Searching for the doubly-charged Higgs bosons in the Georgi-Machacek model at the ep colliders

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Outline

1. Motivation
2. The Georgi-Machacek model
3. Calculation Framework
4. Summary

Motivation

Deviations from SM expectation 

Electroweak symmetry breaking

Mass of elementary particle

Minimal Higgs sector 

Extended Higgs sector

the origin of neutrino mass

the identity of dark matter

relationship with undiscovered sector

…… 

Motivation

How to Extend Higgs sector

SM Higgs boson(iso-doublet) +
- iso-singlet: NMSSM,B-L Higgs
- iso-doublet: MSSM, 2HDM
- higher isospin multiplet: Higgs Triplet,GM

In order to construct on extended Higgs sector, the following two requirements from the experimental data should be taken into account.

- ρ parameter is very close to unity
- FCNC is suppressed

The Georgi-Machacek model

$$\begin{cases} \text{the complex doublet } \left(\phi^{+}, \phi^{0}\right)^{T} \text{ with Y=1} \\ \text{the real triplet } \left(\xi^{+}, \xi^{0}, -\xi^{+*}\right)^{T} \text{ with Y=0} \\ \text{the complex triplet } \left(\chi^{++}, \chi^{+}, \chi^{0}\right)^{T} \text{ with Y=2} \end{cases}$$

$SU(2)_L \times SU(2)_R$ covariant forms of the fields:

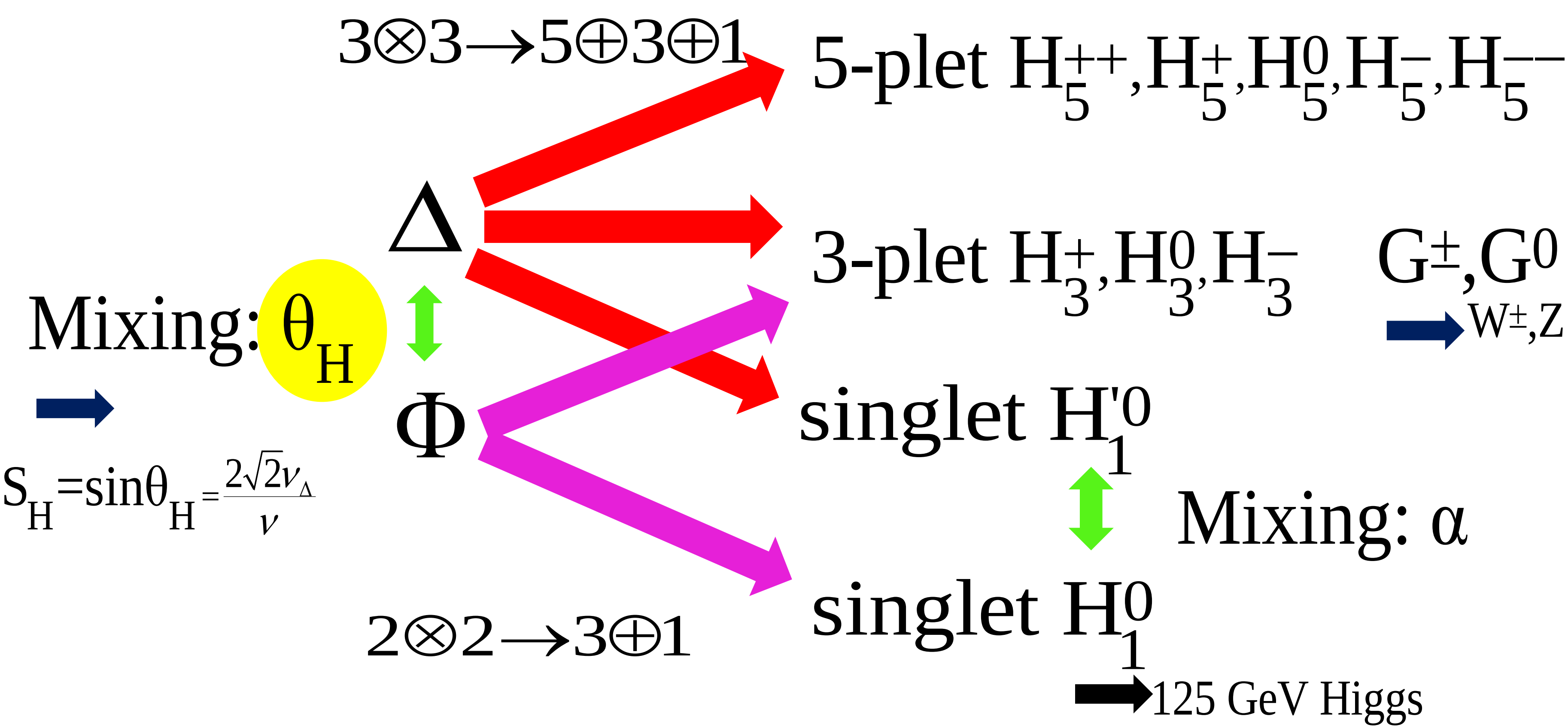
$$\Phi = \begin{pmatrix} \phi^{0*}, \phi^{+} \\ \phi^{+*}, \phi^{0} \end{pmatrix} \qquad \Delta = \begin{pmatrix} \chi^{0*}, & \xi^{+}, & \chi^{++} \\ -\chi^{+*}, & \xi^{0}, & \chi^{+} \\ \chi^{++*}, & -\xi^{+*}, & \chi^{0} \end{pmatrix}$$

$$L = 1/2 \mathrm{Tr}[(D^{\mu}\Phi)^{\dagger} D_{\mu}\Phi] + 1/2 \mathrm{Tr}[(D^{\mu}\Delta)^{\dagger} D_{\mu}\Delta] - V(\Phi, \Delta)$$

$$\begin{aligned} V(\Phi, X) \quad = \quad & \frac{\mu_2^2}{2} \mathrm{Tr}(\Phi^{\dagger}\Phi) + \frac{\mu_3^2}{2} \mathrm{Tr}(\Delta^{\dagger}\Delta) + \lambda_1 [\mathrm{Tr}(\Phi^{\dagger}\Phi)]^2 + \lambda_2 \mathrm{Tr}(\Phi^{\dagger}\Phi)\mathrm{Tr}(\Delta^{\dagger}\Delta) \\ & + \lambda_3 \mathrm{Tr}(\Delta^{\dagger}\Delta\Delta^{\dagger}\Delta) + \lambda_4 [\mathrm{Tr}(\Delta^{\dagger}\Delta)]^2 - \lambda_5 \mathrm{Tr}(\Phi^{\dagger}\tau^a\Phi\tau^b)\mathrm{Tr}(\Delta^{\dagger}t^a\Delta t^b) \\ & - M_1 \mathrm{Tr}(\Phi^{\dagger}\tau^a\Phi\tau^b)(U\Delta U^{\dagger})_{ab} - M_2 \mathrm{Tr}(\Delta^{\dagger}t^a\Delta t^b)(U\Delta U^{\dagger})_{ab}. \end{aligned}$$

The Georgi-Machacek model

$SU(2)_L \times SU(2)_R \xrightarrow{\text{break}} SU(2)_V$

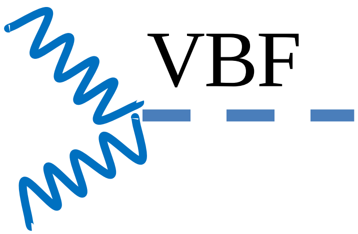


The Georgi-Machacek model

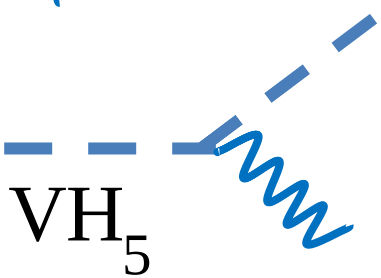
GM model features

- preserves the relationship
  $\rho = 1 \left(\rho = \frac{M^2{}_W}{M^2{}_Z \cos^2\theta_W}\right)$ at the tree level
  via SU(2) custodial symmetry

- implement the seesaw mechanism to make the neutrinos with naturally light Majorana masses (type-II seesaw)



- the tree-level couplings of the SM-like Higgs to fermions and vector bosons may be enhanced in comparison to the SM



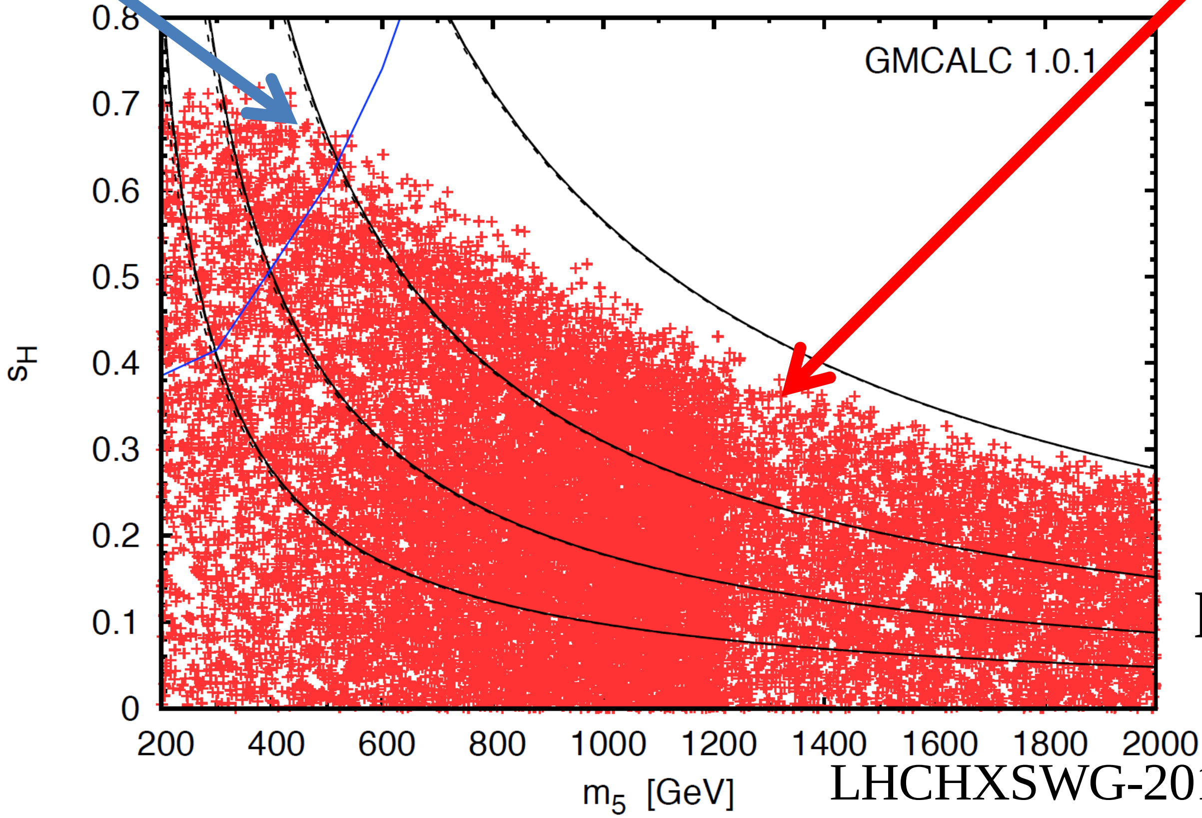
- the appearance of the $H^{\pm}W^{\mp}Z$ coupling at the tree level

- doubly charged scalar particles $\left(H_5^{\pm\pm}\right)$

The Georgi-Machacek model

Parameter scan &
GM model contraints

LHC data Exc.



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S parameter

Perturbative Unitarity

Z-pole observable $R_b = \frac{\Gamma(z \to b\bar{b})}{\Gamma(z \to \text{hadrons})}$

EW vacuum stability

B_s^0-$\bar{B}_s^0$ mixing

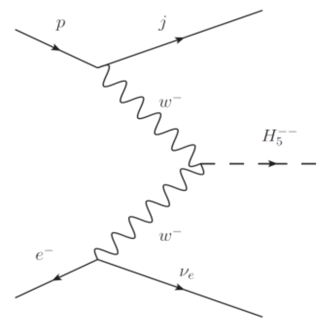
B_s^0-$\mu\bar{\mu}$

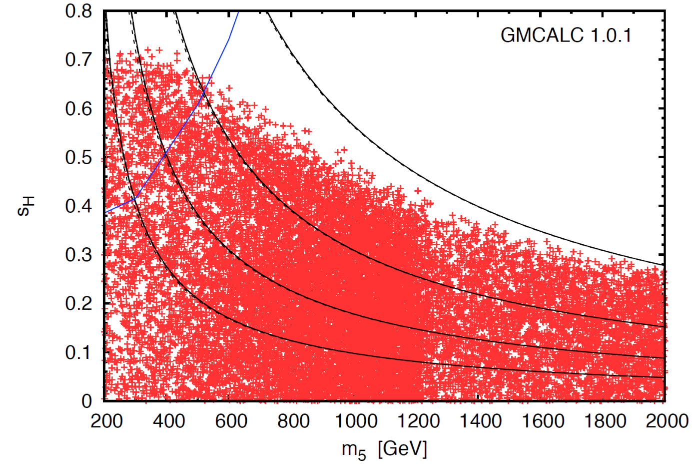
$b \to s\gamma$

$H_5^{++} W^{+*} W^{+*} = e^2 v S_H / \sqrt{2} / S_W^2$

Calculation Framework

$\sigma(e\text{-}p \to \nu_e H_5^{--} j)$

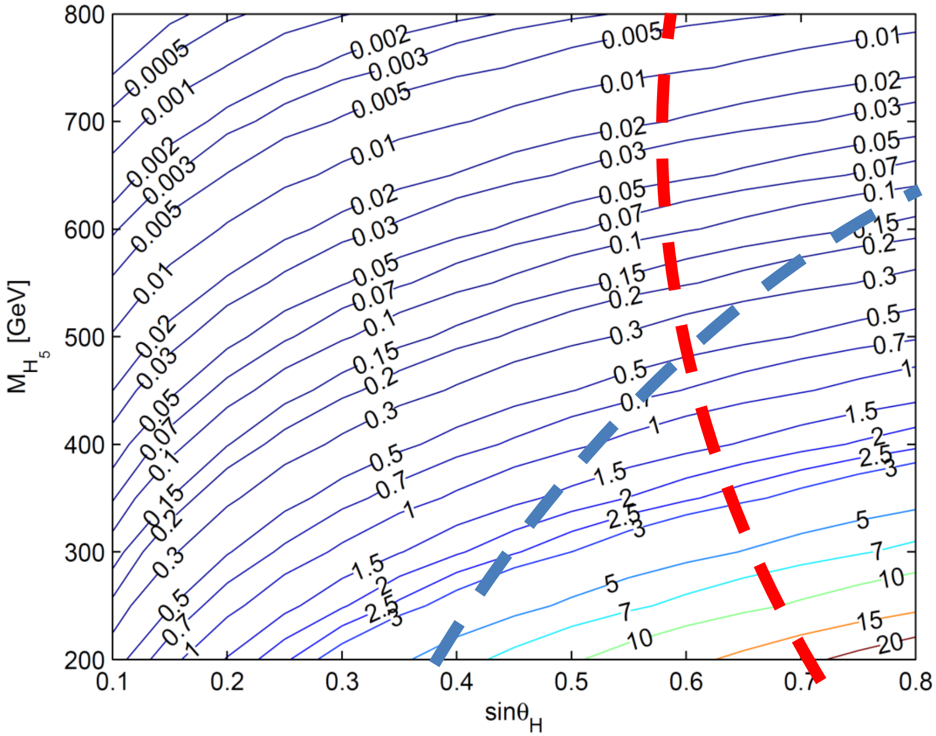


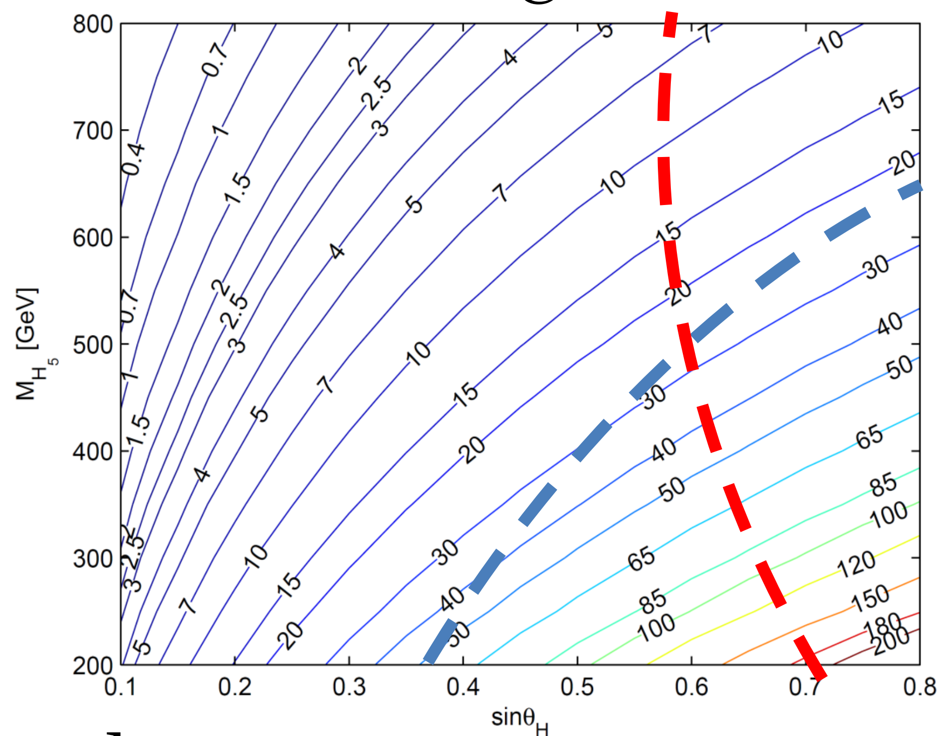


60GeV⊕7TeV@LHeC

60GeV⊕50TeV@FCC-eh

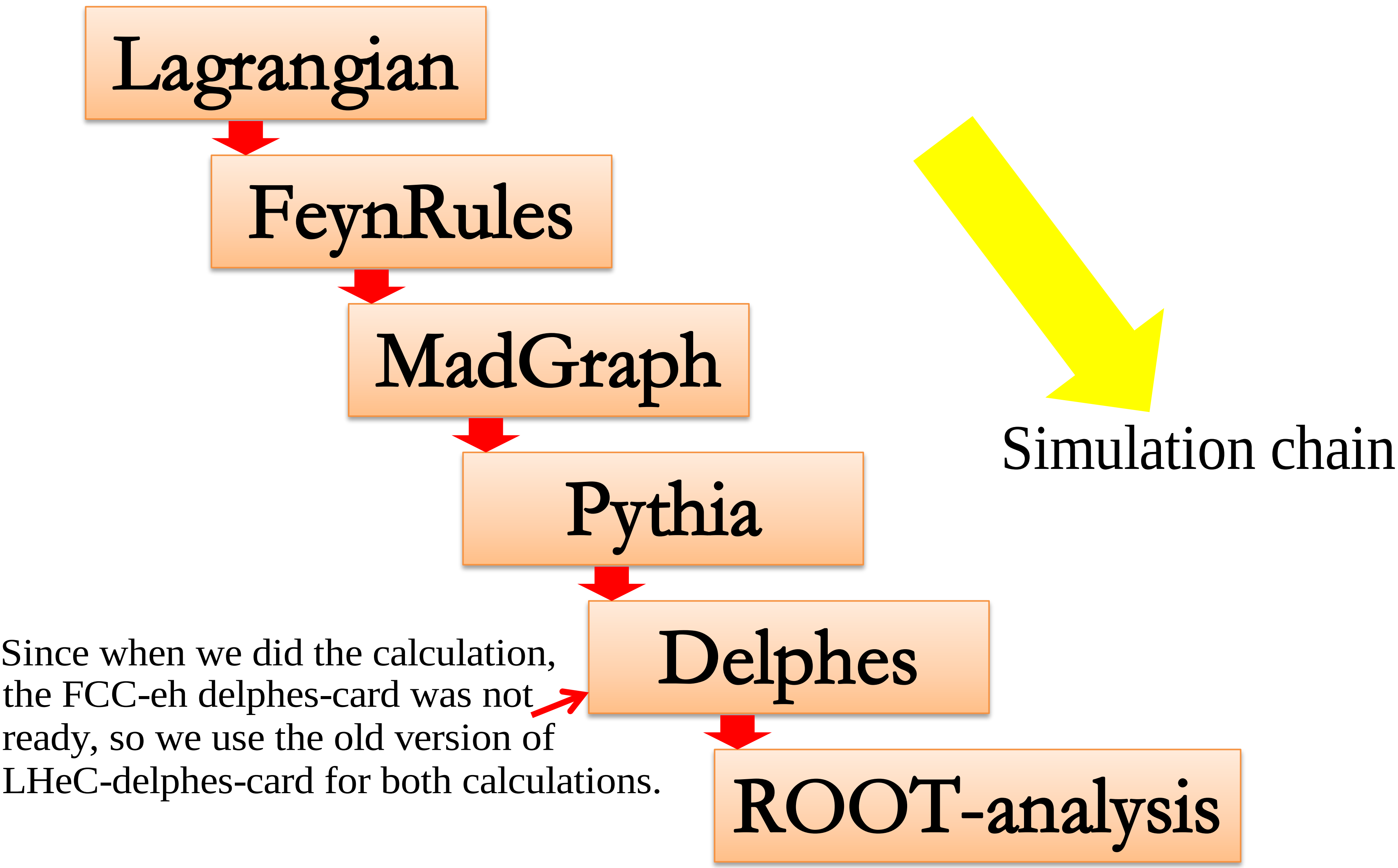
fb





Signal

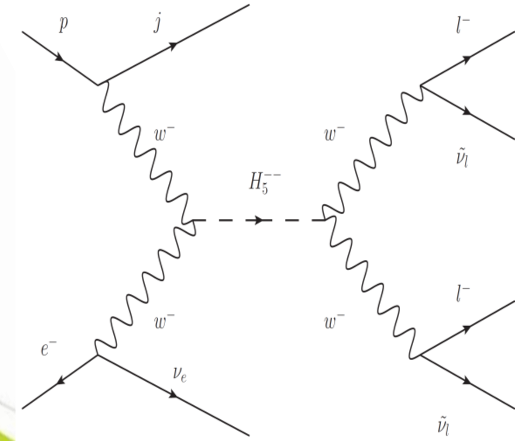
Calculation Framework



Calculation Framework

Signal

$$e^- p \to \nu_e (H_5^{--} \to W^- W^-) j \to \nu_e \bar{\nu}_\ell \bar{\nu}_\ell \ell^- \ell^- j$$



Background

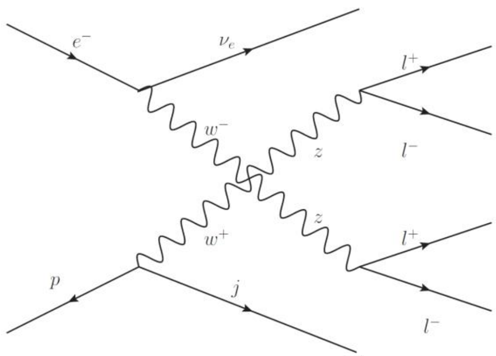
$$\nu_e jww: \quad e^- p \to \nu_e j W^- W^-$$

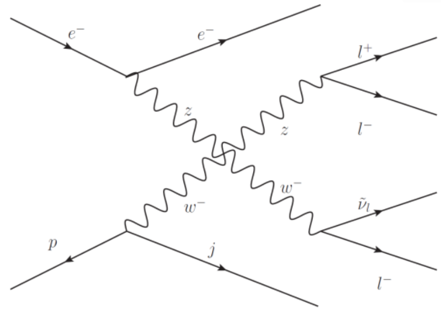
$$\nu_e jwz: \quad e^- p \to \nu_e j W^- Z$$

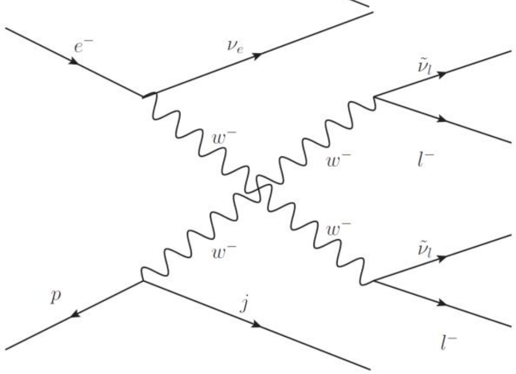
$$\nu_e jzz: \quad e^- p \to \nu_e j ZZ$$

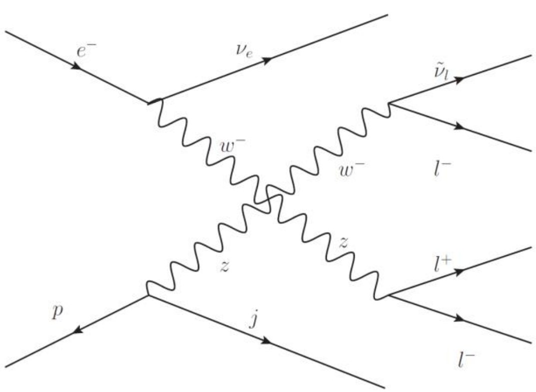
$$ejwz: \quad e^- p \to e^- j W^- Z$$

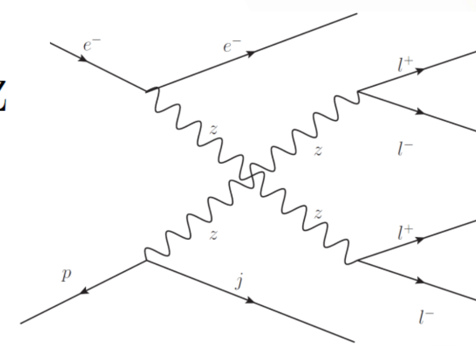
$$ejzz: \quad e^- p \to e^- j ZZ.$$





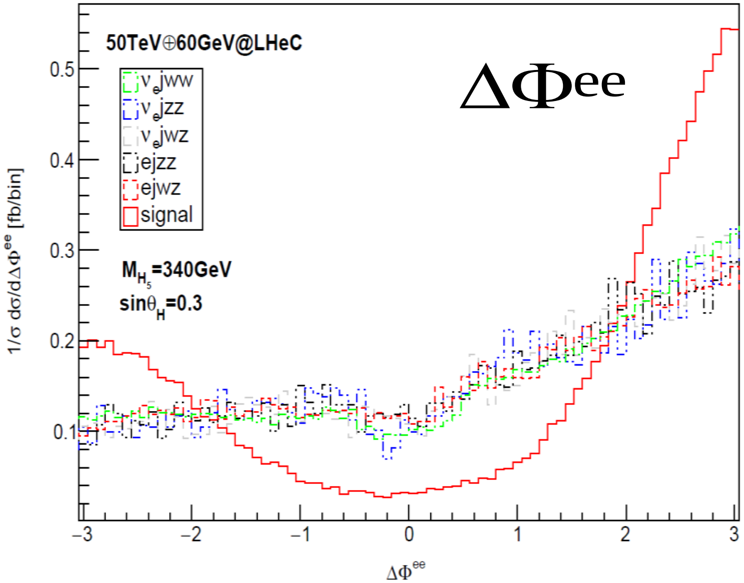


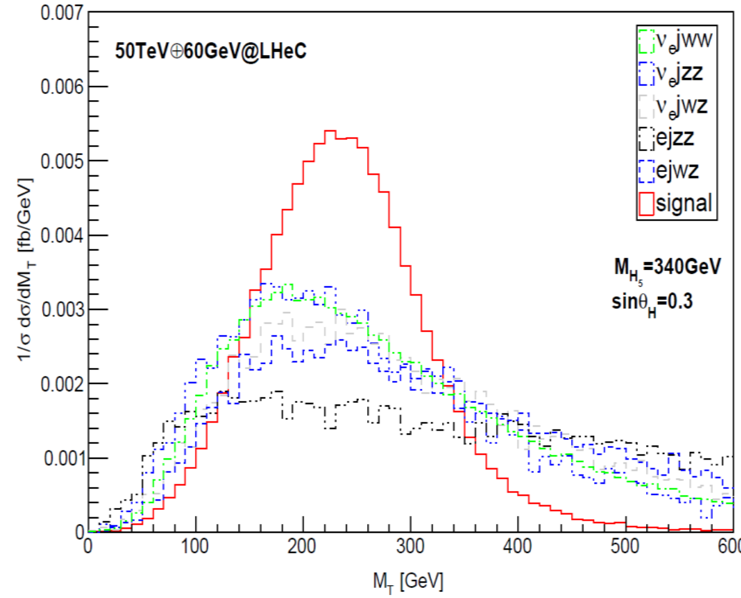


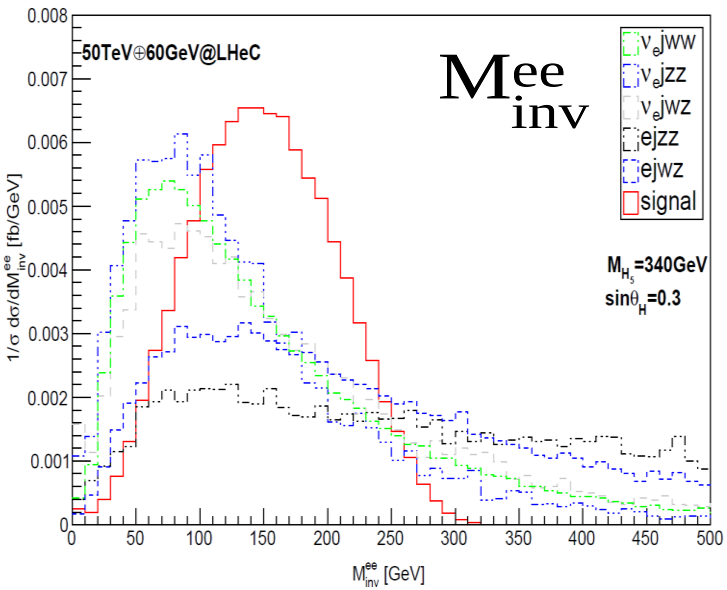


Calculation Framework

$$M^2_T=[\sqrt{M^2_{inv}+(p_T^{vis})^2}+|\not{p}_T|]^2-[p_T^{vis}+\not{p}_T]^2$$







$\not{E}_T \geq 10$GeV
$p^{j,\ell}_T \geq 10$GeV
$|\eta^j| \leq 5, |\eta^\ell| \leq 2.5,$
$\Delta R_{jj} \geq 0.4, \Delta R_{j\ell} \geq 0.4, \Delta R_{\ell\ell} \geq 0.4$

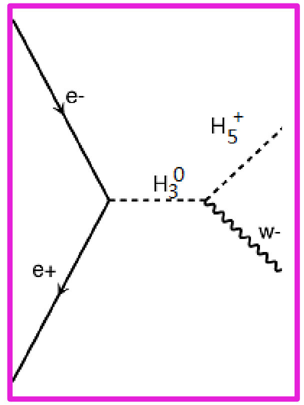
Basic cut

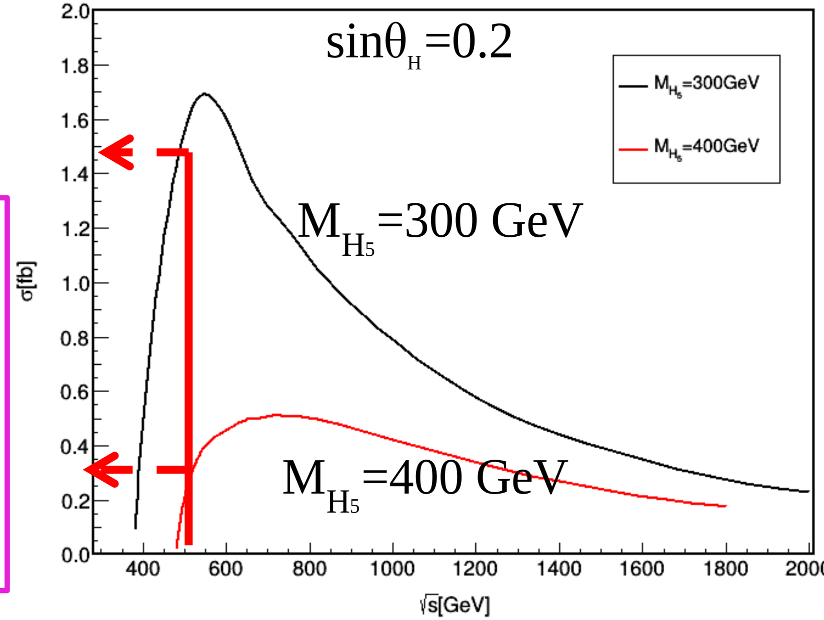
$2\ell^- + \not{E}_T + \geq 1$jet(s)
$\Delta\Phi^{\ell\ell} \in (-\pi,-1.6)$ or $(1.76,\pi)$
$M^{\ell\ell}_{inv} \in (100,280)$GeV,
$M_T \in (130,360)$ GeV

Optimized

Calculation Framework

$$\begin{cases} \sigma(e^{+}e^{-} \rightarrow H_5^{+}\, W^{-}) \\ \sigma(e\text{-}p \rightarrow \nu_e H_5^{-}\, \text{-}j) \end{cases}$$

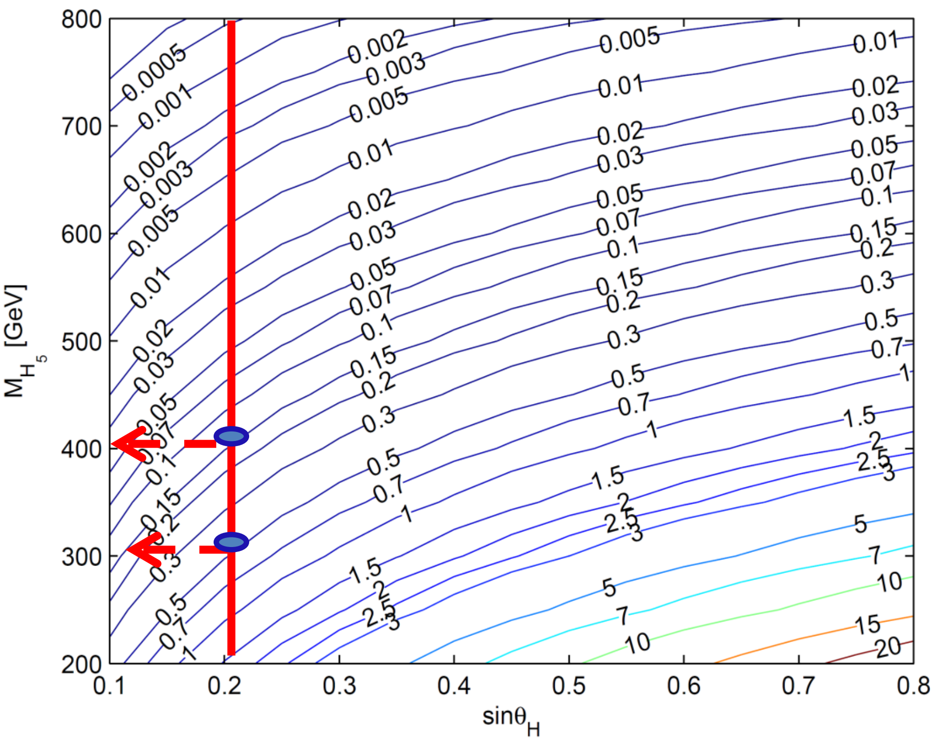


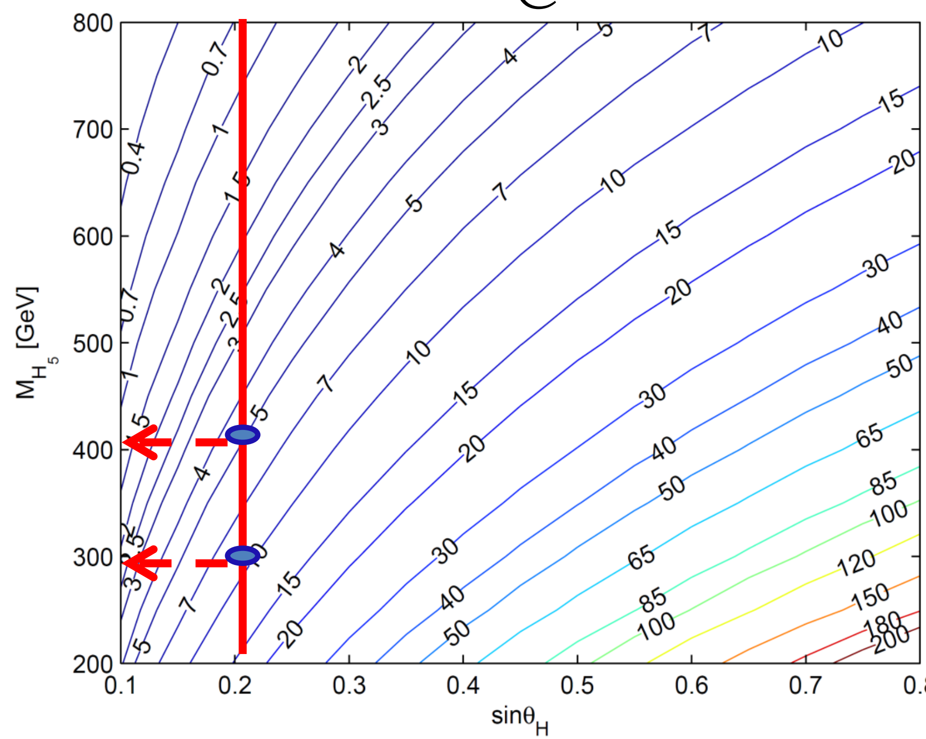


60GeV⊕7TeV@LHeC

fb

60GeV⊕50TeV@FCC-eh

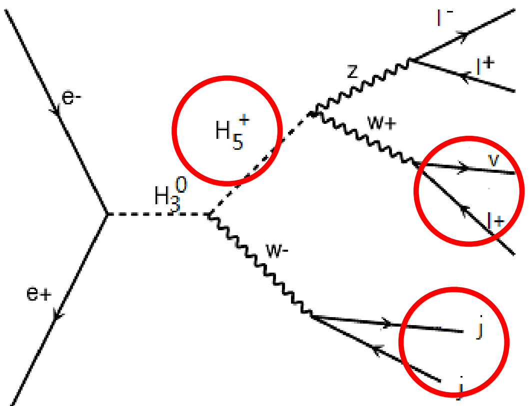


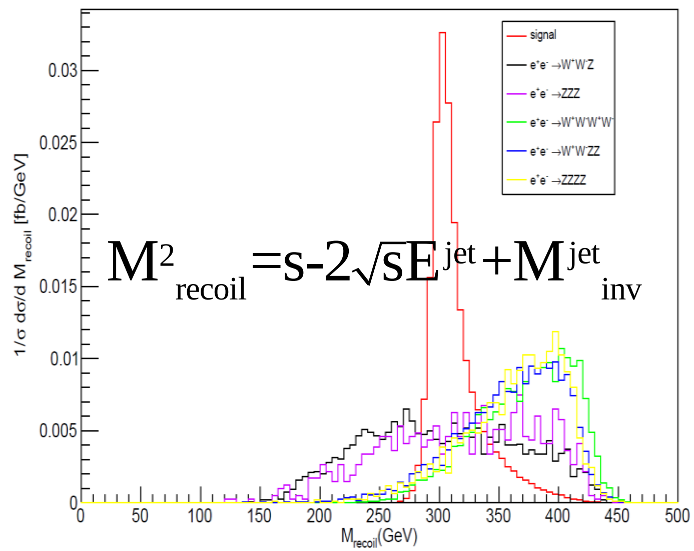


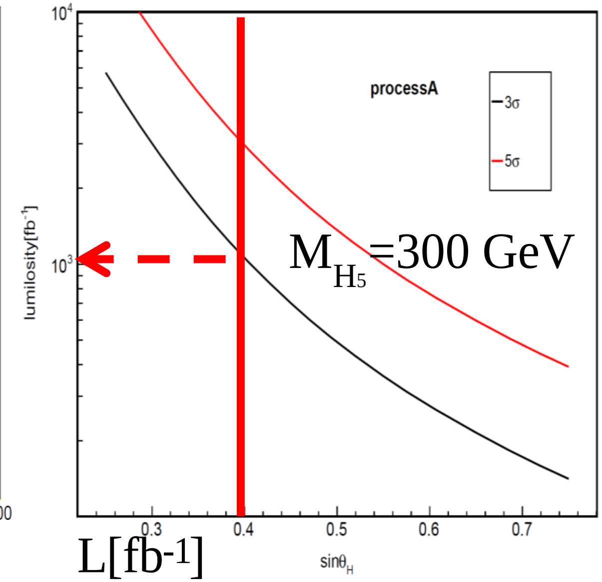
Calculation Framework

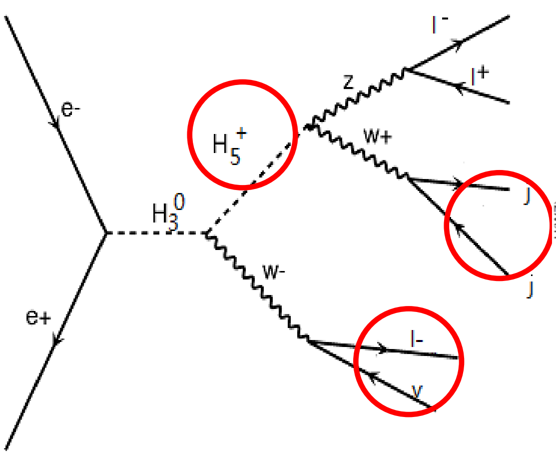
Compare to ILC

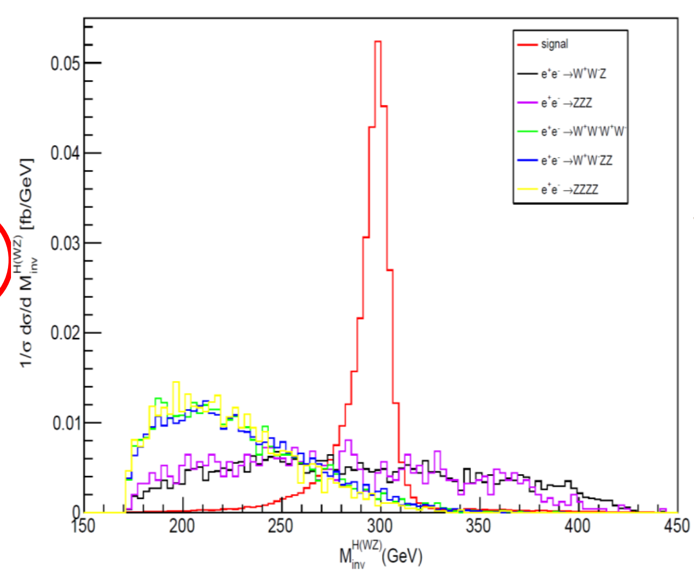
ILC delphes card used

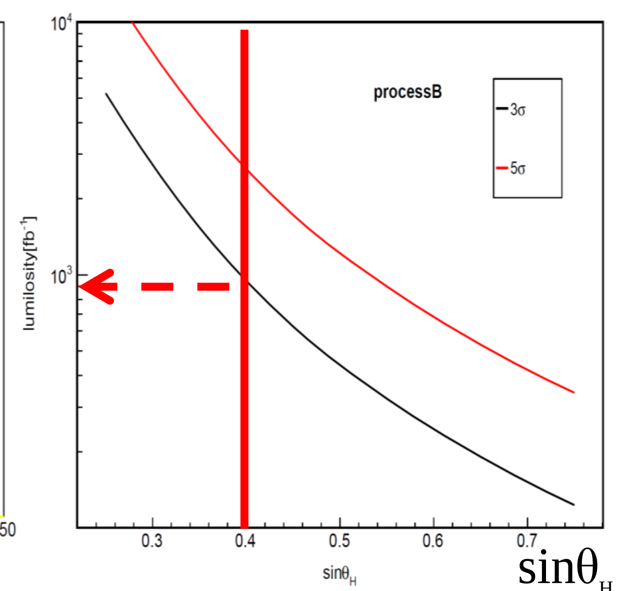








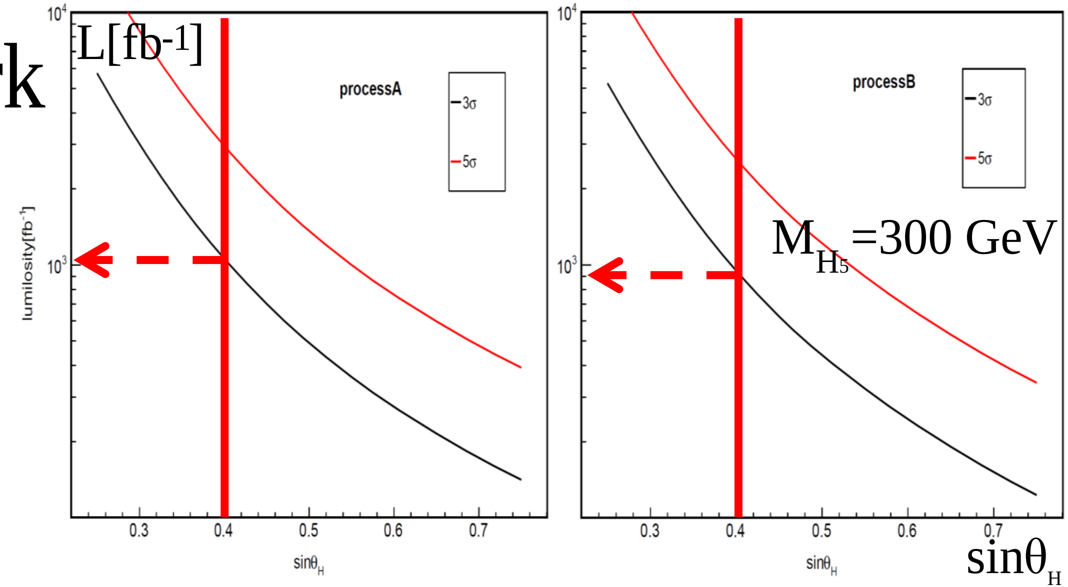


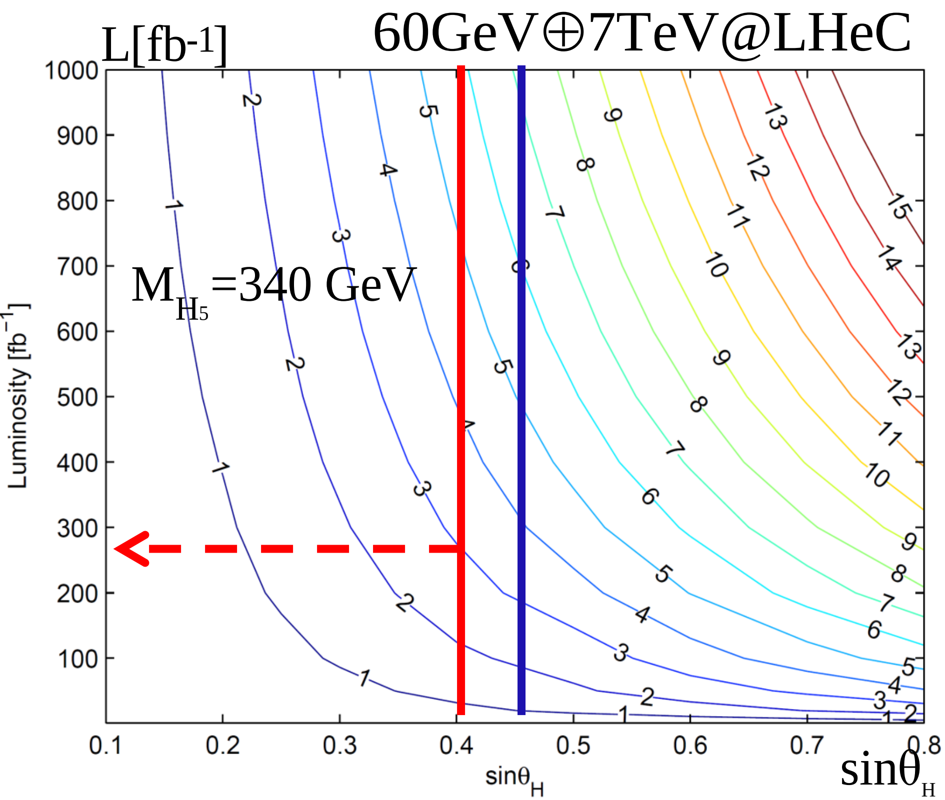


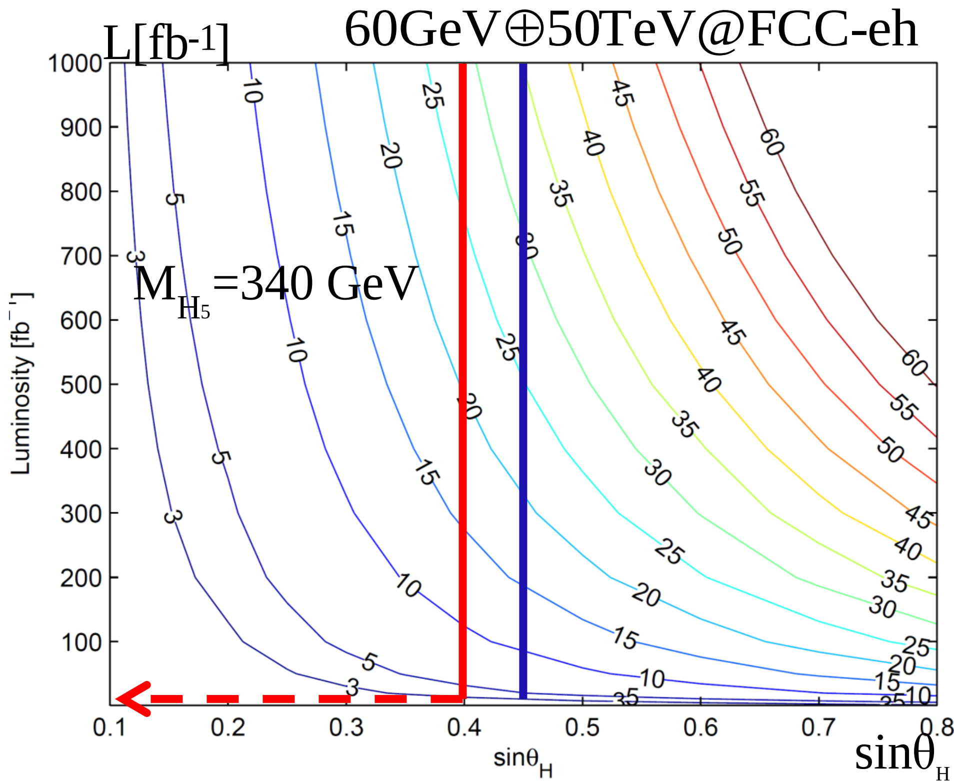
Calculation Framework

Compare to ILC

Significance in L-$\sin\theta_H$ plain



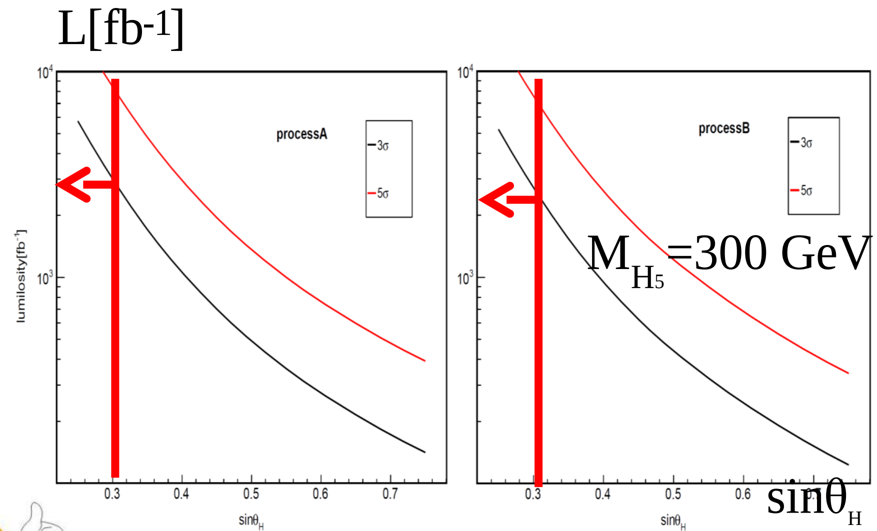




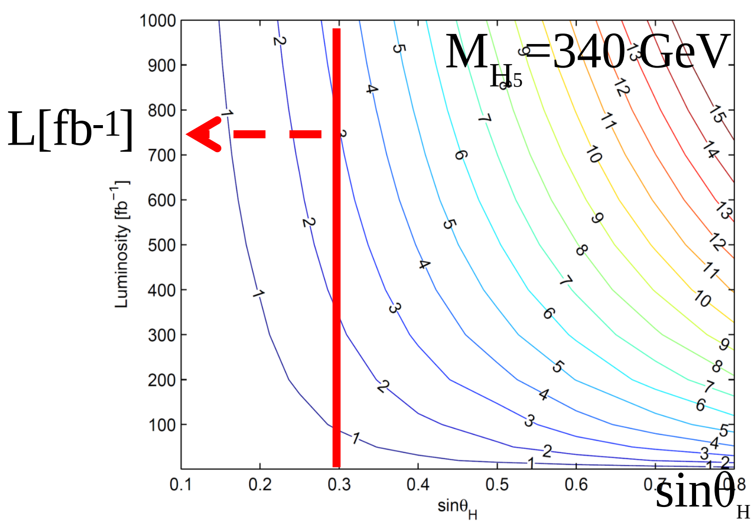
Calculation Framework

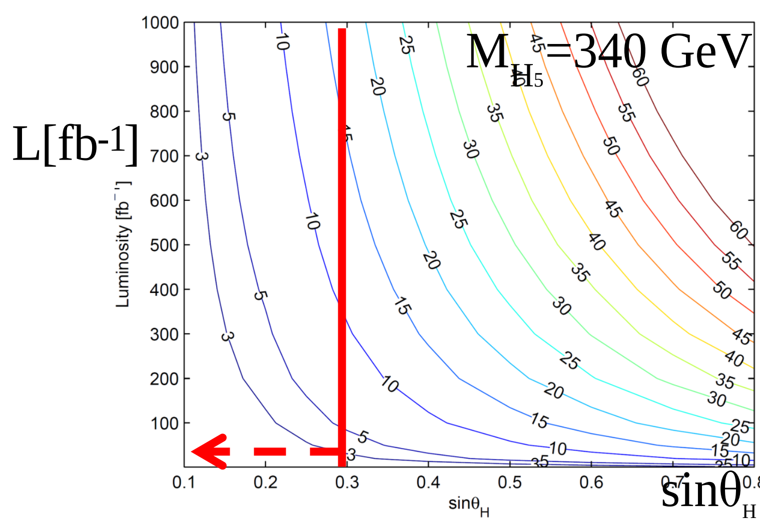
Discovery potential

The Lowest necessary Luminosity with different discovery Significance



L[fb-1]	60 GeV⊕7 TeV@LHeC		60 GeV⊕50 TeV@FCC-eh		500 GeV ILC	
	3σ	5σ	3σ	5σ	3σ	5σ
$\sin\theta_H$=0.3	**750**	**1450**	**29**	**88**	**＞2600**	**＞7225**





Summary

1. In GM, 5-plets have the doubly-charged states, so that the distinct phenomenological features should appear.

2. The LHC data will set more stringent constraints on the parameter space of its production.

3. Here we study doubly-charged Higgs boson VBF production at the ep collider and compare to a similar 5-plet HV associate production at the ILC.

4. We found that at the FCC-eh, the lowest necessary luminosity with the same discovery significance are much reduced than that of LHeC as expected, while both of them are much smaller than that of ILC.


Thanks!