Tommaso Lari
Università and INFN Milano
On behalf of the BSM convenors

Beyond the Standard Model WG Status Report (experimental side)

Outline
- Introduction
- SUSY BSM
- Non-SUSY BSM

Working group Topics

http://allanach.home.cern.ch/allanach/lesHouches/susy.html

- Alternative models for Higgs and EWSB (Grojean and Ferrag)

Choudhury, Ferrag (8 people in 2nd period, 1 not at Les Houches)

- Signature of SUSY breaking scenarii (Lari and Muanza)

Boudjema, Choudhury, Dittmaier, Galanti, Godbole, Heldmann, Hugonie, Lafaye, Laplace, Lari, Lykken, Mangeol, Penaranda Rivas, Polesello, Prieur, Raklev, Richardson, Rizzi, Schumacher, Spira, Sridhar, Tompkins, Zhukov (30 people in 2nd period, 7 not at Les Houches)

- SUSY Les Houches Accord and SPS-like studies (Skands)

Skands (3 people in 2nd period)

- Extra-dimensions (Ferrag and Lykken)

Choudhury, Ferrag, Lykken, Przysieniak (6 people in 2nd period, 1 not at Les Houches)

- Collider physics and cosmology (Allanach)

Lari (6 people in 2nd period, 1 not at Les Houches)

- MC and new tools for the new physics (Skands)

Skands (2 people in 2nd period)

VERY preliminary. List of sub-topics and people to be finalized in these first days.

Some general considerations

- By definition, discovery of BSM physics means observing a deviation from the predictions of the SM.
- A good understanding of the signals produced by the SM physics at the LHC is thus necessary to claim discovery of BSM physics (and after discovery to study it).
  - Understanding the detector performance
  - Validate MC tools for LHC energy
  - Use as much as possible the data to estimate the background.
- During early data taking ATLAS and CMS BSM people would actually work on understanding SM physics
  - As day 0 approachs, emphasis on commissioning, background estimation, detailed detector simulation, grid distributed analysis, etc. increases
  - But still ongoing studies on model signatures and new analysis strategies
- I do expect that also here in Les Houches there will be quite some interactions between SM and BSM groups.

Supersimmetry

Still the most studed BSM class of models. Among SUSY models, R-parity conserving mSUGRA is probably the most popular.

Typical scenario:

- Production of coloured s-particles, decay into lighter gaugini.
- Stable and weakly interacting Lightest Supersymmetric Particle, to provide a Dark Matter candidate
- Coloured particles mass below 1 TeV (no fine-tuning)

Signatures: Squark and gluino decay into (undetected) LSP produce jets, missing energy, leptons…

Possible LHC SUSY timeline:

- Phase 1: Discovery (excess of jets and missing energy)
- Phase 2: Masses and decays - no mass peak since two undetected LSPs, but if a long enough decay chain can be identified, kinematic endpoints can provide all the masses of the (s)particles involved.
- Phase 3: 2nd generation studies: more mass combinations, more decay chains, mass peaks once LSP mass is known, spins, model parameters.

SUSY search strategies (1)

What can be seen and at which scale (Heldmann, Hugonie, Savina, …)
SM background to SUSY searches

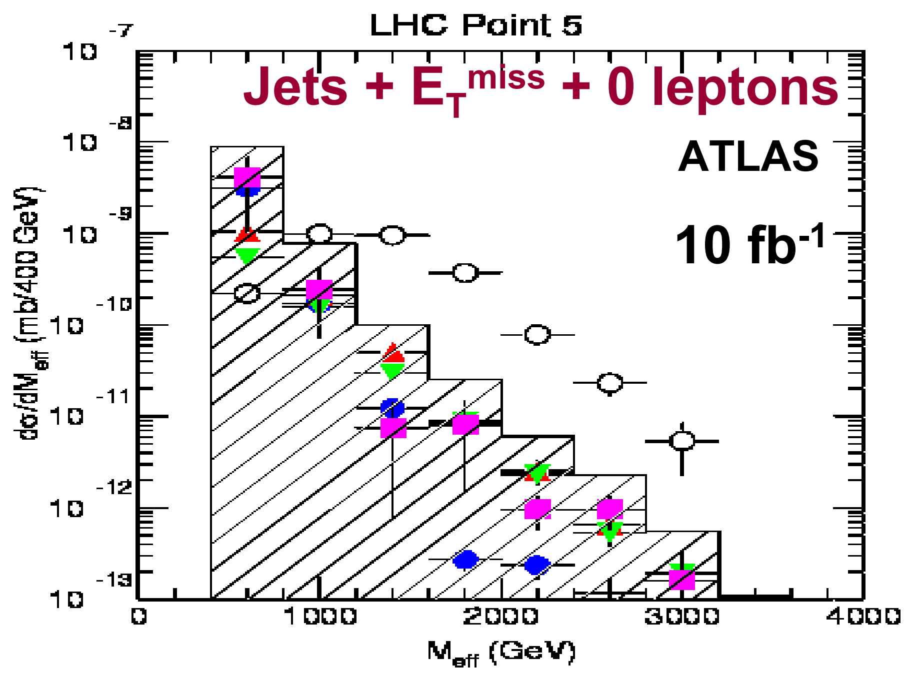
- Best strategy for mSUGRA is usually jets + E_T^{miss} + n-leptons.
- The “Effective Mass”:

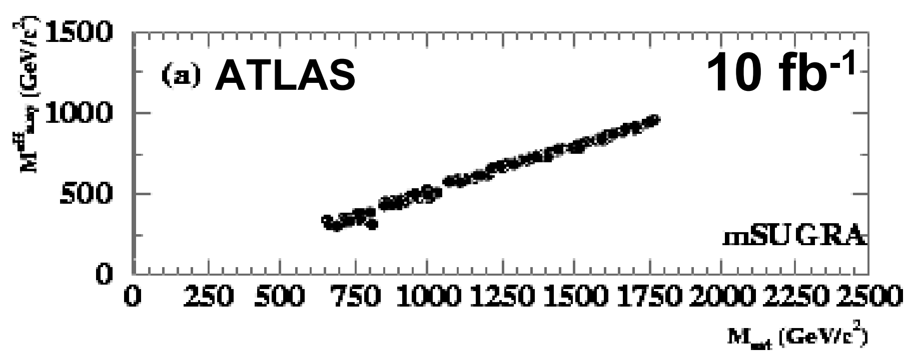
$$M_{eff} = \Sigma|p_T^i| + E_T^{miss}.$$

discriminates SM and SUSY and has a maximum strongly correlated with the mass of the s-particles produced in the pp collision.

Other MSSM models may have different signatures. Long-lived NLSP decaying in gravitino may give excess of taus or photons, secondary vertices, quasi-stable charged sleptons, …

Correlation (M_{eff}–M_{SUSY}) also less good in general MSSM.





SUSY search

What can be seen and at which scale

Heldmann, Hugonie, Savina, …

SM background to SUSY searches

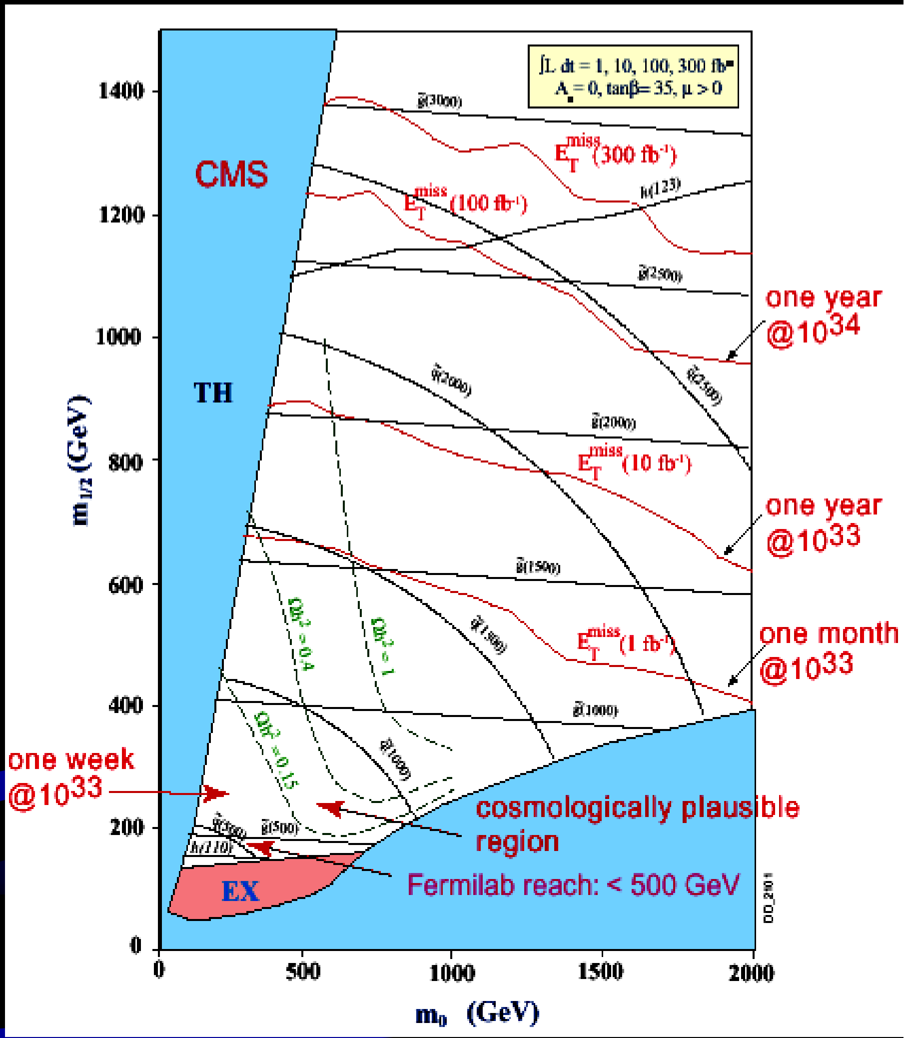
- A parameter scan is performed to evaluate the discovery potential and the trigger efficiency of different signatures.
- Natural mSUGRA models ($m_{SUSY} < 1$ TeV) may be discovered with a few weeks of data (once calorimeter calibration is understood)
- Caveats:

\- Statistical errors only.

-SM background with shower MC (multi-jet xSection too low by orders of magnitude)

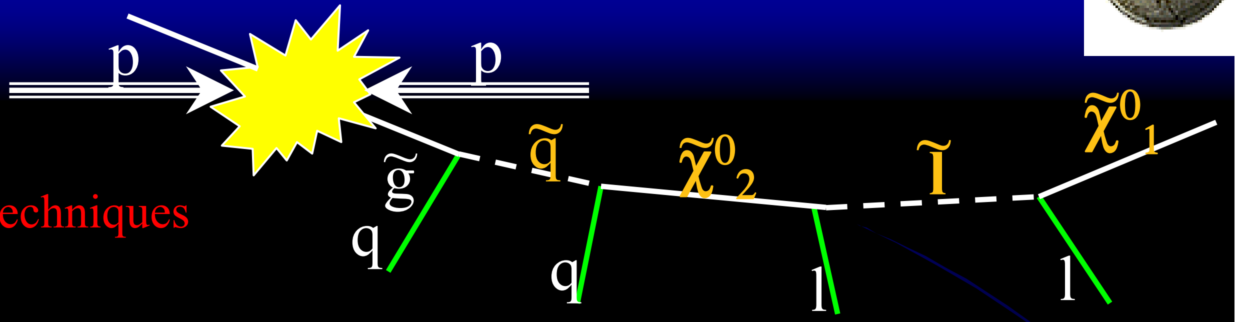
Matrix-element MC providing more accurate multi-jet background can be used to re-evaluate discovery potential and benchmark points backgrounds.

The background would be eventually be measured from data. How? To which precision?



SUSY mass spectroscopy

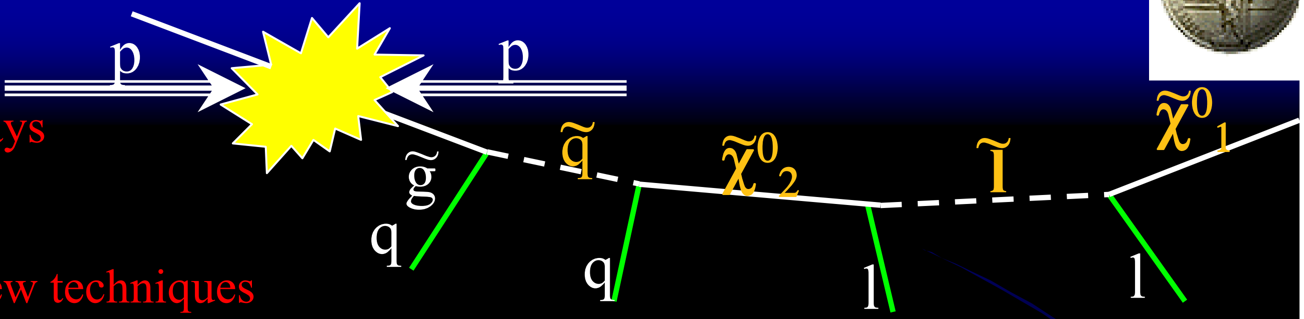
Reconstruction of cascade decays
Galanti, Heldmann, Lari, Mangeol,
Polesello, Zhukov, …
Precision measurements and new techniques
for parameter extraction



- **After discovery: reconstruction of SUSY masses**.
- Two undetected LSP: no mass from one specific decay. Measure mass combinations from kinematic endpoints/thresholds. With long enough decay chain, enough relations to get all masses.
- A point in parameter space is chosen, and decay chains are reconstructed.
  - Analysis should be applicable whenever the specific decay do exist.
  - Leptonic (e/μ) decay of χ^0_2 "golden channel" to start reconstruction. But Higgs and τ decays can also be used.
- Both ATLAS and CMS have studied in great detail some points favoured by cosmology – at low SUSY scale.

  ATLAS Phys. TDR, ATLAS-PHYS-2004-007, CMS-NOTE-2004-029
- Masses can be extracted also by combination of informations from different events (mass relation method, …)

Mass reconstruction: a typical decay chain



Reconstruction of cascade decays

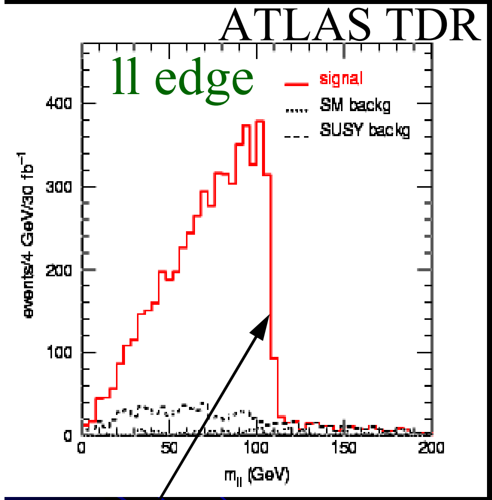
Galanti, Heldmann, Lari, Mangeol, Polesello, Zhukov, …

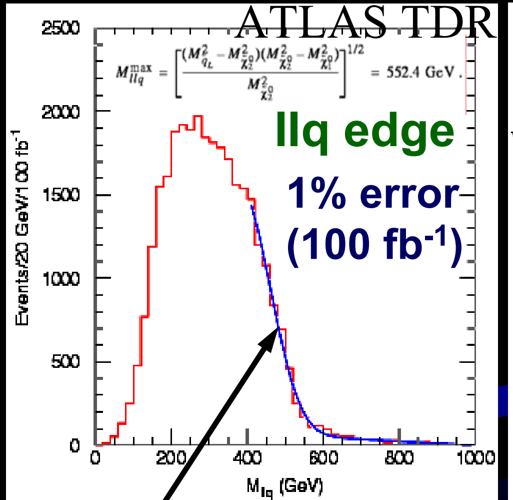
Precision measurements and new techniques for parameter extraction

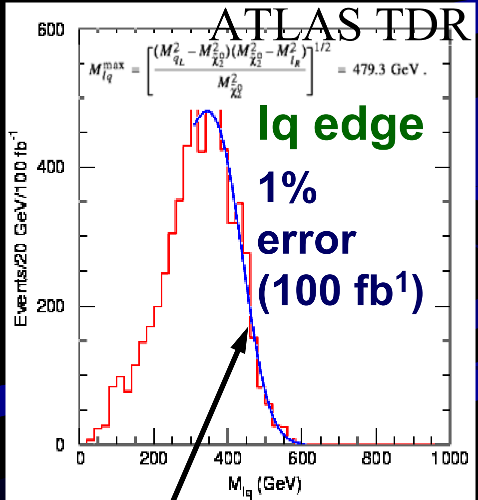
Other possibilities: $\chi^0_2 \to \chi^0_1 l^+l^-$ $\chi^0_2 \to \chi^0_1 h \to \chi^0_1 bb$

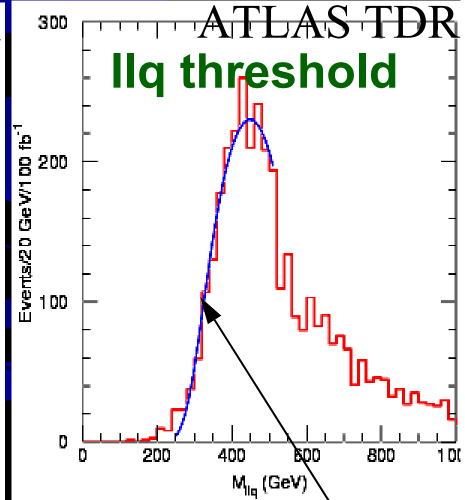
The invariant mass of each combination has a minimum or a maximum which provides one constraint on the masses of $\tilde\chi^0_1$ $\tilde\chi^0_2$ $\tilde l$ $\tilde q$

LHCC Point 5









$$M^{\max}_{ll} = M(\tilde\chi^0_2)\sqrt{1-\frac{M^2(\tilde l_R)}{M^2(\tilde\chi^0_2)}}\sqrt{1-\frac{M^2(\tilde\chi^0_1)}{M^2(\tilde l_R)}}$$

$$M^{\max}_{llq} = \left[\frac{(M^2_{\tilde q_L}-M^2_{\tilde\chi^0_2})(M^2_{\tilde\chi^0_2}-M^2_{\tilde\chi^0_1})}{M^2_{\tilde\chi^0_2}}\right]^{1/2}$$

$$M^{\max}_{lq} = \left[\frac{(M^2_{\tilde q_L}-M^2_{\tilde\chi^0_2})(M^2_{\tilde\chi^0_2}-M^2_{\tilde l_R})}{M^2_{\tilde\chi^0_2}}\right]^{1/2}$$

$$(m^{\min}_{llq})^2 = \left\{ \begin{array}{l} [\; 2\tilde l(\tilde q-\tilde\xi)(\tilde\xi-\tilde\chi)+(\tilde q+\tilde\xi)(\tilde\xi-\tilde l)(\tilde l-\tilde\chi) \\ -(\tilde q-\tilde\xi)\sqrt{(\tilde\xi+\tilde l)^2(\tilde l+\tilde\chi)^2-16\tilde\xi\tilde l^2\tilde\chi}\;]/(4\tilde l\tilde\xi) \end{array}\right.$$

Formulas in Allanach et al., hep-ph/0007009

Model-independent masses

- Combine measurements from edges from different jet/lepton combinations to obtain ‘model-independent’ mass measurements.
- LSP mass poorly determined, and all other masses strongly correlated with it. A Linear Collider input would help a lot!

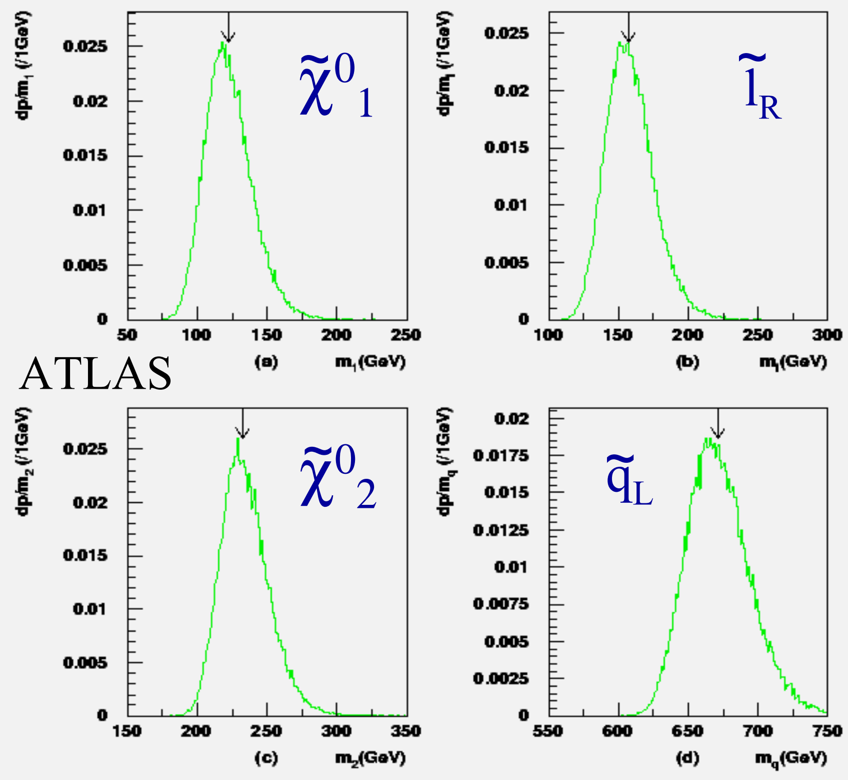
Reconstruction of cascade decays

Galanti, Heldmann, Lari, Mangeol, Polesello, Zhukov, …

Precision measurements and new techniques for parameter extraction

LHC/ILC connection

Boudjema



masses (GeV)	LHCC5	SPS1a
m($\tilde\chi^0_1$)	122	96
m($\tilde l_R$)	157	143
m($\tilde\chi^0_2$)	233	177
m($\tilde q_L$)	687-690	537-543

Sparticle	**Expected precision (100 fb^{-1})**
$\tilde q_L$	**± 3%**
$\tilde\chi^0_2$	**± 6%**
$\tilde l_R$	**± 9%**
$\tilde\chi^0_1$	**± 12%**

Mass peaks

Reconstruction of cascade decays

Galanti, Heldmann, Lari, Mangeol,
Polesello, Zhukov, …

Precision measurements and new techniques for parameter extraction

Once $m(\chi^0_1)$ has been measured, the momentum of the χ^0_2 can be reconstructed from the approximate relation

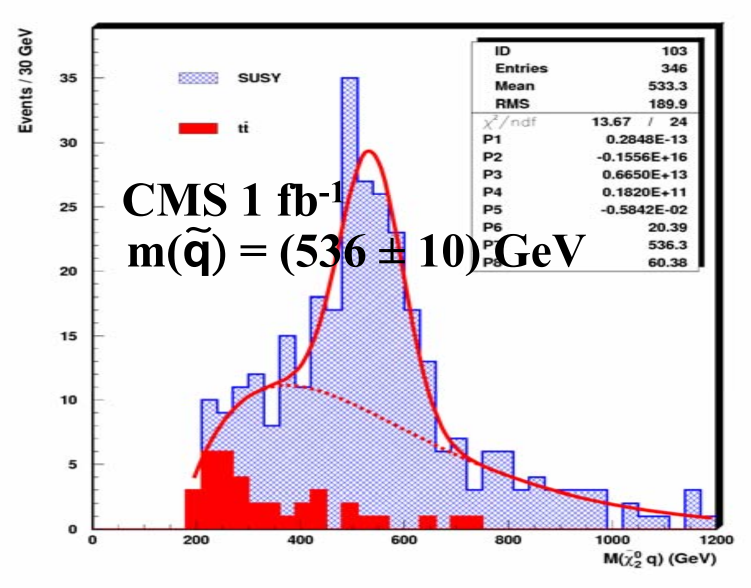
$$p(\chi^0_2) = (\ 1 - m(\chi^0_1)/m(ll)\ )\ p_{ll}$$

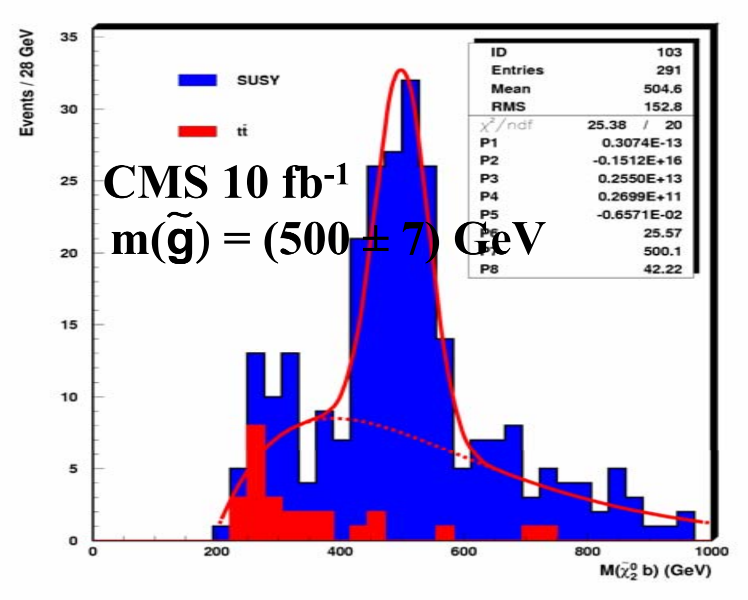
valid m(ll) near the edge.

The χ^0_2 can be combined with jets (b-jets) to reconstruct the squark (gluino, sbottom) mass peaks from $\tilde{g} \to b\tilde{b} \to bb\chi^0_2$ and $\tilde{q} \to q\chi^0_2$

Many other measurements possible:

- $\tau\tau$ invariant mass edge
- q_R – LSP mass difference
- Heavy gaugino mass edges
- ….


CMS 1 fb^{-1}
$m(\tilde{q}) = (536 \pm 10)$ GeV

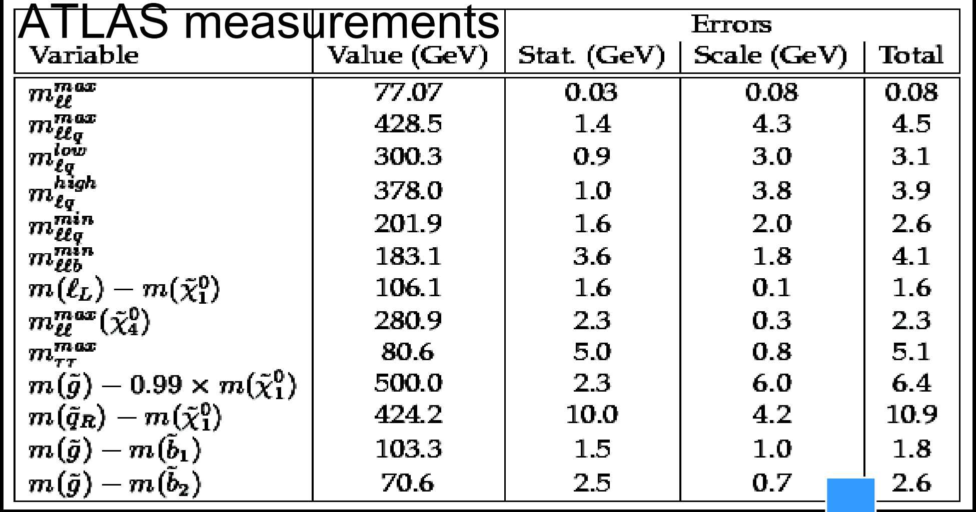

CMS 10 fb^{-1}
$m(\tilde{g}) = (500 \pm 7)$ GeV

From masses to model parameters

Precision measurements and new techniques for parameter extraction
SUSY LHA and SPS-like studies Skands
NMSSM DM and colliders
Requirements on LHC and LC data to match precision data on dark matter Allanach

From a given set of measurements one scans the parameter space and finds the points campatible with data. These points are fed to relic density calculators to get constraints on relic density.

ATLAS measurements



Variable	Value (GeV)	Errors Stat. (GeV)	 Scale (GeV)	 Total
$m_{\ell\ell}^{max}$	77.07	0.03	0.08	0.08
$m_{\ell\ell q}^{max}$	428.5	1.4	4.3	4.5
$m_{\ell q}^{low}$	300.3	0.9	3.0	3.1
$m_{\ell q}^{high}$	378.0	1.0	3.8	3.9
$m_{\ell\ell q}^{min}$	201.9	1.6	2.0	2.6
$m_{\ell\ell b}^{min}$	183.1	3.6	1.8	4.1
$m(\ell_L) - m(\tilde{\chi}_1^0)$	106.1	1.6	0.1	1.6
$m_{\ell\ell}^{max}(\tilde{\chi}_4^0)$	280.9	2.3	0.3	2.3
$m_{\tau\tau}^{max}$	80.6	5.0	0.8	5.1
$m(\tilde{g}) - 0.99 \times m(\tilde{\chi}_1^0)$	500.0	2.3	6.0	6.4
$m(\tilde{q}_R) - m(\tilde{\chi}_1^0)$	424.2	10.0	4.2	10.9
$m(\tilde{g}) - m(\tilde{b}_1)$	103.3	1.5	1.0	1.8
$m(\tilde{g}) - m(\tilde{b}_2)$	70.6	2.5	0.7	2.6

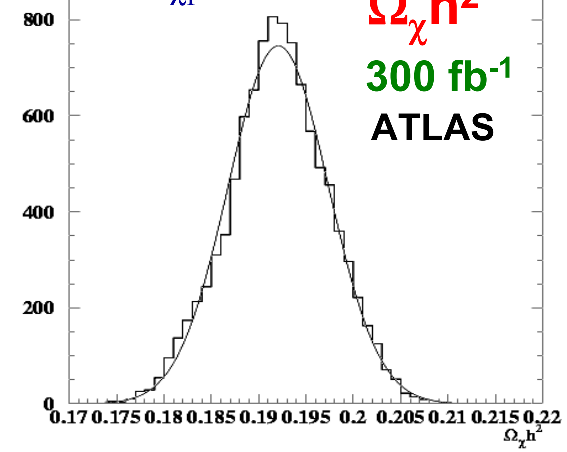
SUSY LHA to interface codes essential here!
Repeat for other benchmark points/models?

Parameter	Expected precision (300 fb^{-1})
m_0	± 2%
$m_{1/2}$	± 0.6%
tan(β)	± 9%
A_0	± 16%

Micromegas 1.1 (Belanger et al.)+ ISASUGRA 7.69

$$\Omega_\chi h^2 = 0.1921 \pm 0.0053$$

$$\log_{10}(\sigma_{\chi p}/pb) = -8.17 \pm 0.04$$



T. Lari BSM report

SUSY and Cosmology

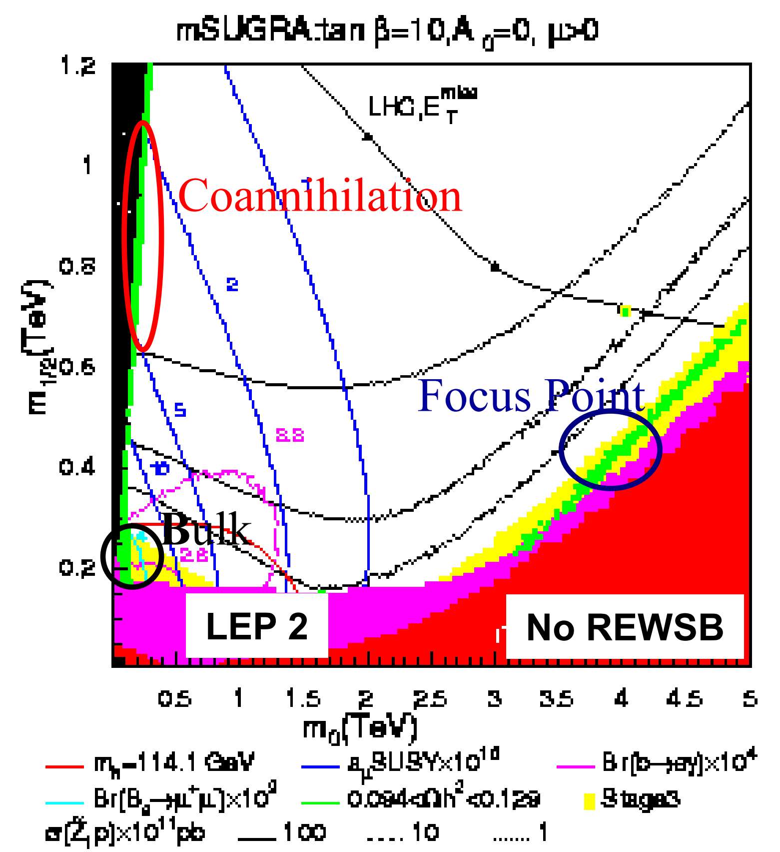
Only tiny mSUGRA space allowed by LEP and cosmology (χ relic density <= DM abundace).

- **Bulk:** low susy masses, most studied in the past.
- **Focus Point:** large scalar mass (> 3 TeV), large mixing in neutralino sector. Higgsino component of χ^0_1 gives rapid s-channel annihilation in early universe. In this region, large differences between mass spectra and relic density predicted by RGE codes (ISAJET, SOFTSUSY, …) Also sensitive to top mass value.
- **Coannihilation:** τ and χ close in mass, relic density reduced by τχ → SM.
- **Higgs funnel:** At large tanβ, neutralino annihilation through Higgs resonance.

Looks like mSUGRA is too constrained. Search for cosmologically motivated points with relaxed universality or in NMSSM?

What can be seen and at which scale
Heldmann, Hugonie, Savina, …
NMSSM DM and colliders

Baer et al. hep-ph/0305191



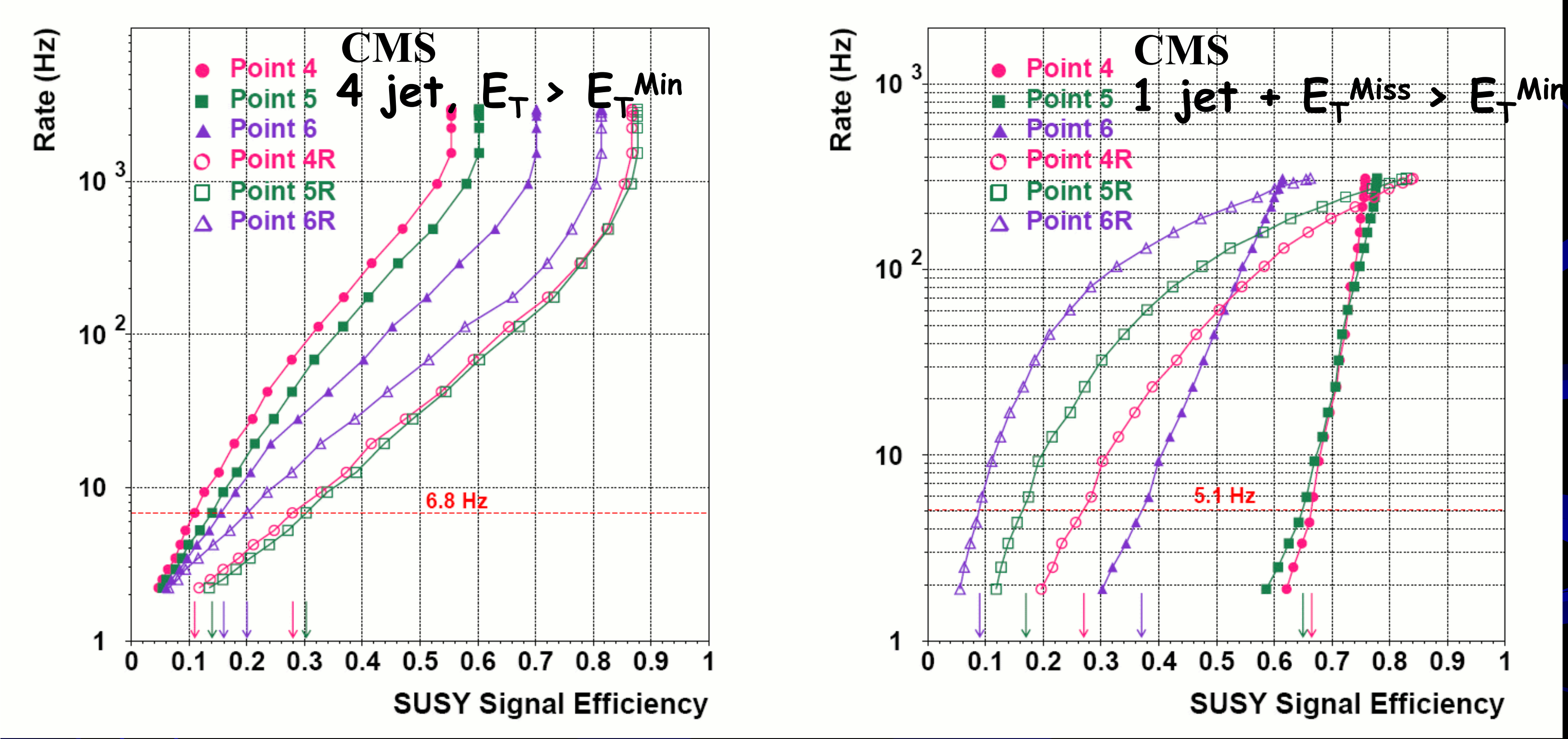
RPV SUSY

What can be seen and at which scale (Heldmann, Hugonie, Savina, …)

Discriminating between models

SUSY LHA - New ingredients: RPV

CMS Study: Trigger rate vs SUSY selection efficiency, varying trasverse energy cut E_T^{min}



Neutralino decay: <u>less missing energy, more jets.</u>

Overall somewhat more difficult to see.

GMSB

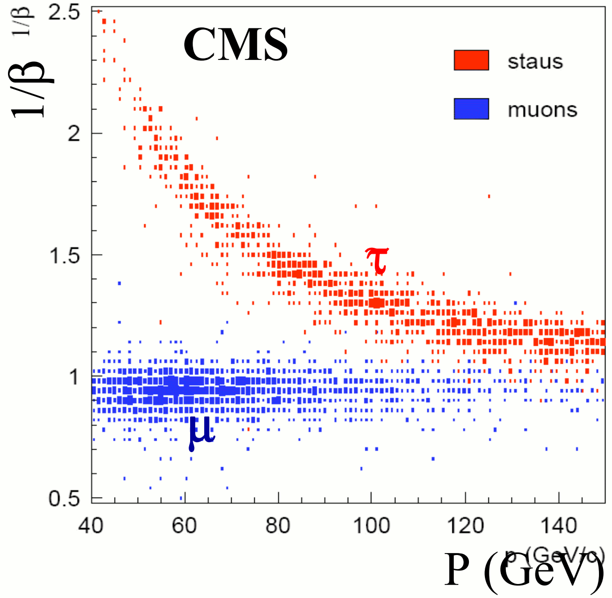
Gravitino LSP. NLSP can be stau or neutralino. Lifetime can be substantial.

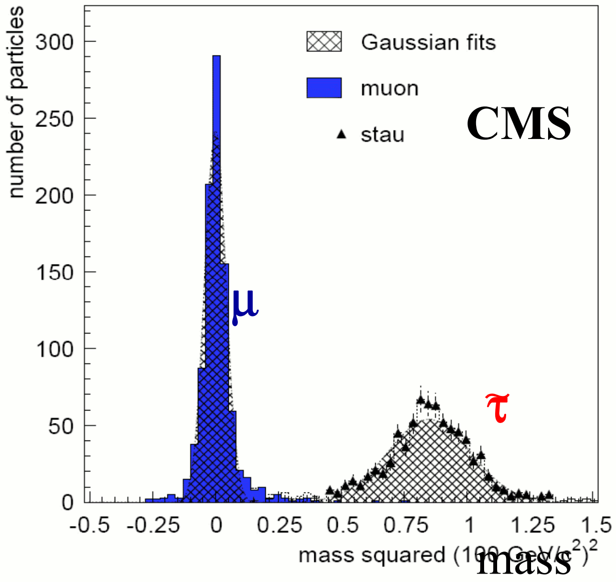
	τ_1 NLSP	**N_1 NLSP**
cτ>>L	Similar to an heavy μ	Similar to mSUGRA
cτ~L	NLSP decay in the detector, possible measurements of lifetime.	
cτ<<L	Decay in 2τ	Decay in 2γ

L=detector size

What can be seen and at which scale (Heldmann, Hugonie, Savina, …)

Discriminating between models





Split SUSY

N. Arkani-Hamed and S.Dimopoulos, hep-th/0405159.
A. Romanino and G.F.Giudice, Nucl. Phys. B699 - 65.

Split SUSY
Lari,Savina

- Ignore hierachy problem (also there for cosmological constants, one may invoke huge number of vacua and antropic principle)
- Keep SUSY (unification of coupling constants, dark matter…)
- Scalar particles are (VERY) heavy
- Gluino is long-lived (decays to gaugini through virtual squarks) – from a narrow resonance to cosmological lifetimes
- If gluino prompt decay: like mSUGRA with heavy scalars (focus-point)
- If gluino lifetime in ps – us range: secondary vertices
- If quasi-stable gluino: neutral and charged R-hadrons produced
  - Charge-exchange reaction every nuclear int. length: charge state changes in calorimeter
  - EM+nuclear interaction: no shower, but more energy loss than heavy muon
  - Energy profile in calorimeter, time-of-flight in muon chambers, … : very typical signature (almost no background expected)
  - LHC sensible up to 1.7 TeV mass

SUSY Higgs sector

2 doublets, 5 physical states: $h^0, H^0, A^0, H^\pm$ (mix if CPV)

h light, SM-like. m < 133 GeV

Lots of free parameters in MSSM

- Often assume heavy SUSY states (no Higgs decay into SUSY nor Higgs production in SUSY decays)
- Define banchmark scenarios. Example (**Carena et al. , Eur.Phys.J.C26,601**):
  - MASSH – maximum h mass allowed by theory
  - **Nomixing** – small h mass (difficult for LHC)
  - gluophobic – reduces hg coupling (and LHC production xSection)
  - **Small α** – reduces hbb and hττ couplings (harms some discovery channels)
- Parameter scans performed on two free parameters ($m_{A,}$ tanβ)
  - SM xSection + MSSM correction factors
  - Higgs decays (FeynHiggs)
  - Efficiency and background from MC studies of different channels
  - Corrections from Higgs width and overlap of states

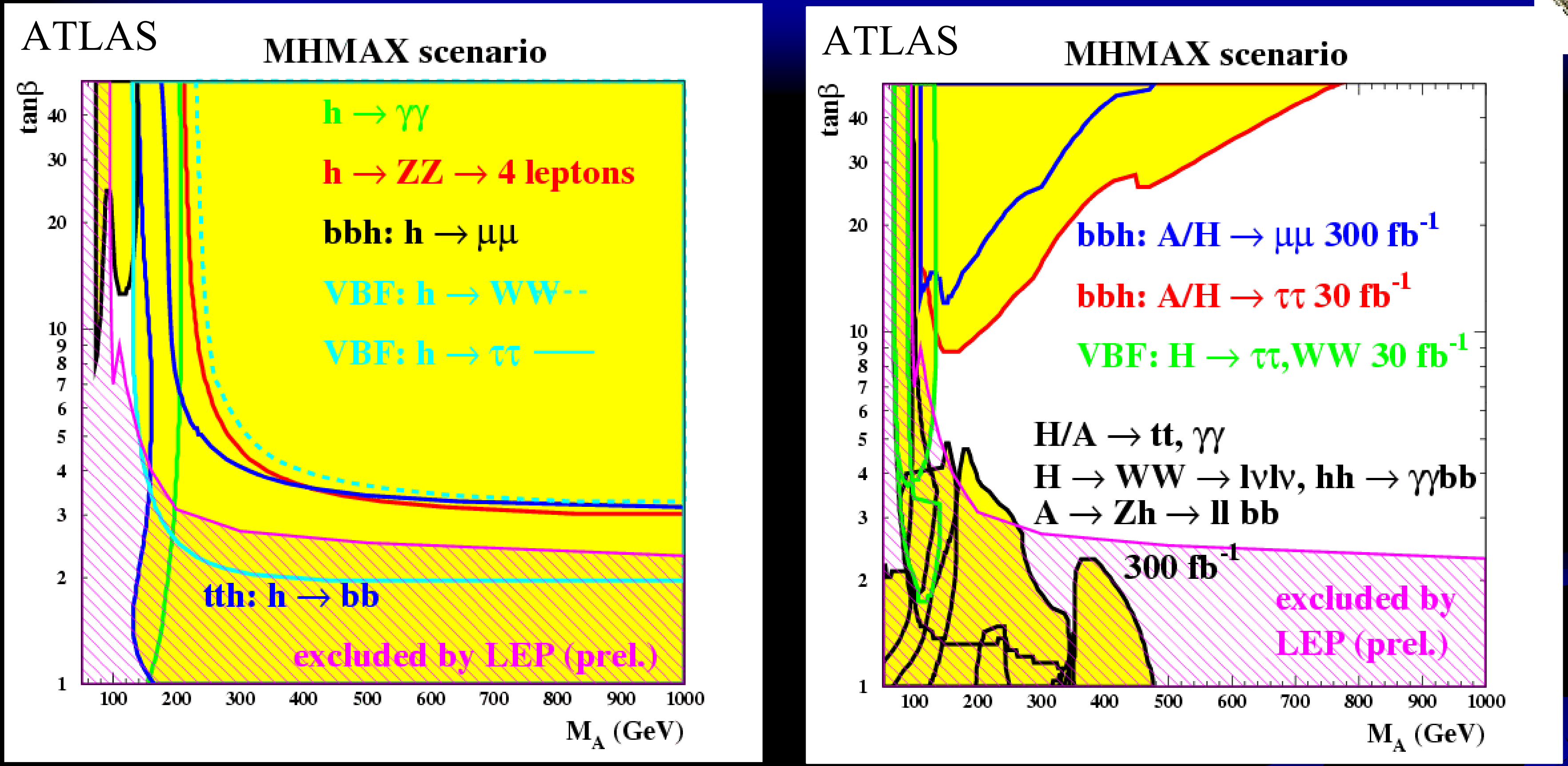
SUSY Higgs

Dittmaier,Penaranda Rivas, Schumacher

SUSY Models with an Heavy Higgs

Invisible Higgs and CP violation in the Higgs sector

SUSY Higgs scans



h discovery curves H/A discovery curves

LEP limit depends on top mass (here $m_{top} = 175$ GeV). No tanβ limit for $m_t > 183$ GeV

Statistic is 30 fb^{-1} or 300 fb^{-1} depending on channels. Stat. errors only.

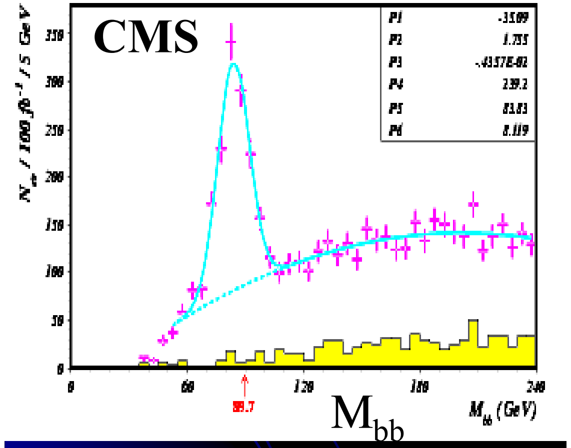
Always at least one Higgs is seen (also for the other scenarios).

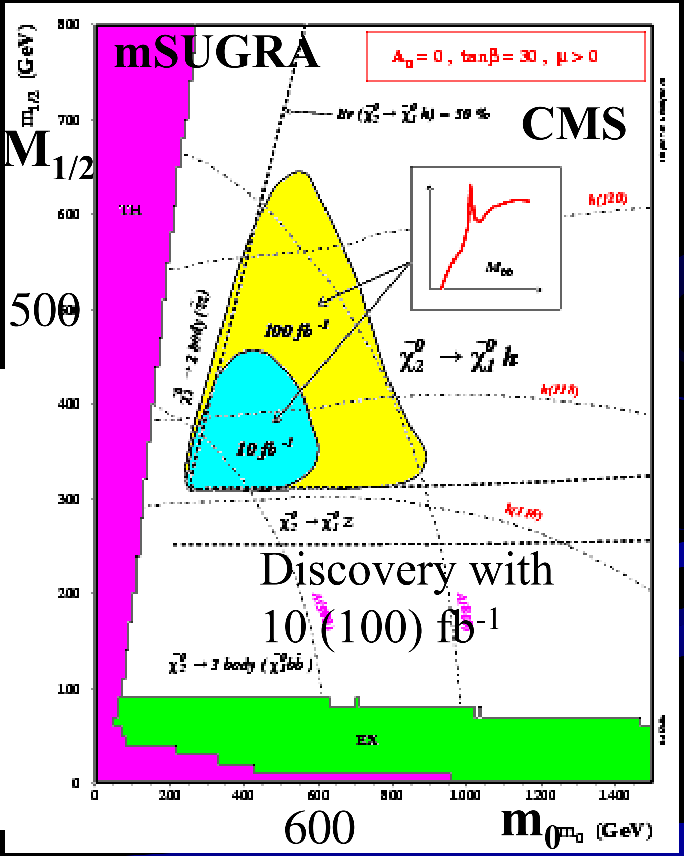
Over a large parameter space, only h is observable and discrimination from SM Higgs is very difficult.

Other SUSY-Higgs studies

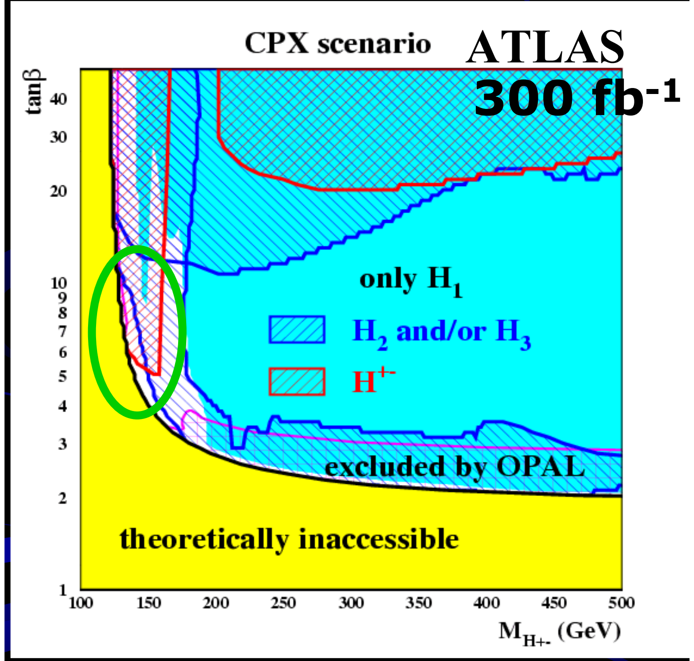
CPV Higgs. Neutral Higgs states mix. Smaller mass for the lightest state allowed by LEP (much below Z mass). For low mass observation by LHC to be studied yet.

Higgs in cascade decays. Peak in bb invariant mass distribution – with SUSY cuts may be much easier to see than SM Higgs.





CPV Higgs states observable.



M_{H1}: < 70 GeV

M_{H2}: 105 to 120 GeV

M_{H3}: 140 to 180 GeV

Non-SUSY BSM

- Of course, lots of ideas….

Leptoquarks, black holes, Left-Right Symmetric Model, excited quarks and leptons, compositness, …

- Many models are built to solve the hierarchy problem as a guideline.
- Focus here on
  - Little Higgs: the SM is part of a symmetry group broken at a few TeV scale. Delays the fine-tuning problem to that scale by introducing new particles that cancel the quadratic divergences to the Higgs mass (a new heavy quark, new gauge bosons, heavy Higgs)
  - Extra dimensions: gravity is strong at the TeV scale (gravitons, excitations of SM particles if they can propagate in extra dimensions)
  - Higgsless models

Little Higgs Models (LH)

Higgs as a Goldstone boson

Known and new Higgs, gauge bosons coming from breaking a SU(5) symmetry at scale *v* (few TeV).
Divergent contribution to the Higgs mass from top, W, Z and Higgs loops are canceled by the new particles:

- Heavy gauge bosons Z_H, W_H, A_H $m < 6$ TeV $(m_h/200\ \text{GeV})^2$
- Heavy quark T (electroweak singlet) $v\sqrt{2} < m < 2$ TeV $(m_h/200\ \text{GeV})^2$
- New Higgs bosons $\Phi^0\ \Phi^+\ \Phi^{++}$ $m < 8$ TeV $(m_h/200\ \text{GeV})^2$

"Littlest Higgs model" (T. Han et al., Phys. Rev. D67, 095004) used for a detailed ATLAS study (G. Azuelos et al. , hep-ph/0402037). Also under study by CMS.
CMS study for generic heavy gauge bosons is also relevant (M. Dittmar et al., hep-ph/0307020).

LH: T Quark Search

Parameters: M_T, λ_1/λ_2

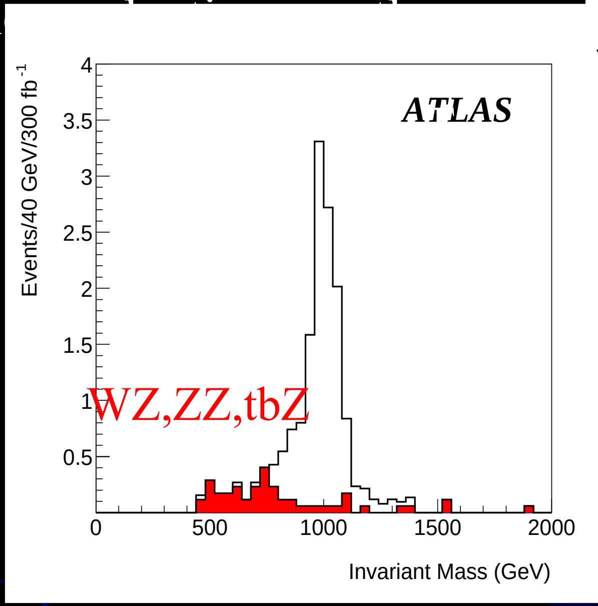
Decays:

$T \rightarrow Wb$ 50% (also 4th gen. q)
$T \rightarrow Zt$ 25%
$T \rightarrow Zh$ 25%

Narrow resonance

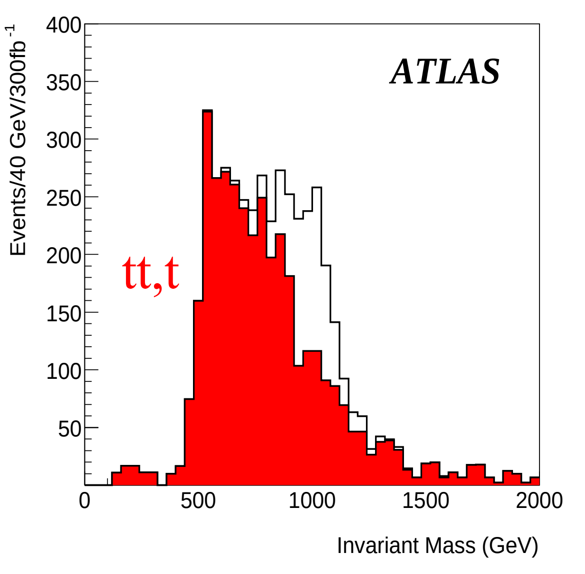
Singl

- ATLAS study (hep-ph/0402037)
- Plots for 300 fb^{-1}
- 5σ discovery limit quoted for $\lambda_1/\lambda_2 = 1$ (2) and 300 fb^{-1}



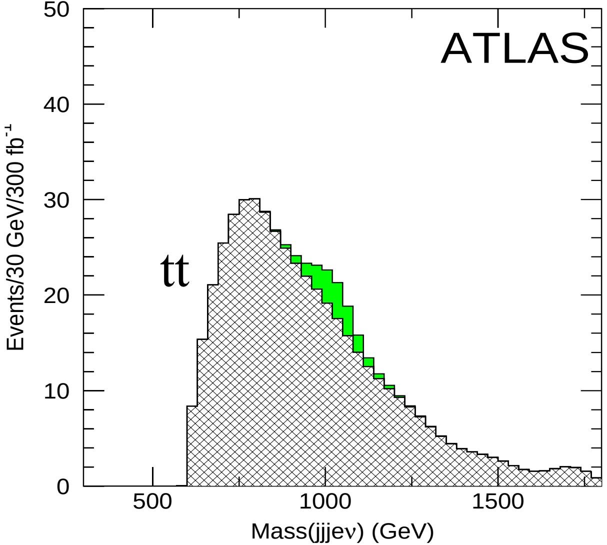
$T \rightarrow Zt \rightarrow l^+l^-l\nu b$

$M_T < 1050$ (1400) GeV



$T \rightarrow Wb \rightarrow l\nu b$

$M_T < 2000$ (2500) GeV



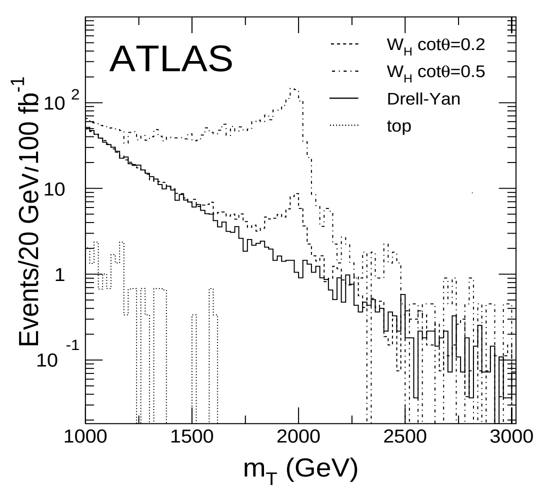
$T \rightarrow ht \rightarrow bbl\nu b$

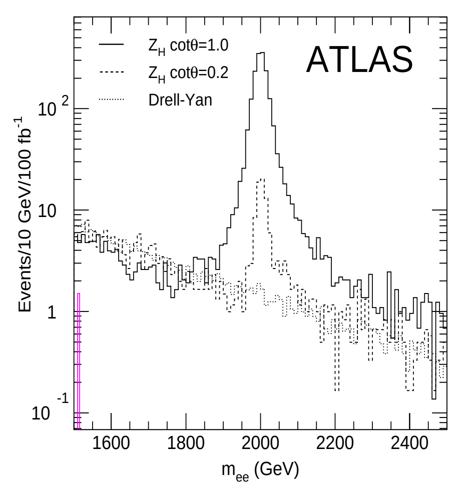
Difficult

LH: New gauge bosons

Lots of models with heavy W/Z bosons.

Following discovery of ee/μμ resonance discriminating among them would required detailed measurements o width, asymmetries, cross section lineshape, etc.





- Discovery:

$A_H/Z_H \to ee, \mu\mu$ $W_H \to e\nu, \mu\nu$

- Up to ~5 TeV, except for small

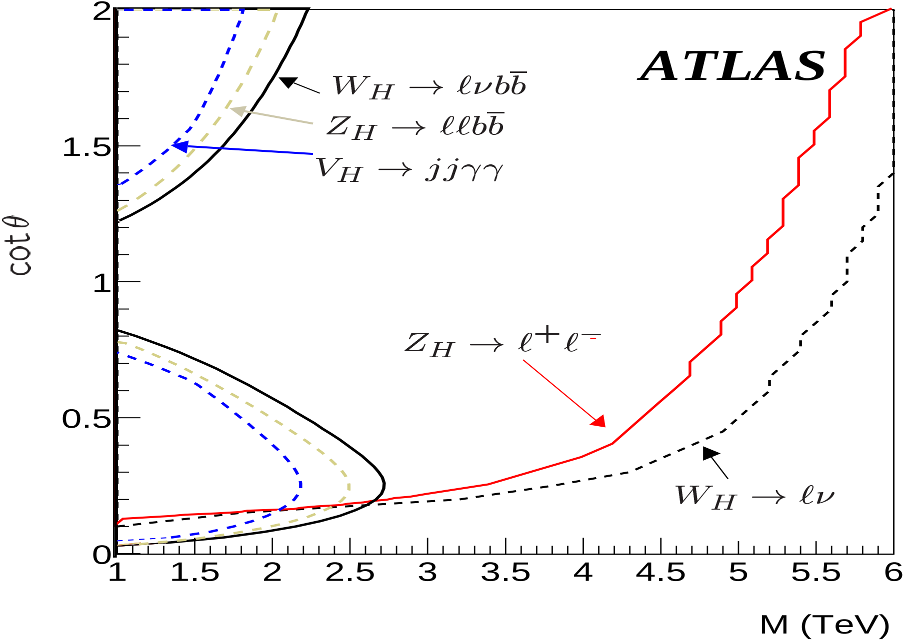
cotθ (Z_H, W_H) and tanθ`≈1.3 (

- CMS reach similar
- Cross section, width measure θ
- Specific of LH models (assuming m_h =120 GeV):

$Z_H \to Zh \to llbb$

$W_H \to Wh \to l\nu bb$

$W_H/Z_H \to W/Z\ h \to qq\gamma\gamma$



Extra Dimensions

Model independent constraints on new gauge bosons
Universal extra Dimensions

Factorized metric
$ds^2 = dr^2 + dt^2 + du^2$

Large xTra Dim
Radius R >> TeV^{-1}
Modify Newton's Law below R
Lower Planck scale to TeV

Only gravitons in xtraDim
(SM fields does not show
Characteristic excited states at scale $R^{-1} << TeV^{-1}$)
Signatures:
- (near-)continuum of graviton states
- Direct production, virtual effects observable

TeV^{-1} scale xTra Dim
Radius R ~ TeV^{-1}
May come with others large xTra Dim.

SM fields allowed in xTra Dim
Tower of KK excitations at TeV scale for each particle in bulk.

Signatures:
Excited states of gauge bosons
Excited states of fermions if live in bulk.

Non-factorizable metric
$ds^2 = f(u)(dr^2 + dt^2) + du^2$

Randall-Sundrum
Radius M^{-1}_{Planck}
But phenomenology at TeV scale.

Graviton discrete excitations
Also new scalar field (radion)

Large extra dimension: direct searches

Direct production of KK gravitons

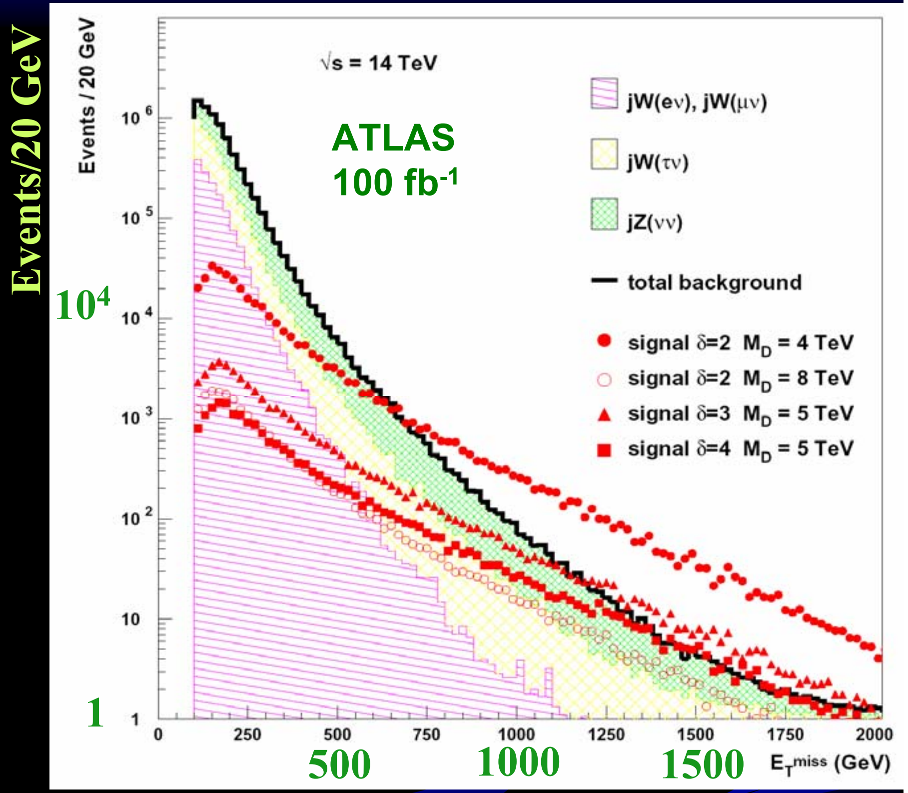
$$\left.\begin{array}{l} \bar{q}q \to gG^{(k)},\ \gamma G^{(k)} \\ qg \to qG^{(k)} \\ gg \to gG^{(k)} \end{array}\right\} \text{jets} + \not{E}_T,\ \gamma + \not{E}_T$$

LEP+Tevatron+Hera limits ~ 1.4/0.6 TeV (δ=2/6)

ATLAS search (L. Vacavant and I. Hinchliffe, J. Phys. G27 , 1839)

δ	M_D^{max} (TeV) LL, 30 fb^{-1}	M_D^{max} (TeV) HL, 100 fb^{-1}	M_D^{min} (TeV)
2	7.7	9.1	~ 4
3	6.2	7.0	~ 4.5
4	5.2	6.0	~ 5

Lower limit is from validity of low-energy effective theory



Jet plus missing energy: discrimination agianst SUSY?

SM background?

Indirect searches also possible (virtual effects from graviton exchange)

TeV^{-1} Extra dimension(s)

Model independent constraints on new gauge bosons

- One of the extra dimensions may have smaller size (TeV^{-1}): all SM fields (**Universal Extra Dimension**) or just gauge boson may propagate in it.
- Tower of excited KK states with mass

$$m_k^2 = m_0^2 + k^2 M_C^2$$

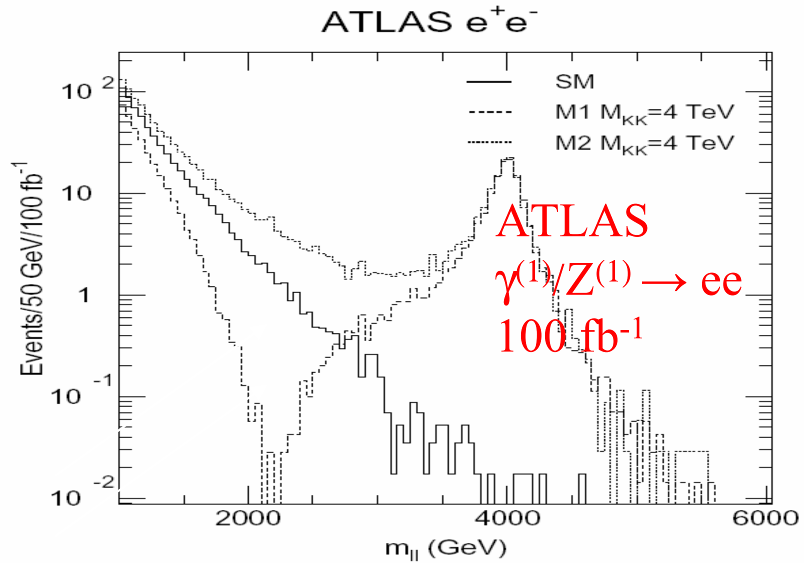
- Gauge bosons KK: probably only first resonance observable (EW data constraints),

discovery with ee, μμ, eν, μν

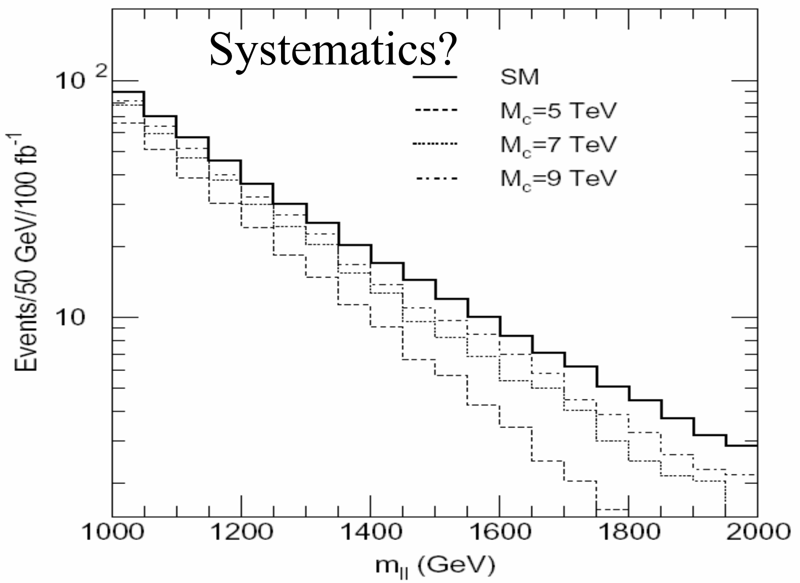
- Precision measurements with electrons

$Z^{(1)}/\gamma^{(1)}$: G.Azuelos and G.Polesello, in hep-ph/0204031
$W^{(1)}$ and $g^{(1)}$ can also be seen by ATLAS

Sensitivity to peak (100 fb^{-1}): 5.8 TeV
Reach with interference, el. (100 fb^{-1}): 9.5 TeV
Ultimate with interference, e+μ, 300 fb^{-1}: 13.5 TeV



ATLAS
$\gamma^{(1)}/Z^{(1)} \rightarrow ee$
100 fb^{-1}



Systematics?

Discrimination of Models

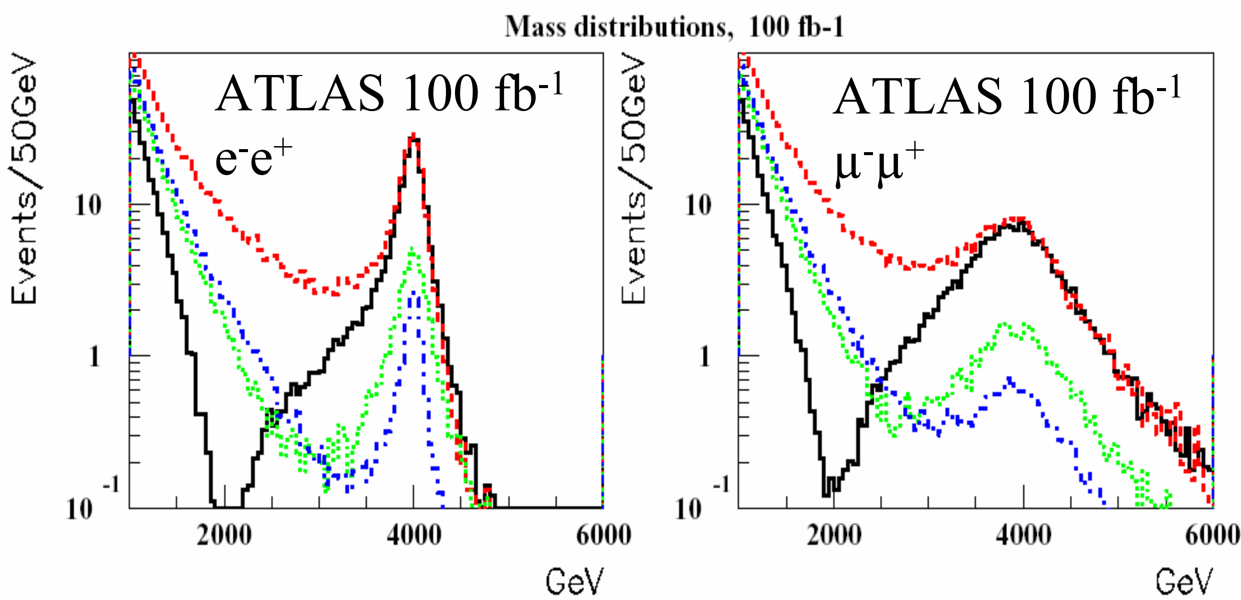
process	$\sigma \times BR(Z^* \to e^+e^-)$ (fb)
$Z^{(1)}/\gamma^{(1)}$	4.05
$Z^{(1)}/\gamma^{(1)}$-M2	11.75
Z'	4.65
$qq \to G^*$	0.20
$gg \to G^*$	0.13
$qq \to e^+e^-$	4.83

- Cross section, width, resonance shape

Not shown: asymmetries

- Discrimination Z $^{(1)}$/Z'/G* possible

W$^{(1)}$/W' difficult



Z/γ M1
- Z/γ M2
- Z'
- G*+SM Drell-Yan resonance

Universal Extra Dimensions

T. Appelquist, HC Cheng and BA Dobrescu, PR D64 (2001) 035002

Universal Extra Dimensions

- **All SM particles in bulk**

⇒ conservation of momentum in extra dimensions

⇒ conservation of KK number

⇒ pair production of KK states

⇒ lower collider bounds: ~ 350-400 GeV

- LKP quasi-stable (decay only via graviton emission)

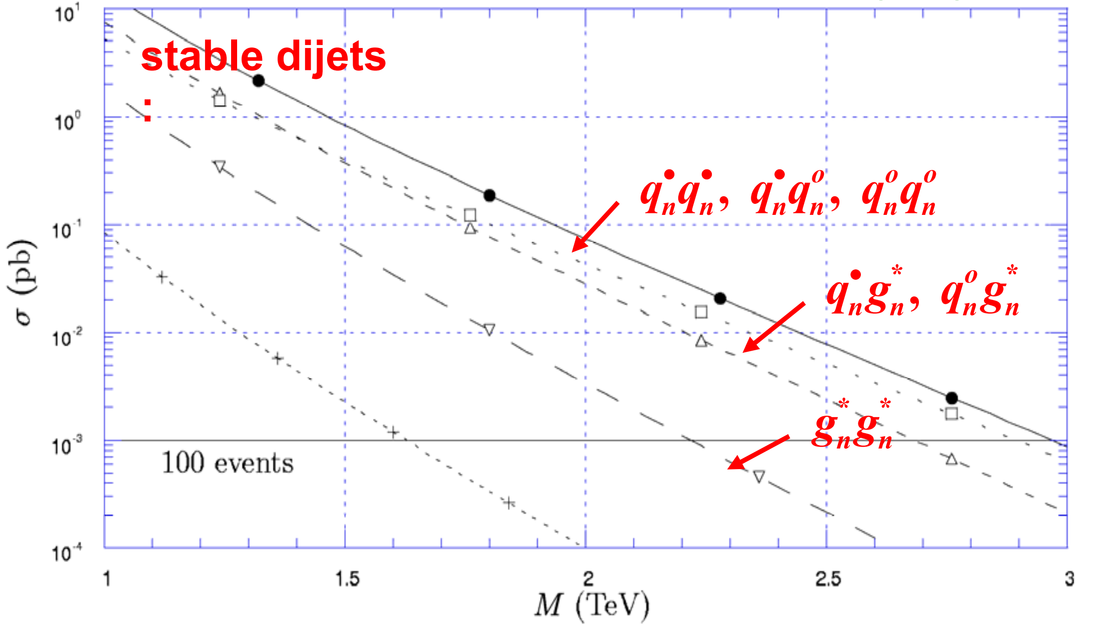
γ^*

- **dijet signals**

$q_1^\bullet q_1^\bullet \to (...+\gamma^*)(...+\gamma^*)(\to \gamma G+\gamma G+X)$

- **ATLAS study in progress**

C. Macesanu, CD McMullen and S. Nandi PR D66 (2001) 015009



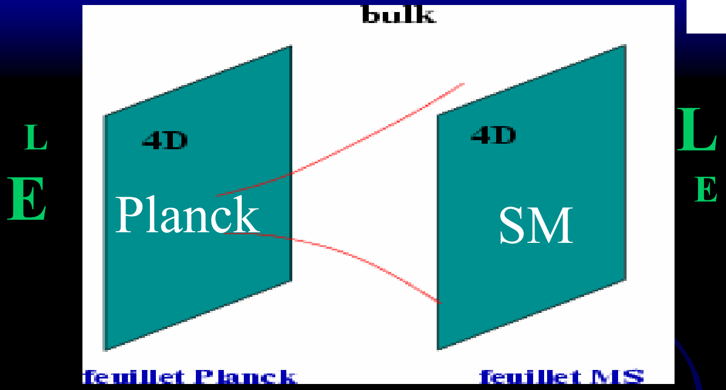
Randall-Sundrum model

L. Randall and R. Sundrum, Phys. Rev. Lett. 83, 3370

- One warped ED:

$$ds^2 = e^{-2ky}\eta_{\mu\nu}dx^\mu dx^\nu + dy^2, \quad y = r_c\phi$$

$\Rightarrow$ distances in 3D shrink as fonction of y



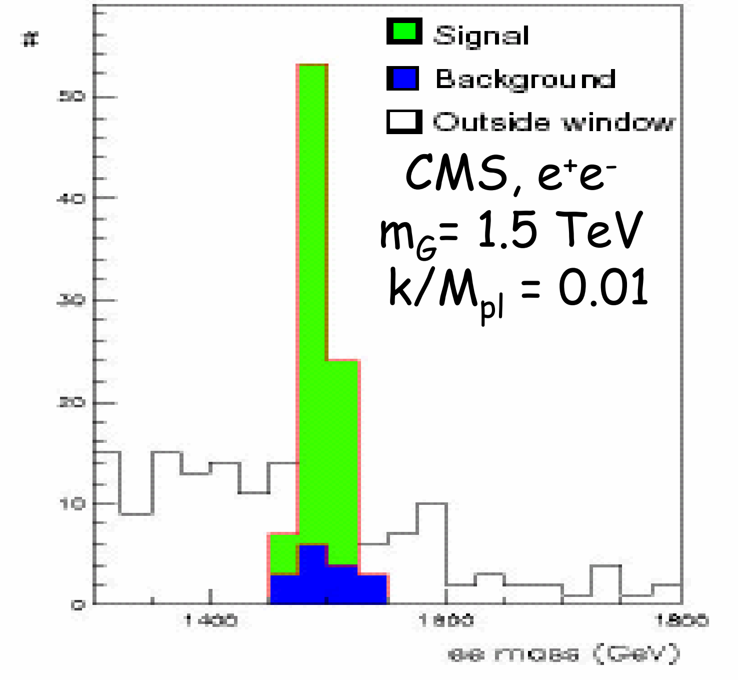
- Warp parameter $k \sim M_{Pl}$;
- Gravity scale $\Lambda_\pi \sim M_{Pl}\, e^{-kr\pi} \sim$ TeV
- Graviton KK excitations as roots of Bessel function: $M_n = kx_n\, e^{-kr\pi}$ with $J_1(x_n) = 0$

2 parameters: m_G and k/M_{Pl}

coupling of KK states $\sim 1/\Lambda_\pi$,

with $\Lambda_\pi = M_{pl}e^{-kr_c\pi} = \dfrac{m_G}{3.83 \times k/M_{Pl}}$

- ATLAS: B.C. Allanach et al.,hep-ph/0211205
- CMS: P. Traczyk et al., hep-ex/0207061



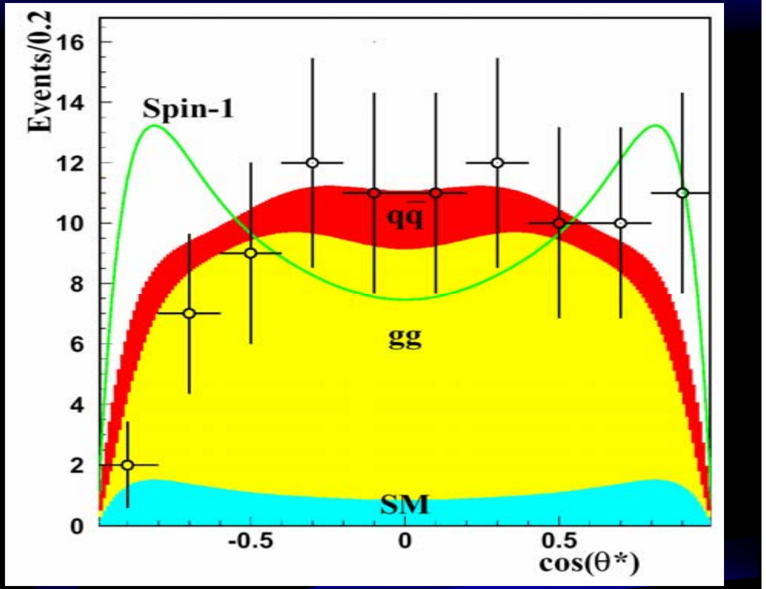
Signatures:

G→ee G→μμ G→γγ

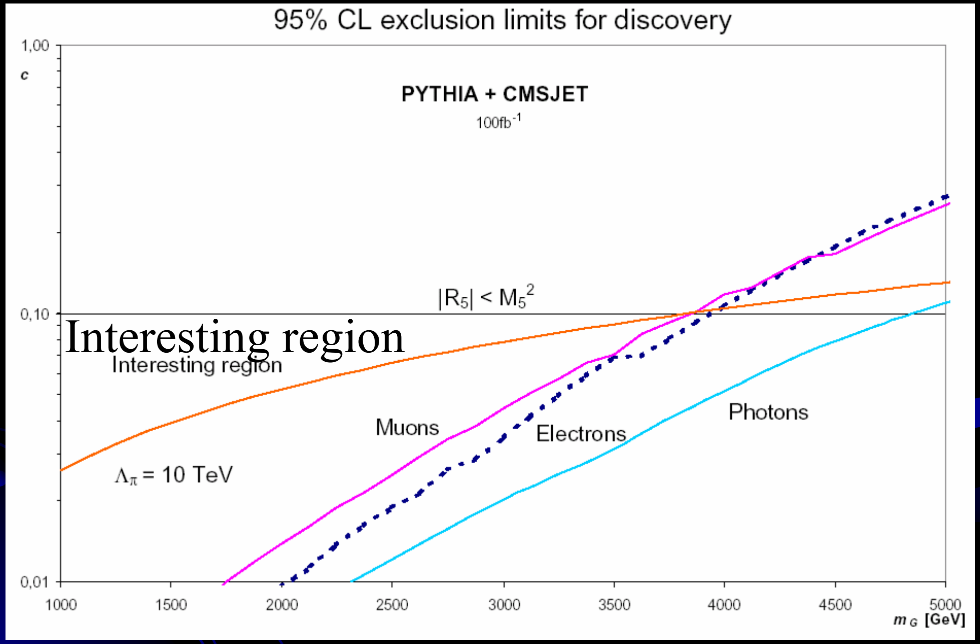
G→WW G→ZZ G→jet jet (more challenging)

Randall-Sundrum model

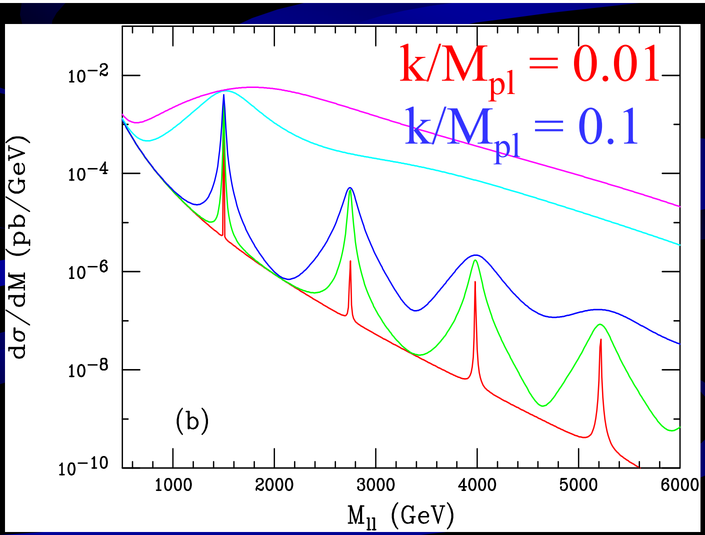
- Model parameters from resonance mass, width and x-section
- May be possible to observe second resonance (spaced as Bessel function zeros)
- Spin measurement possible over most of parameter space



CMS, 95% exclusion limit, 100 fb^{-1}



M_G (GeV)



Higgless models

Warped space, with boundary conditions that break the symmetry on the TeV brane and on the Planck brane:

C. Csáki et al., hep-ph/0310355,
C. Csáki, hep-ph/0412339

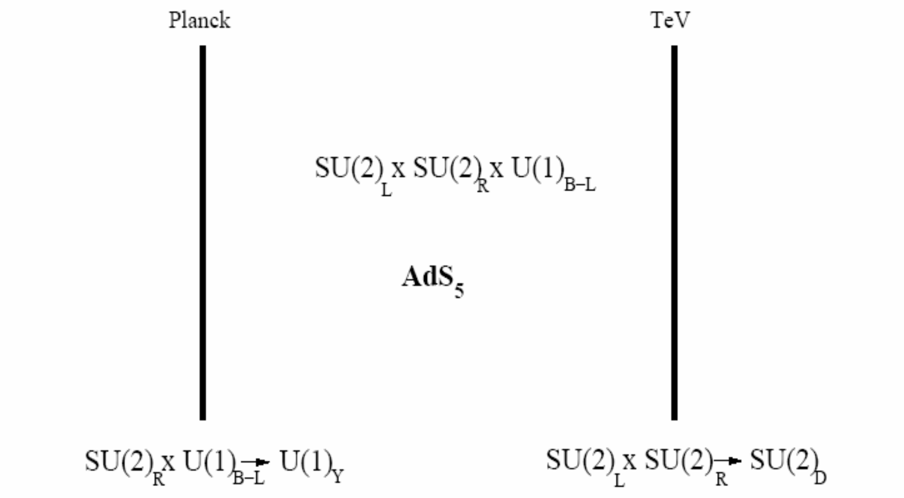


Figure 3: The symmetry breaking structure of the warped higgsless model.

The model explains:

- γ : massless photon (flat wavefunction in bulk)
- W, Z : lowest KK states of massive gauge bosons
- correct ration of W/Z mass

Important constraints:

- S parameter from LEP:
  → weak coupling of Z' to fermions (and possibly light Z')
- unitarity in VB scattering
  → resonances in WZ scattering distinguishable from QCD-like chiral Lagrangian model resonances.
- problems with the top

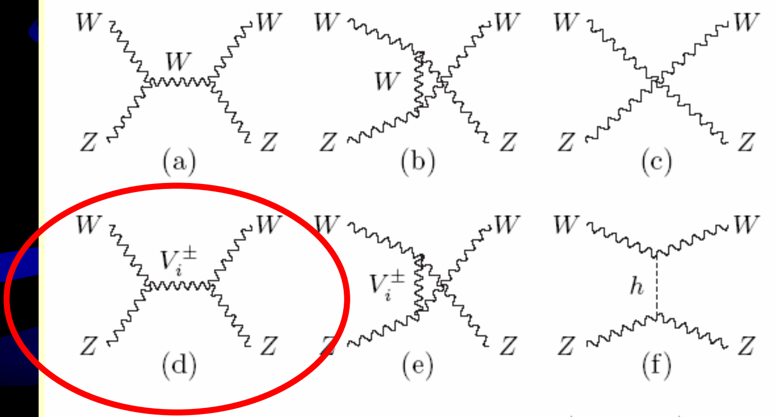


FIG. 1. Diagrams contributing to the $W^\pm Z \rightarrow W^\pm Z$ scattering process: (a), (b) and (c) appear both in the SM and in Higgsless models, (d) and (e) only appear in Higgsless models, while (f) only appears in the SM.

A. Birkedal et al., hep-ph/0412278

resonance in WZ scattering

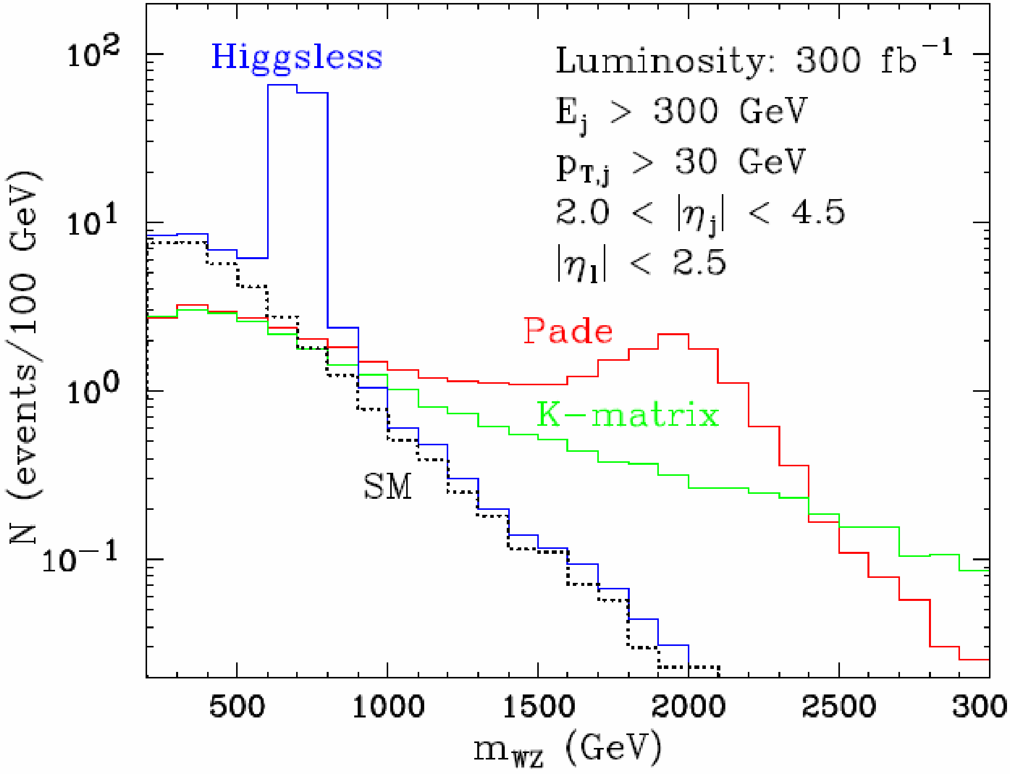


FIG. 4. The number of events per 100 GeV bin in the $2j + 3\ell + \nu$ channel at the LHC with an integrated luminosity of 300 fb^{-1} and cuts as indicated in the figure. The model assumptions and parameter choices are the same as in Fig. 2.

A. Birkedal et al., hep-ph/0412278

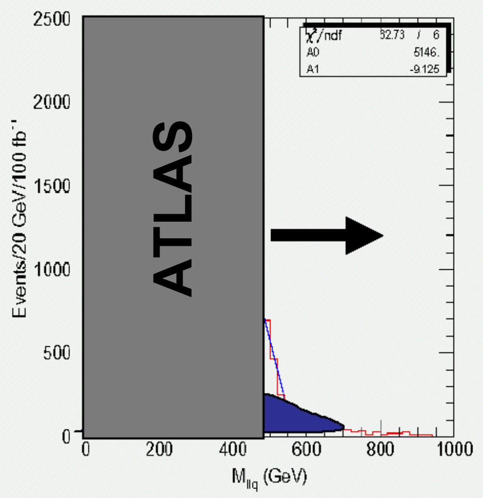
Conclusions

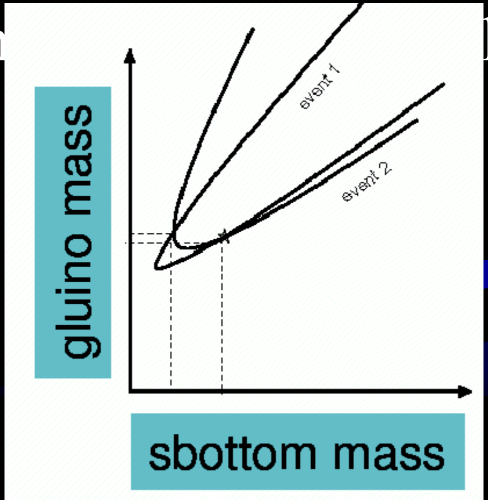
- Lots of work has been made in preparation of LHC start-up on extensions of the Standard Model…
- Even more remains to be done!
- So… have a good workshop!

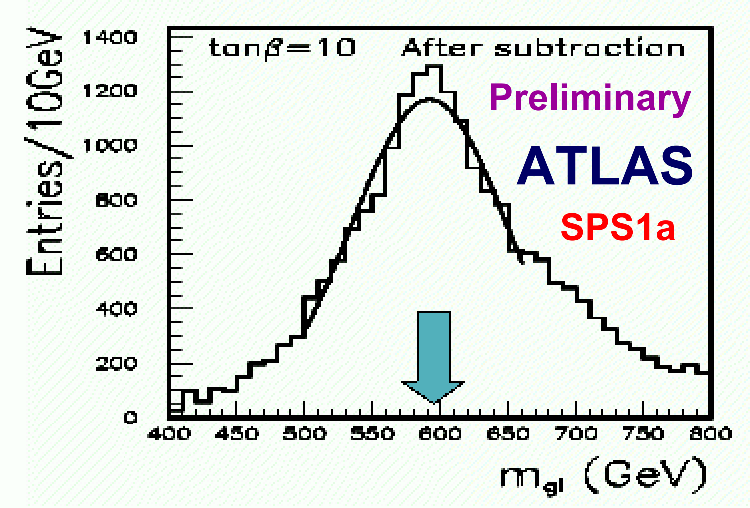
Backup slides

Mass Relation Method

- Hot off the press: new idea for reconstructing SUSY masses!
- ‘Impossible to measure mass of each sparticle using one channel alone’ (Page 8).
    - Should have added caveat: Only if done event-by-event!
- Remove ambiguities by combining different events analytically → ‘mass relation method’ (Nojiri et al.).
- Also allows all events to be used, not just those passing hard cuts



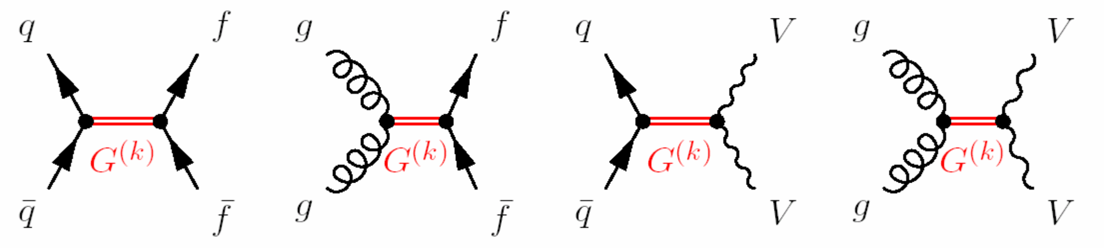




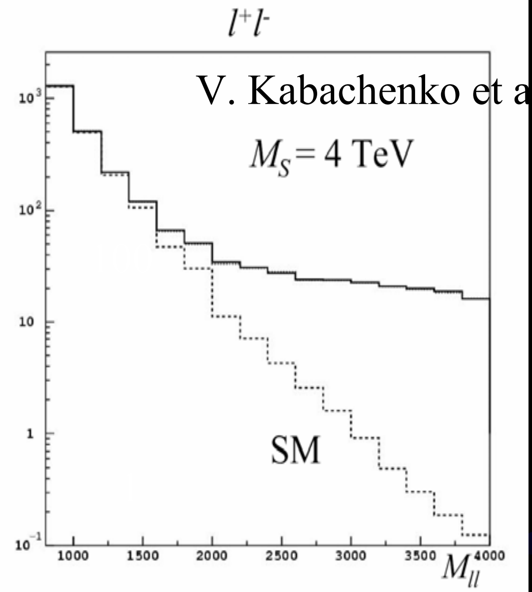
Large ED: indirect searches

- Virtual exchange of gravitons modify Drell-Yan X-sections , asymmetries
- UV divergence, ignorance of full theory – use cut-off M_S

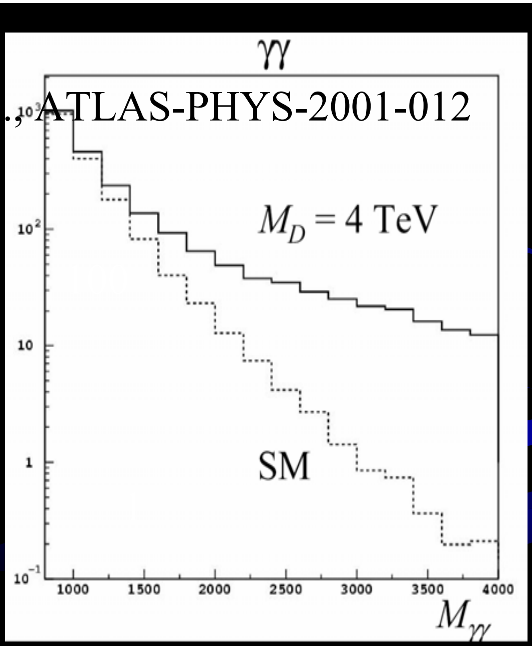
ATLAS, 100 fb^{-1}
$M_S < 5.1$ TeV ll
$M_S < 6.6$ TeV $\gamma\gamma$



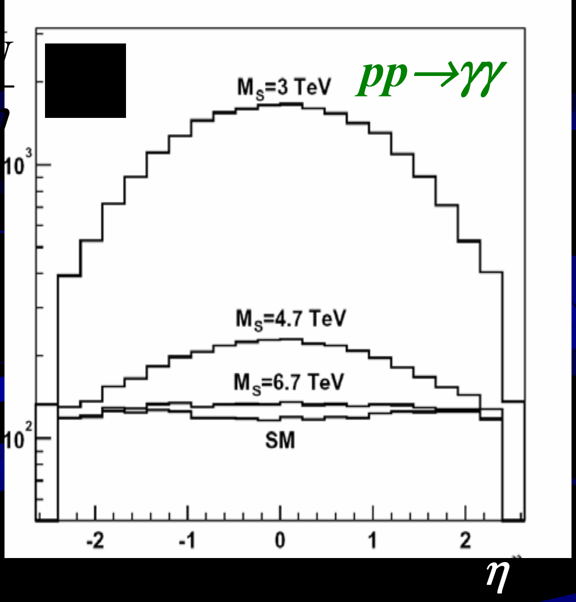
V. Kabachenko et al., ATLAS-PHYS-2001-012



1000 2000 3000
M(ll) (GeV)

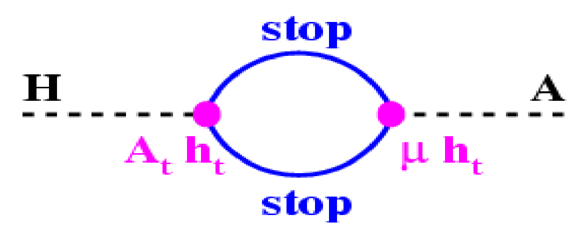


1000 2000 3000
M(γγ) (GeV)

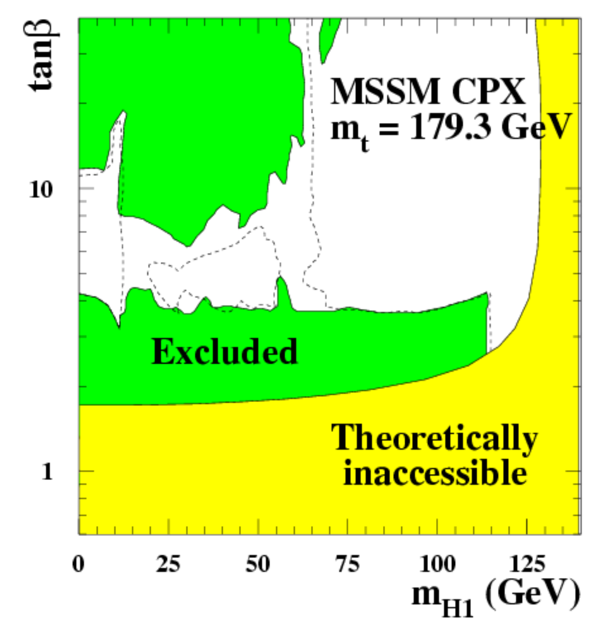


CPV Higgs

- CP conserving at Born level, but CP violation via complex A_t, A_b M_{gl}
- CP eigenstates h, A, H mix to mass eigenstates H_1, H_2, H_3

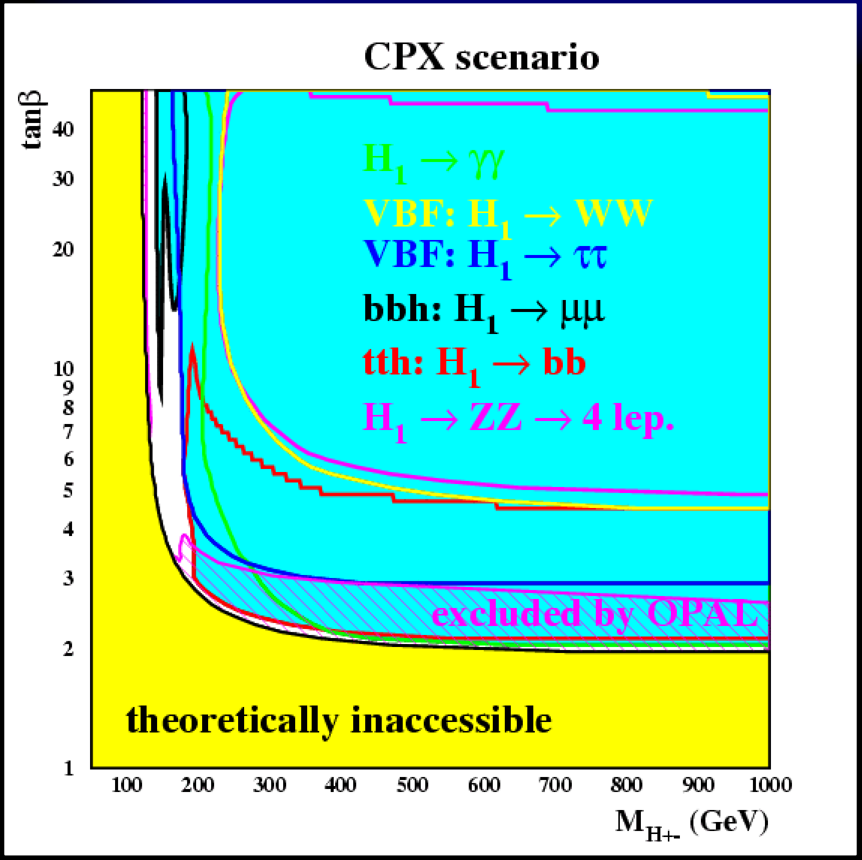


- maximise effect → CPX scenario (Carena et al., Phys.Lett B495 155(2000))
  $\arg(A_t)=\arg(A_b)=\arg(M_{gluino})=90$ degree
- scan of Born level parameters: tanβ and M_{H+-}

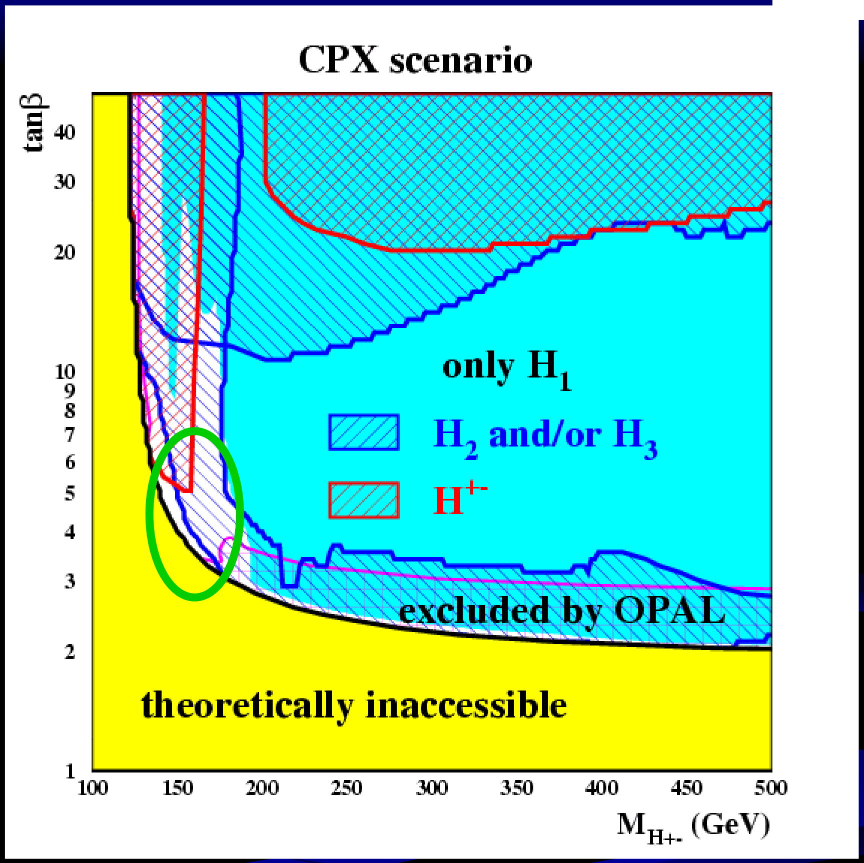


- no absolute limit on mass of H_1 from LEP
- strong dependence of excluded region
  on value for m_{top}
  on calculation used FeynHiggs vs CPH

CPV Higgs scan



Light Higgs (H_1) discovery curves.



Number of Higgs states observable.

LEP limits are weaker (an Higgs lighter than The Z is not excluded). An hole appear in the Discovery plane, since there are no documented MC studies of ATLAS searches for $m_H < 70$ GeV

M_{H1}: < 70 GeV

M_{H2}: 105 to 120 GeV

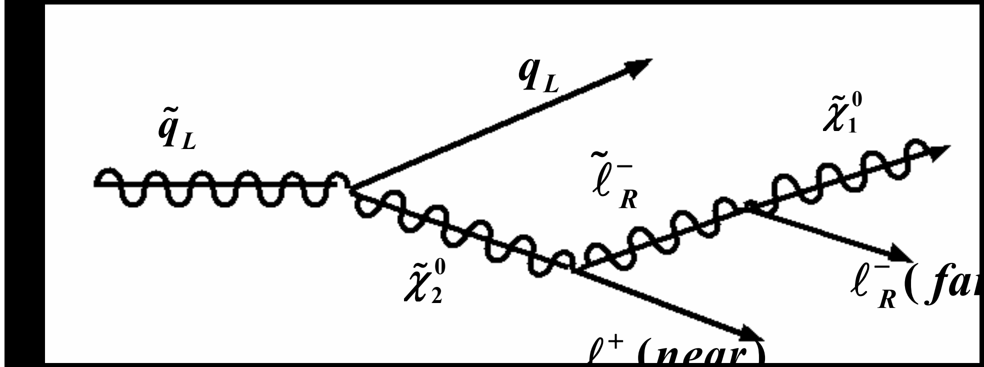
M_{H3}: 140 to 180 GeV

T. Lari BSM report

Supersymmetry – Spin Measurement

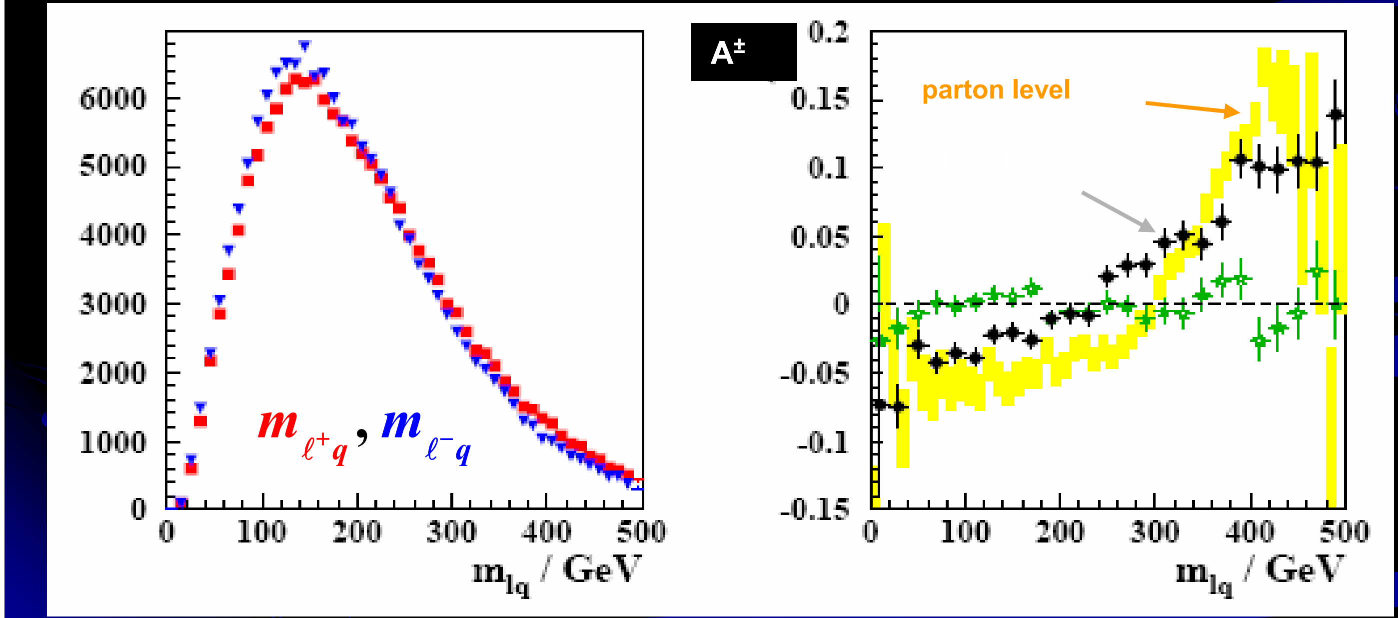
A.J. Barr, hep-ph/0405052

- Evidence for supersymmetry (vs extra dimensions, for example)



polarization of χ_2^0 induces asymmetry

seems feasible, with 150 fb^{-1}



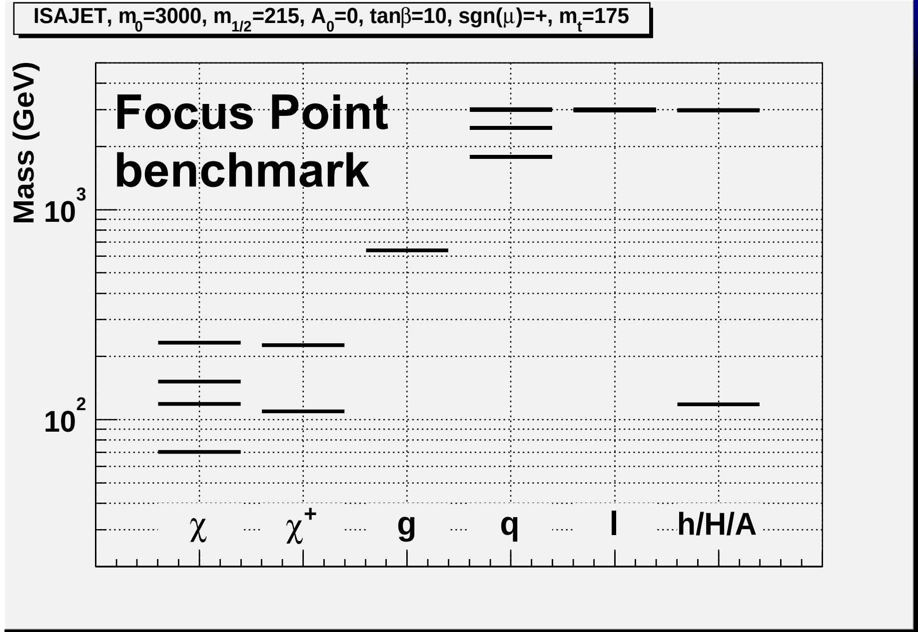
Large Extra Dimensions

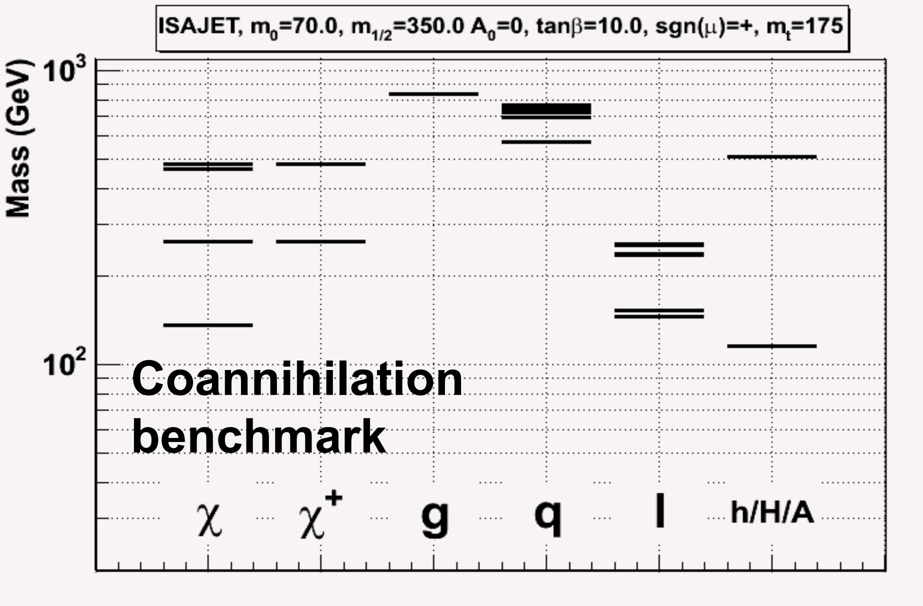
ADD model: **A**rkani-Hamed, **D**imopoulos and **D**vali.

N. Arkhani-Hamed et al., Phys. Lett. B429, 263
N. Arkhani-Hamed et al., Phys. Rev. D59, 086004
I. Antoniadis et al., Phys. Lett. B436, 257

- δ new dimensions of size $\mathrm{TeV}^{-1} \ll R_0 < 0.2$ mm
- Gravity propagates in the whole space (bulk) → increases as $R^{-(2+\delta)}$ for $R < R_0$ and is strong at scale M_D (~ TeV).
- $M_D^{\delta+2} R_0^{\delta} = M_{\mathrm{Planck}}^{2}$ → R_0 ~ 1 mm ($\delta=2$) or 10 fm ($\delta=6$)
- Direct tests of Newton's law exclude $\delta=1$, $\delta=2$ marginal ($R_0 < 190$ μm)
- Stringent (but model-dependent) astrophysical limits
- Low-energy Kaluza-Klein graviton excitations. Universal and weak coupling to SM particles. Large number of states (~ continuum).

Study of DM-motivated points





Scalar particles out of reach.

χχ production (4.5 pb) difficult to separate from SM background

gg production (0.6 pb) and decay into gauginos can be observed. Two mass differences from neutralino leptonic decays. Reconstruction of gaugino MSSM Parameters (M_1,M_2,μ,tanβ) to be demonstrated yet.

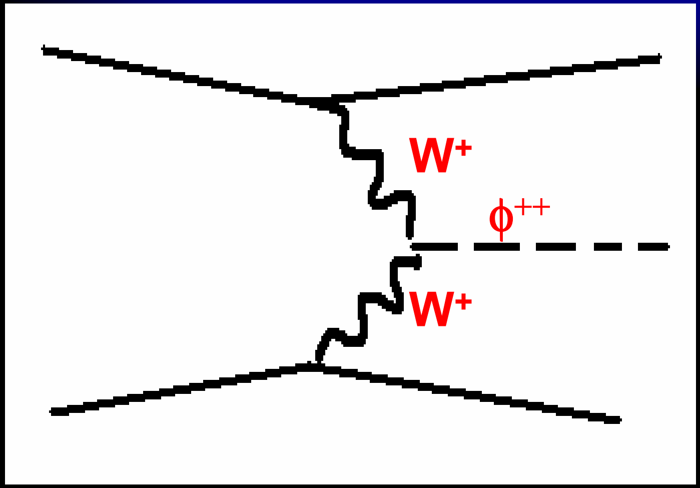
Sleptons close in mass to neutralinos: slow sleptons χ from decay.

Still several mass combination can be reconstructed.

Triplet Higgs

$$q\,q \rightarrow q\,q\,\phi^{++}$$

$$\hookrightarrow\ W^{+}W^{+} \rightarrow \ell^{+}\nu\,\ell^{+}\nu$$



Single production

Main background from $W_T W_T$ scattering