Probing Bottom Quark Yukawa Couplings at Future Electron-Proton Colliders

Two Days with Particle Physics Workshop
at Shahid Beheshti University

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OUTLINE

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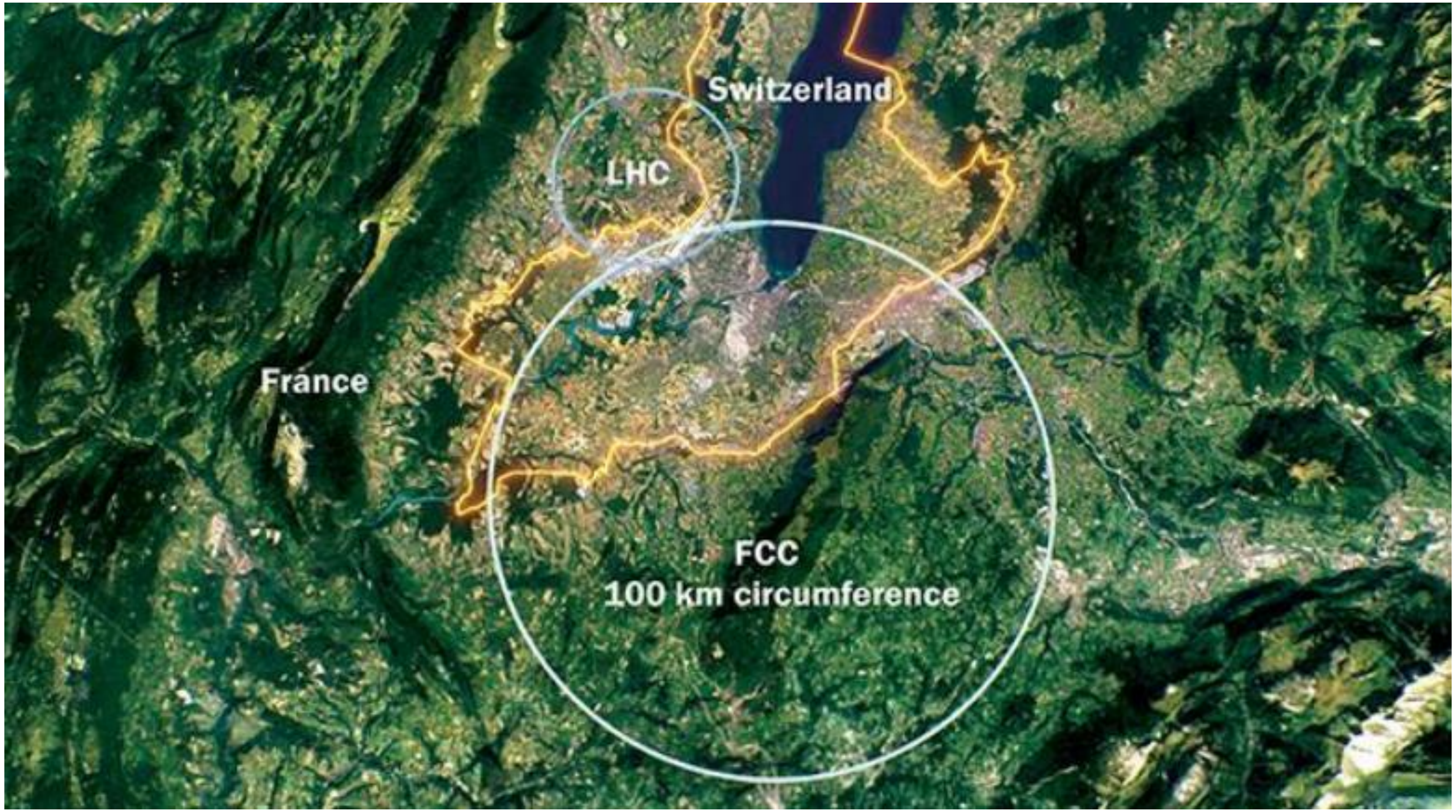
- Conclusion



INTRODUCTION

- After the Higgs boson discovery, the focus shifted toward understanding its couplings to other particles, in particular to the fermions.
- Exploring CP nature of the Higgs couplings has become very important.

CP violation in the Higgs sector → impact on baryogensis problem

The Yukawa coupling of h to the 3rd generation fermions is larger.

Therefore, studying of CP properties with them play an important role.

INTRODUCTION

A crucial aspect ⇨ Measurement of the b-quark Yukawa coupling

- To check the consistency of the SM and beyond.
- Extensive studies have been performed over the years to assess the feasibility of this measurement.
- Nevertheless, the observation of the H → bb decay remains very challenging at the LHC.

Recently, there has been a consideration for high energy ep collisions LHC.

A rich physics program

Very exciting prospects

Direct extraction of y_b

INTRODUCTION

- **Tentative schedule for the LHeC project.**

Year	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
	RF Proto Type Development												
				RF Production and Test Stand Operation									
			Magnet Preseries										
					Magnet Production and Testing								
				Legal Preparation									
						Civil Engineering							
									Infra-structure				
										Installation			
												Operation	

INTRODUCTION

- **Other ep colliders more than LHeC at CERN:**

FCC-ee | FCC-hh | FCC-eh

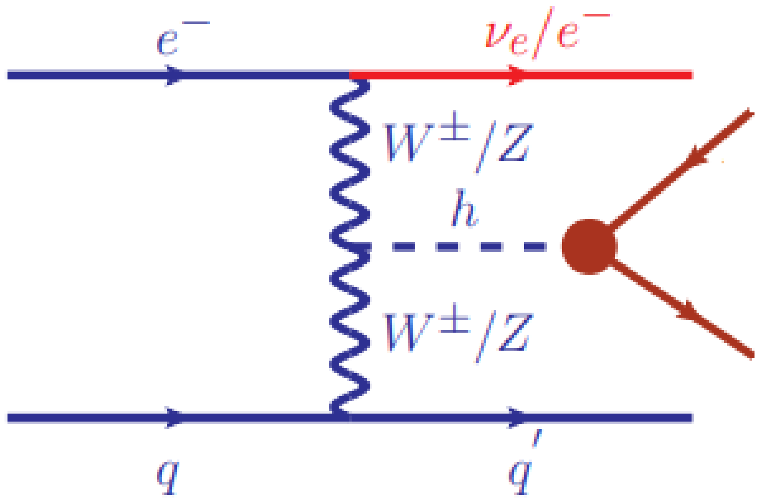
- **Benchmarks:** $\boxed{E_e = 60\,\mathrm{GeV}}$

	Unit	LHeC	HE-LHeC	FCC-eh	FCC-eh
E_p	TeV	7	13.5	20	50
$\sqrt{s}$	TeV	1.30	1.77	2.2	3.46

$$\boxed{\sqrt{s} = 2\sqrt{E_p E_e}}$$

INTRODUCTION

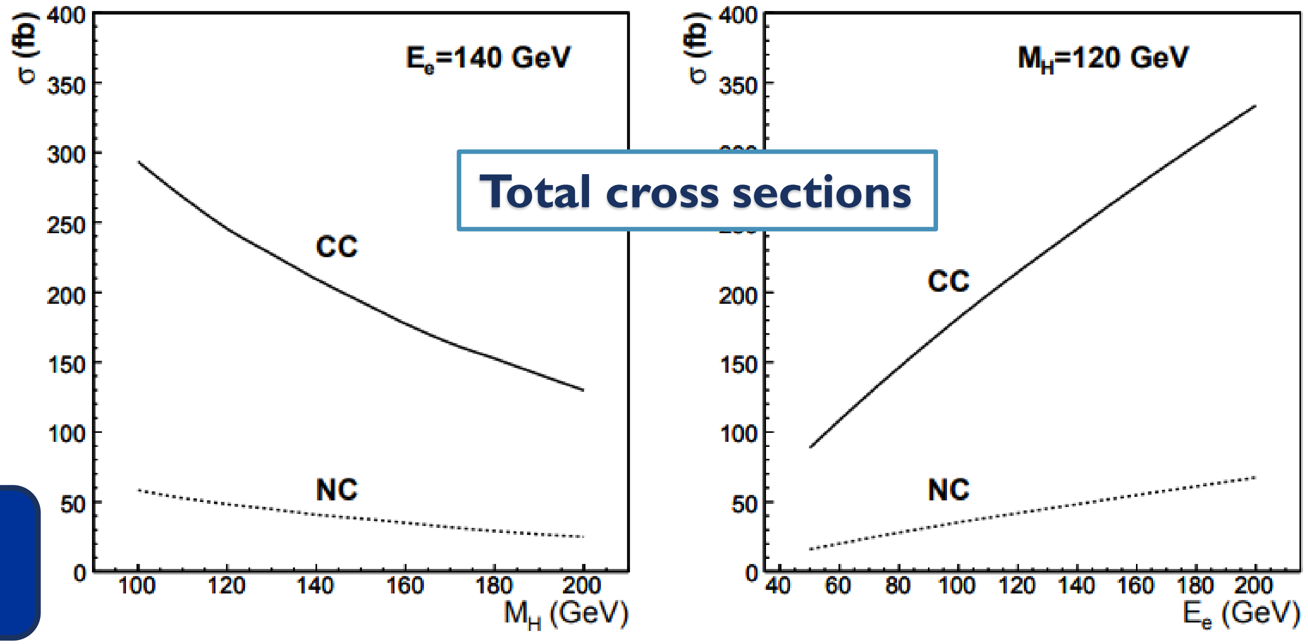
- **Higgs Production at ep collision:**
- Leading order SM diagrams for CC (NC) processes:



the production rate of CC is larger than NC process by about a factor of 4 − 6

- VBF processes:

$$\boxed{eq \to \nu_e H q' \quad \text{and} \quad eq \to eHq}$$



THEORETICAL FRAMEWORK

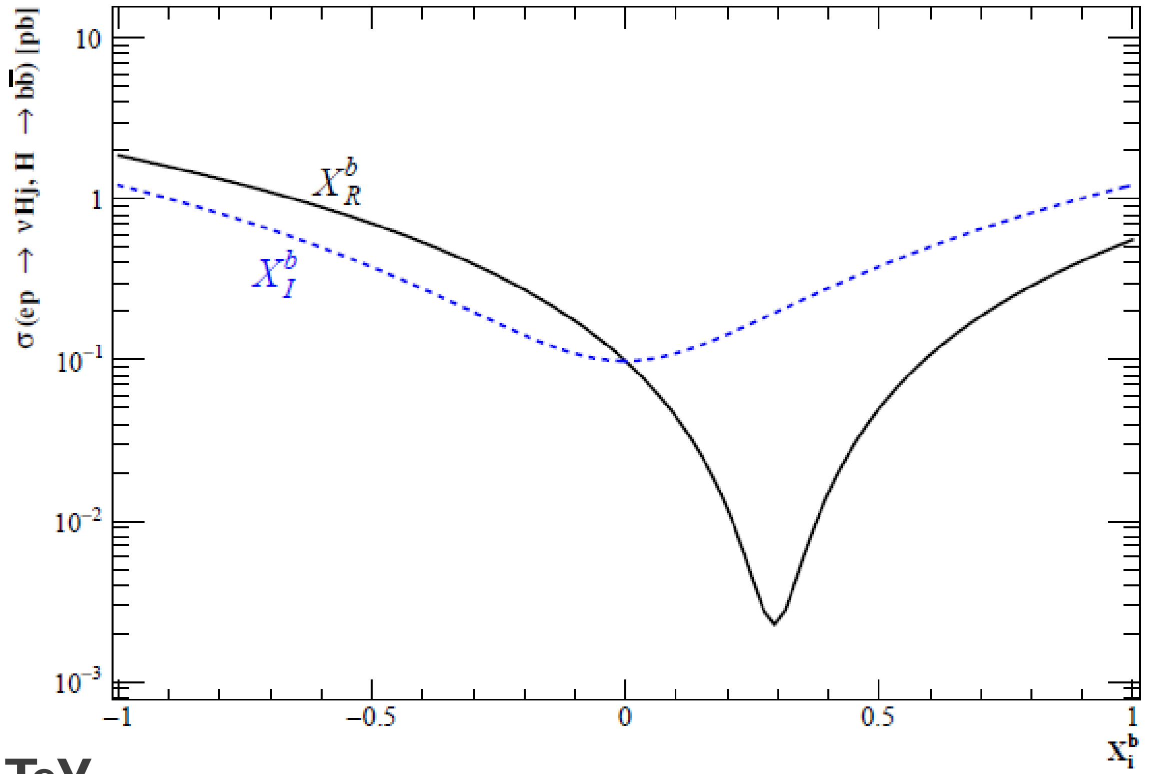
- **The effective Lagrangian for mass and Yukawa terms:**[arXiv:9909265]

$$\mathcal{L}_f = \frac{y_f v}{\sqrt{2}}\left[1+\frac{v^2}{2\Lambda^2}\frac{X_R^f+iX_I^f}{y_f}\right]\overline{f_L}f_R+\frac{y_f}{\sqrt{2}}\left[1+\frac{3v^2}{2\Lambda^2}\frac{X_R^f+iX_I^f}{y_f}\right]\overline{f_L}f_R h$$
$$+\frac{3v}{2\sqrt{2}\Lambda^2}\left(X_R^f+iX_I^f\right)\overline{f_L}f_R hh+\frac{1}{2\sqrt{2}\Lambda^2}\left(X_R^f+iX_I^f\right)\overline{f_L}f_R hhh$$

- **Λ : the energy scale of new physics**
- **y_f :Yukawa coupling for the relevant fermion**
- **$X_{R,I}$: Real and Imaginary part of coefficients of the dimension-six terms.**

DATA SIMULATION

Effective Lagrangian → FeynRule program → Universal FeynRules Output (UFO) → MADGRAPH5_aMC@NLO → PYTHIA 8 (showering) → DELPHES 3 (ILD-like)



- **Two different signal samples ≡ Two I and R coefficients**
- **Dimension-six operator coefficients $X_{I,R}$ =0.1, with Λ = 1 TeV.**

DATA SIMULATION

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- **LHeC & FCC-eh benchmarks**

C.M. Energy (TeV)	1.3	3.46	3.46	3.46
Integrated luminosity (ab^{-1})	1.0	1.0	2.0	10.0

- **Signal process:**

$e^- p \to H j \nu_e$, where $H \to b\bar{b}$ in the effective Lagrangian

- **Background processes:**

- $e^- p \to Z j \nu_e, Z \to b\bar{b}$
- $e^- p \to Z j \nu_e, Z \to c\bar{c}$
- $e^- p \to Z j \nu_e, Z \to jj$
- $e^- p \to b\bar{b} j \nu_e$
- $e^- p \to c\bar{c} j \nu_e$
- $e^- p \to \bar{t} j \nu_e, \bar{t} \to W^- \bar{b}, W^- \to jj$
- $e^- p \to H j \nu_e, H \to b\bar{b}$ in the SM

DATA SIMULATION

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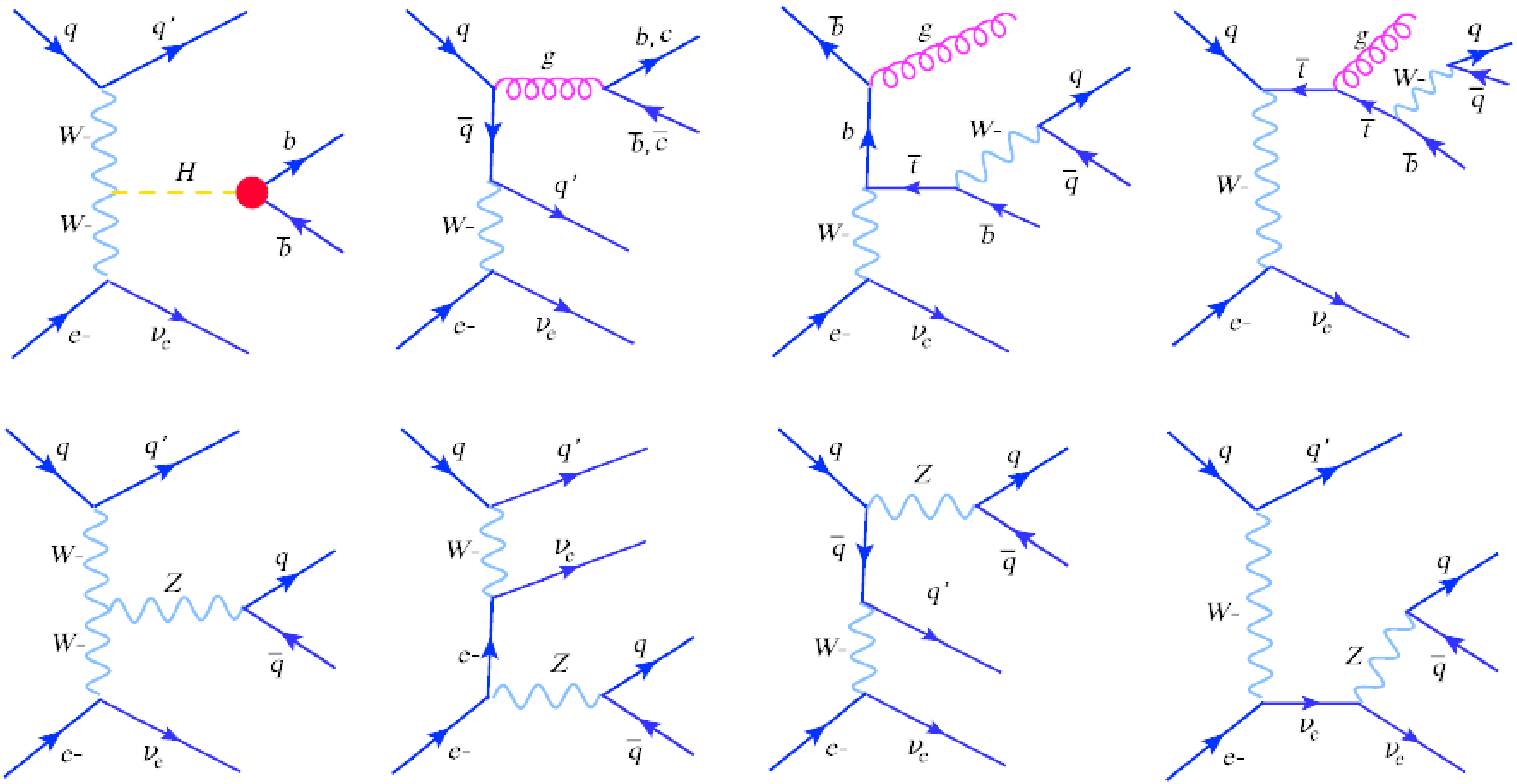


ANALYSIS STRATEGY

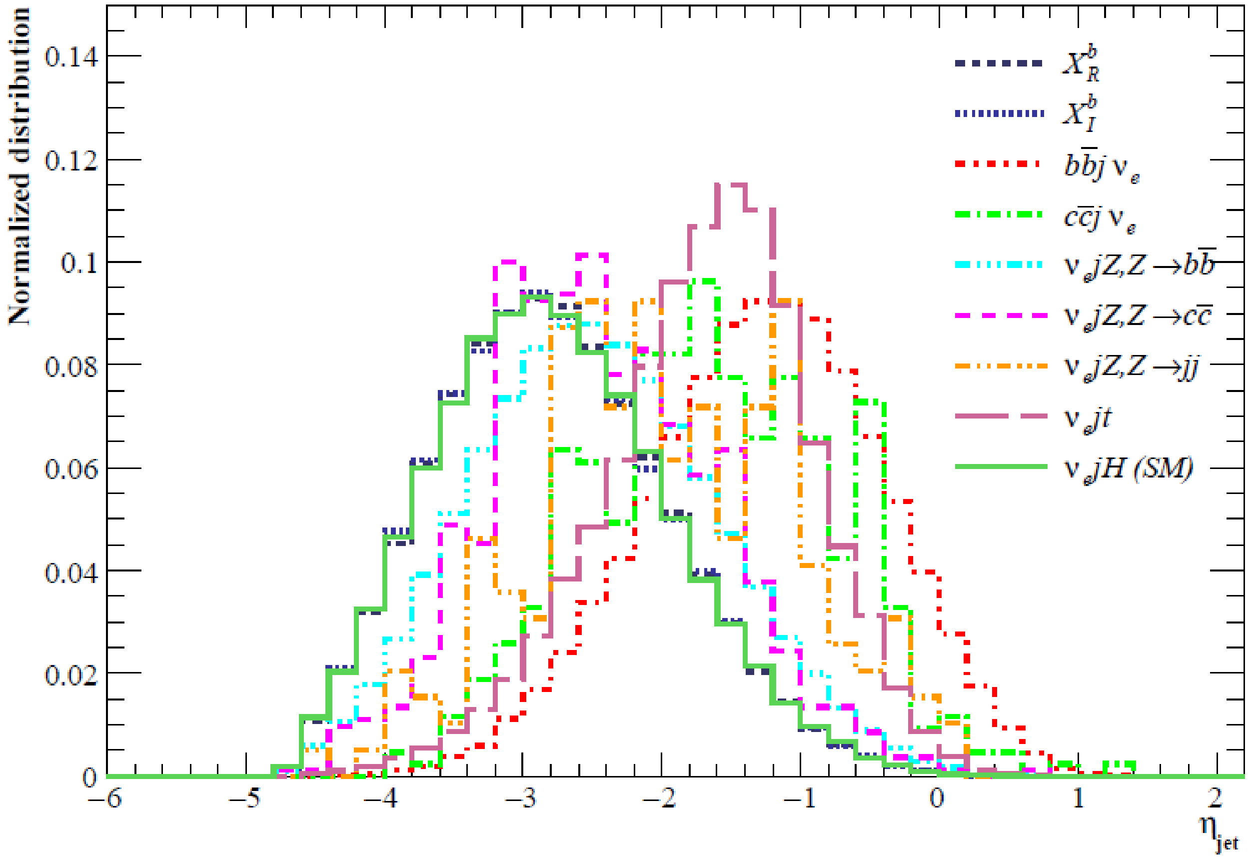
Event selection (preselection cuts)

- **Exactly 2 b-tagged jet**
- **At least 3 jets (Including 1 forward jet)**

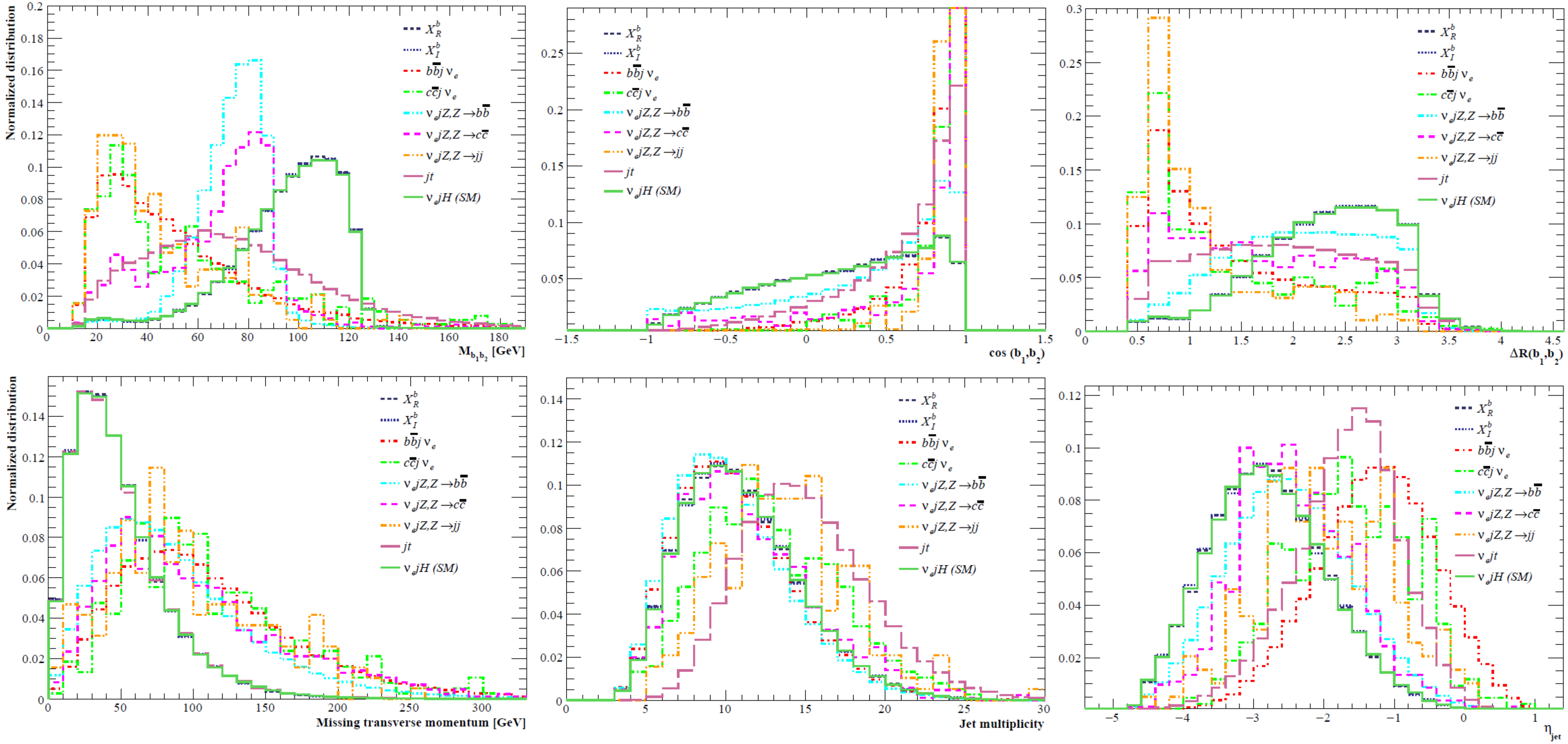
- $P_T > 20$ **GeV for all jets**
- $|\eta| \leq 2.5$ **for b-tagged jets**
- $\Delta R > 0.5$ **GeV for all objects**
- $-5 \leq \eta \leq 1$ **for forward jet**

To enhance the sensitivity, we perform a multivariate analysis (MVA)

Pseudorapidity of the forward jet in ep collision



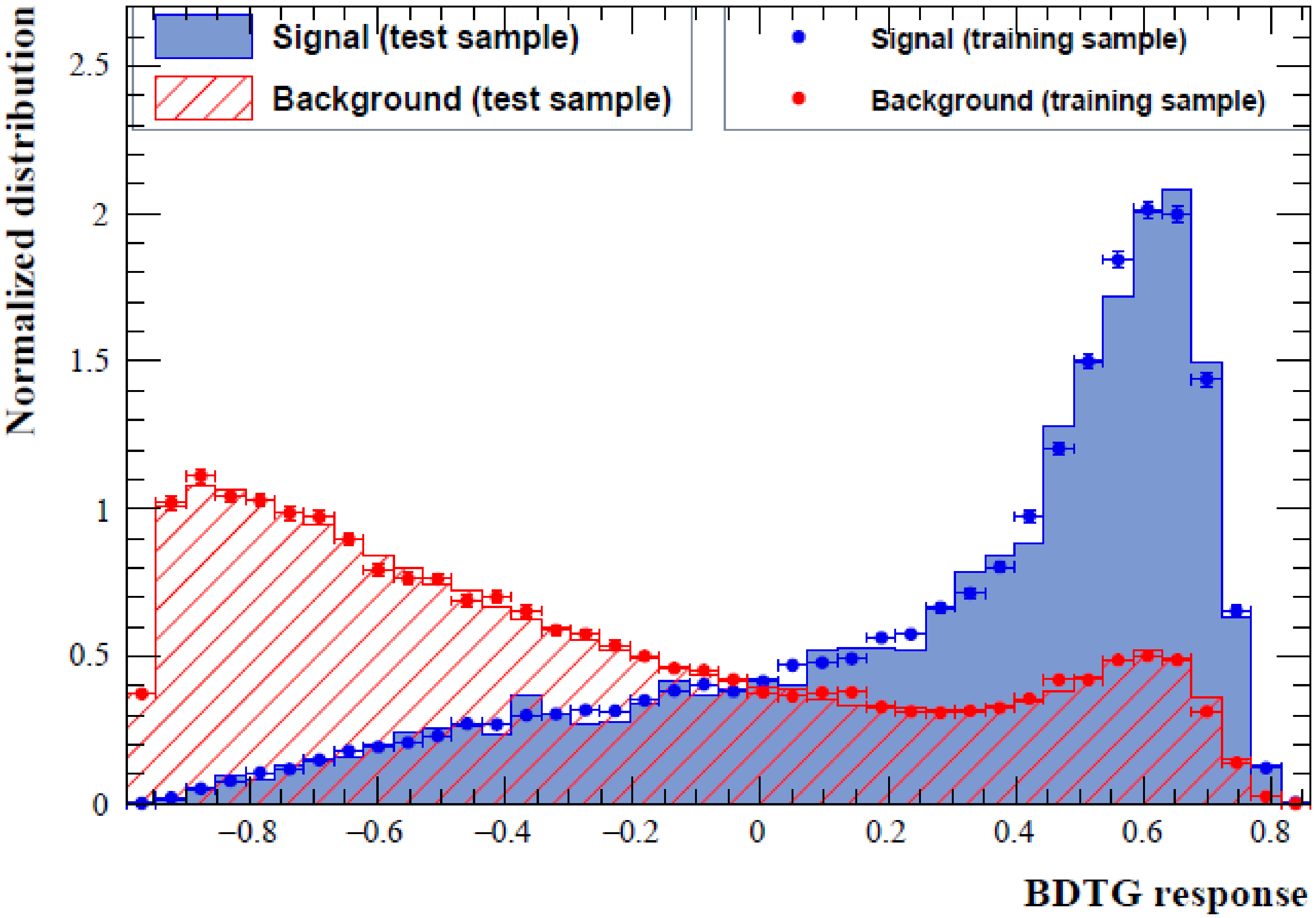
ANALYSIS STRATEGY



ANALYSIS STRATEGY

- **MVA classification output:**

Gradient Boosted Decision Tree



RESULTS

- The coefficients bounds for the center of mass energies of 1.3 and 3.46 TeV with the corresponding integrated luminosities at 95% CL.

Coefficient	1.3 TeV, 1 ab^{-1}	3.46 TeV, 1 ab^{-1}	3.46 TeV, 2 ab^{-1}	3.46 TeV, 10 ab^{-1}
X_R^b	$[-0.004, 0.542]$	$[-0.004, 0.533]$	$[-0.003, 0.532]$	$[-0.001, 0.530]$
X_I^b	$[-0.103, 0.022]$	$[-0.094, 0.022]$	$[-0.088, 0.016]$	$[-0.080, 0.008]$

- Upper limits on X_I^b is about one order of magnitude stronger, and on X_R^b is comparable with recent result in: arXiv:2003.00099

CONCLUSION

- After the Higgs boson discovery, the focus shifted toward understanding its couplings to other particles, in particular to the fermions. CP violation in the Higgs sector impact on baryogensis
- The Yukawa coupling of h to the 3rd generation fermions is larger.
- A crucial aspect is the measurement of the b-quark Yukawa coupling, and the observation of the $H \to bb$ decay remains very challenging at the LHC.
- Recently, there has been a consideration for high energy ep collisions with very exiting prospects.
- Effective Lagrangian with dimension-six operators is used to constrain b Yukawa coupling.
- Data simulation for the LHeC and FCC-eh benchmarks.
- A MVA approach with BDTG method is applied to suppress the background contributions.
- Limits at 95% CL on the coupling coefficients have been obtained for two center-of-mass energies of the LHeC and FCC-eh.
- We show that the MVA increases the sensitivity to the b-quark Yukawa couplings.


فضای هر ظرفی در اثر محتوای خود تنگ‌تر می‌شود مگر ظرف
دانش که با تحصیل علوم، فضای آن بازتر می‌گردد.
حضرت علی (ع)
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