Prospects for future experiments: physics reach and experimental challenges

Nicola Neri
Università di Milano and INFN Milano

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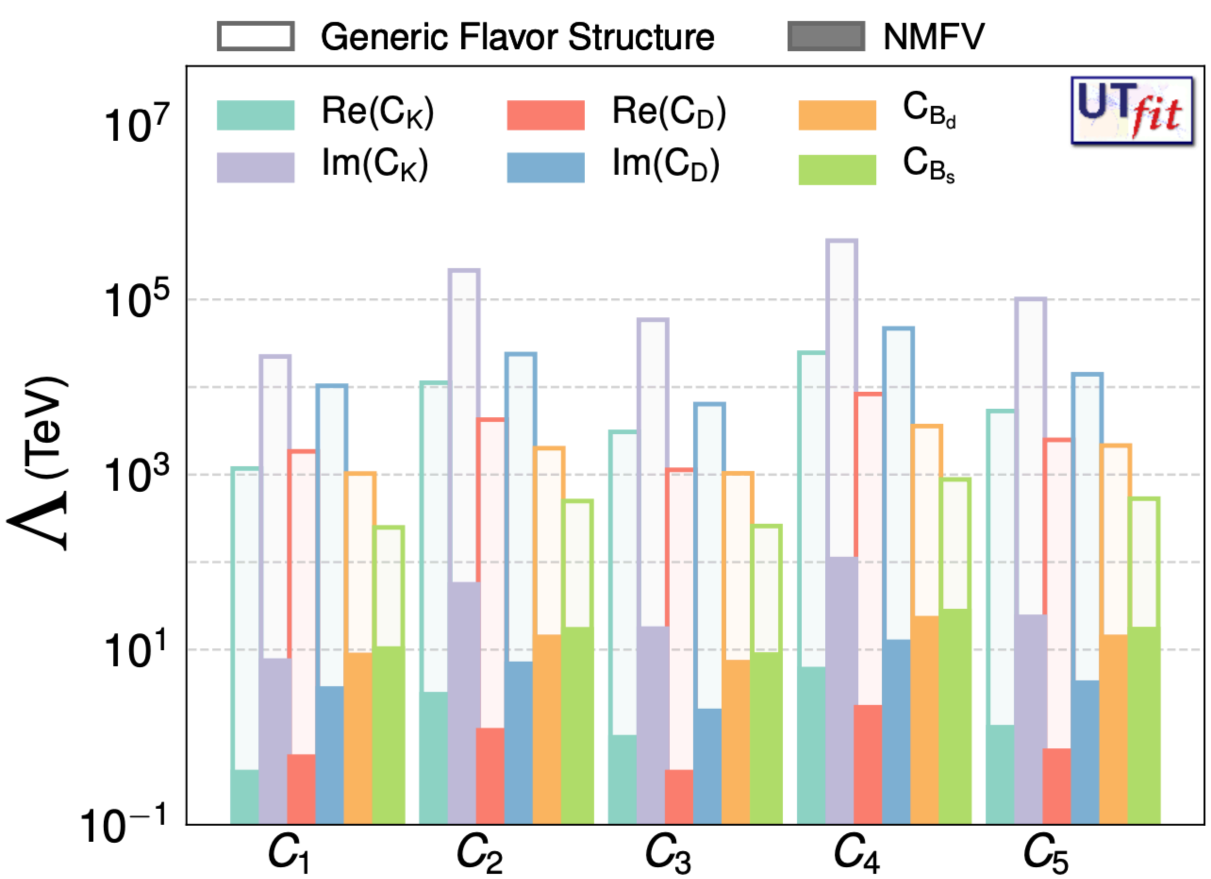
Outline

- Physics motivations
- Physics reach
- Future flavour experiments and challenges
- Summary

Physics motivations

- No direct observations of new physics at LHC so far sets strong bounds on BSM models up to the TeV scale
- Measurements of *CP* violation in kaon, charm, beauty systems can probe much higher energy scales
- Deviations from SM predictions in *CP* violation measurements could indicate the energy scale where new physics can be found



M. Pierini, EPS 2023

$$\mathcal{H}_{\rm eff}^{\Delta B=2} = \sum_{i=1}^{5} C_i Q_i^{bq} + \sum_{i=1}^{3} \tilde{C}_i \tilde{Q}_i^{bq}$$

$$\begin{aligned}
Q_1^{q_i q_j} &= \bar{q}_{jL}^{\alpha}\gamma_\mu q_{iL}^{\alpha}\bar{q}_{jL}^{\beta}\gamma^\mu q_{iL}^{\beta} \,, \\
Q_2^{q_i q_j} &= \bar{q}_{jR}^{\alpha} q_{iL}^{\alpha}\bar{q}_{jR}^{\beta} q_{iL}^{\beta} \,, \\
Q_3^{q_i q_j} &= \bar{q}_{jR}^{\alpha} q_{iL}^{\beta}\bar{q}_{jR}^{\beta} q_{iL}^{\alpha} \,, \\
Q_4^{q_i q_j} &= \bar{q}_{jR}^{\alpha} q_{iL}^{\alpha}\bar{q}_{jL}^{\beta} q_{iR}^{\beta} \,, \\
Q_5^{q_i q_j} &= \bar{q}_{jR}^{\alpha} q_{iL}^{\beta}\bar{q}_{jL}^{\beta} q_{iR}^{\alpha} \,.
\end{aligned}$$

$$C_i(\Lambda) = \frac{F_i L_i}{\Lambda^2}$$

- Generic: $C(\Lambda) = \alpha/\Lambda^2$ $F_i \sim 1$, arbitrary phase
- NMFV: $C(\Lambda) = \alpha \times |F_{SM}|/\Lambda^2$ $F_i \sim |F_{SM}|$, arbitrary phase

Precision flavour physics

- Precise measurements of CKM parameters and CP violating asymmetries
- **Precise** SM predictions, small theoretical uncertainties
  - **clean** observables, e.g. CKM angle γ, leptonic decays, …
  - **calculable** hadronic contributions at subpercent level: non-perturbative techniques, lattice QCD, e.g. V_{ub}, V_{cb}, Δm_s, Δm_d, …
  - **null** tests: no theory inputs, negligible SM contributions, e.g. CP violation in D mixing, …
- **High statistics** data sample
- Excellent **detector performance**, low systematic uncertainties

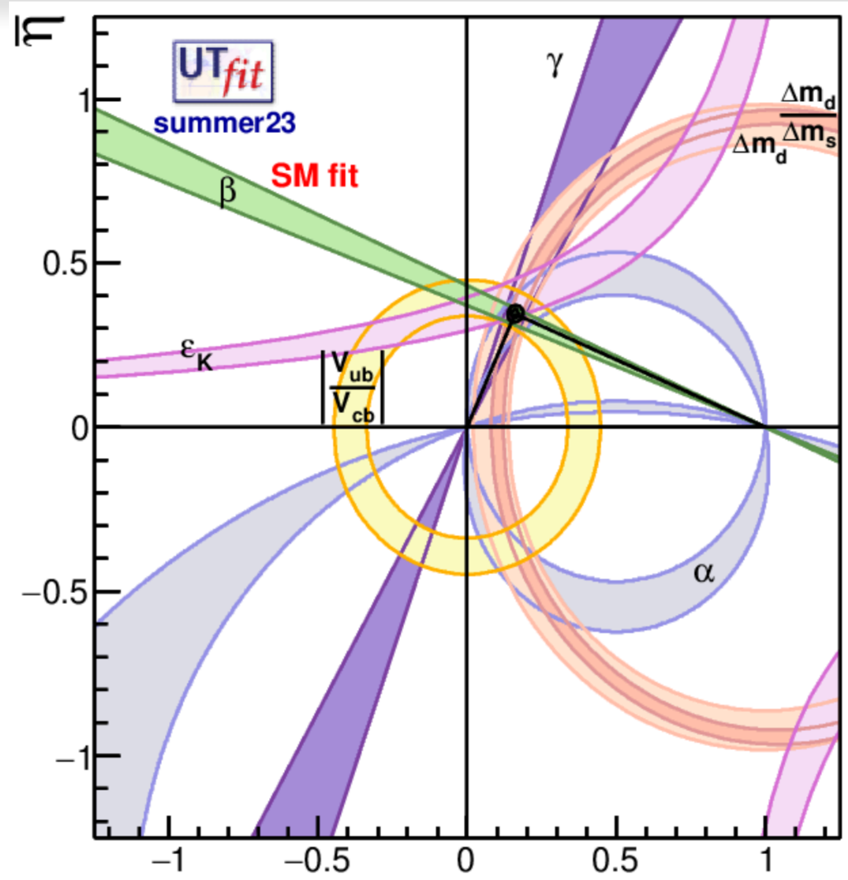
Present and future flavour experiments

- **LHCb**: *B*, *D* physics. pp collisions at $\sqrt{s} \approx$ 14 TeV. Single-arm forward spectrometer Plans for upgrade II and data taking until end HL-LHC, 2041 circa
- **Belle II**: *B, D,* τ physics. e^+e^- collisions at $\sqrt{s} \approx$ 10 GeV energy. Hermetic detector. Coherent $B^0 - \overline{B}^0$ production, $\tau^+\tau^-$ pairs. Plans until 2035 and possibly beyond
- **NA62/(HIKE)**: *K* physics. Collisions of 400 GeV protons on fixed-target. Future projects under review
- **BES III/(SCTF)**: *D* physics. e^+e^- collisions at $\sqrt{s} \approx 2 - 5$ GeV energy. Coherent $D^0 - \overline{D}^0$ production (not covered in this talk)
- **FCC:** e^+e^- collisions at $\sqrt{s} \approx 91 - 365$ in 2045 circa, pp collisions at $\sqrt{s} \approx 100$ TeV in 2070 circa (not covered in this talk)

Unitarity triangle fit

- **Present** constraints on $\bar{\rho}, \bar{\eta}$ with new theory (V_{ud}, LQCD) and experiment updates ($\sin 2\beta, \gamma, \alpha$)

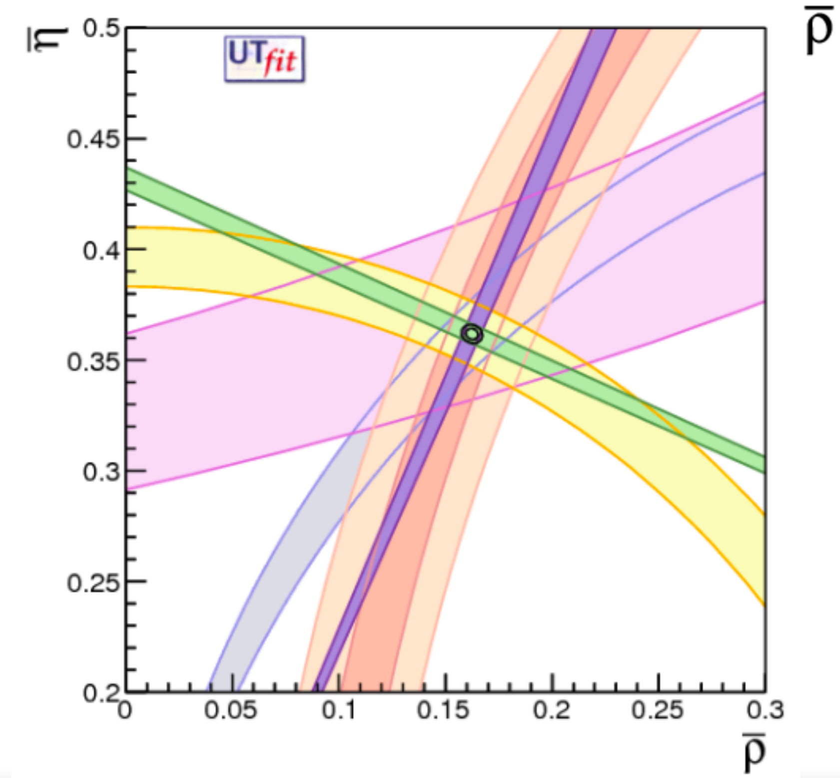
$$\bar{\rho} = 0.160 \pm 0.009 \quad (6\%)$$
$$\bar{\eta} = 0.345 \pm 0.011 \quad (3\%)$$



M. Pierini, EPS 2023

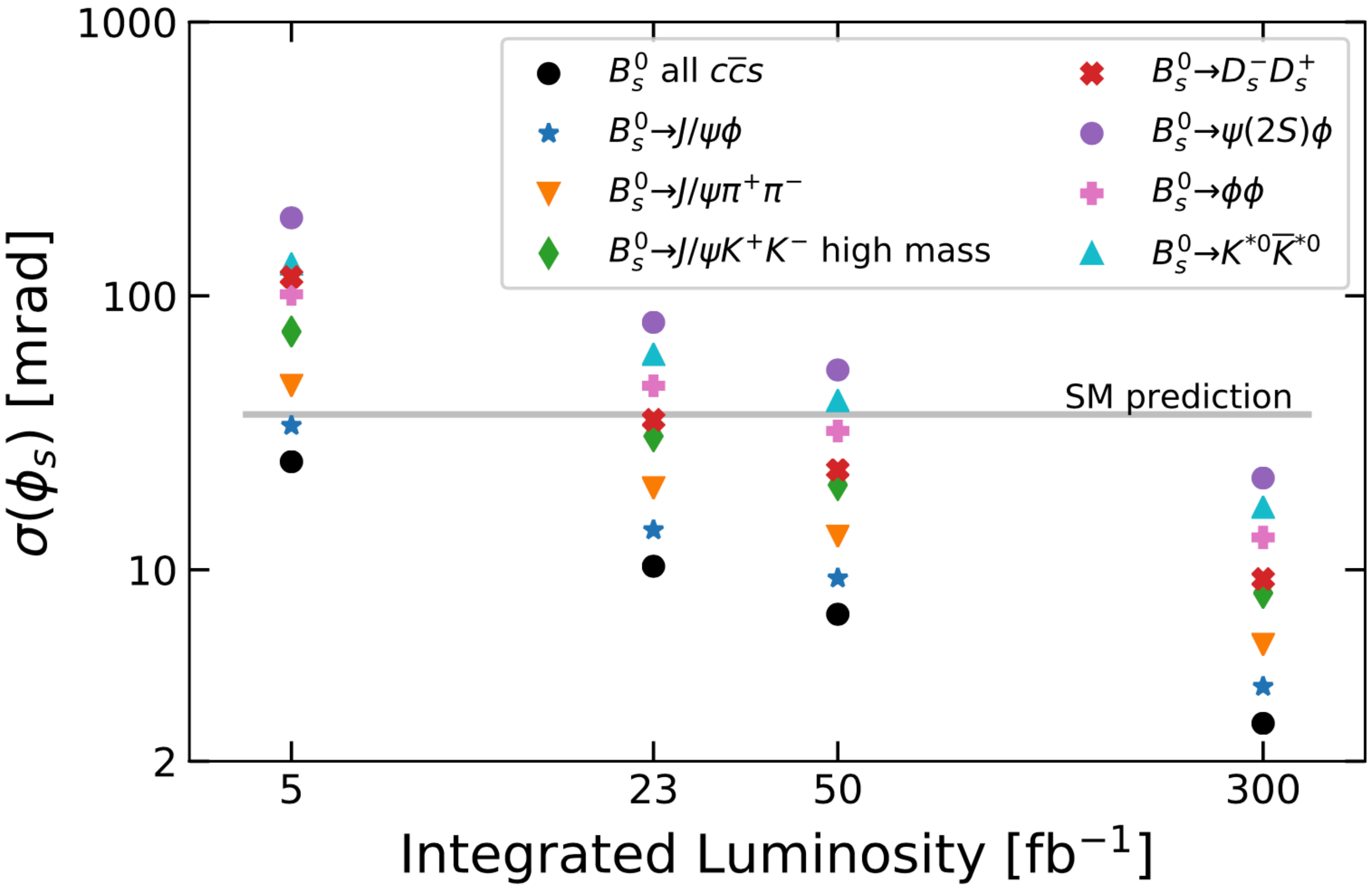
- **Future** constraints on $\bar{\rho}, \bar{\eta}$ parameters using expected improvements from LHCb with 300 fb^{-1} and lattice QCD

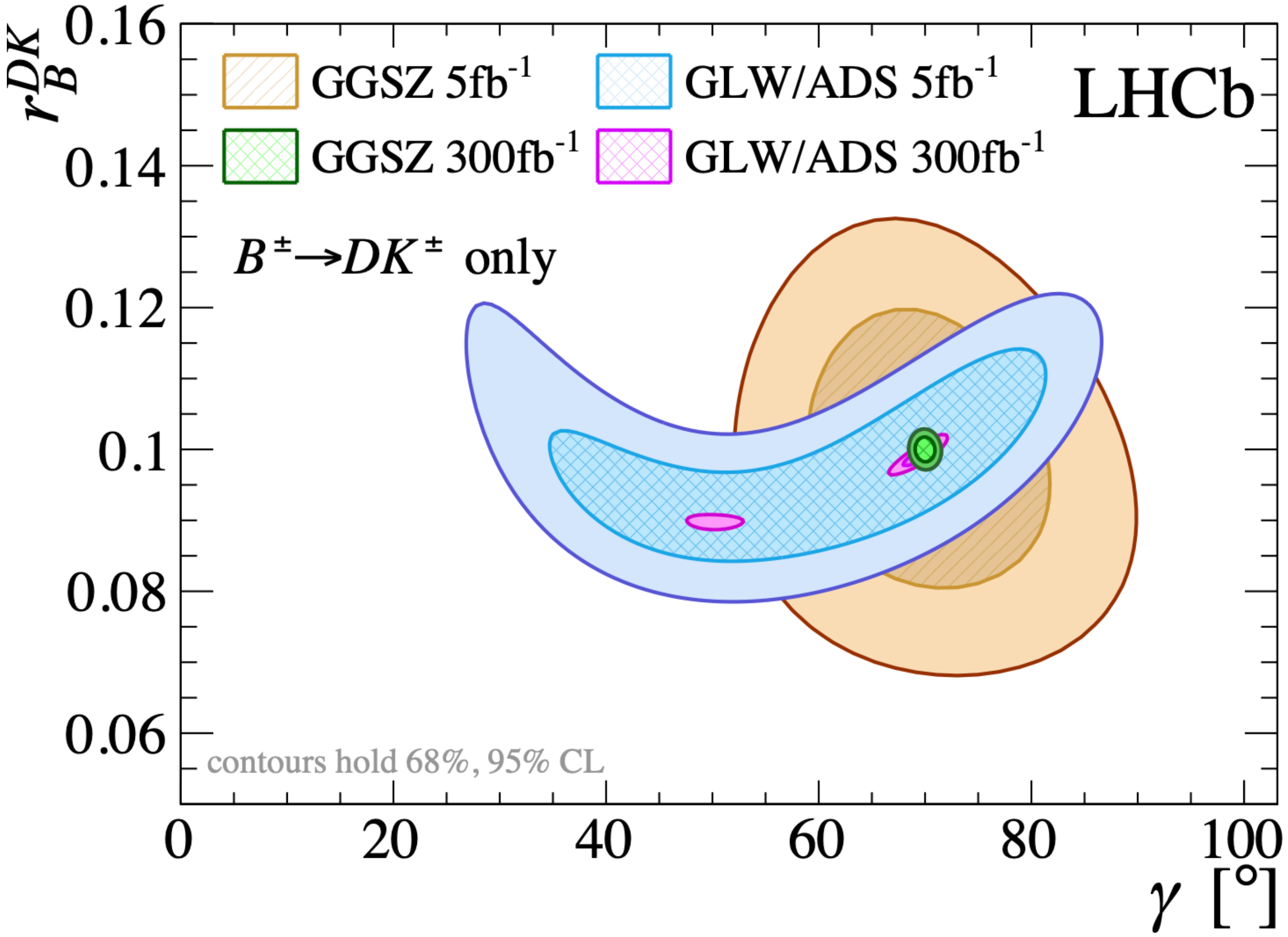
$$\sigma(\bar{\rho}) \approx 0.0016 \quad (1\%)$$
$$\sigma(\bar{\eta}) \approx 0.0021 \quad (0.6\%)$$



CERN-LPCC-2018-06 , arXiv:1812.07638

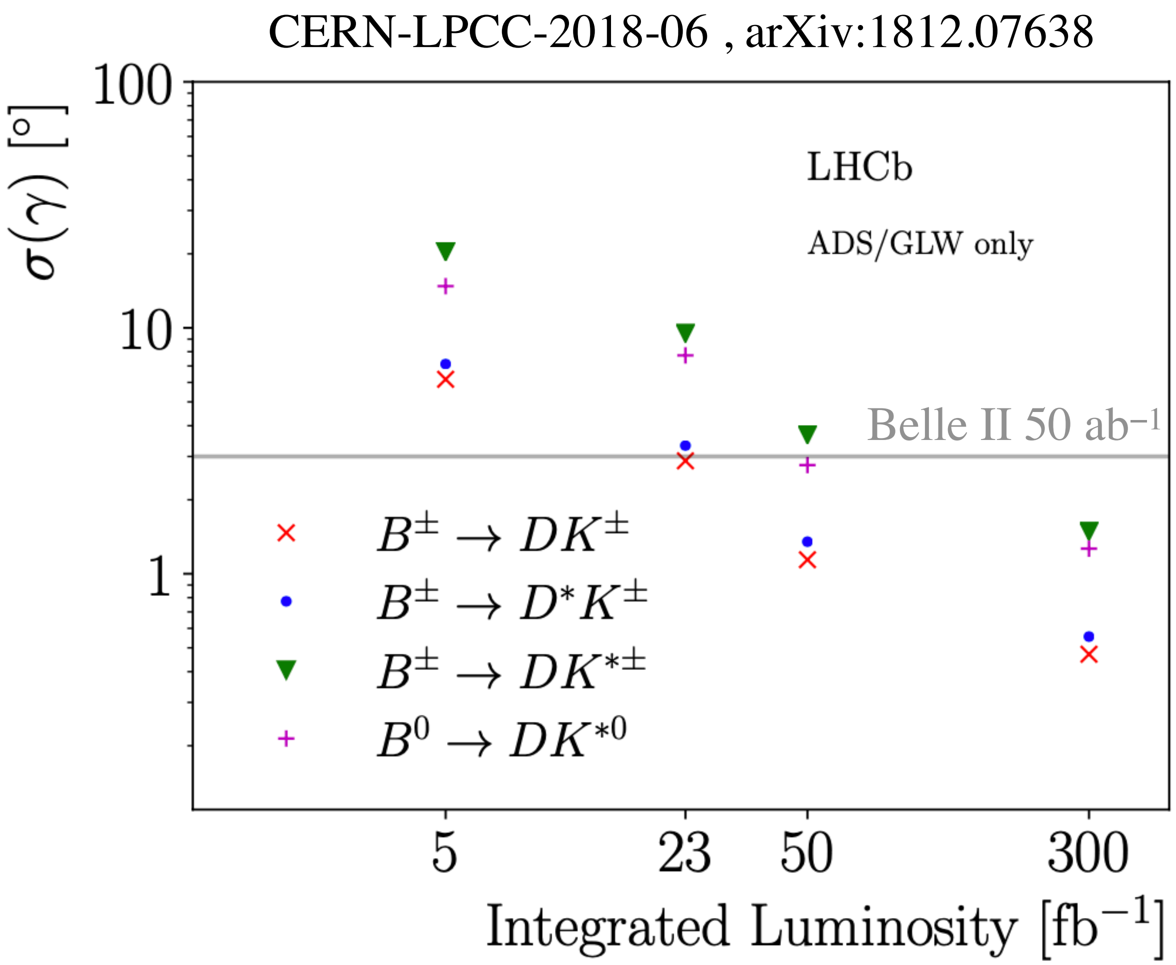
B physics at LHCb upgrade II

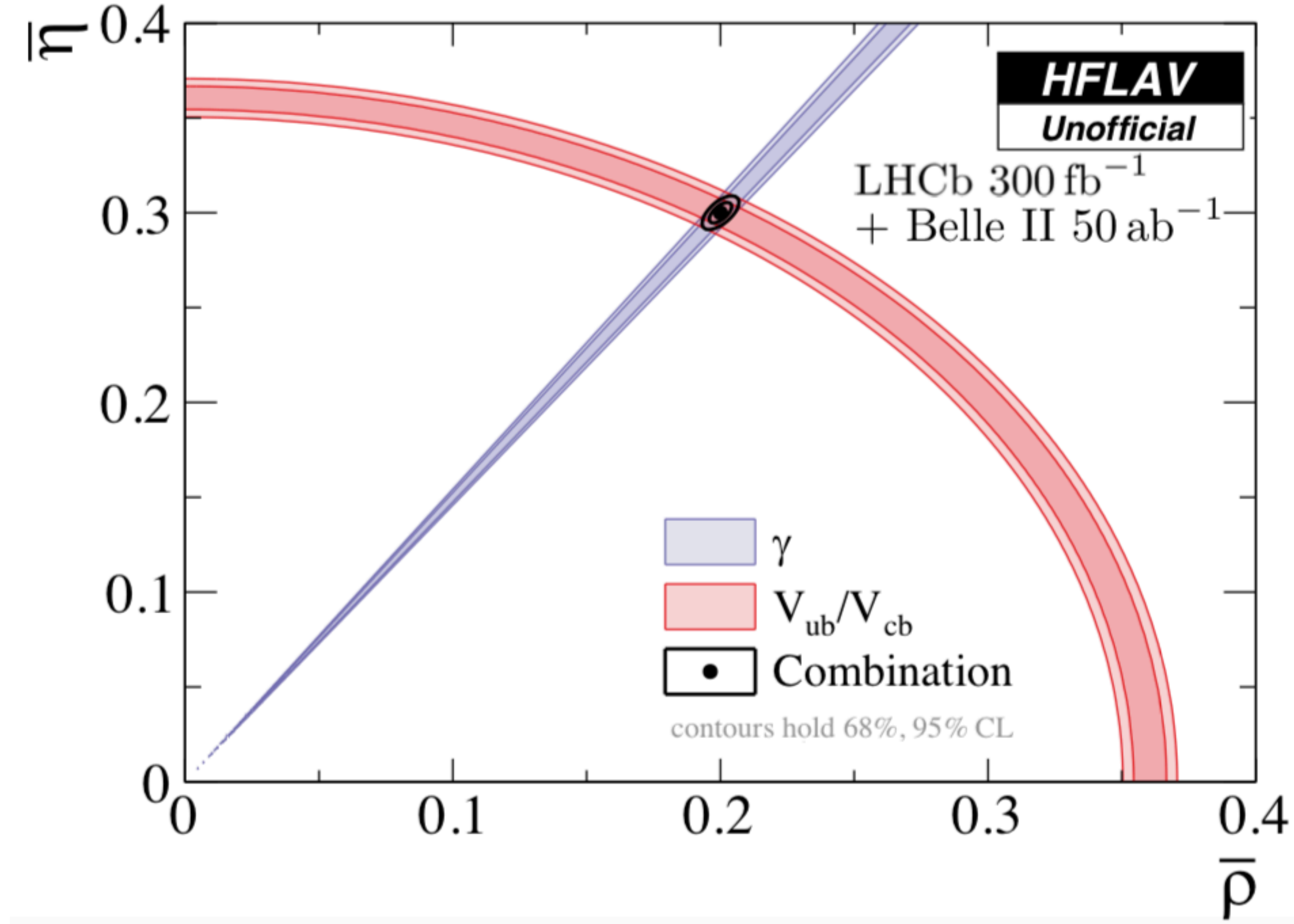




- With 300 fb^{-1} at LHCb upgrade II LHCB-PUB-2018-009
  - $\sigma(\phi_s) \sim 4$ mrad from $B_s^0 \to J/\psi\phi$ time-dependent measurement
  - $\sigma(\gamma) \sim 0.35°$ from $B^\pm \to DK^\pm$ time-integrated measurement

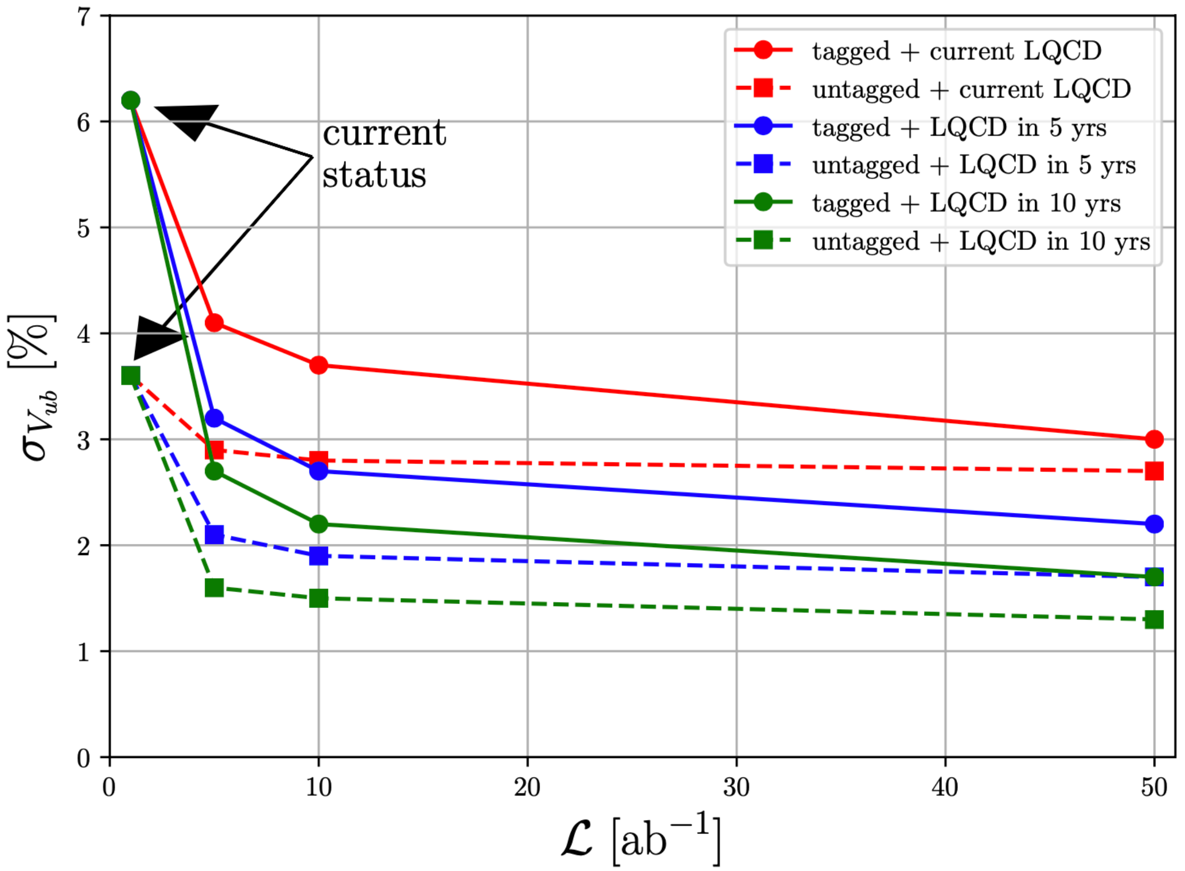
Ultimate γ sensitivity

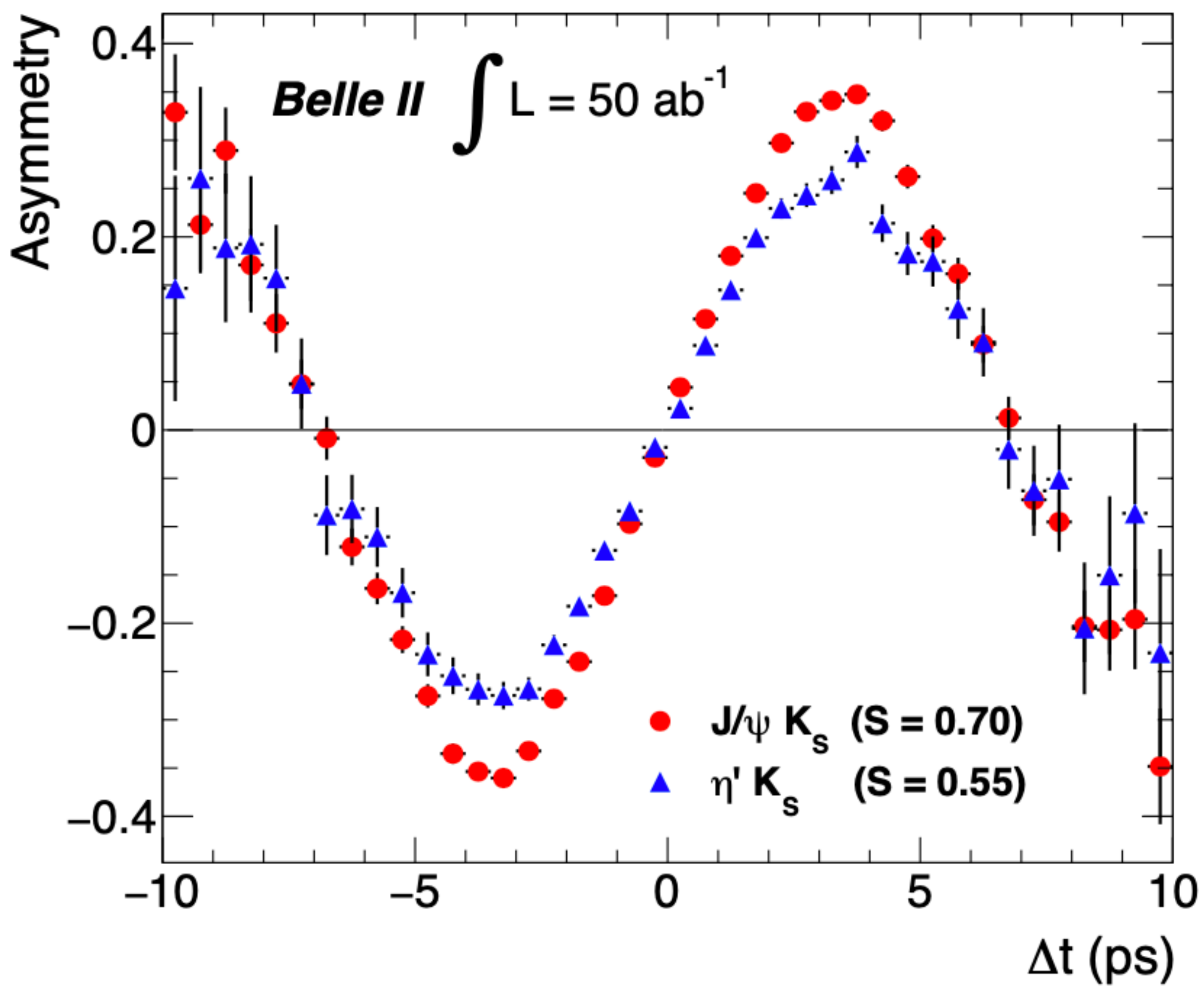




- Sensitivity $\sigma(\gamma) \approx 1.6^{\circ}$ from combination of Belle II results with 50 ab^{-1}
- Measurements of γ from B^+, B_d^0, B_s^0, Λ_b^0 modes will become possible at LHCb upgrade II

B physics at Belle II



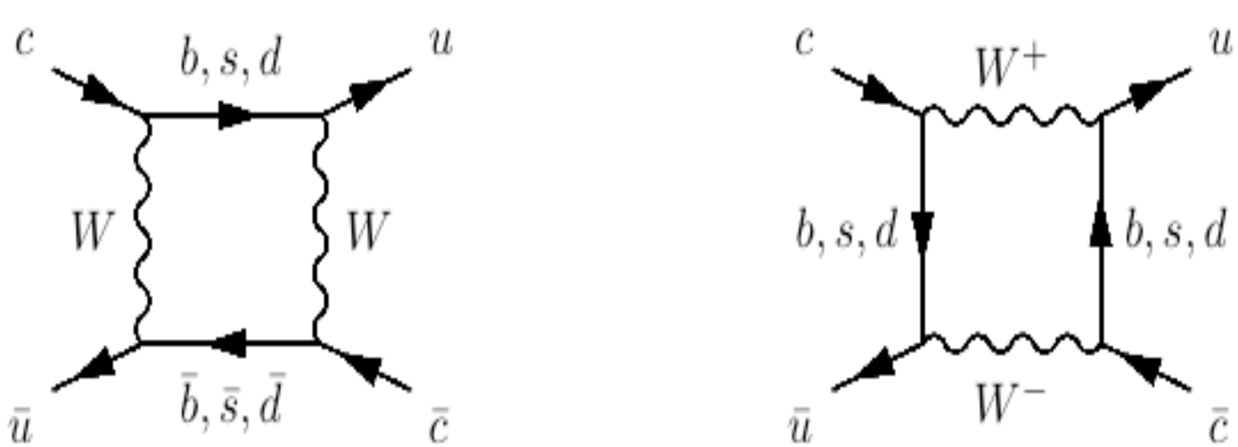


- With 50 fb^{-1} at Belle II BELLE2-PAPER-2018-001
  - $\sigma(V_{ub}) \sim 1\,\%$ from $B \to \pi \ell \nu$ tagged and untagged decays
  - $\sigma(S_f) \sim 0.015$ from $B^0 \to \eta' K^0$ time-dependent measurement

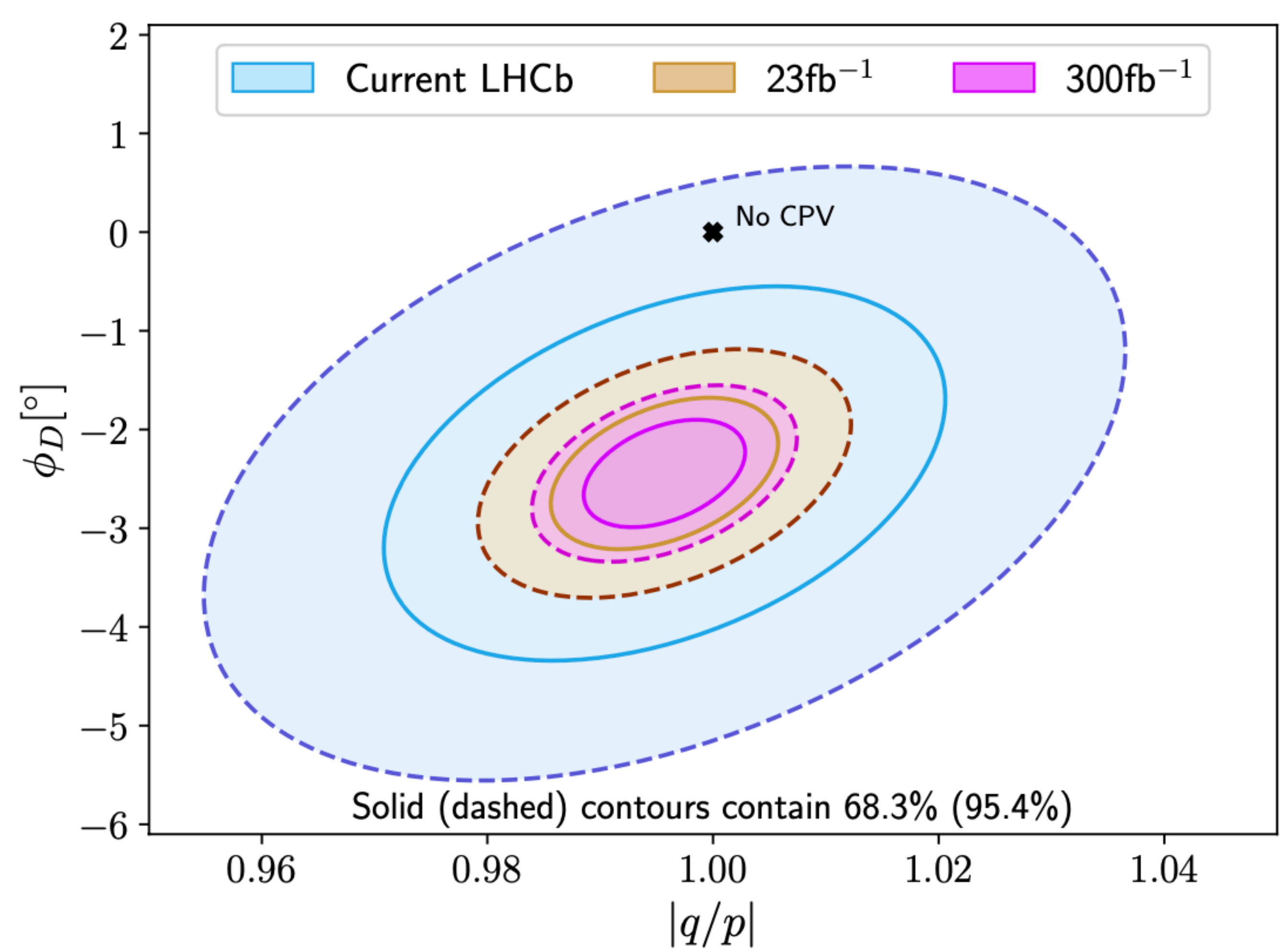
CP violation in charm at LHCb upgrade II

- **Null test**: SM amplitudes for mixing are approximately real and are GIM or CKM suppressed

- CP violation in mixing $q/p \neq 1, \phi \neq 0$ would represent a signature of new physics



LHCB-TDR-023



- Sensitivities at 300 fb^{-1} :

$$\phi \approx 0.15°, \quad q/p \approx 0.002$$

- Test SM predictions for indirect *CPV* at 10^{-4} level

CP violation in charm at Belle II

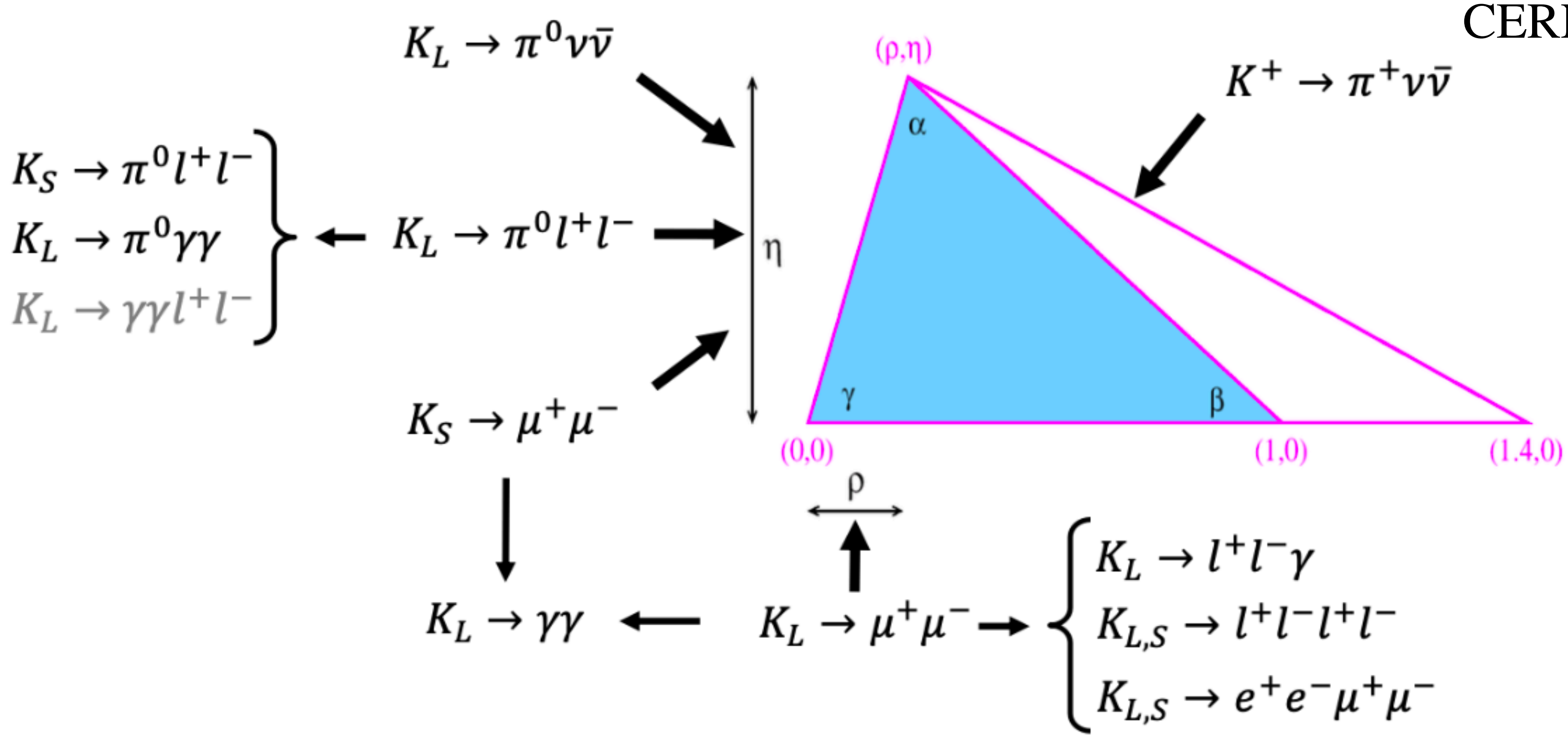
BELLE2-PAPER-2018-001

Observable	Phenomenological impact	Belle II 50 ab^{-1} (%)
$A_{CP}(D^0 \to \pi^0\pi^0)$	SM test with A_{CP} sum rule I	± 0.09
$A_{CP}(D_s^+ \to K^+\pi^0)$	SM test with A_{CP} sum rule II	
$A_{CP}(D^+ \to \pi^+\pi^0)$	SM null test	± 0.17
$A_{CP}(D^0 \to K_S^0 K_S^0)$	Possible near future observation channel of CP violation	± 0.23
$A_{CP}(D^0 \to \rho^0\gamma)$	Radiative decays as probes for new physics	± 2
$A_{CP}(D^0 \to \phi\gamma)$		± 1
$A_{CP}(D^0 \to \overline{K}^{*0}\gamma)$		± 0.3

- Measurements in final states with neutral particles for systematic tests of the SM

Kaon physics at HIKE

CERN-SPSC-2022-031



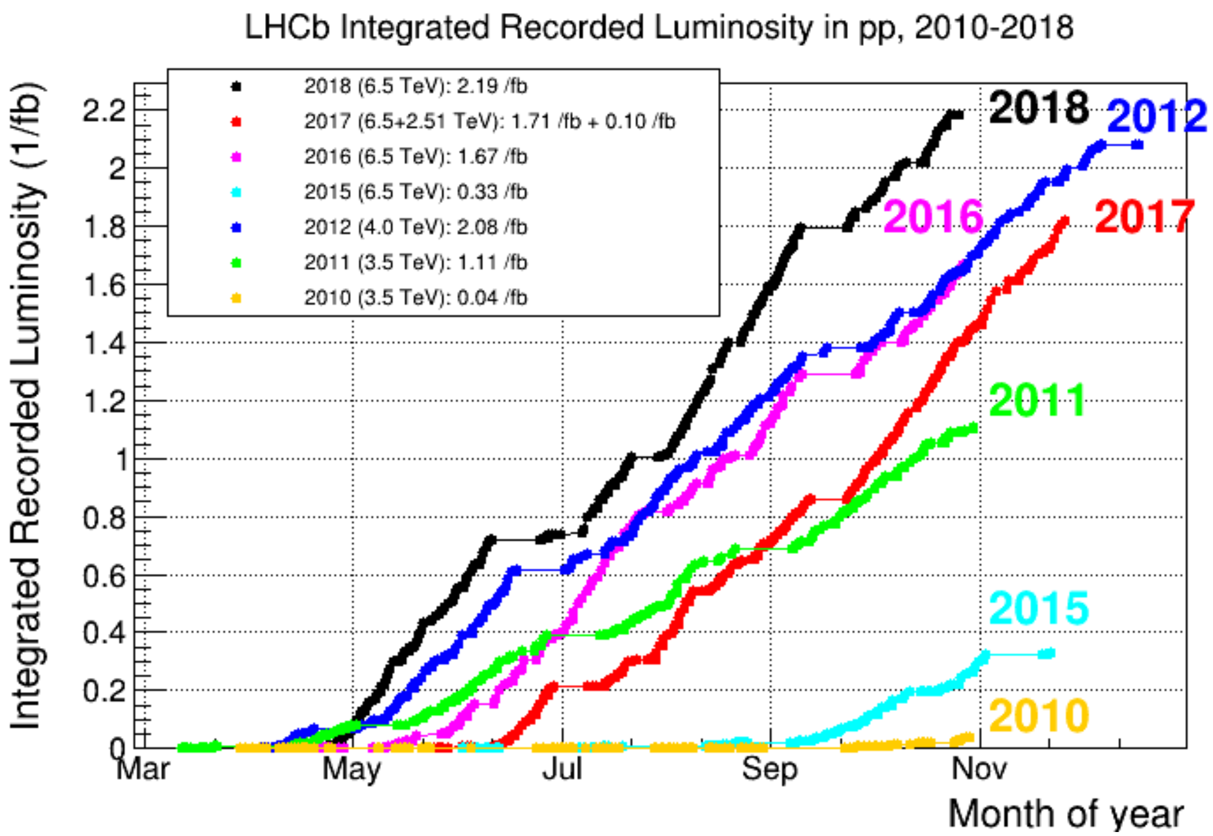
$$\mathcal{B}(K^+ \to \pi^+ \nu\bar{\nu}) = (8.39 \pm 0.30) \times 10^{-11} \left(\frac{|V_{cb}|}{0.0407}\right)^{2.8} \left(\frac{\gamma}{73.2°}\right)^{0.74},$$

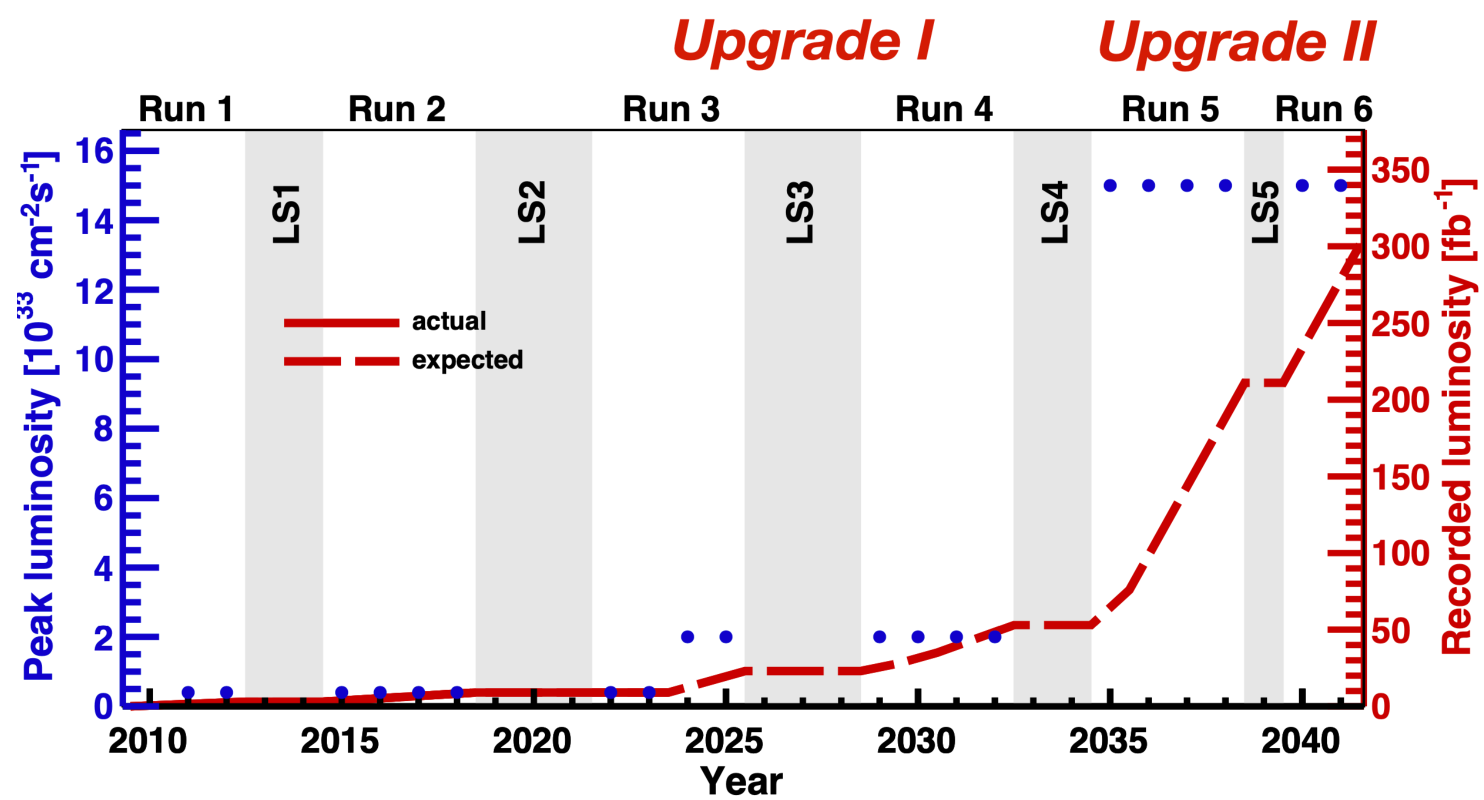
$$\mathcal{B}(K_L \to \pi^0 \nu\bar{\nu}) = (3.36 \pm 0.05) \times 10^{-11} \left(\frac{|V_{ub}|}{3.88 \times 10^{-3}}\right)^{2} \left(\frac{|V_{cb}|}{0.0407}\right)^{2} \left(\frac{\sin\gamma}{\sin 73.2°}\right)^{2}$$

- $\mathscr{B}(K^+ \to \pi^+ \nu\bar{\nu})$ at 5% precision in phase 1
- $\mathscr{B}(K^0_L \to \pi^0 \ell^+ \ell^-)$ at 20% in phase 2
- $\mathscr{B}(K^0_L \to \pi^0 \nu\bar{\nu})$ at 20% precision in phase 3 (KLEVER)

LHCb data sample and plans

Matteo Palutan, RRB October 2023

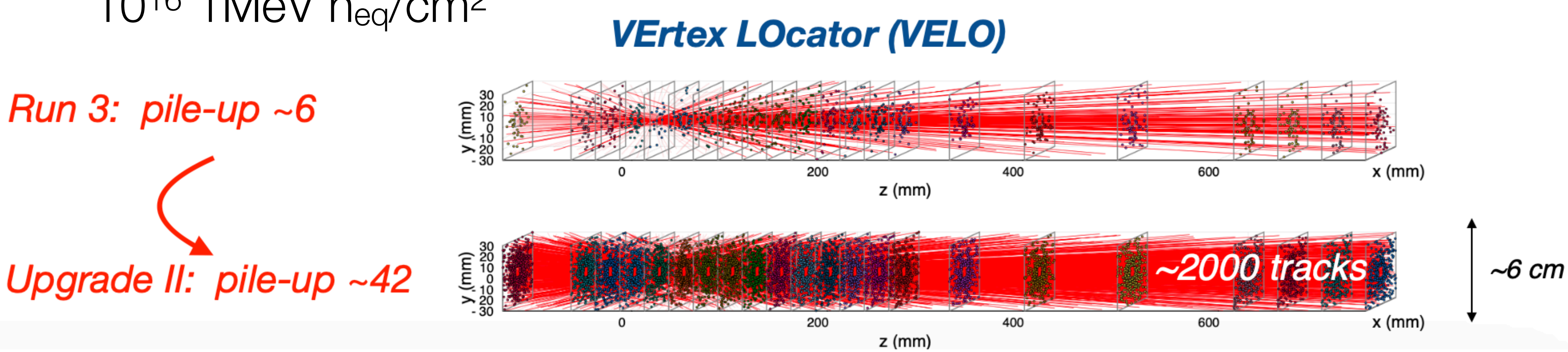




- Collected 9 fb^{-1} in Run 1- Run 2
- **Upgrade I**: major detector upgrade in LS2 designed to collect 50 fb^{-1} by the end of Run 4
- **Upgrade II:** major detector upgrade in LS4 to collect 300 fb^{-1} by the end of HL-LHC

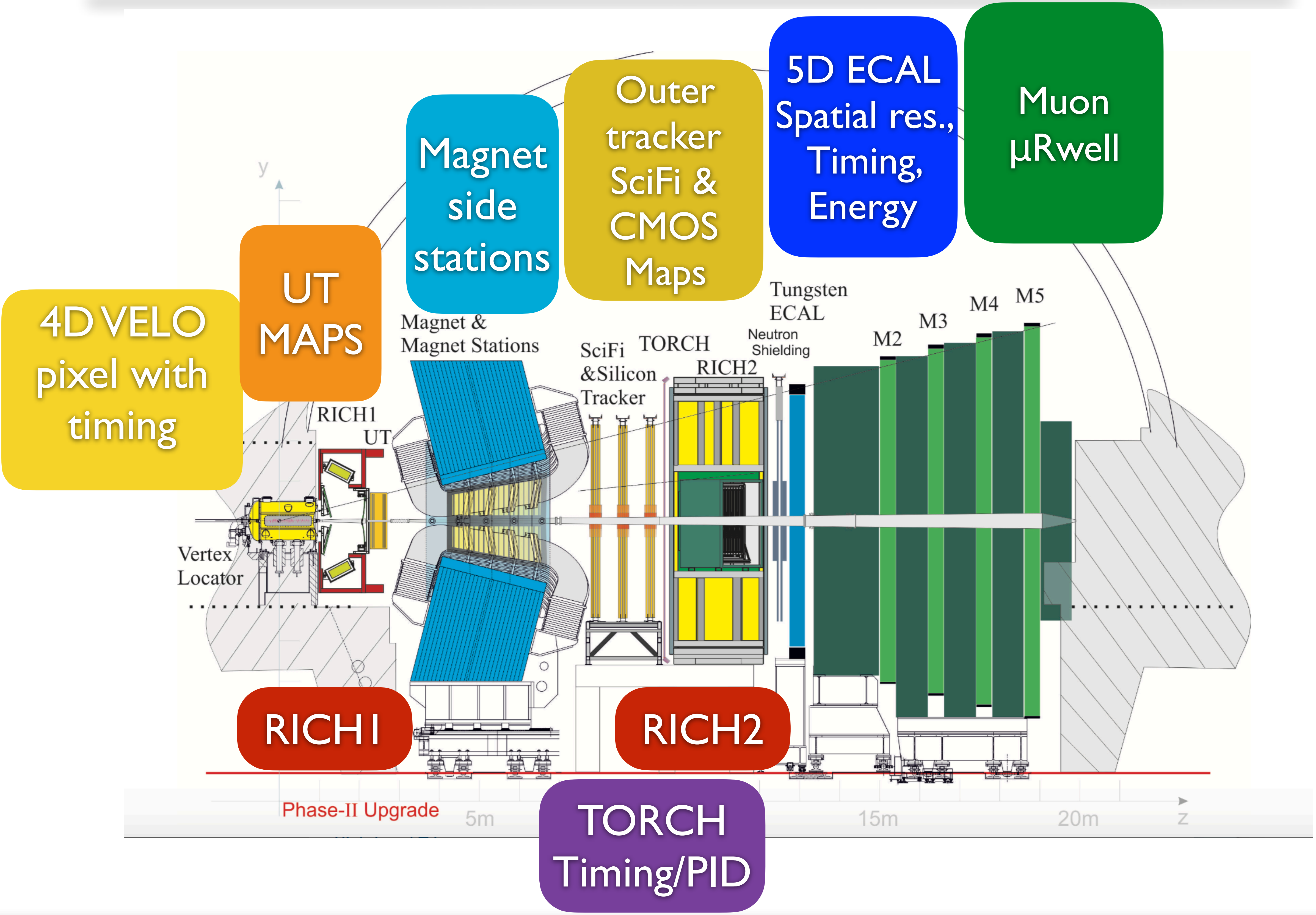
LHCb upgrade II challenges

- Aim at $\mathcal{L}=1.5\times10^{34}\ cm^{-2}s^{-1}$, about 42 visible interactions per crossing
- Tracking: 2000 charged particles/crossing, fluence in excess of 10^{16} 1MeV n_{eq}/cm^2



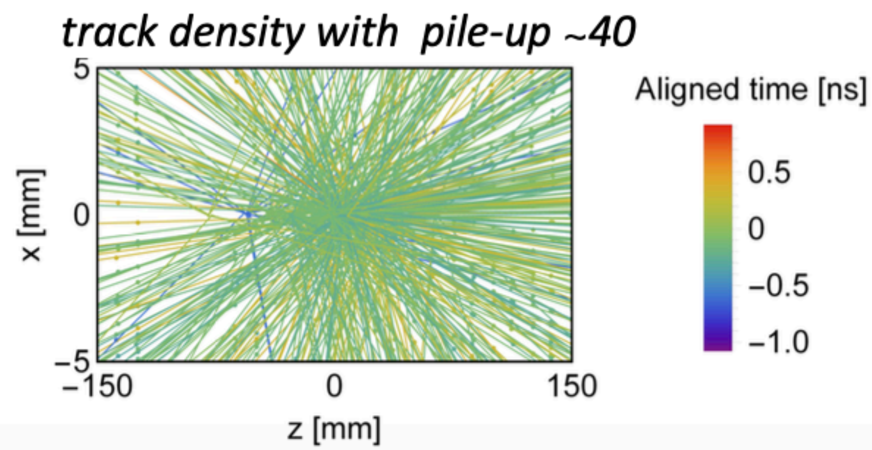
- PID: cope with high occupancy, upgrade the coverage at low ~10 GeV, and high momenta ~100 GeV
- ECAL: sustain radiation dose 100 Mrad, energy resolution $\sigma(E)/E\sim10\%/\sqrt{E}\oplus1\%$, reduce Moliere radius
- TDAQ: biggest data processing challenge in HEP history. Bandwidth >10 TB/s

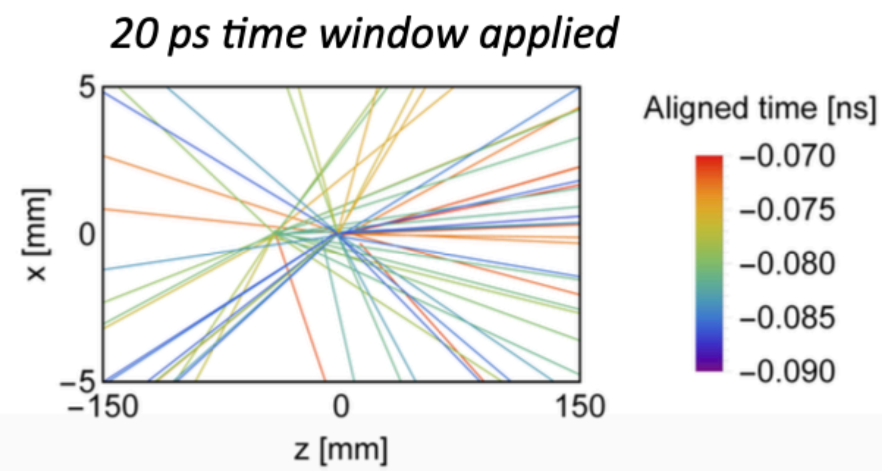
LHCb Upgrade II detector



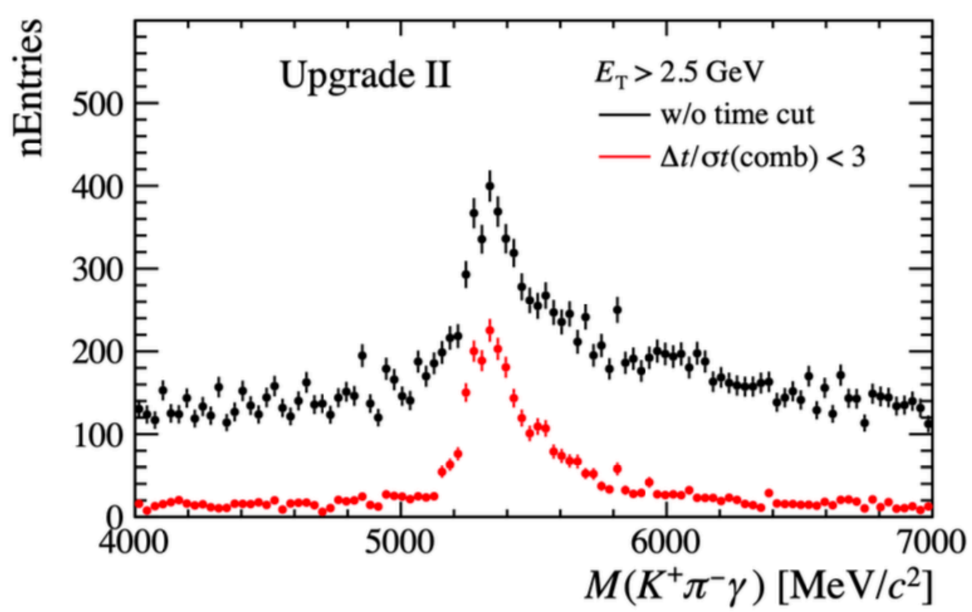
LHCb upgrade II detector

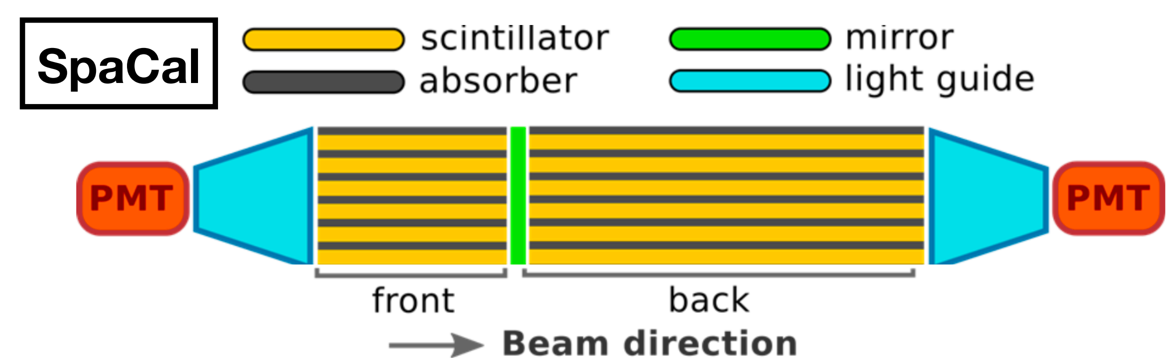
- Detectors with timing resolution of few tens of ps are key to reduce background and pile-up
  - **VELO**: hybrid-pixel, high resistivity silicon sensor + FEE chip (28 nm), 55 µm pitch, 50 ps time resolution

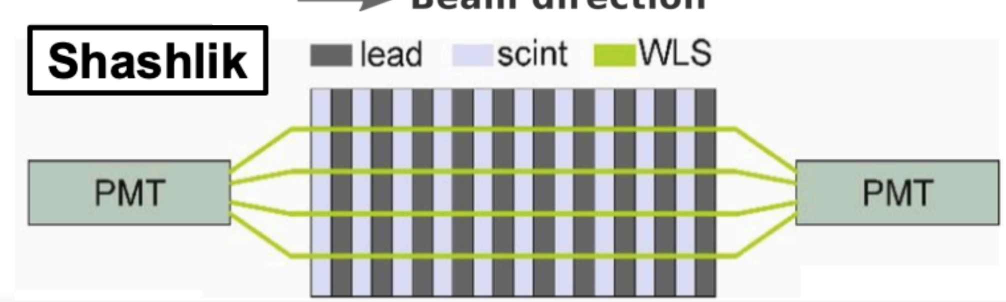




- **ECAL**:SpaCal (inner region,1 MGy), Shashlik (outer region, 40 kGy), 15-50 ps time resolution

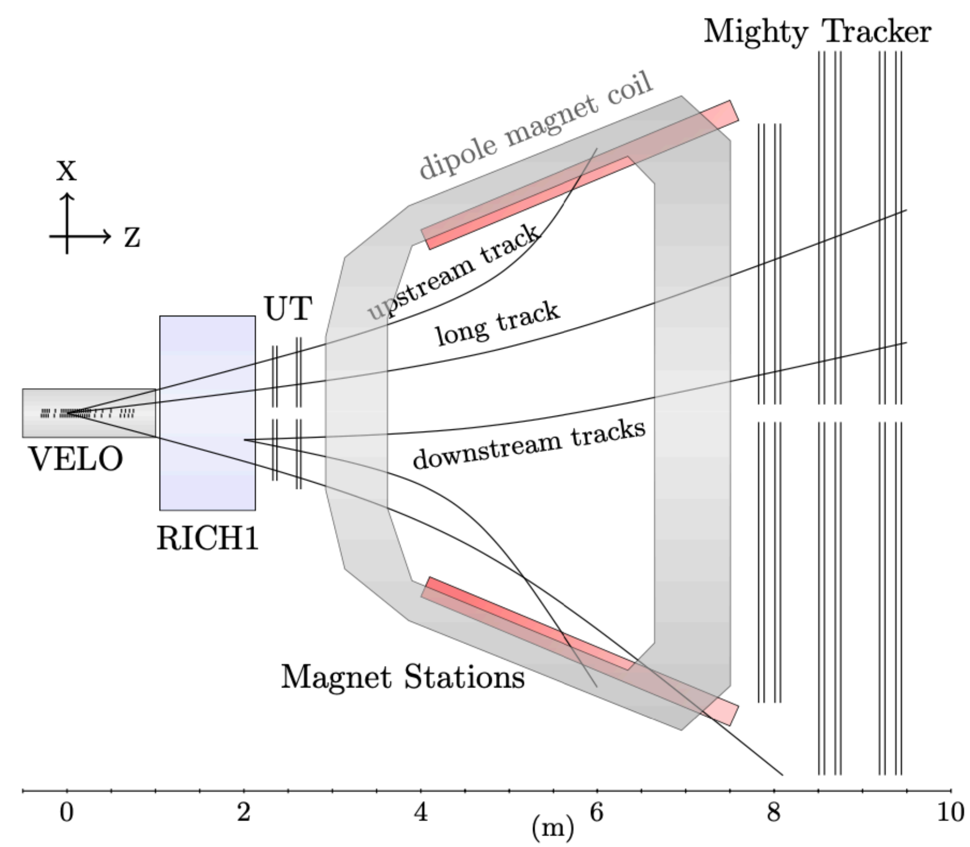




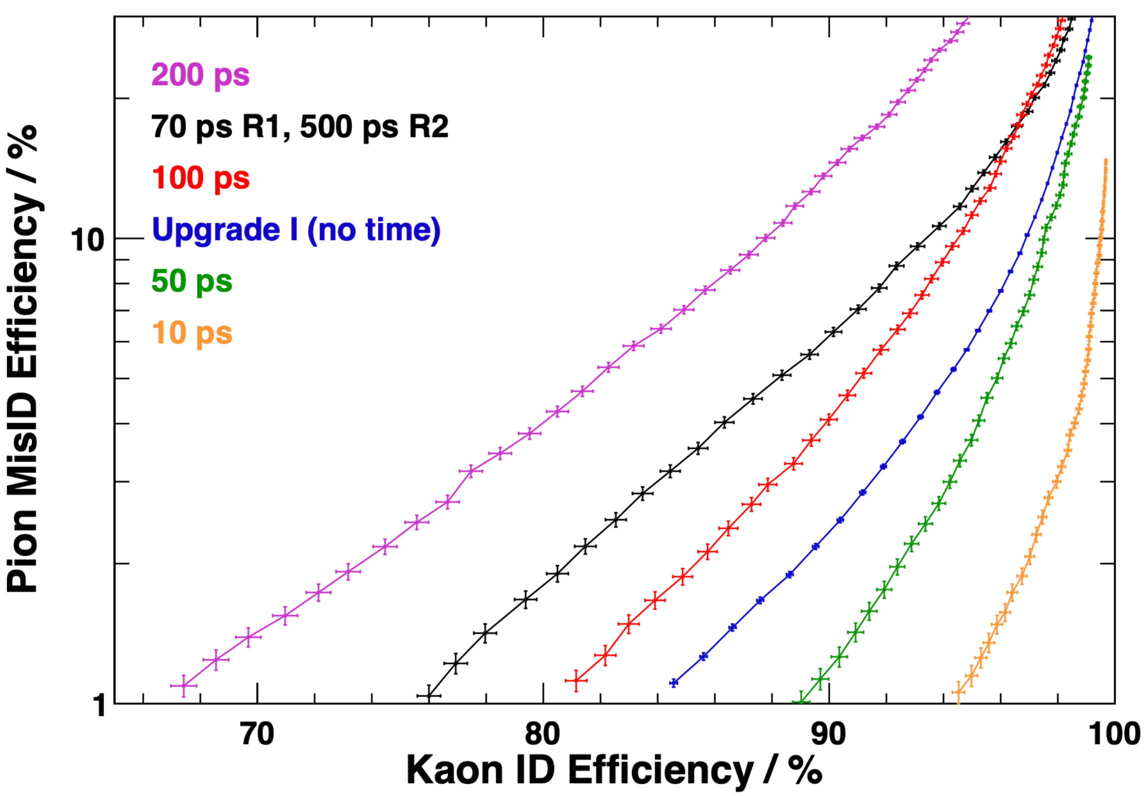


LHCb upgrade II detector

- Tracking: **UT**, 4 layers of MAPS. **Mighty Tracker**, 12 (u/v) layers of scintillator fibers (outer region) and 6 layers of MAPS (inner region), $\sigma(p)/p \approx 0.3 - 0.4\,\%$



- **RICH** with timing. SiPM/MaPMT/MCP. FastRICH ASIC in CMOS 65 nm with 25 ps resolution. 2.6 - 100 GeV/c range (time window $\pm 2\sigma$)

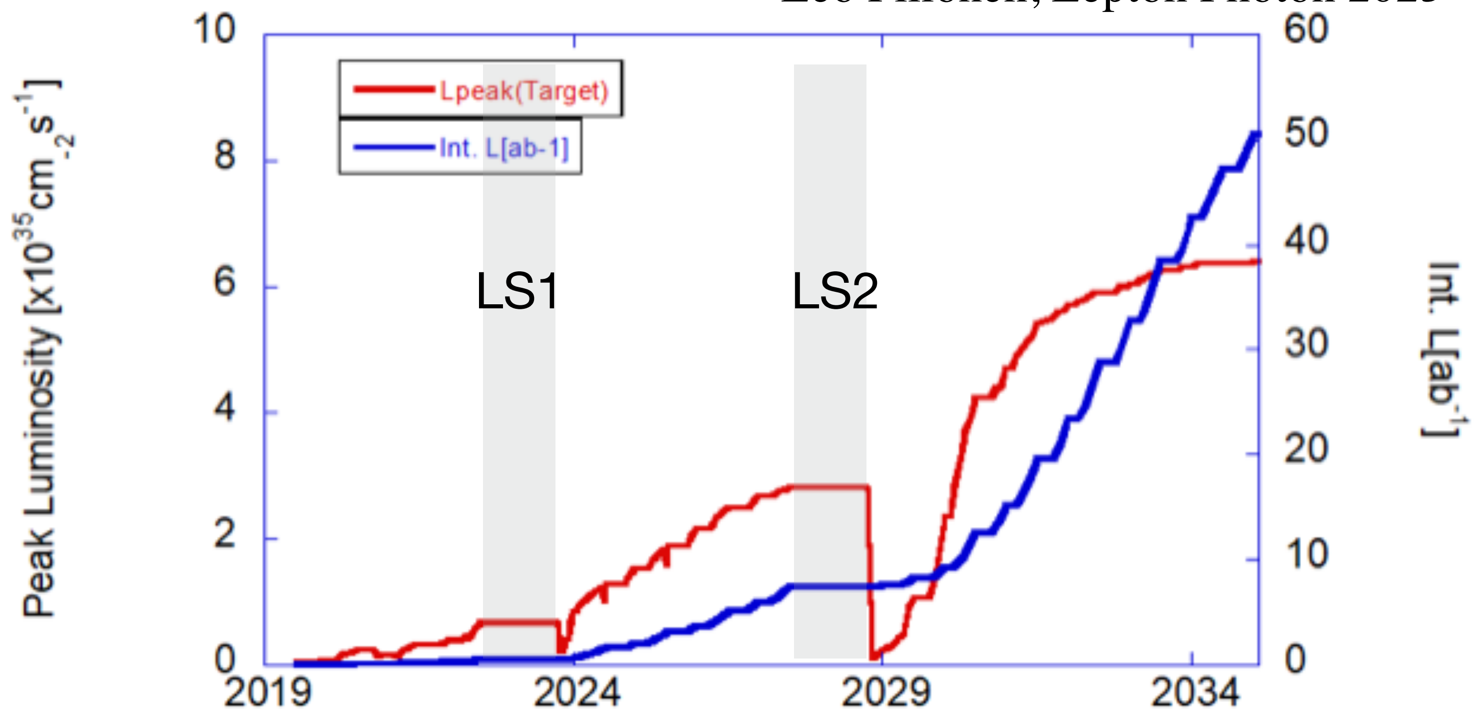


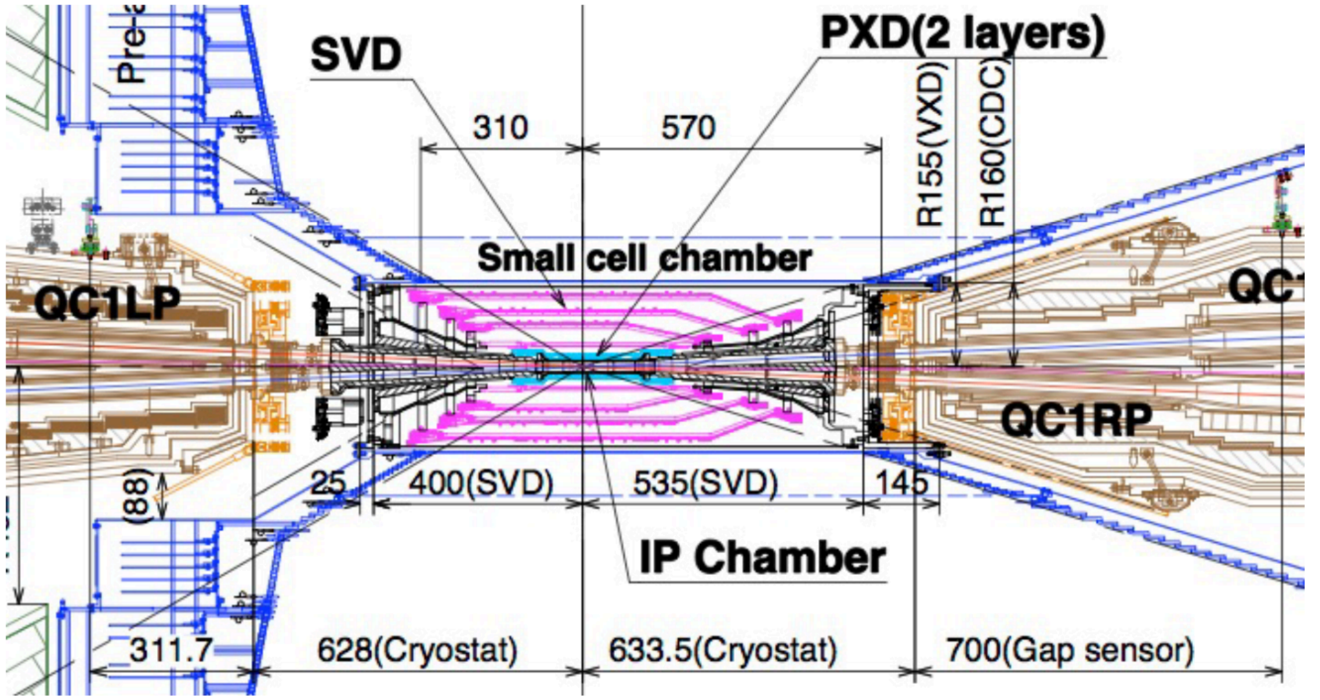
- **Muon**: μ-RWELL to cope with hit rates of few MHz/cm^2 (inner region). Additional shielding with iron and concrete to reduce rates

Belle II plans for upgrade

- Operations 2019-2022: int. lumi 427.8 fb^{-1}, peak lumi 4.7×10^{34} cm^{-2} s^{-1}
- **LS1** (2022-23): accelerator and detector upgrade (e.g. pixel detector, PMTs for PID, PCIe40)
- **LS2** (2028-29): major accelerator upgrade (final focus, higher currents)
- **Long term** (2035 circa): accelerator R&D to reach 250 ab^{-1}, polarised beams

Leo Piilonen, Lepton Photon 2023





Belle II upgrade challenges

Detector performance challenges

- tracking at low momentum (e.g. 50-200 MeV/c slow pions from D^{*+})
- Vertex and IP resolution (background mitigation, time-dependent measurements)
- Calorimeter and lepton ID
- Triggers (high efficiency, rare and forbidden decays, τ physics)
- K/π separation
- K_L^0 detection

Accelerator challenges

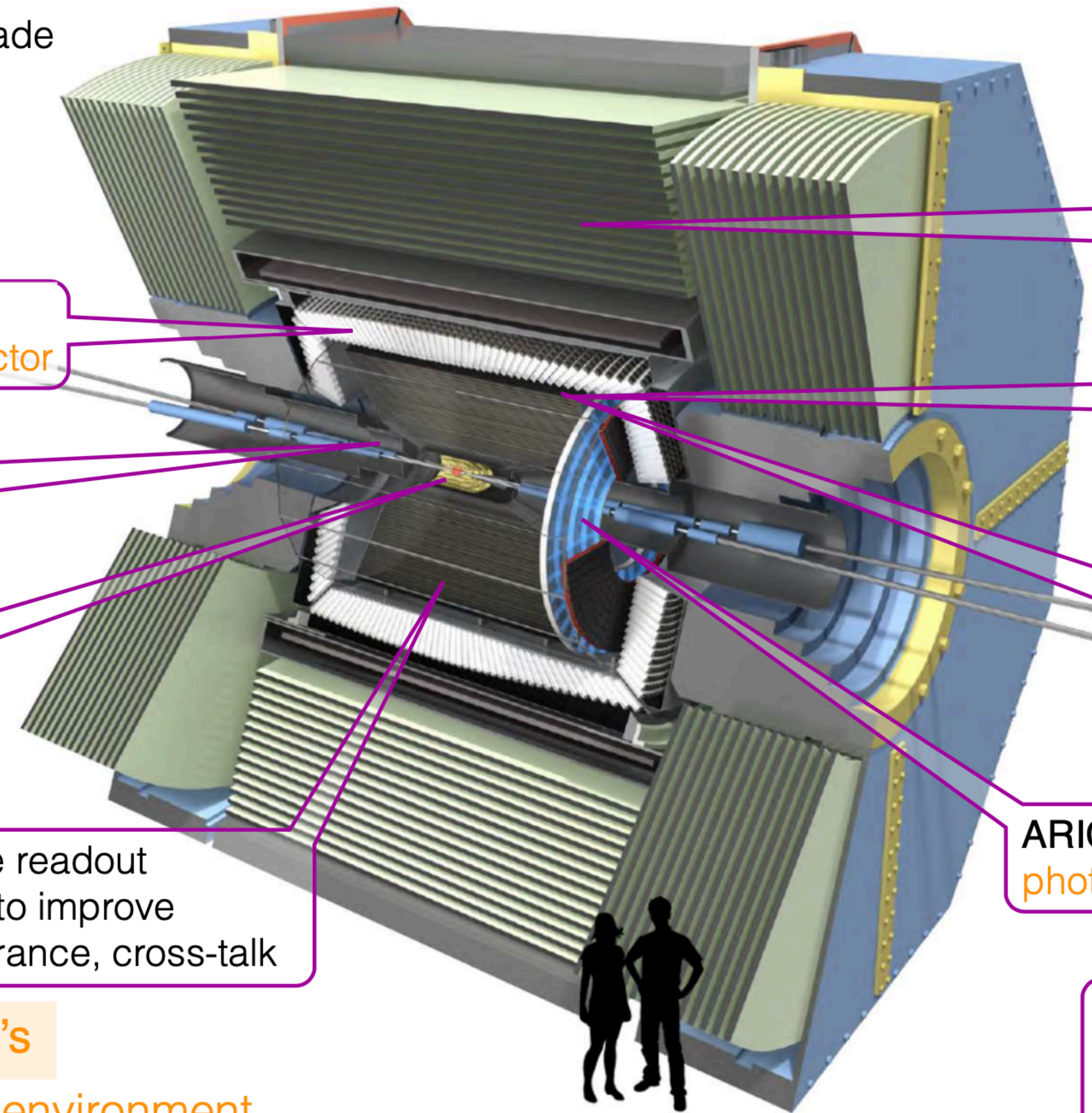
- reach peak lumi 6.5×10^{35} cm^{-2} s^{-1}
- redesign of IR and final focus. Large uncertainties on background
- limit beam-beam effects, preserve beam lifetime, reduce emittance
- Internation Task Force in place

Topic	VXD	CDC	PID	PID	ECL	KLM
$\mathcal{B}(B \to \tau\nu, B \to K^{(*)}\nu\bar{\nu})$	✓			✓	✓	✓
$\mathcal{B}(B \to X_u \ell\nu)$	✓		✓	✓		✓
R, Polarisation$(B \to D^{(*)}\tau\nu)$	✓				✓	
FEI	✓	✓		✓		
$S_{\mathrm{CP}}, C_{\mathrm{CP}}(B \to \pi^0\pi^0, K_S^0\pi^0)$	✓	✓			✓	
$S_{\mathrm{CP}}, C_{\mathrm{CP}}(B \to \rho\gamma)$		✓	✓		✓	
$S_{\mathrm{CP}}, C_{\mathrm{CP}}(B \to J/\psi K_{\mathrm{S}}^0, \eta' K_{\mathrm{S}}^0)$	✓	✓				
Flavour tagger	✓		✓			
τ LFV		✓			✓	
Dark sector searches		✓			✓	✓

Belle II detector upgrade in LS2

Leo Piilonen, Lepton Photon 2023

See Snowmass white papers:
arXiv:2203.11349 for detector upgrade
arXiv:2207.06307 for physics reach
arXiv:2203.05731 for backgrounds



KLM: replace RPCs with scintillators in barrel (some with fast timing for K_L time-of-flight); replace readout

ECL: replace crystals with pure CsI; APD readout; add pre-shower detector

TOP: replace readout to reduce size & power; replace all PMTs with extended-lifetime ALDs (or SiPMs?)

IR: accommodate QCS replacement and repositioning

STOPGAP: close gaps between TOP quartz bars, provide timing layers for track trigger

VXD: all pixels
- DMAPS
- SOI-DUTIP

ARICH: possible photosensor upgrade

CDC: replace readout ASIC+FPGA to improve radiation tolerance, cross-talk

TRIGGER: replace with latest tech to increase bandwidth, allow for new trigger primitives

More distant future: ~mid-2030's

✓ Detector R&D for extreme-$\mathcal{L}$ environment

Plans for Belle II detector upgrades

- Improve detector robustness against backgrounds, radiation resistance, physics performance

J. Baudot, FPCP 2023

EOI	Upgrade ideas scope and technology	Time scale
DMAPS	Fully pixelated Depleted CMOS tracker, replacing the current VXD. Evolution from ALICE ITS developed for ATLAS ITK.	LS2
SOI-DUTIP	Fully pixelated system replacing the current VXD based on Dual Timer Pixel concept on SOI	LS2
Thin Strips	Thin and fine-pitch double-sided silicon strip detector system replacing the current SVD and potentially the inner part of the CDC	LS2
CDC	Replacement of the readout electronics (ASIC, FPGA) to improve radiation tolerance and x-talk	< LS2
TOP	Replace readout electronics to reduce size and power, replacement of MCP-PMT with extended lifetime ALD PMT, study of SiPM photosensor option	LS2 and later
ECL	Crystal replacement with pure CsI and APD; pre-shower; replace PIN-diodes with APD photosensors.	> LS2
KLM	Replacement of barrel RPC with scintillators, upgrade of readout electronics, possible use as TOF	LS2 and later
Trigger	Take advantage of electronics technology development. Increase bandwidth, open possibility of new trigger primitives	< LS2 and later
STOPGAP	Study of fast CMOS to close the TOP gaps and/or provide timing layers for track trigger	> LS2
TPC	TPC option under study for longer term upgrade	> LS2

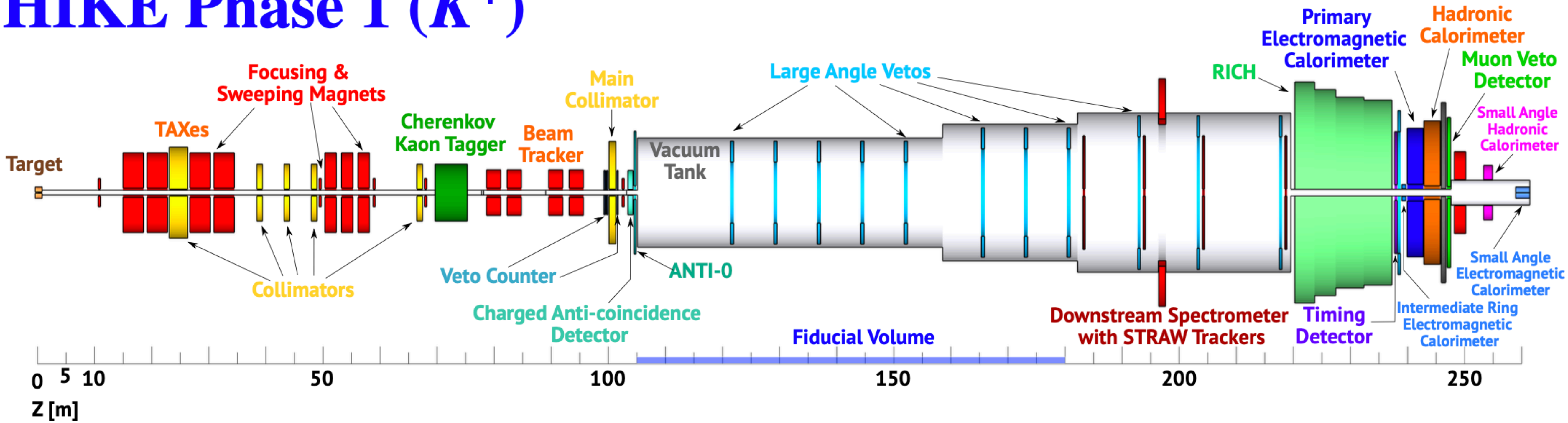
High Intensity Kaon Experiments

North Area of CERN Super Proton Synchrotron (SPS)

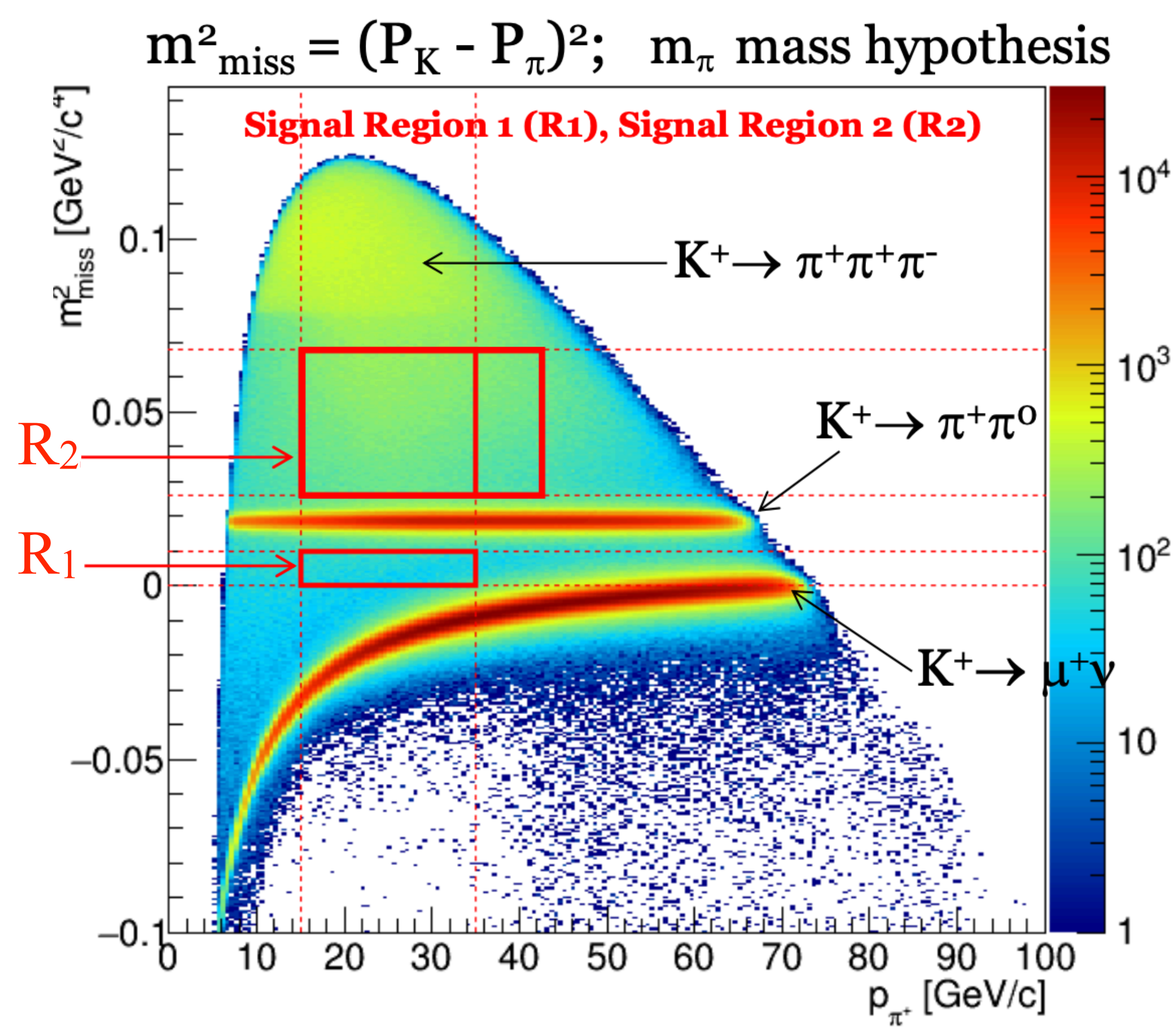
- Unique physics program complementary to LHC experiments
- Experimental apparatus changes over time in 3 phases and adapts to physics goals
- Timescale more than a decade

Phase	Protons on target/spill	K decays/year	Protons on TAX
Phase 1 (K^+)	1.2×10^{13}	2×10^{13}	-
Phase 2 (K_L+tracking)	2×10^{13}	3.8×10^{13}	-
Dump Mode	-	-	$(2–4)\times10^{13}$
Phase 3 (K_L, KLEVER)	2×10^{13}	1.3×10^{13}	-

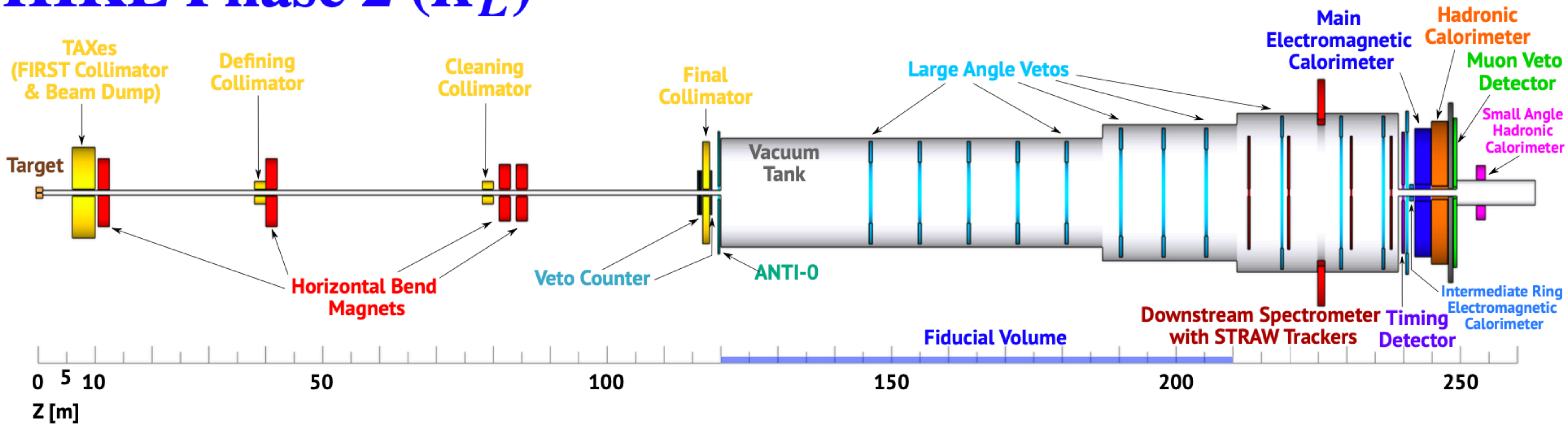
HIKE Phase 1 (K^+)



- Follow the successful NA62 strategy: 75 GeV/c K^+, 4x beam intensity to boost statistical sensitivity
- High-efficiency and high-precision tracking
- High-precision time measurements (20-40 ps) for track matching
- Hermetic veto system for photons and charged particles
- Excellent PID for π/μ discrimination



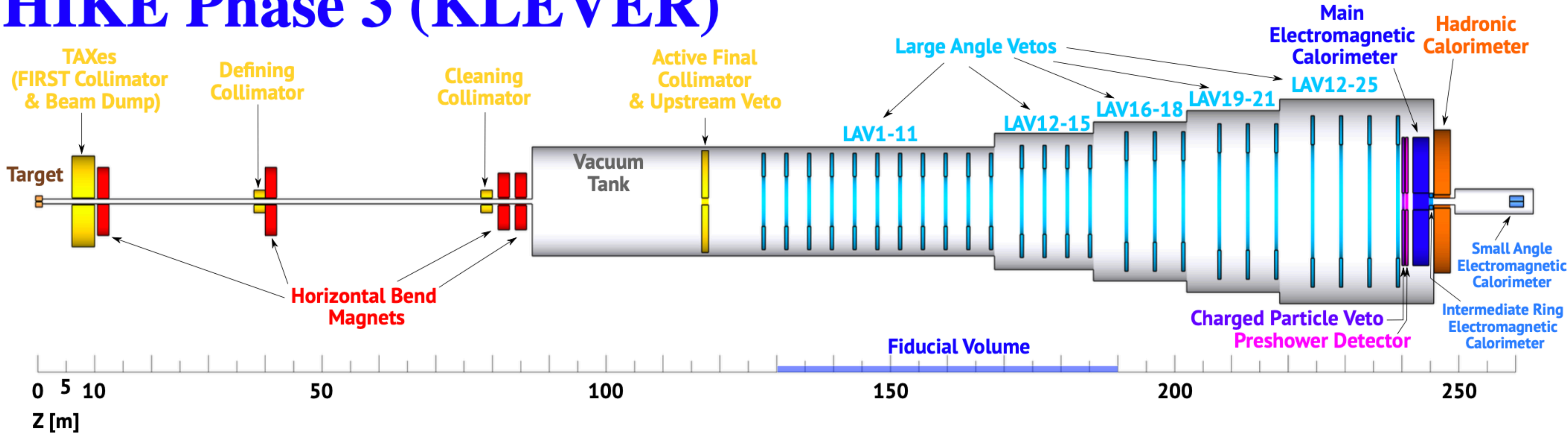
HIKE Phase 2 (K_L)



- Following the NA48 design for the neutral K_L^0 beam
- Detector challenges: 100 ps time resolution for π^0 of few GeV. R&D on calorimeters, innovative scintillators, longitudinal segmentation, oriented high-Z crystals

Mode	Assumed branching ratio	Acceptance	Signal yield in five years
$K_L \to \pi^0 e^+ e^-$	3.5×10^{-11}	2.1%	140
$K_L \to \pi^0 \mu^+ \mu^-$	1.4×10^{-11}	6.0%	160
$K_L \to \mu^+ \mu^-$	7×10^{-9}	17%	2.3×10^5
$K_L \to \mu^\pm e^\mp$	–	16%	–

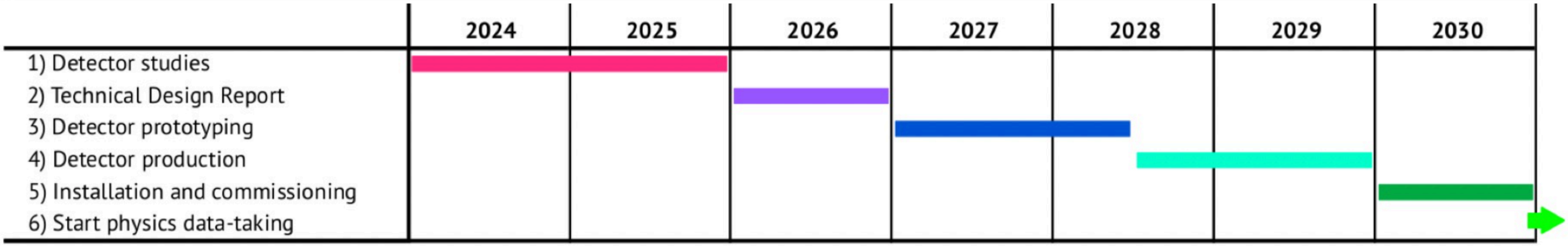
HIKE Phase 3 (KLEVER)



- Neutral secondary beam at 8 mrad. Optimal fiducial volume to maximise sensitivity and minimise background $K_L^0 \to \pi^0\pi^0$, $\Lambda \to n\pi^0$
- KLEVER beam line would need to add 150 m to reduce $\Lambda \to n\pi^0$ background
- Aim at signal yield 60 $K_L^0 \to \pi^0\nu\bar{\nu}$ at SM BR with $S/B = 1$
- Phase 3 data taking possibly before LS5 (in 2038) for about 5 years running

The HIKE Detectors

Detector	Phase 1	Phase 2	Comment	Preliminary group interests
Cherenkov K^+ tagger	upgraded	removed	faster photo-detectors	UK
Beam tracker	replaced	removed	3D-trenched silicon sensor	Italy,CERN,UK,Belgium,Canada,France
Upstream veto detectors	replaced	kept	SciFi	Switzerland
Large-angle vetos	replaced	kept	lead/scintillator tiles	UK
Downstream spectrometer	replaced	kept	STRAW (ultra-thin straws)	CERN,Kazakhstan,Slovakia,Czech Republic
Pion identification (RICH)	upgraded	removed	faster photo-detectors	Italy,Mexico
Main EM calorimeter	replaced	kept	fine-sampling shashlyk	Italy
Timing detector	upgraded	kept	higher granularity	Belgium
Hadronic calorimeter	replaced	kept	high-granularity sampling	Germany
Muon detector	upgraded	kept	higher granularity	Germany
Small-angle calorimeters	replaced	kept	oriented high-Z crystals	Italy
HASC	upgraded	kept	larger coverage	Romania



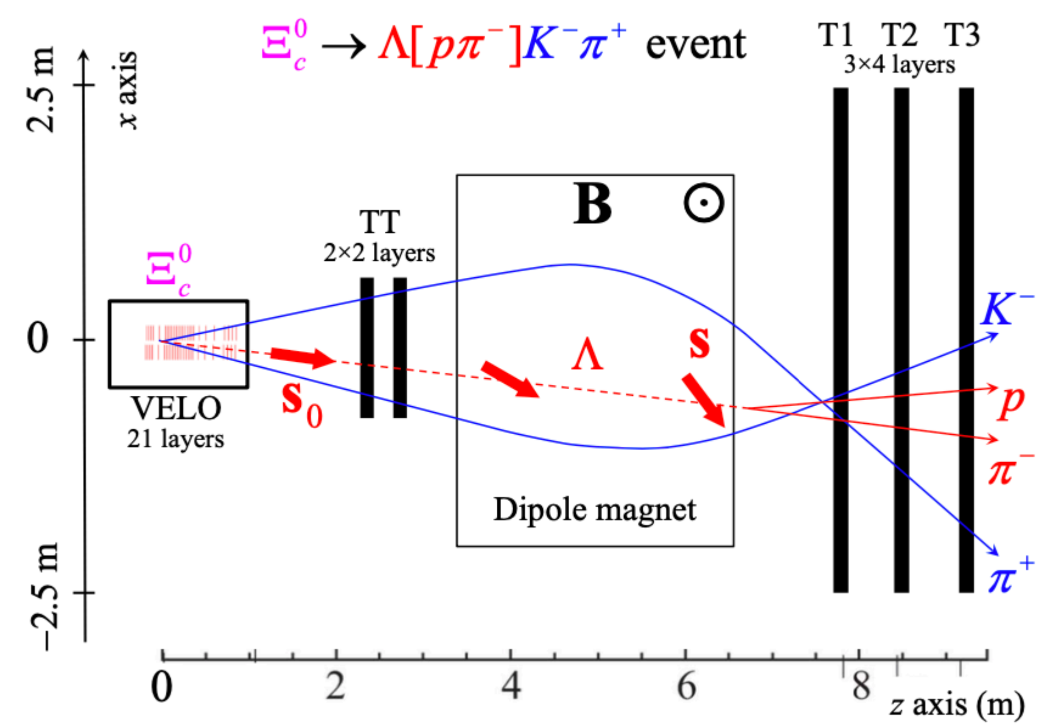
A. Romano, CERN seminar Nov 2023

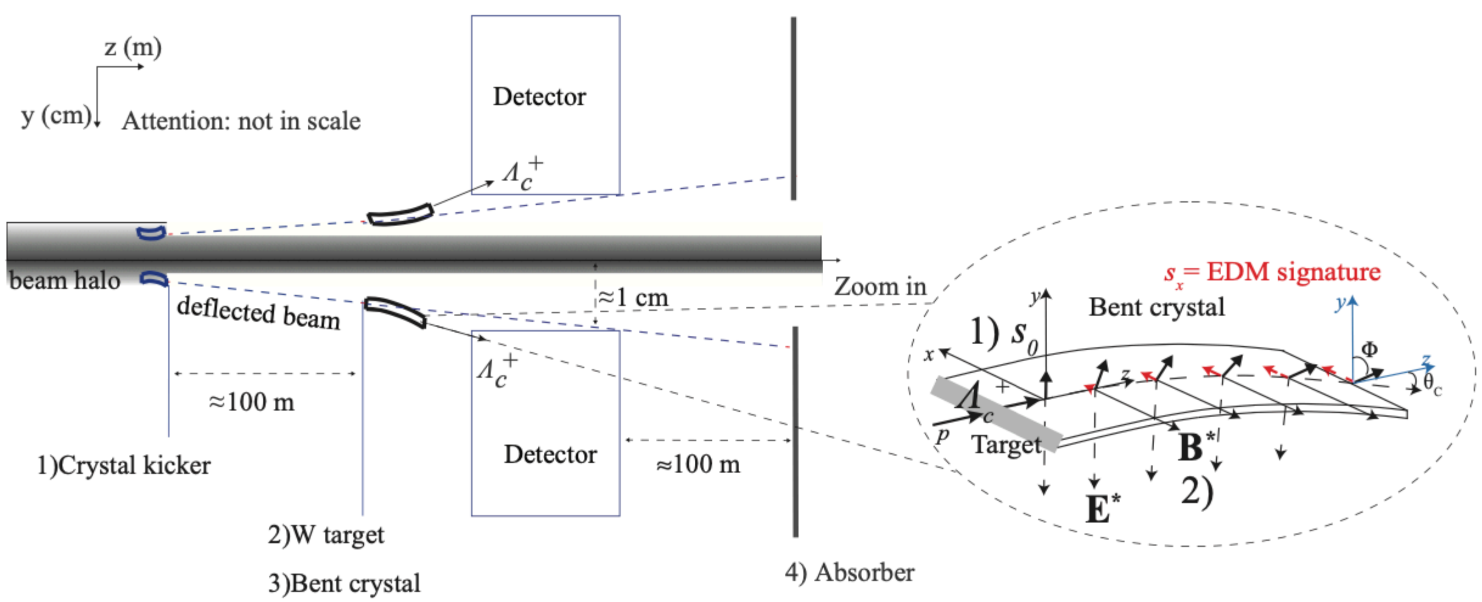
- For KLEVER, additional VETO detectors for π^0 and a pre shower for π^0 direction need to be developed: shaslyk calorimeter, micro pattern gas detector (MPGD)

Further opportunities: CP violation via EDM

- Direct measurements of heavy baryon electric and magnetic **dipole moments**
- Λ **baryon**: spin precession induced by the LHCb magnetic field
- Λ_c^+, Ξ_c^+ **baryons**: spin precession of channeled particles in bent crystals. A new fixed-target setup at LHC has been proposed
- Proof-of-principle test at LHC IR3 scheduled in 2025

LHCB-PUB-2018-009, arXiv:1808.08865





Main challenges

- LHCb upgrade II: precise timing detectors ($\lesssim 50$ ps), radiation hardness (400 Mrad/year inner VELO), TDAQ (>10 TB/s), cost (175 MCHF), timeline (2041 end of HL-LHC)
- Belle II: accelerator upgrade (lumi 6.5×10^{35} $cm^{-2}s^{-1}$), low machine background, cost (≈90 MCHF), radiation hardness (10 Mrad/year inner VXD), low material budget
- HIKE: CERN approval, tracking at 3 GHz incoming beam particles, precise timing detectors ($\lesssim 50$ ps), calorimeter, straw trackers for high rates

Summary and prospects

- Precision **flavour physics** is a fundamental tool for discovery: great physics reach compared to direct and electroweak precision searches
- **Theoretically clean** processes and improvements in lattice-QCD motivate precise experimental measurements of flavour observables
- **LHCb Upgrade II, Belle II, HIKE** : are unique and complementary opportunities for fully exploiting the flavour physics potential at the high-intensity frontier
- **Unique** program for *K, D, B* and τ physics on a timescale more than a decade: studies of CP violation, precision measurements of CKM parameters for an ultimate test of the SM

Backup

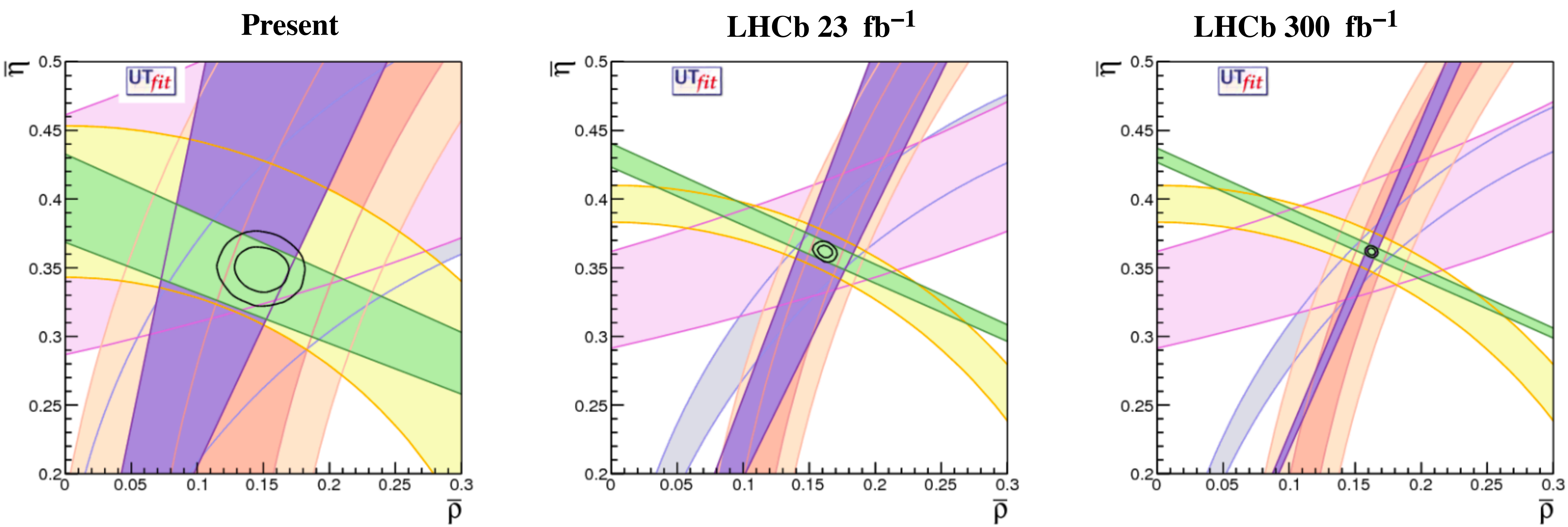
Prospects for future measurements at LHCb

Observable	Current LHCb	LHCb 2025	Upgrade II
EW Penguins			
R_K $(1 < q^2 < 6\,\mathrm{GeV}^2c^4)$	0.1 [5]	0.025	0.007
R_{K^*} $(1 < q^2 < 6\,\mathrm{GeV}^2c^4)$	0.1 [6]	0.031	0.008
R_ϕ, R_{pK}, R_π	–	0.08, 0.06, 0.18	0.02, 0.02, 0.05
CKM tests			
γ, with $B_s^0 \to D_s^+ K^-$	$(^{+17}_{-22})^\circ$ [7]	4°	1°
γ, all modes	$(^{+5.0}_{-5.8})^\circ$ [8]	1.5°	0.35°
$\sin 2\beta$, with $B^0 \to J/\psi K_S^0$	0.04 [9]	0.011	0.003
ϕ_s, with $B_s^0 \to J/\psi\phi$	49 mrad [10]	14 mrad	4 mrad
ϕ_s, with $B_s^0 \to D_s^+ D_s^-$	170 mrad [11]	35 mrad	9 mrad
$\phi_s^{s\bar{s}s}$, with $B_s^0 \to \phi\phi$	154 mrad [12]	39 mrad	11 mrad
a_{sl}^s	33×10^{-4} [13]	10×10^{-4}	3×10^{-4}
$\lvert V_{ub}\rvert/\lvert V_{cb}\rvert$	6% [14]	3%	1%
$\boldsymbol{B_s^0, B^0 \to \mu^+\mu^-}$			
$\mathcal{B}(B^0 \to \mu^+\mu^-)/\mathcal{B}(B_s^0 \to \mu^+\mu^-)$	90% [15]	34%	10%
$\tau_{B_s^0 \to \mu^+\mu^-}$	22% [15]	8%	2%
$S_{\mu\mu}$	–	–	0.2
$\boldsymbol{b \to c\ell^-\bar{\nu}_l}$ **LUV studies**			
$R(D^*)$	0.026 [16, 17]	0.0072	0.002
$R(J/\psi)$	0.24 [18]	0.071	0.02
Charm			
$\Delta A_{CP}(KK - \pi\pi)$	8.5×10^{-4} [19]	1.7×10^{-4}	3.0×10^{-5}
A_Γ $(\approx x \sin\phi)$	2.8×10^{-4} [20]	4.3×10^{-5}	1.0×10^{-5}
$x \sin\phi$ from $D^0 \to K^+\pi^-$	13×10^{-4} [21]	3.2×10^{-4}	8.0×10^{-5}
$x \sin\phi$ from multibody decays	–	$(K3\pi)$ 4.0×10^{-5}	$(K3\pi)$ 8.0×10^{-6}

Unitarity triangle fit

UTFit results

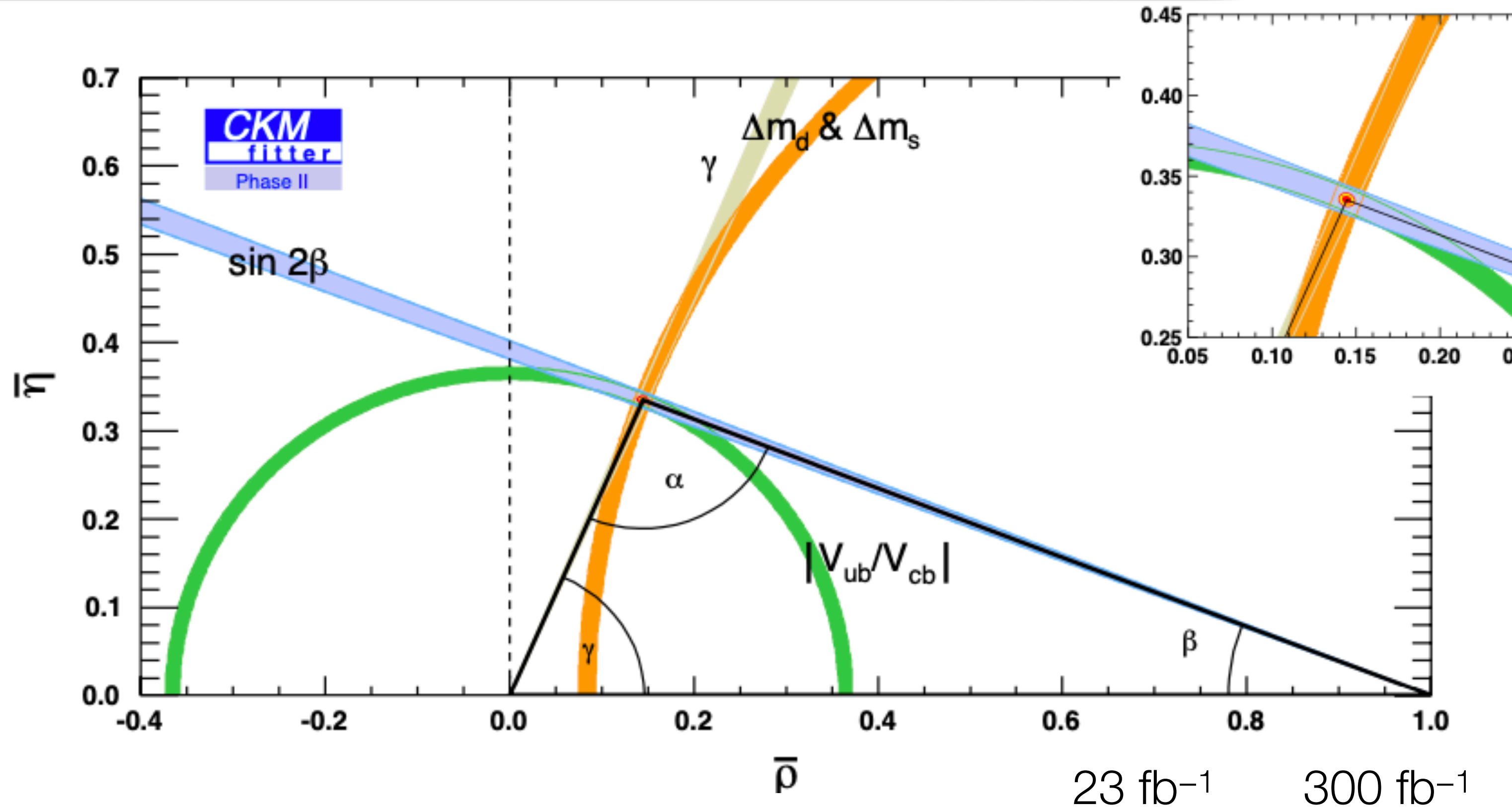
CERN-LPCC-2018-06 , arXiv:1812.07638



		λ	$\bar{\rho}$	$\bar{\eta}$	A	$\sin 2\beta$	γ	α	β_s
	Current	0.12%	9%	3%	1.5%	4.5%	3%	2.5%	3%
23 fb^{-1}	Phase 1	0.12%	2%	0.8%	0.6%	0.9%	0.9%	0.7%	0.8%
300 fb^{-1}	Phase 2	0.12%	1%	0.6%	0.5%	0.6%	0.8%	0.4%	0.5%

CKM fits

- In figure: constraints on $\bar{\rho}, \bar{\eta}$ parameters using only LHCb and lattice QCD expected improvements with 300 fb^{-1}



Quantity	Ref.	present error	short-term (23 fb^{-1})	mid-term (300 fb^{-1})
$(\Delta m_s/\Delta m_d)_{\rm exp}$	[33]	0.4%	-	-
ξ for $(\Delta m_s/\Delta m_d)_{\rm theor}$	[309]	1.4%	0.3%	0.3%
$B\to\pi$: $\lvert V_{ub}\rvert_{\rm exp}$	[309, 334, 340]	2.3%	1.6%	1.1%
$B\to\pi$: $\lvert V_{ub}\rvert_{\rm theor}$	[309]	2.9%	1%	1%
$B\to D$: $\lvert V_{cb}\rvert_{\rm exp}$	[309, 340]	2.0%	1.4%	-
$B\to D$: $\lvert V_{cb}\rvert_{\rm theor}$	[309]	1.4%	0.3%	0.3%
$B\to D^*$: $\lvert V_{cb}\rvert_{\rm exp}$	[340]	1.2%	-	-
$B\to D^*$: $\lvert V_{cb}\rvert_{\rm theor}$	[309]	1.4%	0.4%	0.4%
$\Lambda_b\to p(\Lambda_c)$: $\lvert V_{ub}/V_{cb}\rvert_{\rm exp}$	[334]	6%	1%	1%
$\Lambda_b\to p(\Lambda_c)$: $\lvert V_{ub}/V_{cb}\rvert_{\rm theor}$	[309]	4.9%	1.2%	1.2%

- In figure: constraints on $\bar{\rho}, \bar{\eta}$ parameters using only LHCb and lattice QCD expected improvements with 300 fb^{-1}

	λ	$\bar{\rho}$	$\bar{\eta}$	A	$\sin 2\beta$	γ	α	β_s
Current	0.12%	9%	3%	1.5%	4.5%	3%	2.5%	3%
short-term (23 fb^{-1})	0.12%	2%	0.8%	0.6%	0.9%	0.9%	0.7%	0.8%
mid-term (300 fb^{-1})	0.12%	1%	0.6%	0.5%	0.6%	0.8%	0.4%	0.5%

EDM limits

- Summary of current EDM limits and future planned sensitivities