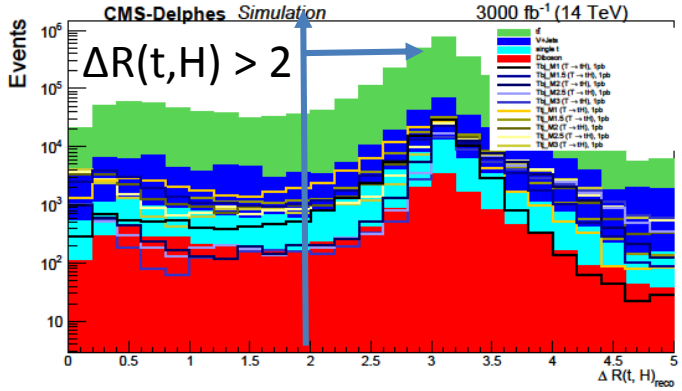


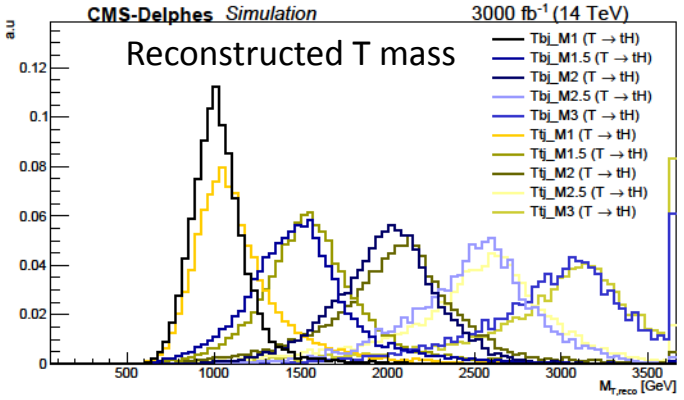


- Permute with up to two AK4jets and minimize a χ^2

$$\chi^2 = \left(\frac{M_{H,MC} - M_{H,rec}}{\sigma_{M_H,MC}}\right)^2 + \left(\frac{M_{t,MC} - M_{t,rec}}{\sigma_{M_t,MC}}\right)^2 + \left(\frac{dR(t,H)_{MC} - dR(t,H)_{rec}}{\sigma_{dR,MC}}\right)^2$$

	mean	width
$M_{H,MC}$	125 GeV	14.5 GeV
$M_{t,MC}$	174 GeV	14.5 GeV
$dR(t,H)_{MC}$	3.15	0.098 * 2



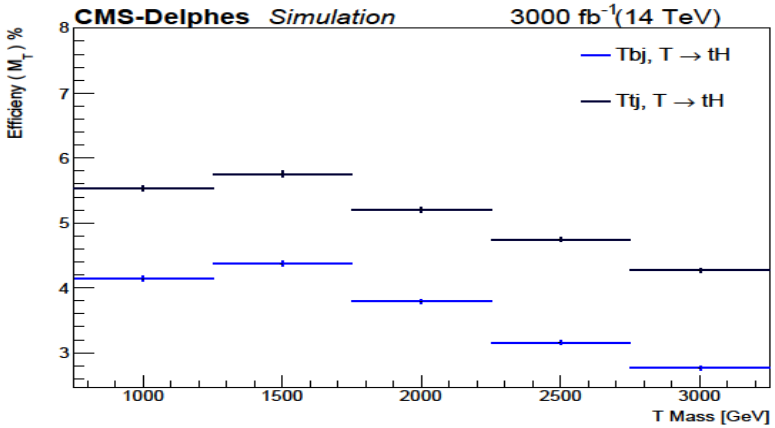


Single VLQ: T → t H (l+jets channel)

Event counts

Sample	Events
$t\bar{t}$+jets	2169581.23 ± 16564.94
V+jets	202116.11 ± 7965.45
single top	32175.97 ± 596.04
Diboson	10896.90 ± 200.73
Total Bkg	2414770.22 ± 18391.33

- Signal efficiencies: 2 to 3 × w.r.t Run 2



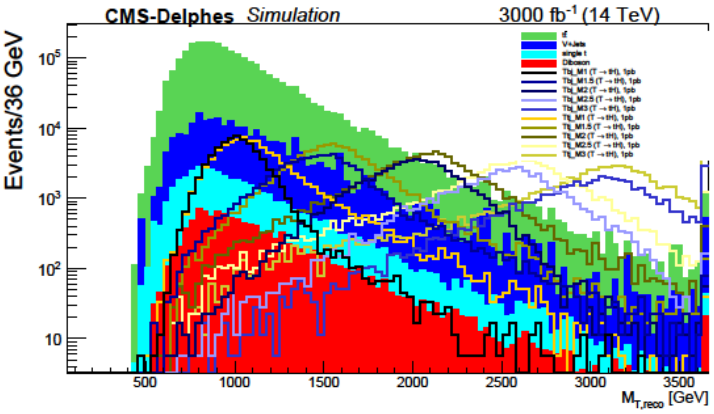
Systematic Uncertainties

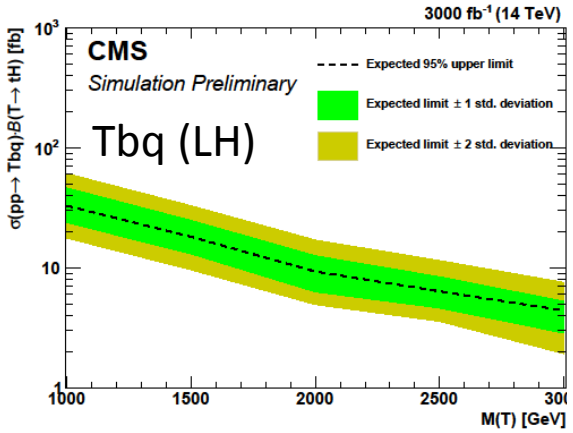
Source	Uncertainty (%)
Luminosity	1.5
$t\bar{t}$ and single top quark normalization	16.0
V+jet and diboson normalization	20.0
b-tagging	2.7
Lepton identification	1.0
Trigger efficiency	1.0
Isolation/QCD estimation	3.0
Jet energy correction	3.8
Jet energy resoloution	1.0

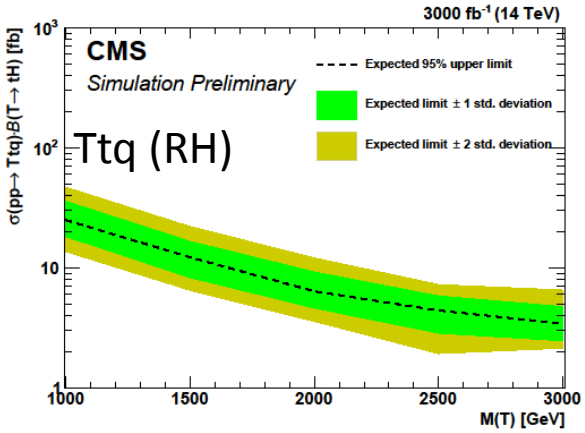
To be updated

Results

Using the reconstructed mass of T, a binned likelihood fit is performed using Bayesian statistics to set limits at 95% CL on the x-section times BR







To do:

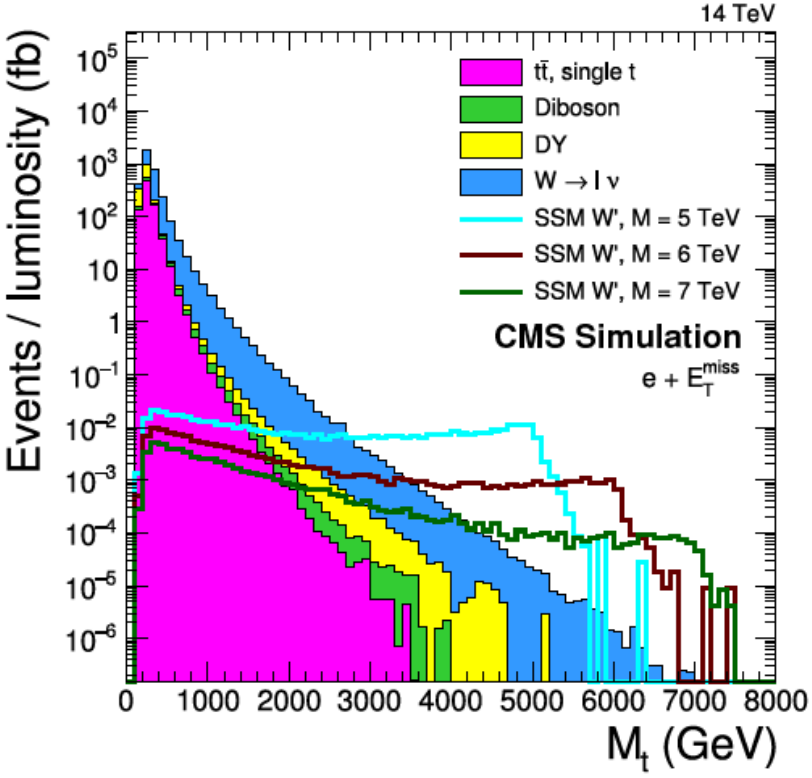
- Compare the sensitivity w.r.t the projection of Run2 analyses
- Compare with the theory model with narrow width approximation

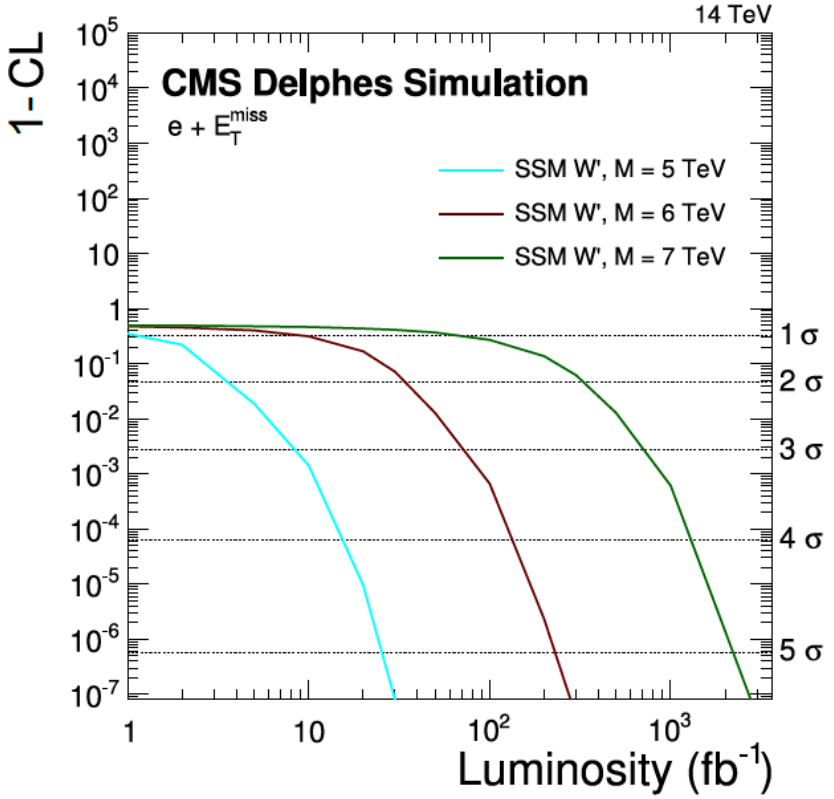
Mass (GeV)	Expected cross section upper limit (fb)	
	Tbq (LH)	Ttq(RH)
1000	32.7	24.9
1500	18.1	12.2
2000	9.28	6.35
2500	6.35	4.39
3000	4.39	3.42

W′→ lν projected DISCOVERY reach

Electron channel with good resolution at very high mass and rather flat resolution. Discriminating variable = M_t from (e, MET)

Detector simulation done with DELPHES, systematics from Run-2 performance.

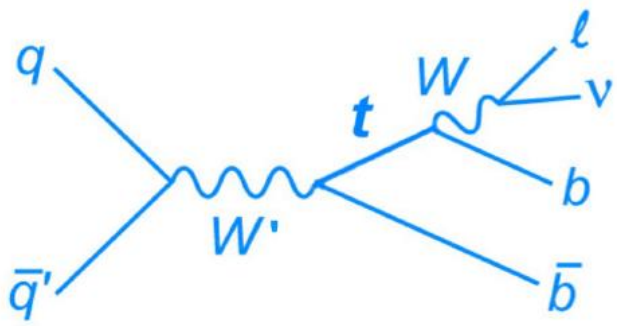




New

W´ → tb Projection from 12.9/fb to 3/ab

W´ → tb search helps probe scenarios which cannot be studied with other channels.
Ex.: $m(\nu_R) > m(W´)$ → forbidden for W´ → lν



Baseline analysis at 13 TeV = B2G-15-004, B2G-16-017

Exclusion limit with 12.9/fb = 2.67 (2.70) TeV obs/exp

Final state
b b {e/μ} ν

Projection technicalities:

- Discriminating variable M(tb) from e/μ+jets and N(b-tags) = 1 or 2
- Background samples simulated at 13 TeV and xsec scaled to 14 TeV
- $W´_R$ signals simulated at 13 TeV with COMPHEP up to 4 TeV mass, xsec from COMPHEP calculation

W´ → tb Systematics

Two scenarios to extrapolate systematics from 12.9/fb to 3000/fb

1) Leave systematics unchanged, simply scale templates with lumi
2) Reduce theory uncertainties by factor 2, others by sqrt(L)

⇒ Small impact on projected exclusion limit: 4(4.2) TeV for case 1(2)

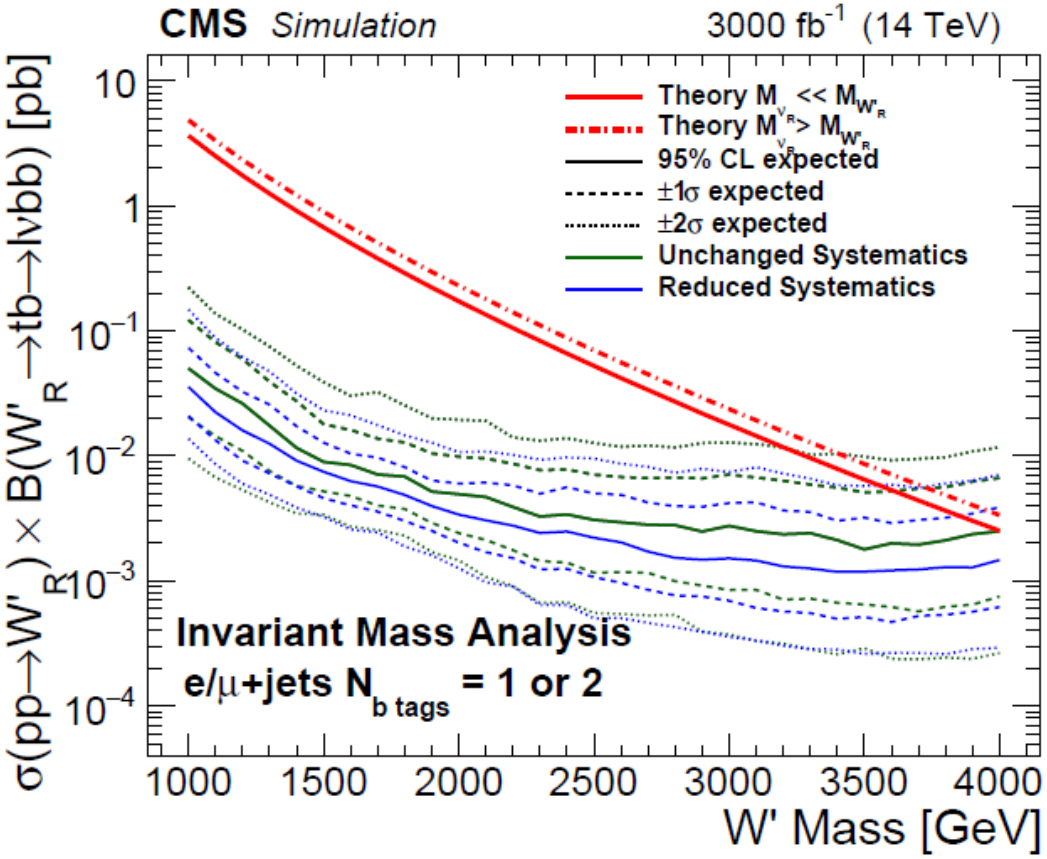
Table 3: Systematic Uncertainties. For shape systematics, the rate uncertainty quoted is approximate.

Source	Rate Uncertainty (Flat)	Rate Uncertainty (Scaled)	Shape?
Luminosity	6.2%	1.5%	No
Trigger Efficiency (e/μ)	2%/5%	1%/1%	No
Lepton ID Efficiency (e/μ)	5%/2%	1%/1%	No
Jet Energy Scale	3.8%	1%	Yes
Jet Energy Resolution	1%	0.07%	Yes
b/c-tagging	2.7%	1%	Yes
light quark mis-tagging	1.2%	1.2%	Yes
W+jets Heavy Flavor Fraction	2.3%	1.1%	Yes
Top p_T Reweighting	18%	6%	Yes
Pileup	1.3%	0.09%	Yes
PDF	6.1%	3%	Yes
Matrix element Q^2 scale	18.9%	9.5	Yes
$t\bar{t}$ Parton matching Q^2 scale	1.7	0.9%	Yes
Theoretical top cross section	15%	7.5%	No
Theoretical bosonic cross section	10%	5%	No

W´→ tb projected exclusion limit

Combination of electron and muon channels and 1,2 b-tags

95% CL exclusion limit



Two scenarios to extrapolate systematics from 12.9/f to 3/ab

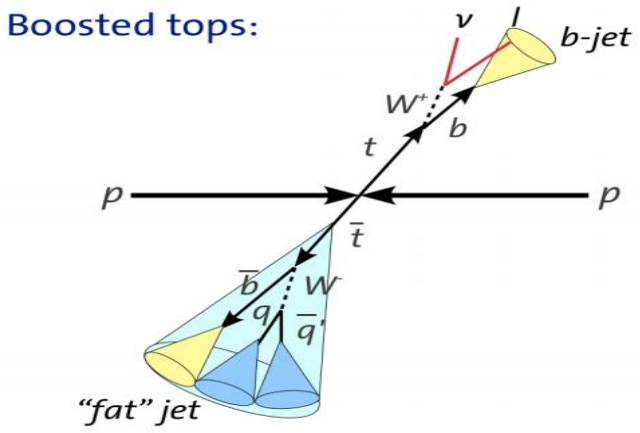
New

Z´ → tt Projection from 2.6/fb to 3/ab

Z´ → ttbar studied in two dinstinct channels distinguished by decay of W (from t→Wb)

- Semileptonic (lepton +jets)
- All-hadronic channel

12 orthogonal categories



Baseline analyses combining semileptonic and hadronic channels at 13 TeV (2015 data with 2.6/fb) = B2G-15-002, B2G-15-003 (Coming soon!)

Projection technicalities:

- Existing signal & bkgr samples scaled to higher L and sqrt(s)
- Discriminating variable is M(tt) reconstructed from final states
- Two scenarios will be considered:
  - Same systematic unceratinties @13 TeV vs reduced uncertainties (to do)

Backup

Single VLQ: T → t H (l+jets channel)