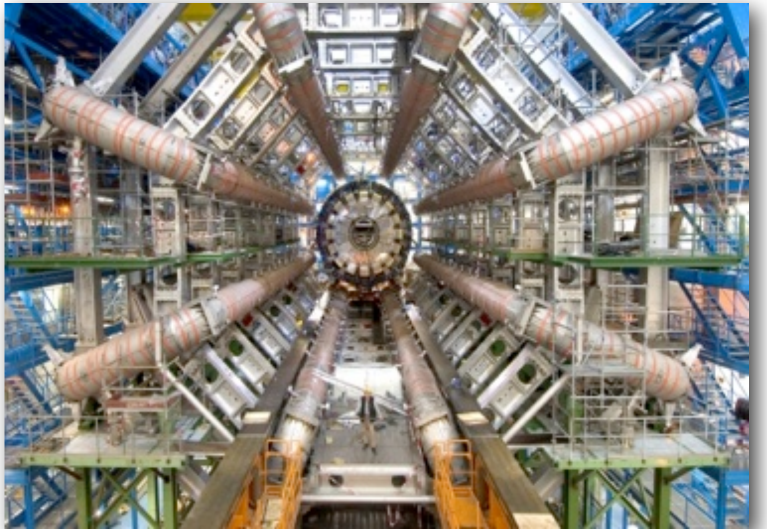
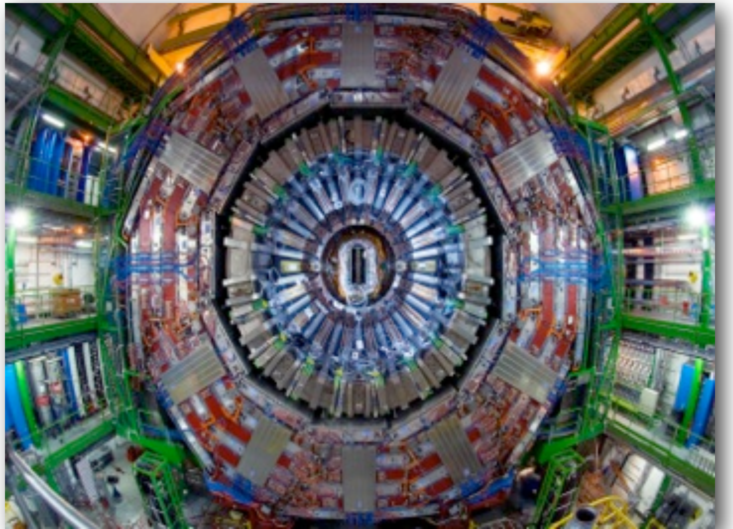
SEARCHES FOR EXOTIC* PHYSICS II





Steve Worm

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Rutherford Appleton Laboratory

Taller de Altas Energías

Benasque, 26 September 2013

*also known as "BSM (non - SUSY) Results II"

Outline

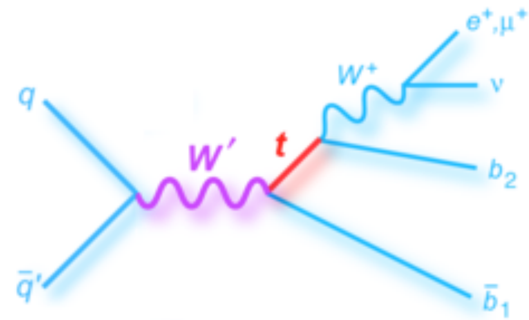
- *What is "Exotic"?*
  - Standard Model, standard problems
  - New energy regime
  - Top example and detectors
- *Resonances and "standard stuff"*
  - Z', ADD
  - Dijet, dijet w/ b-tag
  - 3-jet, 3-jet w/ b-tag
  - black holes (high S_T)
- *Top-like BSM*
  - W' ⟶ tb
  - vector-like T'
  - Q=5/3 top partners
  - X ⟶ tt semi-leptonic, hadronic
- *Di-boson resonance*
  - Boosted techniques
  - W'/ρ_{TC} ⟶ WZ ⟶ 3l + MET
  - G_{bulk} ⟶ WW ⟶ l + jet + MET
  - G_{bulk} ⟶ ZZ ⟶ 2l + 2jets
  - G_{RS} ⟶ WW/ZZ and W' ⟶ WZ
- *Long-lived particles*
  - displaced jets
  - HSCP
- *Dark Matter*
  - monojet
  - monolepton
- *Conclusions*

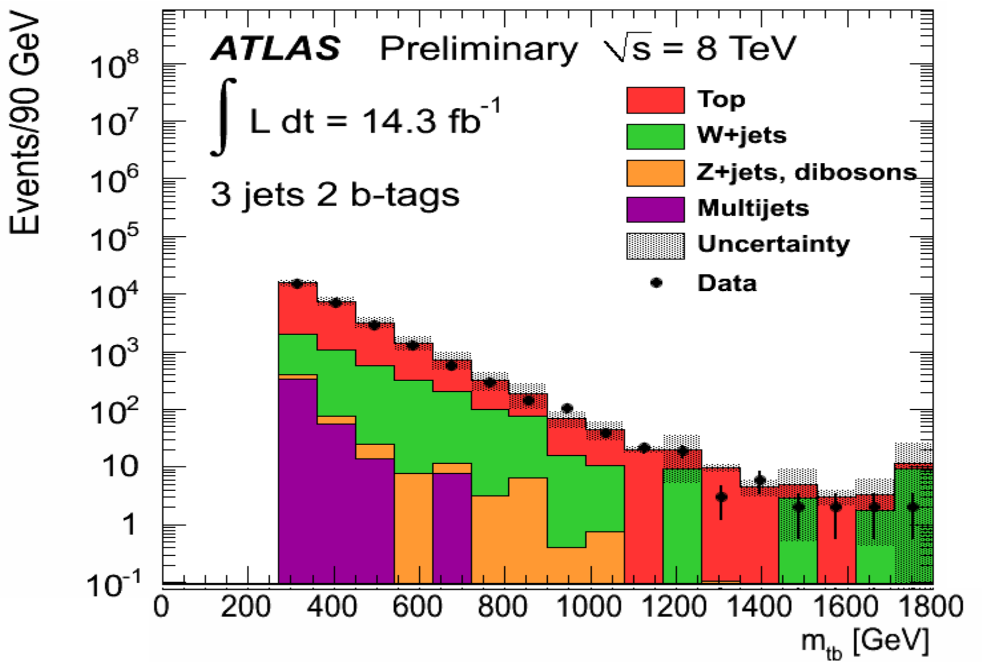
BSM and Top

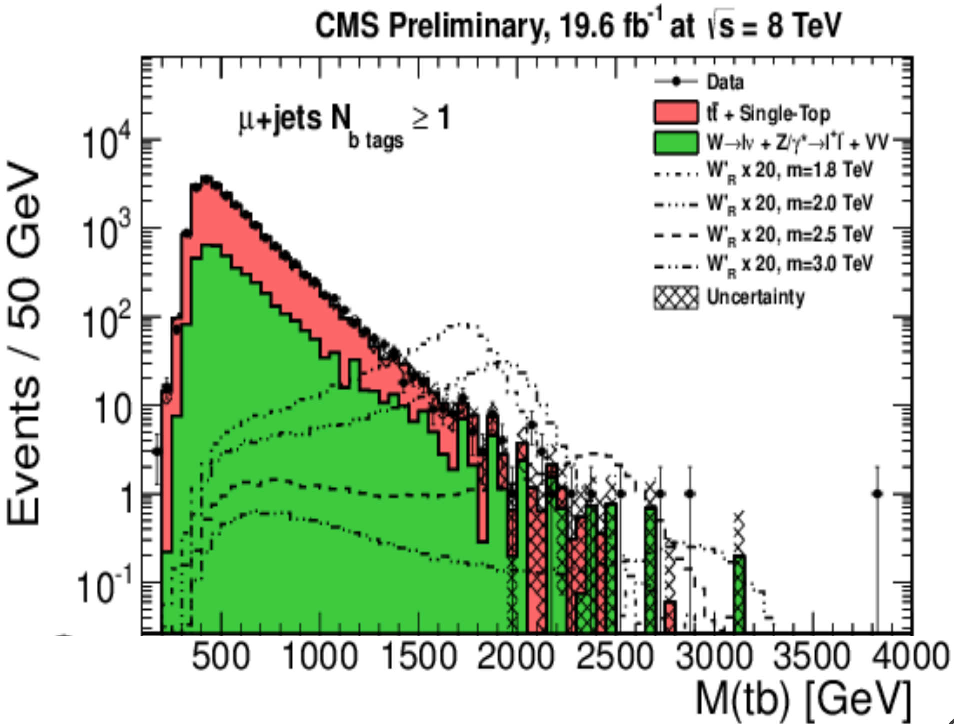
W′ TO TOP + BOTTOM

[ATLAS-CONF-2013-050, CMS B2G-12-010]

- Search lepton (e, μ) plus jets and E_T^{miss} for decays $W' \rightarrow tb$, $t \rightarrow bW \rightarrow bl\nu$,
- Event selection:
  - Several jets, with ≥ 2 b-tag(s)
  - Require small E_T^{miss} (20–35 GeV) to reduce QCD
  - Kinematic cuts to enhance signal (e.g. p_T^{top} or $E_T^{miss} + m_T(W)$)



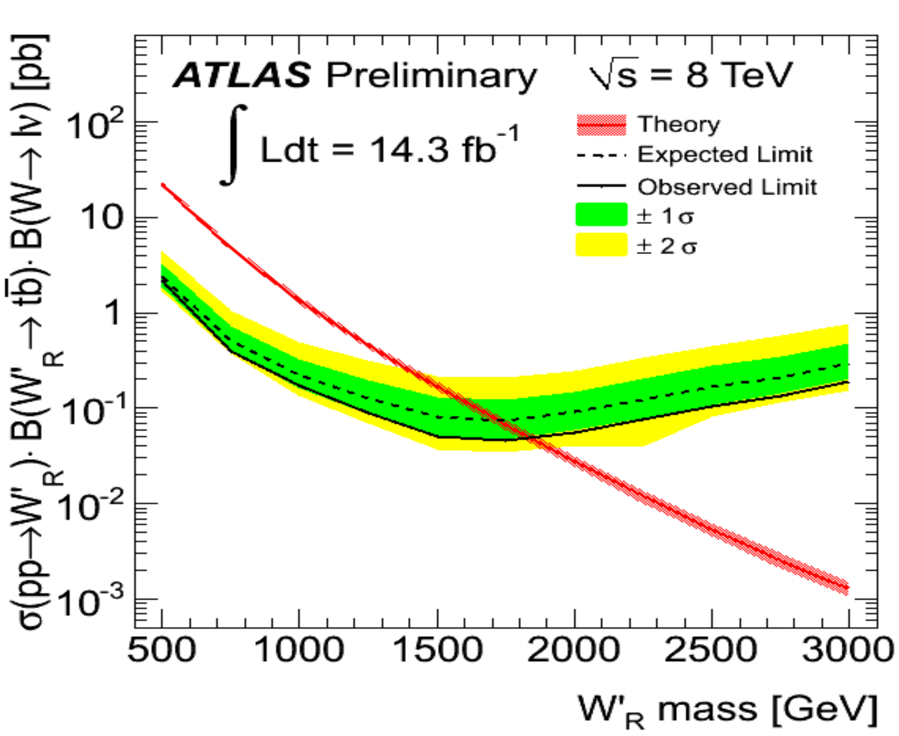


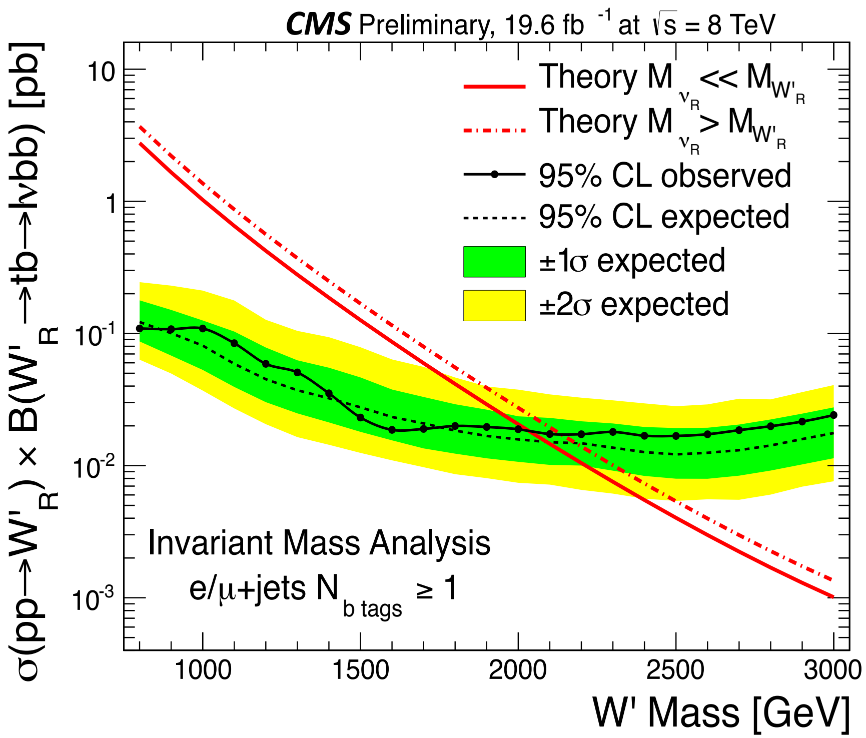


W′ TO TOP + BOTTOM

[ATLAS-CONF-2013-050, CMS B2G-12-010]

- No evidence for W' in data; proceed to set limits at 95% C.L.
- Limits shown below for right-handed W' (no interference with SM)



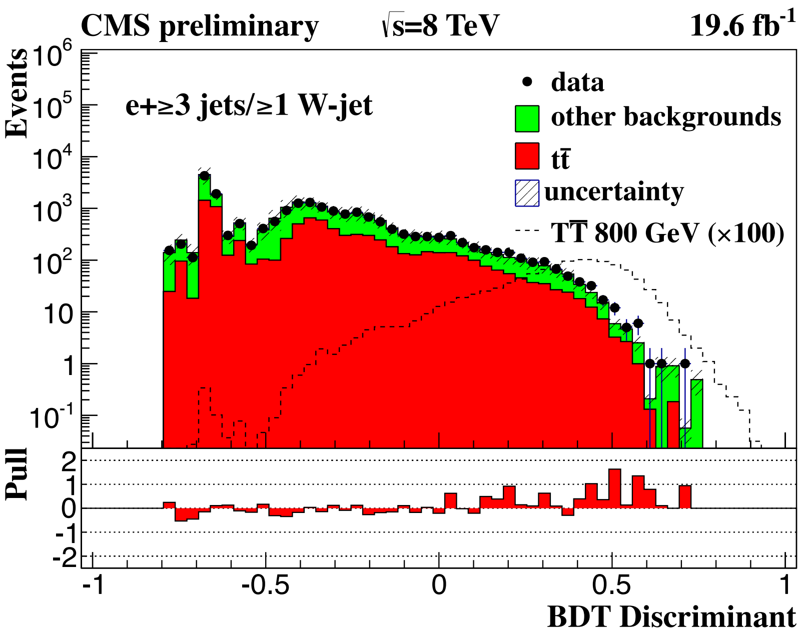


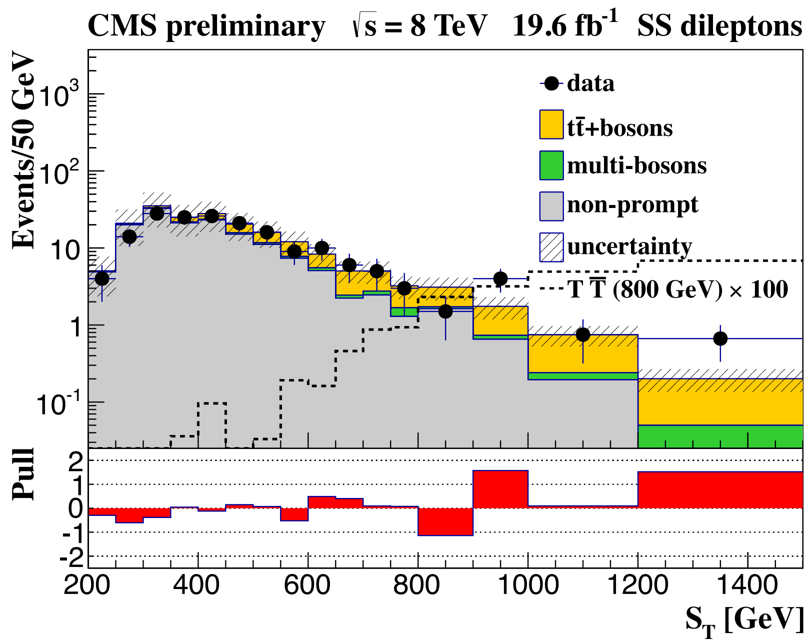
$M_{W'_R(tb)}$ 95% CL	Luminosity	Expected	Observed
ATLAS W'_R	14.3	> 1.72 TeV	> 1.84 TeV
CMS W'_R	19.6	> 2.09 TeV	> 2.03 TeV

Vector-Like T′ ⟶ tZ/tH/bW

[CMS B2G-12-015]

- Combined information from single lepton, SS and OS dilepton, trilepton (+jets)
- Separate bins by W-tags, #jets, #b-jets, H_T, MET, lepton p_T, 3rd/4th jet p_T
  - *Opposite-Sign targeting tZtZ:* on-Z, ≥5 jets, ≥2 b-jets, H_T>500 GeV, S_T>1000 GeV
  - *Opposite-Sign targeting bWbW:* 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



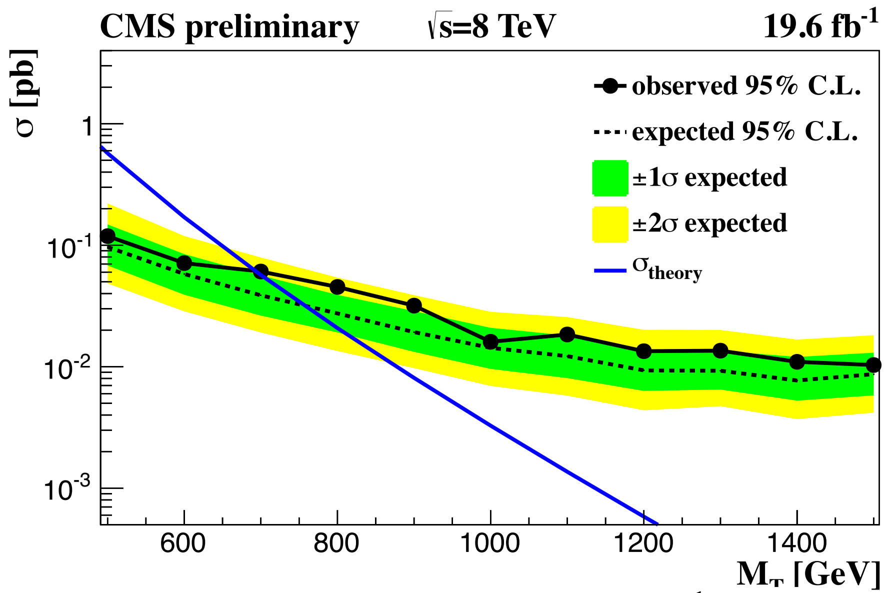


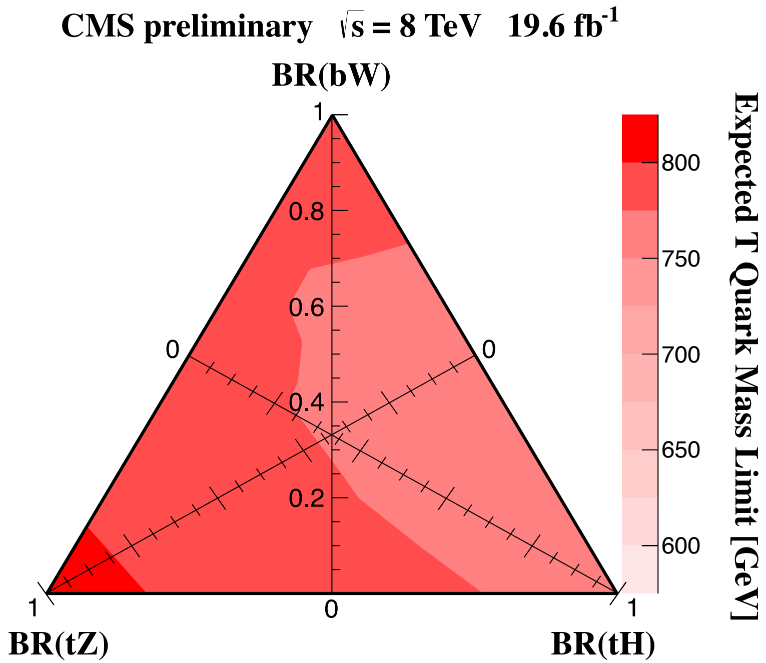
VECTOR-LIKE T′ ⟶ tZ/tH/bW

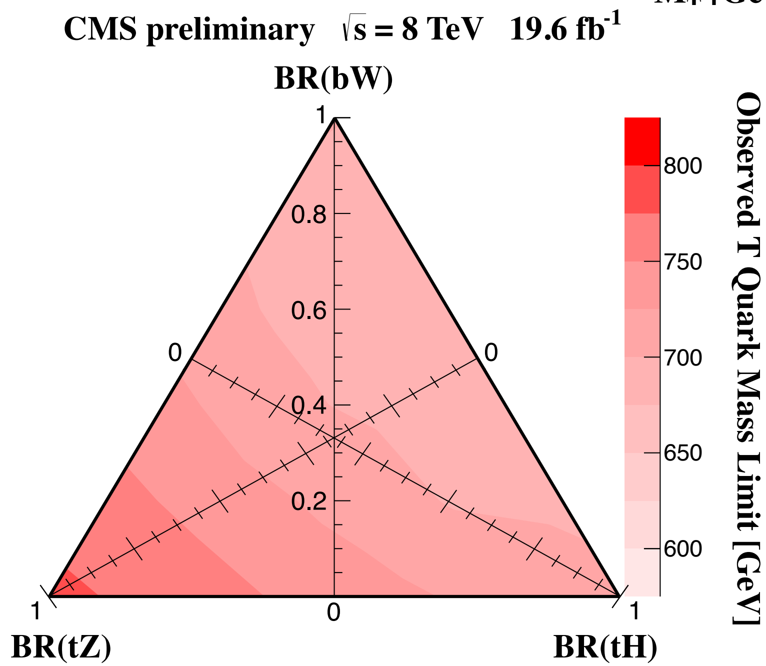
[CMS B2G-12-015]

- 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





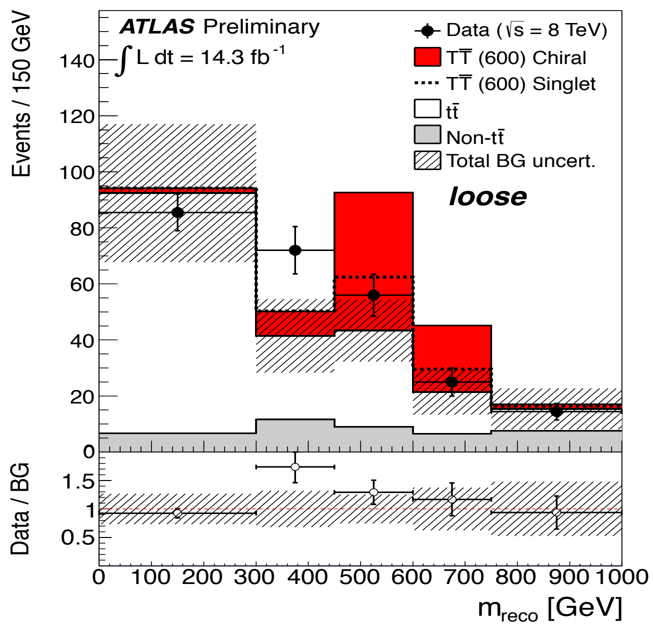


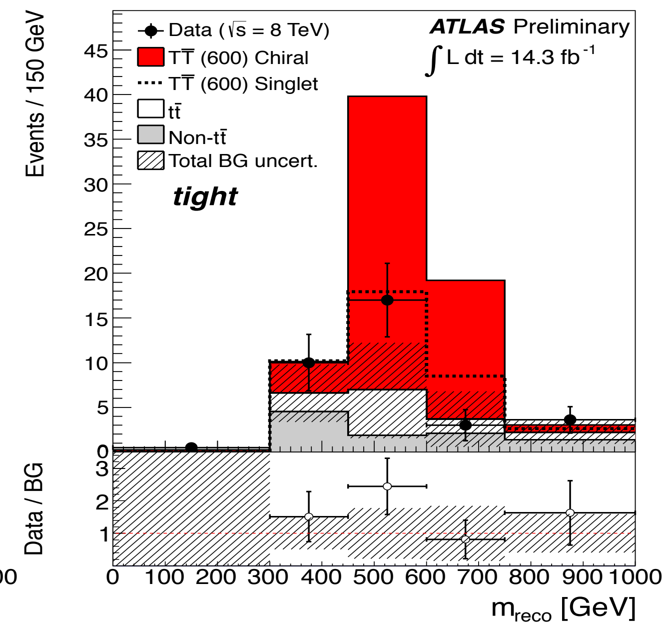
HEAVY TOP-LIKE QUARKS TO bW

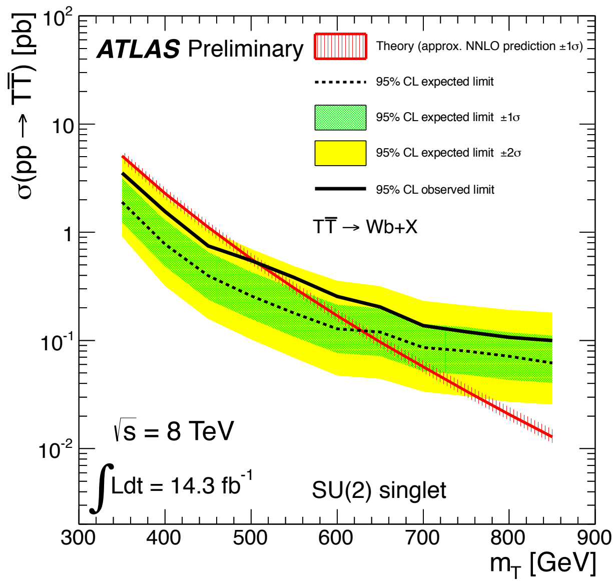
[ATLAS-CONF-2013-060]

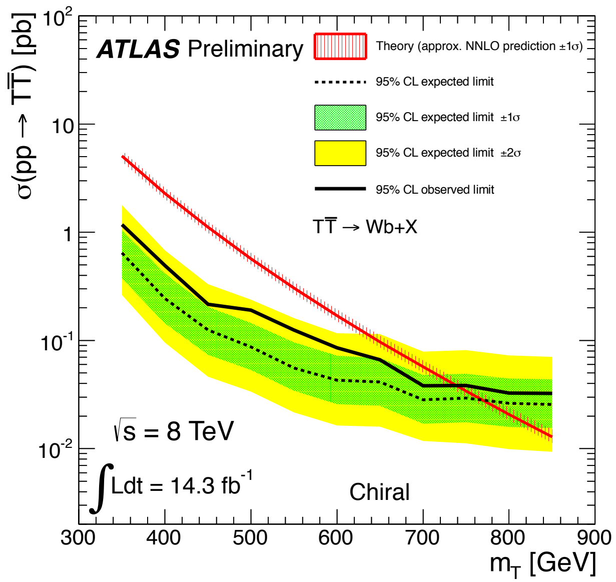
- $TT \rightarrow bW_{lep}bW_{had} \rightarrow l\nu bjjb \rightarrow l+4j+MET$
- W+jets and QCD use data-driven estimates
- Require 1 e or μ, ≥ 1 b, ≥ 4 jets, MET > 20 GeV
- Loose: ≥ 1 W_{had}, HT > 800, $p_T(b_1) > 160$, $p_T(b_2) > 80$, $\Delta R(l,MET) < 1.2$
- Tight: $\min\Delta R(l,b) > 1.4$, $\min\Delta R(W_{had},b) > 1.4$

Combined bW+tH limits on singlet T are $m_T > 670$ GeV





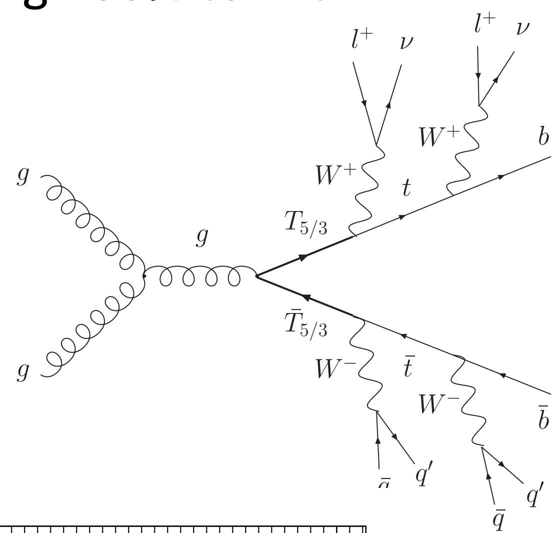


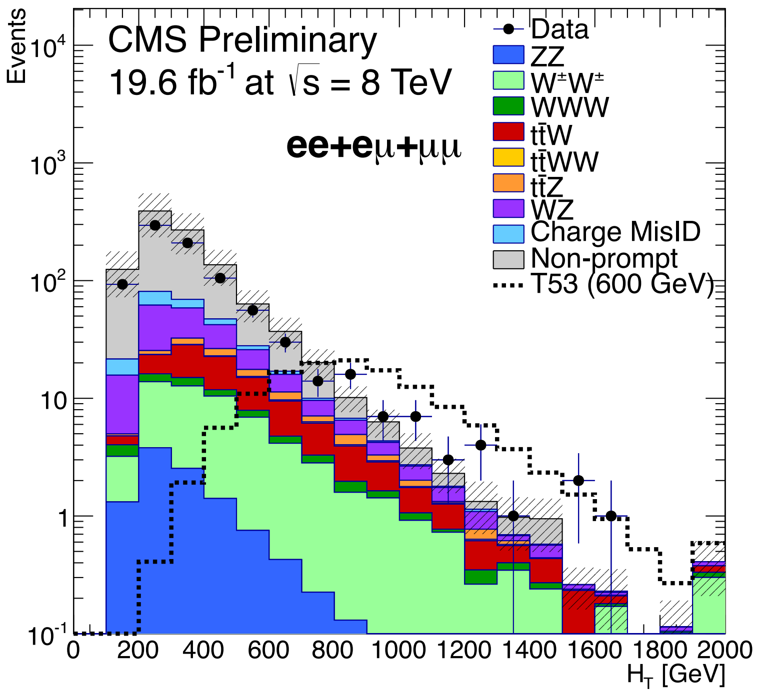


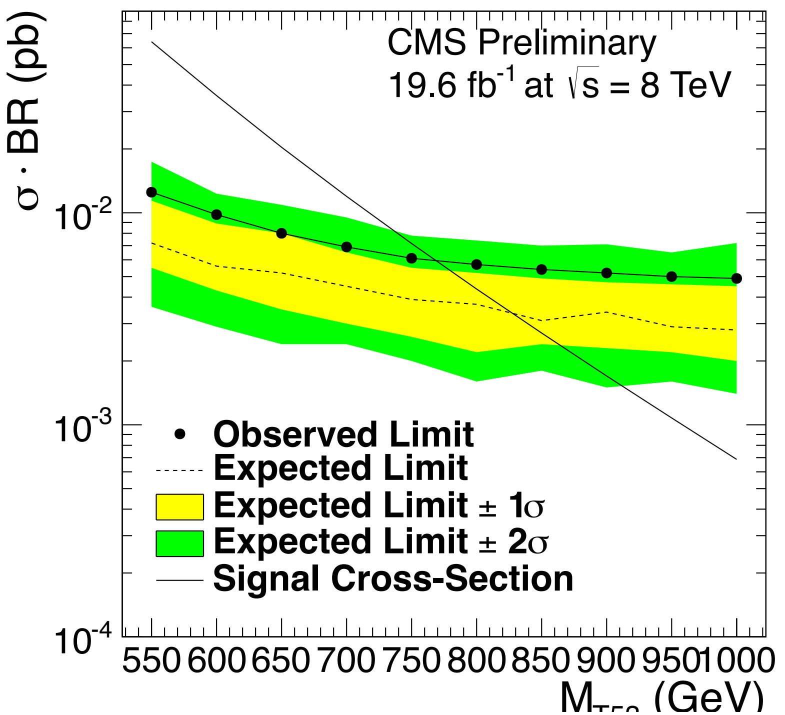
Q=5/3 Top Partners

[CMS B2G-12-012]

- Search for pair production of charge 5/3 top partner decaying 100% to Wt
- Final state signature:
  - 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 (2), or top-tagged jet (3)
- 11 events vs. 6.6 ± 2.0 expected; limit mass up to 770 GeV





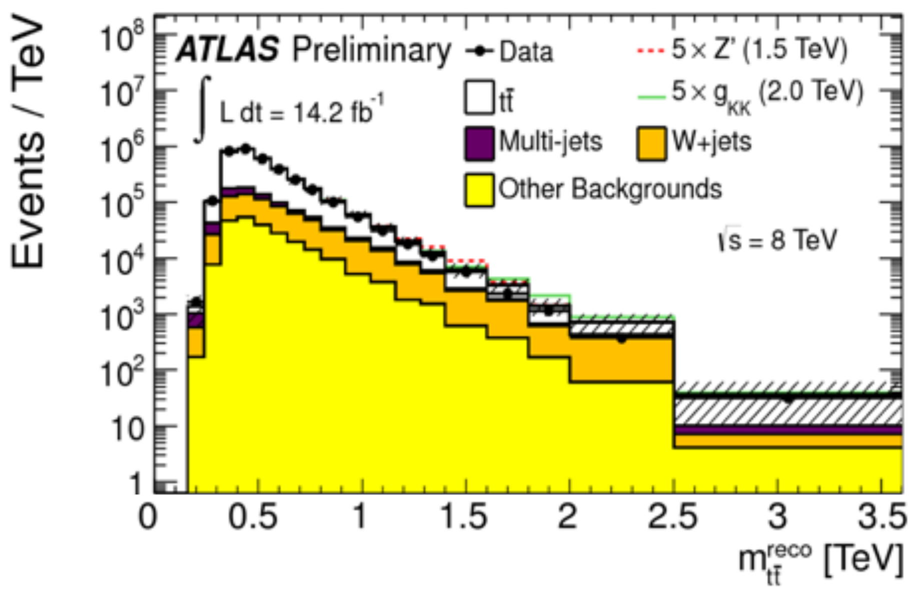


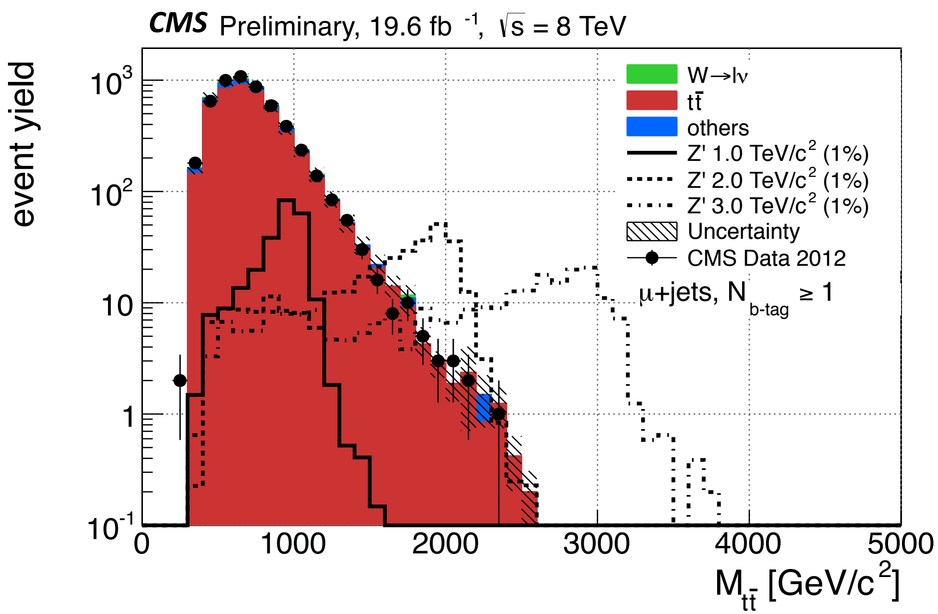
BSM and Boosted Jets

SEMI-LEPTONIC X ⟶ tt RESONANCE

[ATLAS-CONF-2013-052, CMS B2G-12-006]

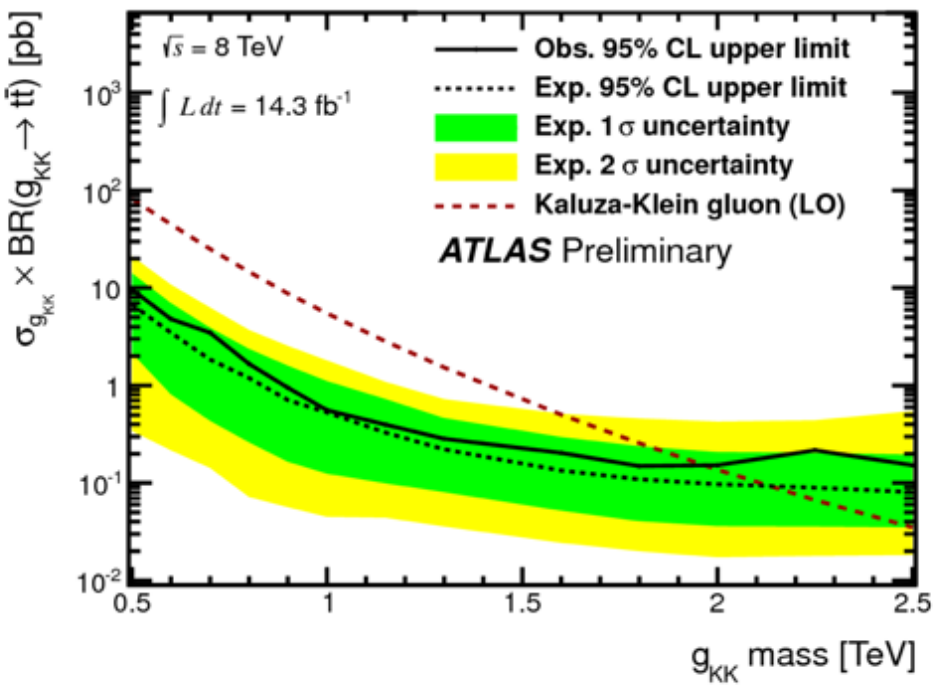
- Search for heavy resonance decaying to ttbar in e or μ plus >2 jets
- Two search regions; resolved jets and high Lorentz boost (above ~1 TeV)
- Backgrounds:
  - ttbar and single top main backgrounds (especially after b-tagging), some W+jets
  - Data-driven techniques used for some backgrounds

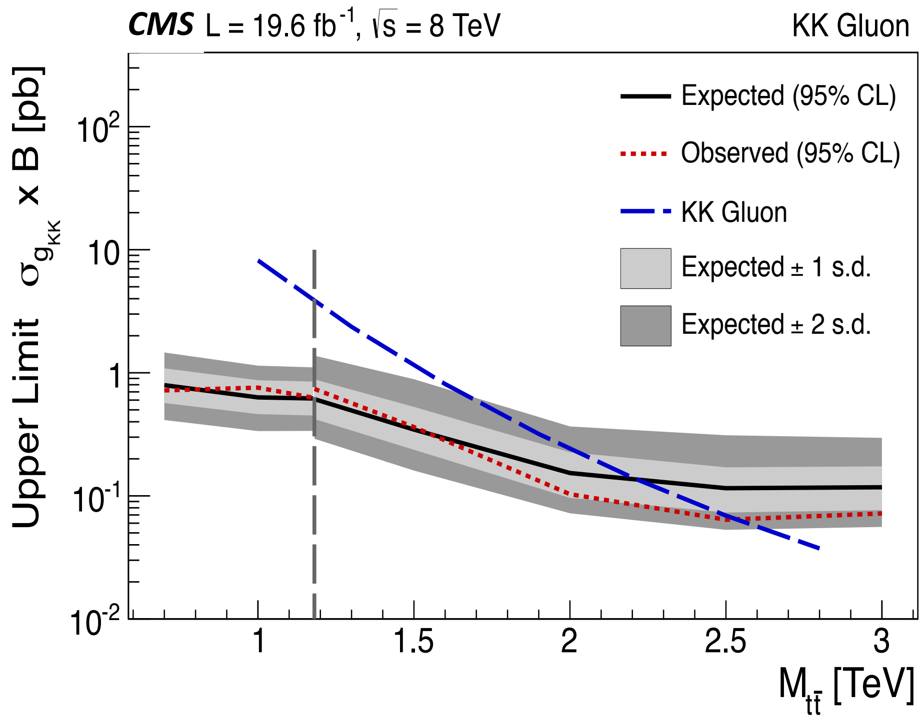




SEMI-LEPTONIC X ⟶ tt RESONANCE

- Leading systematics: jet energy scale (17% ATLAS), background xsections (9%)
- No significant excesses; set limits at 95% C.L.





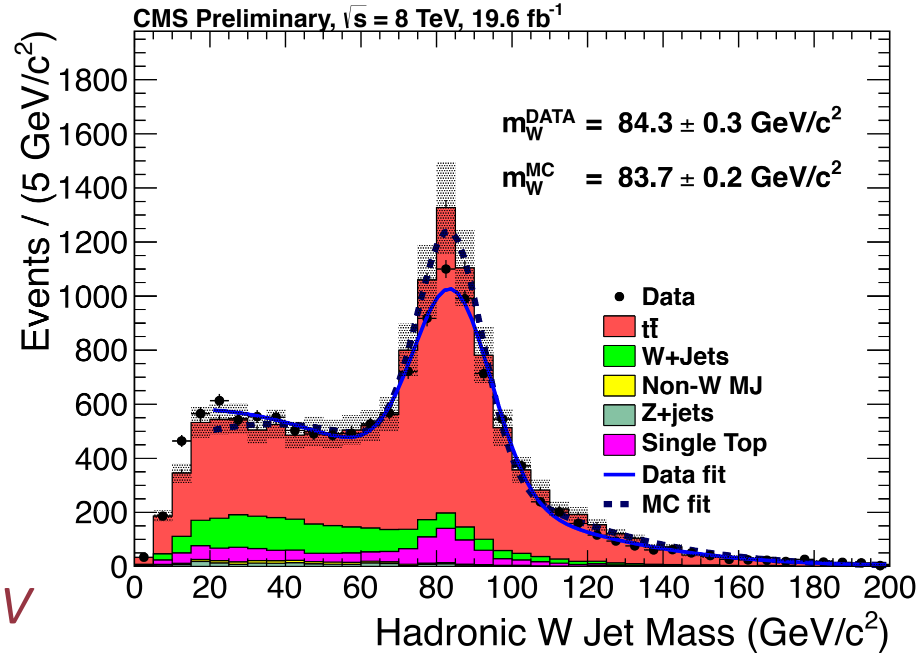
M(Z' or g_{KK}) 95%	Luminosity	Expected	Observed
ATLAS Z'	14.3	> 1.9 TeV	> 1.8 TeV
CMS Z'	19.6	> 2.0 TeV	> 2.1 TeV
ATLAS g_{KK}	14.3	> 2.1 TeV	> 2.0 TeV
CMS g_{KK}	19.6	> 2.2 TeV	> 2.5 TeV

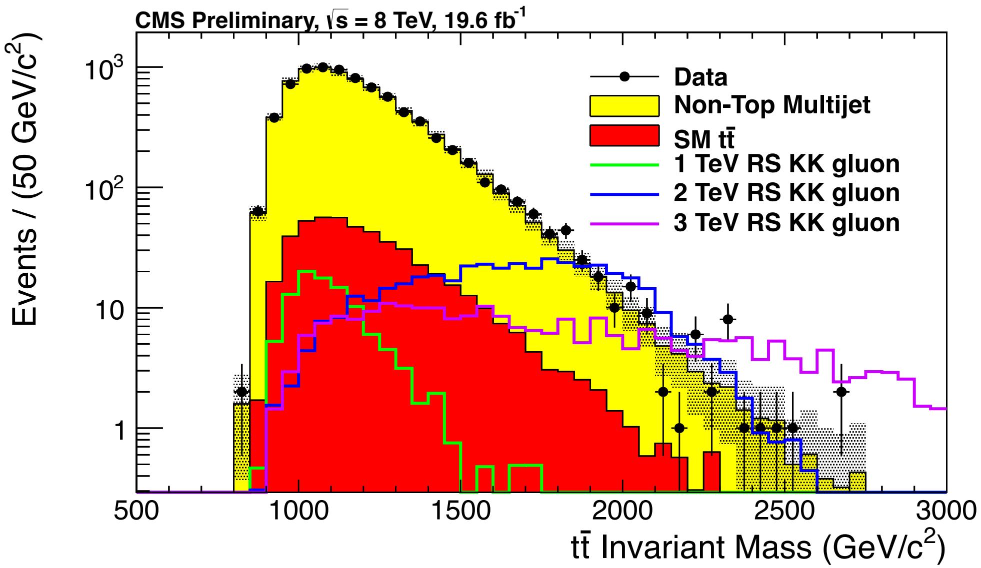
HADRONIC X ⟶ tt RESONANCE

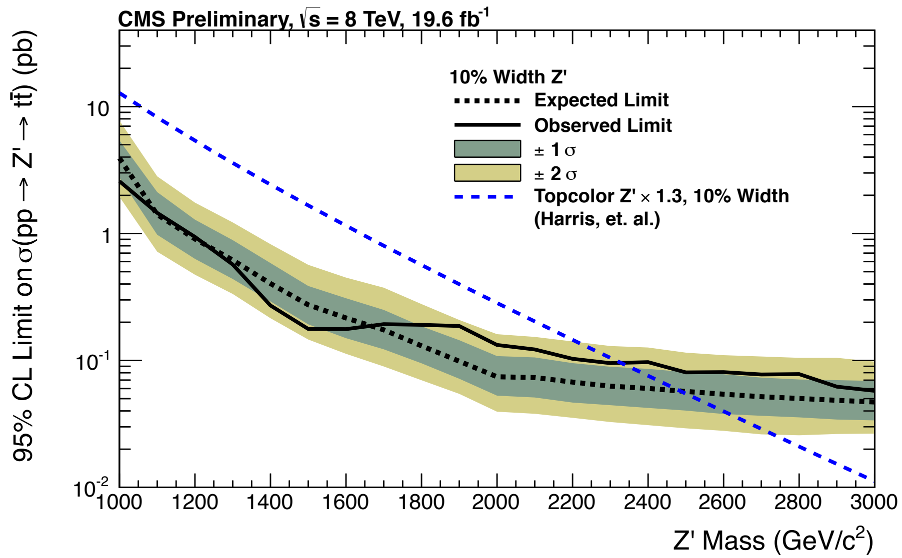
[CMS B2G-12-005]

- 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

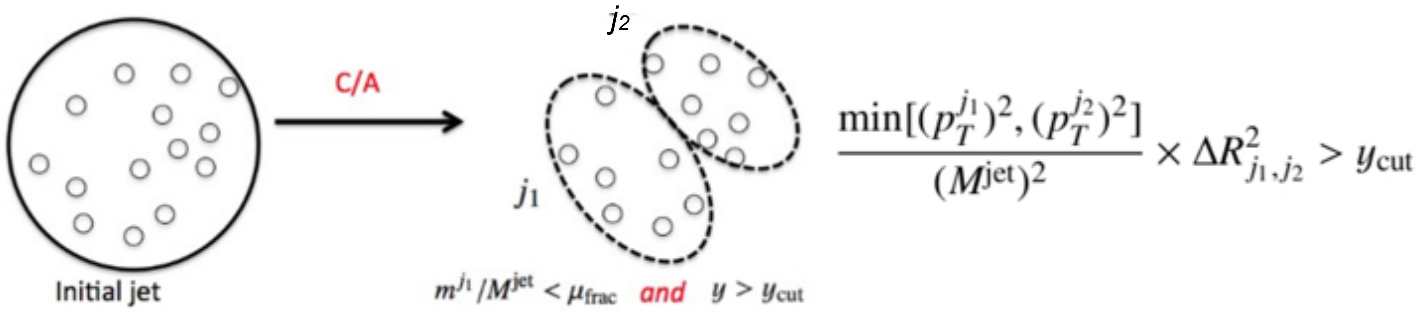




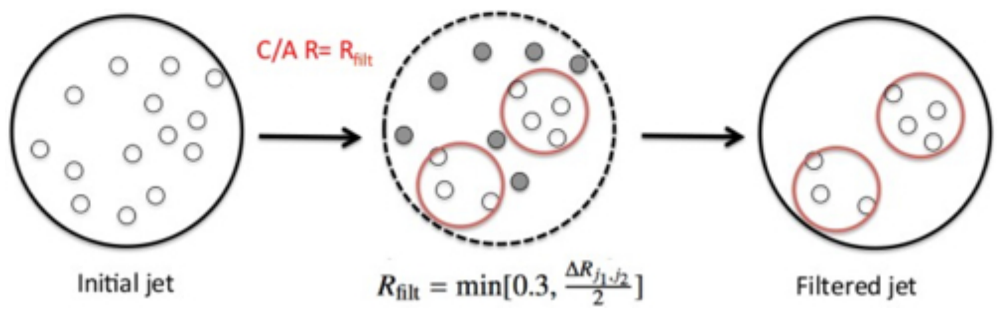


Jet Substructure Techniques

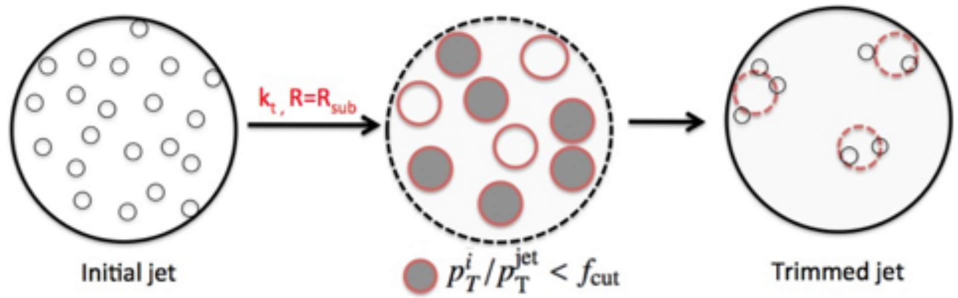
- Mass Drop: identify subjets [arXiv:0802.2470]



- Filtering: recluster constituents of j_1, j_2 [arXiv:0802.2470]

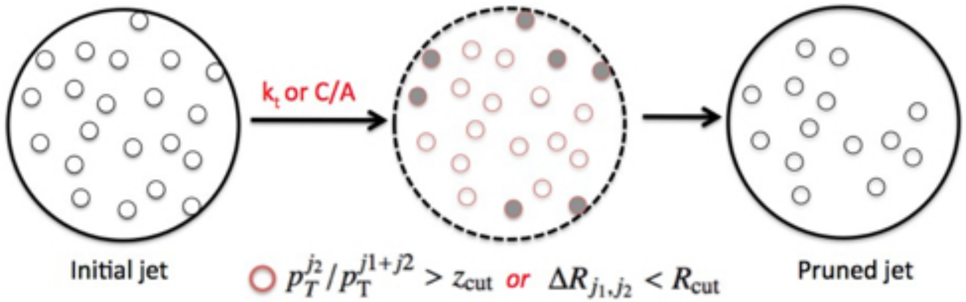


- Trimming: uses k_t algorithm to identify and cut subjets [arXiv:0912.1342]



JET SUBSTRUCTURE TECHNIQUES

- Pruning: cut softer or wider constituents during jet reconstruction [arXiv:0912.0033]



- N-subjettiness: [arXiv:1101.2268]
  - Measure to what degree a jet can be considered to be composed of N-subjets
  - Force a jet algorithm to produce N subjets
  - The N-subjettiness characterizes how close to these jets the p_T is distributed

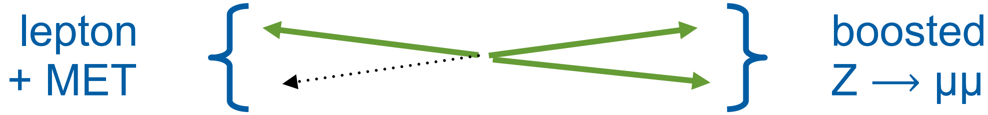
$$\tau_N = \frac{1}{d_0} \sum_k p_{T,k} \min\{\Delta R_{1.k}, \Delta R_{2.k}, ..., \Delta R_{N.k}\}$$

- Q-jets: [arXiv:1201:1914]
  - Instead of clustering according to d_{ij} (as in CA), cluster at each algorithm step *randomly* according to a probability distribution of $P = \exp(-\alpha d_{ij})$
  - Get a probability distribution for the jet substructure instead of just one quantity
  - Discriminator: volatility (~RMS) of the jet mass

HIGH-MASS DIBOSON RESONANCE SEARCHES

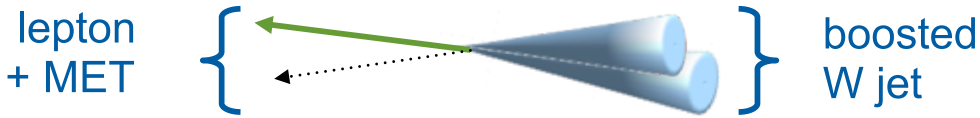
$W'/\rho_{TC} \longrightarrow WZ \longrightarrow 3l + MET$

[CMS EXO-12-025]



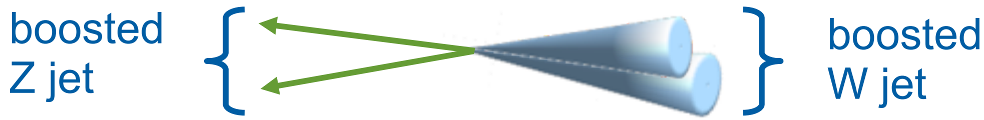
$G_{bulk} \longrightarrow WW \longrightarrow l + jet + MET$

[CMS EXO-12-021, ATLAS-CONF-2013-074]



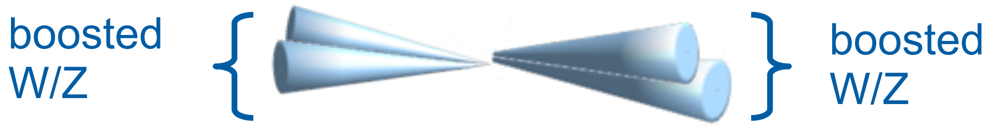
$G_{bulk} \longrightarrow ZZ \longrightarrow 2l + 2jets$

[CMS EXO-12-022, ATLAS-CONF-2013-074]



$G_{RS} \longrightarrow WW/ZZ$ and $W' \longrightarrow WZ$

[CMS EXO-12-024]

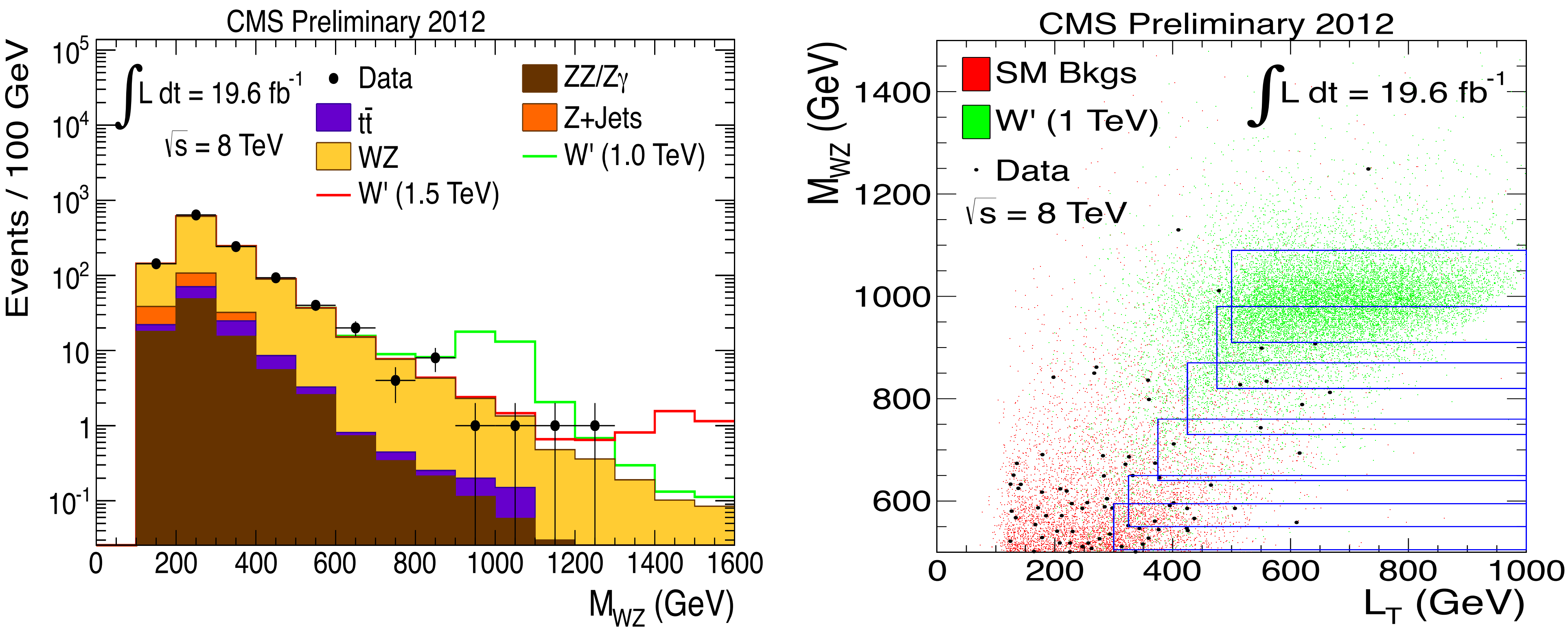


...and many more searches underway

W′/ρ$_{TC}$ ⟶ WZ ⟶ 3l + MET

[CMS EXO-12-025]

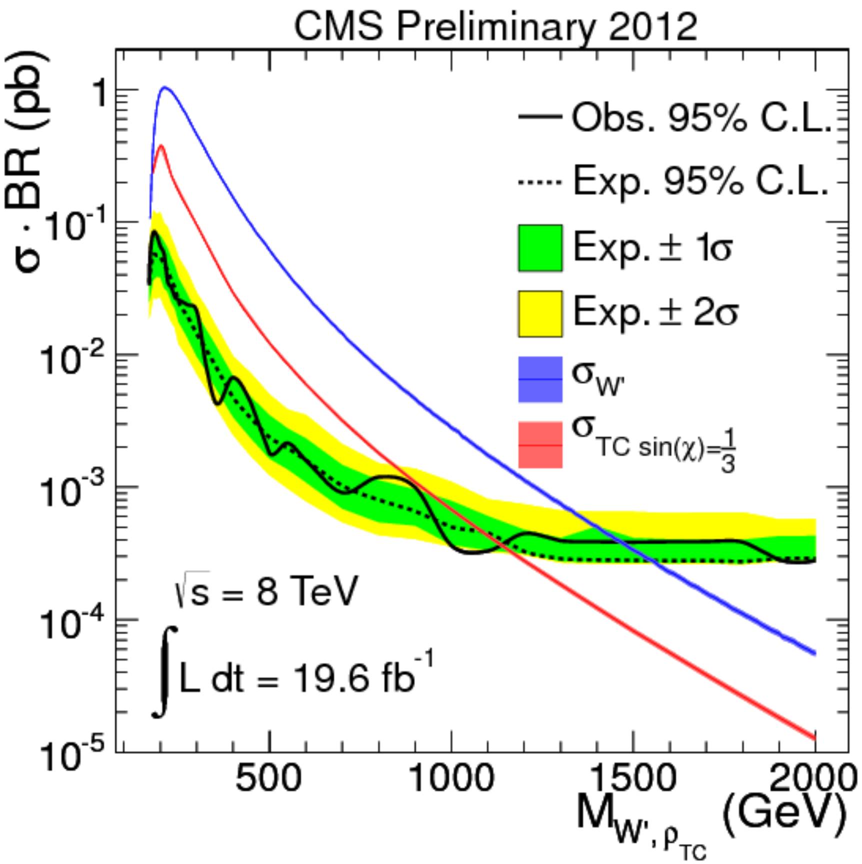
- Analysis approach
  - Compute M_{WZ}, taking MET into account
  - M_{WZ} and L_T (defined to be $\sum P_T[l]$)
  - Main backgrounds from WZ, use simulation (with generous systematics)
  - Special identification and isolation for μ's (from boosted Z)
- Cuts optimized for each signal mass (cut and count - boxes shown in blue)

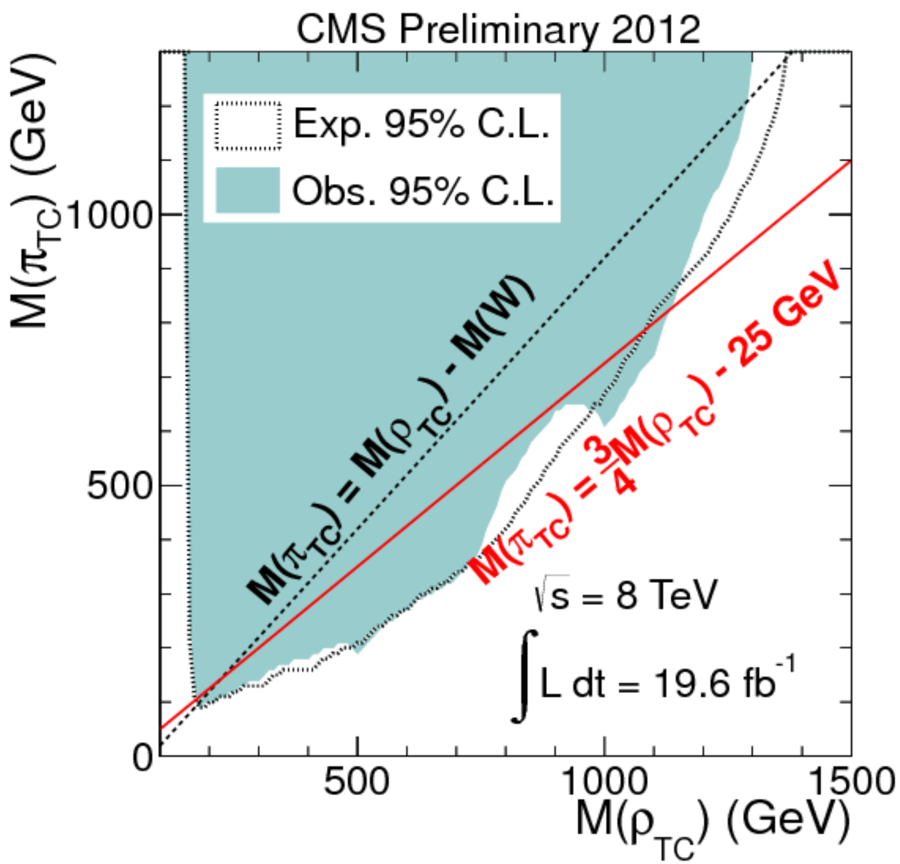


$W'/\rho_{TC} \longrightarrow WZ \longrightarrow 3l + MET$

[CMS EXO-12-025]

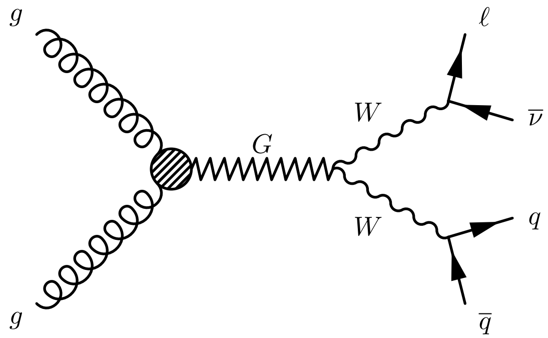
- Limit-setting: counting experiment in each signal box
- $W' \longrightarrow WZ$ excluded in range 0.17 to 1.45 TeV, stringent limits on ρ_{TC}





Semileptonic WW

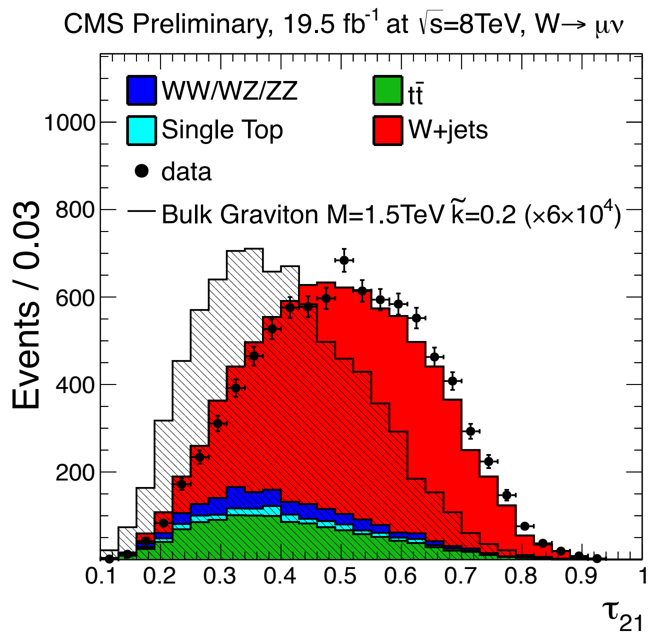
[CMS EXO-12-021]

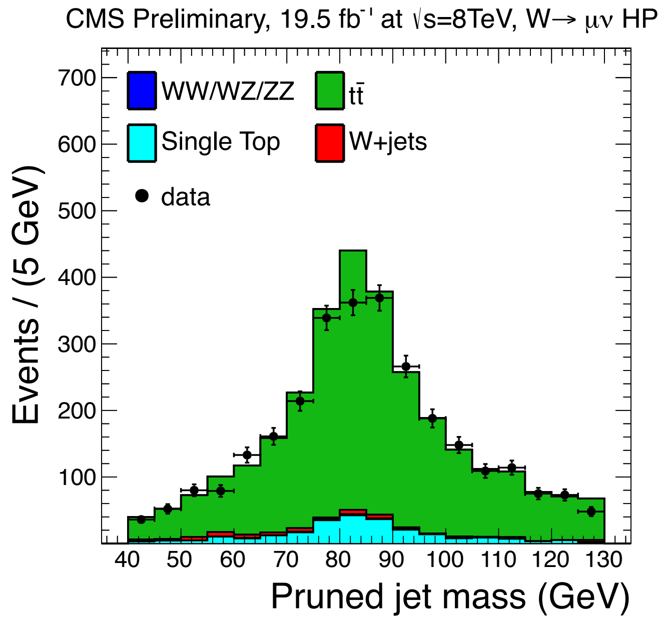


- Search for WW resonance at high mass
- Identify boosted W-jets with "N-subjettiness"
  - Ratio of 2-to-1 jets: $\tau_2/\tau_1 = \tau_{21}$

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

  - 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

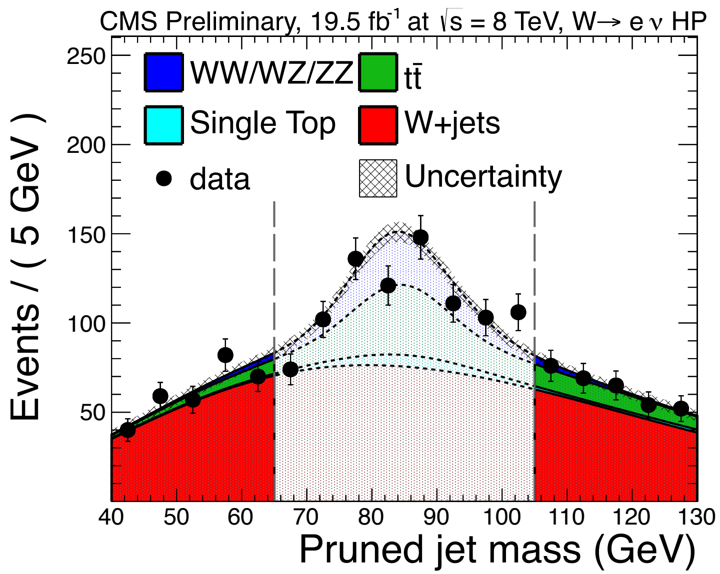


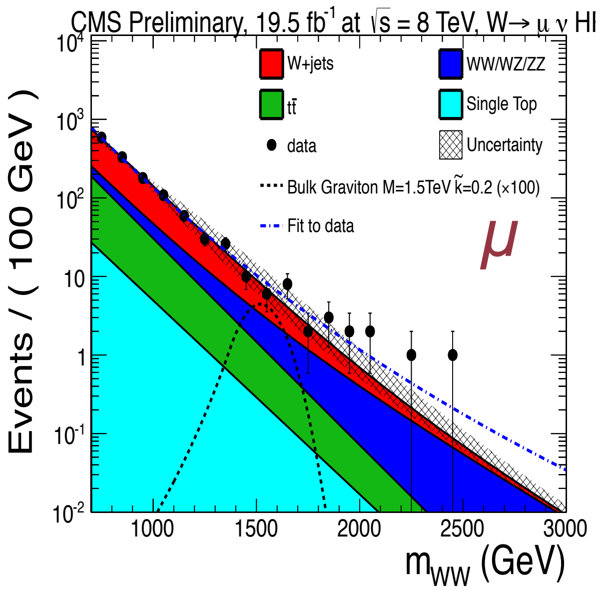


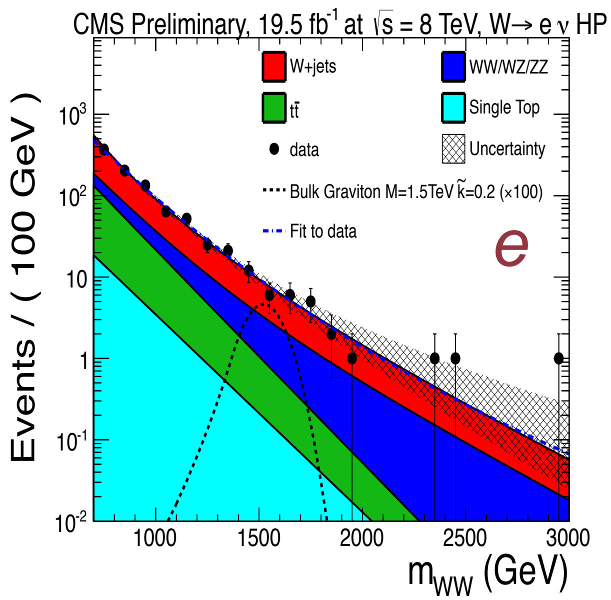
SEMILEPTONIC WW

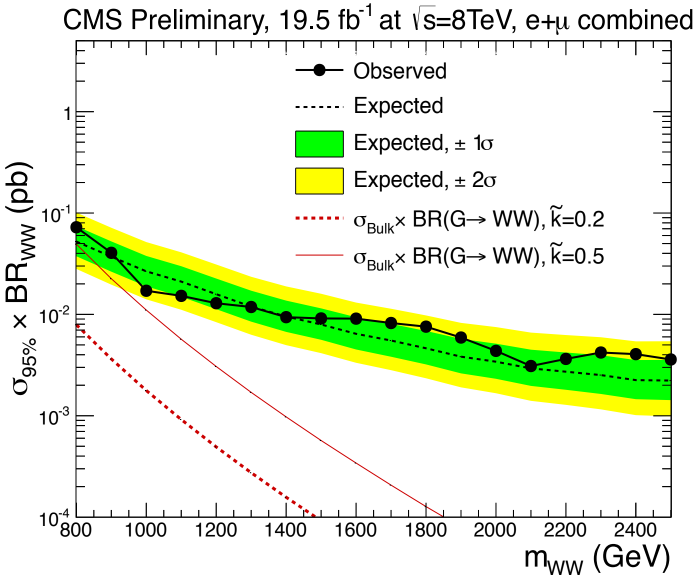
[CMS EXO-12-021]

- 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





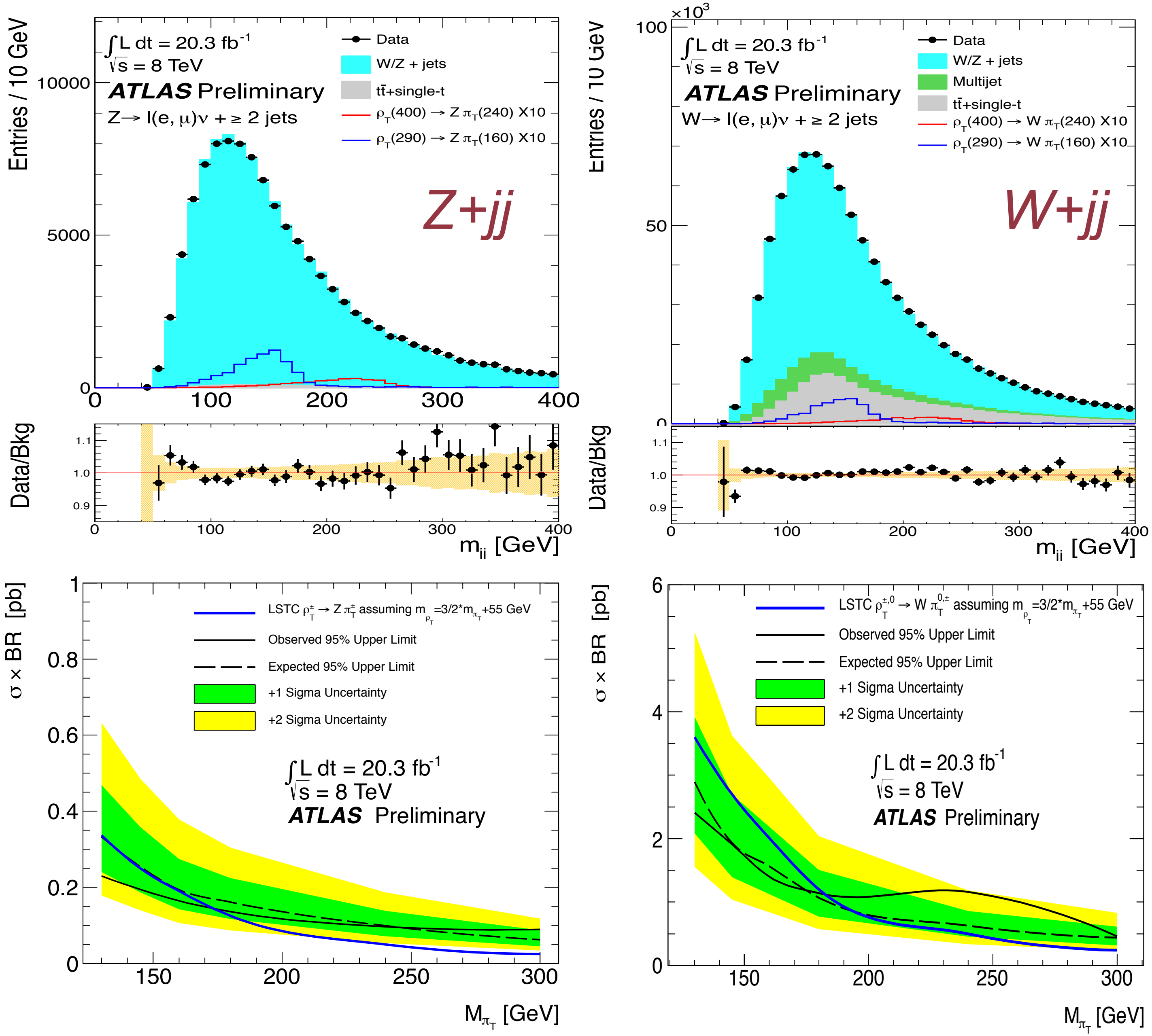




DIJET RESONANCE + W/Z

[ATLAS-CONF-2013-074]

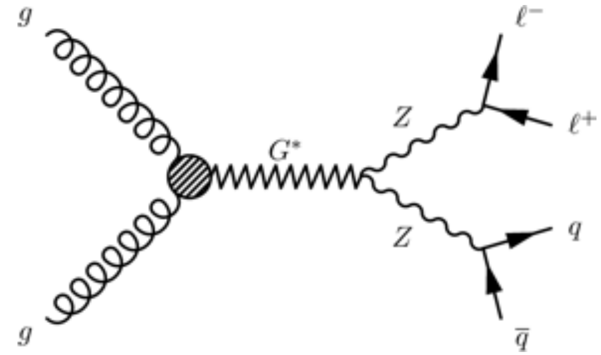
- Search W+jj and Z+jj in *resolved* jet channels
- Targeting lower-mass region (CDF anomaly)
- Limits on low-scale Techicolor model (π_T) using m_{jj} distribution in W/Z-tagged events
- Limits from 2.4 to 0.5 pb on π_T masses from 130 to 300

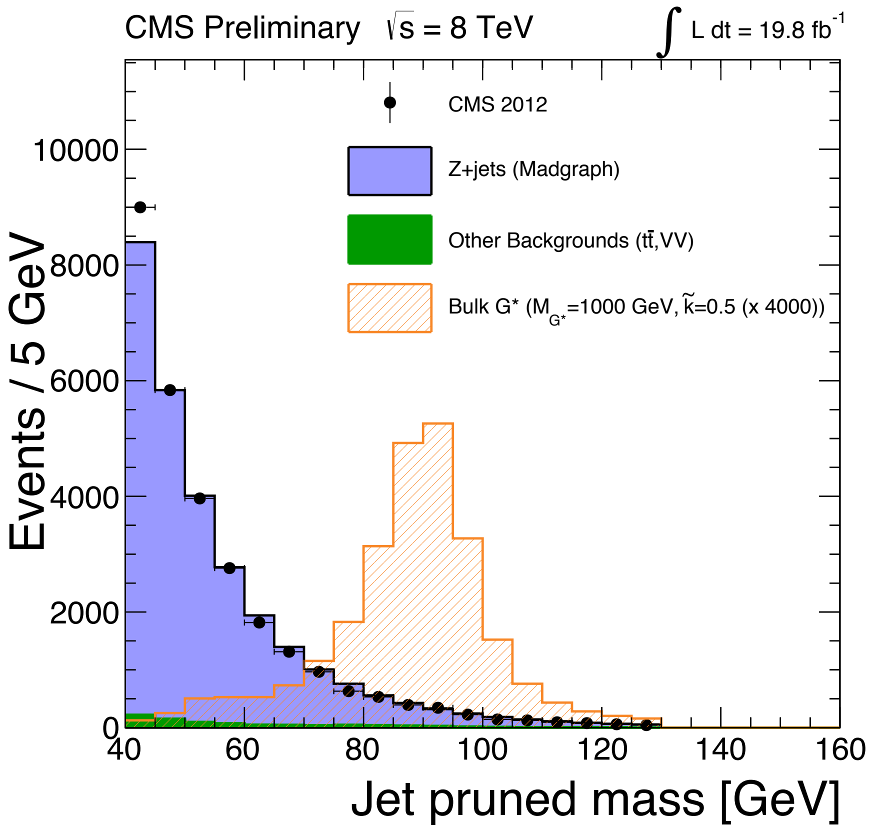


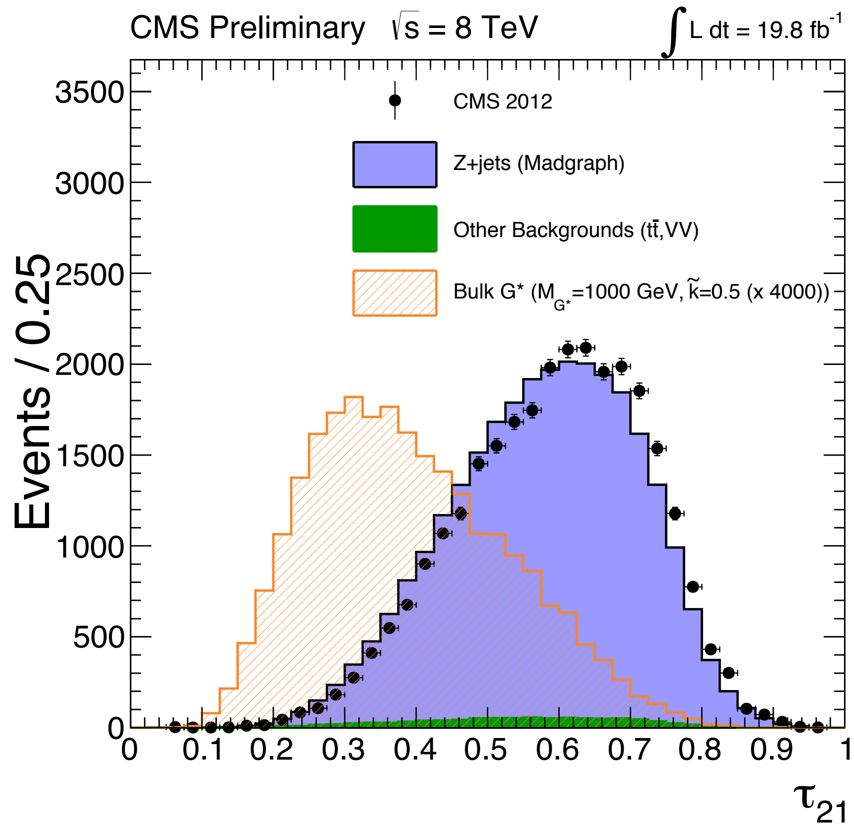
$X \longrightarrow Z\,V \longrightarrow 2l$ + JET

[CMS EXO-12-022]

- $Z \longrightarrow ll$ (M_{ll} in [70, 100] GeV) helps to suppress SM bkgd
- Two isolated l (= e or μ); Hadronic hemisphere selection
  - pruned jet mass in [70, 110] GeV
  - τ_{21} categories re-optimized, same as WV (HP: $\tau_{21} < 0.5$)
  - $p_{T,Z}$ > 80 GeV (less background than WW semileptonic)



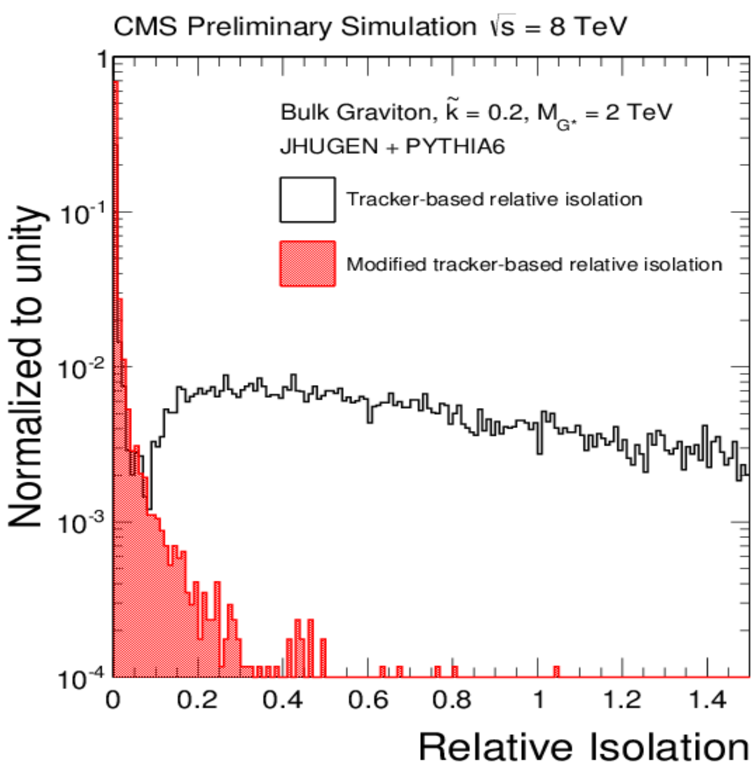


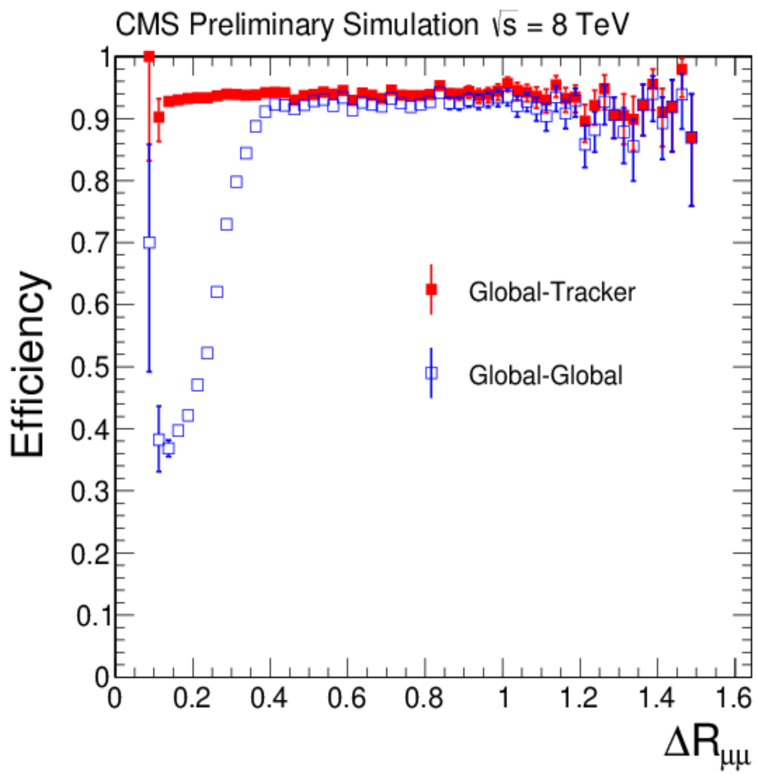


Boosted Leptons

[CMS EXO-12-022]

- Standard lepton identification has low efficiency for μμ with ΔR < ~0.5
  - If muons very close, can get wrong μ chamber hits associated to track
  - Recover by only using inner silicon tracker info for second muon
- Track-based isolation, but remove one μ from the isolation cone of the other μ

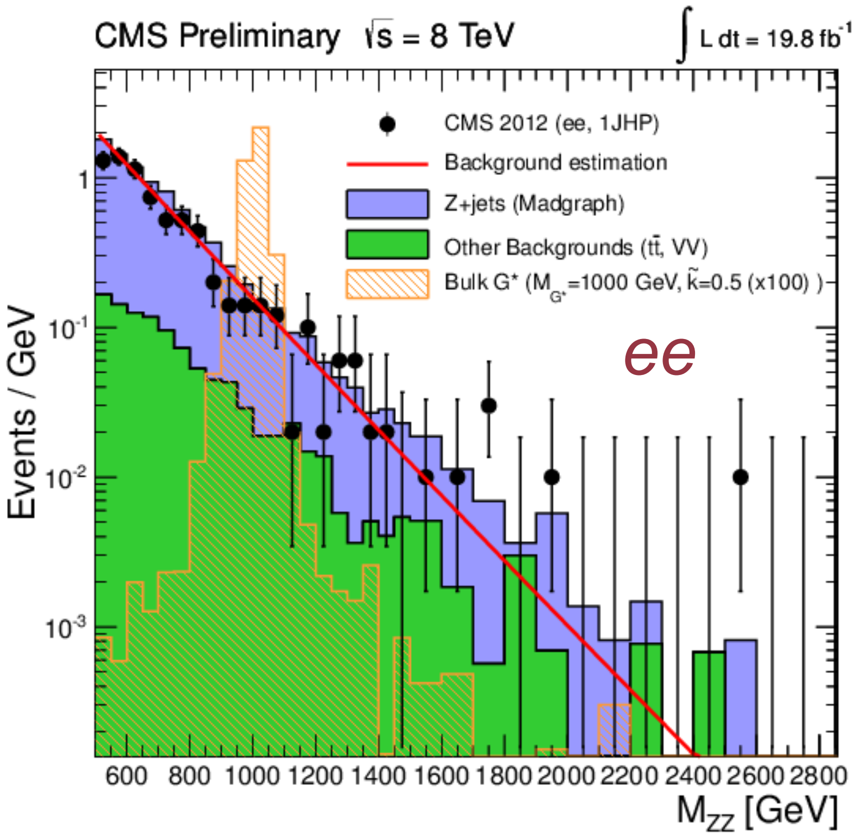


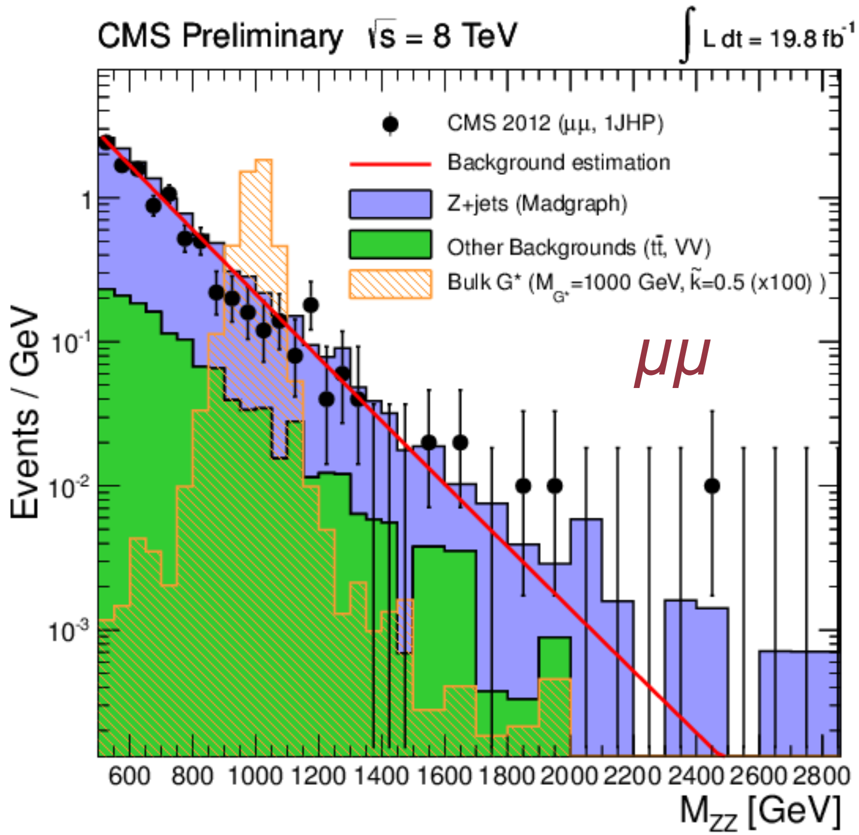


$X \rightarrow ZV \rightarrow 2l$ + JET

[CMS EXO-12-022]

- Background estimation:
  - Control region from m_j sidebands (like WW search)
  - Extrapolate to signal region with MC-based "α" ratio
- Good description of both shape and normalisation

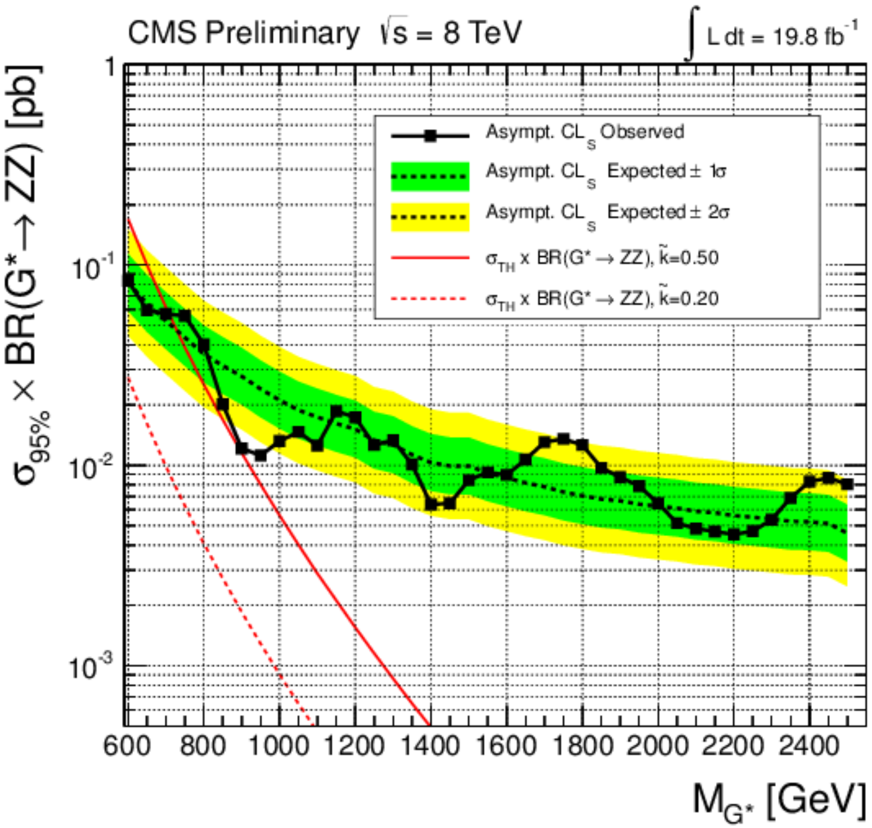




$X \longrightarrow Z\,V \longrightarrow 2l$ + JET

[CMS EXO-12-022]

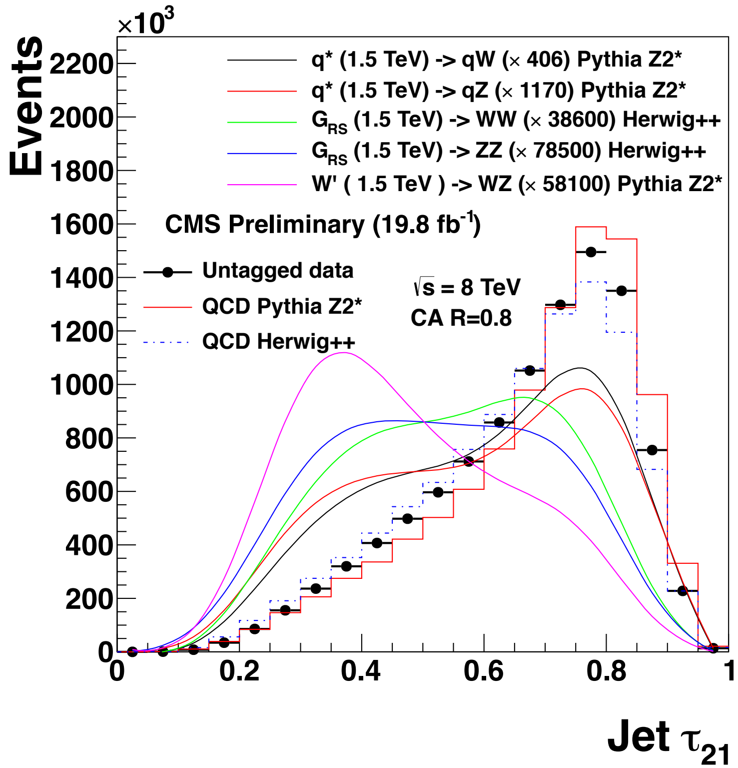
- Limits on narrow bulk graviton mass vs. σxBr(G*⟶ZZ)
- Exclusion at 95% CL between 83 and 4 fb for M_{G*} between 600 and 2500 GeV
- Bulk graviton excluded for M_{G*} < 710 GeV (k/M_{Pl} = 0.5)

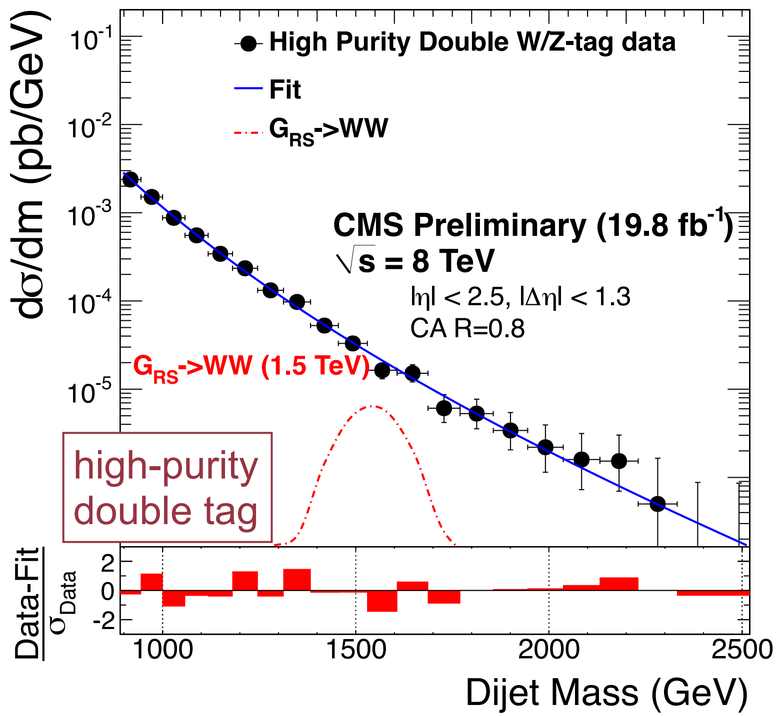


WW / ZZ / WZ IN DIJETS

[CMS EXO-12-024]

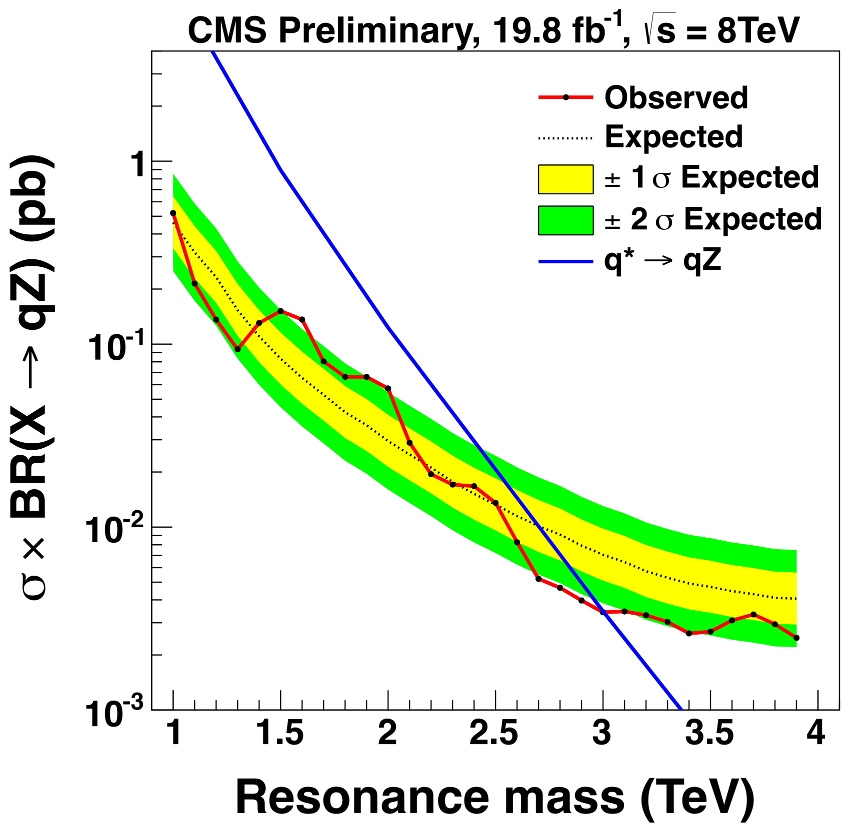
- $G_{RS} \longrightarrow WW/ZZ$ and $W' \longrightarrow WZ$ in dijets
  - Fully hadronic VV decays, $W \longrightarrow jj$ and/or $Z \longrightarrow jj$
  - Jets from W/Z typically boosted and merged into a single jet
  - QCD only significant background, suppressed by $|\eta_{jet1} - \eta_{jet2}| < 1.3$
- 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

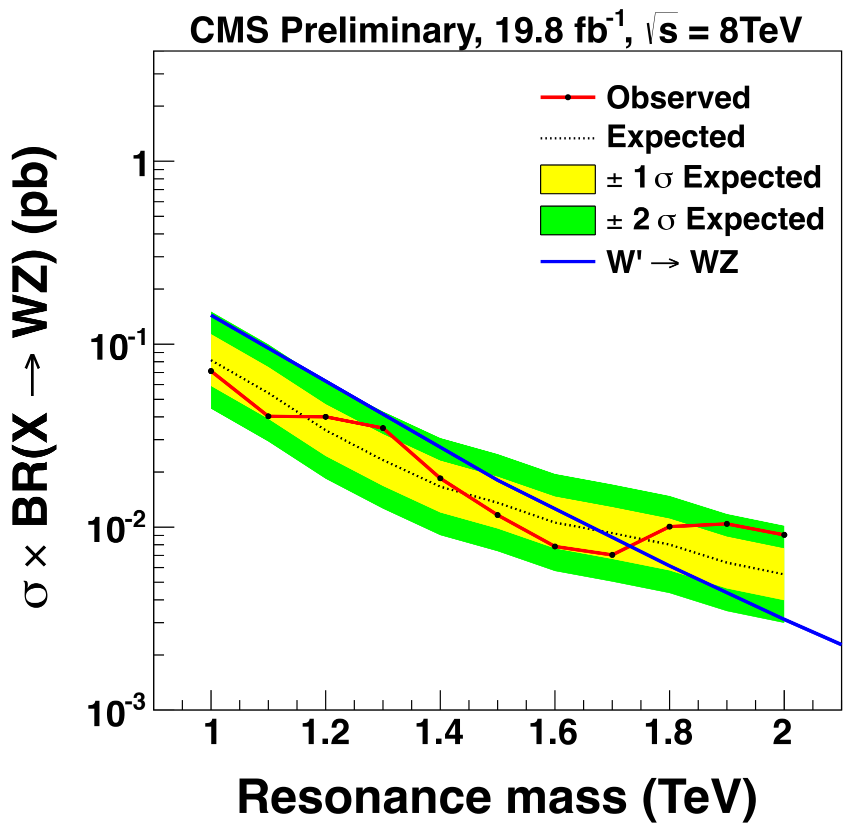




WW / ZZ / WZ IN DIJETS

[CMS EXO-12-024]





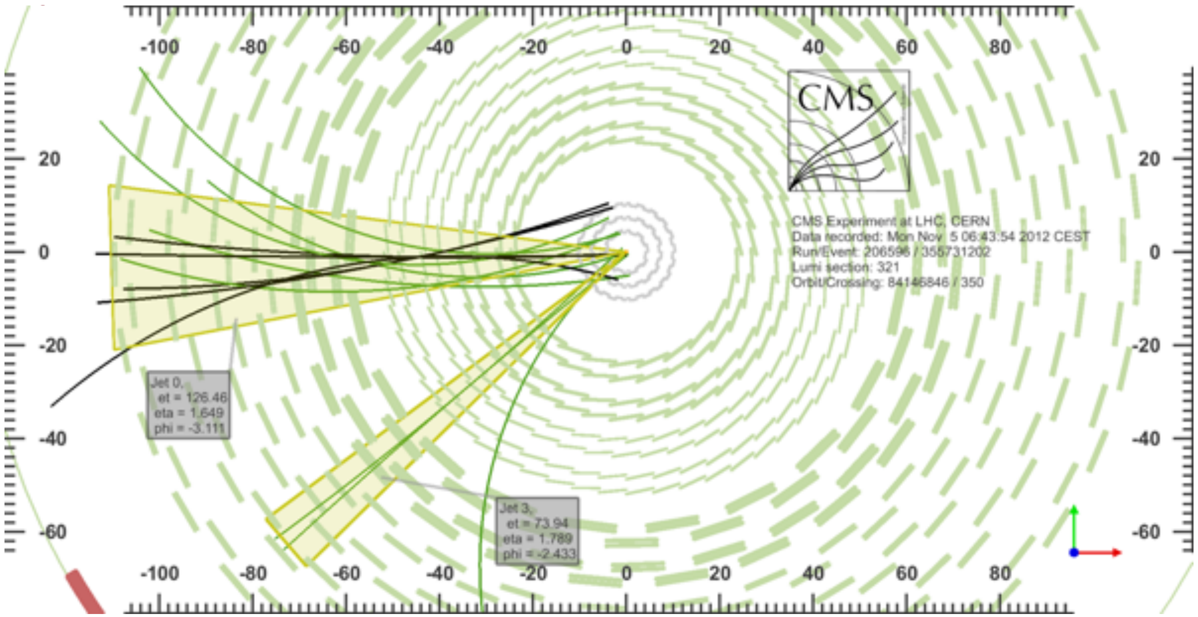
- G_{RS1} (k/M_{PL}=0.1) ⟶ WW(ZZ) excluded in mass range 1.0 to 1.59(1.17) TeV
- W’ ⟶ WZ excluded in mass range 1.0 to 1.73 TeV
- q* ⟶ qW(qZ) excluded in mass range 1.0 to 3.23(3.00) TeV

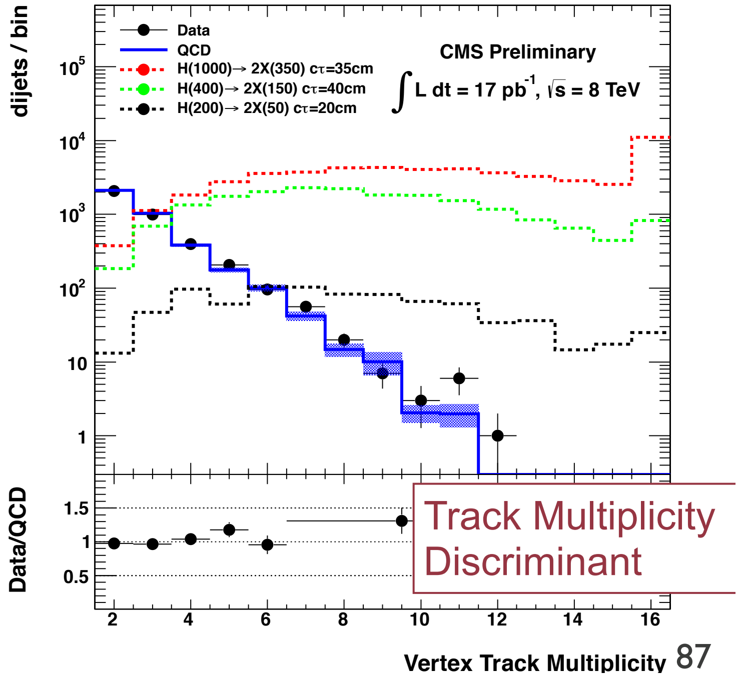
LONG-LIVED PARTICLES

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 $\longrightarrow$ H $\longrightarrow$ XX $\longrightarrow$ (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



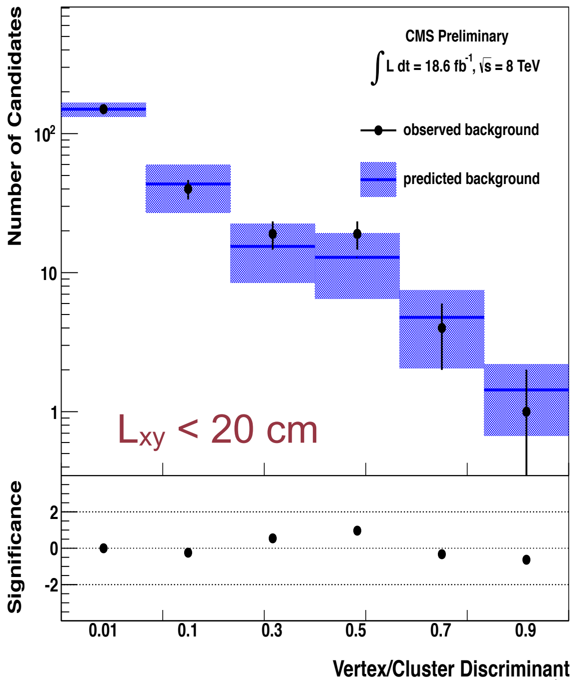


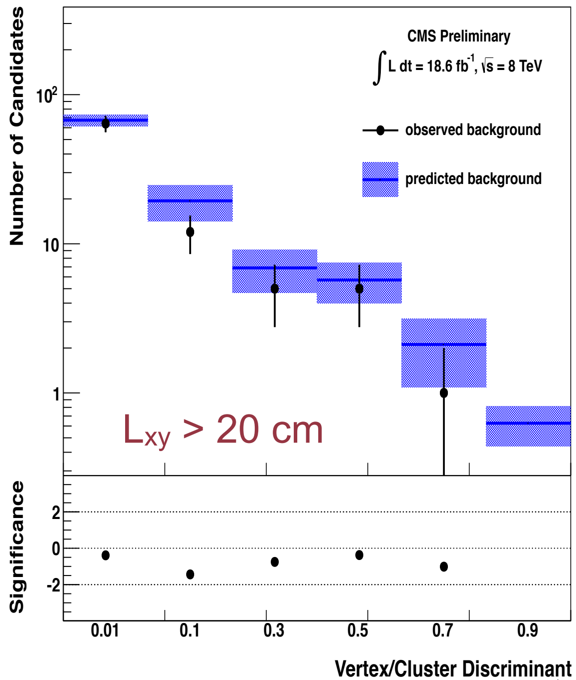
DISPLACED JETS

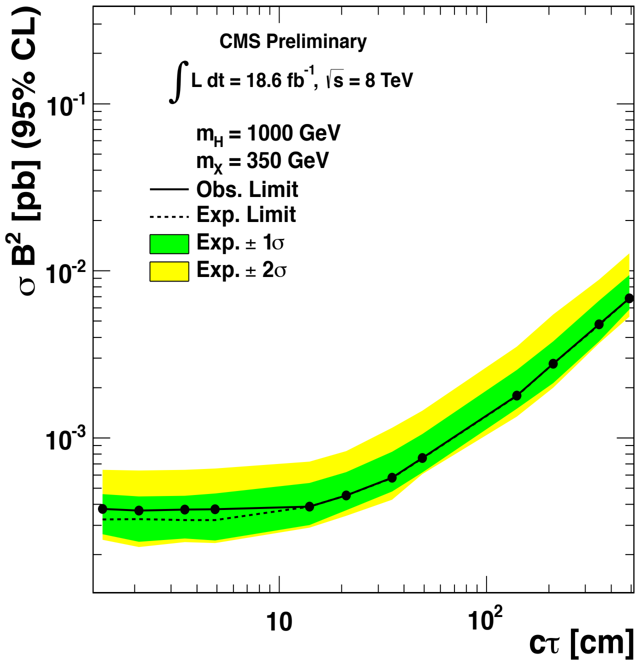
[CMS EXO-12-038]

- Background prediction using ABCD technique: jet1, jet2, secondary vertex details
- Search using "cut & count" technique optimised 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**

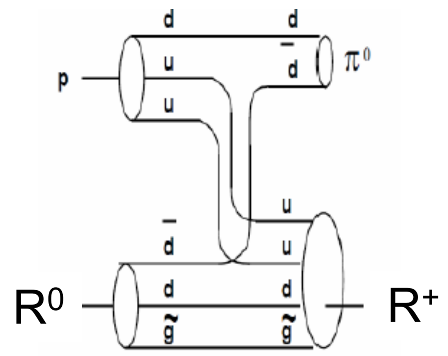






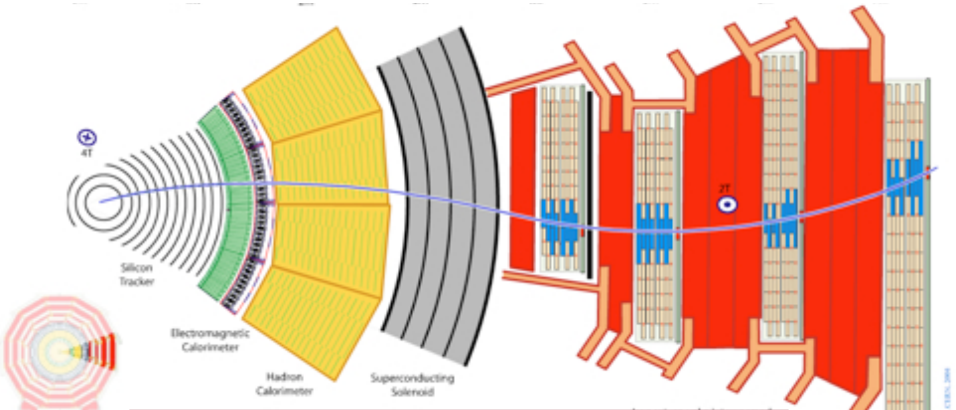
LONG-LIVED CHARGED PARTICLES

[CMS EXO-12-026]

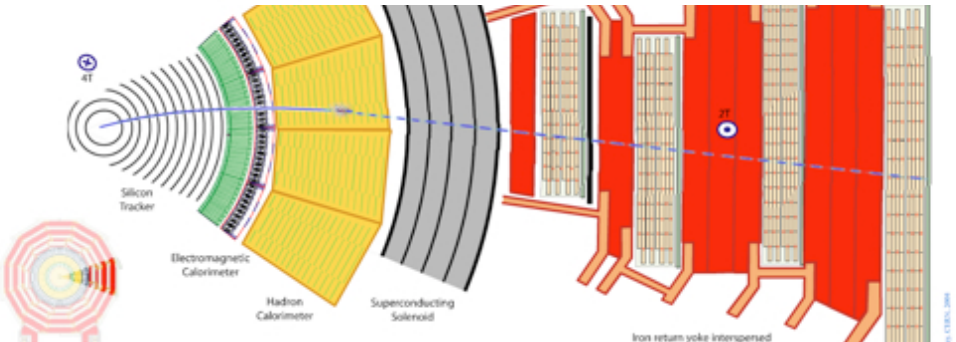


- Heavy, (quasi-)stable, also charged: slow (β<1), high dE/dx, long time-of-flight
- *stau* benchmark model:
  - |Q=e| in GMSB (SPS7)
  - e/3 ≤ |Q| ≤ 8e pair production (neutral under $SU(2)_L$)
- *gluino* (spit SUSY) or *stop* (large gluino masses limit) benchmark
  - form R-hadrons containing a massive parton,
  - uncertainty from hadronization (fraction of gluino balls?) and charge flipping
  - electric charge can change while interacting with the detector
- Selection
  - basic selection: p_T > 45 GeV, $|\eta|$ < 2.1, $|d_{xy}|$ and $|d_z|$< 0.5 cm, very loose isolation, etc.
  - Track p_T : inner tracker transverse momentum
  - Muon 1/β : measured by muon system
  - Track I_{as} : incompatibility of the track energy loss w.r.t MIP expected dE/dx

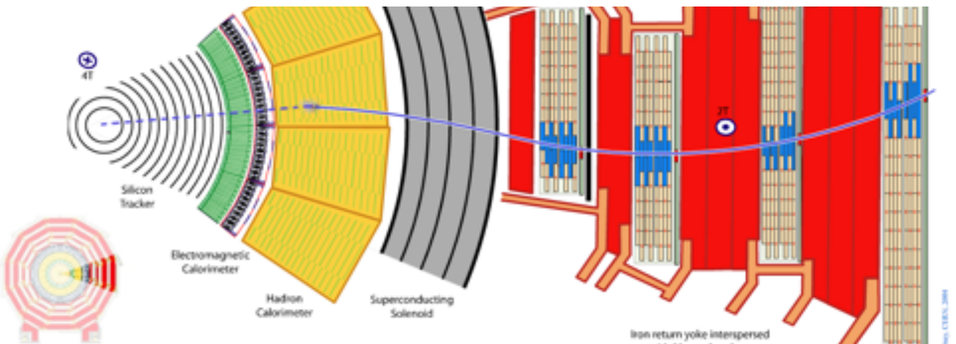
Q=1 HSCP



HSCP unchanged - *Tracker + TOF*



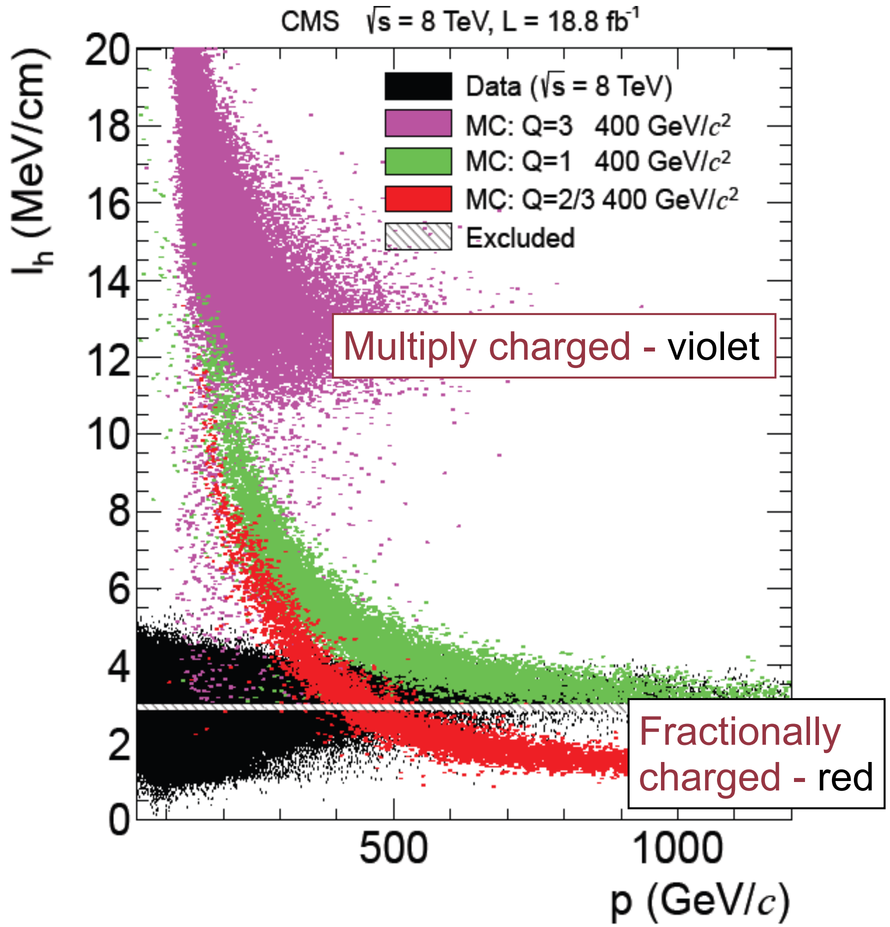
HSCP becoming neutral - *Tracker-only*



HSCP neutral in tracker - *Muon-only*

Q≠1 HSCP

[CMS EXO-12-026]



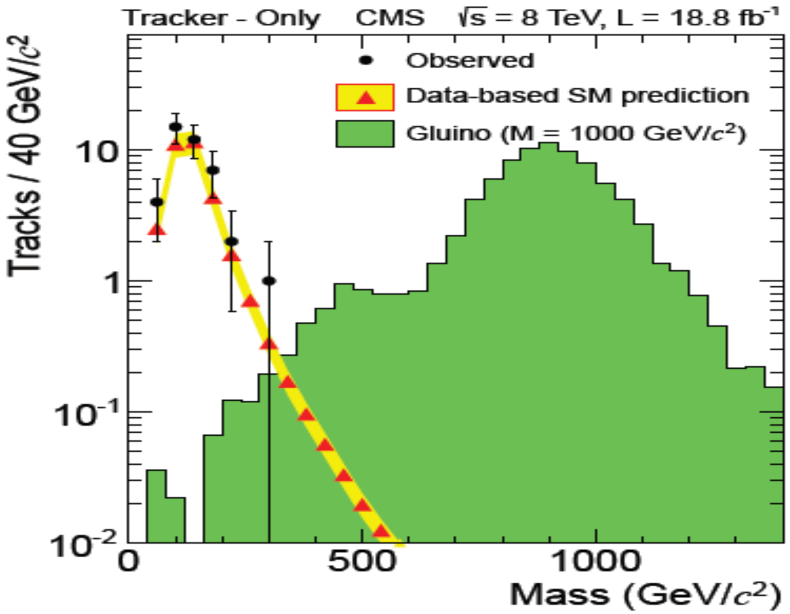
HSCP - Backgrounds and Results

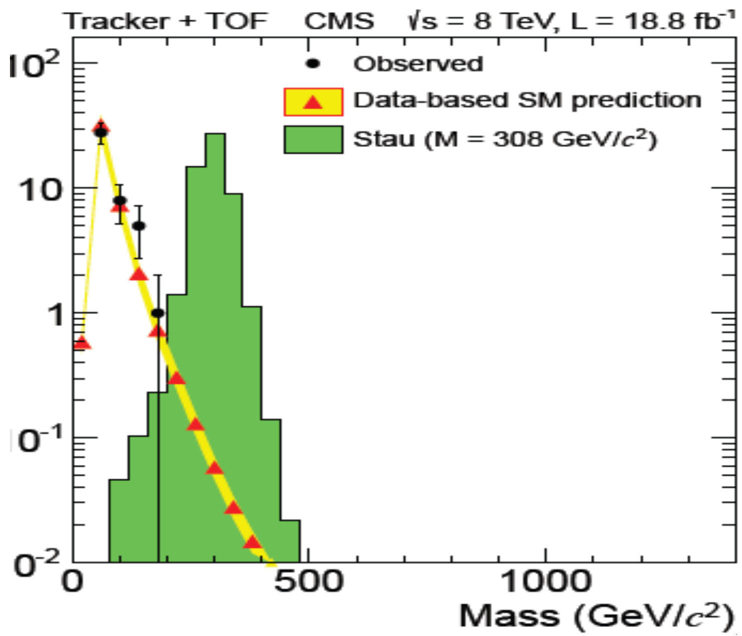
[CMS EXO-12-026]

- ABCD-technique; p_T, dE/dx and 1/β variables
  - Tk-Only — p_T +dE/dx
  - Tk+TOF — p_T +dE/dx +1/β
  - Mu-Only — p_T +1/β
  - multi. charged — dE/dx +1/β
  - frac. charged — p_T +dE/dx
- Tk and Tk+TOF: predict the mass from dE/dx

$$dE/dx \cong K\frac{m^2}{p^2}+C$$

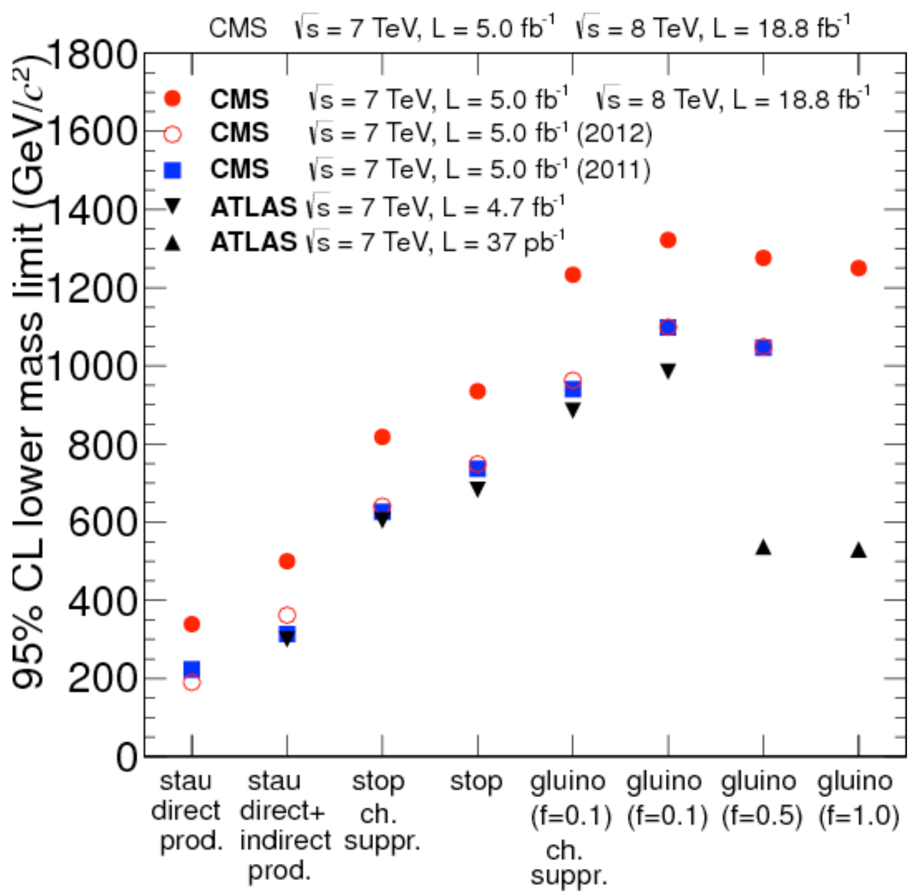
	Mass (GeV/c^2)	$\sqrt{s}=7$ TeV Pred.	$\sqrt{s}=7$ TeV Obs.	$\sqrt{s}=8$ TeV Pred.	$\sqrt{s}=8$ TeV Obs.
Tracker-only	>0	7.1 ± 1.5	8	33 ± 7	41
	>100	6.0 ± 1.3	7	26 ± 5	29
	>200	0.65 ± 0.14	0	3.1 ± 0.6	3
	>300	0.11 ± 0.02	0	0.55 ± 0.11	1
	>400	0.030 ± 0.006	0	0.15 ± 0.03	0
Tracker+TOF	>0	8.5 ± 1.7	7	44 ± 9	42
	>100	1.0 ± 0.2	3	5.6 ± 1.1	7
	>200	0.11 ± 0.02	1	0.56 ± 0.11	0
	>300	0.020 ± 0.004	0	0.090 ± 0.02	0
Muon-only	–	–	–	6 ± 3	3
$\|Q\|>1e$	–	0.15 ± 0.04	0	0.52 ± 0.11	1
$\|Q\|<1e$	–	0.12 ± 0.07	0	1.0 ± 0.2	0

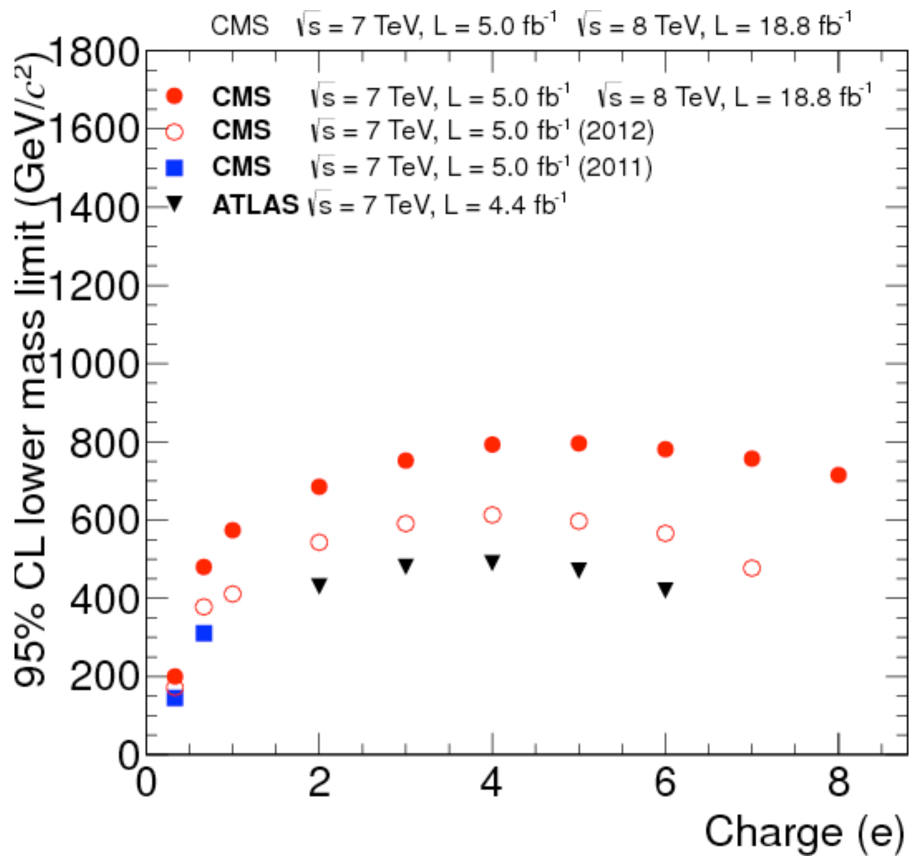




HSCP - LIMITS

[CMS EXO-12-026]





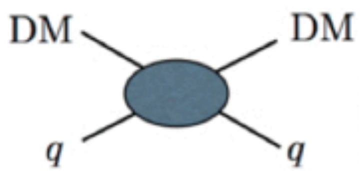
- First CMS limits on gluino fully hadronizing into gluino balls (f=100%)

M_{Gluino} > 1322 GeV, M_{Stop} > 935 GeV

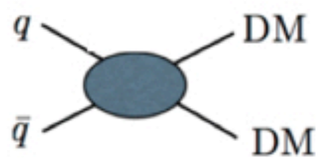
Dark Matter and Extra Dimensions

PRODUCTION OF DARK MATTER AT CMS

- Search for evidence of pair-production of Dark Matter particles (χ)

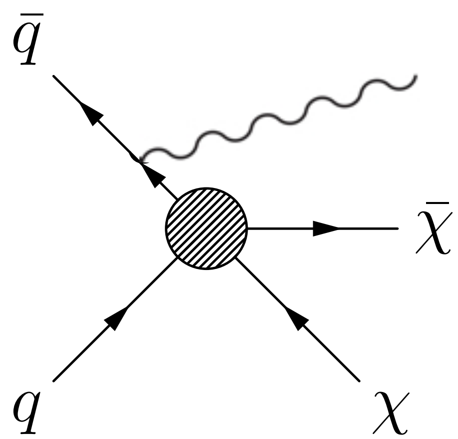


Direct Detection (t-channel)

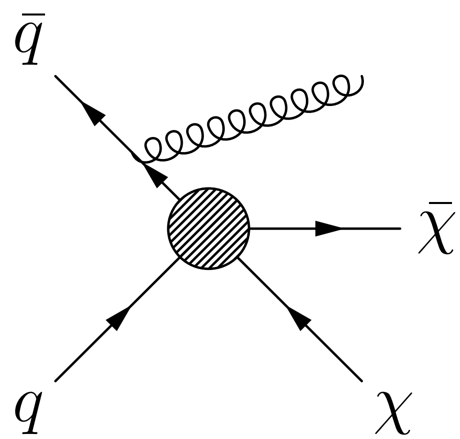


Collider Searches (s-channel)

- Dark Matter production gives missing transverse energy (MET)
- Photons (or jets from a gluon) can be radiated from quarks, giving monophoton (or monojet) plus MET



Monophoton + MET



Monojet + MET

PHENOMENOLOGY

- Pair-production of χ can be characterised by a contact interaction with operators

$$\mathcal{O}_V = \frac{(\bar{\chi}\gamma_\mu\chi)(\bar{q}\gamma^\mu q)}{\Lambda^2}$$

vector --> spin independent (SI)

$$\mathcal{O}_{AV} = \frac{(\bar{\chi}\gamma_\mu\gamma_5\chi)(\bar{q}\gamma^\mu\gamma_5 q)}{\Lambda^2}$$

axial-vector --> spin-dependent (SD)

- Cross section depends on the mass (m_χ) and the scale Λ (for couplings g_χ, g_q)

$$\sigma_{SI} = 9\frac{\mu^2}{\pi\Lambda^4}$$

$$\sigma_{SD} = 0.33\frac{\mu^2}{\pi\Lambda^4}$$

spin-independent and spin-dependent cross sections

$$\Lambda = M/\sqrt{g_\chi g_q} \qquad \mu = \frac{m_\chi m_p}{m_\chi + m_p}$$

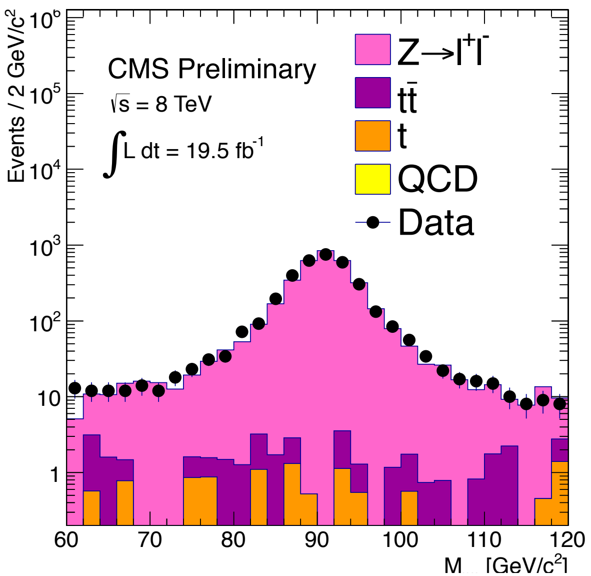
[Bai, Fox and Harnik, JHEP 1012:048 (2010)]

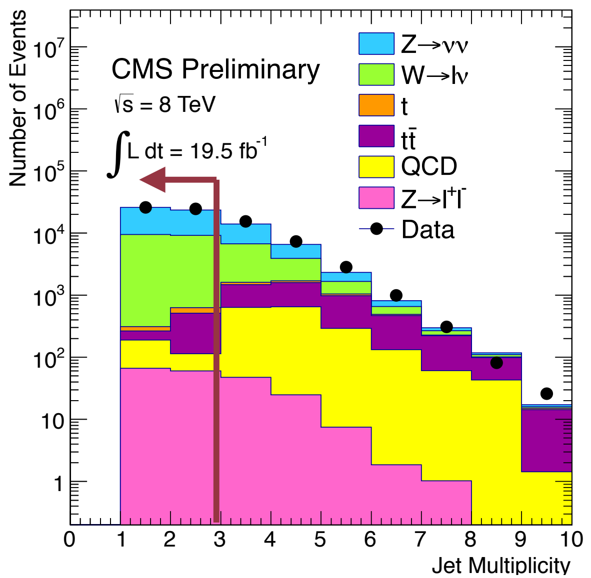
[Goodman, Ibe, Rajaraman, Shepherd, Tait, Yu, Phys.Rev.D82:116010 (2010)]

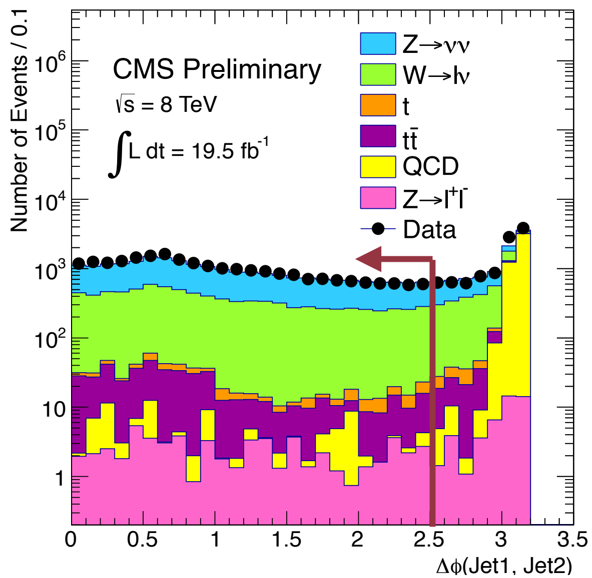
MONOJET SELECTION AND BACKGROUNDS

[CMS EXO-12-048]

- Data-driven Background Estimation (Lepton Identification)
  - Require isolated muon > 20 GeV/c; select 1 and 2 muon events
  - Obtain Z+jet sample from M(μμ), W+jet sample from p_T(μ)+MET
- Basic topological selection
  - Reject events with isolated leptons
  - MET > 250 GeV, # of Jets = 1 or 2
  - Leading Jet: pT > 110 GeV, |η|<2.4
  - Second Jet: pT > 30 GeV
  - Δφ(jet1,jet2) < 2.5



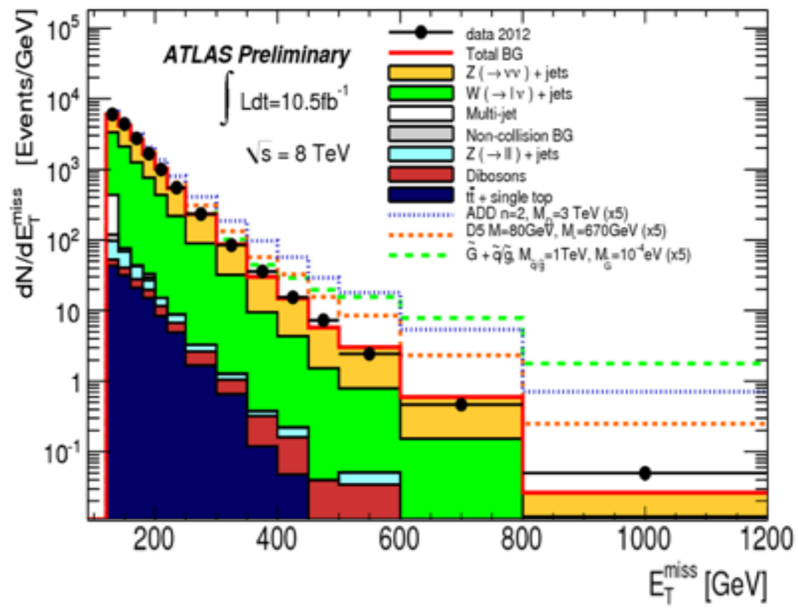


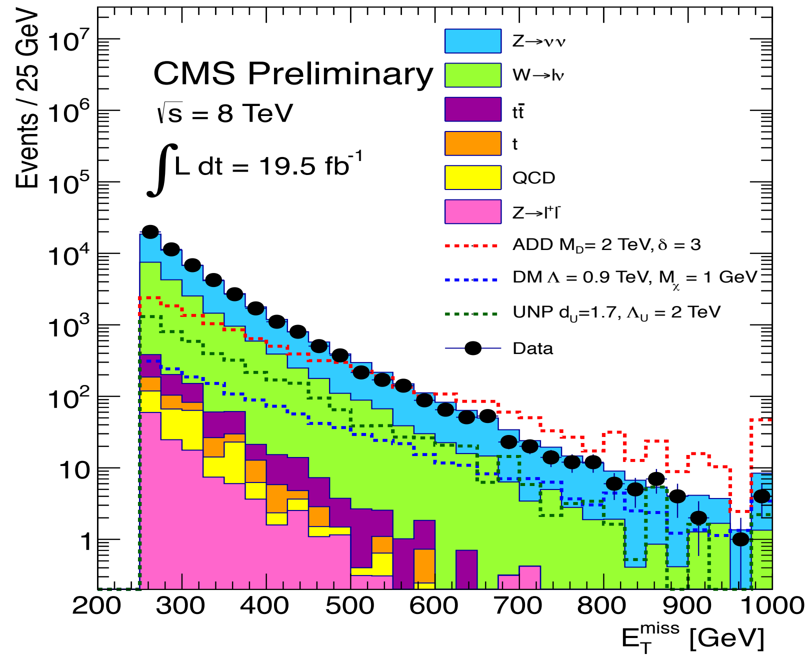


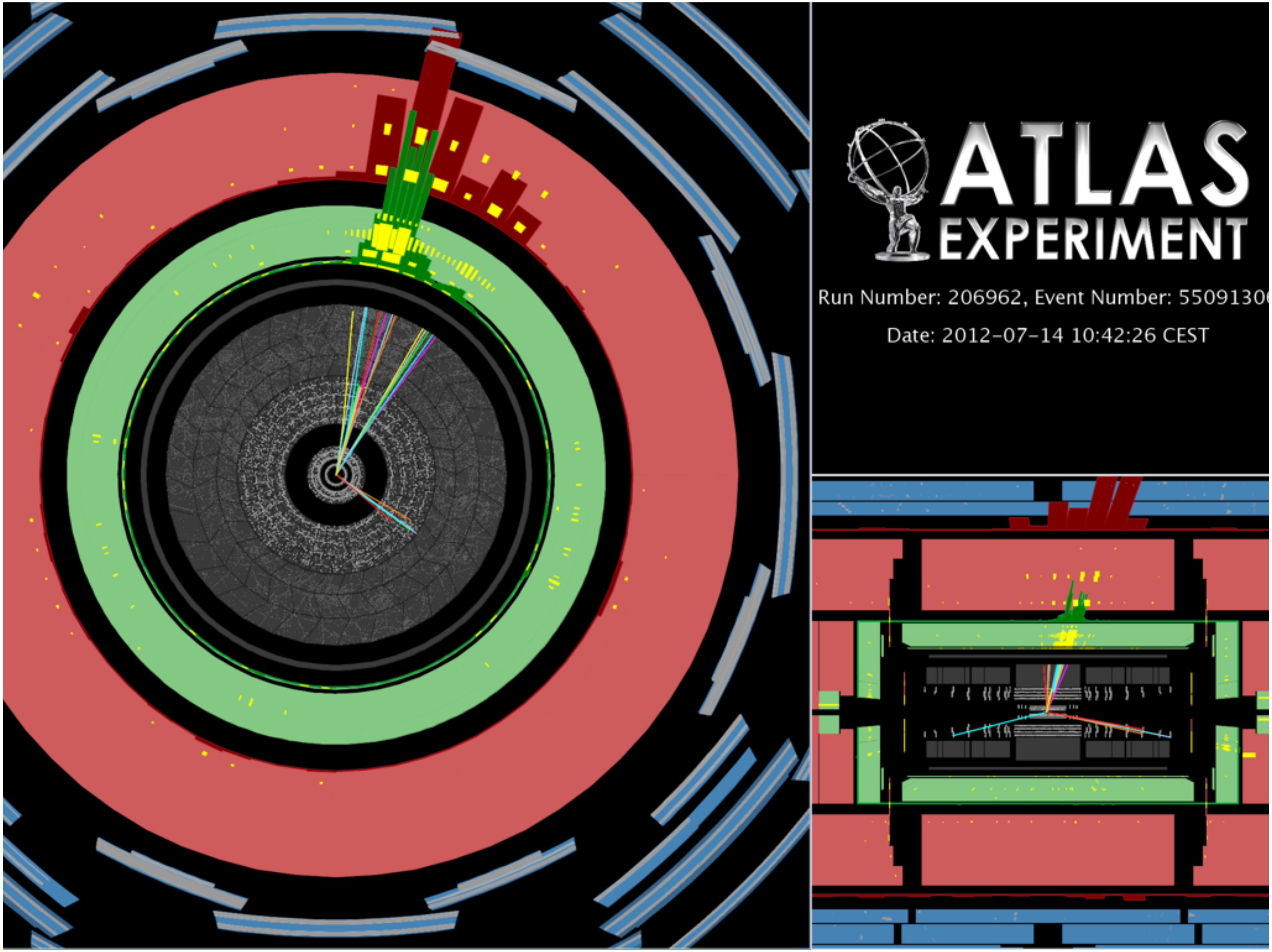
Dark Matter and ADD from Monojets

[ATLAS-CONF-12-147, CMS EXO-12-048]

- Pair-produced Dark Matter or Extra Dimensions
  - Search for missing energy and radiated jet
  - Similar searches in monophoton and other channels
- Monojet Selection for CMS (similar for ATLAS):
  - Leading jet p_T > ~120 GeV
  - topological cuts to reduce QCD, e.g. $\Delta\varphi(j1,j2)<2.5$
  - veto events with isolated leptons
- Backgrounds from Data-Driven and MC
  - Measure Z + jets --> predict Z(νν) + jets
  - Measure W + jets --> predict W(lν) + jets
  - smaller backgrounds from top, QCD, non-collision
- Best limits with E_T^{miss} > 350–400 GeV






ATLAS
EXPERIMENT
Run Number: 206962, Event Number: 5509130
Date: 2012-07-14 10:42:26 CEST

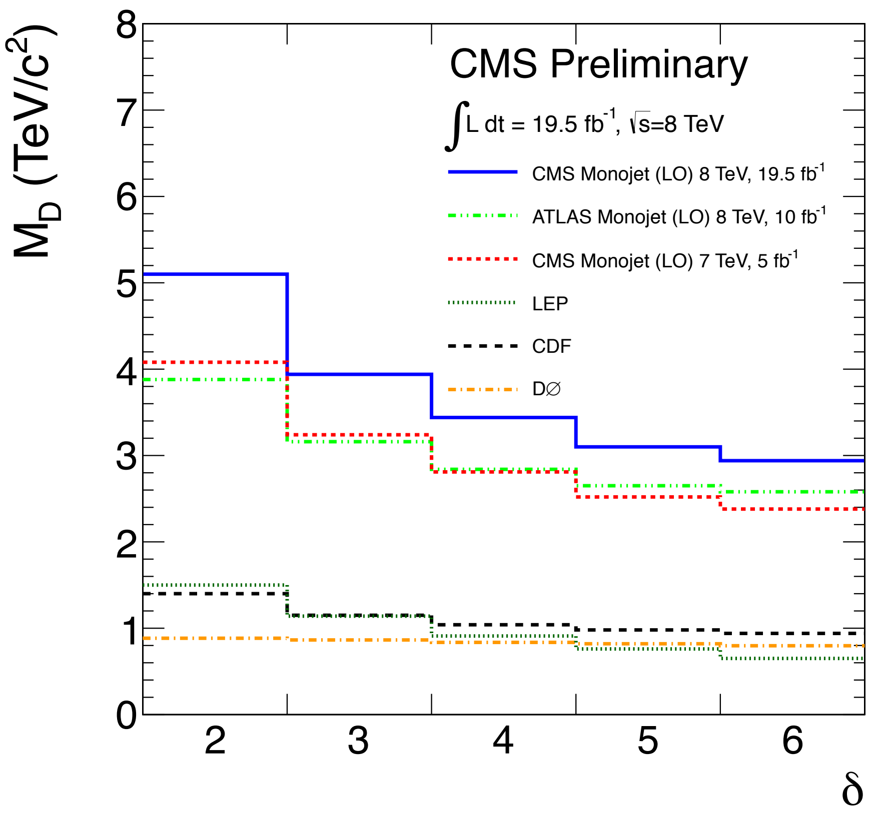
Large Extra Dimensions from Monojets

[ATLAS-CONF-12-147, 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

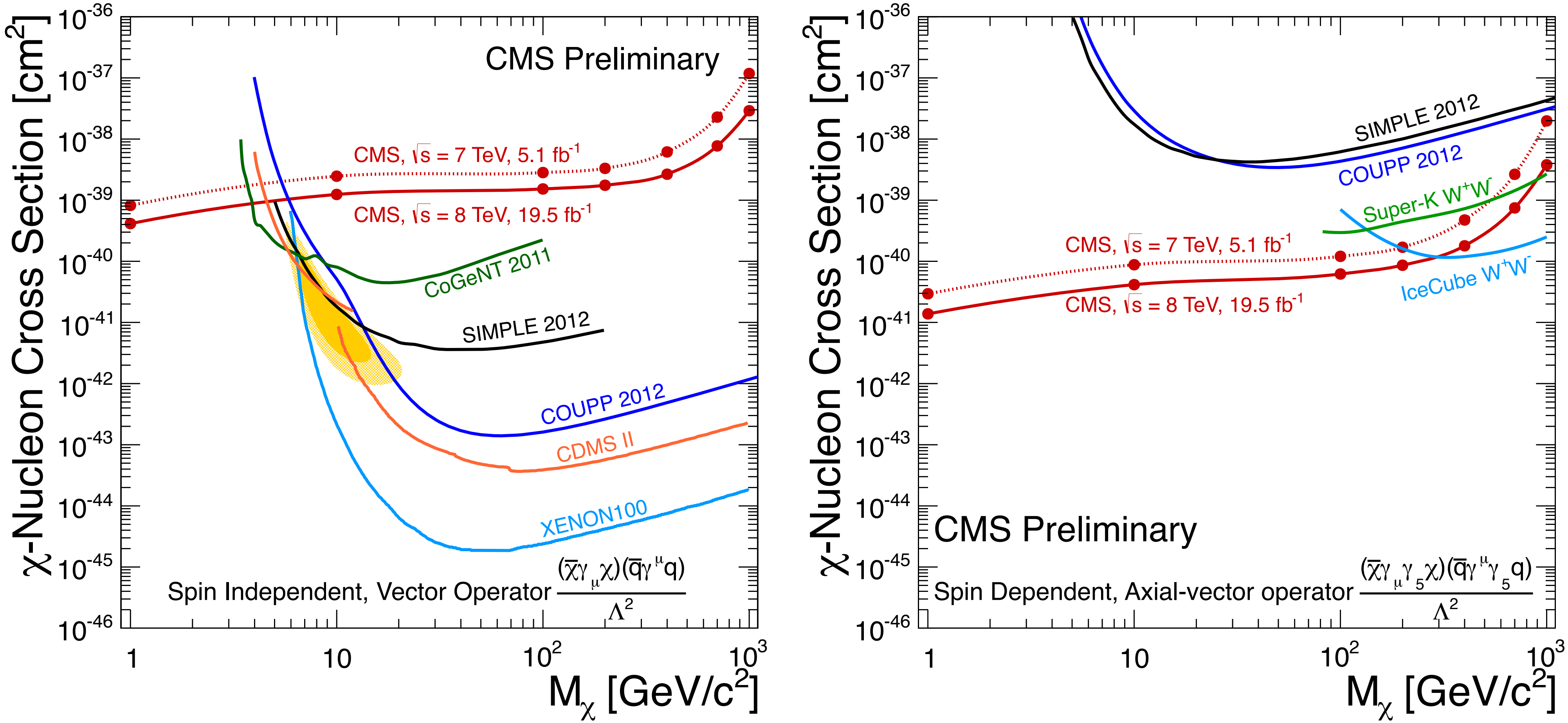


M_D (ADD) at LO 95% CL limits	√s [TeV]	Lumi [fb^{-1}]	δ=3 Exp.	δ=3 Obs.	δ=6 Exp.	δ=6 Obs.
ATLAS Monojet	8	10.5	3.39	3.16	2.69	2.58
CMS Monojet	8	19.5	3.94	3.96	2.95	2.94

DARK MATTER AND MONOJETS

[CMS EXO-12-048]

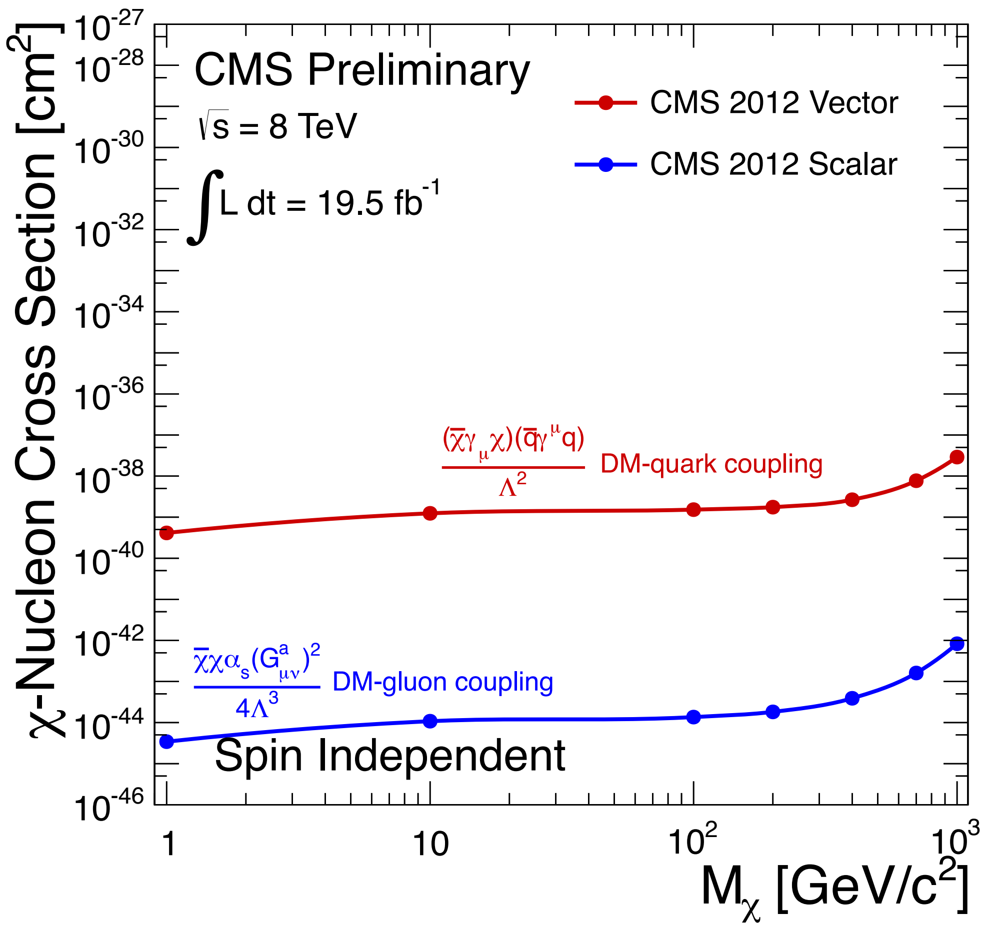
- Pair-production of DM (χ) characterized by a contact interaction effective theory
- Derived limits then compared to direct-detection experiments
- ATLAS & CMS results similar for 7 TeV data, improved with 8 TeV

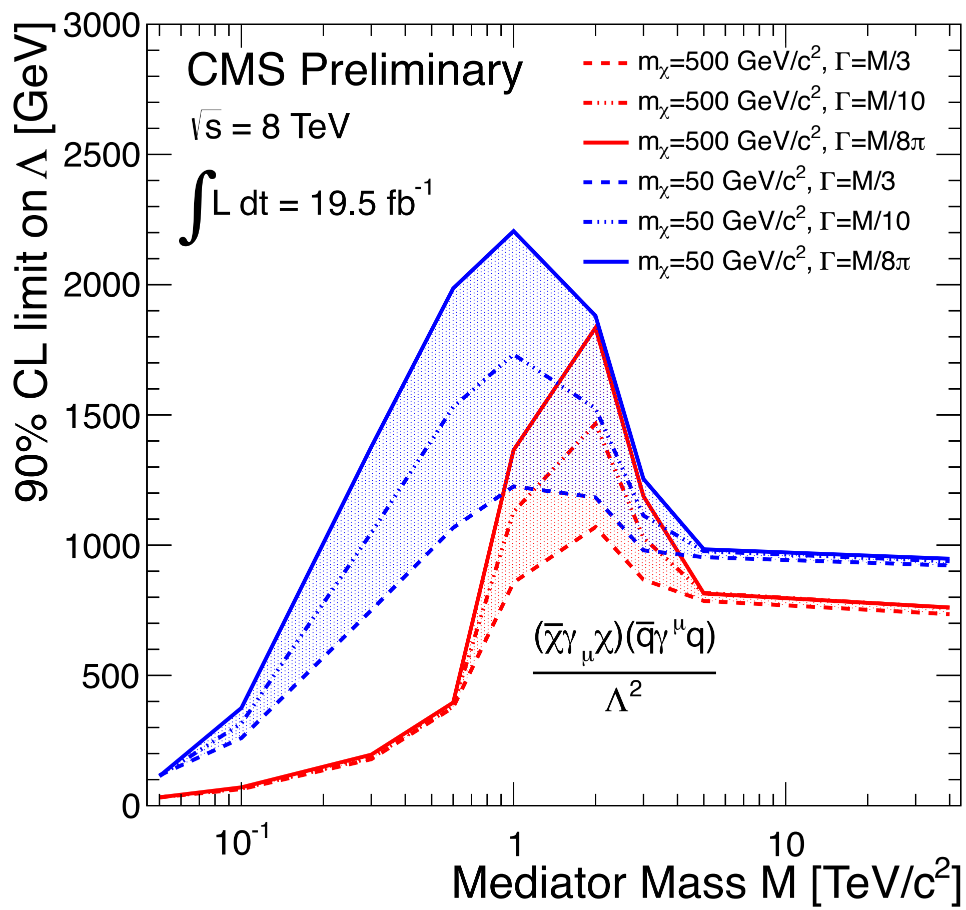


Dark Matter and Monojets

[CMS EXO-12-048]

- Starting to extend simple contact interaction scenario with new operators and a scan over mediator mass

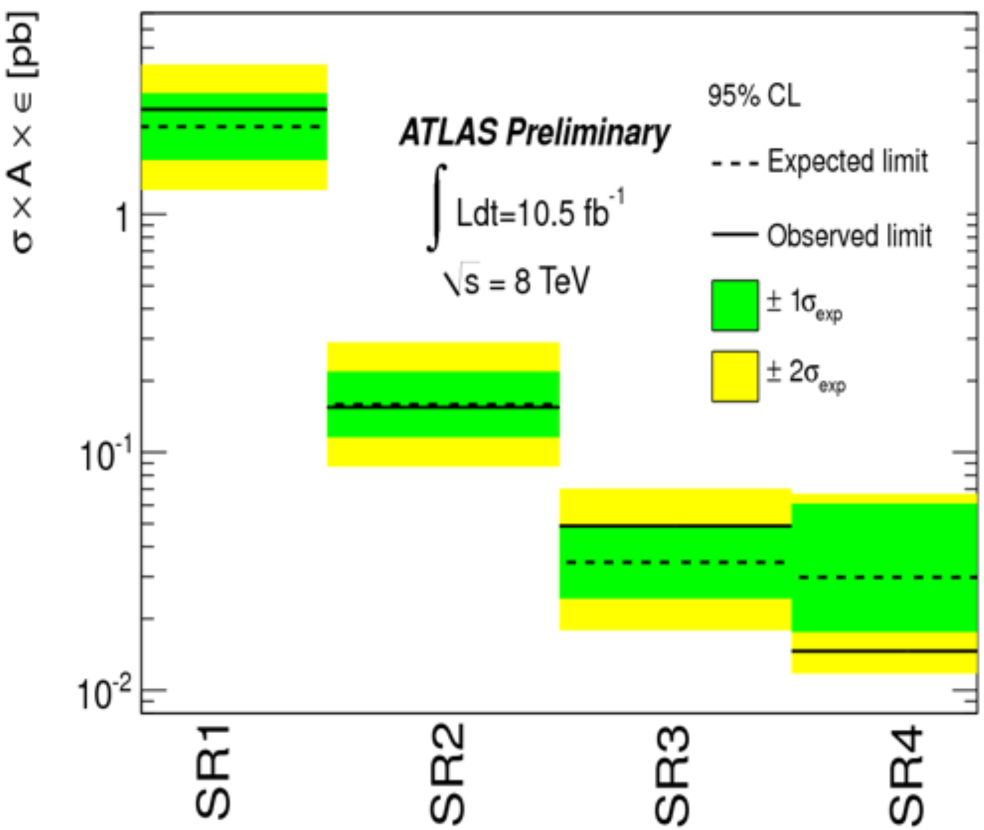


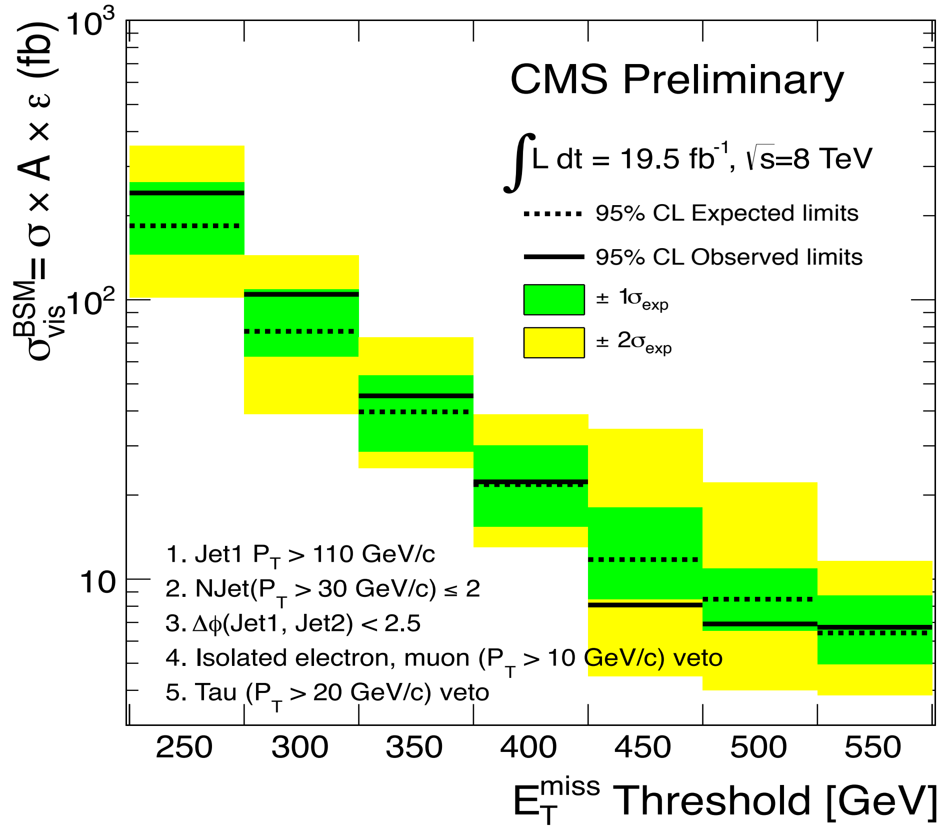


MONOJET MODEL-INDEPENDENT LIMITS

[ATLAS-CONF-12-147, CMS EXO-12-048]

- Both experiments quote model-independent limits for generic applicability to SUSY compressed spectra, invisible Higgs, or any other “monojet” signature

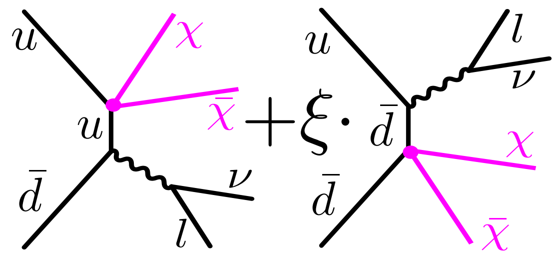




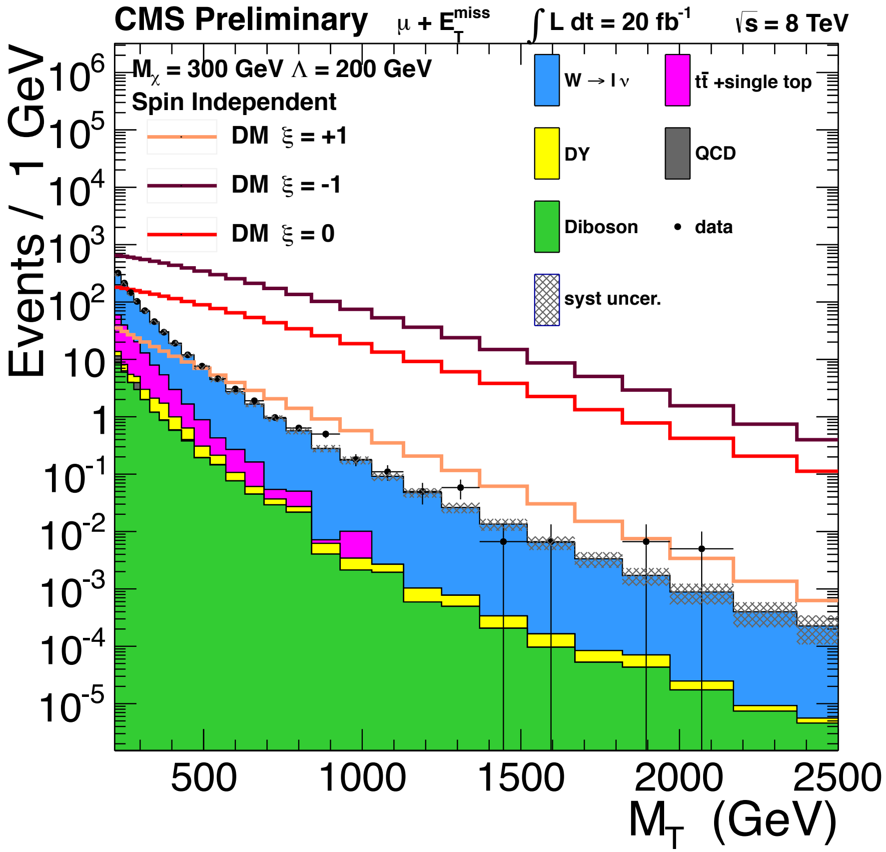
MONOLEPTON DARK MATTER

[CMS EXO-13-004]

- Dark Matter production
  - W recoiling against pair-produced DM
  - Real mediator, not contact interaction
  - Reinterpretation of W' --> lν search (CMS PAS EXO-12-060)



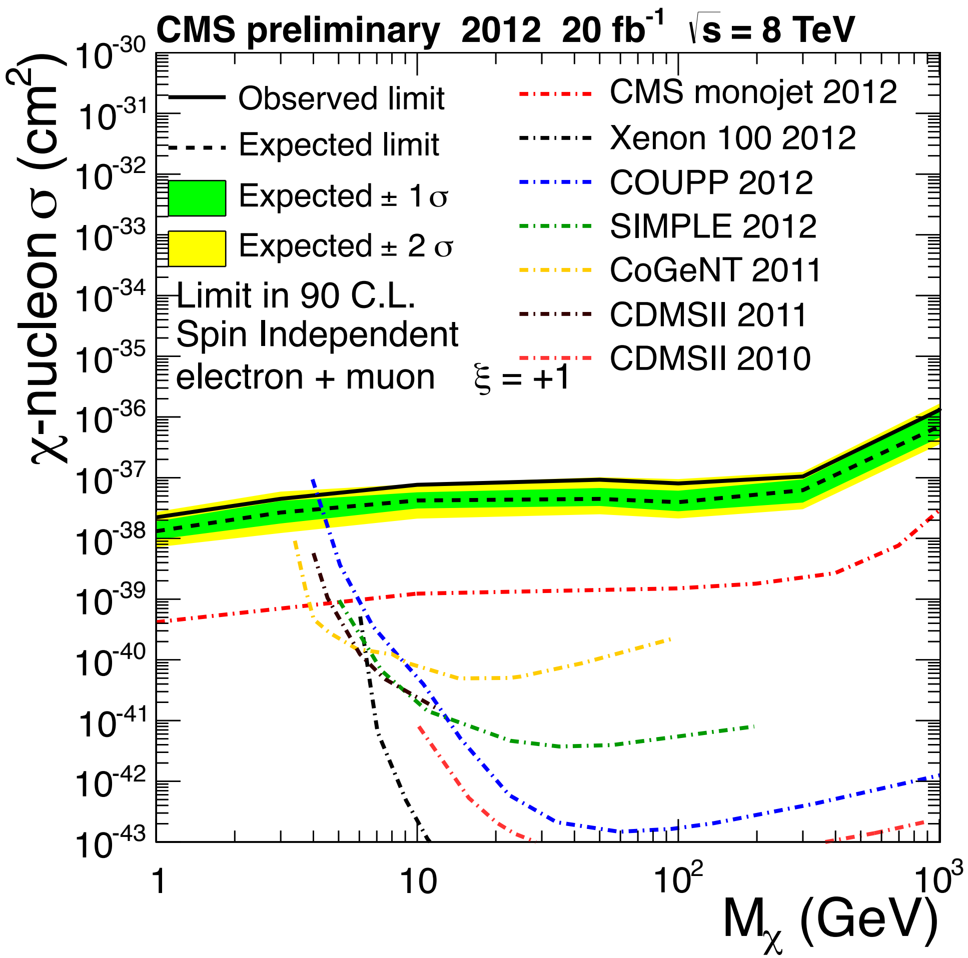
- Consider two couplings, interference
  - vector- and axial-vector couplings considered
  - unlike monojets, have interference effects
  - interference effects parameterised by ξ (W+ diagram at right)

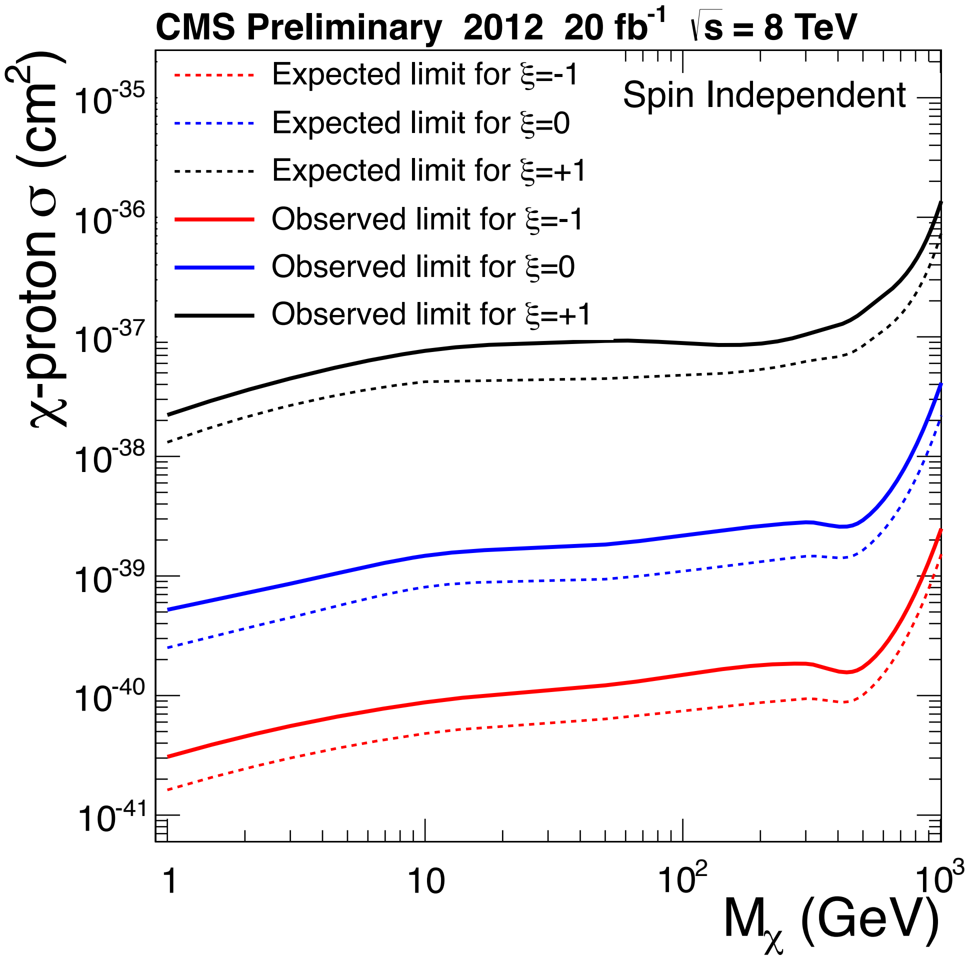


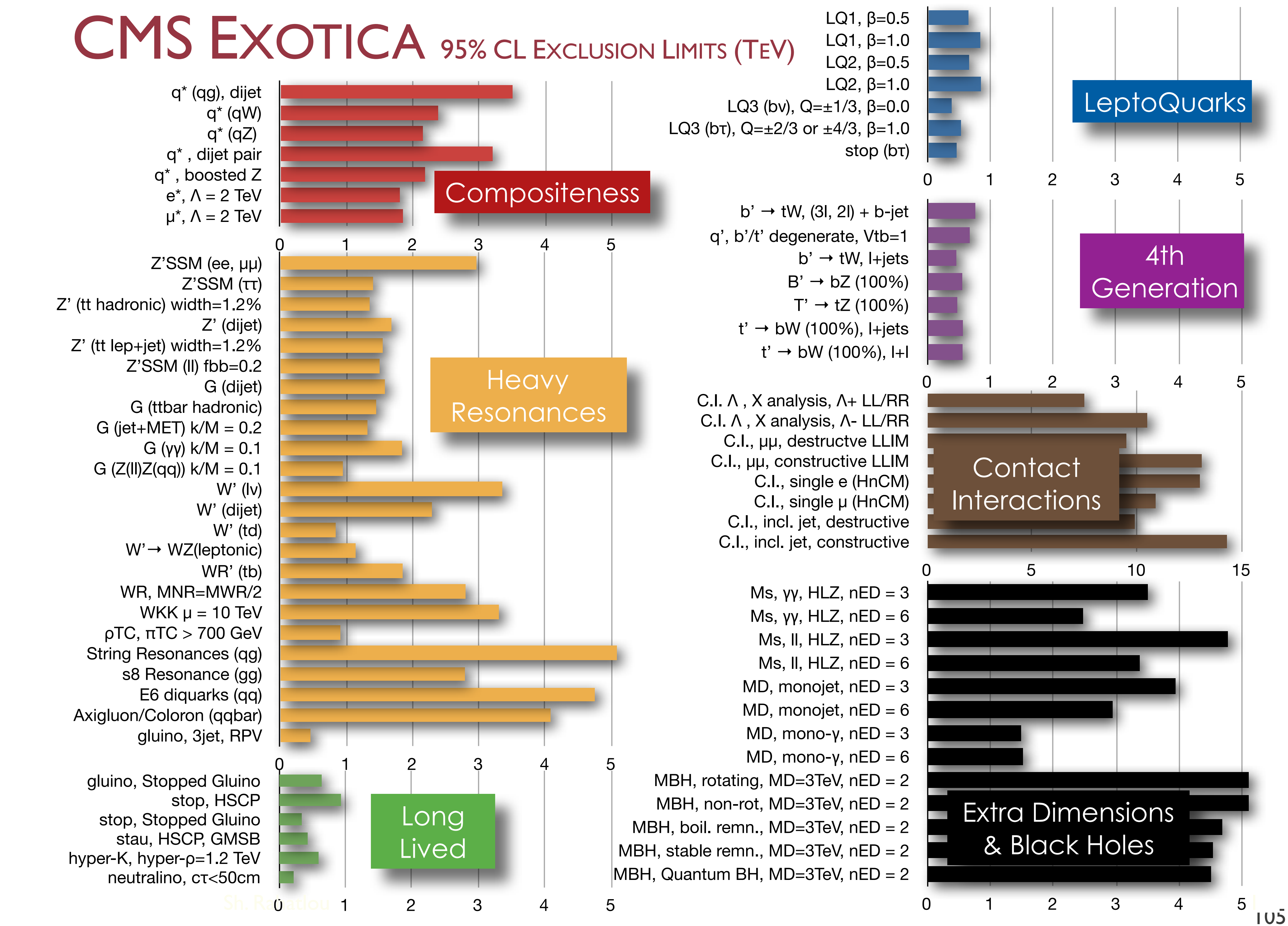
MONOLEPTON DARK MATTER

[CMS EXO-13-004]

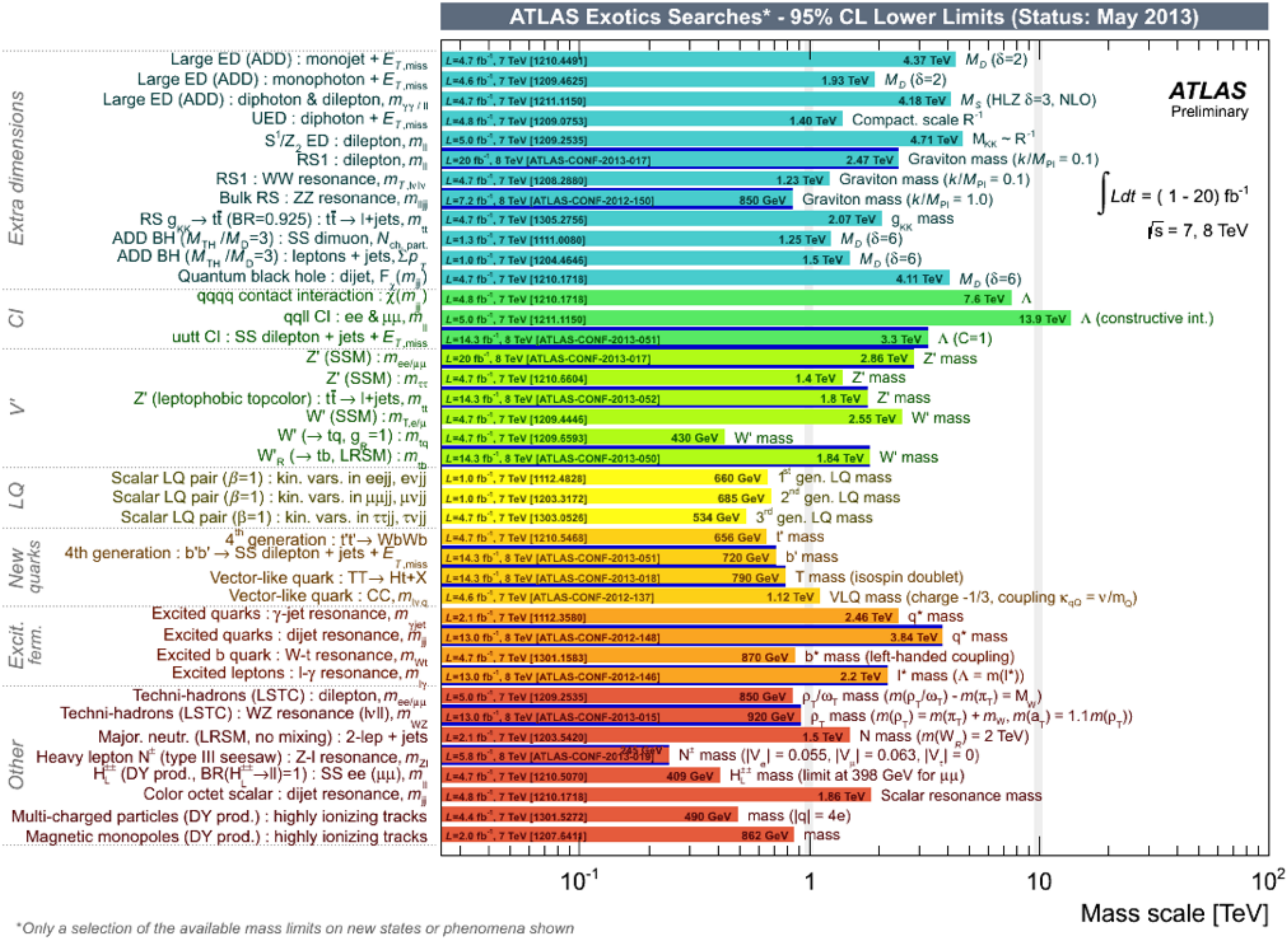
- First limits on "monolepton" Dark Matter







CMS Exotica 95% CL Exclusion Limits (TeV)
q* (qg), dijet
q* (qW)
q* (qZ)
q* , dijet pair
q* , boosted Z
e*, Λ = 2 TeV
μ*, Λ = 2 TeV
Compositeness
Z'SSM (ee, μμ)
Z'SSM (ττ)
Z' (tt hadronic) width=1.2%
Z' (dijet)
Z' (tt lep+jet) width=1.2%
Z'SSM (ll) fbb=0.2
G (dijet)
G (ttbar hadronic)
G (jet+MET) k/M = 0.2
G (γγ) k/M = 0.1
G (Z(ll)Z(qq)) k/M = 0.1
W' (lv)
W' (dijet)
W' (td)
W'→ WZ(leptonic)
WR' (tb)
WR, MNR=MWR/2
WKK μ = 10 TeV
ρTC, πTC > 700 GeV
String Resonances (qg)
s8 Resonance (gg)
E6 diquarks (qq)
Axigluon/Coloron (qqbar)
gluino, 3jet, RPV
Heavy Resonances
gluino, Stopped Gluino
stop, HSCP
stop, Stopped Gluino
stau, HSCP, GMSB
hyper-K, hyper-ρ=1.2 TeV
neutralino, cτ<50cm
Long Lived
LQ1, β=0.5
LQ1, β=1.0
LQ2, β=0.5
LQ2, β=1.0
LQ3 (bν), Q=±1/3, β=0.0
LQ3 (bτ), Q=±2/3 or ±4/3, β=1.0
stop (bτ)
LeptoQuarks
b' → tW, (3l, 2l) + b-jet
q', b'/t' degenerate, Vtb=1
b' → tW, l+jets
B' → bZ (100%)
T' → tZ (100%)
t' → bW (100%), l+jets
t' → bW (100%), l+l
4th Generation
C.I. Λ , X analysis, Λ+ LL/RR
C.I. Λ , X analysis, Λ- LL/RR
C.I., μμ, destructve LLIM
C.I., μμ, constructive LLIM
C.I., single e (HnCM)
C.I., single μ (HnCM)
C.I., incl. jet, destructive
C.I., incl. jet, constructive
Contact Interactions
Ms, γγ, HLZ, nED = 3
Ms, γγ, HLZ, nED = 6
Ms, ll, HLZ, nED = 3
Ms, ll, HLZ, nED = 6
MD, monojet, nED = 3
MD, monojet, nED = 6
MD, mono-γ, nED = 3
MD, mono-γ, nED = 6
MBH, rotating, MD=3TeV, nED = 2
MBH, non-rot, MD=3TeV, nED = 2
MBH, boil. remn., MD=3TeV, nED = 2
MBH, stable remn., MD=3TeV, nED = 2
MBH, Quantum BH, MD=3TeV, nED = 2
Extra Dimensions & Black Holes



ATLAS Exotics Searches* - 95% CL Lower Limits (Status: May 2013)
ATLAS Preliminary
∫Ldt = (1 - 20) fb-1
√s = 7, 8 TeV
Extra dimensions
Large ED (ADD) : monojet + E_T,miss
Large ED (ADD) : monophoton + E_T,miss
Large ED (ADD) : diphoton & dilepton, m_γγ/ll
UED : diphoton + E_T,miss
S1/Z2 ED : dilepton, m_ll
RS1 : dilepton, m_ll
RS1 : WW resonance, m_T,lνlν
Bulk RS : ZZ resonance, m_lljj
RS g_KK → tt̄ (BR=0.925) : tt̄ → l+jets, m_tt
ADD BH (M_TH /M_D=3) : SS dimuon, N_ch. part.
ADD BH (M_TH /M_D=3) : leptons + jets, Σp_T
Quantum black hole : dijet, F_χ(m_jj)
CI
qqqq contact interaction : χ(m_jj)
qqll CI : ee & μμ, m_ll
uutt CI : SS dilepton + jets + E_T,miss
V'
Z' (SSM) : m_ee/μμ
Z' (SSM) : m_ττ
Z' (leptophobic topcolor) : tt̄ → l+jets, m_tt
W' (SSM) : m_T,e/μ
W' (→ tq, g_R=1) : m_tq
W'_R (→ tb, LRSM) : m_tb
LQ
Scalar LQ pair (β=1) : kin. vars. in eejj, eνjj
Scalar LQ pair (β=1) : kin. vars. in μμjj, μνjj
Scalar LQ pair (β=1) : kin. vars. in ττjj, τνjj
New quarks
4th generation : t't'→ WbWb
4th generation : b'b' → SS dilepton + jets + E_T,miss
Vector-like quark : TT→ Ht+X
Vector-like quark : CC, m_lνq
Excit. ferm.
Excited quarks : γ-jet resonance, m_γjet
Excited quarks : dijet resonance, m_jj
Excited b quark : W-t resonance, m_Wt
Excited leptons : l-γ resonance, m_lγ
Other
Techni-hadrons (LSTC) : dilepton, m_ee/μμ
Techni-hadrons (LSTC) : WZ resonance (lνll), m_WZ
Major. neutr. (LRSM, no mixing) : 2-lep + jets
Heavy lepton N± (type III seesaw) : Z-l resonance, m_Zl
H±±_L (DY prod., BR(H±±_L→ll)=1) : SS ee (μμ), m_ll
Color octet scalar : dijet resonance, m_jj
Multi-charged particles (DY prod.) : highly ionizing tracks
Magnetic monopoles (DY prod.) : highly ionizing tracks
L=4.7 fb-1, 7 TeV [1210.4491] 4.37 TeV M_D (δ=2)
L=4.6 fb-1, 7 TeV [1209.4625] 1.93 TeV M_D (δ=2)
L=4.7 fb-1, 7 TeV [1211.1150] 4.18 TeV M_S (HLZ δ=3, NLO)
L=4.8 fb-1, 7 TeV [1209.0753] 1.40 TeV Compact. scale R-1
L=5.0 fb-1, 7 TeV [1209.2535] 4.71 TeV M_KK ~ R-1
L=20 fb-1, 8 TeV [ATLAS-CONF-2013-017] 2.47 TeV Graviton mass (k/M_Pl = 0.1)
L=4.7 fb-1, 7 TeV [1208.2880] 1.23 TeV Graviton mass (k/M_Pl = 0.1)
L=7.2 fb-1, 8 TeV [ATLAS-CONF-2012-150] 850 GeV Graviton mass (k/M_Pl = 1.0)
L=4.7 fb-1, 7 TeV [1305.2756] 2.07 TeV g_KK mass
L=1.3 fb-1, 7 TeV [1111.0080] 1.25 TeV M_D (δ=6)
L=1.0 fb-1, 7 TeV [1204.4646] 1.5 TeV M_D (δ=6)
L=4.7 fb-1, 7 TeV [1210.1718] 4.11 TeV M_D (δ=6)
L=4.8 fb-1, 7 TeV [1210.1718] 7.6 TeV Λ
L=5.0 fb-1, 7 TeV [1211.1150] 13.9 TeV Λ (constructive int.)
L=14.3 fb-1, 8 TeV [ATLAS-CONF-2013-051] 3.3 TeV Λ (C=1)
L=20 fb-1, 8 TeV [ATLAS-CONF-2013-017] 2.86 TeV Z' mass
L=4.7 fb-1, 7 TeV [1210.6604] 1.4 TeV Z' mass
L=14.3 fb-1, 8 TeV [ATLAS-CONF-2013-052] 1.8 TeV Z' mass
L=4.7 fb-1, 7 TeV [1209.4446] 2.55 TeV W' mass
L=4.7 fb-1, 7 TeV [1209.6593] 430 GeV W' mass
L=14.3 fb-1, 8 TeV [ATLAS-CONF-2013-050] 1.84 TeV W' mass
L=1.0 fb-1, 7 TeV [1112.4828] 660 GeV 1st gen. LQ mass
L=1.0 fb-1, 7 TeV [1203.3172] 685 GeV 2nd gen. LQ mass
L=4.7 fb-1, 7 TeV [1303.0526] 534 GeV 3rd gen. LQ mass
L=4.7 fb-1, 7 TeV [1210.5468] 656 GeV t' mass
L=14.3 fb-1, 8 TeV [ATLAS-CONF-2013-051] 720 GeV b' mass
L=14.3 fb-1, 8 TeV [ATLAS-CONF-2013-018] 790 GeV T mass (isospin doublet)
L=4.6 fb-1, 7 TeV [ATLAS-CONF-2012-137] 1.12 TeV VLQ mass (charge -1/3, coupling κ_qQ = ν/m_Q)
L=2.1 fb-1, 7 TeV [1112.3580] 2.46 TeV q* mass
L=13.0 fb-1, 8 TeV [ATLAS-CONF-2012-148] 3.84 TeV q* mass
L=4.7 fb-1, 7 TeV [1301.1583] 870 GeV b* mass (left-handed coupling)
L=13.0 fb-1, 8 TeV [ATLAS-CONF-2012-146] 2.2 TeV l* mass (Λ = m(l*))
L=5.0 fb-1, 7 TeV [1209.2535] 850 GeV ρ_T/ω_T mass (m(ρ_T/ω_T) - m(π_T) = M_W)
L=13.0 fb-1, 8 TeV [ATLAS-CONF-2013-015] 920 GeV ρ_T mass (m(ρ_T) = m(π_T) + m_W, m(a_T) = 1.1m(ρ_T))
L=2.1 fb-1, 7 TeV [1203.5420] 1.5 TeV N mass (m(W_R) = 2 TeV)
L=5.8 fb-1, 8 TeV [ATLAS-CONF-2013-019] 245 GeV N± mass (|V_e| = 0.055, |V_μ| = 0.063, |V_τ| = 0)
L=4.7 fb-1, 7 TeV [1210.5070] 409 GeV H±±_L mass (limit at 398 GeV for μμ)
L=4.8 fb-1, 7 TeV [1210.1718] 1.86 TeV Scalar resonance mass
L=4.4 fb-1, 7 TeV [1301.5272] 490 GeV mass (|q| = 4e)
L=2.0 fb-1, 7 TeV [1207.6411] 862 GeV mass
10-1
1
10
102
Mass scale [TeV]
*Only a selection of the available mass limits on new states or phenomena shown

Conclusions

- The LHC has a very active programme of searches for hints of new physics
- New results presented today include:
  - dilepton Z'
  - dilepton ADD
  - dijet resonance
  - heavy flavor dijet resonance
  - 3-jet resonance, 3-jet w/ b-tag
  - black holes (high S_T)
  - W' ⟶ tb
  - vector-like T'
  - Q=5/3 top partners
  - X ⟶ tt semi-leptonic
  - X ⟶ tt hadronic
  - W'/ρ_{TC} ⟶ WZ ⟶ 3l + MET
  - G_{bulk} ⟶ WW ⟶ l + jet + MET
  - G_{RS} ⟶ WW/ZZ and W' ⟶ WZ
  - displaced jets
  - HSCP
  - monojet
  - monolepton
- More than 100 results out now... many more results available on the web:
  - https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsEXO & B2G
  - https://twiki.cern.ch/twiki/bin/view/AtlasPublic/ExoticsPublicResults

More results on the way
– leaving no stone unturned!