Search for strongly-produced superpartners in final states with two same-sign leptons or three leptons with the ATLAS detector using 20 fb-1 of LHC pp collisions at 8 TeV

Journées de Rencontres des Jeunes Chercheurs 2013
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Thanks to JF Arguin, David Cote, Julien Maurer

SUSY search in final states with **2 same–sign or 3 leptons** in ATLAS experiment

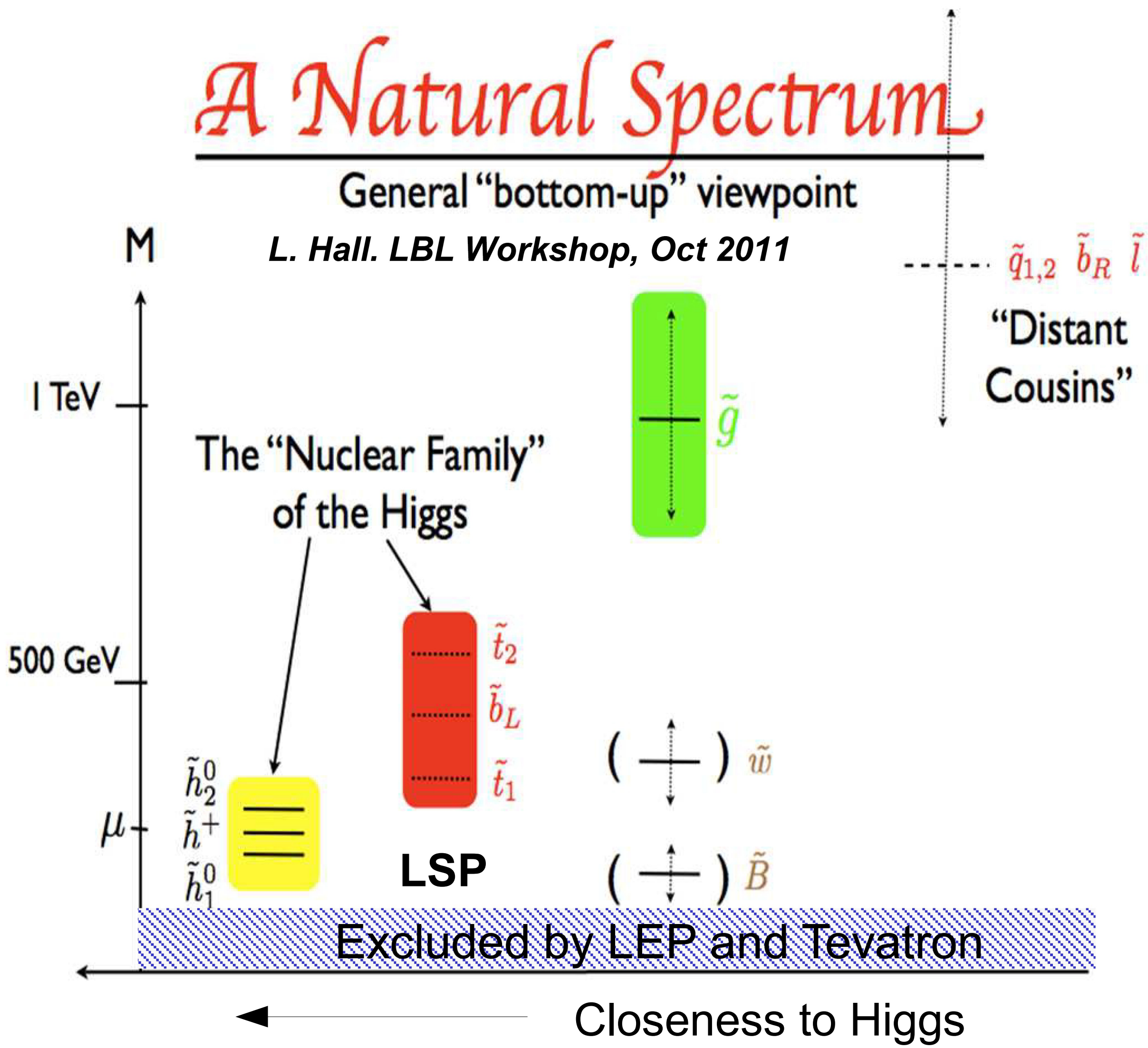
leptons = electrons or muons (no tau)

- Public results → CONF note prepared for Moriond 2013 conference
  - Using all 2012 8 TeV data ~ 20.3 fb^{-1}
  - In the coming months a paper will be released → present main improvements wrt. *Moriond analysis*

Contents of the talk

- Natural SUSY concept
- Why 2 same sign leptons final state
- Target models in this analysis
- Signal regions optimization
- Background classification & validation
- Results and interpretation

A natural SUSY spectrum

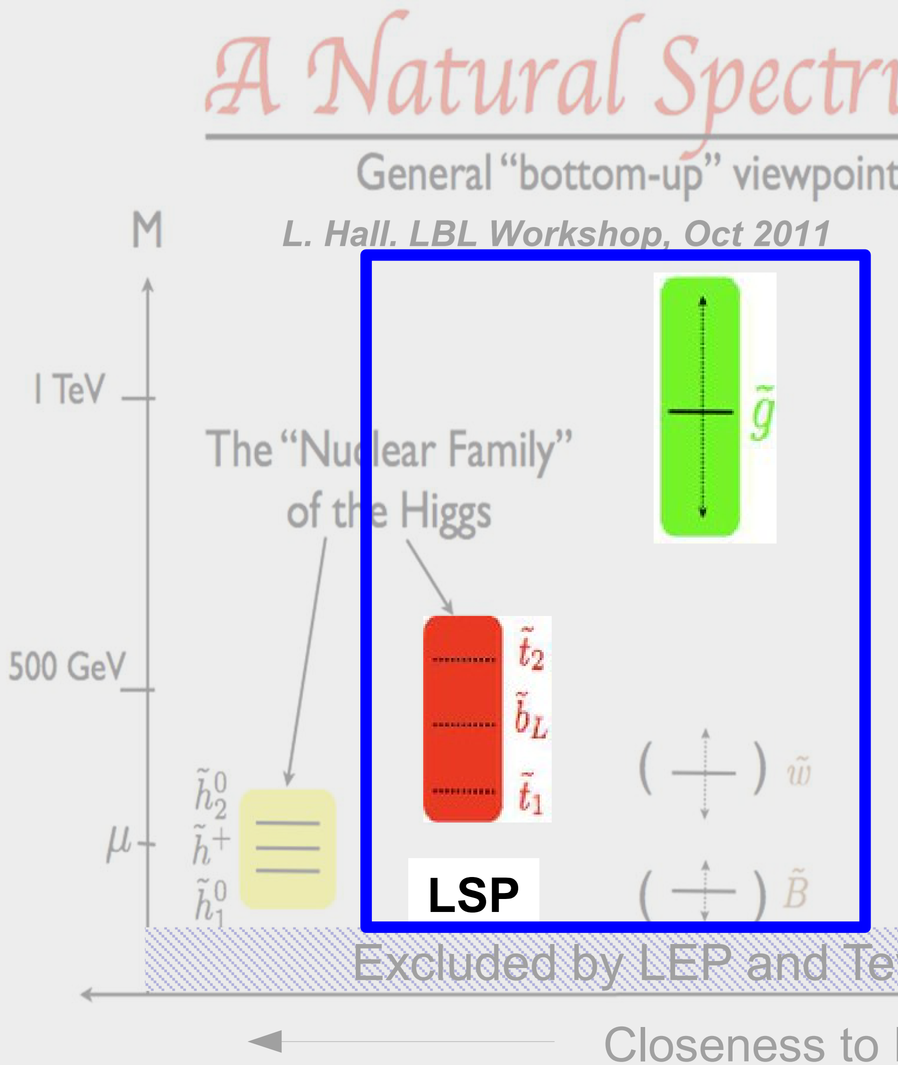


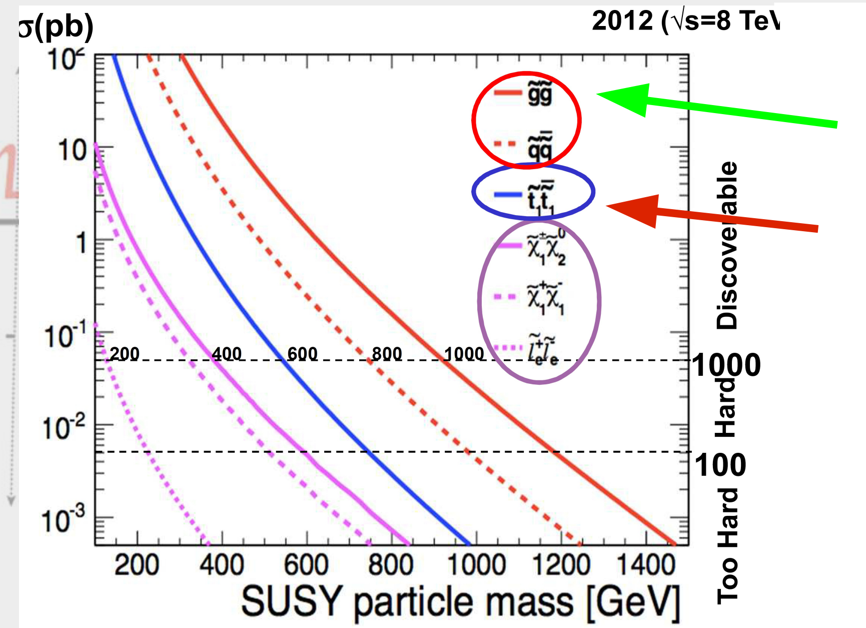
Open spectra

Hard kinematics in the final state

Compressed spectra

Soft kinematics in the final state





Today:

1) **Direct sbottom production**

sbottom → chargino → LSP

2) **Gluino pair production**

gluino → stop → LSP

Why a 2 same-sign lepton analysis?

Two same sign or three leptons production is rare in SM → **low background is expected**

Gluinos are Majorana particles → $\tilde{g} \to q\,\tilde{q}^* / \bar{q}\,\tilde{q}$ with same probability → if there are leptons in the final state → same-sign / opposite-sign same probability

3rd generation searches → top quarks (W bosons) in the intermediate state

→(SS) leptons, (b-) jets, $\not{E}_T$

Searches including leptons → smaller BR but

→ **can impose looser cuts on jet p_T, $\not{E}_T$ or m_T**

→ **can reach uncovered regions of the phase space or compressed spectra**

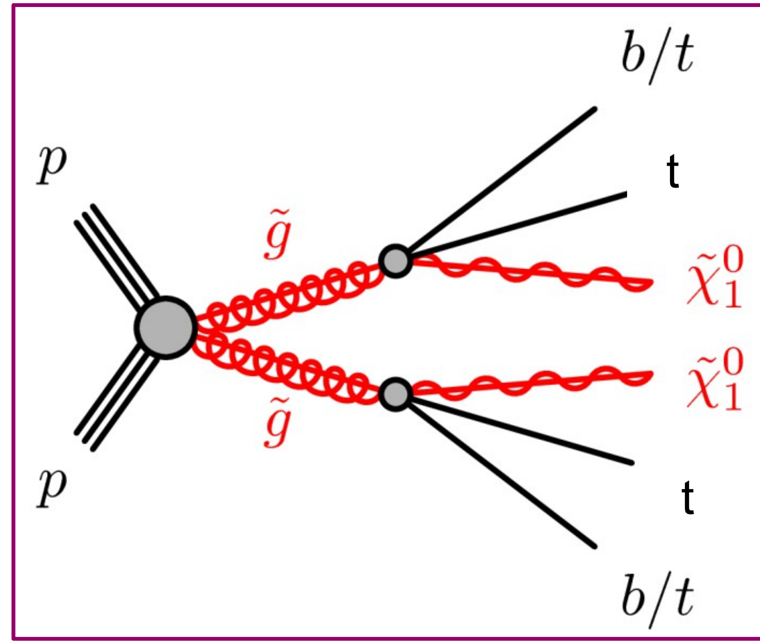
Highly sensitive to physics beyond Standard Model (not only Supersymmetry)

ex: Black hole, double charged Higgs, 4th quark generation, same-sign top pairs

Also, a wide variety of SUSY signals can be accessed (see next slide)

Considered susy models

$\tilde{g} \to t\ \tilde{t}_1$
- $\to t\ \tilde{\chi}_1^0$ — gluino-mediated stop $\to t\ \tilde{\chi}_1^0$
- $\to b\ \tilde{\chi}_1^\pm$, $\tilde{\chi}_1^\pm \to W^{\pm(*)}\tilde{\chi}_1^0$ — gluino-mediated stop $\to b\ \tilde{\chi}_1^\pm$
- $\to c\ \tilde{\chi}_1^0$ — gluino-mediated stop $\to c\ \tilde{\chi}_1^0$
- $\to$ b s — gluino-mediated stop $\to$ bs (RPV)



$\tilde{g}(\tilde{q}) \to qq(q)\ \tilde{\chi}_1^\pm$
- $\to W^\pm \tilde{\chi}_2^0$, $\tilde{\chi}_2^0 \to Z\ \tilde{\chi}_1^0$ — gluino-mediated (direct) squark $\to$ gauginos
- $\to \tilde{\ell}^\pm \nu, \ell^\pm \tilde{\nu}$ — gluino-mediated (direct) squark $\to$ sleptons

$\tilde{g}(\tilde{q}) \to qq(q)\ \tilde{\chi}_2^0$
- $\to \tilde{\ell}\ell, \tilde{\nu}\nu$ — gluino-mediated (direct) squark $\to$ sleptons

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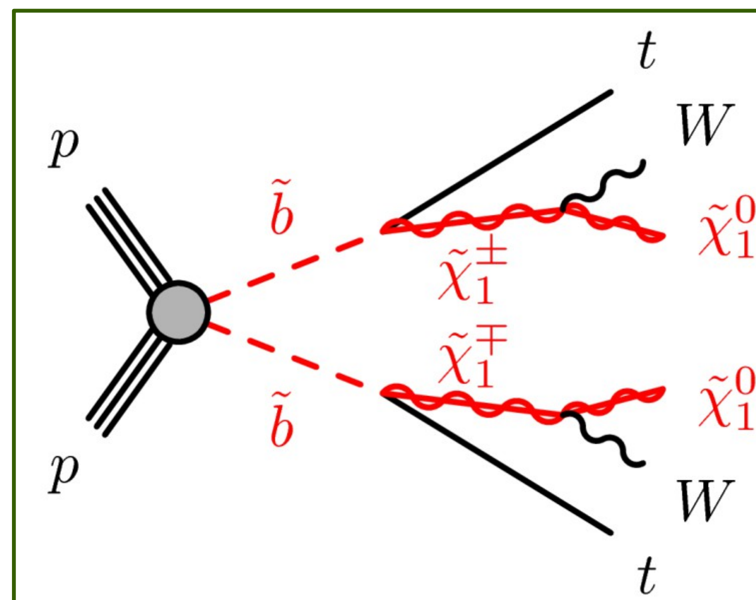
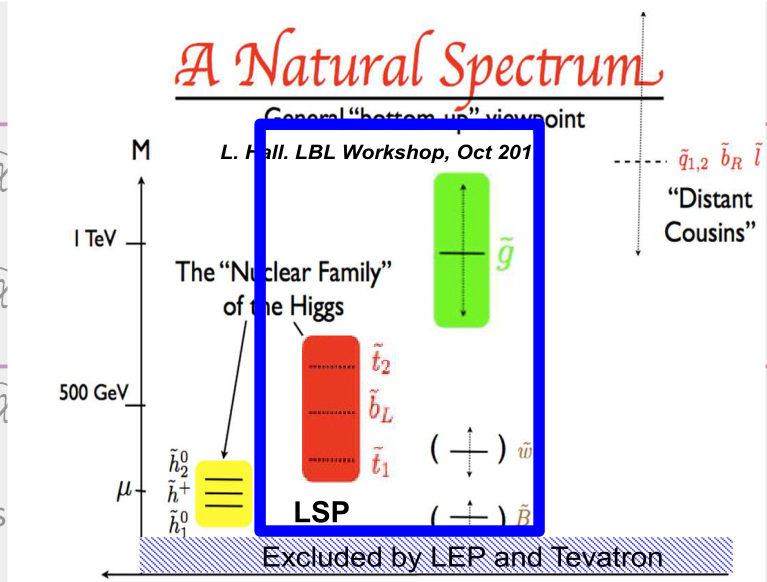
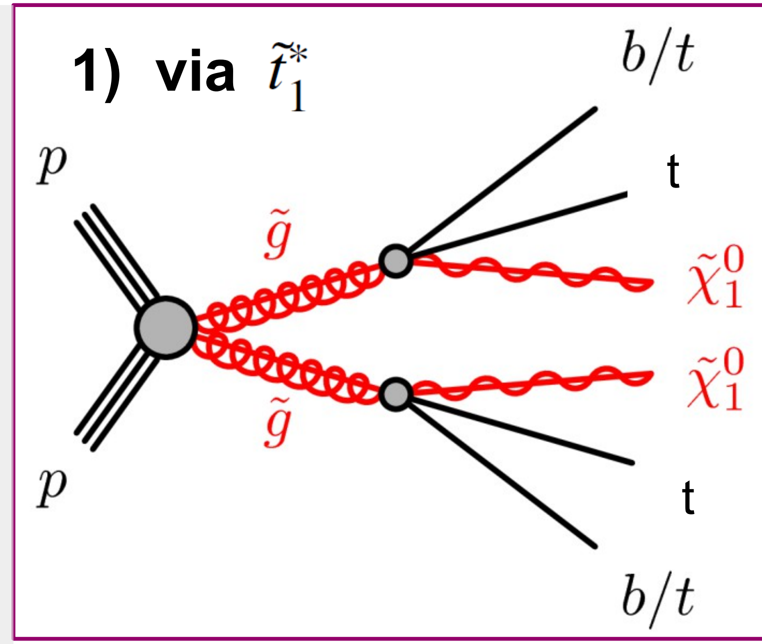
$\tilde{b}_1 \to t_1 \tilde{\chi}_1^\pm$
- $\to W^{\pm(*)}\tilde{\chi}_1^0$
  - direct sbottom ($t\tilde{\chi}_1^\pm$) fixed $m_{\tilde{\chi}_1^0}$
  - direct sbottom ($t\tilde{\chi}_1^\pm$) varied $m_{\tilde{\chi}_1^0}$



Considered susy models





Same sign signature in SUSY models

1) **Gtt** → 4 tops → 4 W → **up to 4 leptons + 4b**

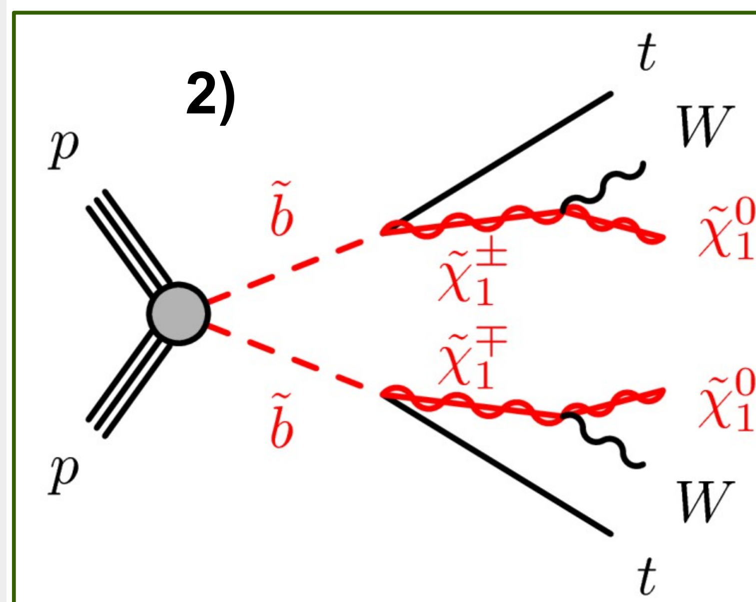
Gtb → via virtual stop → 4 tops → **4 W**

Or via virtual sbottom → 4 tops → **4W**

→ **up to 4 leptons + 4b**

2) **Direct sbottom** → 2 tops + 2 W → **4 W**

→ **up to 4 leptons + 2b**



Event selection

→ using a combination of $\not{E}_T$, single and di-lepton triggers

→ select at least 2 same – sign leptons with p_T > 20 GeV

Signal region definition

→ for 8TeV release → **signal region optimization** → 3 SR depending on b-jet multiplicity

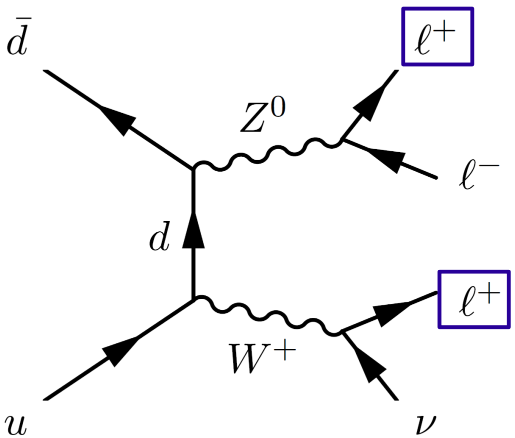
Signal region	N_{b-jets}	Signal cuts (discovery case)	Signal cuts (exclusion case)
SR0b	0	$N_{jets} \geq 3$, E_T^{miss}> 150 GeV m_T> 100 GeV, m_{eff}>400 GeV	$N_{jets} \geq 3$, E_T^{miss}> 150 GeV, m_T> 100 GeV, binned shape fit in m_{eff} for m_{eff} >300 GeV
SR1b	≥1	$N_{jets} \geq 3$, E_T^{miss}> 150 GeV m_T>100 GeV, m_{eff}>700 GeV	$N_{jets} \geq 3$, E_T^{miss}> 150 GeV, m_T>100 GeV, binned shape fit in m_{eff} for m_{eff}>300 GeV
SR3b	≥3	$N_{jets} \geq 4$ -	$N_{jets} \geq 5$, E_T^{miss}< 150 GeV or m_T< 100 GeV

Background sources:
same – sign signature in Standard Model

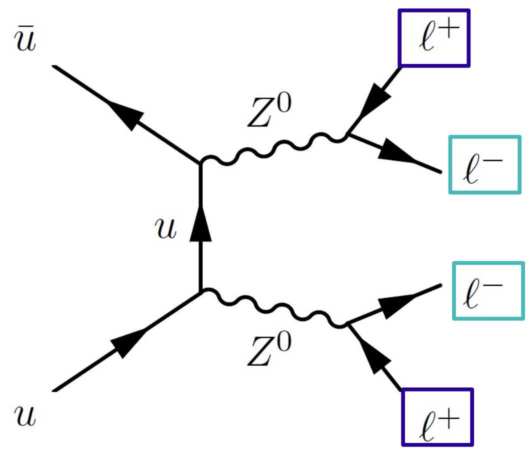
Standard Model background in signal regions → di–boson and tt + Vector boson

→ Small contribution from tt + Higgs, Higgs + Z / W, tri–boson, …

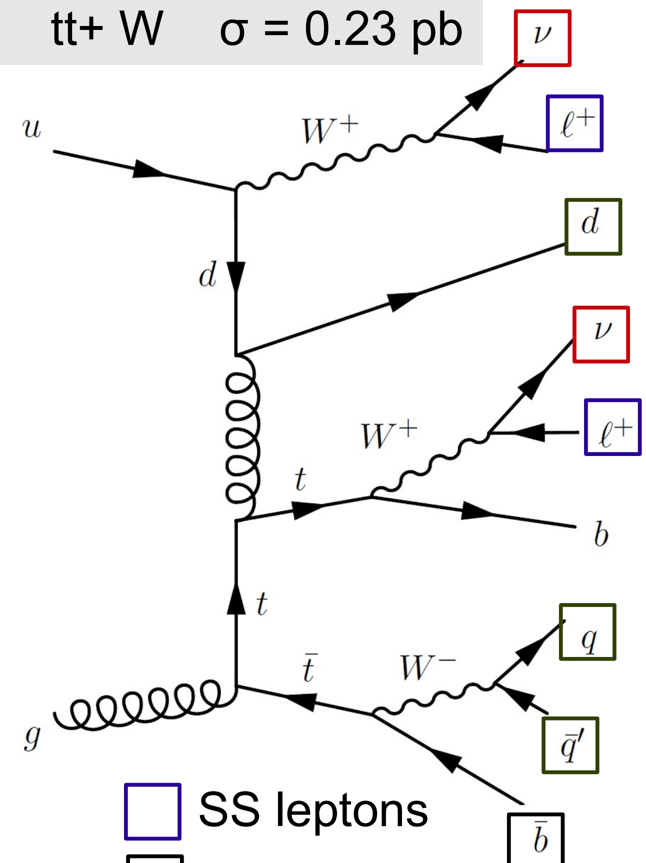
WZ → 3l + v σ = 10.2 pb



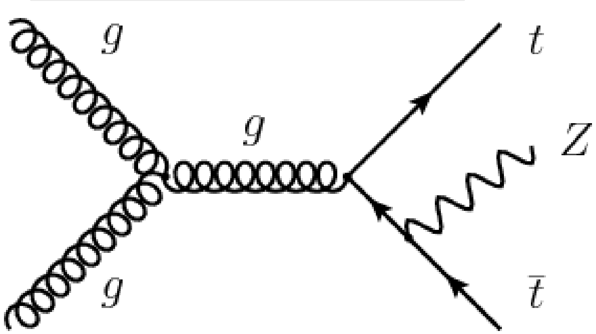
ZZ → 4l σ = 8.7 pb



tt+ W σ = 0.23 pb



tt + Z σ = 0.21 pb



Not a sizable contribution

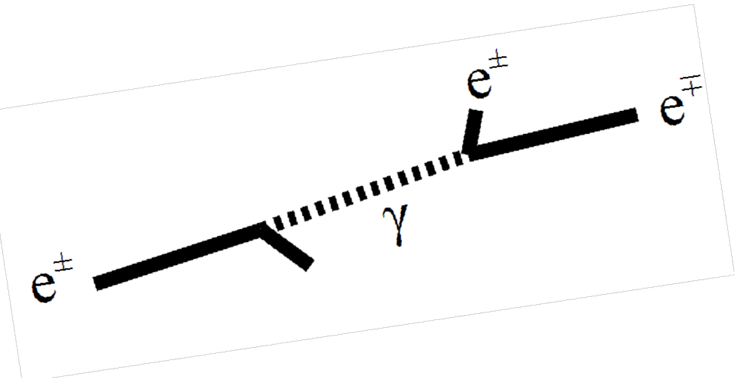
$W^{\pm}W^{\pm}$	WWW^*, WZW^*, ZZZ^*
0.04 pb	0.4 pb

$t\bar{t} + WW$	$t\bar{t} + H$	$WH,\ ZH$
0.001 pb	25% × 0.13 pb	25% × 1.1 pb

SS leptons
b-jets
jets
Missing transverse E

Background sources:
charge flip and fake leptons

Reconstructed electron charge flipped with respect to original electron (not important for μ)

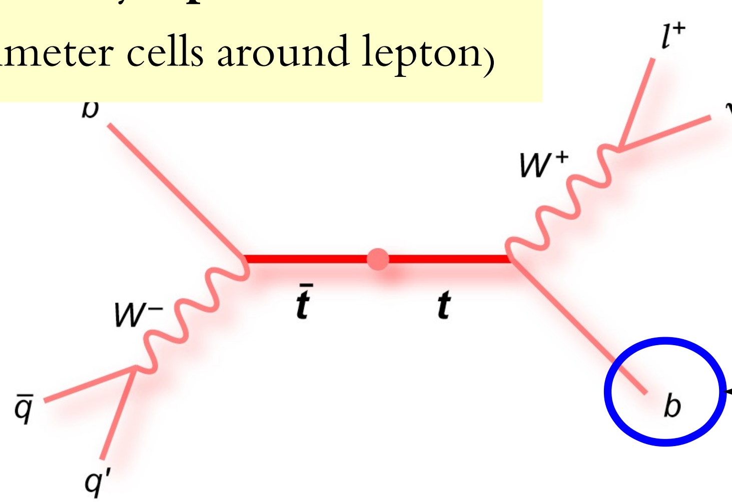


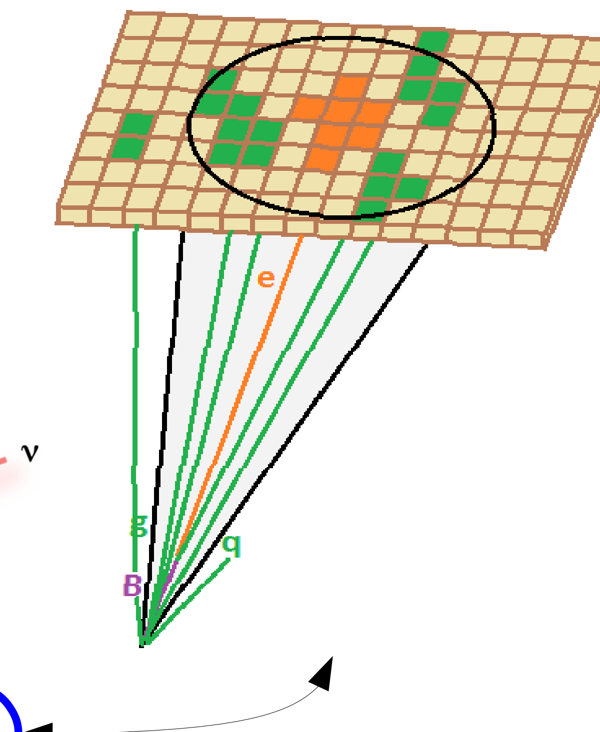
- When wrong track used to reconstruct electron
- Transforms opp-sign into same-sign event
- Estimated by weighting OS_{Data} events by charge flip rate (~0.2 %)

fake leptons produced in the weak b-hadron decay, conversions, meson decay in-fligh, hadrons faking electrons.

- Tag a quark in the final state → not wanted
  → Estimated from data using mainly **lepton isolation**
  (energy of the tracks or calorimeter cells around lepton)

Not always well simulated
→ using data-driven methods





Charge flip rate

Measure the charge flip rate in data → reweight OS_{Data} events → $w = \varepsilon_{lep1}^{misID} + \varepsilon_{lep2}^{misID} - 2\varepsilon_{lep1}^{misID}\varepsilon_{lep2}^{misID}$

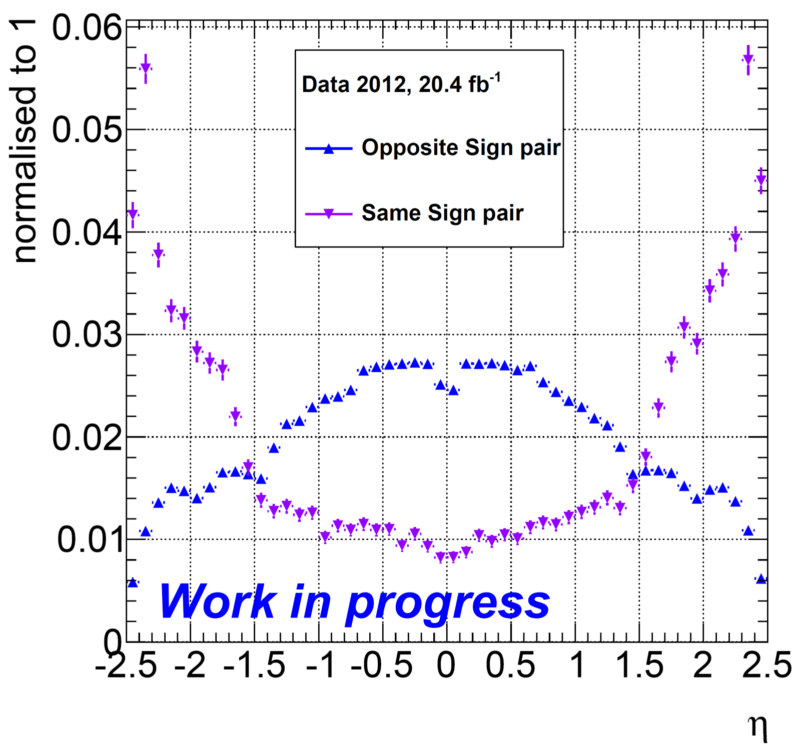
– negligible for muons

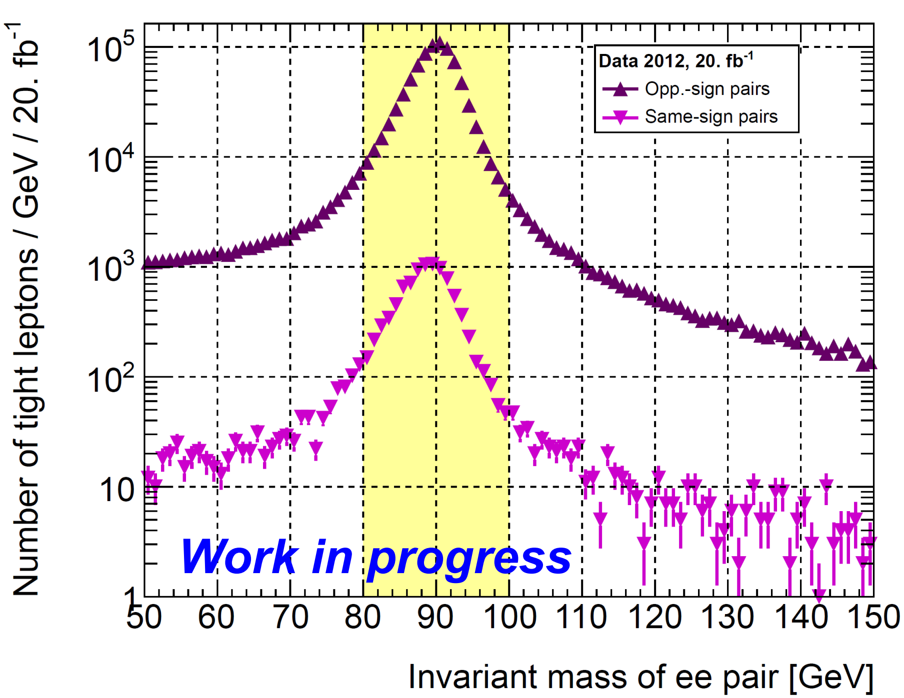
same cuts as applied to SS events

Sensitive to material in front of calorimeter, track curvature in magnetic field ……

– measured as a function of η and p_T in the Z peak region [75,100] GeV

Tag and Probe method used to measure this rate → fully data – driven





Fake leptons estimation

Fake lepton estimation → matrix method → fully data driven method

- Events are classified in 4 categories depending if each lepton passes / fails the signal lepton definition

- Given **r** (**f**) the probabilities that a prompt (fake) lepton passes the isolation criteria

  N[pass,pass] = r^2 N[real,real] + $r\,f$ N[real,fake] + $f\,r$ N[fake,real] + f^2 N[fake,fake]

  similar relations can be written for N[pass,fail], N[fail,pass], N[fail,fail]

- **System of 4 linear equations** can be inverted to find number of real/fake leptons :

$$\begin{pmatrix} NRR \\ NRF \\ NRF \\ NFF \end{pmatrix} = \begin{pmatrix} r1\,r2 & 0 & 0 & 0 \\ 0 & r1\,f2 & 0 & 0 \\ 0 & 0 & f1\,r2 & 0 \\ 0 & 0 & 0 & f1\,f2 \end{pmatrix} \cdot \begin{pmatrix} r1\,r2 & f2\,r1 & f1\,r2 & f1\,f2 \\ r1\,(1-r2) & (1-f2)\,r1 & f1\,(1-r2) & f1\,(1-f2) \\ (1-r1)\,r2 & f2\,(1-r1) & (1-f1)\,r2 & (1-f1)\,f2 \\ (1-r1)\,(1-r2) & (1-f2)\,(1-r1) & (1-f1)\,(1-r2) & (1-f1)\,(1-f2) \end{pmatrix}^{-1} \cdot \begin{pmatrix} npp \\ npf \\ nfp \\ nff \end{pmatrix}$$

needed — *scale to tight* — *system of equations* — *measured*

Need measurement of r, f → done in dedicated samples enriched in real/fake leptons

Electron efficiency identification (r)

Same for muons

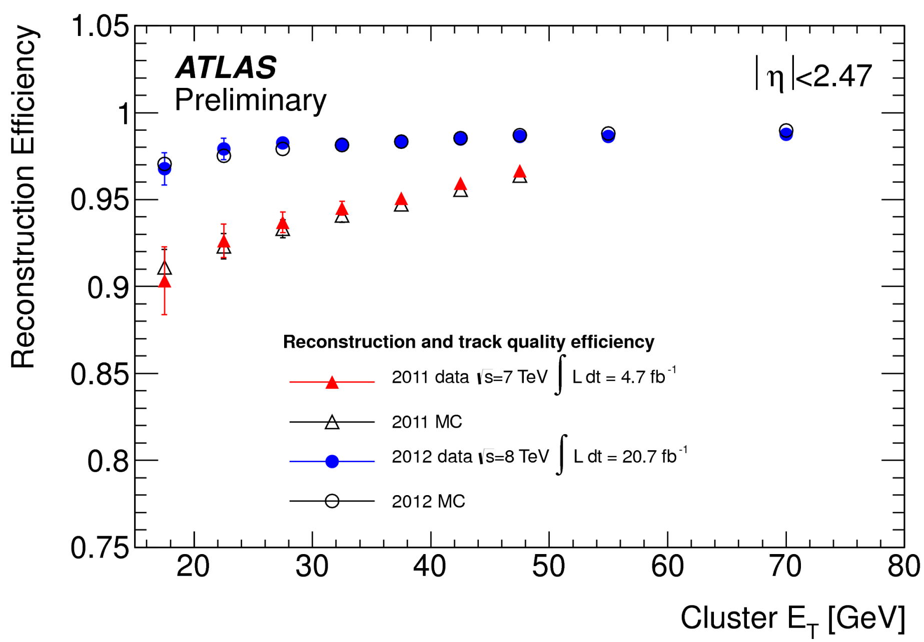
Abundant source of real electrons in data : decays of Z boson in electron pairs

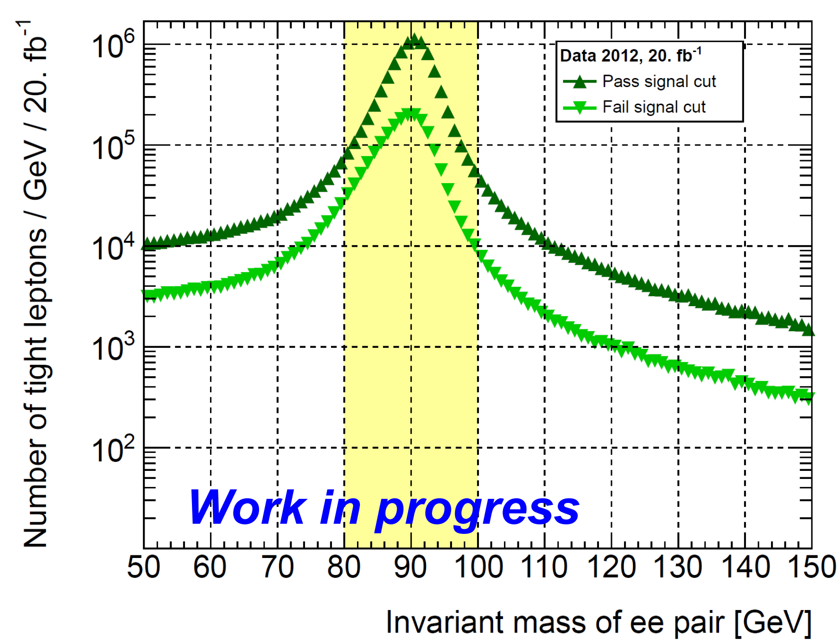
- used to select unbiased sample of electrons with loose ID cuts

r ~ 80 - 90%

→ lepton pairs selected under the Z mass peak [80,100] GeV

- Tightest ID applied to tag electron to remove the background
- Loose selection for the probe electron – used to measure the efficiency as N_{pass} / N_{trial}





Working also on electron performance...

Fake lepton rate (f)

Electron fake rate (**10 – 30%**) → same–sign eμ pairs

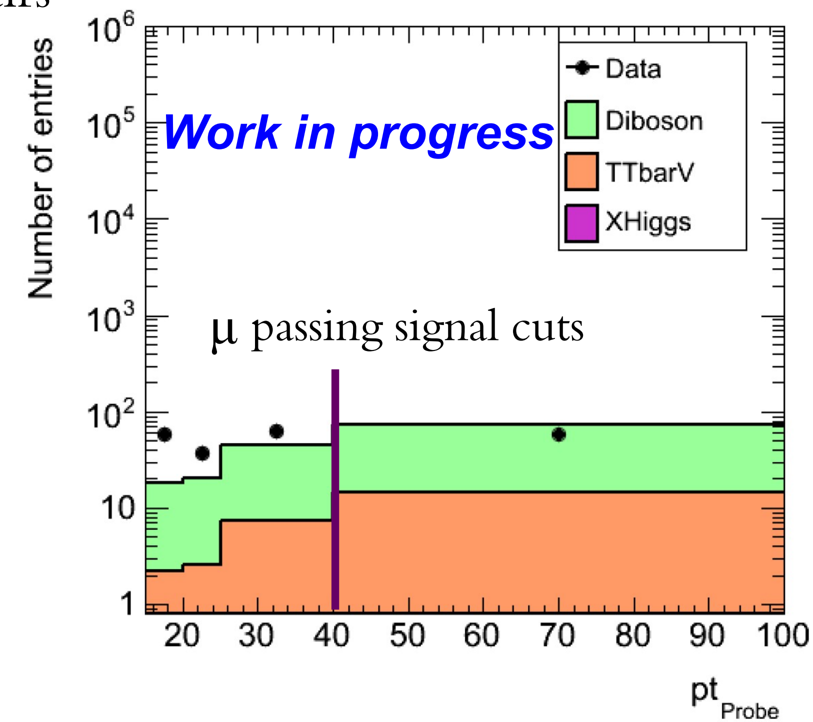
– tag μ ensured to be real
→ pass signal cuts, $p_T > 40$ GeV
corresponding e (probe) most likely a fake

Muon fake rate (**15%**) → same–sign μμ pairs

both muons are considered alternatively for the meas.

– at least 2 jets in the event ; tag μ ensured to be real

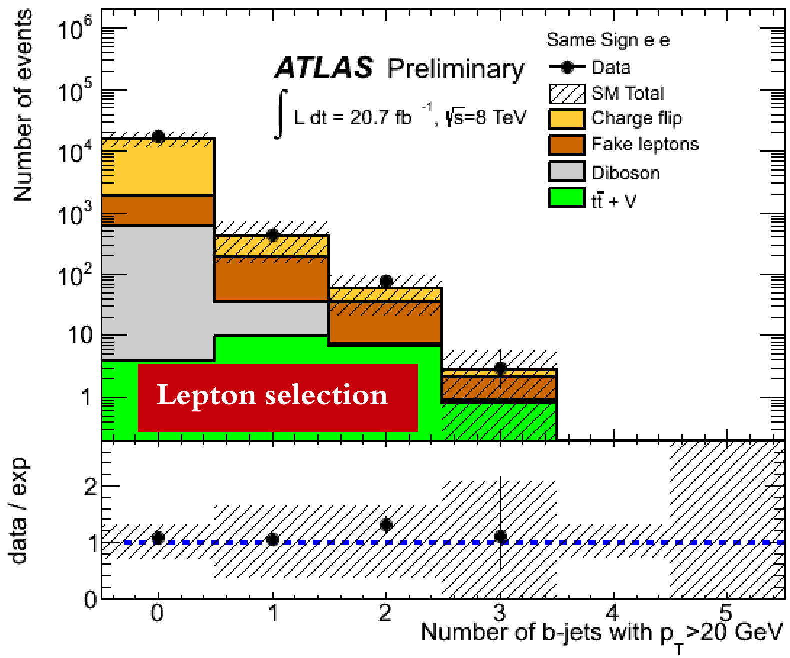
$\mathbf{f = N_T / (N_T + N_L)}$ → for μ above 40 GeV,
not enough statistic in data → $f_{[25,40]bin} * 1.16$ (factor measured in Monte – Carlo)

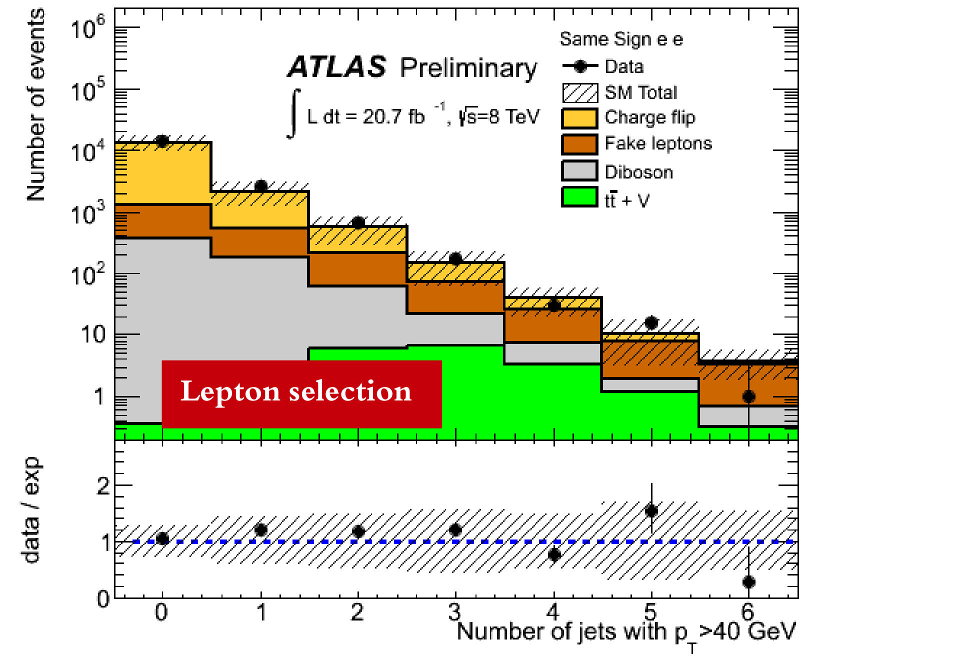


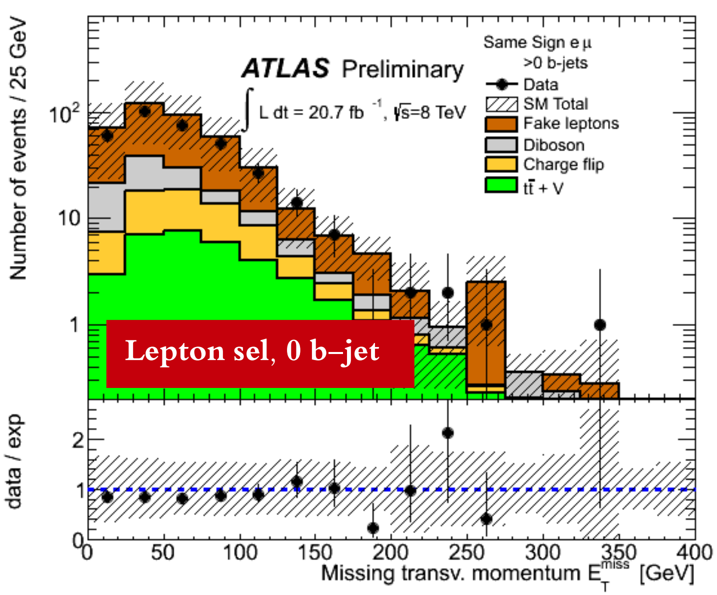
3 b–jets region → fake rate in each channel multiplied with factors measured in MC

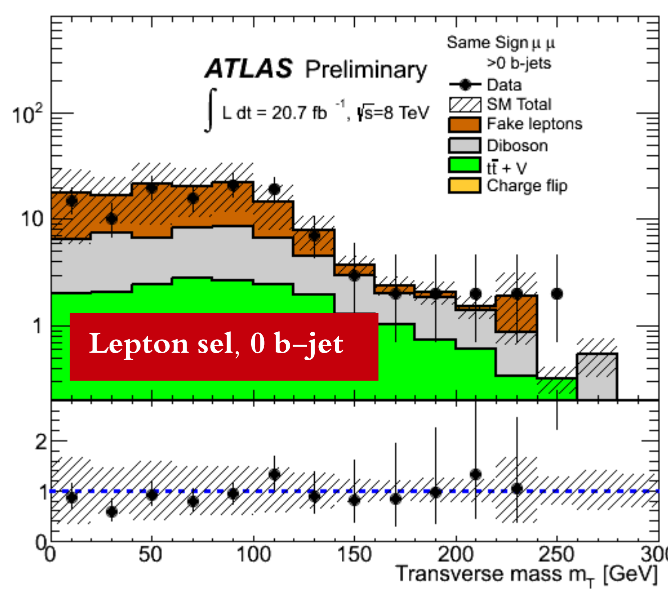
Real lepton contamination, ie. diBoson, ttbarV, ttbarH estimated from Monte – Carlo
while charge flip contamination → estimated from data

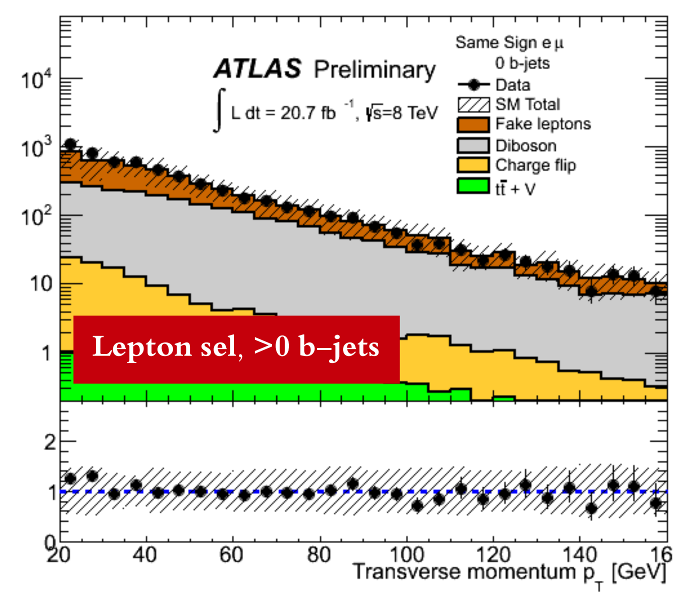
Background validation











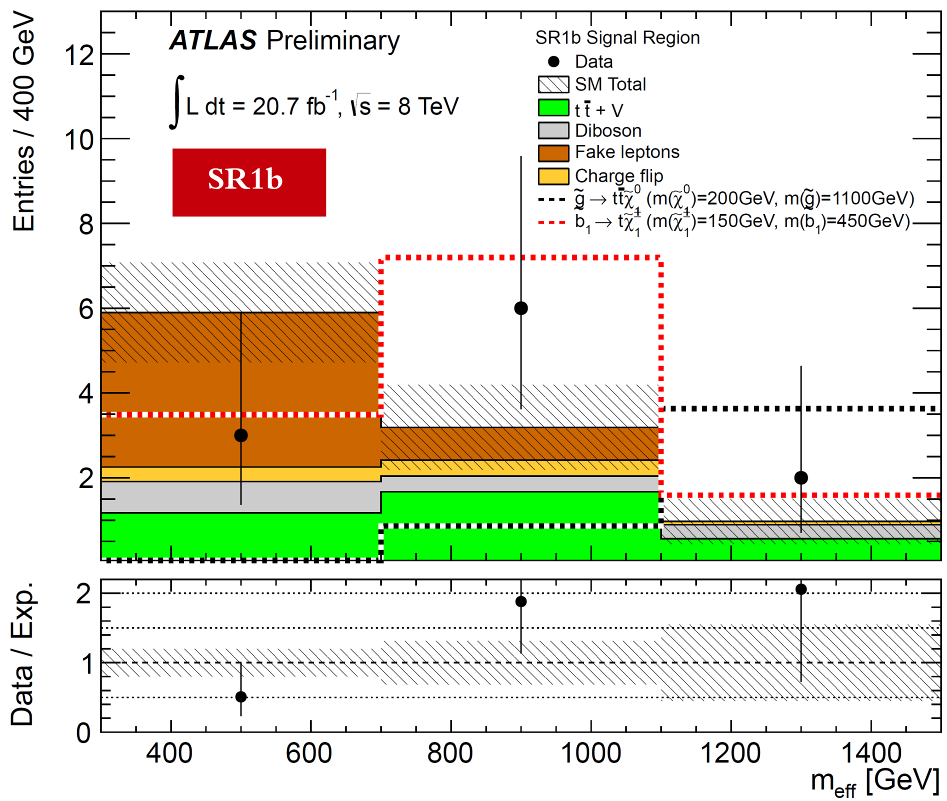
Simultaneous fit method

Perform simultaneous fit across signal regions using *Histfitter* tool

Model independent results 95% CL_s → calculated using the discovery fit (one bin)

Model dependent 95% CL_s → calculated using the exclusion fit

→ fit in m_{eff} – 3 bins SR1b ; overall observed limit → all SRs are combined



Results: signal region, model independent

A) Discovery case	**SR0b**	**SR1b**	**SR3b**
Observed events	5	8	4
Expected background events	7.5 ± 3.3	3.7 ± 1.6	3.1 ± 1.6
Expected $t\bar{t} + V$ events	0.5 ± 0.4	2.2 ± 1.0	1.7 ± 0.8
Expected diboson events	3.4 ± 1.0	0.7 ± 0.4	0.1 ± 0.1
Expected fake lepton events	3.4 ± 3.1	$0.3^{+1.1}_{-0.3}$	$0.9^{+1.4}_{-0.9}$
Expected charge mis-measurement events	0.1 ± 0.1	0.5 ± 0.2	0.4 ± 0.1
p_0	0.50	0.11	0.36

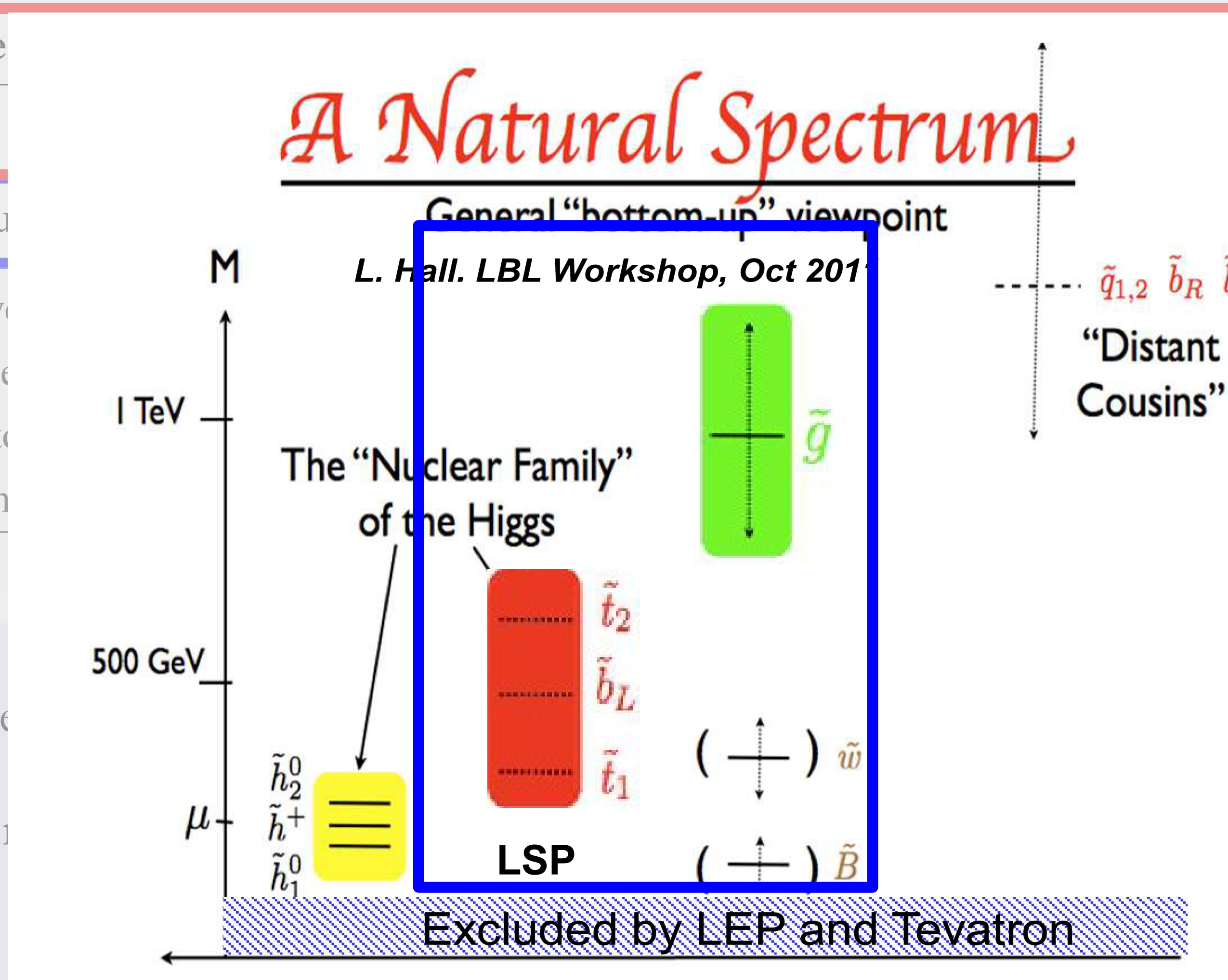
Most SRs are dominated by statistical uncertainty on expected number of bkg events

Systematic uncertainties typically dominated by

– Electron fake rate, ttbarV, JES / JER, MC stat diBoson, b-tagging

Not a significant excess observed → using simplified models to interpret the results

A) Discovery case	SR3b
Observed events	4
Expected backgrou	3.1 ± 1.6
Expected $t\bar{t} + V$ ev	1.7 ± 0.8
Expected diboson e	0.1 ± 0.1
Expected fake lept	$0.9^{+1.4}_{-0.9}$
Expected charge m	0.4 ± 0.1
p_0	0.36



Most SRs are ... bkg events

Systematic u...

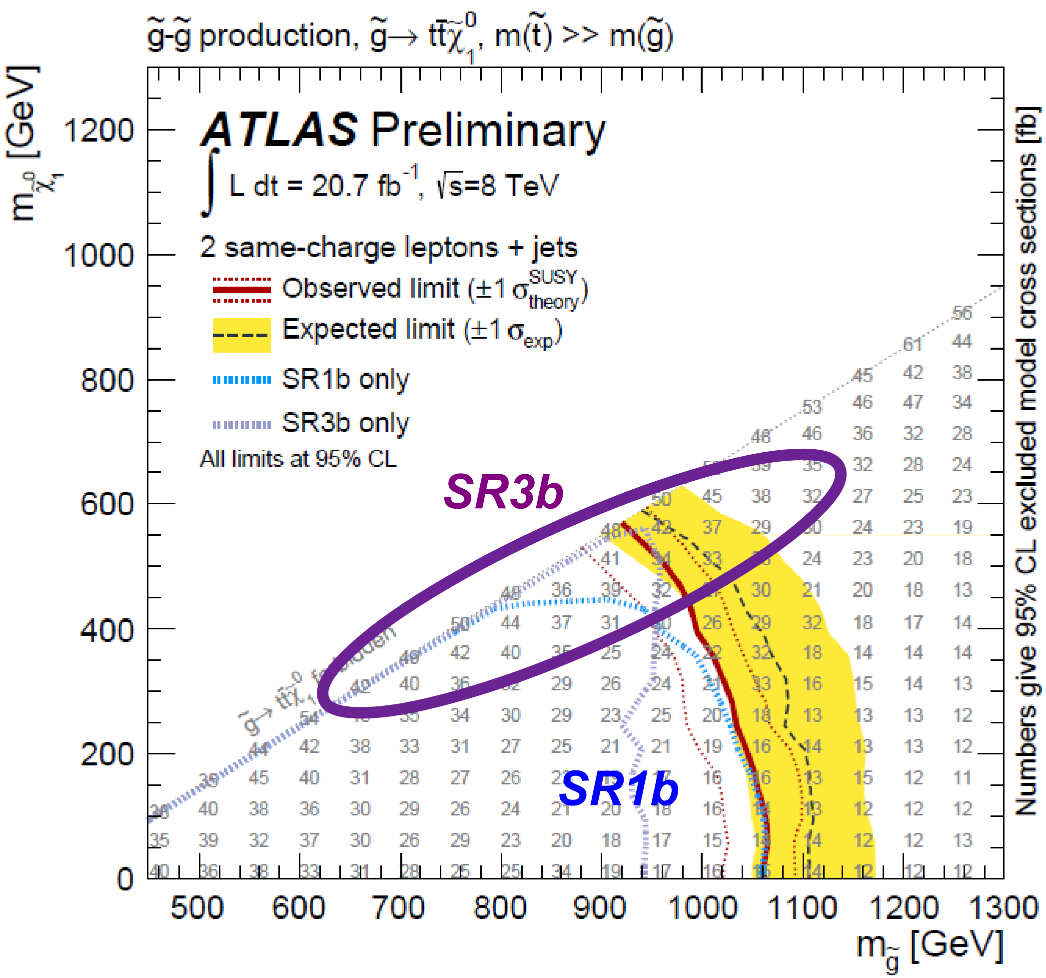
– Electron ...

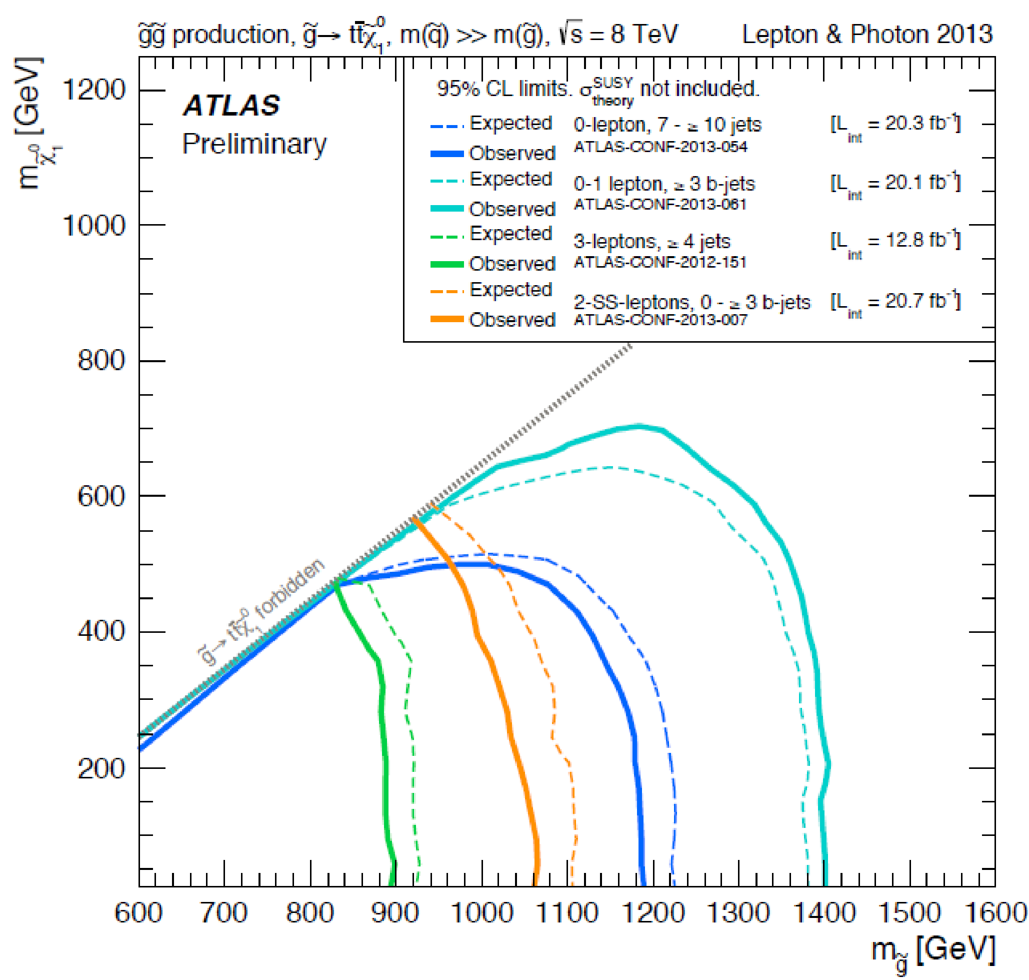
Not a significant excess observed → using simplified models to interpret the results

Interpretation: model dependent limits

Gluino–stop model (t χ^0_1) off – shell

→ the analysis is sensitive to SUSY signal for gluino masses lighter than ~1010 GeV

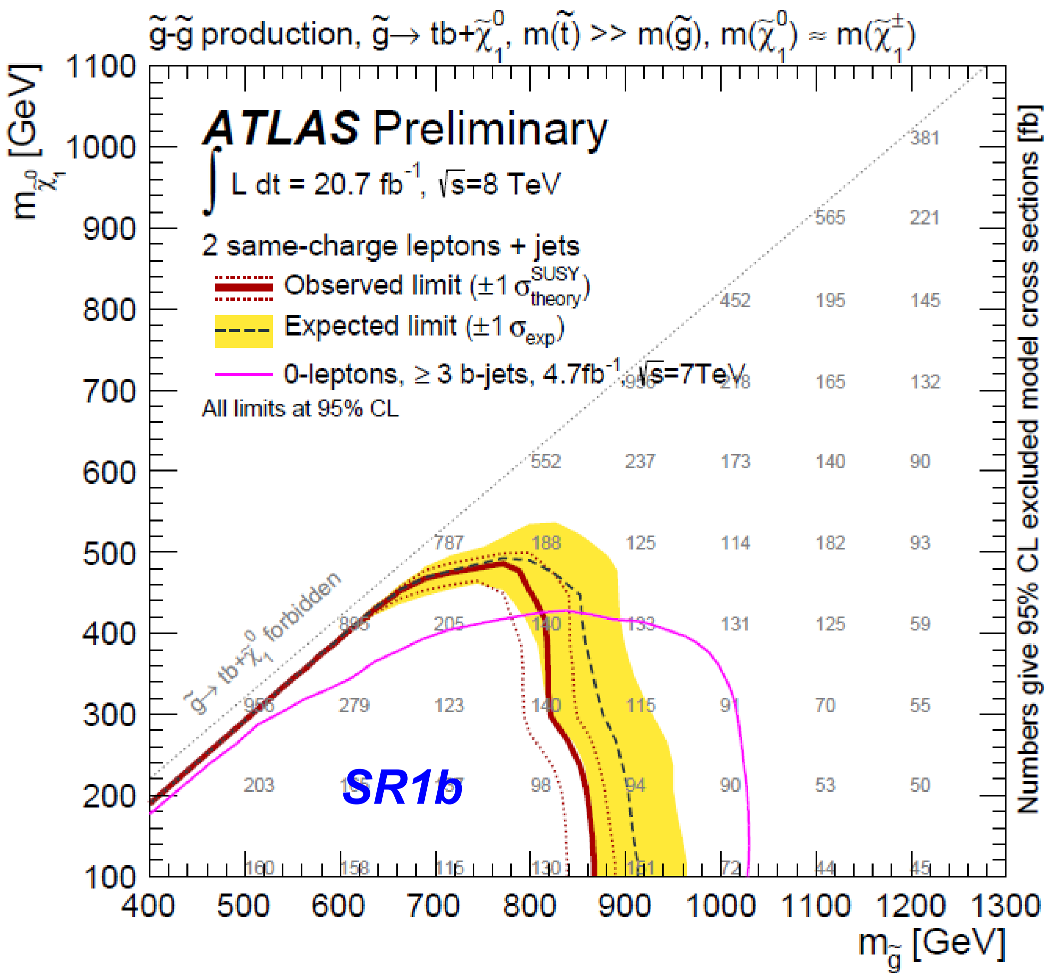


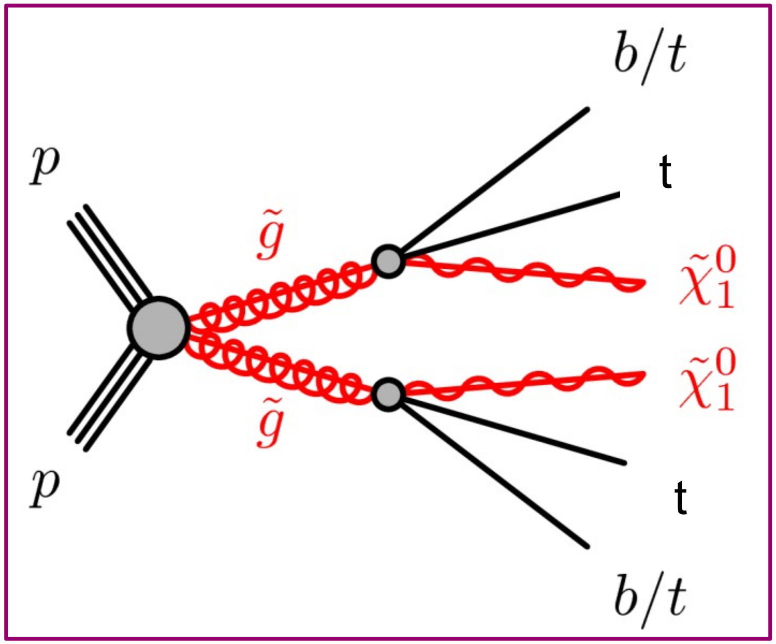


Interpretation: model dependent limits

Gluino–stop model (**b** $\chi^{\pm}_{1}$) **mass degenerate** ( )

→ the analysis is sensitive to SUSY signal for gluino masses lighter than 800 – 900 GeV

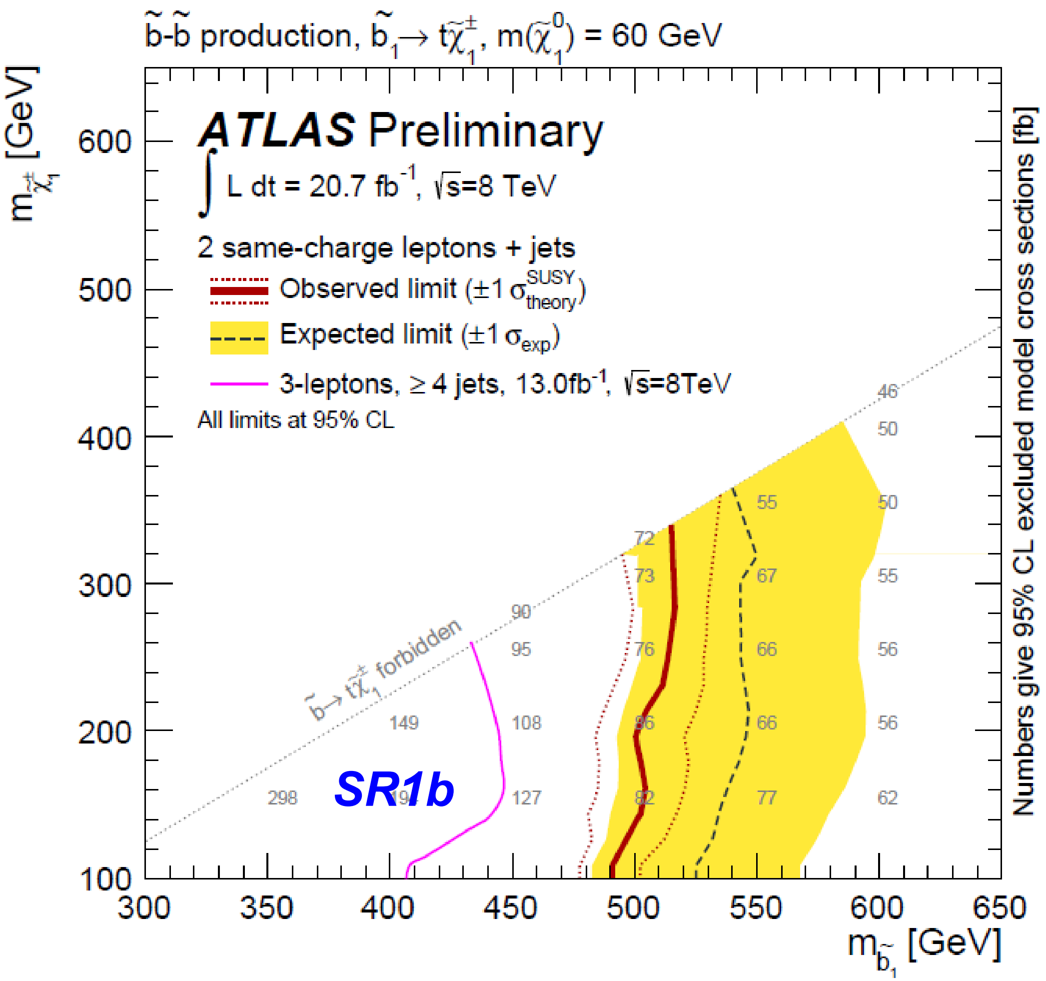




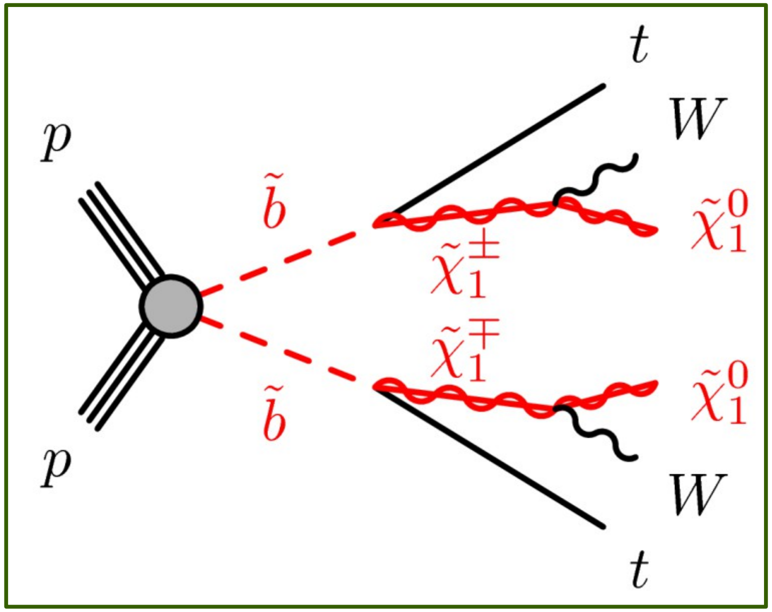
Interpretation: model dependent limits

Direct sbottom model

→ m χ^0_1 = 60 GeV, $\chi^\pm_1$ mass is varied – $m_b - m\,\chi^\pm_1$ plane



The strongest limits in ATLAS



Conclusions

SUSY search in final states with **2 same-sign or 3 leptons** in ATLAS experiment

Very low SM background → high sensitivity to BSM

→ half shared between irreducible bkg and mis-reconstructed objects

Signal regions were re-optimized (only 1 in the previous release)

→ new SRs with b-jets were added, since many models produce up to 4 b's

Include a larger amount of SUSY signatures

New re-optimization for "*Summer paper*" → see next slide

Changes wrt. Moriond analysis

Event selection

Merge Same-Sign pair and 3 leptons signatures → signal regions ***re-optimization***

Sub-leading lepton p_T → 15 GeV to improve the sensitivity to compressed spectra

Signal leptons → isolation variables optimization

Background

Charge flip rate → likelihood method

Fake leptons estimation → generalized matrix method

Fake b-jets (SR3b) → b-jet matrix method as cross-check

Fake leptons → Mc-based fake lepton estimation as cross-check

Interpretation, **new models were added**

Gluino mediated stop decaying to charm (competitive with 0-lepton on the diagonal)

Gluino mediated and direct production of 1^{st} / 2^{nd} generation squarks decaying to WZWZ (competitive to 1-lepton)

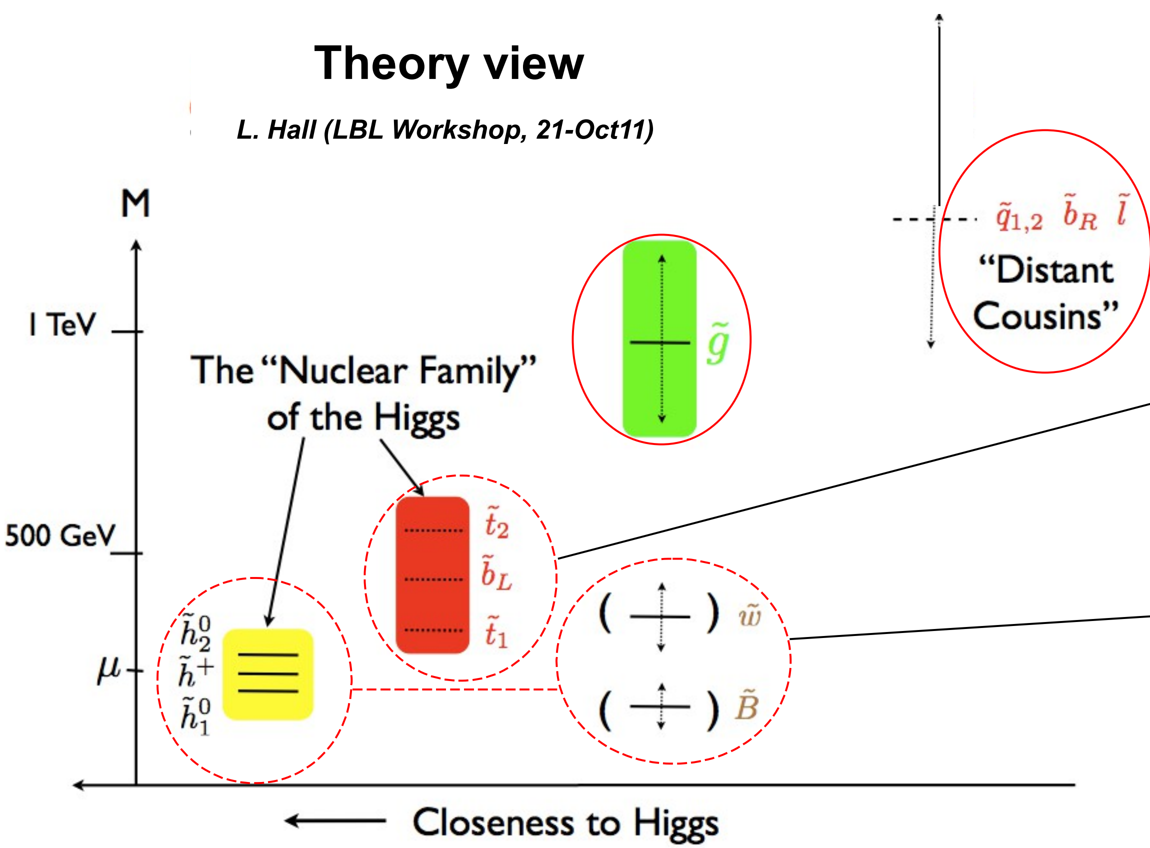
Backup

Natural SUSY searches

- "Natural" SUSY ➔ Dedicated searches

Theory view

L. Hall (LBL Workshop, 21-Oct11)



Experimental view

Light squarks, sleptons :«decoupled»
Direct production: jets + MET (+leptons)

Gluino :
Direct production: jets + MET (+leptons)
but cross-section may be low

3rd generation:
Direct production: bs, Ws, ts + MET (7 TeV)
Gluino mediated: same + jets (8 TeV, 8 TeV, 7 TeV)

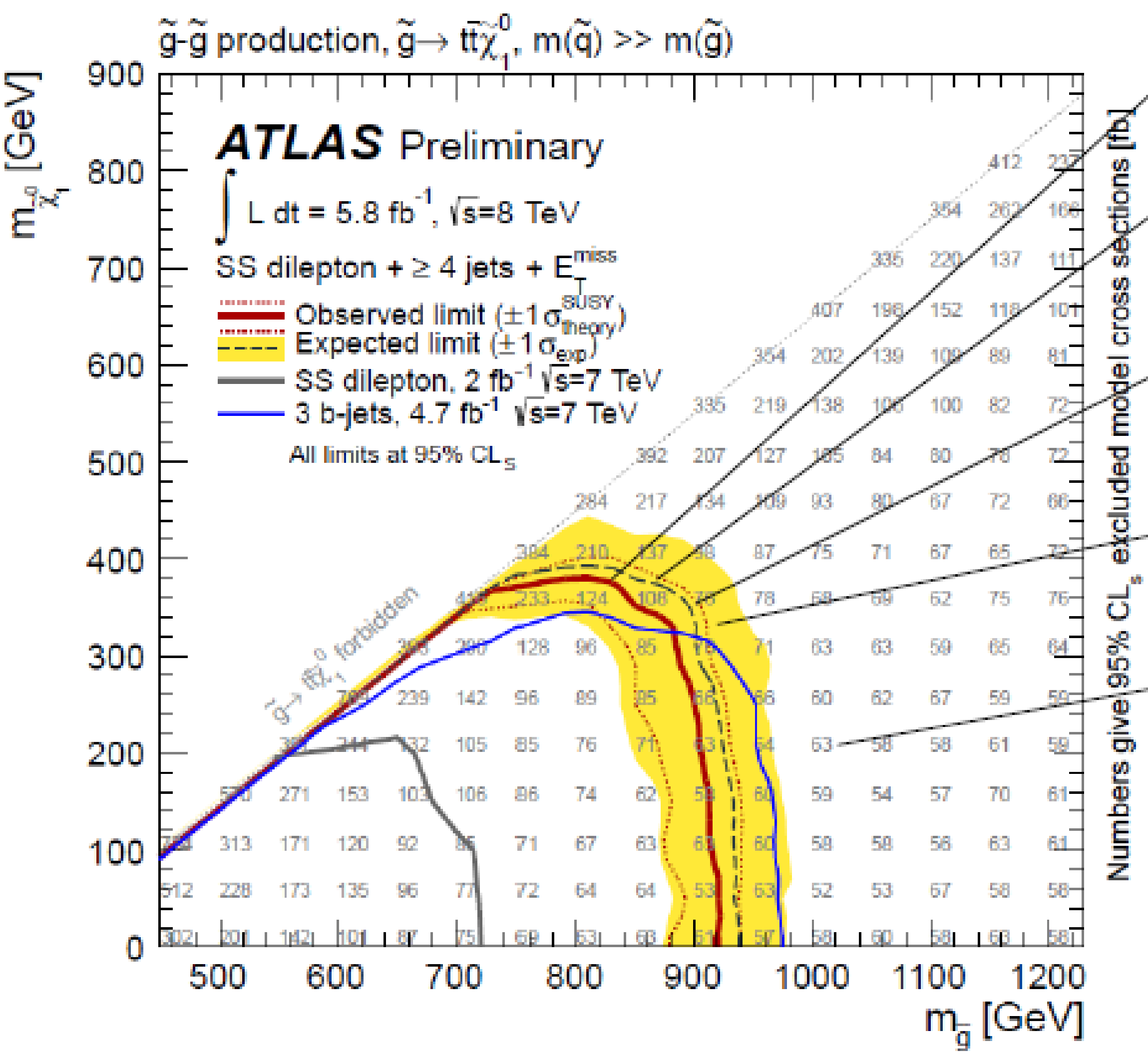
EWK-inos=Gauginos ($\tilde{\chi}_1$=LSP):
Direct production: leptons, MET, Jet veto
Gluino mediated: leptons, jets, MET

➔ Consolidate wrt ICHEP: final results at √s=7 TeV, first results with 8fb^{-1}

Interpretation of results : Gtt model

Julien Maurer

- **Simplified model:** $\tilde{g} \rightarrow t\,\bar{t}\,\tilde{\chi}_1^0$ via offshell stop (2.5TeV), BR 100% , other sparticles decoupled
- No excess observed → one can exclude the sets of parameters that predict « too large » number of events in the signal region
- Formalism for deriving limits uses 95% CL_s exclusion, standard at LHC



Observed limit : what can be excluded given the data observation

SUSY theory uncertainty : error on signal cross-section from variations of pdf and renormalization scales

Expected limit : what would be excluded if observed data was exactly the background prediction

Exp. uncertainty : error on SM bkg prediction (stat + all systematics)

Upper limit on cross-section : this model is not a complete theory. But if this decay chain occurs in a theory, one can compute the cross-section and directly check its viability, since numbers already account for kinematics and detector acceptance