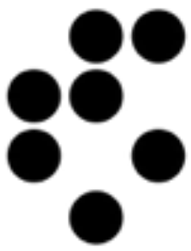
FCC-ee mini-workshop on Flavours

(Additional) Flavour Possibilities at FCC-ee

Jernej F. Kamenik

Univerza *v Ljubljani*



Institut “Jožef Stefan”

1/2/2018

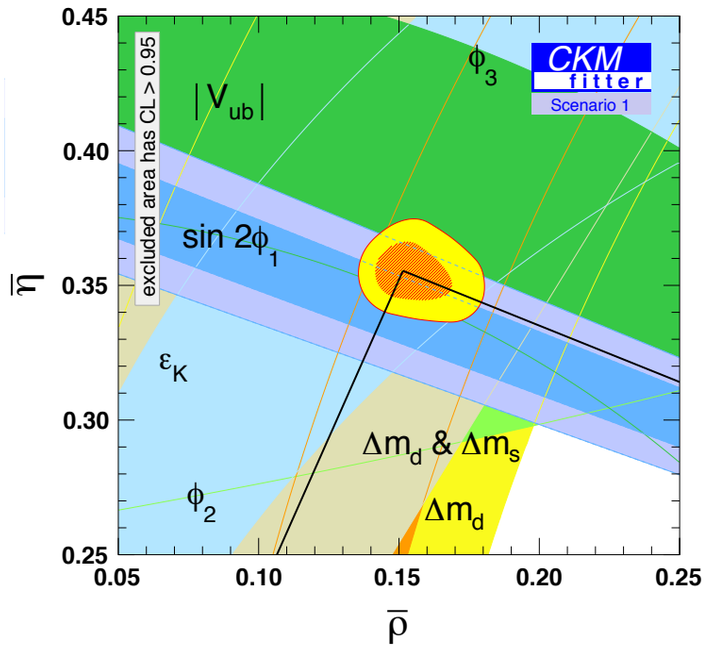
Scope of Flavour Physics @ FCC-ee

- Flavour physics reach with O(10^{13}) Z decays (10^8 W, 10^6 Higgs, top)
  - rare decays of c- and b-hadrons and CP violation in the heavy-quark sector
  - rare lepton decays
    - rare Z, (W, h, t?) decays
- In the context of ultimate potential of the LHCb upgrade and Belle II experiments.
- Possibility/utility of dedicated PID (π / K / p separation) detector
- Baseline focus on combination of conservative benchmarks and exploratory new observables

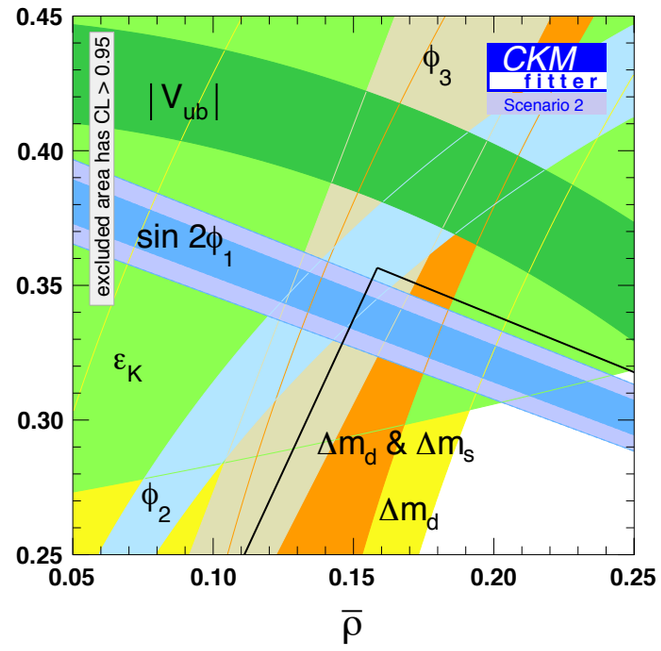
Flavor physics circa 2030: possible scenarios

WA

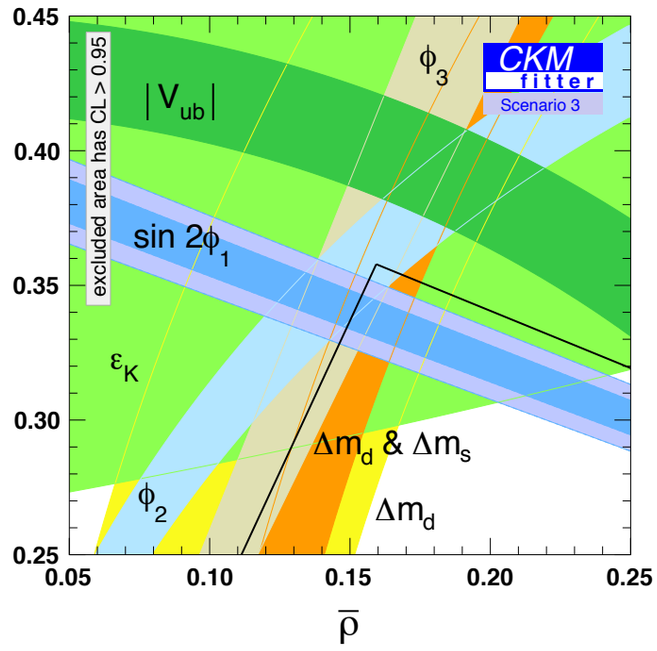
Now



50 ab^{-1} Belle II

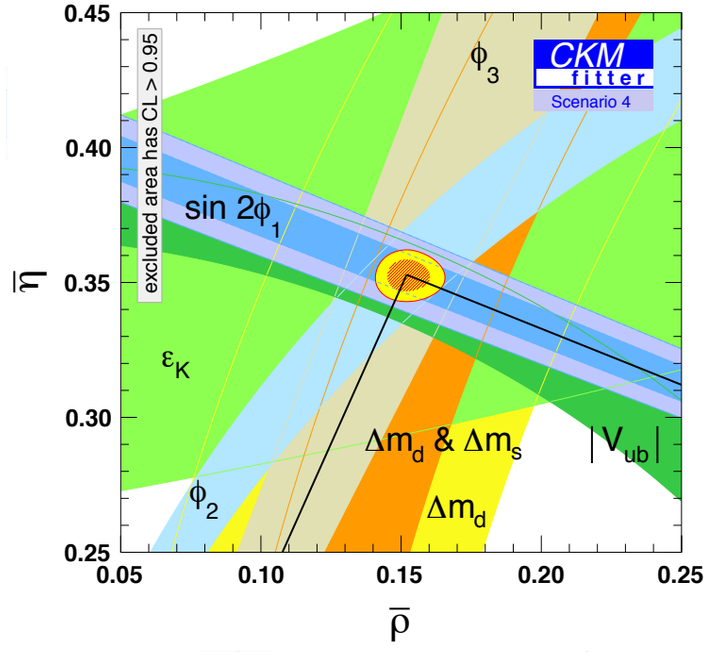


50 ab^{-1} Belle II + LHCb

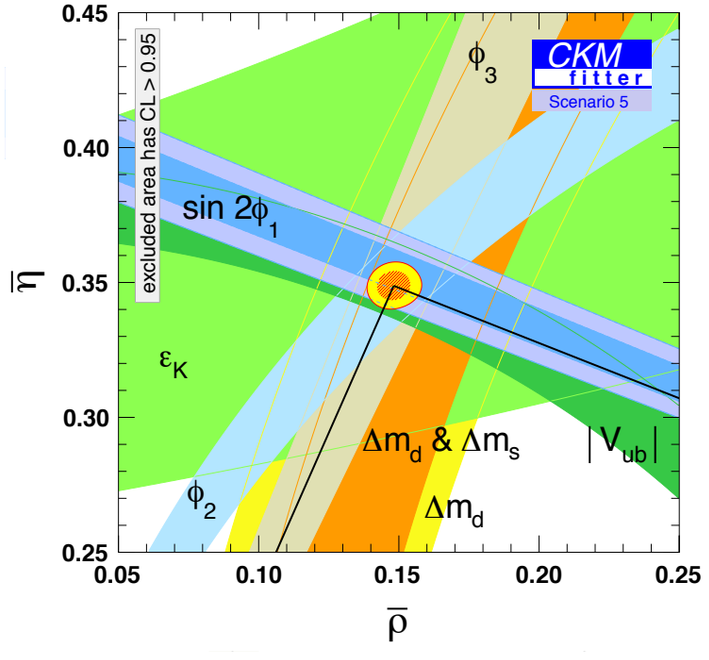


SM-like

50 ab^{-1} Belle II



50 ab^{-1} Belle II + LHCb



+ discoveries or bounds from high-pT searches

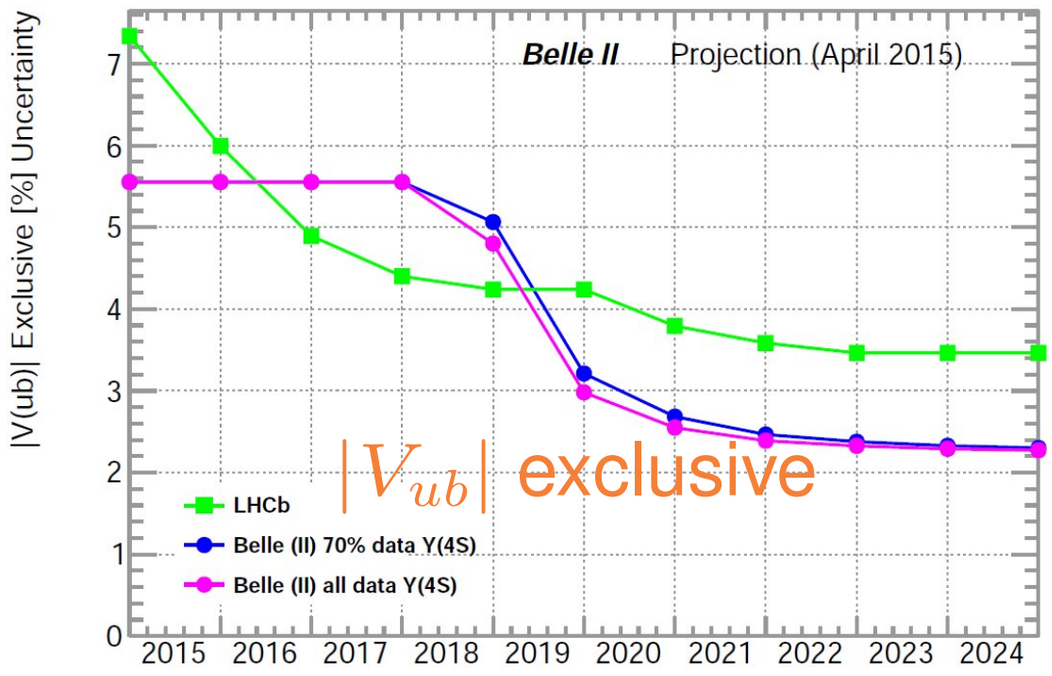
FCC-ee flavour physics benchmarks & explorations

Leptonic or semileptonic decay modes involving B_s, B_c or b–baryon

(see talk by Becirevic)

⇒ $B_{u,c} \to \mu\nu, \tau\nu$

- inclusive $|V_{ub}|$ measurements theory limited,
- final BelleII exclusive precision: ~2.2%



Improvement via $B_{u,c} \to \mu\nu, \tau\nu$ @ FCC-ee?

$$Br(B^- \to \tau^- \bar{\nu}(\gamma))_{\mathrm{SM}} = 1.13(1) \times 10^{-4} \left(\frac{f_B}{0.2\mathrm{GeV}}\right)^2 \left(\frac{|V_{ub}|}{4 \times 10^{-3}}\right)^2$$

$$\left[\frac{\Gamma(B^+ \to \tau^+ \nu)}{\Gamma(B_c^+ \to \tau^+ \nu)}\right]_{SM^*} = 0.782 \left|\frac{V_{ub} f_B}{V_{cb} f_{B_c}}\right|^2$$

Leptonic or semileptonic decay modes involving B_s, B_c or b–baryon

(see also talks by Becirevic, Vale Silva)

Searches for $B_c \to \tau\nu$ at FCC-ee

- BR($B_c \to \tau\nu$) measured in a e^+e^- collider at the Z pole
  - Searches of $B^- \to \tau^-\nu$ above $B_c\,\bar{B}_c$ threshold really measure

    Mangano&Slabospitsky, PLB410(1997)299

$$\overbrace{\text{BR}_{\text{eff}}}^{\text{FCC}-\text{ee}} = \overbrace{\text{BR}(B \to \tau\nu)}^{\text{Belle \& BaBar}} + \overbrace{\frac{f_c}{f_u}}^{\text{TH.input}} \text{BR}(B_c \to \tau\nu)$$

  - B_c contribution suppressed by $f_c/f_u \sim 10^{-3}$-10^{-2} but enhanced by $\frac{|V_{cb}|^2}{|V_{ub}|^2}\frac{f_{B_c}^2}{f_B^2} \sim$ **700**

- f_c/f_u: Fraction of hadronization into B_c over B
  - Traded by experimental data and **computable TH. input**

$$R_\ell = \frac{f_c}{f_u}\frac{\text{BR}(B_c \to J/\psi\mu\nu)}{B \to J/\psi K}$$

  - R_ℓ measured by **CDF** and reconstructed from **LHCb** data

Leptonic or semileptonic decay modes involving B_s, B_c or b–baryon

(see also talks by Becirevic, Vale Silva)

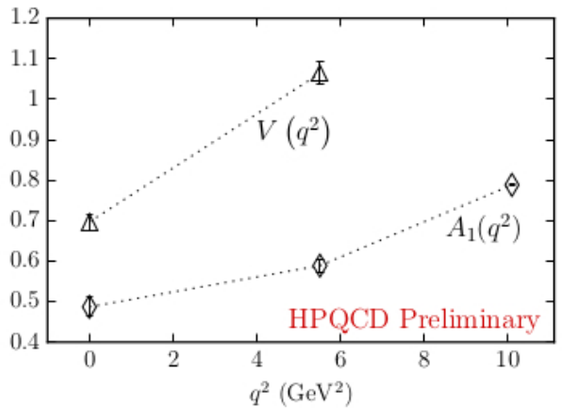
Searches for $B_c \to \tau\nu$ at FCC-ee

- **Model calculations** predict BR($B_c \to J/\psi\mu\nu$) $\in 1 - 7\%$!

	pQCD	WSL[9]	EFG[7]	ISK[6]	HNV[5]	DV[4]
$V^{B_c\to J/\Psi}$	0.42	0.74	0.49	0.83	0.61	0.91
$A_0^{B_c\to J/\Psi}$	0.59	0.53	0.40	0.57	0.45	0.58
$A_1^{B_c\to J/\Psi}$	0.46	0.50	0.50	0.56	0.49	0.63
$A_2^{B_c\to J/\Psi}$	0.64	0.44	0.73	0.54	0.56	0.74

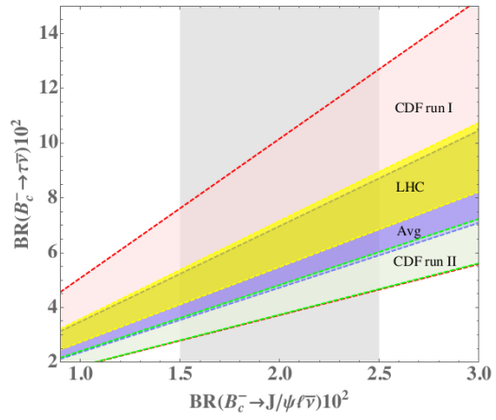
Wang, Fang&Xiao, arXiv: 1212.5903

- **Ongoing efforts in LQCD!**
  - **Preliminary** results to select models



HPQCD Collaboration, PoS LATTICE2016 (2016) 281

  - Constrains BR($B_c \to \tau\nu$) $< 10\%$



Akeroyd&Chen, 1708.04072

M. Acciarri et al. [L3 Collaboration], Phys. Lett. B 396, 327 (1997).
P. Abreu et al. [DELPHI Collaboration], Phys. Lett. B 496, 43 (2000).
R. Barate et al. [ALEPH Collaboration], Eur. Phys. J. C 19, 213 (2001).

Leptonic or semileptonic decay modes involving B_s, B_c or b–baryon

(see also talks by Becirevic, Vale Silva)

Searches for $B_c \to \tau\nu$ at FCC-ee

- **Model calculations** predict BR($B_c \to J/\psi\mu\nu$) $\in 1 - 7\%$!

	pQCD	WSL[9]	EFG[7]	ISK[6]	HNV[5]	DV[4]
$V^{B_c\to J/\Psi}$	0.42	0.74	0.49	0.83	0.61	0.91
$A_0^{B_c\to J/\Psi}$	0.59	0.53	0.40	0.57	0.45	0.58
$A_1^{B_c\to J/\Psi}$	0.46	0.50	0.50	0.56	0.49	0.63
$A_2^{B_c\to J/\Psi}$	0.64	0.44	0.73	0.54	0.56	0.74

Wang, Fang&Xiao, arXiv: 1212.5903

- Projections made for $\sim 10^9 Z$ bosons Akeroyd, Chen, Recksiegel, 0803.3517

Error BR($B^\pm/B_c^\pm \to \tau^\pm\nu$)	High Lum. B Factory (B mesons)	Giga Z (Z bosons)
20%	2.2×10^9	3.2×10^7
4%	8.1×10^{10}	8×10^8

TABLE III: Required number of B mesons (Z bosons) for a precision of 20% and 4% in measurement of BR($B^\pm/B_c^\pm \to \tau^\pm\nu$), assuming a signal of $\mathrm{BR}_{\mathrm{eff}} = 4 \pm 2 \times 10^{-4}$ at L3.

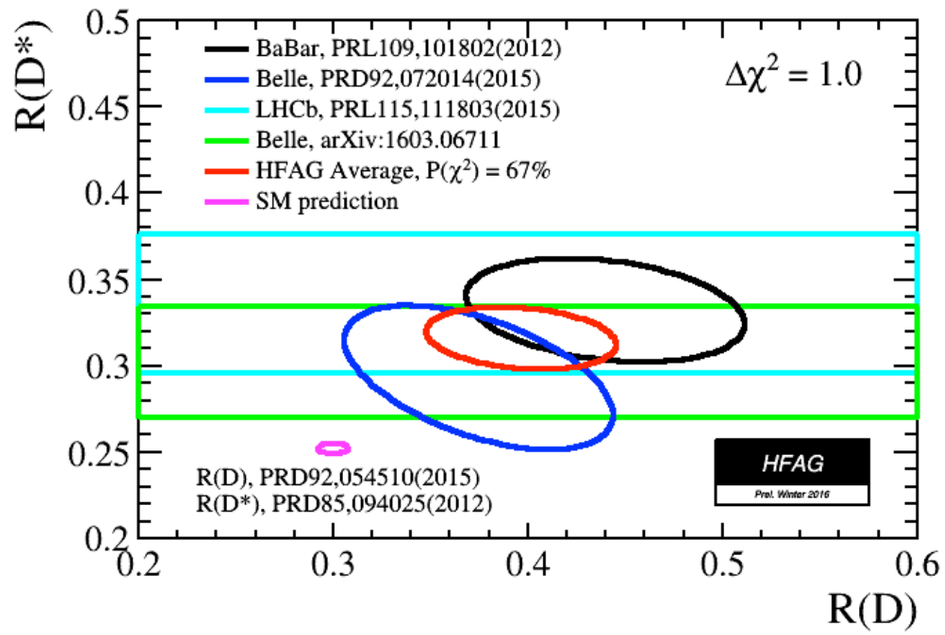
With 10^{13} Z bosons, can look towards other related systems:

$$\left[\frac{\Gamma(B^+ \to \mu^+\nu)}{\Gamma(B^+ \to \tau^+\nu)}\right]_{SM^*} = 4.46 \times 10^{-3} \qquad \left[\frac{\Gamma(B_c^+ \to \mu^+\nu)}{\Gamma(B_c^+ \to \tau^+\nu)}\right]_{SM^*} = 4.15 \times 10^{-3}$$

Leptonic or semileptonic decay modes involving B_s, B_c or b–baryon

(see also talks by Becirevic, Vale Silva)

Especially, given surprising current experimental situation concerning LFU:



$$R(D^{(*)}) \equiv \frac{\Gamma(B \to D^{(*)}\tau\nu)}{\Gamma(B \to D^{(*)}\ell\nu)}$$

With 10^{13} Z bosons, can look towards other related systems:

$$\left[\frac{\Gamma(B^+ \to \mu^+\nu)}{\Gamma(B^+ \to \tau^+\nu)}\right]_{SM^*} = 4.46 \times 10^{-3} \qquad \left[\frac{\Gamma(B_c^+ \to \mu^+\nu)}{\Gamma(B_c^+ \to \tau^+\nu)}\right]_{SM^*} = 4.15 \times 10^{-3}$$

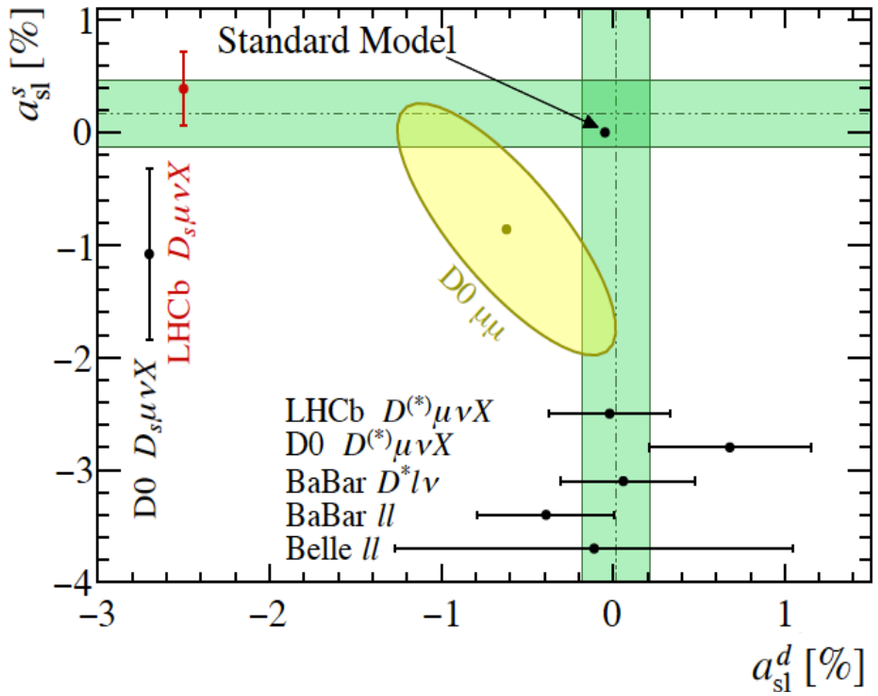
Leptonic or semileptonic decay modes involving B_s, B_c or b–baryon

(see talk by Arogancia)

$\Rightarrow a_{sl}^{(s,d)}$

- Current exp. unc. ~0.5%
- Will be improved by order of magnitude by BelleII & LHCb
- Still order of magnitude above precision of SM predictions:

$$a_{\rm sl}^{s} = (2.22 \pm 0.27) \times 10^{-5} \text{ for } B_s^0$$
$$a_{\rm sl}^{d} = (-4.7 \pm 0.6) \times 10^{-4} \text{ for } B^0$$



Naive extrapolation of LEP results suggests sensitivity of FCC-ee better than 10^{-4}
More detailed studies underway

OPAL, hep-ex/9901017
ALEPH, CERN-EP-2000-105

Leptonic or semileptonic decay modes involving B_s, B_c or b–baryon

(see talks by Monteil, Vale Silva)

⇒ $B_{d,s} \to \tau\tau$

- In the SM known to 6% precision:

Bobeth et al., 1311.0903

$$\begin{aligned} \mathrm{BR}(B_s \to \tau^+\tau^-) &= (7.73 \pm 0.49) \times 10^{-7} \\ \mathrm{BR}(B_d \to \tau^+\tau^-) &= (2.22 \pm 0.19) \times 10^{-8} \end{aligned}$$

- First direct exp. bounds by LHCb:

LHCb-CONF-2016-011

$$\mathrm{Br}(B_s \to \tau^+\tau^-) < 3.0 \times 10^{-3}$$

$$\mathrm{Br}(B_d \to \tau^+\tau^-) < 1.3 \times 10^{-3}$$

- Expected sensitivity at Belle II to BRs of O (10^{-4}) ~ O(10^{-5})
- Sensitivity at FCC-ee could be improved with partial reconstruction techniques (in progress)

Leptonic or semileptonic decay modes involving B_s, B_c or b–baryon

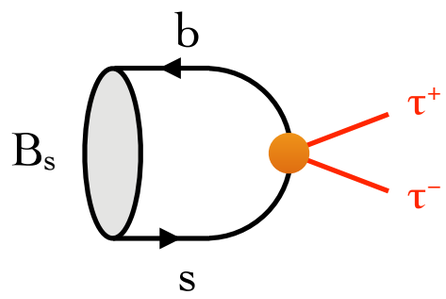
(see talks by Monteil, Vale Silva)

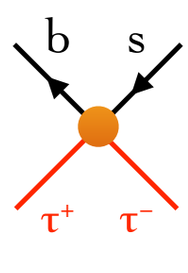
⇒ $B_{d,s} \to \tau\tau$

- Apart from tensors, all BSM bs(d)ττ Lorentz structures can be tested

- Relatively most sensitive probe for scalar and vector operators

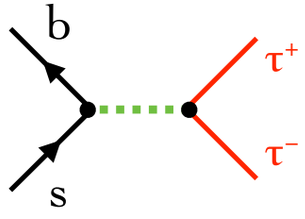
  U. Haisch, 1206.1230



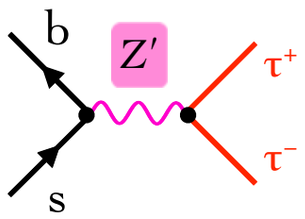


$$Q_{S,AB} = (\bar{s} P_A b)\,(\bar{\tau} P_B \tau)$$

$$Q_{V,AB} = (\bar{s} \gamma_\mu P_A b)\,(\bar{\tau} \gamma^\mu P_B \tau)$$

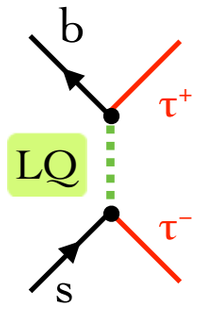


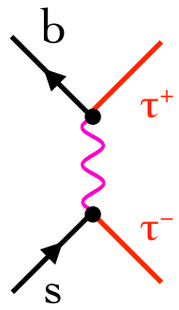
spin 0: S,P



spin 1: V,A

e.g. Z′





e.g. leptoquark (LQ)

U. Haisch @ FCC-ee flavour WG meeting 1

Leptonic or semileptonic decay modes involving B_s, B_c or b–baryon

(see talks by Monteil, Vale Silva)

⇒ b→sττ

- LFU tests with FCNC B decays
- Theoretically extremely clean

$$R_H^{\ell\ell'} = \frac{\mathrm{BR}(B \to H\ell^+\ell^-)}{\mathrm{BR}(B \to H\ell'^+\ell'^-)} ,$$

$$R^{\mu\tau}_{\pi^+} = 1.18 \pm 0.06 \quad , \quad R^{\mu\tau}_{\pi^0} = 1.19 \pm 0.06 ,$$
$$R^{\mu\tau}_{K^+} = 0.87 \pm 0.02 \quad , \quad R^{\mu\tau}_{K^0} = 0.87 \pm 0.02 ,$$

$15\ \mathrm{GeV}^2 < q^2 < 22\ \mathrm{GeV}^2$

Fermilab Lattice & MILC, 1510.02349

$$R^{\mu\tau}_{K^{*+}} = 2.44 \pm 0.09 , \quad R^{\mu\tau}_{K^{*0}} = 2.45 \pm 0.08 ,$$

$15\ \mathrm{GeV}^2 < q^2 < 19.2\ \mathrm{GeV}^2.$

D. M. Straub, flavio

W. Altmannshofer @ FCC-ee flavour WG meeting 2

B2TiP draft report

- QCD 2loop virtual corrections (known) are not included in these predictions (are the ratios affected?)
- NLO QED corrections might lead to few % shifts M. Bordone et al., 1605.07633

  (known for the inclusive $B \to X_s\ell^+\ell^-$ decays, but not yet calculated for the exclusive modes)
- effect of charmonium resonances?

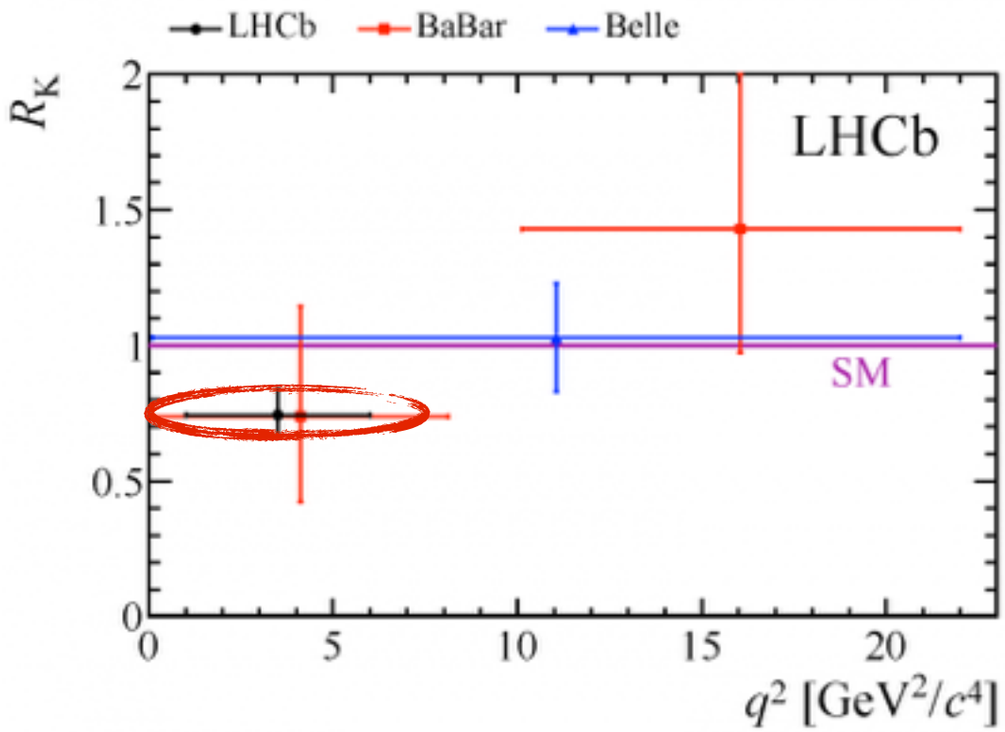
Leptonic or semileptonic decay modes involving B_s, B_c or b–baryon

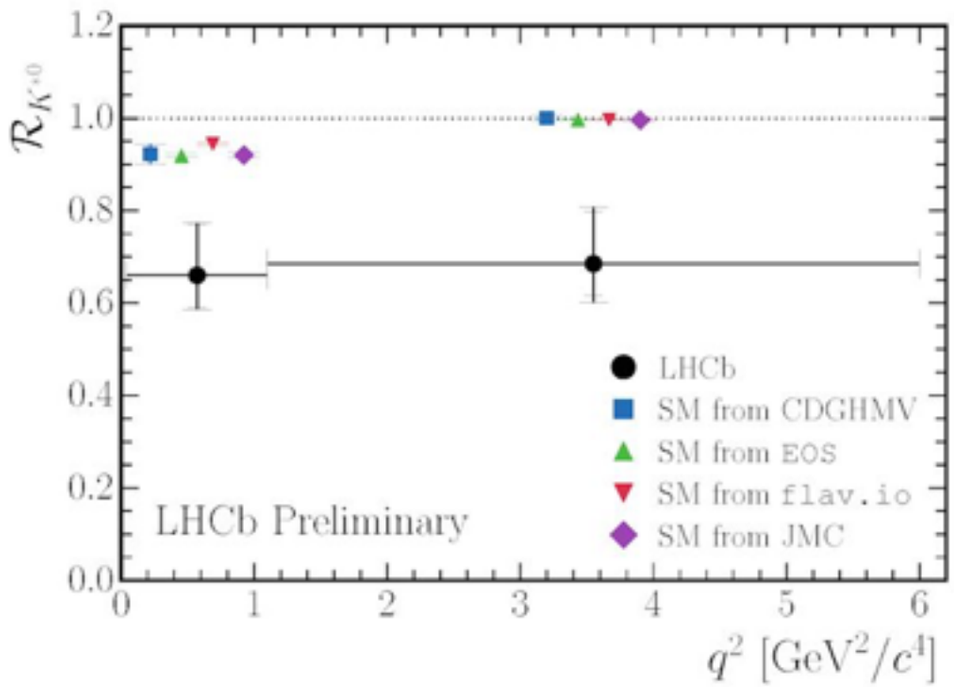
(see talks by Monteil, Vale Silva)

⇒ b→sττ

- LFU tests with FCNC B decays
- Surprising exp. situation (μ/e)

$$R_H^{\ell\ell'} = \frac{\mathrm{BR}(B \to H\ell^+\ell^-)}{\mathrm{BR}(B \to H\ell'^+\ell'^-)} \,,$$





Leptonic or semileptonic decay modes involving B_s, B_c or b–baryon

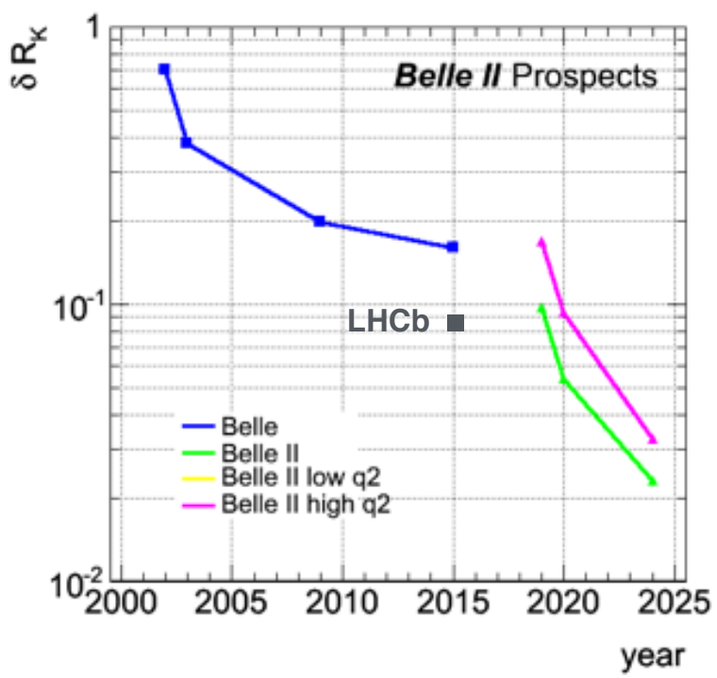
(see talks by Monteil, Vale Silva)

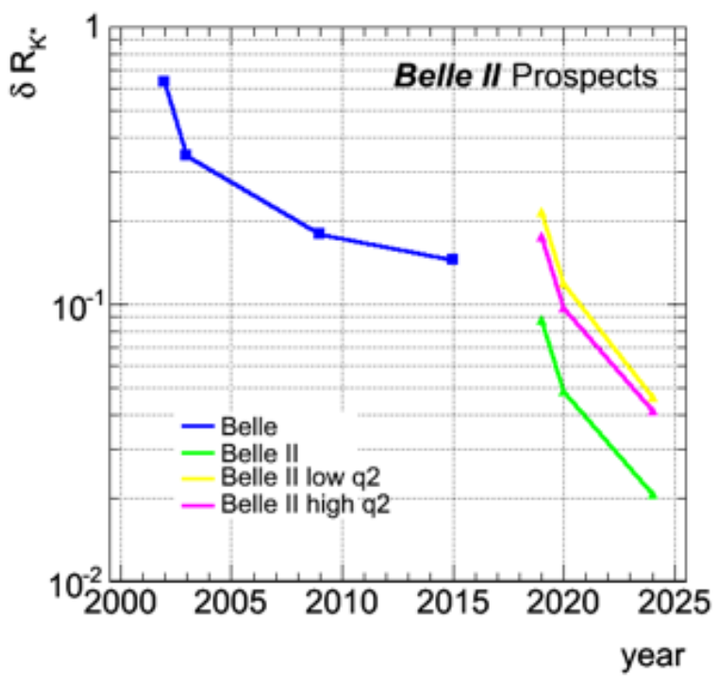
⇒ b→sττ

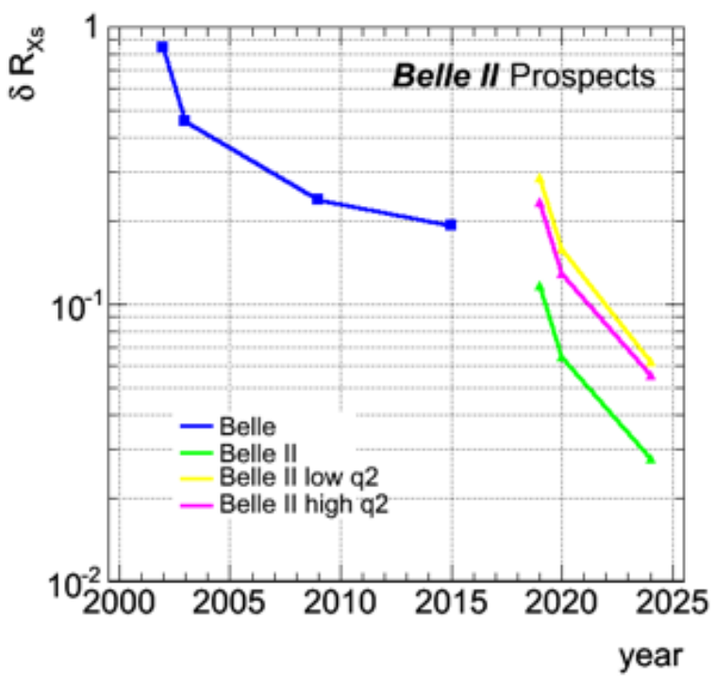
- LFU tests with FCNC B decays
- Surprising exp. situation (μ/e)

$$R_H^{\ell\ell'} = \frac{\mathrm{BR}(B \to H\ell^+\ell^-)}{\mathrm{BR}(B \to H\ell'^+\ell'^-)} \,,$$

- Final Belle II precision <4%







Leptonic or semileptonic decay modes involving B_s, B_c or b–baryon

(see talks by Monteil, Vale Silva)

⇒ b→sττ

- LFU tests with FCNC B decays
- Surprising exp. situation (μ/e)
- Motivates LFU tests with τ's
- Strongest current bound:
  (BaBar, PoS ICHEP 2010, 234)

$$R_H^{\ell\ell'} = \frac{\mathrm{BR}(B \to H\ell^+\ell^-)}{\mathrm{BR}(B \to H\ell'^+\ell'^-)} \,,$$

$$\mathrm{BR}(B \to K\tau^+\tau^-)_{[14.23,\mathrm{max}]} < 3.3 \times 10^{-3}$$

Expected sensitivity at Belle II to BRs of O (10^{-4}) ~ O(10^{-5})

Leptonic or semileptonic decay modes involving B_s, B_c or b–baryon

(see talks by Monteil, Vale Silva)

⇒ b→sττ

- LFU tests with FCNC B decays
- Surprising exp. situation (μ/e)
- Motivates LFU tests with τ's
- Example: BSM explanation of (μ/e) anomaly in terms of gauged τ-μ:

$$R_H^{\ell\ell'} = \frac{\mathrm{BR}(B \to H\ell^+\ell^-)}{\mathrm{BR}(B \to H\ell'^+\ell'^-)} ,$$

$$\begin{aligned}
\mathrm{BR}(B^+ \to K^+\tau^+\tau^-)_{L_\mu - L_\tau} &= (1.46 \pm 0.13) \times 10^{-7} , \\
\mathrm{BR}(B_d \to K^0\tau^+\tau^-)_{L_\mu - L_\tau} &= (1.35 \pm 0.12) \times 10^{-7} , \\
\mathrm{BR}(B^+ \to K^{*+}\tau^+\tau^-)_{L_\mu - L_\tau} &= (1.53 \pm 0.23) \times 10^{-7} , \\
\mathrm{BR}(B_d \to K^{*0}\tau^+\tau^-)_{L_\mu - L_\tau} &= (1.40 \pm 0.21) \times 10^{-7} ,
\end{aligned}$$

(~40% enhancement over SM)

W. Altmannshofer et al., 1403.1269

Leptonic or semileptonic decay modes involving B_s, B_c or b–baryon

(see talks by Monteil, Vale Silva)

⇒ b→sττ

- LFU tests with FCNC B decays
- Surprising exp. situation (μ/e)
- Motivates LFU tests with τ's
- Generic NP in LH-currents: strong existing bounds from correlated mode

$$R_H^{\ell\ell'} = \frac{\mathrm{BR}(B \to H\ell^+\ell^-)}{\mathrm{BR}(B \to H\ell'^+\ell'^-)} ,$$

$$\mathrm{BR}(B^+ \to K^+\nu\bar{\nu}) < 1.6 \times 10^{-7}$$

- Allowed contributions to rare semitaunic decays below projected Belle II sensitivity:

$$\begin{aligned}
\mathrm{BR}(B^+ \to K^+\tau^+\tau^-)_{LH} &< 24.5 \times 10^{-7} , \\
\mathrm{BR}(B_d \to K^0\tau^+\tau^-)_{LH} &< 22.5 \times 10^{-7} , \\
\mathrm{BR}(B^+ \to K^{*+}\tau^+\tau^-)_{LH} &< 22.8 \times 10^{-7} ,
\end{aligned}$$

$$\begin{aligned}
\mathrm{BR}(B_d \to K^{*0}\tau^+\tau^-)_{LH} &< 20.1 \times 10^{-7} , \\
\mathrm{BR}(B_s \to \tau^+\tau^-)_{LH} &< 1.5 \times 10^{-5} ,
\end{aligned}$$

(at most ~ x 20 enhancement over SM)

Leptonic or semileptonic decay modes involving B_s, B_c or b–baryon

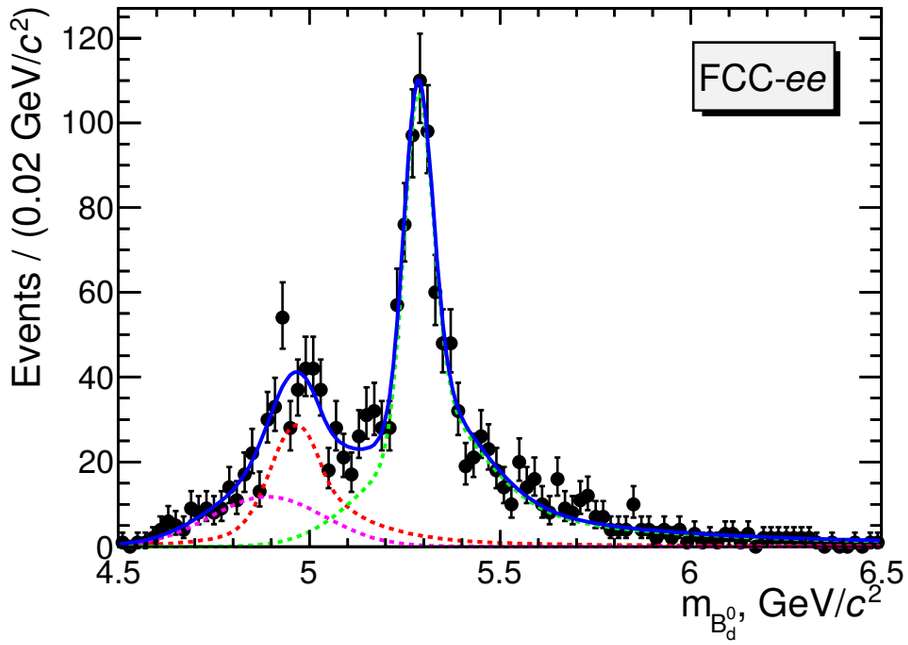
(see talks by Monteil, Vale Silva)

⇒ b→sττ

First FCC-ee sensitivity study of B→K* τ τ

At SM rates expect up to O(1000) reconstructed events at FCC-ee

- Study of distributions
- Access to tau spin



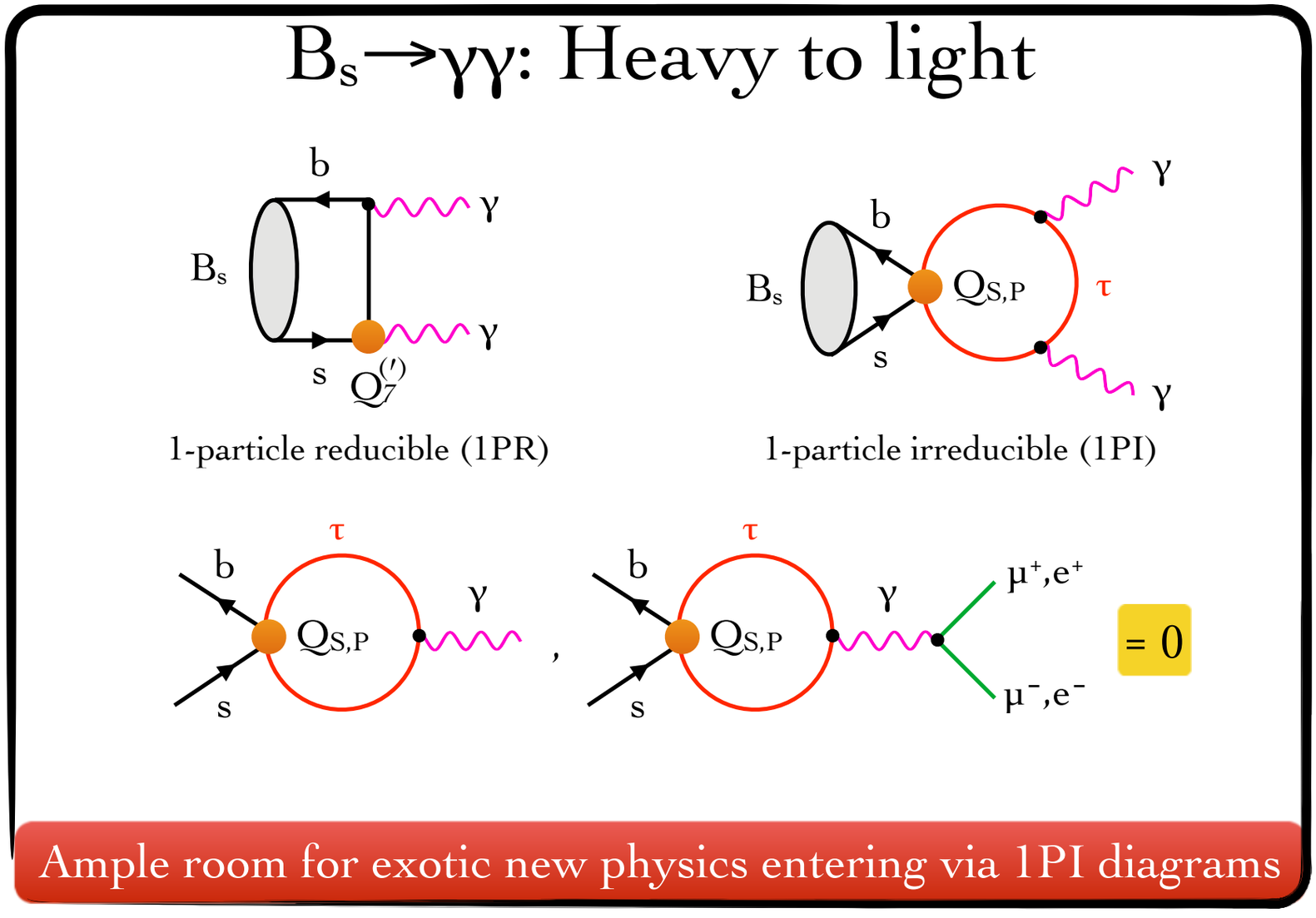
J.F.K., Monteil, Semkiv & Vale Silva, 1705.11106

Bar,

$)^{-4}) \sim$

Decay modes involving B_s, B_c or b–baryon with neutral final state particles

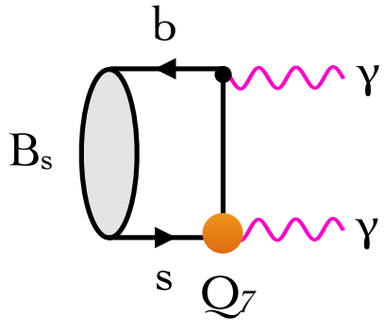
- $B_s \to K_S K_S$, $B_{d,s} \to \gamma\gamma$, $B_s \to X\nu\nu$, CP violation in hadronic B_s decays with neutrals
- Example:



Decay modes involving B_s, B_c or b–baryon with neutral final state particles

- $B_s \to K_S K_S$, $B_{d,s} \to \gamma\gamma$, $B_s \to X\nu\nu$, CP violation in hadronic B_s decays with neutrals
- Example:

$B_s \to \gamma\gamma$: Heavy to light



$$\mathrm{Br}\,(B_s \to \gamma\gamma)_{\mathrm{SM}} \propto \left| V_{ts}^* V_{tb}\, C_7\, \frac{m_{B_s}}{\lambda_{B_s}} \right|^2$$

+ subleading power from 1PI graphs

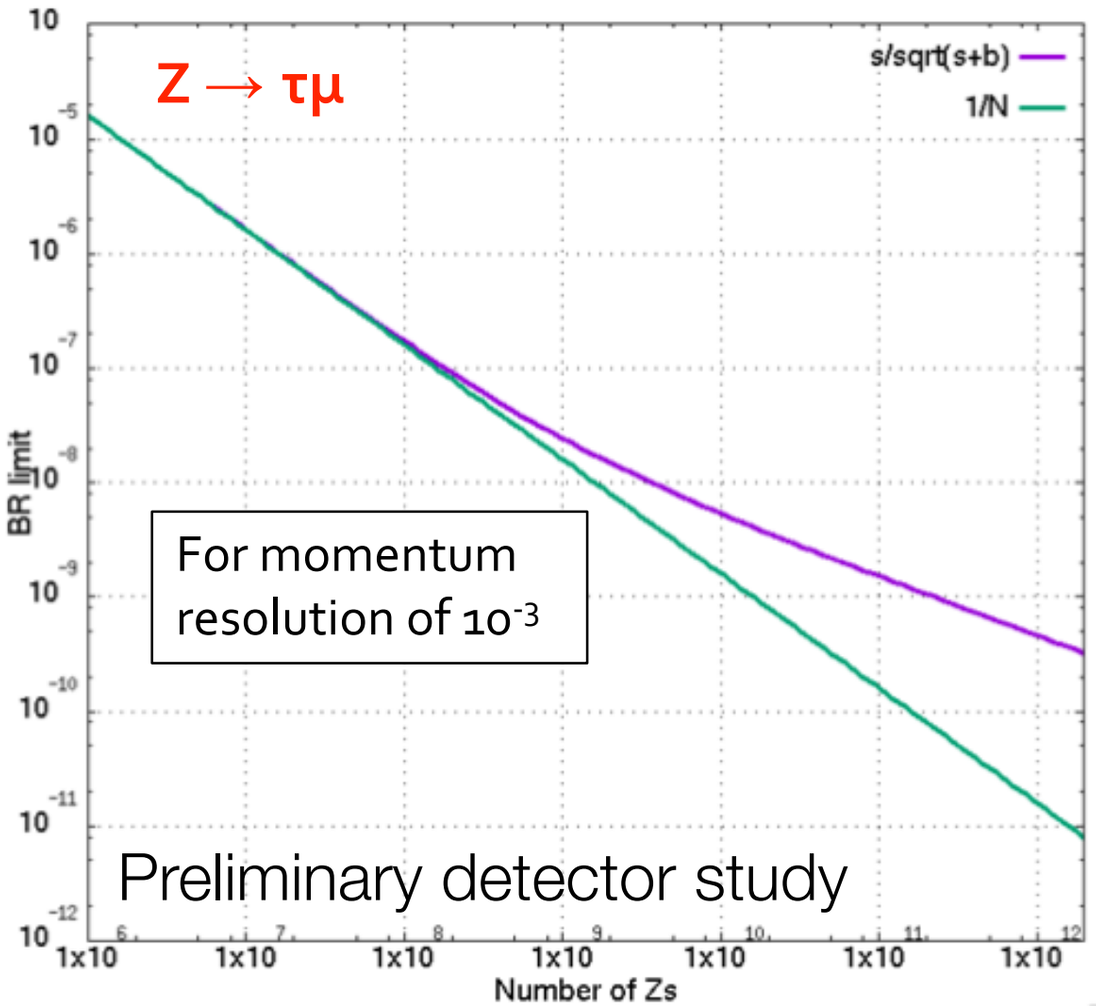
- Double-radiative decay also offers possibility to determine properties of B_s-meson light-cone distribution amplitude, in particular of its inverse moment λ_{Bs}
- Combining $B_s \to \gamma\gamma$ with $B \to \gamma l\nu$, $B_s \to \phi\gamma$, … into global fit might allow to cancel common hadronic uncertainties

Further theoretical studies needed to strengthen physics case

Lepton Flavour violating processes

(see talk by Dam)

- Direct lepton flavour violating processes Z→eμ,eτ,τμ, Lepton flavour violating τ decays, Lepton number violation
- Example:

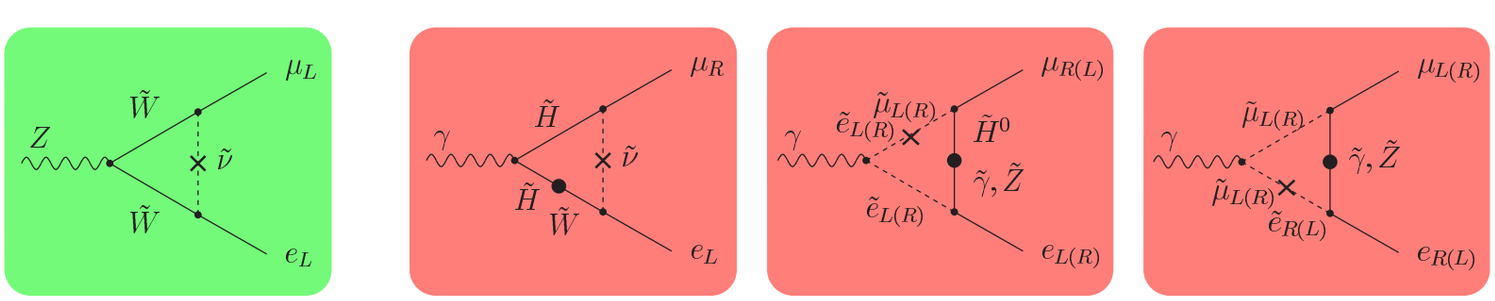


Lepton Flavour violating processes

(see talk by Dam)

- Direct lepton flavour violating processes Z→eμ,eτ,τμ, Lepton flavour violating τ decays, Lepton number violation
- Example:

LFV: Using 10^{12} Z decays



$\delta^{\tilde{\nu}\,12}_{LL}$ $\quad$ $\delta^{\tilde{\nu}\,12}_{LL}\, m_\mu \tan\beta$ $\quad$ $\delta^{\tilde{\ell}\,12}_{LL(RR)}\, m_\mu \tan\beta$ $\quad$ $\delta^{\tilde{\ell}\,12}_{LR}\, m_{\tilde{\gamma},\tilde{Z}}$

for large mass insertions $\delta^{\tilde{\nu}\,13}_{LL}$ ($\delta^{\tilde{\nu}\,23}_{LL}$), small tanβ & light sneutrinos of around 70 GeV, one gets Br(Z→τl) ~ Br(τ→lγ) = O(10^{-8})

[Illiana & Masip, 0207328]

τ→lγ bounds can by avoided allowing for largish Z→τl rates

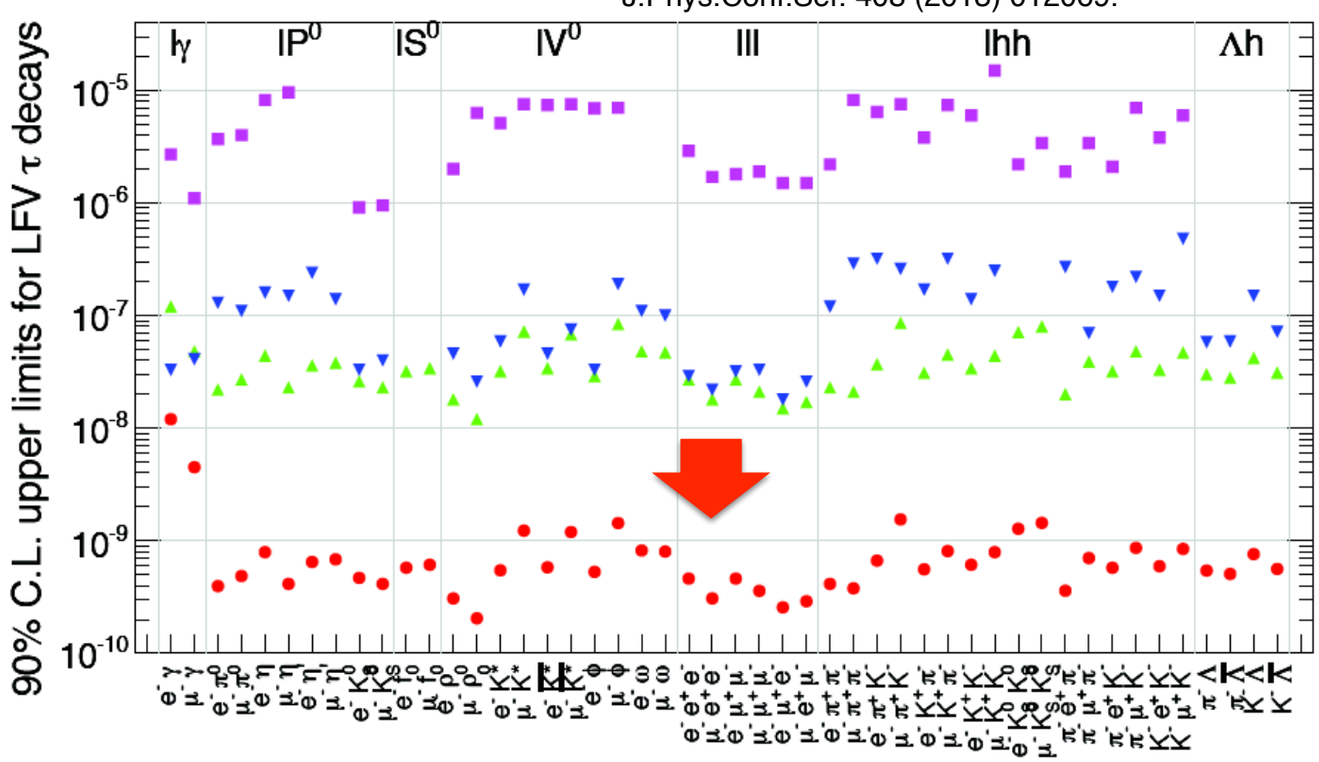
Lepton Flavour violating processes

(see talk by Dam)

- Direct lepton flavour violating processes Z→eμ,eτ,τμ, Lepton flavour violating τ decays, Lepton number violation
- Example:

LFV: Using 10^{12} Z decays

J.Phys.Conf.Ser. 408 (2013) 012069.



Also FCC-ee possibly with comparable sensitivity!

τ→lγ bounds can by avoided allowing for largish Z→τl rates

see also V. de Romeri @ FCC-ee flavour WG meetings 1 & 2

Lepton Flavour violating processes

- Direct lepton flavour violating processes Z→eμ,eτ,τμ, Lepton flavour violating τ decays, Lepton number violation
- Similar possibility in the quark sector? i.e. $Z \to j_b j_{\not b}$
  - Motivation: Probing FCNC Z-penguins directly

c.f. Isidori & Guadagnoli, 1302.3909

- In SM $\mathcal{B}(Z \to s\bar{b}) \sim 10^{-8}$ - could be probed to 1% level?

Need very efficient b-, s-tagging!

	no PID	$\epsilon_K = 95\%$	$\epsilon_K = 90\%$
ϵ_s	7×10^{-2}	4×10^{-2}	3×10^{-2}
ϵ_b	3×10^{-4}	4×10^{-5}	5×10^{-5}

Preliminary study in context of LC

Duarte-Campderros G. Perez, M. Sclaffer, A. Soffer

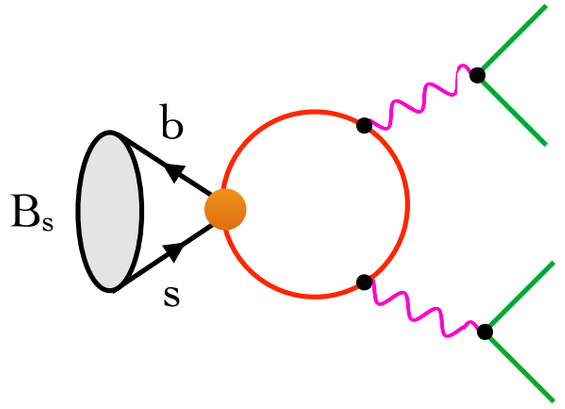
presented at
Top physics at the LC 2017 June 2017

Multibody (meaning 4 and more) hadronic b-hadron decays

- $B_s \rightarrow \psi\eta'$ or $\eta c\Phi$: flavour tagging required for weak mixing phase.
- $B_s \rightarrow D_sK$: PID required to isolate the signal.

see also R. Fleischer @ FCC-ee flavour WG meeting 3

- $B_{d,s,u,c} \rightarrow 4h+$:
  - interesting per se in a standard flavour physics case
  - also for dark portal explorations (can proceed through two scalars, vectors)…



Flavour at high-pT

$W^+ \to c\bar{b}$

- $\sigma(e^+e^- \to W^+W^-) \sim 10\text{pb}$ (in energy range of FCC-ee)

- With SM value of $\mathcal{B}(W^+ \to c\bar{b}) \sim 10^{-3}$ a precision of $\frac{\delta V_{cb}}{V_{cb}} \sim 1\%$ might be within reach...

Need efficient heavy flavour tagging or reconstruction

  - Complementary to conventional measurements at B factories - at the scale of m_W (running of CKM negligible in SM)

- In addition to more conventional measurements at Z pole

$B \to X_c \ell\nu,\ B \to X_c \tau\nu$

Conclusions

- FCC-ee could be a powerful and competitive probe of flavour physics post-2030

- Effort underway to understand the experimental precision with which rare decays of c- and b-hadrons and CP violation in the heavy-quark sector & LFV processes could be measured

  - Currently less explored directions: quarkonia physics, flavour tagging from Higgs, top decays,… (see talk by Bicudo)

Backup

Further FCC-ee & Flavour WG references

- References for the FCC-ee machine in:
    - http://tlep.web.cern.ch/content/accelerator-studies
- First look at the FCC-ee Physics Case:
    - arXiv:1308.6176 / JHEP01 (2014) 164.
- Flavour WG web: http://tlep.web.cern.ch/content/wg6-exp

FCC-ee Flavour WG meetings

- FCC-ee Flavour Physics vidyo meetings:

  https://indico.cern.ch/event/336998/,

  https://indico.cern.ch/event/359433/,

  https://indico.cern.ch/event/380986/,

  https://indico.cern.ch/event/403492/,

  https://indico.cern.ch/event/462662/

- Subscribe to our mailing list!

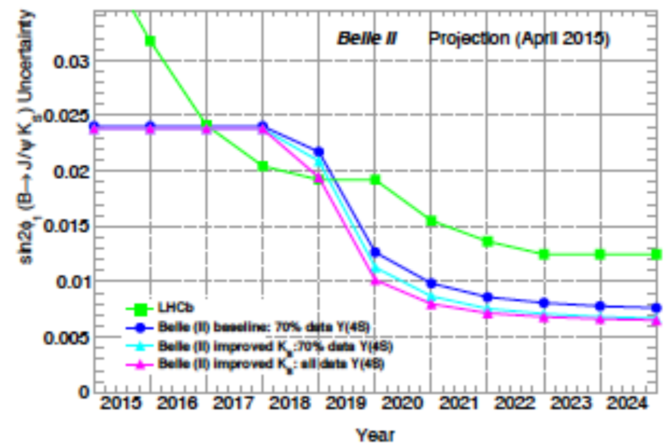
B physics

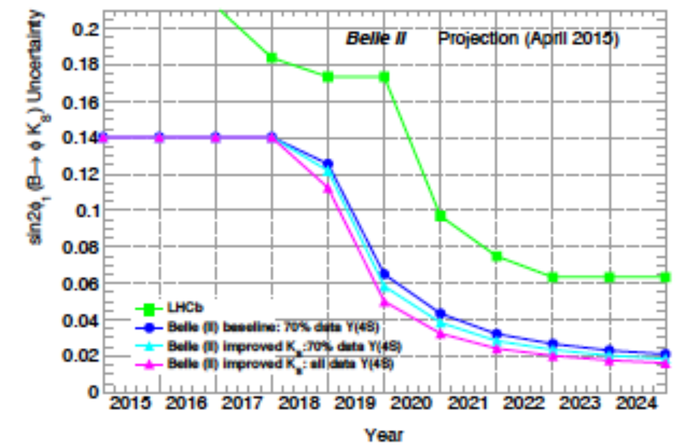
$B_{s,d}$ - oscillations

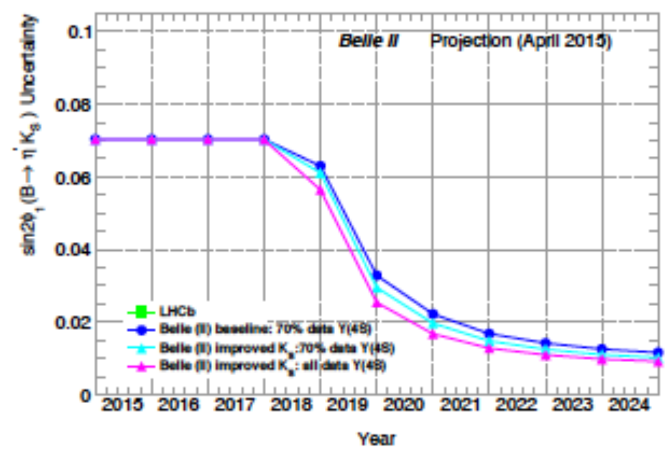
⇒ sin2β, α

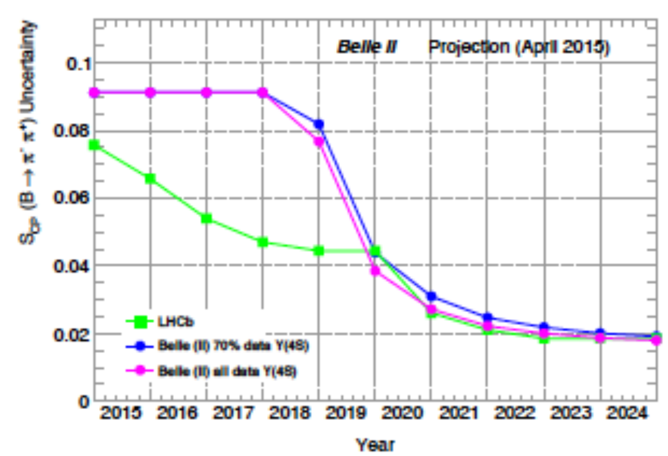
Final BelleII & LHCb precision comparable & statistically dominated

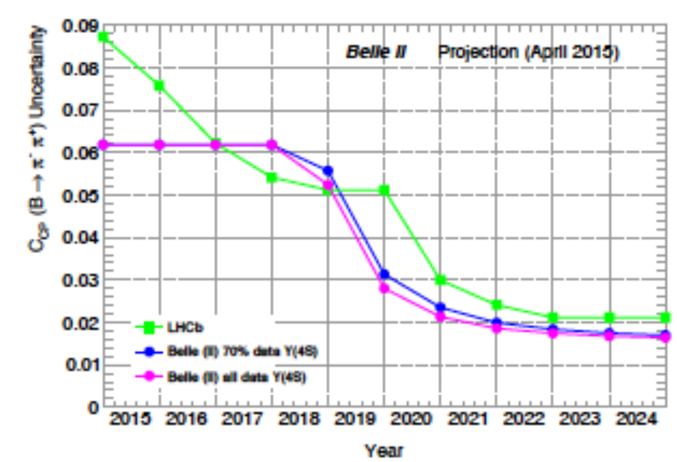
Theory uncertainties (in sin2β) at ~1%









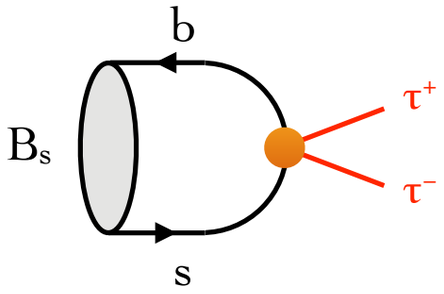


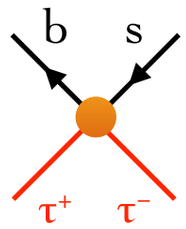
Leptonic or semileptonic decay modes involving B_s, B_c or b–baryon

- $B_{d,s} \to ee, \mu\mu, \tau\tau$, V_{ub} extraction, CP violation in mixing through semileptonic asymmetries, $B_{u,c} \to \mu\nu, \tau\nu$, $b \to s\tau\tau$
- Example: $B_{d,s} \to \tau\tau$
  - Apart from tensors, all bs(d)ττ Lorentz structures are tested
- Present LHCb bounds LHCb-CONF-2016-011

$$Br(B_s \to \tau^+\tau^-) < 3.0 \times 10^{-3}$$

$$Br(B_d \to \tau^+\tau^-) < 1.3 \times 10^{-3}$$





U. Haisch @ FCC-ee flavour WG meeting 1

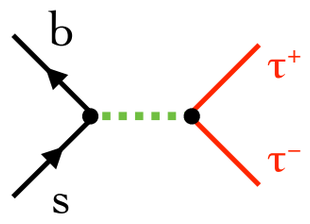
$$Q_{S,AB} = (\bar{s} P_A b)\,(\bar{\tau} P_B \tau)$$

$$Q_{V,AB} = (\bar{s} \gamma_\mu P_A b)\,(\bar{\tau} \gamma^\mu P_B \tau)$$

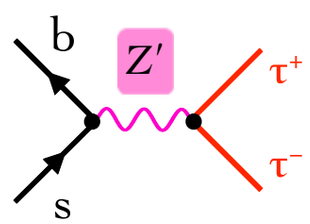
- In the SM: Bobeth et al., 1311.0903

$$\mathrm{BR}(B_s \to \tau^+\tau^-) = (7.73 \pm 0.49) \times 10^{-7}$$
$$\mathrm{BR}(B_d \to \tau^+\tau^-) = (2.22 \pm 0.19) \times 10^{-8}$$

- Best probe for scalar and vector operators U. Haisch, 1206.1230

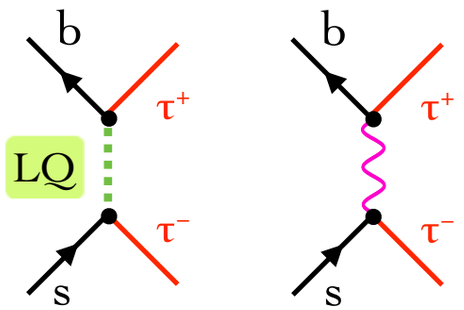


spin 0: S,P



spin 1: V,A

e.g. Z′



e.g. leptoquark (LQ)

Heavy Neutrinos & LNV

$$M_\nu = -M_D M_N{}^{-1} M_D$$

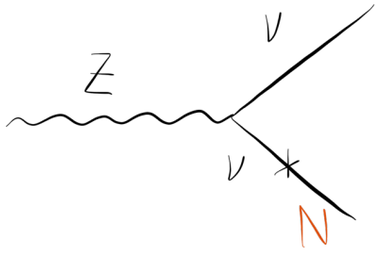
type I and III

on the Z-pole

Gronau, Leung, Rosner '84, ...

large statistics $n_Z \sim 10^{12} - 10^{13}$ over $n_Z \sim 10^6$ at LEP

Delphi '97

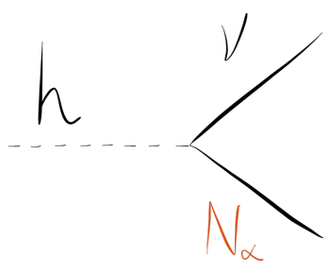


expect a limit of $\left(\frac{m_D}{m_N}\right)^2 < 10^{-11} - 10^{-12}$

Blondel, Graverini, Serra, Shaposhnikov 1411.5230

Higgs decays

FCC-ee $\sqrt{s} = 240$ GeV, $\mathcal{L} = 10$ ab $\rightarrow 2.4 \times 10^6$ Zh



$$\frac{\Gamma_{h\to\nu N}}{\Gamma_{h\to b\bar{b}}} \simeq \frac{1}{N_c}\underbrace{\left(\frac{m_D}{m_N}\right)^2}\left(\frac{m_N}{m_b}\right)^2 < 10^{-9}$$

$$< 10^{-11}$$

competitive between Z and h?

Heavy Neutrinos & LNV

$$M_\nu = -M_D M_N{}^{-1} M_D$$

Left-Right

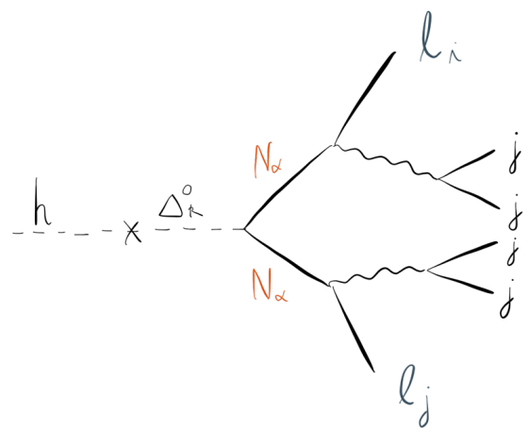
LNV Higgs decays

LHC

fair background, need isolation + cuts

Higgs slightly boosted $\gamma_h \simeq 3$

inefficient for small *N* mass



FCC-ee

no significant background

Higgs boost $\gamma_h = 1.08$

higher efficiency for lower masses

additional tagging *Z*