Probing signature of second Higgs peak

Beyond MSSM

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Sildes based on the following papers:

- Can we have another light (145 GeV) Higgs boson?
  S. Khalil, S. Moretti
- Higgs boson decays into $\gamma\gamma$ and $Z\gamma$ in the MSSM and BLSSM
  A. Hammad, S. Khalil, S. Moretti
- Double Higgs peak in the minimal SUSY B-L model
  W. Abdallah, S. Khalil, S. Moretti
- Search of Heavy Higgs at LHC (Ingoing)
  A. Hammad, S. Khalil, S. Moretti

Outline

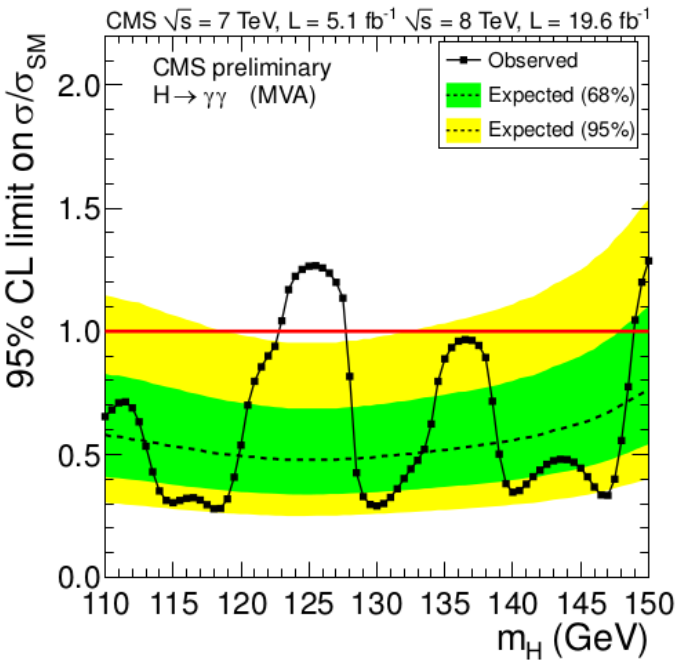
1. Signatures at Run-I
2. MSSM second CP-even Higgs
   - Decoupling region
   - Coupling with SM particles
3. B-LSSM CP-even Higgs
   - Superpotential and gauge mixing
   - CP-even Higgs mass matrix
   - Higgs coupling and unitarity test
4. Comparing theoretical expected with data at Run-I
   - $h' \longrightarrow ZZ \longrightarrow 4l$
   - $h' \longrightarrow \gamma\gamma$
   - $h' \longrightarrow Z\gamma$
5. Ingoing

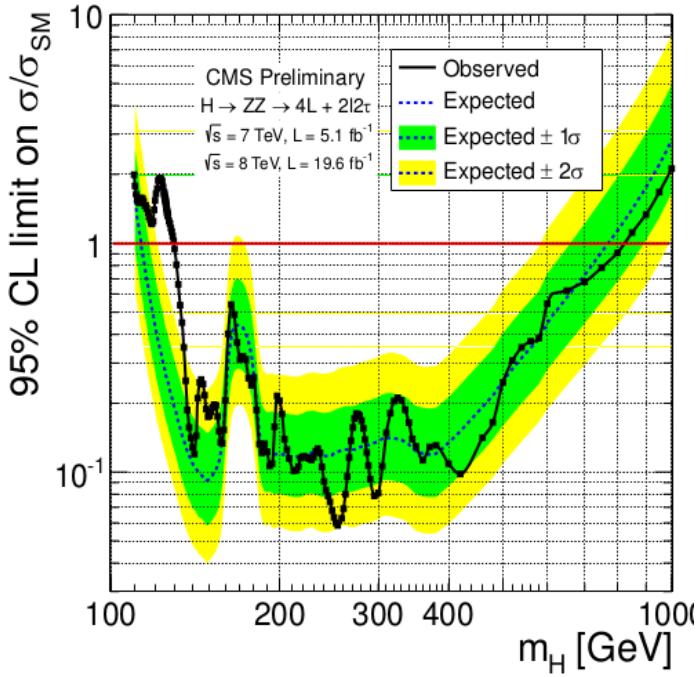
Signatures at Run-I

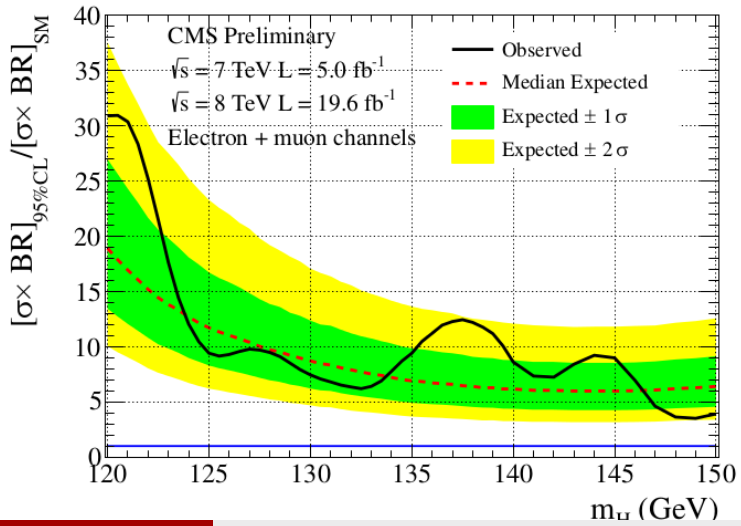
Both ATLAS and CMS have found a two sigma excess of the second Higgs signal over background around $M_h = 140$ GeV in three channels:

1. $h \longrightarrow ZZ \longrightarrow 4l$
2. $h \longrightarrow \gamma\gamma$
3. $h \longrightarrow Z\gamma$

Signatures at Run-I







MSSM second CP-even Higgs

In MSSM we have two have two CP-even Higgs boson, one CP-odd and charged Higgs boson. The CP-even Higgs boson masses defined as:

$$M^2_{h,H} = \frac{1}{2}\left[M^2_A + M^2_Z \mp \sqrt{(M^2_A + M^2_Z) - 4M^2_A M^2_Z \cos^2 2\beta}\right]$$

We adopt h to be SM-like Higgs and H the second heavy Higgs

The physical States obtained by ordinary rotation of the gauge eigenstates by an angle α

$$\begin{pmatrix} h \\ H \end{pmatrix} = \begin{pmatrix} \cos\alpha & \sin\alpha \\ -\sin\alpha & \cos\alpha \end{pmatrix} \begin{pmatrix} h0 \\ H0 \end{pmatrix}$$

Outline

Decoupling region

Conditions

- $M_A \gg M_Z$
- large tan β

Adventages

- SM-Like Higgs reached its maximal masses.
- The coupling of SM-like Higgs h with SM particles approached the SM one.

Veto against other regions!!!

Outline

Coupling with SM particles

For Large $\tan\beta$ and M_A

Coupling with SM gauge bosons

$$g_{hVV} = 1 - \frac{2M_Z^4}{M_A^4 \tan^2\beta} \sim 1$$

$$g_{HVV} = -\frac{2M_Z^2}{M_A^4 \tan^2\beta} \sim 0$$

Coupling with SM fermions

$$g_{hff} = 1 - \frac{2M_Z^2}{M_A^2 \tan^2\beta} \sim 1$$

$$g_{Hff} = -\frac{2M_Z^2}{M_A^4 \tan^2\beta} \sim -\cot\beta$$

End of MSSM route!!!

Coupling with SM particles

The coupling of second CP-even MSSM Higgs boson with SM particles is highly supreesed.

Just look for another less constraint Higgs boson.

B-LSSM CP-even Higgs

$BLSSM \Longrightarrow$ extending SM gauge groups by $U(1)_{B-L}$

$BLSSM \Longrightarrow$ Three generations of superfields right handed neutrinos $\hat{\nu}$.

$BLSSM \Longrightarrow$ Two bileptons χ_1 χ_2, needed to break $U(1)_{B-L}$.

$BLSSM \Longrightarrow$ One gauge boson Z'

Outline

Superpotential and gauge mixing

$$W = Y_u \hat{U}\hat{Q}\hat{H}_u - Y_d \hat{D}\hat{Q}\hat{H}_d - Y_e \hat{E}\hat{L}\hat{H}_d + \mu \hat{H}_u \hat{H}_d + Y_\nu \hat{L}\hat{H}_u \hat{\nu} - \mu' \chi_1 \chi_2 + Y_\chi \hat{\nu}\chi_1 \hat{\nu}$$

$\Longrightarrow$ Yukawa term $Y_\chi \hat{\nu}\chi_1\hat{\nu}$ generates right haneded neutrinos masses

$\Longrightarrow$ at SUSY breaking scale additional soft breaking terms added

$$\mathcal{L}_{\mathcal{BLSSM}} = \mathcal{L}_{\mathcal{MSSM}} - m_0^2 \left[|\chi_1|^2 + |\chi_2|^2 + |\tilde{\nu}|^2\right] + T_\nu \tilde{L} H_u \tilde{\nu}^c + T_x \tilde{\nu}^c \chi_1 \tilde{\nu}^c + B_{\mu'} \chi_1 \chi_2 + h.c$$

$\Longrightarrow$ The gauge coupling mixing arises due to $U(1) \times U(1)_{B-L}$ expreseed as

$$G = \begin{pmatrix} g_1 & \tilde{g} \\ 0 & g_{B-L} \end{pmatrix}$$

$\Longrightarrow$ for high scale $\tilde{g} = 0$ " preserving gauge unification"

Outline

CP-even Higgs mass matrix

After EWSB four Higgs bosons introduced

$$H_{1,2} = \frac{1}{\sqrt{2}}\left(\upsilon_{1,2} + \eta_{1,2} + i\phi_{1,2}\right),$$

$$\chi_{1,2} = \frac{1}{\sqrt{2}}\left(\upsilon'_{1,2} + \eta'_{1,2} + i\phi'_{1,2}\right),$$

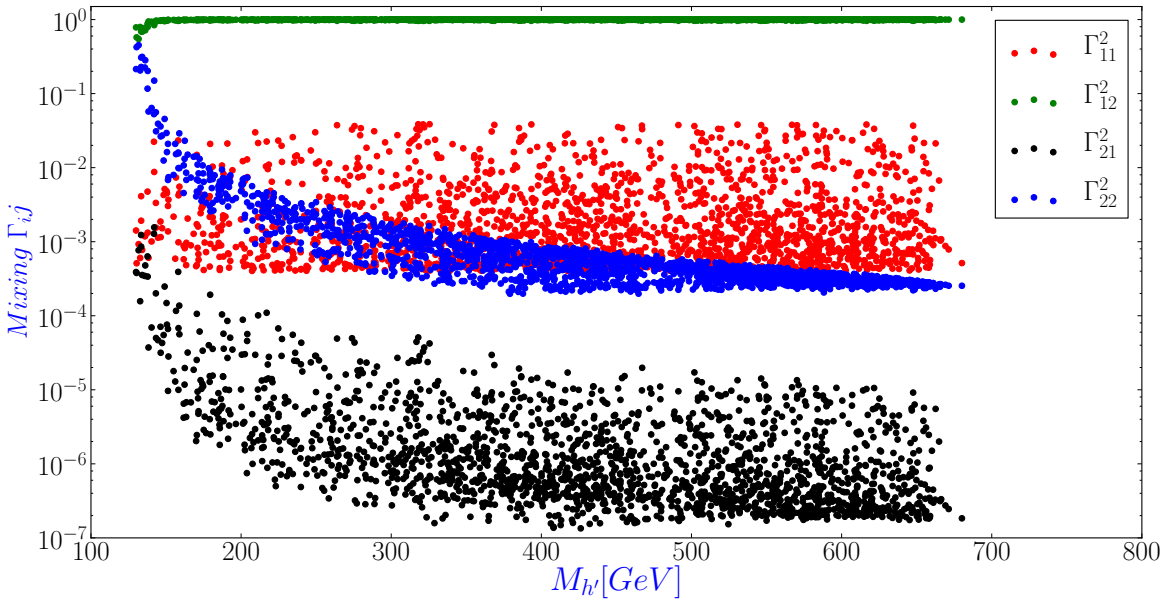
If no gauge kinetic mixing exist e.g. $\tilde{g} = 0$, one end up with $H_{1,2}$ are the MSSM ones

CP-even Higgs mass matrix can be digonalized by unitary 4×4 matrix

$$\Gamma M^2 \Gamma = \left\{m_h^2, m_{h'}^2, m_H^2, m_{H'}^2\right\}$$

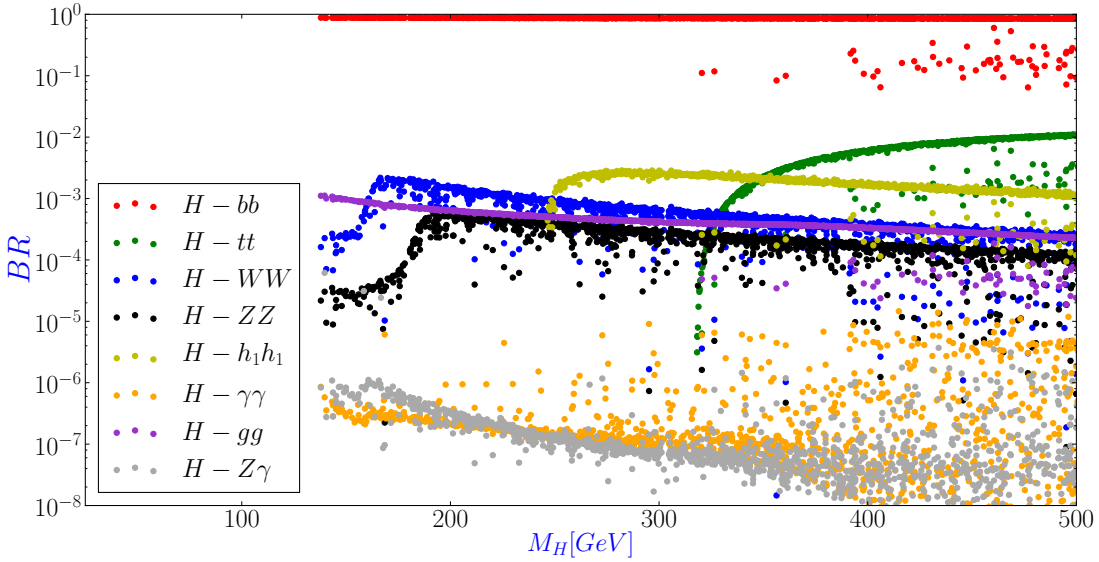
Outline

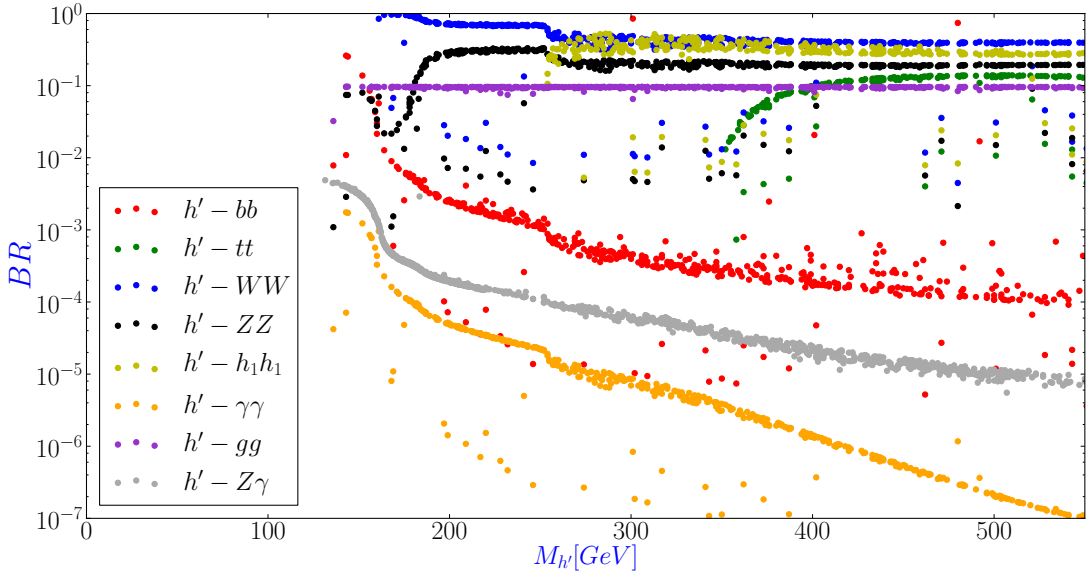
Higgs coupling and unitarity test



- Increasing of h' coupling reduces the couplings of H and H'

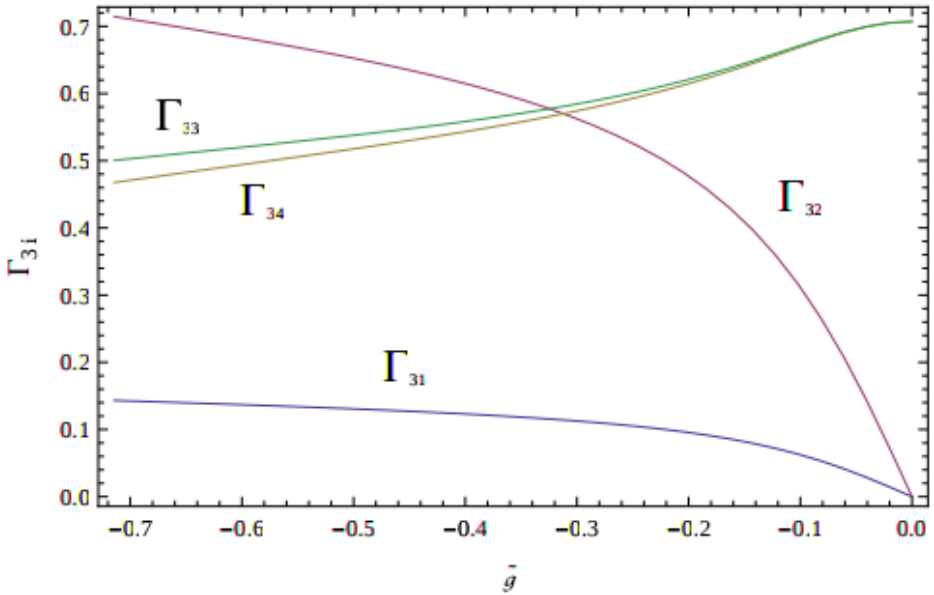
BR MSSM Vs BLSSM



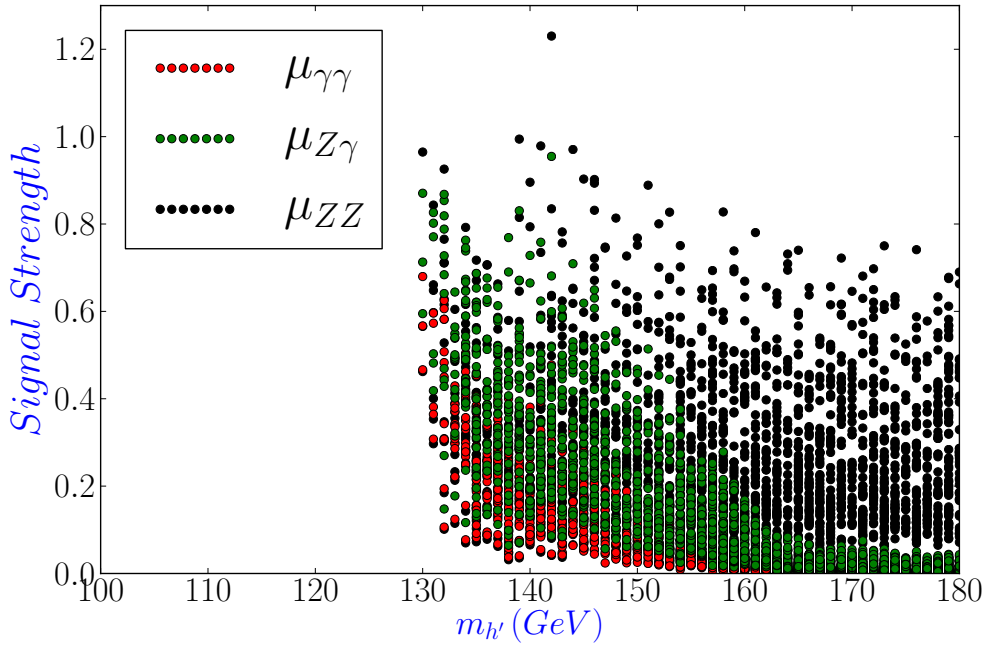


BR MSSM Vs BLSSM

Note: if $\tilde{g} = 0$, h' decoupled with SM particles and couple only with singlets.



Signal strength for Second Higgs



Dont worry about Unitarity condition

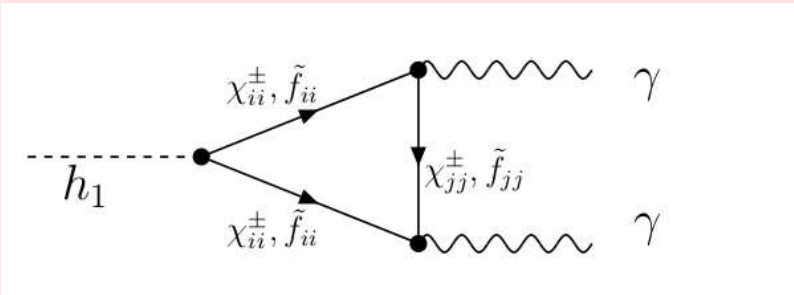
Comparing theoretical expected with data at Run-I

With out getting into deep boring long mathematical expressions

- The effective verices of $h'\gamma\gamma$ and $h'gg$, calculated first by SPheno and added manually to MadGraph.
- The effective vertex of $h'Z\gamma$, we linked between CPsuper-H and SPheno and added the effective coupling manually to MadGraph.
- $h' \longrightarrow \gamma\gamma$ and $h' \longrightarrow Z\gamma$ are calulated up to NLO level
- For NLO claculation we consider the QCD coreection from top and bottom SM quark only.

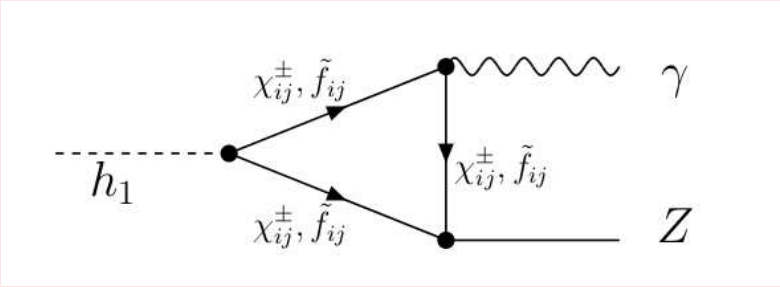
SUSY particles enhancing LO loop vertices

Light SUSY particles enhances loop amplitude.



photons coupled only with diagonal light SUSY coupling "vector coupling only"

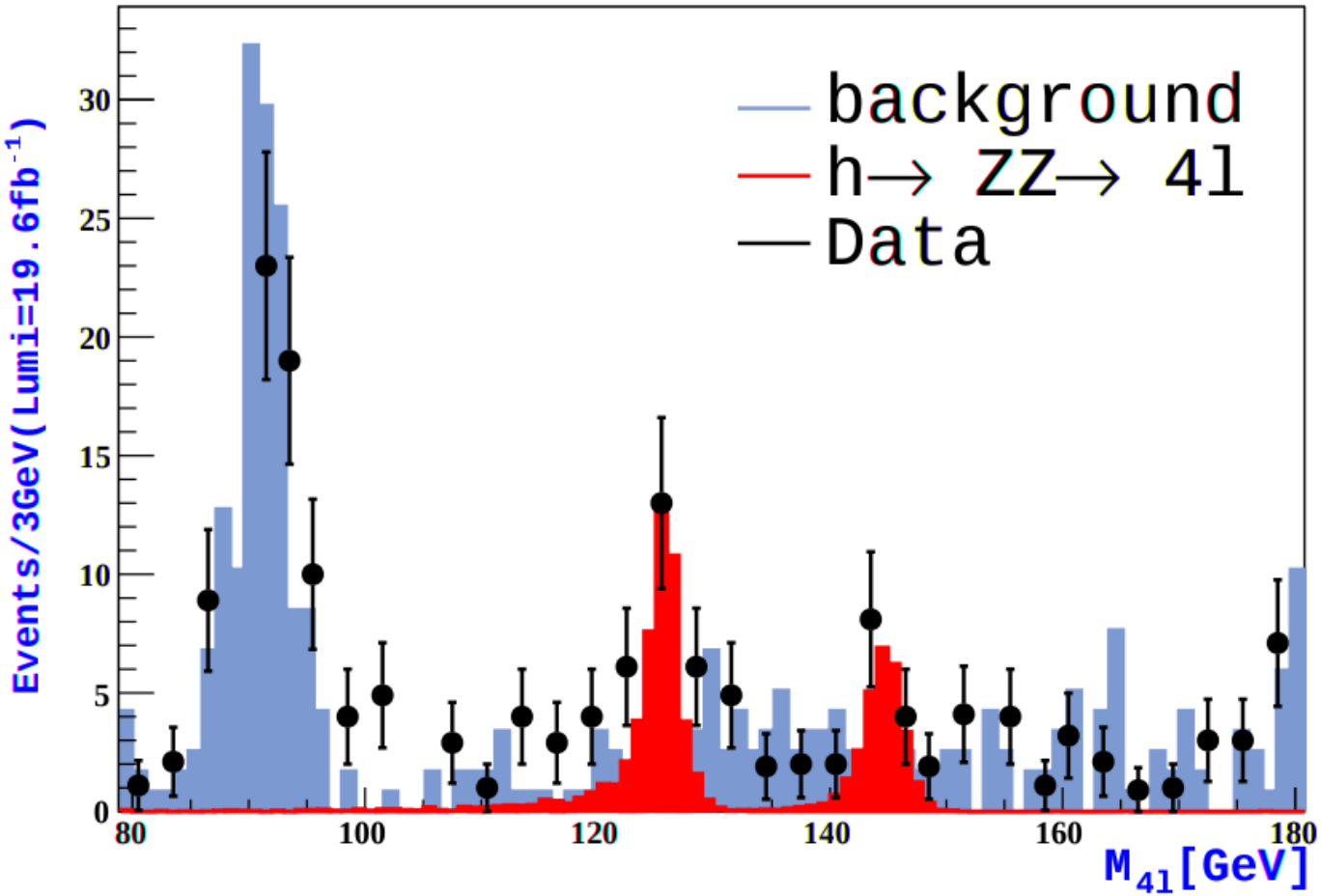
Why light SUSY particles only???? why not the heavy ones????



Z boson coupled with diagonal light SUSY coupling "vector coupling only" and off-diagonal light SUSY coupling "axial coupling"

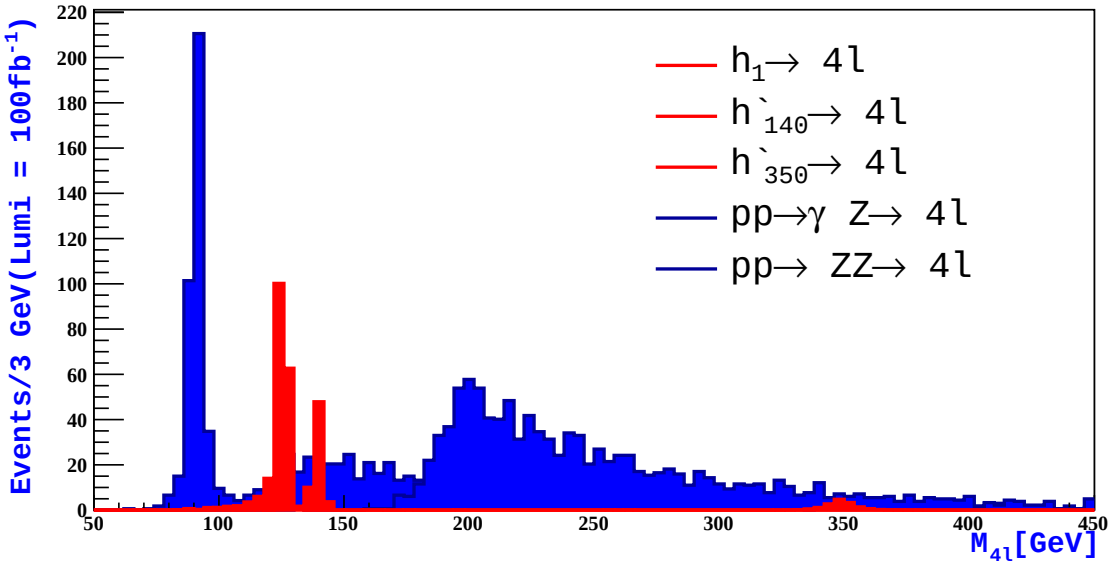
Outline

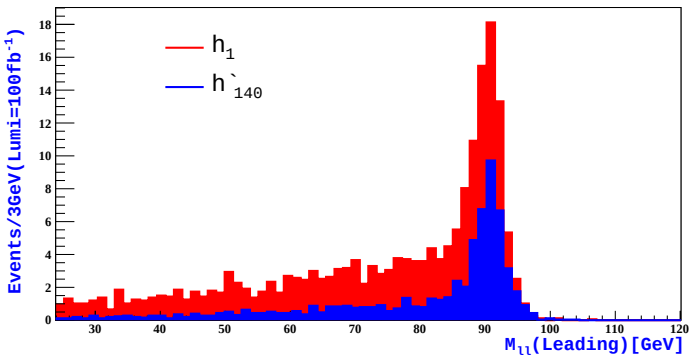
$h' \longrightarrow ZZ \longrightarrow 4l$

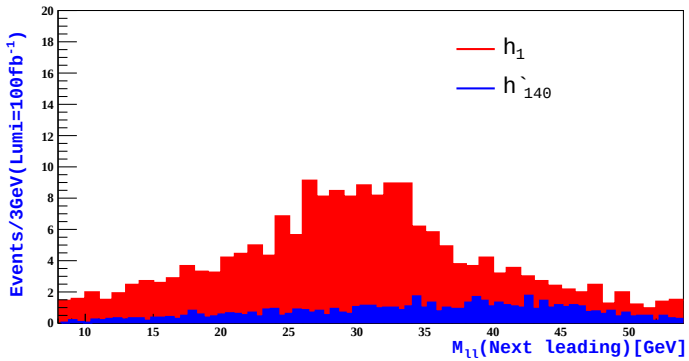


Real data extracted by g3data

$h' \longrightarrow ZZ \longrightarrow 4l$ at Run-II

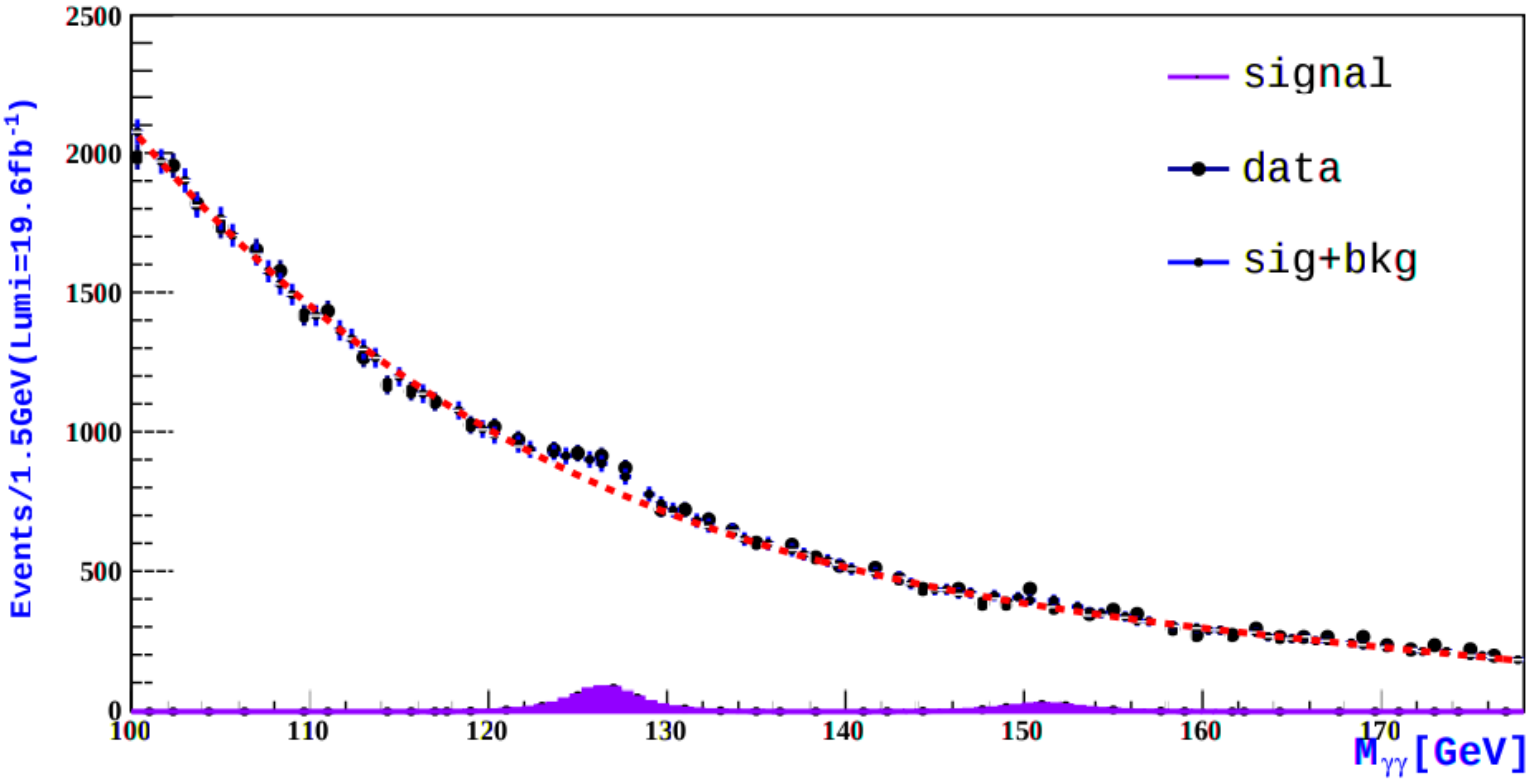






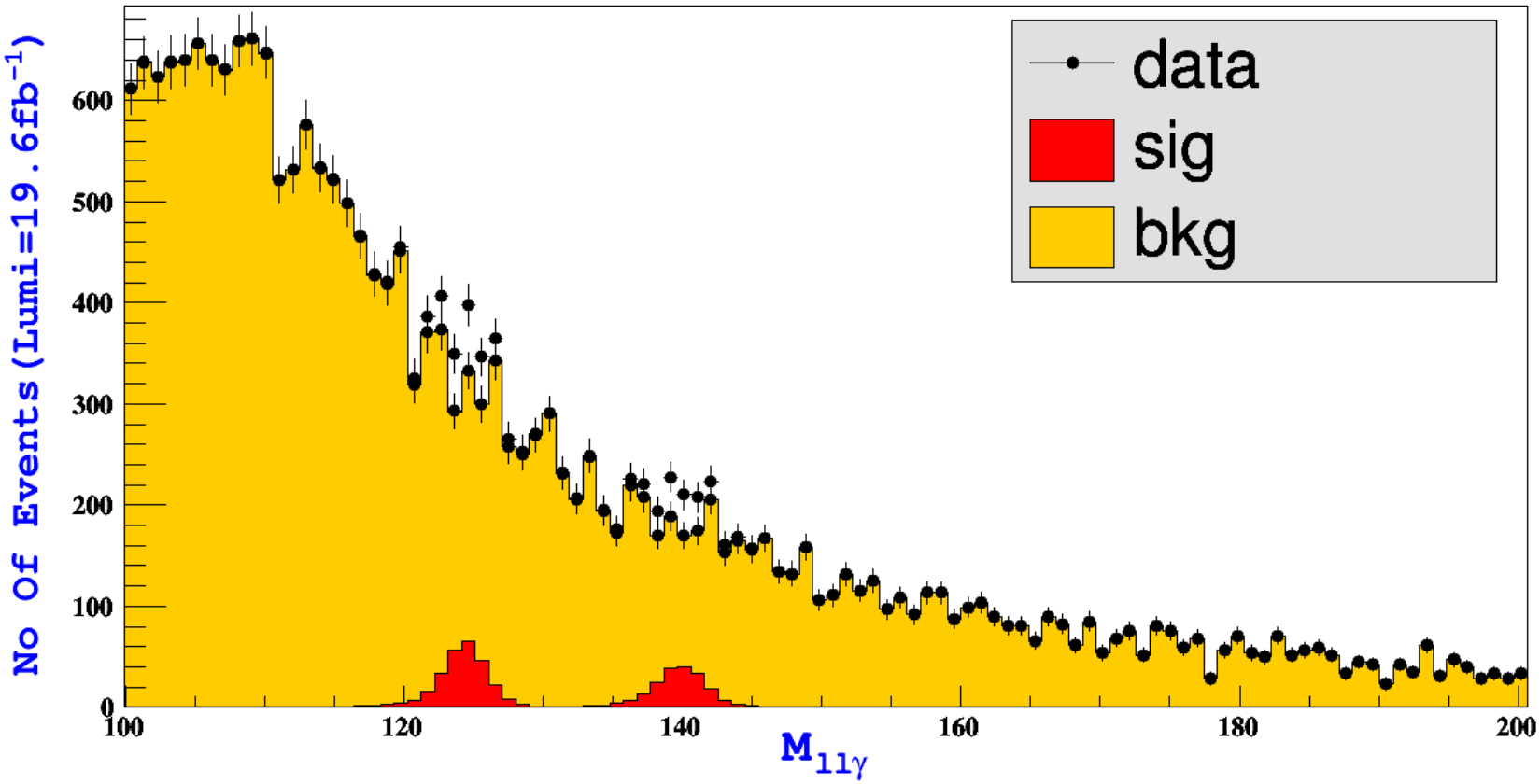
Outline

$h' \to \gamma\gamma$

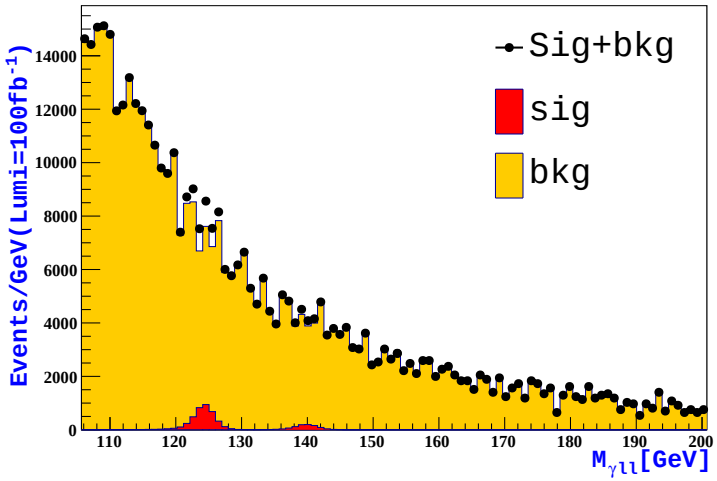


Outline

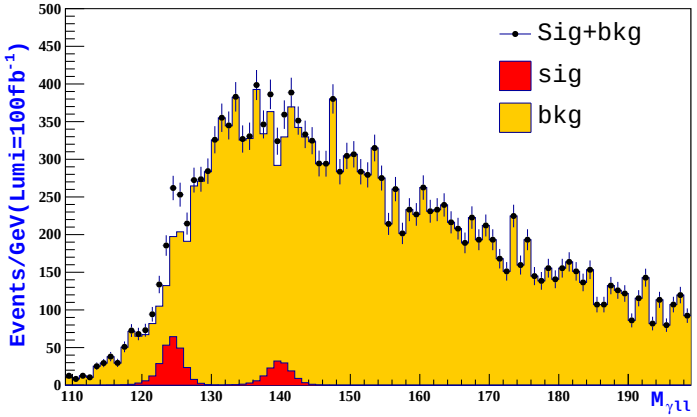
$h' \longrightarrow Z\gamma$



$h' \longrightarrow Z\gamma$ at Run-II



Cut at $P_T(\gamma) \geq 25\ GeV$



Ingoing

- Rescale real data collected at Run-I with the Lumi and total cross section at Run-II
- Caculate the exclusion limit and the two band confidence intervals

Thank you for your patience