Testing Lepton Flavour Universality (LFU) at Future Z Factories

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Joint Workshop of the High Energy CEPC Physics, Software and New Detector Concept
24 May 2022

Disclaimer: Preliminary Results

Why LFU? What is the secret behind generations?

Standard Model:

"Three generations of leptons are the same: having same couplings to the SM gauge bosons, expect having different masses."

Experimental Measurements:

Some deviations!!!

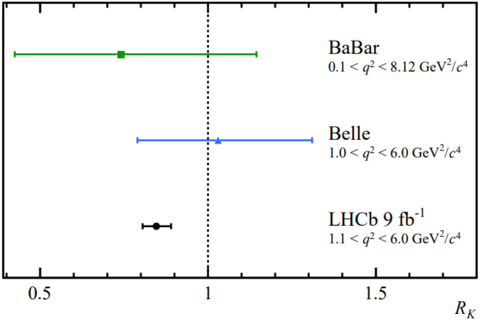
- $R_{D^{(*)}} = \frac{\mathrm{Br}(B \to D^{(*)} \tau \nu)}{\mathrm{Br}(B \to D^{(*)} \ell \nu)}$ (~ 1.3 & 2.7σ)

  [Abdesselam et al. (2019)]

  [Amhis et al. (2019)]

- $R_{J/\psi} = \frac{\mathrm{Br}(B_c \to J/\psi \tau \nu)}{\mathrm{Br}(B_c \to J/\psi \ell \nu)}$ ($\sim 2\sigma$) [Aaij et al. (2018a)]

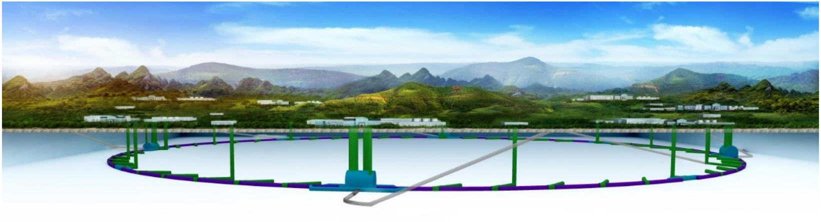
- $R_{K^{(*)}} = \frac{\mathrm{Br}(B \to K^{(*)} \mu\mu)}{\mathrm{Br}(B \to K^{(*)} ee)}$ ($\sim 2 - 3\sigma$) [Aaij et al. (2017)]



[Aaij et al. (2022)]

Goal: Setting baseline for $b \to c\tau\nu$ studies at Tera-Z

Other LFU studies: e.g. $b \to s\tau\tau$ [Li and Liu (2021)], $b \to s\nu\nu$ [Li et al. (2022)]



Advantages of Z-pole (more details, see Lingfeng's talk):

Variety b-hadrons accessible:

- b-factories (e.g. Belle II) can't produce B_c^+, Λ_b^0 (only few B_s^0)

Having ν(s) Produced: (crucial to getting H_b info.)

- Better handle than LHCb

Studying τ Mode:

- More precise info. about τ decay

[Dong et al. (2018); Abada et al. (2019a); Fujii et al. (2019); Berger et al. (2017); Aaij et al. (2018b); Altmannshofer et al. (2018)]

Signals (FCCC: $b \to c\tau\nu$)

$R_{J/\psi} = \frac{\text{Br}(B_c \to J/\psi\tau\nu)}{\text{Br}(B_c \to J/\psi\mu\nu)}$

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

$R_{D_s^{(*)}} = \frac{\text{Br}(B_s \to D_s^{(*)}\tau\nu)}{\text{Br}(B_s \to D_s^{(*)}\mu\nu)}$

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

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

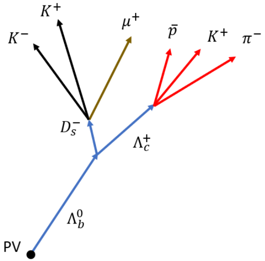
- Identifying $\Lambda_c \to pK\pi$, $\tau \to \mu\nu\bar{\nu}$

H_c **decays to charged final states:** H_c **can be fully reconstructed!**

Backgrounds

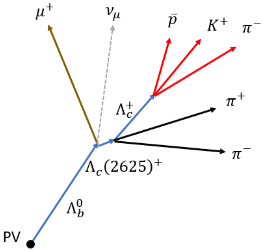
- **Wrong μ production**

  e.g.
  $\Lambda_b \to \Lambda_c D_s(\to (\phi \to KK)\mu)$



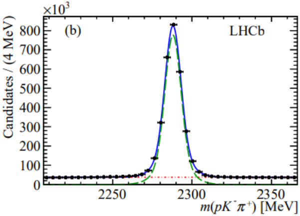
- **Wrong H_c production**

  e.g.
  $\Lambda_b \to \Lambda_c(2625)(\to \Lambda_c\pi\pi)\mu\nu$



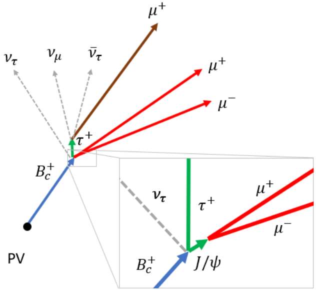
$+$ other types. (See Backups)

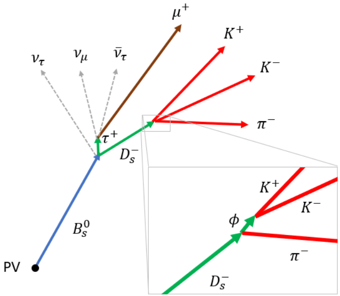
Reconstruction Scheme



1. Reconstruct H_c, and identify muon
2. Deduce b-hadron decay vertex

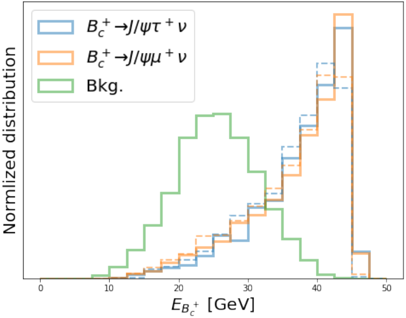
- If H_c is prompt:
  H_b decay vertex $= H_c$ decay vertex
- If H_c is not prompt:
  H_b decay vertex $=$ point at H_c trajectory closest to μ track





Reconstruction Scheme (Cont'd)

3. Deduce b-hadron energy (Detail see Lingfeng's talk): [Li et al. (2022)]
   - Imbalance between 2 'objects' decayed from Z

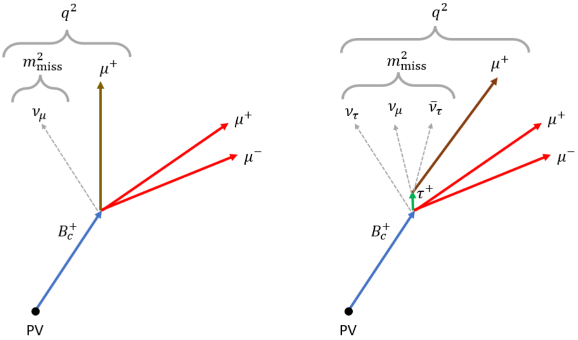


Solid: reconstruction
Dashed: truth

Reconstruction agrees with truth! (error $\sim \mathcal{O}(1\text{GeV})$)

Discriminators for τ, μ Channel Separation

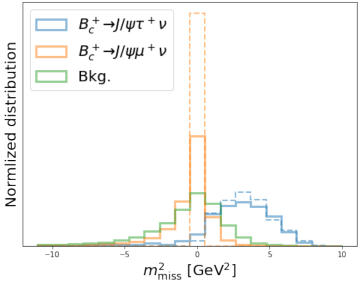
- Momentum transferred to lepton system: $q^2 \equiv (p_{B_c} - p_{J/\psi})^2$
- Missing mass: $m^2_{\text{miss}} \equiv (p_{B_c} - p_{J/\psi} - p_\mu)^2$
- The closest distance between secondary vertex (SV) and muon track



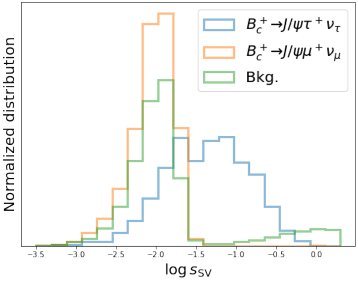
Not only τ/μ, but also Background separation!

Discriminators for τ, μ Channel Separation

Different distribution in μ & τ!
Can also be used to cut backgrounds!!!



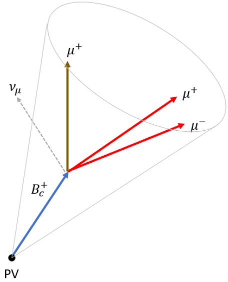
Missing mass
$m^2_{\text{miss}} \equiv (p_{B_c} - p_{J/\psi} - p_\mu)^2$

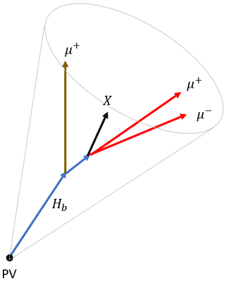


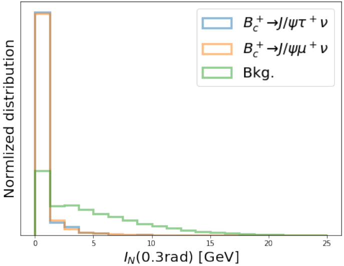
Closest distance between SV and muon track

Discriminators for Background Separation

- Isolation variable: total energy, except the tagged final states, inside 0.3(0.6) rad of B cone







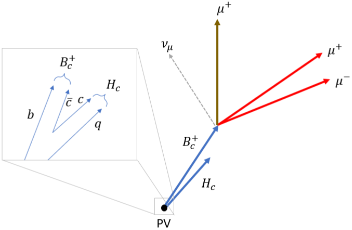
Event shape in $R_{J/\psi}$

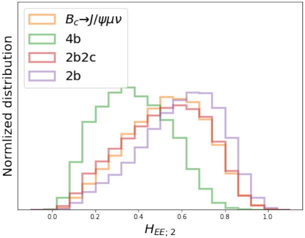
Define the FW Moment [Fox and Wolfram (1978)]:

$$H_{EE;l} = \sum_{i,j} \frac{E_i E_j}{s} P_l(\cos \Omega_{ij})$$

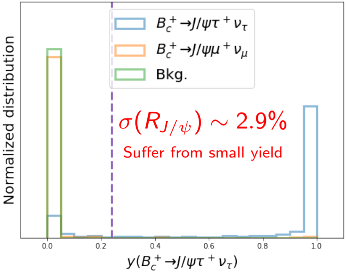
Different types of backgrounds events:

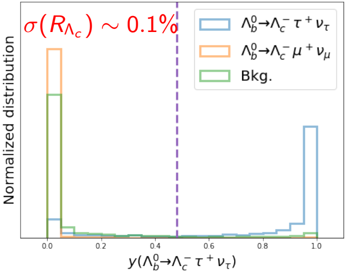
- $4b$: Events of $4b$ quarks created by QCD
- $2b2c$: Events of $b\bar{b}$ and $c\bar{c}$ pairs created by QCD
- $2b$: Events of $2b$ quarks created by QCD

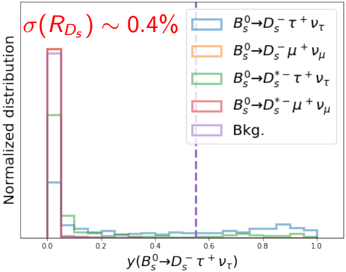


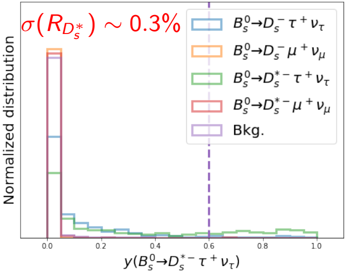


Stat. only BDT results (Preliminary)









Theoretical Workflow

- Model independent description of NP effect at Low-Energy ($\mu_b \simeq m_b$) [Buras et al. (2015); Angelescu et al. (2018); Feruglio et al. (2018); Hu et al. (2019); Alasfar et al. (2020); Fajfer et al. (2021); Cornella et al. (2021)]
- Run LEFT to m_Z and match to SMEFT [Grzadkowski et al. (2010)]
- Run SMEFT to sclae $\Lambda \sim \mathcal{O}(\text{TeV})$
- With assumptions:
  - Ignore theoretical uncertainties of hadron decay form factors
  - Expected values of the measurements $\sim$ SM predictions
  - LFUV effects only show up in τ for FCCC

LEFT

Semileptonic $b \to c\tau\nu$:

$$\mathcal{L}^{\text{eff}}_{b\to c\tau\nu} \supset -\frac{4G_F V_{cb}}{\sqrt{2}}[(1+\delta C^{\tau}_{V_L})O^{\tau}_{V_L} + C^{\tau}_{V_R}O^{\tau}_{V_R} + C^{\tau}_{S_L}O^{\tau}_{S_L} + C^{\tau}_{S_R}O^{\tau}_{S_R} + C^{\tau}_{T}O^{\tau}_{T}] + h.c.^{1} \tag{1}$$

- Contains 5 dimension-6 LEFT operators at Tera-Z
- Covers 4 types of translation:
  - Vector: $R_{J/\psi}$, $R_{D_s^*}$
  - Pseudo-scalar: R_{D_s}
  - Baryon: R_{Λ_c}
  - Annihilation: $\text{Br}(B_c \to \tau\nu)$ [Zheng et al. (2020)]

[1] τ means those violate LFU explicitly

LEFT

FCNC $b \to s\tau\tau$:

$$\mathcal{L}^{\rm eff}_{b\to s\tau^+\tau^-} = +\frac{4G_F V_{tb}V_{ts}^*}{\sqrt{2}}[(C_9^\tau|_{\rm SM} + \delta C_9^\tau)O_9^\tau + (C_{10}^\tau|_{\rm SM} + \delta C_{10}^\tau)O_{10}^\tau \\ + C_9'^\tau O_9'^\tau + C_{10}'^\tau O_{10}'^\tau + C_S^\tau O_S^\tau \\ + C_S'^\tau O_S'^\tau + C_P^\tau O_P^\tau + C_P'^\tau O_P'^\tau \\ + C_T^\tau O_T^\tau + C_{T5}^\tau O_{T5}^\tau] + h.c. \tag{2}$$

- Contains 10 dimension-6 LEFT operators at Tera-Z
- Related to: $\mathrm{Br}(B \to K\tau\tau)$, $\mathrm{Br}(B \to K^*\tau\tau)$, $\mathrm{Br}(B_s \to \phi\tau\tau)$, $\mathrm{Br}(B_s \to \tau\tau)$[Kamenik et al. (2017); Capdevila et al. (2018); Li and Liu (2021)]

FCNC $b \to s\nu\nu$:

$$\mathcal{L}^{\rm eff}_{b\to s\bar{\nu}\nu} = +\frac{4G_F V_{tb}V_{ts}^*}{\sqrt{2}}[C_L^\nu O_L^\nu + C_R^\nu O_R^\nu] + h.c. \tag{3}$$

- Contains 2 dimension-6 LEFT operators at Tera-Z
- Related to: $\mathrm{Br}(B \to K\nu\nu)$, $\mathrm{Br}(B \to K^*\nu\nu)$, $\mathrm{Br}(B_s \to \phi\nu\nu)$[Buras et al. (2015); Li et al. (2022)]

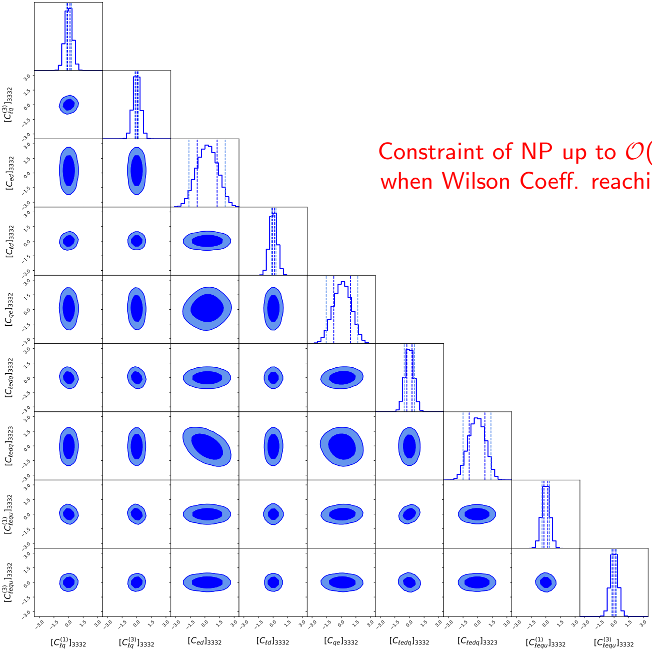
SMEFT

$$\mathcal{L}^{\rm dim6} \supset \frac{1}{\Lambda^2}\sum_{i,j,k,l}\Big([C^{(1)}_{\ell q}]_{ijkl}[O^{(1)}_{\ell q}]_{ijkl} + [C^{(3)}_{\ell q}]_{ijkl}[O^{(3)}_{\ell q}]_{ijkl} + [C_{ed}]_{ijkl}[O_{ed}]_{ijkl}$$
$$+ [C_{\ell d}]_{ijkl}[O_{\ell d}]_{ijkl} + [C_{qe}]_{ijkl}[O_{qe}]_{ijkl} + [C_{\ell edq}]_{ijkl}[O_{\ell edq}]_{ijkl}$$
$$+ [C^{(1)}_{\ell equ}]_{ijkl}[O^{(1)}_{\ell equ}]_{ijkl} + [C^{(3)}_{\ell equ}]_{ijkl}[O^{(3)}_{\ell equ}]_{ijkl}\Big) + h.c.$$

- After matching: 9 LFUV operators in dim6 SMEFT

SMEFT Operator	Expansion in Down Basis
$[O^{(1)}_{lq}]_{3332}$	$(\bar\nu\gamma^\mu P_L\nu + \bar\tau\gamma^\mu P_L\tau)(\bar b\gamma_\mu P_L s)$
$[O^{(3)}_{lq}]_{3332}$	$2V^*_{cs}(\bar\nu\gamma^\mu P_L\tau)(\bar b\gamma_\mu P_L c) - (\bar\nu\gamma^\mu P_L\nu - \bar\tau\gamma^\mu P_L\tau)(\bar b\gamma_\mu P_L s)$
$[O_{ed}]_{3332}$	$(\bar\tau\gamma^\mu P_R\tau)(\bar b\gamma_\mu P_R s)$
$[O_{ld}]_{3332}$	$(\bar\nu\gamma^\mu P_L\nu + \bar\tau\gamma^\mu P_L\tau)(\bar b\gamma_\mu P_R s)$
$[O_{qe}]_{3332}$	$(\bar\tau\gamma^\mu P_R\tau)(\bar b\gamma_\mu P_L s)$
$[O_{ledq}]_{3332}$	$V^*_{cs}(\bar\nu P_R\tau)(\bar b P_L c) + (\bar\tau P_R\tau)(\bar b P_L s)$
$[O_{ledq}]_{3323}$	$(\bar\tau P_R\tau)(\bar s P_L b)$
$[O^{(1)}_{lequ}]_{3332}$	$V^*_{cs}(\bar\nu P_R\tau)(\bar b P_R c)$
$[O^{(3)}_{lequ}]_{3332}$	$V^*_{cs}(\bar\nu\sigma^{\mu\nu} P_R\tau)(\bar b\sigma_{\mu\nu} P_R c)$

Wilson Coefficients Constraints (Preliminary)



Constraint of NP up to $\mathcal{O}$(10 TeV) when Wilson Coeff. reaching $\mathcal{O}$(1)

Conclusion

Z-pole can test Lepton Flavor Universality, the secret behind generations, in a clean way!!!

- Setting up a baseline of $b \to c\tau\nu$ for Tera-Z
- High precision in $R_{J/\psi}$, $R_{D_s^{(*)}}$, R_{Λ_c}: $\mathcal{O}(0.1\%) - \mathcal{O}(1\%)$
  - Abundant and energetic b-hadrons
  - Clean environment
  - Known initial energy
- EFT can prob NP up to 10TeV
  - Constraint of NP up to $\mathcal{O}(10 \text{ TeV})$ when Wilson Coeff. reaching $\mathcal{O}(1)$

Thank you!

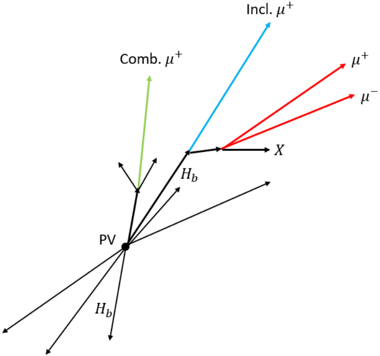
Backup: General Background types

Inclusive Bkg.:

- Feed-down processes, e.g. $B_c \to \chi_c(\to J/\psi X)\ell\nu$
- Different kinematics to signals

Combinatoric Bkg.:

- Wrongly reconstructing unrelated $H_c + \mu$ ($H_c = J/\psi,\ D_s,\ \Lambda_c$)
- Larger isolation variables than signals



- Inclusive: $J/\psi(\mu\mu) + \mu$
- Comb.: $J/\psi\ (\mu\mu) + \mu$

Cascade Bkg.:

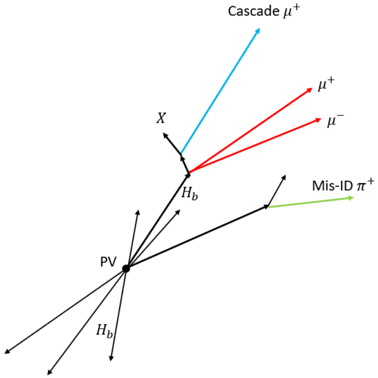
- ℓ is NOT from semileptonic decay, e.g. $B^0 = D^0(\to \ell)J/\psi X$
- Larger isolation variables than signals

Muon mis-ID Bkg.:

- Misidentifying $\pi^{\pm}$ as μ, with $\mathcal{O}(1\%)$ [Lippmann (2012); Yu et al. (2021)]

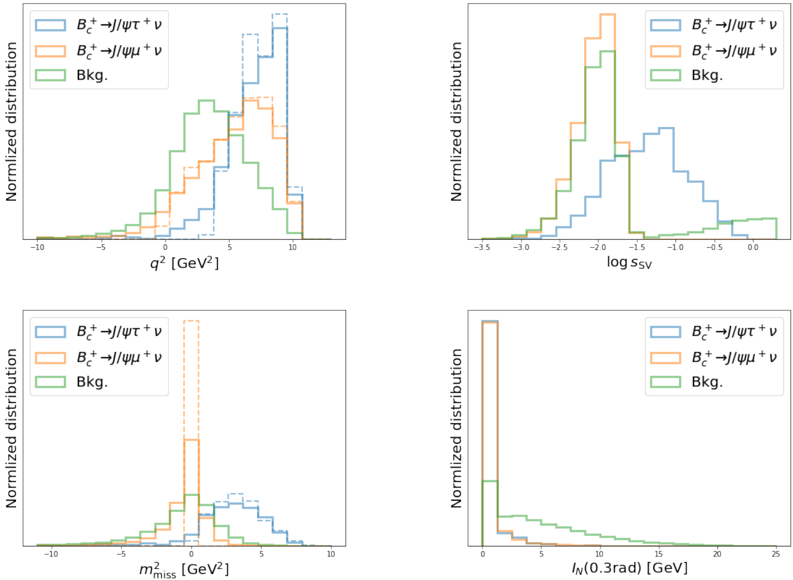
Fake narrow resonance Bkg.:

- Wrongly reconstructing the remnants $H_c = J/\psi,\ D_s,\ \Lambda_c$



- Cascade: $J/\psi(\mu\mu) + \mu$
- Mis-ID: $J/\psi\ (\mu\mu) + \pi$
- Fake resonance: Wrong, e.g. $J/\psi\ (\mu^-\mu^+)$

Backup: J/ψ



$B_c^+ \to J/\psi\tau^+\nu$
$B_c^+ \to J/\psi\mu^+\nu$
Bkg.
Normlized distribution
q^2 [GeV^2]
$\log s_{SV}$
$m^2_{\rm miss}$ [GeV^2]
I_N(0.3rad) [GeV]

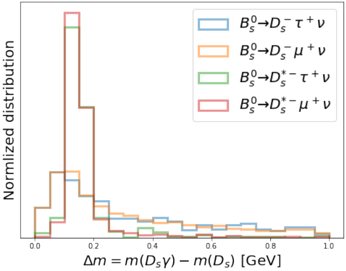
Backup: J/ψ

Channel	Events at Tera-Z	$N(3\mu)$	$N(J/\psi)$	$N(B_c^+)$	Total eff.
$B_c^+ \to J/\psi\tau^+\nu_\tau$	1.20×10^4	7.99×10^3	4.68×10^3	3.76×10^3	31.34%
$B_c^+ \to J/\psi\mu^+\nu_\mu$	2.92×10^5	1.99×10^5	1.18×10^5	1.03×10^5	35.13%
Inclusive bkg.	1.27×10^4	8.20×10^3	5.29×10^3	3.90×10^3	30.63%
Combinatoric bkg.	4.64×10^7	3.93×10^7	2.66×10^7	7.78×10^4	0.17%
Cascade bkg.	1.81×10^4	4.89×10^3	3.32×10^3	1.84×10^3	10.15%
Mis-ID bkg.	$\epsilon_{\mu\pi} \times 1.45 \times 10^9$	$\epsilon_{\mu\pi} \times 1.03 \times 10^9$	$\epsilon_{\mu\pi} \times 6.96 \times 10^8$	$\epsilon_{\mu\pi} \times 1.10 \times 10^8$	7.61%

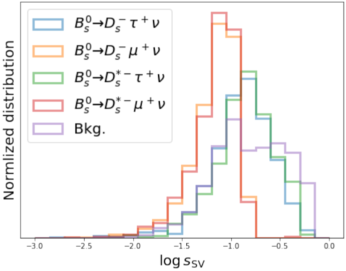
	$y_\tau \geq 0.24$ and $y_\mu < 0.07$	$y_\tau < 0.24$ and $y_\mu \geq 0.07$
$B_c^+ \to J/\psi\tau^+\nu_\tau$	2.87×10^3	3.87×10^2
$B_c^+ \to J/\psi\mu^+\nu_\mu$	9.77×10^2	9.96×10^4
Inclusive bkg.	1.36×10^2	4.99×10^2
Combinatoric bkg.	8.87×10^2	3.55×10^2
Cascade bkg.	3.55×10^2	2.66×10^2
Mis-ID bkg.	$\epsilon_{\mu\pi} \times 6.60 \times 10^4$	$\epsilon_{\mu\pi} \times 4.51 \times 10^5$

$R_{J/\psi}$ Measurement at Tera-Z (10$\times$Tera-Z)					
q^2 range	$B_c^+ \to J/\psi\tau^+\nu_\tau$ rel. uncert.	S/B	$B_c^+ \to J/\psi\mu^+\nu_\mu$ rel. uncert.	S/B	$R_{J/\psi}$ rel. uncert.
Full q^2	2.87×10^{-2} (9.07×10^{-3})	0.95	3.69×10^{-3} (1.17×10^{-3})	16.55	2.89×10^{-2} (9.15×10^{-3})
$q^2 < 7.15$ GeV$/c^2$	5.20×10^{-2} (1.64×10^{-2})	0.62	4.63×10^{-3} (1.46×10^{-3})	13.12	5.22×10^{-2} (1.65×10^{-2})
$q^2 \geq 7.15$ GeV$/c^2$	3.35×10^{-2} (1.06×10^{-2})	1.37	6.12×10^{-3} (1.93×10^{-3})	32.31	3.30×10^{-2} (1.08×10^{-2})

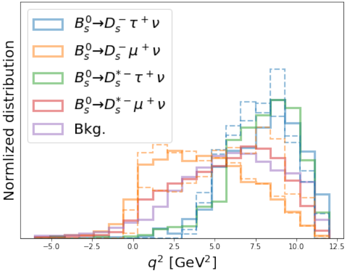
Backup: D_s



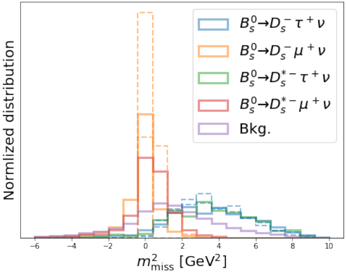
$B_s^0 \to D_s^- \tau^+ \nu$
$B_s^0 \to D_s^- \mu^+ \nu$
$B_s^0 \to D_s^{*-} \tau^+ \nu$
$B_s^0 \to D_s^{*-} \mu^+ \nu$
Normlized distribution
$\Delta m = m(D_s\gamma) - m(D_s)$ [GeV]



$B_s^0 \to D_s^- \tau^+ \nu$
$B_s^0 \to D_s^- \mu^+ \nu$
$B_s^0 \to D_s^{*-} \tau^+ \nu$
$B_s^0 \to D_s^{*-} \mu^+ \nu$
Bkg.
Normlized distribution
$\log s_{SV}$



$B_s^0 \to D_s^- \tau^+ \nu$
$B_s^0 \to D_s^- \mu^+ \nu$
$B_s^0 \to D_s^{*-} \tau^+ \nu$
$B_s^0 \to D_s^{*-} \mu^+ \nu$
Bkg.
Normlized distribution
q^2 [GeV^2]



$B_s^0 \to D_s^- \tau^+ \nu$
$B_s^0 \to D_s^- \mu^+ \nu$
$B_s^0 \to D_s^{*-} \tau^+ \nu$
$B_s^0 \to D_s^{*-} \mu^+ \nu$
Bkg.
Normlized distribution
m^2_{miss} [GeV^2]

Backup: $D_s^{(*)}$

Channel	Events at Tera-Z	$N(KK\pi\mu)$	$N(D_s^-)$	$N(B_s^0)$	Total eff.
$B_s^0 \to D_s^- \tau^+ \nu_\tau$	1.03×10^6	7.92×10^5	6.45×10^5	4.81×10^5	46.77%
$B_s^0 \to D_s^- \mu^+ \nu_\mu$	1.50×10^7	1.18×10^7	9.93×10^6	8.41×10^6	56.08%
$B_s^0 \to D_s^{*-} \tau^+ \nu_\tau$	1.72×10^6	1.30×10^6	1.05×10^6	7.65×10^5	44.61%
$B_s^0 \to D_s^{*-} \mu^+ \nu_\mu$	3.35×10^7	2.56×10^7	2.11×10^7	1.78×10^7	53.11%
Inclusive bkg.	5.78×10^6	4.28×10^6	3.28×10^6	2.72×10^6	47.03%
Combinatoric bkg.	1.36×10^8	1.16×10^8	2.24×10^7	2.17×10^4	0.02%
Cascade bkg.	8.44×10^7	6.20×10^7	2.33×10^7	8.71×10^6	10.33%
Mis-ID bkg.	$\epsilon_{\mu\pi} \times 1.05 \times 10^{10}$	$\epsilon_{\mu\pi} \times 4.33 \times 10^9$	$\epsilon_{\mu\pi} \times 8.41 \times 10^8$	$\epsilon_{\mu\pi} \times 8.50 \times 10^7$	0.81%

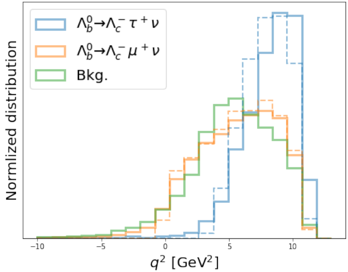
	$y_{D_s\tau} \geq 0.55$, $y_{D_s\mu} < 0.44$, $y_{D_s^*\tau} < 0.60$, $y_{D_s^*\mu} < 0.63$,	$y_{D_s\tau} < 0.55$, $y_{D_s\mu} \geq 0.44$, $y_{D_s^*\tau} < 0.60$, $y_{D_s^*\mu} < 0.63$,	$y_{D_s\tau} < 0.55$, $y_{D_s\mu} < 0.44$, $y_{D_s^*\tau} \geq 0.60$, $y_{D_s^*\mu} < 0.63$,	$y_{D_s\tau} < 0.55$ $y_{D_s\mu} < 0.44$ $y_{D_s^*\tau} < 0.60$ $y_{D_s^*\mu} \geq 0.63$
$B_s^0 \to D_s^- \tau^+ \nu_\tau$	1.85×10^5	5.03×10^4	2.17×10^4	1.18×10^4
$B_s^0 \to D_s^- \mu^+ \nu_\mu$	2.89×10^4	6.90×10^6	8.47×10^3	4.98×10^5
$B_s^0 \to D_s^{*-} \tau^+ \nu_\tau$	9.28×10^4	1.94×10^4	2.05×10^5	6.13×10^4
$B_s^0 \to D_s^{*-} \mu^+ \nu_\mu$	4.05×10^4	4.34×10^6	9.53×10^4	8.89×10^6
Inclusive bkg.	4.35×10^4	3.55×10^5	2.75×10^4	2.73×10^5
Combinatoric bkg.	$\sim 0.00 \times 10^0$	$\sim 0.00 \times 10^0$	$\sim 0.00 \times 10^0$	$\sim 0.00 \times 10^0$
Cascade bkg.	5.49×10^4	1.49×10^5	2.97×10^4	4.58×10^4
Mis-ID bkg.	$\epsilon_{\mu\pi} \times 3.50 \times 10^5$	$\epsilon_{\mu\pi} \times 5.38 \times 10^6$	$\epsilon_{\mu\pi} \times 3.53 \times 10^5$	$\epsilon_{\mu\pi} \times 1.30 \times 10^6$

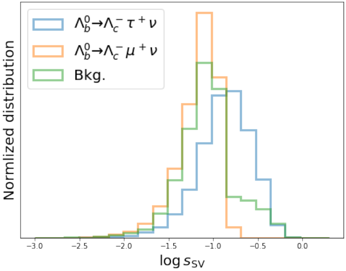
Backup: $D_s^{(*)}$

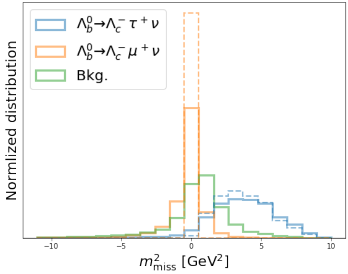
R_{D_s} Measurement at Tera-Z (10$\times$Tera-Z)							
q^2 range	$B_s^0 \to D_s^- \tau^+ \nu_\tau$ rel. uncert.	S/B	$B_s^0 \to D_s^- \mu^+ \nu_\mu$ rel. uncert.	S/B	R_{D_s} rel. uncert.	correlation ρ w/ $R_{D_s^*}$
Full q^2	3.84×10^{-3} (1.22×10^{-3})	0.70	5.42×10^{-4} (1.71×10^{-4})	1.39	4.15×10^{-3} (1.31×10^{-3})	-0.50
$q^2 < 7.15$ GeV	9.30×10^{-3} (2.94×10^{-3})	0.42	5.83×10^{-4} (1.84×10^{-4})	1.71	1.10×10^{-2} (3.47×10^{-3})	-0.59
$q^2 \geq 7.15$ GeV	4.26×10^{-3} (1.35×10^{-3})	0.84	1.39×10^{-3} (4.39×10^{-4})	0.79	4.53×10^{-3} (1.43×10^{-3})	-0.49

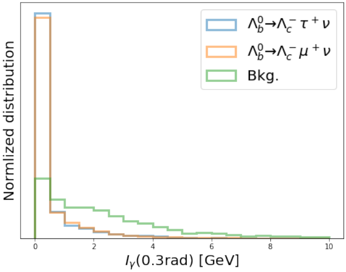
$R_{D_s^*}$ Measurement at Tera-Z (10$\times$Tera-Z)						
q^2 range	$B_s^0 \to D_s^{*-} \tau^+ \nu_\tau$ rel. uncert.	S/B	$B_s^0 \to D_s^{*-} \mu^+ \nu_\mu$ rel. uncert.	S/B	$R_{D_s^*}$ rel. uncert.	correlation ρ w/ R_{D_s}
Full q^2	3.30×10^{-3} (1.04×10^{-3})	1.10	3.97×10^{-4} (1.25×10^{-4})	9.85	3.25×10^{-3} (1.03×10^{-3})	-0.50
$q^2 < 7.15$ GeV	9.91×10^{-3} (3.13×10^{-3})	0.59	5.32×10^{-4} (1.68×10^{-4})	7.73	9.90×10^{-3} (3.13×10^{-3})	-0.59
$q^2 \geq 7.15$ GeV	3.53×10^{-3} (1.12×10^{-3})	1.23	5.91×10^{-4} (1.87×10^{-4})	15.42	3.47×10^{-3} (1.10×10^{-3})	-0.49

Backup: Λ_c









Backup: Λ_c

	$y_\tau \geq 0.48$ and $y_\mu < 0.72$	$y_\tau < 0.48$ and $y_\mu \geq 0.72$
$\Lambda_b^0 \to \Lambda_c^- \tau^+ \nu_\tau$	1.78×10^6	2.47×10^5
$\Lambda_b^0 \to \Lambda_c^- \mu^+ \nu_\mu$	4.95×10^5	4.26×10^7
Inclusive bkg.	4.46×10^4	2.53×10^5
Combinatoric bkg.	$\sim 0.00 \times 10^0$	$\sim 0.00 \times 10^0$
Cascade bkg.	4.25×10^4	2.63×10^4
Mis-ID bkg.	$\epsilon_{\mu\pi} \times 4.65 \times 10^5$	$\epsilon_{\mu\pi} \times 2.68 \times 10^6$

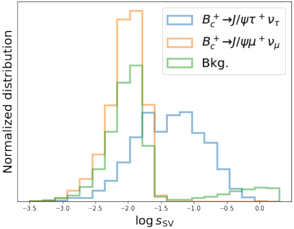
	$s_\tau \geq 0.365$ and $s_\mu < 0.480$	$s_\tau < 0.365$ and $s_\mu \geq 0.480$
$\Lambda_b^0 \to \Lambda_c^- \tau^+ \nu_\tau$	1.79×10^6	2.41×10^5
$\Lambda_b^0 \to \Lambda_c^- \mu^+ \nu_\mu$	5.34×10^5	4.24×10^7
Inclusive bkg.	4.81×10^4	2.44×10^5
Combinatoric bkg.	$\sim 0.00 \times 10^0$	$\sim 0.00 \times 10^0$
Cascade bkg.	4.44×10^4	2.63×10^4
Mis-ID bkg.	$\epsilon_{\mu\pi} \times 4.83 \times 10^5$	$\epsilon_{\mu\pi} \times 2.59 \times 10^6$

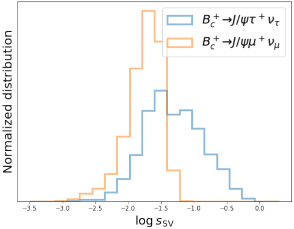
R_{Λ_c} Measurement at Tera-Z ($10\times$Tera-Z)					
q^2 range	$\Lambda_b^0 \to \Lambda_c^- \tau^+ \nu_\tau$ rel. uncert.	S/B	$\Lambda_b^0 \to \Lambda_c^- \mu^+ \nu_\mu$ rel. uncert.	S/B	R_{Λ_c} rel. uncert.
Full q^2	9.58×10^{-4} (3.03×10^{-4})	3.03	1.75×10^{-4} (5.54×10^{-5})	76.93	9.74×10^{-4} (3.08×10^{-4})
$q^2 < 7.15$ GeV	2.00×10^{-3} (6.32×10^{-4})	1.76	2.22×10^{-4} (7.02×10^{-5})	72.70	2.01×10^{-3} (6.36×10^{-4})
$q^2 \geq 7.15$ GeV	1.10×10^{-3} (3.48×10^{-4})	3.96	2.86×10^{-4} (9.04×10^{-5})	78.96	1.14×10^{-3} (3.59×10^{-4})

The Impact from Detector Tracking Resolutions

Most affected: *Vertex Info.* (e.g. distance between μ track to SV)

- Original analysis: inject 10 μm noise to the vertex [Dong et al. (2018); Abada et al. (2019b)]
- Varied analysis: inject 20 μm noise to the vertex



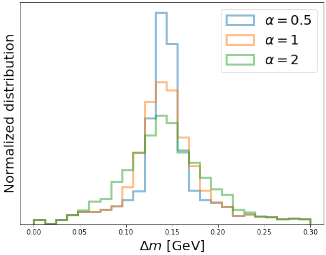


Overall: relative uncertainties of $R_{J/\psi}$, $R_{D_s^{(*)}}$, R_{Λ_c} degraded $\sim 9\% - 22\%$ (Preliminary)

Reconstructed Δm Effects

Varying the ECAL resolution (tagging efficiency):

- $\alpha = 0$: Perfect resolution, setting the limit
- $\alpha = 1$: Original
- $0 < \alpha < 1$: Better efficiency
- $\alpha > 1$: Worse efficiency



α	$B_s \to D_s^* \tau\nu$	$B_s \to D_s^* \mu\nu$
0	39.05%	40.77%
0.1	38.58%	40.62%
0.5	37.75%	39.95%
1	36.80%	39.20%
2	35.03%	37.64%

Table: Efficiency v.s. resolution

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