

Boosted objects from the Higgs Sector

A Strongly Boosted Higgs Sector

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Outline

- 1 EWSB from Strong Dynamics
- 2 Minimal Walking Technicolor
- 3 LHC Phenomenology and Boosted final states

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In collaboration with:

Alexander Belyaev (Southampton U.),
Roshan Foadi (Michigan State U.),
Matti Jařvinen (CP3-Origins),
Alexander Pukhov (Moscow State U.),
Francesco Sannino (CP3-Origins),
Subir Sarkar (Oxford U.)
Alexander Sherstnev (Oxford U.).

A. Belyaev, M.T.F and A. Sherstnev In progress



Composite vs 'SM-like' Higgs sector

- Natural, $v_{EW} \sim F_\Pi$ dynamical.
- Fine-tuning, triviality etc.

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Resonances boosting new physics

Technicolor

EWSB from Strong Dynamics: (Weinberg 78, Susskind 78)

- ① In the SM without a Higgs, QCD breaks the EW symmetry:

$$\langle \bar{u}_L u_R + \bar{d}_L d_R \rangle \neq 0 \quad \rightarrow \quad M_W = \frac{g f_\pi}{2} .$$

- ② Consider a new strongly interacting gauge theory with $F_\Pi = v_{EW} = 246\text{GeV}$.
- ③ Let the electroweak gauge group be a subgroup of the chiral symmetry group.

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Example: **Scaled-up QCD !**

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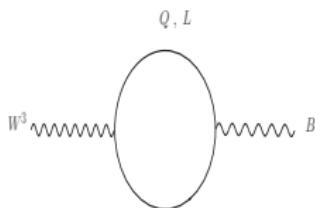
Minimal chiral symmetries: 3 GB's + Custodial + DM.

$$SU_L(2) \times SU_R(2) \times U_{TB}(1) \rightarrow SU_V(2) \times U_{TB}(1) .$$

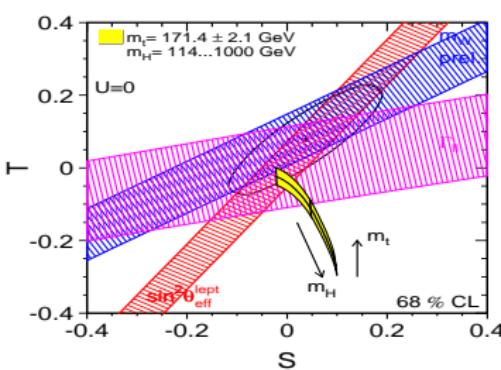
Constraints from LEP

- ① A minimal matter content in the TC sector is favored:

$$S \equiv -16\pi\Pi'_{W^3B}(0), \quad T \equiv \frac{4\pi}{s_W^2 c_W^2 M_Z^2}(\Pi_{W^1W^1}(0) - \Pi_{W^3W^3}(0))$$



$$S_{\text{naive}} = N_D \frac{d(R_{\text{TC}})}{6\pi}$$



(Kennedy and Lynn 89; Peskin and Takeuchi 90; Altarelli and Barbieri 91)

Minimal Models of Walking Technicolor

$$Q_L = \left(U_L^{+1/2}, D_L^{-1/2} \right)^T , \quad U_R^{+1/2} , \ D_R^{-1/2} .$$

(See talk by Sannino)

Minimal Models of Walking Technicolor

MWT model: (Sannino and Tuominen 04)

$G_{TC} = SU(2)$. $\mathcal{R} = \text{Adj. Leptons}$.
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09) • Other TC Models (non-minimal/including ETC):

Farhi and Susskind 79; Eichten and Lane 89; Appelquist and Terning 94;
 Appelquist, Christensen, Pia and Shrock 04; Lane and Martin 06; Ryttov
 and Shrock 10

EFT for strong dynamics @ LHC

common sector:

$$SU_L(2) \times SU_R(2) \times U_{TB}(1) \rightarrow SU_V(2) \times U_{TB}(1).$$

- New states: Lightest (axial)-vector triplets and scalar

$$R_1^{\pm,0}, R_2^{\pm,0}, H. \text{ TIMPs}$$

- Input parameters and constraints:

$$e, G_F, M_Z; S, \text{ Sum Rules.}$$

- Main free parameters:

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(Appelquist, Da Silva and Sannino 99; Foadi, M.T.F, Ryttov and Sannino 07

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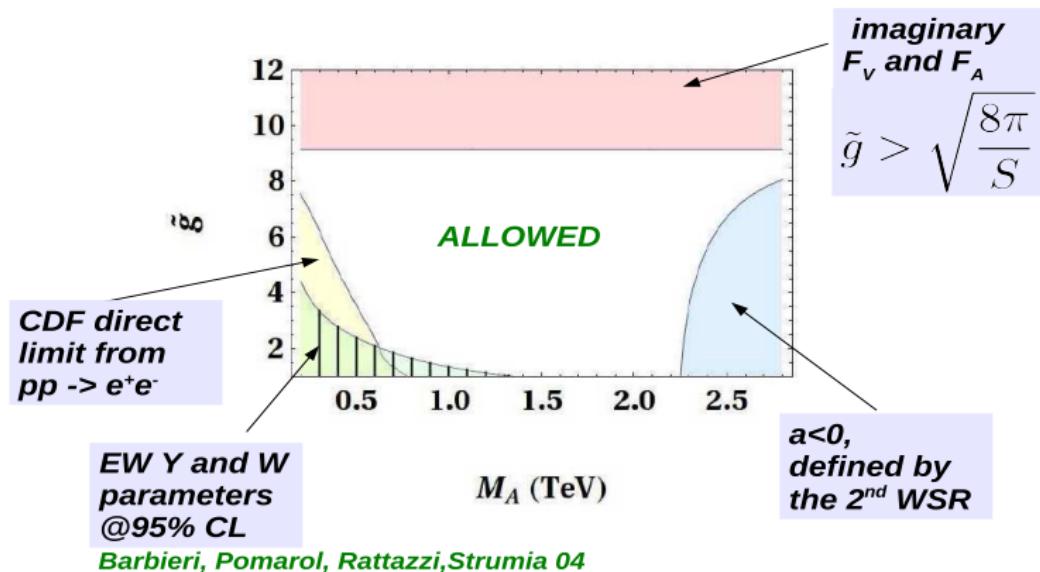
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- EFTs for 'BESS' models, '4-site' models and LSTC Casalbuoni, Deandrea, De Curtis, Dominici, Gatto, Grazzini 95; Lane and Martin 09

Parameter space



Barbieri, Pomarol, Rattazzi, Strumia 04

(Foadi, M.T.F and Sannino 07 ; Belyaev, Foadi, M.T.F, Järvinen, Pukhov, Sannino 08)

Mass spectrum, imposing S and WSR1

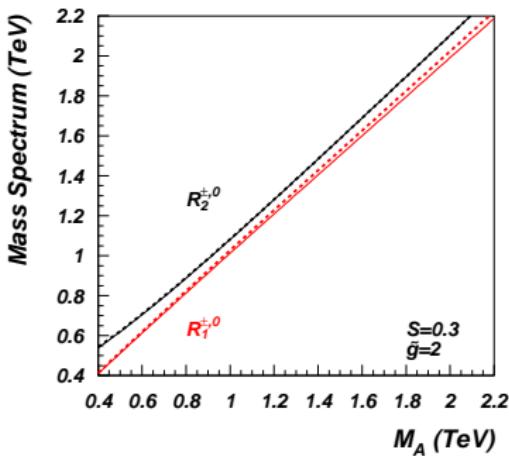
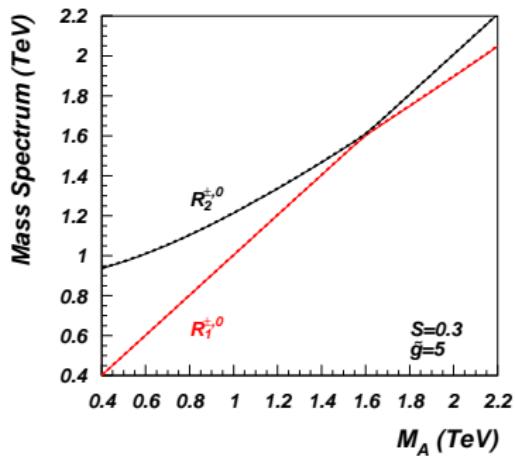


Figure: $R_{1,2}$ spectrum.

(Foadi, M.T.F, Ryttov and Sannion 08)

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- Basic phenomenology controlled by \tilde{g} , M_A , M_H .



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Vector BRs

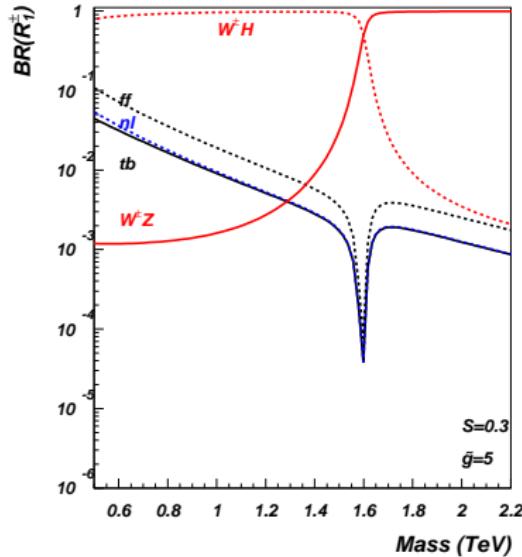
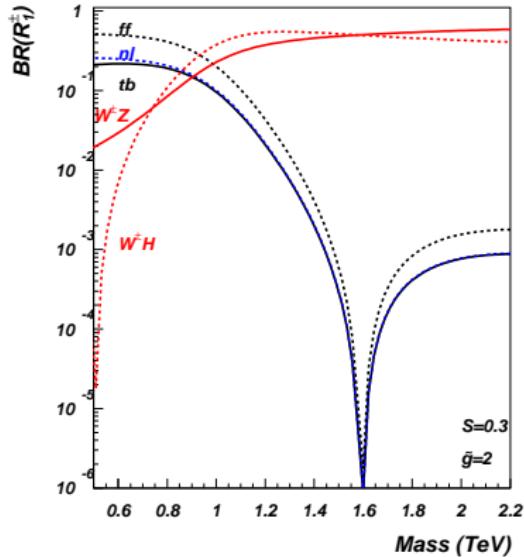


Figure: BR's of R_1 .

Vector Production

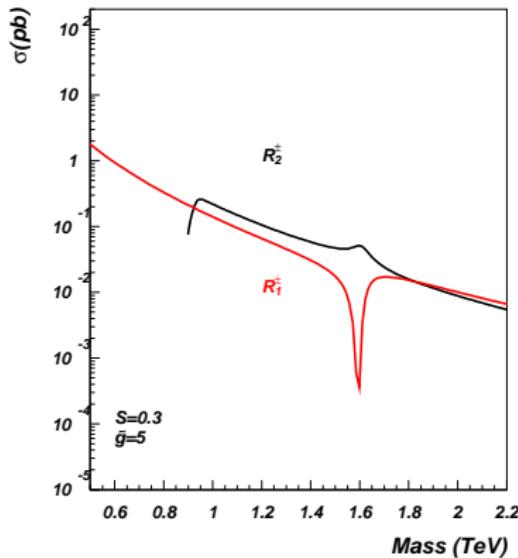
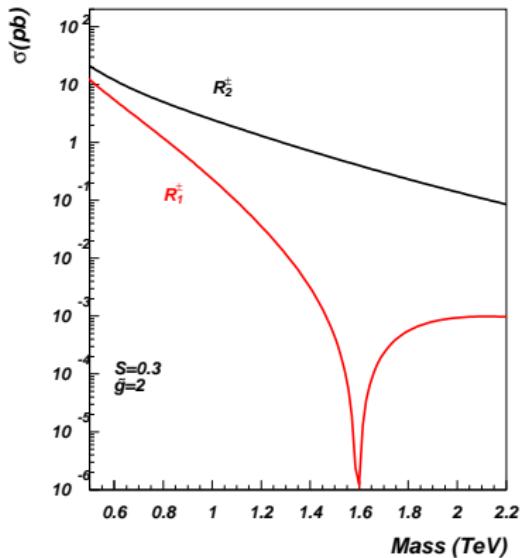


Figure: DY production of $R_{1,2}$.

Boosted h in SM, MSSM and NMSSM

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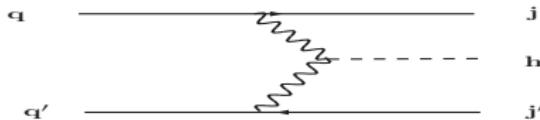
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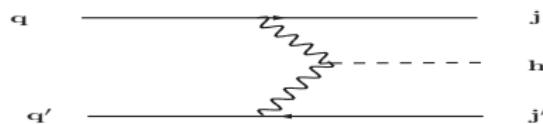
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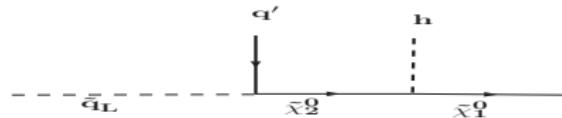


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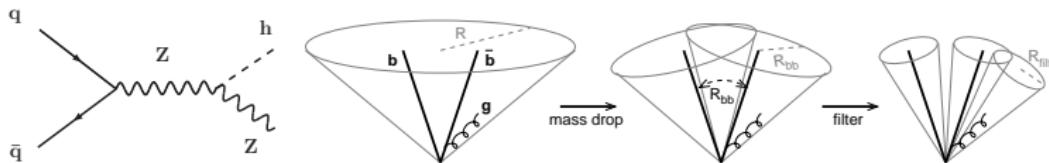


- Boosted h from susy decay chains
 (Butterworth, Ellis and Raklev 07)

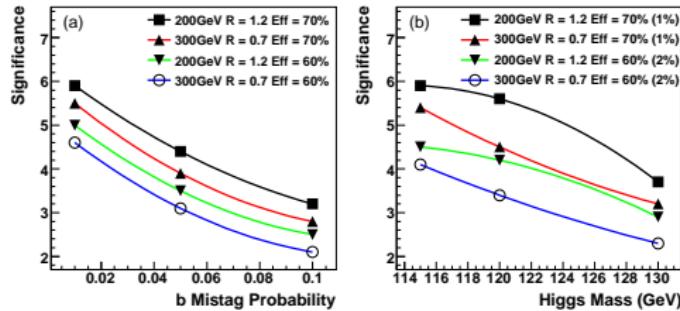


Higgs Strahlung in SM/MSSM

- Fat jets from $Z h(\rightarrow b\bar{b})$



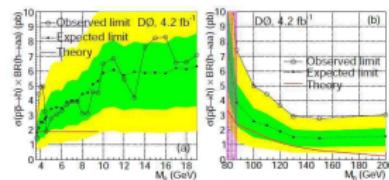
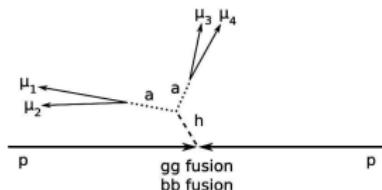
- Significance with 30fb^{-1} :



(Butterworth, Davison, Rubin and Salam 08; Kribs, Martin, Roy and Spannowsky 09)

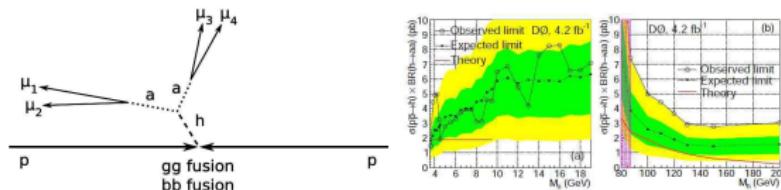
$$\text{Fusion} \rightarrow h \rightarrow aa \rightarrow 4\mu/4g$$

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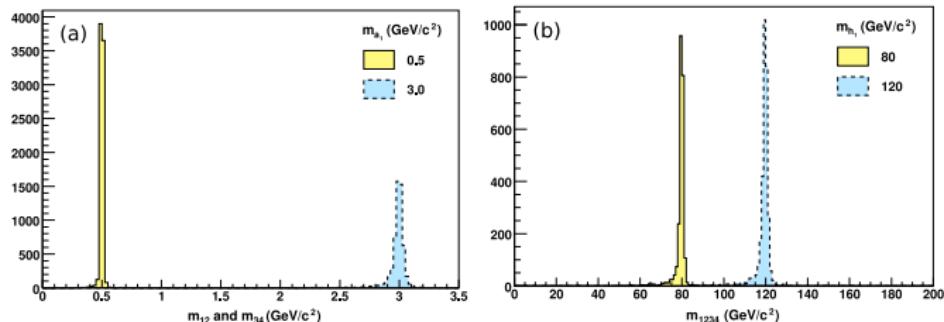


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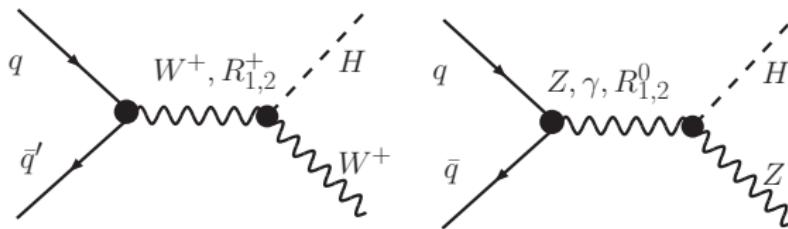
- Precise mass determination with highly collimated μ 's:



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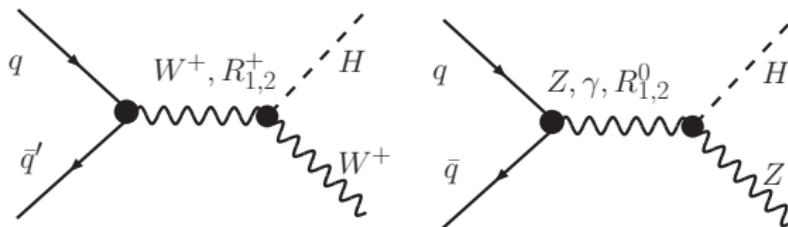
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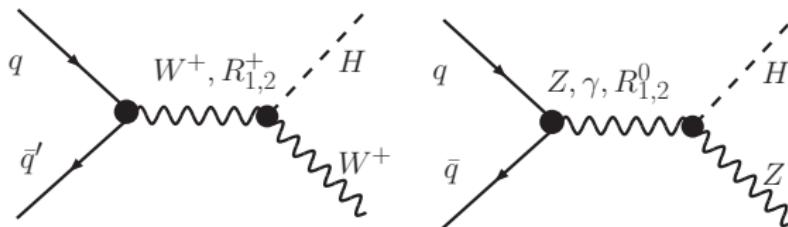
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- $U(1)$ techni-omega, $U(1)$ Z' , axial techni-vector (R_1) resonance
 (Zerwekh 05; Barger, Langacker and Lee 05; Son's talk; Belyaev, Foadi, M.T.F, Järvinen, Pukhov, Sannino 08)

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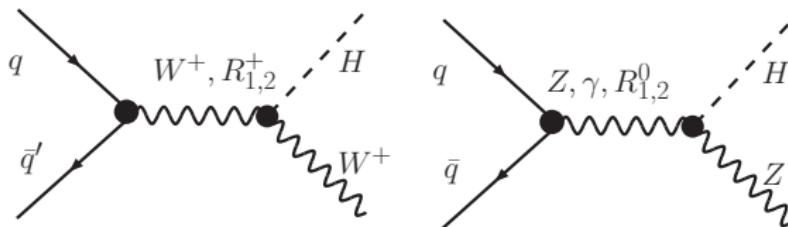
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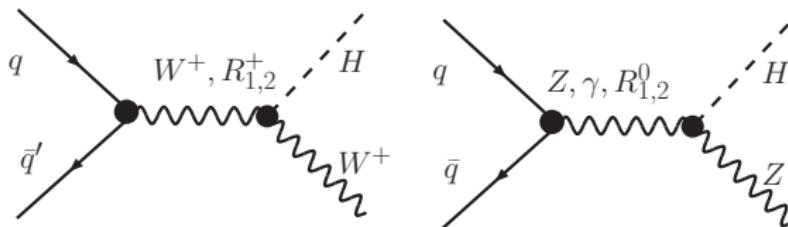
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- $Z(\rightarrow jj)H$ with $H \rightarrow WW(ZZ)$ from a Light Composite Higgs

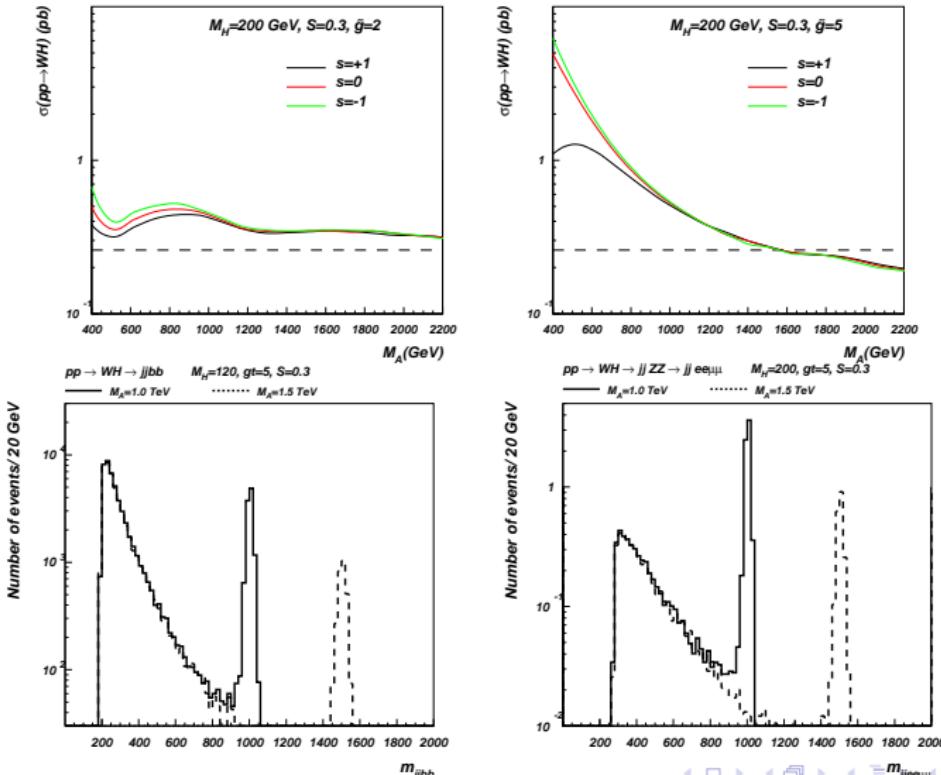
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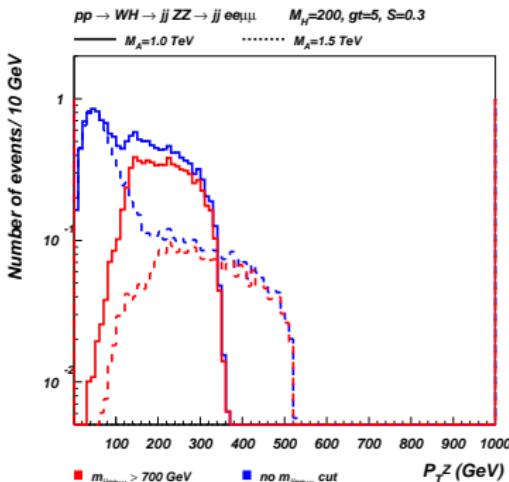
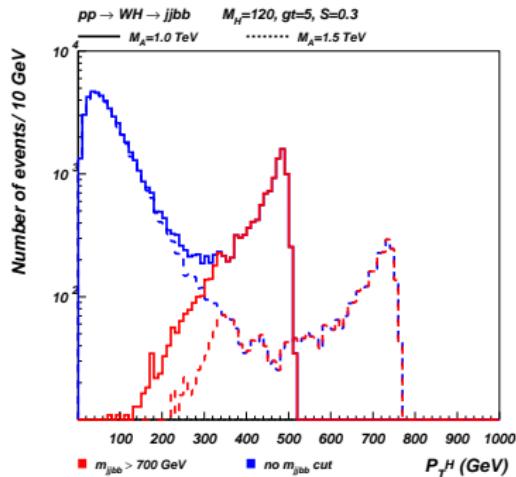


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 - $Z(\rightarrow jj)H$ with $H \rightarrow WW(ZZ)$ from a Light Composite Higgs
 - $ZH(\rightarrow b\bar{b})$ from a very Light Composite Higgs!?

HZ/HW Cross-section and resonance peaks

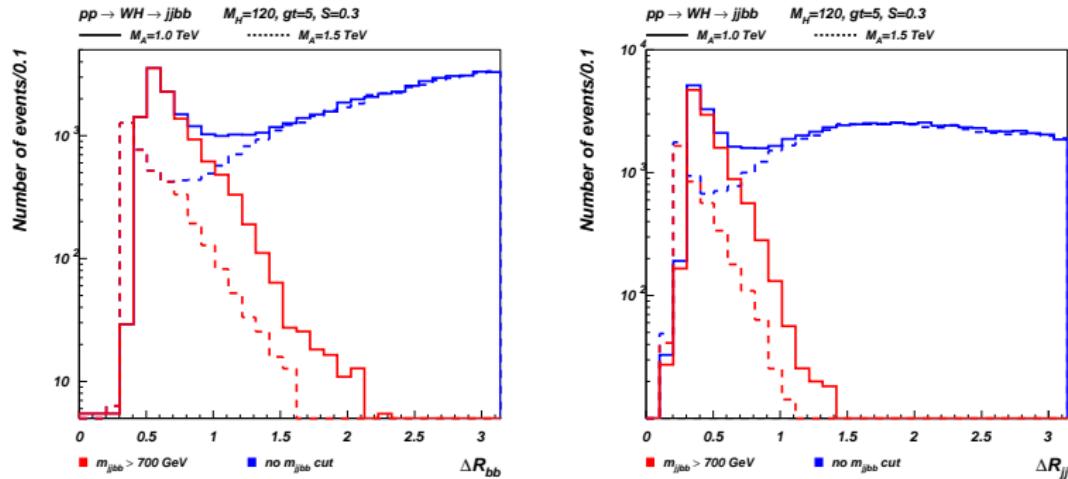


Preliminary analysis



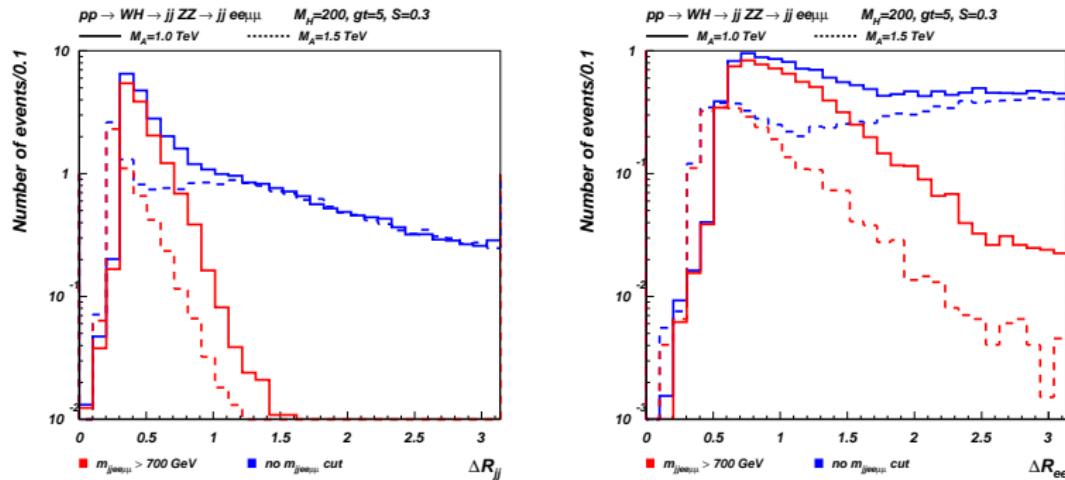
- Large Higgs transverse momenta peaked at $p_T(H) \sim M_{R_1}/2$ (Belyaev, M.T.F and Sherstnev in progress)

Preliminary analysis



- ΔR_{bb} and ΔR_{jj} accordingly small in the $b\bar{b}$ channel: Peaked at $b\bar{b}$ $\Delta R_{bb} \sim 4M_H/M_{R_1}, \Delta R_{jj} \sim 4M_Z/M_{R_1}$
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Preliminary analysis



- Boost analysis also relevant when $M_H > 2M_W$ for the W associated with H and for the Z' s
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- Hadronic decay modes are important to increase resonance signals with special analysis needed for $W/Z \rightarrow \text{jets}$, $H \rightarrow bb$, $H \rightarrow WW/ZZ \rightarrow \text{jets}$

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- Model implementations available for detailed analysis