Dark Matter in the Left Right Twin Higgs Model

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University of Arizona

Work done with
Shufang Su and Jessica Goodman

arXiv:0712.1234v1 [hep-ph]

Outline

- Left-Right Twin Higgs Model
- Relic Density Analysis
- Conclusion

Left-Right Twin Higgs Model

- Chacko, Goh, and Harnik:
  arXiv:hep-ph/0506256v1

- Solution to Little Hierarchy Problem

- To avoid EW precision constraints, add a second Higgs $\hat{H}$ that couples to gauge bosons only

Left–Right Twin Higgs Model

$$H = \begin{pmatrix} H_L \\ H_R \end{pmatrix}$$

Left-Right Twin Higgs Model

$$H = \begin{pmatrix} H_L \\ H_R \end{pmatrix} \rightarrow \text{SM Higgs doublet} \xrightarrow{\text{EWSB}} h_{SM}$$

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Couples only to gauge bosons

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DM candidate

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- The lighter one of $\hat{S}/\hat{A}$ is stable, weakly interacting

→ Natural WIMP candidates

Left-Right Twin Higgs Model

In addition to the CW potential, we can add terms to the Lagrangian:

$$\Delta L = -\hat{\mu}^2 \hat{H}_L^\dagger \hat{H}_L - \lambda_4 |H_L^\dagger \hat{H}_L|^2 - \frac{\lambda_5}{2}((H_L^\dagger \hat{H}_R)^2 + h.c.)$$

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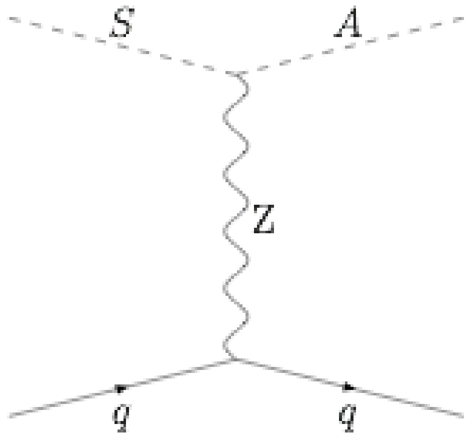

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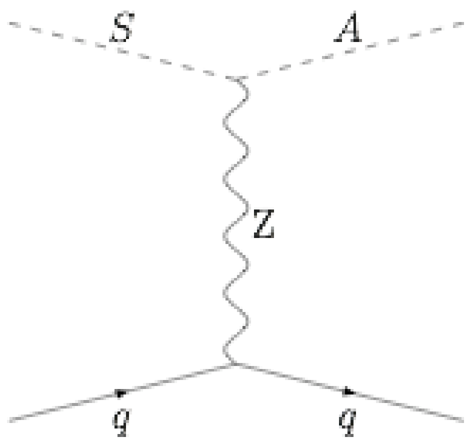

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Impose neutral mass splitting to make it kinematically forbidden.

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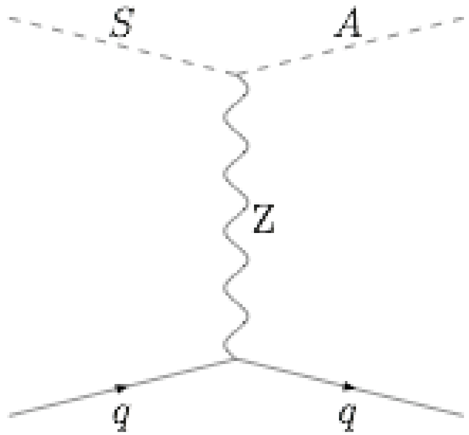

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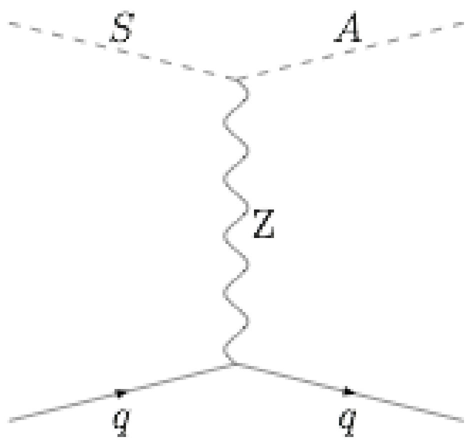

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$$\mathrm{m}^2_{\hat{S}} = m^2_{\hat{h}_2 CW} + \hat{\mu}^2 + \frac{1}{2}\lambda_4 v^2 + \frac{1}{2}\lambda_5 v^2$$
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Parameterize by

$$\delta_2 = m_{\hat{A}} - m_{\hat{S}}$$
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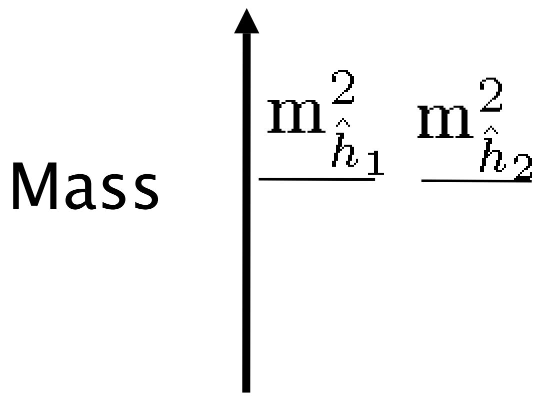

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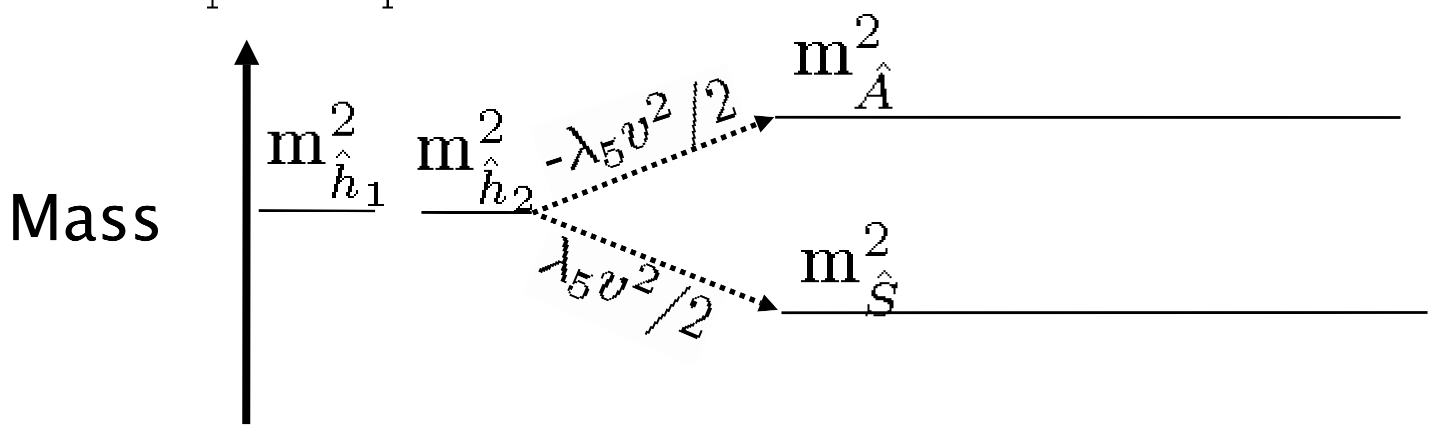

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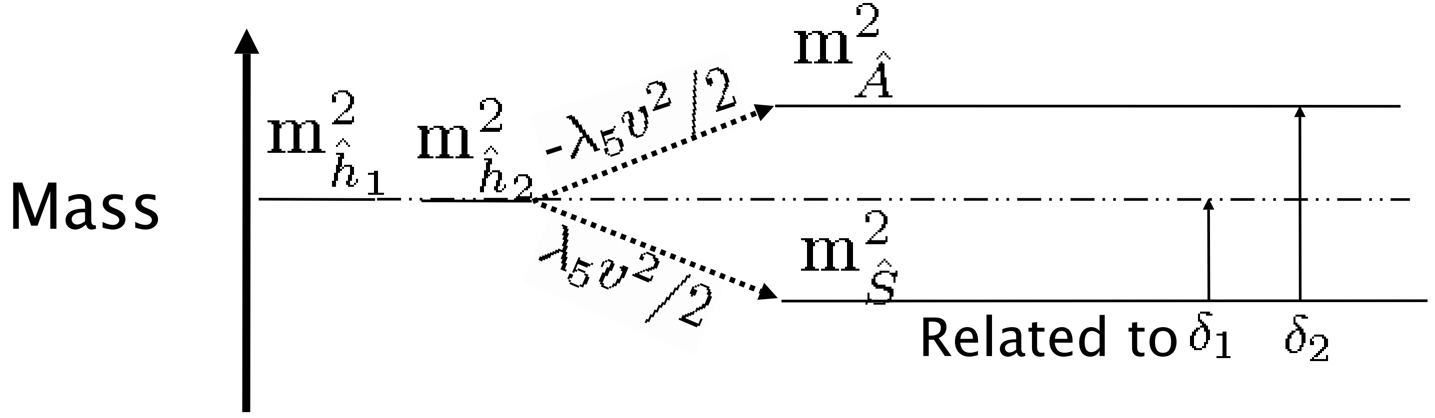

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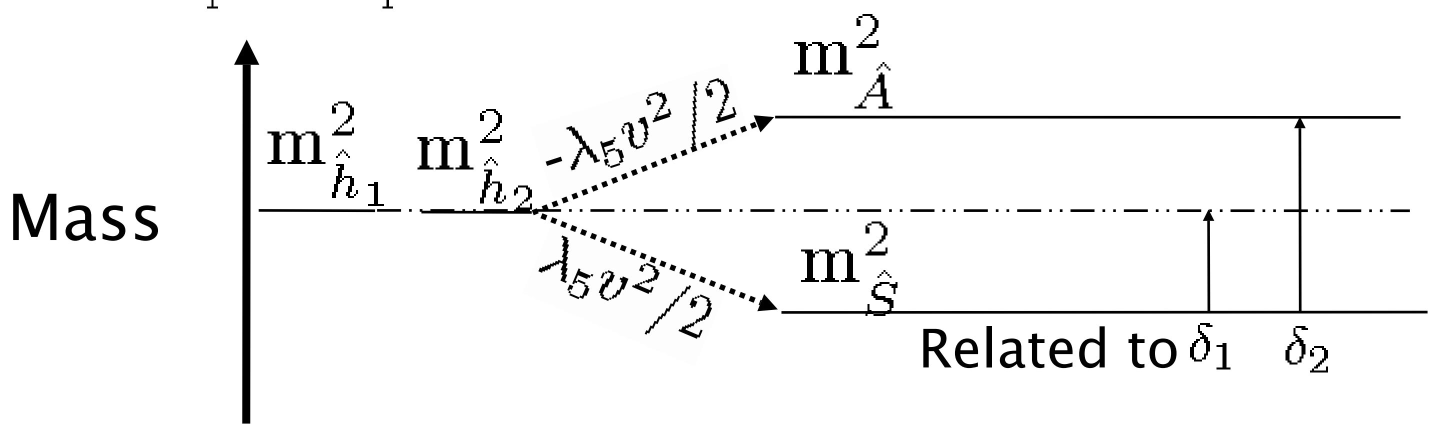


For $\lambda_4 = 0$: $\delta_2 = 2\delta_1$

In general, for $\lambda_4 \neq 0$: $\delta_2 \neq 2\delta_1$

We looked at both cases, treating splittings as free parameters.

Relic Density Analysis

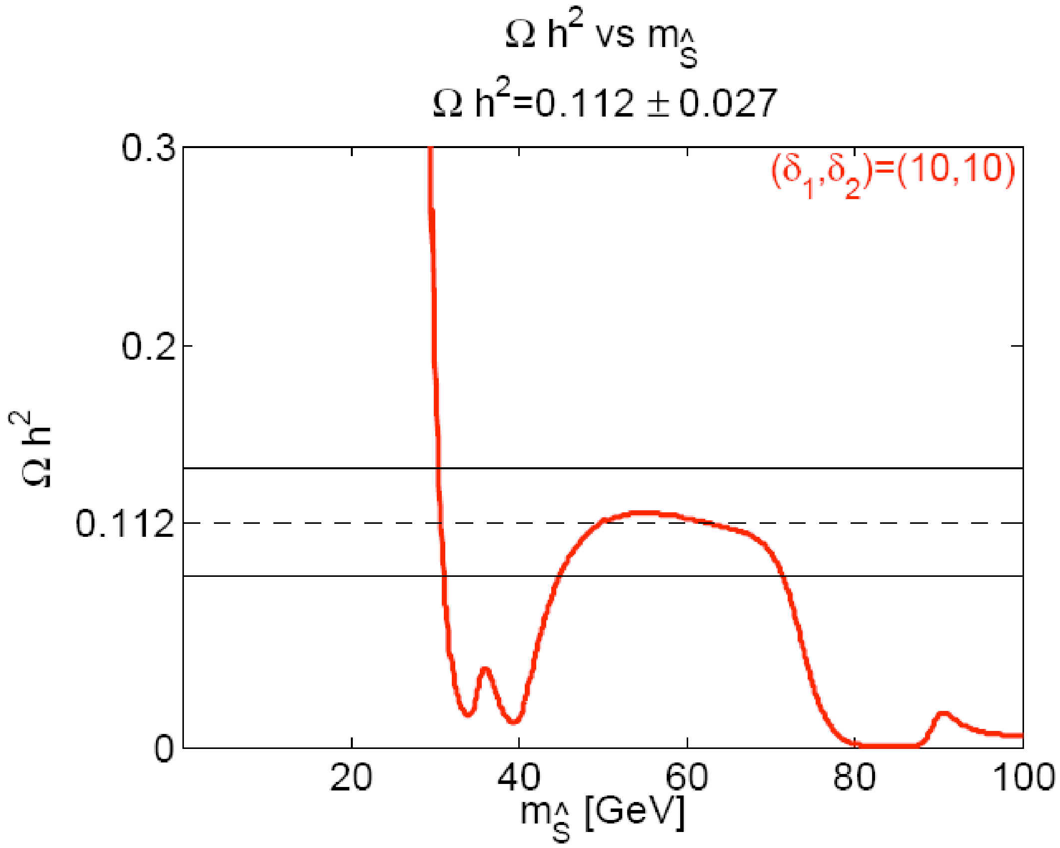
- WMAP: $0.085 < \Omega h^2_{CDM} < 0.139$ at 3σ
- Solve Boltzmann equation

$$\frac{dY}{dT} = \sqrt{\frac{\pi g_*(T)}{45}} M_{Pl} \langle \sigma v \rangle (Y^2(T) - Y^2_{eq}(T))$$

- micrOmegas: considers co-annihilations when mass splittings are small
- Modest choice of parameters yields
  - Low mass region: $m_{\hat{S}} < 100$ GeV
  - High mass region: 400 GeV $< m_{\hat{S}} <$ a few TeV

Relic Density Analysis

Low mass: $\delta_2 \neq 2\delta_1$



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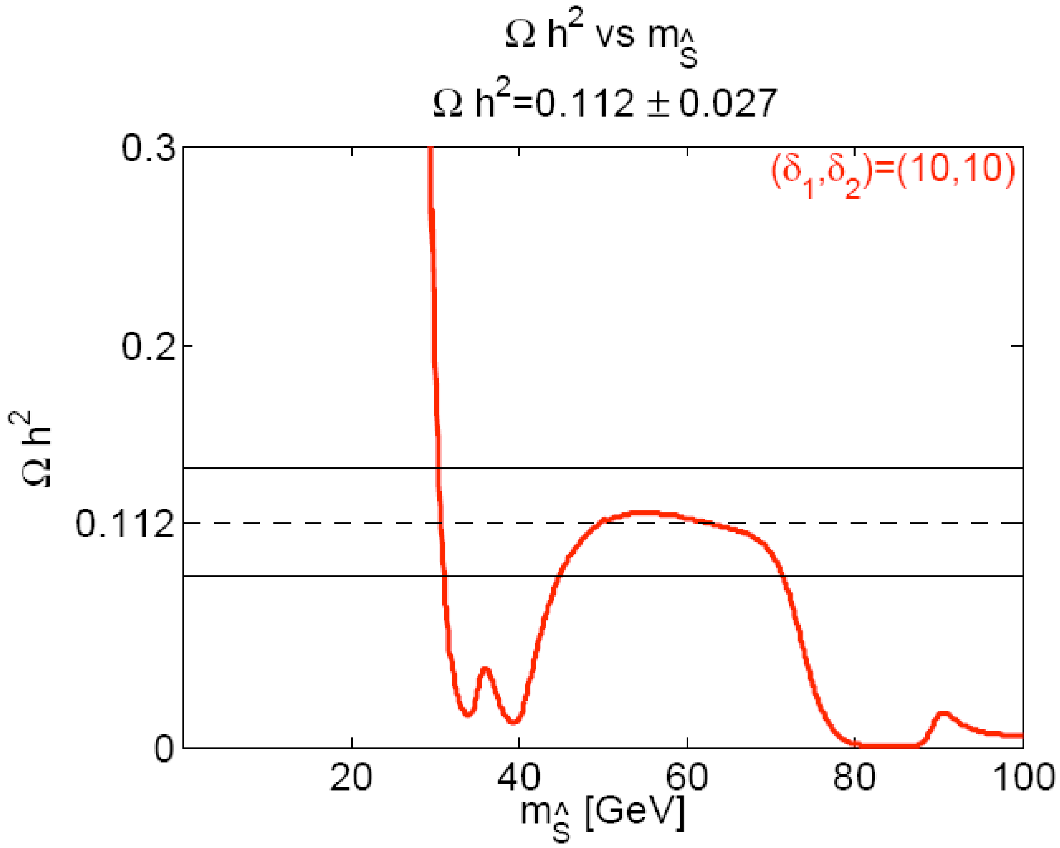

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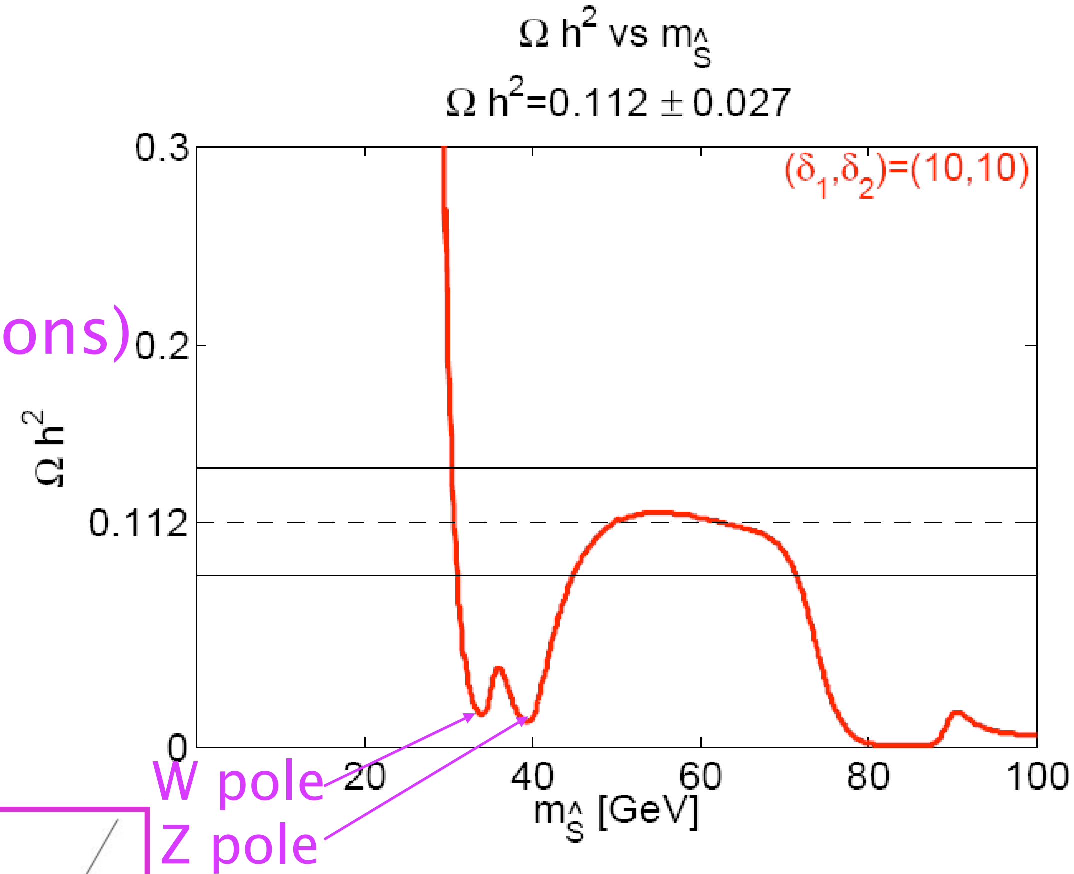

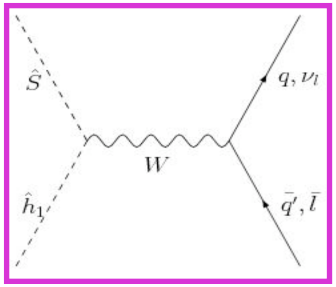

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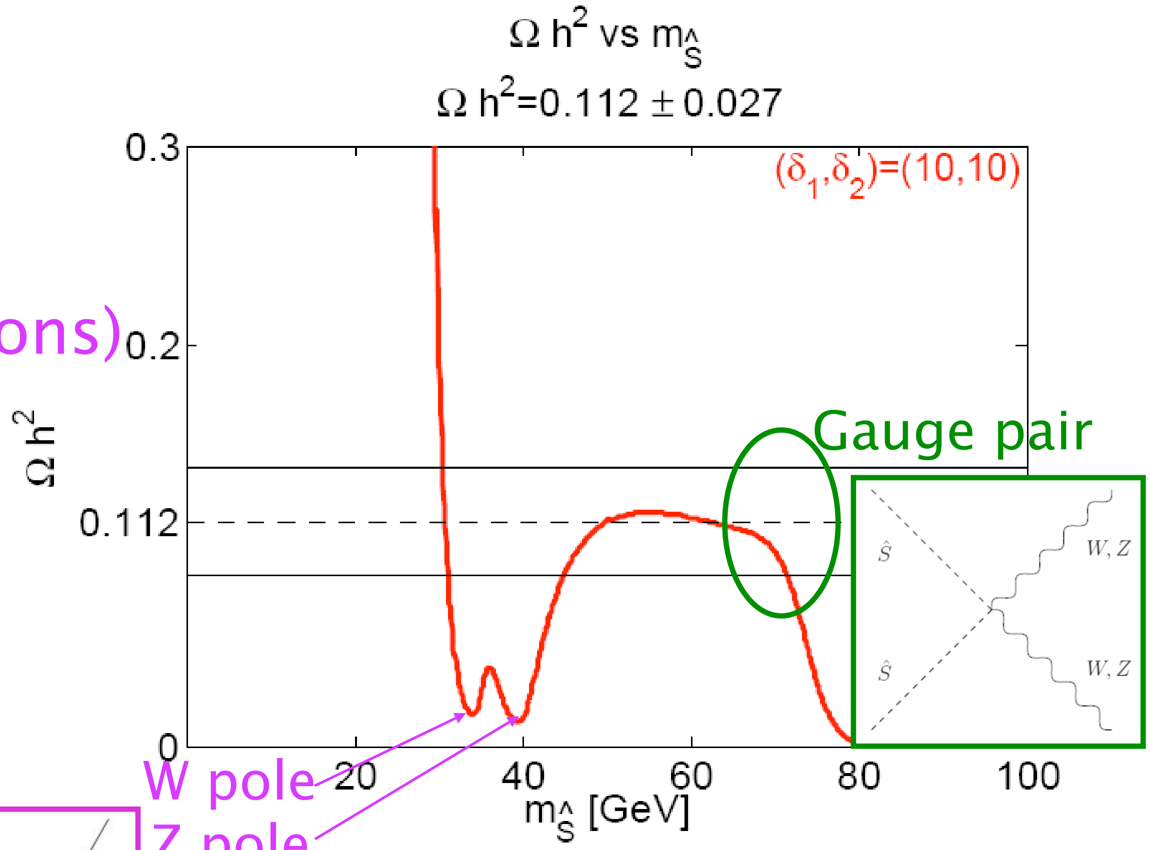

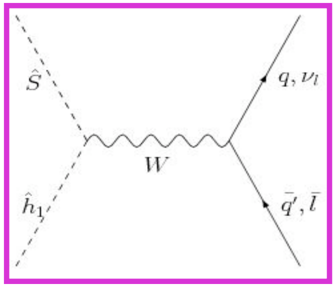

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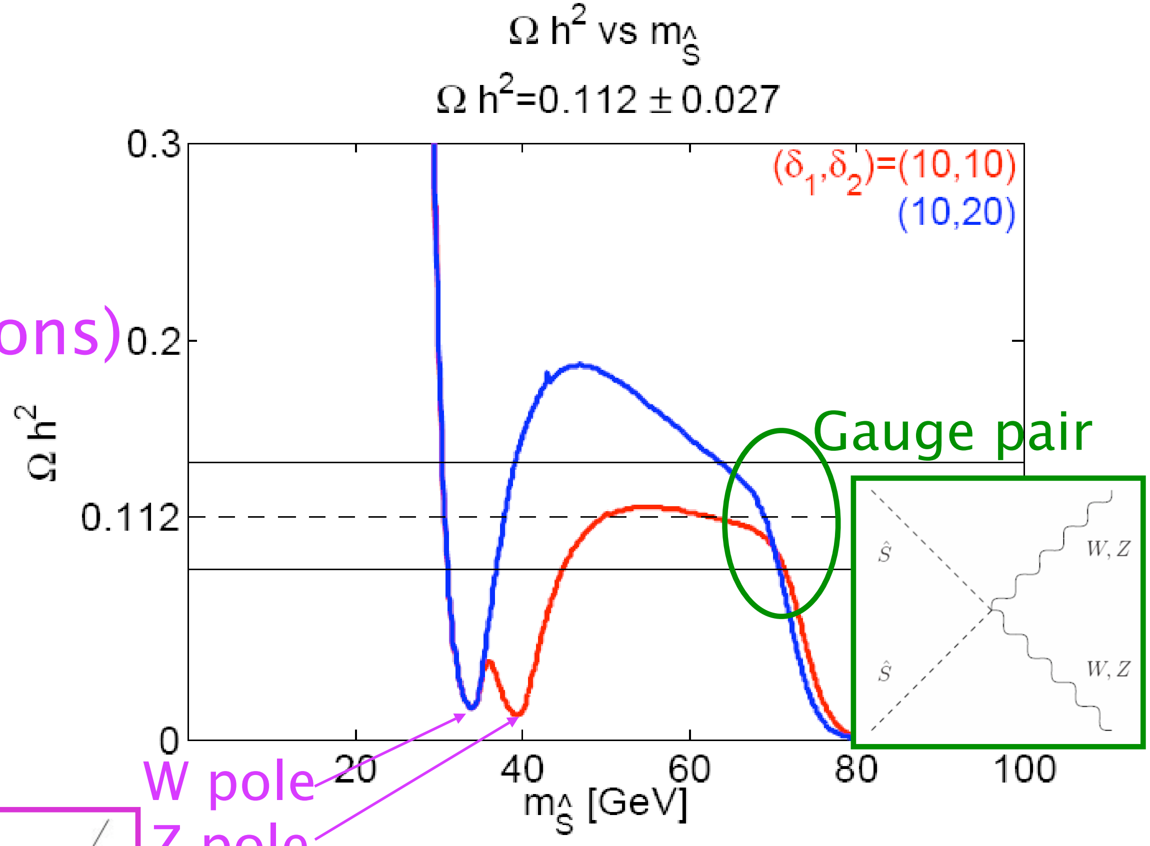

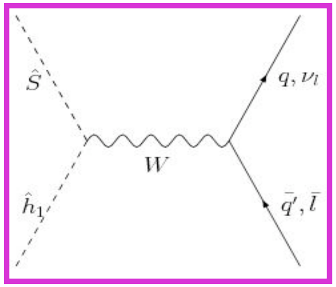

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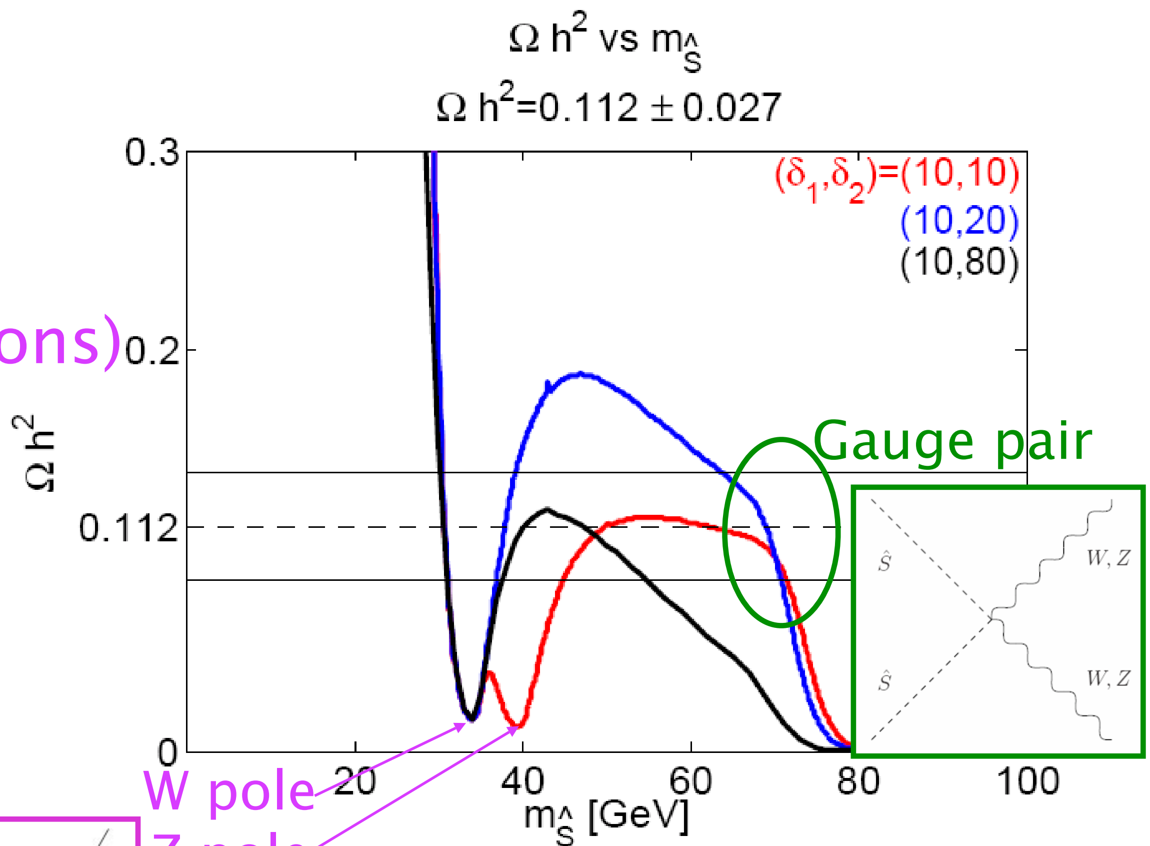

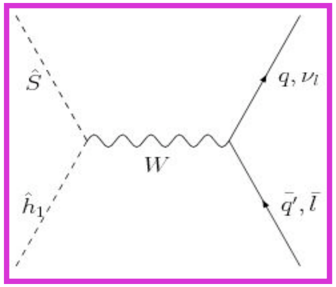

Relic Density Analysis
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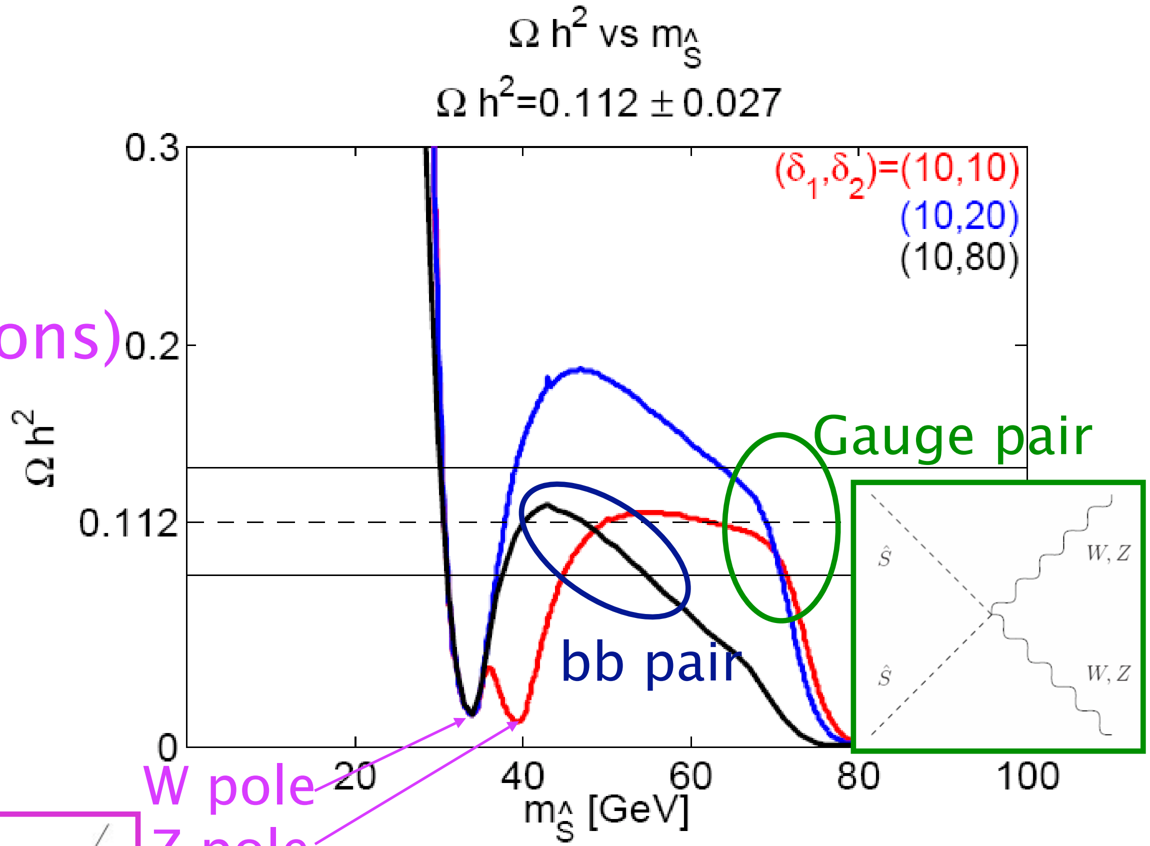
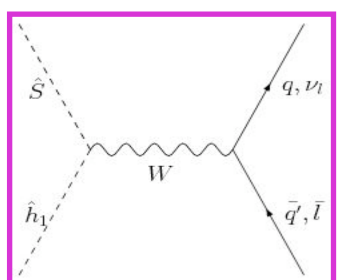
  - bb pair (annihilations)





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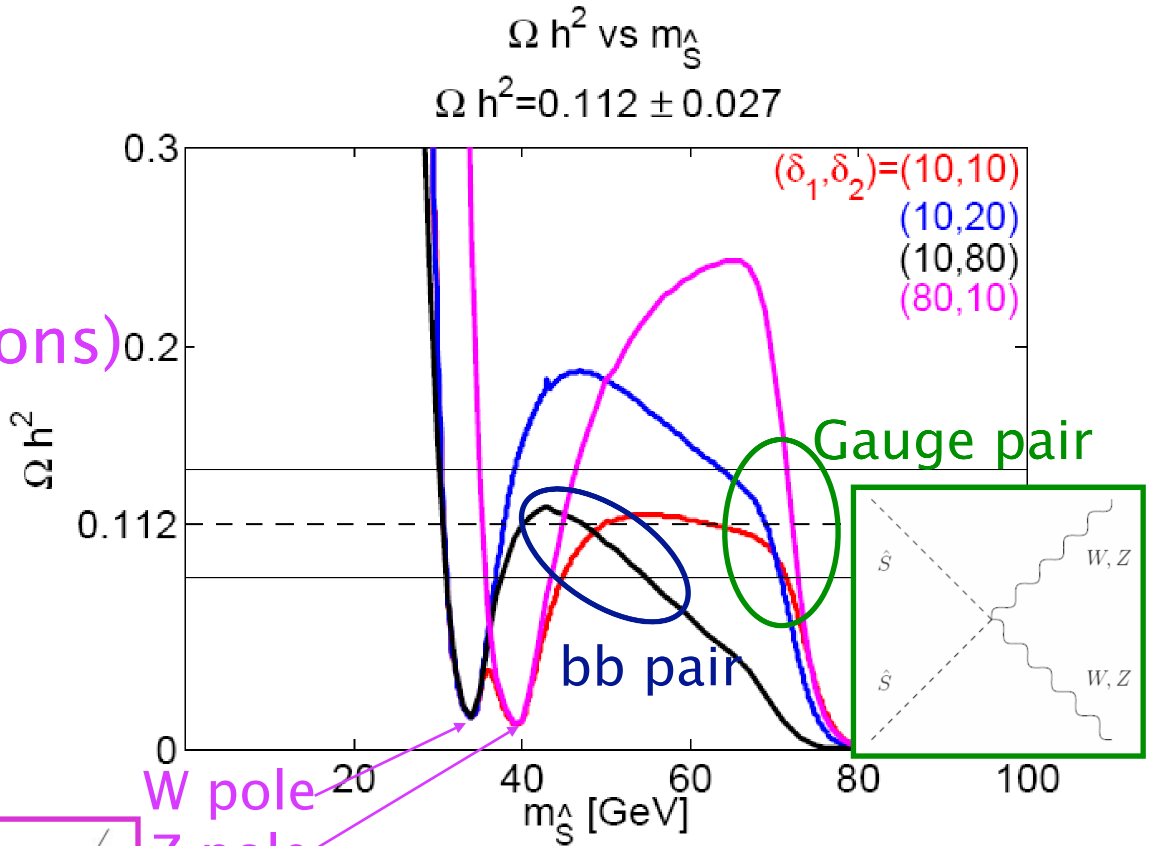

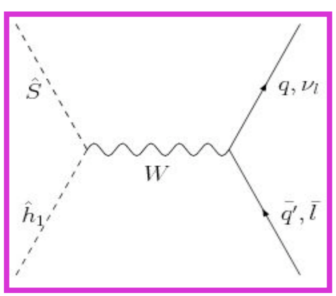

Relic Density Analysis

Low mass: $\delta_2 = 2\delta_1$

- 2 regions:
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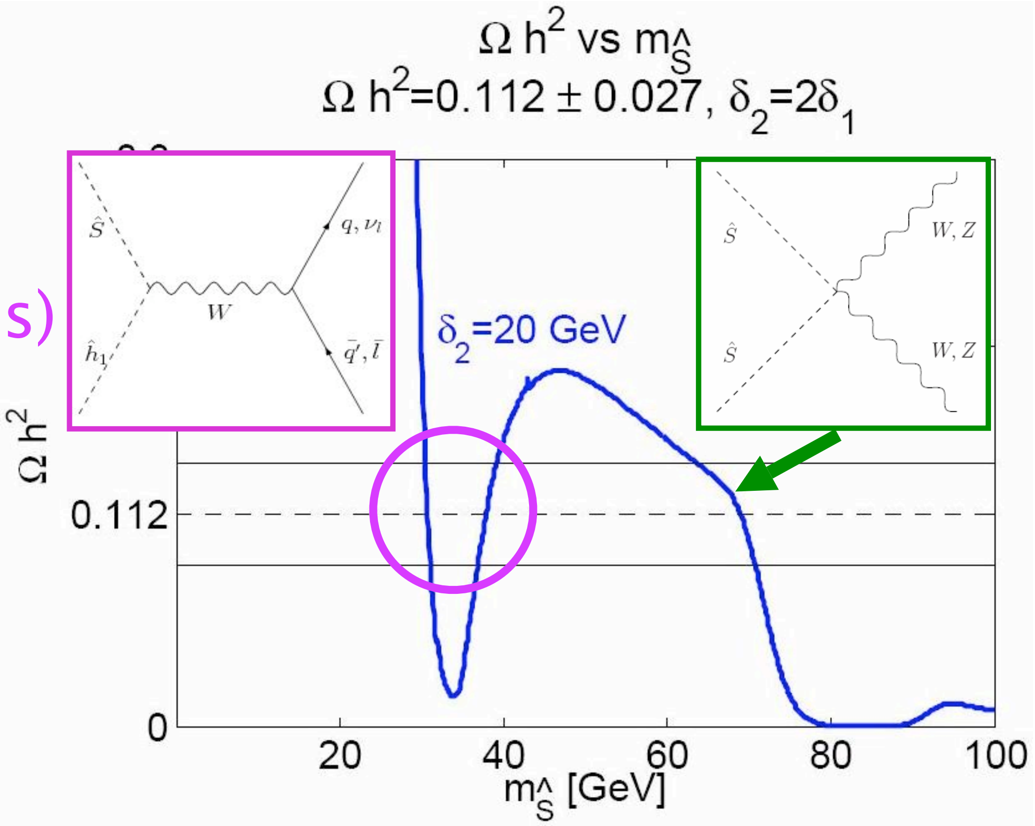

Relic Density Analysis

Low mass: $\delta_2 = 2\delta_1$

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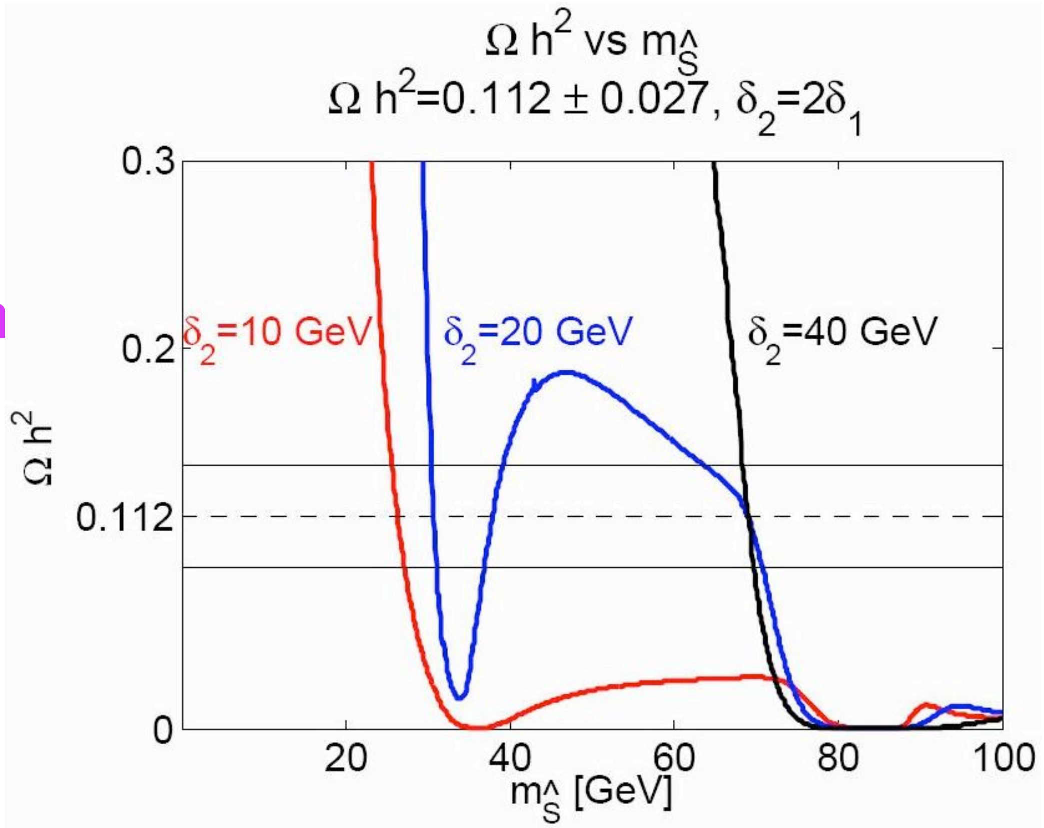
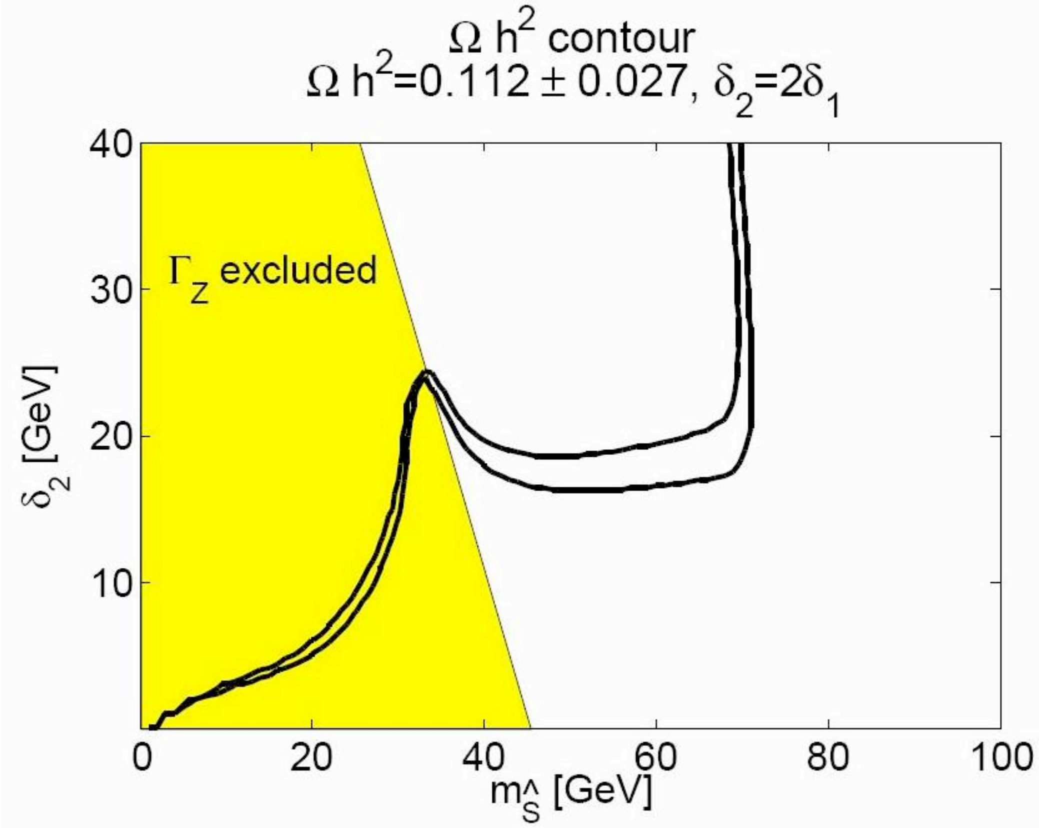
  - Gauge boson pair (annihilations)
- Change with splittings



Relic Density Analysis
Low mass

- $\delta_2 = 2\delta_1$ case



Relic Density Analysis
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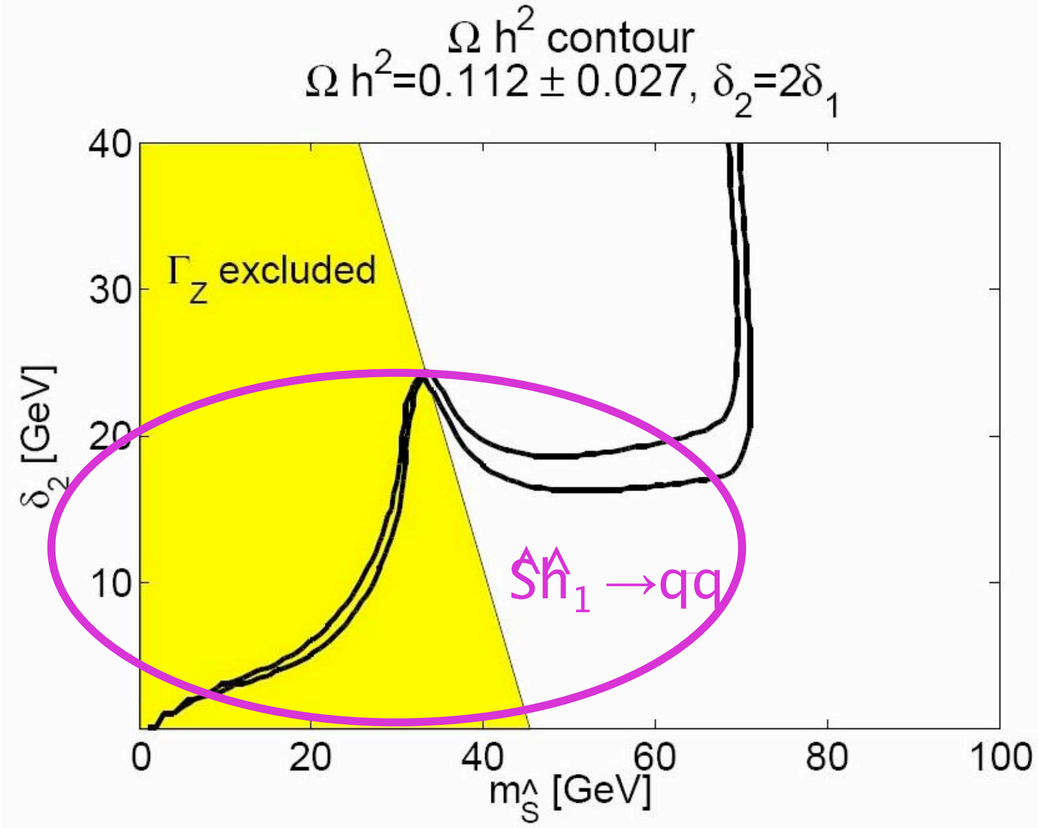
  - Co-annihilations: W/Z pole



Relic Density Analysis
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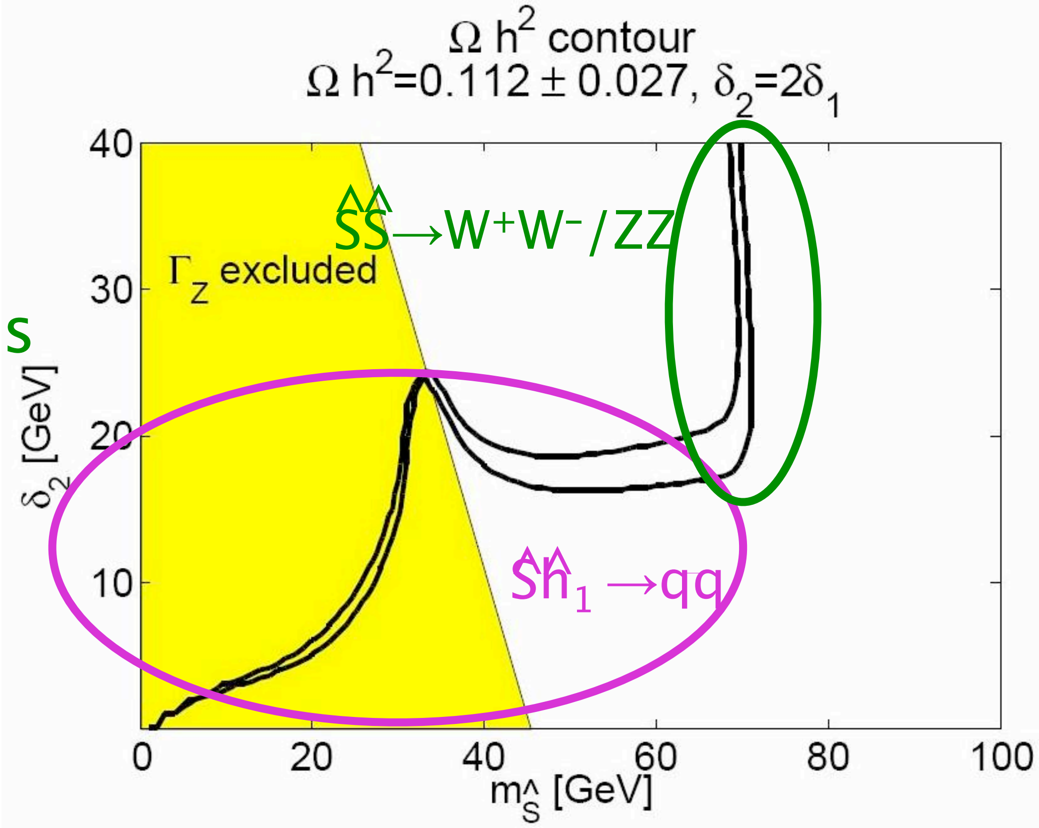

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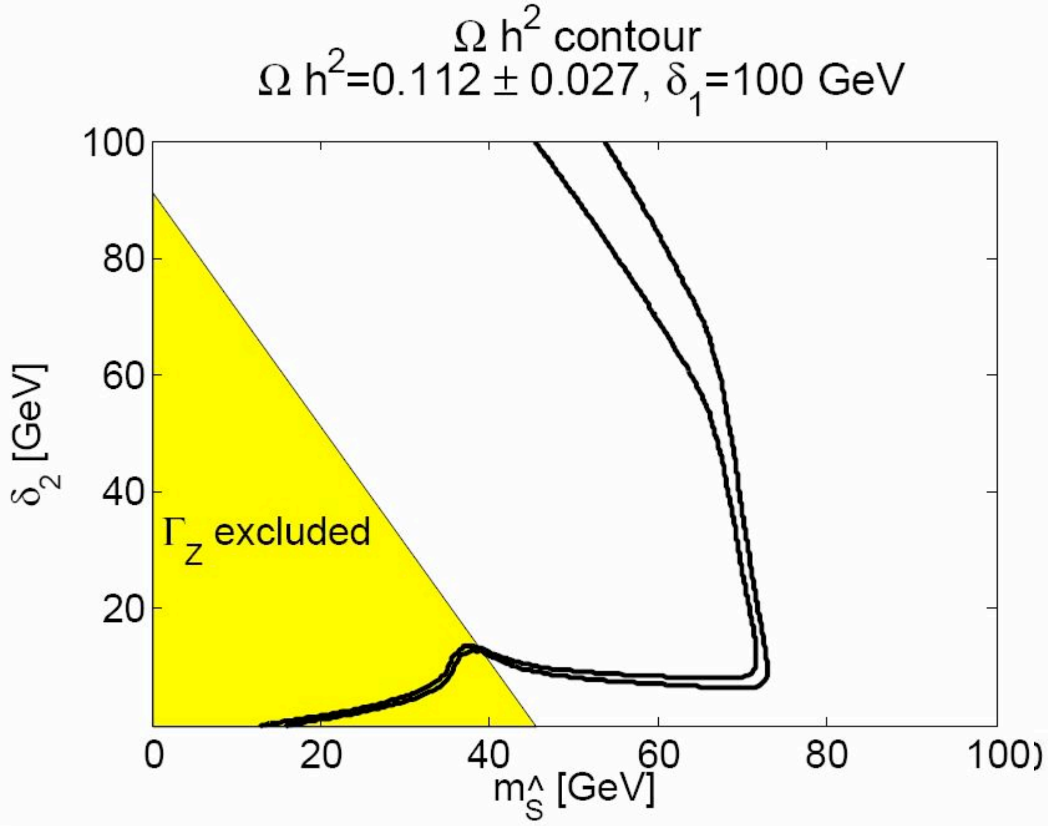

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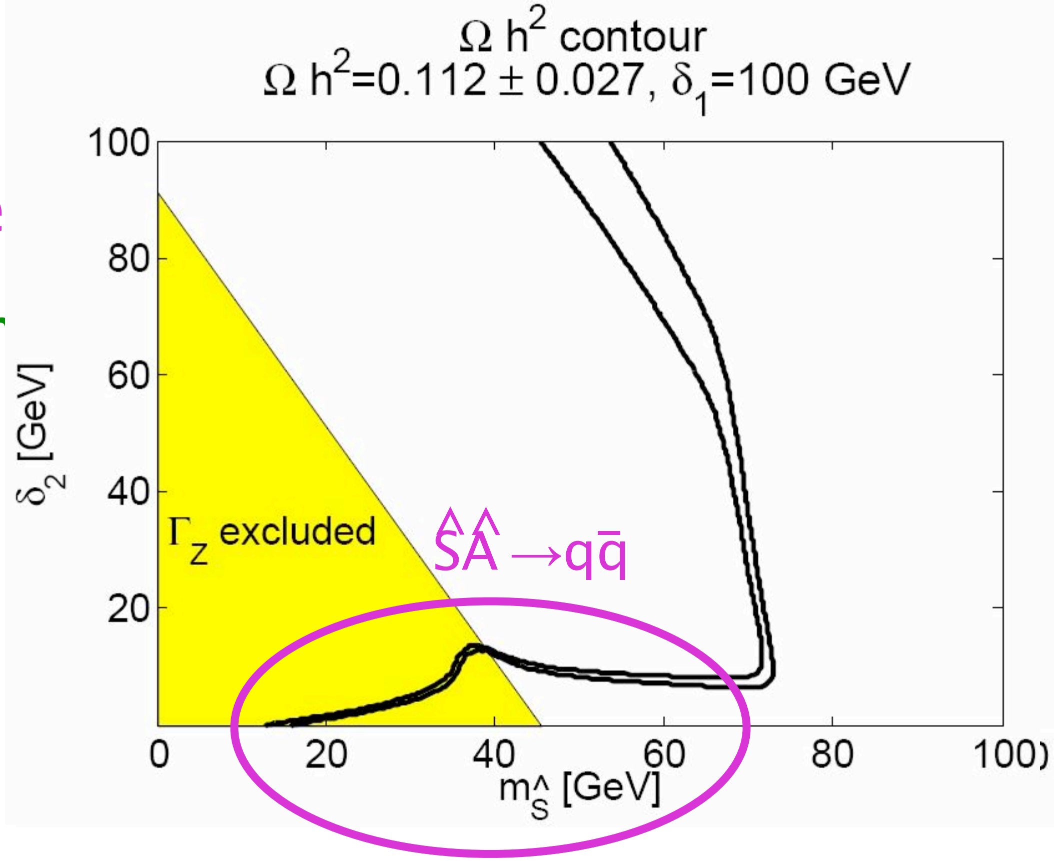

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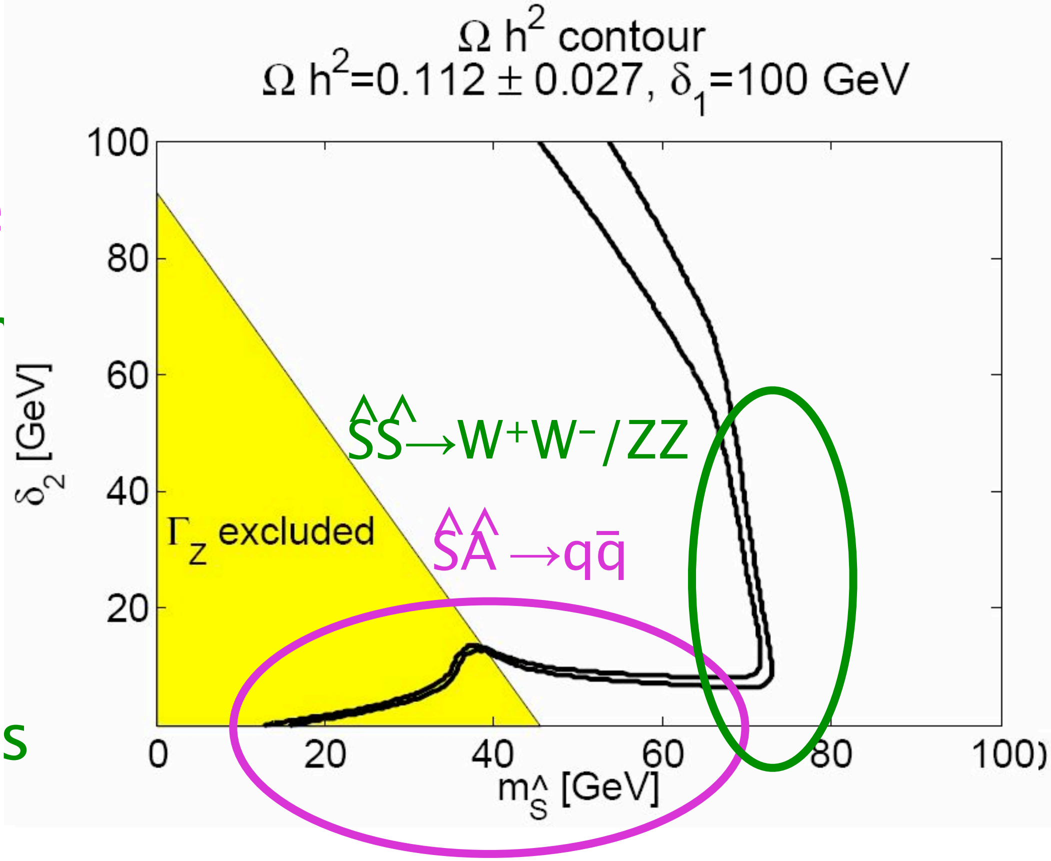

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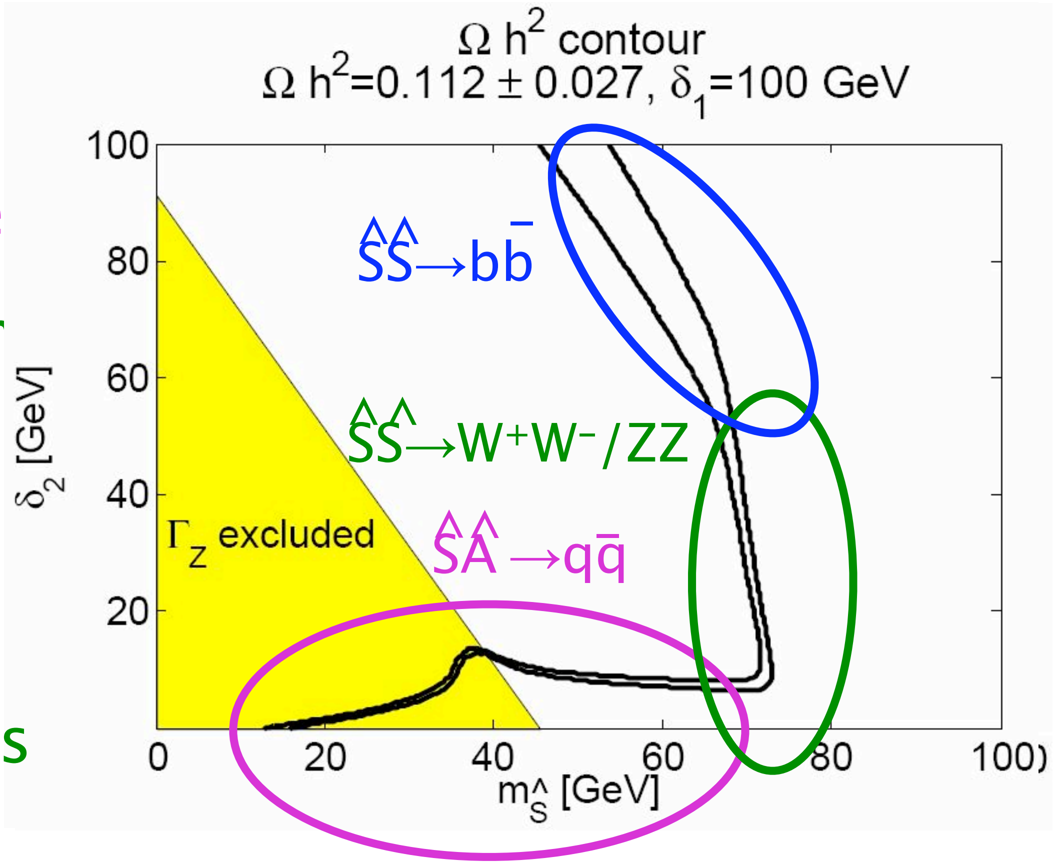
  - Annihilations: bb pair



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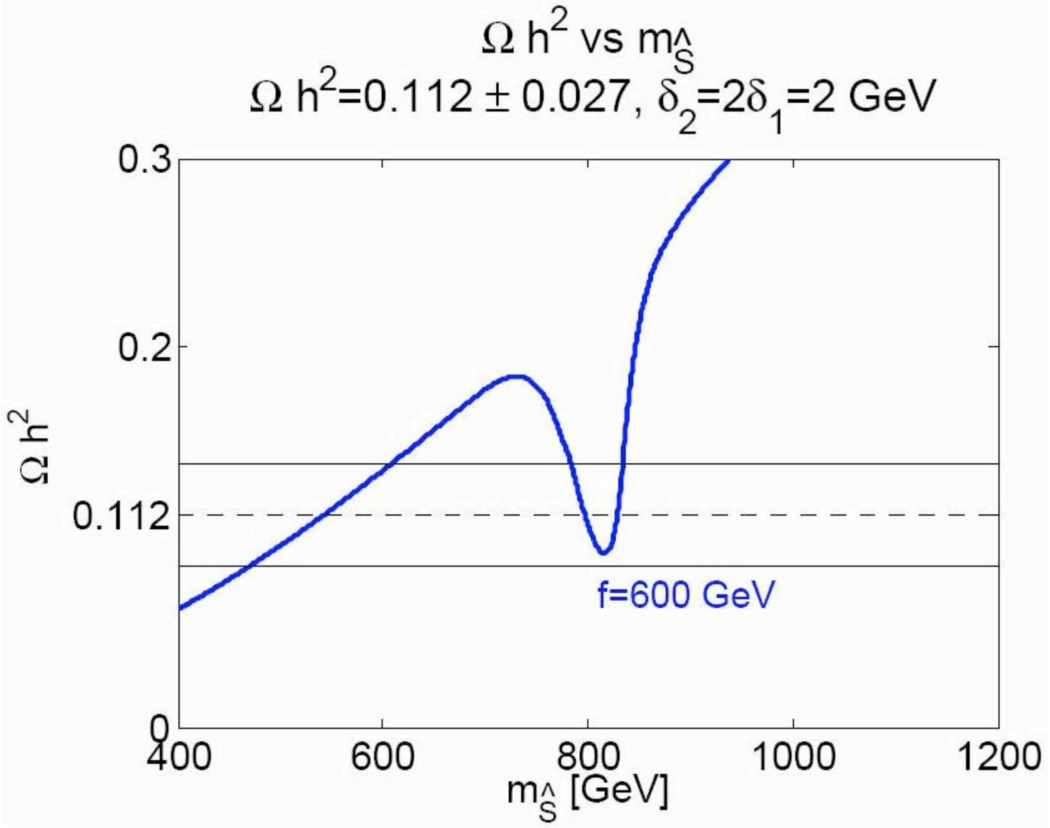
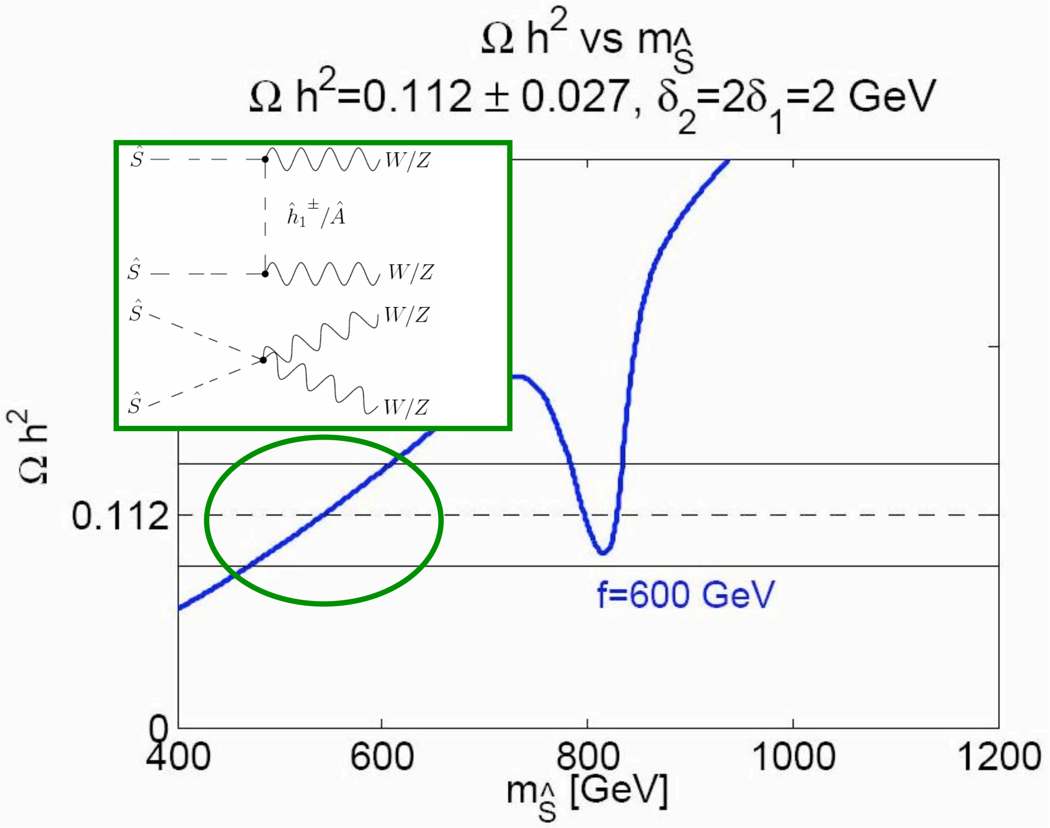


Relic Density Analysis
High mass

- Two regions:
  - Bulk (annihilations)



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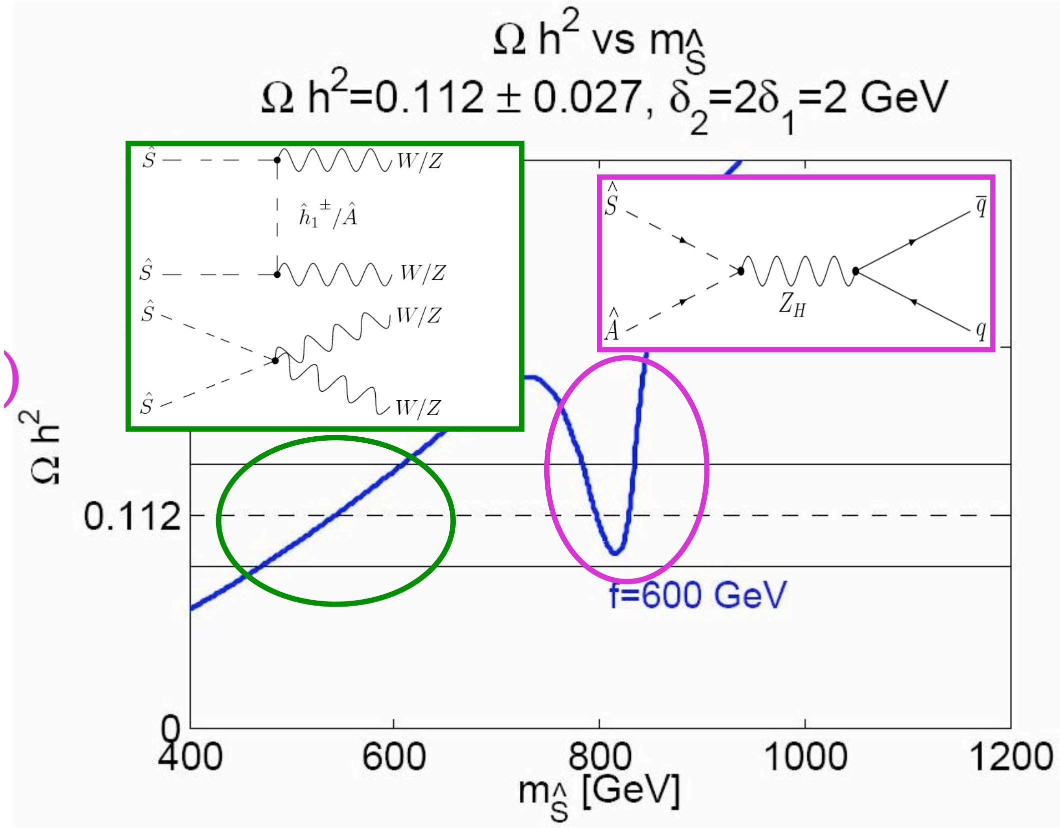
    $m_{\hat{S}} \sim m_{ZH}/2$



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High mass

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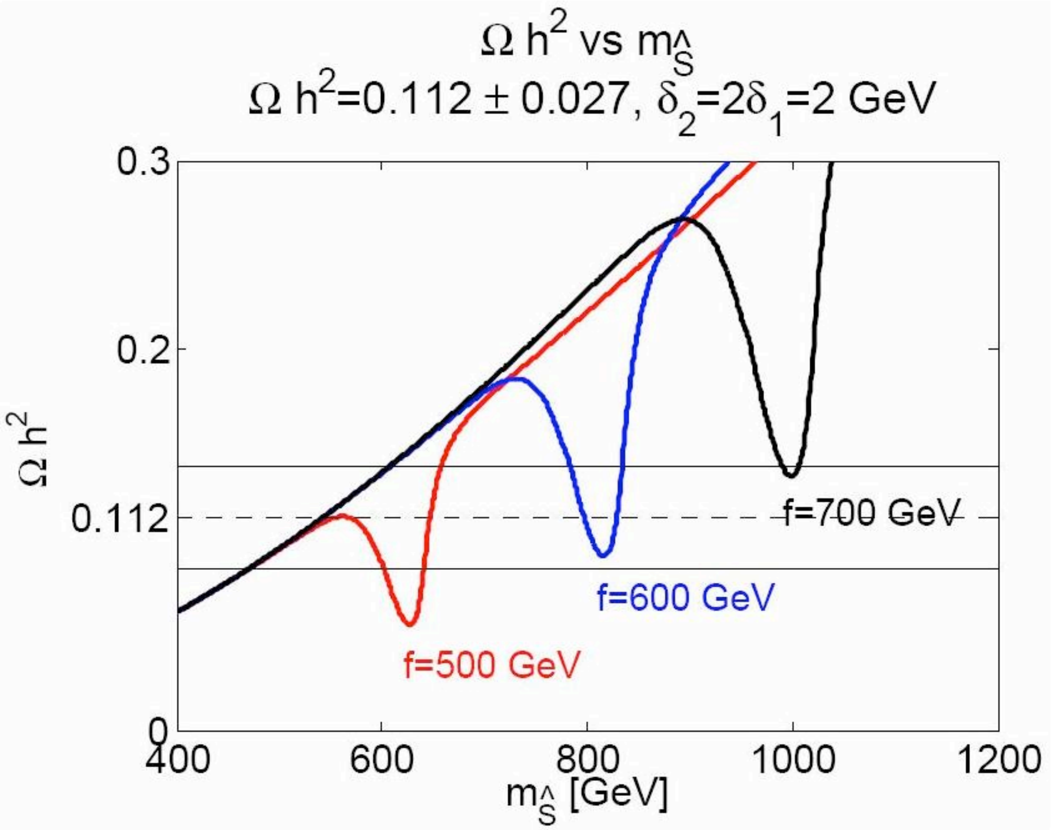
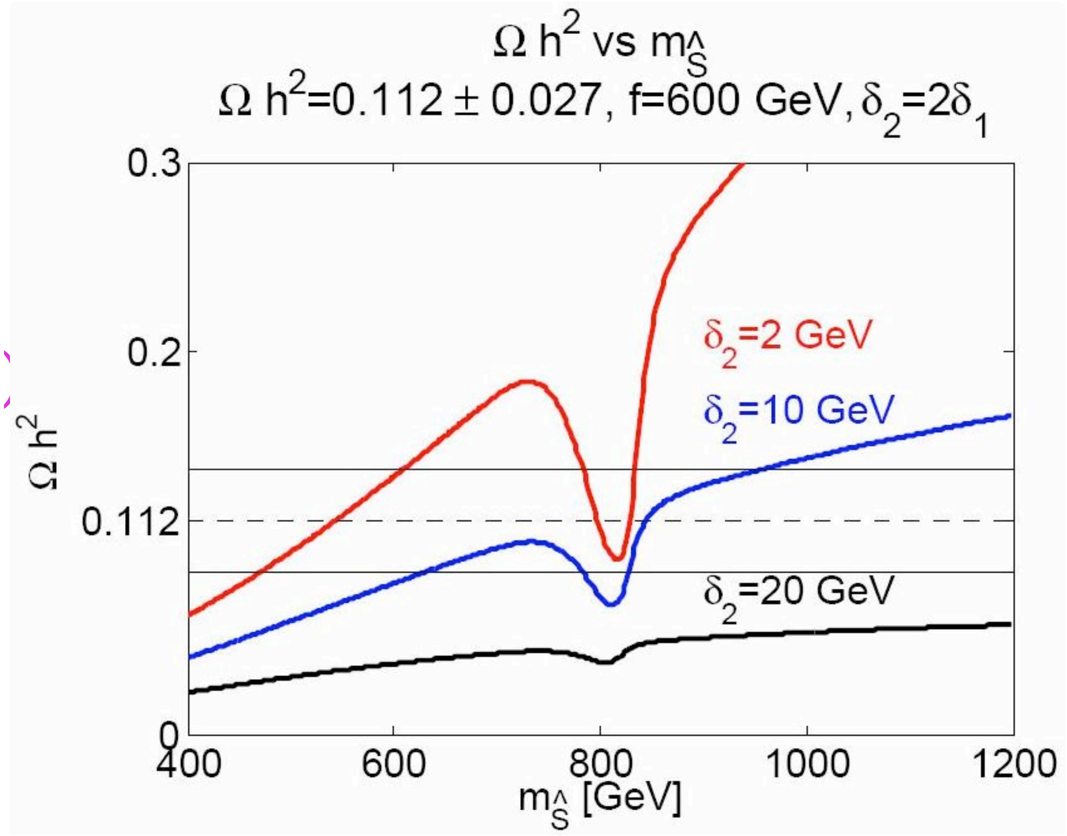
    $m_{\hat{S}} \sim m_{ZH}/2$
- Regions change by:
  - changing f



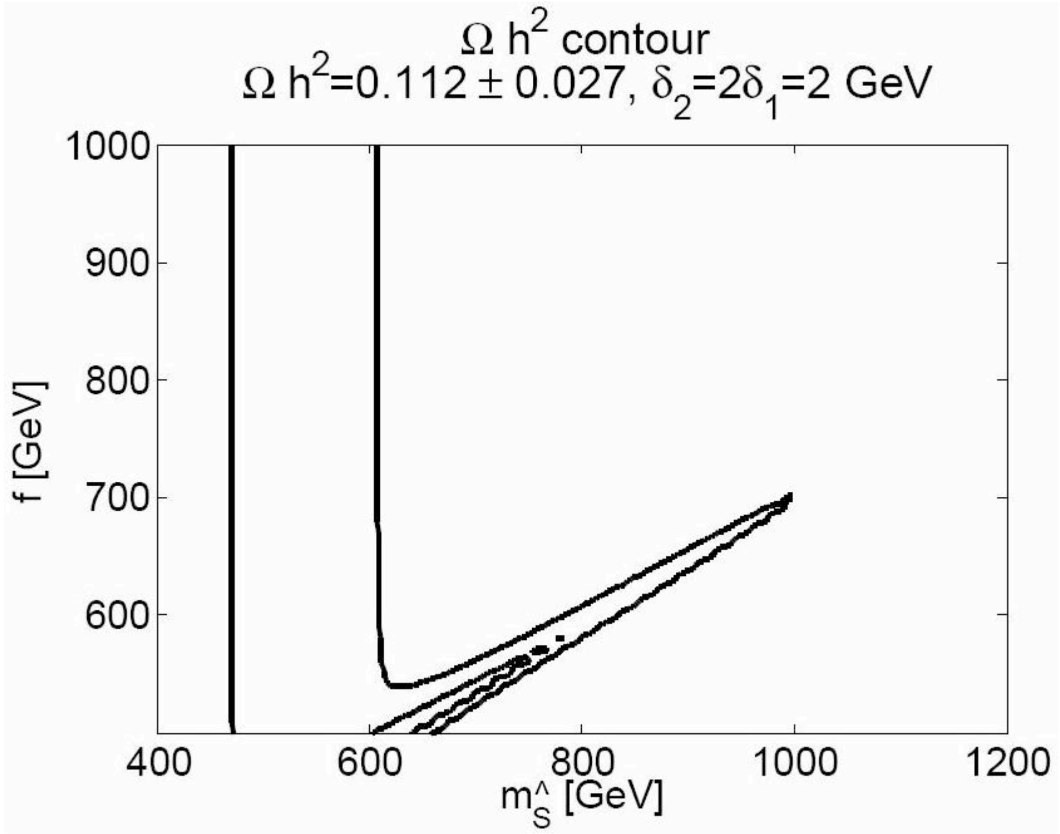
Relic Density Analysis
High mass

- Two regions:
  - Bulk (annihilations)
  - Z_H pole (co-annihilations)
    $m_{\hat{S}} \sim m_{ZH}/2$
- Regions change by:
  - changing f
  - changing $\delta_{1,2}$



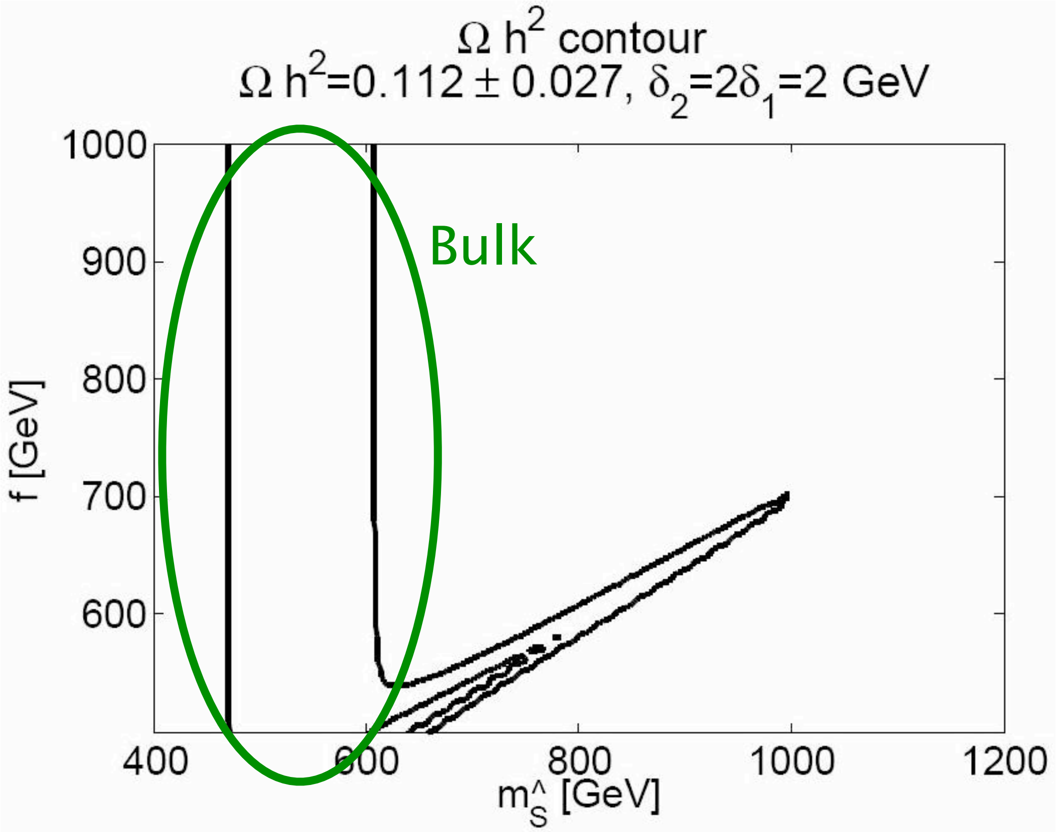
Relic Density Analysis
High mass

- $m_{\hat{S}}$ –f contour



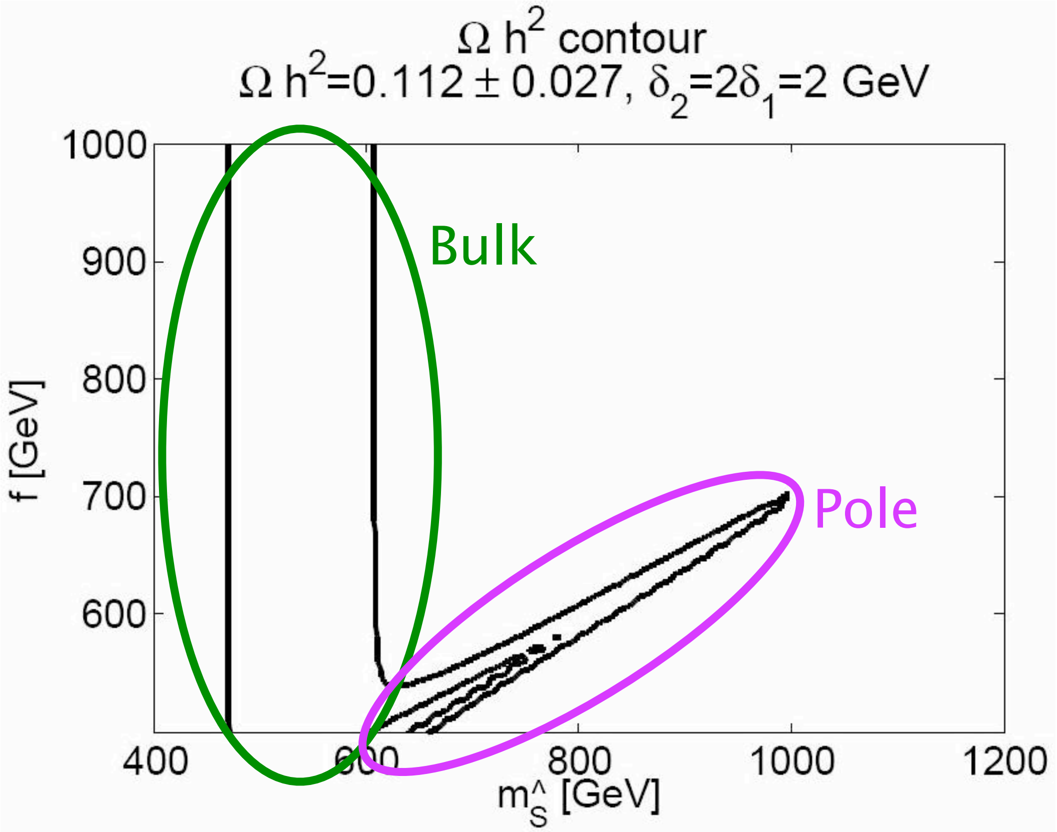
Relic Density Analysis
High mass

- $m_{\hat{S}}$ –f contour
  - Bulk: $m_{\hat{S}}$ constant



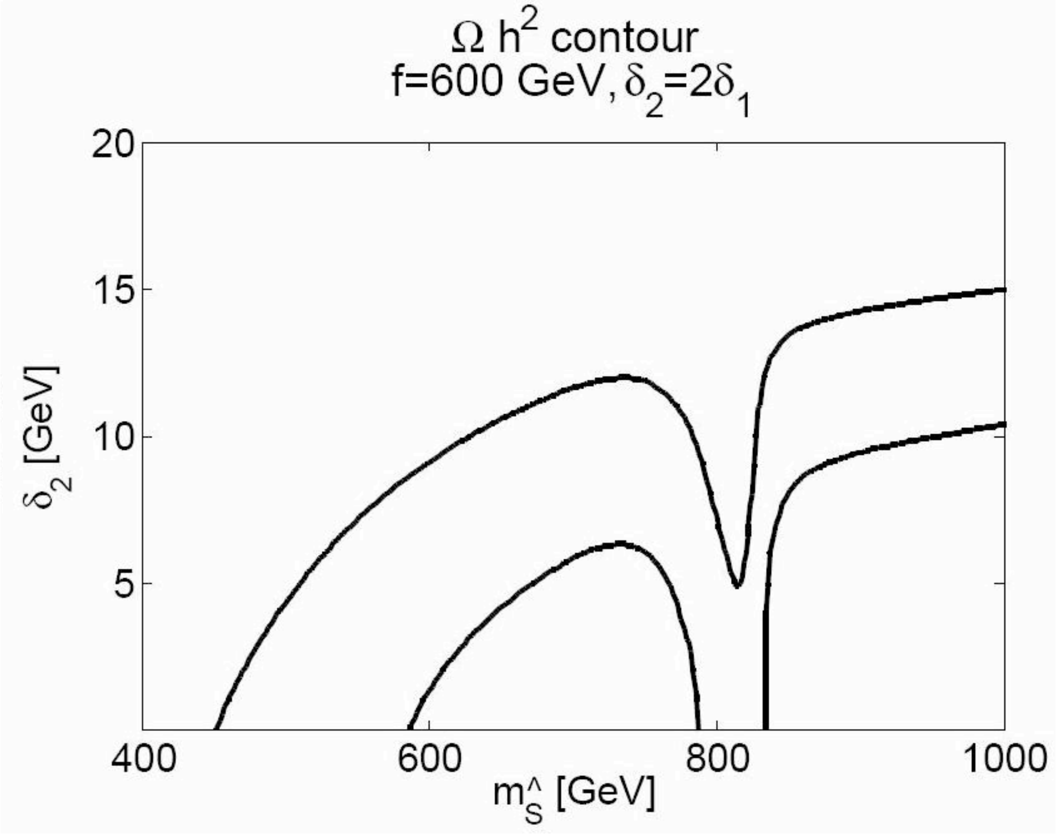
Relic Density Analysis
High mass

- $m_{\hat{S}}$ –f contour
  - Bulk: $m_{\hat{S}}$ constant
  - Pole: $m_{\hat{S}}$ varies ($m_{\hat{S}} \sim m_{ZH}/2$)



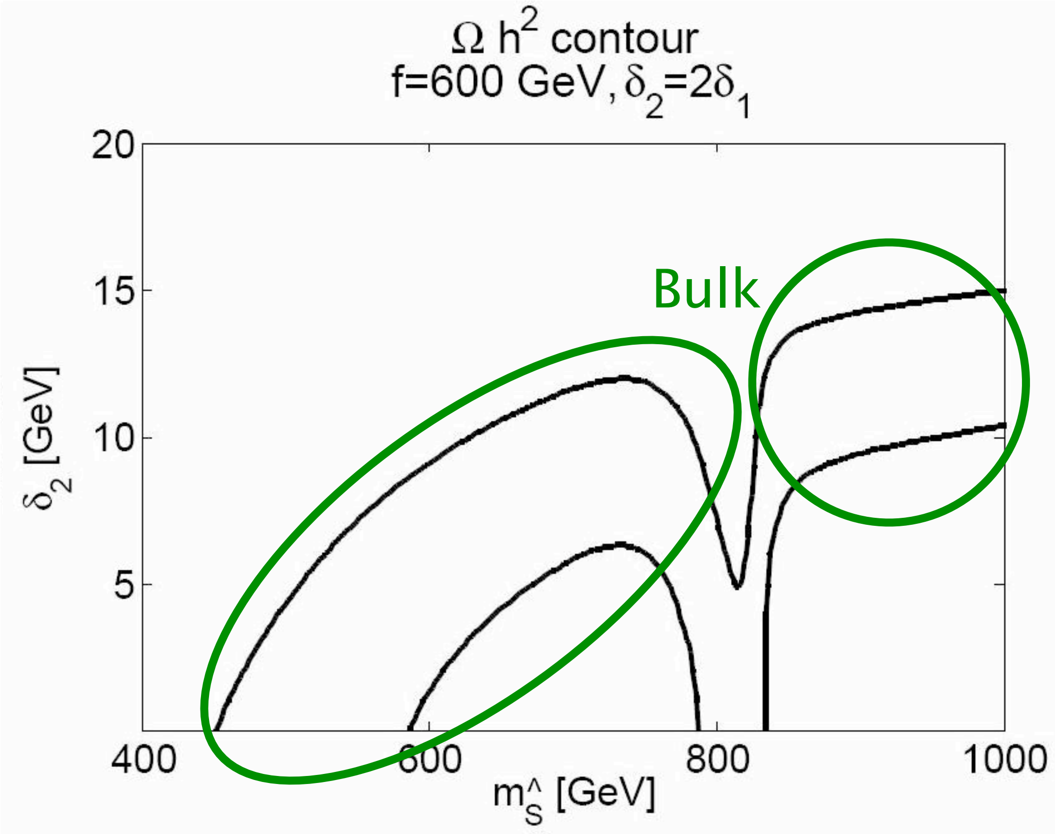
Relic Density Analysis
High mass

- $m_{\hat{S}}$ –f contour
  - Bulk: $m_{\hat{S}}$ constant
  - Pole: $m_{\hat{S}}$ varies ($m_{\hat{S}} \sim m_{ZH}/2$)
- $m_{\hat{S}} - \delta_2$ contour



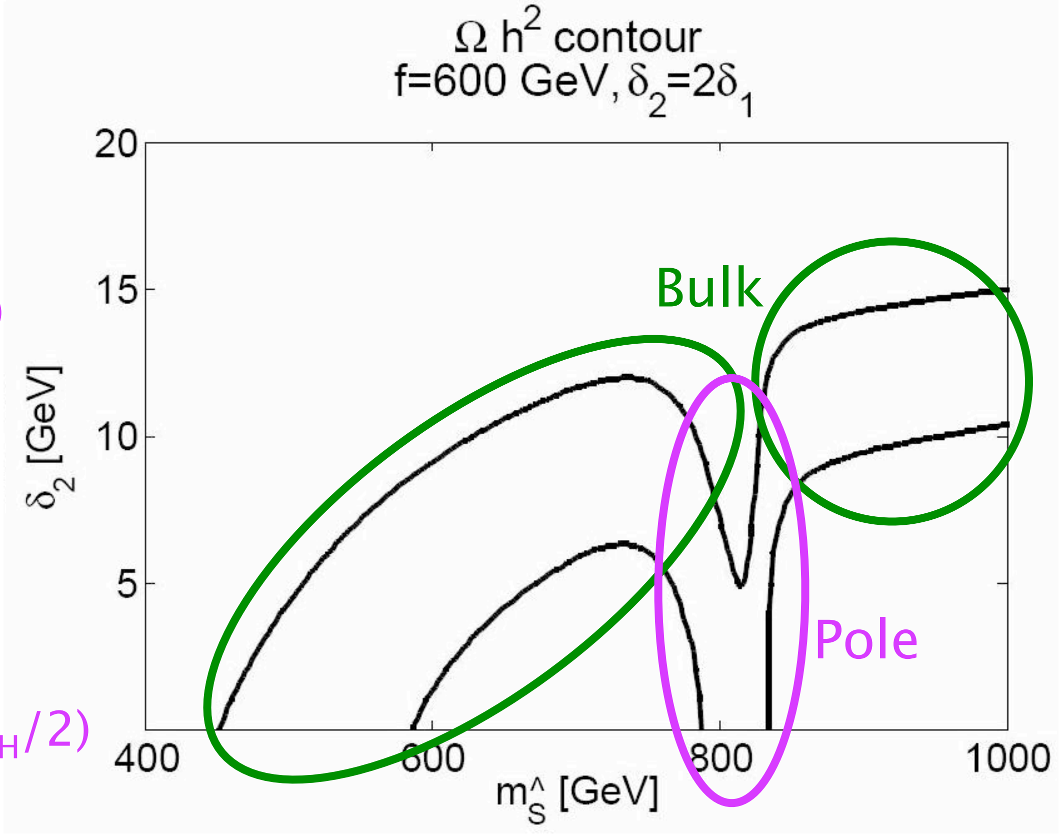
Relic Density Analysis
High mass

- $m_{\hat{S}}$ –f contour
  - Bulk: $m_{\hat{S}}$ constant
  - Pole: $m_{\hat{S}}$ varies ($m_{\hat{S}} \sim m_{ZH}/2$)
- $m_{\hat{S}} - \delta_2$ contour
  - Bulk: $m_{\hat{S}}$ varies



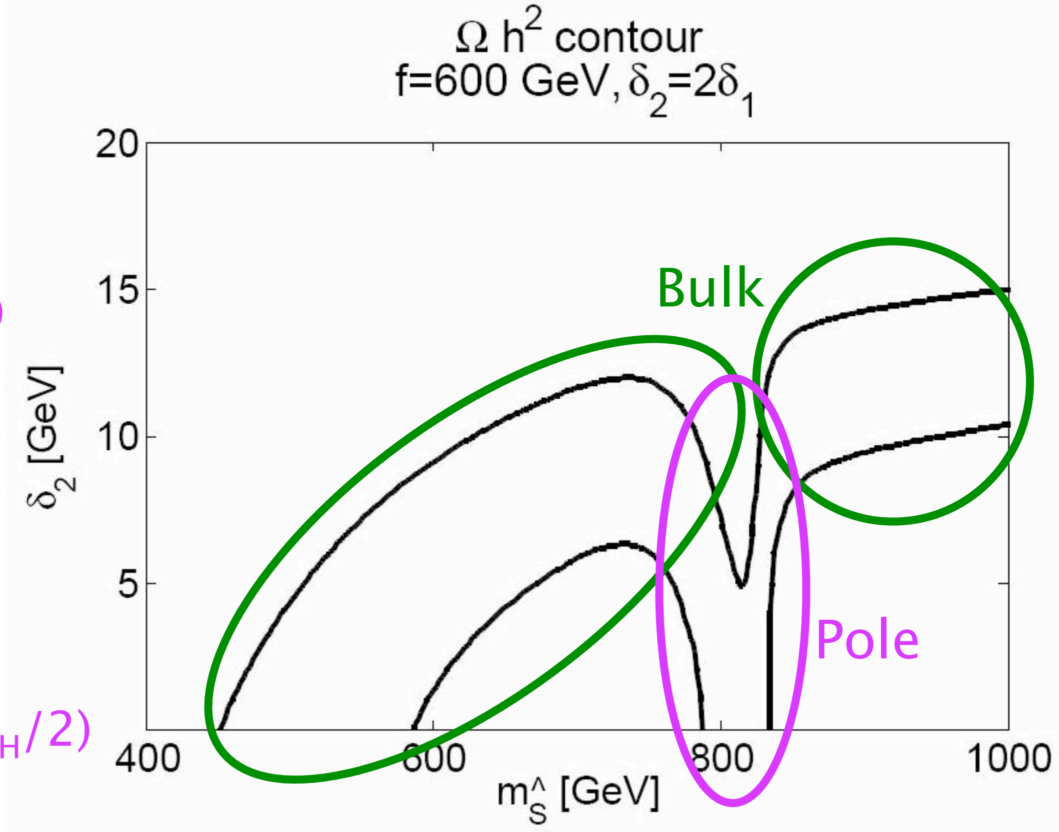
Relic Density Analysis
High mass

- $m_{\hat{S}}$ –f contour
  - Bulk: $m_{\hat{S}}$ constant
  - Pole: $m_{\hat{S}}$ varies ($m_{\hat{S}} \sim m_{ZH}/2$)
- $m_{\hat{S}} - \delta_2$ contour
  - Bulk: $m_{\hat{S}}$ varies
  - Pole: $m_{\hat{S}}$ constant ($m_{\hat{S}} \sim m_{ZH}/2$)



Relic Density Analysis
High mass

- $m_{\hat{S}}$ –f contour
  - Bulk: $m_{\hat{S}}$ constant
  - Pole: $m_{\hat{S}}$ varies ($m_{\hat{S}} \sim m_{ZH}/2$)
- $m_{\hat{S}} - \delta_2$ contour
  - Bulk: $m_{\hat{S}}$ varies
  - Pole: $m_{\hat{S}}$ constant ($m_{\hat{S}} \sim m_{ZH}/2$)



Large areas of parameter space where WMAP results are accessible

Relic Density Analysis
High mass

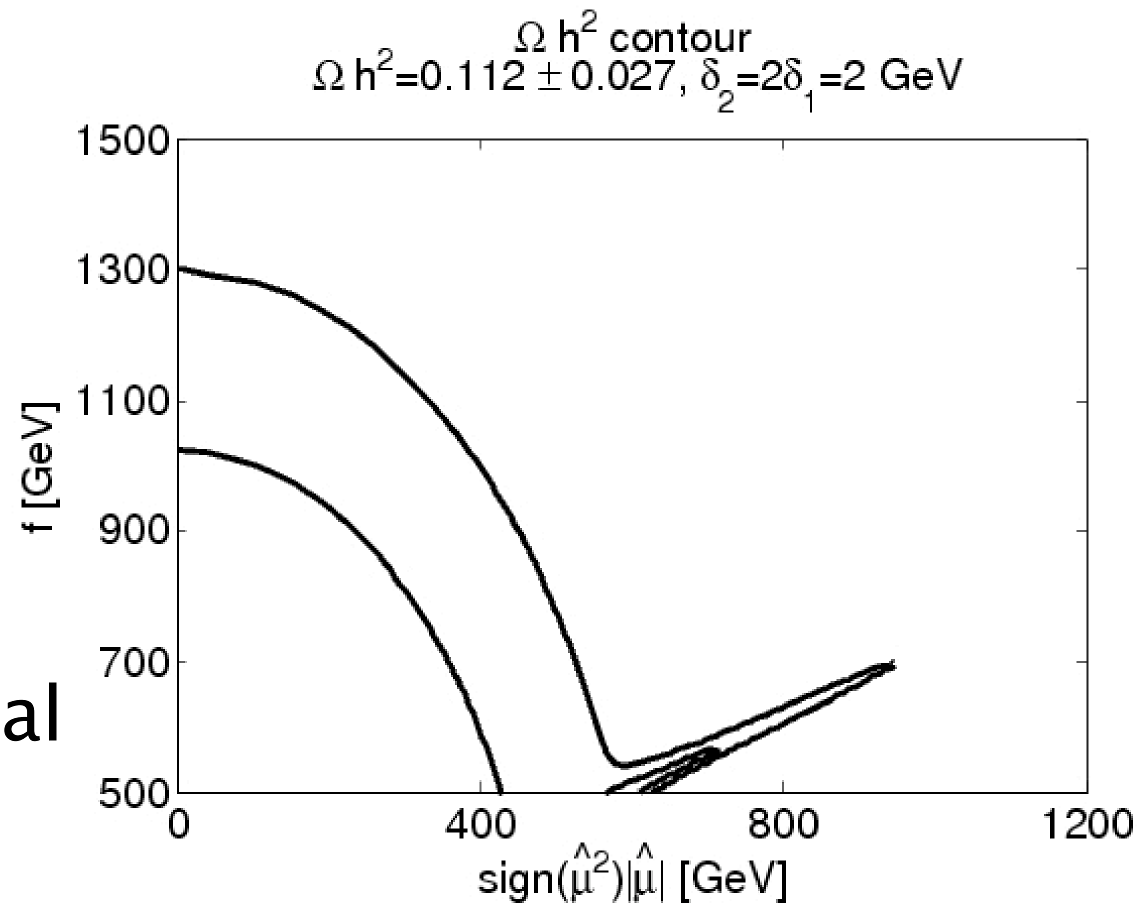
- Recall for $\lambda_4 = 0$:

$$m^2_{\hat{S}} = m^2_{\hat{h}_2 CW} + \hat{\mu}^2 + \frac{1}{2}\lambda_5 v^2$$
$$m^2_{\hat{A}} = m^2_{\hat{h}_2 CW} + \hat{\mu}^2 - \frac{1}{2}\lambda_5 v^2$$
$$m^2_{\hat{h}_1} = m^2_{\hat{h}_1 CW} + \hat{\mu}^2$$

- There exists regions where $\hat{\mu}^2 = 0$

- Bulk mass is then given entirely by CW potential

$$m^2_{\hat{S}} = m^2_{\hat{h}_2 CW} + \frac{1}{2}\lambda_5 v^2$$
$$m^2_{\hat{A}} = m^2_{\hat{h}_2 CW} - \frac{1}{2}\lambda_5 v^2$$
$$m^2_{\hat{h}_1} = m^2_{\hat{h}_1 CW}$$



Conclusion

- Left Right Twin Higgs Model provides a natural dark matter candidate
- Can obtain WMAP results with a wide range of splittings for low mass region
- High mass region requires a little tuning (splittings of a few GeV), and works with minimal setup ($\hat{\mu}^2 = 0$)
- Thank you!