Exotica and SUSY in the Age of the 125 GeV Higgs

Results and Directions from CMS

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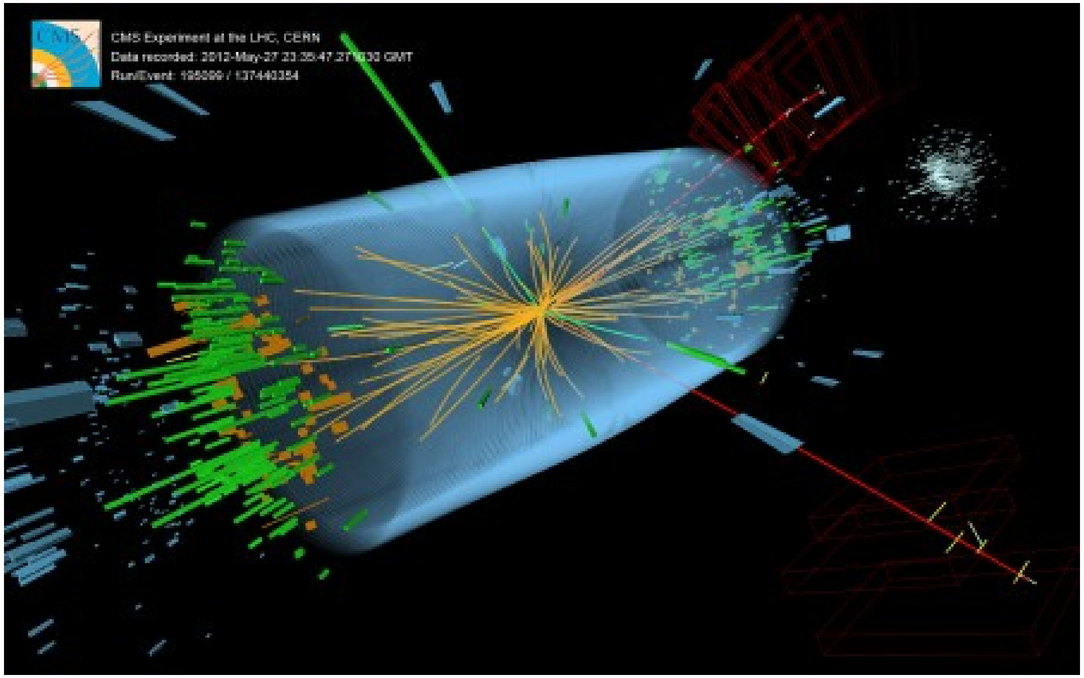
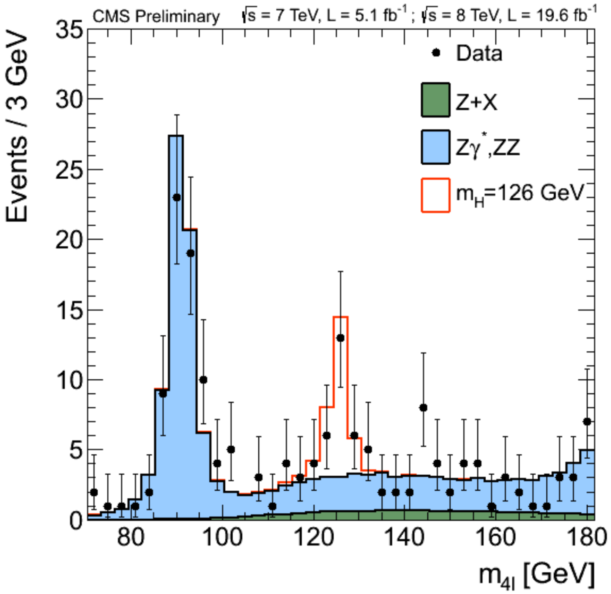
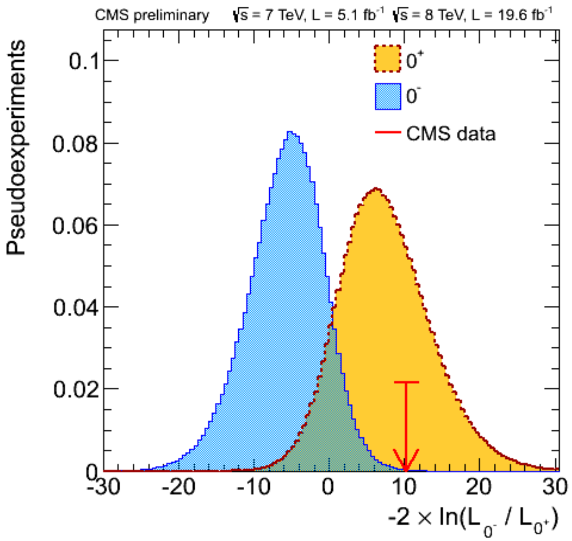


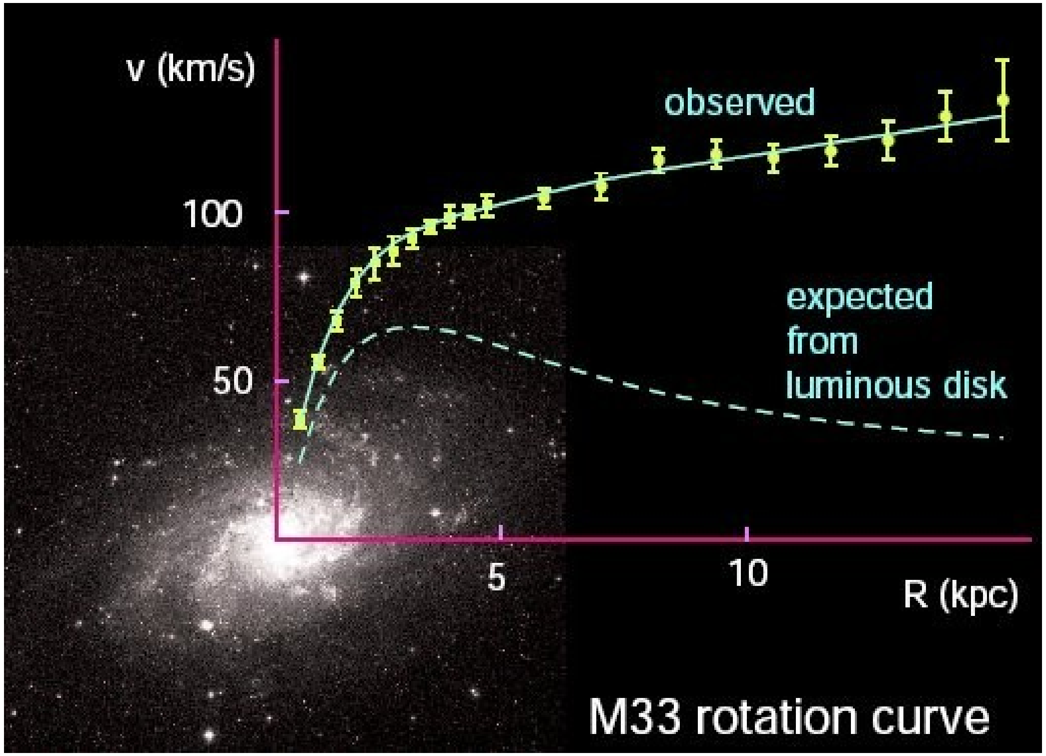
NEXT

- Precision studies of the first new fundamental particle detected since 1994.
- Study key issues raised by Higgs (e.g. Fine-tuning question)
- Study issues with SM which were not resolved by observation of the Higgs

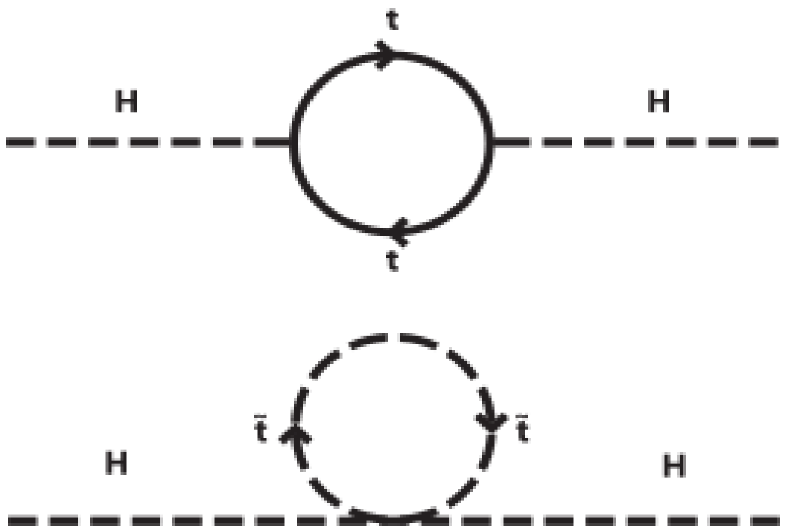




Motivations for Dark Matter



- Astrophysics and cosmology very strongly favor the existence of non-baryonic dark matter as the dominant source of structure formation and galaxy dynamics
  - From astrophysics, dark matter must be neutral and colorless.
  - From cosmology/galaxy formation, dark matter must be cold (easiest if it is heavy)
- No known particle meets these requirements



- By adding a space-time symmetry such that all fermion fields have matched boson fields, Higgs is stabilized up to GUT scale

$e, \mu, \tau \rightarrow \tilde{e}, \tilde{\mu}, \tilde{\tau}$ sleptons

$u, \ldots b, t \rightarrow \tilde{u}, \ldots \tilde{b}, \tilde{t}$ squarks

$H, h, Z, \gamma \rightarrow \chi^0_{1\ldots4}$ neutralinos

$H^\pm, W^\pm \rightarrow \chi^\pm_{1,} \chi^\pm_2$ charginos

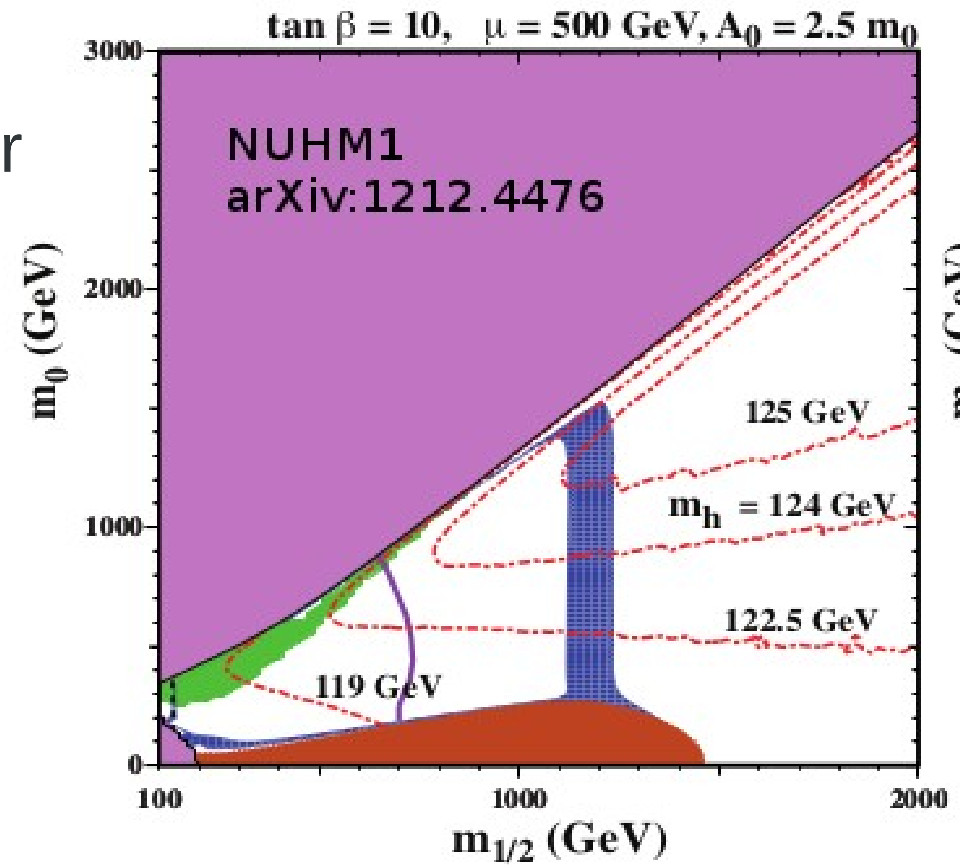
$g \rightarrow \tilde{g}$ gluino

$G \rightarrow \tilde{G}$ gravitino

- With the additional requirement of R-parity conservation, several good dark matter candidates: neutralinos or gravitino
- Inclusion of colored particles (gluino), should have a high production rate at LHC

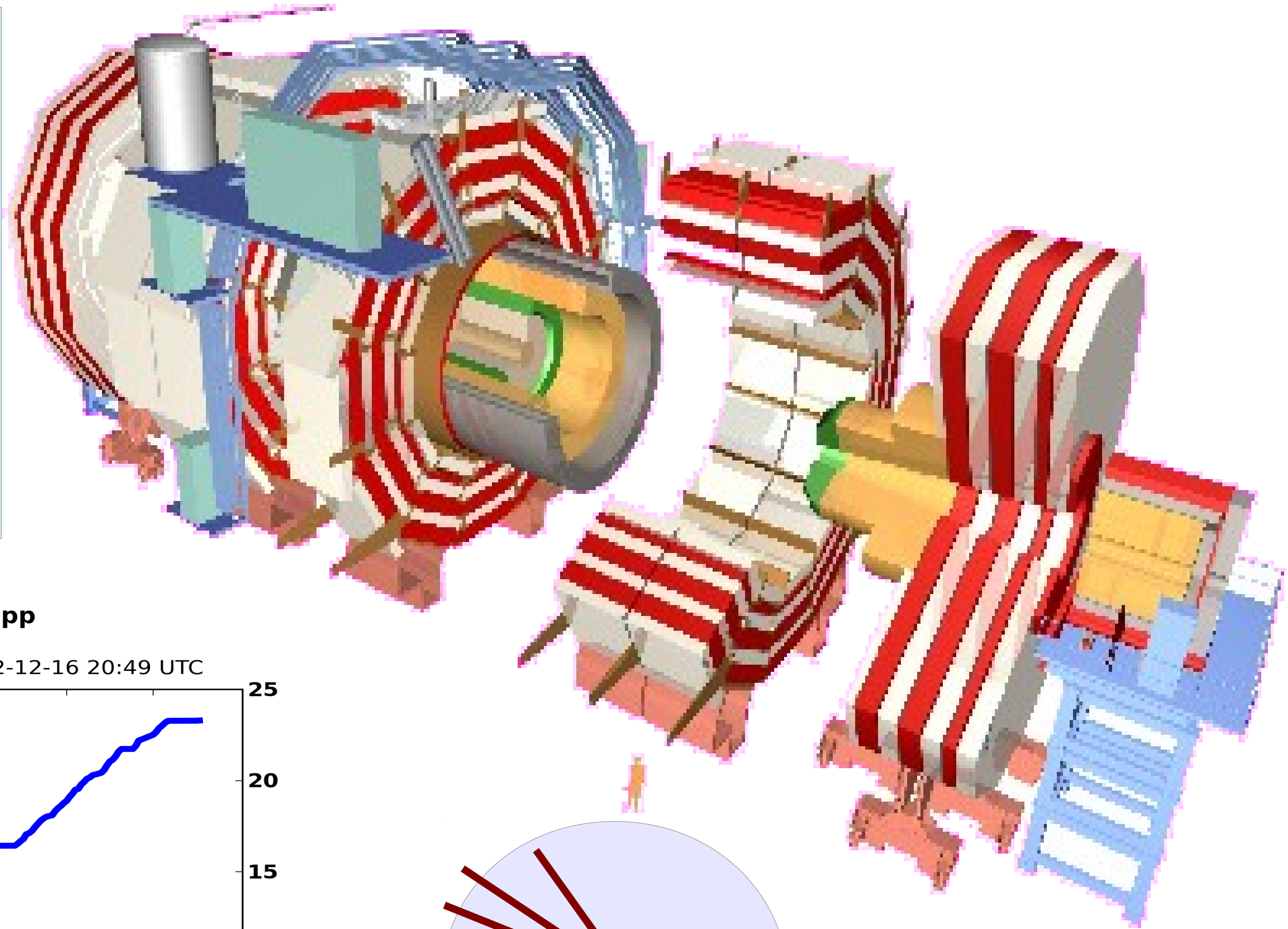
SUSY Constraints

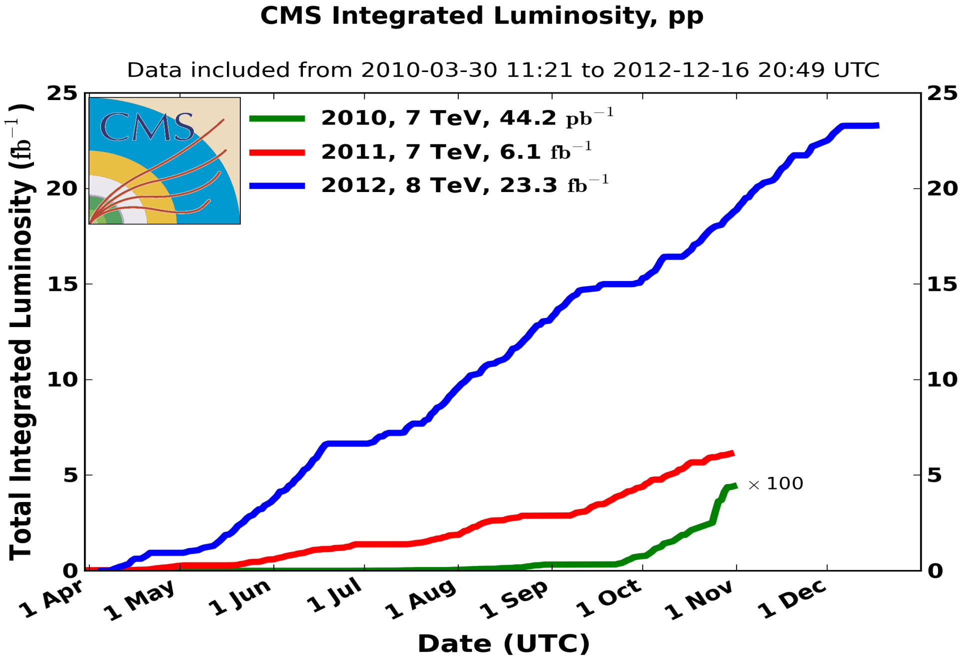
- Previous-to-LHC constraints come from BBN, FCNC, relic density requirements, LEP and the Tevatron
- LHC measurements
  - M_H>124.5 GeV, BR($B_s \rightarrow \mu\mu$) < 1.5 x SM require heavy superpartner masses (>300 GeV, often >1 TeV)
- Active work ongoing studying models with fewer constraints
  - NUHM1, NUHM2
  - Mass-scale unification at scale below GUT

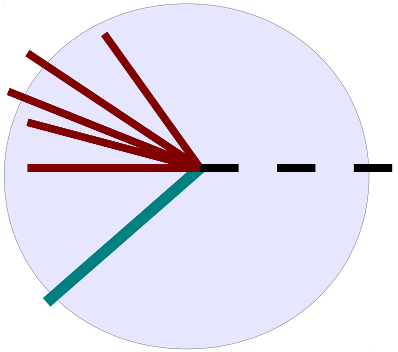


Crucial aspect for dark matter is hermetic coverage out to |η|=5

Collider signature for dark matter production ismissing transverse momentum, confusingly often called "MET"

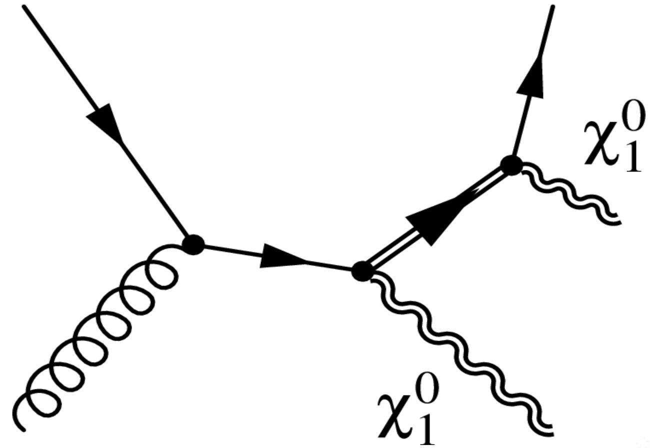


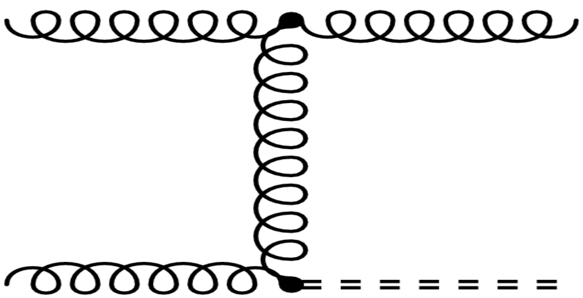


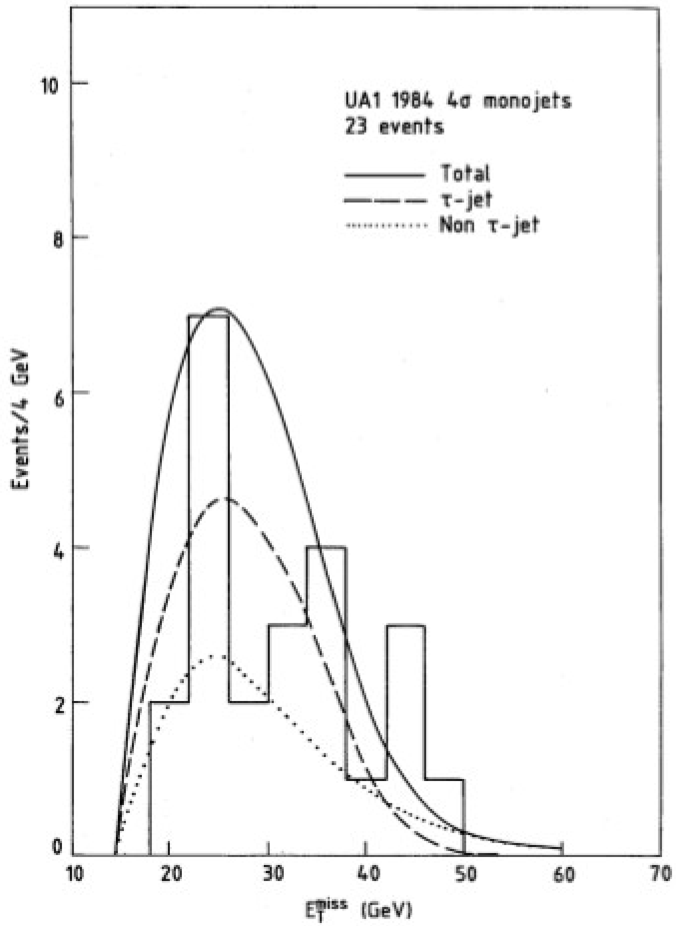


Mono-Jets

- The mono-jet signature is striking due to the apparent violation of momentum conservation
  - Mono-jet signatures have a long history at hadron colliders
- Mono-jets can appear in many models (including both supersymmetry and extra-dimensions models) and are directly tied to a dark matter candidate







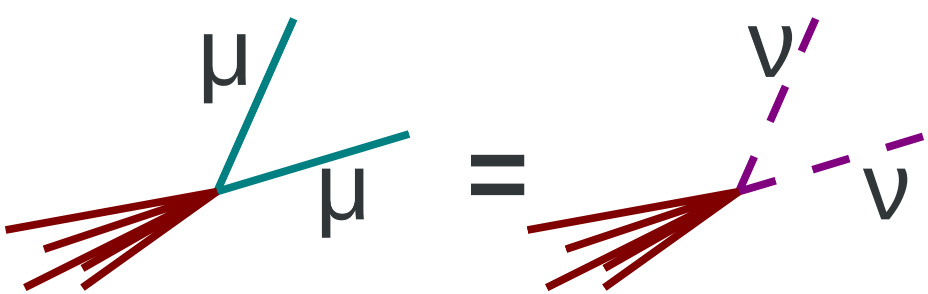
Requirements and Backgrounds

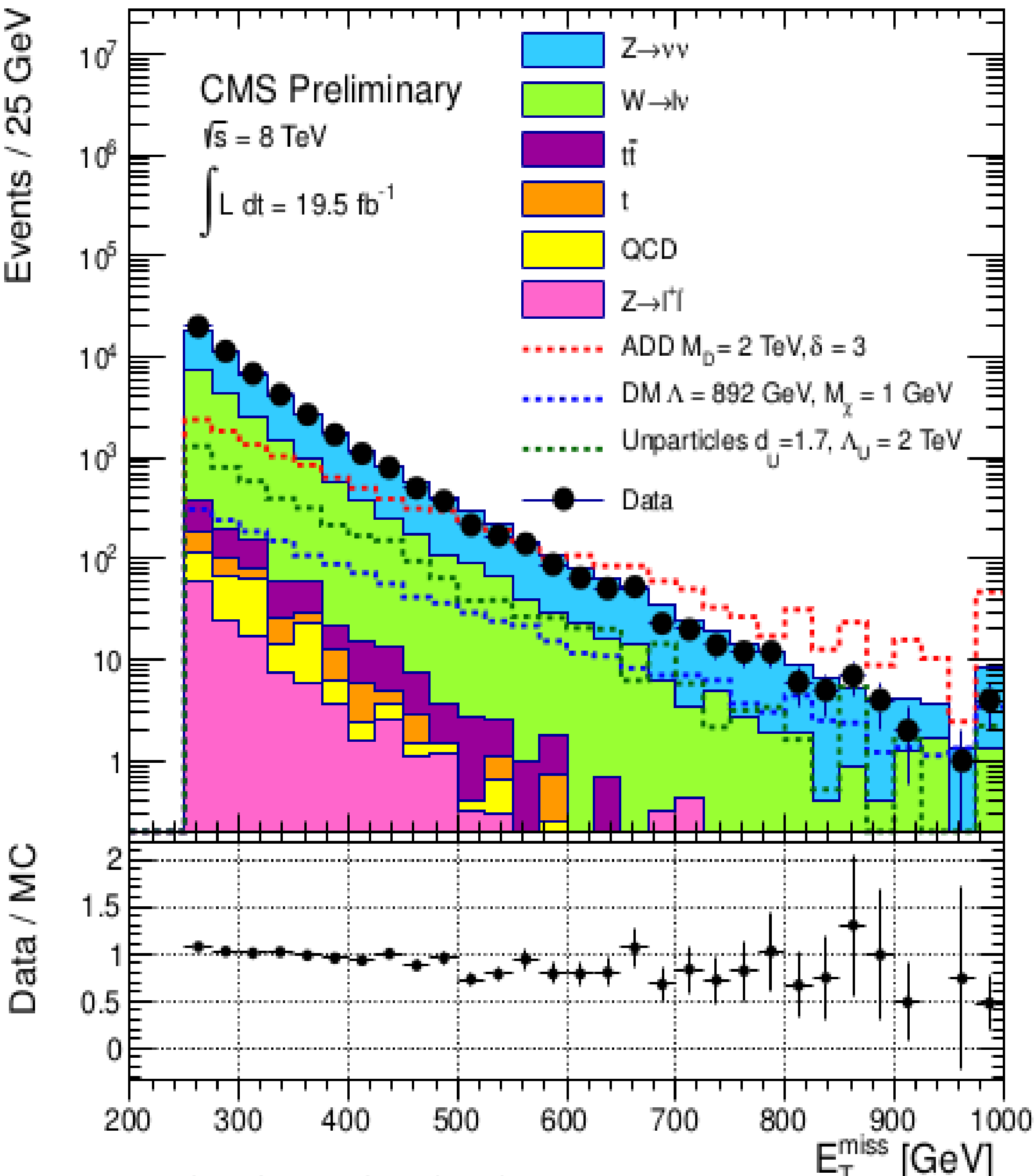
Requirements

- p_T (jet 1) > 110 GeV, at most one additional jet with p_T > 30 GeV, must have $\Delta\varphi$<2.5
- No isolated e/mu with p_T > 10 GeV, no tau with p_T>20 GeV
- Minimum MET = 250 GeV (binned in MET)

Backgrounds

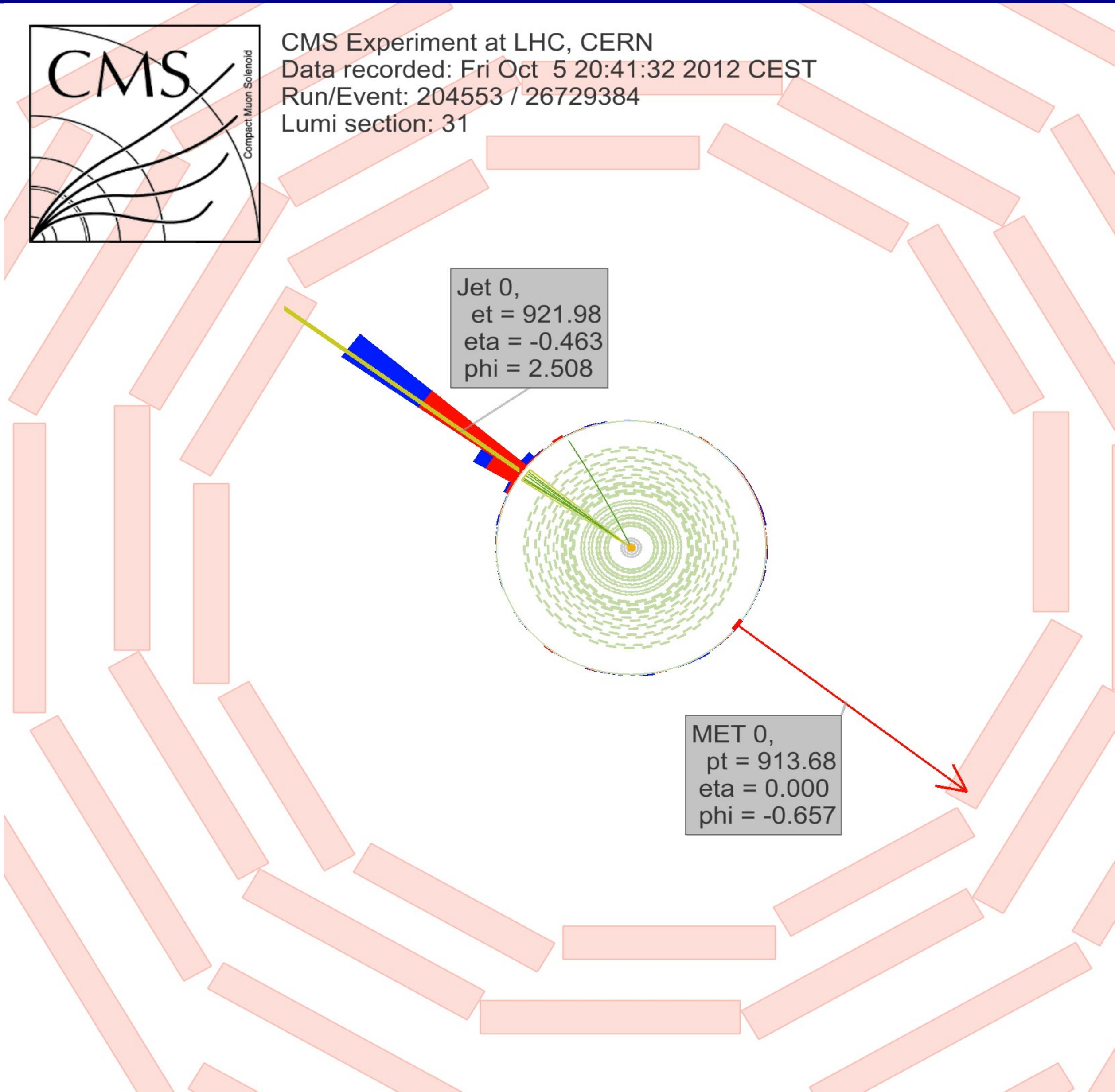
- Leading backgrounds ($Z \rightarrow \nu\nu$ and $W \rightarrow l\nu$) taken from data

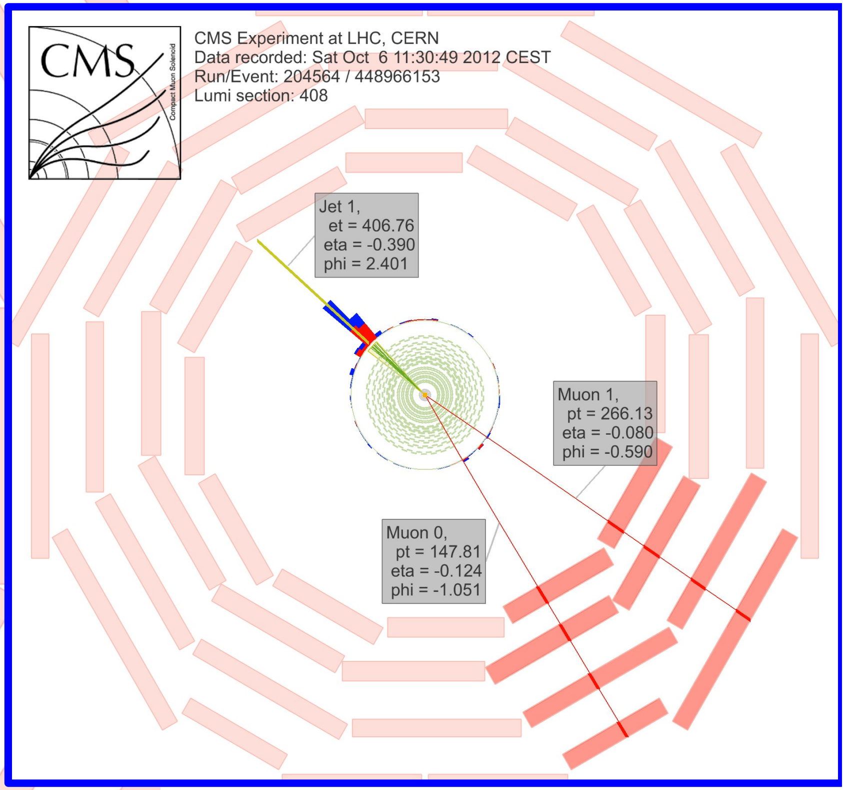




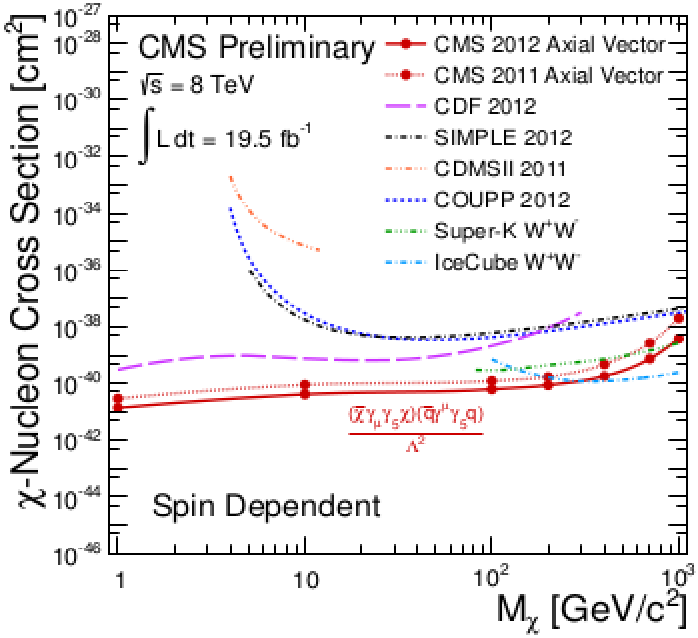
CMS-EXO-12-48

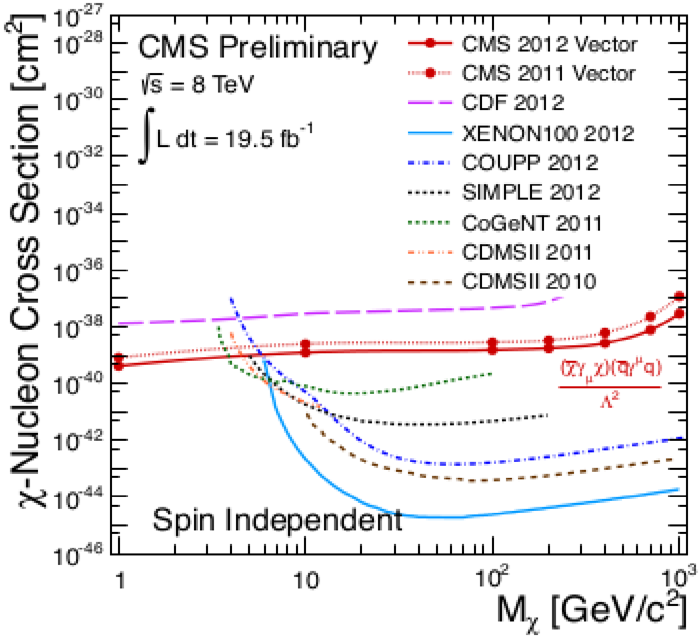
Event Displays

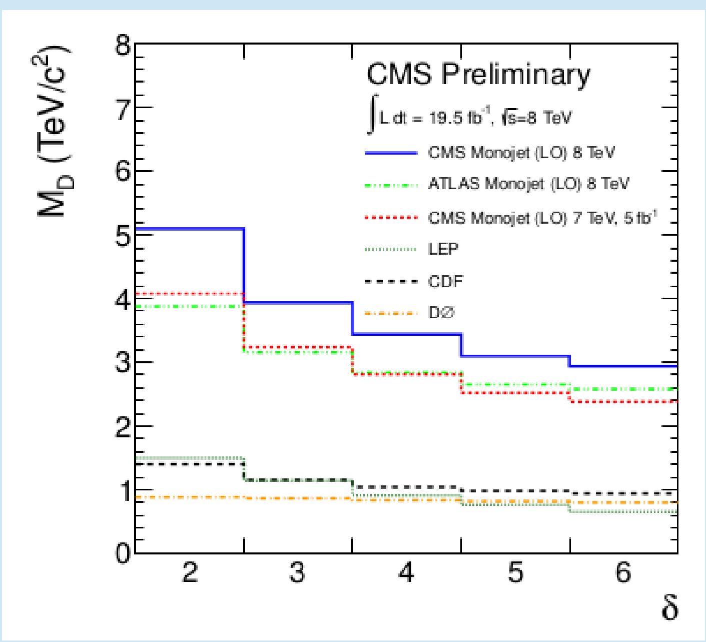


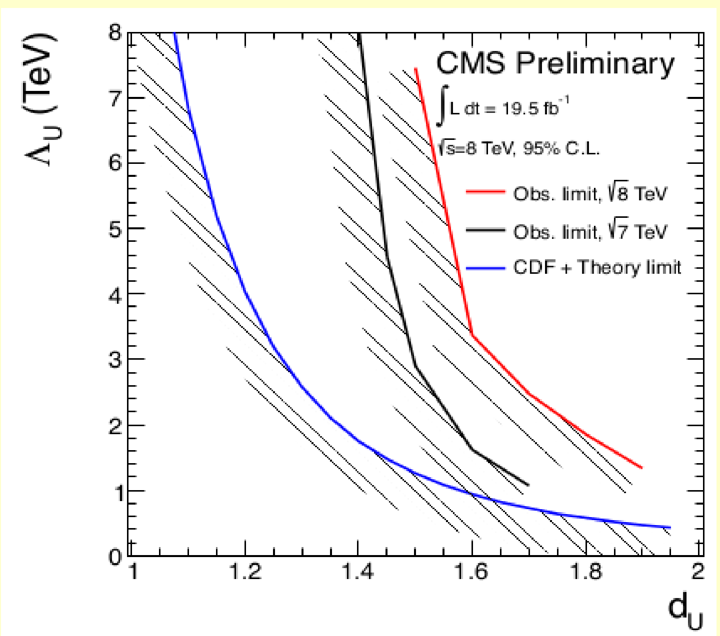


Limits and Interpretations







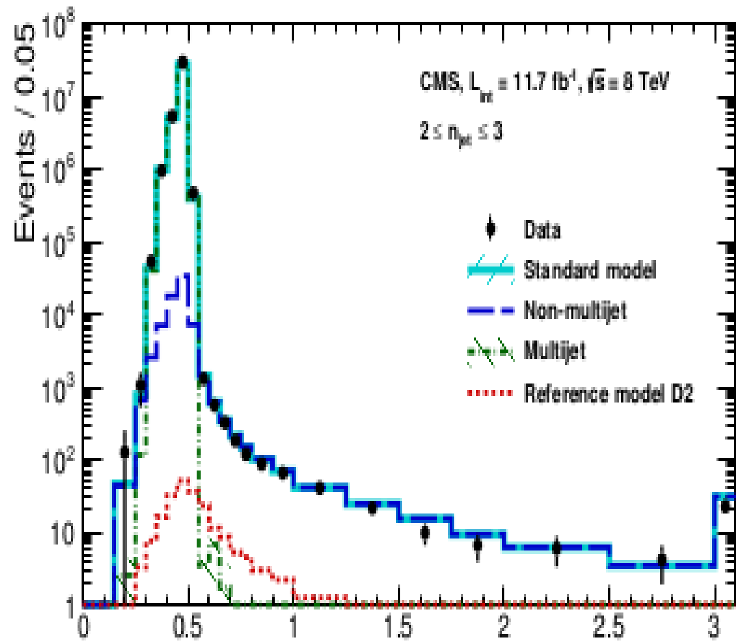


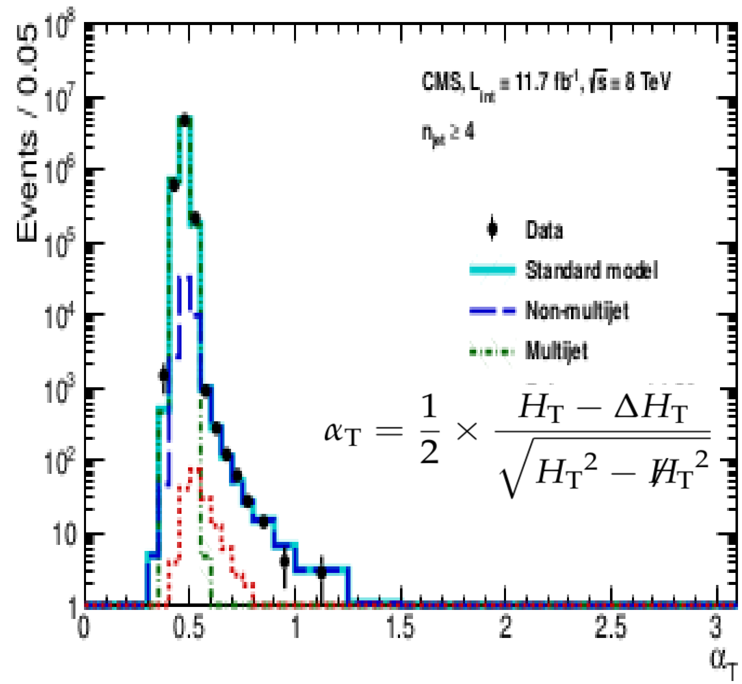
Requirements:

- At least 2 jets with pT > 110 GeV
- Reject events with leptons (pT>10 GeV)
- Study in bins of H_T and bjet count

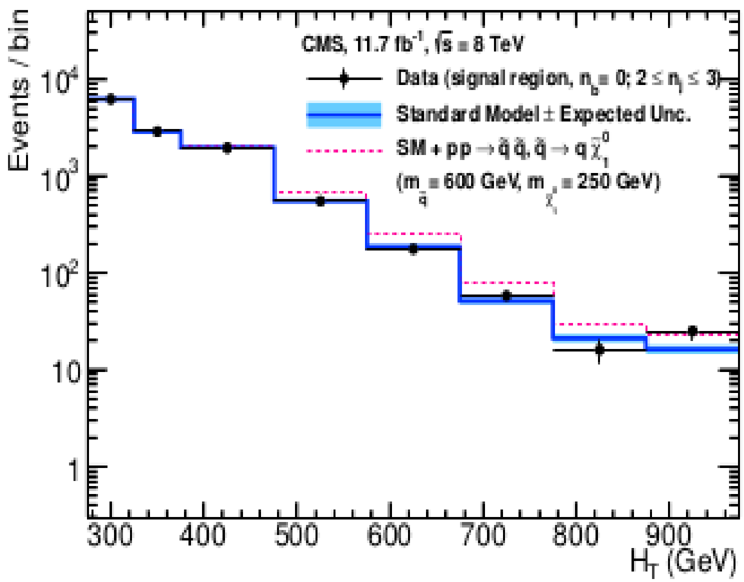
Backgrounds

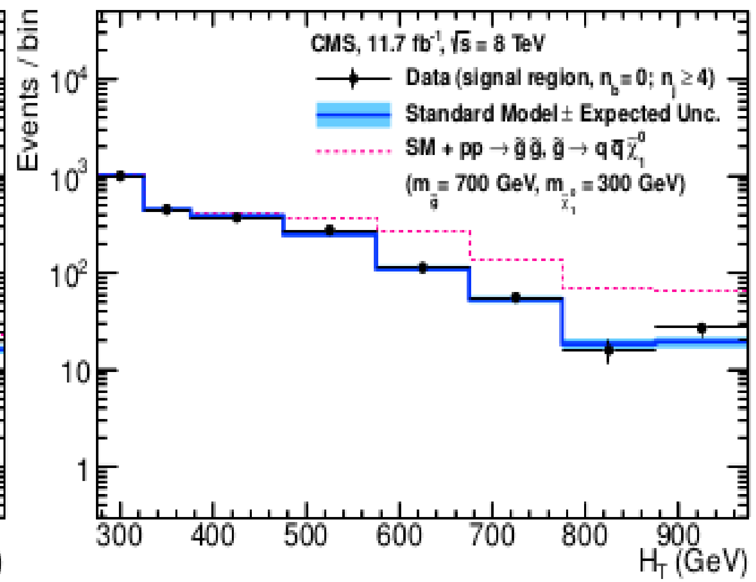
- QCD mulijet suppressed using α_T variable
- Remaining backgrounds estimated in similar manner to monojet

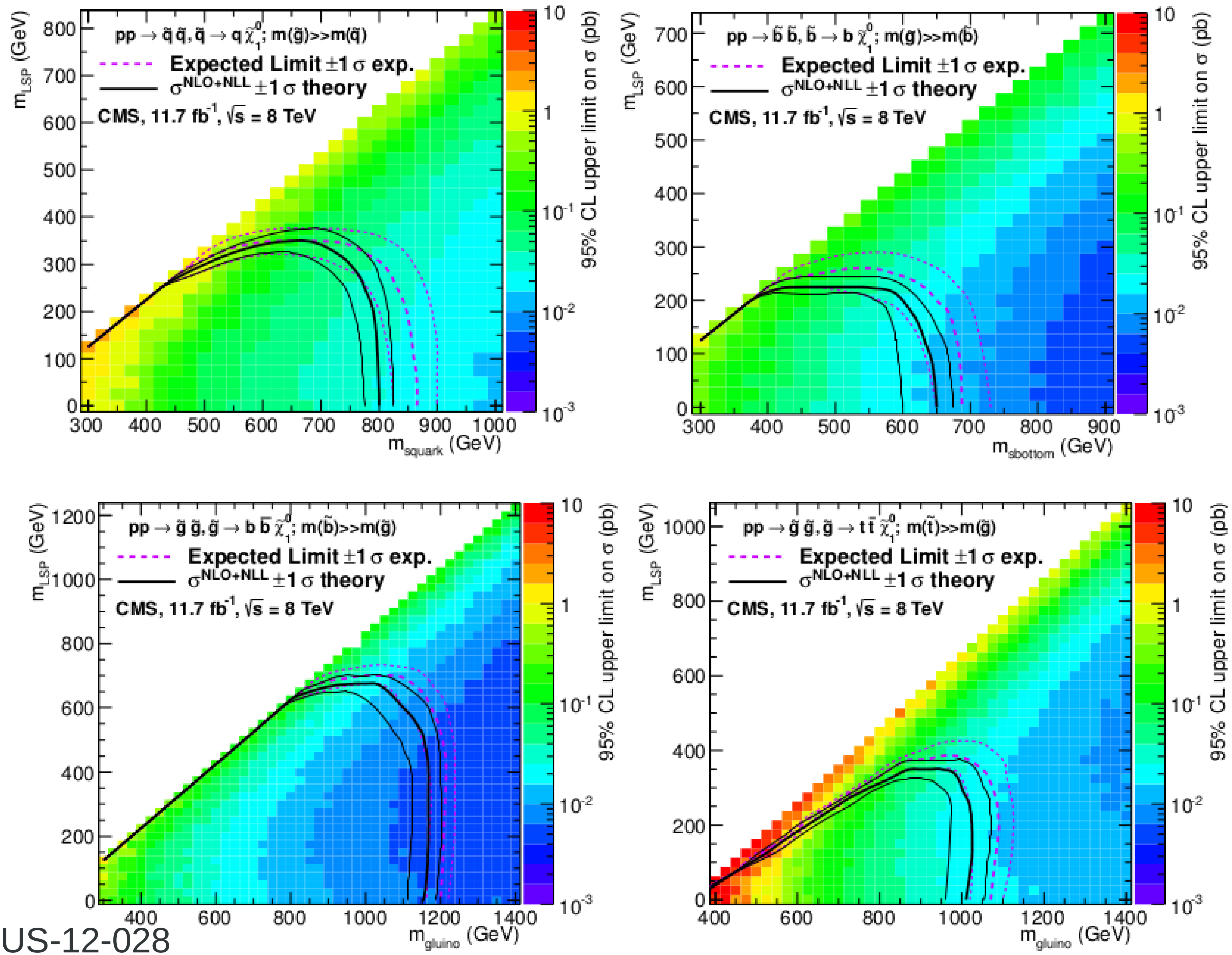




CMS-SUS-12-028

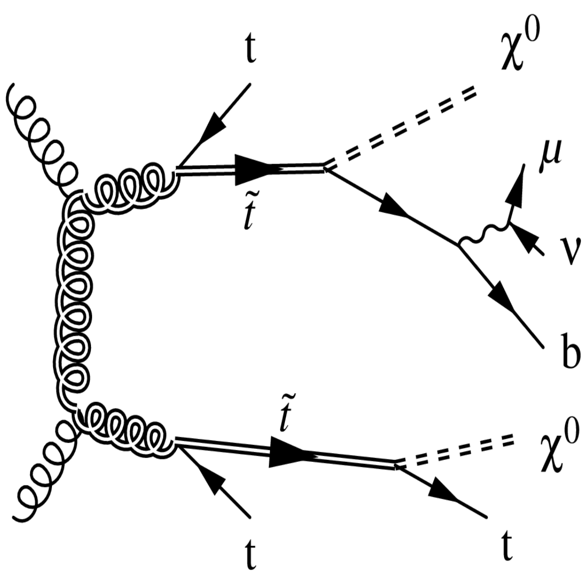


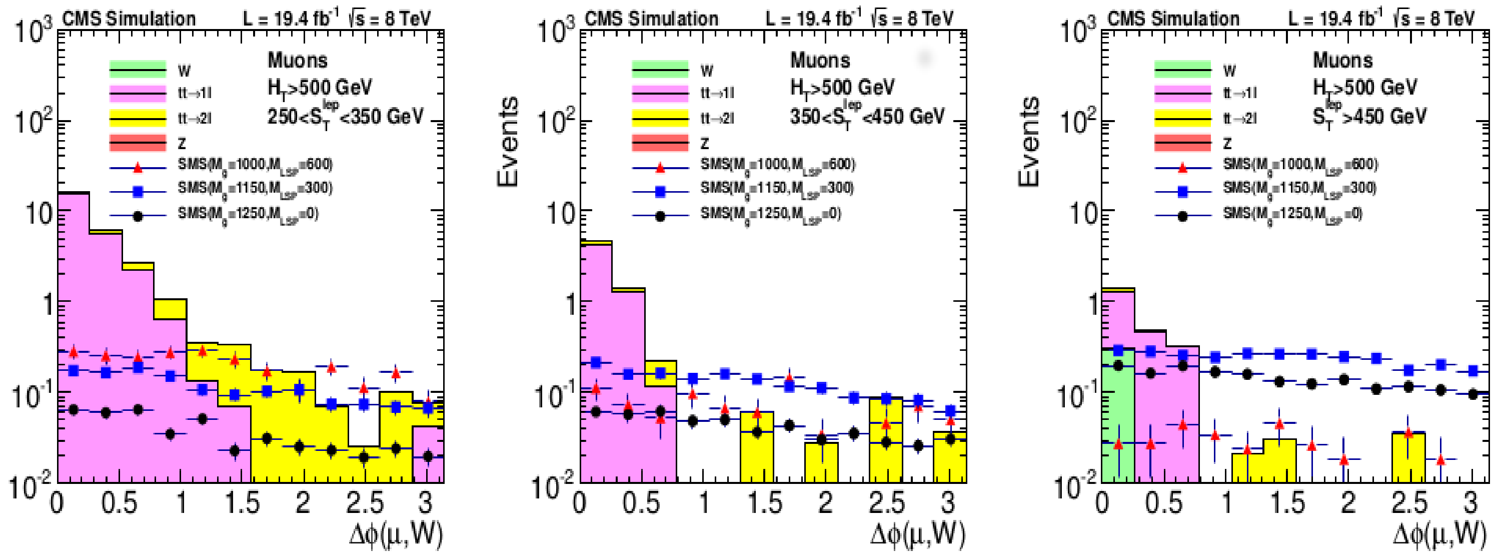




CMS-SUS-12-028

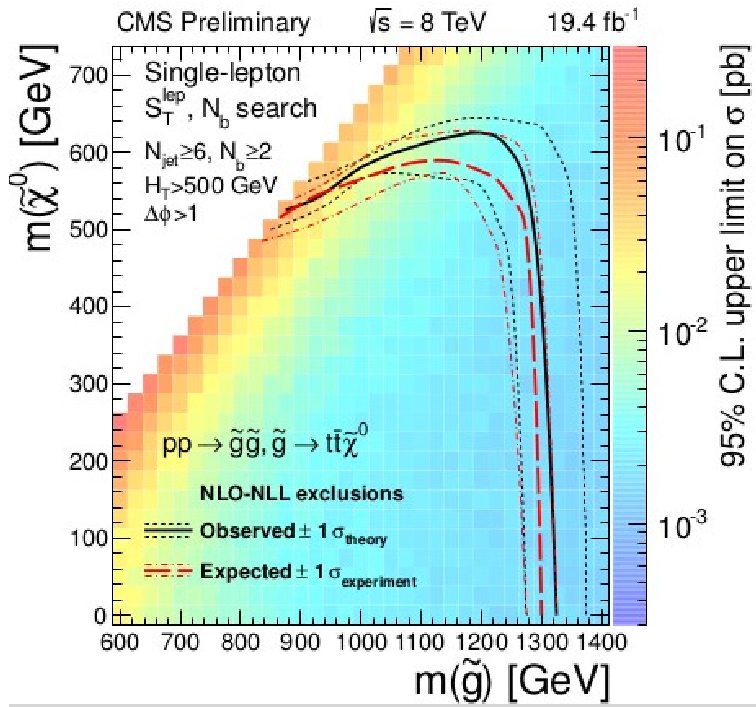
Lepton + b-jets + MET



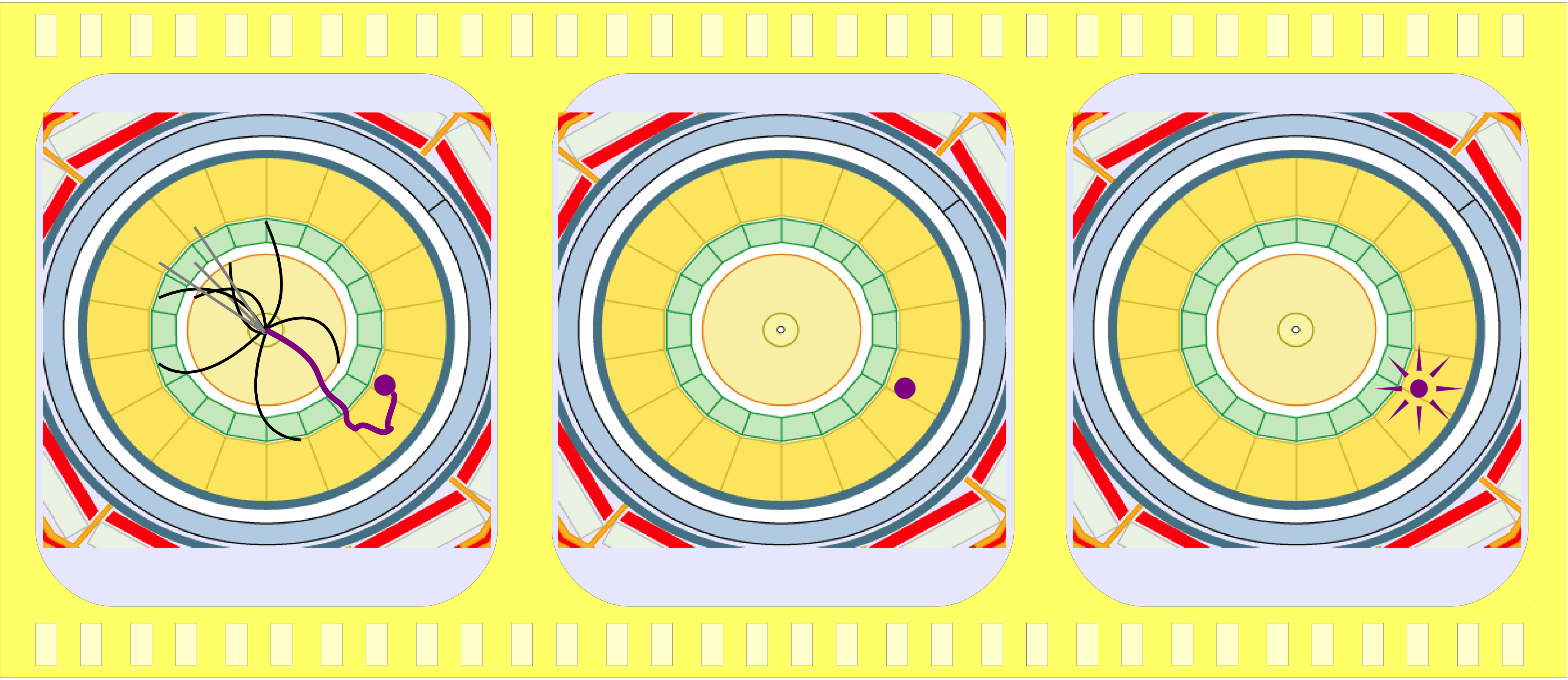


CMS-SUS-13-007

		S_T^{lep} [GeV]	control reg. data	prediction	observation
N_b=2	Muons	[250,350]	141	6.00 ± 2.40 (2.23)	9
		[350,450]	24	1.37 ± 1.19 (1.12)	2
		>450	9	0.0 ± 0.66 (0.66)	0
	Electr.	[250,350]	112	3.83 ± 1.84 (1.75)	9
		[350,450]	28	2.74 ± 2.02 (1.86)	2
		>450	9	0.0 ± 0.42 (0.42)	0
N_b ≥3	Muons	[250,350]	28	1.92 ± 0.95 (0.84)	0
		[350,450]	13	0.57 ± 0.58 (0.52)	0
		>450	2	0.0 ± 0.22 (0.22)	0
	Electr.	[250,350]	45	1.89 ± 1.03 (0.94)	4
		[350,450]	7	0.85 ± 0.80 (0.70)	0
		>450	0	0.0 ± 0.08 (0.08)	0



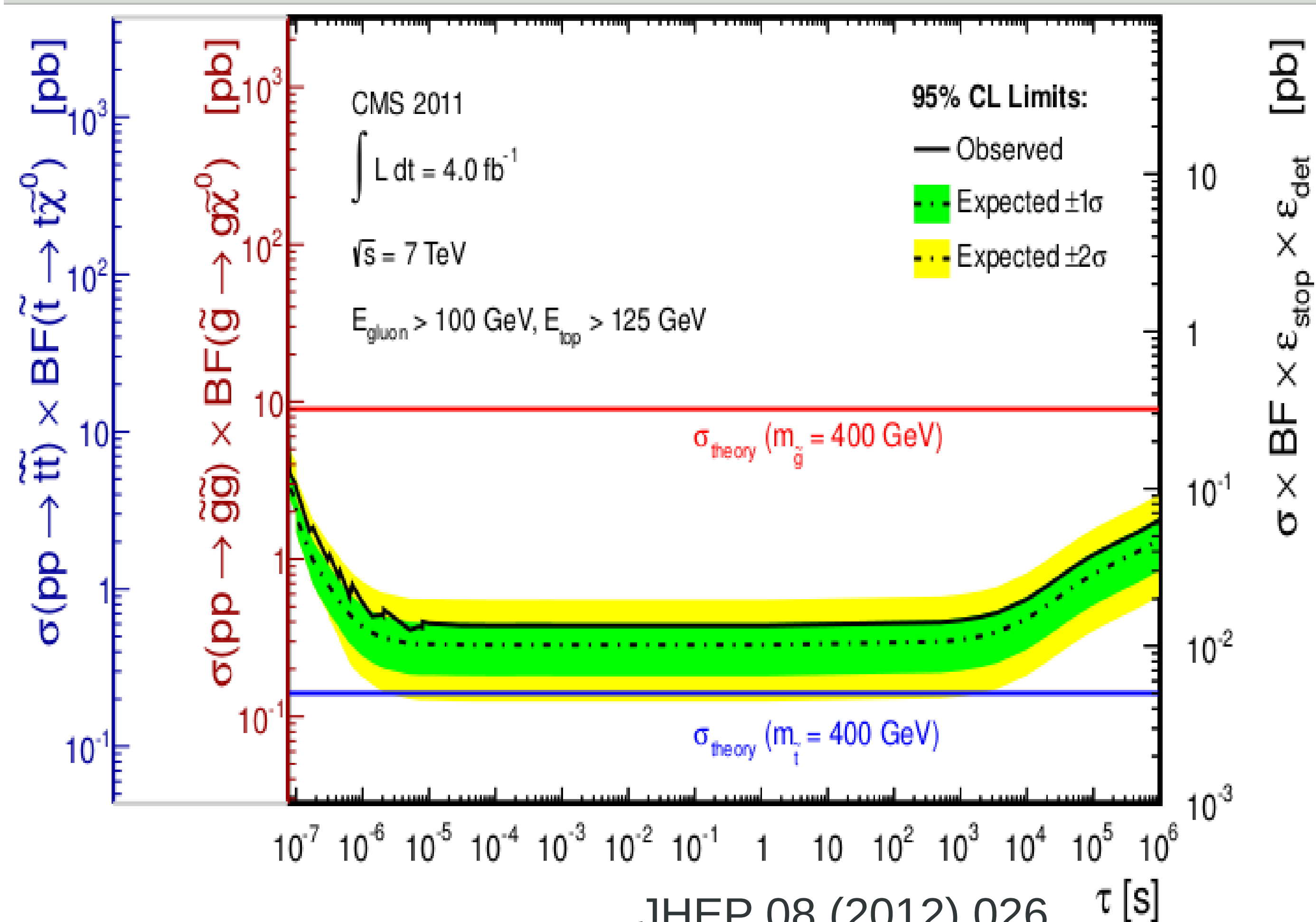
Long-lived particles



- Many of the SUSY requirements for dark matter could be achieved with two particles: one which might be charged and could be produced at a collider, but decays with a long lifetime (>1 ns) into the "astrophysical" dark matter particle.

Stopped Particles Search

Requirements:
- No signal in beam pickups for +/- 50 ns
- “Jet” with energy > 70 GeV
- Rejection of cosmic muons, beam halo, calorimeter noise



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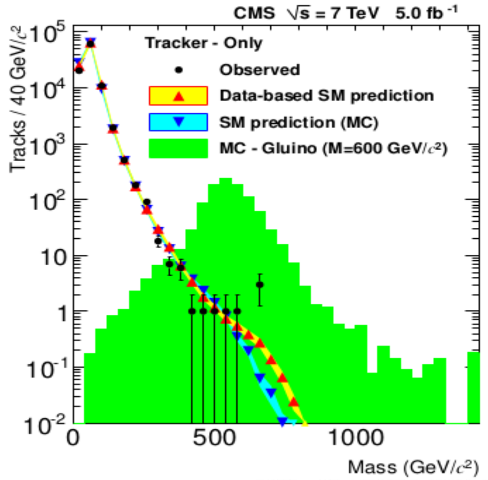
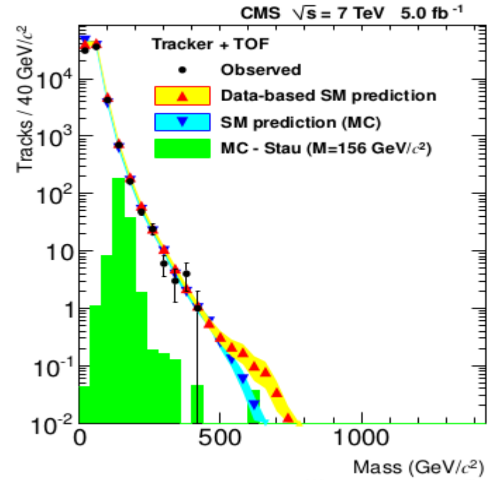
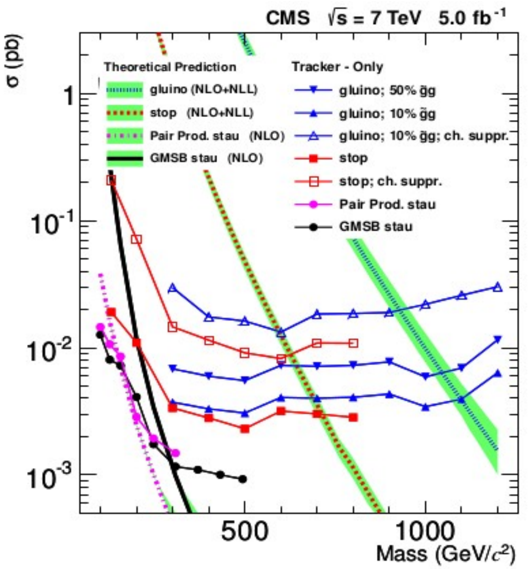
Results:
- No evidence for stopped hadronic particles observed
- Limits on stopped “R-hadrons” and stops published

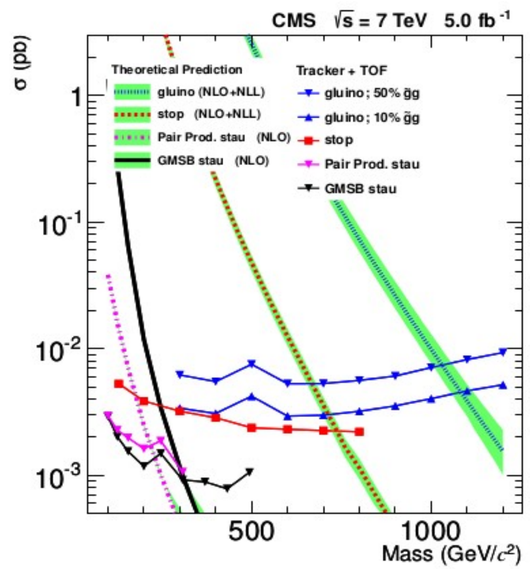
Faster/Shorter-lived Particles



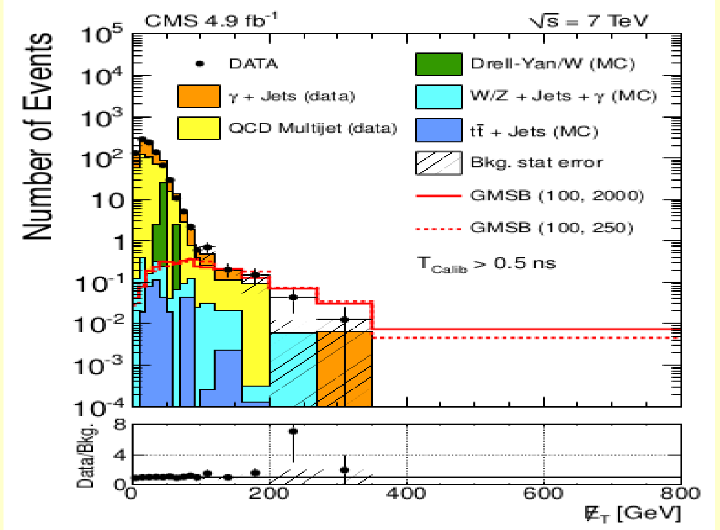
Phys. Lett. B 713 (2012) 408

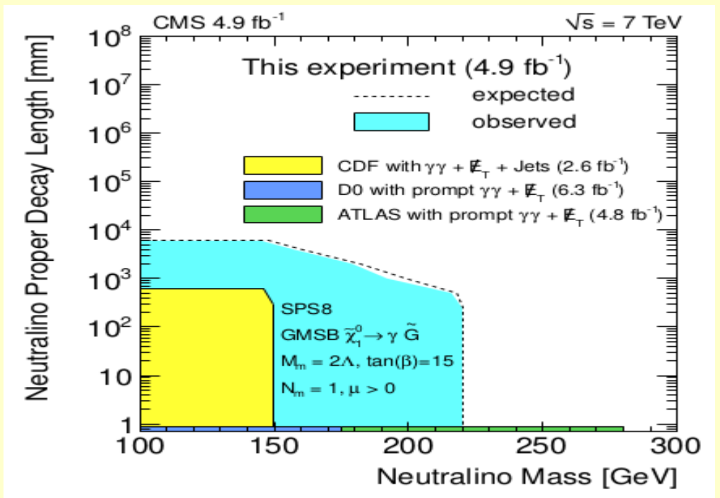






Requirements:
- High dE/dX in tracker, optionally long TOF in muon system



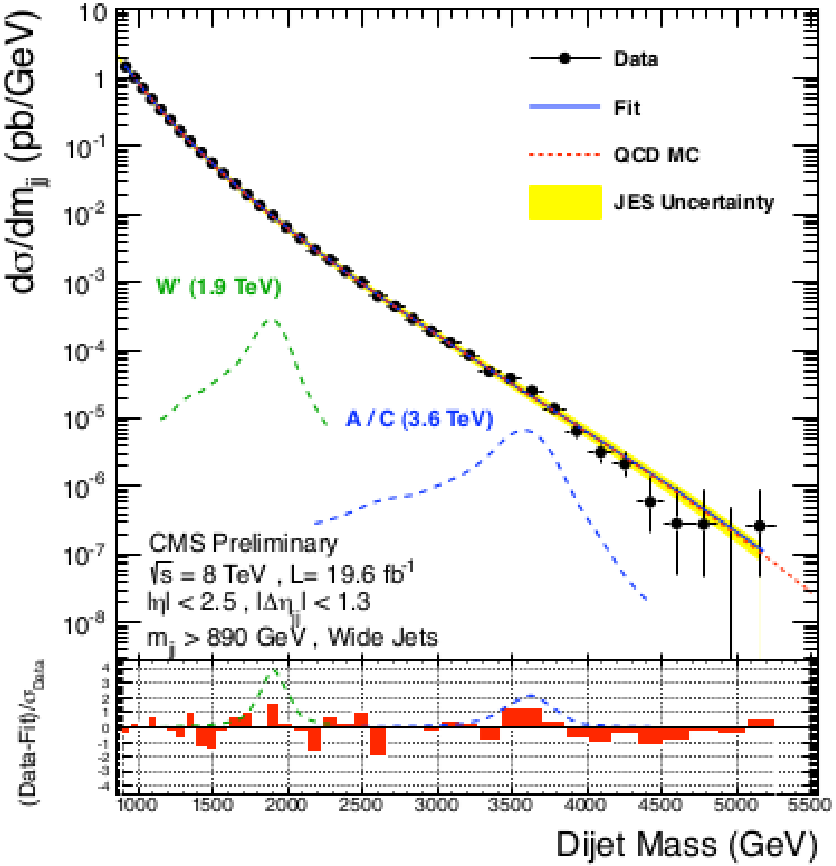


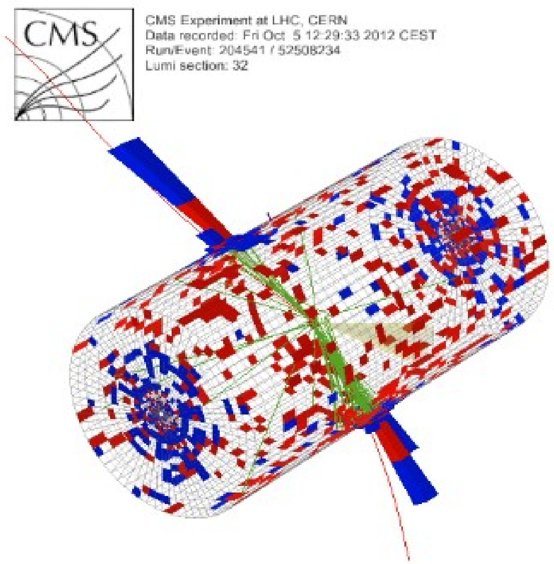
CMS-EXO-11-035

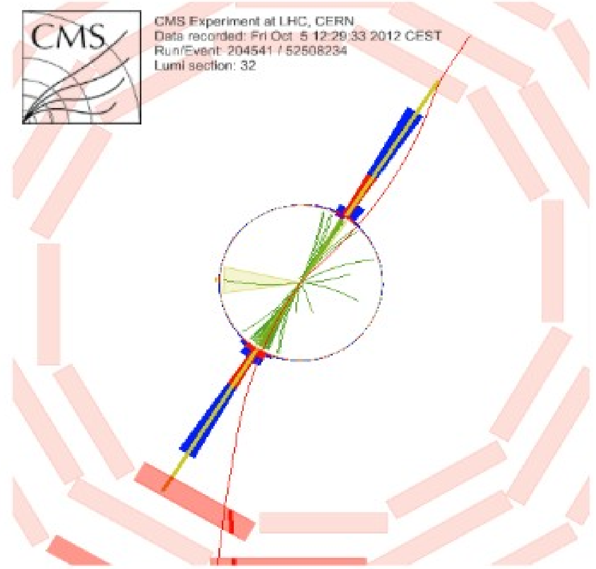
Requirements:
- Out-of-time, “oblong” photon, significant missing ET

“Generic” searches for typical particle decays: difermion signatures

Hadronic Pair-Production

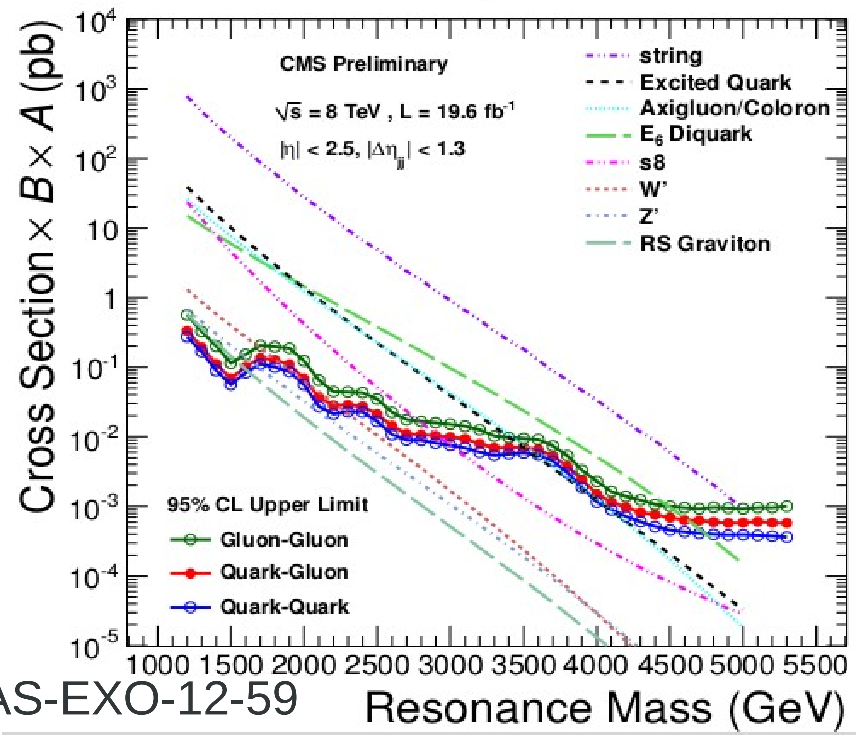






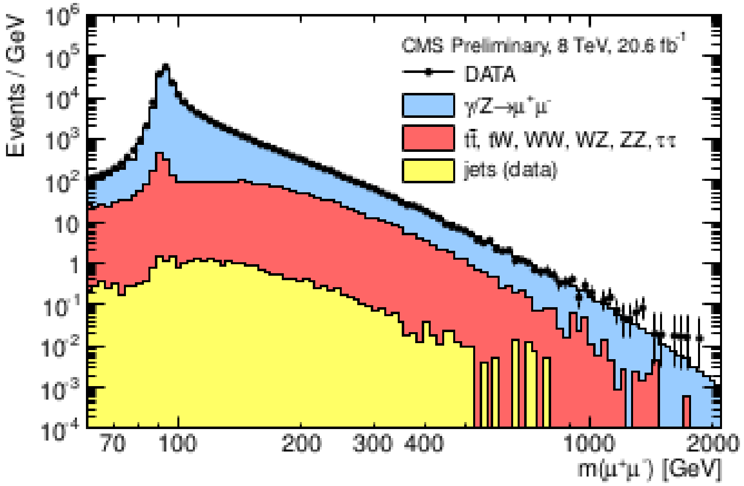
Requirements:

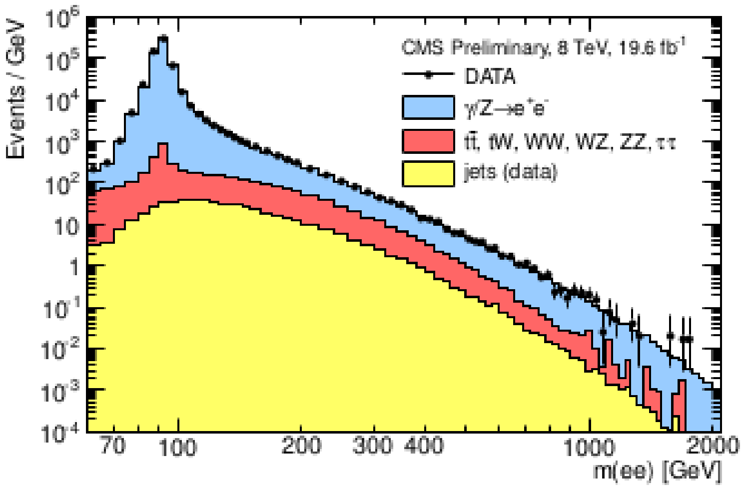
- Reconstruct jets with anti-kT "cone" of 0.5, then combine jets within ΔR < 1.1
- $|\Delta\eta_{jj}| < 1.5$, Mjj > 890 GeV



CMS-PAS-EXO-12-59

Lepton Pair Production





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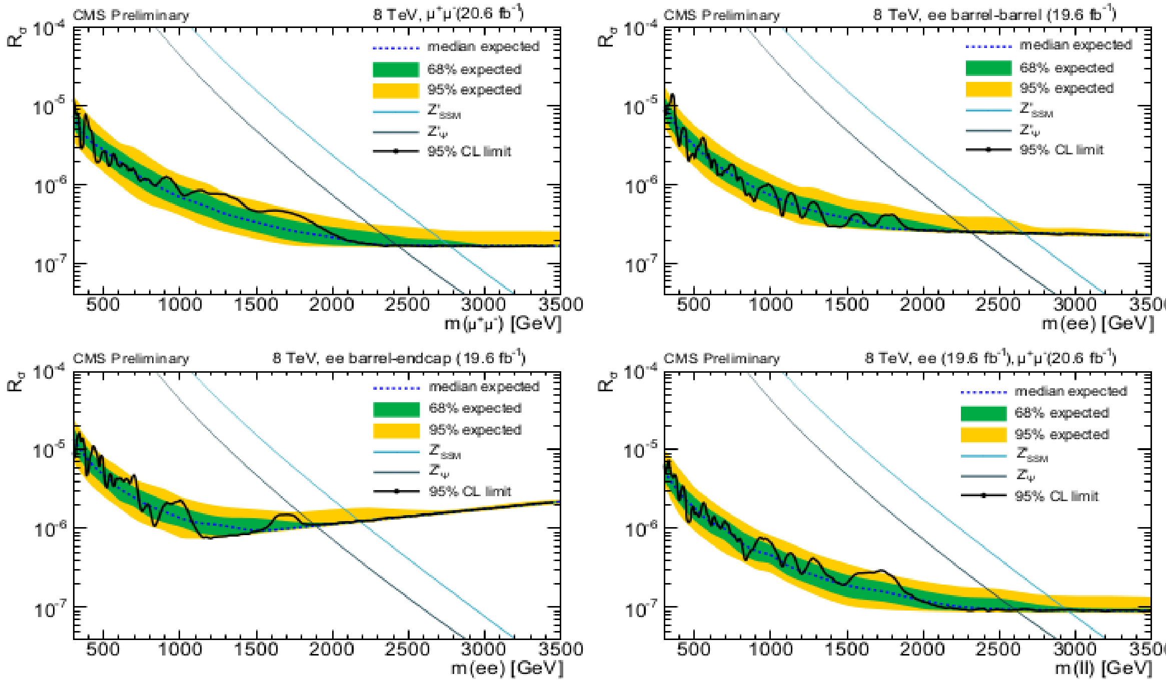
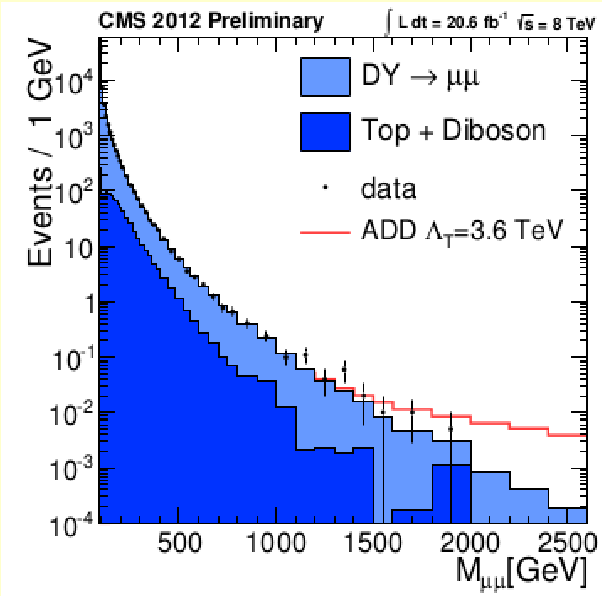
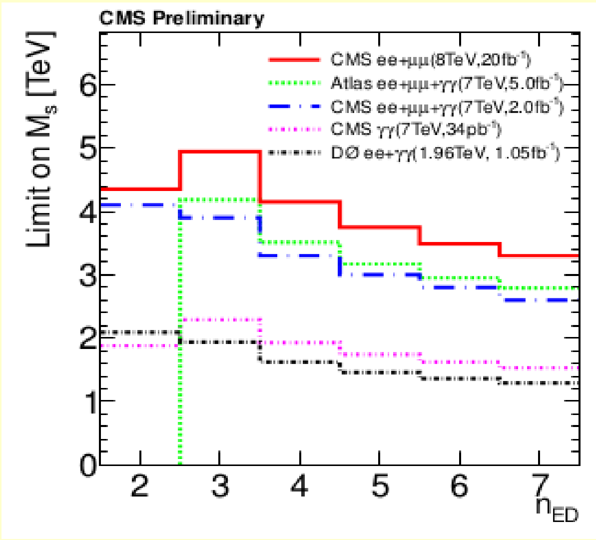
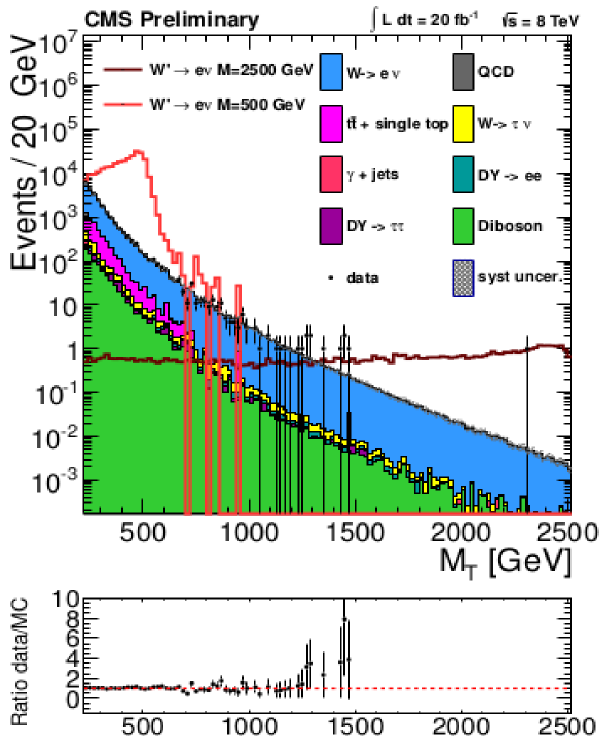
CMS-PAS-EXO-12-27
CMS-PAS-EXO-12-31

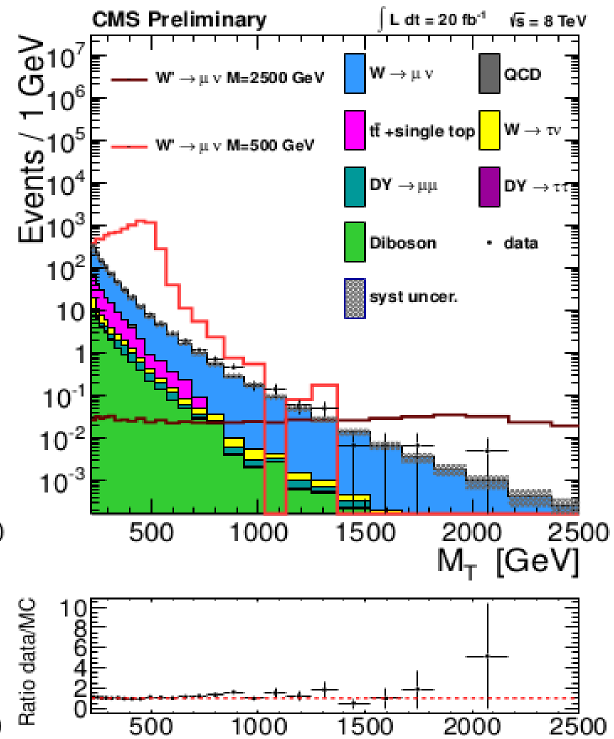






Lepton+MET (W')

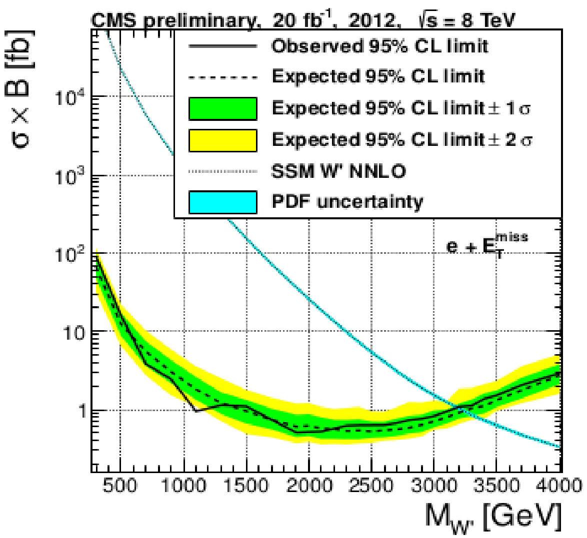


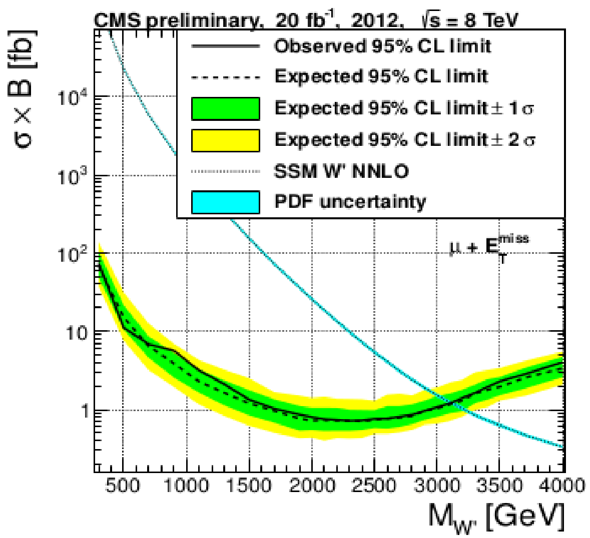


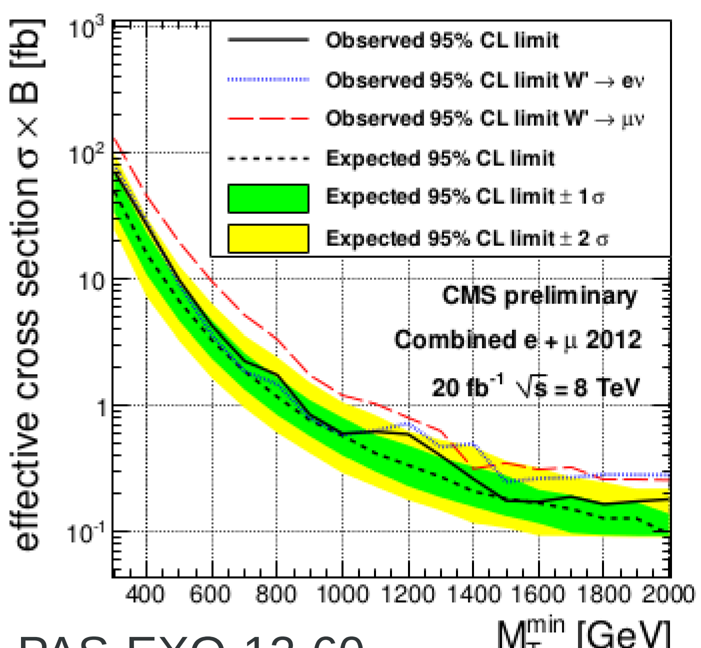
Mu Requirements:
- Isolated muon with p_T>45 GeV, no other muon with p_T>25 GeV

Electron Requirements:
- Isolated electron with p_T>100 GeV (no veto on other leptons)

Other Requirements:
- $\Delta\varphi_{l\nu}$> 0.8π, 0.4 < p_T/MET < 1.5

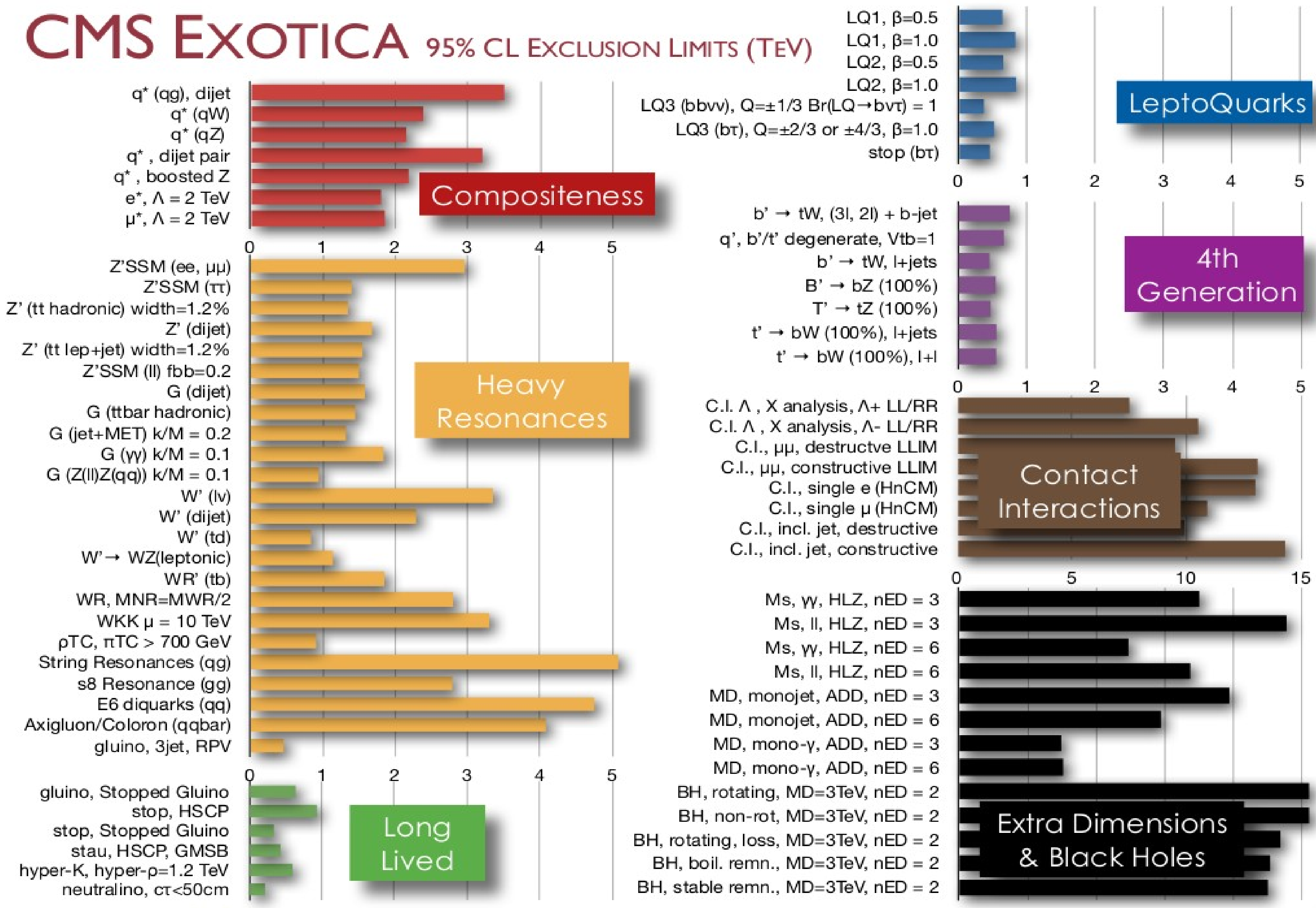






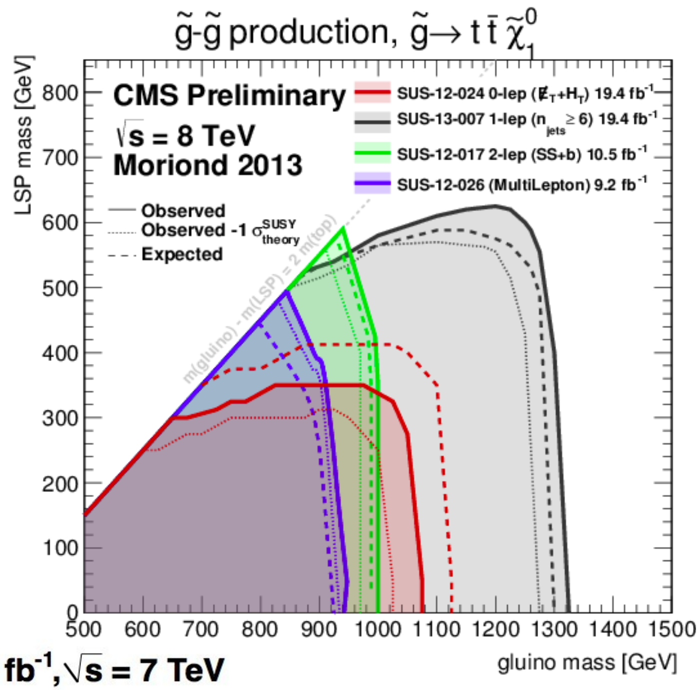
CMS-PAS-EXO-12-60

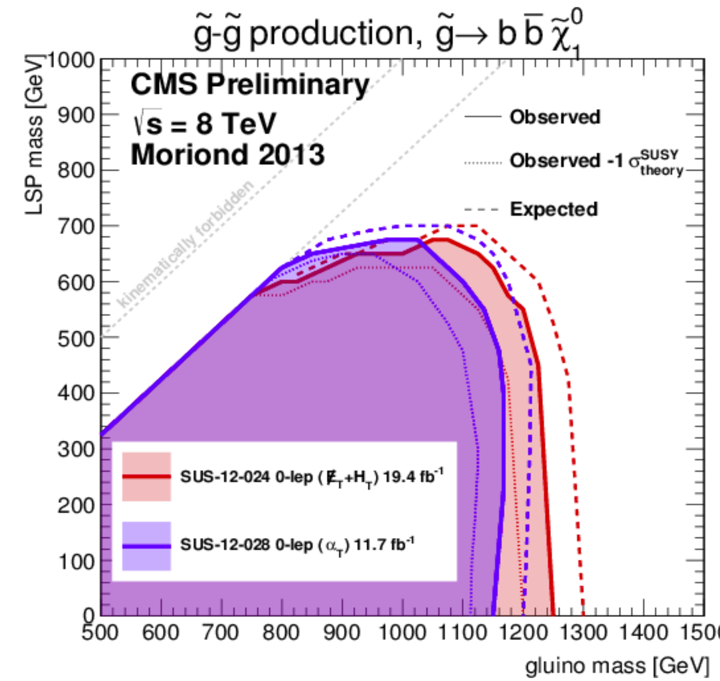
Many more...

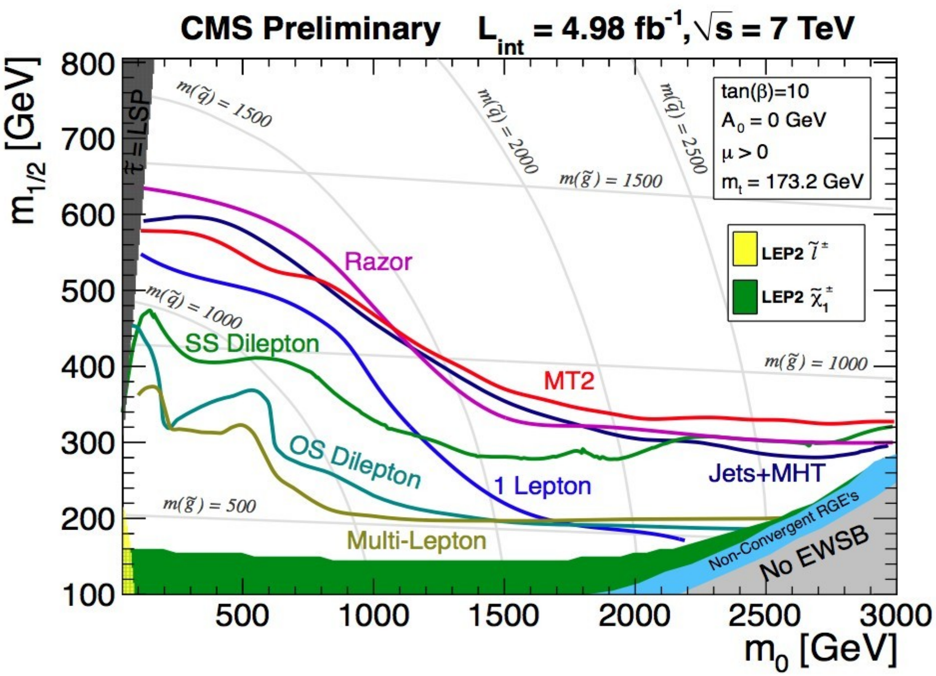


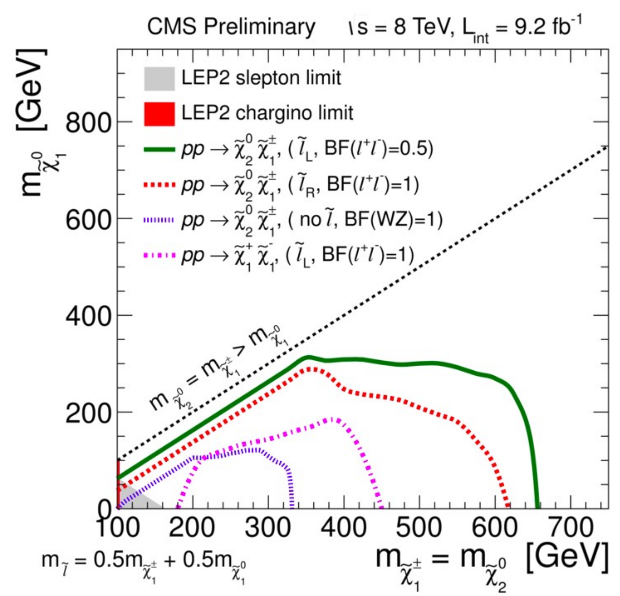
CMS EXOTICA 95% CL EXCLUSION LIMITS (TEV)
q* (qg), dijet
q* (qW)
q* (qZ)
q* , dijet pair
q* , boosted Z
e*, Λ = 2 TeV
μ*, Λ = 2 TeV
Compositeness
Z'SSM (ee, μμ)
Z'SSM (ττ)
Z' (tt hadronic) width=1.2%
Z' (dijet)
Z' (tt lep+jet) width=1.2%
Z'SSM (ll) fbb=0.2
G (dijet)
G (ttbar hadronic)
G (jet+MET) k/M = 0.2
G (γγ) k/M = 0.1
G (Z(ll)Z(qq)) k/M = 0.1
W' (lν)
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 (bbνν), Q=±1/3 Br(LQ→bντ) = 1
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, ll, HLZ, nED = 3
Ms, γγ, HLZ, nED = 6
Ms, ll, HLZ, nED = 6
MD, monojet, ADD, nED = 3
MD, monojet, ADD, nED = 6
MD, mono-γ, ADD, nED = 3
MD, mono-γ, ADD, nED = 6
BH, rotating, MD=3TeV, nED = 2
BH, non-rot, MD=3TeV, nED = 2
BH, rotating, loss, MD=3TeV, nED = 2
BH, boil. remn., MD=3TeV, nED = 2
BH, stable remn., MD=3TeV, nED = 2
Extra Dimensions & Black Holes
0
1
2
3
4
5
10
15

Summary of SUSY Exclusions









Future Reach (one view)