Beyond Standard Model
Summary of searches at LHC
December 2012

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Where is the New Physics?
EXOTICA ?

Where is the New Physics?

First discovery!

What is the nature of Higgs particle?

We need to be looking for NEW stuff...

OUTLINE: BSM at LHC

Warsaw PL

Short introduction

- LHC performance and ATLAS & CMS data taking
- Background for New Physics (Beyond Standard Model) searches:
  - SM precise measurements
  - HIGGS BOSON DISCOVERY !
- Review of searches

Main part

  - Superymmetry
  - Exotica: exotic signals and/or exotic models, e.g.:
    - High mass resonances
    - Black-holes
    - Long-lived particles
    - LeptoQuarks, etc....

LHC Performance

Geneva, 17 December 2012. This morning CERN completed the first LHC proton run. The remarkable first three-year run of the world's most powerful particle accelerator was crowned by a new performance milestone. The **space between proton bunches** in the beams was **halved** to further increase beam intensity.

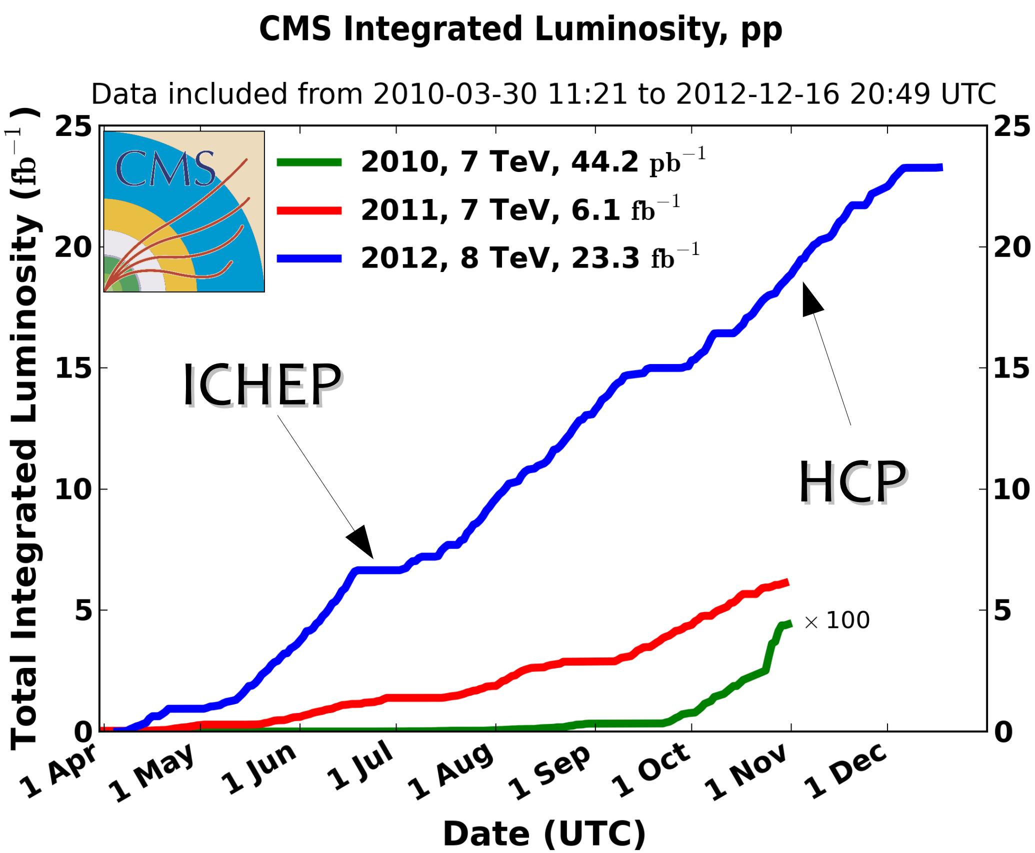
Parameter	2010	2011	2012	Nominal
N (10^{11} p/bunch)	1.2	1.5	1.6-1.7	1.15
k (no. bunches)	368	1380	1380/1374	2808
Bunch spacing (ns)	150	75 / 50	50	25
L ($cm^{-2}s^{-1}$)	2×10^{32}	3.5×10^{33}	7.6×10^{33}	10^{34}
Pile-up	3	19	35	23
Beam Energy (GeV)	**3.5**	**3.5**	**4**	**7**

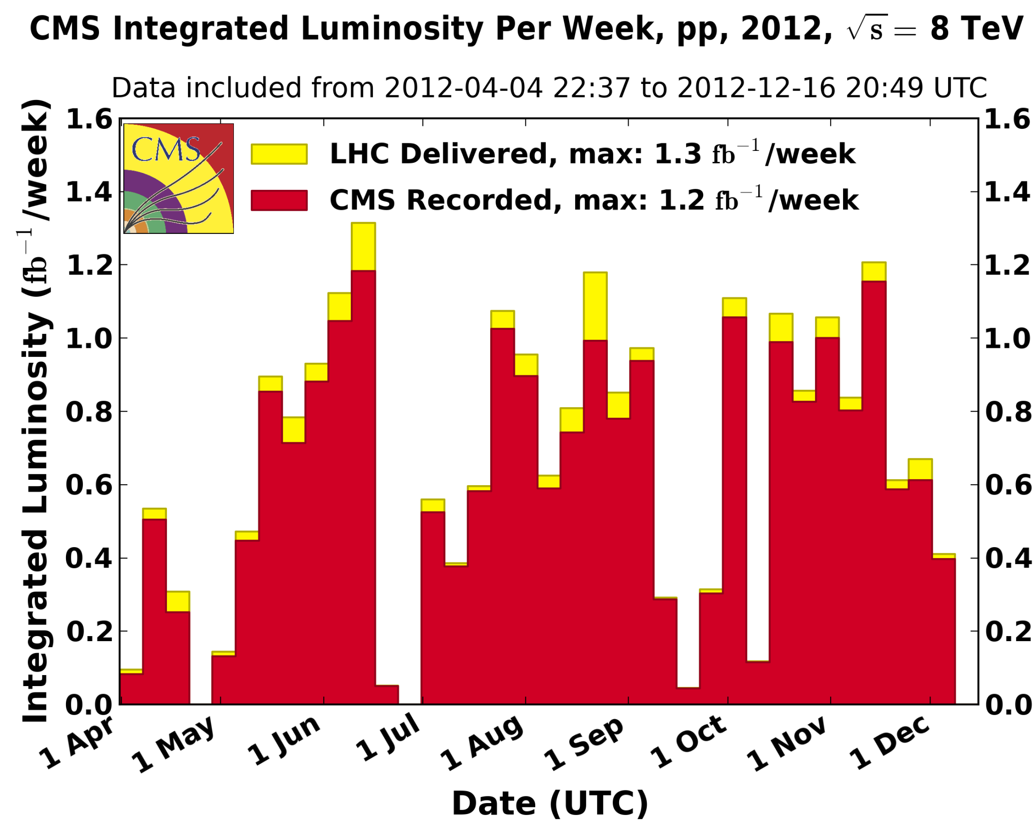
2015 – 6.5 GeV

CMS data taking

2012
- LHC Delivered 23.27 /fb
- CMS Recorded 21.79 /fb

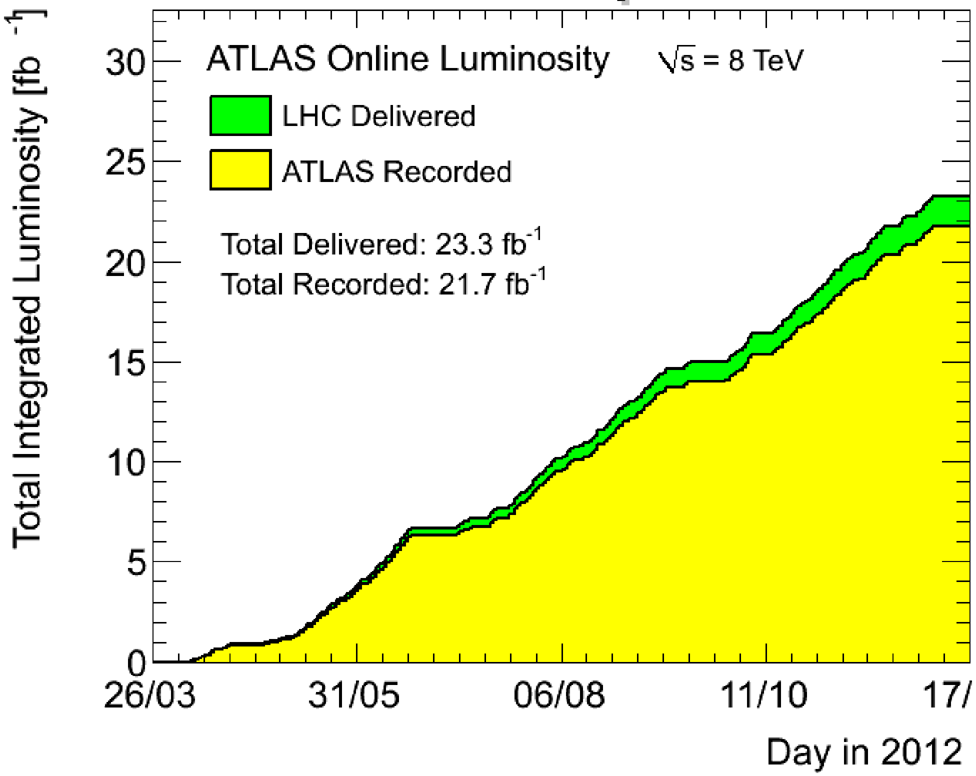
→ For analyses ~20/fb
Actually 5-13/fb used

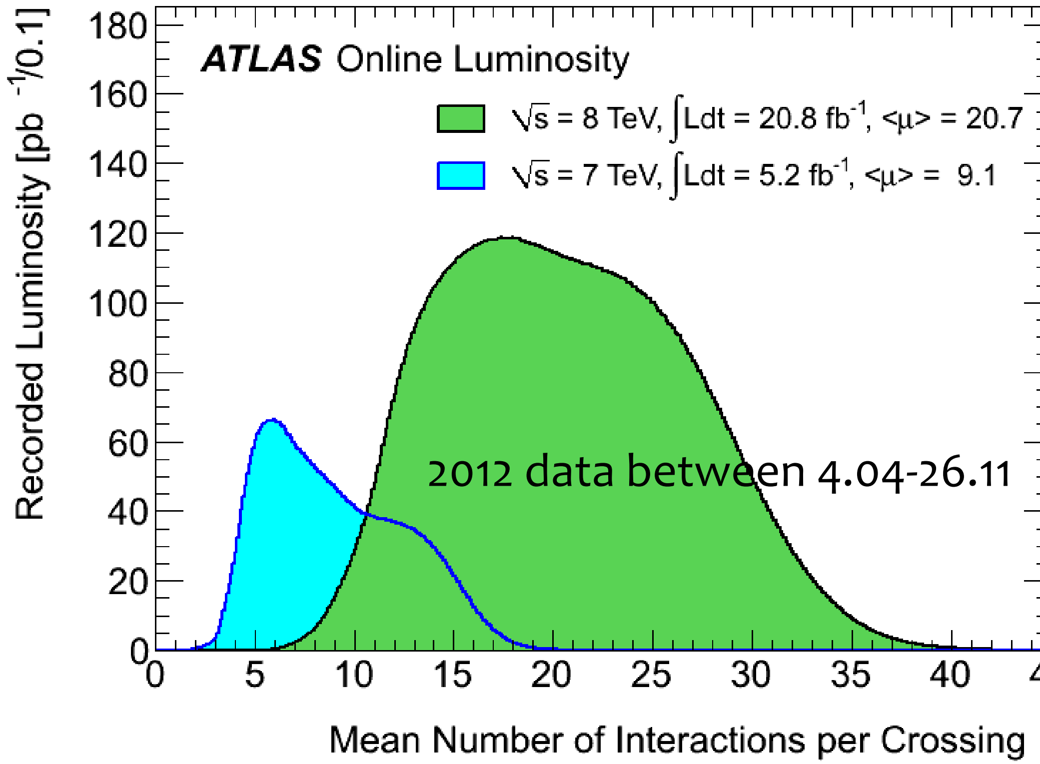




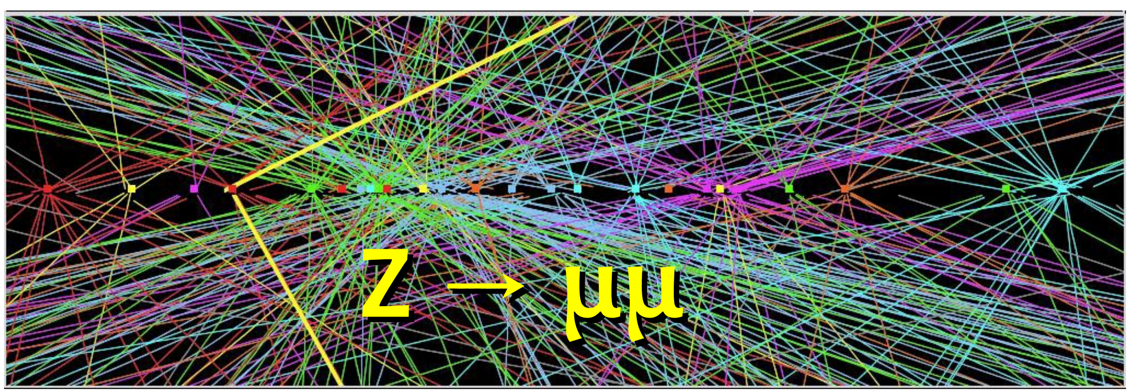
ATLAS data taking

- Even better performance – more good quality data



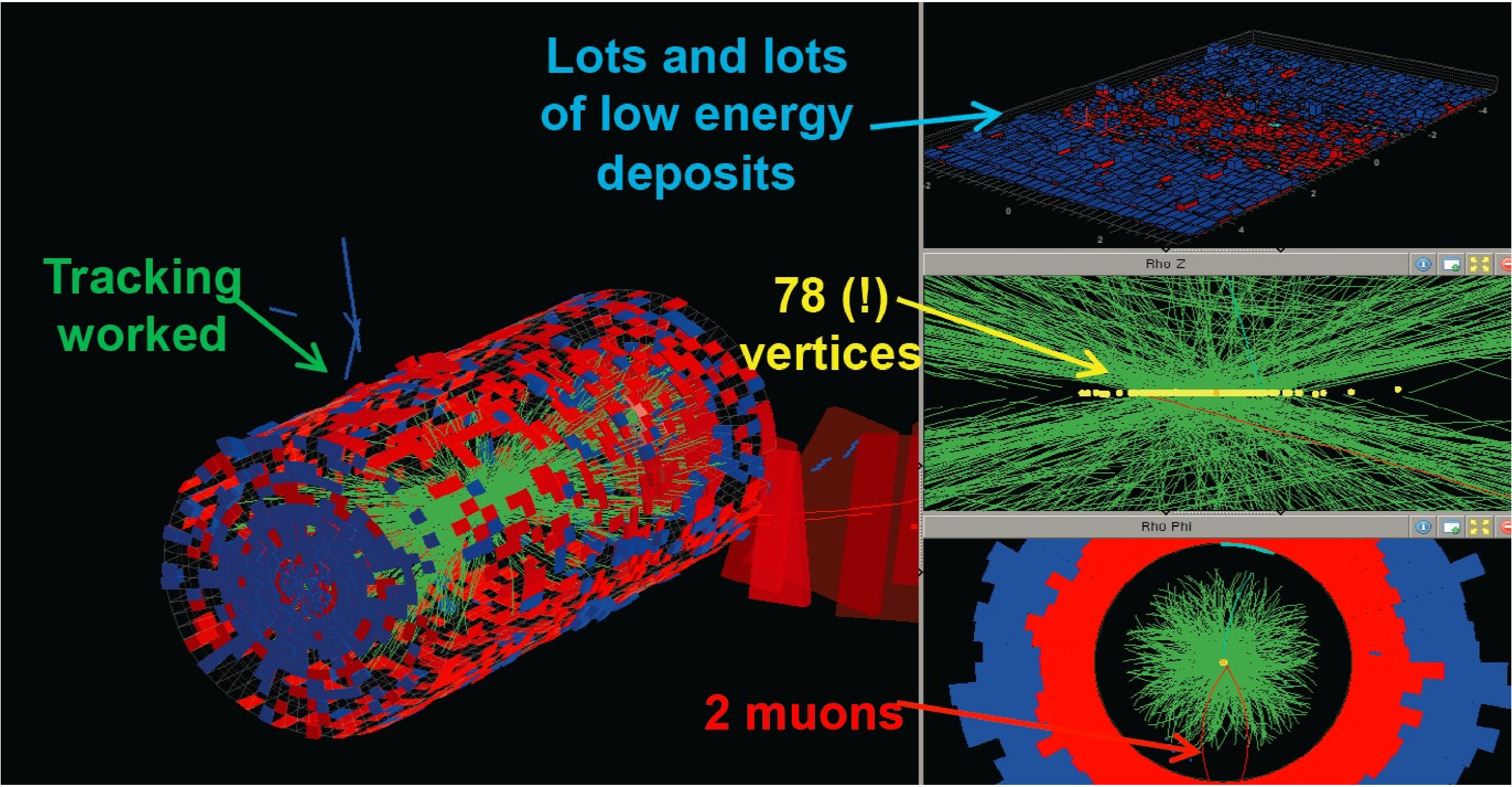


- High pile-up 2012
- ATLAS: $Z \rightarrow \mu\mu$ event with 25 reconstructed vertices



8TeV Pile-up – CMS curio

- Di-muon event with 78 vertices reconstructed



SM tested to per mil level

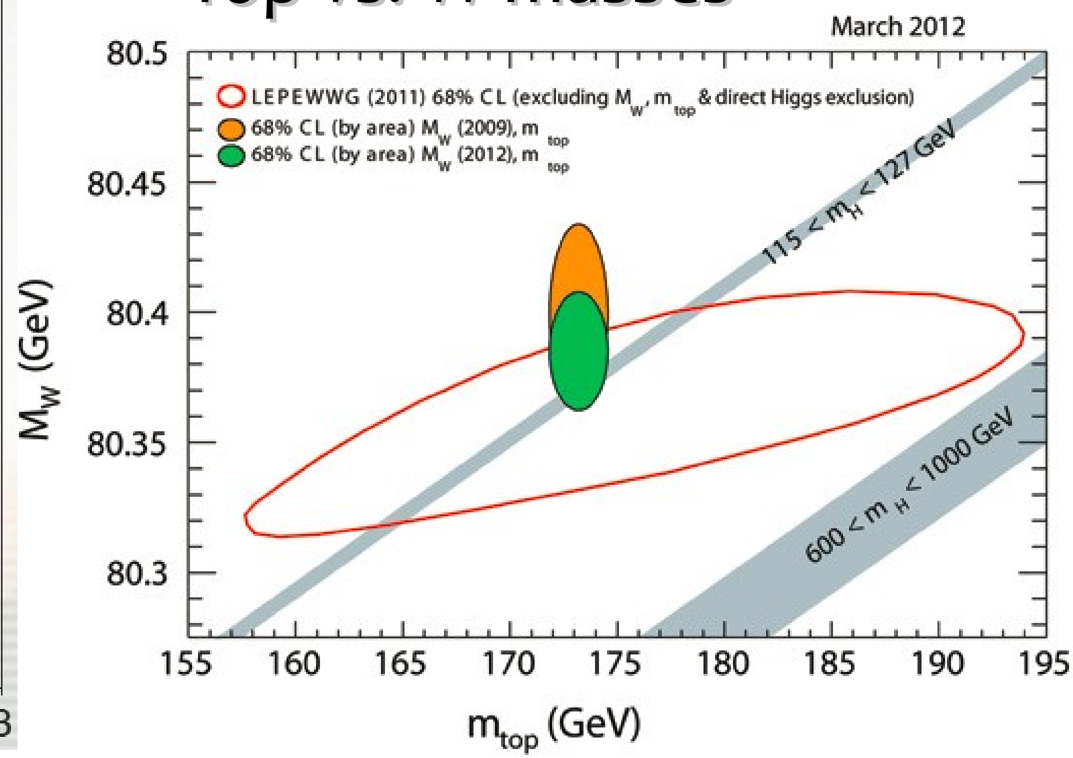
	Measurement	Fit
$\Delta\alpha_{had}^{(5)}(m_Z)$	0.02750 ± 0.00033	0.02759
m_Z [GeV]	91.1875 ± 0.0021	91.1874
Γ_Z [GeV]	2.4952 ± 0.0023	2.4959
σ_{had}^0 [nb]	41.540 ± 0.037	41.478
R_l	20.767 ± 0.025	20.742
$A_{fb}^{0,l}$	0.01714 ± 0.00095	0.01645
$A_l(P_\tau)$	0.1465 ± 0.0032	0.1481
R_b	0.21629 ± 0.00066	0.21579
R_c	0.1721 ± 0.0030	0.1723
$A_{fb}^{0,b}$	0.0992 ± 0.0016	0.1038
$A_{fb}^{0,c}$	0.0707 ± 0.0035	0.0742
A_b	0.923 ± 0.020	0.935
A_c	0.670 ± 0.027	0.668
A_l(SLD)	0.1513 ± 0.0021	0.1481
$\sin^2\theta_{eff}^{lept}(Q_{fb})$	0.2324 ± 0.0012	0.2314
m_W [GeV]	80.385 ± 0.015	80.377
Γ_W [GeV]	2.085 ± 0.042	2.092
m_t [GeV]	173.20 ± 0.90	173.26

$|O^{meas}-O^{fit}|/\sigma^{meas}$: 0 1 2 3

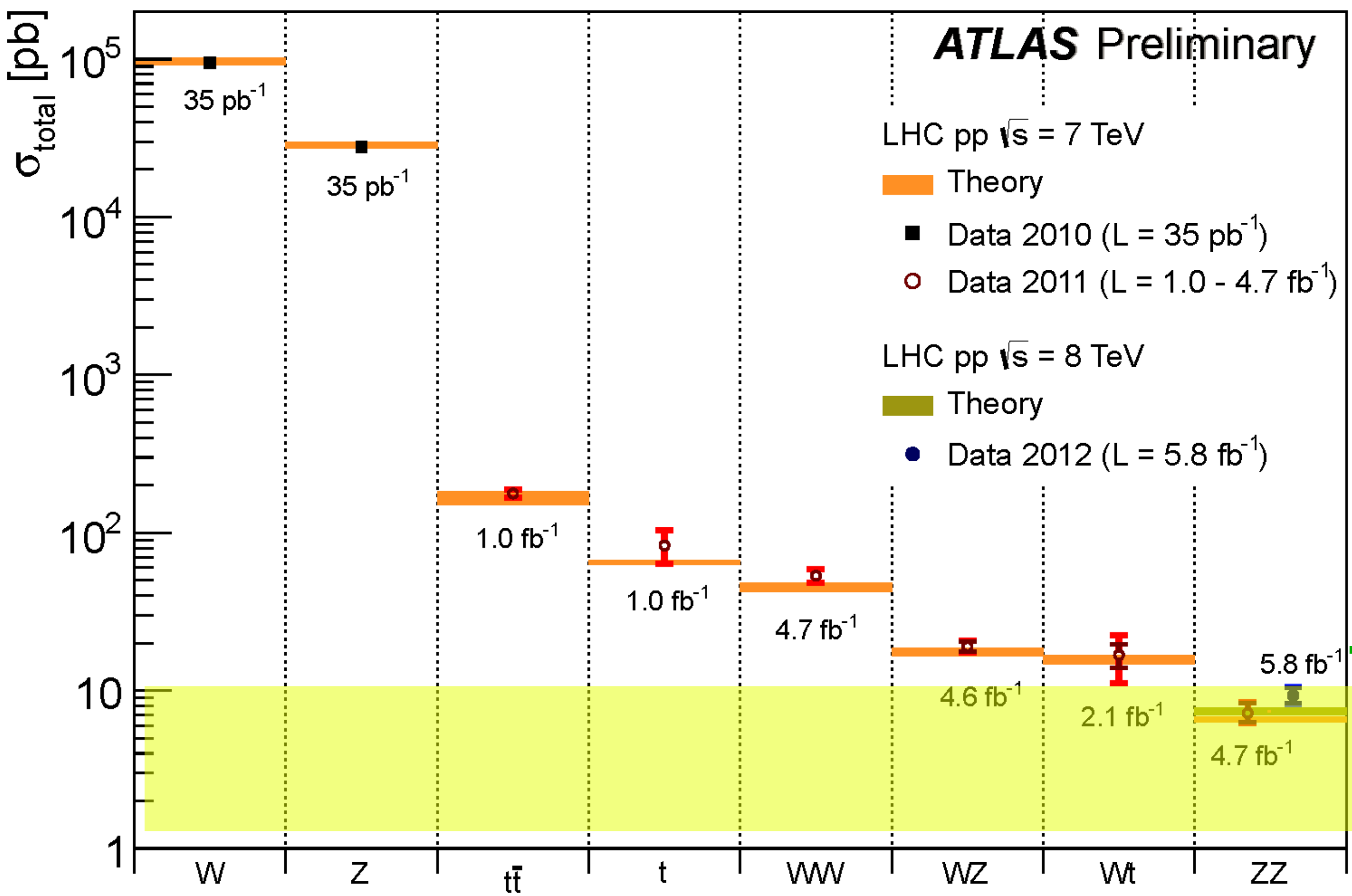
March 2012

- Precise measurements give hints to Higgs properties and shows windows to New Physics

Top vs. W masses



Standard Model



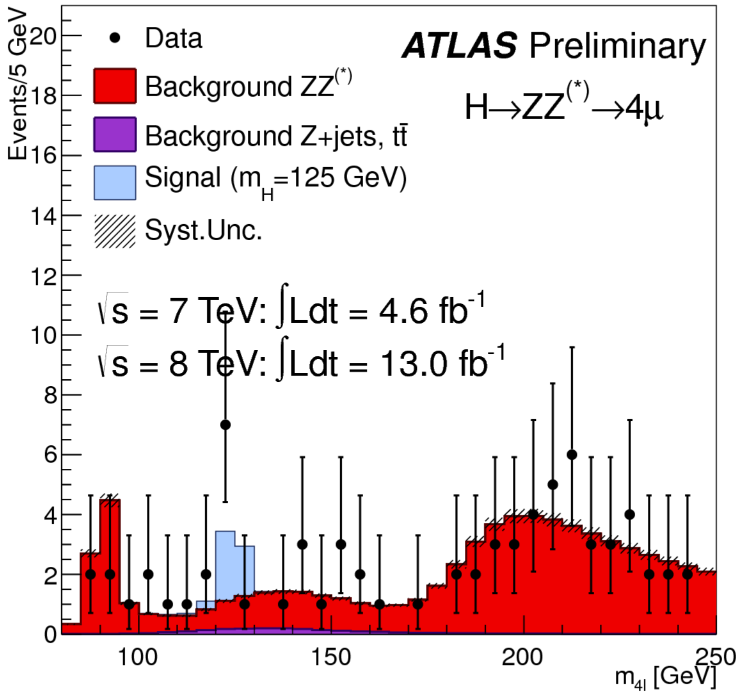
– Higgs
gluon-gluon fusion
(~125 σ~19/fb)

- New Physics: typical cross sections below 10 pb
- Low Mass SUSY had higher cross sections (excluded earlier)

Higgs discovery

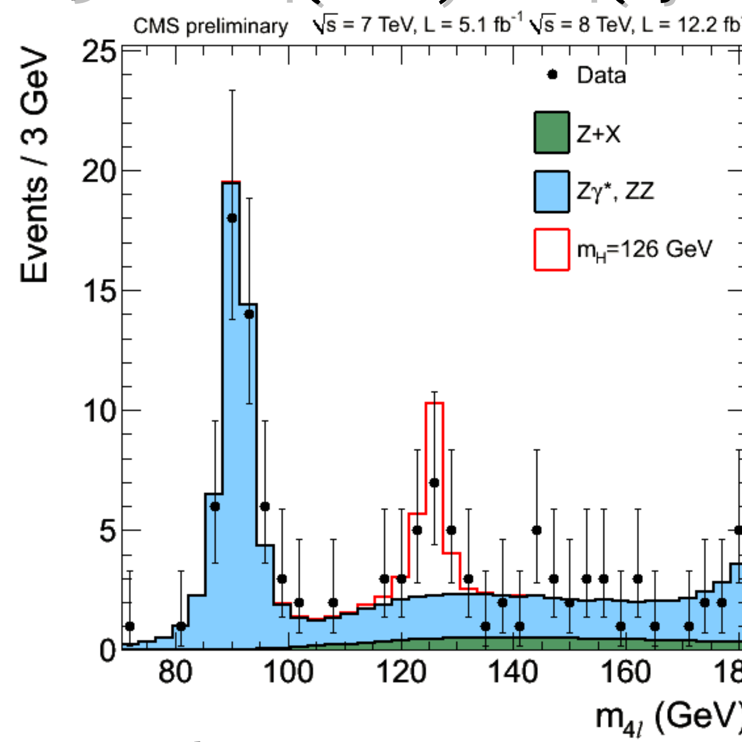
ATLAS average:

125.2±0.3(stat)±0.6(sys) GeV



CMS average:

125.8 ±0.4(stat) ±0.4(syst) GeV

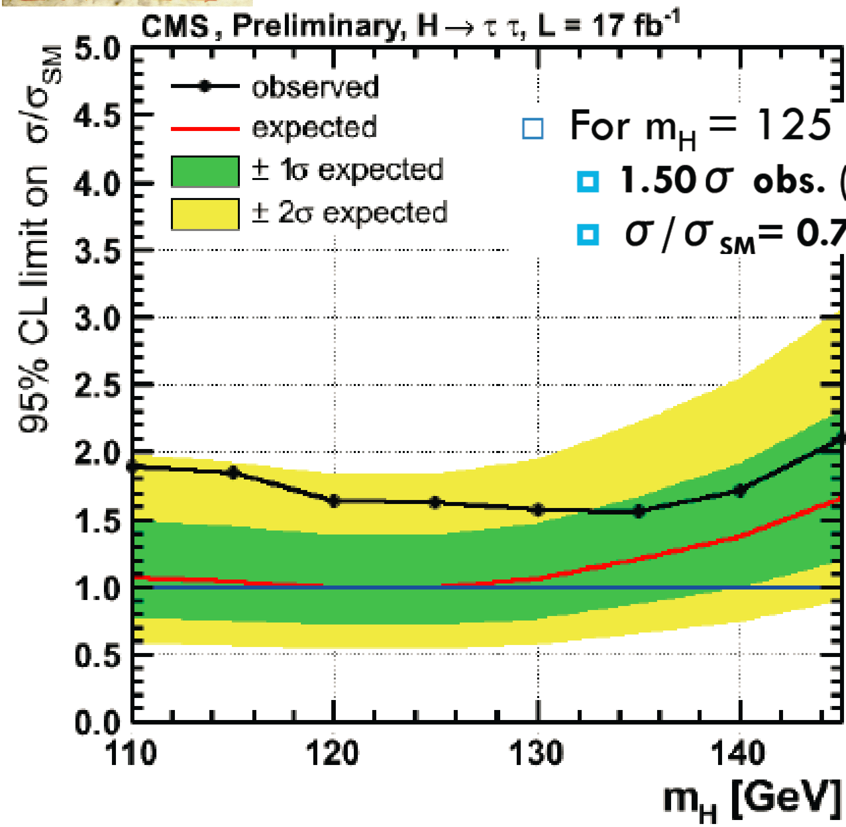


- The newly discovered particle is a boson with spin 0 or 2
  Spin 1 is ruled out by the Landau-Yang theorem, as it can't decay into two photons

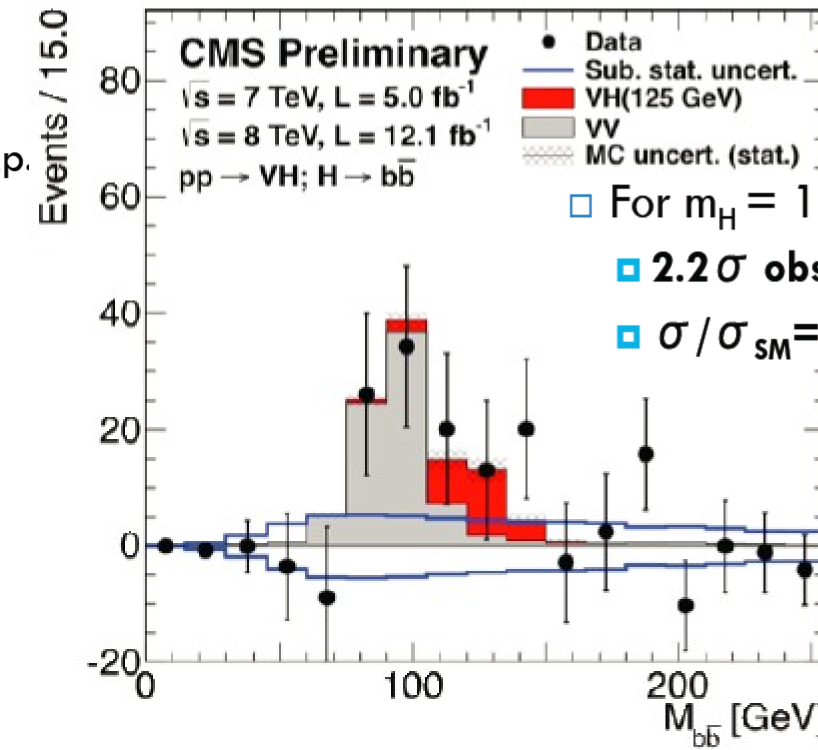
- The coupling structure has been confronted to the SM predictions. Overall very good agreement observed

- No evidence for non-standard higgs production or decay is found in several models (hint from b and tau channels)

Higgs discovery



- For m_H = 125 GeV:
  - **1.50 σ obs.** (2.45 σ exp.)
  - **σ / σ_{SM} = 0.7 ±0.5.**



- For m_H = 125 GeV:
  - **2.2 σ obs.** (2.2 σ exp.).
  - **σ / σ_{SM} = 0.7 ±0.5.**

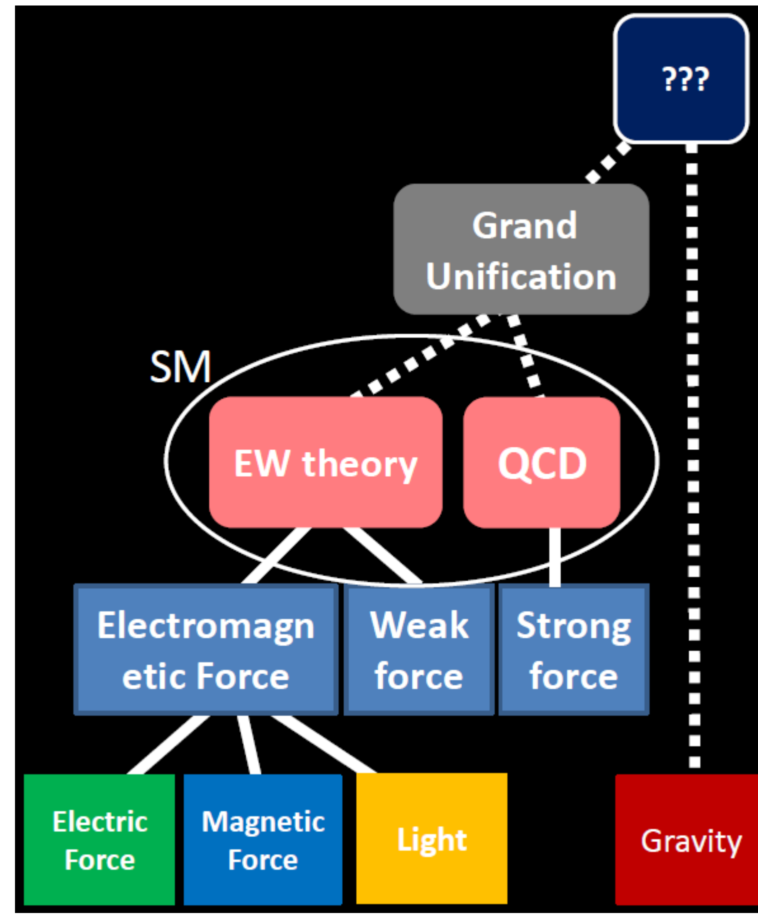
- The newly discovered particle is a boson with spin 0 or 2
  Spin 1 is ruled out by the Landau-Yang theorem, as it can't decay into two photons
- The coupling structure has been confronted to the SM predictions. Overall very good agreement observed
- No evidence for non-standard higgs production or decay is found in several models (hint from b and tau channels)

We still have a lot of questions

- SM is a successful theory!

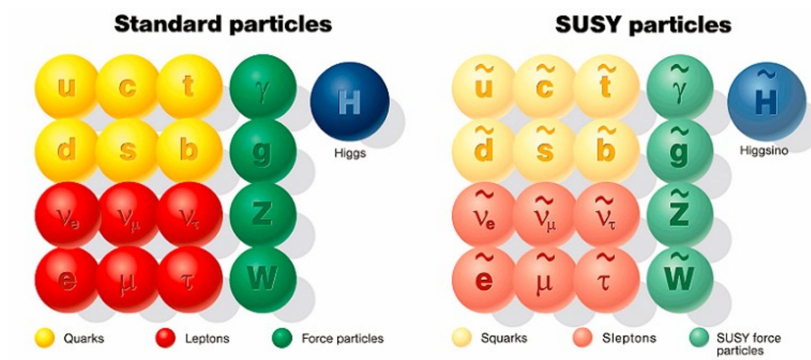
  BUT:

- What is the Dark Matter?
- Why the Higgs boson is so much lighter than the Planck mass? (hierarchy problem)
  - Do fermions have spin-integer partners?
  - Maybe Higgs partners are around corner?
- Why gravity is so weak?
- ...



Attractive SUperSYmmetry

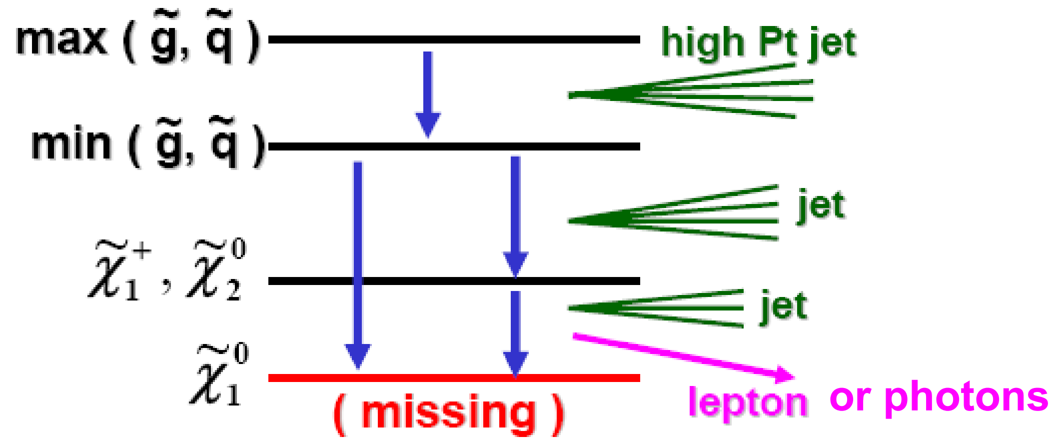
- SUSY provides a solution to the Higgs mass hierarchy problem
  - SUSY contribution cancels SM divergence in mh radiative corrections
- SUSY allows unification of gauge couplings



  - In SM, the couplings "run" but do not cross each other at the same energy while in SUSY they do
- SUSY can predict a Dark Matter candidate
  - R-parity conservation: Lightest SUSY Particle can be the WIMP

Signatures of SUSY

- **PRODUCTION of SUSY event at the LHC:**



- **MAIN SIGNATURE:**

  large MET + multi-jets + (multi-leptons or photons)

- **MAIN BACKGROUND:**

  QCD, ttbar/W/Z associated with jets

- **Basic search CHANNELS:**

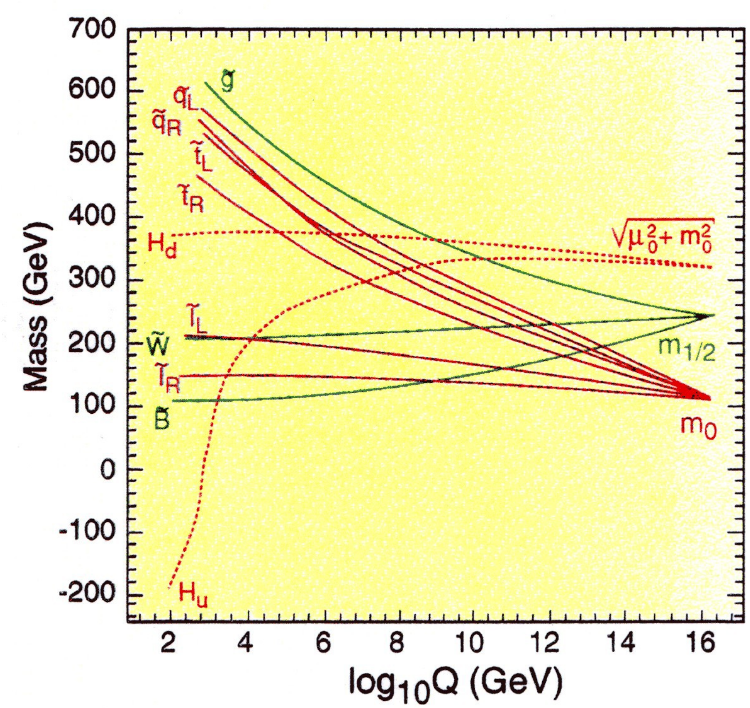
0-leptons	1-lepton	OSDL	SSDL	≥3 leptons	2-photons	γ+lepton
Jets + MET	Single lepton + Jets + MET	Opposite-sign di-lepton + jets + MET	Same-sign di-lepton + jets + MET	Multi-lepton	Di-photon + jet + MET	Photon + lepton + MET

SUSY Analysis

- **Event selection cuts and definition of signal regions:**
  - Cut in a set of variables that can discriminate between signal and backgrounds
- **Background determination:**
  - QCD and fake backgrounds: estimate from data
  - top, W/Z+jets: estimate from data when possible or with transfer factors using background enhanced control regions
  - Smaller irreducible background using MC
- **Estimate all uncertainties:**
  - Experimental uncertainties: jet energy scale calibration, b-tagging eff….
  - Theoretical uncertainties: renormalisation and factorisation scales, PDF….
- **Look into the signal region: Excess in data?**
  - If not, derive exclusion limits
- **Interpretation**

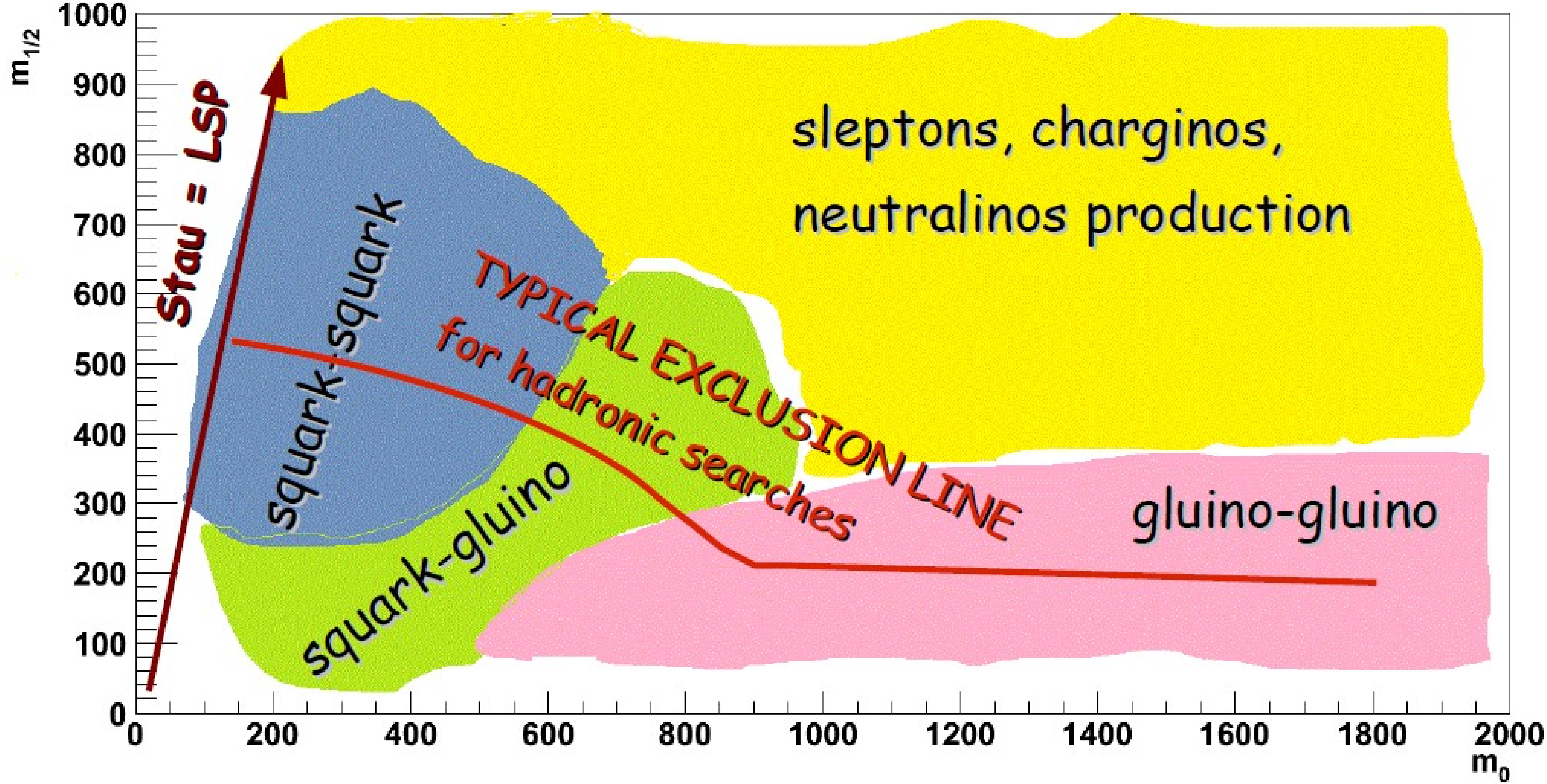
Popular framework for SUSY
BEGINNING

- MSSM: the most popular Minimal Supersymmetric extension of the Standard Model
  - too many free parameters...
- assuming simple scenario of SUSY breaking:
  - Constrained MSSM
  - [m_0 ,$m_{1/2}$,Ao ,tanβ ,signμ]
  - Typically:
    - gluino mass = ~2.7 $m_{1/2}$
    - squark mass = √(~6 $m^2_{1/2}$ + m^2_0)



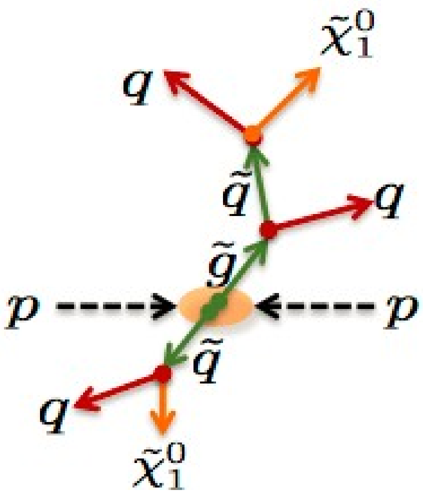
Anatomy of CMSSM

- Dominant processes of SUSY events production at LHC



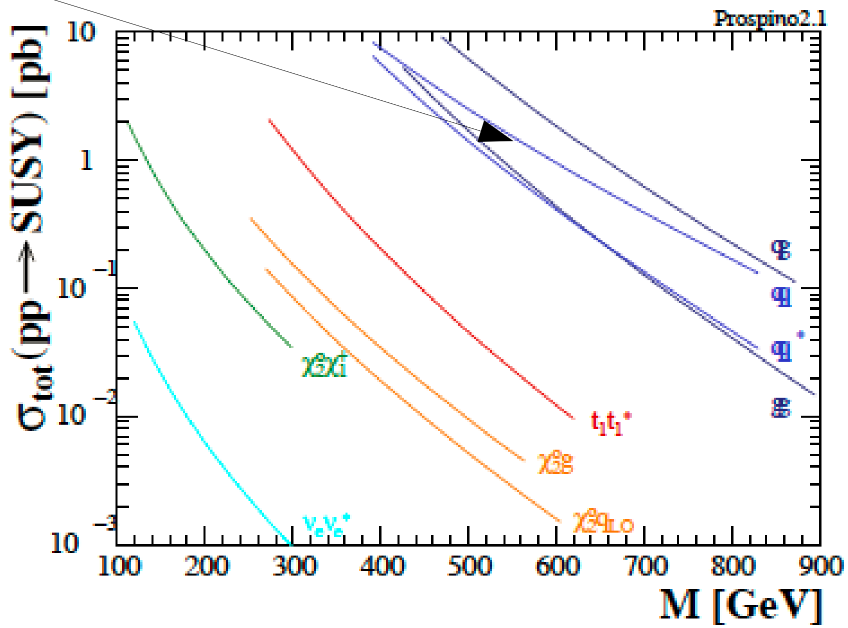
SUSY STRONG production

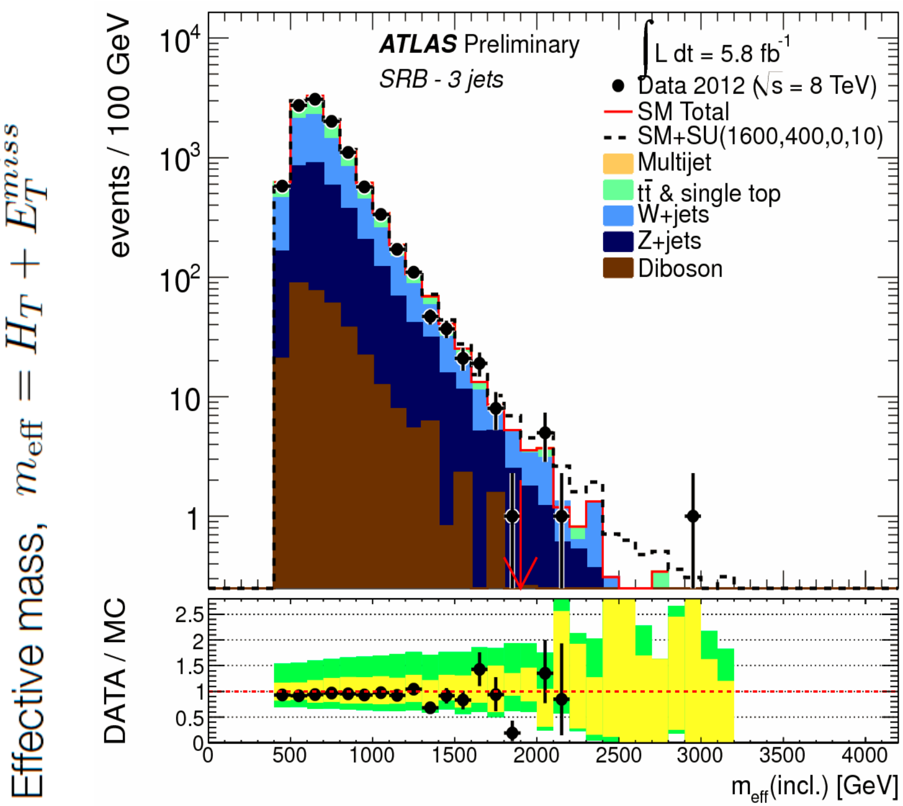
ATLAS-CONF-2012-109

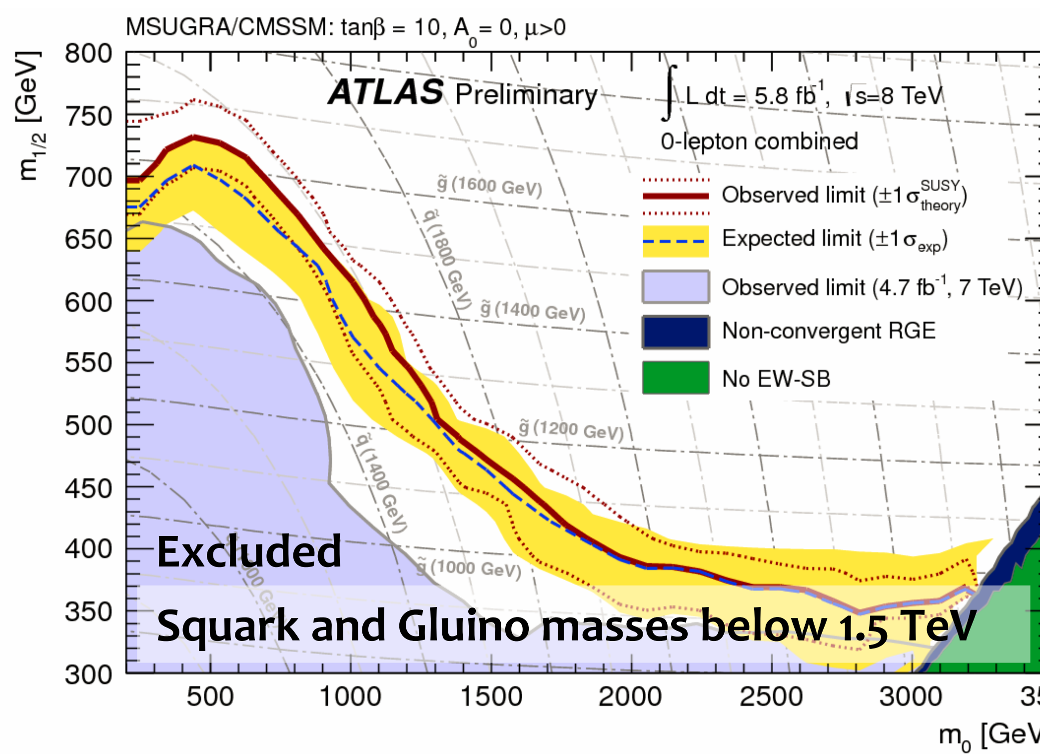


Jets + Et^{miss}

no Leptons

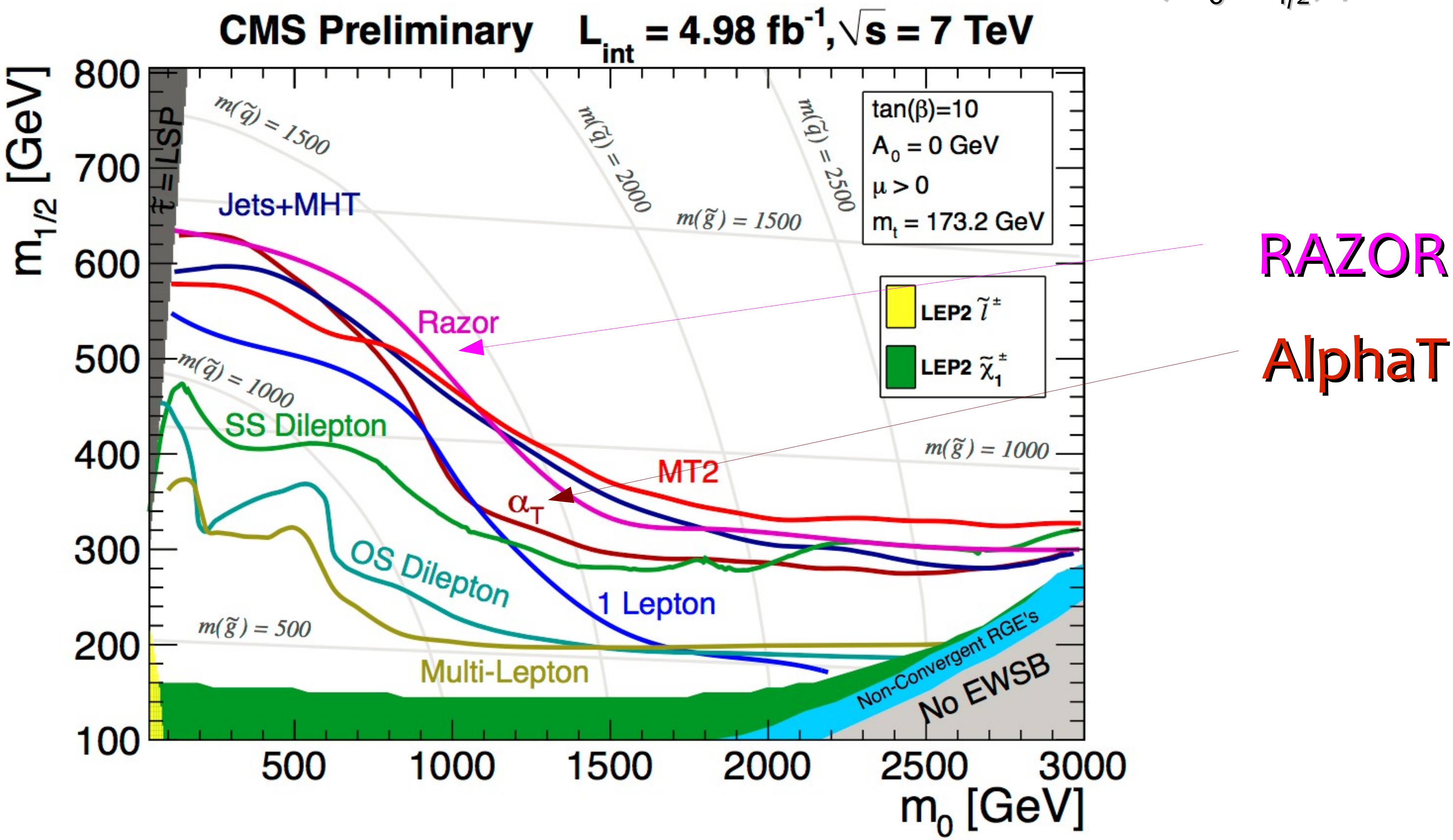






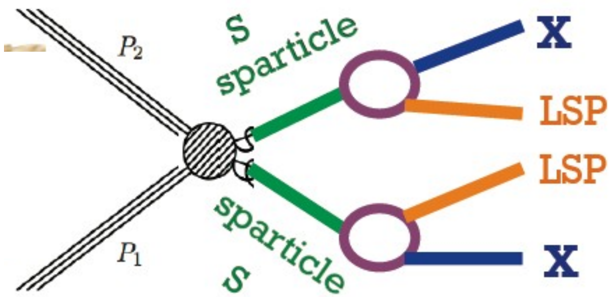
CMS Spaghetti

- Observed limits from several 2011 CMS SUSY searches plotted in the CMSSM (m_0,$m_{1/2}$) plane



RAZOR

- **Razor variables R** and **M_R** designed for final state topology characteristic of R-parity SUSY
- **Selection:**
  Group all final state objects (jets,leptons) into **two mega-jets**



In simple case:
S = squark
X = jet

$$M_R = \sqrt{(|\vec{p}_{j_1}| + |\vec{p}_{j_2}|)^2 - (p_z^{j_1} + p_z^{j_2})^2}$$

Peaks at

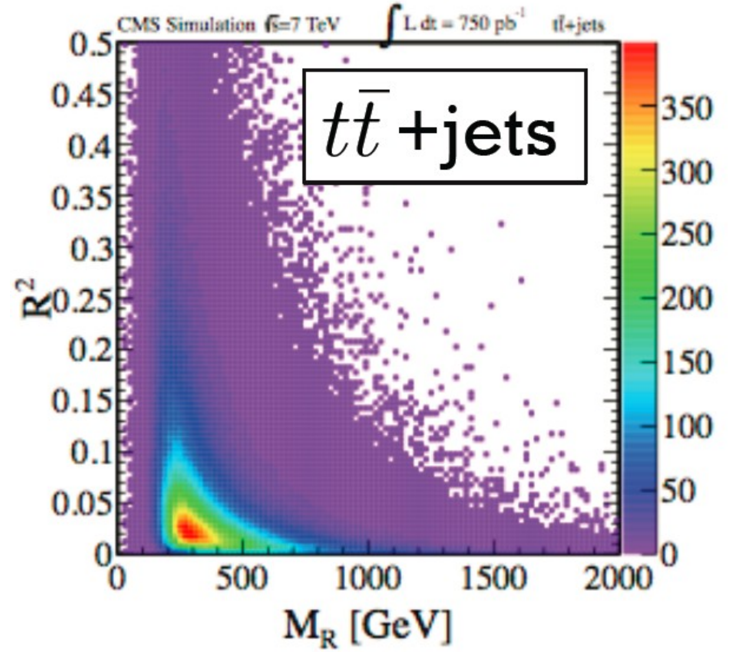
$$M_\Delta = \frac{M_S^2 - M_{LSP}^2}{M_S}$$

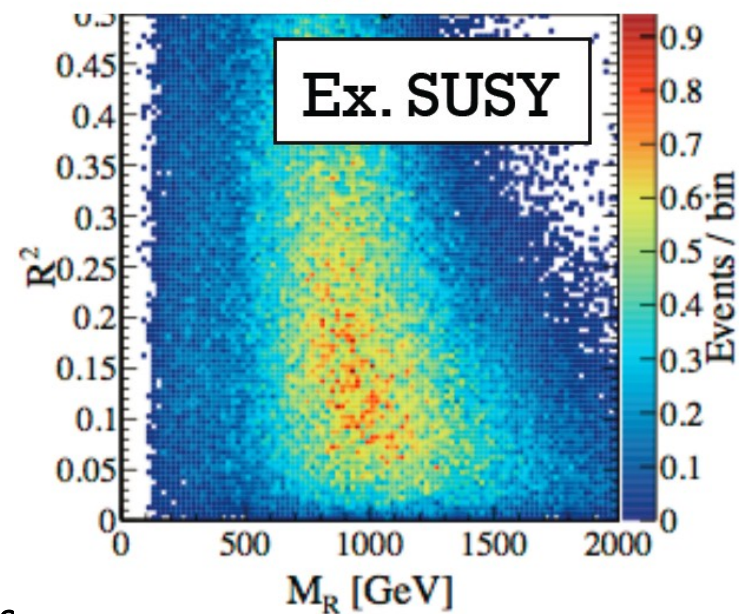
$$M_T^R = \sqrt{\frac{E_T^{miss}(p_T^{j_1} + p_T^{j_2}) - \vec{E}_T^{miss} \cdot (\vec{p}_T^{j_1} + \vec{p}_T^{j_2})}{2}}$$

Edge at M_Δ

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

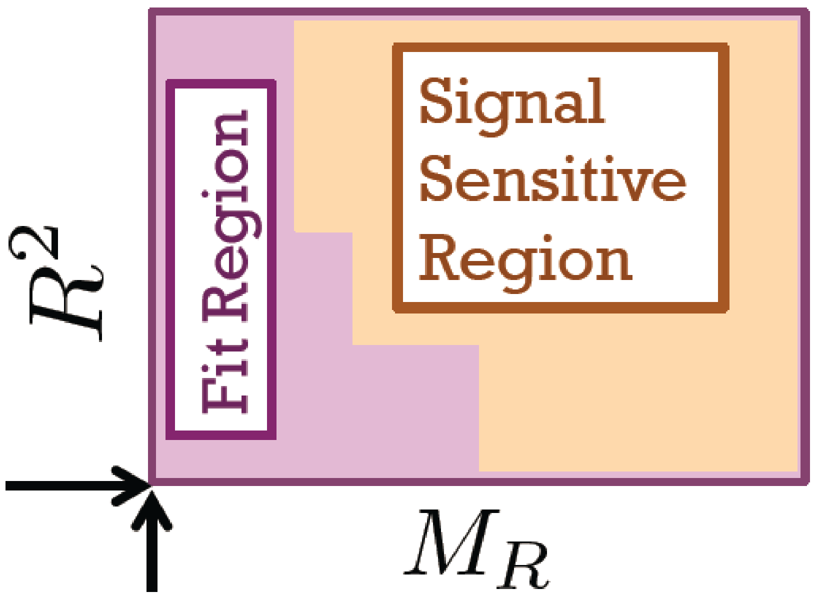
Ratio of two estimators of SUSY scale – describes transverse shape of event



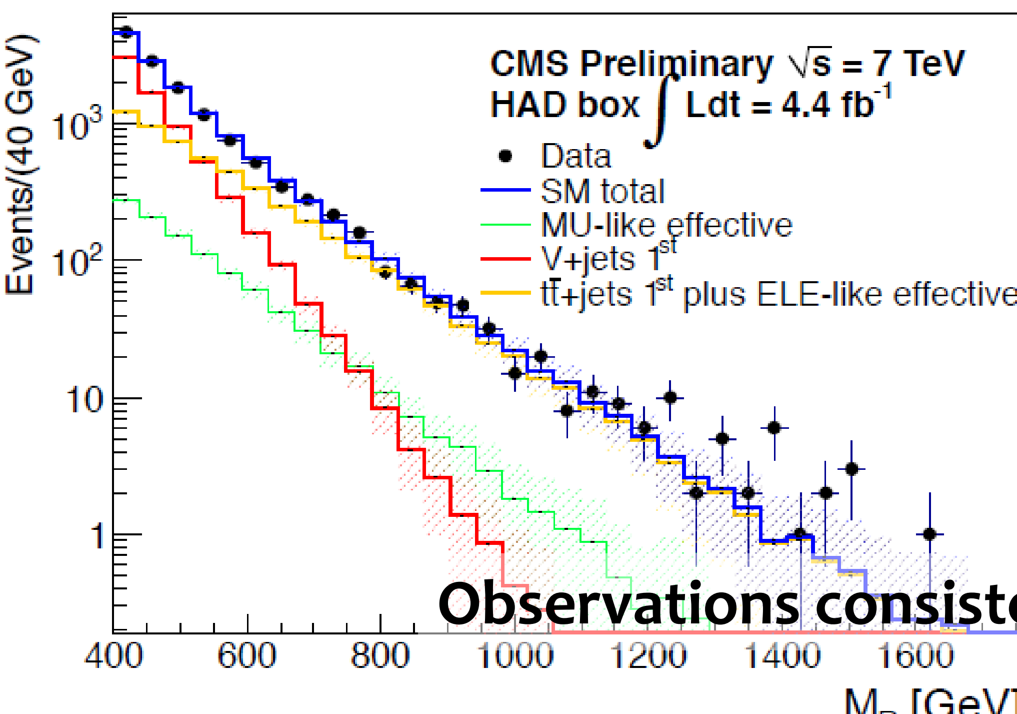


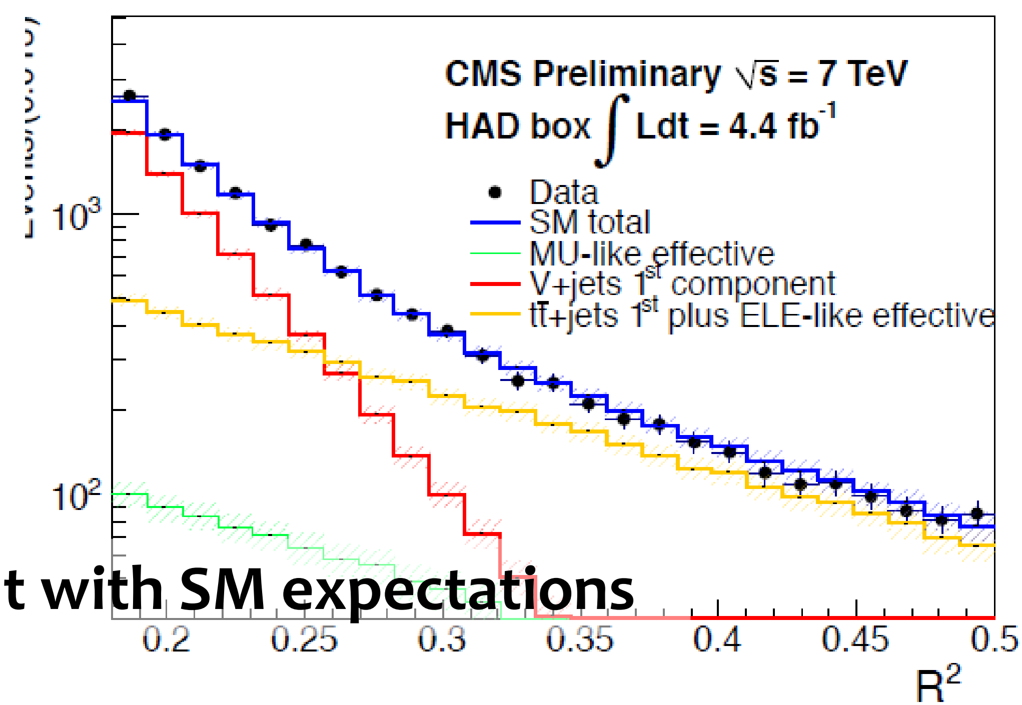
Inclusive Razor

CMS-PAS-SUS-2012-005



- Selection classify final states into exclusive boxes: HADron and LEP(e,μ) ones
- Background functionally extrapolated to signal region
- 2D fit performed independently for BOXes





Observations consistent with SM expectations

AlaphaT

- AlphaT: For events with 2 (pseudo-) jets:

$$\alpha_T = E_T^{j2} / M_T = E_T^{j2} / \sqrt{H_T^2 - \not{H}_T^2}$$

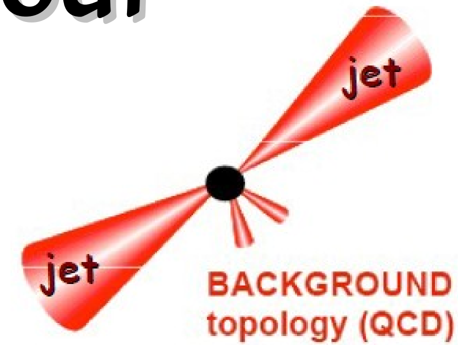
less energetic jet — transverse mass of di-jet system

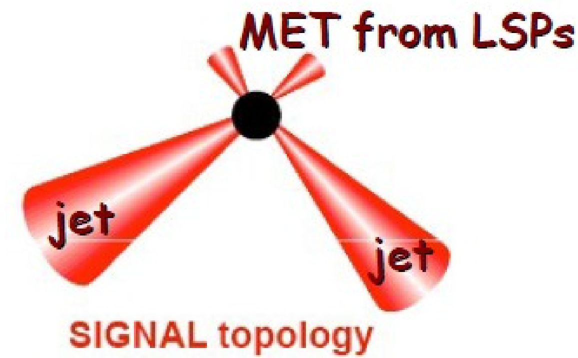
- HT: Scalar sum of the transverse energy of jets $H_T = \sum_{i=1}^{N_{jet}} E_T$
- MHT: Magnitude of the vector sum of the transverse momenta of jets

$$\not{H}_T = \left| \sum_{i=1}^{N_{jet}} \vec{p}_T \right|$$

- **αT** is used as the **main discriminator** between events with **genuine and miss-reconstructed MET** → **QCD multi-jet background can be suppressed significantly with a cut on αT**

AlphaT behaviour





- For a perfectly measured dijet event with ETj1 = Etj2 jets are back-to-back in φ in the limit of large jet momenta compared to their masses αT = 0.5

- **αT is smaller than 0.5**

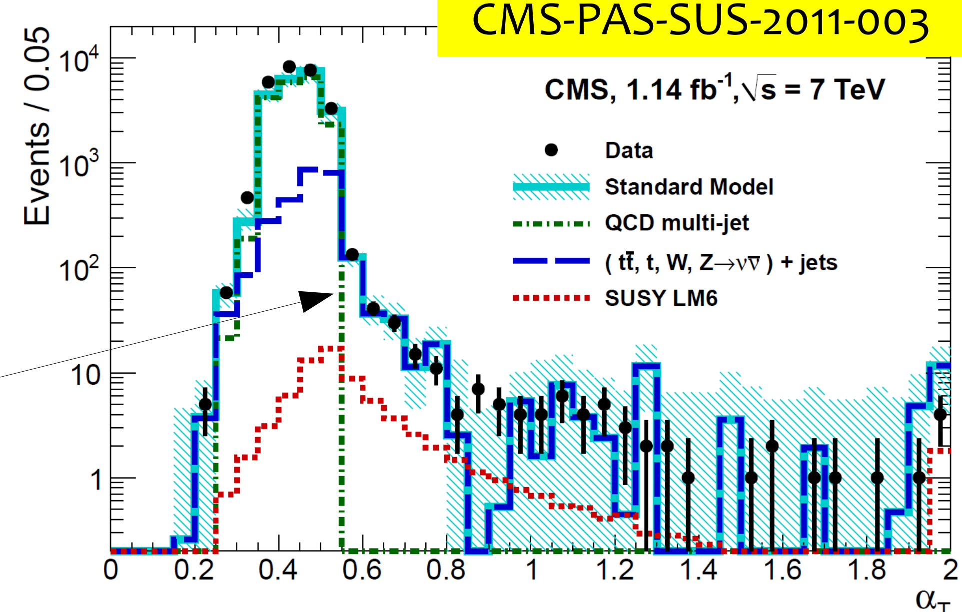
  in the case of an imbalance in the measured ETs of back-to-back jets

- **αT is greater than 0.5**

  when the two jets are not back-to-back and balancing genuine MET

- Final selection: **αT > 0.55** makes background QCD free

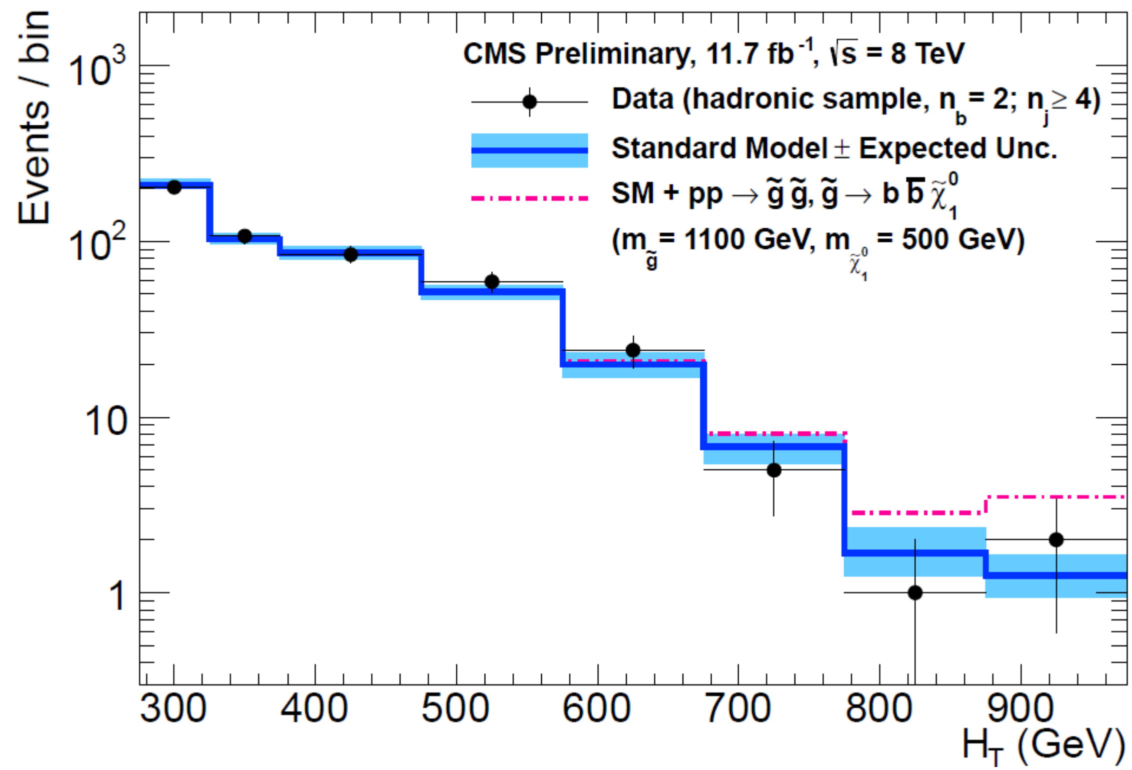
CMS-PAS-SUS-2011-003



Recent AlphaT with b-jets

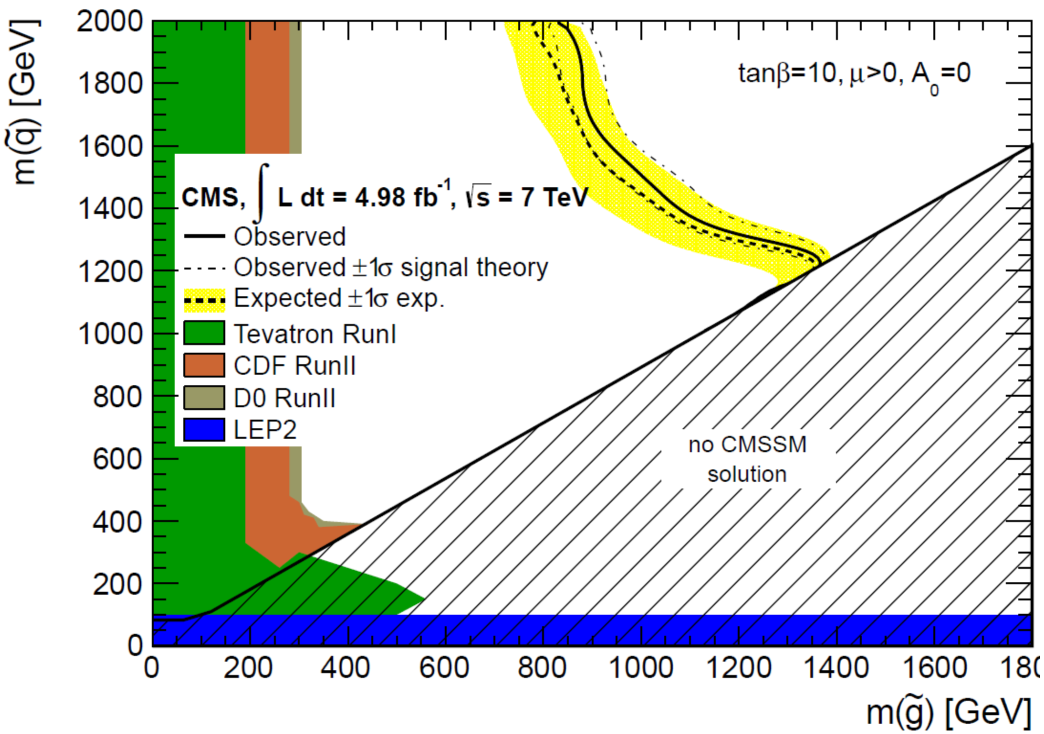
CMS-PAS-SUS-2012-028

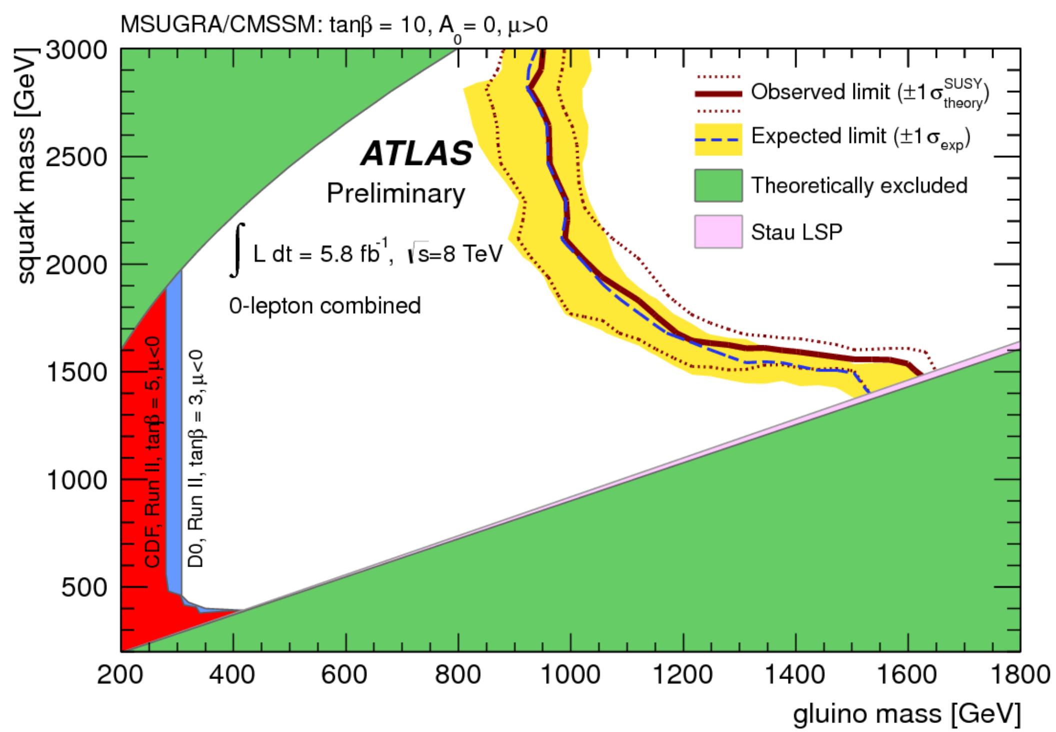
- New inclusive search with 11.7/fb at √s=8 TeV
- Suppress QCD by requiring αT>0.55
- Z,W and top backgrounds measured in (2)μ+jets and γ+jet control regions
- Fit in HT and b-jet multiplicity (0 – 4)
- No excess observed anywhere



CMSSM Limits on Sparticles

- Limits in terms of squark and gluino masses
  - m_squark > ~1.5 TeV
  - m_gluino > ~900 GeV





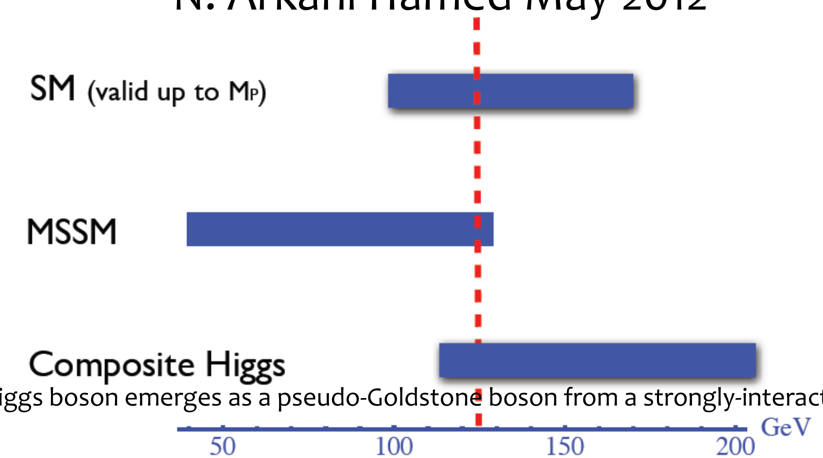
SUSY/CMSSM under pressure

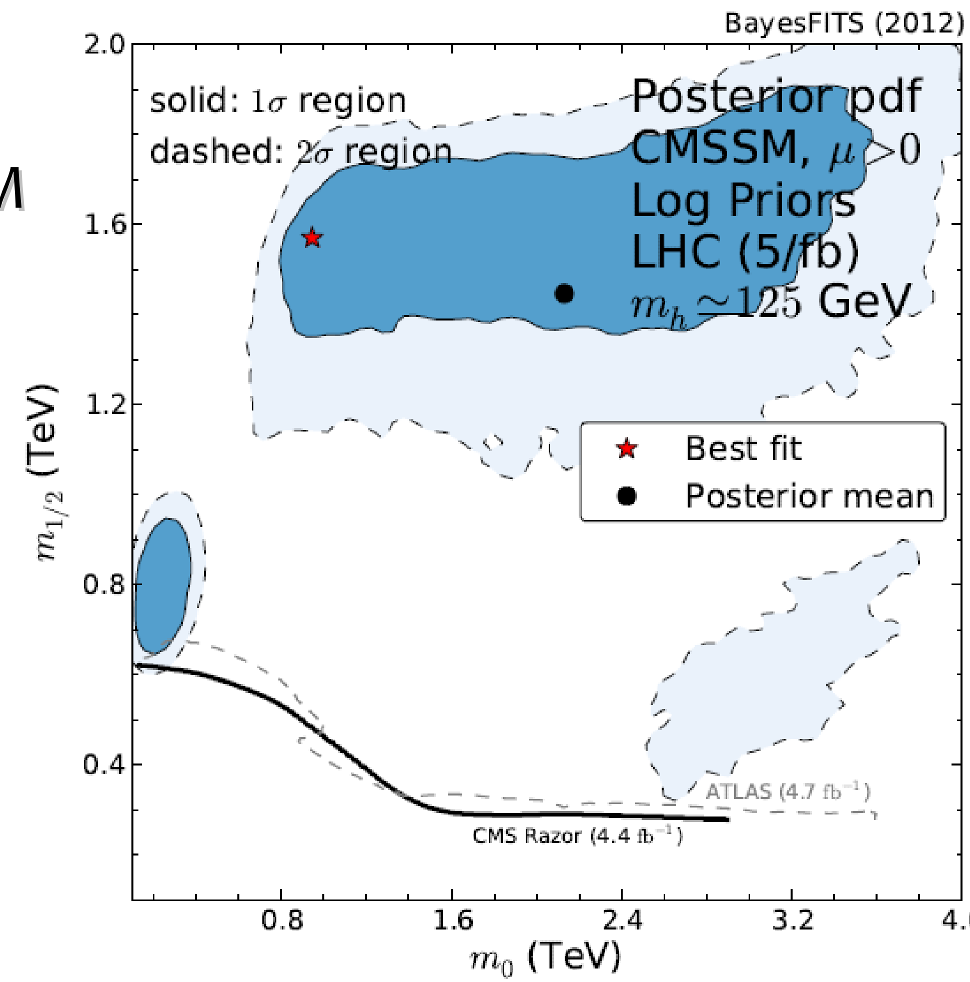
- Strong constrains from direct searches
- Allowed phase space is getting squeezed
- Flavour physics (recent result from LHCb Bs → 2 μ) remains in good agreement with SM
- Light Higgs-like boson at high end of CMSSM preference

Phys.Rev. D86 (2012) 075010 arXiv:1206.0264

Higgs mass range

N. Arkani Hamed May 2012

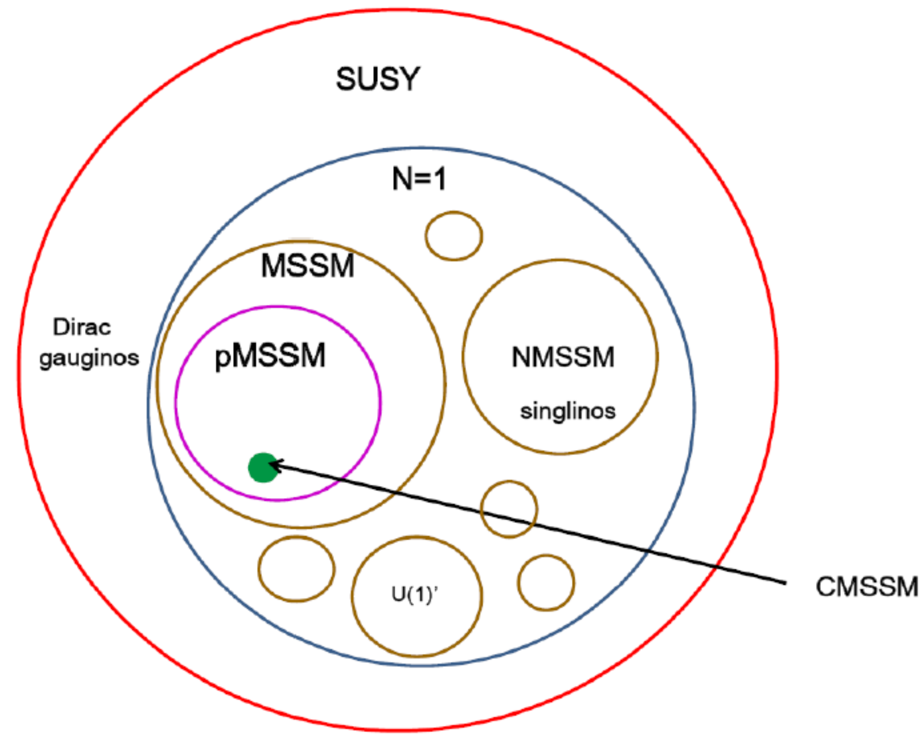




SUSY – not just one model

- Many possible variations
- SUSY breaking mechanism:
  gravity-, gauge-, anomaly-mediated, .
  - Long lived sparticles ?
- Is R-parity = $(-1)^{3(B-L)+2S}$ conserved?
  - If not, RPViolating models
- **Wide range of possible signatures** for SUSY to be searched for and **many ways to hide**

SUSY Theory phase space

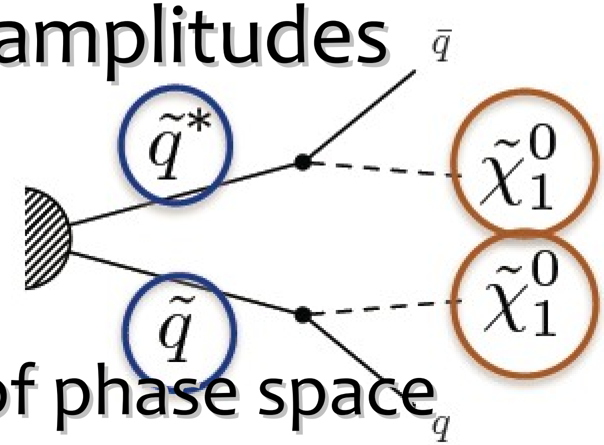


T. Rizzo (SLAC Summer Institute, 01-Aug-12)

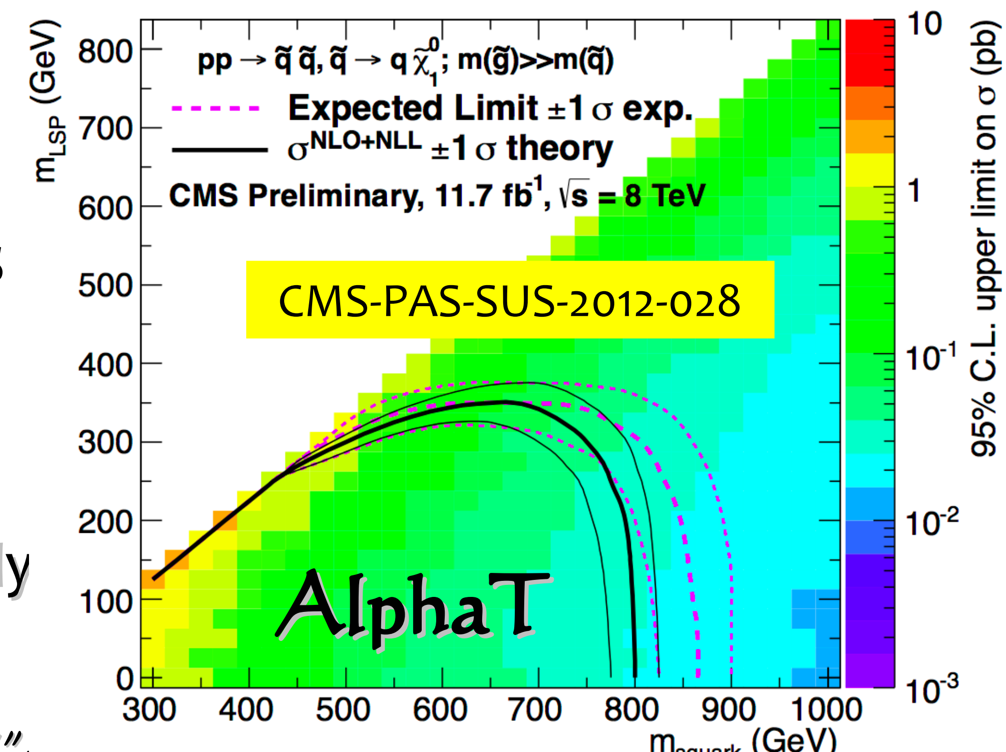
- **The goal is to find hints of SUSY particles in the LHC range**
  → **New interpretation of results preferred**

Simplified Models (SMS)

- Final state kinematics from SUSY particle production determined mostly by pdfs and decay amplitudes

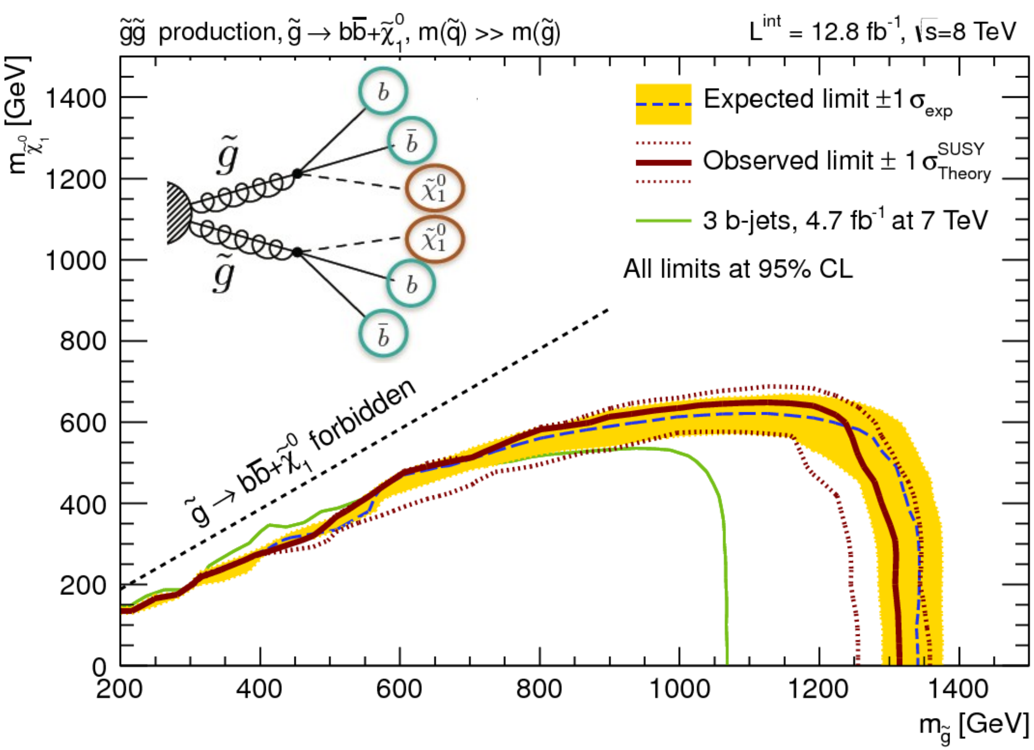


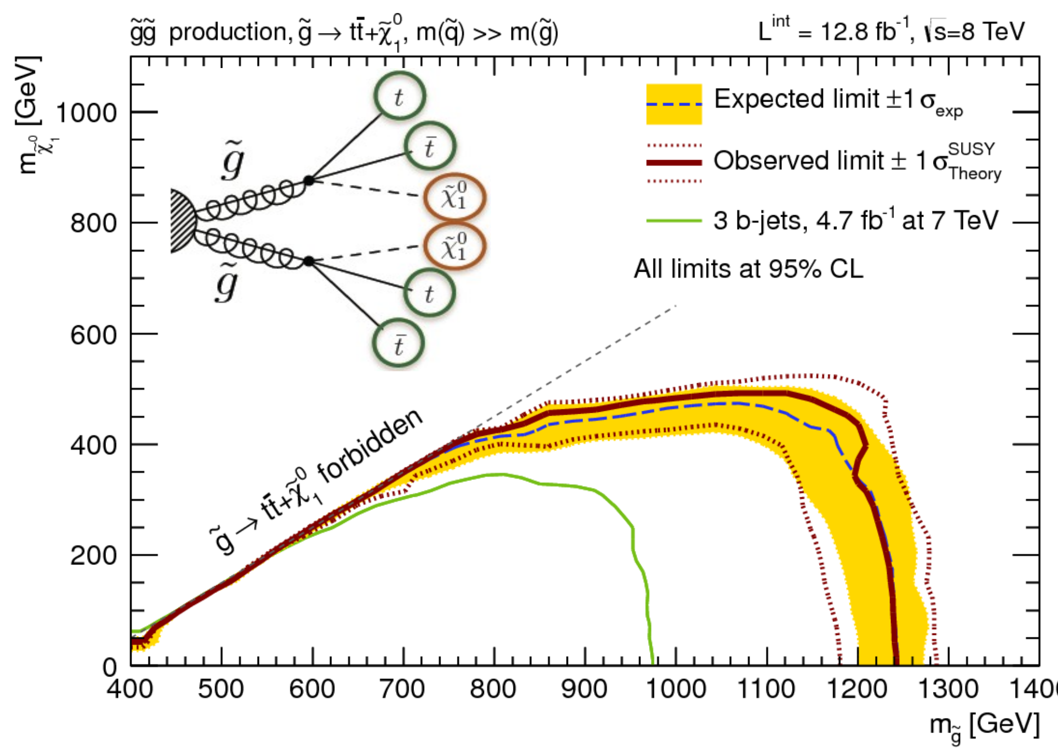
- **SMS limited to a few particles, 2-3 body decay chains**
- Topological signatures group large sectors of phase space
- **SMS limits can be used as reference and translated to different theoretical models**
  - Mass limits assume SUSY cross section production
  - Illustrate sensitivity independently of SUSY-breaking model



All-hadronic SMS at ATLAS

- Final states with ≥3 b-jets of pT>30 GeV and large MET probe gluino mediated off-shell stop and sbottom production
- Signal regions defined for M_{EFF}4j , Δφmin (4j,MET), and MET>200 GeV





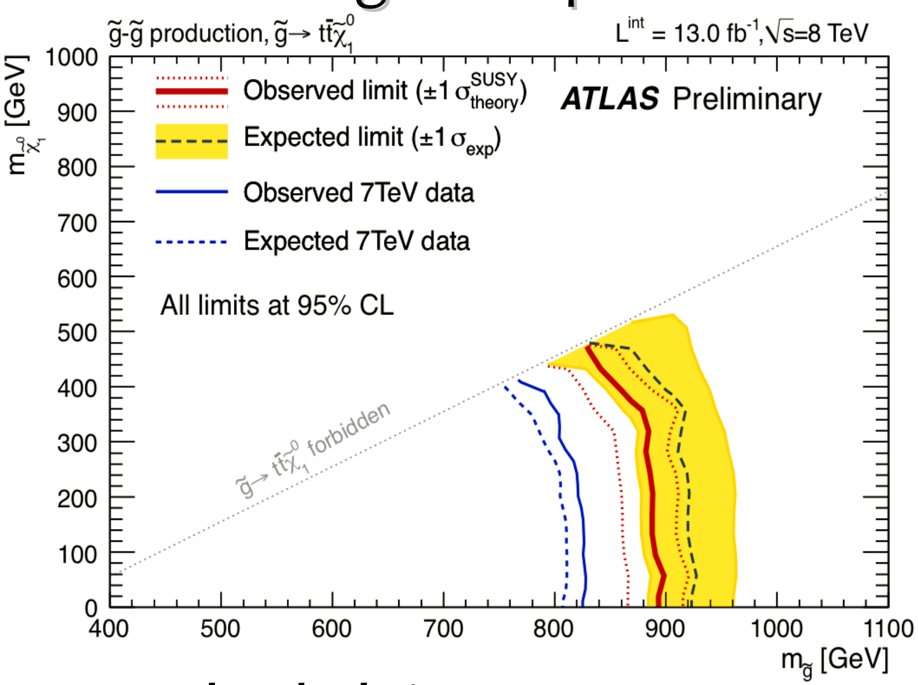
ATLAS-CONF-2012-145

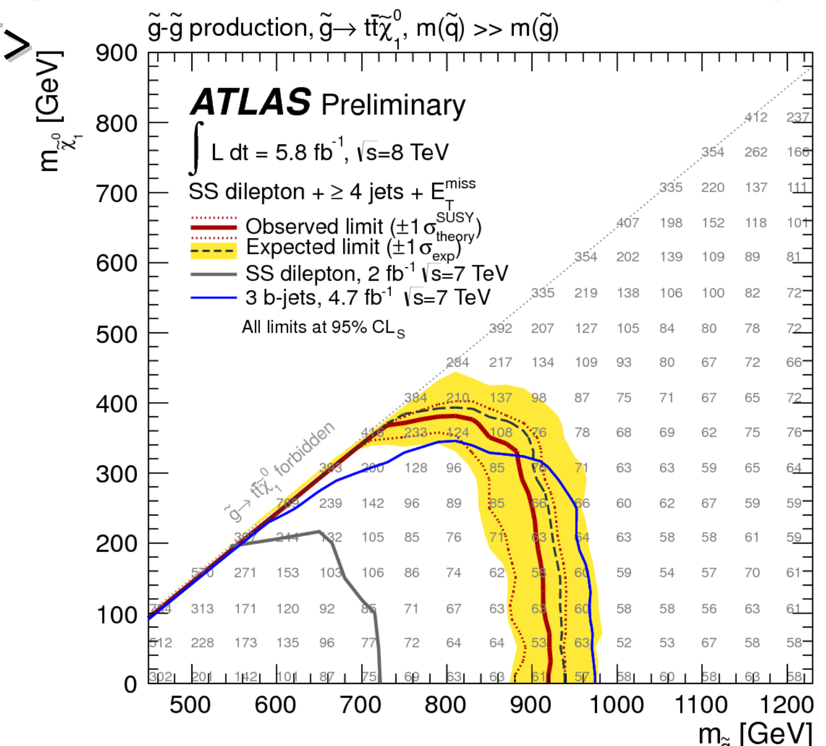
- Probed gluino up to ~1.3 (1.25) TeV for T1bbbb (T1tttt) SMS models

Leptonic searches at ATLAS

- **Final states with leptons and MET** are also used in ATLAS to test models with a gluino pair decaying to 4 tops and neutralinos
- **Tri-lepton search:** ≥3 iso leptons of pT>15 GeV, either eee, μμμ, and eμμ or μee (with SS or OS e/μ pairs). Search regions based on Njets, MET
- **Same Sign lepton search:** ee,μμ,eμ with pT>20 GeV and ≥4 jets with pT>50 GeV. Search region requirement of MET>

ATLAS-CONF-2012-151



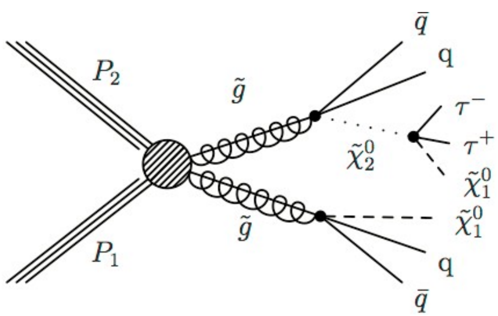


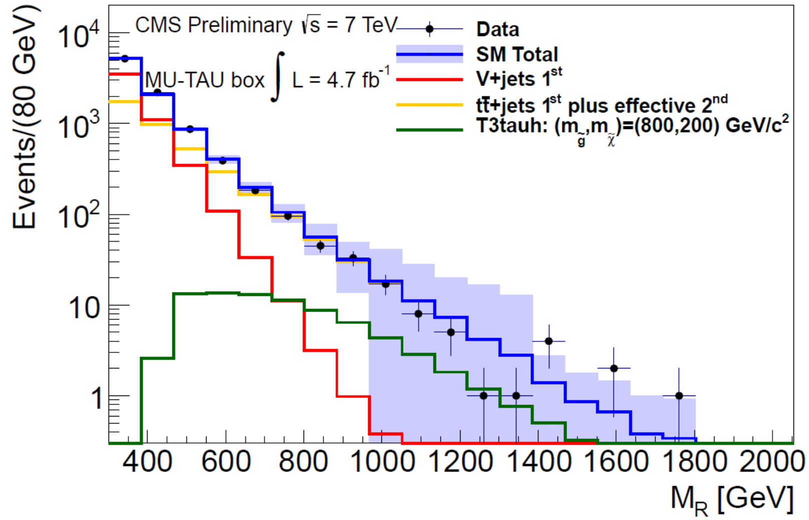
ATLAS-CONF-2012-105

- Probed gluino up to ~900 GeV for the T1tttt SMS model

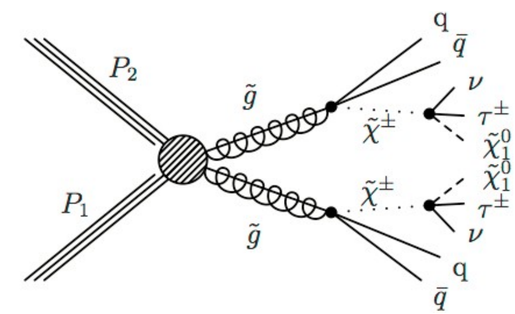
Search for τ's with Razor

- Razor applied to τ+jets final state

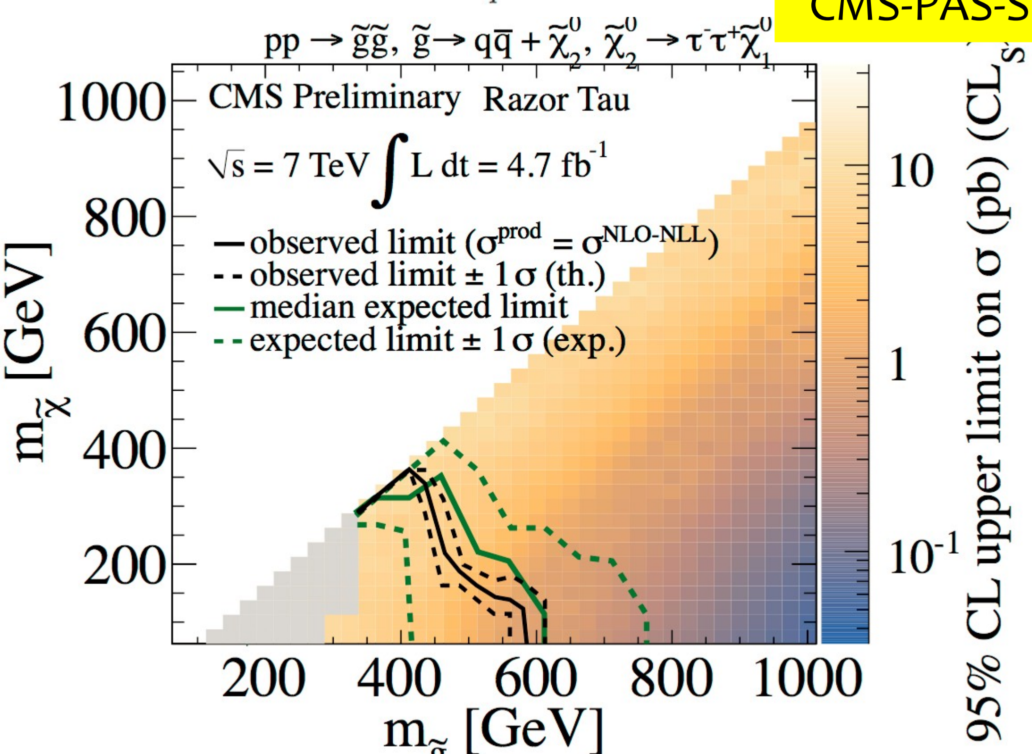


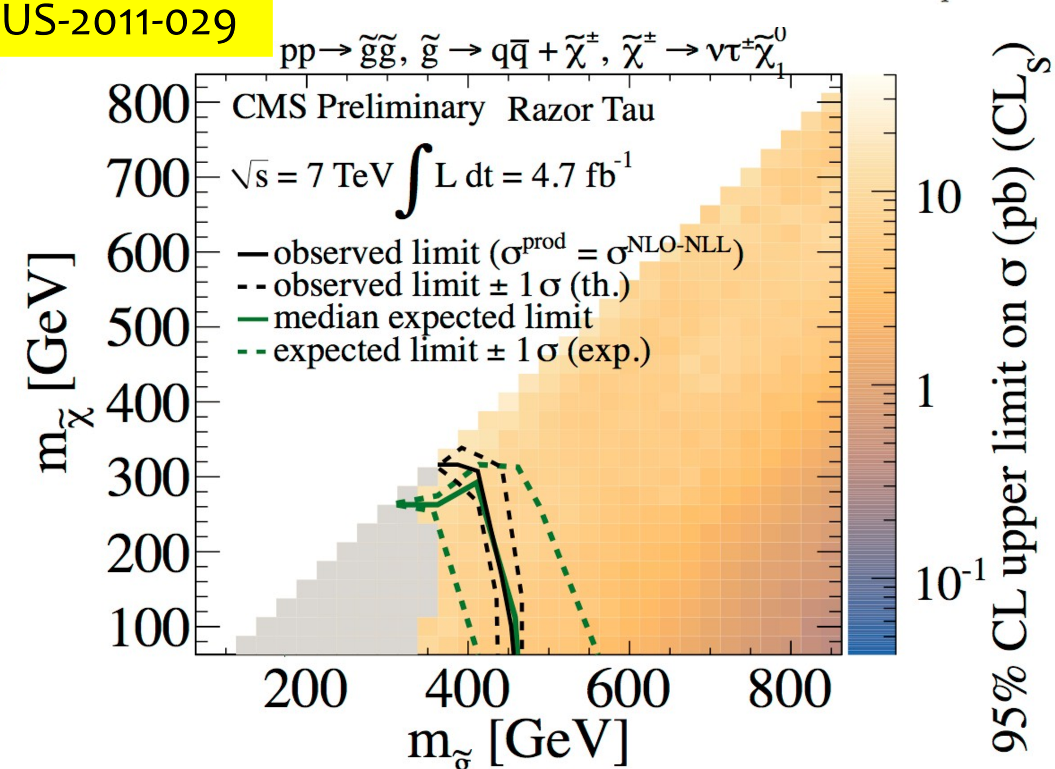


- 4 boxex
  1st :MU-TAU
  τ >=1 & μ>=1 & 0e



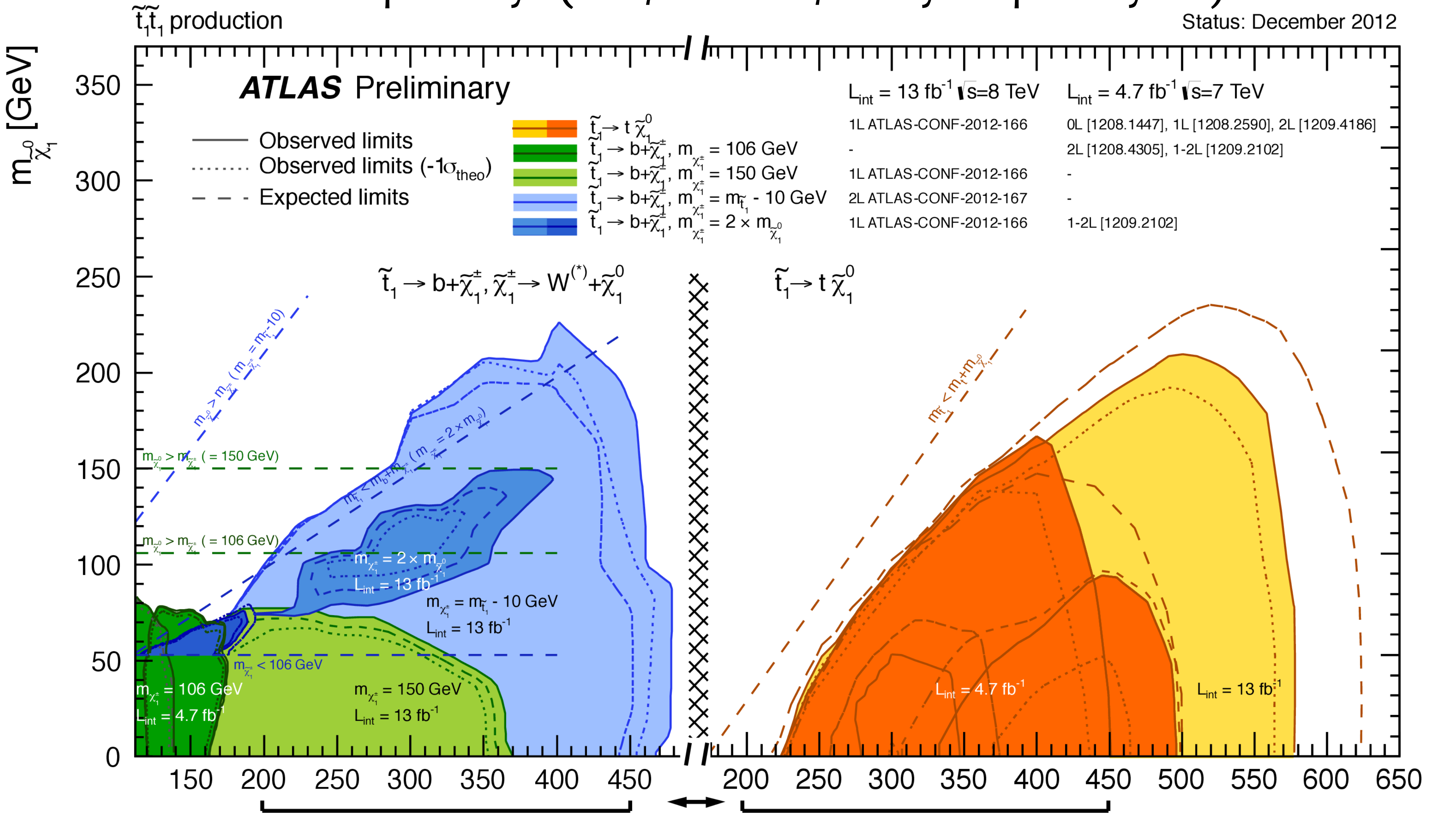
CMS-PAS-SUS-2011-029





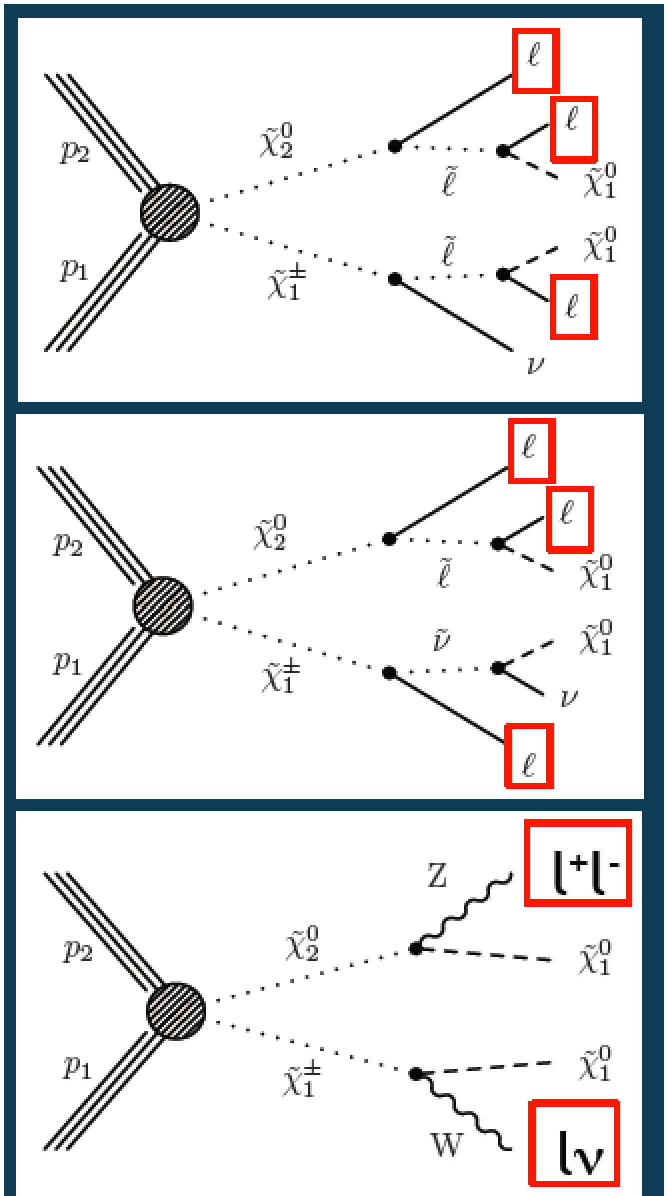
Direct stop production

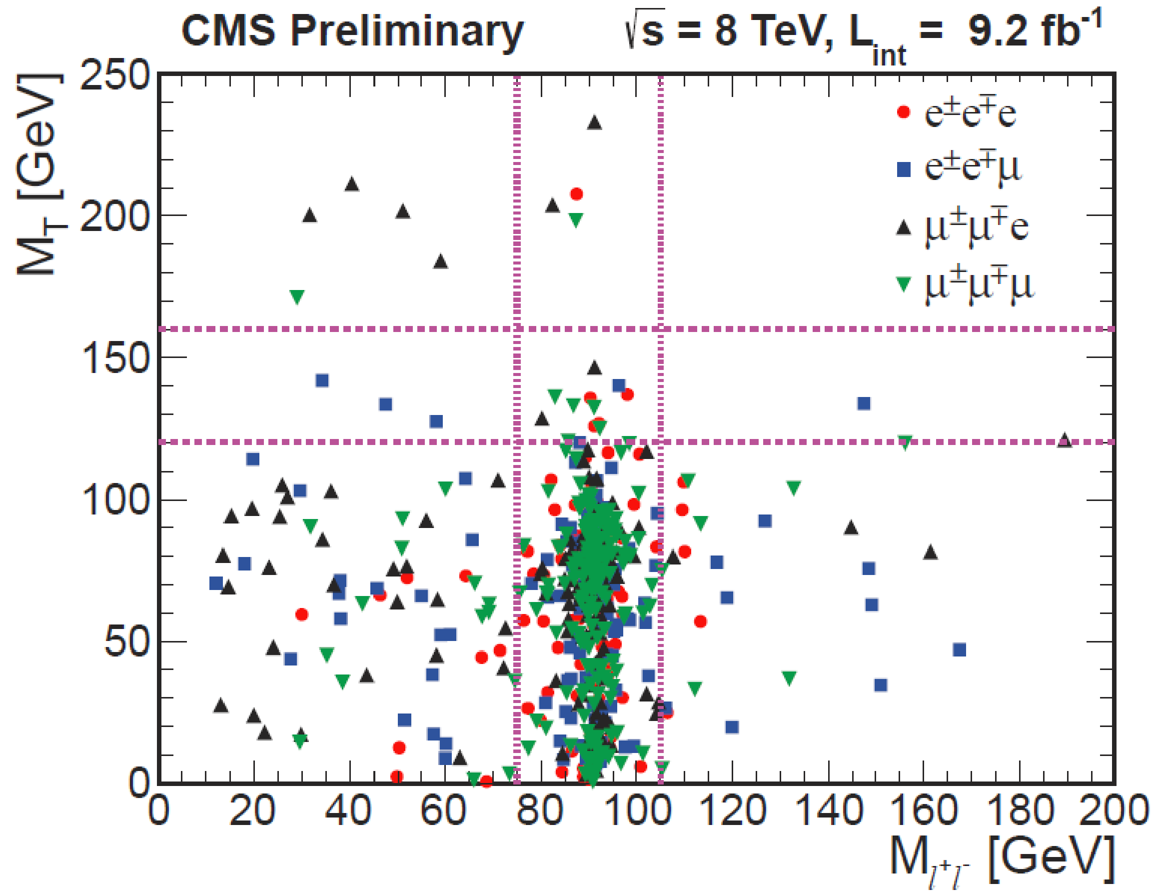
Searches use 0/1/2-lepton final states optimized for different sparticle masses and stop decays (low/medium/heavy stop analyses)



- Impressive coverage of the new territory

Search for neutralino-chargino





CMS-PAS-SUS-2012-022

Three-lepton events with an ee or μμ OSSF dilepton pair, where the third lepton is either an electron or a muon

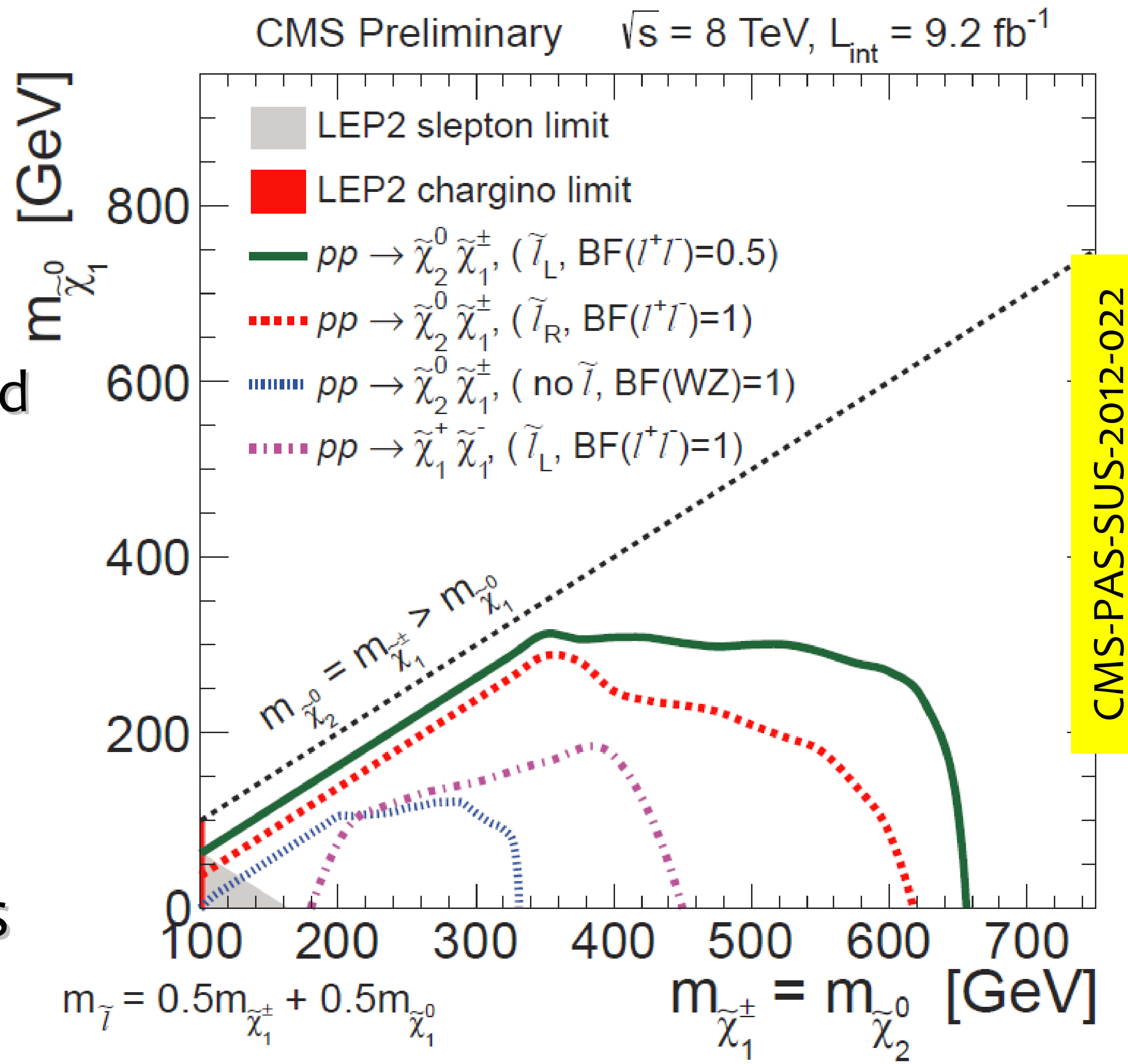
M_T (GeV)	E_T^{miss} (GeV)	$M_{\ell\ell} < 75$ GeV		75 GeV $< M_{\ell\ell} <$ 105 GeV	
		total bkg	observed	total bkg	observed
> 160	50 – 100	2.1±0.5	4	3.3±0.5	3
	100 – 150	1.7±0.4	0	1.8±0.2	1
	150 – 200	0.8±0.3	1	0.63±0.16	1
	> 200	0.25±0.20	0	0.58±0.19	1

Search for neutralino-chargino

- Summary of results for chargino-neutralino production with decays to left-handed sleptons, right-handed sleptons, or direct decays to vector bosons, and chargino-pair production

- **Chargino-neutralino limits extended up to ~650 GeV**

- Slepton (chargino) mass limits extended up to ~275 (450) GeV

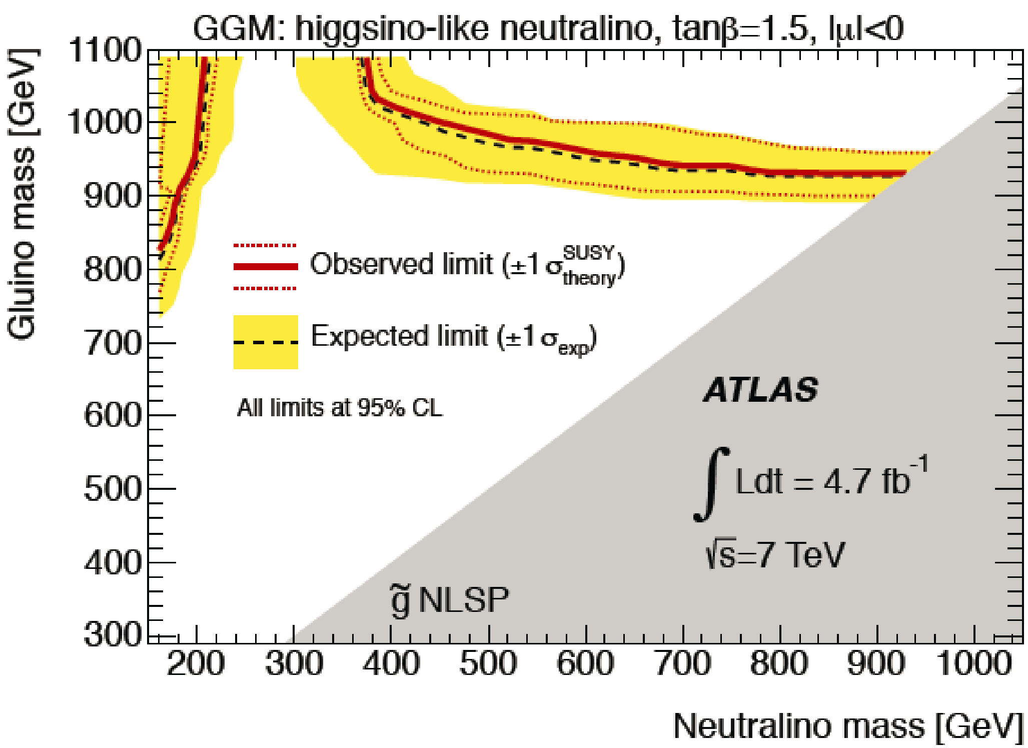


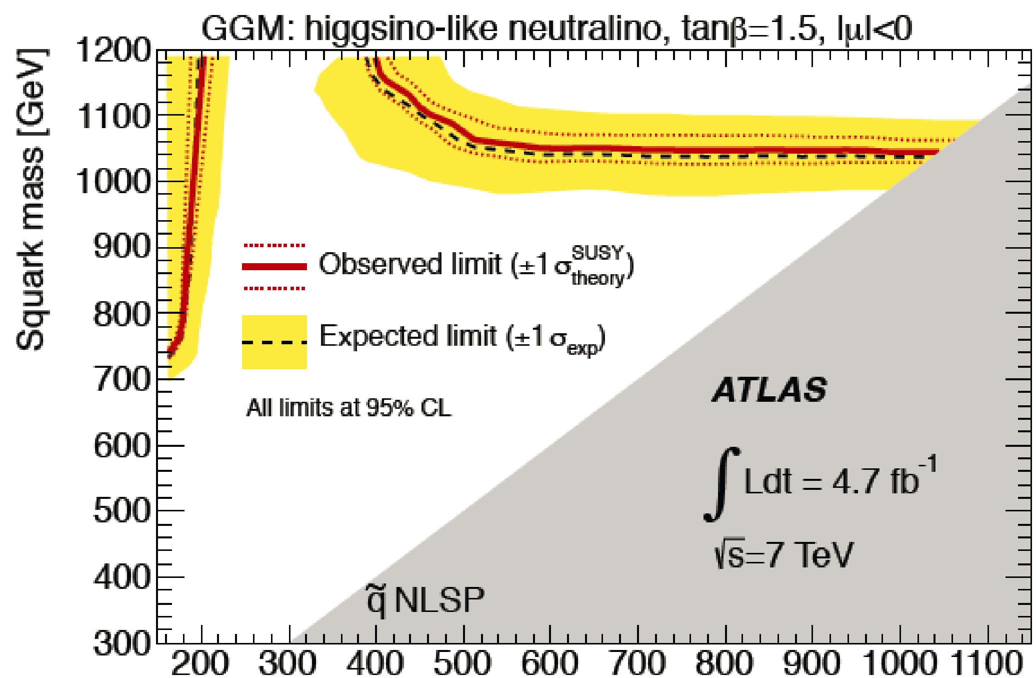
Single Photon Search

- Single γ analysis from higgsino-like neutralino NLSP GMSB model
  - Selection: one iso photon, one b-jet, and MET

1 photon ($p_T > 125$ GeV)	$m_T(\gamma, E_T^{miss}) > 100$ GeV
≥ 2 jets ($p_T > 20$ GeV)	$\Delta\phi\ (E_T^{miss}, \text{jet}) > 0.4$
≥ 1 b-tagged jet	veto e/μ
$E_T^{miss} > 150$ GeV	veto second photon

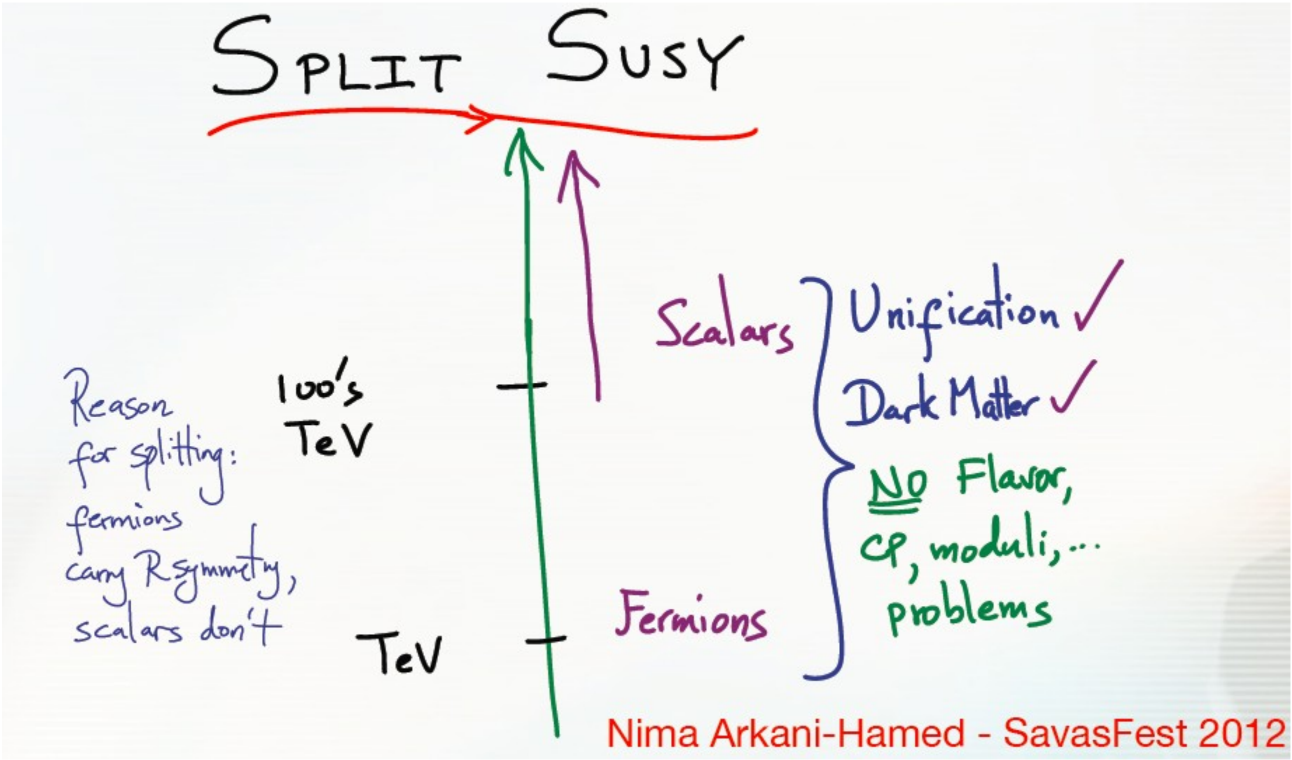
- **For higgsino-like neutralino masses > 220 GeV, gluino masses are excluded < 900 and squark < 1020 GeV**





arXiv:1211.1167

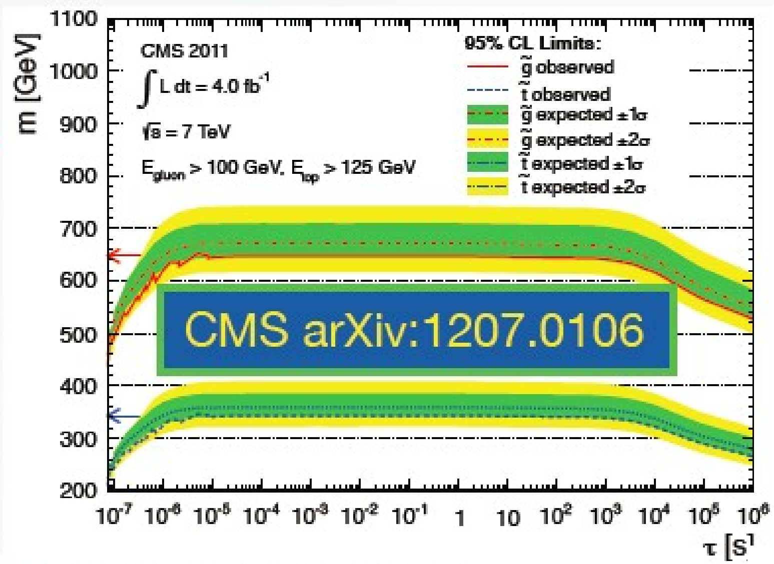
Maybe SPLIT SUSY ?



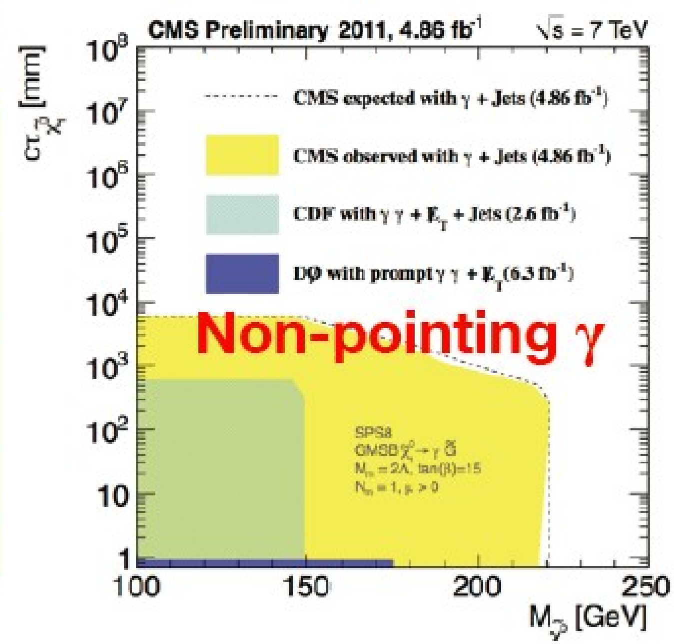
- In SPLIT SUSY, the light Higgs implies particular characteristic cτ, which is similar to generic case of heavy SUSY
- Preferred SUSY breaking scale of 10^4-10^{10} TeV implies cτ ~ 10^{-20} – 1 s
- cτ ~ 1-100 ns – very challenging range experimentally

Long-lived Particles searches

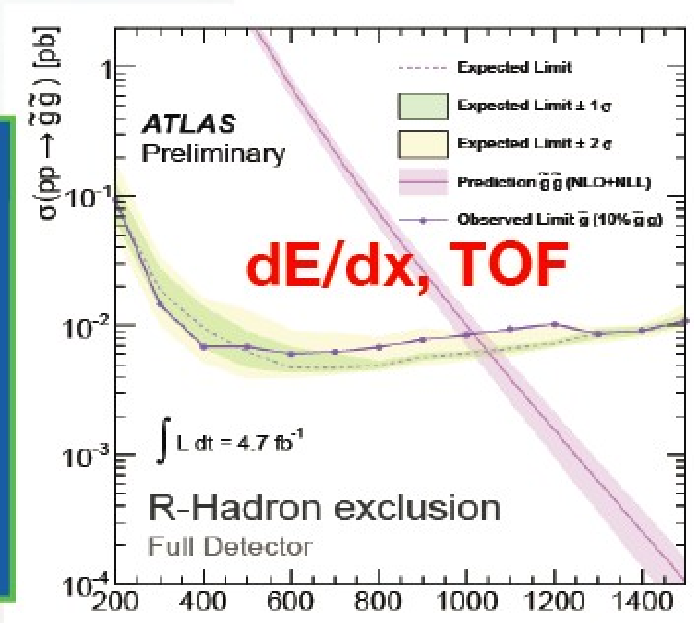
Stopped gluinos & stops decaying during no-beam periods



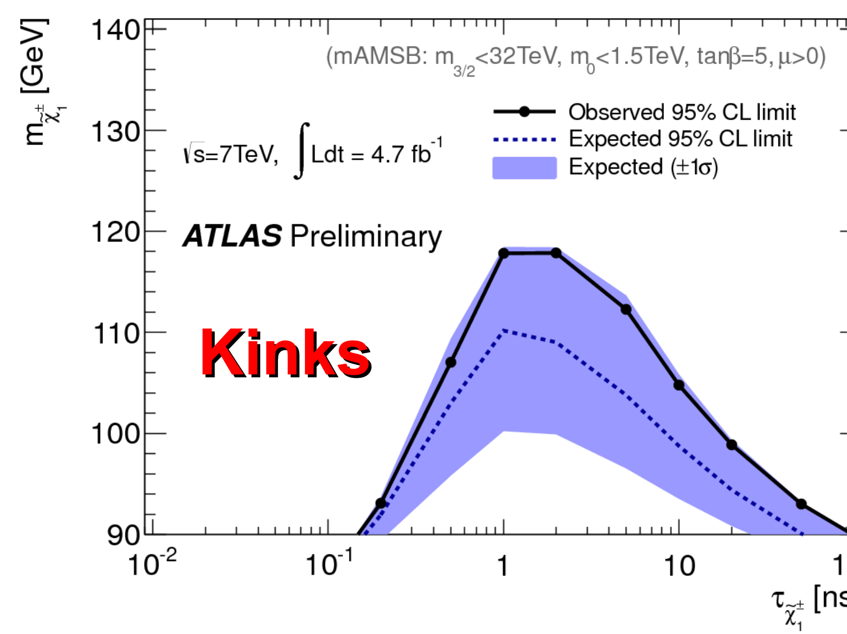
CMS-EXO-11-035



ATLAS-CONF-12-075



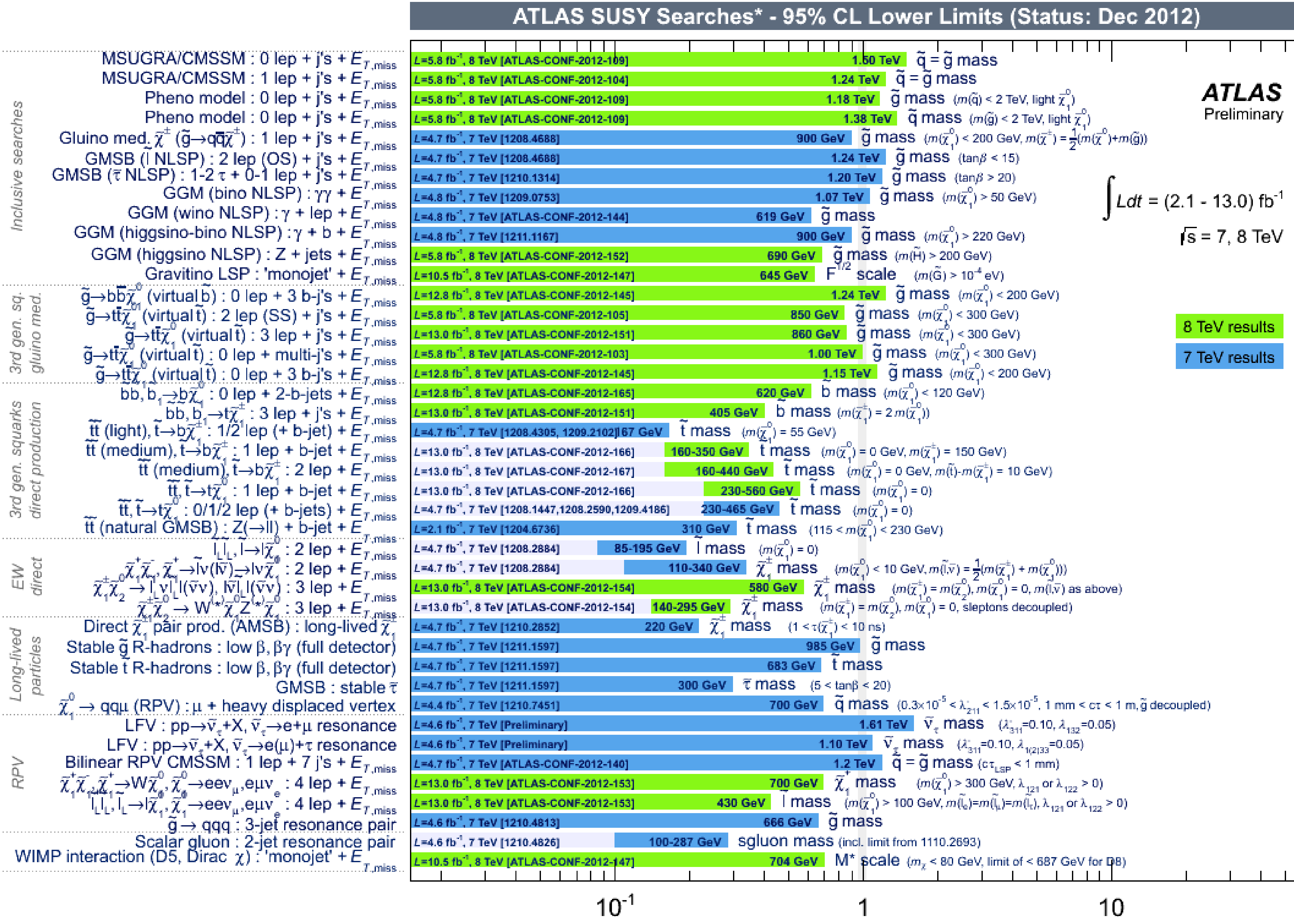
ATLAS-CONF-12-034



SUSY Summary

- ATLAS and CMS performed a **large set of inclusive searches** with different signatures and methods
- No evidence of SUSY particle production found
- Squark and gluino production (1st /2nd generation)
  - Mass limits above ~1.5 TeV in context of cMSSM and SMS
- Sbottom/stop masses probed up to ~650/430 GeV for some SMS

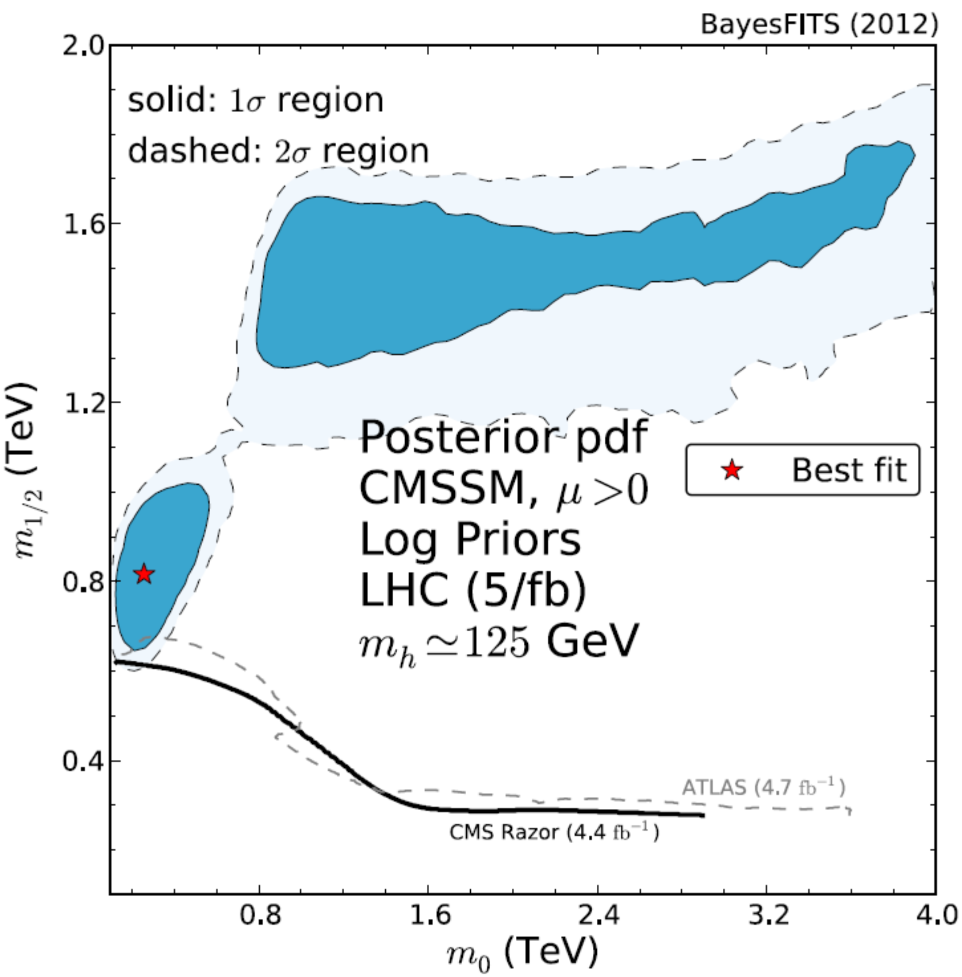
- **SUSY not restricted to the simple cMSSM or SMS is examined**
  - Different SUSY breaking mechanism
  - Compressed spectra, low MET
  - Beyond MSSM (nMSSM, etc), R-parity violating models

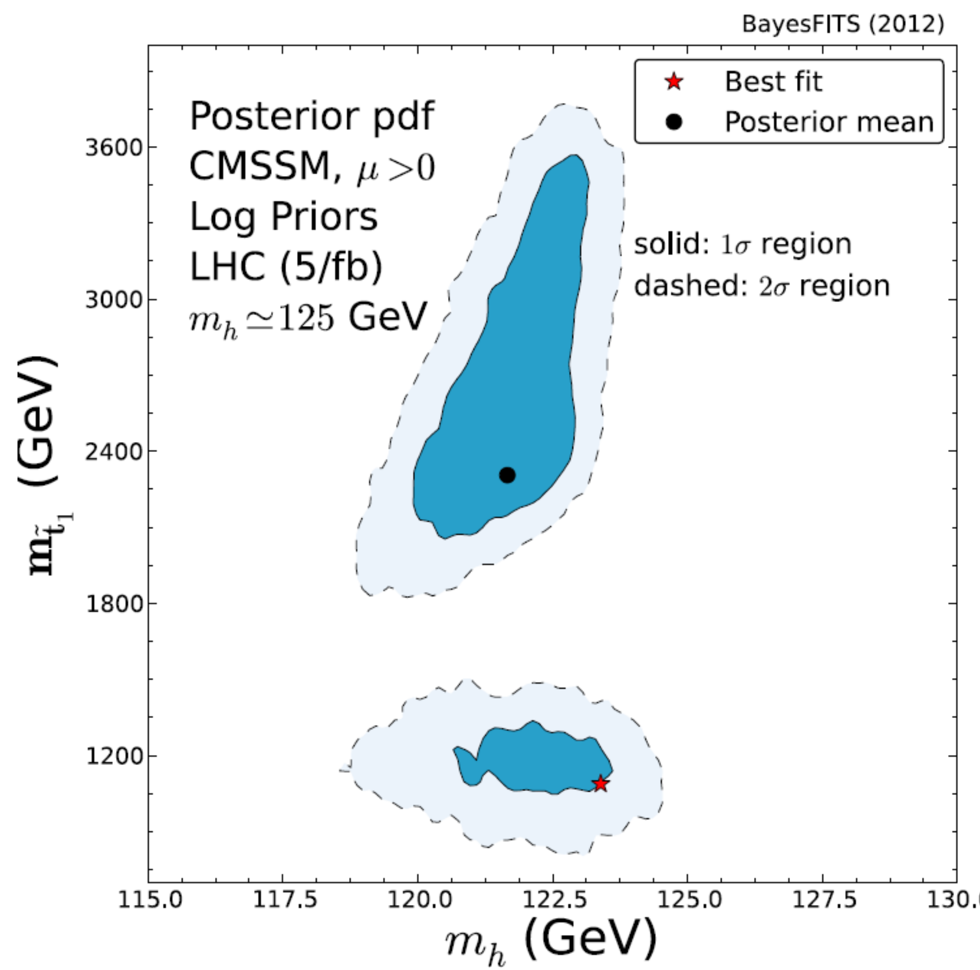


*Only a selection of the available mass limits on new states or phenomena shown.
All limits quoted are observed minus 1σ theoretical signal cross section uncertainty.

So…. where is SUSY ?

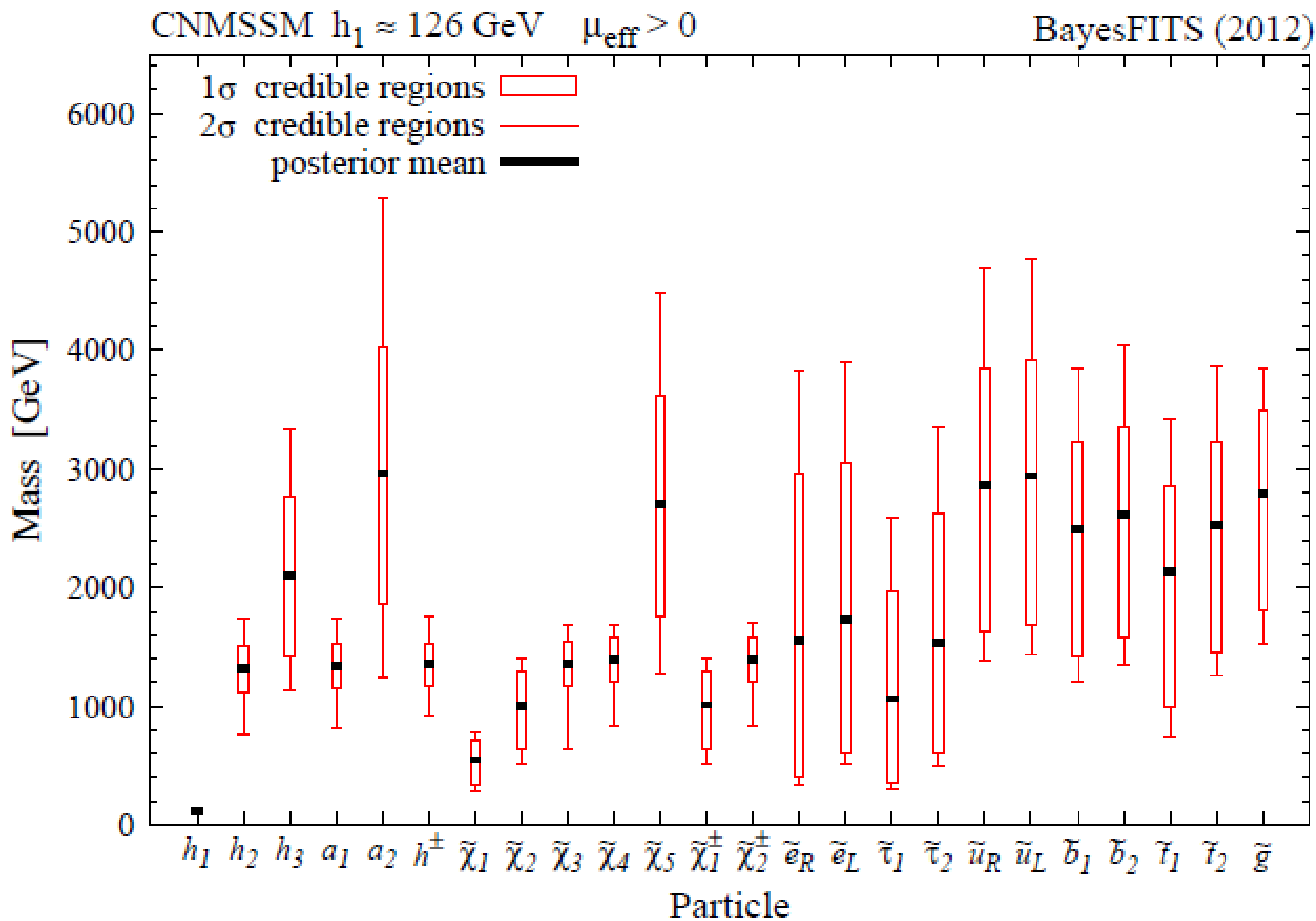
- Let's make a global fit to all available measurements from LHC and beyond for the CMSSM





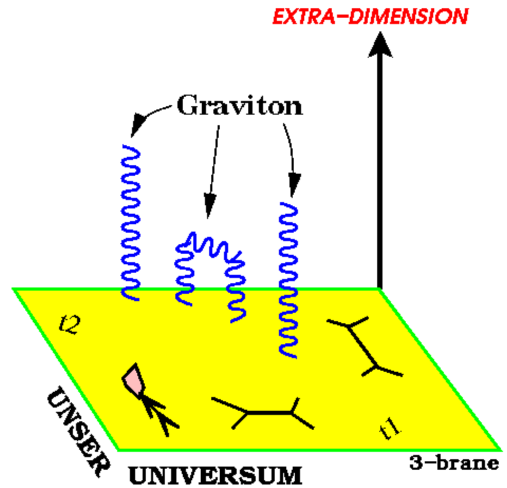
So…. where is SUSY ?

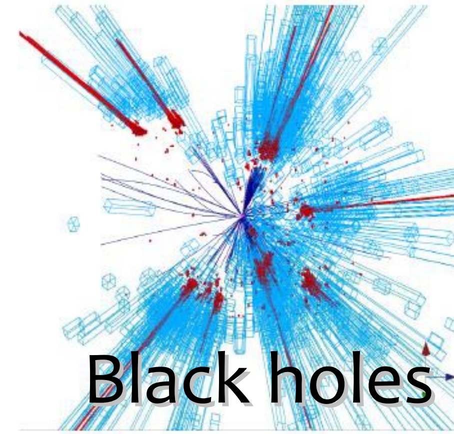
- We can "predict" new supersymmetric masses



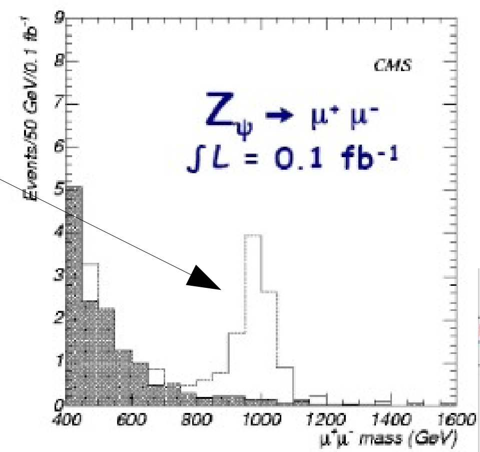
Exotic New Physics ?

- **Extra dimensions**
  - Lower Planck scale
  - KK towers
  - Black holes

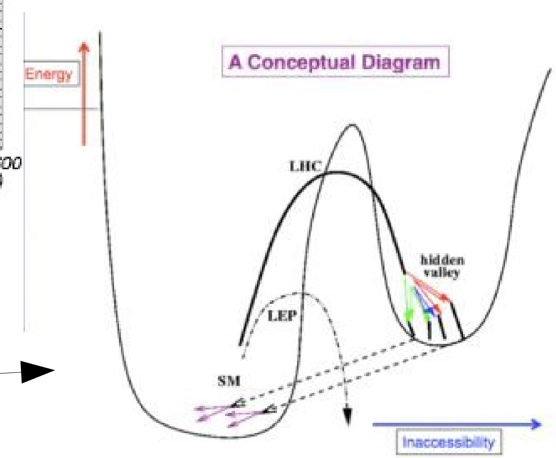




- **New Gauge Bosons**

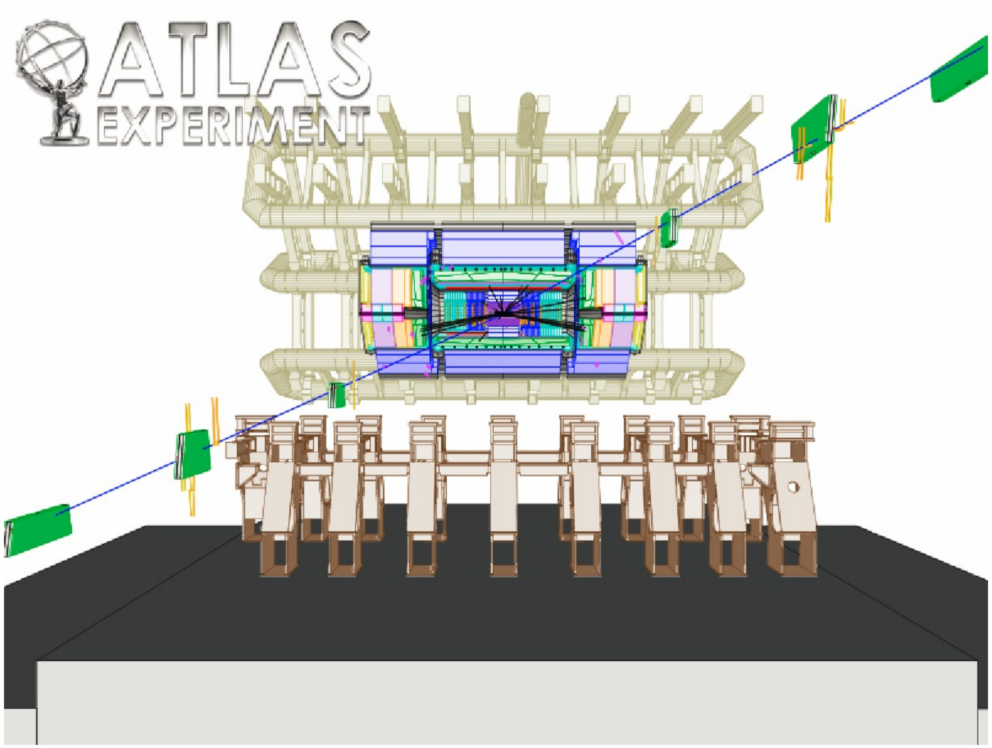


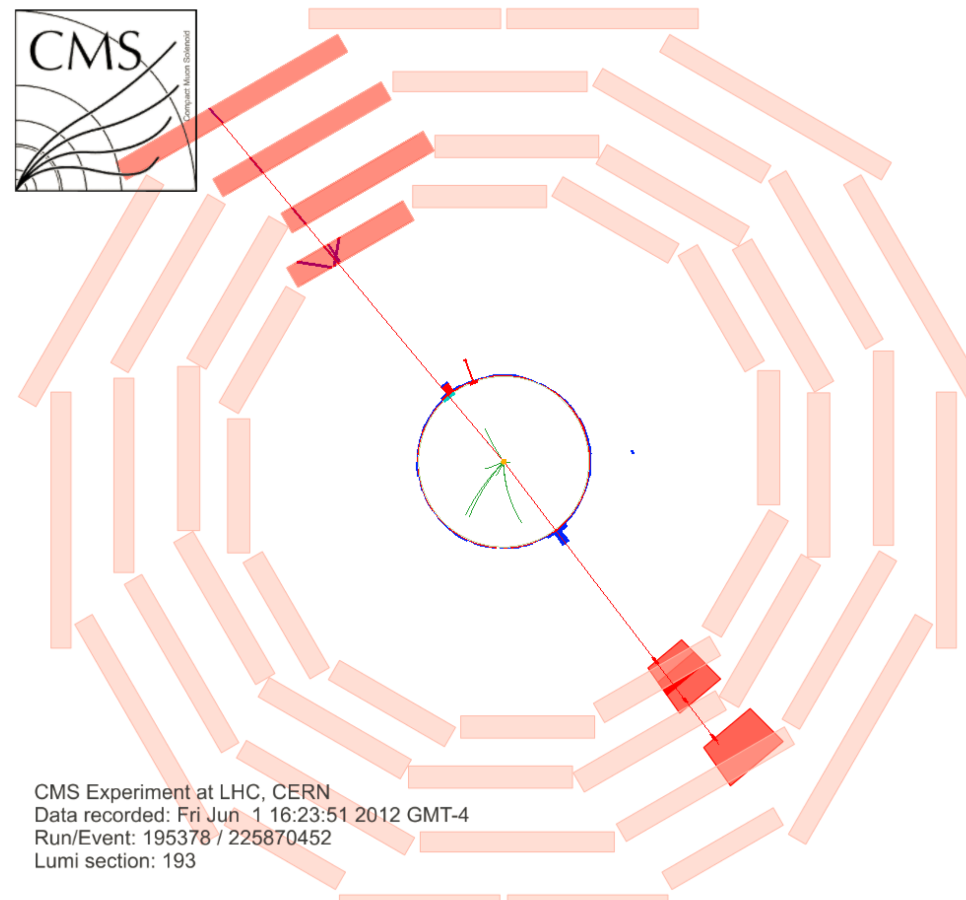
- **Little Higgs theories**
  - Push scale of new physics up
  - Top quark and W boson have partners
- **Hidden valley**



Dilepton Resonances

- ATLAS and CMS di-muon candidates

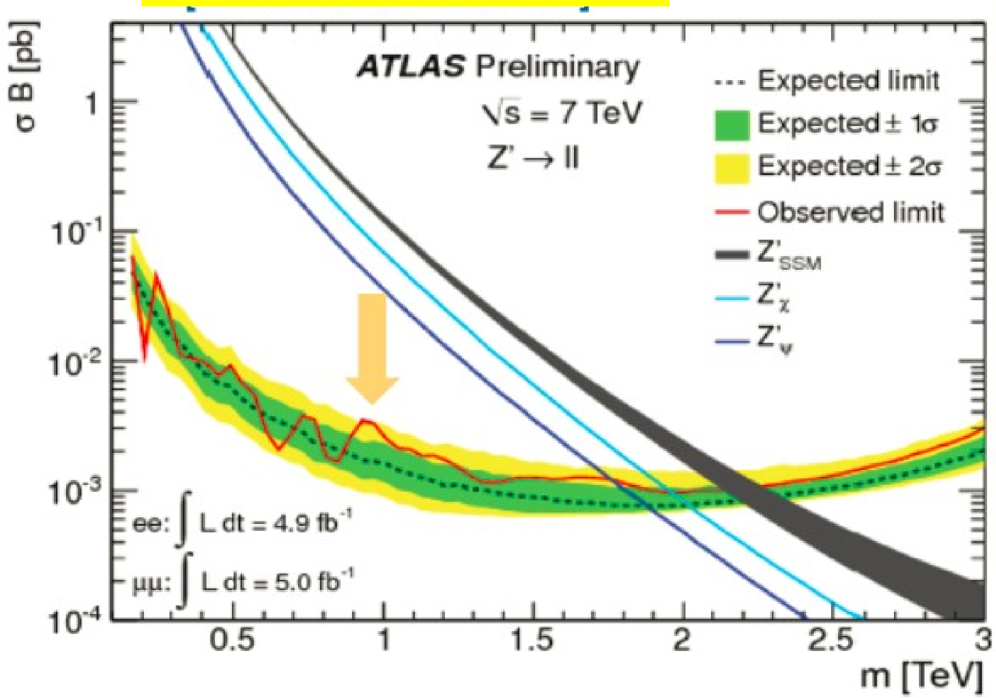




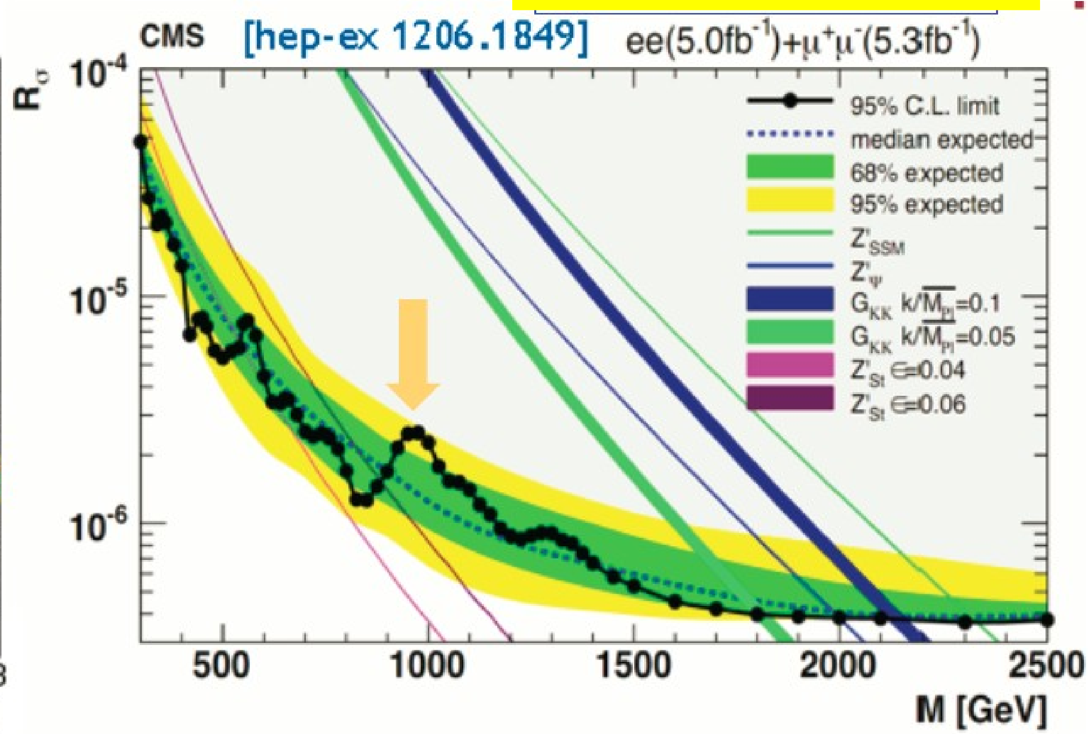
Dilepton resonances from Z'/G_{KK}

- Many BSM models predict narrow *di-lep* resonances
  - Z' with sm like couplings (Γ=30 GeV @ M=1 TeV)
  - Z' of grand unified theories (Γ=6 GeV @ M=1 TeV)
- Some excitement in 2011 data

ATLAS-CONF-2012-007

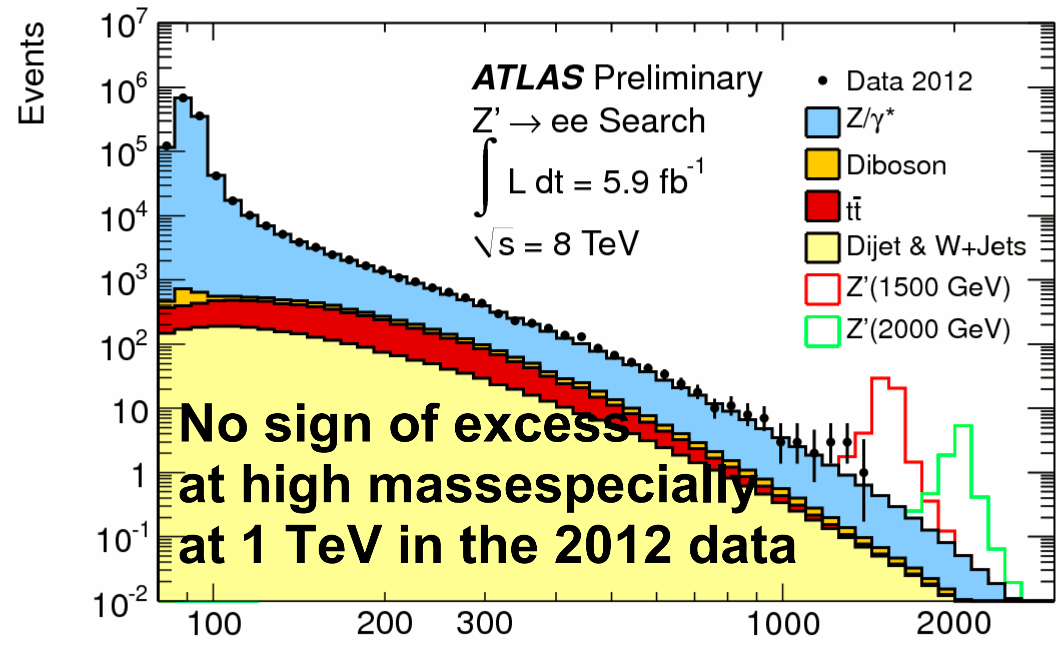


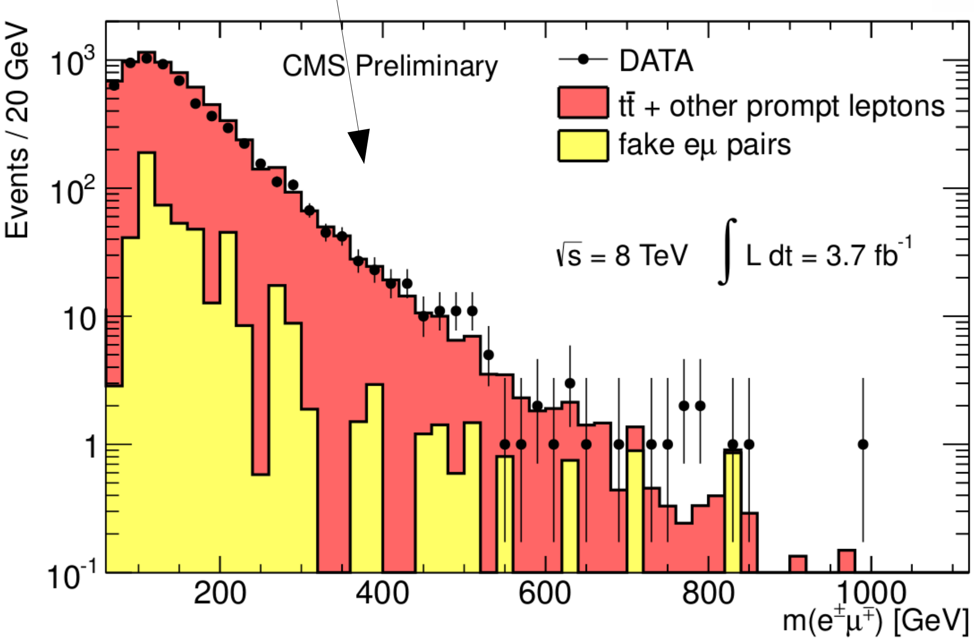
CMS-PAS-EXO-2012-015

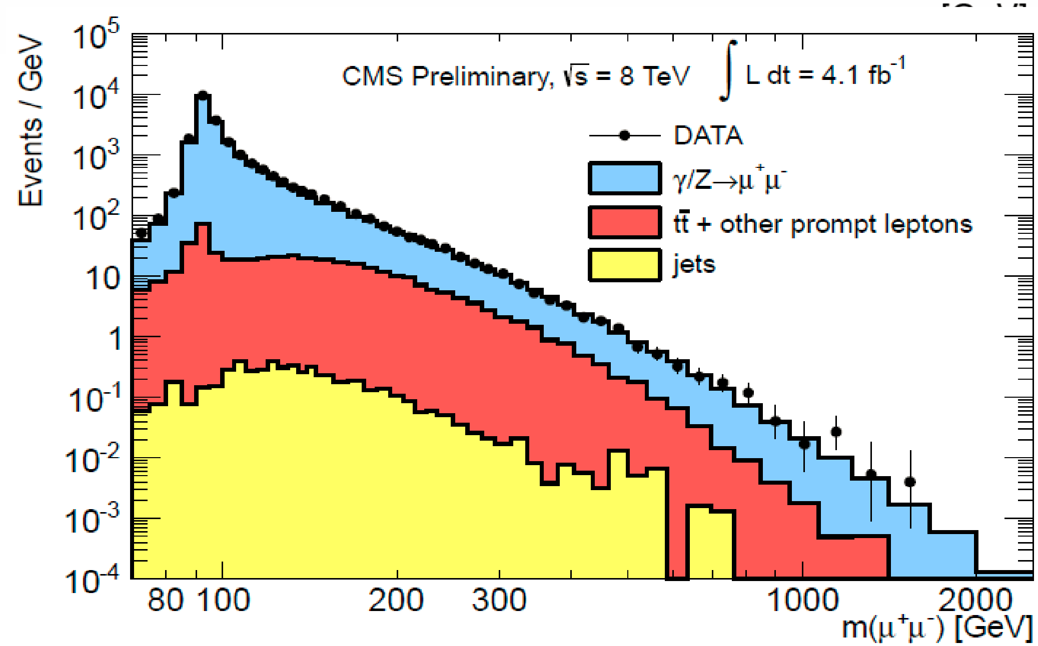


Dilepton resonances from Z'/G_{KK}

- **Event selection:**
  - isolated electron and muons (with dedicated TeV-like reconstruction)
- **Background estimation**
  from data or MC-based







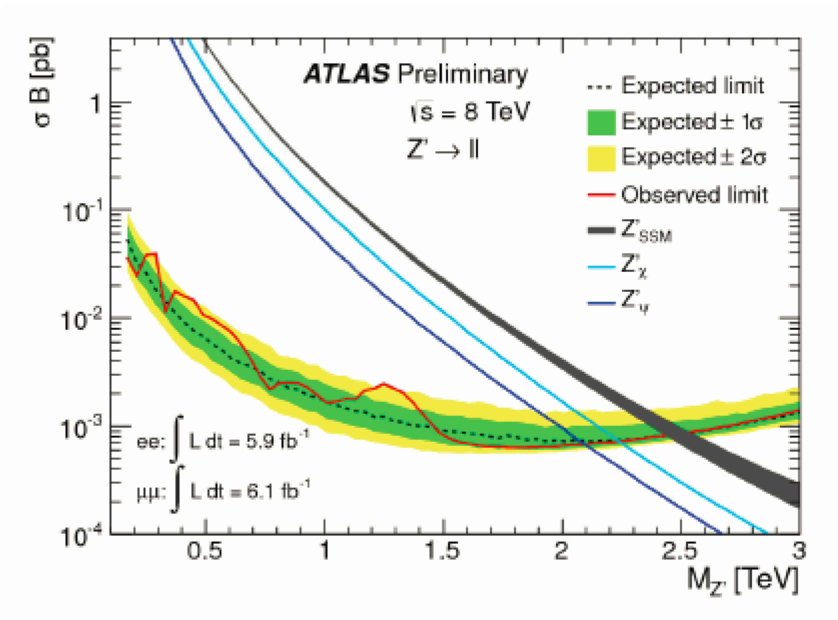
Z' results

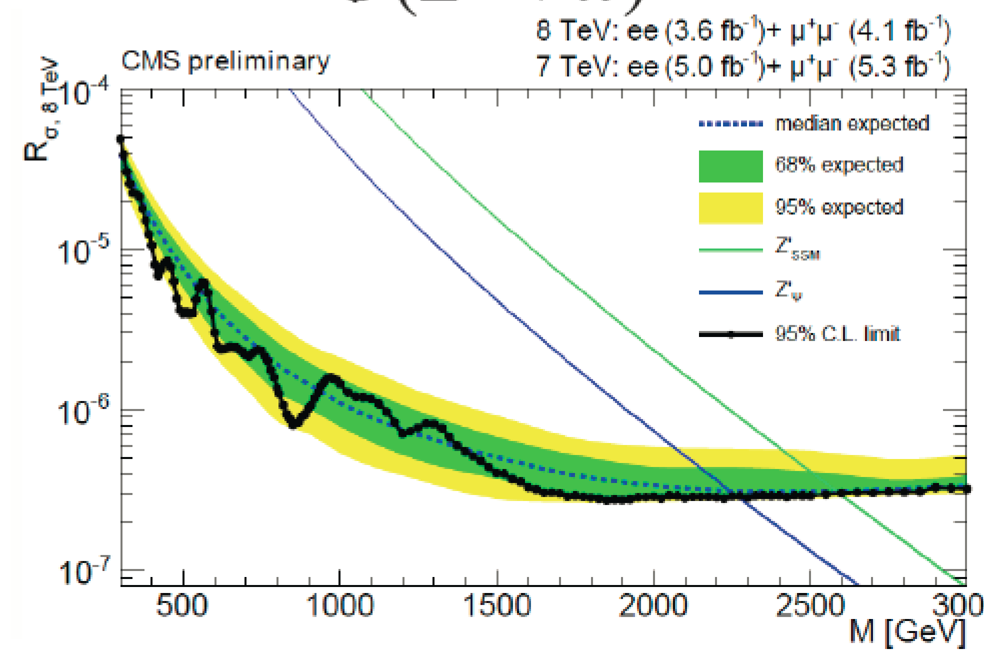
- ATLAS limits

Search for narrow [4-14% σ(M)/M] resonance predicted in many models.

CMS limits on

$$R_\sigma = \frac{\sigma(Z' \to ll)}{\sigma(Z \to ll)}$$





SSM $M_{Z'} > 2.49$ TeV
GUTs: $M_{Z'} > 2.09$ TeV

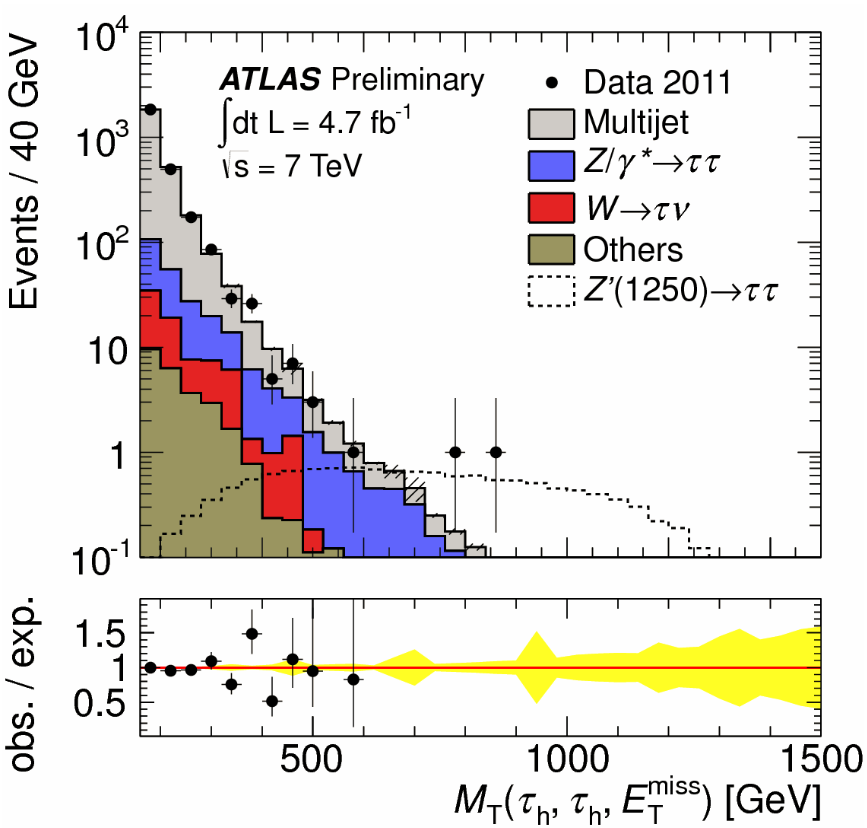
SSM: $M_{Z'} > 2.59$ TeV

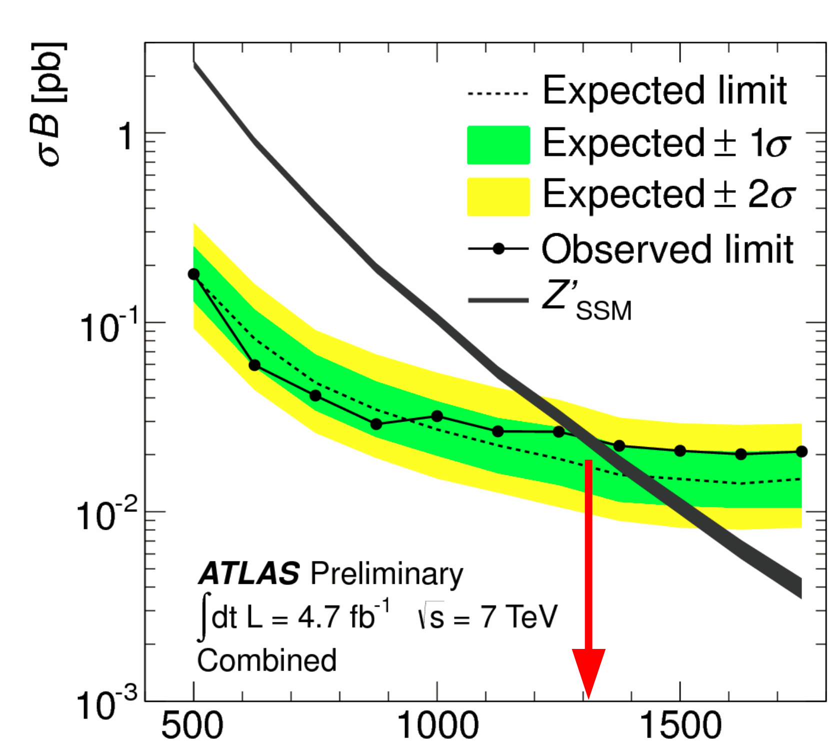
GUTs: $M_{Z'} > 2.26$ TeV

τ τ Resonances

- In some models Z' couples preferentially to 3rd generation
- Decays: had-had (42%), mu-had (23%), e-mu (6%) considered
- Check effective transverse mass

$$M(\tau_1, \tau_2, \not{E}_T) = \sqrt{(E_{\tau_1} + E_{\tau_2} + \not{E}_T)^2 - (\vec{p}_{\tau_1} + \vec{p}_{\tau_2} + \vec{\not{E}}_T)^2}$$



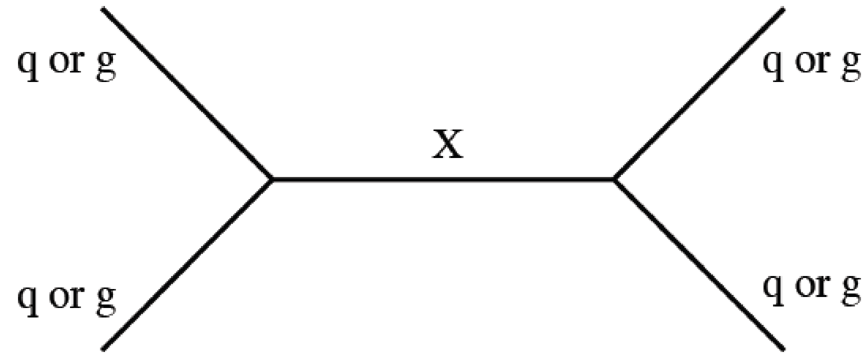


Limit SSM: $M_{Z'} > 1.3$ TeV

ATLAS-CONF-2012-067

Dijets Resonances

- Many models of New Physics predict resonance decaying into dijets

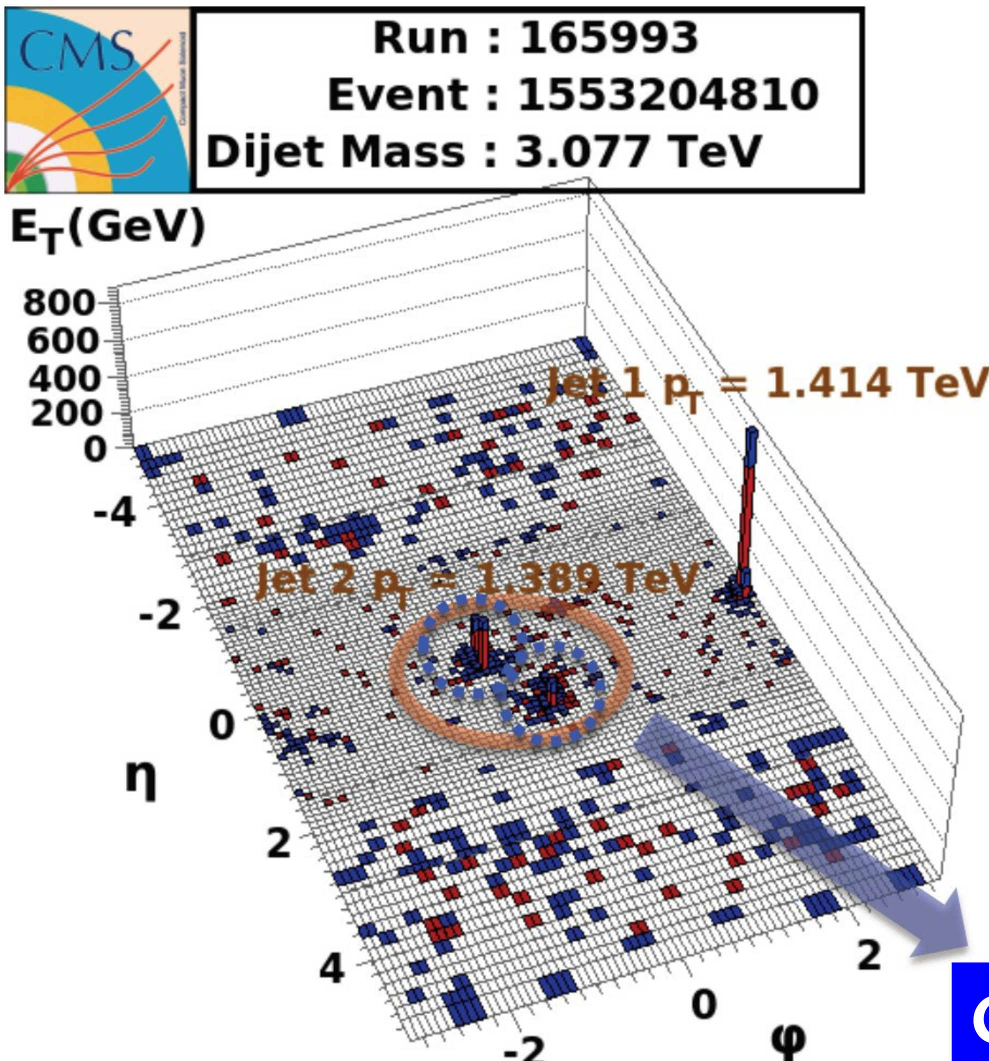


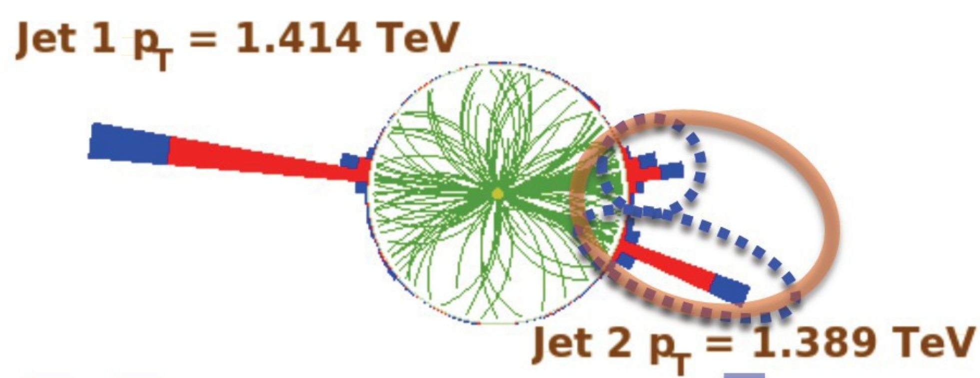
- **Event selection:**
- Trigger based on HT > 550 GeV
- At least 2jets with $|\eta| < 2.5$ & $\Delta\eta_{12} < 1.3$
- Events with dijet invariant mass
  M > 838 GeV
  are selected without any
  requirements on pT of leading jets
- Jets Algos: Particle Flow jets with
  cone 0.5 and 0.7 used for checks
- Special algo: WIDE JET implemented

Models	X
Excited quark	q*
E_6 Diquark	D
Axigluon	A
Coloron	C
RS Graviton	G
Heavy W	W'
Heavy Z	Z'
String	S

Wide Jets

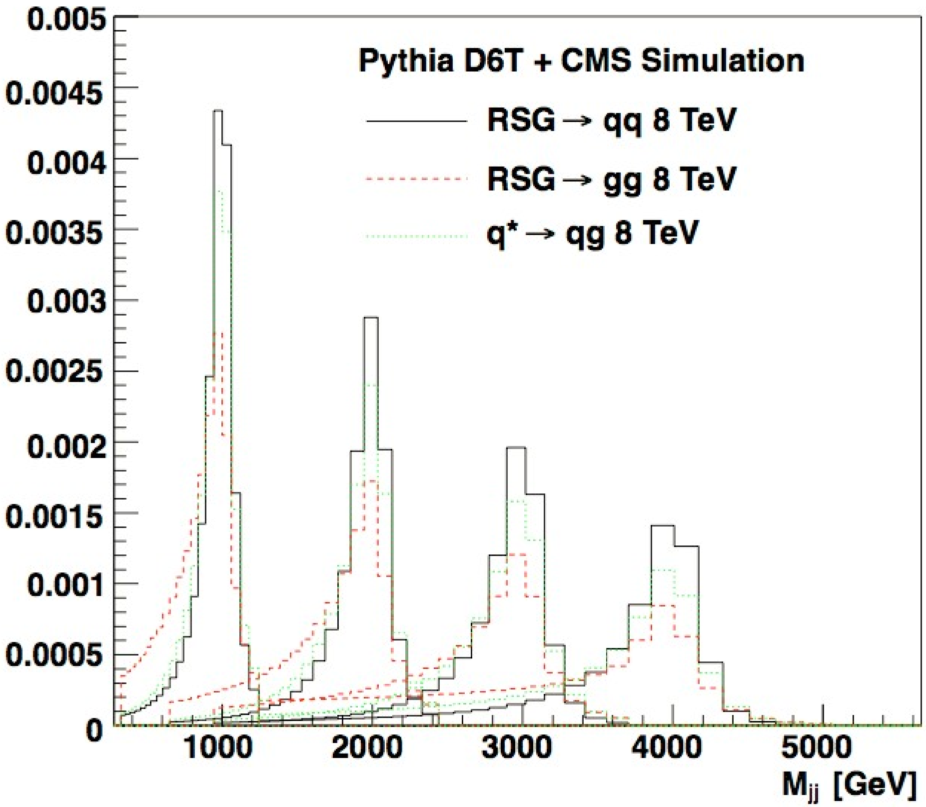
WIDE JETs optimize dijet resonance mass resolution by recombining FSR into the two leading jets

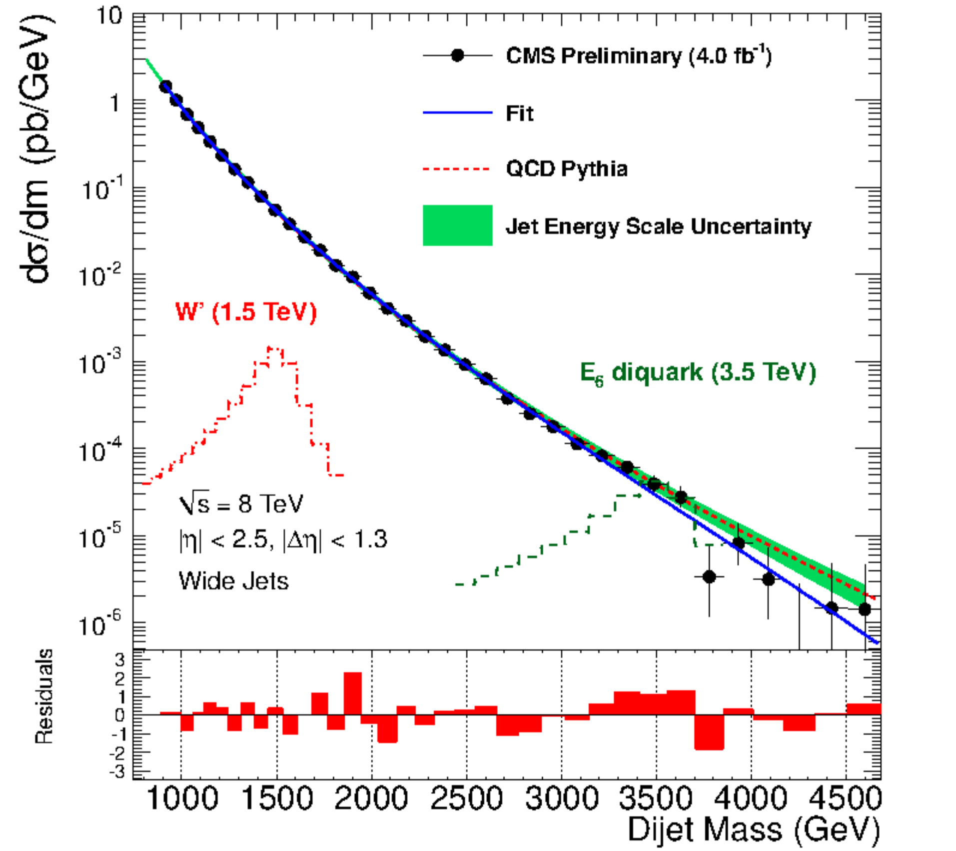




Combined into one WIDE JET

Dijets Resonances





- Resonance shapes from CMS simulation:
  - Resonance decaying to qq, qg, gg
  - Width increases with number of gluons due to FSR

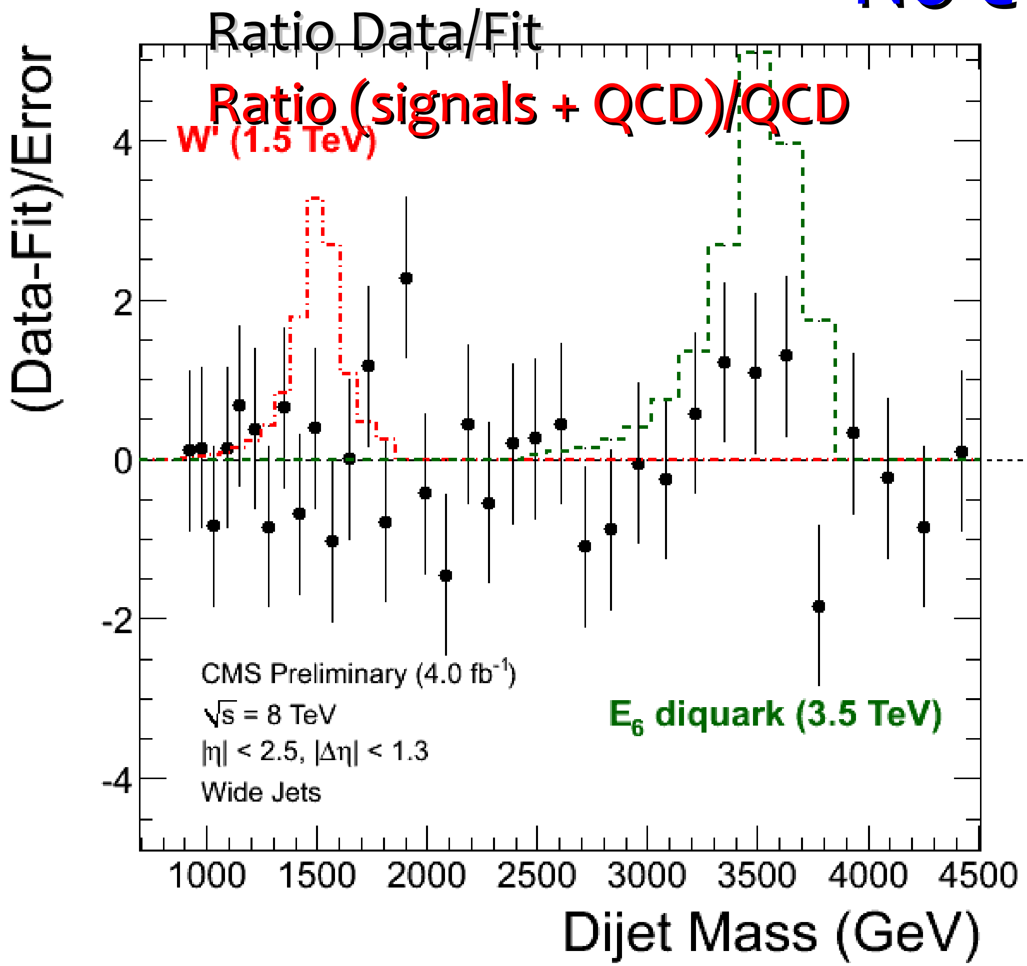
Data fitted with parametrization used also by CDF and ATLAS

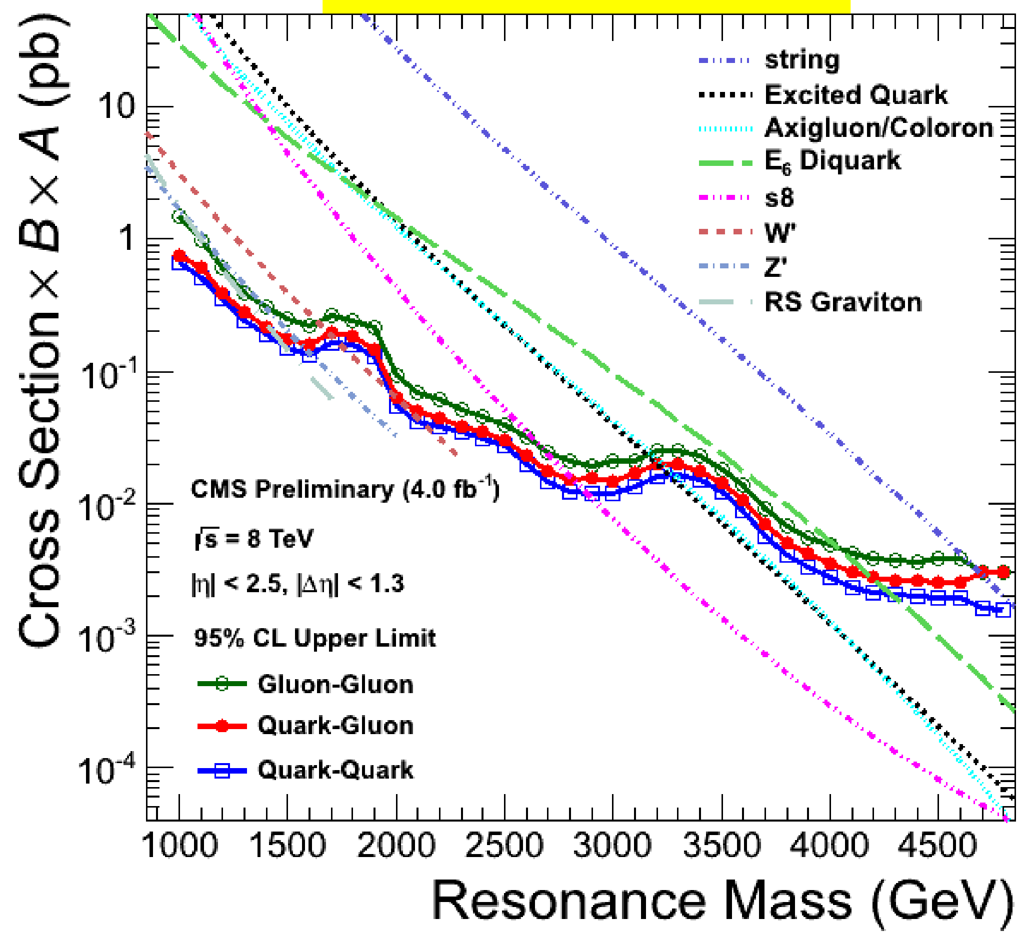
$$\frac{d\sigma}{dm} = \frac{P_0(1 - m/\sqrt{s})^{P_1}}{(m/\sqrt{s})^{P_2 + P_3 \ln(m/\sqrt{s})}}$$

Dijets Resonances LIMITS

- No evidence!

CMS-PAS-EXO-2012-016



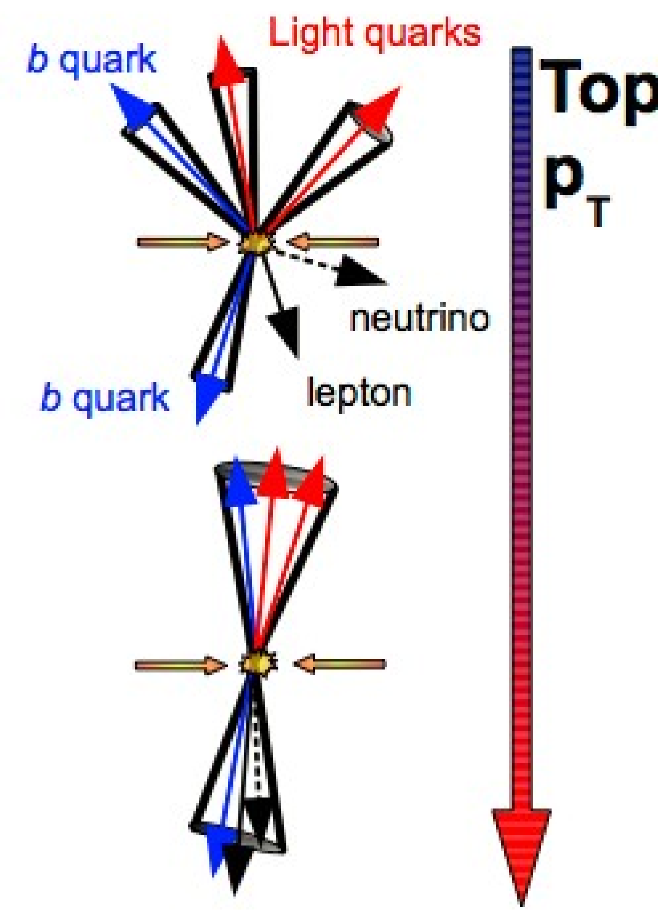


Exclusion limits depend on the model and on the resonance decay mode, because the increase of the width and the shift toward lower masses are enhanced with number of gluons in the final state

The observed 95% CL upper limits for the dijet analysis on $\sigma \times$ Branching Ratio $\times$ Acceptance

Massive TTbar Resonances

- Many models of new physics have large couplings to the top quark and prefer the 3rd generation
- **Benchmark models:**
  - leptophobic topcolor Z'
    (hep-ph/9911288)
  - KK gluon
    (PRD 76 (2007) 115016)
- As we probe higher and higher mass scales, the phenomenology of the top quarks produced in collision events changes
  - Boosted regime



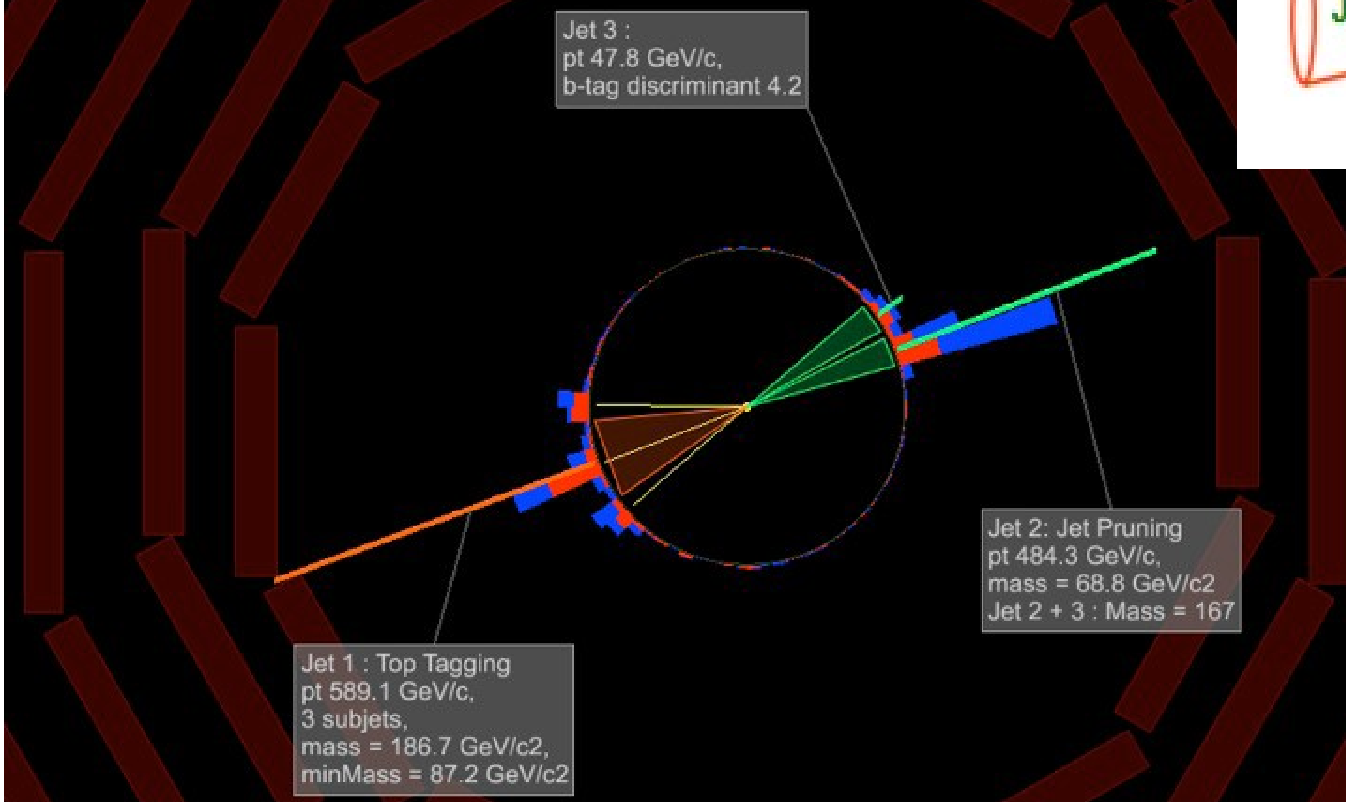
Concept:
recover information from boosted hadronic final states

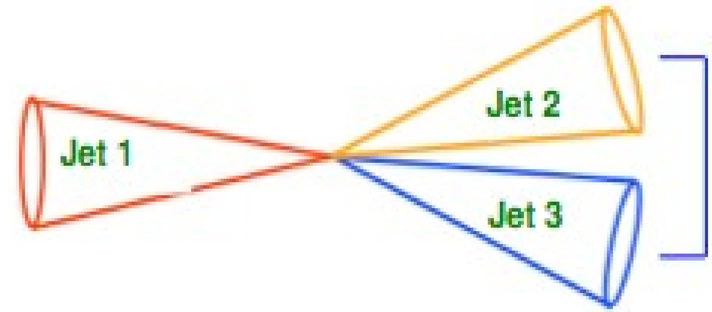
Strategy:
Boosted hadronic objects have a mass scale and different kinematics than QCD

TTbar candidate from CMS

Candidate of TYPE 1+2 jets

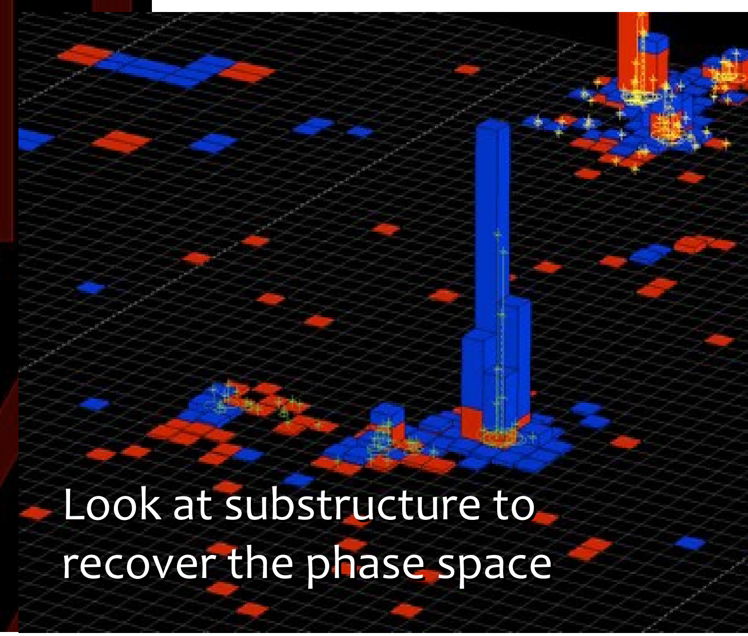
1 top tagged jet + 2 jets (with 1 W-tagged jet)





Tops are boosted for high mass Z'

Search for top quarks in the all hadronic decay channel

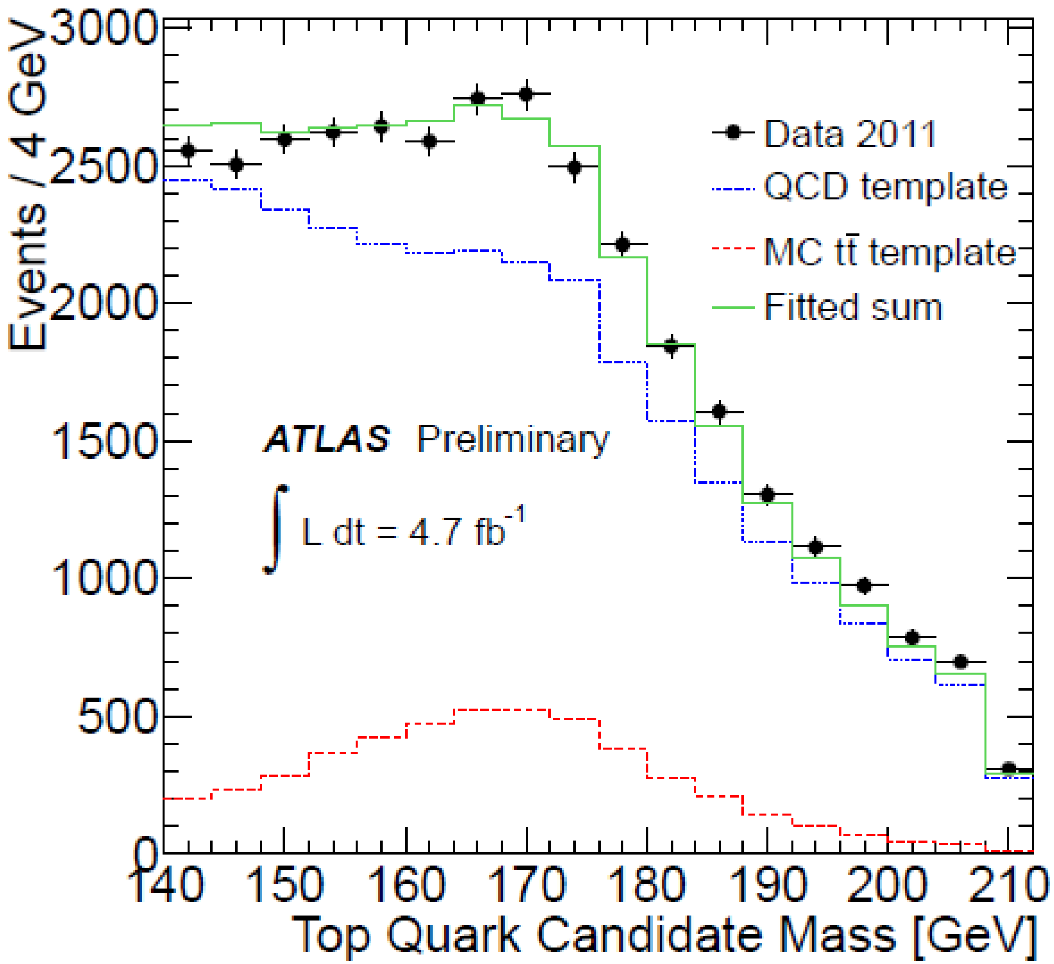


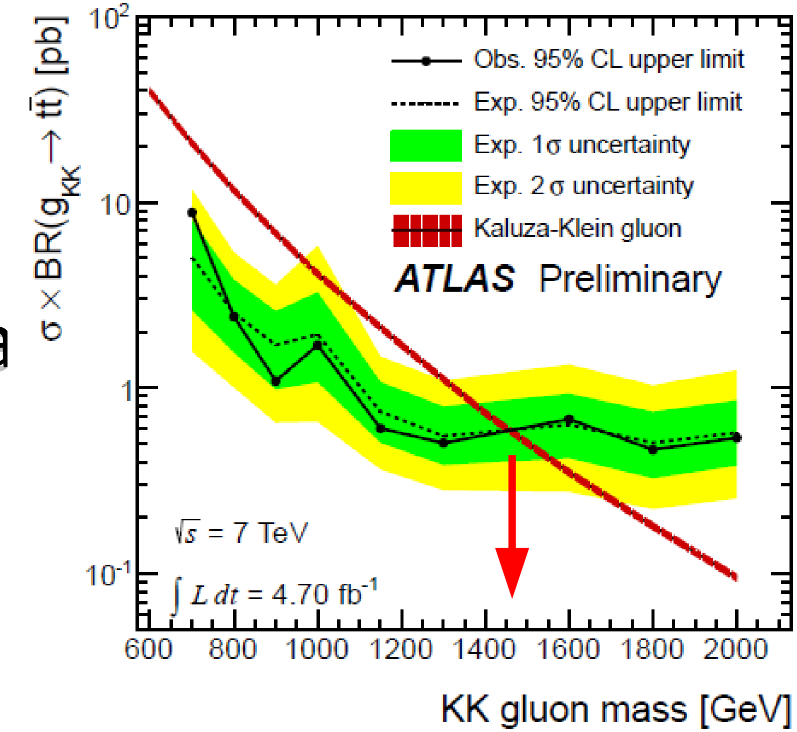
Look at substructure to recover the phase space

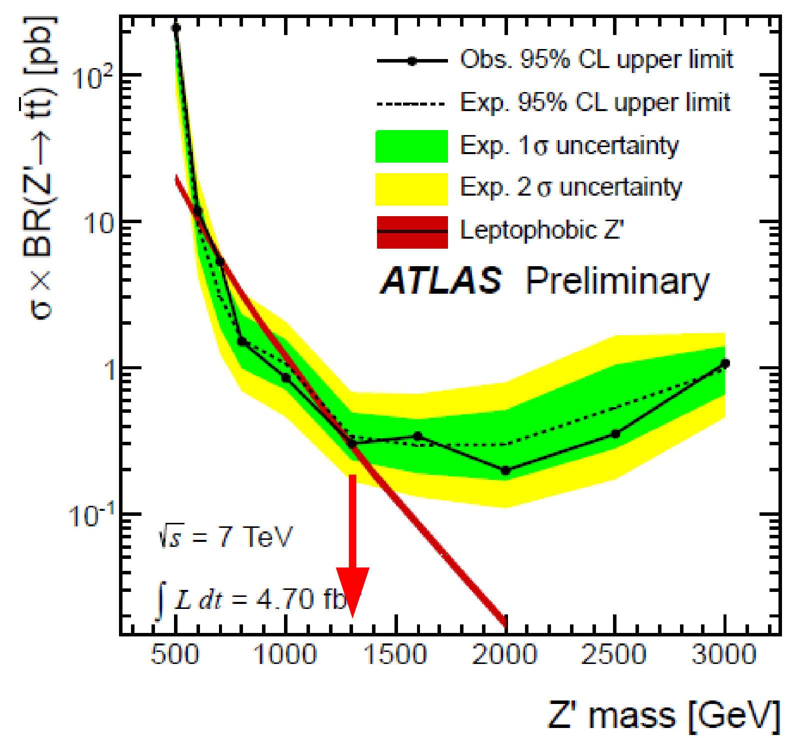
TTbar limits

ATLAS-CONF-2012-102

- New ATLAS result for 7TeV data



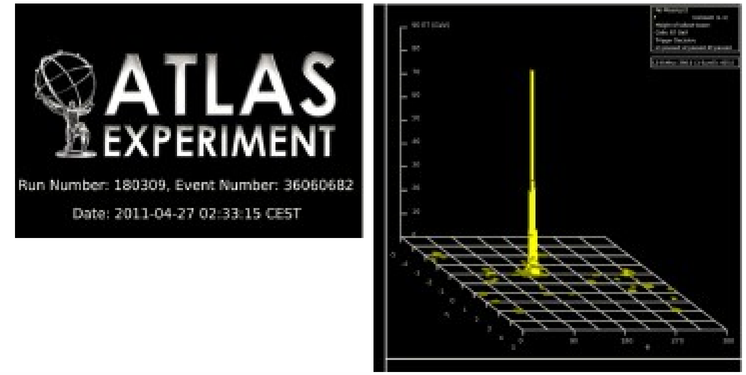




MonoJets/Photons

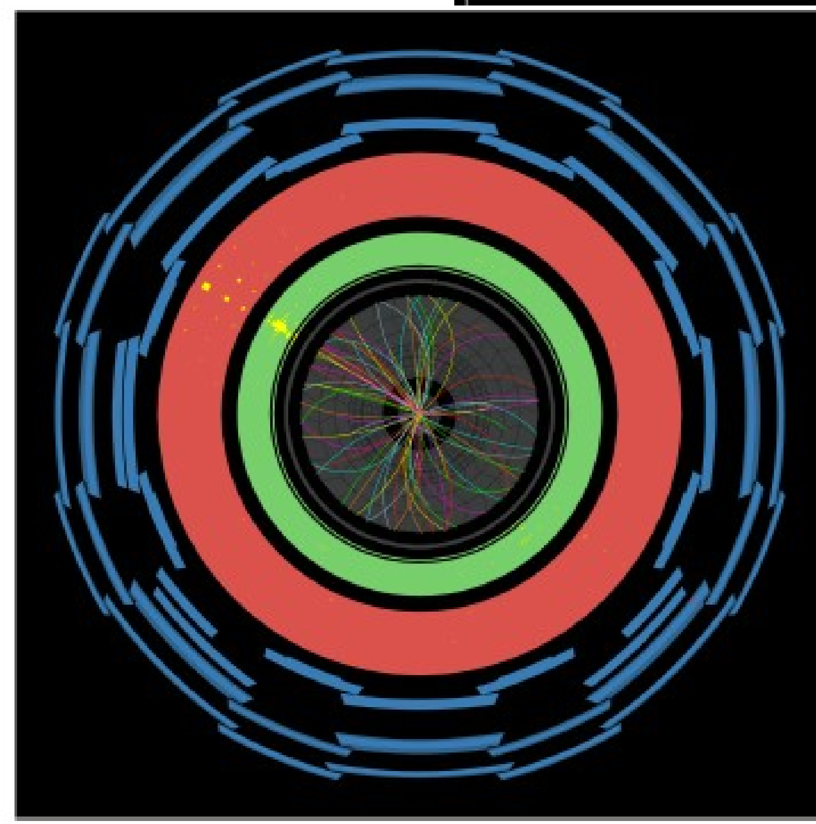
Large Extra-Dimension model:

- δ extra dimensions compactified over a torus with radius R



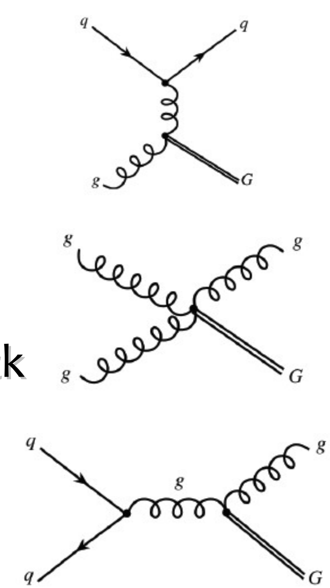
Dark Matter particles WIMPs (χ)

- assume Dirac fermions
- relate production at LHC to χ nucleon interactions



Mono- signature:

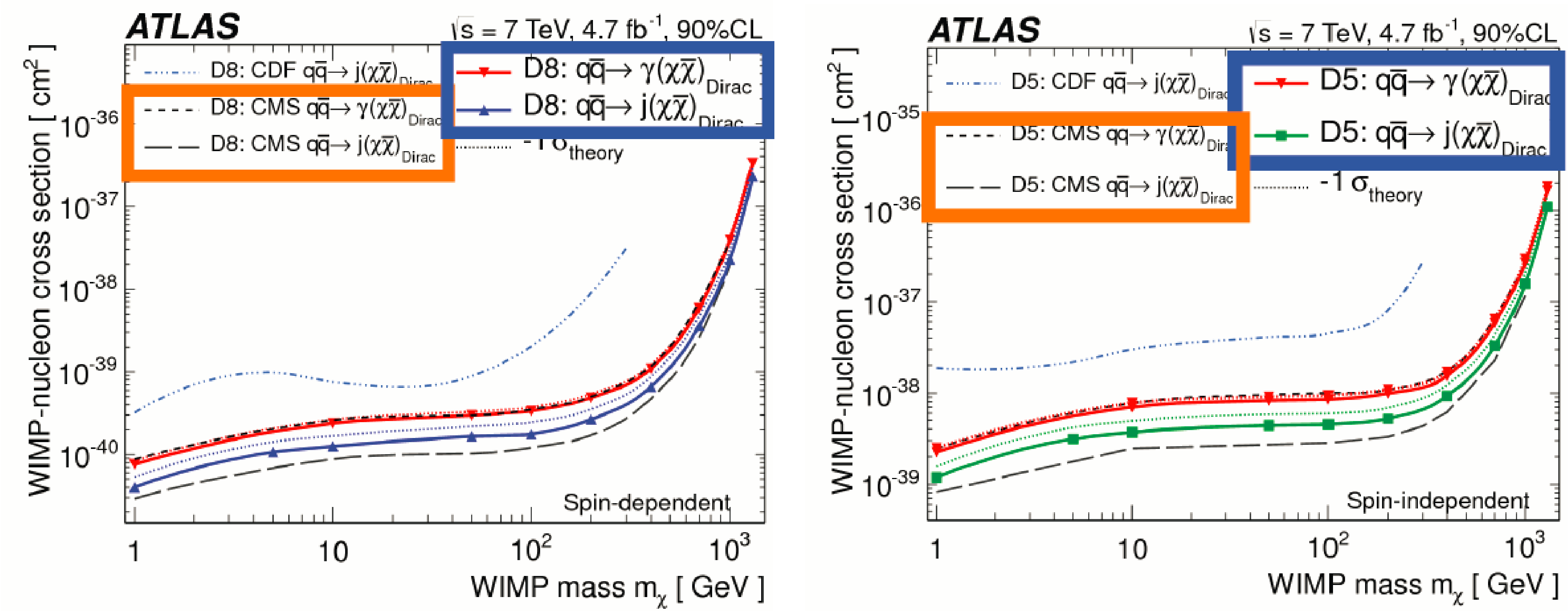
- **One high pT** (~hundred GeV) **jet** in the central region, although 2nd less energetic jet is allowed
- **Large MET** (from Graviton); same magnitude as jet, typically back-to-back



Background:

- from Z(νν)+jets, W+jets

Limits on Dark Matter from MonoJets/Photons

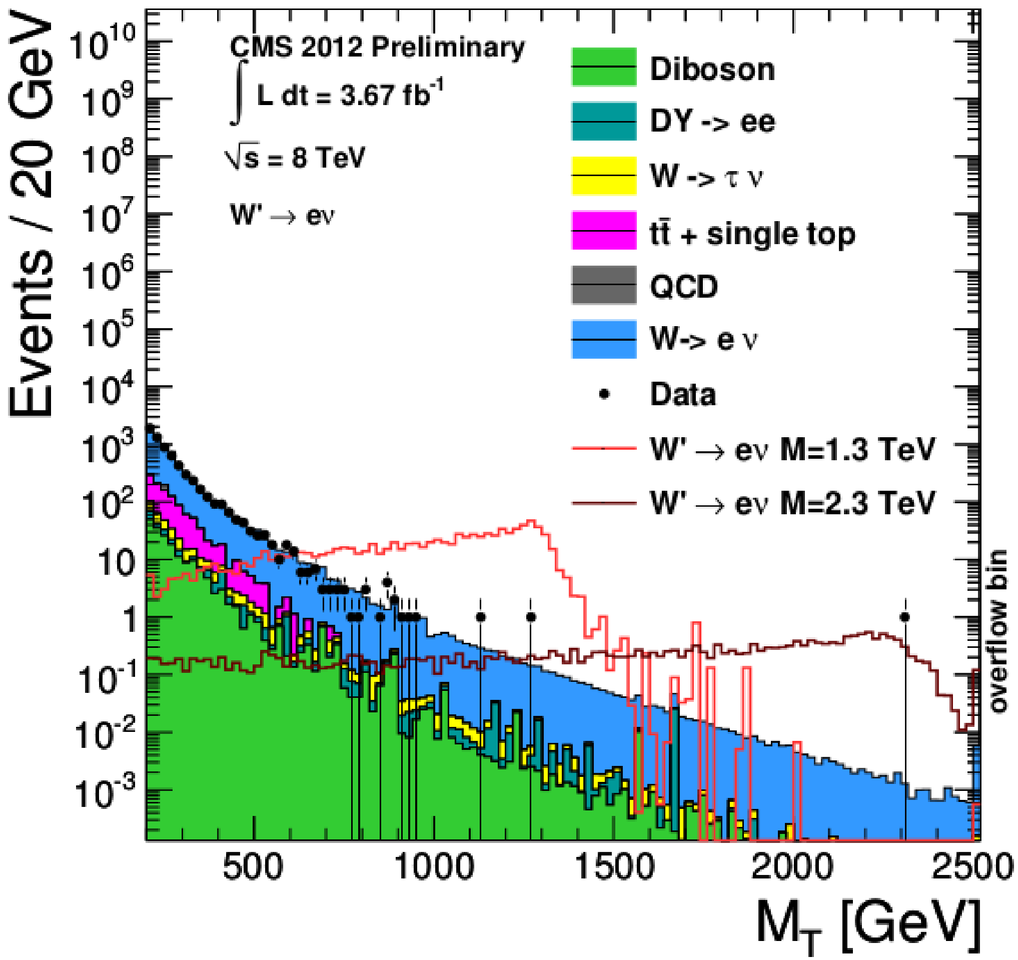


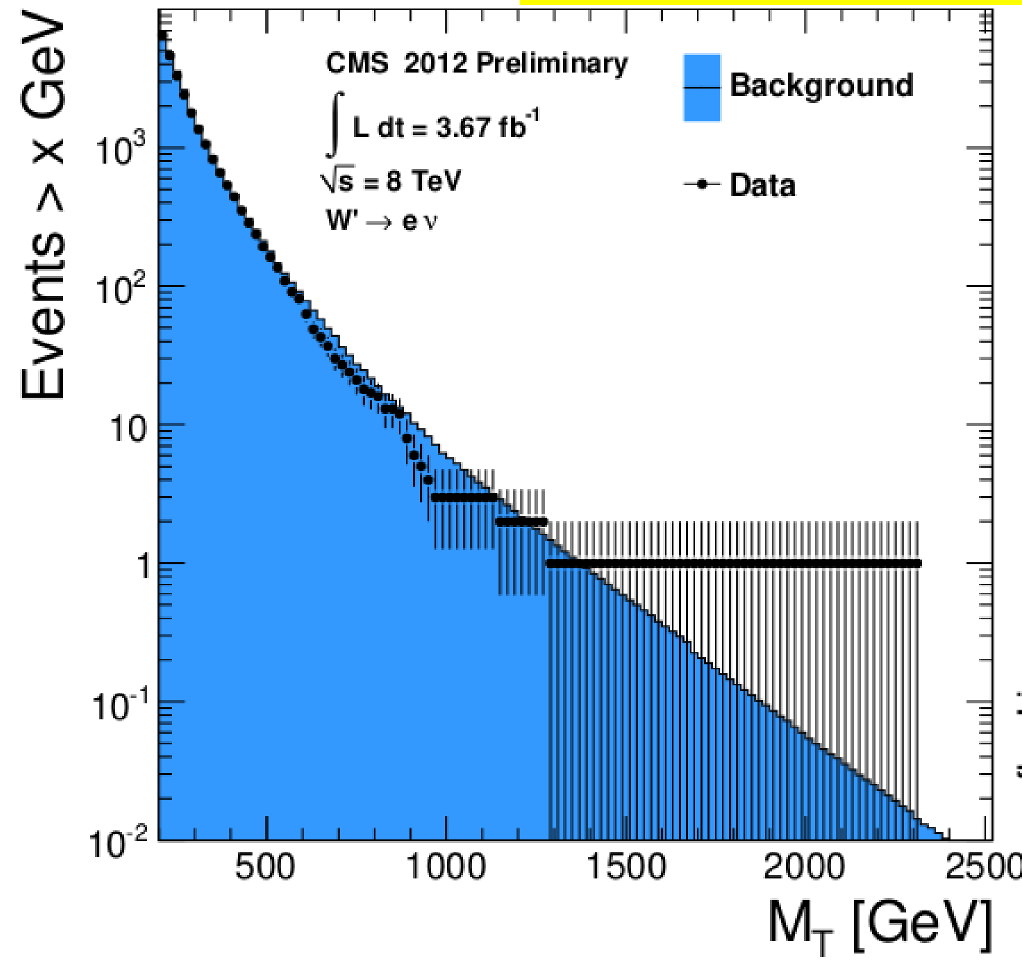
LHC results complement direct detection experiments

- Exceed sensitivity of cryogenic searches for DM spin dependent DM couplings
- Add to reach for low DM masses, M<10 GeV, for spin independent couplings

W' with leptonic decay
Electron Channel

CMS-PAS-EXO-2012-010



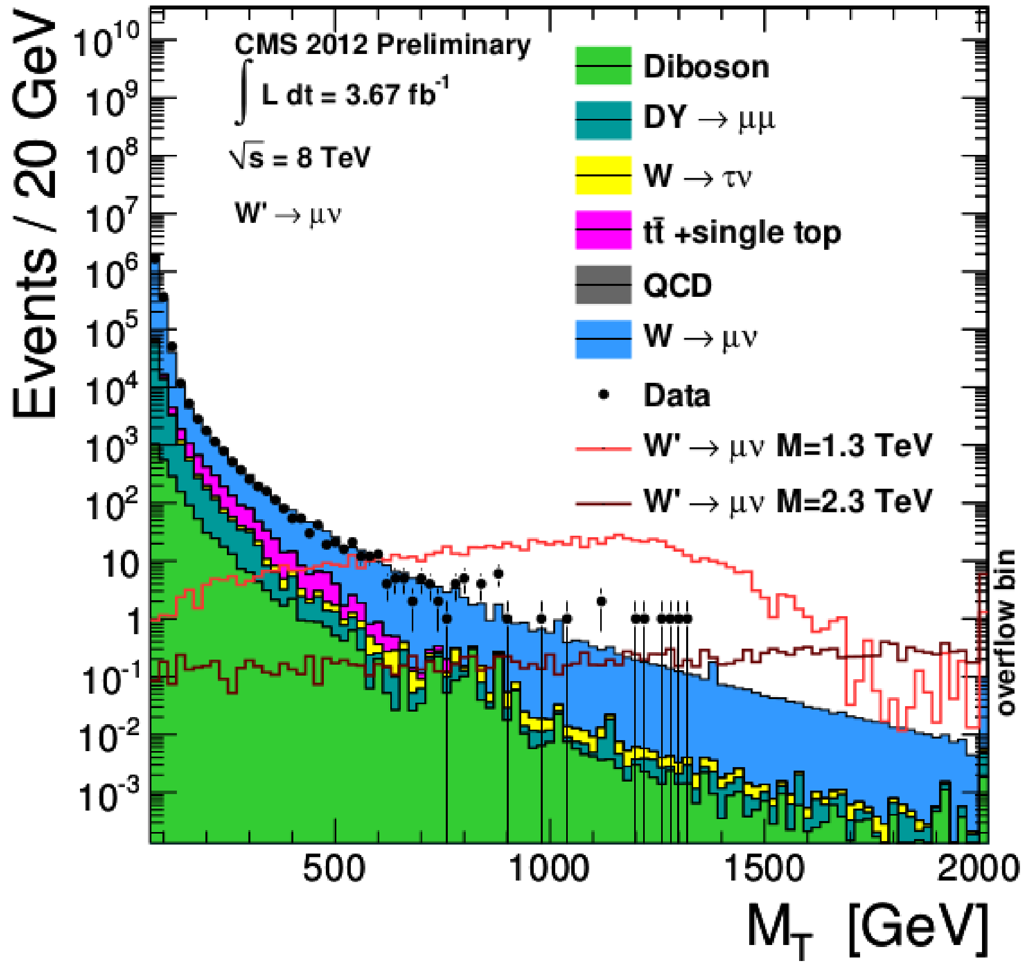


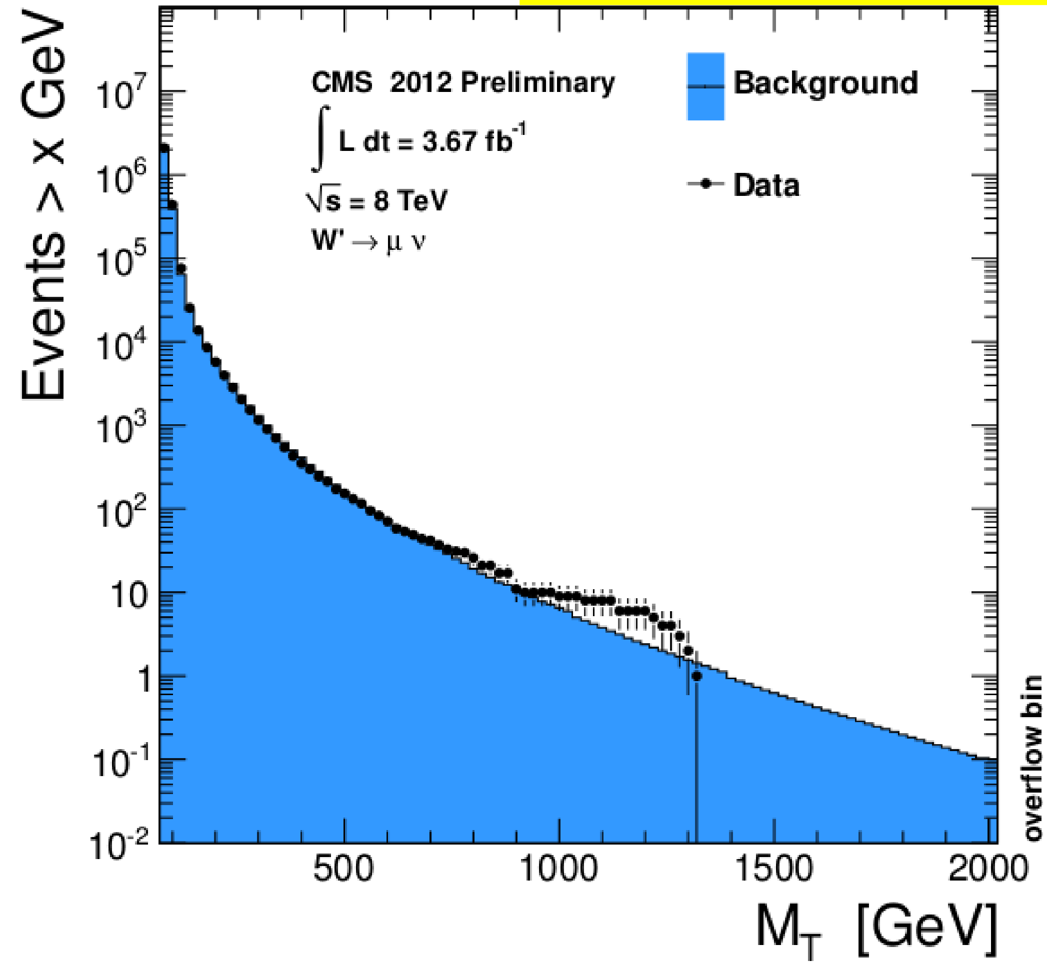
$$M_{\mathrm{T}} = \sqrt{2 \cdot p_{\mathrm{T}}^{\ell} \cdot E_{\mathrm{T}}^{\mathrm{miss}} \cdot (1 - \cos \Delta\phi_{\ell,\nu})}$$

single-electron trigger **pT > 85 GeV**

W' with leptonic decay
Muon Channel

CMS-PAS-EXO-2012-010

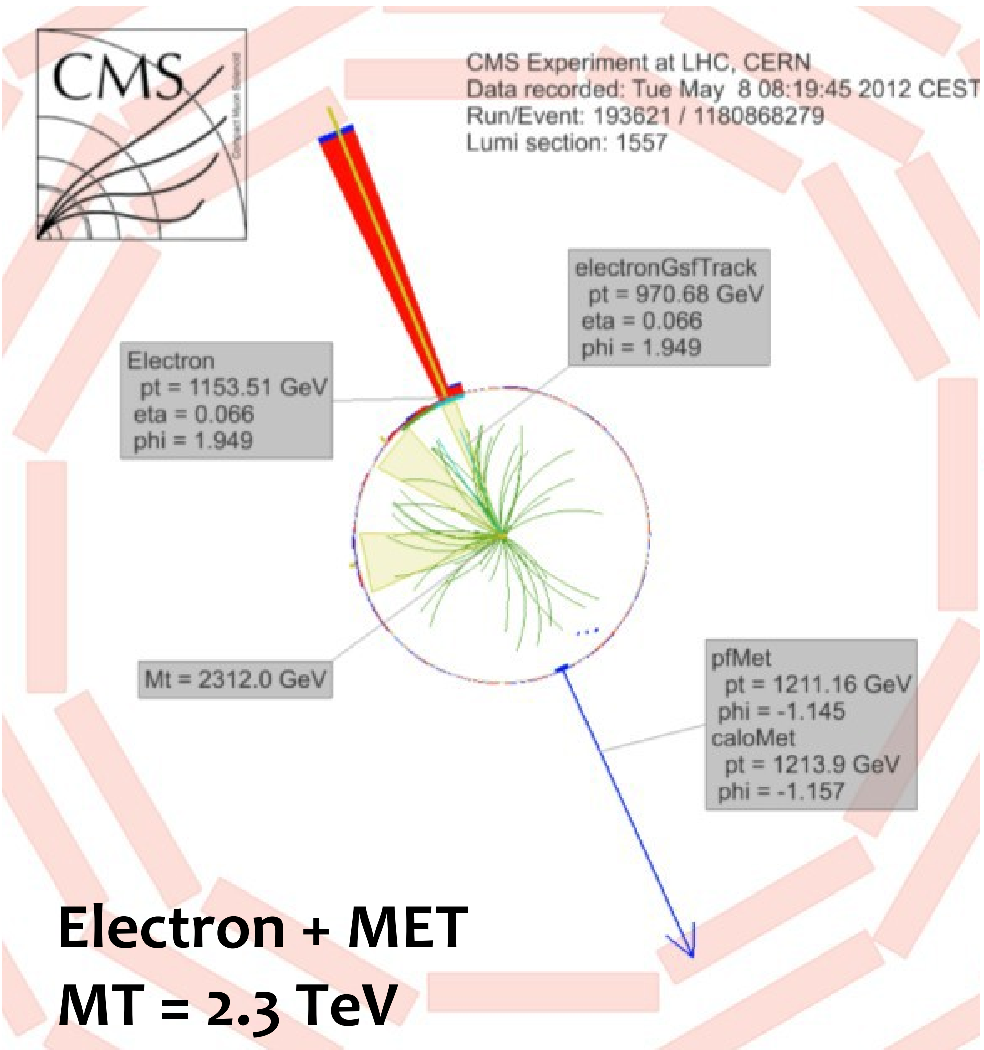




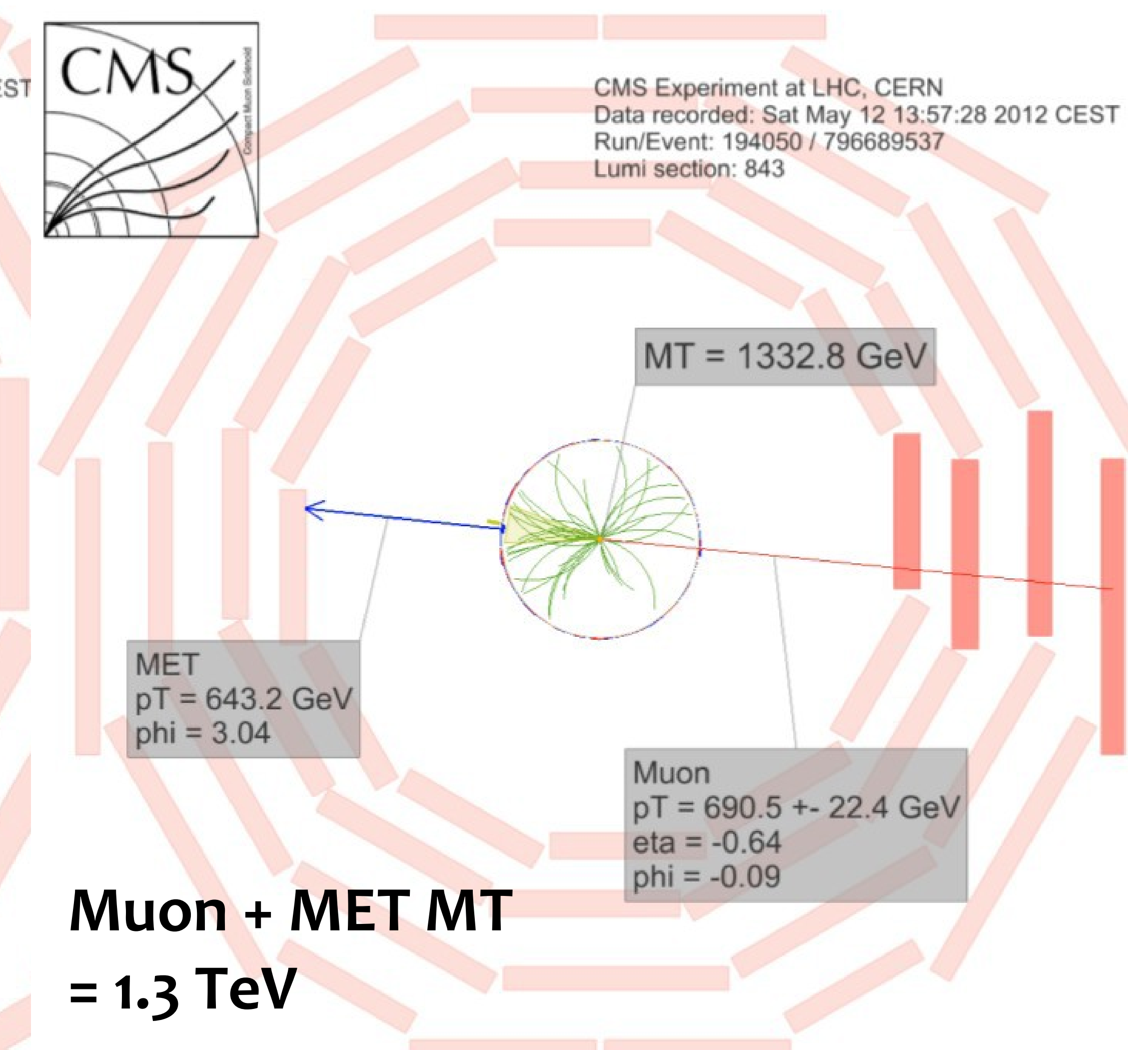
$$M_{\rm T} = \sqrt{2 \cdot p_{\rm T}^{\ell} \cdot E_{\rm T}^{\rm miss} \cdot (1 - \cos \Delta\phi_{\ell,\nu})}$$

single-muon trigger **pT > 40 GeV**

W' candidates



Electron + MET
MT = 2.3 TeV

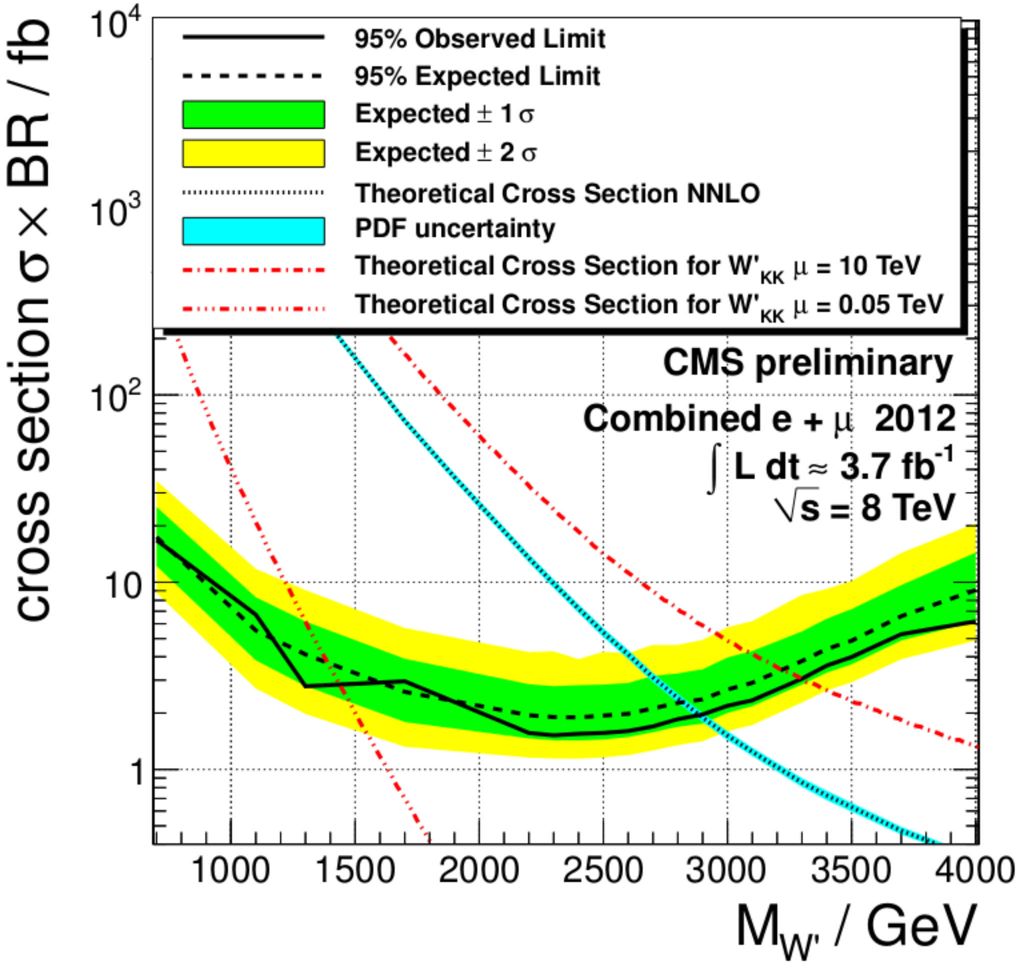


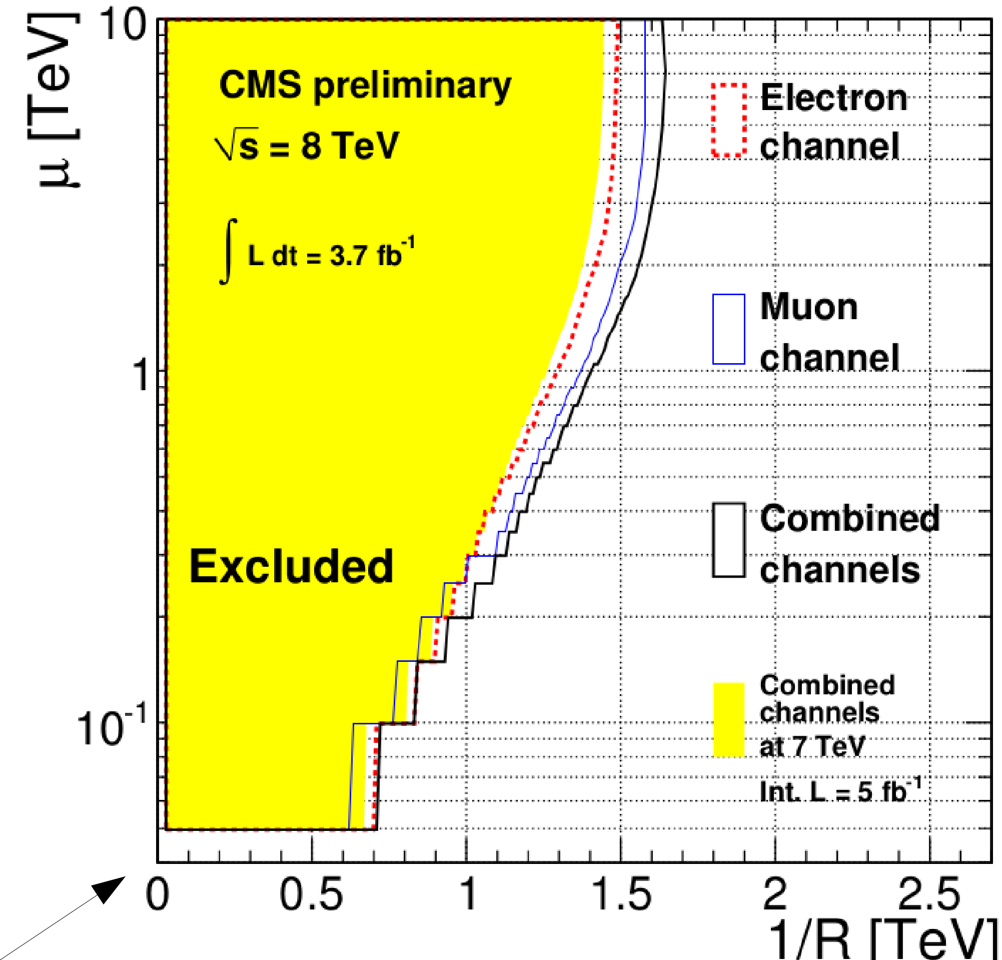
Muon + MET MT
= 1.3 TeV

Limits on W'

- **Combined elec+muon**

CMS-PAS-EXO-2012-010





The SPLIT-UED parameter space is defined by two parameters [1/R, μ] with μ being the bulk mass parameter of the fermion field in five dimensions

95% CL limit on SPLIT-UED derived from the W' mass limits taking into account the corresponding width of the $W2_{KK}$ state

Microscopic Black Holes

- The possibility of production of microscopic black holes in particle collisions has been predicted in models with low scale gravity

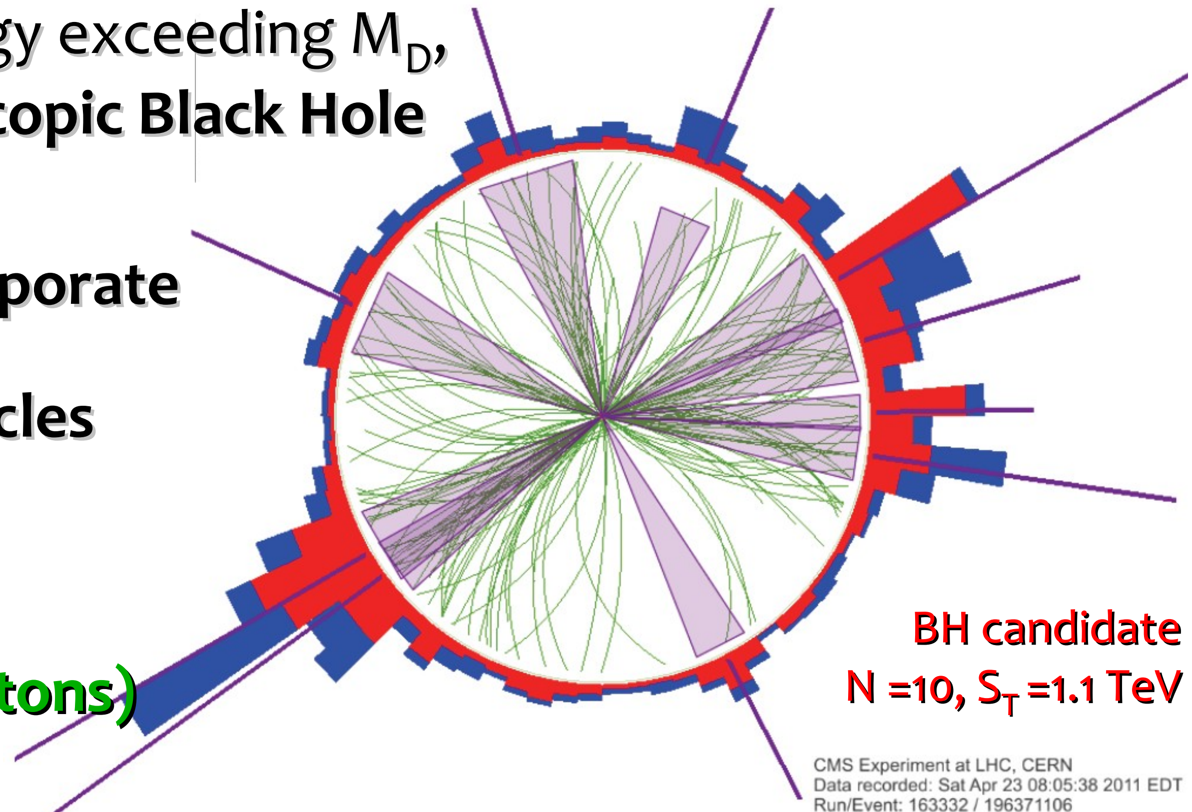
ADD ED, [Arkani-Hamed, Dimopoulos, Dvali, Phys. Lett. B 429, 263 & Phys. Rev. D59,086004]

- If the **"true" Planck scale M_D** is in the 1 TeV range, partons colliding with energy exceeding M_D, may **collapse into a Microscopic Black Hole**

- Once produced, the **BH evaporate** almost instantaneously by **emitting energetic particles**

- **Multi-particle signature**

  N objects (jets,leptons,photons)



BH candidate

N =10, S_T =1.1 TeV

Microscopic Black Holes

CMS Analysis strategy: Events with large total transverse energy have been analyzed for the presence of multiple energetic jets, leptons, and photons, typical of a signal from an evaporating black hole

- **Multiplicity (N)**
  Number of objects (jet,lep,γ) with pT>50 GeV in an event, excluding MET

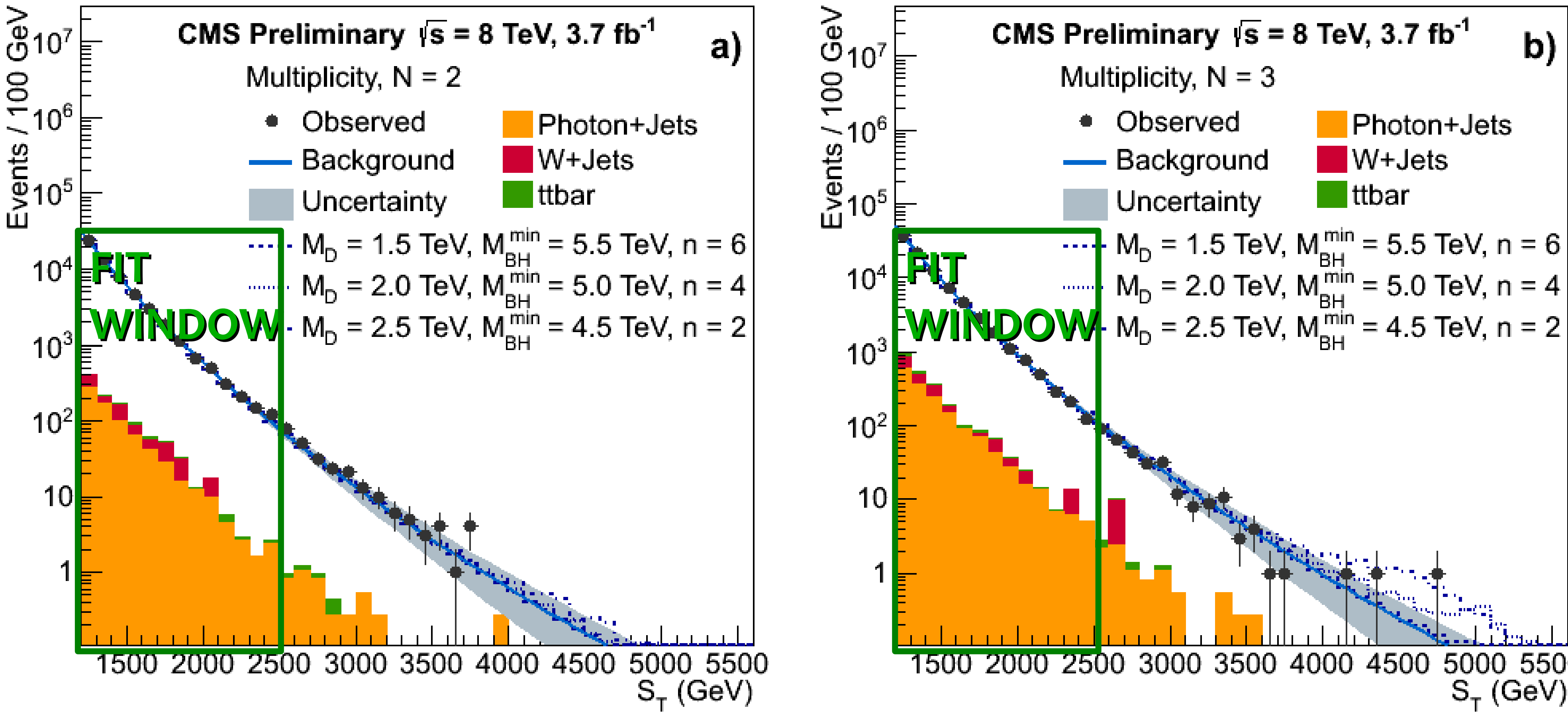
- **S_T Scalar**
  p_T sum of all objects with ET>50 GeV + MET (if greater >50 GeV)
  S_T is almost independent of the final state multiplicity N
  => QCD bkg. estimation

- **Separation**
  ΔR (jet, lep/γ) > 0.5 and ΔR (lep/γ, lep/γ) > 0.3

- **Trigger** on total jet activity H_T in 350 - 550 GeV
  100% eff for S_T > 700 GeV

Microscopic Black Holes

Exclusive multiplicities for bkg. estimation



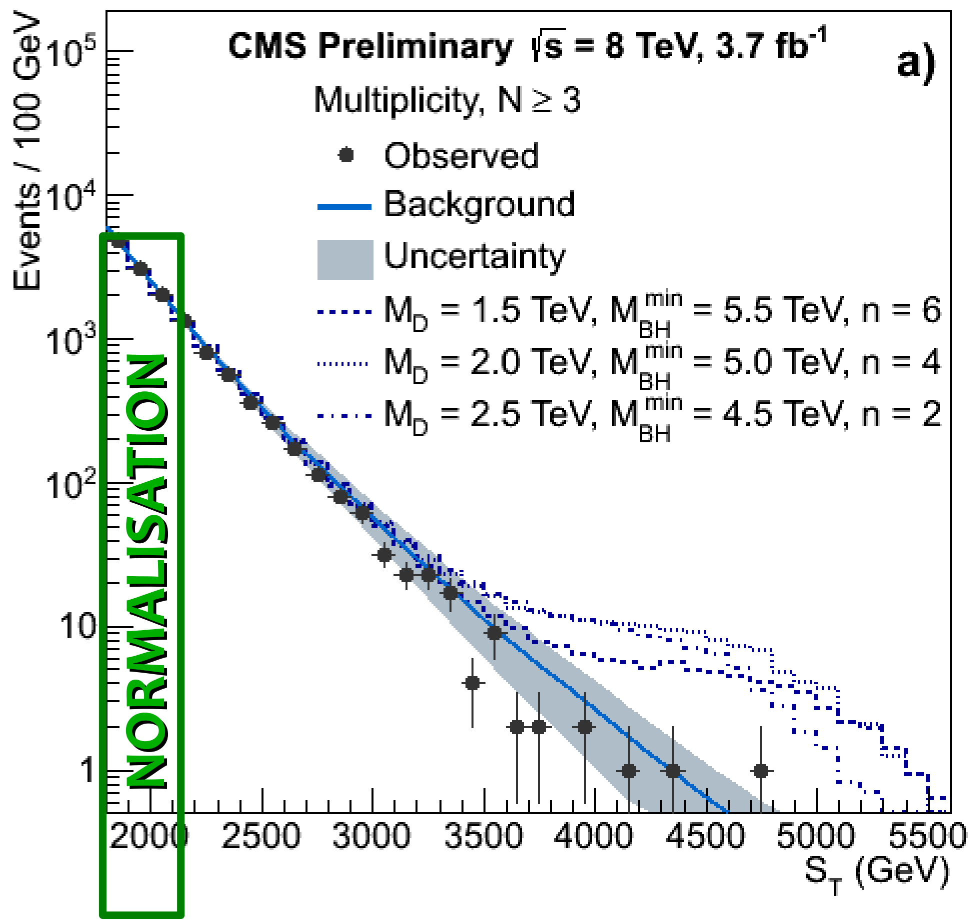
- Non-QCD backgrounds < 1% of data-driven bkg.

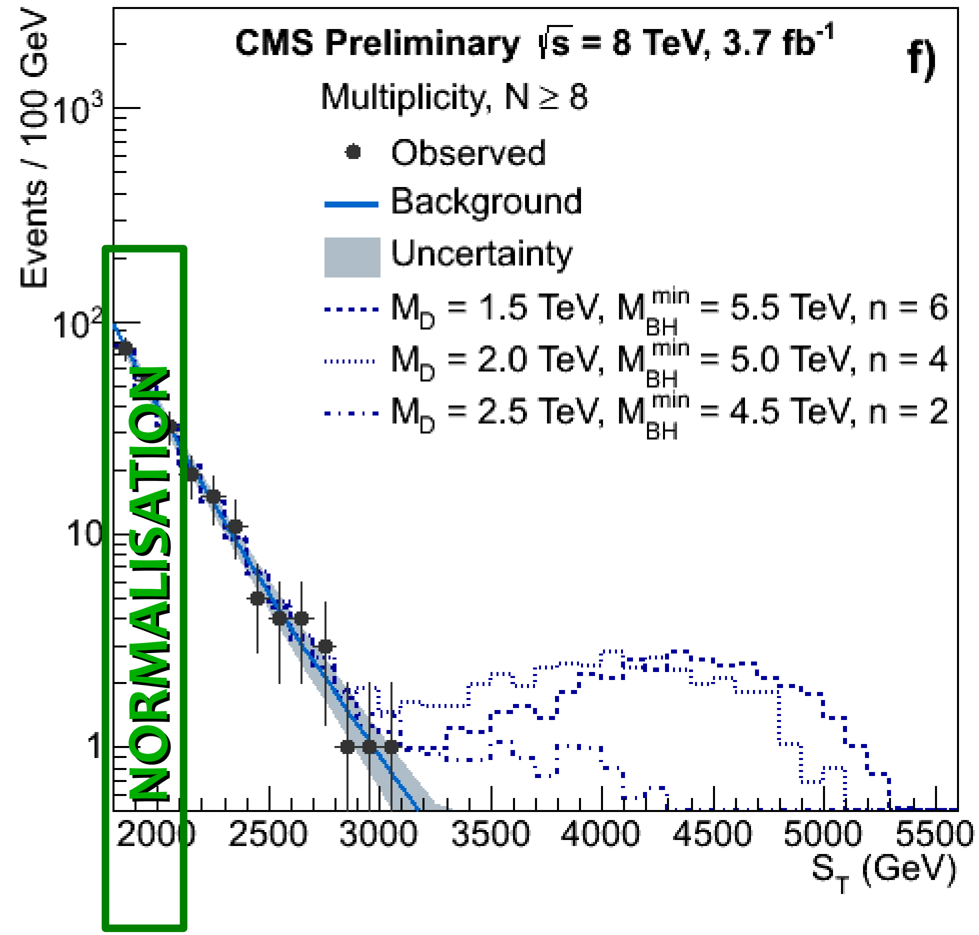
CMS-PAS-EXO-2012-009

- There is no signal contamination in the fitting and normalization region
- Data-driven bkg. describes data consistently in

Microscopic Black Holes

Inlusive multiplicities for searches from N >=3 to 8





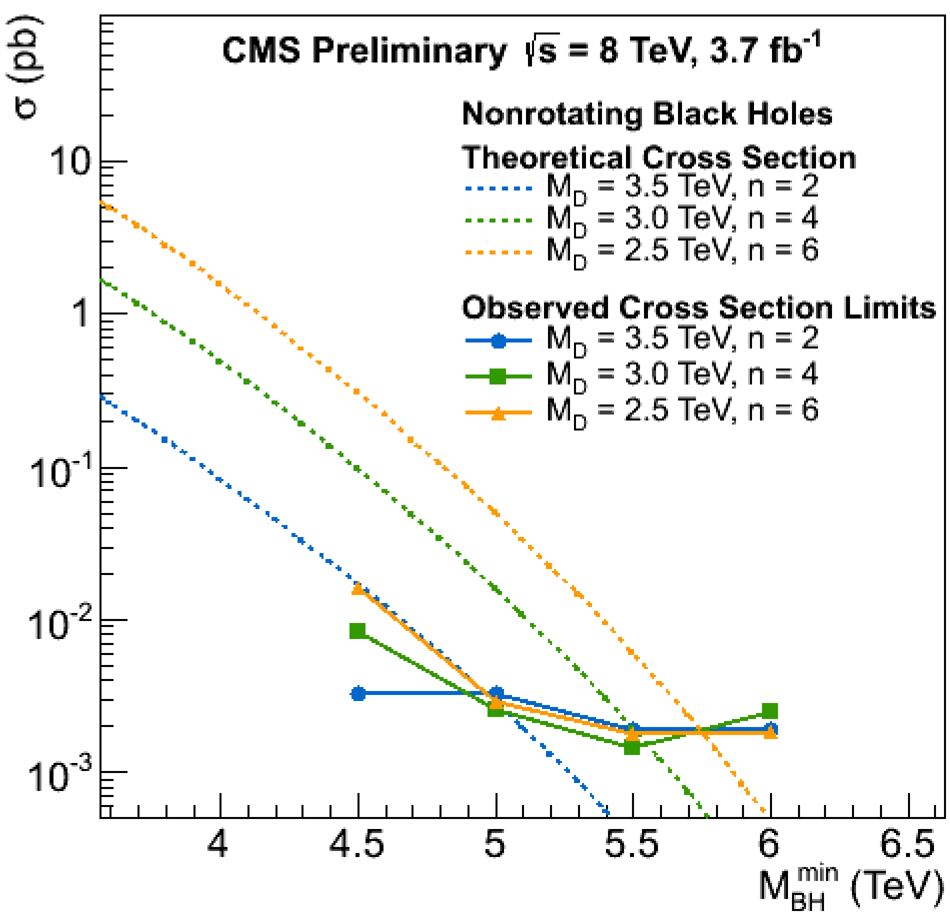
CMS-PAS-EXO-2012-009

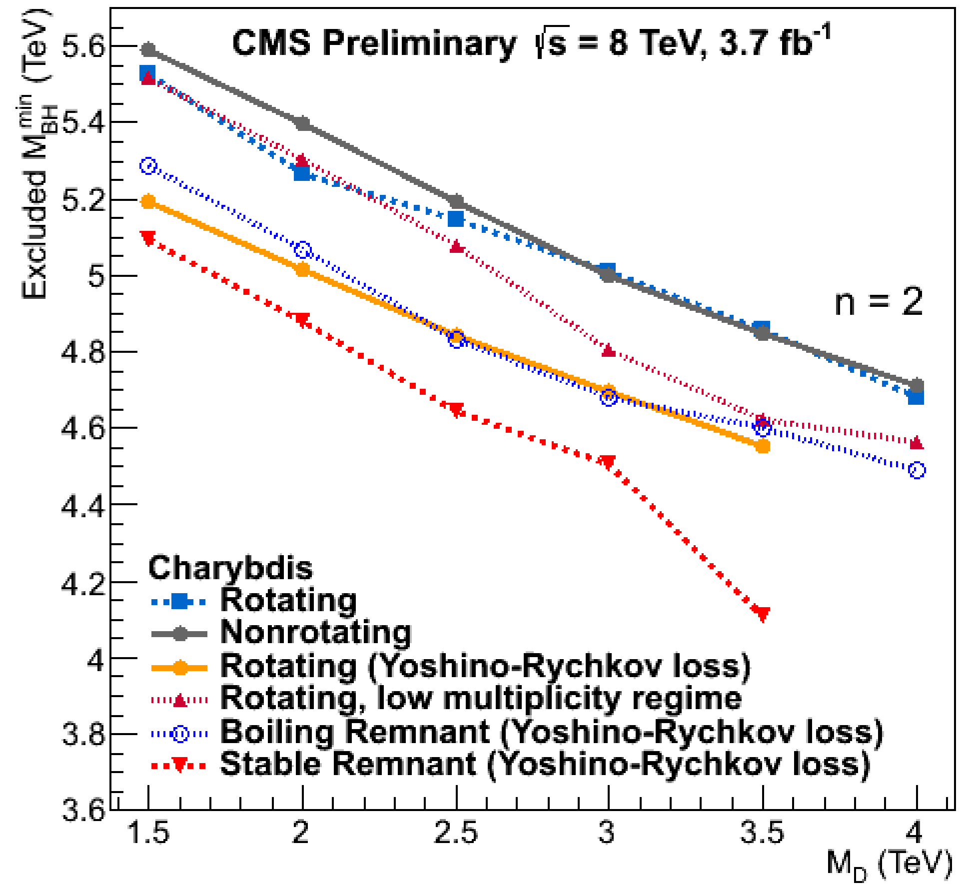
- No excess in the signal !

Microscopic Black Holes

CMS-PAS-EXO-2012-009

- Many limits can be set





Black Hole Mass limits 5, 5.5, 5.8 TeV

The 95% confidence level limits on the **black hole mass** as a function of the **multi-dimensional Planck scale MD** for various Charybdis black hole models with or without the stable remnant and number of extra dimensions of two.

The area below each curve is excluded by this search.

Exotica SUMMARY

- ATLAS and CMS – we have not yet found any *exotic island*, but we keep searching
- Many analyses with full 2012 data set are at an approval stage
- Plenty of different limits available

- Maybe next ideas should come to our mind and be tested at LHC?

Exotica SUMMARY

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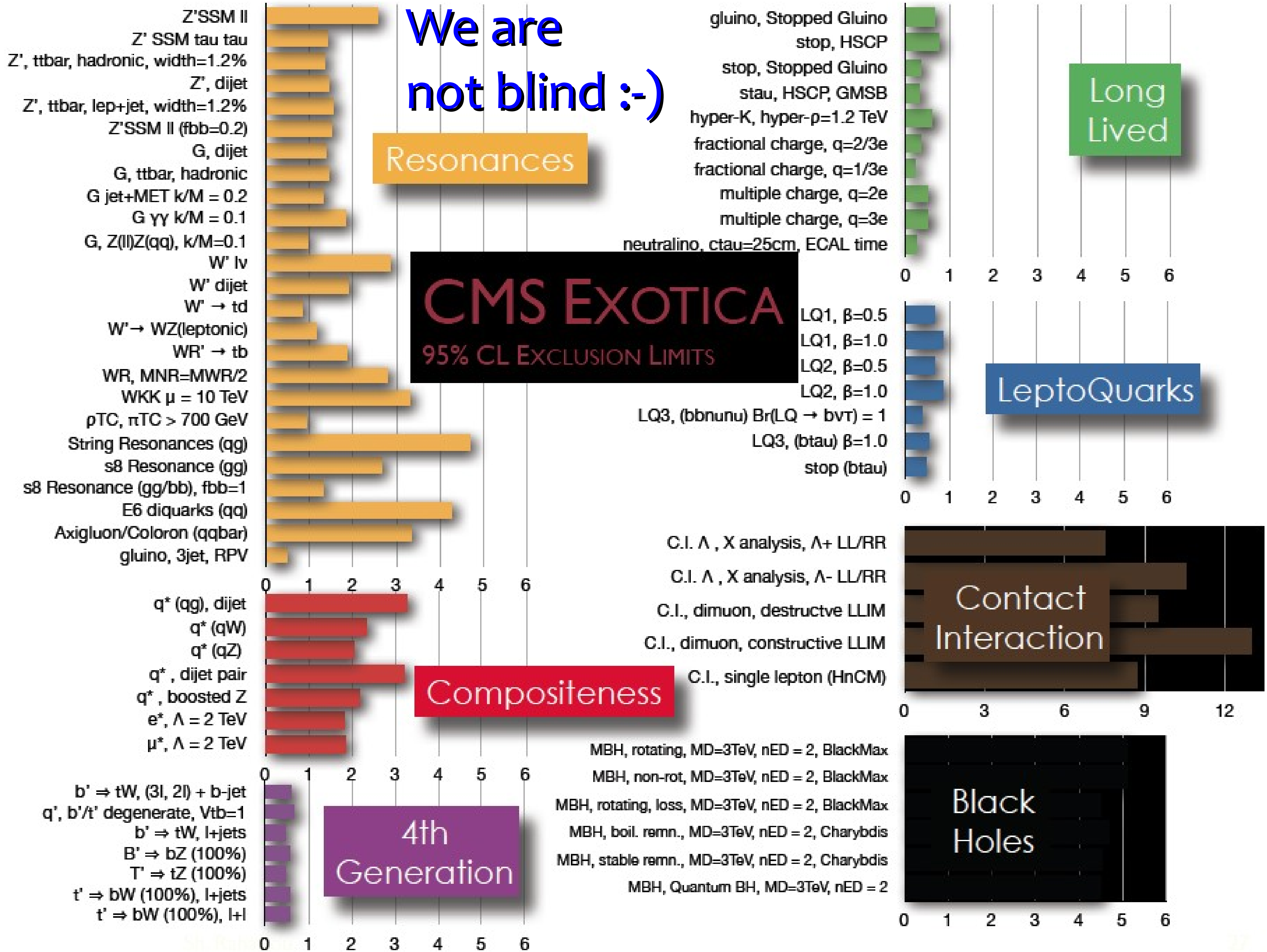
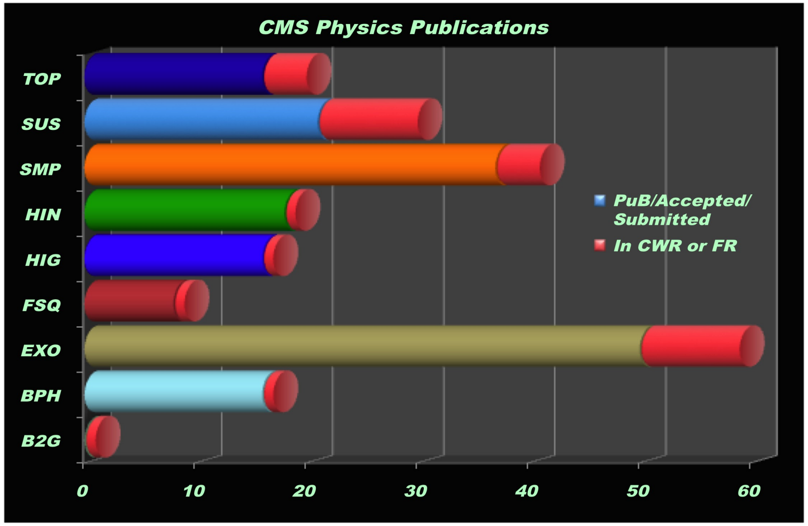
- Maybe next ideas should come to our mind and be tested at LHC?
- Or we are blind?



We are
not blind :-)
CMS EXOTICA
95% CL EXCLUSION LIMITS
Resonances
Z'SSM ll
Z' SSM tau tau
Z', ttbar, hadronic, width=1.2%
Z', dijet
Z', ttbar, 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' lv
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)
s8 Resonance (gg/bb), fbb=1
E6 diquarks (qq)
Axigluon/Coloron (qqbar)
gluino, 3jet, RPV
0 1 2 3 4 5 6
Compositeness
q* (qg), dijet
q* (qW)
q* (qZ)
q* , dijet pair
q* , boosted Z
e*, Λ = 2 TeV
μ*, Λ = 2 TeV
0 1 2 3 4 5 6
4th Generation
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
0 1 2 3 4 5 6
Long Lived
gluino, Stopped Gluino
stop, HSCP
stop, Stopped Gluino
stau, HSCP, GMSB
hyper-K, hyper-ρ=1.2 TeV
fractional charge, q=2/3e
fractional charge, q=1/3e
multiple charge, q=2e
multiple charge, q=3e
neutralino, ctau=25cm, ECAL time
0 1 2 3 4 5 6
LeptoQuarks
LQ1, β=0.5
LQ1, β=1.0
LQ2, β=0.5
LQ2, β=1.0
LQ3, (bbnunu) Br(LQ → bντ) = 1
LQ3, (btau) β=1.0
stop (btau)
0 1 2 3 4 5 6
Contact Interaction
C.I. Λ , X analysis, Λ+ LL/RR
C.I. Λ , X analysis, Λ- LL/RR
C.I., dimuon, destructve LLIM
C.I., dimuon, constructive LLIM
C.I., single lepton (HnCM)
0 3 6 9 12
Black Holes
MBH, rotating, MD=3TeV, nED = 2, BlackMax
MBH, non-rot, MD=3TeV, nED = 2, BlackMax
MBH, rotating, loss, MD=3TeV, nED = 2, BlackMax
MBH, boil. remn., MD=3TeV, nED = 2, Charybdis
MBH, stable remn., MD=3TeV, nED = 2, Charybdis
MBH, Quantum BH, MD=3TeV, nED = 2
0 1 2 3 4 5 6

Final SUMMARY

- **We have been searching very hard** for large variety of supersymmetric or exotic signals
  - 233 ATLAS & 231 CMS publications:
  - dominant contribution from EXO



https://twiki.cern.ch/twiki/bin/view/AtlasPublic

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

- **No sign of New Physics *yet***
- **Discovery of Higgs boson makes implications on New Physics searches**
- **Let's be patient ;-)**
  - More data will be analysed
  - More sophisticated analyses will be performed

Standard Model only ?

Statement

- For purpose of this seminar, materials previously shown have been used