Search for new Physics at Hadron Collider

Outline:

- Introduction
- Search for new Physics
  - Model driven
  - Signature based

Do we need New Physics?

Present "Observational" Evidence for New Physics

- NEUTRINO MASSES ☆☆☆
- DARK MATTER ☆☆☆
- MATTER-ANTIMATTER ASYMMETRY ☆☆
- INFLATION ☆

What kind of New Physics?

At Hadron Collider

- High Mass Resonances (Z', W', Graviton, Sneutrino, Axigluon)
- SUSY
- Technicolor
- New or Excited Fermions
- LeptoQuarks
- Extra Dimensions

Search for New Physics

The breaking mechanism determines the phenomenology and the search strategies:

Model Driven:

- theory driven, optimize analysis to the searches
- explore large region of parameter space

Signature Based:

- search for unusual final states (not SM)
- optimize selections to minimize background
- interpret the results in terms of several models

Global Searches:

- maximize the parameter space coverage
- less sensitivity but can give hint on possible deviation from SM

Experimental Approach

- Lepton-only final states
  - e/μ identification well understood
  - τ id more complex
  - straightforward and efficient approach to search for anomalies
- MET and/or Photons
  - wealth of models and exotic process
  - detector effect are important, need to be understood
- Jets and Heavy Flavor
  - more complex signatures
  - Need to maintain high S/B

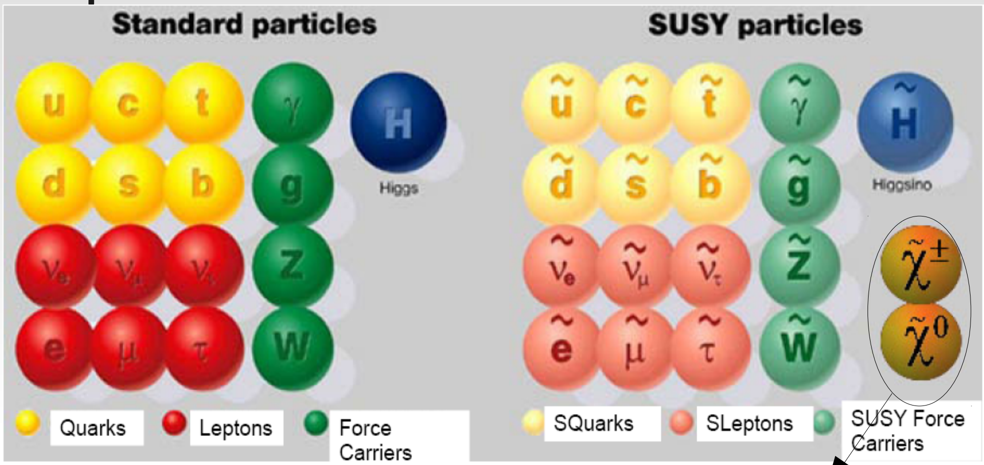
Model Driven Searches

SUperSYmmetry

- Standard Model is theoretically incomplete
- SUSY: spin-based symmetry that relates Fermions to Bosons

  Q|Boson> = Fermion

  Q|Fermion> = Boson



gaugino/higgsino mixing gives chargino and neutralino

- Define R parity: $(-1)^{3(B-L)+2s}$

  R=1 SM particles

  R=-1 MSSM partners

If R conserved in production and decay provides Dark Matter Candidate (Lightest Supersymmetric Particle)

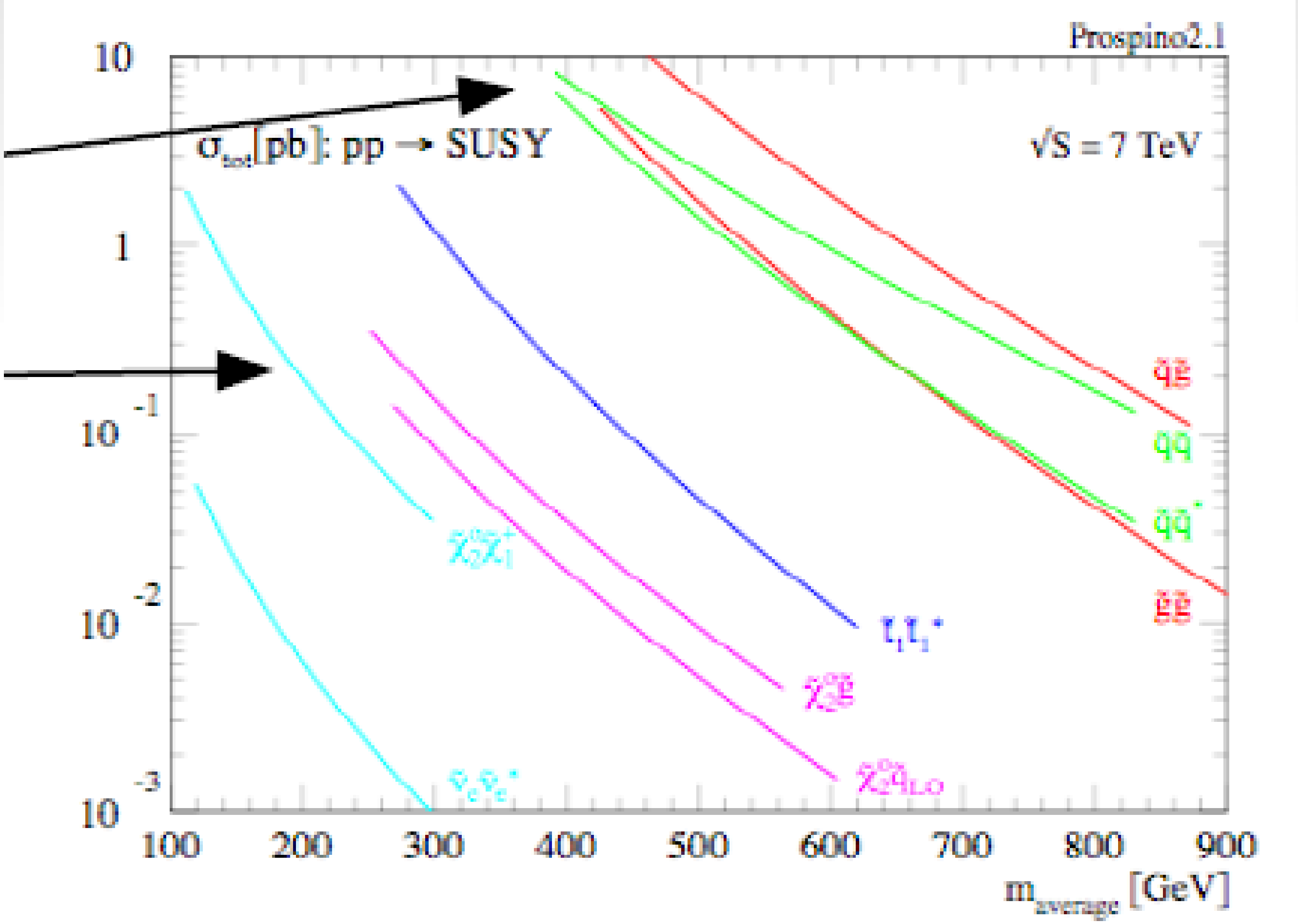
- No SUSY particles found yet
  - SUSY must be broken

    -> models depend on many parameters even in "minimal" models

SuSy Production

Highest production cross section from squark and gluino

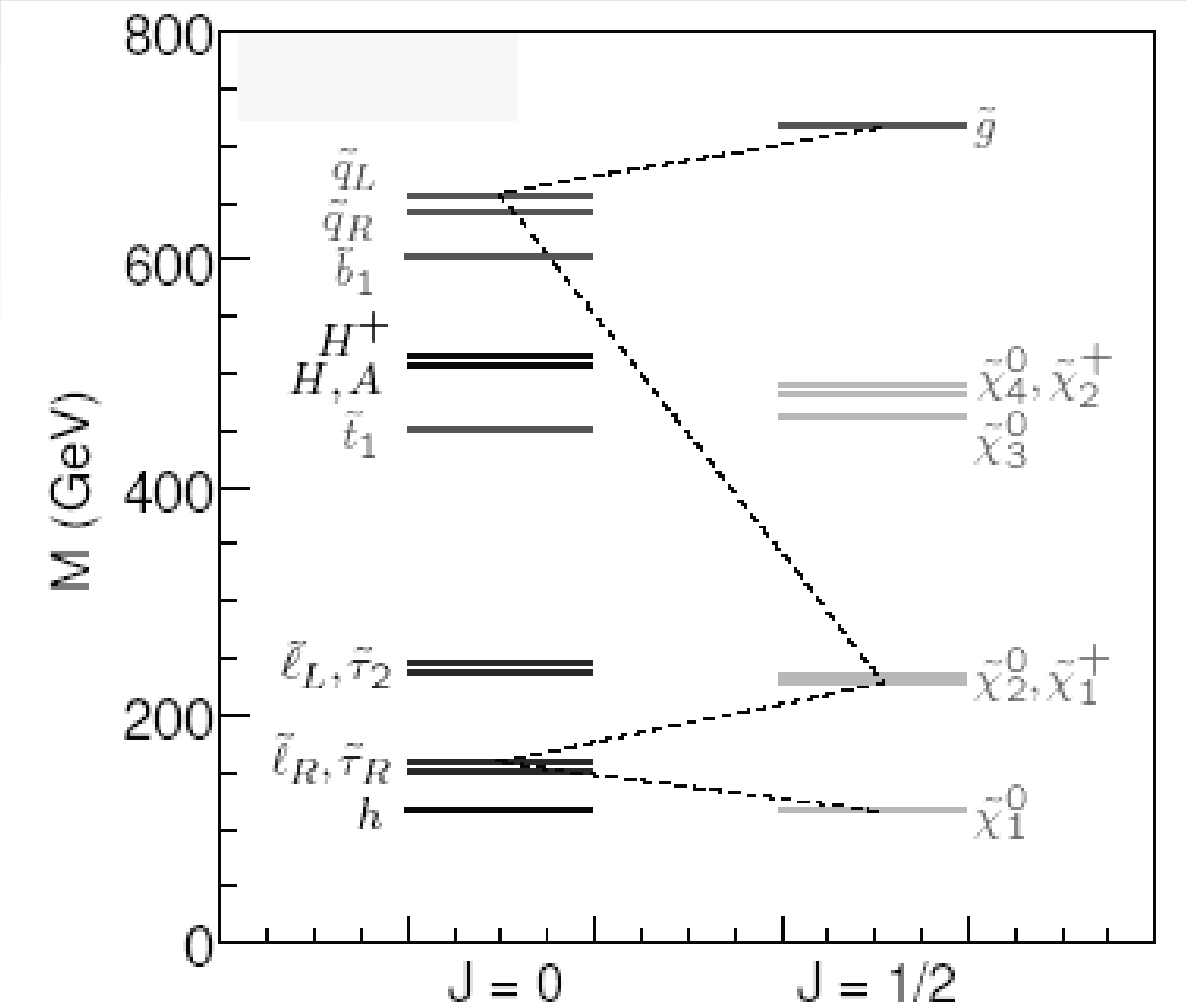
Electroweak chargino/neutralino production accessible



SuSy Particles

$m_0 = 100\,GeV, m_{1/2} = 300\,GeV$

$A_0 = -300, \tan\beta = 6, \mu > 0$



SuSy Decay

Superparticle decays

Gluino decays: always to $q\,\tilde{q}$.

If $M_{\tilde{g}} < M_{\tilde{q}}$, then gluino will decay via an off-shell squark:
3-body decays, $\tilde{g} \to q\tilde{q}^* \to q\bar{q}\widetilde{N}_i$ or $q\bar{q}'\widetilde{C}_i$

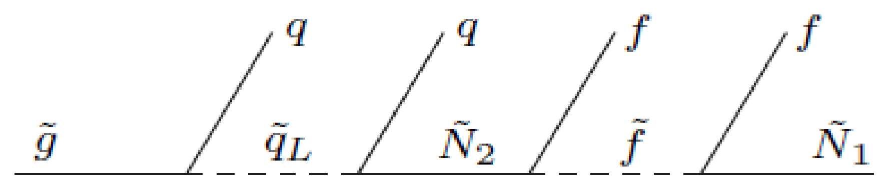
Squark decays:
To $q\,\tilde{g}$ (strong coupling) if kinematically allowed.
Otherwise $q\,\widetilde{N}$ or $q\,\widetilde{C}$ or (for 3rd gen.) $q\,\widetilde{H}$.
Decay branching fractions controlled by squark and -ino compositions.

Slepton decays: to $\ell\,\widetilde{N}$ or $\ell\,\widetilde{C}$ ($\ell = \ell^\pm$ or ν as appropriate)

Neutralino and chargino decays: to $\ell\,\tilde{\ell}$ or $q\,\tilde{q}$,
or to gauge or Higgs boson + lighter neutral-/charg-ino

Typically get decay chains, which always end with the LSP.

For example:



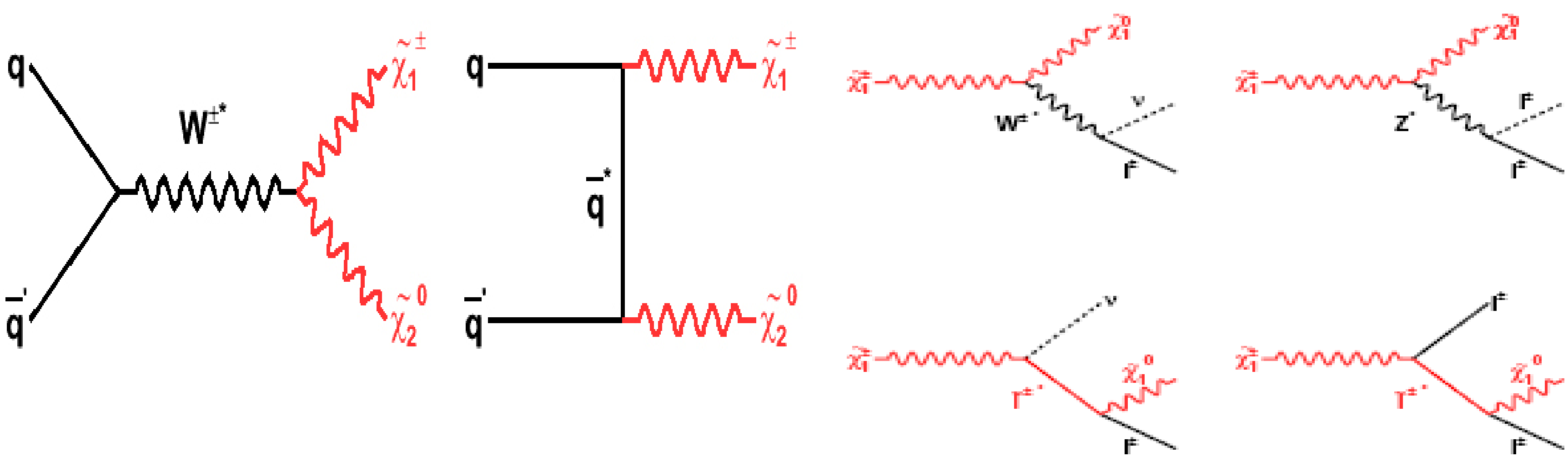
H. Logan https://indico.fnal.gov/conferenceOtherViews.py?view=standard&confId=3532

SuSy Searches Signatures

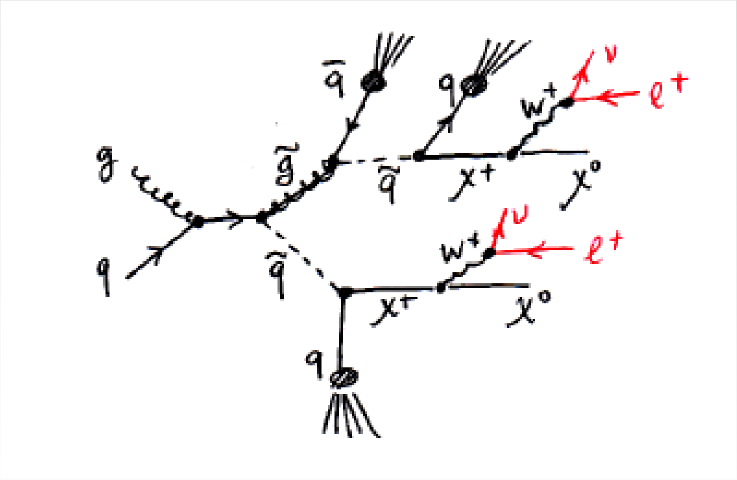
Assume R^p conservation and $\tilde{\chi}^0_1$ is LSP (light stable particle)

Signatures depend on the decay chain but ending with a LSP → MET:

- MET (LSP +v)
- isolated leptons from W/Z or $\tilde{\chi}^{\pm}$
- jets



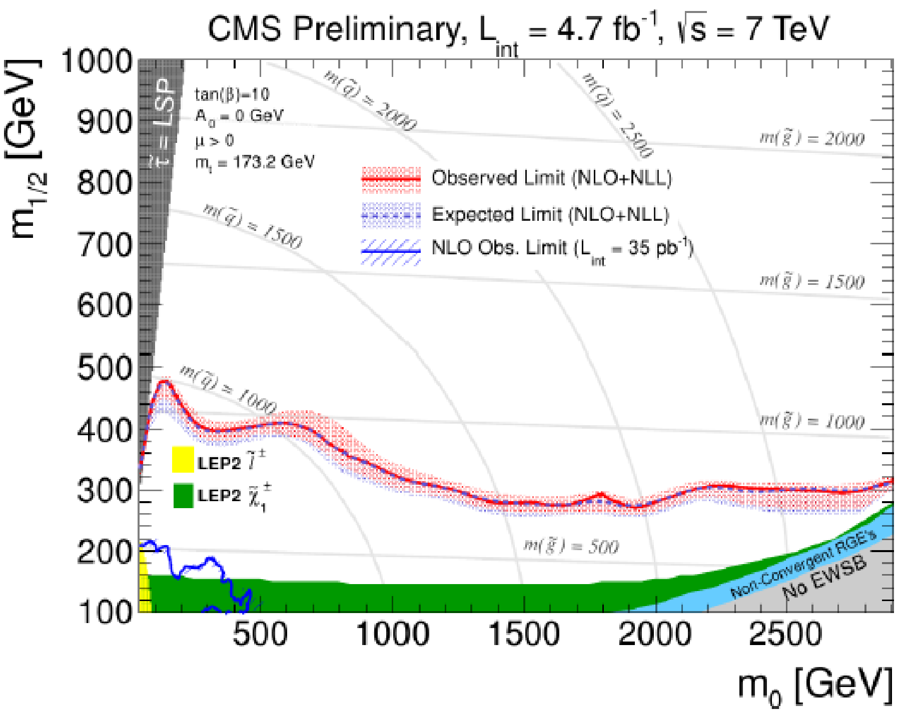
Same Sign di-lepton SuSy Searches



Production of squark and gluino

Event: Same sign leptons, MET jets

Background from lepton+jets, but rare processes like WW, WZ,ZZ become important



m_0: universal scalar mass

$m_{1/2}$ universal gaugino mass

Multi-lepton SuSy Searches

Multi-lepton production is sensitive to many models

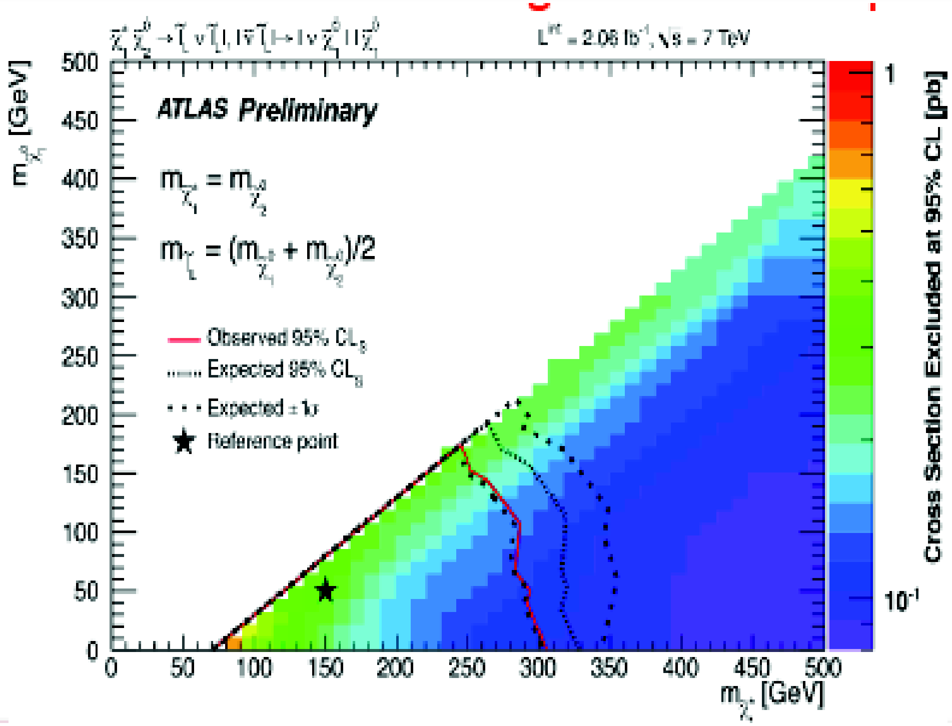
Charginos can decay: sleptons ($\tilde{\nu}\ell$), sneutrinos ($\tilde{\ell}\nu$) or W bosons ($W^{\pm}\tilde{\chi}^0_1$),

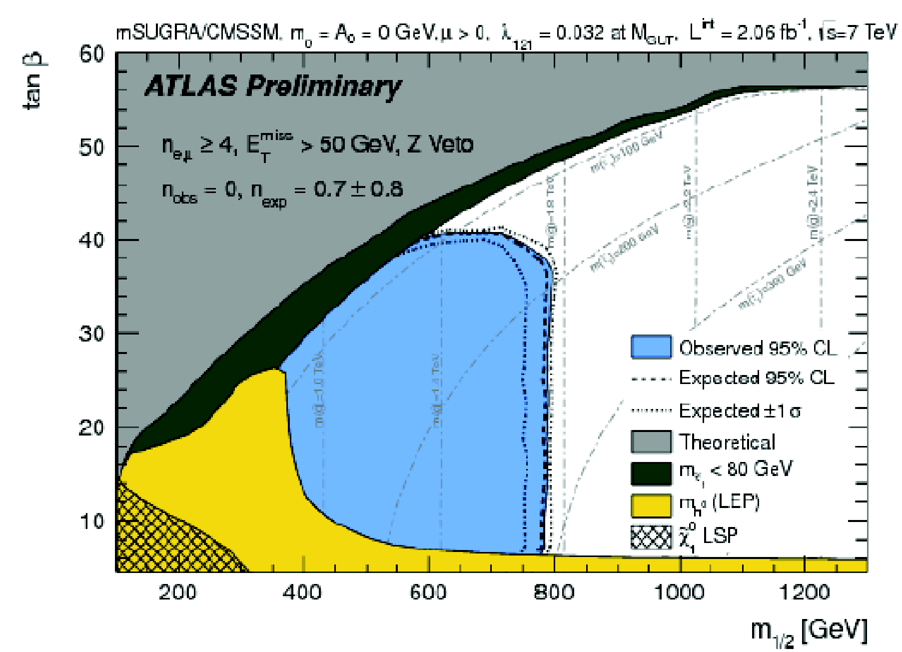
neutralinos can decay: $\ell\tilde{\ell}$, $\nu\tilde{\nu}$, or $Z\,\tilde{\chi}^0_1$

Signal Event: 3 or 4 leptons, MET

Background: WW,WZ,ZZ, tt, Z+jets, Drell-Yan

Direct chargino/neutralino production





Third SuSy Generation Searches

The third SuSy generation is somehow special:
- should be light for SuSY naturalness
- stop, sbottom, stau masses can be lower than other generation

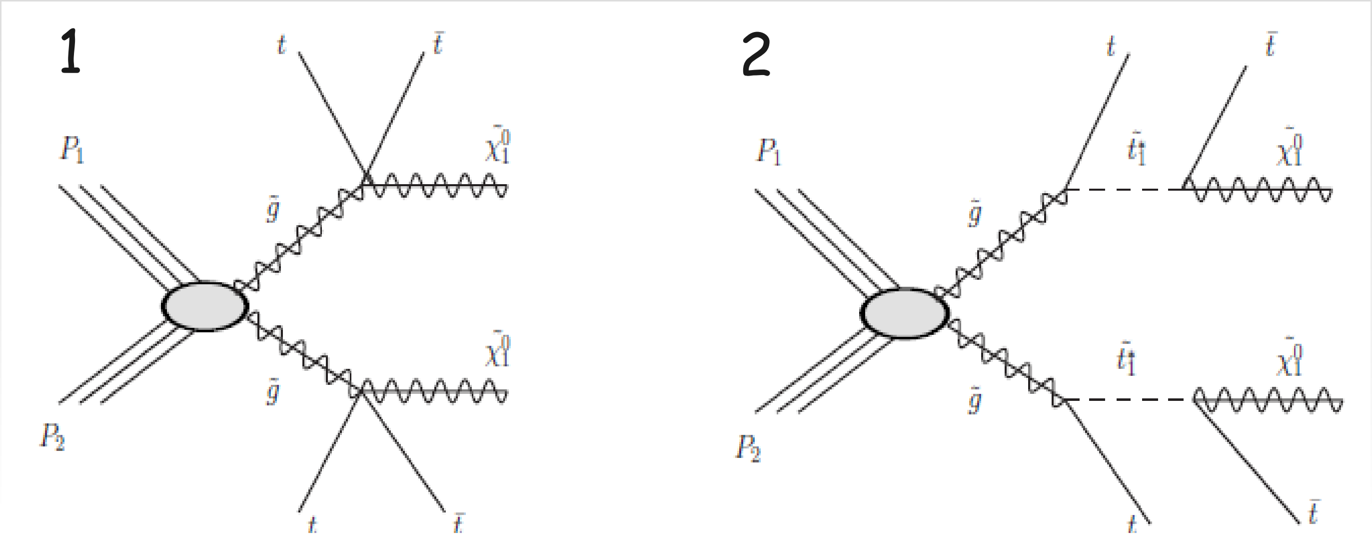
Several possible events selection that will give different sensistivity to different processes.

Consider as example: two same-sign lepton + b-jets
- 2 same-sign lepton
- 2 b-tagged jets
- MET

Define many signal region (SR) for different kinematic

Main backgroun due to $t\bar{t}$

Top Squark Searches



Possible searches:

1. three-body gluino decay mediated by virtual stop: $\tilde{g} \to t\bar{t}\tilde{\chi}^0_1$

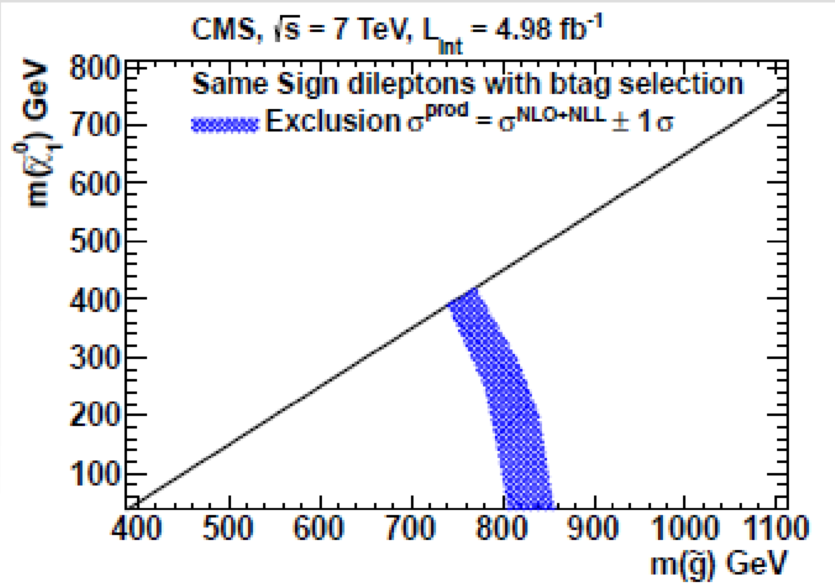
2. two-body gluino decay to a top-stop pair: $\tilde{g} \to \bar{t}\tilde{t}_1$, $\tilde{t}_1 \to t\tilde{\chi}^0_1$

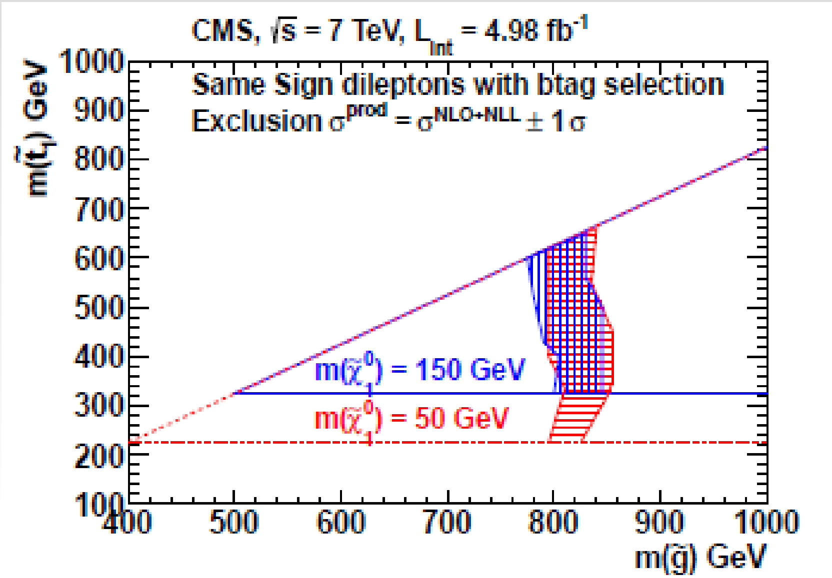
In 1. the assumption is that the gluoino is lighter than all the squarks and the stop is the lightest squark.

In 2. the stop is similar to 1. but with the stop so light to be on-shell

Final states with $t\bar{t}t\bar{t}\tilde{\chi}^0_1\tilde{\chi}^0_1$: 4b-jets, high Pt leptons , MET

Top Squark Searches Results

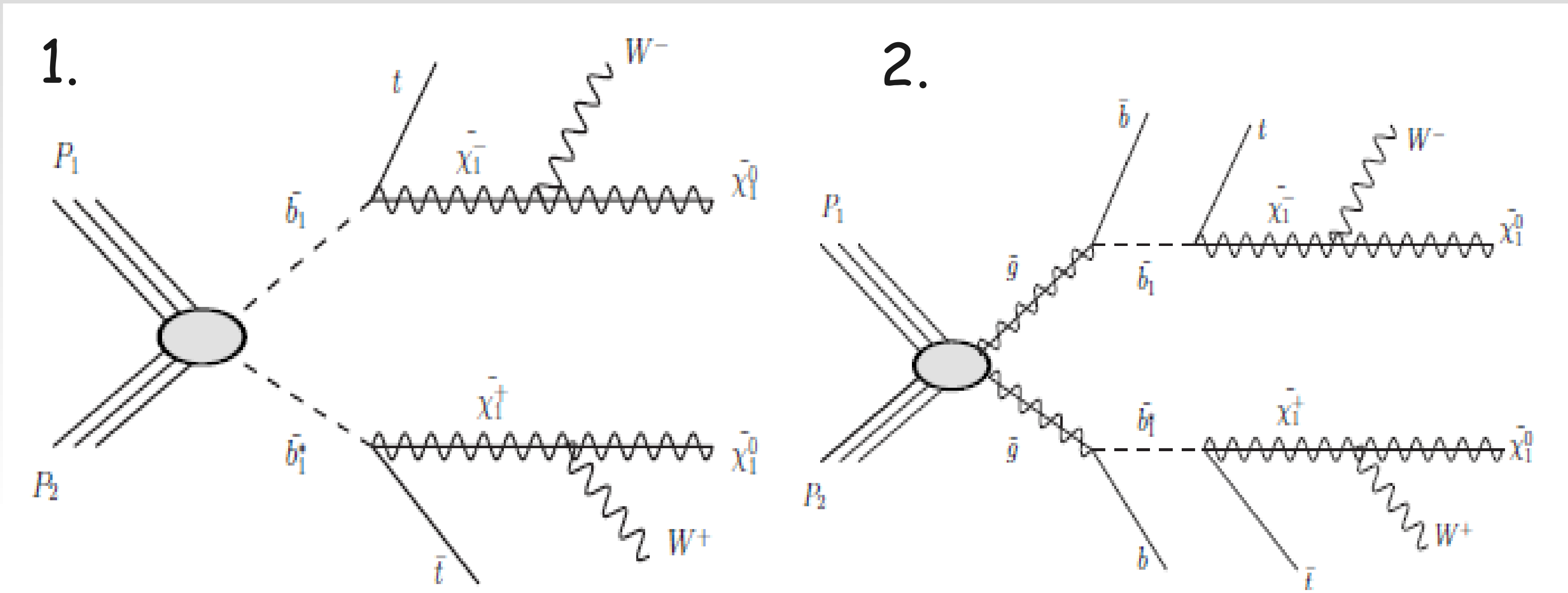




1. esclusion plot $m(\tilde{\chi}^0_1)$ vs $m(\tilde{g})$
2. esclusion plot $m(\tilde{t}_1)$ vs $m(\tilde{g})$

Solid line: kinematic limit, colored band; theoretical uncertainty

Bottom Squark Searches

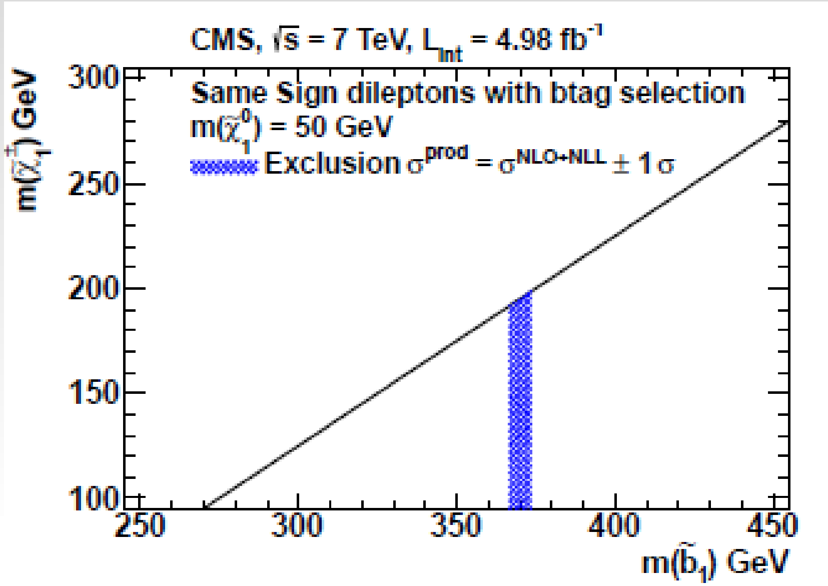


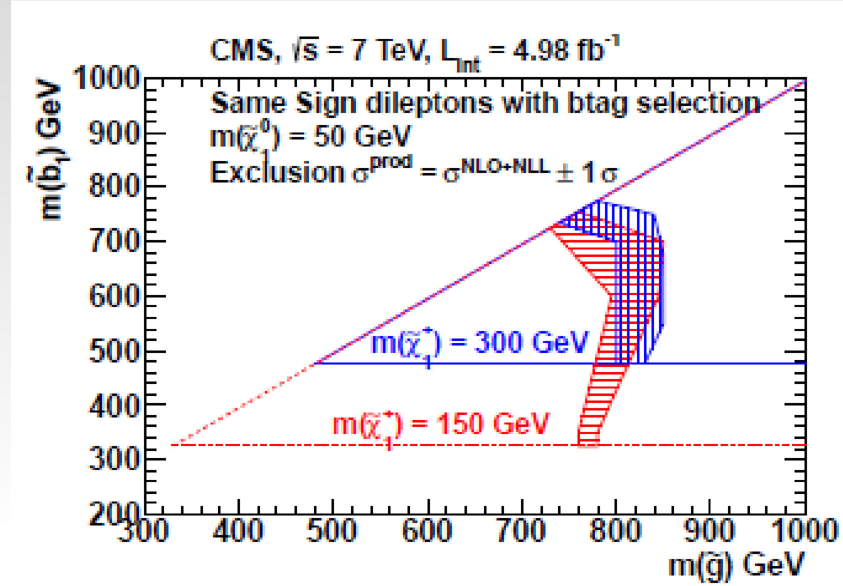
1. $pp \to \tilde{b}_1 \tilde{b}^*_1$, $\tilde{b}_1 \to t \tilde{\chi}^-_1$
2. $pp \to \tilde{g}\tilde{g}$ or $pp \to \tilde{g}\,\tilde{b}_1$ with $\tilde{g} \to \tilde{b}_1 \bar{b}$

Final states are:

1. $t\bar{t}W^+W^-\tilde{\chi}^0_1\tilde{\chi}^0_1$ $\to$ b-jets, leptons, MET
2. mixture of ttWW + $\tilde{\chi}^0_1\tilde{\chi}^0_1$ $\to$ b-jets, leptons, MET

Bottom Squark Searches Results

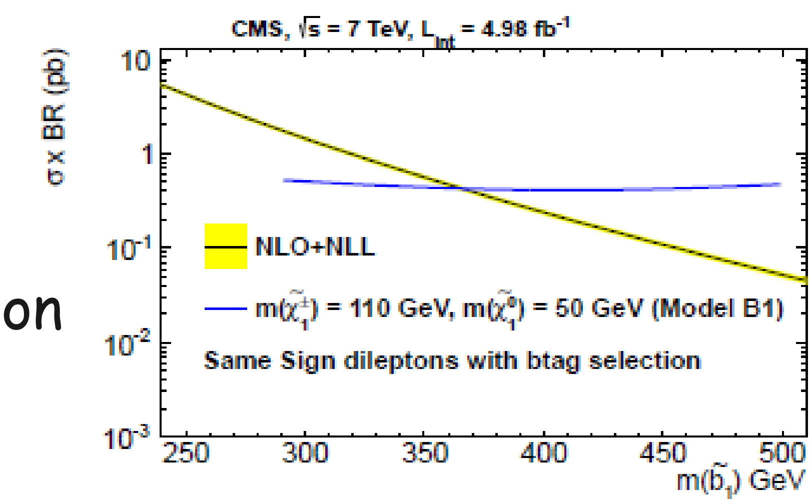




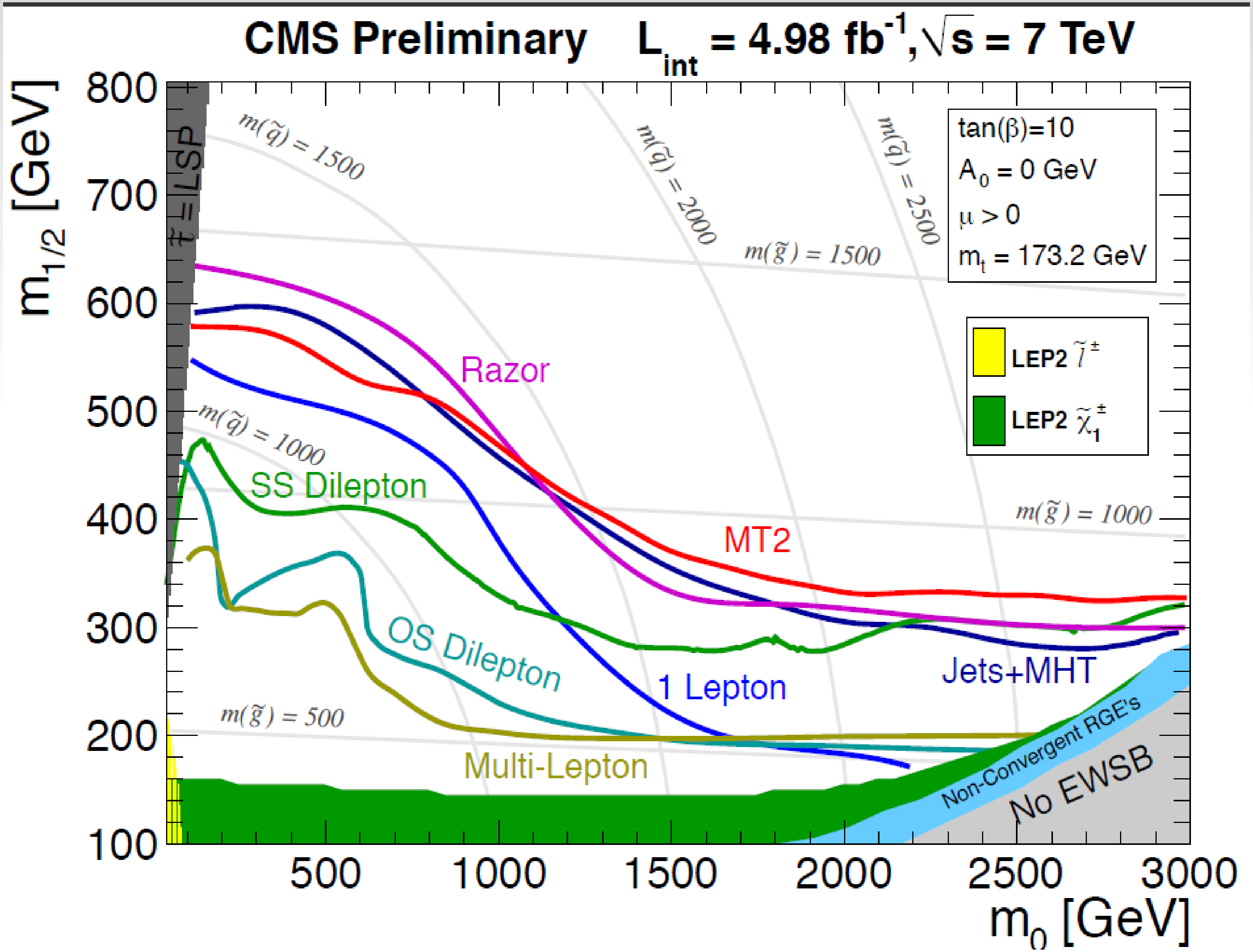
Solid line: kinematic limit, colored band; theoretical uncertainty

1. esclusion plot $m(\tilde{\chi}^0_1)$ vs $m(\tilde{b}_1)$
2. esclusion plot $m(\tilde{b}_1)$ vs $m(\tilde{g})$

Limit on cross section



SUSY Searches Summary

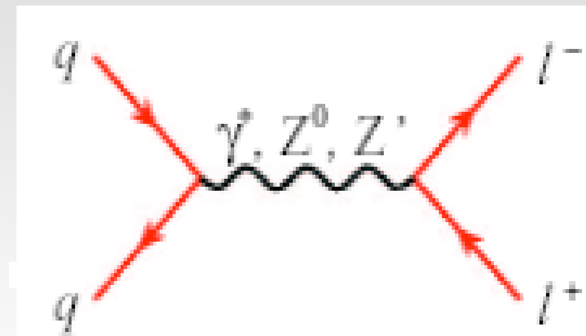


Signature Based Searches

Di-leptons Searches: Starting Point

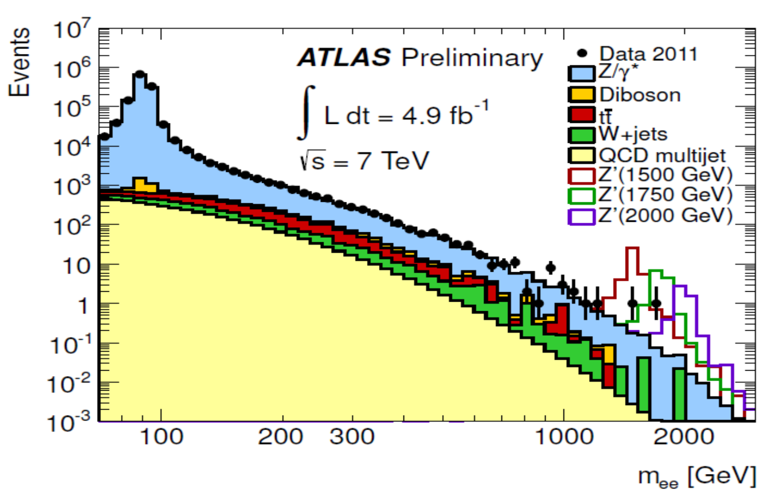
Search for resonances or excess in ee/μμ in the high mass region

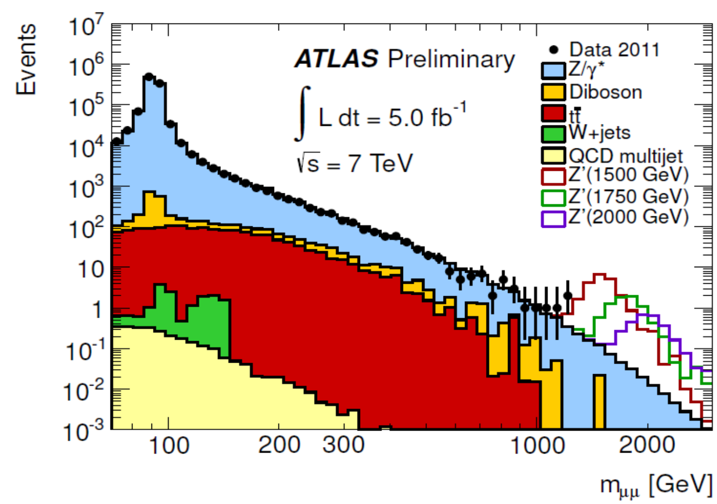
- lepton id well under control
- Z peak used as reference
- clean events



Several extentions of SM predict:

- heavy spin-1 neutral gauge bosons such as Z', Z*
- techni-mesons
- spin-2 Randall-Sundrum gravitons, G*, with a narrow intrinsic width
  $K/\bar{M}_{Pl} < 0.1$ k=space-time curvature in extradimensions, $\bar{M}_{Pl}=M_{Plank}$ reduced

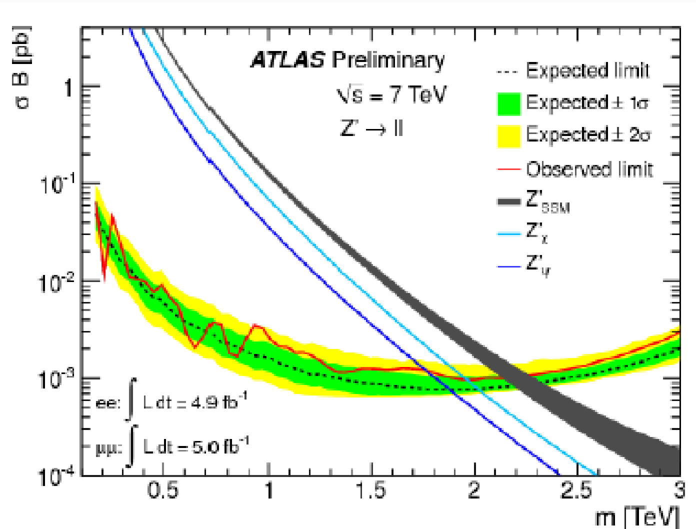




New Phyiscs Searches Di-leptons Resonances

Analysis Method

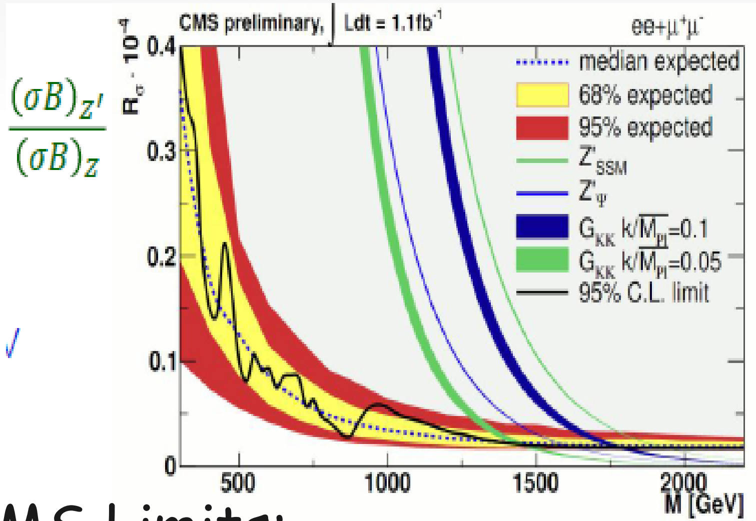
- understand very well data spectrum in term of SM process
- calculate new signal acceptances and trigger efficiencies
- derive the number of expected new physics events
- if no events found in data calculate 95% CL cross section limit and set particle mass limit



Atlas Limits:

–Sequential SM: $m_{Z'}$>2.21TeV

–RS graviton, k/M_{Pl}=0.1: m_G>2.16TeV



CMS Limits:

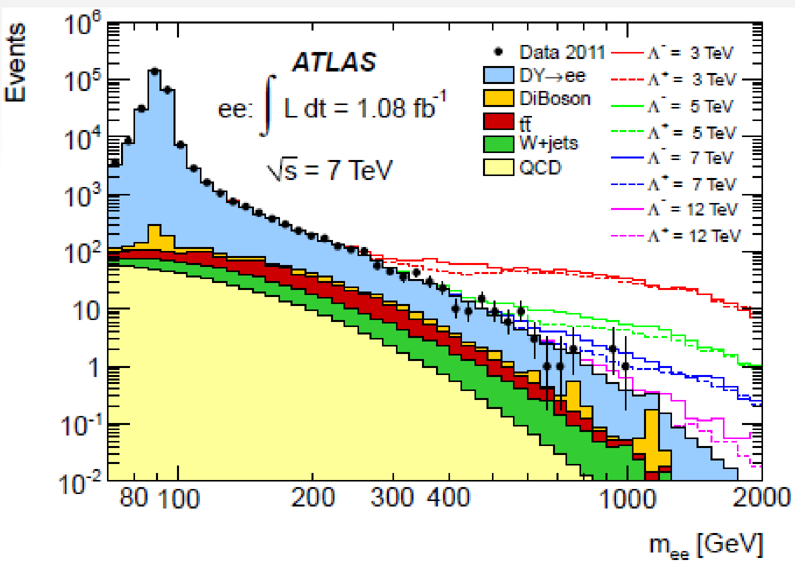
–Sequential SM: mZ'>1.94 TeV

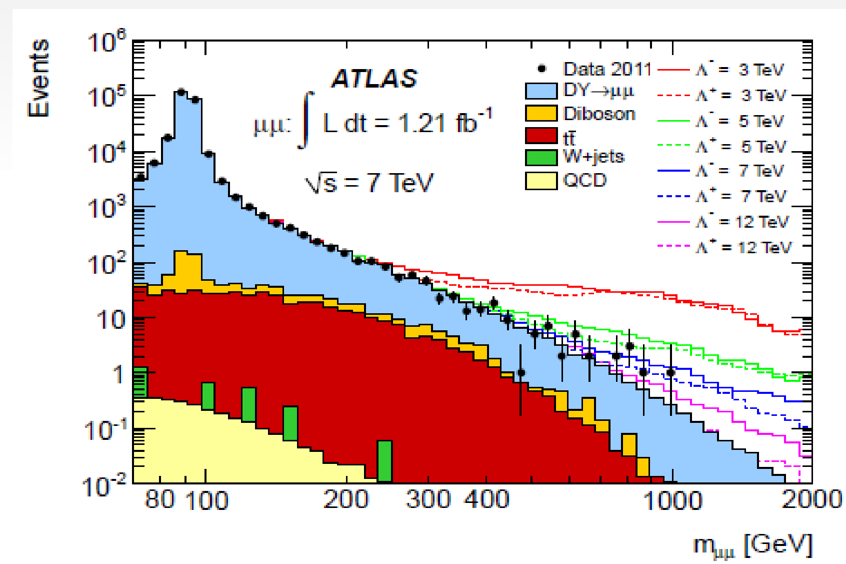
–RS graviton, k/M_{Pl}=0.1: m_G>1.98TeV

New Phyiscs Searches Di-leptons Excess

Excess of events not forming a resonance → Physics beyond SM

Composite quarks and leptons with at least one common constituent, have an effective four-fermion contact interaction at energies well below the compositeness scale which alter the Drell-Yan production





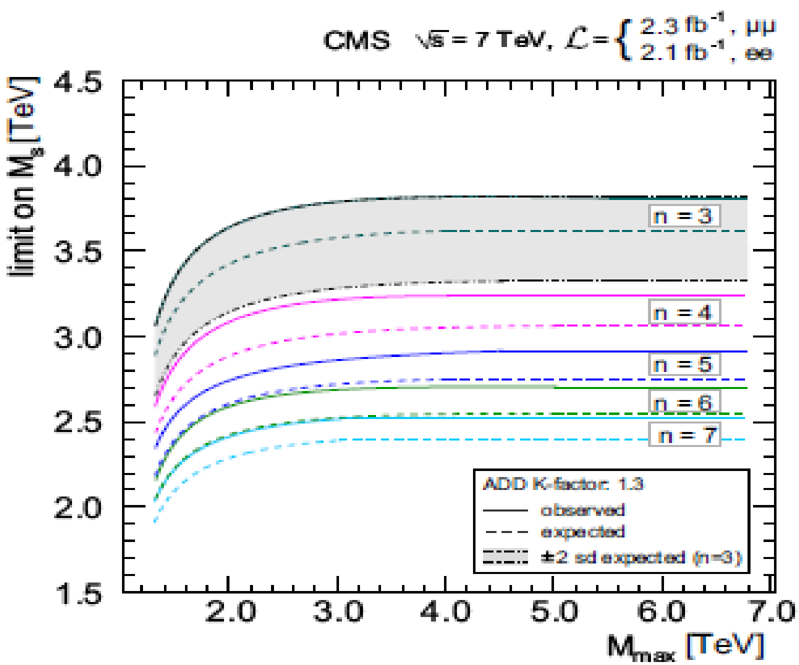
Limit:

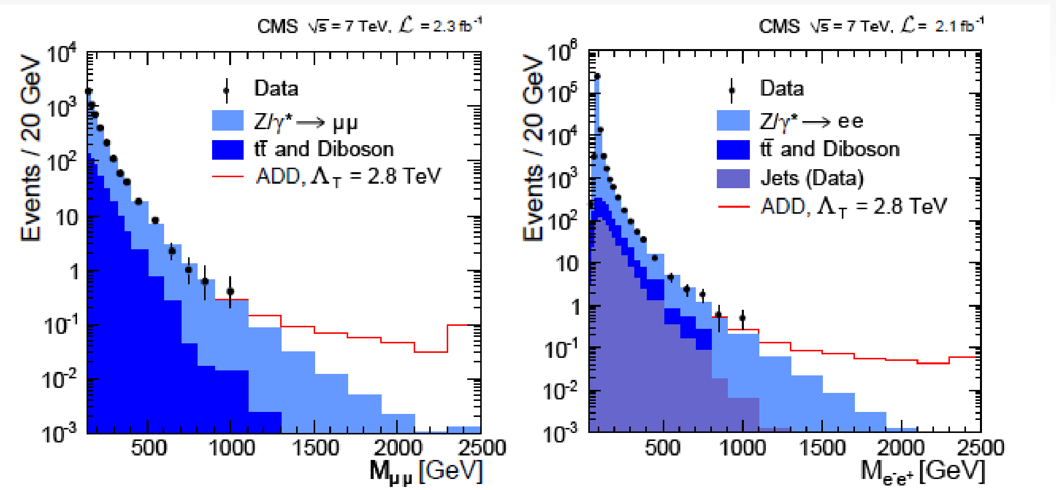
- constructive interaction Λ^- >10 TeV (ee) Λ^- >8 TeV (μμ)
- destructive interaction Λ^+ >9.4 TeV (ee) Λ^+ >7 TeV (μμ)

New Phyiscs Searches Di-leptons Excess

Models with extended spce-time structure predict new phenomena, beyond SM. Additional spatial dimensions, essential for formulating quantum gravity in the context of string theory, have been proposed as a solution to the SM hierarchy problem. Arkani-Hamed, Dimopoulos, Dvali (ADD) model the graviton can modify the Drell Yan production.

Predictions for n>3 depend on one parameter Λ





M_s=effective Planck scale in ADD model

M_{max}=max $\sqrt{s}$

$\Phi \rightarrow \tau\tau$ searches

The Higgs sector: neutral Higgs h^0(SM), A^0,H^0 and charged H^+,H^-

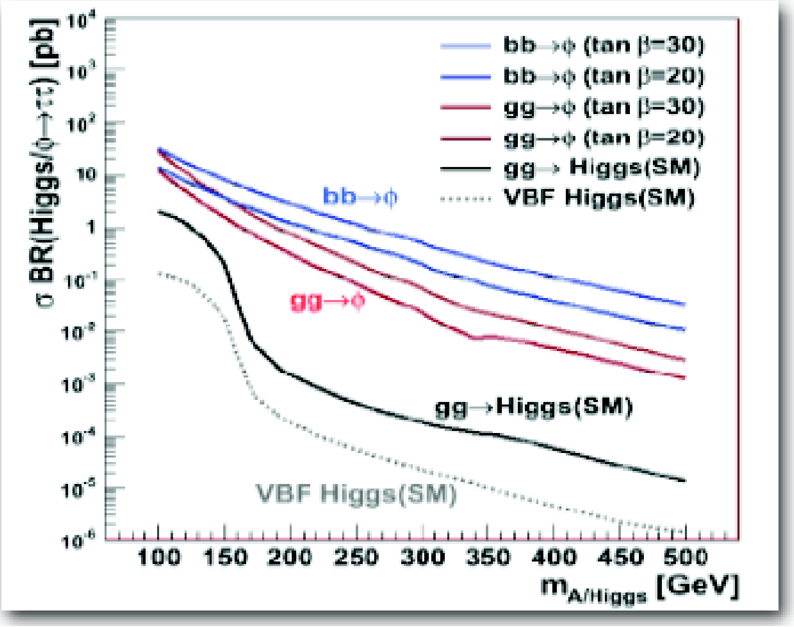
CP=- CP=+

mass relations among the neutral MSSM Higgs bosons:

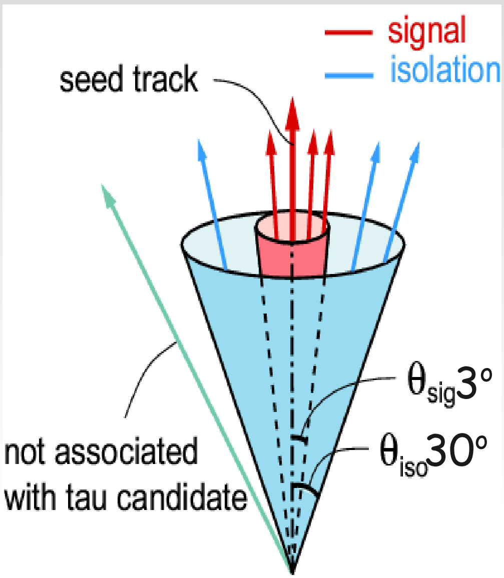
- m_A< 130 GeV, at large values of tan(β) h and A are ~degenerate in mass and m_H ~130 GeV.
- m_A> 130 GeV, A and H are ~degenerate, and m_h ~130 GeV.

Assume Φ the mass degenerate state:

Φ->bb (90%), Φ->$\tau^+\tau^-$ (10%)

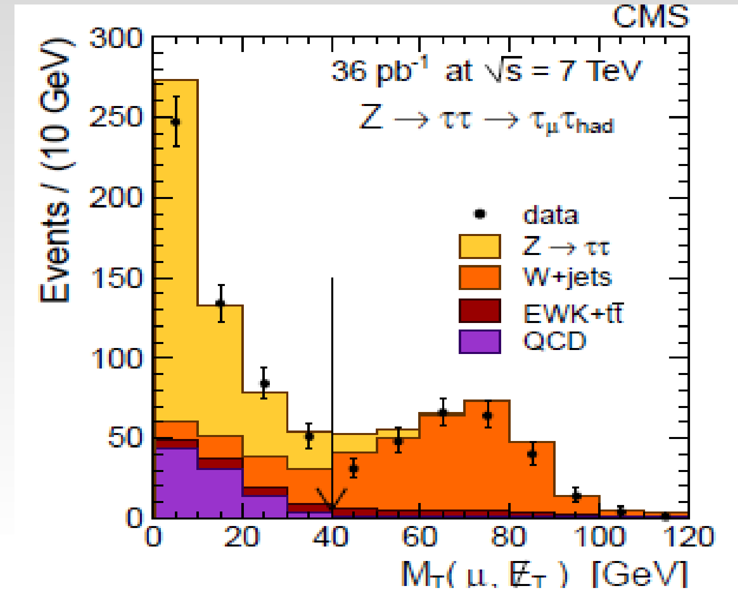


Tau final States Reconstruction



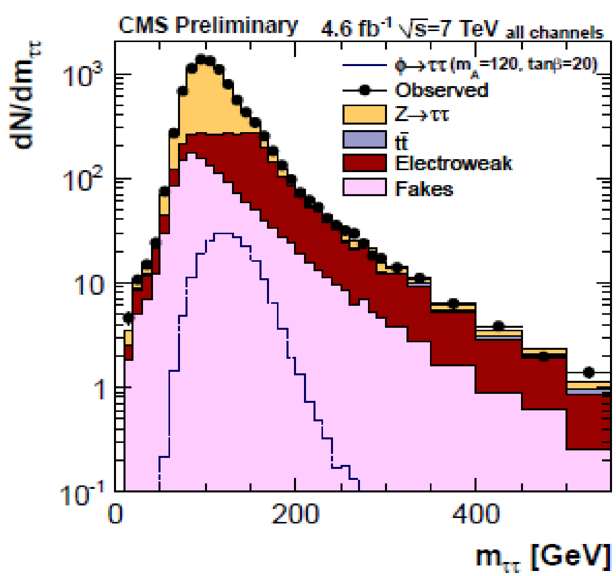
Di-taus: $\tau \to \ell\nu\nu$ $\tau \to$ hadrons

Hadronic τ reconstructed with 1 or 3 tracks in an isolated cone, technique used for $Z \to \tau\tau$

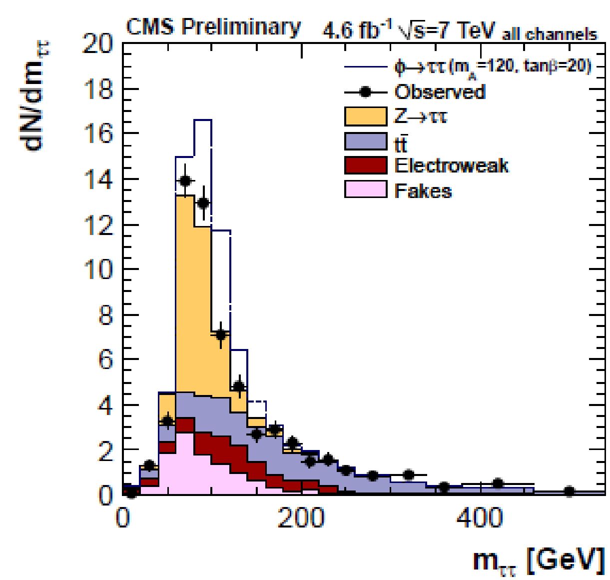


For inclusive Φ searches use:

- final states with ($\mu\nu$, $e\nu$), ($\mu\nu$, had) ($e\nu$, had)
- sample splitted as function of b-tag jets

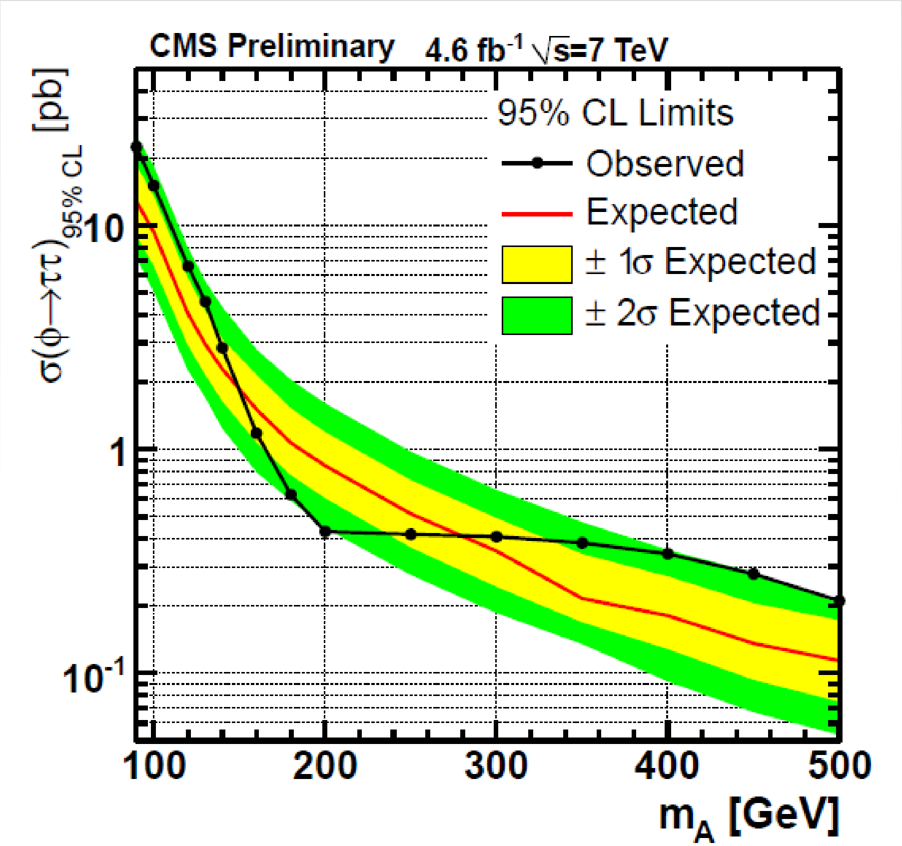


no b-tag

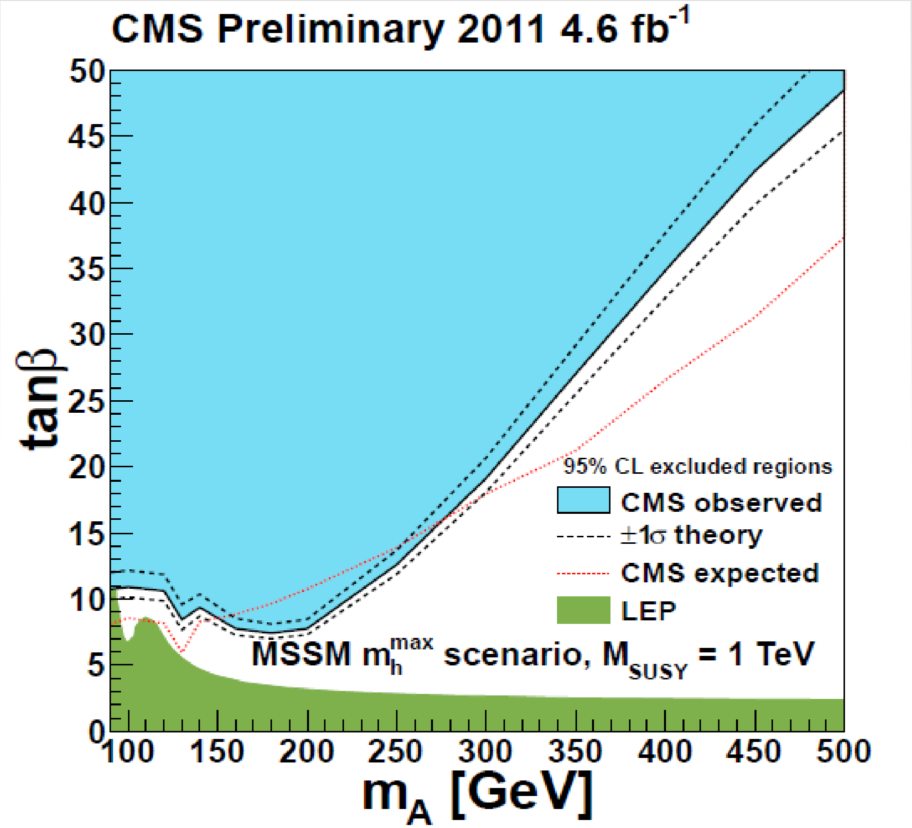


b-tag

Φ→ττ Limits



CMS Preliminary 4.6 fb-1 √s=7 TeV
95% CL Limits
Observed
Expected
± 1σ Expected
± 2σ Expected
σ(φ→ττ)95% CL [pb]
mA [GeV]



CMS Preliminary 2011 4.6 fb-1
95% CL excluded regions
CMS observed
±1σ theory
CMS expected
LEP
MSSM mhmax scenario, MSUSY = 1 TeV
tanβ
mA [GeV]

Di-jets Final States

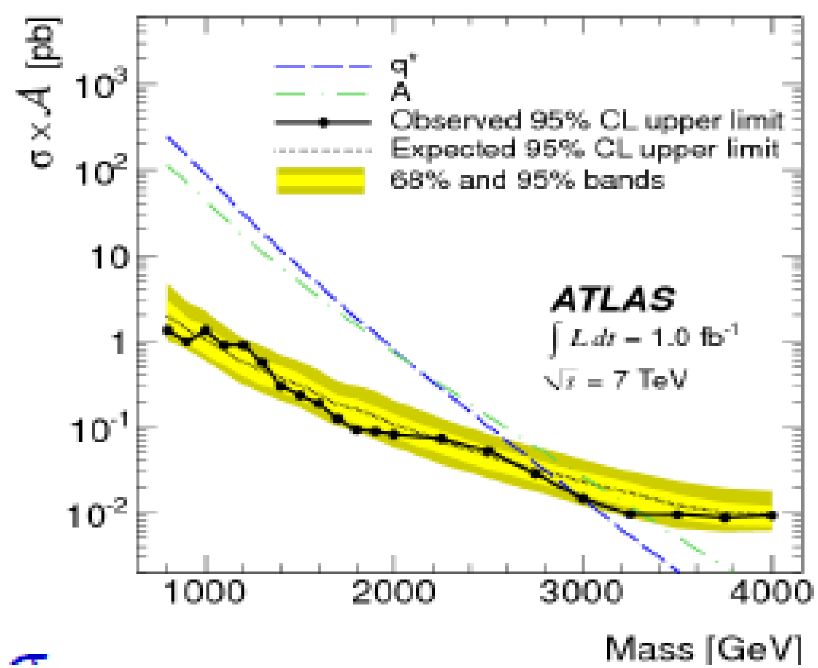
Selects events with two high P_t jets

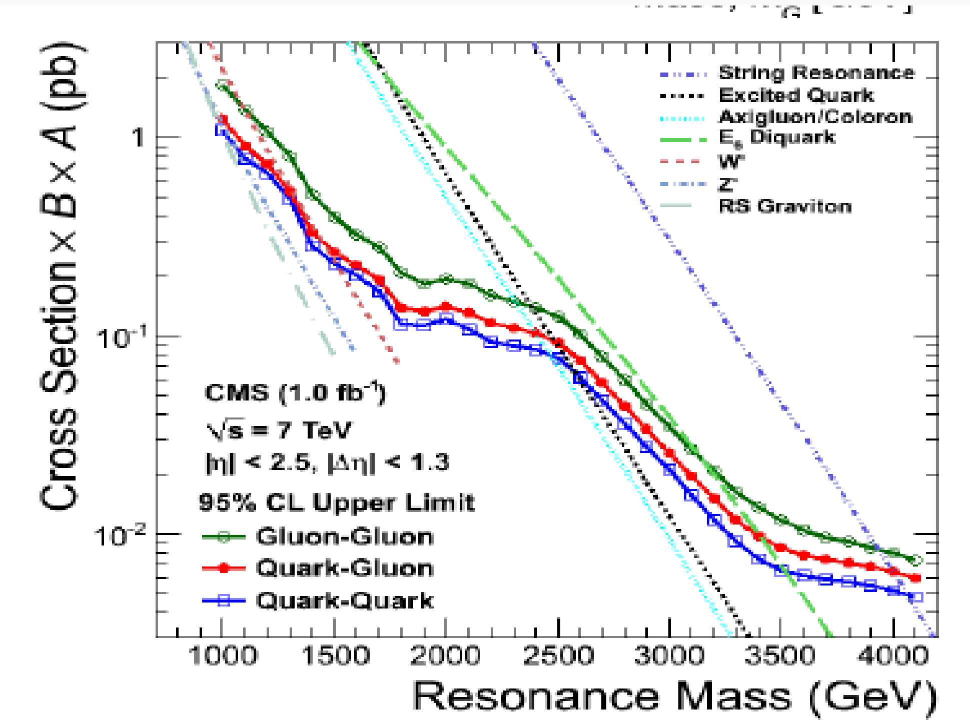
Look for bumps in M_{jj} cross section

Excited quarks: q*->qg

m(q*)>2.99 TeV

Axigluon m(A)>3.32 TeV

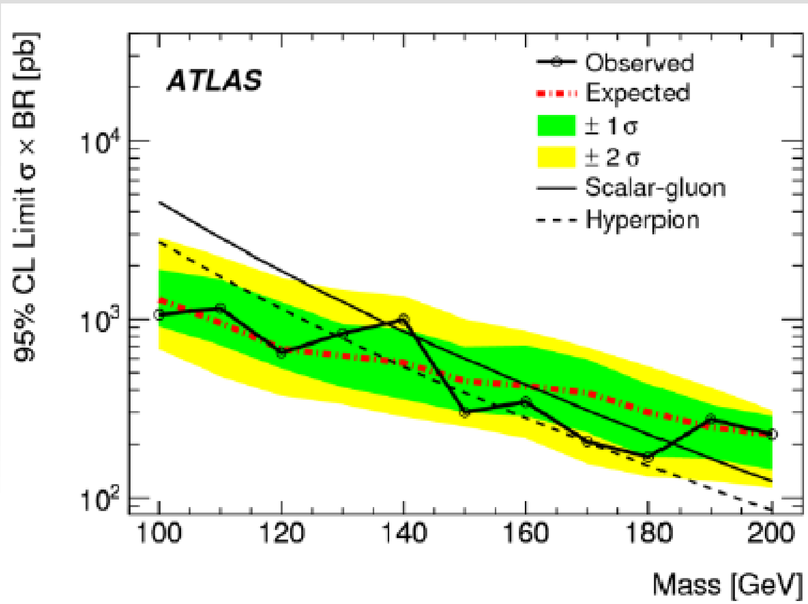


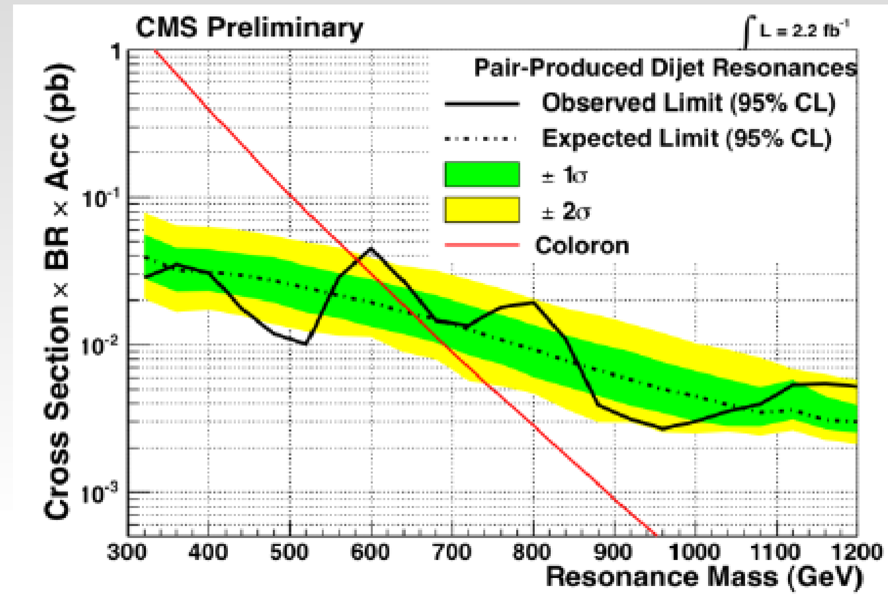


String resonance m>4 TeV

Heavy Bosons mW'>1.5 TeV

Di-jets Final States

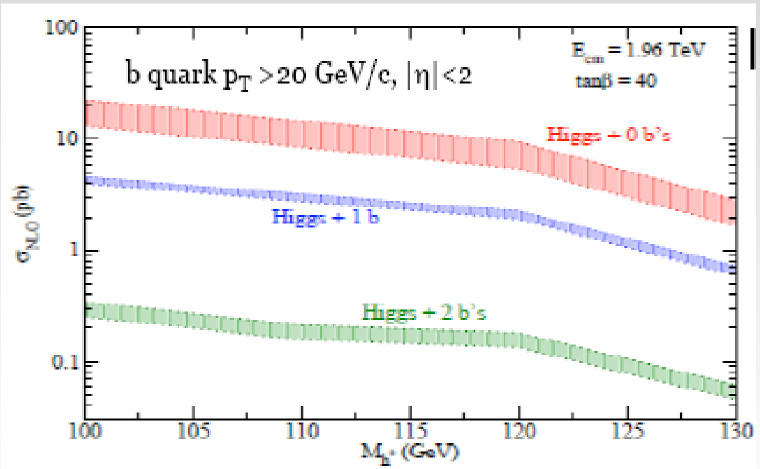




- Hyperpions for (100, 155) GeV
- Scalar gluons (100, 185) GeV

Limit on coloron m>580 GeV

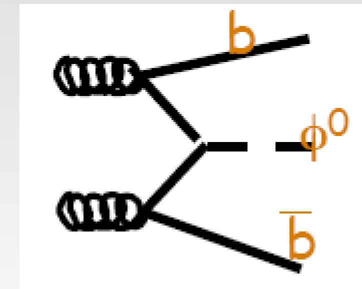
Di-jets Final States: $b\bar{b}$



Inclusive bb hard due to QCD bck

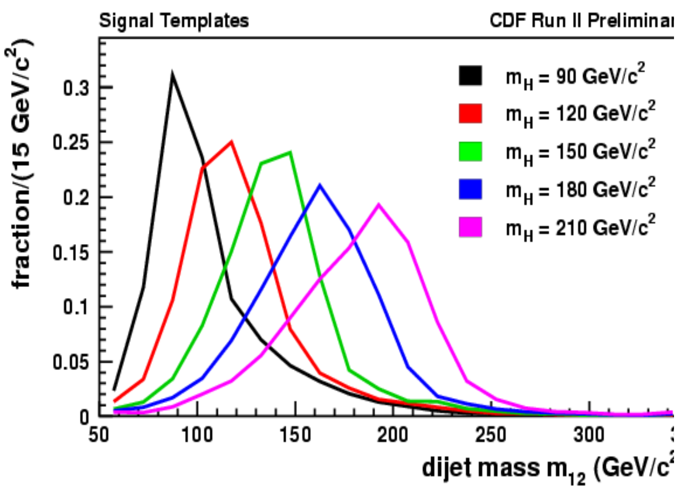
Require a 3d b-jets

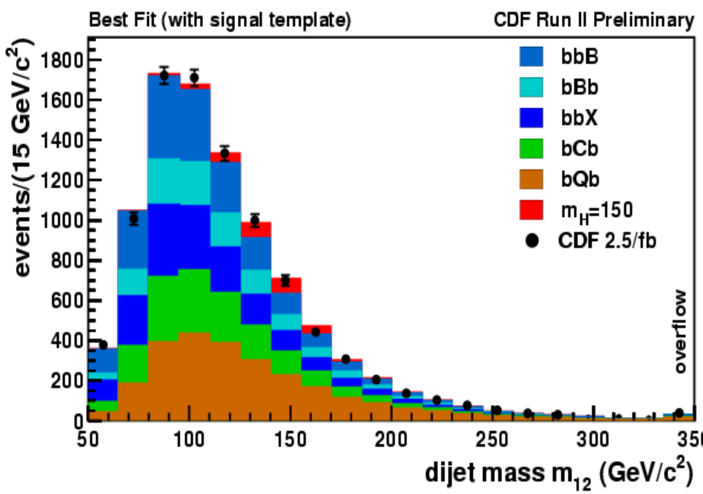
Good compromise between signal and background rate

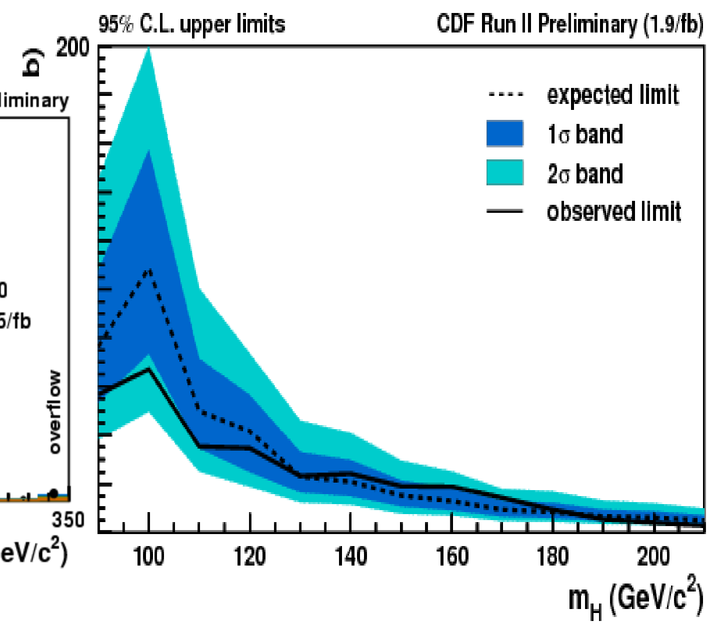


M_{12}, inv. mass 2 leading jets separate signal from background

Result:







Leptoquarks searches

Leptoquarks are proposed as link among quarks and leptons, with fractionally-charged color-triplet bosons carrying both lepton and baryon quantum numbers. Leptoquarks appear in a wide range of theories including SU(5) grand unification, superstrings, SU(4) Pati-Salam, and compositeness models.

Leptoquark couple only with one generation to avoid flavor violation

1st Generation	2nd Generation	3rd Generation
$LQ\,\overline{LQ} \rightarrow e^- e^+ q\bar{q}$	$LQ\,\overline{LQ} \rightarrow \mu^+ \mu^- q\bar{q}$	$LQ\,\overline{LQ} \rightarrow \tau^+ \tau^- q\bar{q}$
$LQ\,\overline{LQ} \rightarrow e^{\pm} \nu_e q_i q_j$	$LQ\,\overline{LQ} \rightarrow \mu^{\pm} \nu_\mu q_i q_j$	$LQ\,\overline{LQ} \rightarrow \tau^{\pm} \nu q_i q_j$
$LQ\,\overline{LQ} \rightarrow \nu_e \nu_e q\bar{q}$	$LQ\,\overline{LQ} \rightarrow \nu_\mu \nu_\mu q\bar{q}$	$LQ\,\overline{LQ} \rightarrow \nu_\tau \nu_\tau q\bar{q}$

Final states with:

-jets

-leptons

-neutrinos (MET)

Leptoquarks searches cont'd

First generation:

* di-electrons + jets
* electron + MET + jets
* MET + jets

Main background:
W+jets, top, Z+jets

Second generation:

* di-muons + jets
* muon + MET + jets
* MET + jets

Main background:
W+jets, top, Z+jets

Third generation:

* di-taus + jets
* tau + MET + jets
* MET + jets

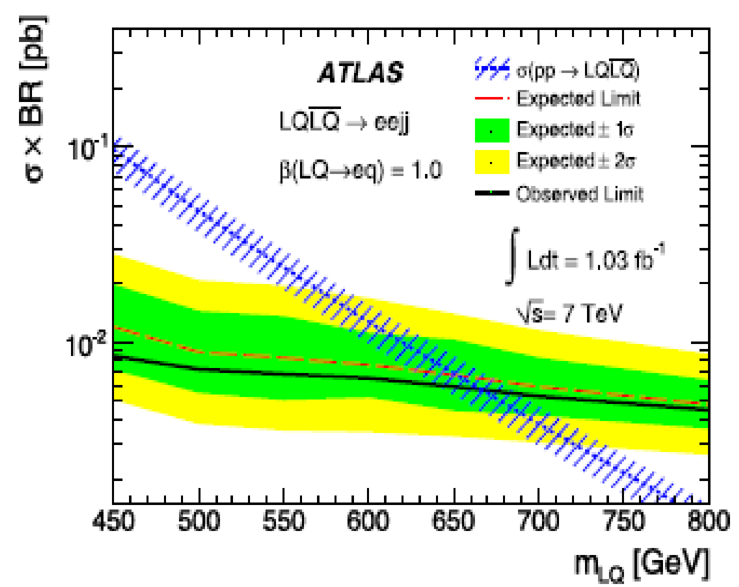
Main background:
W+jets, Z, QCD

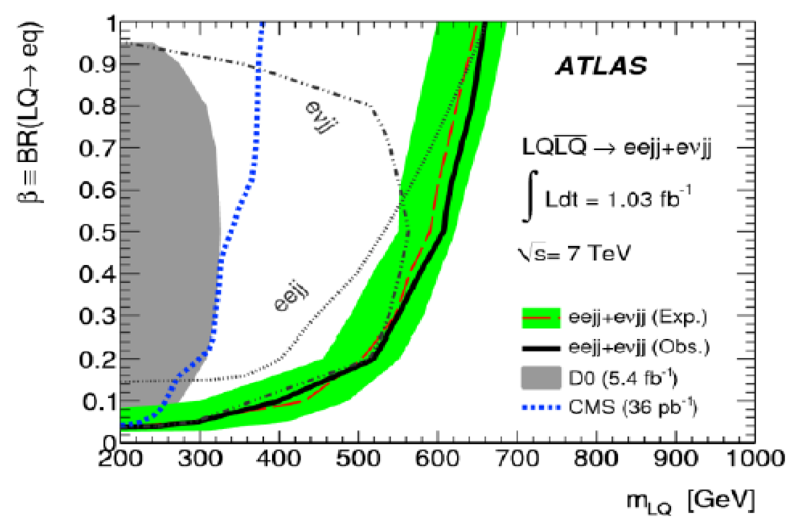
First Generation Leptoquarks Results

β is the branching ratio LQ → ℓq
1-β is the branching ratio LQ → νq

Atlas :
final states with eejj eνjj
Limits:
- mLQ>660 GeV for β=1
- mLQ>607 GeV for β=0.5

Phys. Lett. B 709, 158 (2012)





Second Generation Leptoquarks Results

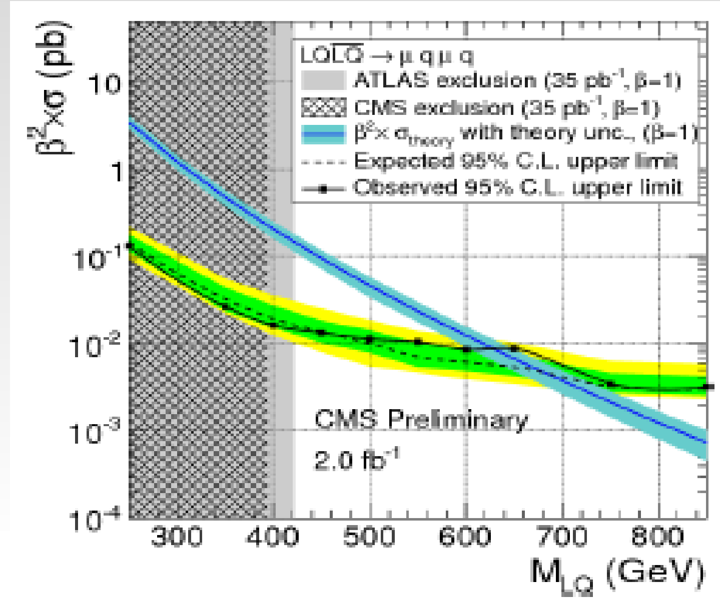
Final states with μμjj μνjj

CMS

Limits:

-mLQ>632 GeV for β=1

-mLQ>523 GeV for β=0.5

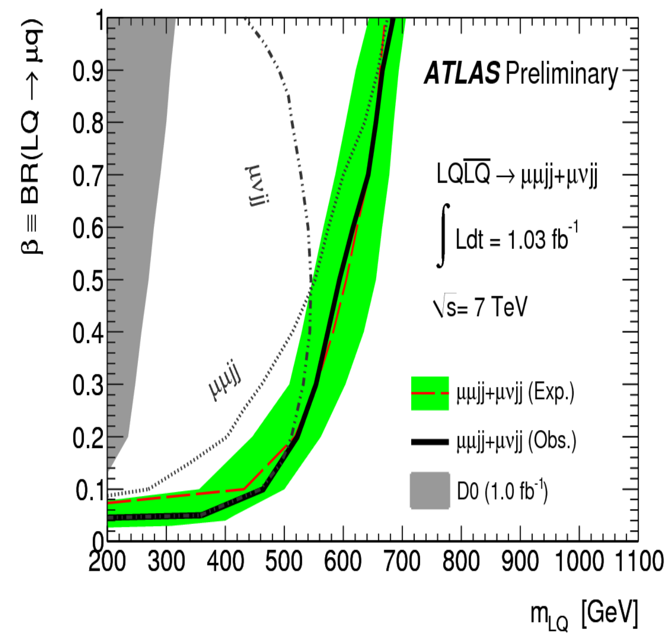


Atlas

Limits:

-mLQ>685 GeV for β=1

-mLQ>594 GeV for β=0.5

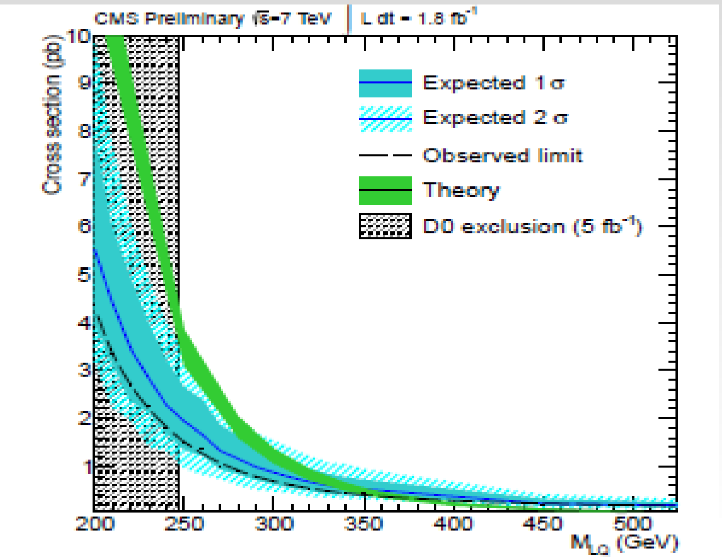


Third Generation Leptoquarks Results

CMS :

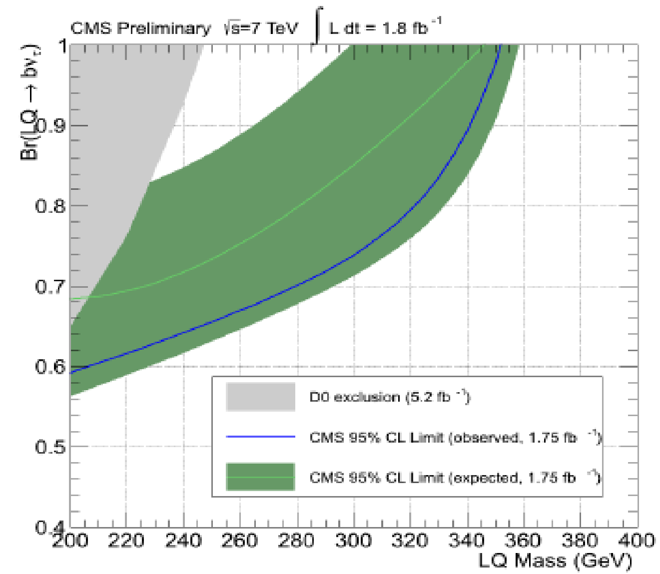
final states with $\nu_\tau \nu_\tau bb$

Use variables optimized to search for heavy mass particles



Limits:

-m_{LQ}>350 GeV for β=1



What if the evidence evaporates in ‘12?

Can we do without the Higgs?

Suppose we take the gauge symmetric part of the SM and put masses by hand.

What is the fatal problem at the LHC scale?

The most immediate disease that needs a solution is the occurrence of unitarity violations in some amplitudes

To avoid this either there is one or more Higgs particles or some new states (e.g. new vector bosons)

Thus something must happen at the few TeV scale!!

Altarelli, Moriond EW12

Is New Physics discovery possible for LHC?

The "energy desert" between electroweak and GUT scale is possible if Higgs is between 130 and 180 GeV

Ellis, Espinosa, Giudice, Hoecher, Riotto quoted by Masiero.