Anomalous Decays of the Top Quark at CMS

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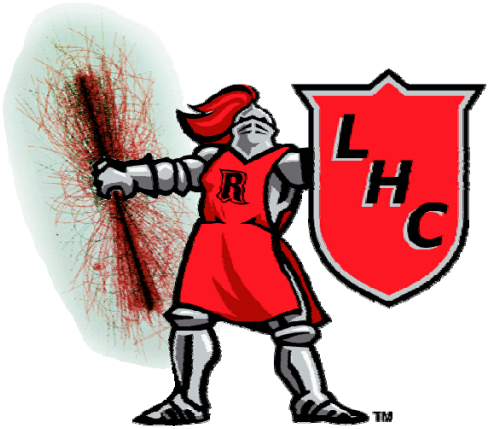
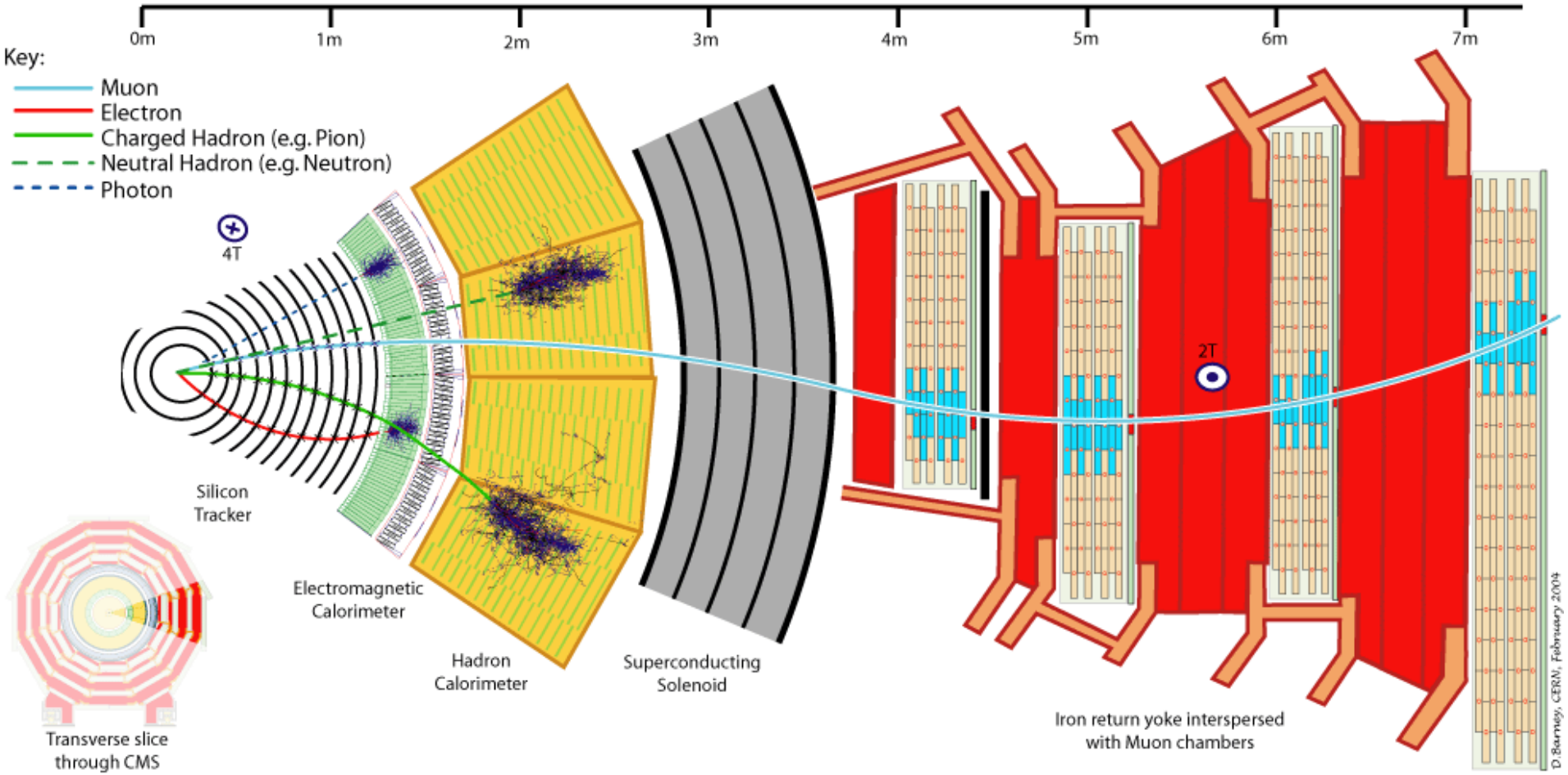


Outline

- Anomalous decays – A different BSM search avenue.
- Top → bW almost 100%.(right?) What else is possible?
  - Top + higgs FCNC production: top → charm+higgs (t→ch) branching ratio using multileptons (new result for SUSY'13)
  - Top + Z FCNC production (also trileptons, resonant)
  - Top → Everything else: top →bW branching ratio Rb
  - Top → μ bc Baryon Number Violation
- No time for:
  - W helicity in top decays
  - ttV production (V=γ,W,Z)(weak couplings)

CMS = Compact MUON solenoid



Top → Charm + Higgs with multileptons (New for SUSY'13)

- Physics motivation: t→ch is FCNC and practically non-existent in SM. New physics if seen. "2HDM-III" 0.1%
- Signature: pp → ttbar → (bW)(ch)
  - Best multilepton sensitivity when higgs → WW

    ttbar → (bW)(ch) → (bW)(cWW) [3W's → 3 leptons]
  - Higgs → ZZ and $\tau\tau$ modes also contribute.
- This t → ch result is *one of the applications* of cms-sus-13-002, which is a (wide) open inclusive multilepton search.
  - Andrea Gozzelino yesterday, Jeff Richman SUSY plenary tomorrow.

CMS Inclusive Multilepton Search, Briefly

CMS SUS-13-002

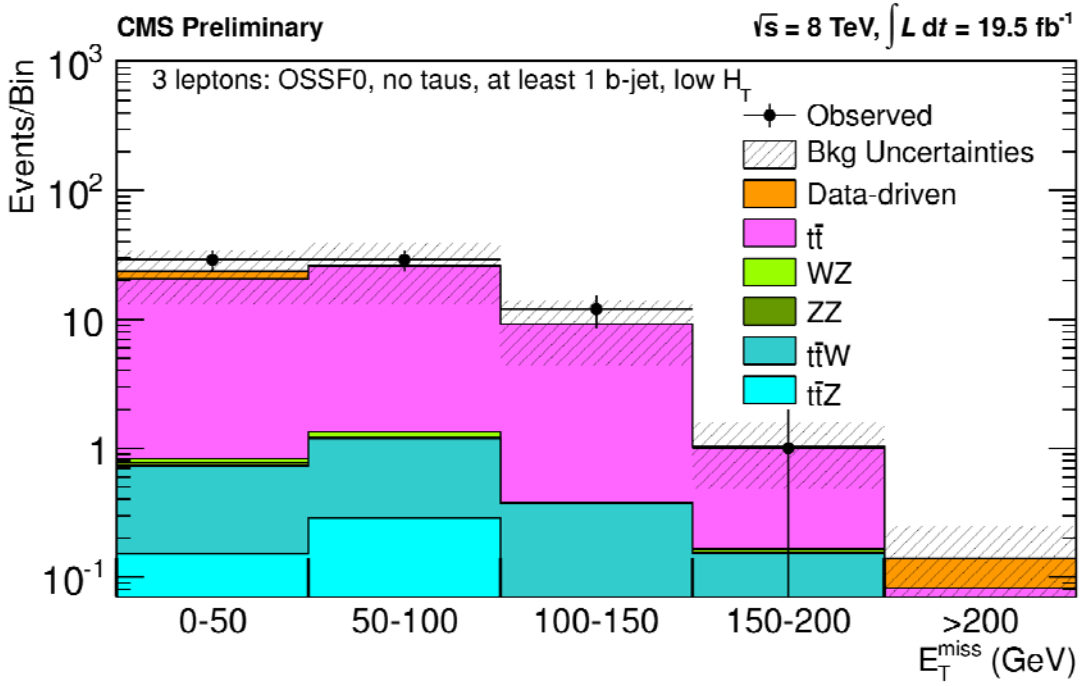
- Three or more e/μ/τ, at least two (e/μ)
- Bin in lepton number, flavor (e/μ vs $\tau_{hadronic}$), b-jets, opposite-sign same-flavor pairs, MET, HT and dilepton pair mass (on-Z etc).
- SM backgrounds using data-driven methods for Z+jets, τ and internal γ conversions, validated MC for ttbar, WZ and rare SM such as ttV.
- Many SUSY interpretations including natural Higgsino, GMSB, SMS and also top → charm+higgs.

Multilepton Search Tables for Three Leptons

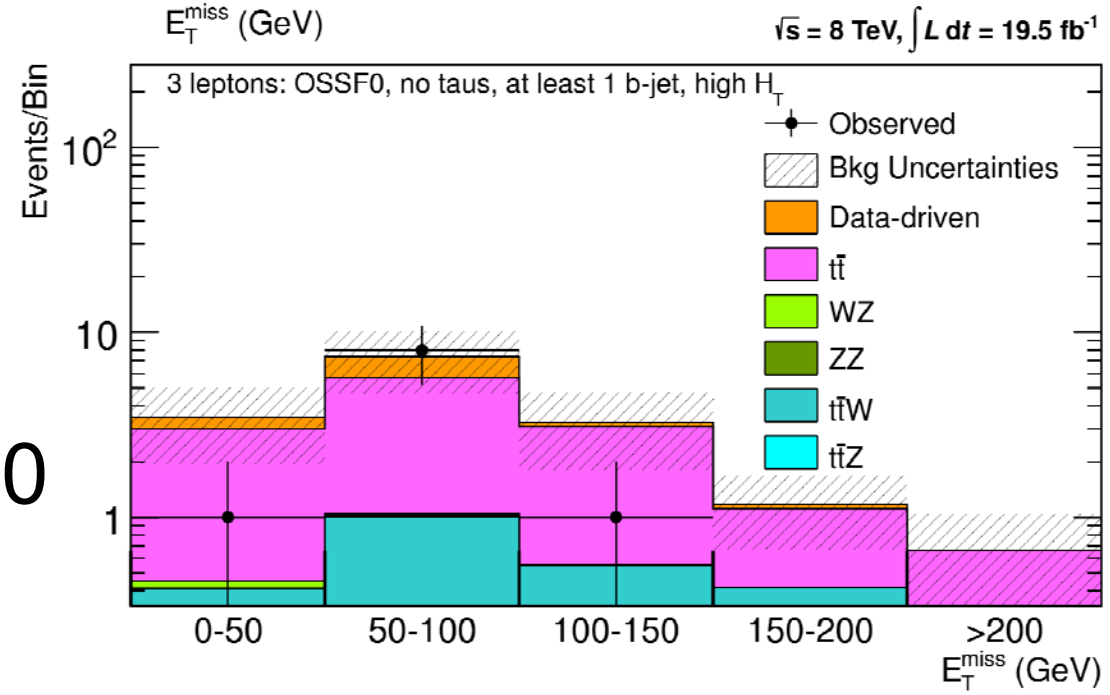
Selection 3 Lepton Results		E_T^{miss}	$N(\tau_h)=0$, $N_{b-jets}=0$ obs	exp	$N(\tau_h)=1$, $N_{b-jets}=0$ obs	exp	$N(\tau_h)=0$, $N_{b-jets}\geq 1$ obs	exp	$N(\tau_h)=1$, $N_{b-jets}\geq 1$ obs	exp
OSSF0 $H_T > 200$	NA	(100,∞)	5	3.7 ± 1.6	35	33 ± 14	1	5.5 ± 2.2	47	61 ± 30
OSSF0 $H_T > 200$	NA	(50,100)	3	3.5 ± 1.4	34	36 ± 16	8	7.7 ± 2.7	82	91 ± 46
OSSF0 $H_T > 200$	NA	(0,50)	4	2.1 ± 0.8	25	25 ± 9.7	1	3.6 ± 1.5	52	59 ± 29
OSSF1 $H_T > 200$	above-Z	(100,∞)	5	3.6 ± 1.2	2	10 ± 4.8	3	4.7 ± 1.6	19	22 ± 11
OSSF1 $H_T > 200$	below-Z	(100,∞)	7	9.7 ± 3.3	18	14 ± 6.4	8	9.1 ± 3.4	21	23 ± 11
OSSF1 $H_T > 200$	on-Z	(100,∞)	39	61 ± 23	17	15 ± 4.9	9	14 ± 4.4	10	12 ± 5.8
OSSF1 $H_T > 200$	above-Z	(50,100)	4	5 ± 1.6	14	11 ± 5.2	6	6.8 ± 2.4	32	30 ± 15
OSSF1 $H_T > 200$	below-Z	(50,100)	10	11 ± 3.8	24	19 ± 6.4	10	9.9 ± 3.7	25	32 ± 16
OSSF1 $H_T > 200$	on-Z	(50,100)	78	80 ± 32	70	50 ± 11	22	22 ± 6.3	36	24 ± 9.8
OSSF1 $H_T > 200$	above-Z	(0,50)	3	7.3 ± 2	41	33 ± 8.7	4	5.3 ± 1.5	15	23 ± 11
OSSF1 $H_T > 200$	below-Z	(0,50)	26	25 ± 6.8	110	86 ± 23	5	10 ± 2.5	24	26 ± 11
OSSF1 $H_T > 200$	on-Z	(0,50)	*135	127 ± 41	542	543 ± 159	31	32 ± 6.5	86	75 ± 19

Selection 3 Lepton Results		E_T^{miss}	$N(\tau_h)=0$, $N_{b-jets}=0$ obs	exp	$N(\tau_h)=1$, $N_{b-jets}=0$ obs	exp	$N(\tau_h)=0$, $N_{b-jets}\geq 1$ obs	exp	$N(\tau_h)=1$, $N_{b-jets}\geq 1$ obs	exp
OSSF0 $H_T < 200$	NA	(100,∞)	7	11 ± 4.9	101	111 ± 54	13	10 ± 5.3	87	119 ± 61
OSSF0 $H_T < 200$	NA	(50,100)	35	38 ± 15	406	402 ± 152	29	26 ± 13	269	298 ± 151
OSSF0 $H_T < 200$	NA	(0,50)	53	51 ± 11	910	1035 ± 255	29	23 ± 10	237	240 ± 113
OSSF1 $H_T < 200$	above-Z	(100,∞)	18	13 ± 3.5	25	38 ± 18	10	6.5 ± 2.9	24	35 ± 18
OSSF1 $H_T < 200$	below-Z	(100,∞)	21	24 ± 9	41	50 ± 25	14	20 ± 10	42	54 ± 28
OSSF1 $H_T < 200$	on-Z	(100,∞)l	150	152 ± 26	39	48 ± 13	15	14 ± 4.8	19	23 ± 11
OSSF1 $H_T < 200$	above-Z	(50,100)	50	46 ± 9.7	169	139 ± 48	20	18 ± 8	85	93 ± 47
OSSF1 $H_T < 200$	below-Z	(50,100)	142	125 ± 27	353	355 ± 92	48	48 ± 23	140	133 ± 68
OSSF1 $H_T < 200$	on-Z	(50,100)	*773	777 ± 116	1276	1154 ± 306	56	47 ± 13	81	75 ± 32
OSSF1 $H_T < 200$	above-Z	(0,50)	178	196 ± 35	1676	1882 ± 540	17	18 ± 6.7	115	94 ± 42
OSSF1 $H_T < 200$	below-Z	(0,50)	510	547 ± 87	9939	8980 ± 2660	34	42 ± 11	226	228 ± 63
OSSF1 $H_T < 200$	on-Z	(0,50)	*3869	4105 ± 666	*50188	50162 ± 14984	*148	156 ± 24	906	925 ± 263

SM Backgrounds for Two Relevant Channels



HT<200



CMS SUS-13-002

HT>200

Sunil Somalwar,

t→charm+Higgs: Contributing Multilepton Channels

OSSF pair	$E_{\mathrm{T}}^{\mathrm{miss}}$ [GeV]	H_T [GeV]	b-tag	data	background	signal
below Z	0–50	> 200	✓	5	9.4 ± 2.6	12.3 ± 3.2
below Z	50–100	> 200	✓	10	9.3 ± 3.6	12.7 ± 3.4
below Z	50–100	0–200	✓	48	51 ± 25	39.5 ± 9.9
below Z	0–50	0–200	✓	35	43 ± 12	23.9 ± 5.2
n/a	50–100	0–200	—	29	28 ± 14	21.8 ± 4.6
below Z	50–100	0–200	—	146	125 ± 29	41 ± 11
n/a	0–50	0–200	✓	30	24 ± 11	16.1 ± 3.8
above Z	0–50	0–200	✓	17	18.5 ± 6.7	10.8 ± 2.7
on Z	50–100	0–200	✓	58	44 ± 13	16.0 ± 3.5
below Z	50–100	> 200	—	11	11.0 ± 3.8	7.1 ± 2.1

Three e/mu's. Assume B(t→ch)=1% for signal

Top → Charm + Higgs Result

CMS SUS-13-002

- For pp → ttbar → (bW)(ch) → multileptons:

Higgs Decay Mode	observed	expected	1σ range
$h \to WW$ (BR = 22.3 %)	0.37 %	0.38 %	(0.26–0.52) %
$h \to \tau\tau$ (BR = 6.24 %)	8.4 %	7.6 %	(5.8–11.2) %
$h \to ZZ$ (BR = 2.76 %)	1.23 %	0.97 %	(0.74–1.42) %
combined	0.31 %	0.31 %	(0.21–0.46) %

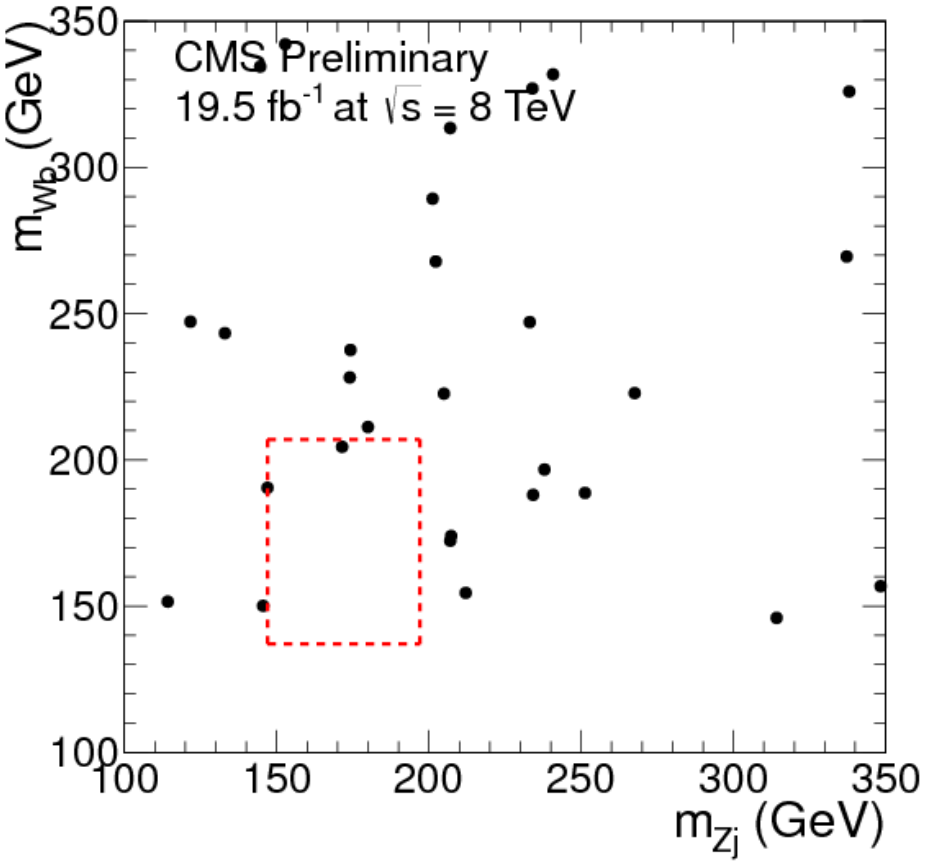
λ_{tch} = $\sqrt{|\lambda^h_{tc}|^2 + |\lambda^h_{ct}|^2} < 0.10$ ~ 2sqrt(BR)

- ATLAS: 0.83% (obs), 0.53% (exp) (h → $\gamma\gamma$) (atlas-conf-2013-081)

Top → Z + q

CMS PAS TOP-12-037

- pp → ttbar → (bW)(Z+x) (W&Z decay leptonically)
- Resonant dileptons on Z
  - + third lepton
  - + exactly1 b-tag
  - + 2 jets + MET > 30
- Backgrounds:
  - 0 b-tag : Drell Yan, WZ
  - 2 b-tags: ttbar, ttV, tbZ
- One event seen,
  - 3.14 expected



Top → Z + q

CMS PAS TOP-12-037

Dileptons on Z + third lepton + exactly1 b-tag + 2 jets + MET

Selection	data-driven estimation	SM MC prediction
$t \to Zq$ ($B = 0.1\%$)	—	$6.36 \pm 0.08 \pm 1.27$
WZ	$1.54 \pm 0.12 \pm 0.74$	$0.87 \pm 0.10 \pm 0.62$
ZZ		$0.07 \pm 0.01 \pm 0.05$
Drell-Yan		$0.00 \pm 0.03 \pm 0.02$
$t\bar{t}$	$1.60 \pm 4.96 \pm 0.44$	$0.74 \pm 0.70 \pm 0.52$
$Zt\bar{t}$		$1.09 \pm 0.13 \pm 0.77$
$Wt\bar{t}$		$0.09 \pm 0.05 \pm 0.06$
tbZ		$0.33 \pm 0.02 \pm 0.23$
Total background	$3.14 \pm 4.97 \pm 1.17$	$3.19 \pm 0.72 \pm 2.26$
Observed events	1	—
Expected limit	$\mathcal{B}(t \to Zq) < 0.10\%$	—
Observed limit	$\mathcal{B}(t \to Zq) < 0.07\%$	

BF < 0.05% (7+8 TeV)

Top → Everything but Wb

CMS PAS TOP-12-035

- Rb = BR(t→bW) / BR(t→qW) ➔(1-Rb) = BR(t→All but bW)
- Challenge: Correctly assign the observed b/non-b jet to the parent top. Systematics dominated measurement.
- Method:
  - Dilepton (ttbar) sample, off-Z, MET>40, at least two jets away from leptons by $\Delta R>0.3$
  - B-tag efficiency ε_b, ±~1-3% measured in multijet data with muons in jets.
  - Light jets passing b-tag (mistags: ε_q ~14%,±~11%) measured with negative tags.
  - Jet misassignment (missed top jets, ISR jets, backgrounds etc)
  - Study: Number of b-tags distribution for ee, eμ and μμ .

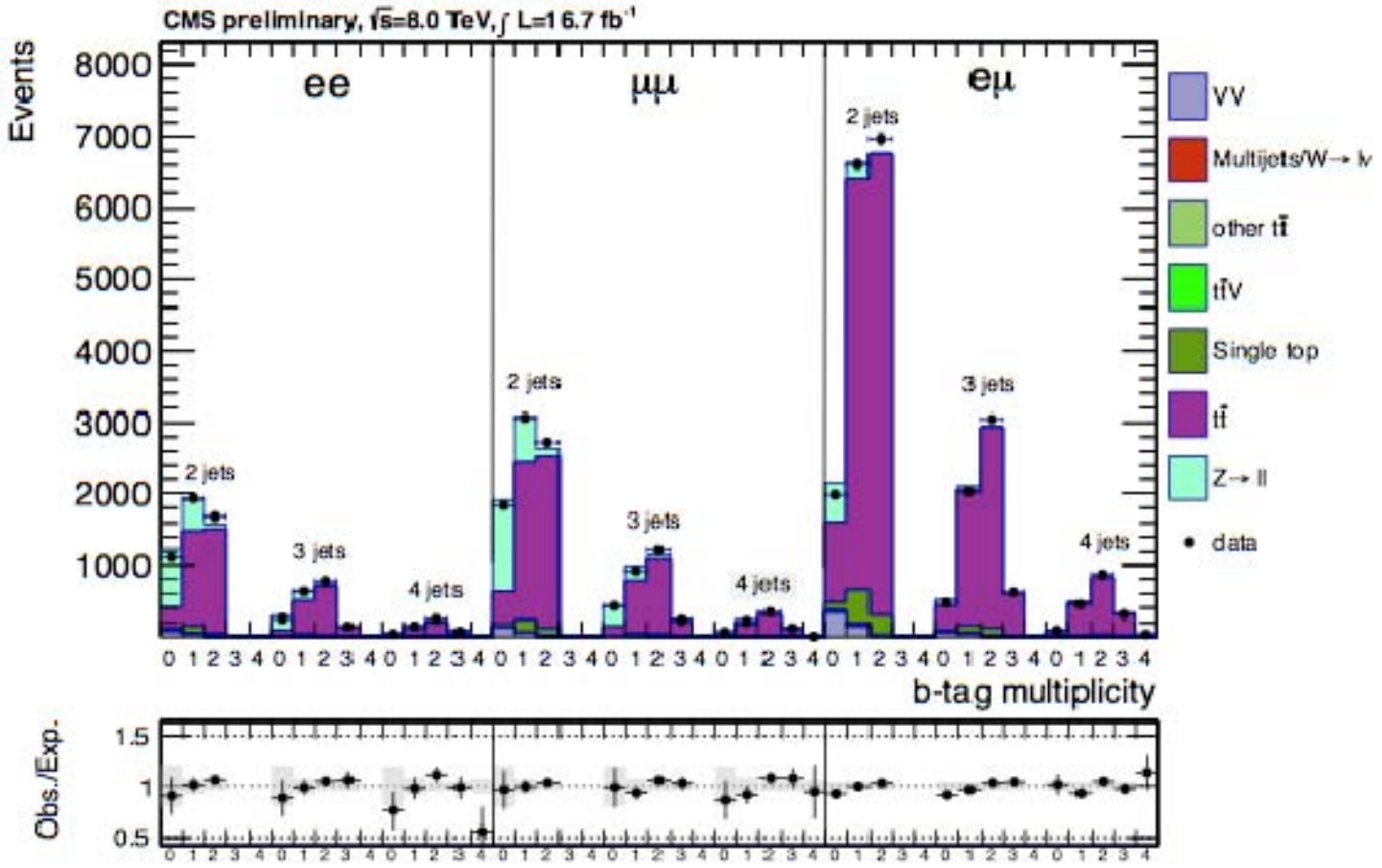
    Lepton-jet invariant mass.

Top → Everything but Wb

CMS PAS TOP-12-035

Probing heavy flavor content of the daughter jets :

tagging efficiency and mistags



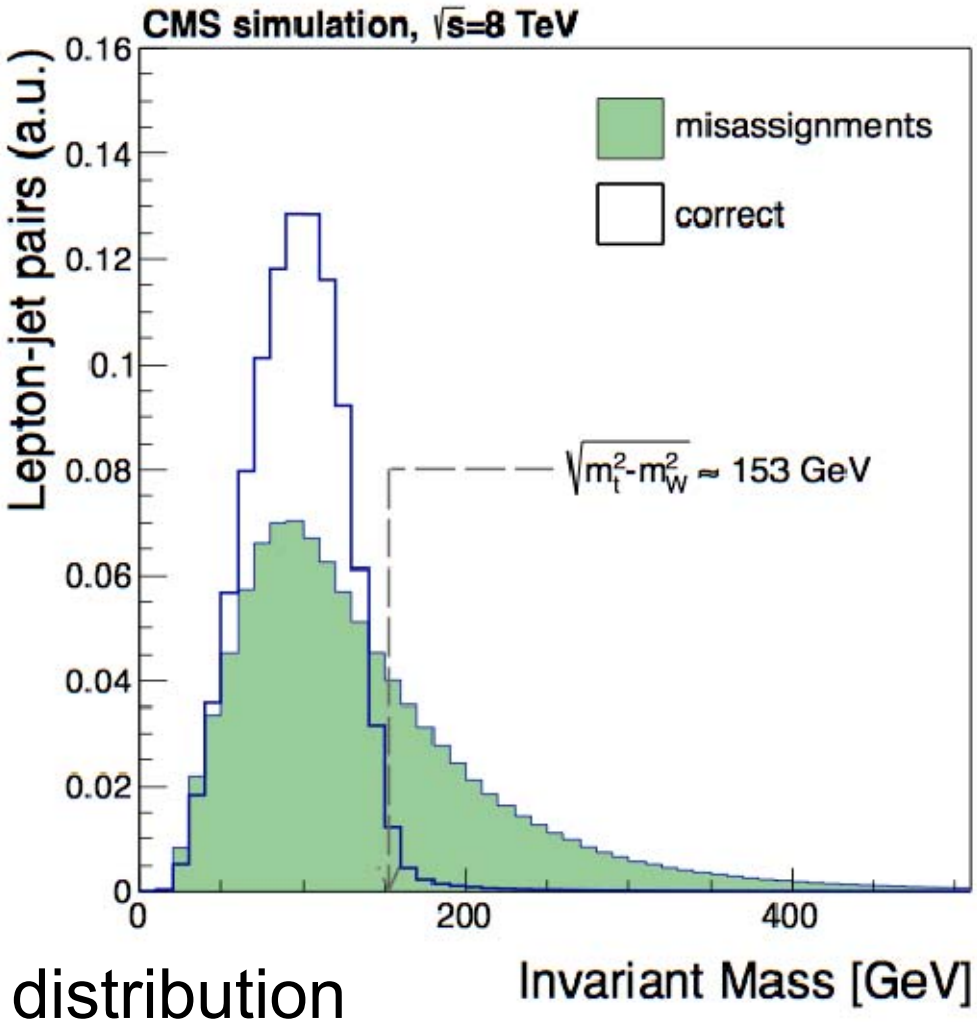
b-tag multiplicity distribution for dilepton flavors vs R=1MC

Top → Everything but Wb

CMS PAS TOP-12-035

Probing heavy flavor content of the daughter jets:

Jet misassignment



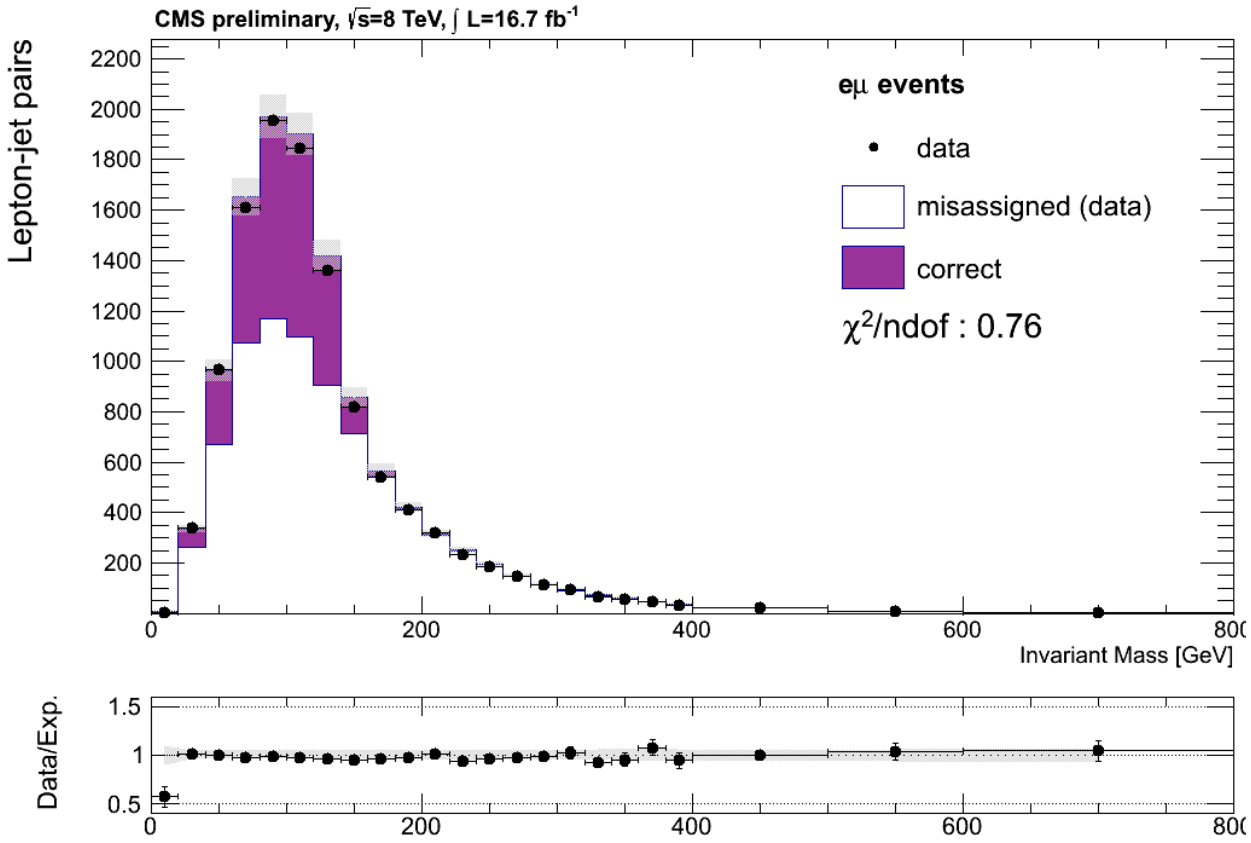
lepton-jet invariant mass distribution

Top → Everything but Wb

CMS PAS TOP-12-035

Probing heavy flavor content of the daughter jets:

Jet misassignment from empirical data-based model



lepton-jet invariant mass distribution

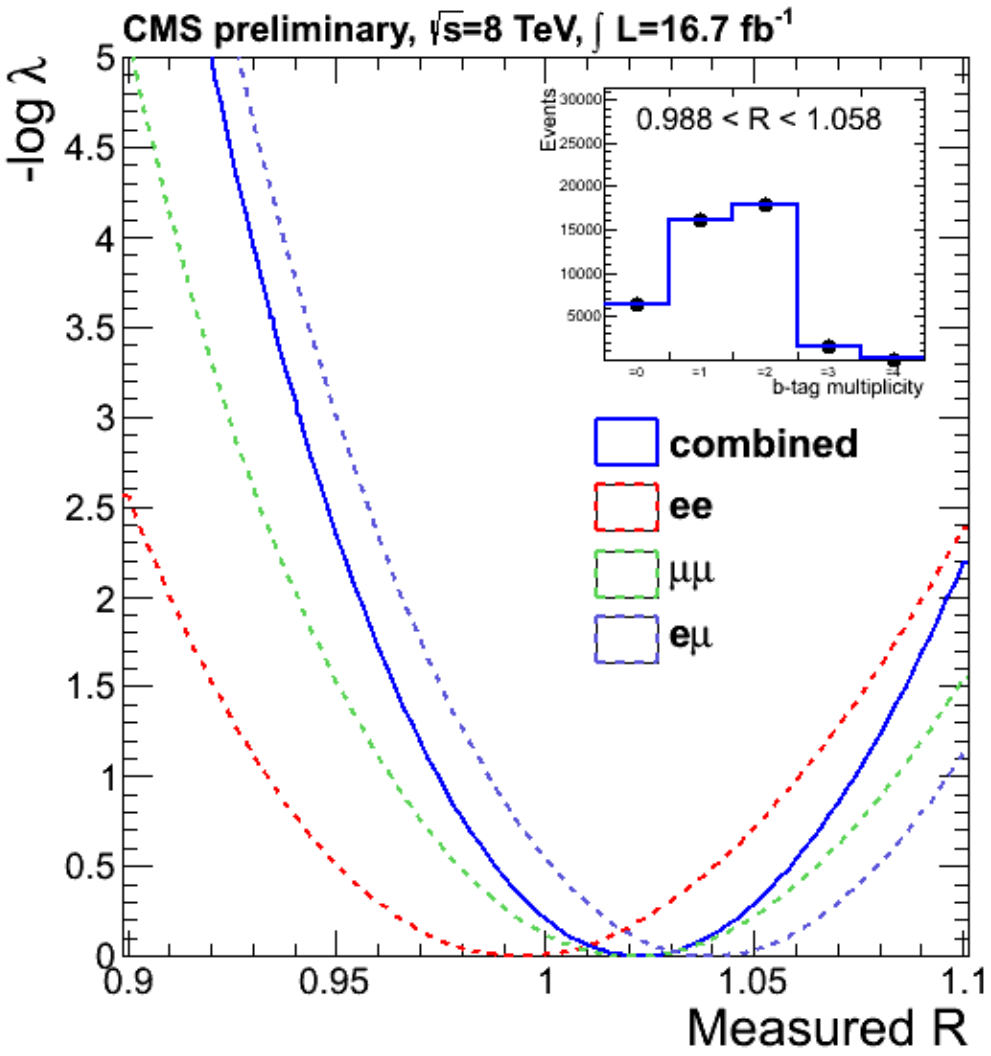
Top → Everything but Wb

CMS PAS TOP-12-035

Measured Rb
(combined channels)

Rb > 0.945
@ 95% CL
Vtb > 0.972

Very little room for
everything else!



Top → muon +b +c (Baryon Number Violation)(BNV)

- Supersymmetry, Grand Unified Theories and black-hole physics naturally allow Baryon Number violation (**BNV**).
  - stringent limits from precision measurements in nucleon, tau, HF mesons and Z bosons, but top to μbc not excluded

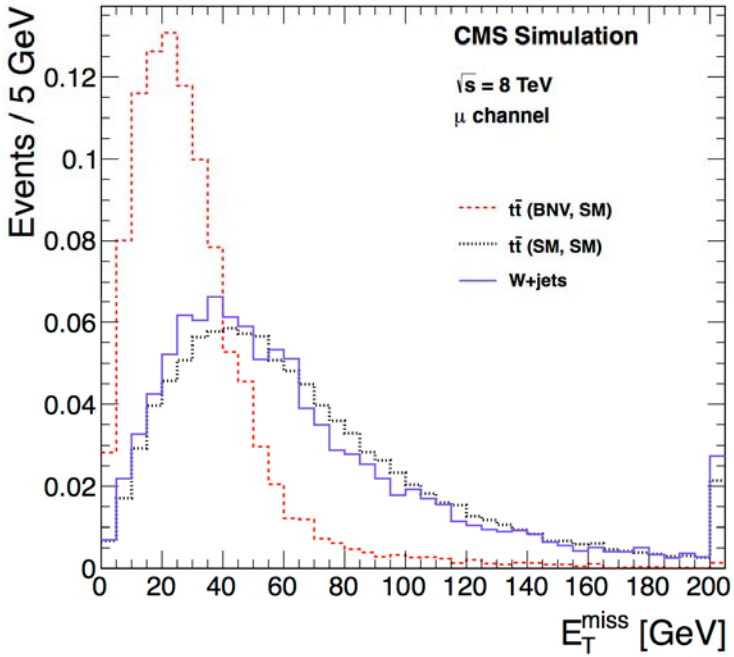
    (like proton →lepton + pi0)

- pp → ttbar → (bW)(μbc)

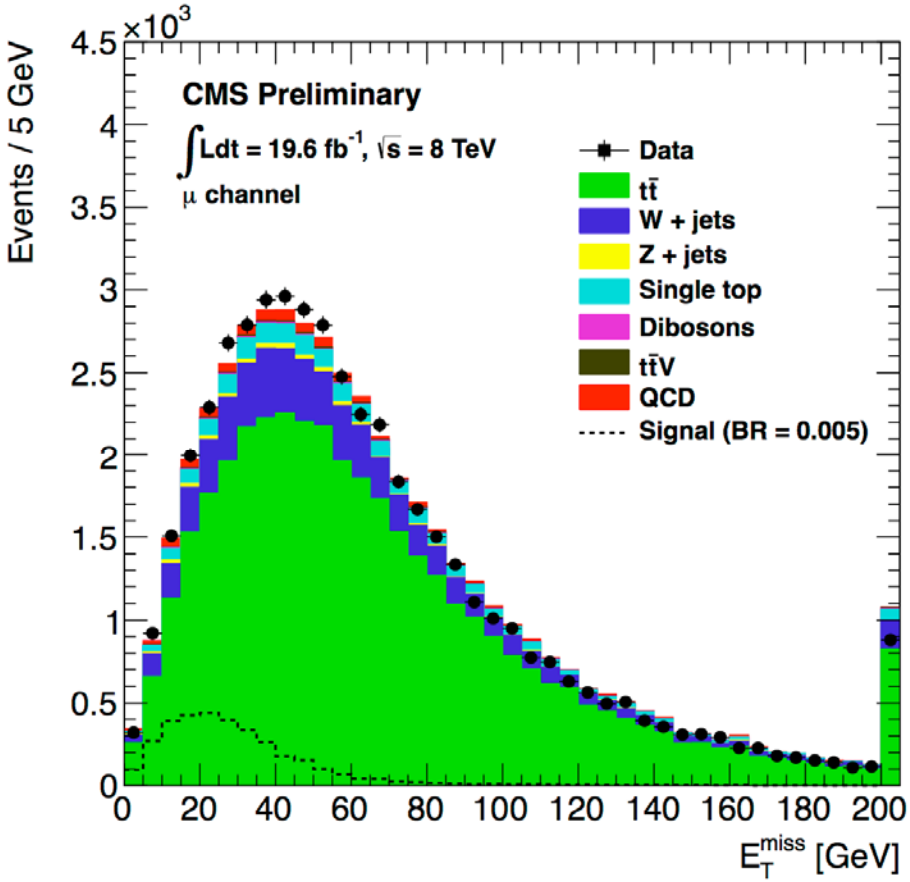
  → (bqq)(μbc)

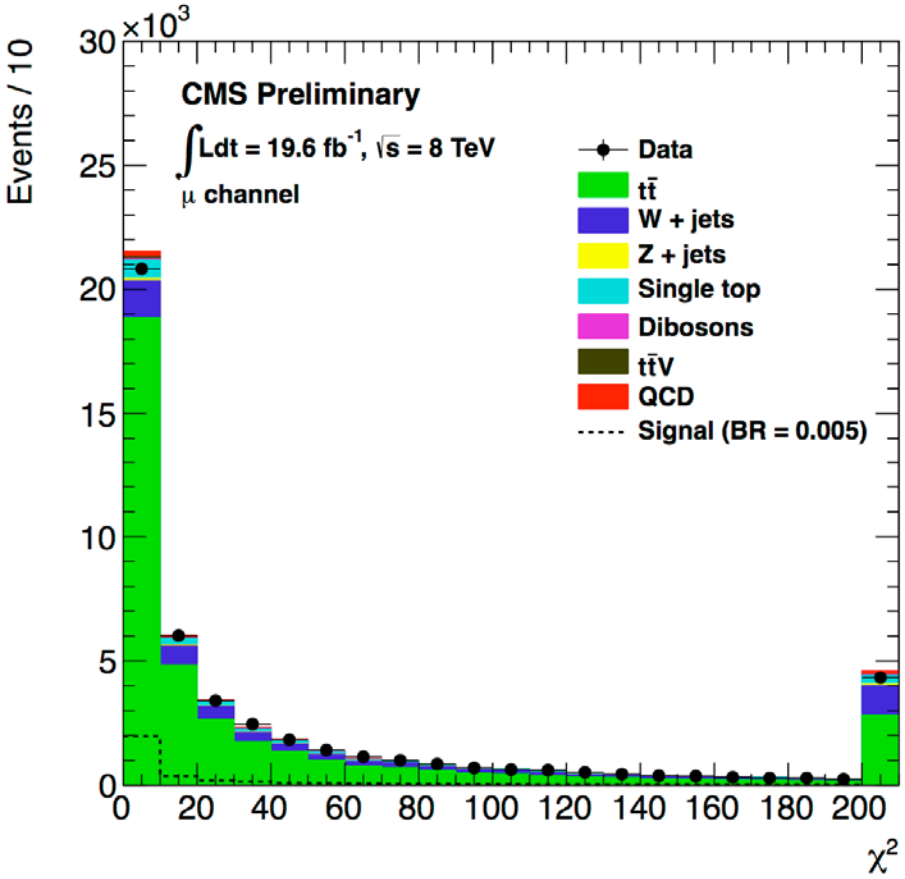
  lepton + 5 jets + no MET

CMS PAS B2G-12-023



top → μbc Baryon Number Violation

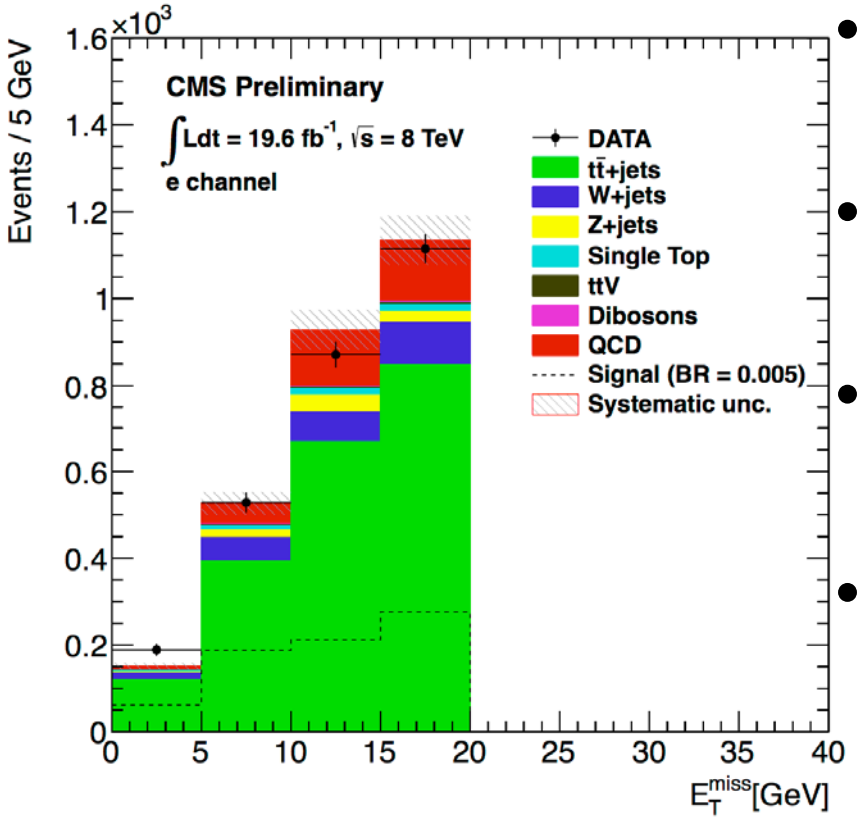




- Chi2 reconstruction of hadronic top system, then low MET (<20)
- Fit to BR and selection efficiency

CMS PAS B2G-12-023

Search for Baryon Number Violation in top decays



- QCD multijet background from Z+jets events
- Good data/MC agreement even in challenging e+jets channel
- Limits in μ (e) channels:

  BF< 0.016 (0.017)
- First limits on BNV in top sector!

Conclusions

- Top → bW more than 94.5% (Rb dileptons)
- Multileptons FCNC: BR(t→ch) < 0.3% (new result)
  BR(t→qZ) < 0.05%
- Top → μ bc Baryon Number Violation BF < ~1%