Exotic Searches at CMS

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EXOTICA IN CMS

- 2012 data
  - 5 preliminary results
- 2011 data
  - 40 submitted
- A number of searches with 2011 data available as preliminary result

Preliminary Results - 2012 Run

Analysis	Approved Plots	CDS Entry	Luminosity
Search for dijet resonances	EXO12016	PAS EXO12016	4/fb
Search for black holes	EXO12009	PAS EXO12009	4/fb
Search for dilepton resonances	EXO12015	PAS EXO12015	4/fb
Search for W' with lepton+MET	EXO12010	PAS EXO12010	4/fb
Search for a heavy neutrino and right-handed W	EXO12017	PAS EXO12017	4/fb

Preliminary Results - 2011 Run

Analysis	Approved Plots	CDS Entry	Luminosity
Search for Jet Extinction in the Inclusive Jet pT Spectrum NEW	EXO11068	PAS EXO11068	5/fb
Search for Multijet Resonances in the 8-jet Final State NEW	EXO11075	PAS EXO11075	5/fb
Search for Unparticles in Z+MET NEW	EXO11043	PAS EXO11043	5/fb
Search for b-jet Resonances NEW	EXO11008	PAS EXO11008	5/fb
Search for qW/qZ/WW/WZ/ZZ-Resonances in the WZ-tagged Dijet Mass Spectrum NEW	EXO11095	PAS EXO11095	5/fb
Search for Long-Lived Particles using Displaced Photons NEW	EXO11035	PAS EXO11035	5/fb
Search for multi-charged Heavy Stable Charged Particles NEW	EXO11090	PAS EXO11090	5/fb
Search for B' to tZ NEW	EXO11066	PAS EXO11066	5/fb
Search for ADD Extra-dimensions in Dielectrons	EXO12013	PAS EXO12013	5/fb
Search for high-mass resonances decaying to ll in the lepton+jets channel	EXO11083	PAS EXO11083	5/fb
Search for narrow resonances decaying to Z(ll)Z(qq)	EXO11102	PAS EXO11102	5/fb
Search for Evidence of Contact Interactions in Dimuon Mass Spectrum	EXO11009	PAS EXO11009	5/fb
Search for exotic resonances decaying into V+Z using final states with a jet and a lepton pair	EXO11081	PAS EXO11081	5/fb
Search for Dijet Resonances in the Dijet Delta Eta Ratio	EXO11025	PAS EXO11025	2.2/fb
Search for Randall-Sundrum Gravitons Decaying into a Jet plus Missing ET	EXO11061	PAS EXO11061	4.7/fb
Search for Z' to ttbar in high-mass (e+jets) channel	EXO11092	PAS EXO11092	4.7/fb
Search for New Physics in the Paired Dijet Mass Spectrum	EXO11016	PAS EXO11016	2.2/fb

Journal Publications - 2010 Run

Hide

Analysis	ArXiv Entry	Luminosity	Publication Status
Search for Three-Jet Resonances in pp Collisions at √s = 7 TeV	1107.3084 [hep-ex]	36/pb	10.1103/PhysRevLett.107.101801
A Search for excited leptons in pp Collisions at √s = 7 TeV	1107.1773 [hep-ex]	36/pb	10.1016/j.PhysLetB.2011.09.021
Search for New Physics with a Mono-Jet and Missing Transverse Energy in pp Collisions at √s = 7 TeV	1106.4775 [hep-ex]	36/pb	10.1103/PhysRevLett.107.201804
Search for Light Resonances Decaying into Pairs of Muons as a Signal of New Physics	1106.2375 [hep-ex]	35/pb	10.1007/JHEP07(2011)098
Search for Same-Sign Top-Quark Pair Production at √s = 7 TeV and Limits on Flavour Changing Neutral Currents in the Top Sector	1106.2142 [hep-ex]	35/pb	10.1007/JHEP08(2011)005
Search for First Generation Scalar Leptoquarks in the evjj channel in pp collisions at √s = 7 TeV	1105.5237 [hep-ex]	36/pb	10.1016/j.PhysLetB.2011.07.069
Search for Large Extra Dimensions in the Diphoton Final State at the Large Hadron Collider	1103.4279 [hep-ex]	36/pb	10.1007/JHEP05(2011)085
Search for Resonances in the Dilepton Mass Distribution in pp collisions at √s = 7 TeV	1103.0981 [hep-ex]	40/pb	10.1007/JHEP05(2011)093
Search for a W' boson decaying to a muon and a neutrino in pp collisions at √s = 7 TeV	1103.0030 [hep-ex]	36/pb	10.1016/j.PhysLetB.2011.05.048
Search for a Heavy Bottom-like Quark in pp Collisions at √s = 7 TeV	1102.4746 [hep-ex]	34/pb	10.1016/j.PhysLetB.2011.05.074

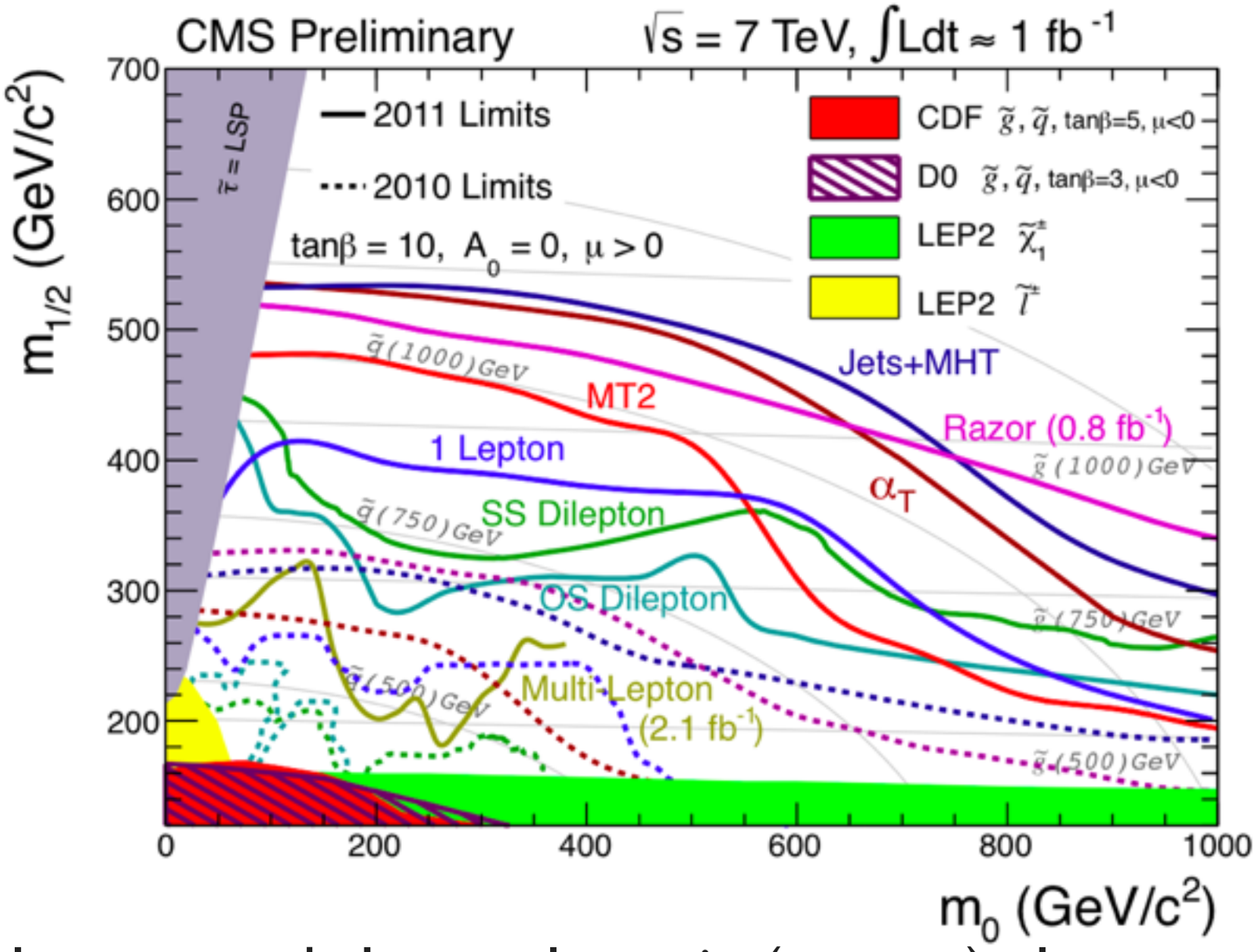
Journal Publications - 2011 Run

Analysis	ArXiv Entry	Luminosity	Publication Status
Search in leptonic channels for heavy resonances decaying to long-lived neutral particles NEW	ar30v:1211.2472	5/fb	submitted to JHEP
Search for new light bosons from Higgs boson decays using multi-muon events NEW	ar30v:1210.7619	5/fb	submitted to PLB
Search for Third-Generation Leptoquarks and Scalar Bottom Quarks NEW	ar30v:1210.5627	5/fb	submitted to JHEP
Search for third generation leptoquarks in tau+b NEW	ar30v:1210.5629	5/fb	submitted to PRL
Search for New Physics in Highly Boosted Z0 Decays to Dimuon NEW	ar30v:1210.0867	5/fb	submitted to PLB
Search for pair produced fourth-generation up-type quarks in pp collisions at 7 TeV with a lepton in the final state NEW	ar30v:1209.0471	5/fb	10.1016/j.physletb.2012.10.038
Search for a heavy neutrino and right-handed W NEW	ar30v:1210.2402	5/fb	submitted to PRL
Search for fractionally charged particles NEW	ar30v:1210.2311	5/fb	submitted to PRL
Search for Excited Leptons NEW	ar30v:1210.2422	5/fb	submitted to PLB
Search for narrow resonances and quantum black holes in inclusive and b-tagged dijet mass spectra NEW	ar30v:1210.2387	5/fb	submitted to JHEP
Search for Type III seesaw from pp collisions at 7 TeV NEW	ar30v:1210.1797	5/fb	submitted to PLB
Search for a narrow, spin-2 resonance decaying to a pair of Z bosons in the q qbar l+ l- final state NEW	ar30v:1209.3807	5/fb	submitted to PLB
Inclusive search for quarks of a sequential fourth generation	ar30v:1209.1062	5/fb	submitted to PRD
Search for Three-Jet Resonances	ar30v:1208.2931	5/fb	10.1016/j.physletb.2012.10.048
Search for W' -> t b in lepton + jets	ar30v:1208.0956	5/fb	submitted to PLB
Search for 1st or 2nd generation LQ	ar30v:1207.5406	5/fb	10.1103/PhysRevD.86.052013
Search for Heavy Majorana Neutrinos with same sign dileptons	ar30v:1207.6079	5/fb	10.1016/j.physletb.2012.09.012
Search for new physics with long-lived particles decaying to photons and missing energy	ar30v:1207.0627	2.1/fb	submitted to JHEP
Search for Stopped HSCPs	ar30v:1207.0106	5/fb	10.1007/JHEP08(2012)026
Search for Dark Matter and Large Extra Dimensions in Monojet Events	ar30v:1206.5663	5/fb	10.1007/JHEP09(2012)094
Search for W' decaying into t and d quarks	ar30v:1206.3921	5/fb	10.1016/j.physletb.2012.09.048
Search for Resonances to Dileptons	ar30v:1206.1849	5/fb	10.1016/j.physletb.2012.06.051
Search for resonances decaying into ditaus	arxiv:1206.1725	5/fb	10.1016/j.physletb.2012.07.062
Search for Search for W' (or techni-rho) to WZ	arxiv:1206.0433	5/fb	10.1103/PhysRevLett.109.141801
Search for HSCPs	ar30v:1205.0272	5/fb	10.1016/j.physletb.2012.06.023
Search for Anomalous Production of Multilepton Events and R-Parity-Violating Supersymmetry	ar30v:1204.5341	5/fb	10.1007/JHEP06(2012)169
Search for W' to lepton+MET	ar30v:1204.4764	5/fb	10.1007/JHEP08(2012)023
Search for Z' to ttbar (boosted tops)	ar30v:1204.2488	5/fb	10.1007/JHEP09(2012)029
Search for t' to bW (dilepton channel)	ar30v:1203.5410	5/fb	10.1016/j.physletb.2012.07.059
Search for Heavy Bottom-like Quarks	ar30v:1204.1088	5/fb	10.1007/JHEP05(2012)123
Search for Dark Matter and Large Extra Dimensions in the γ+MET Final States	ar30v:1204.0821	5/fb	10.1103/PhysRevLett.108.261803
Search for Quark Compositeness in Dijet Angular Distributions	ar30v:1202.5535	2.2/fb	10.1007/JHEP05(2012)055
Search for Black Holes	ar30v:1202.6396	4.7/fb	10.1007/JHEP04(2012)061
Search for Large Extra Dimensions in Dielectron and Dimuon Events	ar30v:1202.3827	2.2/fb	10.1016/j.physletb.2012.03.029
Search for signatures of extra dimensions in the diphoton mass spectrum at the Large Hadron Collider	ar30v:1112.0688	2.2/fb	10.1103/PhysRevLett.108.111801
Search for a Vector-like Quark with Charge 2/3 in t + Z Events from pp Collisions at √s = 7 TeV	ar30v:1109.4985	1.1/fb	10.1103/PhysRevLett.107.271802
Search for Resonances in the Dijet Mass Spectrum from 7 TeV pp Collisions at CMS	ar30v:1107.4771	1/fb	10.1016/j.PhysLetB.2011.09.015

A VERY PRODUCTIVE 2012

- 40 results produced by CMS on 2011 data so far
  - with 2-3 exceptions all using full 2011 data set of 5 fb^{-1}
- Comprehensive review requires a few hours
- Focus mostly on most recent results
  - Few preliminaries with full 2012 data
  - New results using full 2012 dataset to be presented at Moriond
- Complete list of results
  - CMS: https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsEXO

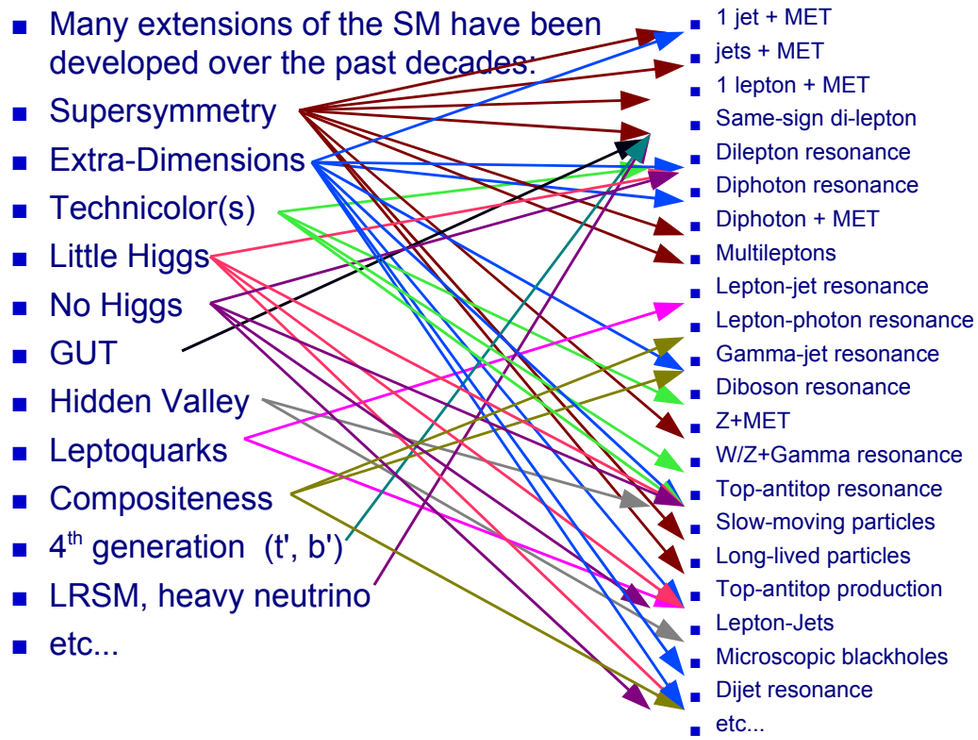
SUSY or Exotica?



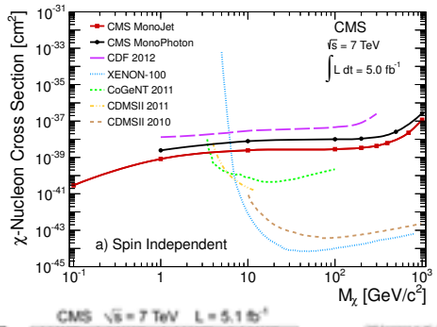
- SUSY results reported almost always in (m_0,$m_{1/2}$) plane
  - Relation between mass of supersymmetric particles
- Large missing transverse energy usually the primary signature
- In exotica we look for particles and resonances that are not necessarily needed or predicted in supersymmetry

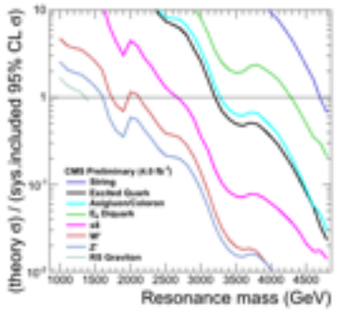
SIGNATURE- OR TOPIC-BASED?

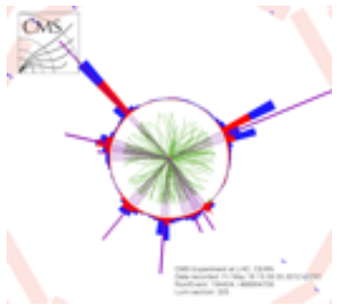
- Same final state often probing very different models or topics
  - 2 leptons, 2jets + MET, lepton+jet+MET
- Topological presentation requires jumping between very different models
- I will follow mostly a topic-based approach
  - easier to combine constraints on model from different topologies
  - Same final state is not simple re-interpretation
    - often optimization redone to deal with different acceptance for very different models
    - different analysis strategy and signal extraction methods

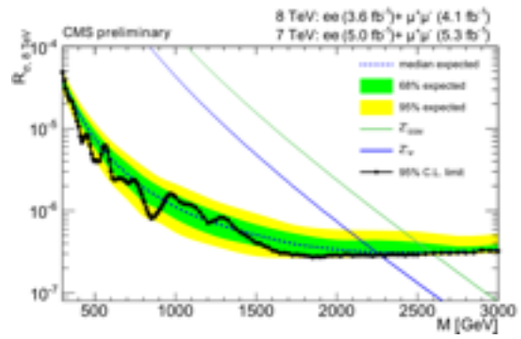


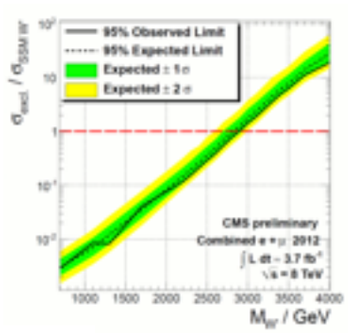
EXOTICA IN ONE PAGE

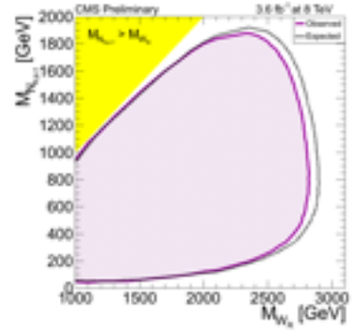


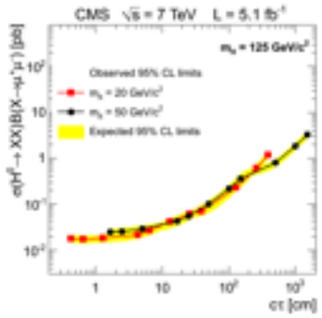


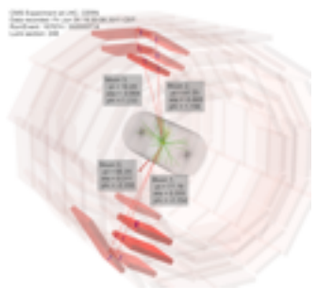


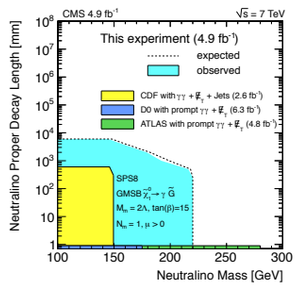


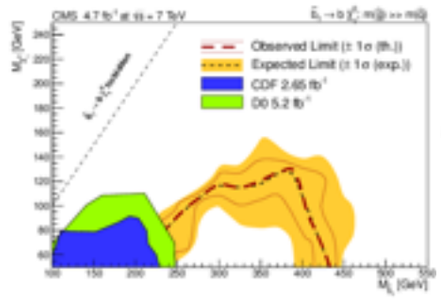


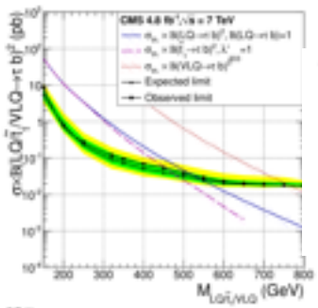


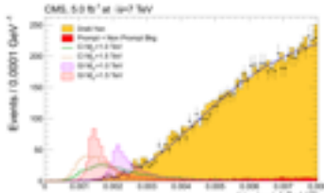


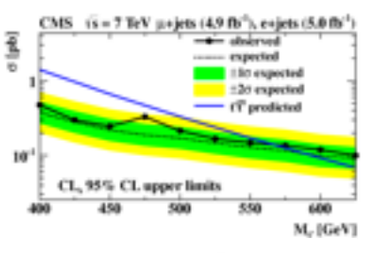


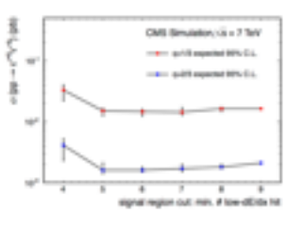


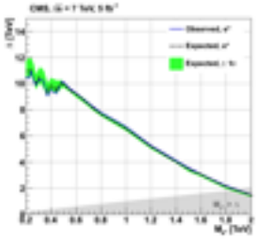


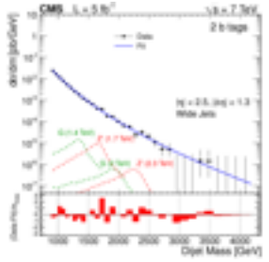


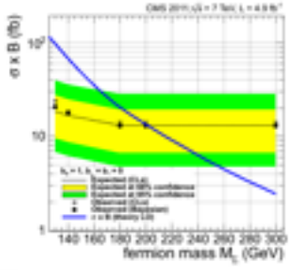


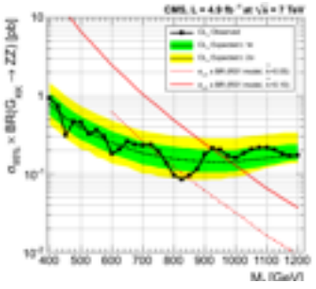


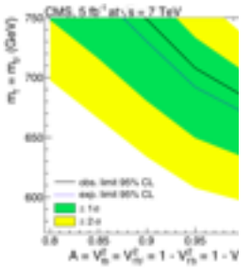


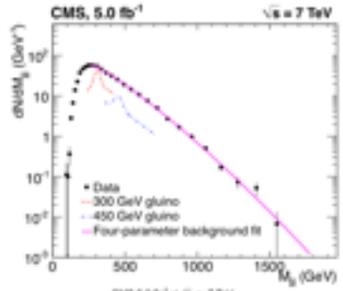


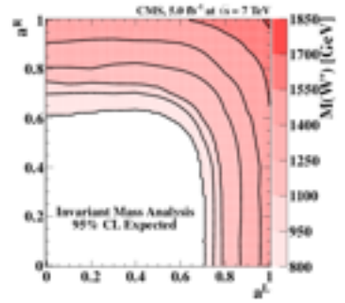


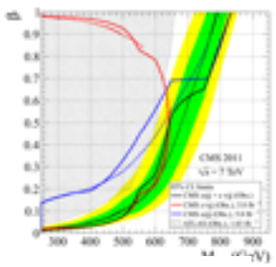


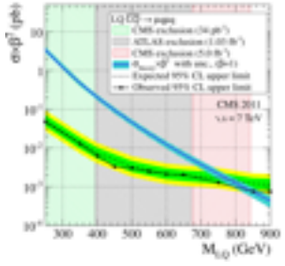


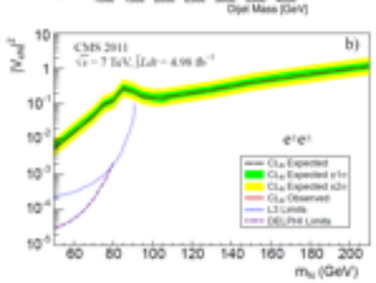


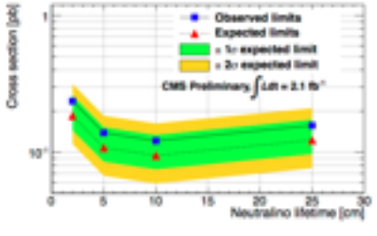


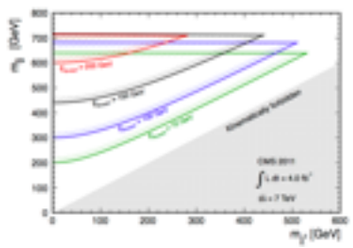


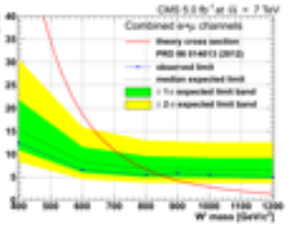


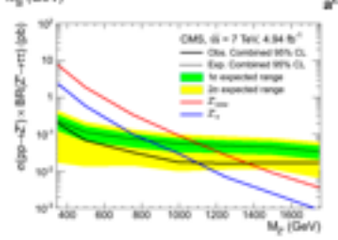


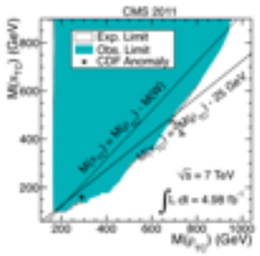


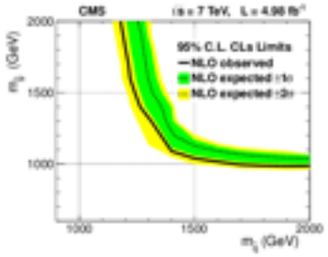


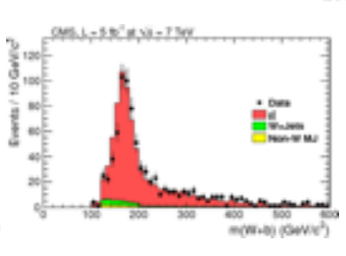


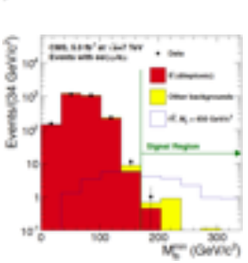


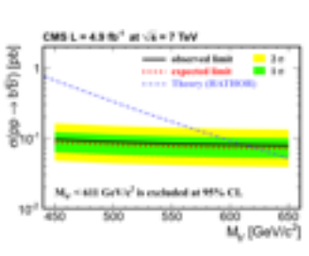


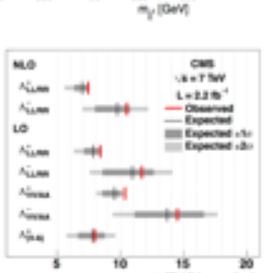




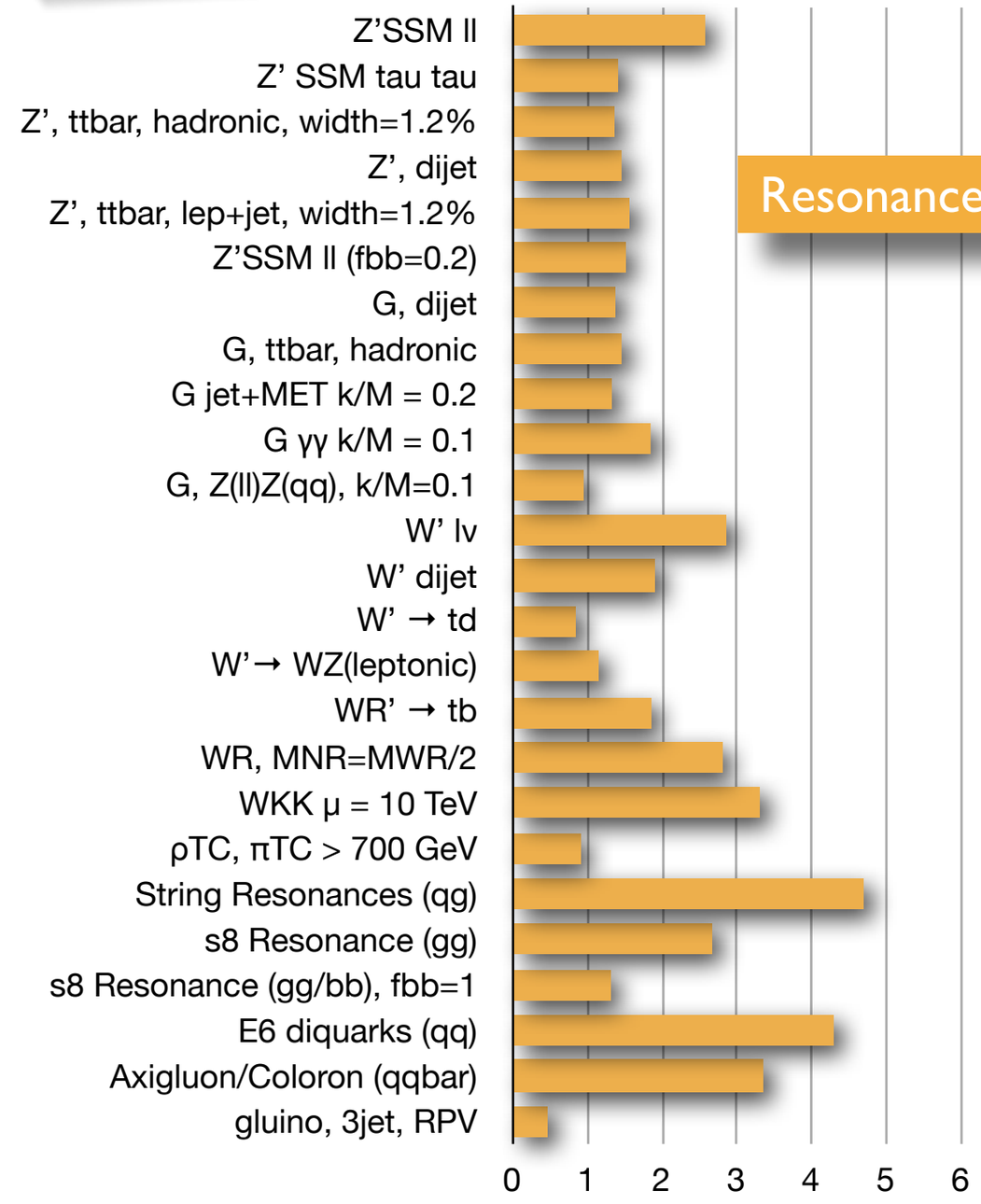


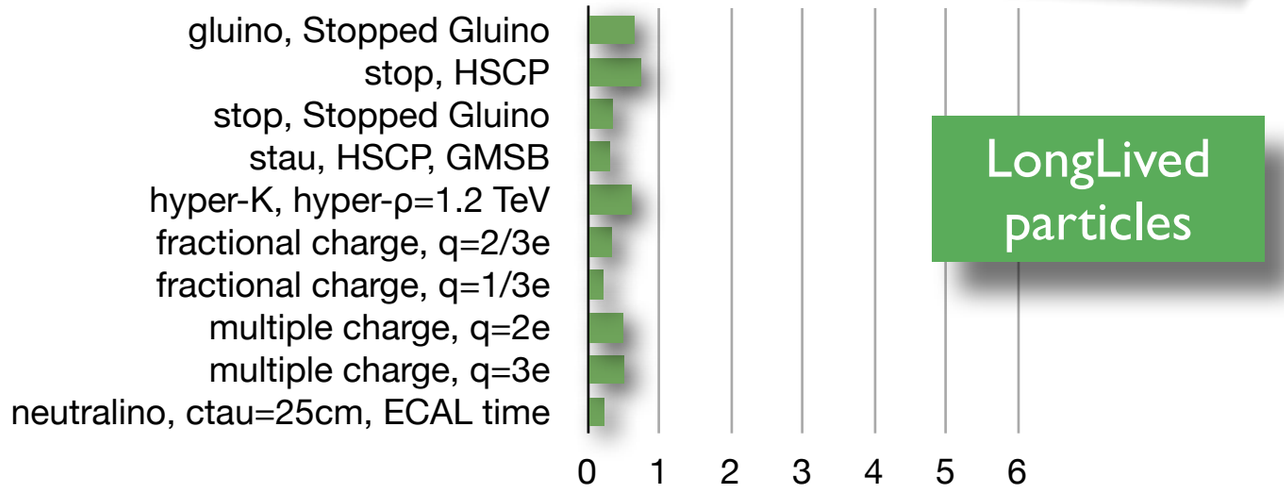


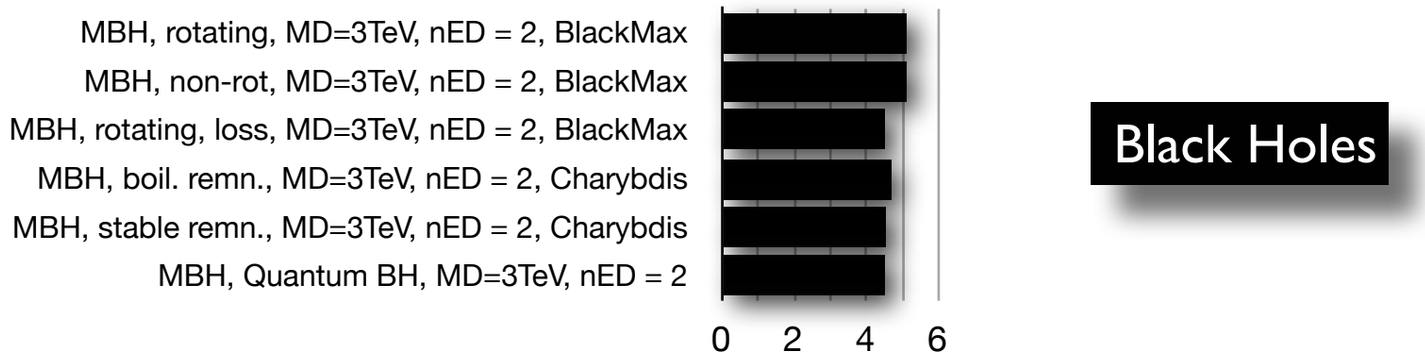


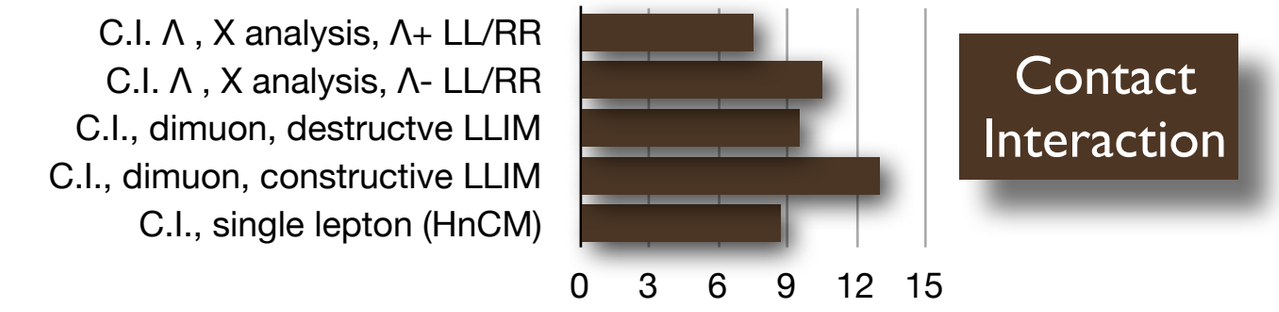


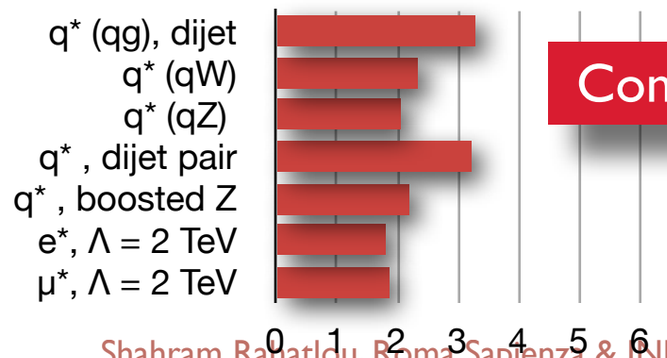
An Attempt at Summery!

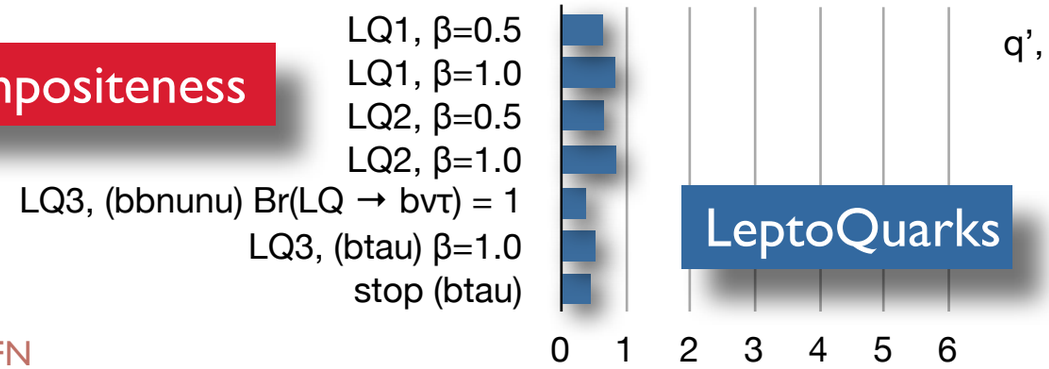


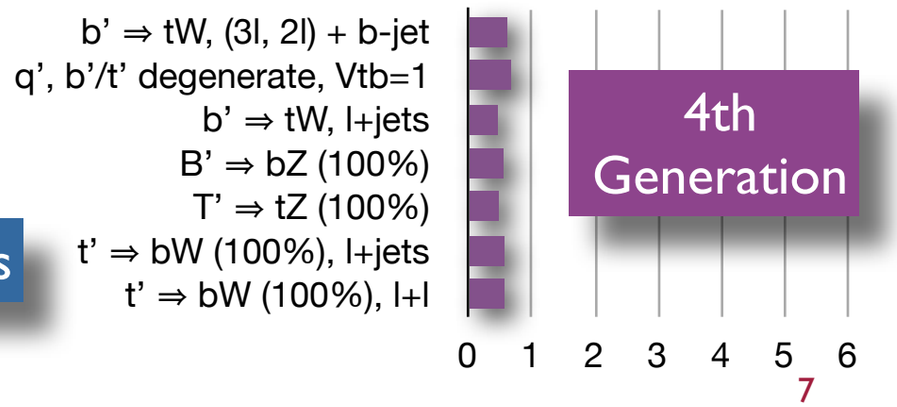






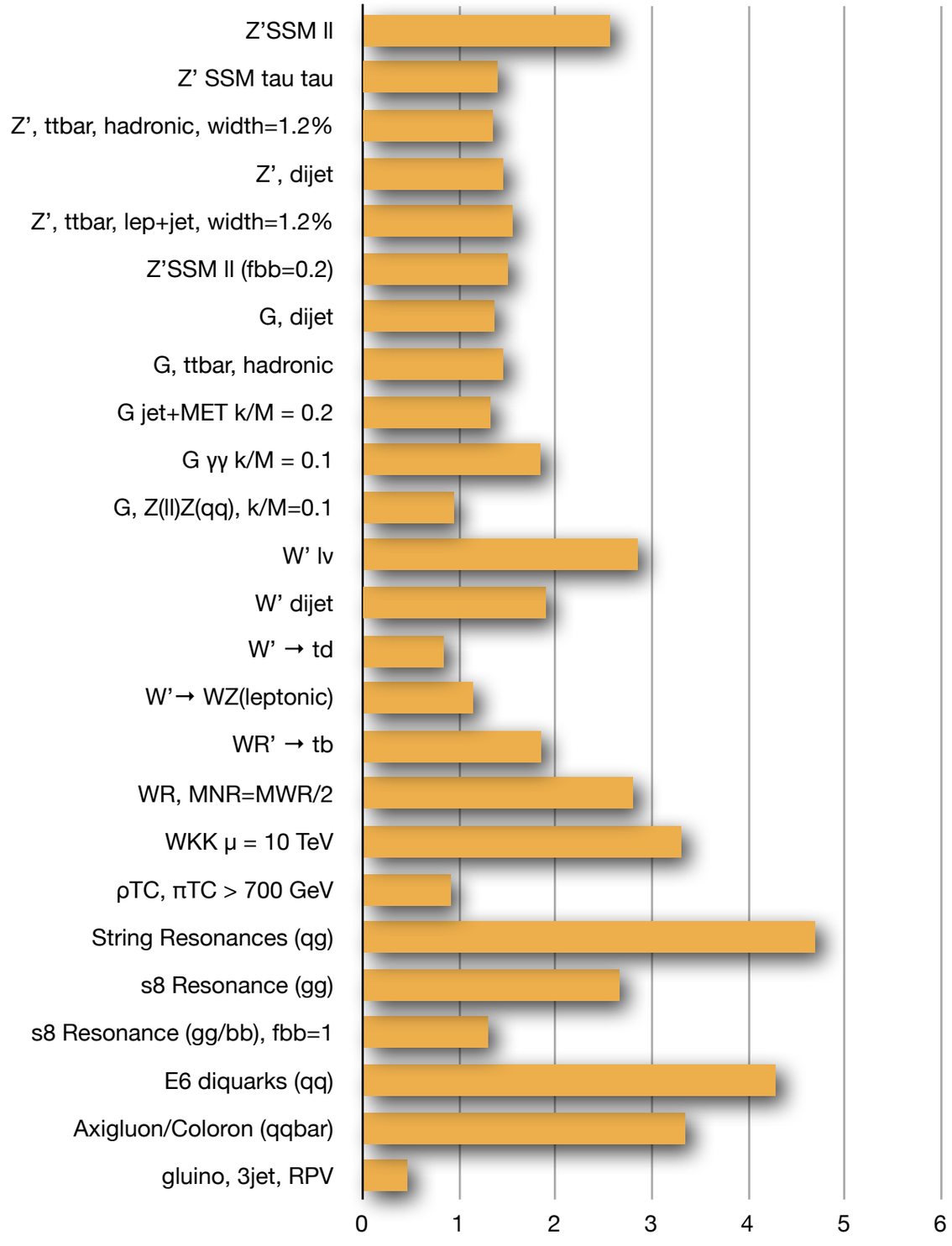






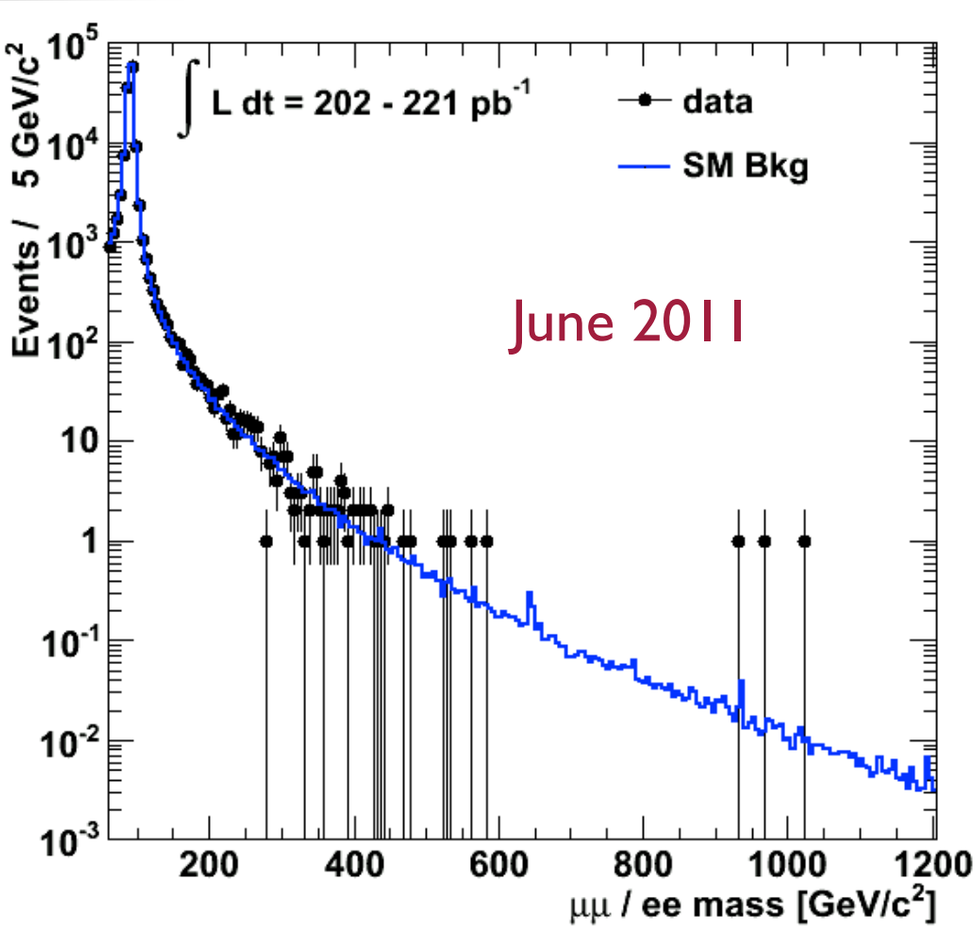
RESONANCES

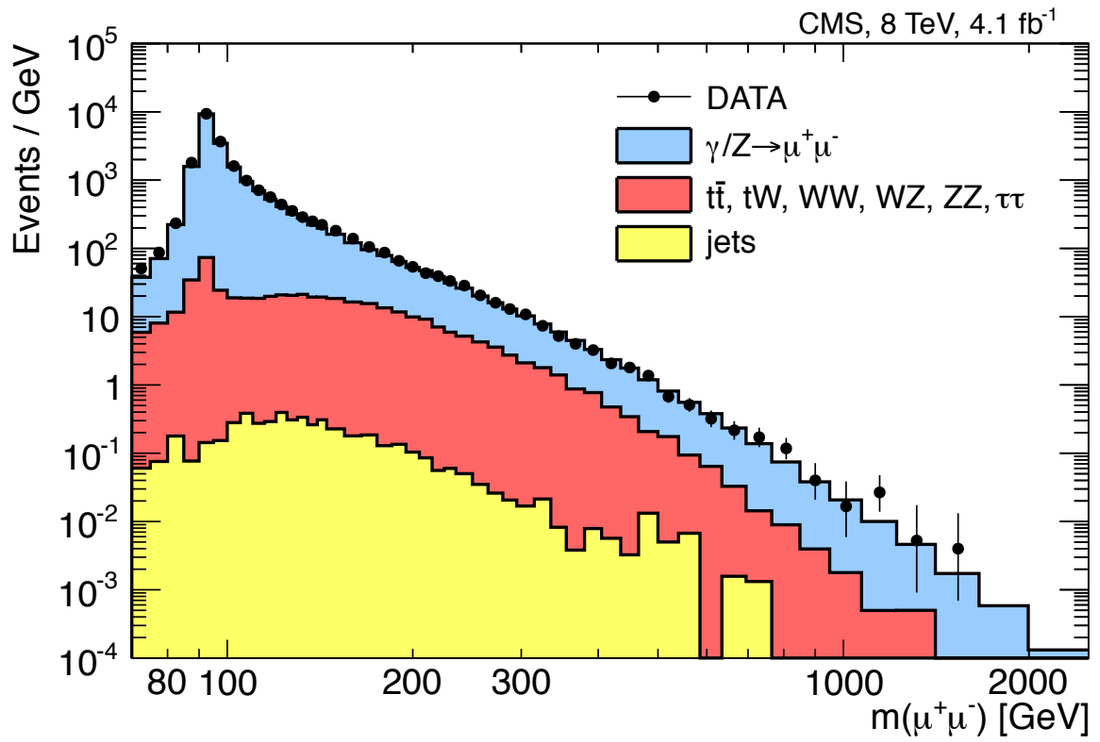
- Comprehensive list of signatures
  - di-leptons
    - e,mu,tau
    - lepton+MET
  - di-bosons (W/Z)
    - 3l+MET
    - 2l+2j
  - 2-photon
- Backgrounds
  - relatively clean with good S/B
  - mostly tails of SM processes
- Experimental challenges
  - detector resolution can be a key player
  - 1.3% - 2.4% for electrons and 7% for muons at 1 TeV mass
  - extra care for energy/momentum reconstruction above 1 TeV

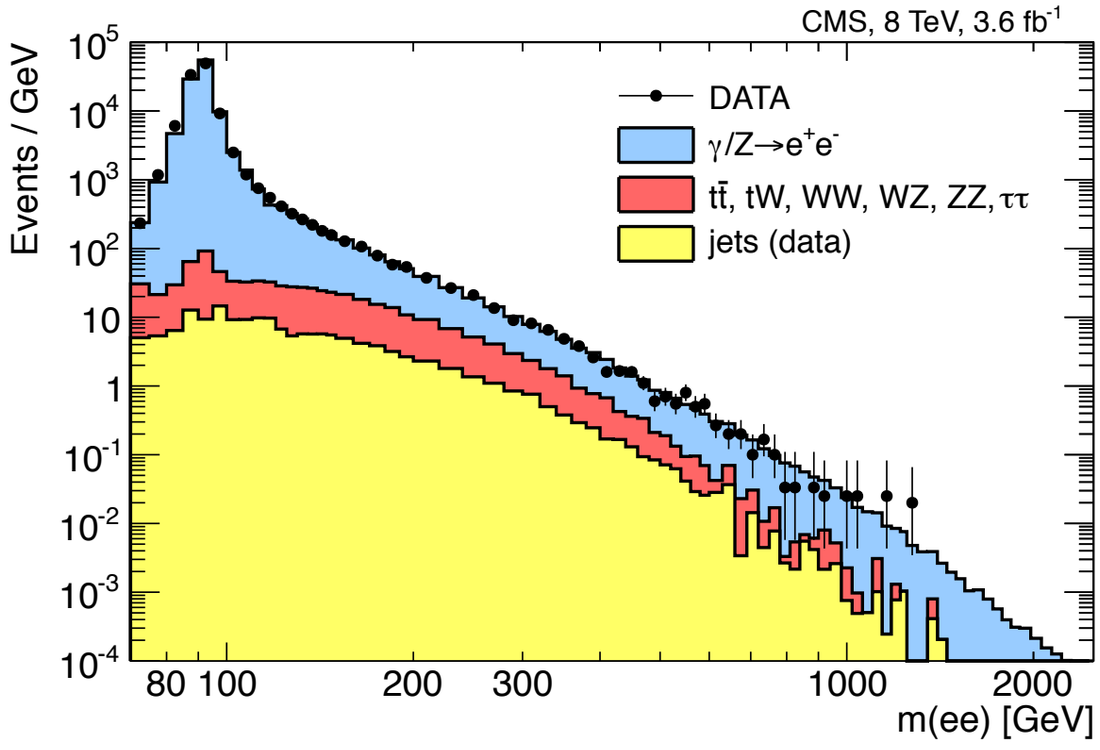


DI-LEPTON

EXO-12-015

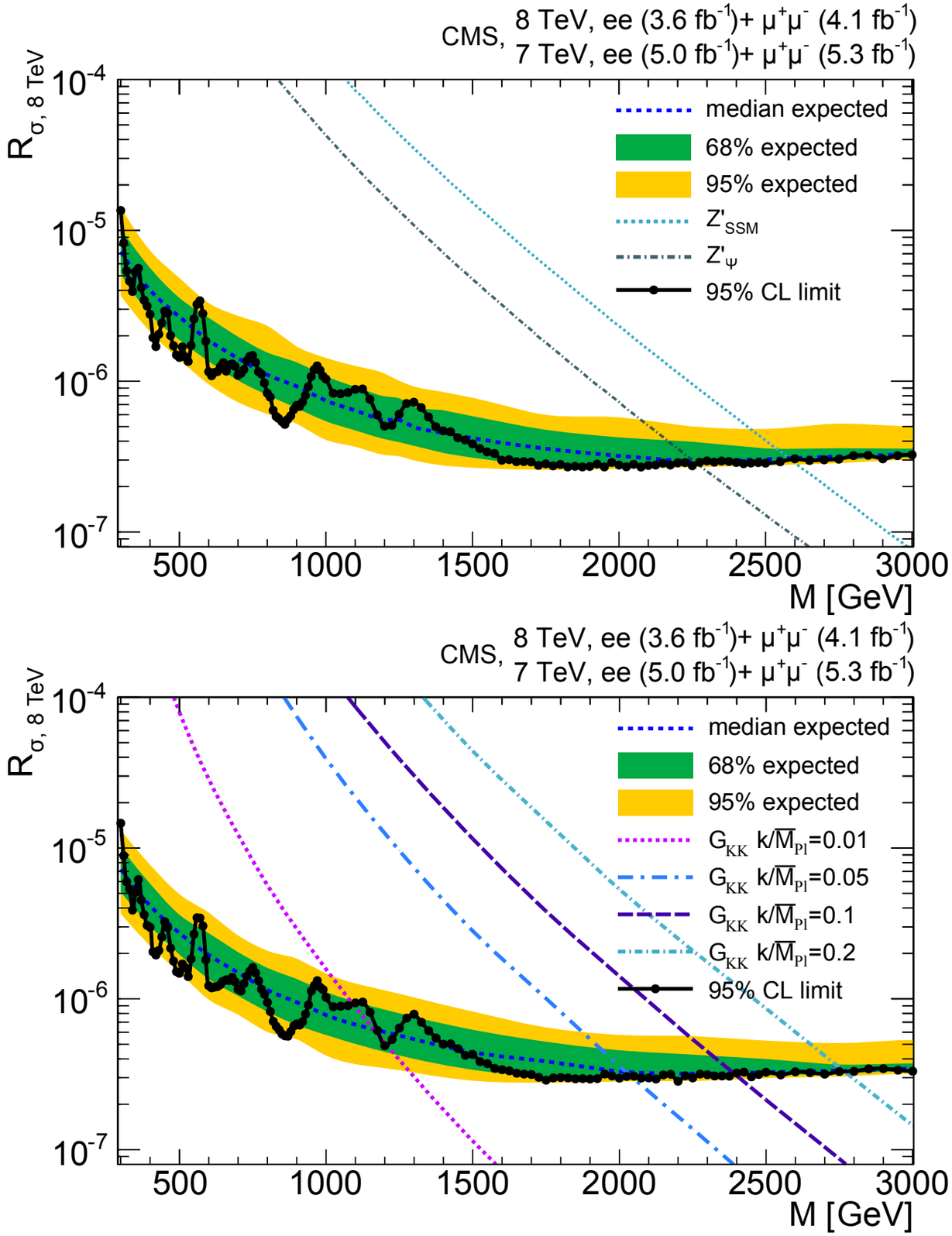






- High hopes at start of 8 TeV run
  - enhanced cross section
- Now only a nice Drell-Yan tail and no peak
- Next stop summer of 2015
  - cross section increase of > x3 above 1 TeV

Di-Lepton Exclusion Limits

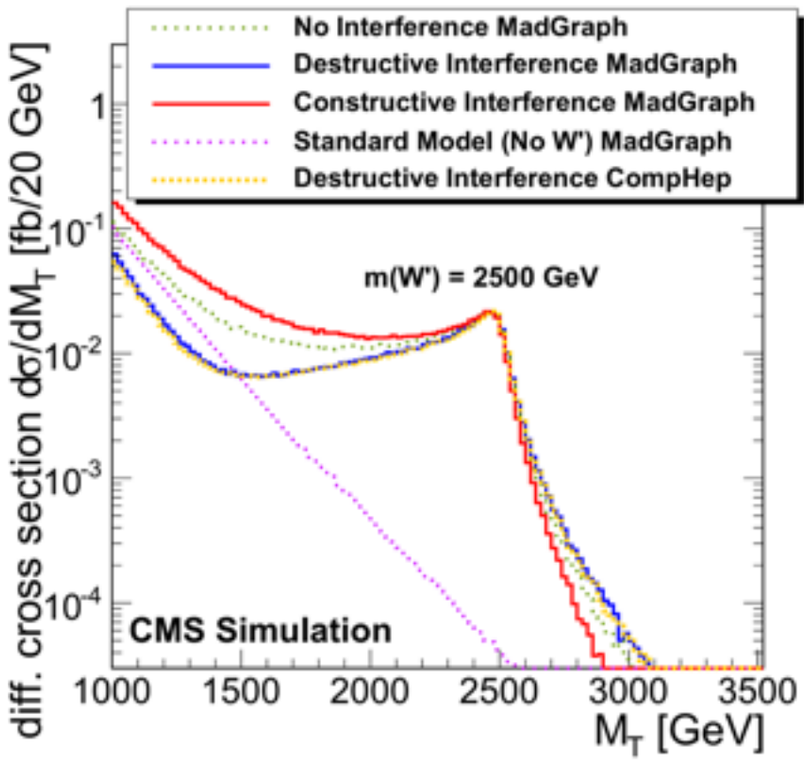


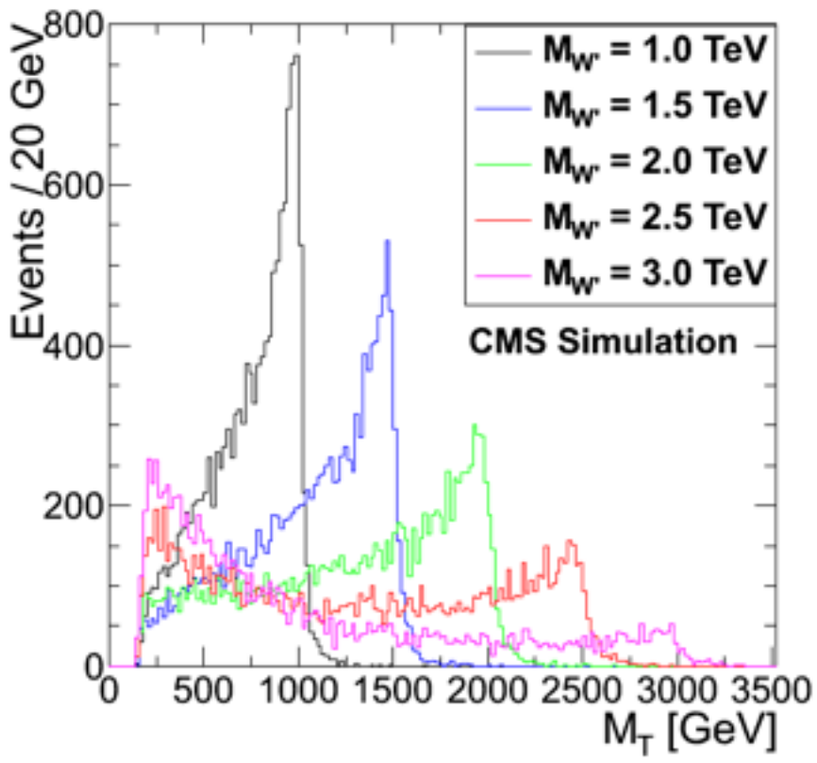
spin 1

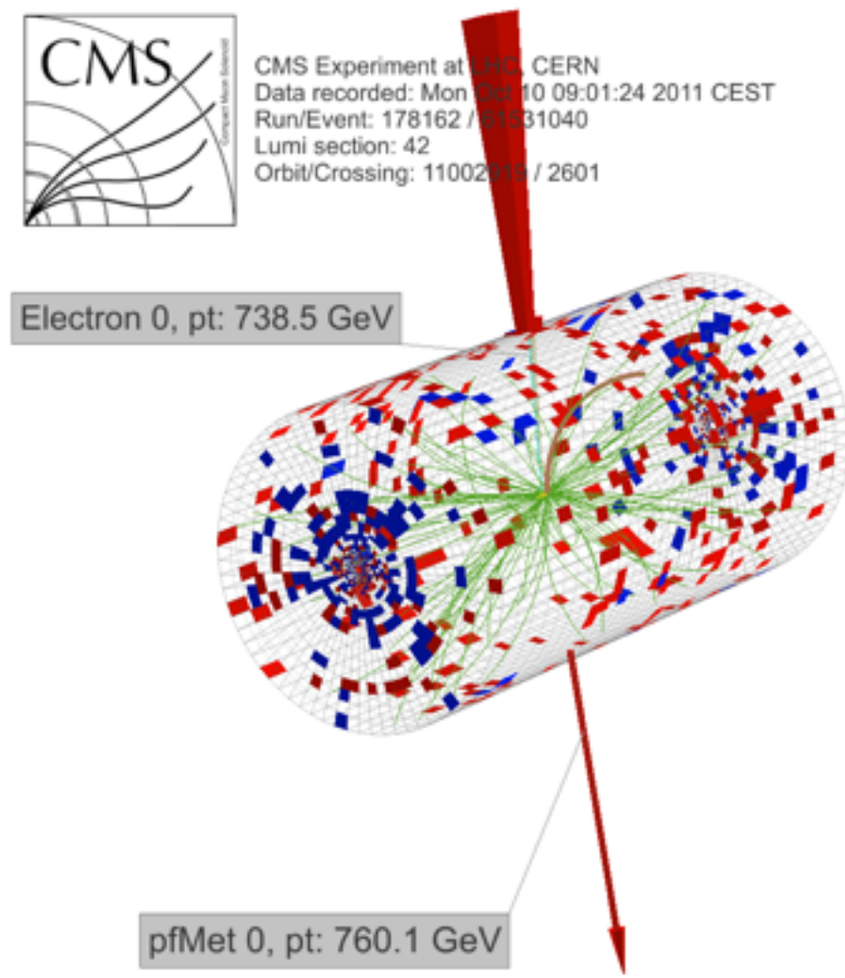
spin 2

LEPTON+MET

EXO-12-010





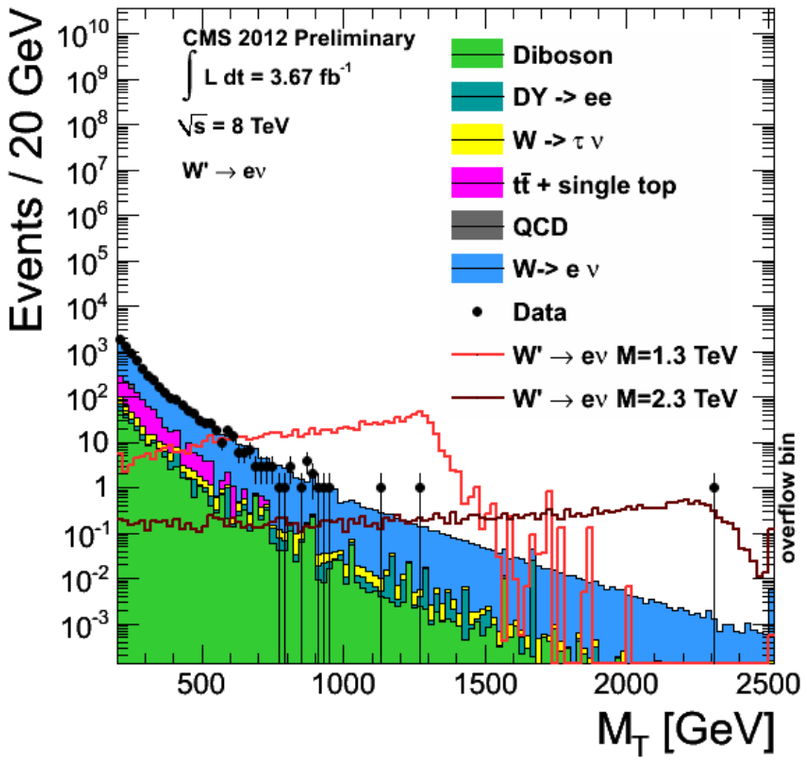


- Look for heavy W-like Jacobian peak in transverse

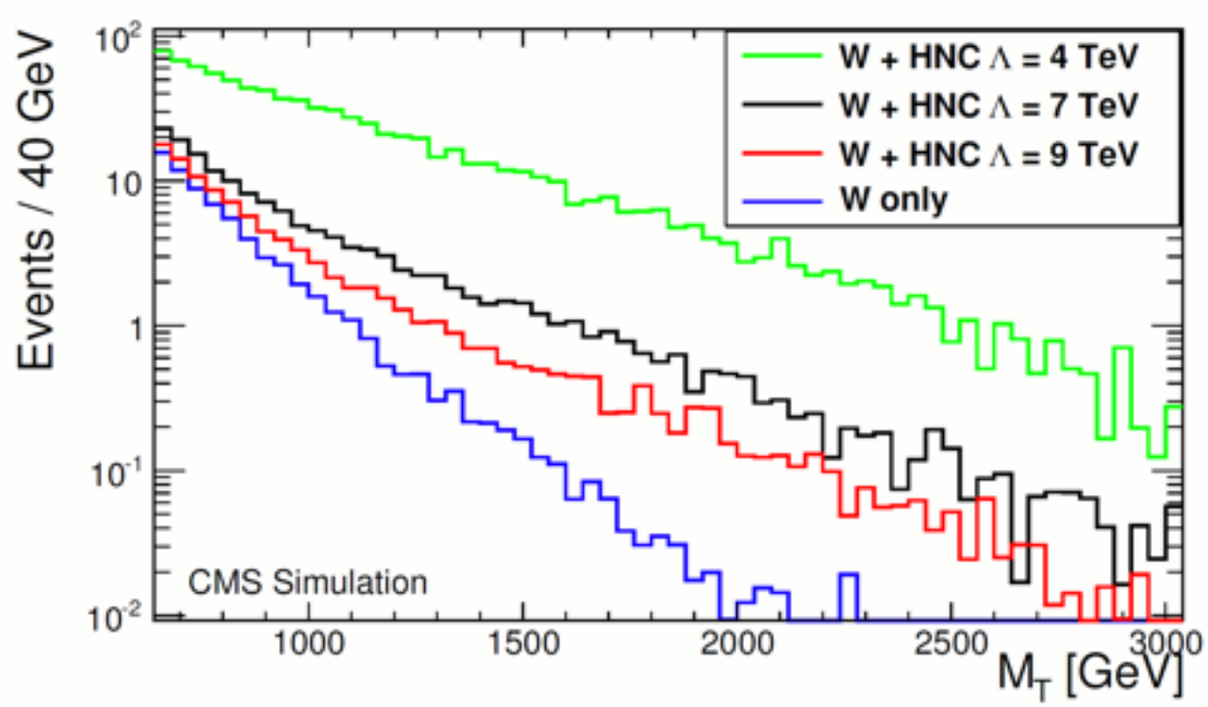
$$m_T = \sqrt{2 p_T \not{E}_T (1 - cos\Delta\phi_{\ell,\not{E}_T})}$$

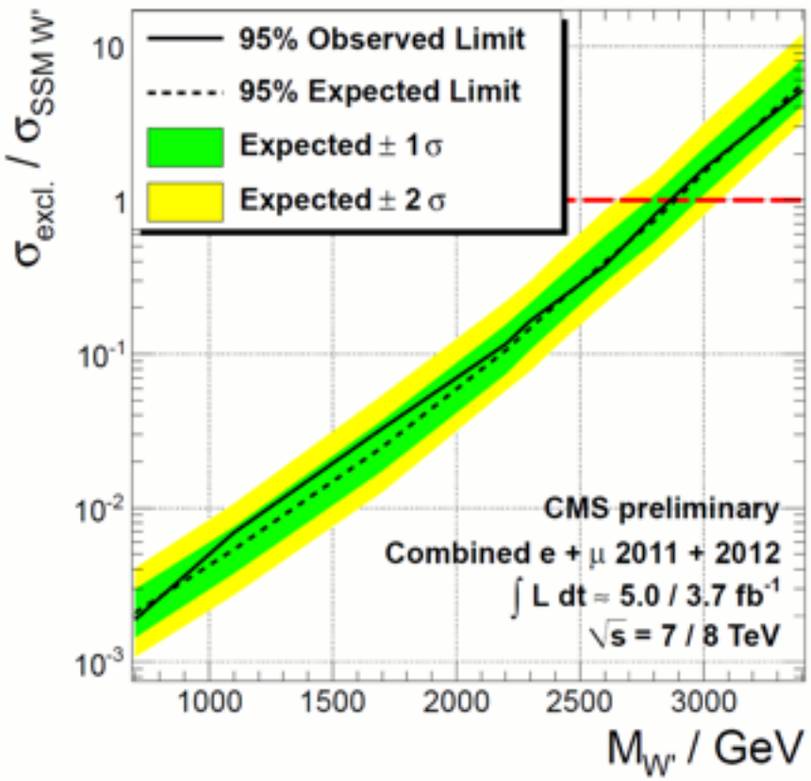
- Dominant background: W production in Standard Model
- Now also take into account interference with SM

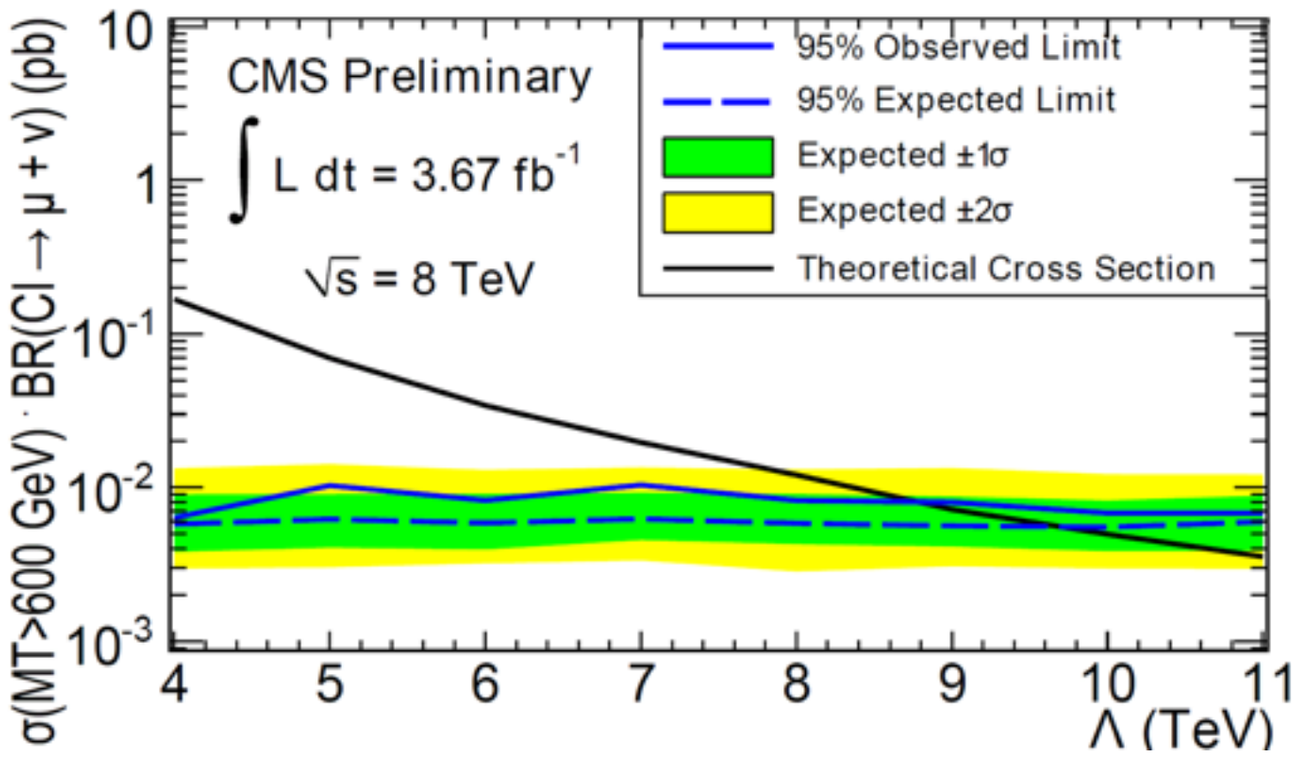
W' → lν Exclusion Limits



Contact Interaction Interpretation

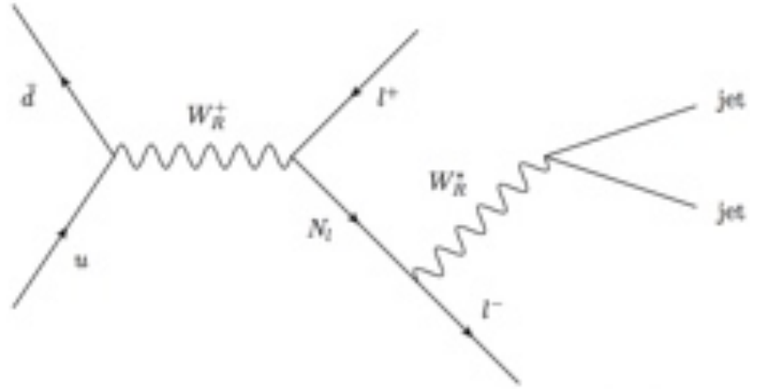






HEAVY NEUTRINO AND L-R SYMMETRY

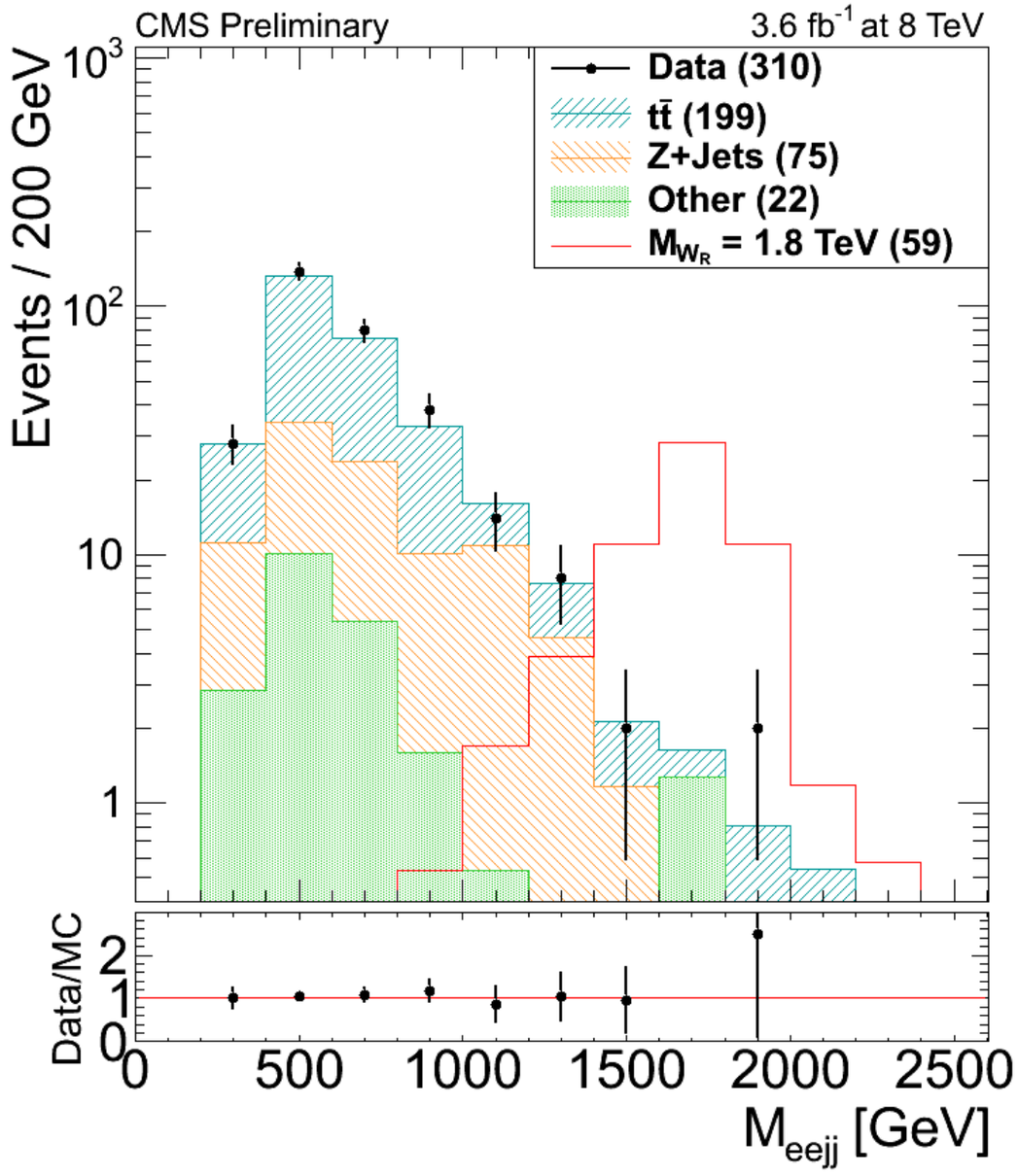
	Standard Model	Left-Right-Symmetric Extension (LRSM)
Gauge group	$SU(2)_L$ X $U(1)_Y$	$SU(2)_L$ **X $SU(2)_R$** X $U(1)_{B-L}$
Fermions	LH doublets: $Q_L = (u^i, d^i)_L$, $L_L = (l^i, \nu^i)_L$ RH singlets: $Q_R = u^i_R$, d^i_R , $L_R = l^i_R$	LH doublets: $Q_L = (u^i, d^i)_L$, $L_L = (l^i, \nu^i)_L$ RH doublets: $Q_R = (u^i, d^i)_R$, $L_R = (l^i, N^i)_R$
Neutrinos	ν^i_R do not exist ν^i_L are massless & pure chiral	N^i_R are heavy partners to the ν^i_L N^i_R Majorana in the Minimal LRSM
Gauge bosons	$W^{\pm}_L$, Z^0, γ	$W^{\pm}_L$, **$W^{\pm}_R$**, Z^0, **Z'**, γ



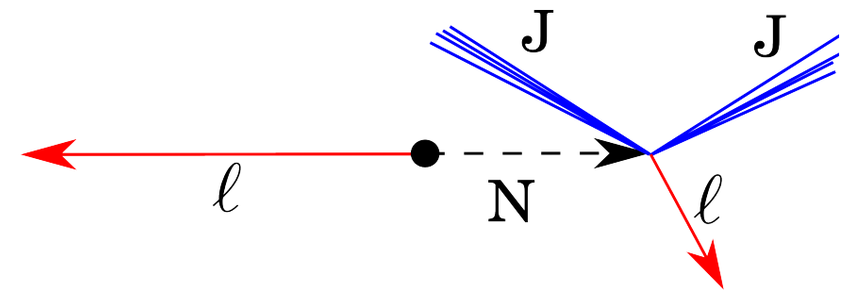
- Parity violation built-in for the Standard Model
  - Parity violation in LRSM via symmetry breaking at intermediate mass scale
- Neutrino oscillations require massive neutrinos
  - but neutrinos mass forbidden in SM
  - "See saw" mechanism in LRSM can explain small mass of neutrinos via heavy partners

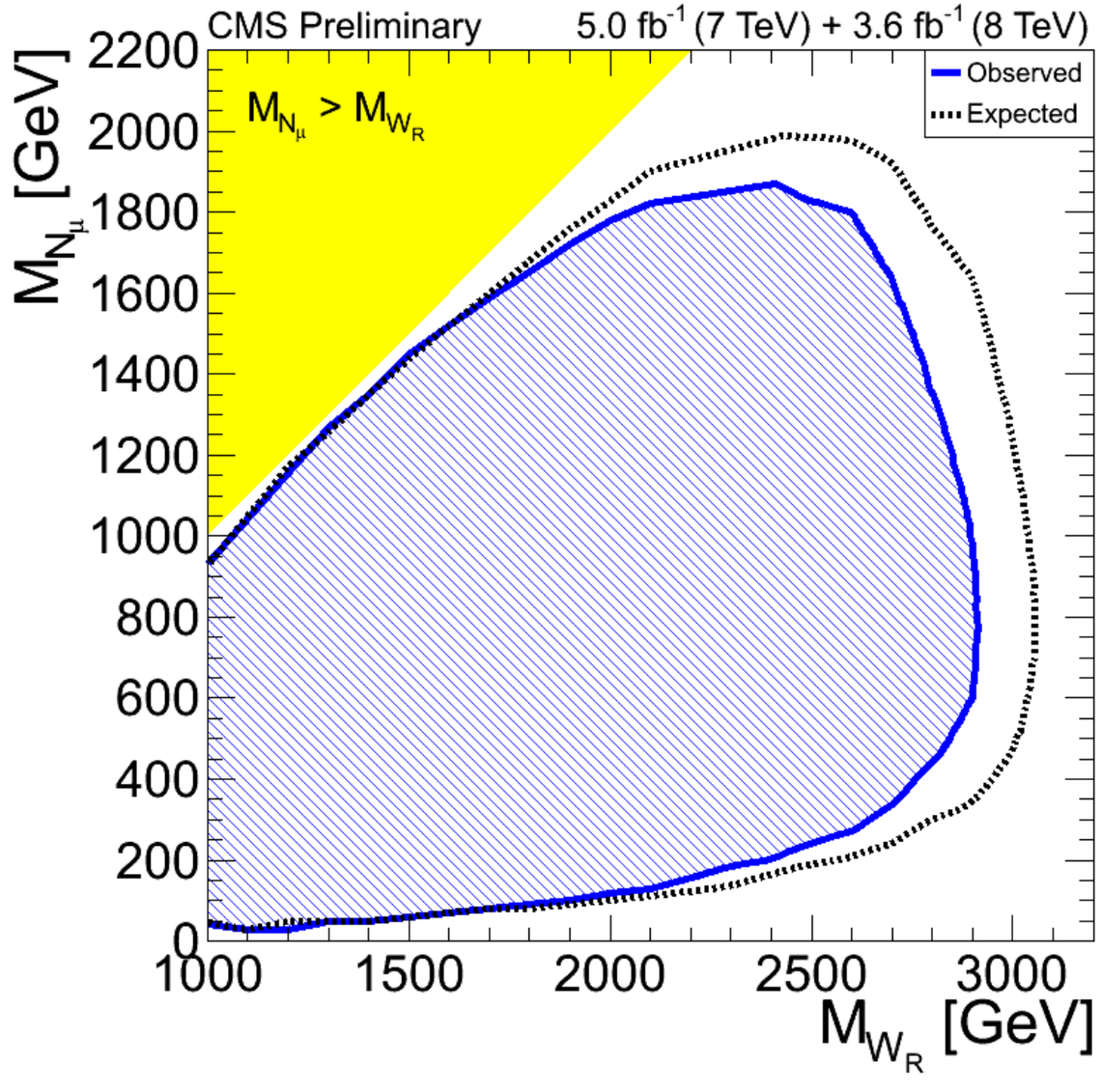
HEAVY NEUTRINO AND W_R

EXO-12-017



$$W_R \to \mu_1 N_\mu \to \mu_1 \mu_2 W_R^* \to \mu_1 \mu_2 jj$$

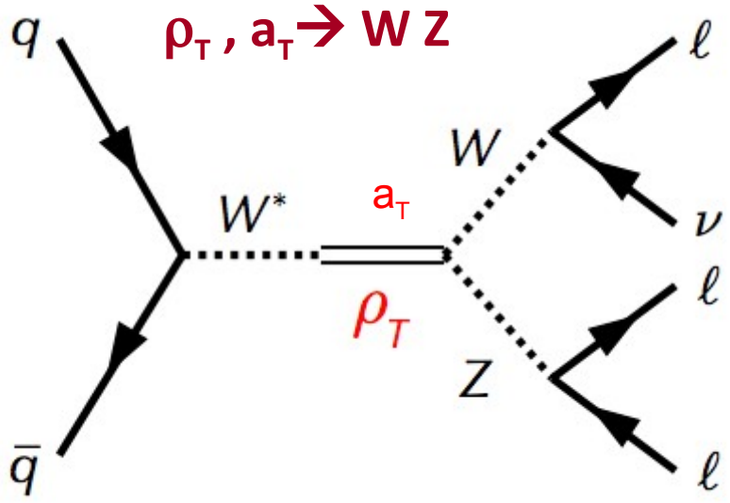




- Mass limits approaching 3 TeV
  - Most stringent limits today!

WZ Resonances

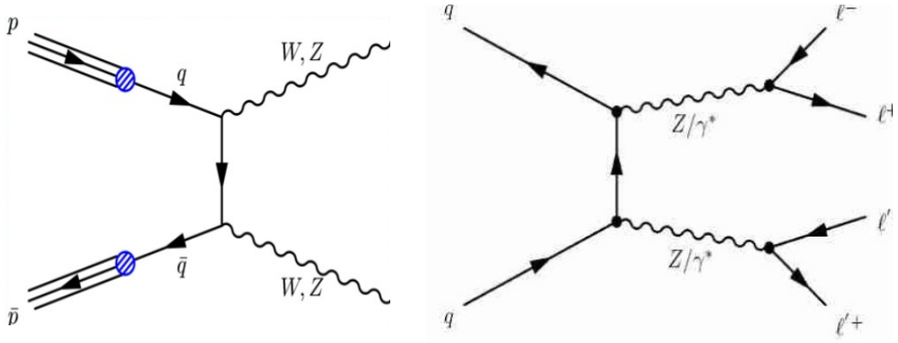
EXO-11-041

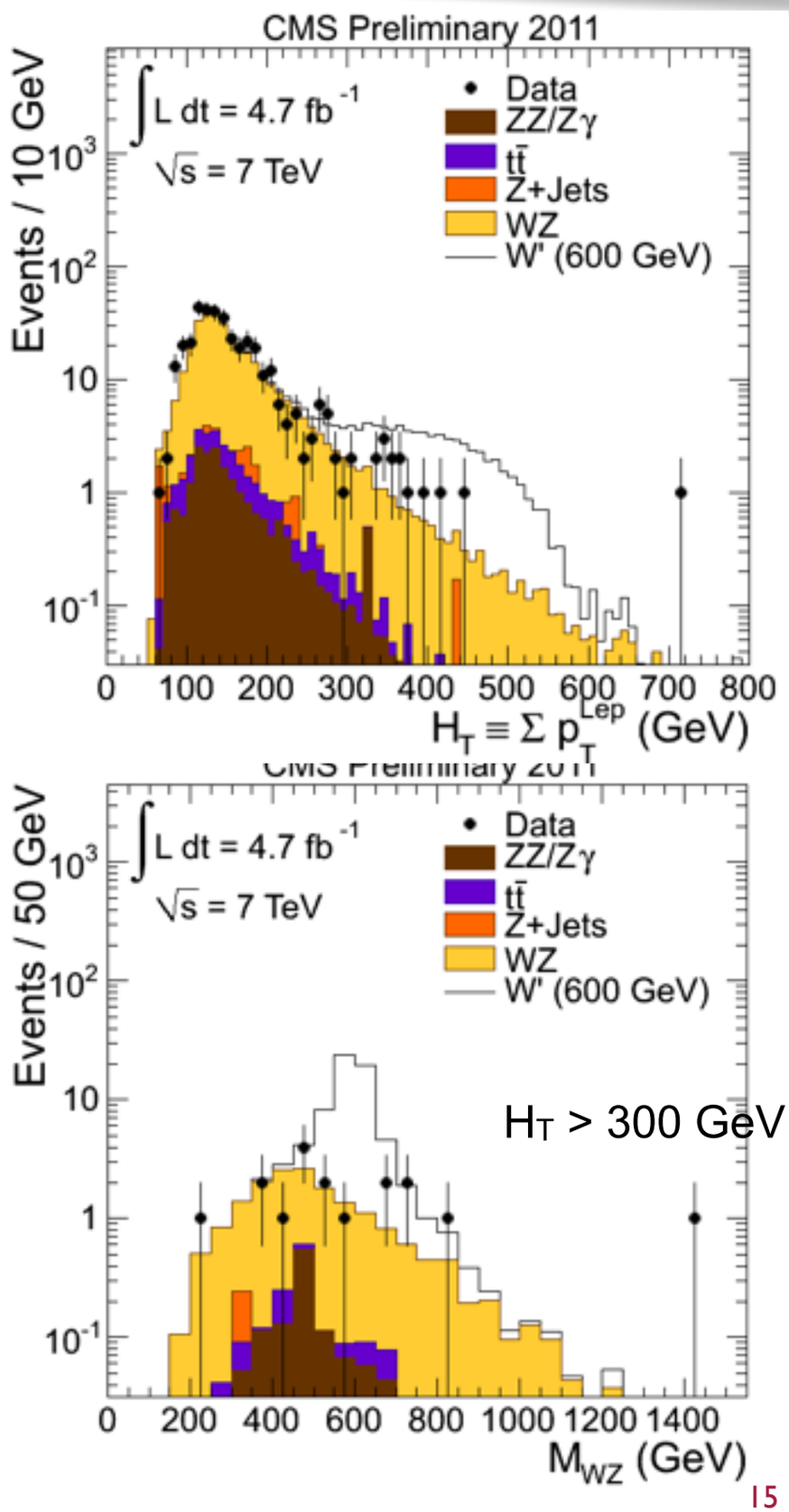


ρ_T , a_T → W Z

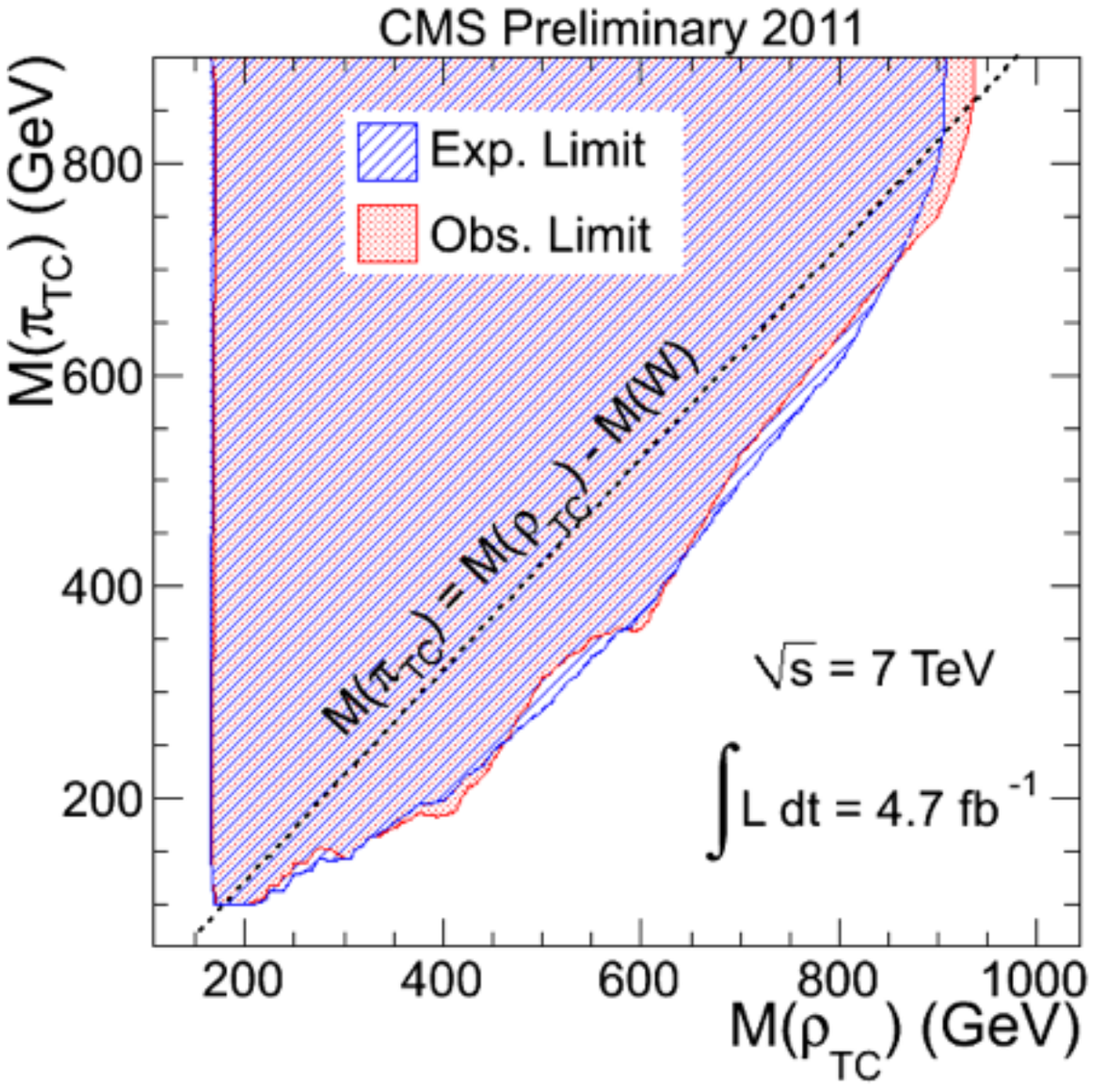
- Sensitive to sequential SM and techni-hadrons
- 3 leptons + missing energy
  - Sum of lepton Pt
  - WZ invariant mass with W mass constraint

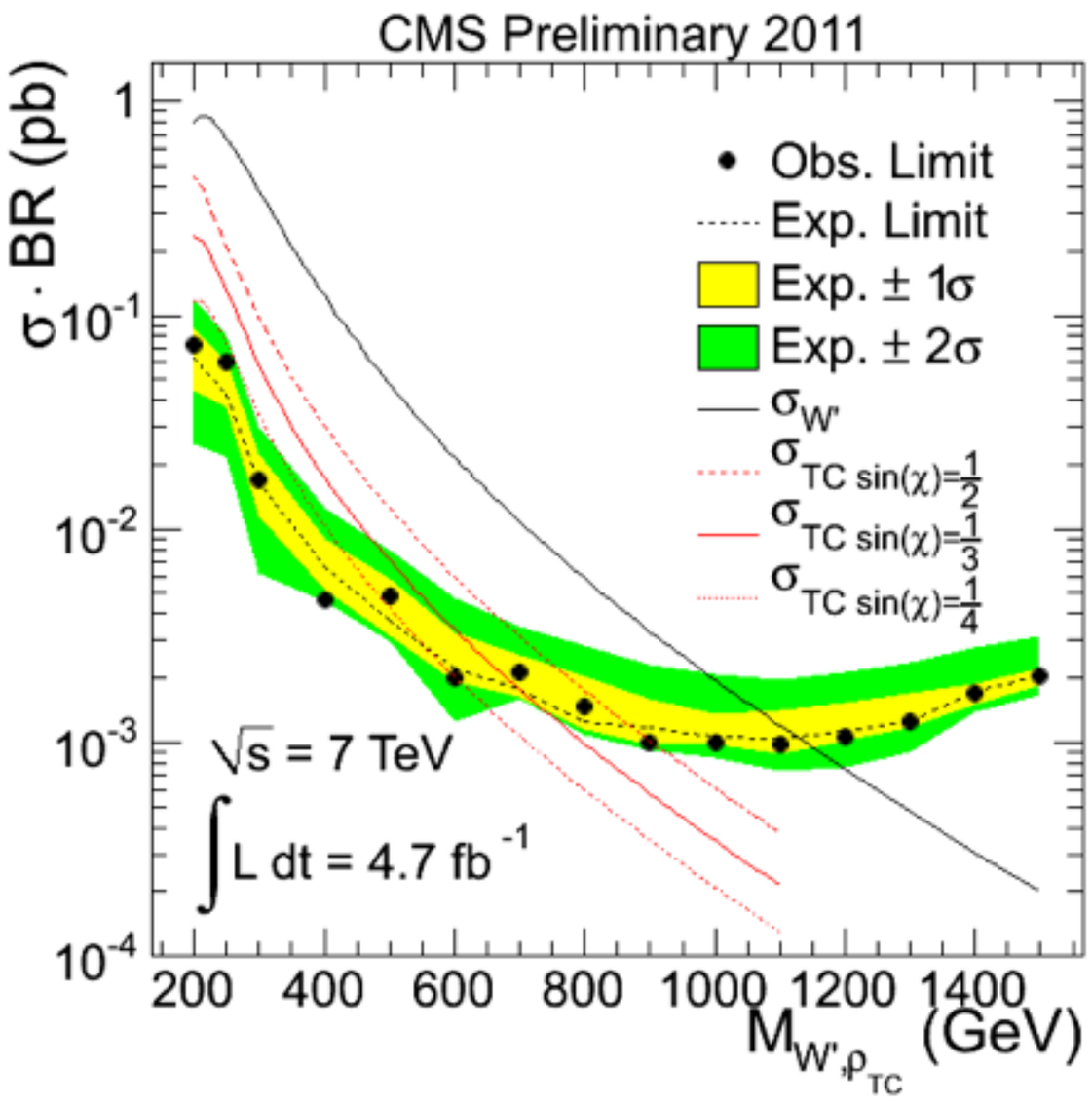
- Scalar sum of transverse momenta a key discriminator to reject SM background





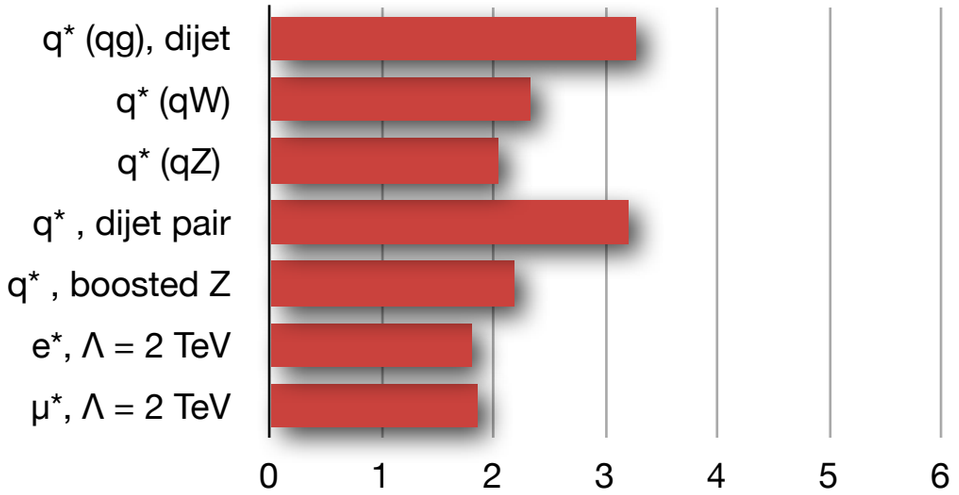
WZ Exclusion Limits

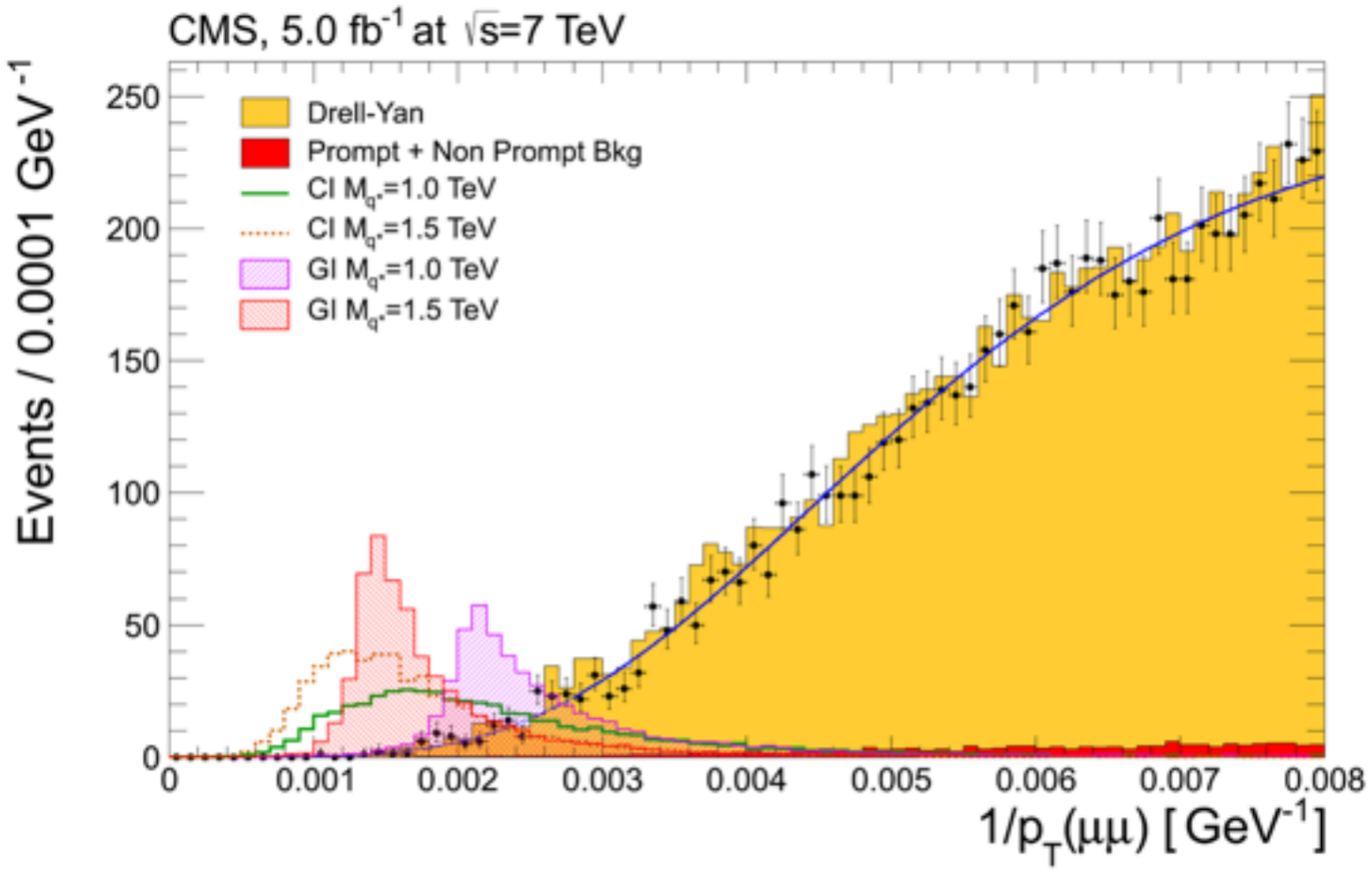




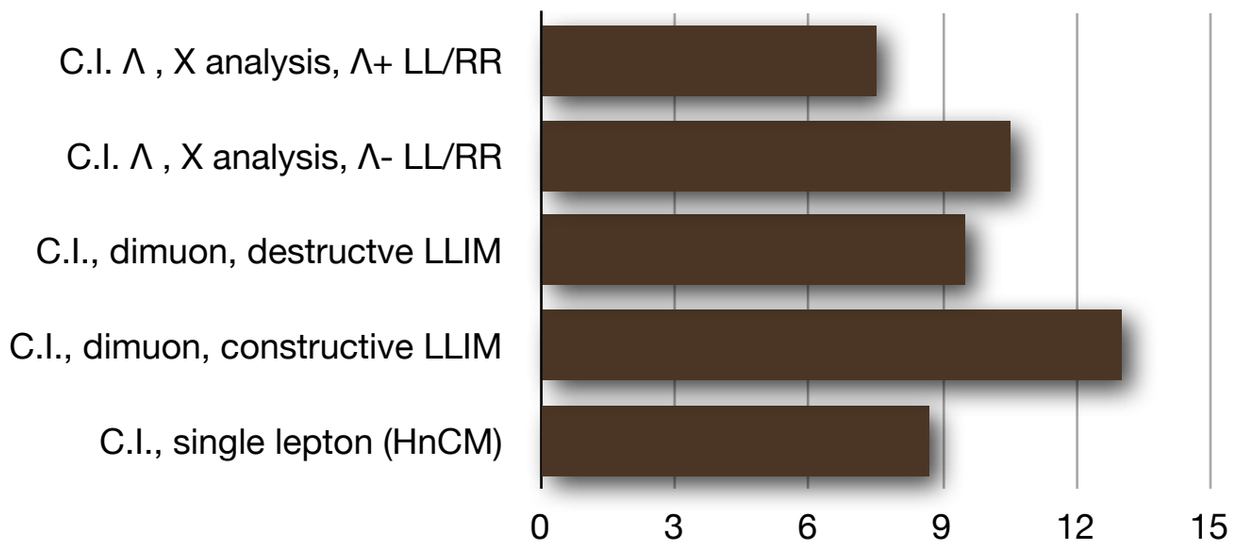
COMPOSITENESS AND CONTACT INTERACTION

EXO-11-025



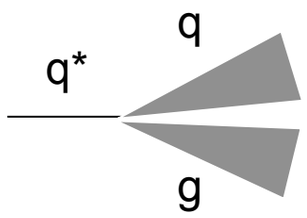


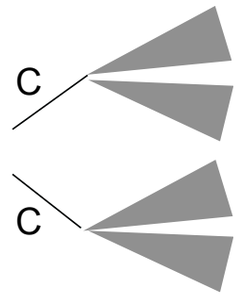
- Excited quarks and leptons
- Both leptonic and hadronic sta1
  - lepton + photon (l* -> l + gam
  - 2-jet (q* -> q glu)
  - boosted Z spectrum in q* -> q Z
- Contact interaction
  - di-jet angular analysis
  - re-interpretation of di-lepton
  - re-interpretation of W'

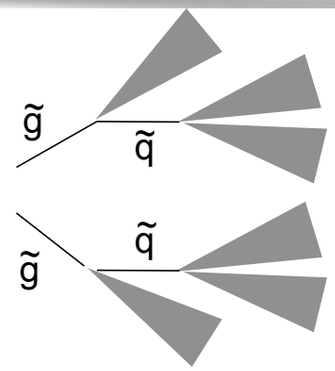


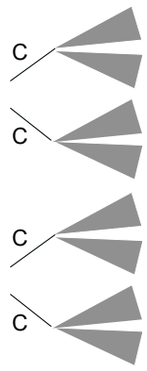
HADRONIC RESONANCES

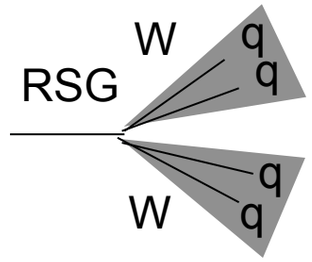
- Extremely rich and productive hadronic program
- Variety of signatures and models explored
  - standard jets
  - b-jets
  - fat jets
  - jet substructure for W/Z tag









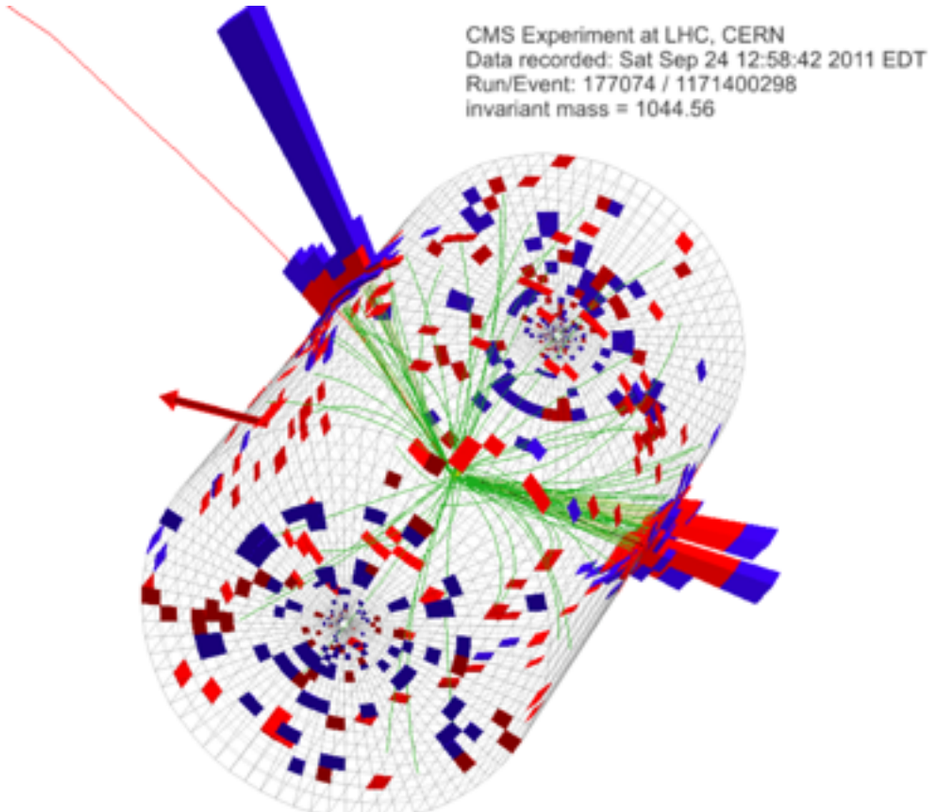


String resonances, S (qq,qg,gg)
Scalar diquarks, D (qq)
Excited quarks, q* (qg,qW,qZ)
Axigluons, A (qq)
Color-octet colorons, C (qq, qqqq)
Color-octet scalar, S8 (gg,bb)
W‘ bosons (qq,WZ)
Z‘ bosons (qq,bb,tt)
RPV SUSY gluinos (qqqqq)
RS gravitons (qq,gg,WW,ZZ)

Hadronic inspired

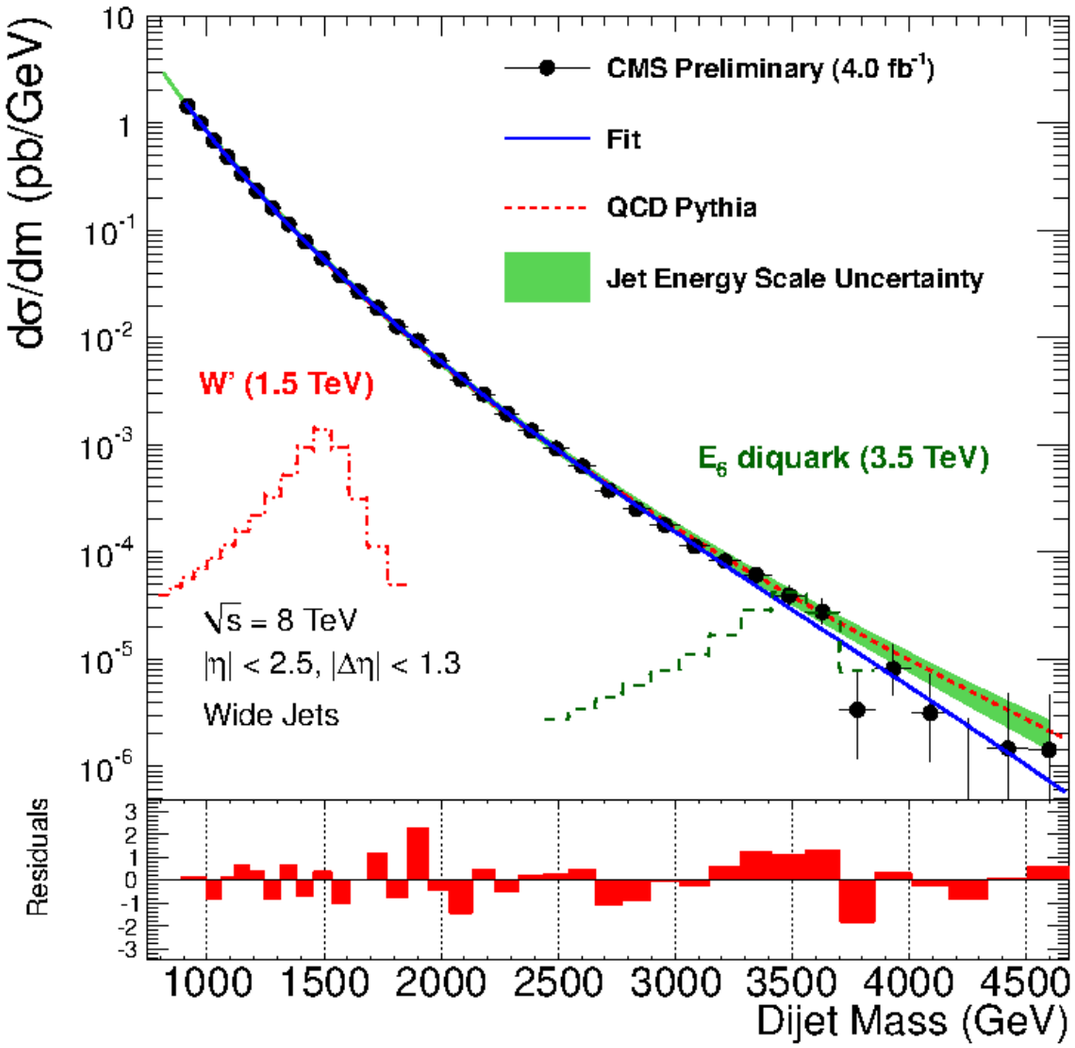
EWK inspired

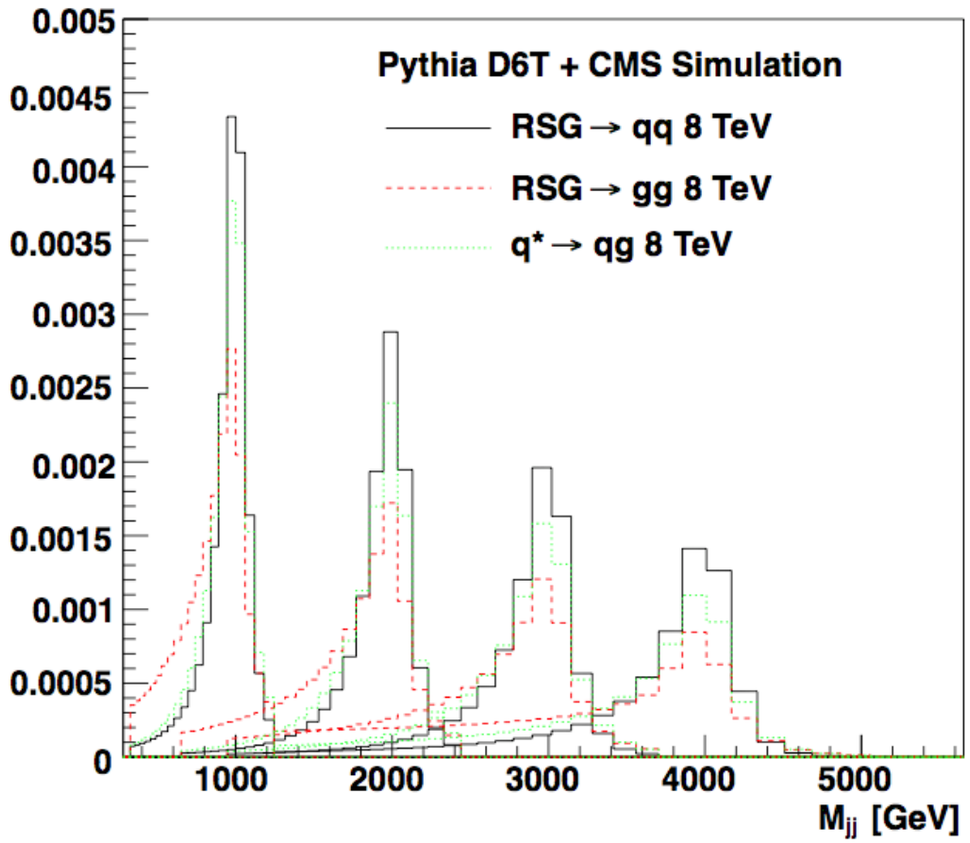
Gravitation inspired

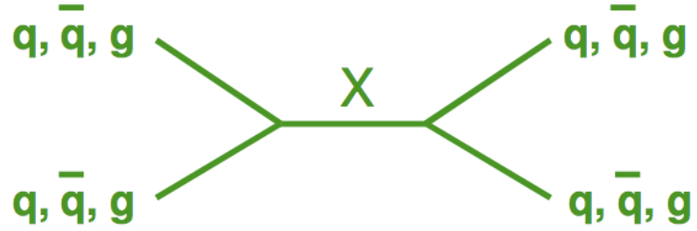


DI-JET

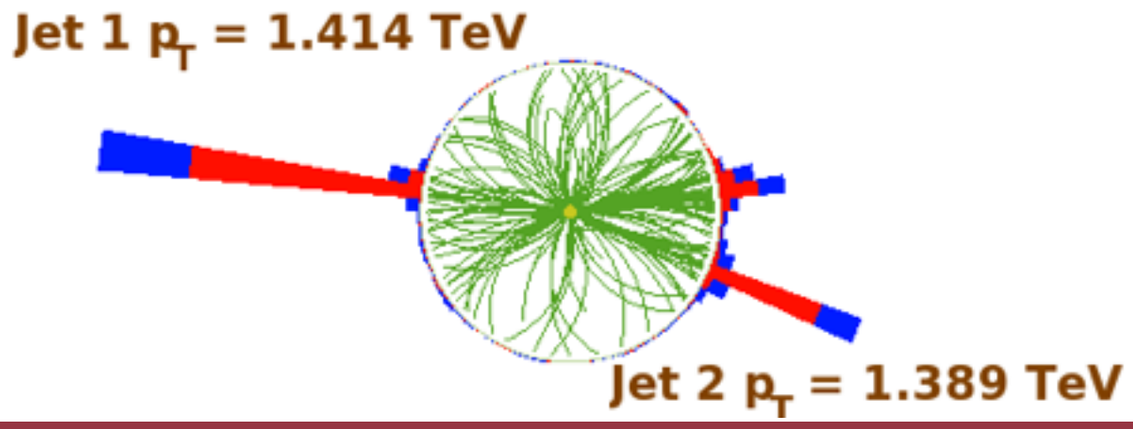
EXO-12-016





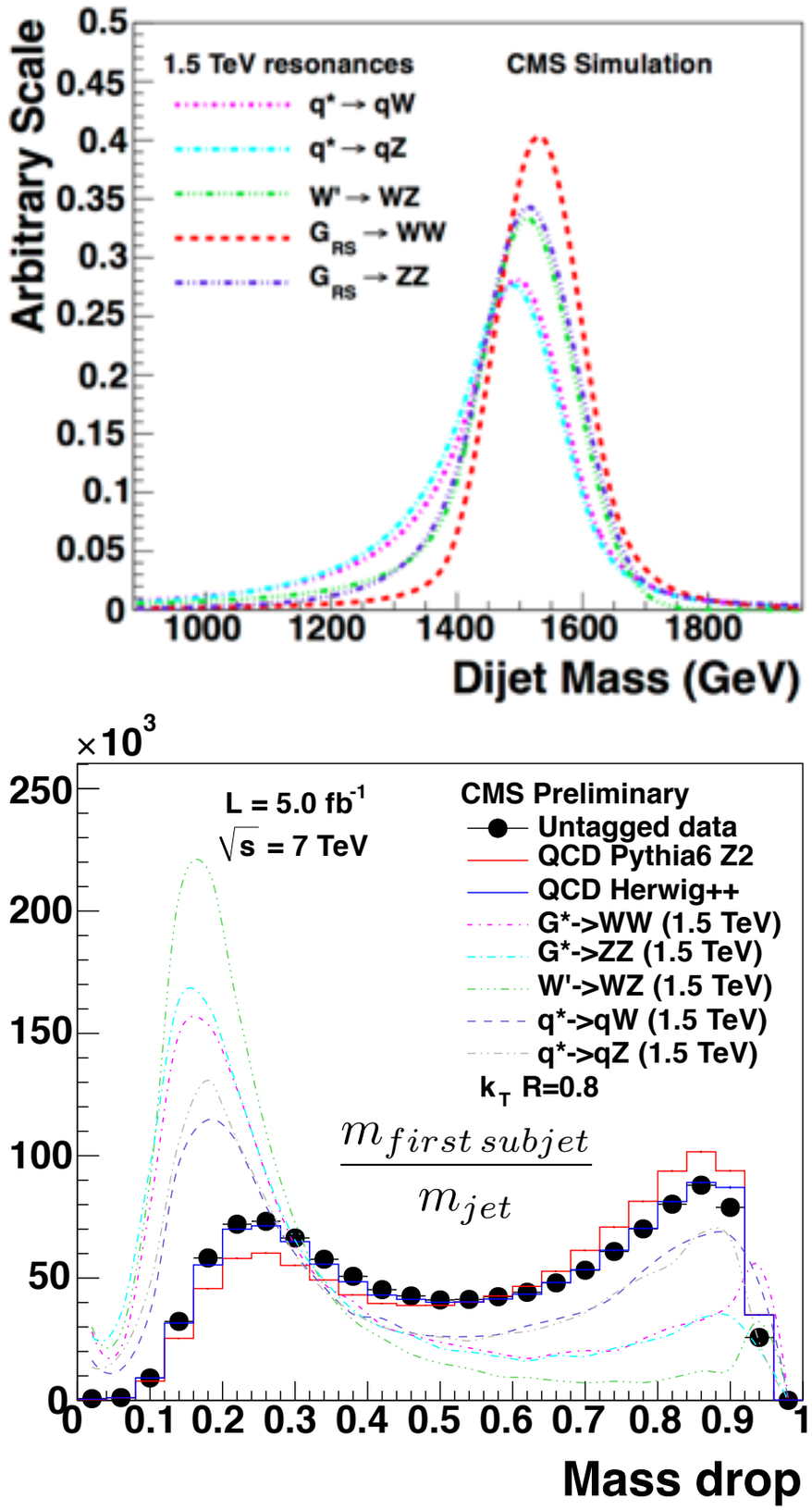


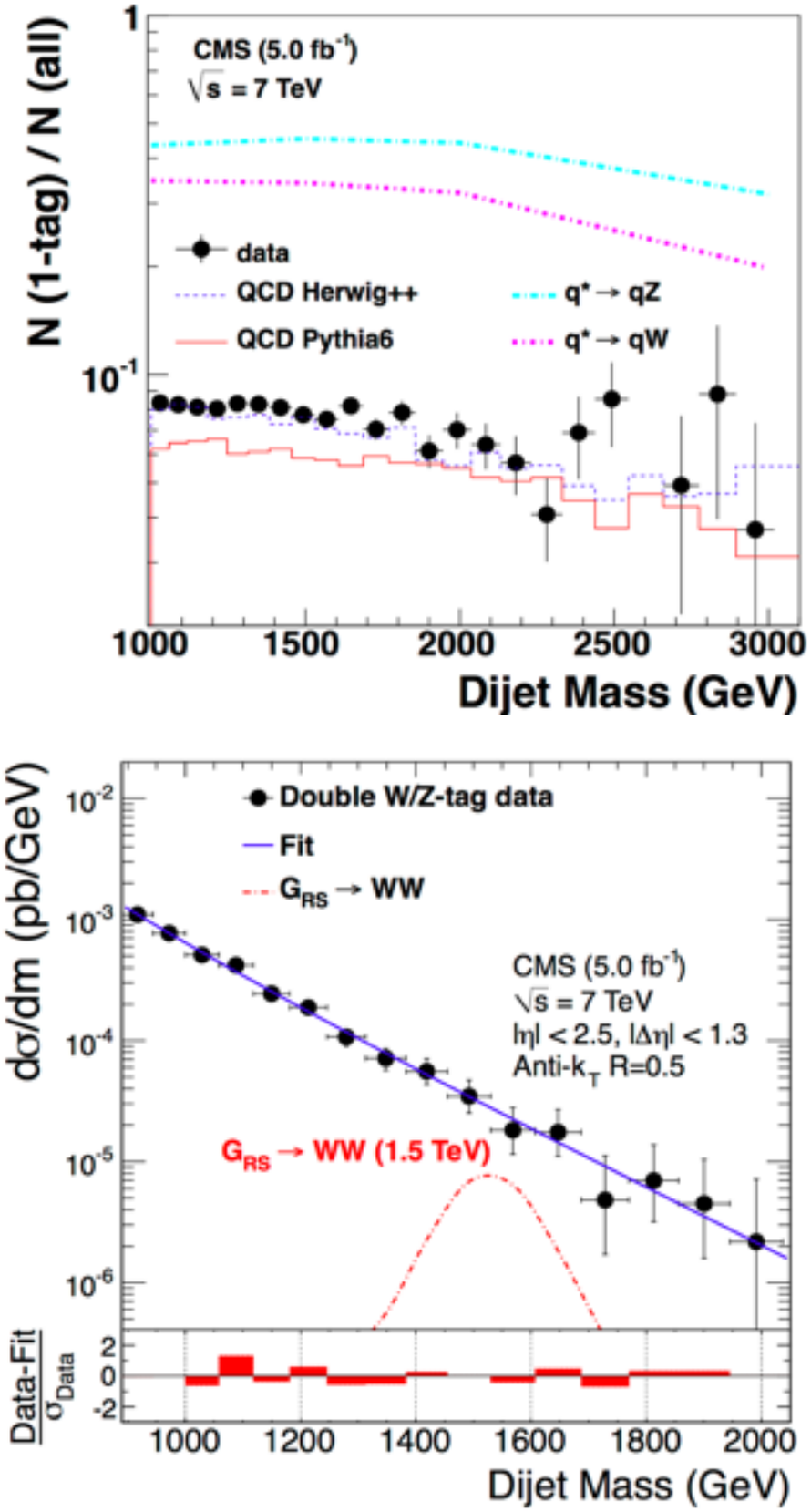
- Resonances predicted in numerous models
  - larger branching fraction compared to dileptons
  - much higher background from QCD
- Wide jets to recover radiation
  - divide event in 2 hemispheres

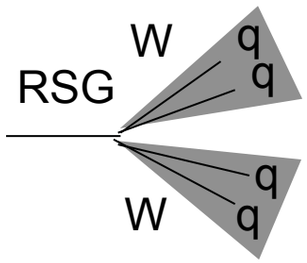


W/Z TAGGED DI-JET

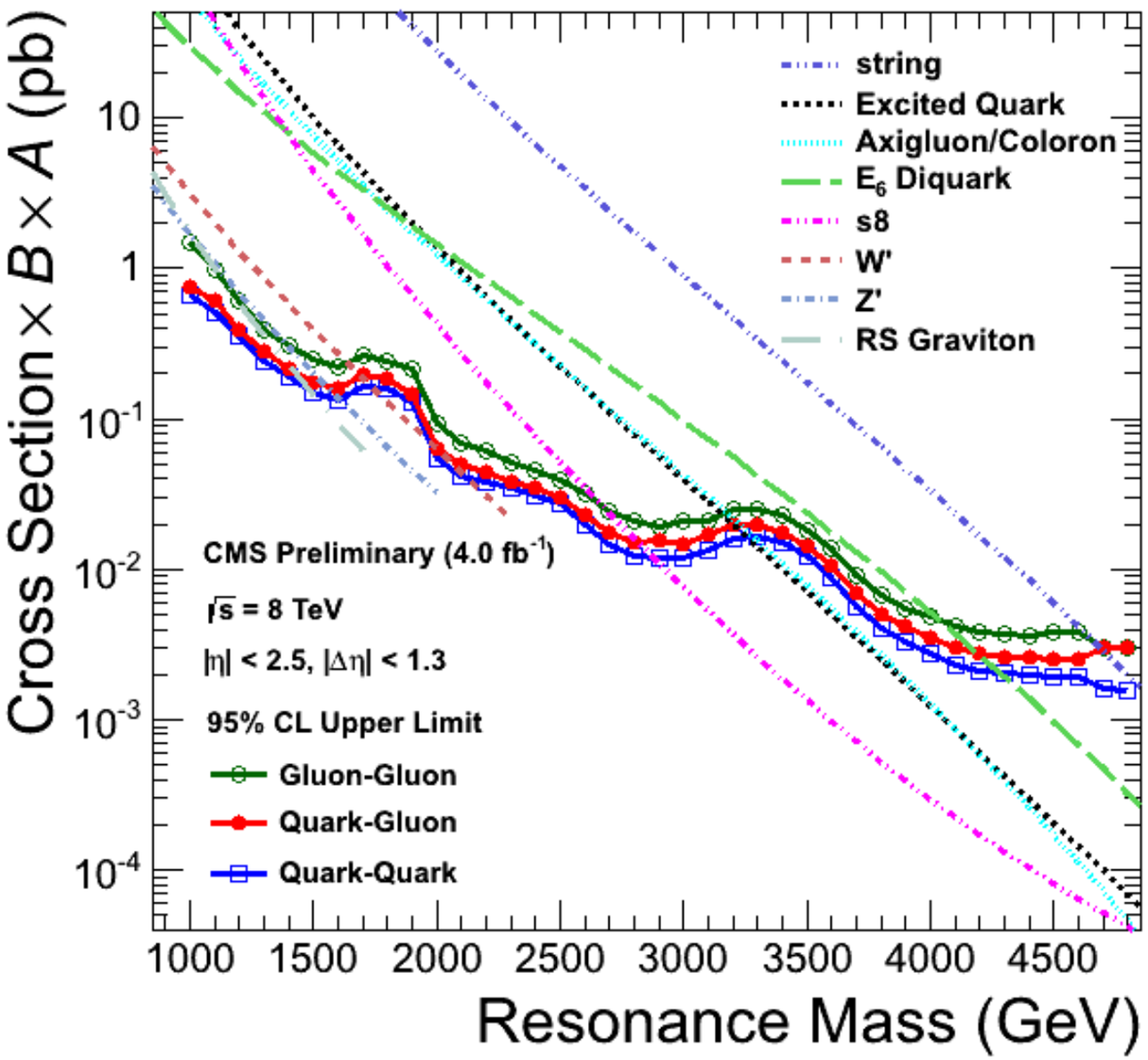
EXO-11-095

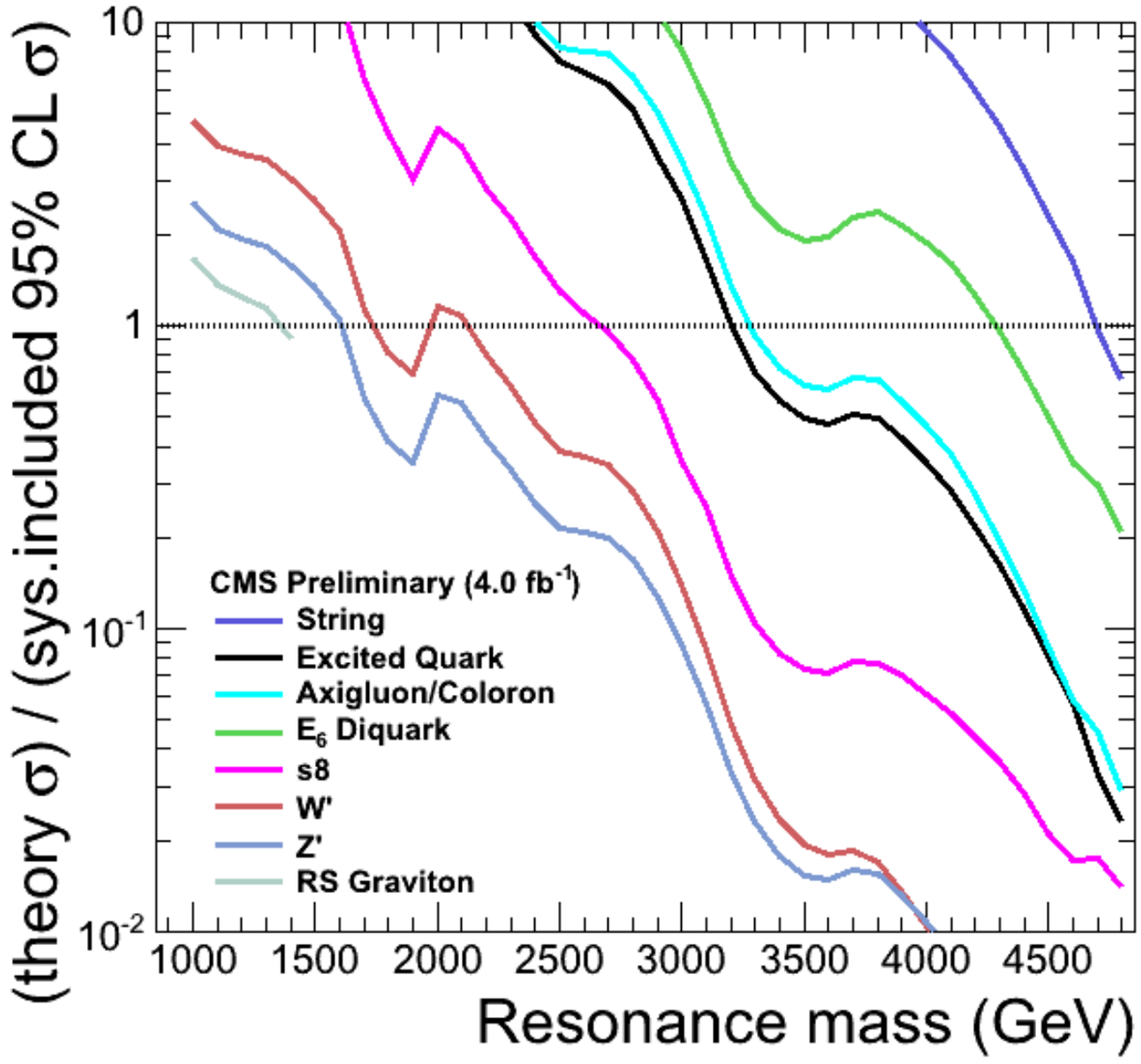






DI-JET EXCLUSION LIMITS

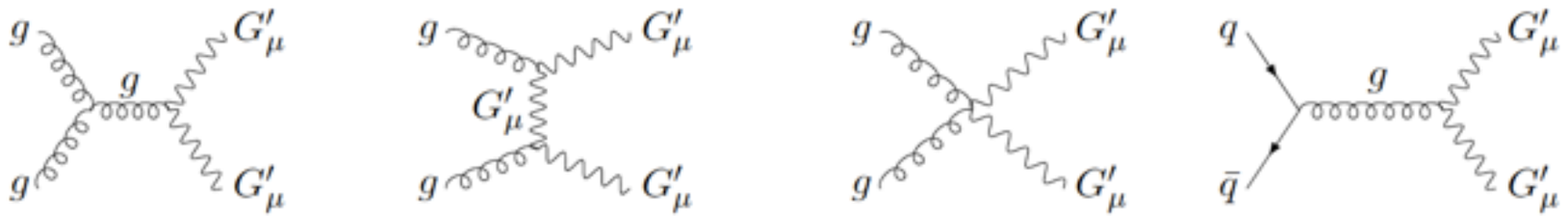


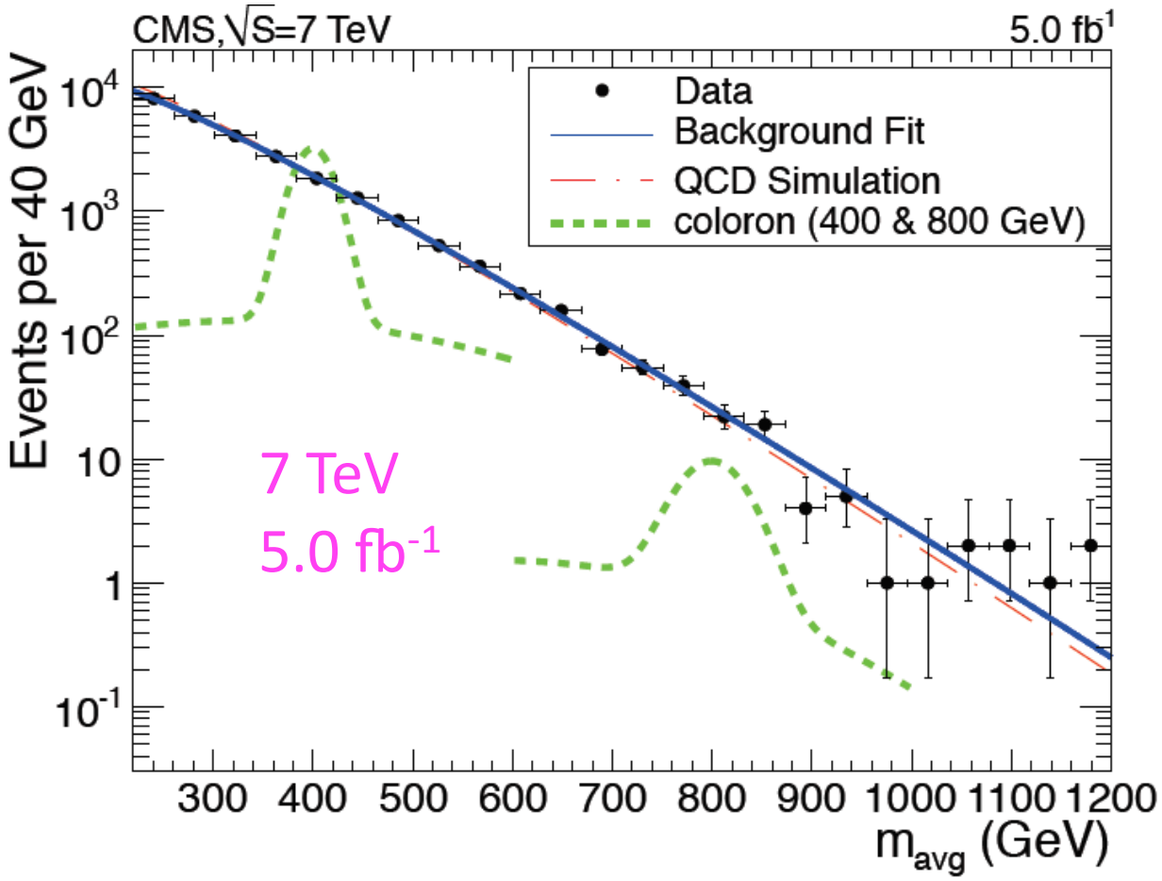


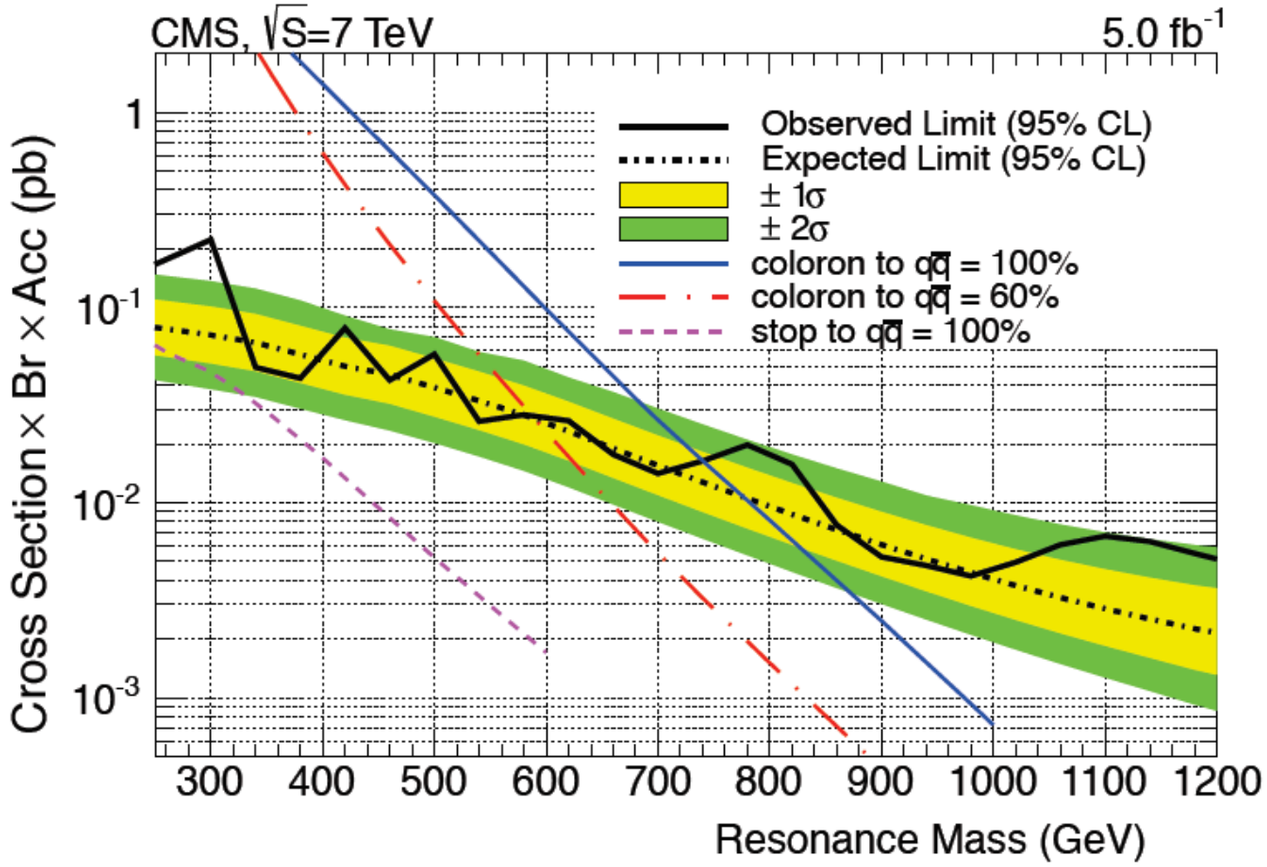
- Now excluding resonances below 2.5 TeV for variety of models

DI-JET PAIR

EXO-11-016







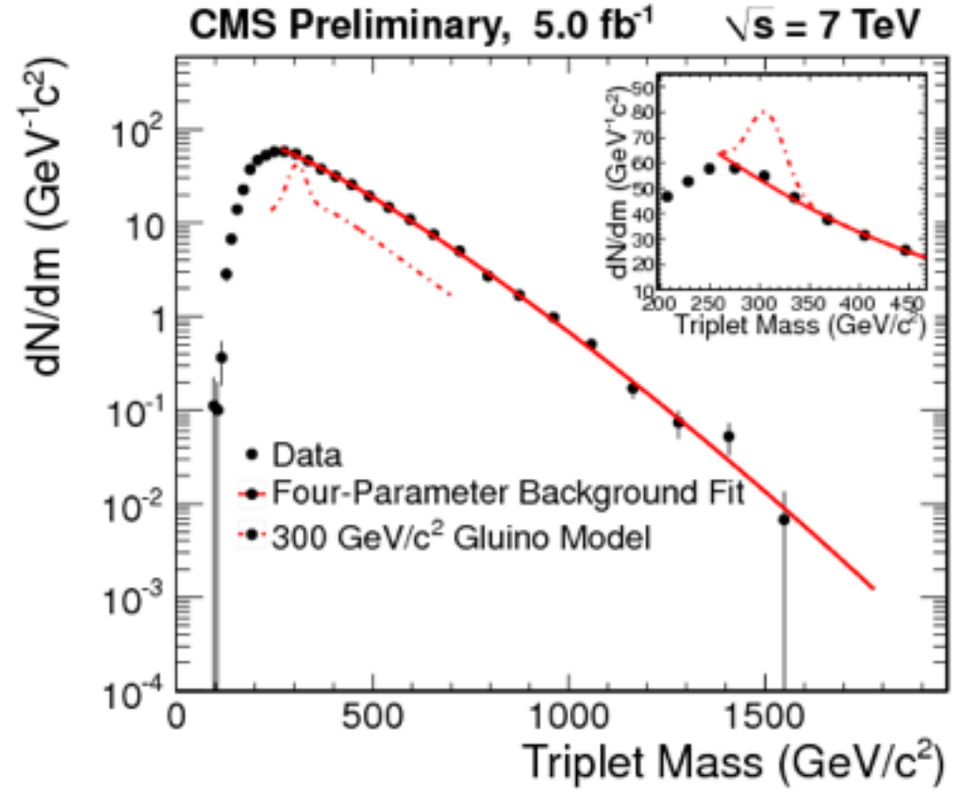
- Events with at least 4 jets and pt > 150 GeV
- Sensitive to colorons at low mass

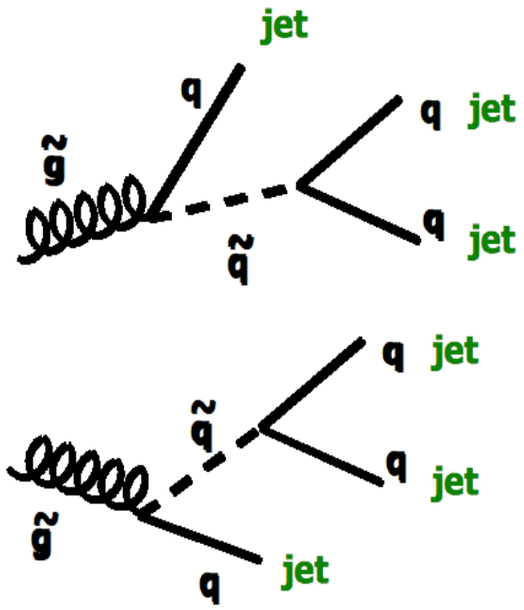
TRI-JET RESONANCE

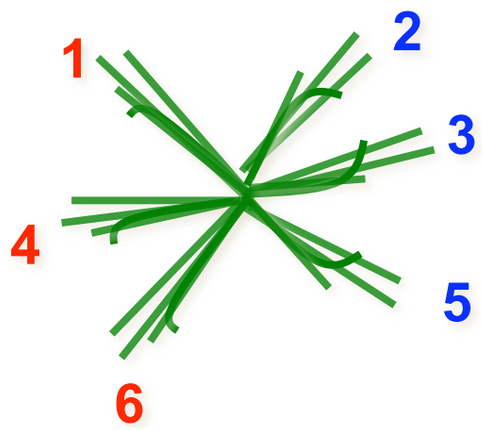
EXO-11-060

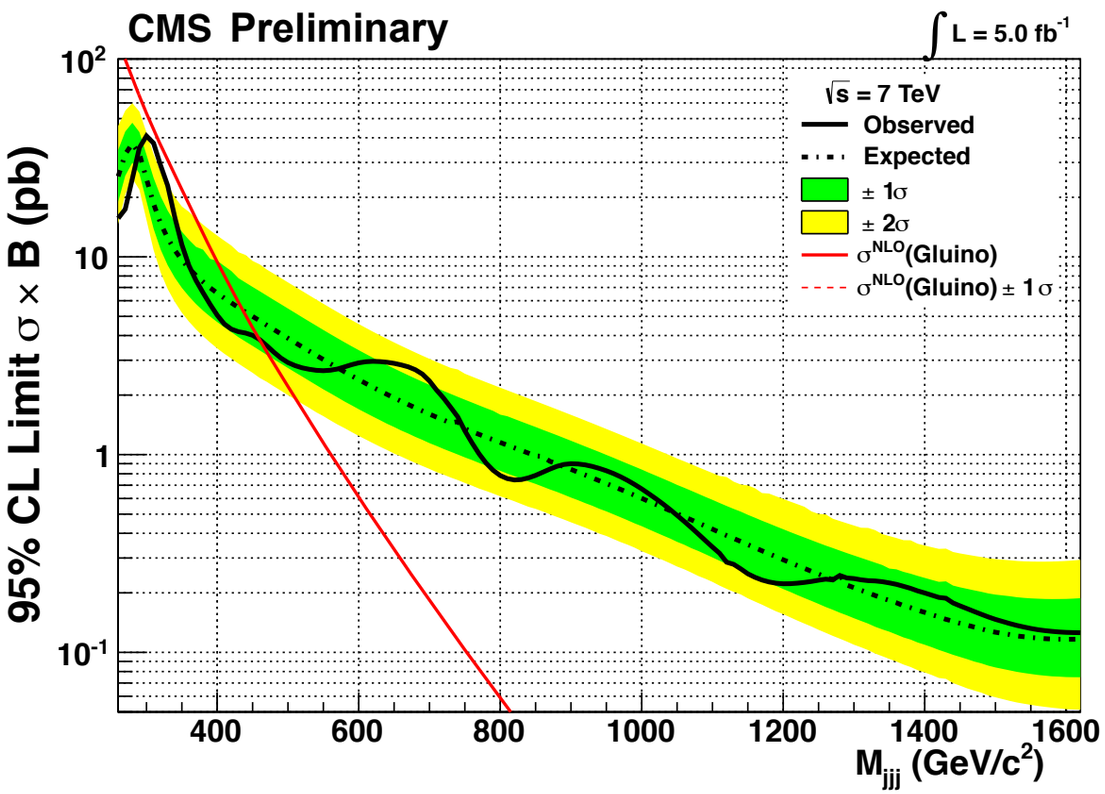
- 6 jets in several theoretical models
  - Q = g = SU(3)C Adjoint Majorana Fermion
  - R-Parity violating (No Missing ET)
- Modeled as R-parity violating gluino (negligible intrinsic width)

$$pp \rightarrow QQ \rightarrow 3j + 3j$$



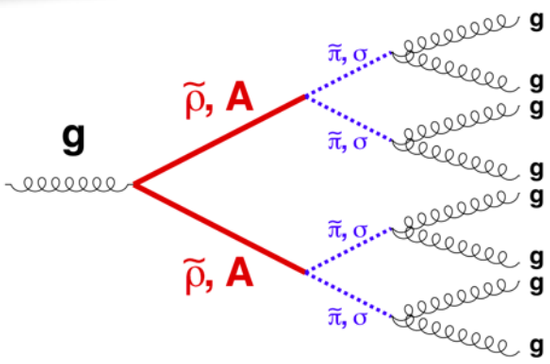


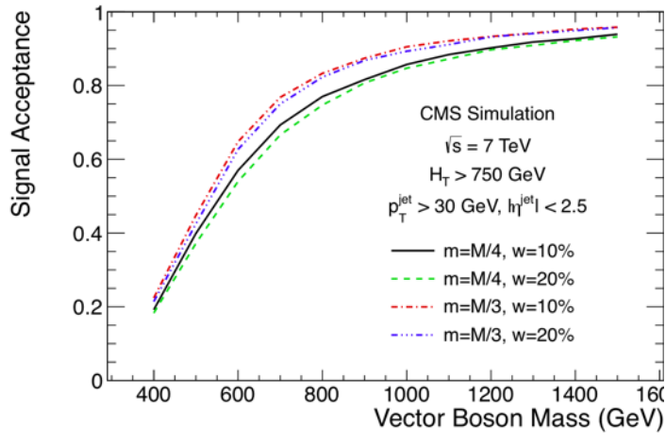


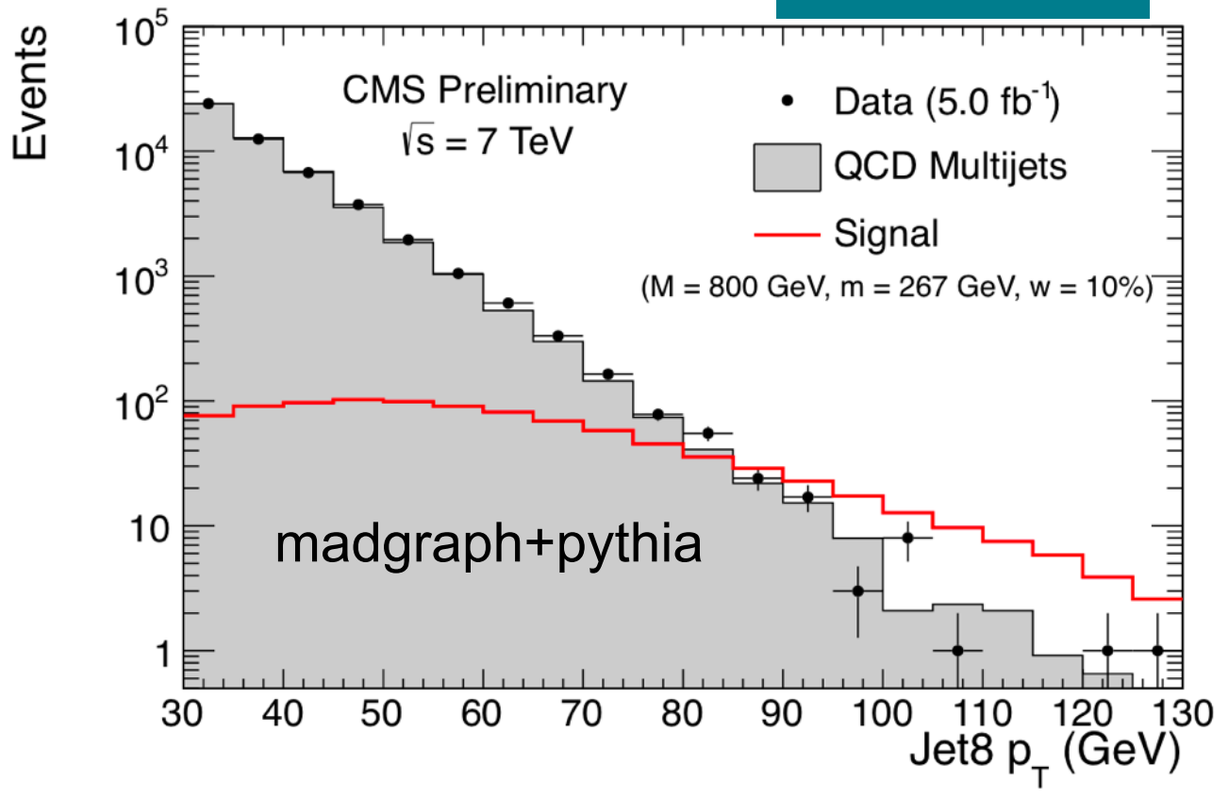


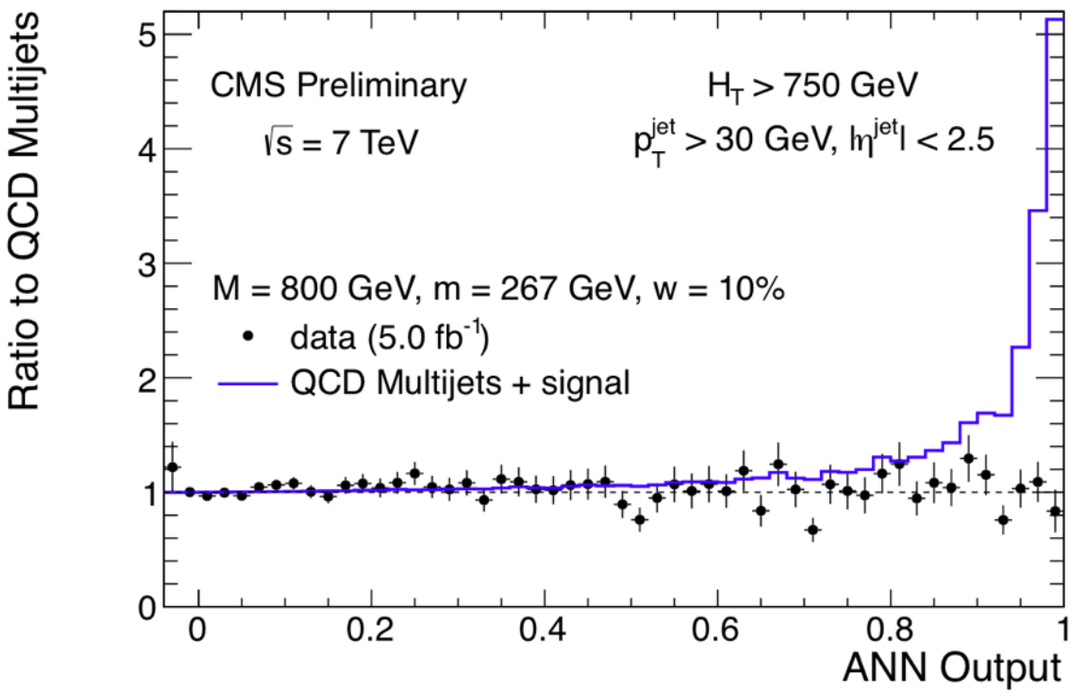
QUAD-JET RESONANCE

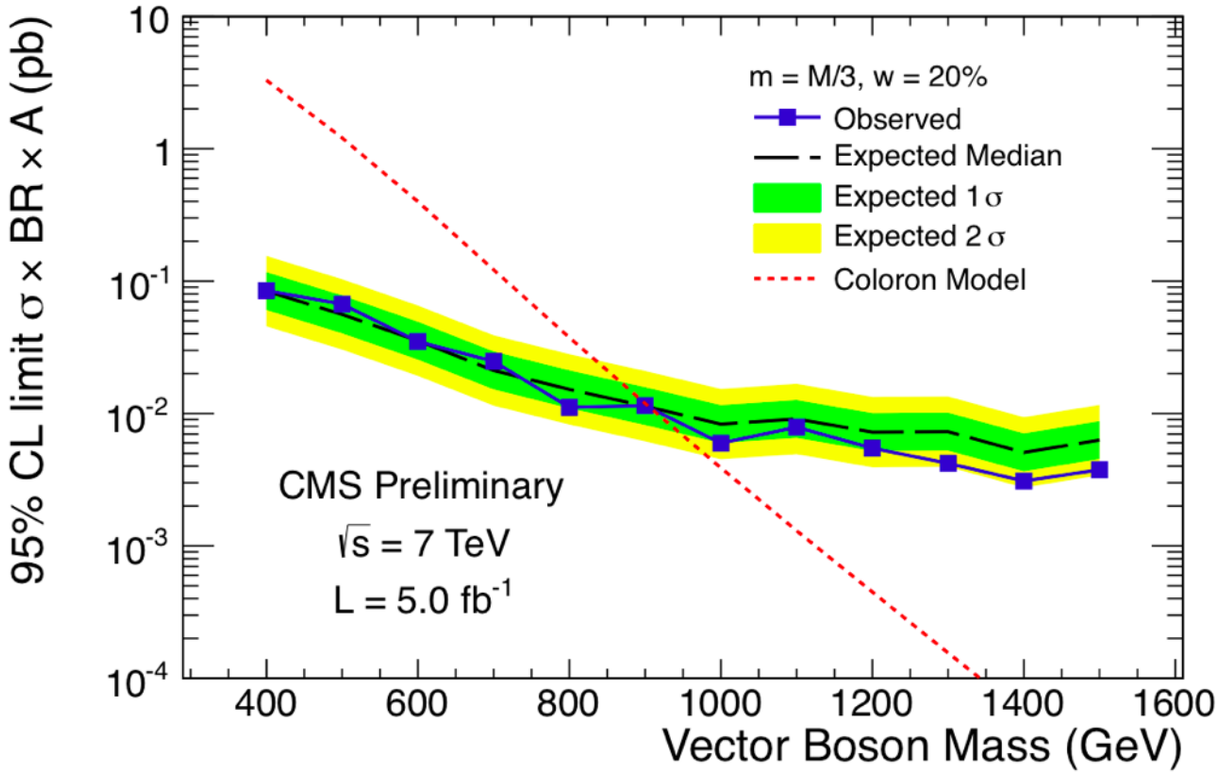
EXO-11-075











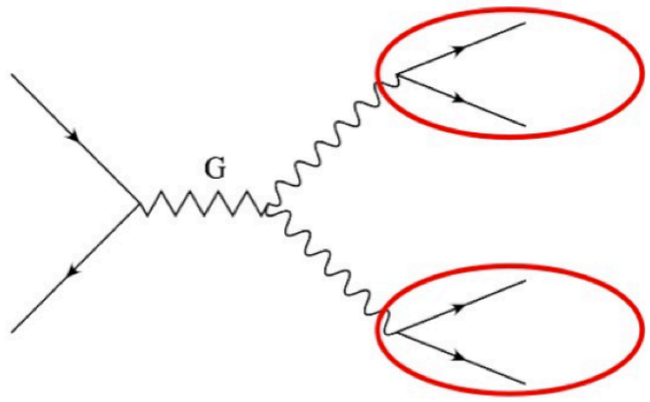
- Multivariate analysis for max. QCD rejection
  - pt of 1st,4th, 7th, and 8 jets
  - H_T
  - 8-jet invariant mass

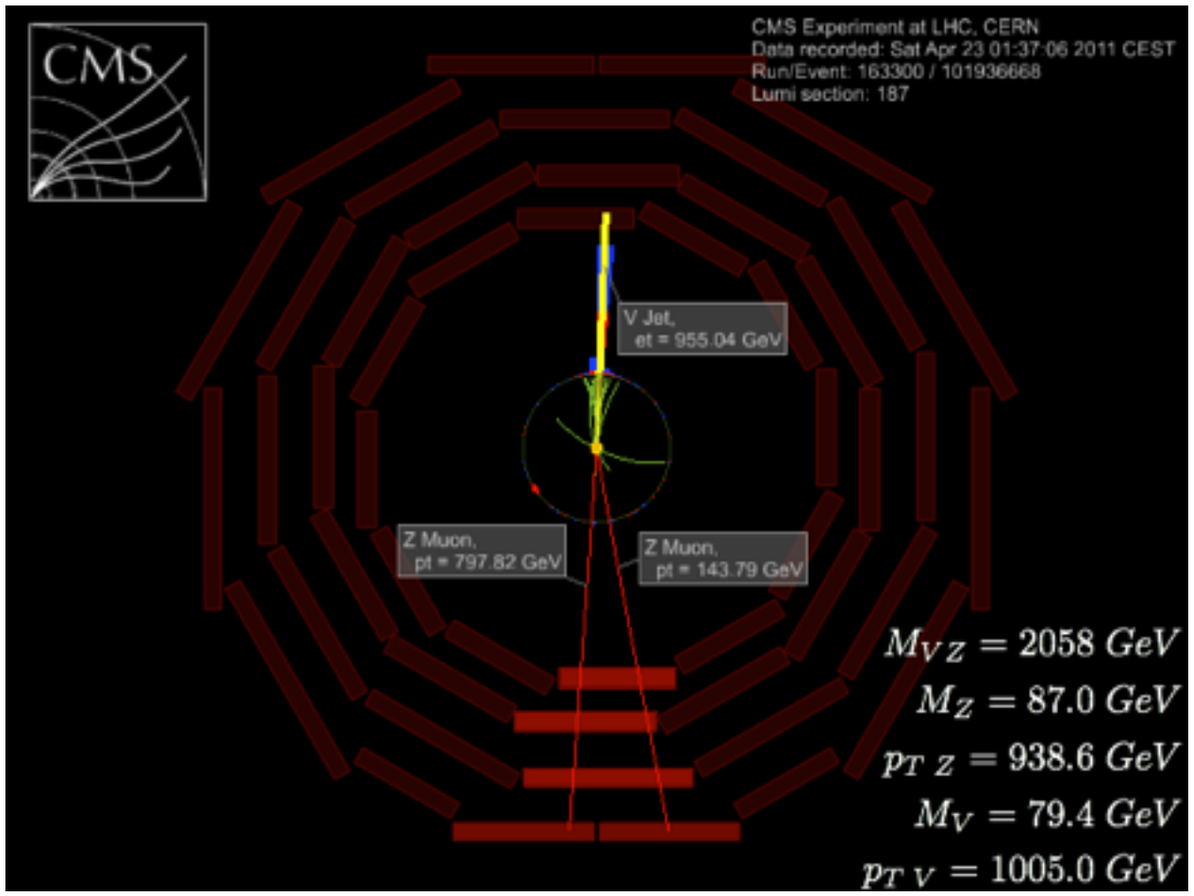
WZ AND ZZ RESONANCES

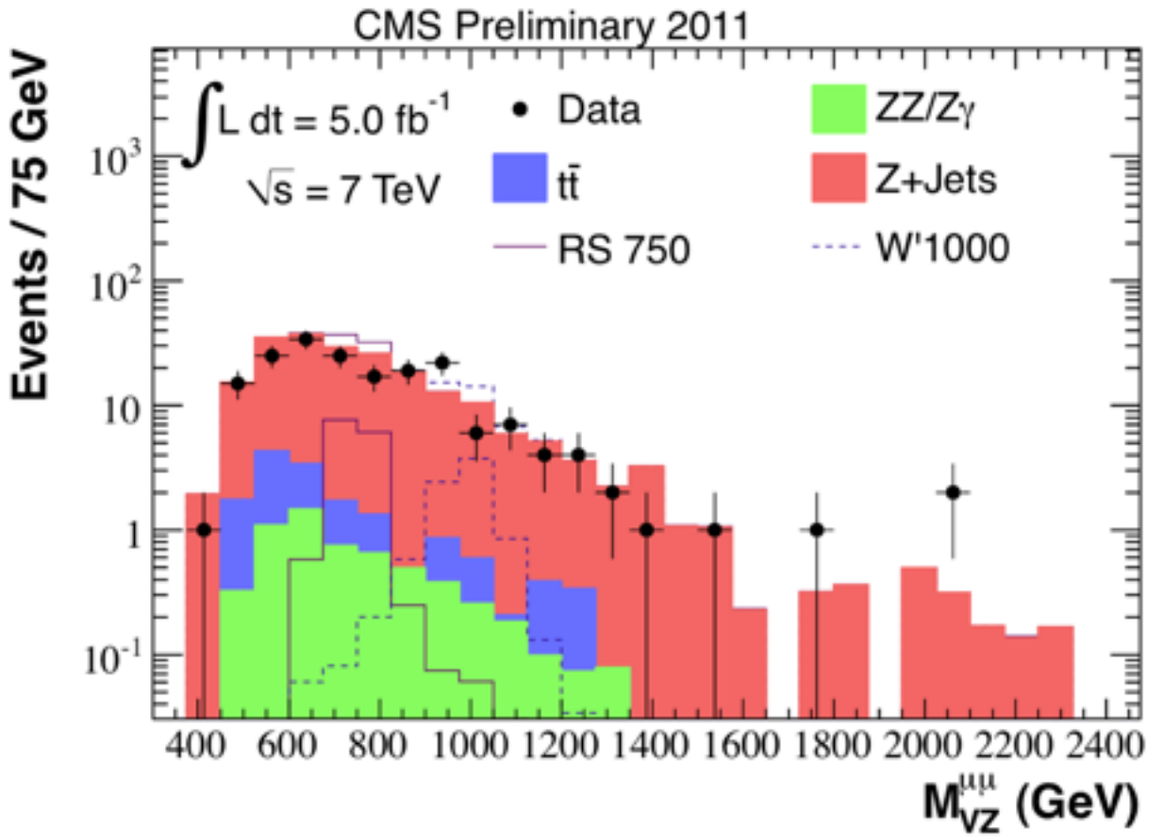
EXO-12-014

$$pp \to G^* \to ZZ \to q\bar{q}\,l^+l^-$$

$$pp \to W' \to WZ \to q\bar{q}\,l^+l^-$$





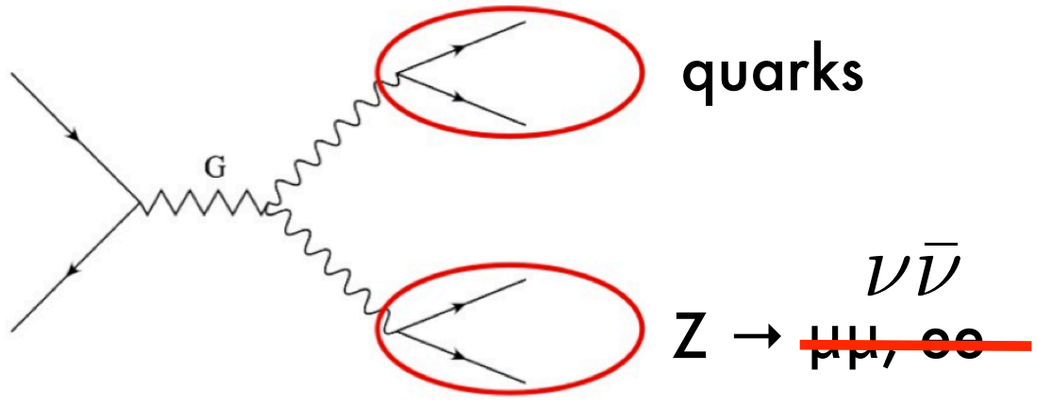


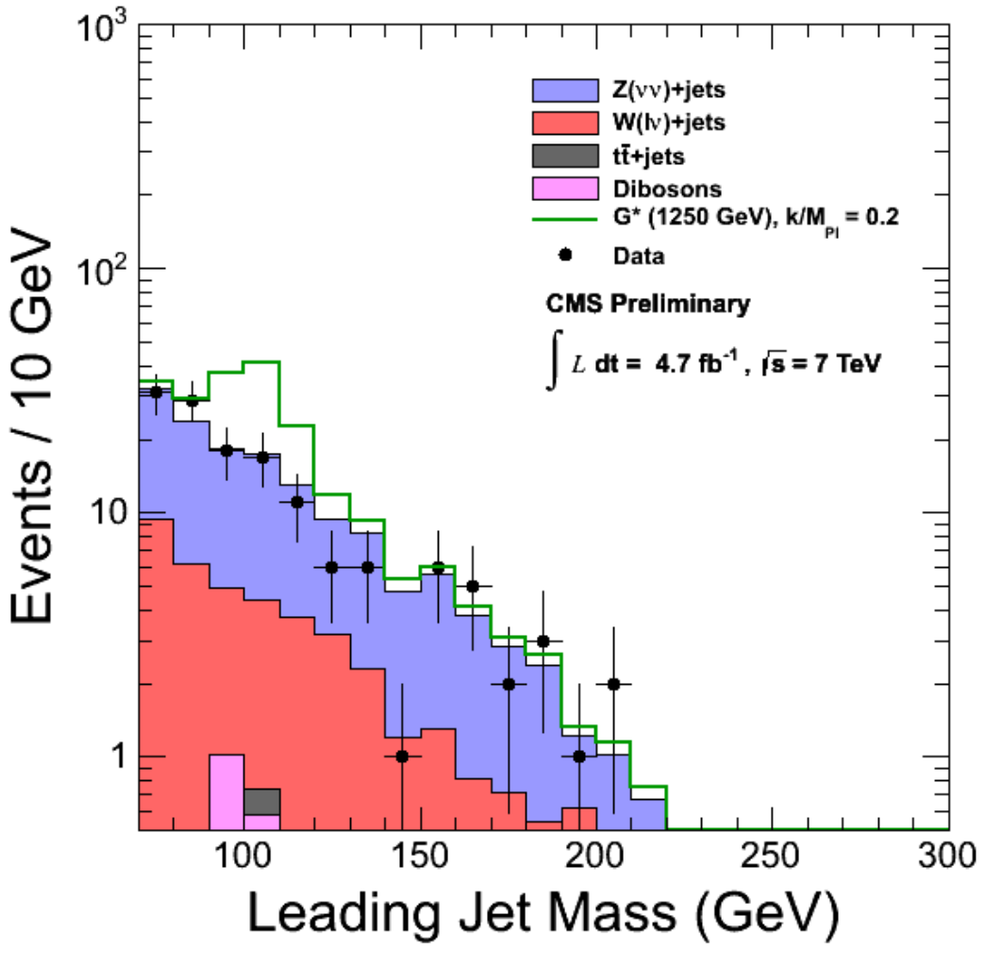
- For very heavy resonances hadronic W and Z merge in one fat jet
  - jet energy resolution

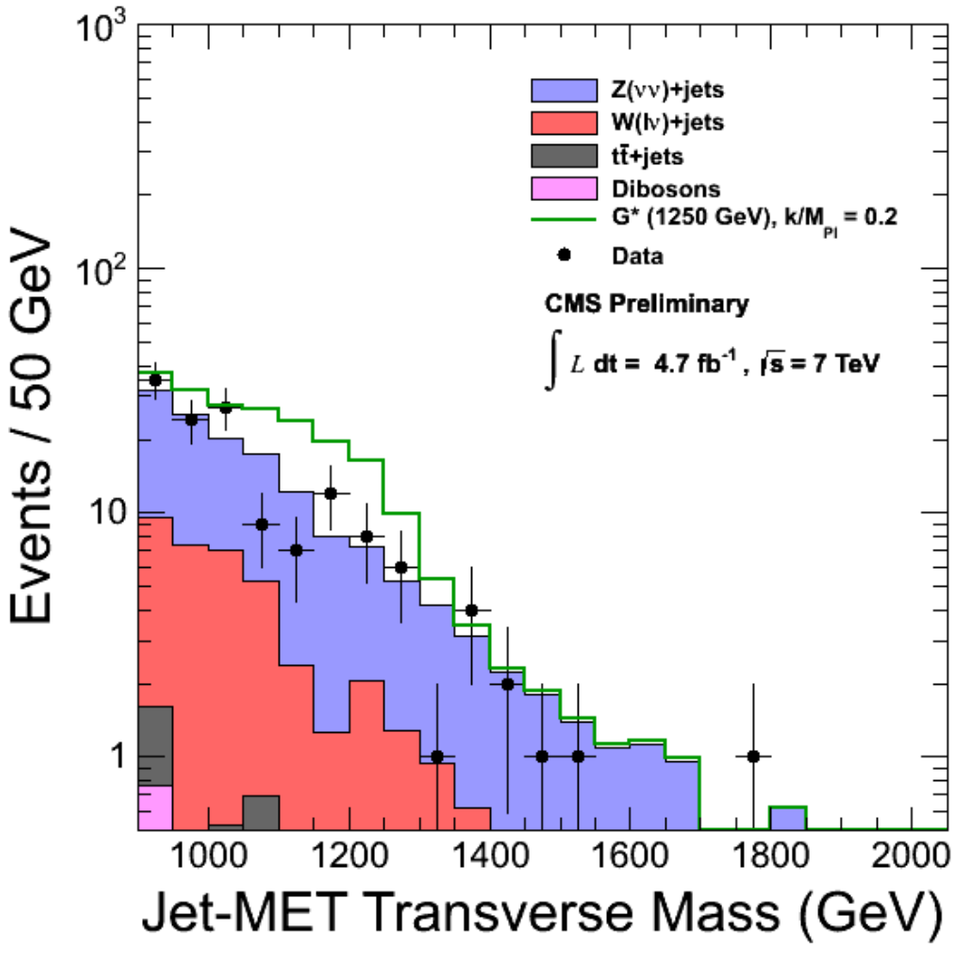
ZZ Resonance

EXO-12-014

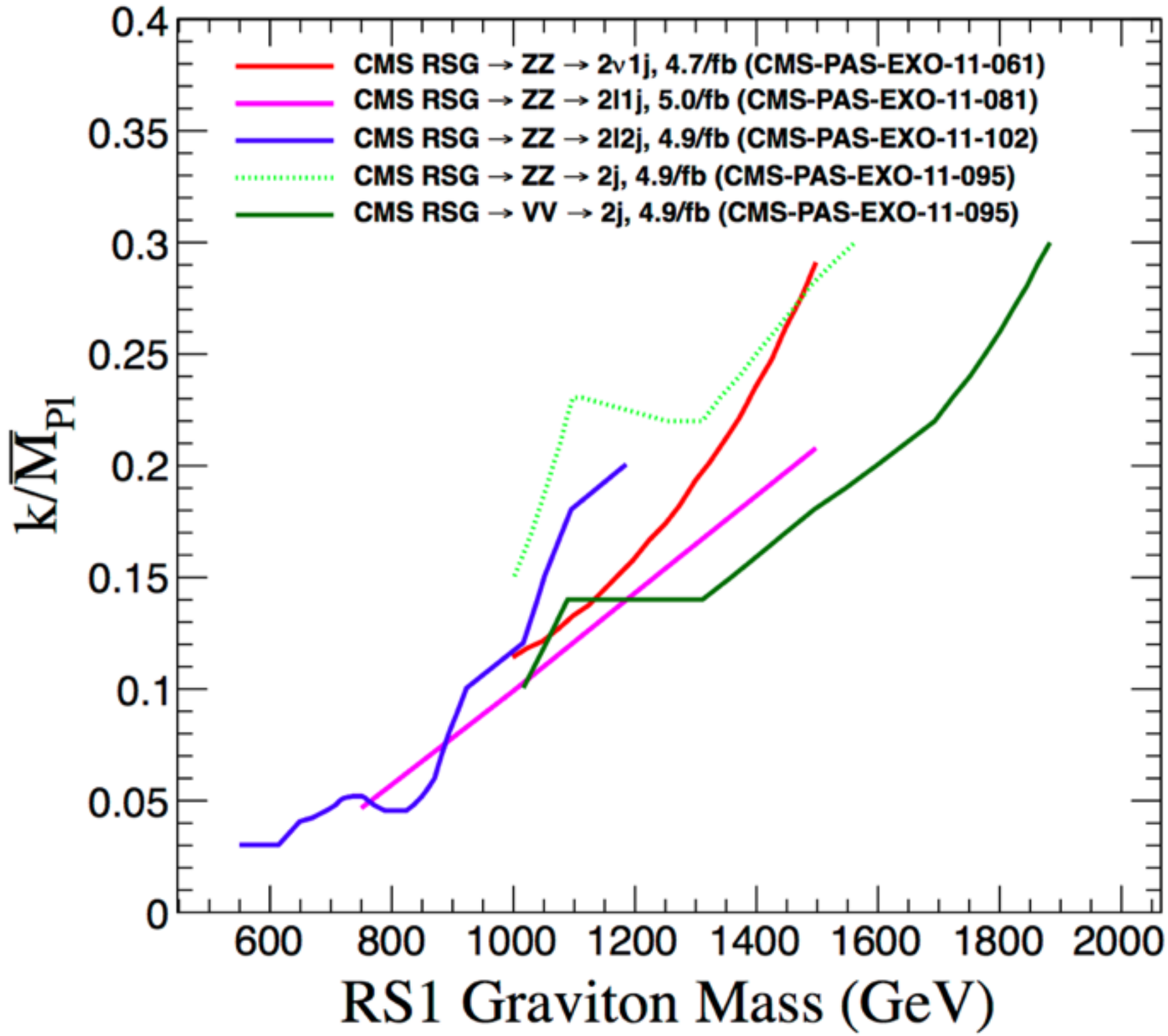
$$pp \to G^* \to ZZ \to q\bar{q}\,\nu\bar{\nu}$$







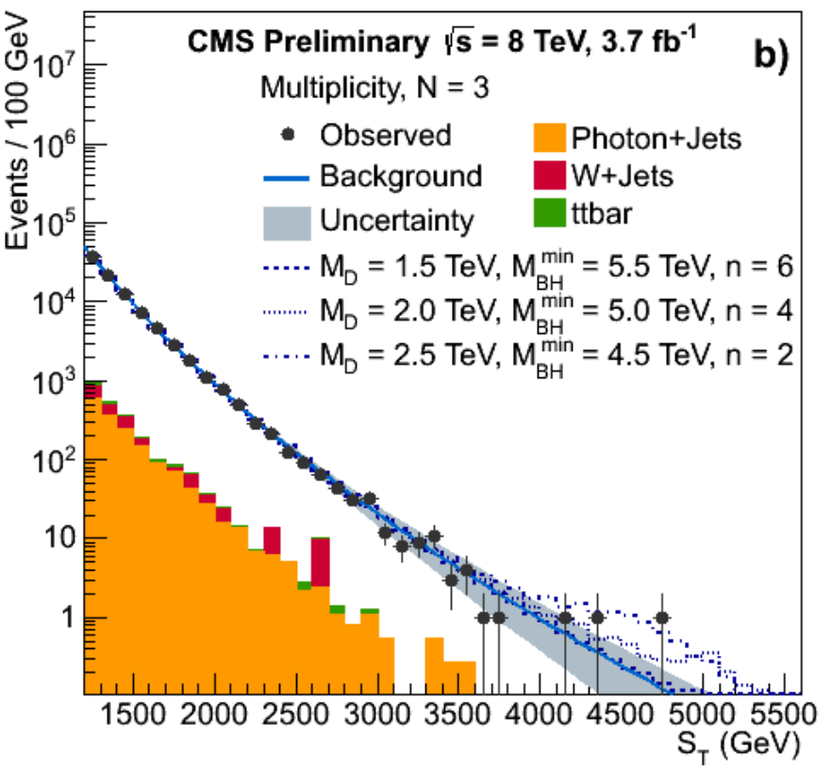
CONSTRAINTS ON GRAVITONS

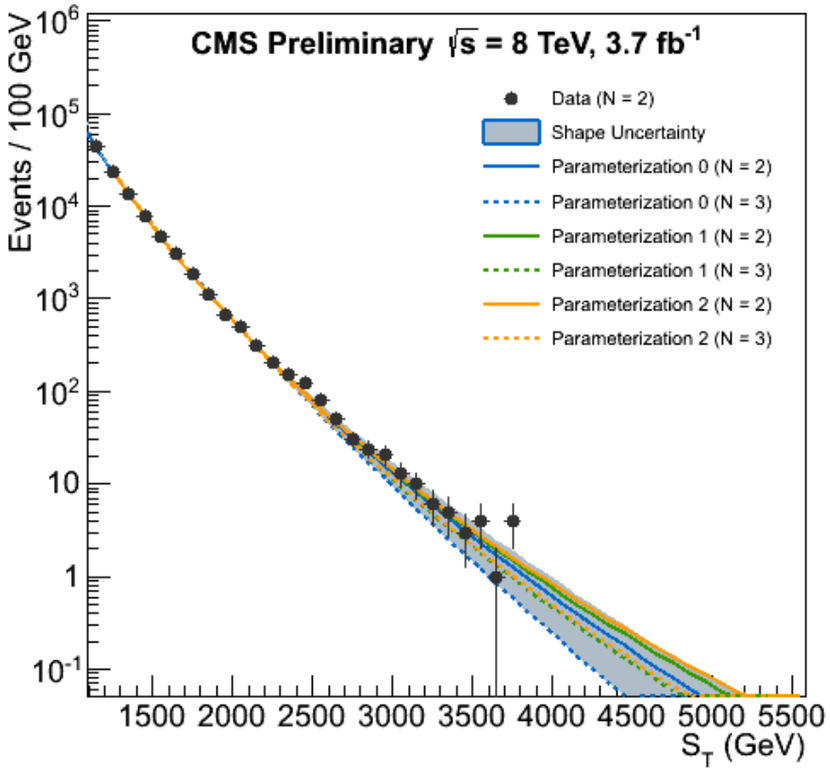


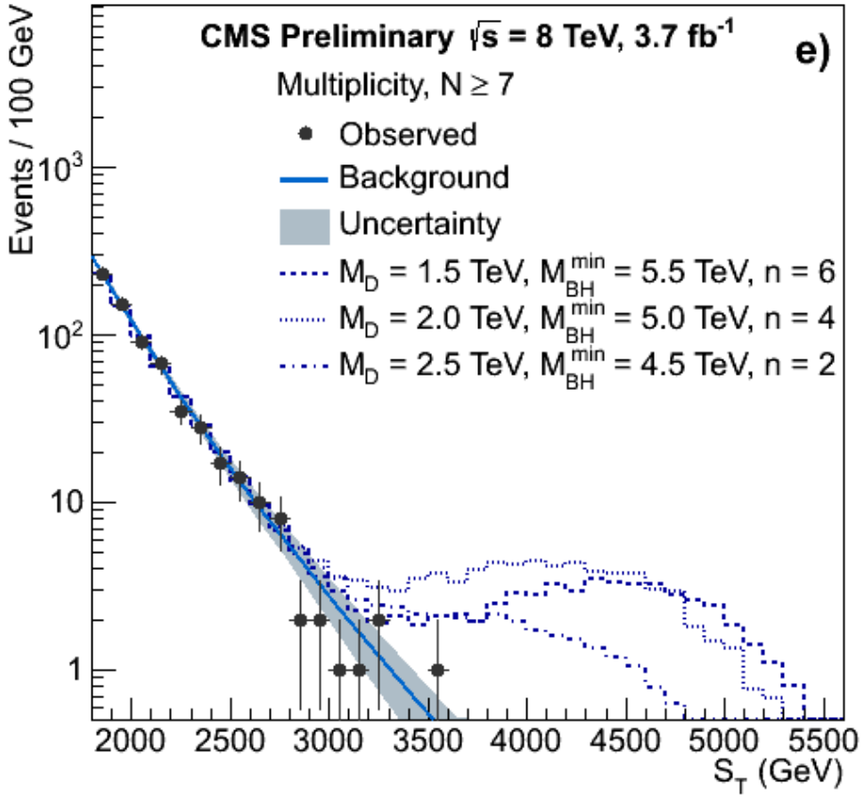
MICROSCOPIC BLACK HOLES

EXO-12-009

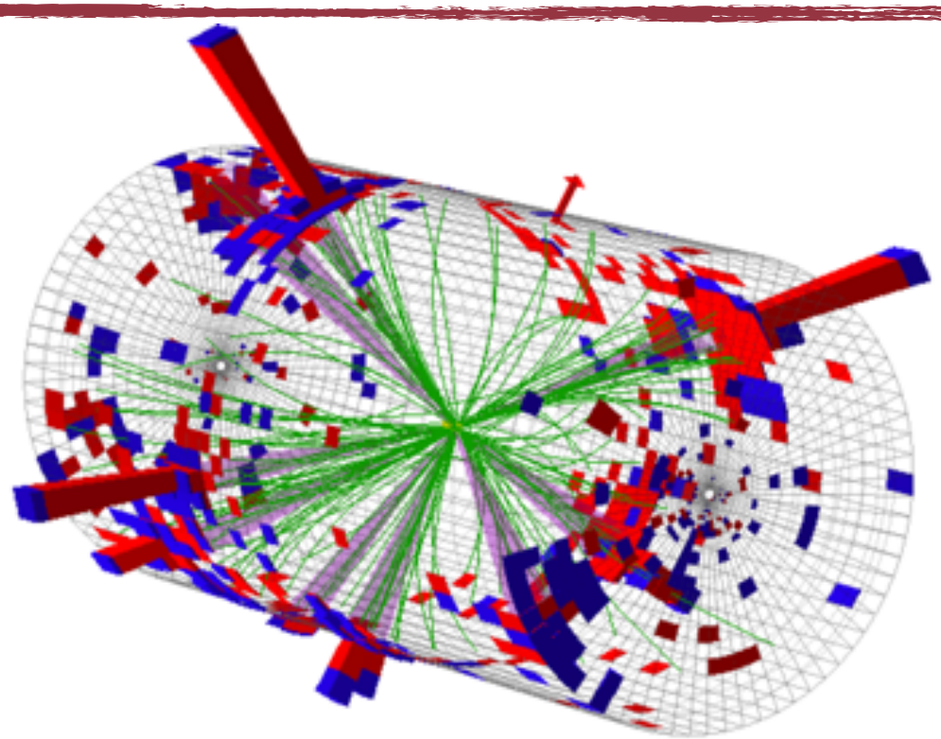
- Analysis strategy: events with large transverse energy, multiple high- energy jets, leptons, and photons
- Main Standard Model background: QCD multijet production
- Discrimination variable: visible transverse energy
  - scalar sum of ET for identified physics objects and MET
- Estimate background shape from low multiplicity events

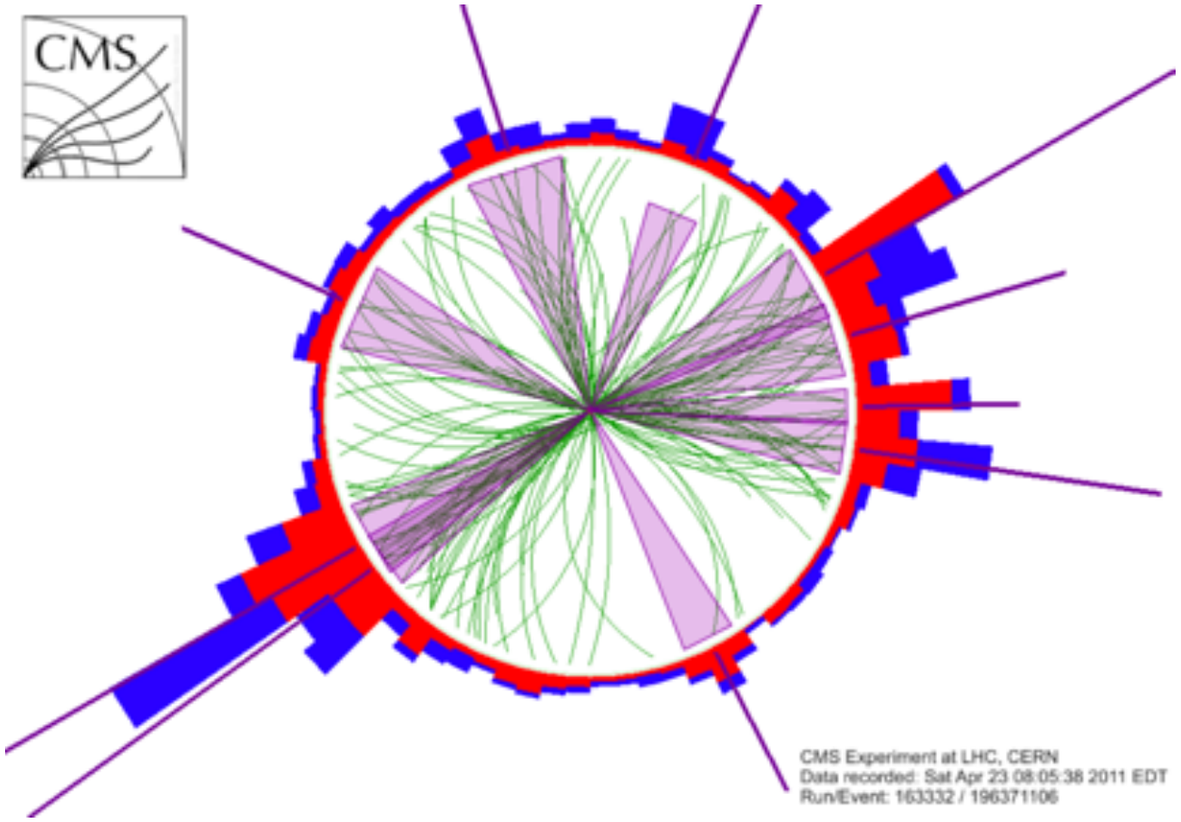




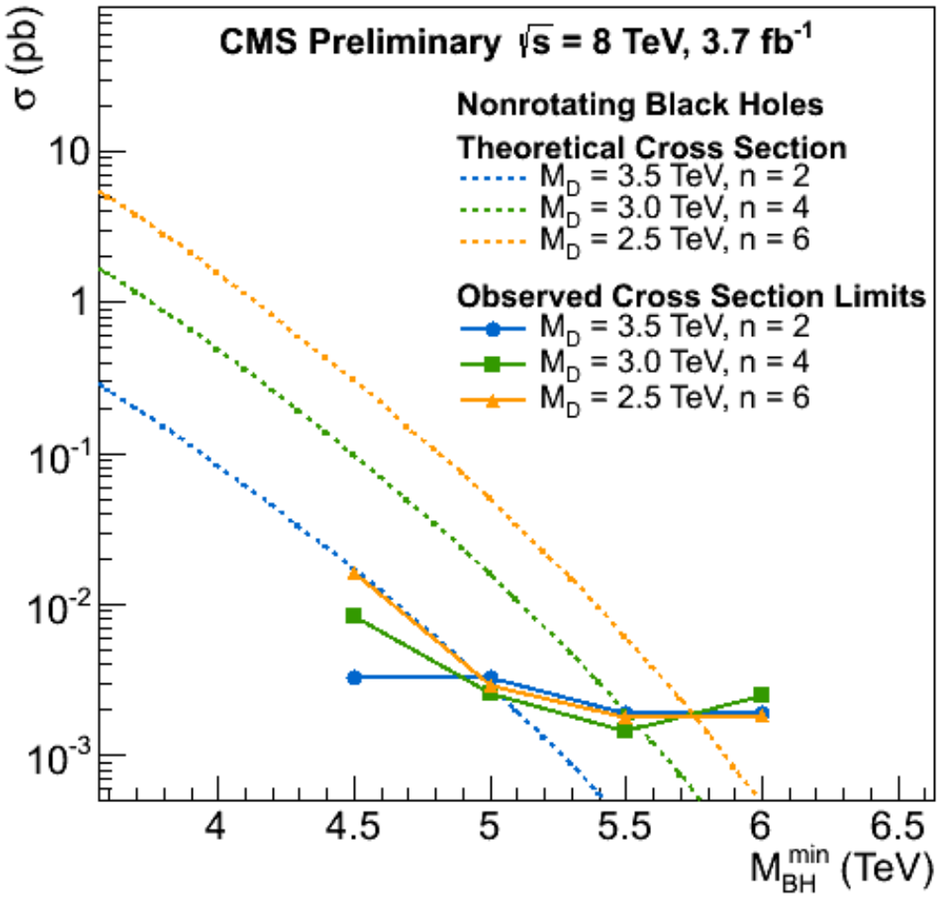


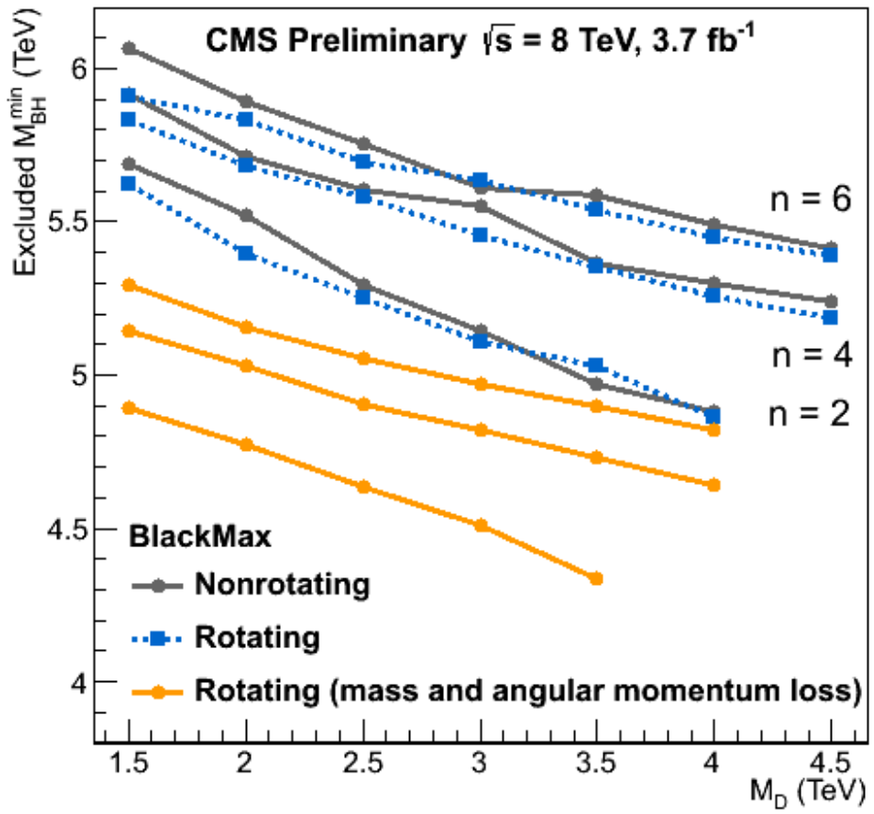
MULTIJET EVENT AS BLACK HOLE CANDIDATE

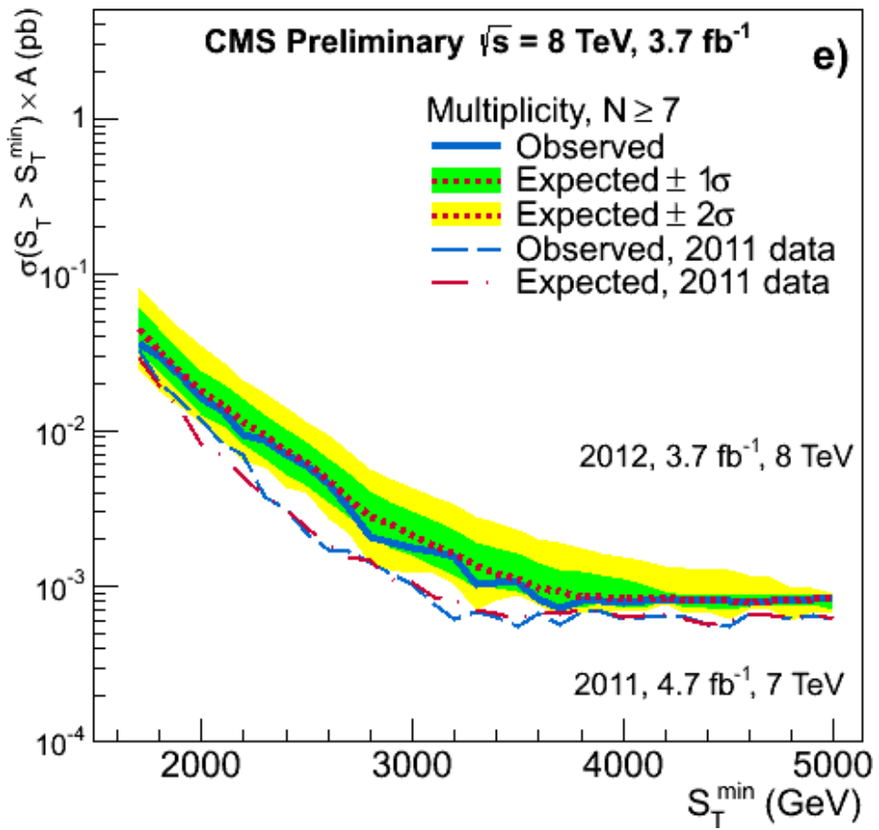




LIMITS ON BLACK HOLES



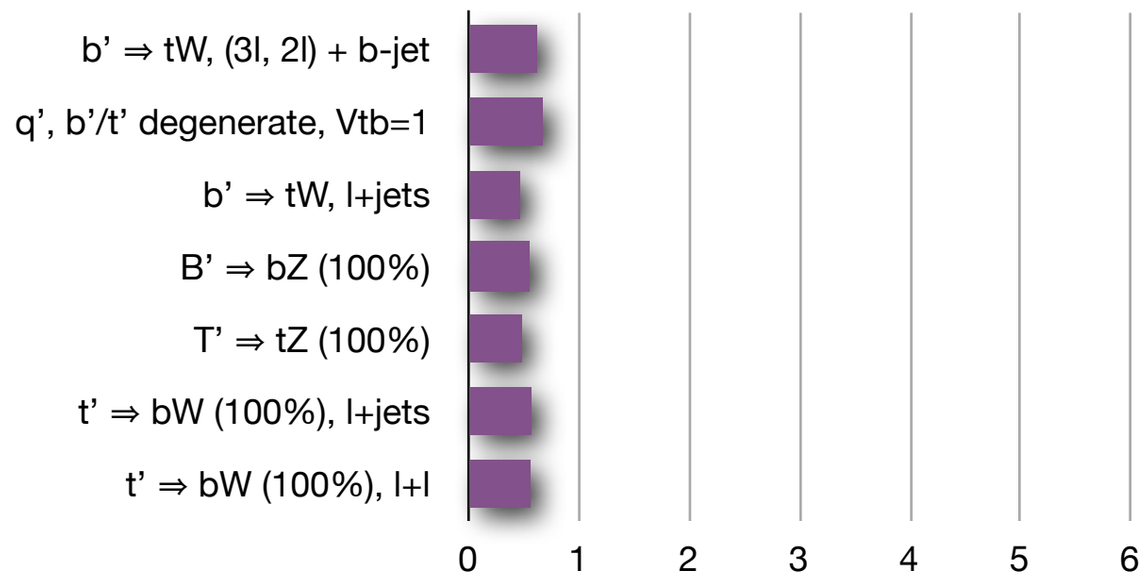


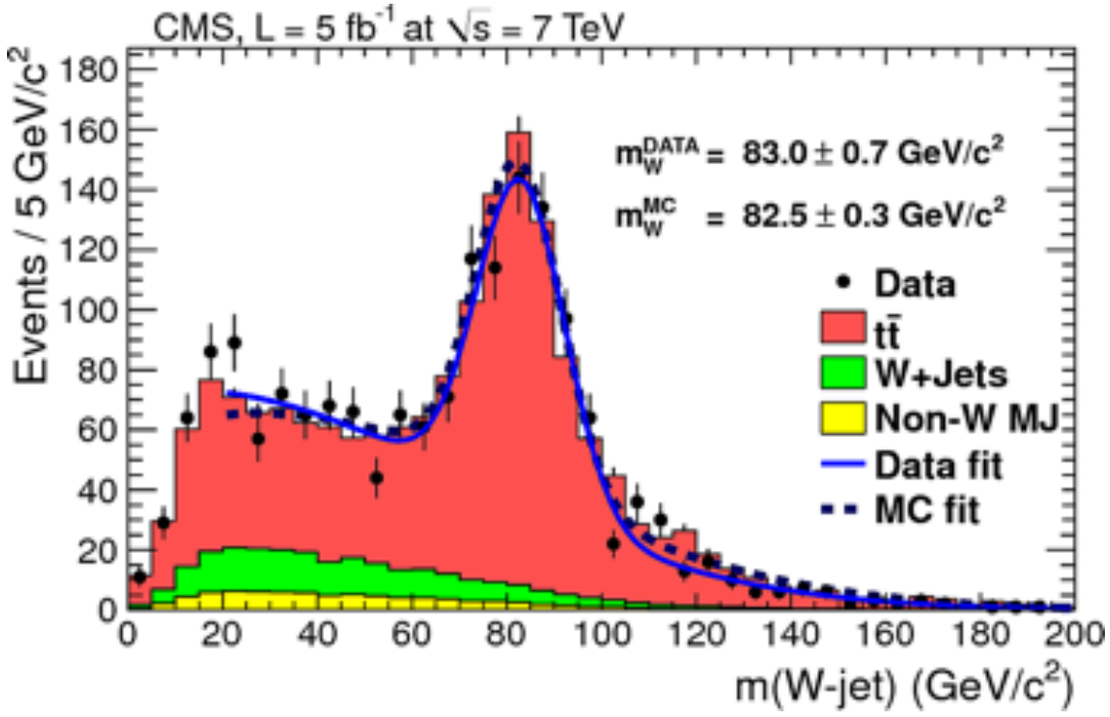


- Significant increase in signal cross section at 8 TeV
  - no signal yet unfortunately
- Model-independent limits useful to constrain new theoretical models

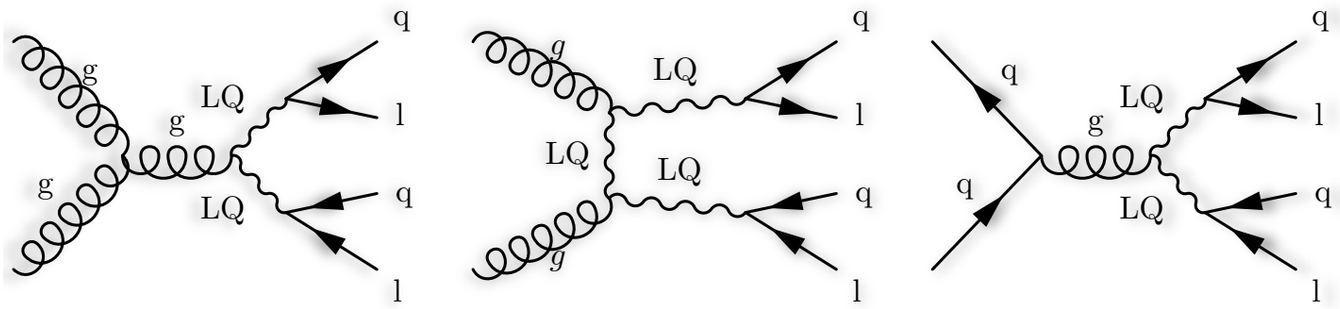
4TH GENERATION AND TTBAR

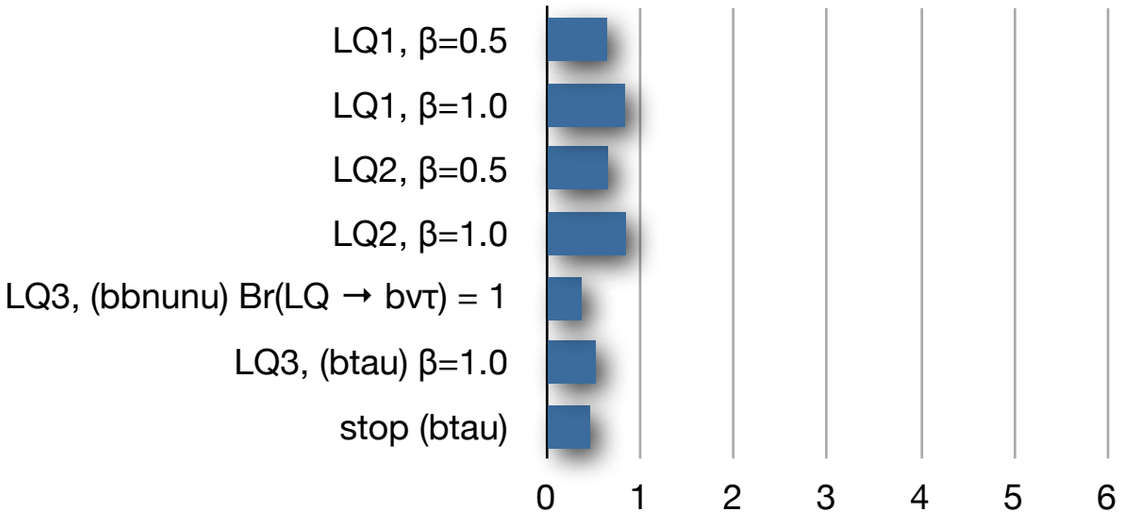
- Extremely rich program with at least one top in final state
- Serval searches for 4th generation heavy quarks
  - leptons
  - lepton+jets
  - all hadronic
- ttbar resonances across the spectrum
  - alla hadronic boosted top technique at high mass
  - lepton + jets
  - close interaction with top group to coordinate low (1<1 TeV) and high mass analyses
- Search for exotic q=5/3 top partners ongoing



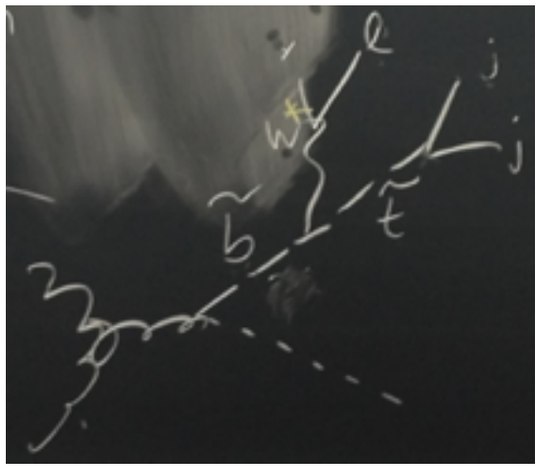


LEPTON + JETS





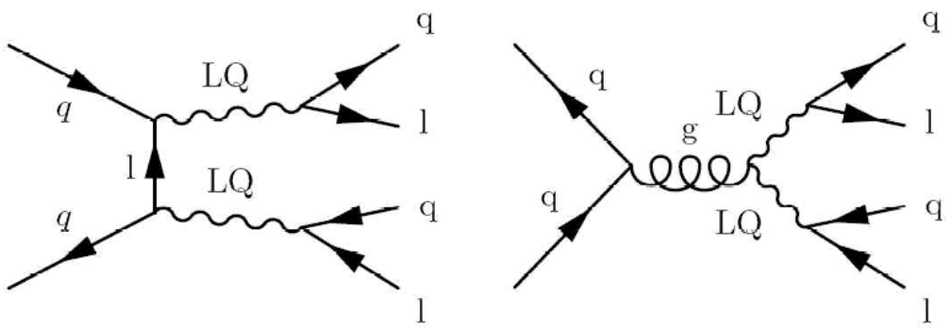
- Lepton and jets used usually for leptoquark searches
  - now also first 3rd generation searches
- Same final state sensitive also to RPV SUSY

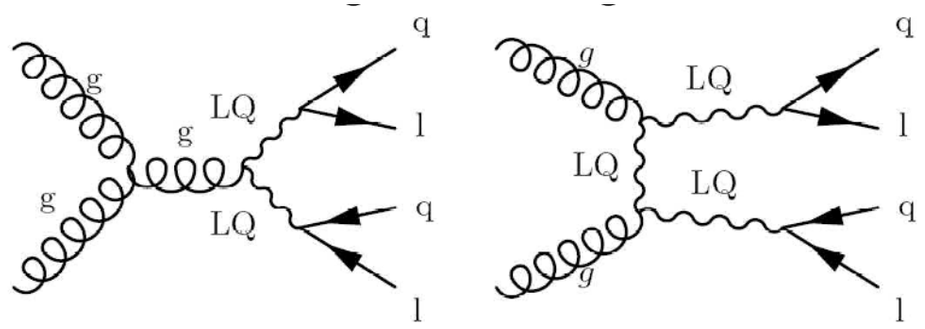


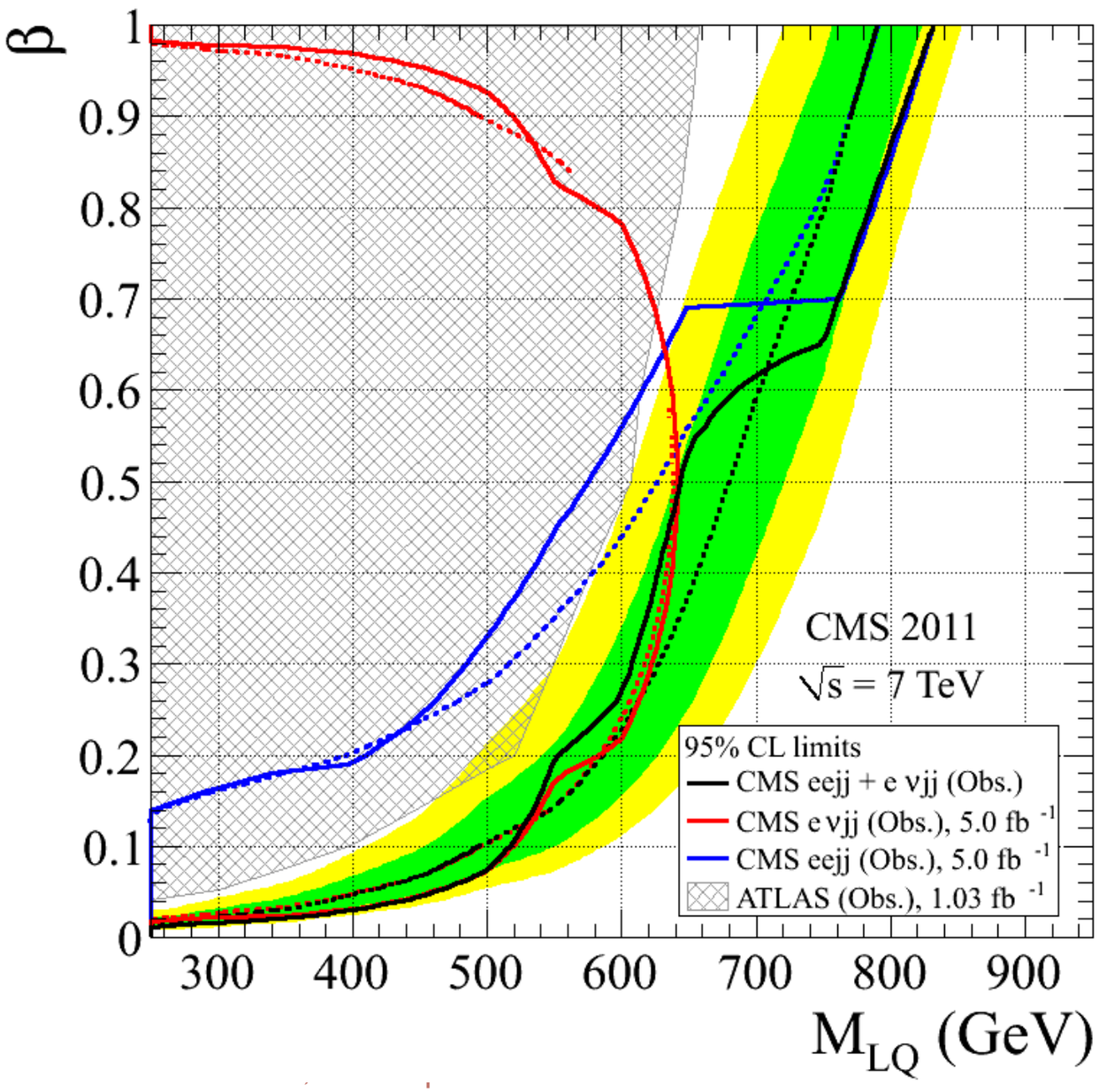
- Extending program to single LQ production and top+tau final states

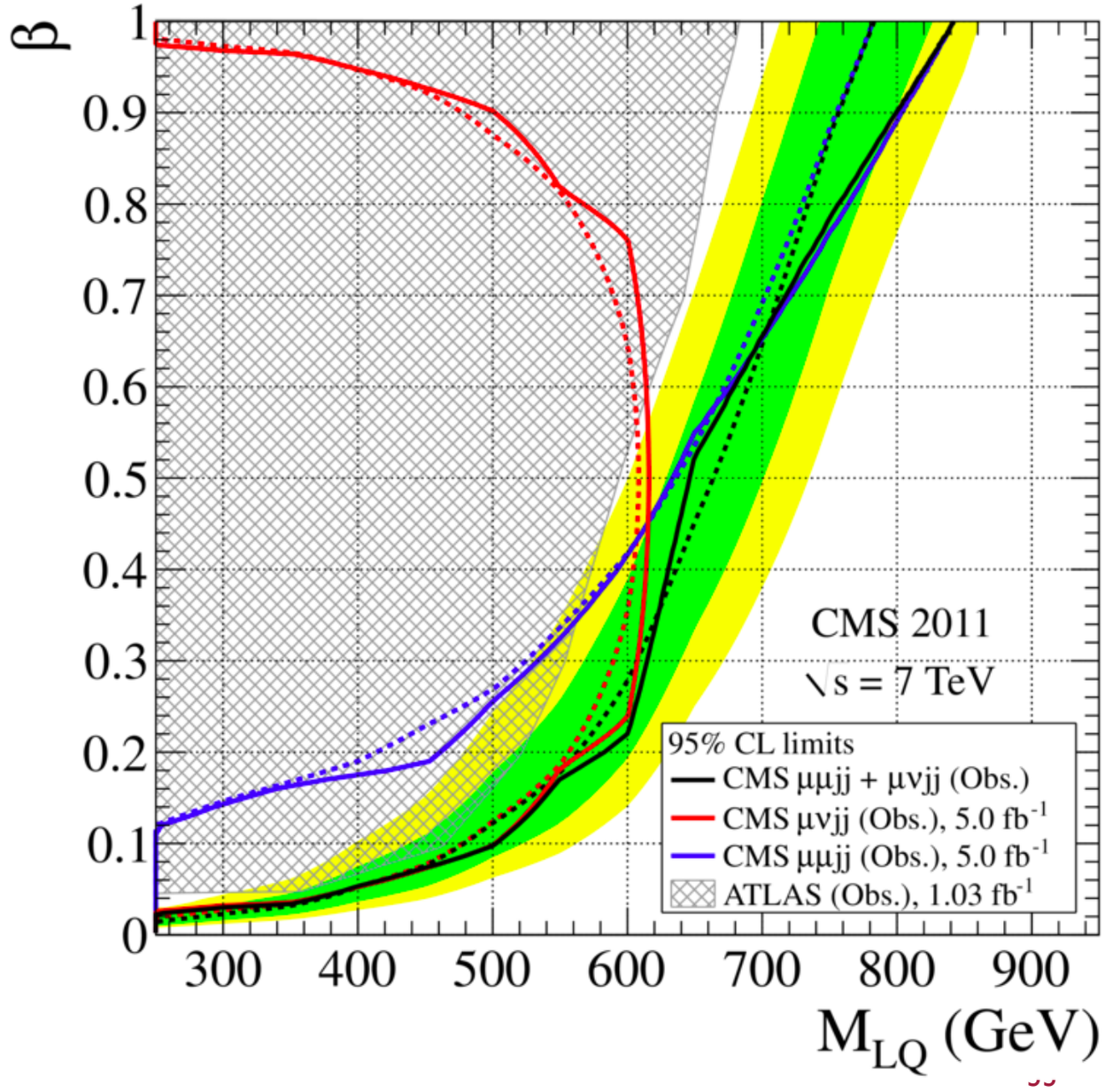
LEPTOQUARKS

EXO-11-028



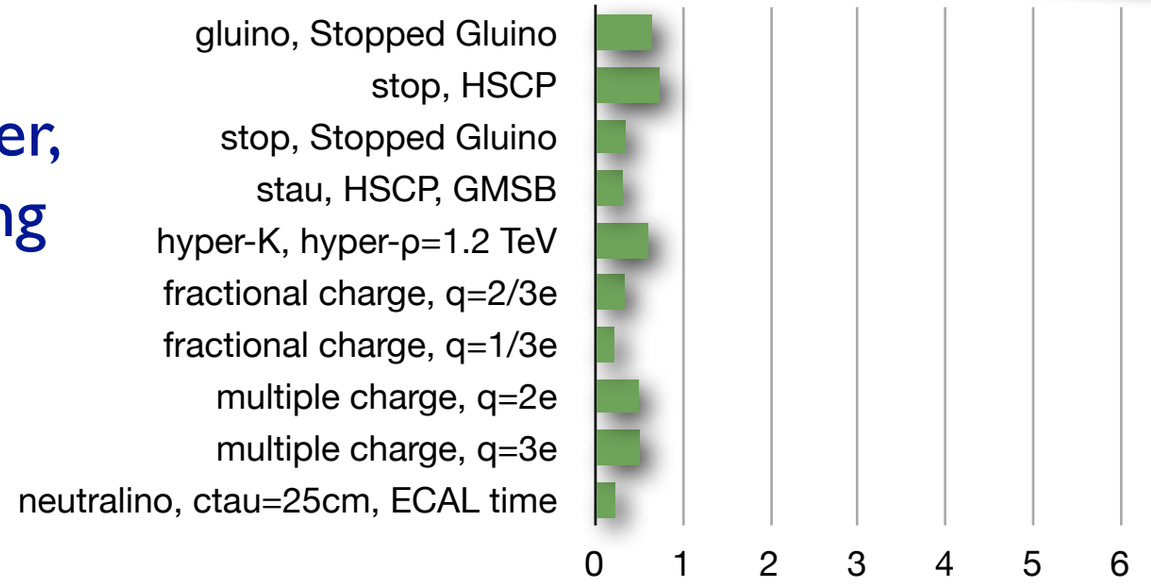


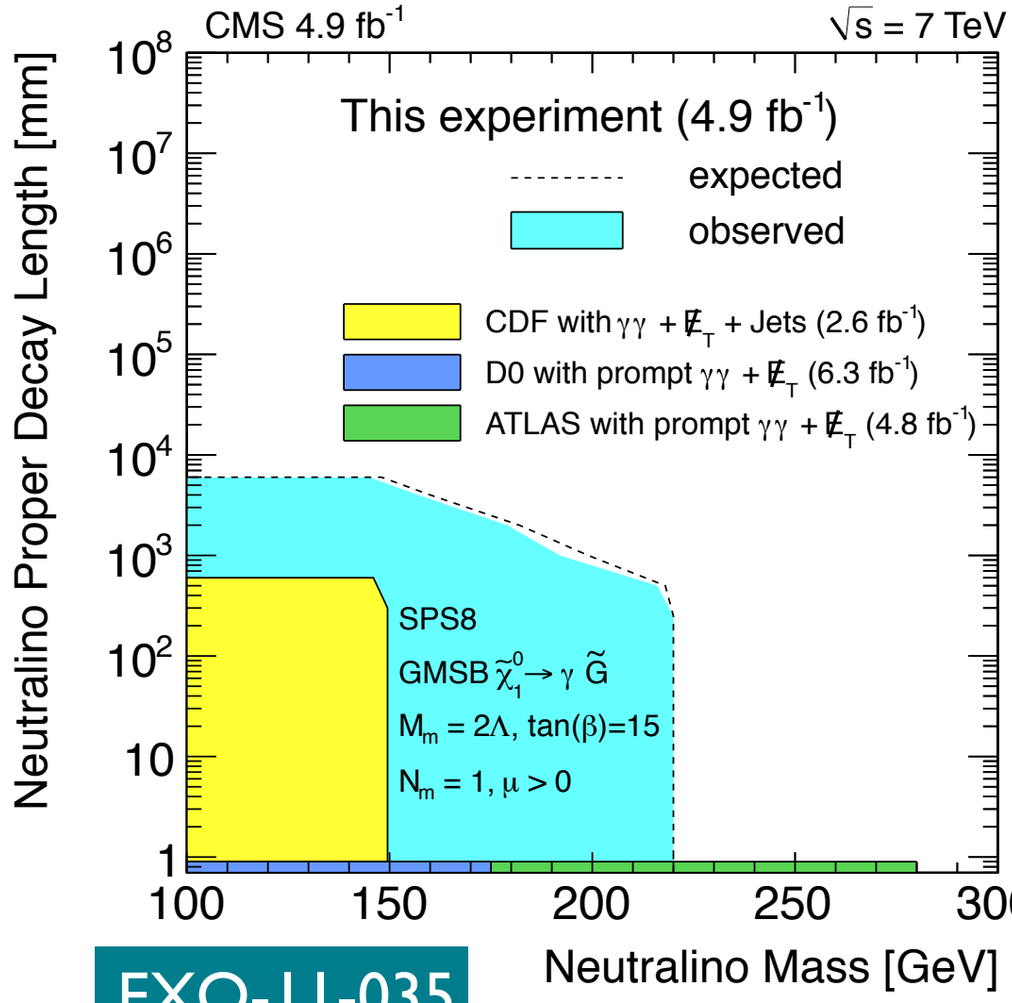




LONG-LIVED PARTICLES

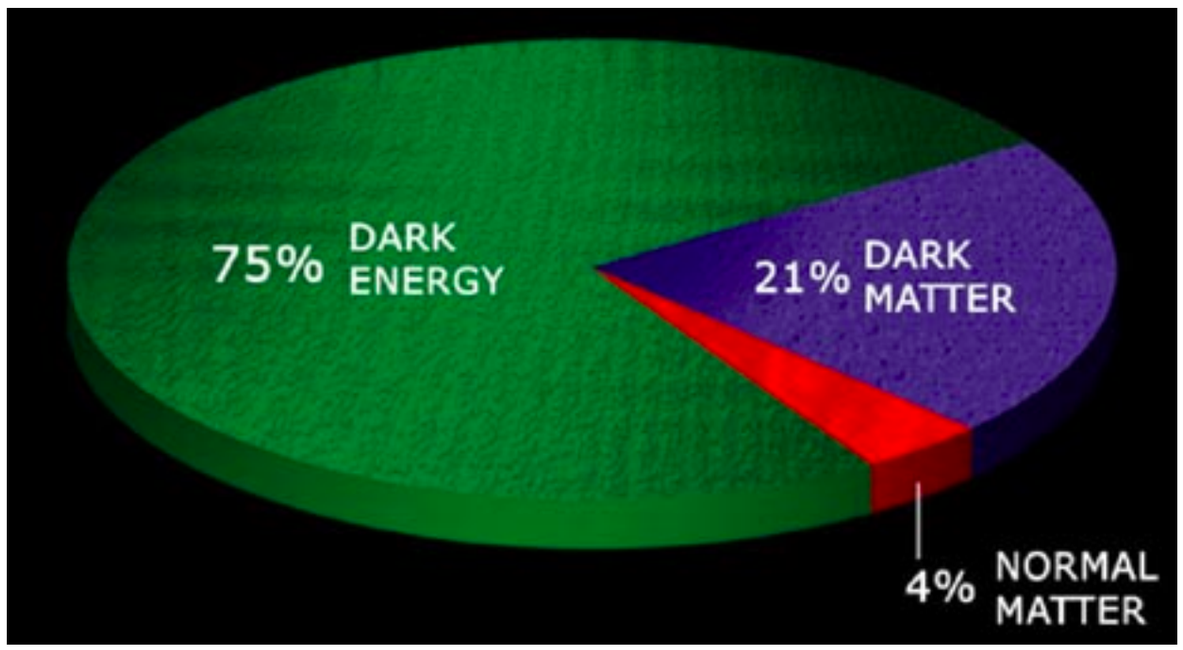
- Most exotic part of exotica
  - requires dedicated reconstruction, trigger, and detailed detector level understanding unlike other searches
- Heavy stable charge particles
  - slow muon-like objects
    - dE/dx, TOF, proper reco
  - also q > 1
- Stopped gluino
  - dedicated data taking conditions and understanding of beam conditions
- Fractionally charged particles
  - dE/dx in tracker
- Displaced leptons and vertices
- Displaced photons
  - first analysis using time measurement in ECAL



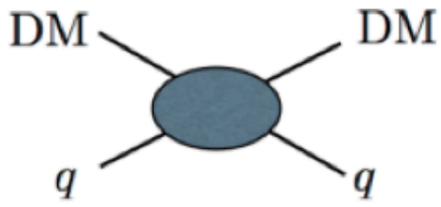


EXO-11-035

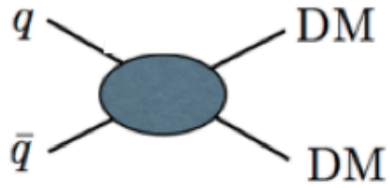
Dark Matter



DARK MATTER QUEST

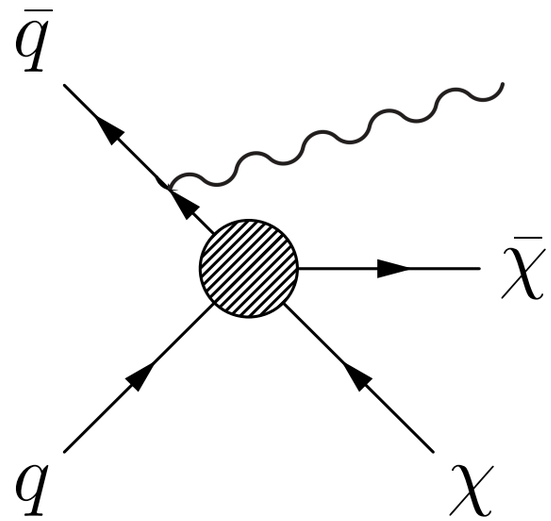


Direct Detection (t-channel)

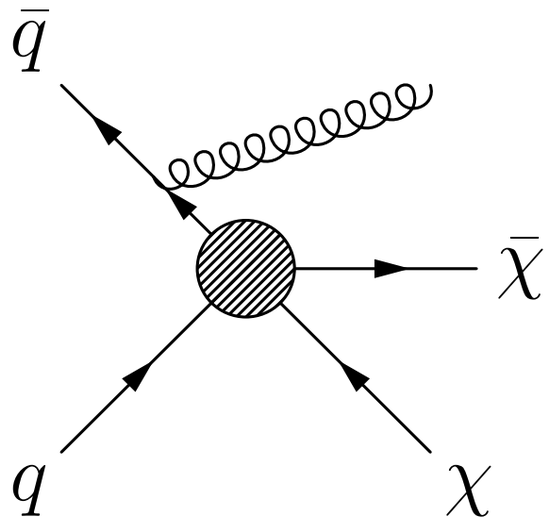


Collider Searches (s-channel)

- Pair production of Dark Matter candidates at colliders accompanied by Initial State Radiation of gluon or photon
  - More sensitive in low mass region than direct detection



Monophoton + MET



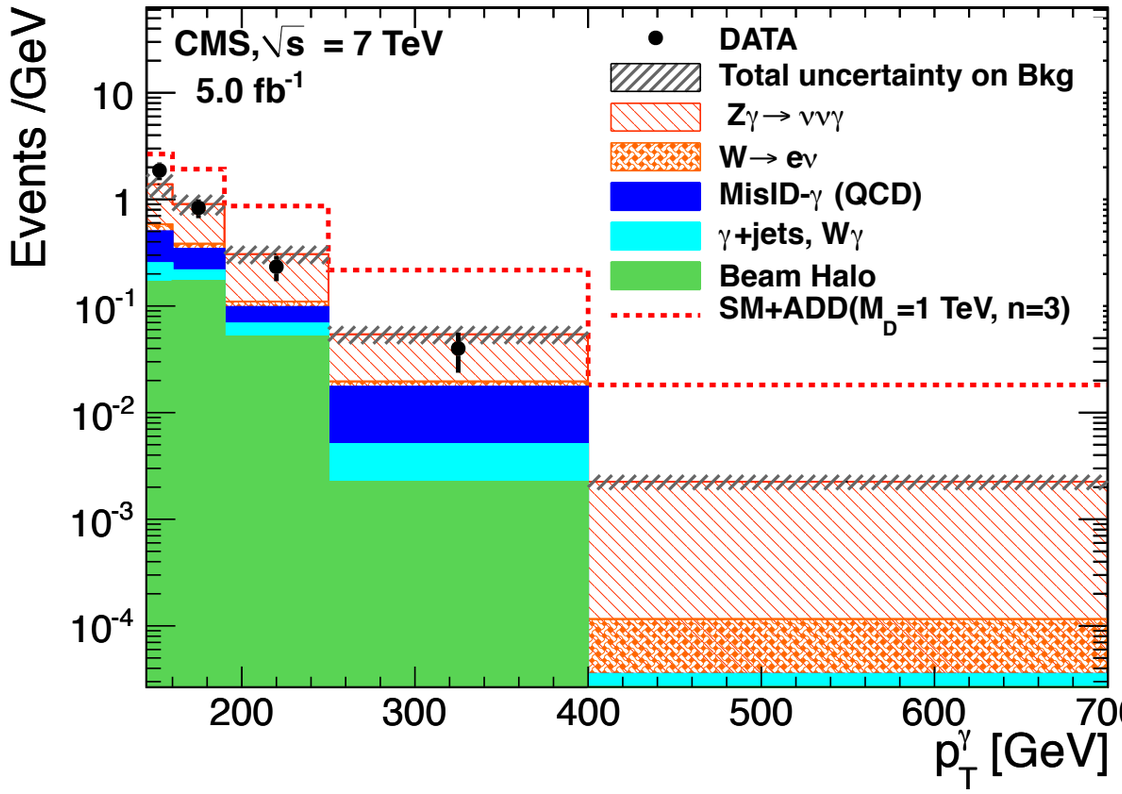
Monojet + MET

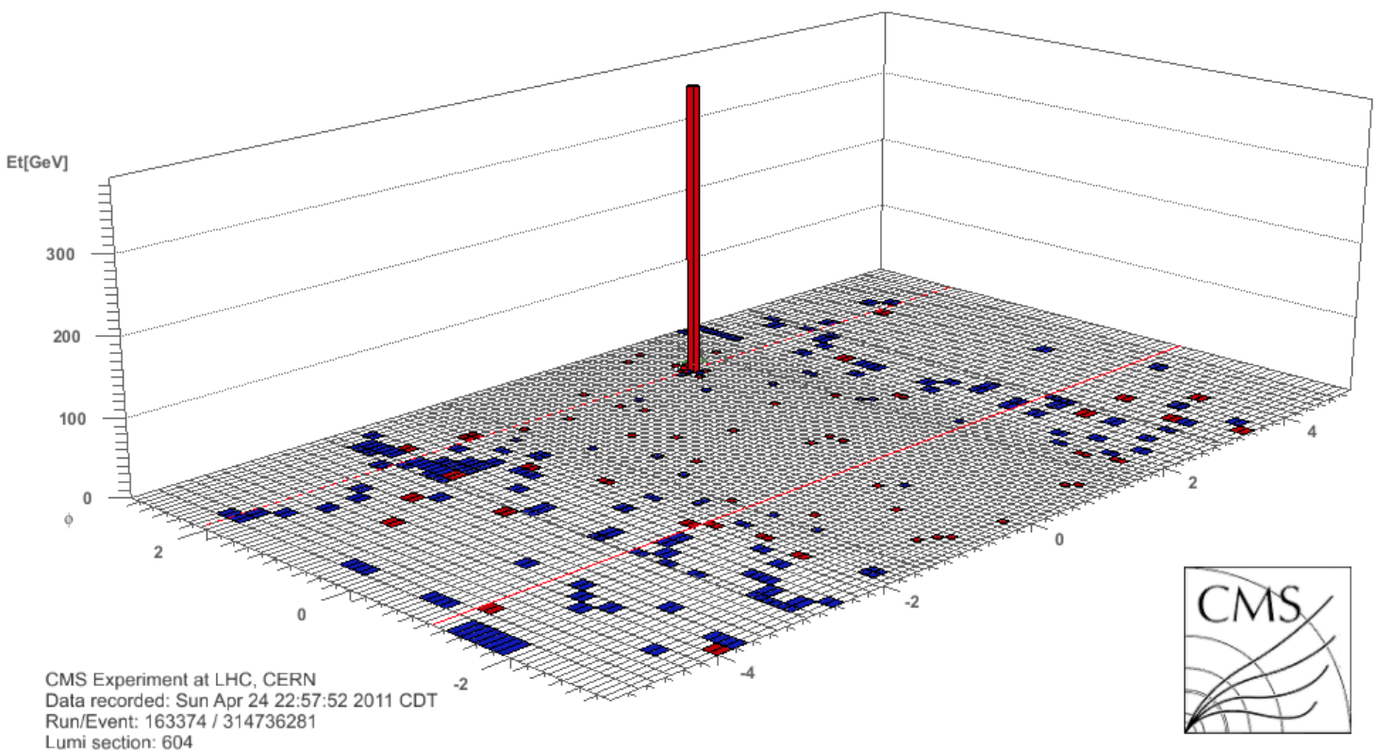
- Search for just one photon or jet and large missing transverse energy

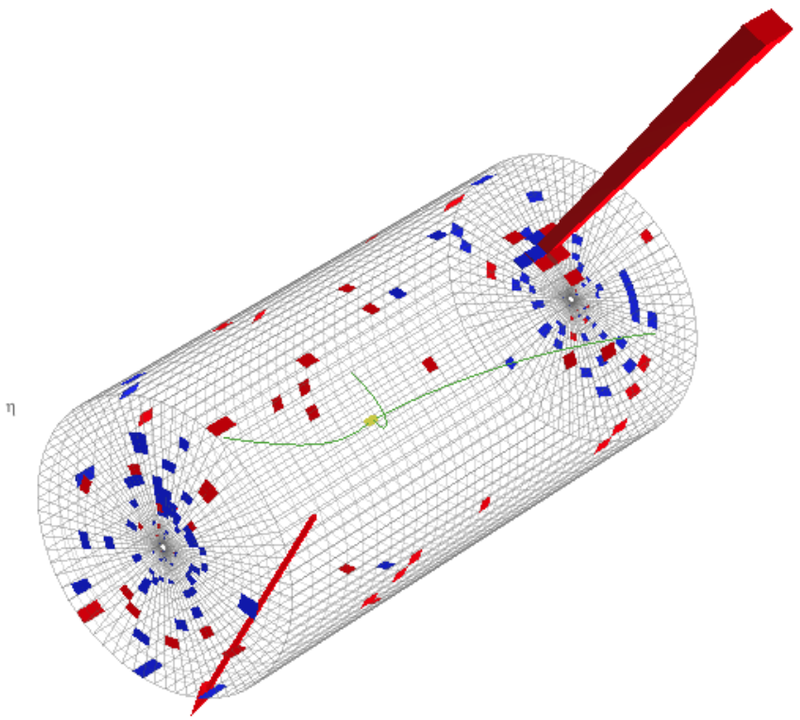
MONO-PHOTON + MET

EXO-11-096

- Experimentally challenging
  - 1 photon, MET and no other activity
  - excellent estimate of non-beam background with ECAL time measurement
- Look for excess in photon p_T spectrum



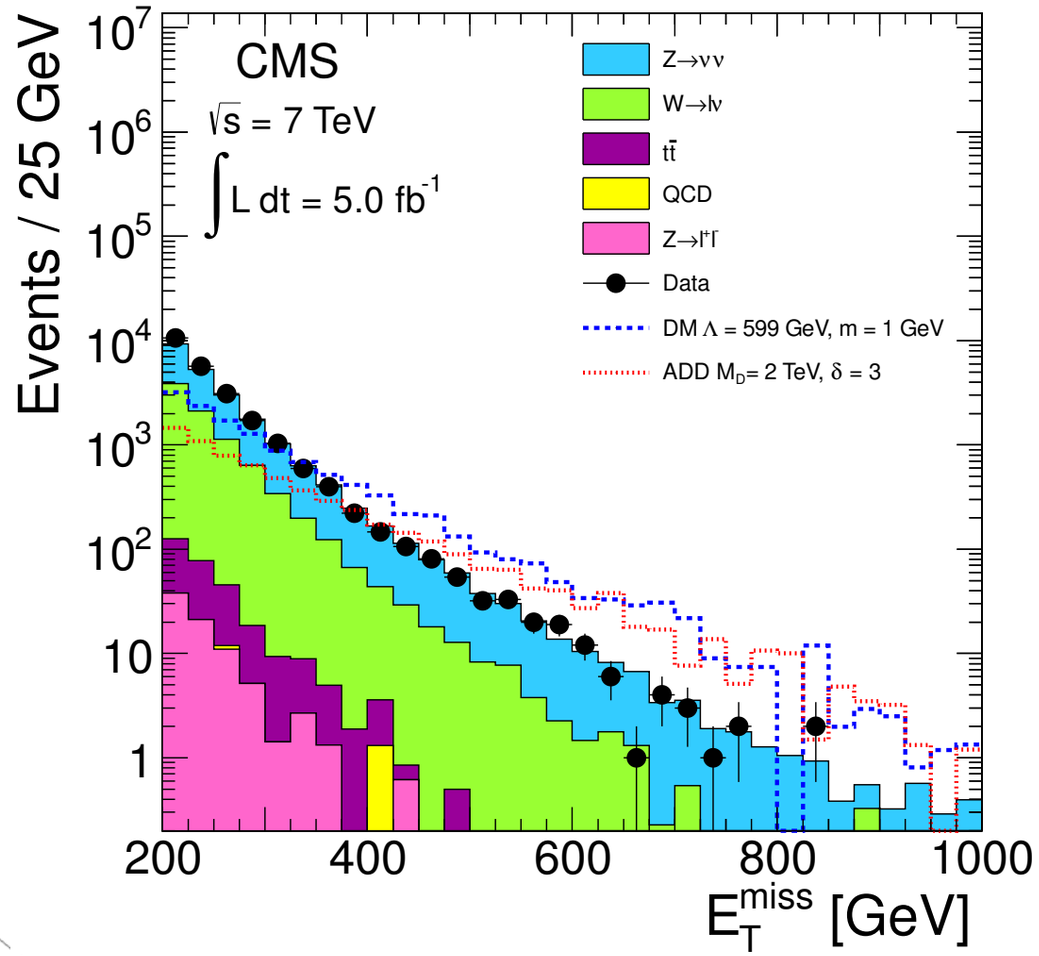


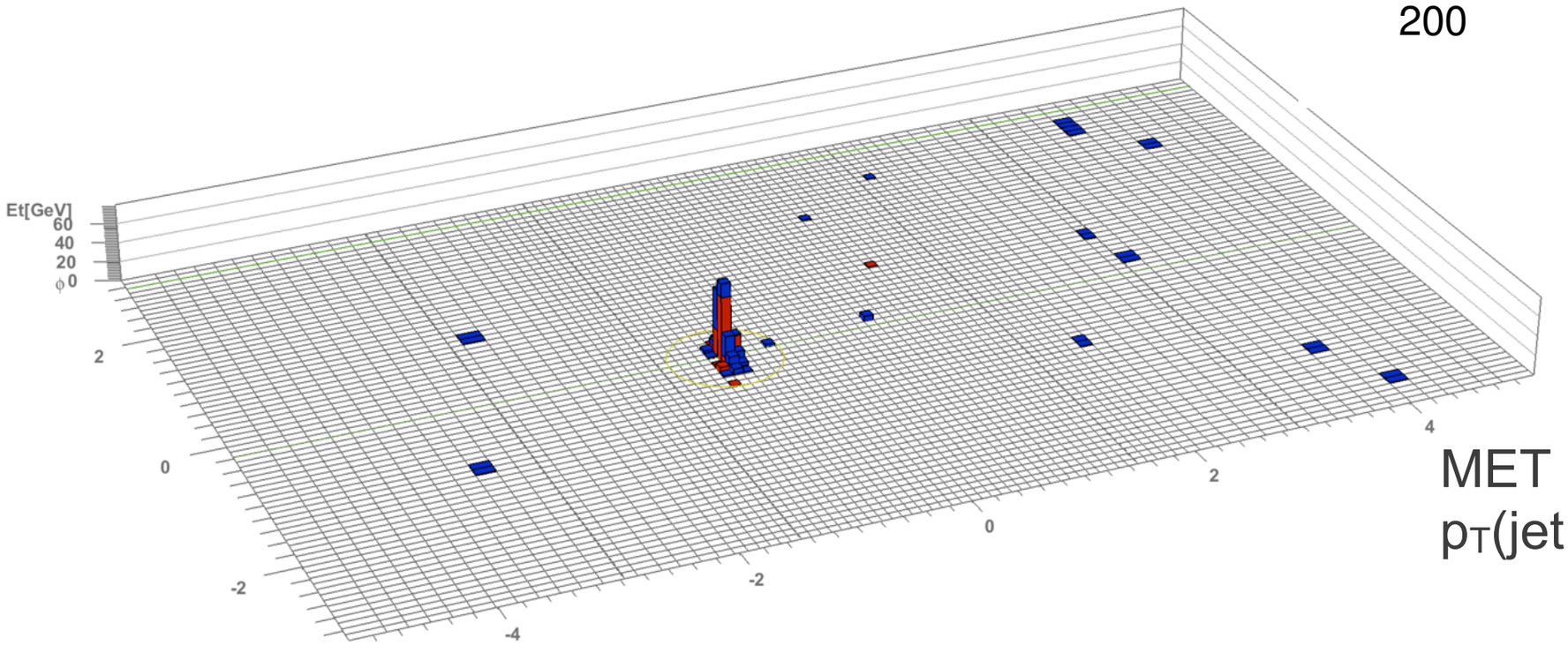


MONO-JET + MET

EXO-11-059

- Higher cross section than monophoton
  - main background from invisible Z decays in Z+jets measured with data driven method
- Require one high pt jet and possibly a second jet
  - recover radiation
  - reject events with close-by leptons





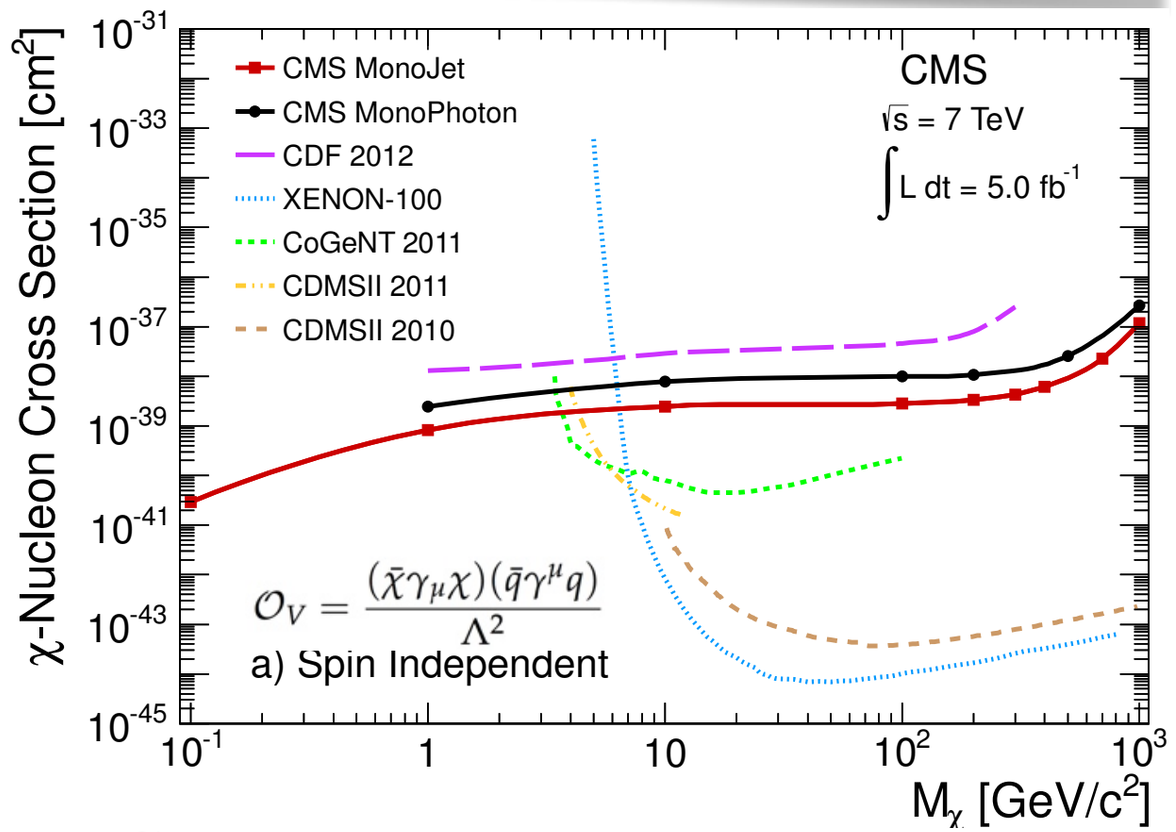
MET = 359 GeV
p_T(jet1) = 331 GeV

DARK MATTER LIMITS

- Pair production modeled as contact interaction

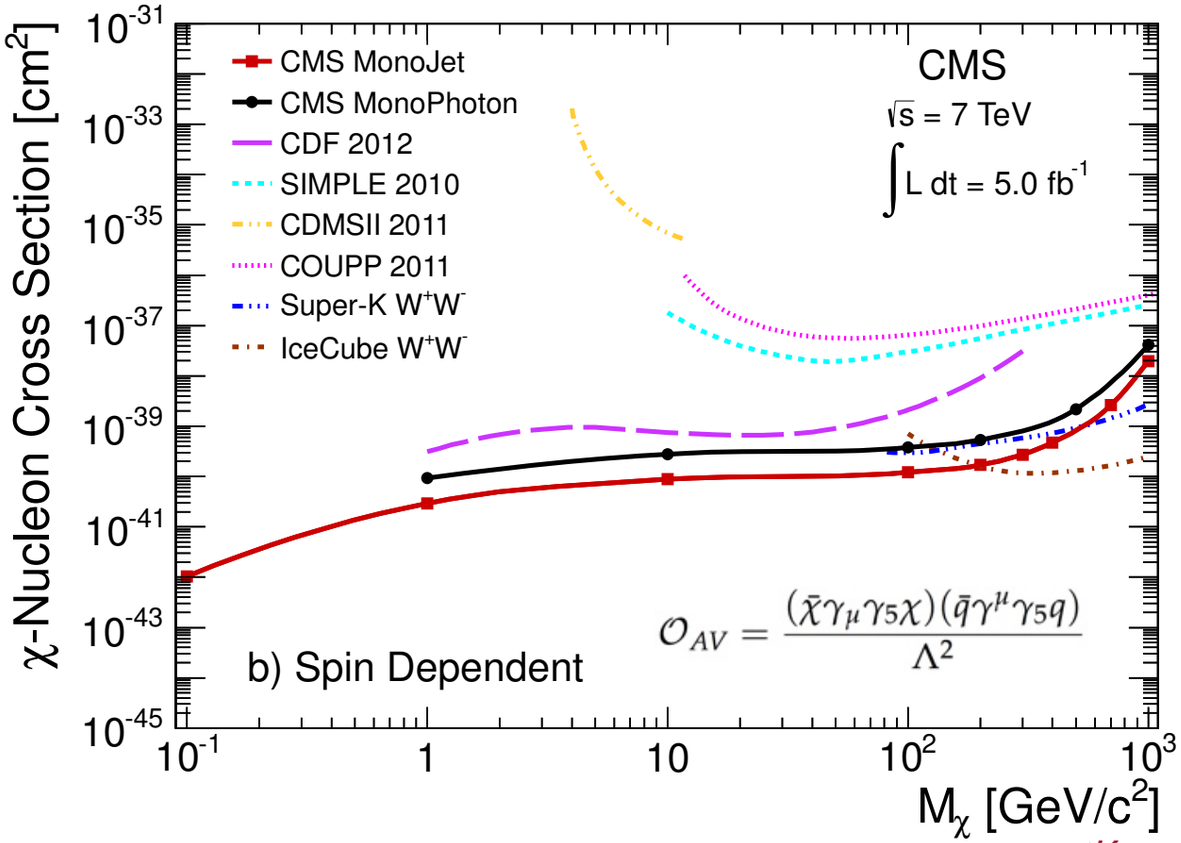
- Spin-independent

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



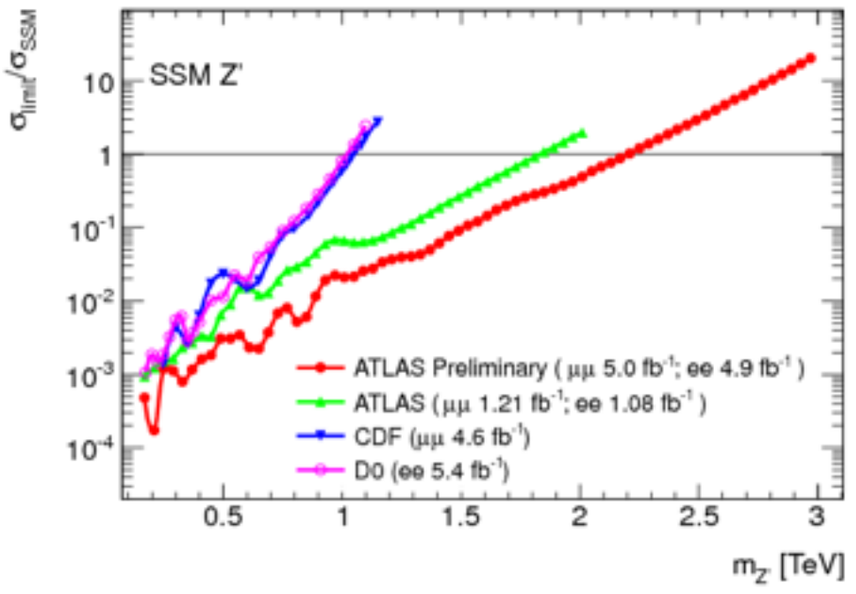
- Spin-dependent

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



OUTLOOK AND PROSPECTS

- Heavy resonances excluded past 2 TeV
- 4th generation excluded up to ~0.5 TeV
- Increase of x35 in data from 2010 to Summer 2011 improved exclusion limits sometime less than 20%
  - Increase in luminosity not a game changer in search



- Higher center-of-mass energy opens new doors
- Higher beam energy increases cross section by x2-3
  - 1 TeV resonance: x1.5 @ 8 TeV and x2 @ 9 TeV
  - 2 TeV resonance: x2.1 @ 8 TeV and x3.6 @ 9 TeV
- Exotic scenarios can be probed with little data in 2015