



STATUS AND PLANS FOR EXOTICA

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LHC Strategies Workshop

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DIPARTIMENTO DI FISICA



SAPIENZA
UNIVERSITÀ DI ROMA



EXOTICA IN CMS

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

Journal Publications - 2011 Run

Analysis	ArXiv Entry	Luminosity
Search for Stopped HSCPs NEW	arXiv:1207.0106	5/fb
Search for Dark Matter and Large Extra Dimensions in Monojet Events NEW	arXiv:1206.5663	5/fb
Search for W' decaying into t and d quarks NEW	arXiv:1206.3921	5/fb
Search for Resonances to Dileptons NEW	arXiv:1206.1849	5/fb
Search for resonances decaying into ditaus	arxiv:1206.1725	5/fb
Search for Search for W' (or techni-rho) to WZ	arxiv:1206.0433	5/fb
Search for HSCPs	arXiv:1205.0272	5/fb
Search for Anomalous Production of Multilepton Events and R-Parity-Violating Supersymmetry	arXiv:1204.5341	5/fb
Search for W' to lepton+MET	arXiv:1204.4764	5/fb
Search for Z' to ttbar (boosted tops)	arXiv:1204.2488	5/fb
Search for t' to bW (dilepton channel)	arXiv:1203.5410	5/fb
Search for Heavy Bottom-like Quarks	arXiv:1204.1088	5/fb
Search for Dark Matter and Large Extra Dimensions in the γ +MET Final States	arXiv:1204.0821	5/fb
Search for Quark Compositeness in Dijet Angular Distributions	arXiv:1202.5535	2.2/fb
Search for Black Holes	arXiv:1202.6396	4.7/fb
Search for Large Extra Dimensions in Dielectron and Dimuon Events	arXiv:1202.3827	2.2/fb
Search for signatures of extra dimensions in the diphoton mass spectrum at the Large Hadron Collider	1112.0688 (hep-ex)	2.2/fb
Search for a Vector-like Quark with Charge 2/3 in t + Z Events from pp Collisions at $\sqrt{s} = 7$ TeV	1109.4985 (hep-ex)	1.1/fb
Search for Resonances in the Dijet Mass Spectrum from 7 TeV pp Collisions at CMS	1107.4771 (hep-ex)	1/fb

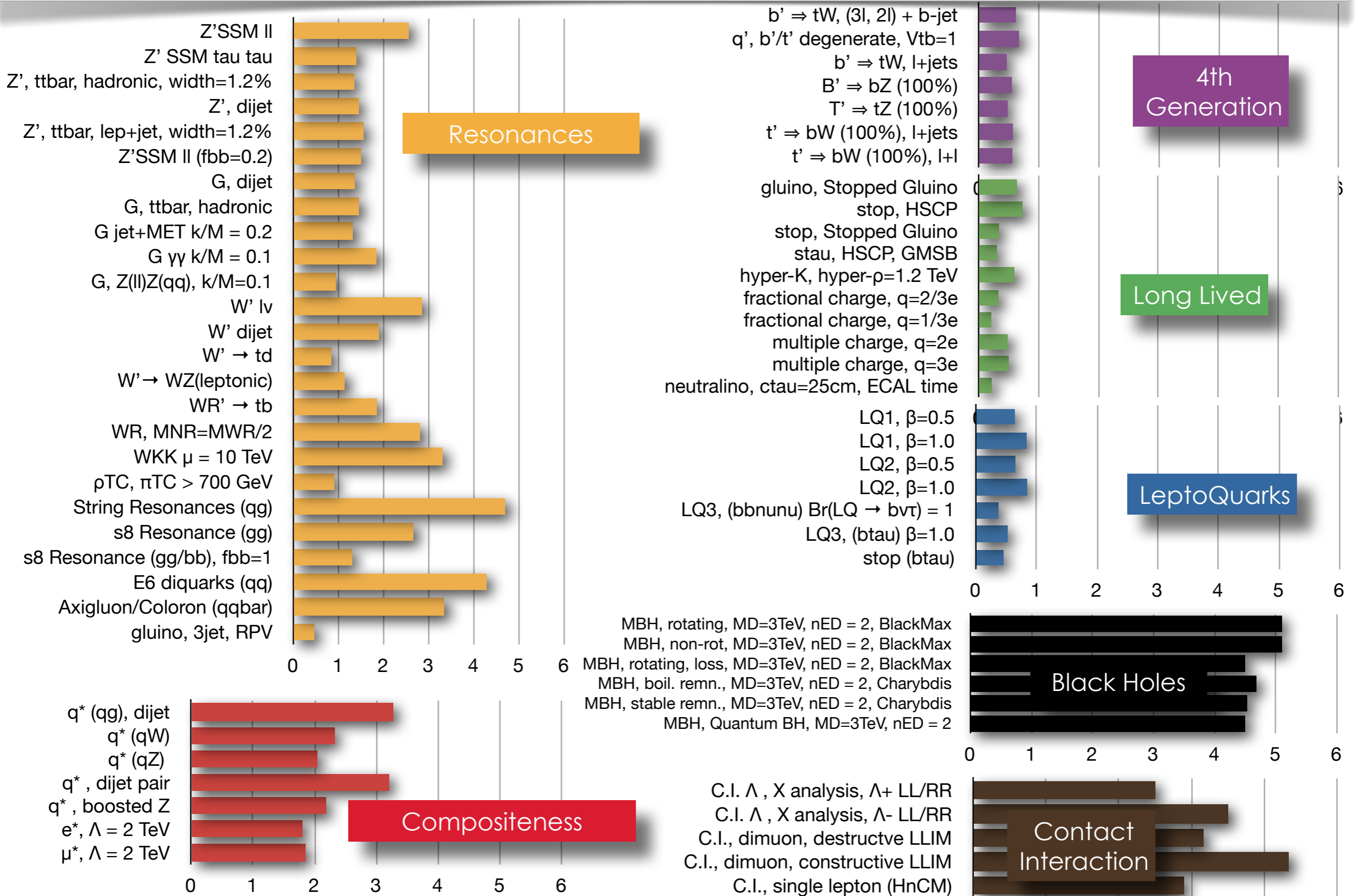
Non trivial pressure on MC production due to way too many tiny signal samples

Shahram Rahatlou, Roma Sapienza & INFN

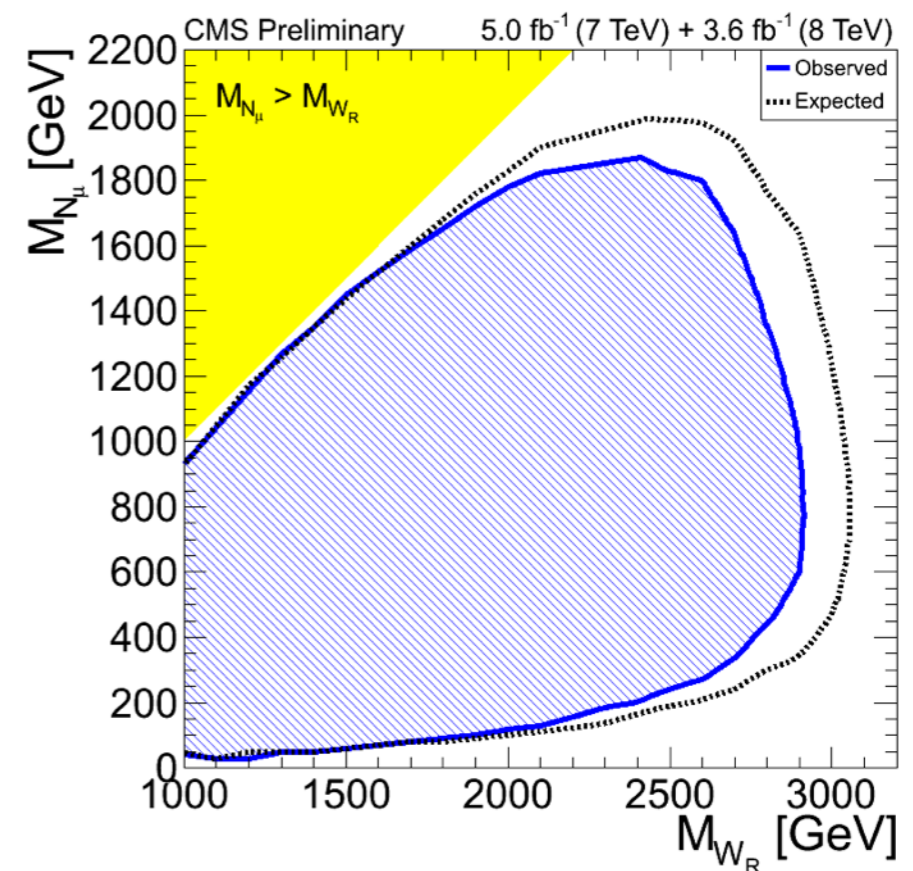
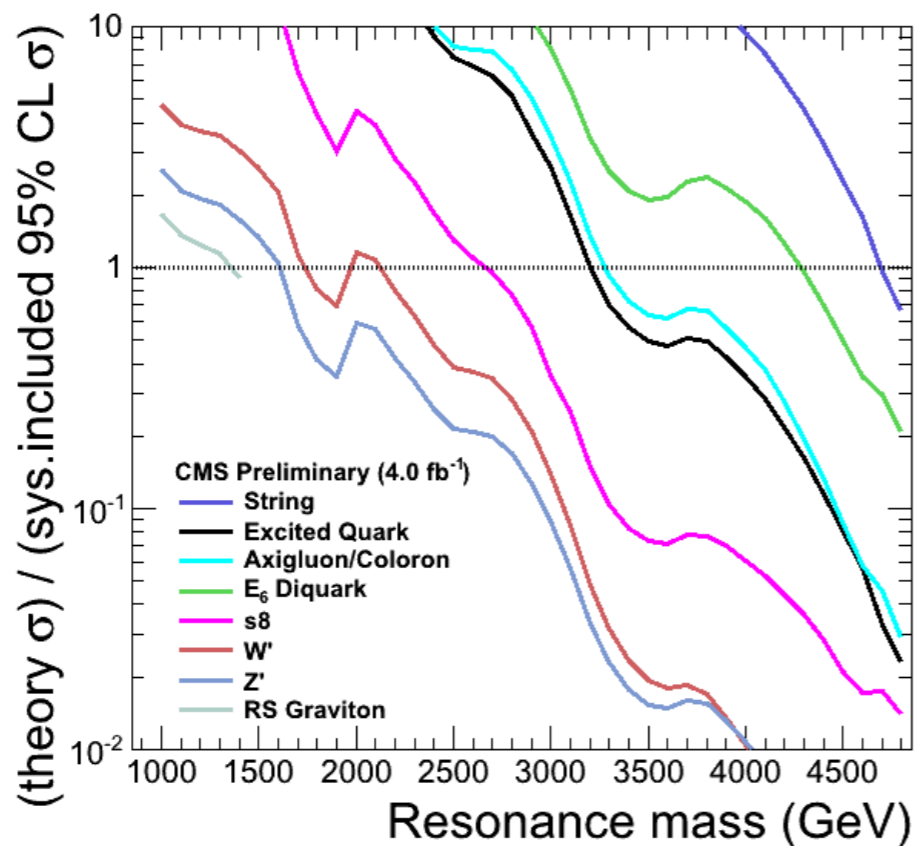
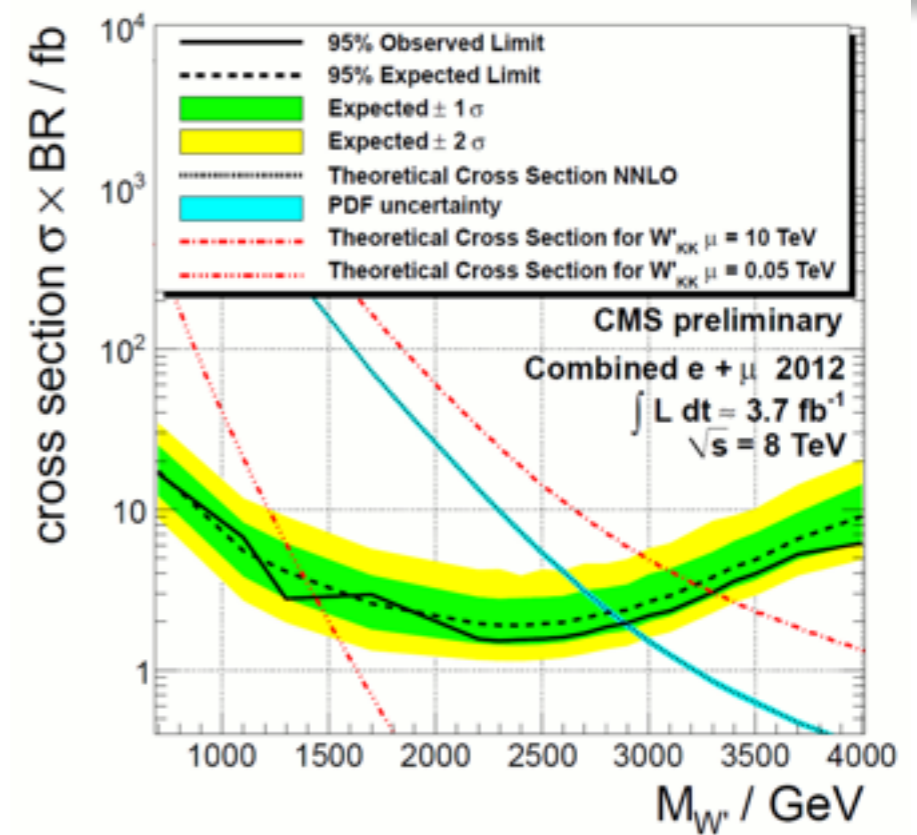
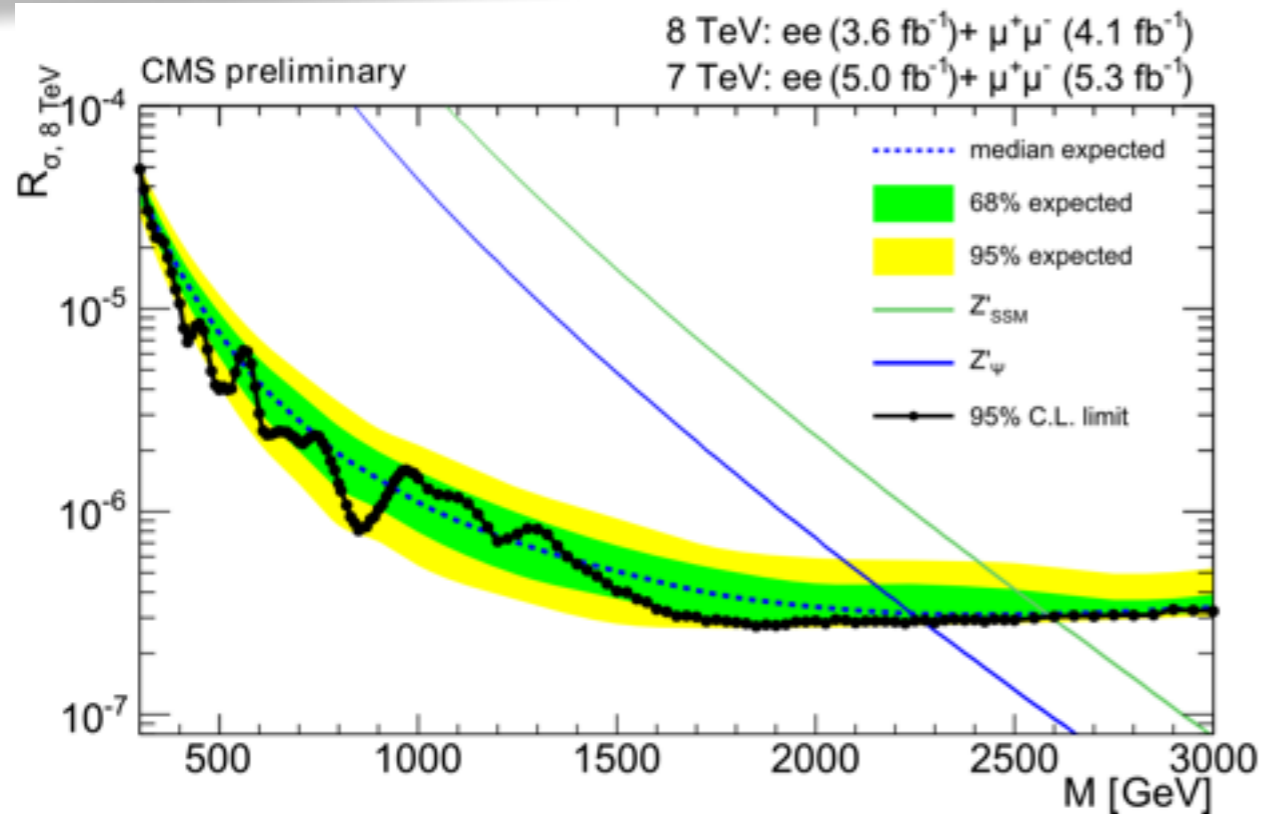
Preliminary Results - 2011 Run

Analysis	Approved Plots	CDS Entry	Luminosity
Search for 1st generation LQ	EXO11027		5/fb
Search for 2nd generation LQ	EXO11028		5/fb
Search for Heavy Majorana Neutrinos with same sign dileptons NEW	EXO11076		5/fb
Search for Narrow Resonances using the Dijet Mass Spectrum NEW	EXO11094	PAS EXO11094	5/fb
Search for b-jet Resonances NEW	EXO11008	PAS EXO11008	5/fb
Search for qW/qZ/WW/WZ/ZZ-Resonances in the W/Z-tagged Dijet Mass Spectrum NEW	EXO11095	PAS EXO11095	5/fb
Search for Excited Leptons NEW		PAS EXO11034	5/fb
Search for third generation leptoquarks in tau+b NEW	EXO12002	PAS EXO12002	5/fb
Search for Long-Lived Particles using Displaced Photons NEW	EXO11035	PAS EXO-11-035	5/fb
Search for multi-charged Heavy Stable Charged Particles NEW	EXO11090	PAS EXO11090	5/fb
Search for fractionally charged tracks NEW	EXO11074	PAS EXO11074	5/fb
Search for B' to bZ NEW	EXO11066	PAS EXO11066	5/fb
Inclusive search for a sequential fourth generation of quarks NEW	EXO11098	PAS EXO-11-098	5/fb
Search for Heavy Resonances Decaying to Long-Lived Neutral Particles in the Displaced Lepton channel	EXO11101	PAS EXO-11-101	5/fb
Search for ADD Extra-dimensions in Dielectrons	EXO12013	PAS EXO12013	5/fb
Search for high-mass resonances decaying to tt in the lepton+jets channel	EXO11093	PAS EXO-11-093	5/fb
Search for a heavy neutrino and right-handed W	EXO11091		5/fb
Search for narrow resonances decaying to Z(l)Z(qq)	EXO11102	PAS EXO-11-102	5/fb
Search for New Physics in Highly Boosted Z0 Decays to Dimuon	EXO11025	PAS EXO-11-025	5/fb
Search for Evidence of Contact Interactions in Dimuon Mass Spectrum	EXO11009	PAS EXO-11-009	5/fb
Updated Search for Three-Jet Resonances	EXO11060		5/fb
Search for exotic resonances decaying into V+Z using final states with a jet and a lepton pair	EXO11081	PAS EXO-11-081	5/fb
Search for W' -> t b in lepton + jets	EXO12001	PAS EXO-12-001	5/fb
Search for Dijet Resonances in the Dijet Delta Eta Ratio	EXO11026	PAS EXO-11-026	2.2/fb
Search for the pair production of a fourth-generation up-type quark (t') in events with a lepton and at least 4 jets	EXO11099	PAS EXO-11-099	4.7/fb
Search for Randall-Sundrum Gravitons Decaying into a Jet plus Missing ET	EXO11061	PAS EXO-11-061	4.7/fb
Search for Z' to ttbar in high-mass (e+jets) channel	EXO11092	PAS EXO-11-092	4.7/fb

EXOTICA IN COLORS



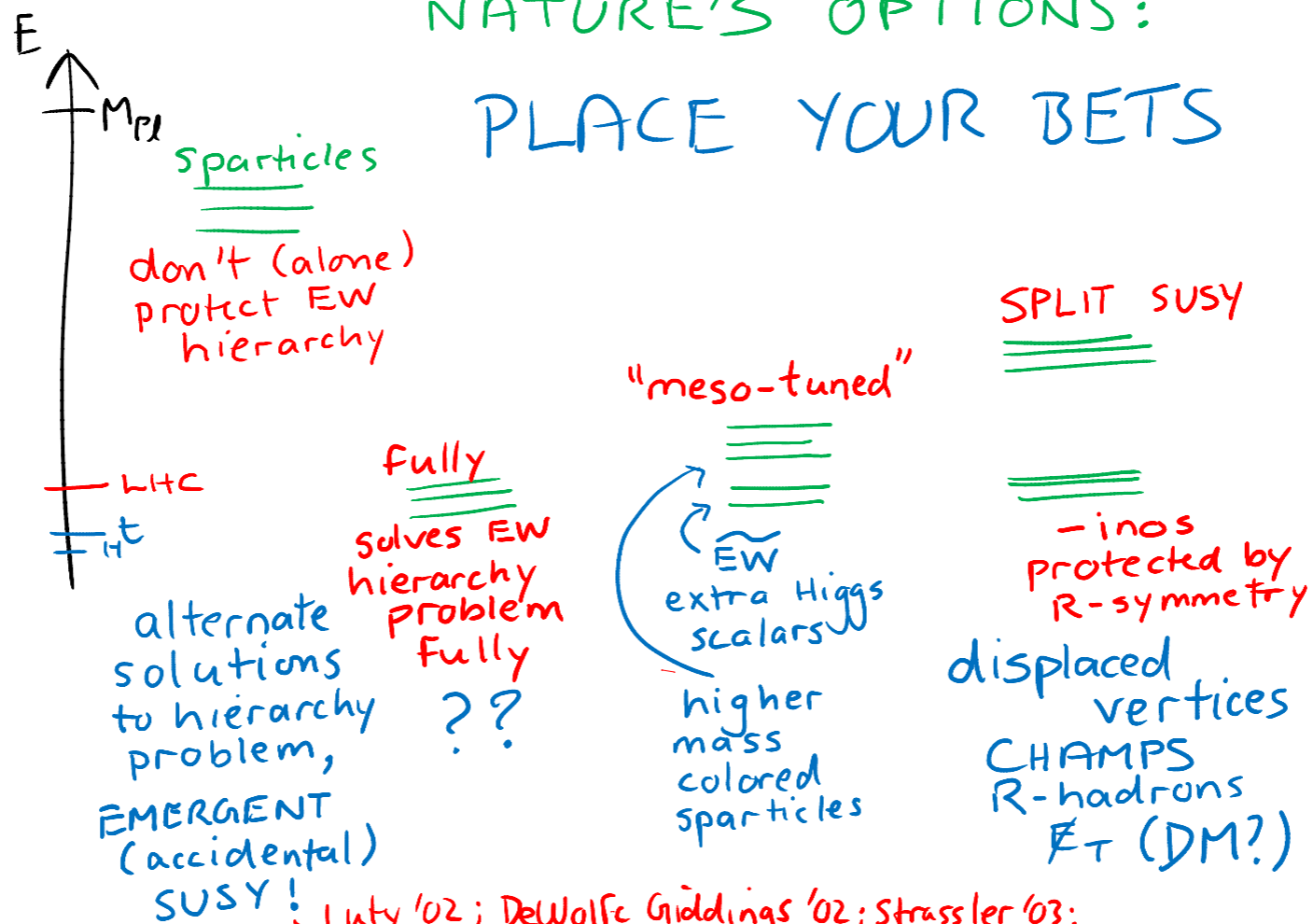
8 TeV SEARCHES AT ICHEP



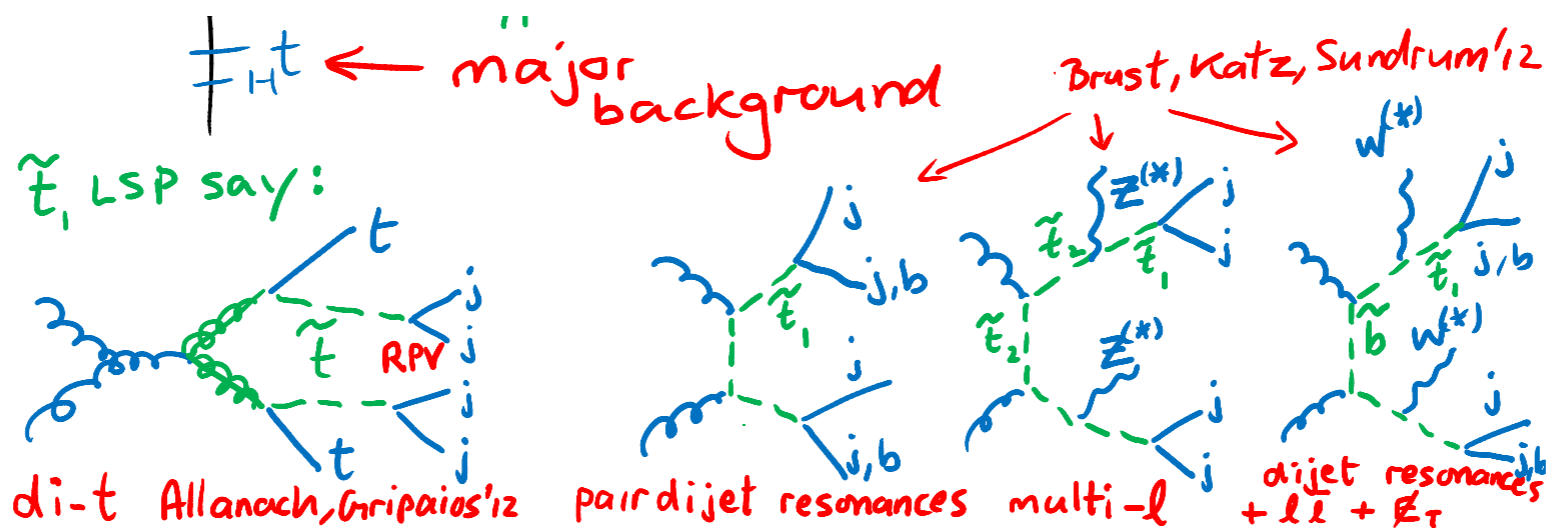
SUNDRUM @ ICHEP

NATURE'S OPTIONS:

PLACE YOUR BETS

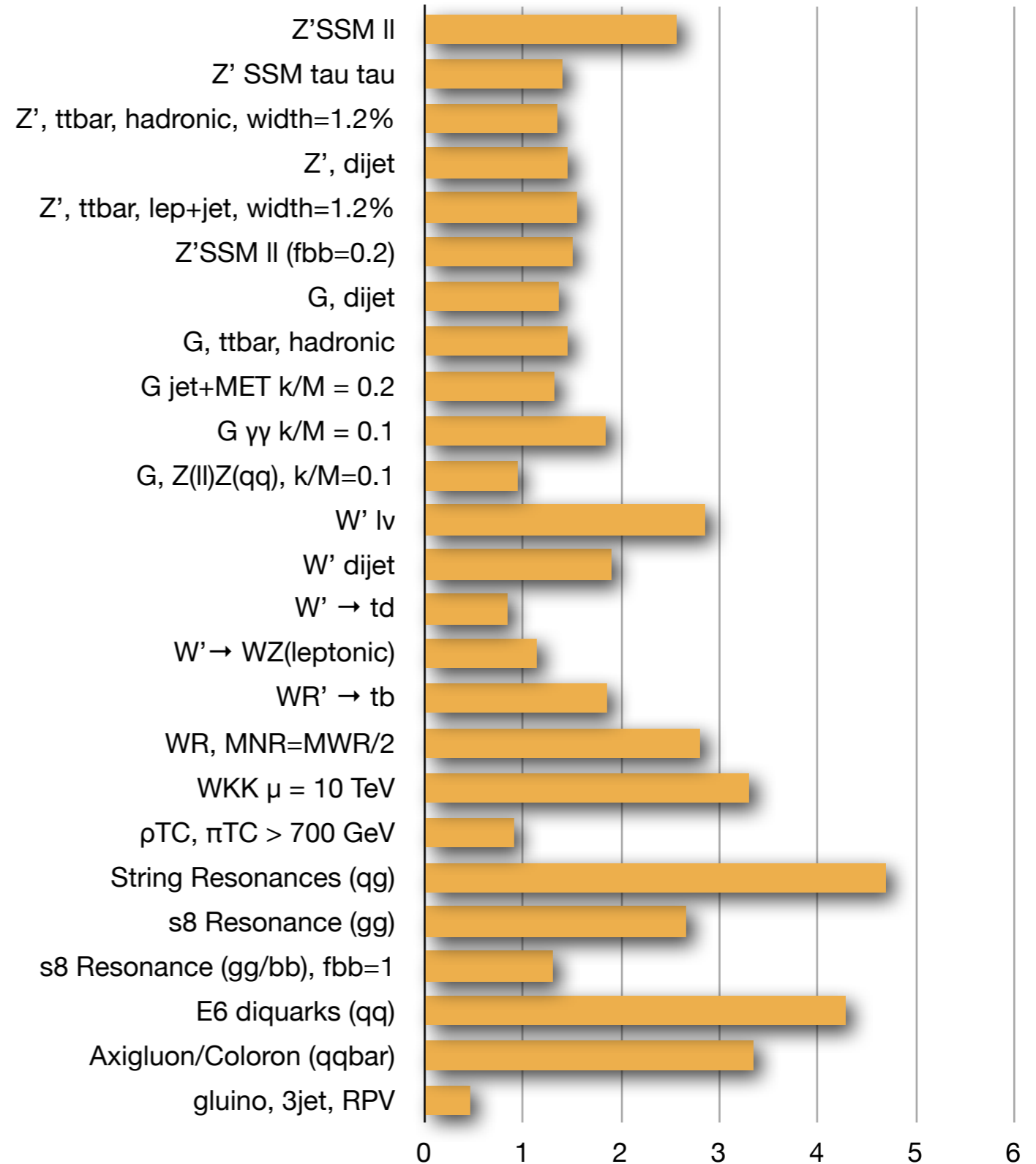


→ Luty '02; DeWolfe Giddings '02; Strassler '03; Gherghetta, Pomarol '03; Groh, Luty, Ng '03; Sundrum '09

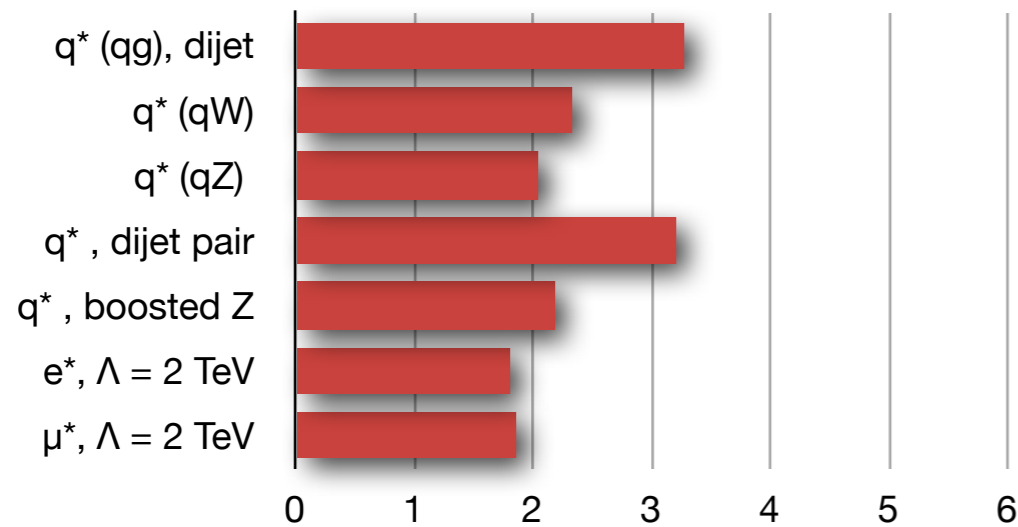


RESONANCES

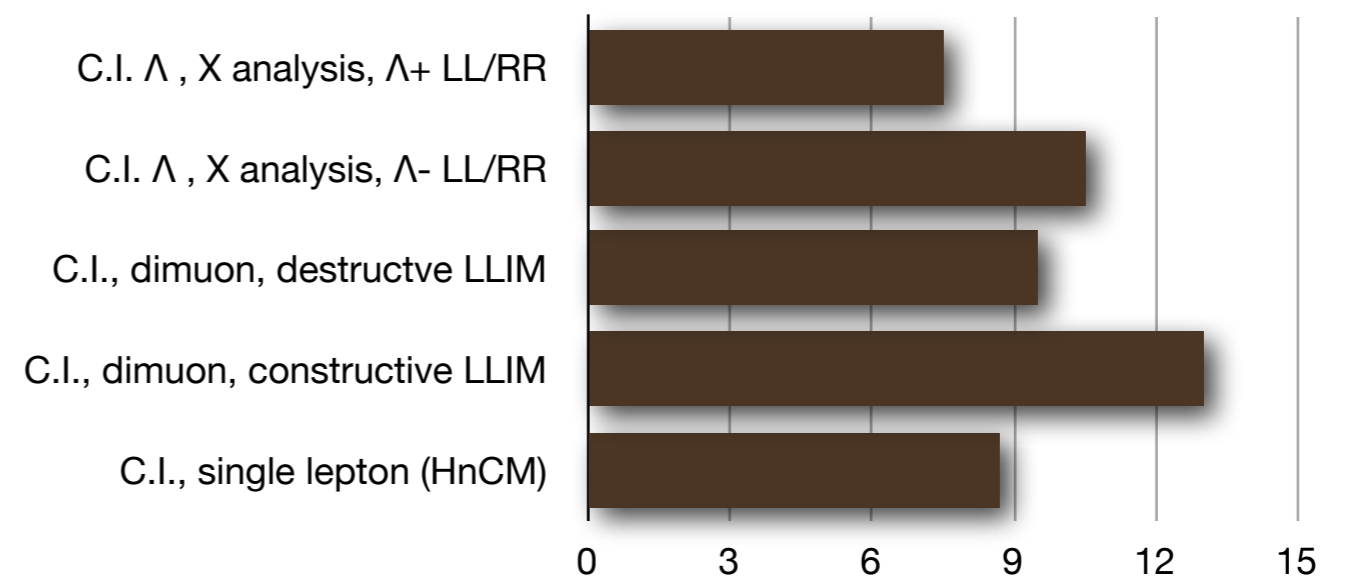
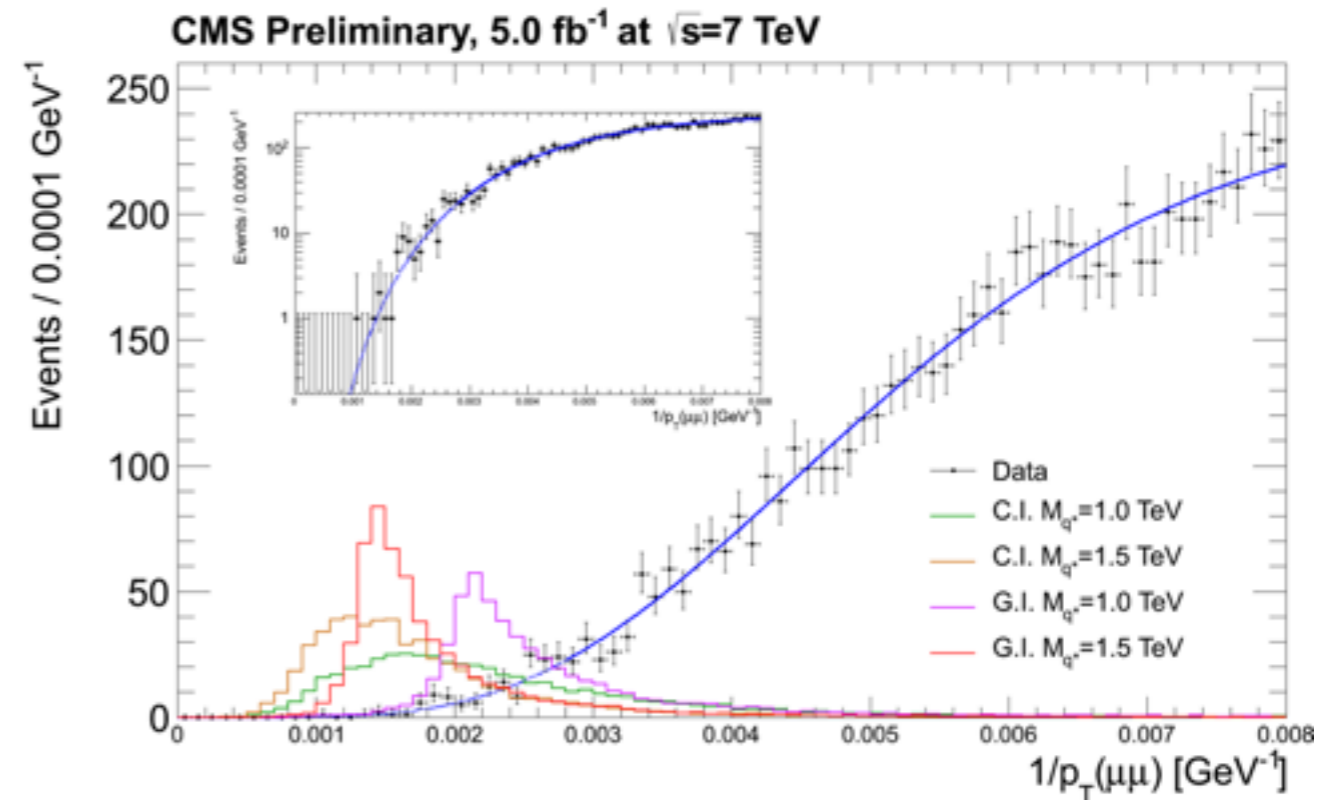
- Comprehensive list of signatures
 - dileptons(e,mu,tau), lepton +MET
 - 2-jet, 2--b-jet, ttbar, 3-jet, 4-jet
 - di-bosons (W/Z)
 - ▶ 3l+MET
 - ▶ 2l+2j
 - ▶ fatjet+MET, fatjet+l+MET
 - ▶ jet substructure for W/Z tag
 - 2-photon
- Variety of models tested
 - Flavors of extra dimensions
 - SSM, GUT
 - strings, axiguons, colorons
 - technicolor



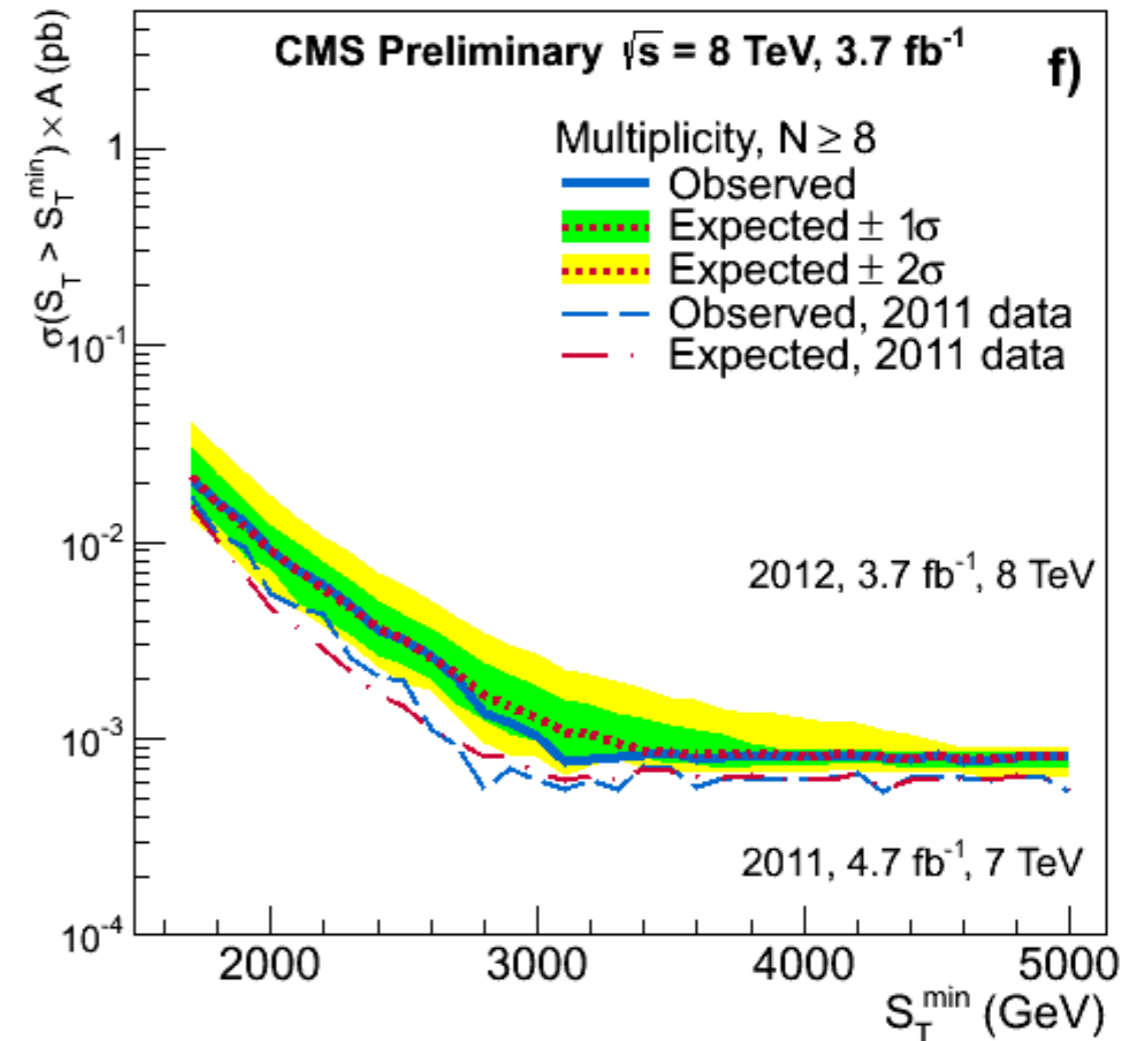
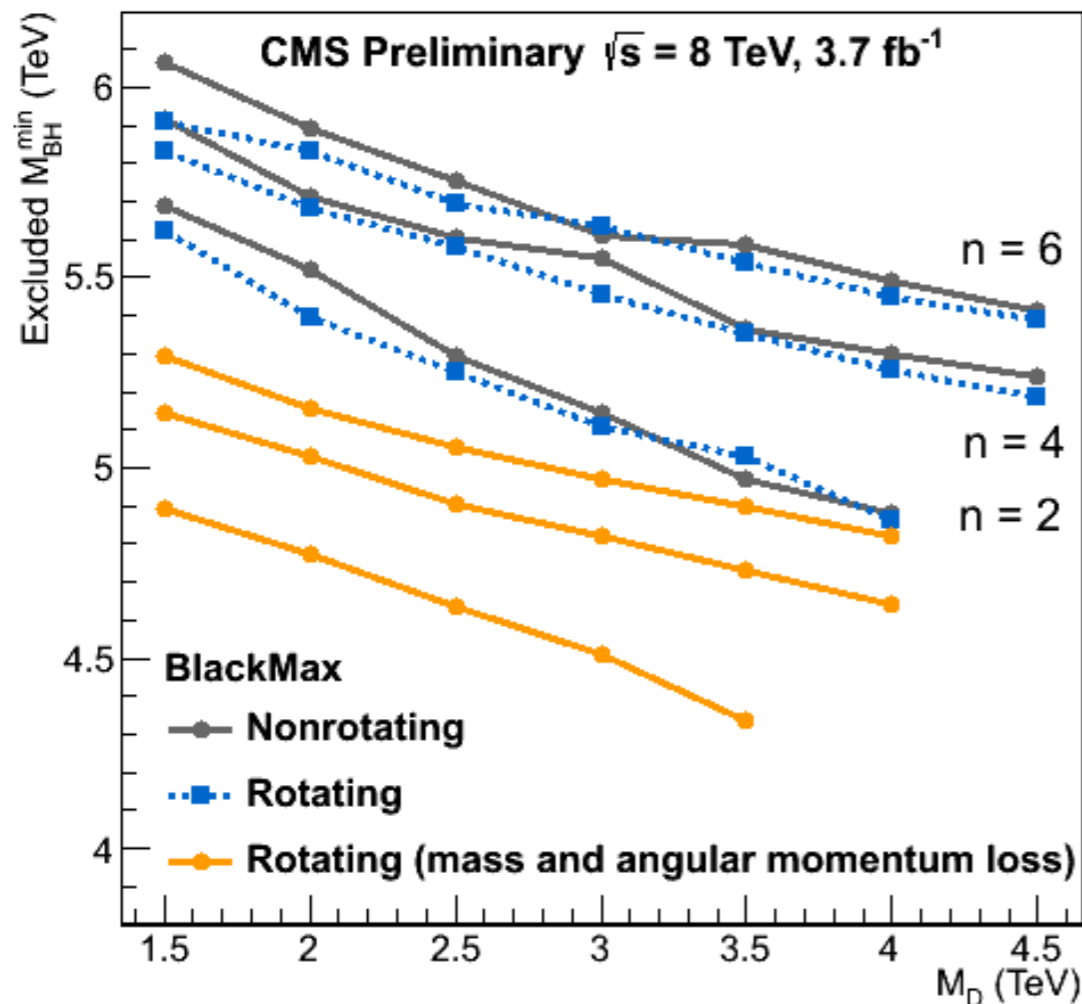
COMPOSITENESS AND CONTACT INTERACTION



- Excited quarks and leptons
- Both leptonic and hadronic states
 - lepton + photon ($l^* \rightarrow l + \text{gamma}$)
 - 2-jet ($q^* \rightarrow q \text{ glu}$)
 - boosted Z spectrum in $q^* \rightarrow q Z$
- Contact interaction
 - di-jet angular analysis
 - re-interpretation of di-lepton
 - re-interpretation of W'

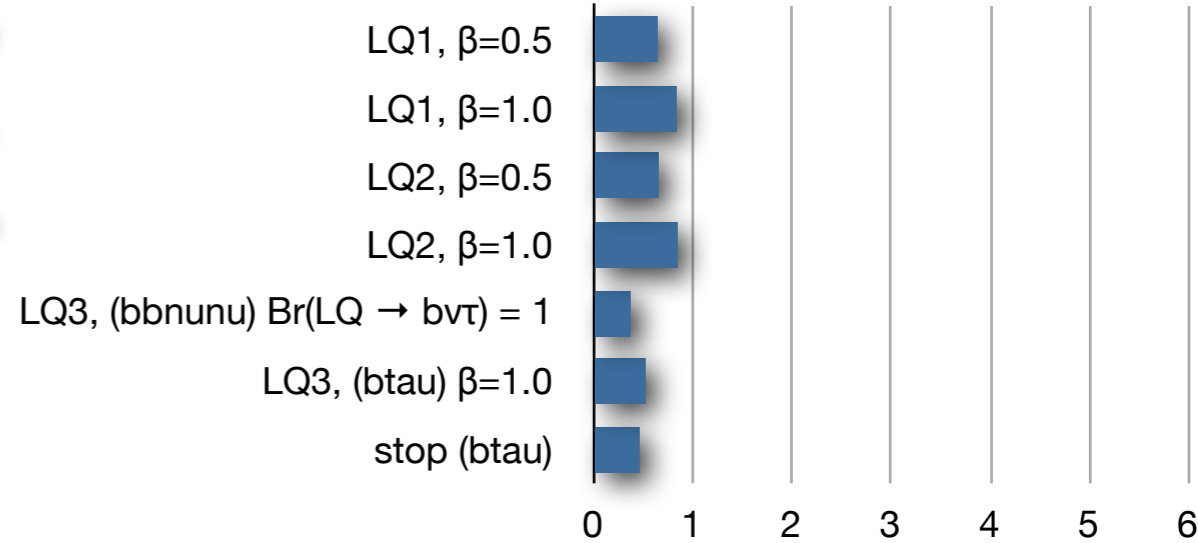
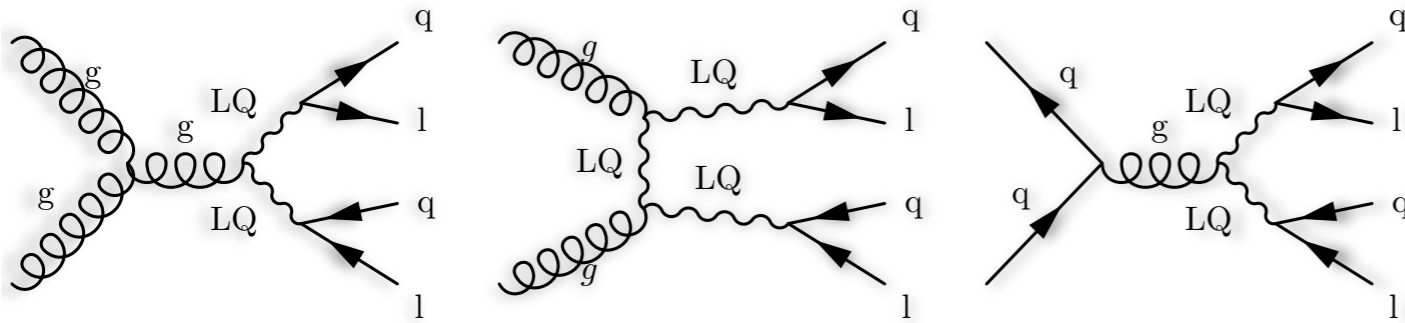


BLACK HOLES

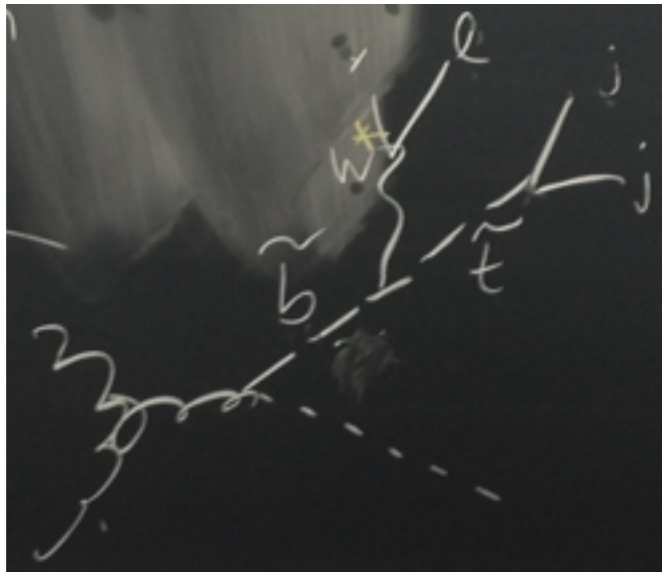


- Significant increase in signal cross section at 8 TeV
 - no signal yet unfortunately
 - Limits already competitive with full 2011 data
- Model independent limit useful for model building
 - S_{T} : sum of all p_{T} of reconstructed objects of interest

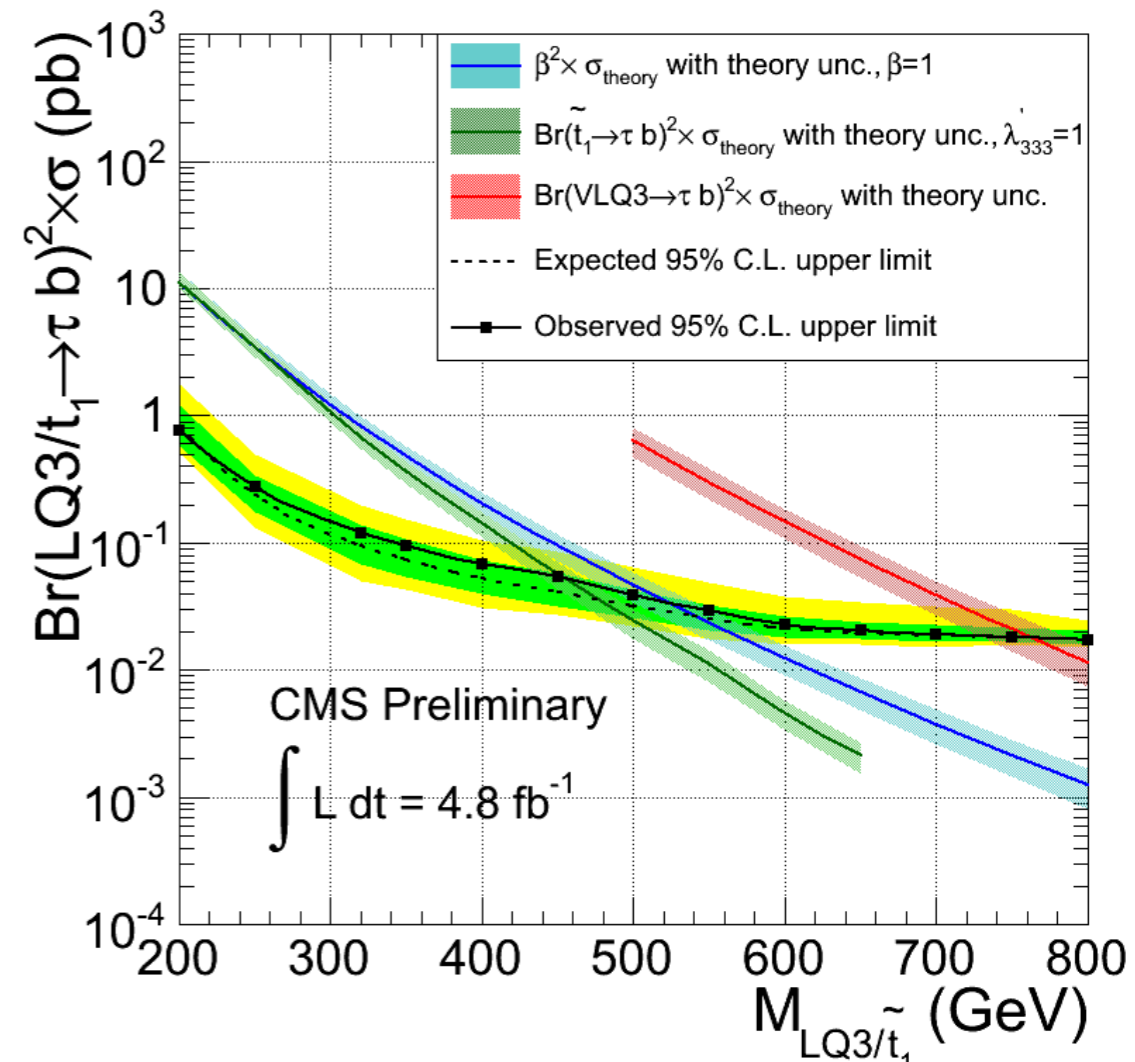
LEPTOQUARKS (AND MORE)



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

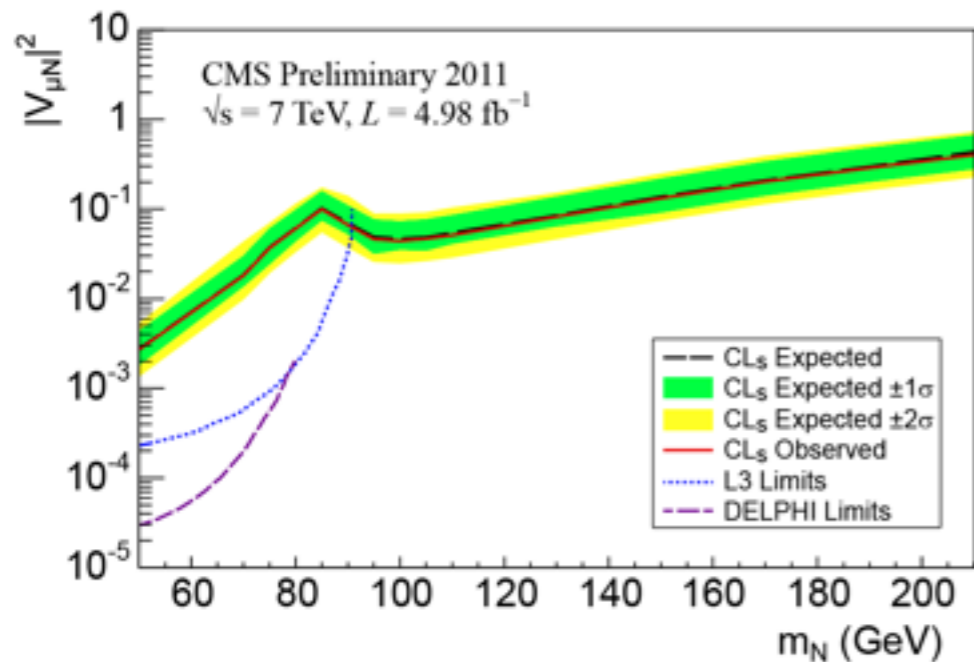
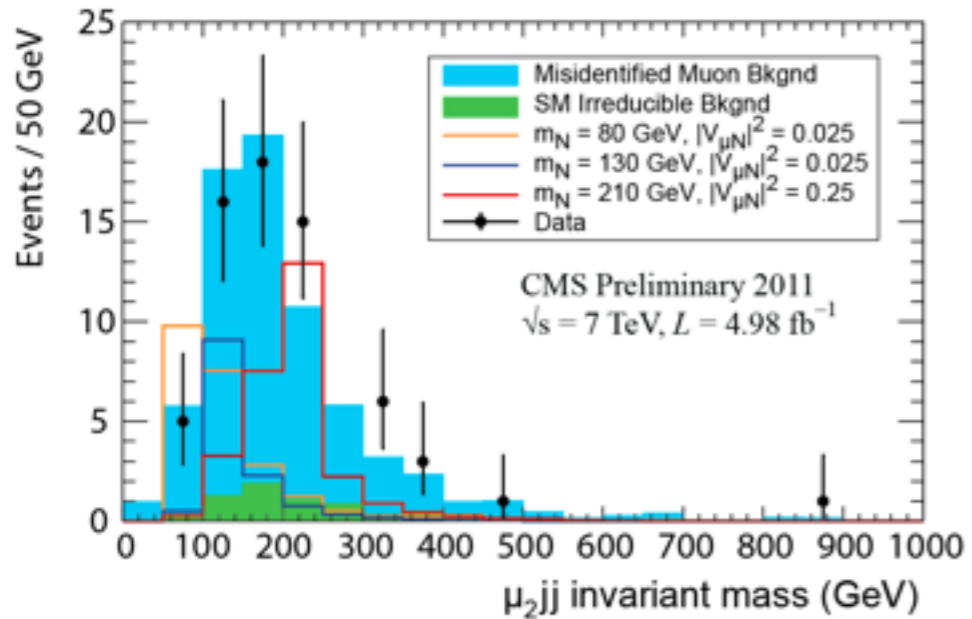
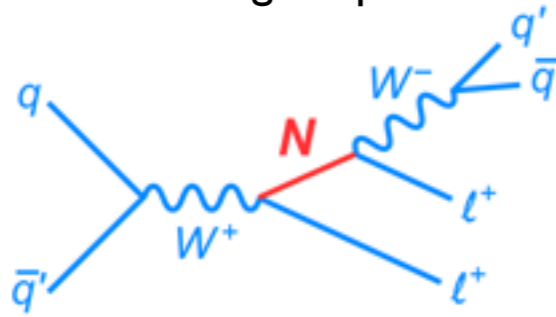


- Also used for heavy neutrino searches
- Flavor violation studies as at Hera not considered yet

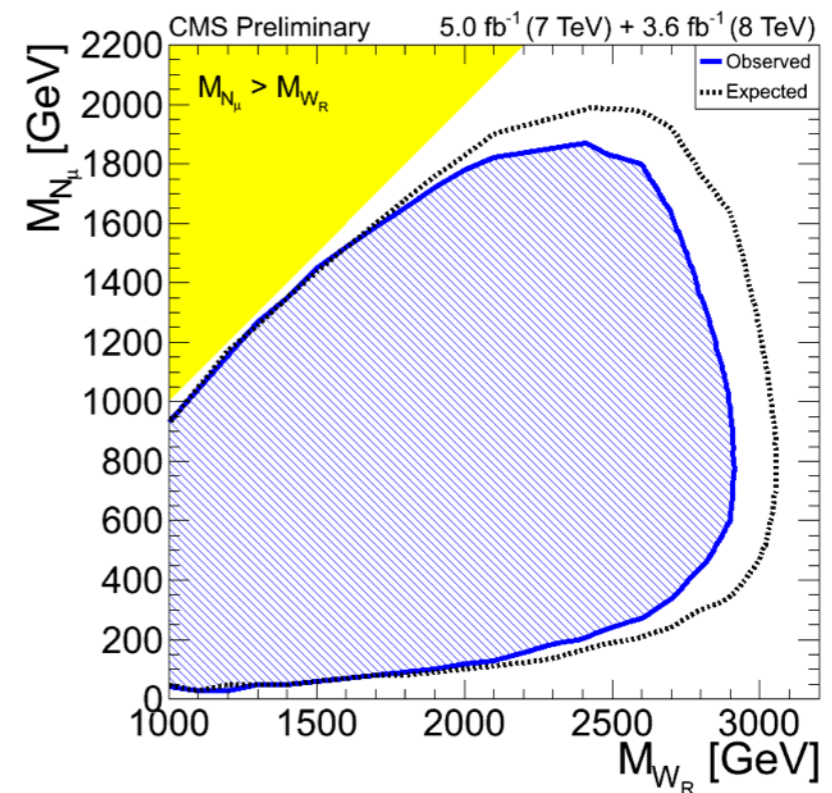
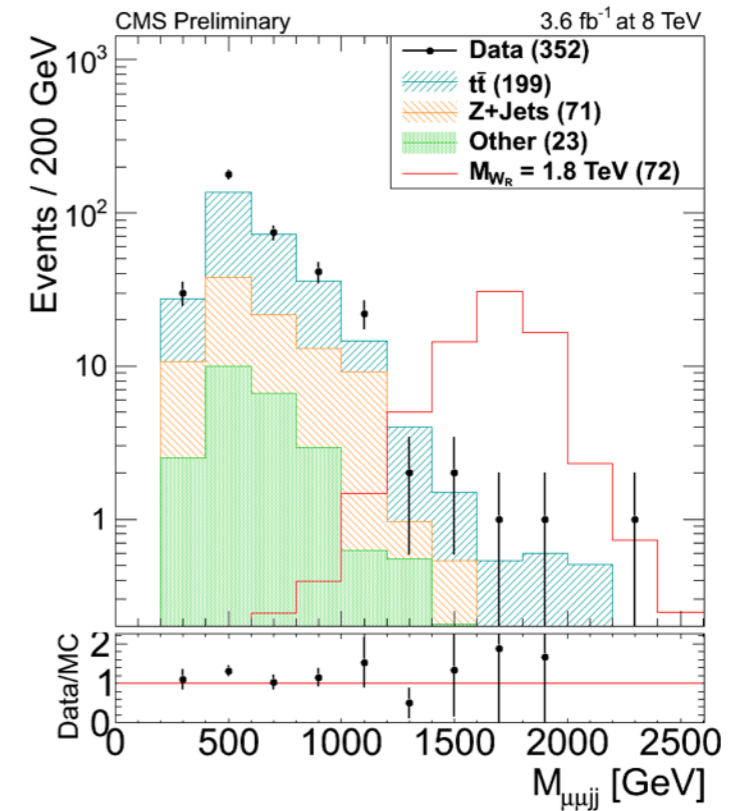


NEUTRINOS

Majorana Neutrino
with same sign dilepton

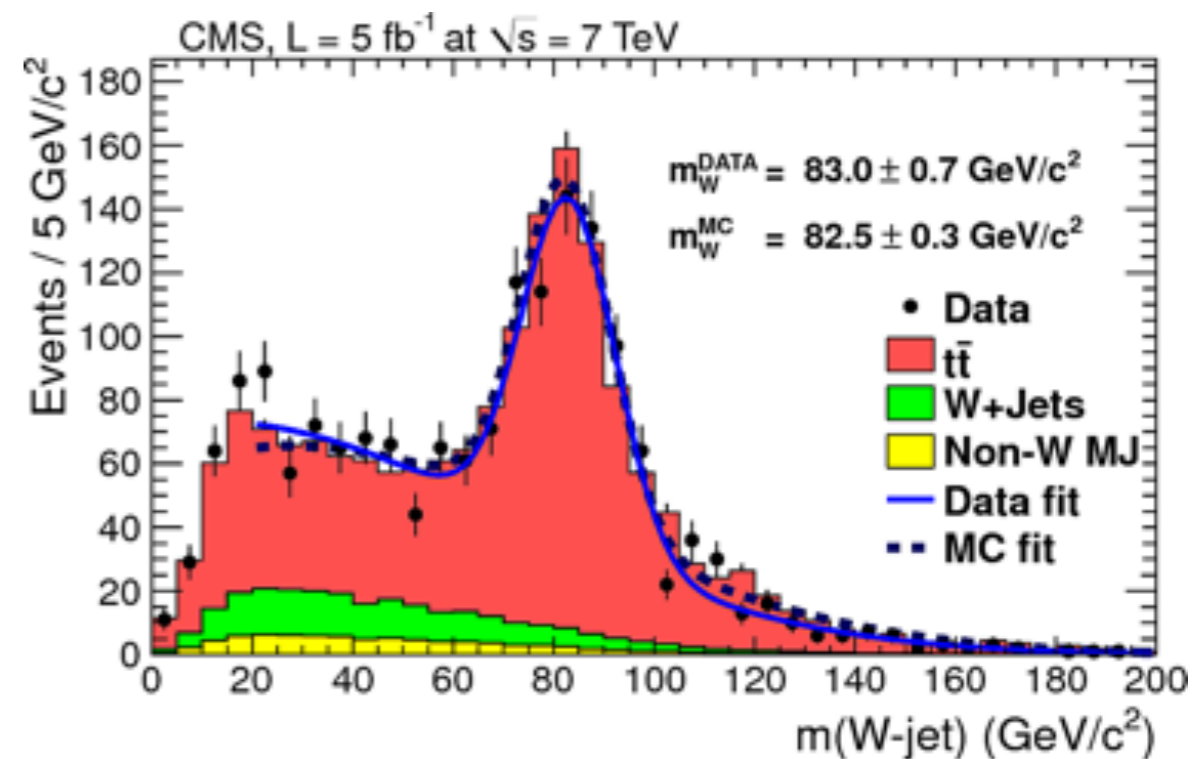
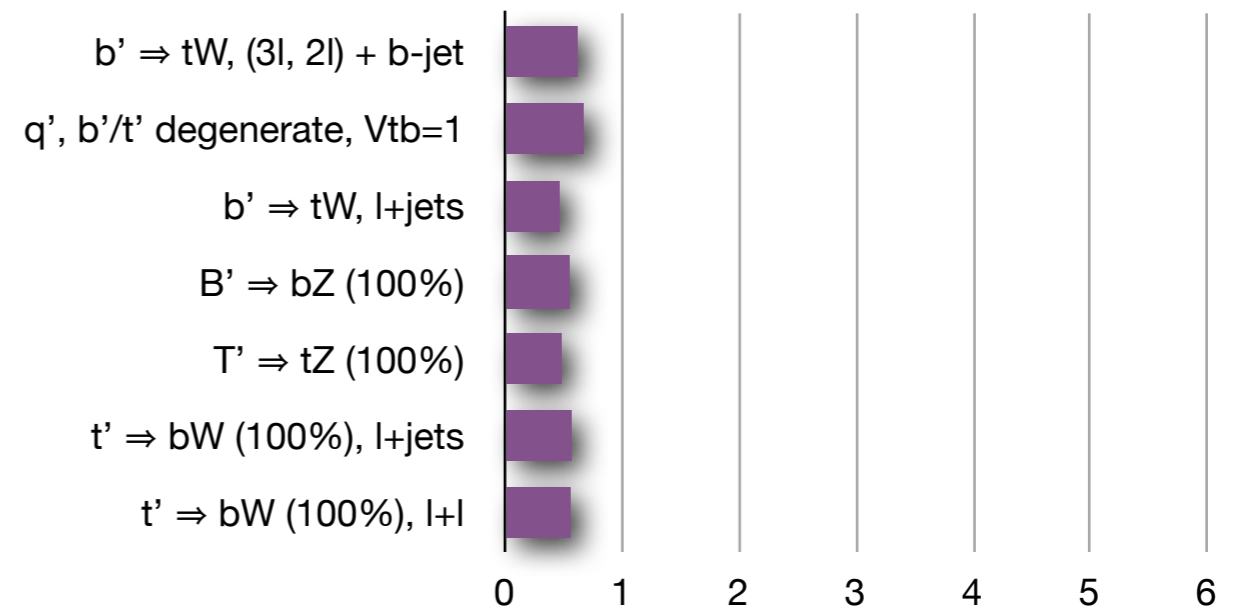


$$W_R \rightarrow \mu_1 N_\mu \rightarrow \mu_1 \mu_2 W_R^* \rightarrow \mu_1 \mu_2 jj$$

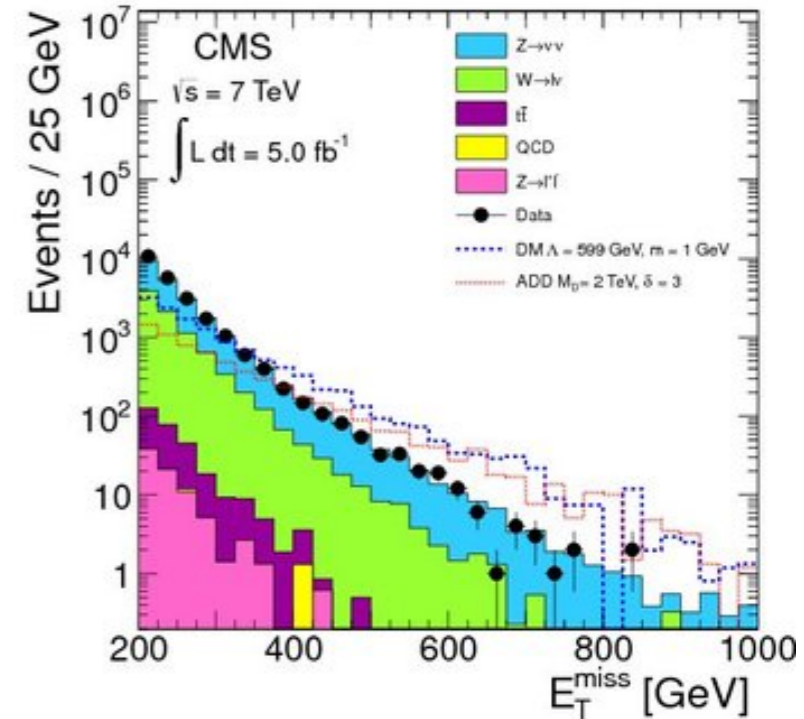
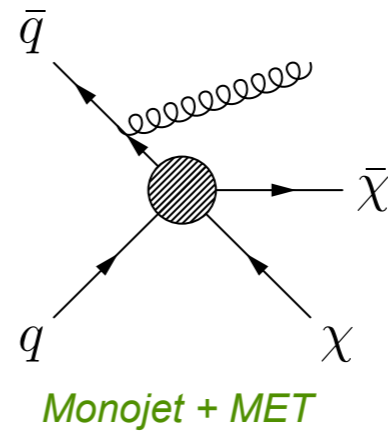
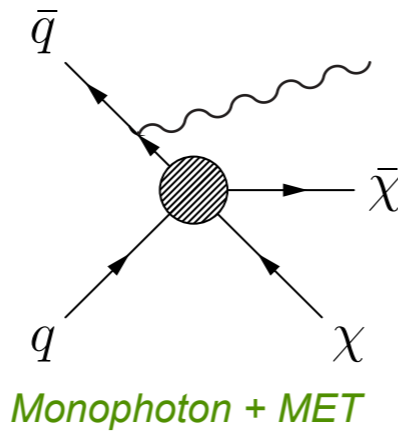
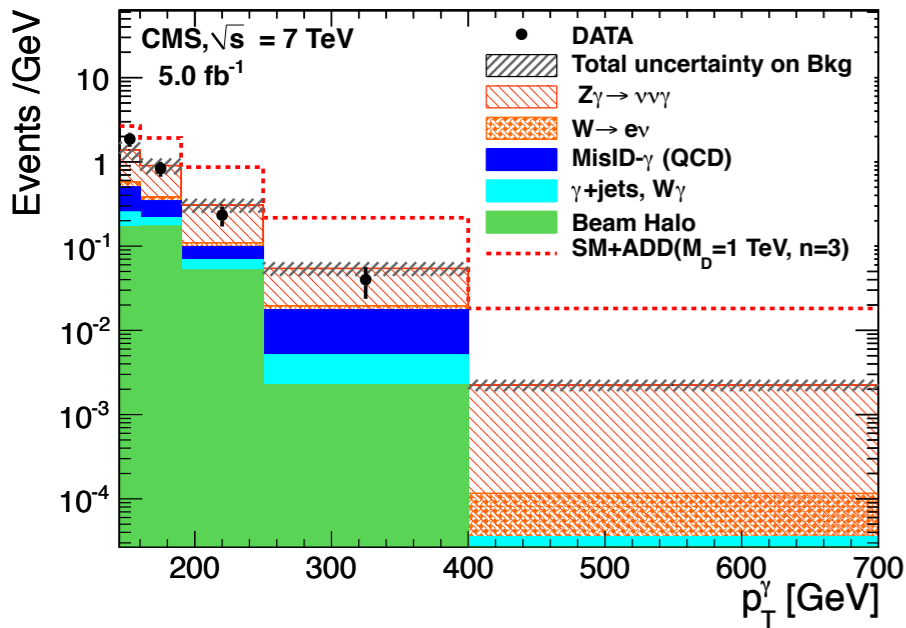


4TH GENERATION AND TTBAR

- Rich program for 4th generation
 - leptons
 - lepton+jets
 - all hadronic
- More challenging modes like top +gamma not yet done
- ttbar resonances across the spectrum
 - boosted top technique at high mass
 - lepton + jets
- More exotic top partners understudy
 - some discussed yesterday
- Rich program now handed to dedicated analysis group for further extension

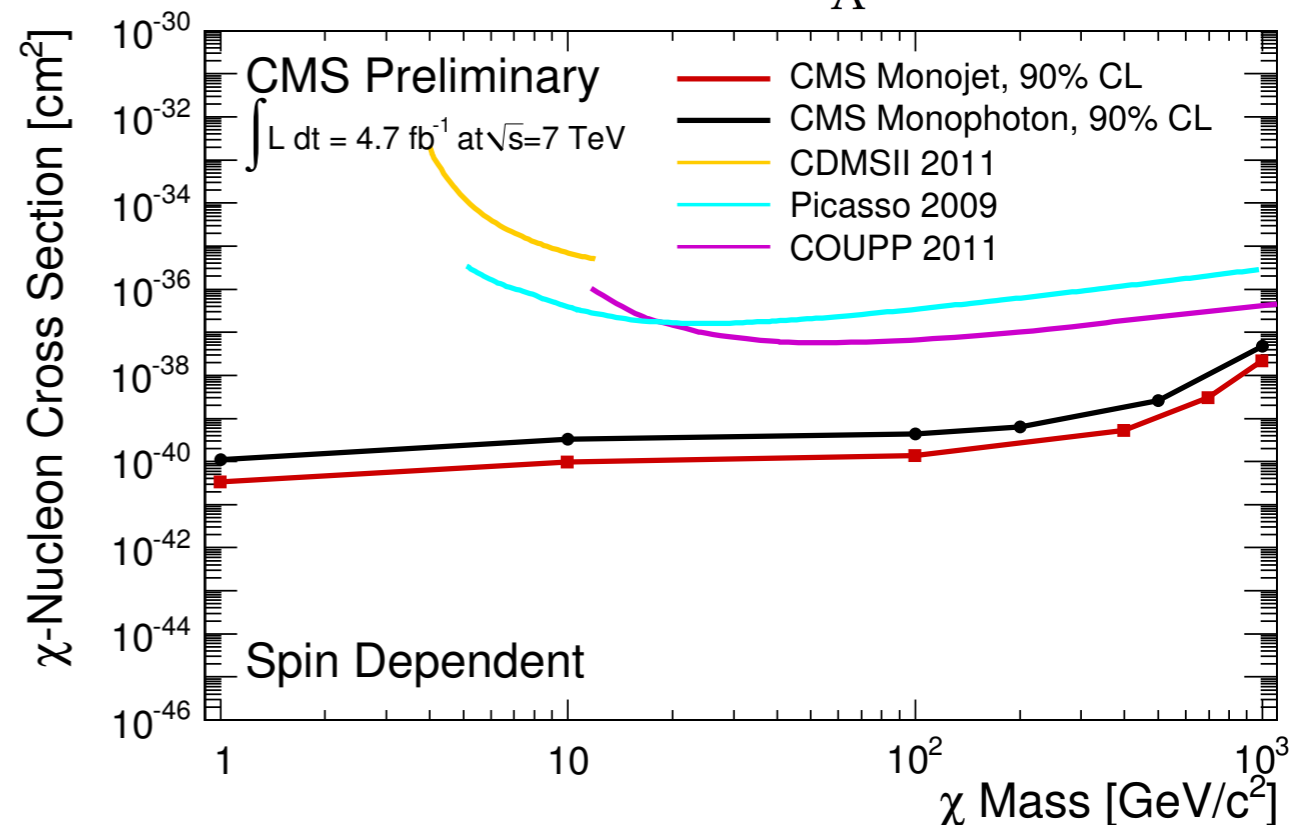
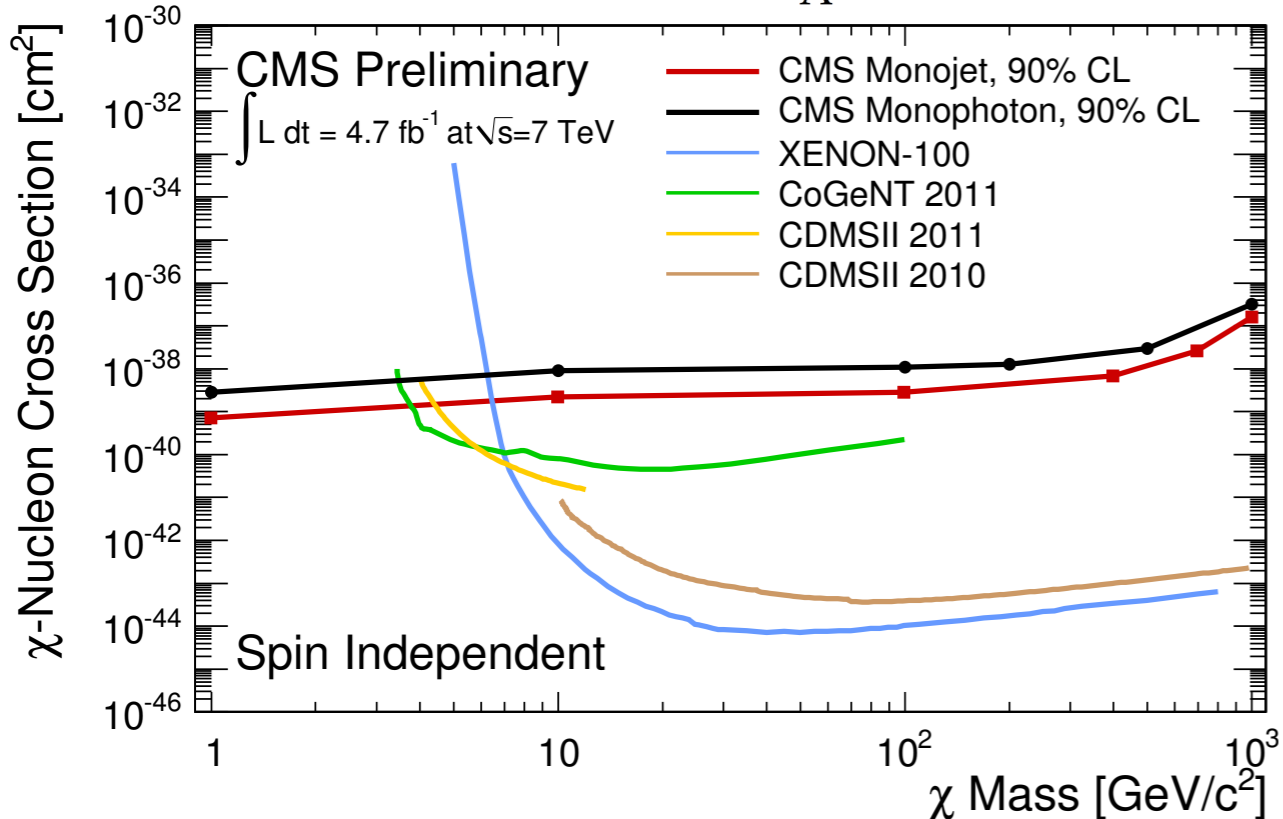


DARK MATTER



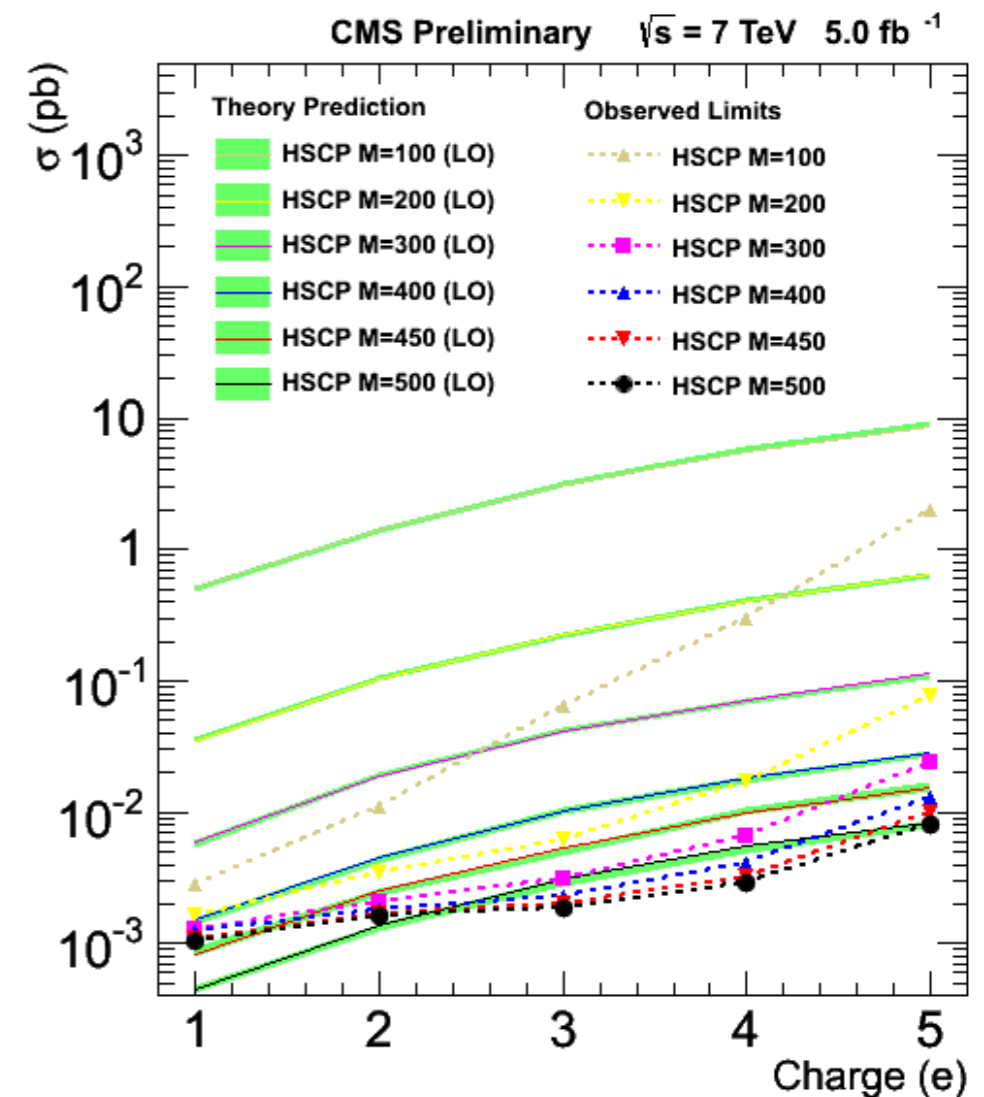
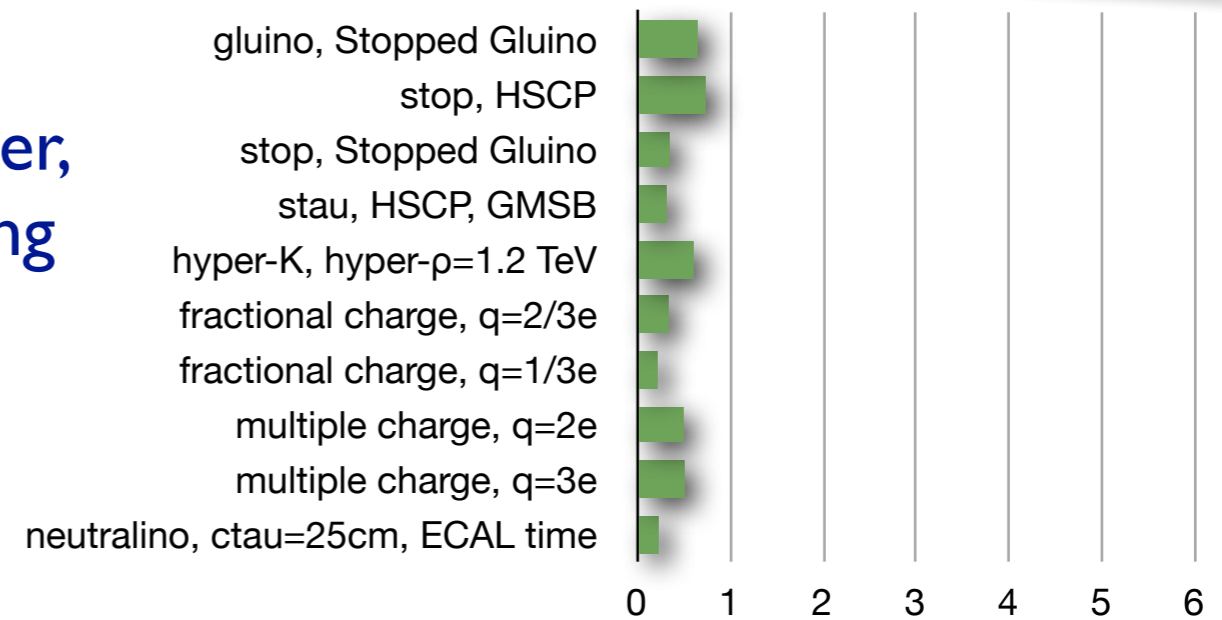
$$\mathcal{O}_V = \frac{(\bar{\chi}\gamma_\mu\chi)(\bar{q}\gamma^\mu q)}{\Lambda^2}$$

$$\mathcal{O}_{AV} = \frac{(\bar{\chi}\gamma_\mu\gamma_5\chi)(\bar{q}\gamma^\mu\gamma_5q)}{\Lambda^2}$$



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
 - now also multiple charge
- 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



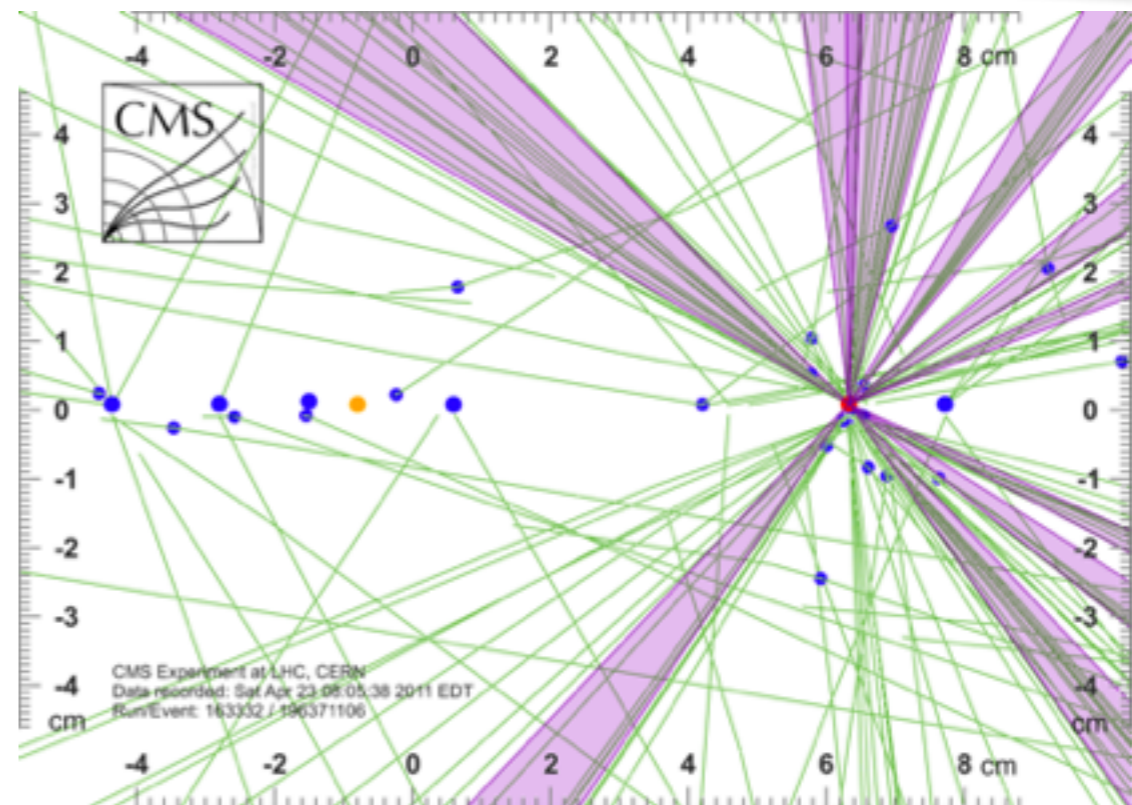
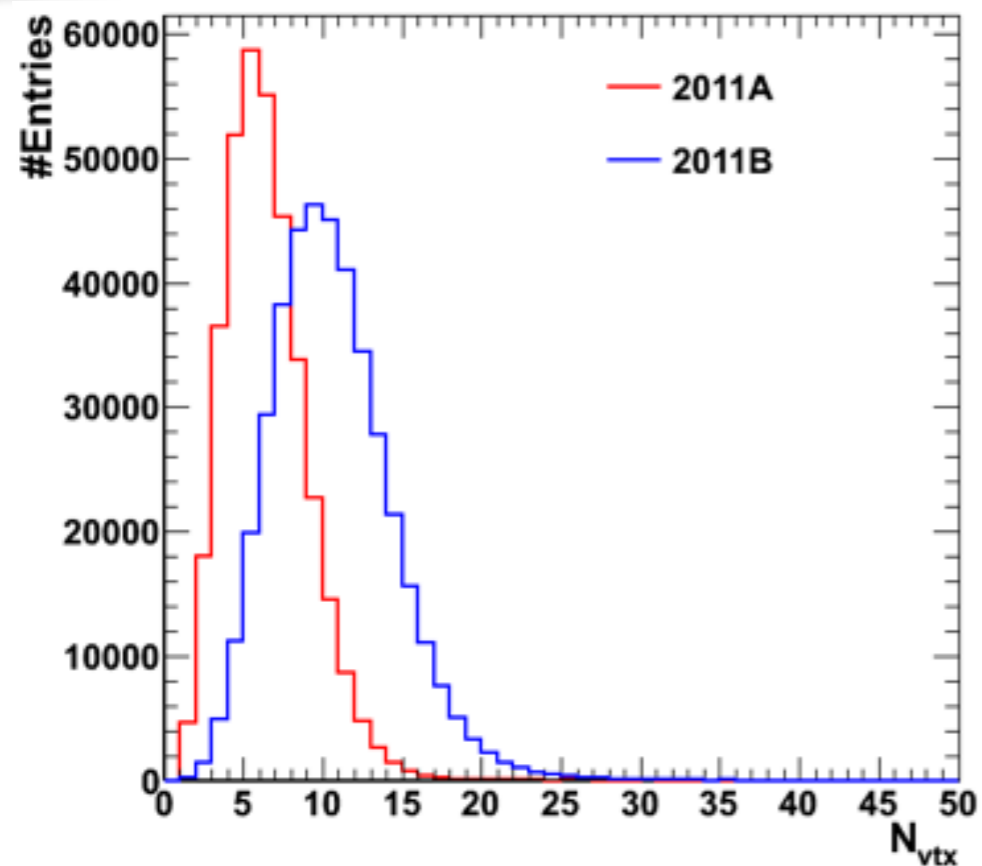
LET THERE BE PHOTONS

- Relatively few searches using photons
 - diphoton ADD and RS graviton
 - ▶ still only 2/fb
 - displaced photon with MET and jets
 - di-photon+jet+met in SUSY
- Not too many exotic signature include photons
 - Child of a minor god? Interesting scenarios during RPV parallel
- Experimental challenges
 - backgrounds can be tough
 - ▶ genuine di-photons dominate at high mass
 - Triggers also a concern
 - ▶ Single Photon thresholds up from 75 GeV (low!) to 135 GeV in 2011
 - ▶ now a new (cleaned) path with $p_t > 70$ GeV
 - Fighting ECAL spikes
 - ▶ time requirements make it more complicated for long-lived studies

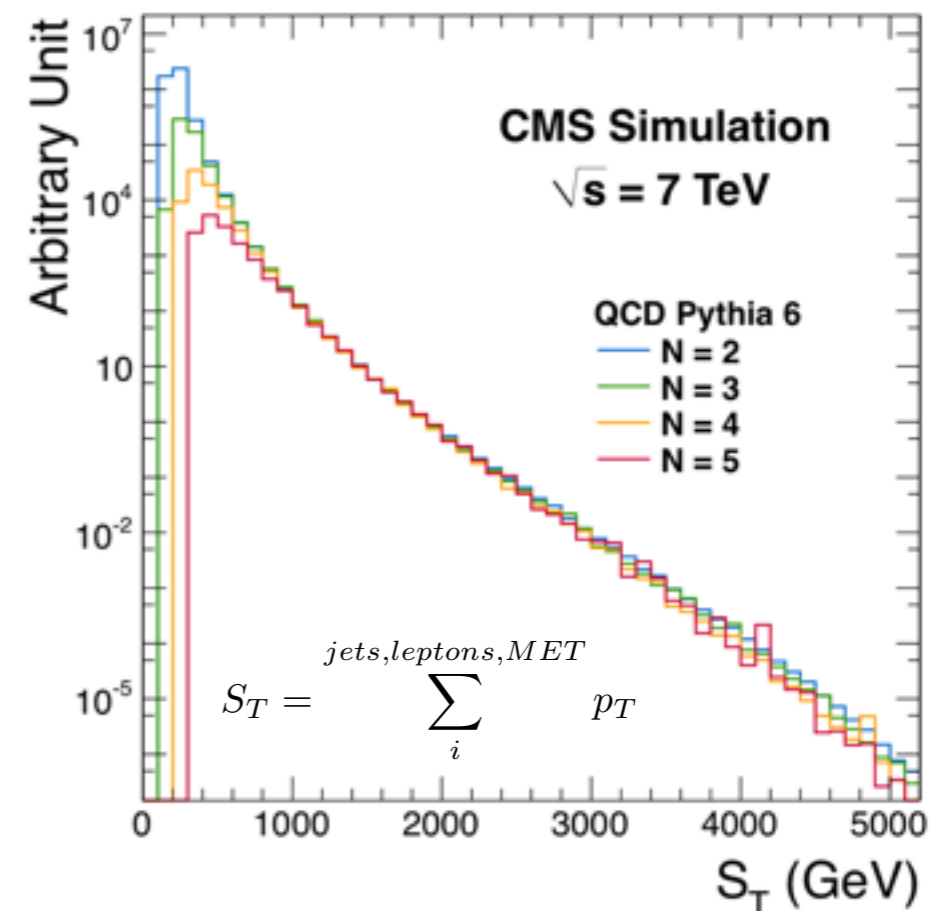
EXPERIMENTAL CHALLENGES

- Trigger thresholds
 - Standard dijet search starts at 1 TeV
 - dijet stream a nice addition to probe low mass region
 - Single photon trigger now at 70 GeV with some more isolation
 - ▶ cross trigger in 2011 to keep 90 GeV + 3 jets
 - ➔ Are we sure there is no low pt photon signature of interest?
- Weird reconstruction
 - fractionally charged: understanding impact of detector geometry
 - displaced photons need to redo photons from un-cleaned clusters
- Long-lived searches
 - time measurement in ECAL
 - ▶ later calibration and certification compared to energy
 - ➔ no other analyses using it hence less urgent
 - ▶ useful also for monopole search

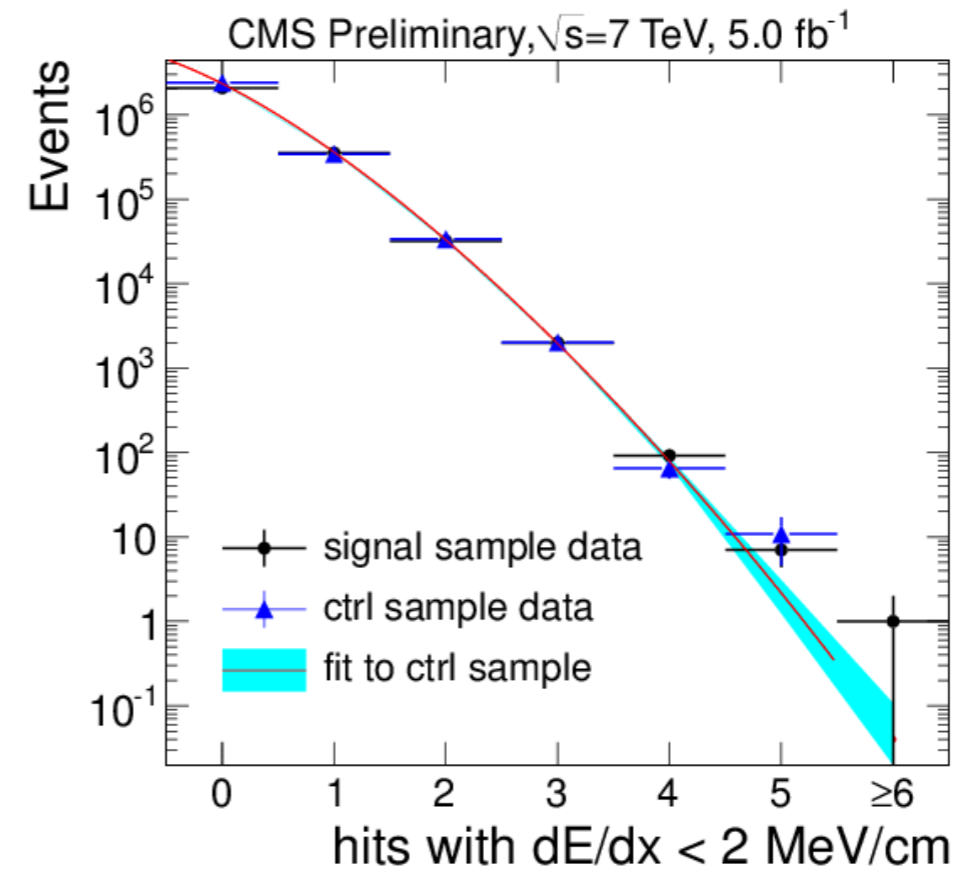
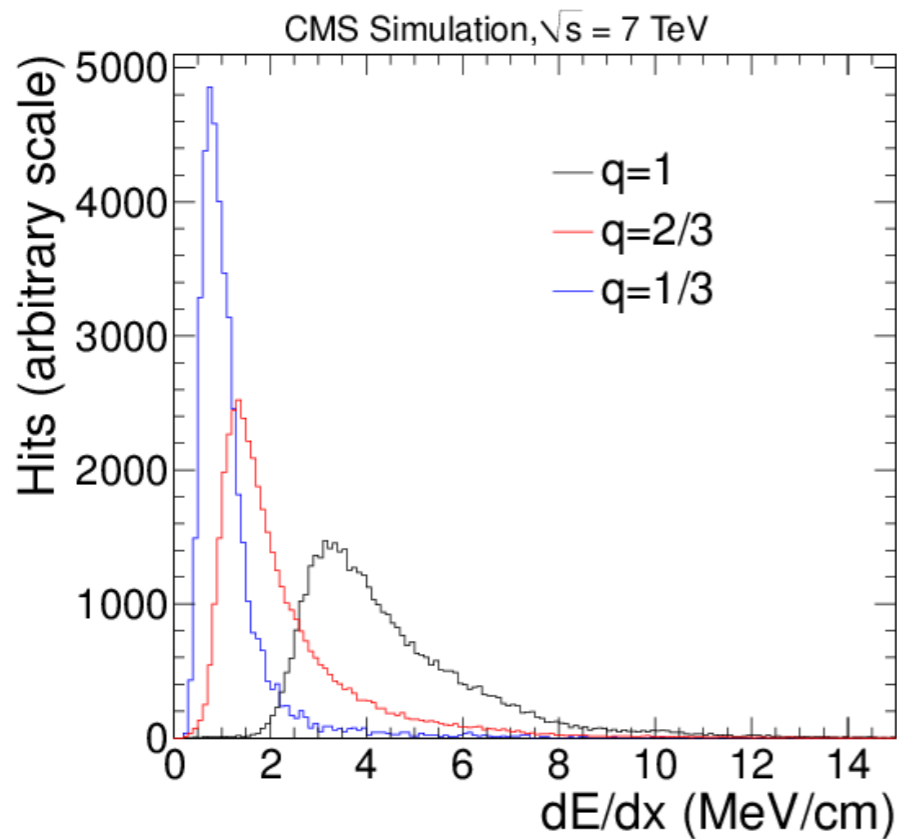
OUR BIG ENEMY: PILE-UP



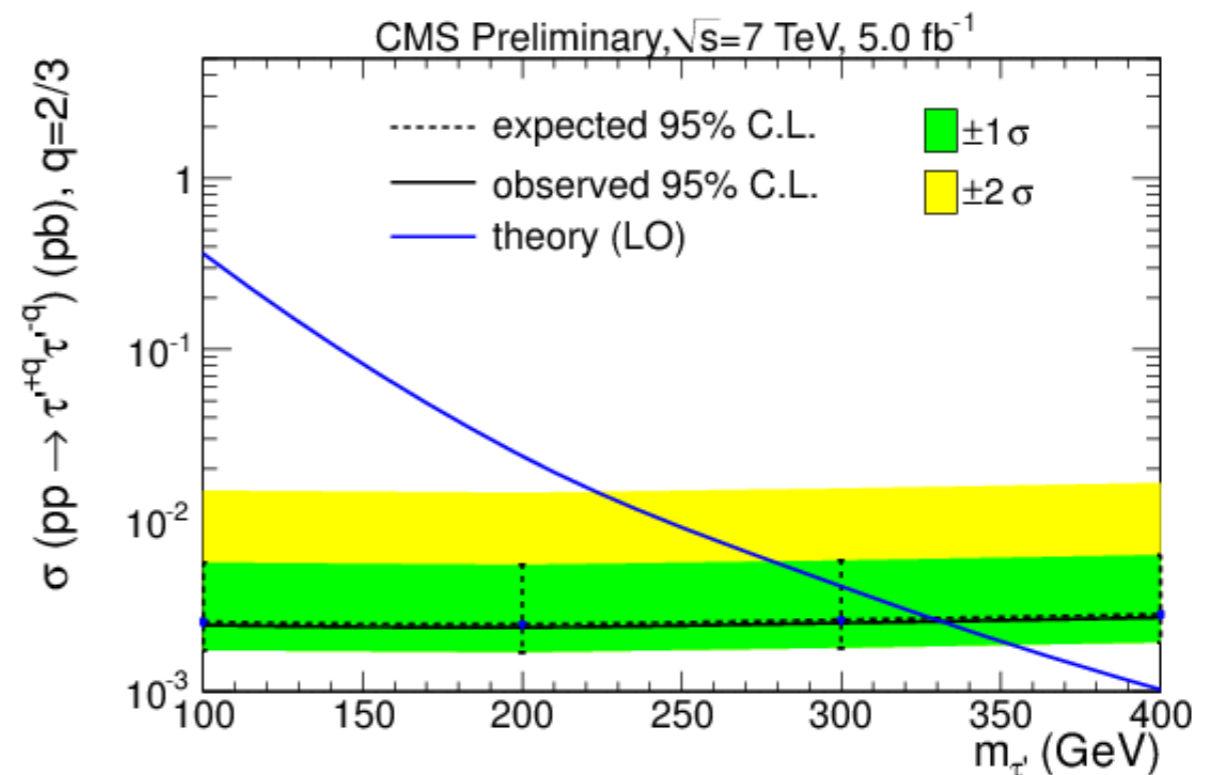
- Not a problem yet for most of searches due to high p_T objects
 - relative isolation much less affected
 - average increase in event energy density not big compared to high p_T objects from hard scattering
 - primary vertex of hard scattering not critical and identified $> 80\%$ if needed



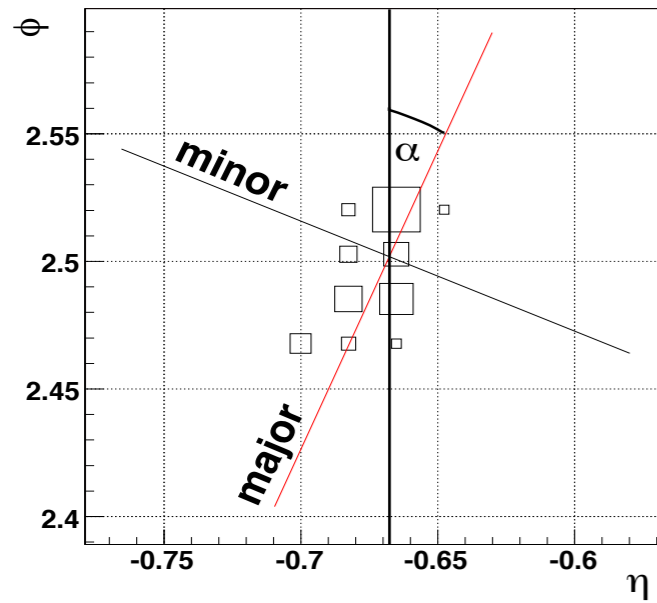
FRACTIONALLY CHARGED PARTICLES



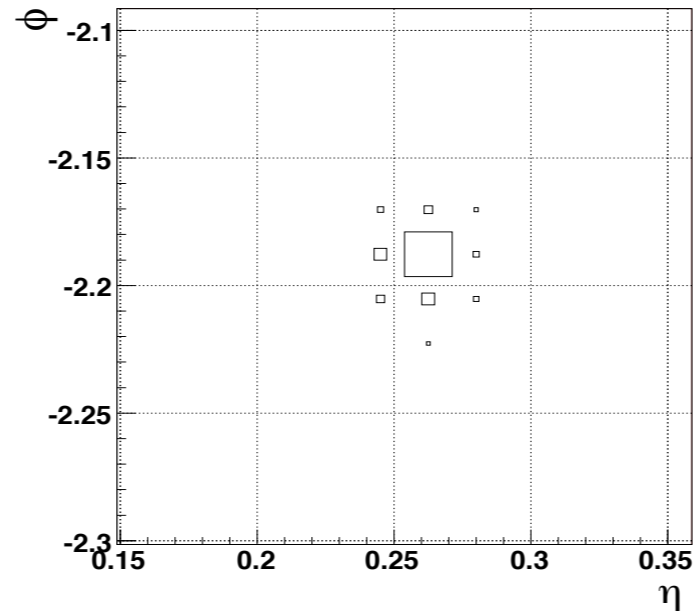
- low dE/dx tracks with many hits
- backgrounds estimated from data
- take into account geometrical effects when tracks intersect several sensor layers near the edge
 - correlation between dE/dx and number of hits



DISPLACED PHOTON (GMSB SCENARIO)

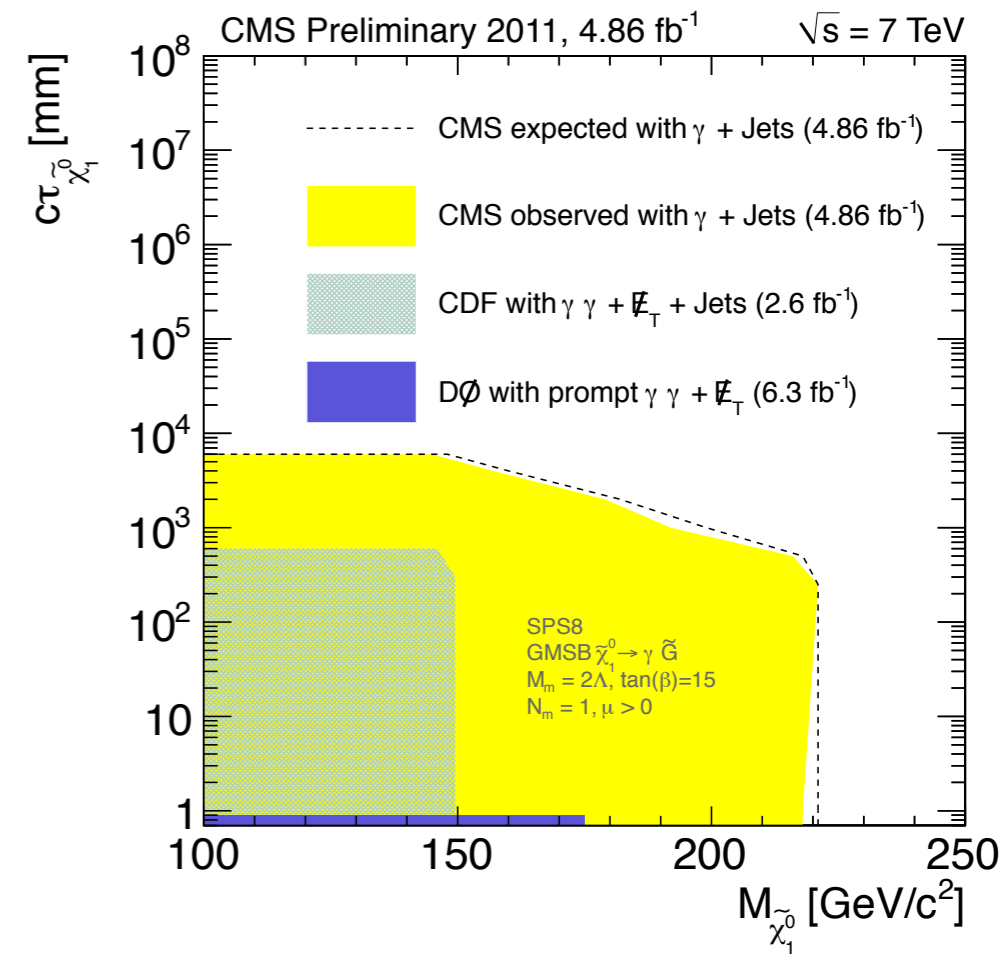
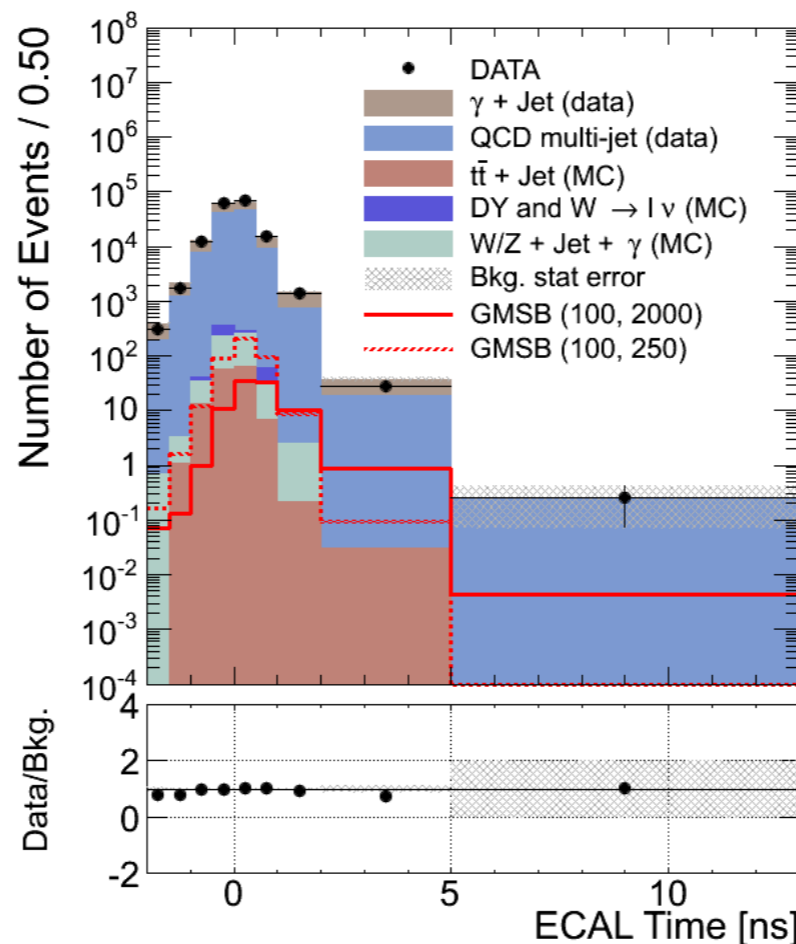
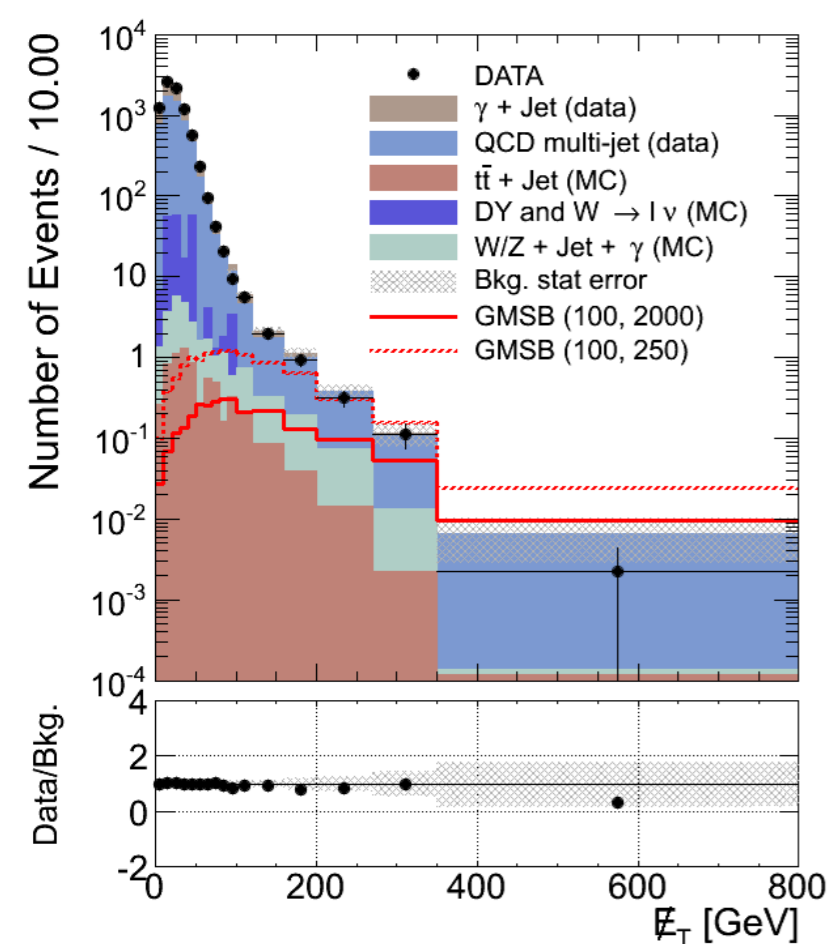
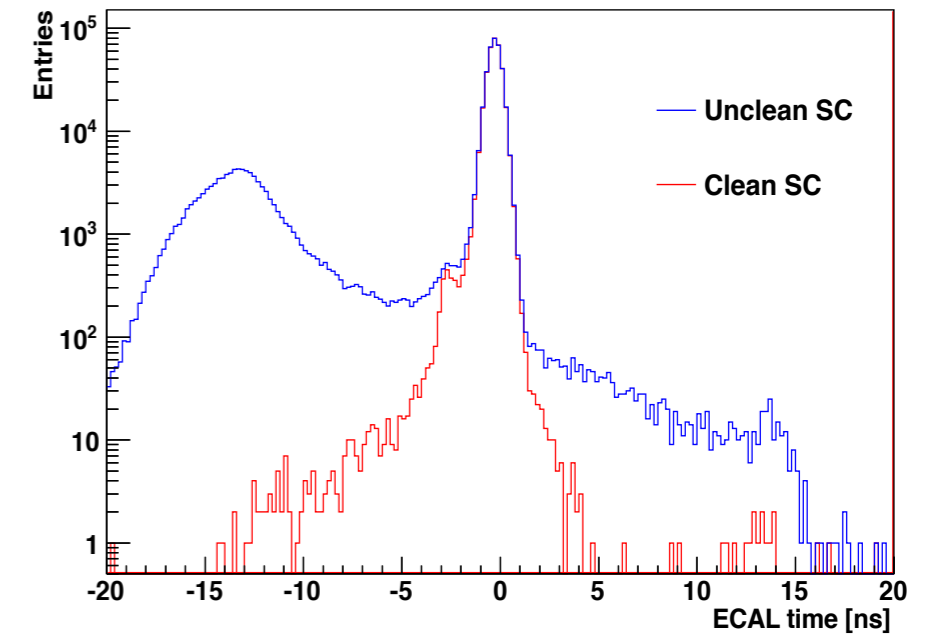


CMS Preliminary 2011, 4.86 fb⁻¹ $\sqrt{s} = 7$ TeV



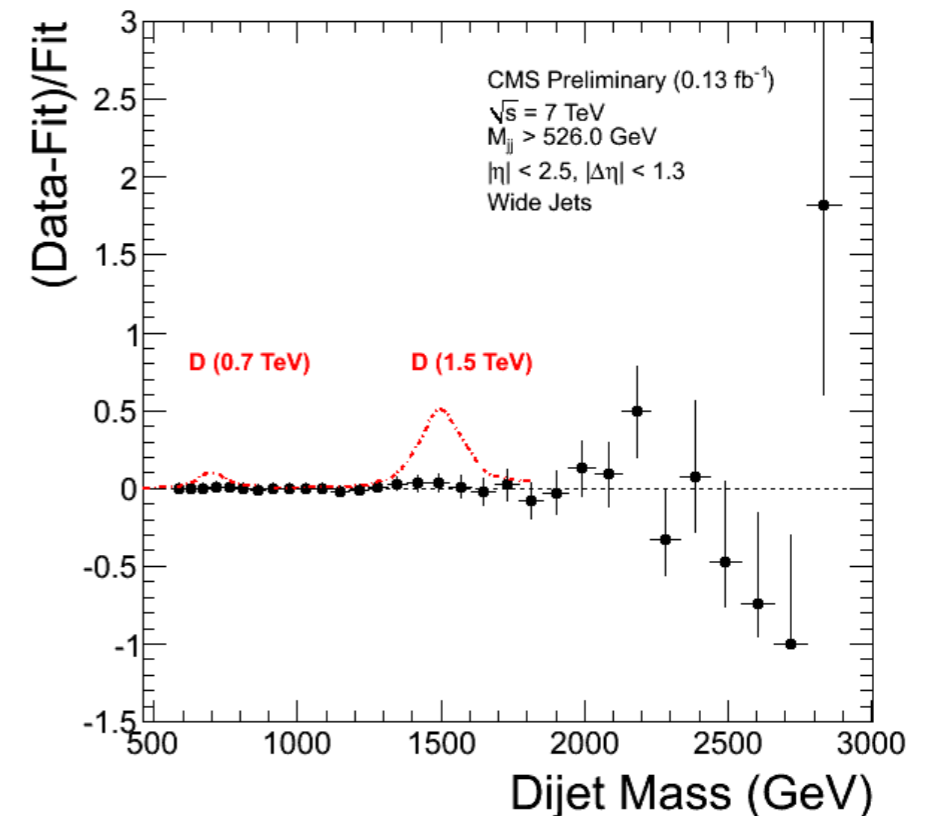
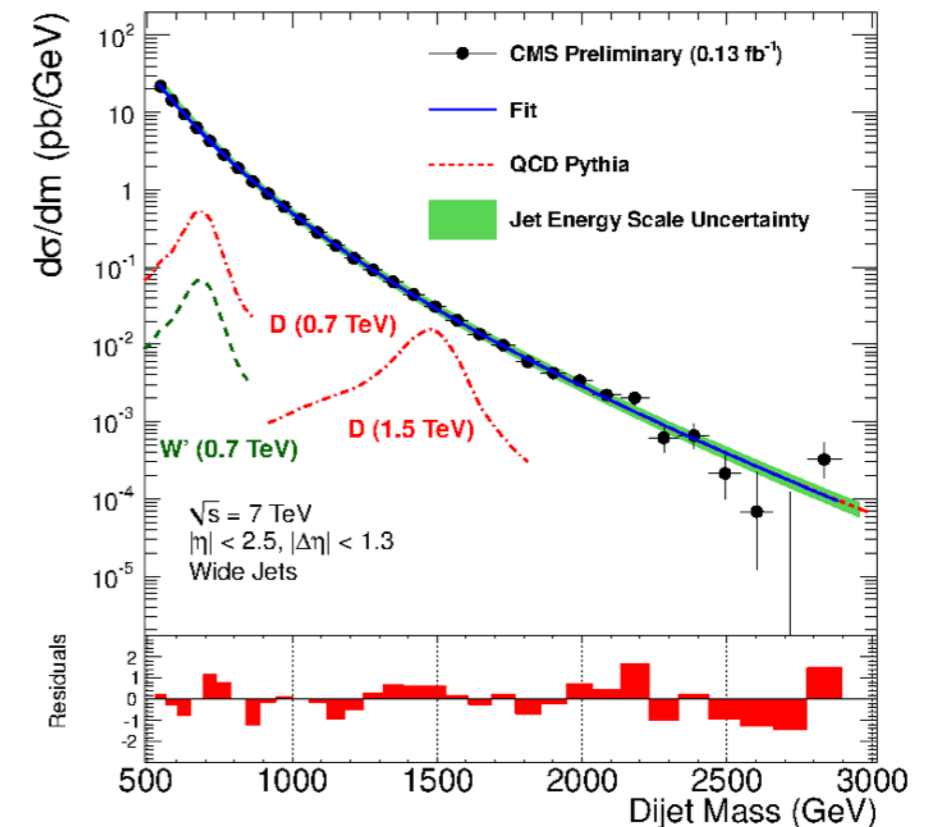
CMS Preliminary 2011, 4.86 fb⁻¹ $\sqrt{s} = 7$ TeV

ptPhot > 80 GeV, l etal < 1.4: MayReReco



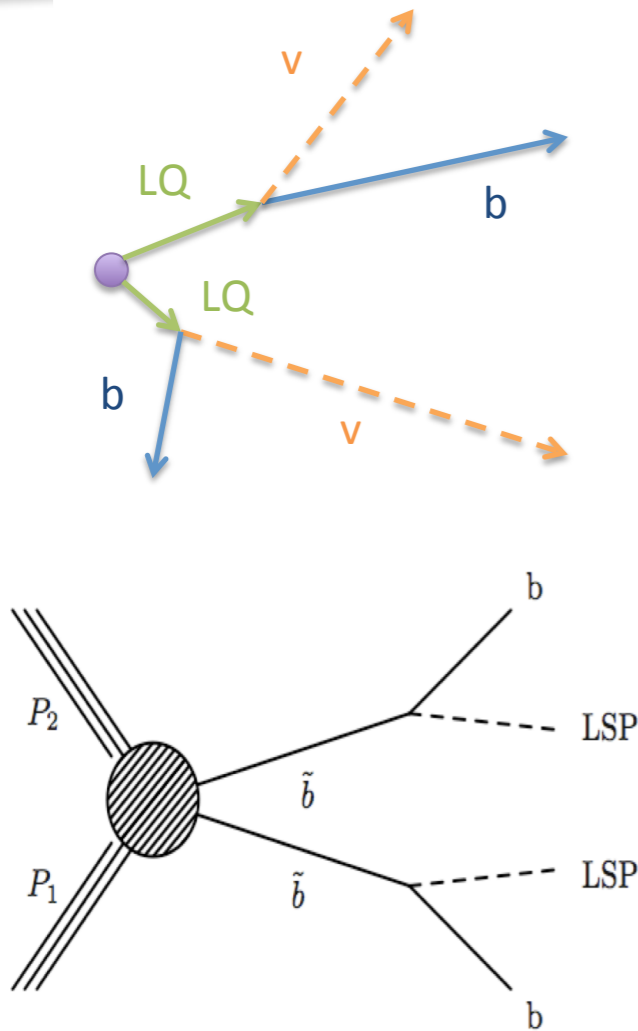
LOW MASS DI-JET SEARCH

- Novel trigger, DAQ, and analysis strategy for dijet mass < 1 TeV
 - Low threshold jet-trigger
 - ▶ rate \sim KHz
 - Store only HT jets
 - ▶ bandwidth under control
- "data scouting" in regions otherwise inaccessible due to trigger constraints
- what we will achieve with data parking in 2012

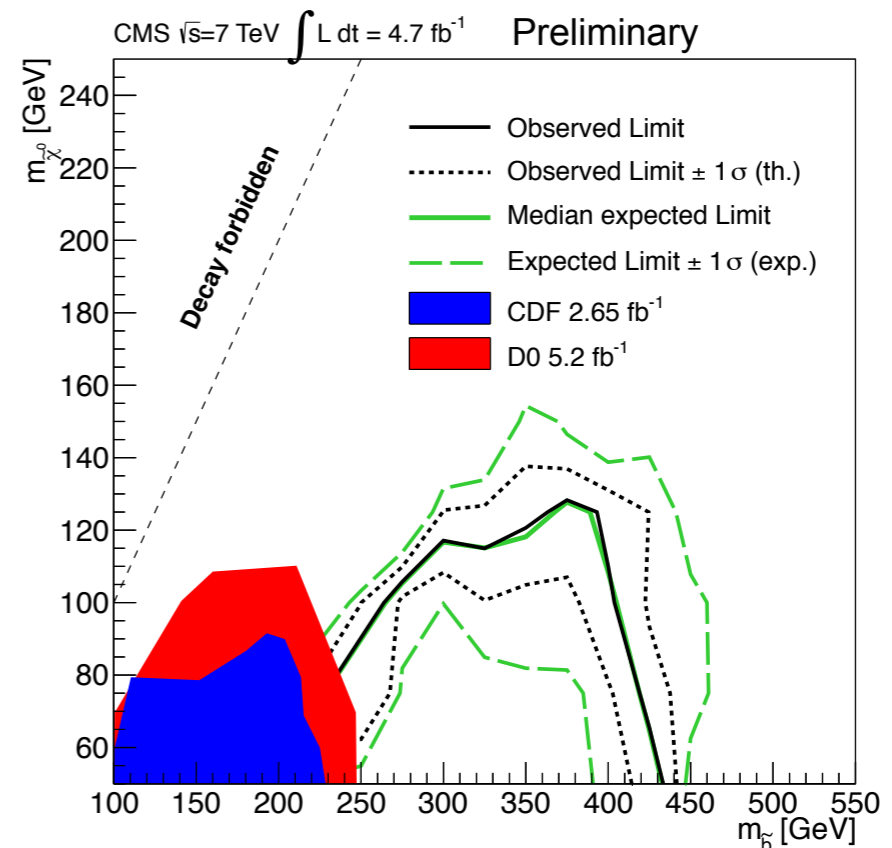
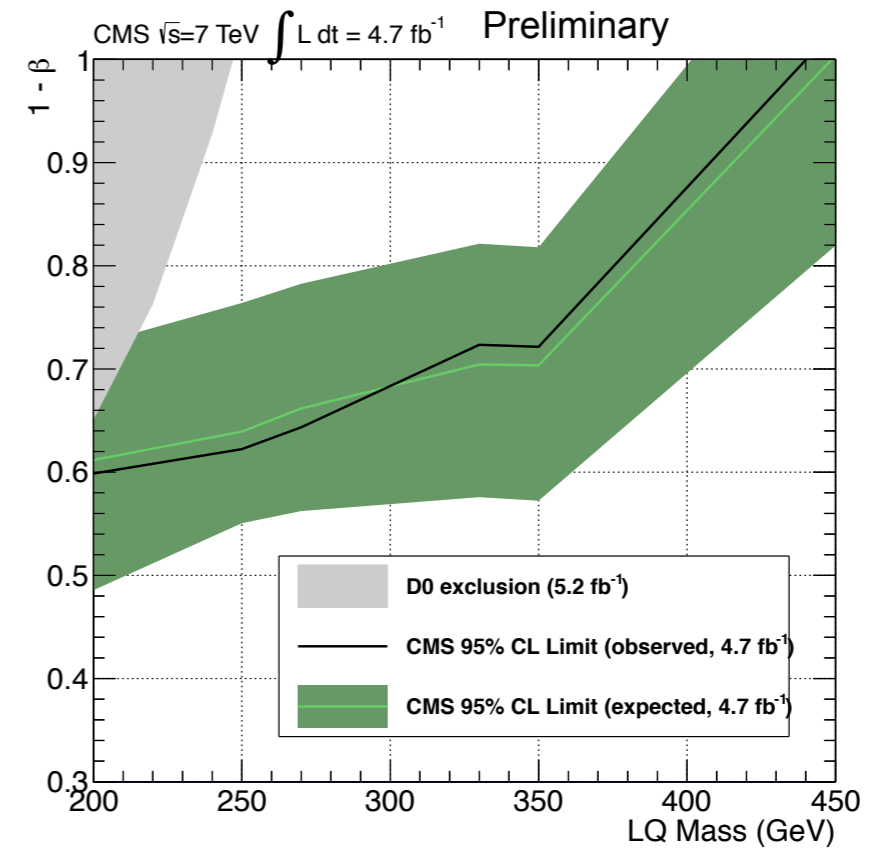


NEW RESULTS SINCE ICHEP

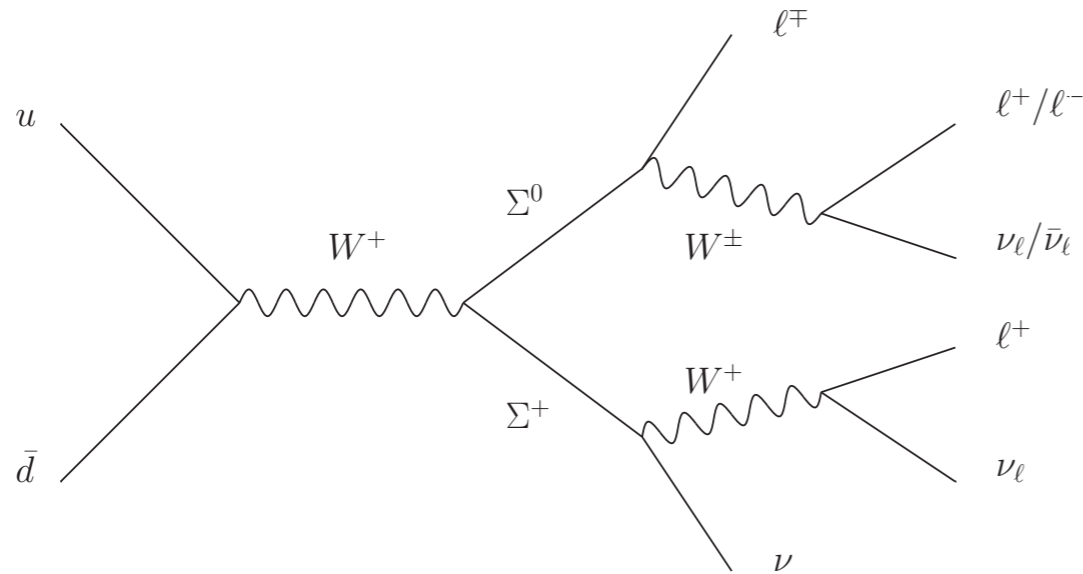
LQ3 AND SBOTTOM



- Signature: 2 bjets + MET
- Sensitive to both LQ3 and sbottom decays in SMS
- Use razor variables well established in SUSY searches



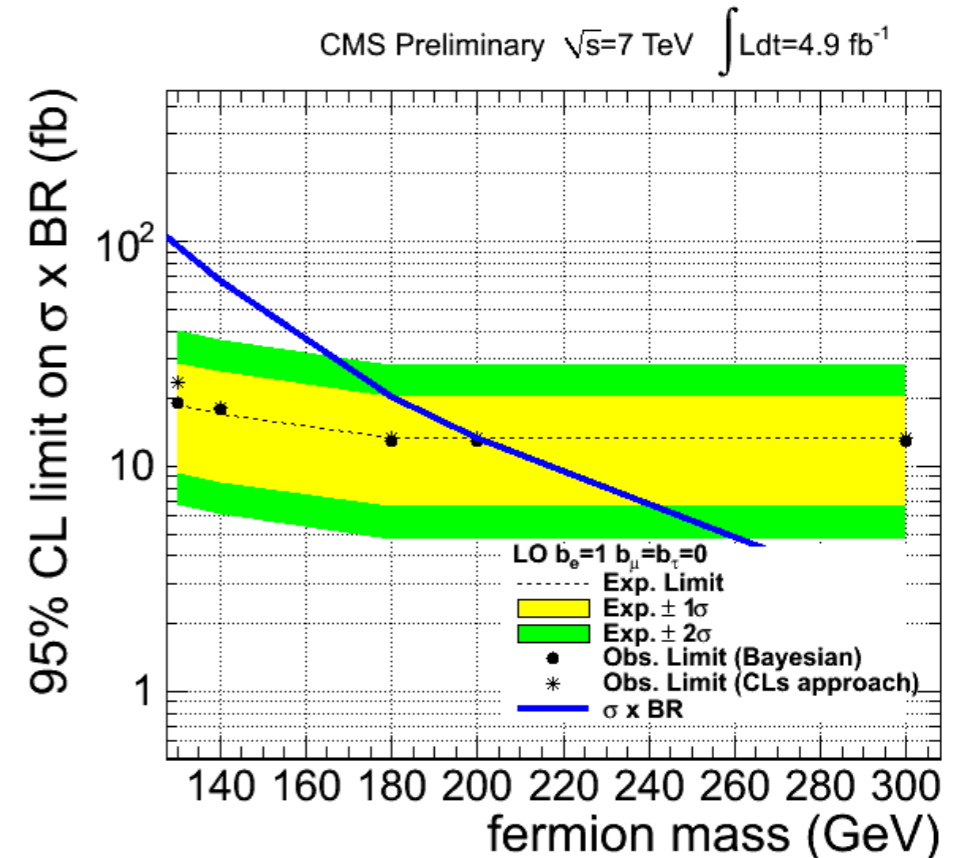
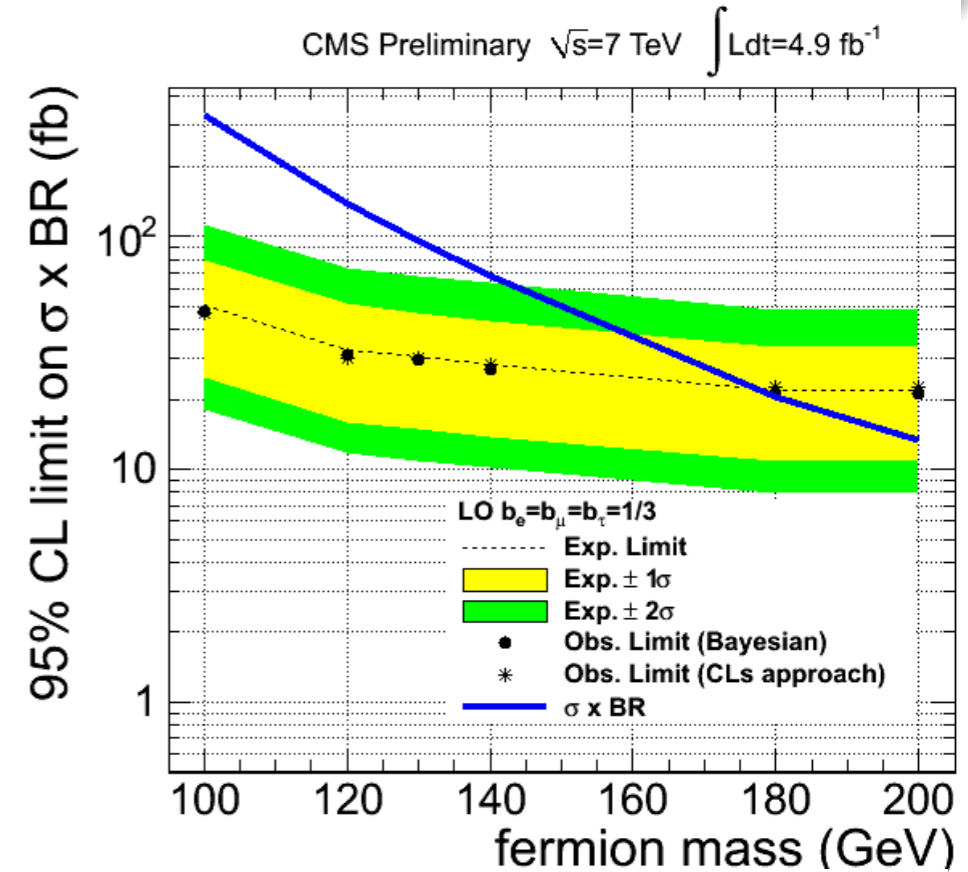
TYPE III SEESAW



- Multilepton analysis with constraint on sum of lepton charges

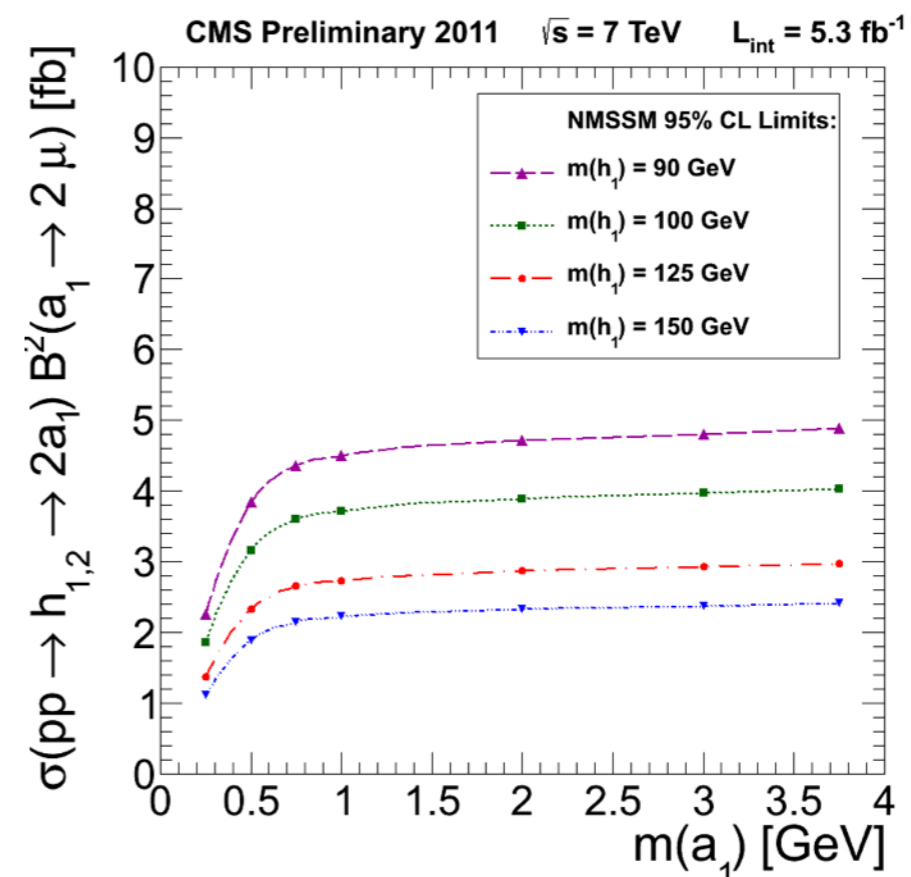
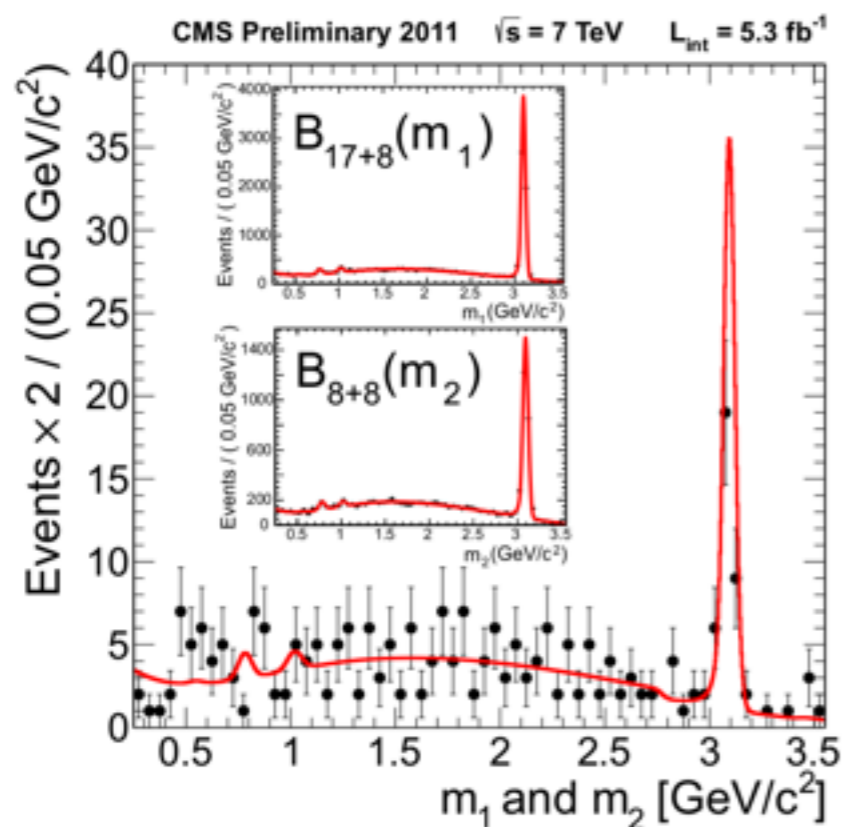
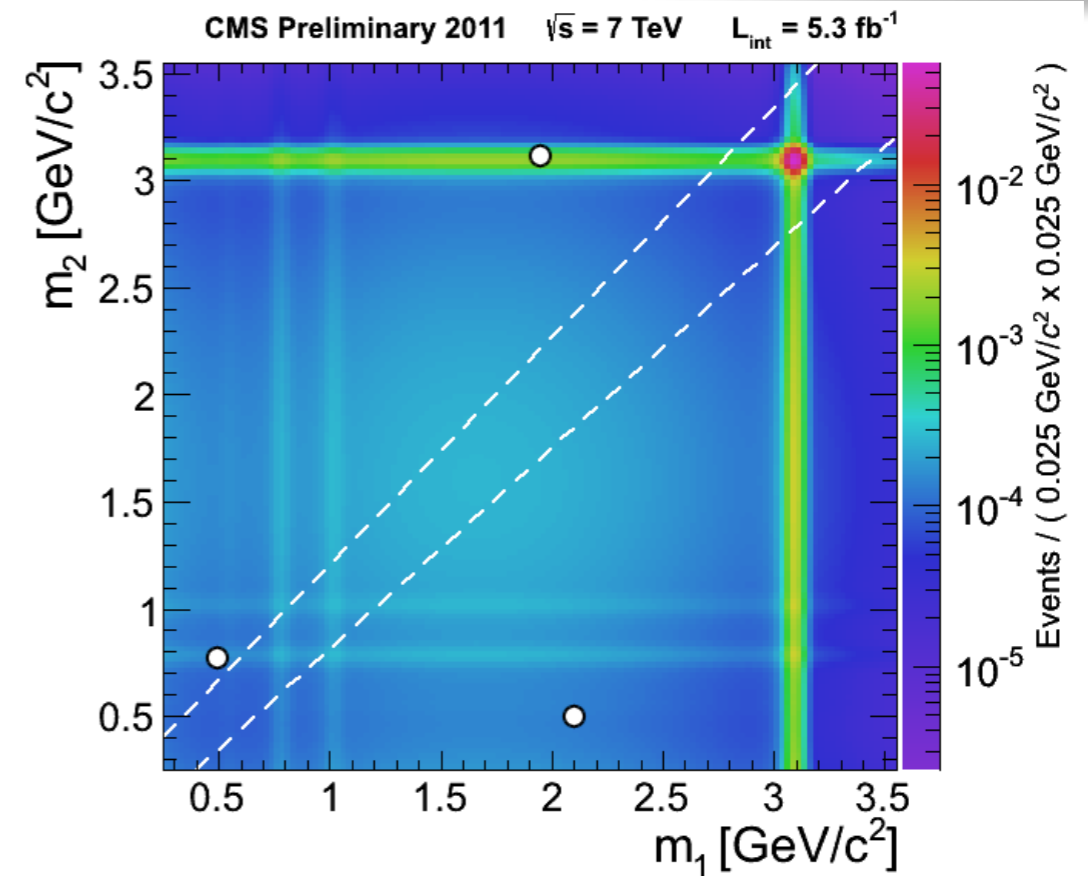
- $p_t > 18, 15, 10$ GeV for leptons
- $MET < 30$ GeV
- $HT > 100$ GeV

	VV	VVV	V γ	Misidentified jets	$\gamma^* \rightarrow \mu(\mu)$
$\mu^- e^+ e^+$	0.28 ± 0.07	0.09 ± 0.01	-	0.38 ± 0.38	-
$\mu^- e^+ \mu^+$	3.7 ± 0.27	0.19 ± 0.01	-	3.1 ± 1.2	-
$\mu^- \mu^+ \mu^+$	4.6 ± 0.3	0.11 ± 0.01	-	5.7 ± 1.9	0.69 ± 0.20
$e^- \mu^+ \mu^+$	0.26 ± 0.07	0.09 ± 0.01	-	0.76 ± 0.54	-
$e^- e^+ \mu^+$	4.6 ± 0.3	0.21 ± 0.02	-	3.0 ± 1.2	0.38 ± 0.11
$e^- e^+ e^+$	2.35 ± 0.21	0.06 ± 0.01	1.4 ± 1.0	1.07 ± 0.62	-



EXOTIC HIGGS BOSONS

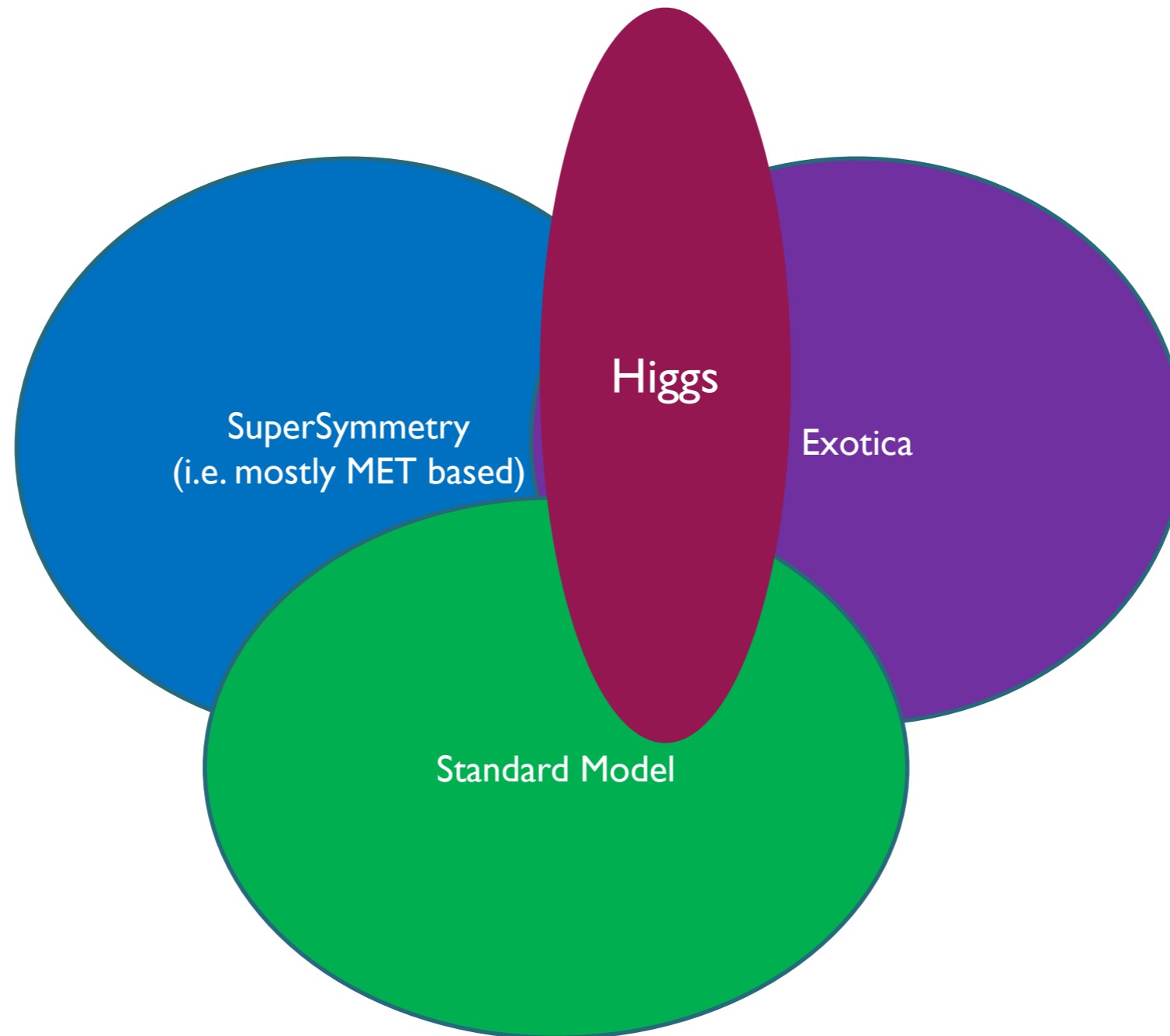
- New Higgs bosons predicted in NMSSM and Dark SUSY
 - $h \rightarrow aa + X \rightarrow 4\mu + X$
- Two low-mass dimuon pairs
- Main background from bb -bar
 - each pair isolation from other tracks (sum $pt < 3$ GeV)
 - vertices within 0.1 cm in Z
- pt dependent mass resolution from J/psi



WHAT WE HAVE NOT DONE YET

- Quirks
 - D0 in 2010
- Diquarks
 - some results from dijets
 - Several analyses sensitive to model but not interpreted yet
- Unparticles (with jet+MET in 36/pb)
 - Aim to have new results soon
- Long-lived particles
 - displaced jets and gluinos under study but progress slow
 - monopoles (result from ATLAS recently): high ionization and can use ECAL time measurement
- Re-interpretation of existing searches
 - Several decays discussed during parallel sessions could be constrained already
 - MC samples needed and effort to re-interpret
 - ▶ recently done for LQ searches

EXOTICA IN 2013



- Rich Exotic program covering multitude of final states of interest to SUSY and Higgs
 - Probing connections to Higgs, SUSY, Top, Dark Matter

FOOD FOR THOUGHT

- Many searches already saturating with ICHEP data
 - x3 more data helps smoothing out spectrum but not opening too many new doors in flagship searches (with large S/B)
- Almost all final states up to 3 or 4 particles
 - including di-bosons with leptons and jets, even boosted topologies
 - can we do more with photons?
- Exponential increase in luminosity led to race for higher mass limits
 - Have we explored sufficiently excluded masses in benchmark models?
- Should we look into couplings in addition to just mass limits if no signal found?
- More advanced analysis technique instead of bread&butter cut & count
- Concerted effort to for maximal interpretation of existing searches for natural SUSY
 - Many searches driven by one (max 2) models
- **How to improve communication of vast program to theorists?**
- Signatures we have ignored?

