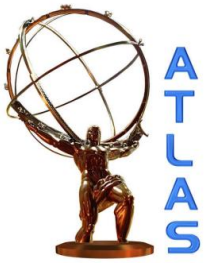

BSM physics at the LHC

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Physics Beyond the Standard Model and Predictable Observables
7 Jan. 2011

Why BSM?

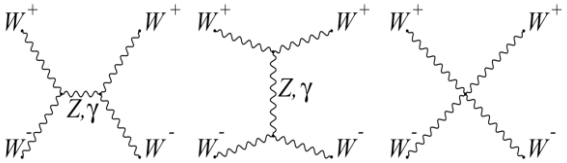
- If SM Higgs exists
  - To solve the hierarchy and naturalness problems
  - O(1 TeV)

Quadratic divergence of Higgs mass

$$\delta m_H^2 = \text{---}\bigcirc\text{---} = \frac{y_f^2 v^2}{16\pi^2}\Lambda^2$$

- If SM Higgs does not exist
  - New mechanism for EWSB
  - O(1 TeV)

Unitarity Violation in W^+W^- scattering

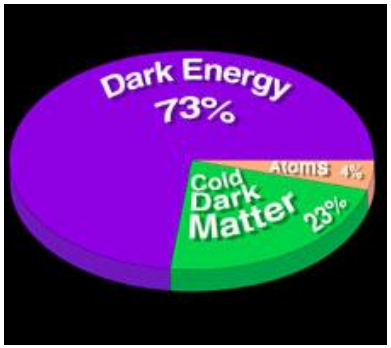


$$\sigma_{W^+W^-\to W^+W^-} \propto \frac{1}{v^2}(s+t)$$

- O(1 TeV) is the scale of BSM physics related to EWSB

Why BSM? Cont'd

- SM cannot give the answers to the problems
  - Dark Energy (73%), Dark Matter (23%)
  - Baryogenesis / Leptogenesis (4%)
  - Charge quantization
  - Fermion mass/mixing
  - Unification of EW and strong/gravity interactions.
  - …
- Need BSM physics to solve the problems
- BSM scale depends on model
  - O(100 GeV) ~ O(10^{19} GeV)
- Should search BSM physics at Energy Frontier, LHC!



Outline

- I can present public results from ATLAS and CMS
  - Unfortunately, dozen of results to be presented at coming Winter conference can not be given. So your favorites might not be covered.
  - Signatures
    - Dijet resonance
    - Dijet non-resonance
    - High E_T Multi-object
    - Lepton + Missing E_t
    - Diphoton + Missing E_t
    - Particle stopped inside Detector
- Prospect on SUSY golden channel, jets + missing E_T
  - SUSY discovery potential with MC by ATLAS
  - Preliminary exclusion by CMS

Dijet Resonance

- Possible new physics
  - Excited quark in compositeness : q* → qg
    - CDF : $m_{q*} > 870$ GeV
  - String resonance (Regge excitations of quark and gluon)
  - Axigluon (axial vector gluon) in chiral color model
  - E_6 diquark
  - Heavy bosons
    - W' or Z' in new gauge group
    - KK tower of SM bosons in Extra Dimension models
  - RS Graviton
- Observable
  - Invariant mass of dijet

3.1 pb^{-1}

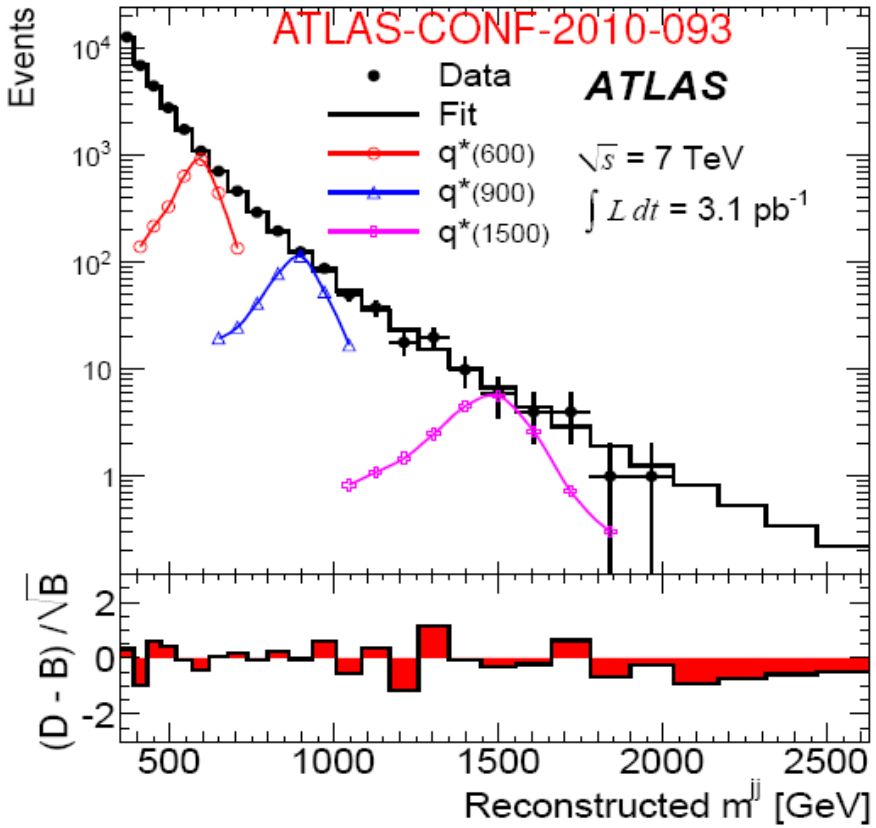
Search for Dijet Resonance

- Jet selection
  - Anti-Kt jet algorithm R=0.6
  - $E_T^1 > 150$ GeV
  - $E_T^2 > 30$ GeV
  - $|\eta| < 2.5$
    - excluding crack region $1.3 < |\eta| < 1.8$
  - $|\Delta\eta| < 1.3$
    - exclude forward-backward jets events
- SM Background shape
  - modeled with an empirical function used at Tevatron

$$f(x) = p_0 \frac{(1-x)^{p_1}}{x^{[p_2+p_3 \ln(x)]}},$$

$$x = M_{jj}/\sqrt{s}$$

- Consistent with SM

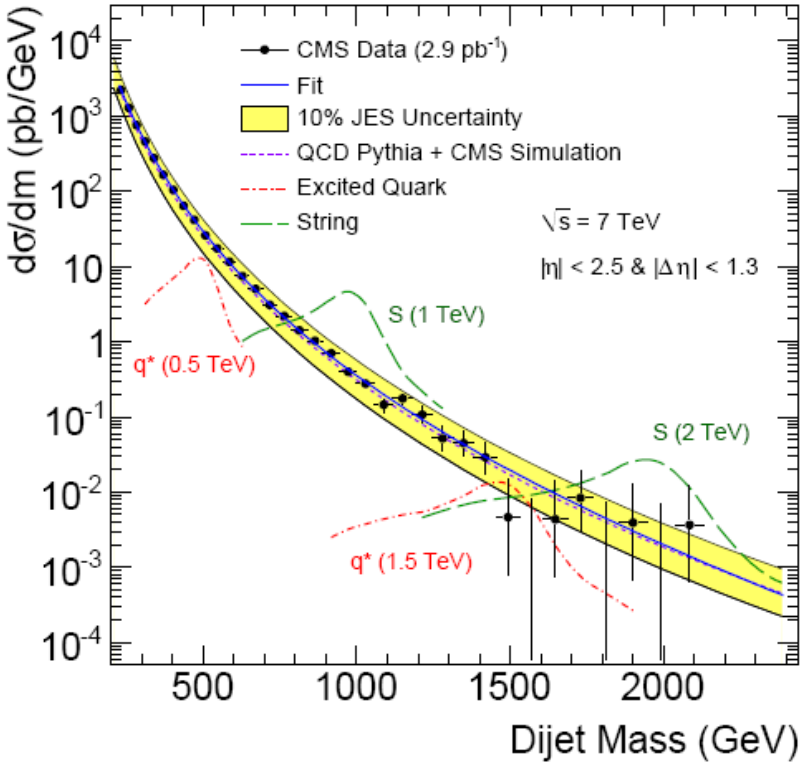


2.9 pb^{-1}

Search for Dijet Resonance

- Anti kT algorithm with R=0.7
- Jet selection
  - $|\eta| < 2.5$
  - $|\Delta\eta| < 1.3$
  - $M_{jj} > 220$ GeV

Analysis is similar to that in ATLAS



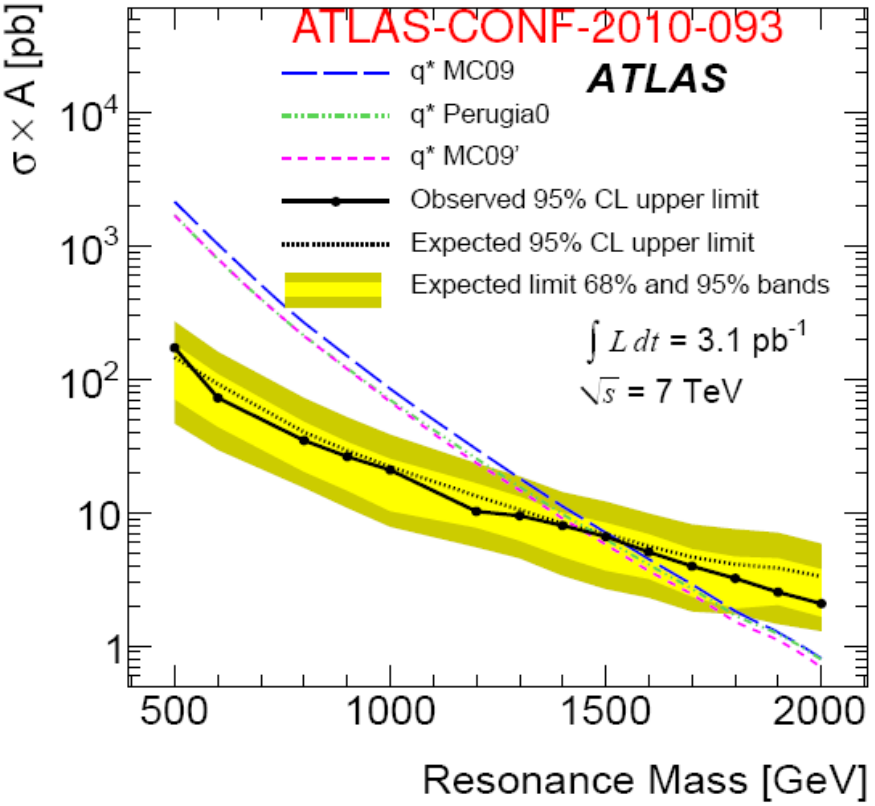
3.1 pb^{-1}

2.9 pb^{-1}

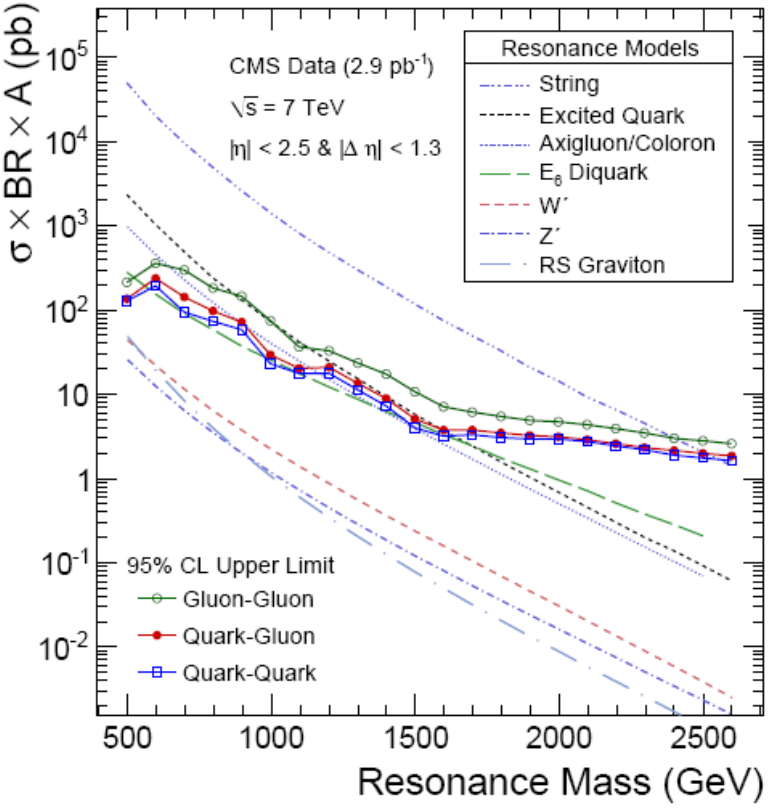
Limit on q*

- Lower limit
  - m_{q^*} > 1.53 TeV

cf, CDF : m_{q^*} > 870 GeV



- Lower limit on cross sections for three processes are given
- m_{q^*} > 1.58 TeV

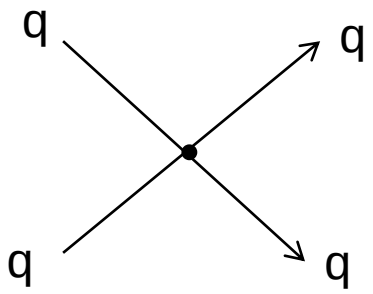


d the Standard Mo
table Observables

Dijet Non-Resonance

- Angular distribution of dijet events are modified by some new physics models without making resonance.

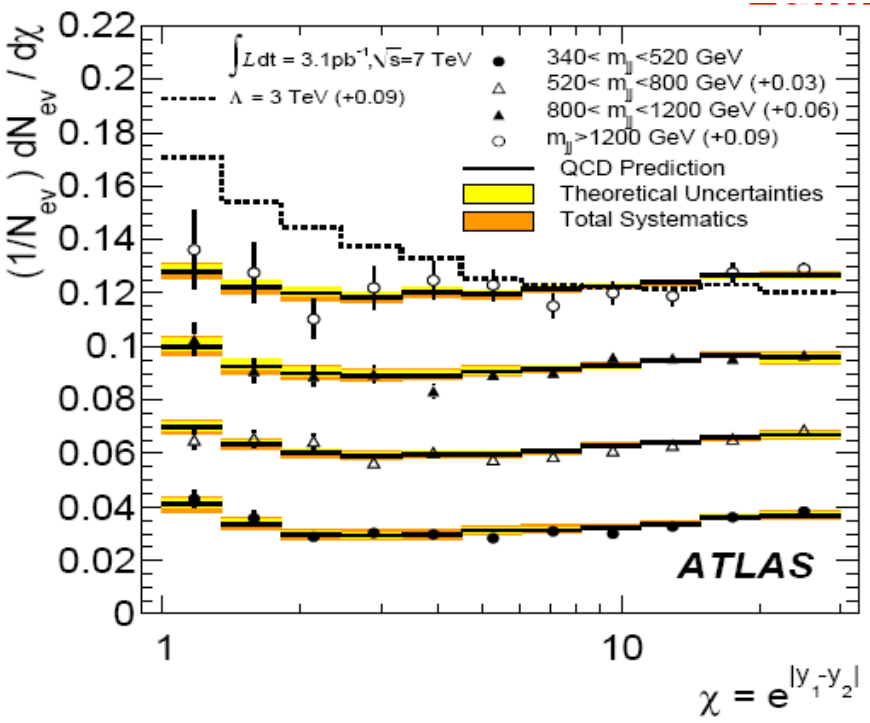
- Benchmark model : Quark contact interaction
  - Compositeness scale Λ
    - $L_{eff} = (\pm 2\pi/\Lambda^2)(\bar{q}_L \gamma^\mu q_L)(\bar{q}_L \gamma_\mu q_L)$
  - D0 set the lower limit $\Lambda > 2.4$ TeV



3.1 pb^{-1}

Search for Contact interaction

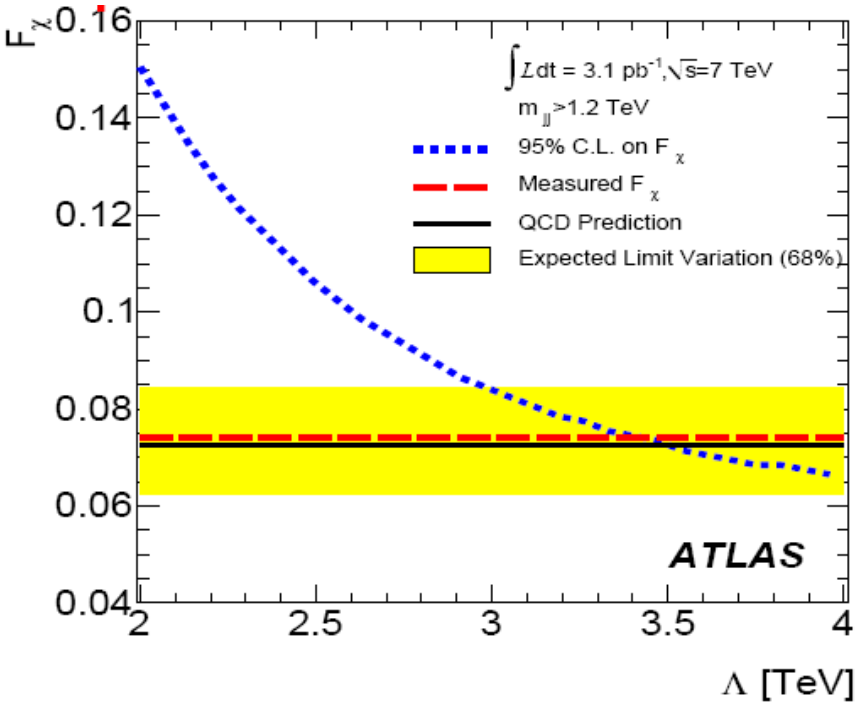
- Event selection
  - Anti-Kt jet algorithm with R=0.6
  - $E_T^1 > 60$ GeV, $E_T^2 > 30$ GeV
  - $|\eta| < 2.8$
  - $|\eta_1 + \eta_2| < 1.5$
- Observable
  - $\chi = \exp(\eta_1 - \eta_2)$
  - Almost flat distribution for QCD while excess at low χ for new physics signal.
    - Signal : mainly s-channel
    - QCD background : t-channel
- Data agree with SM prediction



3.1 pb^{-1}

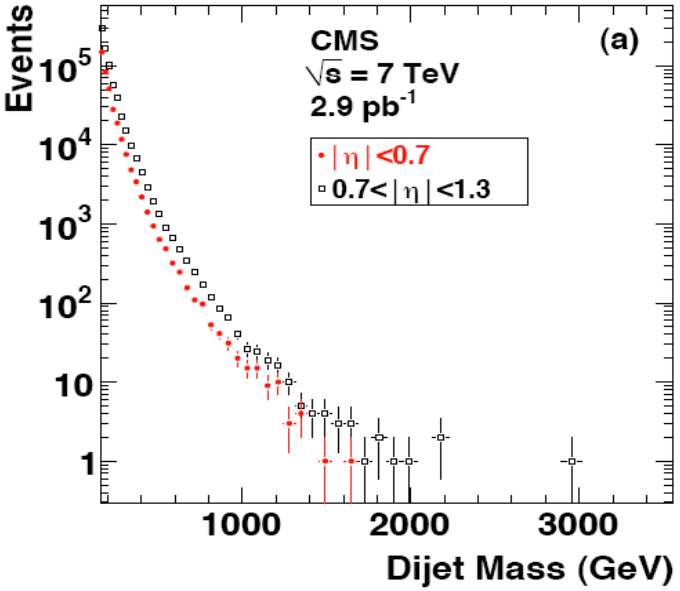
Limit on Λ with F_χ

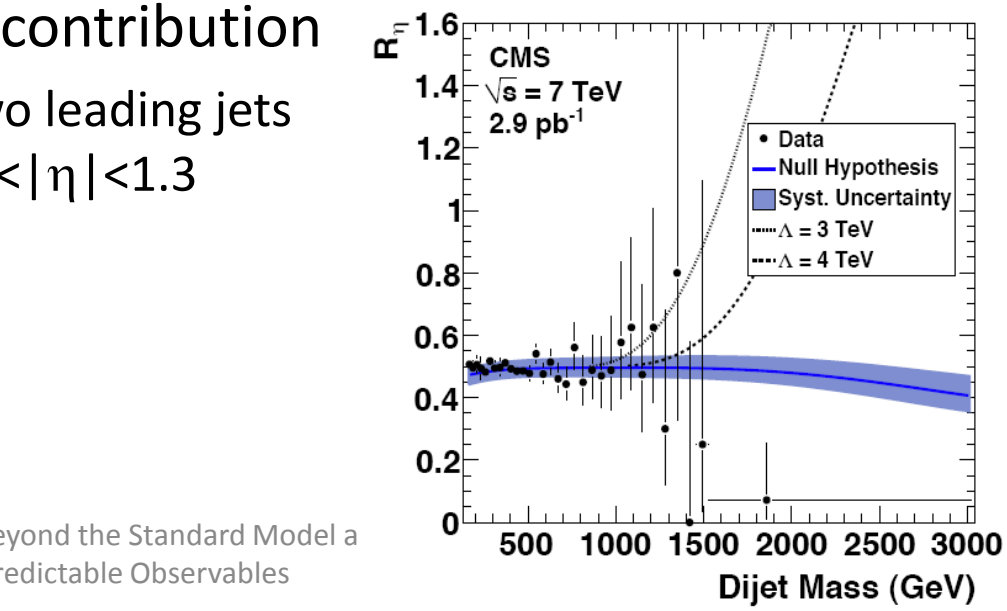
- Define F_χ to set limit
  - Ratio of the entries in first four χ bins to those in all bins
- Exclude the compositeness scale $\Lambda > 3.4$TeV which corresponds to a distance of 6×10^{-5} fm
  - *cf.* D0 : $\Lambda > 2.4$ TeV



Search for Contact Interaction

- Event Selection
  - Anti kT jet algorithm with R=0.7
  - Jet E_T depending on datasets (triggers)
    - 15, 30, 50GeV
  - $|\eta| < 1.3$
  - $M_{jj} > 156$ GeV
- Define R_η to evaluate CI contribution
  - Ratio of # of events for two leading jets in $|\eta|<0.7$ to those in $0.7<|\eta|<1.3$





Limit on Λ

- Limit setting using Log Likelihood Ratio

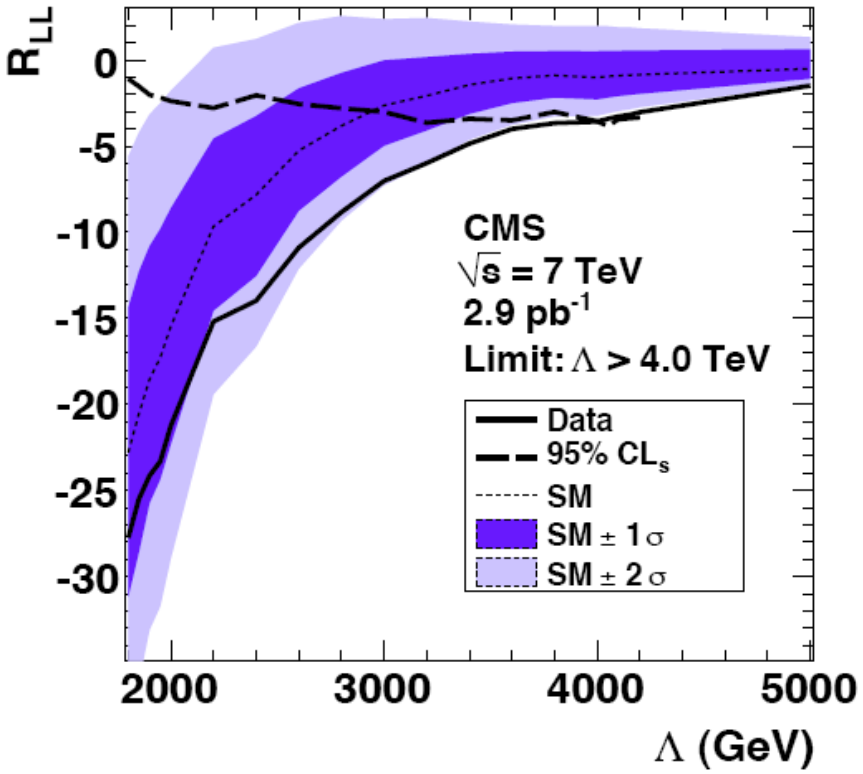
$$\mathcal{R}_{LL} = \ln \mathcal{L}_{\text{alt}} - \ln \mathcal{L}_{\text{QCD}}$$

  - Likelihood for each mass bin

$$\mathcal{L}_i = \mathcal{P}(n_{\text{tot},i}|\mu_{\text{tot},i})\mathcal{B}(n_{\text{in},i}|n_{\text{tot},i},\rho_i)$$

$$\rho_i\,(\rho = R_\eta/(1+R_\eta))$$

- Λ > 4.0TeV

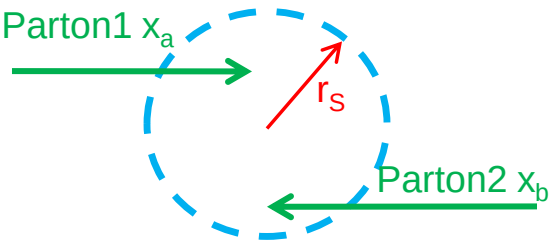


High E_T Multi Object

- Large Extra Dimension model predicts Black Hole or String Ball production at the LHC if gravity scale M_D is enough low.
- If impact parameter of partons is smaller than two times of Schwartzschild radius r_s, BH can be produced.

$$r_S = \frac{1}{\sqrt{\pi} M_D}\left[\frac{M_{\mathrm{BH}}}{M_D}\frac{8\Gamma\left(\frac{n+3}{2}\right)}{n+2}\right]^{\frac{1}{n+1}}$$

n : number of extra dimensions

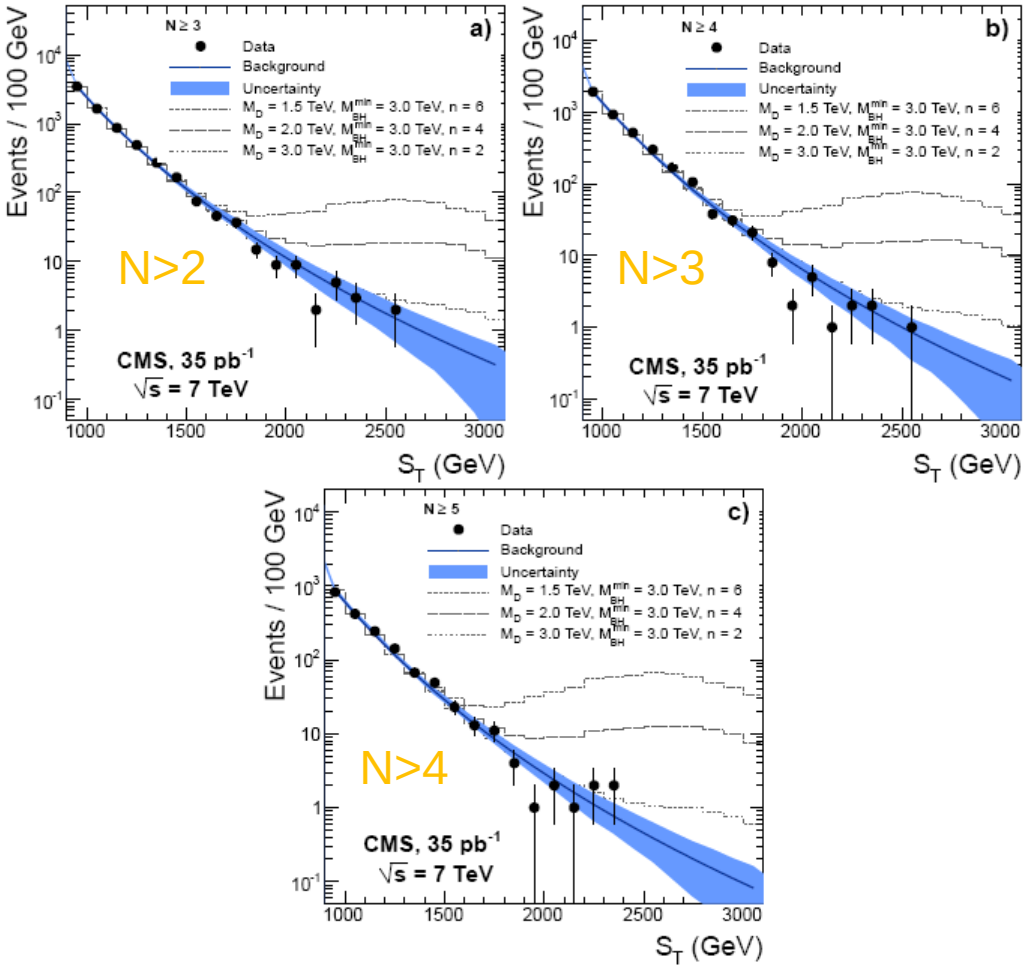


- Assumptions of Black Hole
  - High multiplicity decays
  - Democratic decay to all degrees of freedom in the SM
  - Conservations of charge, baryon number and lepton number

35 pb^{-1}

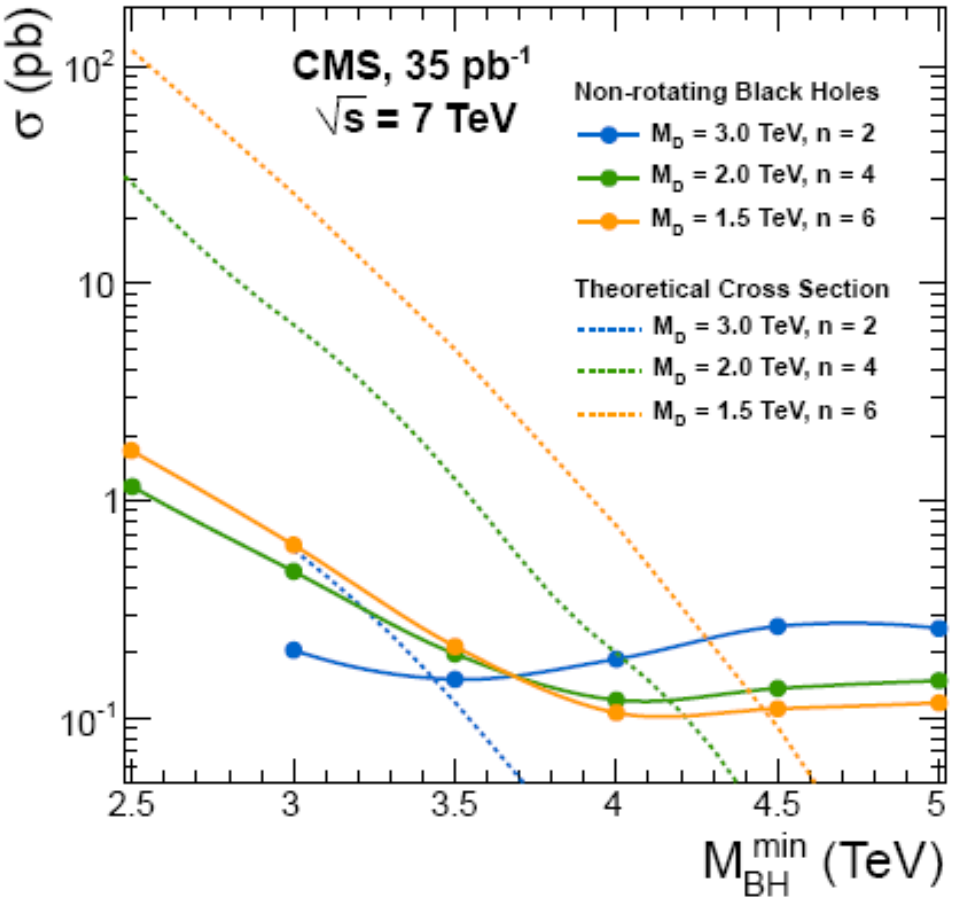
Search for Black Hole

- Selection
  - Jet : E_T > 20GeV, $|\eta|$<2.6
  - Electron or photon : E_T > 20GeV
  - Muon : p_T > 20GeV
- Observable
  - $S_T = \Sigma E_T$ + missing E_T
  - Number of objects with E_T>50GeV > 2



Limit on BH Mass

- Exclude BH mass < 3.5~4.5 TeV



Lepton + Missing E_T

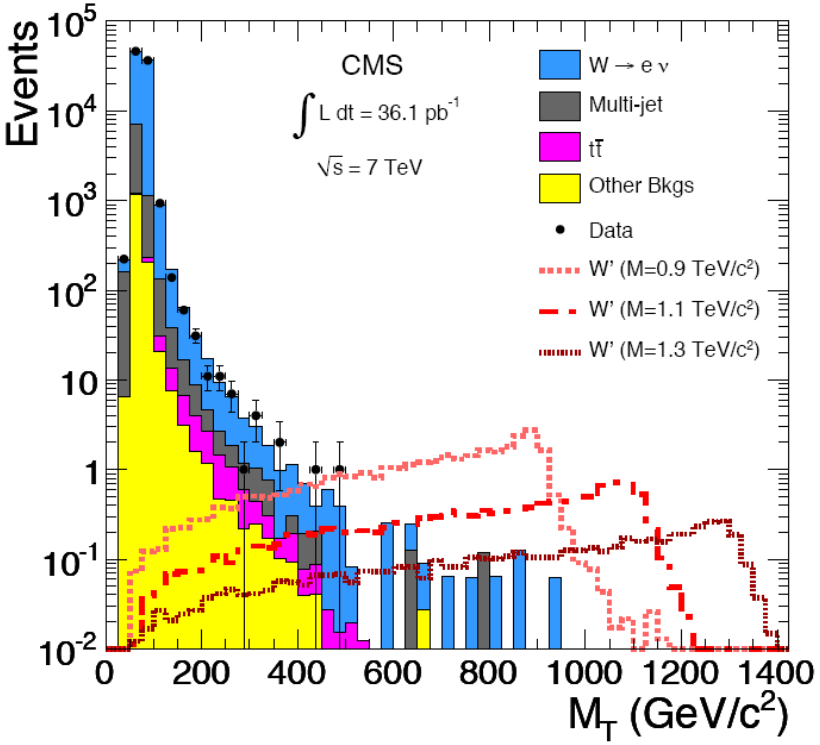
- W' appears in new SU(2) gauge group or in Extra dimension models as KK tower
- We assume property of W' is same as SM W except mass is heavier (so called sequential SM)
  - Leptonic decay is the best channel to search for W'
  - B(W' → eν) = 8.5% for $M_{W'} >> 180$GeV (W'→tb opened)
  - D0 : $M_{W'} > 1.1$TeV

35 pb^{-1}

Search for W'

- Electron channel
- Selection
  - Electron E_T > 30GeV
  - Electron and neutrino tend to be balanced
    - $0.4 < E_T^{ele}/E_T^{miss} < 1.5$
    - $\Delta\phi_{ele\text{-}miss} < 2.5$
- Observable
  - Transverse mass

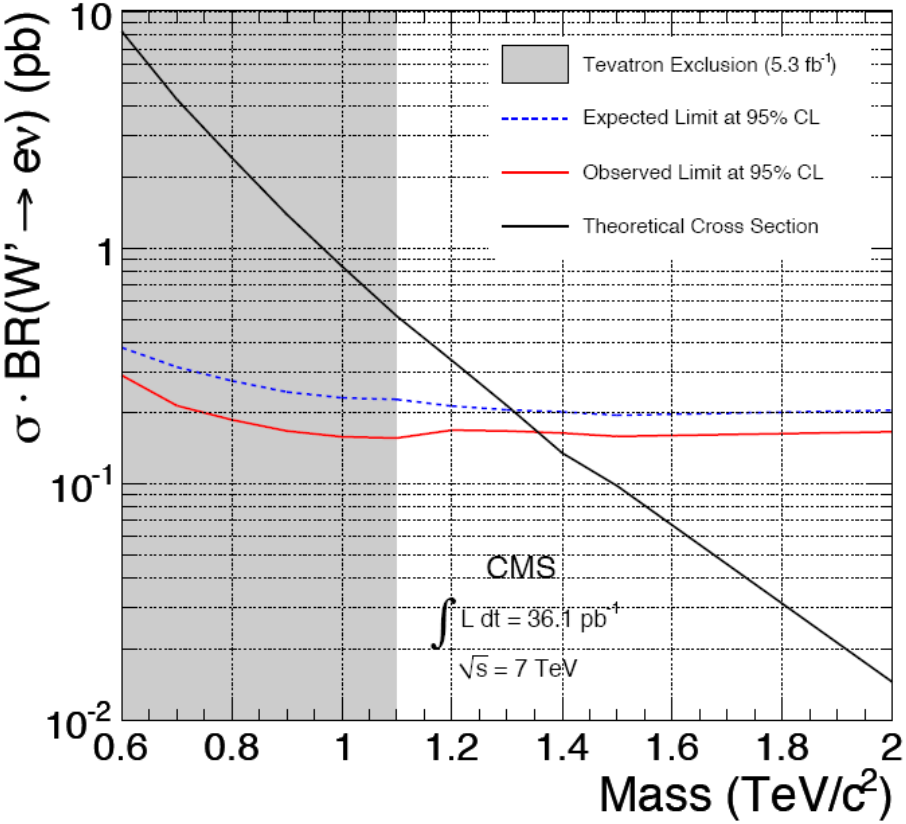
$$M_T = \sqrt{2 \cdot E_T^{ele} \cdot E_T^{miss} \cdot (1 - \cos \Delta\phi_{eE_T^{miss}})}$$



35 pb^{-1}

Limit on W’

- $m_{W'} > 1.36$TeV
  - *cf.* D0 1.1TeV in muon channel



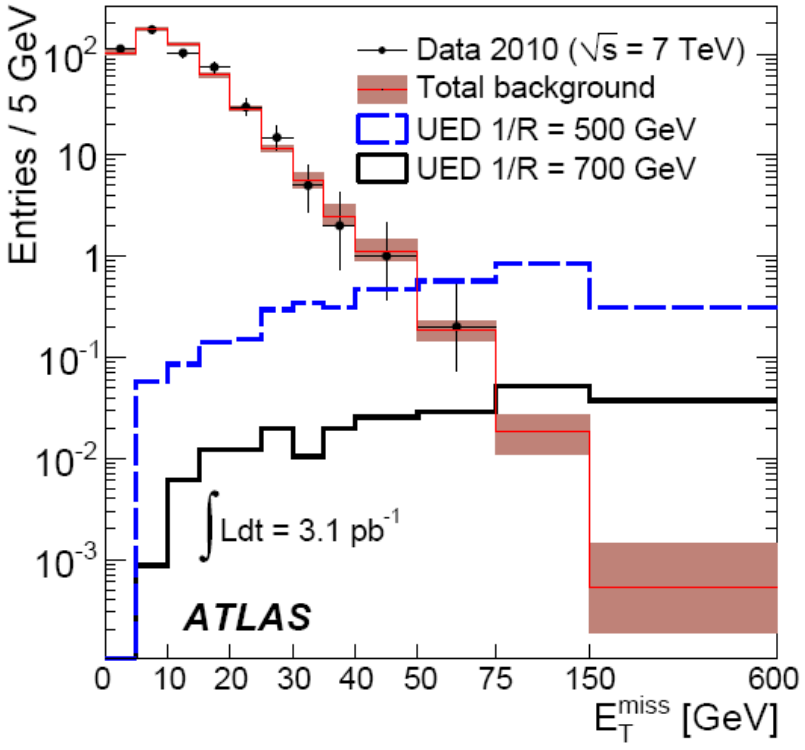
Diphoton + Missing E_T

- Universal Extra Dimension + Large Extra Dimension
  - One additional RS type space dimension with compactification radius R where all SM particles can propagate → KK towers of SM particles
    - Lightest KK particle is KK photon $\gamma^{(1)}$
    - The mass difference of the successive towers are ~ 1/R
    - Bear masses of KK particles in the same level degenerate but radiative correction split the masses which is charactarized with UV cut off scale Λ
    - pair production of KK gluon at LHC
  - The 5-dim UED is embedded on N dimensional LED where only gravity can propagate.
    - KK photon can decay into graviton via gravitational coupling
    - $\gamma^{(1)} \rightarrow \gamma + G$
- Assumption
  - $\Lambda R = 20$

3.1 pb^{-1}

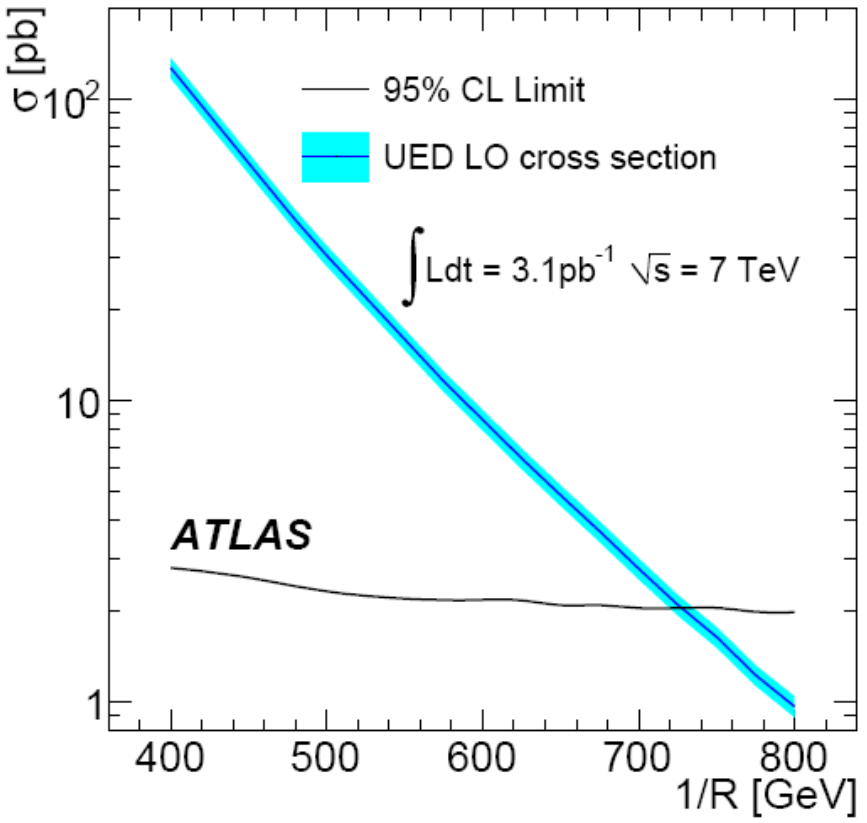
Search for UED+LED

- Selection
  - Photon : $|\eta| < 1.81$, $E_T > 25$GeV
  - Calo objects for Missing E_T calculation : $|\eta| < 4.5$
- Observable
  - Missing E_T



Limit on R

- 1/R < 728GeV
  - *cf*. D0 < 477GeV



Particles Stopped inside Detector

- Long lived charged heavy particles can stop inside detector if momentum is low, and then decays seconds, hours or days later
- Benchmark model
  - Long lived gluino in Split SUSY
    - large gluino-squarks mass splitting
  - forms R-hadron ($g\tilde{}q\bar{q}$, $g\tilde{}qqq$, $g\tilde{}\bar{q}\bar{q}\bar{q}$, $g\tilde{}g$)
  - Assumption

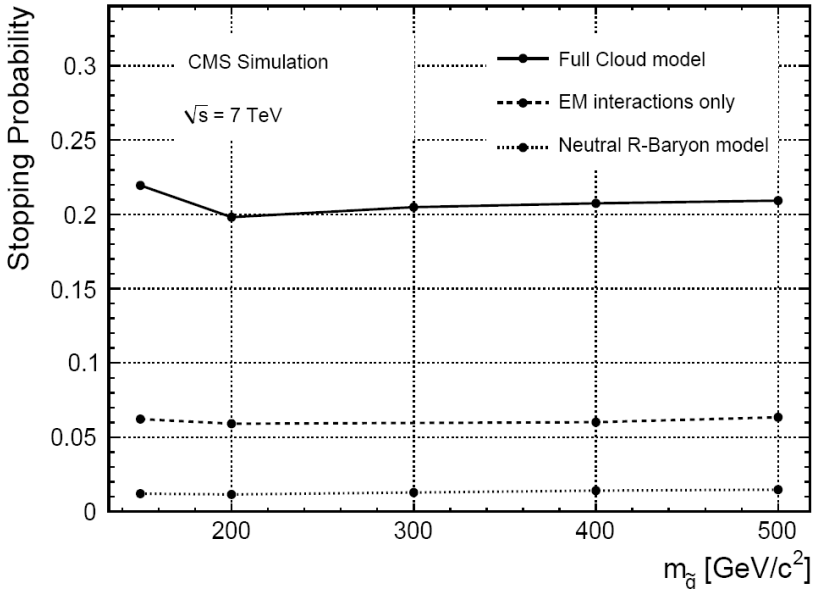
$$\mathrm{BR}(\tilde{g} \rightarrow g\tilde{\chi}_1^0) = 100\%$$

    - No three body decays propagated by squarks

10 pb^{-1}

Search for R-Hadron

- Stopping probability
  - 20% for “could model”
  - R-Hadron interacts with matter
    - exchange gluon
    - annihilate with anti-quark in the R-hadron
    - Charge exchange
- Search late decays in empty bunches or after LHC beam dump.
  - Special triggers are prepared
  - Number of empty bunches
    - 3600(bucket)-400(filled, at most)=2200
- Selection
  - HCal Jet $|\eta| < 1.3$
  - Jet $E_T > 50$GeV
  - Hcal pulse shape consistent with signal
  - Cosmic veto

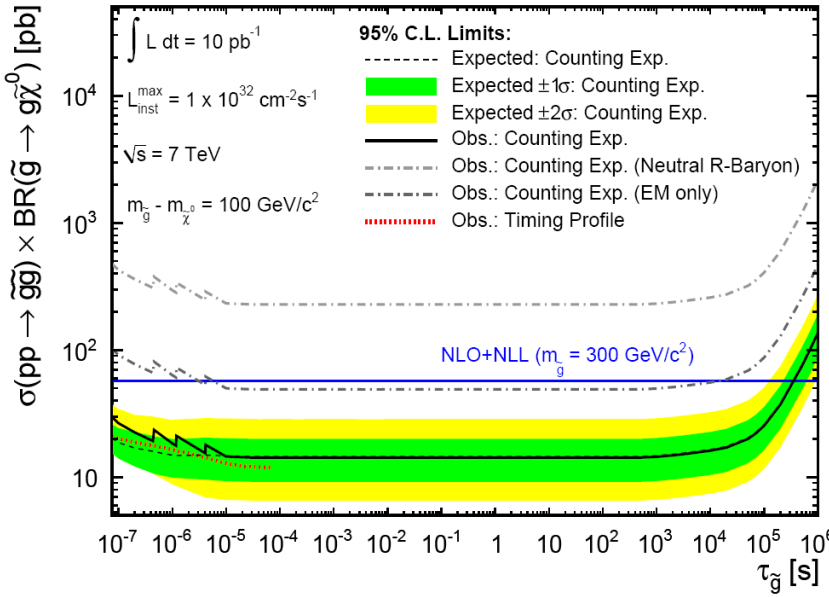


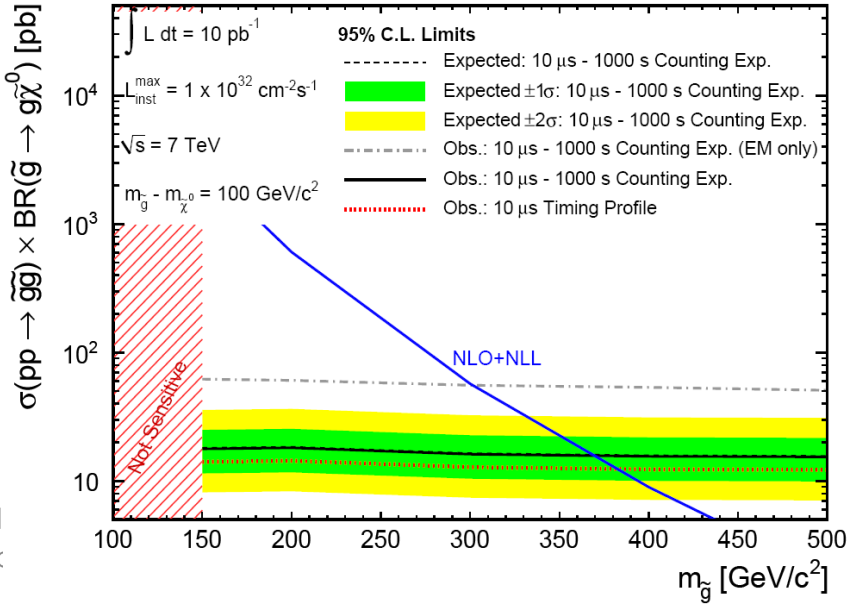
10 pb^{-1}

Limit on R-Hadron

- Observed events are consistent with background
- Set limit on cross section as a function of lifetime for 300GeV gluino
  - $\sigma < 15$ pb for 10us $< \tau <$ 10ks
- Set limit on gluino mass
  - 370GeV

Lifetime [s]	Expected Background ($\pm$ stat. $\pm$ syst.)	Observed
1×10^{-7}	$0.8 \pm 0.2 \pm 0.2$	2
1×10^{-6}	$1.9 \pm 0.4 \pm 0.5$	3
1×10^{-5}	$4.9 \pm 1.0 \pm 1.3$	5
1×10^{6}	$4.9 \pm 1.0 \pm 1.3$	5





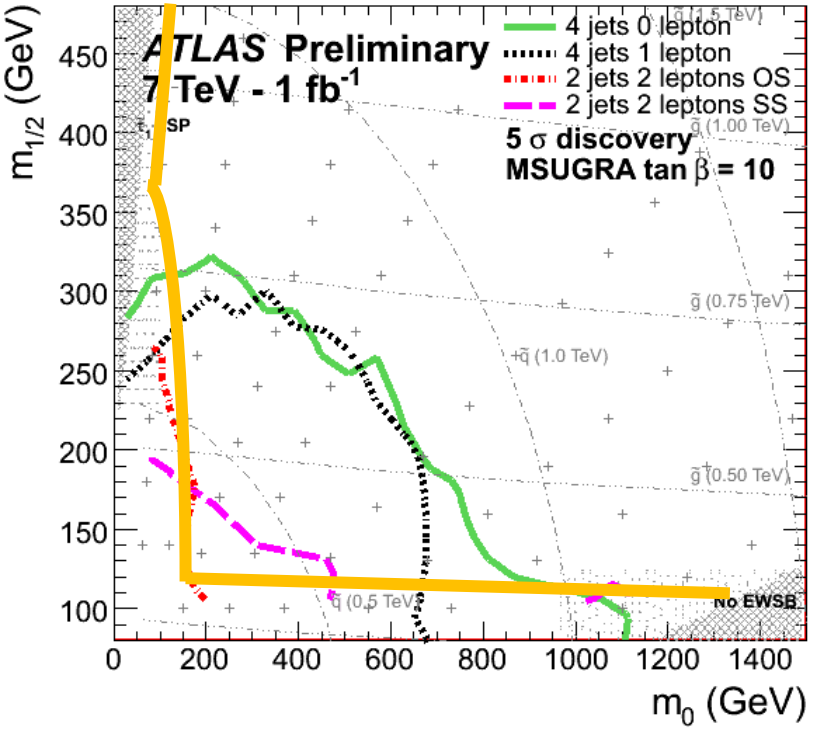
Future Prospect on SUSY

- (conference) Papers on search for SUSY with golden mode, jets + missing E_T, are not public yet by ATLAS nor CMS.
  - SUSY is one of the most promising new physics.
- So just show a future prospect and a preliminary figure

Discovery Potential of SUSY

- Assuming 1 fb^{-1} at 7TeV
- 4 jets + 0/1 missing ET are golden modes
  - Bulk region almost covered
  - Squark mass 750GeV can be excluded

DM $\Omega < 0.3$

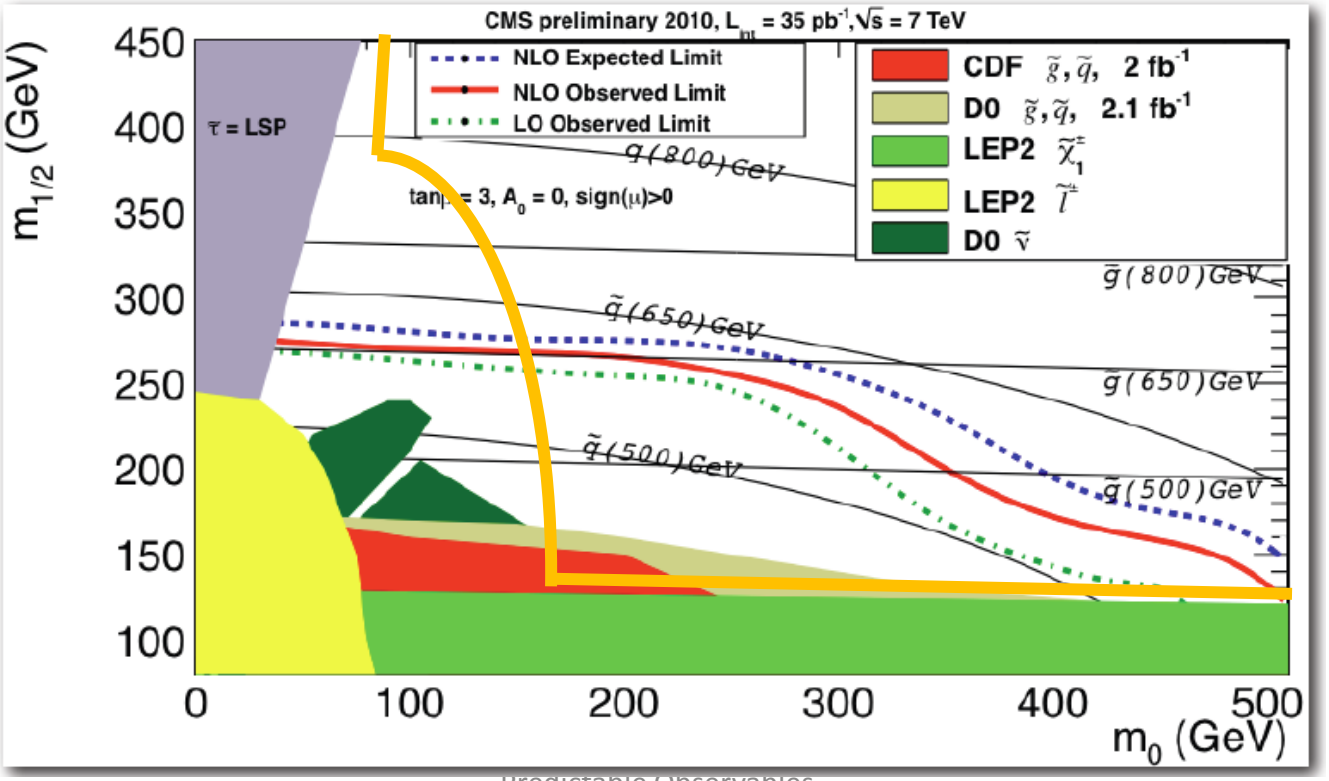


35 pb^{-1}

Preliminary Exclusion on SUSY

- Unfortunately, only this figure was presented at LHC Jamboree.
  - Details are not known but they will publish very soon (and ATLAS also…)
  - Half of bulk regions where χ~ DM does not overclose are excluded

DM $\Omega < 0.3$



Summary

- ATLAS and CMS are giving better limits on BSM physics than CDF and D0 only with 3~40pb^{-1} data
  - q*, string
  - Quark contact interaction
  - Black Hole
  - W'
  - UED+LED
  - R-handron
- New results will be presented at Winter conference.
  - SUSY : jets + n lepton + MET
  - Other new physics signatures
- Stay tuned !