New physics searches in $b \to c\ell\nu$, $b \to s\ell\ell$ and τ decays

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Prospective Physique des particules
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▸ *Highlights of FCC-ee in tau & b physics*

In the last few years LHCb, B-factory experiments reported some "anomalies" (= *deviations from SM predictions*) in semi-leptonic B-meson decays.

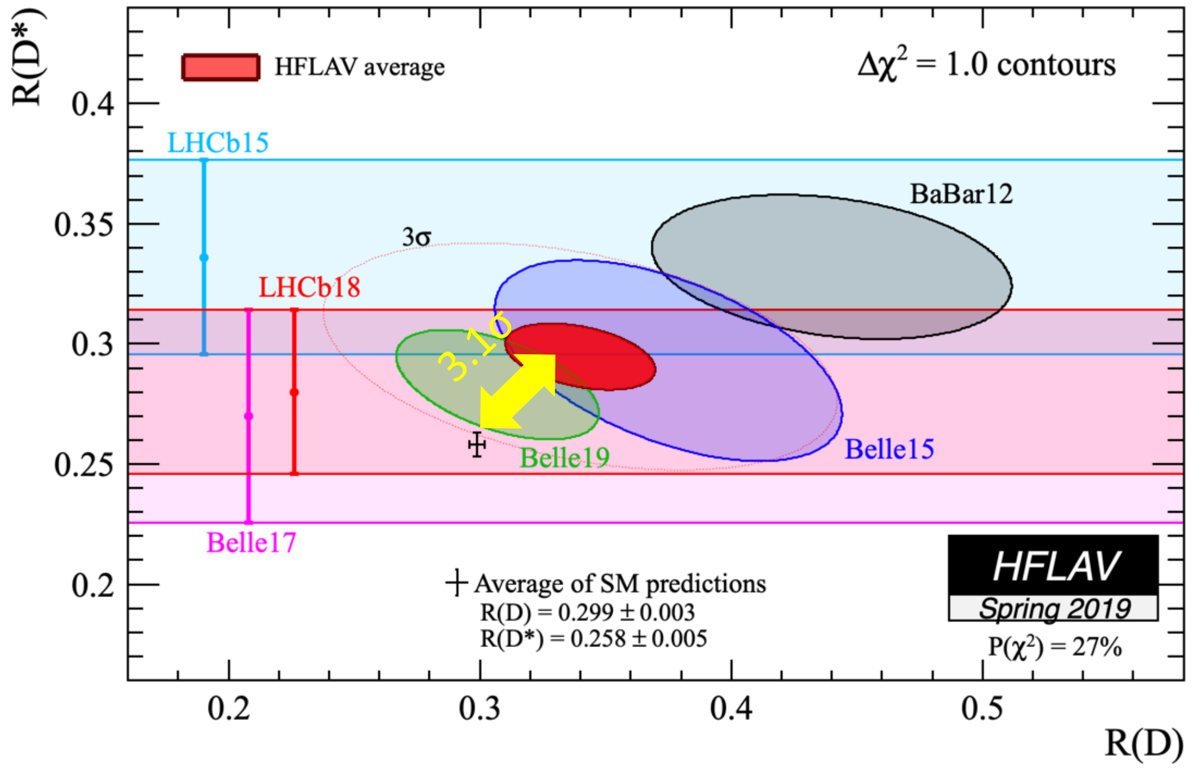
Data seem to indicate a different (*non-universal*) behavior of different lepton species in specific b (3^{rd} gen.) $\rightarrow$ c,s (2^{nd}) processes:

- $b \rightarrow c$ charged currents: τ vs. light leptons (μ, e) [R_K, R_{K^*},...]
- $b \rightarrow s$ neutral currents: μ vs. e [R_D, R_{D^*}]

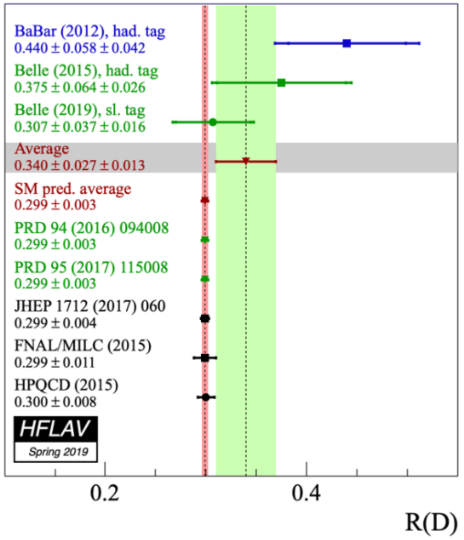
IF taken together... this is probably the largest "coherent" set of deviations from the SM we have ever seen...

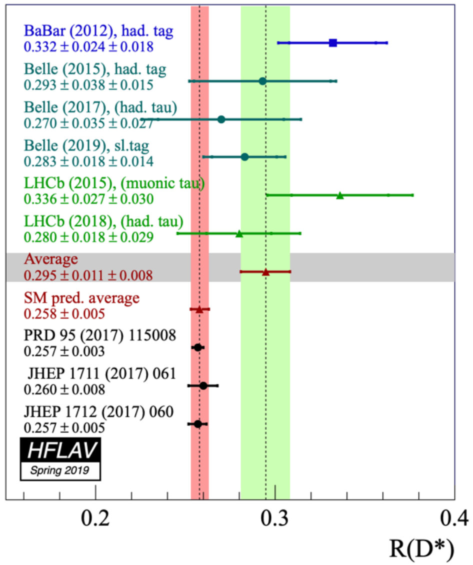
LFUV in charged currents

B→D*τν/B→D*ℓν



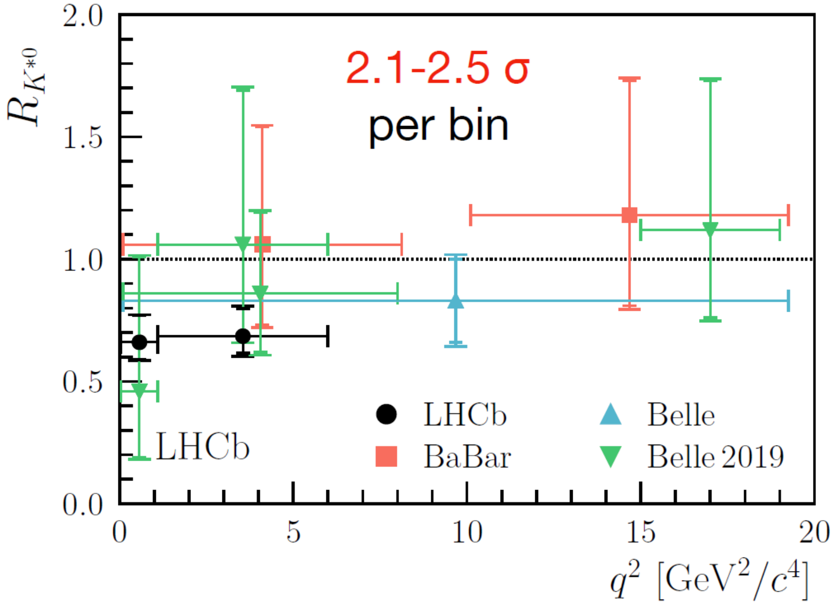
B→Dτν/B→Dℓν



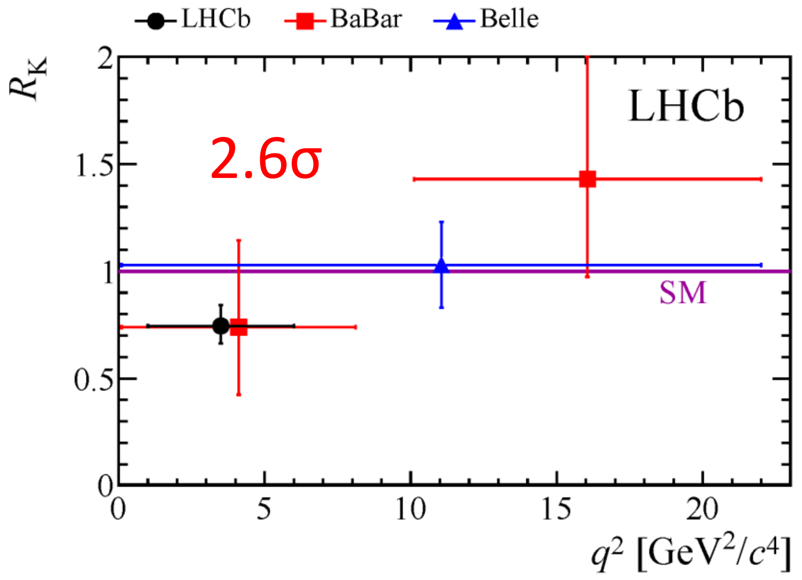


LFUV in neutral currents

$B \to K^{*}\mu\,\mu$ vs $B \to K^{*}ee$



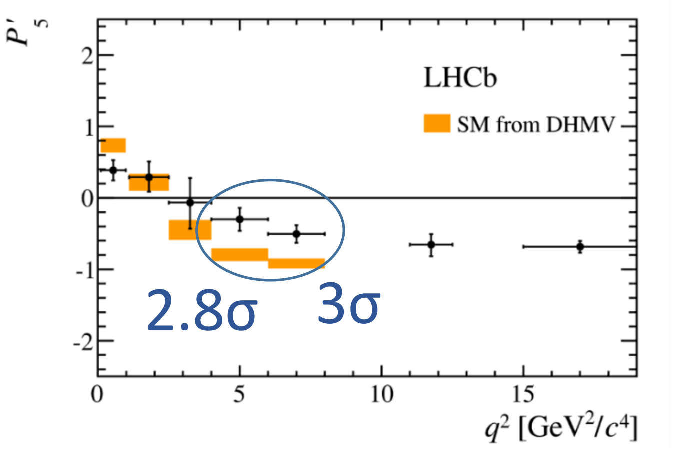
$B \to K\mu\mu$ vs $B \to Kee$



LHCb also measure RpK in $\Lambda_b \to pK\ell\ell$, still limited statistically but goes in the same direction

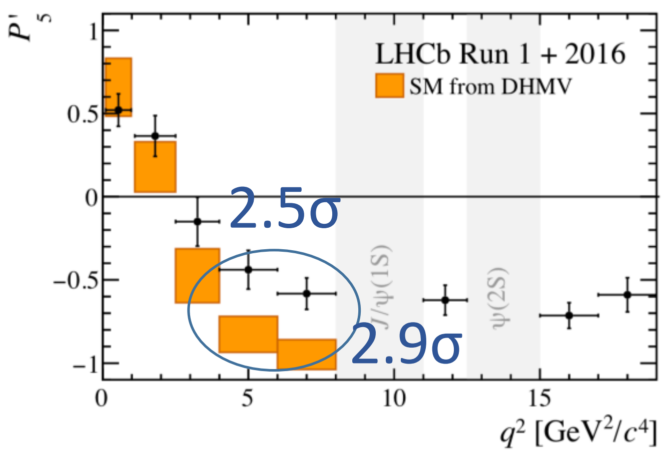
$B \to K^*\mu\mu$ angular analysis

Run1

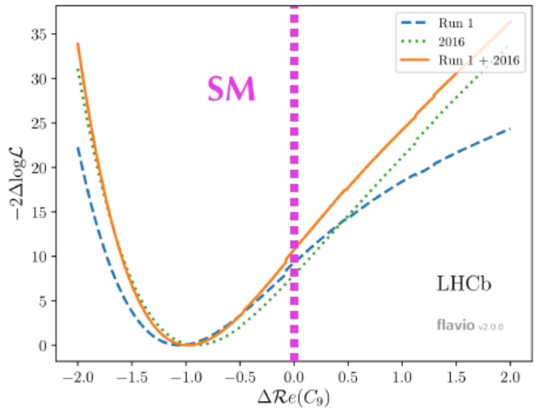


Run1+2016

Theory predictions from JHEP 12 (2014) 125, JHEP 09 (2010) 089,

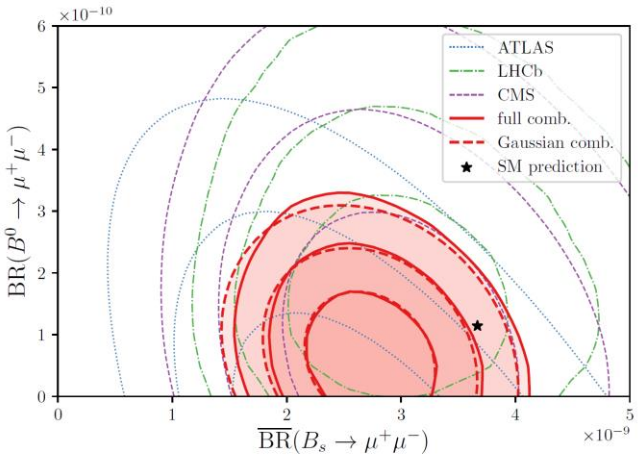


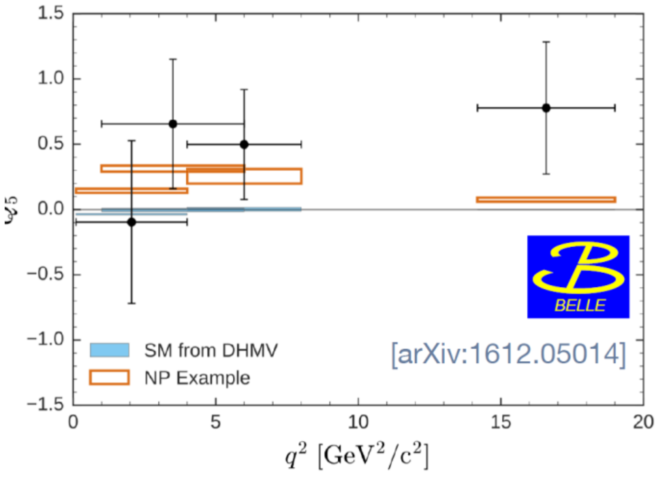
- Tension in P'_5 confirmed though mildly decreasing
- Global fit of all observables shows an increase of the discrepancy from 3.0 to 3.3 σ

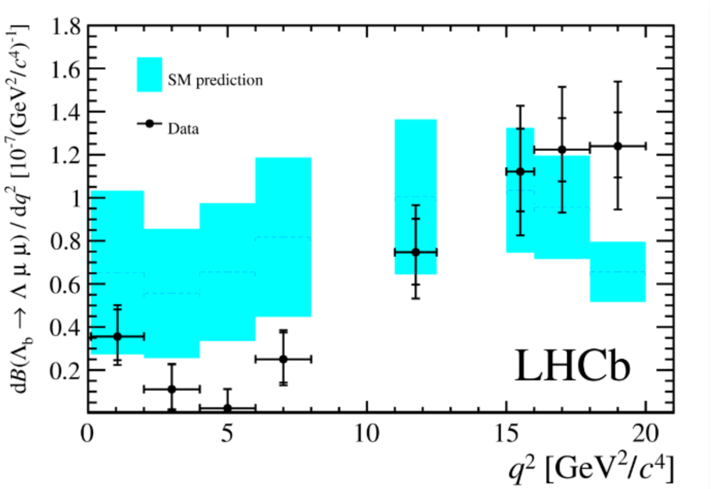


Other b → sℓℓ observables

- $B_{(s)} \to \mu\mu$: BR about 2σ from SM
- LFUV in angular observables
- BR($b \to s\mu\mu$) up to 3σ from SM in some q^2 bin
- …and many more…

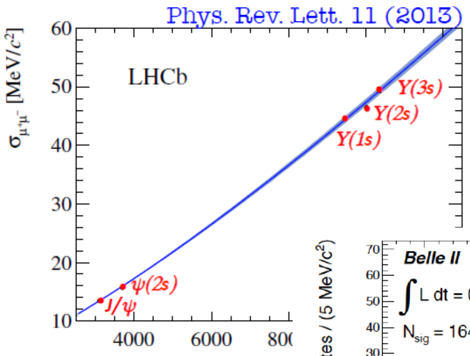


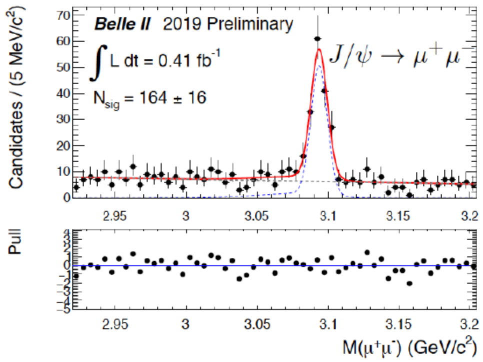


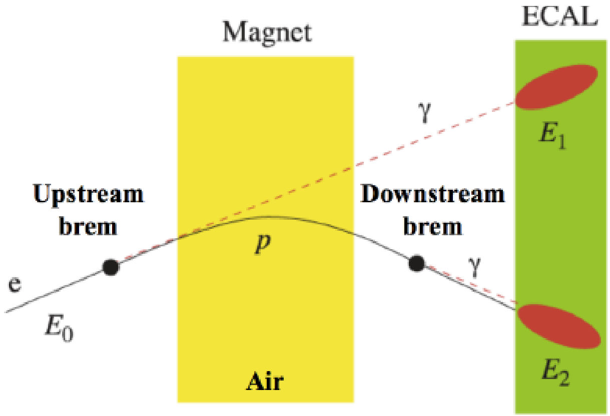


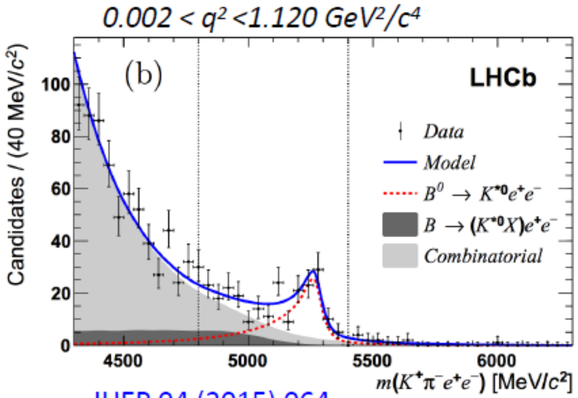
Lepton reconstruction

- Muons: easy thanks to dedicated detector, very good dimuon resolution
- Electrons: similar as muons for e+e- machines, difficult for hadronic machines
    - Calorimeter has high occupancy
    - High energy loss due to bremsstralhung
    - Can be partially recovered but resolution worse than muons and high partially reconstructed bkg

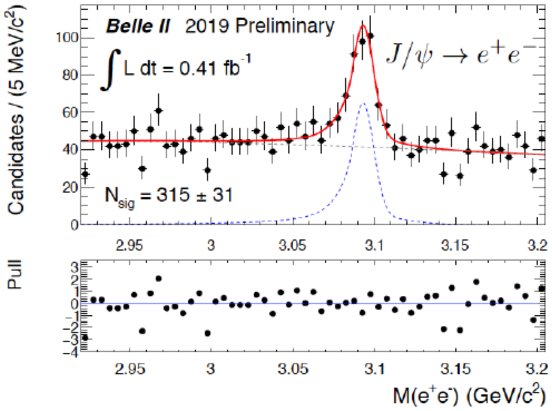








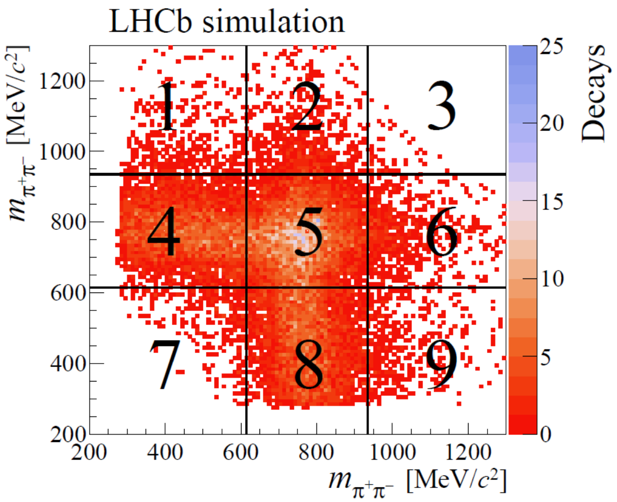
JHEP 04 (2015) 064

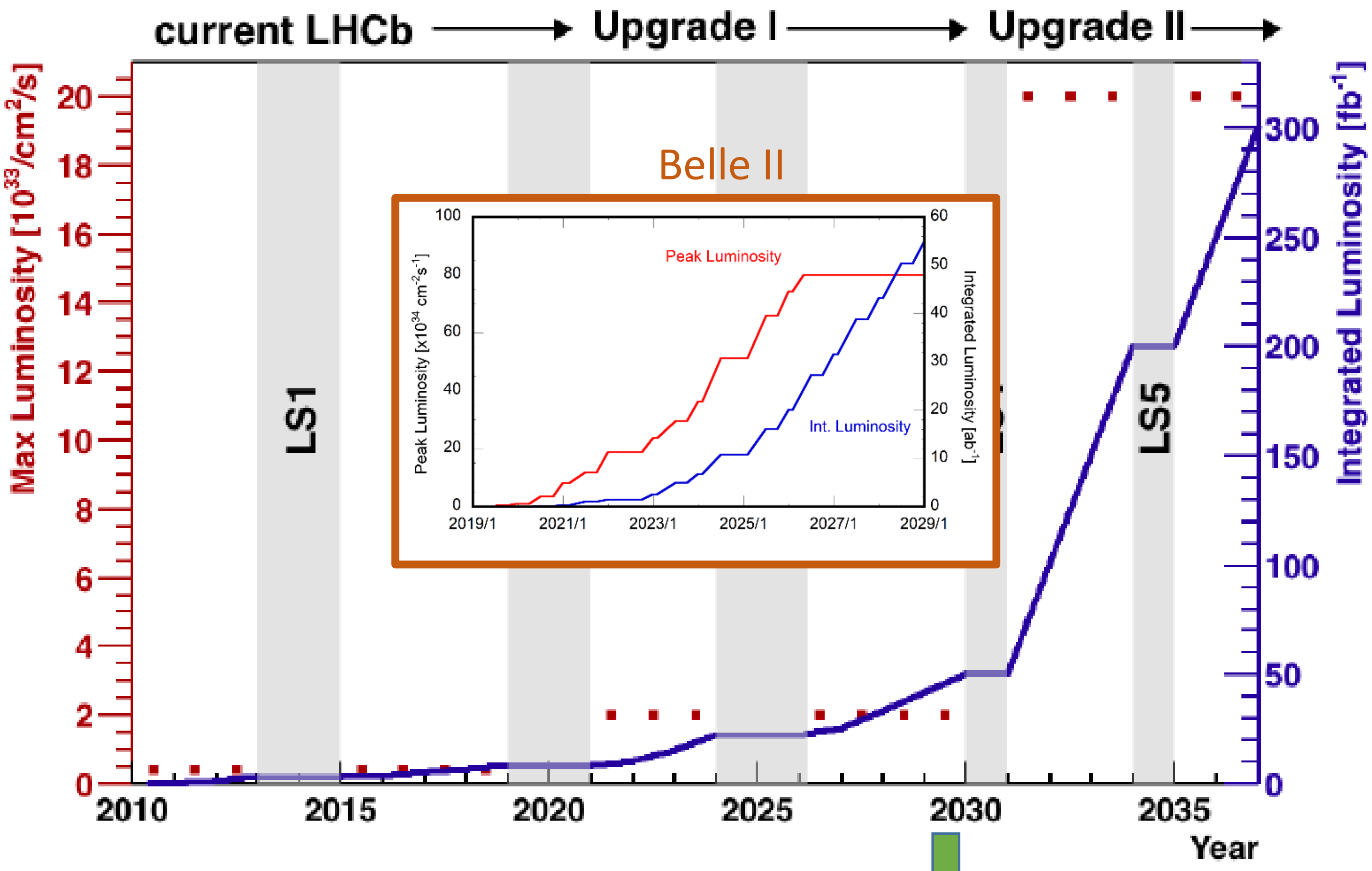


Lepton reconstruction

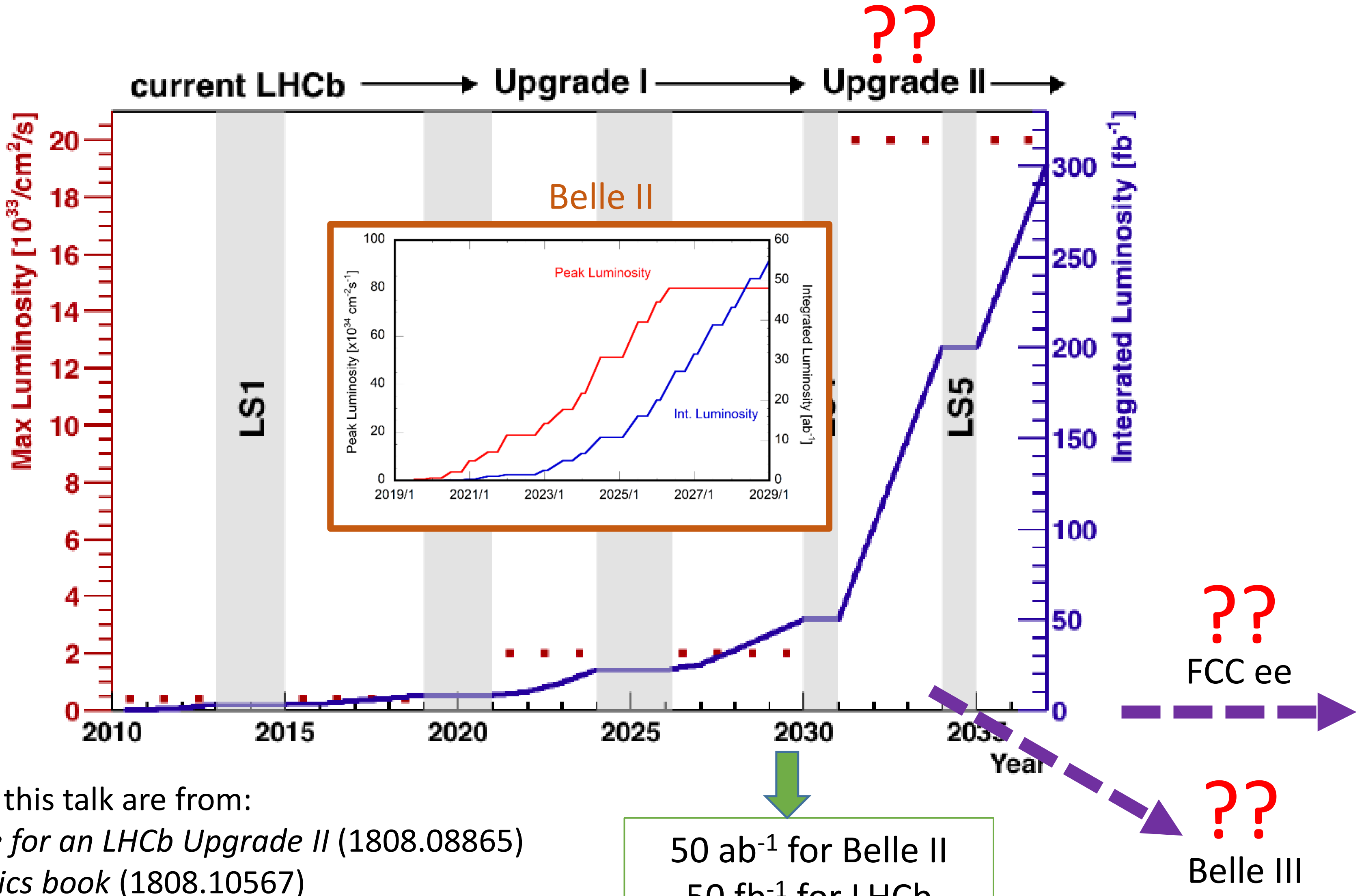
- Taus : Difficult due to final state neutrinos
  - LHCb uses muon and 3π final state
  - B factories use mainly one prong decay and reconstruct the entire event
  - Final states with τ are still much less known than their e/μ counterpart

τ decay	BR (%)
$\tau^+ \to \mu^+\nu\nu$	17.39±0.04
$\tau^+ \to e^+\nu\nu$	17.82±0.04
$\tau^+ \to \pi^+\nu$	10.82±0.05
$\tau^+ \to \pi^+ \pi^0\nu$	25.49±0.09
$\tau^+ \to \pi^+ \pi^0 \pi^0\nu$	9.26±0.10
$\tau^+ \to \pi^+ \pi^+ \pi^-\nu$	9.31±0.05
$\tau^+ \to \pi^+ \pi^+ \pi^- \pi^0\nu$	4.62±0.05





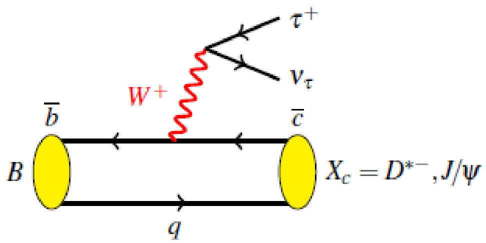
50 ab^{-1} for Belle II
50 fb^{-1} for LHCb



Numbers in this talk are from:
Physics case for an LHCb Upgrade II (1808.08865)
Belle II Physics book (1808.10567)

50 ab^{-1} for Belle II
50 fb^{-1} for LHCb

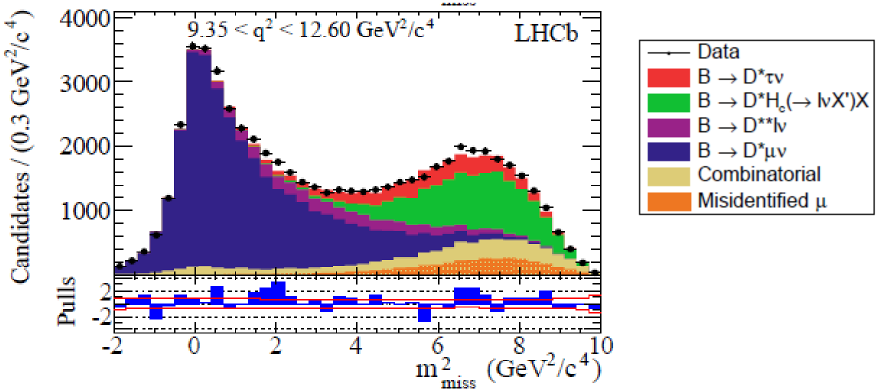
b → cℓν



τ^+
W^+
ν_τ
$\bar{b}$
$\bar{c}$
B
$X_c = D^{*-}, J/\psi$
q
τ^+
ν_τ
$\bar{b}$
$\bar{c}$
B
LQ
X_c
q
τ^+
H^+
ν_τ
$\bar{b}$
$\bar{c}$
B
X_c
q

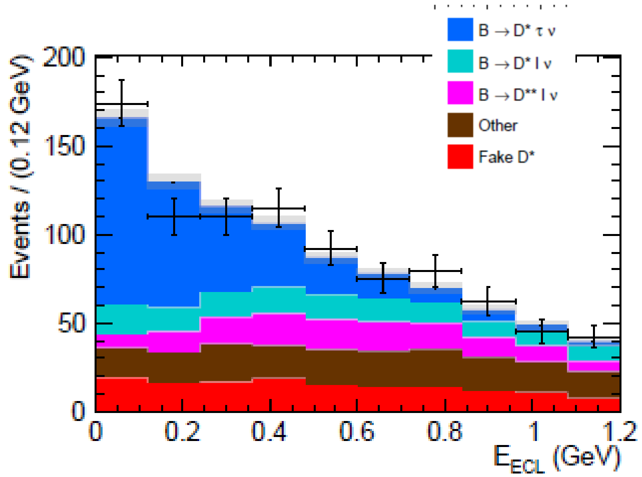
b → cℓν : LHCb vs B factories

- Measure R(D*) with $B^0 \to D^{*+}(D^0\pi^+)\tau^-\nu$ and 3 prong or muonic τ decay



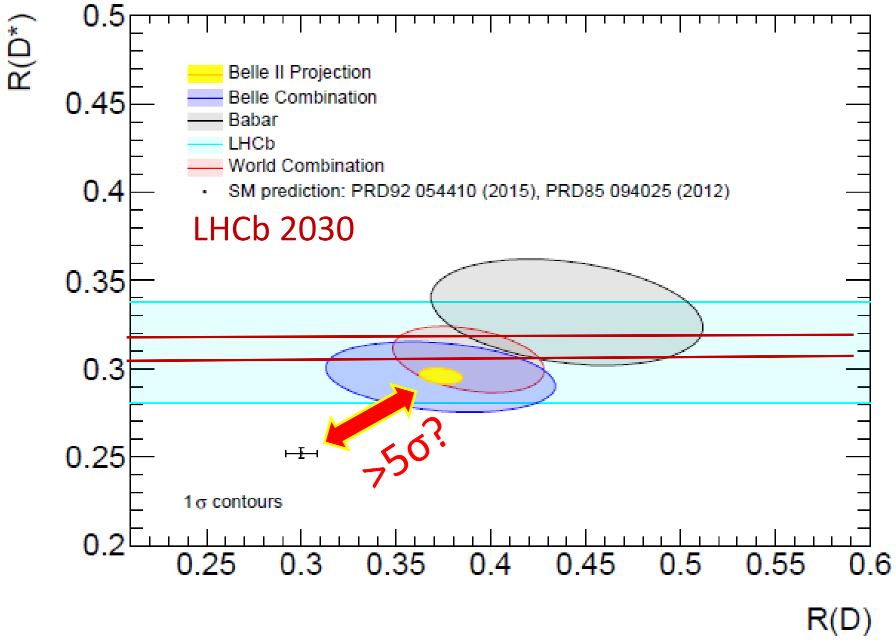
- Systematically limited due to simulation sample size (being fixed), and background modelling (data driven)
- Also measured R(J/Ψ)= $B_c \to J/\Psi\tau\nu$ / $B_c \to J/\Psi\mu\nu$, about 2σ above SM

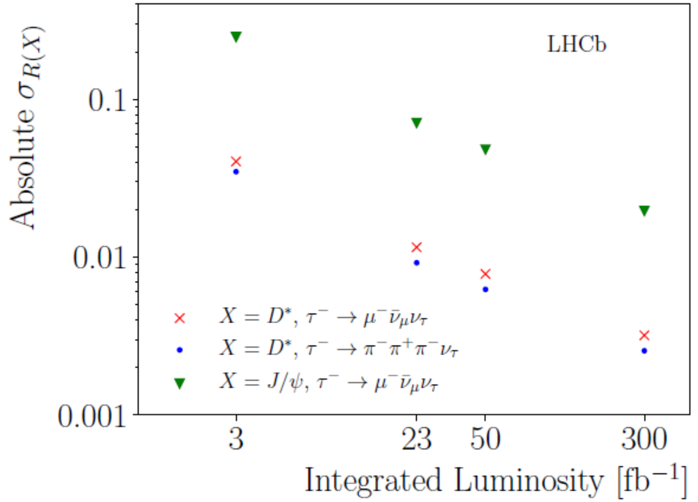
- Measure R(D*) and R(D) from B^0 and B^+ events, using semileptonic or hadronic tagging and one prong τ decay
- Also measure the τ polarization in R(D*)
- Statistics limited



Prospects for b → cℓν

- LHCb and Belle II will reach ~same sensitivity on R(D*) by 2030
- Improvements will come from:
  - More statistics
  - More channels: $R(D^0)$, $R(D^{(*)}_s)$, $R(\Lambda_c)$,.. but also b → uℓν decays



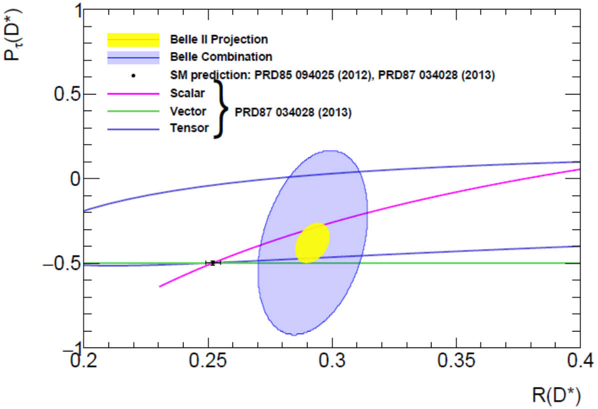


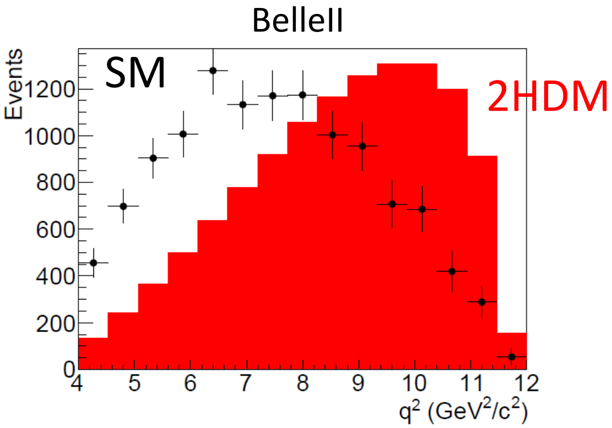
Belle II Relative uncertainty

	$5\ ab^{-1}$	$50\ ab^{-1}$
R_D	$(\pm 6.0 \pm 3.9)\%$	$(\pm 2.0 \pm 2.5)\%$
R_{D^*}	$(\pm 3.0 \pm 2.5)\%$	$(\pm 1.0 \pm 2.0)\%$
$P_\tau(D^*)$	$\pm 0.18 \pm 0.08$	$\pm 0.06 \pm 0.04$

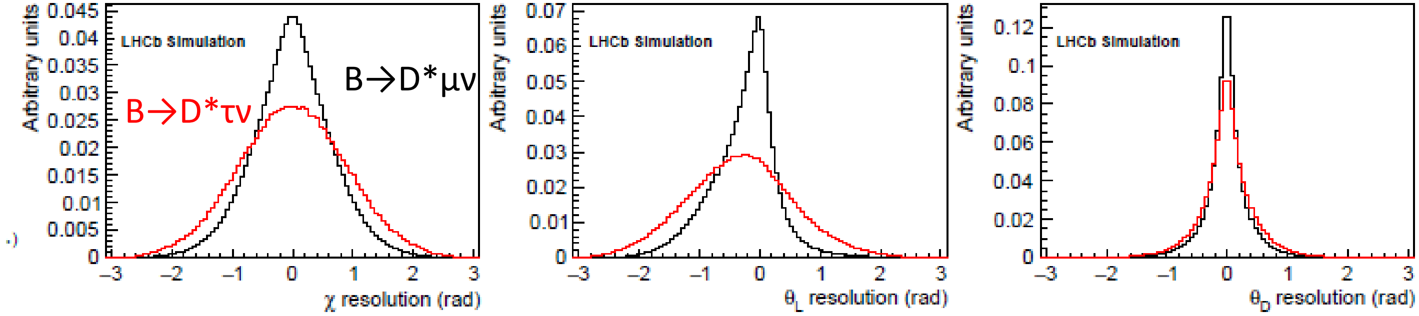
Prospects for b → cℓν

- More observables: D*, τ polarizations and angular analysis (see e.g. JHEP11(2019)133)



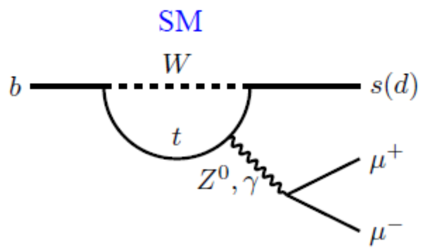


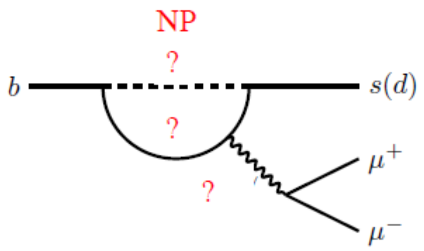
LHCb U2 expected resolutions



R(D) and R(D*) are just the beginning
Very rich progamm from LHCb and Belle II

$b \to s\ell\ell$

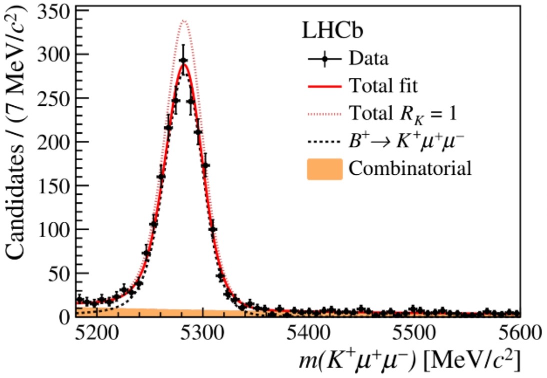


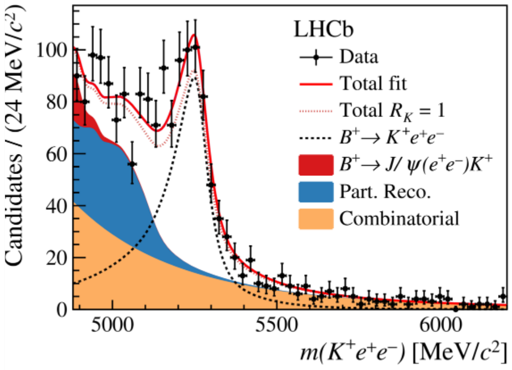


$b \to s\ell\ell$: LHCb vs B factories

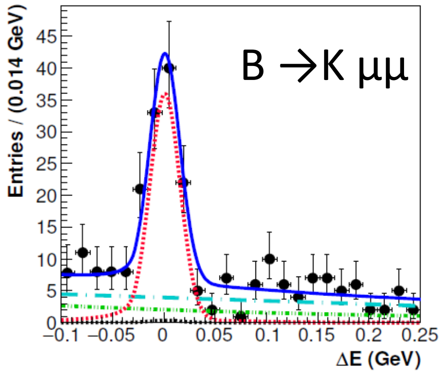
- ☺ Very High statistics of b hadrons
- ☺ Access to different species
- ☹ large bremsstralhung emission for electrons
  - → poor mass resolution
- 😐 Muon and electron have ≠ efficiencies, triggers
- → measure double ratios for LFU studies

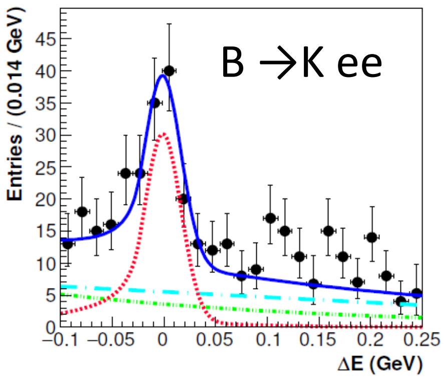
$$R_K = \frac{\mathcal{B}(B^+ \to K^+\mu^+\mu^-)}{\mathcal{B}(B^+ \to K^+ J/\psi(\mu^+\mu^-))} \Big/ \frac{\mathcal{B}(B^+ \to K^+e^+e^-)}{\mathcal{B}(B^+ \to K^+ J/\psi(e^+e^-))}$$





- ☹ Low statics of b hadrons
- ☹ Only B^0 and B^+ produced
- ☺ Good reconstruction of neutrals
  - → access inclusive $B \to X \ell\ell$ decays
- ☺ Good hermiticity
  - → access to $b \to s\nu\nu$
- ☺ electron ~ muon reconstruction
- ☺ No trigger bias





Prospects for RK(*)

	Belle II 50 ab^{-1}	LHCb 50 fb^{-1}	LHCb 300 fb^{-1}
RK [1,6 GeV2]	3.6%	1.7%	0.7%
RK*[1,6 GeV2]	3.2%	2.0%	0.8%

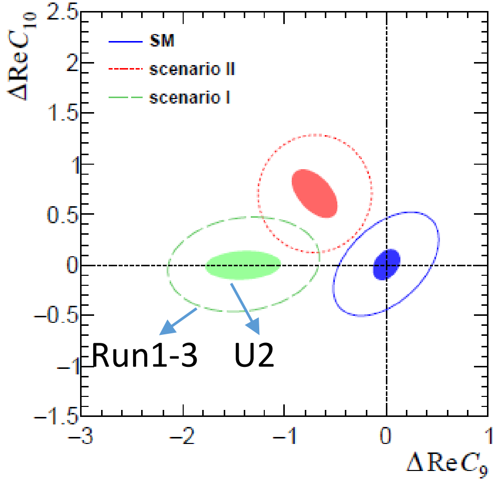
Still stat. limited

Need to reduce syst. < 1%

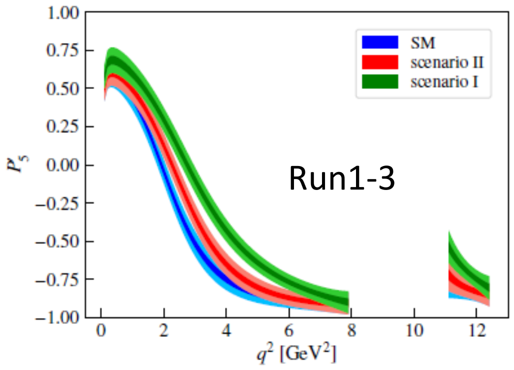
- Precision at the % level
- Belle II will also measure RX_s with 4% precision and test LFUV in angular observables
- LHCb (is) will also measure Rϕ, RpK, Rπ,…
- Precision limited by electron modes, can be mitigated in U2 thanks to
  - Less material before magnet
  - Higher granularity
  - Use of timing

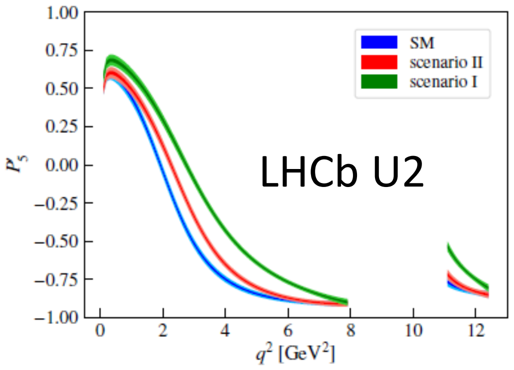
R_X precision	Run 1 result	9 fb^{-1}	23 fb^{-1}	50 fb^{-1}	300 fb^{-1}
R_K	$0.745 \pm 0.090 \pm 0.036$ [274]	0.043	0.025	0.017	0.007
$R_{K^{*0}}$	$0.69 \pm 0.11 \pm 0.05$ [275]	0.052	0.031	0.020	0.008
R_ϕ	–	0.130	0.076	0.050	0.020
R_{pK}	–	0.105	0.061	0.041	0.016
R_π	–	0.302	0.176	0.117	0.047

Scenario I and II = NP

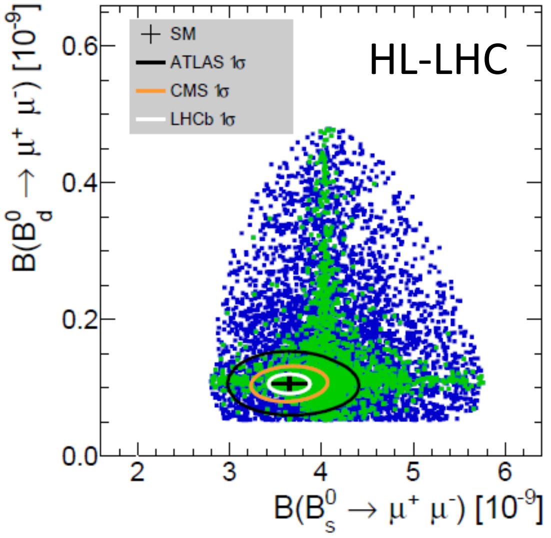


Prospects for b → sℓℓ





- Precision on angular obervables in K*ℓℓ similar for Belle II and LHCb Run 1-3
- Some NP scenarios hard to distinguish without U2 !
- Precision of differential BR will be limited by normalization mode B → J/ΨX
- ATLAS and CMS can also play a role for muon final states!



- LHCb/Belle II will record a large statistics of electronic final state
  → access to the photon polarization, precision of 3% (1%) with Run3 (300 fb^{-1}) for LHCb, Belle II can reach ~3% with 50ab^{-1} (statistics limited)

b → sνν

- If b → sℓℓ anomalies are due to NP, b → sνν should also be affected !
- Require fully reconstruct the event → only Belle II can do it
- Efficiency about x2 better compared to Belle thanks to Full Event Interpretation tagging algorithm (arXiv:1807.08680)
- Can be observed with few ab^{-1}

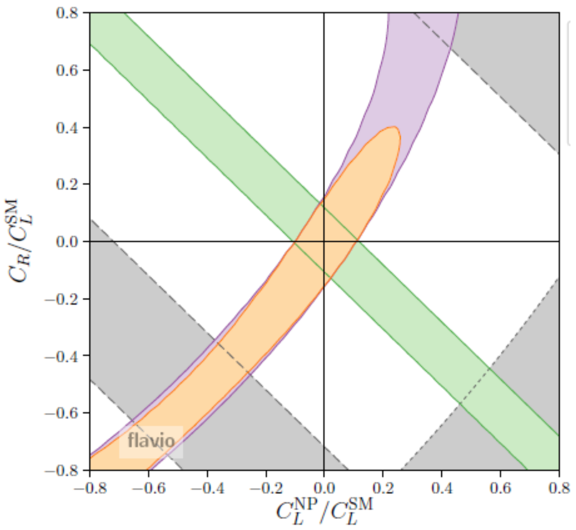
Observables	Belle 0.71 ab^{-1} (0.12 ab^{-1})	Belle II 5 ab^{-1}	Belle II 50 ab^{-1}
$\mathrm{Br}(B^+ \to K^+ \nu\bar{\nu})$	$< 450\%$	30%	11%
$\mathrm{Br}(B^0 \to K^{*0} \nu\bar{\nu})$	$< 180\%$	26%	9.6%
$\mathrm{Br}(B^+ \to K^{*+} \nu\bar{\nu})$	$< 420\%$	25%	9.3%
$F_L(B^0 \to K^{*0} \nu\bar{\nu})$	–	–	0.079
$F_L(B^+ \to K^{*+} \nu\bar{\nu})$	–	–	0.077
$\mathrm{Br}(B^0 \to \nu\bar{\nu}) \times 10^6$	< 14	< 5.0	< 1.5
$\mathrm{Br}(B_s \to \nu\bar{\nu}) \times 10^5$	< 9.7	< 1.1	–

Excluded by Belle+Babar

BR(B → Kνν)

BR(B → K*νν)

F_L(B → K*νν)



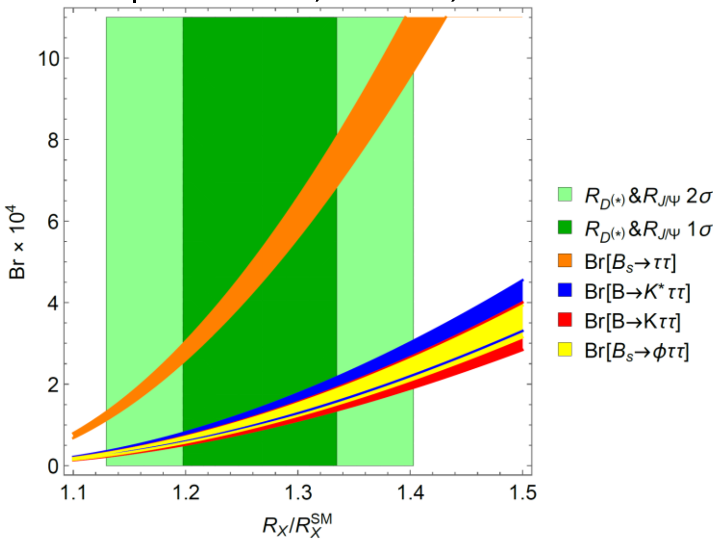
b → sττ

- Anomalies seen in LFUV suggests a special role of the 3rd family
  - enhancements of τ → μ/e and B → τ μ/e LFV decays
  - enhancements of b→sττ decays

- Very challenging experimentally

Decays	SM prediction	Best 90% CL UL
$B^0 \to \tau\tau$	$(2.22\pm0.19)\ 10^{-8}$	$1.6\ 10^{-3}$ [LHCb]
$B_s \to \tau\tau$	$(7.73\pm0.49)\ 10^{-7}$	$5.2\ 10^{-3}$ [LHCb]
$B \to K^*\tau\tau$	$(0.98\pm0.10)\ 10^{-7}$	-
$B \to K\tau\tau$	$(1.20\pm0.12)\ 10^{-7}$	$2.25\ 10^{-3}$ [Babar]

B. Capdevila et al, *PRL 120, 181802*



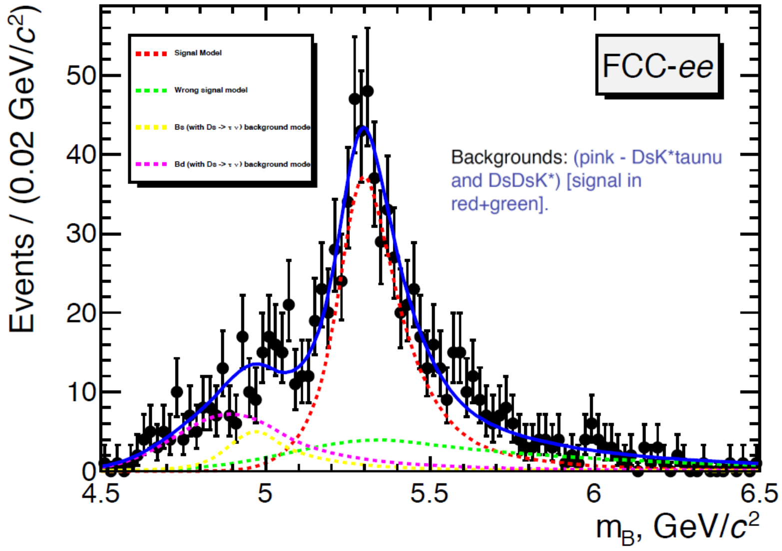
Prospects for b → sττ

- Belle II will benefit from new tagging algorithm

Observables	Belle $0.71\,\mathrm{ab}^{-1}$ $(0.12\,\mathrm{ab}^{-1})$	Belle II $5\,\mathrm{ab}^{-1}$	Belle II $50\,\mathrm{ab}^{-1}$
$\mathrm{Br}(B^+ \to K^+\tau^+\tau^-)\cdot 10^5$	< 32	< 6.5	< 2.0
$\mathrm{Br}(B^0 \to \tau^+\tau^-)\cdot 10^5$	< 140	< 30	< 9.6
$\mathrm{Br}(B^0_s \to \tau^+\tau^-)\cdot 10^4$	< 70	< 8.1	–

- LHCb will benefit from higher trigger efficiency from Upgrade I and additional tracking stations from LS3 (+ further possible tracking improvements)
    - expect limits at ~10^{-4} for $B_s \to \tau\tau$, 10^{-5} for $K^*\ \tau\tau$

- FCCee : Dedicated study for B → K*ττ analysis
    - Make use of partial reconstruction technique to solve the kinematic of the decay
    - Assume detector performance similar to ILD
    - At baseline luminosity, assuming SM BR more than 1000 events observables!
    - Other B → τ decays should be feasible



LFV

B LFV decays

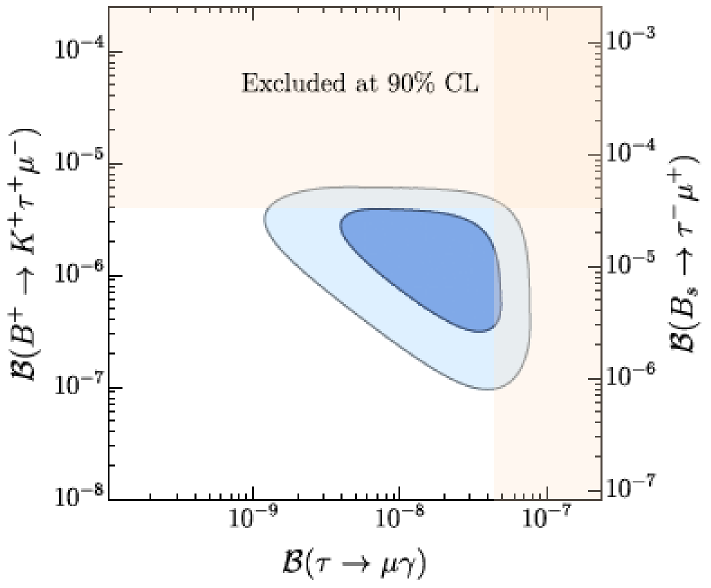
- Forbidden in SM : the cleanest probe for NP!
- LFUV models generally implies LFV

- eμ final state
  - B → (K^+)eμ limits by LHCb ~10^{-9} with Run1
  - Other B → Xeμ dominated by B factories, limits ~10^{-7}

- τμ final state
  - B → π^+/K^+ τμ limits by Babar at ~10^{-5}
  - B(s) → (K)τμ limits by LHCb at ~10^{-5}

- eτ final state
  - B → π^+/K^+ τe limits by Babar at ~10^{-5}
  - Very difficult for LHCb

Interpretation of the anomalies in terms of vector leptoquarks

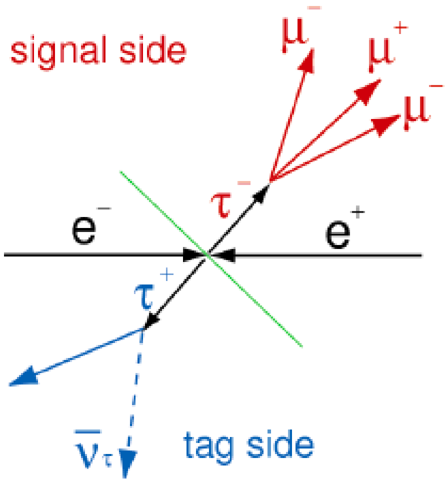


C. Cornella et al, JHEP 1907 (2019) 168

All these limits can be improved by 1-2 order of magnitude by 2030
→ Start to probe very interesting NP phase space!

Tau LFV: Belle II vs LHC

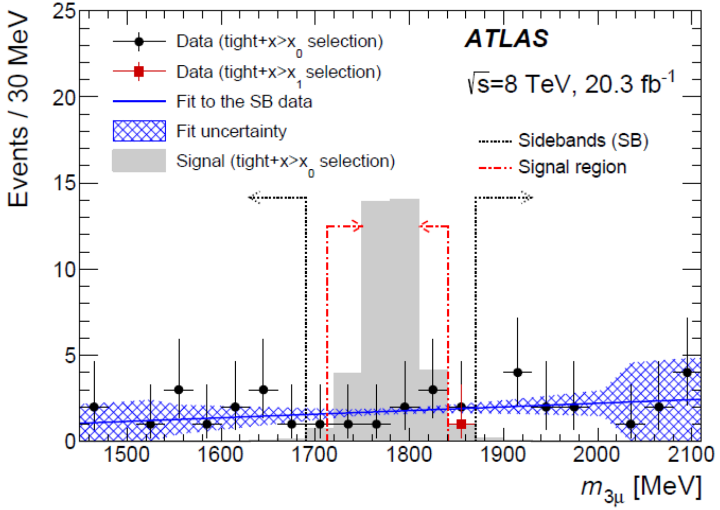
- $\sigma_{\tau\tau}$=0.9 nb ~ σ_{bb} : B factories are also τ factories
- Reconstruct the entire events
- Most of LFV analyses are background free



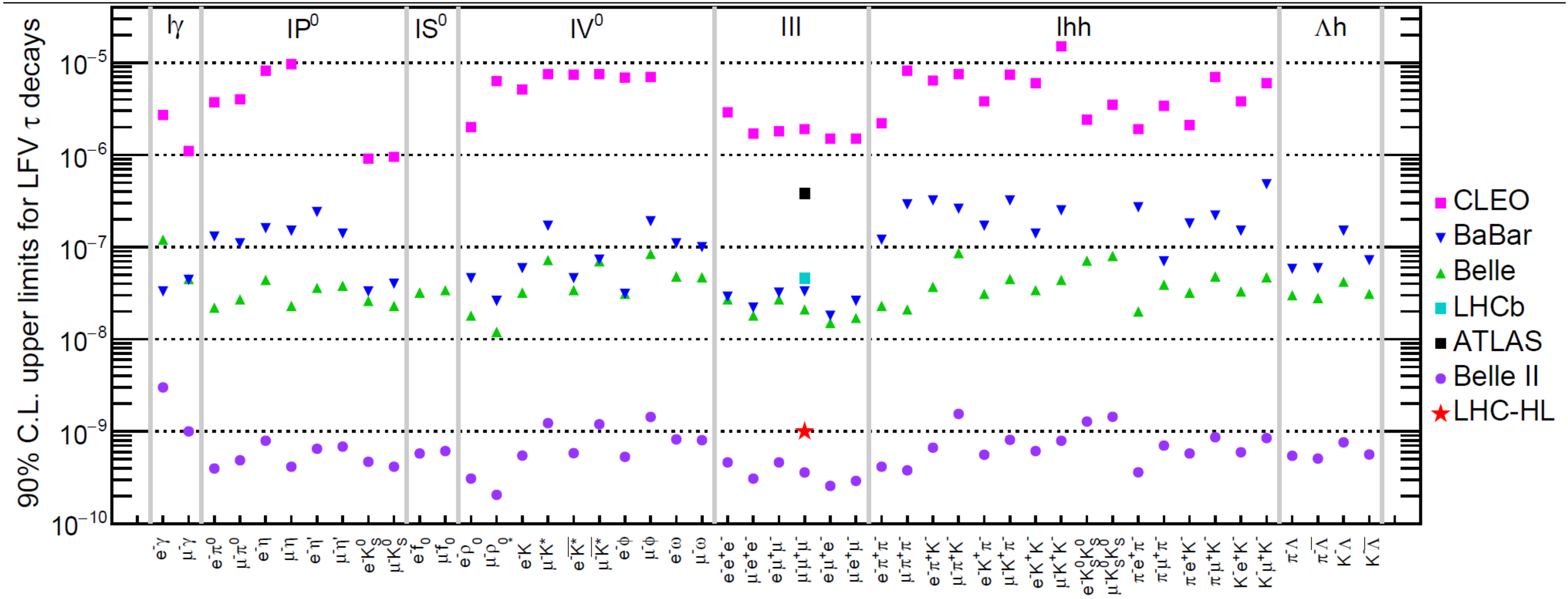
- More τ analysis can be done : EDM, CPV, g-2 (see Belle II contribution)

- $\sigma_{\tau\tau}$ at the LHC about 5 orders of magnitude larger than at Belle II
- Reconstruct only τ decay products (no tagging)
- Use τ produced from $D_s \to \tau\nu$ (LHCb) and/or $W \to \tau\nu$ (ATLAS)

EPJC 76(2016)232



From HL-LHC and HE-LHC opportunities arXiv:1812.07638



Current limits at few 10^{-8} dominated by Belle, expect to gain 2 orders of magnitude with Belle II

NB: In μ→e transitions, limits are at 10^{-13} level

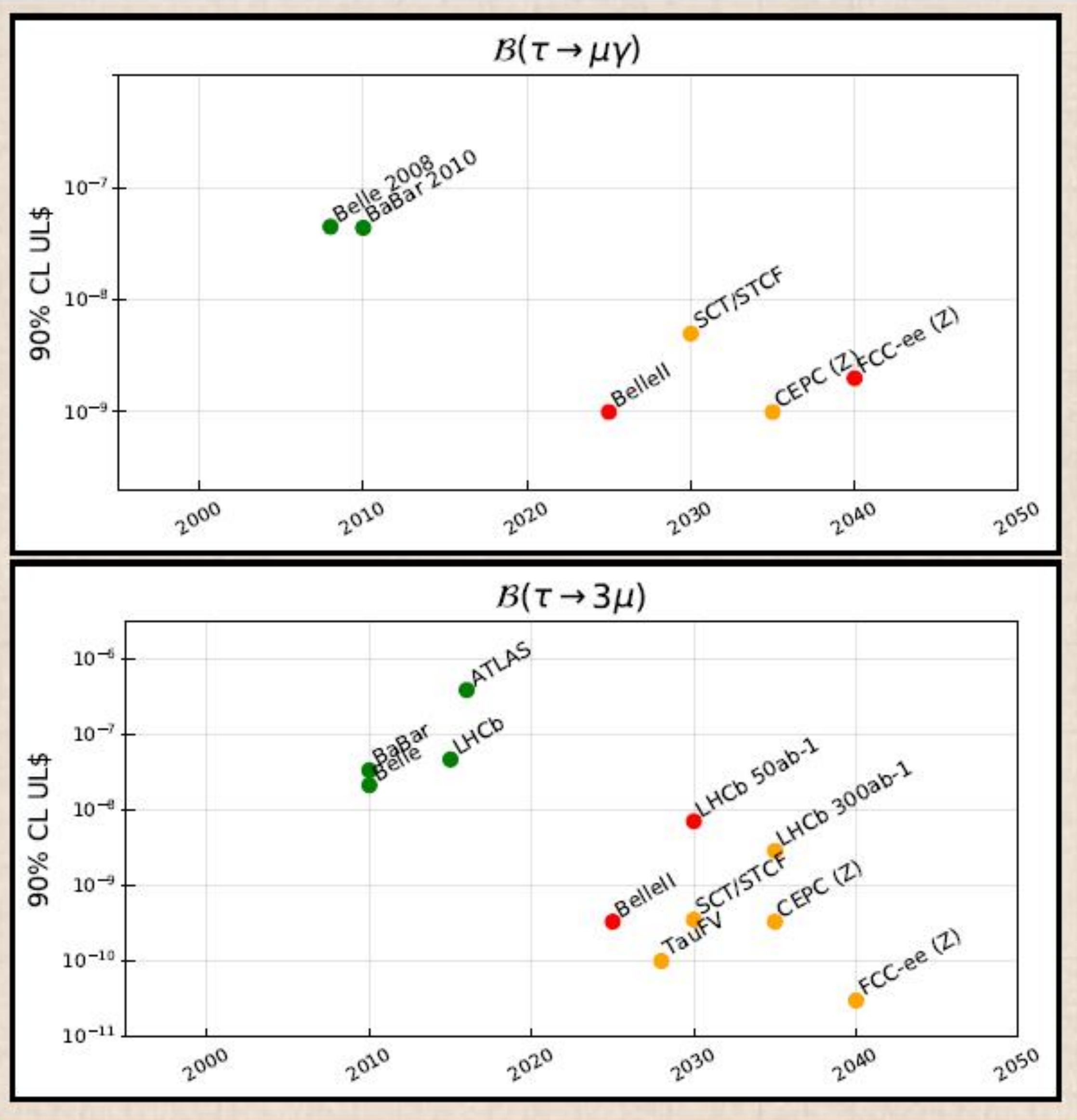
Indicative benchmarks

Green are published
Red are reliable estimate based on dedicated studies
Orange are estimates with less solid fundations

At Z peak:

- FCCee: 15×10^{10} tau pairs
- Dedicated study gives a limit at 2 10^{-9} on $\tau \rightarrow e/\mu\gamma$ and $<10^{-10}$ on $\tau \rightarrow 3\ell$
- CEPC in China: 3×10^{10} tau pairs

Only FCCee can go below the level of 10^{-10}

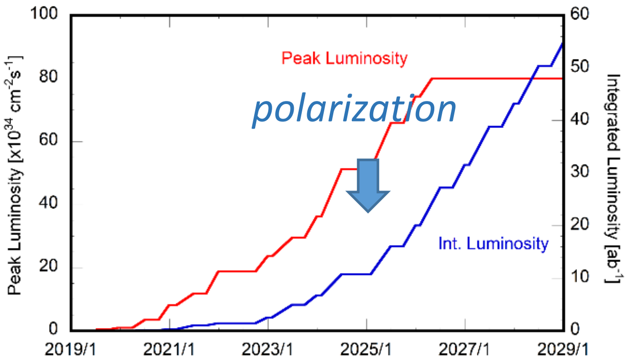


Beyond current Belle II

polarized e⁻ beam

Aim for 70% polarization
Record 20 to 40 ab^{-1} with polarized beam
'New' topic, white paper foreseen for summer 2020
Physics interests:

- Rich high precision electroweak program
  → see Roman's talk
- Can probe dark sector
- Improve precision on τ EDM and (g-2)
- …



$50ab^{-1} \rightarrow 250ab^{-1}$

Working group created recently to:

- Check the impact of $L=5 \times L_{design}$ on Belle II → Belle III
- how much the luminosity can be increased before major detector upgrades are required?

Vertex detector upgrade

- Prepare mitigation measures to cope with harsher machine conditions and limited safety factor: relevant in period of the existing program
- Several IN2P3 labs involved
- EOI foreseen for 2021

Conclusion

- Broad program to search for NP through MANY flavour observables in the coming decade
- French groups are involved in all decays presented here
- Belle II and LHCb provide complementary informations
- Expect confirmation of the anomalies in neutral currents by Belle II

- Most of measurements in rare decays will still be statistically limited with Belle II and LHCb upgrade I

⇨ Need LHCb U2 and Belle III even if the anomalies disappear (unlikely!)

- Only FCC-ee can allow to gain 1 to 2 order of magnitude for $b \rightarrow \tau$ and τ LFV decays decays

Report on the ECFA Early-Career Researchers Debate on the 2020 European Strategy Update for Particle Physics

arXiv:2002.02837

General The ECRs feel that the attractiveness of our field is at risk and that dedicated actions need to be taken to safeguard its future. When continuing on the current path, the field will likely be unable to attract the brightest minds to particle physics. The ESU must therefore include sociological and sustainability aspects in addition to technical ones related to machine feasibility and particle physics research. It is of high priority that funding for non-permanent positions is converted to funding for permanent positions, i.e. fewer post-docs in exchange for more staff. In addition, particle physics should play an exemplary role for sustainable behaviour, being inspirational for both society and other sciences. Overwhelming consensus was reached on the idea to establish a permanent ECR committee as part of ECFA. Such a committee would be able to give a mandate to a few individuals representing the ECRs in various bodies.

I think these aspects have to be discussed within the IN2P3 prospective, especially in the context of LPPR

Backup

Very rough comparison

observable	Belle II 50 ab^{-1}	Belle II 250 ab^{-1}	LHCb 50 fb^{-1}	LHCb 300 fb^{-1}	FCCee
R(D), R(D*)	*** polarisations	*** polarisations	*** D*polarisation	*** polarisations	***
RK, RK*	**	***	**	***	***
Other RX			***	***	***
b → sℓℓ	**	***	***	***	***
b → sνν	***	***			****
b → sττ	**	***	**	***	****
B LFV	***	***	**	***	***
τ LFV	***	***	*	**	****

Limitation:
statistics
Systematics (often scale with stat)

Very uncertain column

Very uncertain column

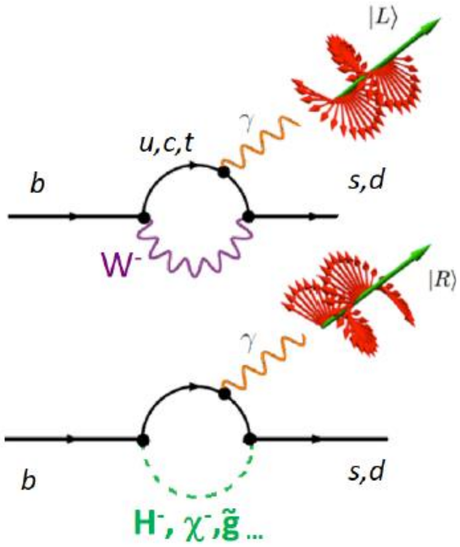
Activités de la communauté

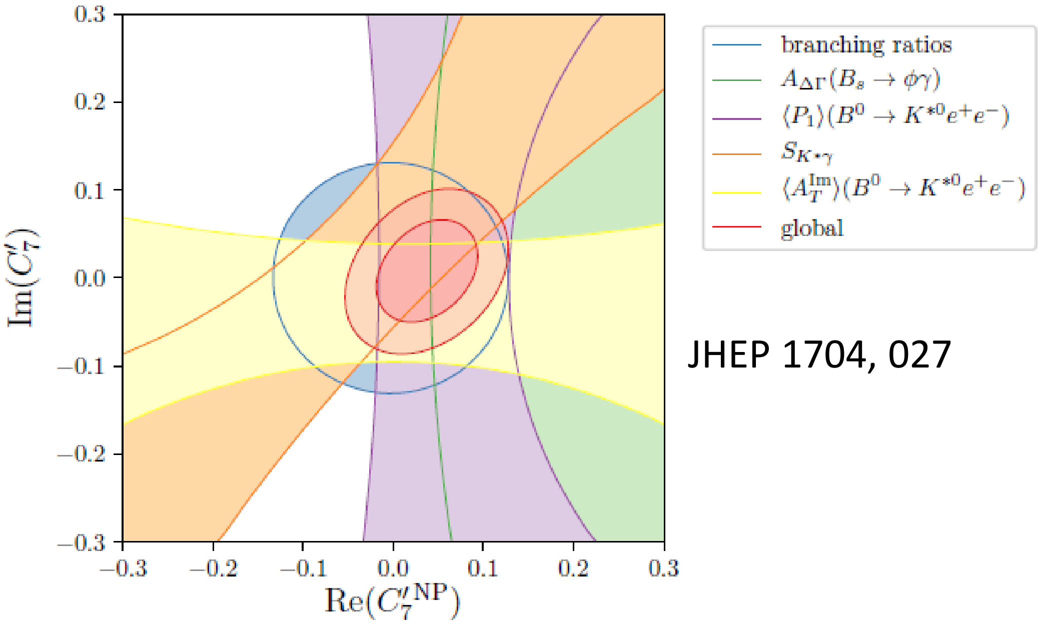
- b → $c\ell\nu$: CPPM, IJCLab, LPNHE
- b → $s\ell\ell$: IJCLab, LPNHE
- b → $s\nu\nu$: IPHC
- b → $s\tau\tau$: CPPM, IJClab
- B LFV: CPPM, CPPM, LPNHE
- τ LFV: CPPM, IJCLab

LHCb
Belle II

Photon polarization

- In SM, photon from b →sγ transitions are predominantly left handed
- NP can induce right handed photons
- Several complementary approaches, bringing additional constraints with respect to BR





JHEP 1704, 027

Photon polarization

- Angular observables of B →K*ee at low q2: AT2
  - LHCb extrapolating Run1 analysis expect a precision of 7% (2%) with Run3 (300 fb-1) Belle II can reach ~6% with 50ab-1 (statistics limited)

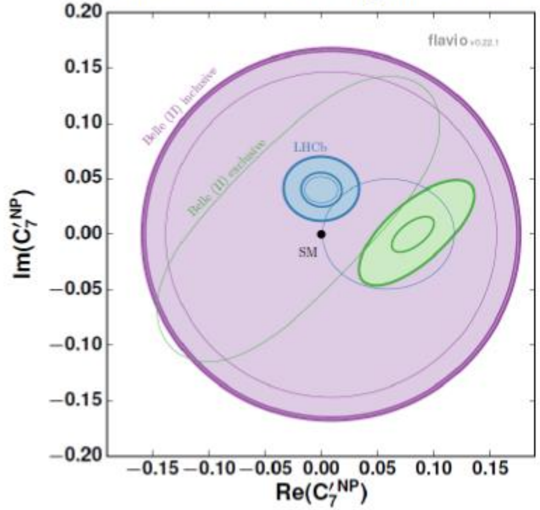
- Time dependent analysis of B → $f_{CP}\gamma$
  - LHCb expect 10k of tagged B^0 →$K_s\pi\pi\gamma$ with U2
  - Belle II can also study $K_s\pi^0$ final state, reaching 2% on S

- Amplitude analysis of B → K_{res}(→Kππ)γ
  - LHCb U2 can reach 1% precision on photon polarisation with K+π+π- final state
  - Belle II can also study K+π+π^0 final state

$$A_T^{(2)}(q^2 \to 0) \simeq 2\frac{\mathcal{R}e(C_7'^*)}{|C_7|} \quad A_T^{\rm Im}(q^2 \to 0) \simeq 2\frac{\mathcal{I}m(C_7'^*)}{|C_7|}$$

$$\Gamma(B^0_{(s)}(\overline{B}^0_{(s)}) \to f_{CP}\gamma)(t) \sim e^{-\Gamma_s t}\Big[\cosh\left(\frac{\Delta\Gamma_{(s)}}{2}\right) - \mathcal{A}^\Delta \sinh\left(\frac{\Delta\Gamma_{(s)}}{2}\right) \pm \pm \mathcal{C}_{CP}\cos\left(\Delta m_{(s)}t\right) \mp \mathcal{S}_{CP}\sin\left(\Delta m_{(s)}t\right)\Big],$$

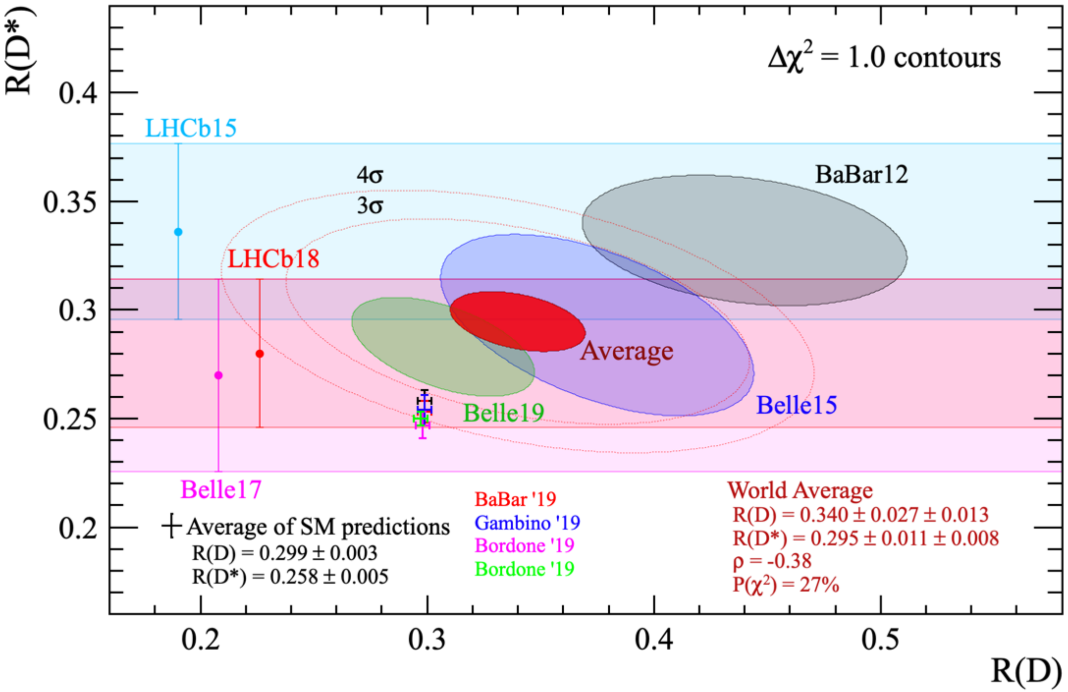
Straub, Belle II Physics book



https://arxiv.org/pdf/1709.10308.pdf

Table 49: Composition of the systematic uncertainty in each Belle analysis. Relative uncertainties in percent are shown. The analysis method and the τ decay mode are indicated in the parentheses; their meaning is explained in the caption of Table 48.

Source	Belle (Had, ℓ^-) R_D	Belle (Had, ℓ^-) R_{D^*}	Belle (SL, ℓ^-) R_{D^*}	Belle (Had, h^-) R_{D^*}
MC statistics	4.4%	3.6%	2.5%	$^{+4.0}_{-2.9}$%
$B \to D^{**}\ell\nu_\ell$	4.4%	3.4%	$^{+1.0}_{-1.7}$%	2.3%
Hadronic B	0.1%	0.1%	1.1%	$^{+7.3}_{-6.5}$%
Other sources	3.4%	1.6%	$^{+1.8}_{-1.4}$%	5.0%
Total	7.1%	5.2%	$^{+3.4}_{-3.5}$%	$^{+10.0}_{-9.0}$%



	R(D)	R(D*)	RD-RD* #σ from SM	RD* only #σ from SM
Bernlochner et al. PRD95(2017)115008	0.299±0.003	0.257 ± 0.003		
Bigi et al. JHEP1711(2017)061		0.260 ± 0.008		
Jaiswal el al. JHEP1712(2017)060	0.299±0.004	0.257 ± 0.005		
HFLAV	**0.299±0.004**	**0.258 ± 0.005**	**3.08**	**2.5**
BaBar PRL123(2019),091801		0.253 ± 0.005	3.43	2.8
Gambino et al. PLB795(2019)386		0.254 ± 0.007	3.16	2.6
Bordone et al. ArXiv:1908.09398 (no exp.)	0.298±0.003	0.247 ± 0.006	3.77	3.2
Bordone el al. ArXiv:1908.09398	0.297±0.003	0.250 ± 0.003	3.87	3.2

Prospects for HL-LHC

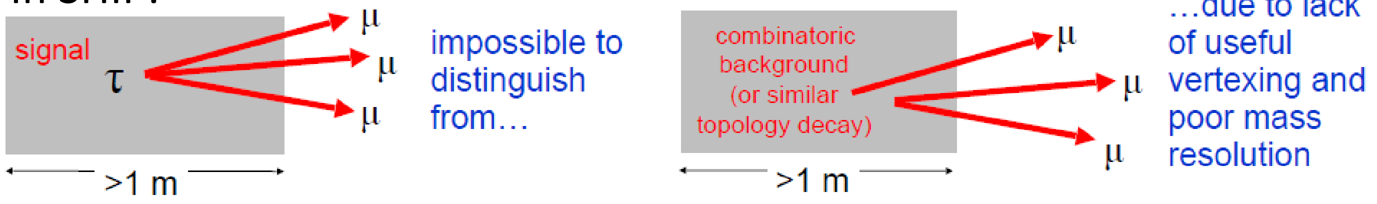
Opportunities in flavour physics at the HL-LHC and HE-LHC, arxiv:1812.07638

$BR(\tau \to 3\mu)$ (90% CL limit)	Ref.	Comments
3.8×10^{-7}	ATLAS [429]	Actual limit (Run 1)
4.6×10^{-8}	LHCb [428]	Actual limit (Run 1)
3.3×10^{-8}	BaBar [417]	Actual limit
2.1×10^{-8}	Belle [423]	Actual limit
3.7×10^{-9}	CMS HF-channel at HL-LHC	Expected limit (3000 fb^{-1})
6×10^{-9}	ATLAS W-channel at HL-LHC	Expected limit (3000 fb^{-1})
2.3×10^{-9}	ATLAS HF-channel at HL-LHC	Expected limit (3000 fb^{-1})
$\mathcal{O}(10^{-9})$	LHCb at HL-LHC	Expected limit (300 fb^{-1})
3.3×10^{-10}	Belle-II [196]	Expected limit (50 ab^{-1})

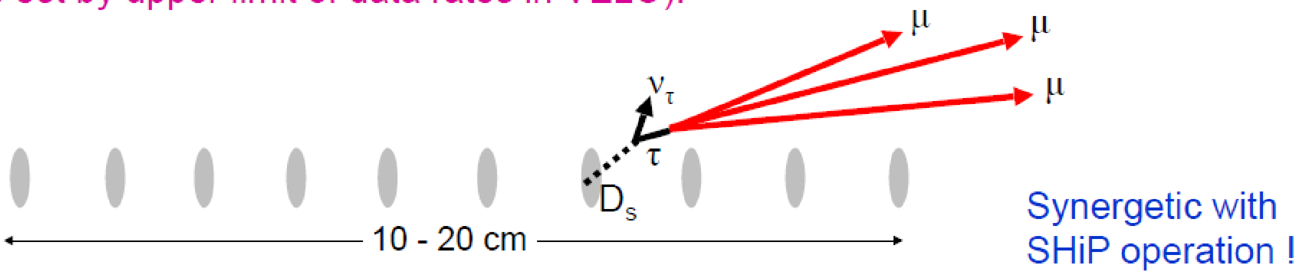
τ → μμμ @ tauFV

- « A fixed target experiment to search for flavour violation in tau decays »
- Proposal discussed in the ‘physics beyond collider’ workshops organized at CERN ([here]) and [ESPP]
- Beam dump experiment located at the SPS, upstream of SHIP

In SHIP:



Instead, design dedicated experiment upstream of SHiP, with thin, distributed targets, to bleed off ~2% of the beam intended for SHiP → 2 mm of tungsten (this value also set by upper limit of data rates in VELO).



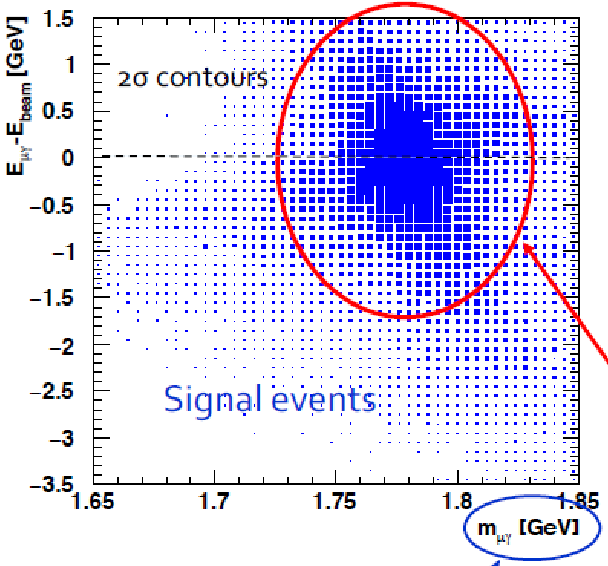
- Earliest start date : 2026-2027 (2030 more realistic)
- B(τ → μμμ) UL down to ~10^{-10}
- Other τ →3l, kaon and charm decays can be studied

$\tau \rightarrow \mu\mu\mu$ @Z peak

Talk by M. Dam at TAU 2018

- FCC-ee at CERN, running at Z peak: 15×10^{10} tau pairs
- Dedicated study gives a limit at $2\ 10^{-9}$ on $\tau \rightarrow e/\mu\gamma$ and $<10^{-10}$ on $\tau \rightarrow 3\ell$

- CEPC in China, running at Z peak: 3×10^{10} tau pairs



In order to de-correlate the E and m variables, this mass, $m_{\gamma\mu}$, is in fact the measured mass scaled by measured energy over beam energy:

$$m_{\gamma\mu} = m_{raw} \times (E_{\gamma\mu}/E_{beam})$$

Smear with assumed FCC-ee detector resolutions:

- Muon momentum [GeV]

  $\sigma(p_T)/p_T = 2 \times 10^{-5} \times p_T \oplus 1 \times 10^{-3}$
- Photon ECAL energy [GeV]

  $\sigma(E)/E = 0.165/\sqrt{E} \oplus 0.010/E \oplus 0.011$
- Photon ECAL spatial

  $\sigma(x) = \sigma(y) = (6/E \oplus 2)$ mm

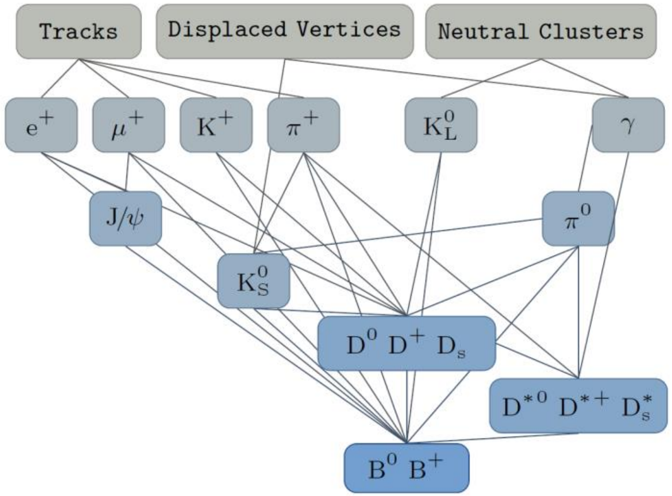
From this, determine **FCC-ee** effective detector resolution for $\tau \rightarrow \mu\gamma$

$\sigma(m_{\gamma\mu}) = 26$ MeV; $\sigma(E_{\gamma\mu}) = 850$ MeV

Prospects for Belle II : tagging

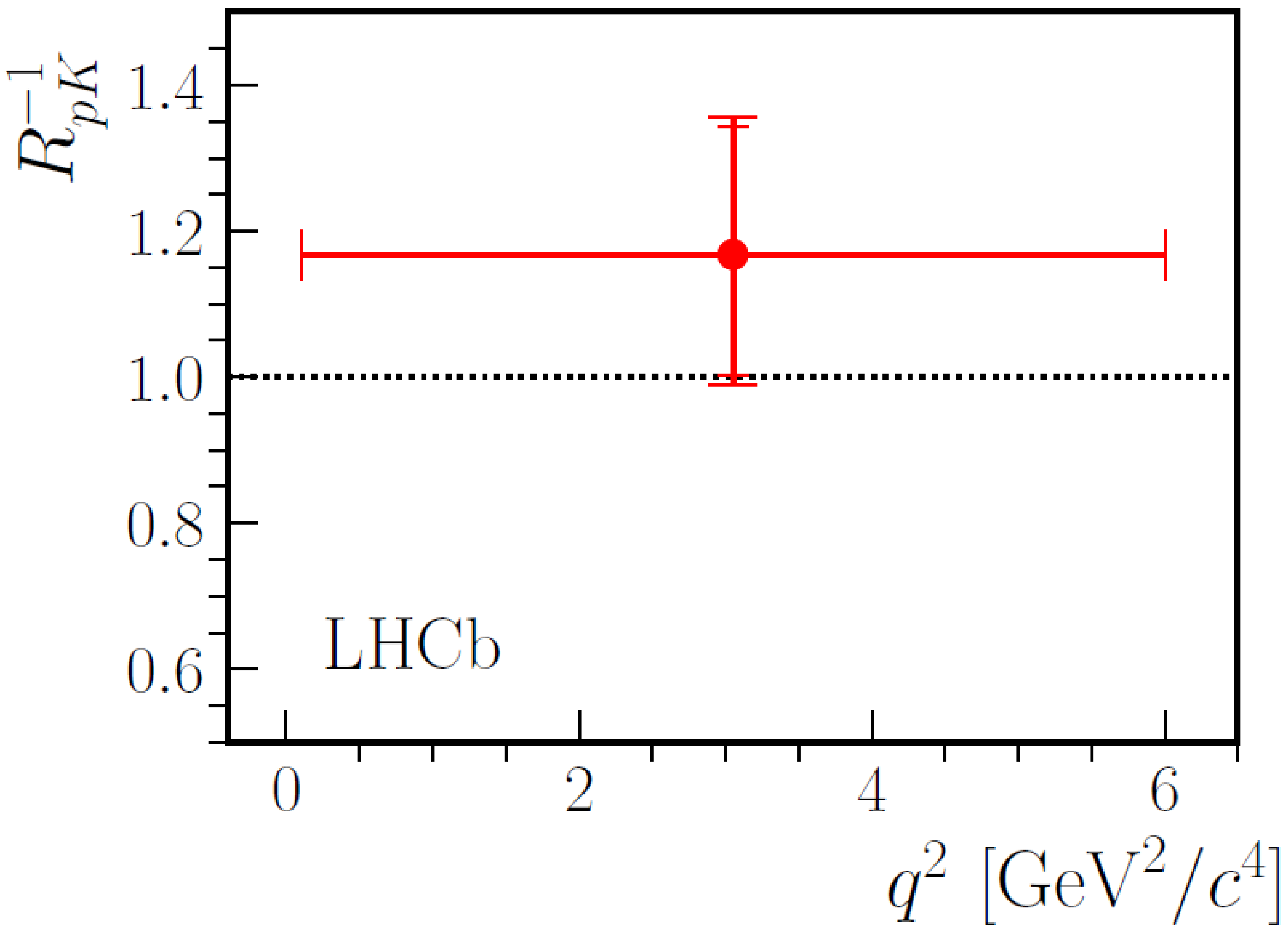
- Improved tagging thanks to Full Event Interpretation tagging algorithm (arXiv:1807.08680)
    - Hierarchical approach
    - MVA-based
    - Highly tunable
    - Already used in Belle analyses

Tag	FR[10] @ Belle	FEI @ Belle MC	FEI @ Belle II MC
Hadronic B^+	0.28 %	0.49 %	0.61 %
Semileptonic B^+	0.67 %	1.42 %	1.45 %
Hadronic B^0	0.18 %	0.33%	0.34 %
Semileptonic B^0	0.63 %	1.33%	1.25 %



Other possible improvements:

- Use of semileptonic tagging, as e.g. in Belle B→ hνν analysis (PRD 96(2017)091101)
- Use inclusive analysis (no tagging): for B→ τμ, CLEO reached limit at 3.8 10^{-5} with $10fb^{-1}$! PRL93(2004)241802 (1.7x Babar)
- Additionnal tau modes



R_{pK}^{-1}
1.4
1.2
1.0
0.8
0.6
LHCb
0
2
4
6
q^2 [GeV^2/c^4]

Prospects for Belle II: B→τ

From Belle II physics book, arXiv:1808.10567

Observables	Belle $0.71\,\mathrm{ab}^{-1}$ $(0.12\,\mathrm{ab}^{-1})$	Belle II $5\,\mathrm{ab}^{-1}$	Belle II $50\,\mathrm{ab}^{-1}$
$\mathrm{Br}(B^+ \to K^+\tau^+\tau^-) \cdot 10^5$	< 32	< 6.5	< 2.0
$\mathrm{Br}(B^0 \to \tau^+\tau^-) \cdot 10^5$	< 140	< 30	< 9.6
$\mathrm{Br}(B_s^0 \to \tau^+\tau^-) \cdot 10^4$	< 70	< 8.1	–
$\mathrm{Br}(B^+ \to K^+\tau^\pm e^\mp) \cdot 10^6$	–	–	< 2.1
$\mathrm{Br}(B^+ \to K^+\tau^\pm \mu^\mp) \cdot 10^6$	–	–	< 3.3
$\mathrm{Br}(B^0 \to \tau^\pm e^\mp) \cdot 10^5$	–	–	< 1.6
$\mathrm{Br}(B^0 \to \tau^\pm \mu^\mp) \cdot 10^5$	–	–	< 1.3

With 70% polarized electron beam get unprecedented precision for neutral current vector couplings

Final State Fermion	SM g_v^f (M_Z)	World Average[1] g_v^f	Chiral Belle σ 20 ab^{-1}	Chiral Belle σ 40 ab^{-1}	Chiral Belle σ $\sin^2\Theta_W$ 40 ab^{-1}
b-quark (selection eff.=0.3)	-0.3437 ± .0001	-0.3220 ±0.0077 (high by 2.8σ)	0.002 Improve x4	0.002	0.003
c-quark (eff. = 0.3)	+0.1920 ±.0002	+0.1873 ±0.0070	0.001 Improve x7	0.001	0.0008
Tau (eff. = 0.25)	-0.0371 ±.0003	-0.0366 ±0.0010	0.001 (similar)	0.0007	0.0004
Muon (eff. = 0.5)	-0.0371 ±.0003	-0.03667 ±0.0023	0.0007 Improve x3	0.0005	0.0003
Electron (eff. = 0.015)	-0.0371 ±.0003	-0.03816 ±0.00047	0.0007	0.0005	0.0003 *(all leptons will give ~current* WA error)

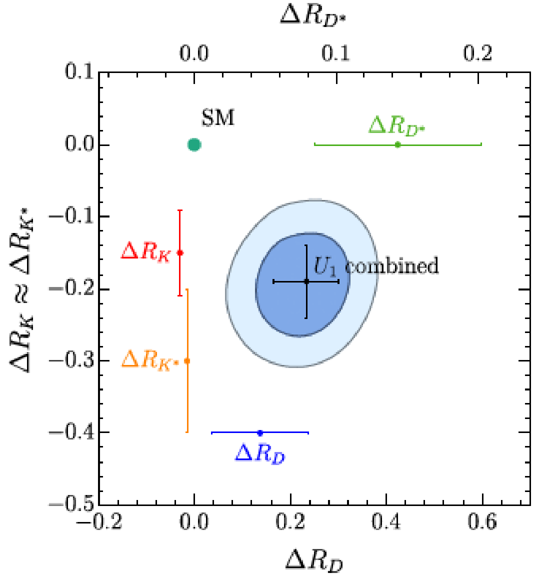
1 - Physics Report Vol 427, Nos 5-6 (2006), ALEPH, OPAL, L3, DELPHI, SLD

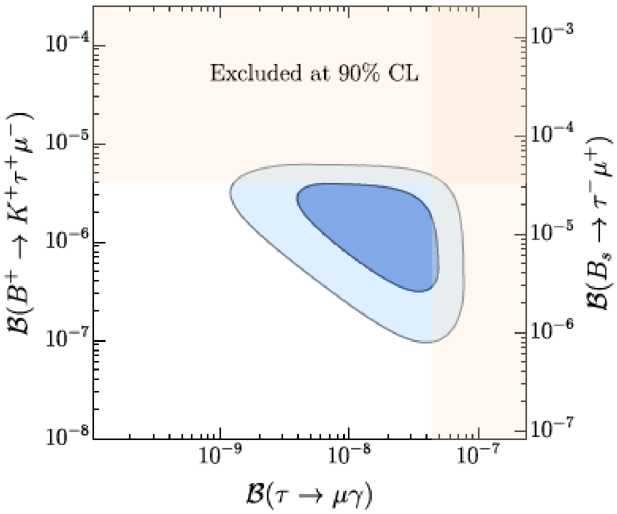
$\sin^2\Theta_W$ - all LEP+SLD measurements combined WA = 0.23153 ± 0.00016

Polarization in SuperKEKB

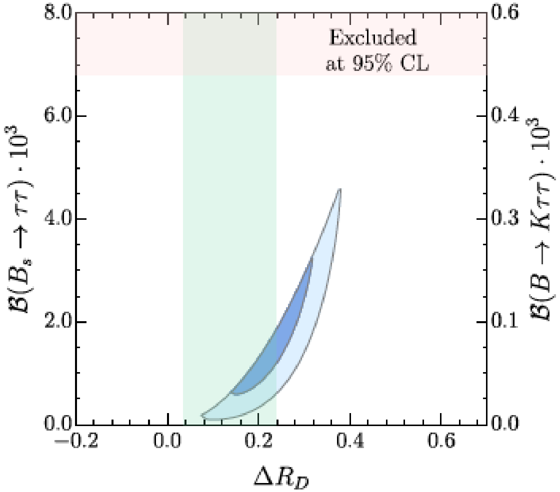
- Aim for ~70% polarization with 80% polarized source (SLC had 75% polarization at the experiment)
- Electron helicity would be set randomly pulse-to-pulse by controlling the circular polarization of the source laser illuminating a GaAs photocathode.
- Inject vertically polarized electrons into the High Energy Ring (HER -> electron ring)
  - use polarized electron source similar to SLC source
  - needs low enough emittance source to be able to inject.
- Rotate spin to longitudinal before IP, and then back to vertical after IP using solenoidal and dipole fields
- Use Compton polarimeter to monitor longitudinal polarization with ~1% absolute precision, higher for relative measurements (arXiv:1009.6178) - needed for real time polarimetry

Interpretation of the anomalies in terms of vector leptoquarks





C. Cornella, J. Fuentes-Martin, et G. Isidori, *arXiv:1903.11517* , JHEP 1907 (2019) 168



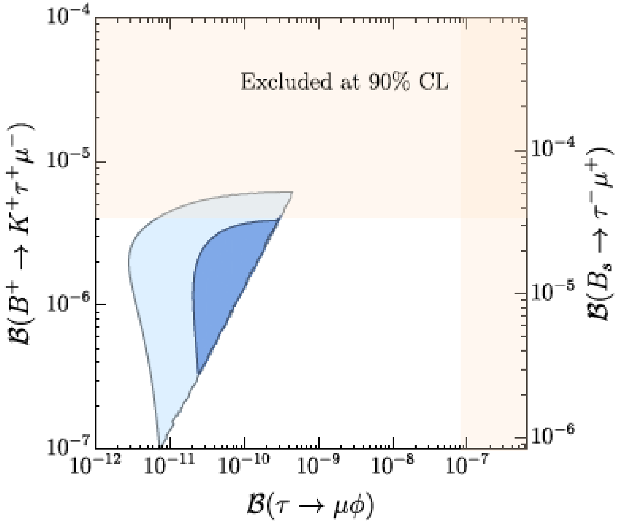
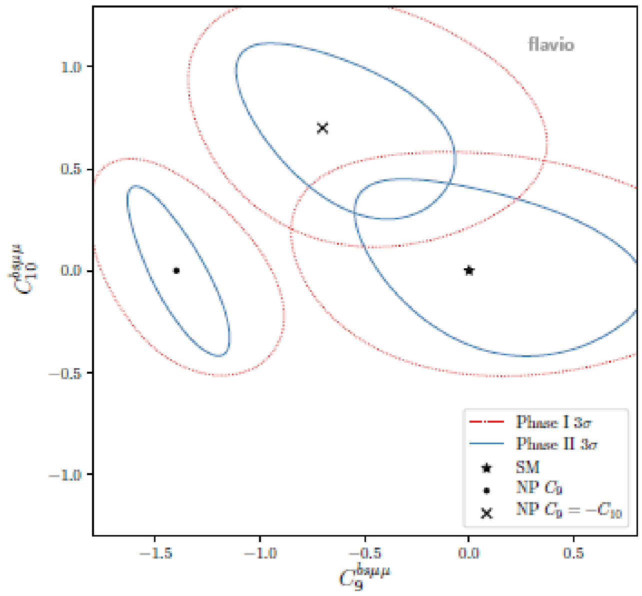


Fig. 5.9: Combined sensitivity of LHCb, ATLAS and CMS after the HL-LHC phase to potential new physics in $b \to s\mu\mu$ processes, motivated by recent anomalies (from Ref. [309]). New physics benchmarks with leptonic vector current (new physics only in C_9) or pure left-handed current ($C_9 = -C_{10}$), as well as the SM predictions are shown. The observables included are the branching ratio of the $B_s \to \mu^+\mu^-$ decay and the angular observables of the decay $B^0 \to K^{*0}\mu^+\mu^-$ in the low-q^2 region. See Ref. [309] for details.



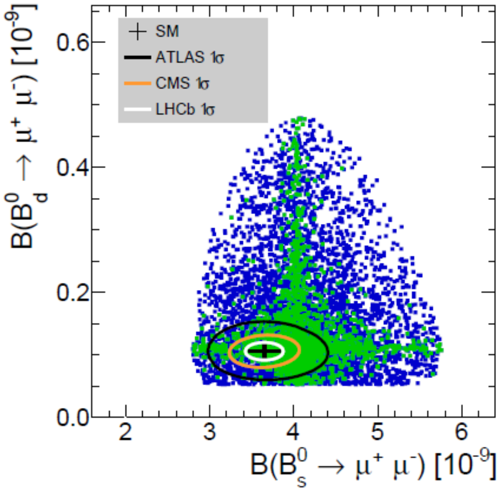


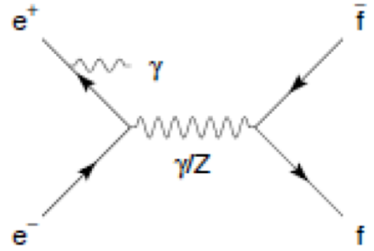
Fig. 5.7: BR($B^0_s \to \mu^+\mu^-$) vs. BR($B^0_d \to \mu^+\mu^-$) in the SM (black cross), and in a particular supersymmetric unified model (green points are consistent with other constraints). The coloured contours show the expected 1σ HL-LHC sensitivity of ATLAS, CMS, and LHCb Upgrade II. From Ref. [309].

Precision electroweak measurements at Belle II with polarized beams

Left-Right asymmetries (A_{LR}) yield measurements of unprecedented precision of the neutral current vector couplings (g_v) to each of five fermion flavour, f:

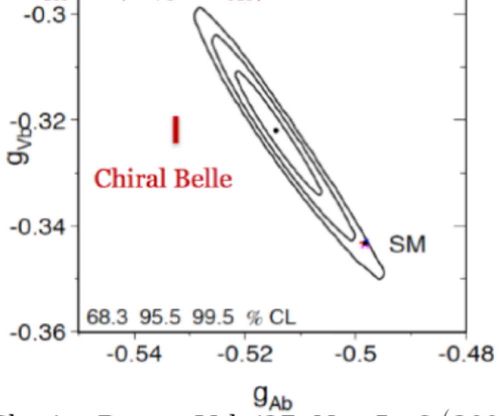
beauty (D), charm (U), tau, muon, electron

g_V^f gives θ_W in SM $\begin{cases} g_A^f = T_3^f \\ g_V^f = T_3^f - 2Q_f \sin^2\theta_W \end{cases}$



Existing tension in data on the Z pole

$g_{Rb} = (g_{Vb} - g_{Ab})/2$ is 3σ from SM



Physics Report Vol 427, Nos 5−6 (2006)
ALEPH, OPAL, L3, DELPHI, SLD

$$A_{LR} = \frac{\sigma_L - \sigma_R}{\sigma_L + \sigma_R} = \frac{4}{\sqrt{2}}\left(\frac{G_F s}{4\pi\alpha Q_f}\right) g_A^e g_V^f \langle Pol \rangle$$

$$\propto T_3^f - 2Q_f \sin^2\theta_W$$

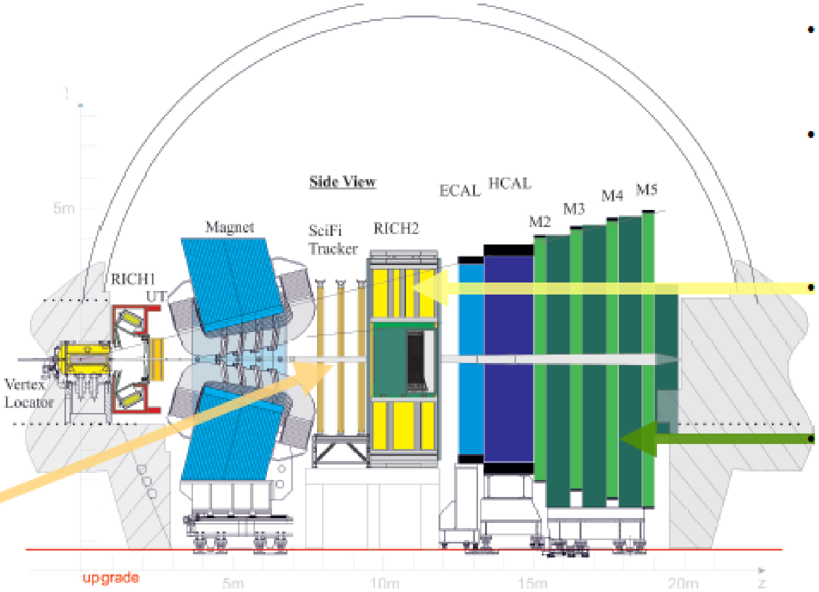
$$\langle Pol \rangle = 0.5\left\{\left(\frac{N_R^{e-} - N_L^{e-}}{N_R^{e-} + N_L^{e-}}\right)_R - \left(\frac{N_R^{e-} - N_L^{e-}}{N_R^{e-} + N_L^{e-}}\right)_L\right\}$$

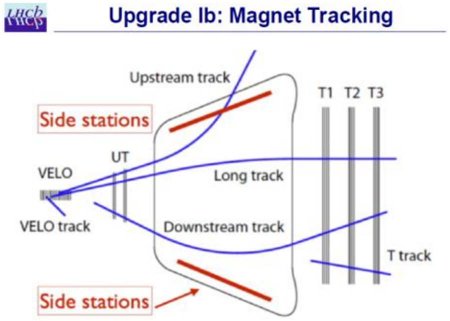
(with beams with 70% polarisation)

will yield $\sin^2\theta_W$ measurements with precision comparable/better to those at the Z-pole

LHCb Phase-II upgrade / 2

- **VELO**
  Thinner & smaller σ_t<200 ps/hit
- **UT**
  Microstrip and **RETINA** tracking (no CPU)
- **Magnet**
  New SciFi stations inside the dipole for low p_T tracking
- **Mighty tracker**
  New silicon around beam line





- **HCAL**
  Remove
- **ECAL**
  Improve granularity and σ_t ~50ps/hit
- **TORCH**
  PID for p<10 GeV and σ_t~15 ps
- **Muon stations**
  Improve shielding and replace Multi Wire Proportional Chambers