Recent Exotic Searches with CMS

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On behalf of the CMS Collaboration

Les Rencontres de Physique

de la Vallée d'Aoste

La Thuile, 1-7 March 2015

BSM Searches in Many Final States

(Borrowing the metaphor from F. Riva this morning)

- Our goal when searching for BSM physics in many final states …

BSM Searches in Many Final States

- Try to eat as much as we can!

Inspired by F. Riva this morning

Outline of This Talk

- BSM Physics - trying to eat as much as we can …

Heavy resonances **Dark Matter** **Long-Lived**

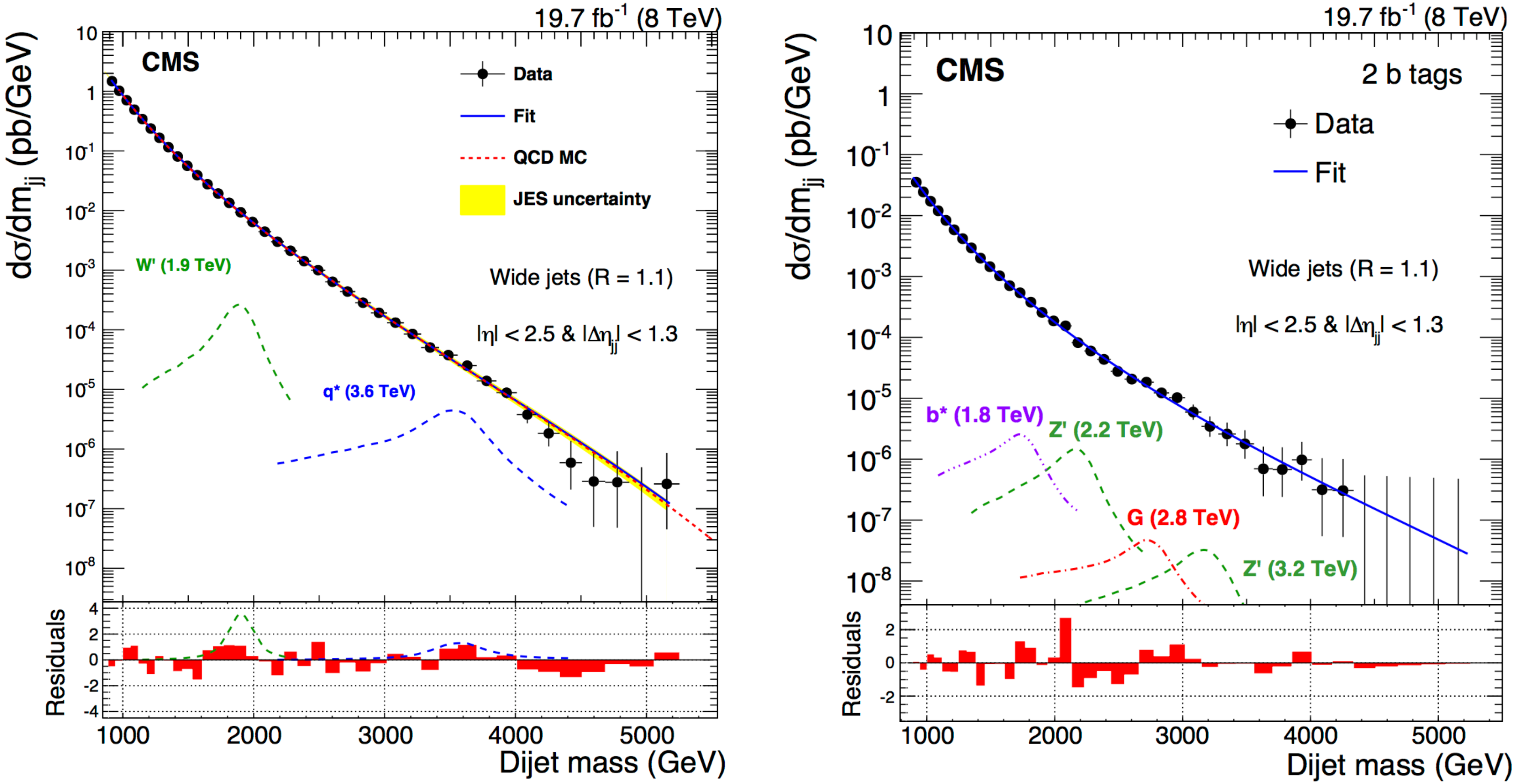
Heavy Resonances – Brief Overview

- Heavy resonance would be unambiguous signal of new physics
- Many possible BSM sources; a common one is:
- Z':
  - mediator of some new U(1) gauge field
  - frequent signature of BSM enlarged symmetry groups breaking down to SM= $SU(3)_C \times SU(2)_L \times U(1)_Y$
- (Can also interpret high-mass spectrum in terms of non-resonant excesses, eg Large Extra Dimensions (ADD), via virtual graviton exchange)

Dijet Resonance Search (EXO-12-059)

- Jet p_T>30 GeV; inclusive jets and b-tagged jets categories
- Uses "wide jets" - less sensitive to gluon radiation
- No evidence for resonance in dijet mass

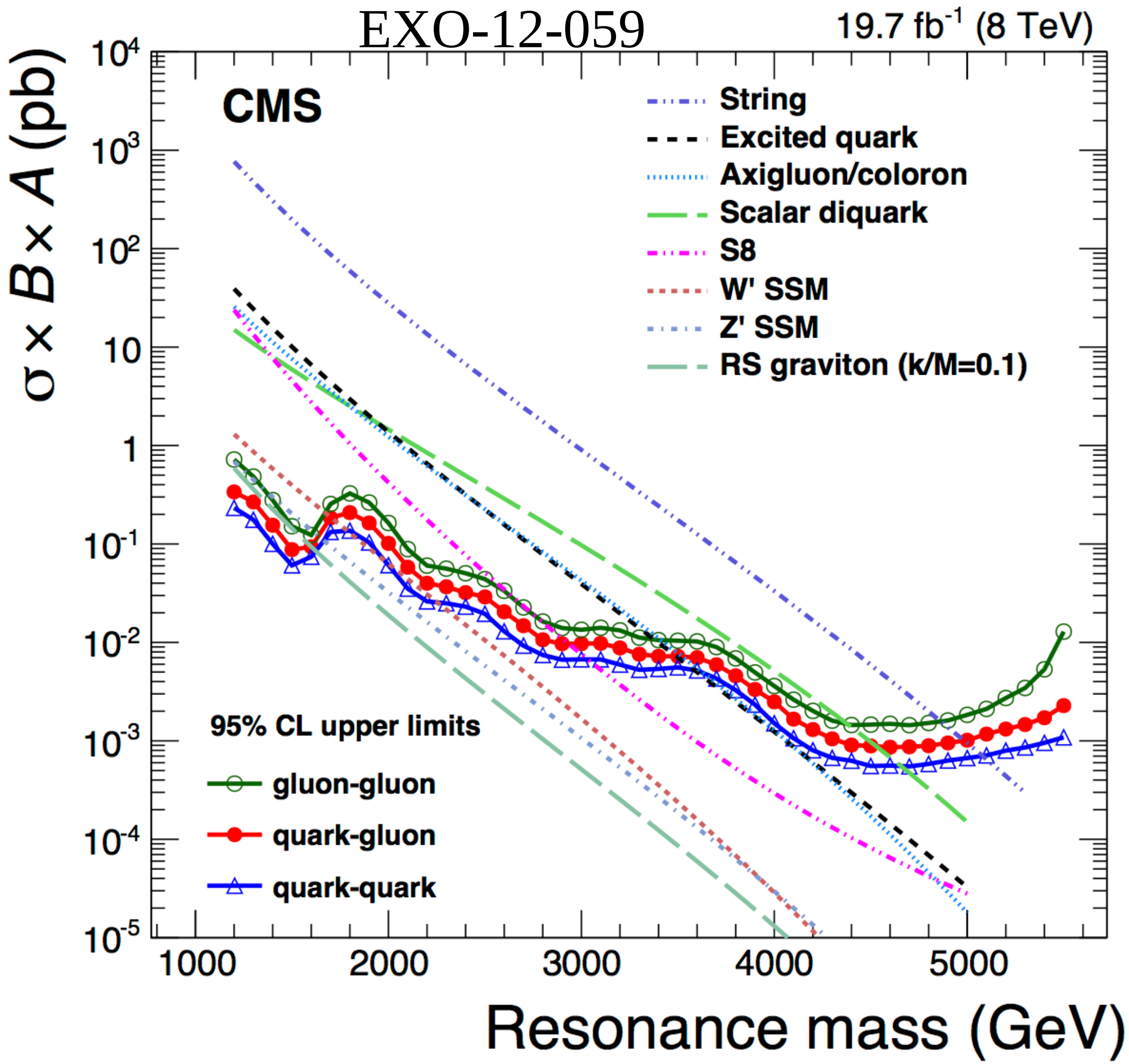
arXiv:1501.04198



Dijet Limits

- Can set limits on many possible new physics scenarios producing dijets
- Example: “coloron” (new massive strongly-interacting gauge boson) excluded with masses below 3.7 TeV

EXO-12-059

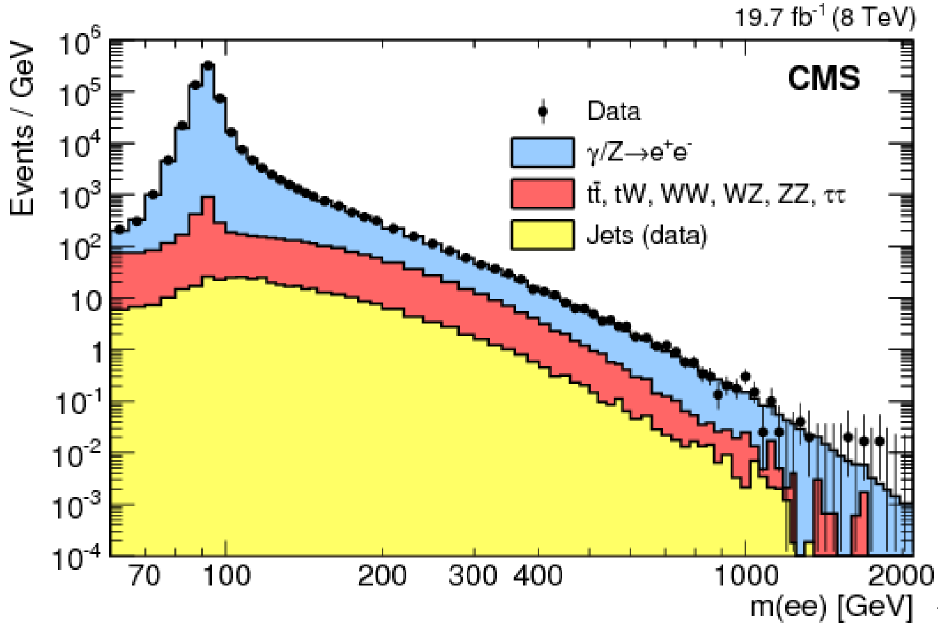


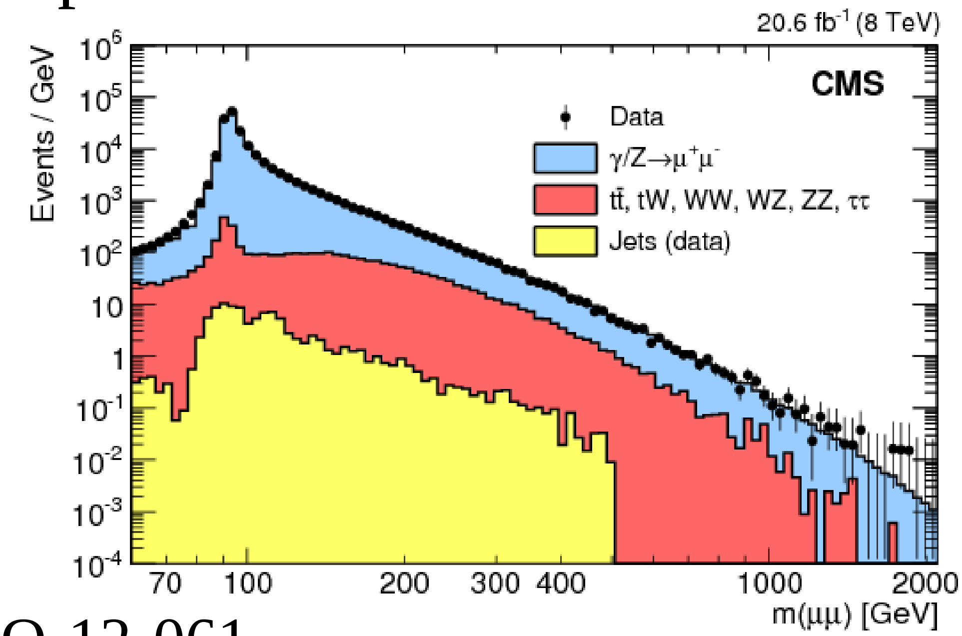
Search for New Physics in Dilepton Mass

- Dielectron and dimuon channels

arXiv:1412.6302

- Resonant signal in dilepton mass possible from Z' or Randall-Sundrum graviton; non-resonant excesses from Large Extra Dimensions (ADD) or Contact Interactions
- Main background from Drell-Yan; also ttbar and diboson processes produce two real leptons in final state

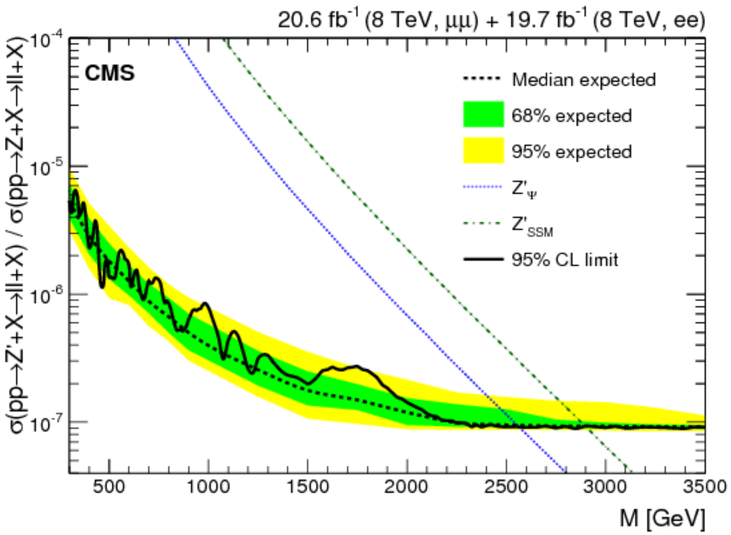


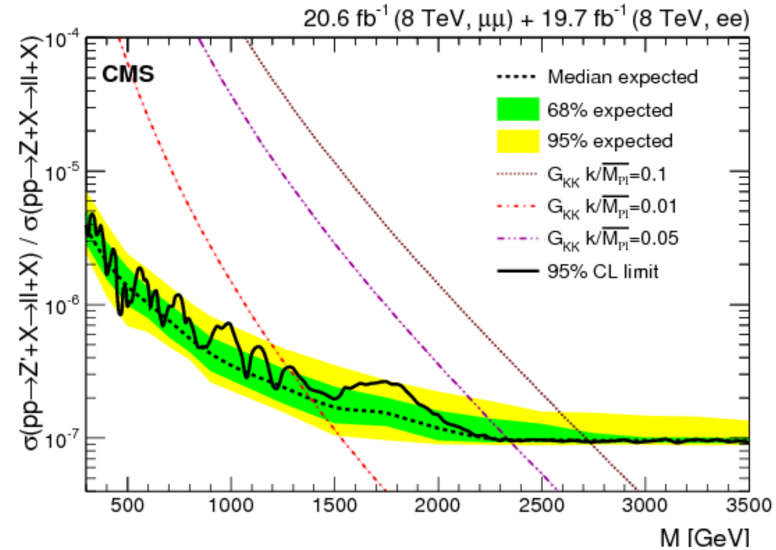


EXO-12-061

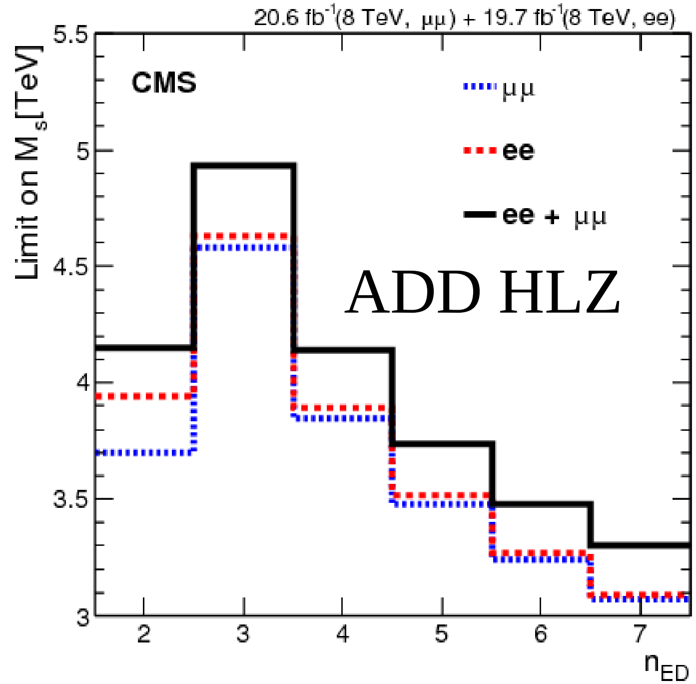
Dilepton Limits (EXO-12-061)

EXO-12-061



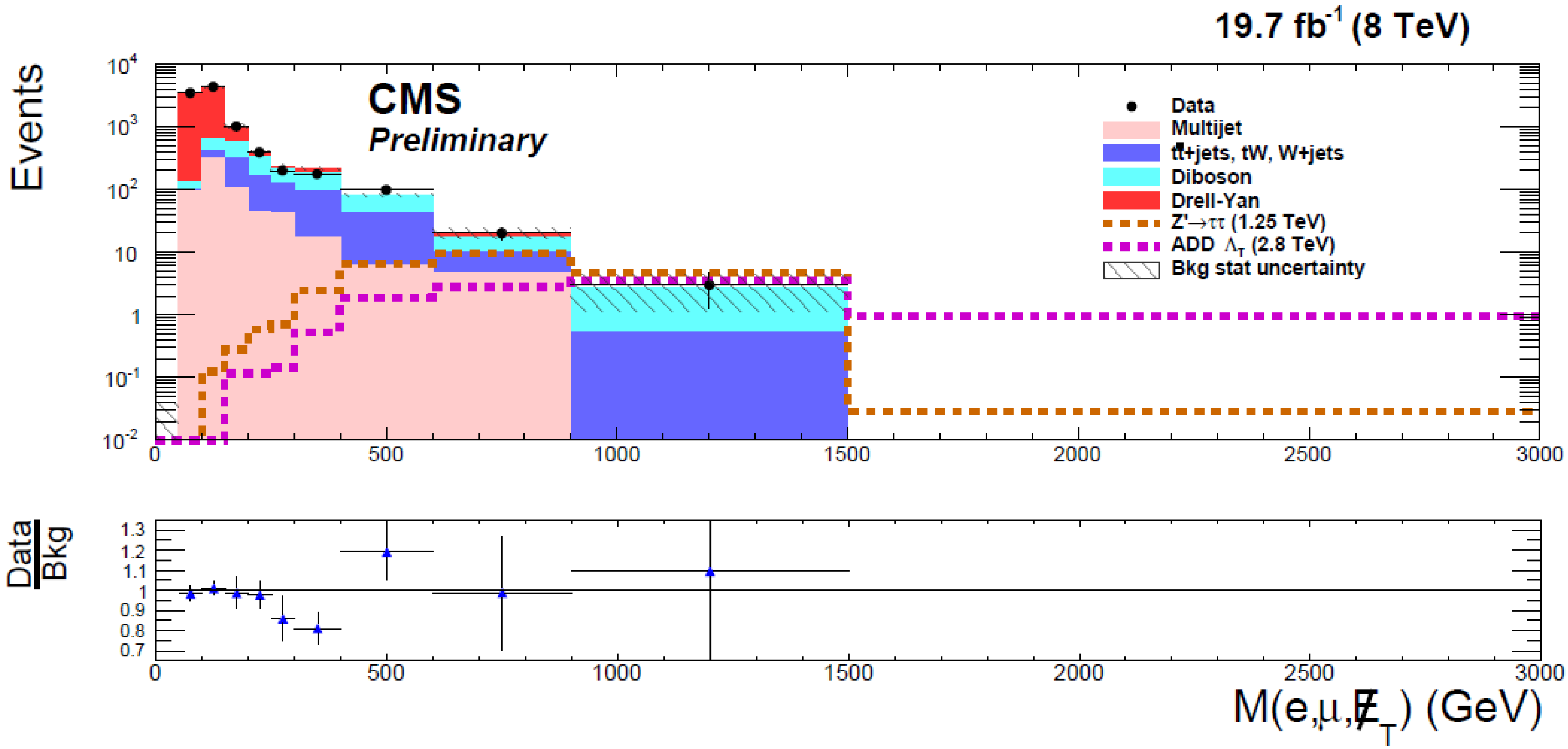


- 95% CL exclusion limits set on:
- Z'_{SSM} M>2.90 TeV
- RS graviton M_1> 2.73 TeV (k/M_{Pl}=0.1)
- ADD: Λ_T > 4.14 TeV (GRW convention)



$\tau\tau$ in eμ Decay Channel (EXO-12-046)

- $\tau\tau$ in eμ decay channel, with Missing E_T (MET) from ν

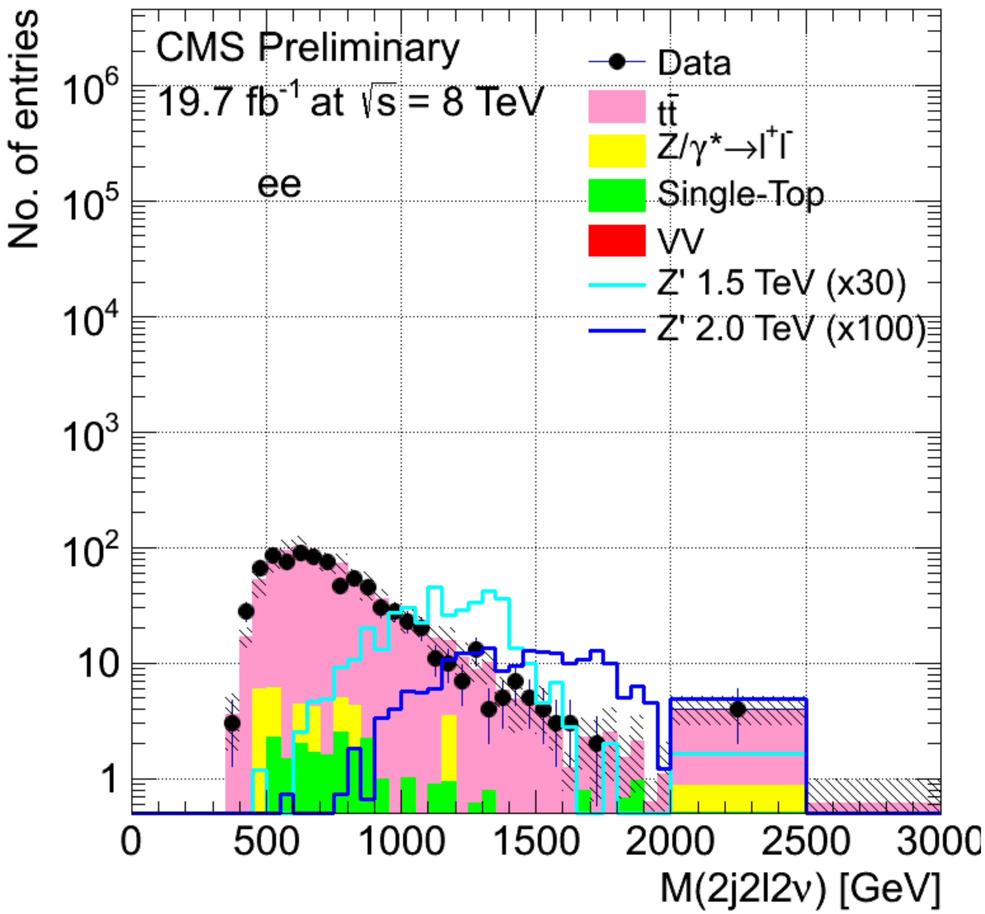


- 95% CL: Z'_{SSM} M>1.3 TeV
- ADD Extra dim.:

Limit	GRW	HLZ - M_S GeV				
	Λ_T (GeV)	n=3	n=4	n=5	n=6	n=7
Observed (K factor = 1.3)	2800	3330	2800	2530	2350	2230

Top-Antitop Resonance in Dilepton Channel (B2G-12-007)

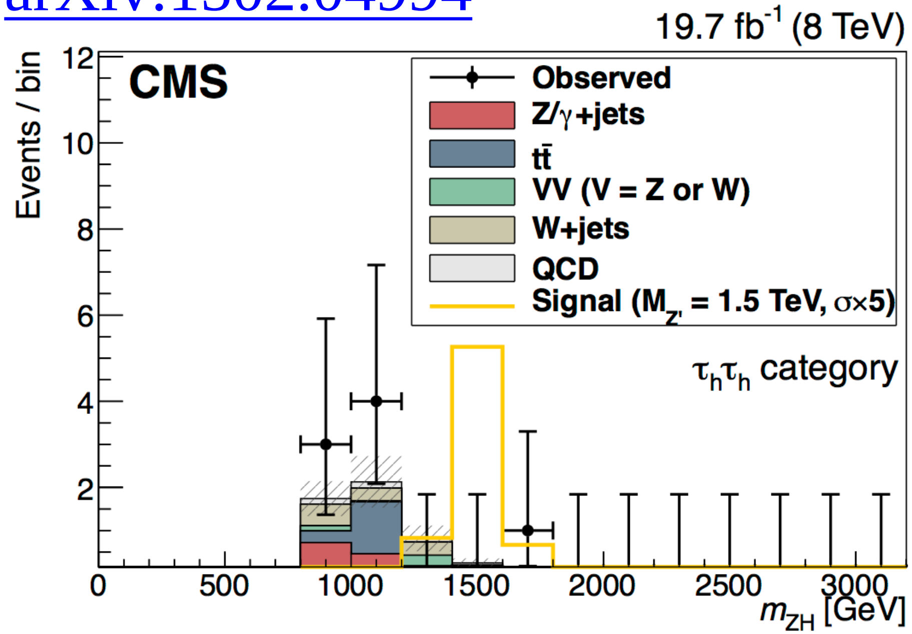
- tt → bWbW, W→lν
- Identify b-jets by secondary vertex
- Consider both narrow and wide resonances
- Exclusion limits:
- Narrow Z', M>1.5 TeV
- Wide Z', M>2.0 TeV

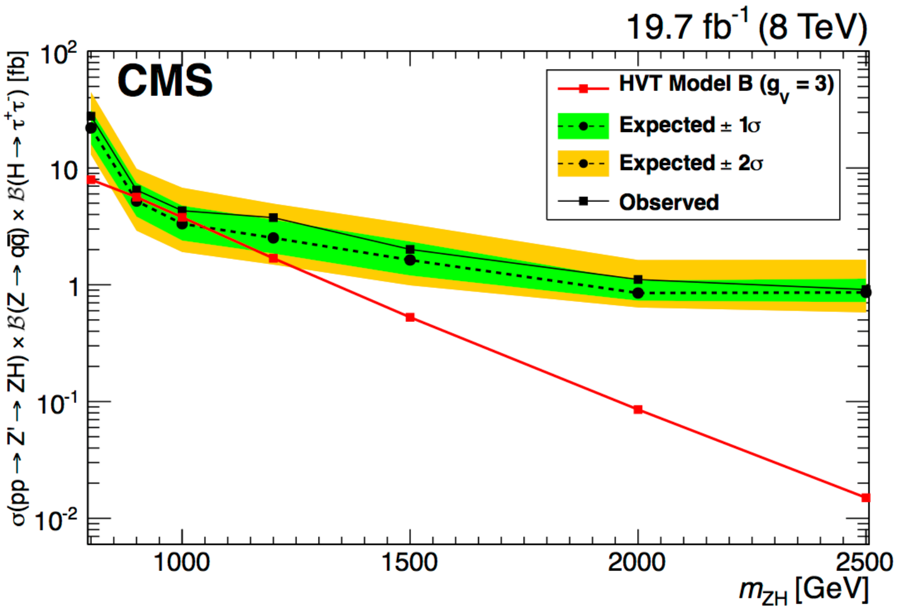


Z-Higgs Resonance Search (EXO-13-007)

- $Z \rightarrow qq$, $H \rightarrow \tau\tau$
- $Z \rightarrow qq$ reconstructed as single "Z-jet"
- τ pair from H highly boosted; e, μ and hadronic decay channels all considered
- Exclude σ x BR of 27.8 fb – 0.9 fb, for M_{ZH} 800-2500 GeV

arXiv:1502.04994





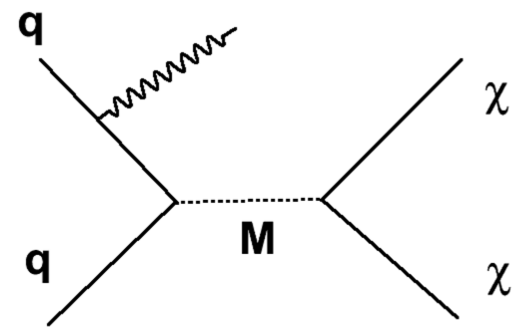
Dark Matter at the LHC

- Dark Matter (existence inferred from galaxy rotation curves, gravitational lensing, etc) - comprises 23% of the universe, but is not compatible with any SM particle
- But a stable particle of mass ~0.1-1 TeV and weak-scale interactions would be a good DM candidate – the "WIMP Miracle"!
- Several BSM theories predict such a particle … could we observe DM production in LHC collisions?

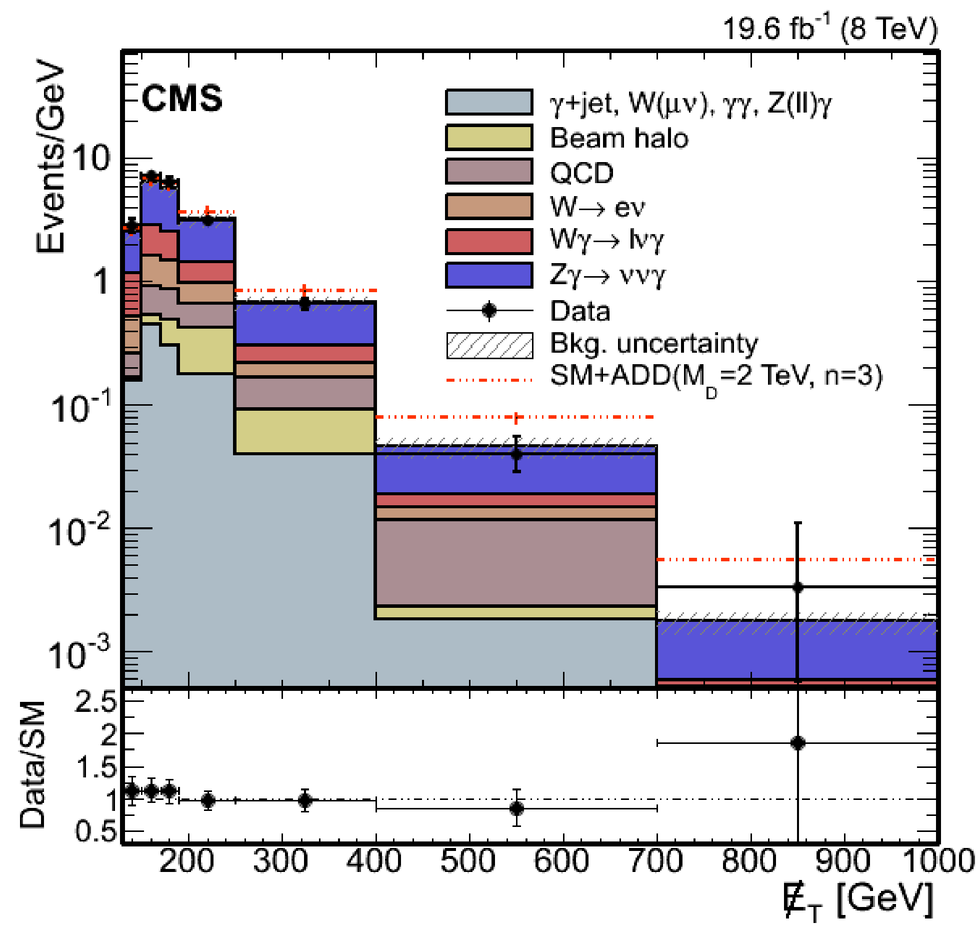
Bullet Cluster

Monophoton Search (EXO-12-047)

- Photon $E_T > 145$ GeV; MET > 140 GeV; veto leptons
- Dominant background at high MET: $Z(\rightarrow\nu\nu)\gamma$
- Data found to be consistent with background prediction …
- (Can also interpret as limit on ADD: real graviton emission)

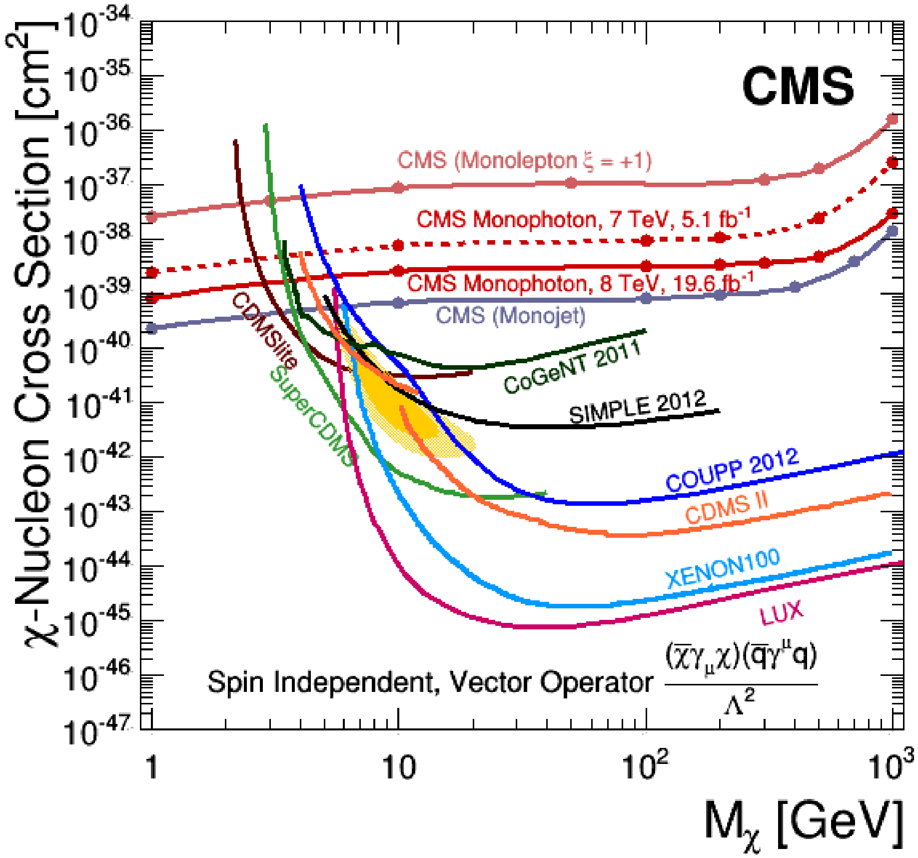


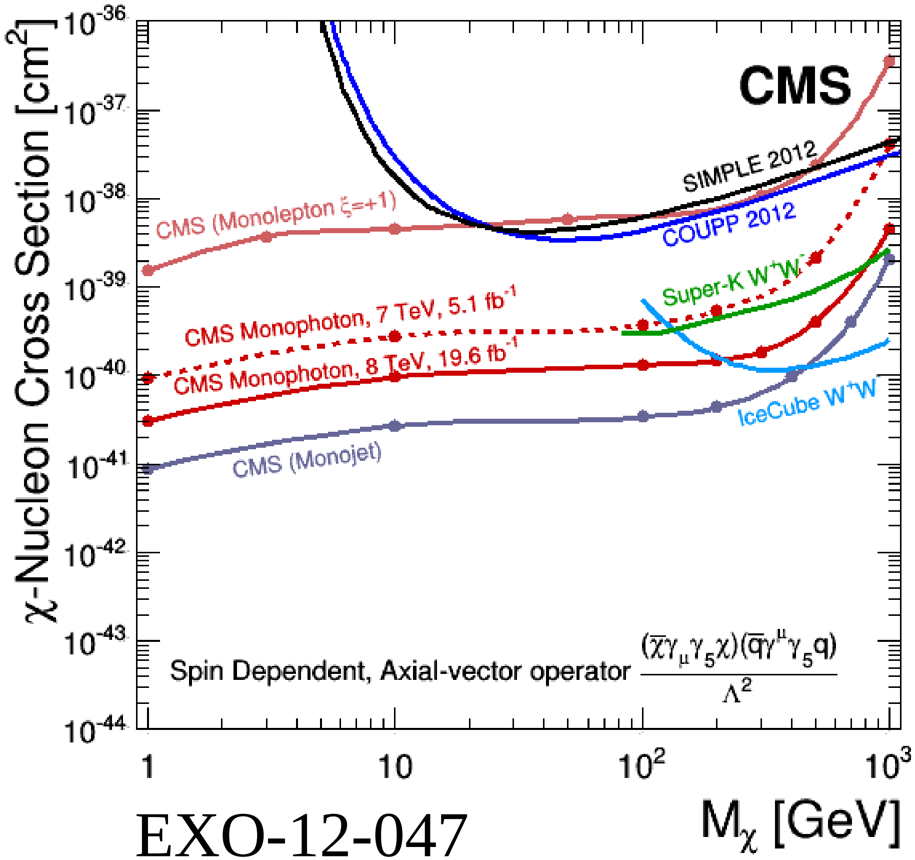
arXiv:1410.8812



Monophoton Limits

- Translate results to limit on DM-nucleon scattering cross-section, compare with DM direct detection experiments
- Spin-independent and spin-dependent DM interactions





EXO-12-047

Long Lived Particle Searches

- Long-lived new physics can give novel detector signatures – new reconstruction and analysis techniques needed for these

Stopped R-Hadrons (EXO-12-036)

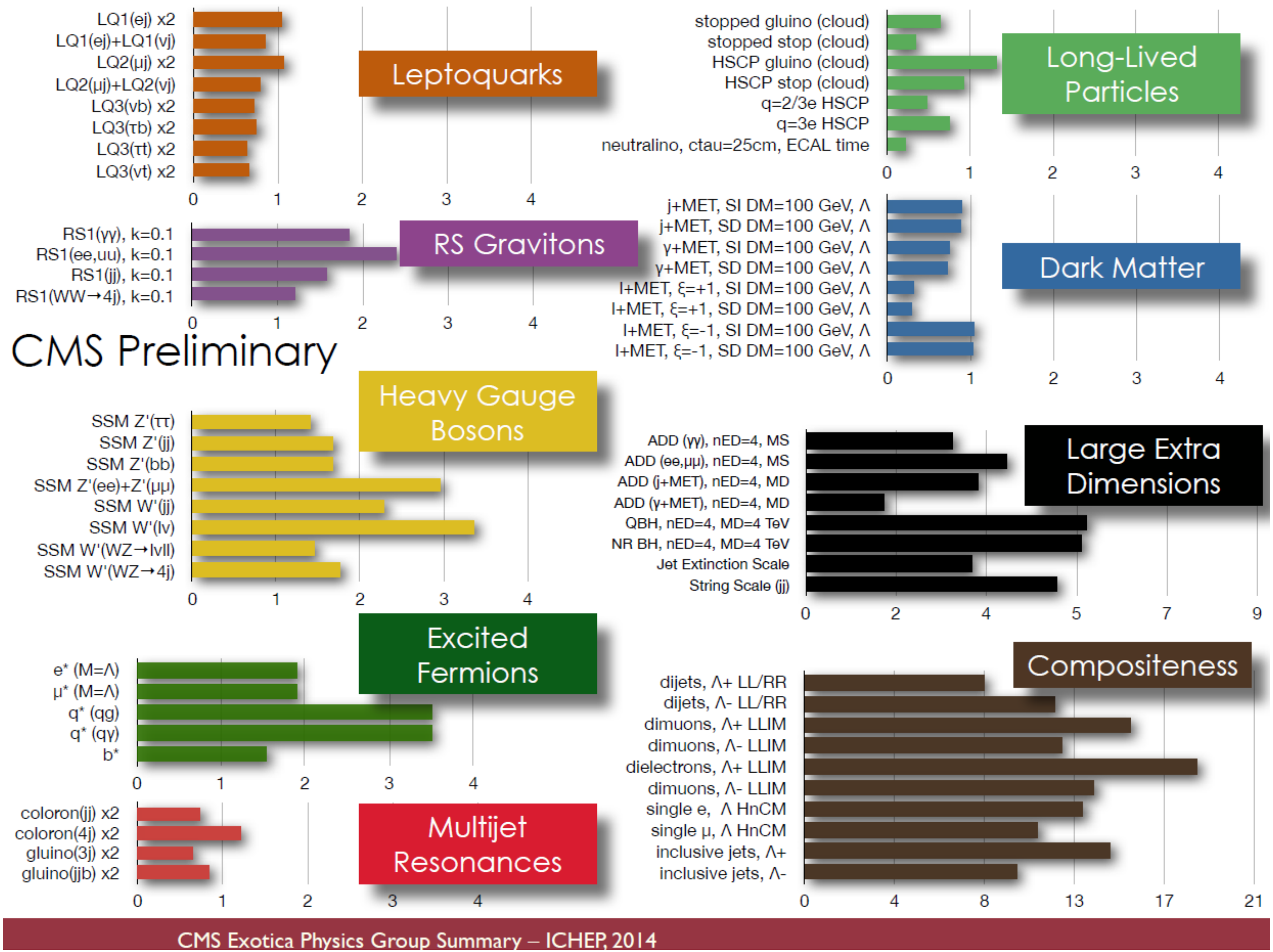
- Long-lived colored particle (gluino or top squark) can form 'R-hadron'; large dE/dx, can come to rest in detector, then decay at some later time
- Signature: large energy deposit in calorimeter, in time interval *between* LHC collisions!
- Background: brem from cosmic or beam halo muons; noise

Period	Trigger livetime (h)	$N^{\mathrm{bkg}}_{\mathrm{noise}}$	$N^{\mathrm{bkg}}_{\mathrm{cosmic}}$	$N^{\mathrm{bkg}}_{\mathrm{halo}}$	$N^{\mathrm{bkg}}_{\mathrm{total}}$	N^{obs}
2010	253	$0.0^{+2.3}_{-0.0}$	4.8 ± 3.6	—	$4.8^{+4.3}_{-3.6}$	2
2012	281	$0.0^{+2.6}_{-0.0}$	5.2 ± 2.5	8.0 ± 0.4	$13.2^{+3.6}_{-2.5}$	10

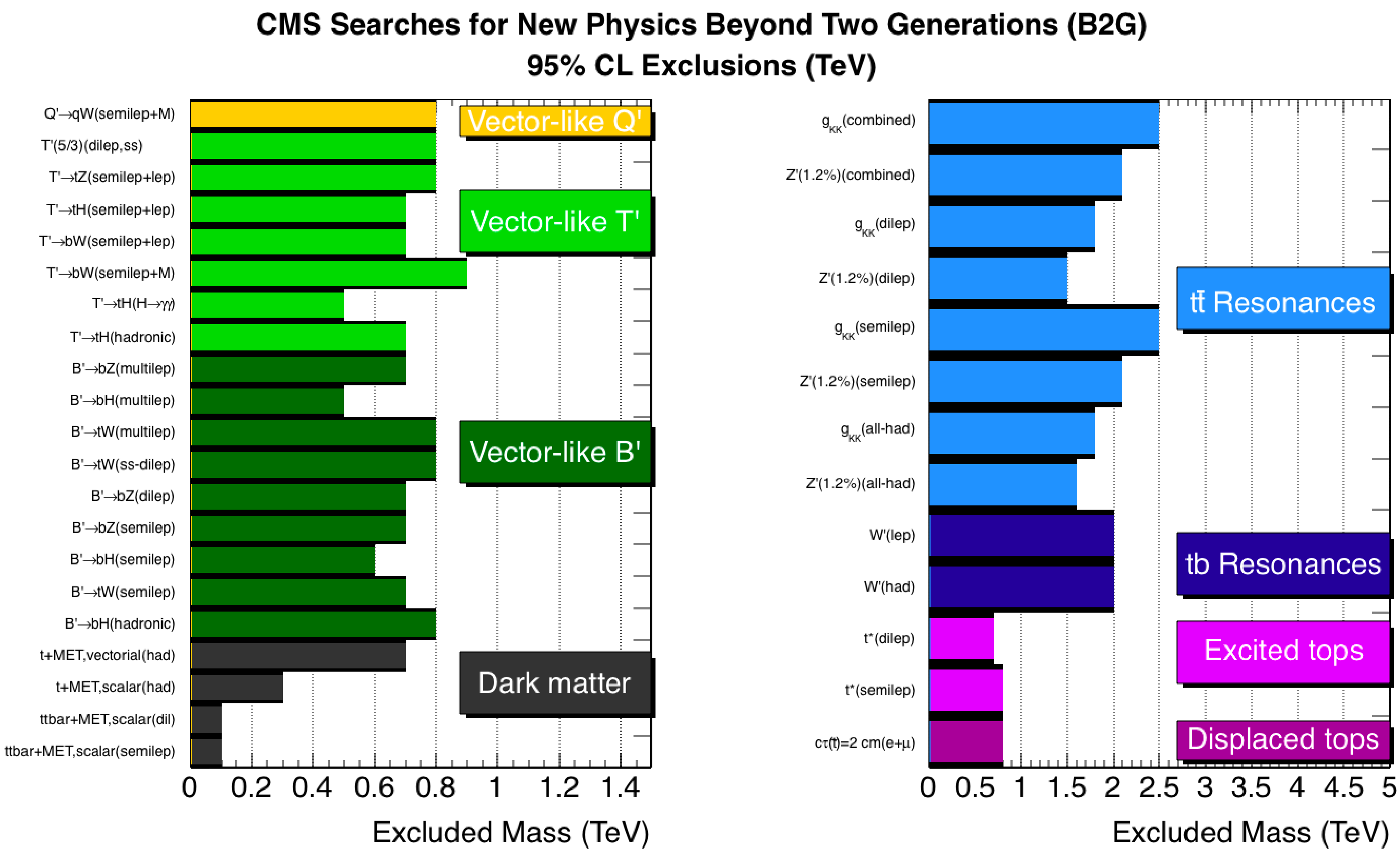
- Data events consistent with background – assuming R-hadron interaction model, exclude gluino M <1000 GeV, top squark M <525 GeV, for lifetimes 1μs – 1000s

arXiv:1501.05603

CMS EXO Results Summary



B2G Results Summary



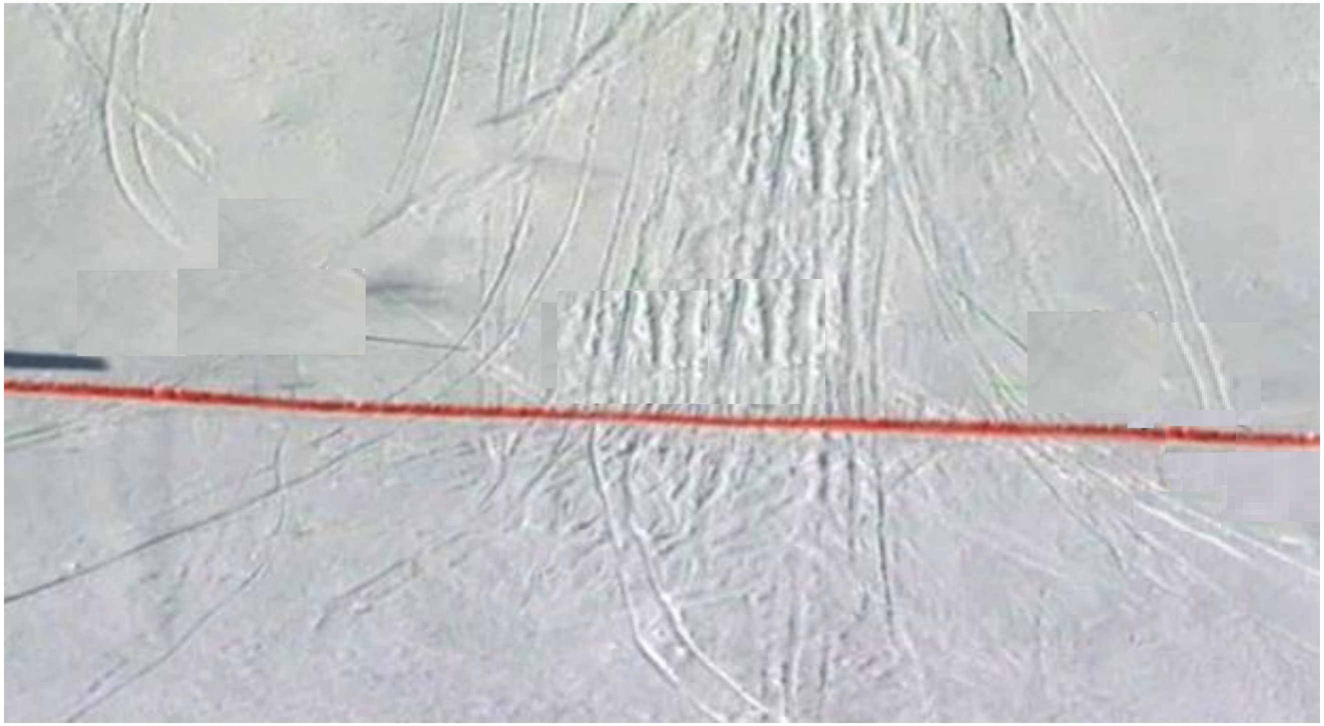
Summary

- LHC Run 1 complete, ~20 fb^{-1} collected at 8 TeV
- CMS has performed many searches for BSM physics, results can be found at:
- https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsEXO
- https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsB2G
- Many final states explored, but no evidence yet for Beyond-SM physics

Outlook

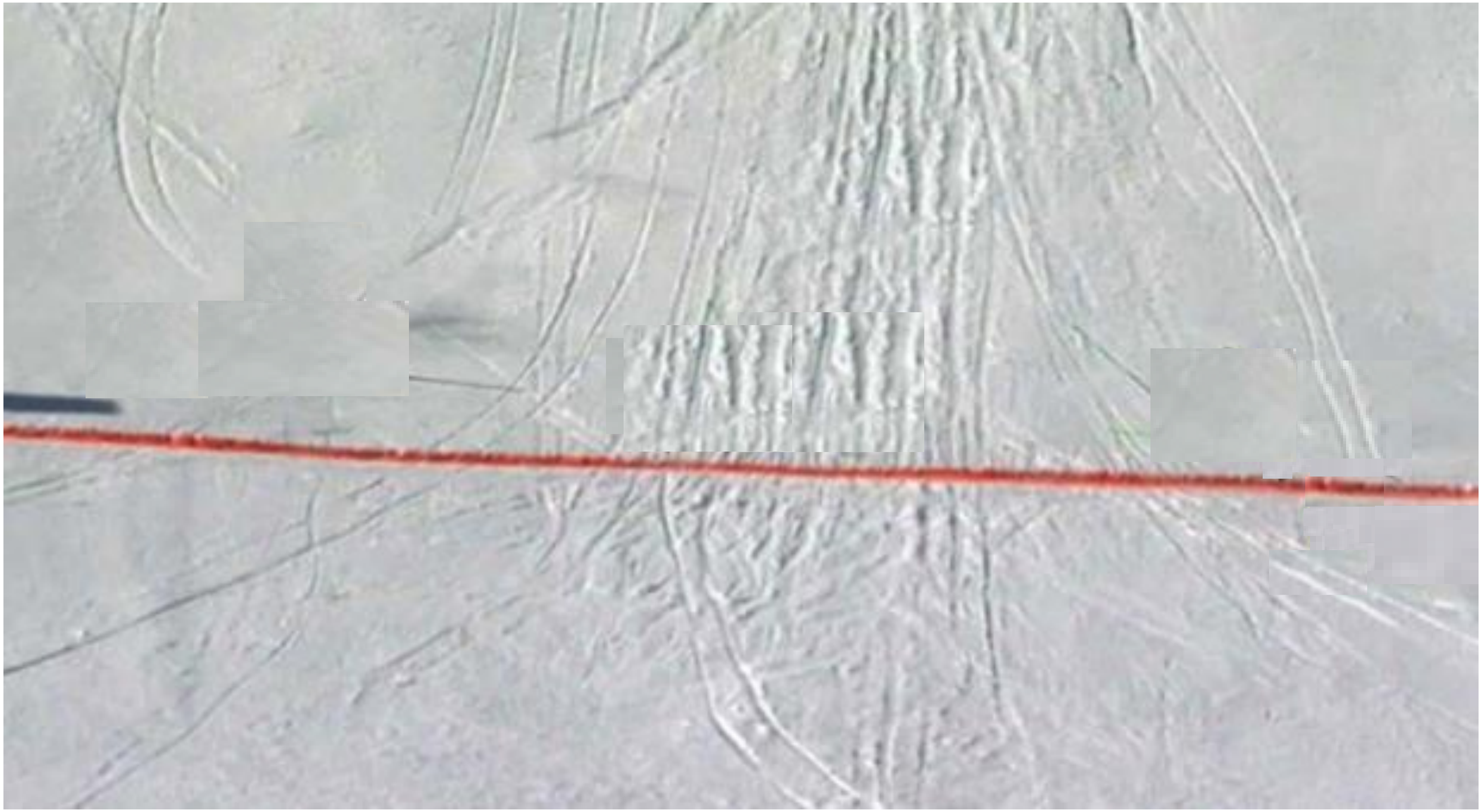
- LHC Run 2: increase collision energy to 13 TeV and increase rate of accumulating data
- The race to discover new physics beyond the Standard Model …

New Physics Finish Line?



Outlook

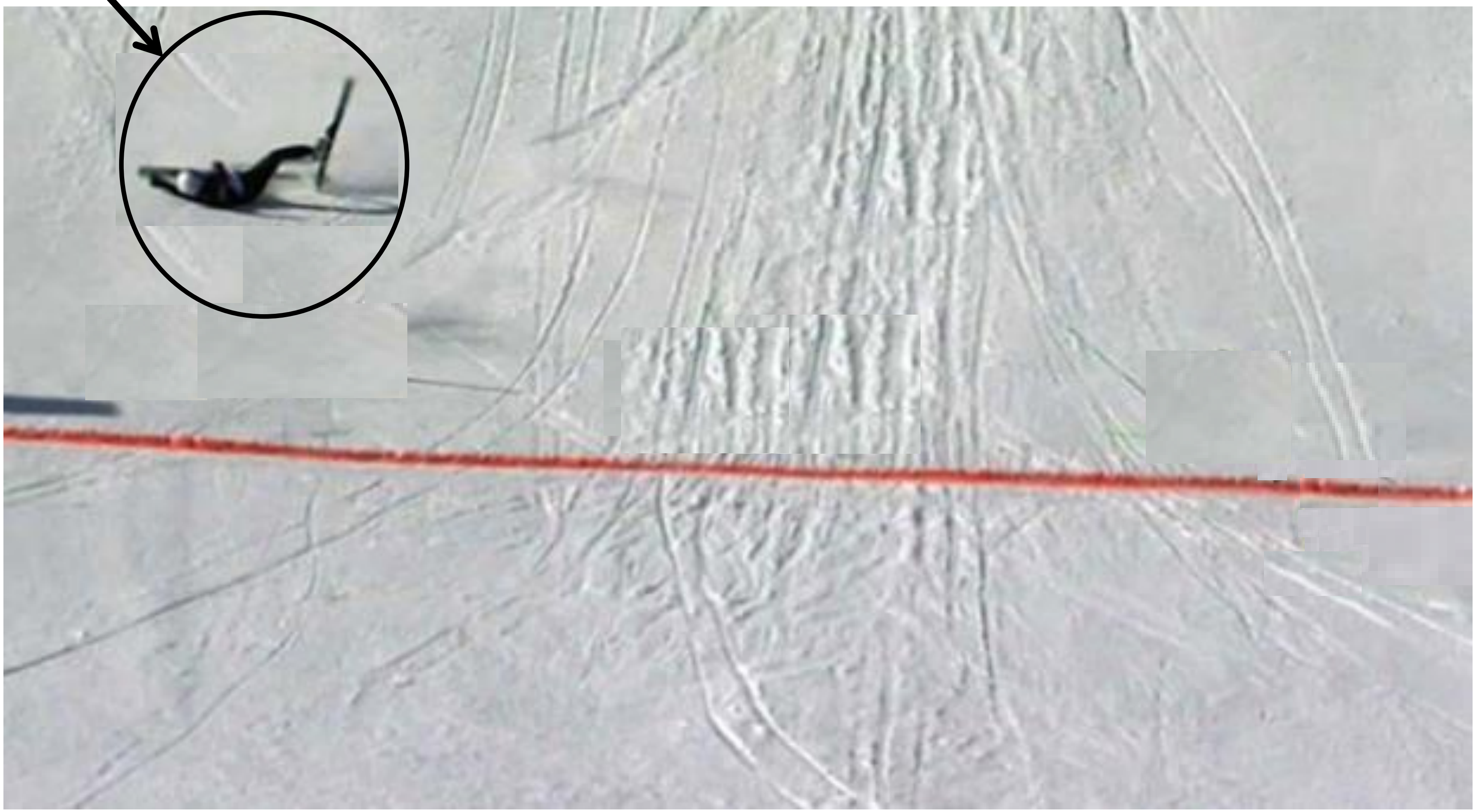
New
Physics
Finish
Line



Outlook

Tevatron?

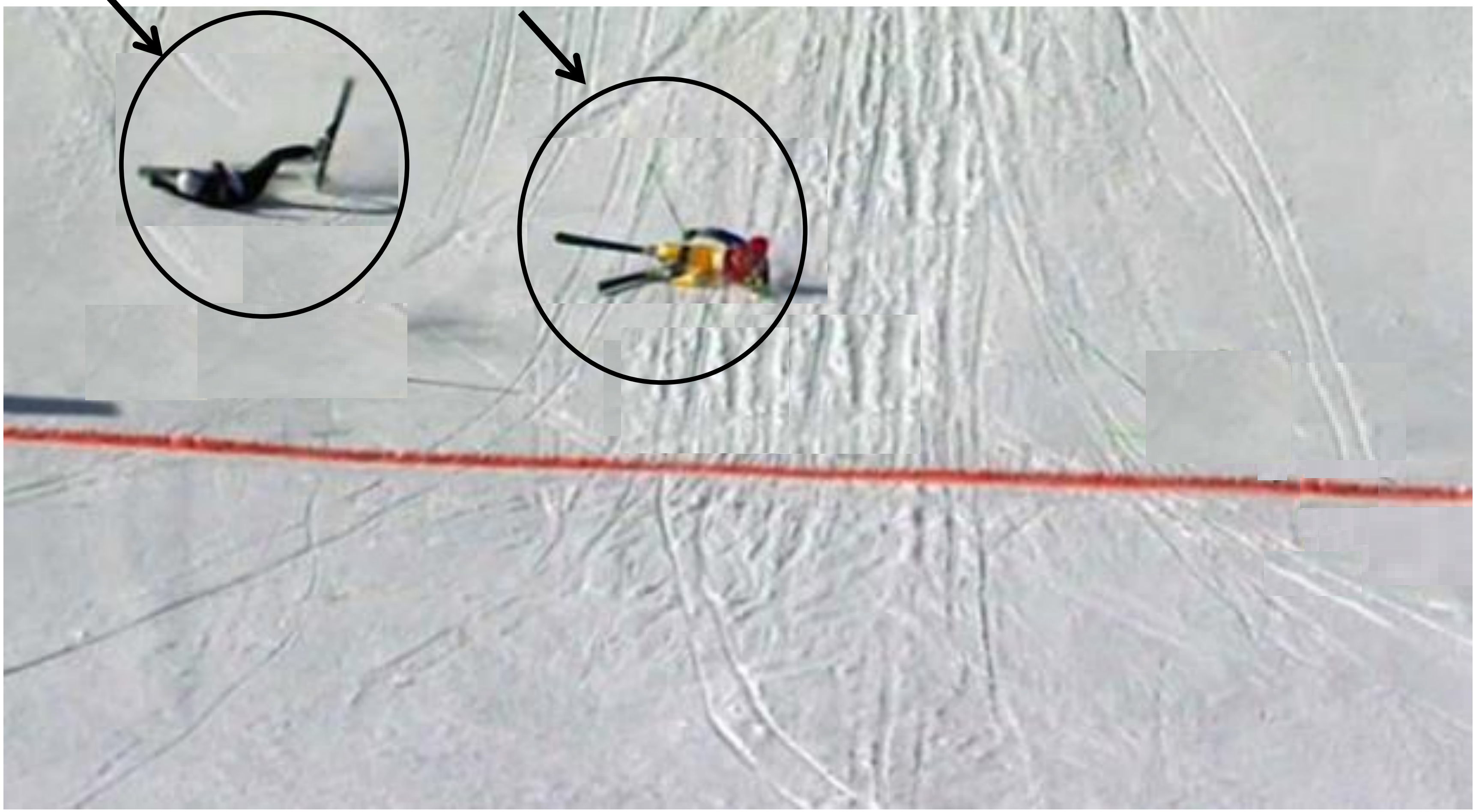
New
Physics
Finish
Line



Outlook

Tevatron?   LHC, 7 TeV?

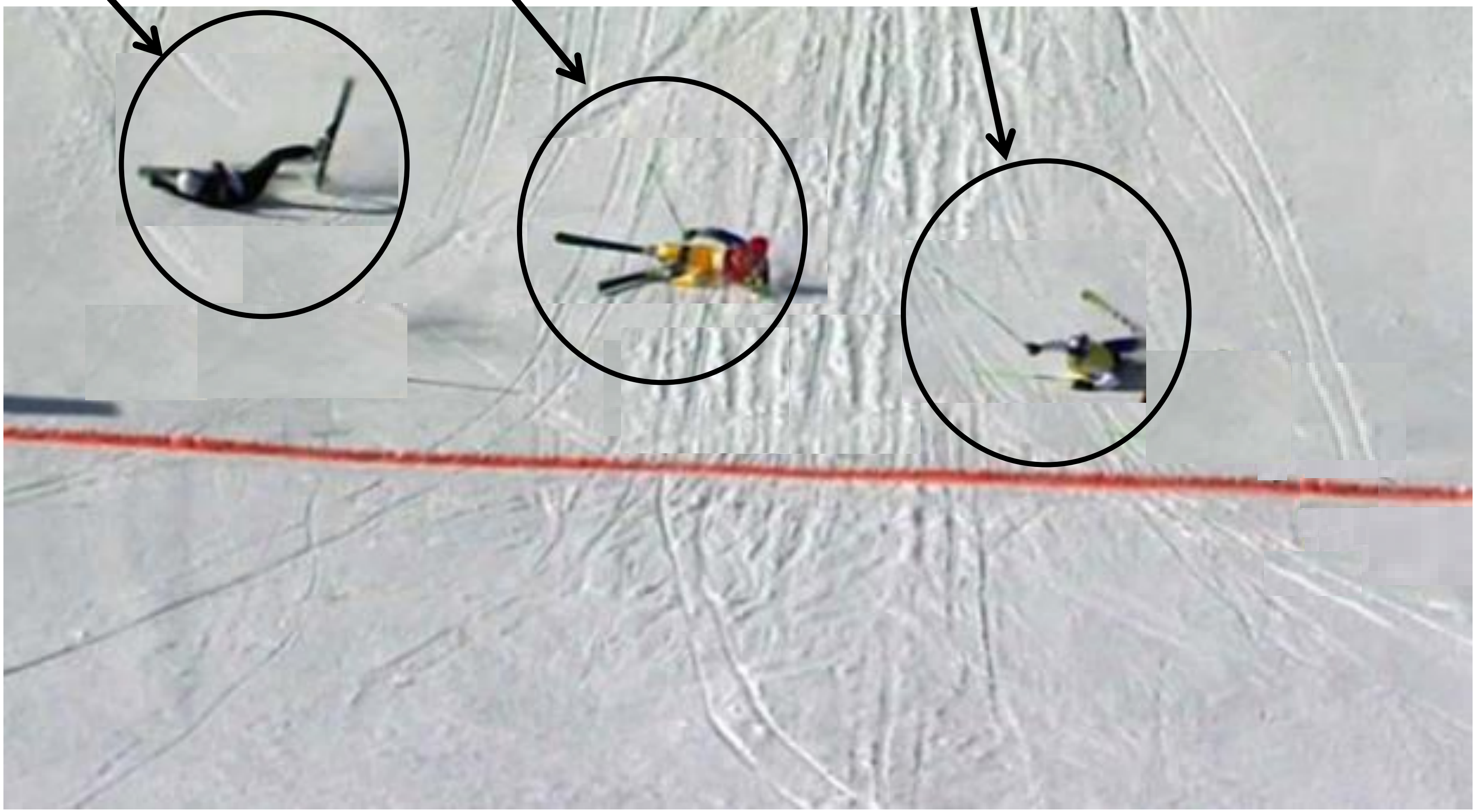
New
Physics
Finish
Line



Outlook

Tevatron? LHC, 7 TeV? LHC, 8 TeV?

New Physics Finish Line

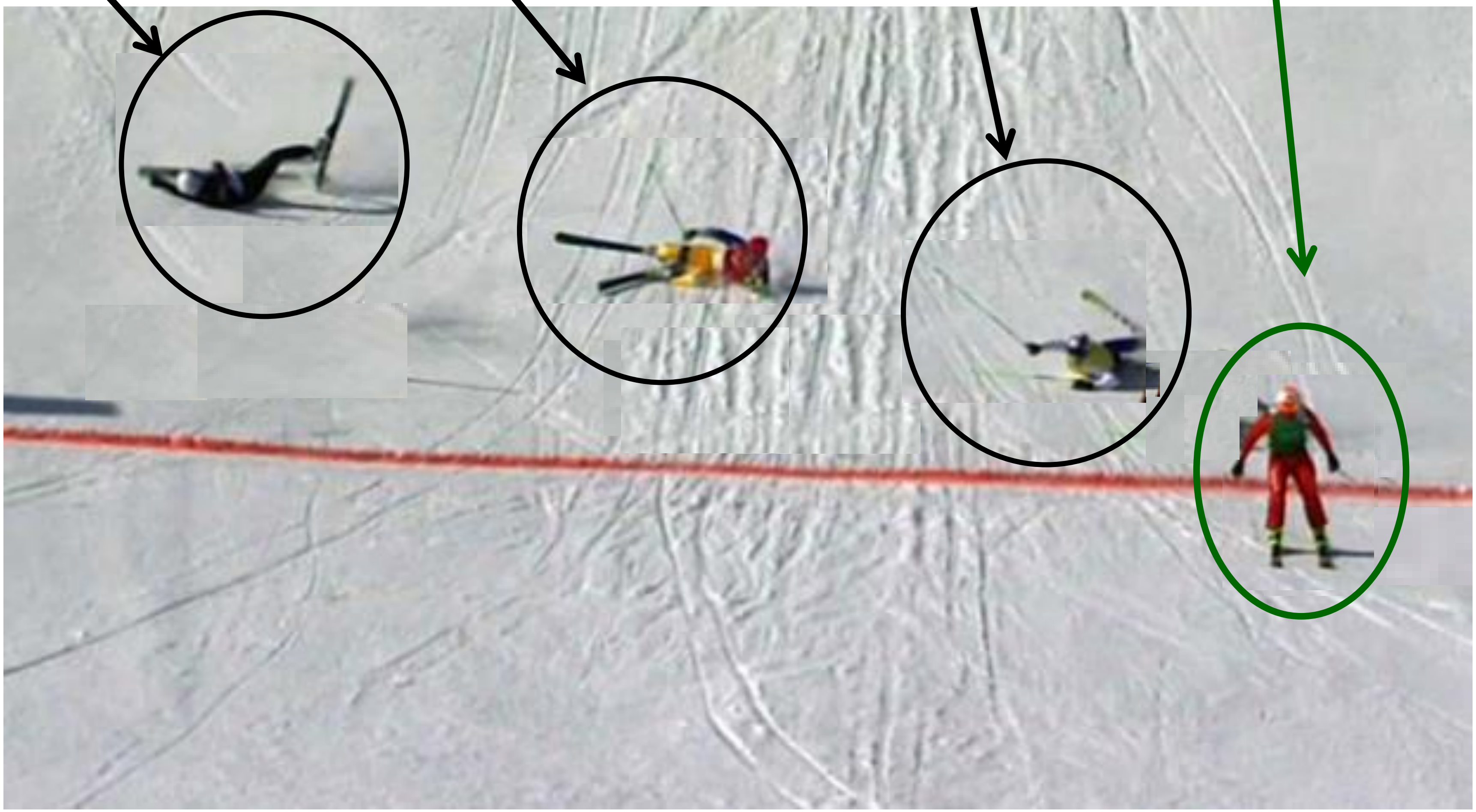


Outlook

LHC at 13 TeV?

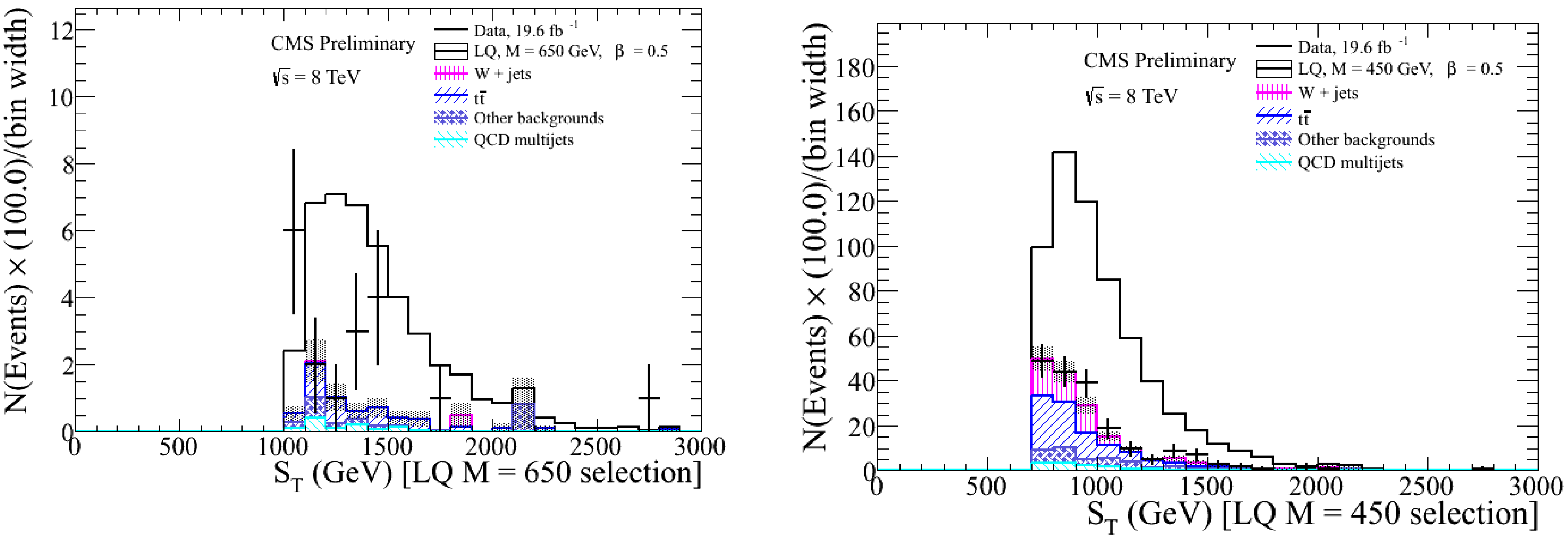
Tevatron? LHC, 7 TeV? LHC, 8 TeV?

New Physics Finish Line



Backup

1^{st} Generation Leptoquarks (EXO-12-041)



- In evjj channel, *with selection optimised for LQ mass=650 GeV*, 2.6 sigma excess of data over bkg – spread out, no peak in m_{ej}

ττ in eμ Decay Channel (EXO-12-046)

- Dilepton trigger 17+8 GeV; offline e,mu pT>20 GeV; MET> 20 GeV

To more effectively distinguish between lower mass backgrounds from tau lepton pairs from new particle production, the visible tau decay products and the $\not{E}_T$ are used to reconstruct the mass:

$$M(\mu, e, \not{E}_T) = \sqrt{(E_\mu + E_e + \not{E}_T)^2 - (\overrightarrow{p_\mu} + \overrightarrow{p_e} + \overrightarrow{\not{E}_T})^2}. \quad (5)$$

Table 1: Number of observed events in data and estimated background events, for different $M(\mu, e, \not{E}_T)$ mass ranges. The errors on the estimated background events represent the statistical uncertainty from the MC samples.

$M(\mu, e, \not{E}_T)$ (GeV)	[50,100]	[100,150]	[150,200]	[200,250]	[250,300]
Expected bkg	3480±120	4250±130	1010±70	396±19	230±24
Data	3428	4296	1000	388	198
$M(\mu, e, \not{E}_T)$ (GeV)	[300,400]	[400,600]	[600,900]	[900,1500]	[0,1500]
Expected bkg	217±13	82±5	20±4	2.7±1.6	9680±190
Data	176	98	20	3	9607

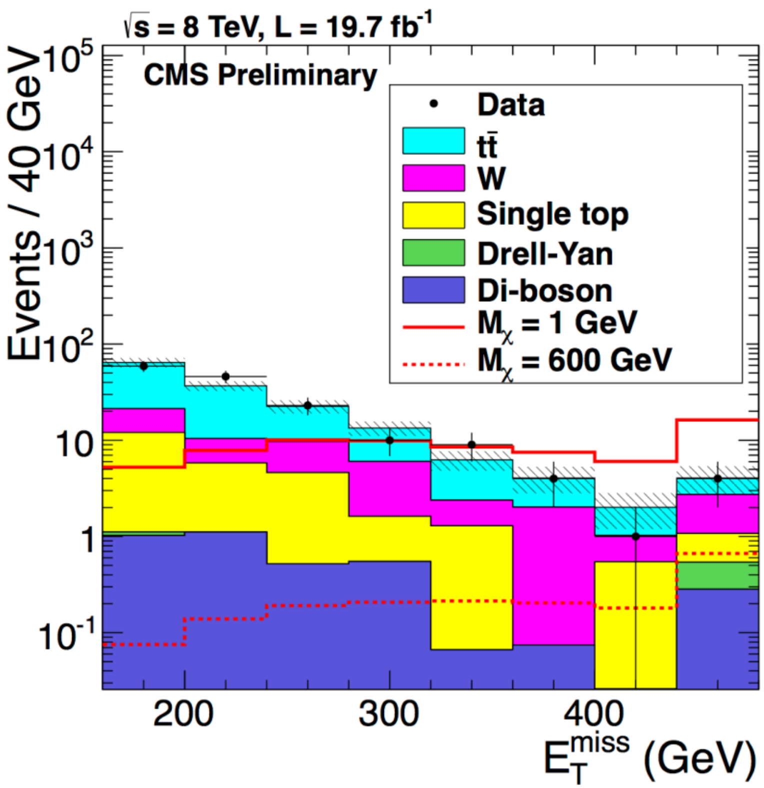
Z-Higgs Resonance Search (EXO-13-007)

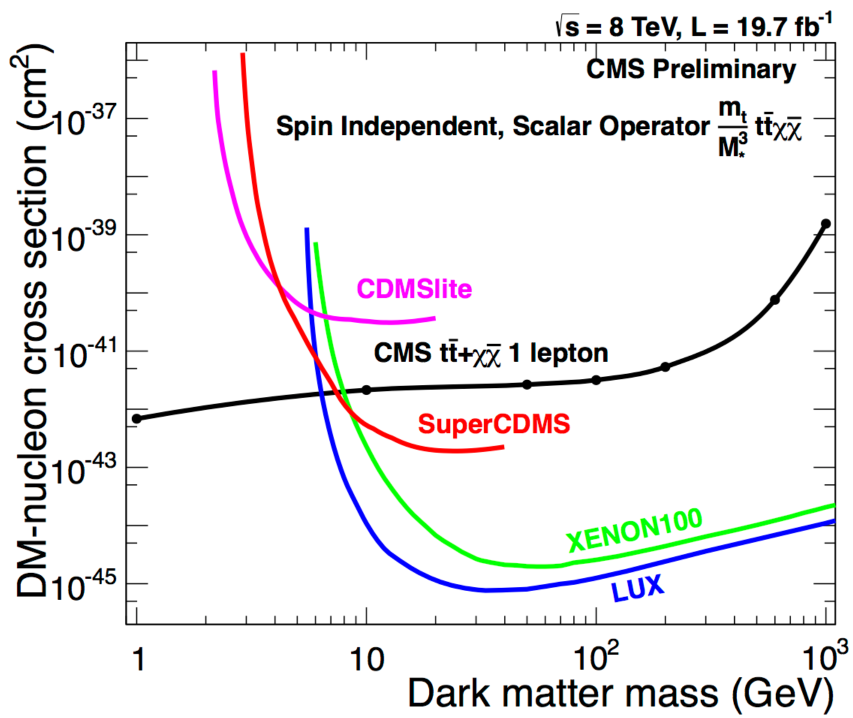
Dark Matter + ttbar (B2G-14-004)

- Scalar DM-quark interaction small due to light quark mass

$$\mathrm{L_{int}} = \frac{m_q}{M_*^3}\bar{q}q\bar{\chi}\chi$$

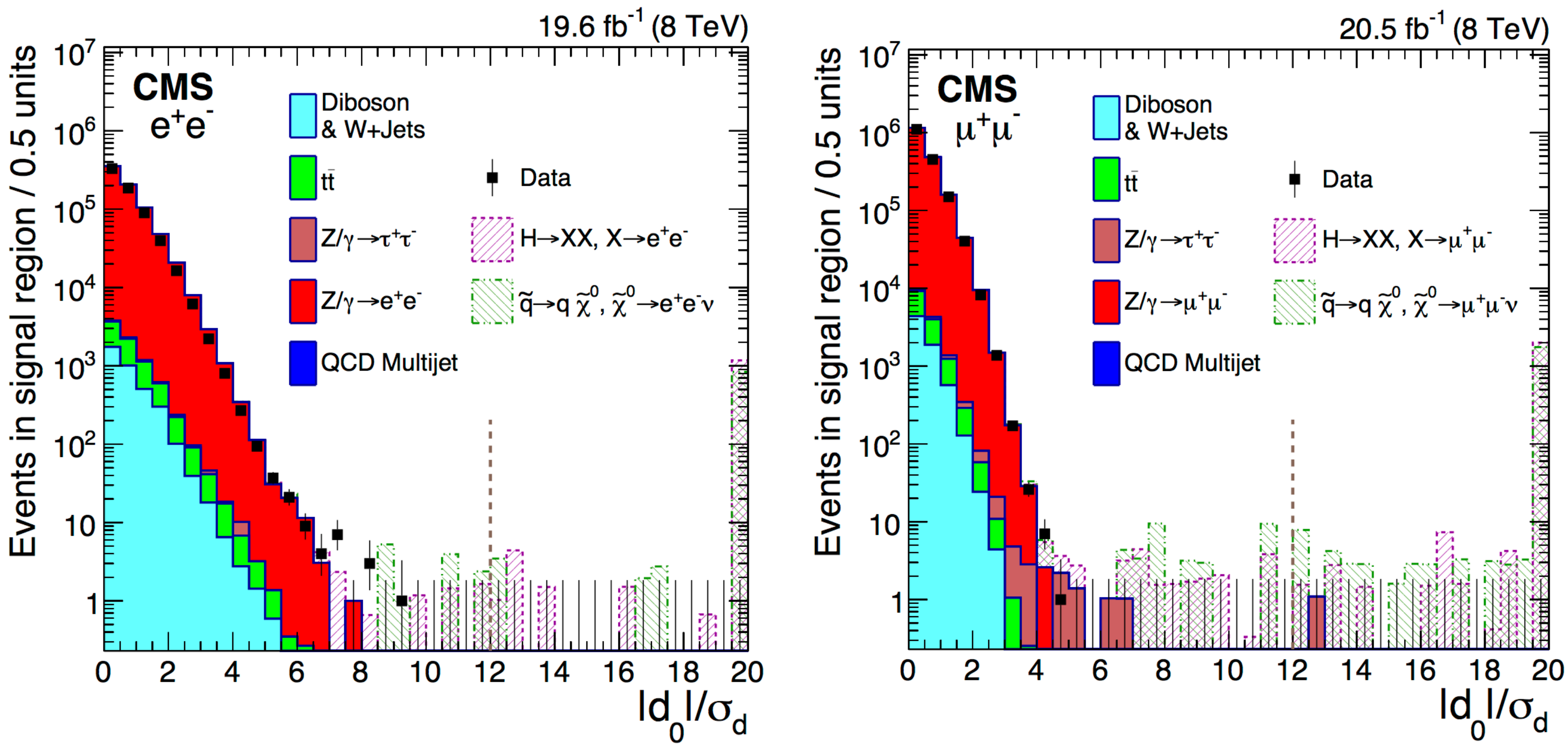
- Motivates search for DM + top quark pair → ttbar + MET
- Increases LHC sensitivity to scalar DM interaction





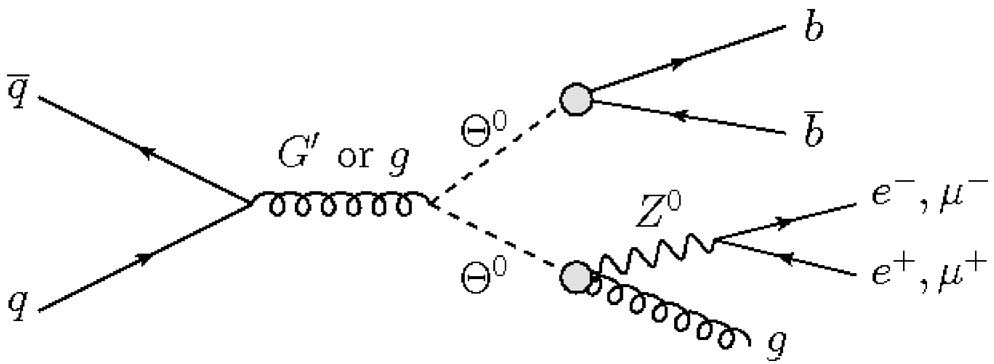
Displaced Dilepton Pairs (EXO-12-037)

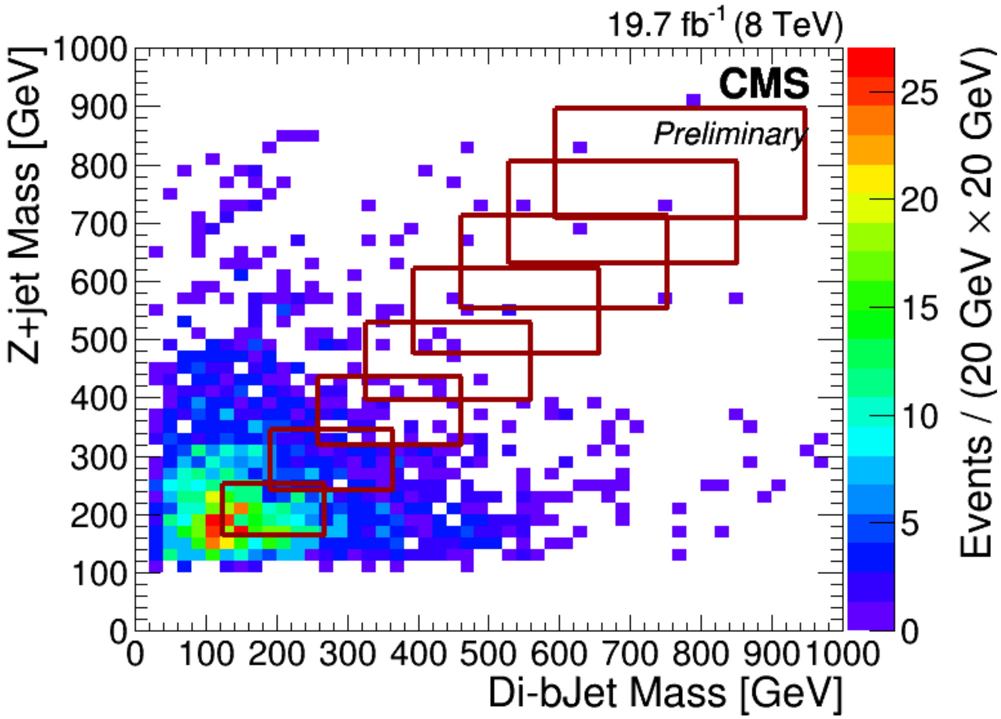
- Pair of charged leptons from a displaced vertex – would indicate long-lived particle decay
- Seek displaced vertex lepton pairs 12 std dev from primary vertex – no such events seen in data [arXiv:1411.6977]

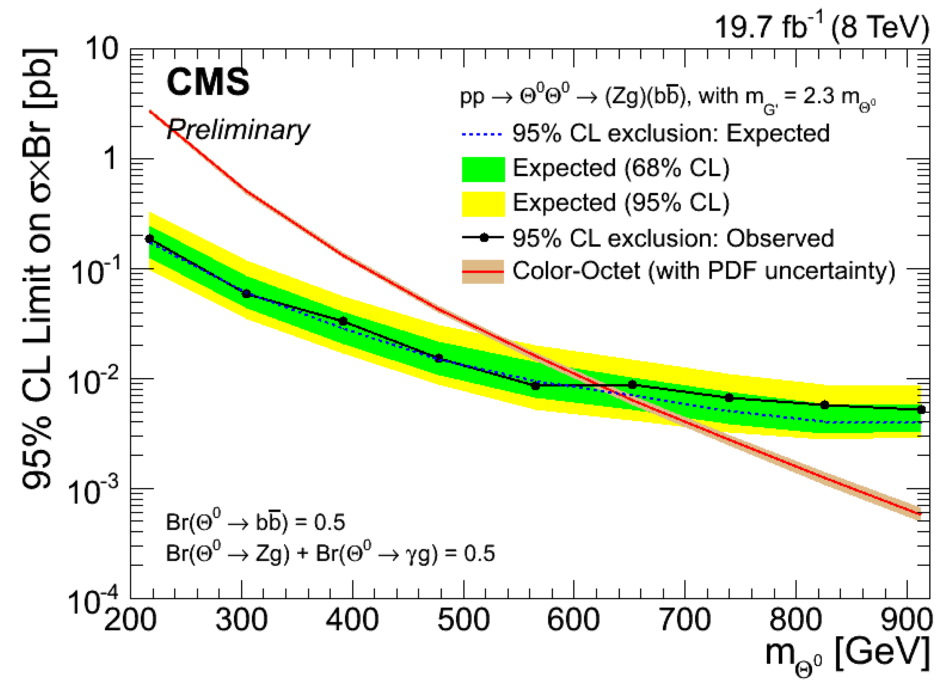


Color-Octet, Weak-triplet (EXO-12-007)

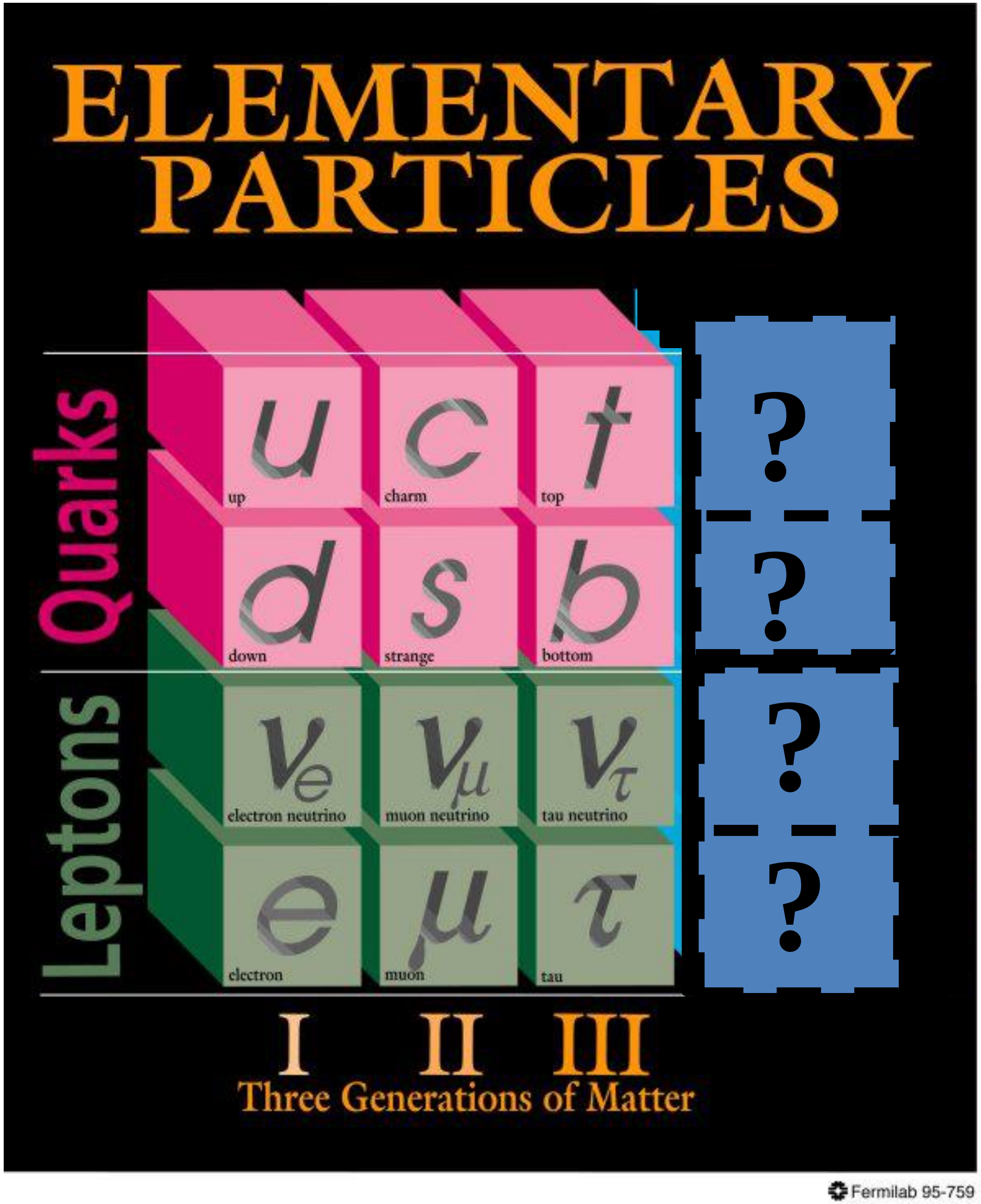
- Color-octet, weak-triplet, neutral scalar boson Θ^0
- Pair-produced,
- decaying to bb and Z+g







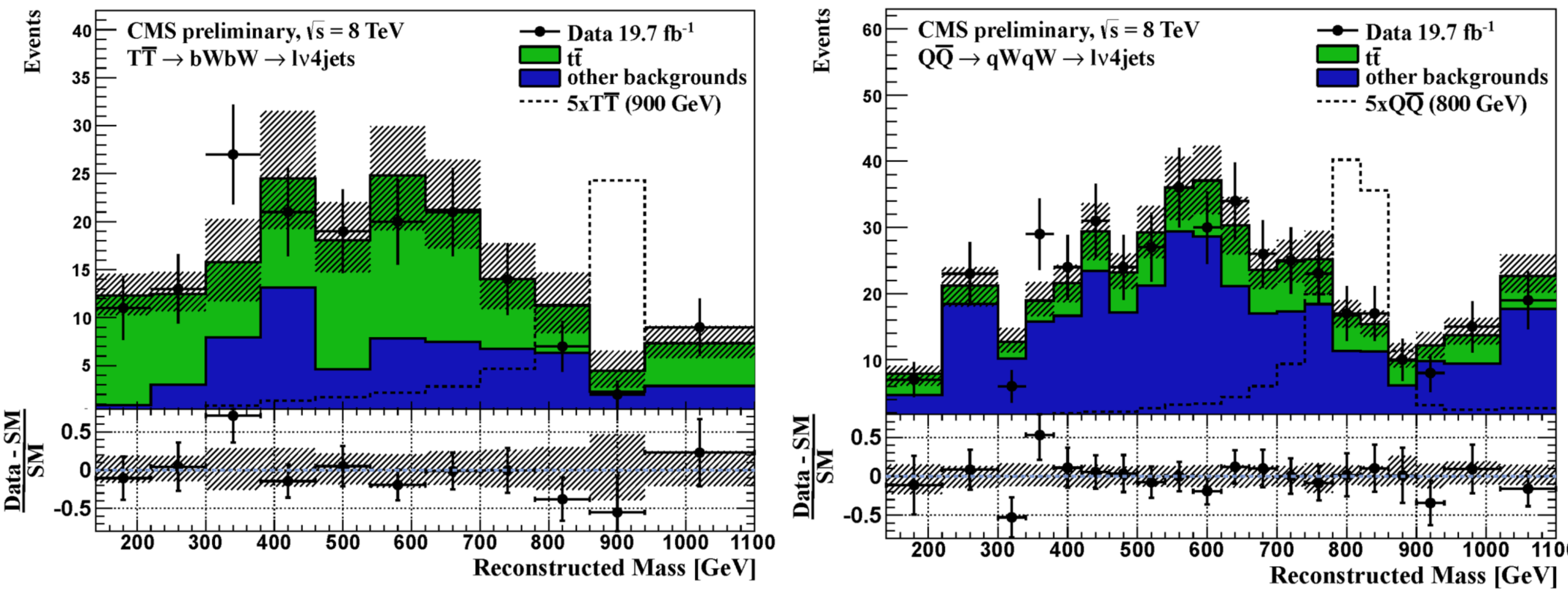
New BSM Fermion States



- "Vector-like" quarks:
  - 4^{th} generation quarks, but "non-chiral" (SM quarks are chiral, ie only LH state couples to Weak interaction)
- Heavy Majorana Neutrinos:
  - A heavy neutrino which is its own anti-particle

Vector-like Quark (B2G-12-017)

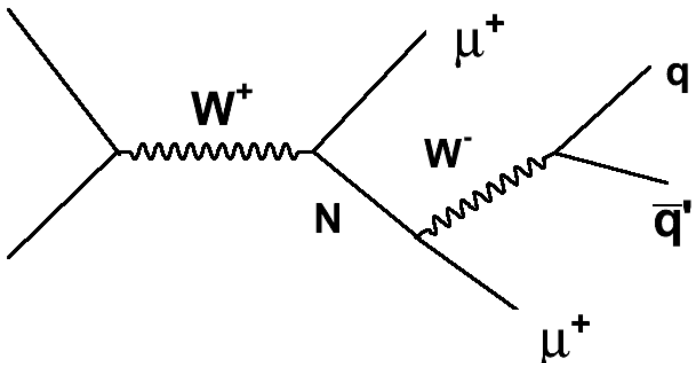
- Consider TT → bWbW and QQ → qWqW (one W hadronic, other W leptonic decay)
- Hadronic W highly boosted – use 'jet-pruning'

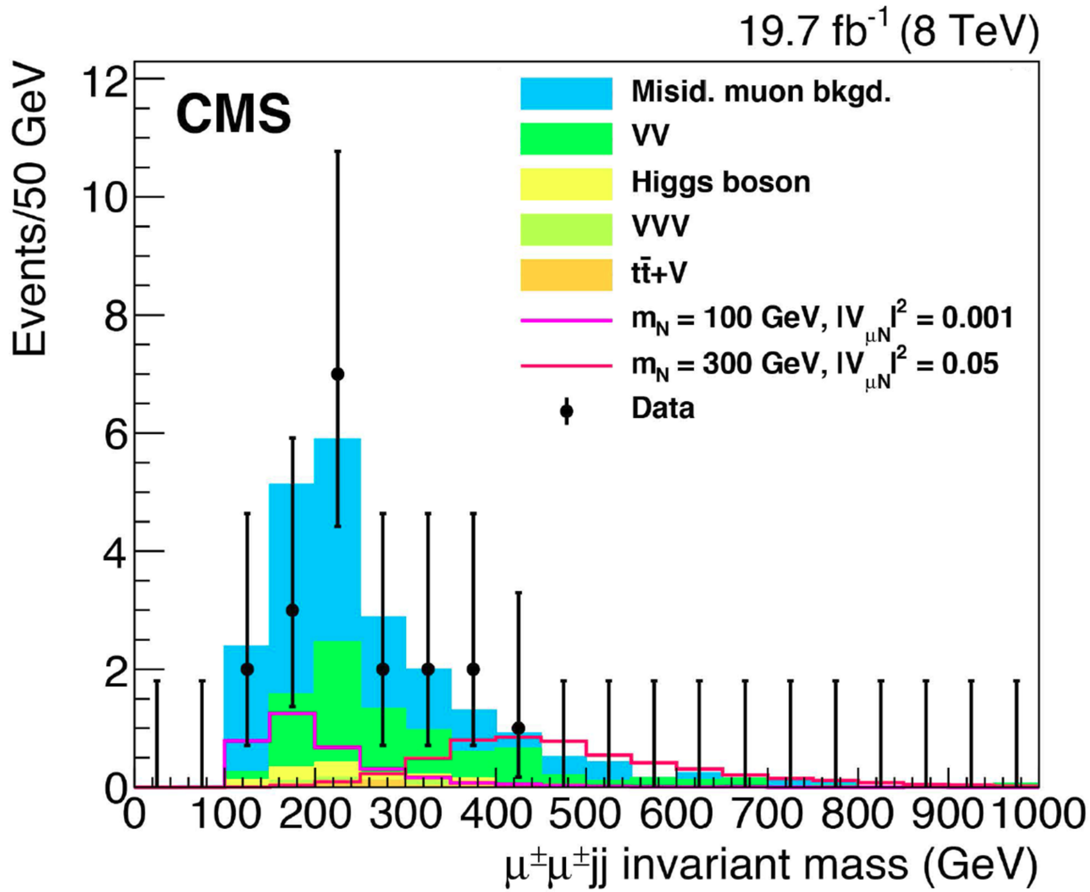


- Exclude T, M<912 GeV and Q, M<788 GeV

Heavy Majorana Neutrino (EXO-12-057)

- Signature: same-sign dimuon pair (only possible if heavy neutrino N is Majorana) +2jets
- Set limits on $V_{\mu N}$, mixing element of N with SM ν_μ, as function of N mass

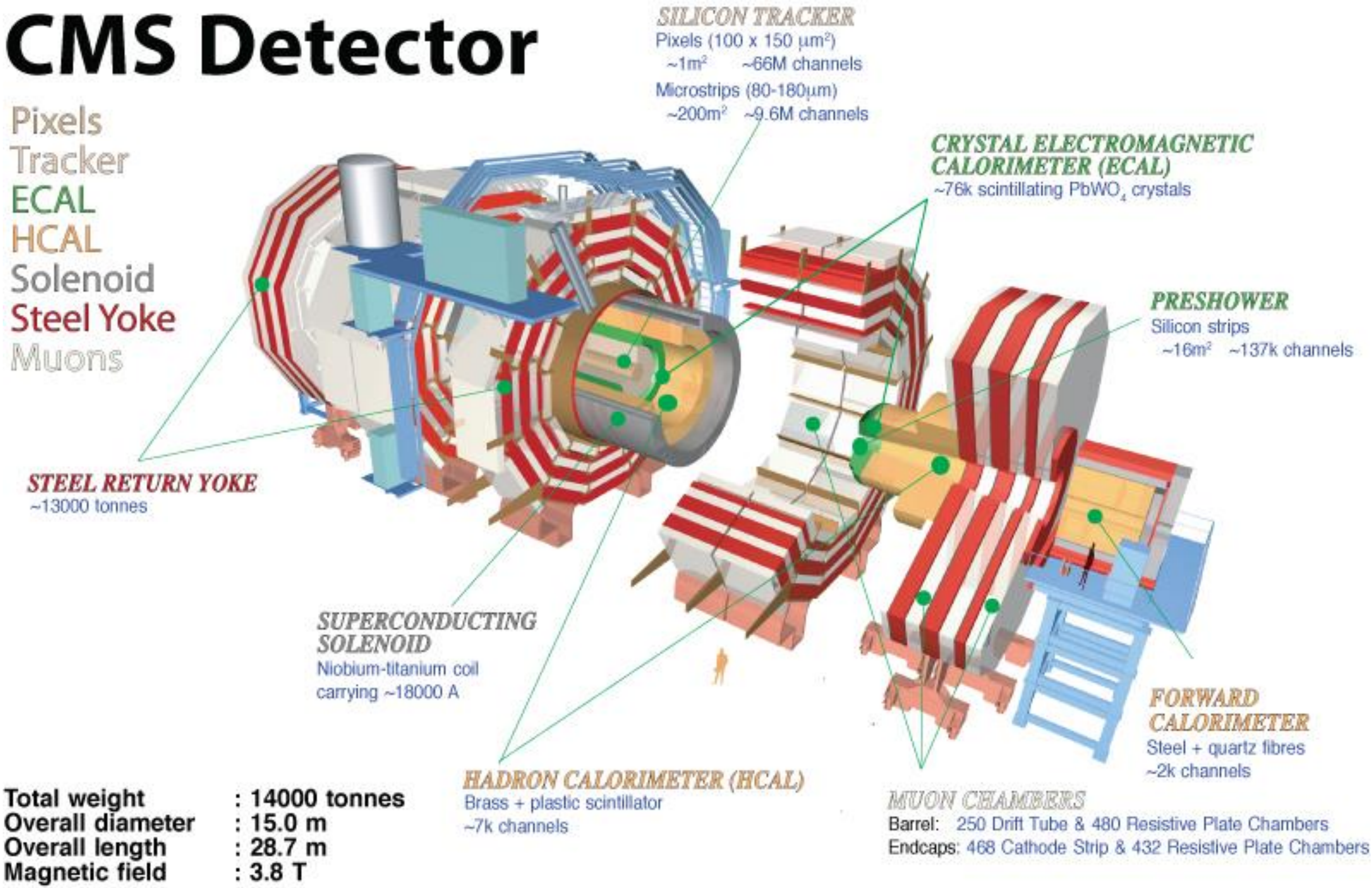




Heavy Majorana Neutrino (EXO-12-057)

- μ pT > 20,15 GeV, 2 jets pT > 20 GeV
- Veto 3rd μ, to suppress WZ bkg; veto b-tag jet to suppress ttbar bkg
- Additional refinement based on on-shell Ws, for low-mass and high-mass separately
- Major bkgs are: WZ, ZZ etc; W+jets, dijets, with jet faking muon (via heavy flavour decay, usually); the contribution from charge-mis-measured muons at CMS is negligible for this pT range

CMS Detector



Outlook

- LHC Run 2: increase collision energy to 13 TeV and increase rate of accumulating data
- We look forward to exciting times in this new frontier!

New Physics Finish Line

LHC at 13 TeV?