W/Z/t/h Signals From Strong Dynamics

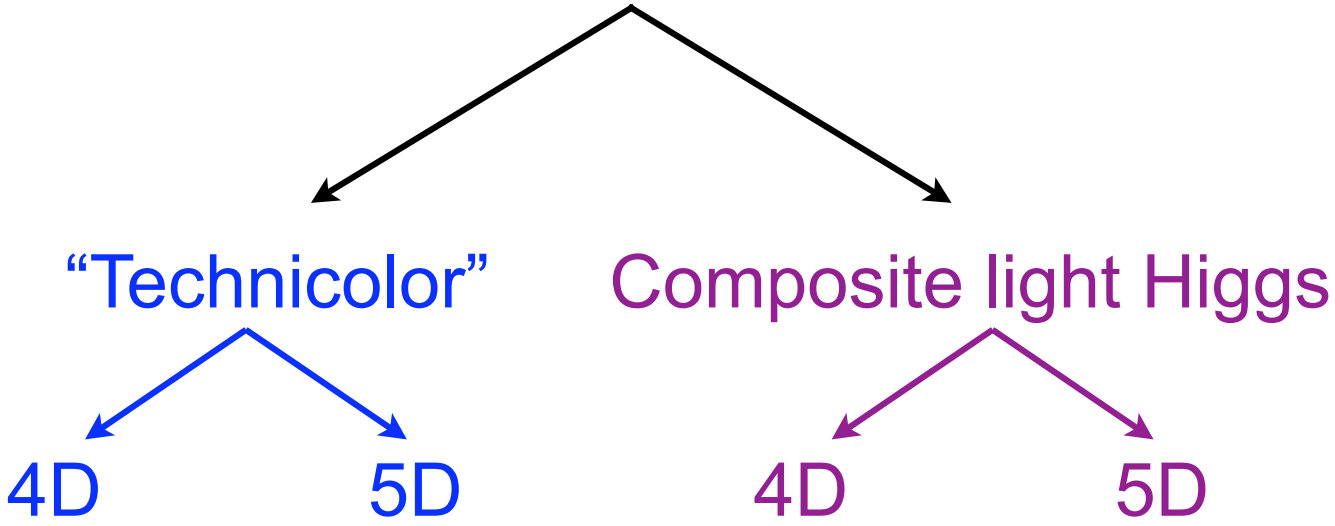
Markus Luty
UC Davis

with Spencer Chang and Jared Evans

A work in progress...

Strong Higgs Sector

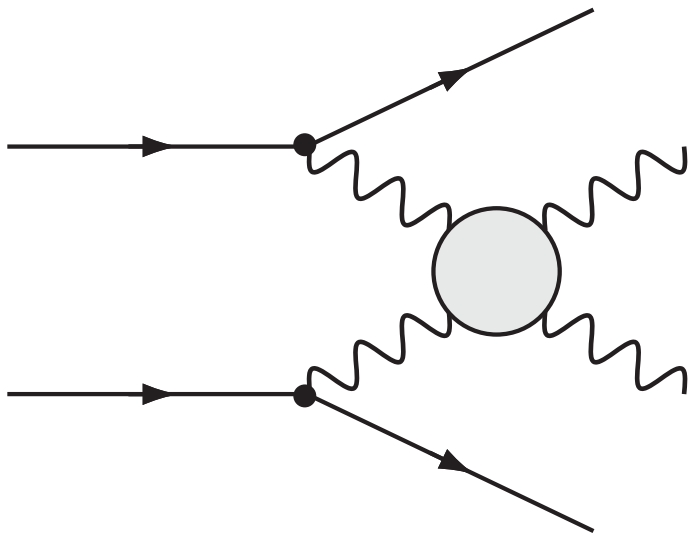
Higgs sector may have
strong dynamics at the TeV scale



How do we test these ideas?

W, Z, t have largest mass
⇒ "portals" to the Higgs sector

LHC as a W/Z Collider



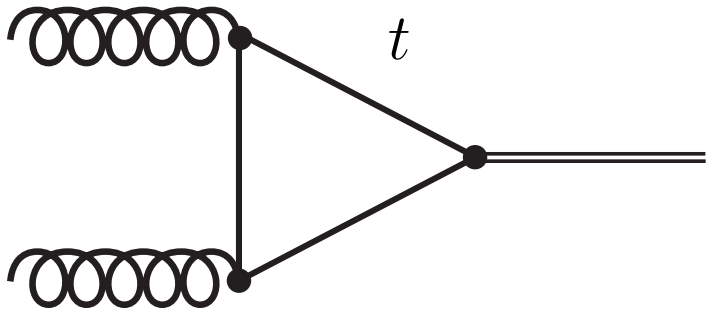
W_L, Z_L composite ⇒ interact strongly at TeV

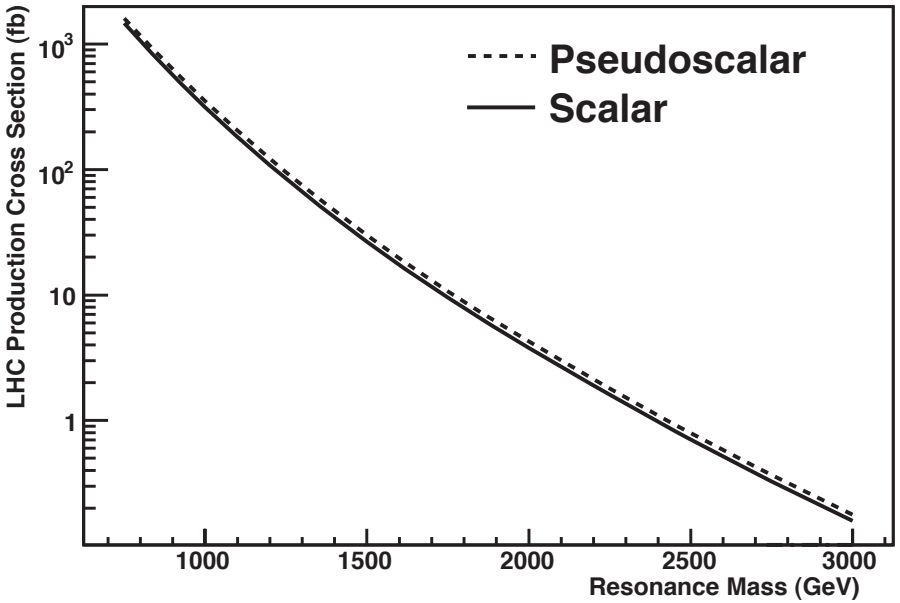
Resonances have strong 2-body decay ⇒ broad

Strong WW scattering well-studied,

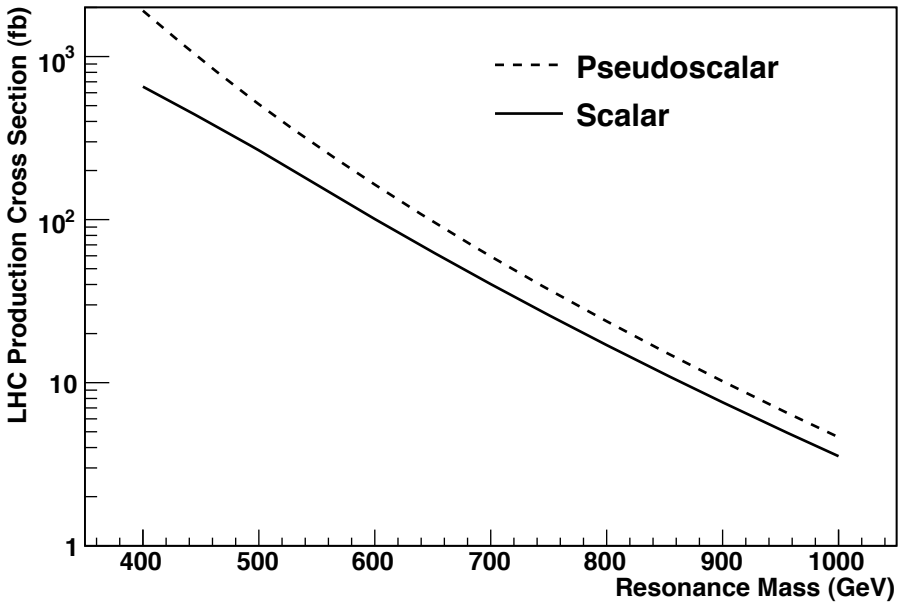
not discussed here

LHC as a Top Collider





14 TeV



7 TeV

Origin of Top Mass

- Yukawa coupling

  $\Delta\mathcal{L} = \bar{Q}_L t_R \mathcal{H} + \text{h.c.}$

  e.g. $\mathcal{H} = \bar{\psi}\psi$ in technicolor

  $\mathcal{H}$ creates states with $J = 0, I = 0, 1, \ldots$

- Top compositeness

  Top mixes with composite state (RS models)

  Top is composite (“topcolor”)

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decay to $W_L W_L$ forbidden

$A^0 \to \bar{t}t,\ W_L W_L Z_L,\ Z_L Z_L Z_L$

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Modeling Higgs Sector

Requirements:

- No unphysical growing amplitudes
- Proper treatment of widths, QCD radiation, etc.
- Well-defined parameter space

⇒ Lagrangian!

2 Higgs doublet model is simplest “simplified model”

Modeling Higgs Sector

Requirements:

- No unphysical growing amplitudes
- Proper treatment of widths, QCD radiation, etc.
- Well-defined parameter space

linearly realized

⇒ Lagrangian!

2 Higgs doublet model is simplest “simplified model”

Minimal 2HDM

Impose custodial $SU(2)$

$$h^0, H^0 \qquad I = 0$$

$$(A^0, H^\pm) \quad I = 1$$

Impose $H_1 \to -H_1,\ H_2 \to +H_2$

$$V = m_1^2|H_1|^2 + m_2^2|H_2|^2 + \tfrac{1}{4}\lambda_1|H_1|^4 + \tfrac{1}{4}\lambda_2|H_2|^4 + \lambda_3|H_1|^2|H_2|^2 + \tfrac{1}{4}\lambda_4(H_1^\dagger H_2 + \text{h.c.})^2$$

$$\mathcal{L}_{\text{top}} = \lambda_t \bar{Q}_L t_R(\cos\gamma H_1 + \sin\gamma H_2)$$

$m_1^2,\ m_2^2,\ \lambda_1,\ \ldots,\ \lambda_4,\ \lambda_t,\ \gamma =$ 6 free parameters

($v,\ m_t$ fixed)

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M2HDM Parameter Space

Define angles $\alpha,\ \beta$

$$\begin{pmatrix} h^0 \\ H^0 \end{pmatrix} = \begin{pmatrix} \cos\alpha & \sin\alpha \\ -\sin\alpha & \cos\alpha \end{pmatrix} \begin{pmatrix} H_1^0 \\ H_2^2 \end{pmatrix}$$

$$\tan\beta = \frac{v_1}{v_2}$$

Parameterize model by

$$m_{h^0},\ m_{H^0},\ m_{A^0} = m_{H^\pm},\ \alpha,\ \beta,\ \gamma$$

Angles control couplings, e.g.

$$g_{h\bar{t}t} = \frac{m_t \cos(\alpha+\gamma)}{v\sin(\beta+\gamma)} \qquad g_{hWW} = g m_W \sin(\beta-\alpha)$$

Search Parameter Space

Rate uncertain ⇒ treat as free parameter by reweighting

Parameterize search for a given topology by relevant masses and rate

Benchmark angles (couplings) and irrelevant masses

Simplified Models Suck

...especially for strong dynamics

Unitarity ⇒ relation between widths and rates
Violated by rescaling rates

Can be correctly modeled for specific signals, but not practical for wide range of topologies

Do we really expect experimentalists to search for inconsistent models?

Yes, if they can be RECAST

“Technicolor” Topologies

- A^0 kinematically accessible, couples to $\bar{t}t$

$$gg \to A^0 \to \bar{t}t,\ W^+W^-Z,\ ZZZ$$

- A^0 kinematically accessible, suppressed coupling to $\bar{t}t$

$$gg, VV \to h^0 \to A^0 Z$$
$$\to W^+W^-ZZ,\ ZZZZ$$

- A^0 not kinematically accessible

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$A^0 \to Zh^0,$
$h^0 \to WW,\ ZZ$

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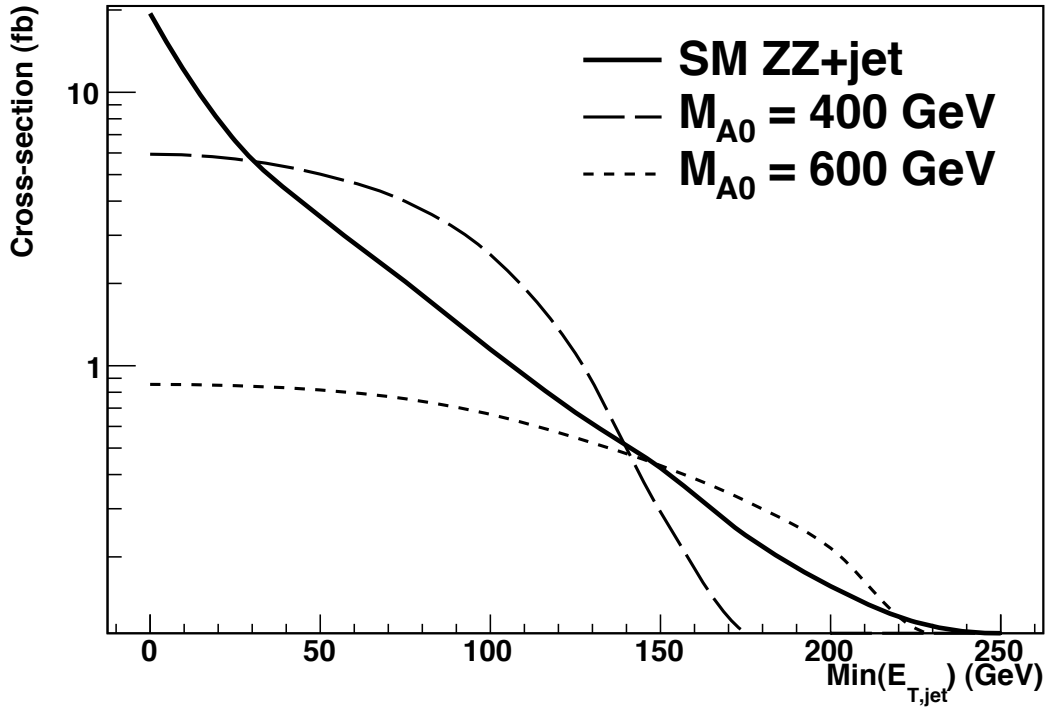
Example: ZZZ

$$gg \to A^0 \to ZZZ \to \ell^+\ell^- + \text{jets} + E_{T,\text{miss}}$$

Parameterize search by $m_A,\ m_h,$ rate



7 TeV LHC, $m_h = \frac{1}{2}m_A$

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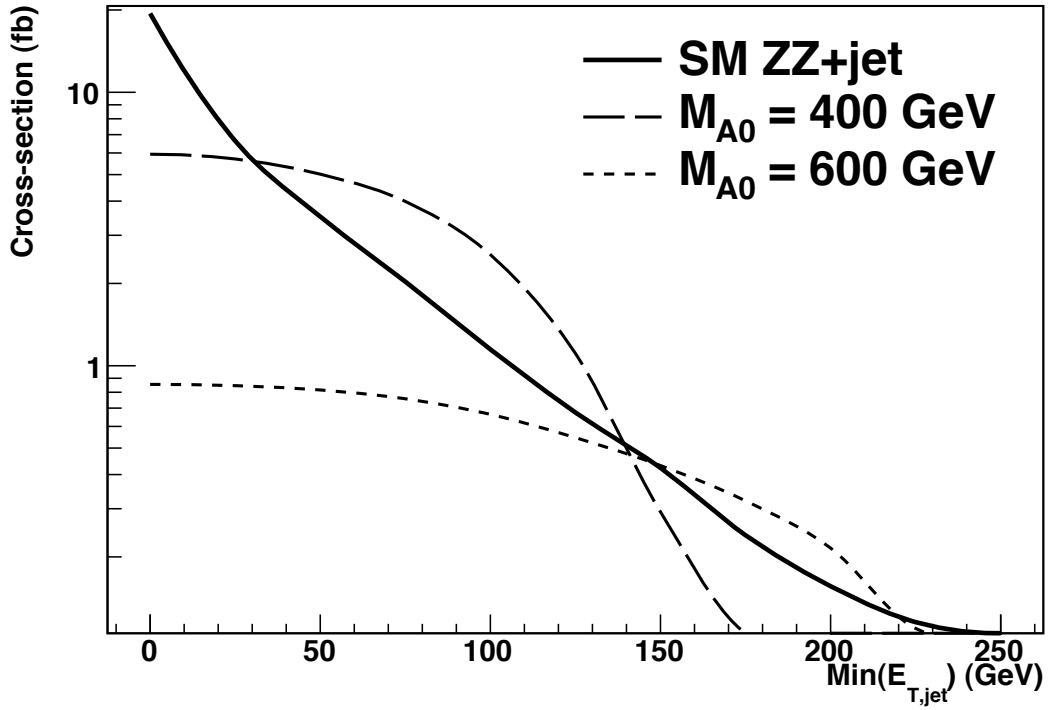
Parameterize search by m_A, m_h, rate

controls kinematics



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Composite Higgs Topologies

- A^0 kinematically accessible, couples to $\bar{t}t$

$$gg \to A^0 \to Zh^0$$

- A^0 kinematically accessible, suppressed coupling to $\bar{t}t$

$$gg,\ VV \to H^0 \to A^0 Z,\ H^{\pm} W^{\mp}$$
$$\to ZZh^0,\ W^+W^-h^0$$

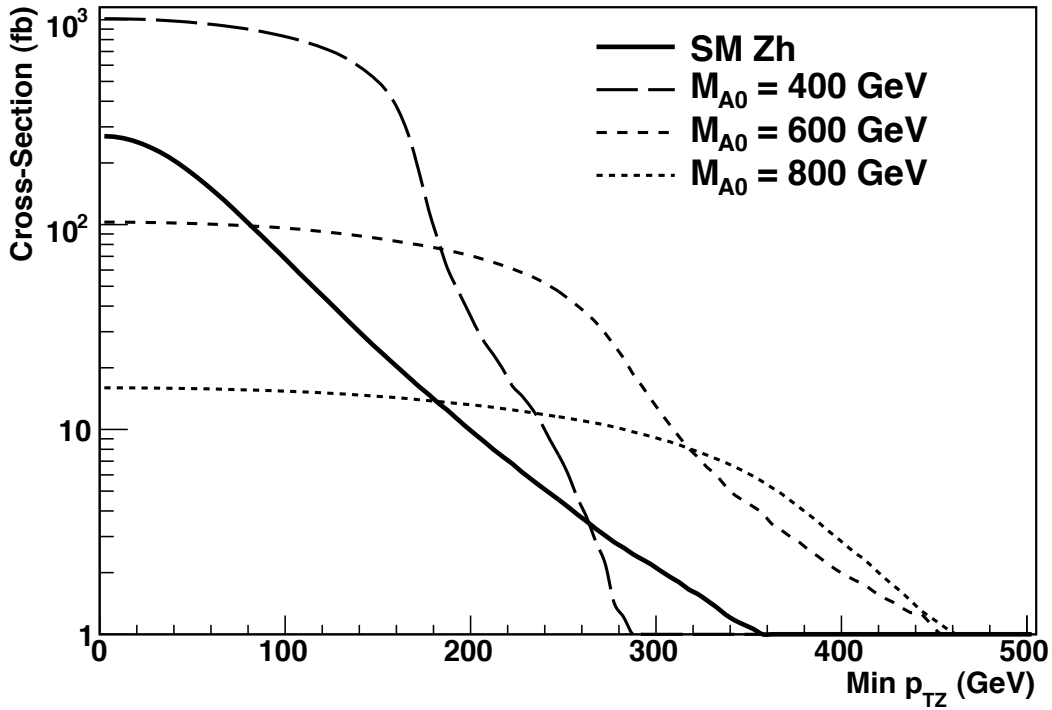
- A^0 not kinematically accessible

$$gg, VV \to H^0 \to h^0 h^0$$

Example: Zh

$$gg \to A^0 \to Zh^0$$

Parameterize search by $m_A,\ m_h,$ rate



7 TeV LHC, $m_h = 120$ GeV

Monte Carlo

`MadGraph` implementation in `2HDM4TC`

- Calculator: `2HDM4TCCalc`

  Input: $m_h,\ m_H,\ m_A,\ \alpha,\ \beta,\ \gamma$

  Generates `param_card.dat`

  Warnings for large quartic couplings

- Model file: `2HDM4TC`

  Includes ggh^0 (*etc.*) vertices using form factor

  $gggh^0$ (e.g. for radiation) not supported

Conclusions

- 2 Higgs doublet model is a useful “simplified model” for signals motivated by top + strong Higgs sector
  Also interesting on its own...

- Proposed priority topologies for searches

- Possible sensitivity in early LHC ($7\ \mathrm{TeV},\ 1\ \mathrm{fb}^{-1}$)

- Lots to do...

FIGHT THE

SUSY POWER

Backup Slides

Example: WWZ

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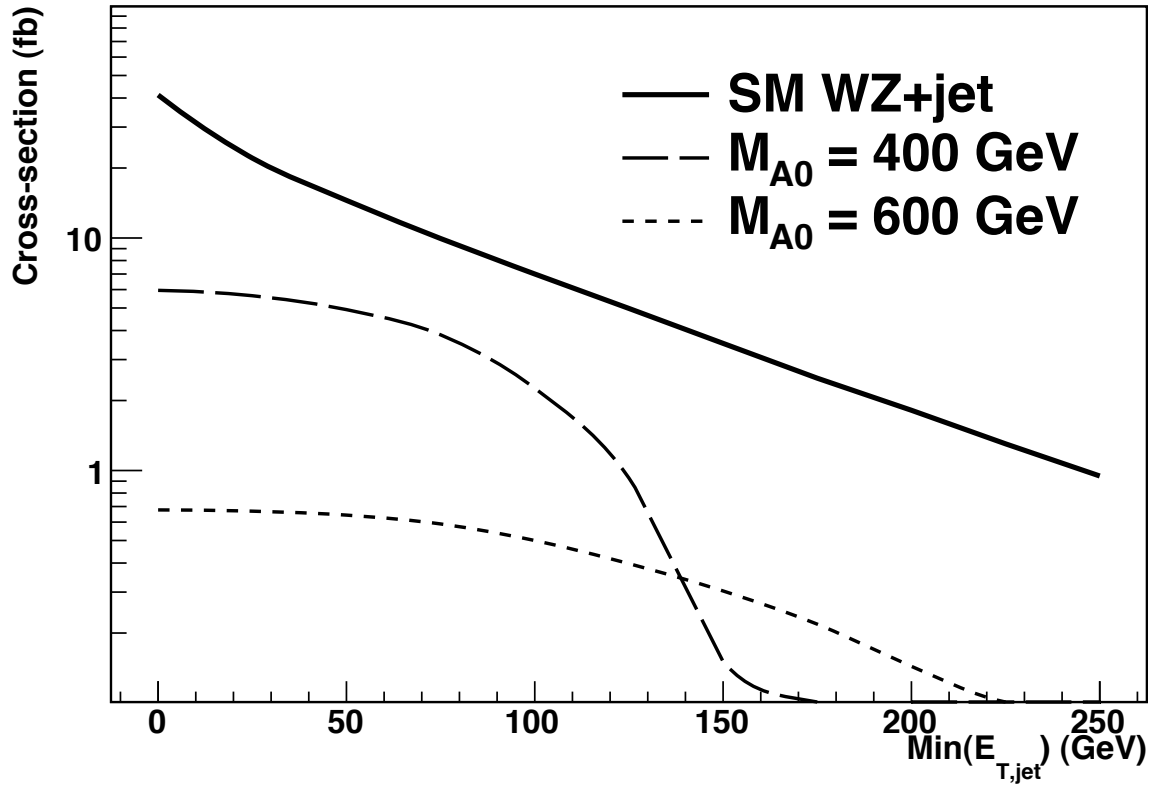

7 TeV

$$m_h = \tfrac{1}{2} m_A$$

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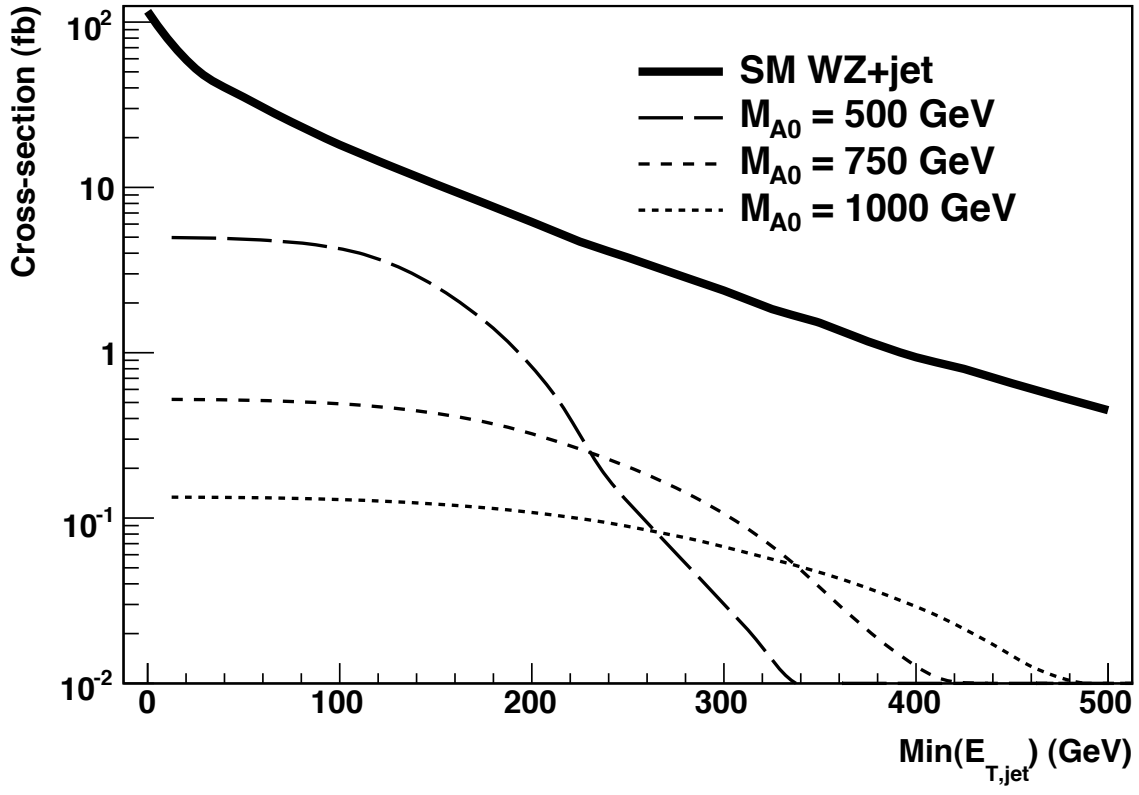

14 TeV

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Example: ZZZ

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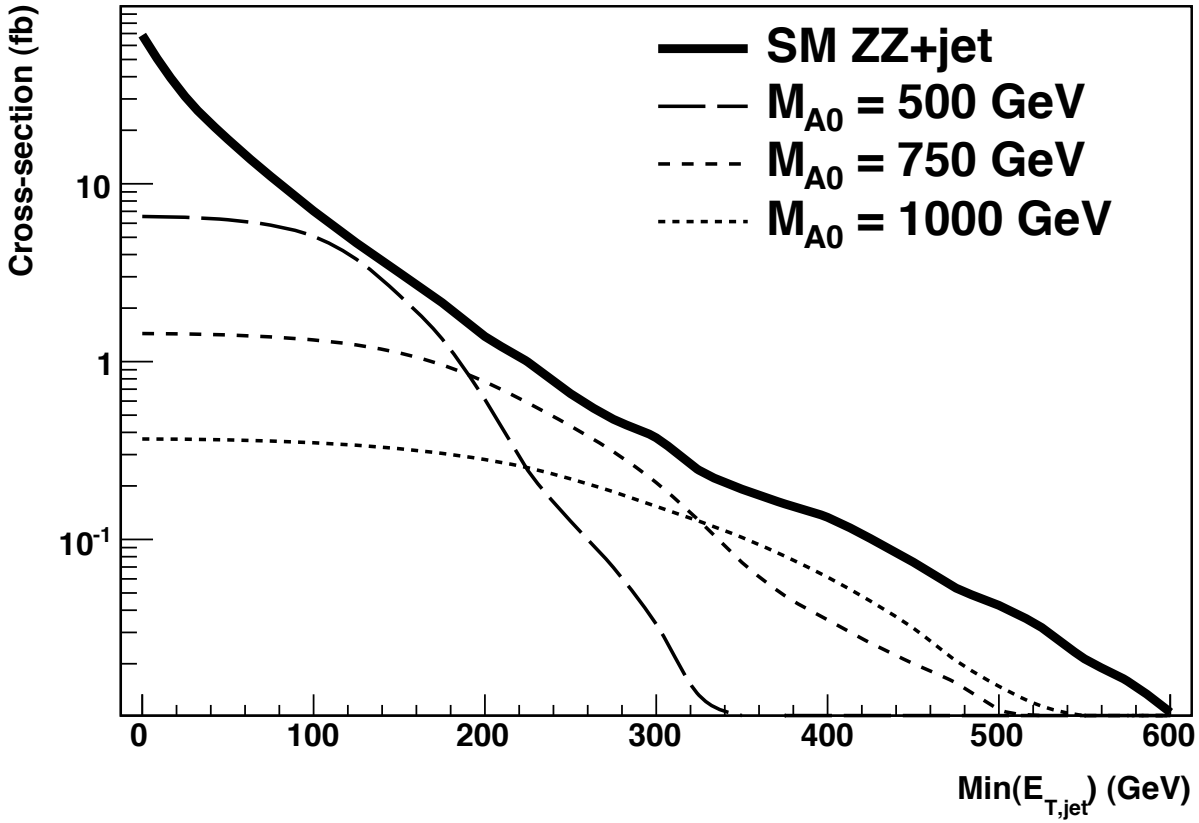

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