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For Heavy Flavors & QCD @ Nanjing

Semileptonic b Decays at the Electron-Ion Collider

JIANG Xuhui
蒋 旭辉

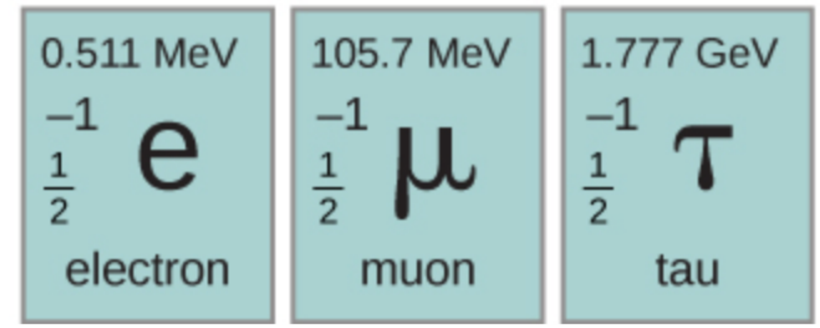
Email: jiangxh at ihep dot ac dot cn

Based on: 2503.02605, with Yongjie Deng, Tianbo Liu (Shandong U.) and Bin Yan (IHEP)

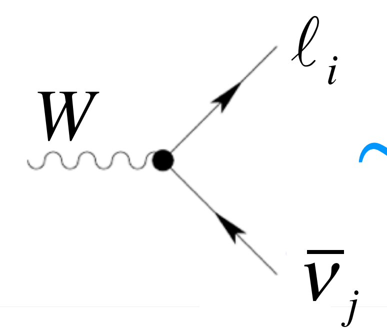
Lepton Flavor Universality

- Standard Model (SM): lepton flavors

- Different masses



- A universal coupling to gauge



$\sim g\delta_{ij}$

LFU: as one of the hypotheses in the SM

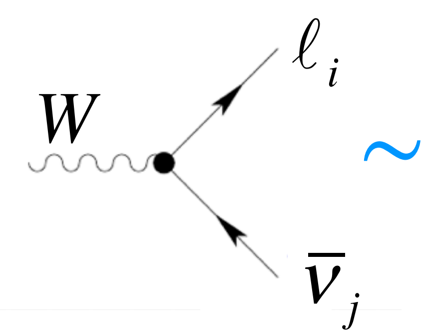
[Nicely reviewed in Xinqiang and Qidong's talks]

- Precise measurements:
  - *SM validity test*
  - *Hints for BSM*

Flavors & BSM

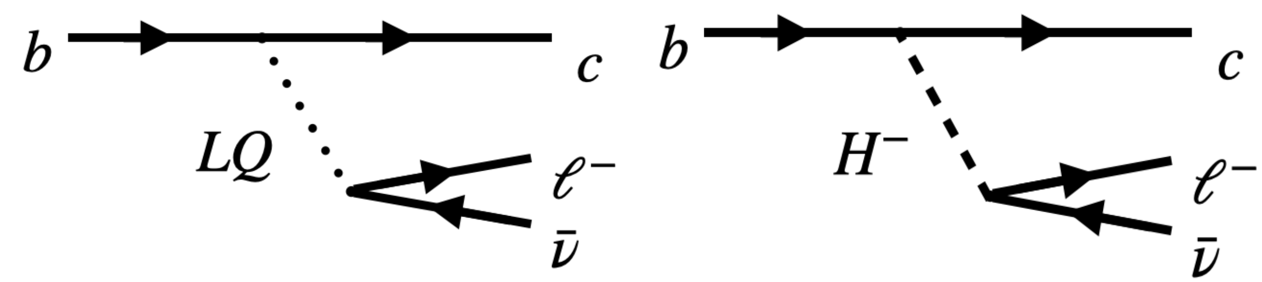
- BSM: to be sensitive in flavor physics
- Particular in FCCC decays:

- SM:



$\sim g\delta_{ij}$

- BSM even at tree-level:



Either leptoquark (colored)
or extra Higgs (uncolored)

A simple dimensional analysis:

$$\Gamma \sim \frac{m_f^3}{\boxed{m_W^2}} \xrightarrow[\text{As the new particle mass scale?}]{\text{To be replaced by } \Lambda_{NP}} \Gamma_{\mathrm{BSM}}\ ?$$

Decays: to be changed significantly!

Relevant Observables

- FCCC & R-scores

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

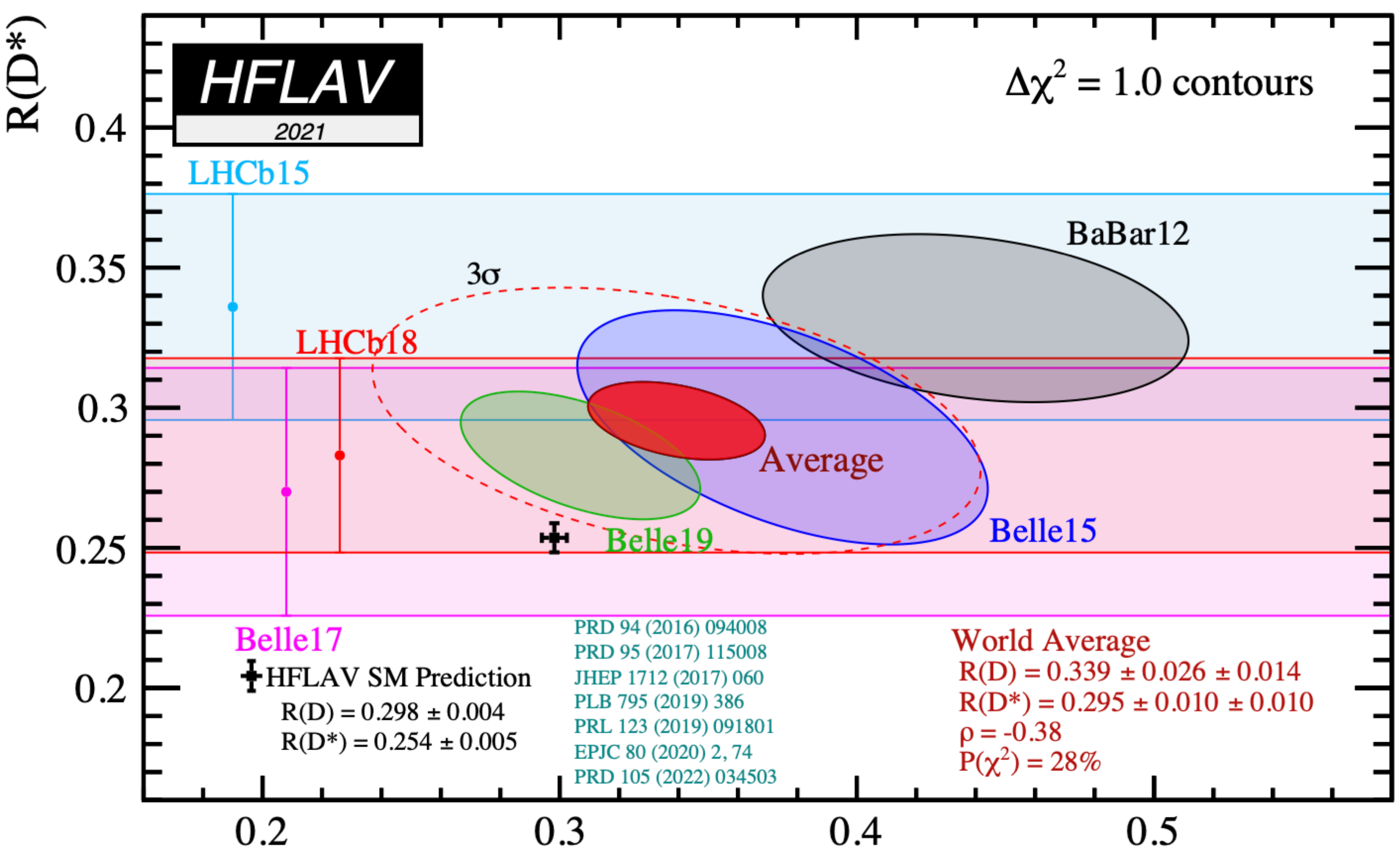
H_b hadron containing b quark
H_c hadron containing c quark

- Various transitions (based on H_c properties)
  - 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 Experimental 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]

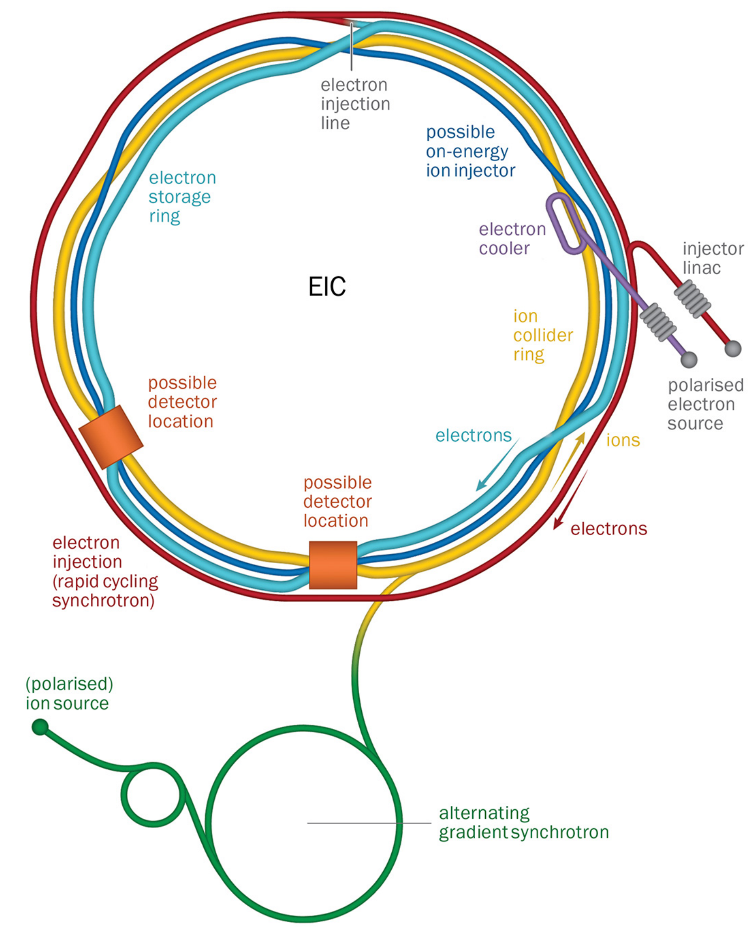
Either averagely over 3σ,

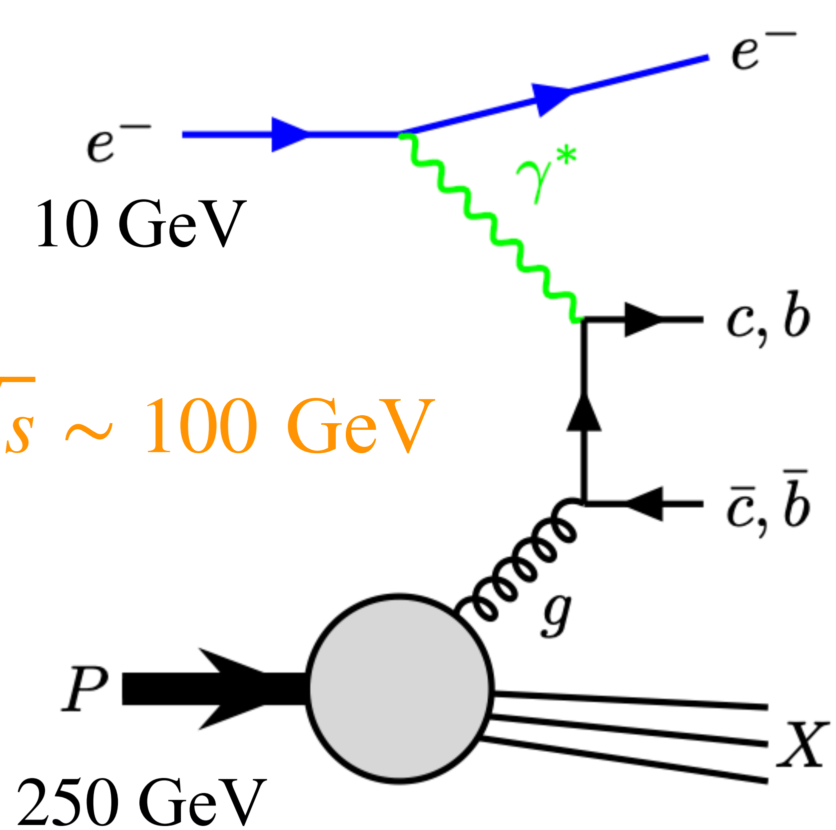
or yet unknown.

LFU-violating BSM or fluctuations?

Electron Ion Collider

- EIC, w flavor opportunities
  - To consider ep collision firstly
  - Not limited to nuclear structure
  - Heavy flavors: DIS processes





$\sqrt{s} \sim 100$ GeV

Up to 1000 /fb

Higher energy

	Belle II	LHCb	Tera-Z	EIC
$B^0, \bar{B}^0$	5.3×10^{10}	6×10^{13}	1.2×10^{11}	1.2×10^{9}
$B^\pm$	5.6×10^{10}	6×10^{13}	1.2×10^{11}	1.2×10^{9}
$B_s, \bar{B}_s$	5.7×10^{8}	2×10^{13}	3.1×10^{10}	3.2×10^{8}
$B_c^\pm$	-	4×10^{11}	1.8×10^{8}	2.4×10^{6}
$\Lambda_b, \bar{\Lambda}_b$	-	2×10^{13}	2.5×10^{10}	6.2×10^{8}

Cleaner

Signal Channels

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

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

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

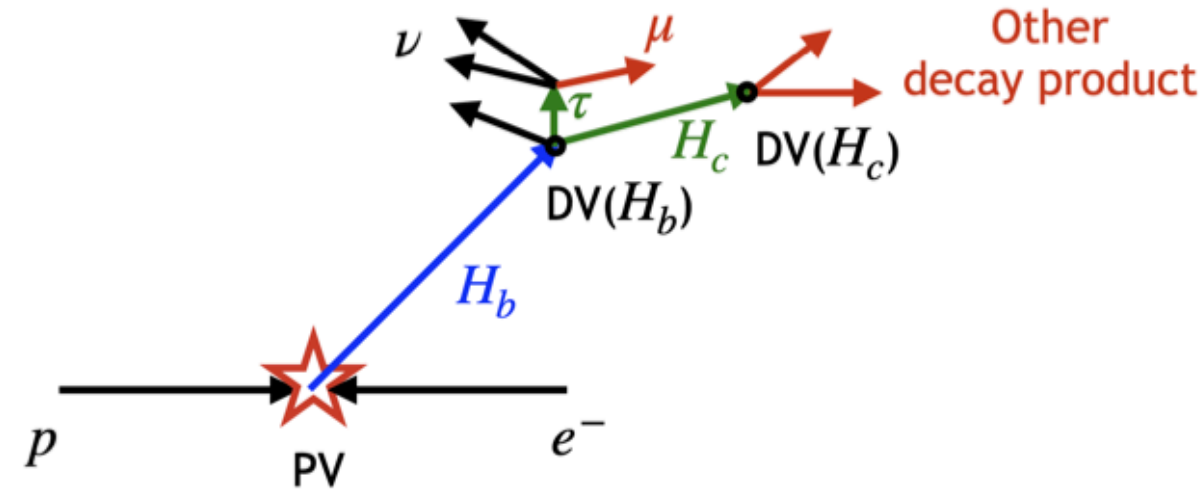
$$D_s^* \to D_s\gamma, D_s \to \phi(\to KK)\pi, \tau \to \mu\nu\bar{\nu}$$

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

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

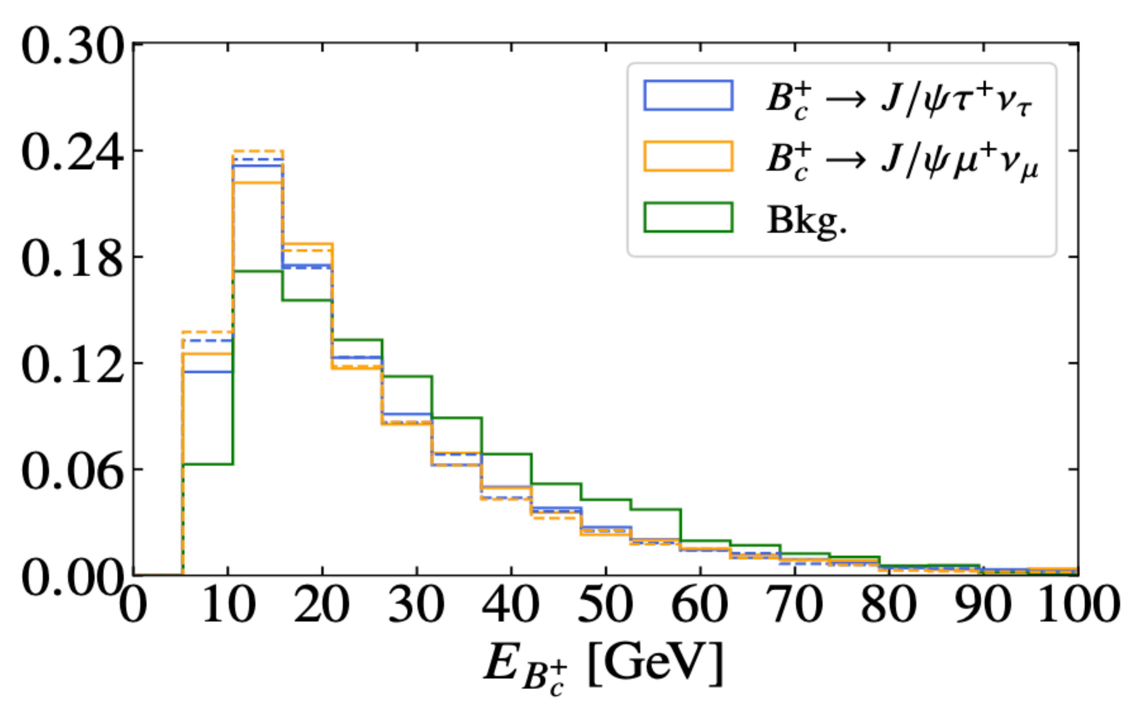
Reconstruction

- Decay topology



- To trace back
  - Decay vertex: DV(H_c) = DV(H_b) + (vector H_c moves)
  - **Approximation** needed, due to neutrinos
- At the EIC:
  - Solid vs. Dashed: reconstructed vs. truth
  - Error well controlled

Of $\mathcal{O}(1)$ GeV!



Expected Results

	H_b	H_c	SM Prediction	Experimental Average	LHCb Upgrade II	EIC
$R_{J/\psi}$	B_c	J/ψ	0.289	$0.71 \pm 0.17 \pm 0.18$	2%	150%
R_{D_s}	B_s	D_s	0.393	N/A	2.5%	58.6%
$R_{D_s^*}$	B_s	D_s^*	0.303	N/A	2.5%	43.7%
R_{Λ_c}	Λ_b	Λ_c	0.334	0.242 ± 0.076	2%	3.58%
$\mathrm{Br}(B_c \to \tau\nu)$						150%

- $R_{J/\psi}$ limited by a low rate of B_c production
- $R_{D_s^{(*)}}$ detectable, comparable with LHCb

(Though based on a simple luminosity rescaling)

- R_{Λ_c} to compete with LHCb Upgrade II

Baryonic modes promising;

With simple decay topology, more suppressed bkgs

Theory: Low-energy EFT

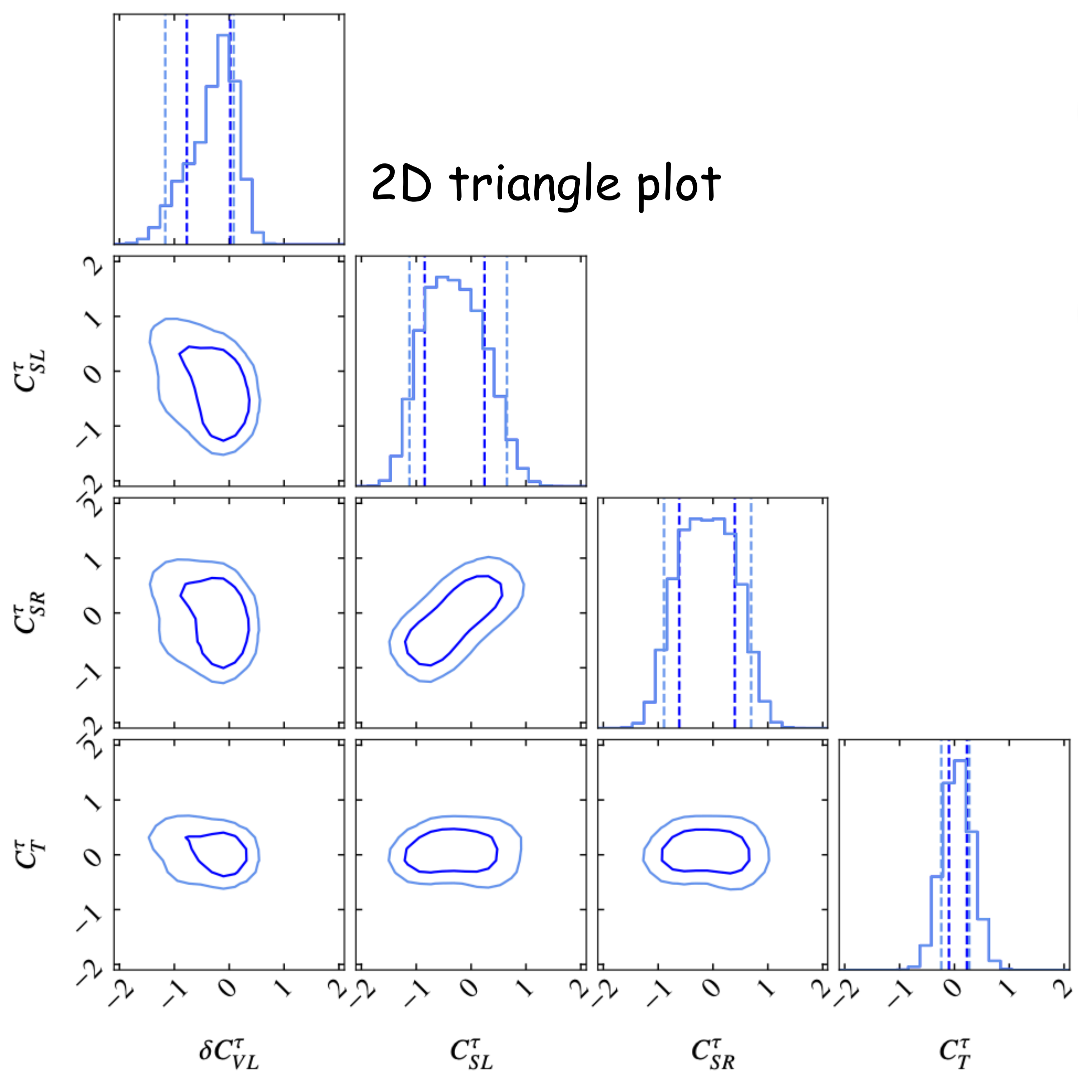
- Heavy dof: integrated out
- Various operators

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

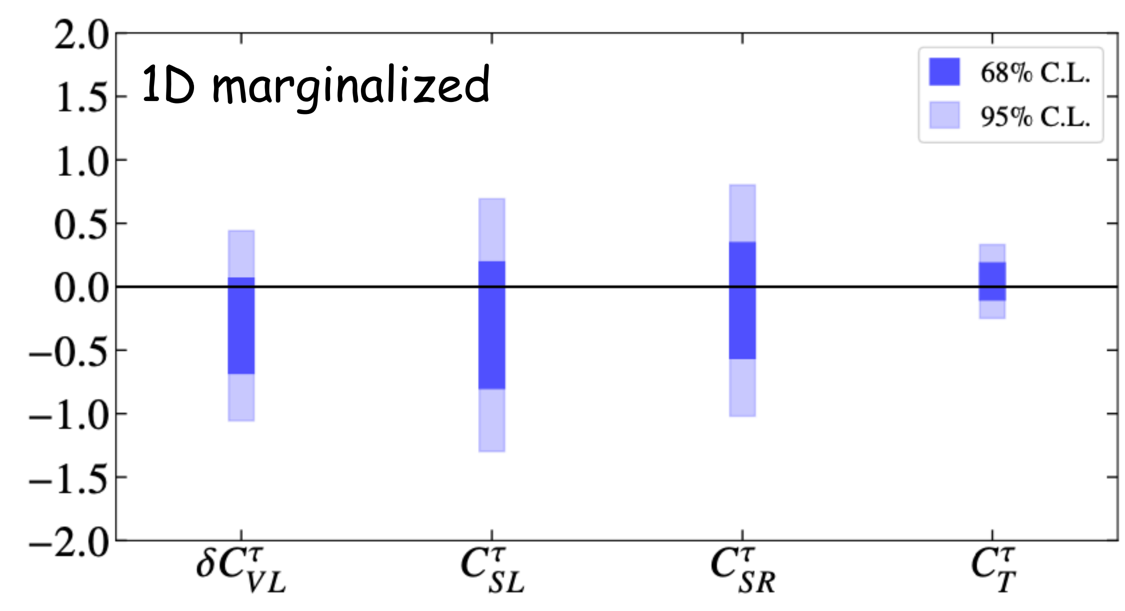
[Jenkins et al. (2018)]

Different Lorentz structures: new forces?

- A fit: R-scores providing multiple directions



- 4 operators on [O_{VR} off]
- Well constrained at $\mathcal{O}(0.1)$

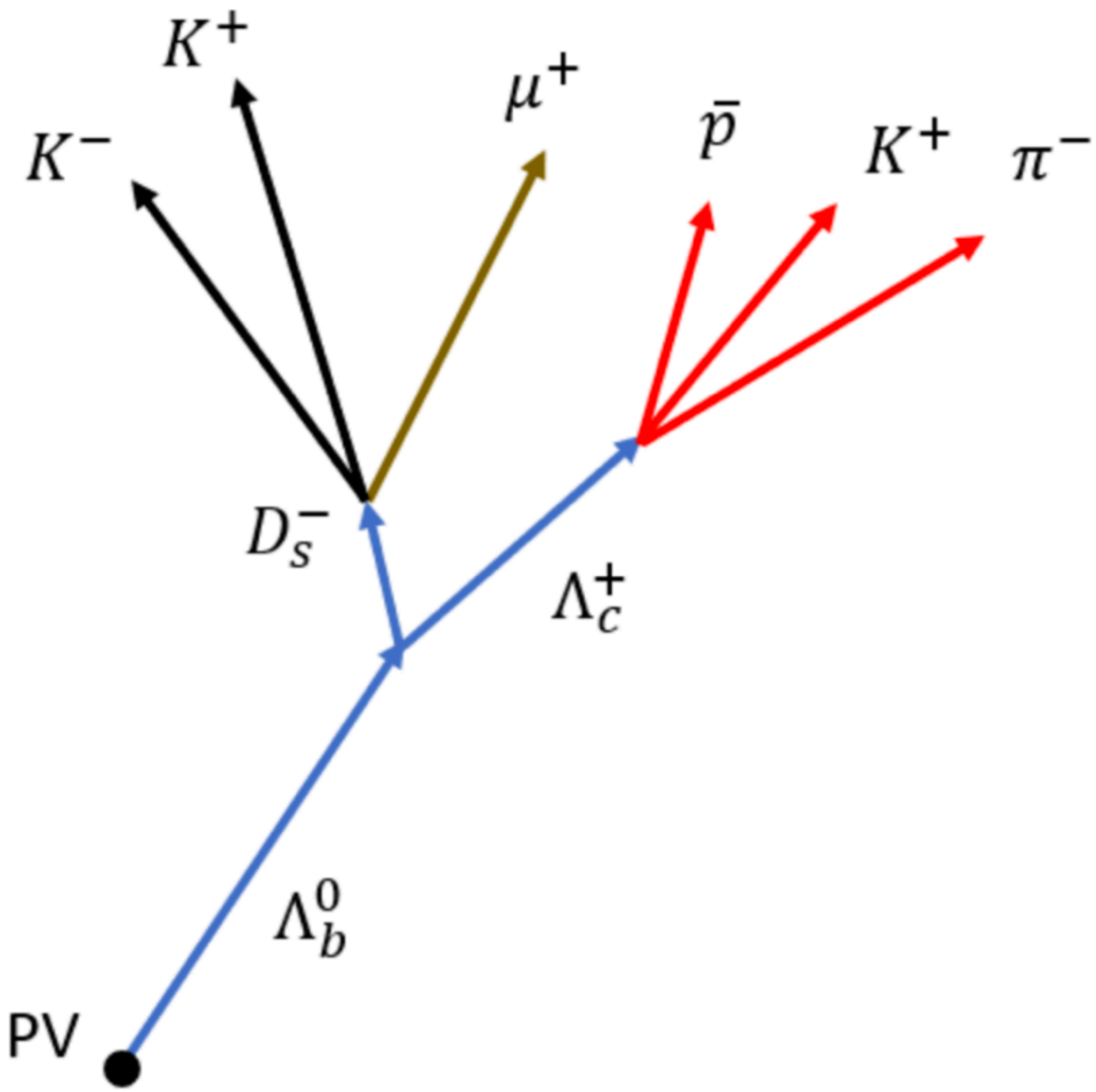


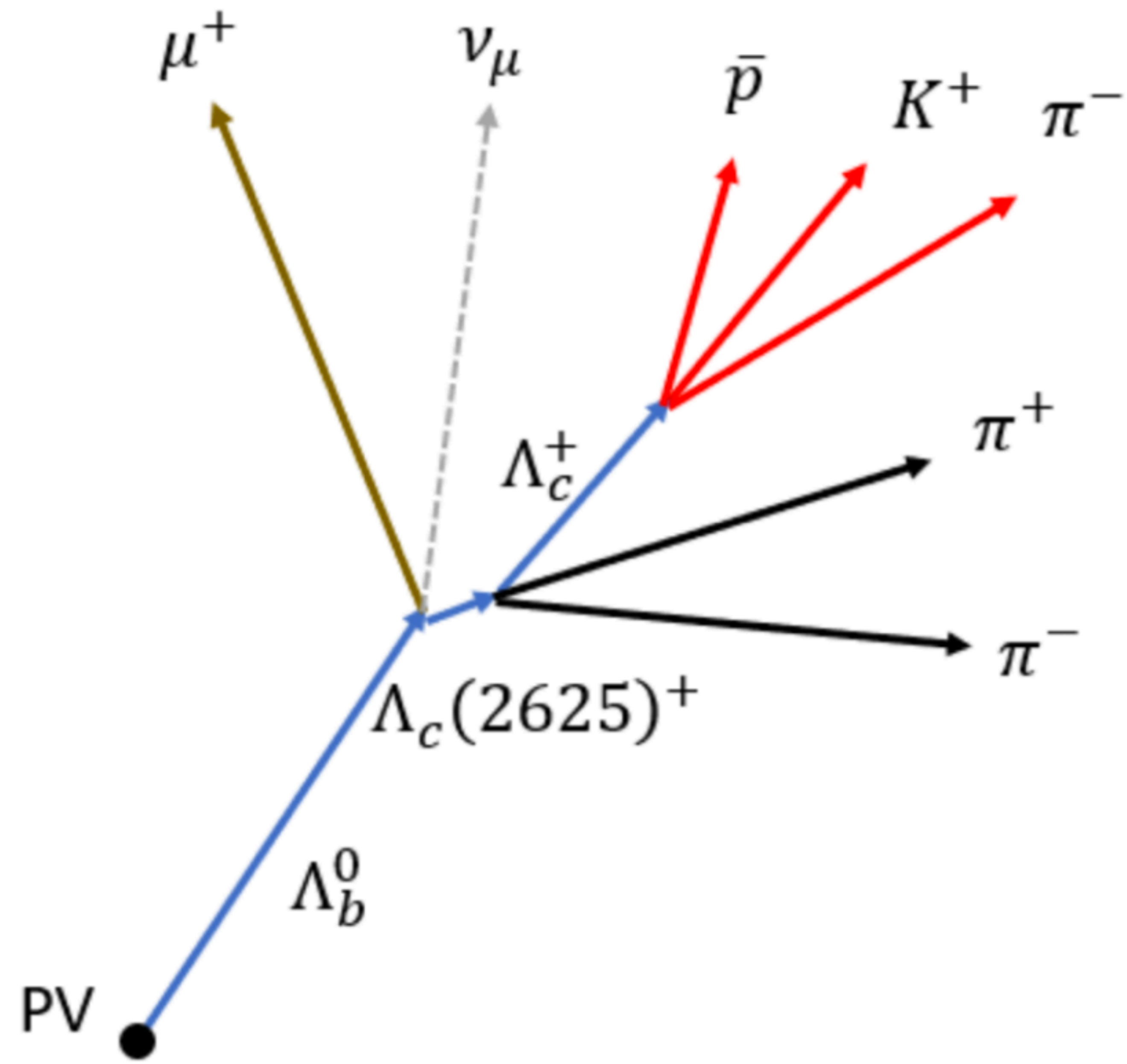
Summary

- Flavor matters
- EIC: an excellent flavor facility
- LFU test w FCCC: promising
- More opportunities?
  - FCNC channels at the EIC?
  - Not only Br, but differential quantities?
  - With electron polarisation?

Back-Up

Possible Backgrounds





- "Wrongly" produced Muon
- "Wrongly" produced H_c

+ Other SM irreducible bkgs

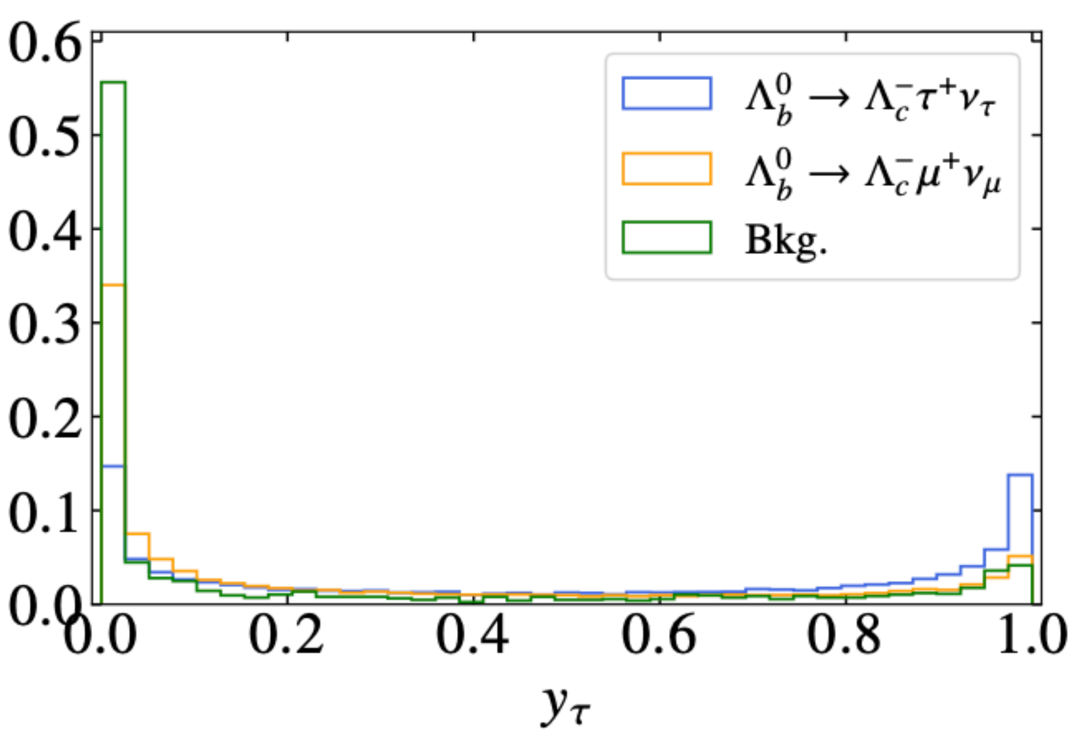
S/B Separation

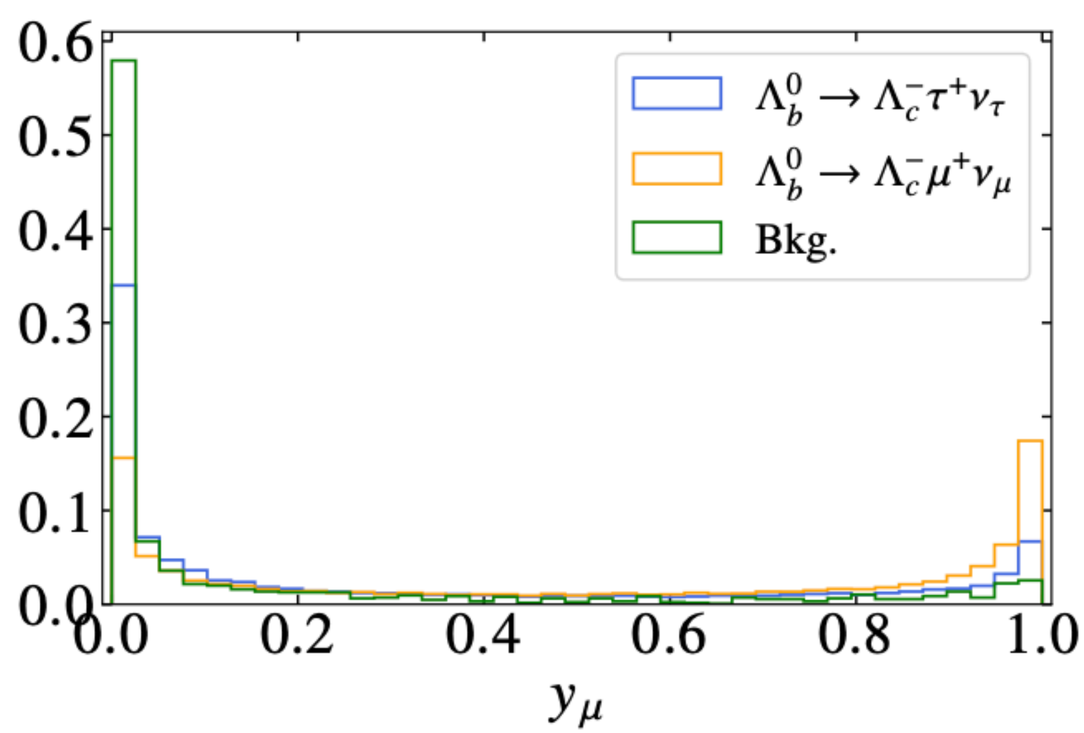
- BDT
- With 12 inputs
- S/B separation

- The minimal distance between the muon track and its closest track;
- The minimal distance between the Λ_c^- decay vertex and the muon track;
- m^2_{miss};
- The invariant mass of the $\bar{p}K^+\pi^-\mu^+$ system: $m_{\bar{p}K^+\pi^-\mu^+}$;
- The magnitude of the muon momentum: $|\vec{p}_\mu|$;
- Corrected mass, defined as: $m_{\text{corr}} = \sqrt{m^2(\Lambda_c^-\mu^+) + p_\perp^2(\Lambda_c^-\mu^+)} + p_\perp(\Lambda_c^-\mu^+)$;
- The magnitude of the reconstructed momentum of the Λ_b^0: $|\vec{p}_{\Lambda_b}|$;

. . .

Variables ranked

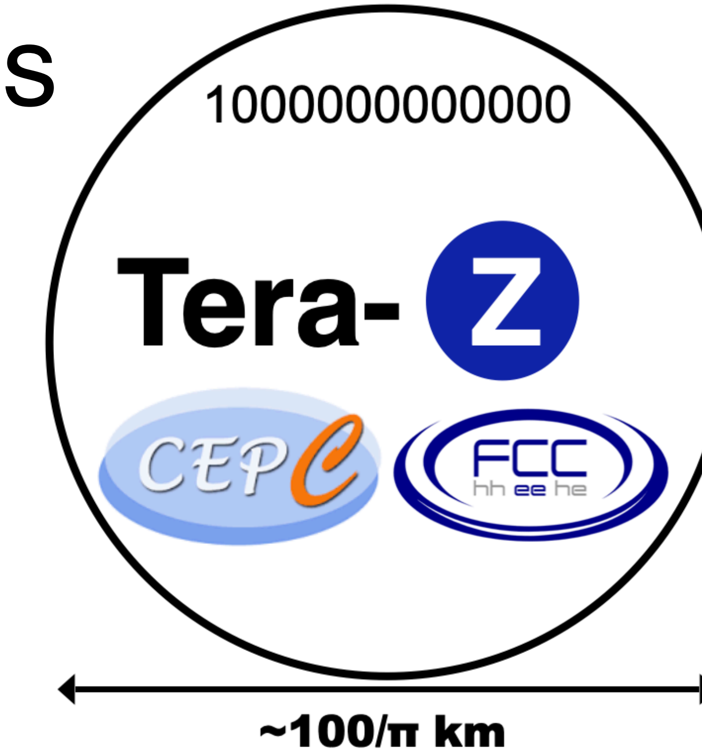




Separated well

Z Factories

- Z factories, as flavor machines
  - Not limited to EW
  - Abundant b production: $e^+e^- \to Z \to b\bar{b}$
  - A clean environment
  - Advanced tech for reconstruction



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