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Testing Lepton Flavor Universality at the EIC

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OverView

Testing Lepton Flavor Universality at the EIC

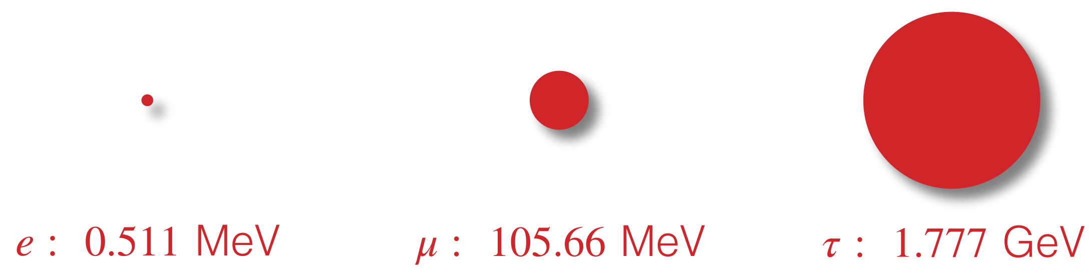
- What is LFU?
- Why to be interesting?
- Relevant Observables
- Current status

- What is EIC? Its potential?
- Collider analysis
- From a theory perspective

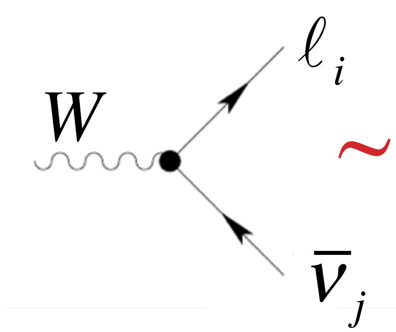
What is LFU?

Standard Model (SM): with 3 generations of leptons

- Different masses



- A universal coupling to gauge



$\sim g\delta_{ij}$

LFU: as one of the hypotheses in the SM

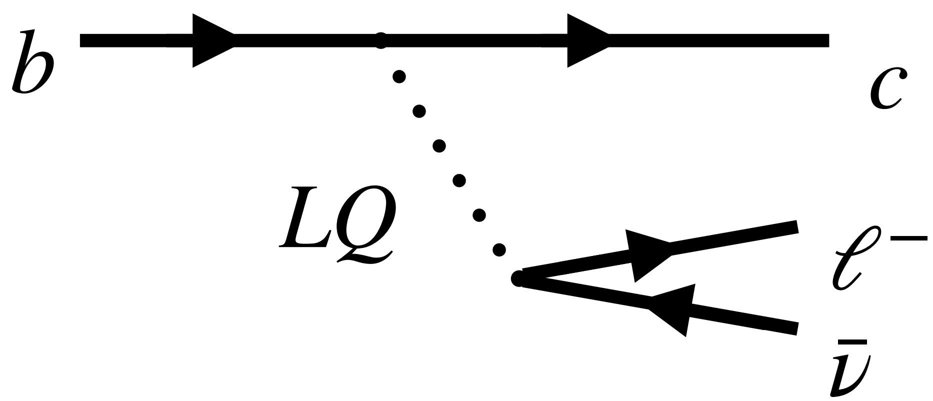
Precise measurements:

- *SM validity test*
- *Hints for BSM*

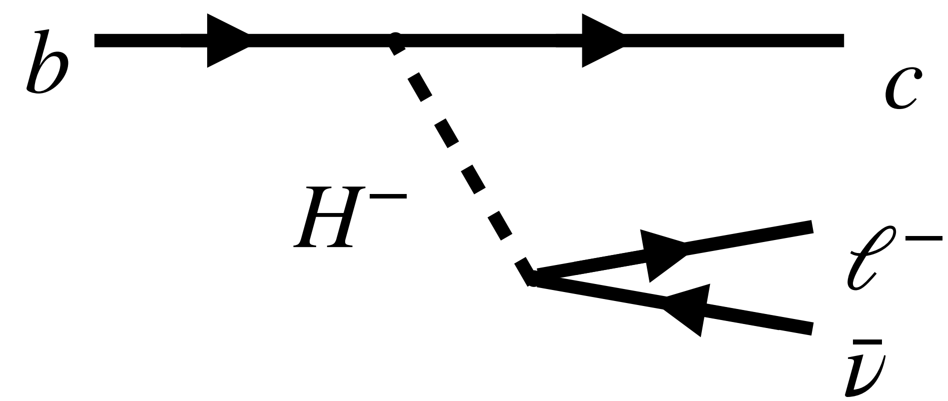
What to be interesting?

BSM: to be sensitive in flavour physics

Tree-level realisation:

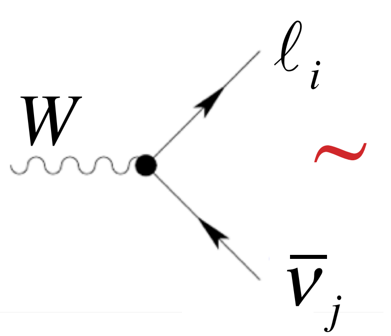


Leptoquark
(Coloured)



Extra Higgs
(Uncoloured)

SM:



$\sim g\delta_{ij}$

$$\Gamma \sim \frac{m_f^3}{\boxed{m_W^2}}$$

To be replaced by Λ_{NP}

As the new particle mass scale?

Decays: to be changed significantly!

Relevant Observables

Flavour Changing Charged Current:

$$R_{H_c} = \frac{\mathrm{Br}(H_b \to H_c \tau \nu)}{\mathrm{Br}(H_b \to H_c \ell \nu)}$$

H_b hadron containing b quark

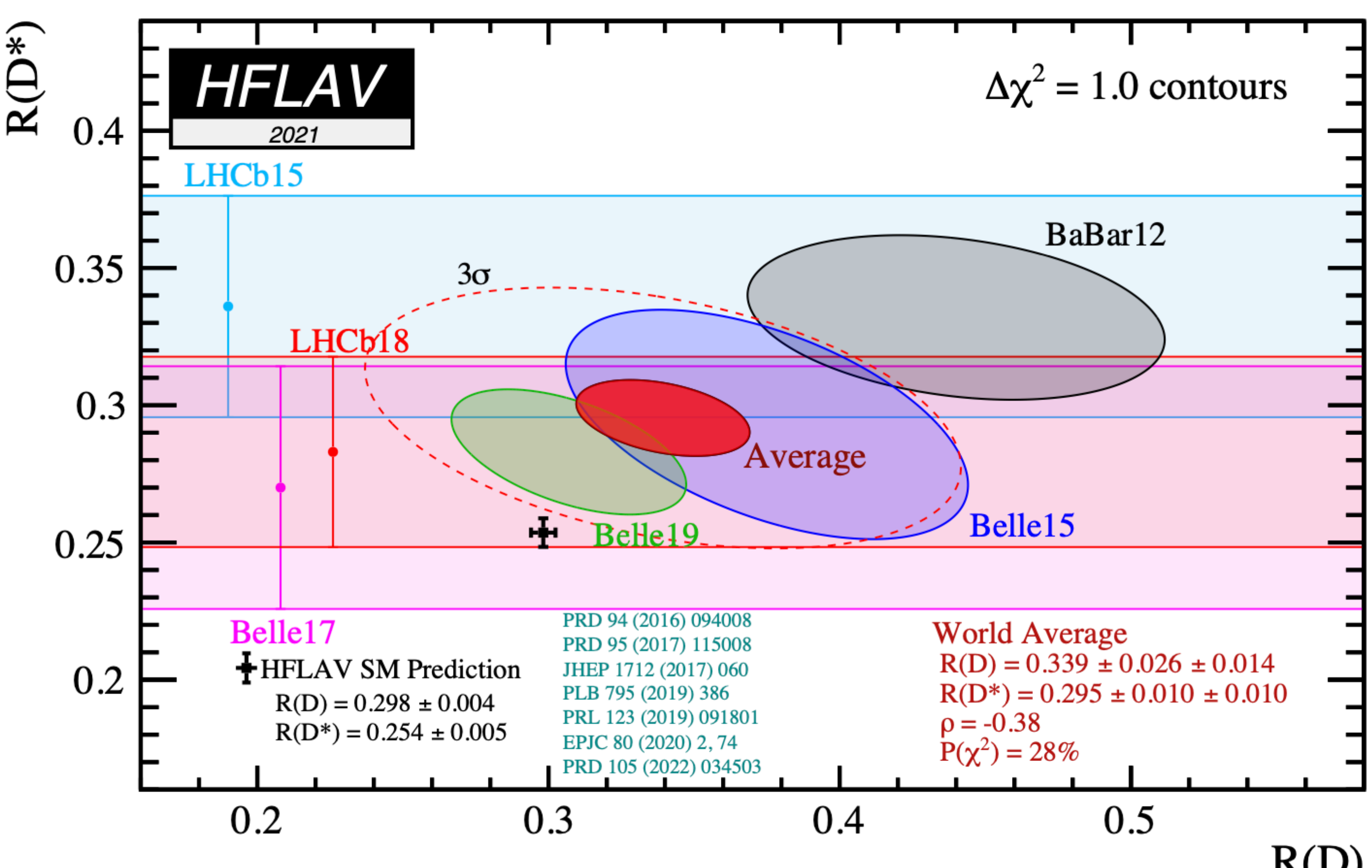
H_c hadron containing c quark

- Vector $R_{J/\psi}$ $(B_c \to J/\psi)$ $R_{D_s^*}$ $(B_s \to D_s^*)$
- Pseudoscalar R_{D_s} $(B_s \to D_s)$
- Baryonic R_{Λ_c} $(\Lambda_b \to \Lambda_c)$
- Annihilation $\mathrm{Br}(B_c \to \tau \nu)$

Current Status

	H_b	H_c	SM Prediction [2]	Experimental Average
R_D	$B^0,\ B^\pm$	$D^0,\ D^\pm$	0.307 [1, 2]	0.340 ± 0.030 [3]
R_{D^*}	$B^0,\ B^\pm$	$D^{*0},\ D^{*\pm}$	0.253 [1, 2]	0.295 ± 0.014 [3]
$R_{J/\psi}$	B_c	J/ψ	0.289 [4–6]	$0.71 \pm 0.17 \pm 0.18$ [7]
R_{D_s}	B_s	D_s	0.393 [2, 8–13]	N/A
$R_{D_s^*}$	B_s	D_s^*	0.303 [2, 8, 10, 13]	N/A
R_{Λ_c}	Λ_b	Λ_c	0.334 [14–18]	0.242 ± 0.076 [19]

[Ho, **Jiang**, Kwok, Li and Liu]



[HFLAV Collaboration]

Either averagely over 3σ,

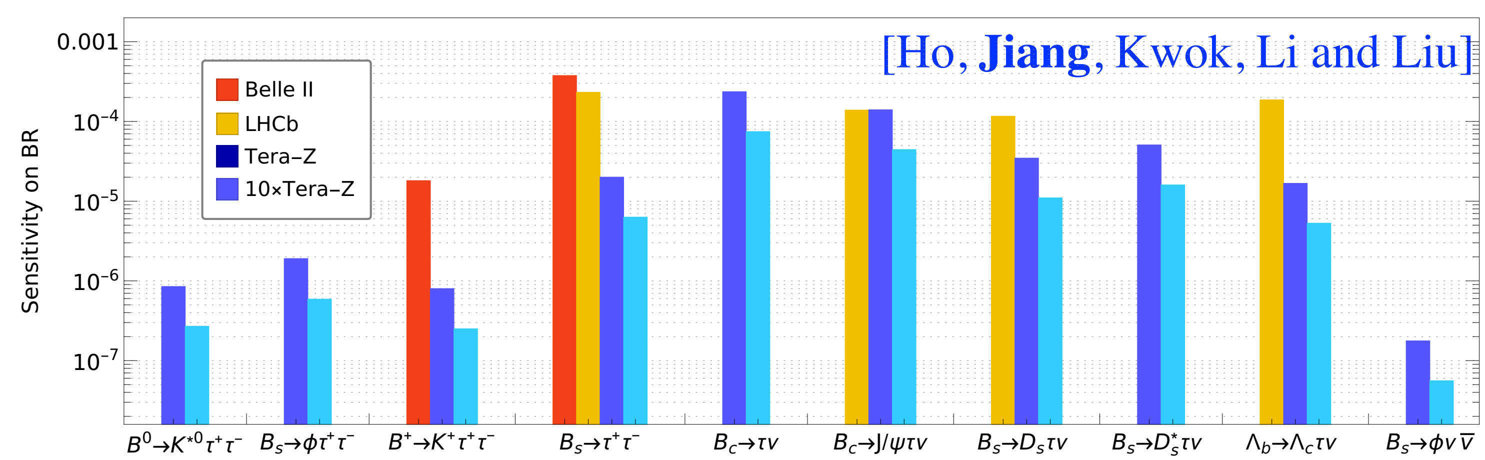
or yet unknown.

LFU-violating BSM or fluctuations?

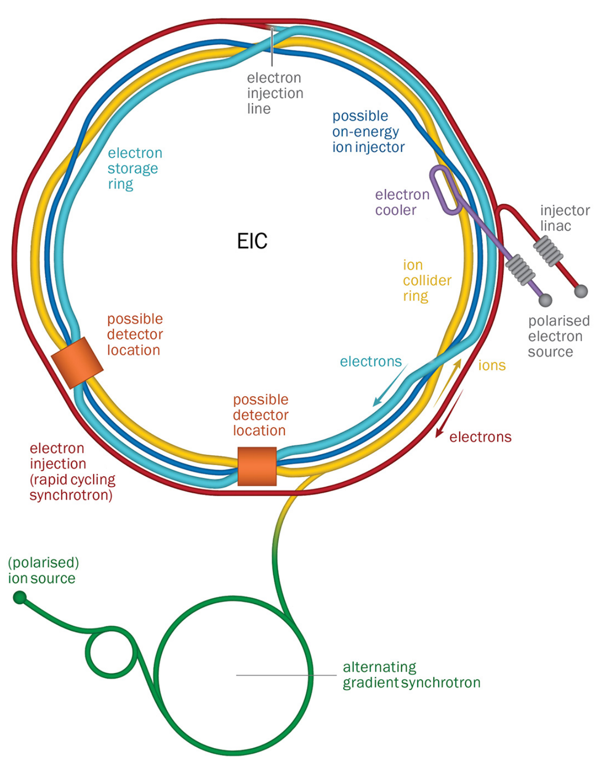
Facilities

Already many measurements...

See Qidong's talk



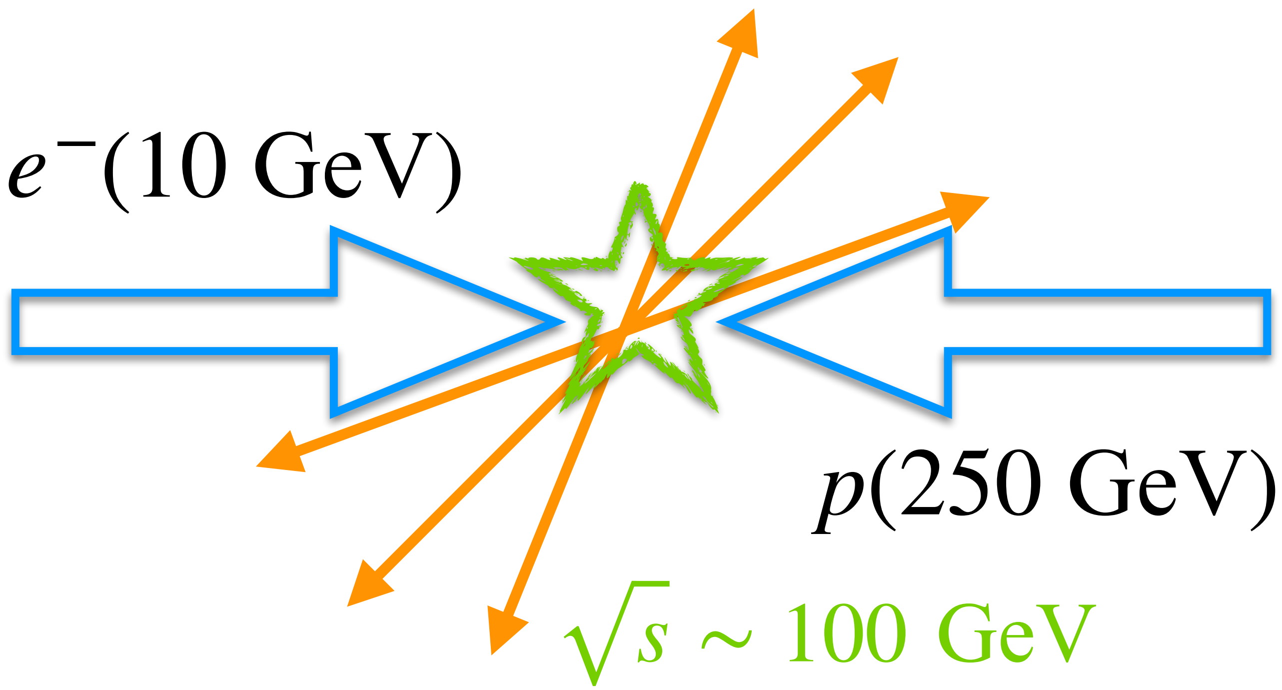
What about Electron-Ion Collider (EIC)?

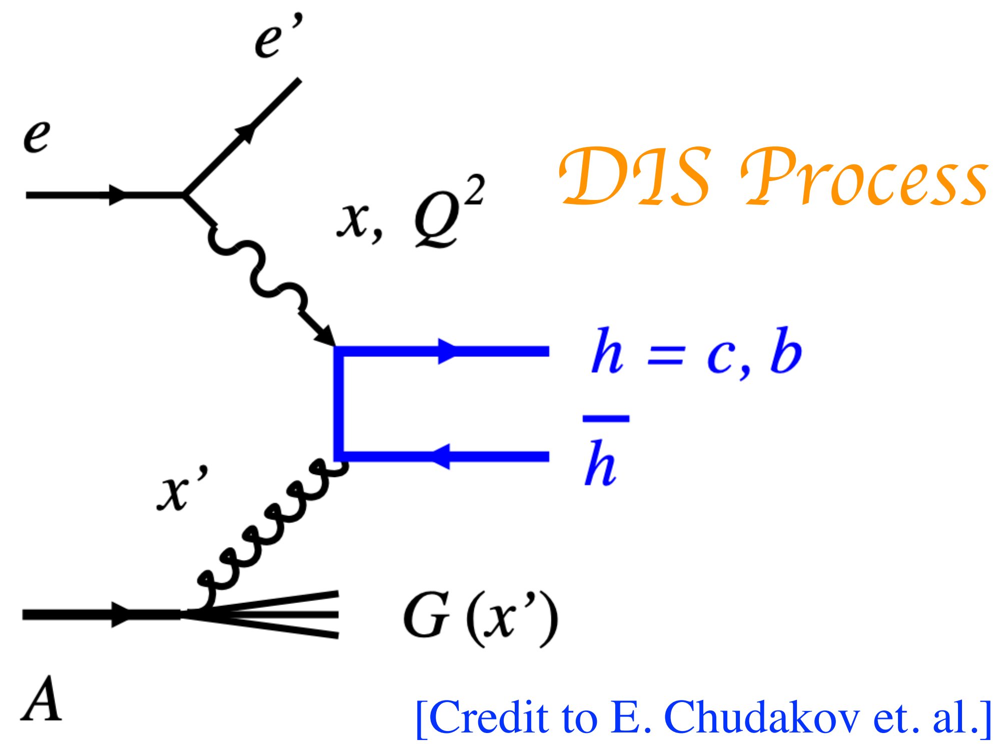


The first LFU work at the EIC!

EIC and its Potential

At Brookhaven National Lab





- To consider ep collision firstly
- To explore nuclear structure
- Chance for BSM search, as a flavour machine

b-hadron production

	Belle II	LHCb	Tera-Z	EIC
B^0, $\bar{B}^0$	5.3×10^{10}	6×10^{13}	1.2×10^{11}	1.3×10^{10}
$B^\pm$	5.6×10^{10}	6×10^{13}	1.2×10^{11}	1.3×10^{10}
B_s, $\bar{B}_s$	5.7×10^{8}	2×10^{13}	3.1×10^{10}	3.4×10^{9}
$B_c^\pm$	-	4×10^{11}	1.8×10^{8}	2.3×10^{7}
Λ_b, $\bar{\Lambda}_b$	-	2×10^{13}	2.5×10^{10}	6.7×10^{9}

Up to 1000 /fb: abundant!

Decay Channels

- $$R_{J/\psi} = \frac{\mathrm{Br}\,(\mathrm{B}_c \to J/\psi \tau \nu)}{\mathrm{Br}\,(B_c \to J/\psi \mu \nu)}$$

$$J/\psi \to \mu\mu, \tau \to \mu\nu\bar{\nu}$$

- $$R_{D_s^{(*)}} = \frac{\mathrm{Br}\,(\mathrm{B}_s \to D_s^{(*)} \tau \nu)}{\mathrm{Br}\,(B_s \to D_s^{(*)} \mu \nu)}$$

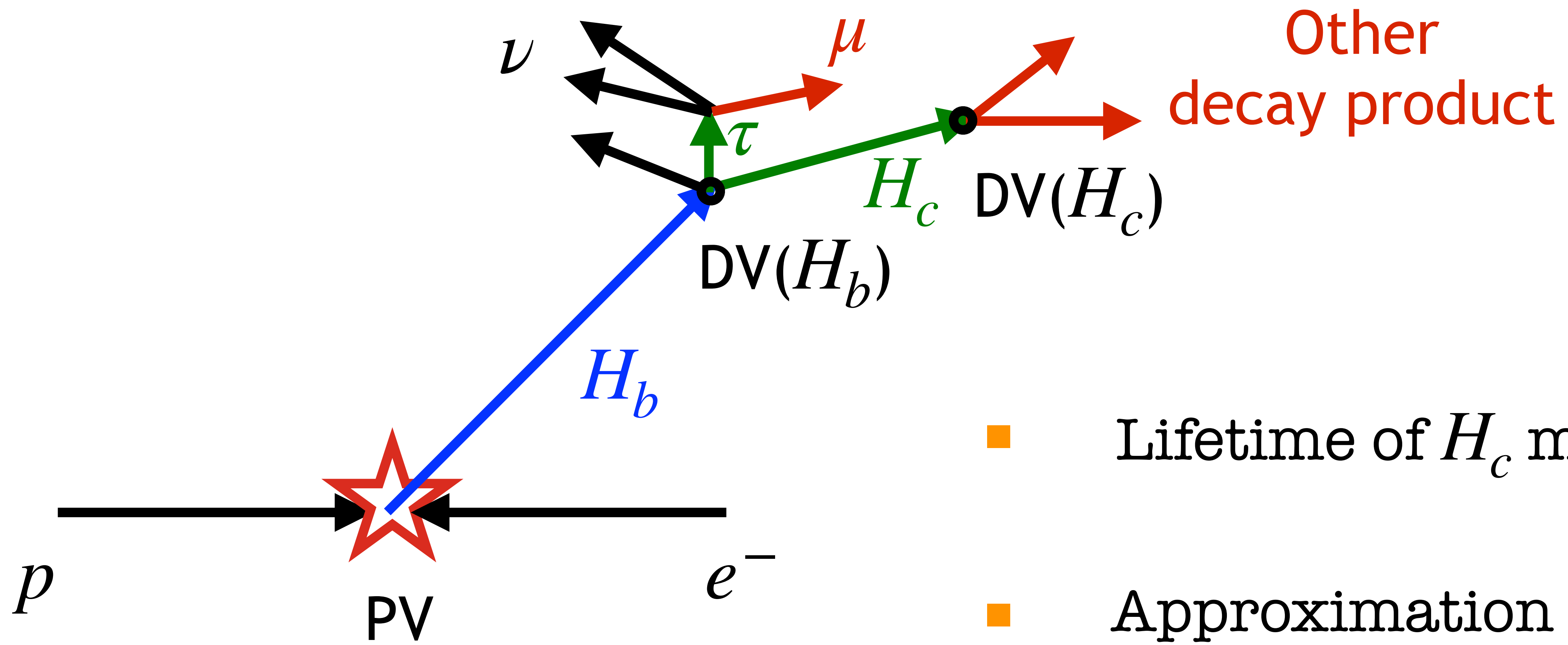
$$D_s^* \to D_s \gamma, D_s \to \phi(\to KK)\pi, \tau \to \mu\nu\bar{\nu}$$

- $$R_{\Lambda_c} = \frac{\mathrm{Br}\,(\Lambda_b \to \Lambda_c \tau \nu)}{\mathrm{Br}\,(\Lambda_b \to \Lambda_c \mu \nu)}$$

$$\Lambda_c \to pK\pi, \tau \to \mu\nu\bar{\nu}$$

Reconstruction

Trace back, from decay products to PV



- Lifetime of H_c matters
- Approximation due to neutrinos, such as:

$$p^z_{H_b} = \frac{m_{H_b}}{m_{vis}} p^z_{vis}$$

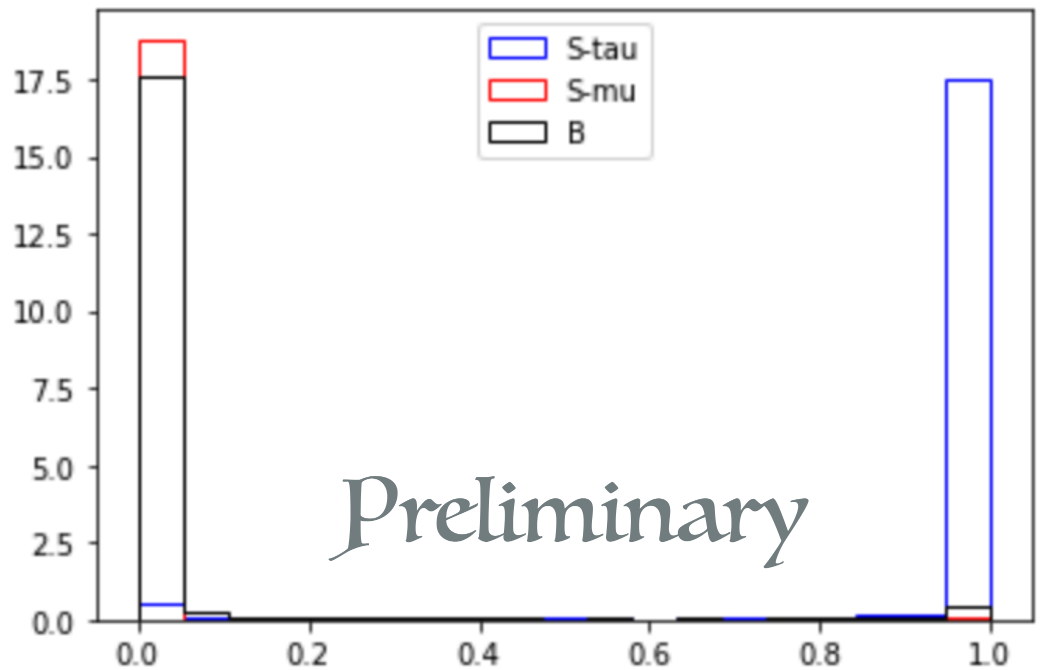
[LHCb Collaboration]

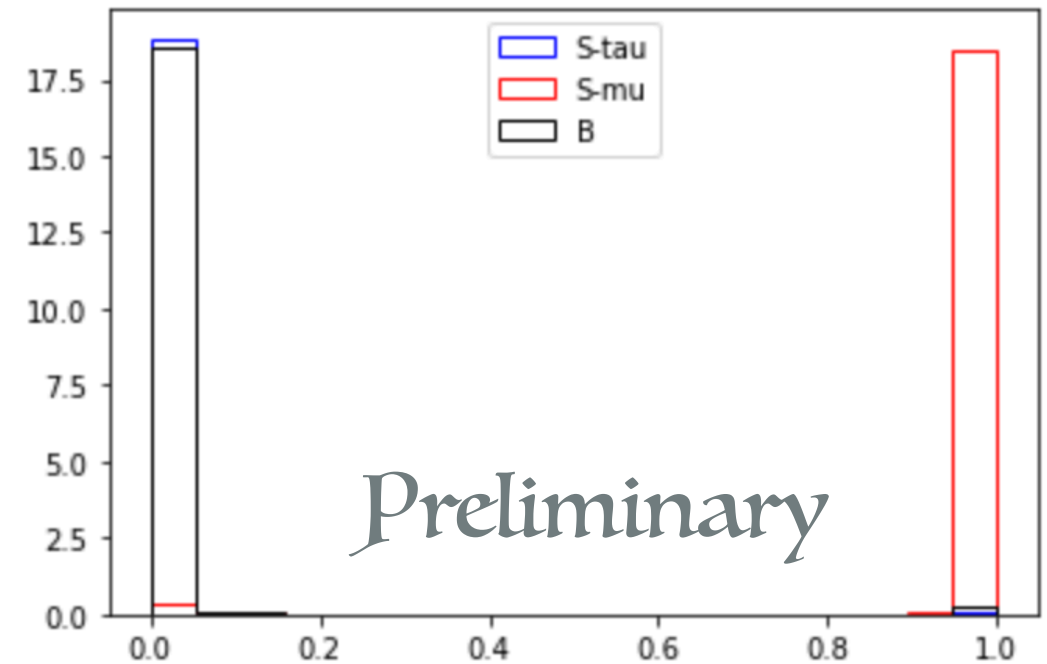
- To consider inclusive bkg
- Without track vertex smearing

BDT

Take $B_c \to J/\psi$ for illustration

BDT trained with 12 observables





Well separated!

Results (R.L. Uncertainties)

[Ho, **Jiang**, Kwok, Li and Liu]

Physical Quantity	SM Value	Tera-Z	EIC
$R_{J/\psi}$	0.289	4.25×10^{-2}	0.48
R_{D_s}	0.393	4.09×10^{-3}	0.19
$R_{D_s^*}$	0.303	3.26×10^{-3}	0.12
R_{Λ_c}	0.334	9.77×10^{-4}	0.011
$\mathrm{BR}(B_c \to \tau\nu)$	2.36×10^{-2}	0.01	~ 0.5

[Zheng. et al.]

- $\mathcal{O}(0.1)$:

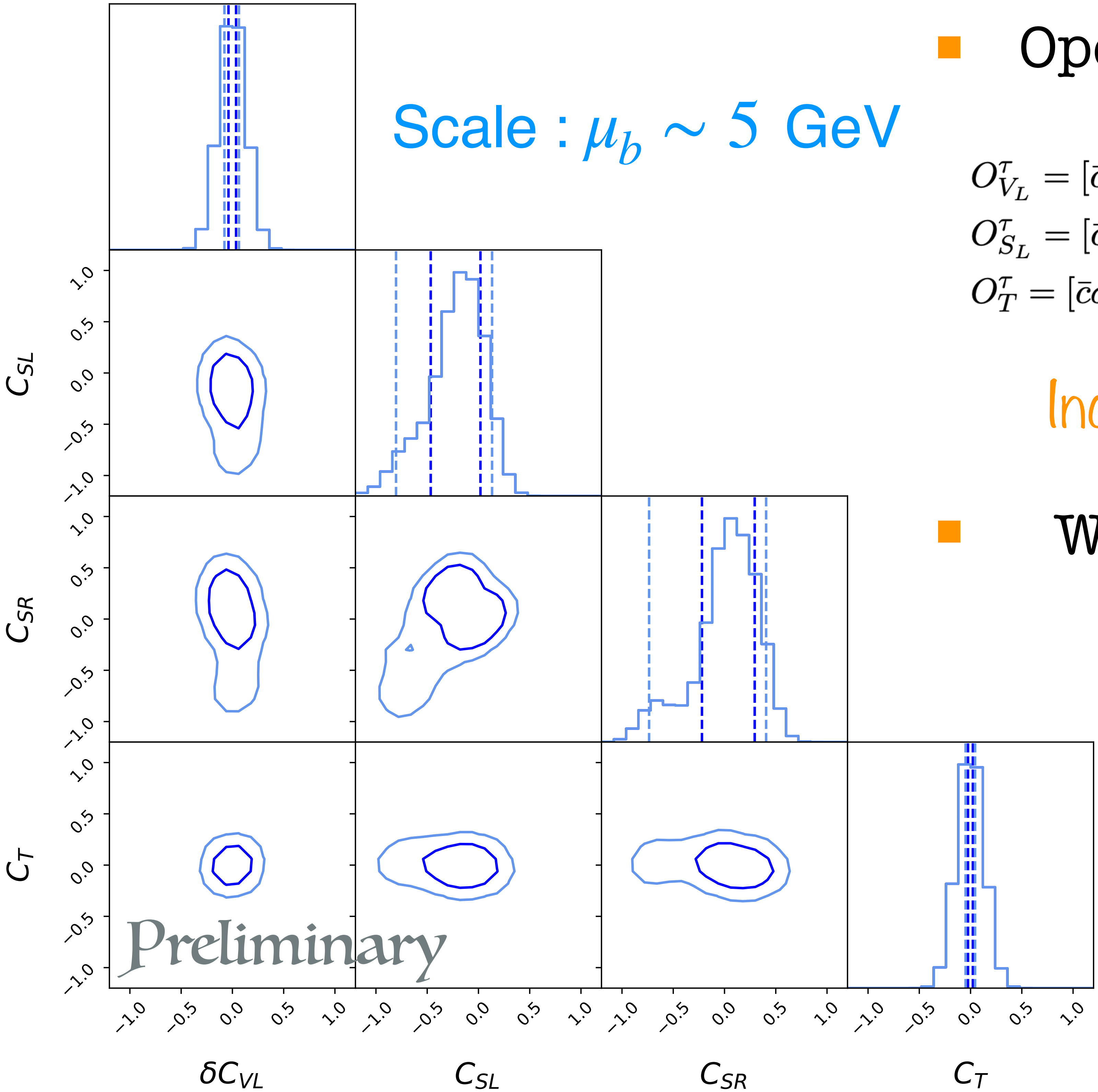
  worse than Tera-Z,
  and comparable with current LHCb

- B_c annihilation :

  estimated by a brute force comparison,
  to be conservative

From a Theory Perspective

Low-Energy EFT works.



Scale : $\mu_b \sim 5$ GeV

- Operators vary

$$O^{\tau}_{V_L} = [\bar{c}\gamma^{\mu}P_L b][\bar{\tau}\gamma_{\mu}P_L\nu]\ , \quad O^{\tau}_{V_R} = [\bar{c}\gamma^{\mu}P_R b][\bar{\tau}\gamma_{\mu}P_L\nu]\ ,$$
$$O^{\tau}_{S_L} = [\bar{c}P_L b][\bar{\tau}P_L\nu]\ , \quad O^{\tau}_{S_R} = [\bar{c}P_R b][\bar{\tau}P_L\nu]\ ,$$
$$O^{\tau}_{T} = [\bar{c}\sigma^{\mu\nu}b][\bar{\tau}\sigma_{\mu\nu}P_L\nu]\ .$$

Indicating different BSM structures

- Wilson coeff $\sim \mathcal{O}(0.1)$

To be matched to
SMEFT later
for its UV completion

Summary & Outlook

- Opportunities of flavour physics at the EIC
- Cross validation with current LHCb

- FCNC channels?
- Not only Br, but differential quantities?
- Electron polarisation?

Many thanks!

Back-Up

BDT Observables

Take $B_c \to J/\psi$ for illustration

1. Minimal distance between the B_c^+ (or J/ψ) decay vertex and the μ_3 track
2. Lorentz-invariant observables: $m^2_{\rm miss}$
3. Momentum of the reconstructed B_c^+: $|\vec{p}_{B_c^+}|$
4. Minimal distance between the μ_3 track and its closest track
5. Corrected mass: $m_{\rm corr} = \sqrt{m^2(J/\psi\mu^+) + p_\perp^2(J/\psi\mu^+)} + p_\perp(J/\psi\mu^+)$
6. Distance between the J/ψ decay vertex and the PV
7. Momentum of the reconstructed J/ψ: $|\vec{p}_{J/\psi}|$
8. Invariant mass $m_{3\mu}$
9. Minimal distance between the reconstructed J/ψ trajectory and its closest track
10. Lorentz-invariant observables: q^2
11. Momentum of the unpaired muon μ_3: $|\vec{p}_{\mu_3}|$
12. $J/\psi\mu^+$ momentum transverse to the B_c^+ moving direction: $p_\perp(J/\psi\mu^+)$

Based on ranking shown in [Ho, **Jiang**, Kwok, Li and Liu]