SUSY and Exotica searches by CMS

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INR RAS
on behalf of the CMS collaboration

LHC on the march
November 2011,Protvino,Russia

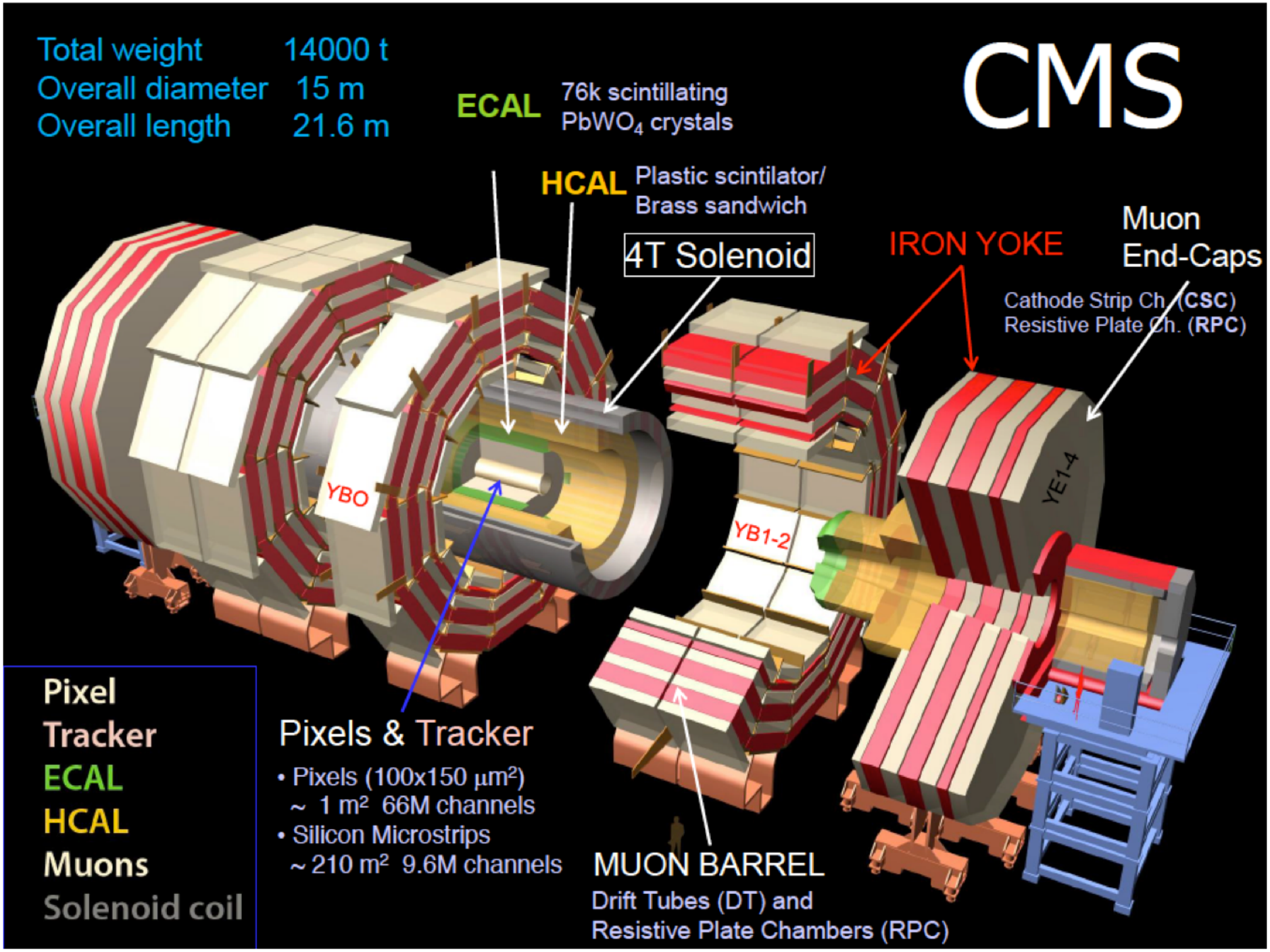
OVERVIEW

1. Supersymmetry
   1. Jets + MET
   2. Lepton(s) + MET
   3. Multileptons + jets + MET
   4. Photon(s) + jet + MET
   5. Razor Variables
2. Heavy Resonances
   1. Dileptons
   2. Lepton+MET
   3. Diphotons
   4. Dijets
   5. ttbar resonances
   6. Heavy neutrinos (separate talk)
   7. WZ
3. Xtra dimensions
   1. Dileptons & diphotons
   2. Jet/photon+MET
   3. Black Holes
4. Leptoquarks
   1. 1st generation
   2. 2nd generation
5. 4th generation b'/t'
   1. All hadronic
   2. Semileptonic
6. Long-lived particles
   1. HSCP
   2. Stopped particles

https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResults

LHC PERFORMANCE

- LHC is providing pp collisions at a 7 TeV center-of-mass energy
- LHC performed splendidly this year
  - $3.5*10^{33}$ cm^{-2} s^{-1} peak luminosity
  - >100 pb^{-1} per day
  - 5.7 fb^{-1} delivered
  - 5.2 fb^{-1} recorded by CMS
- **These results use about 1 fb^{-1}**

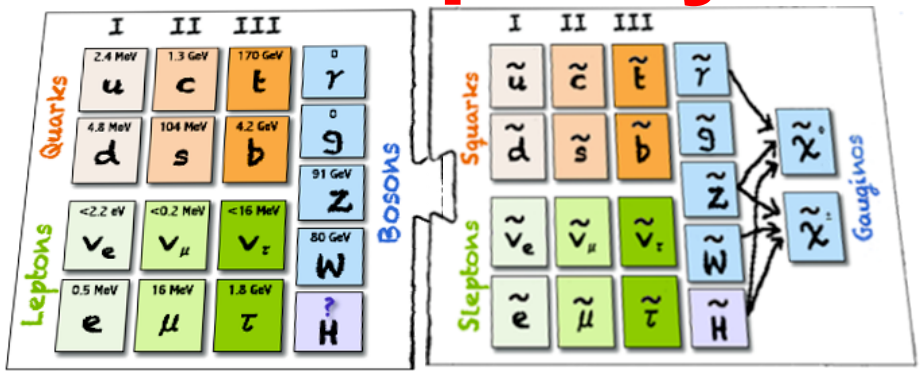

Total weight 14000 t
Overall diameter 15 m
Overall length 21.6 m
ECAL 76k scintillating $PbWO_4$ crystals
CMS
HCAL Plastic scintilator/ Brass sandwich
4T Solenoid
IRON YOKE
Muon End-Caps
Cathode Strip Ch. (CSC)
Resistive Plate Ch. (RPC)
YBO
YB1-2
YE1-4
Pixel
Tracker
ECAL
HCAL
Muons
Solenoid coil
Pixels & Tracker
• Pixels (100x150 μm²) ~ 1 m² 66M channels
• Silicon Microstrips ~ 210 m² 9.6M channels
MUON BARREL
Drift Tubes (DT) and Resistive Plate Chambers (RPC)

CMS DETECTOR PERFORMANCE

- 3.8T solenoid
- Silicon tracker:
  $\sigma(pT)/pT = 15\%$ at 1 TeV
- EMcal: homogeneous Pb-Tungstate crystal
  $\sigma_E/E = 3\%/\sqrt{E[GeV]} + 0.5\%$
- HADcal: Brass-scint, $7\lambda_0$
  $\sigma_E/E = 100\%/\sqrt{e[GeV]} + 5\%$
- Muon spectrometer (Resistive Plate Counters, Drift Tubes, Cathode Strip Chambers) in magnet return yoke

1. Supersymmetry

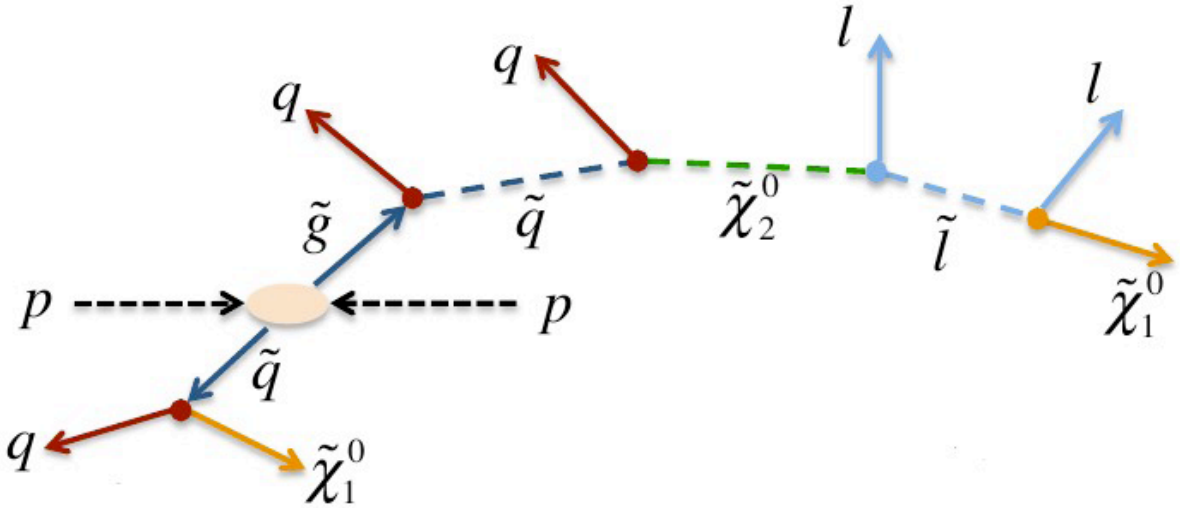
Illustration from: X.Portell PIC11



$$R \equiv (-1)^{2S+3(B-L)}$$

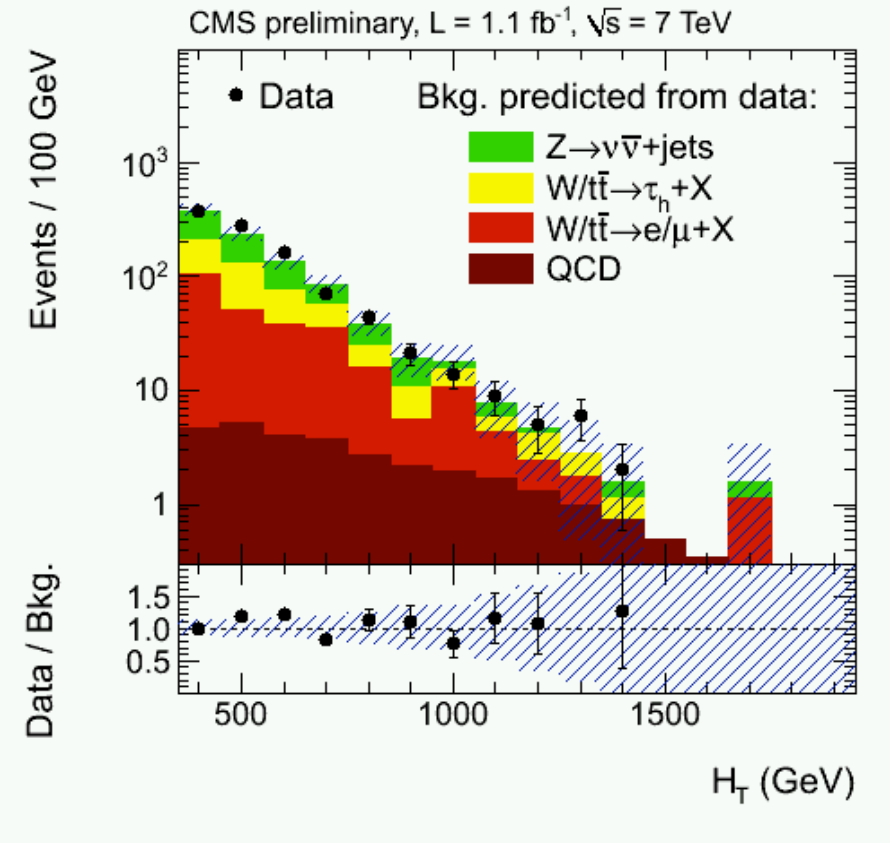
- Supersymmetry introduces new particles – partners of the SM particles to address the gauge hierarchy problem.
- These new particles may include neutral, stable, and weakly interacting particles that are good dark-matter candidates
- In many models, dark-matter candidates are stable as a result of a conserved quantity. In SUSY this quantity is R parity, and its conservation requires all SUSY particles to be produced in pairs and the **lightest SUSY particle (LSP)** to be stable
- **Coloured SUSY particles can be pair-produced copiously at the LHC. These particles will decay directly into SM particles and an LSP or via intermediate colour-singlet states that ultimately decay into an LSP**
- **The LSP will pass through the detector without interacting -> missing transverse momentum (p_T) and/or transverse energy (E_T)**

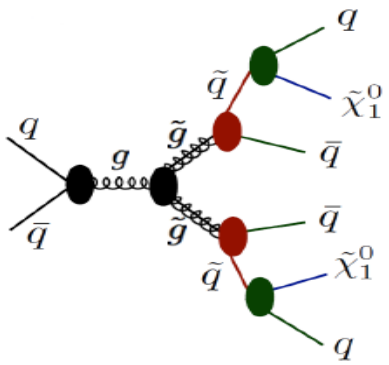
1. Supersymmetry



- Decay chain ends with Lightest Supersymmetric Particle (LSP) which escapes detection --> importance of Missing Transverse Energy (MET)
- Production @LHC
  - j+MET: dominant production via squark and gluino
  - leptons + jet +MET: lower xsection/BR but complementary
  - b/t: lower xsection, wait for more data
  - photons+ MET: GMSB models
- Searches are topology-based, independent from models
- Most strategies based on tails of MET distributions
- Lowest lepton p_T cuts to probe largest phase space
- Background estimate: data driven to minimize dependance on MC

1.1 Jets + MET





$$\tilde{q} \to q\tilde{\chi}_1^0$$

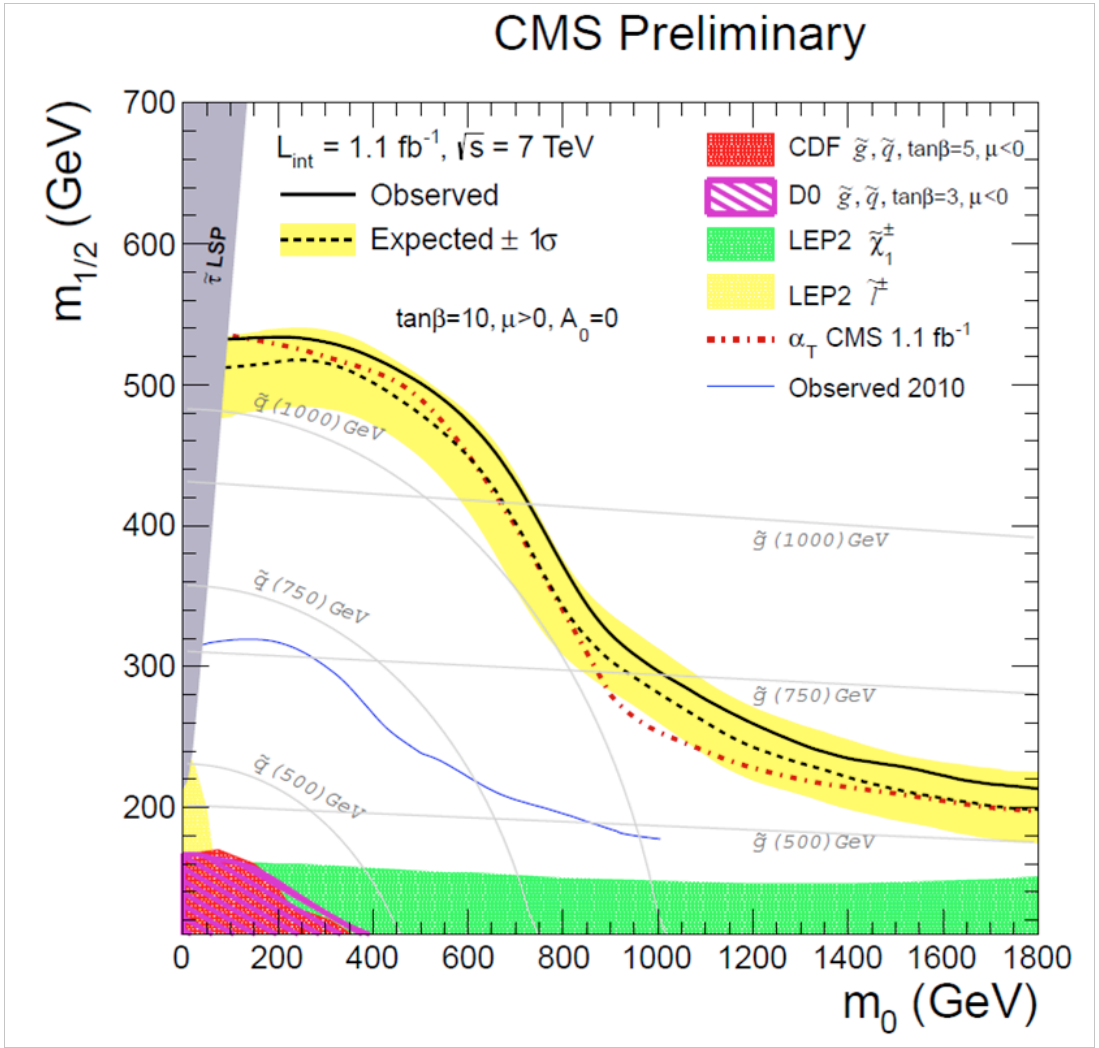
$$\tilde{g} \to qq\tilde{\chi}_1^0$$

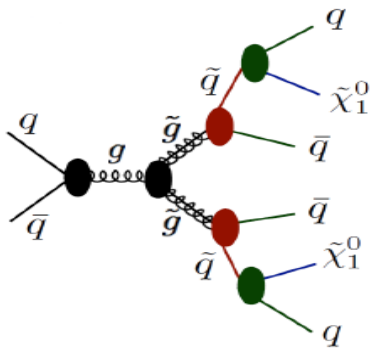
$$H_T \equiv \sum_{i=1}^{N_{JETS}} (p_T)_i$$

CMS-PAS-SUS-11-004
Other algorithms:
- CMS PAS SUS-11-005
- CMS PAS SUS-10-009
- CMS PAS SUS-10-003
- CMS PAS SUS-11-001
- CMS PAS SUS-11-003

•The most model-independent channel
• Large backgrounds:
Z-->nunubar; (W-->lnubar)+jets with missing lepton; QCD events with large MET

1.1 Jets + MET





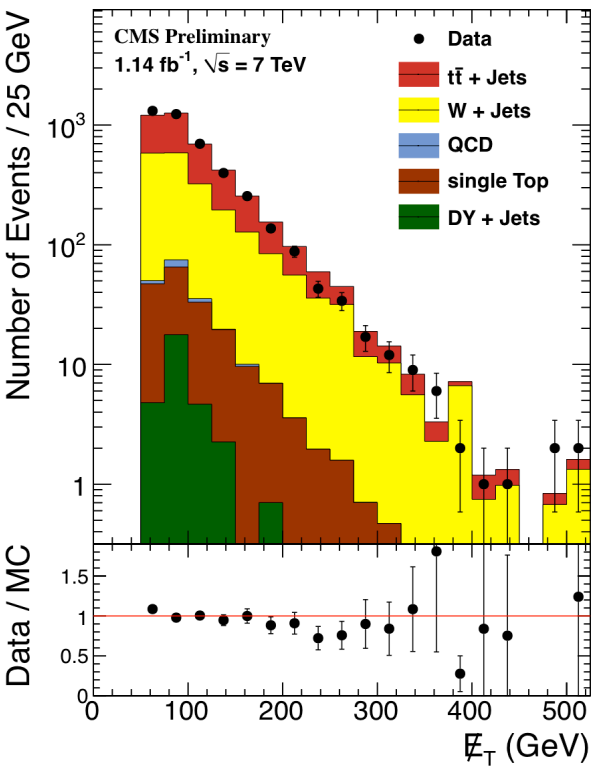
$$\tilde{q} \rightarrow q\tilde{\chi}_1^0$$

$$\tilde{g} \rightarrow qq\tilde{\chi}_1^0$$

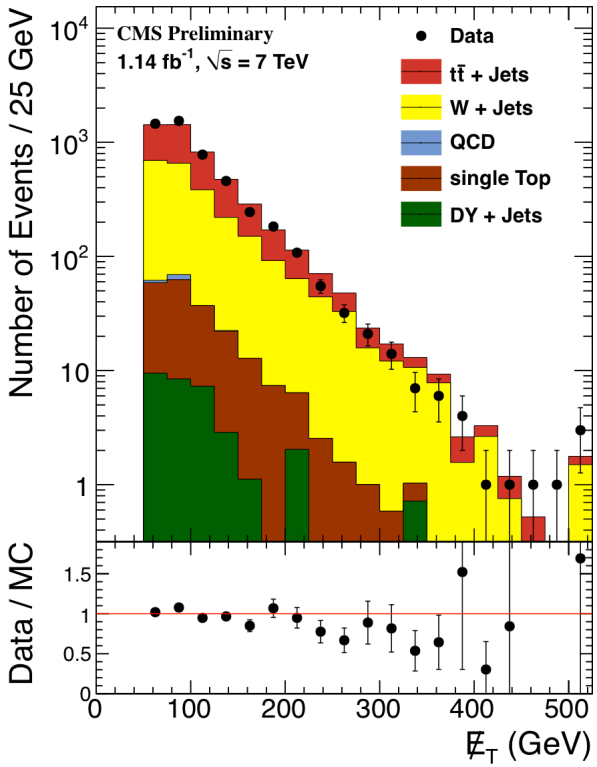
CMS-PAS-SUS-11-004
Other algorithms:
- CMS PAS SUS-11-005
- CMS PAS SUS-10-009
- CMS PAS SUS-10-003
- CMS PAS SUS-11-001
- CMS PAS SUS-11-003

1.2 lepton(s)+ jets + MET

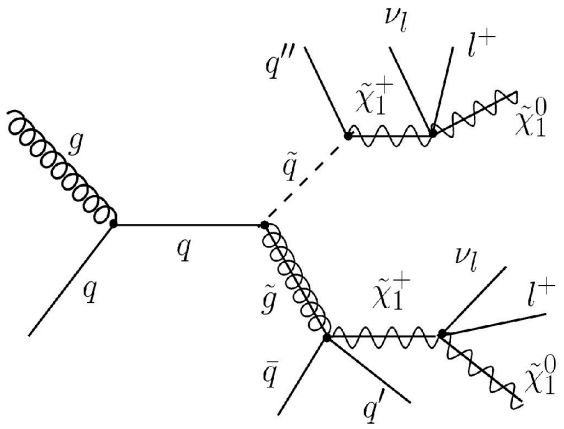
Electron



Muon



ONE LEPTON

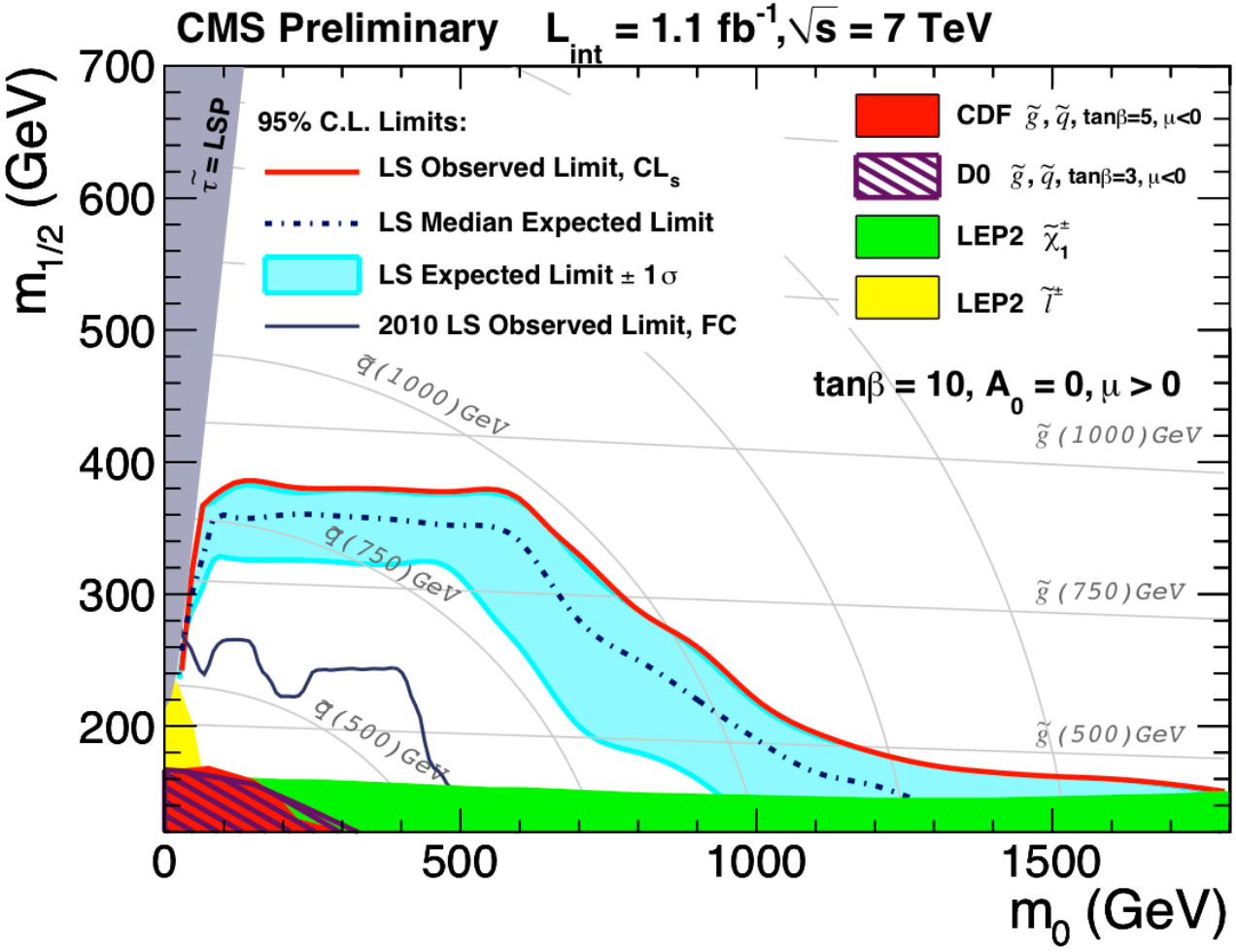


CMS PAS SUS-11-015

Leptons come from slepton/charginos/W/Z decays
Smaller BR --> weaker limits but complementary
May use W/Z mass cuts

1.2 lepton(s)+ jets + MET

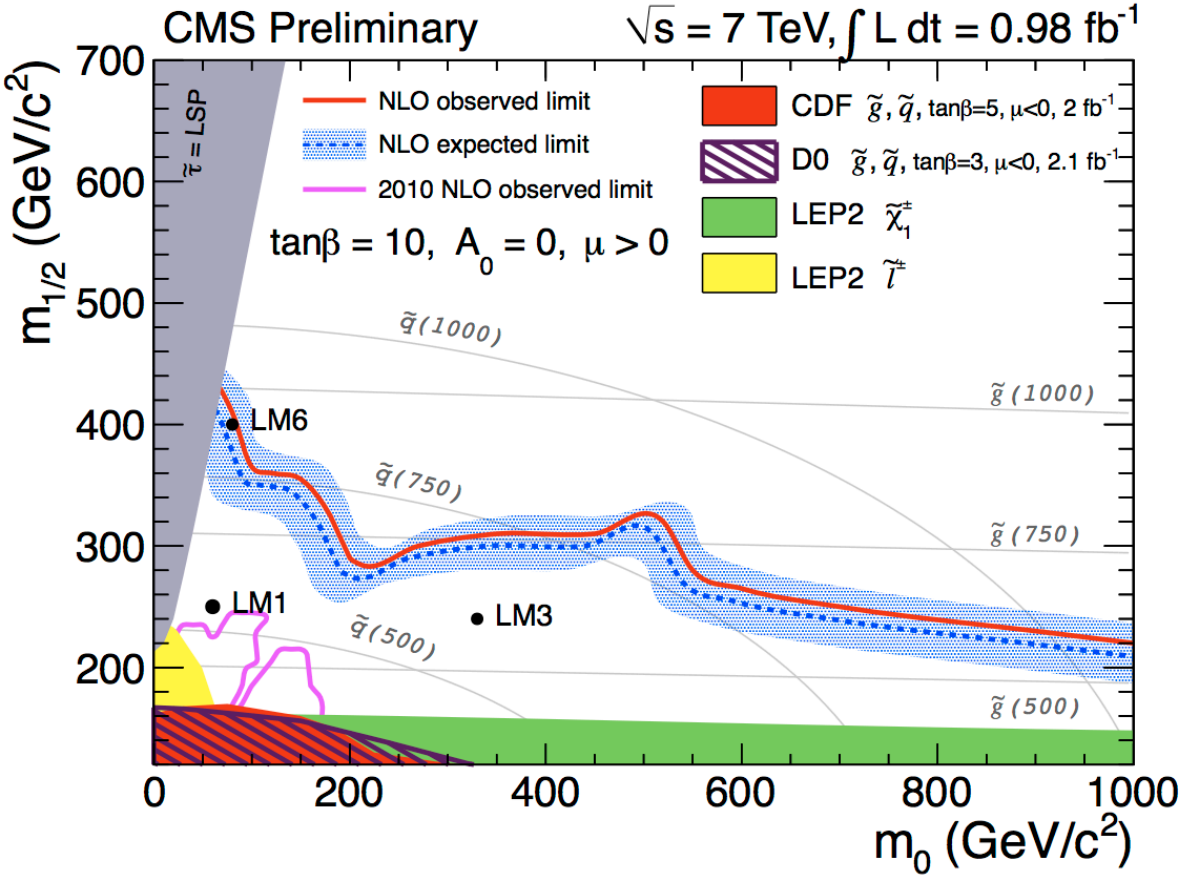
ONE LEPTON



CMS PAS SUS-11-015

1.2 lepton(s)+ jets + MET

OPPOSITE SIGN DILEPTONS



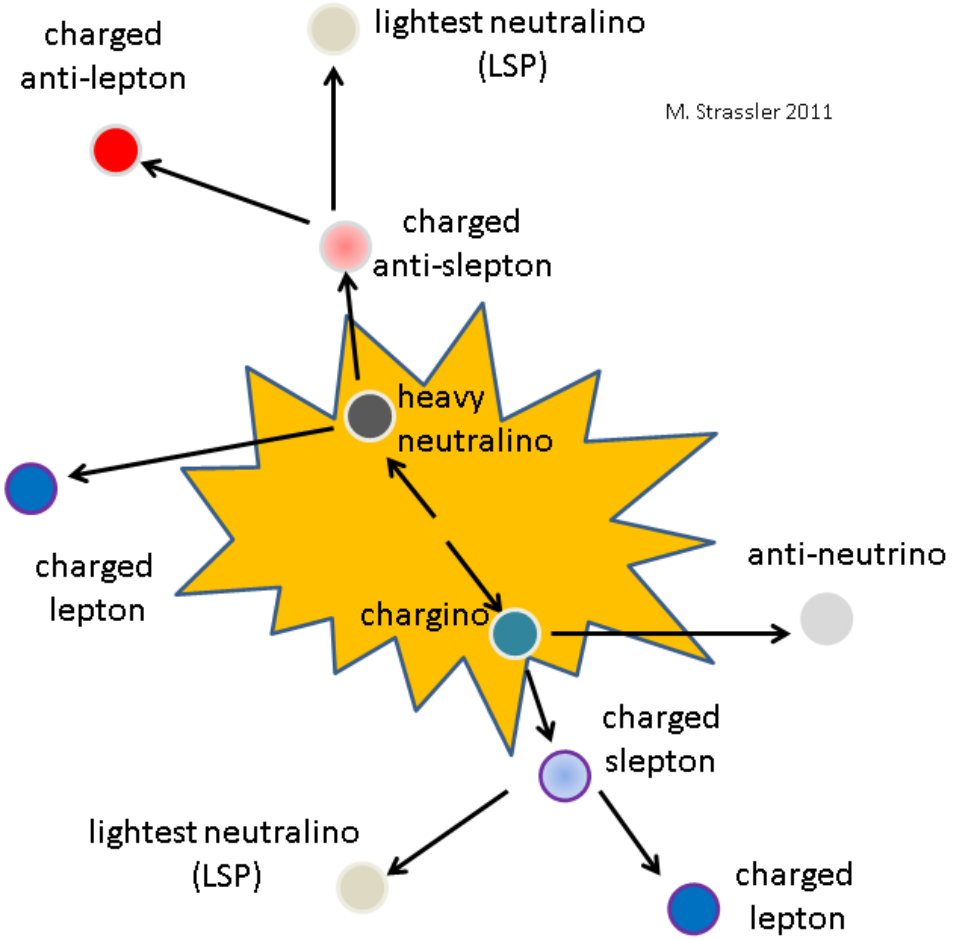
CMS PAS SUS-11-011
Other limits:
CMS PAS SUS-11-012; PAS SUS-11-017
CMS PAS SUS-11-010; arxiv:1104.3168
arxiv:1106.0933

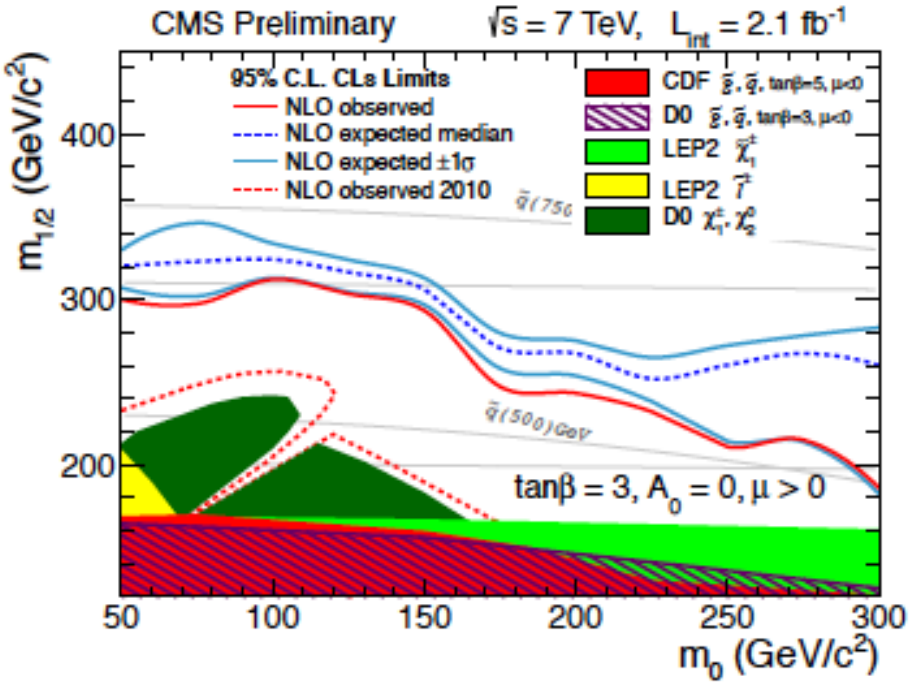
1.2 lepton(s)+ jets + MET

Other limits:

- CMS PAS SUS-11-012 Search for Physics Beyond the Standard Model in Z + MET + Jets events at the LHC
- CMS PAS SUS-11-017 Search for New Physics in Events with a Z Boson and Missing Transverse Energy
- CMS PAS SUS-11-010; arxiv:1104.3168 Search for new physics with same-sign isolated dilepton events with jets and missing energy
- arxiv:1106.0933 Search for Physics Beyond the Standard Model Using Multilepton Signatures in pp Collisions at sqrt(s) = 7 TeV
- CMS PAS EXO-11-045 Search for RPV in multileptons

1.3 multileptons + MET

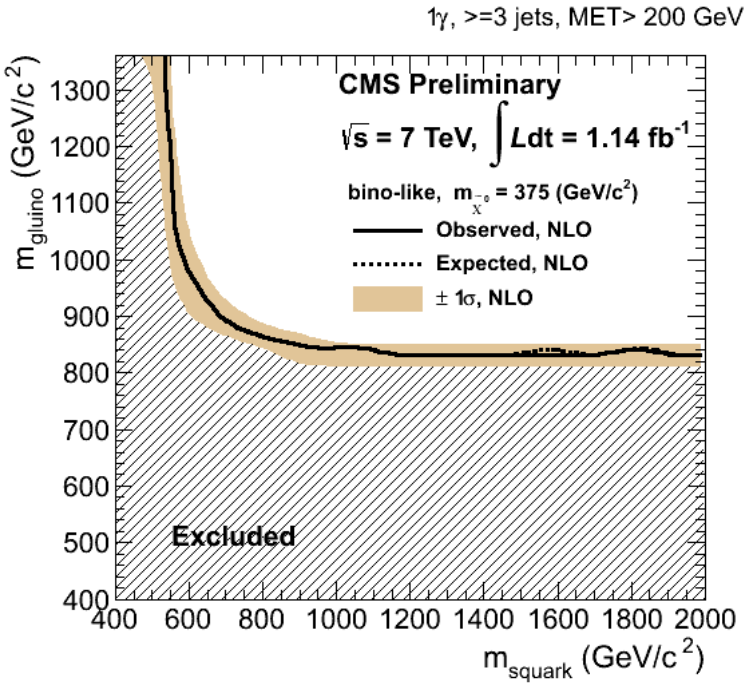


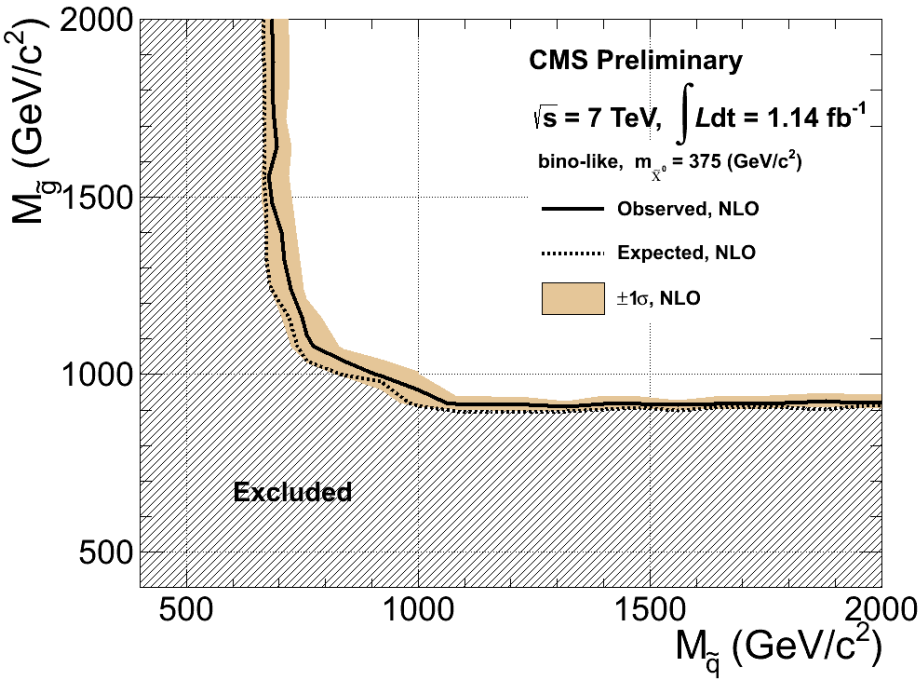


SUS-11-013

1.4 Photon(s) + jet + MET

CMS PAS SUS-11-09





DIPHOTONS

SINGLE PHOTONS

Where do photons come from ?

In Gauge-Mediated SUSY

•NLSP (Neutralino and Chargino) --> LSP (Gravitino) + photon/W/Z

Backgrounds: QCD with fake MET, EWK with true MET

1.5 SUSY search with Razor V.

Introduced "Razor" variables, R and M_R, designed to discover and characterize massive pair-production

arXiv:1006.2727

Arranging all reconstructed objects into two hemispheres, with 3-momenta $\vec{p}$ and $\vec{q}$

MET$= \vec{M}$

Example: $\tilde{q}\tilde{q} \to (q\tilde{\chi}_1^0)(q\tilde{\chi}_1^0)$

Scale:

$$M_R = \sqrt{(|\vec{p}| + |\vec{q}|)^2 - (p_z + q_z)^2}$$

→ **Peaks at** $M_\Delta = \dfrac{m_{\tilde{q}}^2 - m_{\tilde{\chi}_1^0}^2}{2m_{\tilde{q}}}$

$$M_T^R = \sqrt{\frac{|\vec{M}|(|\vec{p}| + |\vec{q}|) - \vec{M}\cdot(\vec{p}+\vec{q})}{2}}$$

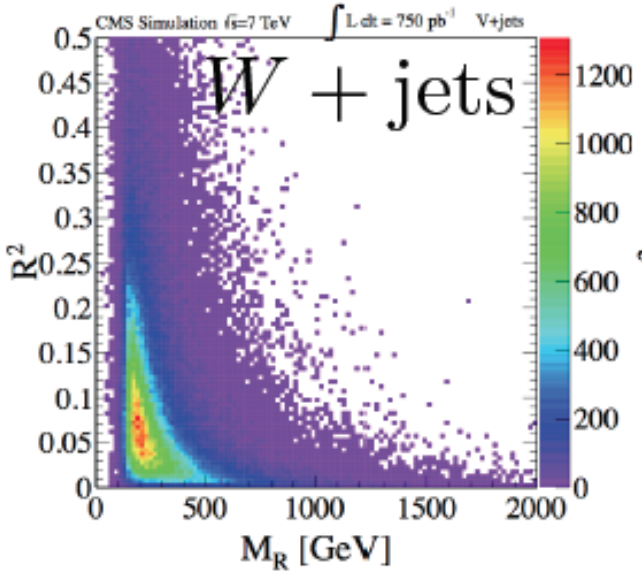
→ **Edge at** $M_\Delta = \dfrac{m_{\tilde{q}}^2 - m_{\tilde{\chi}_1^0}^2}{2m_{\tilde{q}}}$

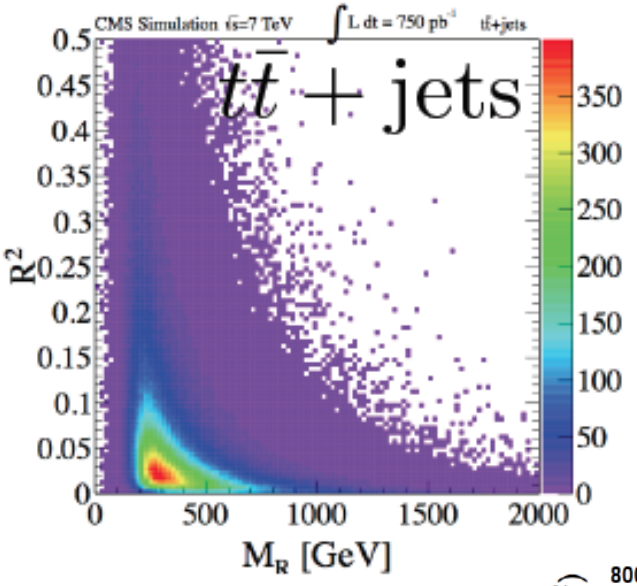
Angle:

$$R = \frac{M_T^R}{M_R}$$

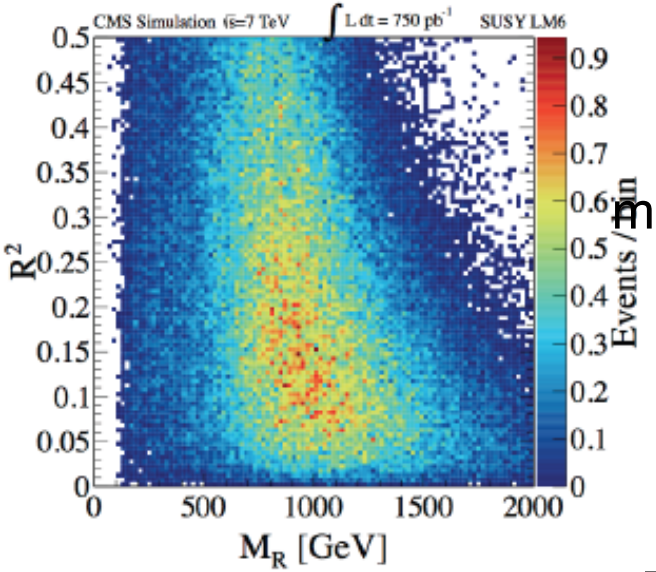
SUS-11-008

1.5 SUSY search with Razor V.

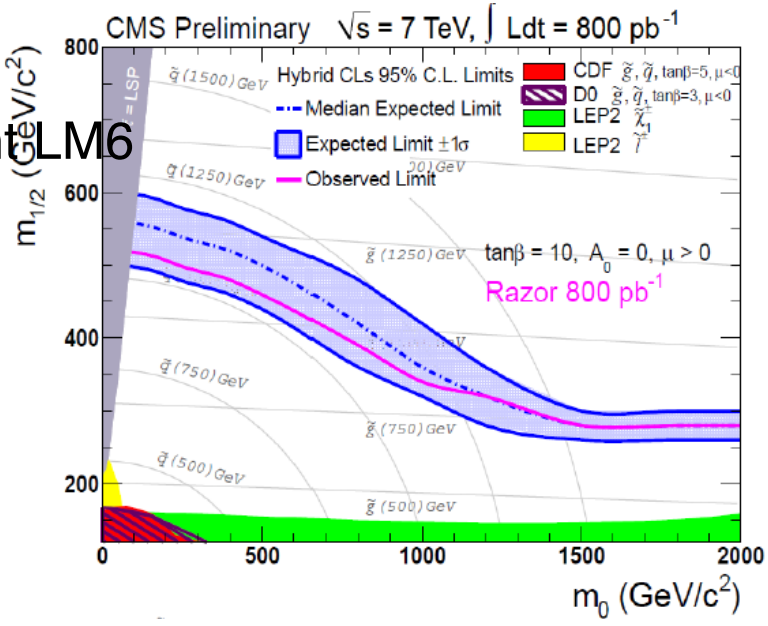




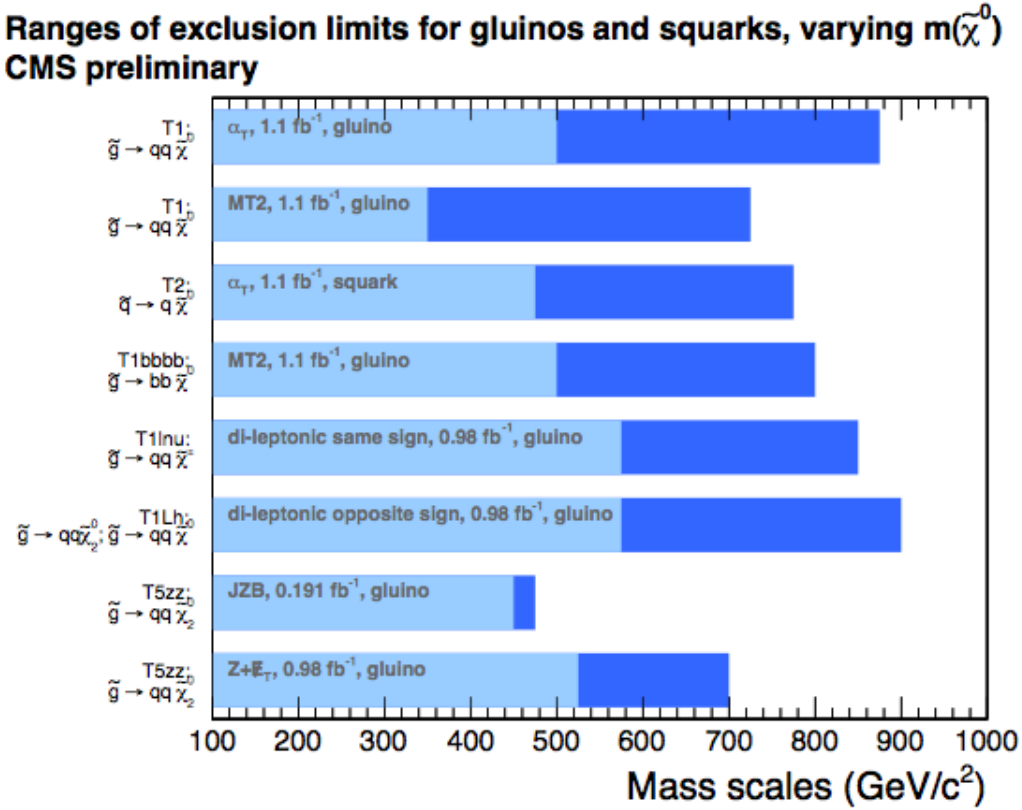
- Lepton and hadron “boxes”
- Special triggers used, deployed after May TS
- No significant excess over BG observed
- CLs limit setting

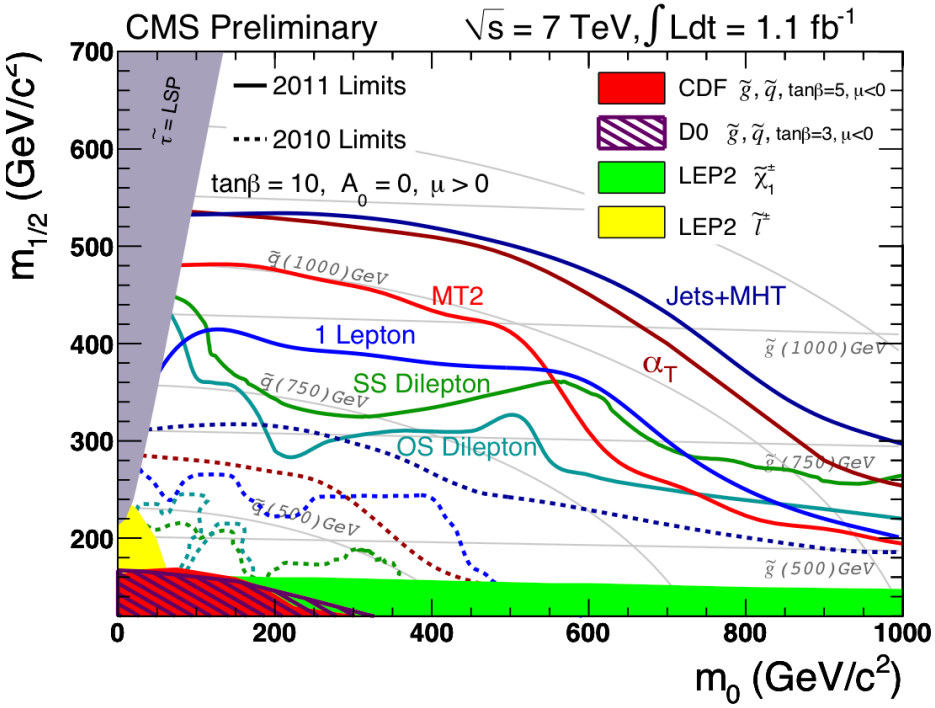


←MSUGRA point LM6
m_0=85 GeV
$m_{1/2}$=400 GeV



Summary supersymmetry





For limits on m($\tilde{g}$), m($\tilde{q}$) >> m($\tilde{g}$) (and vice versa). $\sigma^{prod} = \sigma^{NLO\text{-}QCD}$.

$m(\tilde{\chi}^\pm), m(\tilde{\chi}^0_2) = \frac{m(\tilde{g}) + m(\tilde{\chi}^0)}{2}$.

m($\tilde{\chi}^0$) is varied from 0 GeV/c^2 (dark blue) to m($\tilde{g}$)-200 GeV/c^2 (light blue).

Results obtained using ~1 fb^{-1} of data

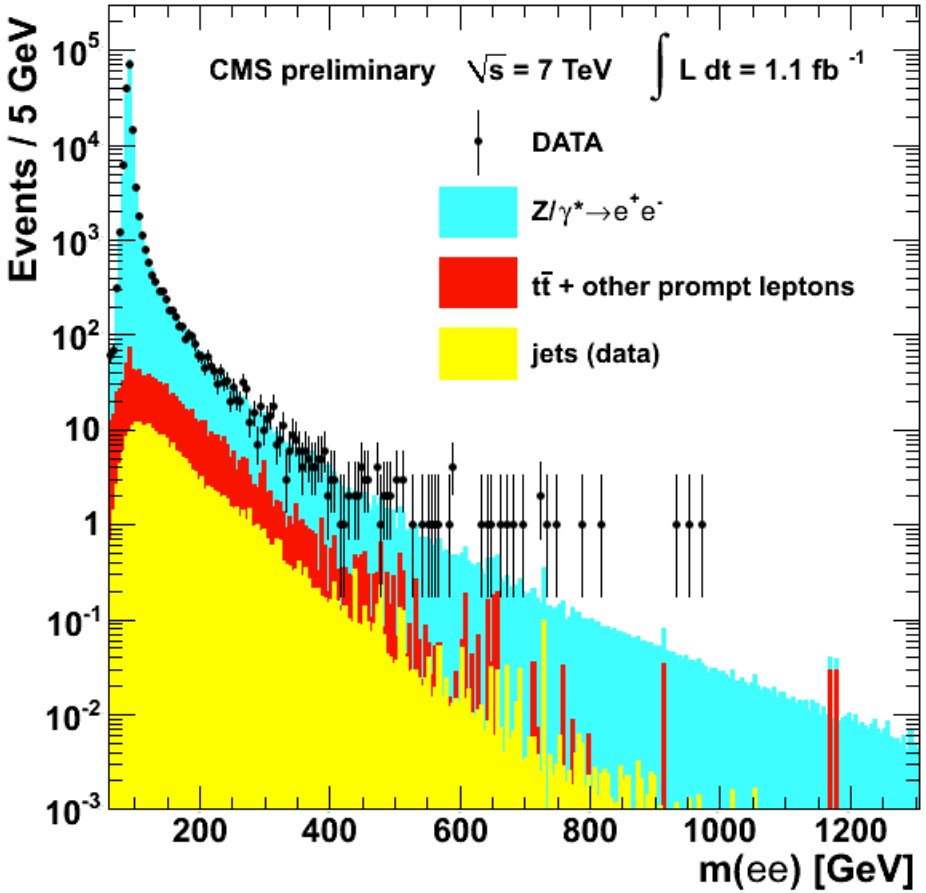
No analyses show significant deviation from SM

2. Heavy Resonances

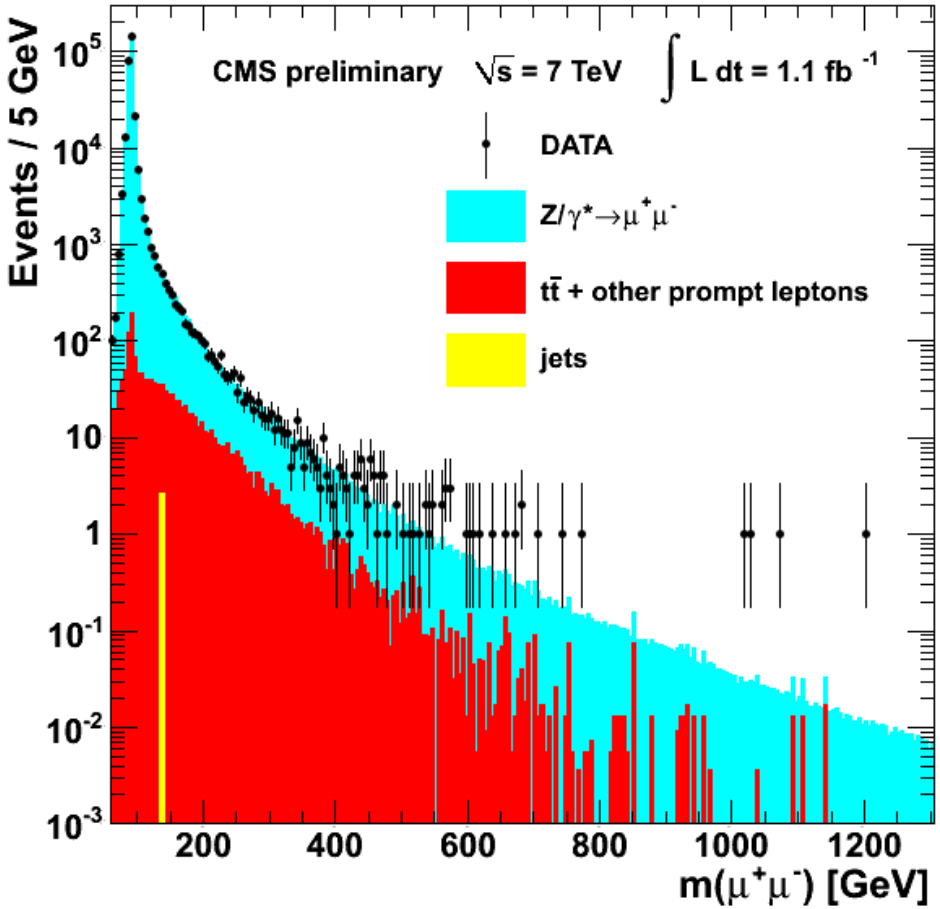
- Predicted by many extensions of the SM with no precise hint of mass:
  - The Sequential Standard Model Z'_{SSM} with standard - model - like couplings;
  - the $Z'\psi$ predicted by grand unified theories;
  - Kaluza–Klein graviton excitations arising in the Randall – Sundrum (RS) model of extra dimensions;
  - Etc etc
- **Experimentally challenging, search for signals over the high mass tails of the invariant mass distributions of backgrounds**
- **Need:**
  - **Great momentum/energy resolution**
  - **Accurate momentum/energy scale over 1TeV**
- **Backgrounds: SM processes**

2.1 Dileptons

Electrons

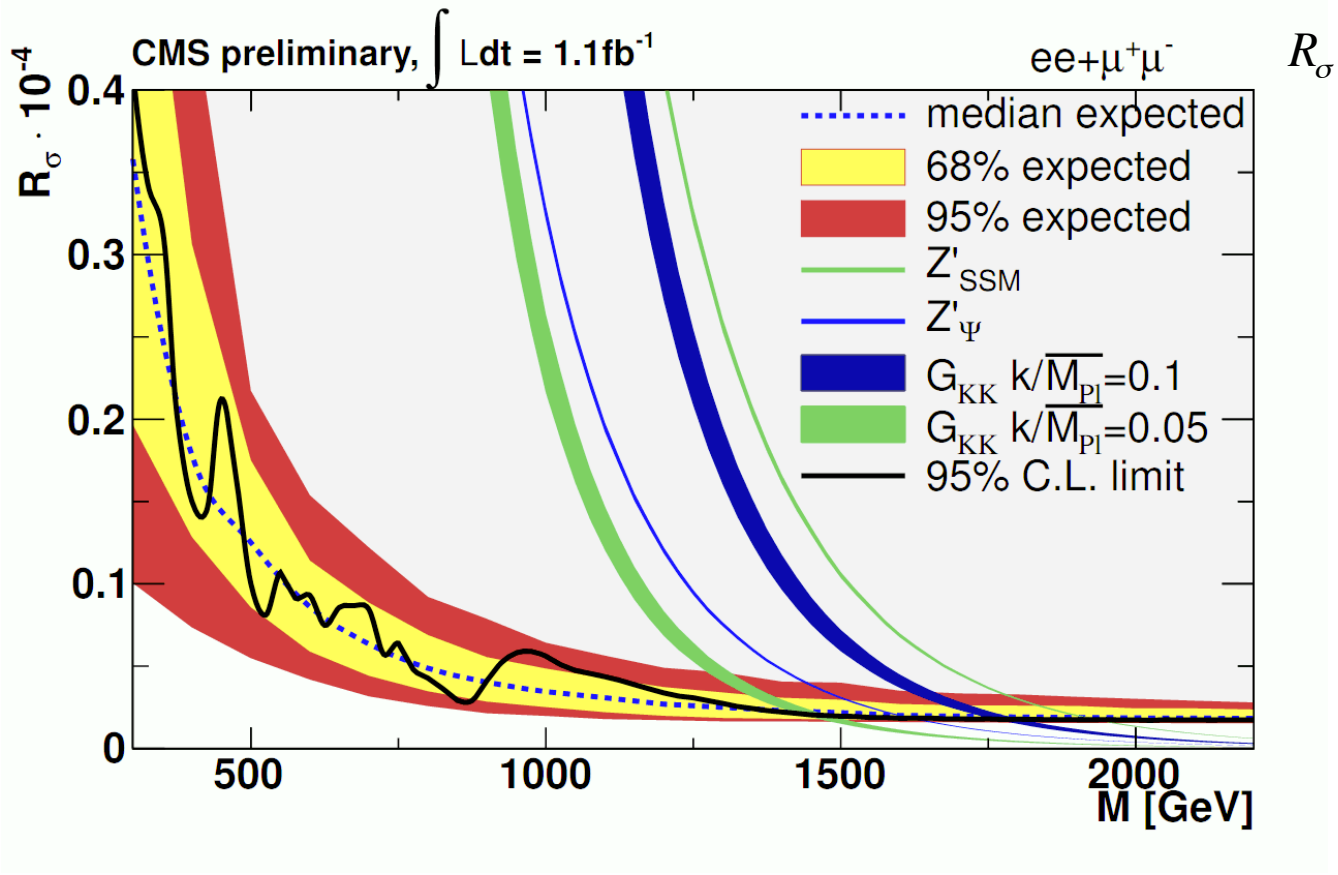


Muons



CMS PAS EXO-11-019

2.1 Dileptons - Limits

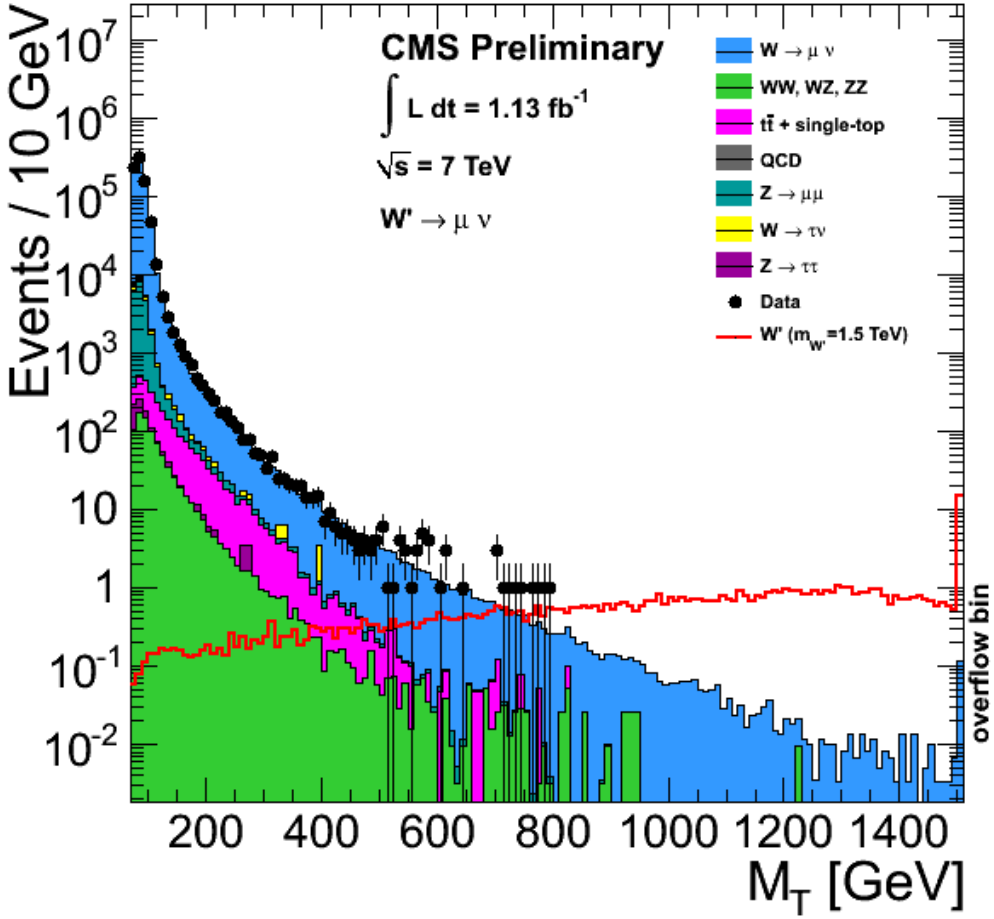


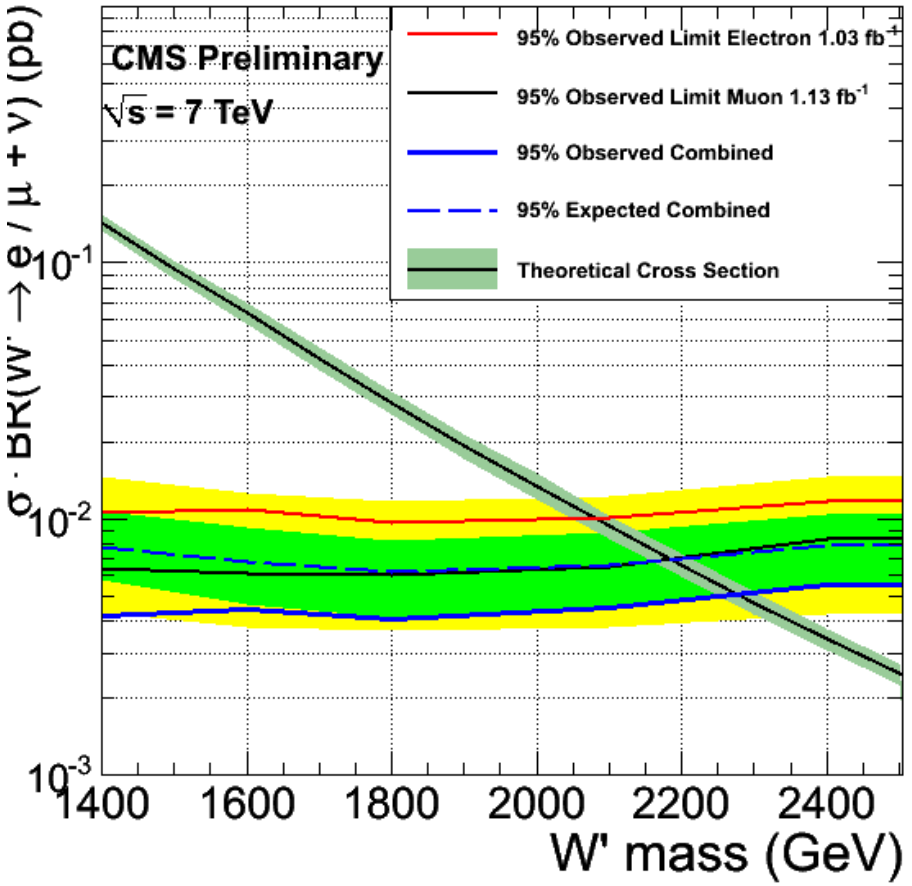
$$R_\sigma \equiv \frac{\sigma(pp \to Z' + X \to \ell\ell + X)}{\sigma(pp \to Z + X \to \ell\ell + X)}$$

CMS PAS EXO-11-019

Limits now close to 2TeV

2.2 Lepton + MET

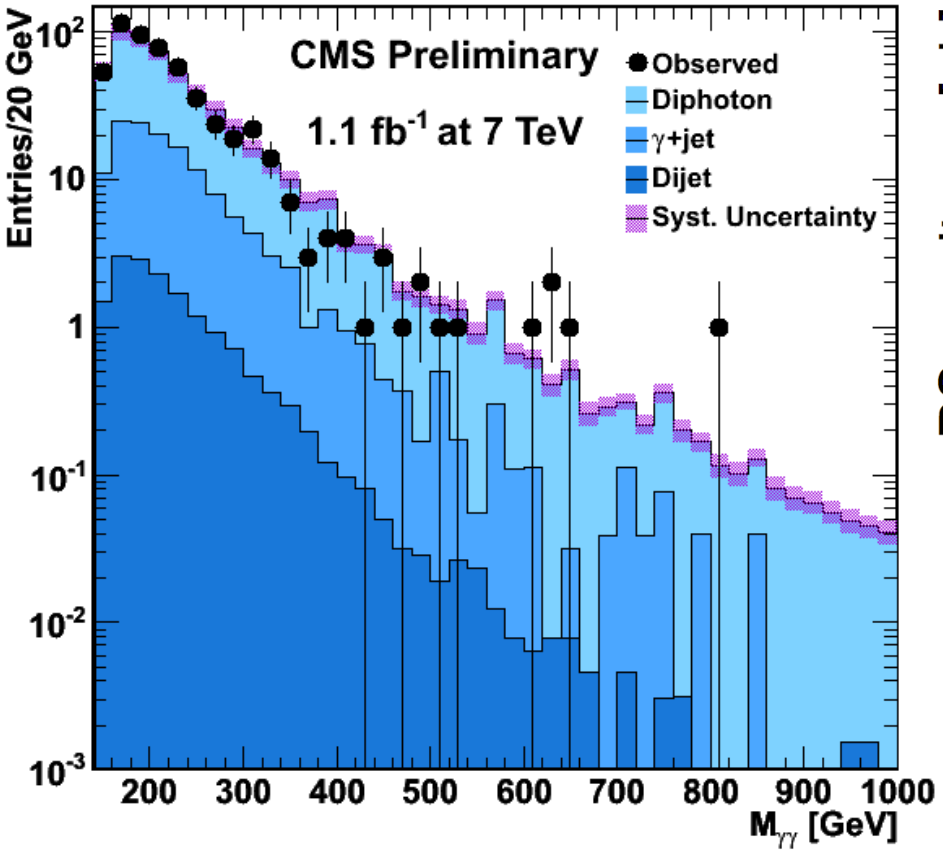


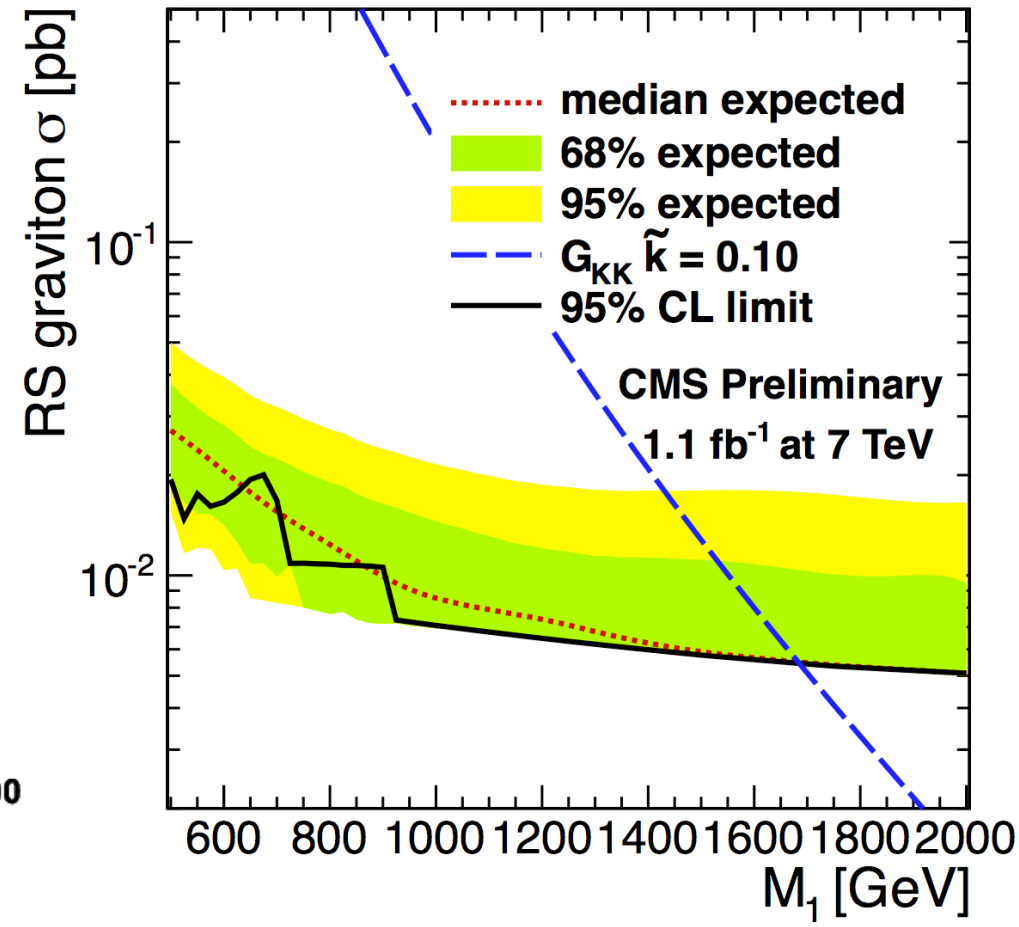


Signature is W-like, at high mass (jacobian peak in transverse mass)
Background is SM W production

CMS PAS EXO-11-024

2.3 Diphotons

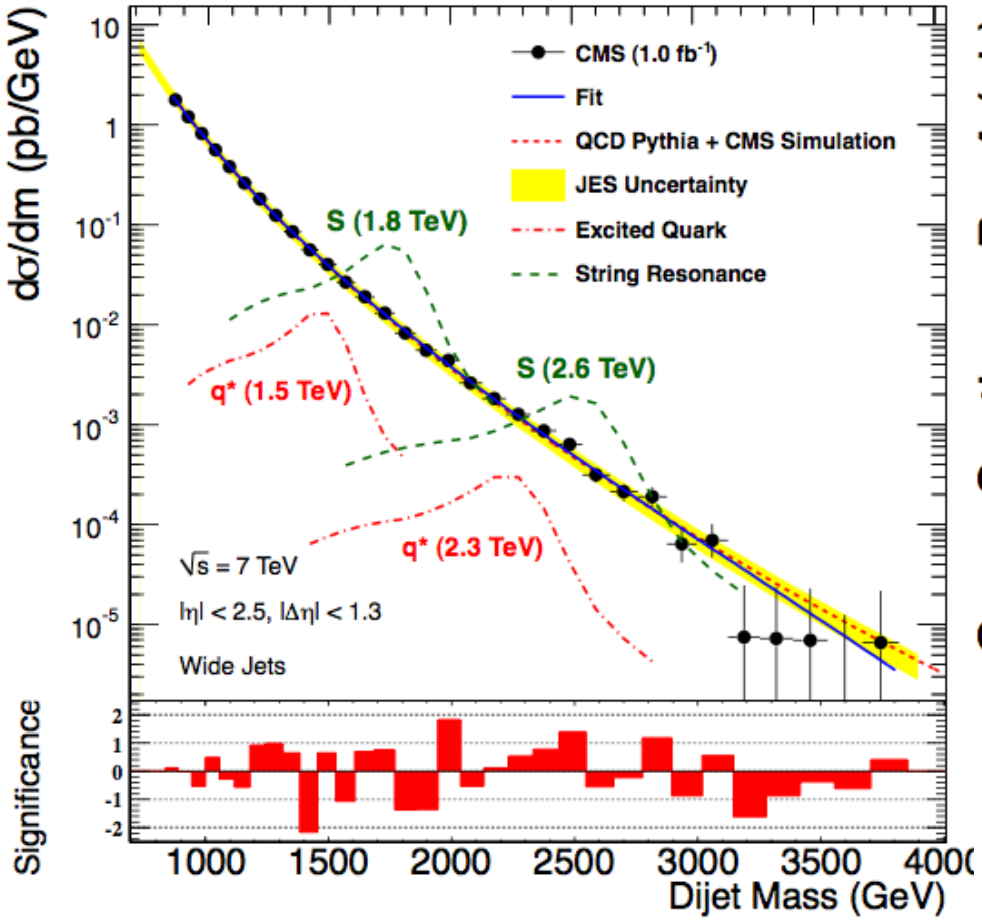


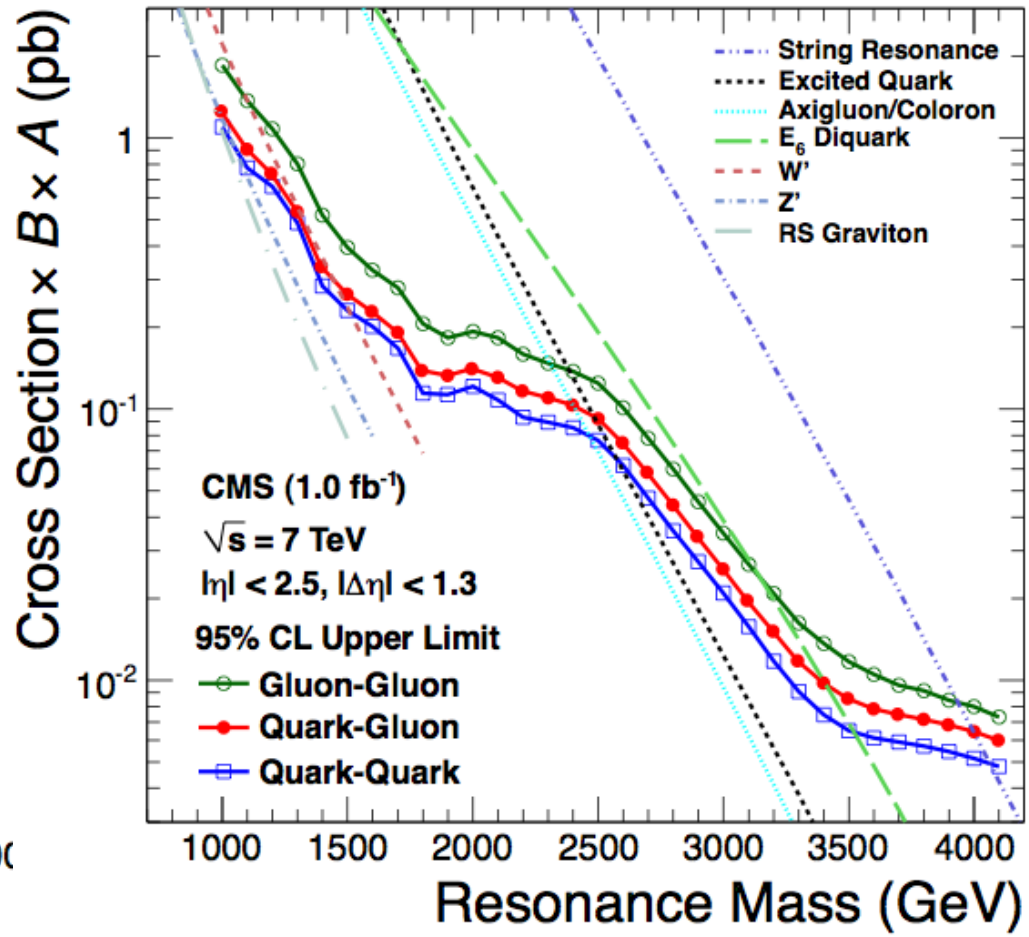


Emitted by graviton in Randall-Sundrum models.

CMS PAS EXO-11-038

2.4 Dijets

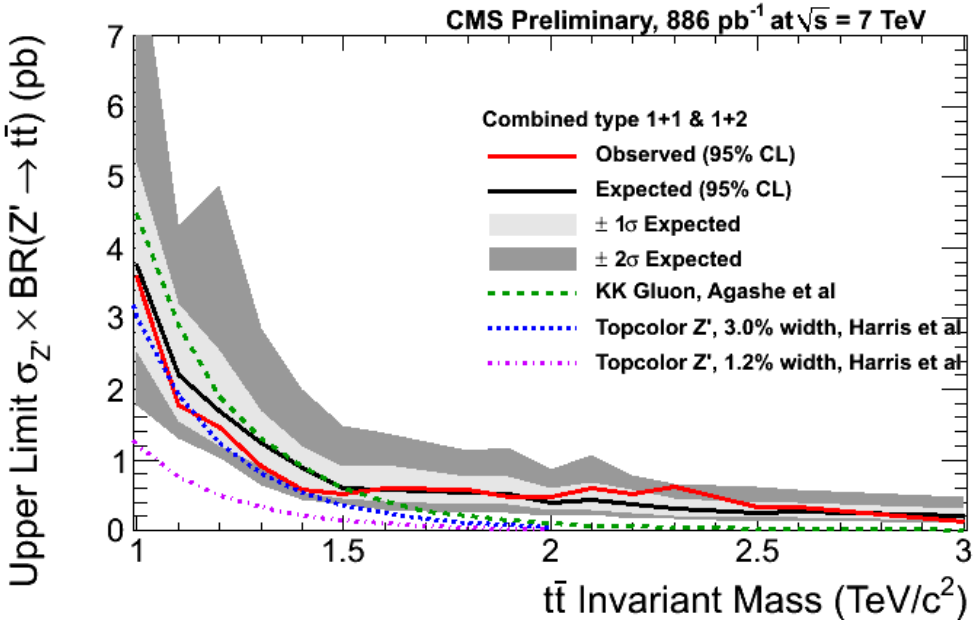


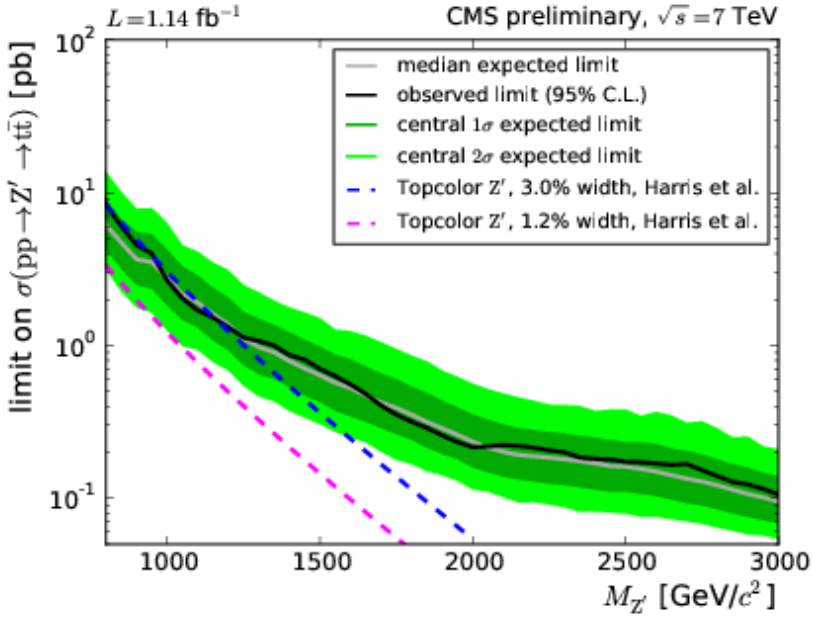


CMS arxiv 1107:4771

Hi-mass Dijets predicted by many models.
Larger branching ratios compared to dileptons but MUCH higher QCD backgrounds

2.5 ttbar pair resonances

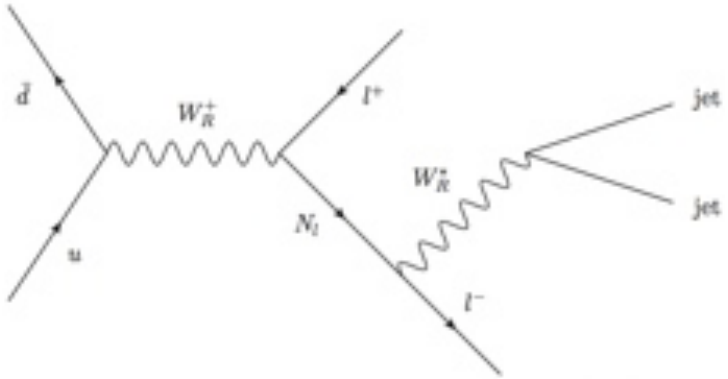


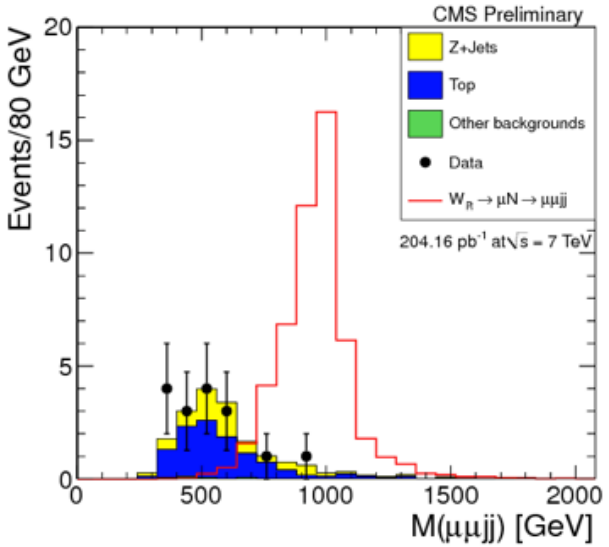


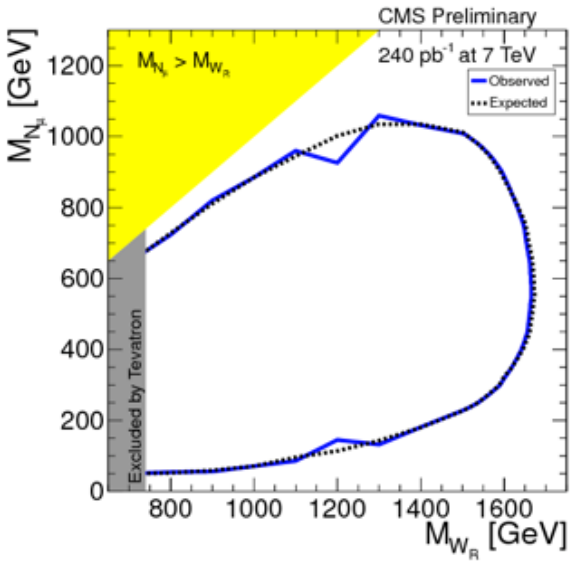
Boosted all-hadronic
CMS EXO-2011-006

Muon+jets
CMS EXO-2011-055

2.6 Heavy neutrinos



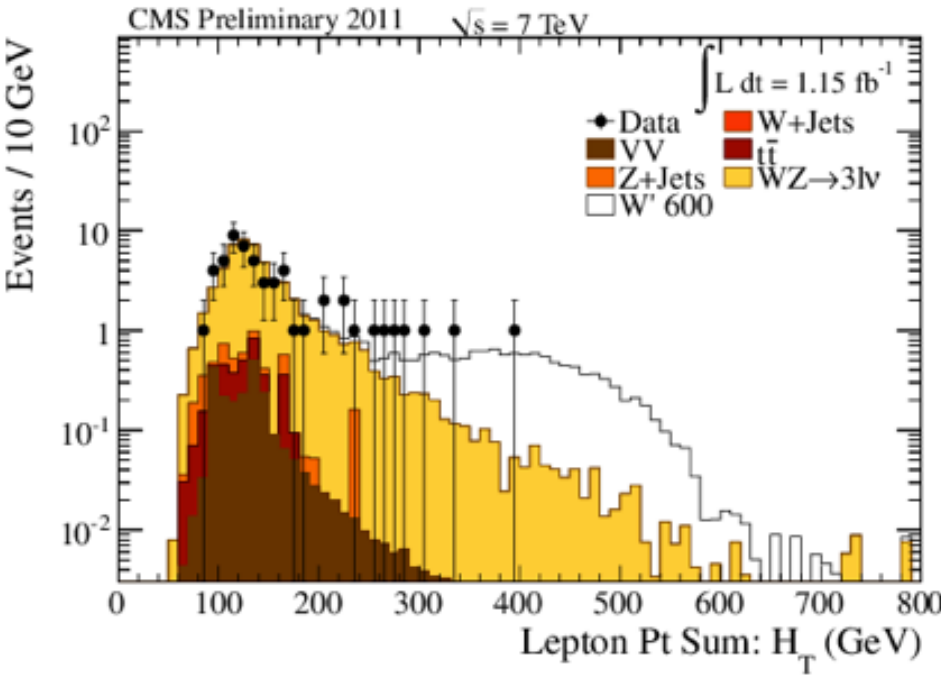


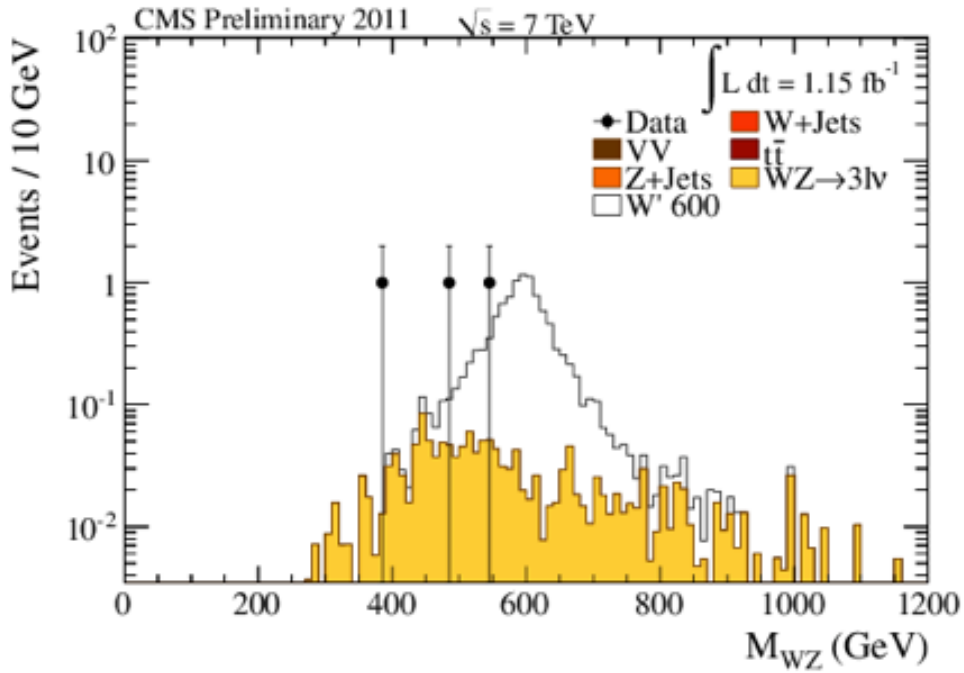


Signature is a lepton+lepton+jet+jet resonance

CMS PAS EXO-11-002

2.7 WZ resonances

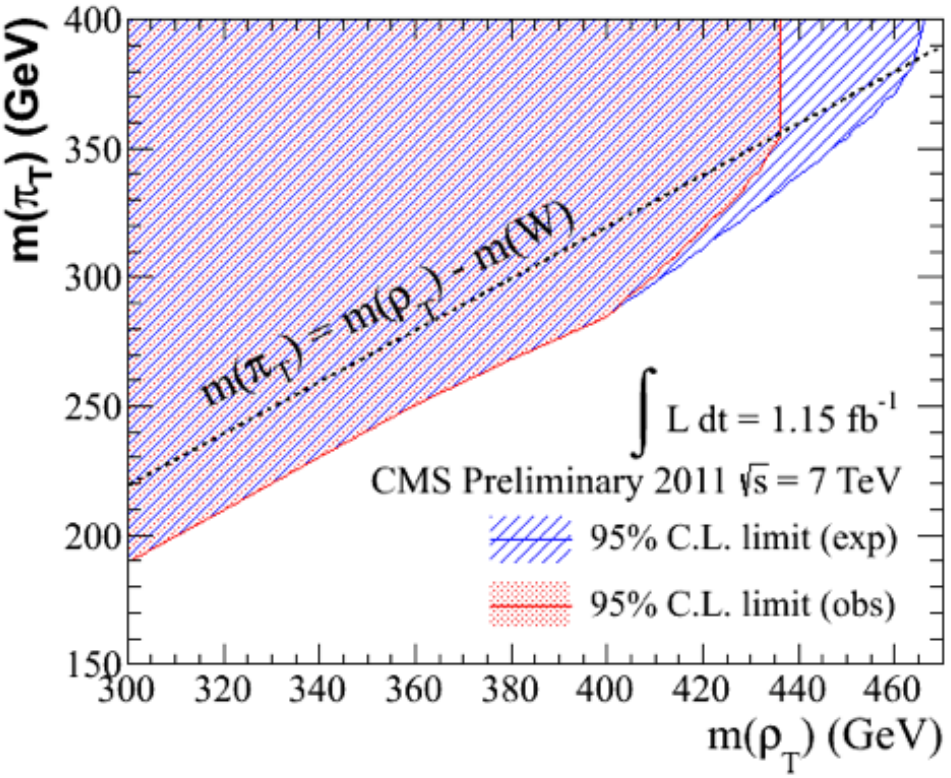


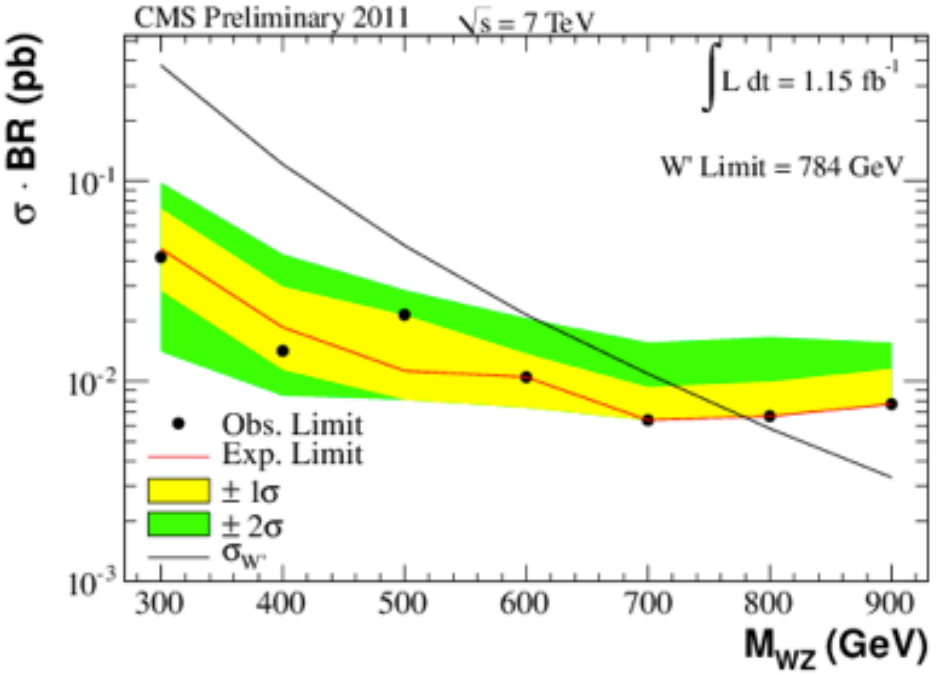


Signature is three leptons + MET

CMS PAS EXO 11-041

2.7 WZ resonances





Signature is three leptons + MET

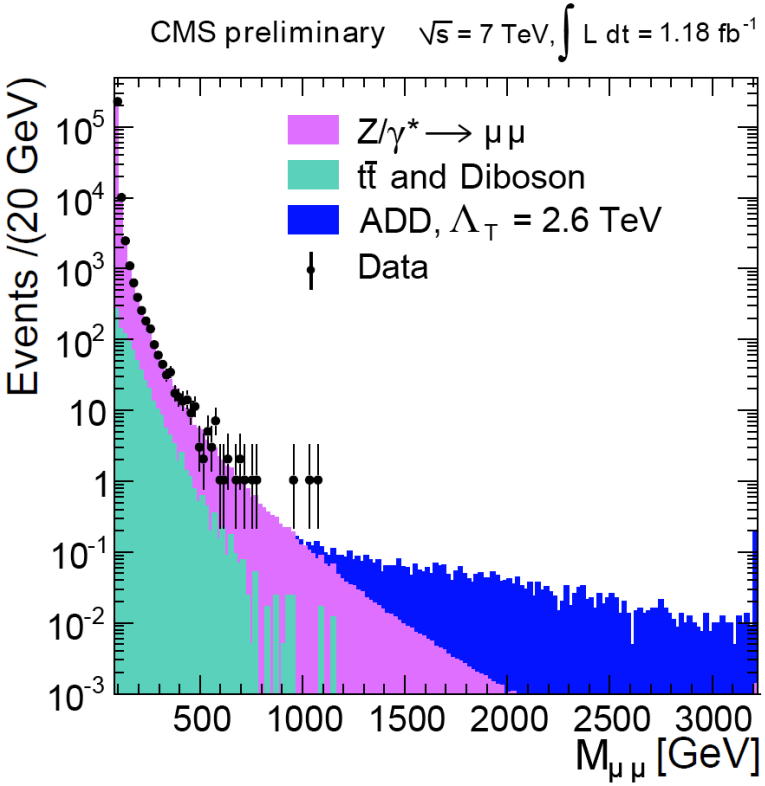
CMS PAS EXO 11-041

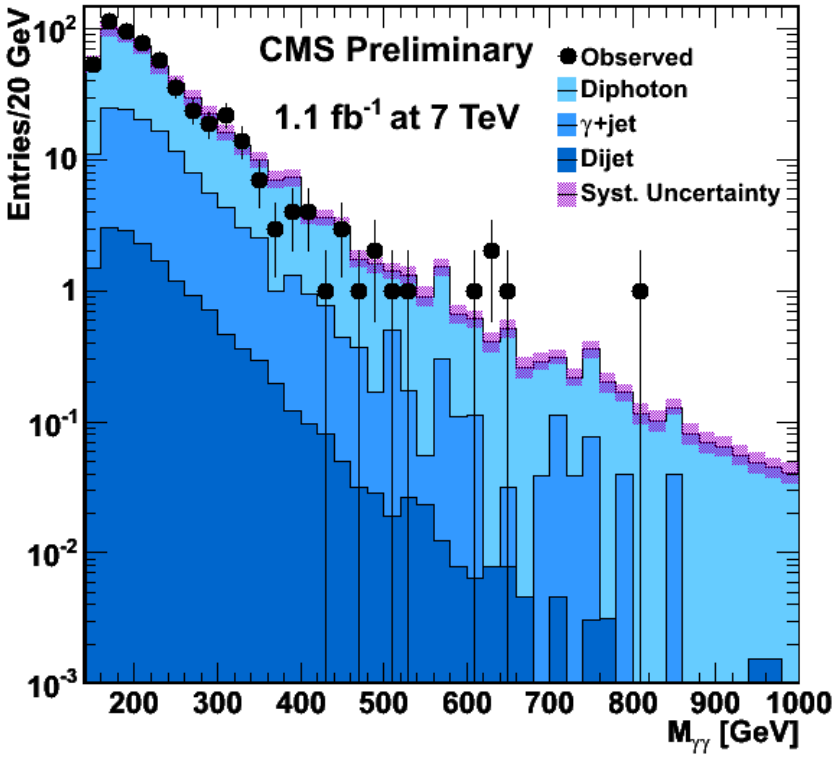
3 Xtra dimensions

The existence of extra spatial dimensions is a scenario that may solve the hierarchy problem of the SM, the puzzling fact that the fundamental scale of gravity 10^{19} GeV is so much higher than the electroweak symmetry breaking scale 10^{3} GeV. With such a difference in scales, it is difficult to protect the Higgs boson mass from radiative corrections without a very high degree of fine-tuning.

The original proposal to use extra dimensions to solve the hierarchy problem was presented by Arkani-Hamed, Dimopoulos, and Dvali (ADD). They posited a scenario wherein the SM is constrained to the common 3+1 space-time dimensions (brane), while gravity is free to propagate through the entire multidimensional space (bulk). Thus, the gravitational flux in 3+1 dimensions is effectively diluted by virtue of the multidimensional Gauss's Law.

3.1 Dileptons & diphotons



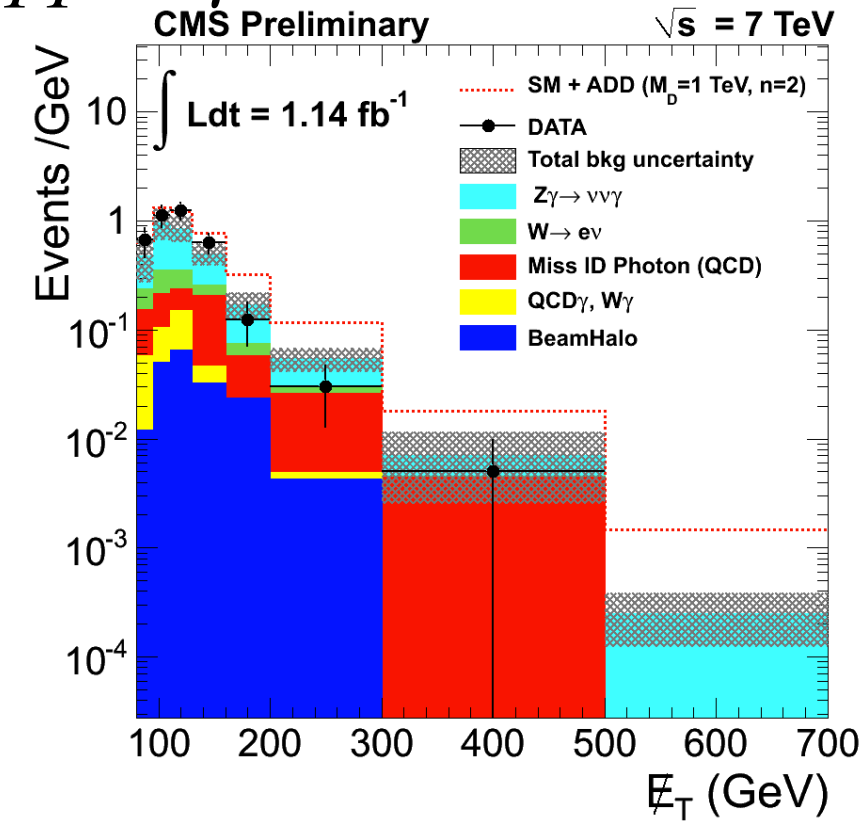


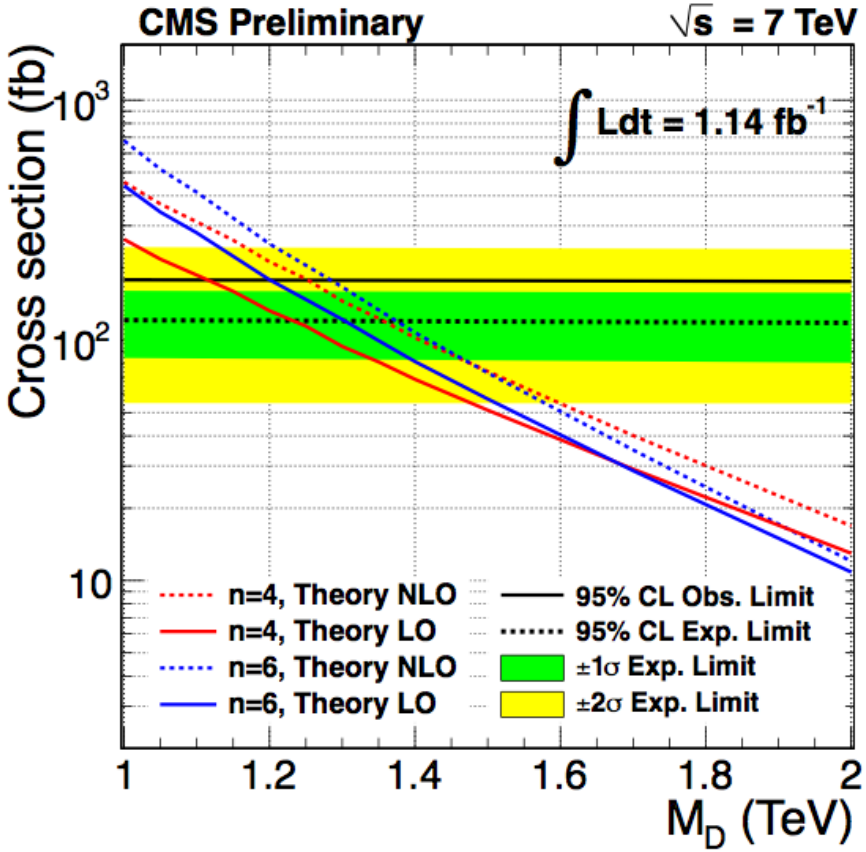
CMS PAS EXO-11-039; EXO-11-038

Virtual graviton production of dilepton pairs
Real Graviton decays to diphoton
Signature is hi-energy tail enhancement of SM continuum

3.2 photon + MET

$q\bar{q} \rightarrow \gamma G$



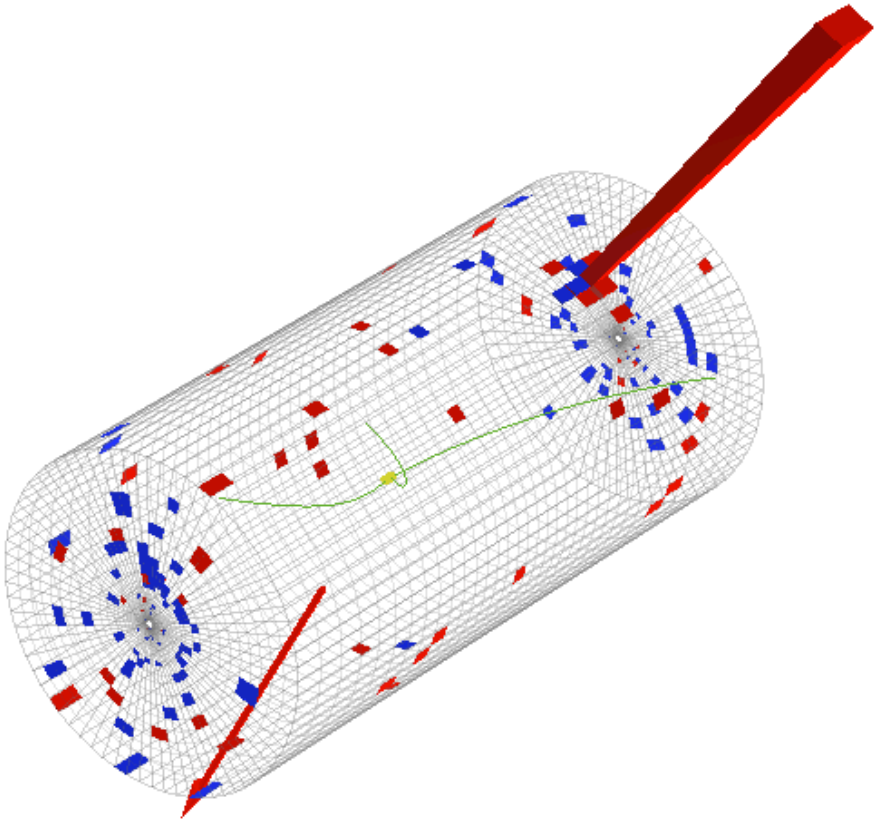


CMS PAS EXO-11-058

$$M_{Planck}^2 = M_D^{n+2} R^n$$

Signature is challenging: one photon and nothing else, with Graviton escaping detector.
Main background Zγ-->νν̄ + γ , W-->e nu

3.2 photon + MET



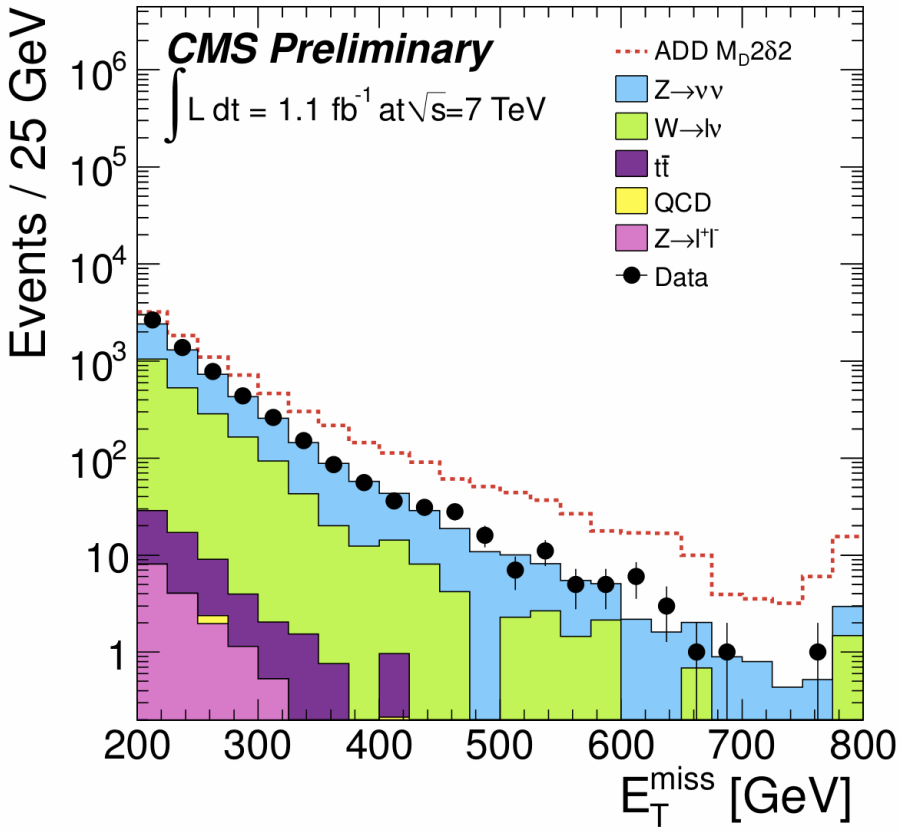
$$q\bar{q} \rightarrow \gamma G$$

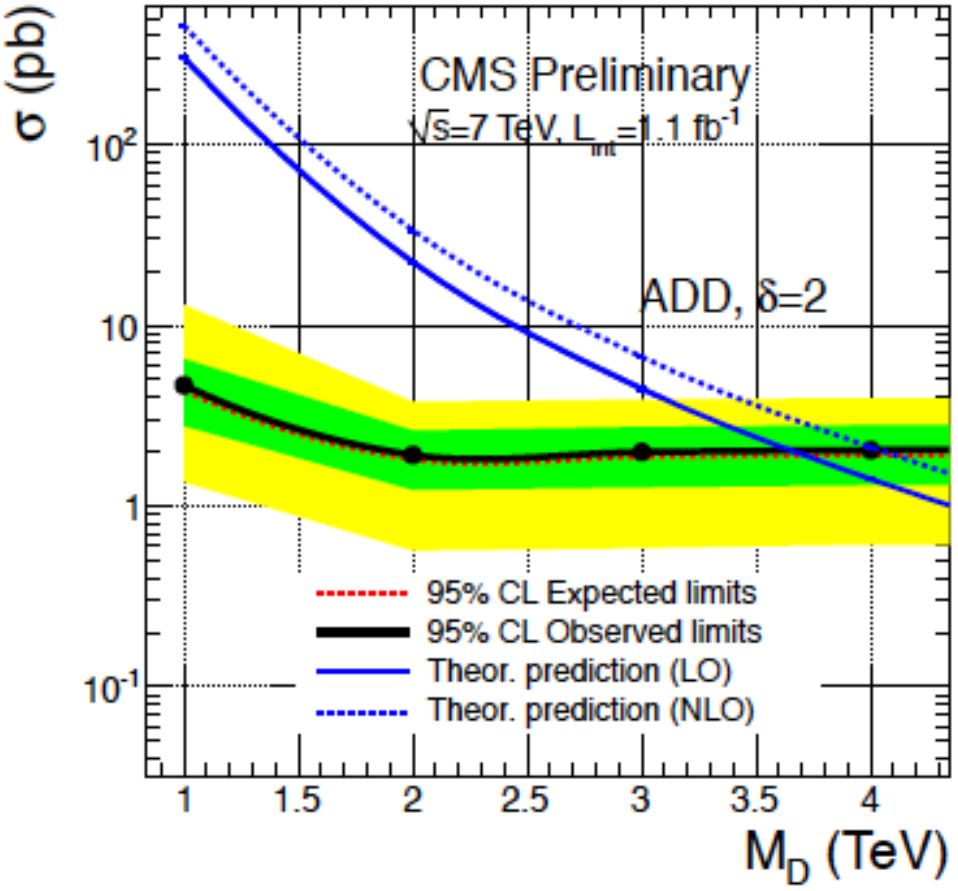
CMS Experiment at LHC, CERN
Data recorded: Sun Apr 24 22:57:52 2011 CDT
Run/Event: 163374 / 314736281
Lumi section: 604

CMS PAS EXO-11-058

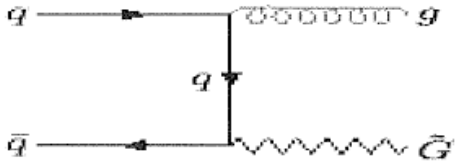
Signature is challenging: one photon and nothing else, with Graviton escaping detector.
Main background Zγ-->νν̄ + γ , W-->e nu

3.2 Jet + MET



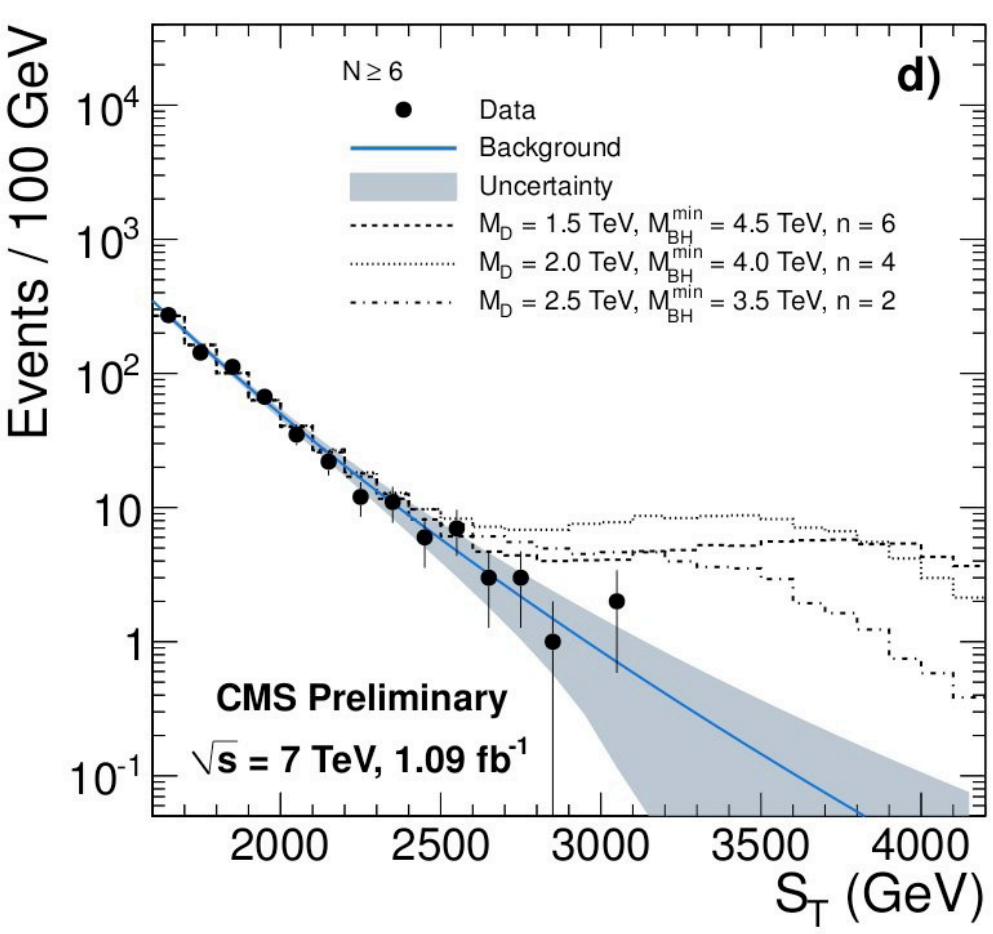


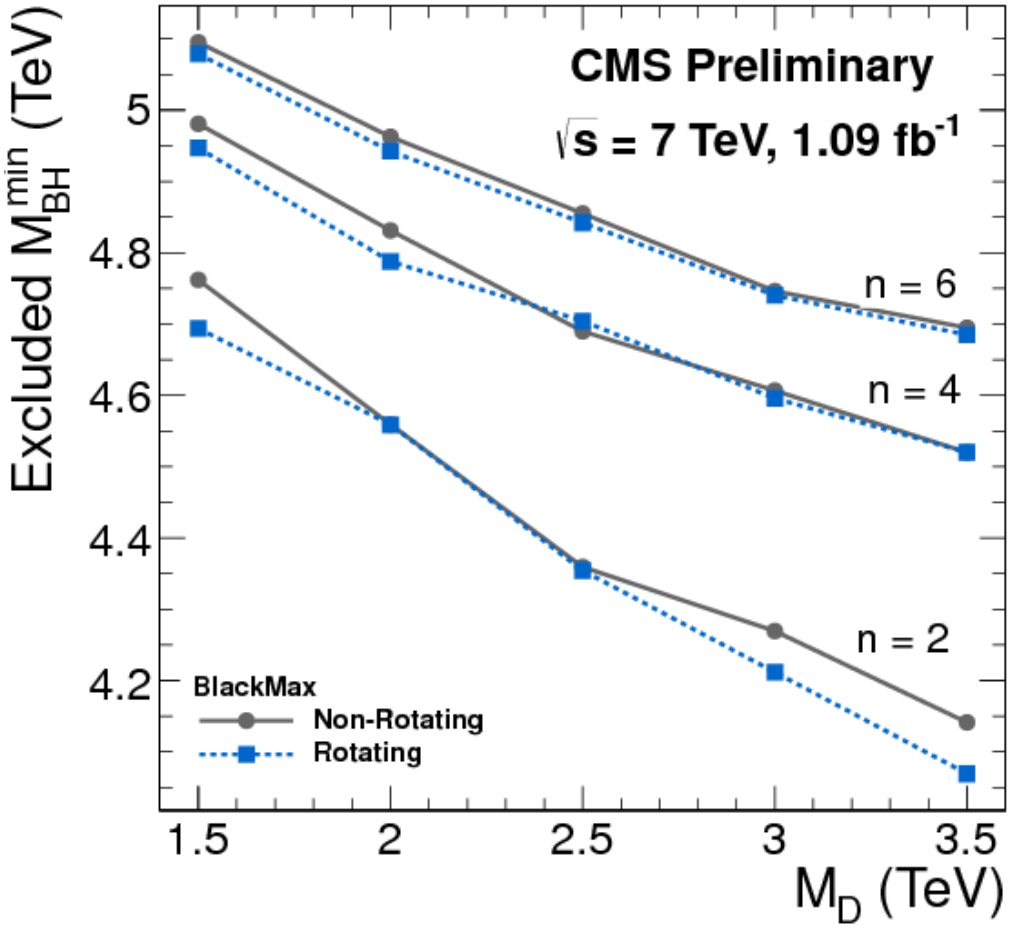
CMS PAS EXO-11-059



Signature is challenging: one jet and nothing else, with Graviton escaping detector.
Main background Z-->νν̄ + jet

3.3 Black Holes



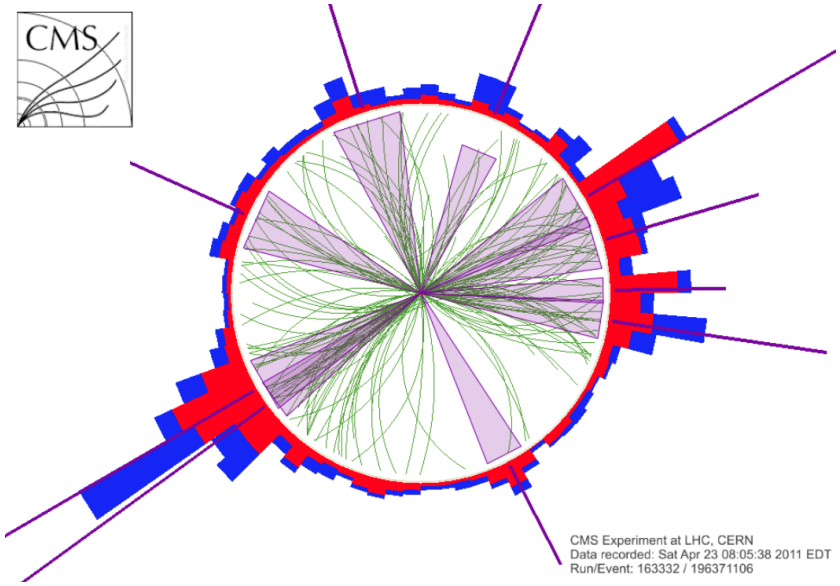


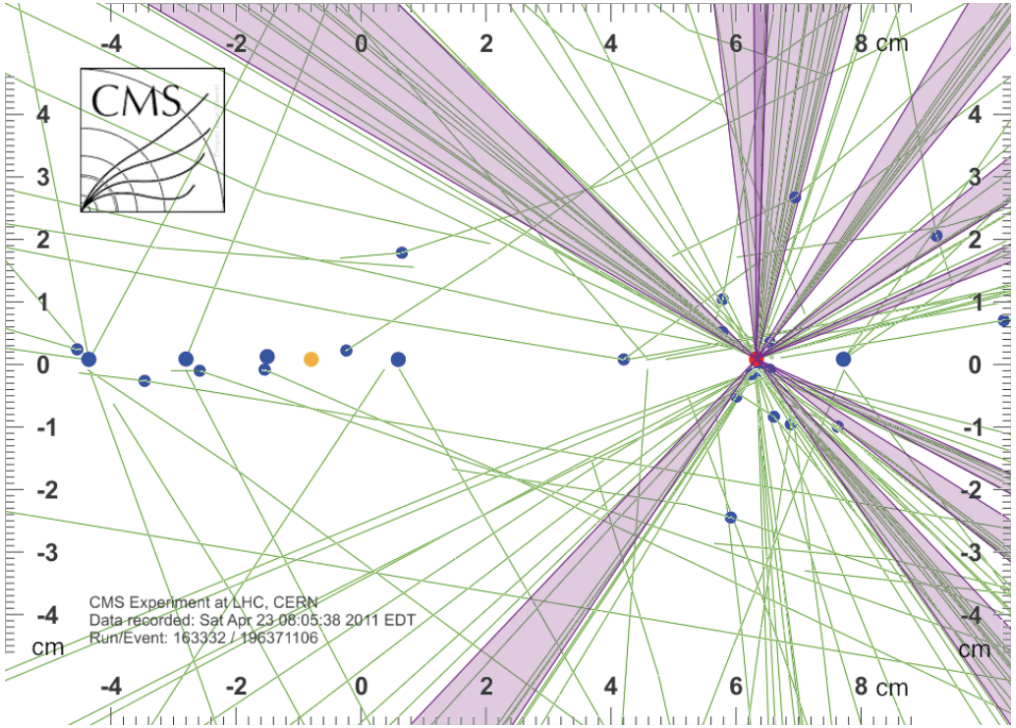
BH decaying due to Hawking radiation. $S_T \equiv \sum E_T$ PAS EXO 11-071

Signature is isotropic decay to all SM species --> hi-multiplicity final states

Use H_T triggers (threshold on S_T)

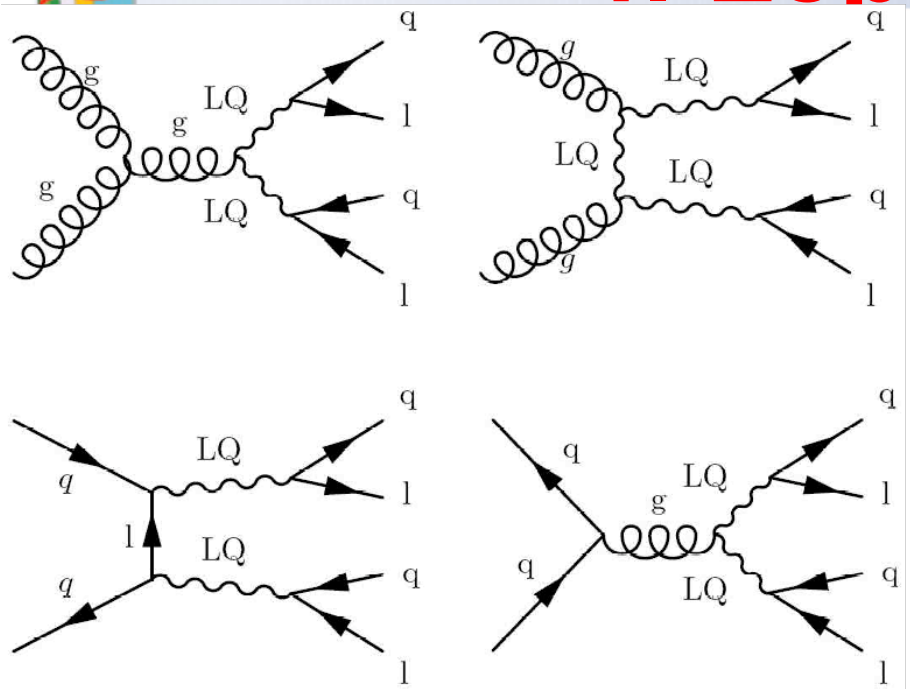
3.3 Black Holes





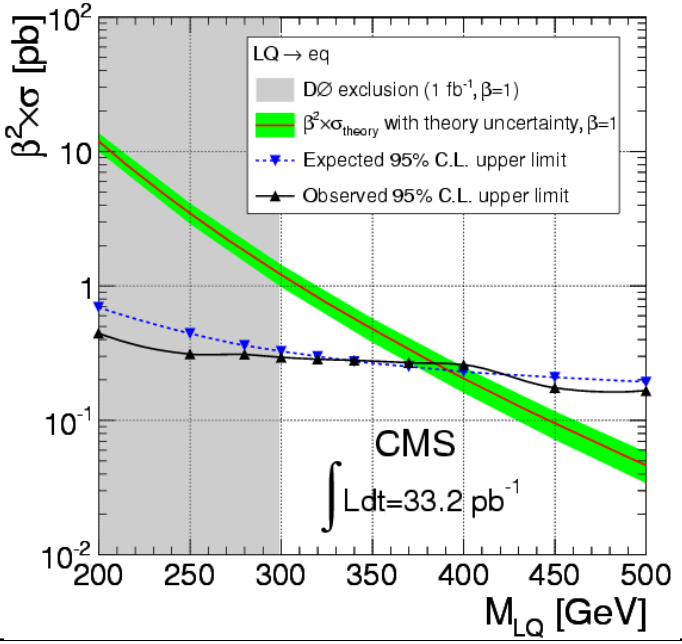
Black Hole candidate (PAS 11-071) with S_T = 1.1 TeV.
On the right plot the vertex region is shown. Pile-up vertices are seen.

4. Leptoquarks



An LQ carries color, has fractional electric charge, can have spin 0 or spin 1, and couples to a lepton and a quark with coupling strength β.

An LQ would decay to a charged lepton and a quark, with an unknown branching fraction λ, or a neutrino and a quark. with branching fraction 1- β



CERN-PH-EP-2010-052

5. 4th generation b'/t'

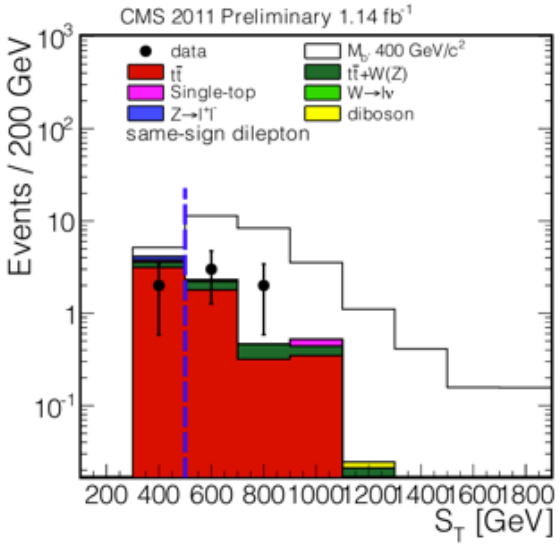
Excluded in the 90's by EWK results on the number of ν species.

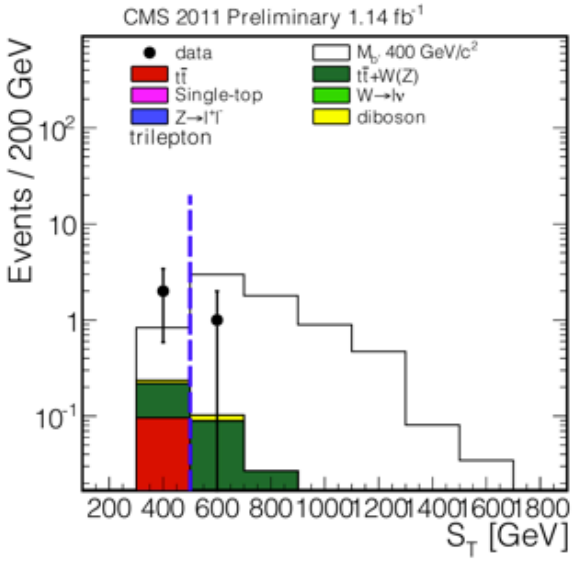
Recently renewed interest, since it has been shown that the EWK bounds are less constraining for a non-degenerate fourth generation.

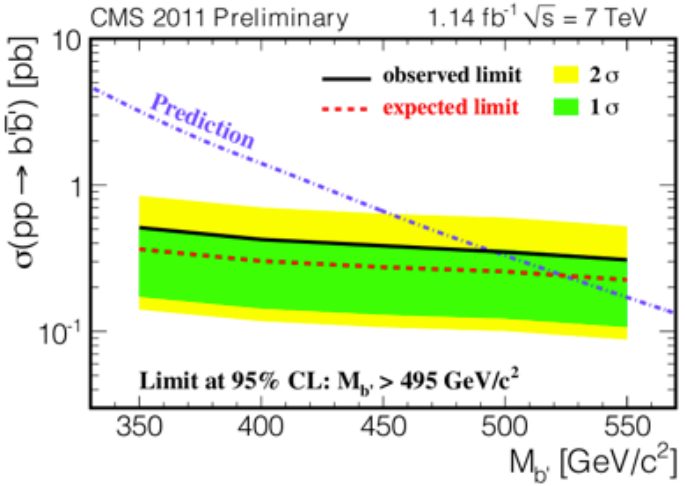
With a fourth generation, indirect bounds on the Higgs boson mass can be relaxed, and an additional generation of quarks may possess enough intrinsic matter and anti-matter asymmetry to be relevant for the baryon asymmetry of the Universe.

5.1 4th generation: b'--> t + W

$$b'\bar{b}' \rightarrow tW^-\bar{t}W^+ \rightarrow bW^+W^-\bar{b}W^-W^+$$







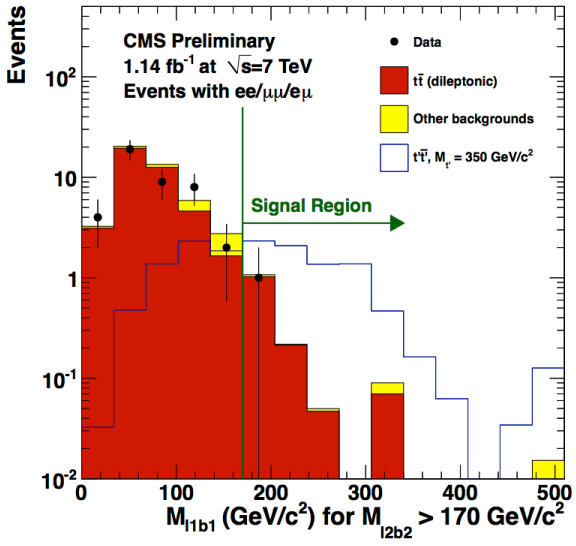
$$S_T \equiv \sum p_T(jets) + \sum p_T(leptons) + \not{E}_T$$

Signature: at least 1 b-jet, 2 or 3 leptons
Dominant systematic uncertainty: b-tagging and lepton efficiency
Discriminating variable is total transverse energy S_T

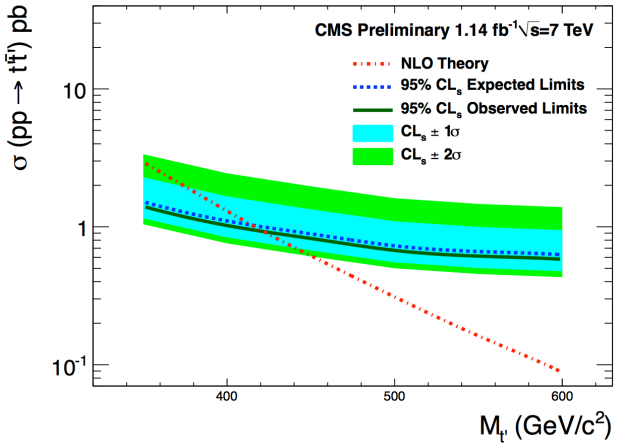
CMS EXO-11-036

5.2 4th generation: t'

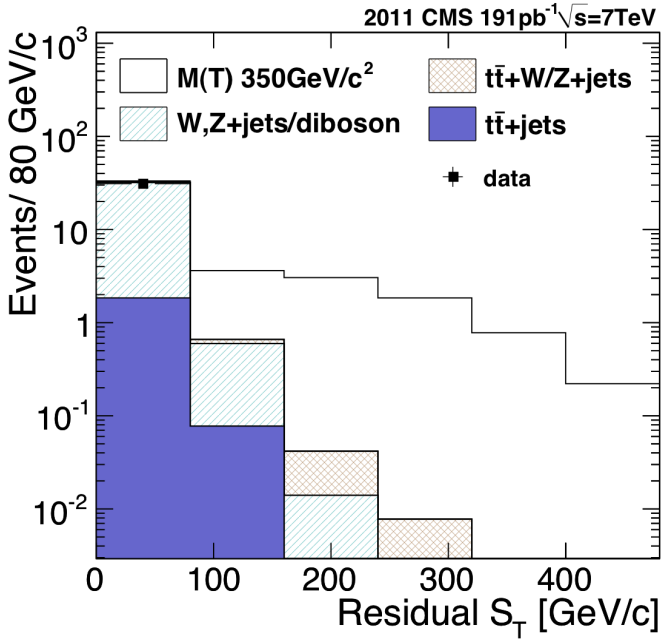
$t'\bar{t}' \to bW^+\bar{b}W^- \to b\ell^+\nu\bar{b}\ell^-\bar{\nu}$

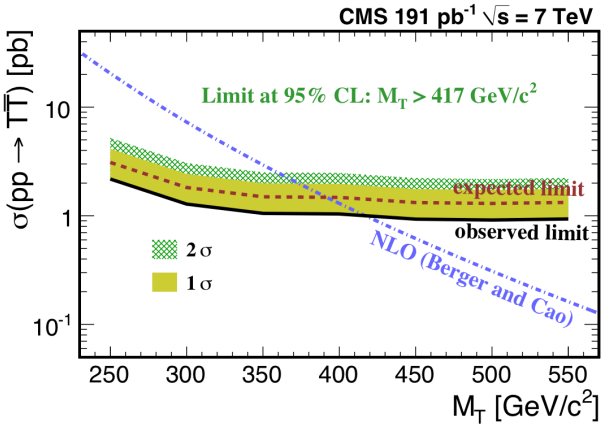


CMS PAS EXO-2011-050



$t'\bar{t}' \to tZ\ \bar{t}Z \to bW^+W^-\bar{b}ZZ$





CMS PAS EXO-2011-005

5.3 4th generation: summary

Decay	channel	Excluded mass [Gev]	Luminosity [fb^{-1}]	Notes	Reference
b'-->t+W	Lepton+jet	495	1.1		EXO-11-036
t'-->b+W	dilepton	422	1.1		EXO-11-050
t'-->b+W	Lepton+jet	450	1.1		EXO-11-051
t'-->t+Z	Lepton+jet	475	1.1		EXO-11-005

6. Long Lived particles

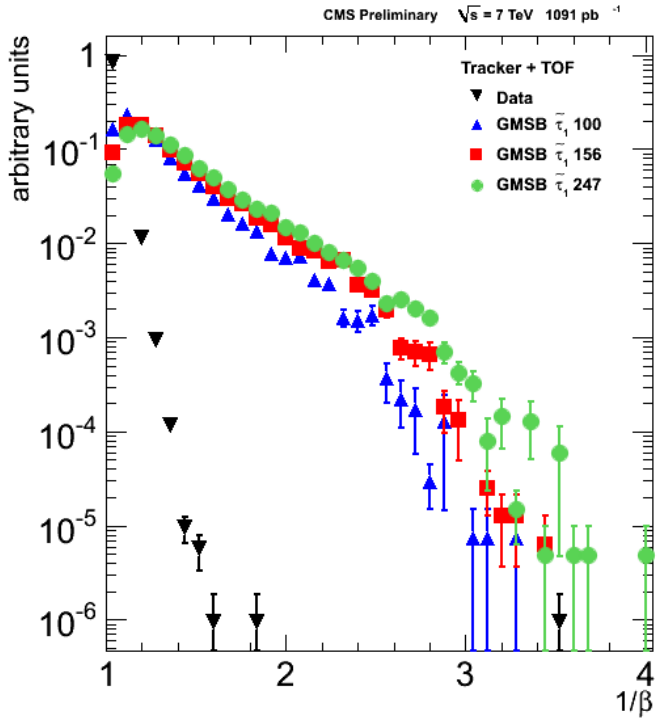
Heavy Stable (or long-lived) Charged Particles (HSCPs) appear in various extensions to the SM

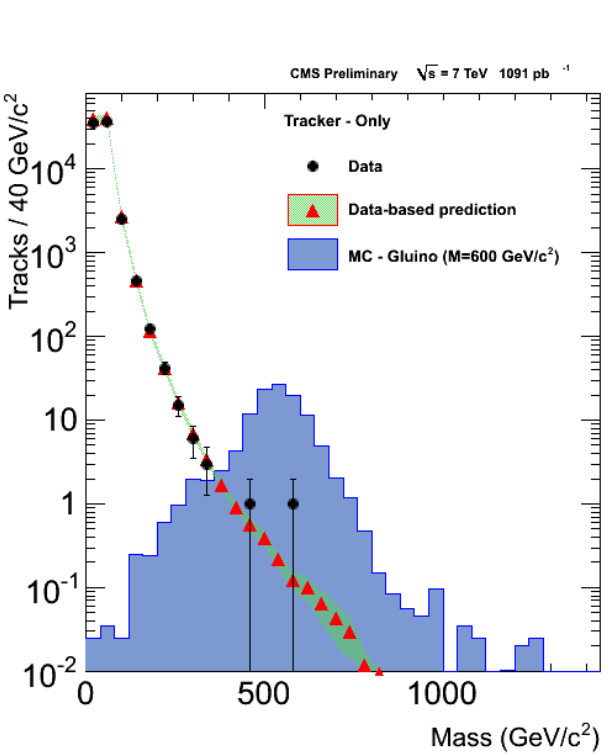
If the lifetime of an HSCP produced at the LHC is longer than a few nanoseconds, the particle will travel over distances that are comparable or larger than the size of a typical particle detector. In addition, if the HSCP mass is >100 GeV/c^2, a significant fraction of these particles will have a velocity β smaller than 0.9.

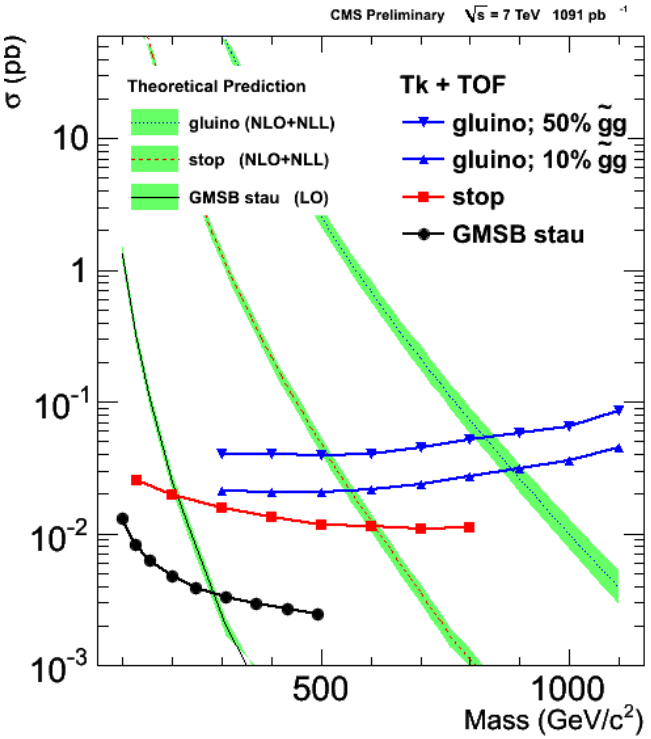
These HSCPs will be directly observable:

- **a high momentum particle with an anomalously large rate of energy loss through ionization (dE/dx) and**
- **an anomalously long time-of-flight (TOF).**

6.1 Heavy Stable Charged Particles



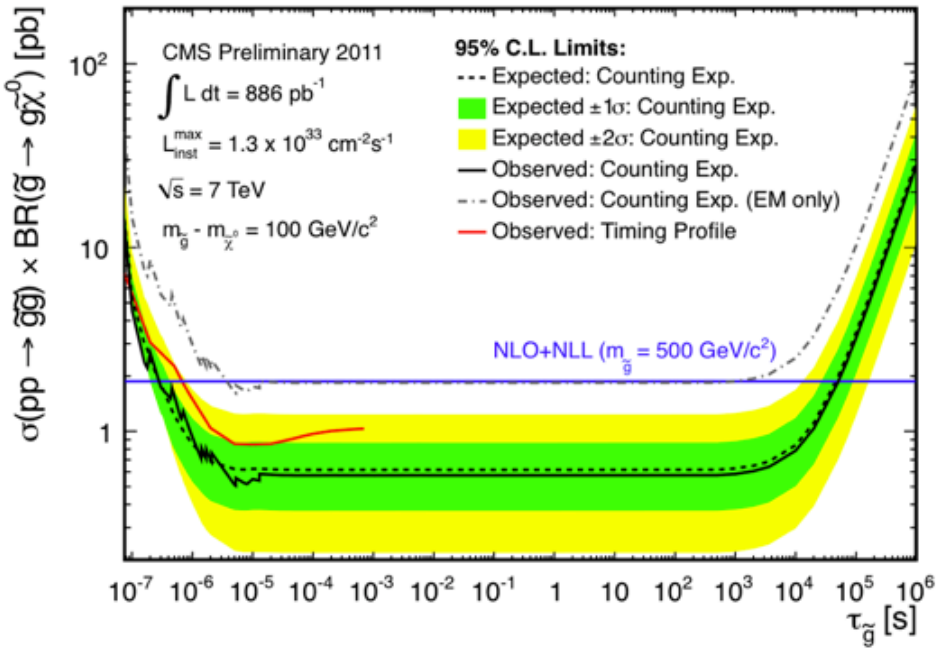




- **Gluinos and stops may hadronize in heavy and slow and R-hadrons**
- **Signatures:**
  - **Large ionization in silicon tracker**
  - **Very slow --> long Time of Flight**

CMS PAS EXO 11-022

6.2 Stopped particles



CMS PAS -EXO-11-020

Lifetimes of O(100–1000) seconds are especially interesting in cosmology since such decays would affect the primordial light element abundances, and could resolve the present discrepancy between the measured ^{6}Li and ^{7}Li abundances and those predicted by conventional big-bang nucleosynthesis.

Signature: stopping of heavy and slow R-hadrons due to large hadronization

CONCLUSIONS & OUTLOOK

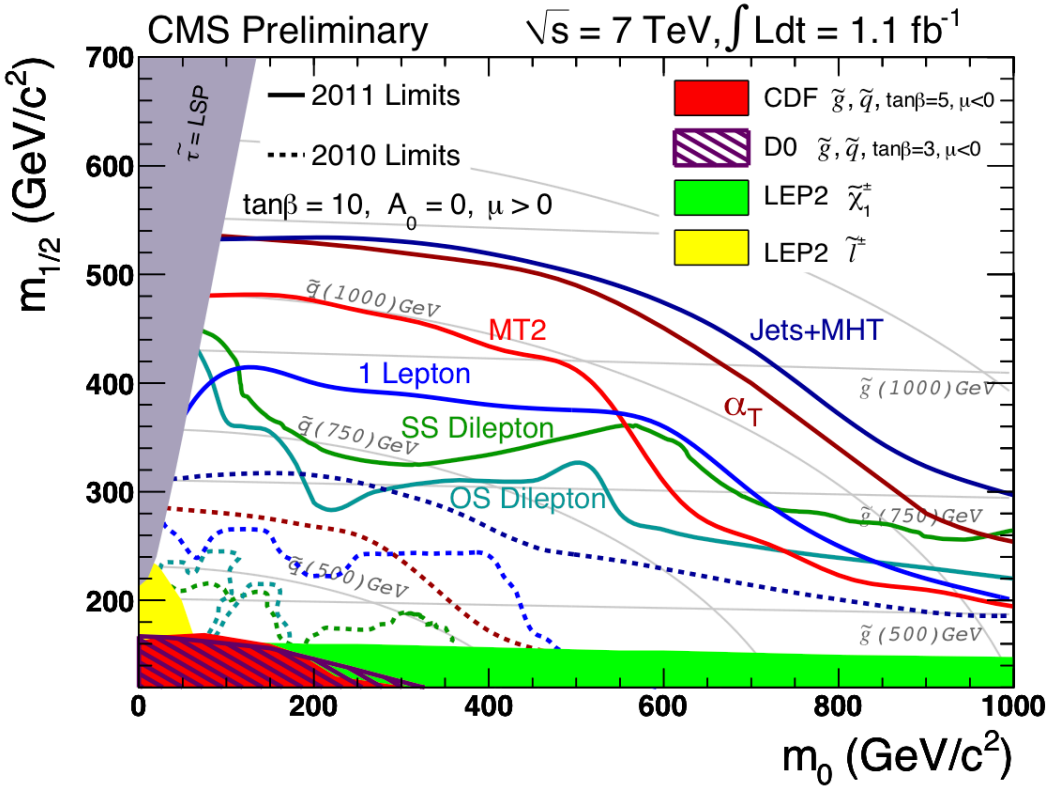
- Outstanding performance of LHC
- CMS works well and produce results timely
- Montecarlo simulations under excellent control
- Physics results summary at $1fb^{-1}$:
  - SUSY explored up to ~1TeV
  - 4th generation explored up to ~0.5TeV
  - Heavy resonances explored up to ~ 2TeV
- No hints of New Physics (yet)
- 4.7 fb^{-1} of data are being analysed

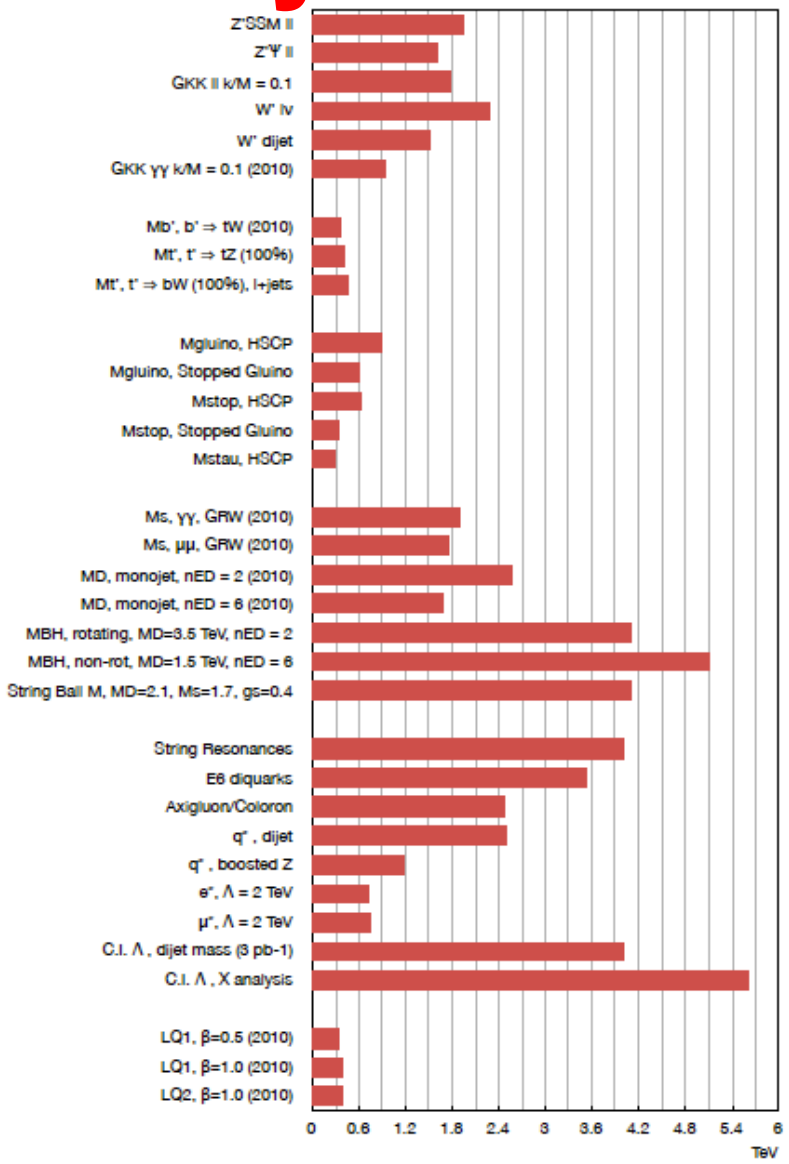
CONCLUSIONS & OUTLOOK

- No hints of 1TeV spectacular SUSY
  - (probably already excluded by LEP EW data ?)
- Perhaps a world where SM and SUSY are deeply decoupled:
  - a light Higgs goes along with a heavy SUSY ?
  - heavy stops and gluinos ?
- What do we gain in limits from 1fb^{-1} to 10fb^{-1} ?
- Do we double limits to 300fb^{-1} ?
- Increase of energy no big effect, unless we double it
- **A big research effort ongoing at LHC, stay tuned !**

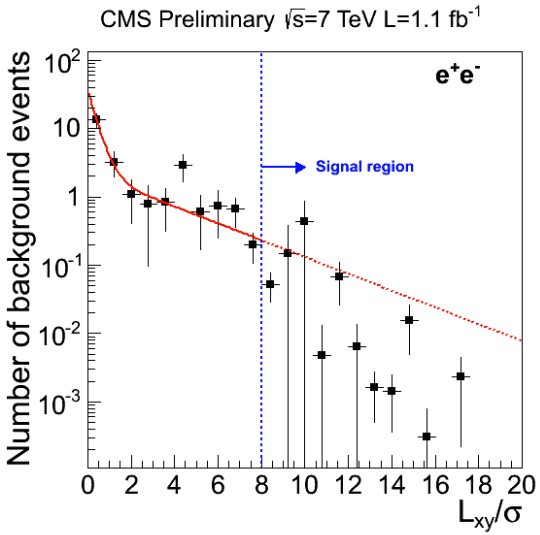
backup

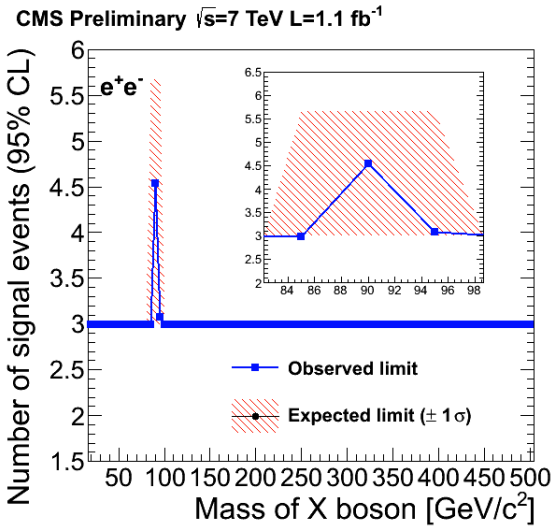
GrandSummary

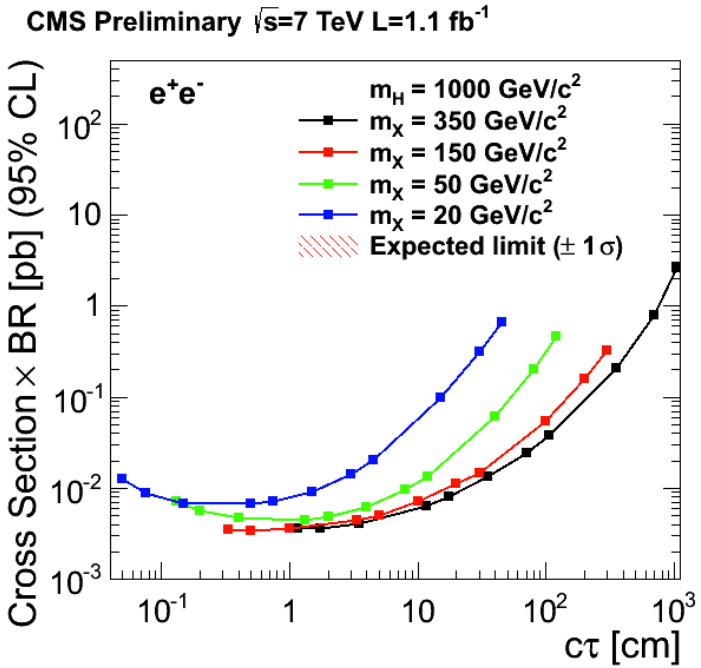




6.3 Displaced vertices







Signature: non-pointing leptons from decay of heavy long-lived