Istituto Nazionale di Fisica Nucleare
Laboratori Nazionali di Frascati

The Belle II experiment at SuperKEKB: status and prospects

B. Oberhof
LNF-INFN, Italy

14th November 2019

Belle II

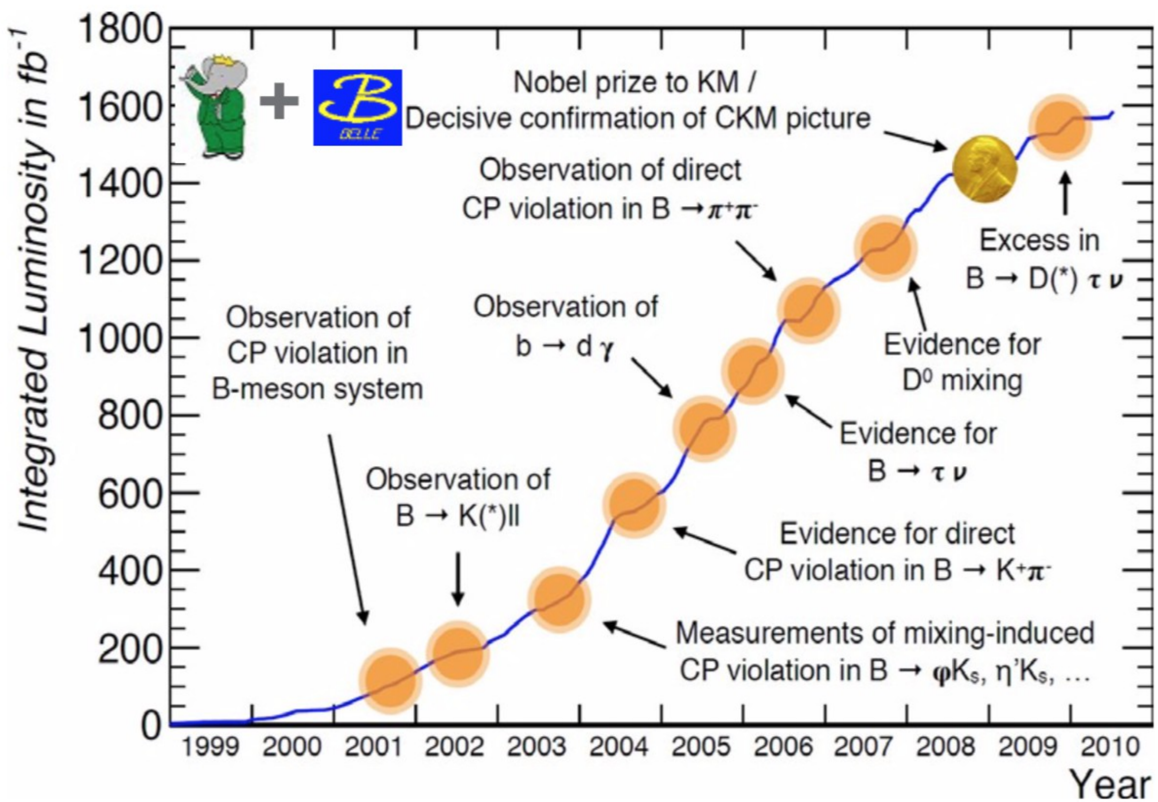
Outline

- The B-factories and their legacy
- The Intensity Frontier
- The SuperKEKB collider
- The Belle II detector
- Physics program
- Results from early data
- Schedule & prospects

Introduction

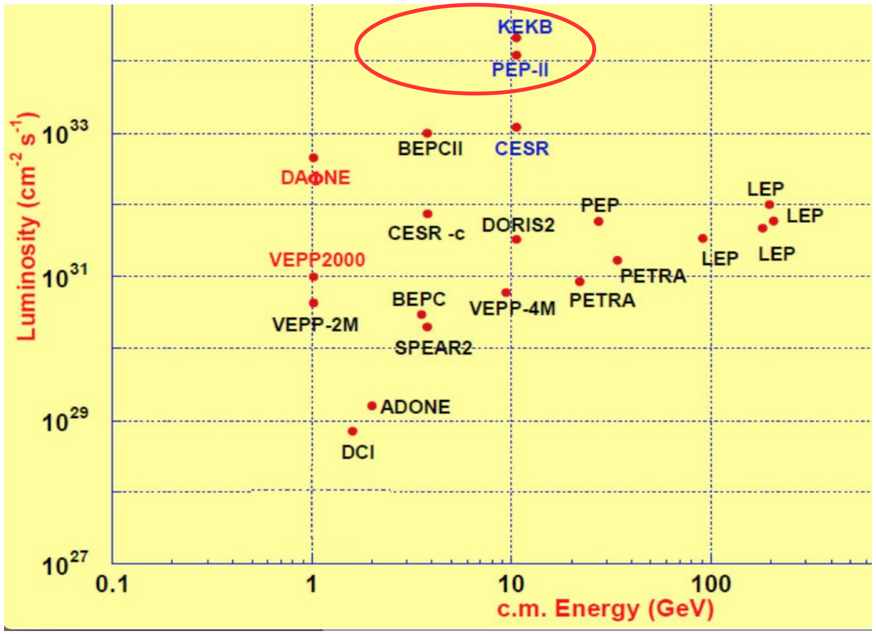
B-factories: history

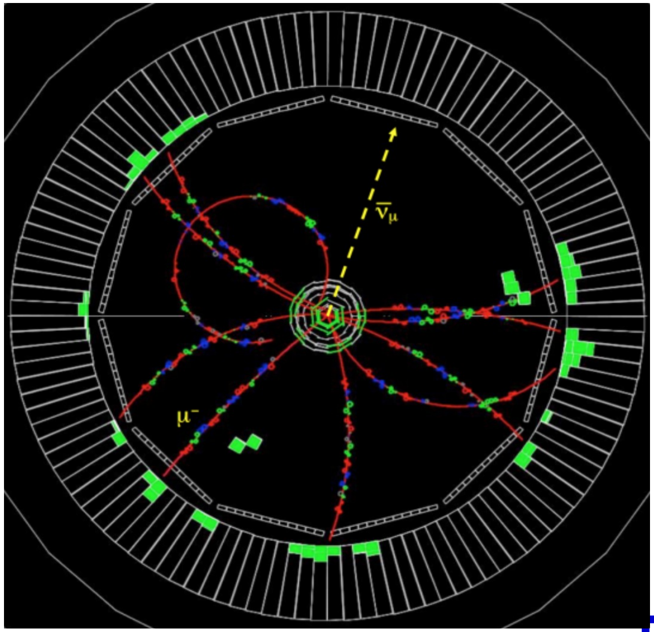
- Belle II follows the path defined by the BaBar (SLAC, USA) and Belle (KEK, Japan) experiments which started taking data 20 years ago
- The primary aim of the two experiments was the measurement of CP-violation in the $B^0\overline{B^0}$ meson system and test of the CKM paradigm, however physics results were not limited to that



B-factories: key ingredients

- Collider performance:
  - high luminosity (steadily improved)
  - long term steady operations & machine background control
- Environment of e^+e^- colliders:
  - very clean production process
  - no additional interactions → low backgrounds, high trigger efficiency
- Detector performance:
  - Precise, efficient, fast, almost hermetic
  - Multi purpose: tracking, vertexing, particle ID, neutral reconstruction etc.



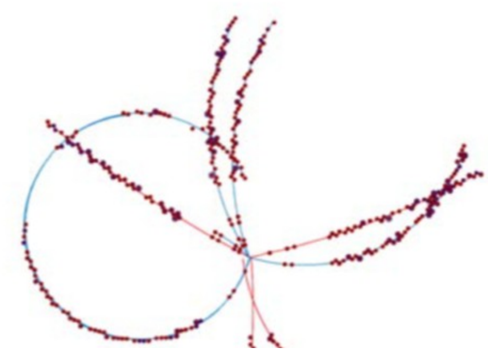


B-factories: heritage

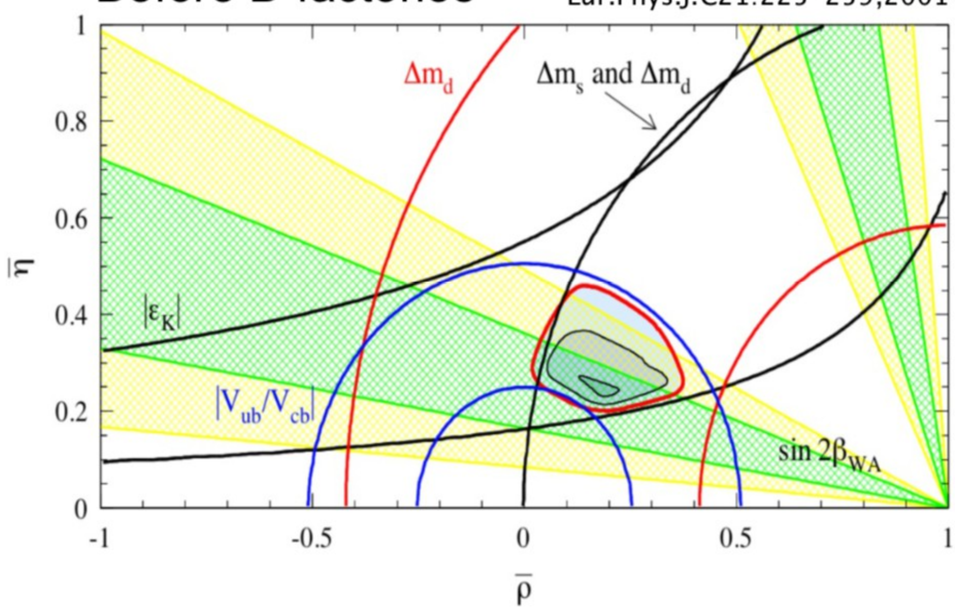
- Many important results over the years in the beauty, charm and τ sectors → O(1000) papers published (jointly)
- Confirmation of the CKM paradigm and precise determination of the unitarity triangle
- No evidence for physics beyond the SM

The Physics of the B Factories

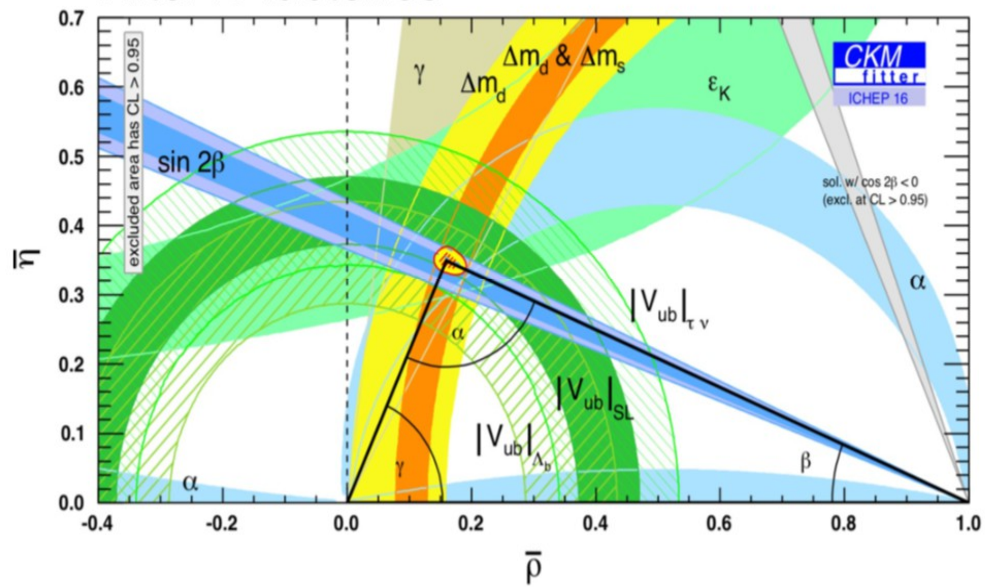
EPJ C74, 3026 (2014)



Before B-factories   Eur.Phys.J.C21:225-259,2001

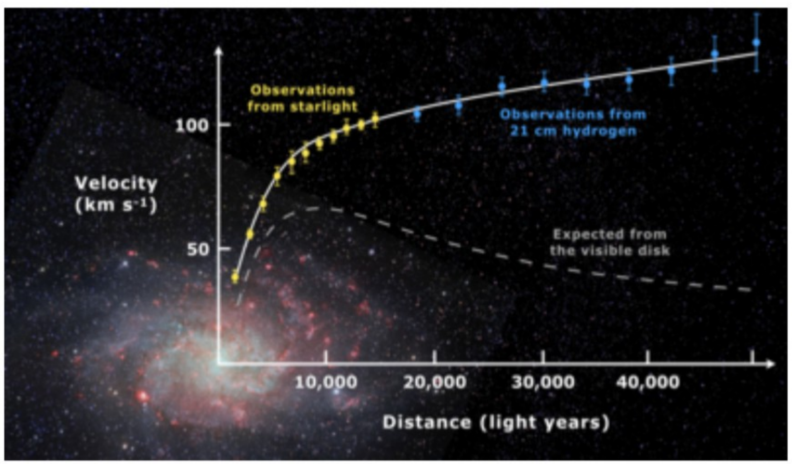


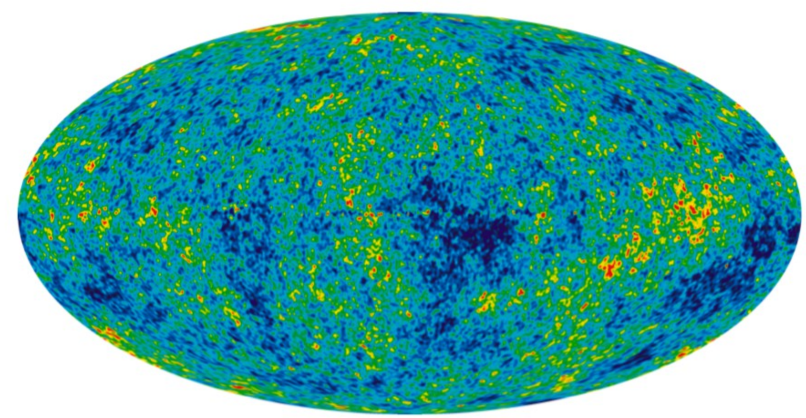
After B-factories



New-generation B-factory

- Given the success of BaBar and Belle, why should one build a new B-factory?
- Nowadays there is strong evidence that physics beyond the SM exists:
  - Temperature fluctuations of cosmic background radiation and rotation curves from spiral galaxies indicate existence of Dark Matter

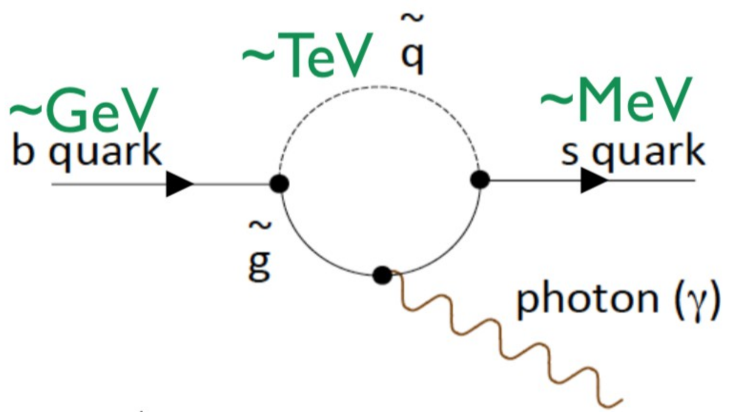


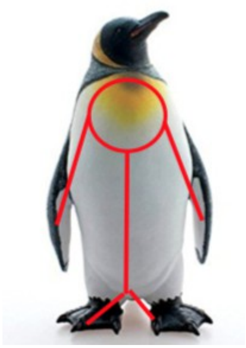


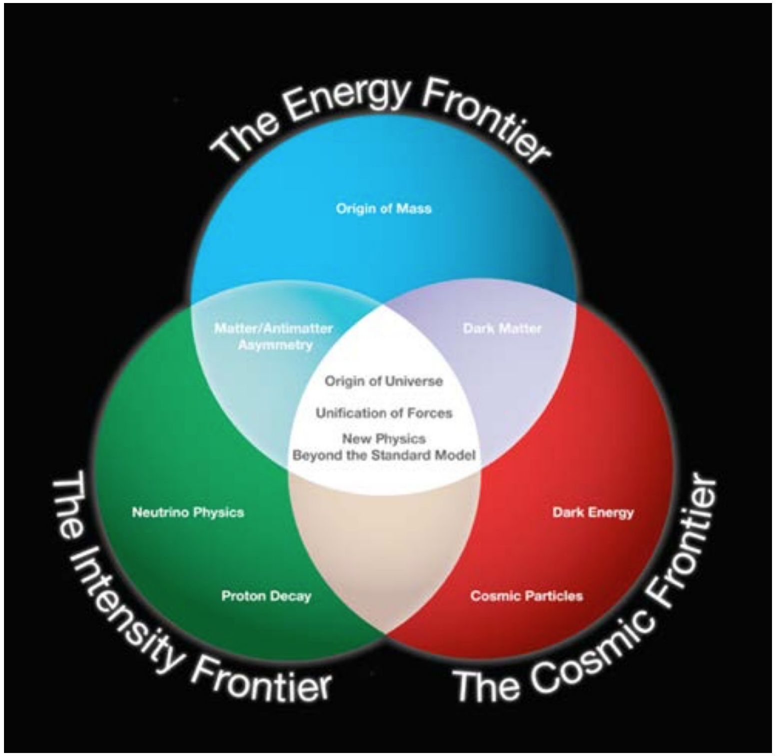
  - CP-violation predicted by the CKM matrix is several orders of magnitudes too small to account for the observed matter anti-matter asymmetry in the universe

The Intensity Frontier

- Belle II is a leading experiment in the "Intensity Frontier"
- In three fold approach of near-mid term particle physics, Flavor Physics explores its goals with highest reachable intensity
- Belle II will be sensitive to New Physics up to the TeV scale through penguin diagrams



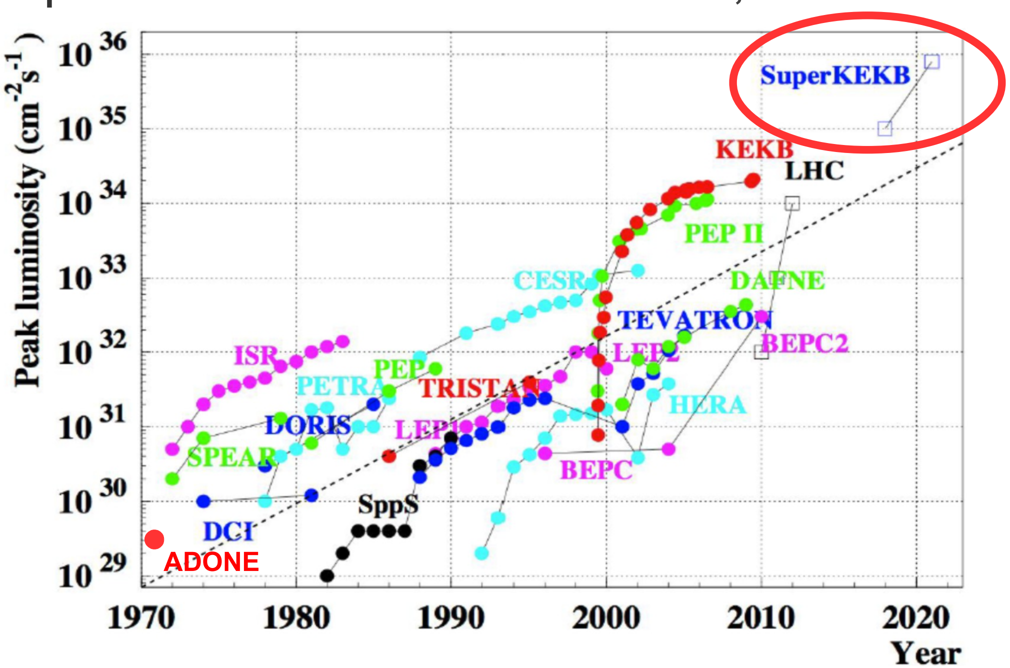




- Indirect search for NP → new particles in loops affect SM predictions
- Widely endorsed approach, e.g. EPPSU 2018-2020
- Belle II complements with LHCb, similar goals, but different environment

Intensity Frontier Requirements

- In order to meet the physics goals the data sample should exceed 50 ab^{-1}
- This requires an increase of a factor of 40 in instantaneous luminosity → new collider, SuperKEKB
- Higher luminosity = possibly much higher beam backgrounds. To keep required performance → new detector, Belle II



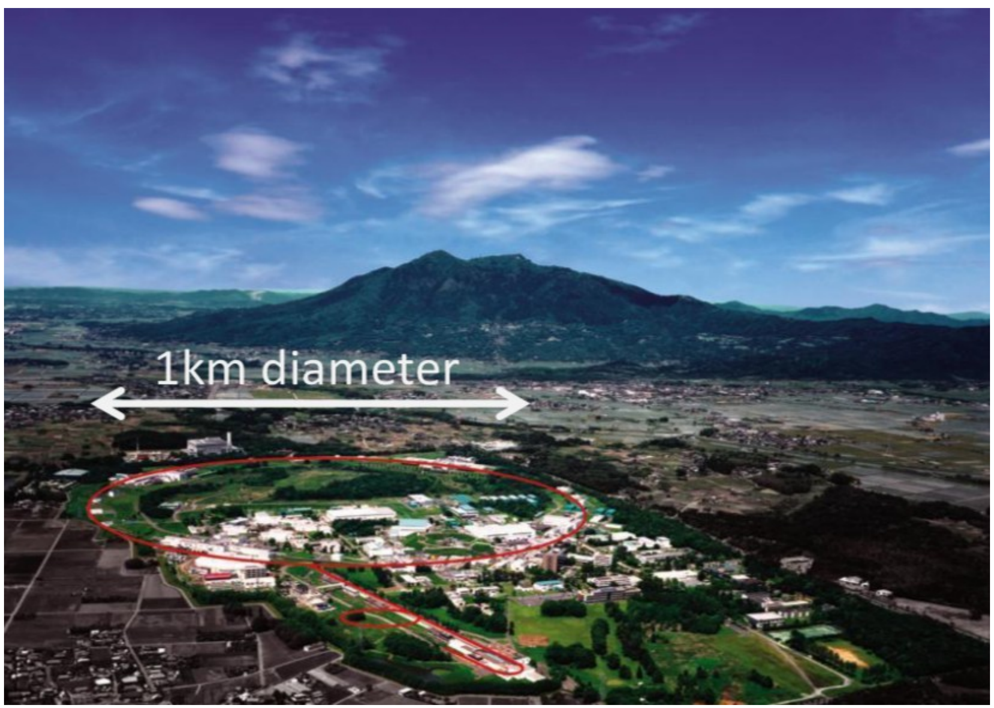
The facility

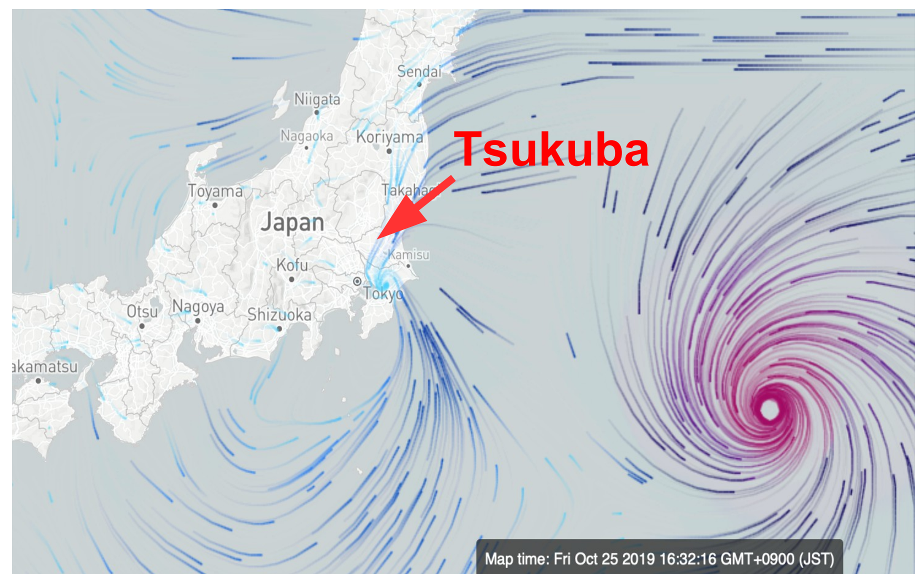
BelleII & SuperKEKB @ KEK

- KEK stays for 高 エネルギー 加速器 研究 機構

	高	エネルギー	加速器	研究	機構
	Kō	*Energī*	*Kasokuki*	*Kenkyū*	*Kikō*
which translates as:	*High*	*Energy*	*Accelerator*	*Research*	*Organization*

- KEK is the largest HEP laboratory in Japan, located in Tsukuba, ~50 Km north-east of Tokyo
- Besides SuperKEKB it hosts two photon factories (PF and AR-PF)





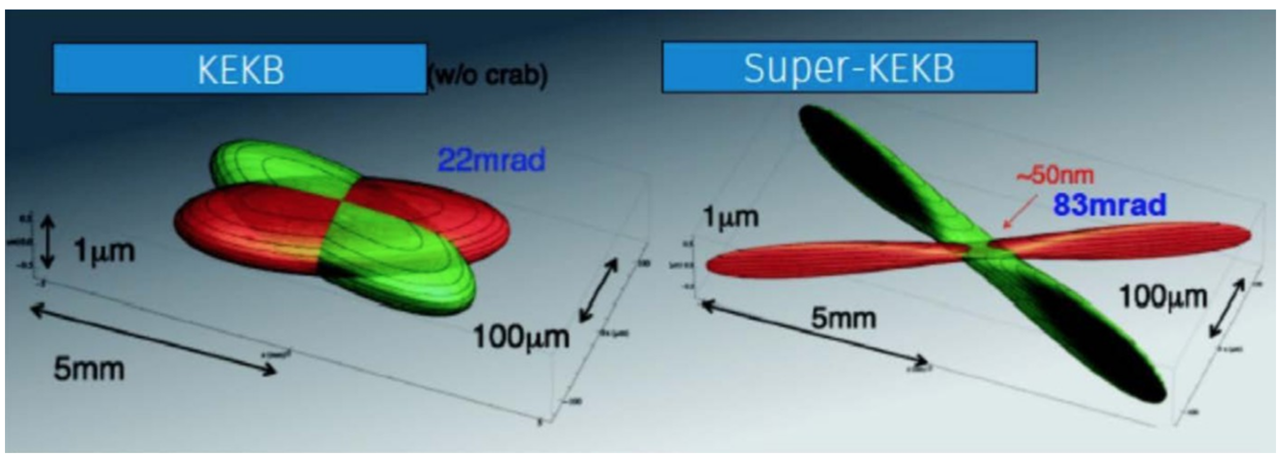
The challenge: 8×10^{35} cm^{-2} s^{-1}

- How to gain a factor 40 in (instantaneous) luminosity w.r.t. KEKB?

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

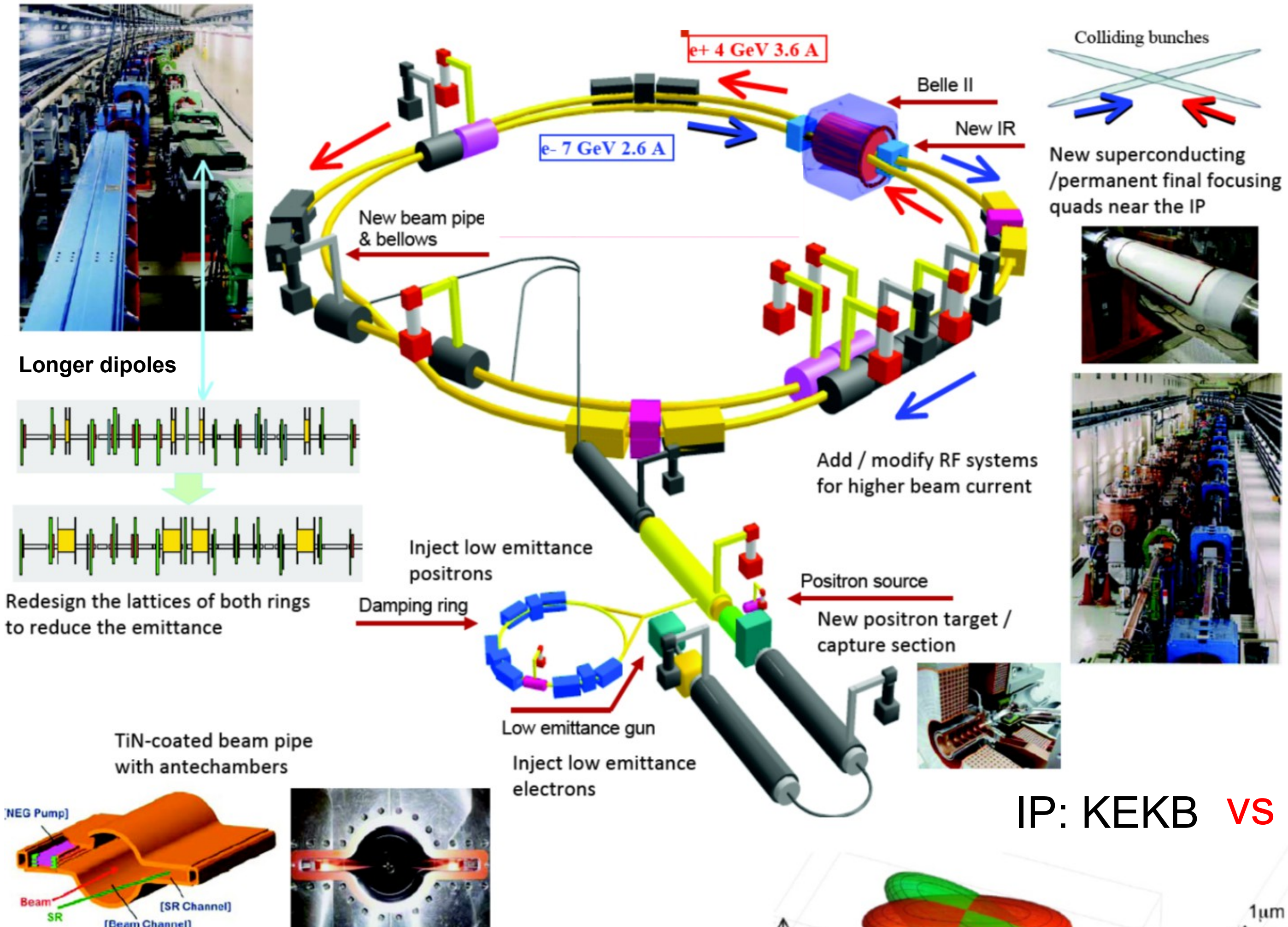
Lorentz factor
beam current
beam-beam parameter
geometrical reduction factors
beam aspect ratio at the IP
vertical beta-function at the IP

- “Nano beams” scheme: proposed by P. Raimondi for SuperB: lower emittance and β*, higher crossing angle, large Piwinsky angle → x20 gain



- Beam currents: → x2 gain by increasing beam currents

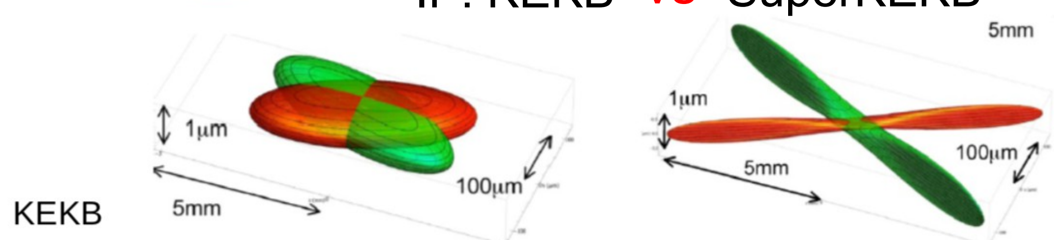
SuperKEKB



Peak luminosity:
- KEKB =
$2.11 \times 10^{34}\ cm^{-2}\,s^{-1}$
- SuperKEKB =
$8.0 \times 10^{35}\ cm^{-2}\,s^{-1}$

Beam Energies:
- KEKB =
8.0 / 3.5 GeV
- SuperKEKB =
7.0 / 4.0 GeV

IP: KEKB vs SuperKEKB



KEKB vs SuperKEKB

		KEKB		SuperKEKB		
		LER (e^+)	HER (e^-)	LER (e^+)	HER (e^-)	Units
Beam energy	E	3.5	8.0	4.0	7.007	GeV
Circumference	C	3016.262		3016.315		m
Half crossing angle	θ_x	$0(11^{(*)})$		41.5		mrad
Piwinski angle	ϕ_{piw}	0	0	24.6	19.3	rad
Horizontal emittance	ε_x	18	24	3.2(1.9)	4.6(4.4)	nm
Vertical emittance	ε_y	150	150	8.64	12.9	pm
Coupling		0.83	0.62	0.27	0.28	%
Beta function at IP	β_x^*/β_y^*	1200/5.9	1200/5.9	32/0.27	25/0.30	mm
Horizontal beam size	σ_x^*	147	170	10.1	10.7	μm
Vertical beam size	σ_y^*	940	940	48	62	nm
Horizontal betatron tune	ν_x	45.506	44.511	44.530	45.530	
Vertical betatron tune	ν_y	43.561	41.585	46.570	43.570	
Momentum compaction	α_p	3.3	3.4	3.20	4.55	10^{-4}
Energy spread	σ_ε	7.3	6.7	7.92(7.53)	6.37(6.30)	10^{-4}
Beam current	I	1.64	1.19	3.60	2.60	A
Number of bunches	n_b	1584		2500		
Particle/bunch	N	6.47	4.72	9.04	6.53	10^{10}
Energy loss	U_0	1.64	3.48	1.76	2.43	MeV
Long. damping time	τ_z	21.5	23.2	22.8	29.0	msec
RF frequency	f_{RF}	508.9		508.9		MHz
Total cavity voltage	V_c	8.0	13.0	9.4	15.0	MV
Total beam power	P_b	~ 3	~ 4	8.3	7.5	MW
Synchrotron tune	ν_s	-0.0246	-0.0209	-0.0245	-0.0280	
Bunch length	σ_z	~ 7	~ 7	6.0(4.7)	5.0(4.9)	mm
beam-beam parameters	ξ_x/ξ_y	0.127/0.129	0.102/0.090	0.0028/0.088	0.0012/0.081	
Luminosity	L	2.108×10^{34}		8×10^{35}		$cm^{-2}s^{-1}$
Integrated luminosity	$\int L$	1.041		50		ab^{-1}

× 1/20 β_y

$\sigma_y \approx$ 50-60 nm

(similar as ILC/ATF2)

× 2-3 beam currents

similar beam-beam strength (tune-shift)

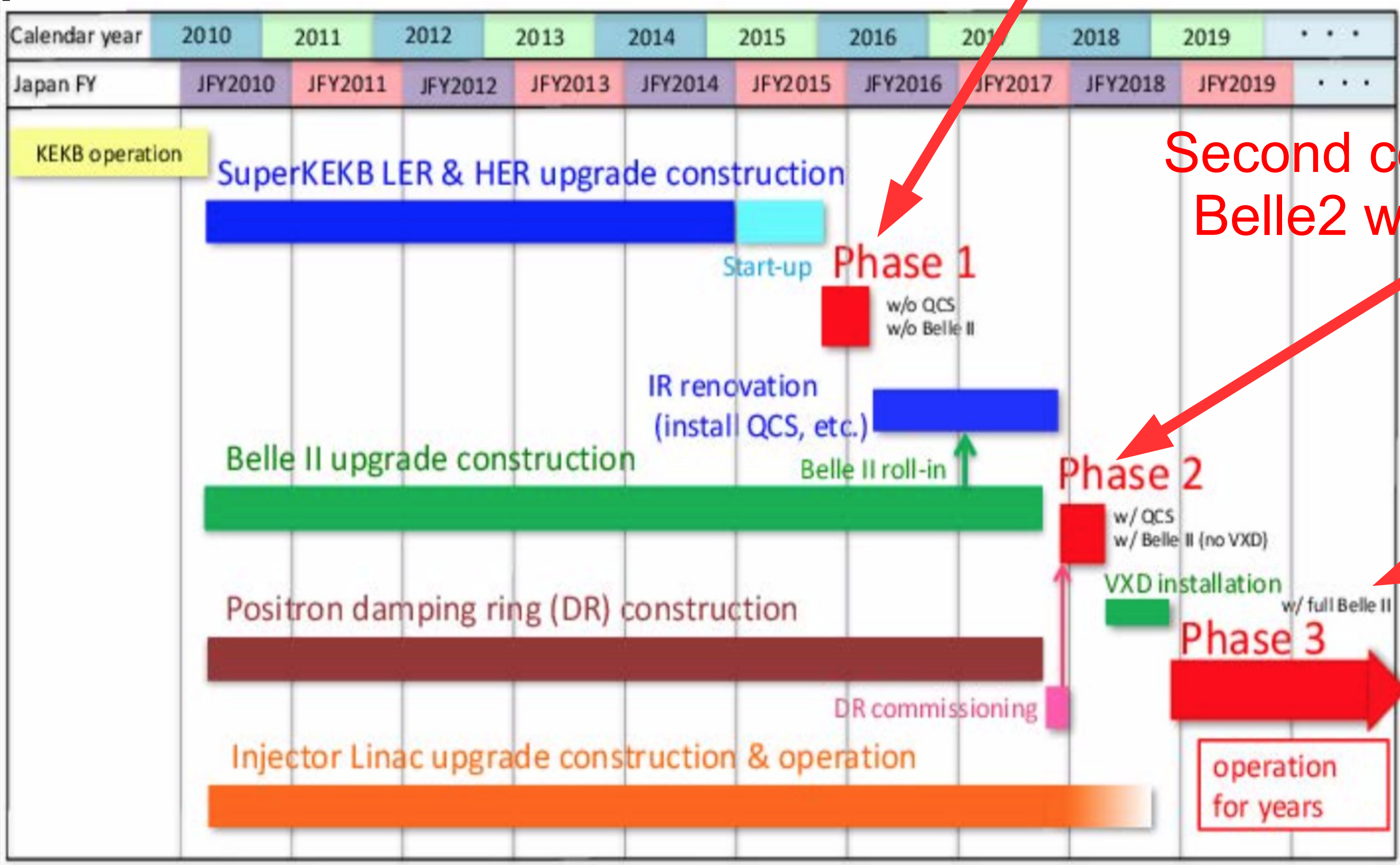
→ × 40 peak luminosity

SuperKEKB Schedule

First commissioning run, no Belle2, commissioning detector called BEAST

Second commissioning run, Belle2 w/o vertex detector

Physics run full Belle II

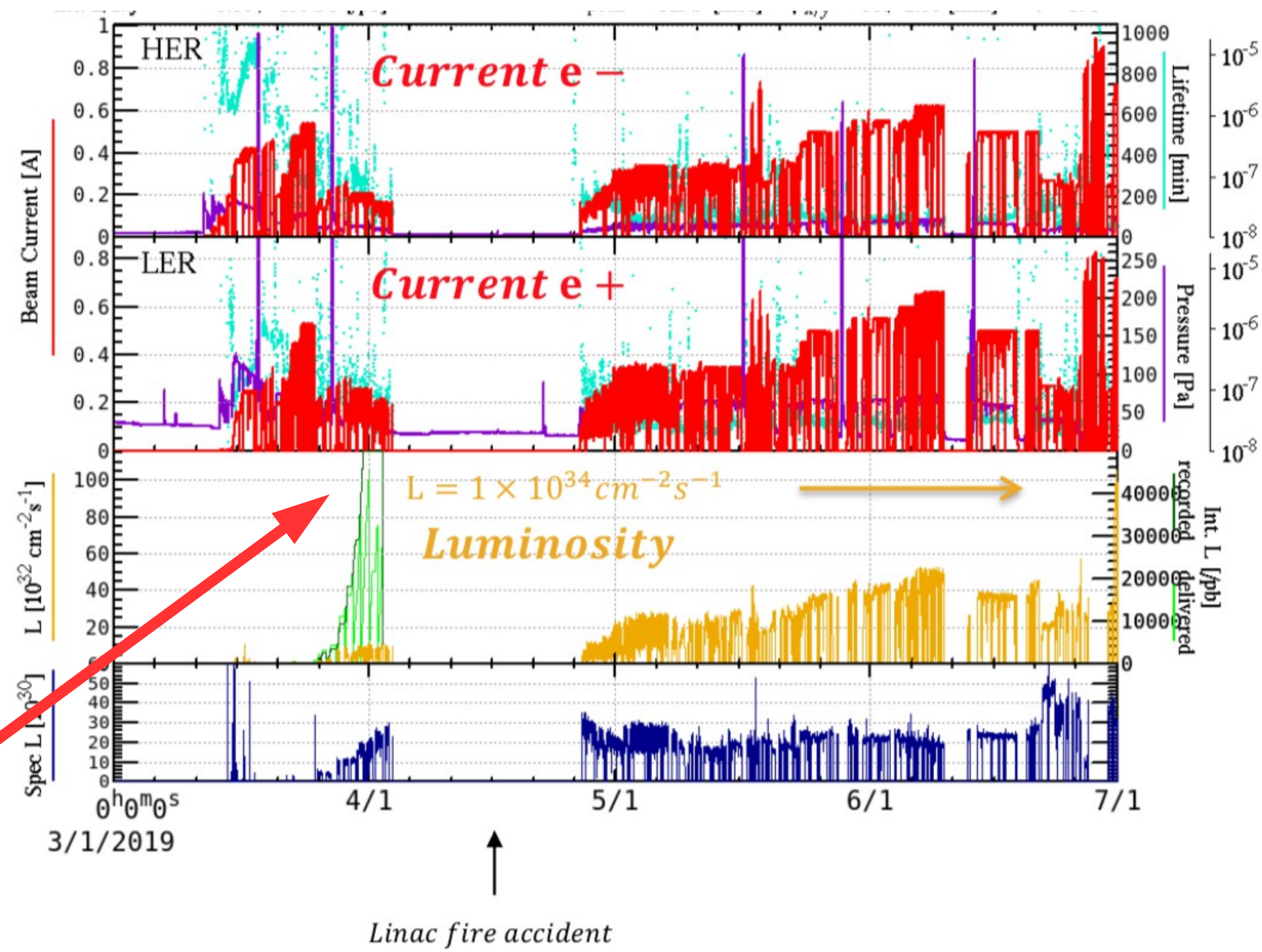


BEAST = Beam Exorcism for A Stable experiment

SuperKEKB works!

- First physics run with full Belle2 detector: Phase3, March to June 2019
- Background decreased by factor 10 from Phase2 with improved collimation
- About one month lost because of fire accident in LINAC (April 2019)

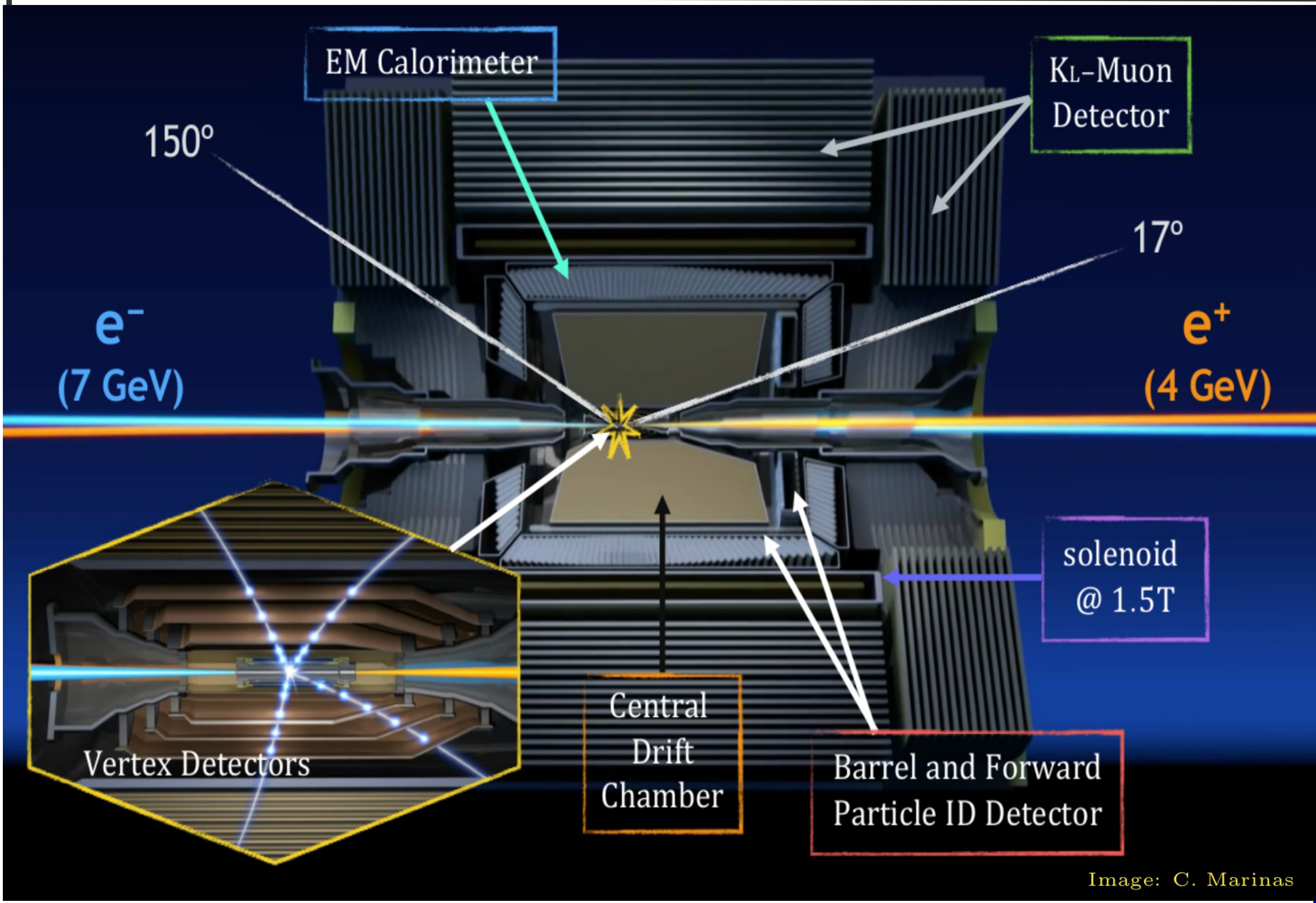
- Stable operation with I = 500 mA
- Squeezed β* down to 2 mm
- About 6.5 fb^{-1} of data recorded
- Peak luminosity $1x10^{34}$ cm^{-2} s^{-2}



1/2 of KEKB peak lumi

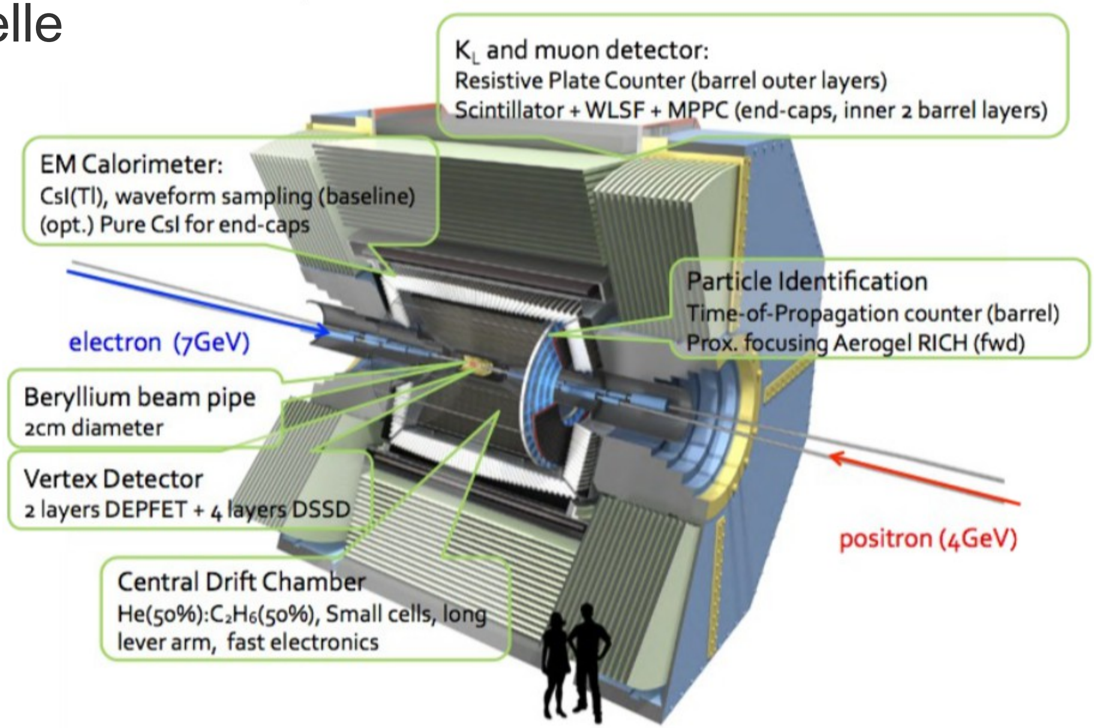
The detector

The Belle II Detector



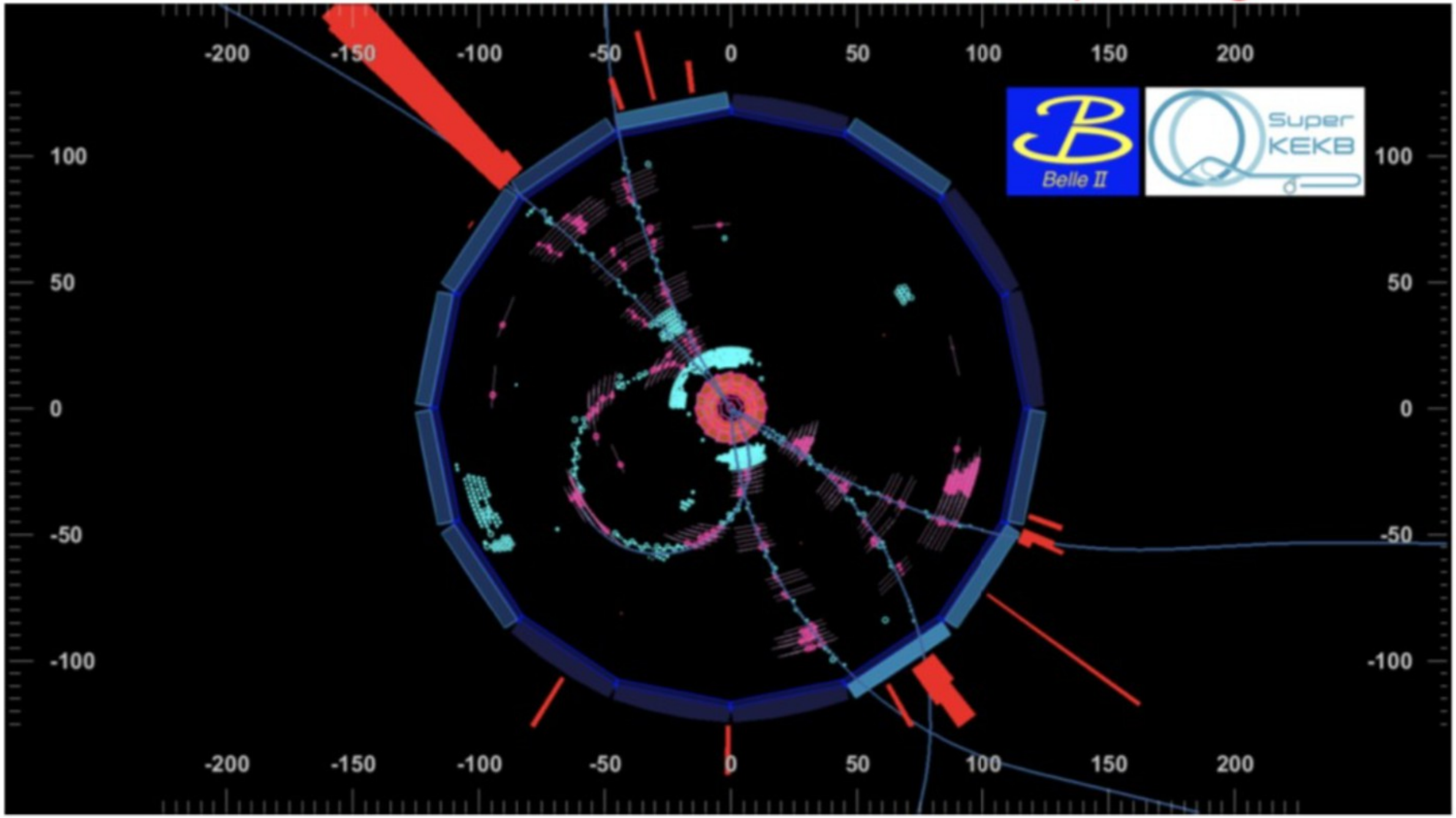
Belle → Belle II

- Belle II is an upgrade of the Belle detector designed to improve performance, especially with new machine conditions, in particular:
  - Higher background environment of SuperKEKB w.r.t. KEKB
  - Reduced CM boost w.r.t. Belle
- Highlights:
  - Vertex detector:
    - 2 layers of pixels
    - 4 layers of DSSD with extended coverage
  - Particle-ID:
    - new TOP + ARICH (FWD)
  - Drift chamber:
    - smaller cell size, longer lever arm
  - K_L & muons:
    - Inner (barrel) and FWD RPCs replaced with scintillators



Belle2 works!

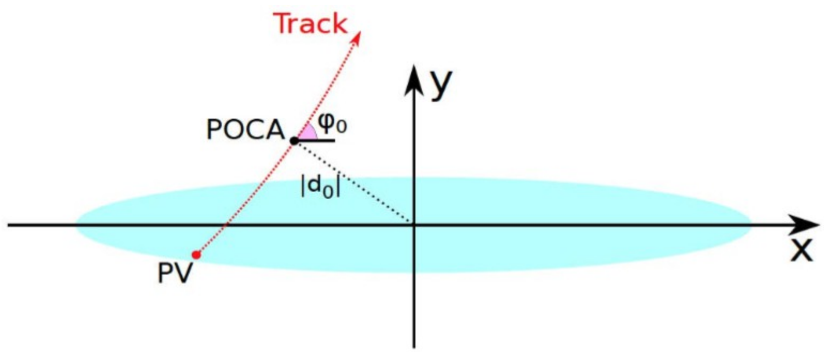
Second "First" SuperKEKB collision on March 11th
Phase III - Full detector installed and operating

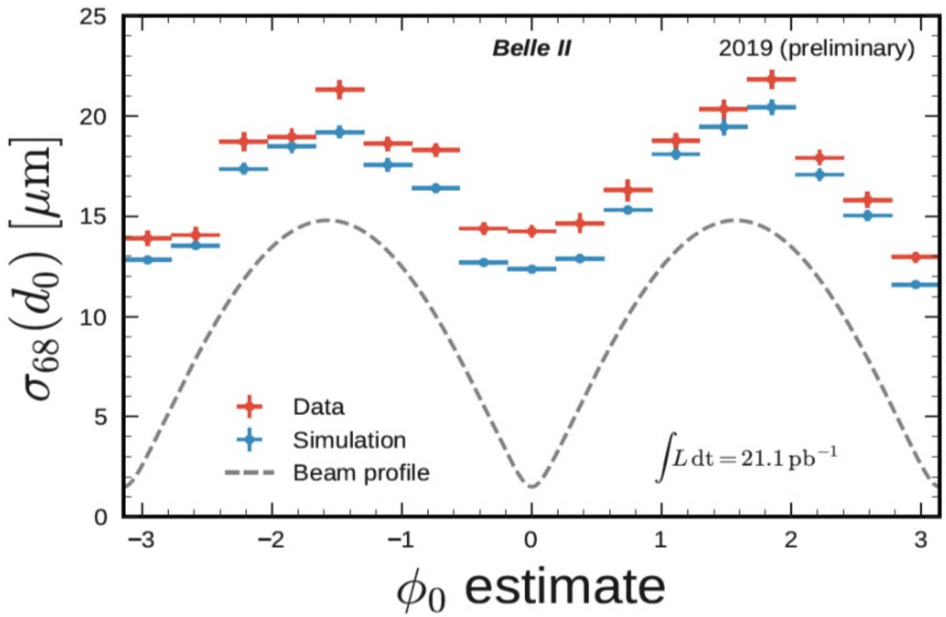


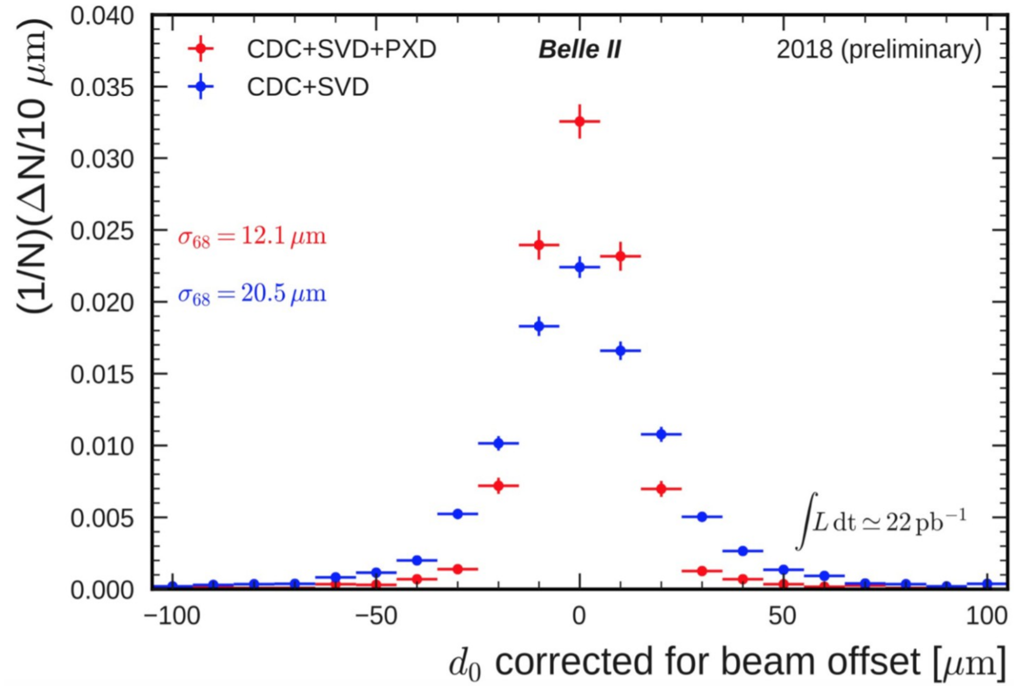
B-factories are back in the game

Tracking

- Because of a damage to the pixel ladders during assembly procedure only the innermost layer of the PXD is completely installed
- VXD resolution in impact parameter ~14 μm: 2 times better than Belle



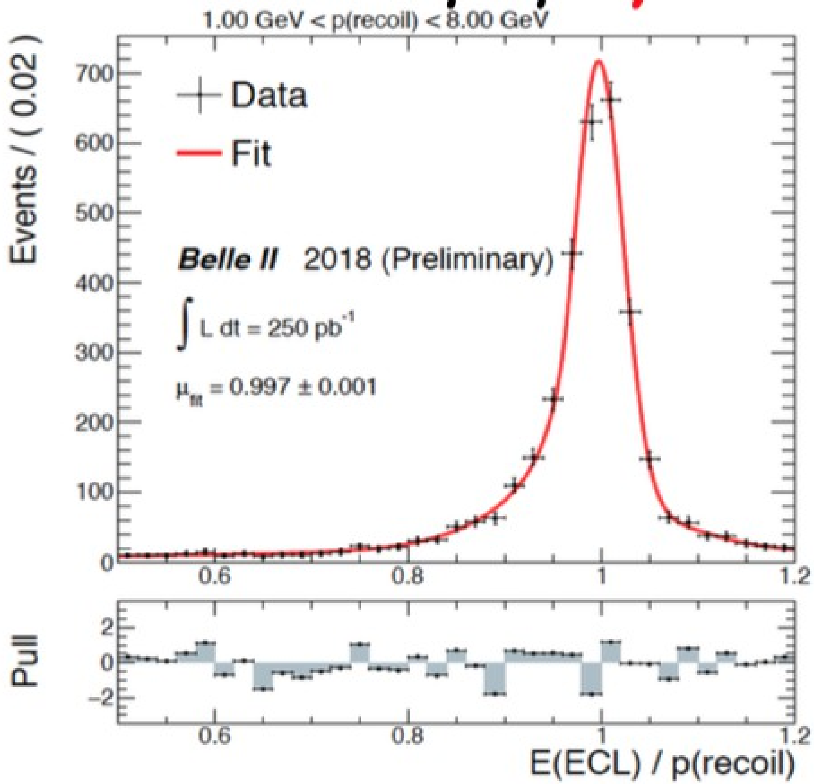




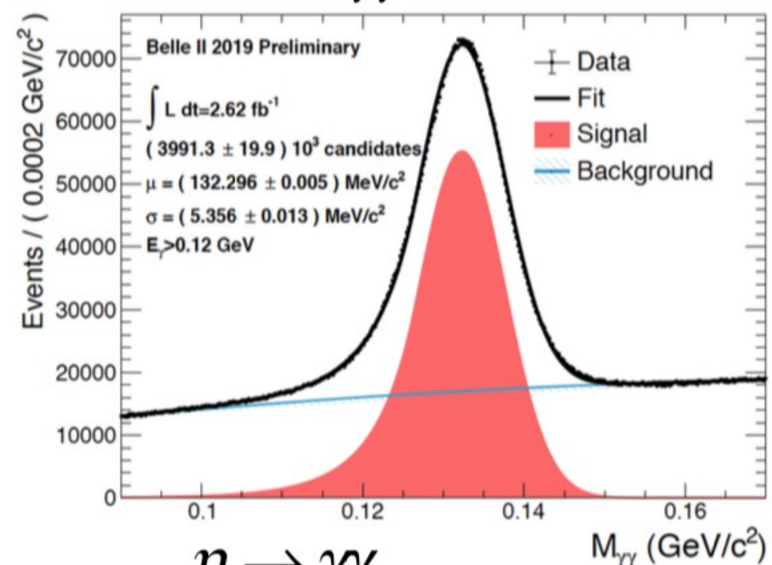
Neutrals

- The electromagnetic calorimeter is performing very well
- Belle2 benefits from a unique single photon trigger for dark sector searches

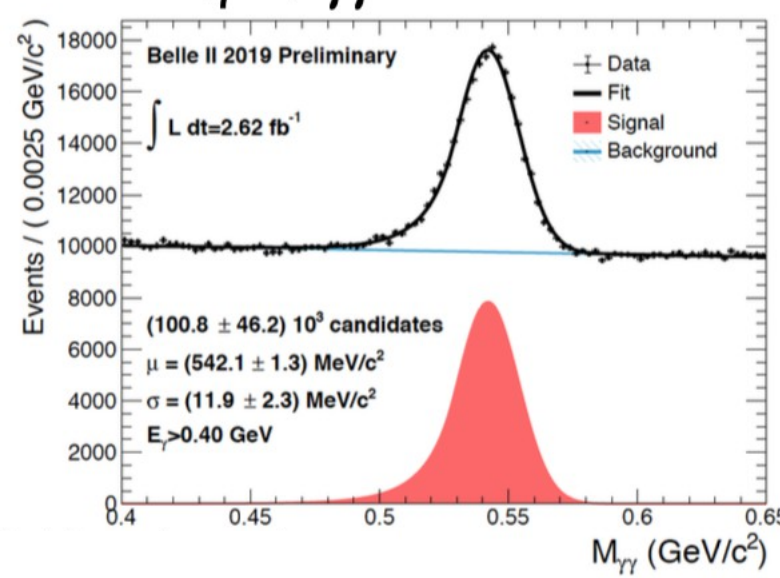
$e^+e^- \rightarrow \mu^+\mu^-\gamma$



$\pi^0 \rightarrow \gamma\gamma$

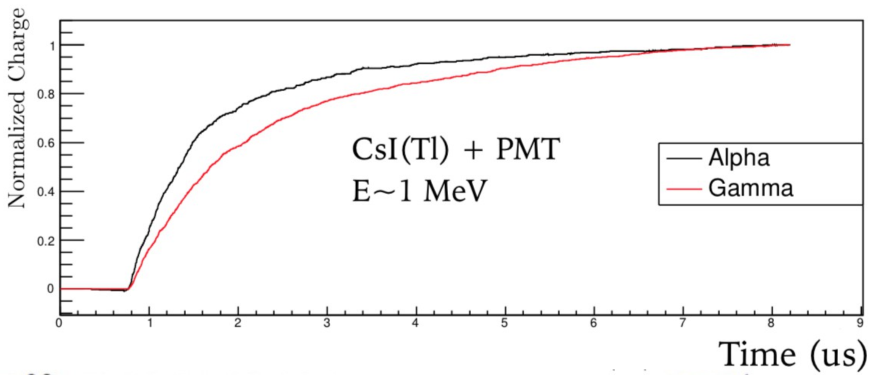


$\eta \rightarrow \gamma\gamma$



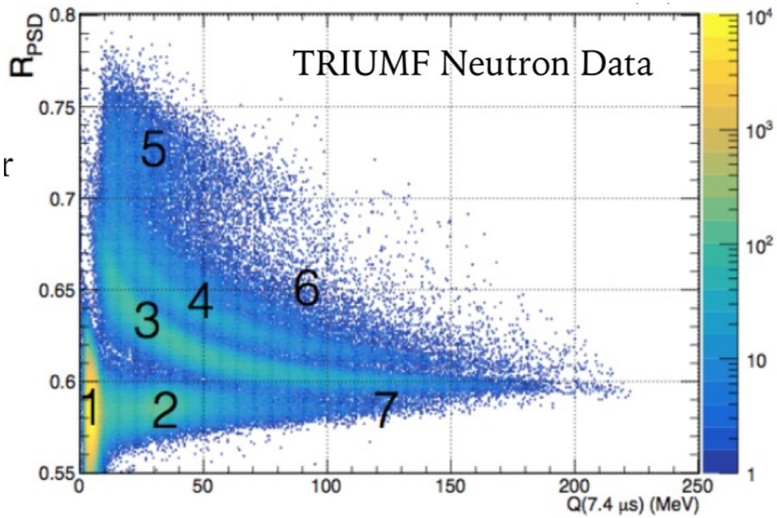
Neutral Particle ID

- A unique feature of Belle II is the Pulse Shape Discrimination to distinguish photons and neutral hadrons in the electromagnetic calorimeter (ECL)
- Basic idea: the shape of a CsI(Tl) scintillation pulse depends on the dE/dx

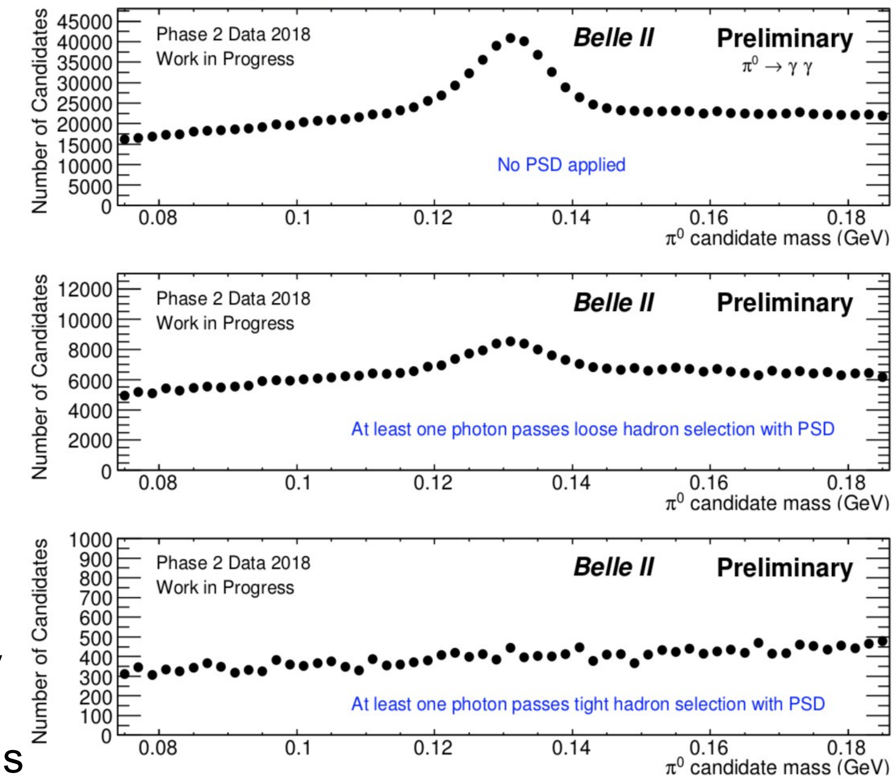


$$R_{\mathrm{PSD}} = \frac{Q(1.2\mu s)}{Q(7.4\mu s)}$$

S. Longo and J. M. Roney JINST 13 P03018 arXiv:1801.07774



1 photons
2 muons
3 single proton
4 double proton
5 alfa
6-7 high multiplicity hadronic interactions



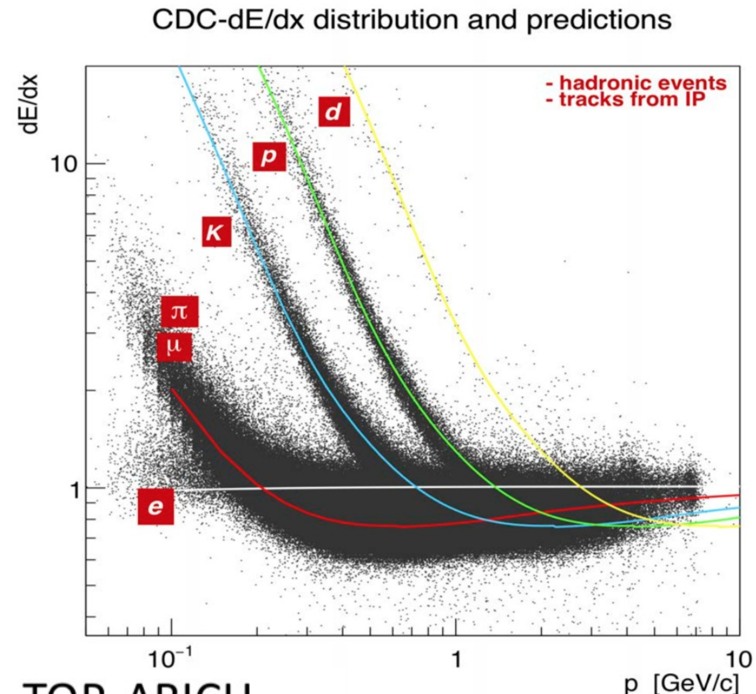
- Belle II currently uses MVA discriminators which look at the whole cluster

Charged Particle ID

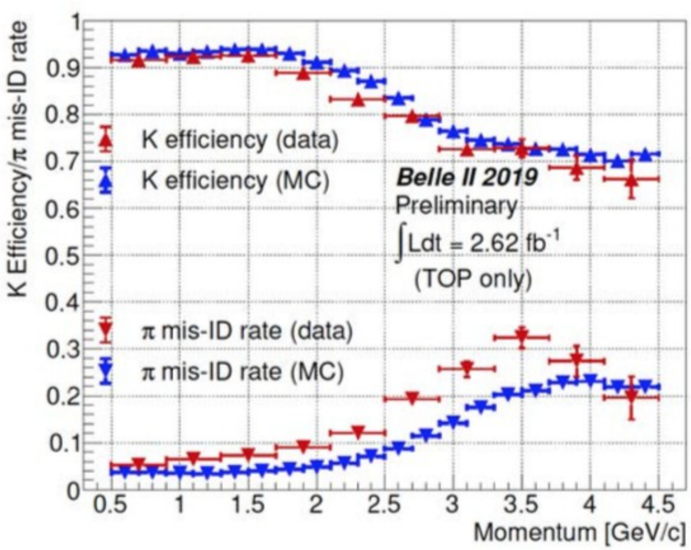
- Particle ID is crucial for most analyses
- Contributions from various sub-detectors, in particular: CDC, TOP, ARICH
- Measured on a control samples, e.g. (for K)

$$D^{*+} \to D^0 \pi_s^+ ; D^0 \to K^- \pi^+$$

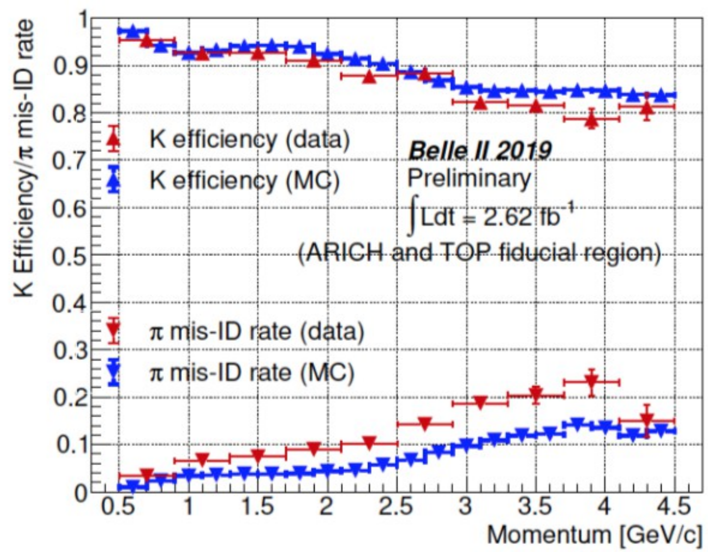
- Good performance, detector study ongoing



K ID from TOP only



K ID from CDC, TOP, ARICH



Physics Program

Physics Overview

- Belle II has a rich physics program in beauty, charm, τ and dark sectors:

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
$\|V_{cb}\|$ 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			
$S(B \to \phi K^0)$	***	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
$\mathcal{B}(B \to K\nu\overline{\nu})$ $[10^{-6}]$	***	20%	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
$\|q/p\|(D^0 \to K_S^0\pi^+\pi^-)$	***	0.03	Belle II
$\phi(D^0 \to K_S^0\pi^+\pi^-)$ [°]	***	4	Belle II
Tau			
$\tau \to \mu\gamma$ $[10^{-10}]$	***	< 50	Belle II
$\tau \to e\gamma$ $[10^{-10}]$	***	< 100	Belle II
$\tau \to \mu\mu\mu$ $[10^{-10}]$	***	< 3	Belle II/LHCb

Precision CKM Unitarity Triangle

CP Violation in b ⟶ s penguin decays

(Semi-)leptonic B decays

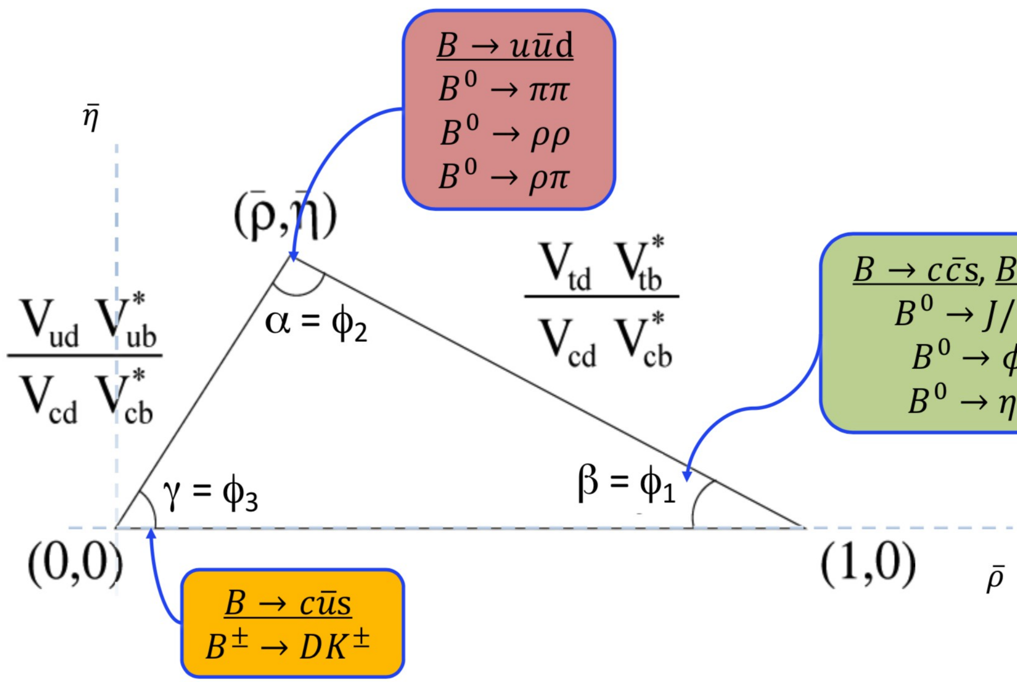
Radiative & EW Penguins

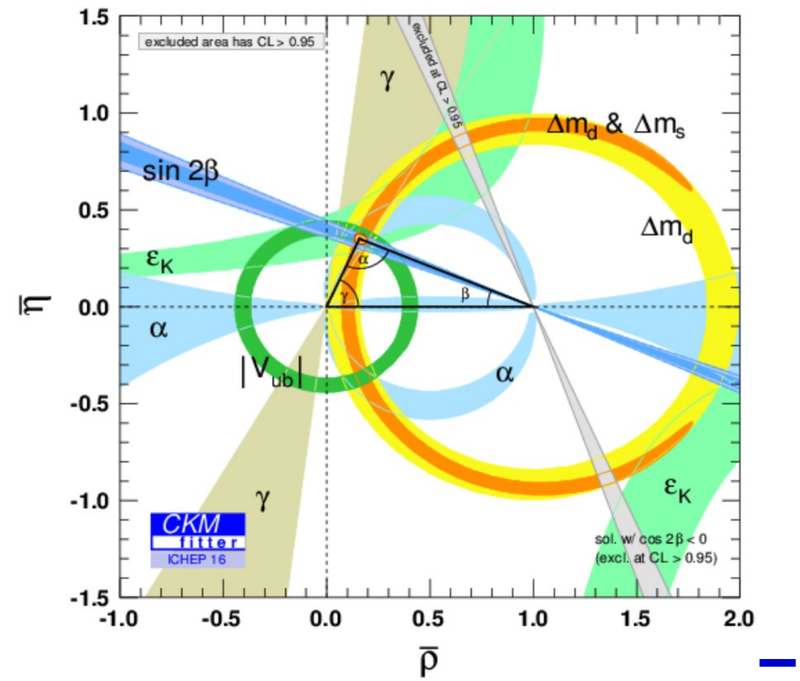
Charm

Lepton flavor violating τ decays
+ Dark sector & much more…

Unitarity Triangle from B Decays

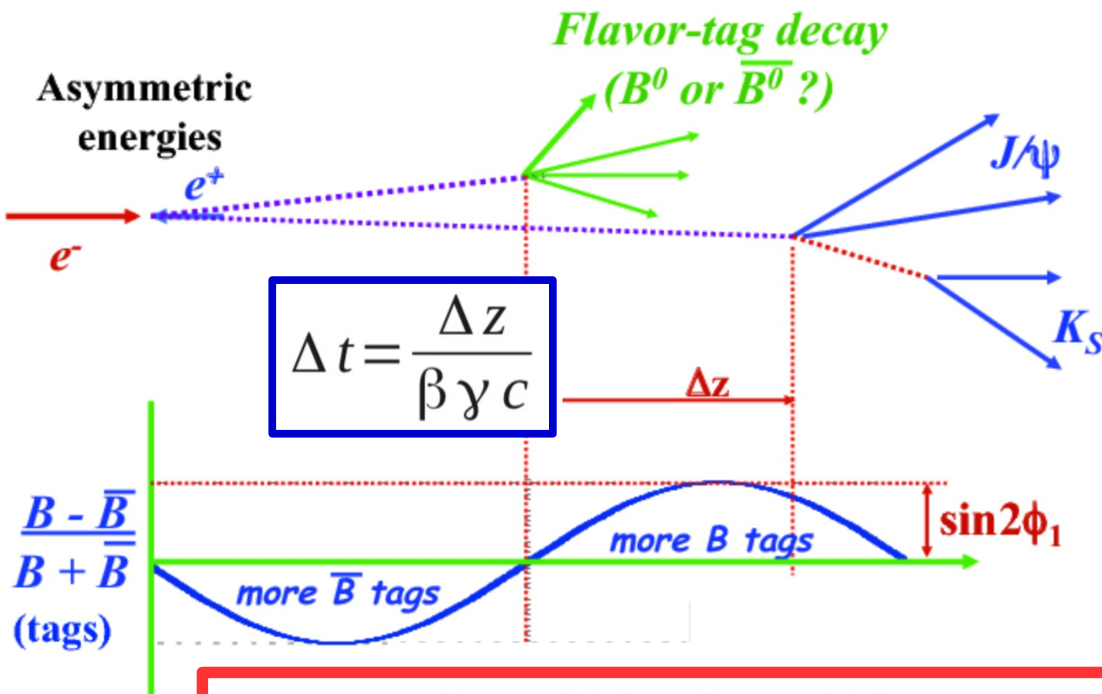
- Quark interactions described by the CKM unitary matrix V_{CKM}
- Off-diagonal elements of $V^{\dagger}V=I$ can be represented by triangles in complex plane
  - Sides ~ Amplitudes ~ Branching fractions
  - Angles ~ Phases ~ CPV
- Most common triangle from $\Sigma_i V_{id}V_{ib}^*$, i=u,c,t (be aware that $\varphi_1 = \beta$, $\varphi_2 = \alpha$, $\varphi_3 = \gamma$!)
- All angles can be accessed at B-factories



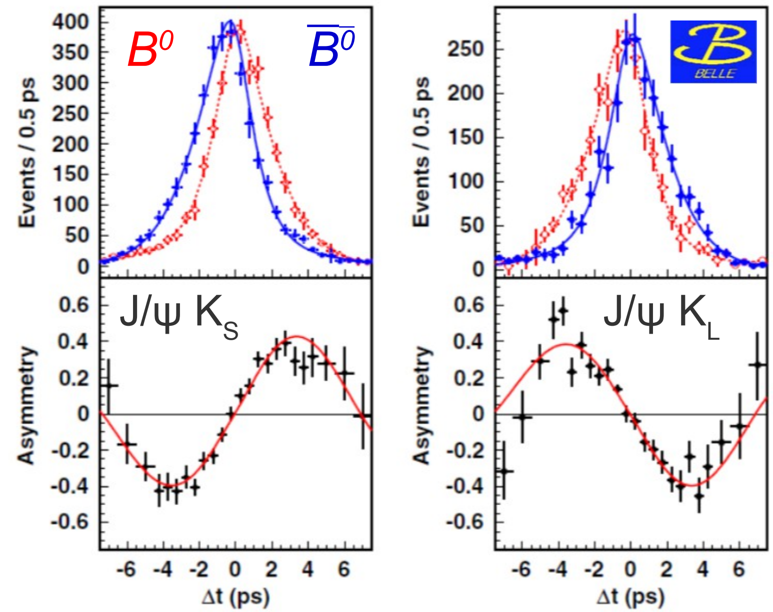


φ_1 and φ_2 at B-factories

- $B\bar{B}$ mixing and decay amplitudes interfere → time-dependent CP asymmetry
- The $B\bar{B}$ are produced in an entangled state, the flavor of the first decaying B (tag) defines the flavor of the other B (signal) at that time
- Need to measure Δt between tag B and signal B, hence a difference in Δz
- Υ(4S) → $B\bar{B}$ pairs at rest in the CM frame → asymmetric beam energies



$$\Delta t = \frac{\Delta z}{\beta\gamma c}$$



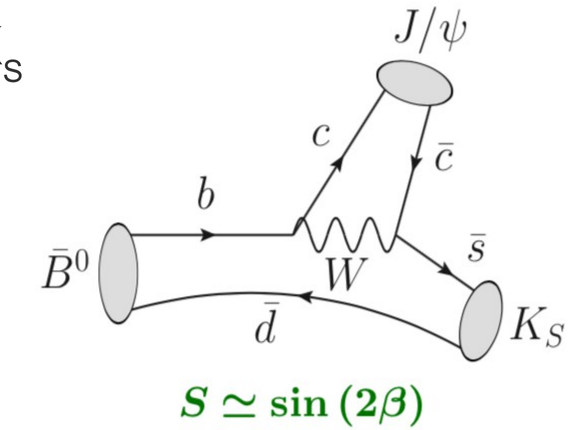
PRL108,171802 (2012)

$$a_{f_{cp}}(\Delta t) \equiv \frac{\Gamma_{\bar{B}\to f_{cp}}(\Delta t) - \Gamma_{B\to f_{cp}}(\Delta t)}{\Gamma_{\bar{B}\to f_{cp}}(\Delta t) + \Gamma_{B\to f_{cp}}(\Delta t)} = S\sin(\Delta M\Delta t) - C\cos(\Delta M\Delta t)$$

$S = -\xi_f \sin 2\phi_1$ and $C \approx 0$

$\sin(2\varphi_1)$ in $b \to c\bar{c}s$

- Tree dominated modes, golden channel $B \to J/\psi K_S$
  - Theoretically clean process, $S = -\xi_f \sin(2\varphi_1)$, $C \sim 0$
  - Clean experimental signature: 4 tracks
- Recent theoretical improvements in the calculation of penguin pollution



Worst case scenario, same systematics as Belle

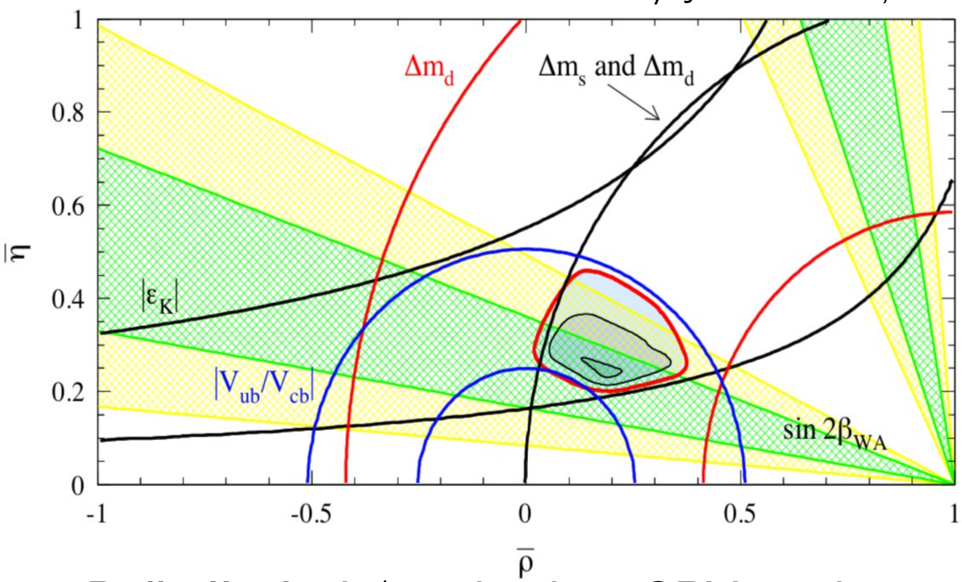
Sample	Quantity	Value	Stat. ($\times 10^{-3}$)	Syst. (1) ($\times 10^{-3}$) Red.	Syst. (1) ($\times 10^{-3}$) Non-red.	Syst. (2) ($\times 10^{-3}$) Red.	Syst. (2) ($\times 10^{-3}$) Non-red.
		Belle (1 ab^{-1}) PRL 108 171802					
$B \to J/\psi K_S$	$\mathcal{S}$	+0.67	29	-	13	-	-
	$\mathcal{A} \equiv -\mathcal{C}$	-0.015	21	-	+45, -23	-	-
$b \to c\bar{c}s$	$\mathcal{S}$	+0.667	23	-	12	-	-
	$\mathcal{A} \equiv -\mathcal{C}$	+0.006	16	-	12	-	-
		Belle II (50 ab^{-1})					
$B \to J/\psi K_S$	$\mathcal{S}$	-	3.5	1.2	8.3	1.2	4.4
	$\mathcal{A} \equiv -\mathcal{C}$	-	2.5	0.7	+43, -22	0.7	+42, -11
$b \to c\bar{c}s$	$\mathcal{S}$	-	2.7	2.6	7	2.6	3.6
	$\mathcal{A} \equiv -\mathcal{C}$	-	1.9	1.4	10.6	1.4	8.7

With expected improvement due to better vertexing

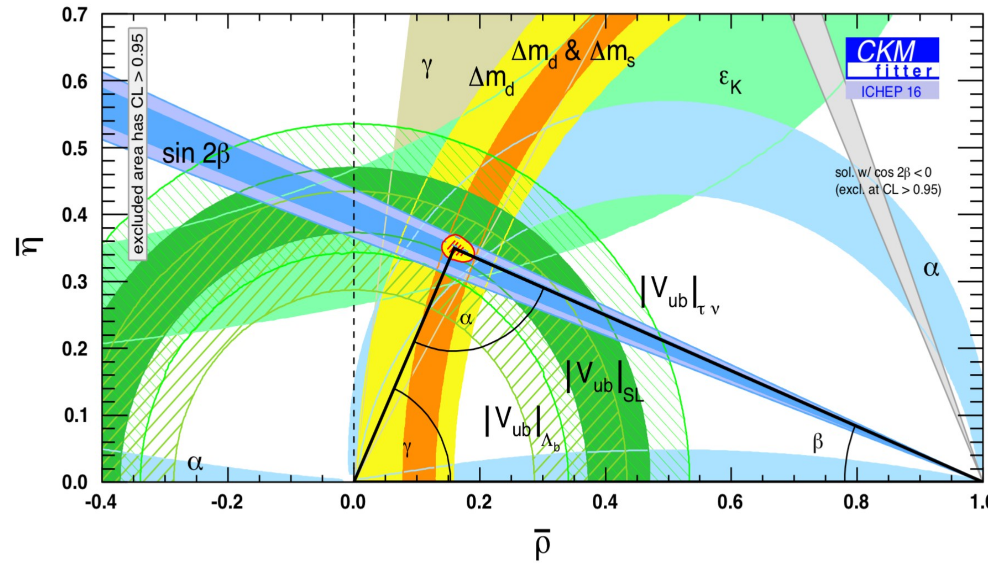
UT @ Belle II

Before B-factories

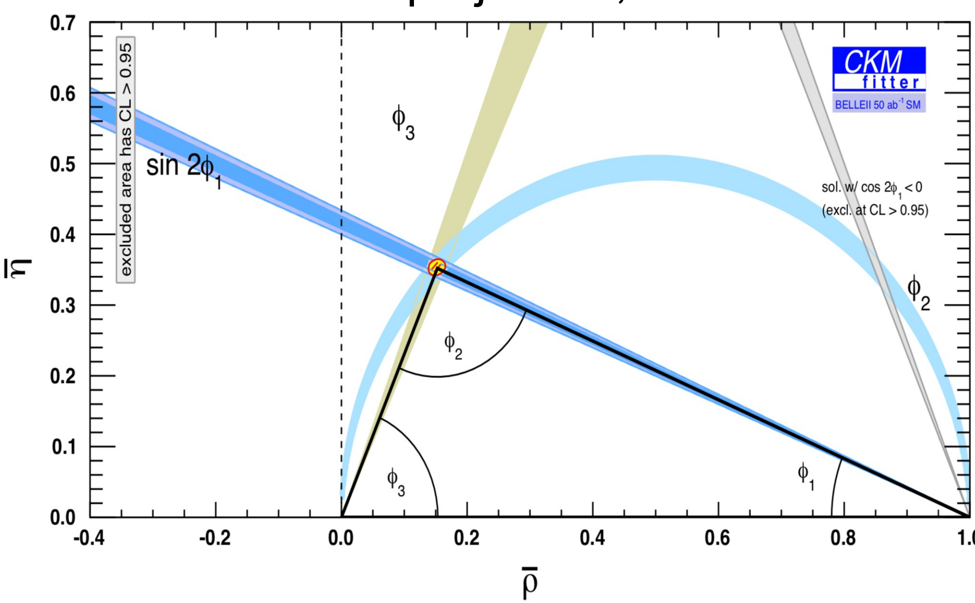
Eur.Phys.J.C21:225-259,2001



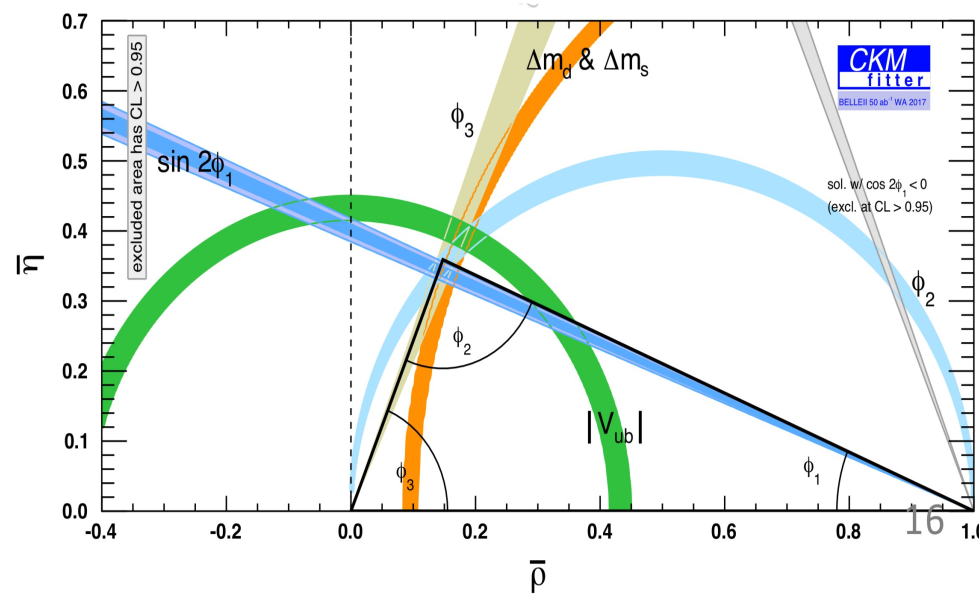
After B-factories



Belle II 50 ab^{-1} projection, CPV modes only

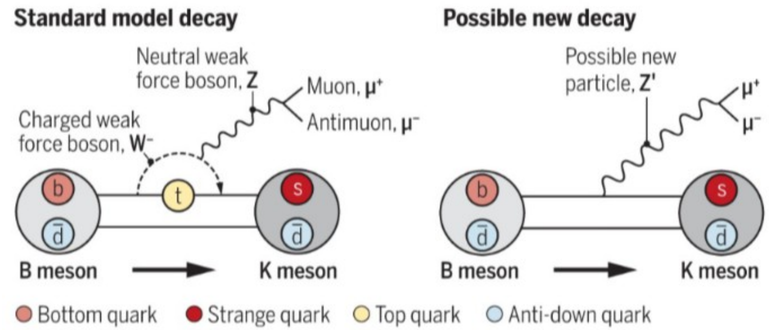


Belle II 50 ab^{-1} projection, all constraints

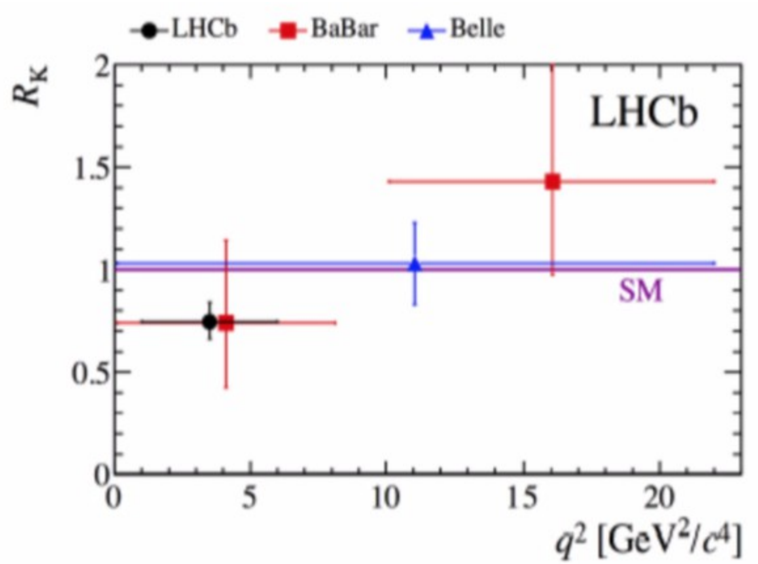


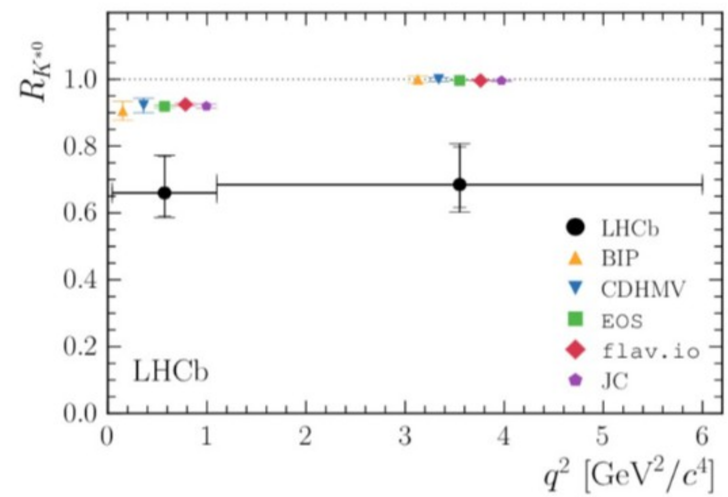
$B \to K^{(*)}l^+l^-$ and $R_{K^{(*)}}$

- LHCb measurements in tension with SM expectations for the ratio of muonic and electronic final states



$$R_{K^{(*)}}(q^2) = \frac{BF(B \to K^{(*)}\mu^+\mu^-)}{BF(B \to K^{(*)}e^+e^-)}$$

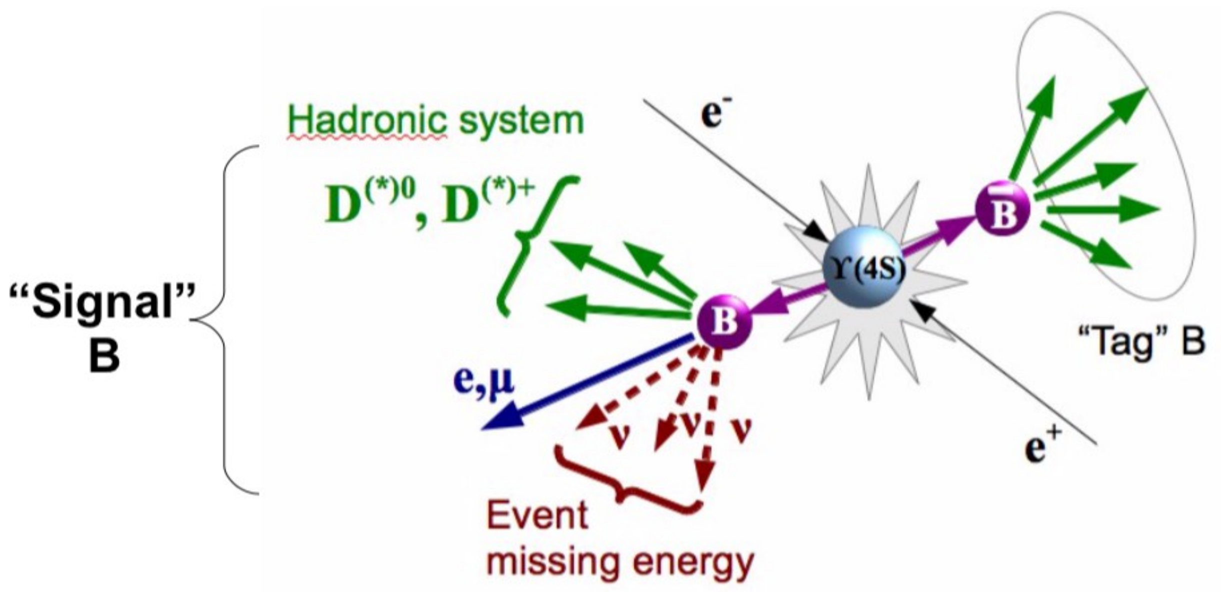




- But there are also: $B^+ \to K^{(*)+}l^+l^-$, $B \to \pi l^+l^-$, $B \to X_{s/d}l^+l^-$, $B \to K^{(*)}\tau^+\tau^-$, $B \to K^{(*)}\nu\bar{\nu}$
- All this final states can be measured at Belle II
- This will allow to disentangle various new physics scenarios

Missing Energy

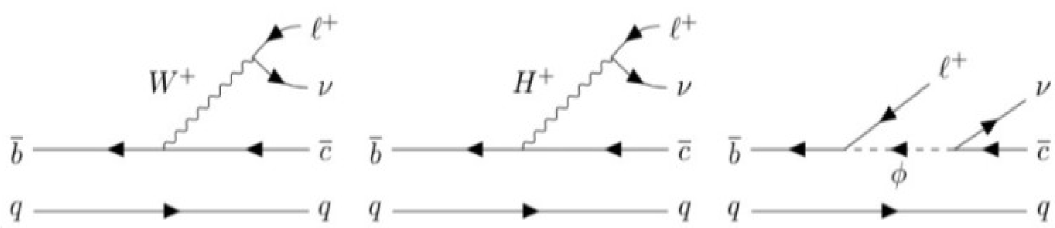
- Belle II has the unique capability to study B decay modes with missing E
  - FCNC modes such as $B \to K^{(*)}\nu\bar{\nu}$, $B^0 \to \nu\bar{\nu}$, $B \to K^{(*)}\tau^+\tau^-$
  - Semileptonic B decays such as $B \to D^{(*)}\tau^+\nu$, $B^+ \to \mu^+\nu$, and $B^+ \to \tau^+\nu$
- Precisely known CM energy, combined with exclusive hadronic reconstruction of the tagging B allow the decay daughters of missing energy decays to be exactly identified

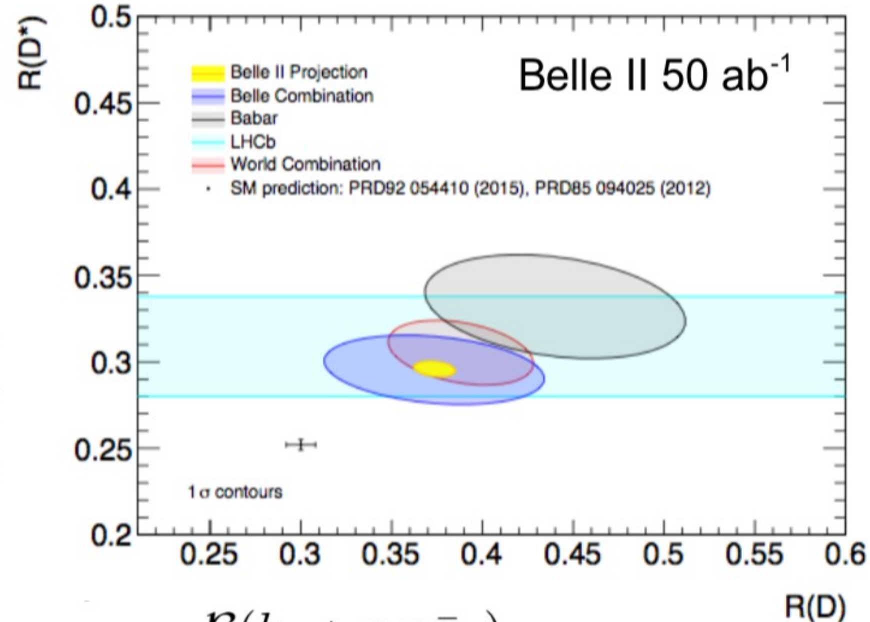


$$m_{BC} \equiv \sqrt{E^{*2}_{\text{beam}} - p^{*2}_B}$$
$$\Delta E^* \equiv E^*_B - E^*_{\text{beam}}$$

$B \to D^{(*)}\tau\nu$

- $B \to D\tau\nu$ and $B \to D^*\tau\nu$ are tree-level SM decays containing 3rd generation quarks and leptons





- Ratio of heavy-to-light lepton modes provides robust theoretical prediction

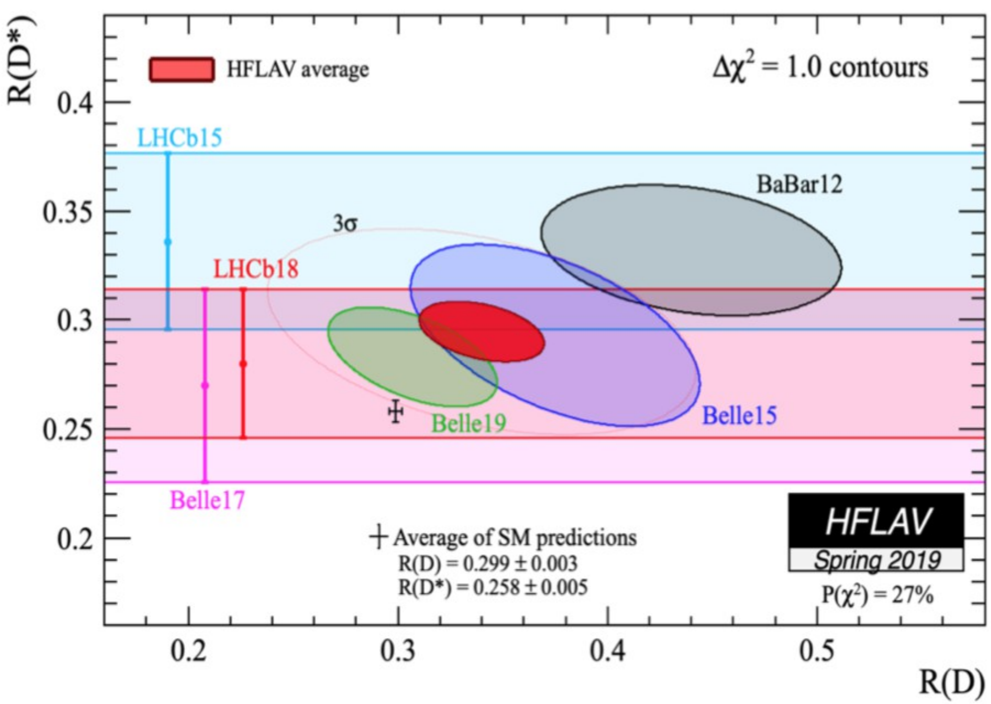
$$R = \frac{\mathcal{B}(b \to q\,\tau\,\bar{\nu}_\tau)}{\mathcal{B}(b \to q\,\ell\,\bar{\nu}_\ell)}$$

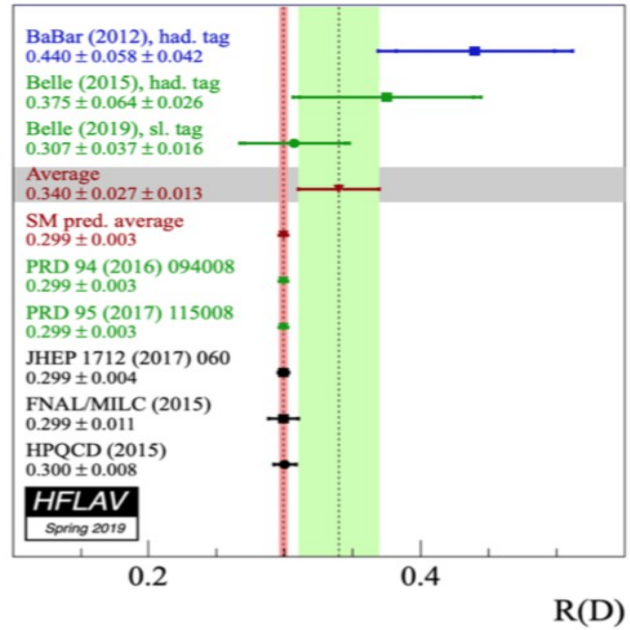
$$\ell = e, \mu$$

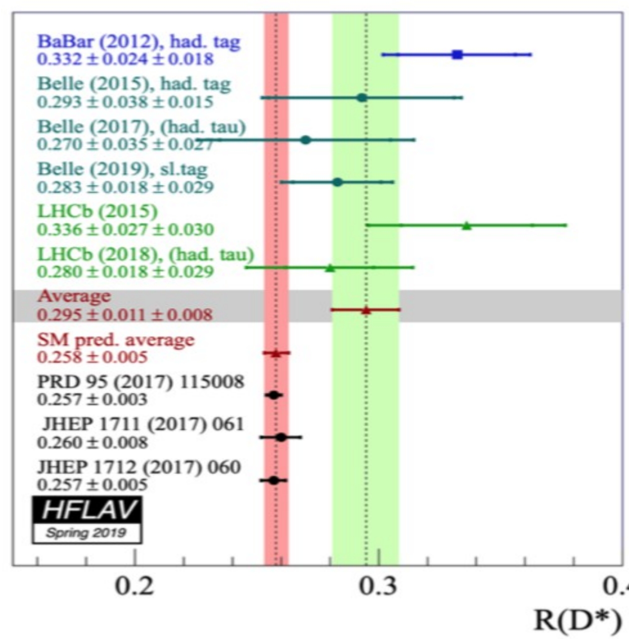
- Measurements from BaBar, Belle and LHCb all independently deviate from SM (combined ~4σ)
- Belle II can measure both charged and neutral B and various final states
- This allows to precisely determine R(D) and R(D*) to constrain or identify different new physics scenarios

Update on $B \to D^{(*)}\tau\nu$

- Belle has recently presented new measurements of $R(D^{(*)})$
- The new average is closer to the SM prediction, however, on average, a 3.1 σ discrepancy is still observed

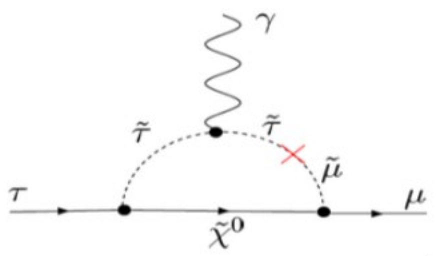


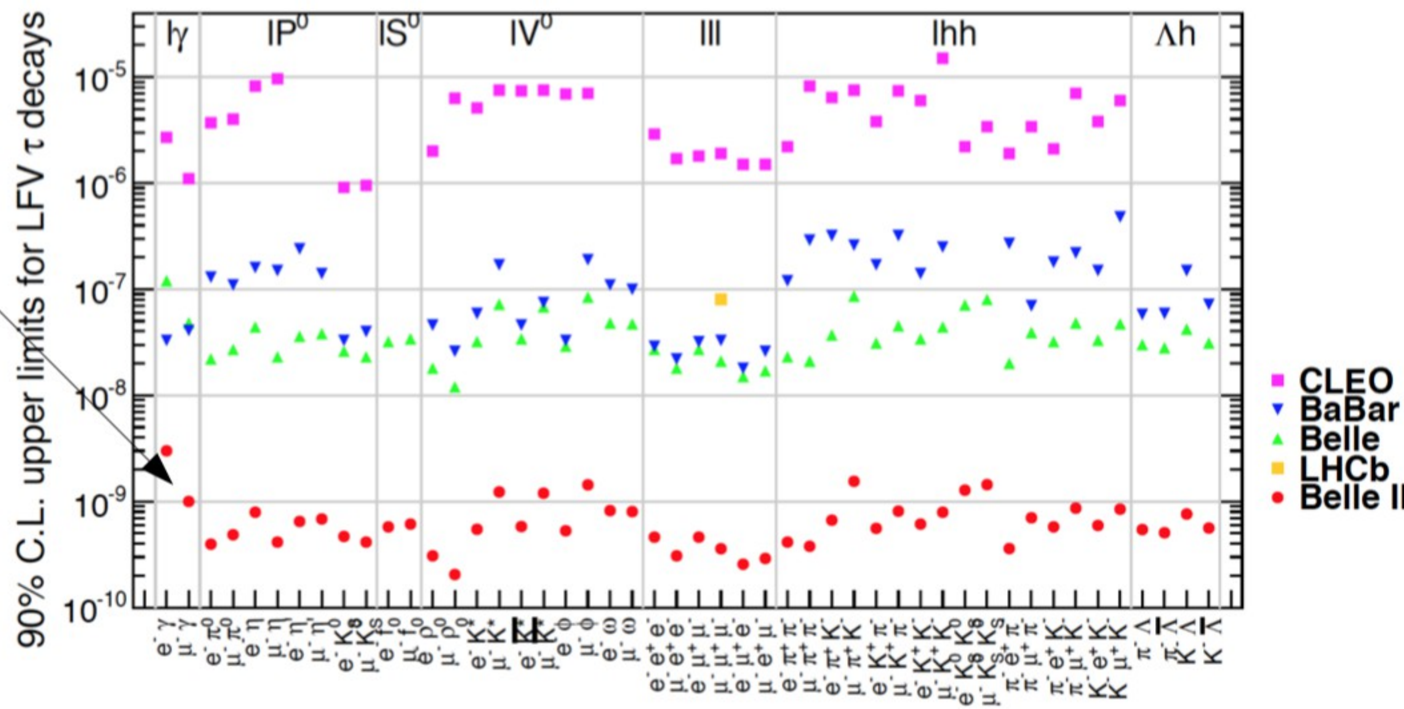




Lepton Flavor Violation

- Processes that are suppressed or forbidden within the SM can potentially be dramatically enhanced by new physics contributions
- Golden channel: lepton flavor violation in τ decays: negligible in the SM, but many NP models predictions are close to existing limits
- Very clean searches at B-factories and unambiguous signal of new physics

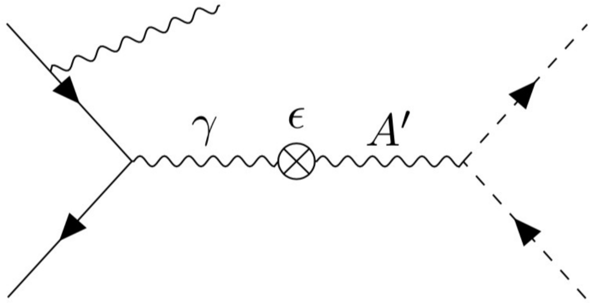




Expected Belle II sensitivity with full data sample

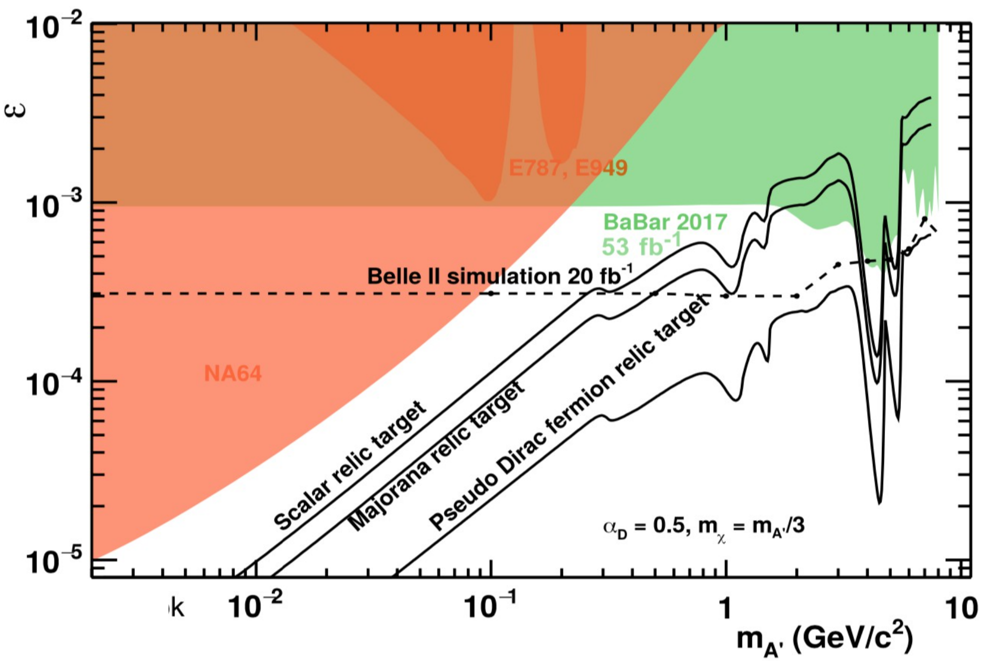
Dark Forces

- A "dark photon" is a new vector o pseudo-vector particle that couples to the SM photon via electromagnetic current

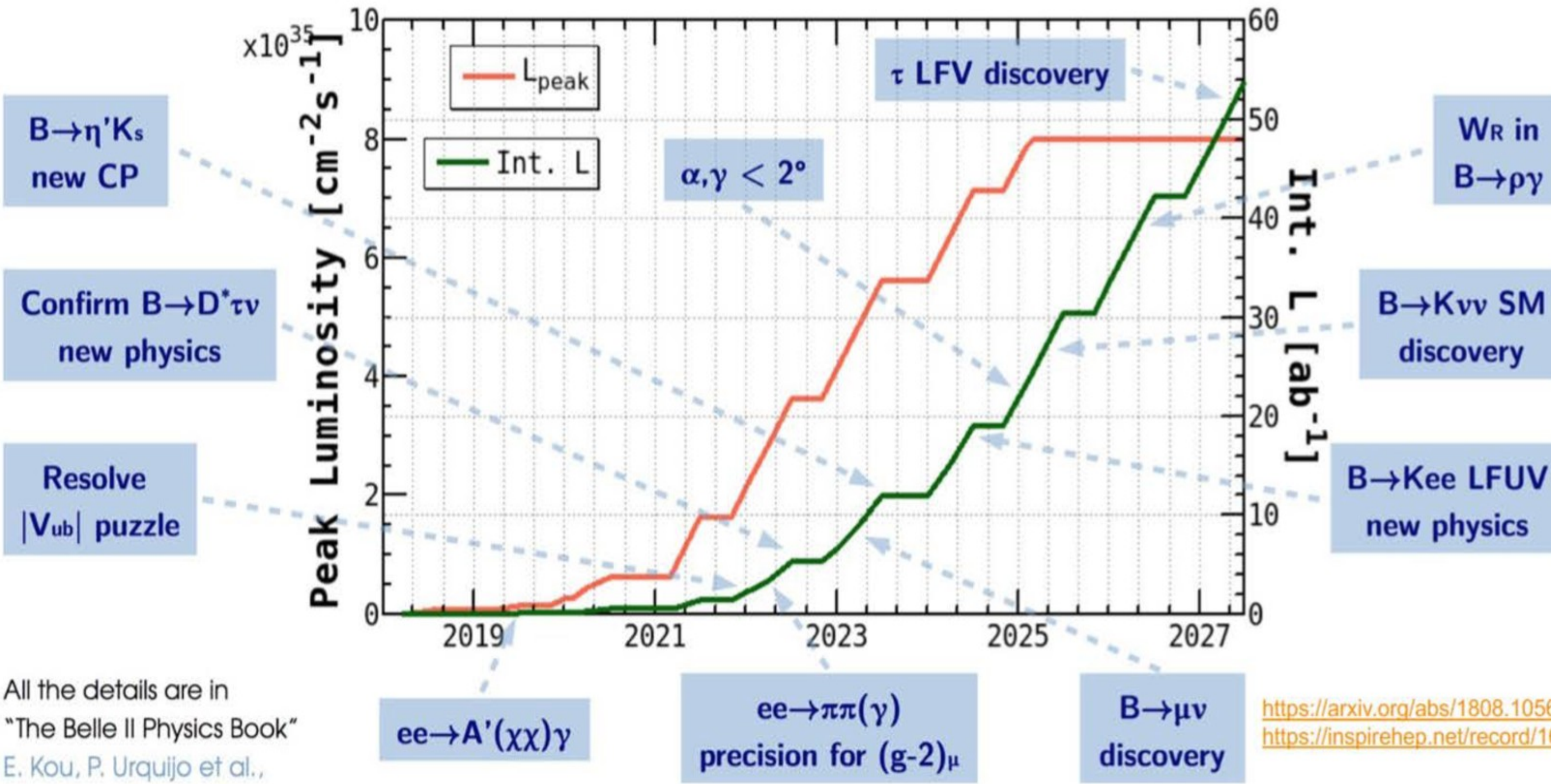


$$\mathscr{L} \supset \epsilon A_\mu J^\mu_{\mathrm{SM}}$$

- Two scenarios:
  - The dark photon couples to → visible final state
  - It does not couple to SM fermions (less constrained) → invisible final state (exp. more difficult)
- Experimental signature: bump in the recoil mass
- Key ingredients:
  - Single photon trigger
  - Hermetic detector (as much as possible)



A possible physics roadmap



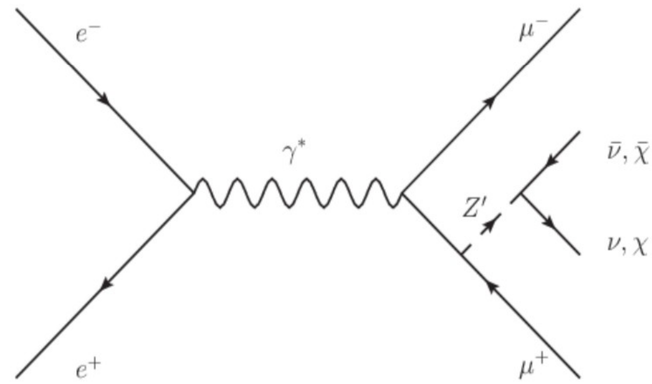
https://arxiv.org/abs/1808.10567
https://inspirehep.net/record/1692393/

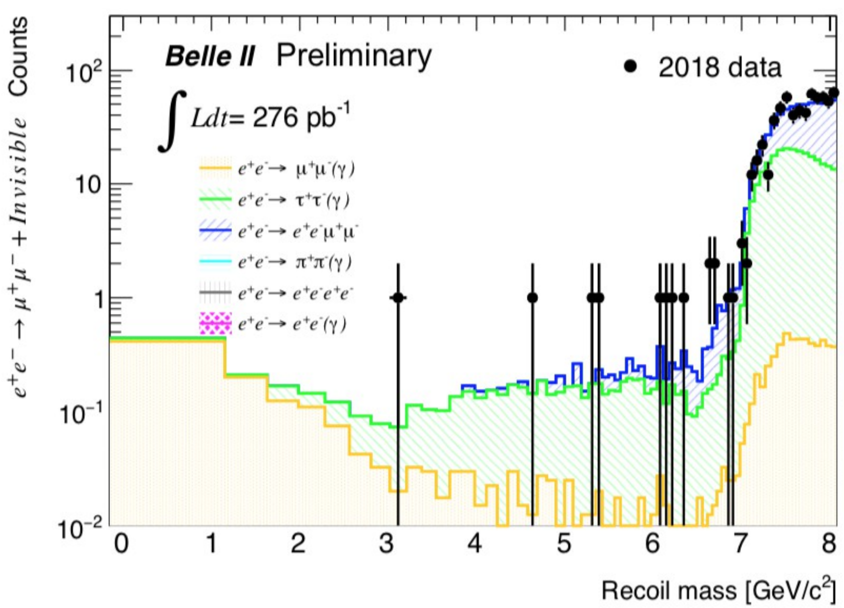
From F. Forti, EPS-HEP 2019

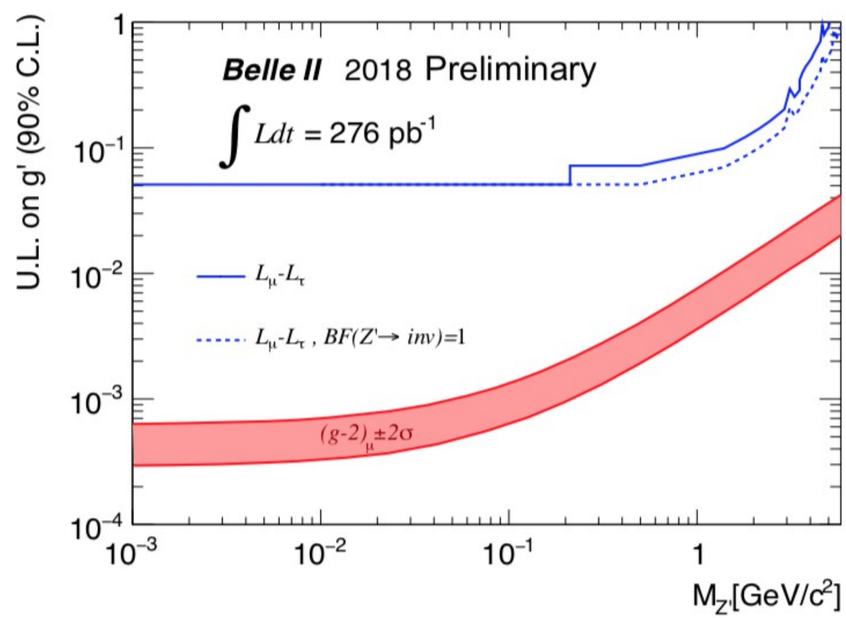
First Physics Results

Search for Z'

- Assume there is a Z' vector particle which does not mix with SM photon but couples to SM fermions
- Using 2018 data we measure the cross section for $e^+e^- \rightarrow \mu^+\mu^- Z'$ ($Z' \rightarrow$ invisible)
- We found no evidence for such a process and we set 90% CL UL

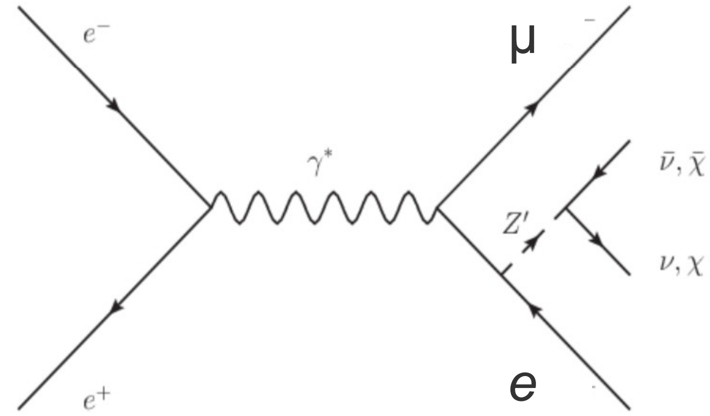


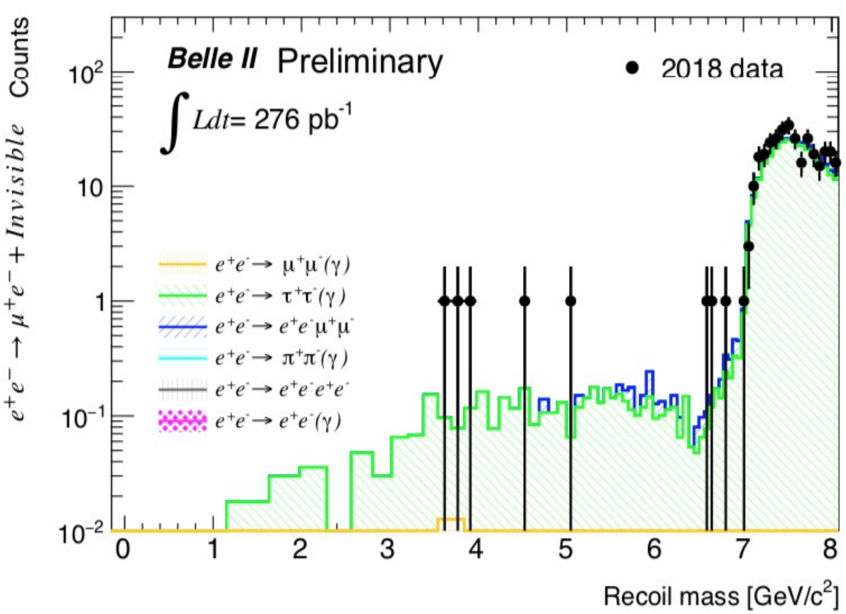


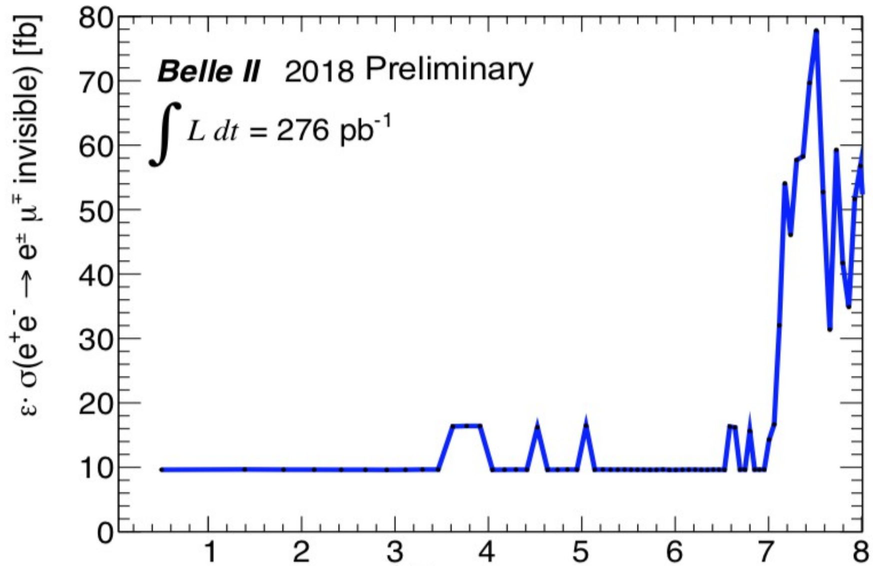


Search for LFV Z'

- If we allow the Z' to have LFV coupling we can get some new signatures
- Using 2018 data we measure the cross section for $e^+e^- \to \mu^+ l^-$ (l=e, τ) Z' (Z' → invisible) → no evidence
- For 0 lost energy this is a search for sterile neutrinos







Status & Schedule

The Belle II Collaboration

- In few years the Belle II collaboration has grown to ~1000 researchers from 112 institutions and 26 countries (>300 graduate students active!)
- This is rather unique in Japan (and Asia), the only comparable example is the T2K experiment at JPARC which is also an international collaboration

- 981 active members
  - 326 graduate (MSc+PhD) students
- 118 institutes
- 26 countries

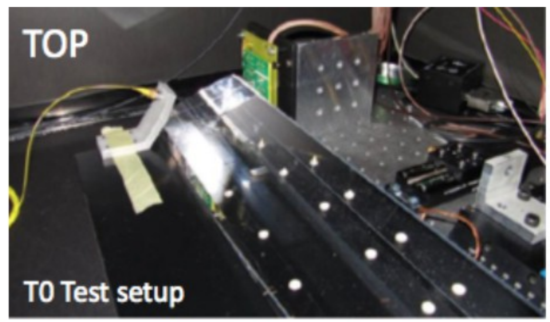
(B2MM on October 24, 2019)

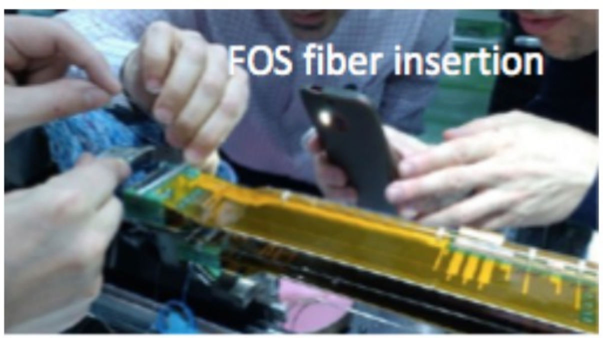
The Italian Collaboration

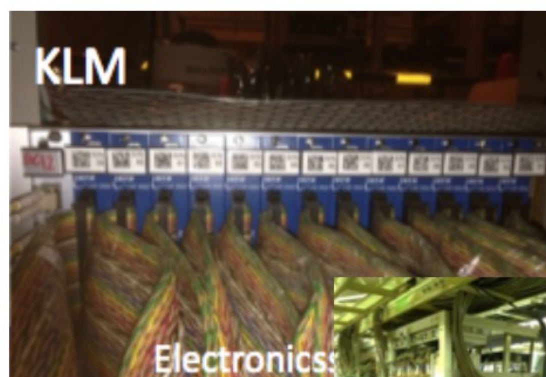
- INFN plays an important role in Belle II with 82 people of 9 institutions
- The Italian collaboration is constantly growing:

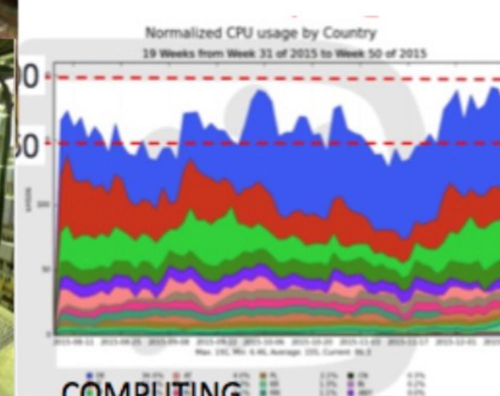
2014	→	2016	→	2018	→	2020		
51		67		76		82	=	46.5 FTE

- The Italian collaboration is active in almost every sub-detector system as well as in computing, SW and physics analysis



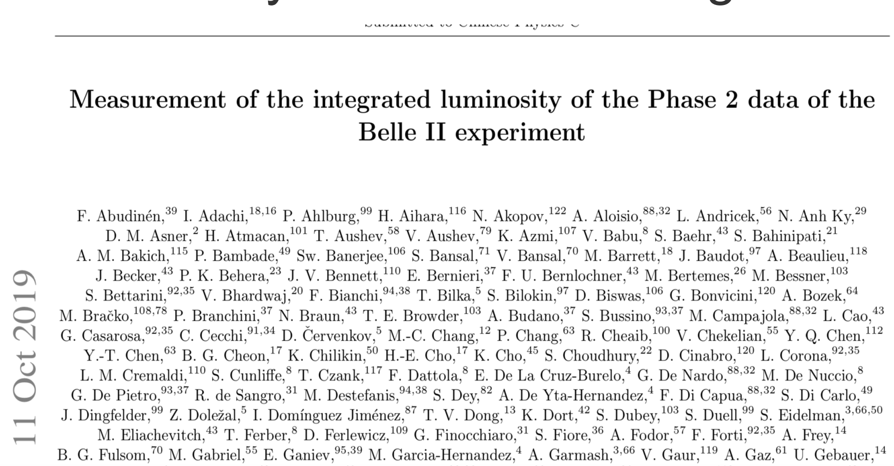






Papers in the pipeline

- 1) “Measurement of the integrated luminosity of the Phase II data of the Belle II experiment”, arXiv:1910.05365[hep-ex]
  - Submitted to “Chinese Physics C” after a long and thorough review!



Measurement of the integrated luminosity of the Phase 2 data of the Belle II experiment

11 Oct 2019

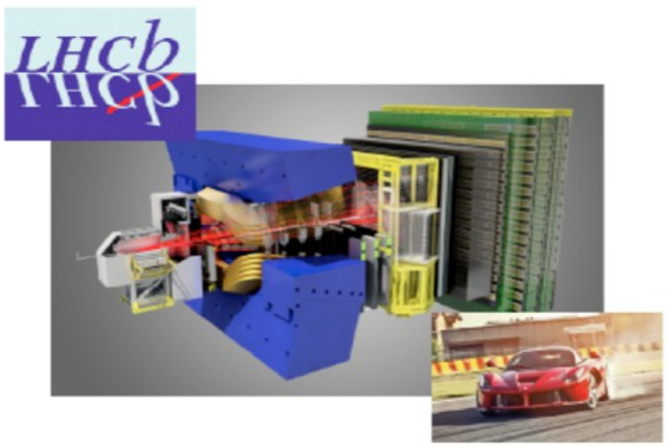
F. Abudinén,[39] I. Adachi,[18,16] P. Ahlburg,[99] H. Aihara,[116] N. Akopov,[122] A. Aloisio,[88,32] L. Andricek,[56] N. Anh Ky,[29] D. M. Asner,[2] H. Atmacan,[101] T. Aushev,[58] V. Aushev,[79] K. Azmi,[107] V. Babu,[8] S. Baehr,[43] S. Bahinipati,[21] A. M. Bakich,[115] P. Bambade,[49] Sw. Banerjee,[106] S. Bansal,[71] V. Bansal,[70] M. Barrett,[18] J. Baudot,[97] A. Beaulieu,[118] J. Becker,[43] P. K. Behera,[23] J. V. Bennett,[110] E. Bernieri,[37] F. U. Bernlochner,[43] M. Bertemes,[26] M. Bessner,[103] S. Bettarini,[92,35] V. Bhardwaj,[20] F. Bianchi,[94,38] T. Bilka,[5] S. Bilokin,[97] D. Biswas,[106] G. Bonvicini,[120] A. Bozek,[64] M. Bračko,[108,78] P. Branchini,[37] N. Braun,[43] T. E. Browder,[103] A. Budano,[37] S. Bussino,[93,37] M. Campajola,[88,32] L. Cao,[43] G. Casarosa,[92,35] C. Cecchi,[91,34] D. Červenkov,[5] M.-C. Chang,[12] P. Chang,[63] R. Cheaib,[100] V. Chekelian,[55] Y. Q. Chen,[112] Y.-T. Chen,[63] B. G. Cheon,[17] K. Chilikin,[50] H.-E. Cho,[17] K. Cho,[45] S. Choudhury,[22] D. Cinabro,[120] L. Corona,[92,35] L. M. Cremaldi,[110] S. Cunliffe,[8] T. Czank,[117] F. Dattola,[8] E. De La Cruz-Burelo,[4] G. De Nardo,[88,32] M. De Nuccio,[8] G. De Pietro,[93,37] R. de Sangro,[31] M. Destefanis,[94,38] S. Dey,[82] A. De Yta-Hernandez,[4] F. Di Capua,[88,32] S. Di Carlo,[49] J. Dingfelder,[99] Z. Doležal,[5] I. Domínguez Jiménez,[87] T. V. Dong,[13] K. Dort,[42] S. Dubey,[103] S. Duell,[99] S. Eidelman,[3,66,50] M. Eliachevitch,[43] T. Ferber,[8] D. Ferlewicz,[109] G. Finocchiaro,[31] S. Fiore,[36] A. Fodor,[57] F. Forti,[92,35] A. Frey,[14] B. G. Fulsom,[70] M. Gabriel,[55] E. Ganiev,[95,39] M. Garcia-Hernandez,[4] A. Garmash,[3,66] V. Gaur,[119] A. Gaz,[61] U. Gebauer,[14]

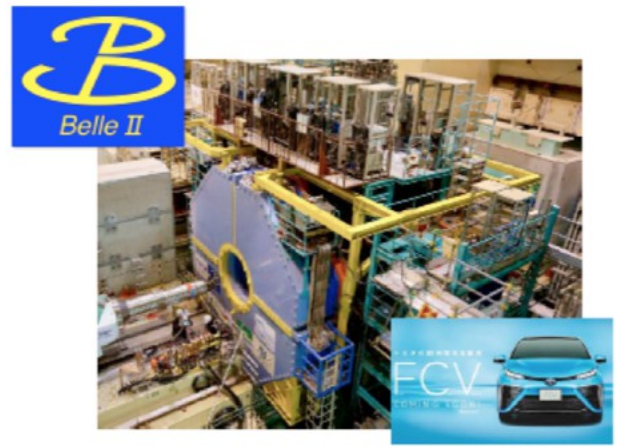
- 2) “Search for an invisibly decaying Z’ boson at Belle II in $e^+e^- \to \mu^+\mu^-$ $(e^+\mu^-)$ + missing energy final states”
  - [BELLE2-PUB-DRAFT-2019-004]
- 3) “Search for Axion-Like Particles produced in e^+e^- collisions at Belle II”
  - Unblinding of Phase II data set is in progress

Short Term Plan

Toward 2020, 2021

Competition with LHCb will be tough !



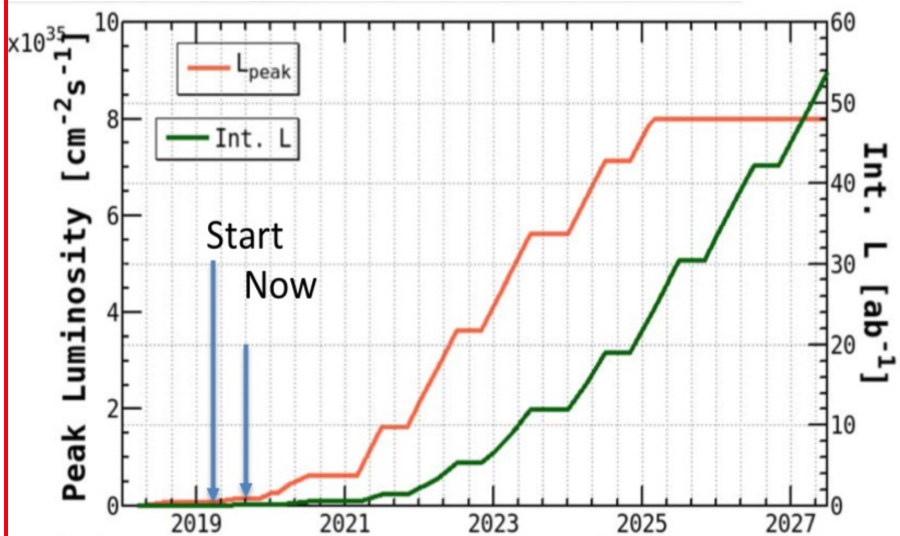


- Before LHCb resumes operation in 2021 we aim to
  - Demonstrate that Belle II performance > Belle performance
  - Catch up LHCb (and also Belle and BaBar)

We expect to have 200 to 400 fb^{-1} by 2020 summer

Medium to Long Term Plan

- SuperKEKB
- We will learn how luminosity and background changes by squeezing beams (now β_y^*=2.0 mm→1.0 mm)
- Trying to respect original schedule



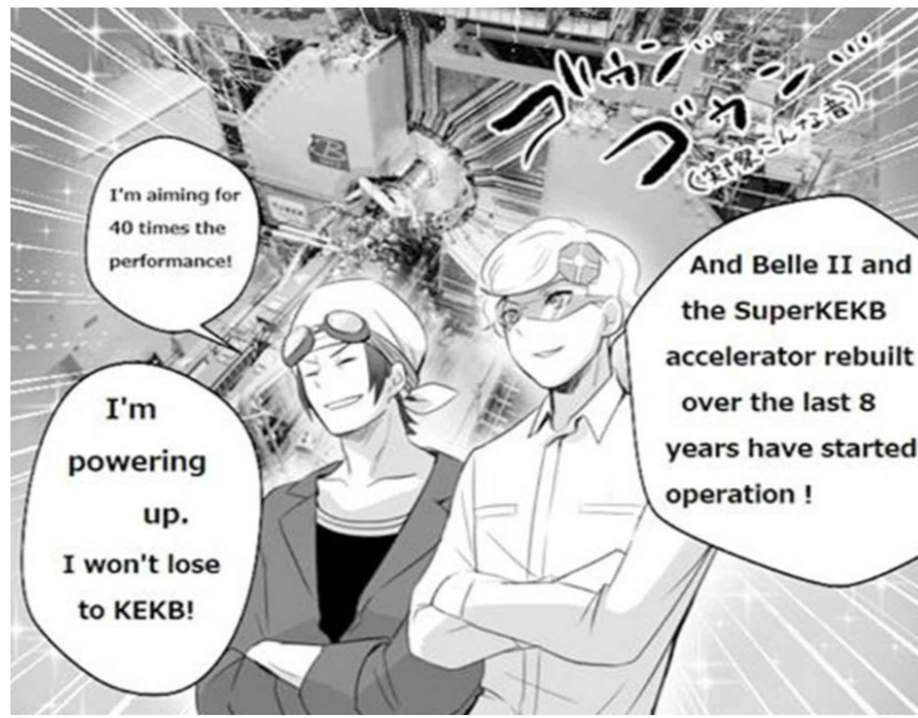
- (Even) longer term: study luminosity upgrade possibilities (high luminosity task force created)

- Belle II:
- Full PXD installation: make it ready as soon as possible, install it as late as possible (requires a long shutdown which has to be planned taking in account many factors)
- Replacement of TOP PMTs with ALD PMT (can be installed at any summer shutdown, most likely in 2021)
- DAQ upgrade: new PCIe40 read-out system

Outlook

- Belle and BaBar have been successful in testing the CKM paradigm
- Belle II and SuperKEKB represent a major upgrade B-factory
- The first physics run in 2019 has collected 6.5 fb^{-1} of e^+e^- collisions
- Machine and detector initial performance are good

  → we are on the right track!
- Luminosity and beam background are the main challenges
- Belle II is BOTH competitive AND complementary to LHCb



..looking forward for more data, the fun has just started!

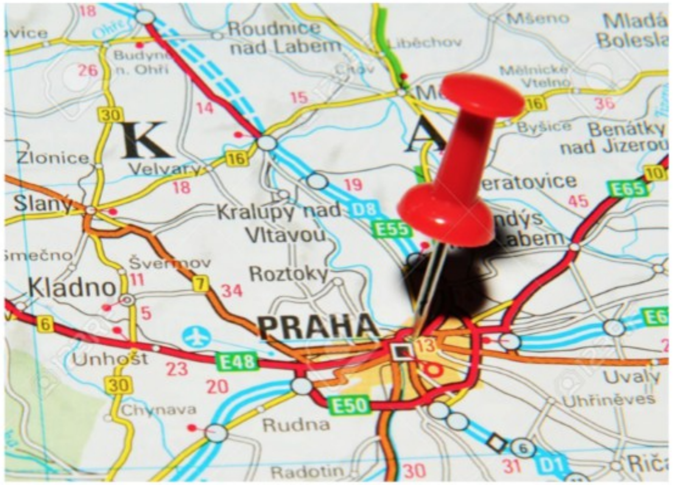
ありがとうございました！

(Thanks!)

Backups

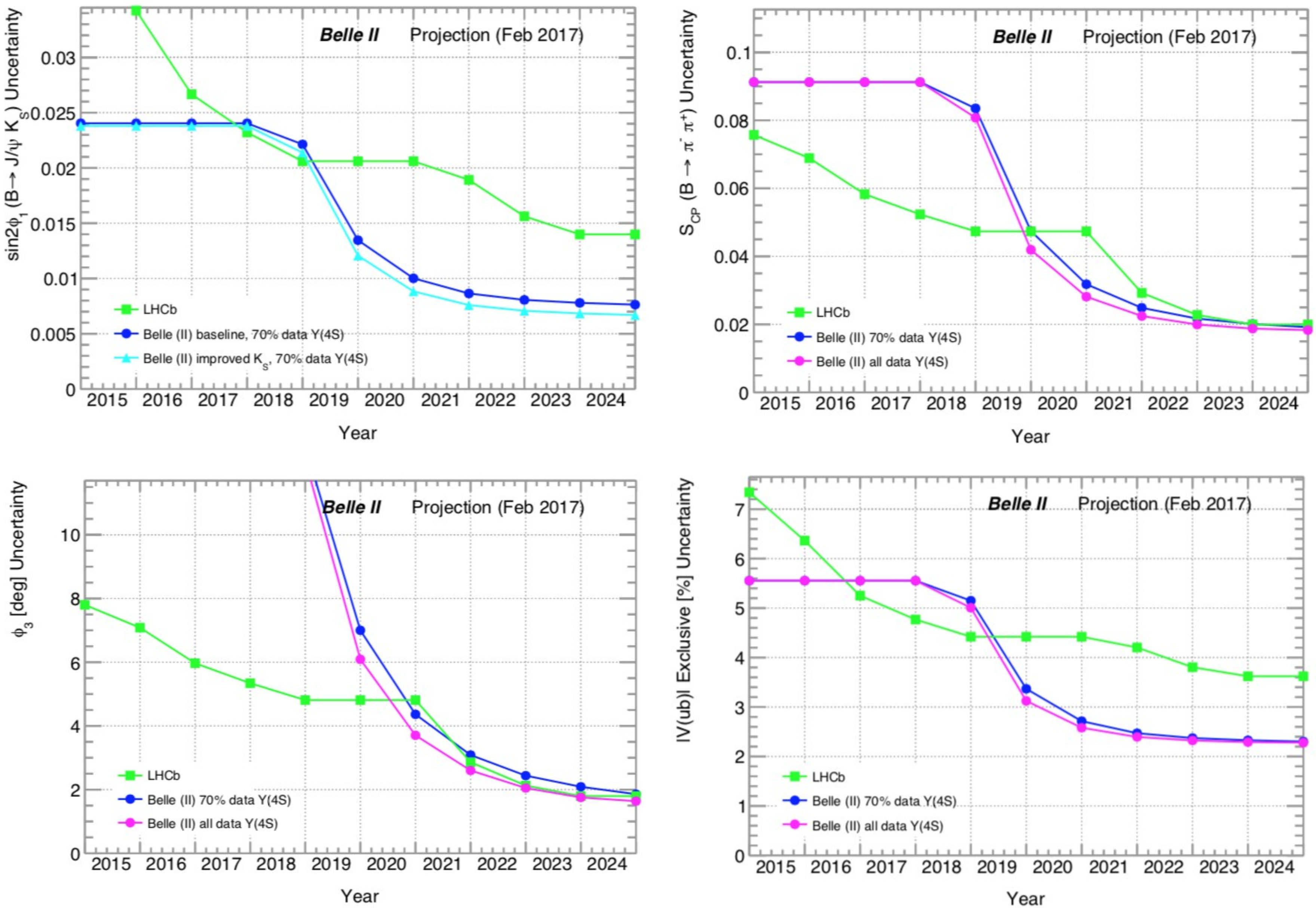
Short Term Physics

Goals for Summer 2020 (200 fb^{-1})

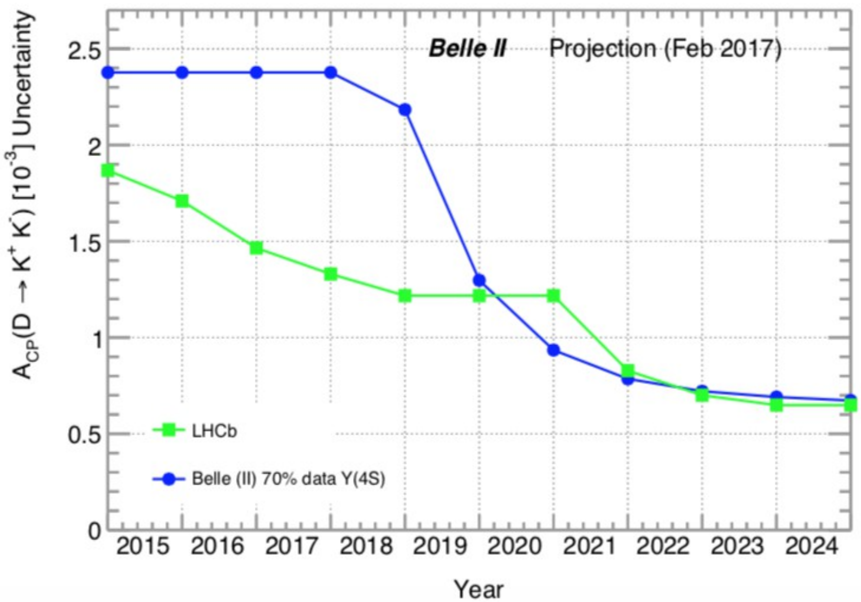


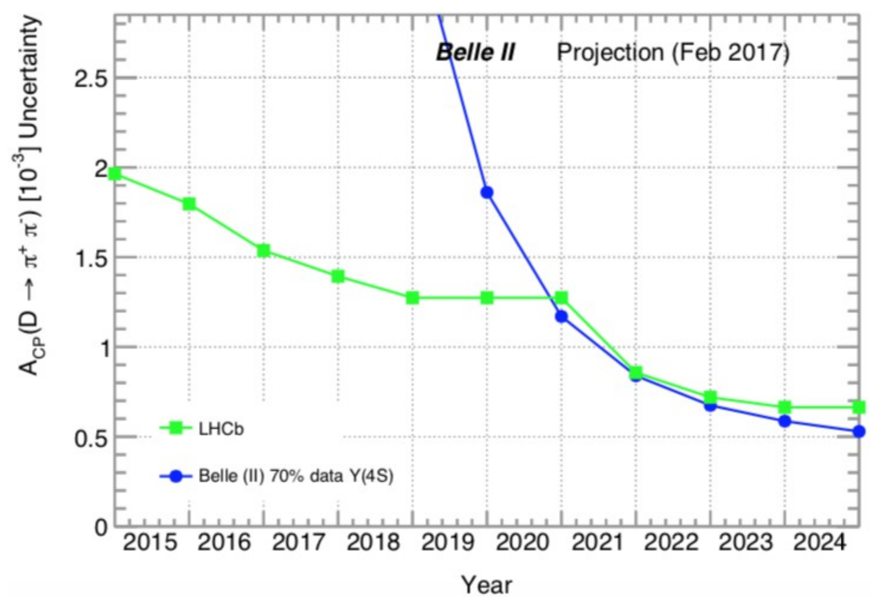
- Exclusive V_{ub} from $B \to \pi l \nu$;
- Rediscovery of $B \to D^* \tau \nu$;
- Rediscovery of $b \to s l^+ l^-$ and of inclusive $b \to s \gamma$;
- Publication quality measurement of TD CP asymmetry in $B^\circ \to J/\psi K^\circ$;
- Rediscovery of $B^\circ \to \pi^\circ \pi^\circ$;
- Resolution and systematics on $D^\circ \to K_s \pi^+ \pi^-$ Dalitz Plot;
- First look at ϕ_3 with GLW and (Belle + Belle II) GGSZ;
- Z charged states, search for Y states in ISR;
- Analysis of $\tau \to h \omega \nu$ and $\tau \to l \alpha (\to \text{invis.})$;
- More Z' searches, Dark Photon and Long Lived Particles (LLP's);
- Perform measurements for which BaBar and Belle did not use full luminosity.

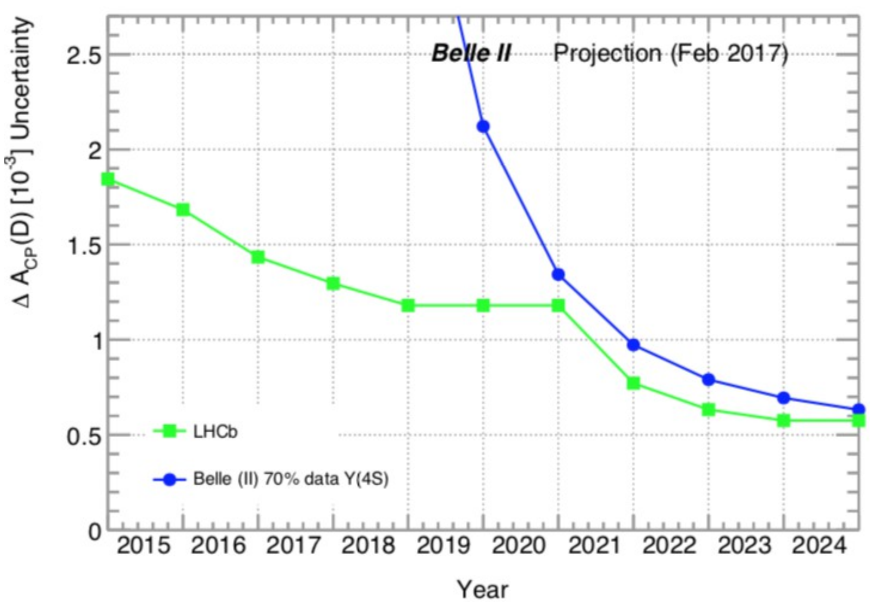
Belle II vs LHCb in beauty

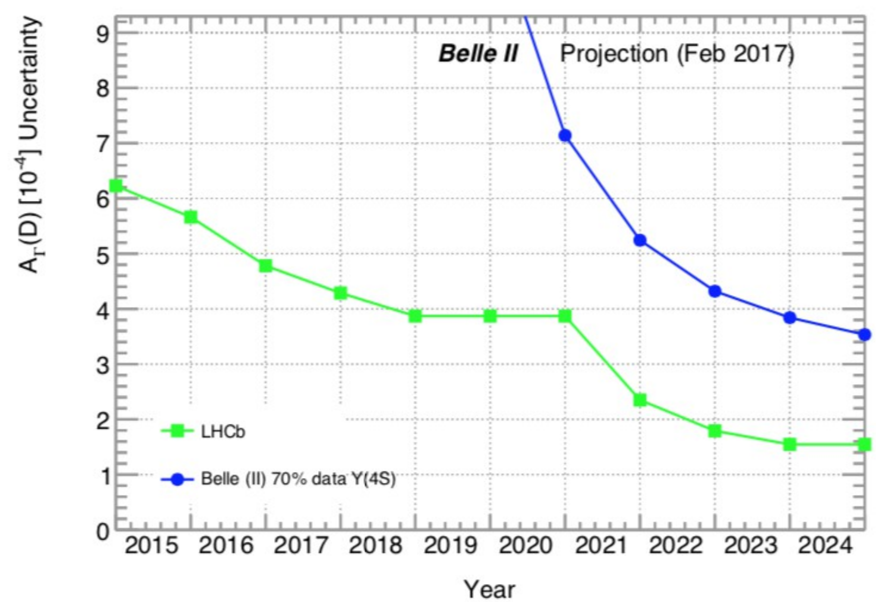


Belle II vs LHCb in charm



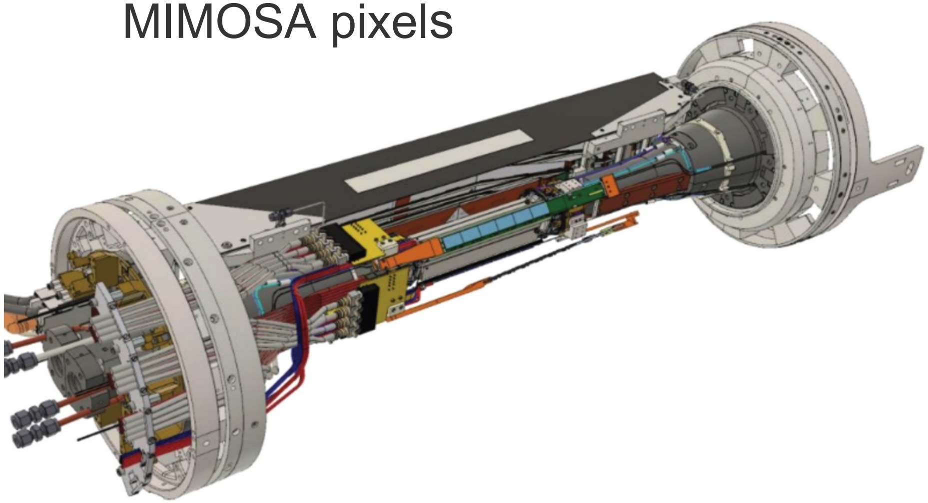


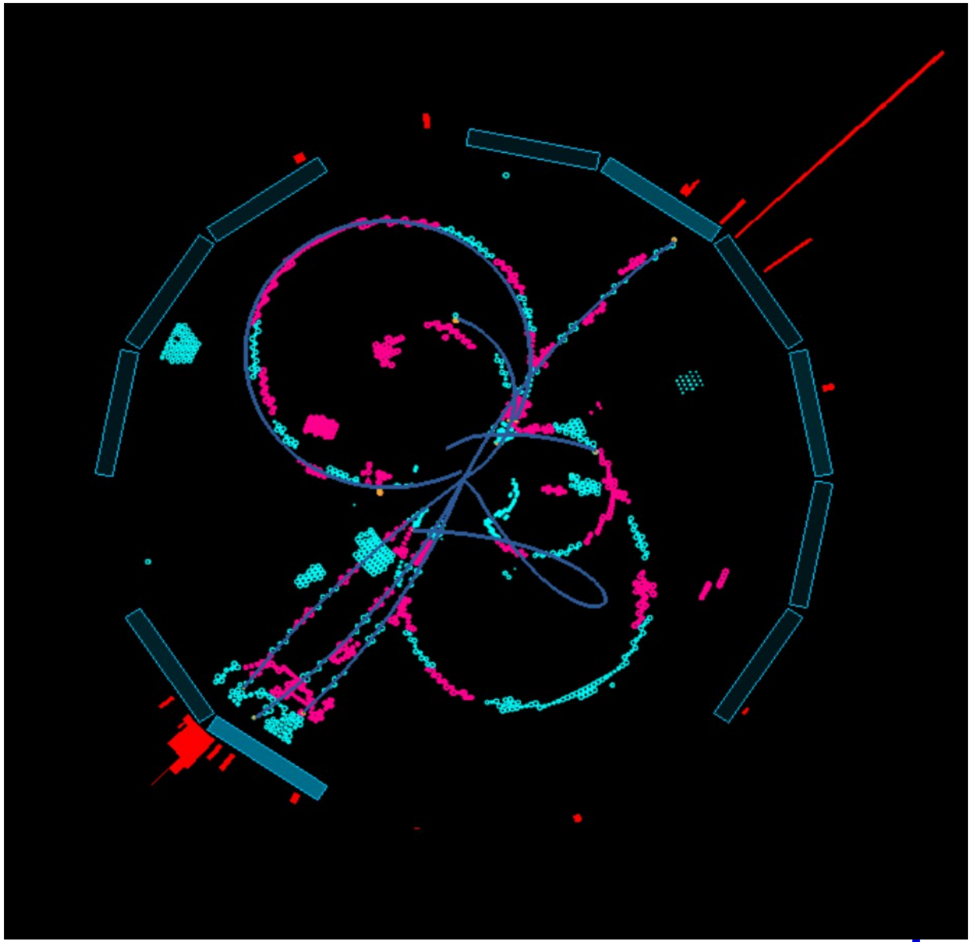




Belle II Phase2

- Belle II has recorded its first collisions on April 26th 2018 and has continued taking data until July 17th 2018 with a commissioning vertex detector called BEAST-II in order to study beam-backgrounds close to the IP (Phase 2)
- 2 PXD and 4 DSSD ladders where the highest background is expected
- FANGS - FE-I4 based hybrid pixel to study Synchrotron Radiation
- CLAWS - for trickle injection bkg
- PLUME - double-sided high granularity MIMOSA pixels





$B \to D^{(*)}\tau\nu$ Belle II vs LHCb

Belle II LHCb

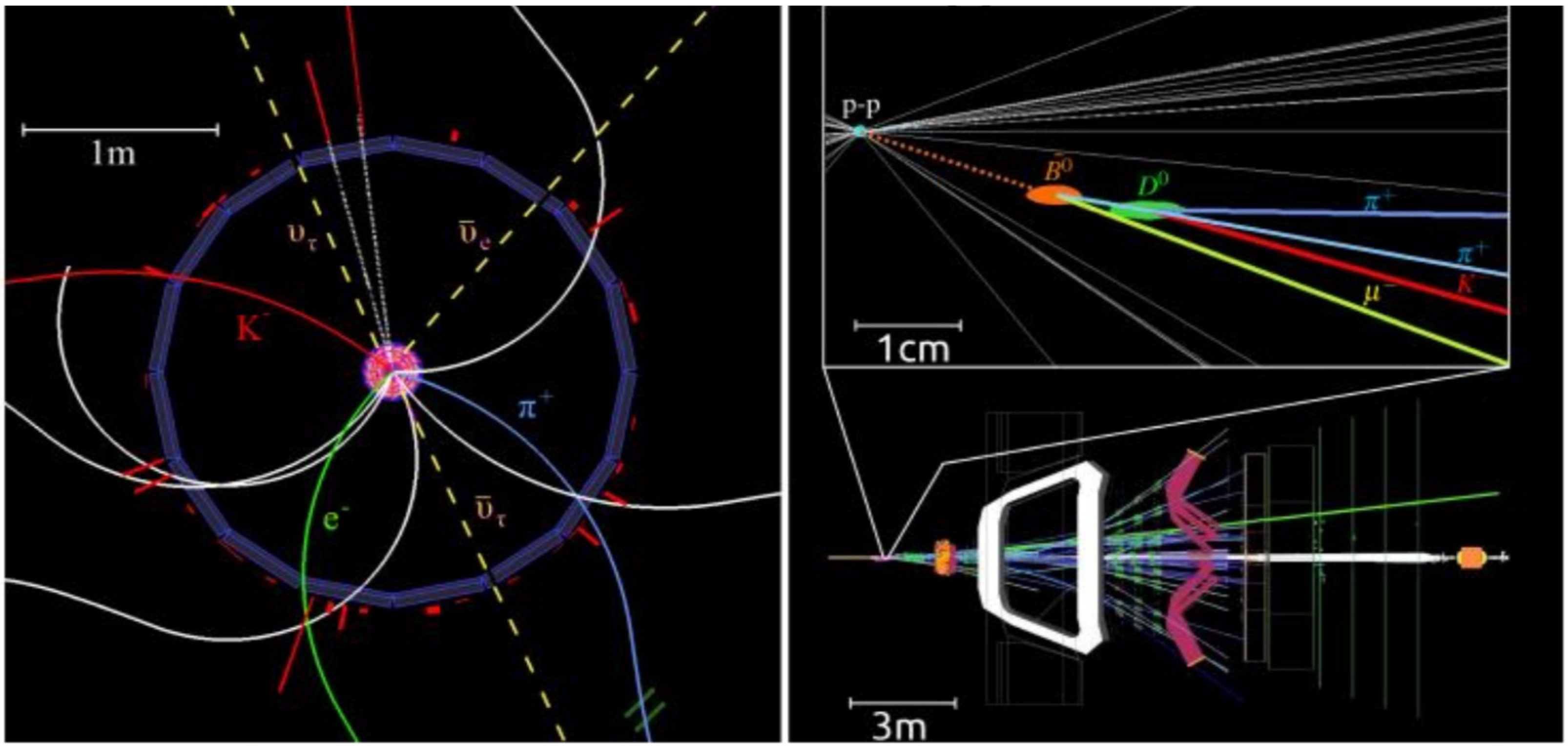


Figure 2. Belle (a) and LHCb (b) single event displays illustrating the reconstruction of semileptonic B meson decays: Trajectories of charged particles are shown as colored solid lines, energy deposits in the calorimeters are depicted by red bars. The Belle display is an end view perpendicular to the beam axis with the silicon detector in the center (small orange circle) and the device measuring the particle velocity (dark purple polygon). This is a $\Upsilon(4S) \to B^+B^-$ event, with $B^- \to D^0\tau^-\bar{\nu}_\tau$, $D^0 \to K^-\pi^+$ and $\tau^- \to e^-\nu_\tau\bar{\nu}_e$, and the B^+ decaying to five charged particles (white solid lines) and two photons. The trajectories of undetected neutrinos are marked as dashed yellow lines. The LHCb display is a side view with the proton beams indicated as a white horizontal line with the interaction point far to the left, followed by the dipole magnet (white trapezoid) and the Cherenkov detector (red lines). The area close to the interaction point is enlarged above, showing the tracks of the charged particles produced in the pp interaction, the B^0 path (dotted orange line), and its decay $\bar{B}^0 \to D^{*+}\tau^-\bar{\nu}_\tau$ with $D^{*+} \to D^0\pi^+$ and $D^0 \to K^-\pi^+$, plus the μ^- from the decay of a very short-lived τ^-.

Belle II Dataset

Official Data Set

Jake Bennett at al.

Official phase 3 data processing

- Current state of the art: proc9 + prompt (bucket7)

arXiv:1910.05365

Exp	Energy	Run range	Lumi good runs	Total good lumi	Lumi all runs	Campaign
3	4S	529-5613	**496.7±0.3±3.5/pb[1]**		-	Proc 9
7	4S	909-4120	**555.62 /pb**	**5.15 fb-1 (4S)** **6.01 fb-1 (total)**	642.8 /pb	
8	4S	43-1022, 1036-1554	**1827 /pb**		1982.3 /pb	
	Continuum	1703-1835	**39.02 /pb**		39.02 /pb	
	Scan	1025-1031	**826.79 /pb**		827.0 /pb	
	4S	1836-3123	**2764 /pb**		2973 /pb	Prompt

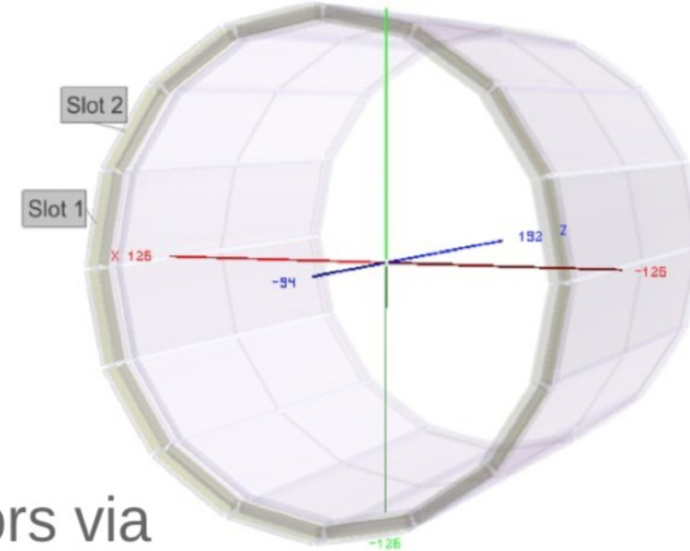
- Full data sample available on the GRID (mDST) and at KEKCC (HLT skims also at KEKCC)
  - Path to samples at KEKCC indicate Good/Bad runs
- Next official reprocessing (proc10) is underway
  - Will include all 2019a data (experiment 7 and 8 only) and will use release-04

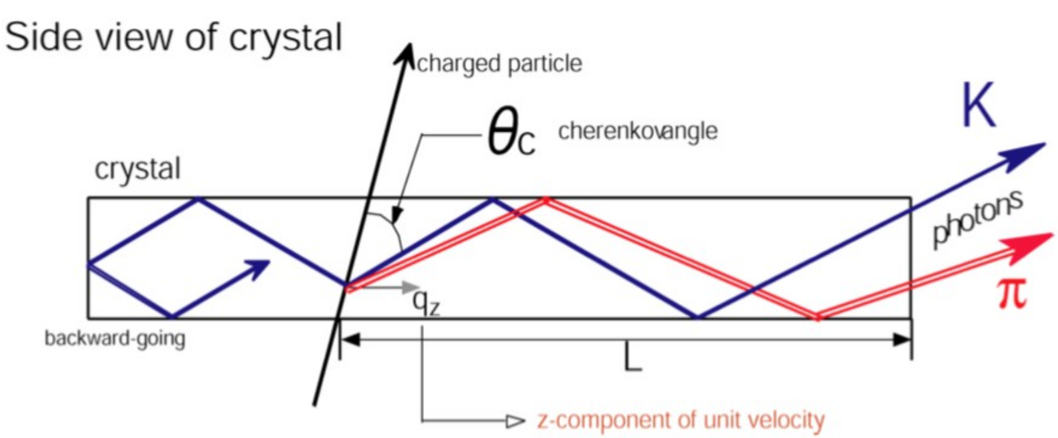
https://confluence.desy.de/display/BI/Phase+3+data

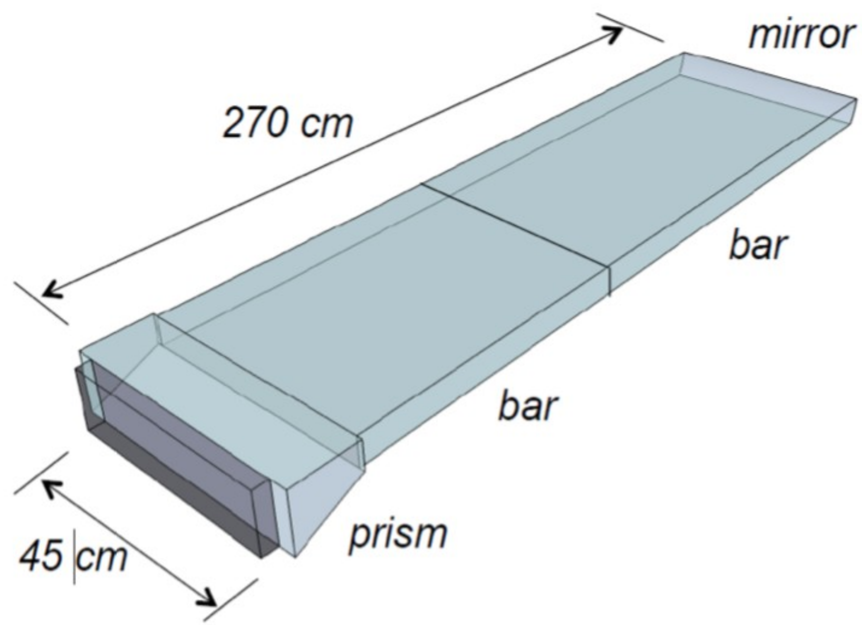
1

TOP: Concept

- 16 Quartz Cherenkov radiator bars
  - 270cm * 45cm * 2cm each
  - Small expansion volume
- Cherenkov photons propagate to sensors via total internal reflection





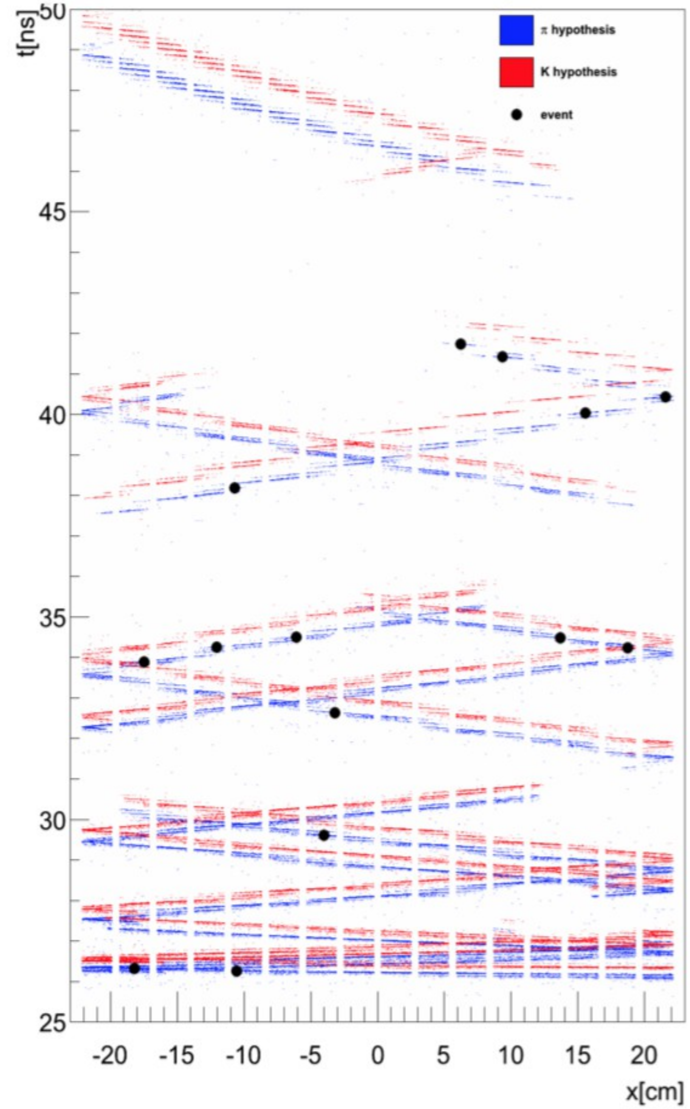


TOP Reconstruction

TOP: Reconstruction

- 20-30 photons/particle/event
  - +5-10 beam background photons
- Compare spatial/temporal distribution with pion/kaon hypothesis
  - PDFs depend on exact particle trajectory, recalculated event-by-event
- Sensor requirements:
  - single photon efficiency
  - <50ps single photon time resolution
  - ~few mm spatial resolution
  - Operation in 1.5T B-field
- Readout requirements:
  - 30KHz trigger rate
  - <<100ps full system time resolution

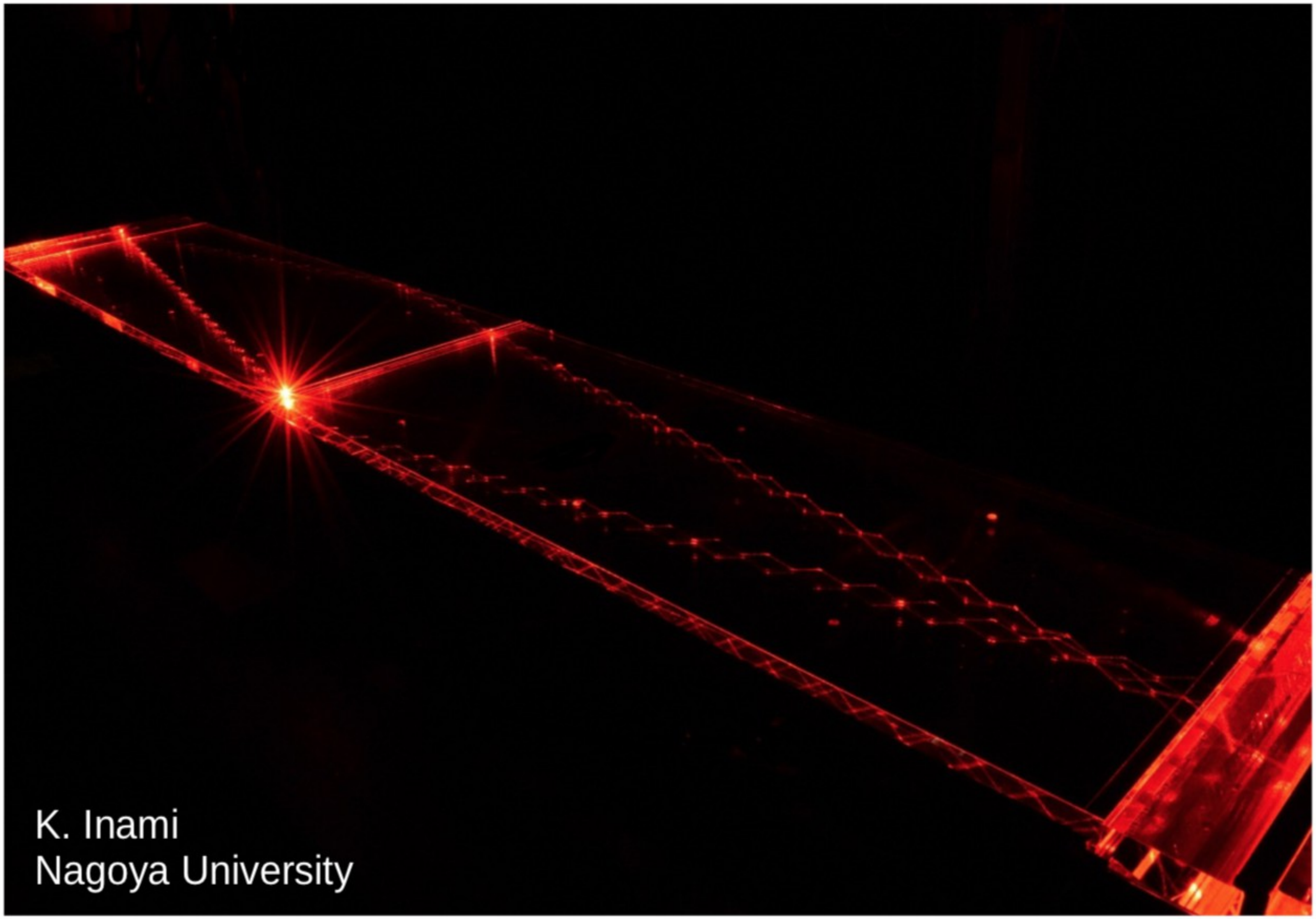
MC w/o chromatic dispersion



7

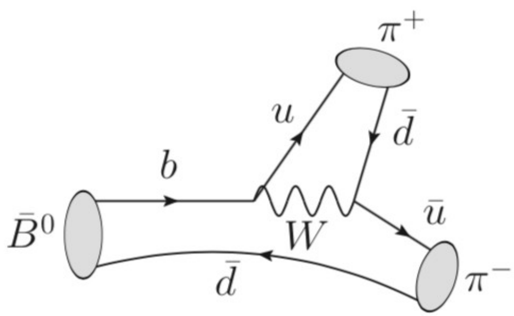
TOP quartz bar

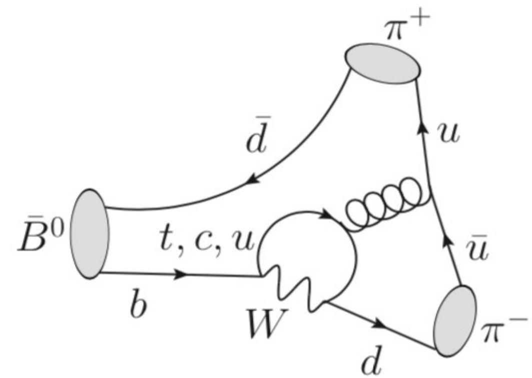
TOP: Total Internal Reflection



$\sin(2\varphi_2)$: isospin analysis in B → hh

- $\sin(2\varphi_2)$ can be extracted from time-dependent analysis of B → ππ, ρρ, πρ
- Tree and penguin contribution are comparable but additional weak and strong phases





- $S = \sin(2\varphi_{2,\,\mathrm{eff}})$, $\varphi_{2,\,\mathrm{eff}} = \varphi_2 + \delta\varphi_{\mathrm{peng}}$
- Disentangle the tree contribution and extract δφ by isospin analysis

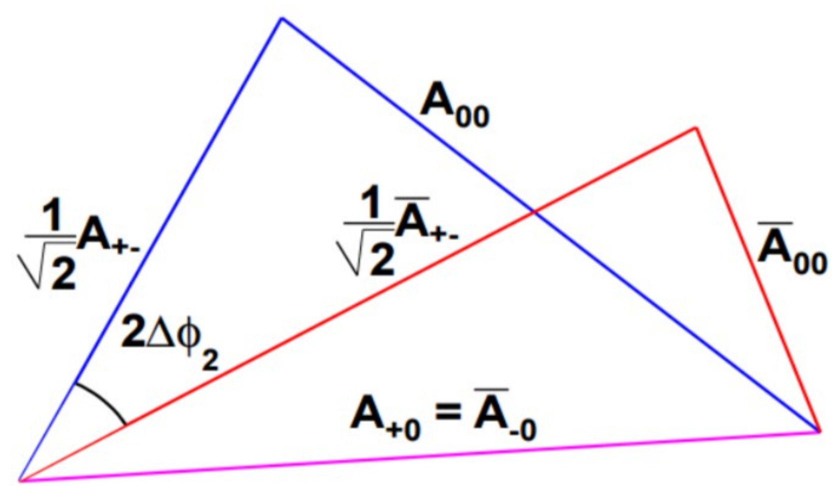
$$A^{(i,j)} \equiv \mathcal{A}(B^{i+j} \to h^i h^j)\ (h = \pi, \rho\ /\ i,j = \pm, 0)$$

$$A^{+-}/\sqrt{2} + A^{00} = A^{+0}$$

$$\bar{A}^{+-}/\sqrt{2} + \bar{A}^{00} = \bar{A}^{+0}$$

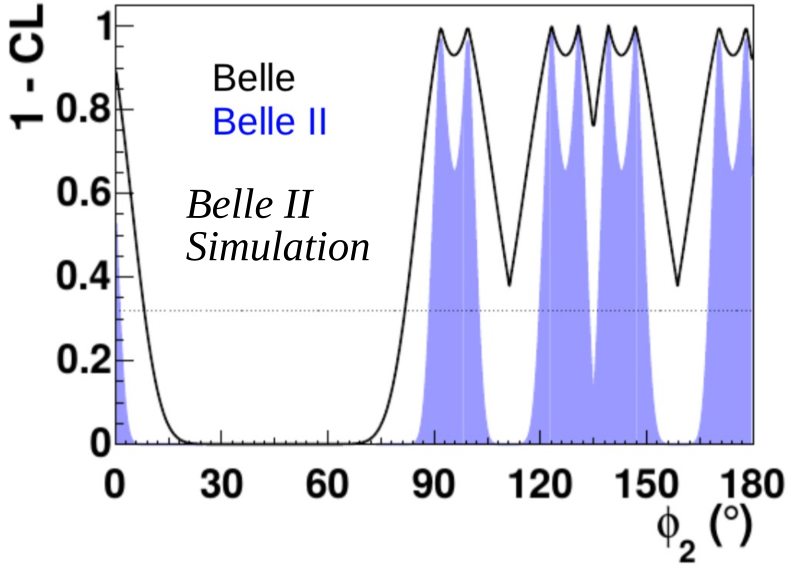
$$|A^{+0}| = |\bar{A}^{+0}|$$

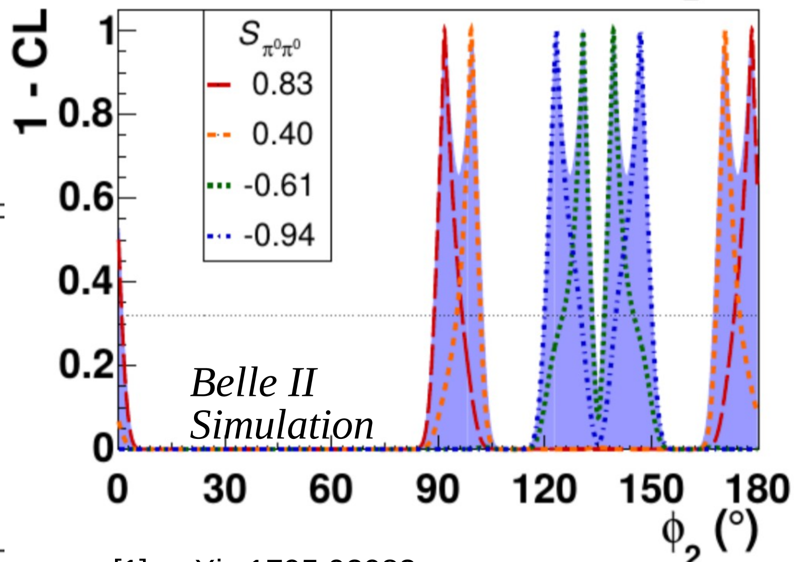
M. Gronau and D. London, PRL 65 3381 (1990)



$\sin(2\varphi_2)$: $B \to \pi\pi$

- Up to date $S_{\pi^0\pi^0}$ has never been measured → eightfold ambiguity on φ_2
- We need the decay vertex, experimentally:
  - $B^0_{sig} \to \pi^0_{\gamma\gamma} (\to \gamma\gamma)\ \pi^0_{\gamma\gamma} (\to \gamma\gamma)$
  - $B^0_{sig} \to \pi^0_{dal} (\to e^+e^- \gamma)\ \pi^0_{\gamma\gamma} (\to \gamma\gamma)$
  - $B^0_{sig} \to \pi^0_{\gamma^*\gamma} (\to \gamma^* (\to e+e-)\ \gamma)\ \pi^0_{\gamma\gamma} (\to \gamma\gamma)$
- Photon conversion in the inner detector:
  - 3% of $B^0 \to \pi^0 \pi^0$ events
  - ~ 5% including π^0 Dalitz decay
- Reconstruction efficiency is crucial!





	Value	Belle @ 0.8 ab^{-1}	Belle2 @ 50 ab^{-1}
$\mathcal{B}_{\pi^+\pi^-}$ $[10^{-6}]$	5.04	$\pm0.21 \pm 0.18$ [2]	$\pm0.03 \pm 0.08$
$\mathcal{B}_{\pi^0\pi^0}$ $[10^{-6}]$	1.31	$\pm0.19 \pm 0.18$ [1]	$\pm0.04 \pm 0.04$
$\mathcal{B}_{\pi^+\pi^0}$ $[10^{-6}]$	5.86	$\pm0.26 \pm 0.38$ [2]	$\pm0.03 \pm 0.09$
$C_{\pi^+\pi^-}$	-0.33	$\pm0.06 \pm 0.03$ [3]	$\pm0.01 \pm 0.03$
$S_{\pi^+\pi^-}$	-0.64	$\pm0.08 \pm 0.03$ [3]	$\pm0.01 \pm 0.01$
$C_{\pi^0\pi^0}$	-0.14	$\pm0.36 \pm 0.12$ [1]	$\pm0.03 \pm 0.01$
$S_{\pi^0\pi^0}$	—	—	$\pm0.29 \pm 0.03$

[1]: arXiv:1705.02083
[2]: PRD 87(3) 031103
[3]: PRD 88(9) 092003

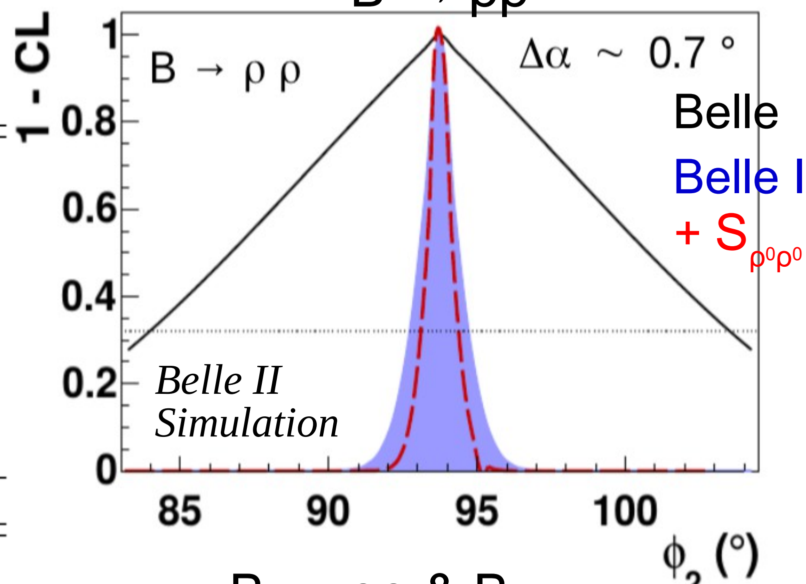
Belle II expectation: $\Delta\varphi_{2,\pi\pi} \sim 2°$

sin(2φ_2): B → ρρ

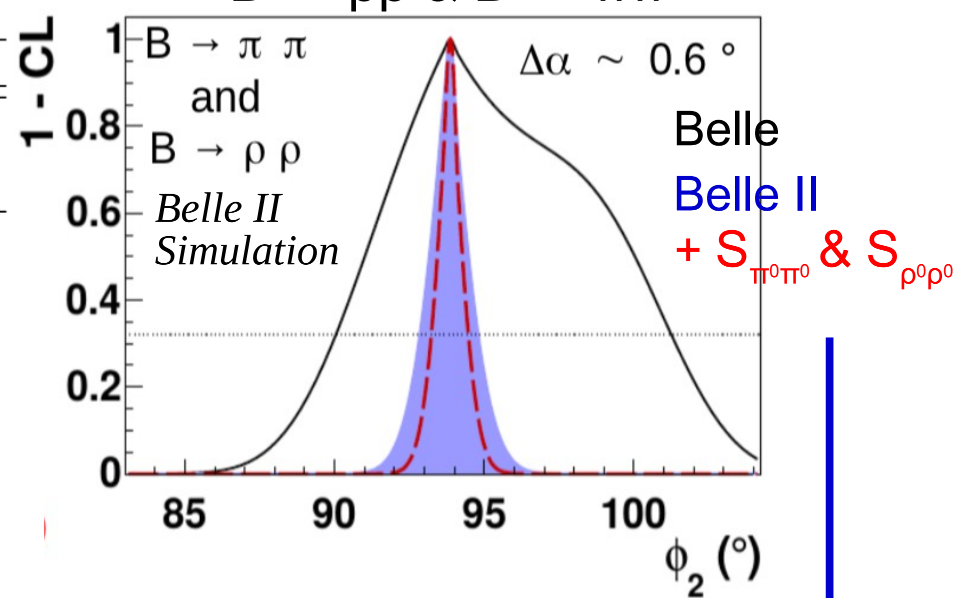
	Value	Belle Belle @ 0.8 ab^{-1}	Belle II Belle2 @ 50 ab^{-1}
$f_{L,\rho^+\rho^-}$	0.988	$\pm 0.012 \pm 0.023$ [1]	$\pm 0.002 \pm 0.003$
$f_{L,\rho^0\rho^0}$	0.21	$\pm 0.20 \pm 0.15$ [2]	$\pm 0.03 \pm 0.02$
$\mathcal{B}_{\rho^+\rho^-}$ [10^{-6}]	28.3	$\pm 1.5 \pm 1.5$ [1]	$\pm 0.19 \pm 0.4$
$\mathcal{B}_{\rho^0\rho^0}$ [10^{-6}]	1.02	$\pm 0.30 \pm 0.15$ [2]	$\pm 0.04 \pm 0.02$
$C_{\rho^+\rho^-}$	0.00	$\pm 0.10 \pm 0.06$ [1]	$\pm 0.01 \pm 0.01$
$S_{\rho^+\rho^-}$	-0.13	$\pm 0.15 \pm 0.05$ [1]	$\pm 0.02 \pm 0.01$
	Value	Belle @ 0.08 ab^{-1}	Belle2 @ 50 ab^{-1}
$f_{L,\rho^+\rho^0}$	0.95	$\pm 0.11 \pm 0.02$ [3]	$\pm 0.004 \pm 0.003$
$\mathcal{B}_{\rho^+\rho^0}$ [10^{-6}]	31.7	$\pm 7.1 \pm 5.3$ [3]	$\pm 0.3 \pm 0.5$
	Value	BaBar @ 0.5 ab^{-1}	Belle2 @ 50 ab^{-1}
$C_{\rho^0\rho^0}$	0.2	$\pm 0.8 \pm 0.3$ [4]	$\pm 0.08 \pm 0.01$
$S_{\rho^0\rho^0}$	0.3	$\pm 0.7 \pm 0.2$ [4]	$\pm 0.07 \pm 0.01$

[1] Phys. Rev. D78, 071104 (2008)
[2] Phys. Rev. Lett., 91, 221801 (2003)
[3] Phys. Rev. D93, 032010 (2016)
[4] Add Phys. Rev. D89, n.11, 119903 (2014)

B → ρρ



B → ρρ & B → ππ



Belle II expectation: $\Delta\varphi_{2,\rho\rho} \sim 0.7°$

Combined: $\Delta\varphi_2 \sim 0.6°$