Early SUSY Searchs at the LHC (From a Theorist's Point of View)

Andre Lessa

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LAPTH Seminar - September 9th, 2010

- **H. Baer, V. Barger, AL and X. Tata**, JHEP 0909:063,2009.
- **H. Baer, V. Barger, AL and X. Tata**, JHEP 1006:102,2010.
- **H. Baer, S. Kraml, AL, and S. Sekmen**, JHEP 1002:055,2010.
- **H. Baer, S. Kraml, AL, S. Sekmen and X. Tata**, arXiv:1007.3897.

Outline

- What is SUSY?
- Where is SUSY?
- LHC7 Reach
  - mSUGRA
  - Non mSUGRA Models
- Conclusions

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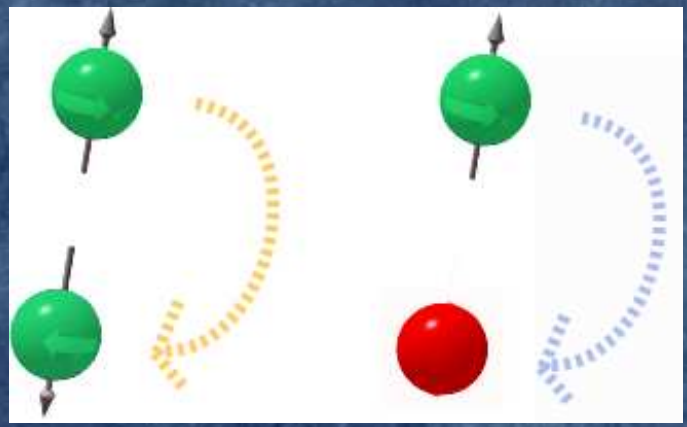

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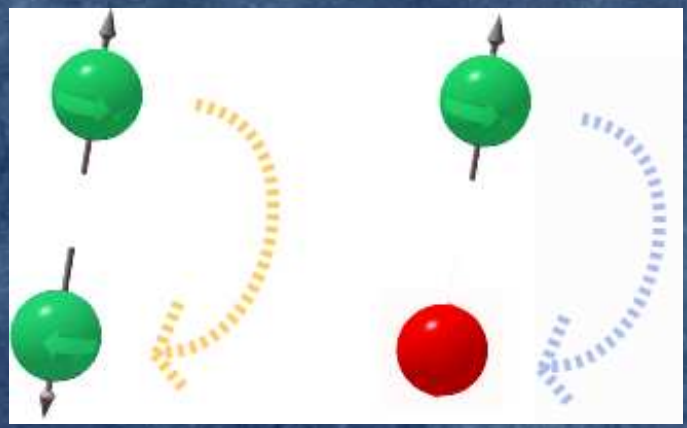

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- Fermions $\leftrightarrow$ Bosons

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  $\Rightarrow$ All interactions are ($\sim$) known!

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- Breaking (soft) terms have the correct form!
  If $\mathbf{m}$, $\mathbf{A}, \mathbf{M} \sim 1$ TeV:

  $\Rightarrow$ light matter fermions and gauge bosons (SM)
  $\Rightarrow$ heavy matter scalar and gauginos (MSSM)

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...However it has over 100 (soft) parameters just in the MINIMAL (unconstrained) model!

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  - Standard SUSY channels:
    - $\not{E}_T$ + jets
    - OS, SS dileptons + jets
    - Trilepton
    - jets + γ, ...

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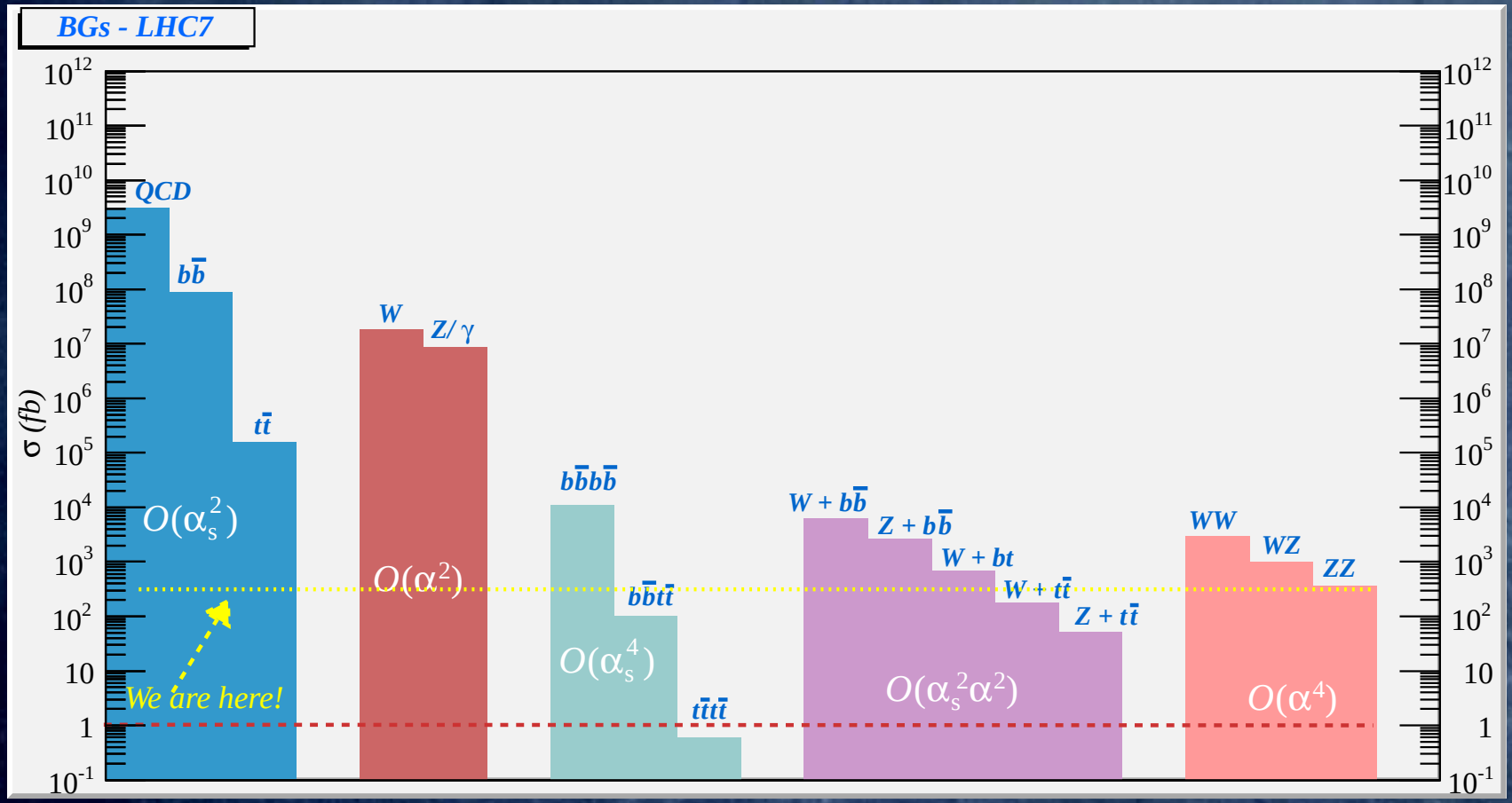
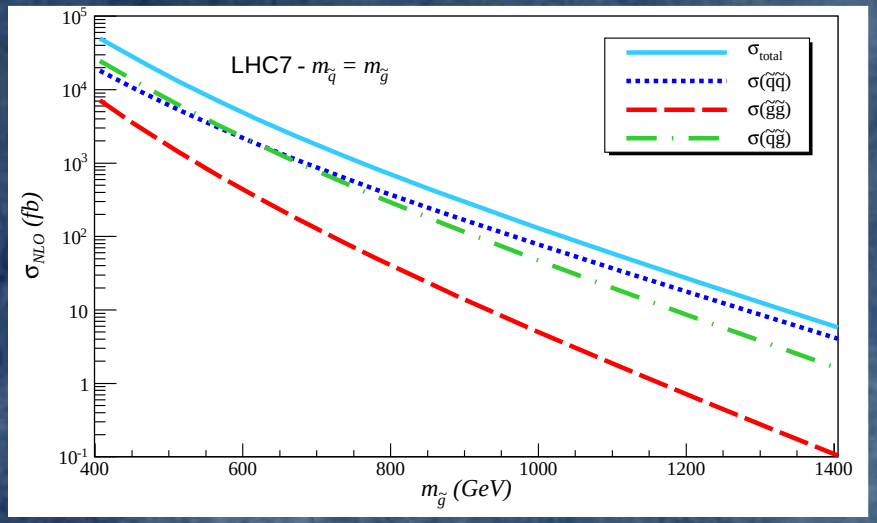
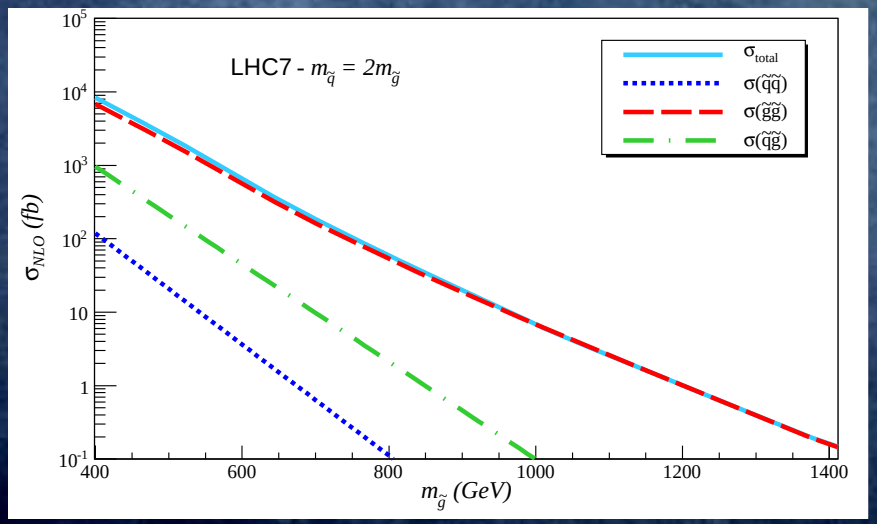
SM Backgrounds



SUSY Signal

- For LHC7 we can focus on strong cross-sections





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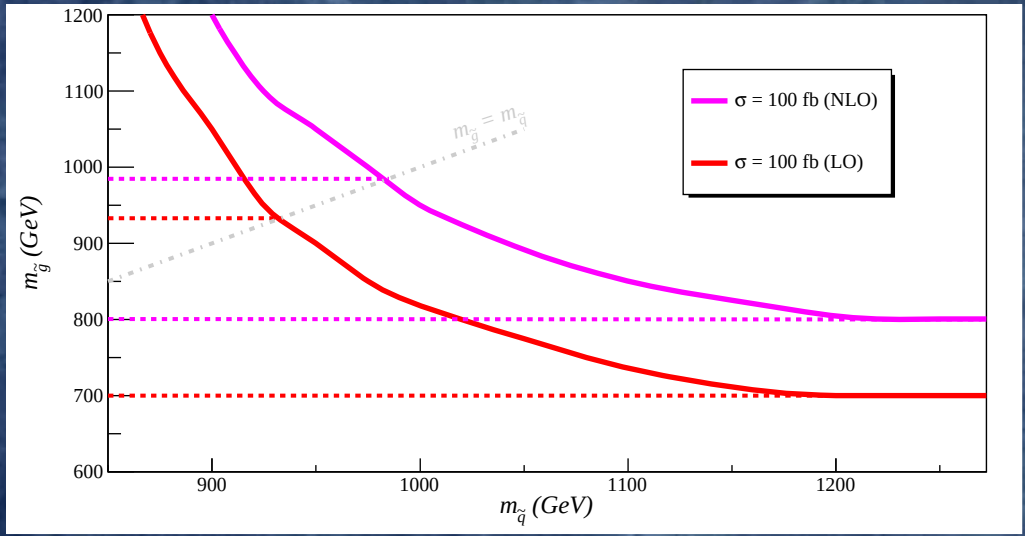

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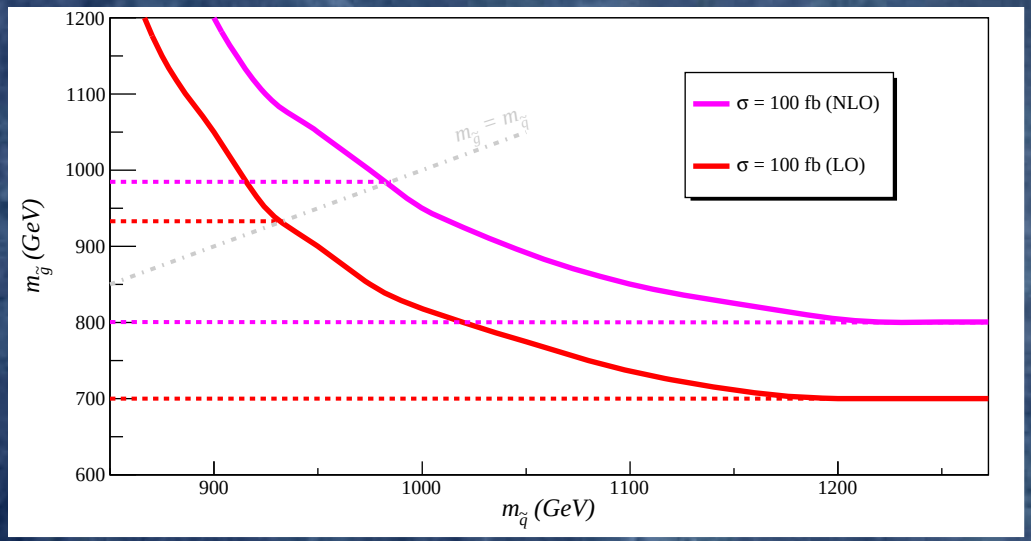

$$0.7 \pm 0.1 \text{ TeV} \lesssim m_{\tilde{g}} \lesssim 0.9 \pm 0.1 \text{ TeV}$$

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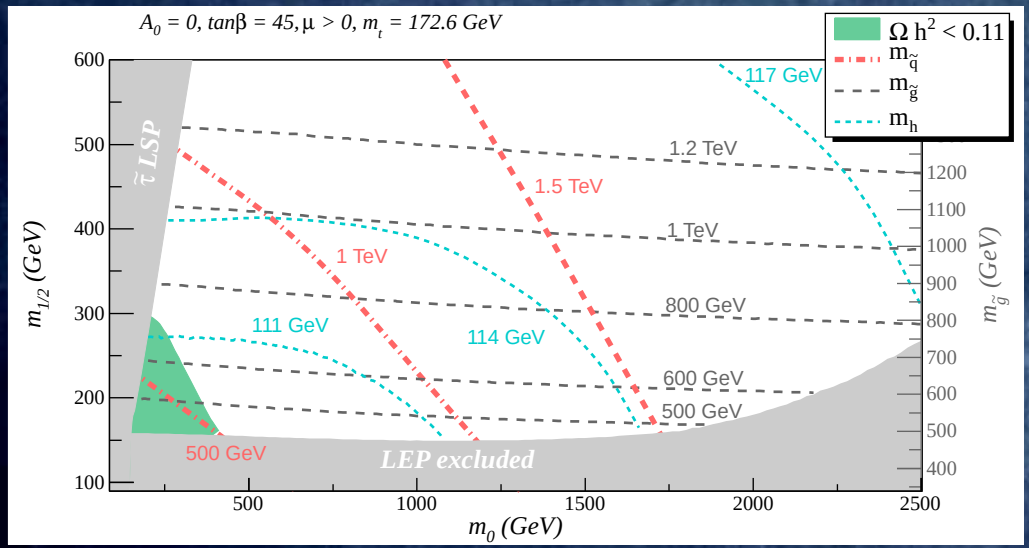

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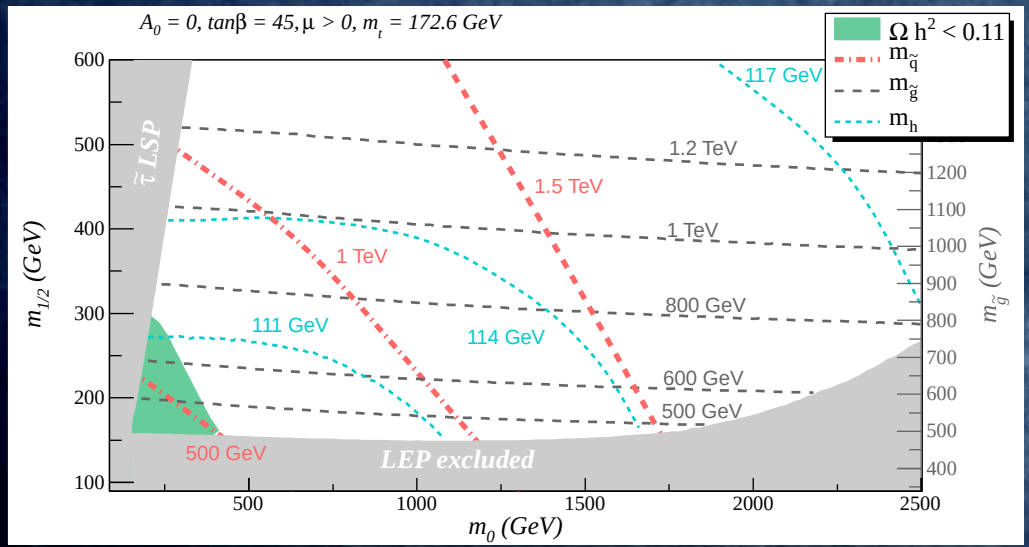

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→ Should not be taken too seriously, since mSUGRA is just a "prototype" model

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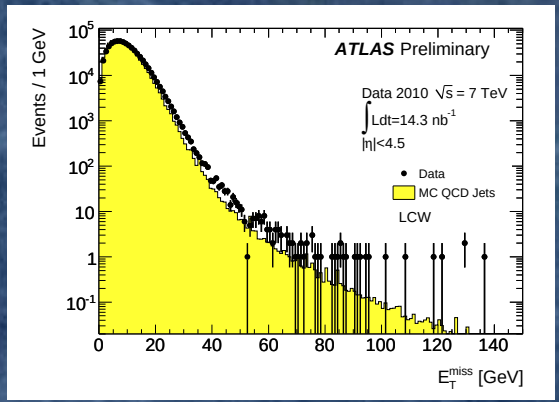

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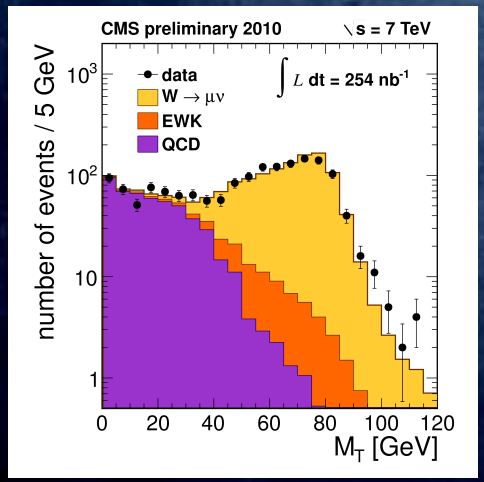

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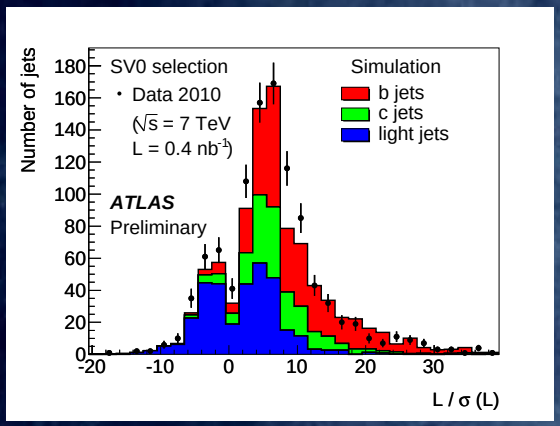

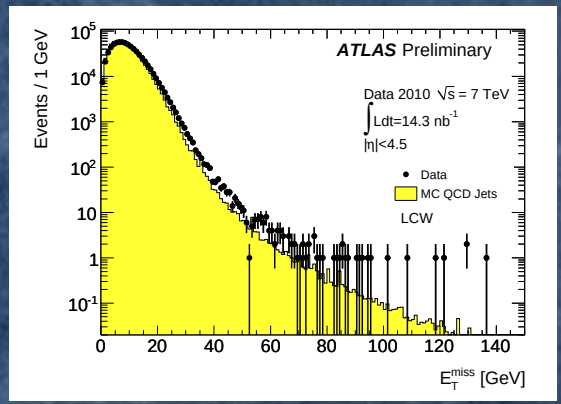

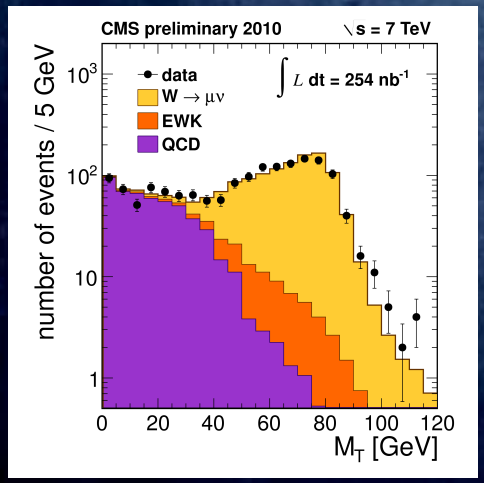

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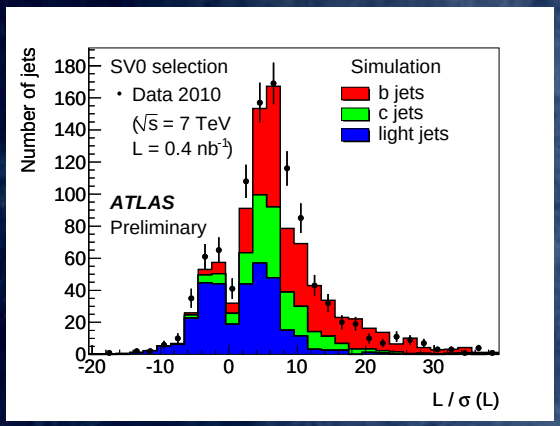

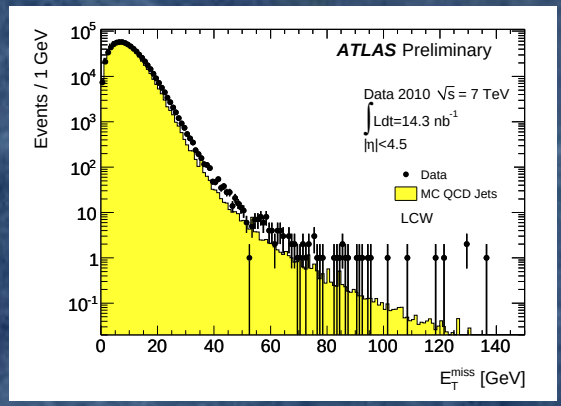

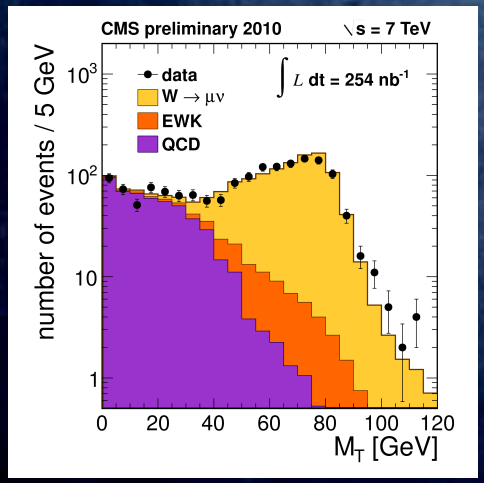

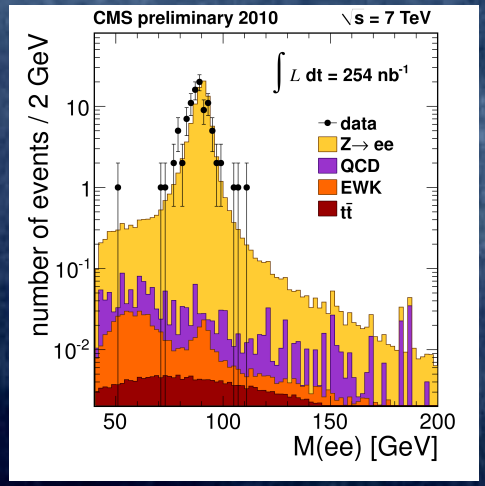

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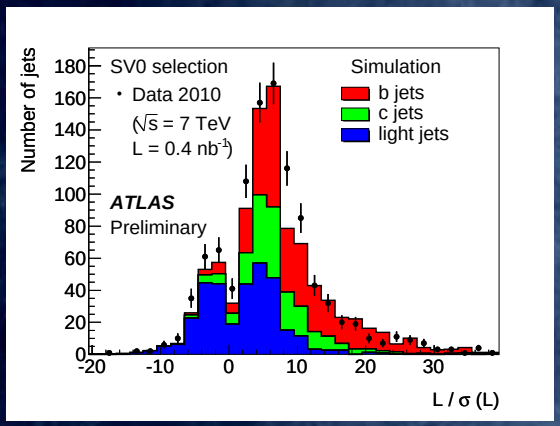

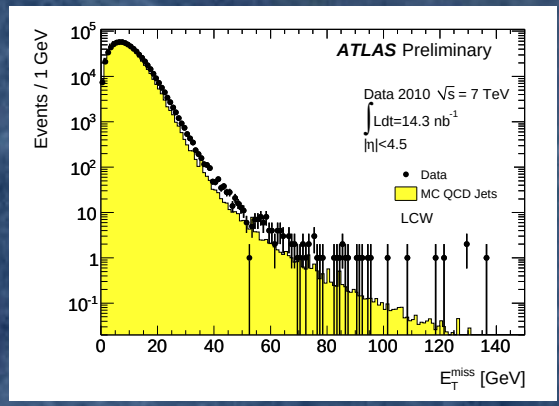

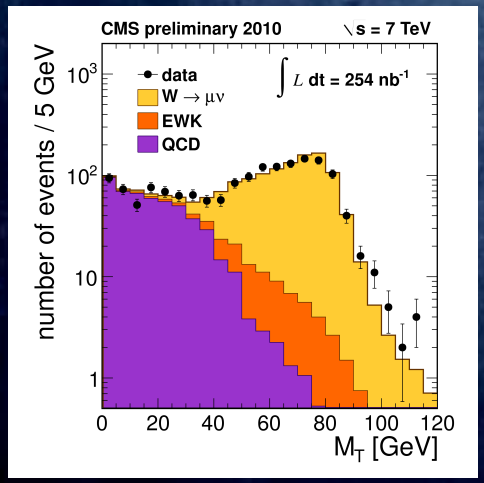

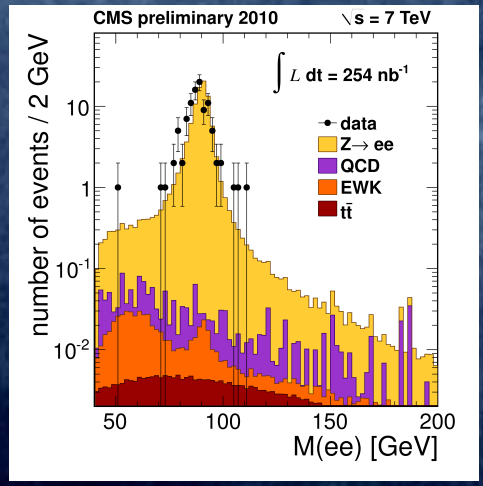

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- b-tagging and
- lepton ID should be available for early analysis!
- More than 3 pb^{-1} of data by now!

Search Channels

- Full Analysis (optimized search):
  - $\not{E}_T > 100$ - 1000 GeV
  - $n(jets) \geq 2$, 3, 4, 5 or 6
  - $n(b) \geq 0$, 1, 2 or 3
  - $E_T(j_1) > 50$ - 1000 GeV
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  - $n(\ell) = 0$, 1, 2, 3, OS, SS and inclusive channel: $n(\ell) \geq 0$
  - 10 GeV$\leq m(\ell^+\ell^-) \leq 75$ GeV or $m(\ell^+\ell^-) \geq 105$ GeV
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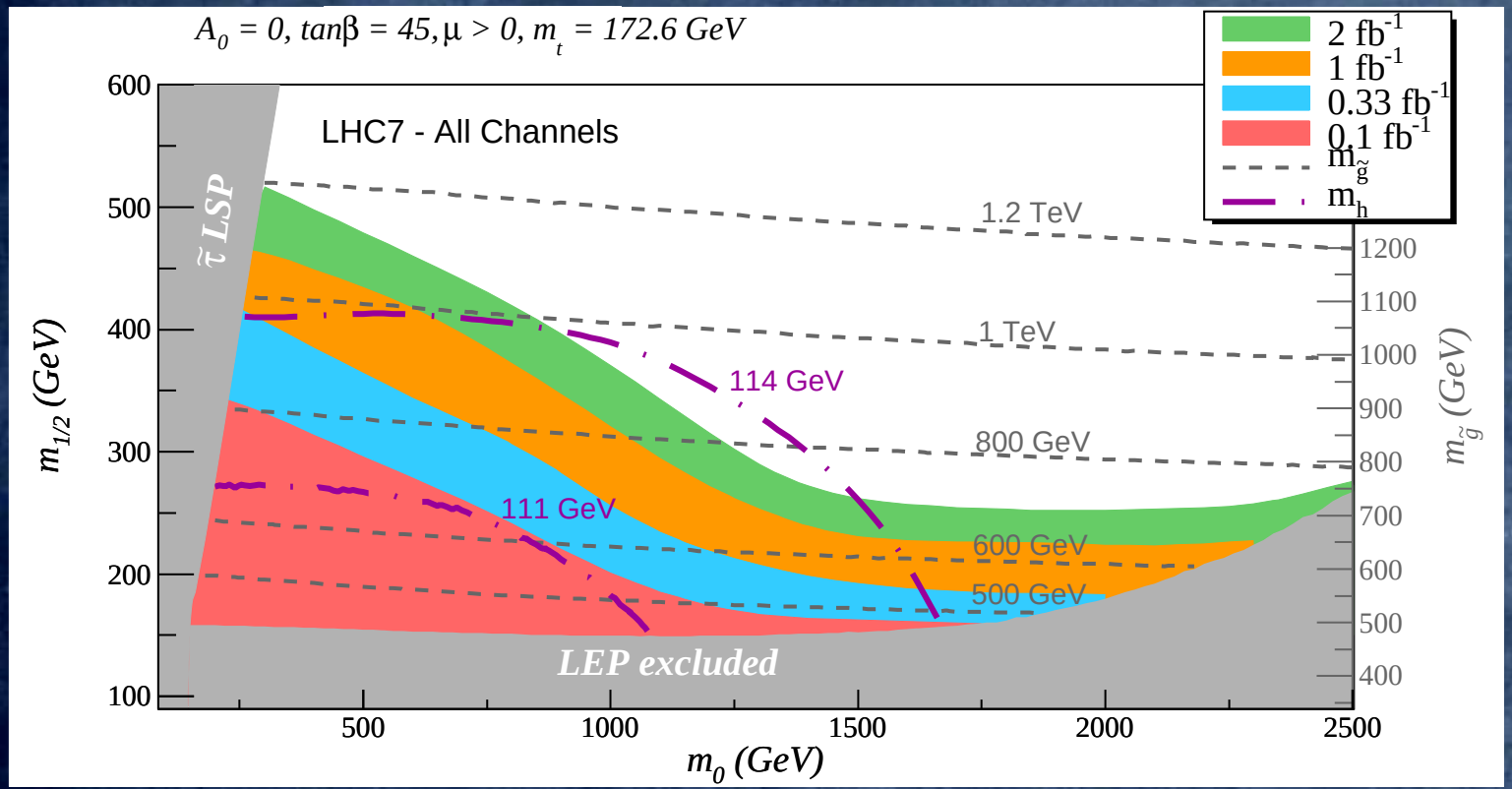
- **Channel is chosen such that:**
  - Signal is visible ($S \geq \max[5, 5\sigma\sqrt{BG}, 0.2BG]$)
  - Maximizes $S/\sqrt{S+BG}$

mSUGRA Reach

- Full Analysis results:



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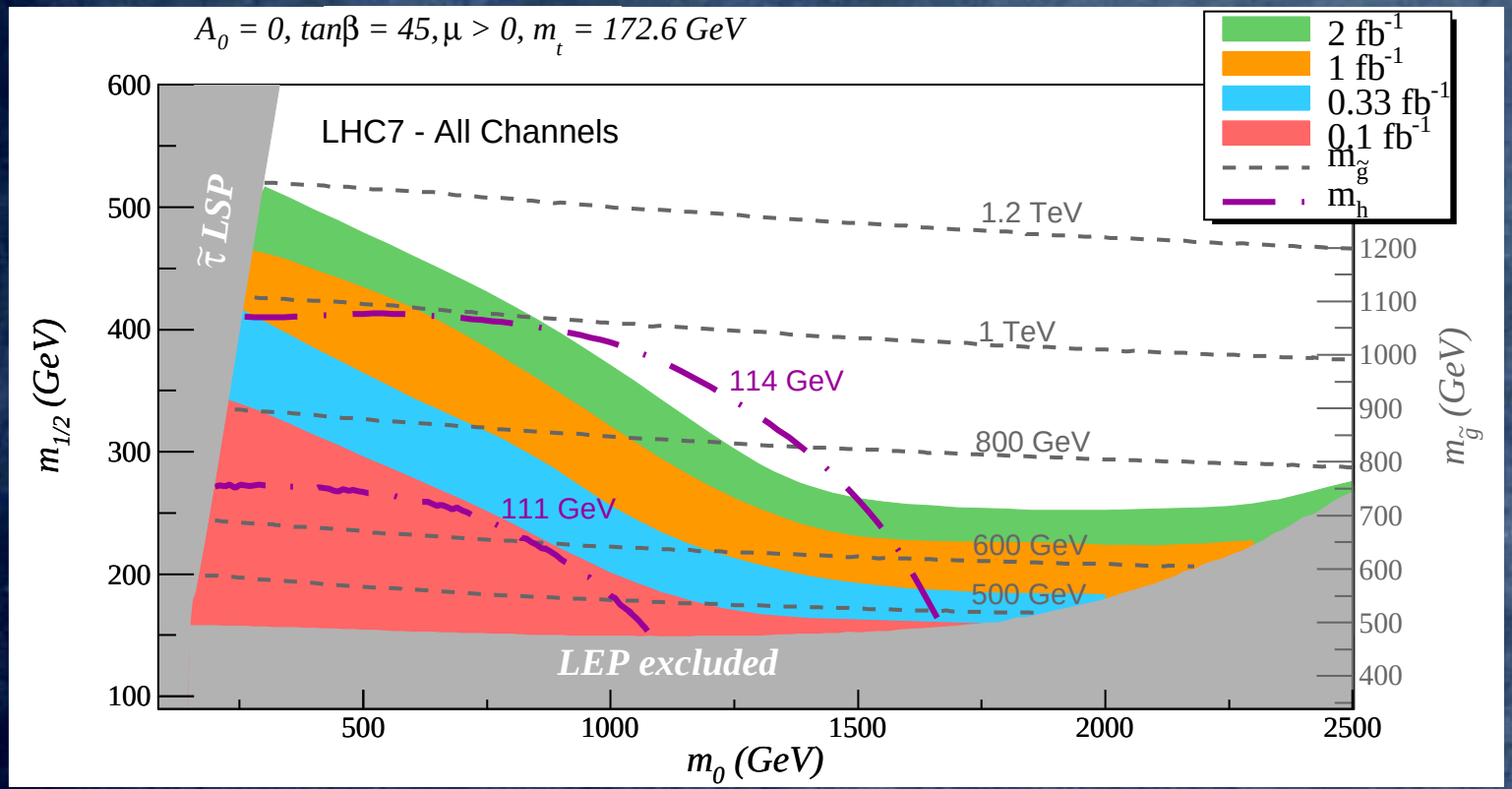

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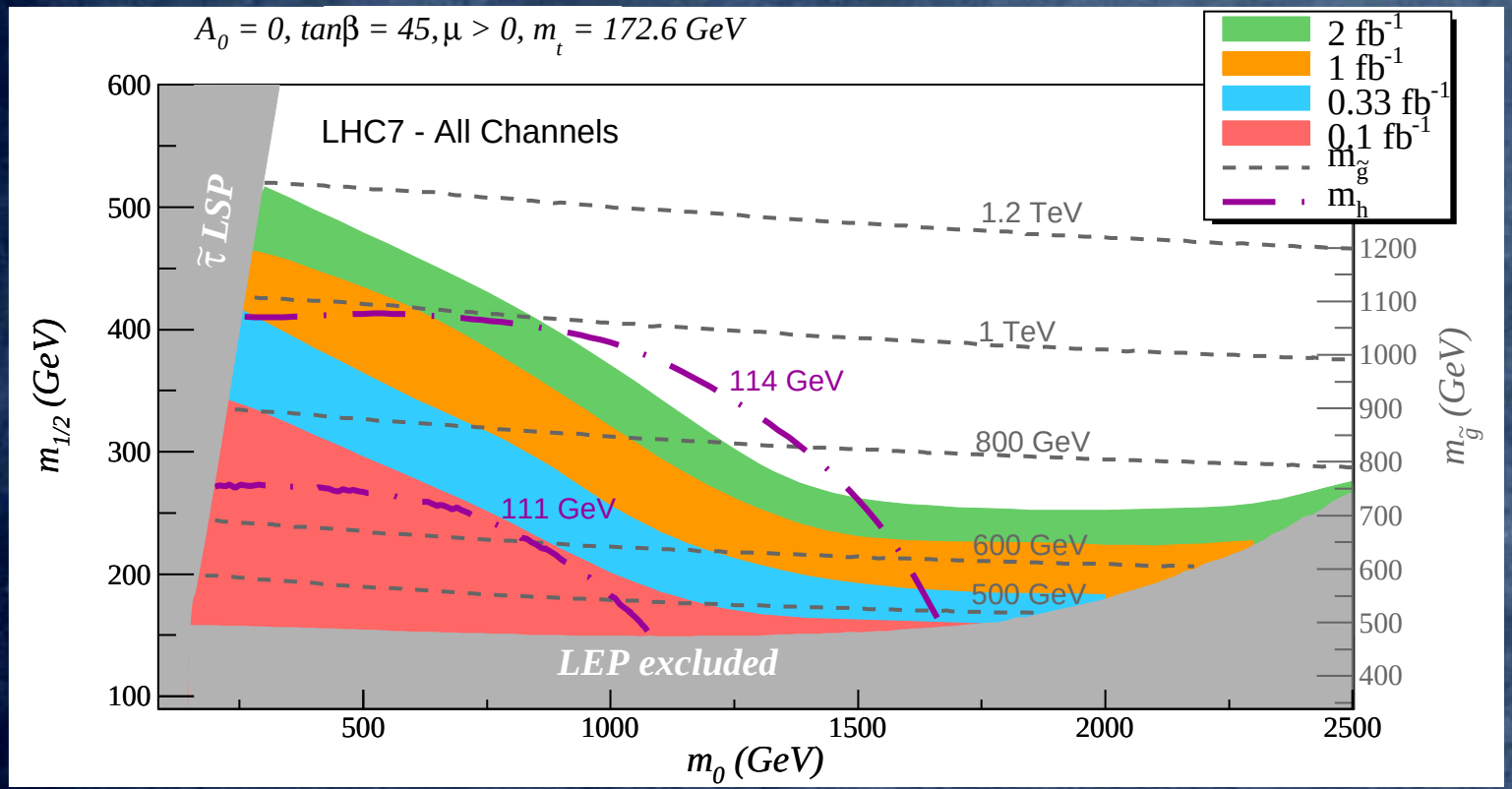

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$\Rightarrow$ Agrees with estimated reach!

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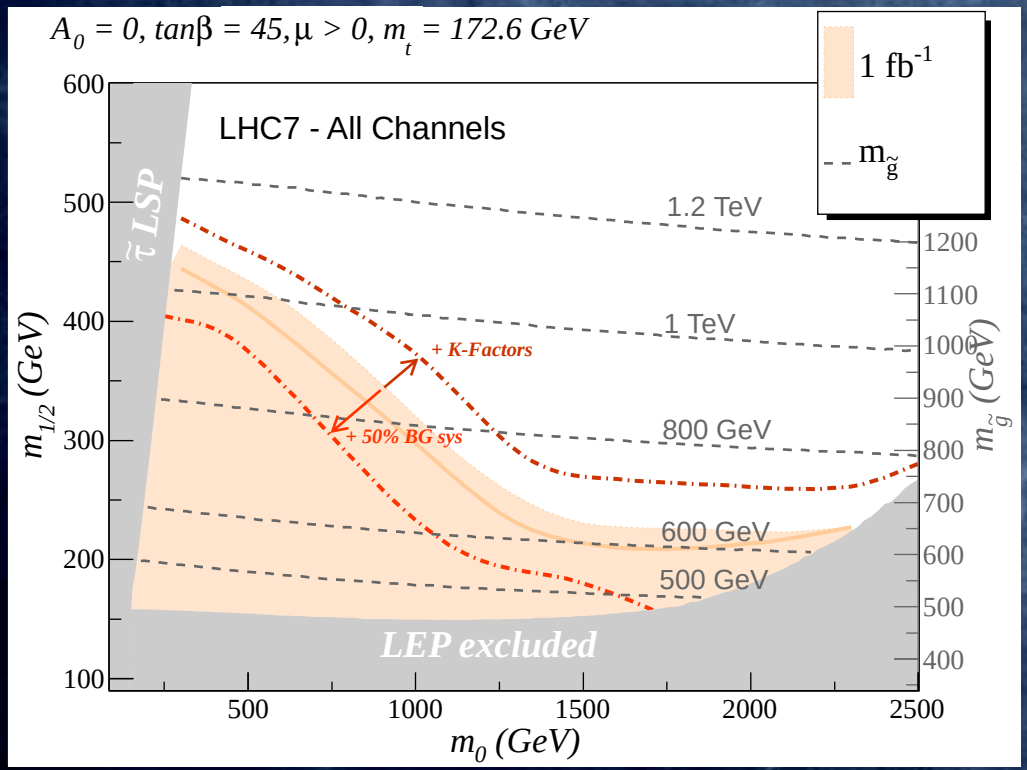

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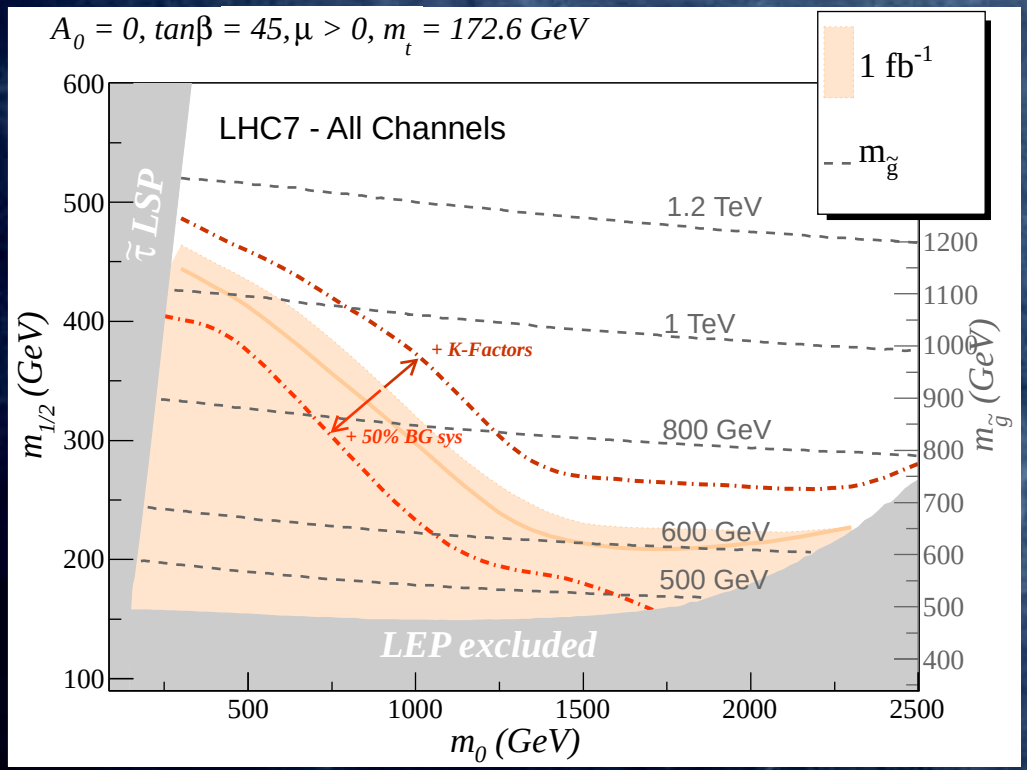
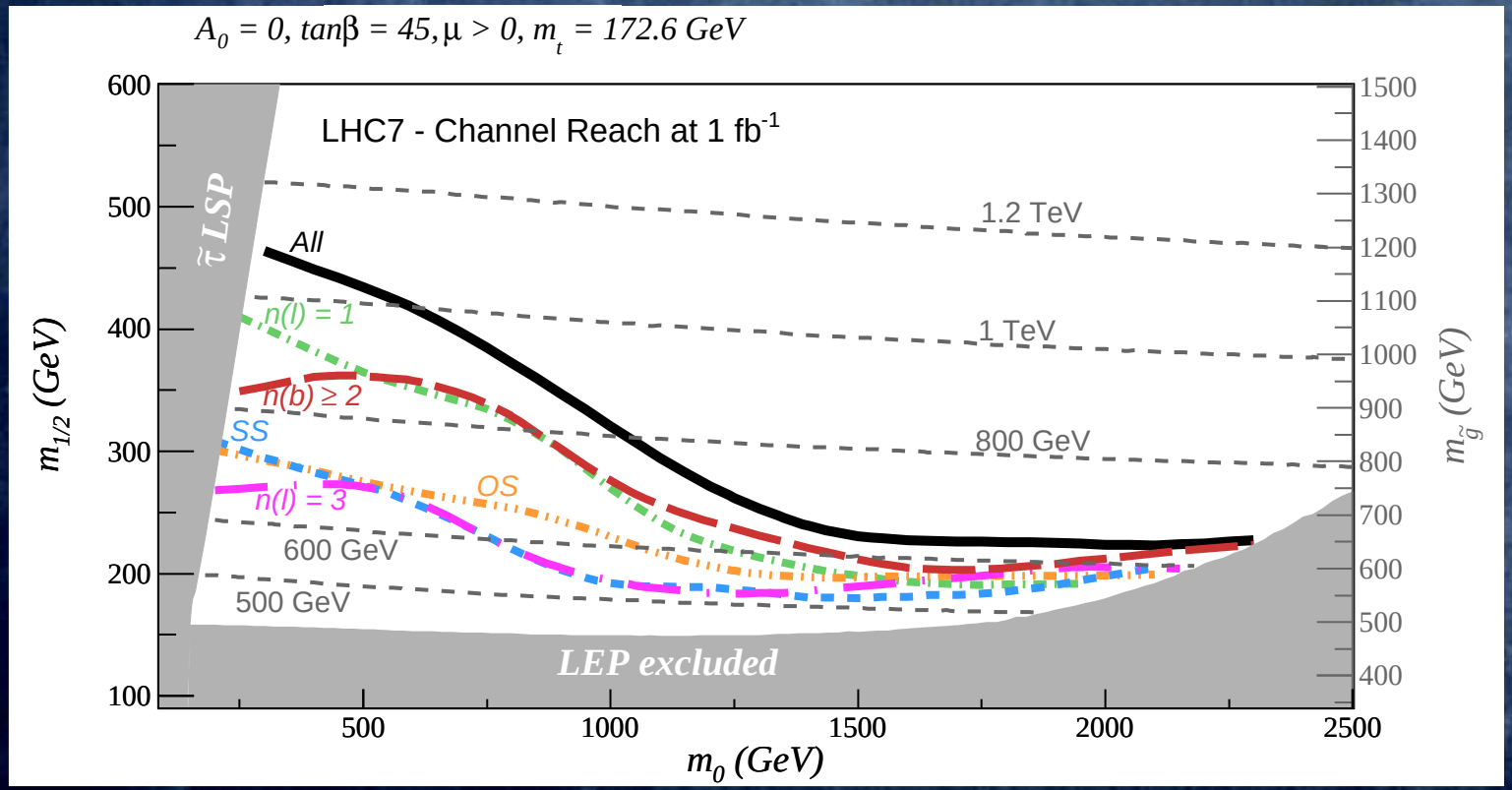


- A proper reach analysis has to be ultimately done by the experimental groups:
  - Full detector simulation
  - Data driven BG
  - Systematical error effects (NLO, PDFs...)

Reach X-Ray

- Which channels are relevant?



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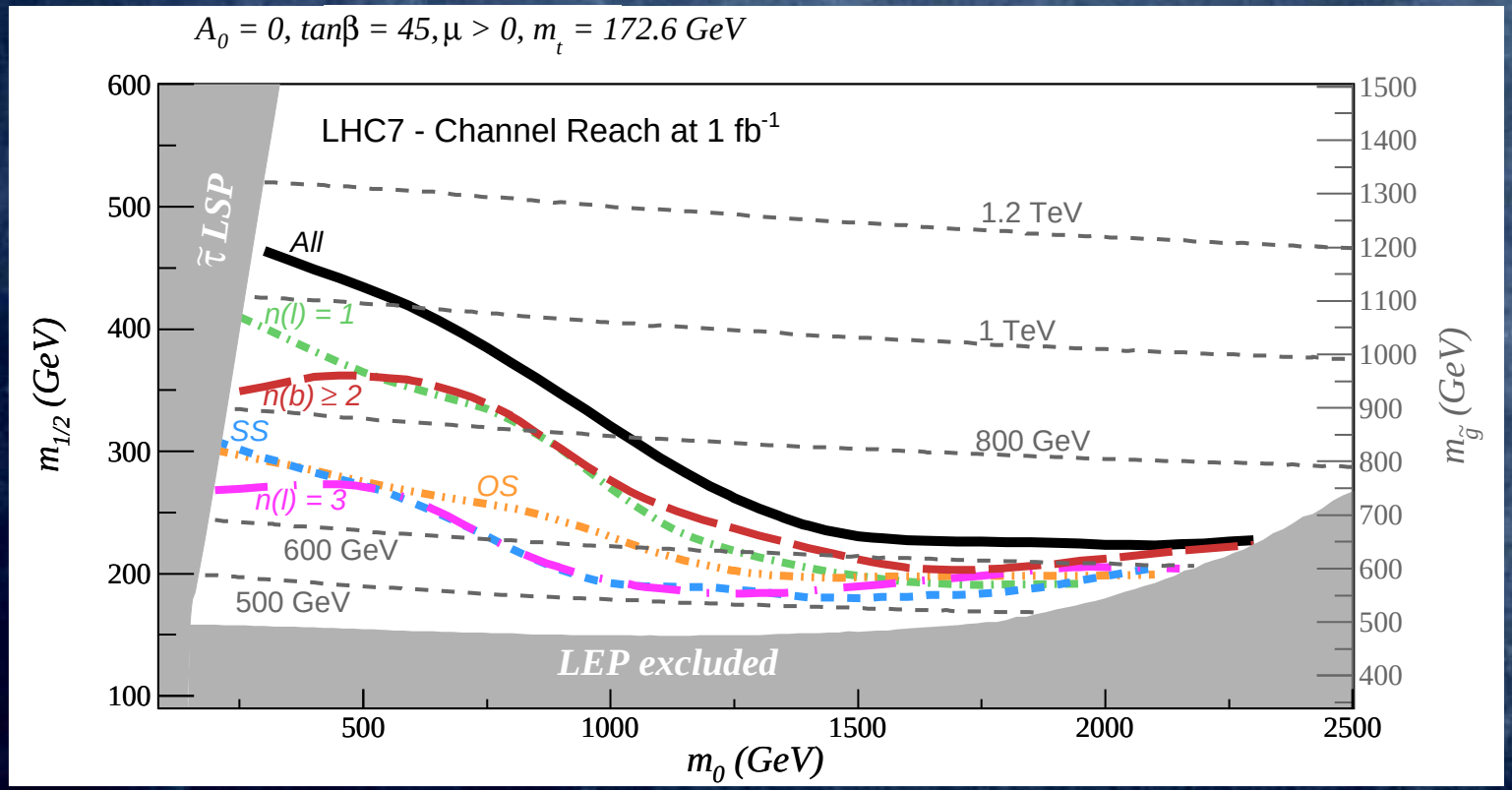

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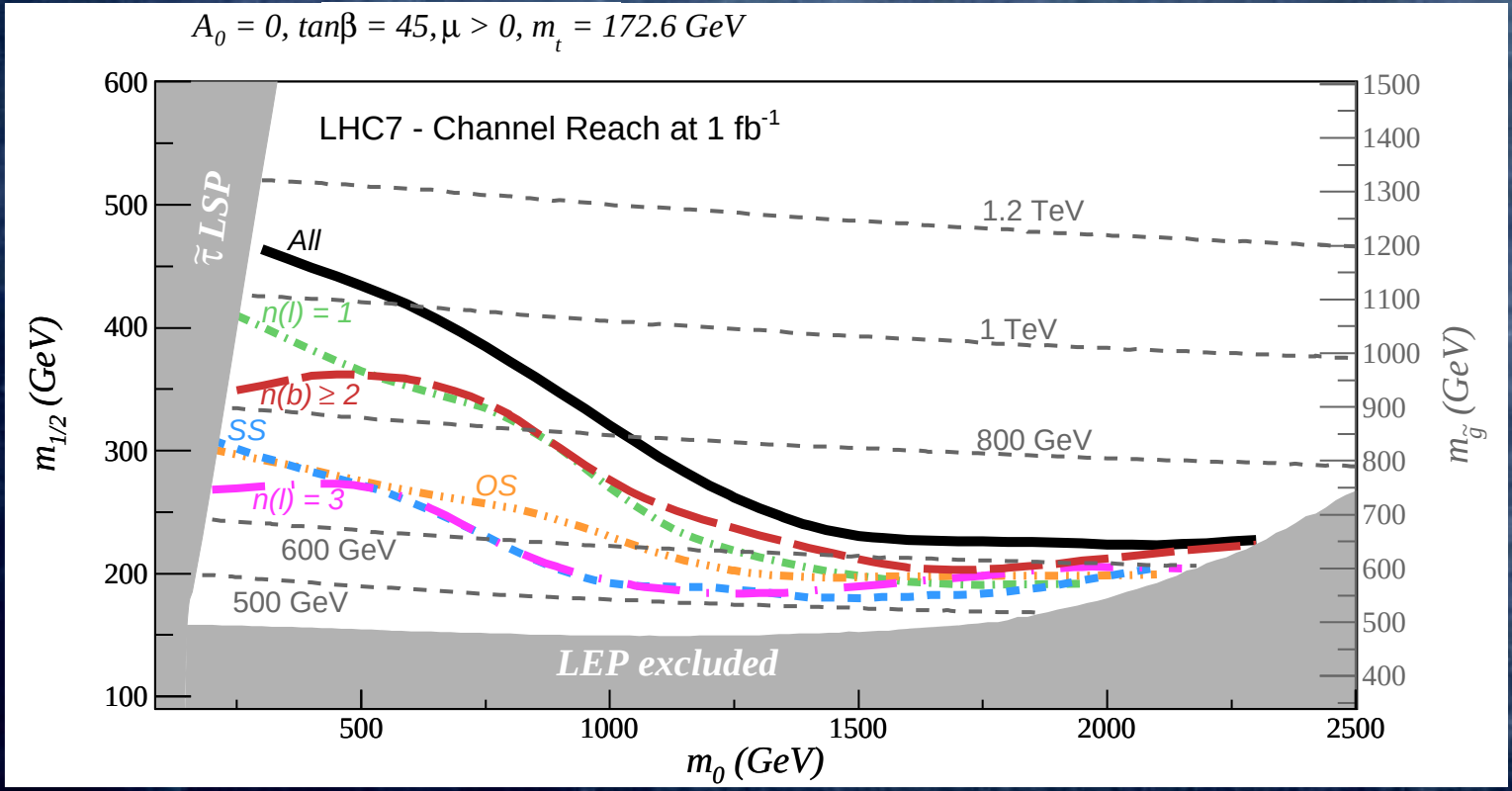

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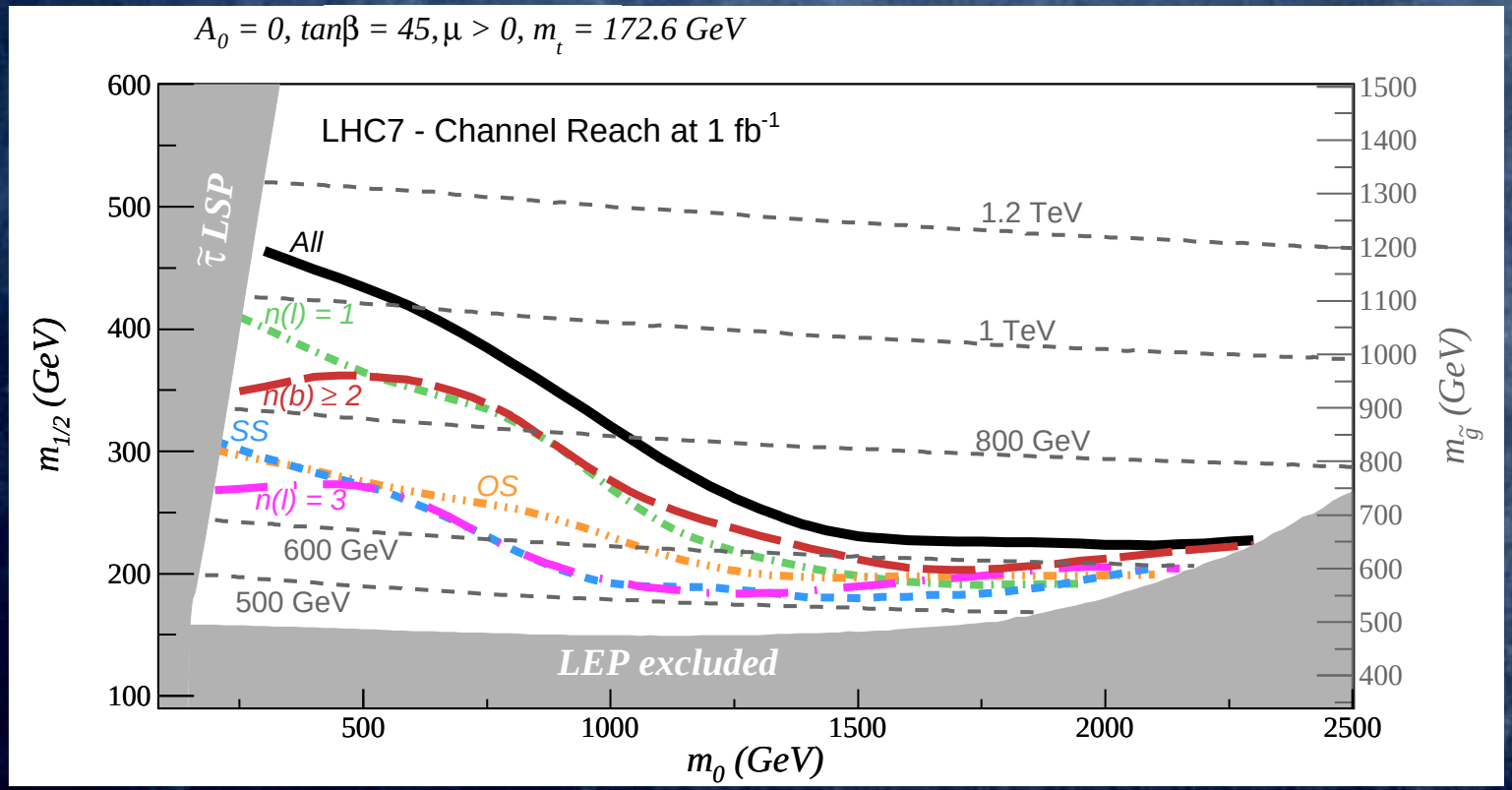

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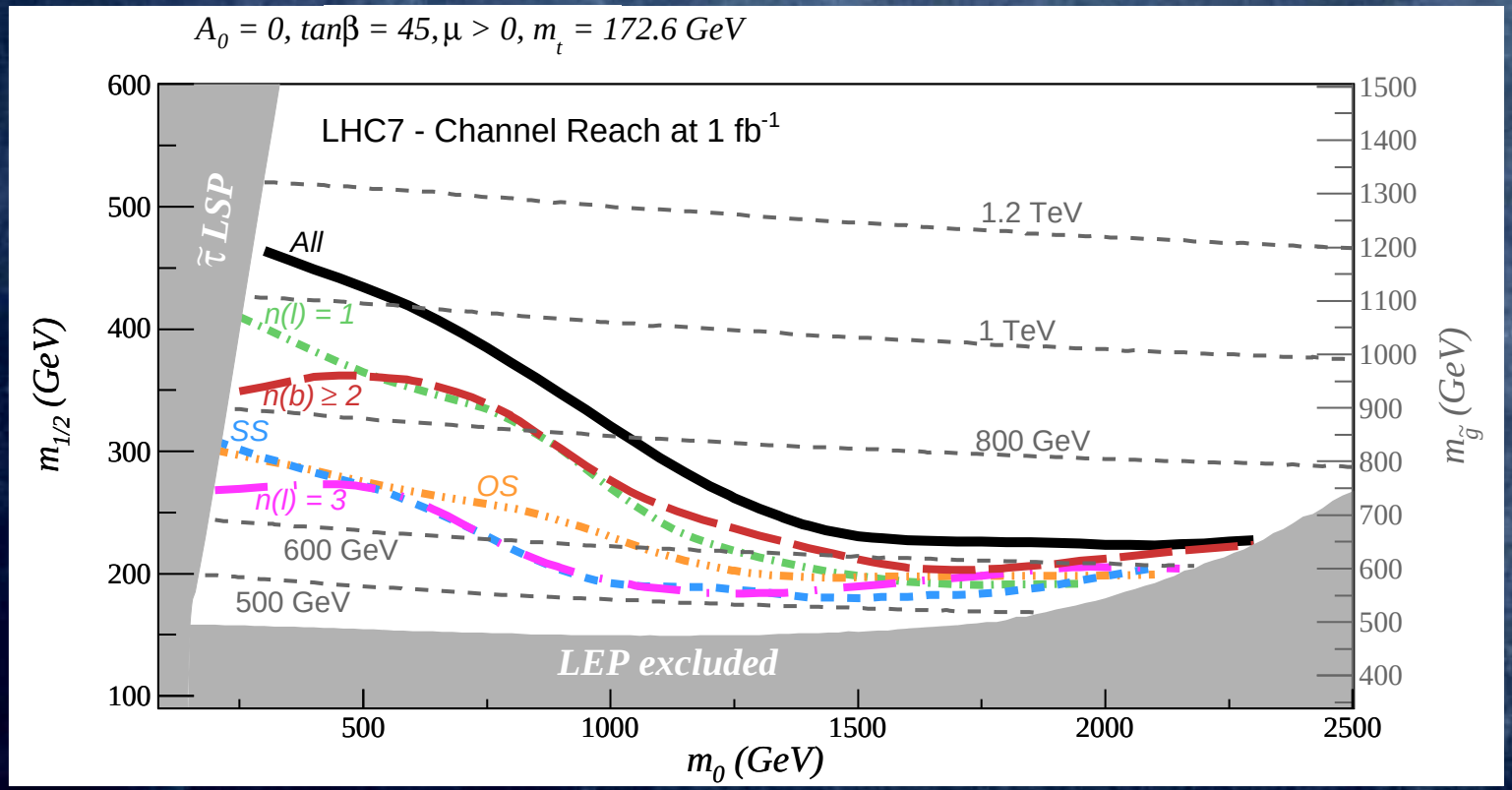
- Which channels are relevant?
  - Multi-jets + $\not{E}_T$: largest cross-sections $\rightarrow$ maximum reach
  - Complementary signals:
    - Multi-b's
    - Multi-leptons



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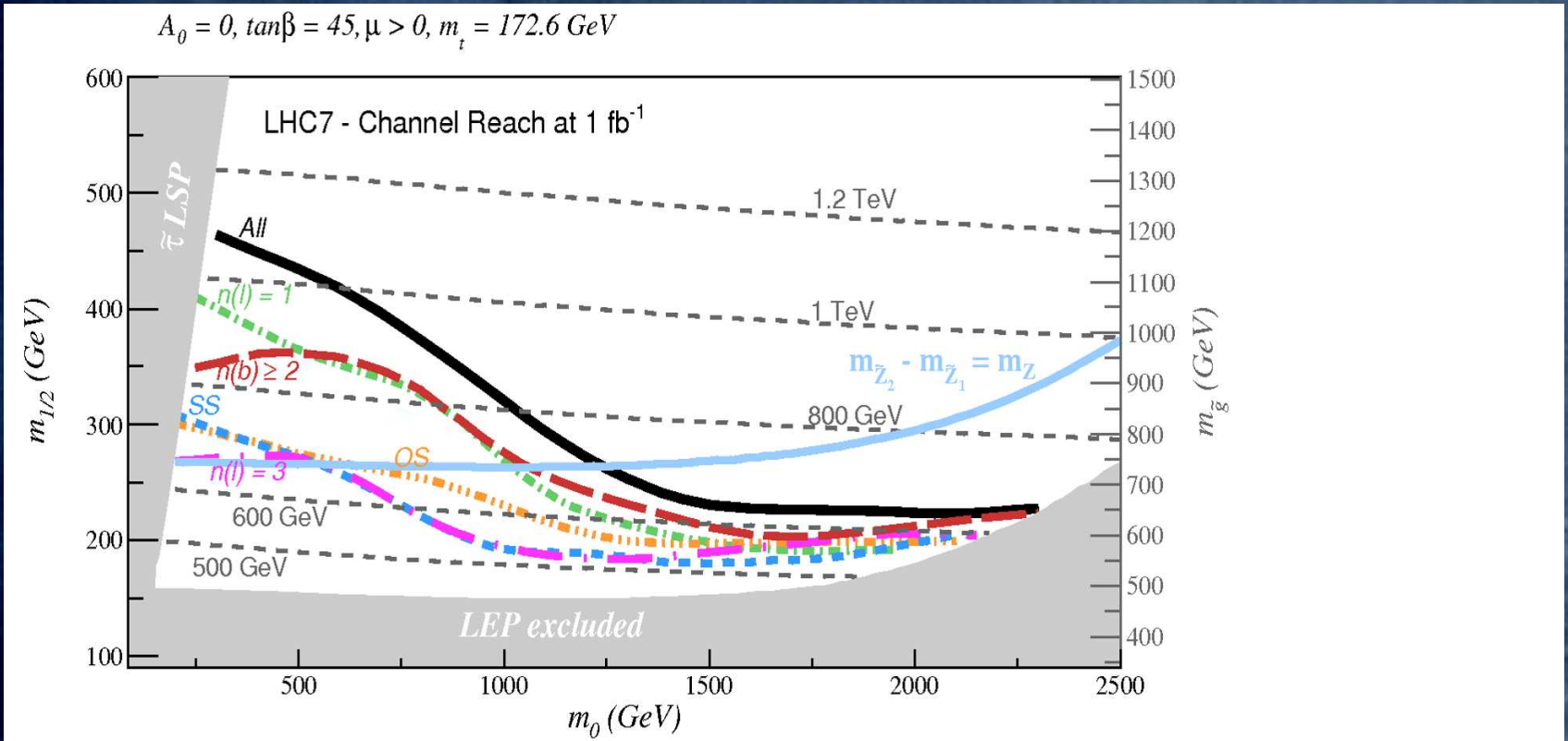
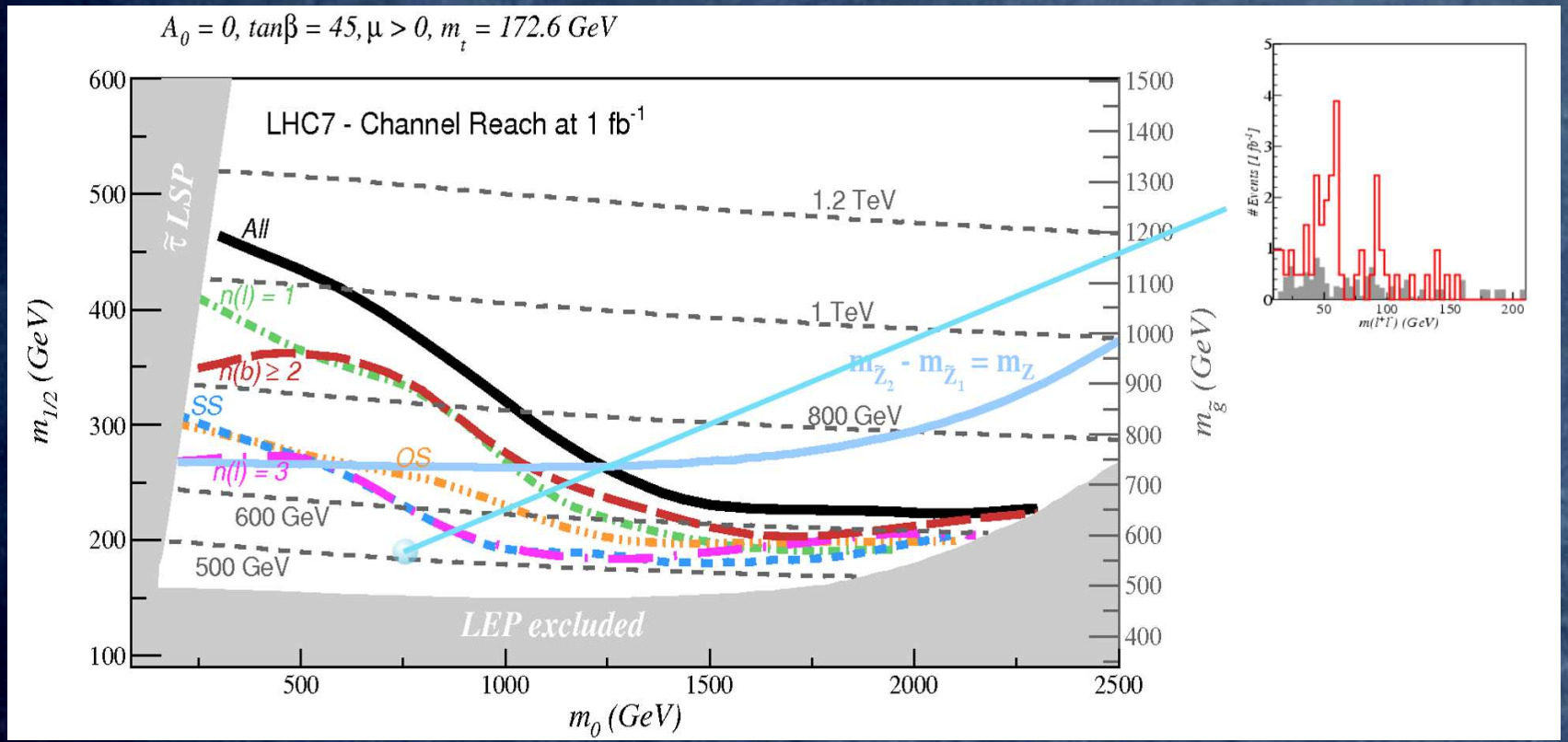

$A_0 = 0, \tan\beta = 45, \mu > 0, m_t = 172.6\ GeV$
LHC7 - Channel Reach at 1 fb^{-1}
$\tilde{\tau}$ LSP
All
n(l) = 1
n(b) ≥ 2
SS
OS
n(l) = 3
1.2 TeV
1 TeV
800 GeV
600 GeV
500 GeV
$m_{\tilde{Z}_2} - m_{\tilde{Z}_1} = m_Z$
LEP excluded
$m_{1/2}$ (GeV)
m_0 (GeV)
$m_{\tilde{g}}$ (GeV)
600
500
400
300
200
100
500
1000
1500
2000
2500
1500
1400
1300
1200
1100
1000
900
800
700
600
500
400

Reach X-Ray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m(l$^+$l$^-$) (GeV)

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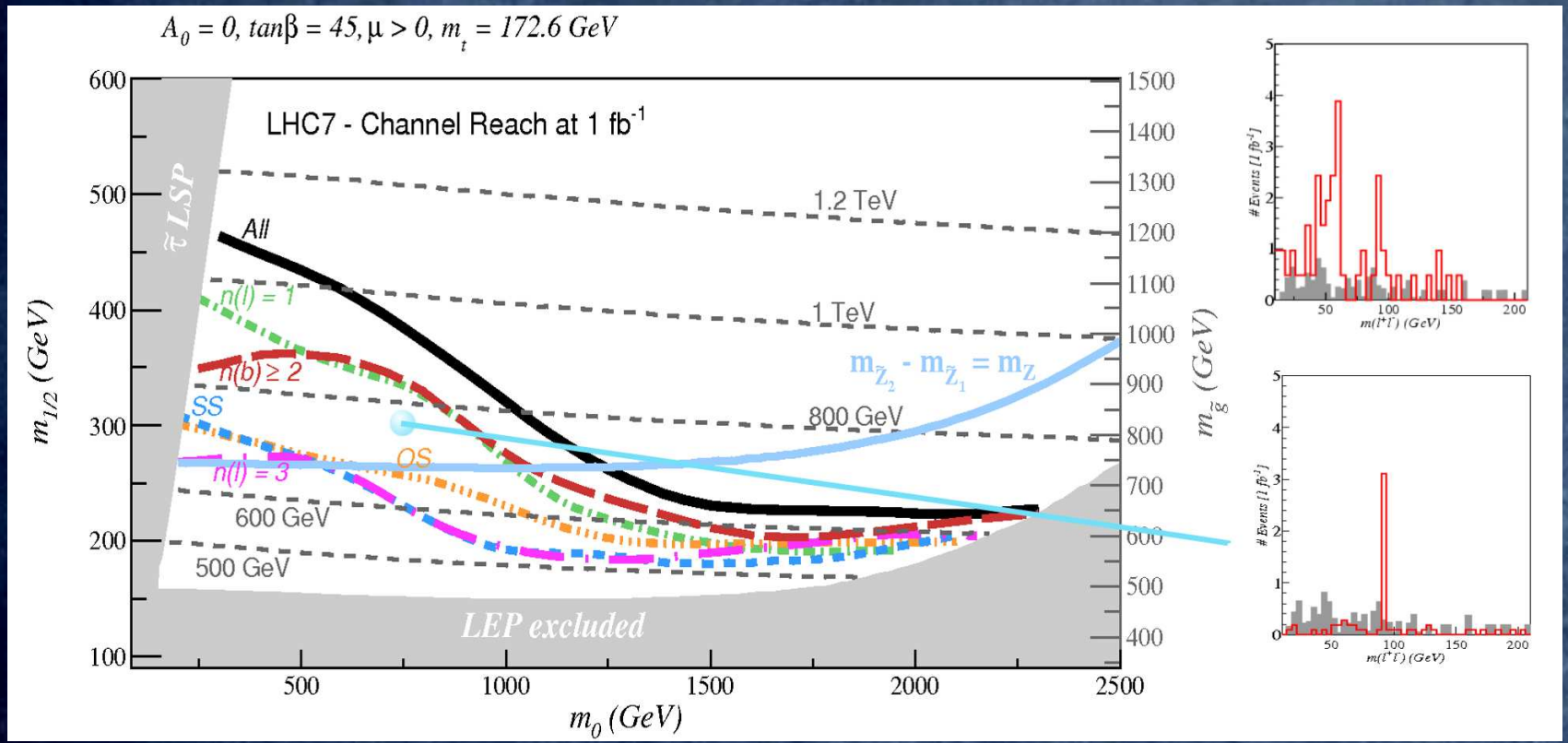
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Non mSUGRA Models

How much of the previous results are model dependent?

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- Viable leptogenesis scenarios...

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Minimal Yukawa coupling: $\mathcal{L}_{Yuk} = f\,\bar{\Psi}\Gamma_a\Psi H_a \Rightarrow f_t = f_b = f_\tau$

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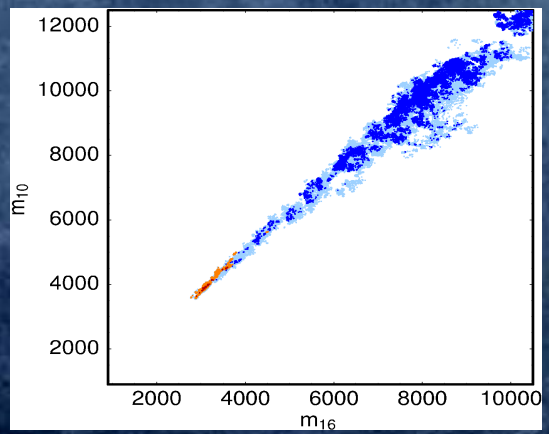
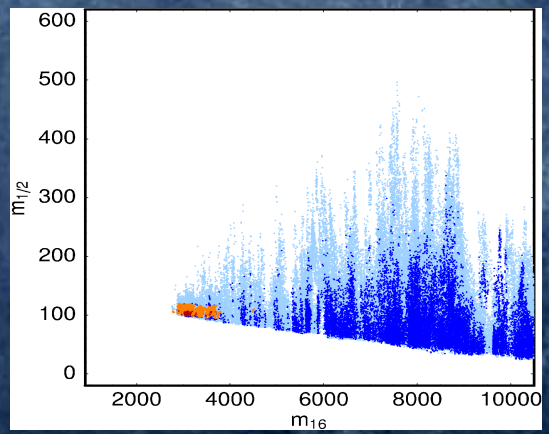
- MCMC scan:

$$R = \frac{\max[f_t, f_b, f_\tau]}{\min[f_t, f_b, f_\tau]}$$

$R < 1.1, 1.05$





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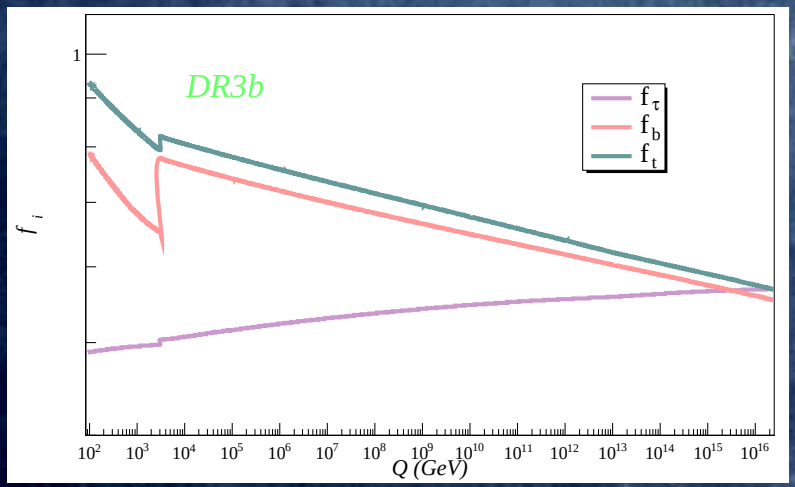

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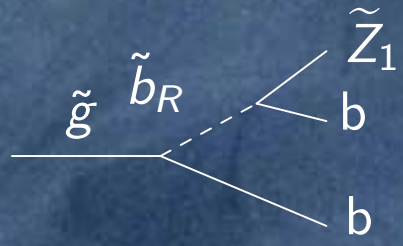

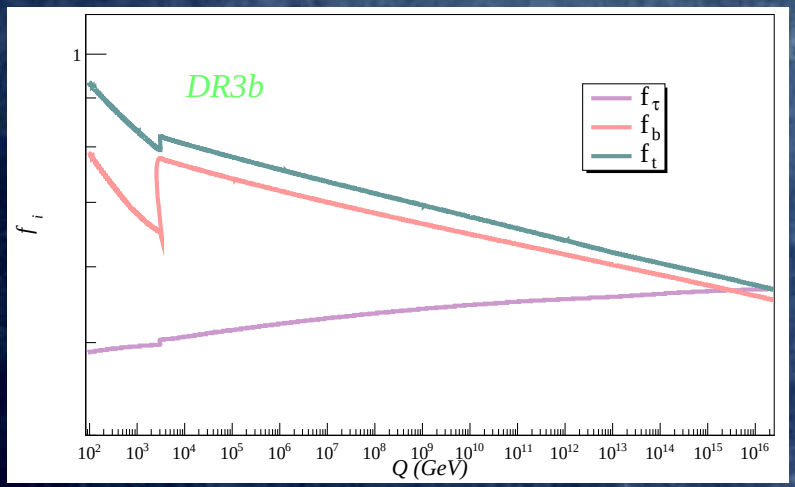

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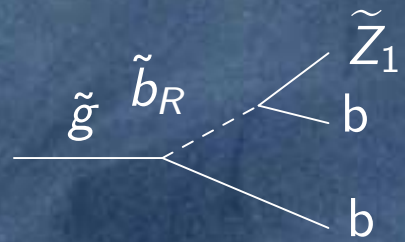
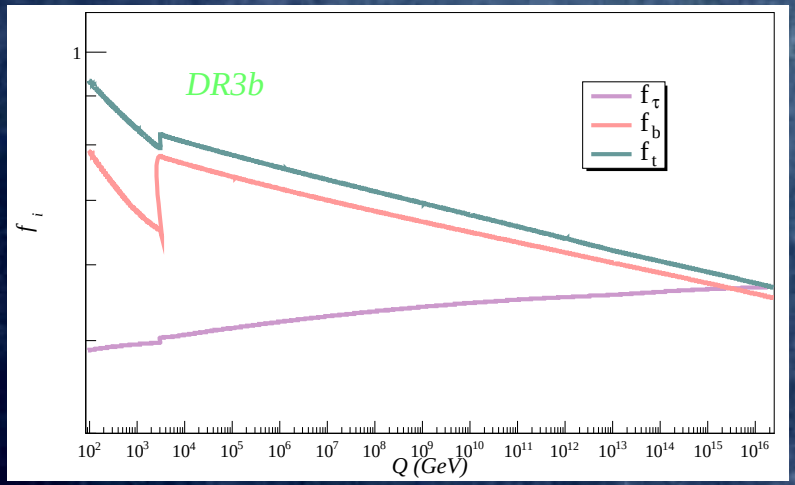
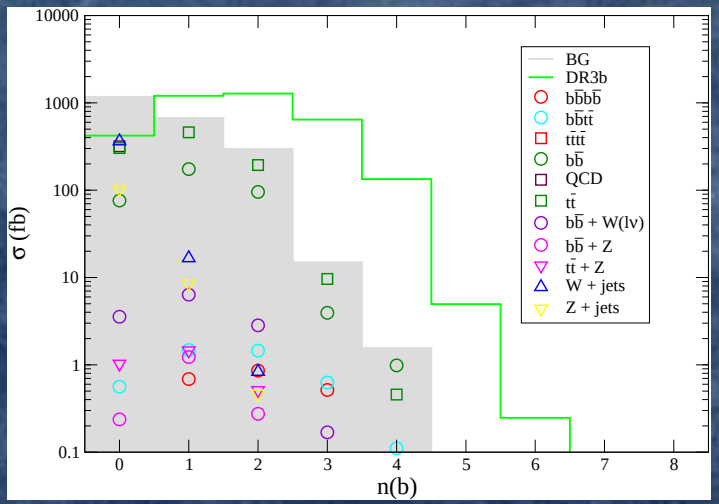
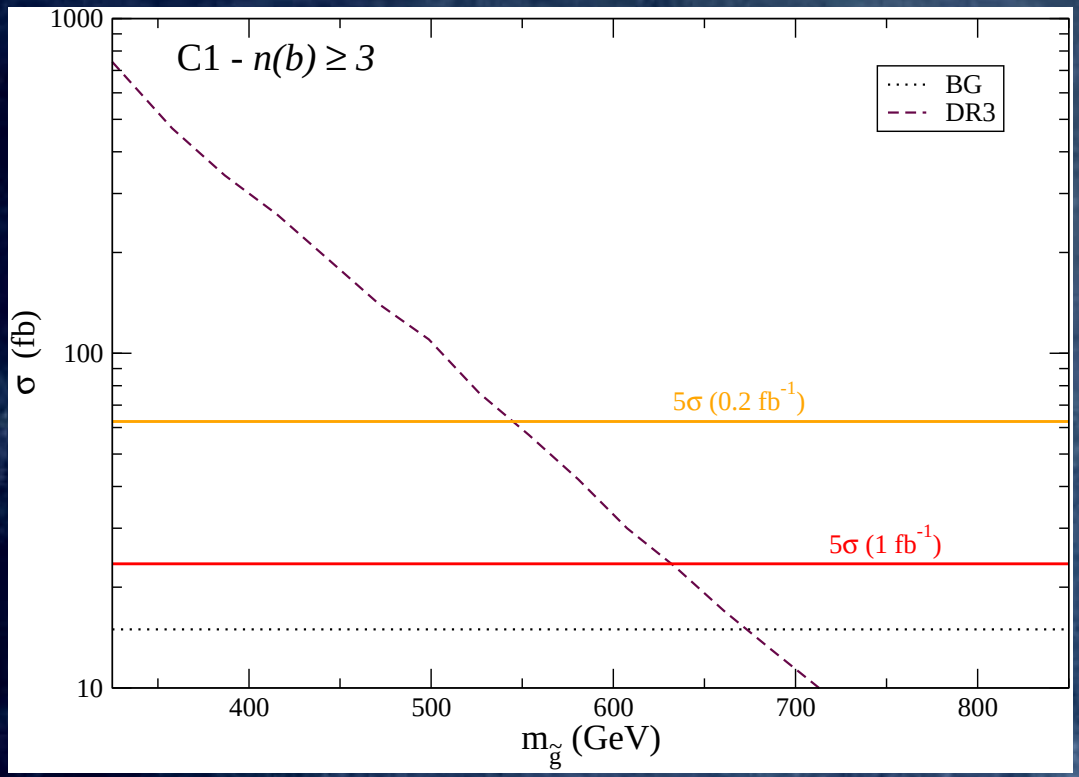






DR3 Reach



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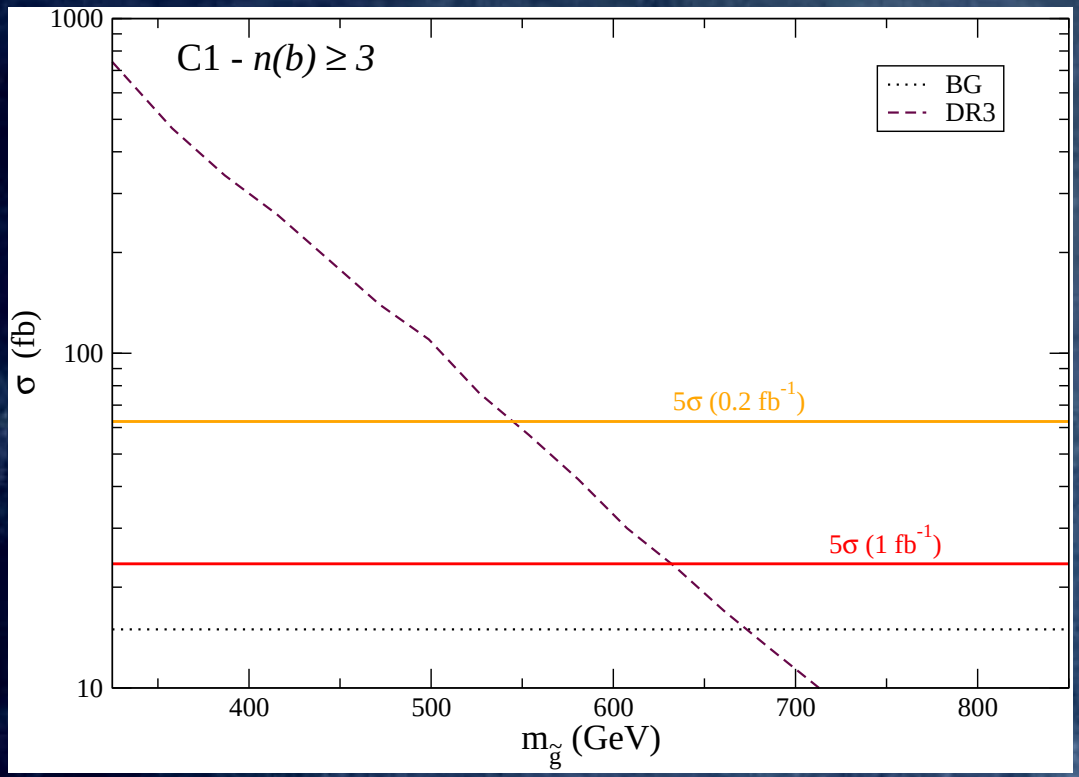

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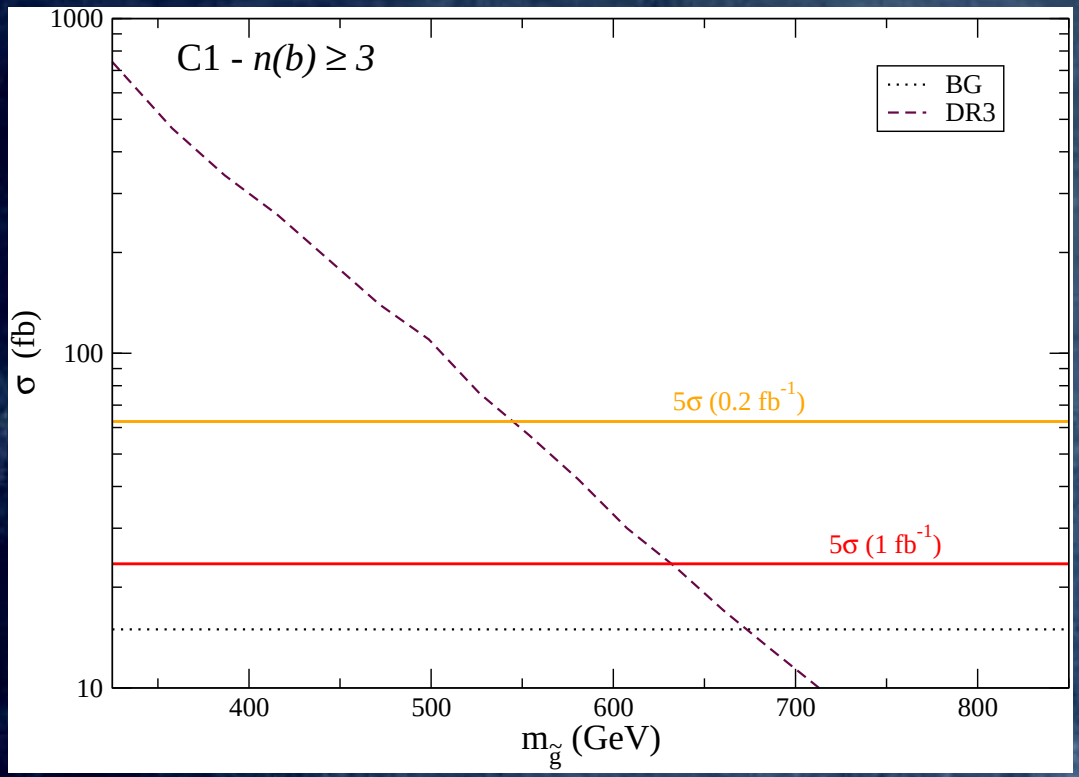
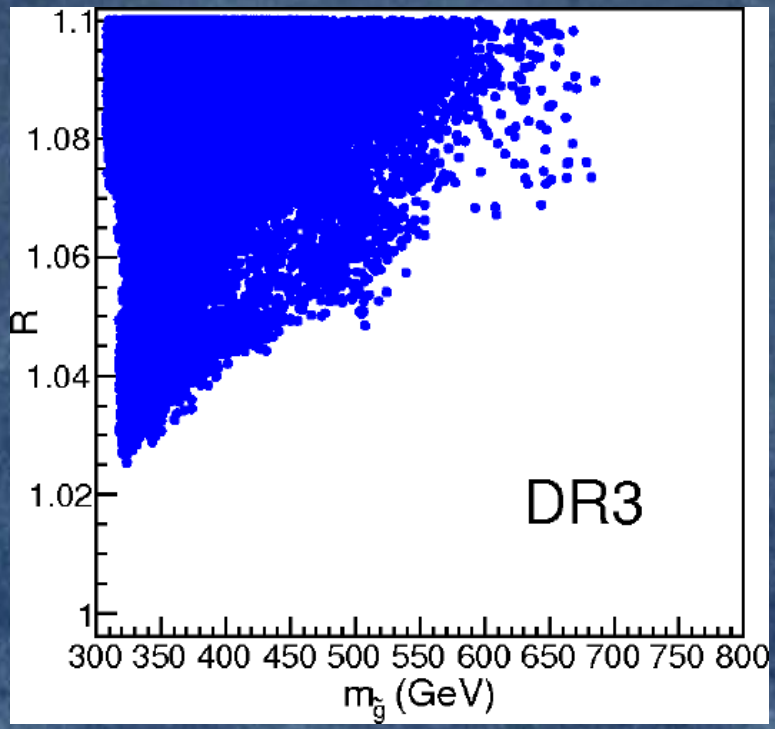
⇒ Once again agrees with estimated reach!

DR3 Reach





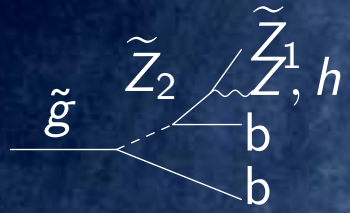
$m_{\tilde{g}} \lesssim 650$ GeV

⇒ Once again agrees with estimated reach!

⇒ Can exclude models with unification up to 10% !

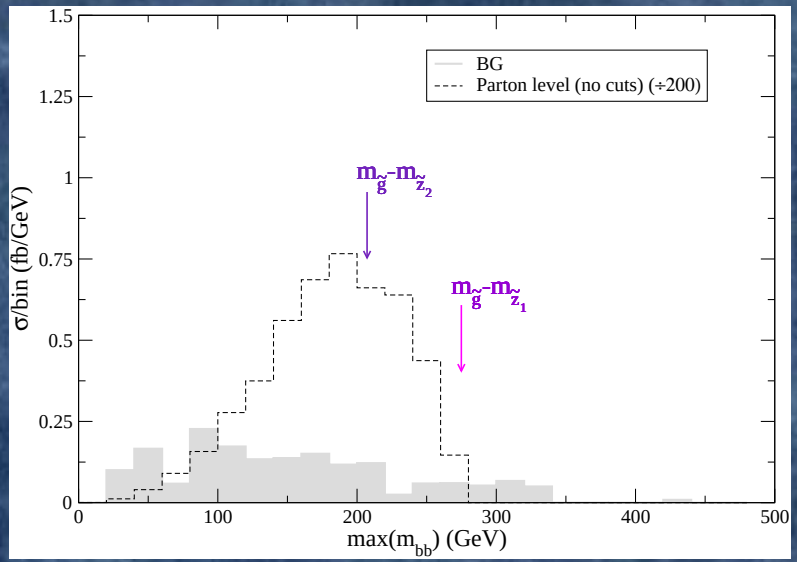
Minimal SO(10)

- Measuring masses? *(No $\not{E}_T$ cuts, $n(b) \geq 4$)*



$$\Rightarrow m(b,b) \leq m_{\tilde{g}} - m_{\tilde{Z}_2}$$

$$\Rightarrow m(b,b) \leq m_{\tilde{g}} - m_{\tilde{Z}_1}$$



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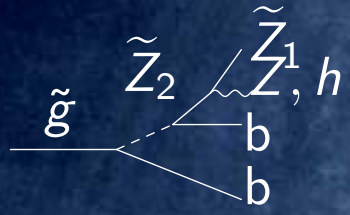

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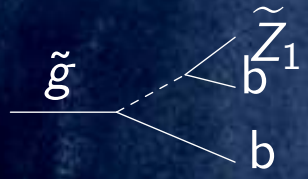

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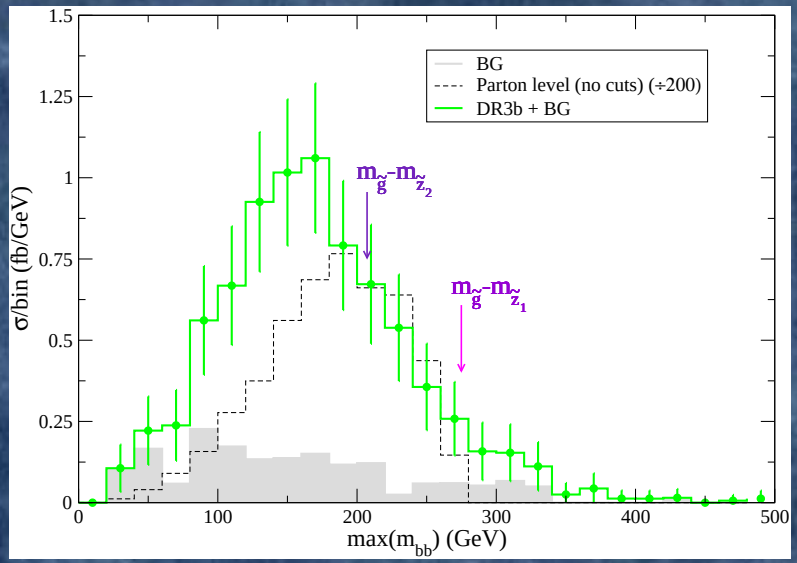

Effective Supersymmetry (ESUSY)

- DR3: motivated by high scale physics (M_{GUT})
  - but $m_{\tilde{t},\tilde{b}} \sim 1.5 - 4$ TeV
    $\rightarrow$ large fine-tunning to stabilize the EW scale

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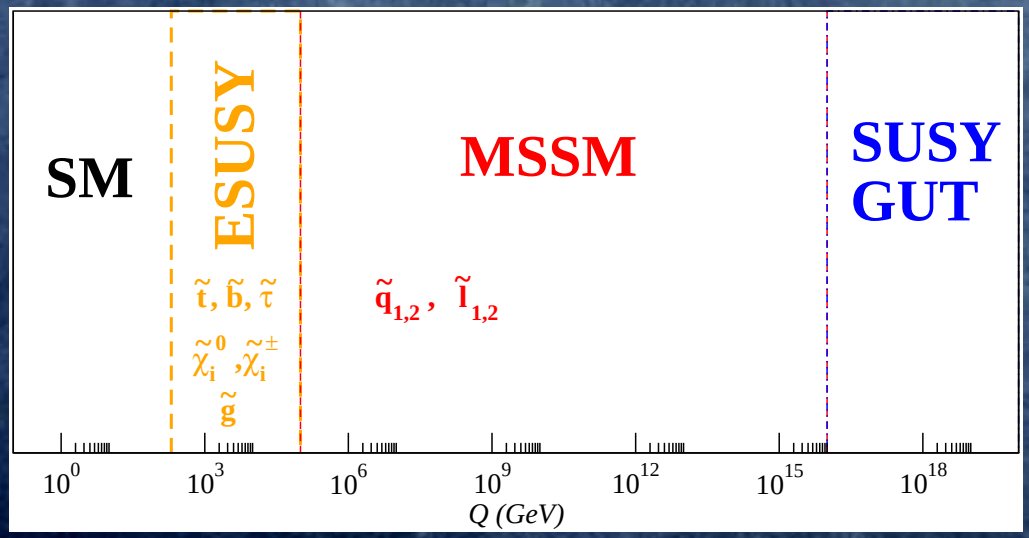
  - Unlike DR3, can have heavy gluinos!

ESUSY

- At the weak scale:

$$
\begin{aligned}
m_{\tilde{t},\tilde{\tau},\tilde{b}} &\lesssim 1 \text{ TeV} \\
m_{\widetilde{B},\widetilde{W}} &\lesssim 1 \text{ TeV} \\
m_{\tilde{q},\tilde{l}}(1,2) &\gtrsim 10\text{-}100 \text{ TeV}
\end{aligned}
$$



ESUSY - Phenomenology

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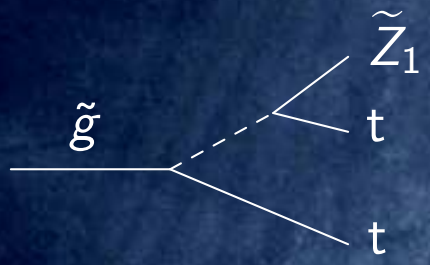

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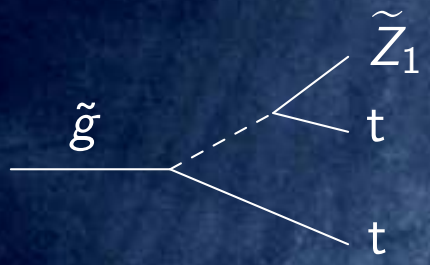

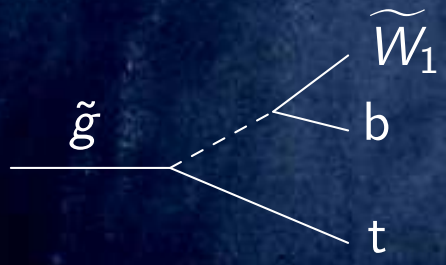

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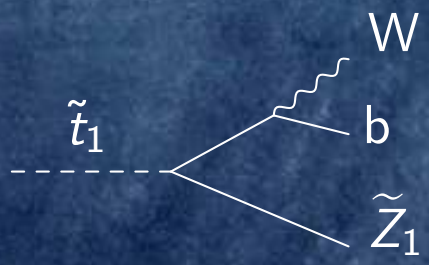

Multi-b jets

$\not{E}_T$ + *leptons*

Soft jets and/or leptons
(if $m_{\tilde{t}_1} \sim m_{\widetilde{Z}_1}$)

ESUSY - Phenomenology

- Benchmark points:
  - ES1:

$$m_{\tilde{g}} = 524 \text{ GeV},\ m_{\tilde{t}_1} = 656 \text{ GeV},\ m_{\tilde{Z}_1} = 69 \text{ GeV},\ m_{\tilde{t}_2, \tilde{b}_i, \tilde{\tau}_i} \sim 1 - 2 \text{ TeV}$$

  - ES2:

$$m_{\tilde{g}} = 2.4 \text{ TeV},\ m_{\tilde{t}_1} = 612 \text{ GeV},\ m_{\tilde{Z}_1} = 441 \text{ GeV},\ m_{\tilde{t}_2, \tilde{b}_i, \tilde{\tau}_i} \sim 0.8 - 1.4 \text{ TeV}$$

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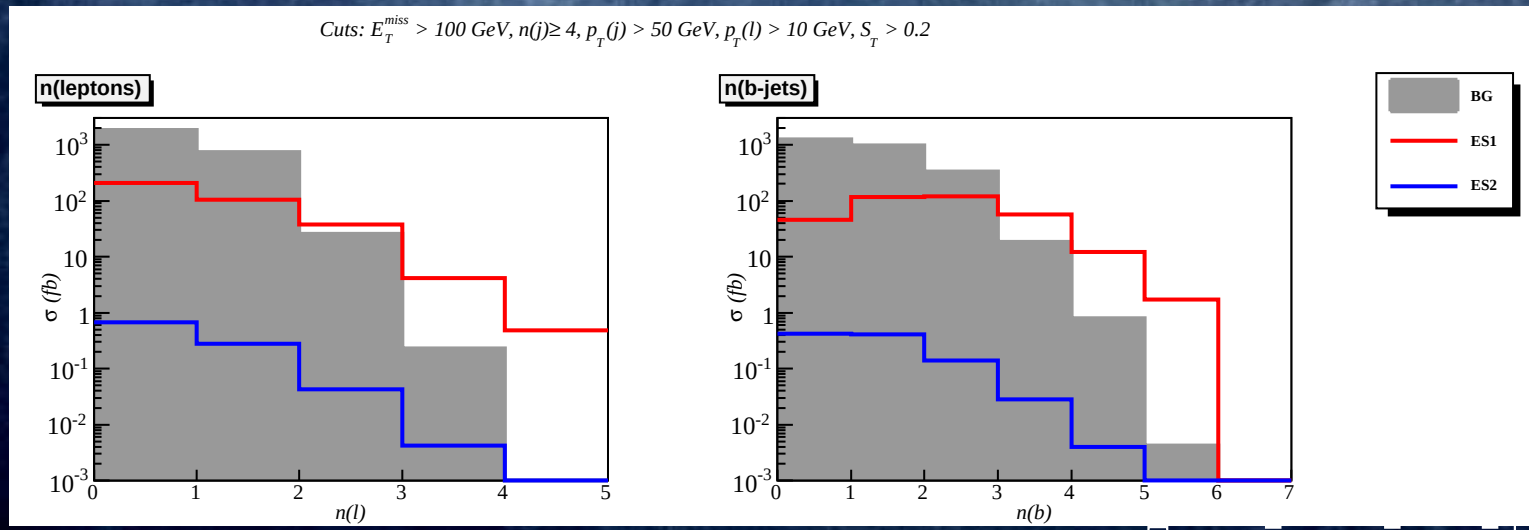

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- If we are lucky, several new physics mass scales will be inferred from data (mass edges, M_{eff}, m_{T2}...)

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Thanks!

Backup slides

Simulation Details

- **Background Simulation**: AlpGen (MLM matching) + Pythia

SM process	Cross section	number of events
QCD: 2, 3 and 4 jets	3.0×10^9 fb	26M
$t\bar{t}$: $t\bar{t}$ + 0, 1 and 2 jets	1.6×10^5 fb	5M
$b\bar{b}$: $b\bar{b}$ + 0, 1 and 2 jets	8.8×10^7 fb	91M
Z + jets: $Z/\gamma(\rightarrow l\bar{l}, \nu\bar{\nu})$ + 0, 1, 2 and 3 jets	8.6×10^6 fb	13M
W + jets: $W^{\pm}(\rightarrow l\nu)$ + 0, 1, 2 and 3 jets	1.8×10^7 fb	19M
$Z + t\bar{t}$: $Z/\gamma(\rightarrow l\bar{l}, \nu\bar{\nu}) + t\bar{t}$ + 0, 1 and 2 jets	53 fb	0.6M
$Z + b\bar{b}$: $Z/\gamma(\rightarrow l\bar{l}, \nu\bar{\nu}) + b\bar{b}$ + 0, 1 and 2 jets	2.6×10^3 fb	0.3M
$W + b\bar{b}$: $W^{\pm}(\rightarrow l\nu) + b\bar{b}$ + 0, 1 and 2 jets	6.4×10^3 fb	9M
$W + t\bar{t}$: $W^{\pm}(\rightarrow l\nu) + t\bar{t}$ + 0, 1 and 2 jets	1.8×10^2 fb	9M
$W + tb$: $W^{\pm}(\rightarrow l\nu) + \bar{t}b(t\bar{b})$	6.8×10^2 fb	0.025M
$t\bar{t}t\bar{t}$	0.6 fb	1M
$t\bar{t}b\bar{b}$	1.0×10^2 fb	0.2M
$b\bar{b}b\bar{b}$	1.1×10^4 fb	0.07M
WW: $W^{\pm}(\rightarrow l\nu) + W^{\pm}(\rightarrow l\nu)$	3.0×10^3 fb	0.005M
WZ: $W^{\pm}(\rightarrow l\nu) + Z(\rightarrow all)$	3.4×10^3 fb	0.009M
ZZ: $Z(\rightarrow all) + Z(\rightarrow all)$	4.0×10^3 fb	0.02M

Simulation Details

- Signal Simulation:
  - Isajet 7.79 (all $2 \rightarrow 2$ susy processes)
- Detector Simulation:
  - Toy detector with
    - Energy smearing
    - b-tag efficiency (60 %) and mistagging
    - Cone jet algorithm
- Luminosity:
  - $\gtrsim 1$ fb^{-1} for BG (except QCD)
  - $\gtrsim 2$ fb^{-1} for Signal

- But...
  - $\not{E}_T$ has just been measured at low E_T events
  - Fake $\not{E}_T$ grows with $\sum E_T$
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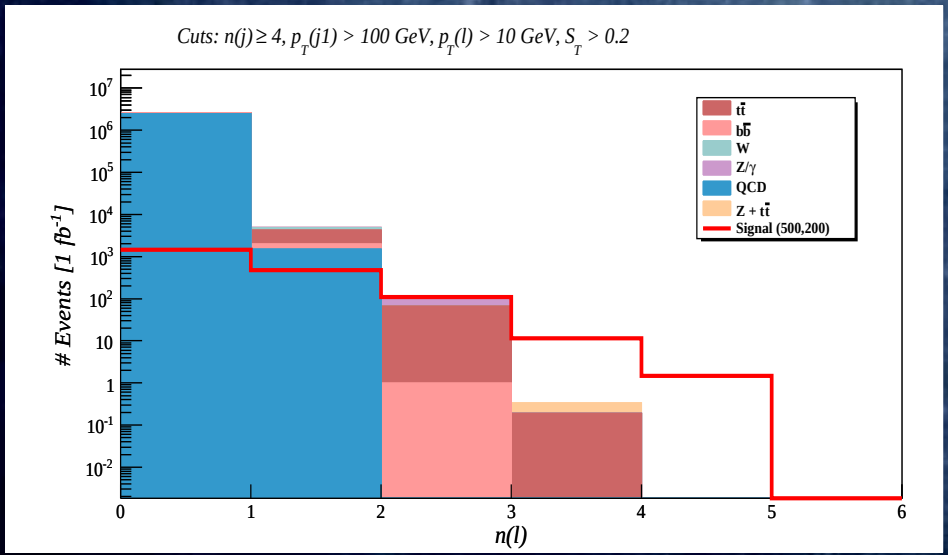

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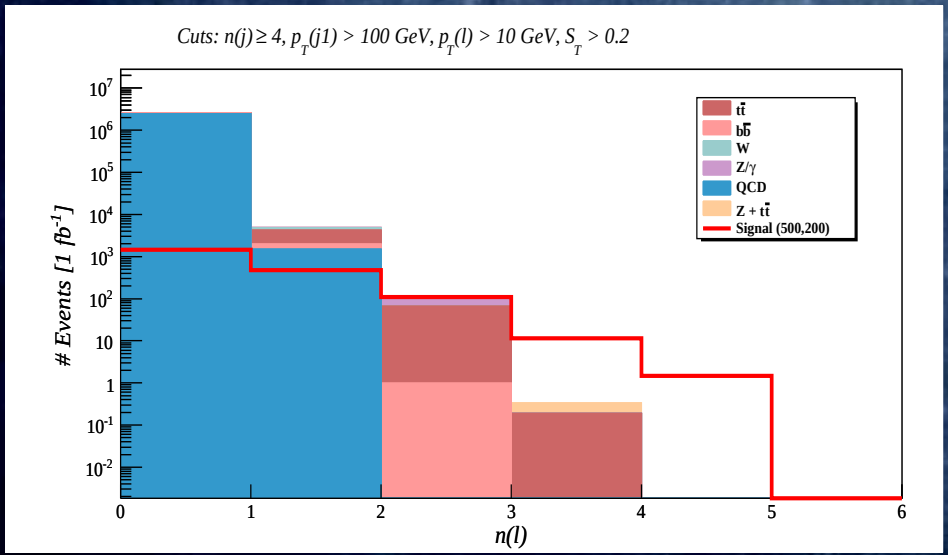

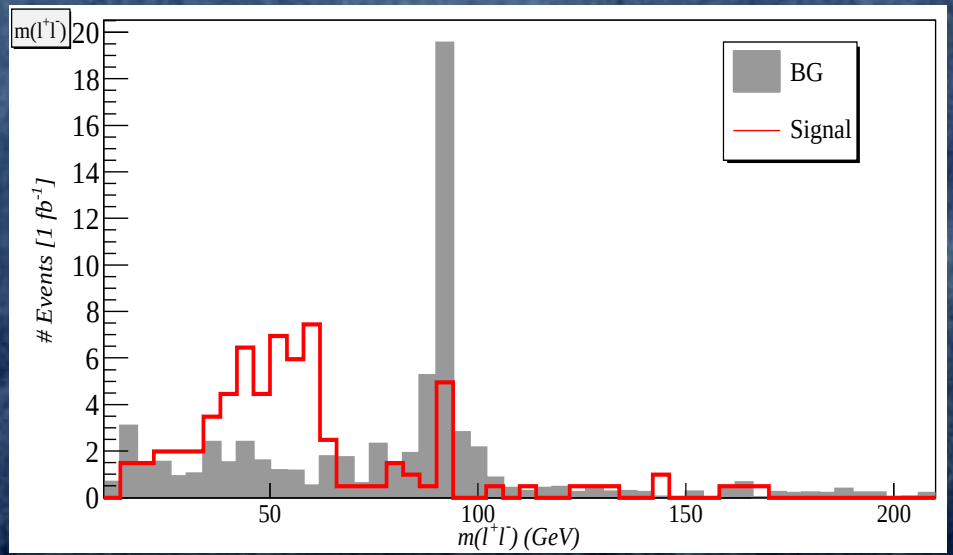

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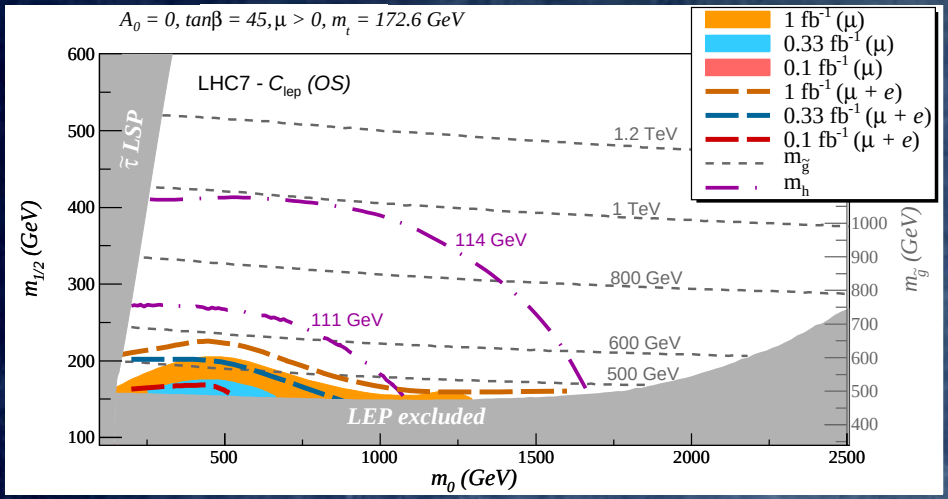

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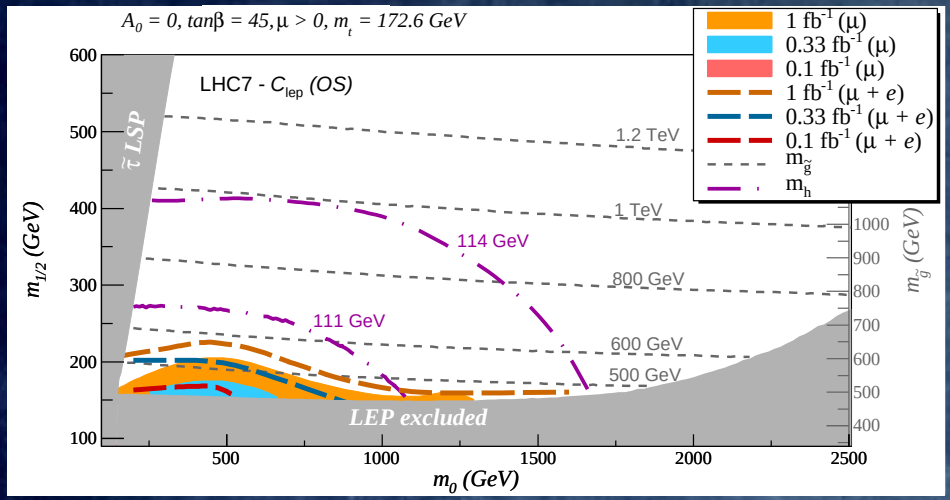

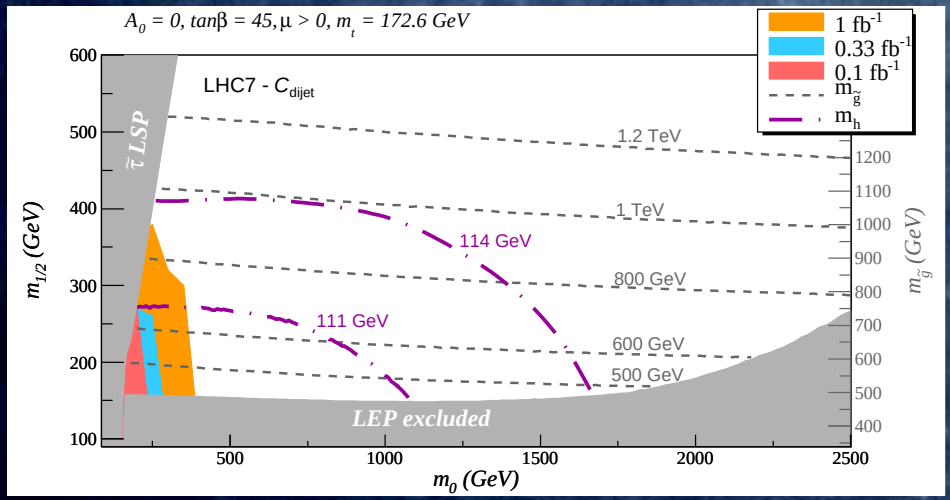

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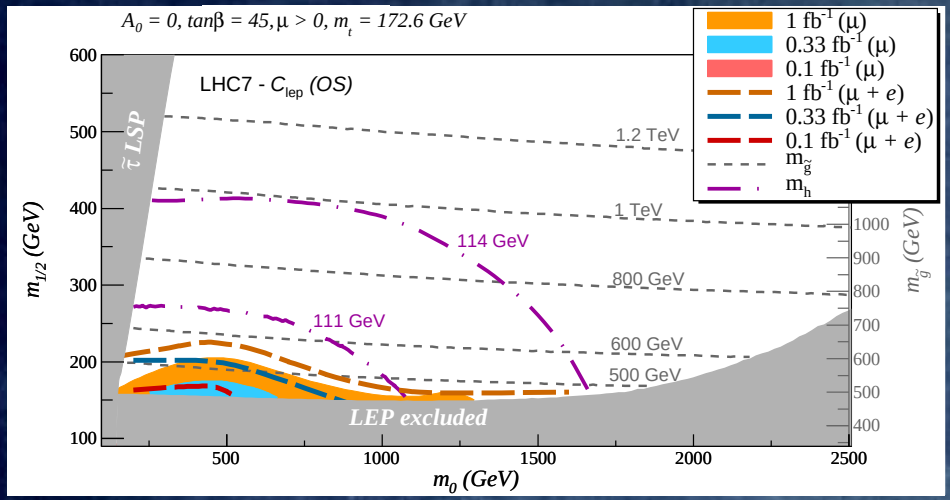

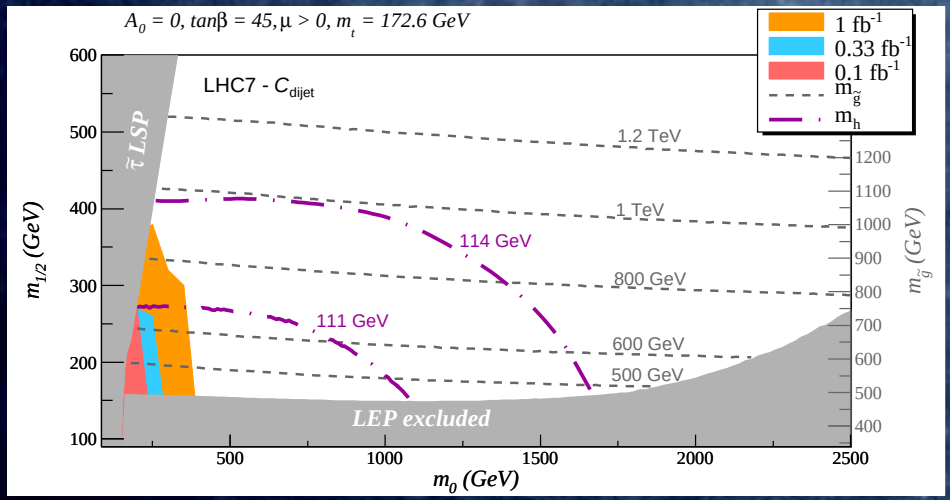

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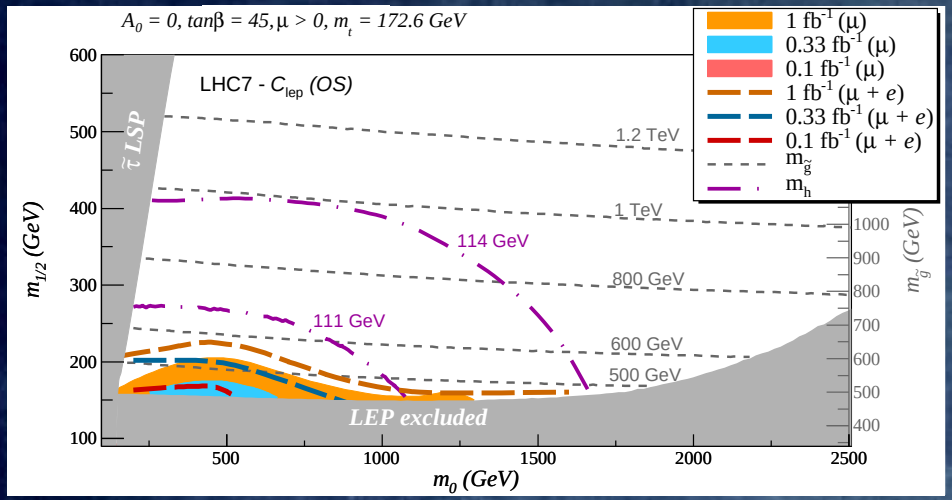

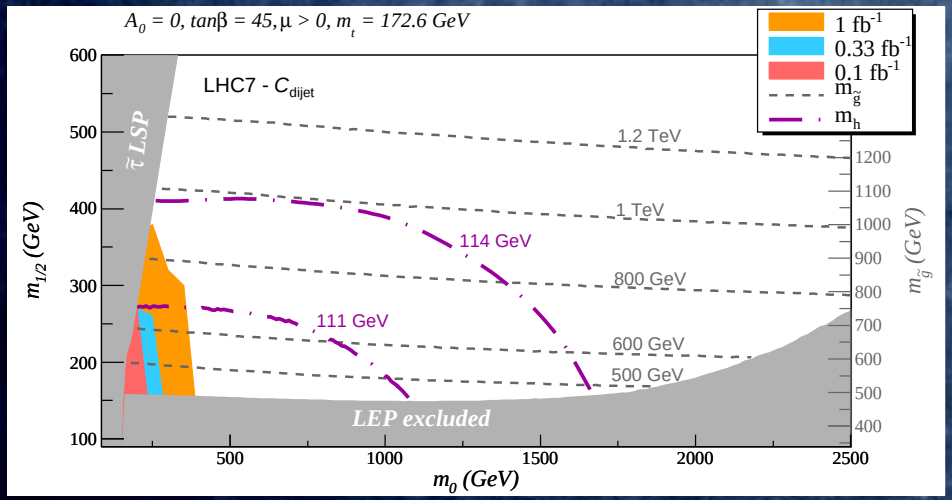

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for 0.33 fb^{-1}:

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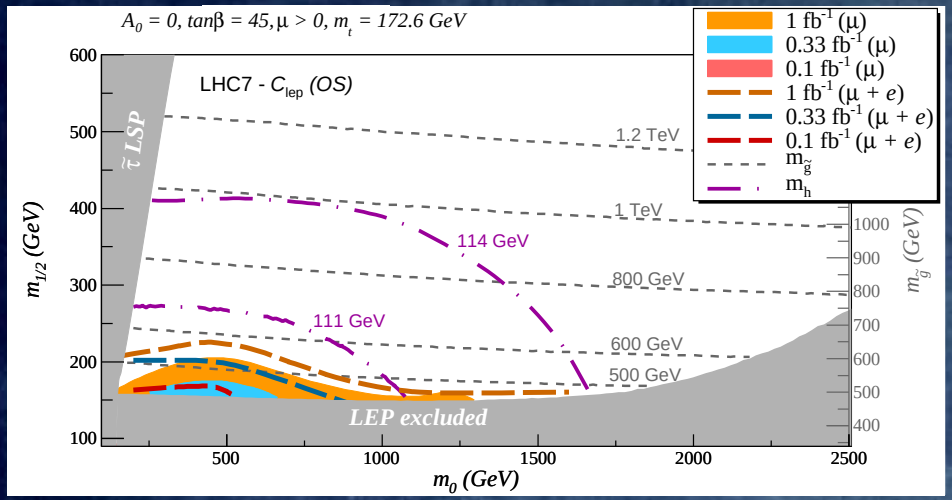

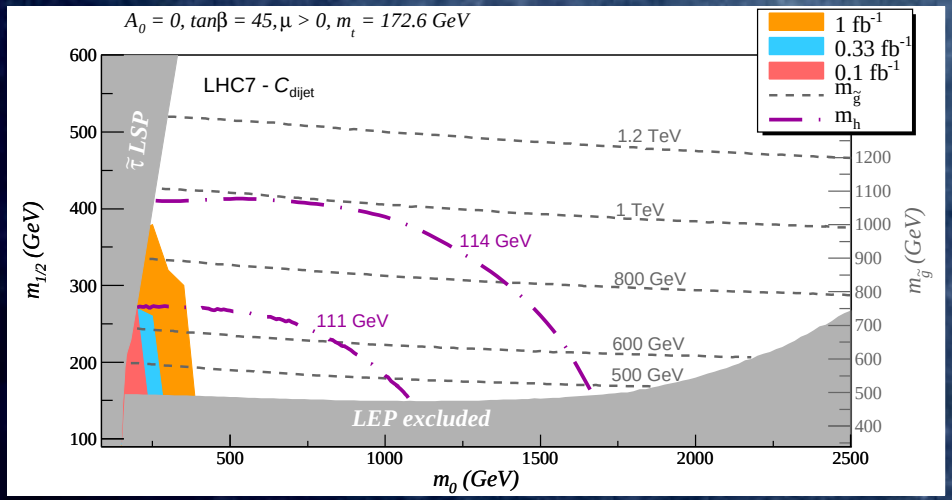

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$\rightarrow$ Already competitive with Tevatron bounds!
($m_{\tilde{g}} \gtrsim 300 - 400$ GeV)

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- mSUGRA Best Fit:
  $m_0 = 60$ GeV, $m_{1/2} = 310$ GeV, $A_0 = 130$ GeV, $\tan\beta = 11$
  (O. Buchmueller et al., Eur.Phys.J.C64:391-415,2009)

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  - $\Omega h^2 = 0.11$, $\delta a_\mu = 38 \times 10^{-10}$, $BF(b \to s\gamma) = 2.6 \times 10^{-4}$
  - **Visible at:** $n(j) \geq 2$, $\not{E}_T > 200$ **GeV,** $(S = 909, BG = 460)$
- mSUGRA Best Fit:
  $m_0 = 60$ GeV, $m_{1/2} = 310$ GeV, $A_0 = 130$ GeV, $\tan\beta = 11$
  (O. Buchmueller et al., Eur.Phys.J.C64:391-415,2009)
  - $m_{\tilde{g}} = 740$ GeV, $m_{\tilde{q}} \sim 650$ GeV, $m_{\tilde{Z}_1} = 122$ GeV, $m_{\tilde{\tau}_1} = 129$ GeV
  - $\Omega h^2 = 0.08$, $\delta a_\mu = 27 \times 10^{-10}$, $BF(b \to s\gamma) = 3.1 \times 10^{-4}$

mSUGRA Reach

- Some Benchmark points:
- SPSla':
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  - $\Omega h^2 = 4.4$, $\delta a_\mu = 3 \times 10^{-10}$, $BF(b \to s\gamma) = 3.1 \times 10^{-4}$

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  - $m_{\tilde{g}} = 658$ GeV, $m_{\tilde{q}} \sim 600$ GeV, $m_{\tilde{Z}_1} = 110$ GeV
  - $\Omega h^2 = 0.05$, $\delta a_\mu = 33 \times 10^{-10}$, $BF(b \to s\gamma) = 3.9 \times 10^{-4}$

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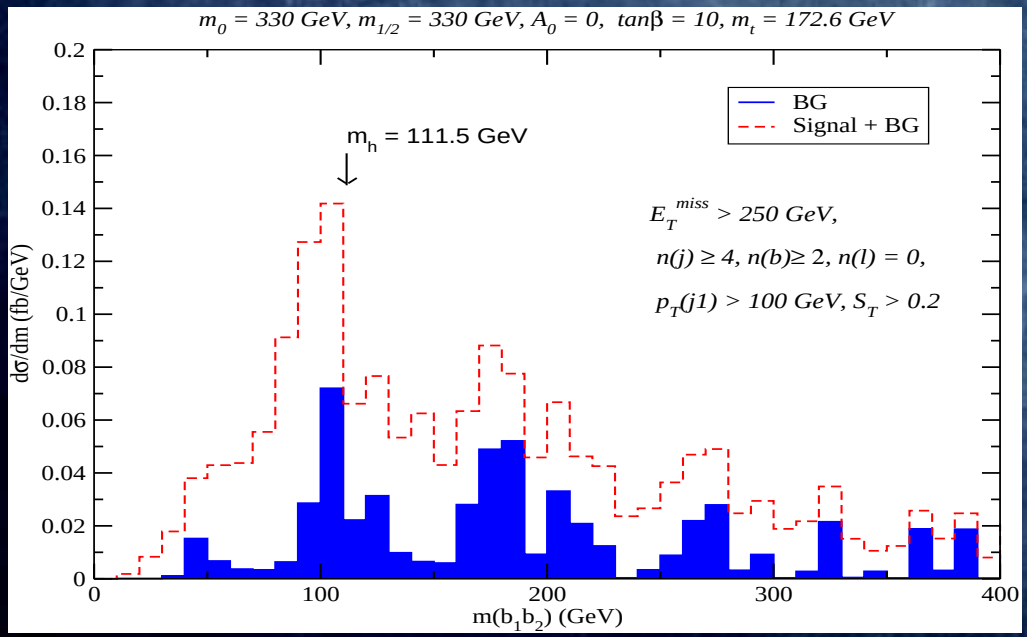

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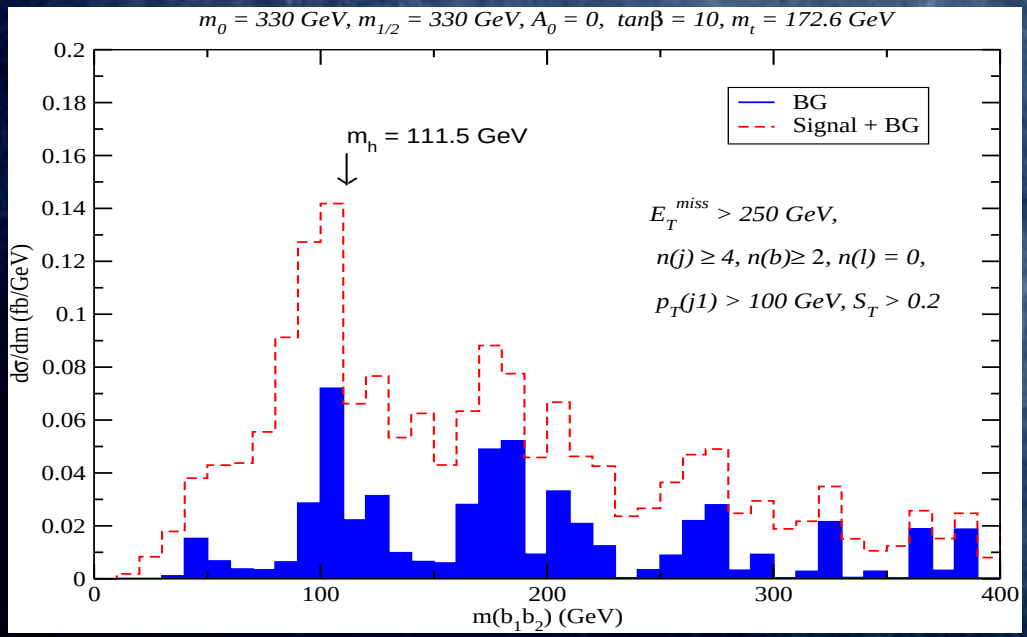

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$\Rightarrow$ Hope?