Prospects on Flavor Physics at Belle II

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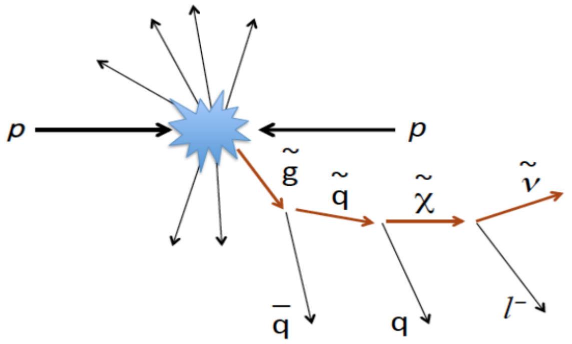
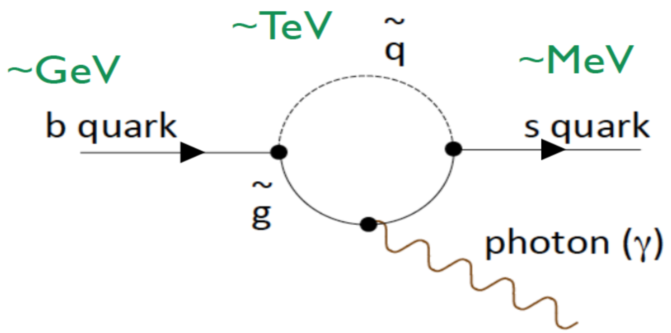
On Behalf of the Belle II Collaboration

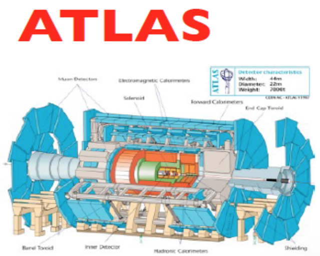
Physics beyond the Standard Model, Quy Nhon, Vietnam, Sep 15-21, 2019

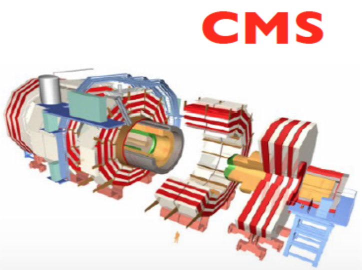
Flavor Physics Beyond the Standard Model

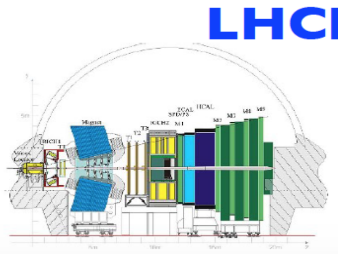
- Extremely successful Standard Model (SM). But many fundamental questions remain unanswered
  - hierarchy problem, matter-antimatter asymmetry in the Universe, dark matter…→ New Physics (NP) beyond the SM.
- Role of flavor physics: search for NP through processes sensitive to presence of virtual heavy particles.
- Direct search at LHC energy frontier, indirect search at precision frontier.
- If NP is seen by one of the experiments, confirmation by the other would be important.

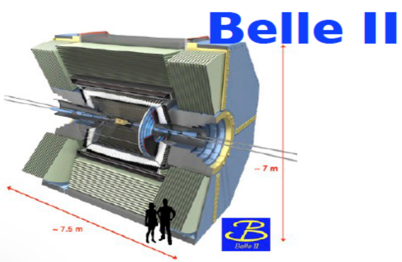








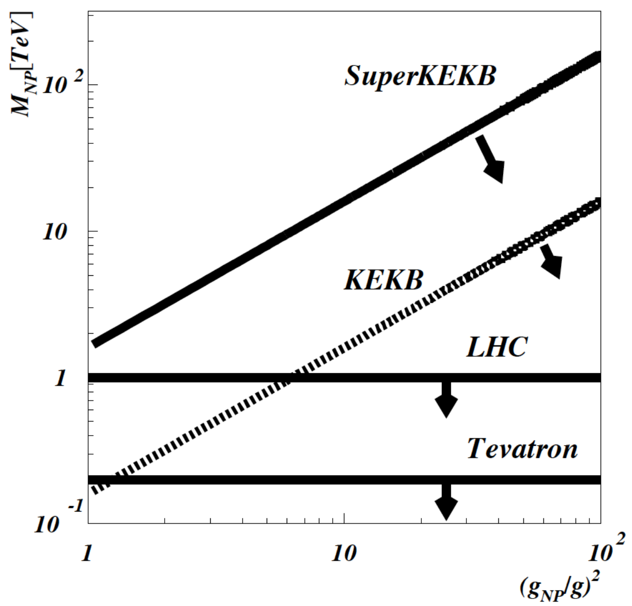




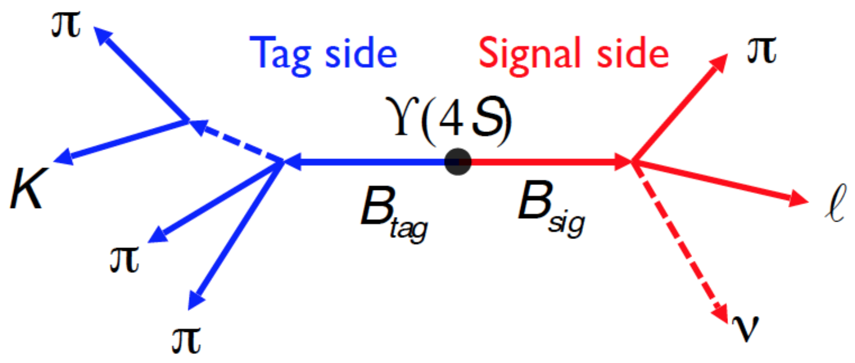
Advantage of e^+e^- Flavor Factories

- New physics models that we search for in Belle II are those that include more specific flavor couplings, for which indirect searches can push the new physics scale much higher than the direct search programs.

sensitivity to NP



- Advantage of e^+e^- flavor factories
  - Low backgrounds, high trigger efficiency, negligible trigger bias, excellent γ and π^0 reconstruction…
  - Quantum correlated $B^0\overline{B^0}$ pairs. High flavor-tagging efficiency (~36% @Belle II, ~3.5-6%@LHCb).
  - Good kinematic resolutions. Decays with large missing mass analyses are possible.
  - Large sample of τ leptons. Search for Lepton Flavor Violation τ decays at $O(10^{-9})$.



Belle II Physics Program

The primary goals of Belle II, are to search for NP in the flavor sector and to improve the precision of measurements of SM parameters.

- CKM precision
  - new physics through precision tests of the unitarity triangle
- New CP violation phase?
  - CPV in B and D decays
- Signature of charged Higgs boson or leptoquarks?
  - $B \to \tau\nu$ and $B \to D^{(*)}\tau\nu$
- Lepton Flavor Violation decays.
- Electroweak penguin decays $b \to sl^{+}l^{-}, s\nu\bar{\nu}$
- New Physics in flavor changing neutral current transitions?
- …

Bell II Physics book, arXiv1808.10567

Broad program to search New Physics in B, D and τ decays

Observables	Expected the. accuracy		Expected exp. uncertainty	Facility (2025)
UT angles & sides		**CKM**		
ϕ_1 [°]	***		0.4	Belle II
ϕ_2 [°]	**		1.0	Belle II
ϕ_3 [°]	***		1.0	LHCb/Belle II
$\|V_{cb}\|$ incl.	***		1%	Belle II
$\|V_{cb}\|$ excl.	***		1.5%	Belle II
$\|V_{ub}\|$ incl.	**		3%	Belle II
$\|V_{ub}\|$ excl.	**		2%	Belle II/LHCb
CP Violation		**CPV**		
$S(B \to \phi K^0)$	***		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		**SL**		
$\mathcal{B}(B \to \tau\nu)$ $[10^{-6}]$	**		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		**EWP**		
$\mathcal{B}(B \to X_s\gamma)$	**		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
$\mathcal{B}(B \to K^*\nu\bar{\nu})$ $[10^{-6}]$	***		15%	Belle II
$\mathcal{B}(B \to K\nu\bar{\nu})$ $[10^{-6}]$	***		20%	Belle II
$R(B \to K^*\ell\ell)$	***		0.03	Belle II/LHCb
Charm		**D**		
$\mathcal{B}(D_s \to \mu\nu)$	***		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
$\|q/p\|(D^0 \to K_S^0\pi^+\pi^-)$	***		0.03	Belle II
$\phi(D^0 \to K_S^0\pi^+\pi^-)$ [°]	***		4	Belle II
Tau		**τ**		
$\tau \to \mu\gamma$ $[10^{-10}]$	***		< 50	Belle II
$\tau \to e\gamma$ $[10^{-10}]$	***		< 100	Belle II
$\tau \to \mu\mu\mu$ $[10^{-10}]$	***		< 3	Belle II/LHCb

Belle II Physics Potential

KEK Preprint 2018-27
BELLE2-PAPER-2018-001
FERMILAB-PUB-18-398-T
JLAB-THY-18-2780
INT-PUB-18-047
UWThPh 2018-26

arXiv 1808.10567

The Belle II Physics Book

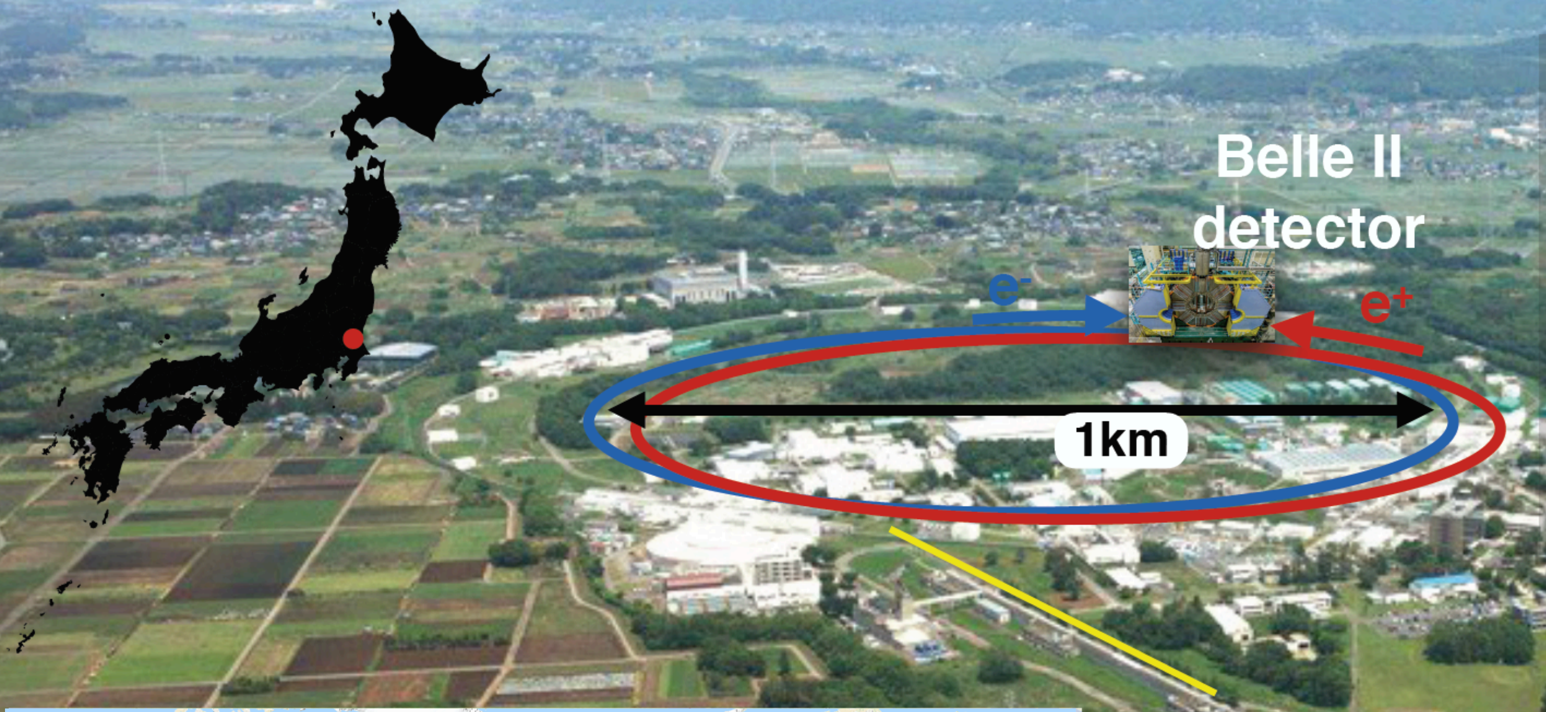
E. Kou[74,¶,†], P. Urquijo[143,§,†], W. Altmannshofer[133,¶], F. Beaujean[78,¶], G. Bell[120,¶], M. Beneke[112,¶], I. I. Bigi[146,¶], F. Bishara[148,16,¶], M. Blanke[49,50,¶], C. Bobeth[111,112,¶], M. Bona[150,¶], N. Brambilla[112,¶], V. M. Braun[43,¶], J. Brod[110,133,¶], A. J. Buras[113,¶], H. Y. Cheng[44,¶], C. W. Chiang[91,¶], M. Ciuchini[58,¶], G. Colangelo[126,¶], H. Czyz[154,29,¶], A. Datta[144,¶], F. De Fazio[52,¶], T. Deppisch[50,¶], M. J. Dolan[143,¶], J. Evans[133,¶], S. Fajfer[107,139,¶], T. Feldmann[120,¶], S. Godfrey[7,¶], M. Gronau[61,¶], Y. Grossman[15,¶], F. K. Guo[41,132,¶], U. Haisch[148,11,¶], C. Hanhart[21,¶], S. Hashimoto[30,26,¶], S. Hirose[88,¶], J. Hisano[88,89,¶], L. Hofer[125,¶], M. Hoferichter[166,¶], W. S. Hou[91,¶], T. Huber[120,¶], S. Jaeger[157,¶], S. Jahn[82,¶], M. Jamin[124,¶], J. Jones[102,¶], M. Jung[111,¶], A. L. Kagan[133,¶], F. Kahlhoefer[1,¶], J. F. Kamenik[107,139,¶], T. Kaneko[30,26,¶], Y. Kiyo[63,¶], A. Kokulu[112,138,¶], N. Kosnik[107,139,¶], A. S. Kronfeld[20,¶], Z. Ligeti[19,¶], H. Logan[7,¶], C. D. Lu[41,¶], V. Lubicz[151,¶], F. Mahmoudi[140,¶], K. Maltman[171,¶], S. Mishima[30,¶], M. Misiak[164,¶],

- The Belle II Physics Book is the outcome of the B2TIP (Belle II Theory Interface) Workshops
- Emphasis is on New Physics searches.

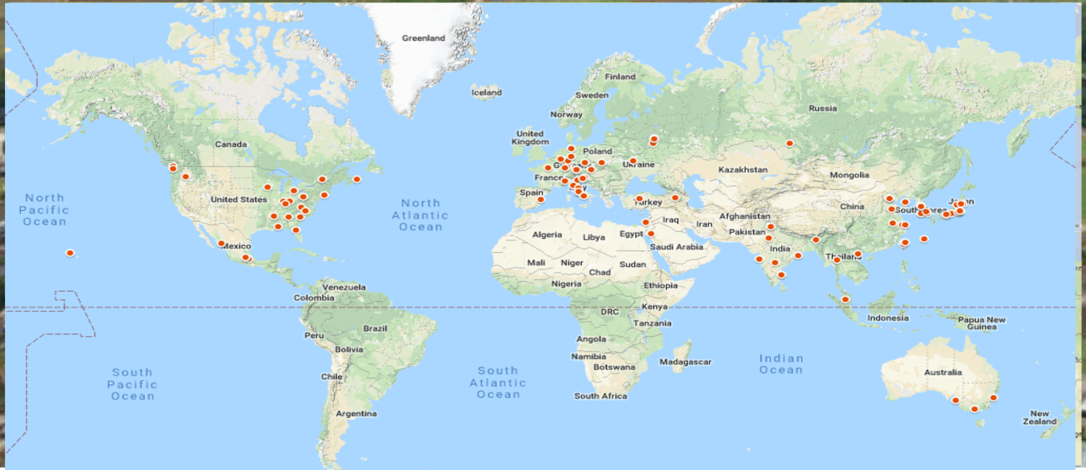
- Strong participation from theory community, lattice QCD community and Belle II experimenters.
- published by Oxford University Press.
- More details about Belle II physics potential can be found in the book.

Belle II @ Super-KEKB

Intensity frontier B-factory experiment, Successor to Belle @KEKB (1999-2010)



- 7 GeV e^-, 4 GeV e^+
- E_{CM} $\Upsilon(4S)$ = 10.58 GeV + scans
- $\Upsilon(4S) \rightarrow$ B anti-B
- B + Charm + τ factory



Belle II now has grown to >900 researchers (~330 graduate students) from 26 countries, 112 institutes

SuperKEKB Accelerator

- Major upgrade to the KEKB accelerator with x 40 designed luminosity (8×10^{35} $cm^{-2}s^{-1}$)

Machine parameters

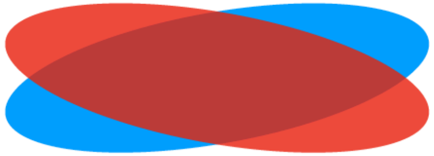
	SuperKEKB LER/HER	KEKB LER/HER
E(GeV)	4.0/7.0	3.5/8.0
ε_x (nm)	3.2/4.6	18/24
β_y at IP(mm)	0.27/0.30	5.9/5.9
β_x at IP(mm)	32/25	120/120
Half crossing angle(mrad)	41.5	11
I(A)	3.6/2.6	1.6/1.2
Lifetime	~10min	130min/200min
L($cm^{-2}s^{-1}$)	80×10^{34}	2.1×10^{34}

x20

x2

- Small beam spot size (6 x 0.06 x 150) μm^3 comparing to Belle beam spot (120 x 5 x 8000) μm^3
- Tiny beam size is crucial to achieve the luminosity and is a useful constraint for TDCPV analyses.

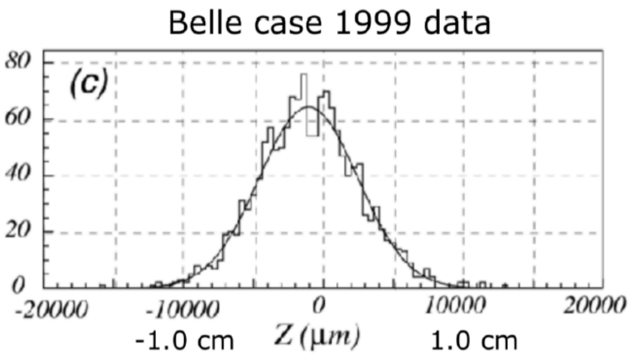
KEKB



SuperKEKB

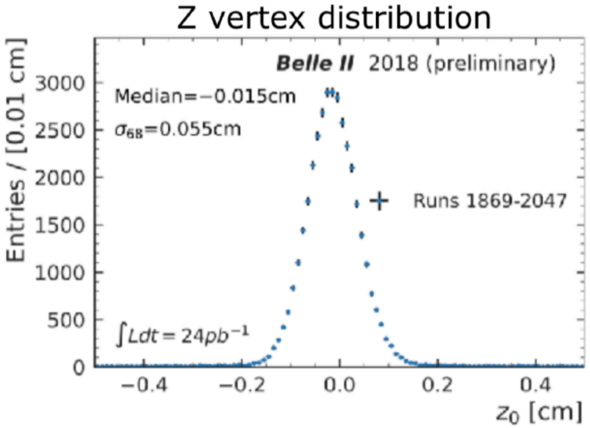
The vertex distribution is constrained in the nano-beam scheme.

Ordinary collision (KEKB)



σ = 4.5 mm

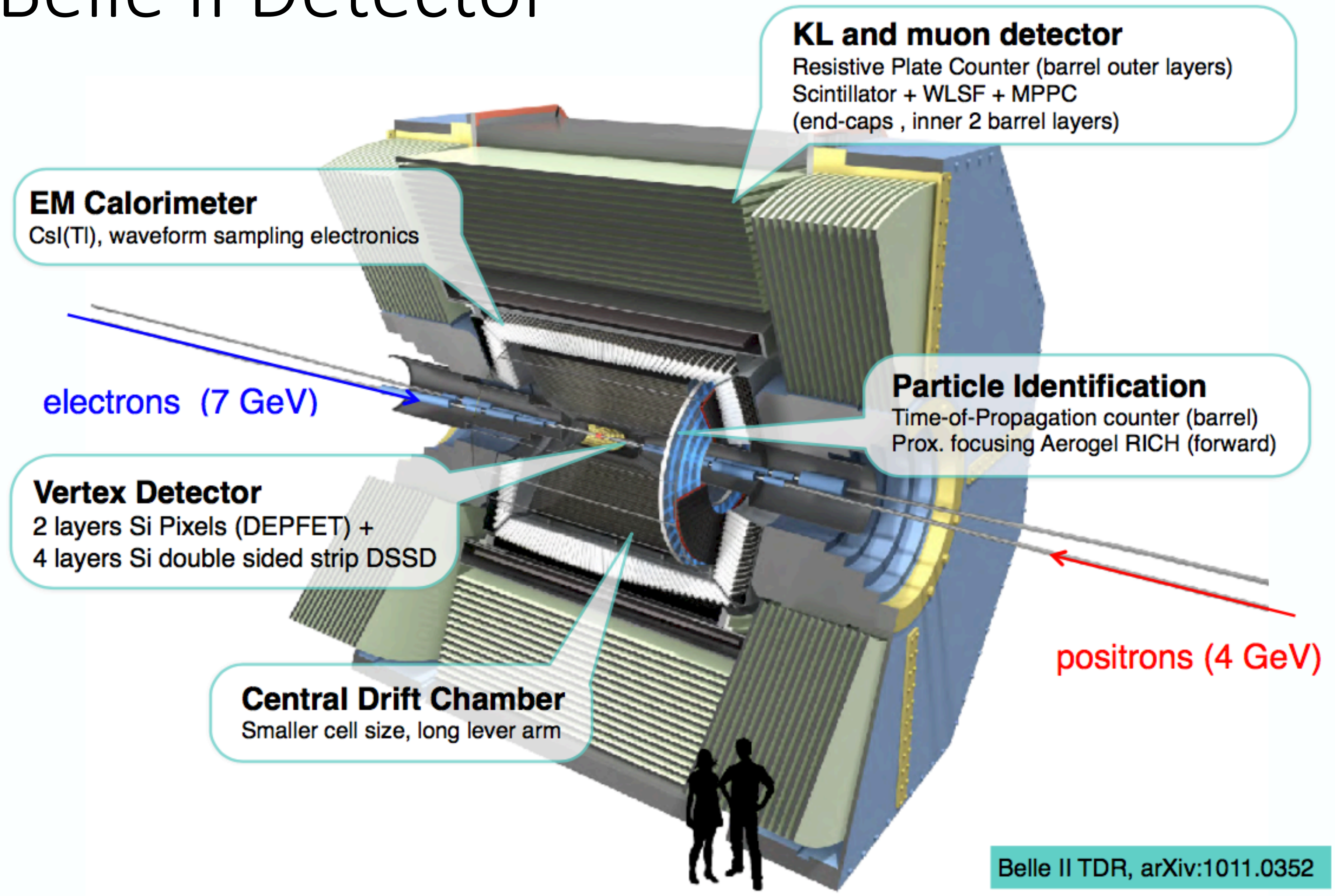
Nano-Beam (SuperKEKB Phase2)



σ = 550 μm

- As expected, the effective bunch length is reduced from ~5 mm (KEKB) to 0.5mm (SuperKEKB)

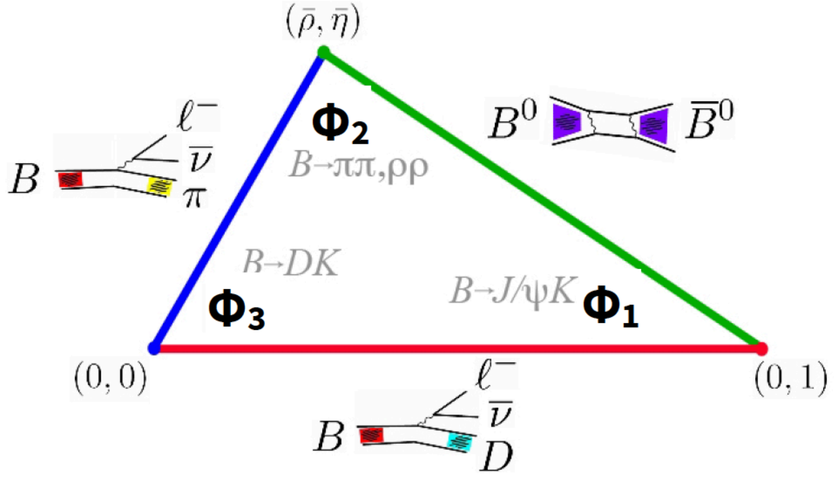
Belle II Detector



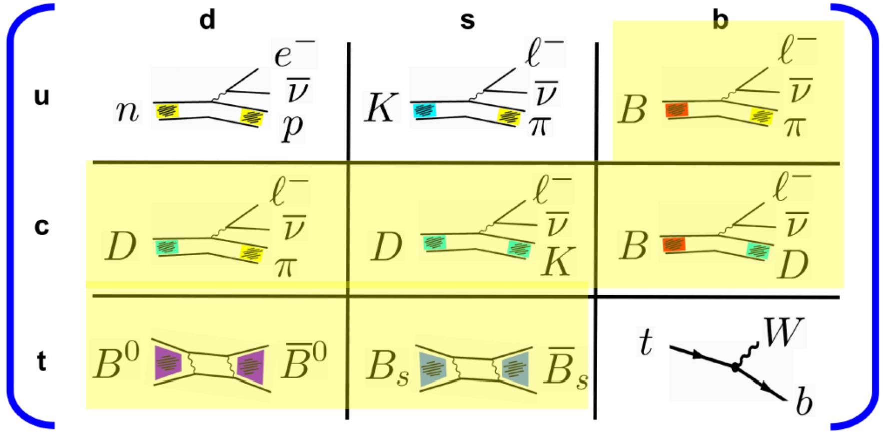
- Belle II is a significant upgrade of Belle. Goal: 50 ab^{-1} of data.
- Better vertexing: PXD + SVD.
- New CDC: larger coverage and smaller cells.
- iTOP (imaging time-of-propagation) and ARICH (Aerogel Ring-Imaging Cherenkov detector) for Particle Identification.
- Electromagnetic Calorimeter: waveform sampling.
- KLM: RPC + Scintillators.

CKM Precision

- The main goal of Belle II is to precisely measure the CKM unitary triangle, and look for BSM physics using precision measurements.



V =



$B\to\pi\pi,\ \rho\rho$	$\alpha\ /\ \Phi_2$	$B\to D^*\,l\,\nu\ /\ b\to c\,l\,\nu$	$\lvert V_{cb}\rvert$ via Form factor / OPE
$B\to D^{(*)}\,K^{(*)}$	$\gamma\ /\ \Phi_3$	$B\to\pi\,l\,\nu\ /\ b\to u\,l\,\nu$	$\lvert V_{ub}\rvert$ via Form factor / OPE
$B\to J/\psi\,K_s$	$\beta\ /\ \Phi_1$	$M\to l\,\nu\,(\gamma)$	$\lvert V_{UD}\rvert$ via Decay constant f_M
$B_s\to J/\psi\,\Phi$	β_s	$\Delta m_d,\ \Delta m_s$	$\lvert V_{tb}\,V_{t\{d,s\}}\rvert$ via Bag factor B_B

current World Average

$\phi_1^{HFLAV} = (22.2 \pm 0.7)^o$

$\phi_2^{HFLAV} = (84.9^{+5.1}_{-4.5})^o$

$\phi_3^{HFLAV} = (71.1^{+4.6}_{-5.3})^o$

$|V_{ub}| = (3.98 \pm 0.08 \pm 0.22)\ 10^{-3}$

$|V_{cb}| = (41.8 \pm 0.4 \pm 0.6) \times 10^{-3}$

- In the presence of NP, additional phases might lead to an overall inconsistency of the constraints on the CKM Unitarity Triangle. This would be a clear indication of NP.

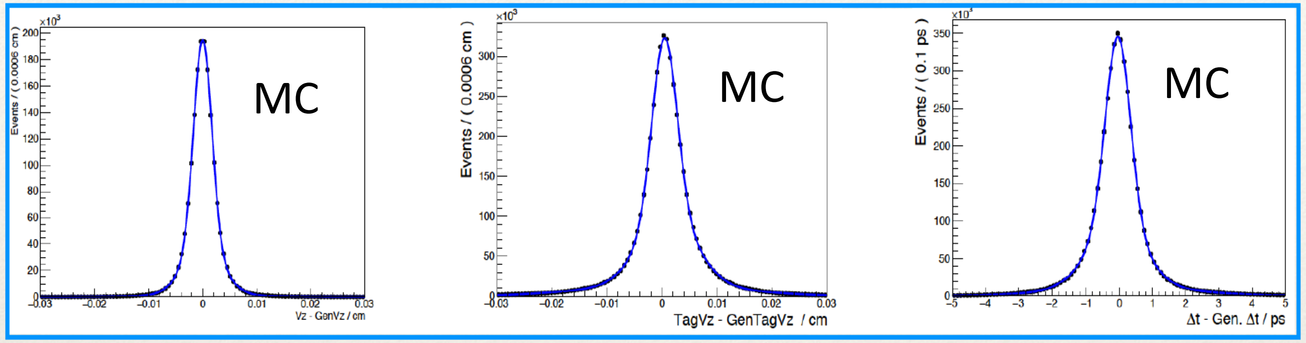
Time-Dependent CP Violation Measurement

for $\phi_1(\beta)$ and $\phi_2(\alpha)$ measurements

- Time-dependent CPV effects are related to interference between $\mathrm{B}^0\overline{B^0}$ mixing and decay amplitudes.
- ϕ_1 and ϕ_2 can be measured in TD CPV analyses of $b \to c\bar{c}s$ and $b \to u\bar{u}\mathrm{d}$.

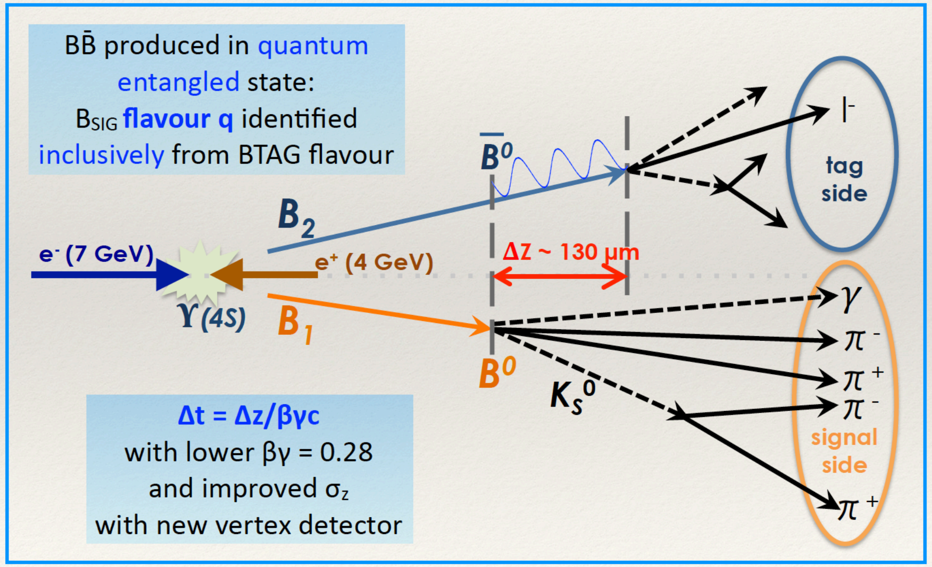
$$\mathcal{P}(\Delta t, q) = \frac{e^{-|\Delta t|/\tau_{B^0}}}{4\tau_{B^0}}\left[1 + q\left(\mathcal{A}_{CP}\cos\Delta m_d\Delta t + S_{CP}\sin\Delta m_d\Delta t\right)\right]$$

arXiv: 1808.10567 $\quad \mathcal{A}_{CP} = 0 \qquad S_{CP} \sim \sin 2\phi_{1,2}$ (at tree order)

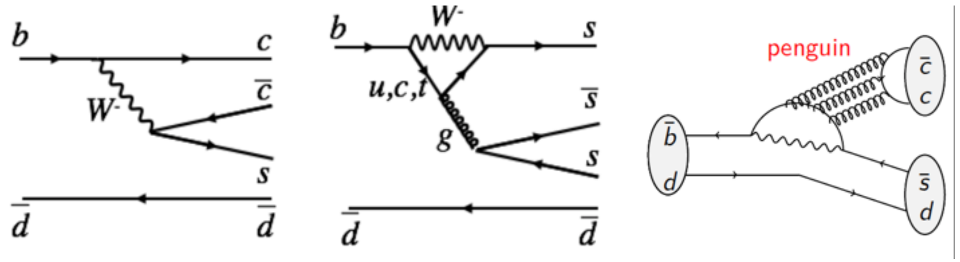


Δz resolution J/ψ → μμ		Δz resolution Tag Vertex		Δt resolution	
Belle	Belle II	Belle	Belle II	Belle	Belle II
43 μm	26 μm	89 μm	53 μm	0.92 ps	0.77 ps

- The $\mathrm{B}^0\overline{B^0}$ pairs from Υ(4S) are produced in a coherent, entangled quantum mechanical state. When $\mathrm{B}^0(\overline{B^0})$ decays, the flavor wavefunction of other $\overline{B^0}$ (B^0) collapses and it propagates alone.
- CP violation, mixing and lifetime are coming together and can be found in the fit to Δt distribution.

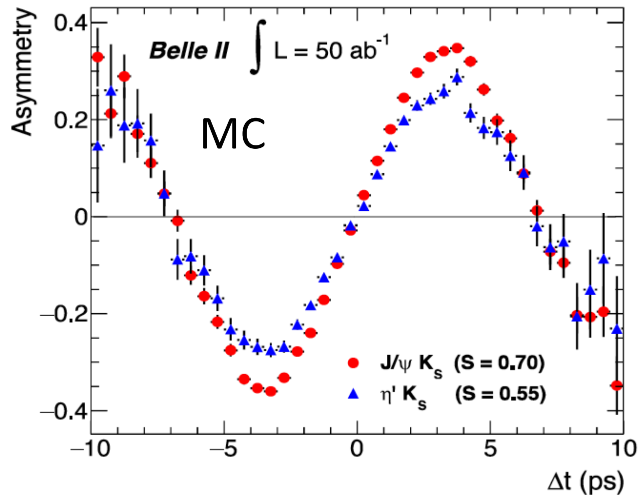


Belle II Prospects for $\phi_1(\beta)$



- Tree
- Gluonic Penguin (NP sensitive)
- Constrains penguin pollutions

- ϕ_1 is the most precisely measured UT parameter:
  - $\phi_1^{HFLAV} = (22.2 \pm 0.7)^o$
- Tree-dominated $b \to c\bar{c}s$, golden mode $B^0 \to J/\psi K_S$
  - small theoretical uncertainty and clean experimental signature.
  - syst. due to vertex and Δt resolution will be the limiting uncertainty with 50 ab^{-1} of data.
  - contribution of penguin diagrams with a different CKM phase is expected to be at less than 1% level.
  - $B^0 \to J/\psi\pi^0$ to estimate penguin pollution.
- Expected total uncertainty: $\delta\phi_1 \leq 0.1°$ with 50 ab^{-1}
- For penguin-dominated modes $b \to q\bar{q}s$: $B^0 \to \phi K_S, \eta' K_S, \omega K_S\ \pi^0 K_S$
  - particularly sensitive to NP.

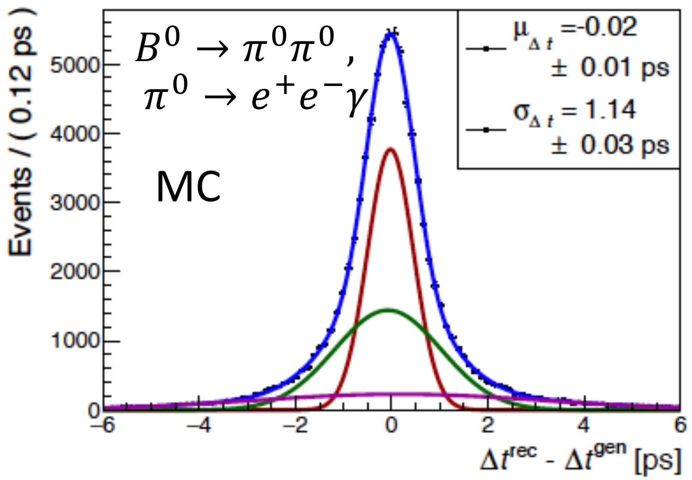


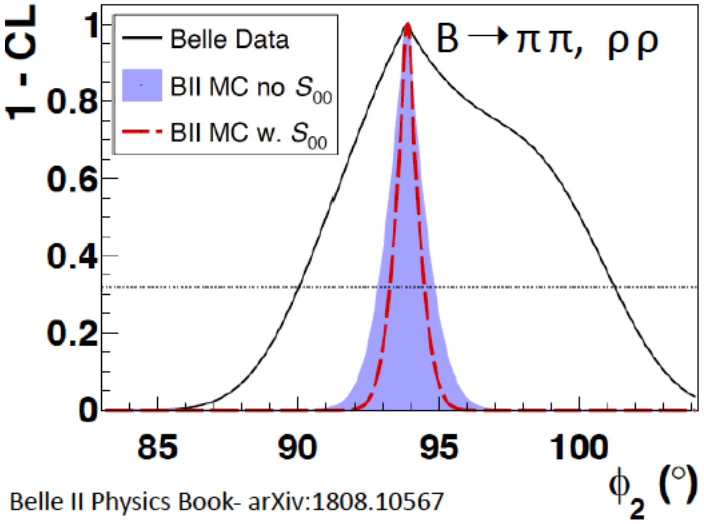
$$A_{CP} = A\cos(\Delta M \Delta t) + S\sin(\Delta M \Delta t)$$

	WA (2017)		5 ab^{-1}		50 ab^{-1}	
Channel	$\sigma(S)$	$\sigma(A)$	$\sigma(S)$	$\sigma(A)$	$\sigma(S)$	$\sigma(A)$
$J/\psi K^0$	0.022	0.021	0.012	0.011	0.0052	0.0090
ϕK^0	0.12	0.14	0.048	0.035	0.020	0.011
$\eta' K^0$	0.06	0.04	0.032	0.020	0.015	0.008
ωK_S^0	0.21	0.14	0.08	0.06	0.024	0.020
$K_S^0\pi^0\gamma$	0.20	0.12	0.10	0.07	0.031	0.021
$K_S^0\pi^0$	0.17	0.10	0.09	0.06	0.028	0.018

Belle II Prospects for $\phi_2(\alpha)$

- ϕ_2 measurement based on $b \to u\bar{u}d$ processes. Significant contributions from Penguins: $\phi^{\mathrm{eff}}{}_2 = \phi_2 + \Delta\phi_2$
- Most precise determination of ϕ_2 from isospin analysis of $B^0 \to \pi\pi, \rho\rho$ decays.
- $B^0 \to \pi^0\pi^0$(never measured so far):
  - π^0 mainly decays to two photons which do not provide information to reconstruct the vertex of the B.
  - eight-fold ambiguity on ϕ_2 .
  - challenge of Belle II: B^0 decay vertex reconstructed based on γ conversion and Dalitz π^0 decay ($\pi^0 \to e^+e^-\gamma$).
- Current precision: $\phi_2^{HFLAV} = (84.9^{+5.1}_{-4.5})^{\circ}$
- Expected total uncertainty: $\delta\phi_2 \leq 1°$ with 50 ab^{-1}.





Belle II Physics Book- arXiv:1808.10567

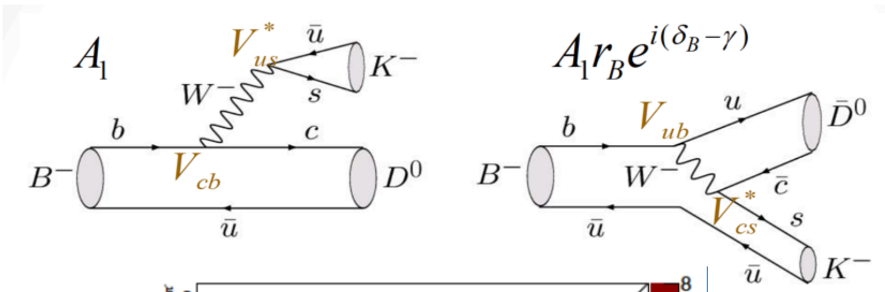
arXiv: 1808.10567	Current	50 ab^{-1} projection
ϕ_2:		
Experimental:	4.2°	0.6°
Theoretical:	1.2°	< 1.0°

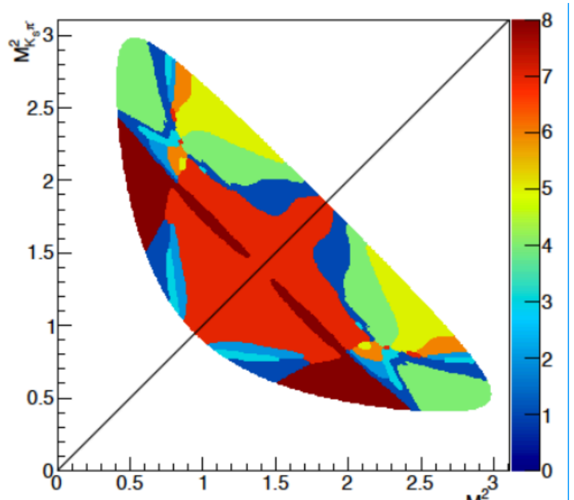
Belle II Prospects for $\phi_3(\gamma)$

- ϕ_3 is the phase between b-->u and b --> c transition : accessible at tree level. Very precise theoretical prediction.
- Same final state for D and $\bar{D}$ → interference → possibility of CPV

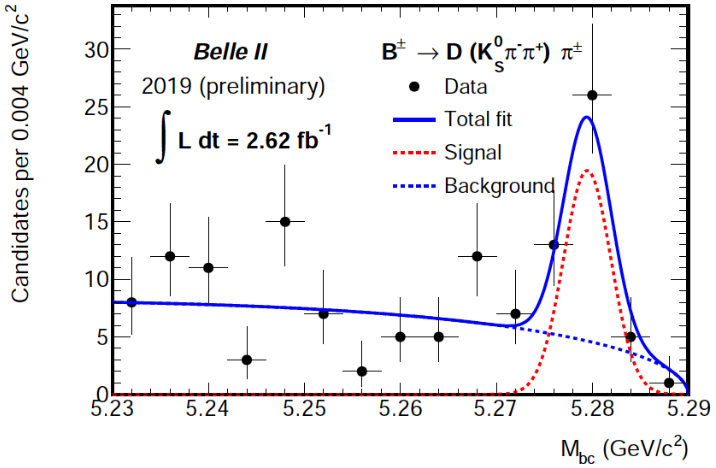
$$\frac{A^{suppr.}(B^- \to \bar{D}^0 K^-)}{A^{favor.}(B^- \to D^0 K^-)} = r_B\, e^{i(\delta_B - \phi_3)}$$

- Measured via the interference between $B^- \to D^0 K^-$ and $B^- \to \bar{D}^0 K^-$, various D^0 channels:
  - CP-eigenstates [GLW]
  - CF and DCS decays ($K^+\pi^-$)[ADS]
  - Self-conjugate multibody states: $K_S h^+ h^-$ [Dalitz/GGSZ]
  - SCS: $K_S K^+ \pi^-$ [GLS]
- Golden method in Belle II: GGSZ $B^- \to D^0(K_S\pi^+\pi^-)K^-$
  - Model-independent binned Dalitz plot.
  - Precise D strong phase measurement needed to match Belle II statistics precision. Expected from BESIII D decays.
- Current precision: $\phi_3^{HFLAV} = (71.1^{+4.6}_{-5.3})^{\circ}$, statistics limited.
- Expected total uncertainty: $\delta\phi_3 \leq 1.6°$ with 50 ab^{-1}.



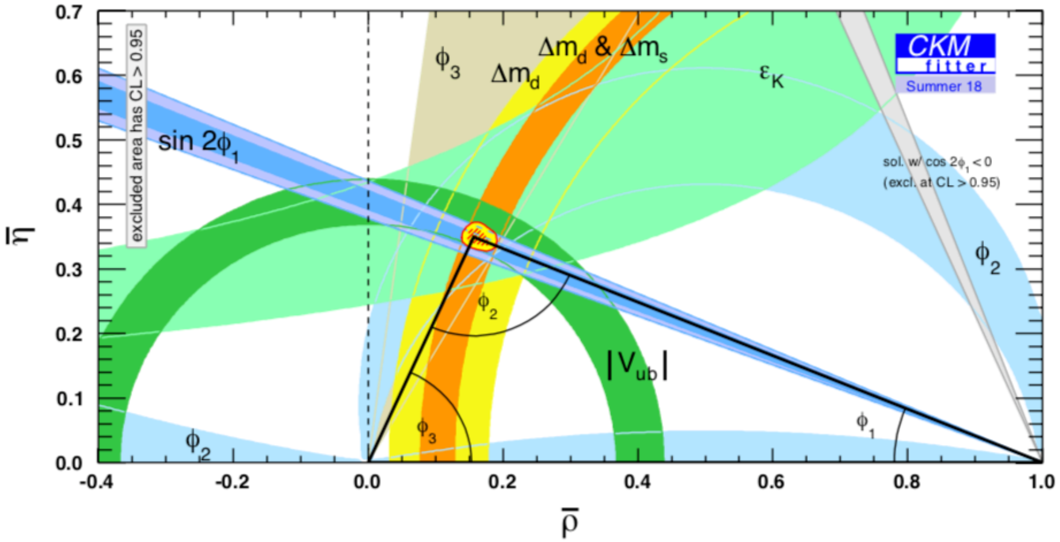


Belle II Physics Book - arXiv:1808.10567

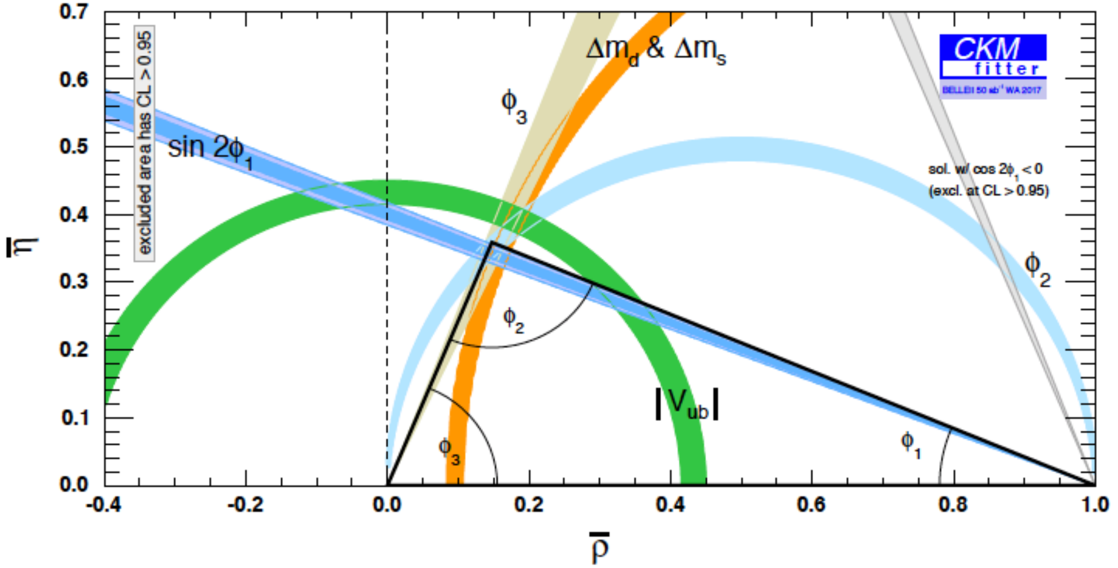


CKM Global Fit Projection

Current world average



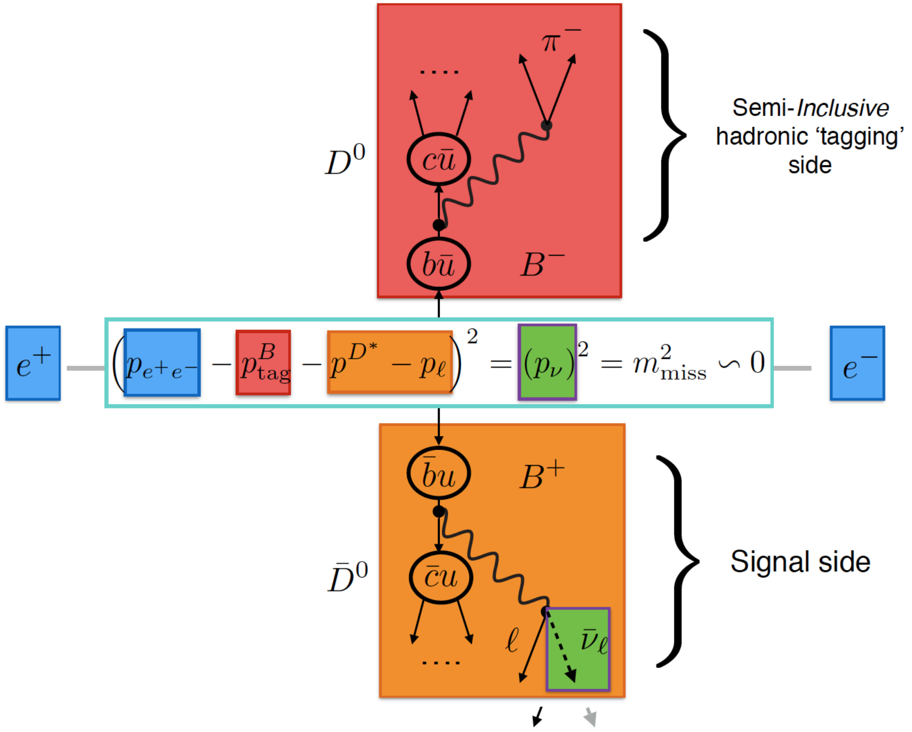
Belle II projection @ 50 ab^{-1}



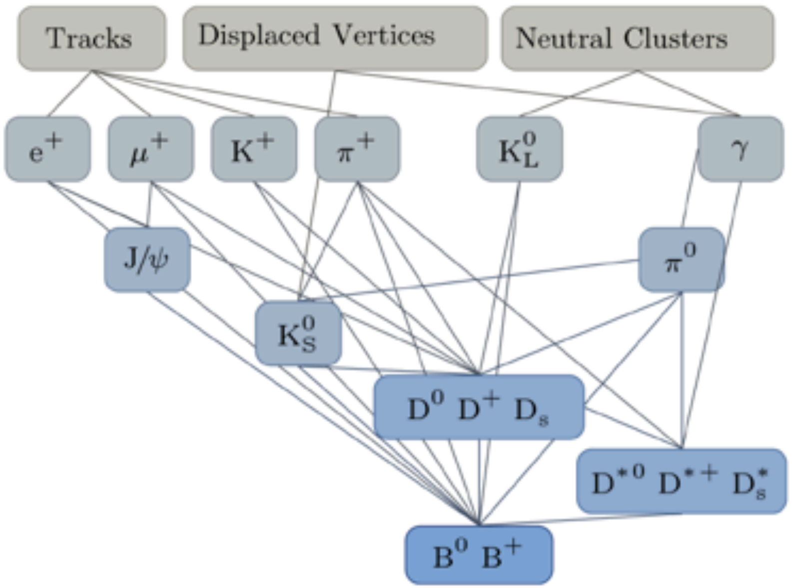
- CKM angles measurements will improve quickly already with 5-10 ab^{-1} of Belle II data.
- There is excellent potential at Belle II to discover new physics through precision tests of the unitarity triangle.
- In order to clarify the significance of the agreement or deviation, global fits may be necessary.

(Semi-)Leptonic B Decays

- Belle II analyses use semi-leptonic and hadronic tagging for flavor, charge, kinematics.
- Signal fits based on M^2_{miss}, calorimeter extra energy…
- Belle II has developed a new "Full Event Interpretation" tool based on fast Boosted Decision Trees (>1000 B decay modes).
- $|V_{ub}|$ measured to about 10% accuracy → 1% at Belle II.
- 5 σ discoveries of B→ τ ν and B→ μν expected with < 5 ab^{-1}



Full Event Interpretation @ Belle II



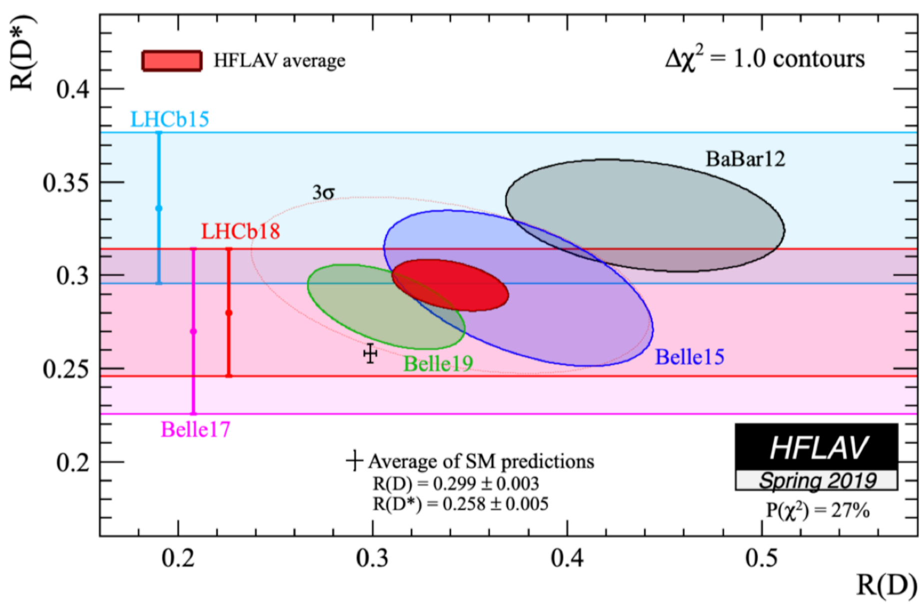
Observables	Belle	Belle II	
	(2017)	5 ab^{-1}	50 ab^{-1}
$\|V_{cb}\|$ incl.	$42.2 \cdot 10^{-3} \cdot (1 \pm 1.8\%)$	1.2%	–
$\|V_{cb}\|$ excl.	$39.0 \cdot 10^{-3} \cdot (1 \pm 3.0\%_{ex.} \pm 1.4\%_{th.})$	1.8%	1.4%
$\|V_{ub}\|$ incl.	$4.47 \cdot 10^{-3} \cdot (1 \pm 6.0\%_{ex.} \pm 2.5\%_{th.})$	3.4%	3.0%
$\|V_{ub}\|$ excl. (WA)	$3.65 \cdot 10^{-3} \cdot (1 \pm 2.5\%_{ex.} \pm 3.0\%_{th.})$	2.4%	1.2%
$\mathcal{B}(B \to \tau\nu)$ $[10^{-6}]$	$91 \cdot (1 \pm 24\%)$	9%	4%
$\mathcal{B}(B \to \mu\nu)$ $[10^{-6}]$	< 1.7	20%	7%
$R(B \to D\tau\nu)$ (Had. tag)	$0.374 \cdot (1 \pm 16.5\%)$	6%	3%
$R(B \to D^*\tau\nu)$ (Had. tag)	$0.296 \cdot (1 \pm 7.4\%)$	3%	2%

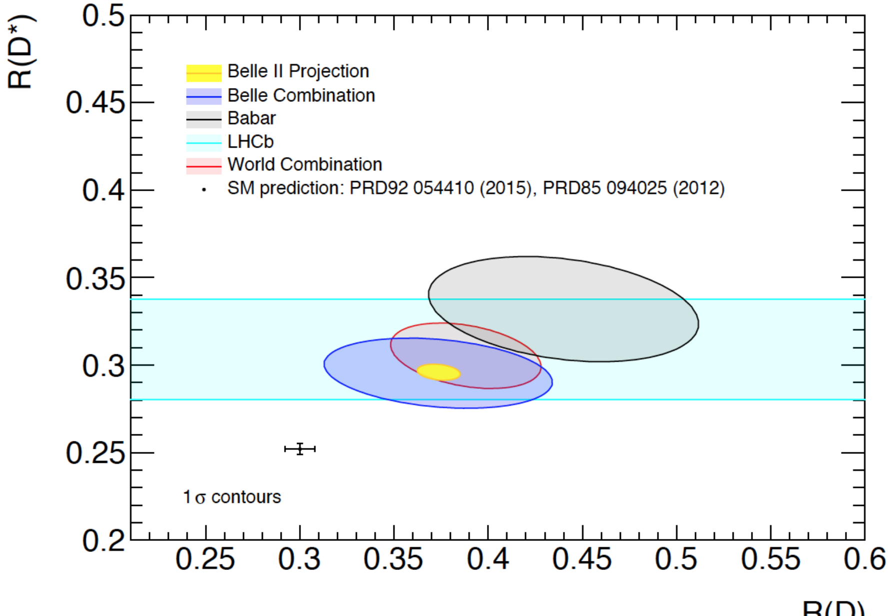
$B \to D^* l\nu$ Lepton Universality

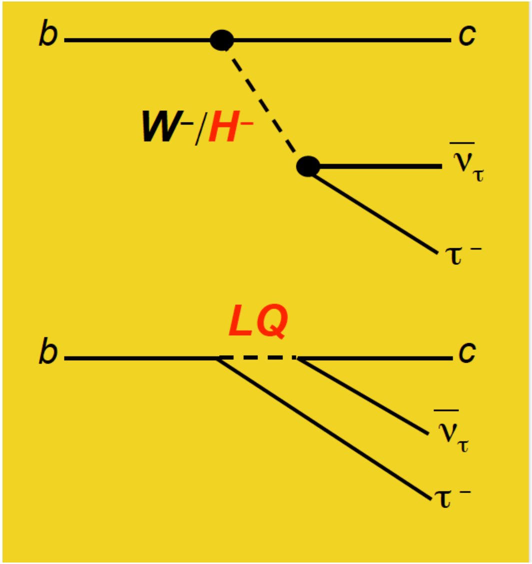
- In the SM, the difference between B→D $^{(*)}$ $\tau\nu$ and B→D$^{(*)}$$\mu\nu$, is the mass of the leptons. Theoretical uncertainties in form factors and $|V_{cb}|$ largely cancel out

$$R(D^{(*)}) = \frac{Br(\bar{B}\to D^{(*)}\tau^- \overline{\nu_\tau})}{Br(\bar{B}\to D^{(*)} l^- \overline{\nu_l})} \; (l = e,\ \mu)$$

- Sensitive to NP because of the 3rd generation quark and leptons are involved.
- Current world average of R(D*) is in tension with SM, has drew great attention recently.
  - NP: Leptoquarks(LQ) model…
- A better understanding of these anomalous results is of high priority at Belle II.

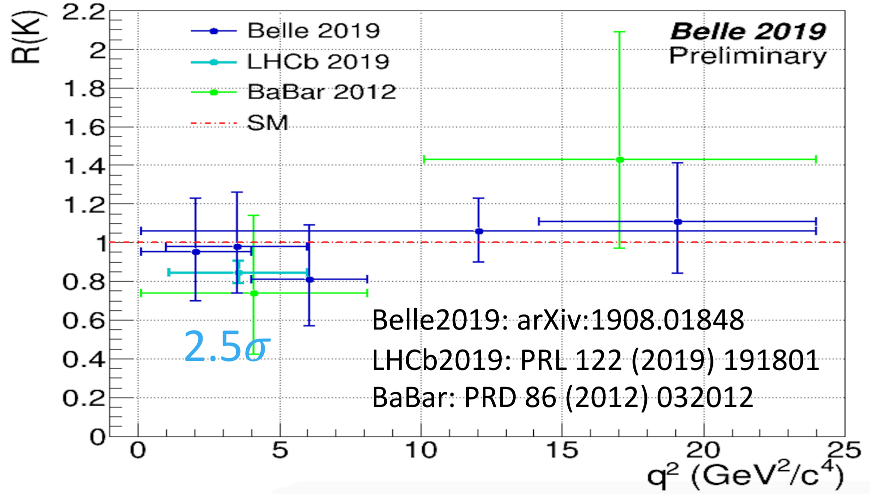


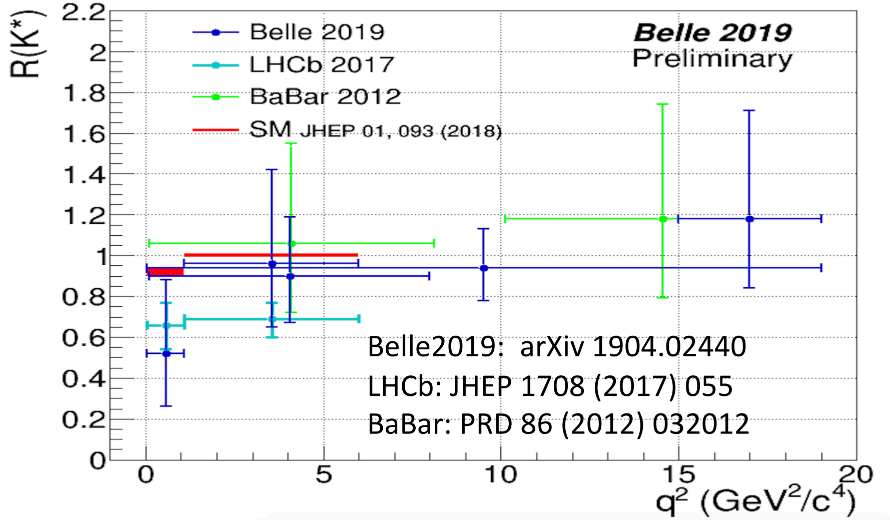


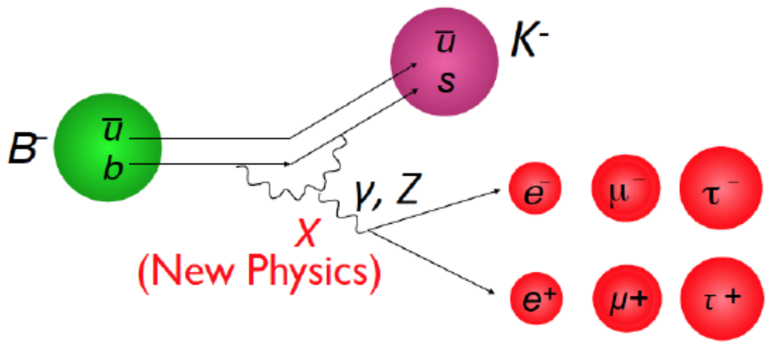


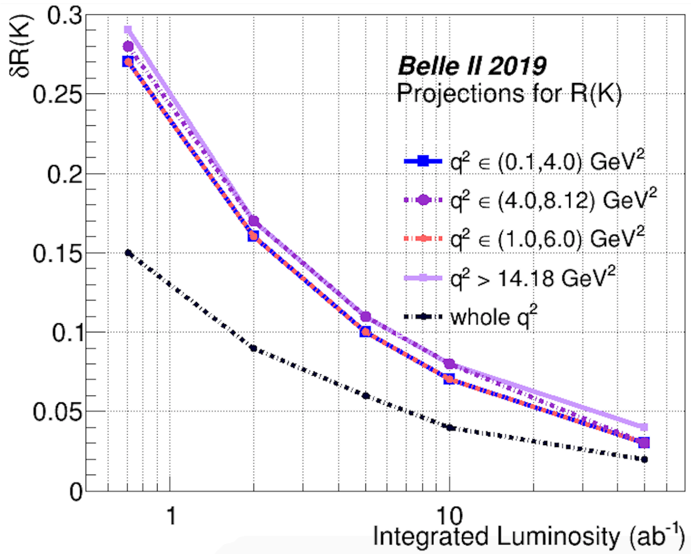
$B \to K^{(*)} l^+ l^-$ Lepton Universality (loop)

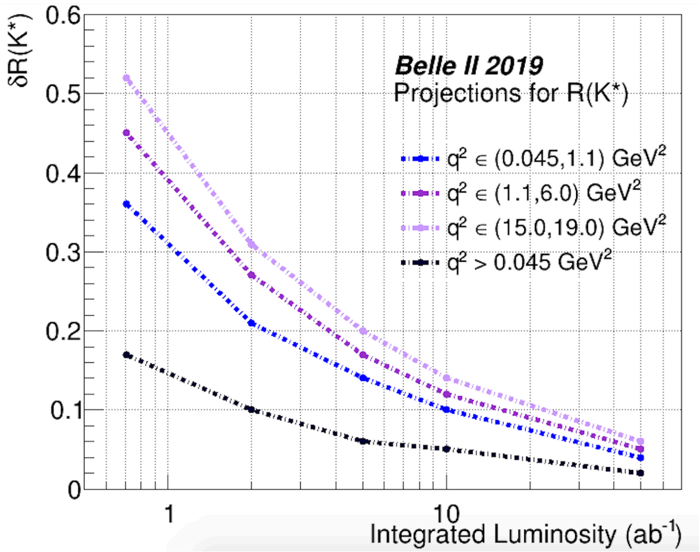
$$R(K^{(*)}) = \frac{Br(B \to K^{(*)}\mu^+\mu^-)}{Br(B \to K^{(*)}e^+e^-)}$$











- Belle II data will help clarify the role of new physics in b→ sll transitions.
- Belle II can provide data from inclusive measurements (less theory ambiguity)

Charm Physics

- Charm mixing parameters.
- Golden method at Belle II: $D^{*+} \to D^0\pi^+_{slow}$
  - flavor tagging
  - observables: D^0 invariant mass ; $\Delta M \equiv m(D^{*+}) - m(D^0)$
- Direct Charm CPV
  - excellent γ and π^0 reconstruction will allow Belle II to search for CPV in complementary final states that contain neutral particles.
  - $D^0 \to K_S K_S,\ D^+ \to \pi^+\pi^0, D^0 \to \gamma\phi, \gamma\rho$

$$A_{CP} = \frac{N(D\to f) - N(\bar{D}\to \bar{f})}{N(D\to f) + N(\bar{D}\to \bar{f})}$$

- (semi-)leptonic decays $D_{(s)} \to hl^+\nu$, for V_{cd} and V_{cs} and decay constants f_D, f_{Ds}
- Rare decays $D^0 \to l^+l^-, D^0 \to \bar{\nu}\nu$

Belle II data: clearly demonstrates the combined performance of the VXD system. World average: $\tau_{D^0} = 410$ fs.

D^0 Lifetime in Belle II Phase 3 data: $\tau_{D^0} = 370 \pm 40$ (stat.) fs

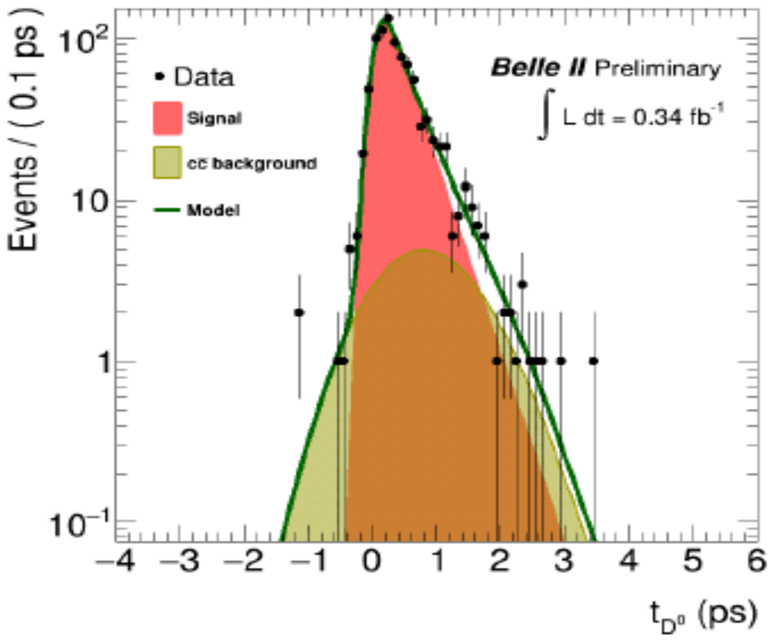
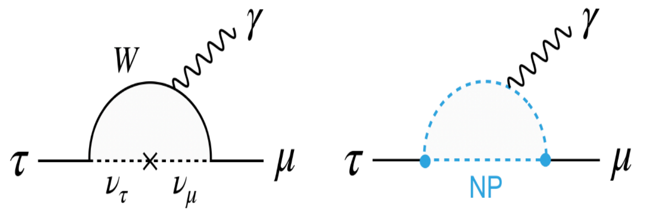


Table 12: Expected errors on several selected charm physics observables.

Observables	Belle (2017)	Belle II 5 ab^{-1}	Belle II 50 ab^{-1}
$x(D^0 \to K^0_S\pi^+\pi^-)$ $[10^{-2}]$	$0.56 \pm 0.19 \pm ^{0.07}_{0.13}$	0.16	0.11
$y(D^0 \to K^0_S\pi^+\pi^-)$ $[10^{-2}]$	$0.30 \pm 0.15 \pm ^{0.05}_{0.08}$	0.10	0.05
$\lvert q/p\rvert(D^0 \to K^0_S\pi^+\pi^-)$	$0.90 \pm ^{0.16}_{0.15} \pm ^{0.08}_{0.06}$	0.12	0.07
$A_{CP}(D^+ \to \pi^+\pi^0)$ $[10^{-2}]$	$2.3 \pm 1.2 \pm 0.2$	0.54	0.17
$A_{CP}(D^0 \to \pi^0\pi^0)$ $[10^{-2}]$	$-0.03 \pm 0.64 \pm 0.10$	0.28	0.09
$A_{CP}(D^0 \to K^0_S\pi^0)$ $[10^{-2}]$	$-0.21 \pm 0.16 \pm 0.09$	0.08	0.02
$A_{CP}(D^0 \to K^0_S K^0_S)$ $[10^{-2}]$	$0.02 \pm 1.53 \pm 0.17$	0.66	0.23
$A_{CP}(D^0 \to \phi\gamma)$ $[10^{-2}]$	$-9.4 \pm 6.6 \pm 0.1$	± 3.0	± 1.0
f_{D_s}	2.5%	1.1%	0.3%

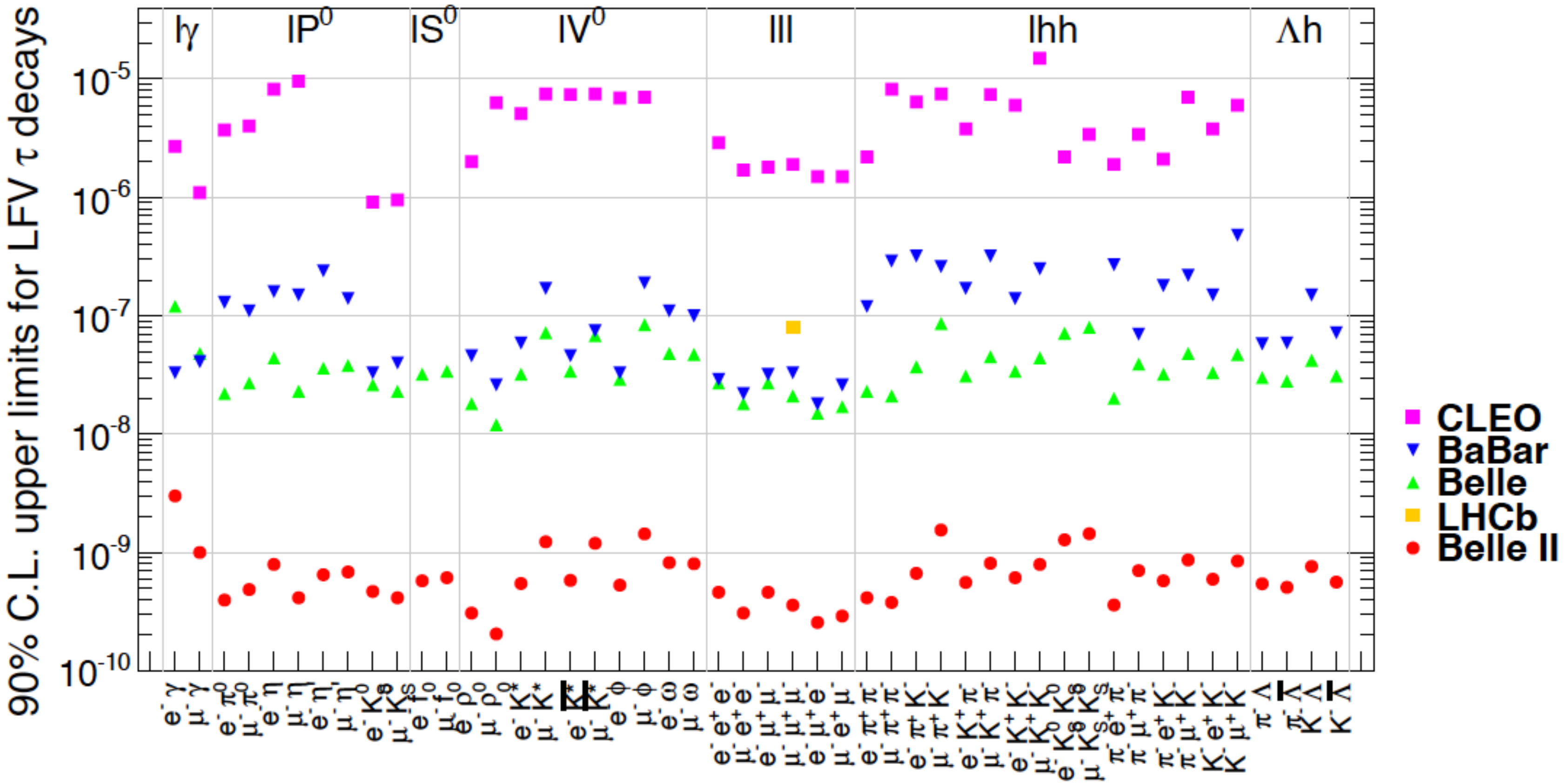
Charged Lepton Flavor Violation(LFV)

- LFV is highly suppressed in the SM even if neutrino oscillation is taken into account; experimentally unreachable.
- Several NP models predict to enhance LFV to be $O(10^{-13}\text{-}10^{-7})$, observable in “near” future experiments.
- Belle II will push down the current bounds further by more than an order of magnitude (below 10^{-9}).



$$\mathcal{B}_{\nu SM}(\tau \to \mu\gamma) = \frac{3\alpha}{32\pi}\left|U^*_{\tau i}U_{\mu i}\frac{\Delta m^2_{3i}}{m^2_W}\right|^2 < 10^{-40}$$

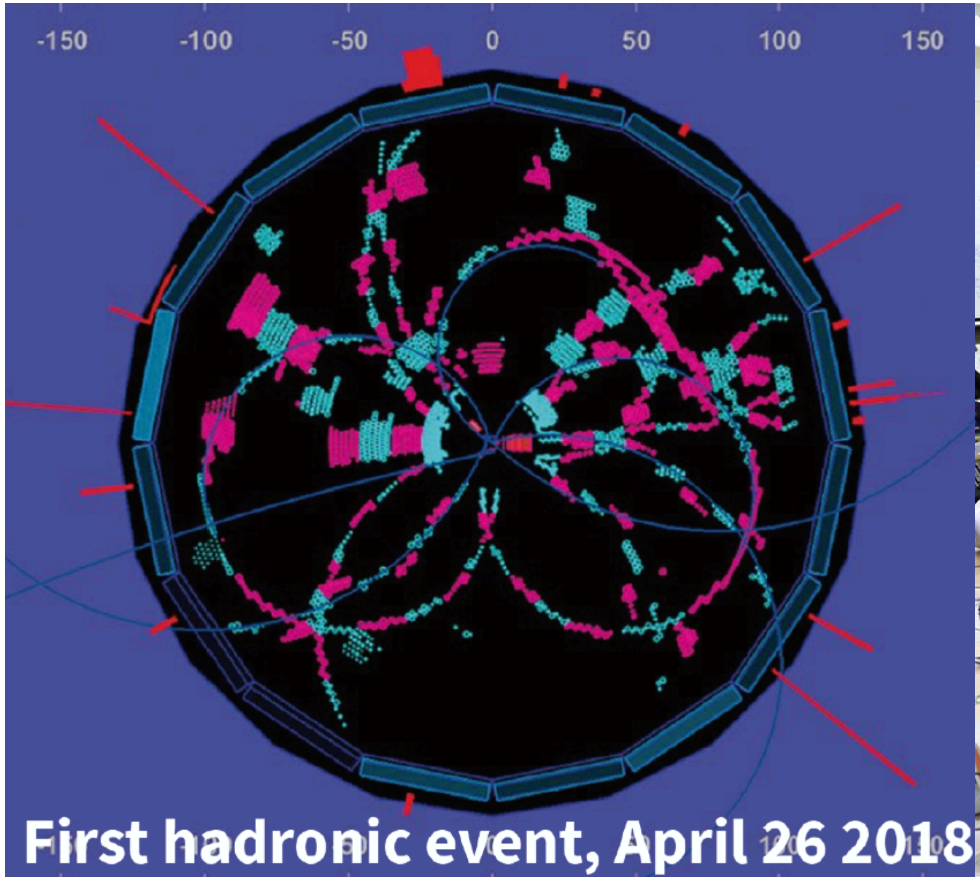
arXiv: 1808.10567



Status of Belle II Experiment

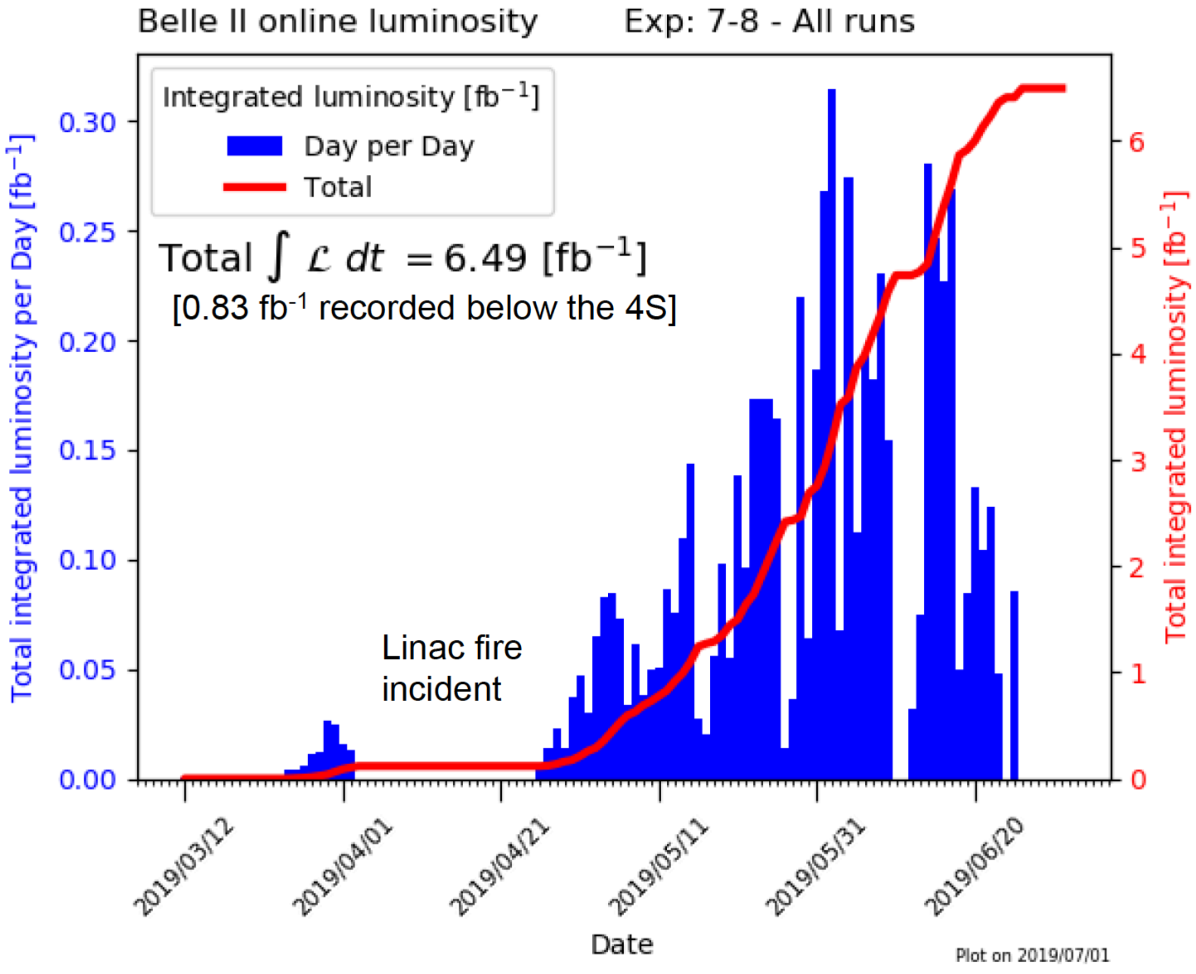
Belle II First Collision!

0:38, April 26, 2018



Spring 2019, First Phase 3 Physics Run

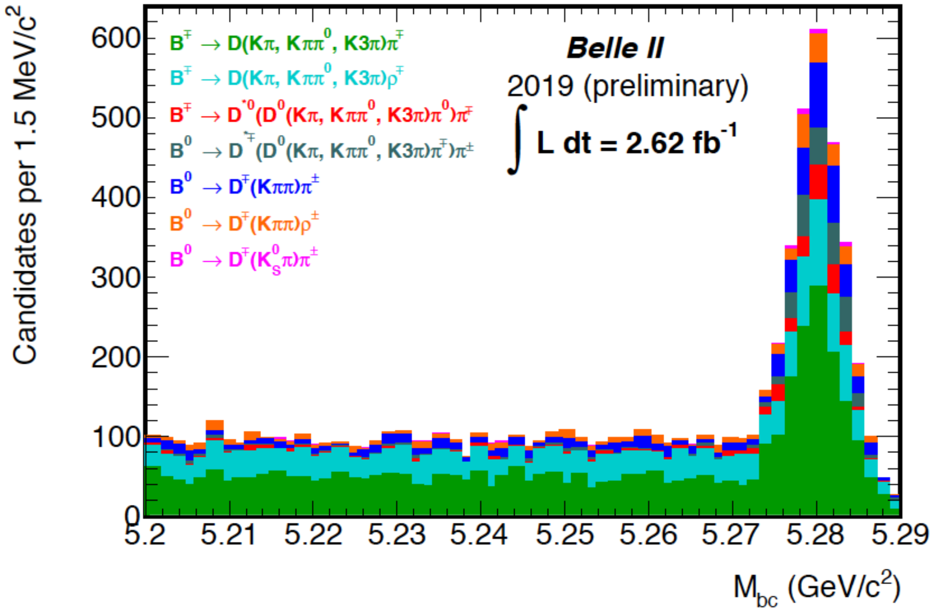
- Phase3: 2 months of collisions in 2019 so far. 6.49fb^{-1} data.
- L(peak) ~ 6.1 x 10^{33} cm^{-2} s^{-1}
- L(SuperKEKB peak) ~1.2 x 10^{34} cm^{-2} s^{-1}
  - comparable to PEP-II best but background too high to turn on Belle II
- Most of the Belle II detector subsystems are working well.
- Phase3 run will resume in Oct. 2019.



Beauty "Rediscovery"

~1/2 of Phase 3 data

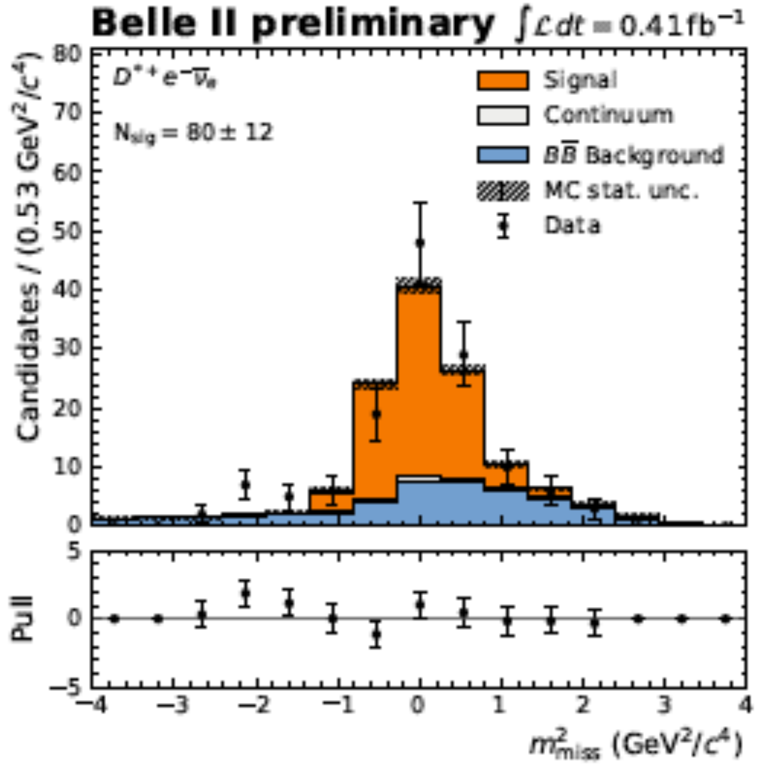
2200 Fully reconstructed hadronic B decays



$$M_{bc} = \sqrt{(E_{cm}/2)^2 - p^2_{recon}}$$

- Demonstration of Belle II's B physics capabilities: Modes with neutrals, and K_S mesons are efficiently reconstructed along with all-charged final states.

~1/10 of the Phase 3 data

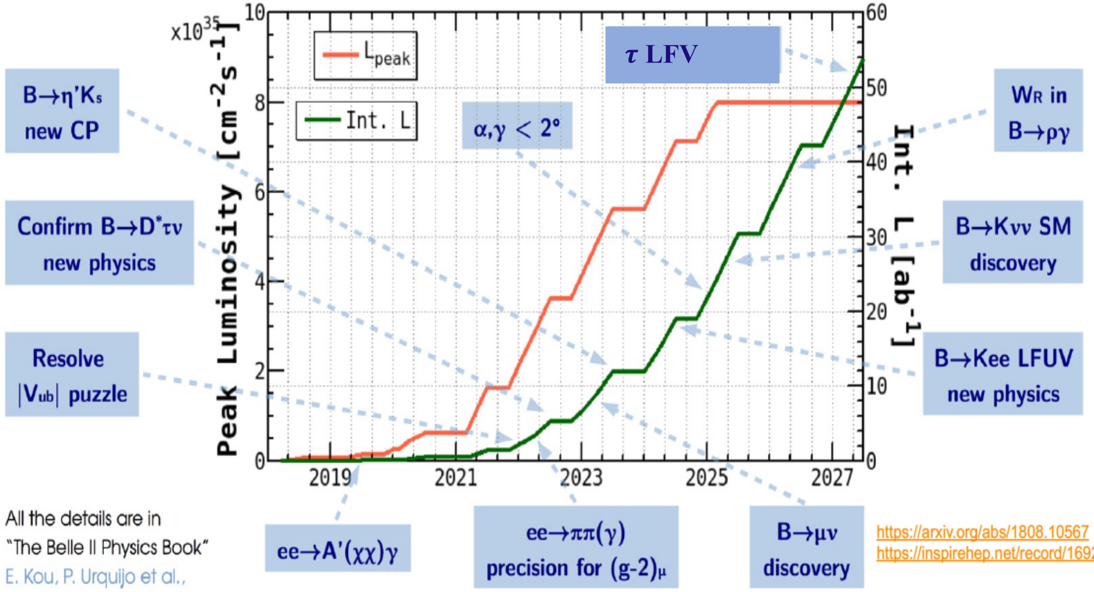


- Signals for $B \to D^{*+} l^- \nu$, $D^{*+} \to D^0 \pi^+$ using the recoil-mass technique or M_{miss}^2 variable.
- Clear signals are seen.

Summary

- Belle II experiment at SuperKEKB aims to find New Physics beyond the SM with precision measurements. Complementary and competitive to LHCb.
- We have just completed the first physics run in the Super *B* Factory mode (Phase 3) in spring 2019.
- Successful detector commissioning so far but further progress requires high-efficiency data-taking by Belle II and much more operation time for SuperKEKB.
- Potential for exciting results in the first years of data taking.

Belle II RoadMap



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

https://arxiv.org/abs/1808.10567
https://inspirehep.net/record/1692393/

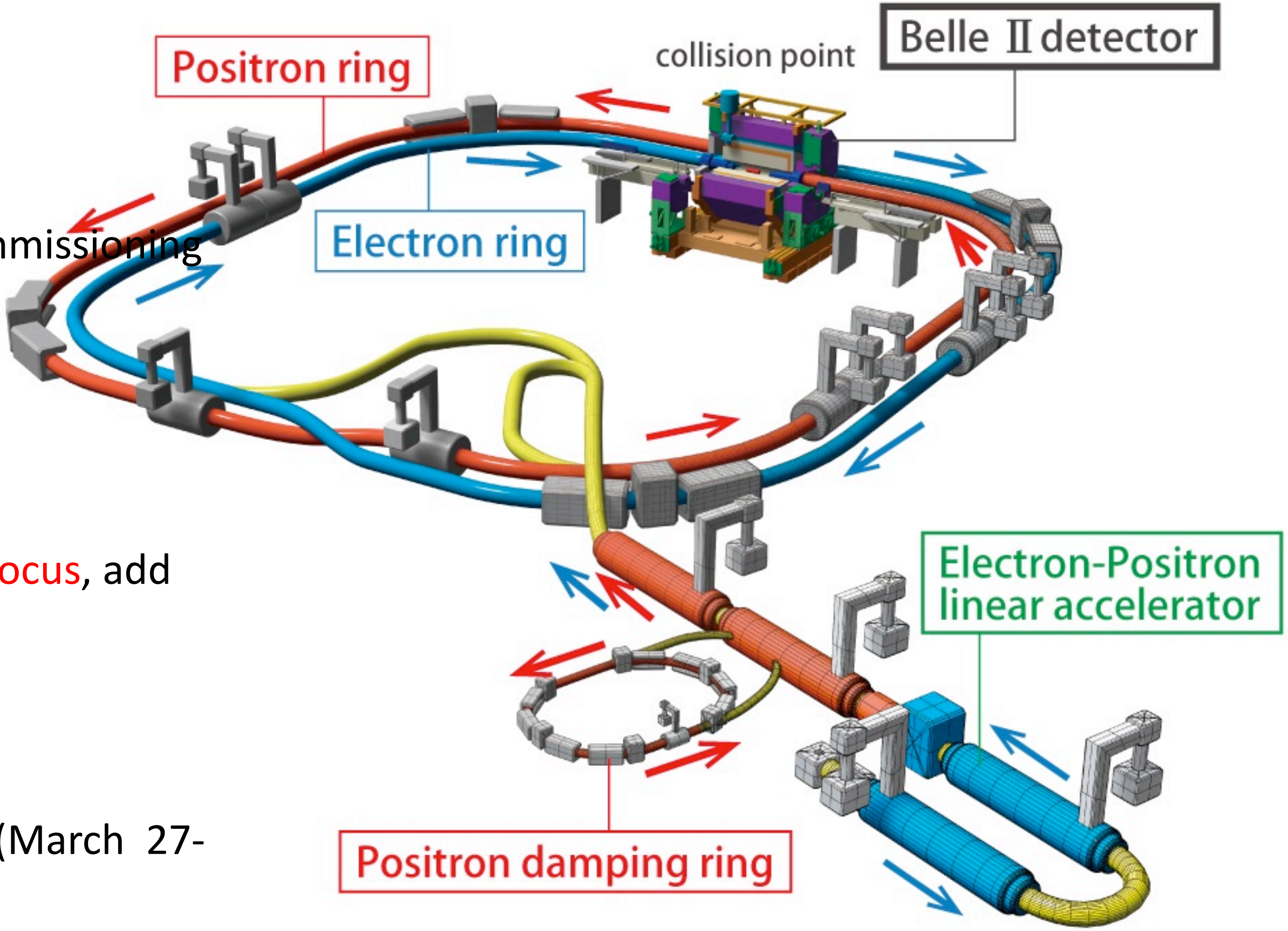
Backup Slides

SuperKEKB, the first new collider in particle physics since the LHC in 2008 (electron-positron (e^+e^-) rather than proton-proton (pp))

Phase 1:
Background, Optics Commissioning
Feb-June 2016.
Brand new
3 km positron ring.

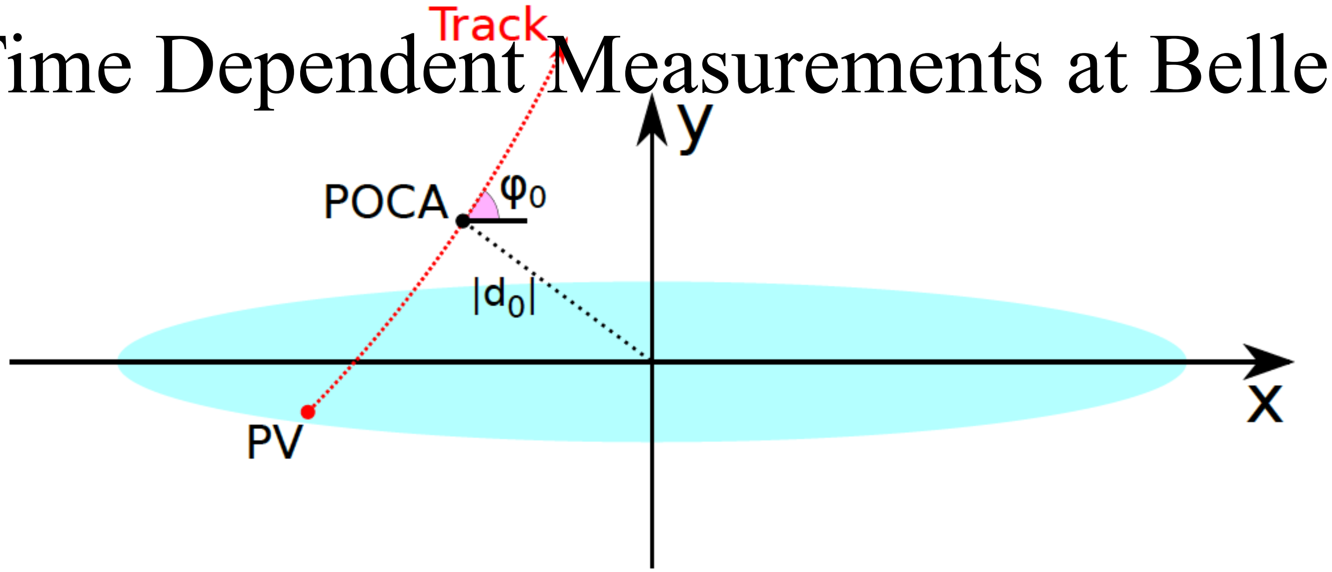
Phase 2: Pilot run
Superconducting Final Focus, add positron damping ring,
First Collisions (0.5 fb^{-1}).
April 27-July 17, 2018

Phase 3: → Physics run (March 27-June 30th, 2019)



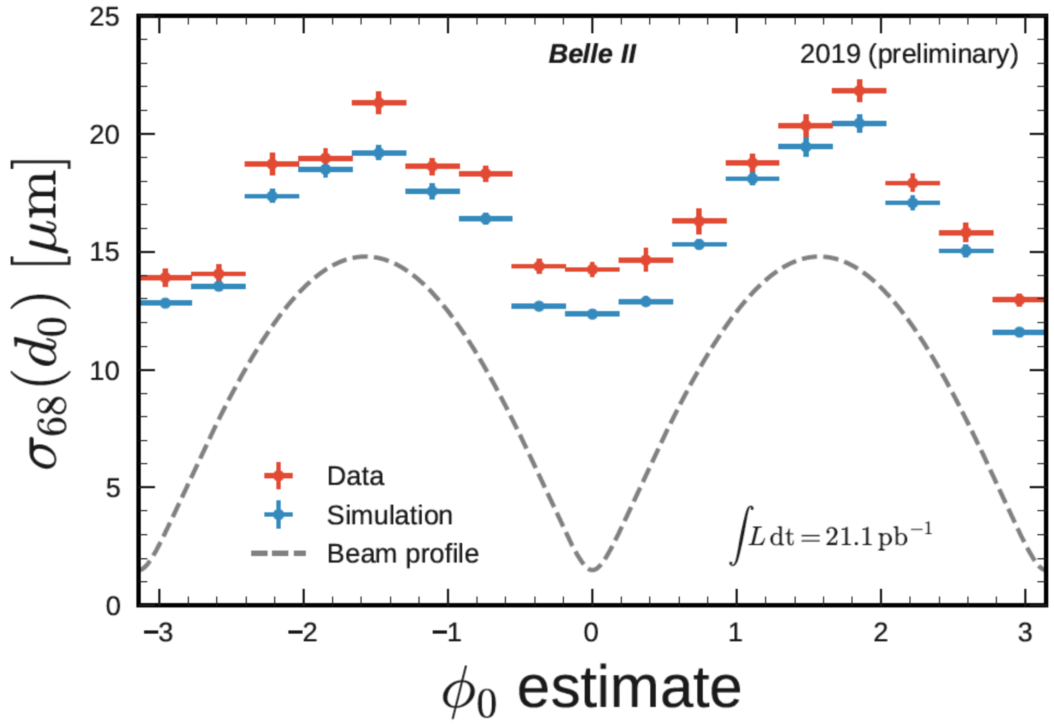
2019: First Collisions in the Phase 3 Physics Run (the VXD is installed in Belle II).

Time Dependent Measurements at Belle II



Impact parameter distributions in two-track events. *Alignment and calibration are working well.*

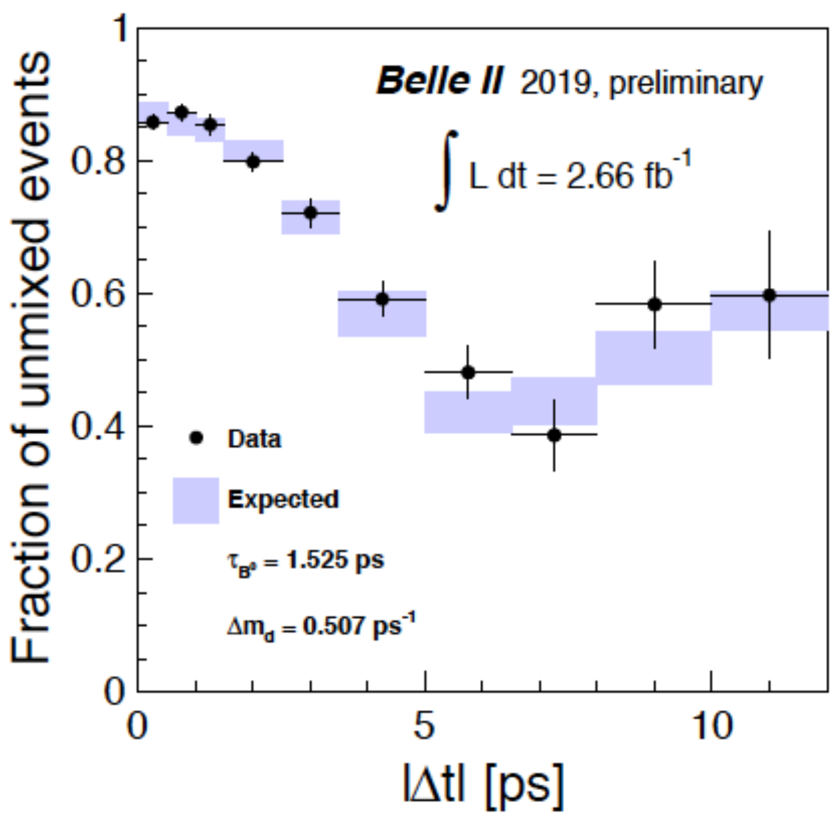
Width of impact parameter resolution distribution



VXD resolution in impact parameter ~14 microns

Time-dependent B-Bbar mixing signature

First oscillation



$$\overline{B}^0 \to D^{*+}\ell^-\nu \to (D^0)\pi_s^+\ell^-\nu$$

Partial reconstruction and time determination uses only Lepton tagging. (Belle II data)

Check $M\nu^2$ sideband (consistent with MC) and continuum with loose cuts (no oscillation)

Not CP violating:

$f_{unmix}(t)= K\ [1+ \cos(\Delta m_d\ \Delta t)]$

Use flavor specific final states but requires tagging. Verifies Belle II VXD capabilities for CP violation.

Charged Lepton Flavor Violation