Searches for Exotic Beyond Standard Model Physics at CMS

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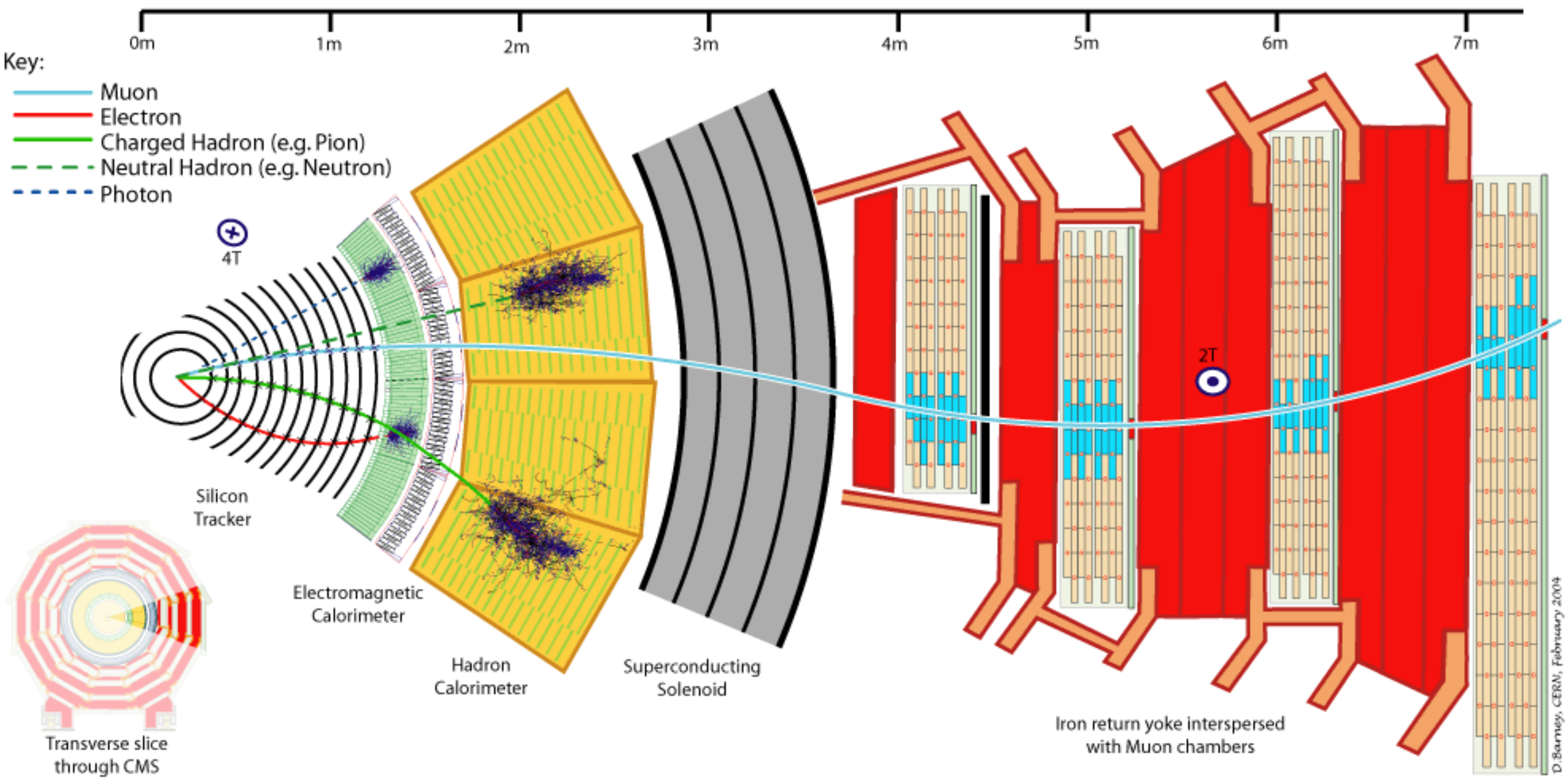
What is Exotics?

- Physics Beyond Standard Model
  - SUSY searches by Jeff Richman, earlier (& Carlos Wagner ☺)
  - Higgs is not BSM, alas - Sridhara Dasu, earlier

- Observed action is between 100 & 200 GeV (W/Z – higgs – top)
  - Searches with higgs in the final state
  - New physics in top decays , e.g. t→c+higgs? (LHC as a top factory)

- Other considerations
  - Recent results

CMS = Compact MUON solenoid

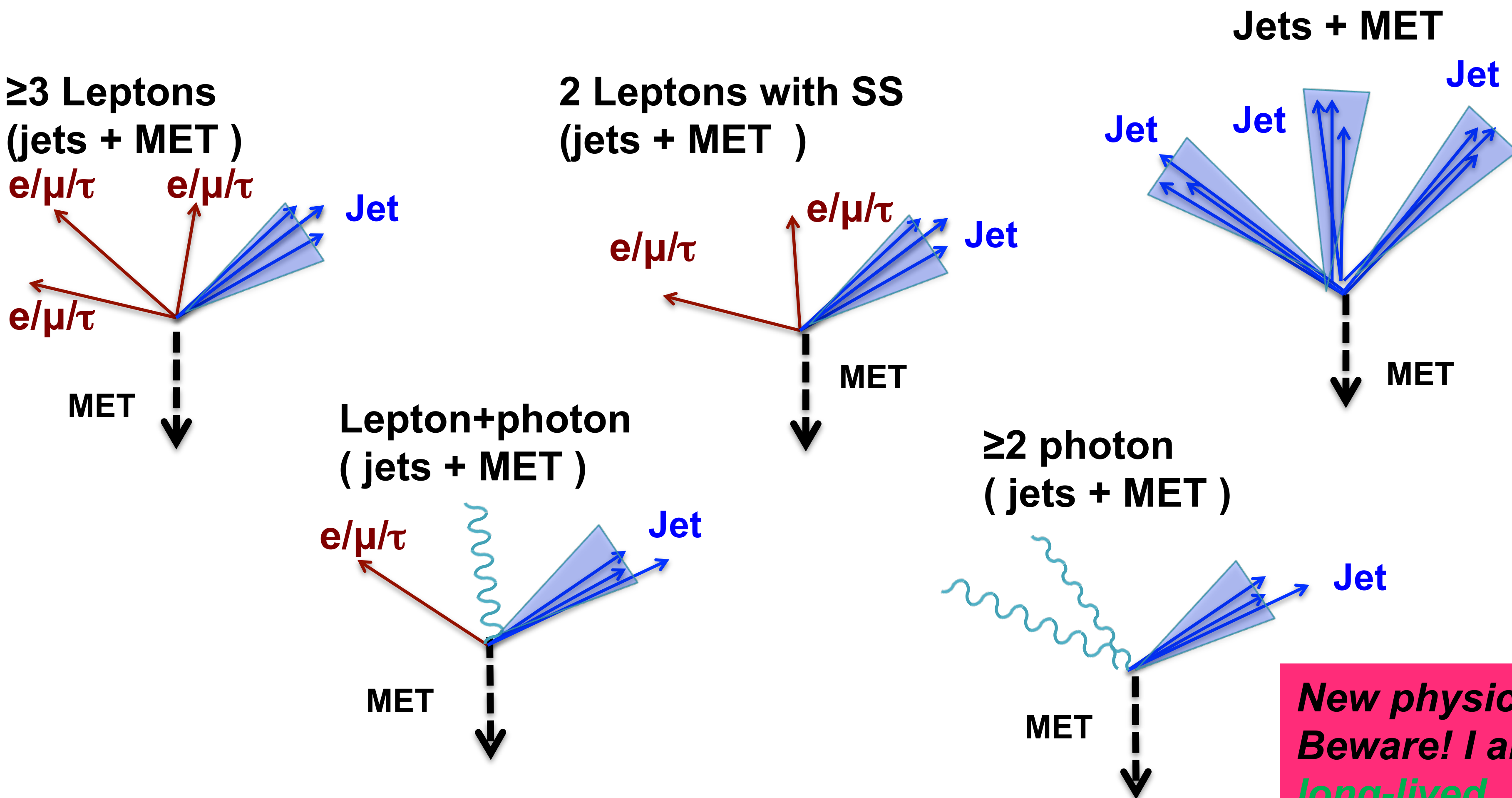


Search Tools

- Muons, electrons, (hadronic) tau's
- Missing ET
- Jets:
  - Number of jets (about 30 GeV, say)
  - HT = sum of Jet Pt's
  - ST = sum of all relevant transverse quantities
  - B tagged jets
- Smart objects
  - Particle flow
  - Substructure
- Particle Flow
- Kinematics
  - Invariant masses (resonances), edges,etc
  - Fancy variables
  - Kinematics on Viagra (NN, BDT, PNA's)
- Finite lifetimes, displaced tracking, dE/dx, etc

Conventional Search Axes (are getting old…)

(MET or jets/HT etc not guaranteed!)



New physics: Beware! I am long-lived.

Standard Model Background Prediction

Why not just Monte Carlo all the backgrounds?

→ 110M Z/g* dileptons vs 1000 (multilepton) signal, say

→ The devil is in da tails.

→ Data-driven backgrounds (“fake” rates)

- →Large data samples available

MC for “irreducible” backgrounds (eg WZ)

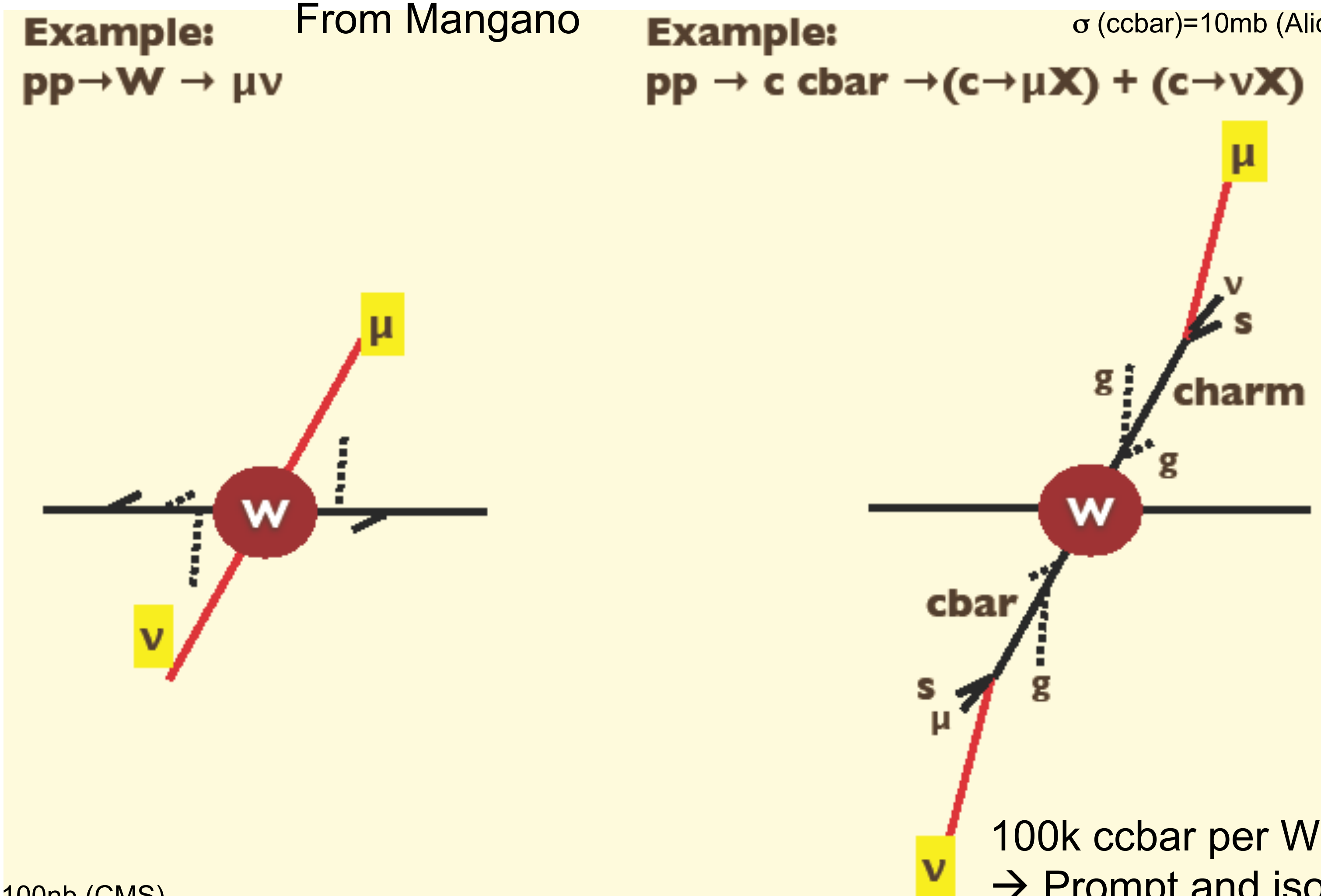
→Smaller cross sections means tails peter out

→Validate/adapt in control regions.

Prompt and Isolated

From Mangano

σ (ccbar)=10mb (Alice random doc)



100k ccbar per W
→ Prompt and isolated tails

σ(W)=100nb (CMS)

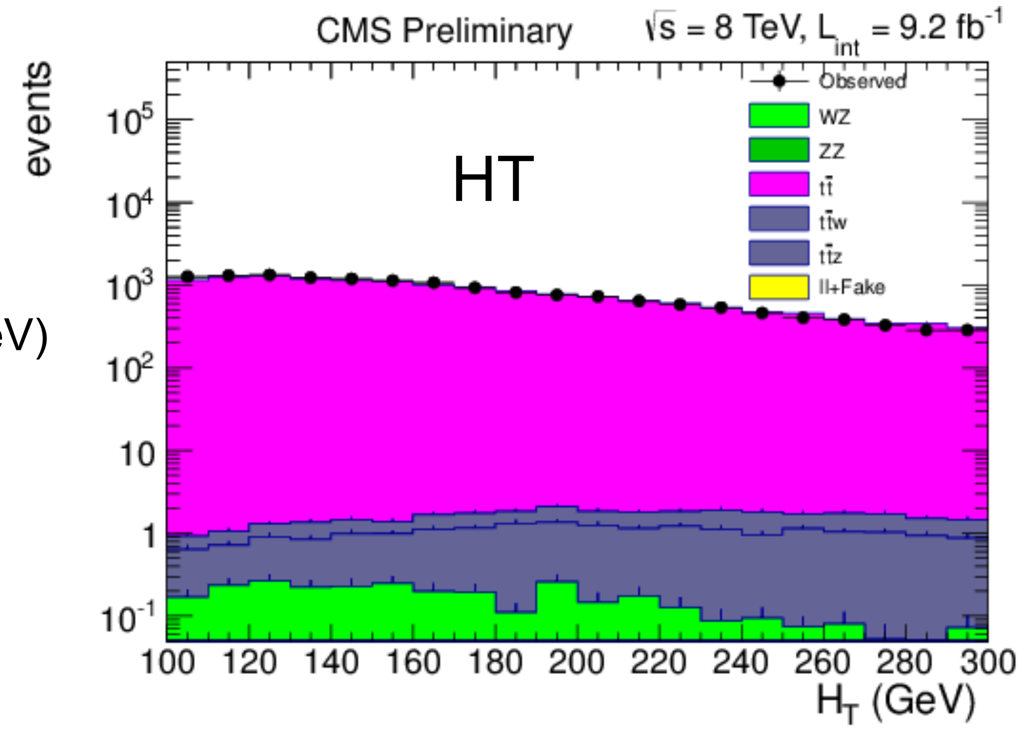
Cautionary tell-tale tail: Simulated ttbar

ttbar MC for a **trilepton** search: Opposite sign electron-muon pairs

(different lepton flavor – Drell-Yan background suppression)

HT = Σ (jet pt) for

jets with pt>30 GeV)



- OK, nice agreements for dileptons. How about three leptons (dilepton+"fake")?
- Fake = Prompt/isolated tail of non-prompt/non-isolated real lepton distribution.

→ MC does not get it → tell-tale is in *single-lepton* isolation distribution → Use it to adjust the "fake" rate in the dilepton sample → Verify in trilepton control regions.

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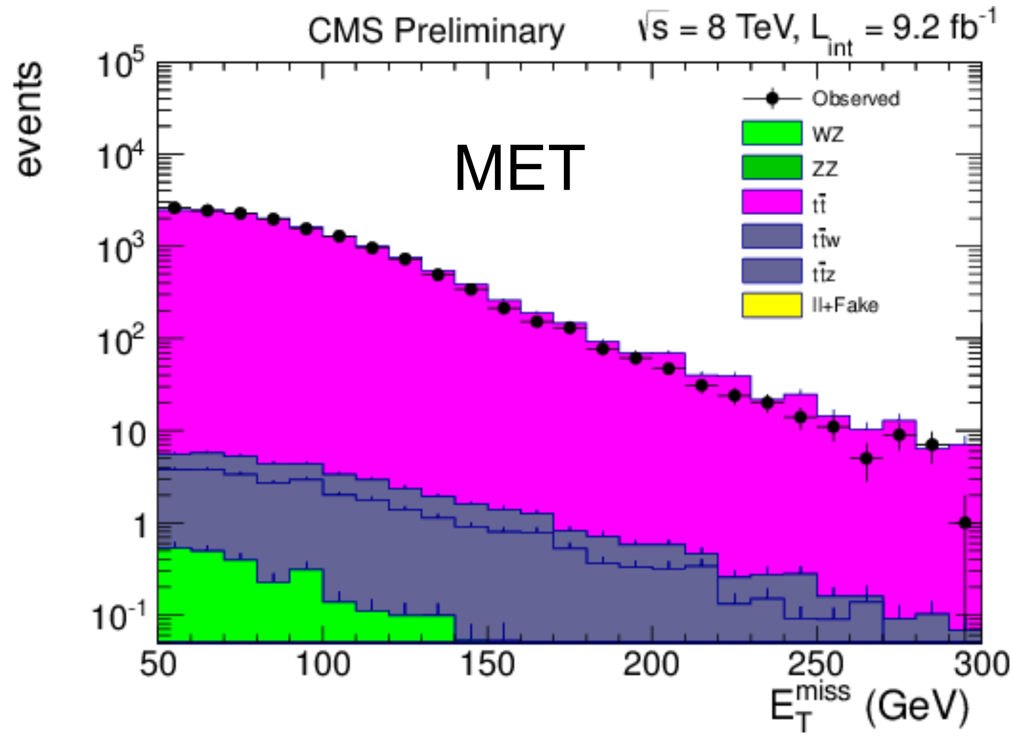

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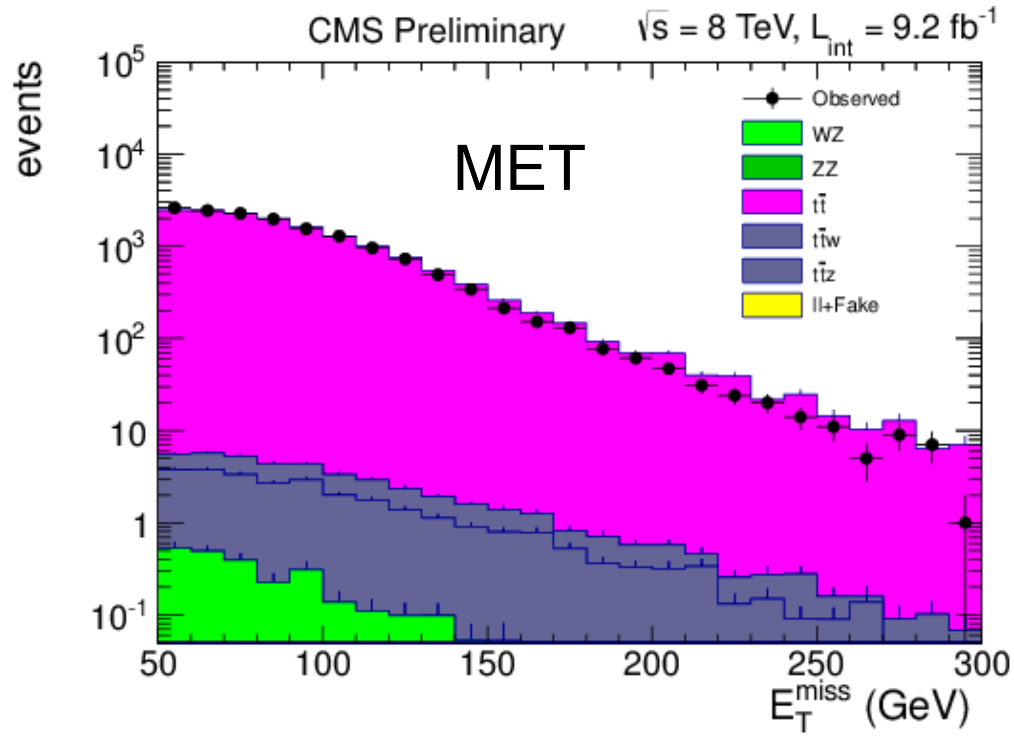

• OK, nice agreements for dileptons. How about three leptons (dilepton+"fake")?
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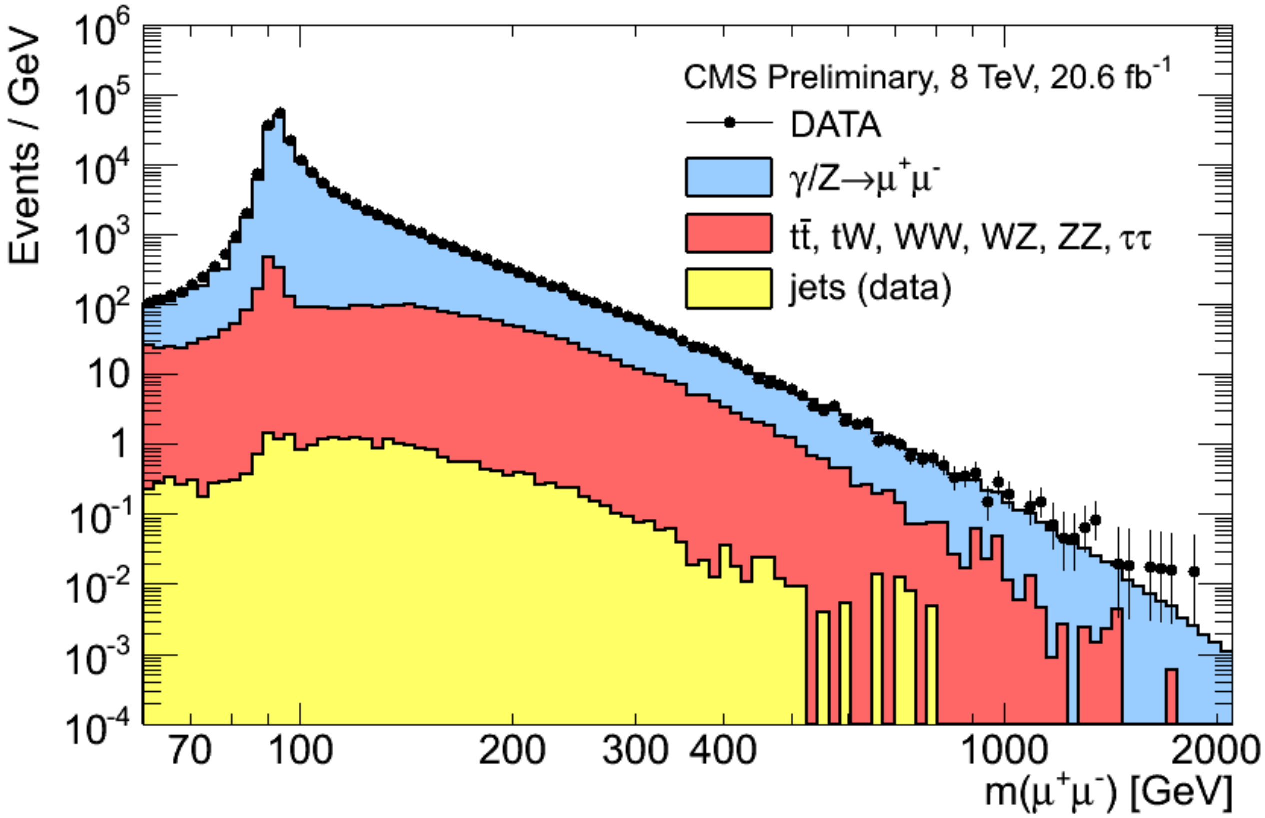
Table of Contents

- Resonances
  - Dilepton Z', ADD
  - 3-jet, 3-jet w/ b-tag
  - X $\longrightarrow$ tt
- *LHC as a top factory*
  - top $\longrightarrow$ .NOT. (bW) ?
  - top $\longrightarrow$ charm + Higgs
  - top $\longrightarrow$ qZ
  - top $\longrightarrow$ muon + b + c (BNV)
- The family formerly known as the 4th generation (and friends)
  - vector-like T'
  - vector-like B'
  - Q=5/3 top partners
- Di-boson signatures (high mass)
  - $W'/\rho_{TC} \longrightarrow WZ \longrightarrow 3l + MET$
  - $G_{bulk} \longrightarrow WW \longrightarrow l + jet + MET$
  - $G_{RS} \longrightarrow WW/ZZ$ and $W' \longrightarrow WZ$
- Long-lived particles
  - displaced jets
- Dark Matter
  - monojet
  - Monolepton
- *Higgs in the final state recap*

Resonances: Dileptons (Z′)

[CMS EXO-12-061]

- E_T (e1,e2) > 35 GeV, p_T (μ1,μ2) > 45 GeV, plus isolation criteria
- Backgrounds Z/γ*, tt, tW, VV, Z ⟶ ττ, multijets with ≥1 jet reconstructed as lepton, estimated by functional fit



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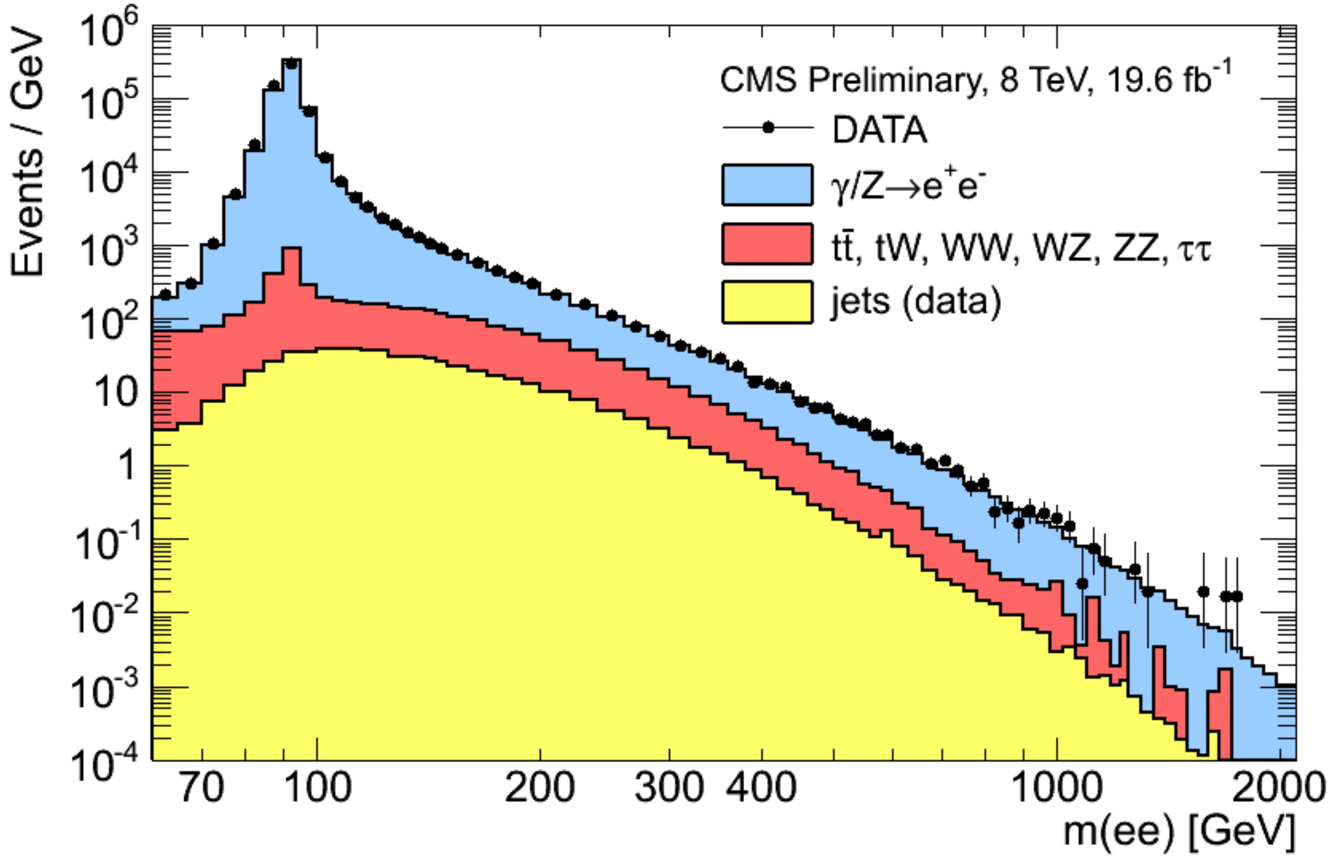

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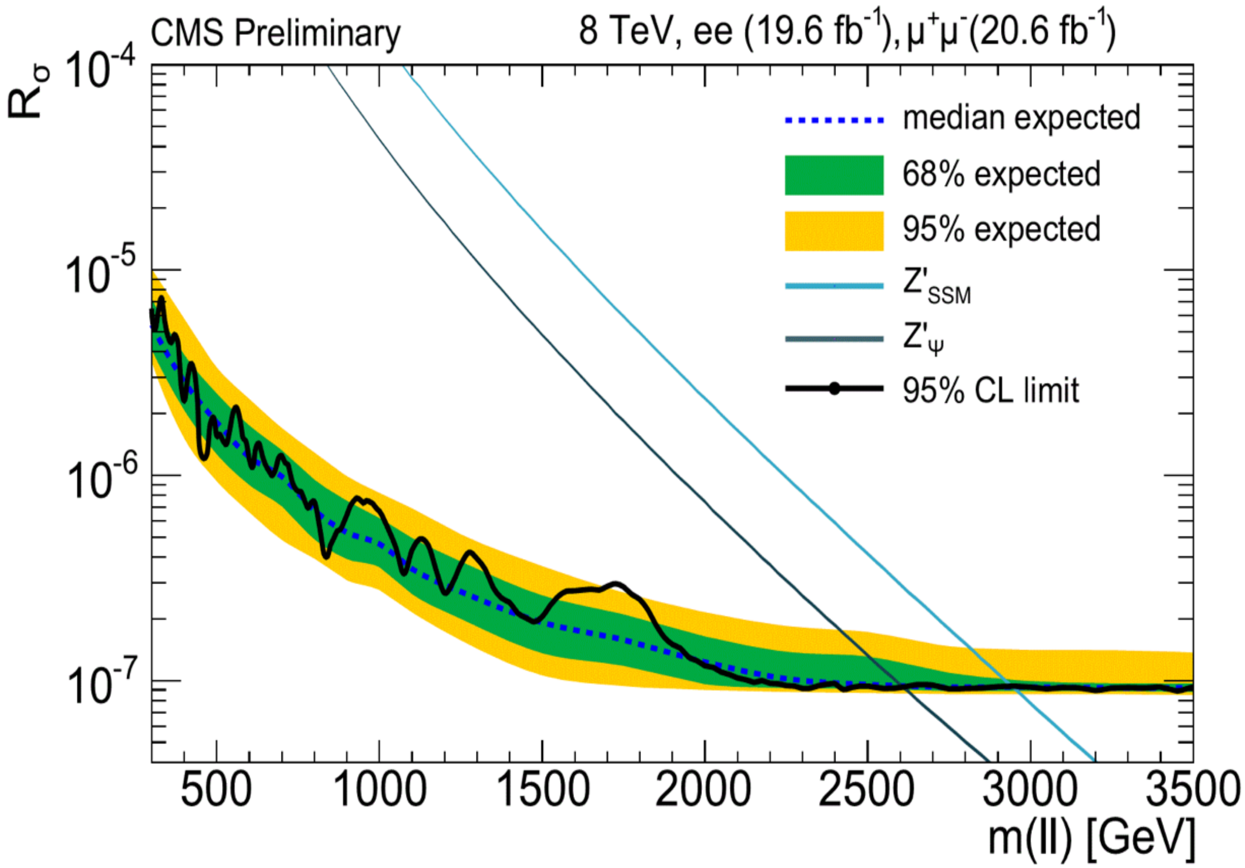
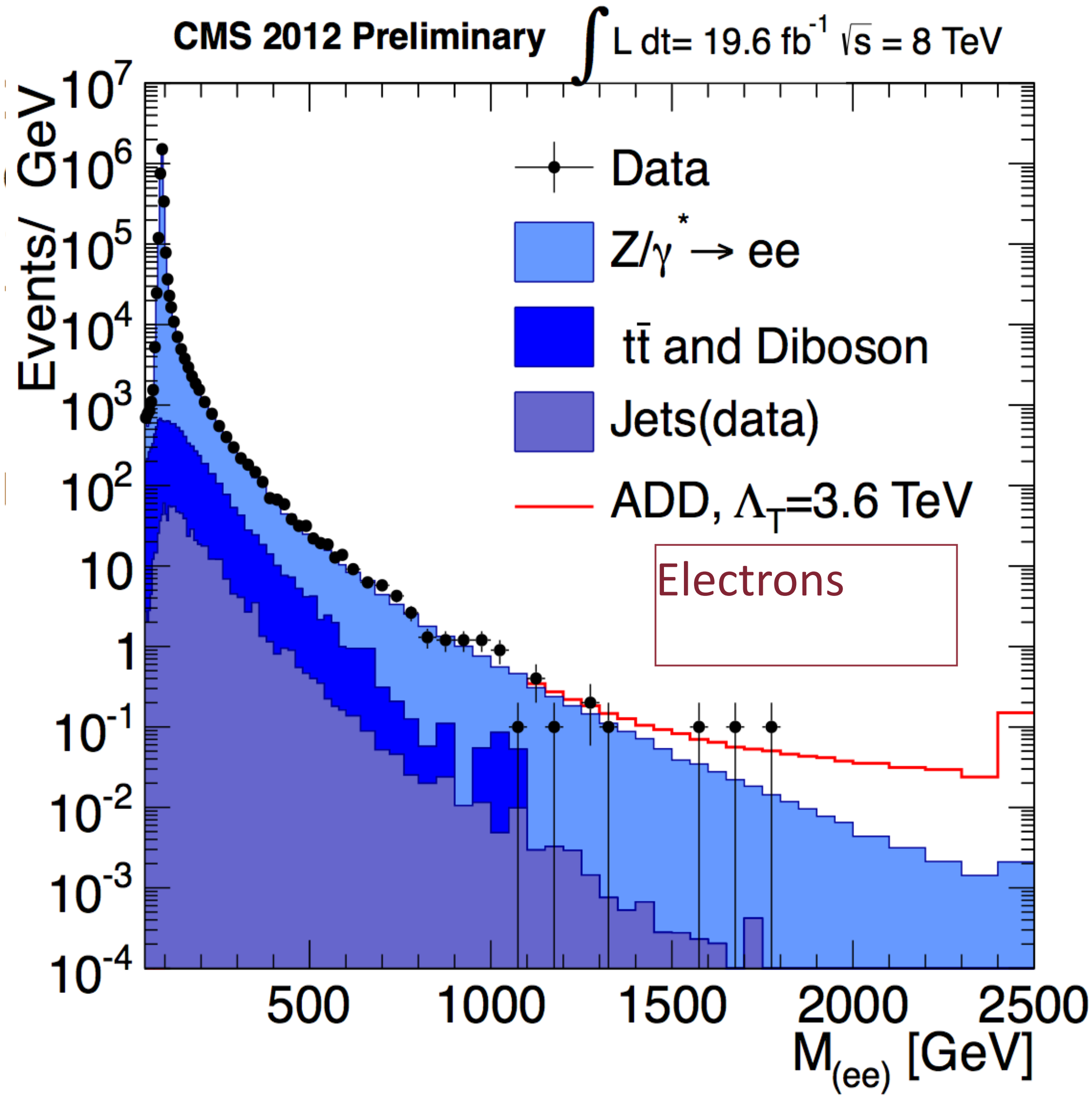


- "Excessitement" from 7TeV went away
- Limits on narrow resonances (Z'SSM, Z'ψ)
- M(Z'SSM) > 2.96 TeV (expected=observed)

Resonances: Z' →Extra Dimensions

[CMS EXO-12-027, CMS EXO-12-031]



Integrate the dilepton invariant mass spectrum above a mass threshold

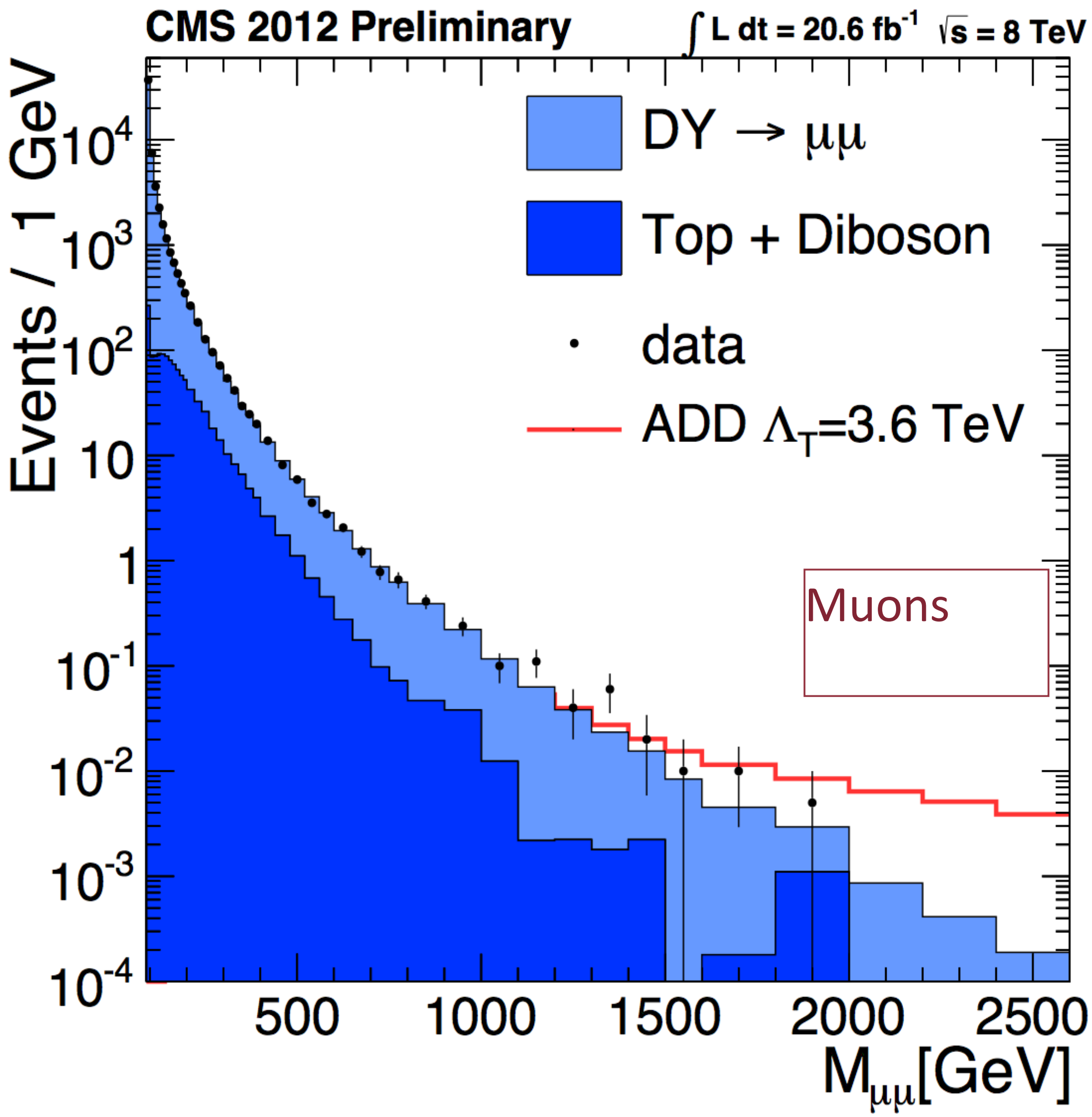
Leading systematics from momentum scale (muons) and PDF (electrons)

Mass limits from 3.4 to 4.8 TeV depending on the convention etc

Observed ~ Expected

Resonances: Z' →Extra Dimensions

[CMS EXO-12-027, CMS EXO-12-031]



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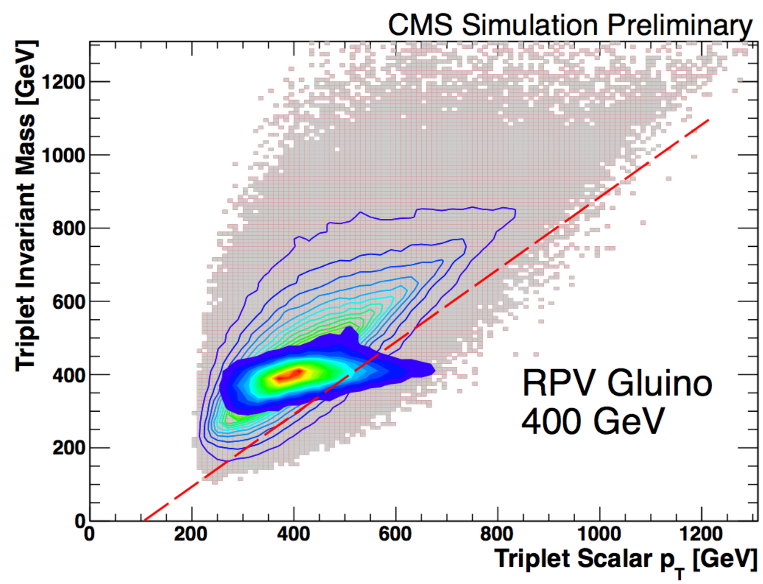
Observed ~ Expected

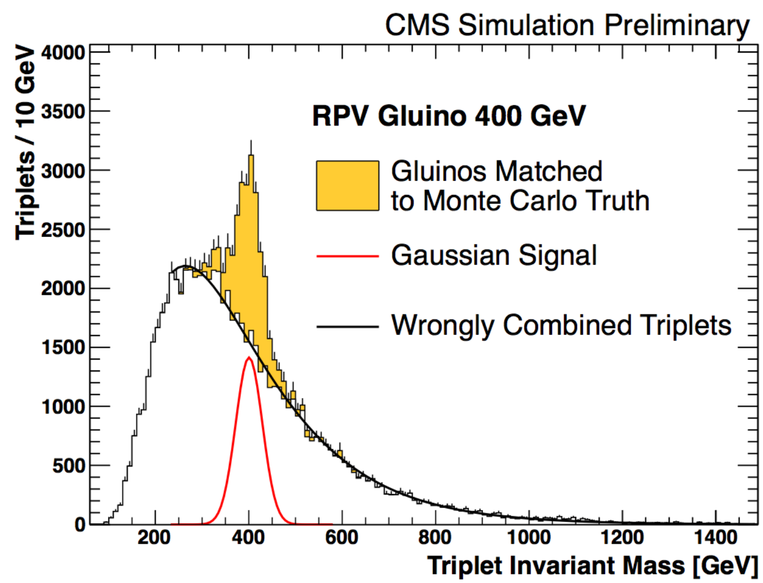
Resonances: Paired Three Jets

[CMS EXO-12-049]

- A ⟶ BB⟶(jjj)(jjj)
- e.g. pair-produced gluinos to three jets through UDD RPV coupling (signal to burn)
- Event Selection
  - ≥6 jets > 60 GeV (1st–4th jet > 80 GeV)
  - Use sphericity against high mass backgrounds
  - b-tagging for gluino ⟶ udb/csb scenarios
- Combine the six highest p_T jets into 20 unique triplet combinations
- To suppress wrong combinations and QCD, only accept triplets that satisfy

$$M_{jjj} < \sum_{i=1}^{3} |p_T|_i - \Delta$$



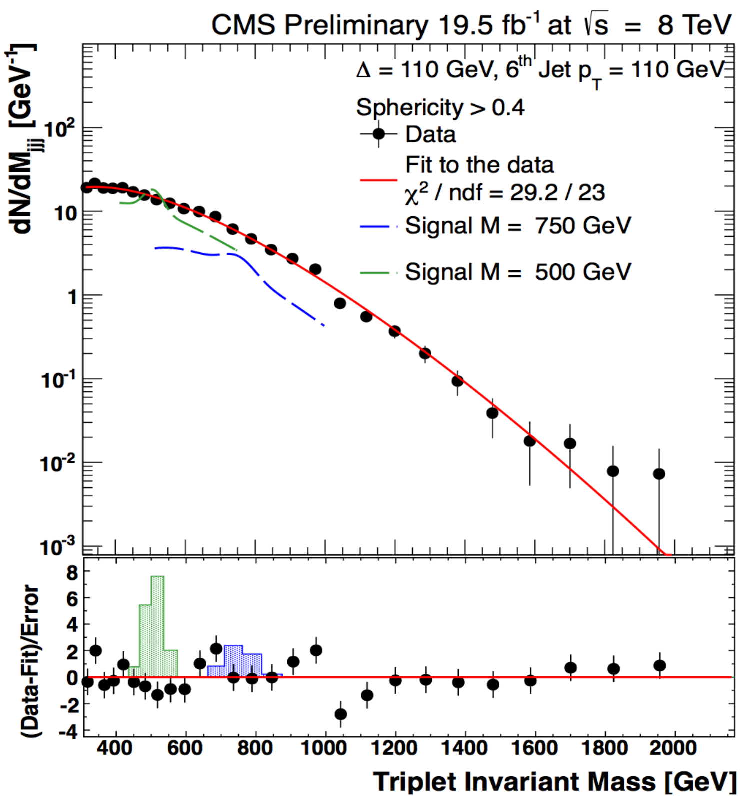


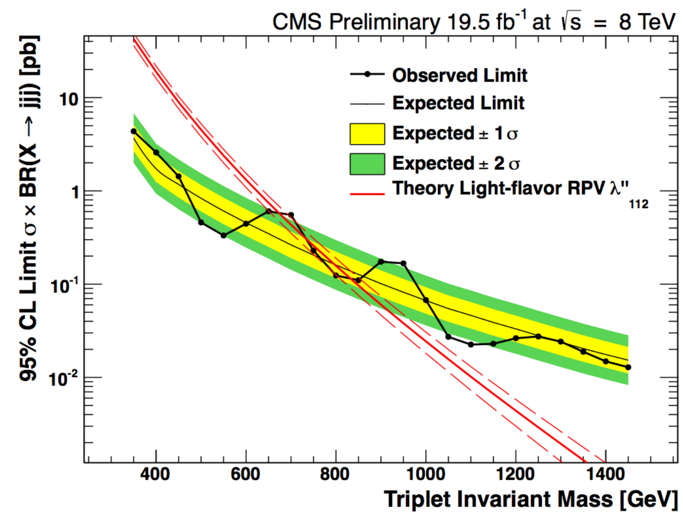
Pair-Produced Three Jet Resonances

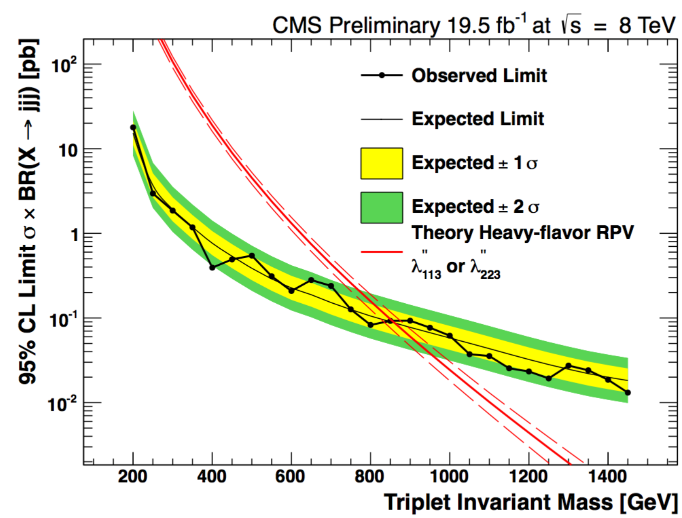
[CMS EXO-12-049]

- Look for bump in falling spectrum
  - For b-tagged result, QCD shape from b-vetoed data
  - All-hadronic top bkgnd consistent w/ SM rate

Limits on RPV gluinos < 650 GeV (light-flavor) and between 200 and 835 GeV (heavy-flavor)



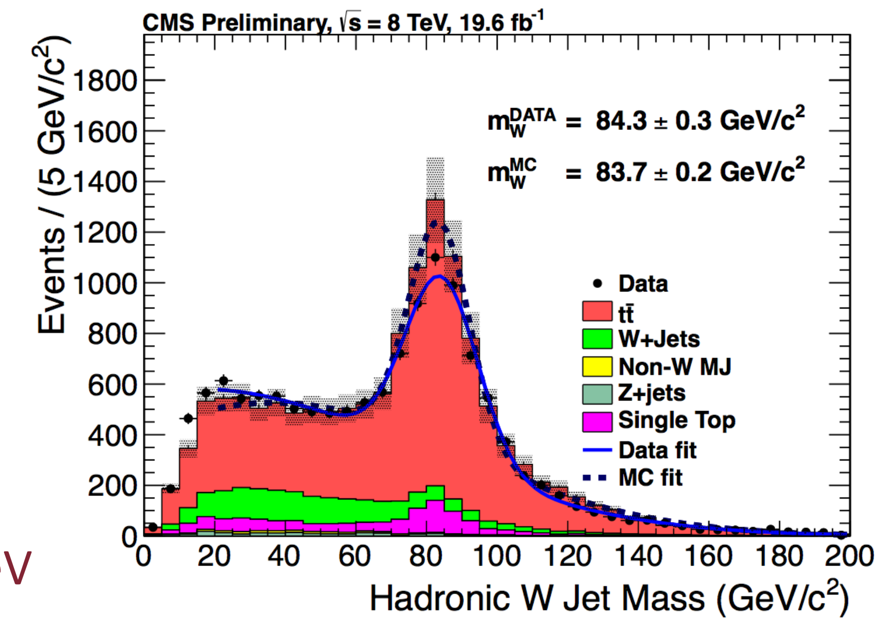




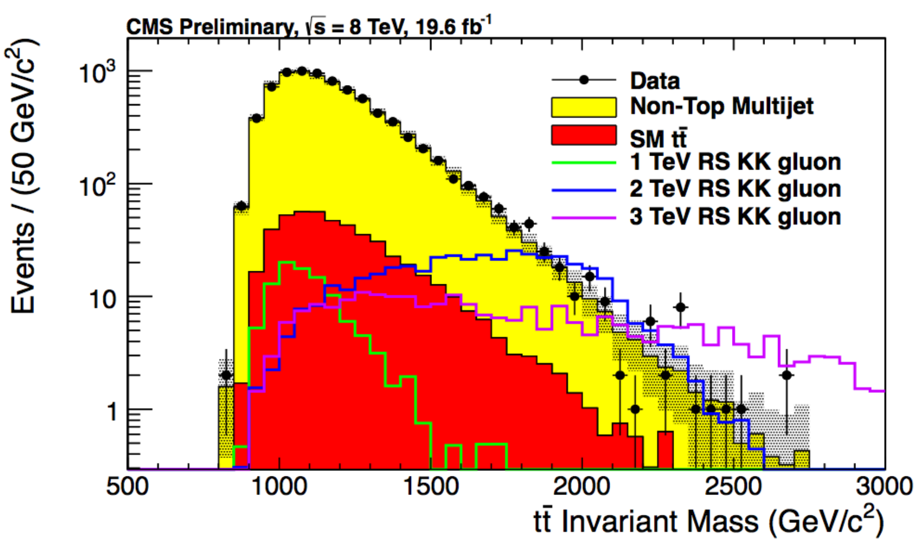
Hadronic X ⟶ tt Resonance

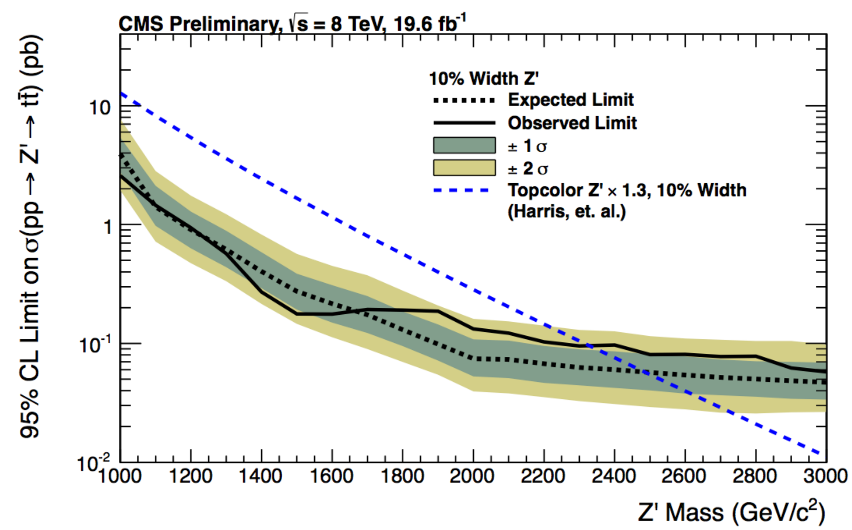
[CMS B2G-12-005]

- Selection and tagging:
  - Top-tagging: requirements on # of subjets, jet mass, minimum pair- wise mass (W)
  - 2 jets, Cambridge-Aachen with R=0.8
  - Scale factor measured in orthogonal muon+jets sample
- QCD bkgnd determined from applying mistag rate to un-tagged dataset



Limits on $M(G_{KK}) < 1.8$ TeV, $M(Z') < 2.5$ TeV





LHC as a top factory

Anomalous top Decays – a Different BSM 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

Top → Charm + Higgs with multileptons

New for SUSY'13
sus-13-002

- t→ch is FCNC non-existent in SM.
- New physics, e.g. "2HDM-III" 0.1%
- 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.
- t → ch is *one application* of the CMS inclusive multilepton search which is a (wide) open search.
  - Andrea Gozzelino earlier on RPC SUSY. tch, b' in this talk, Ben Hooberman electroHiggs susy yesterday, Matt Walker RPV SUSY later today, 2Higgs Doublet, ttV, Flavored DM, See-saw etc in the works.

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 Results for Three Leptons

CMS SUS-13-002

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	$N(\tau_h)=0, N_{b-jets}\geq1$ obs	exp	$N(\tau_h)=1, N_{b-jets}\geq1$ 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	$N(\tau_h)=0, N_{b-jets}\geq1$ obs	exp	$N(\tau_h)=1, N_{b-jets}\geq1$ 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

Multilepton Results for Four Leptons

CMS SUS-13-002

Selection 4 Lepton Results		E_T^{miss}	N(τ_h)=0, N_{b-jets}=0 obs	exp	N(τ_h)=1, N_{b-jets}=0 obs	exp	N(τ_h)=0, $N_{b-jets}\geq$1 obs	exp	N(τ_h)=1, $N_{b-jets}\geq$1 obs	exp
OSSF0 $H_T > 200$	NA	(100,∞)	0	0.01 ± 0.03	0	0.01 ± 0.06	0	0.02 ± 0.04	0	0.11 ± 0.08
OSSF0 $H_T > 200$	NA	(50,100)	0	0 ± 0.02	0	0.01 ± 0.06	0	0 ± 0.03	0	0.12 ± 0.07
OSSF0 $H_T > 200$	NA	(0,50)	0	1e-05 ± 0.02	0	0.07 ± 0.1	0	0 ± 0.02	0	0.02 ± 0.02
OSSF1 $H_T > 200$	off-Z	(100,∞)	0	0.005 ± 0.02	1	0.25 ± 0.11	0	0.13 ± 0.08	0	0.12 ± 0.12
OSSF1 $H_T > 200$	on-Z	(100,∞)	1	0.1 ± 0.06	0	0.5 ± 0.27	0	0.42 ± 0.22	0	0.42 ± 0.19
OSSF1 $H_T > 200$	off-Z	(50,100)	0	0.07 ± 0.06	1	0.29 ± 0.13	0	0.04 ± 0.04	0	0.23 ± 0.13
OSSF1 $H_T > 200$	on-Z	(50,100)	0	0.23 ± 0.11	1	0.7 ± 0.31	0	0.23 ± 0.13	1	0.34 ± 0.16
OSSF1 $H_T > 200$	off-Z	(0,50)	0	0.02 ± 0.03	0	0.27 ± 0.12	0	0.03 ± 0.04	0	0.31 ± 0.15
OSSF1 $H_T > 200$	on-Z	(0,50)	0	0.2 ± 0.08	0	1.3 ± 0.47	0	0.06 ± 0.04	1	0.49 ± 0.19
OSSF2 $H_T > 200$	off-Z	(100,∞)	0	0.01 ± 0.02	-	-	0	0.01 ± 0.06	-	-
OSSF2 $H_T > 200$	on-Z	(100,∞)	1	0.15 ± 0.16	-	-	0	0.34 ± 0.18	-	-
OSSF2 $H_T > 200$	off-Z	(50,100)	0	0.03 ± 0.02	-	-	0	0.13 ± 0.09	-	-
OSSF2 $H_T > 200$	on-Z	(50,100)	0	0.8 ± 0.4	-	-	0	0.36 ± 0.19	-	-
OSSF2 $H_T > 200$	off-Z	(0,50)	1	0.27 ± 0.13	-	-	0	0.08 ± 0.05	-	-
OSSF2 $H_T > 200$	on-Z	(0,50)	5	7.4 ± 3.5	-	-	2	0.8 ± 0.4	-	-

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CMS SUS-13-002

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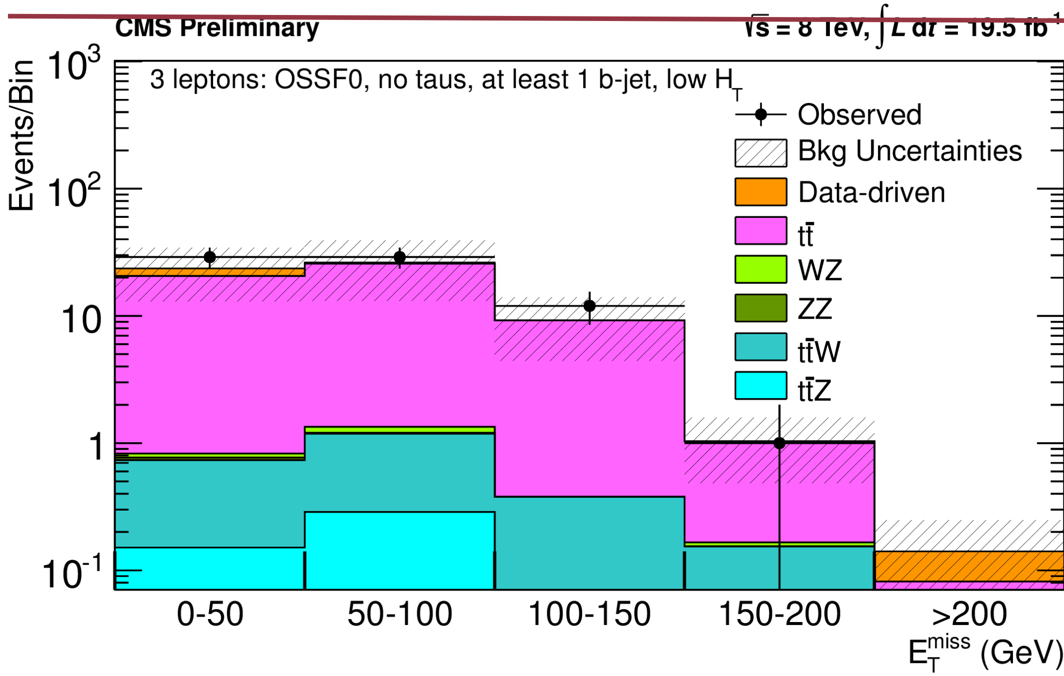
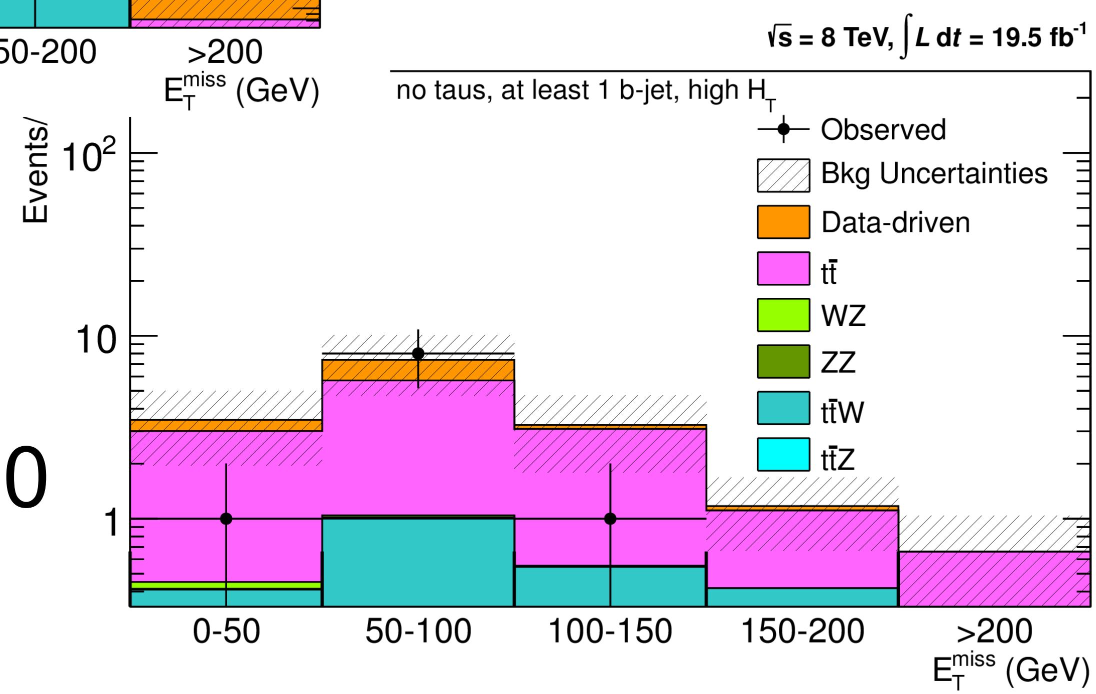
OSSF0 $H_T < 200$	NA	$(100,\infty)$	0	0.11 ± 0.08	0	0.17 ± 0.1	0	0.03 ± 0.04	0	0.04 ± 0.04
OSSF0 $H_T < 200$	NA	(50,100)	0	0.01 ± 0.03	2	0.7 ± 0.33	0	0 ± 0.02	0	0.28 ± 0.16
OSSF0 $H_T < 200$	NA	(0,50)	0	0.01 ± 0.02	1	0.7 ± 0.3	0	0.001 ± 0.02	0	0.13 ± 0.08
OSSF1 $H_T < 200$	off-Z	$(100,\infty)$	0	0.06 ± 0.04	3	0.6 ± 0.24	0	0.02 ± 0.04	0	0.32 ± 0.2
OSSF1 $H_T < 200$	on-Z	$(100,\infty)$	1	0.5 ± 0.18	2	2.5 ± 0.5	1	0.38 ± 0.2	0	0.21 ± 0.1
OSSF1 $H_T < 200$	off-Z	(50,100)	0	0.18 ± 0.06	4	2.1 ± 0.5	0	0.16 ± 0.08	1	0.45 ± 0.24
OSSF1 $H_T < 200$	on-Z	(50,100)	2	1.2 ± 0.34	9	9.6 ± 1.6	2	0.42 ± 0.23	0	0.5 ± 0.16
OSSF1 $H_T < 200$	off-Z	(0,50)	2	0.46 ± 0.18	15	7.5 ± 2	0	0.09 ± 0.06	0	0.7 ± 0.31
OSSF1 $H_T < 200$	on-Z	(0,50)	4	3 ± 0.8	41	40 ± 10	1	0.31 ± 0.15	2	1.5 ± 0.47
OSSF2 $H_T < 200$	off-Z	$(100,\infty)$	0	0.04 ± 0.03	-	-	0	0.05 ± 0.04	-	-
OSSF2 $H_T < 200$	on-Z	$(100,\infty)$	0	0.34 ± 0.15	-	-	0	0.46 ± 0.25	-	-
OSSF2 $H_T < 200$	off-Z	(50,100)	2	0.18 ± 0.13	-	-	0	0.02 ± 0.03	-	-
OSSF2 $H_T < 200$	on-Z	(50,100)	4	3.9 ± 2.5	-	-	0	0.5 ± 0.21	-	-
OSSF2 $H_T < 200$	off-Z	(0,50)	7	8.9 ± 2.4	-	-	1	0.23 ± 0.09	-	-
OSSF2 $H_T < 200$	on-Z	(0,50)	*156	159 ± 34	-	-	4	2.9 ± 0.8	-	-

SM Backgrounds for Two Relevant Channels



HT<200



HT>200

CMS SUS-13-002

t→charm+Higgs: Most Sensitive Channels

Three e/mu's.

OSSF pair	E_T^{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

Signal assuming 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) %

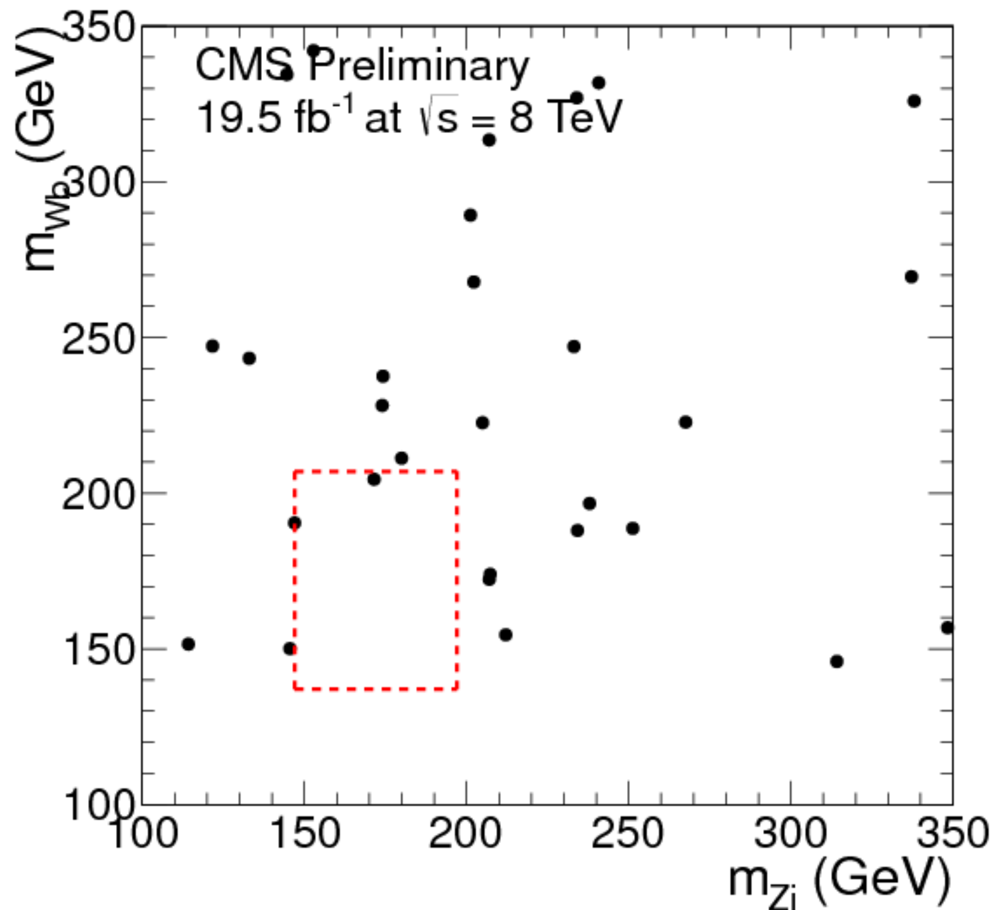
λ_{tch} = $\sqrt{|\lambda^h_{tc}|^2 + |\lambda^h_{ct}|^2} < 0.10$ ~ 2sqrt(BR)

- ATLAS: 0.83% (obs), 0.53% (exp) (h → γγ) (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 (A priori box)



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

BF < 0.05% (7+8 TeV)

Top → Everything but Wb

CMS PAS TOP-12-035

- R_b = BR(t→bW) / BR(t→qW) ➔(1-R_b) = 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 $\mu\mu$.

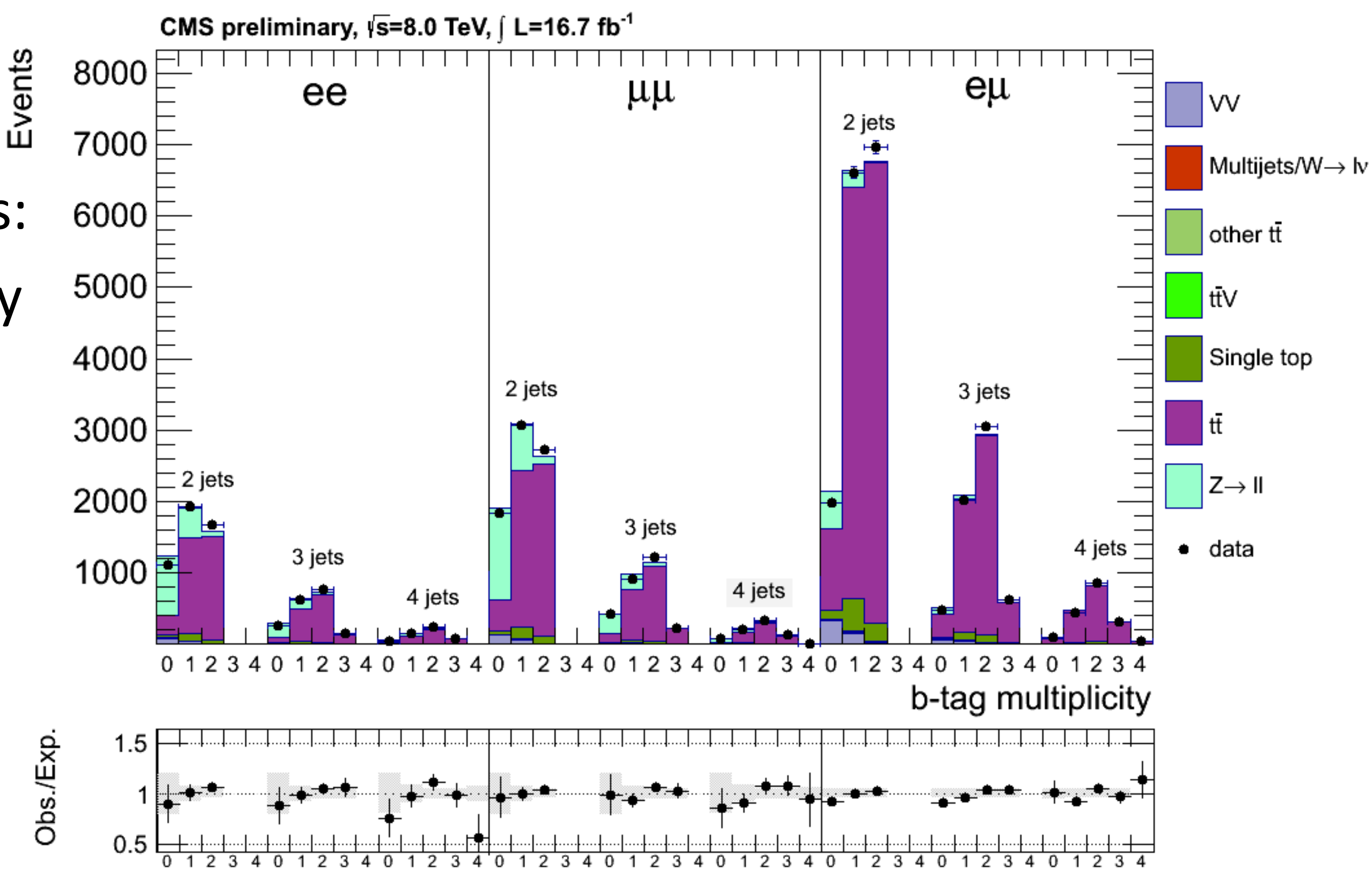
    Lepton-jet invariant mass.

Top → Everything but Wb

CMS PAS TOP-12-035

Probing heavy flavor content of the daughter jets:

Tagging efficiency and mistags



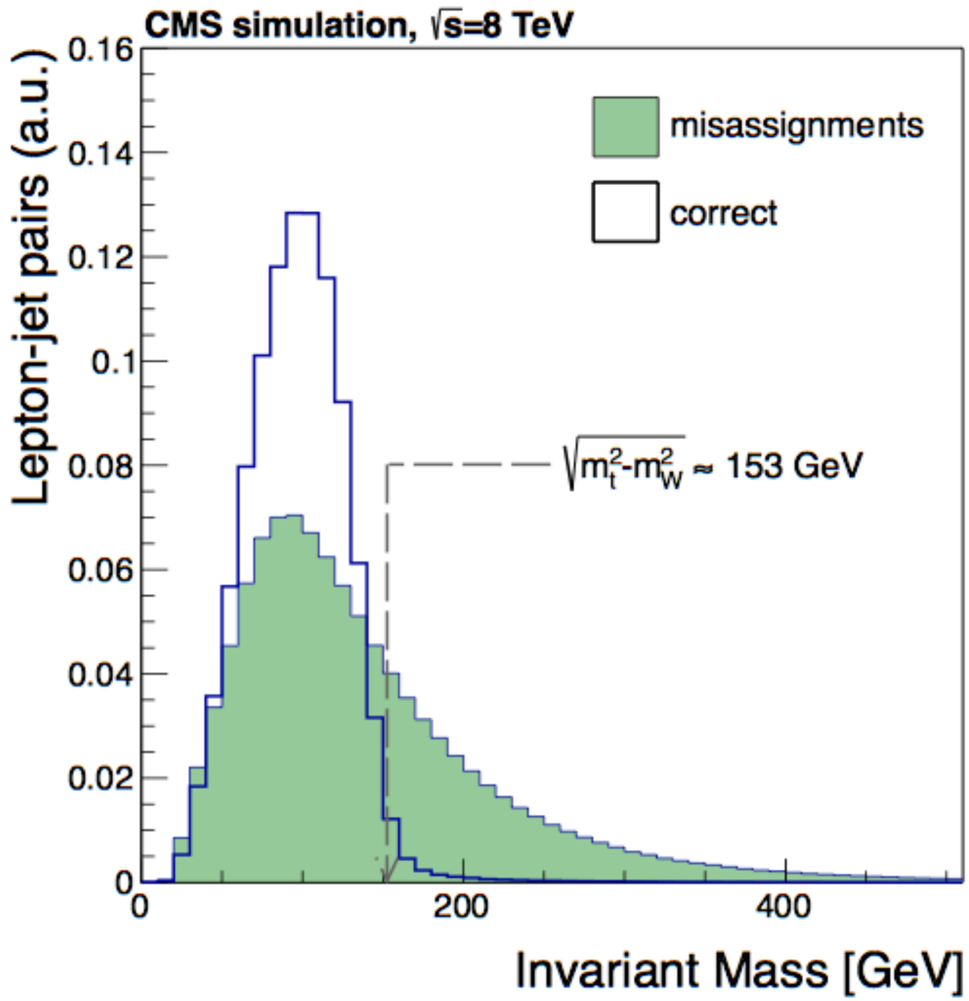
b-tag multiplicity for dilepton flavors vs MC (R=1)

Top → Everything but Wb

CMS PAS TOP-12-035

Probing heavy flavor content of the daughter jets:

Jet misassignment



lepton-jet invariant mass distribution

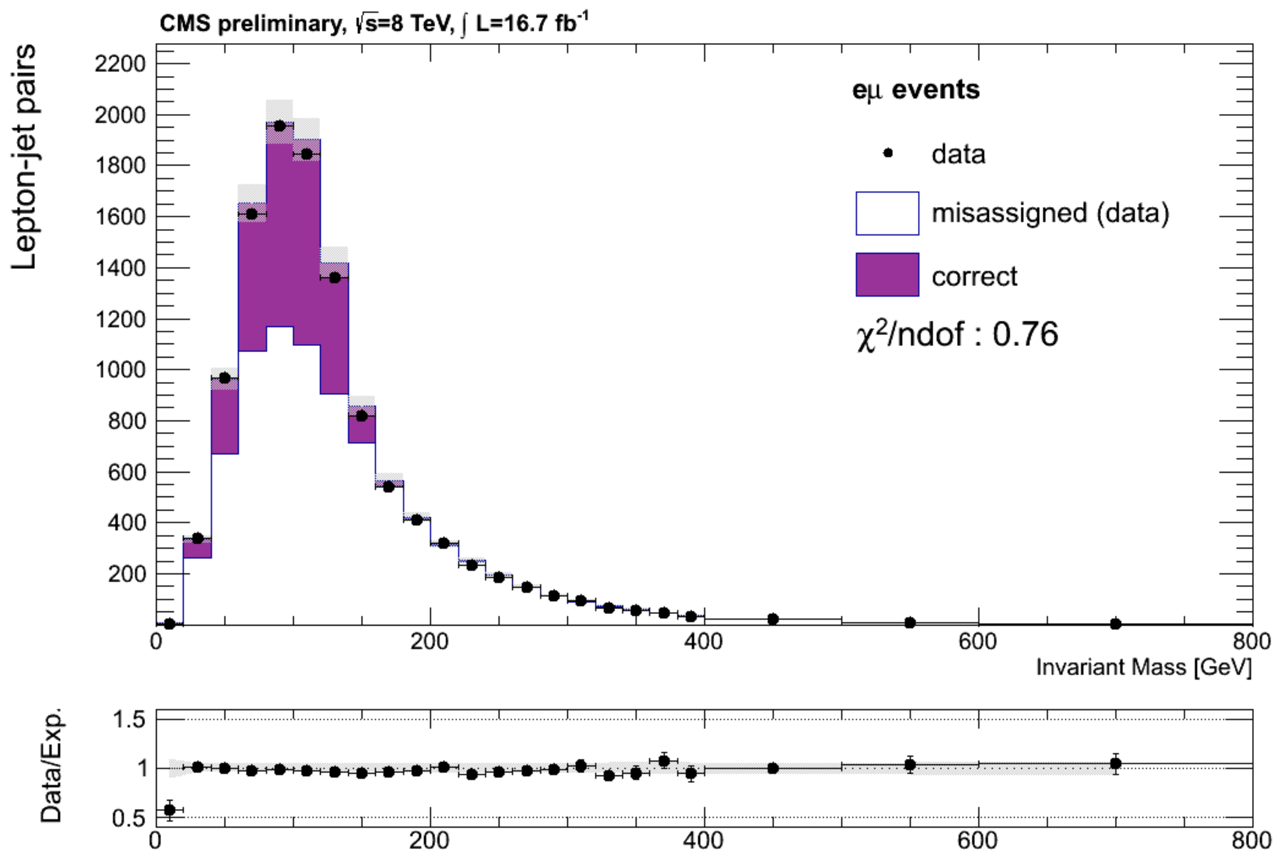
Top → Everything but Wb

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

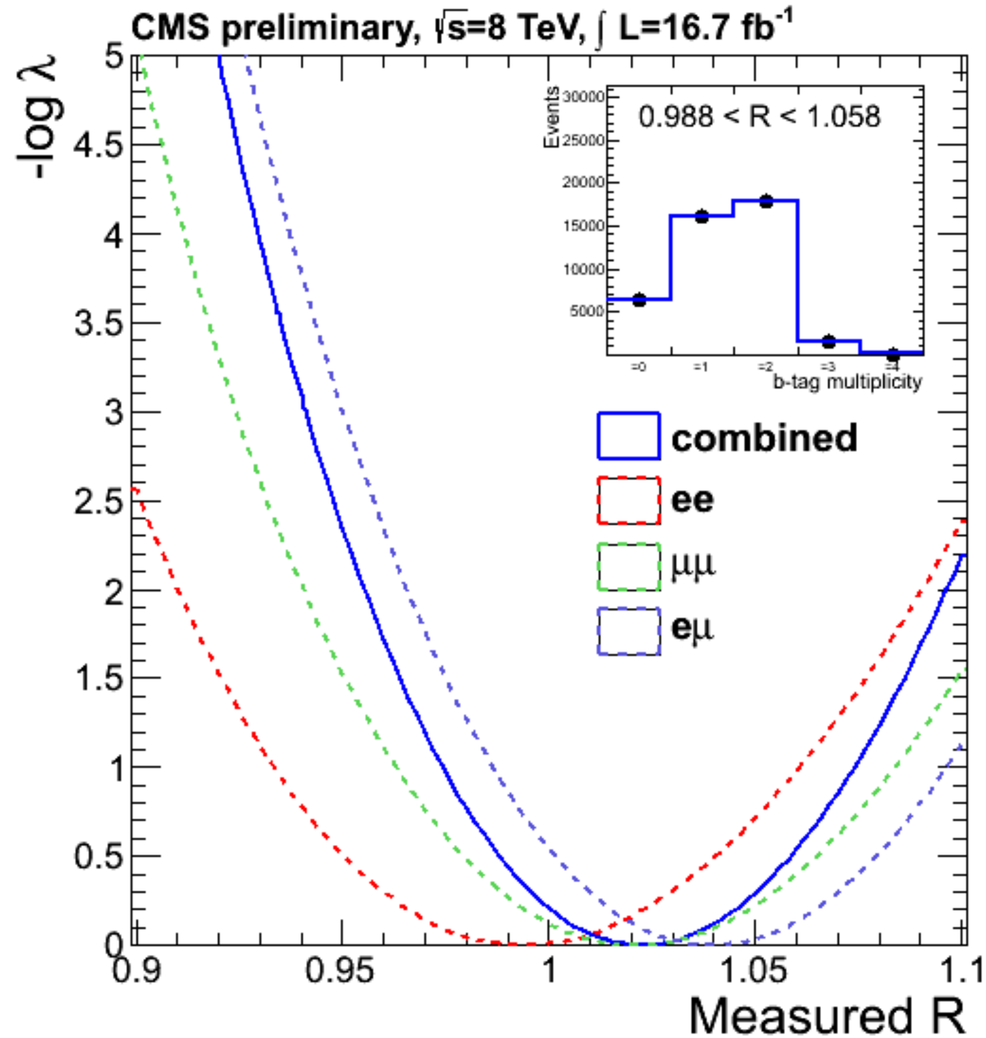
Top → Everything but Wb

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 NumberViolation(BNV)

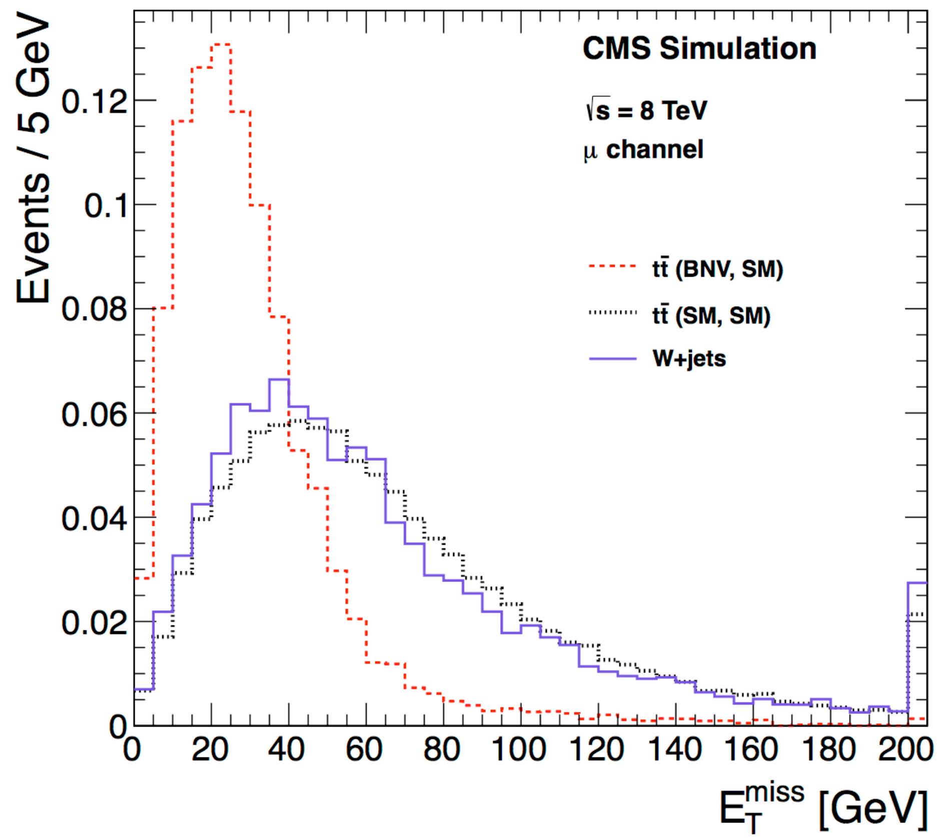
- Supersymmetry, Grand Unified Theories and black-hole physics naturally allow Baryon Number violation (**BNV**).
  - stringent limits from precision measurements in nucleon, tau, HF mesons and Z bosons, but top to μbc not excluded

    (a la proton →lepton + pi0)

- pp → ttbar → (bW)(μbc)

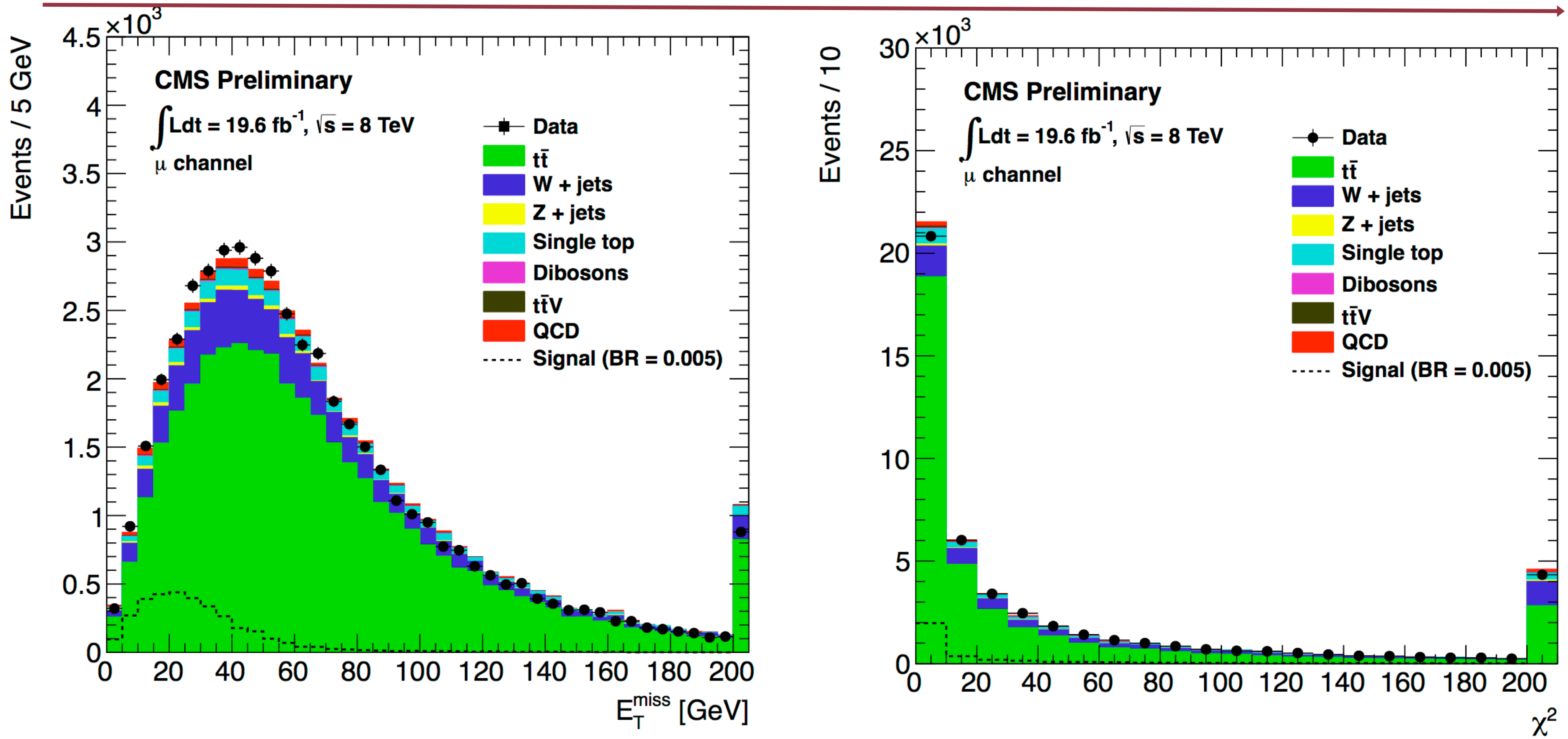
  → (bqq)(μbc)

lepton + 5 jets + low MET



CMS PAS B2G-12-023

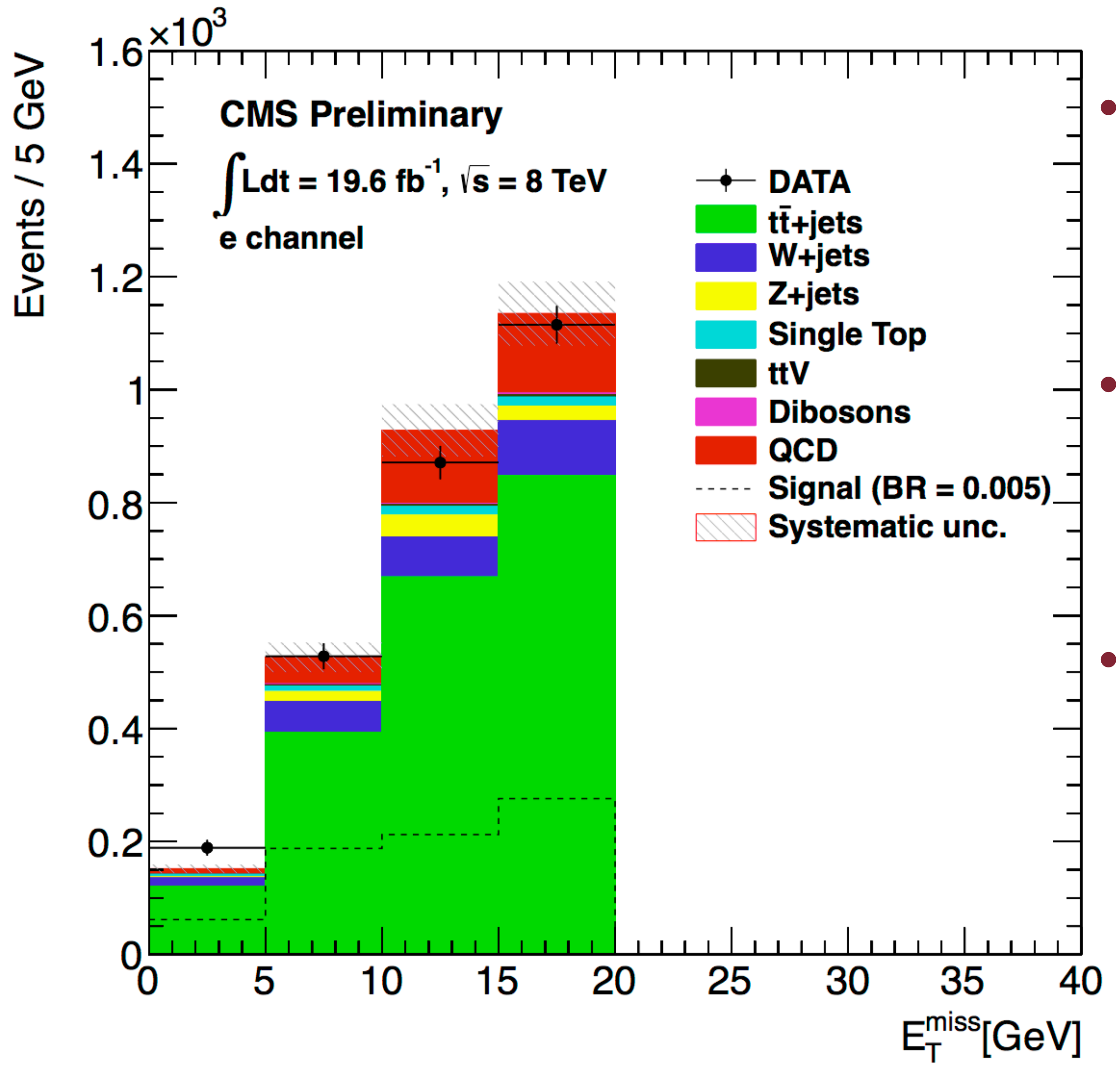
top → μbc Baryon Number Violation



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

CMS PAS B2G-12-023

Baryon Number Violation in top decays



- QCD multijet background from Z+jets
- Limits in μ (e) channels: BF< 0.016 (0.017)
- First limits on BNV in top sector!

Former 4th Generation

Vector-Like T′ ⟶ tZ/tH/bW

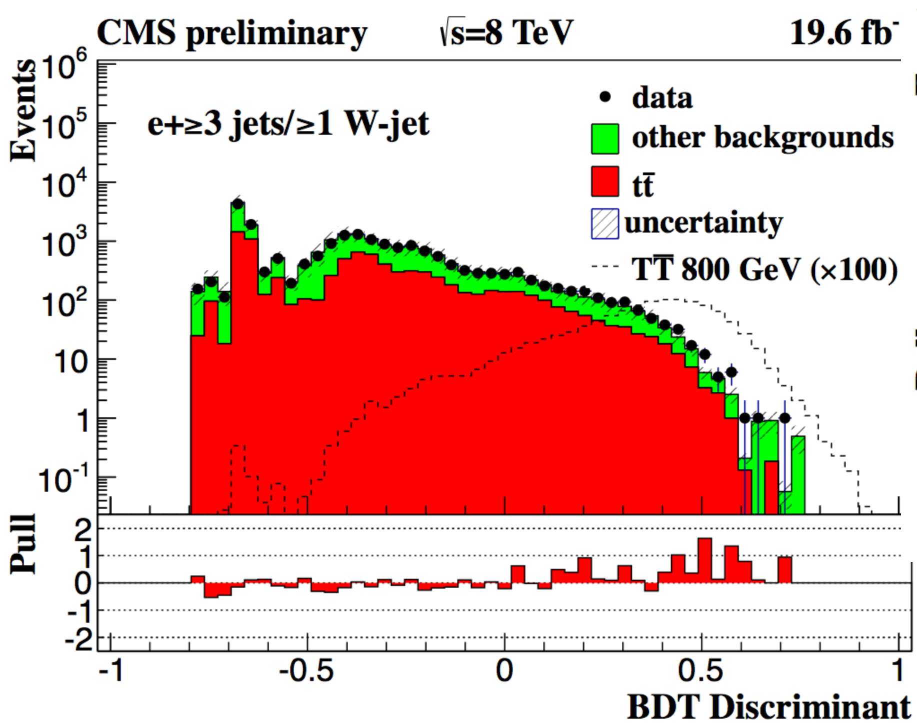
[CMS B2G-12-015]

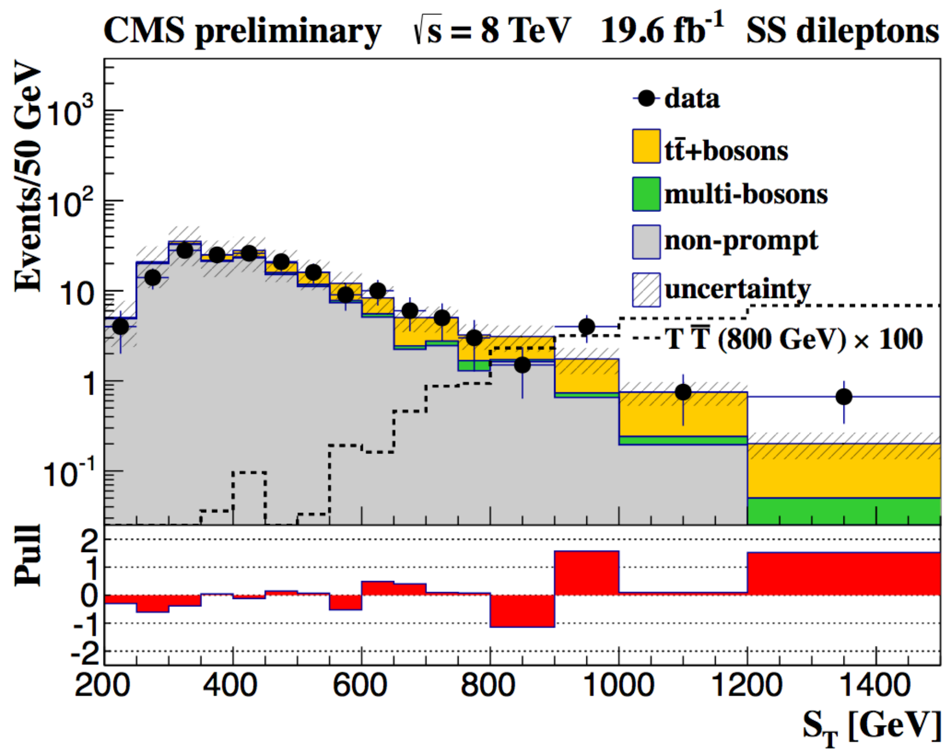
- Targeted/tailored analysis for a pair-produced heavy object with multiple decay possibilities
- Use ST (effective mass) and multiple channels to catch the decay products
- Combined information from single lepton, SS and OS dilepton, trileptons
- Separate bins by W-tags, #jets, #b-jets, H_T, MET, lepton p_T, 3rd/4th jet p_T
  - Opposite-Sign targeting tZ(tZ): on-Z, ≥5 jets, ≥2 b-jets, H_T>500 GeV, S_T>1000 GeV
  - Opposite-Sign targeting bW(bW): off-Z, 2-3 jets, H_T>300 GeV, S_T>900 GeV
  - Same-Sign targeting tZ or tH: ≥3 jets, H_T>500 GeV, S_T>700 GeV + further categorization based on lepton flavor
  - Multilepton category targeting tZ or tH: ≥3 jets, H_T>500 GeV, S_T>700 GeV + further categorization based on lepton flavor

Vector-Like T′ ⟶ tZ/tH/bW

[CMS B2G-12-015]

- OS reso: on-Z, ≥5 jets, ≥2 b-jets, H_T>500 GeV, S_T>1000 GeV
- OS non-reso: off-Z, 2-3 jets, H_T>300 GeV, S_T>900 GeV
- SS: ≥3 jets, H_T>500 GeV, S_T>700 GeV + further categorization based on lepton flavor
- Multileptons: ≥3 jets, H_T>500 GeV, S_T>700 GeV + further categorization based on lepton flavor



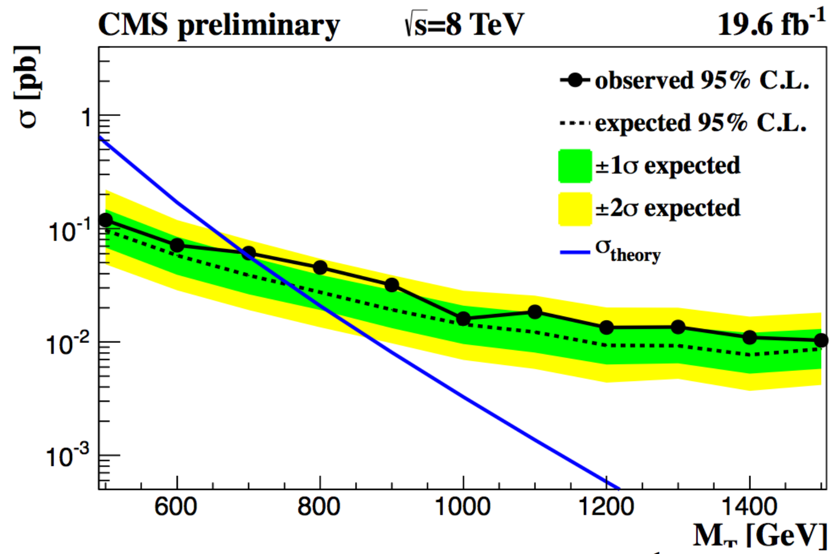


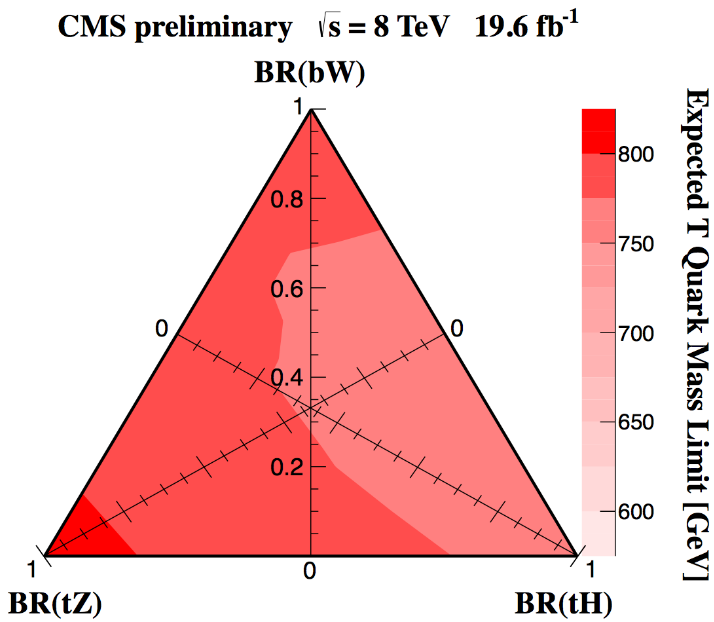
Vector-Like T′⟶ tZ/tH/bW

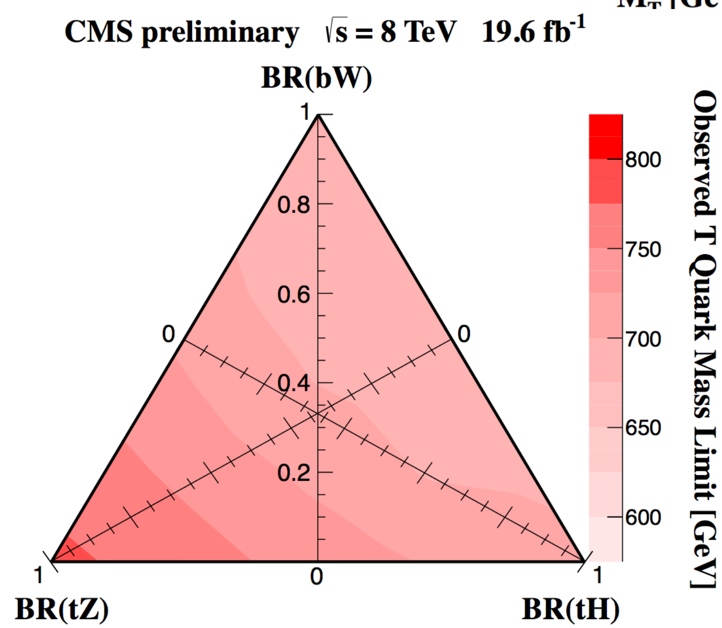
[CMS B2G-12-015]

- Combine all channels to get limits
  - At right: specific BR assumption of BR(T'→bW/tH/tZ)=50/25/25%
  - At bottom: limits for all possible BR

Limits between 690 and 782 GeV





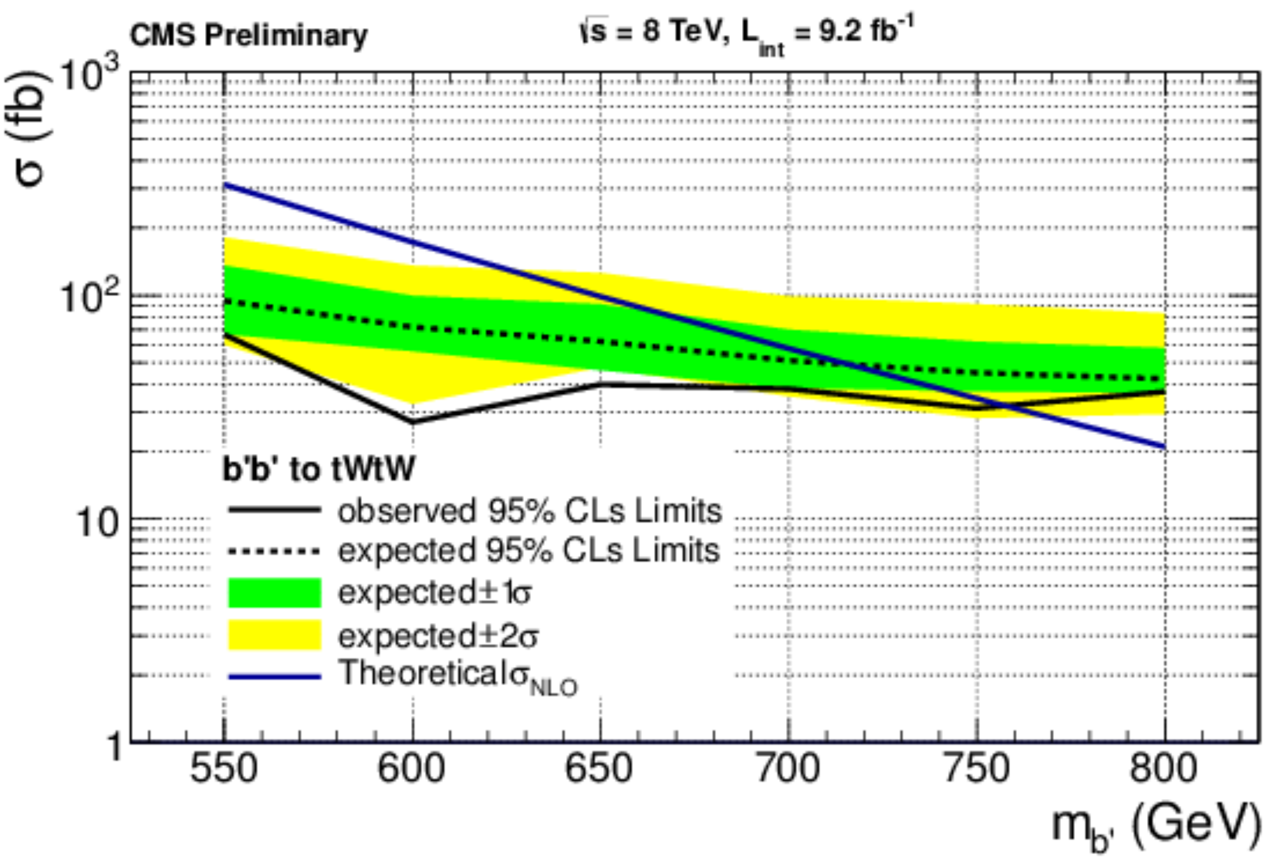


Vector-like b'

- Four mutually exclusive approaches:
  - Multileptons (on-Z and off-Z) - catches everything
  - Same-sign dilepton - catches multilepton inefficiencies
  - Single lepton + jets with V-tagging
  - Resonant Opposite-sign dilepton – good for b' → bZ

Vector-Like b′⟶ multileptons + b-jets

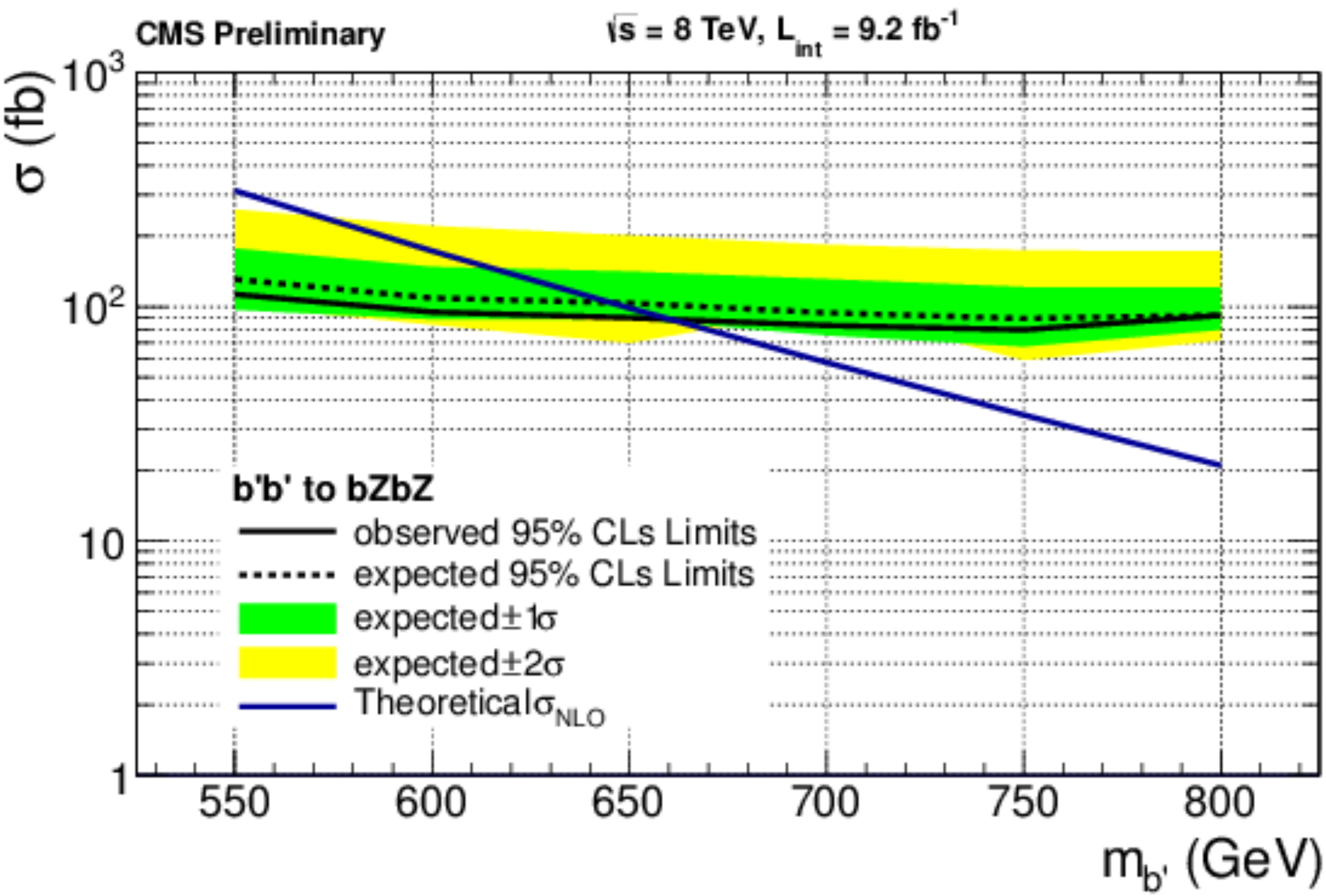
- Illustrates the versatility of a multibinned approach where "signal" and "control" channels are all treated uniformly. Some signals, e.g. b' → bZ show up in the "control" channels.
- (Note 9.2 ifb. Full update soon)



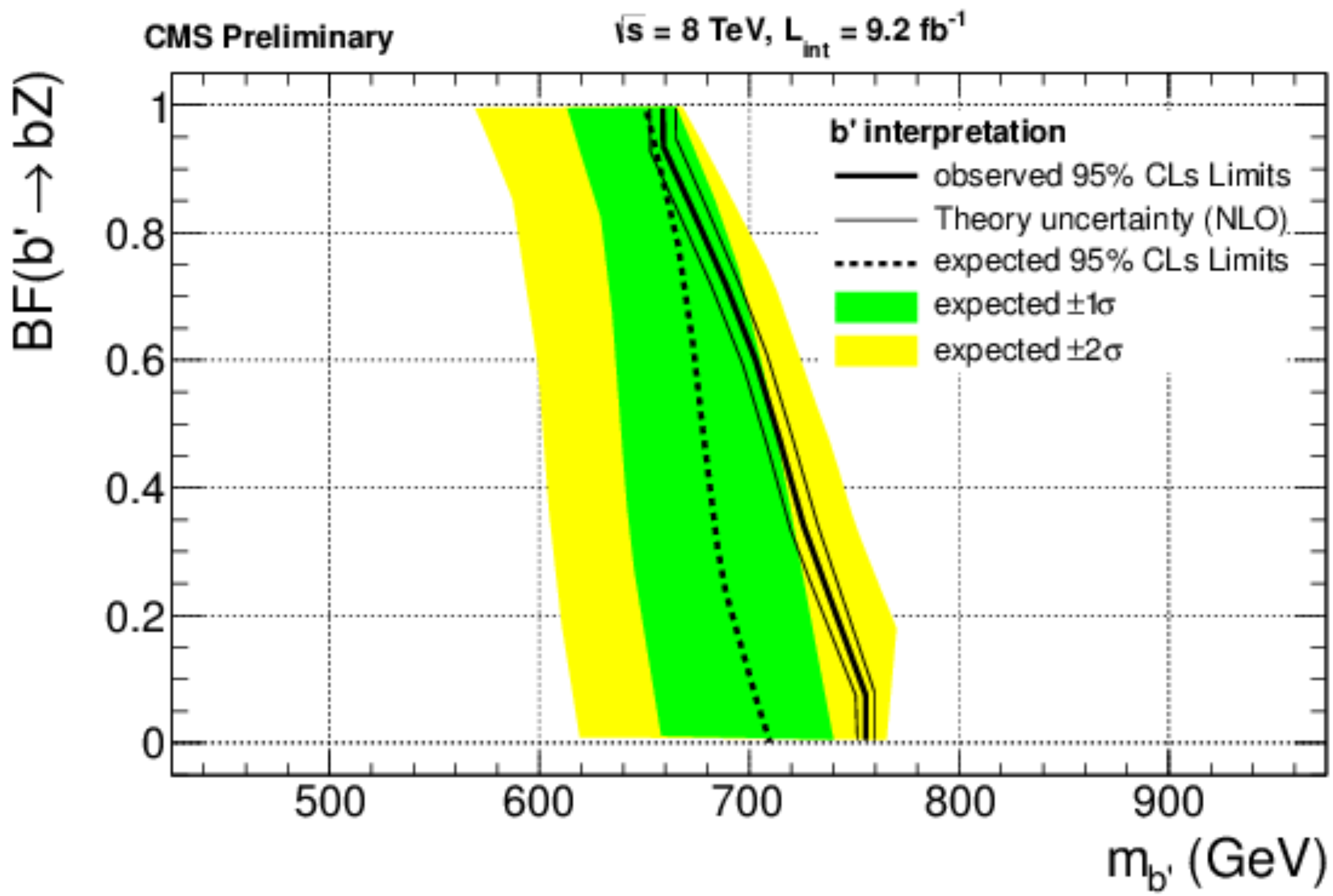
b'b'→tWtW
→bWWbWW

b' – contd (multileptons)

(Note 9.2 ifb. Full update soon)



b' – tW to bZ transition (multileptons)



Note 9.2 ifb. Full update soon with b' → bH included

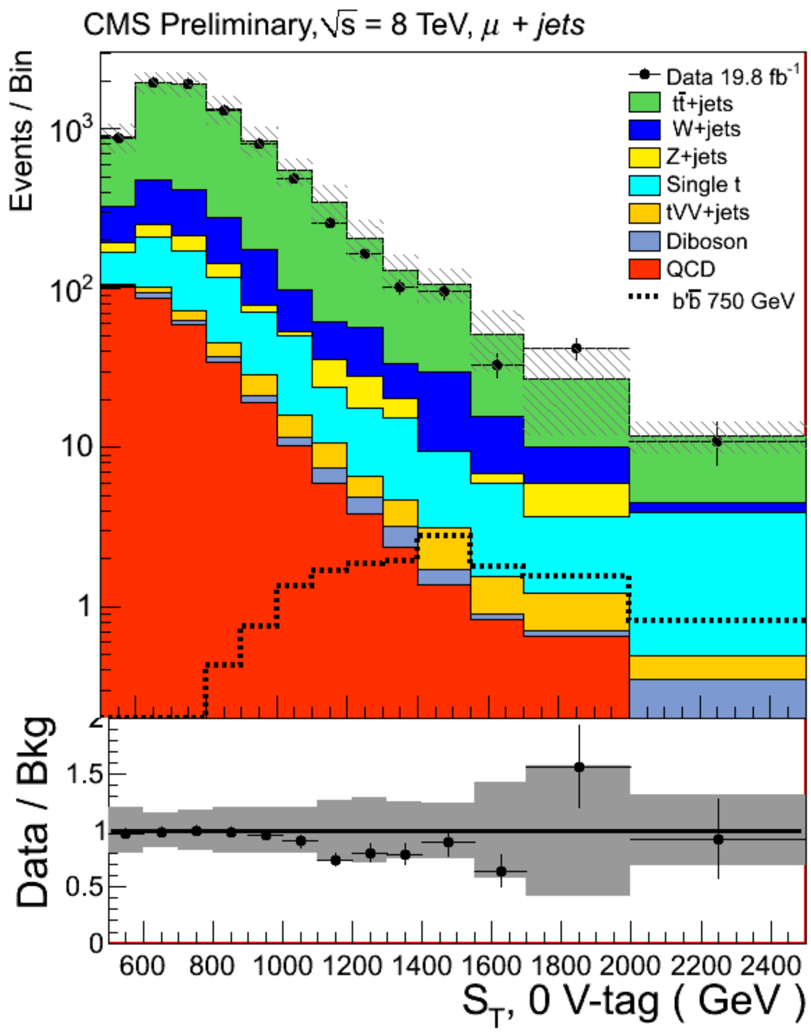
b' → Lepton + jets

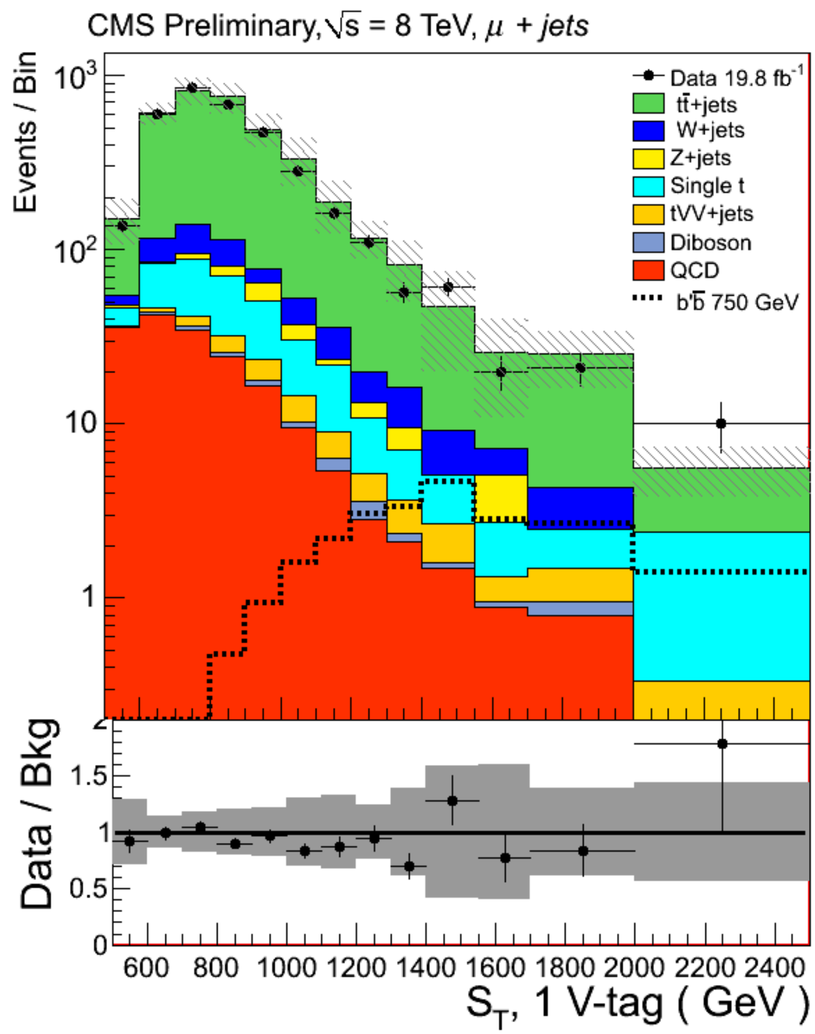
- Best sensitivity when b' → tW → bWW:
  - Single lepton (e/mu)
  - At least four "usual" jets, at least one with b-tag
  - Stiff lepton + MET + jet activity → ST (Effective mass)
  - "V-tags" to get the W [could come from b'→bH→b(WW)]

- "Usual" jets:
  - Anti-KT with R=0.5 (AK5) jets (and b-tag)
- Special "V-tag" algorithm for boosted W,Z:
  - Cambridge-Aachen R=0.8 (pt>200GeV) CA8 jets
  - Then pruning, invariant mass between 50-150GeV etc

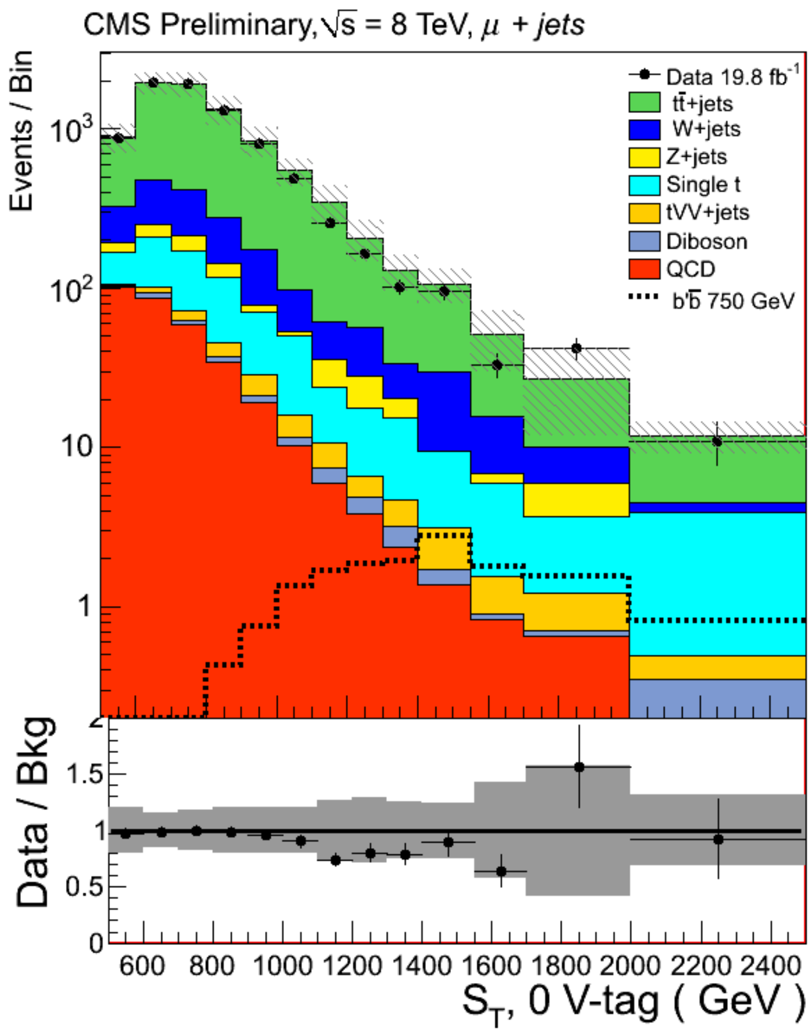
- High ST searches → Background guaranteed to be from ttbar

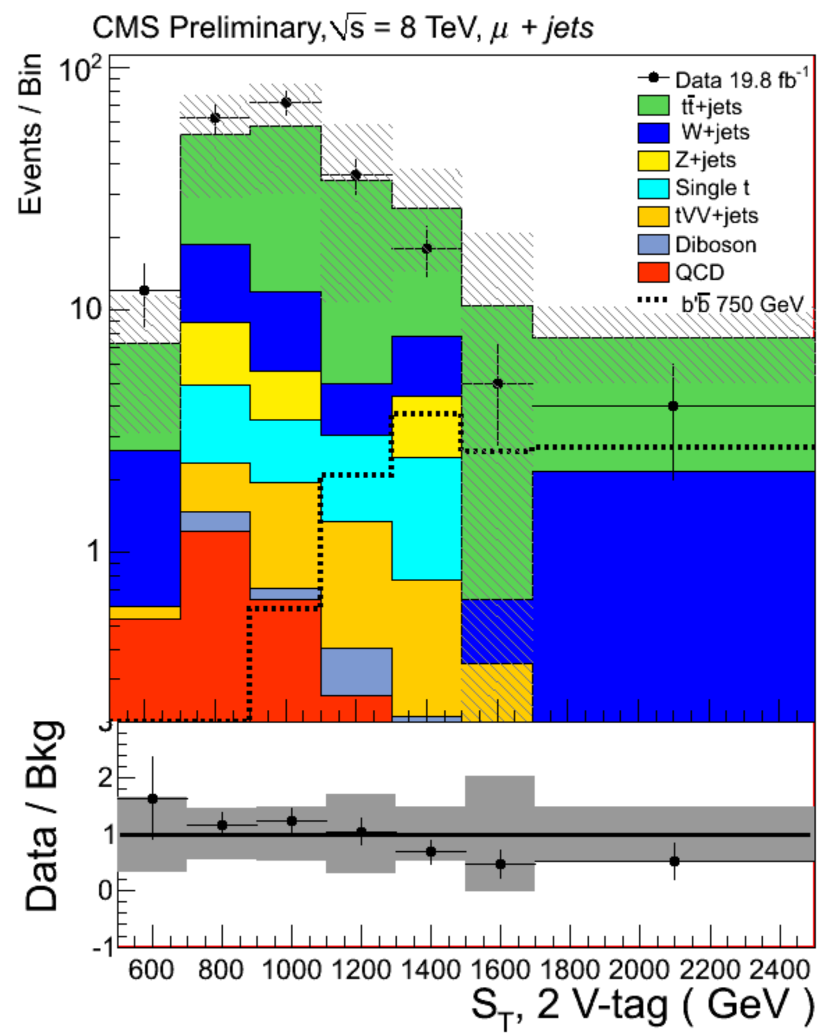
b' → Lepton + jets



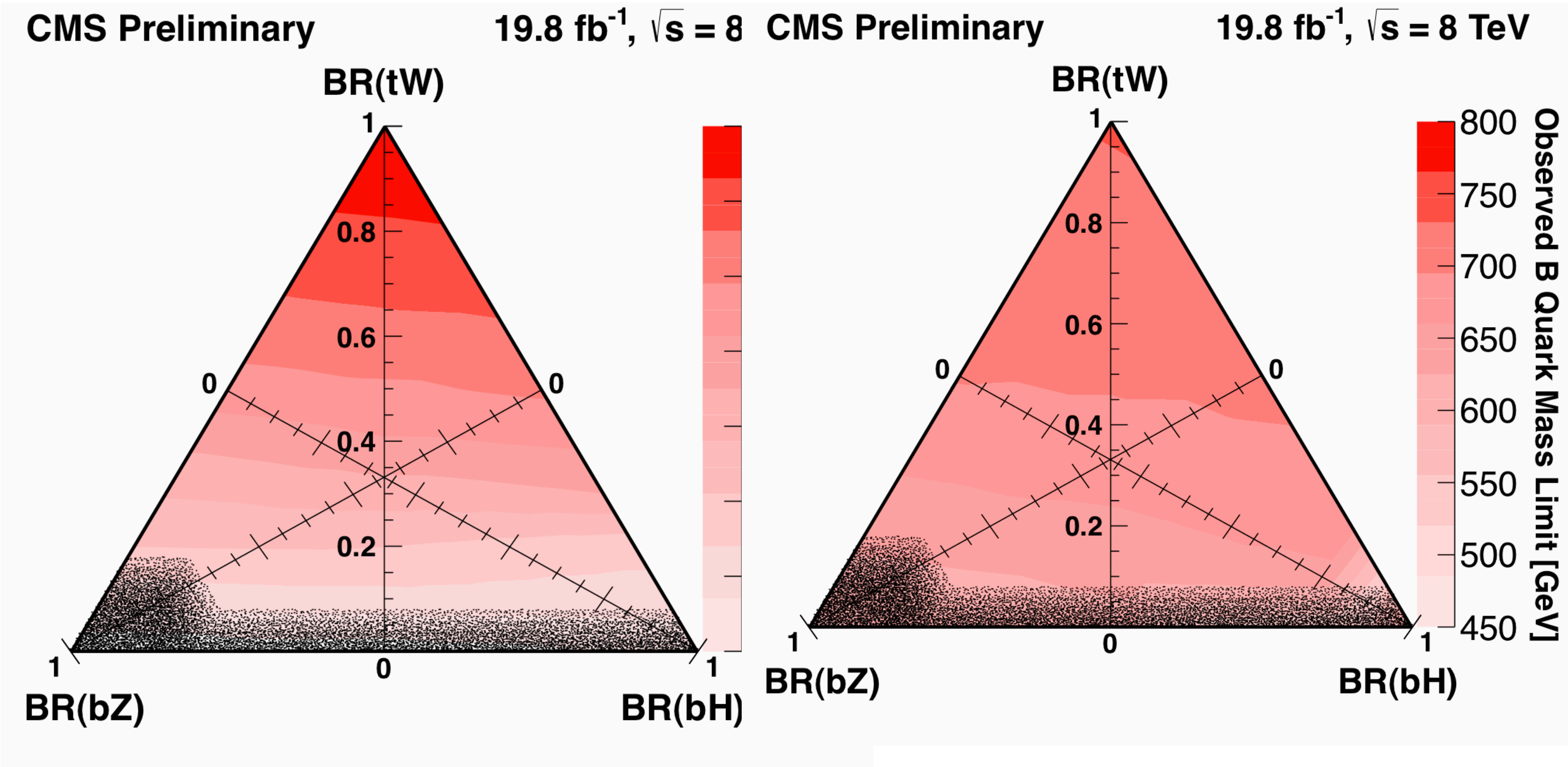


b' → Lepton + jets





b' → Lepton + jets



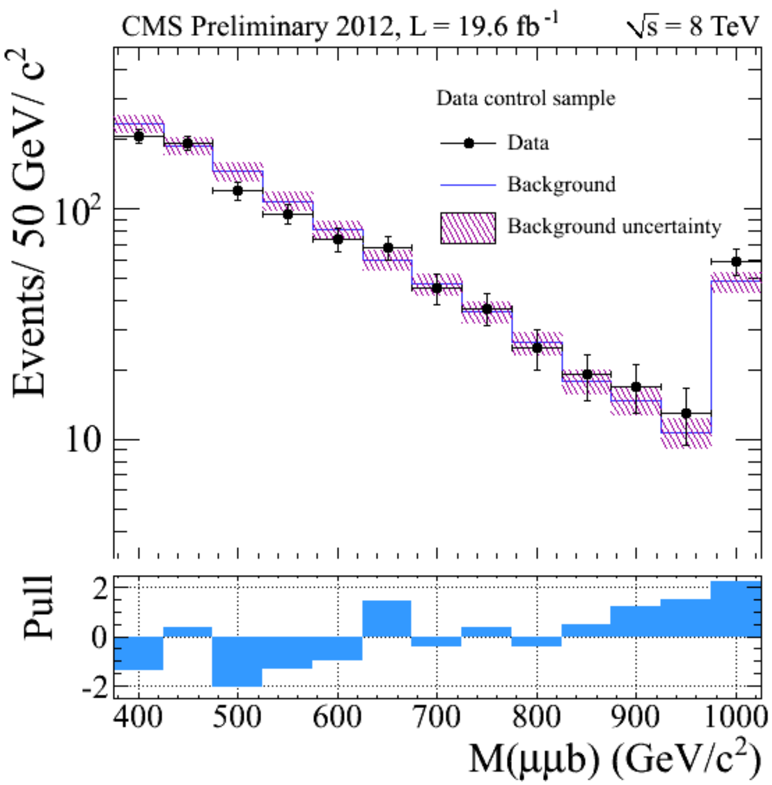
582 GeV to 732 GeV exclusions, depending on the BR

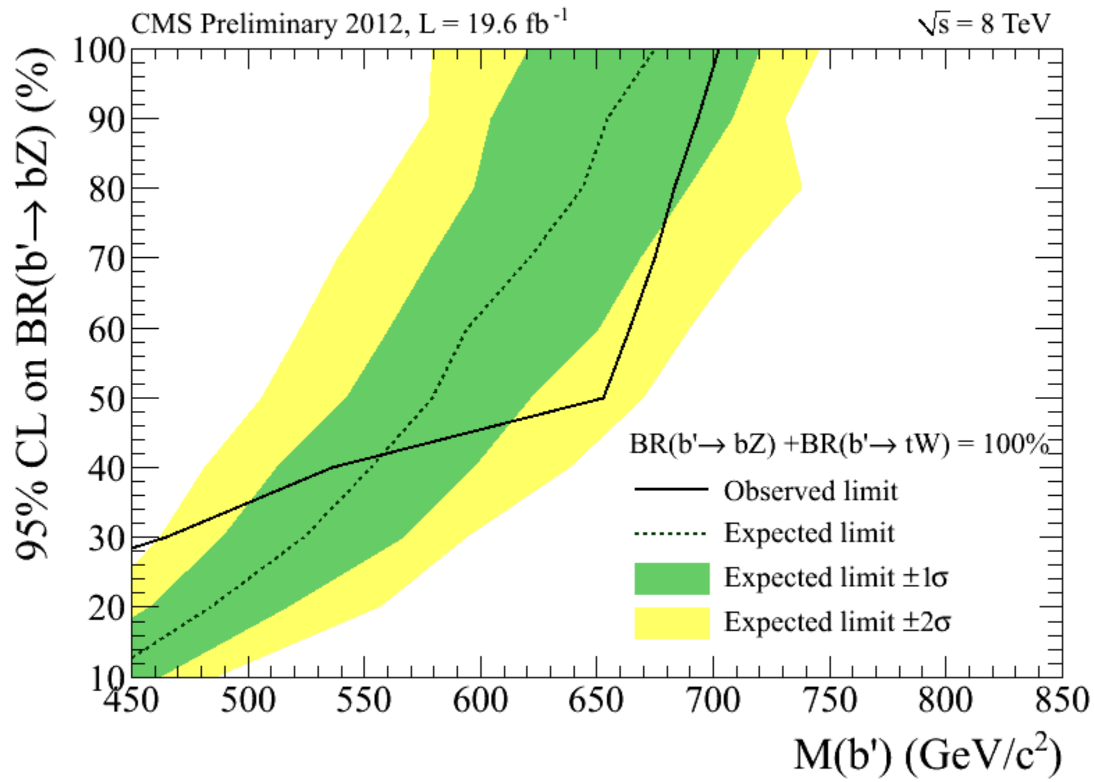
Vector-Like b′⟶ bZ (Resonant)

New! [CMS B2G-12-021]

- Assume decay to bZ or tW
  - Reconstruct a dilepton resonance + b-tagged jets
  - Search for a bZ resonance

700 GeV limit for 100% bZ decay

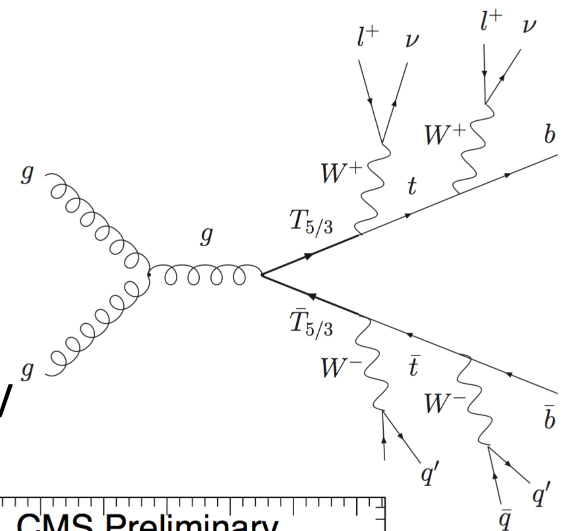


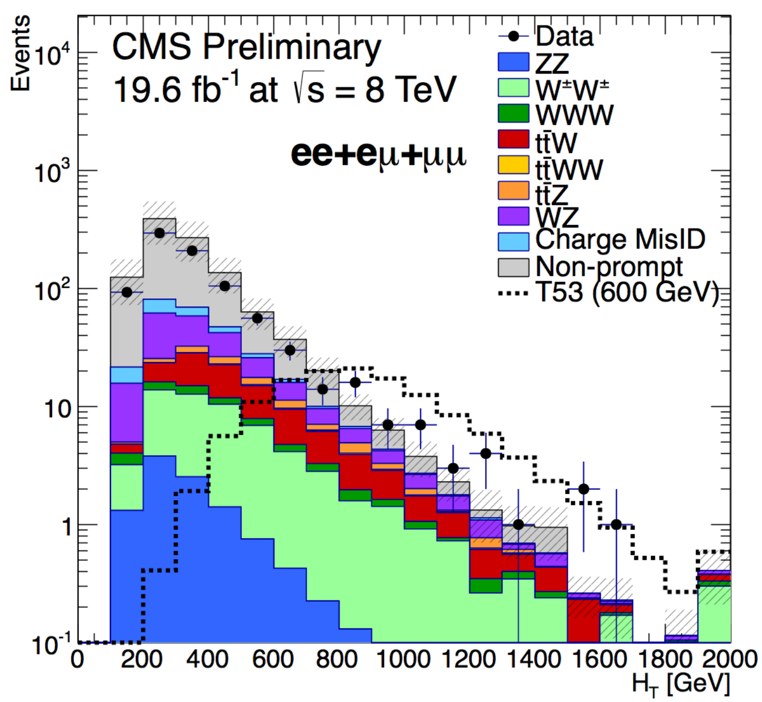


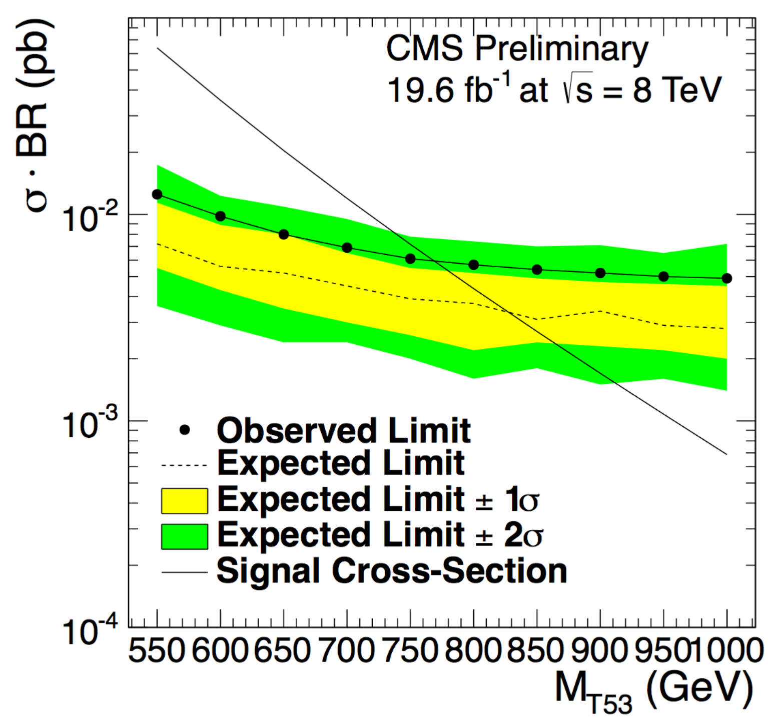
Q=5/3 Top Partners

[CMS B2G-12-012]

- Pair production of charge 5/3 top partner
- 100% decay to tW → bW^+W^+
  - same-sign leptons outside Z window + H_T>900 GeV
  - Require ≥5 "constituents" in addition to two SS leptons
  - Constituent = lepton, jet, V-tagged jet, or top-tagged jet
- 11 events vs. 6.6 ± 2.0 expected; limit mass up to 770 GeV



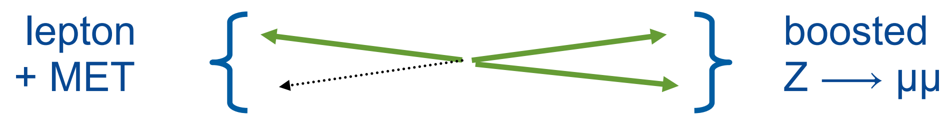




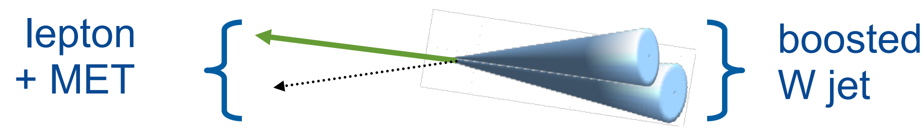
High Mass Dibosons

High-Mass Diboson Signatures

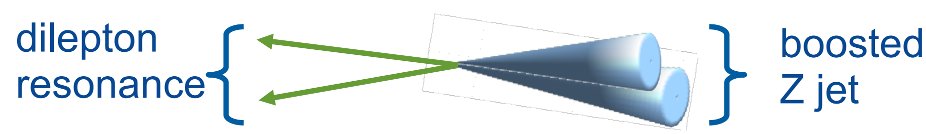
- EXO-12-025:
  $W'/\rho_{TC} \longrightarrow WZ \longrightarrow 3l + MET$



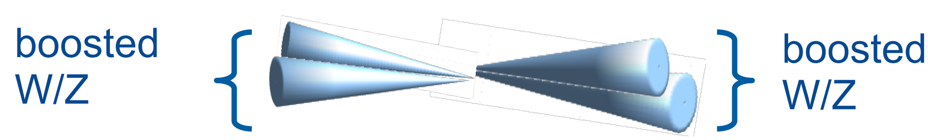
- EXO-12-021:
  $G_{bulk} \longrightarrow WW \longrightarrow l + jet + MET$



- EXO-12-022:
  $G_{bulk} \longrightarrow ZZ \longrightarrow 2l + 2jets$



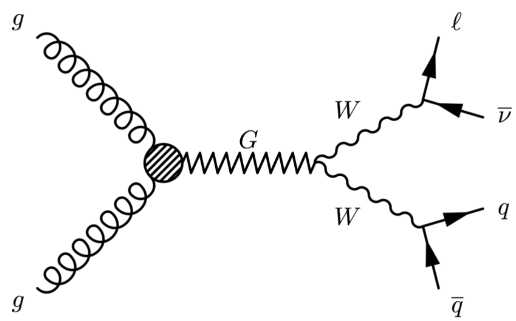
- EXO-12-024:
  $G_{RS} \longrightarrow WW/ZZ$ and $W' \longrightarrow WZ$



...and other searches underway

Semileptonic WW

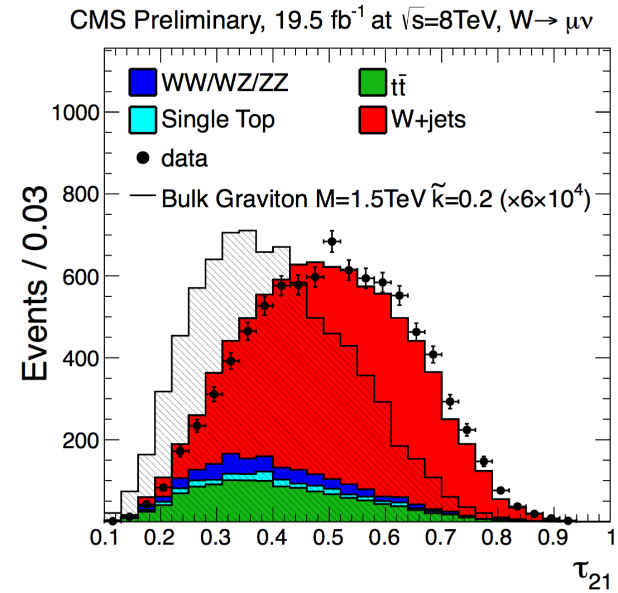
[CMS EXO-12-021]

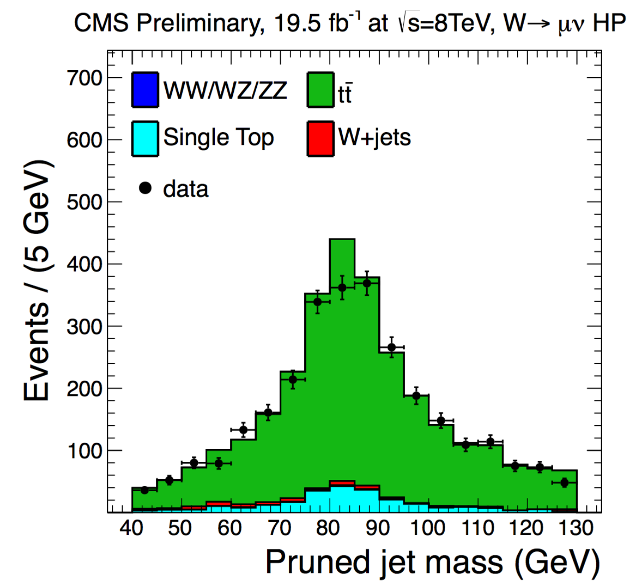


- Search for WW resonance at high mass
- Identify boosted W-jets with "N-subjettiness"
  - Ratio of 2-to-1 jets: $\tau_2/\tau_1 = \tau_{21}$

$$\tau_N = \frac{1}{d_0} \sum_k p_{T,k} \min\{\Delta R_{1.k}, \Delta R_{2.k}, ..., \Delta R_{N.k}\}$$

  - N-subjettiness: $\tau_{21} < 0.5$ for high purity, and $0.5 < \tau_{21} < 0.75$ for low
- Study performance of "W-tagging" in data
  - derive data/MC scale factor (SF) for each analysis
  - error on "substructure SF" ⟶ systematic on signal
- Study merged hadronic W's from tt
  - boosted enough to merge jets from W
  - not so boosted that the b quark also merges

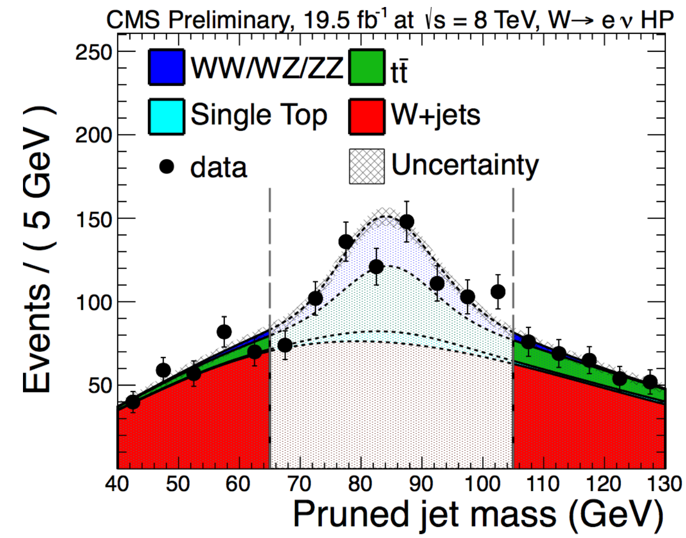


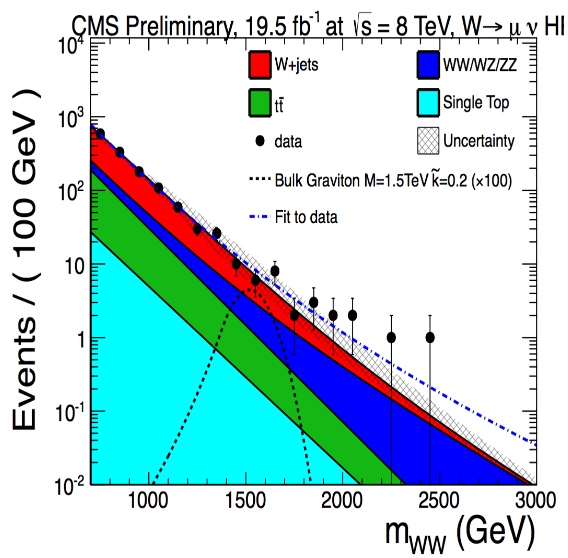


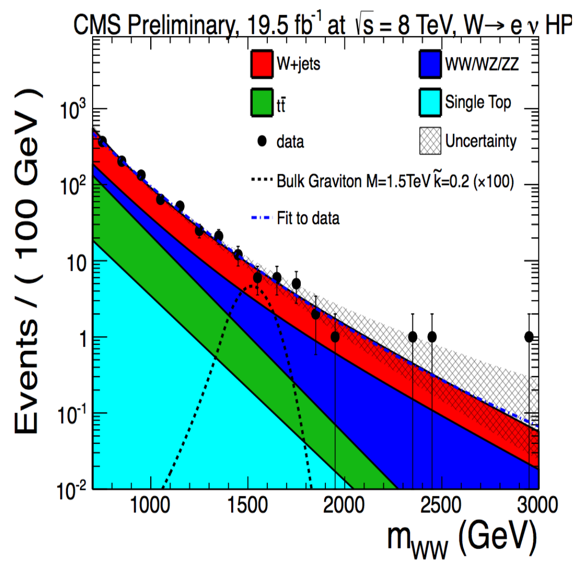
Semileptonic WW

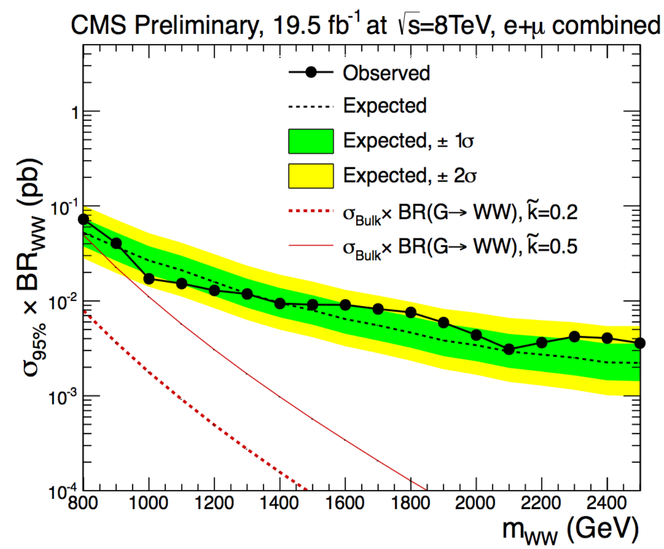
[CMS EXO-12-021]

- Dominant W+jets backgrounds data-driven
  - Side-band region M_{jet}=[40,65] GeV
  - W signal region M_{jet}=[65,105] GeV
  - W+jets: M_{WW} obtained from scaled M_{jet} sidebands
- Limits set on bulk graviton production times BR
  - 70 fb for 0.8 TeV mass
  - 3 fb for 2.5 TeV mass





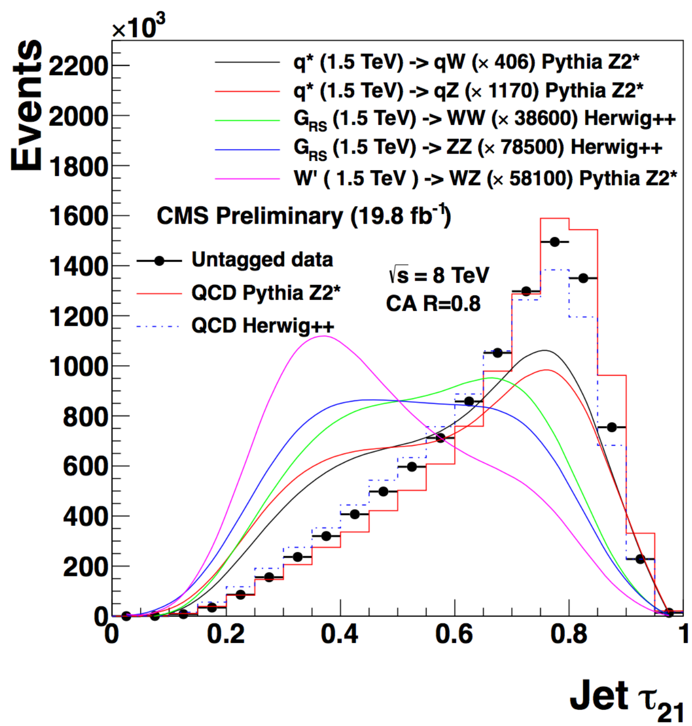


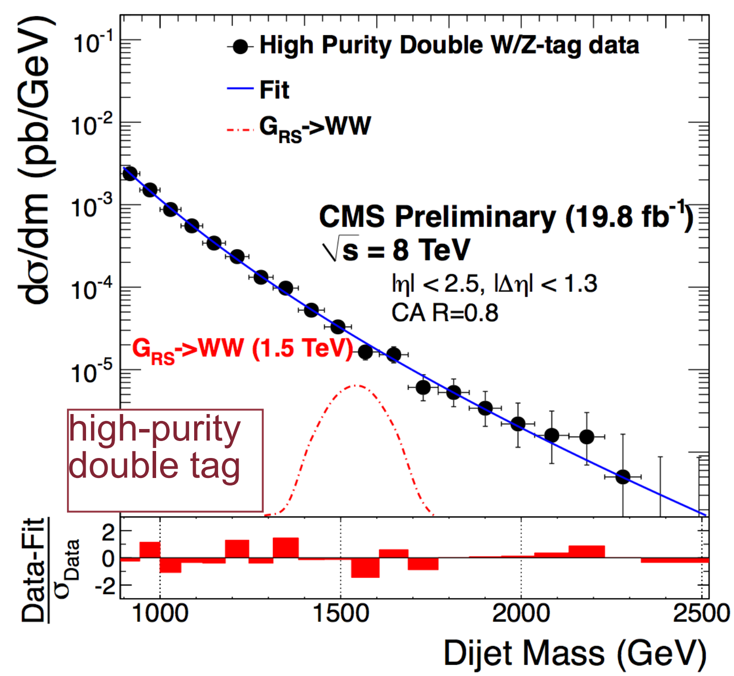


WW / ZZ / WZ in dijets

[CMS EXO-12-024]

- $G_{RS} \longrightarrow WW/ZZ$ and $W' \longrightarrow WZ$ in dijets
  - Fully hadronic VV decays, $W \longrightarrow jj$ and/or $Z \longrightarrow jj$
  - Jets from W/Z typically boosted and merged into a single jet
  - QCD only significant background, suppressed by $|\eta_{jet1} - \eta_{jet2}| < 1.3$
- Each jet is required to pass the "W/Z-tagger"
  - pruned jet mass: $70 < M_{jet} < 100$ GeV/c^2
  - N-subjettiness (same as previous): $\tau_{21} < 0.5$ for high purity, and $0.5 < \tau_{21} < 0.75$ for low

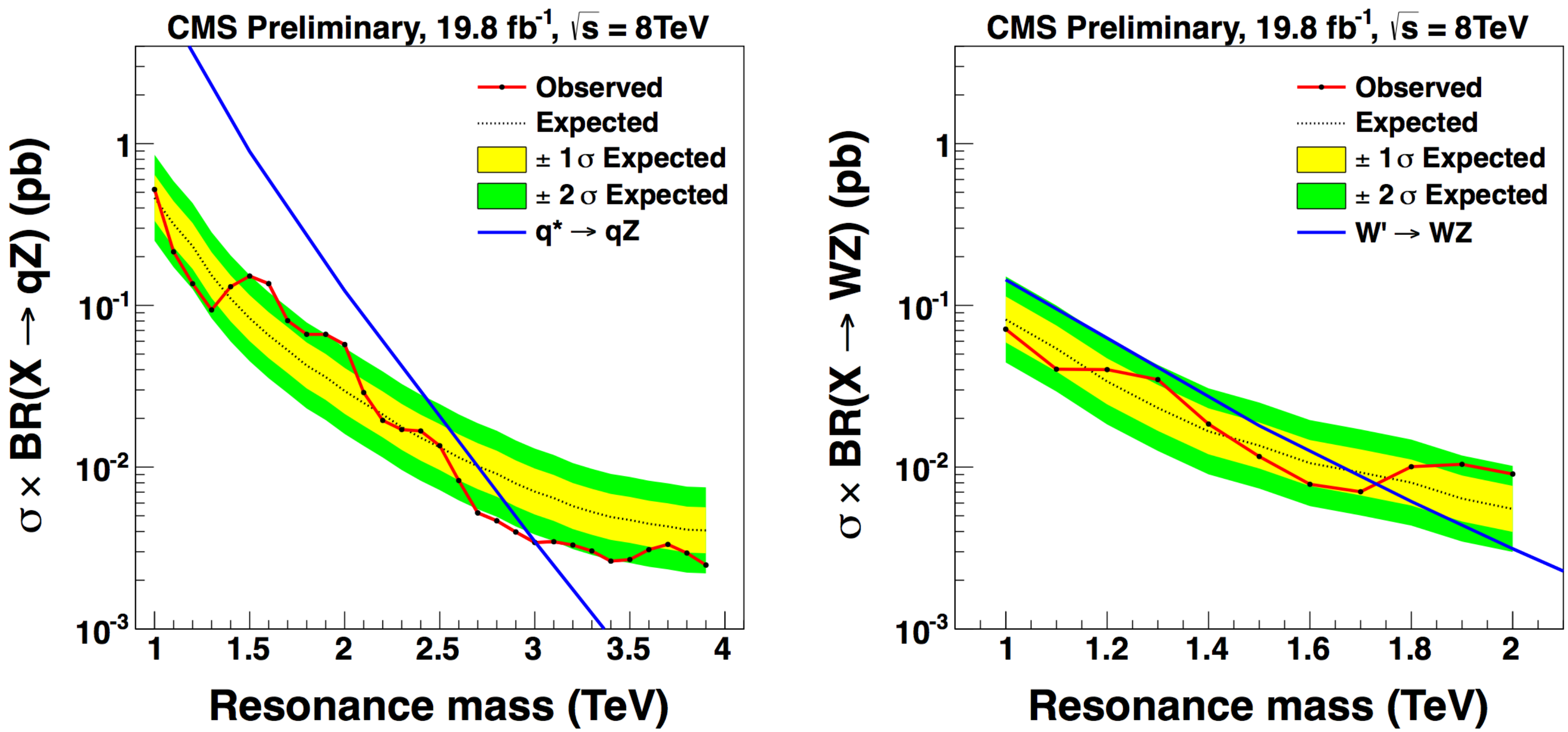




high-purity double tag

WW / ZZ / WZ in dijets

[CMS EXO-12-024]



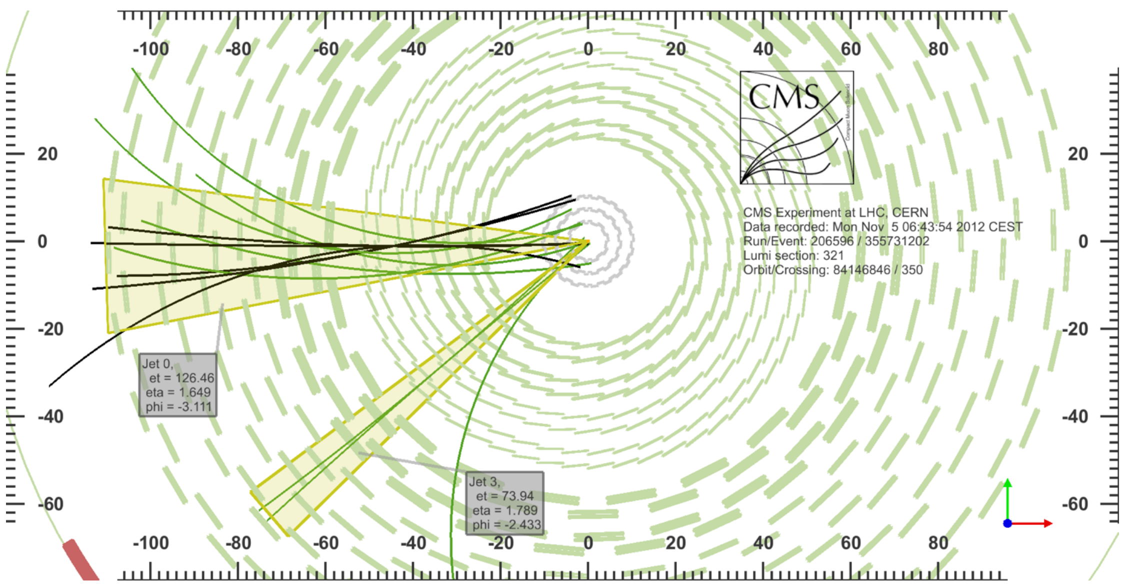
- G_{RS1} (k/M_{PL}=0.1) ⟶ WW(ZZ) excluded in mass range 1.0 to 1.59(1.17) TeV
- W' ⟶ WZ excluded in mass range 1.0 to 1.73 TeV
- q* ⟶ qW(qZ) excluded in mass range 1.0 to 3.23(3.00) TeV

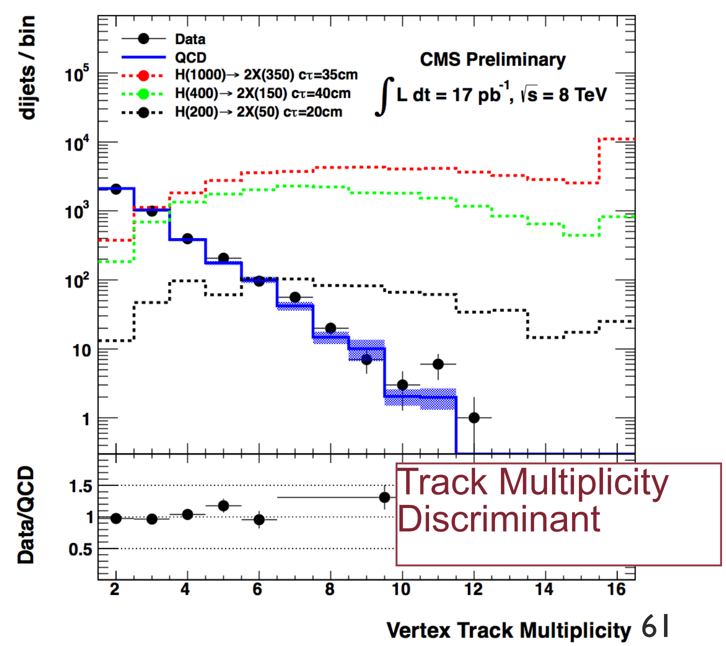
Displaced Jets, Monojets, Monolepton, DM

Displaced Jets

[CMS EXO-12-038]

- Massive long-lived particles can decay to (displaced) jets
  - Split SUSY, RPV SUSY, Gauge Mediated SUSY, Hidden Valley models, etc.
  - gg ⟶ H ⟶ XX ⟶ (qq) (qq)
  - M_H = [200, 400, 1000] GeV, M_X = [50, 150, 350] GeV, $c\tau_X$ = [3, 30, 300] cm
- Search for events with dijets from a common, displaced vertex
  - Trigger: events with H_T > 300 GeV and ≥ 2 jets with small fraction of prompt tracks
  - Offline: form multivariate discriminant based on vertex track multiplicity, fraction of tracks with positive d0, and variables from a dedicated track clustering algorithm



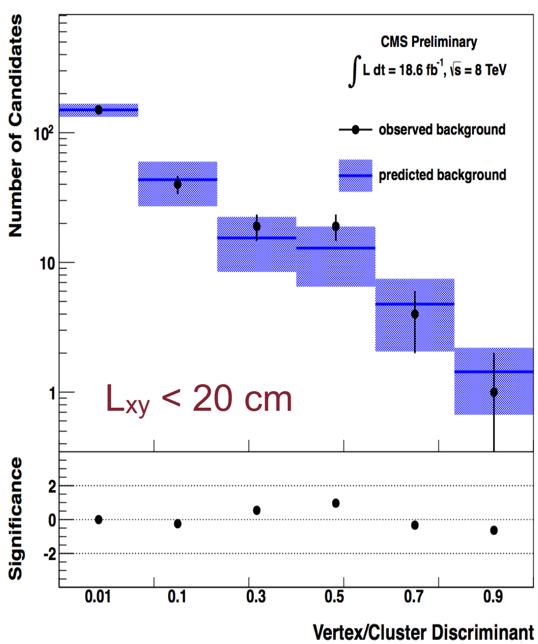


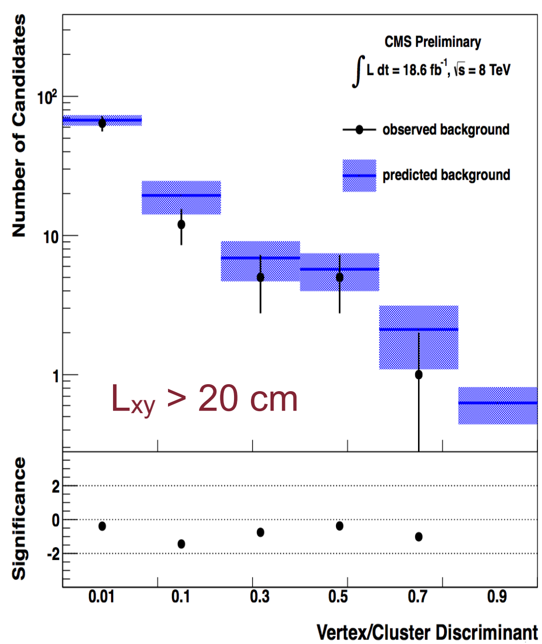
Displaced Jets

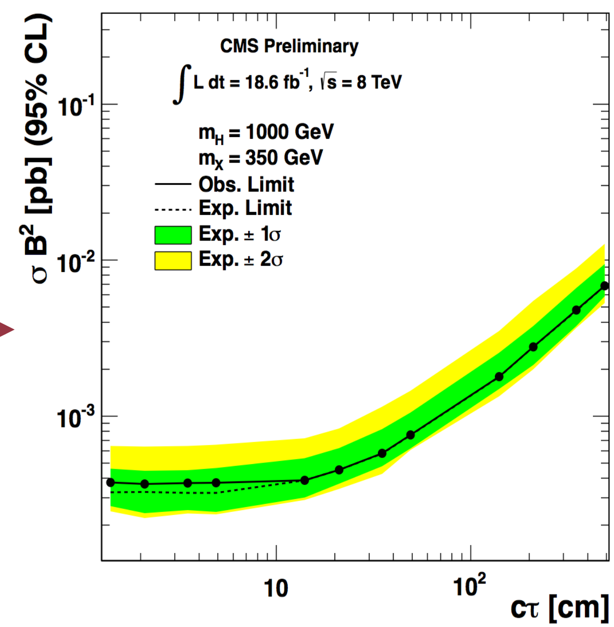
[CMS EXO-12-038]

- Background prediction with ABCD technique: jet1, jet2, secondary vertex details
- "Cut & count" optimized for L_{XY} < 20 cm and > 20 cm
- For X^0 mean proper lifetimes of 0.1 to 200 cm, limits typically 0.3−300 fb.

$\mathbf{L_{xy}}$	$< \mathbf{20\ cm(low)}$	$> \mathbf{20\ cm(high)}$
prompt tracks	≤ 1	≤ 1
prompt energy fraction	< 0.15	< 0.09
vertex/cluster disc.	> 0.9	> 0.8
expected background	$1.60 \pm 0.26(stat.) \pm 0.51(syst.)$	$1.14 \pm 0.15(stat.) \pm 0.52(syst.)$
observed	**2**	**1**

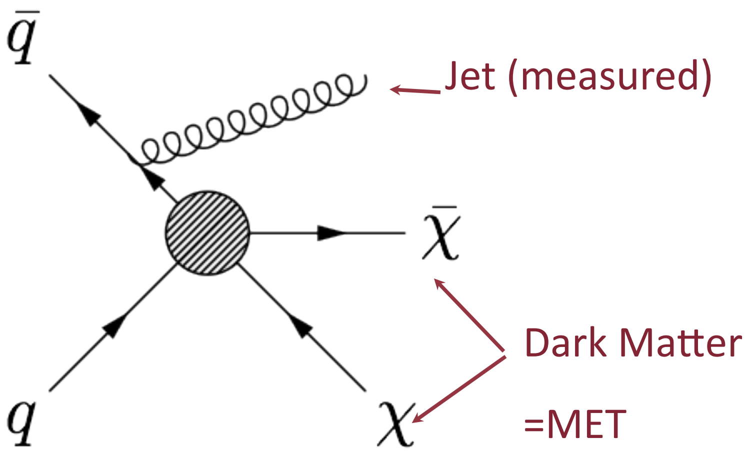






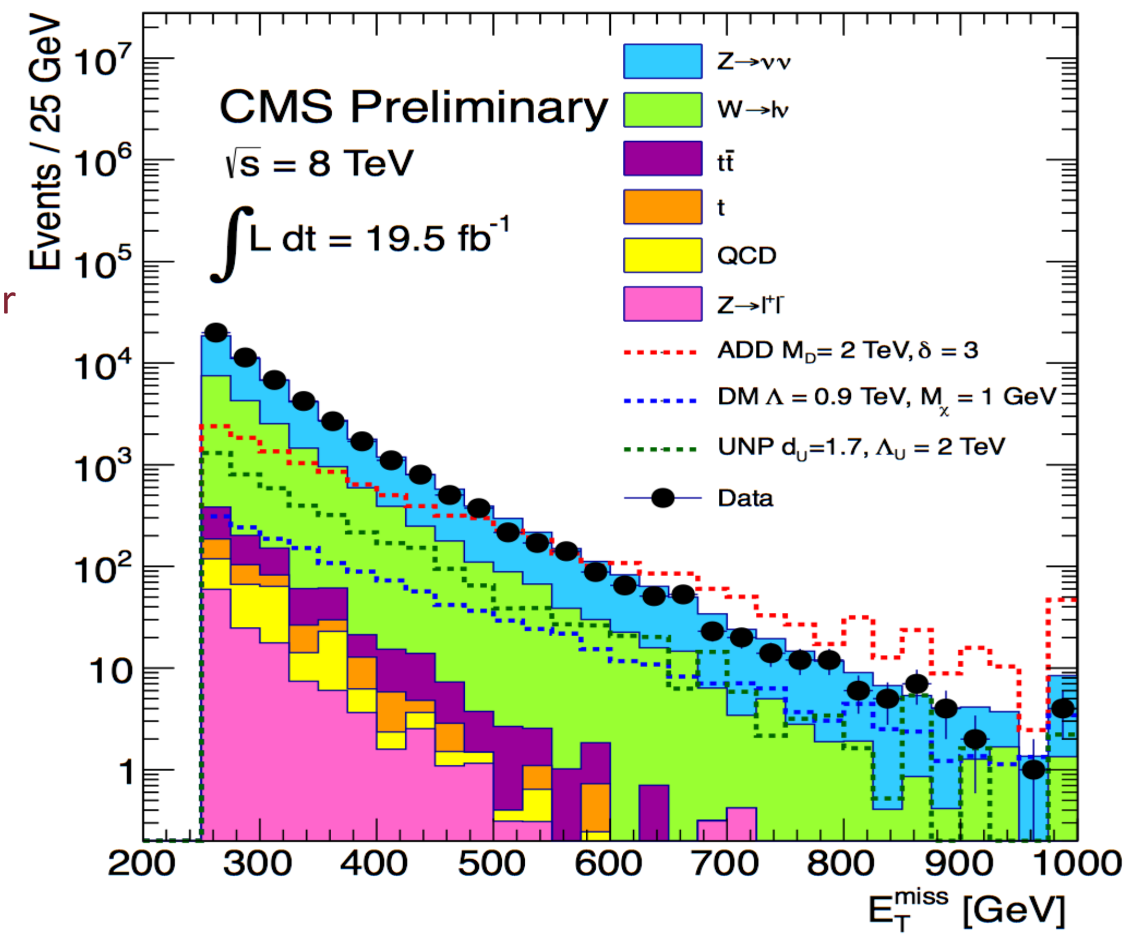
Dark Matter and ADD from Monojets

[CMS EXO-12-048]



Best limits expected with

E_T^{miss} > 350–400 GeV



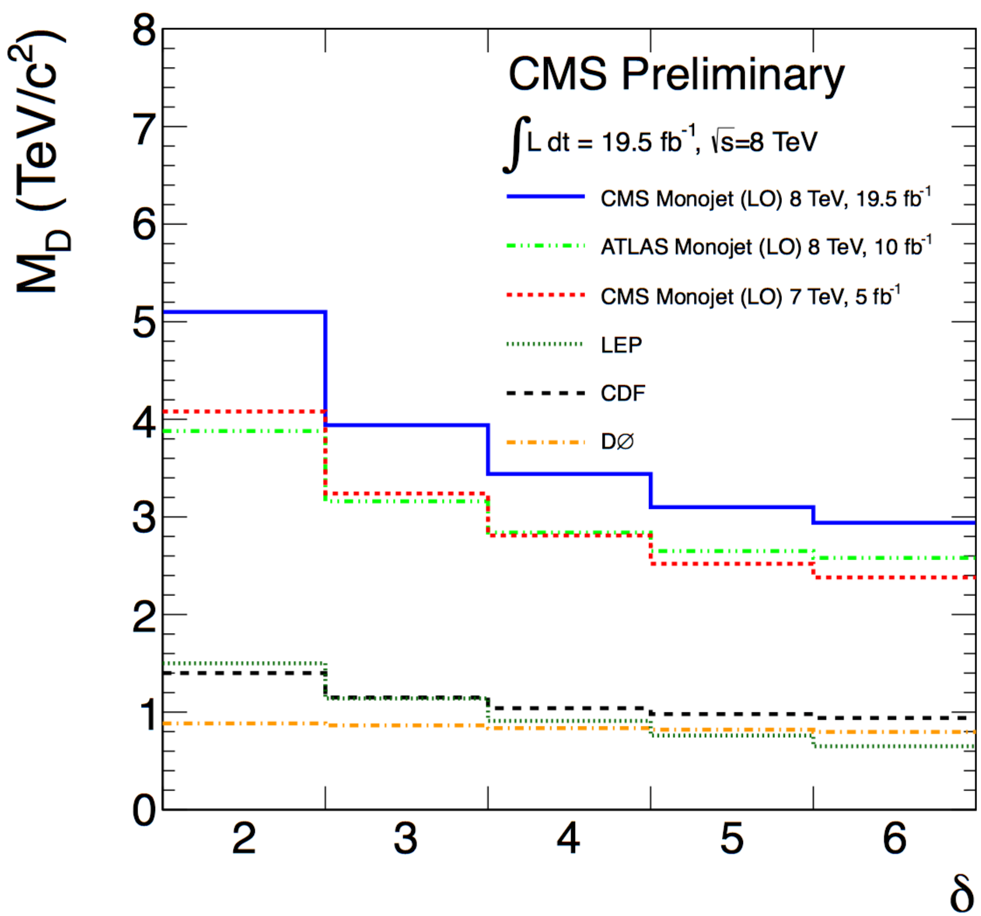
Large Extra Dimensions from Monojets

[CMS EXO-12-048]

- Large Extra Dimensions: Arkani-Hamed, Dimopoulos, Dvali (ADD)

$$M_{Pl}{}^{2} \sim M_{D}{}^{2+n} R^{n}$$

M_{Pl} = 4-dimensional Planck scale
M_D = fundamental (4+n)-dimensional Planck scale
n = number of the extra dimensions
R = size of the extra dimensions

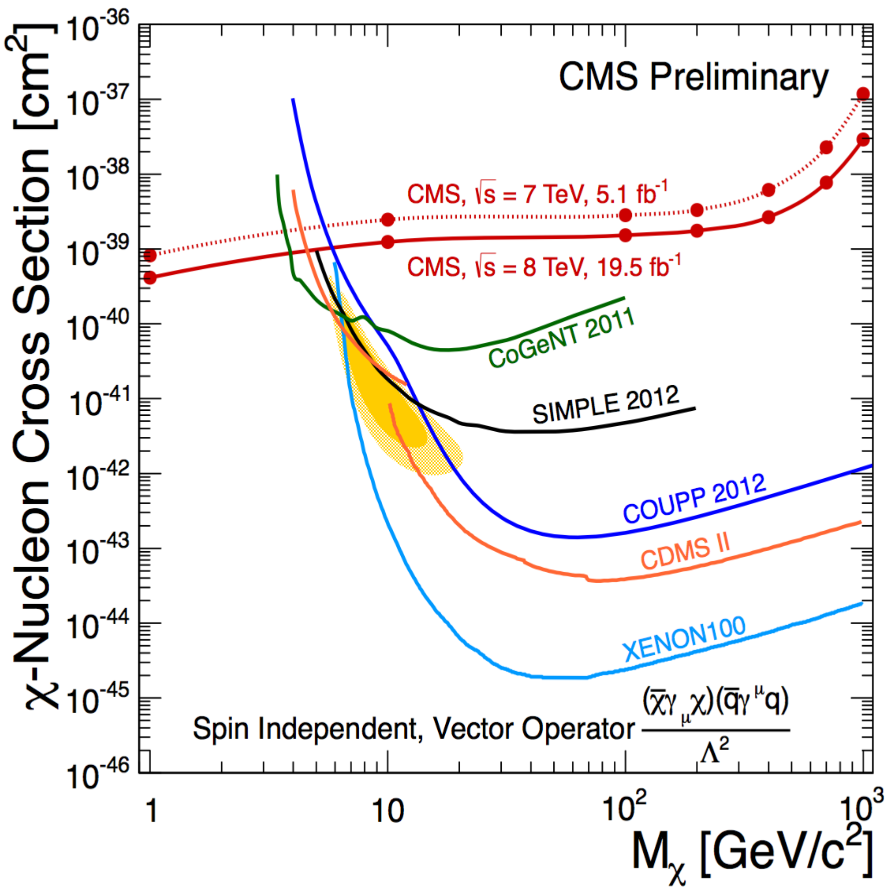


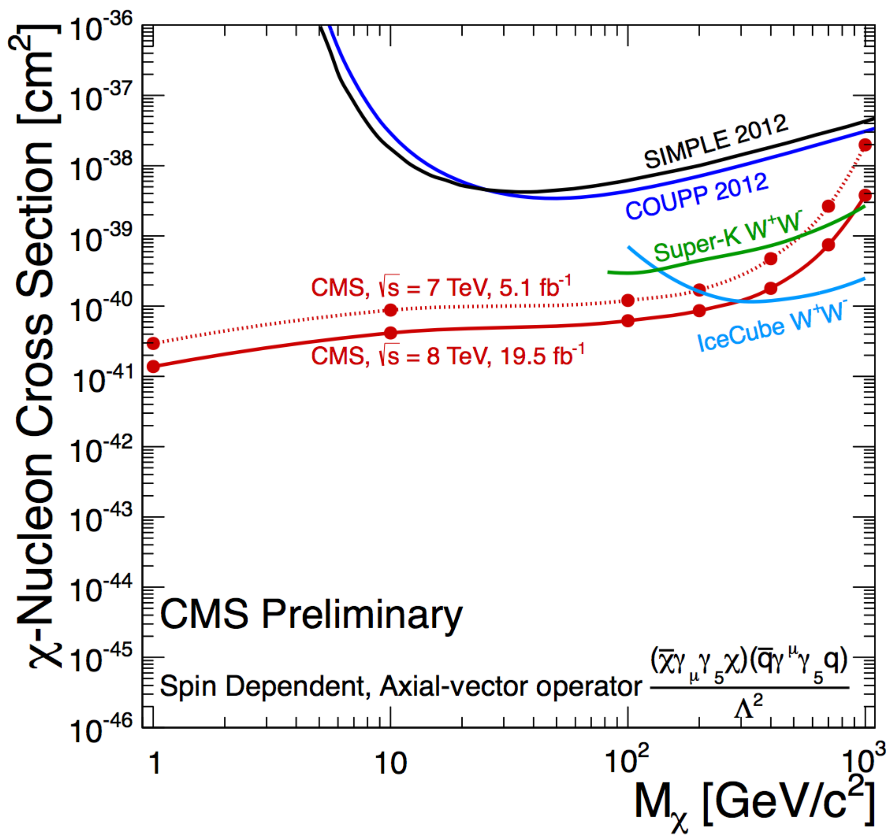
3.0 and 4.0 TeV M_D ADD limits for δ=6 and 3. Obs=exp

Dark Matter and Monojets

[CMS EXO-12-048]

- Pair-produced DM (χ) characterized by a contact interaction effective theory



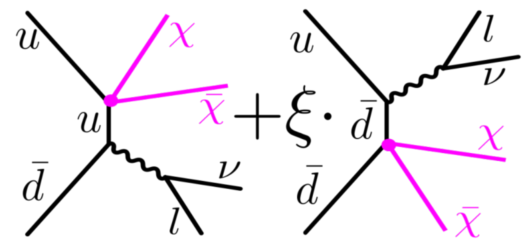


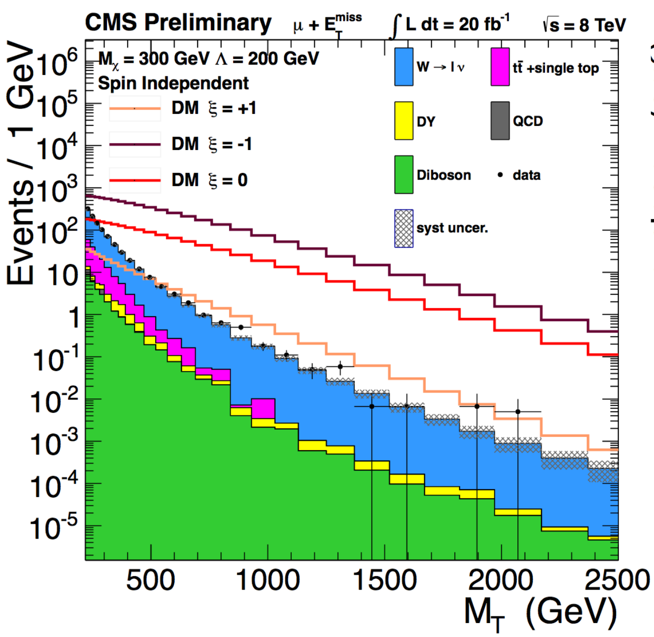
- (mass fraction vs spin fraction)
- Extending contact scenario to new operators/models, scan mediator mass

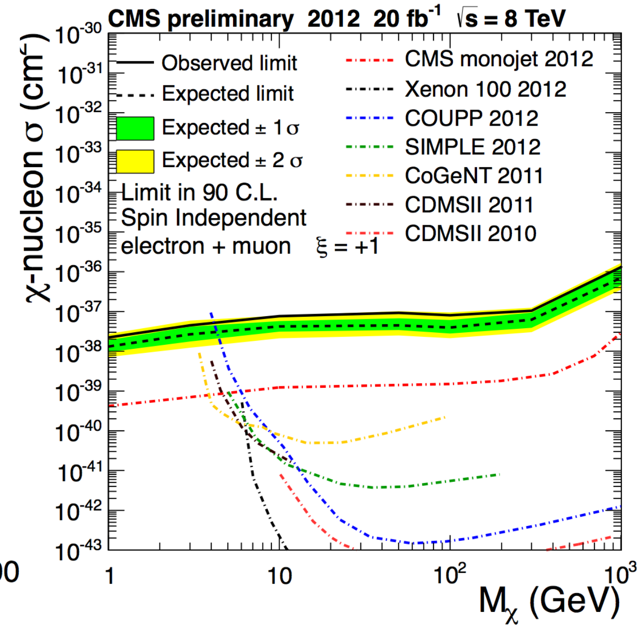
Monoleptons

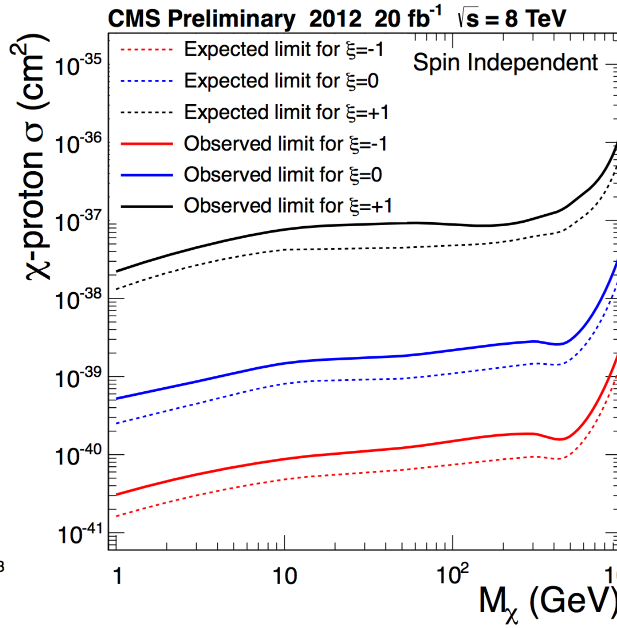
[CMS EXO-13-004]

- Dark Matter production: W recoiling against pair-produced DM
  - Reinterpretation of W' --> lν search (EXO-12-060)
- Consider two couplings, interference
  - vector- and axial-vector like couplings considered
  - unlike monojets, have interference effects
  - interference effects parameterised by ξ (W+ diagram at right)
- First limits on "monolepton" Dark Matter









Conclusion: LHC vs BSM Models

Slide Credit: Stephen Martin

Conclusion: BSM possibilities: ways to go

New physics

Conclusion/Credits

- New Physics search ideas have flourished
- "New thinking" coming on line continuously.
- e.g. Higgs in the final state: t', b', t→ch, in SUSY: electroweak Higgs, natural higgsino…., boosted final states and jet substructure, long lived objects, generalized recoil searches (Dark Matter interpretation)…
- Will exotics from 2012 data be as interesting for SUSY'14?
- ---------------------
- SUSY'13 organizers !!
- LHC staff, CMS collaborators and leadership.

- B2G-12-015: Inclusive search for top partners in single- and multiple-leptons
- B2G-12-023: Baryon number violating top-quark decays
- B2G-12-005: Anomalous Top Quark Pair Production in Boosted All-Hadronic
- B2G-12-006: ttbar resonances in semileptonic final states in pp collisions
- B2G-12-014: Pair produced resonances to a top quark and jet in lepton+jets
- B2G-12-010: Narrow t+b resonances in the leptonic final state
- B2G-12-012: Top partners with charge 5e/3 in the same-sign dilepton final state
- b' and t' reinterpretations of SUS-12-027

- EXO12026: Heavy Stable Charged Particles
- EXO12009: black holes
- EXO12017: a heavy neutrino and right-handed W
- EXO13004: dark matter in the mono-lepton channel
- EXO12038: long-lived neutral particles decaying to dijets
- EXO12049: Three-Jet Resonances In Multijet Final States
- EXO12024: heavy resonances in the W/Z-tagged dijet mass spectrum
- EXO12025: a W’ or techno-rho decaying into WZ in pp collisions
- EXO12051: jet extinction in the inclusive jet spectrum
- EXO12042: pair-production of 2nd generation scalar leptoquarks
- EXO12023: Heavy Resonances Decaying into bb and bg Final States
- EXO12048: new physics with monojets
- EXO12027: Large Extra Dimensions in Dimuon Events
- EXO12031: Large Extra Dimensions in Dielectron Events
- EXO12060: leptonic decays of W' bosons (supersedes EXO12010)
- EXO12061: Resonances in the Dilepton Mass Distribution (supersedes EXO12015)
- EXO12059: Narrow Resonances using the Dijet Mass Spectrum (supersedes EXO12016)

Big Words on Dark Matter

Complementary approach to direct and indirect searches. Model-independent for interaction between SM particles and dark matter candidates. WIMP chi is Dirac Fermion (conclusions for Majorana Fermions also possible). SM – chi mediator is very heavy, chi is only new particle in LHC reach. Effective field theory approach: Contact Interaction. Lmits in terms of the WIMP mass and the suppression scale M*. Interaction can happen via different operators, (eg vector interaction operator D5). Limits can be compared to thermal relic density from WMAP. Effective field theory allows comparison of collider limits to (in)direct detection experiments. Depending on the interaction operator, bounds on WIMP-nucleon cross section for spin-dependent or spin-independent cases (e.g. spin-dependent axial-vector operator D8 and tensor operator D9). Collider bounds are especially powerful for low WIMP masses (< 10 GeV).

(from an ATLAS poster.)