Trends in Flavour Physics

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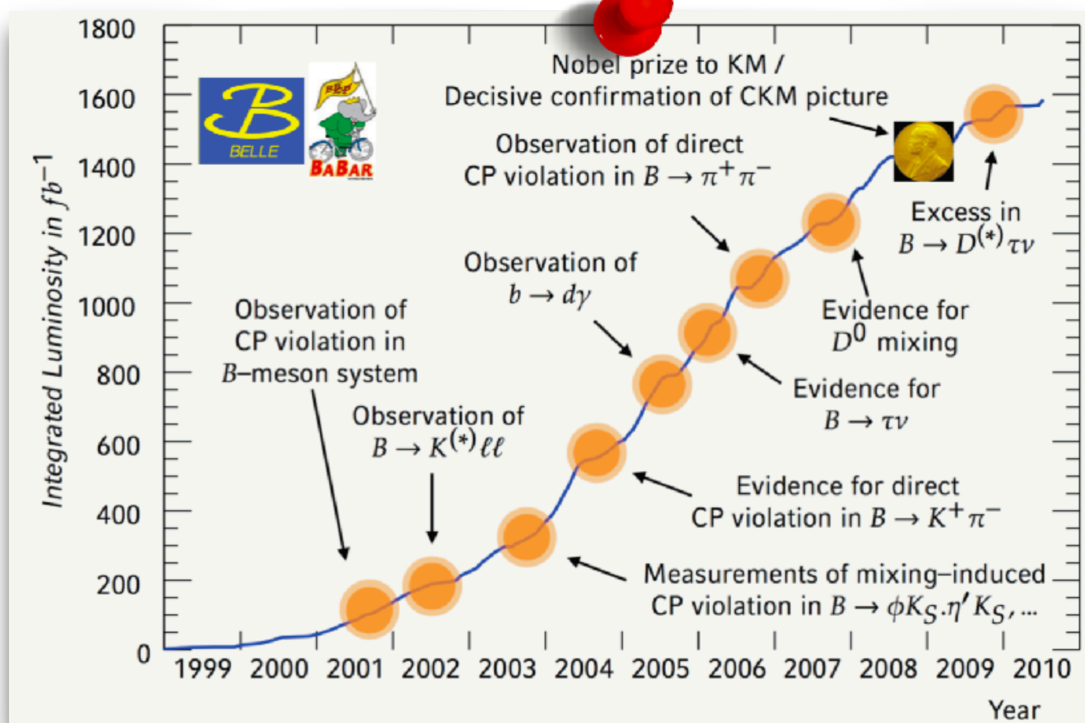


Prospectives DPhP

16 octobre 2017
Ferme du Manet

PREAMBLE

- ➡ Flavours physics used to be a strong asset of the DPhP
  - ✓ Kaon experiments: CPLEAR, NAxx and consorts
  - ✓ B-factory BaBar
- ➡ No physicists from the DPhP currently involved in any flavour (quarks and charged leptons) physics dedicated programs
- ➡ Thus, made a broad panorama of the field.

Overview

- ✓ Charged lepton flavour violation
- ✓ Muon anomalous g-2
- ✓ Flavour in Kaons
- ✓ **Heavy Flavours**

CHARGED LEPTON FLAVOUR VIOLATION

SM LFV due to neutrinos masses $\Longrightarrow \mathcal{B}(\mu \to X_{LFV}) \approx 10^{-54}$!

$\mu \to e\,\gamma$ @ MEG (PSI)

Best $\mathcal{B} < 4\ 10^{-13}$ (MEG)

MEG-II (2019-2021) 10^{-14}

$\mu \to eee$ @ Mu3e (PSI)

Best $\mathcal{B} < 4\ 10^{-12}$ (SINDRUM)

Phase 1 (2019) 10^{-15}

Phase 2 (?) 10^{-16}

$\mu\,N \to e\,N$

Best $R_{\mu e} < 7\ 10^{-13}$ (SINDRUM)

$\Longrightarrow$ aim at $R_{\mu e} < 10^{-17}$

Mu2e @ FNAL: (starts 2022)

COMET @ JPARC

- ✓ Phase 1 (starts 2019) 10^{-15}
- ✓ Phase 2 (?)

$\tau \to X_{LFV}$

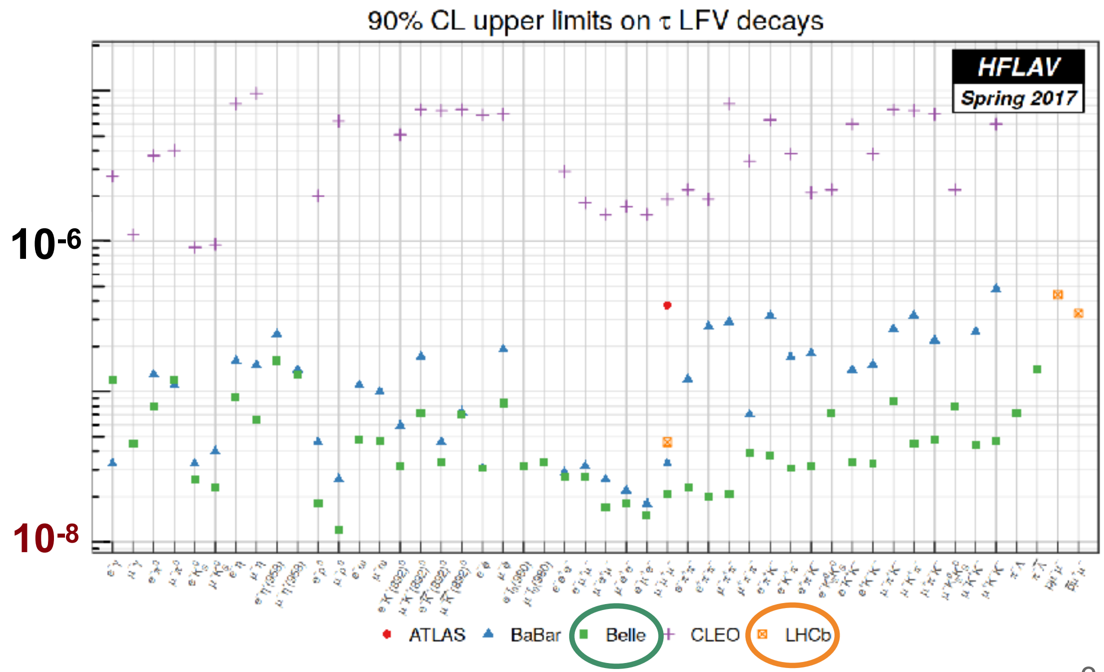
Colliders !

NP could couple more to third family (*i.e.* H^+ …)

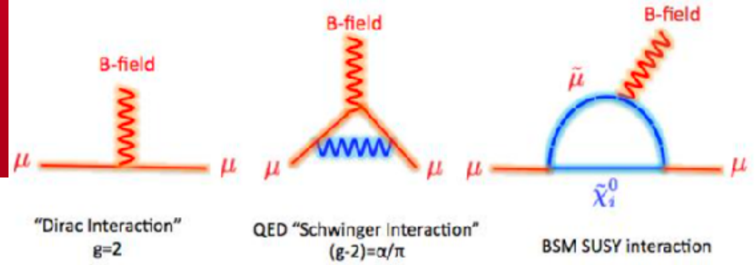
Current best limits $\mathcal{O}(10^{-8})$ B-factories!

Good prospects for Belle-II / ee colliders: $\mathcal{O}(10^{-10})$

LHC: mostly $\tau \to \mu\mu\mu$



MUON G-2



Muon anomalous Magnetic Dipole Moment : a 15 years saga!

$a_\mu^{E821} - a_\mu^{SM} = [\ 309 \pm (\ 63_{exp.} \oplus 42_{HVP} \oplus 39_{LbL} \oplus 1_{weak}\ )\ \times 10^{-11}$ ~ 3-4 σ discrepancy

⟹ **reduce δ_{exp} by 4 (δ_{exp} = 0.14 ppm)** 5-8 σ discrepancy! **Major milestone**

➡ E989 @ Fermilab

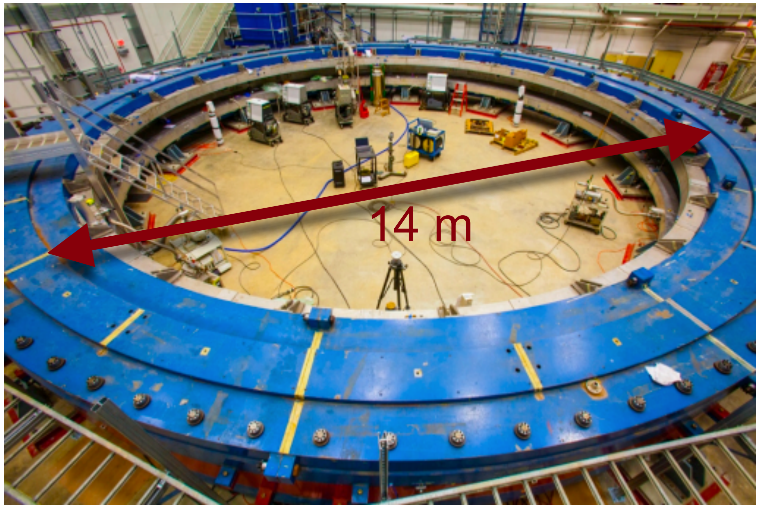
Same strategy as E821 with 20 times more statistics

First stored beam in May 2018!

First results by 2019 (δ = 0.50 ppm)

Final result 2020 : δ = 0.14 ppm

Fnal muon storage ring now operating



➡ J-PARC strategy

Use ultra-cold muons

⟹ higher and more homogenous B-field

Start 2020, proof of concept ⟹ δ = 0.50 ppm

Flavour changes in SM: W interaction and CKM matrix

Flavour physics goal

➡ Measure CKM parameters using tree level theoretically clean observables

Check unitarity!

➡ Measure SM loop-mediated processes

NP physics could have a sizeable contribution vs SM

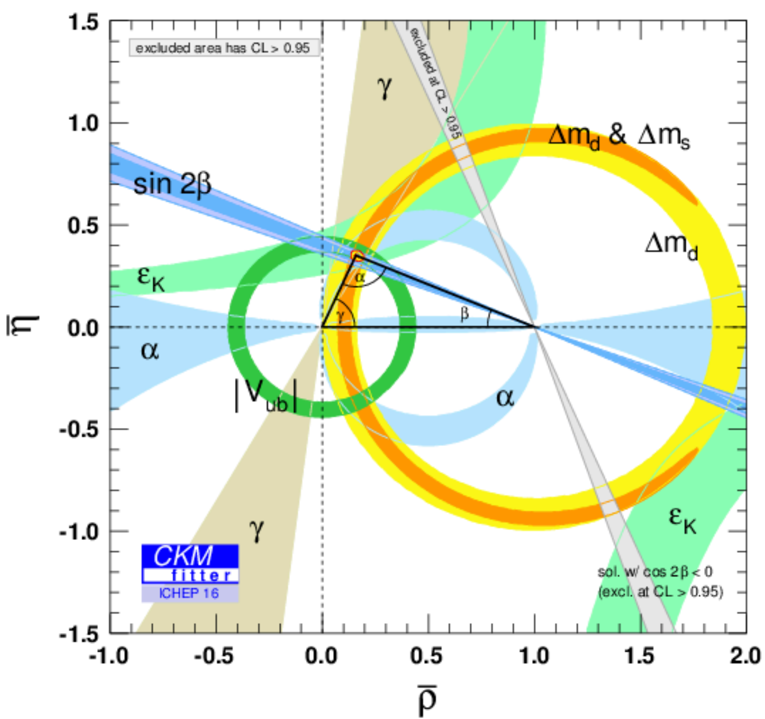
Can probe very high NP energy scale Λ

$$\mathcal{L}_{\mathrm{eff}} = \mathcal{L}_{\mathrm{SM}} + \frac{C_{\mathrm{NP}}}{\Lambda^2} O_{ij}^{(6)}$$

$$V_{\mathrm{CKM}} = \begin{pmatrix} V_{\mathrm{ud}} & V_{\mathrm{us}} & V_{\mathrm{ub}} \\ V_{\mathrm{cd}} & V_{\mathrm{cs}} & V_{\mathrm{cb}} \\ V_{\mathrm{td}} & V_{\mathrm{ts}} & V_{\mathrm{tb}} \end{pmatrix}$$

Unitary triangle (UT)

⊥ of 1st and 3rd columns of V_{CKM}



$$\frac{\epsilon'_K}{\epsilon_K}[theo] = (1.1 \pm 5.1) \times 10^{-4} \quad \text{vs} \quad \frac{\epsilon'_K}{\epsilon_K}[exp] = (16.6 \pm 2.3) \times 10^{-4}$$ 3 σ discrepancy

ε'/ε prediction difficult… but lattice progressing

Current hype K → π ν ν *with robust SM predictions*

(but several other interesting observables)

$K^+ \rightarrow \pi^+ \nu \nu$: $\mathcal{B}_{SM} = 8 \,.\, 10^{-11}$

NA62 (CERN) with 10% accuracy (2019?)

$K_L \rightarrow \pi^0 \nu \nu$: $\mathcal{B}_{SM} = 3 \,.\, 10^{-11}$

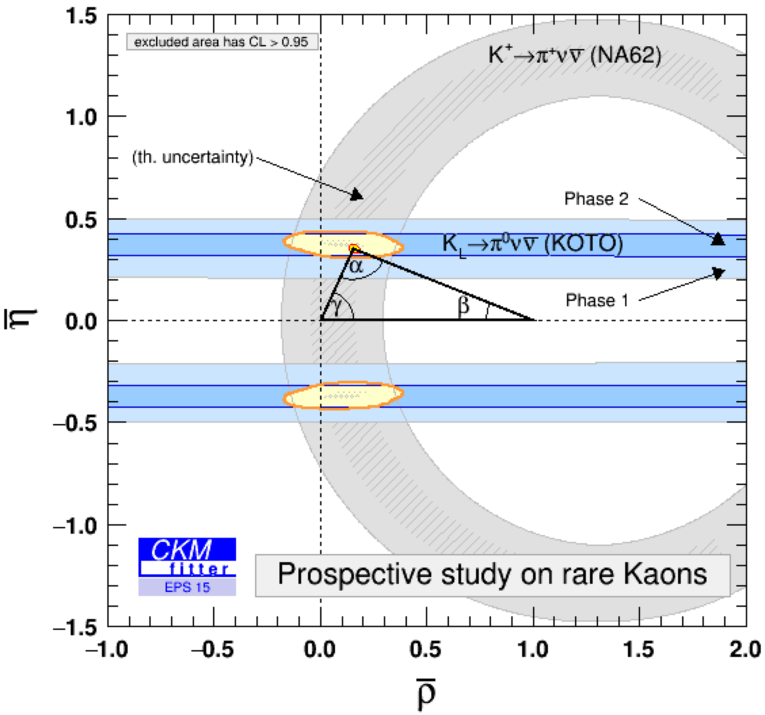
KOTO (J-PARC) with 10% accuracy (?)

Phase-1 (2021) aim for single event sensitivity ($\mathcal{B} < 10^{-10}$)

Phase-2 (after phase-1 :) 100kW J-PARC p beam

KLEVER (CERN)? 2026-2029, KOTO competitor.
Expression of Interest to SPSC (spring 2018)
Opportunity for the DPhP ?

KOTO / NA62 constrains



Heavy Flavour - Main Actors

- B-factories era over: Belle BaBar
- BESIII still taking data (charm physics)
  - ➡ potential High Intensity Electron Positron Accelator in China (HIEPA) to take over BEPCII
- The grown up: **LHCb**
- New kid on the block: **Belle-II**
  - ➡ Physics data-taking: 2019

Precision era! One example

Compare CP asymmetries

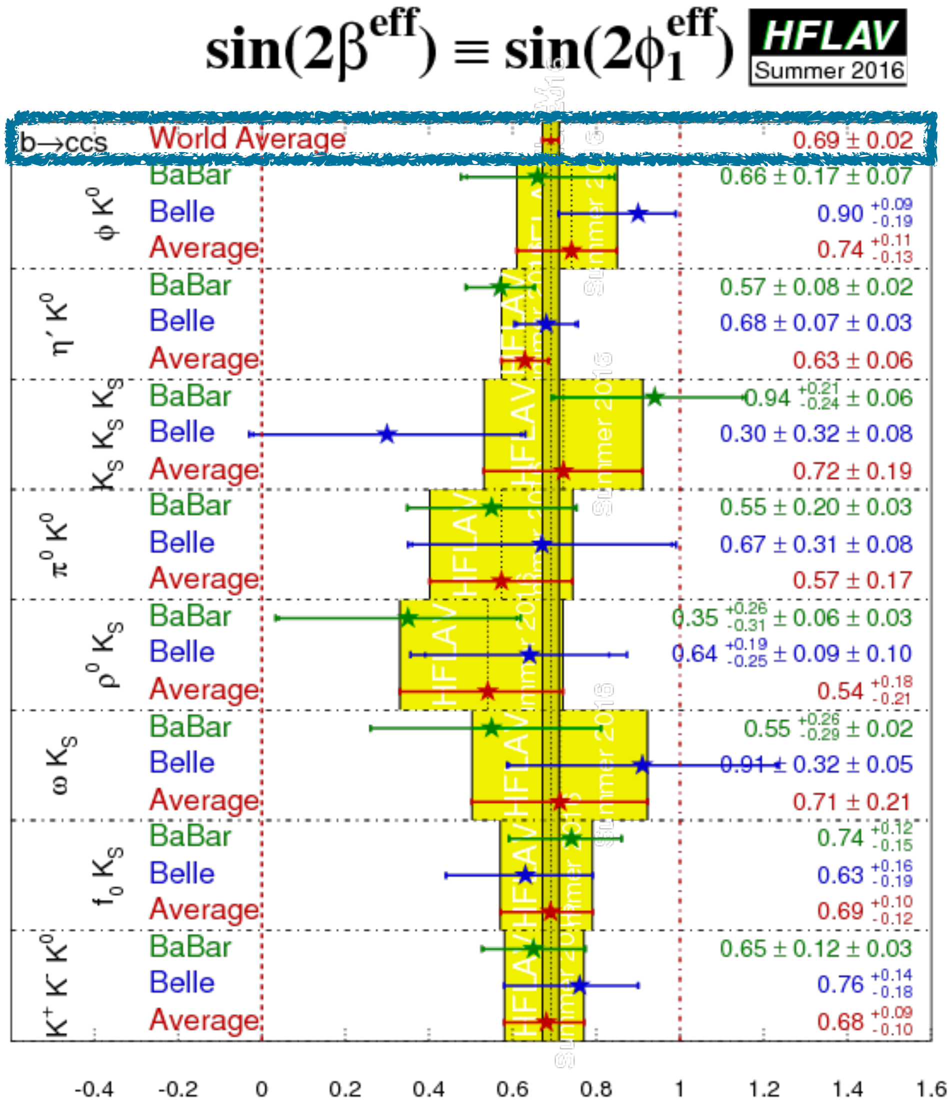
b→qqs b→ccs

loop-mediated vs tree level

⟹ **Probing NP**

Everything consistent but:

➡ Penguins limited by statistics
➡ Penguin modes tough for LHCb !
(fully hadronic or π^0)



Usually semi-leptonic decays used to measure V_{xx}

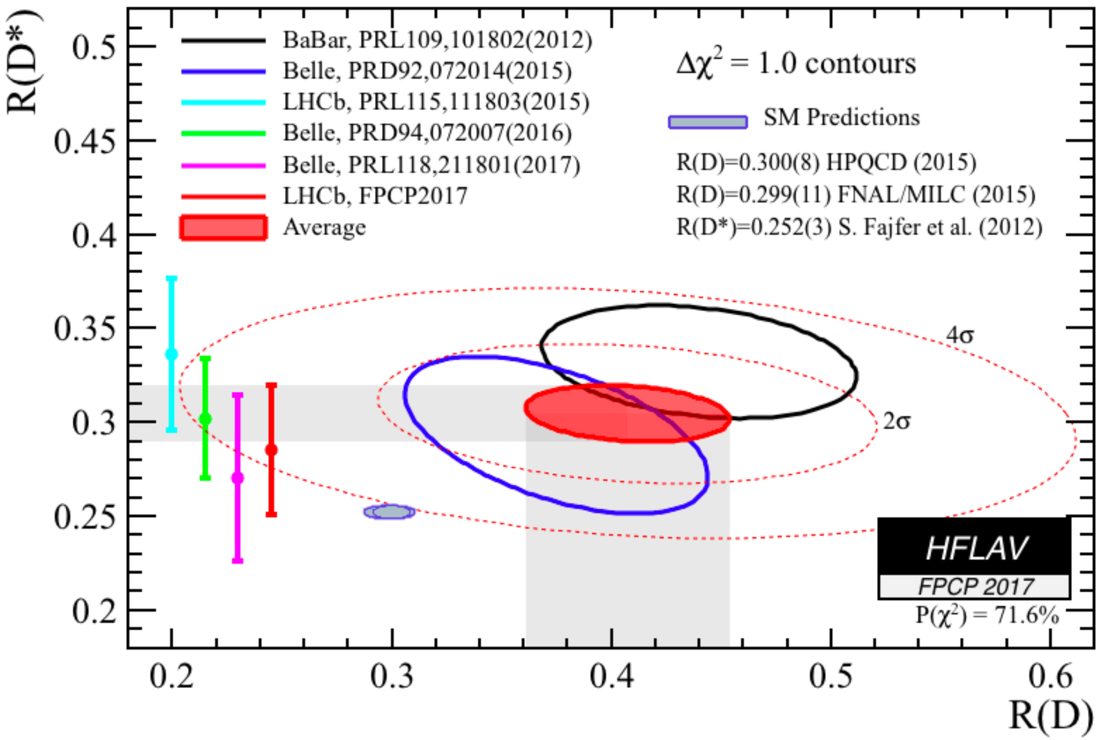
B semi tauonic decays disagree with muon/electron!

$$R(X) = \frac{\mathcal{B}(B \to X \tau \nu)}{\mathcal{B}(B \to X \ell \nu)}$$

About 4σ discrepancy!

➡ LHCb only R(D*)

$$H_{t0}^{2\mathrm{HDM}} = H_{t0}^{\mathrm{SM}} \times \left(1 - \frac{\tan^2\beta}{m_{H^\pm}^2} \frac{q^2}{1 \mp m_c^2/m_b^2}\right)$$

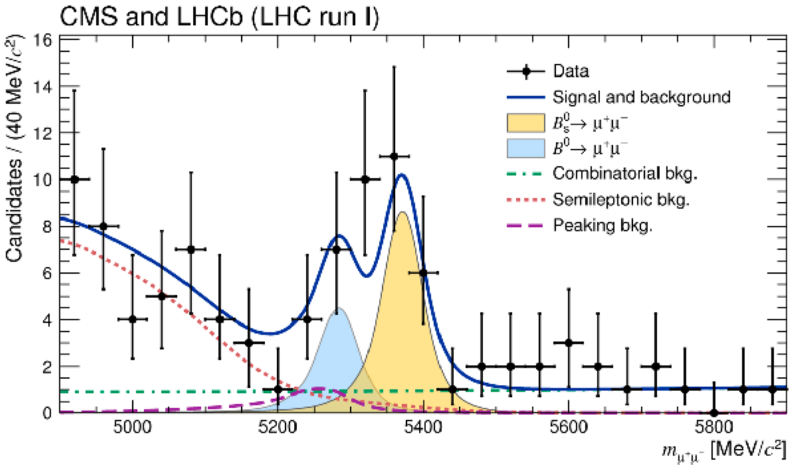


Precision era! Again look at loop induced processes

$B_{s/d} \rightarrow \mu^+\mu^-$ $\mathcal{B}_{SM} = 3.6\ 10^{-9}$

MSSM could give very large deviations

$\mathcal{B}_{CMS+LHCb} / \mathcal{B}_{SM} = 0.76 \pm 0.20$ ☹



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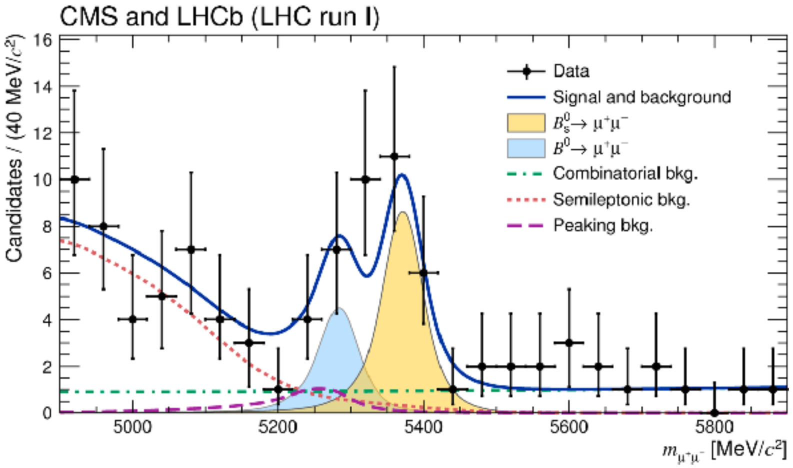


$b \rightarrow s\,\ell\ell$

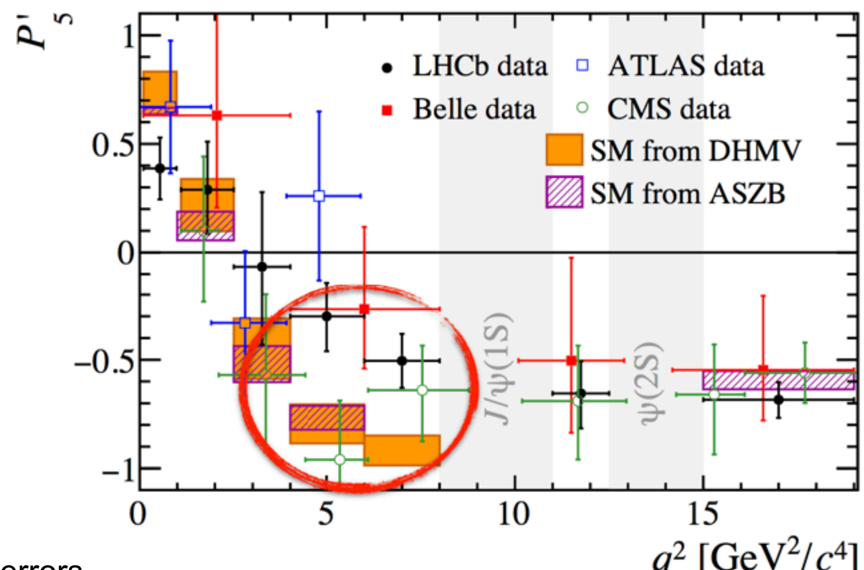
CP asymmetries in $B \rightarrow K^*\mu^+\mu^-$

LHCb data not in agreement with SM

Similar behaviour in several modes

NB: Still some debates on SM predictions

Sometimes there's more fun!

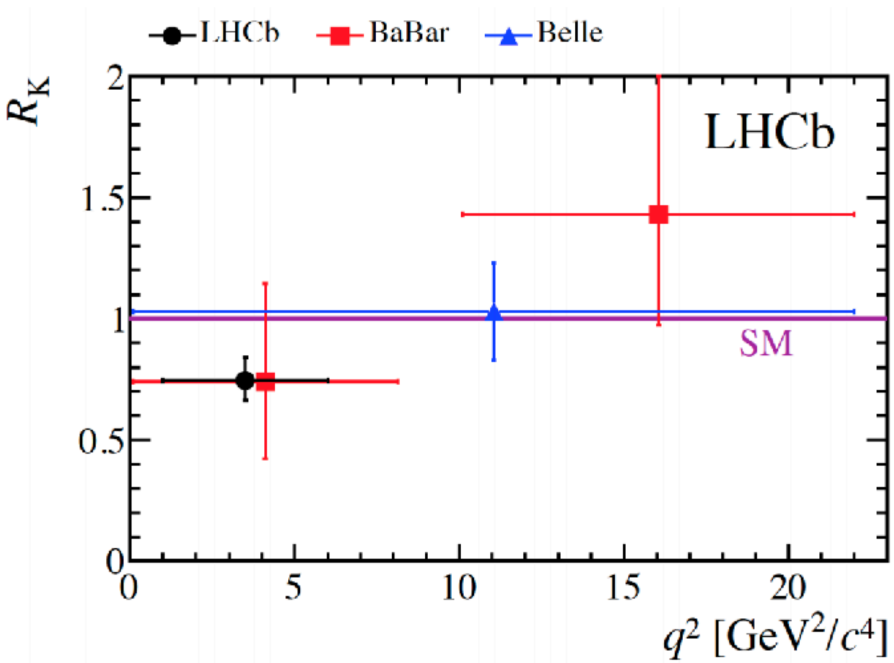


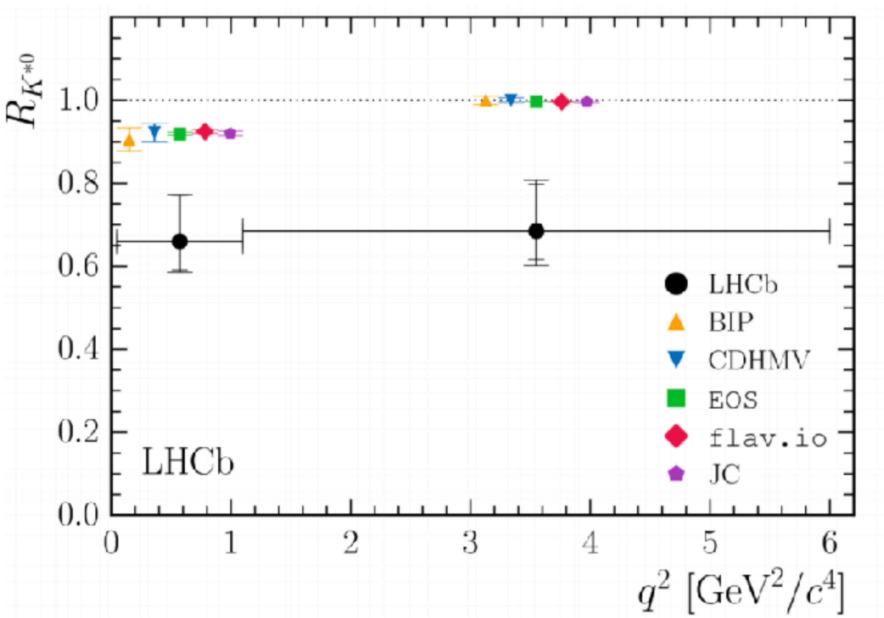
P5' combination of observables « immune » to form factor errors b → s ℓℓ Lepton Flavour Universality test

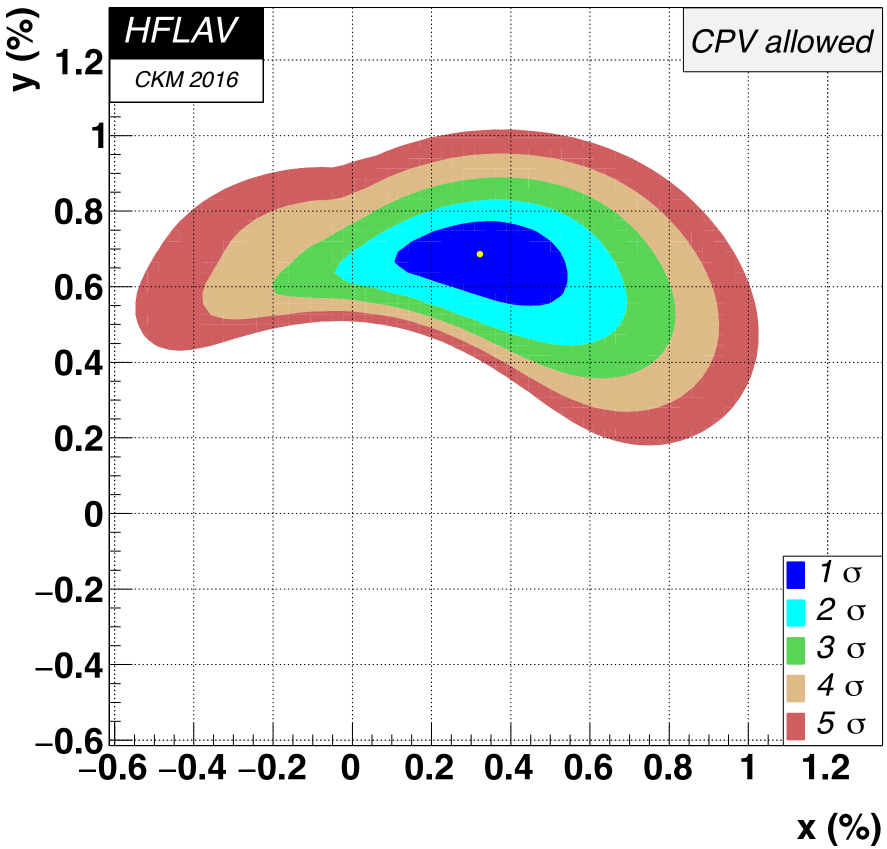
R[K(*)] = ℬ(B →K(*)μ+μ-)/ℬ(B →K(*)e+e-)

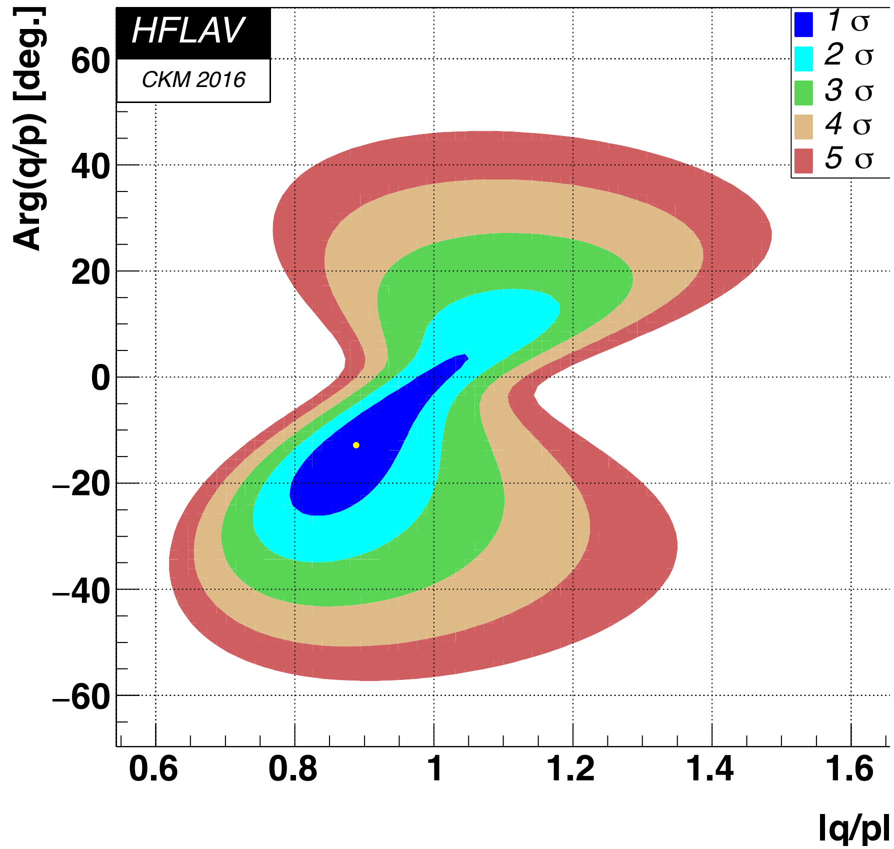
Another disagreement in LHCb data

⟹ Challenging LFU (2 σ level in both channels)







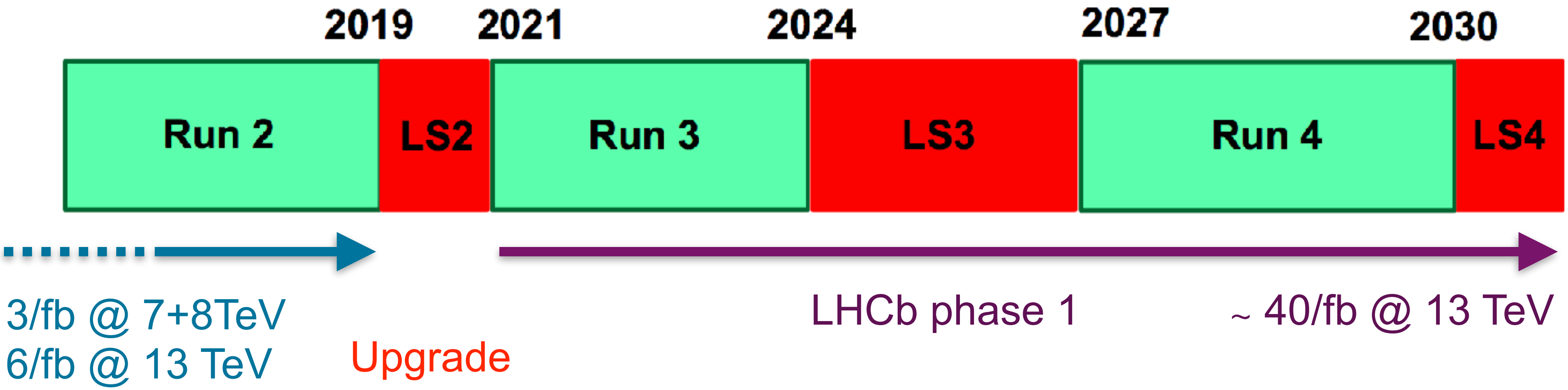


with LHCb run2

precision on x will be improved

CP violation likely to be not observed

LHCb & LHCb Upgrade

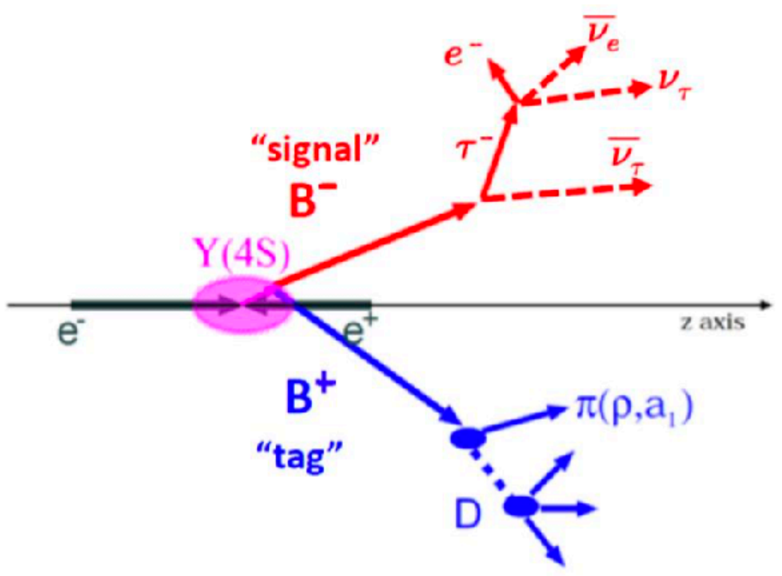


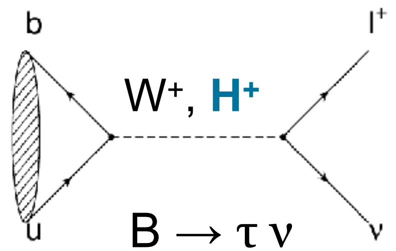
- Phase 1: *Full* software trigger $\Longrightarrow \mathcal{L} = 2 \times 10^{33}\ cm^{-2}\ s^{-1}$ ($\mathcal{L}_{2017} \times 5$)
  - ➡ Detector readout at 40MHz. (NB: 1MHz currently)
  - ➡ Redesign tracking system & upgrade RICHs (Particle ID)
  - ➡ Full hadronic mode trigger efficiency x 2 !
  - ➡ **With 50/fb, $\delta_{exp.} \sim \delta_{theo.}$** for many modes but

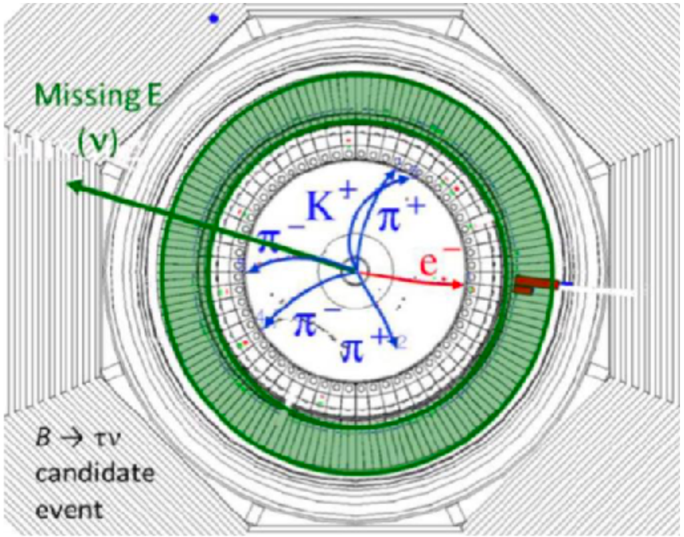
    more precision needed on B_s mixing and UT parameters
- Beyond 2030: Phase 2 $\Longrightarrow \mathcal{L} = 2 \times 10^{34}\ cm^{-2}\ s^{-1}$
  - ➡ Proposal well received by LHCC
  - ➡ Integrate up to 500/fb

LHCb tremendous statistics, yes… B-factories have advantages

➡ **B-beam.** Fully reconstruct a tag B (4-vector of recoil B). Inclusive decays (*e.g.* $b \to s\,\gamma$..), decays with neutrinos (*e.g.* $B \to \tau\,\nu$)







BELLE-II, WHY ?

LHCb tremendous statistics, yes… B-factories have advantages

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➡ Clean environment, no trigger issue (good eff. for fully hadronic modes)

➡ **Neutral particles identification**

- ✓ Photons / π^o: mostly impossible in LHCb
- ✓ Electrons: difficult for LHCb
- ✓ K_L : good efficiency in B-factories

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  - ✓ Photons / π^0: mostly impossible in LHCb
  - ✓ Electrons: difficult for LHCb
  - ✓ K_L : good efficiency in B-factories
- ➡ Coherent $B\bar{B}$ production: flavour tagging easier (increase statistical power!)
  - ✓ BaBar ε[FlavTag] ~ 31% [PRD 79 (2009) 072009]
  - ✓ LHCb ε[FlavTtag] ~ 3% [PRL 115 (2015) 031601]

Flavour Tagging: identification of the B flavour (B or Bbar) at t = 0 (before oscillations), mandatory for time asymmetries

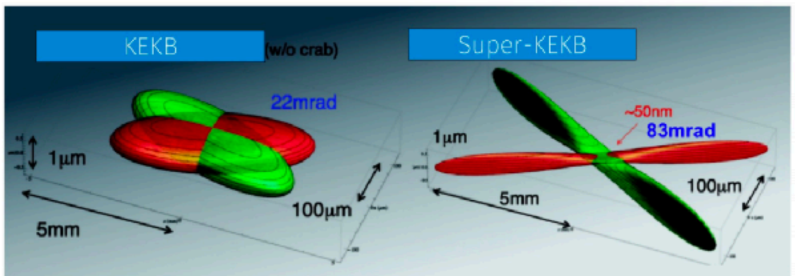
Super KEKB, How and When ?

Nano-beam structure

beam current

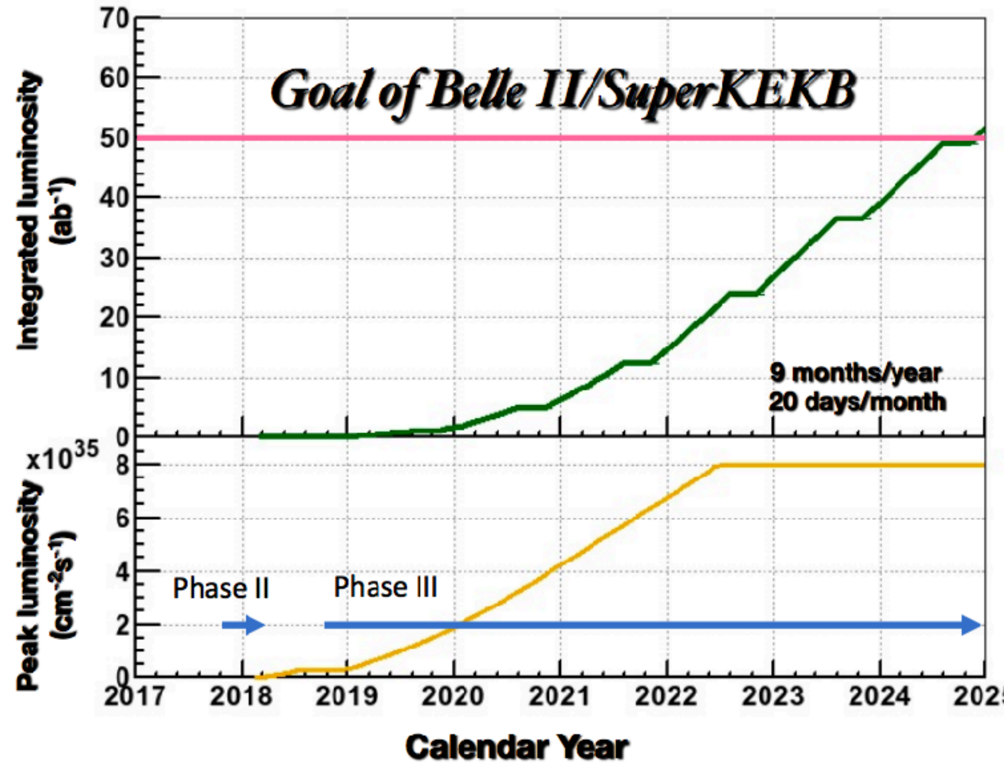
$$L=\frac{\gamma_\pm}{2er_e}\left(1+\frac{\sigma_y^*}{\sigma_x^*}\right)\frac{I_\pm\xi_{y\pm}}{\beta_{y\pm}}\frac{R_L}{R_{\xi_y}}$$

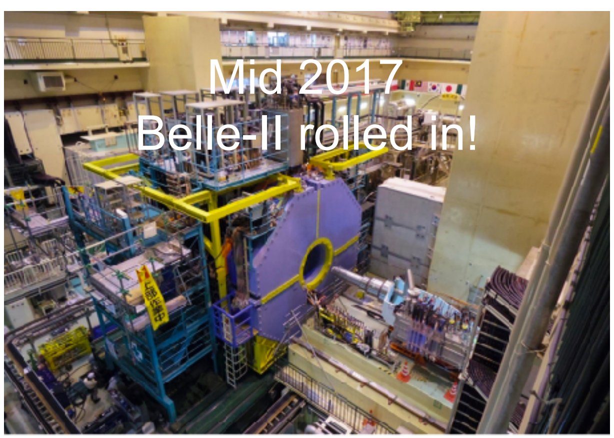
vertical beta function at IP



	E (GeV) LER/HER	β*y (mm) LER/HER	β*x (cm) LER/HER	φ (mrad)	I (A) LER/HER	L (cm⁻²s⁻¹)
KEKB	3.5/8.0	5.9/5.9	120/120	11	1.6/1.2	2.1×10^{34}
SuperKEKB	4.0/7.0	0.27/0.30	3.2/2.5	41.5	3.6/2.6	80×10^{34}

factor 20 factor 2-3





$\mathcal{L}_{SuperKEK} = 8 \times 10^{35}\ cm^{-2}\ s^{-1}$

$= 40 \times \mathcal{L}_{KEK}$

Belle-II 50/ab by 2025!

LHCb & Belle-II

Observables	Expected th. accuracy	Expected exp. uncertainty	Facility (2025)
UT angles & sides			
ϕ_1 [°]	***	0.4	Belle II
ϕ_2 [°]	**	1.0	Belle II
ϕ_3 [°]	***	1.0	Belle II/LHCb
$S(B_s \to J/\psi\phi)$	***	0.01	LHCb
$\|V_{cb}\|$ incl.	***	1%	Belle II
$\|V_{cb}\|$ excl.	***	1.5%	Belle II
$\|V_{ub}\|$ incl.	**	3%	Belle II
$\|V_{ub}\|$ excl.	**	2%	Belle II/LHCb
CPV			
$S(B \to \phi K^0)$	***	0.02	Belle II
$S(B \to \eta' K^0)$	***	0.01	Belle II
$\beta_s^{\rm eff}(B_s \to \phi\phi)$ [rad]	**	0.1	LHCb
$\beta_s^{\rm eff}(B_s \to K^{*0}\bar{K}^{*0})$ [rad]	**	0.1	LHCb
$A(B \to K^0\pi^0)[10^{-2}]$	***	4	Belle II
$A(B \to K^+\pi^-)$ $[10^{-2}]$	***	0.20	LHCb/Belle II
(Semi-)leptonic			
$\mathcal{B}(B \to \tau\nu)$ $[10^{-6}]$	**	3%	Belle II
$\mathcal{B}(B \to \mu\nu)$ $[10^{-6}]$	**	7%	Belle II
$R(B \to D\tau\nu)$	***	3%	Belle II
$R(B \to D^*\tau\nu)$	***	2%	Belle II/LHCb
Radiative & EW Penguins			
$\mathcal{B}(B \to X_s\gamma)$	**	4%	Belle II
$A_{CP}(B \to X_{s,d}\gamma)$ $[10^{-2}]$	***	0.005	Belle II
$S(B \to K_S^0\pi^0\gamma)$	***	0.03	Belle II
$2\beta_s^{\rm eff}(B_s \to \phi\gamma)$	***	0.05	LHCb
$S(B \to \rho\gamma)$	**	0.07	Belle II
$\mathcal{B}(B_s \to \gamma\gamma)$ $[10^{-6}]$	**	0.3	Belle II
$\mathcal{B}(B \to K^*\nu\bar{\nu})$ $[10^{-6}]$	***	15%	Belle II
$\mathcal{B}(B \to K\nu\bar{\nu})$ $[10^{-6}]$	***	20%	Belle II
$q_0^2 A_{\rm FB}(B \to K^*\mu\mu)$	**	0.05	LHCb/Belle II
$\mathcal{B}(B_s \to \tau\tau)$ $[10^{-3}]$	***	< 2	Belle II
$\mathcal{B}(B_s \to \mu\mu)$	***	10%	LHCb/Belle II
Charm			
$\mathcal{B}(D_s \to \mu\nu)$	***	0.9%	Belle II
$\mathcal{B}(D_s \to \tau\nu)$	***	2%	Belle II
$\Delta A_{CP}(D^0 \to K^+K^-)$ $[10^{-4}]$	**	0.1	LHCb
$A_{CP}(D^0 \to K_S^0\pi^0)$ $[10^{-2}]$	**	0.03	Belle II
$\|q/p\|(D^0 \to K_S^0\pi^+\pi^-)$	***	0.03	Belle Ii
$\phi(D^0 \to K_S^0\pi^+\pi^-)$ [°]	***	4	Belle II
Tau			
$\tau \to \mu\gamma$ $[10^{-9}]$	***	< 5	Belle II
$\tau \to e\gamma$ $[10^{-9}]$	***	< 10	Belle II
$\tau \to \mu\mu\mu$ $[10^{-9}]$	***	< 0.3	Belle II/LHCb

Belle-II Theory Interface Platform (B2TIP)

Certainly biased but take home message

Belle-II

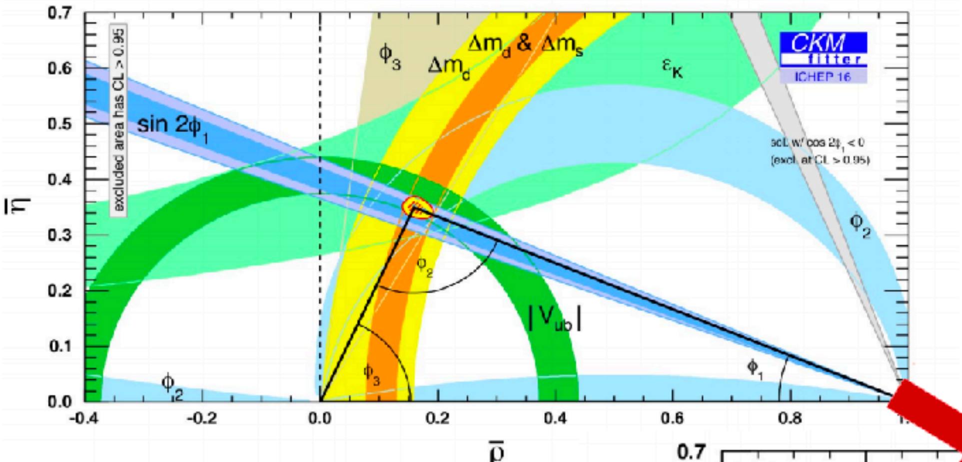
- ✓ modes with neutrinos / taus
- ✓ UT ultimate precision
- ✓ LFV in tau decay

LHCb

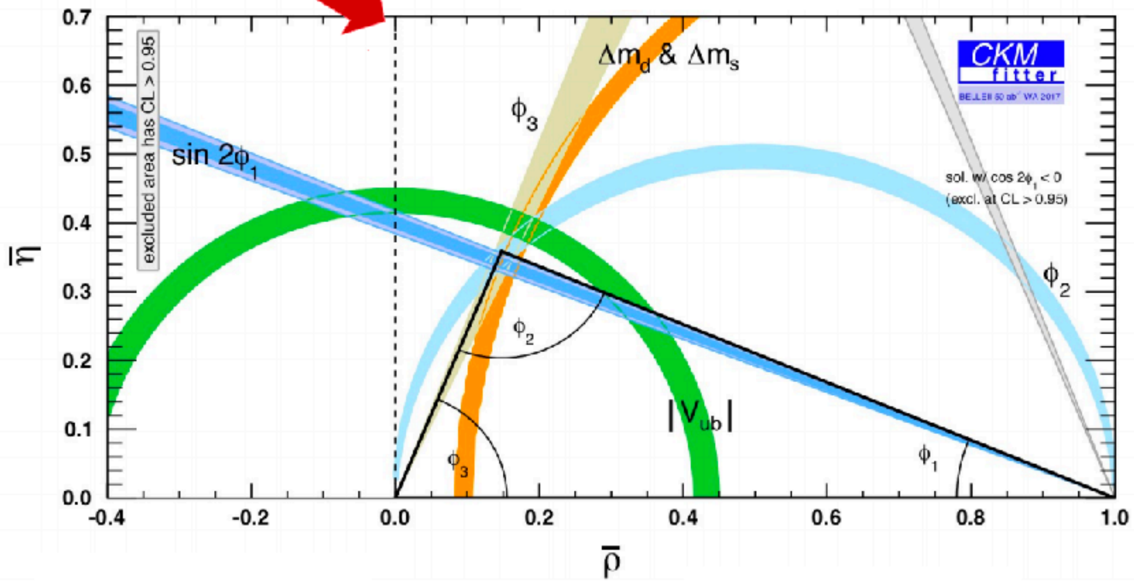
- ✓ B_s sector
- ✓ b-hadron physics

Belle-II a **very** good opportunity for the DPhP?

Enhanced precision of UT parameters (sides, angles)

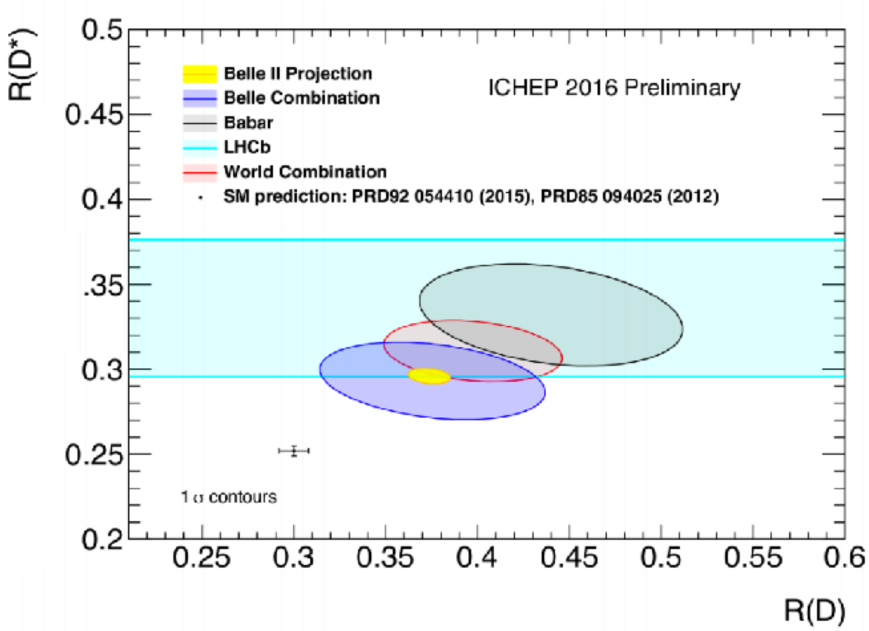


UT angles with ~ 1% uncertainity for 50 ab^{-1}

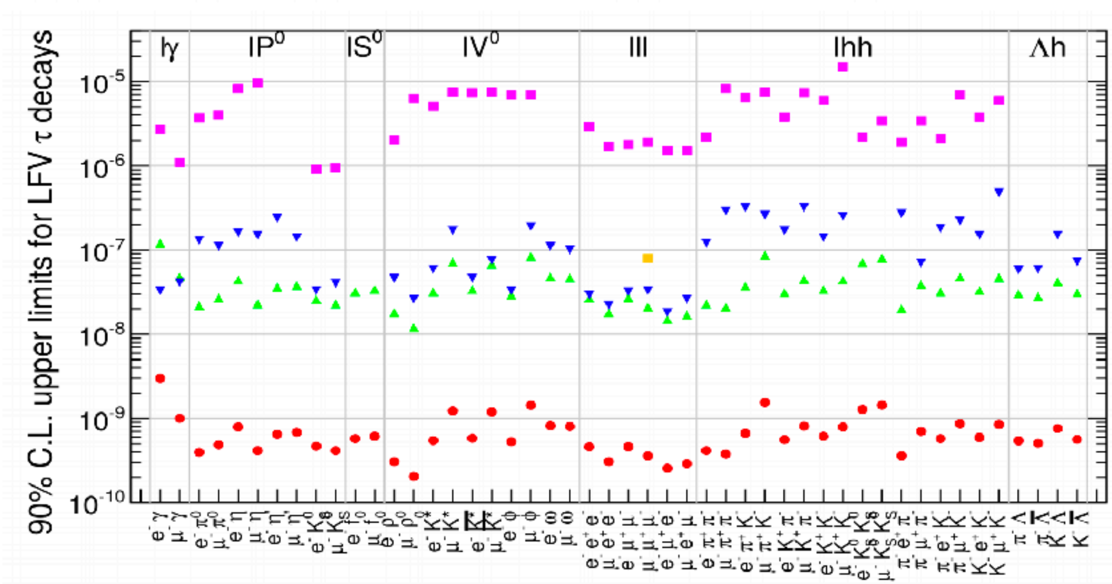


Inconsistency between angles or/and sites → New Physics

BELLE-II PROSPECTS (2)



R(D) / R(D*) close the issue
3 % precision

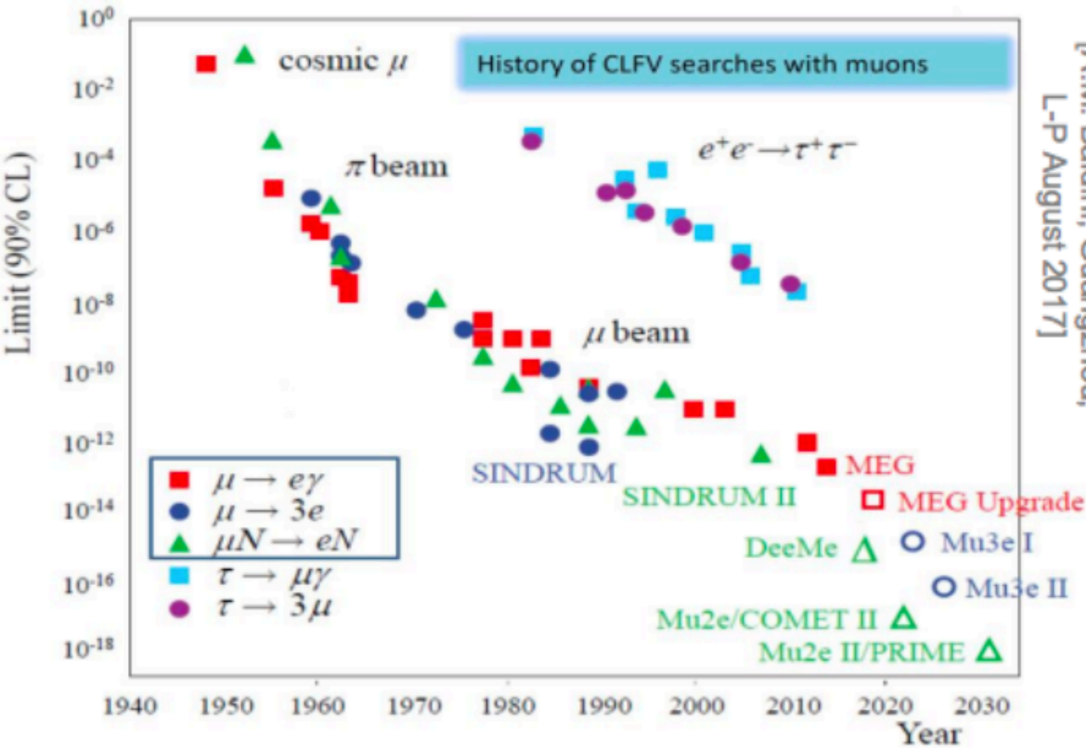


τ lepton LFV
Gain 1-2 orders of magnitude in sensitivity

Conclusions

- A very broad physics program, only scratch the surface
  - ✓ Top quark: a flavour laboratory by itself (CMS, Atlas)
  - ✓ Future ee colliders: tremendous samples of $Z \rightarrow bb/cc/\tau\tau$ (+LFV)
  - ✓ Neutrinos (see Sandrine and Mathieu reports)
- A Win-win situation
  - ✓ No NP at LHC: constrain much higher scale with flavour
  - ✓ NP at LHC: fundamental to get the overall NP structure
- DPhP stopped flavour physics! Want to revive the field ?
  - ✓ Kaons: KLEVER interesting?
  - ✓ Heavy flavours physics (guaranteed rich physics output)
    - ➡ LHCb is doing superb physics (upgrade 2030?)
    - ➡ **Belle-II** a ***really great*** opportunity for the lab… but this is now

Can an important lab as the DPhP be absent from such a physics program?



[A.M. Baldini, Guangzhou, L-P August 2017]

G-2

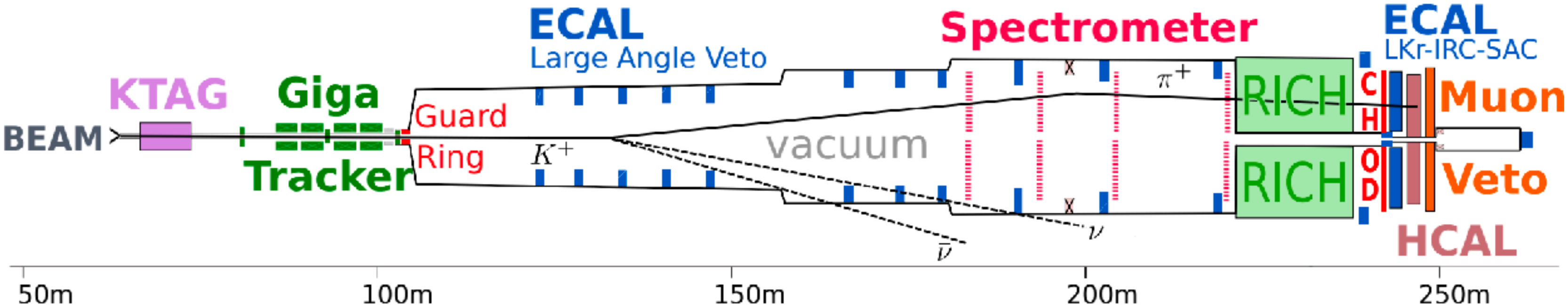
$$\vec{\omega}_a = \vec{\omega}_S - \vec{\omega}_C = \vec{\omega}_a = -\frac{Q}{m}\left[a_\mu \vec{B} - \left(a_\mu - \frac{1}{\gamma^2 - 1}\right)\frac{\vec{\beta}\times\vec{E}}{c}\right]$$

Fnal: p_μ = 3.014GeV ⟹ γ = 29.3 cancelling the 2d term
J-PARC: p_μ = 0 ⟹ no need for focussing E , E=0!

Contribution	$a_\mu \times 10^{11}$	Reference
QED (leptons)	116 584 718.853 ± 0.036	Aoyama et al. '12
Electroweak	153.6 ± 1.0	Gnendiger et al. '13
HVP: LO	6889.1 ± 35.2	Jegerlehner '15
NLO	-99.2 ± 1.0	Jegerlehner '15
NNLO	12.4 ± 0.1	Kurz et al. '14
HLbL	102 ± 39	Jegerlehner '15 (JN '09)
NLO	3 ± 2	Colangelo et al. '14
Theory (SM)	116 591 780 ± 53	
Experiment	116 592 089 ± 63	Bennett et al. '06
Experiment - Theory	309 ± 82	3.8 σ

Mathieu Perrin-Terrin

NA62 Apparatus



Decay Products Instrumentation

- Kinematics (Spectrometer)
- Photon Detection (ECAL)
- π and μ identification (RICH, HCAL and, Muon Veto)
- Arrival time measurement (all + CHOD for charged particles)

$K_L^0 \to \pi^0 \nu \bar{\nu}$ - KOTO

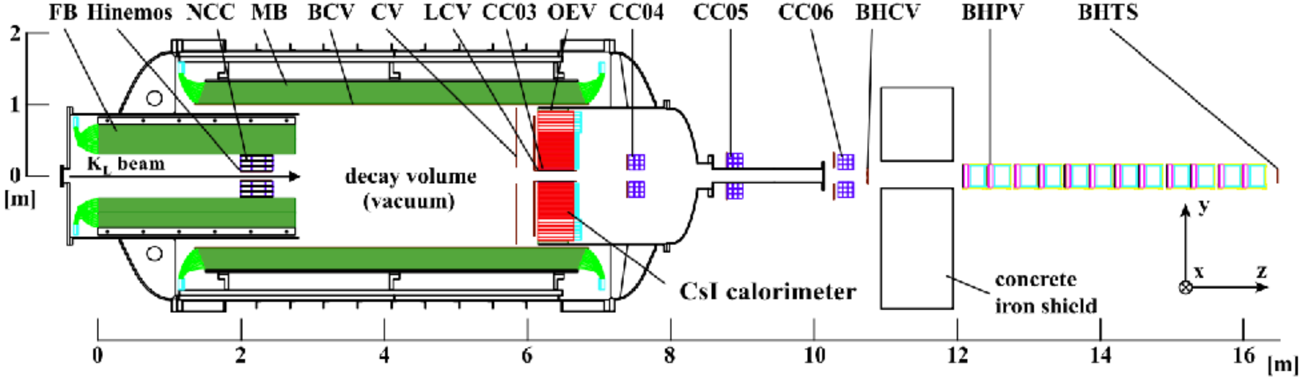
Mathieu Perrin-Terrin

Goal and Time Line

- **E391a** ran in 2004/5: $\mathcal{B}(K_L^0 \to \pi^0 \nu \bar{\nu}) < 2600 \times 10^{-11}$ [PR D81,072004 (2010)]
- **Upgrade**: KOTO aiming at reaching SM single-event-sensitivity
- **KOTO** commissioned in 2013 and taking data (see next)

Experiment

- Low energy beam: 1.2GeV/c
- **Signal Signature**: 2γ and no other particle
- EM calorimeter to catch π^0 and vetoes surrounding decay region



Mathieu Perrin-Terrin

$K^+ \to \pi^+ \nu \bar{\nu}$ Analysis Strategy

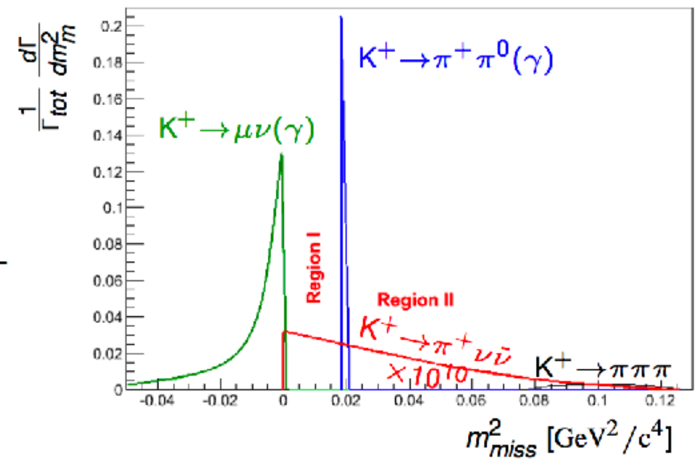
Background Sources

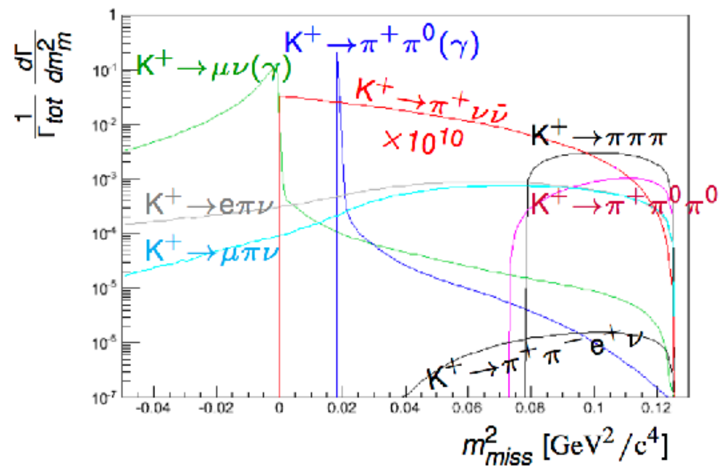
- K^+decay incorrectly reconstructed
- Particle accidentally in time with a K^+

Analysis

- Main variable $m^2_{miss} = |p_K - p_\pi|^2$
- Look for signal in regions I and II
- $p_\pi \in [15, 35]$ GeV/c (RICH, kinematics, γ rejection, accidental from $\pi^+ \to \mu^+ \nu$)
- Background suppression needed:

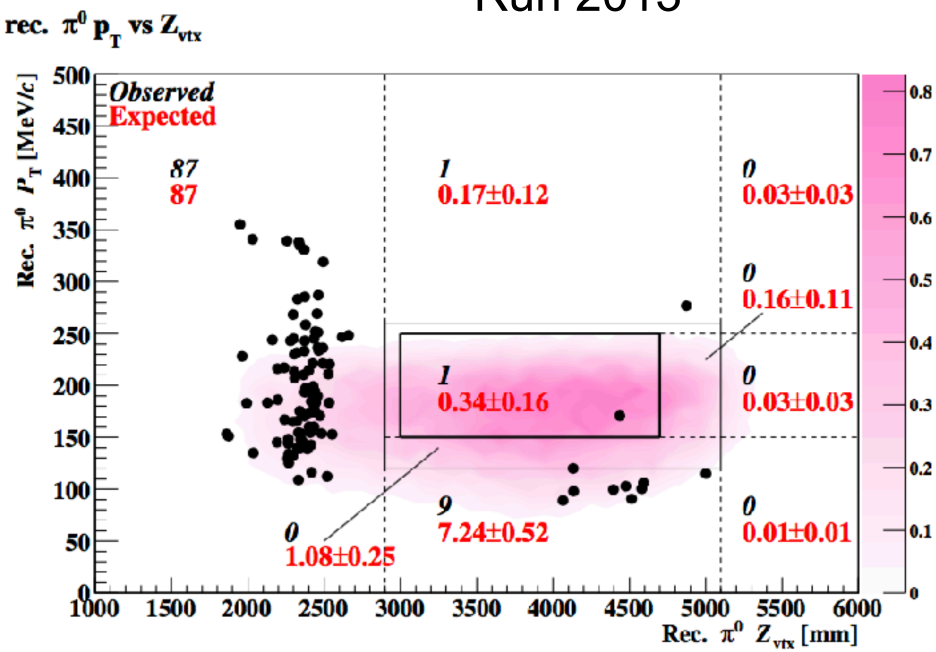
Kinematics	10^{-4}	Charged PID	10^{-7}
π^0's γ Rejection	10^{-8}	Timing	10^{-2}





KOTO Results

Run 2013

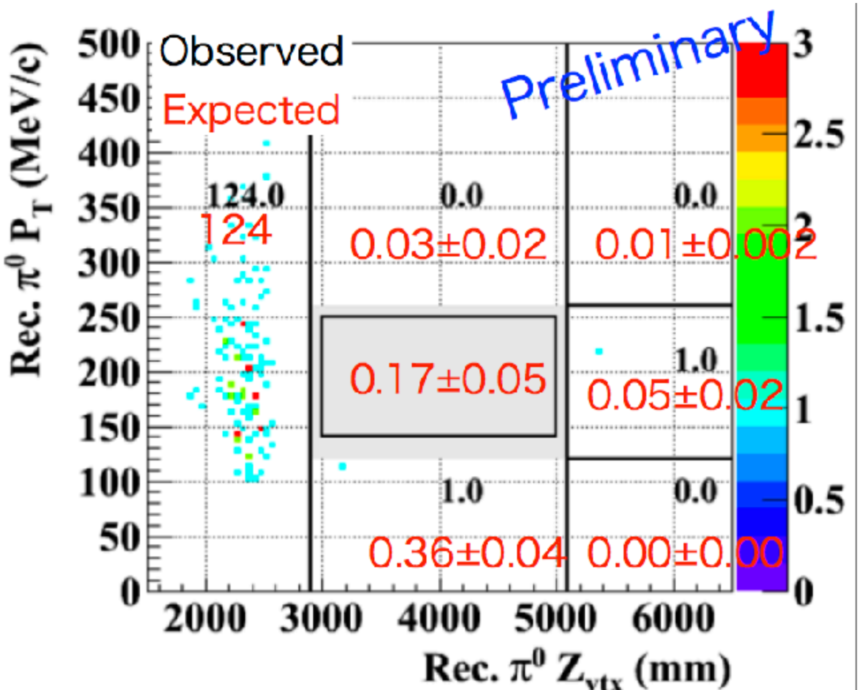


arXiv:1609.03637

$\beta < 5.\ 10^{-8}$

SES: $6\ 10^{-9}$

Run 2015



Production Target

50 kW target
- April, 2015 -
- Indirect cooling
- Currently working

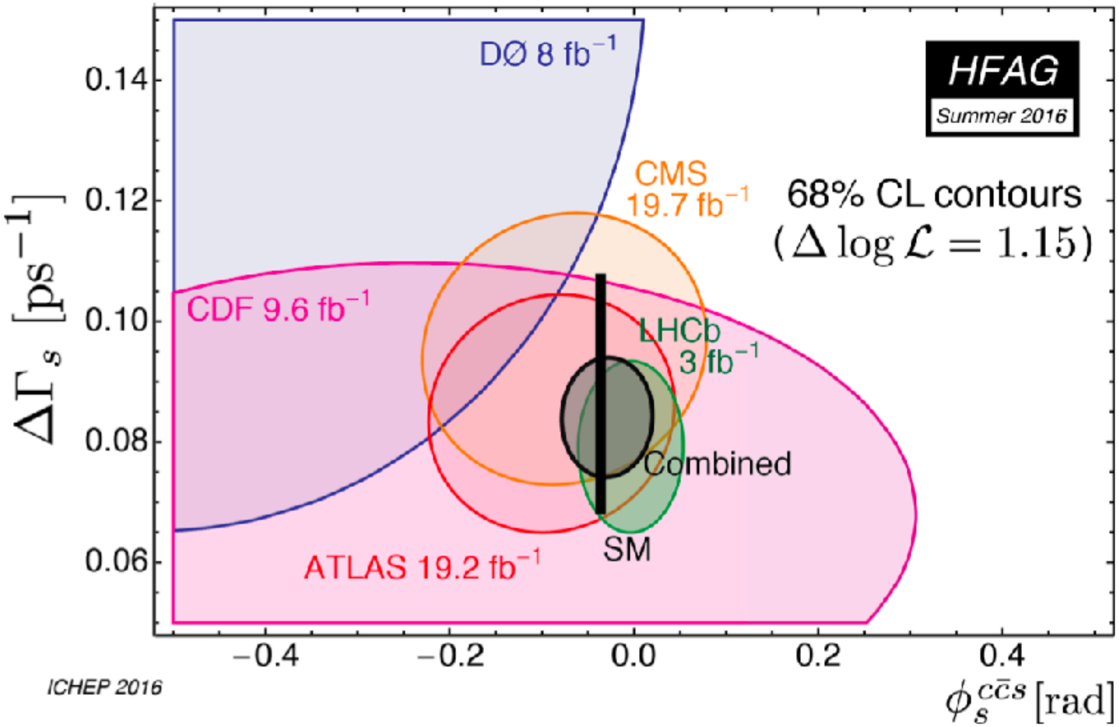
80 kW target
- Fall, 2017 or 2018 -
- Indirect cooling
- Ready to manufacture

>100 kW target
- Around 2020/2021 -
- Direct cooling
- Under R&D

Shin'ya Sawada,
International workshop on progress on J-Parc 2016

Guy Wilkinson, IPPP Flavour

CPV in B_s mixing-decay interference: φ_s



Another theoretically clean observable, which must be measured as well as possible. LHCb uncertainty will halve in run 2. Will need still higher precision to reach regime of real interest, and to probe for deviations from SM expectation.

T Head, 2014 JINST 9 C09015

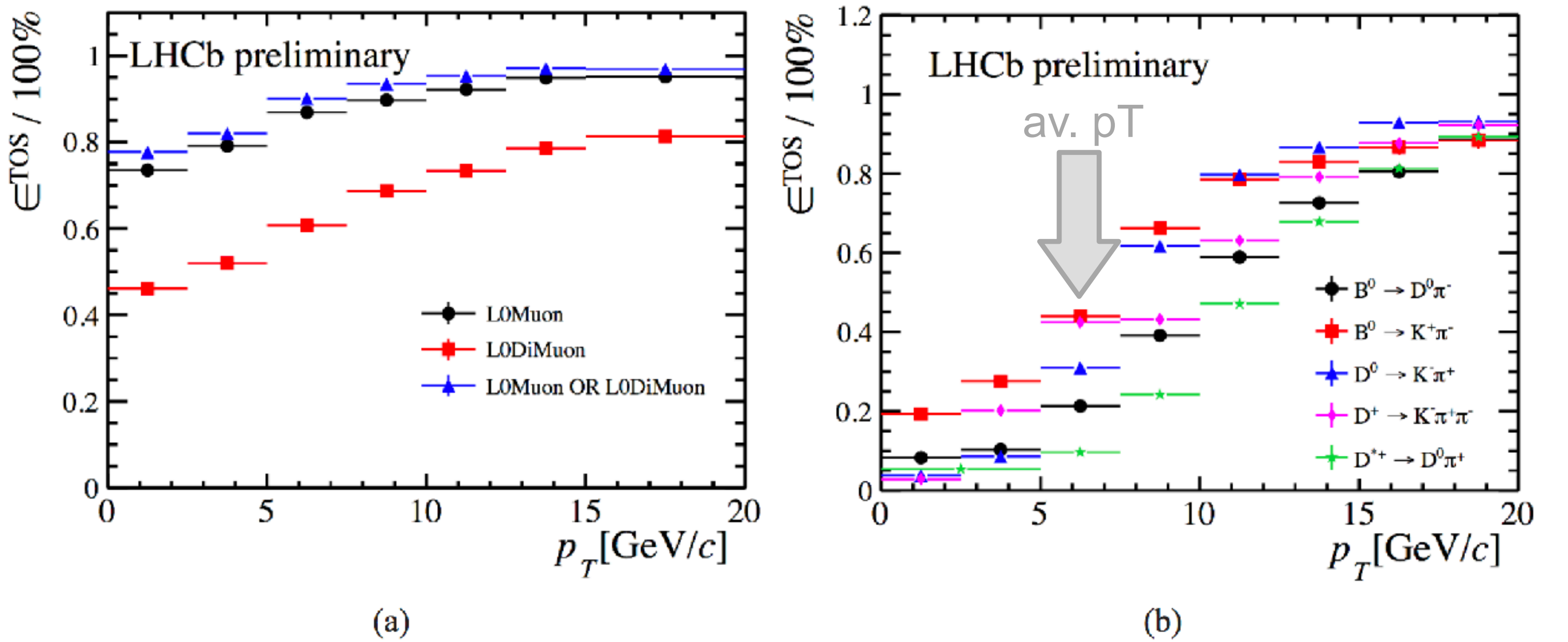


Figure 2: L0 efficiencies for data taken during 2012 of (a) L0 muon requirements for $B^\pm \to J/\psi(\to \mu^+\mu^-)K^\pm$ and (b) L0 hadron requirements for several fully hadronic decay modes as a function of the parent p_T.

Upgrade: Hadronic mode efficiency x 2!

LHCb UPGRADE EXPECTATIONS

Type	Observable	Current precision	LHCb 2018	**Upgrade** ($50\,\mathrm{fb}^{-1}$)	Theory uncertainty
B_s^0 mixing	$2\beta_s\ (B_s^0 \to J/\psi\ \phi)$	0.10 [138]	0.025	0.008	~ 0.003
	$2\beta_s\ (B_s^0 \to J/\psi\ f_0(980))$	0.17 [214]	0.045	0.014	~ 0.01
	a_{sl}^s	6.4×10^{-3} [43]	0.6×10^{-3}	0.2×10^{-3}	0.03×10^{-3}
Gluonic penguins	$2\beta_s^{\mathrm{eff}}(B_s^0 \to \phi\phi)$	–	0.17	0.03	0.02
	$2\beta_s^{\mathrm{eff}}(B_s^0 \to K^{*0}\bar{K}^{*0})$	–	0.13	0.02	< 0.02
	$2\beta^{\mathrm{eff}}(B^0 \to \phi K_S^0)$	0.17 [43]	0.30	0.05	0.02
Right-handed currents	$2\beta_s^{\mathrm{eff}}(B_s^0 \to \phi\gamma)$	–	0.09	0.02	< 0.01
	$\tau^{\mathrm{eff}}(B_s^0 \to \phi\gamma)/\tau_{B_s^0}$	–	5 %	1 %	0.2 %
Electroweak penguins	$S_3(B^0 \to K^{*0}\mu^+\mu^-; 1 < q^2 < 6\,\mathrm{GeV}^2/c^4)$	0.08 [67]	0.025	0.008	0.02
	$s_0\ A_{\mathrm{FB}}(B^0 \to K^{*0}\mu^+\mu^-)$	25 % [67]	6 %	2 %	7 %
	$A_{\mathrm{I}}(K\mu^+\mu^-; 1 < q^2 < 6\,\mathrm{GeV}^2/c^4)$	0.25 [76]	0.08	0.025	~ 0.02
	$\mathcal{B}(B^+ \to \pi^+\mu^+\mu^-)/\mathcal{B}(B^+ \to K^+\mu^+\mu^-)$	25 % [85]	8 %	2.5 %	$\sim 10\,\%$
Higgs penguins	$\mathcal{B}(B_s^0 \to \mu^+\mu^-)$	1.5×10^{-9} [13]	0.5×10^{-9}	0.15×10^{-9}	0.3×10^{-9}
	$\mathcal{B}(B^0 \to \mu^+\mu^-)/\mathcal{B}(B_s^0 \to \mu^+\mu^-)$	–	$\sim 100\,\%$	$\sim 35\,\%$	$\sim 5\,\%$
Unitarity triangle angles	$\gamma\ (B \to D^{(*)}K^{(*)})$	~ 10–12° [244, 258]	4°	0.9°	negligible
	$\gamma\ (B_s^0 \to D_s K)$	–	11°	2.0°	negligible
	$\beta\ (B^0 \to J/\psi\ K_S^0)$	0.8° [43]	0.6°	0.2°	negligible
Charm *CP* violation	A_Γ	2.3×10^{-3} [43]	0.40×10^{-3}	0.07×10^{-3}	–
	$\Delta\mathcal{A}_{CP}$	2.1×10^{-3} [18]	0.65×10^{-3}	0.12×10^{-3}	–

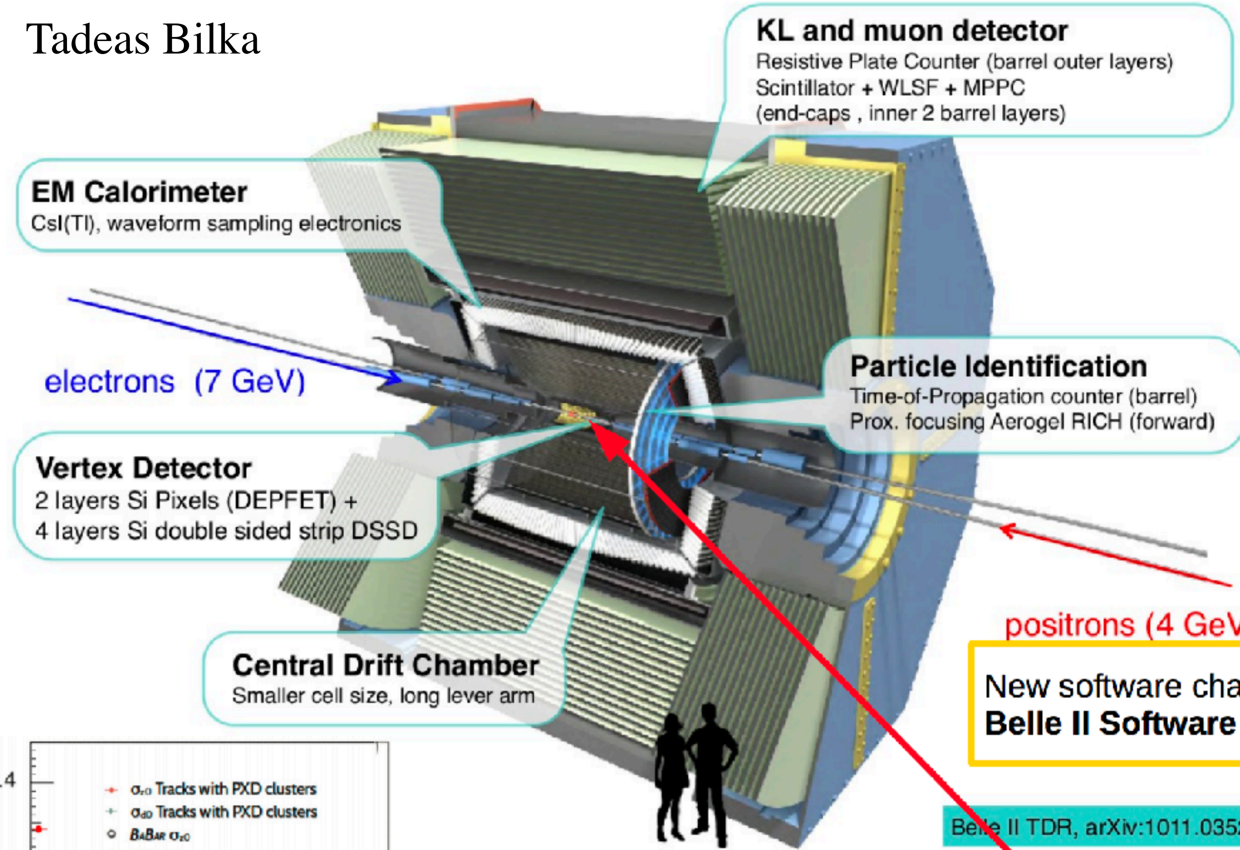
B SAMPLES

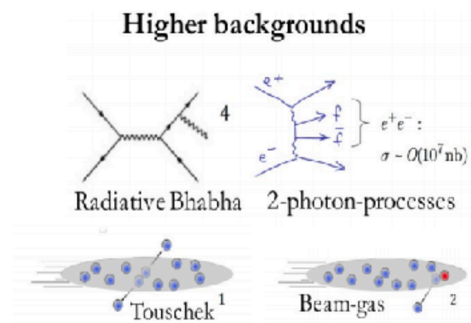
σ(b - LHCb) = 230 μb   L = 50/fb

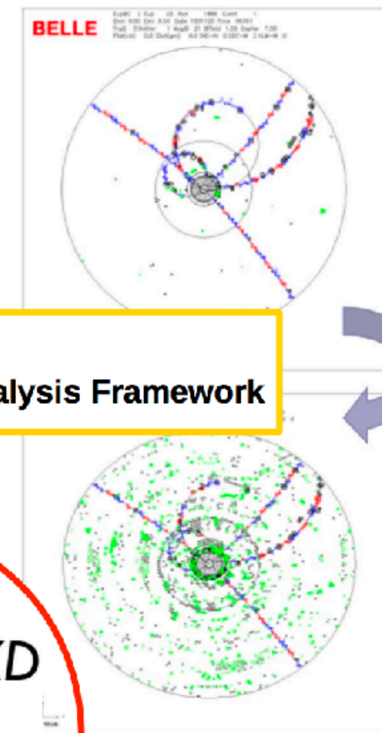
σ(BB Y(4S)) =   1 nb   L = 50/ab

BELLE-II DETECTOR

Tadeas Bilka

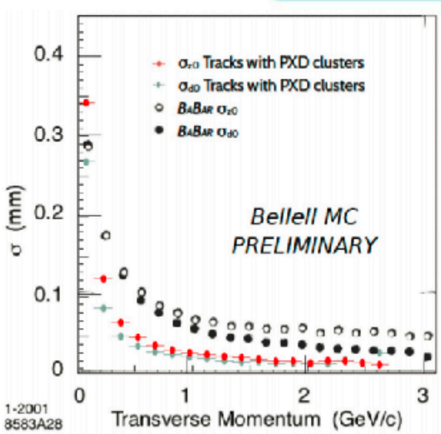


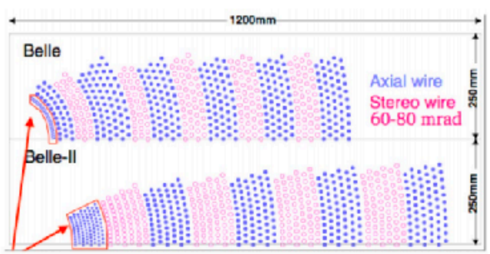


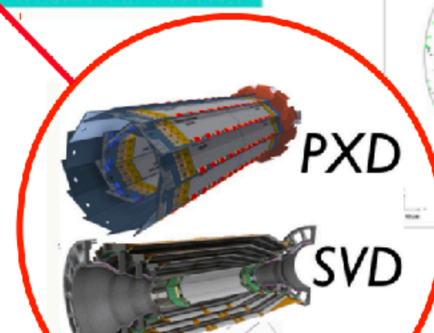


New software challenges:
Belle II Software and Analysis Framework

Belle II TDR, arXiv:1011.0352





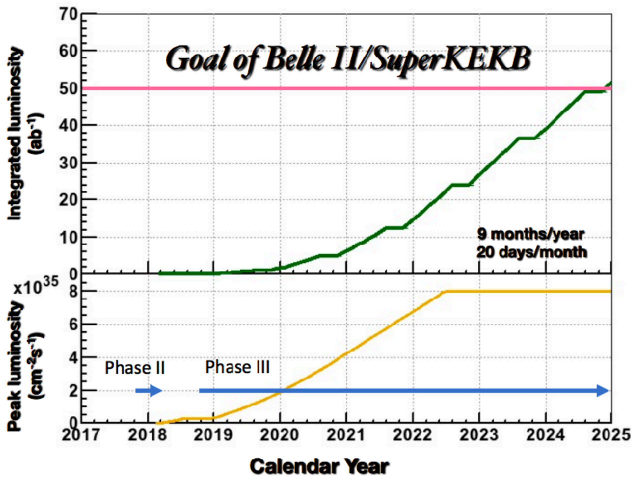


6

SUPER KEKB & BELLE-II

parameters		KEKB		SuperKEKB		units
		LER	HER	LER	HER	
Beam energy	E_b	3.5	8	4	7	GeV
Half crossing angle	ϕ	11		41.5		mrad
Horizontal emittance	ε_x	18	24	3.2	4.6	nm
Emittance ratio	κ	0.88	0.66	0.37	0.40	%
Beta functions at IP	β_x^*/β_y^*	1200/5.9		32/0.27	25/0.30	mm
Beam currents	I_b	1.64	1.19	3.60	2.60	A
beam-beam parameter	ξ_y	0.129	0.090	0.0881	0.0807	
Luminosity	L	2.1×10^{34}		8×10^{35}		$cm^{-2}s^{-1}$

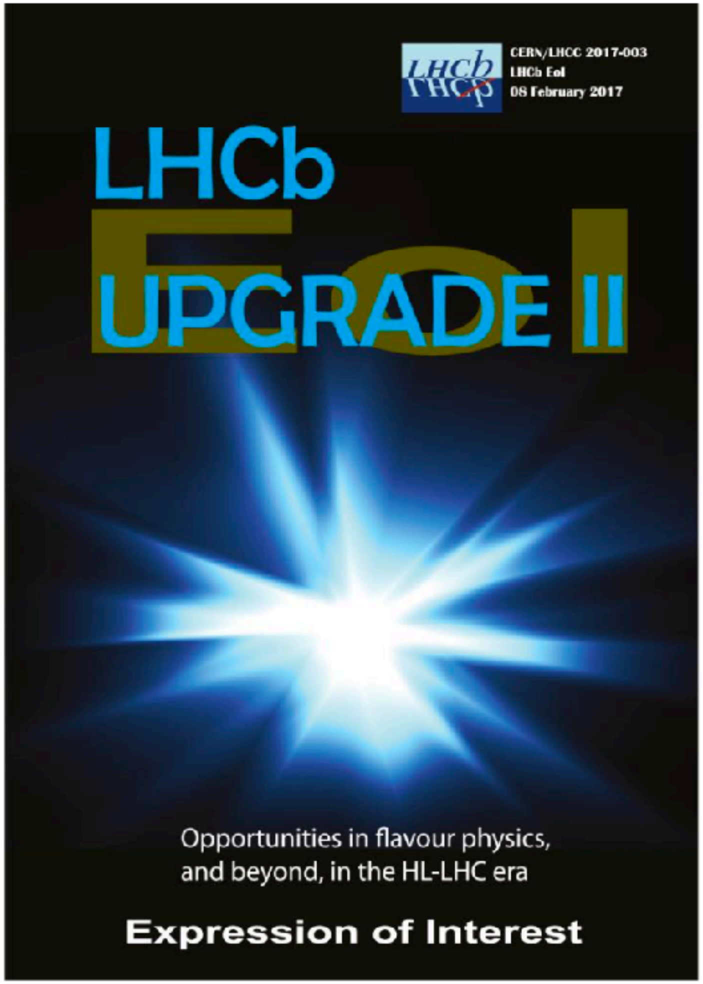
- **Nano-beams and a factor of two more beam current** to increase luminosity
- **Large crossing angle**
- **Change beam energies** to solve the problem of short lifetime for the LER



- Phase I (2016)
  - Circulated both beams but no collisions;
  - Tune accelerator optics, etc.; vacuum scrubbing
  - Beam Background studies with dedicated BEAST II/1 detector
- Phase II
  - First collisions
  - Beam Commissioning
  - Background measurements with BEAST II/2
  - Physics run with Belle II w/o VTX
    - on Υ(4S) and Υ(6S)
- Phase III
  - Physics run

LHCb UPGRADE PHASE 2 (> 2030)

Guy Wilkinson, IPPP Flavour



- Install in LS4 (~2030), after Phase-I Upgrade.
- Detector to be able to operate at ~2 x 10^{34} $cm^{-2}s^{-1}$
- Integrate ~300 fb^{-1}
- Comprehensive flavour physics programme + general-purpose forward physics (as now), but targeting clean measurements currently limited by statistics, and new observables
- Straw-man detector design with candidate solutions to challenges, including new capabilities in key areas
- Define initial R&D plan, and possible first steps in LS3, which will help physics of Phase I