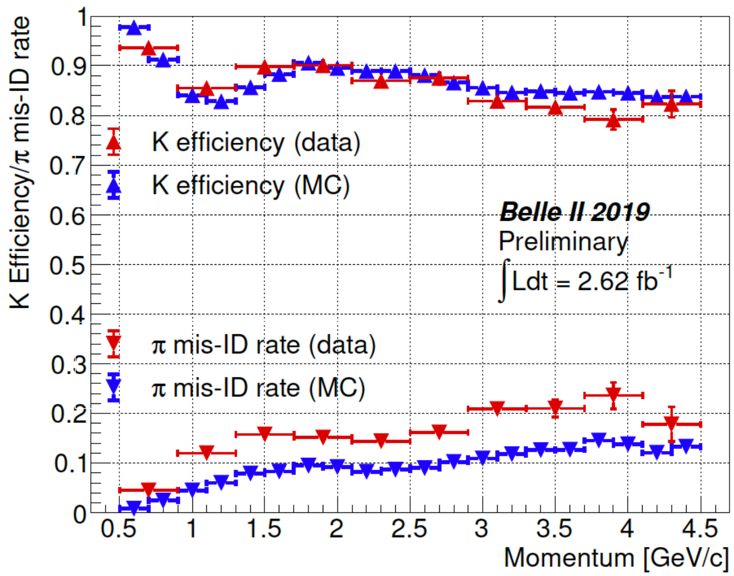
Belle II status and prospects



Gagan Mohanty

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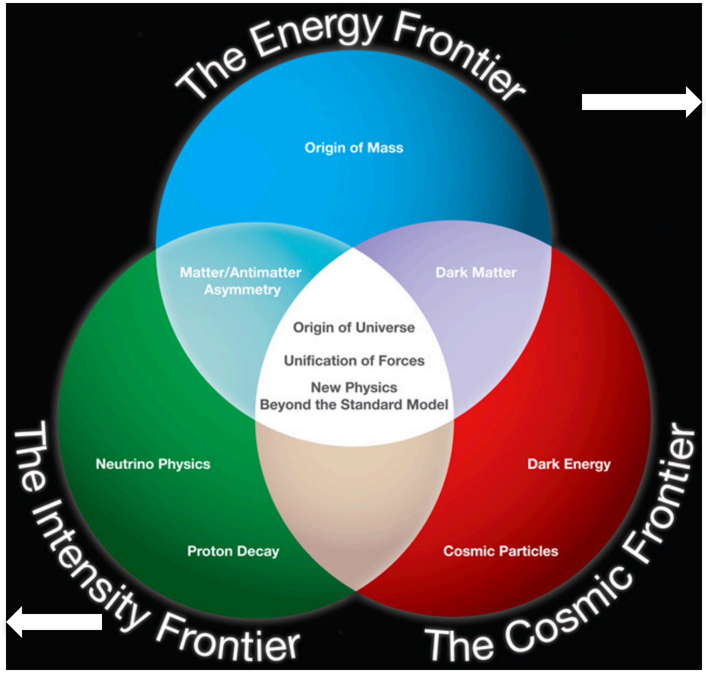
BEAUTY 2019

18th INTERNATIONAL CONFERENCE ON B-PHYSICS AT FRONTIER MACHINES

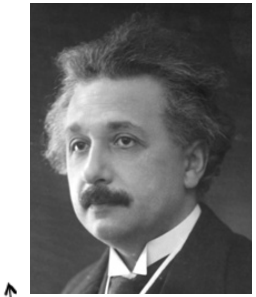
Ljubljana, Slovenia

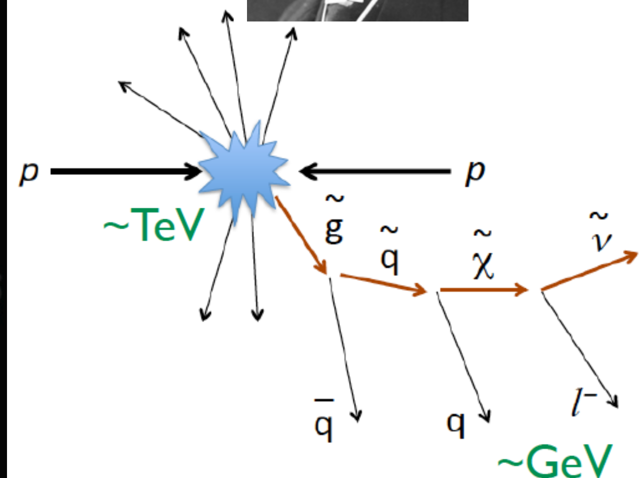
September 30 - October 4, 2019

Flavor physics: why?

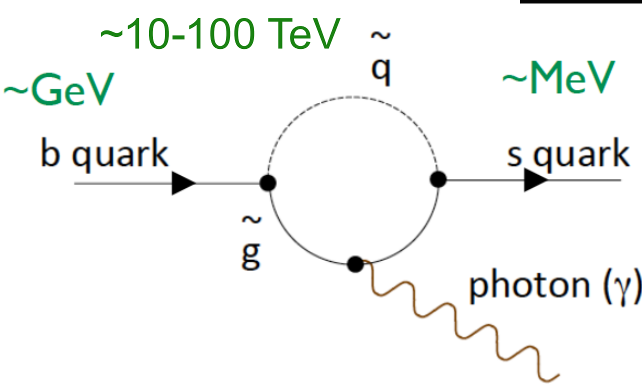


E ~ m



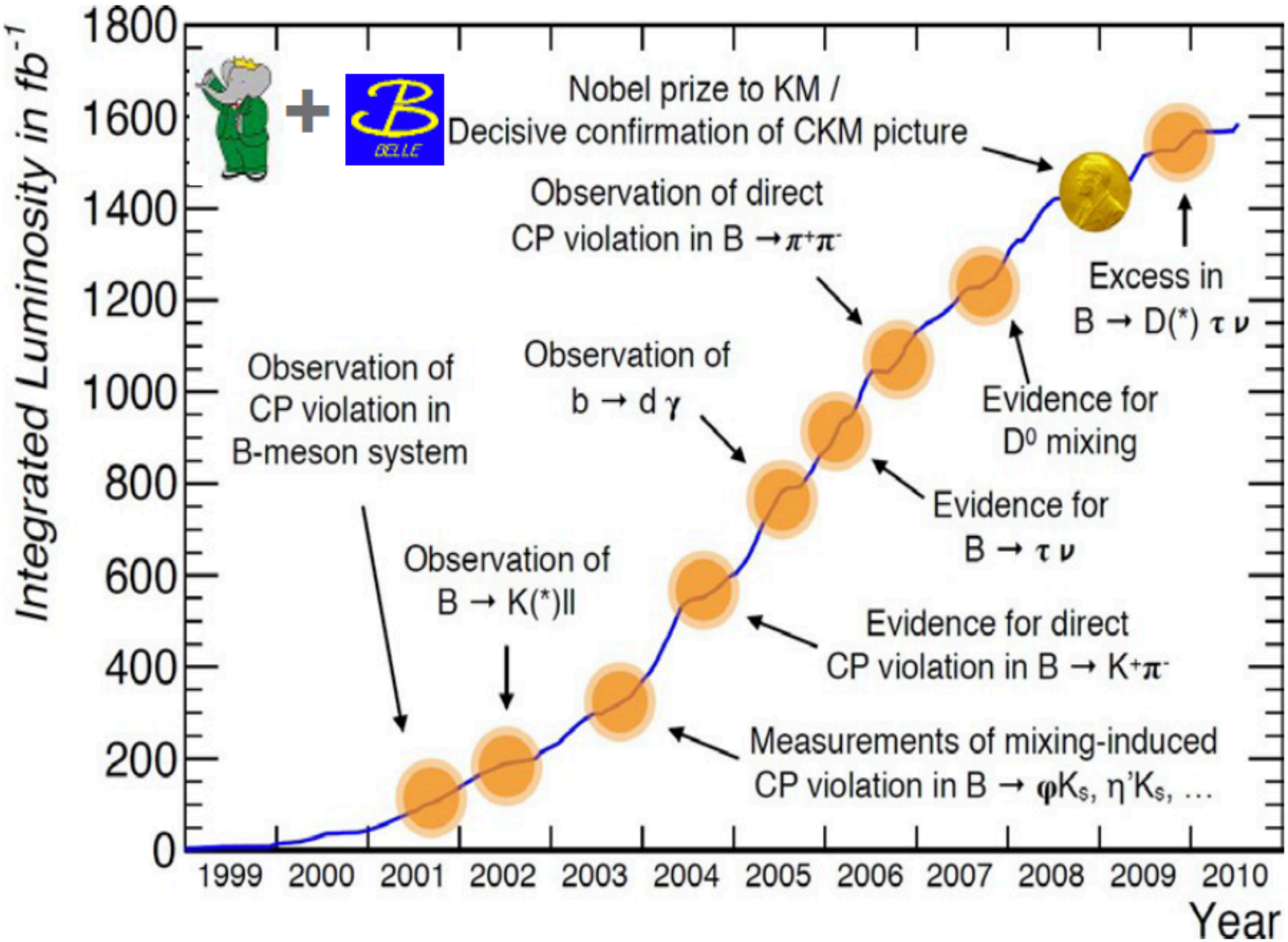


Δm.Δt ~ 1



- ❑ Provides a unique probe to unravel deeper mysteries of universe with intense sources and highly sensitive detectors

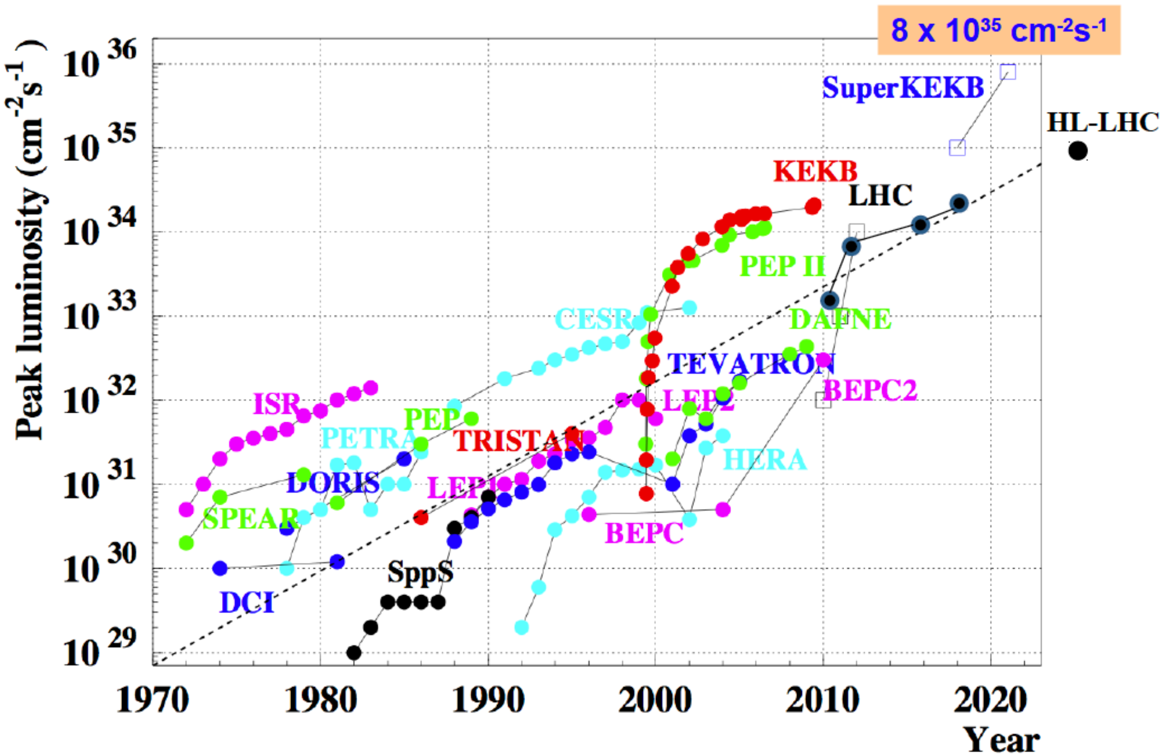
First-generation e^+e^- flavor factories



- ❑ Success culminated in 2008 Nobel prize in Physics
- ❑ Rich legacy left for next-gen expt. EPJ C74, 3026 (2014)

So, why another e^+e^- flavor factory?

- ❑ Precision CKM metrology ➔ Standard Model (SM) candle
- ❑ New CP violating phase? ➔ CP violation in B and D decays
- ❑ Any imprints of new physics beyond SM in FCNC transitions? ➔ radiative and electroweak penguin decays
- ❑ How about charged Higgs boson or leptoquark? ➔ tree-level B decay to $\tau\nu$ or $D^{(*)}\tau\nu$ final state
- ❑ New physics in the charged lepton sector ➔ search for lepton flavor violating tau decays
- ❑ Can we chase down dark matter from bottom? ➔ probe hidden dark sector



☞ Belle II @ SuperKEKB will address these questions with almost two orders of magnitude larger dataset than Belle+BaBar

Snapshots of what Belle II can achieve?

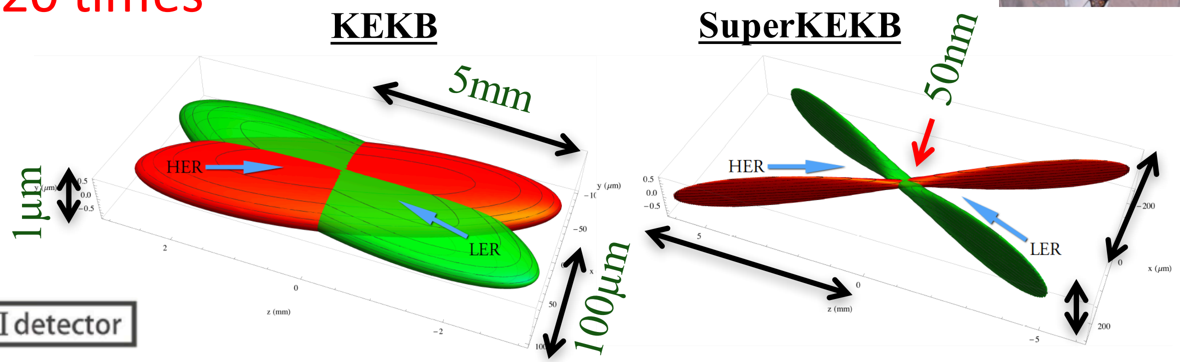
Observables	Expected the. accuracy	Expected exp. uncertainty	Facility (2025)
UT angles & sides			
ϕ_1 [°]	***	0.4	Belle II
ϕ_2 [°]	**	1.0	Belle II
ϕ_3 [°]	***	1.0	LHCb/Belle II
$\lvert V_{cb}\rvert$ incl.	***	1%	Belle II
$\lvert V_{cb}\rvert$ excl.	***	1.5%	Belle II
$\lvert V_{ub}\rvert$ incl.	**	3%	Belle II
$\lvert V_{ub}\rvert$ excl.	**	2%	Belle II/LHCb
CP Violation			
$S(B \to \phi K^0)$	***	0.02	Belle II
$S(B \to \eta' K^0)$	***	0.01	Belle II
$\mathcal{A}(B \to K^0\pi^0)[10^{-2}]$	***	4	Belle II
$\mathcal{A}(B \to K^+\pi^-)$ $[10^{-2}]$	***	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
$S(B \to \rho\gamma)$	**	0.07	Belle II
$\mathcal{B}(B_s \to \gamma\gamma)$ $[10^{-6}]$	**	0.3	Belle II
$\mathcal{B}(B \to K^*\nu\overline{\nu})$ $[10^{-6}]$	***	15%	Belle II
$R(B \to K^*\ell\ell)$	***	0.03	Belle II/LHCb
Charm			
$\mathcal{B}(D_s \to \mu\nu)$	***	0.9%	Belle II
$\mathcal{B}(D_s \to \tau\nu)$	***	2%	Belle II
$A_{CP}(D^0 \to K_S^0\pi^0)$ $[10^{-2}]$	**	0.03	Belle II
$\lvert q/p\rvert(D^0 \to K_S^0\pi^+\pi^-)$	***	0.03	Belle II
$A_{CP}(D^+ \to \pi^+\pi^0)$ $[10^{-2}]$	**	0.17	Belle II
Tau			
$\tau \to \mu\gamma$ $[10^{-10}]$	***	< 50	Belle II
$\tau \to e\gamma$ $[10^{-10}]$	***	< 100	Belle II
$\tau \to \mu\mu\mu$ $[10^{-10}]$	***	< 3	Belle II/LHCb

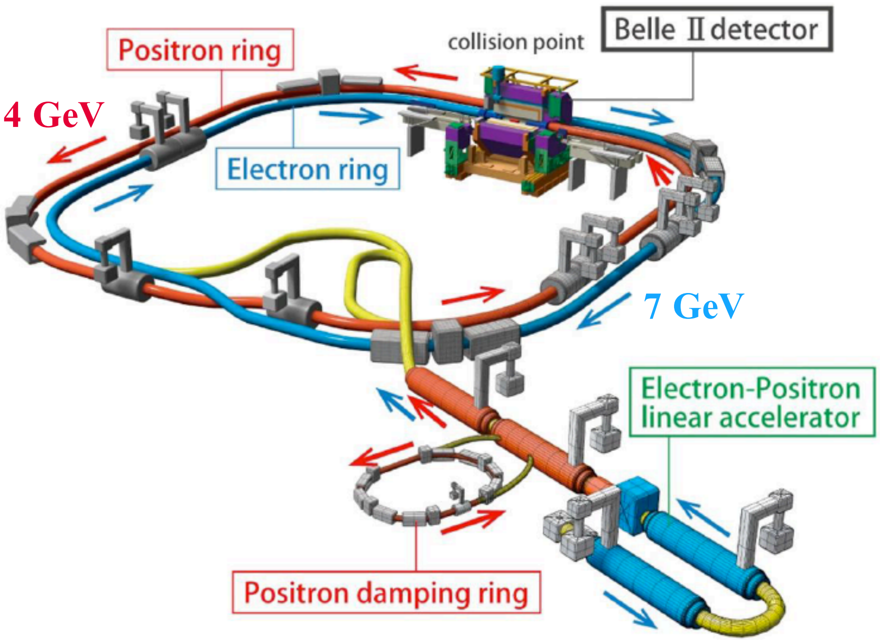
☞ From Belle II physics book arXiv:1808.10567

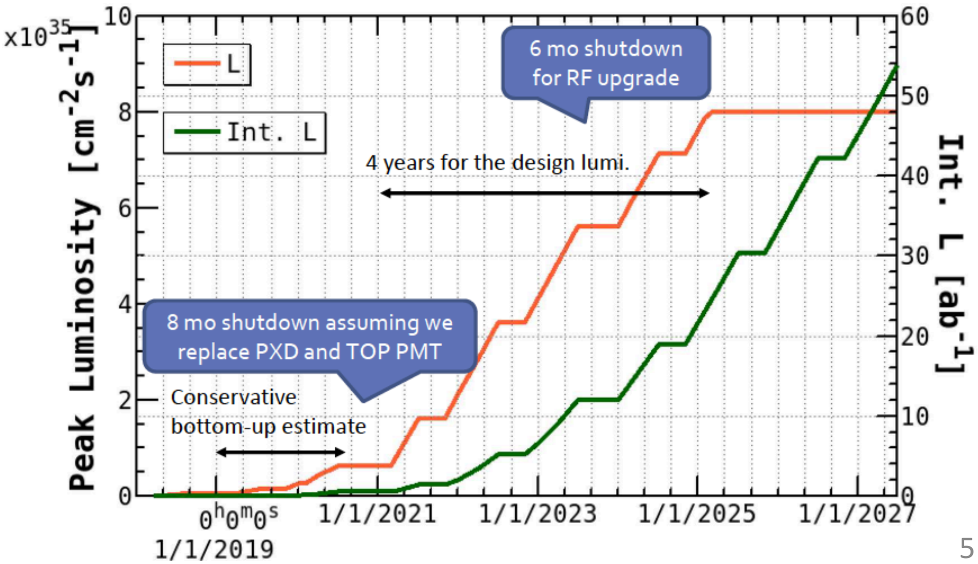
- Precision CKM metrology
- Direct and mixing-induced CP violation in B decays
- (Semi-)leptonic B decays
- Radiative & electroweak penguins
- Vibrant charm program
- Search of LFV tau decays

SuperKEKB: New intensity frontier machine

- Targets to deliver e^+e^- collisions at a peak luminosity of $8 \times 10^{35}\ cm^{-2}s^{-1}$, 40 times that of KEKB
  - ✧ Increase beam currents twice
  - ✧ Reduce beam size by 20 times

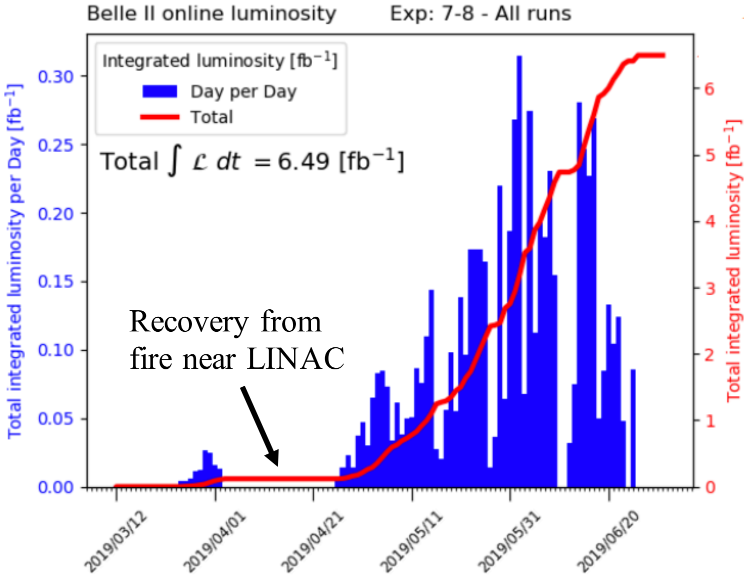






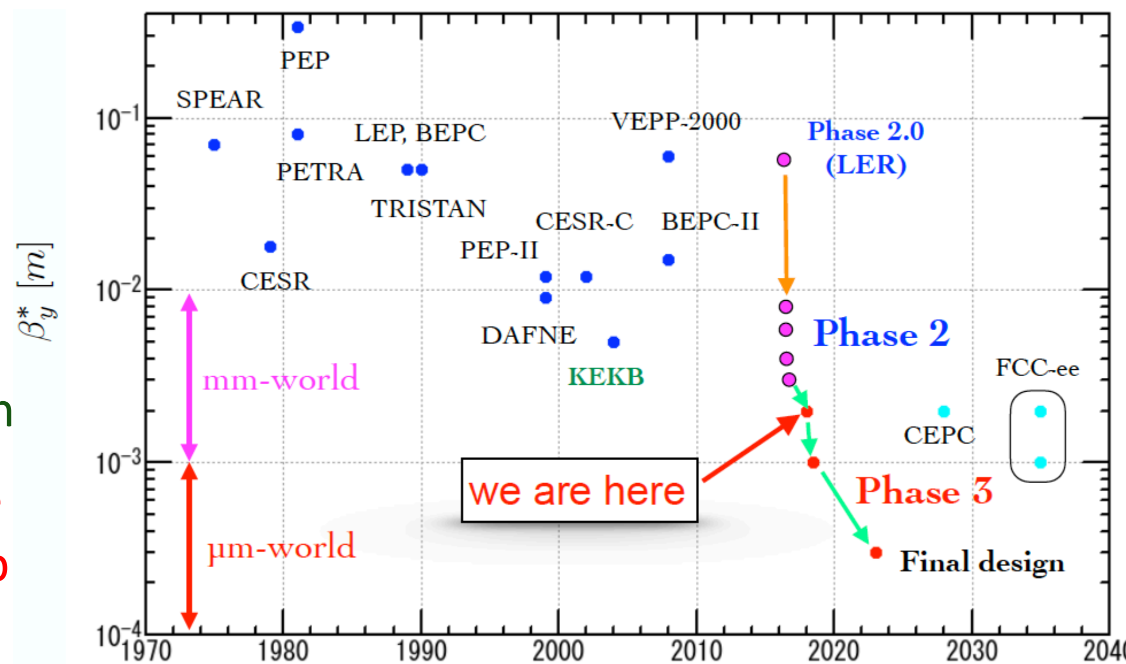
- ➢ First new particle collider after LHC!

How far have we gone?



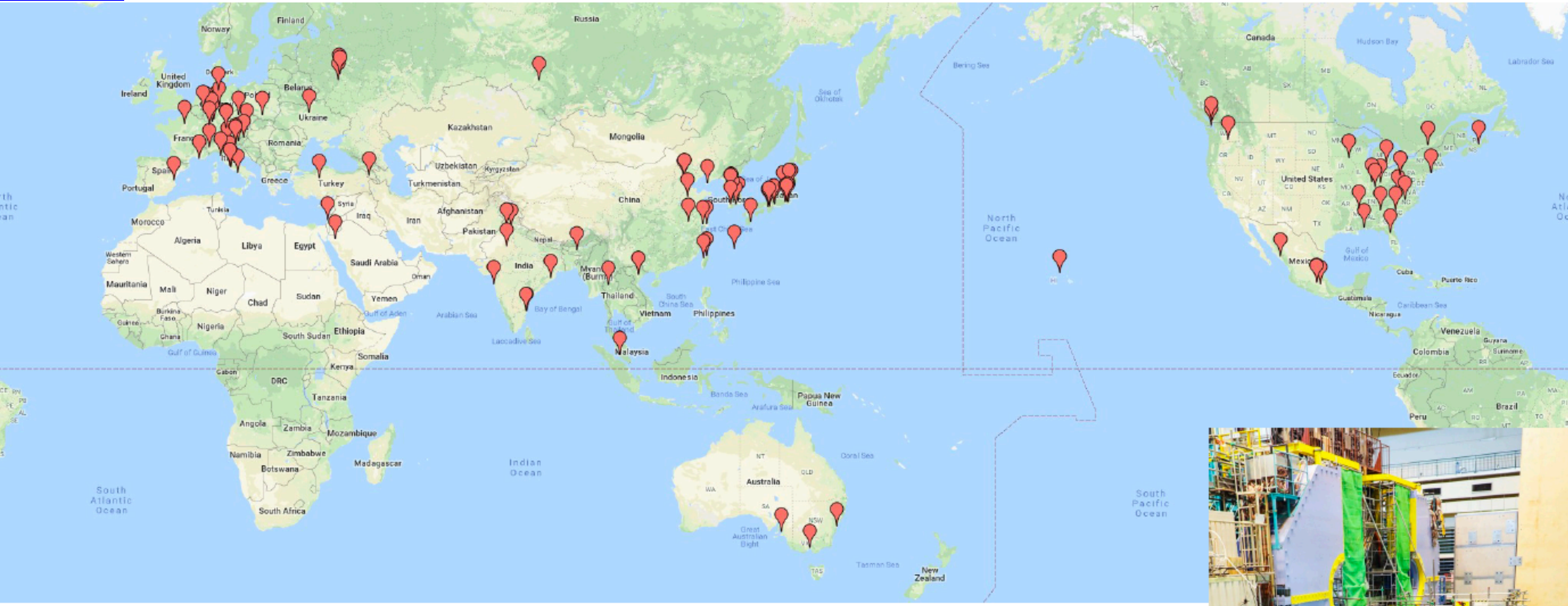
- ❑ Phase 2 (2018): beam commissioning (establish nano-beam scheme, reach the KEKB luminosity, and measure beam backgrounds) as well as for doing some physics with partial vertex detector
- ❑ Phase 3 (2019 onward): physics run with almost complete vertex detector

- ❑ Reached $\beta_y^\star$ = 33 mm in 2018
- ❑ Went down $\beta_y^\star$ = 2 mm by end of Summer 2019 (with Belle II off) ➔ starting point for fall run
- ☞ Design luminosity requires one more order-of-magnitude jump to $\beta_y^\star$ = 0.3 mm



- ❑ Currents achieved: 880 (940) mA for e^+ (e^-) beam ➔ need 3 (4)× scale up

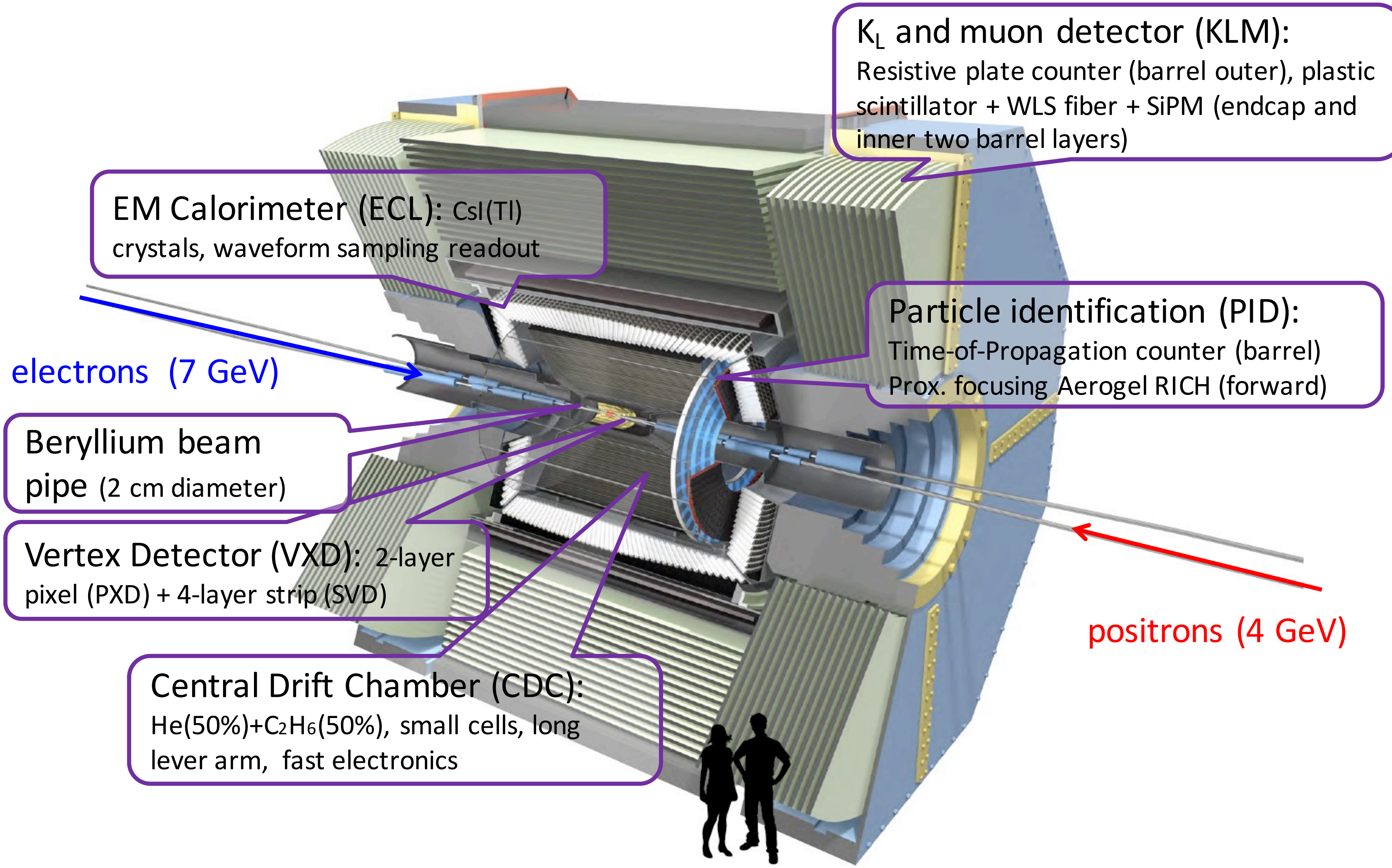
Belle II collaboration



- ❑ Close to 950 researchers from 112 institutions in 26 countries
- ❑ Slovenia is an important player
- ☞ Leadership position, as well as key contributions to detector, reconstruction software and computing

Belle II: A 21st century HEP experiment

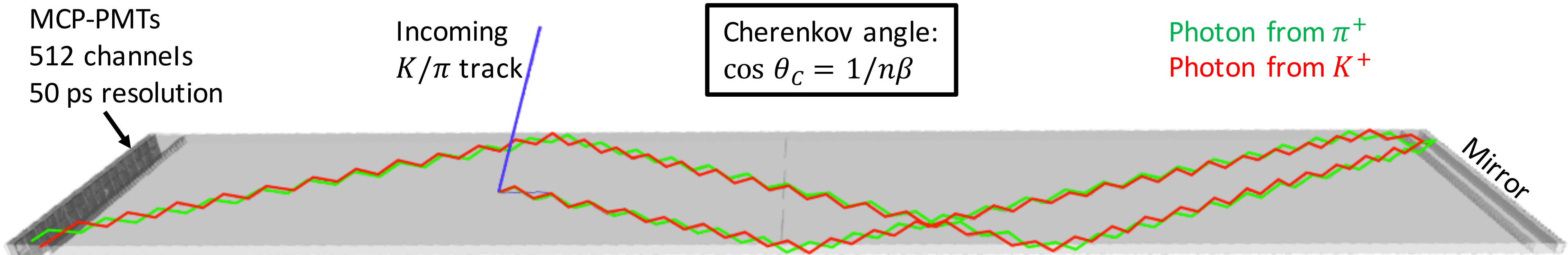
☞ Designed to operate with a performance similar or better than Belle, but in a harsh beam background condition



Two detector highlights

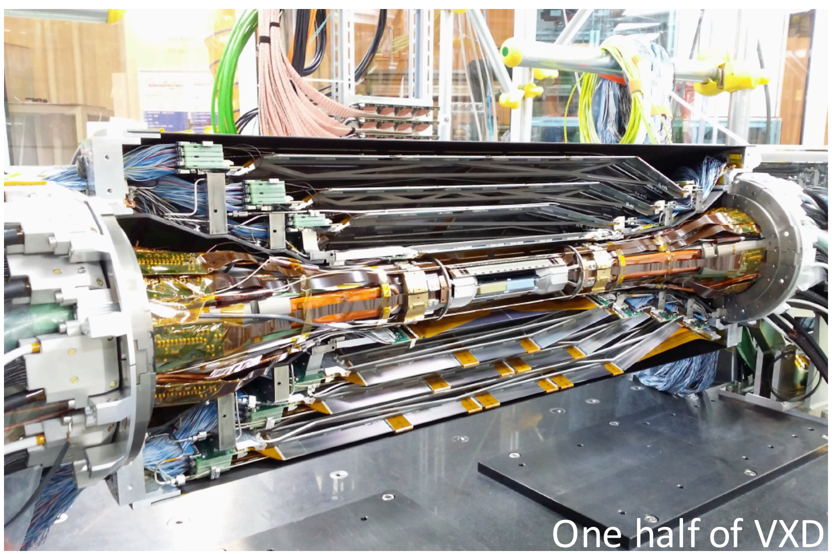
Barrel PID (uses Cherenkov radiation)

☞ The paths of Cherenkov photons from a 2 GeV pion and kaon interacting in a TOP quartz bar (Japan, US, Slovenia and Italy)



Quartz bar (length = 2600 mm, width = 450 mm, thickness = 20 mm)

VXD (6 layer Si for vertexing & inner tracking)



Beampipe r = 10 mm

DEPFET pixels (Germany, Czech Republic, Spain…)

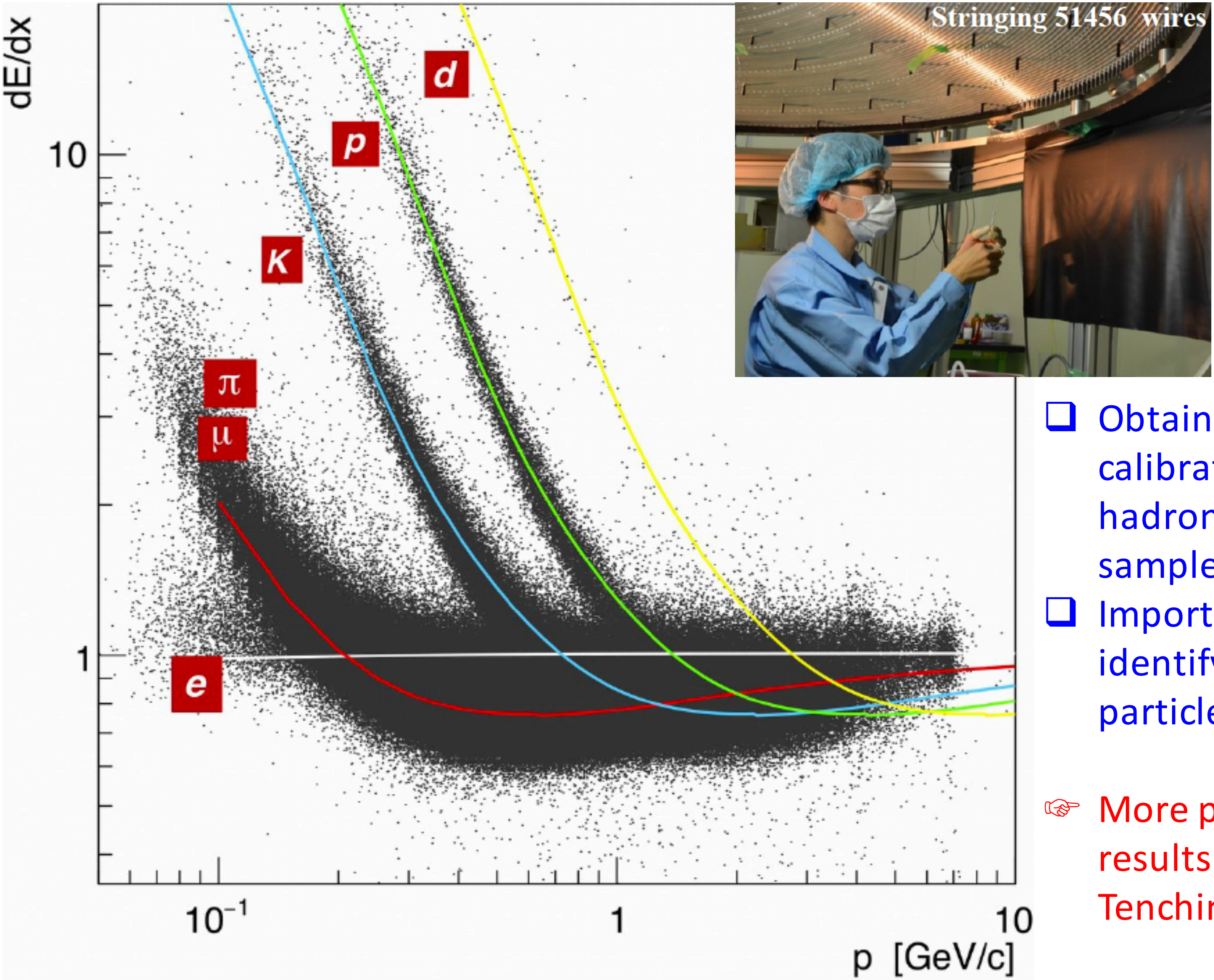
- Layer 1 r = 14 mm
- Layer 2 r = 22 mm (1/6 now, rest in 2020)

DSSD (double sided silicon micro-strips)

- Layer 3 r = 38 mm (Australia)
- Layer 4 r = 80 mm (India)
- Layer 5 r = 115 mm (Austria)
- Layer 6 r = 140 mm (Japan)

FWD/BWD Italy

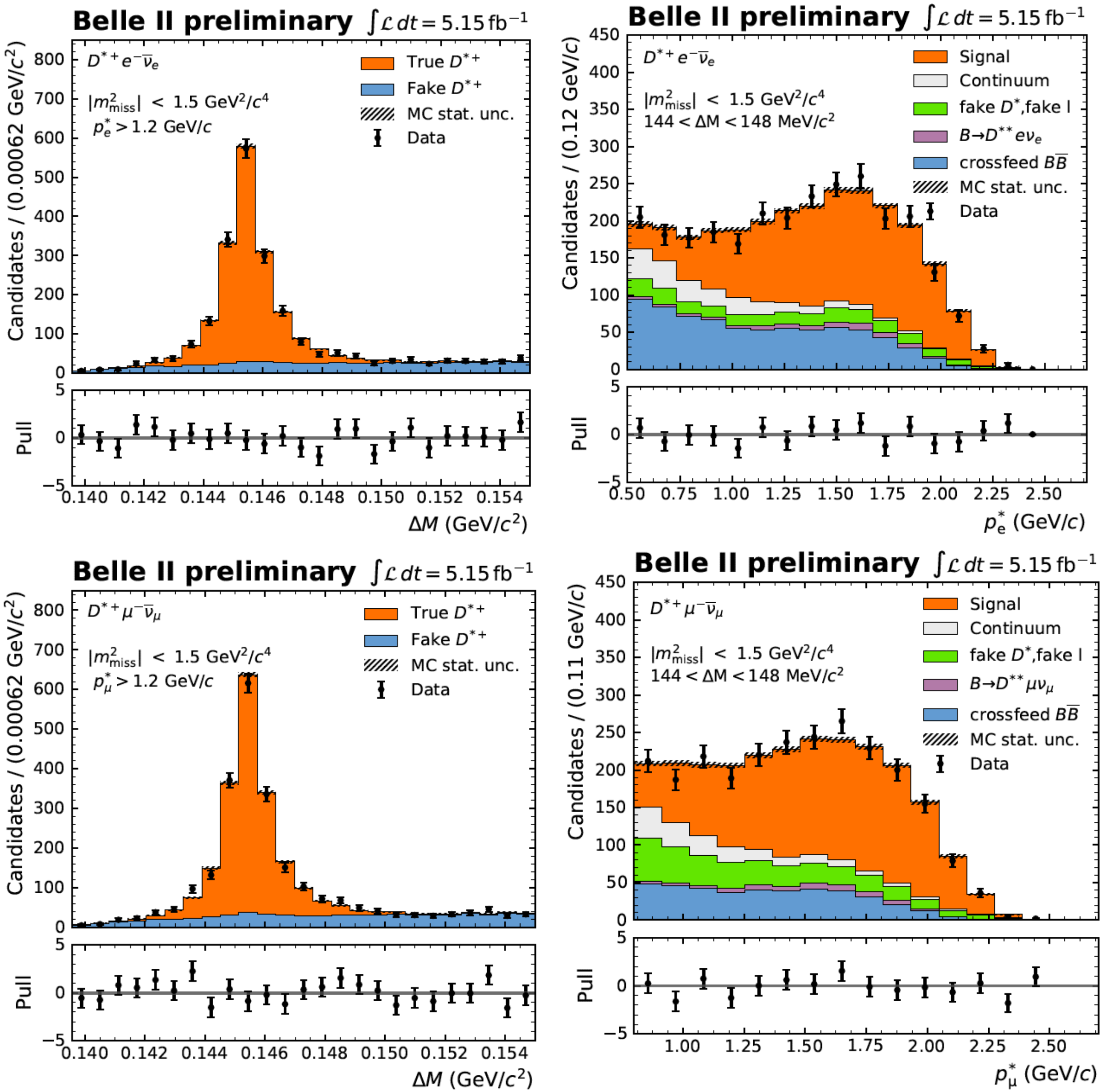
A performance example: dE/dx in CDC



- Obtained with early calibrations in the hadronic event sample
- Important role in identifying charged particles

☞ More performance results will be in Tenchini's talk

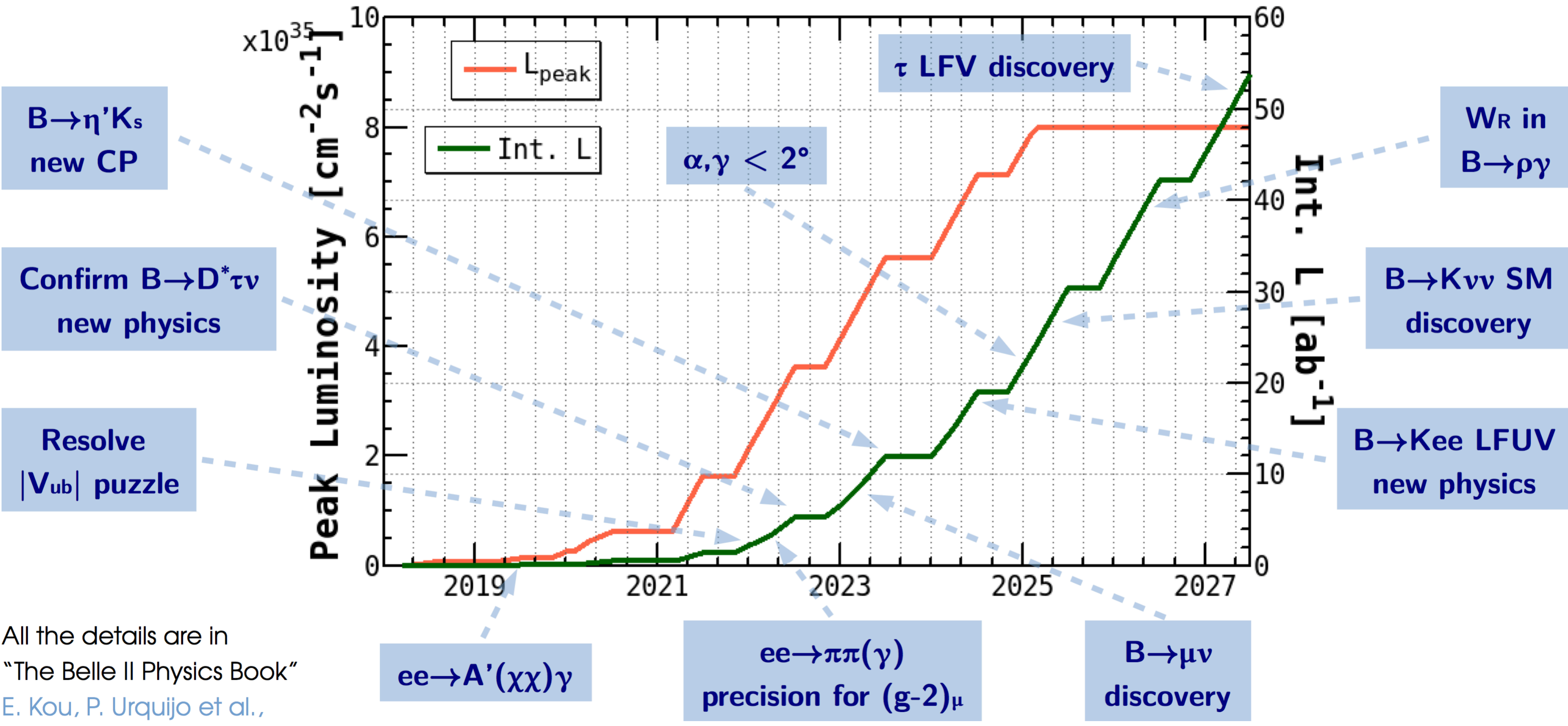
A physics example: fresh from 



- Study of untagged $B \rightarrow D^* \ell \nu_\ell$ channel using 5.15 fb^{-1} early phase-3 data
- Over 1k signal events in both electron and muon channels

☞ For more on physics, see talks by Graziani, Yonenaga, Yusa and Kwon

Prospects: physics harvesting



All the details are in
"The Belle II Physics Book"
E. Kou, P. Urquijo et al.,
arXiv:1808.10567

☞ Adapted from Forti's talk at EPS-HEP 2019

Prospects: improvements to detector

- Short term:
  - Replacement of MCP-PMTs with ALD PMTs for TOP
  - Complete installation of VXD layer-2
  - DAQ upgrade

- Medium term:
  - Looking at options for making the detector more resilient against the background and radiation bursts

- Long term:
  - Started thinking about possibilities for luminosity upgrade
  - ☞ e.g., Belle II VXD open workshop http://indico.cern.ch/event/810687/

Closing words

- Belle II will probe new physics at the intensity frontier → complementary to high p_T programs of ATLAS and CMS

- As for LHCb, there is healthy competition and complementarity between the two

- 1st physics run in Spring 2019 has completed delivering ~6.5 fb^{-1} → fall run is about to begin

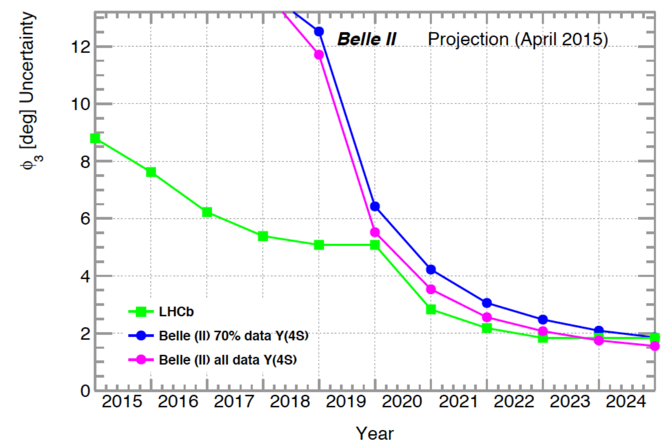
- Detector and machine initial performances have been good, though the road ahead is pretty long to achieve the design goal

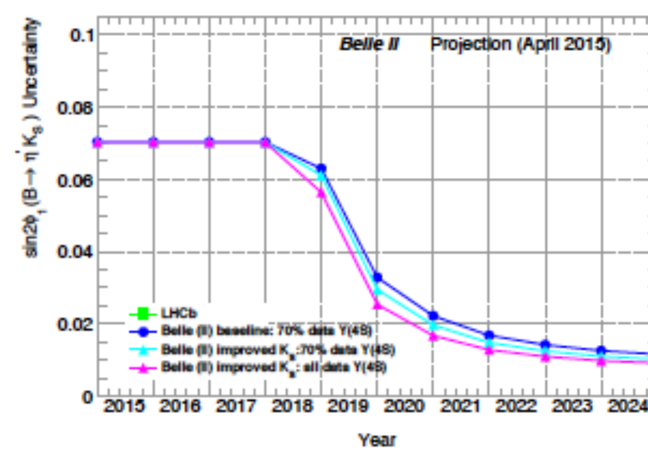
Additional information

Belle II vs. LHCb

Observable	Expected th. accuracy	Expected exp. uncertainty	Facility
CKM matrix			
$\lvert V_{us}\rvert$ [$K \to \pi\ell\nu$]	**	0.1%	K-factory
$\lvert V_{cb}\rvert$ [$B \to X_c\ell\nu$]	**	1%	Belle II
$\lvert V_{ub}\rvert$ [$B_d \to \pi\ell\nu$]	*	4%	Belle II
$\sin(2\phi_1)$ [$c\bar{c}K^0_S$	***	$8 \cdot 10^{-3}$	Belle II/LHCb
ϕ_2		1.5°	Belle II
ϕ_3	***	3°	LHCb
CPV			
$S(B_s \to \psi\phi)$	**	0.01	LHCb
$S(B_s \to \phi\phi)$	**	0.05	LHCb
$S(B_d \to \phi K)$	***	0.05	Belle II/LHCb
$S(B_d \to \eta' K)$	***	0.02	Belle II
$S(B_d \to K^*(\to K^0_S\pi^0)\gamma))$	***	0.03	Belle II
$S(B_s \to \phi\gamma))$	***	0.05	LHCb
$S(B_d \to \rho\gamma))$		0.15	Belle II
A^d_{SL}	***	0.001	LHCb
A^s_{SL}	***	0.001	LHCb
$A_{CP}(B_d \to s\gamma)$	*	0.005	Belle II
rare decays			
$\mathcal{B}(B \to \tau\nu)$	**	3%	Belle II
$\mathcal{B}(B \to D\tau\nu)$		3%	Belle II
$\mathcal{B}(B_d \to \mu\nu)$	**	6%	Belle II
$\mathcal{B}(B_s \to \mu\mu)$	***	10%	LHCb
zero of $\mathrm{A_{FB}(B \to K^*\mu\mu)}$	**	0.05	LHCb
$\mathcal{B}(B \to K^{(*)}\nu\nu)$	***	30%	Belle II
$\mathcal{B}(B \to s\gamma)$		4%	Belle II
$\mathcal{B}(B_s \to \gamma\gamma)$		$0.25 \cdot 10^{-6}$	Belle II (with 5 ab^{-1})
$\mathcal{B}(K \to \pi\nu\nu)$	**	10%	K-factory
$\mathcal{B}(K \to e\pi\nu)/\mathcal{B}(K \to \mu\pi\nu)$	***	0.1%	K-factory
charm and τ			
$\mathcal{B}(\tau \to \mu\gamma)$	***	$3 \cdot 10^{-9}$	Belle II
$\lvert q/p\rvert_D$	***	0.03	Belle II
$arg(q/p)_D$	***	1.5°	Belle II

- Great for neutral and missing energy modes
- Inclusive measurement: OK
- Excellent flavor tagging and K_S reconstruction





Comparison: KEKB vs. SuperKEKB

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}		$cm^{-2}s^{-1}$