Seeking Supersymmetry at LHC7

XERXES TATA
University of Hawaii

Howie Baer, Vernon Barger, Andre Lessa, XT

arXiv:1004.3594

see also arXiv:0909.1922 for 10 TeV operation

We are in a very exciting era for particle physics

- ⋆ Direct DM detection: CDMS, XENON-100 (DAMA, COGeNT, COUP....)
- ⋆ Indirect DM detection: Pamela, Fermi, ATIC, AMS-02, IceCube.....
- ⋆ The Large Hadron Collider, $\sqrt{s} = 14$ TeV pp collider, currently operating at 7 TeV (LHC7).

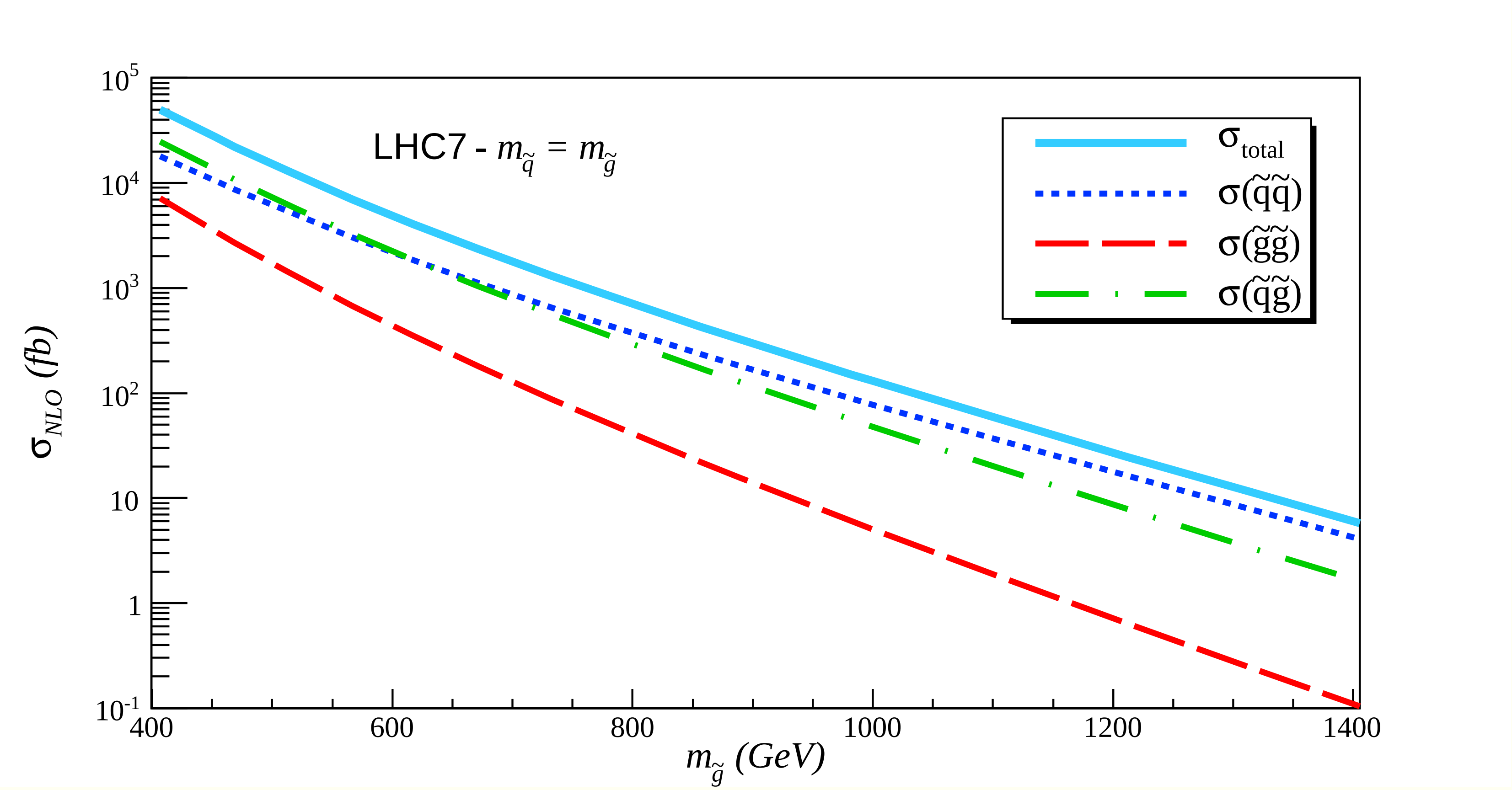
3 times energy of Fermilab

25 bunches $\rightarrow$ 48 bunches

Integrated luminosity delivered 1.6 pb^{-1} + 0.25 pb^{-1}

Expected to be $\sim$1 fb^{-1} by the end of the run.

I want to convince you that LHC7 presents a great opportunity for new discoveries.

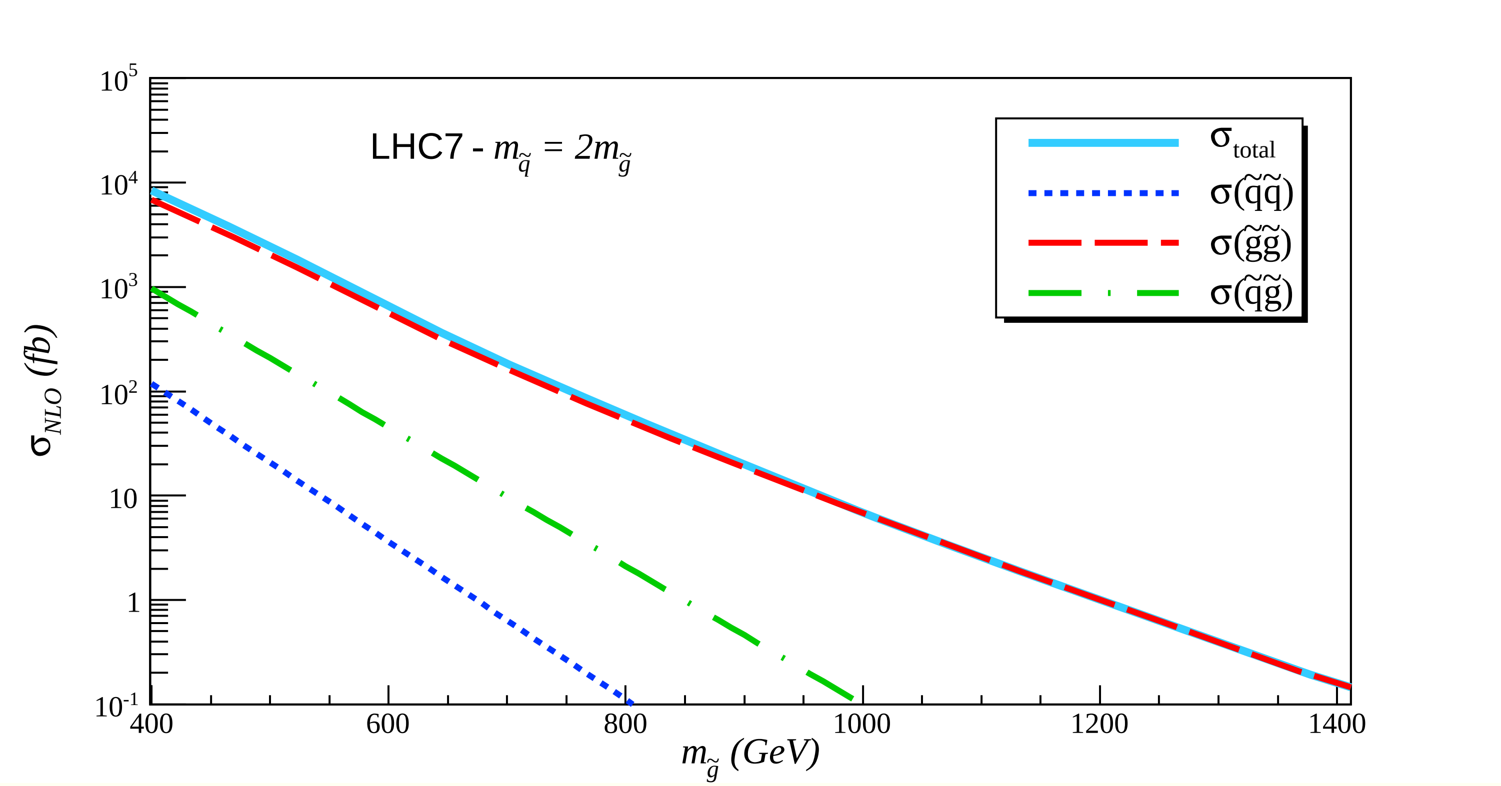


Cross section exceeds 100 fb if $m_{\tilde{q}} = m_{\tilde{g}} < 1$ TeV.

Mostly $\tilde{q}\tilde{g}$ and $\tilde{q}\tilde{q}$ production.

CTN=360 GeV*

*CTN refers only to gluino and squark cross sections



Cross section exceeds 100 fb if squarks are very heavy but $m_{\tilde{g}} \lesssim 700$ GeV.

Mostly $\tilde{g}\tilde{g}$ production.

CTN=320 GeV*

*CTN refers only to gluino and squark cross sections

How long will it take LHC detectors to do physics?

- ⋆ The first data demonstrate that the performance of the detector and quality of the reconstruction and simulation software are better than expected at this (initial) stage of the experiment ....

Fabiola Gianotti (ICHEP 2010).

CMS guys utilize their excellent segmentation to improve the measurements from the purely calorimetric ones. Tracking and particle flow algorithms seem to be working!

- ⋆ ICHEP talk by Guido Tonelli also very encouraging. Data and simulations in good agreement. Confirming W/Z physics and starting the beginning of top physics.

These considerations suggest that, contrary to expectations just a year ago when it was thought that detectors would take time to be well-enough understood for $\not{E}_T$ (and perhaps also electron ID) analyses, it now appears that
these analyses will be possible even at an early stage of the LHC data.

However, keep in mind that....

⋆ $\not{E}_T \stackrel{<}{\sim} 80-100$ GeV, $\sum E_T$ is also limited compared to what we need for many SUSY analyses. (Fake $\not{E}_T \sim \sqrt{\sum E_T}$. Remember the D0 bump!)

I hope that everything will go well – as appears to be the case right now – and focus on results for the situation where we can utilize $\not{E}_T$ as well as electron information, and briefly mention (if time permits) what happens if $\not{E}_T$ cannot be utilized.

Early LHC reach with an "understood detector"

The search channels include:

- ⋆ multi-jet + $\not{E}_T$ events;
- ⋆ $1\ell, 2\ell$ (OS or SS), 3ℓ + jets $+\not{E}_T$ events;
- ⋆ Events with 1-3 tagged b-jets ($\epsilon_b = 60\%$).

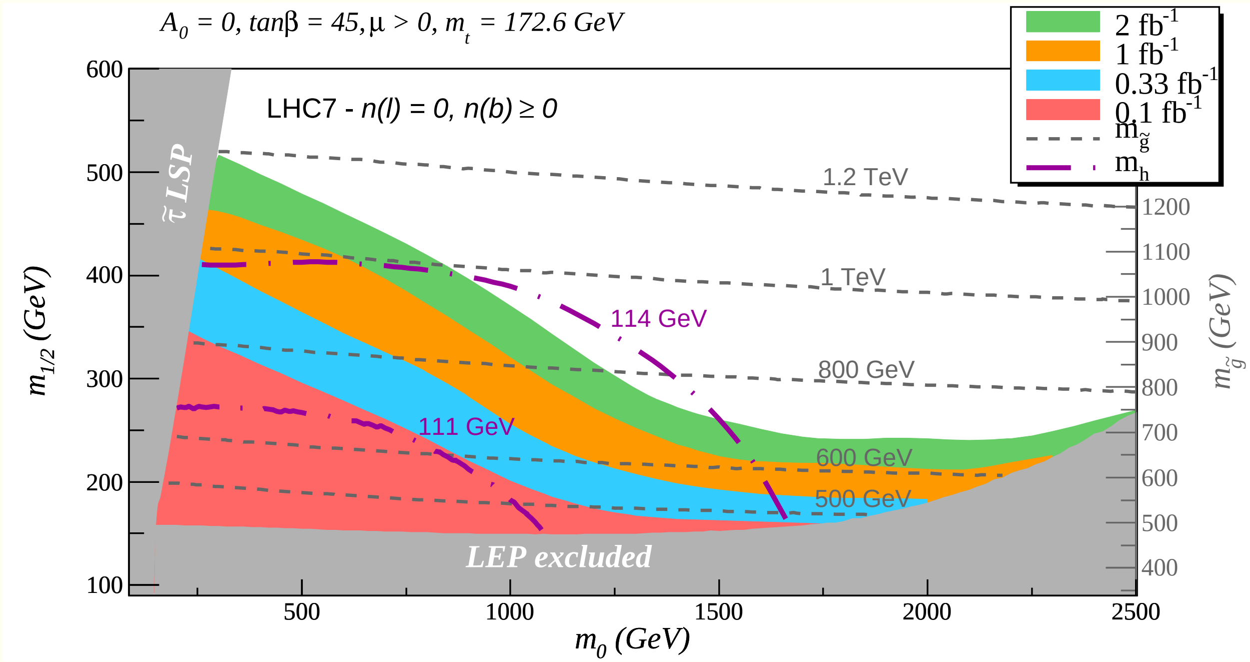
Multiple sources of SM backgrounds

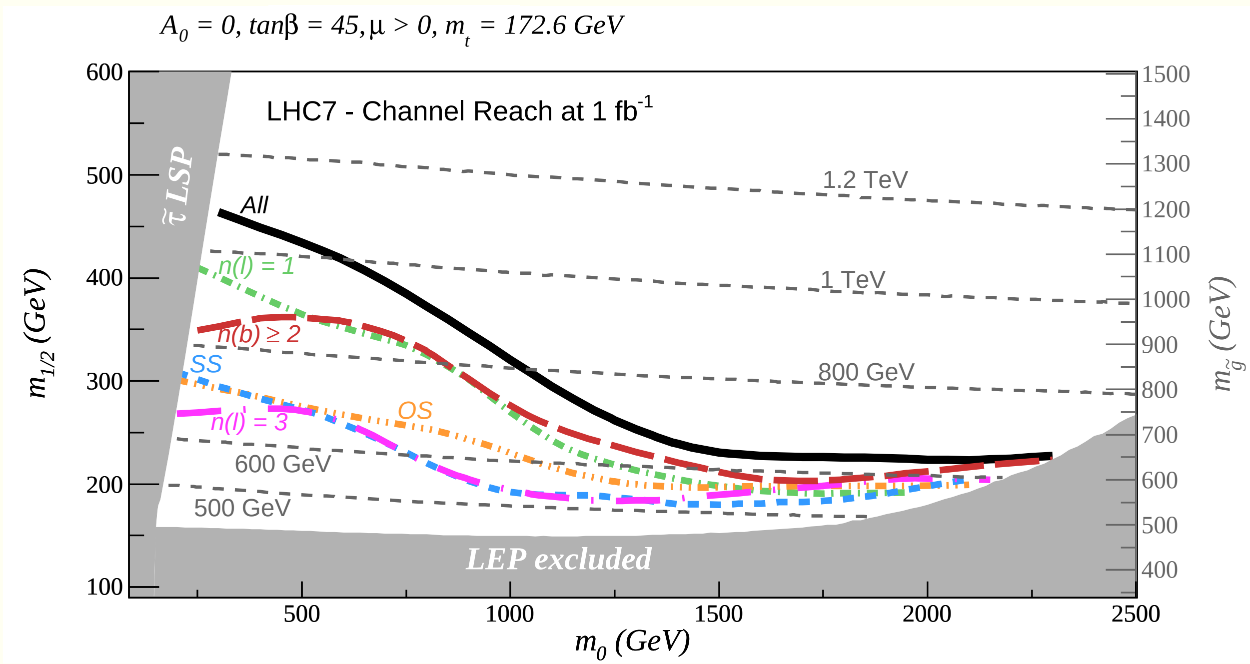
SM process	Generator	Cross section	number of events
QCD: 2, 3 and 4 jets (40 GeV$< E_T(j1) < 100$ GeV)	AlpGen	2.6×10^9 fb	26M
QCD: 2, 3 and 4 jets (100 GeV$< E_T(j1) < 200$ GeV)	AlpGen	3.9×10^8 fb	44M
QCD: 2, 3 and 4 jets (200 GeV$< E_T(j1) < 500$ GeV)	AlpGen	1.6×10^7 fb	16M
QCD: 2, 3 and 4 jets (500 GeV$< E_T(j1) < 3000$ GeV)	AlpGen	9.4×10^4 fb	0.3M
$t\bar{t}$: $t\bar{t}$ + 0, 1 and 2 jets	AlpGen	1.6×10^5 fb	5M
$b\bar{b}$: $b\bar{b}$ + 0, 1 and 2 jets	AlpGen	8.8×10^7 fb	91M
Z + jets: $Z/\gamma(\rightarrow l\bar{l}, \nu\bar{\nu})$ + 0, 1, 2 and 3 jets	AlpGen	8.6×10^6 fb	13M
W + jets: $W^\pm(\rightarrow l\nu)$ + 0, 1, 2 and 3 jets	AlpGen	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	AlpGen	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	AlpGen	2.6×10^3 fb	0.3M
$W + b\bar{b}$: $W^\pm(\rightarrow l\nu) + b\bar{b}$ + 0, 1 and 2 jets	AlpGen	6.4×10^3 fb	9M
$W + t\bar{t}$: $W^\pm(\rightarrow l\nu) + t\bar{t}$ + 0, 1 and 2 jets	AlpGen	1.8×10^2 fb	9M
$W + tb$: $W^\pm(\rightarrow l\nu) + \bar{t}b(t\bar{b})$	AlpGen	6.8×10^2 fb	0.025M
$t\bar{t}t\bar{t}$	MadGraph	0.6 fb	1M
$t\bar{t}b\bar{b}$	MadGraph	1.0×10^2 fb	0.2M
$b\bar{b}b\bar{b}$	MadGraph	1.1×10^4 fb	0.07M
WW: $W^\pm(\rightarrow l\nu) + W^\pm(\rightarrow l\nu)$	AlpGen	3.0×10^3 fb	0.005M
WZ: $W^\pm(\rightarrow l\nu) + Z(\rightarrow all)$	AlpGen	3.4×10^3 fb	0.009M
ZZ: $Z(\rightarrow all) + Z(\rightarrow all)$	AlpGen	4.0×10^3 fb	0.02M

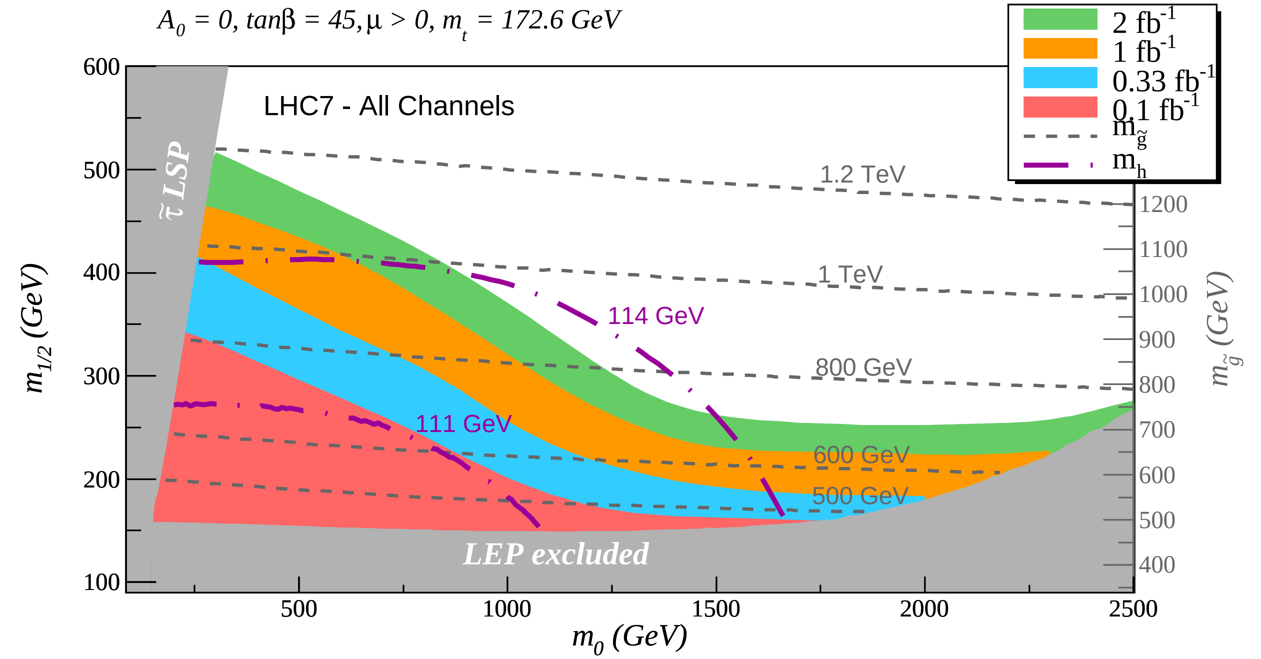
Optimized reach using $\not{E}_T$

- $\not{E}_T >$ 100 - 1000 GeV (in steps of 100 GeV),
- $n(jets) \geq$ 2, 3, 4, 5 or 6,
- $n(b - jets) \geq$ 0, 1, 2 or 3,
- $E_T(j_1) >$ 50 - 300 GeV (in steps of 50 GeV) and 400-1000 GeV (in steps of 100 GeV) (jets are ordered $j_1 - j_n$, from highest to lowest E_T),
- $E_T(j_2) >$ 50 - 200 GeV (in steps of 30 GeV) and 300, 400, 500 GeV,
- $n(\ell) =$ 0, 1, 2, 3, OS, SS and inclusive channel: $n(\ell) \geq$ 0. (Here, $\ell = e,\ \mu$).
- 10 GeV$\leq m(\ell^+\ell^-) \leq 75$ GeV or $m(\ell^+\ell^-) \geq 105$ GeV (for the OS, same flavor (SF) dileptons only),
- transverse sphericity $S_T > 0.2$.

We define the signal to be observable if $S \geq max[5\sqrt{B}, 5, 0.2B]$


A0 = 0, tanβ = 45, μ > 0, mt = 172.6 GeV
LHC7 - n(l) = 0, n(b) ≥ 0
2 fb-1
1 fb-1
0.33 fb-1
0.1 fb-1
mg̃
mh
τ̃ LSP
1.2 TeV
1 TeV
800 GeV
600 GeV
500 GeV
114 GeV
111 GeV
LEP excluded
m1/2 (GeV)
m0 (GeV)
mg̃ (GeV)


A0 = 0, tanβ = 45, μ > 0, mt = 172.6 GeV
LHC7 - Channel Reach at 1 fb-1
τ̃ LSP
All
n(l) = 1
n(b) ≥ 2
SS
OS
n(l) = 3
1.2 TeV
1 TeV
800 GeV
600 GeV
500 GeV
LEP excluded
m1/2 (GeV)
m0 (GeV)
mg̃ (GeV)



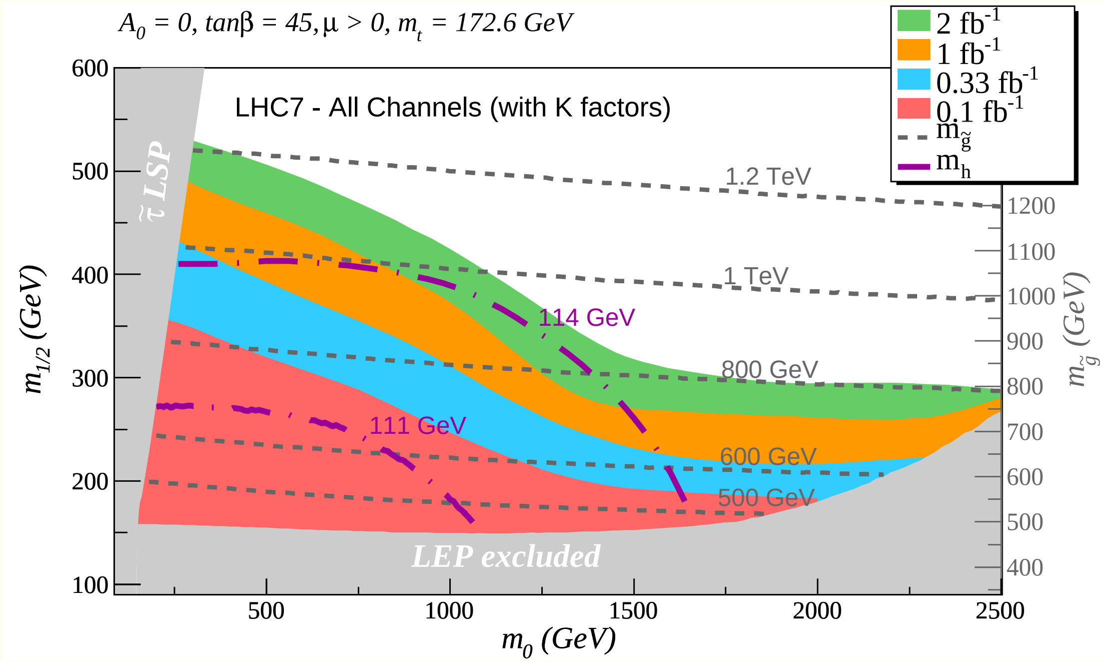
Combined reach essentially the reach in the multi-jet+$\not{E}_T$ channel.

Reach in other channels lends support to the hypothesis that one is seeing SUSY cascade decays.

We have not used any NLO enhancement on the signal in these reach plots.

NLO enhancements and other matters

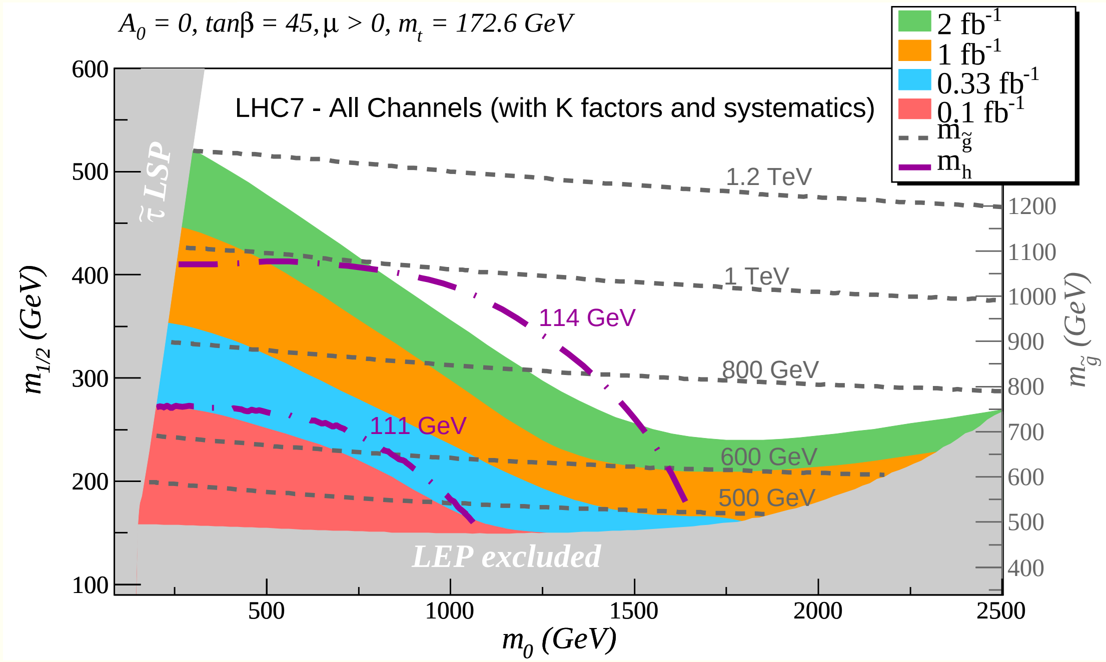
Here is what happens if we normalize $\tilde{g}\tilde{g} + \tilde{g}\tilde{q} + \tilde{q}\tilde{q}$ production to Prospino NLO value



Reach in $m_{1/2}$ increased by $\sim 5\%$ for low value of m_0 and by 15-20% for large m_0 values.

Backgrounds will be determined using data. Background fluctuations, and also systematic errors guesstimated by ATLAS guys to be $\sim 50\%$.

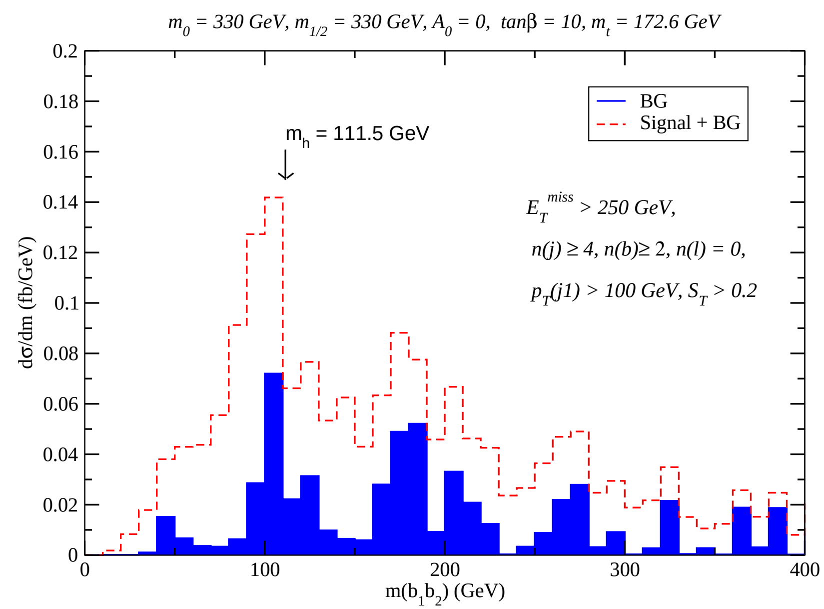
This will reduce the reach from the value that we projected.



Just few percent reduction from original projection for 1 fb^{-1}, but as much as 25% reduction for 100 pb^{-1}!

Discovery of h may also be possible via SUSY cascades if we are lucky.

Often $\tilde{g}$ or $\tilde{q}_L \to \widetilde{Z}_2 \to h$ has a healthy branching fraction if $\widetilde{Z}_2 \to h\widetilde{Z}_1$ is open.



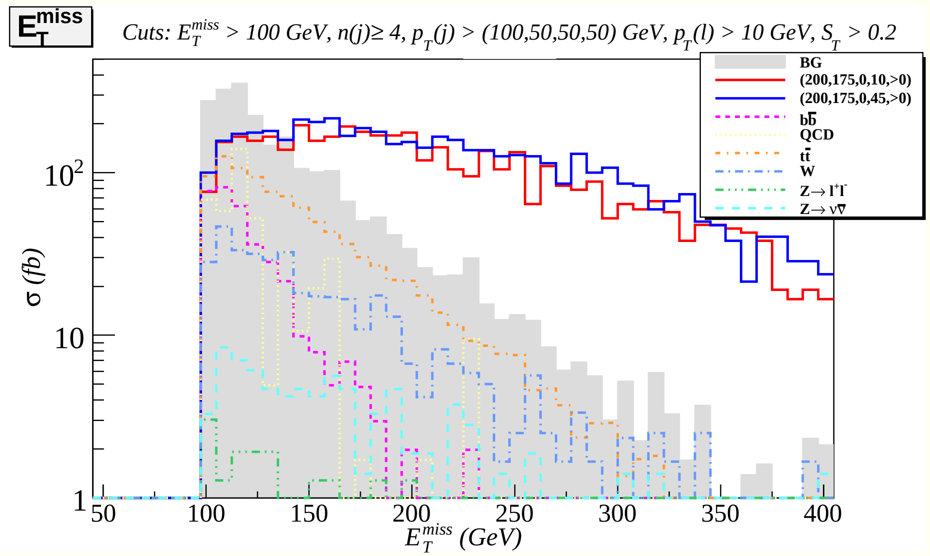
$B(\tilde{g} \to \tilde{t}_1 t) = 0.46$; $B(\tilde{g} \to \tilde{b}_1 b) = 0.29$; $B(\tilde{q}_L \to q\widetilde{Z}_2) = 0.3$;
$B(\tilde{t}_1 \to t\widetilde{Z}_2) = 0.15$; $B(\tilde{b}_1 \to b\widetilde{Z}_2) = 0.20$; $B(\widetilde{Z}_2 \to h\widetilde{Z}_1) = 0.79$.

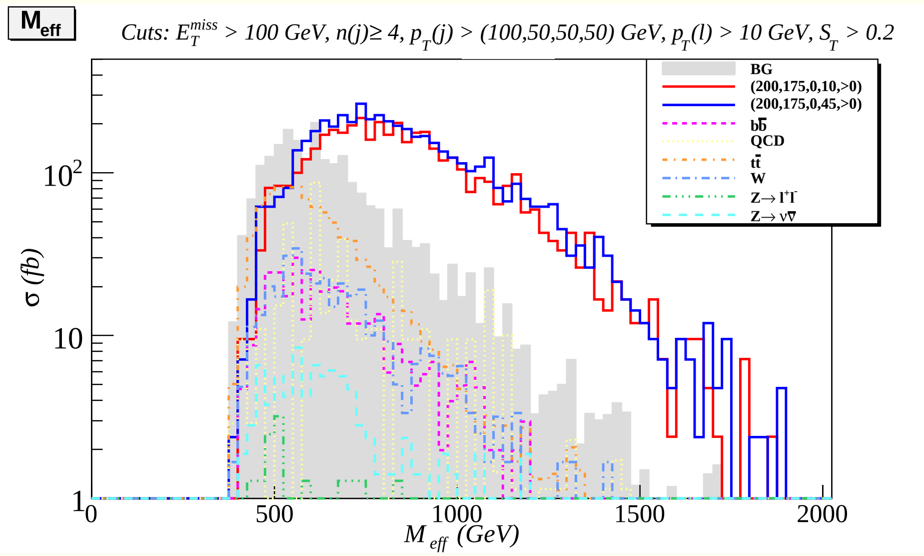
Can see a bump with 2-3 fb^{-1} total (combined ATLAS + CMS analysis)

Advanced Sambulance-Chasing

Can LHC experiments see a signal this year?

Go beyond a counting experiment and look at distributions.





$m_{\tilde{q}} \simeq m_{\tilde{g}} \simeq 450$ GeV, $\tilde{t}_1/\tilde{b}_1$ lighter.

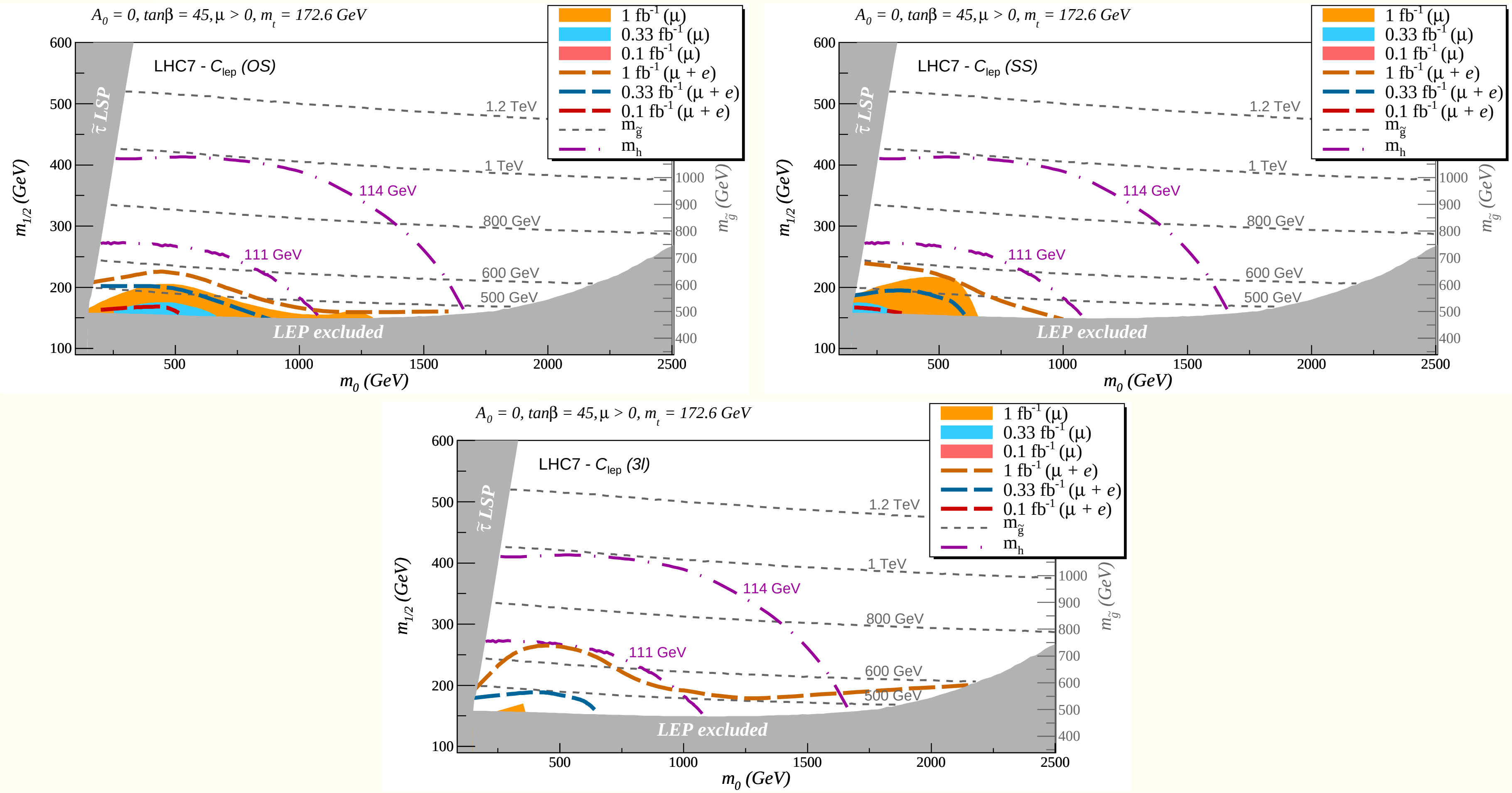
$\sigma = 4.3(4.9)$ pb.

Any SUSY signal will distort the shape of the distributions, with tens of events in the low b/g region for just 10 pb^{-1}.

LHC7 reach without $\not{E}_T$

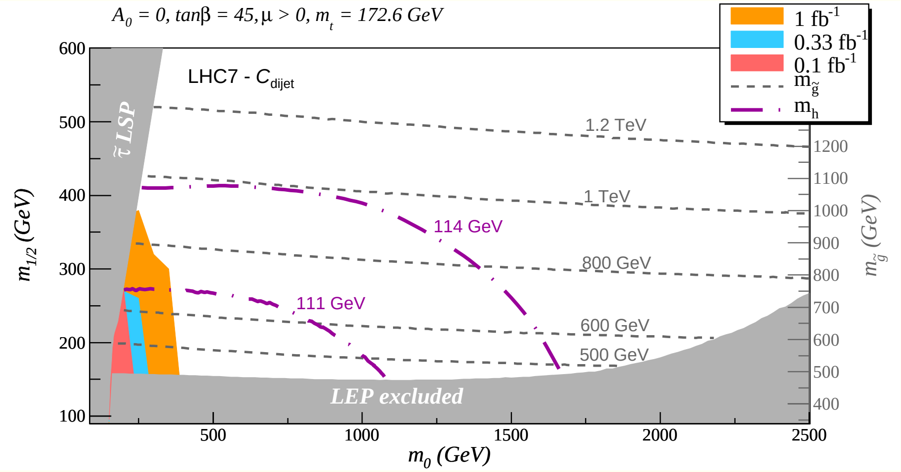
- ⋆ Isolated multilepton searches; $E_T(\ell) > 10$ GeV; $n_j \geq 4, E_T(j_1) \geq 100$ GeV; $E_T(j) \geq 50$ GeV; Z-veto.
- ⋆ Acollinear di-jets, since jet directions can be relatively well-determined even with incompletely understood detectors. $n_j = 2$; $E_T(j) \geq 50$ GeV; $E_T(j_1) + E_T(j_2) \geq 650$ GeV; $\Delta\phi(jj) < 2.4$.

MULTI-LEPTON SEARCHES WITHOUT $\not\!\!E_T$



- ⋆ With only multimuons, no reach in the trilepton channel This is because the signal is severely rate-limited. Earliest reach is in the OS dimuon channel, but SS dimuons (because of smaller b/g) yield the greater reach i there is enough integrated luminosity.
- ⋆ With electrons included, the situation is different. The trilepton channel yields the best reach. W/in mSUGRA, the reach effectively probes $m_{\tilde{g}}$ out to 680 GeV. Small event numbers, but OS (same flavour) dilepton events would tend to cluster a bit below the dilepton mass edge

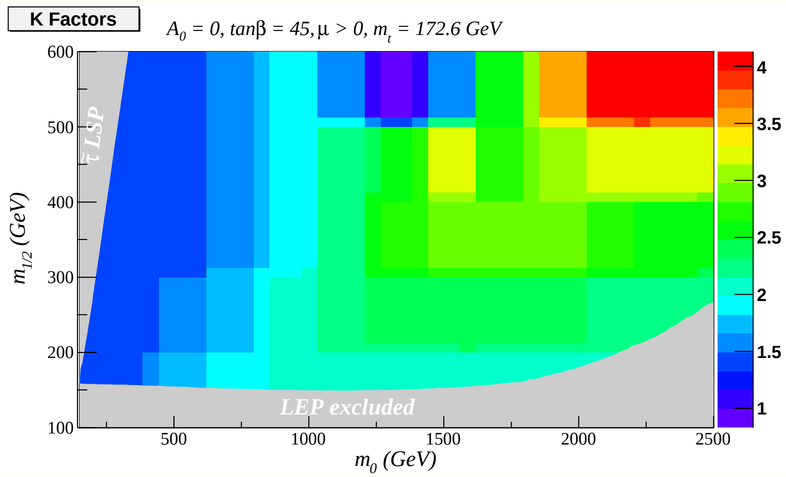
Acollinear di-jets



For (approximately degenerate gluinos and squarks) the reach extends out to $m_{\tilde{q}} \sim 0.9$ TeV with 1 fb^{-1}, and is somewhat complementary to the multilepton search.

- ⋆ With just 1 fb^{-1}, the signal in the acollinear di-jet channel can probe gluinos and squarks out to 1.1 TeV or so if $m_{\tilde{q}} \sim m_{\tilde{g}}$ at LHC10.

FOR SURE, WE CAN LOOK FORWARD TO AN EXCITING TIME AHEAD.


K Factors
A_0 = 0, tanβ = 45, μ > 0, m_t = 172.6 GeV
$\tilde{\tau}$ LSP
LEP excluded
$m_{1/2}$ (GeV)
m_0 (GeV)
600
500
400
300
200
100
500
1000
1500
2000
2500
4
3.5
3
2.5
2
1.5
1