Round Table on the Future of Flavor Physics

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Zoltan Ligeti, David MacFarlane, Patrick Robbe, Guy Wormser

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Questions for Round Table participants

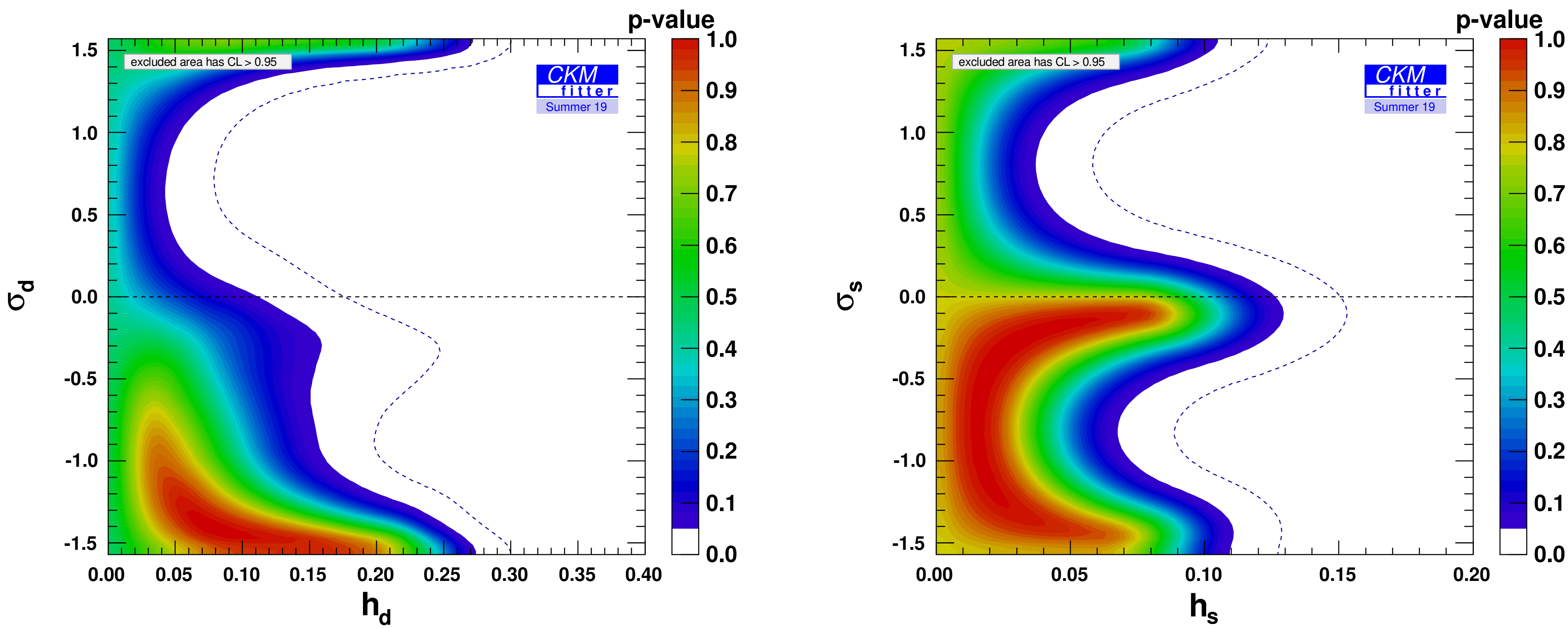
Context: Collectively pursuing a program of future precision measurements which combined will make a stringent test of the SM and can guide expectations for where the field as a whole (including future HEP colliders) should design and pursue searches for new physics

1. What future measurement (precision and timescale) do you consider the highlight and most impactful in terms of new physics searches from your experiment/facility?
2. Are there implications of LFV searches on quark flavor studies? Or vice versa? On future HEP colliders?
3. Are there implications for quark/lepton favor studies for Z-factory measurements? Or vice versa?

Zoltan Ligeti: Theory

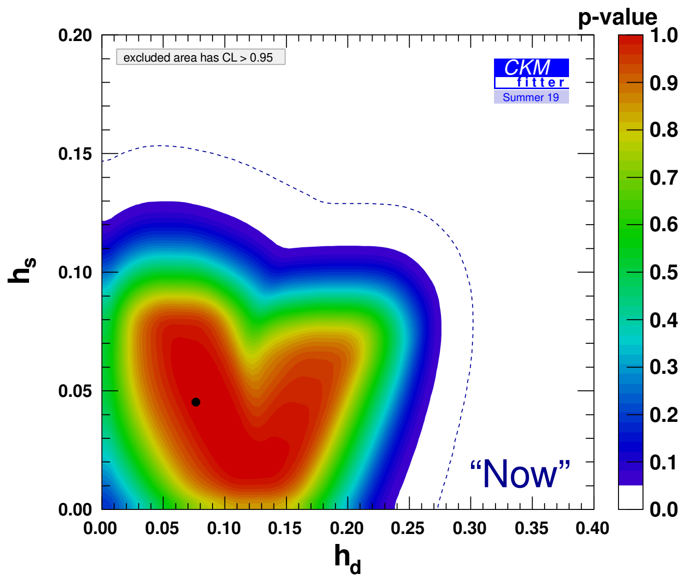
Bounds on new physics in mixing

- Constraints on NP in B_s mixing became better than in B_d (as expected)



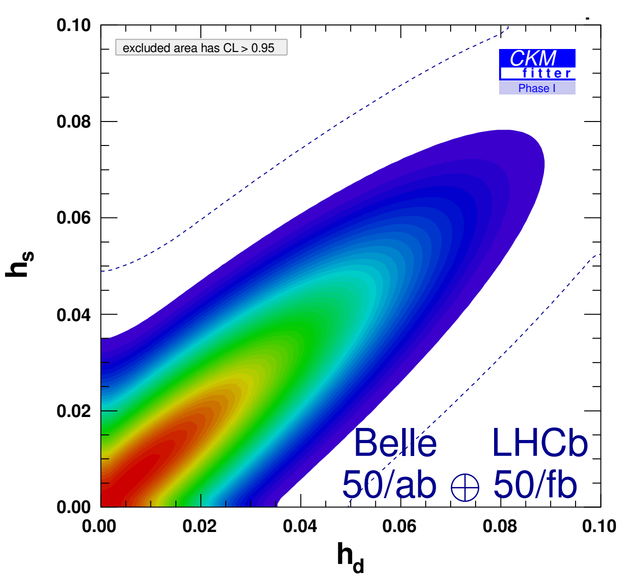
- h is the magnitude of the ratio of NP/SM contributions to M_{12}

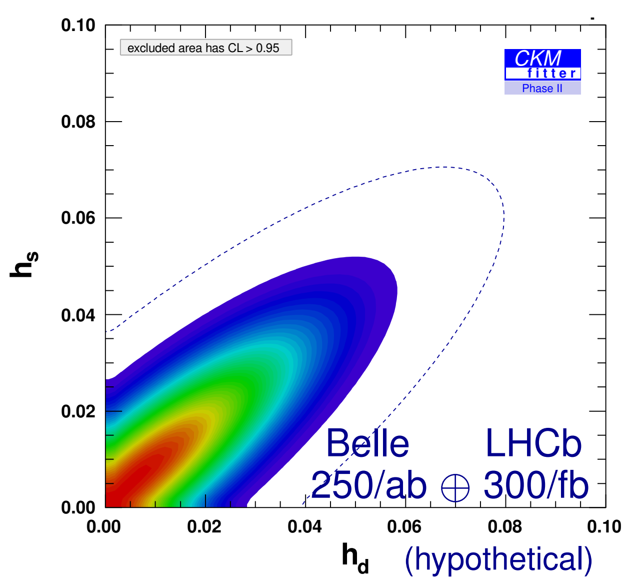
Future sensitivity to NP in B mixing



- What NP parameter space can be probed?
- $h_{d,s} \Leftrightarrow$ NP scale: $h \simeq \dfrac{|C_{ij}|^2}{|V_{ti}^* V_{tj}|^2} \left(\dfrac{4.5\ \text{TeV}}{\Lambda}\right)^2$ [2006.04824]

Couplings	NP loop order	Sensitivity for Summer 2019 [TeV]		Phase I Sensitivity [TeV]		Phase II Sensitivity [TeV]	
		B_d mixing	B_s mixing	B_d mixing	B_s mixing	B_d mixing	B_s mixing
$\lvert C_{ij}\rvert = \lvert V_{ti}V_{tj}^*\rvert$	tree level	9	13	17	18	20	21
(CKM-like)	one loop	0.7	1.0	1.3	1.4	1.6	1.7
$\lvert C_{ij}\rvert = 1$	tree level	1×10^3	3×10^2	2×10^3	4×10^2	2×10^3	5×10^2
(no hierarchy)	one loop	80	20	2×10^2	30	2×10^2	40





Big improvements in 2020s

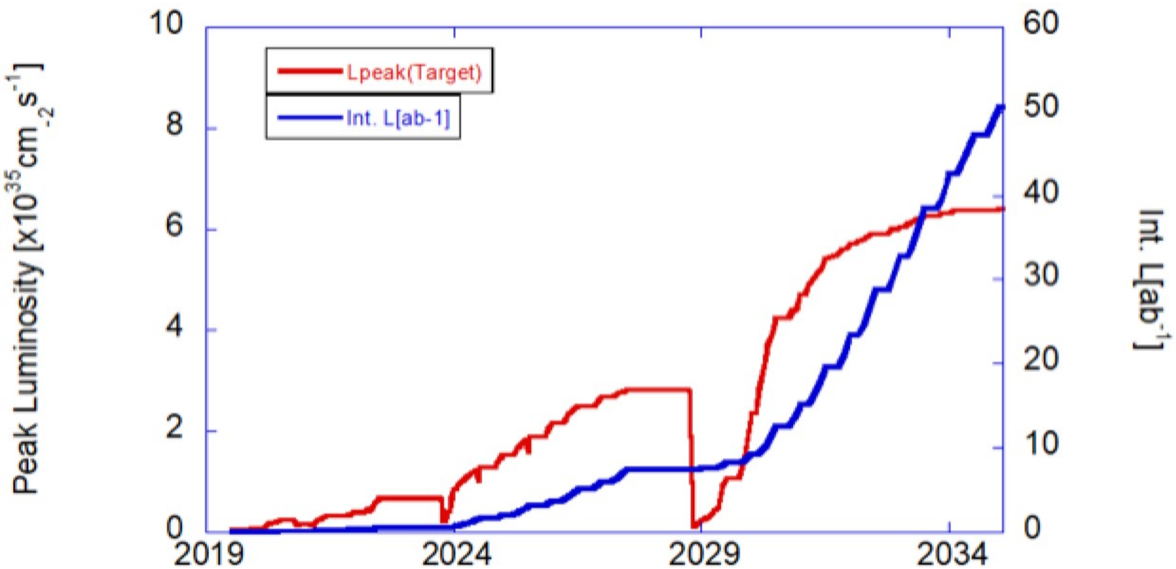
Complementary to high-p_T searches

Then theory improves or progress slows

Main bottlenecks: (i) $|V_{cb}|$ precision,

(ii) mixing param's from LQCD and η_B

Belle II and LHCb: clear plans



(Discussions about further upgrade)

	LHC era			HL-LHC era	
	Run 1 (2010-12)	Run 2 (2015-18)	Run 3 (2021-24)	Run 4 (2027-30)	Run 5+ (2031+)
ATLAS, CMS	25 fb^{-1}	150 fb^{-1}	300 fb^{-1}	⟶	3000 fb^{-1}
LHCb	3 fb^{-1}	9 fb^{-1}	23 fb^{-1}	50 fb^{-1}	*300 fb^{-1}

* assumes a future LHCb upgrade to raise the instantaneous luminosity to 2×10^{34} $cm^{-2}s^{-1}$

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Zoltan's responses

2. Are there implications of LFV searches on quark flavor studies? Or vice versa? On future HEP colliders?

There certainly are such connections, and there are many studies in the literature. I am not an expert, because in the absence of a clear discovery of LFV, I have been focusing elsewhere. However, should LFV be discovered, it seems obvious that it will explode into a broad program to map out the details. (Generation structure, the nature of the interaction, etc.)

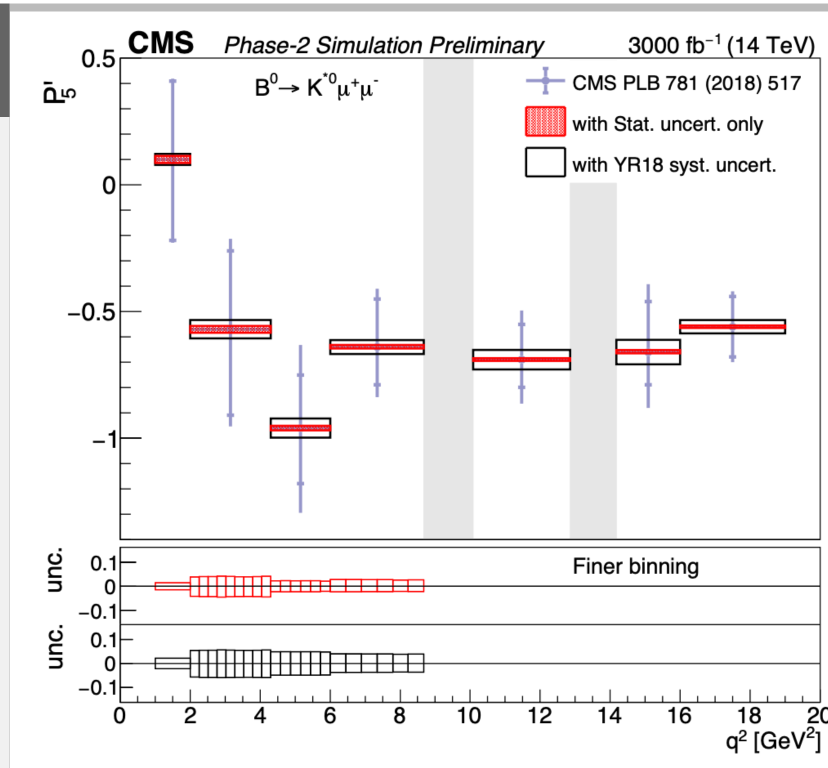
3. Are there implications for quark/lepton favor studies for Z-factory measurements? Or vice versa?

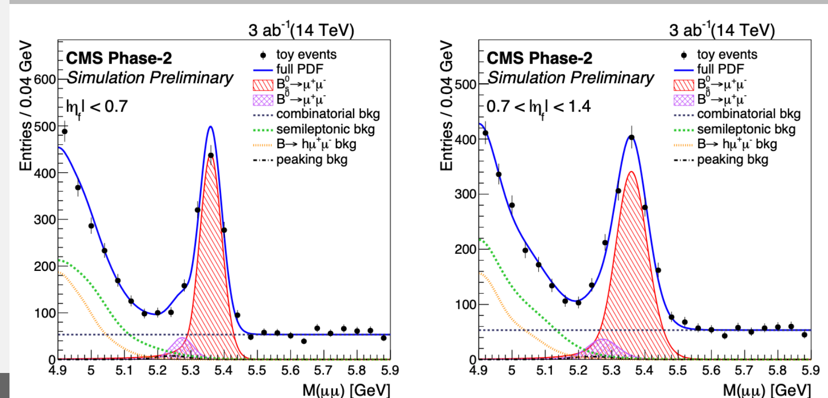
Most certainly. I am actually working on some things related to this. My gut feeling is that there are interesting things that haven't been considered yet in detail. Reducing systematic uncertainties as much as possible will be critical for tera-Z.

Daniel Del Re: ATLAS and CMS at LHC

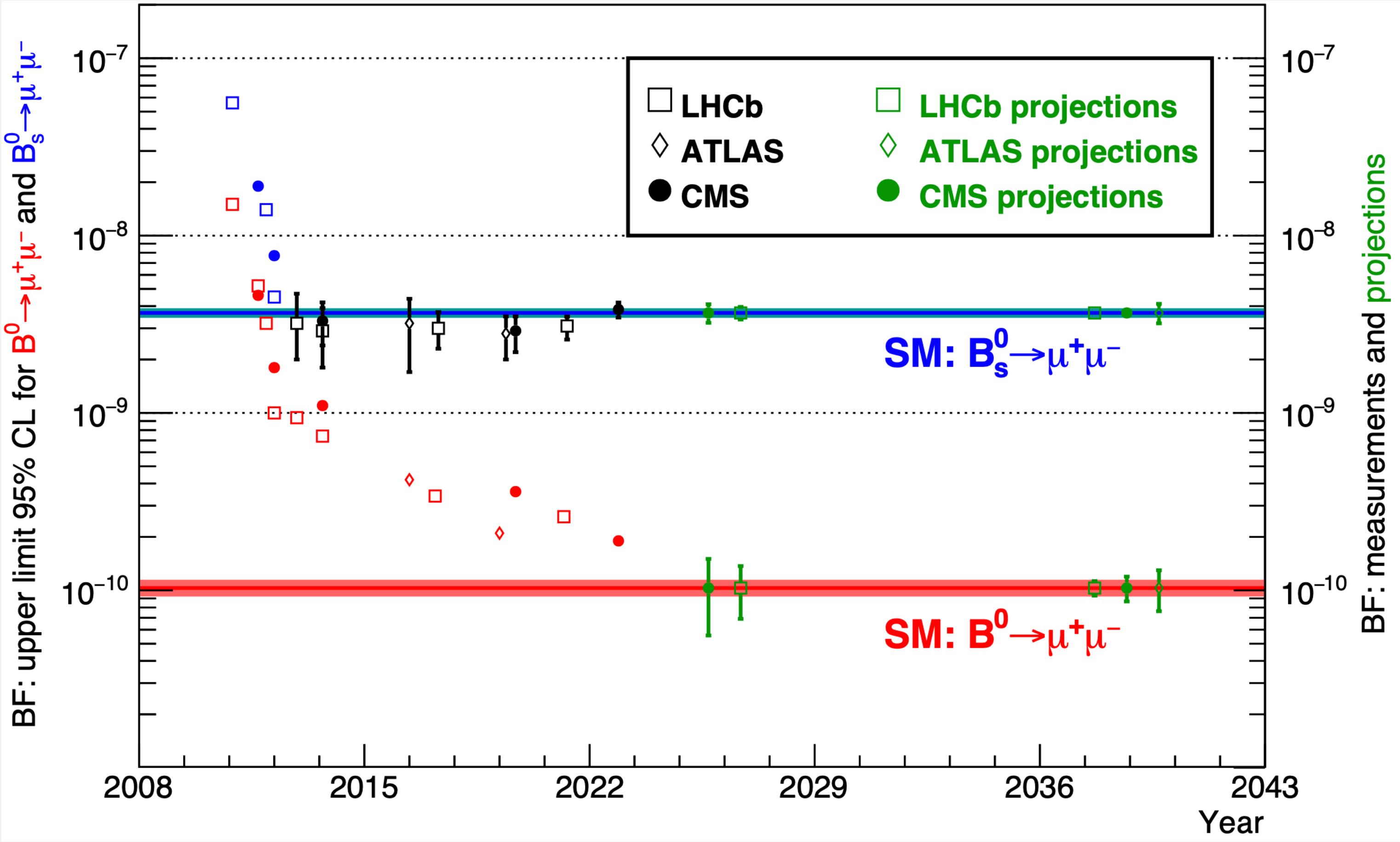
PERSPECTIVES FOR HL-LHC

- At **HL-LHC** we expect to **collect 3000 fb^{-1}** (by 2040)
  - Improved detector to cope with higher pileup
- **Several studies** assuming the gain in statistics and the performance of the upgraded detector in CMS
- $B^0 \rightarrow K^{*0}\mu\mu$ (FTR-18-033)
  - **P5′ uncertainties improved by up to a factor of 15** compared to measurement with 20 fb−1 of 8 TeV data (plot on the right)
- $B_s \rightarrow \mu\mu$ (FTR-18-013)
  - **Inner tracker** of the Phase-2 detector **improves mass resolution by order of 40-50%**
  - **Effective lifetime** measured with **error of ~0.05 ps**
  - $B^0 \rightarrow \mu\mu$ **observed** with **more than 5 standard** deviation significance



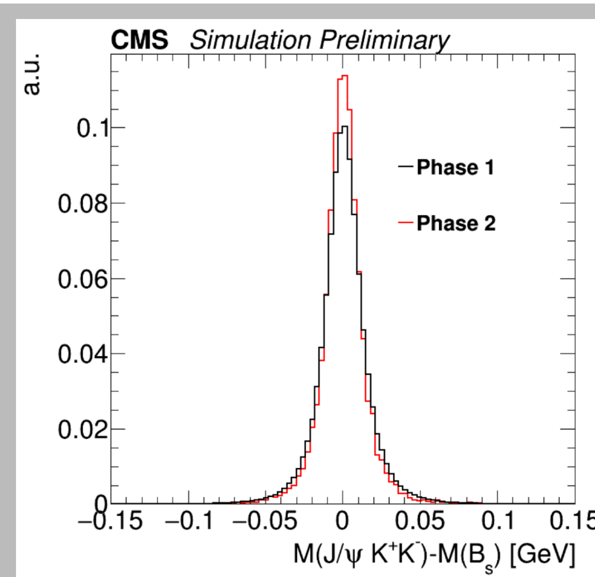


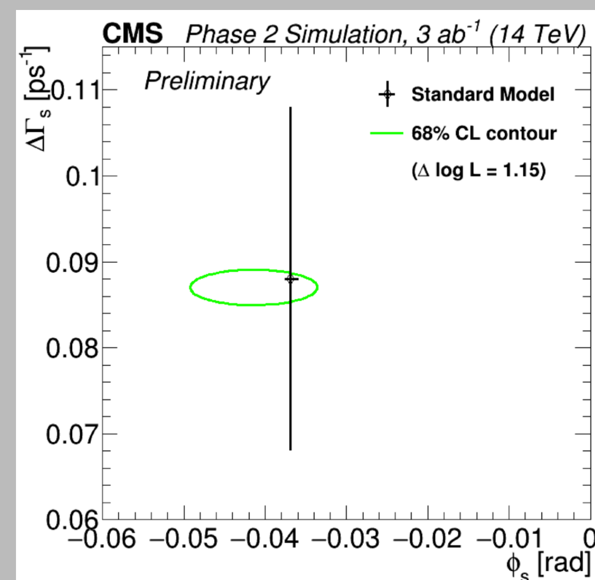
$B_{(s)} \to \mu\mu$ PERSPECTIVES



HL-LHC: $B_s \rightarrow J/\psi\phi$

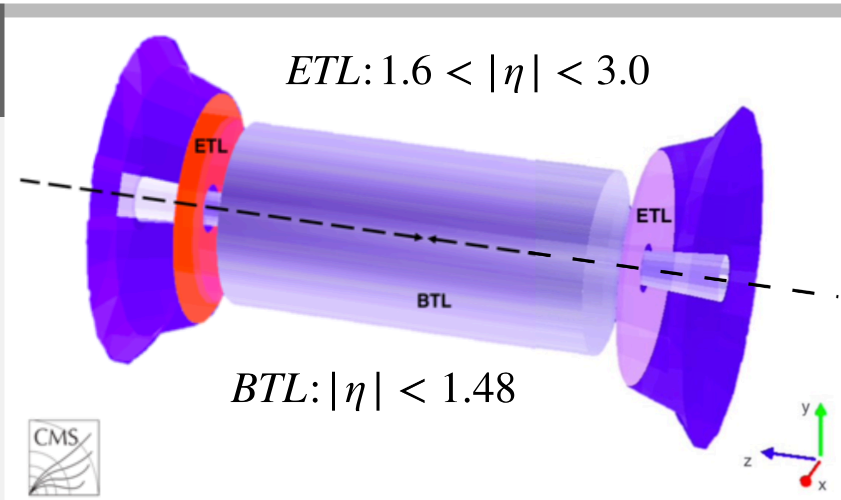
- Improvements from **new detector provides a better resolution thanks to new tracker with extended coverage (mass and impact parameter)**
- **Tested different scenarios with tagging power in the range 1.2–2.4%**
- Expect **statistical uncertainty on ϕ_s ~ 5–6 mrad** at the end of Phase 2 data taking
  - **Improves the current world average** uncertainty by a **factor of five** (FTR-18-041)
- **Same improvements and analysis approach** can be **used for** $B \rightarrow J/\psi K_s$

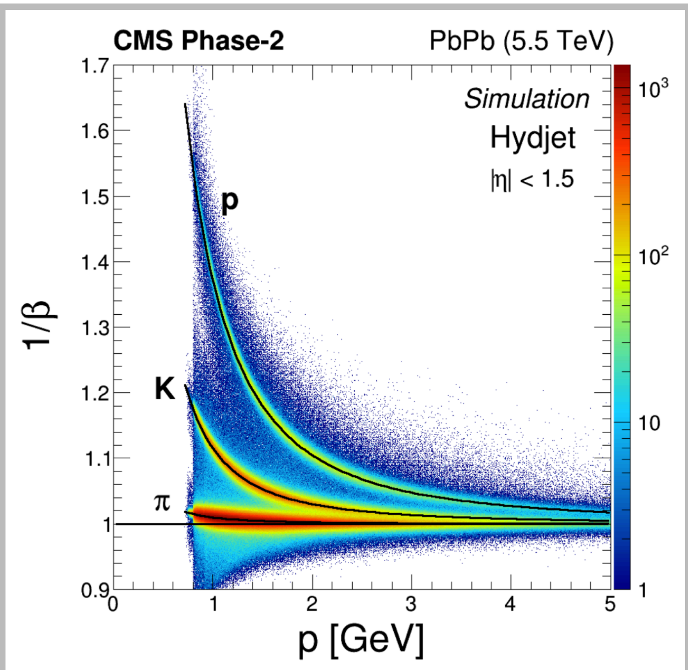




PID AT HL-LHC (MTD)

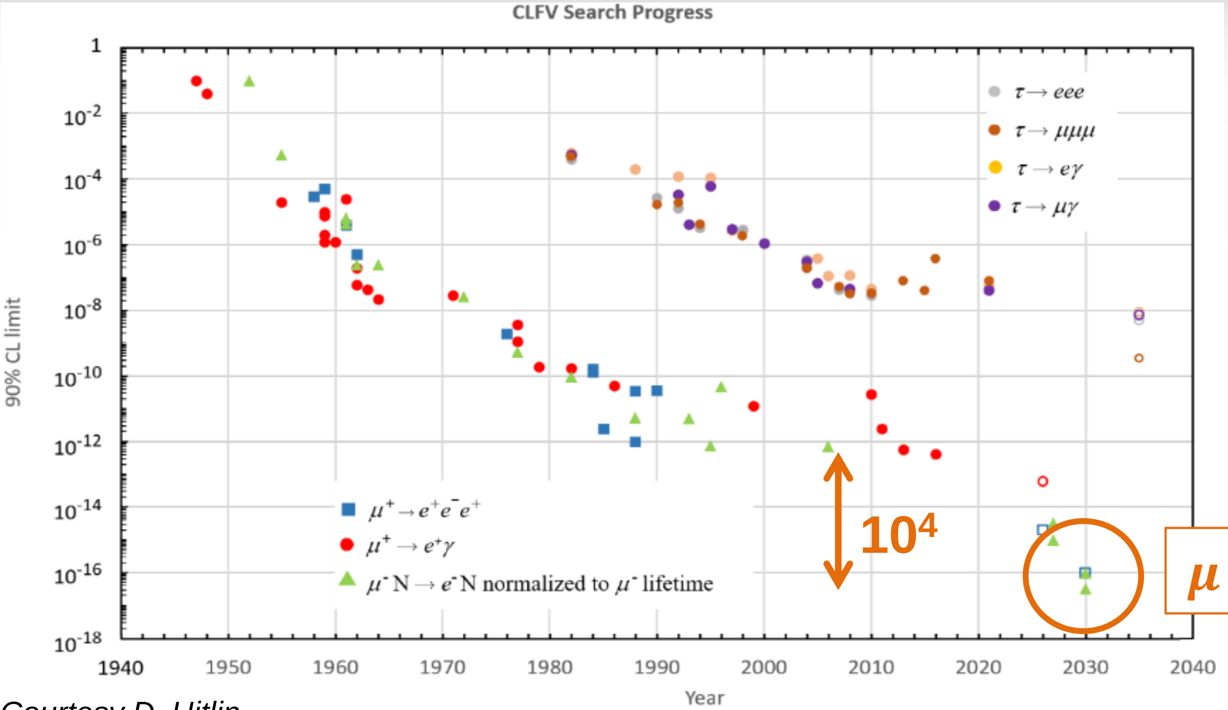
- **CMS proposes to build a Minimum Ionizing Particle** (MIP) Timing Detector (MTD):
  - Measurement of timing of charged tracks
  - 30-40ps time resolution for MIPs (beginning of HL-LHC)
  - Main purpose is pileup rejection and better primary vertex reconstruction
- **Different technologies, depending on radiation**
  - **Barrel** (fluence ~ 10^{14} neq/cm^2) LYSO:Ce crystal bars coupled to SiPM
  - **Endcap** (fluence ~ 10^{15} neq/cm^2) Low Gain Avalanche Diodes with ASIC readout
- Allows for **Time-of-flight PID at low momenta**:
  - **π/K separation** up to **~2.5 GeV**, **K/p up to ~5 GeV**
- **Large benefits** expected **for CPV and LVF**
  - ~+20% in tagging efficiency for $B_s \to J/\psi\phi$ (see here)





Bertrand Echenard: CLFV

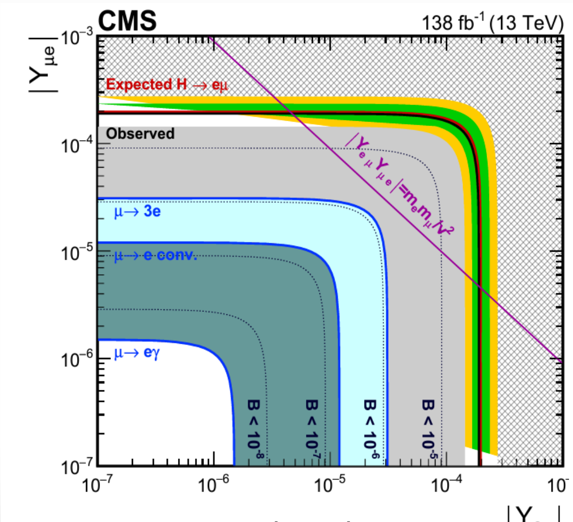
Future measurements – my pick



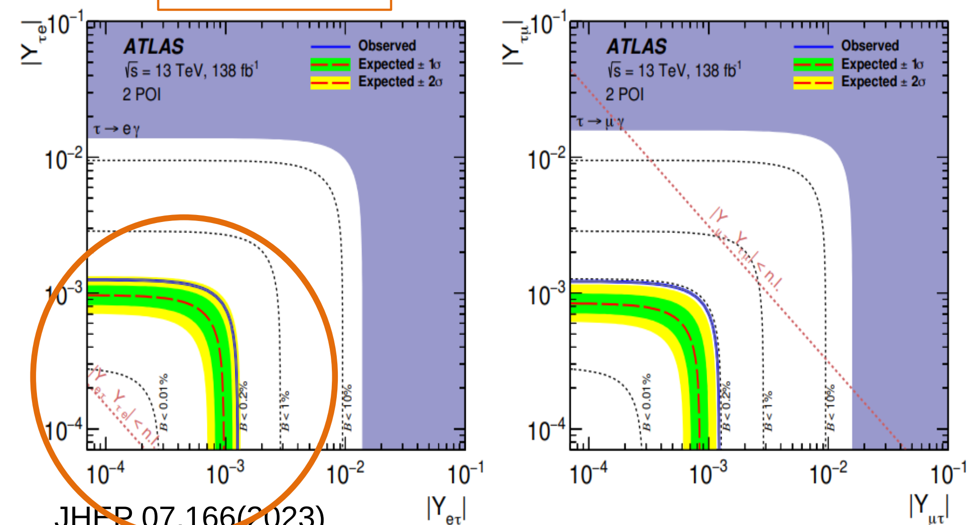
Courtesy D. Hitlin

μ → e @ Mu2e and COMET

H → ll′

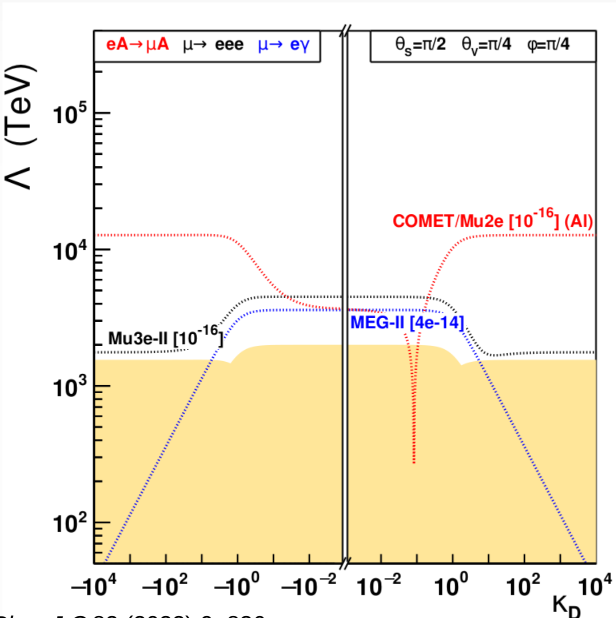


PRD 108,072004 (2023)

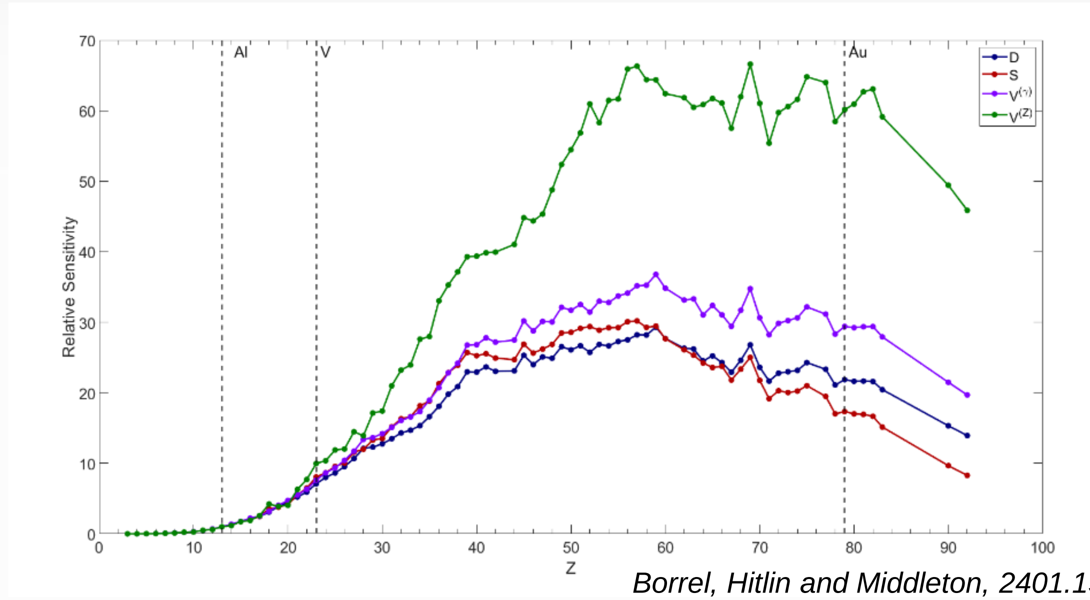


JHEP 07,166(2023)

Reach and complementarity of muon probes

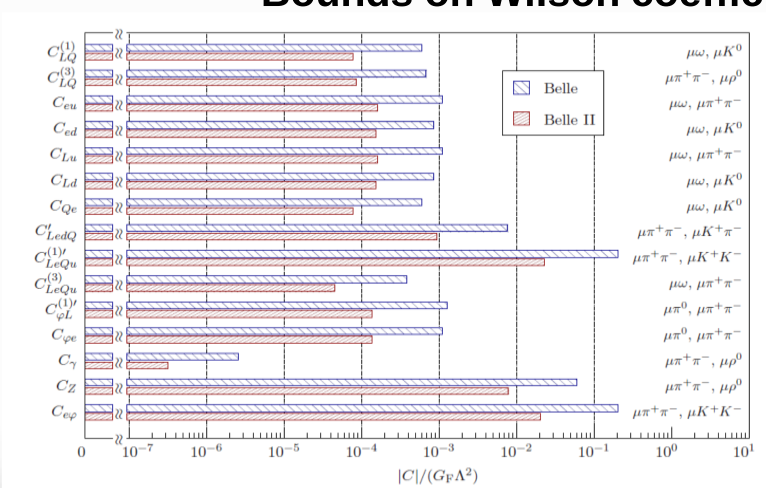


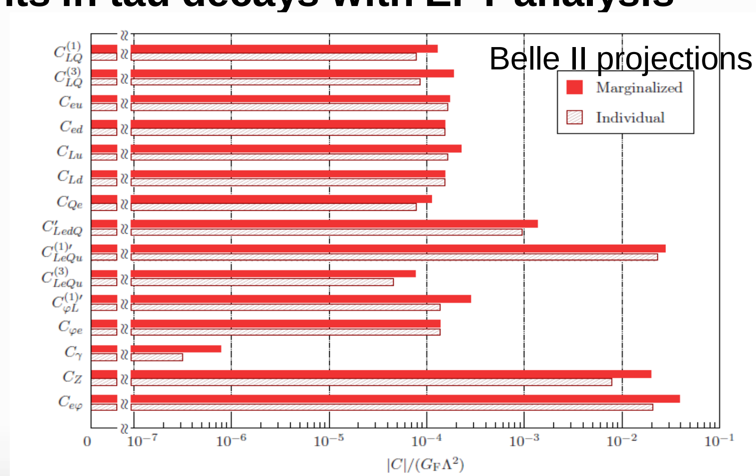
Eur.Phys.J.C 82 (2022) 9, 836



Borrel, Hitlin and Middleton, 2401.15025

Bounds on Wilson coefficients in tau decays with EFT analysis



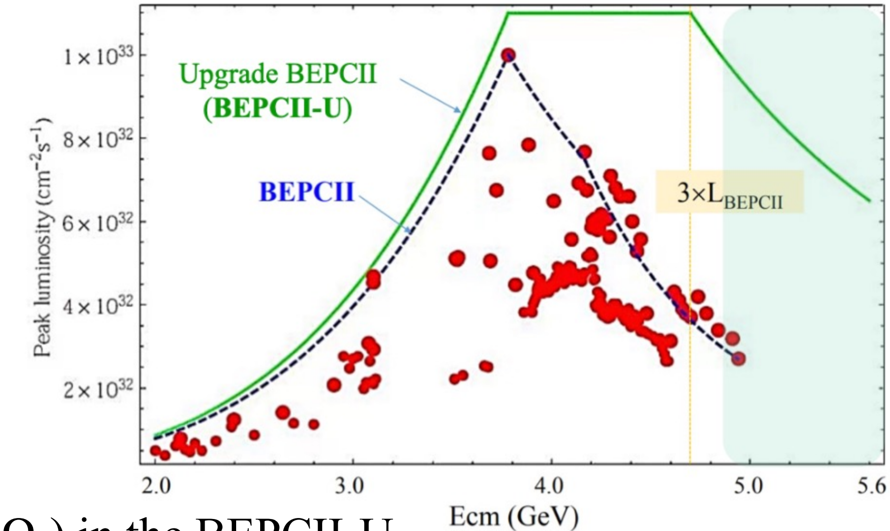


S. Banerjee et al., arxiv:2203.14919

Isabella Garzia: BES-III

Summary and Outlook

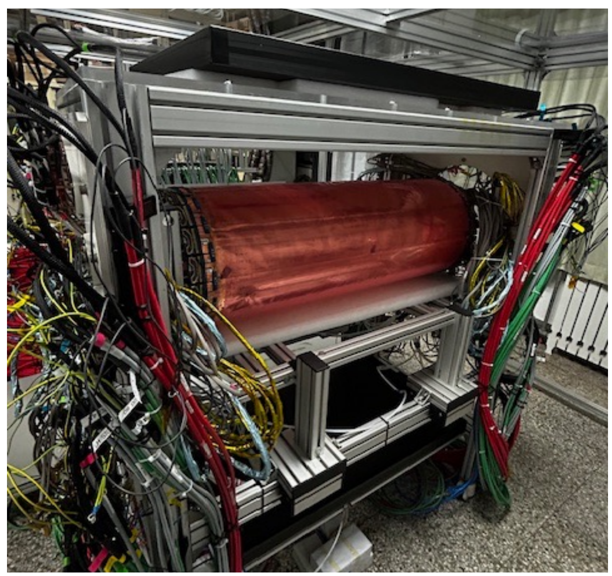
- Complementary information to B-factories and LHCb experiments
  - LFUV searches
  - Strong phases measurements
  - Amplitude analyses
  - Charmed baryons studies



- BESIII whitepaper Chinese Physics C 44, 040001 (2020) with outline of physics program for the next years
- Further upgrade in energy (5.6 GeV) and luminosity (BEPCII-U, 3x) planned for the next year

✓ Opportunities to study other charmed baryons (Σ_c, Ξ_c, Ω_c) in the BEPCII-U

- Inner MDC ➔ CGEM-IT



@LIU Yu Dong

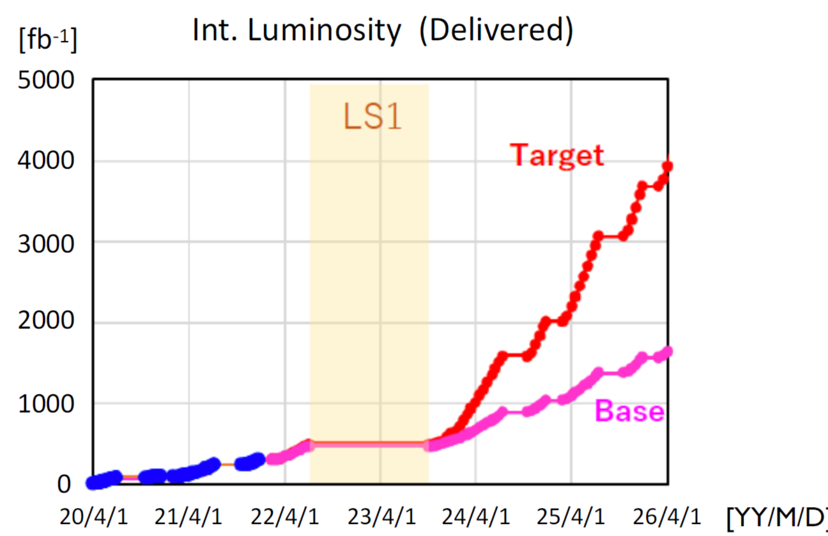
	BEPCII	BEPCII-U
luminosity $[10^{32}cm^{-2}s^{-1}]$ @2.35GeV	3.5	11
β_y^* [cm]	1.5	1.35
Beam current[mA]	400	900
SR Power [kW]	110	250
$\xi_{y,lum}$	0.029	0.033
emittance[nmrad]	147	152
couple [%]	0.53	0.35
Bucket Height	0.0069	0.011
$\sigma_{z,0}$ [cm]	1.54	1.07
σ_z [cm]	1.69	1.22
Rf voltage	1.6MV	3.3MV

Thanks for your attention

James Libby: Belle-II

Belle II: after current shutdown

- We have not collected the sample size planned to date
  - Beam conditions
- Since summer 2022 until **Feb 2004** shutdown for accelerator upgrades to mitigate background and increase luminosity
- Detector upgrades too
  - two-layer pixel detector installed
- **Path to 2×10^{35} cm $^{-2}$s^{-1} but new final focus to go beyond**
  - **Proposed upgrade from 2028+**
  - **see C. Checci and M. Roney next**



Goals with current data to a few inverse ab^{-1}

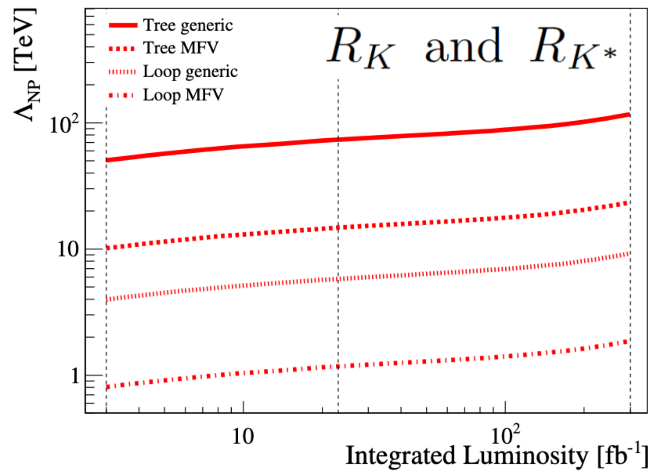
- Semileptonic decay:
  - V_{cb} can we make progress on the inclusive vs. exclusive tension
    - KEK report in preparation
  - **R(D)-R(D*)**
- Electroweak penguin
  - **Missing energy modes** like $B \to K\tau\tau$ and $K\nu\nu$
- CP violation
  - α and the **gluonic penguins**
- tau
  - **LFV and precision**
- Charm
  - final states with neutrals, e.g., $D \to \pi^0\pi^0$
- Quarkonium
  - Y(10753) scan and isospin partners (ISR and *B* decay)
- Dark sector and low multiplicity
  - dark photon and $e^+e^- \to \pi^+\pi^-$

Our Snowmass submission is the most up to date prospects document

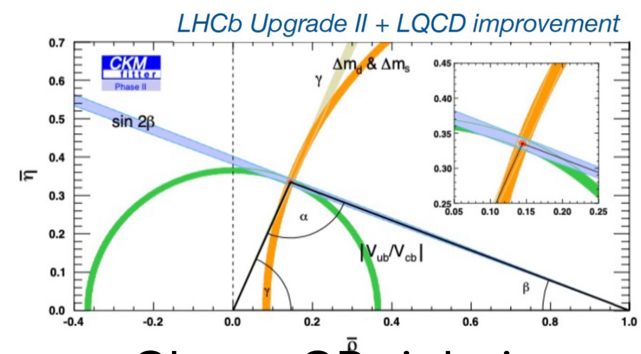
Guy Wormser and Patrick Robbe: LHCb

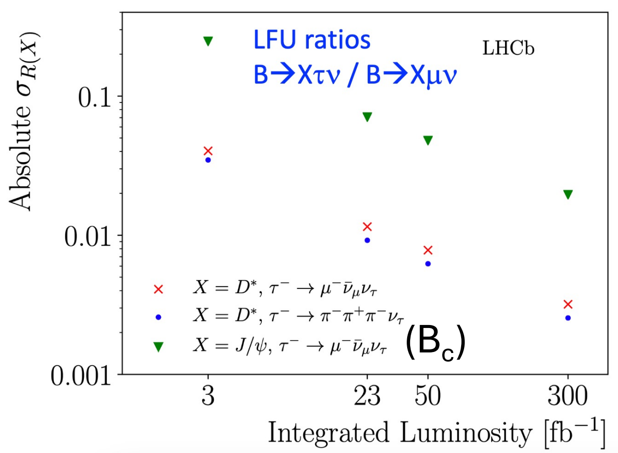
LHCb Upgrades

LHCC-2018-027

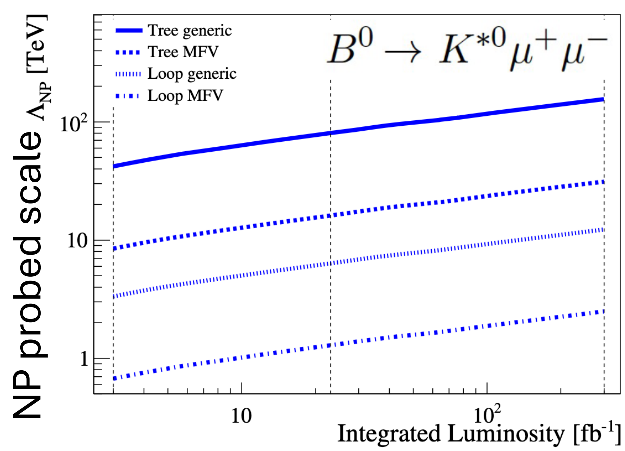


CP violation



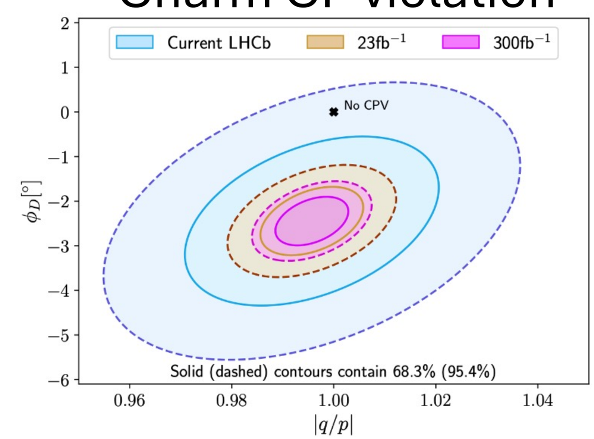


Semi-leptonic decays



Rare decays

Charm CP violation



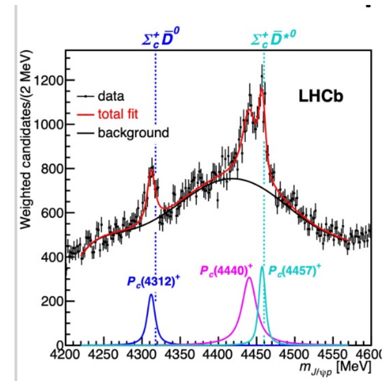
LHCb Upgrades

Observable	Current LHCb (up to $9\,\text{fb}^{-1}$)		Upgrade I ($23\,\text{fb}^{-1}$)	Upgrade I ($50\,\text{fb}^{-1}$)	Upgrade II ($300\,\text{fb}^{-1}$)
CKM tests					
γ ($B \to DK$, *etc.*)	4°	[9, 10]	1.5°	1°	0.35°
ϕ_s ($B_s^0 \to J/\psi\phi$)	32 mrad	[8]	14 mrad	10 mrad	4 mrad
$\lvert V_{ub}\rvert/\lvert V_{cb}\rvert$ ($\Lambda_b^0 \to p\mu^-\overline{\nu}_\mu$, *etc.*)	6%	[29, 30]	3%	2%	1%
a_{sl}^d ($B^0 \to D^-\mu^+\nu_\mu$)	36×10^{-4}	[34]	8×10^{-4}	5×10^{-4}	2×10^{-4}
a_{sl}^s ($B_s^0 \to D_s^-\mu^+\nu_\mu$)	33×10^{-4}	[35]	10×10^{-4}	7×10^{-4}	3×10^{-4}
Charm					
ΔA_{CP} ($D^0 \to K^+K^-, \pi^+\pi^-$)	29×10^{-5}	[5]	13×10^{-5}	8×10^{-5}	3.3×10^{-5}
A_Γ ($D^0 \to K^+K^-, \pi^+\pi^-$)	11×10^{-5}	[38]	5×10^{-5}	3.2×10^{-5}	1.2×10^{-5}
Δx ($D^0 \to K_S^0\pi^+\pi^-$)	18×10^{-5}	[37]	6.3×10^{-5}	4.1×10^{-5}	1.6×10^{-5}
Rare Decays					
$\mathcal{B}(B^0 \to \mu^+\mu^-)/\mathcal{B}(B_s^0 \to \mu^+\mu^-)$	69%	[40, 41]	41%	27%	11%
$S_{\mu\mu}$ ($B_s^0 \to \mu^+\mu^-$)	—		—	—	0.2
$A_{\text{T}}^{(2)}$ ($B^0 \to K^{*0}e^+e^-$)	0.10	[52]	0.060	0.043	0.016
A_{T}^{Im} ($B^0 \to K^{*0}e^+e^-$)	0.10	[52]	0.060	0.043	0.016
$\mathcal{A}_{\phi\gamma}^{\Delta\Gamma}(B_s^0 \to \phi\gamma)$	${}^{+0.41}_{-0.44}$	[51]	0.124	0.083	0.033
$S_{\phi\gamma}(B_s^0 \to \phi\gamma)$	0.32	[51]	0.093	0.062	0.025
$\alpha_\gamma(\Lambda_b^0 \to \Lambda\gamma)$	${}^{+0.17}_{-0.29}$	[53]	0.148	0.097	0.038
Lepton Universality Tests					
R_K ($B^+ \to K^+\ell^+\ell^-$)	0.044	[12]	0.025	0.017	0.007
R_{K^*} ($B^0 \to K^{*0}\ell^+\ell^-$)	0.12	[61]	0.034	0.022	0.009
$R(D^*)$ ($B^0 \to D^{*-}\ell^+\nu_\ell$)	0.026	[62, 64]	0.007	0.005	0.002

LHCb Upgrades

- Spectroscopy: large statistics to understand the nature of tetraquarks and pentaquarks.
  - For example, O(10M) $\Lambda_b^0 \rightarrow J/\psi p K^-$ for pentaquark studies, or O(1M) $\Lambda_b^0 \rightarrow \Lambda_c \bar{D}^{*0} K^-$ with open charm final states.
- Double-heavy tetraquarks: T_{cc}^+ $[cc\bar{u}\bar{d}]$ triggered huge interest. T_{bc} $[bc\bar{u}\bar{d}]$ could be observed during Run 3 but T_{bb} $[bb\bar{u}\bar{d}]$ observation requires Upgrade 2 statistics.
  - Large binding energy predicted for T_{bc} and T_{bb}, only weak decays possible: important input to understand exotic hadrons

PRL 122 (2019) 222001



$\Lambda_b^0 \rightarrow J/\psi p K^-$

Nature Comm. 13 (2022) 3351

Nature Physics 18 (2022) 751