The 21st Particles & Nuclei International Conference

1-5 September 2017, IHEP, Beijing, China

The Belle II Experiment: status and physics prospects

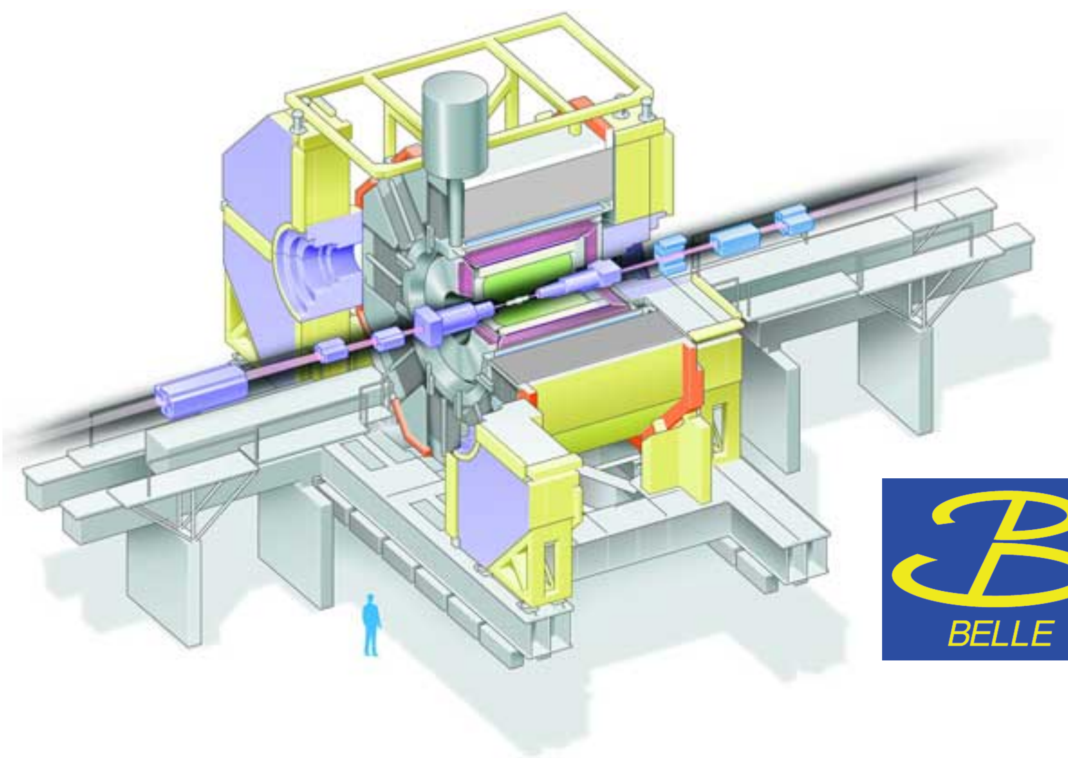
Jake Bennett
Carnegie Mellon University

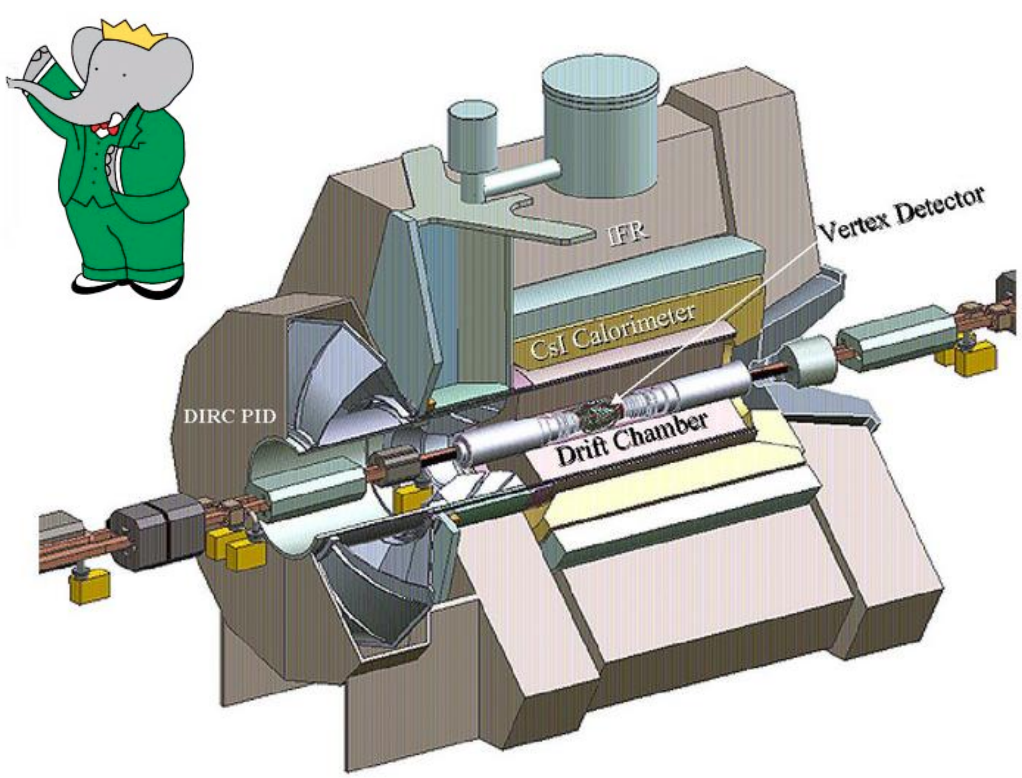
SuperKEKB

Belle II

Carnegie Mellon

B factories

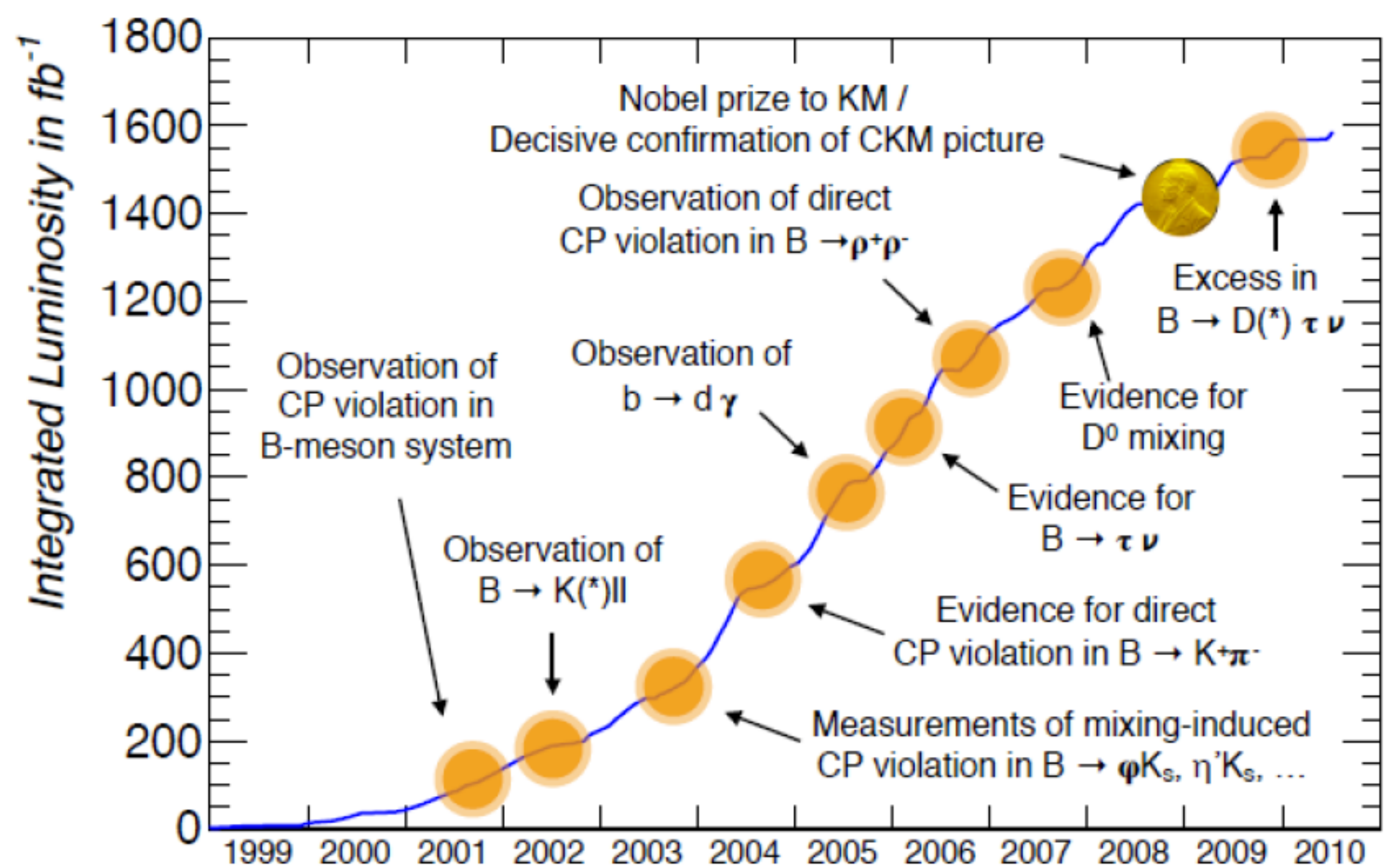




Belle/KEKB (KEK) and BaBar/PEP-II (SLAC)

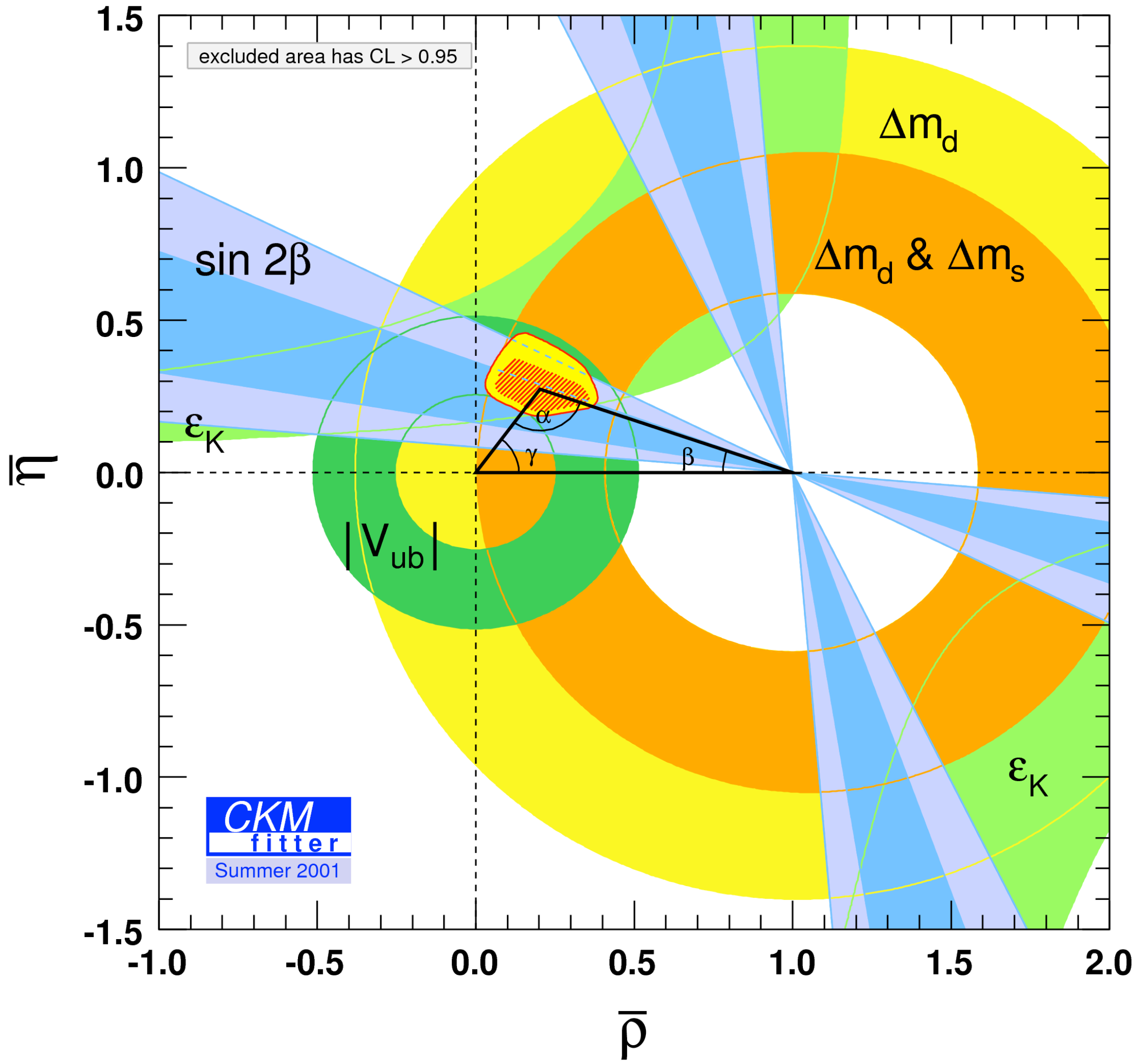
Very successful physics programs with a total recorded sample over 1.5 ab^{-1} (1.25 x 10^{9} B$\bar{B}$)

— Experimental confirmation of CKM mechanism as source of CPV in the SM

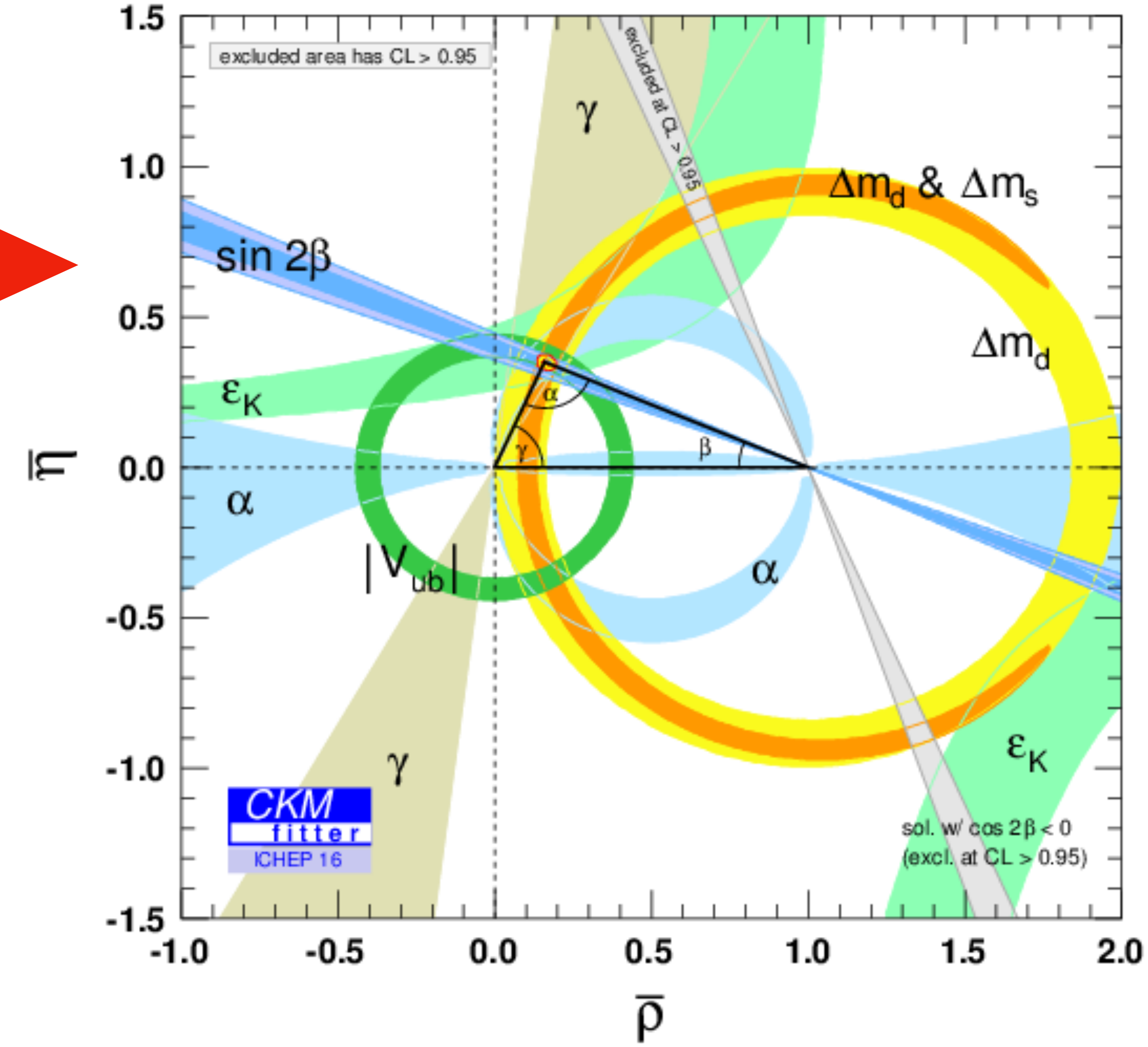


Results from global fits to data

2001: CP violation in the B system is established following the first measurements of the CKM parameter sin2β by BaBar and Belle



State of the art:
ICHEP **2016** conference

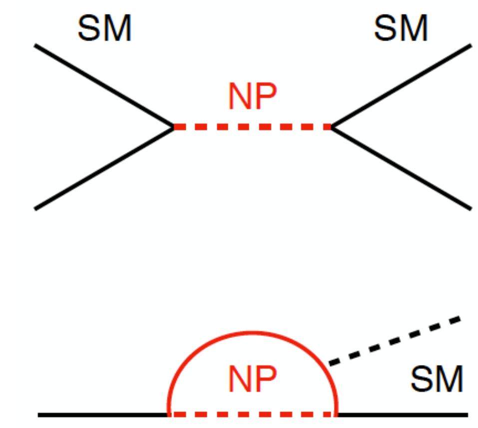


Excellent agreement between SM and results from B-factories and LHCb

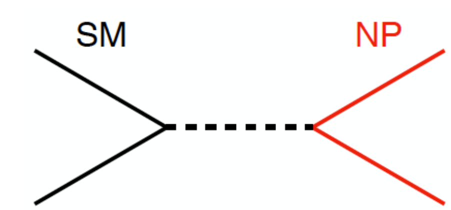
Prospects for New Physics at Belle II

- Search for NP in the flavor sector at the **intensity frontier**
  - Flavor physics as a probe for beyond the TeV scale
- Signatures of new particles or processes observed through measurements of suppressed flavor physics reactions or from deviations from SM predictions
  - An observed discrepancy can be interpreted in terms of NP models
  - Need significantly more data to make this possible
  - Ultimate goal of Belle II: 50 ab^{-1} data sample

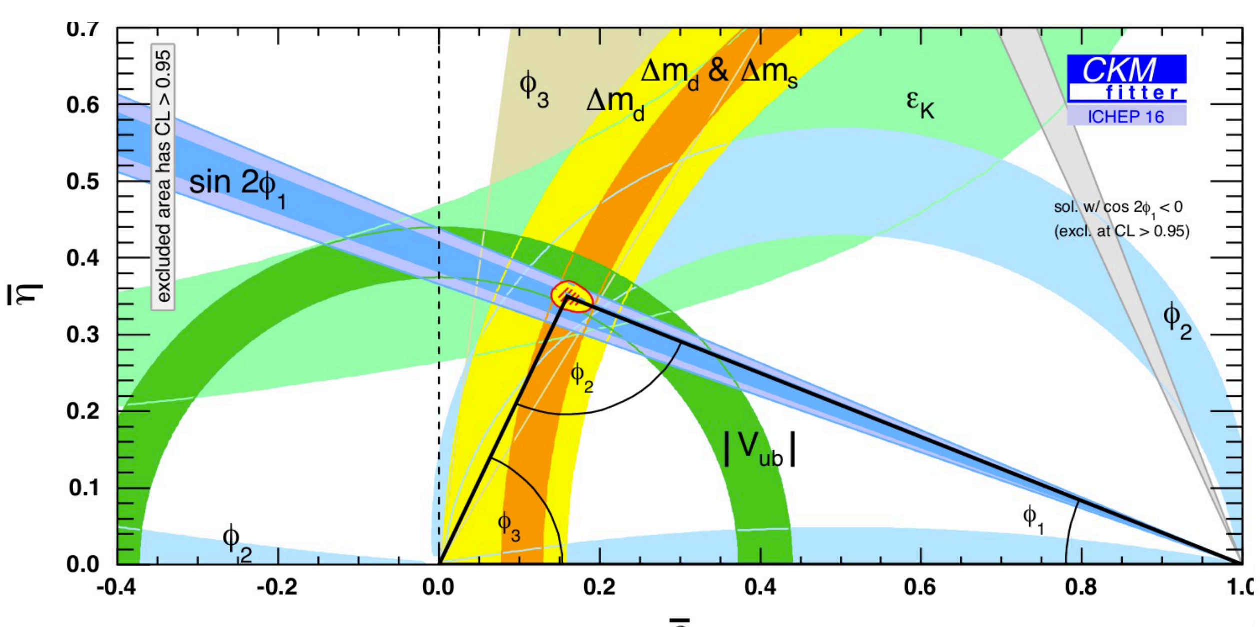
Intensity frontier:
indirectly reveal NP virtual particles in loops – probe energy above 10 TeV



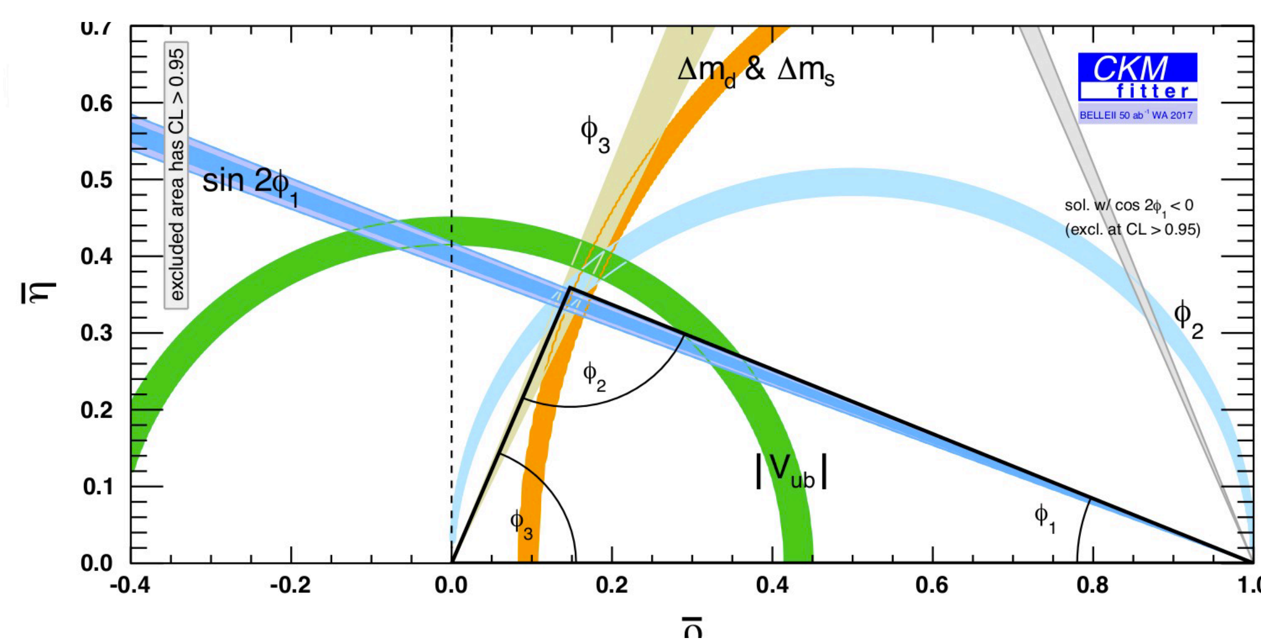
Energy frontier
Direct production of new particles - limited by beam energy



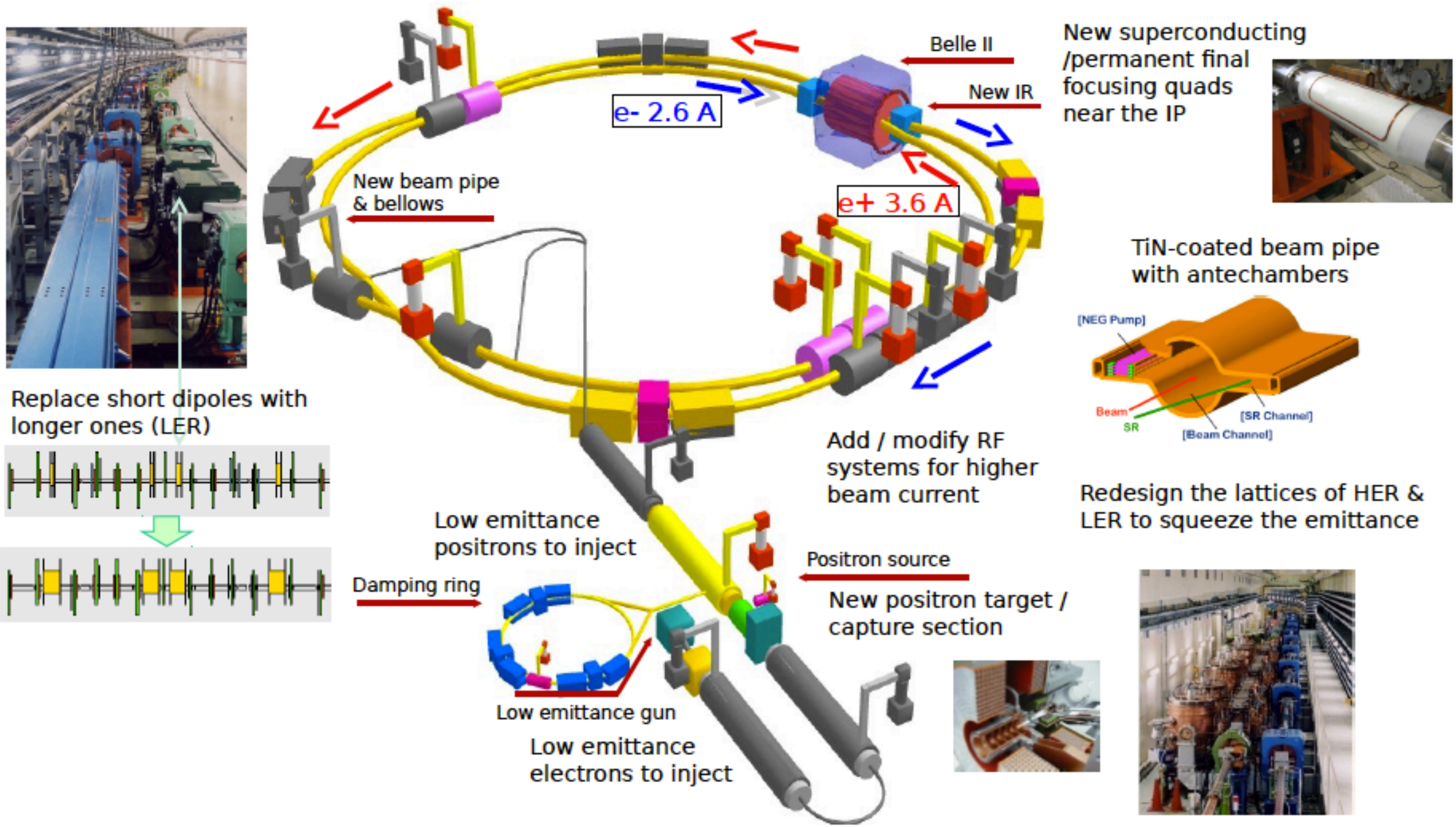
State of the art 2016



Belle II 50 ab^{-1}



SuperKEKB
The next generation B-factory



*gray - recycled, color - new

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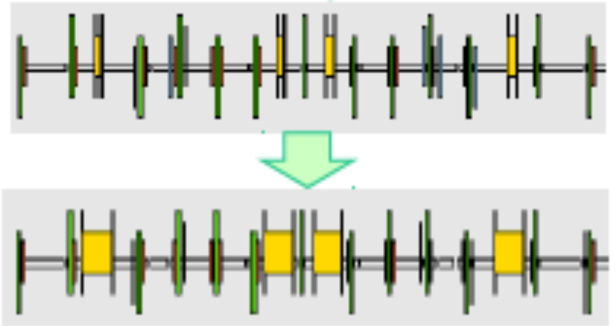

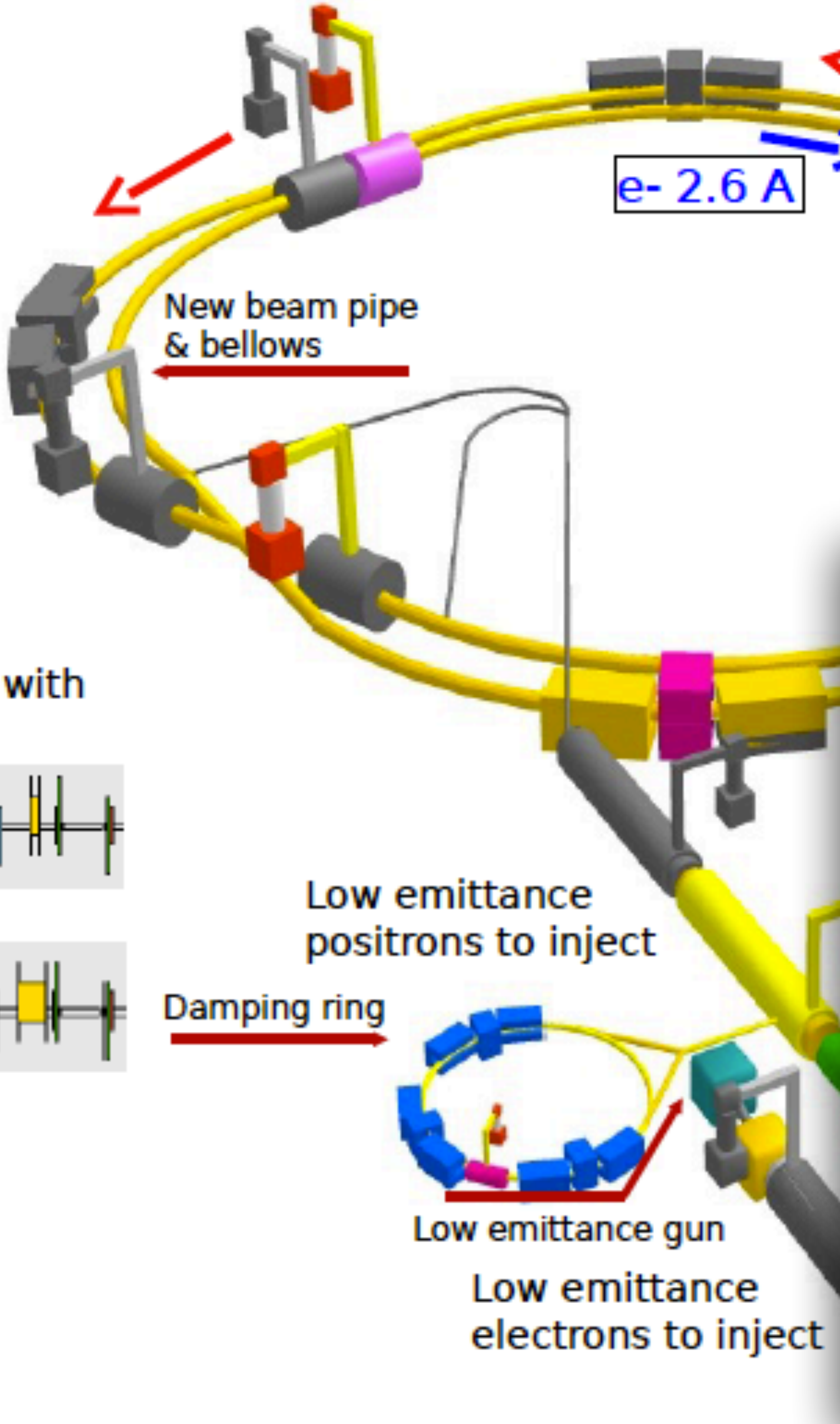

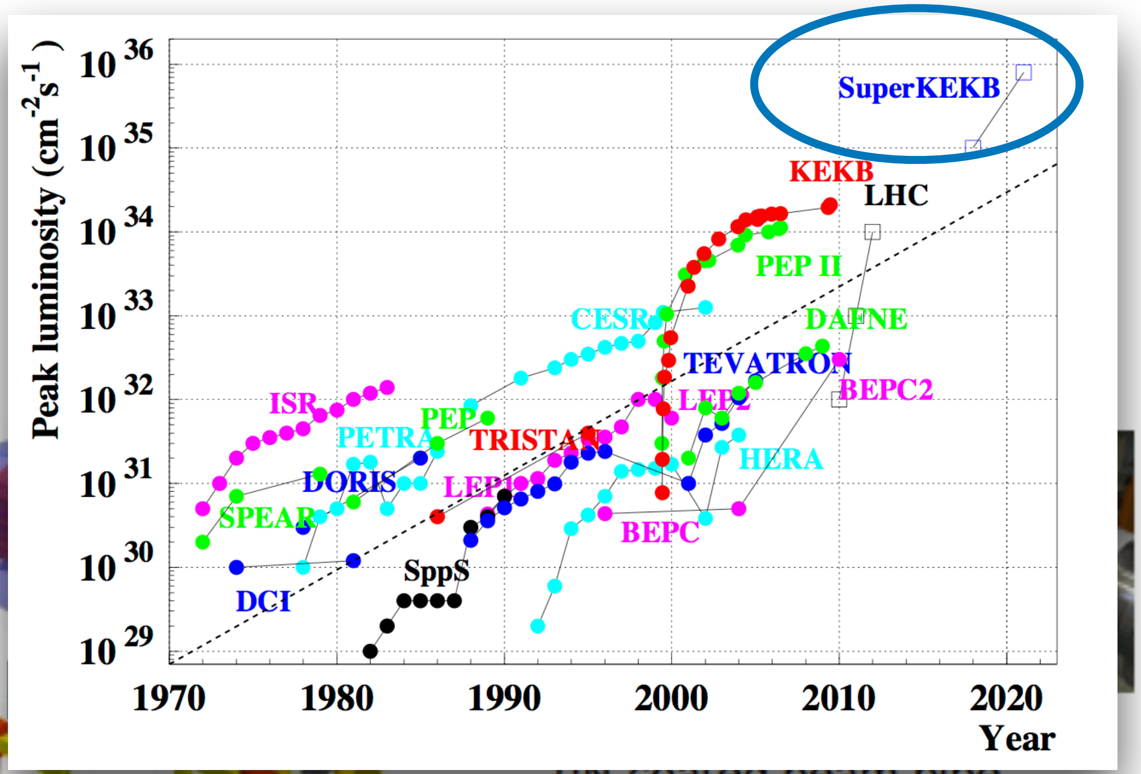

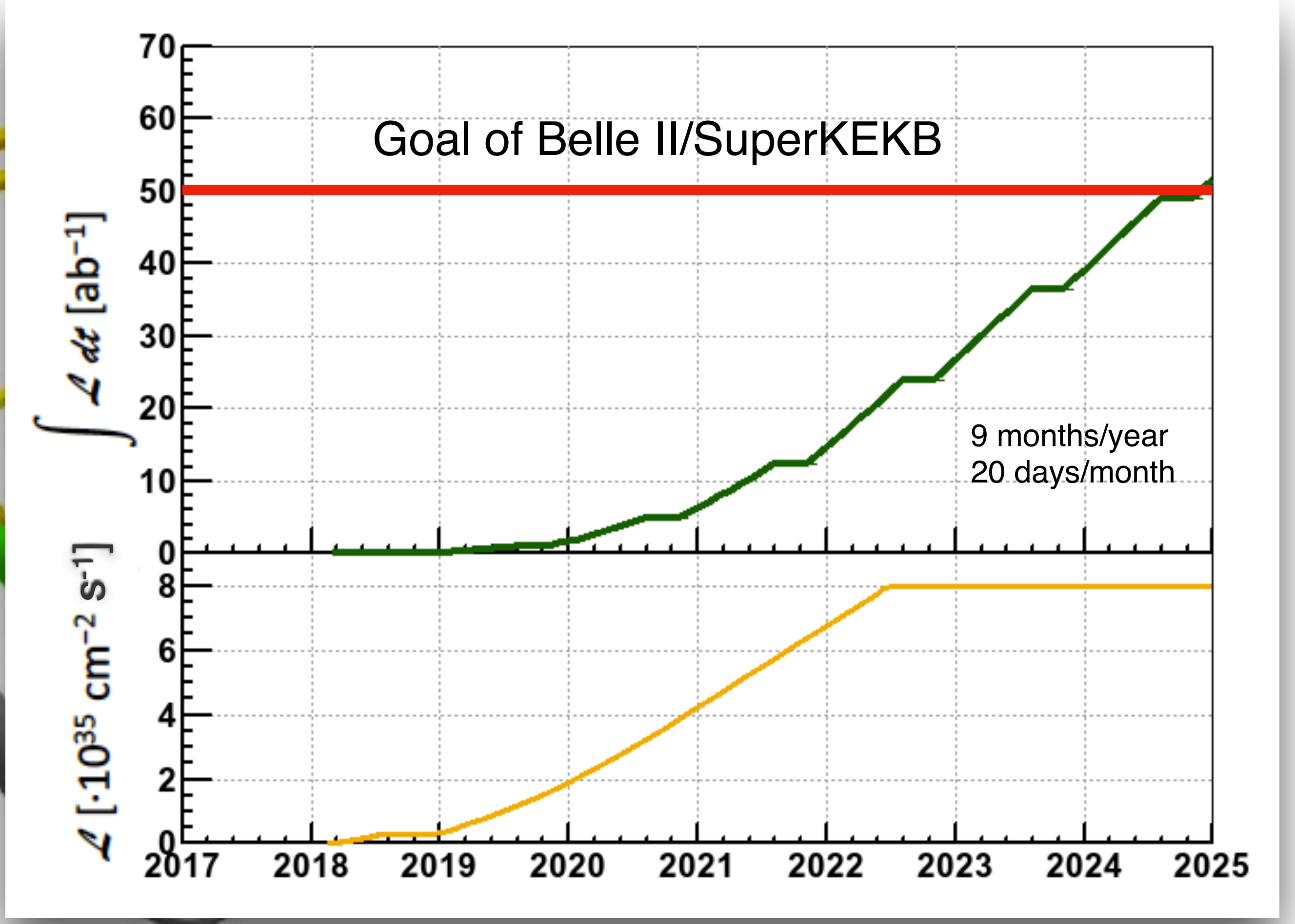

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SuperKEKB nanobeams

To get 40x luminosity of KEKB

Reduce beam size to a few 100 atomic layers!

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

Lorentz factor

Beam current

Beam-Beam parameter

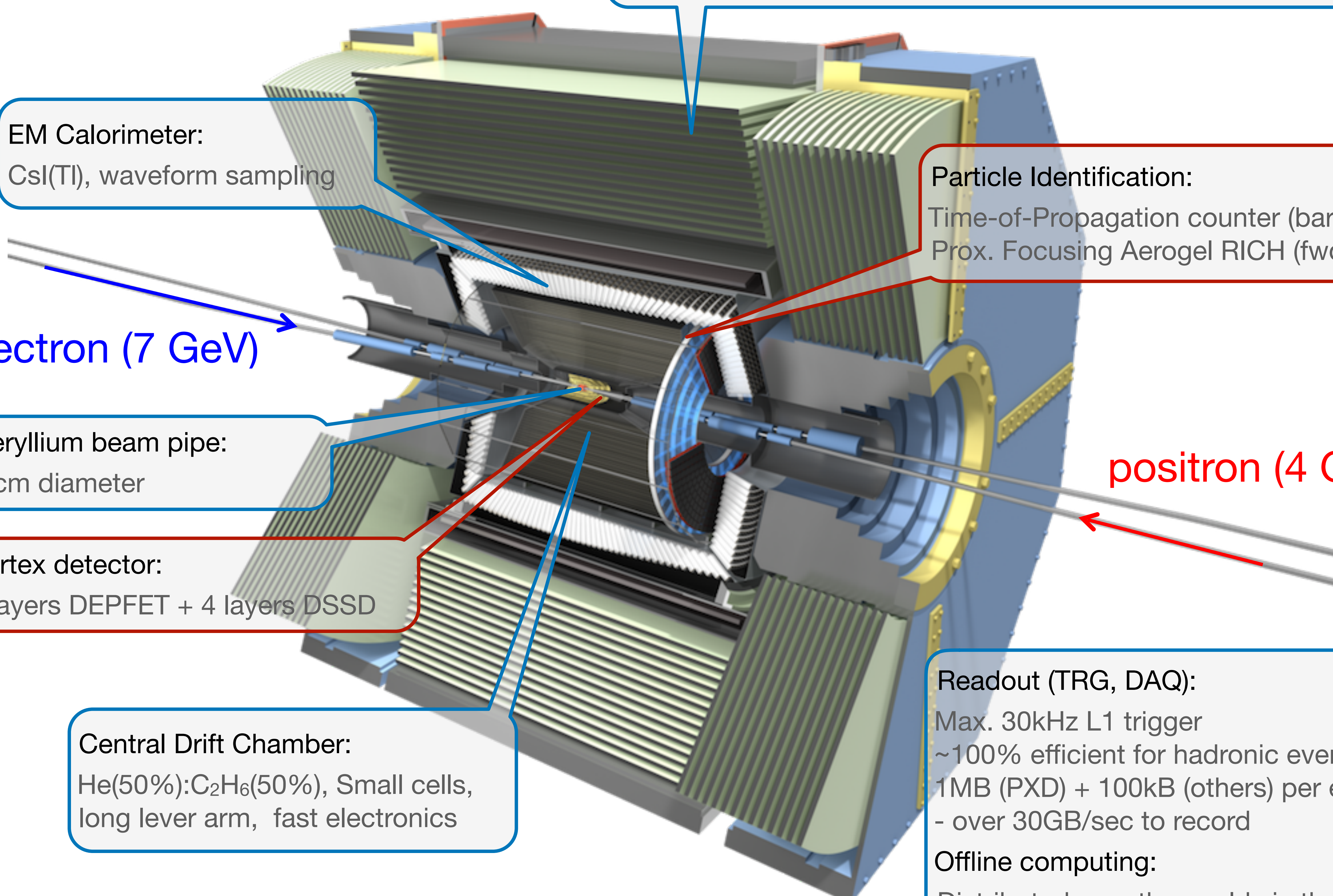
Geometrical reduction factors (crossing angle, hourglass effect)

Beam aspect ratio at IP

Vertical beta function at IP

Parameter		KEKB LER	KEKB HER	SuperKEKB LER	SuperKEKB HER	units
beam energy	E_b	3.5	8	4	7	GeV
CM boost	$\beta\gamma$	0.425		0.28		
half crossing angle	ϕ	11		41.5		mrad
horizontal emittance	ε_x	18	24	3.2	4.6	nm
beta-function at IP	β_x^*/β_y^*	1200/5.9		32/0.27	25/0.30	mm
beam currents	I_b	1.64	1.19	3.6	2.6	A
beam-beam parameter	ξ_y	0.129	0.090	0.0881	0.0807	nm
beam size at IP	σ_x^*/σ_y^*	100/2		10/0.059		µm
Luminosity	L	2.1×10^{34}		8×10^{35}		$cm^{-2}s^{-1}$

The Belle II detector



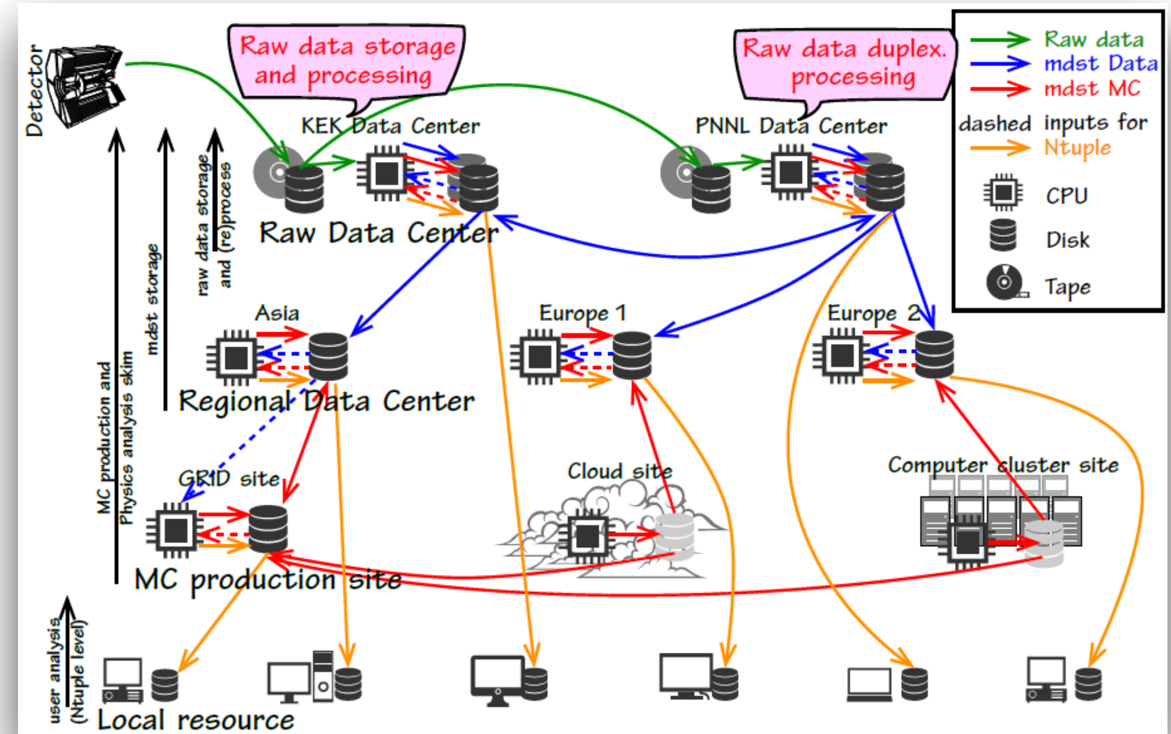
First new particle collider since the LHC
(intensity rather than energy frontier; e^+e^- rather than pp)

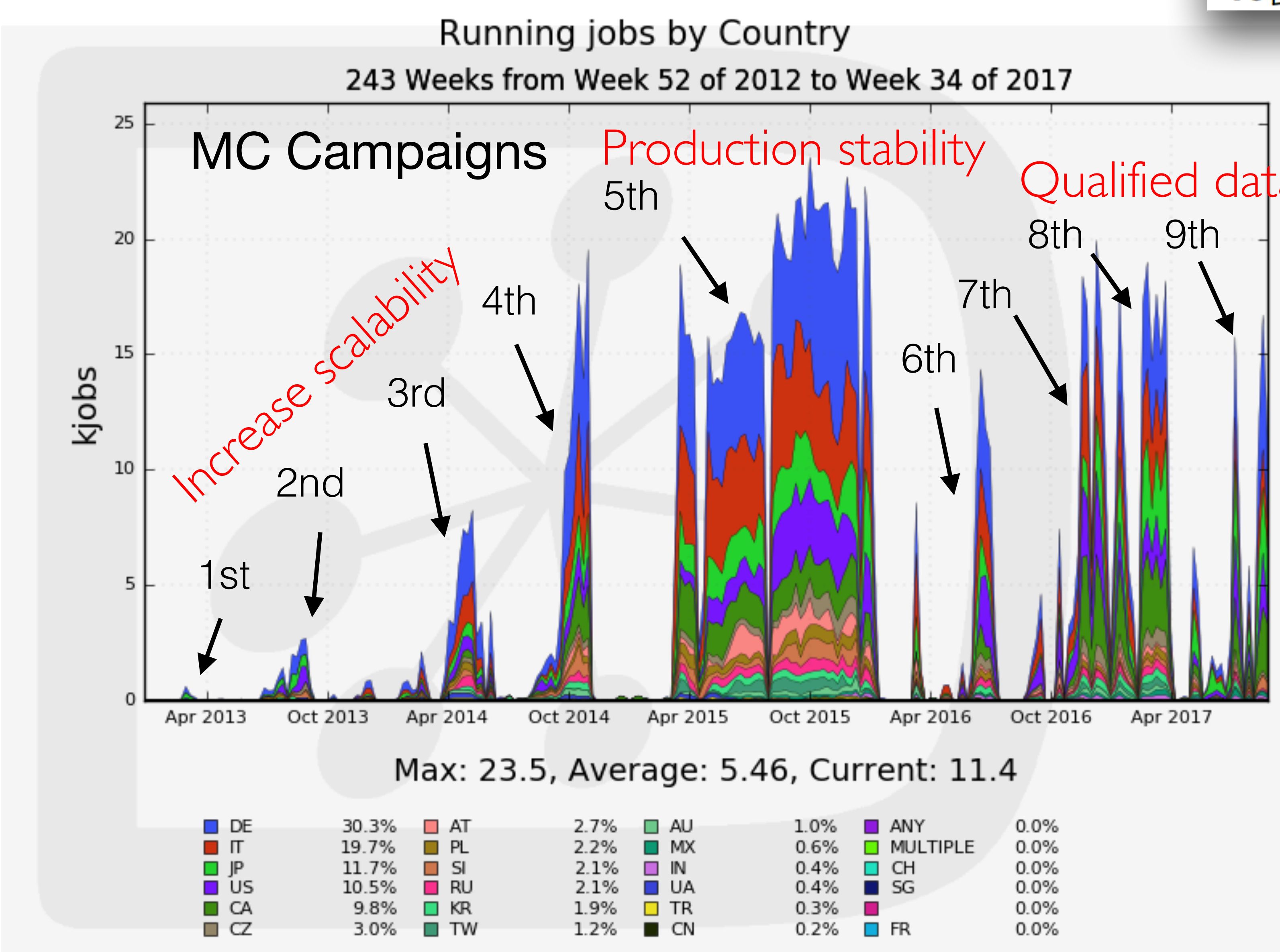
arXiv:1011.0352 [physics.ins-det]

Offline computing

Distributed computing following the LHC model

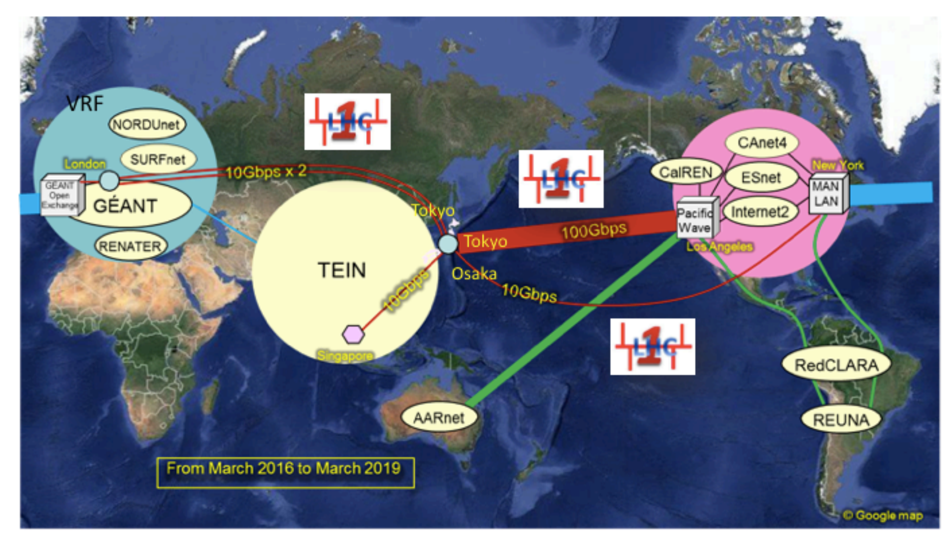
- Manage the processing of massive data sets
- Production of large MC samples
- Many concurrent user analysis jobs





High speed networking data challenge in 2016:

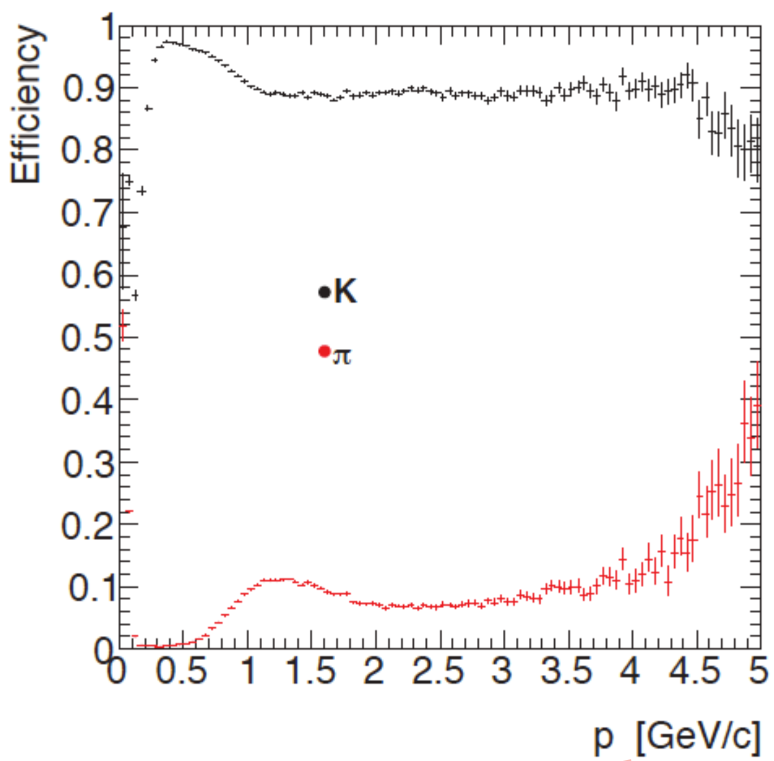
- Belle II networking requirements are satisfied



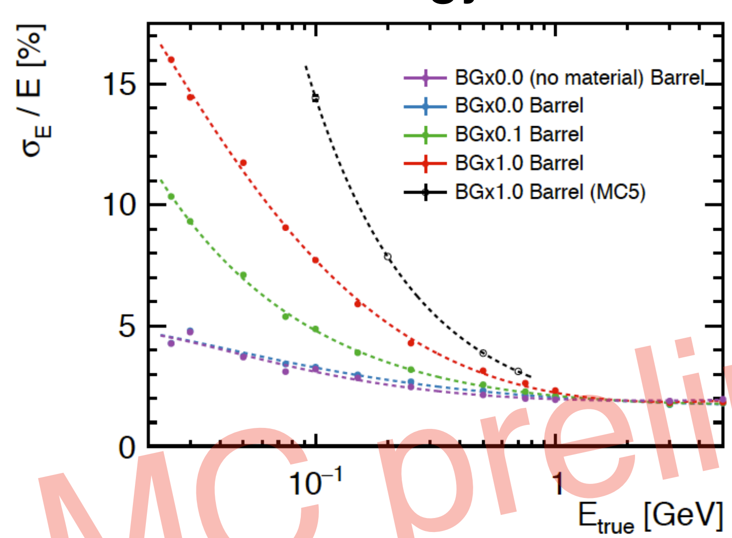
Reconstruction performance (from Belle II MC)

Belle II works similar to or better than Belle despite ~20 times higher beam background!

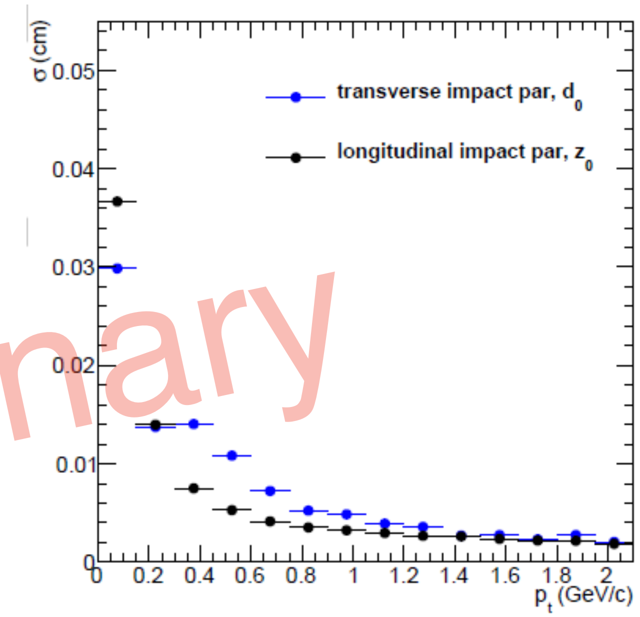
PID performance



Photon energy resolution

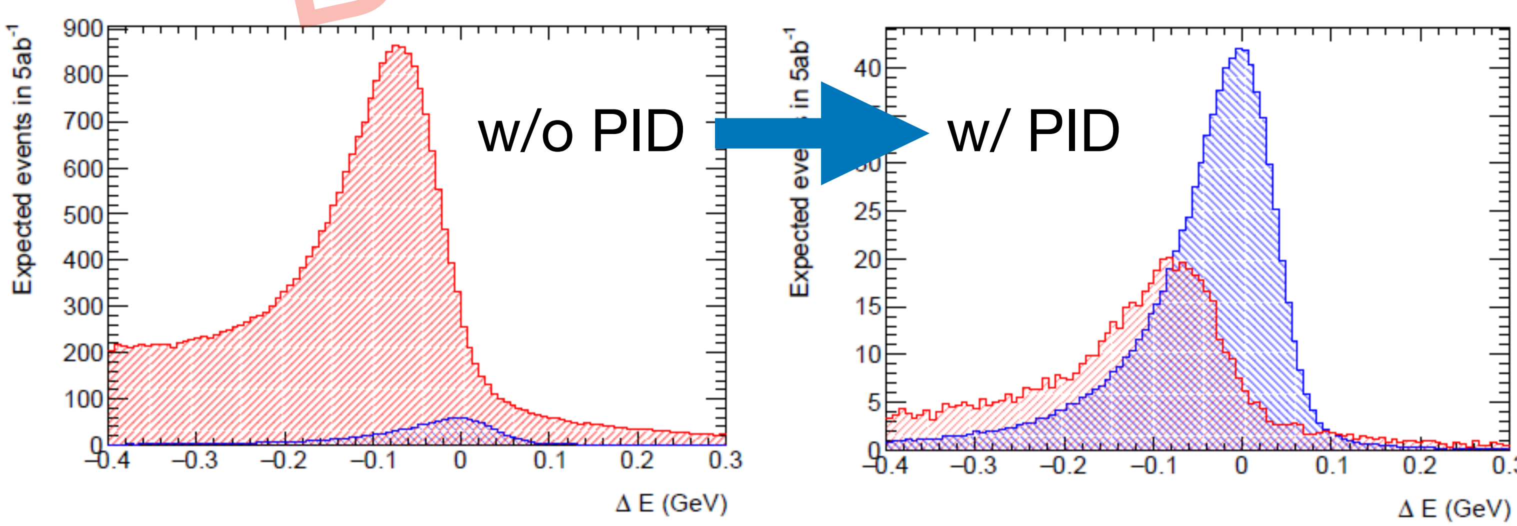


IP resolution

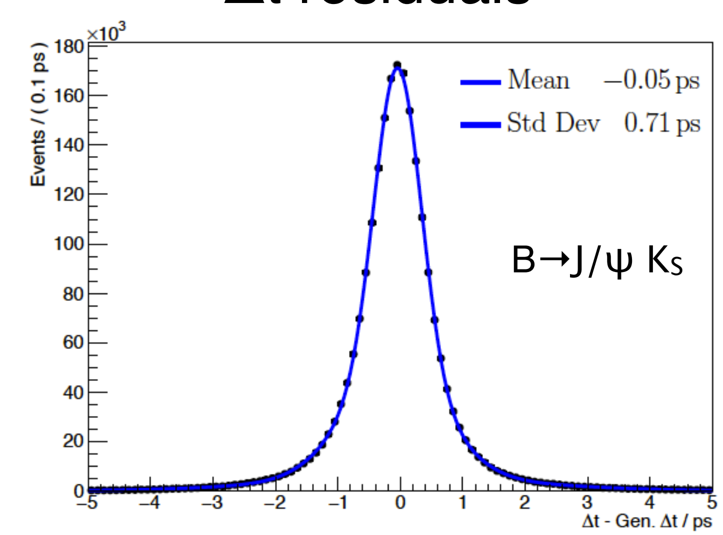


Belle II MC preliminary

$B^0 \to \rho^0\gamma$ vs. $K^{*0}\gamma$

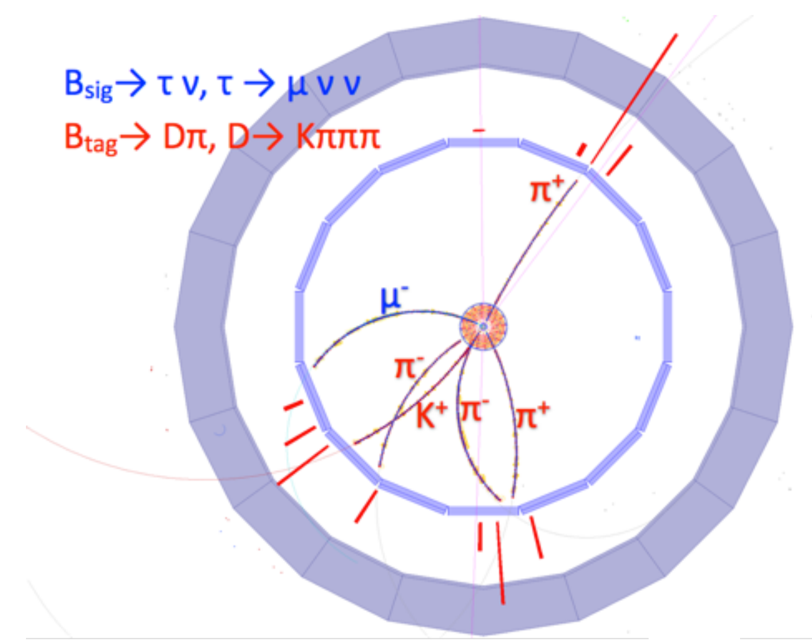


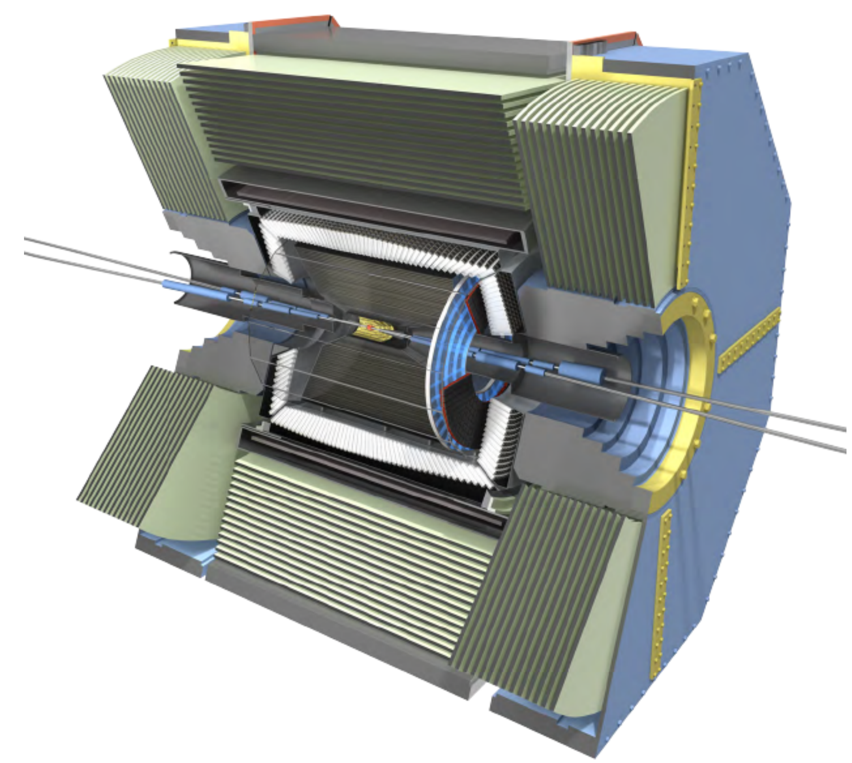
Δt residuals



Advantages of SuperKEKB and Belle II

- Very clean sample of quantum correlated $B^0\bar{B}^0$ pairs
- High effective flavor-tagging efficiency
  - Belle II ~34% efficient vs. LHCb ~3%
  - Belle II can also measure K_S and K_L (impacts most time dependent CPV measurements)
- Large sample of τ leptons for measurements of rare decays and searches for LFV
- Efficient reconstruction of neutrals (π^0, η, …)
- Dalitz plot analyses, missing mass analyses straightforward
- Systematics quite different than those of LHCb → NP seen by one experiment should be confirmed by the other

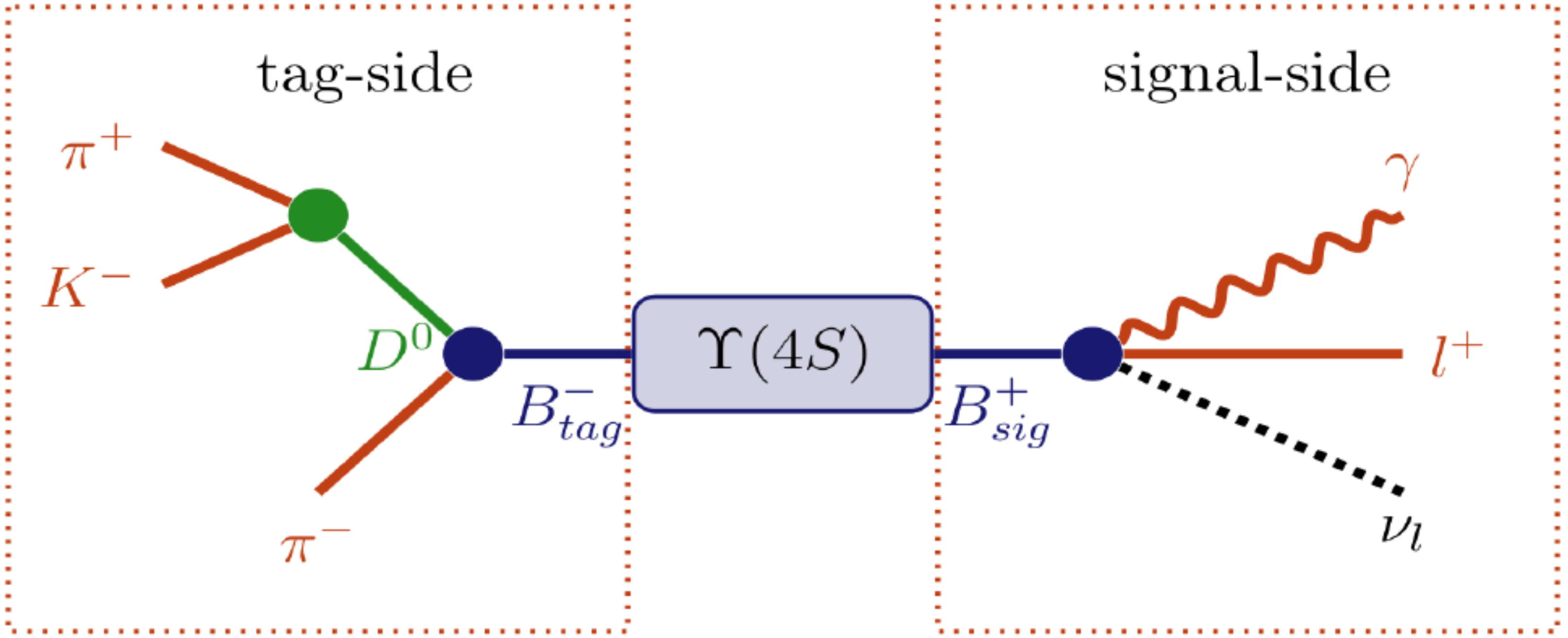




Full reconstruction tagging

- A powerful benefit of physics at B factories: fully reconstruct one B to tag the flavor of the other B, determine its momentum, isolate tracks of signal side

Signal side:
$B \to X\ell\nu$ - Precise meas. of $|V_{ub}|$
$B \to \tau\nu$ - Search for NP
$B \to K\nu\nu$ - Search for NP



- Excellent tool for missing energy, missing mass analyses!
  - e.g. provide important high-mass sensitivity to the charged Higgs in the multi-TeV range

Belle II physics program

- Belle II physics at PANIC 2017
  - Exotic and conventional bottomonium physics - Roberto Mussa
  - Study of charmoniumlike states with ISR - XiaoLong Wang
  - CP Violation sensitivity - Luo Tao
  - Measurement of the gamma CKM angle - Hulya Atmacan
  - Charm physics - Longke Li
  - Studies of missing energy decays - Yinghui Guan
  - Dark Sector Physics - Fabrizio Bianchi

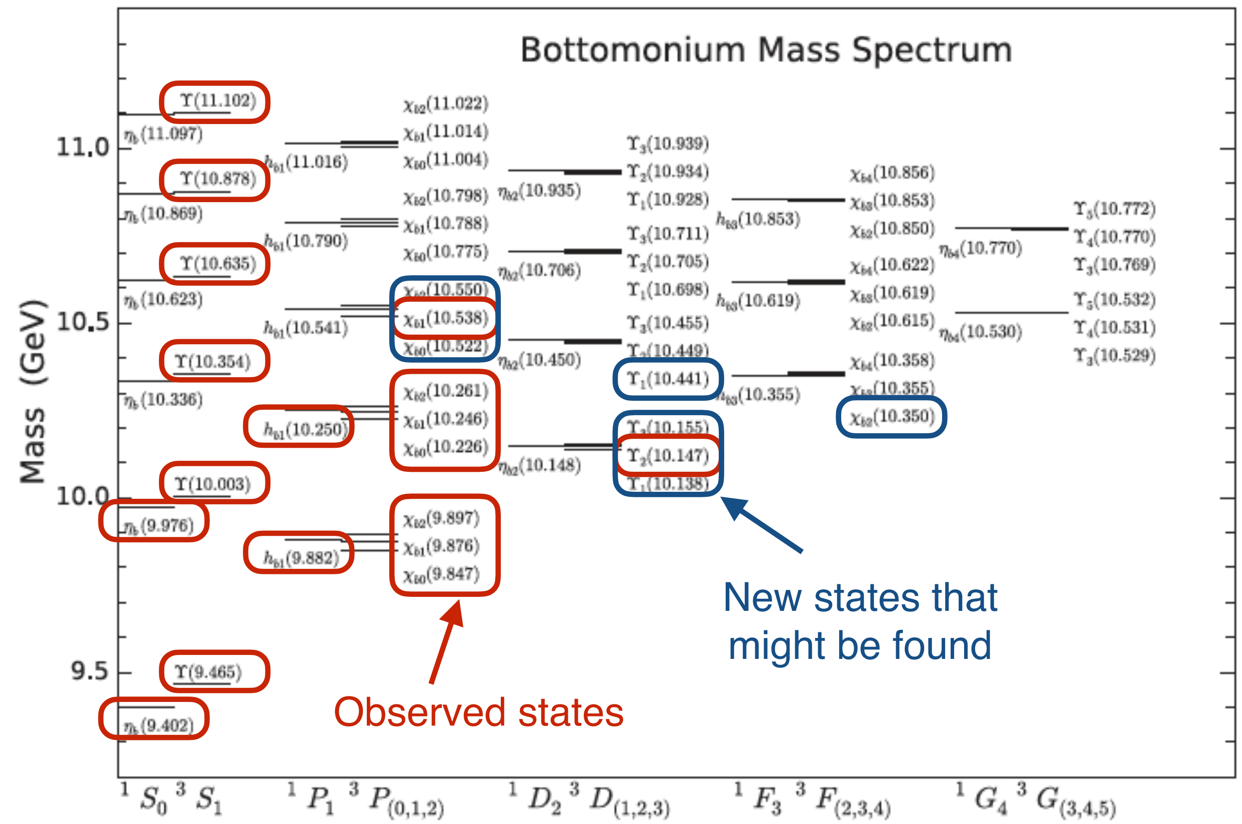
- Review of Belle II to be published in the B2TiP report later this year
  - Includes description of detector, software, analysis tools, etc.
  - https://confluence.desy.de/display/BI/B2TiP+ReportStatus

Early Belle II physics

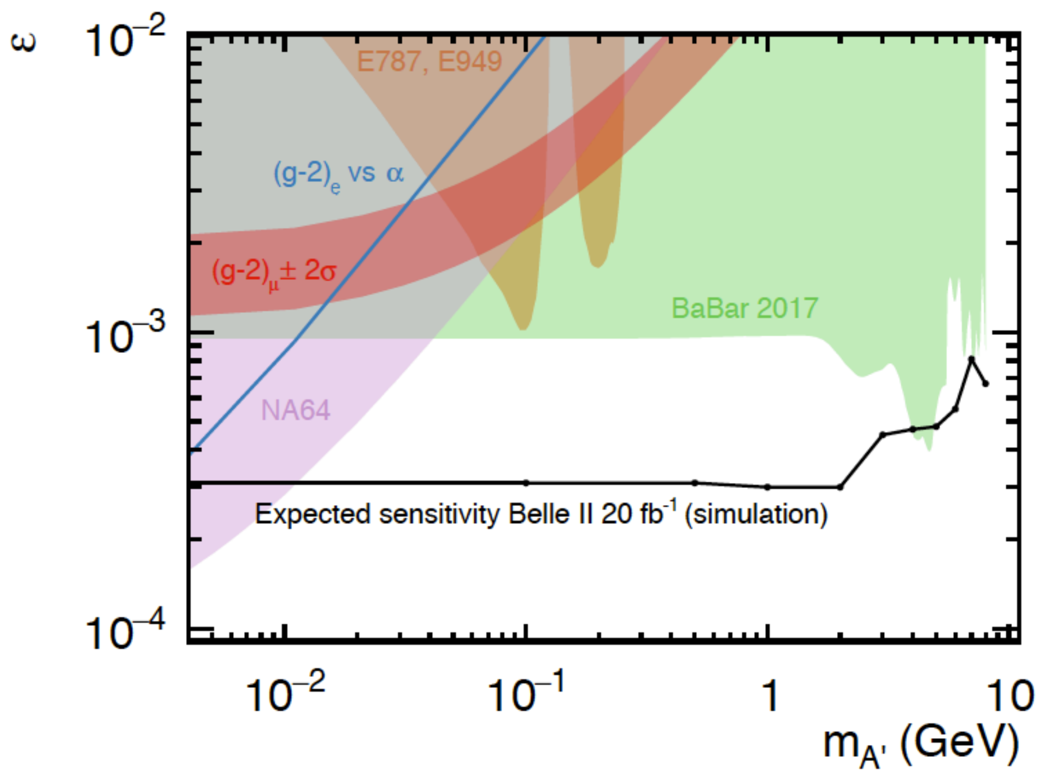
Quarkonium spectroscopy

- Considerable progress recently in Lattice QCD
- Belle II has the opportunity to search for missing states
- Much to be done to quantify/confirm XYZ states!

PHYSICAL REVIEW D **92**, 054034 (2015)

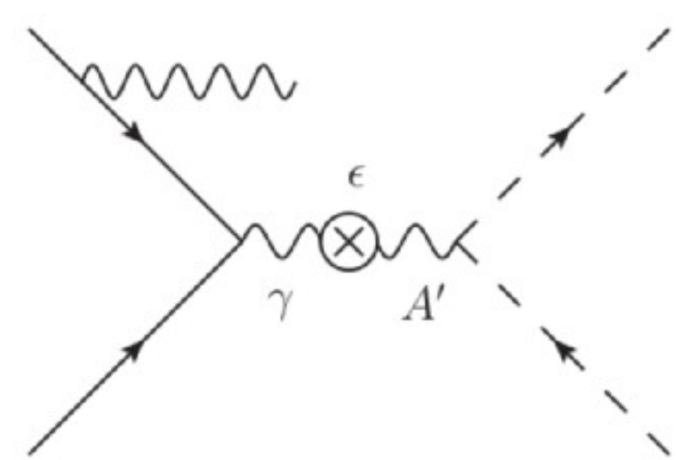


*Belle II has good calorimeter hermeticity and KLM efficiency



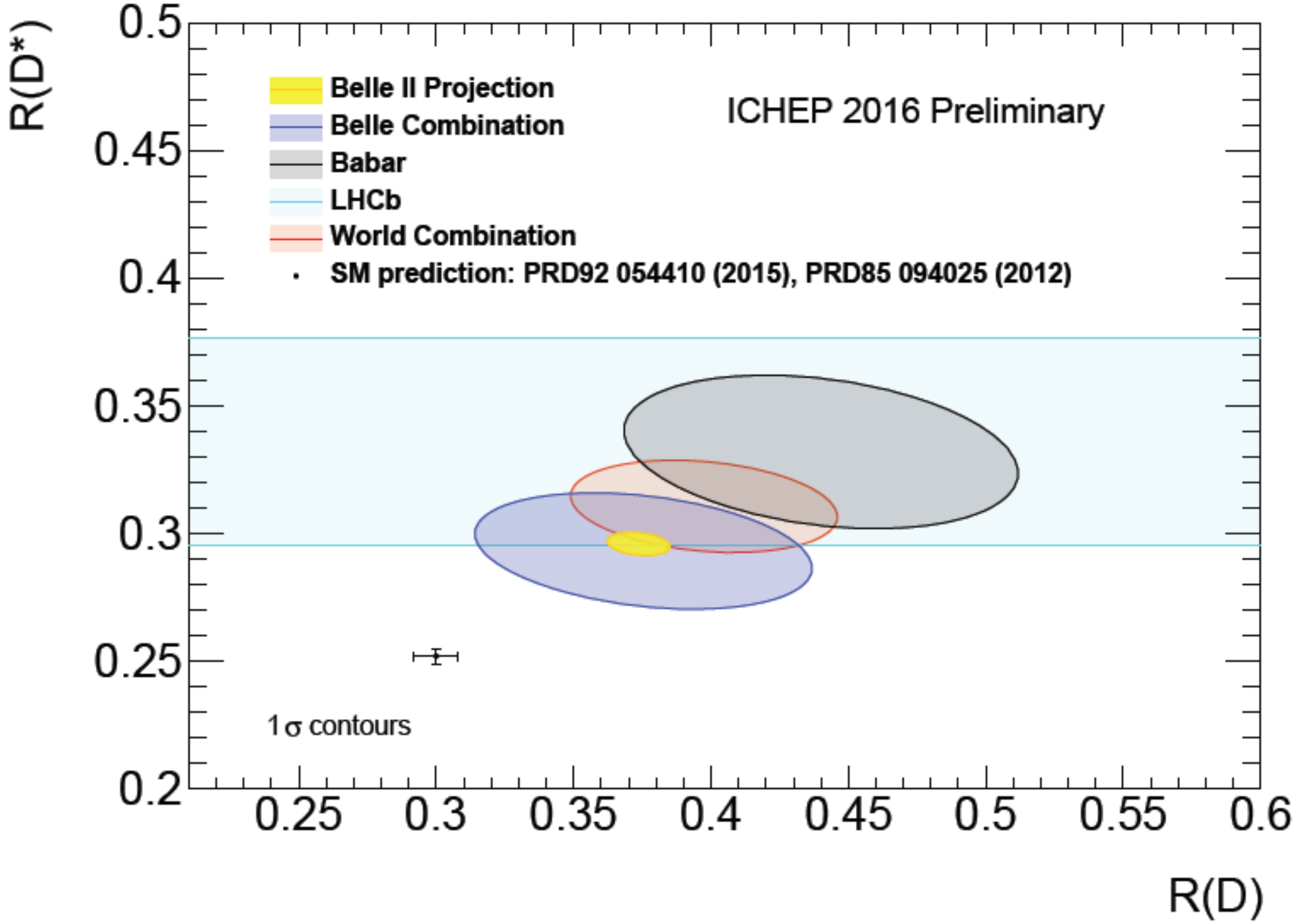
Light dark matter searches

e.g. dark photon: $A' \rightarrow \gamma$ + invisible



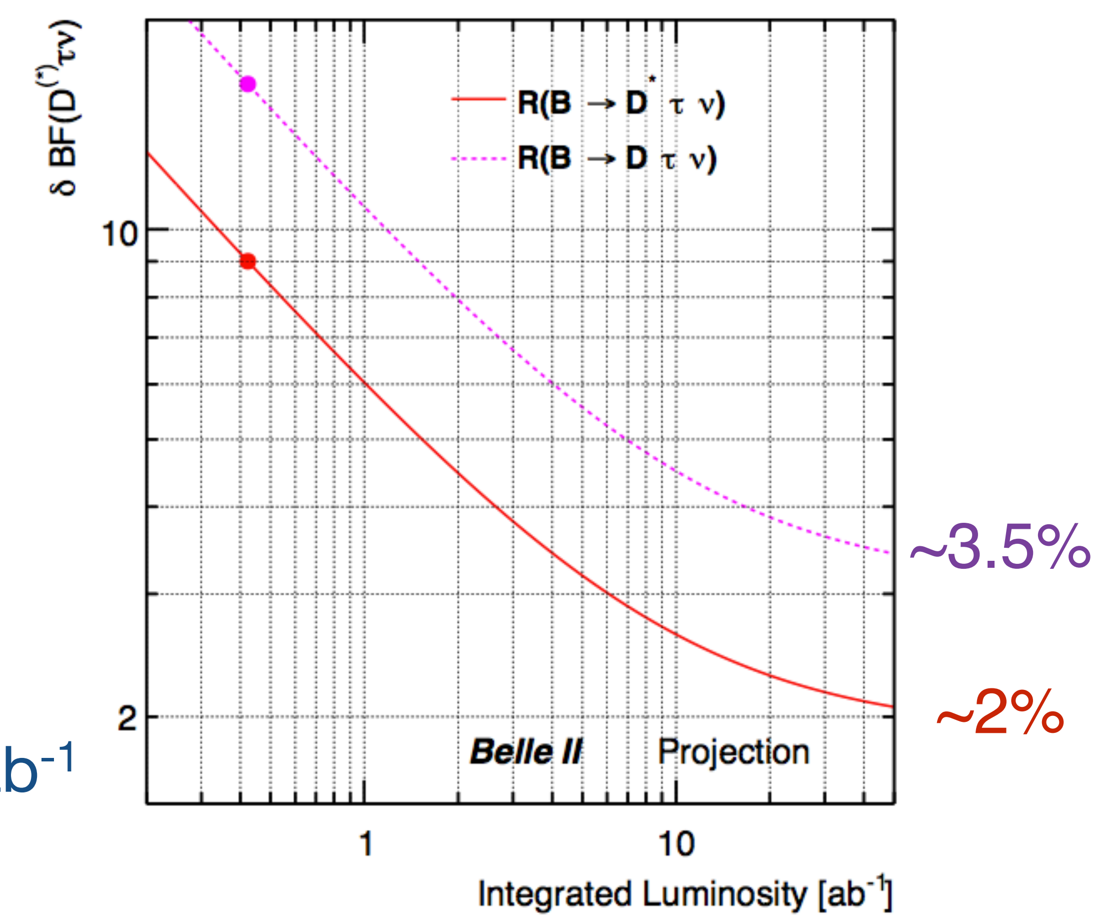
Flavor anomaly in R(D) and R(D*)

Observable: $R = \frac{Br(B \to D^{(*)}\tau\nu)}{Br(B \to D^{(*)}\ell\nu)}$



Belle II should be able to confirm the excess with ~5 ab^{-1}

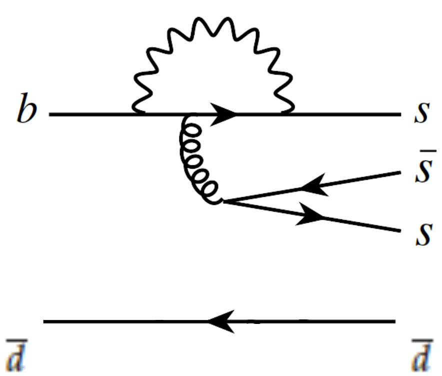
- Combined significance of 4.1σ disagreement with SM
- Not compatible with type II 2HDM, could be accommodated by more general charged Higgs or NP



Are there new CP violating phases?

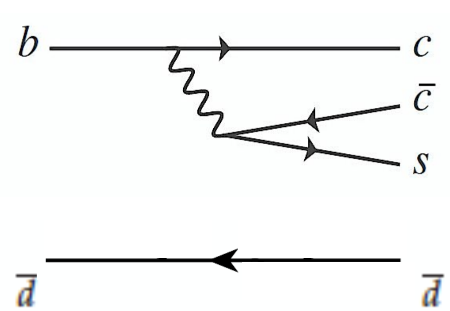
- Most theories involving NP include additional CP-violating phases
  - Some allow large deviations from SM predictions for B meson decays
- Search for new sources of CPV by comparing mixing-induced CP asymmetries in penguin transitions with tree-dominated modes
- Time-dependent CPV in b → s decays such as B → ϕK^0, $\eta' K^0$, $K^0 K^0 K^0$

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

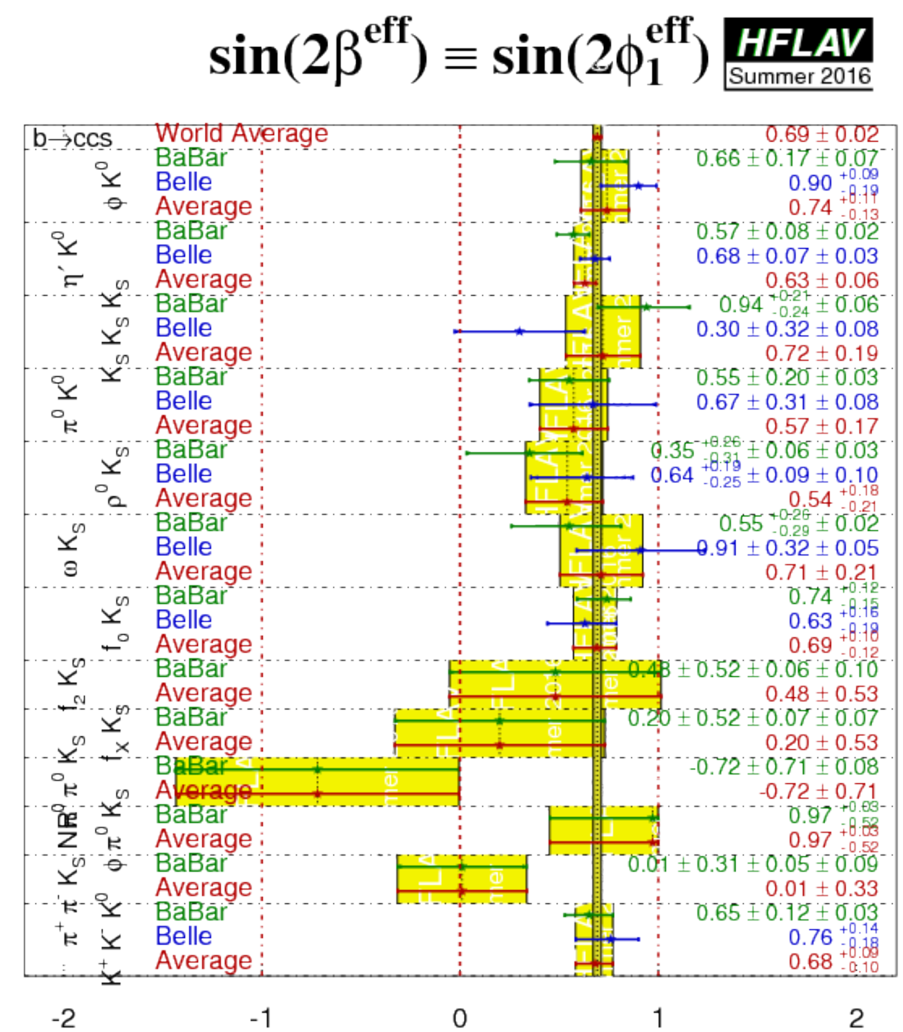


SM:
$|S_{b\to c} - S_{b\to s}| \simeq 0$

NP in loop:
$|S_{b\to c} - S_{b\to s}| > 0$



- Discrepancies with respect to J/ψ K^0 could provide evidence for NP



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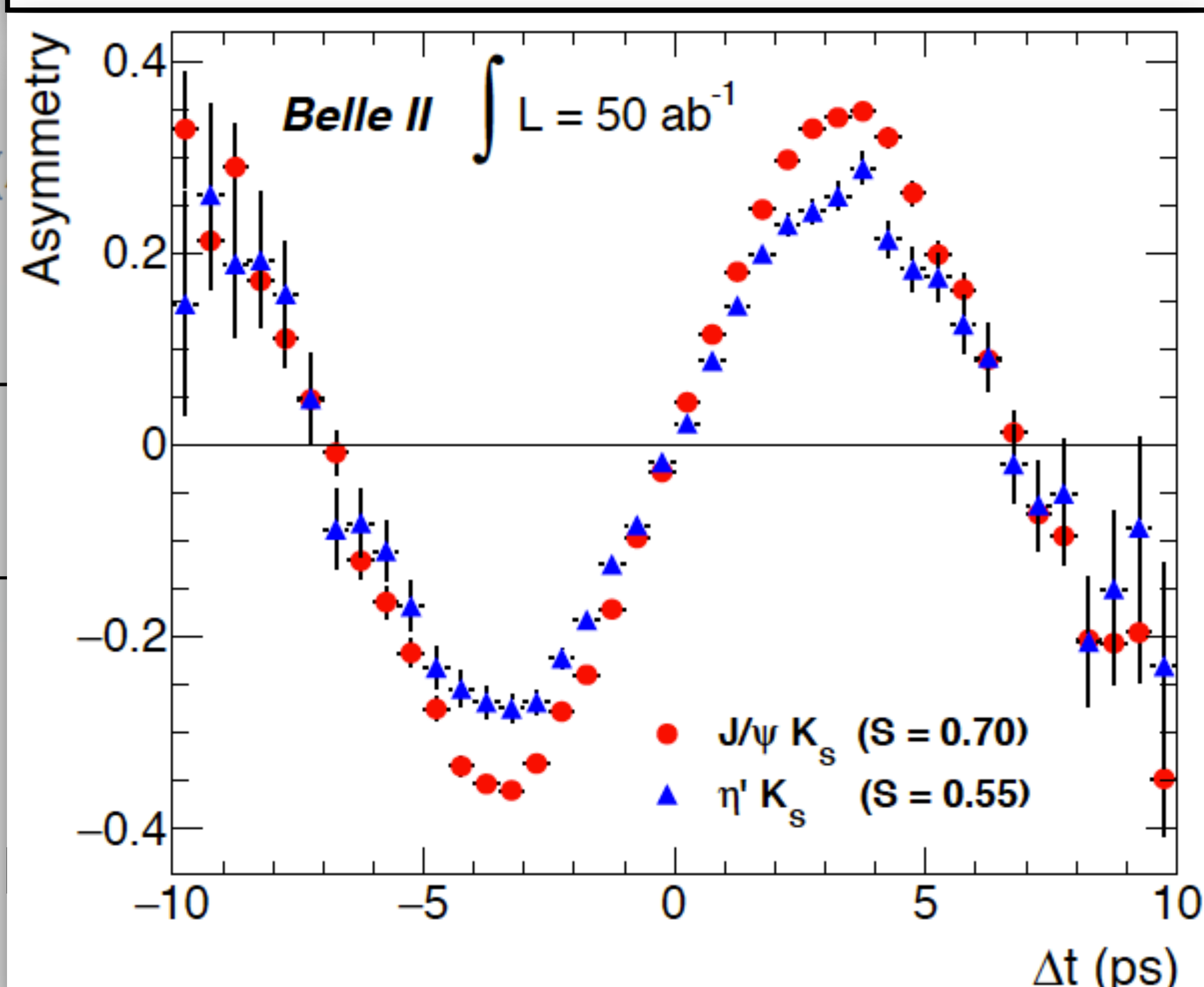
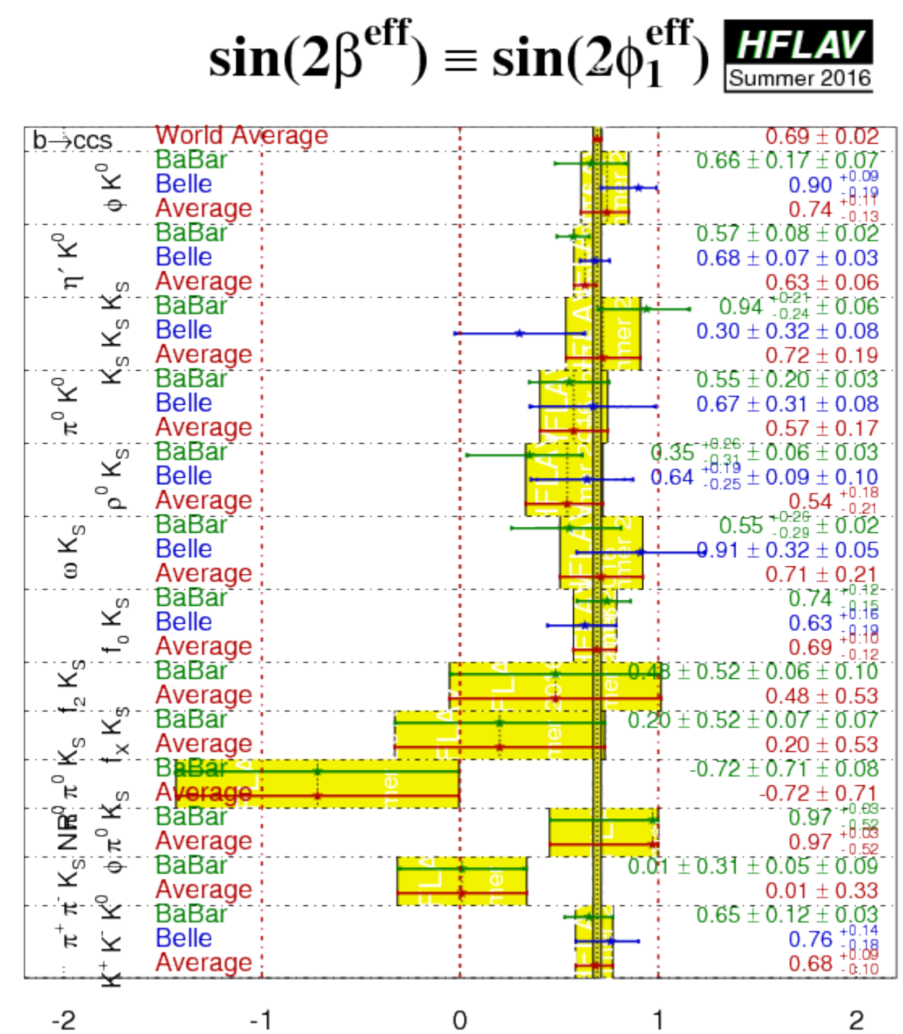
- ... ch as B → ϕK^0, $\eta' K^0$, $K^0K^0K^0$
- ... d

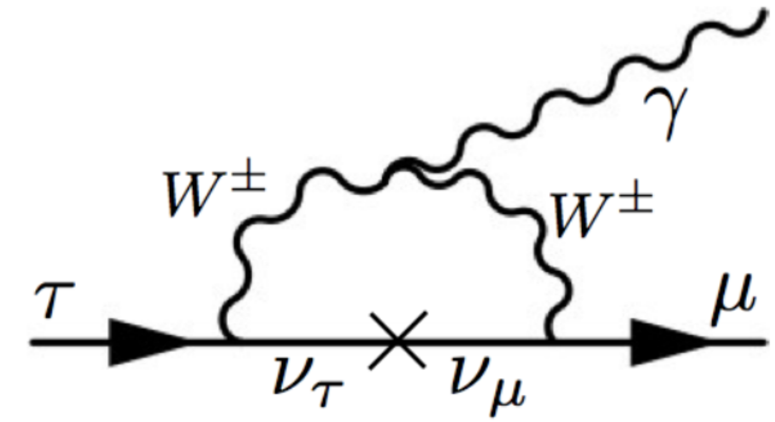
Unambiguous sign of New Physics, easily detectable at Belle II

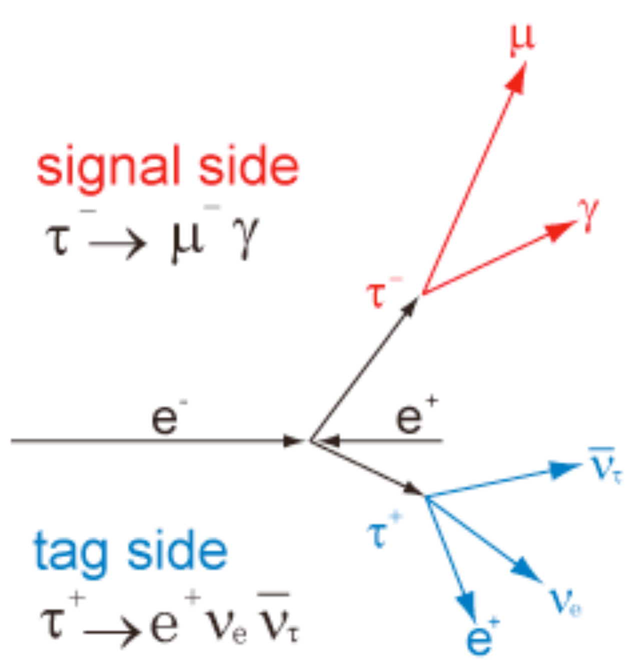


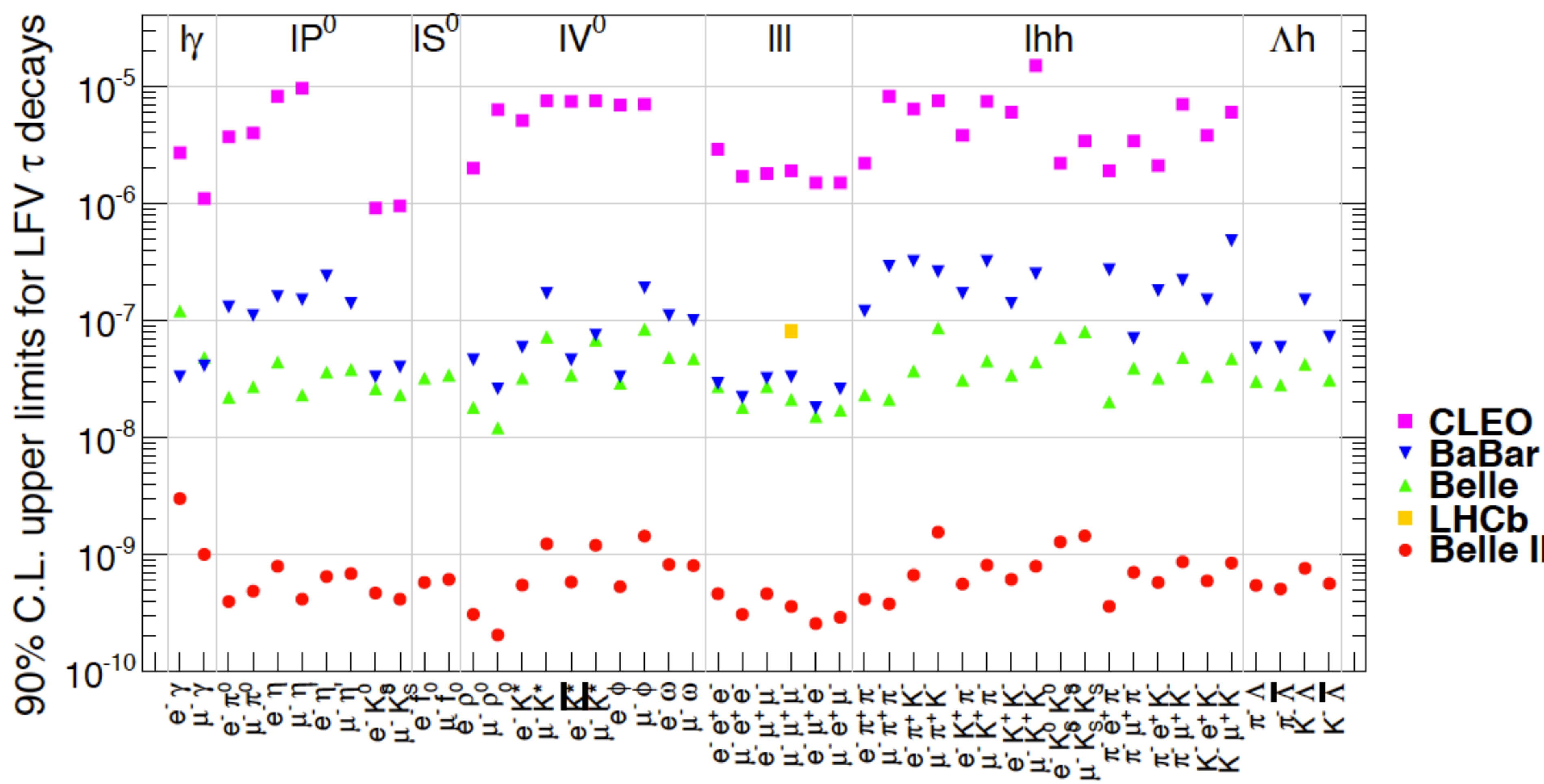


Lepton Flavor Violation

- Highly suppressed in the SM
  - BF on the order of 10^{-40} ($\tau \to \ell\gamma$) to 10^{-54} ($\tau \to \ell\ell\ell$)
- Clean probes for NP effects
- τ decays uniquely studied at B-factories
  - Hadron machines not competitive - trigger and track p_T limiting

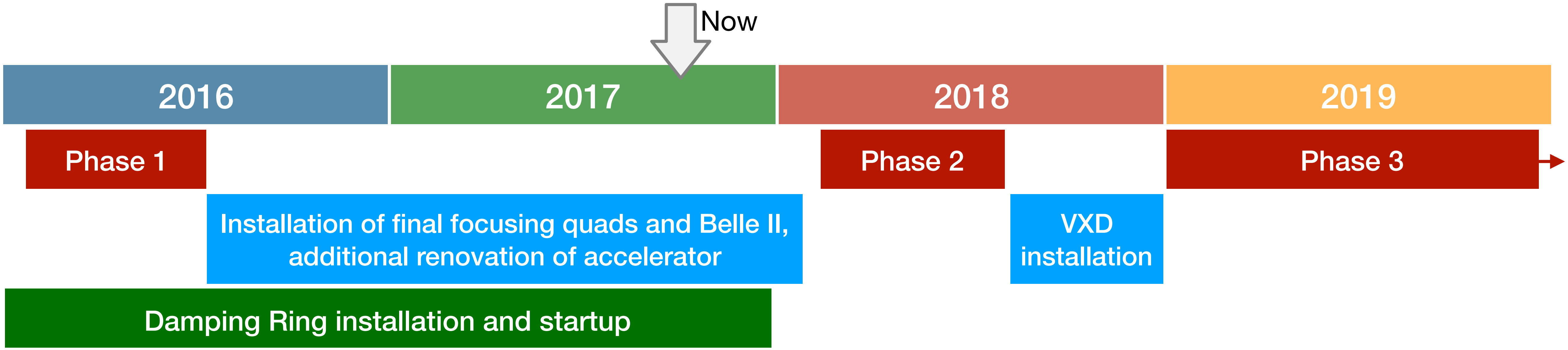






Belle II can access LFV decay rates more than an order of magnitude smaller than Belle!

SuperKEKB/Belle II schedule



SuperKEKB/Belle II schedule

Now

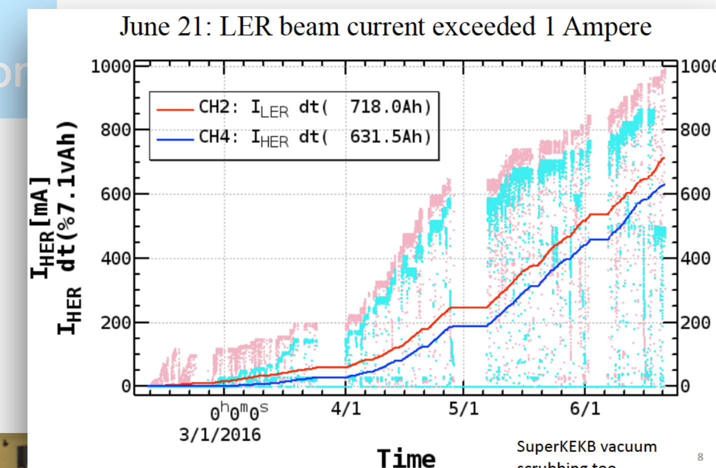
2016	2017	2018	2019

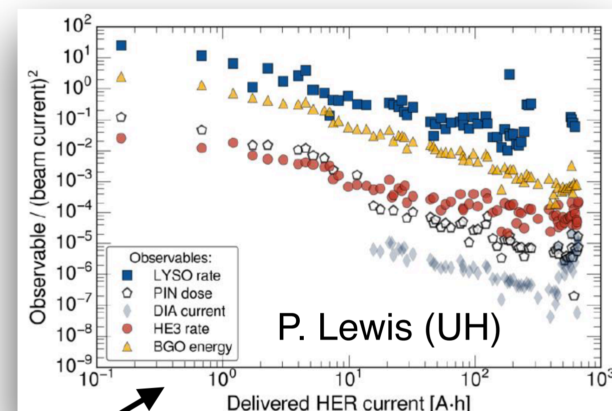
- Phase 1
- Phase 2
- Phase 3
- Installation of final focusing quads and Belle II, additional renovation of accelerator
- VXD installation
- Damping Ring installation and startup

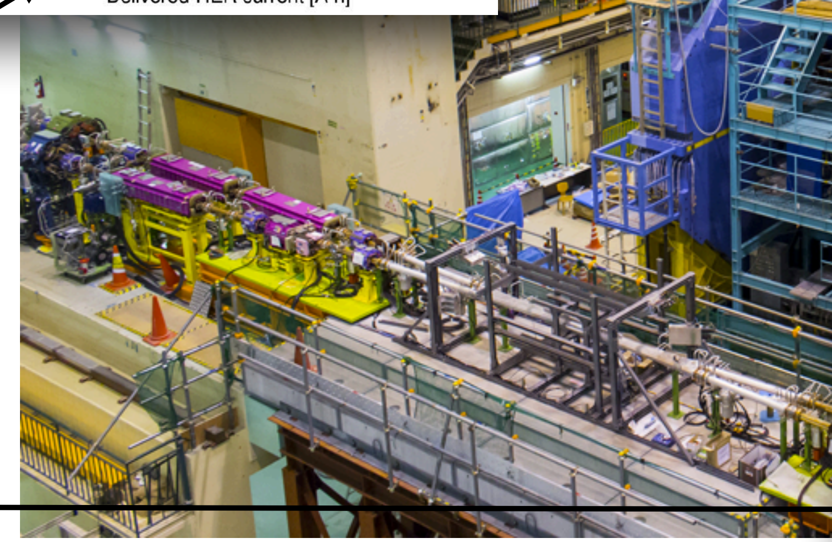
Beam Exorcism for A Stable Experiment
Dedicated background monitors

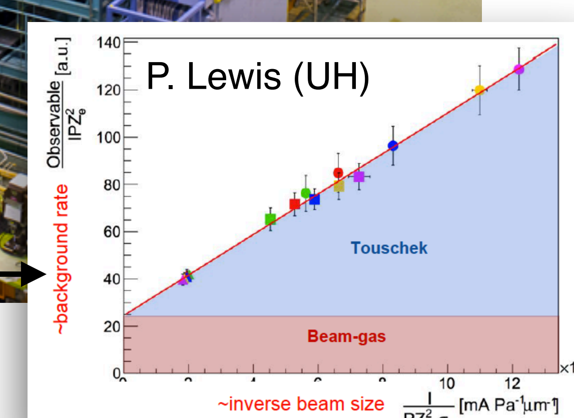
SuperKEKB Commissioning Detector
BEAST II 獣
Belle II Collaboration

- **“BEAST” Phase 1: Started in Feb 2016**
  - Simple background commissioning detector (diodes, TPCs, crystals). No final focus. Only single beam background studies possible
  - Tune accelerator optics, etc., vacuum scrubbing, beam studies, validation of Belle II beam background simulations









”First measurements of beam backgrounds at SuperKEKB", to be submitted to NIM-A in late 2017

SuperKEKB/Belle II schedule

Now

2016 | 2017 | 2018 | 2019

Phase 1

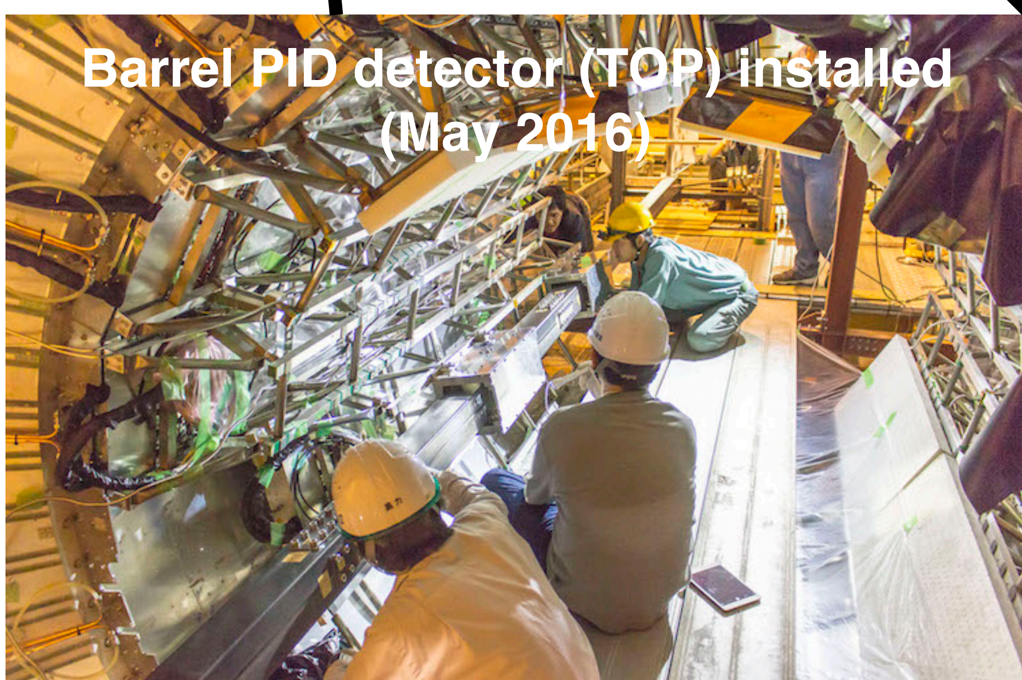
Phase 2

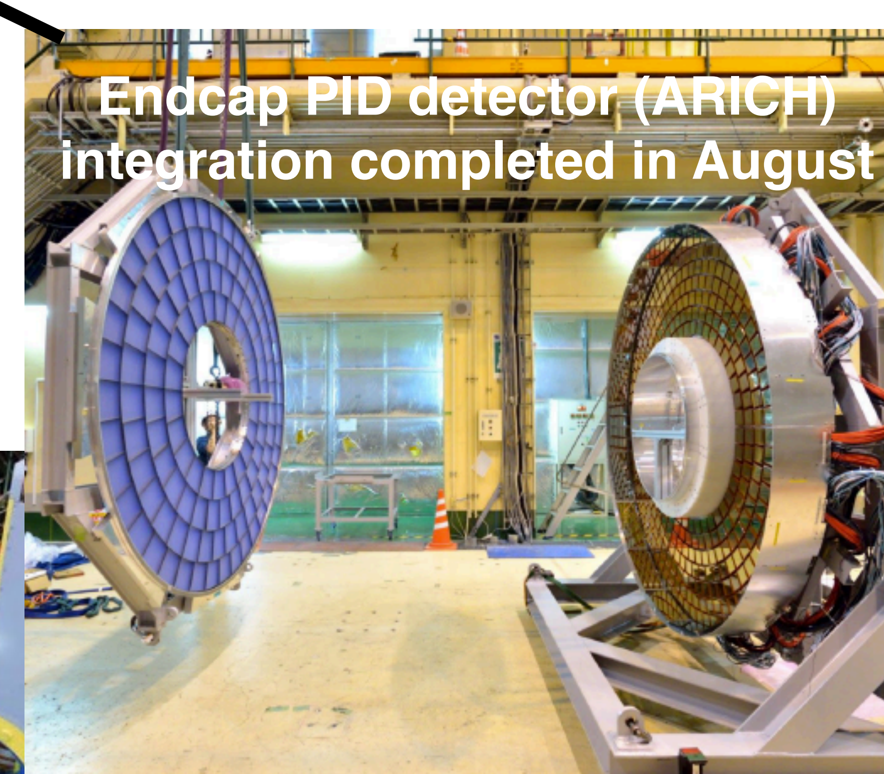
Phase 3

Installation of final focusing quads and Belle II, additional renovation of accelerator

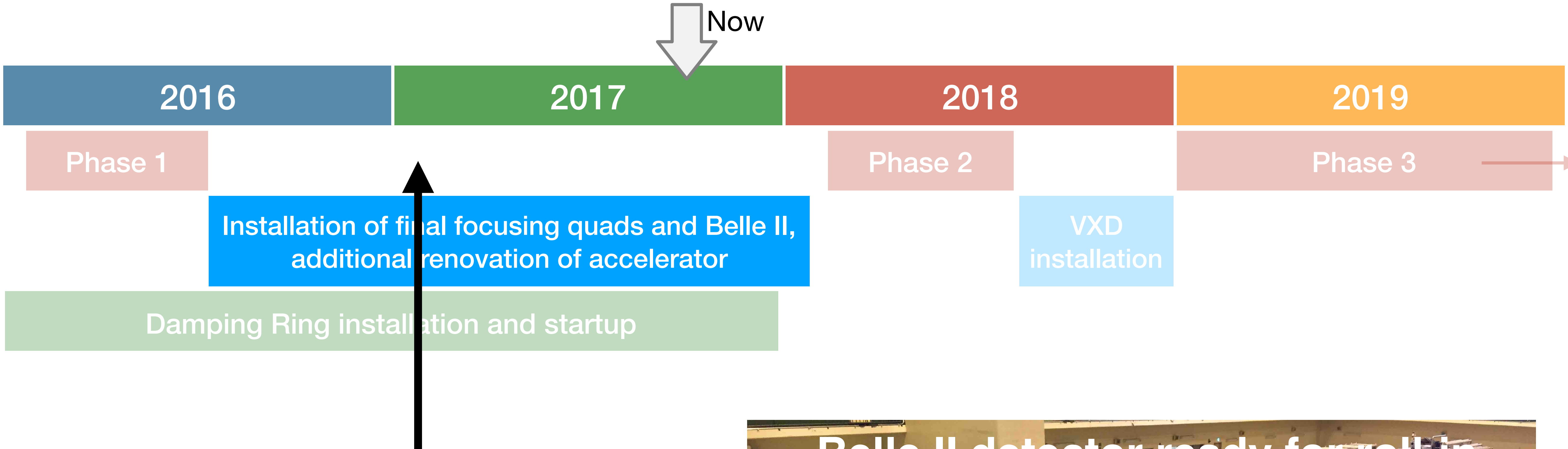
VXD installation

Damping Ring installation and startup



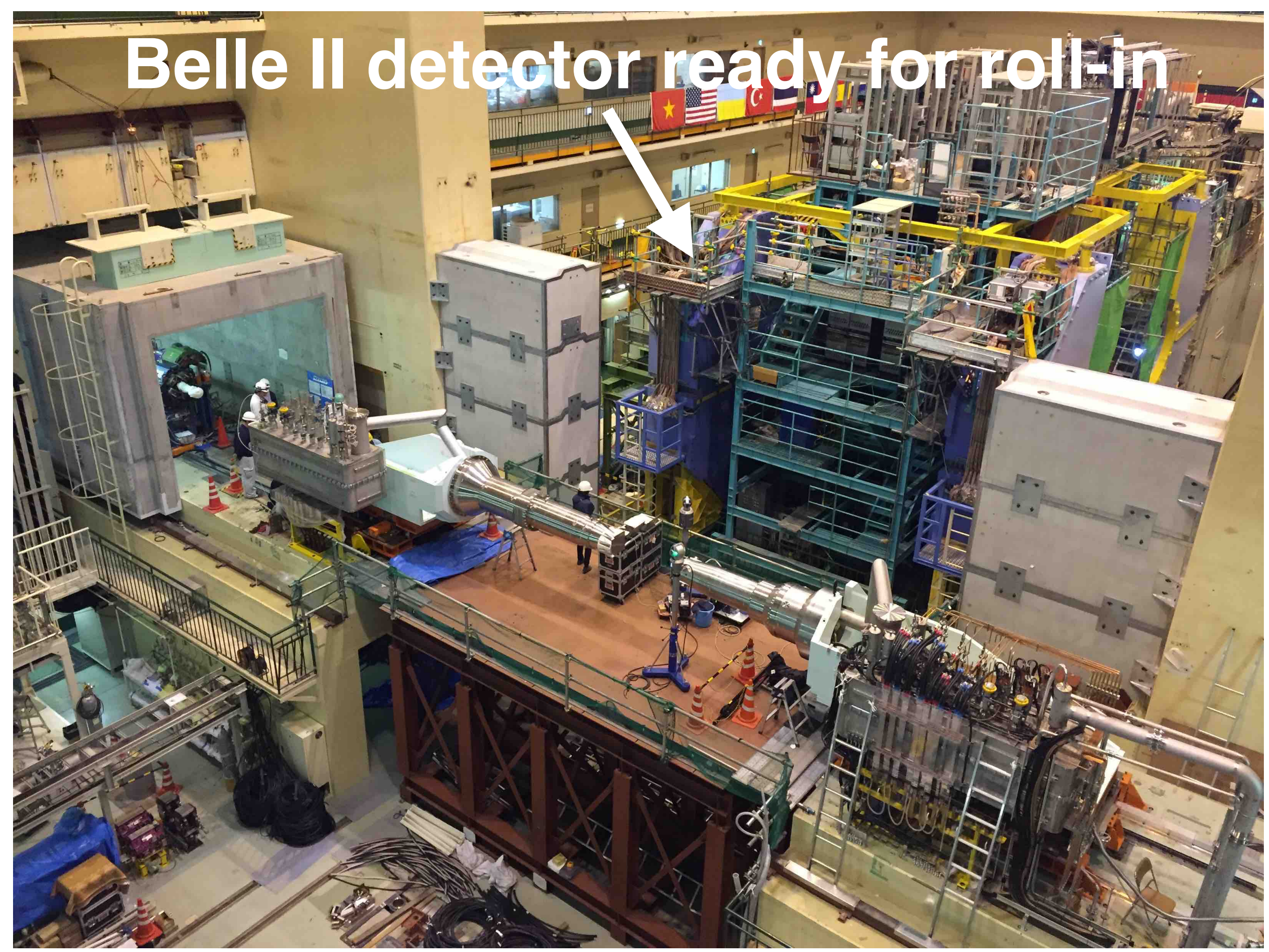


SuperKEKB/Belle II schedule



QCSL cooled and excited in Dec. 2016 for the first time

QCSR delivered on Feb. 13, 2017



SuperKEKB/Belle II schedule

Now

2016 | 2017 | 2018 | 2019

Phase 1

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Phase 3

Installation of final focusing quads and Belle II, additional renovation of accelerator

VXD installation

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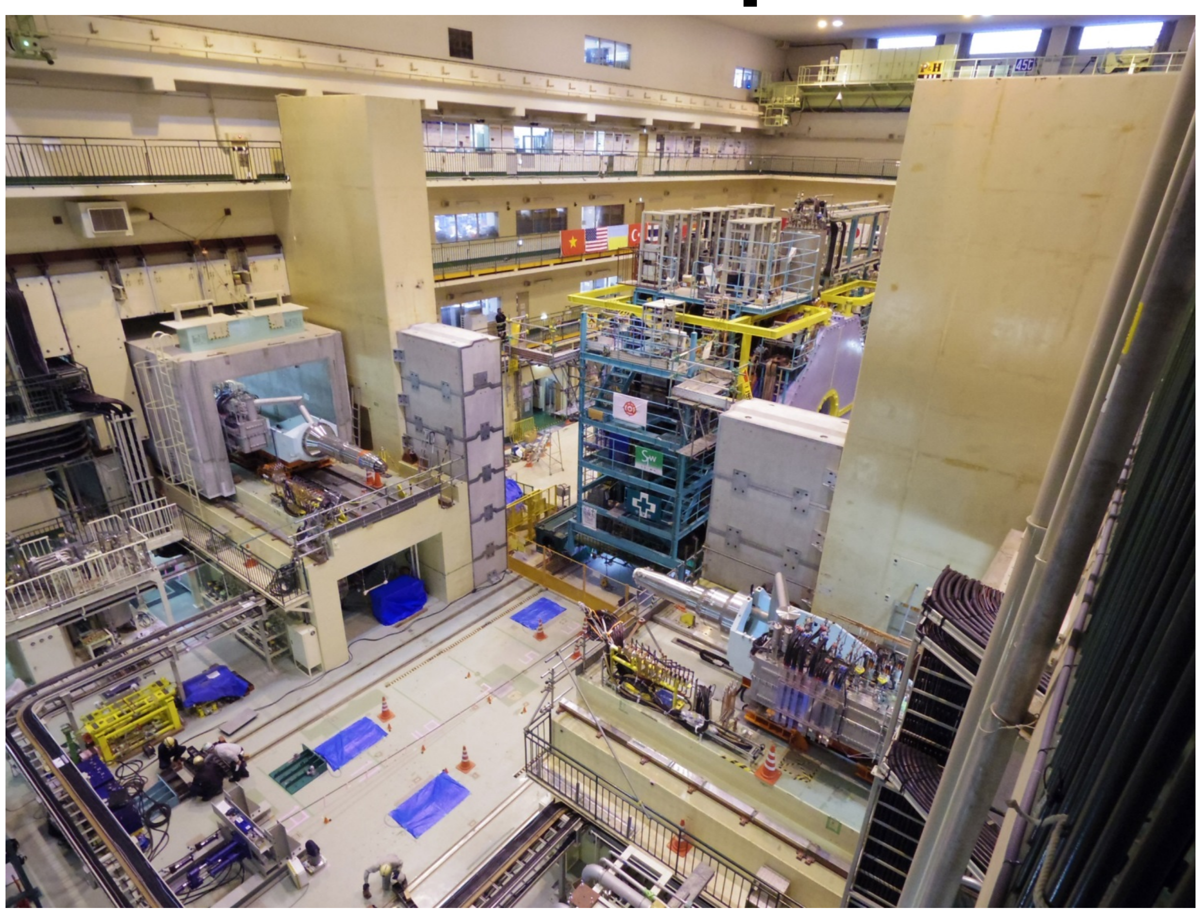
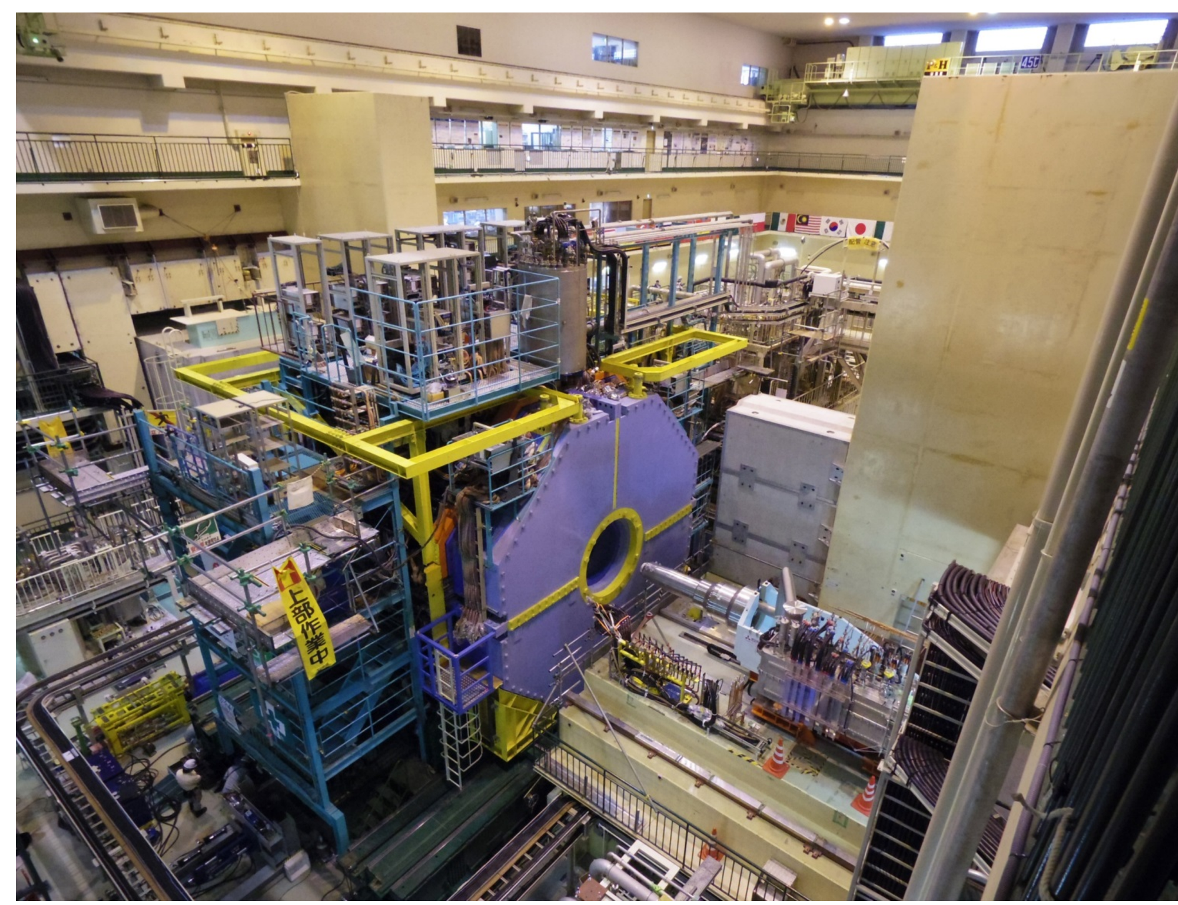
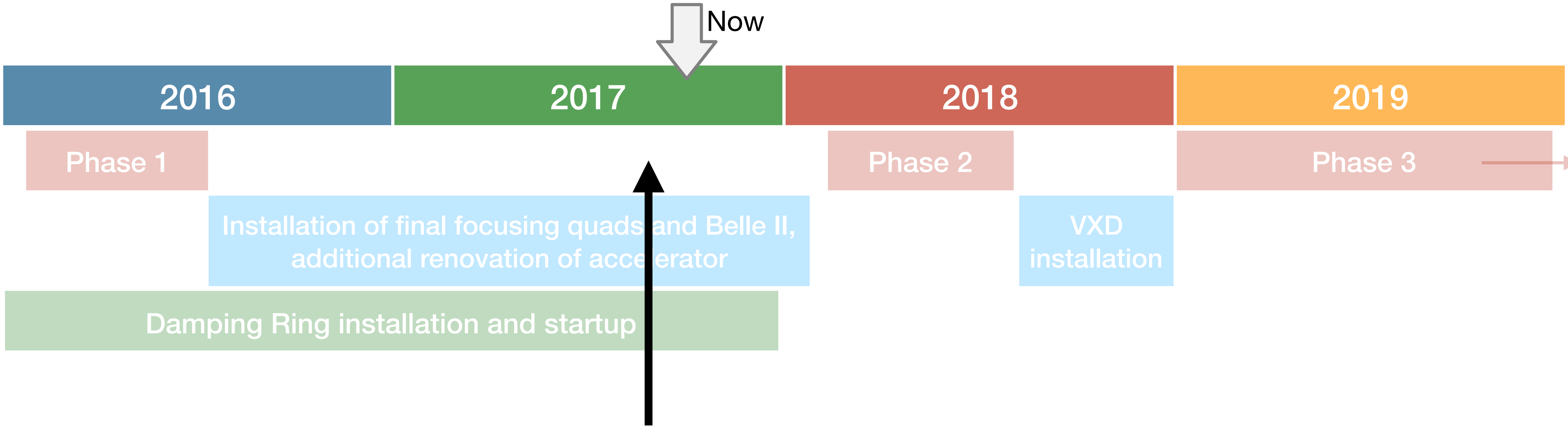
Belle II “roll-in” April 11, 2017



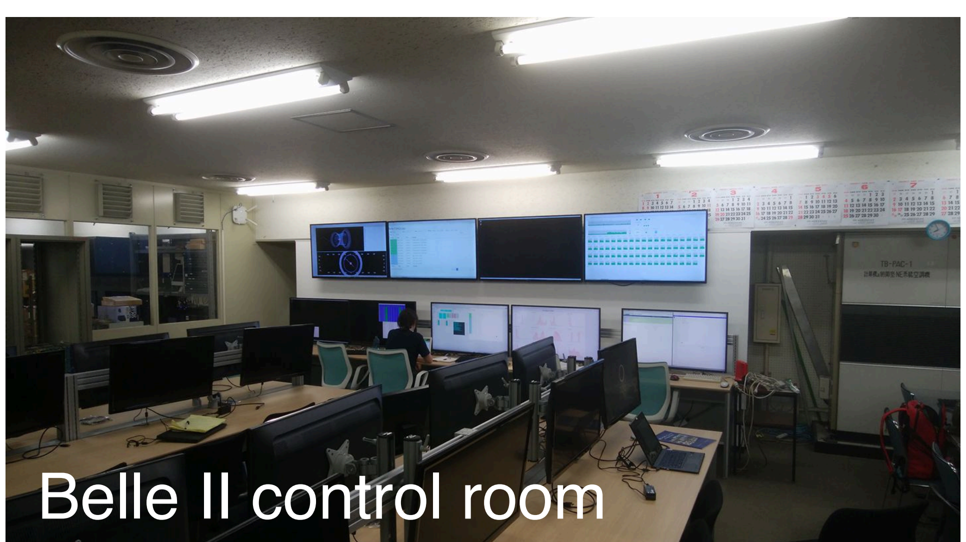


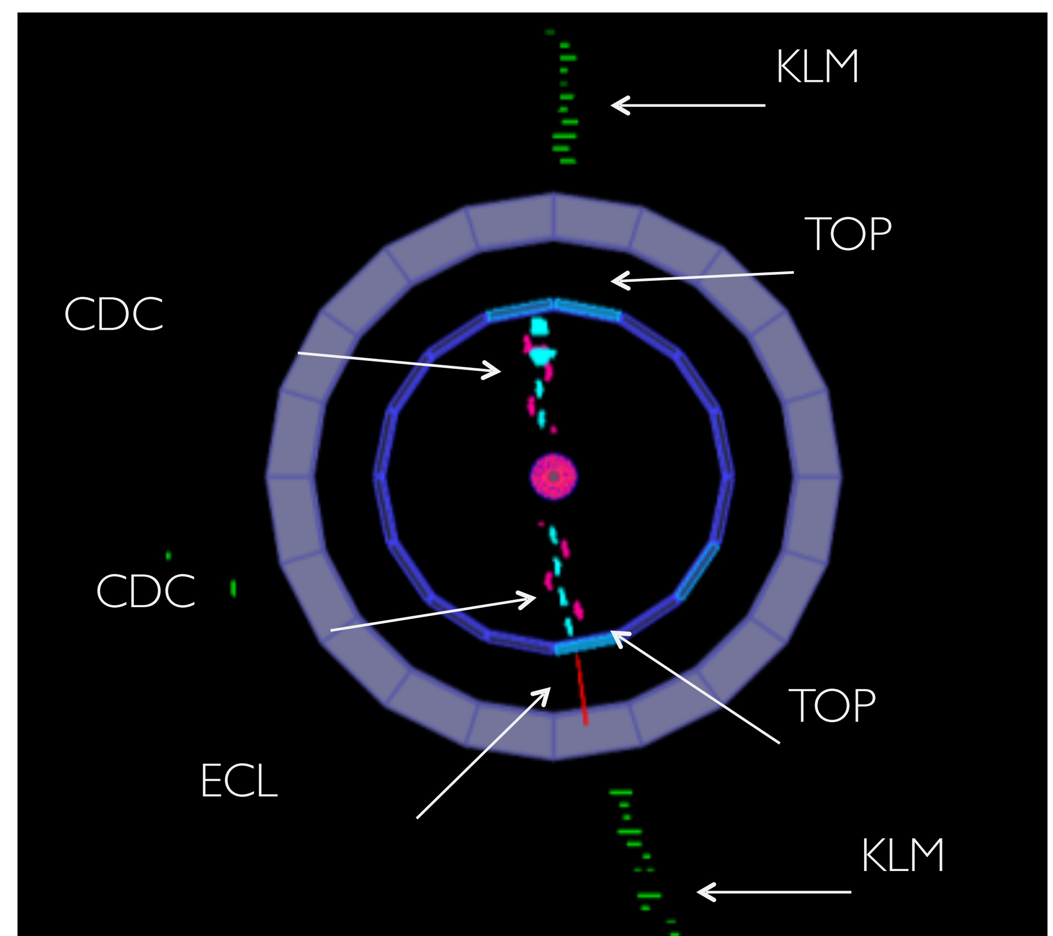
Belle II roll in: 1400 tons, 8m x 8m, moved 13m horizontally

SuperKEKB/Belle II schedule



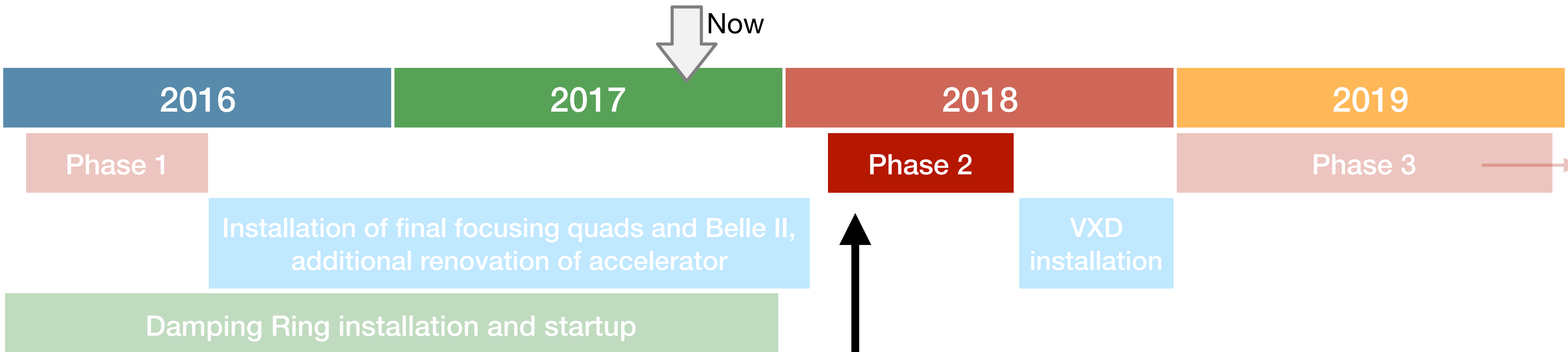
- **Belle II global cosmic run (July - August 2017)**
  - Final 1.5T solenoid field
  - Readout integration of installed sub-detectors and central DAQ in progress

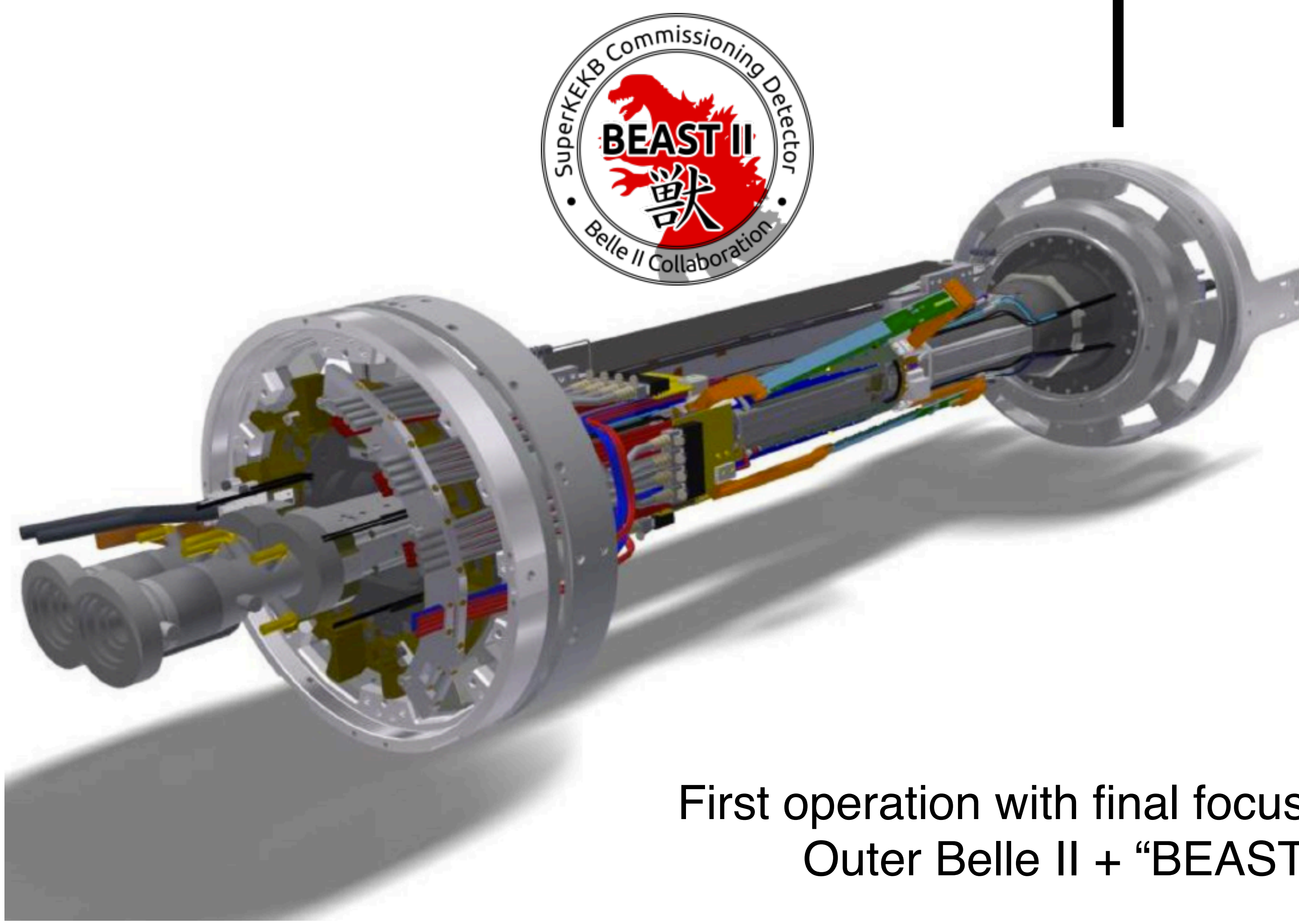




Hits in four outer subdetectors

SuperKEKB/Belle II schedule





SuperKEKB phase 2 commissioning:

- Dec. 2017 - Damping Ring
- Feb. 2018 - Main Ring

Phase 2 goals

- Verification of nanobeams (luminosity > 10^{34} $cm^{-2}s^{-1}$)
- Beam background study, especially in VXD volume
- First physics!

First operation with final focus (collisions!)
Outer Belle II + “BEAST-VXD”

SuperKEKB/Belle II schedule

Now

2016	2017	2018	2019

Phase 1 — Phase 2 — Phase 3 →

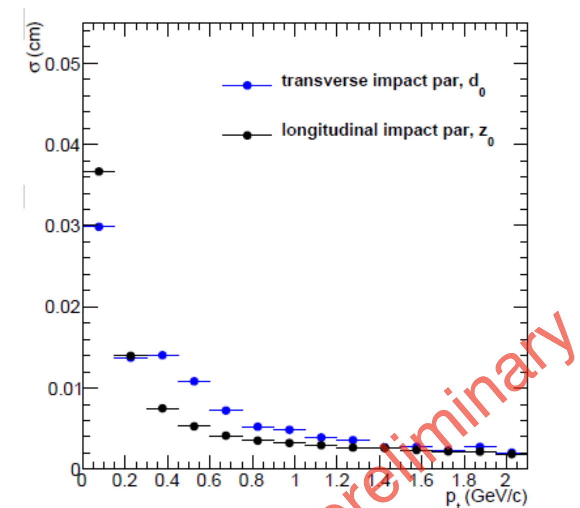
Installation of final focusing quads and Belle II, additional renovation of accelerator

VXD installation

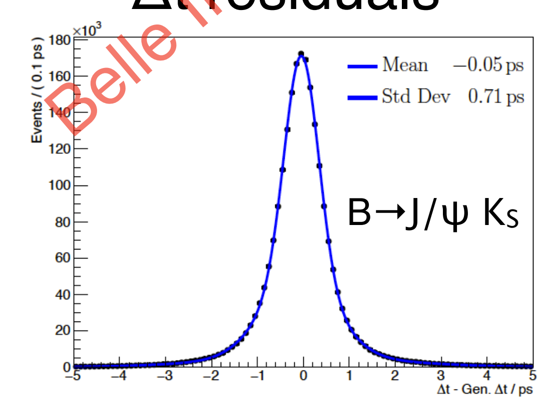
Damping Ring installation and startup

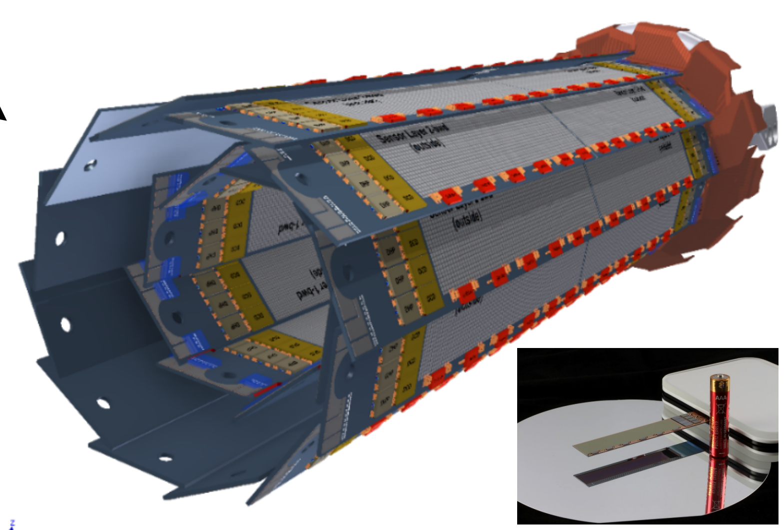
- Vertex detector (VXD)
  - Pixel Detector (PXD): 2 layers of DEPFET pixels
  - Silicon Vertex Detector (SVD): 4 layers of double-sided silicon detectors
- Increased VXD radius: significant improvement expected with respect to Belle in vertex resolution

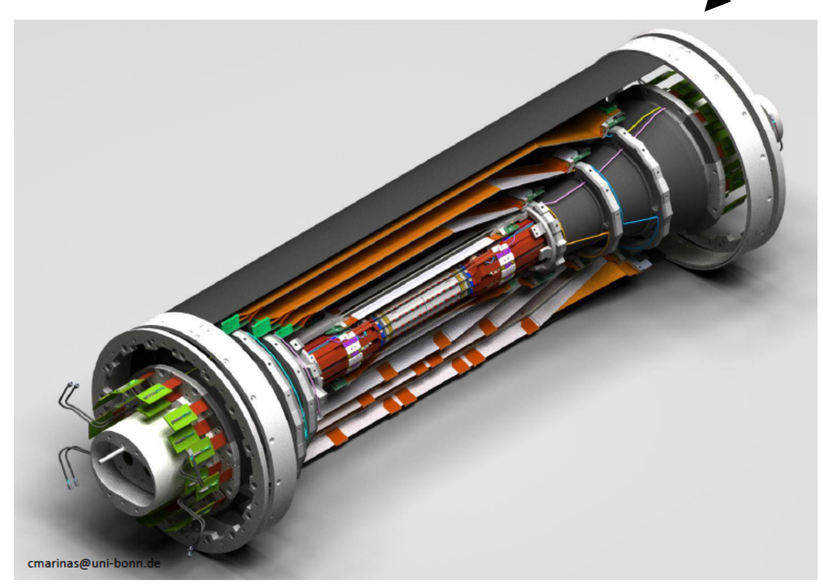
IP resolution



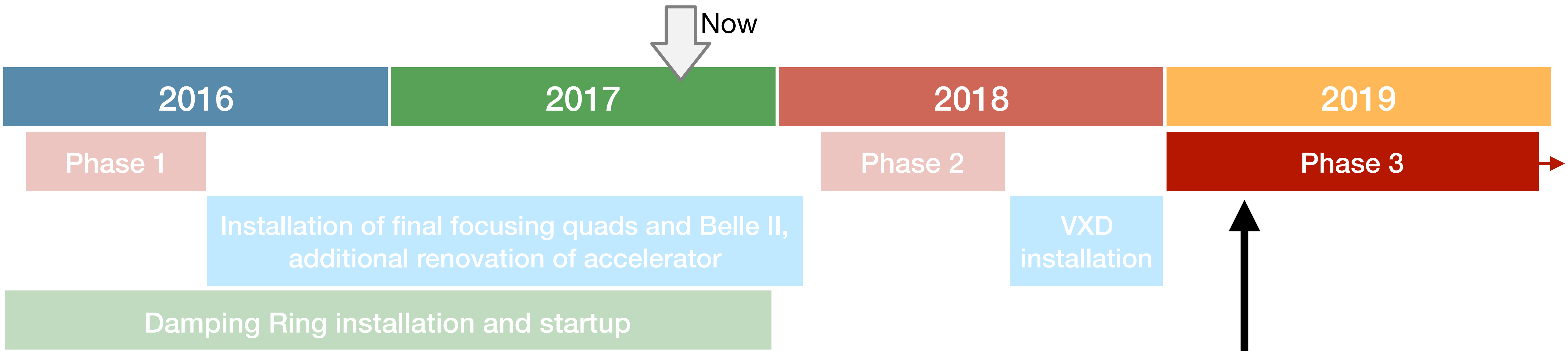
Δt residuals

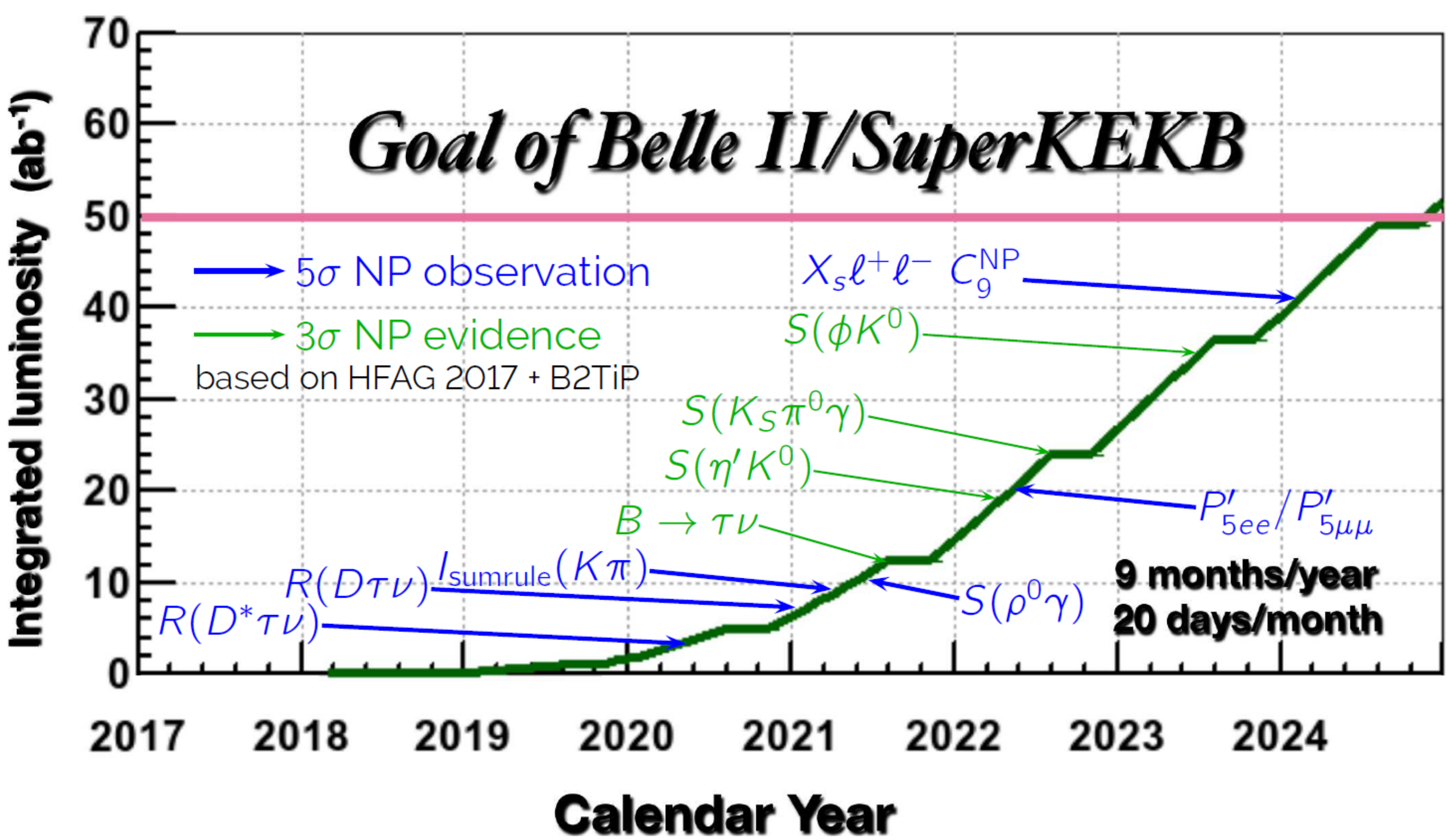






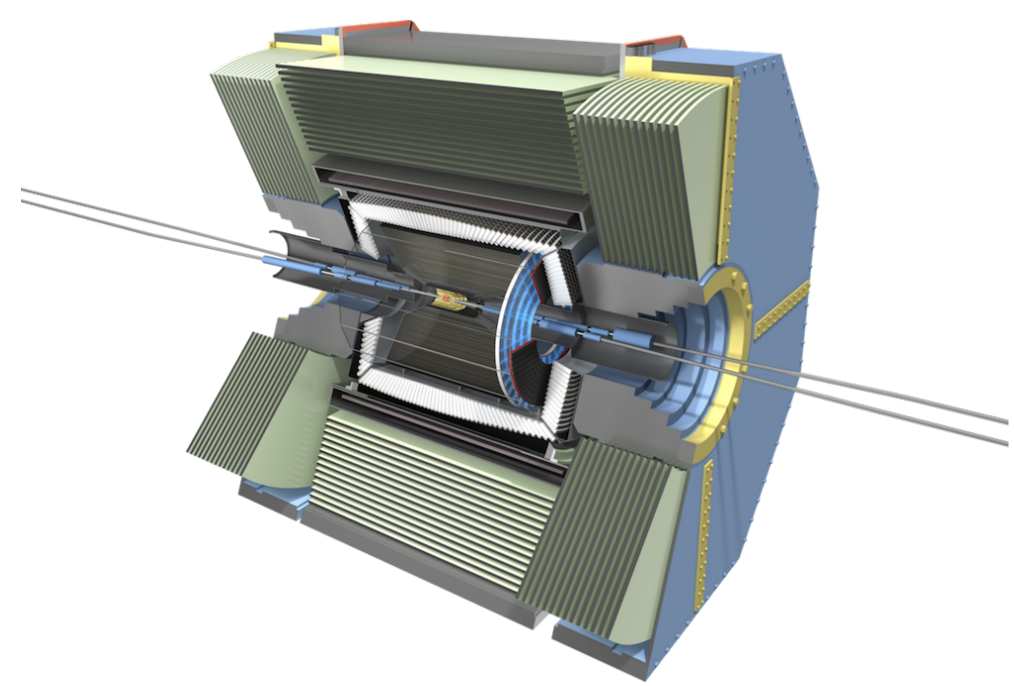
SuperKEKB/Belle II schedule





Complete Belle II detector

Goal: 50 ab^{-1}

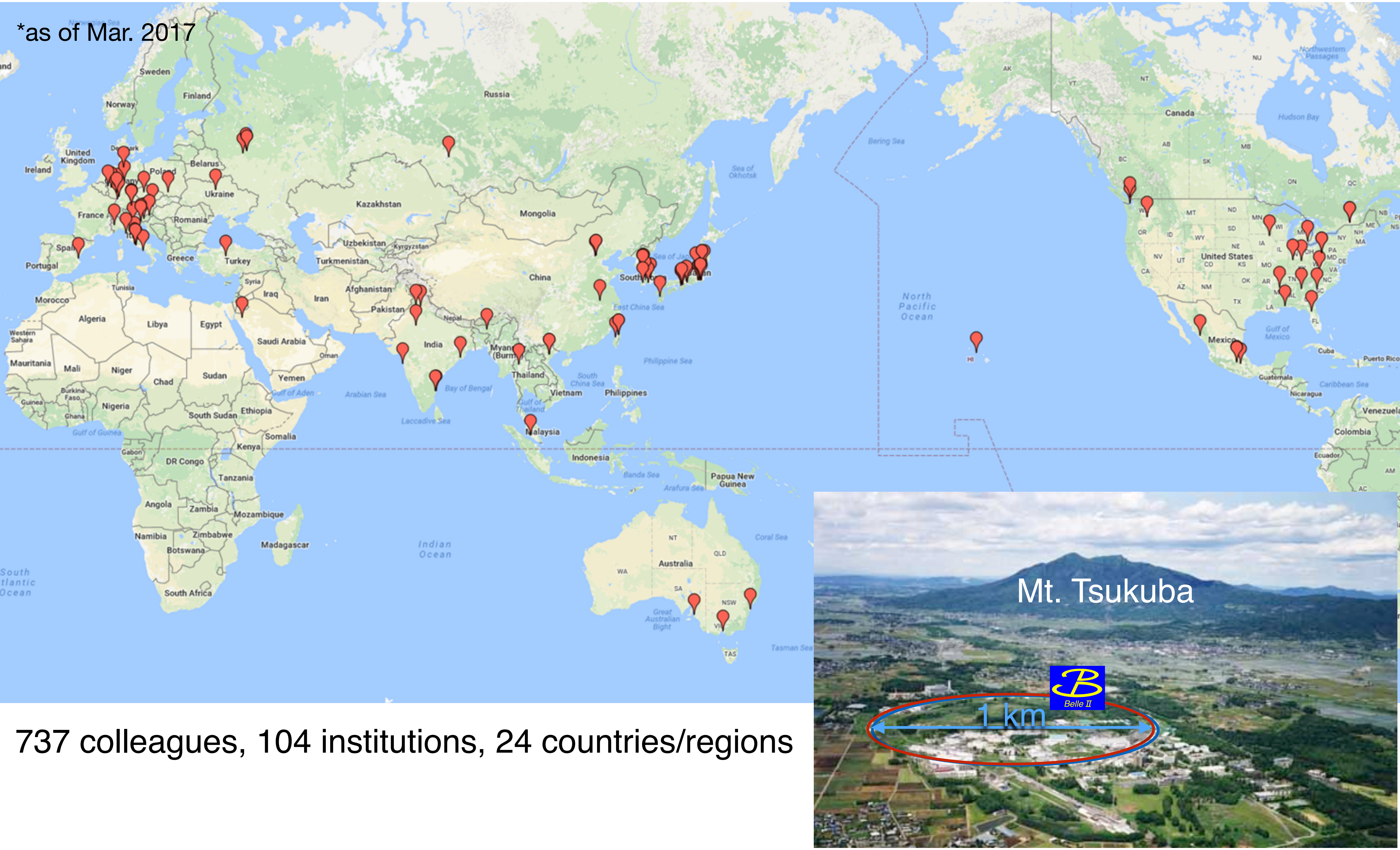


Summary

- Major upgrade at KEK for the next generation B-factory
  - Many detector components and electronics replaced, software and analysis tools also improved!
- Belle II has a rich physics program, complementary to existing experiments and energy frontier program
- Successful phase 1 operation in 2016
- Cosmic data taking with central DAQ in 2017
- First physics without vertex detectors in early 2018
- Full detector operation in late 2018/early 2019

Extra slides

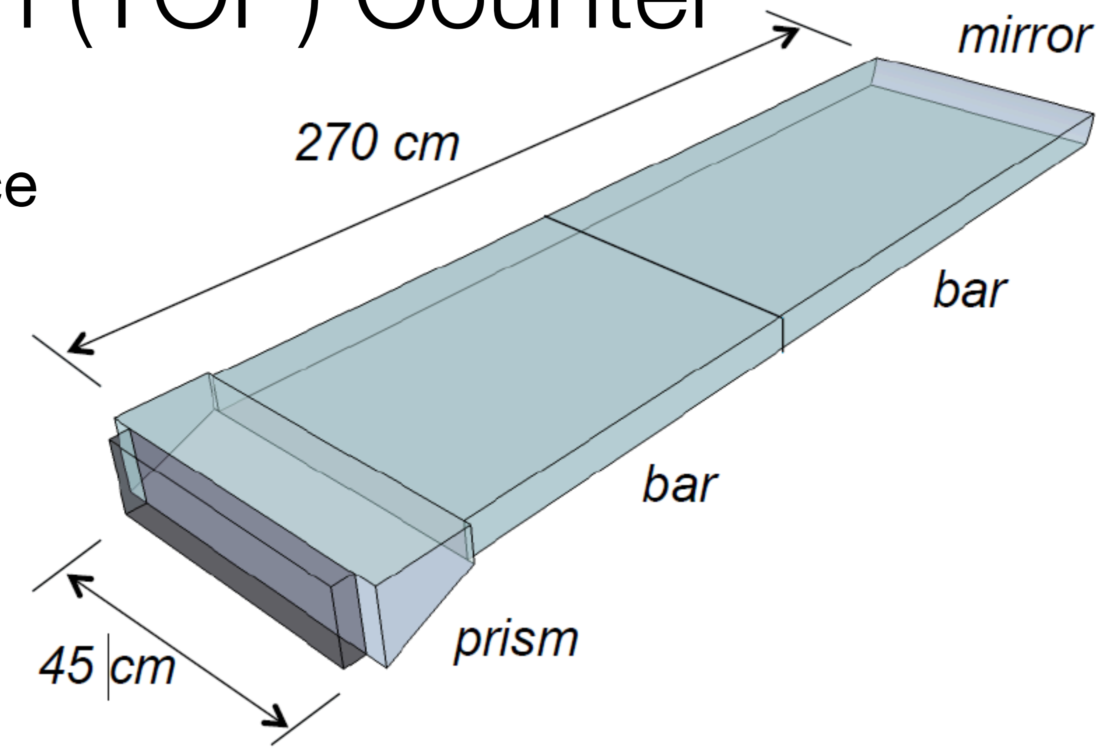
The Belle II Collaboration

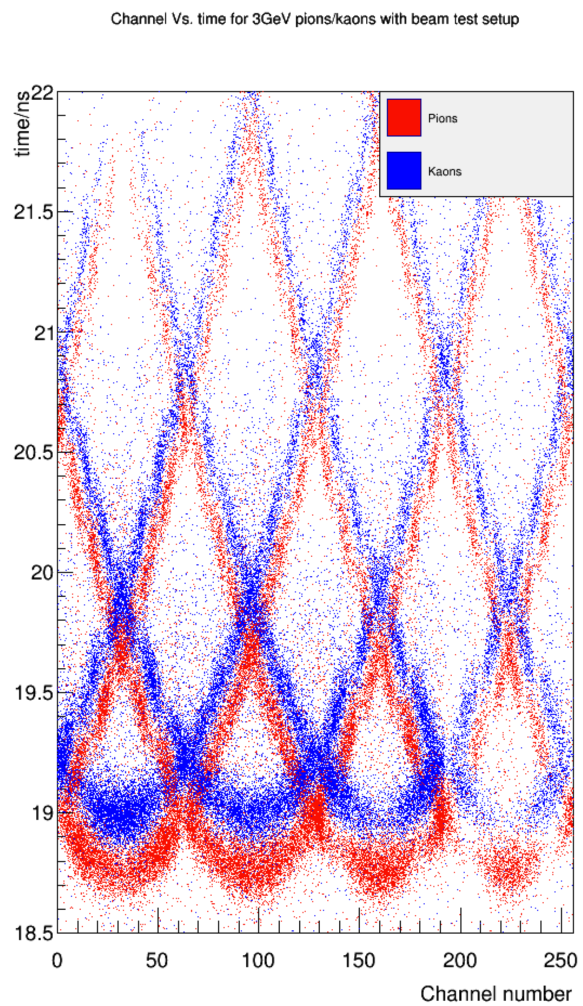


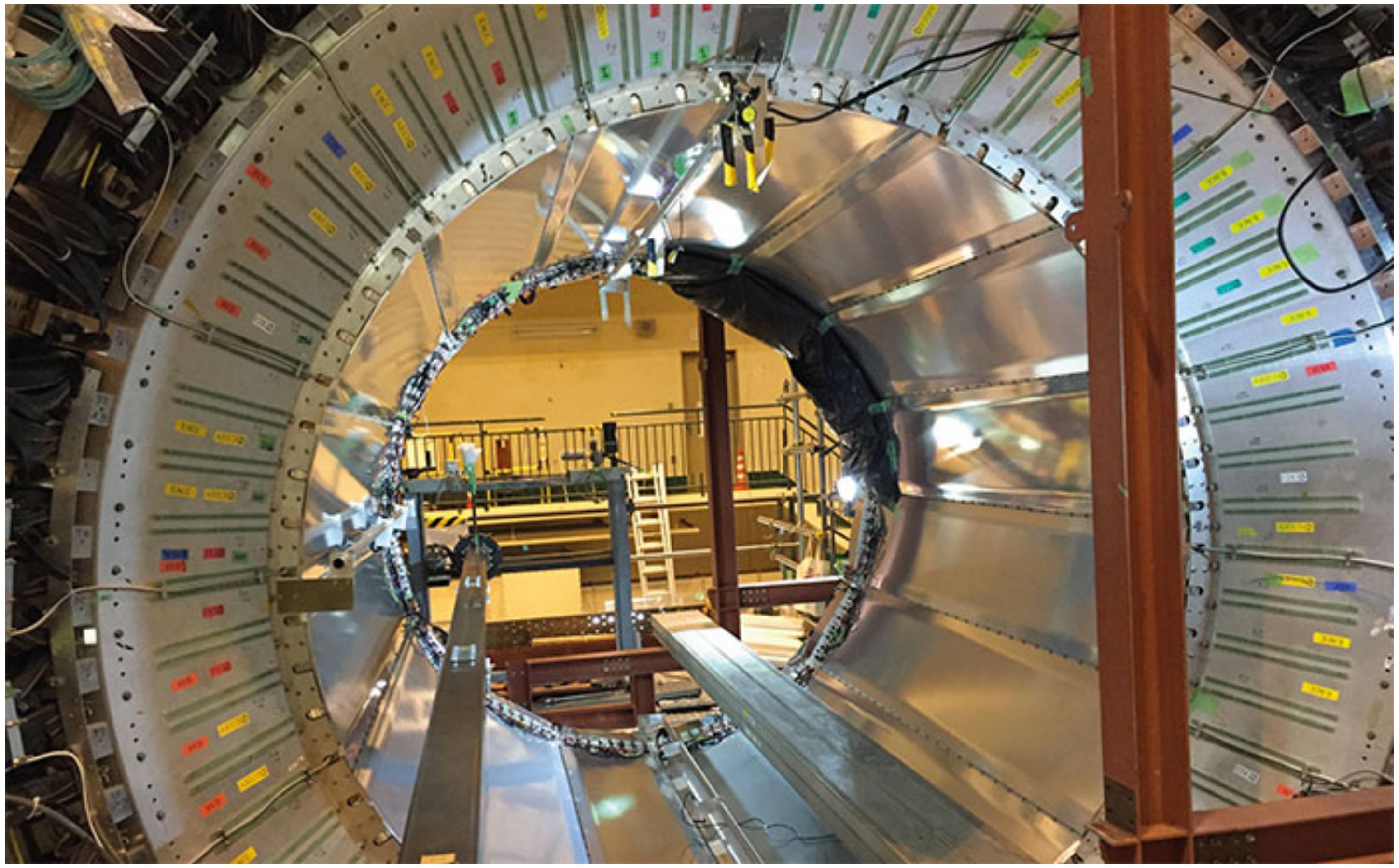
737 colleagues, 104 institutions, 24 countries/regions

Imaging Time-Of-Propagation (TOP) Counter

- Barrel ring-imaging Cherenkov (RICH) device
  - Total internal reflection of Cherenkov photons emitted in the quartz radiator
  - Fast, position-sensitive detector of single photons



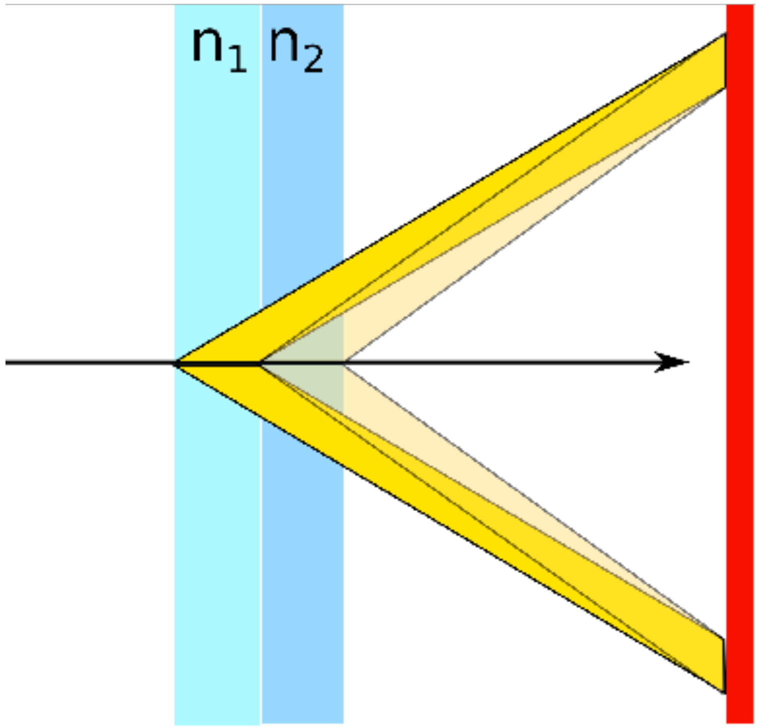


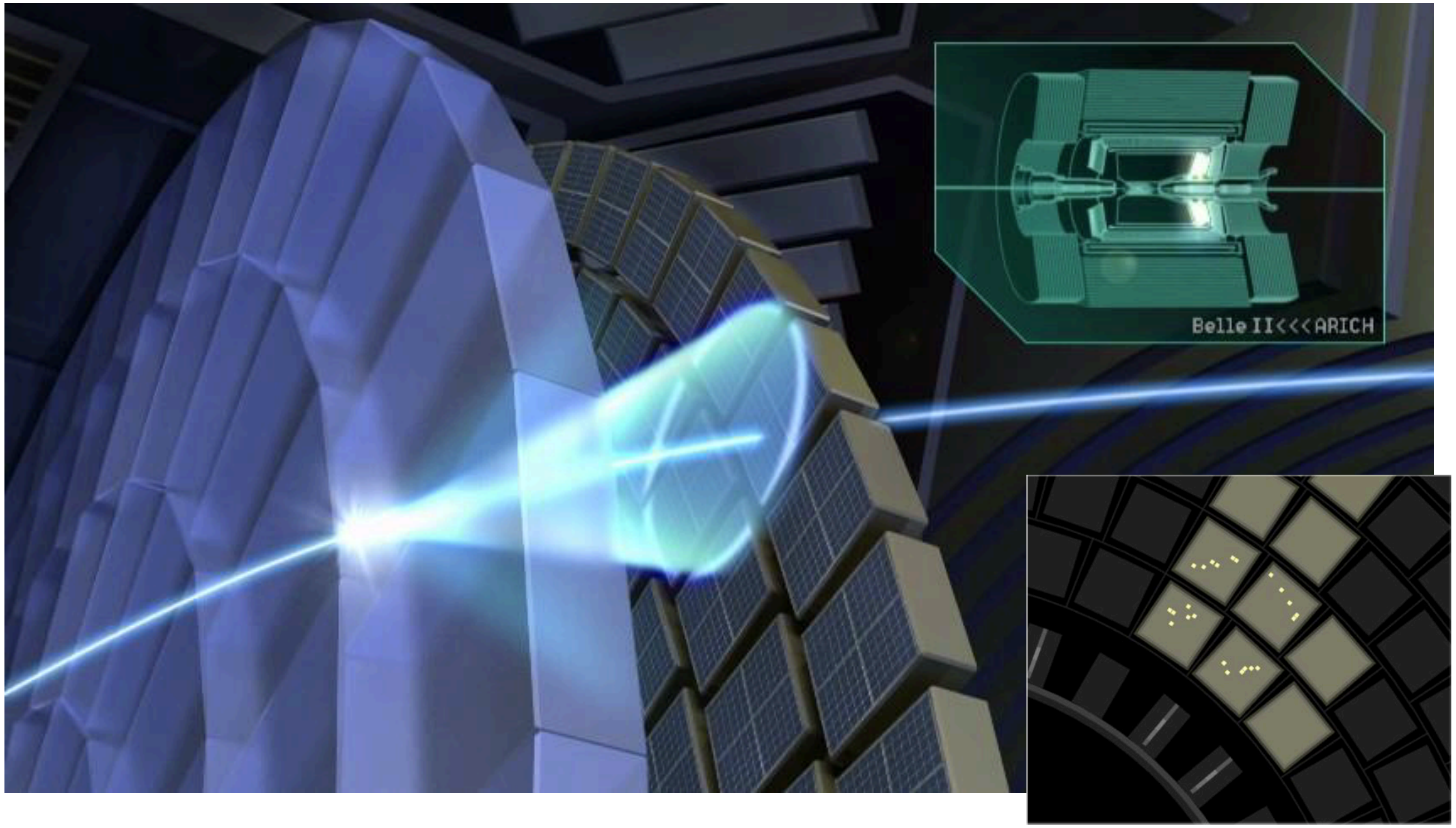


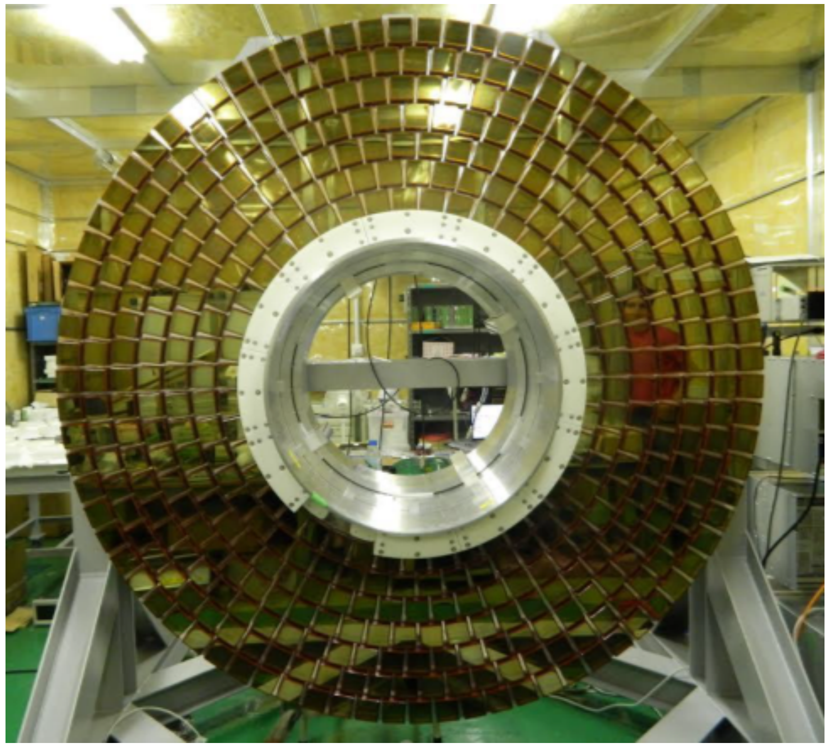
NIM A494 (2002) 430-435; NIM A595 (2008) 96-99

Aerogel RICH detector

- End-cap RICH device
  - Aerogel tiles are used as a radiator
  - Photons propagate through an expansion volume before detection with HAPD photodetectors

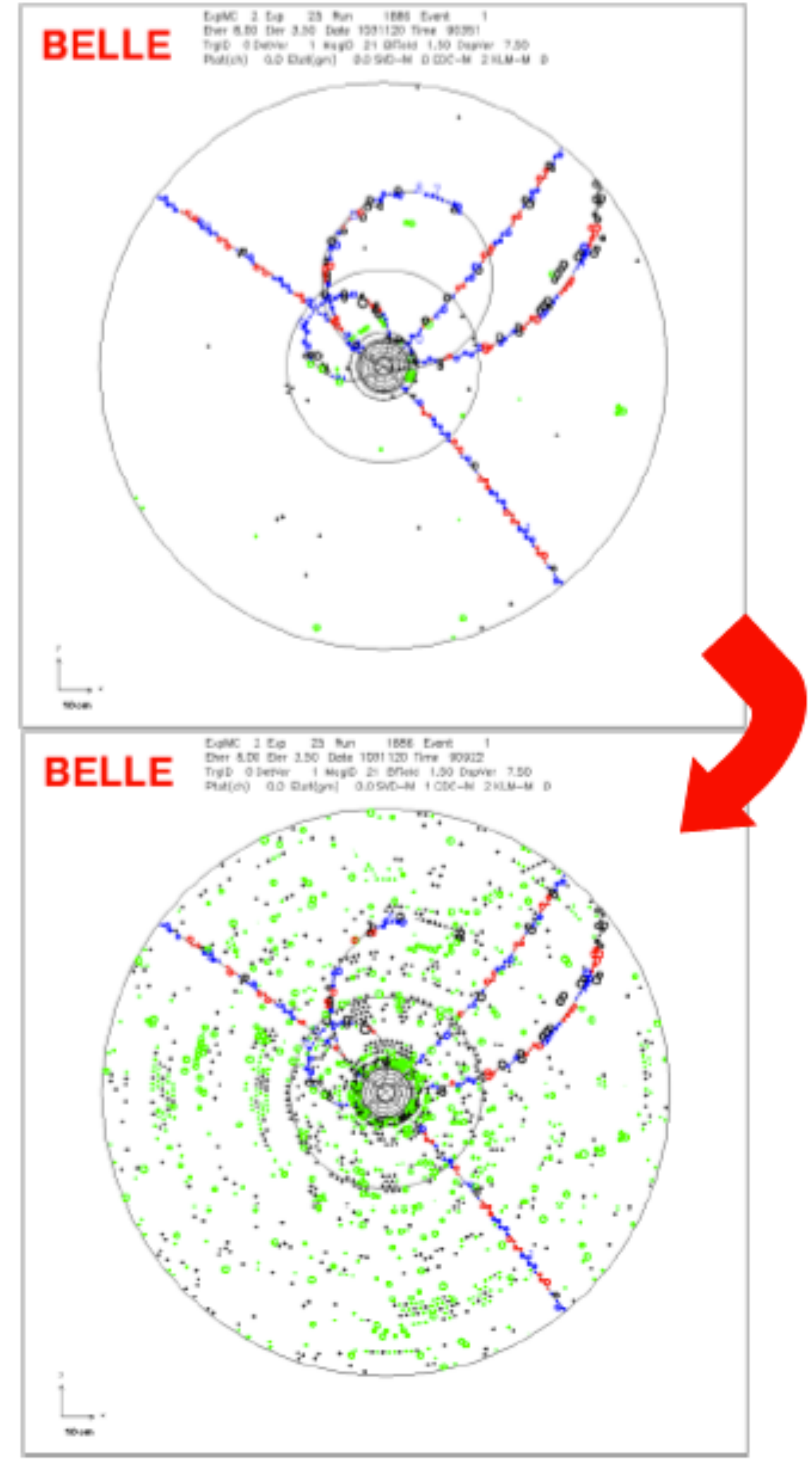






Beam backgrounds

- In Belle/KEKB, unexpected backgrounds burned a hole in the beam pipe and damaged the inner detectors
- Especially dangerous at SuperKEKB (10-20x higher background rate)
  - Temporary damage or faults in electronics
  - Obscure physics processes
  - Fake interesting physics signals
  - Rejecting fake signals also lowers efficiency
- Purpose of BEAST: **B**eam **E**xorcism for **A St**able Belle II Experiment



Phase 1 (no collisions)

***Touschek* scattering:**
- intra-bunch scattering process
- dominant with highly compressed beams
- 20 times higher

Beam-gas scattering:
- Bremsstrahlung (negligible) & Coulomb interactions (up to 100 times higher) with residual gas atoms & molecules

Synchrotron radiation:
- emission of photons by charged particles (e^+e^-) when deflected in *B*-field

Phase 2 (collisions)

***Radiative Bhabha* process:**
- photon emission prior or after *Bhabha* scattering
- interaction with iron in the magnets leads to neutron background

***Two photon* process:**
- very low momentum e^+e^- pairs via $e^+e^- \rightarrow e^+e^-e^+e^-$
- increased hit occupancy in inner detectors

Injection Background:

Belle II physics goals

- Rich physics program
  - Precision CKM,
    new sources of CPV,
    Lepton Flavor Violation,
    Dark Sectors,
    QCD exotics
- Competitive and complementary to LHCb physics program
  - Belle II strong in missing energy modes, time dependent CPV, very strong in CKM metrology

Expected uncertainties on several selected flavor observables with an integrated luminosity of 5 ab^{-1} and 50 ab^{-1} of Belle II data

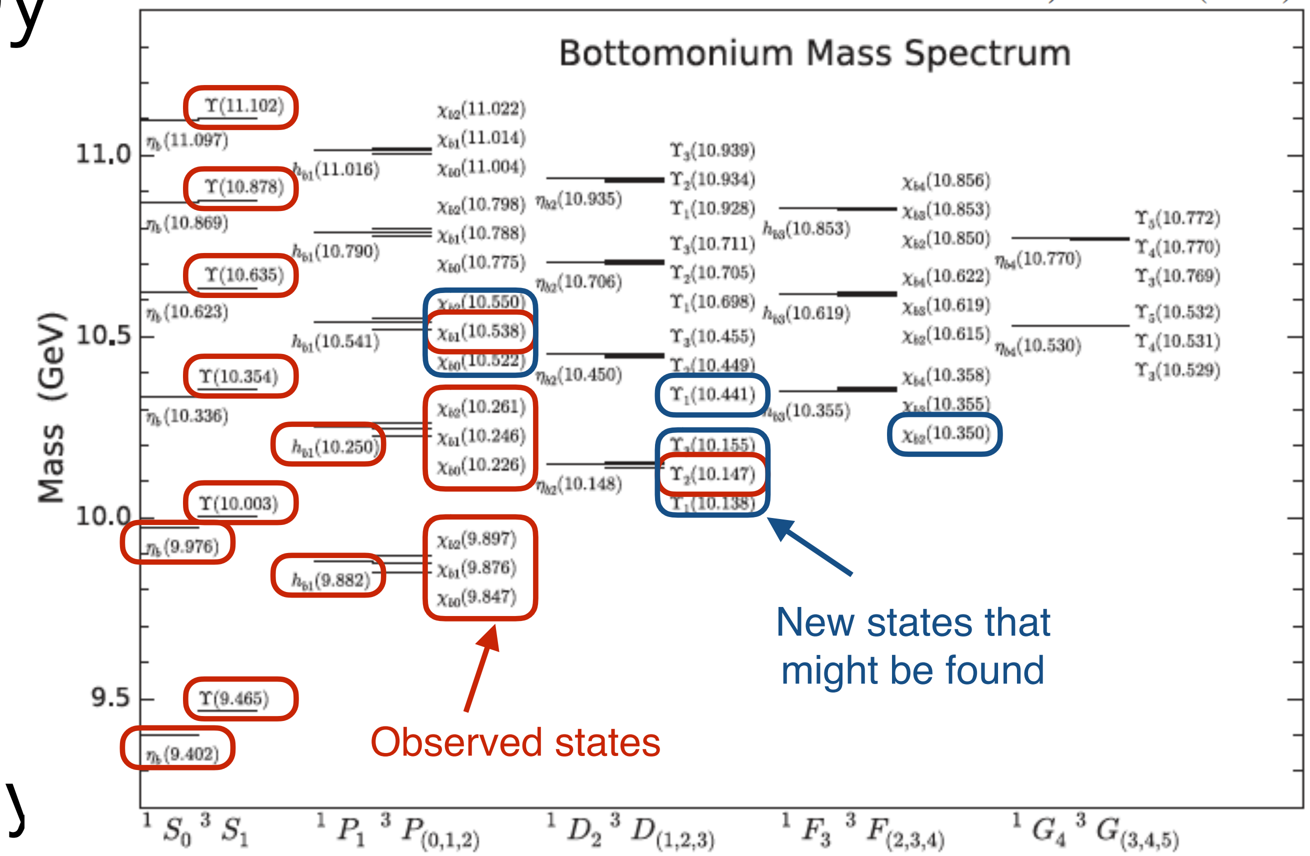
	Observables	Belle (2014)	Belle II 5 ab^{-1}	Belle II 50 ab^{-1}
UT angles	$\sin 2\beta$	$0.667 \pm 0.023 \pm 0.012$ [56]	0.012	0.008
	α [°]	85 ± 4 (Belle+BaBar) [24]	2	1
	γ [°]	68 ± 14 [13]	6	1.5
Gluonic penguins	$S(B \to \phi K^0)$	$0.90^{+0.09}_{-0.19}$ [19]	0.053	0.018
	$S(B \to \eta' K^0)$	$0.68 \pm 0.07 \pm 0.03$ [57]	0.028	0.011
	$S(B \to K_S^0 K_S^0 K_S^0)$	$0.30 \pm 0.32 \pm 0.08$ [17]	0.100	0.033
	$\mathcal{A}(B \to K^0 \pi^0)$	$-0.05 \pm 0.14 \pm 0.05$ [58]	0.07	0.04
UT sides	$\lvert V_{cb}\rvert$ incl.	$41.6 \cdot 10^{-3}(1 \pm 1.8\%)$ [8]	1.2%	
	$\lvert V_{cb}\rvert$ excl.	$37.5 \cdot 10^{-3}(1 \pm 3.0\%_{ex.} \pm 2.7\%_{th.})$ [10]	1.8%	1.4%
	$\lvert V_{ub}\rvert$ incl.	$4.47 \cdot 10^{-3}(1 \pm 6.0\%_{ex.} \pm 2.5\%_{th.})$ [5]	3.4%	3.0%
	$\lvert V_{ub}\rvert$ excl. (had. tag.)	$3.52 \cdot 10^{-3}(1 \pm 9.5\%)$ [7]	4.4%	2.3%
Missing E decays	$\mathcal{B}(B \to \tau\nu)$ [10^{-6}]	$96(1 \pm 27\%)$ [26]	10%	5%
	$\mathcal{B}(B \to \mu\nu)$ [10^{-6}]	< 1.7 [59]	20%	7%
	$R(B \to D\tau\nu)$	$0.440(1 \pm 16.5\%)$ [29]†	5.2%	3.4%
	$R(B \to D^*\tau\nu)^\dagger$	$0.332(1 \pm 9.0\%)$ [29]†	2.9%	2.1%
	$\mathcal{B}(B \to K^{*+}\nu\bar{\nu})$ [10^{-6}]	< 40 [31]	< 15	20%
	$\mathcal{B}(B \to K^{+}\nu\bar{\nu})$ [10^{-6}]	< 55 [31]	< 21	30%
Rad. & EW penguins	$\mathcal{B}(B \to X_s\gamma)$	$3.45 \cdot 10^{-4}(1 \pm 4.3\% \pm 11.6\%)$	7%	6%
	$A_{CP}(B \to X_{s,d}\gamma)$ [10^{-2}]	$2.2 \pm 4.0 \pm 0.8$ [60]	1	0.5
	$S(B \to K_S^0 \pi^0 \gamma)$	$-0.10 \pm 0.31 \pm 0.07$[20]	0.11	0.035
	$S(B \to \rho\gamma)$	$-0.83 \pm 0.65 \pm 0.18$ [21]	0.23	0.07
	C_7/C_9 $(B \to X_s\ell\ell)$	~20% [37]	10%	5%
	$\mathcal{B}(B_s \to \gamma\gamma)$ [10^{-6}]	< 8.7 [40]	0.3	–
	$\mathcal{B}(B_s \to \tau\tau)$ [10^{-3}]	–	< 2 [42]‡	–
Charm Rare	$\mathcal{B}(D_s \to \mu\nu)$	$5.31 \cdot 10^{-3}(1 \pm 5.3\% \pm 3.8\%)$ [44]	2.9%	0.9%
	$\mathcal{B}(D_s \to \tau\nu)$	$5.70 \cdot 10^{-3}(1 \pm 3.7\% \pm 5.4\%)$ [44]	3.5%	3.6%
	$\mathcal{B}(D^0 \to \gamma\gamma)$ [10^{-6}]	< 1.5 [47]	30%	25%
Charm CP	$A_{CP}(D^0 \to K^+K^-)$ [10^{-2}]	$-0.32 \pm 0.21 \pm 0.09$ [61]	0.11	0.06
	$A_{CP}(D^0 \to \pi^0\pi^0)$ [10^{-2}]	$-0.03 \pm 0.64 \pm 0.10$ [62]	0.29	0.09
	$A_{CP}(D^0 \to K_S^0\pi^0)$ [10^{-2}]	$-0.21 \pm 0.16 \pm 0.09$ [62]	0.08	0.03
Charm Mixing	$x(D^0 \to K_S^0\pi^+\pi^-)$ [10^{-2}]	$0.56 \pm 0.19 \pm {}^{0.07}_{0.13}$ [50]	0.14	0.11
	$y(D^0 \to K_S^0\pi^+\pi^-)$ [10^{-2}]	$0.30 \pm 0.15 \pm {}^{0.05}_{0.08}$ [50]	0.08	0.05
	$\lvert q/p\rvert(D^0 \to K_S^0\pi^+\pi^-)$	$0.90 \pm {}^{0.16}_{0.15} \pm {}^{0.08}_{0.06}$ [50]	0.10	0.07
	$\phi(D^0 \to K_S^0\pi^+\pi^-)$ [°]	$-6 \pm 11 \pm {}^{4}_{5}$ [50]	6	4
Tau	$\tau \to \mu\gamma$ [10^{-9}]	< 45 [63]	< 14.7	< 4.7
	$\tau \to e\gamma$ [10^{-9}]	< 120 [63]	< 39	< 12
	$\tau \to \mu\mu\mu$ [10^{-9}]	< 21.0 [64]	< 3.0	< 0.3

P. Urquijo / Nuclear and Particle Physics Proceedings 263–264 (2015) 15–23

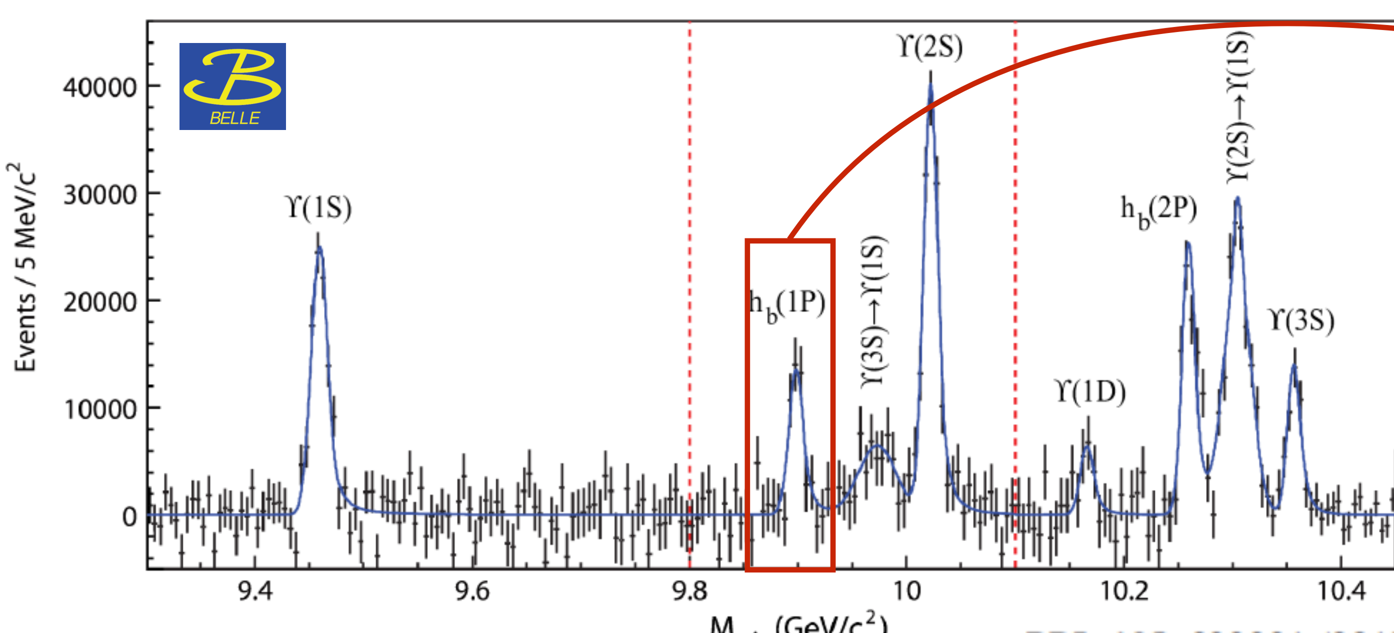
Bottomonium spectroscopy

- Considerable progress recently in Lattice QCD
- Belle II has the opportunity to search for missing states
- Clean environment
  - Search for new states inclusively
  - Reconstruct a single resonance and search the recoiling system

PHYSICAL REVIEW D **92,** 054034 (2015)

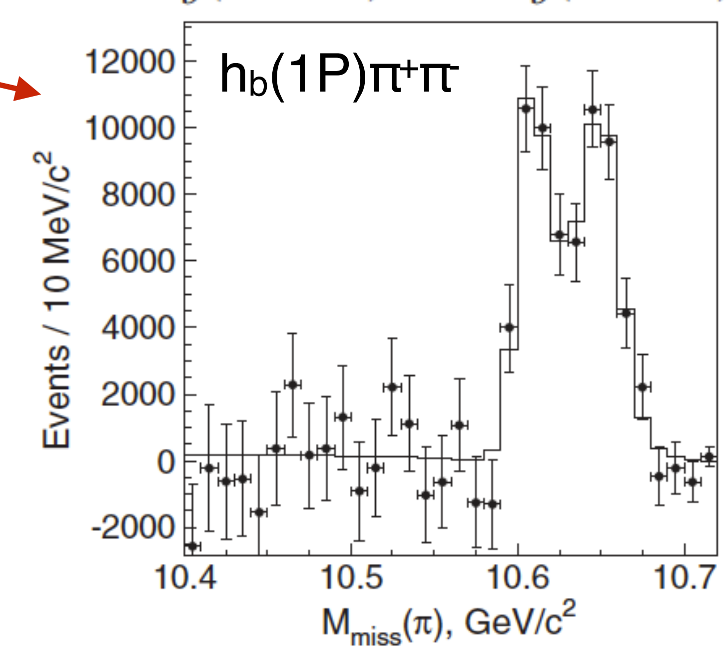


First Observation of the *P*-Wave Spin-Singlet Bottomonium States $h_b(1P)$ and $h_b(2P)$



PRL **108,** 032001 (2012)

$Z_b(10\,610)$ and $Z_b(10\,650)$



PRL **108,** 122001 (2012)

XYZ Spectroscopy (a subset)

2015 — X(5568), $P_c(4380)$, $P_c(4450)$

2013 — $Z_c(3900)$, $Z_b(10610)$, $Z_b(10650)$

2011 — Y(4140), Y(4274)

2009 — X(4350), X(4630)

2007 — G(3900), Y(4320), Y(4660), $Z^+(4430)$, $Z_2(4250)$, X(4160), $Z_1(4050)$, Y(4008)

2005 — Y(4260), X(3940), X(3915)

2003 — X(3872)

- Many interesting states (recently) discovered
  - Molecular bound states?
  - Diquarks or Tetraquarks (deeply bound)?
  - Hybrids?
  - Kinematical effects?
- Much to be done to quantify/confirm these states!

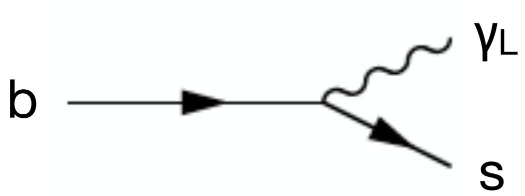
Other probes for NP

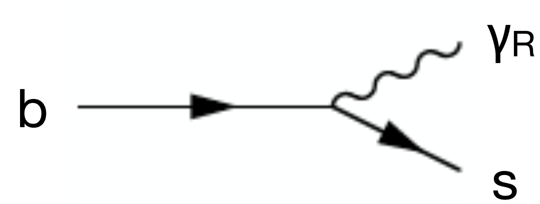
- Radiative and electroweak processes
    - b → sγ (B → K*γ), b → dγ (B → ργ, ωγ), b → sll (B → K(*)ll)

Starts at one-loop order Suppressed by two orders of magnitude

- NP contribution could be different for each process
    - Always one-loop or higher in b → s(d)γ, but may be tree level in b → s(d)ll
- For example helicity-changing NP models and $B^0 \to K_S \pi^0 \gamma$

$$\frac{dN}{dt} = e^{-\Gamma t}[1 + q(A\cos(\Delta m t) + S\sin(\Delta m t))]$$



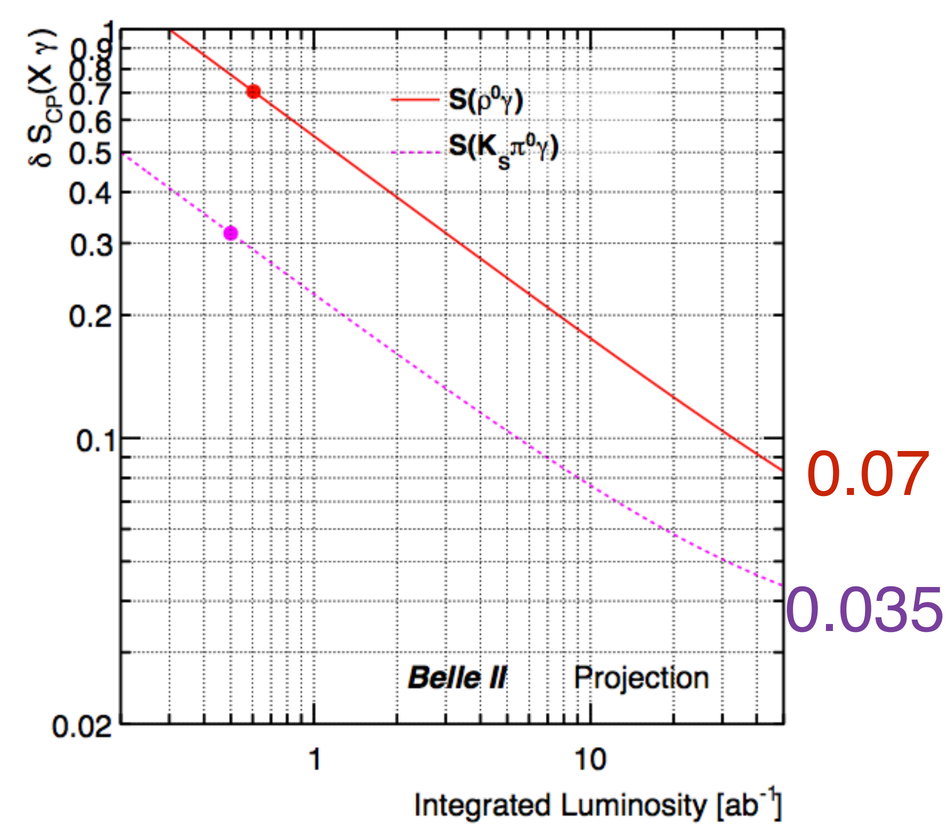


Standard Model

$$S^{SM}_{K_S\pi^0\gamma} = -2\frac{m_s}{m_b}\sin(2\beta) \sim -0.03$$

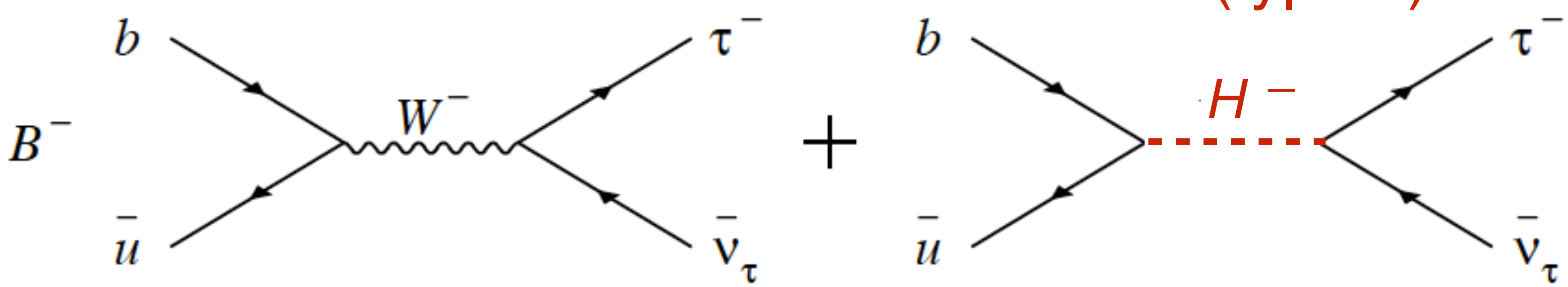
Left-Right symmetric model

$$S^{LR}_{K_S\pi^0\gamma} = 0.67\cos(2\beta) \sim 0.5$$



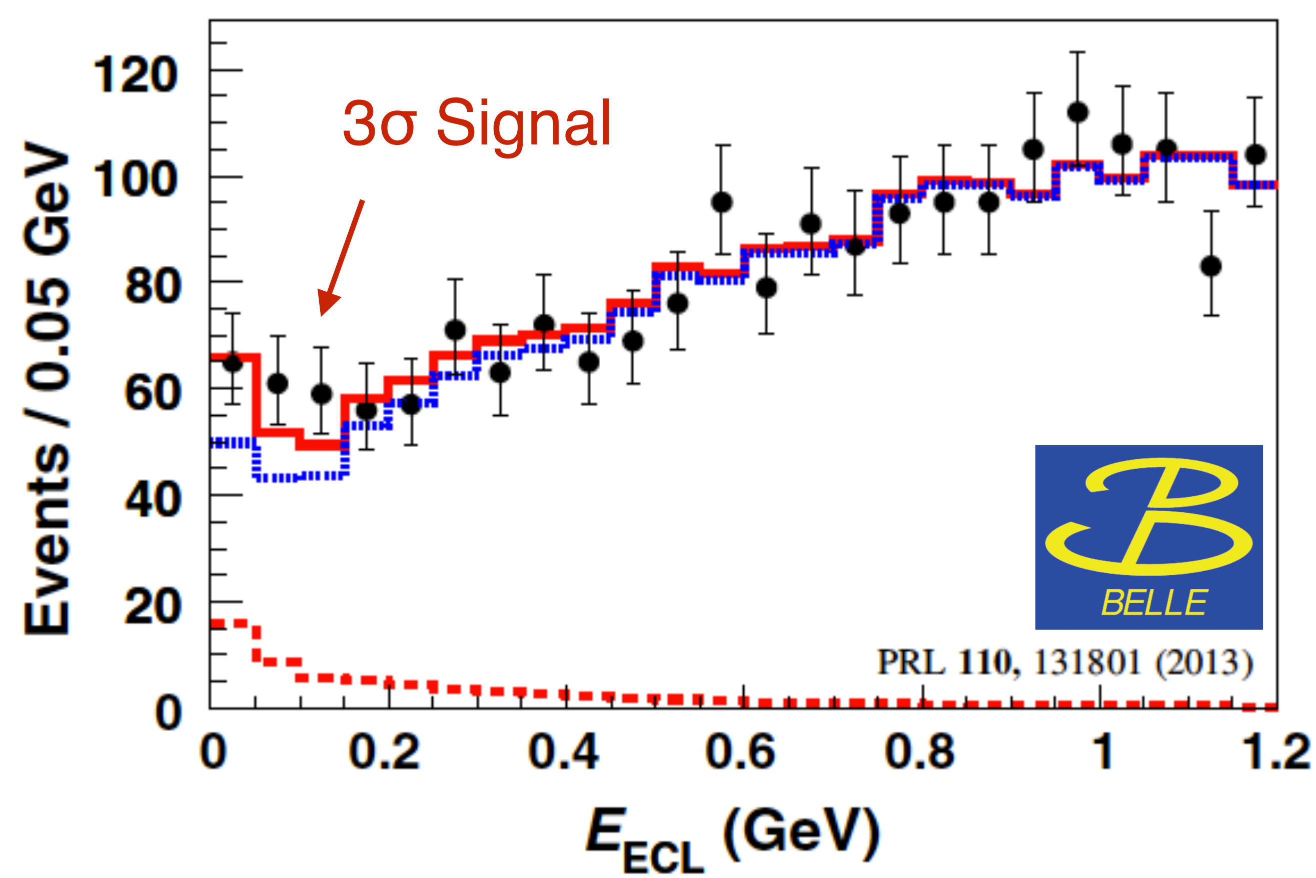
Leptonic B decays

2HDM (type II)



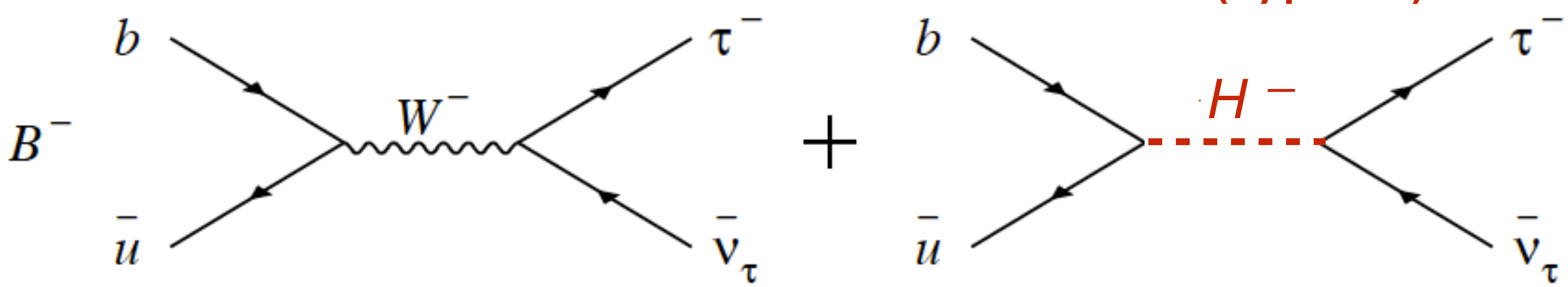
$$\underbrace{\mathcal{B}(B \to \ell\nu) = \frac{G_F^2 m_B m_\ell^2}{8\pi}\left(1 - \frac{m_\ell^2}{m_B^2}\right)^2 f_B^2 |V_{ub}|^2 \tau_B}_{B^{SM}} \times \underbrace{\left(1 - m_B^2 \frac{\tan^2\beta}{m_{H^\pm}^2}\right)^2}_{r_H}$$

- Experimentally challenging
  - >1 neutrino in the final state
  - Signal side only has 1 charged track ($\tau \to \mu\nu\nu$, $e\nu\nu$, $\pi\nu$)
- Use fully reconstructed hadronic and semileptonic tags
- Useful for $|V_{ub}|$ measurement (becomes competitive with semileptonic decays with 50 ab^{-1})



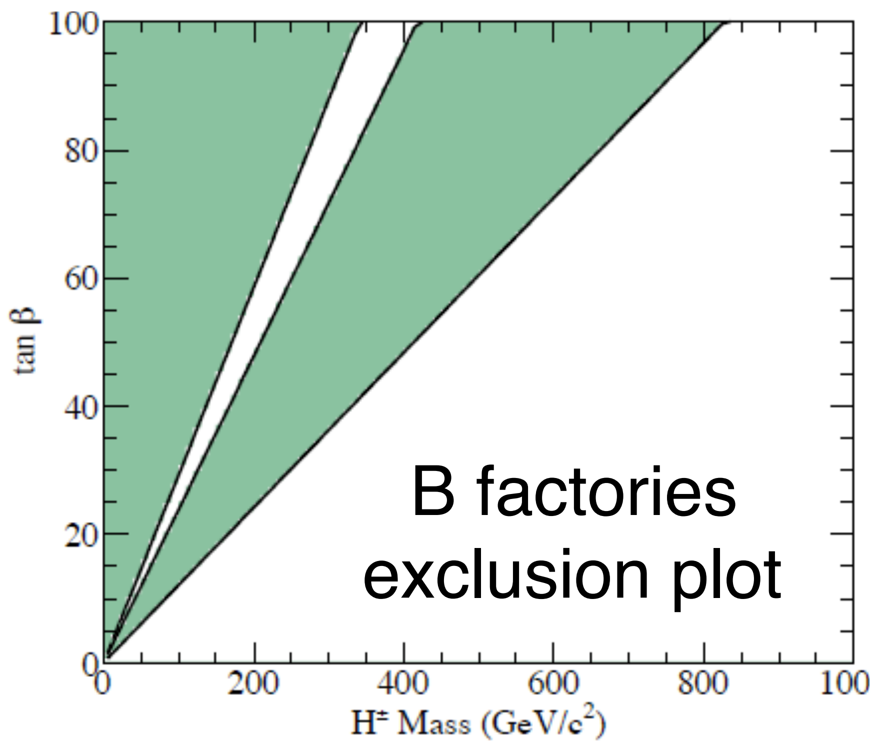
Leptonic B decays

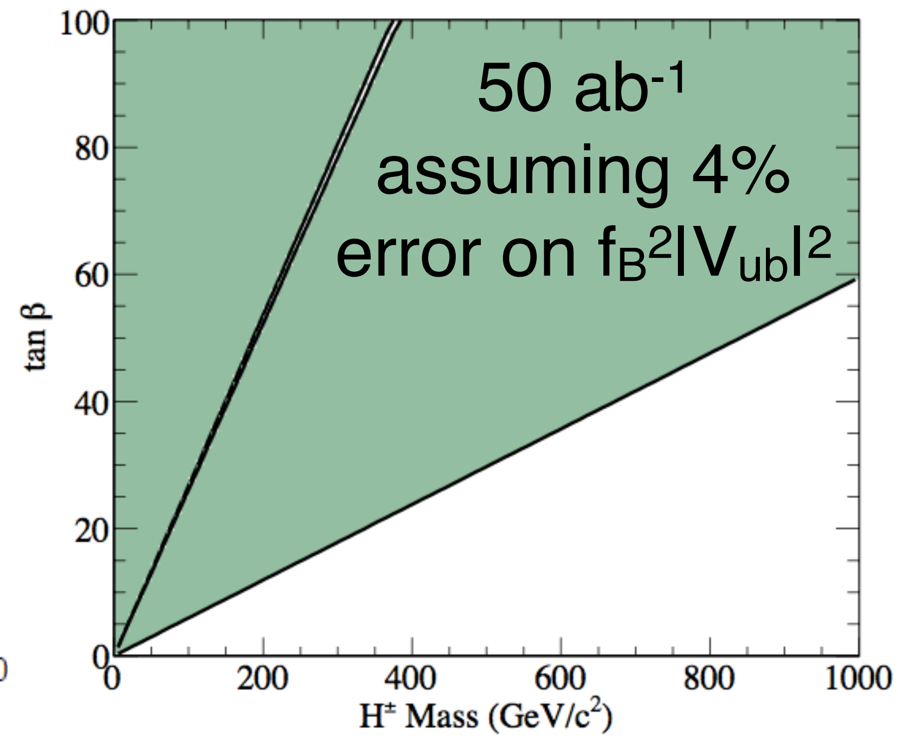
2HDM (type II)



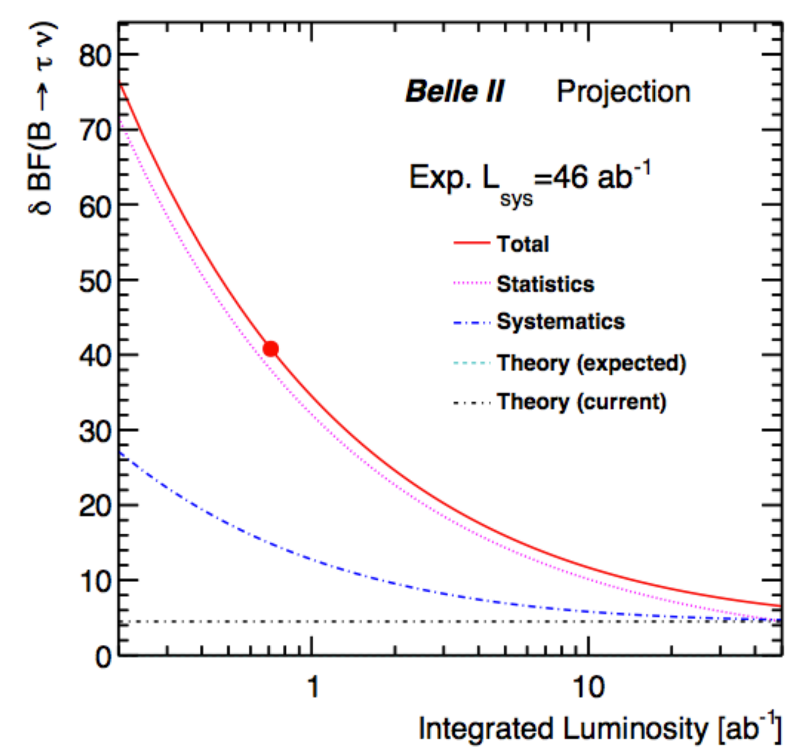
$$\mathcal{B}(B\to\ell\nu)=\frac{G_F^2 m_B m_\ell^2}{8\pi}\left(1-\frac{m_\ell^2}{m_B^2}\right)^2 f_B^2|V_{ub}|^2\tau_B \times \left(1-m_B^2\frac{\tan^2\beta}{m_{H^\pm}^2}\right)^2$$

Constraints on tan β and m_H greatly improve with 50 ab^{-1}



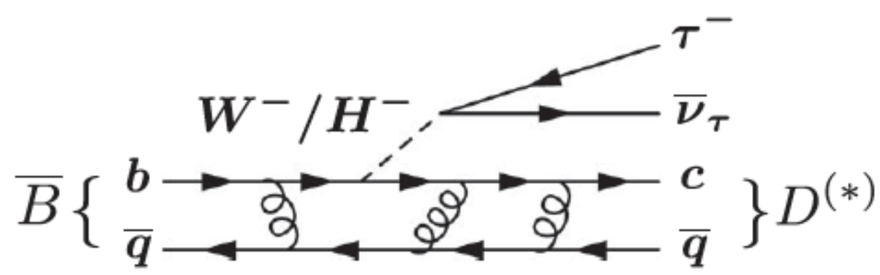


Aim to measure B(B → τν) with precision of 3-5%



Semileptonic B decays

- Proceed via first-order electroweak interactions (mediated by W)

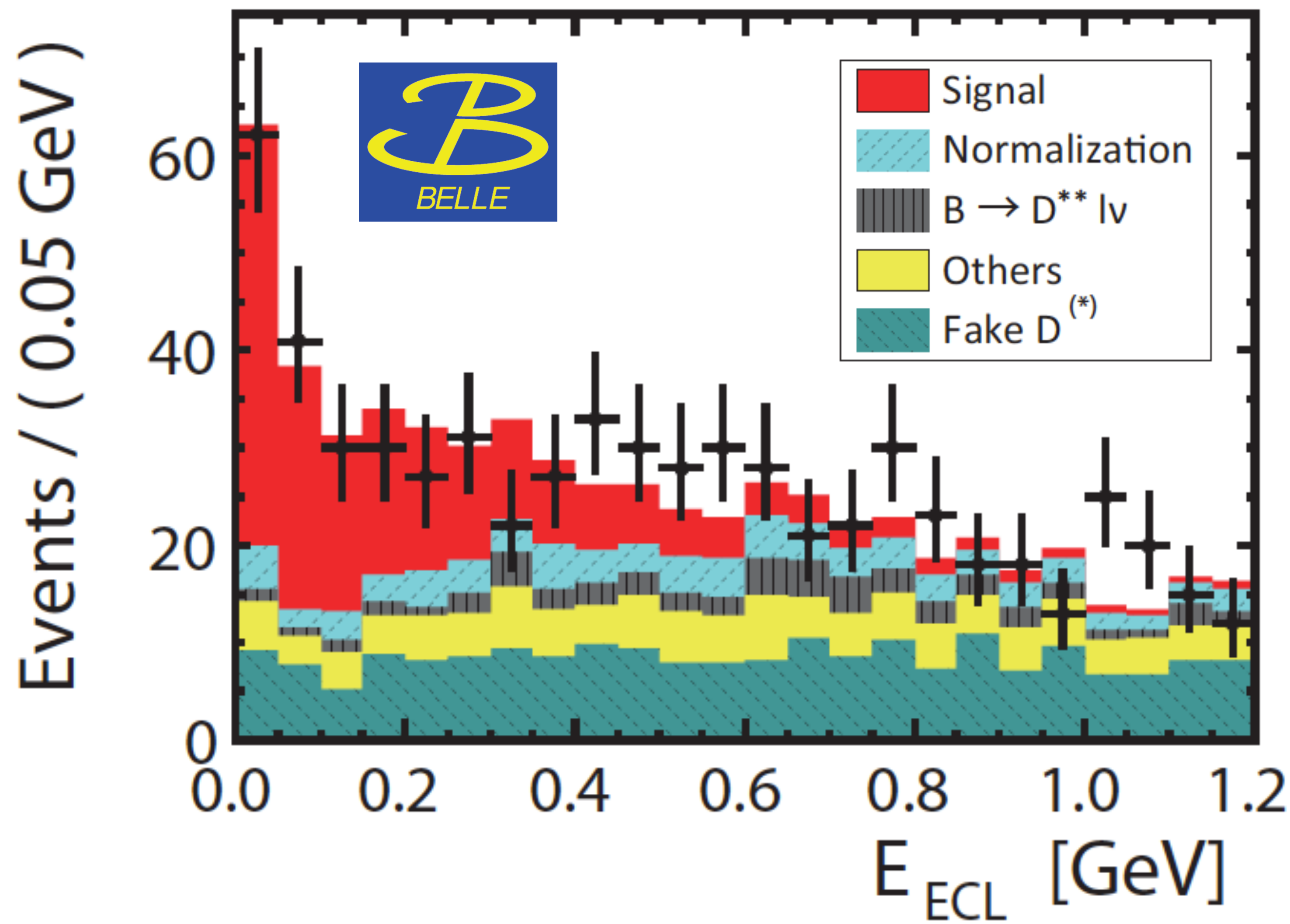


2HDM:

$$B = B_{SM} \times m_{W^\pm} \left(\frac{\tan\beta}{m_{H^\pm}} \right)$$

- Decays involving electrons and muons less sensitive to non-SM contributions
  - Measure CKM elements $|V_{cb}|$ and $|V_{ub}|$
- Decays involving τ also sensitive to additional amplitudes
  - Search for NP
  - Experimentally challenging

arxiv1603.06711:Belle-CONF-1602



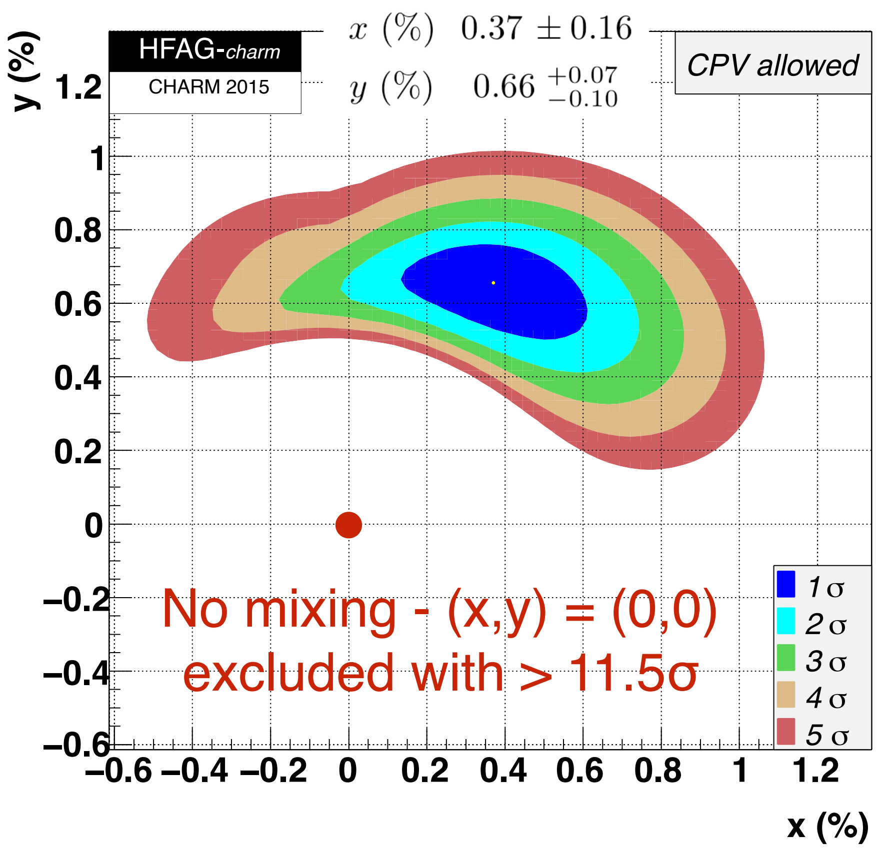
CPV in D^0-$\bar{D}^0$ mixing

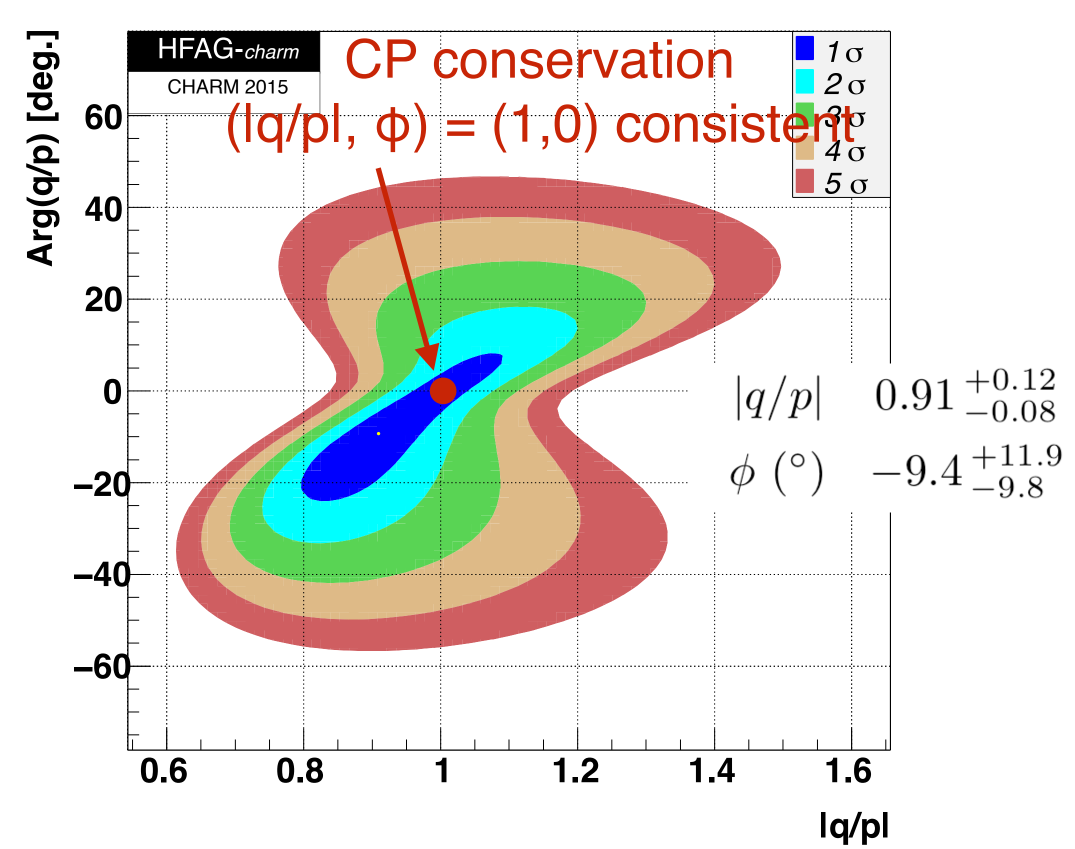
- SM mixing rate is sufficiently small that NP contributions may be detectable
- Mass eigenstates are superpositions of flavor eigenstates

$$D_{\frac{1}{2}} = pD^0 \pm q\bar{D}^0$$

In the absence of CPV, D_1 is CP-even, D_2 is CP-odd

$$x \equiv (m_1 - m_2)/\Gamma \qquad y \equiv (\Gamma_1 - \Gamma_2)/(2\Gamma) \qquad \Gamma \equiv (\Gamma_1 + \Gamma_2)/2 \qquad \phi = \mathrm{Arg}(q/p)$$



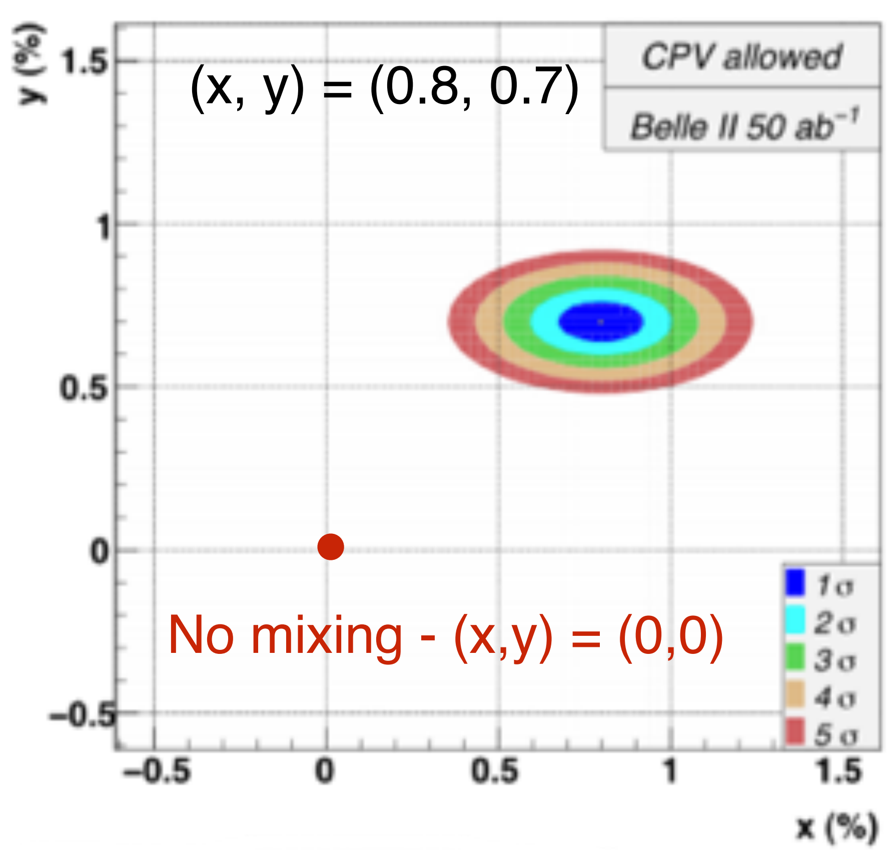


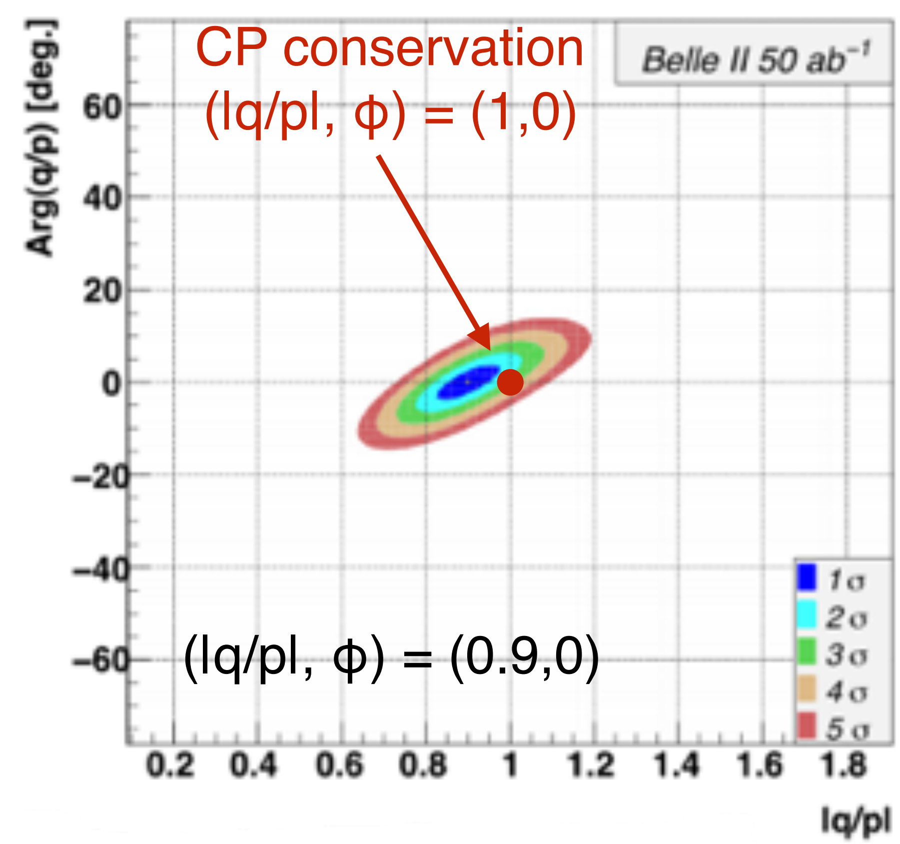
CPV in D^0-$\bar{D}^0$ mixing

- Current measurements of x,y give many constraints on NP models
- LHCb will dominate most of these measurements, but Belle II should be competitive in a few
  - If LHCb sees NP, important for Belle II to independently confirm!

Expected uncertainties (M. Staric, KEK FFW14)

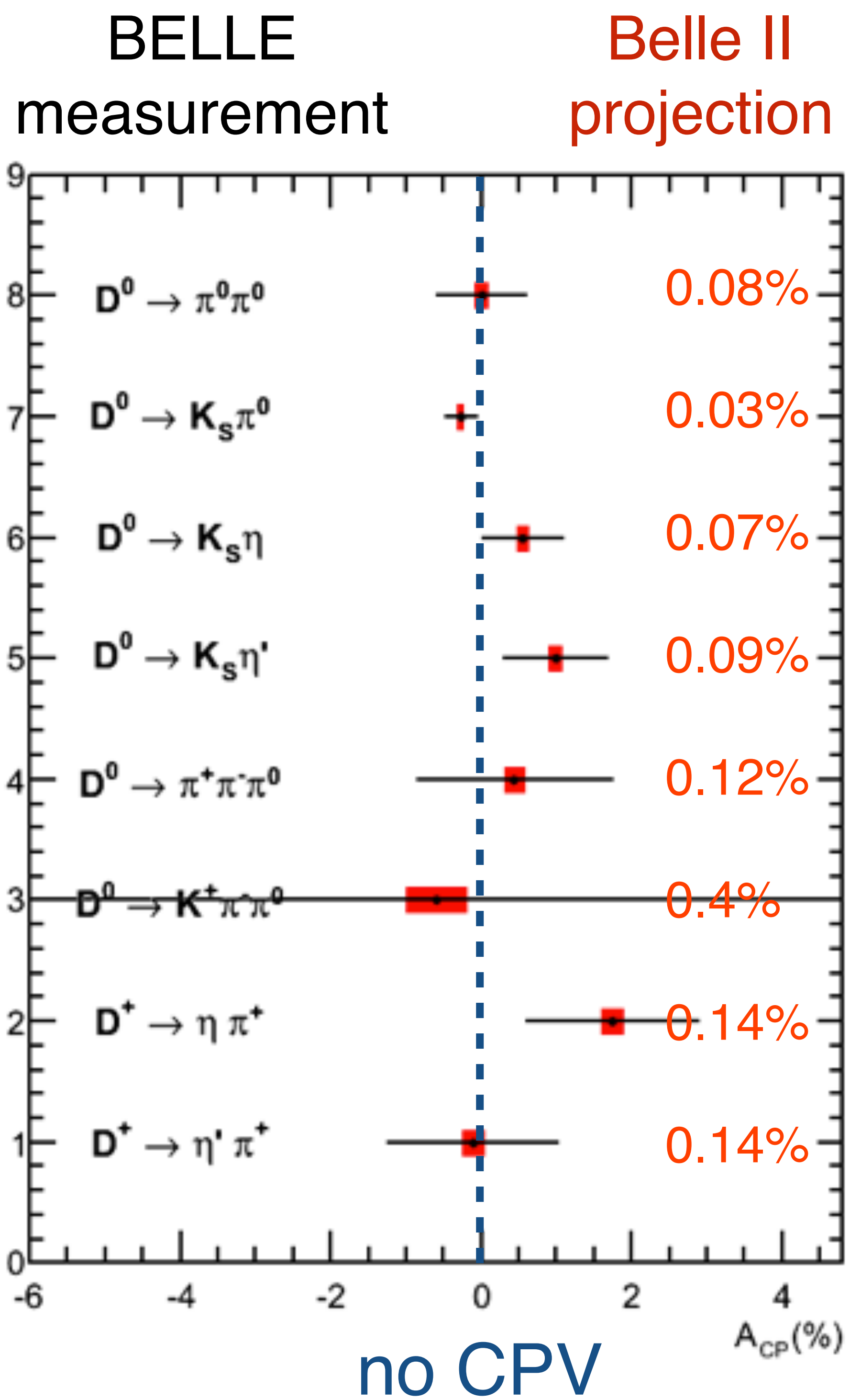
Analysis	Observable	Uncertainty (%) Now ($\sim$1 ab^{-1})	Uncertainty (%) $\mathcal{L}$ = 50 ab^{-1}
$K_S^0\pi^+\pi^-$	x	0.21	0.08
	y	0.17	0.05
	$\lvert q/p\rvert$	18	6
	ϕ	0.21 rad	0.07 rad
$\pi^+\pi^-$, K^+K^-	y_{CP}	0.25	0.04
	A_Γ	0.22	0.03
$K^+\pi^-$	x'^2	0.025	0.003
	y'	0.45	0.04
	$\lvert q/p\rvert$	0.6	0.06
	ϕ	0.44	0.04 rad





Direct CPV in Charm

$$A_{CP}^{f} = \frac{\Gamma(D^0 \to f) - \Gamma(\overline{D}^0 \to \overline{f})}{\Gamma(D^0 \to f) + \Gamma(\overline{D}^0 \to \overline{f})}$$

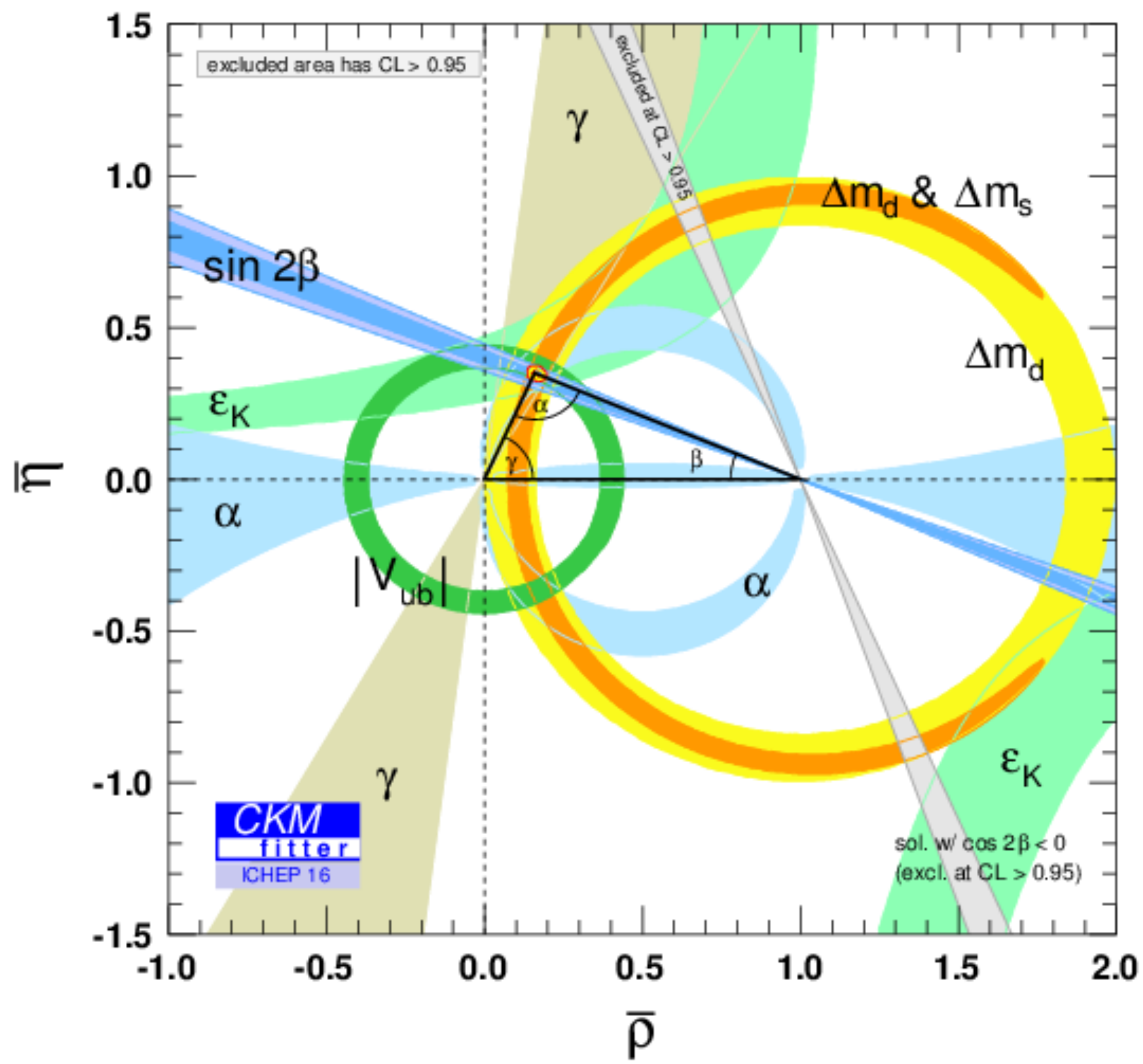


- Major Belle II contribution will be in channels with neutrals in the final state
- Most measurements will be systematics limited

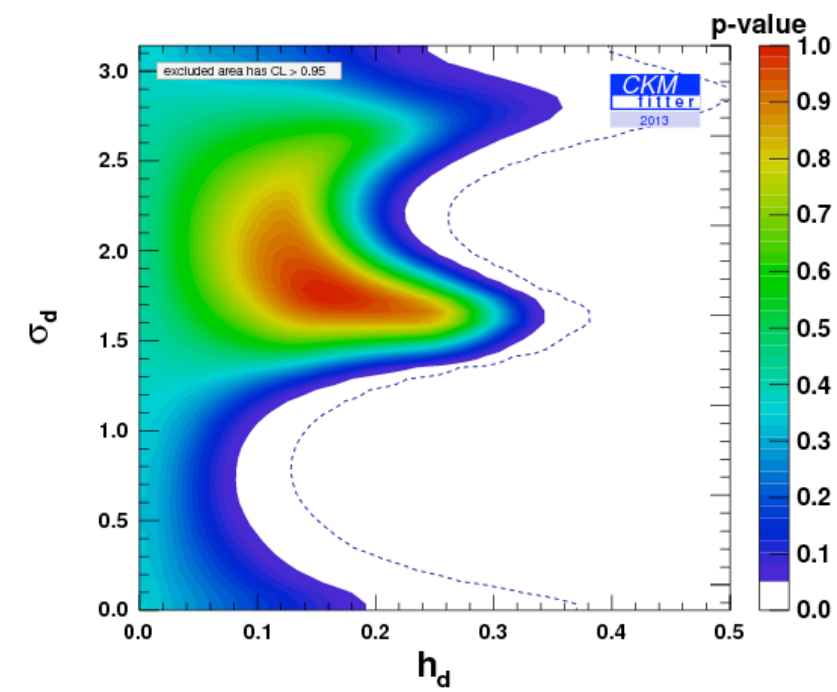
mode	$\mathcal{L}$ (fb^{-1})	A_{CP} (%)	Belle II at 50 ab^{-1}
$D^0 \to K^+K^-$	976	$-0.32 \pm 0.21 \pm 0.09$	± 0.03
$D^0 \to \pi^+\pi^-$	976	$+0.55 \pm 0.36 \pm 0.09$	± 0.05
$D^0 \to \pi^0\pi^0$	976	$\sim \pm 0.60$	± 0.08
$D^0 \to K_s^0\pi^0$	791	$-0.28 \pm 0.19 \pm 0.10$	± 0.03
$D^0 \to K_s^0\eta$	791	$+0.54 \pm 0.51 \pm 0.16$	± 0.07
$D^0 \to K_s^0\eta'$	791	$+0.98 \pm 0.67 \pm 0.14$	± 0.09
$D^0 \to \pi^+\pi^-\pi^0$	532	$+0.43 \pm 1.30$	± 0.13
$D^0 \to K^+\pi^-\pi^0$	281	-0.60 ± 5.30	± 0.40
$D^0 \to K^+\pi^-\pi^+\pi^-$	281	-1.80 ± 4.40	± 0.33
$D^+ \to \phi\pi^+$	955	$+0.51 \pm 0.28 \pm 0.05$	± 0.04
$D^+ \to \eta\pi^+$	791	$+1.74 \pm 1.13 \pm 0.19$	± 0.14
$D^+ \to \eta'\pi^+$	791	$-0.12 \pm 1.12 \pm 0.17$	± 0.14
$D^+ \to K_s^0\pi^+$	977	$-0.36 \pm 0.09 \pm 0.07$	± 0.03
$D^+ \to K_s^0K^+$	977	$-0.25 \pm 0.28 \pm 0.14$	± 0.05
$D_s^+ \to K_s^0\pi^+$	673	$+5.45 \pm 2.50 \pm 0.33$	± 0.29
$D_s^+ \to K_s^0K^+$	673	$+0.12 \pm 0.36 \pm 0.22$	± 0.05

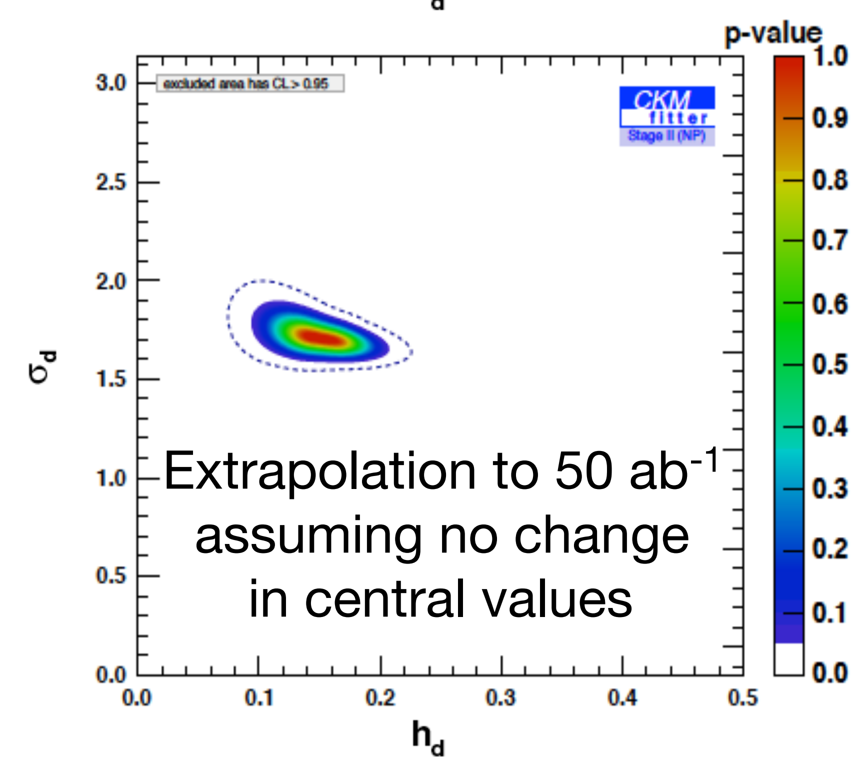
(table by Marko Staric)

Results from global fits to data



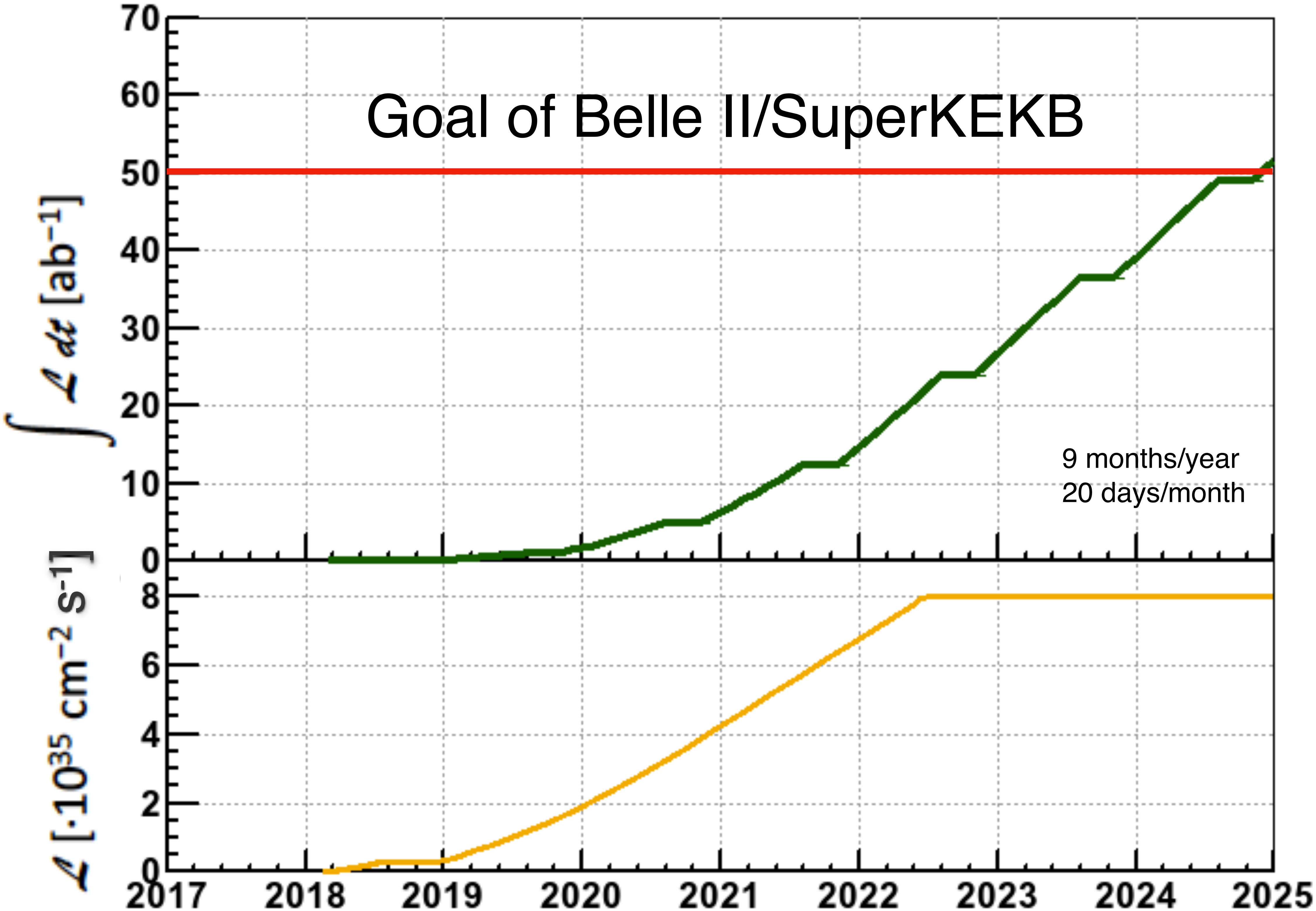
Parameterize NP contributions to the $B_{d,s}$ mixing amplitudes as $M^{d,s}_{12} = (M^{d,s}_{12})_{CM} \times (1 + h_{d,s}\, e^{2i\sigma_{d,s}})$





PHYSICAL REVIEW D **89,** 033016 (2014)

- There is still room for new physics contributions (FCNC, LFV, $B \to \tau$ tree-level NP, new sources of CPV)
- A 10-20% NP amplitude in B_d mixing is perfectly compatible with all current data
    - Scale ~20 TeV for tree-level, ~2 TeV at one loop



Goal of Belle II/SuperKEKB
9 months/year
20 days/month
$\int \mathcal{L}\, dt$ [ab^{-1}]
$\mathcal{L}$ [$\cdot 10^{35}$ cm^{-2} s^{-1}]
70
60
50
40
30
20
10
0
8
6
4
2
0
2017
2018
2019
2020
2021
2022
2023
2024
2025

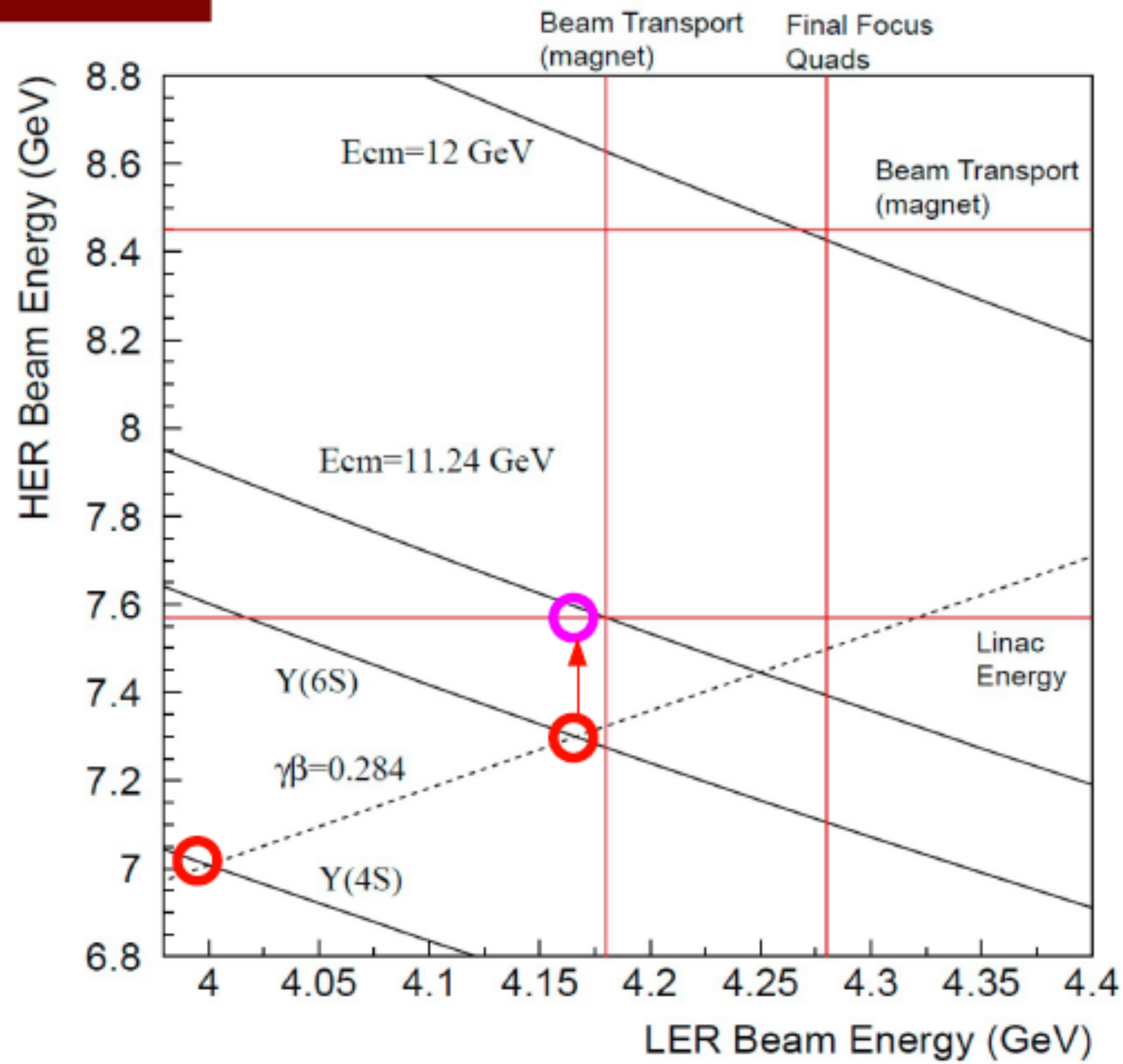
Super KEKB limitations

Y(6S) peak energy can be reached keeping the same beam asymmetry (i.e. the same boost) used for standard running at Y(4S)

The LER beam is limited by magnets in the beam transport line.

To reach Ecm=11.24 GeV ($\overline{\Lambda}_b \Lambda_b$ threshold) we can increase HER energy only, up to 7.55 GeV. (max Linac Energy)

$\overline{B}_c B_c$ threshold: 12.55 GeV

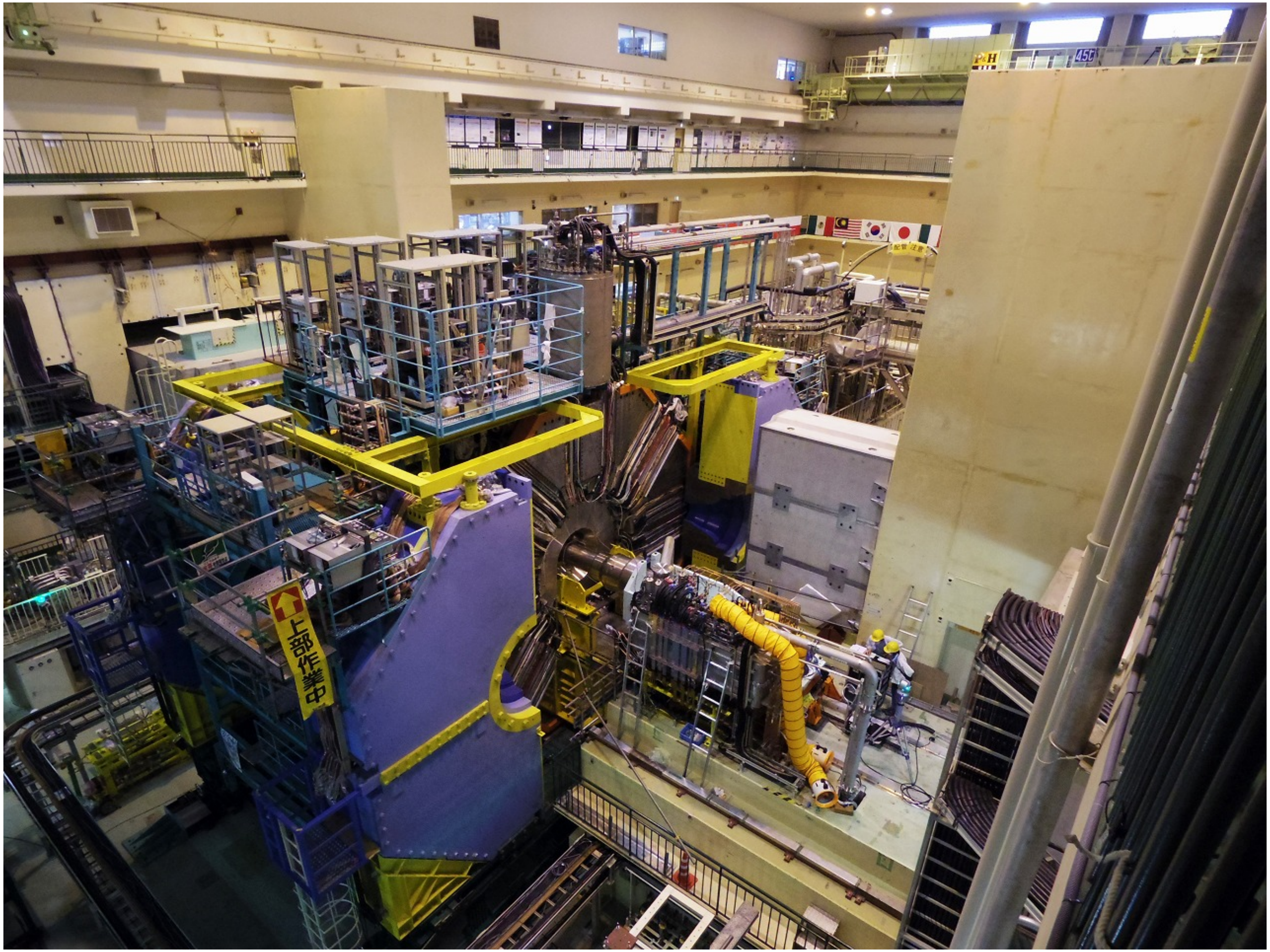


First Physics

Energy	Outcome	Lumi (fb^{-1})	Comments
$\Upsilon(1S)$ On	N/A	60+	-No interest identified -Low energy
$\Upsilon(2S)$ On	New physics searches	20+	-Requires special trigger
$\Upsilon(1D)$ Scan	Particle discovery	10-20	-Accessible in B Factories?
$\Upsilon(3S)$ On	Many -onia topics	200+	-Known resonance -Luminosity requirement: Phase 3
$\Upsilon(3S)$ Scan	Precision QED	~10	-Understanding of beam conditions needed
$\Upsilon(2D)$ Scan	Particle discovery	10-20	-Unknown mass
>$\Upsilon(4S)$ On	Particle discovery?	10+?	-Energy to be determined
$\Upsilon(6S)$ On	Particle discovery?	30+?	-Upper limit of machine energy
Single γ	New physics?	30+	-Special triggers required

Experiment	Scans/Off. Res.	$\Upsilon(5S)$		$\Upsilon(4S)$		$\Upsilon(3S)$		$\Upsilon(2S)$		$\Upsilon(1S)$	
		10876 MeV		10580 MeV		10355 MeV		10023 MeV		9460 MeV	
	fb^{-1}	fb^{-1}	10^6	fb^{-1}	10^6	fb^{-1}	10^6	fb^{-1}	10^6	fb^{-1}	10^6
CLEO	17.1	0.4	0.1	16	17.1	1.2	5	1.2	10	1.2	21
BaBar	54	R_b scan		433	471	30	122	14	99	–	
Belle	100	121	36	711	772	3	12	25	158	6	102

This spring: Belle II “roll-in” April 11, 2017



1400 tons, 8m x 8m, moved 13m horizontally