Belle II: Status and Physics prospects

Milind Purohit

University of South Carolina

for the Belle II collaboration

Belle II: Status and Physics prospects

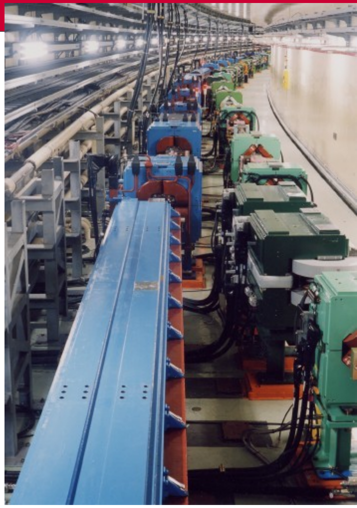
Milind Purohit (USC, for the Belle II collaboration)

Columbia, SC, USA

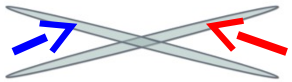
Tsukuba, Japan

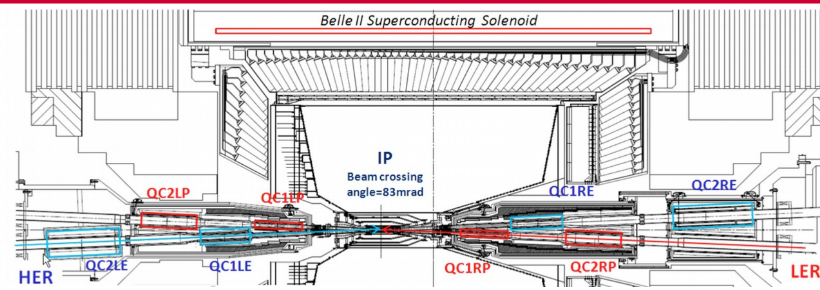
Outline

- SuperKEKB accelerator
- Belle II Detector and Status
- Belle II Physics Prospects



2015: Basic hardware (except final focus) now in place





8 new SC final focusing magnets near the IP: 2017.

e⁺ 3.6A

e⁻ 2.6A

KEKB → SuperKEKB

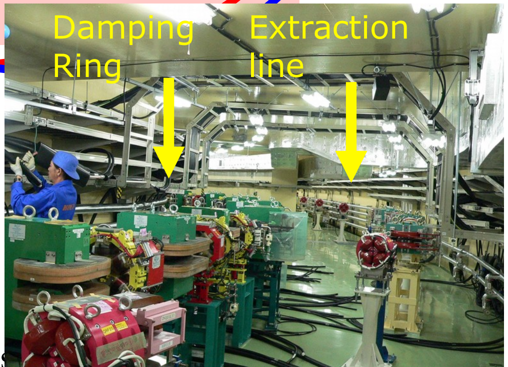
- Nano-Beam scheme
  - extremely small β_y^*
  - low emittance
- Beam current x2

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

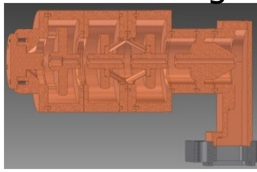
40x higher $\mathcal{L}$ than KEKB!

Reduce emittance (longer dipoles, more wiggler cycles) (*all magnets installed 8/2014*)

Alignment work complete.



Low emittance RF electron gun

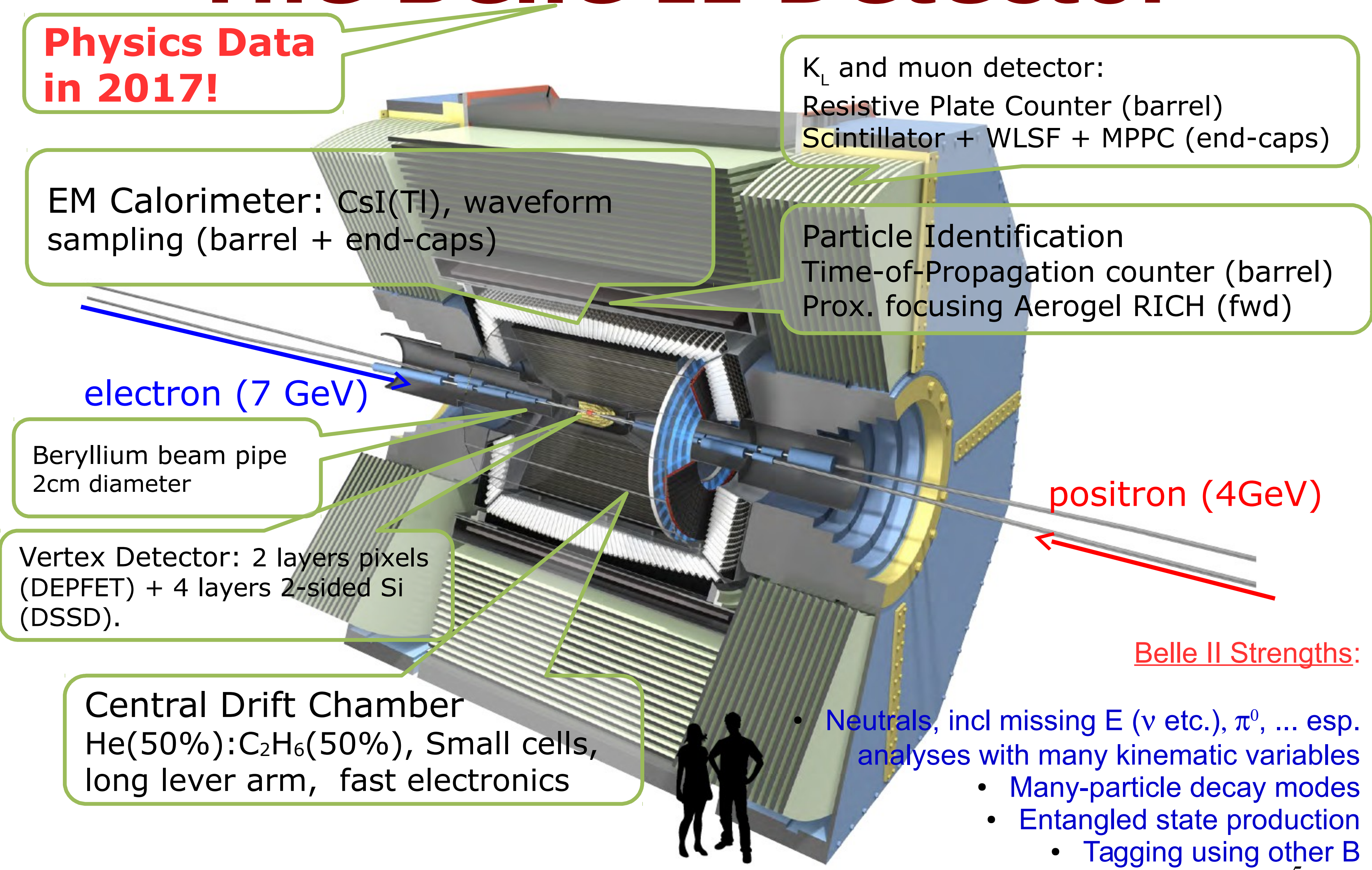


Parameters for KEKB and SuperKEKB

	KEKB Design	KEKB with crab	SuperKEKB Nano-Beam
Energy (GeV) (LER/HER)	3.5/8.0	3.5/8.0	4.000/7.007
β_y^* (mm)	10/10	5.9/5.9	0.27/0.30
β_x^* (mm)	330/330	1200/1200	32/25
ε_x (nm)	18/18	18/24	3.2/4.6
ε_y (pm)	180/180	153/154	8.64/11.5
σ_y(nm)	1900	940	48/62
σ_z (mm)	4	6 - 7	6/5
I_{beam} (A)	2.6/1.1	1.64/1.19	3.6/2.6
$N_{bunches}$	5000	1584	2500
Luminosity (10^{34} cm^{-2} s^{-1})	1	2.11	80

Nano-beams are key (σ_y ~50nm !!). Also, lower boost reduces Touschek effect losses, especially in the LER.

The Belle II Detector



Belle II Strengths:

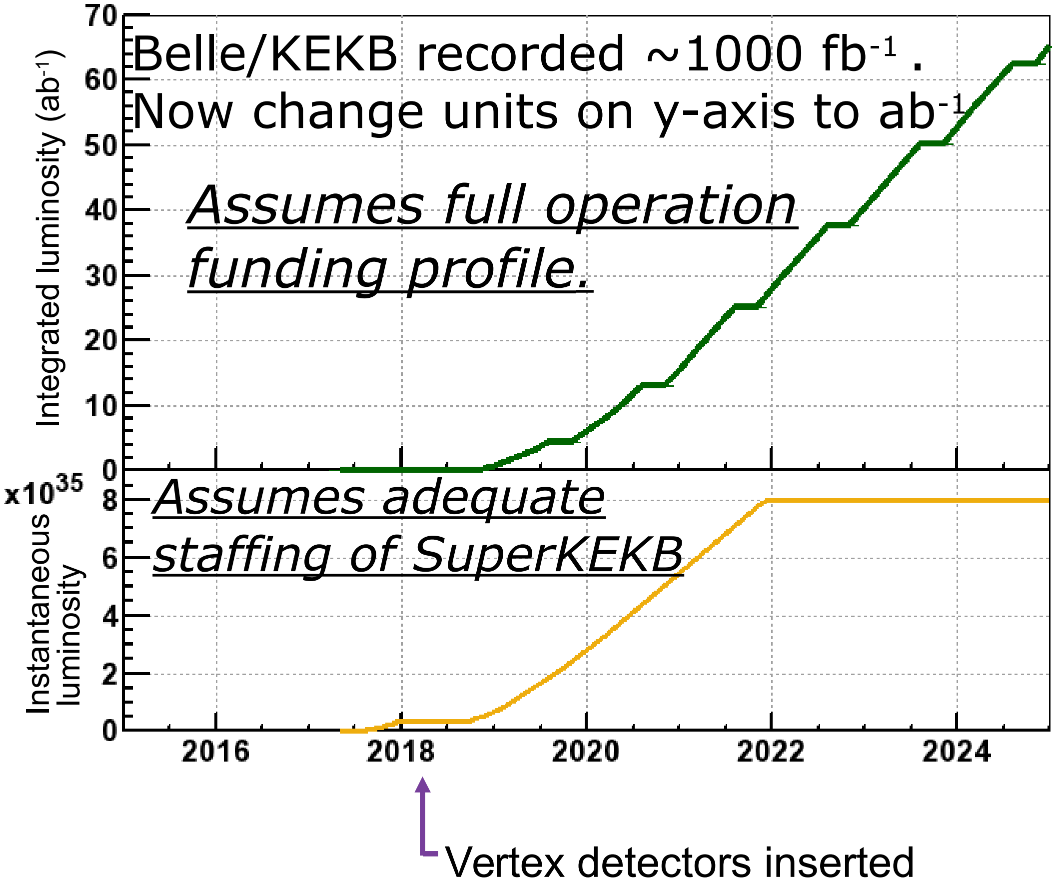
- Neutrals, incl missing E (ν etc.), π^0, ... esp. analyses with many kinematic variables
- Many-particle decay modes
- Entangled state production
- Tagging using other B

Belle II: New Components and their Status

Detector	What's New	Status
Vertex Detector (VXD)	4-layer DSSD replaced with 2 DEPFET layers + 4 DSSD layers smaller inner radius, larger outer radius ● better vertex resolution ● improved efficiency for slow pions and K^0_S	PXD: To be installed ~ Spring 2018. SVD: To be installed ~ Oct, 2017. VXD: To be installed ~ Oct, 2018. Large beam test for entire VXD in 2016.
Central Drift Chamber (CDC)	Smaller cells and a larger outer radius lead to improved $\delta p/p$ as well as dE/dx	Strung, finished in Tsukuba Hall Cosmic Rays seen. Full Cosmic Ray test ~ Mar end, 2016.
Particle ID (hadrons)	Aerogel Cherenkov Counter (ACC) + Time Of Flight (TOF) replaced with Time-Of-Propagation (TOP: barrel) and aerogel RICH (ARICH: forward). These changes result in less material in front of the calorimeter and improved hadron ID.	TOP: quartz, electronics both done. Installation & Integration to be complete ~ Summer 2016? ARICH: Protection Circuits added to prevent flash-over. System test Mar 2016.
Electromagnetic Calorimeter (ECL)	Waveform sampling technique to cope with increased background.	Backend electronics modified. Cosmics seen. Endcap goes in ~Summer 2016.
K^0_L-μ detector (KLM)	RPC's in endcaps and first two layers of barrel replaced with scintillator counters to cope with increased neutron background.	Barrel & Endcap done. Electronics produced.

Belle II Schedule

- Beam commissioning starts in Jan 2016.
- Installation of sub-detectors in Belle II will begin in earnest in spring 2016 and will be completed before the end of 2016.
- Commissioning with cosmic rays will continue to the end of 2017.
- Belle II to roll into the beam line in the spring of 2017.
- During 2016 and 2017: Commissioning of the detector (will help with beam commissioning as well).
- Data taking in 2018 onwards.



Physics Goals of Belle II

- **Continuing Studies / Precision Physics Topics**
  - CPV in B decays, other B decay physics
    - CPV only seen in the meson sector; CPV in B decays is theoretically clean
    - Related: Is there CPV in the charm sector? If so, does it accord with the SM?
    - B / Bottomonium spectroscopy
  - Charm Physics
    - CPV in mixing, direct CPV, ...
    - QCD
    - Semileptonic Decays
    - Charm / Charmonium spectroscopy
  - Tau Physics
    - Confirm R(D) and R(D*). Consistent with new Higgs / other high mass particles?
    - Do we see rare and forbidden decays such as $\tau \rightarrow \mu\gamma$, $\tau \rightarrow eee$?
    - Do we see CPV in decays such as $\tau \rightarrow K_S^0\pi\nu$?

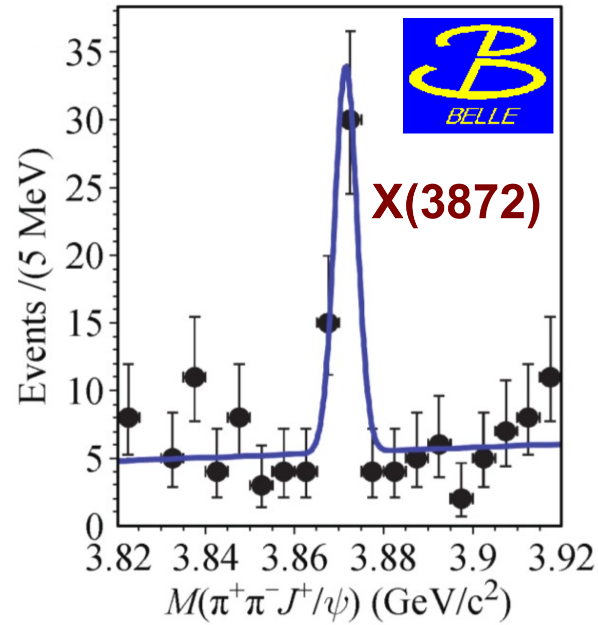
- **Beyond the Standard Model / New Physics (BSM / NP)**
  - An important check: if there are new Higgses, do we see evidence for them?
  - Are there indications of new CPV phases, of right-handed currents or other new weak bosons? Is there CPV in charm decays and can we interpret it correctly?
  - Is there further evidence of LFV and / or FCNC in new decay modes?
  - Do we see new low mass dark photons or other light dark matter particles?

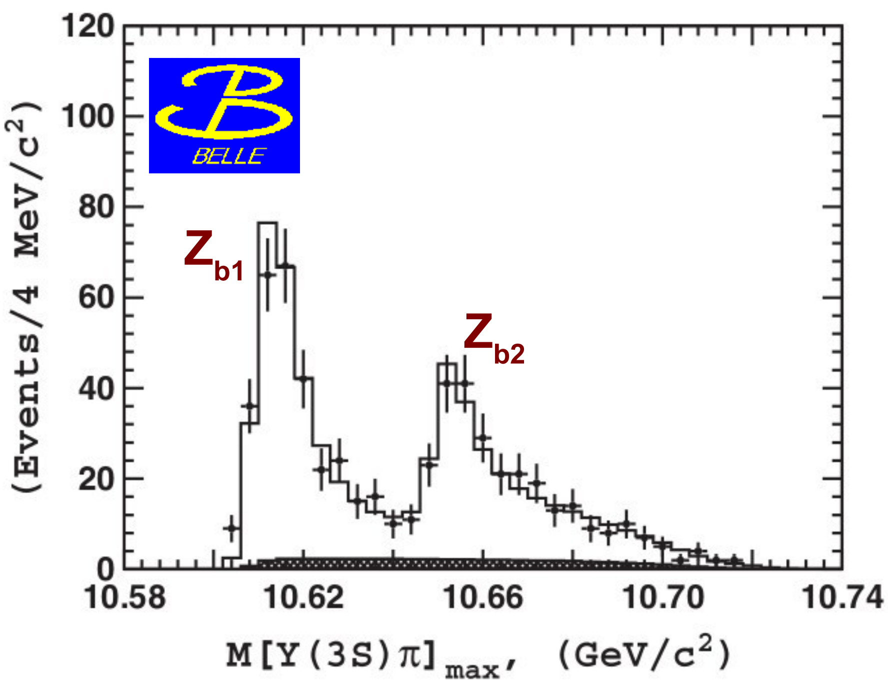
Early Physics Topics on Belle II

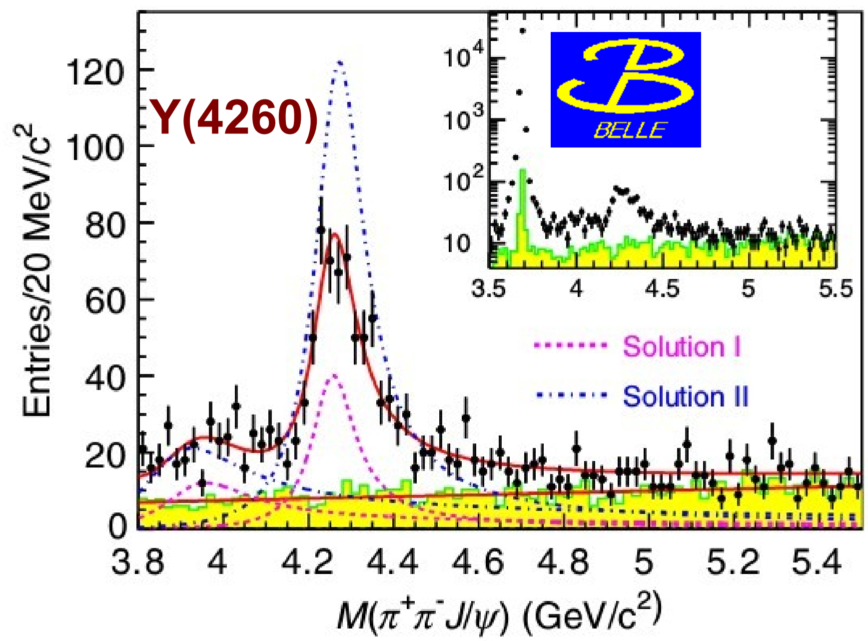
Energy	Outcome	Lumi (fb^{-1})	Comments
$\Upsilon(1S)$ On	N/A	60+	-No interest identified for Phase 2 -Low energy
$\Upsilon(2S)$ On	N/A	200	-No interest identified for Phase 2
$\Upsilon(1D)$ Scan	Particle discovery	10-20	-Better Study needed for $\Upsilon(1D_2)$ -$\Upsilon(1D_{1,3})$ to be discovered
$\Upsilon(3S)$ On	Many topics	200+	-Known resonance -High luminosity needed: Phase 3
$\Upsilon(3S)$ Scan	Precision QED	~10	-Understanding of beam conditions needed
$\Upsilon(2D)$ Scan	Particle discovery	10-20	-$\Upsilon(2D)$ to be discovered
$\Upsilon(5S)$+ Scan	Particle discovery?	10+?	-Energy to be determined
Y(6S) On	Particle discovery?	30+?	-Upper limit of machine energy
Single γ	New physics?	30+	-Special triggers required

Spectroscopy

- There is a large number of new and interesting states, labeled X, Y, Z, many of which do not fit in the traditional quark model, see e.g., refs. XYZ-1, -2, -3, -4, -5. Three are shown here, many more are seen.
- We should expect even more such in Belle II. Studies should elucidate the production, J^{PC}, other properties.
- Could be some of the earliest physics (2017).







$D^0\overline{D}^0$ Mixing at Belle II

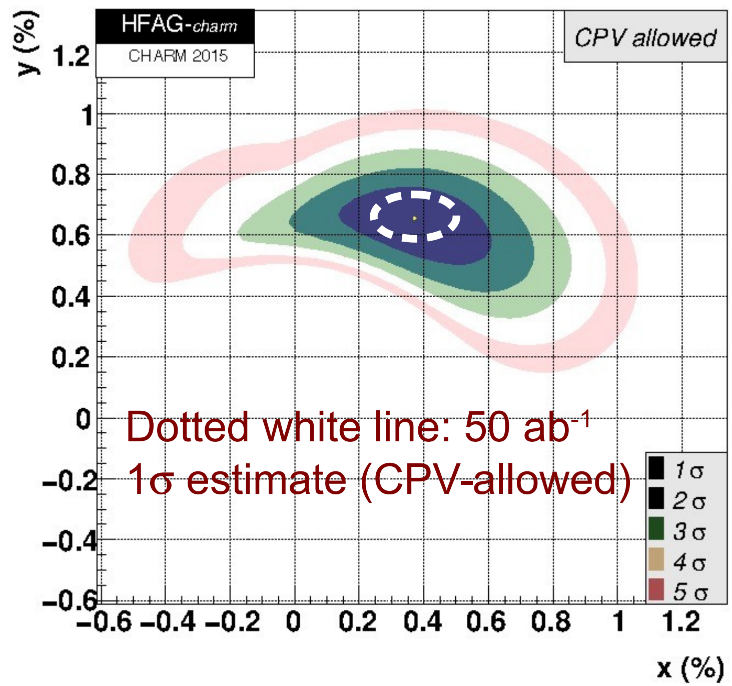
- As in neutral kaon mixing, we can define a basis with (almost) CP-eigenstates:

$$\begin{aligned} |D_1\rangle &= p|D^0\rangle + q|\overline{D}^0\rangle \\ |D_2\rangle &= p|D^0\rangle - q|\overline{D}^0\rangle \end{aligned}$$

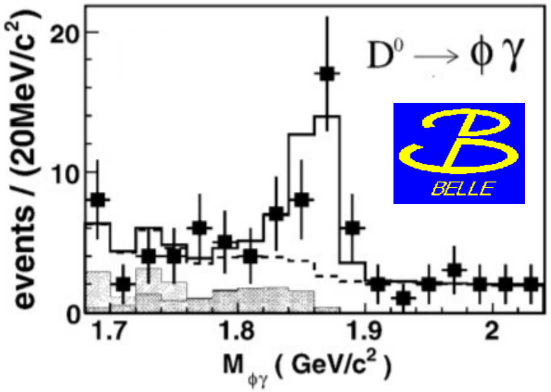
[D_1 ~ CP-odd]

- There are 4 quantities of interest. Defining $\Gamma = (\Gamma_1 + \Gamma_2)/2$, the four are
  $x = (M_2 - M_1)/\Gamma$, $y = (\Gamma_2 - \Gamma_1)/2\Gamma$, the magnitude $|q/p|$, and the phase ϕ of (q/p).
- Below are the current errors on these quantities from Belle, and what we may expect from Belle II, in the $K_S\pi^+\pi^-$ decay mode.[Ch-1]

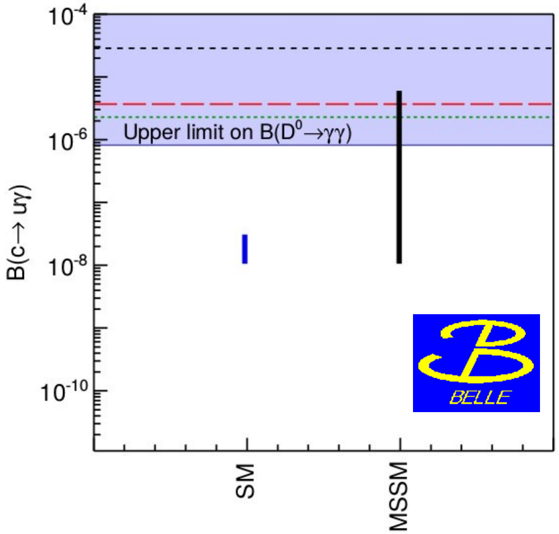
	BELLE (~0.9 ab^{-1}) uncertainty	BELLE II (~50 ab^{-1}) uncertainty
x	~0.21%	~0.08%
y	~0.17%	~0.05%
|q/p|	~0.18	~0.06
ϕ	~0.21	~0.07



Rare Charm Decays



- D^0 decays to $\phi\gamma$, $\rho\gamma$ may have direct A_{CP} ~2% and ~10% respectively.[Ch-2] [$D^0 \to \varphi\gamma$ was first observed by Belle with 78 fb^{-1}.][Ch-3]
- Belle II should achieve a sensitivity δA_{CP} ~1%.



- SM predicts BF($D^0 \to \gamma\gamma$) to be ~ 4 x 10^{-8}, gluino exchange can enhance this by x200 or so. In 2015 Belle obtained the limit [Ch-4] BF($D^0 \to \gamma\gamma$) < 8.5 x 10^{-7}, at 90% CL.
- Belle II should achieve limits for BF($D^0 \to \gamma\gamma$) in the range 2x10^{-8} to 2x10^{-7}, depending on how the luminosity scales ($\sqrt{N}$ or N). Useful mode to parameterize Long Distance (LD) effects.

- Rare Decays, 3-, 4-, and 5-body modes: current limits all ~ 10^{-5} – 10^{-4}.
  LFV, LNV, (BNV+LNV): current limits also ~10^{-5} – 10^{-4}.

Belle II should be able to achieve several orders of magnitude improvement.

More Symmetry Violation Searches in Charm Decays

Some of the best direct A_{CP} measurements (2015):

A_{CP} ($D^\pm \rightarrow K^+K^-\pi^\pm$) < ~0.3% (PDG, BaBar)

A_{CP} ($D^\pm \rightarrow K^0_S\pi^\pm$) < ~0.1% (PDG, Belle)

A_{CP} ($D^\pm \rightarrow K^0_SK^\pm$) < ~0.2% (PDG, LHCb)

A_{CP} ($D^0 \rightarrow K^-\pi^+\pi^0$) < ~0.5% (PDG, CLEO-c)

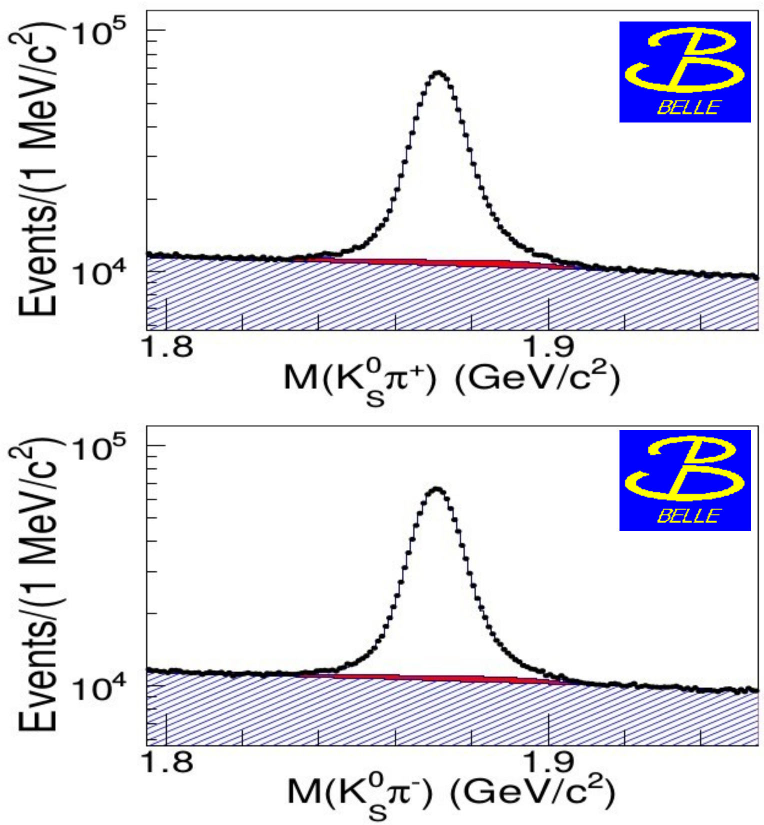
A_T ($D^\pm \rightarrow K^0_SK^\pm\pi^+\pi^-$) < ~1.0% (PDG, BaBar)

A_{CPT} ($D^0 \rightarrow K^-\pi^+$) < ~0.2% (PDG, Focus)

A_{TV} ($D^0 \rightarrow K^-K^+\pi^+\pi^-$) < ~1.0% (PDG, BaBar)

Most of these are from Belle / BaBar and should be ~ x10 better with 50 ab^{-1} from Belle II, which can comprehensively cover neutral modes.

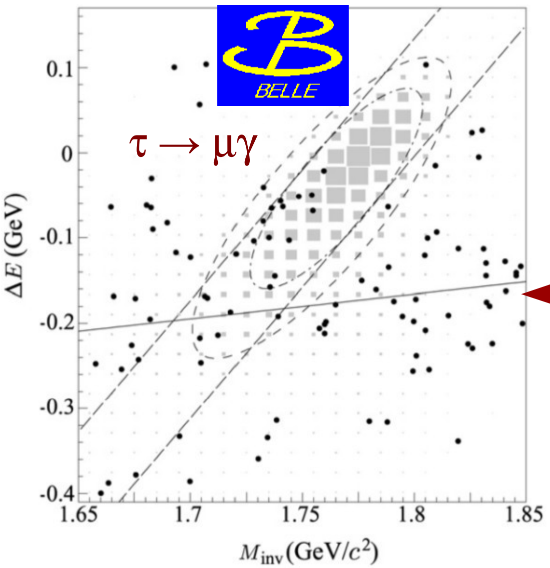
A_{CP} ($D^\pm \rightarrow K^0_S\pi^\pm$) [ref. B1-1]



Tau Physics

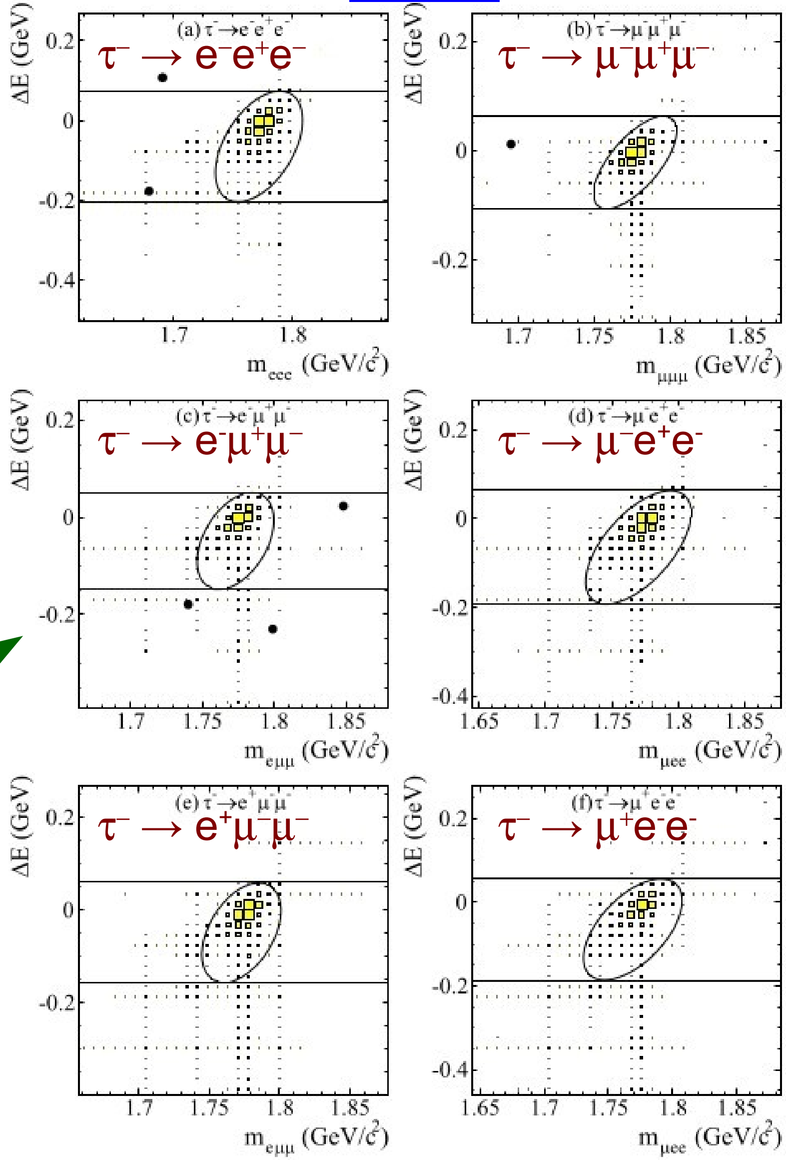
τ decays are a hot area to search / measure for LFV, CP violation, edm, g−2, $|V_{us}|$, Rare and forbidden τ decays

- 50 ab^{-1} of Belle II data provides a LFV sensitivity x7 better than Belle for background limited modes such as $\tau \to \mu\gamma$ and up to x50 better for the cleanest searches such as $\tau \to eee$ to limits of 5×10^{-10}.
- Measure CPV at a level that bounds many models of NP in a complementary way to the LFV searches. For example, CPV in $\tau \to K_S{}^0\pi\nu$, which is very precisely predicted in the SM, is expected to be measured with 10^{-4} precision, *an order of magnitude better than Belle.*



ΔE and M_{inv} limits cover 5σ region. 1σ, 2σ ellipses.

90% signal containment ellipses.



Figures from Ref. B1-2.

CPV in B decays

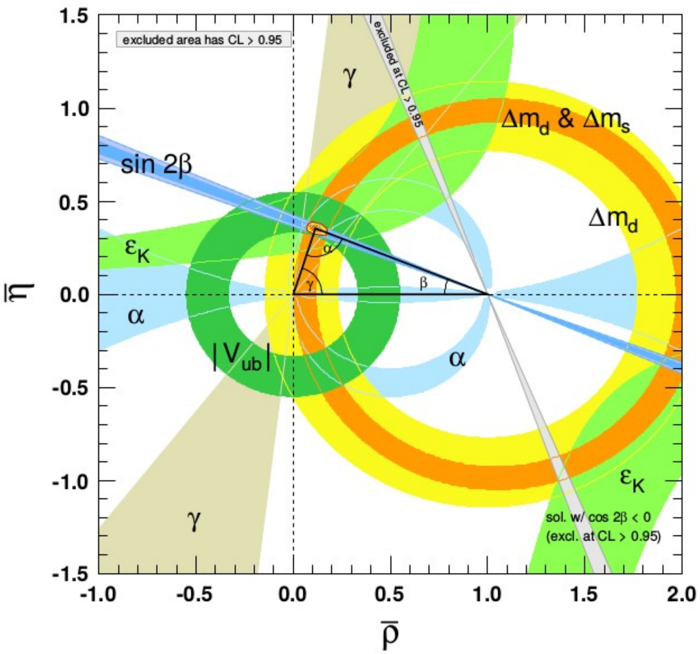
- Do the unitarity angles add up to 180°?
  Today $\alpha+\beta+\gamma = (175 \pm 9)^\circ$ [PDG]
- Is $S \equiv \sin(2\beta) \equiv \sin(2\phi_1)$ the same in $s\bar{q}q$ modes as in $J/\psi\, K_S$? ***With 50 ab^{-1} of Belle II data, even a small deviation $\Delta S \sim 0.02$ could be established with 5σ significance.*** [Refs.: CP-1, CP-2.]

$\sin(2\beta)$	0.682 ± 0.019
α	$(85.4\ ^{+3.9}_{-3.8})^\circ$
γ	$(68.0\ ^{+8.0}_{-8.5})^\circ$

[PDG]

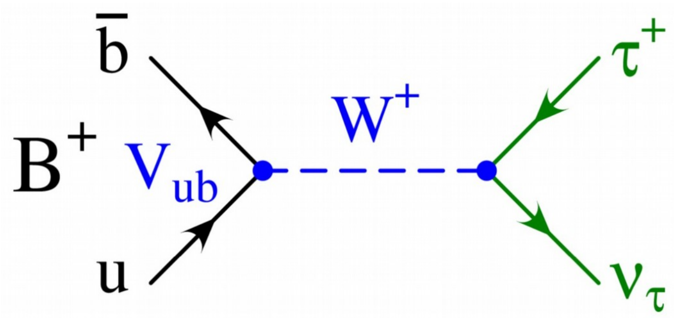
- Extrapolating from Belle analyses and considering some vertex reconstruction errors to be irreducible predicts, for 50 ab^{-1}, an uncertainty of 0.008 for $\sin(2\beta)$, down from ~0.026 for Belle, and an uncertainty of 0.007 for the direct CPV parameter A, down from ~0.020 for Belle.

- Thus, we expect that the uncertainty on
  the angle β will be ~0.3°.
  the angle α will be ~1.0°, and
  the angle γ will be ~1.5°.
- The theory uncertainty on β and γ will be lower still, but the theory uncertainty on α is expected to remain significant.
- At the same time, improvement in precision should help resolve the tension in inclusive and exclusive measurements of $|V_{ub}|$ and $|V_{cb}|$.
- Similarly, measuring β in $s\bar{s}s$ modes and comparing to measurements in $s\bar{c}c$ modes is necessary to resolve tensions there.



[PDG]

BF(B⁺ → τν)



Sensitive to existence of a charged Higgs

Measurable via other modes*
Lattice QCD*

$$\mathcal{B}_{\rm SM}(B^+\to\tau^+\nu_\tau) = \frac{G_F^2 m_B}{8\pi} m_\tau^2 \overbrace{\left(1-\frac{m_\tau^2}{m_B^2}\right)^2} f_B^2 \overbrace{|V_{ub}|^2 \tau_B}$$

$$= 0.75^{+0.10}_{-0.05} \times 10^{-4}$$

Helicity suppression
Makes $\tau\nu \gg \mu\nu \gg e\nu$
but with precisely determined ratios

- In the type II 2-Higgs doublet model (2HDM) [ref. TH-1, TH-2],

$$\mathcal{B}(B\to\tau\nu) = \mathcal{B}_{\rm SM} \times r_H, \quad r_H = \left(1-\tan^2\beta\frac{m_B^2}{m_{H^\pm}^2}\right)^2 \quad \text{If } \tan^2\beta\frac{m_B^2}{m_{H^\pm}^2} \begin{array}{l} < 2, \quad r_H < 1, \\ \gg 2, \quad r_H \gg 1. \end{array}$$

$\tan\beta$ is the ratio of the vevs of the two doublets.

- For a charged Higgs to break lepton universality we need a “type III” 2HDM (types I, II respect universality). Leptoquark or other models may be better fits.
- Belle II should make a 5% measurement of the BF.

$^*V_{ub} = (3.70 \pm 0.12 \pm 0.26) \times 10^{-3}$
$f_{B_s} = (225.6 \pm 1.1 \pm 5.4)$ MeV
$f_{B_s}/f_{B_d} = 1.205 \pm 0.004 \pm 0.007$
from <http://ckmfitter.in2p3.fr> in early 2014.

BF($B^+ \to D(^*)\tau\nu$)

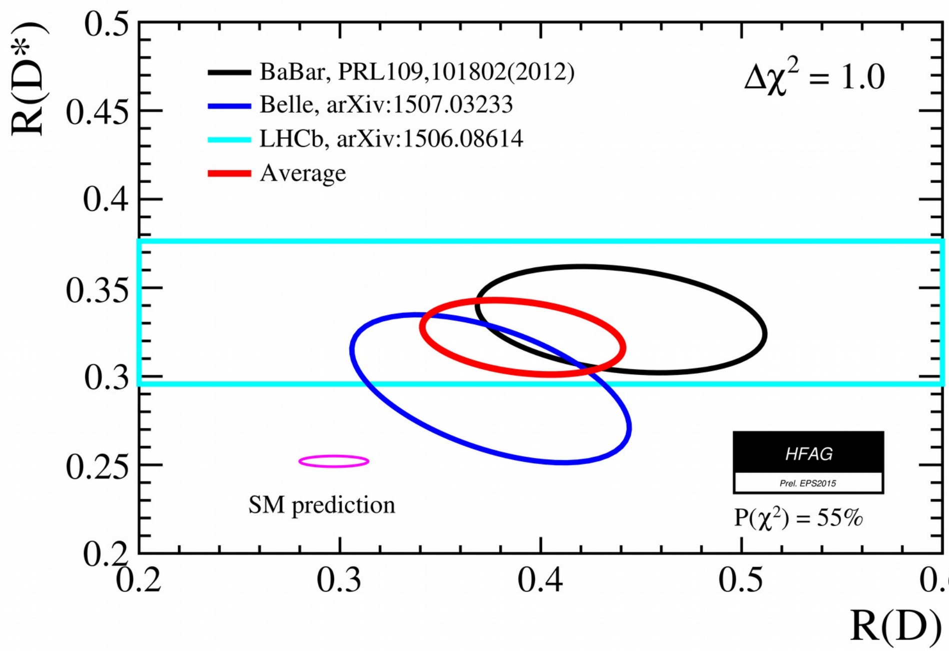
- The Belle, BaBar collaborations studied B semileptonic decays and found evidence for LFV [B3-1, B3-2] in the ratios

- $R(D^{(*)}) \equiv BF(B^+ \to D^{(*)}\tau\nu) \,/\, BF(B^+ \to D^{(*)}\ell\nu)$. Since then, measurements are available also from Belle and LHCb:

	$R(D)$	$R(D^*)$
BaBar	$0.440 \pm 0.058 \pm 0.042$	$0.332 \pm 0.024 \pm 0.018$
Belle	$0.375^{+0.064}_{-0.063} \pm 0.026$	$0.293^{+0.039}_{-0.037} \pm 0.015$
LHCb		$0.336 \pm 0.027 \pm 0.030$
Average	0.388 ± 0.047	0.321 ± 0.021
SM expectation	0.300 ± 0.010	0.252 ± 0.005
Belle II, 50/ab	± 0.010	± 0.005

- As is clear from the table, Belle II will improve the uncertainty considerably on these measurements, making for a meaningful comparison with the SM and firmly establishing (or not) an excess.

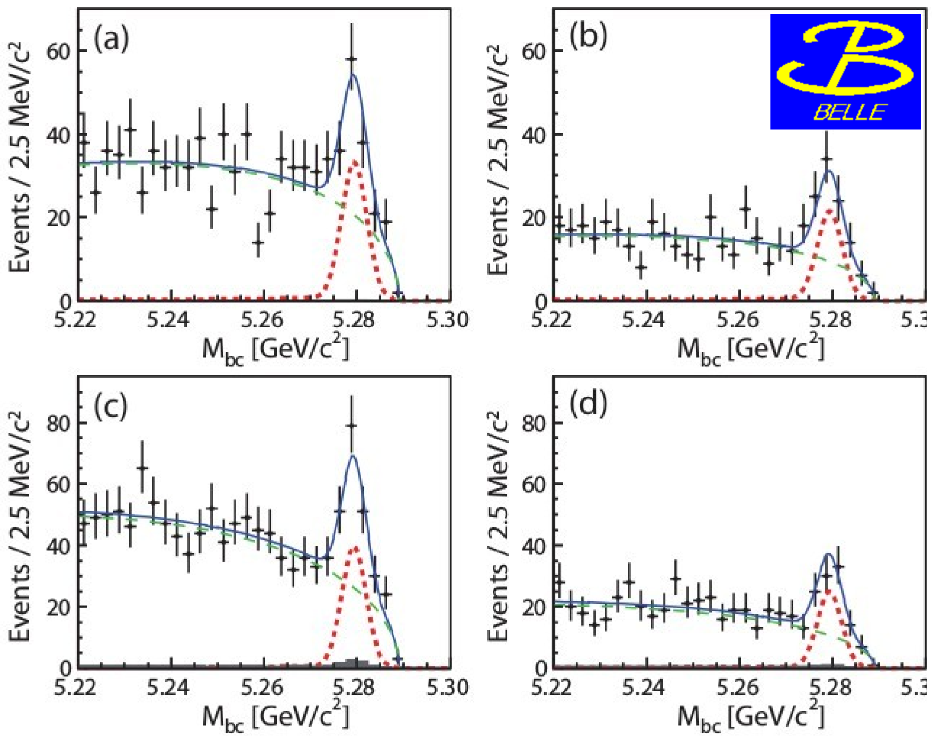
- It is important to measure differential rates to establish the nature of deviations from the SM.[TH-3]

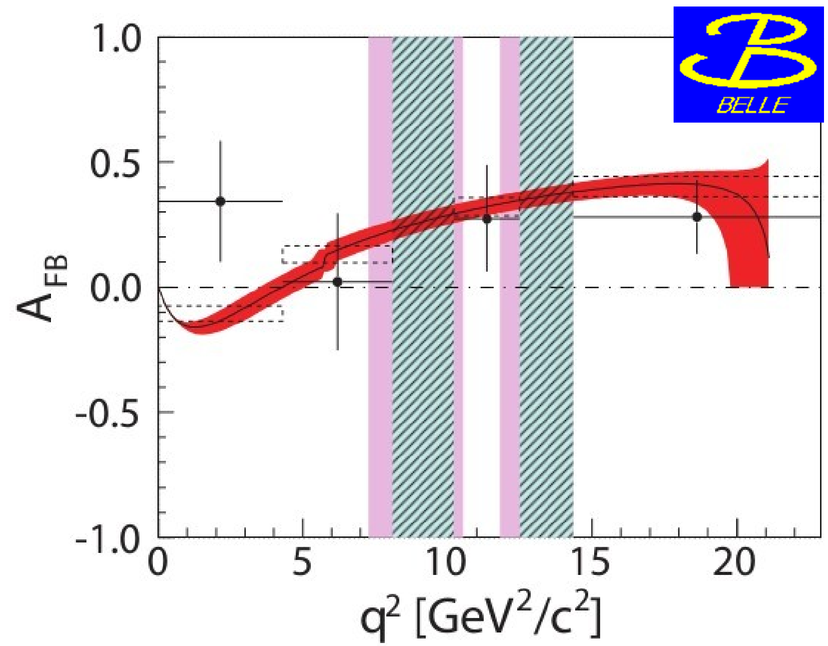


The combined $R(D)$ and $R(D^*)$ result exceeds the SM predictions at 3.9σ level, with a p-value of 1.1 x 10^{-4}. The $R(D)$ and $R(D^*)$ correlation of -0.29 is shown.

b→sγ decays

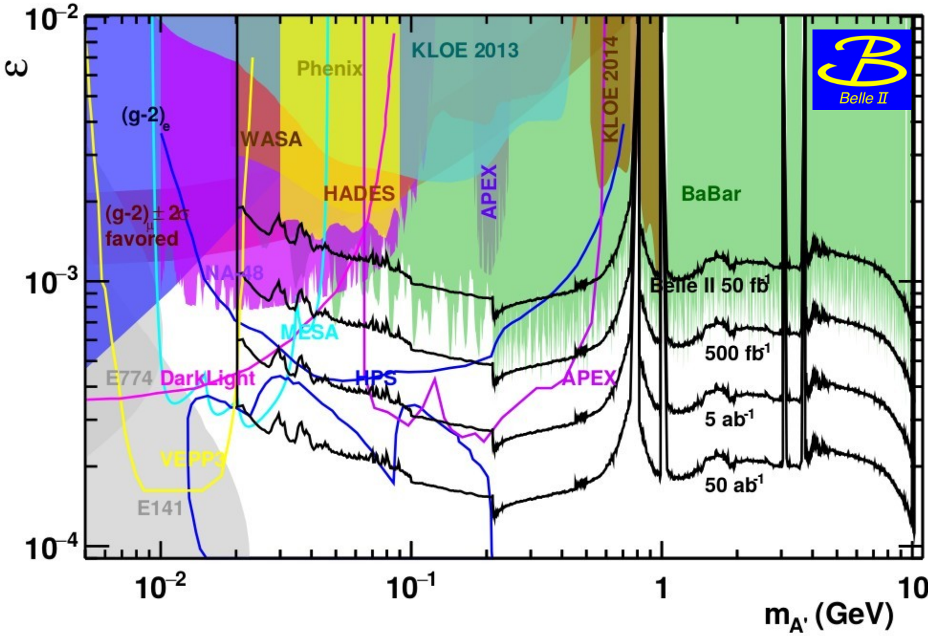
- Potential for NP to be seen in $b \to s\gamma$ decays (e.g., $K^*\gamma$) in the decay rates, CP asymmetries, angular distributions, …
- Similar studies will be done in $b \to s\ell^+\ell^-$ decays. See figures below and ref. B1-3 for the asymmetry in $B \to X_s\ell^+\ell^-$ decays.
- Should be able to investigate $B \to K^*\nu\bar{\nu}$ at the SM expected rate. [B4-1.]
- Inclusive modes are theoretically cleaner
- Exclusive modes with e's will be precisely measured; with tau's will be searched

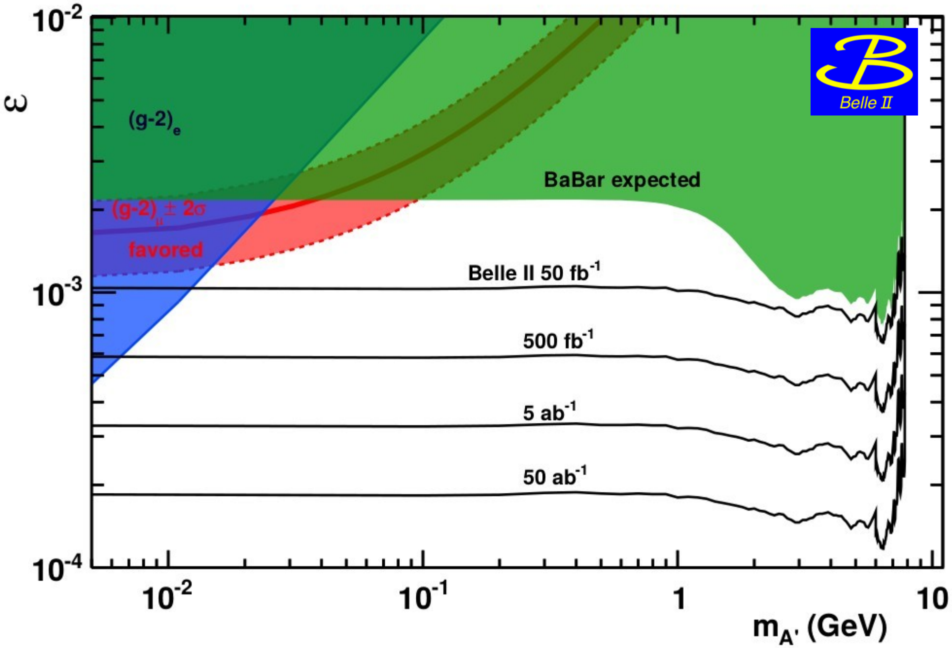




Other b, c, τ physics

- Charmless B decays; e.g., CPV in $B \to K\pi$ indicates loop NP (SM trees CKM-supp.)
- B_s physics at $\Upsilon(5S)$; e.g., rates for $B \to \gamma\gamma$, $B \to \tau\tau$, absolute BF for $B \to \mu\mu$
- Semileptonic decays; τ modes sensitive to NP, including handedness of the NP current
- Search for dark matter (dark photons, dark Higgs, other dark particles). For example, the figures below (from ref. B2-2) show exclusion regions for the parameter ε as a function of A' mass, for various experiments and projections for Belle II. Here A' mixes with strength ε with the SM photon.
- A long list of other topics (production & fragmentation, $\mu^+\mu^-$ asymmetry, ...)





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Conclusions

- B-factories in the 2000's have fulfilled promises such as
  - CPV in B-decays ($J/\psi\ K_S$ etc.)
  - D meson mixing
  - A long list of other topics (almost 1000 published papers)
- And provided unexpected new results such as
  - Spectroscopy: new states such as the X, Y, and Z
  - Hints of lepton non-universality
- The Belle-II experiment under construction should similarly deliver on
  - Unitarity triangles, Charm Physics, spectroscopy, NP explorations via loops, … a vast number of topics
  - *And provide exciting new results on new topics ??, ??, …*
  - *Stay tuned to Belle II Theory Interface Program (B2TIP)* @ Pittsburgh in May via https://kds.kek.jp/indico/event/19723/

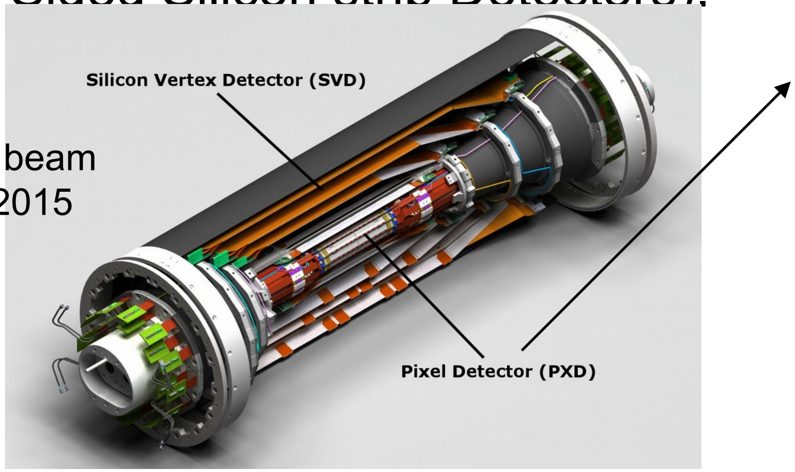
Many thanks to V. Bhardwaj, T. Browder, Z. Dolezal, B. Fulsom, C. Hearty, Y. Kwon, A. Loos, C. Rosenfeld, A. Schwartz, M. Staric, P. Urquijo, and all members of the Belle II collaboration and KEK whose comments, papers, talks and other efforts have helped prepare this talk directly and indirectly.

Extra Slides

Vertex Detectors

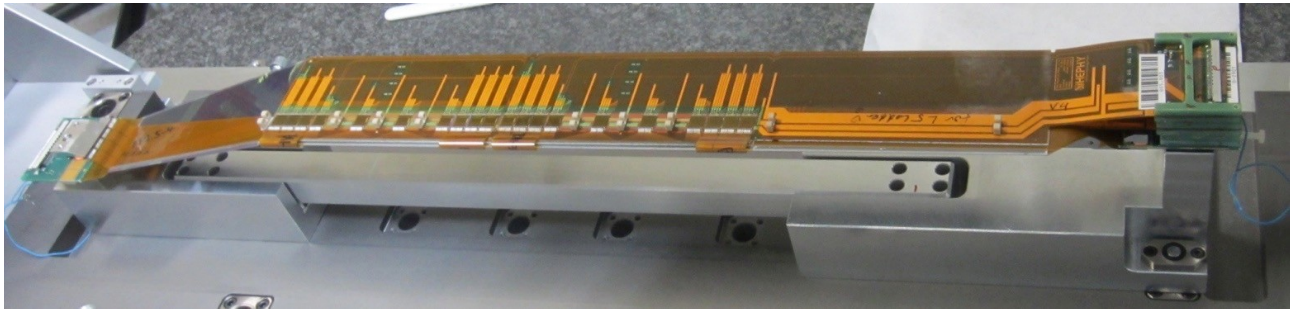
Beam pipe radius reduced from 2cm-1.5cm for Belle to 1cm for Belle II.

New vertex detectors: 2 layers of pixels (DEPFETs: Depleted P- Channel Field Effect Transistor) and 4 layers of DSSD (Double Sided Silicon strip Detectors).



Into test beam in June 2015

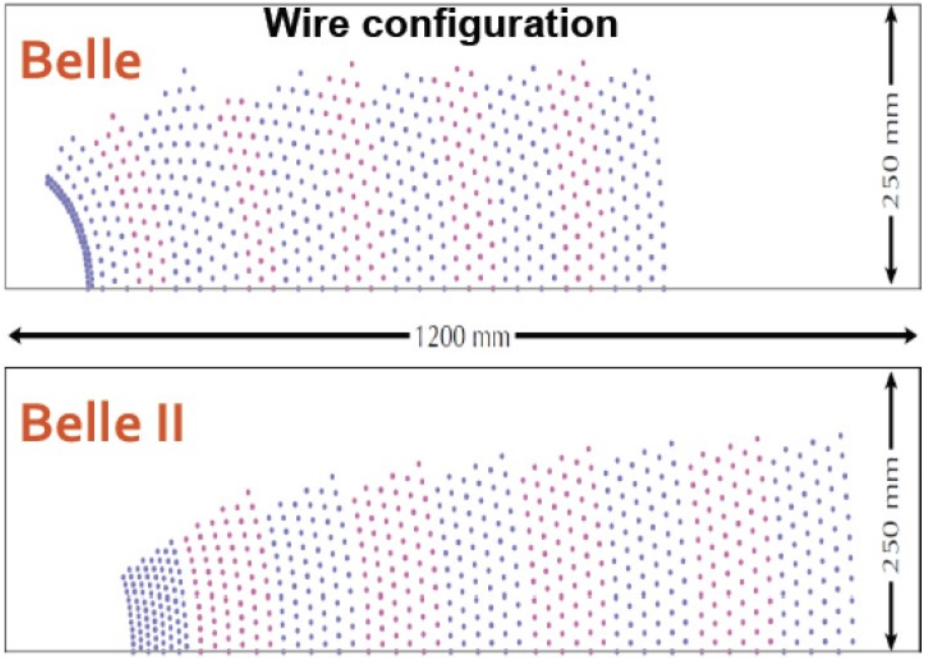
Beam Pipe		**r = 10mm**
DEPFET		
	Layer 1	**r = 14mm**
	Layer 2	**r = 22mm**
DSSD		
	Layer 3	**r = 38mm**
	Layer 4	**r = 80mm**
	Layer 5	**r = 115mm**
	Layer 6	**r = 140mm**



First working SVD ladder readout at Vienna in April

Central Drift Chamber

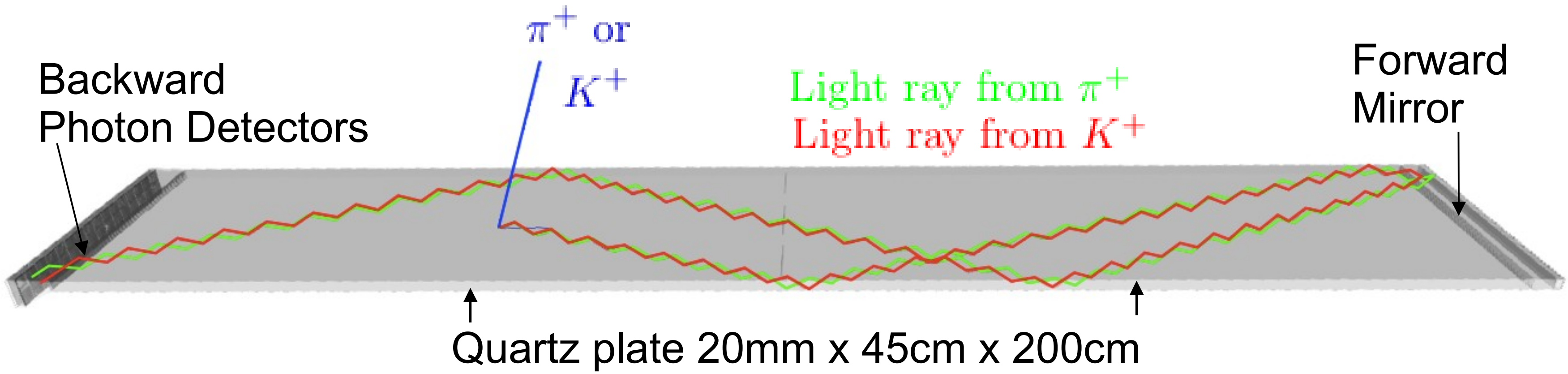
- Outer radius of Belle II CDC is 28% bigger than the Belle CDC.
- Stringing of 51456 wires was completed in January 2014.
- Commissioning with cosmic rays is ongoing.



	Belle	Belle II
Innermost sense wire	r=88mm	r=168mm
Outermost sense wire	r=863mm	r=1111.4mm
Number of layers	50	56
Total sense wires	8400	14336
Gas	He:C_2H_6	He:C_2H_6
Sense wire	W(Φ30μm)	W(Φ30μm)
Field wire	Al(Φ120μm)	Al(Φ120μm)

iTOP Detector

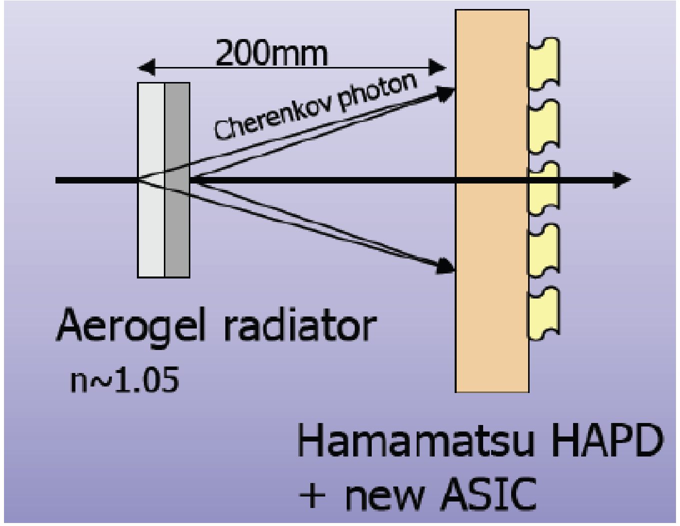
- The Imaging Time of Propagation (iTOP) detector does particle ID from a perch between the CDC and EM calorimeter, a gap of ~10cm.
- It operates both as a time-of-flight detector and a ring imaging Cherenkov counter.



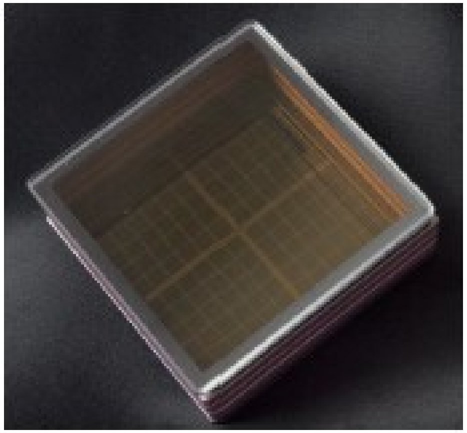
- The light rays never have the opportunity to form a ring image in space only. The "image" is in space-time and thus requires superb time measurement to resolve.
- The point of impact and the angle of the trajectory are determined from CDC data.

Aerogel RICH

- The ARICH does particle ID in the forward endcap.
- In contrast with the iTOP it detects Cherenkov light as rings in space only.

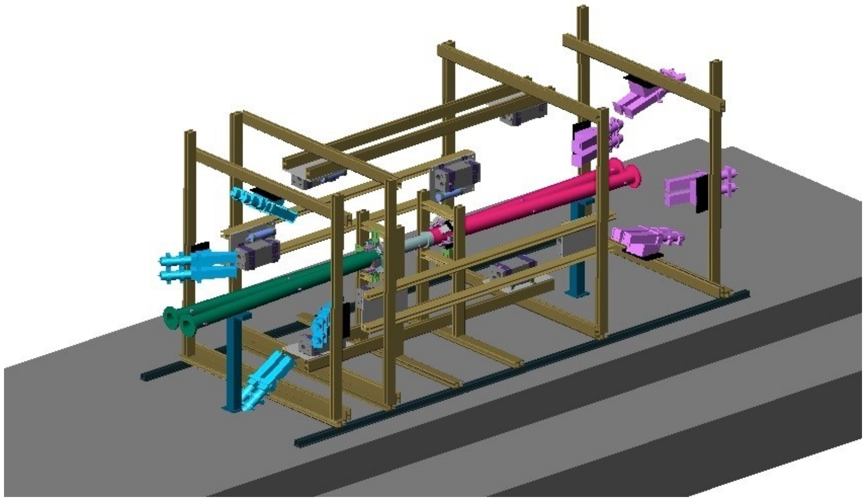


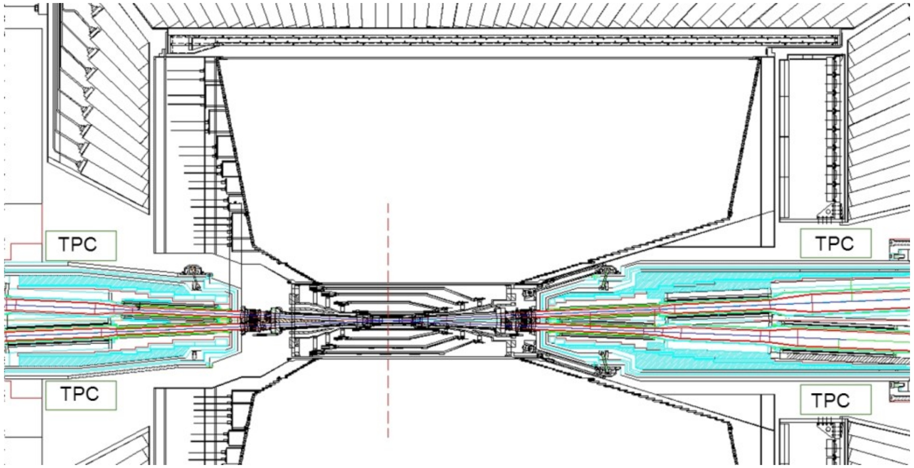
HAPD



- ARICH incorporates 420 Hybrid Avalanche Photo Detectors (HAPD), each with 144 channels.

Two Phases of the Commissioning Detector (BEAST)



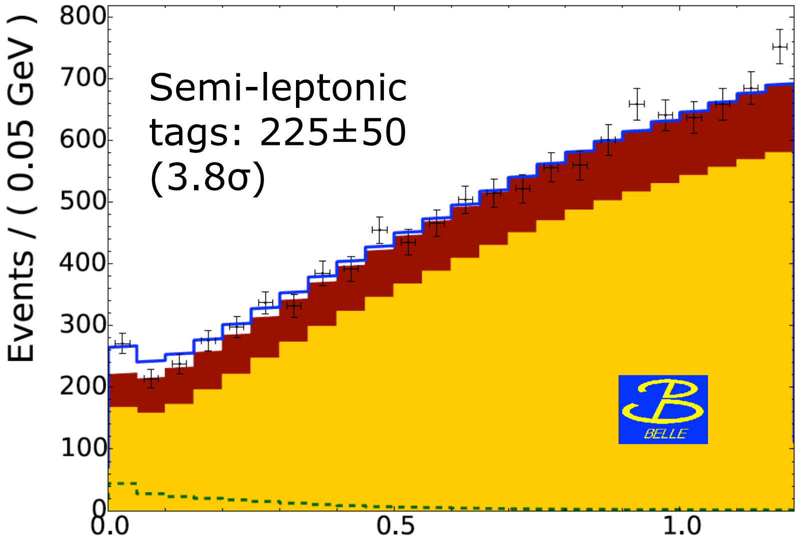


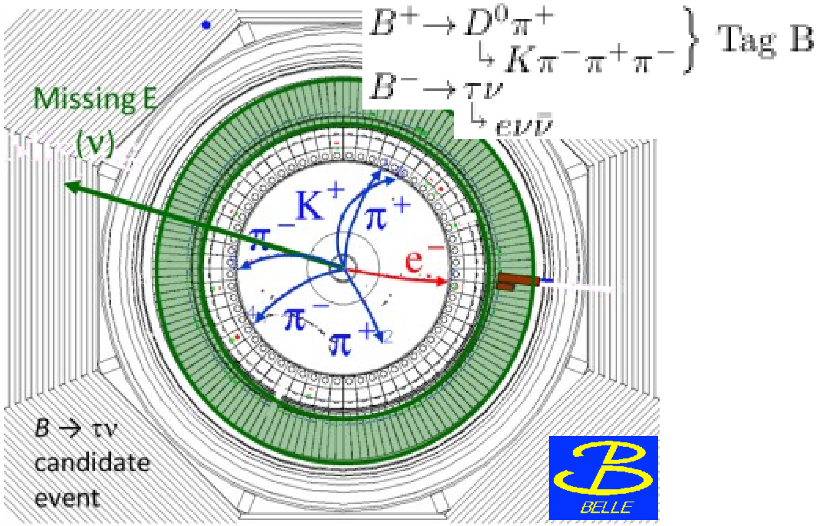
BEAST Phase 1: Jan 2016
- Variety of subsystems on fiberglass support structure
- **No Belle DAQ, only BEAST DAQ**

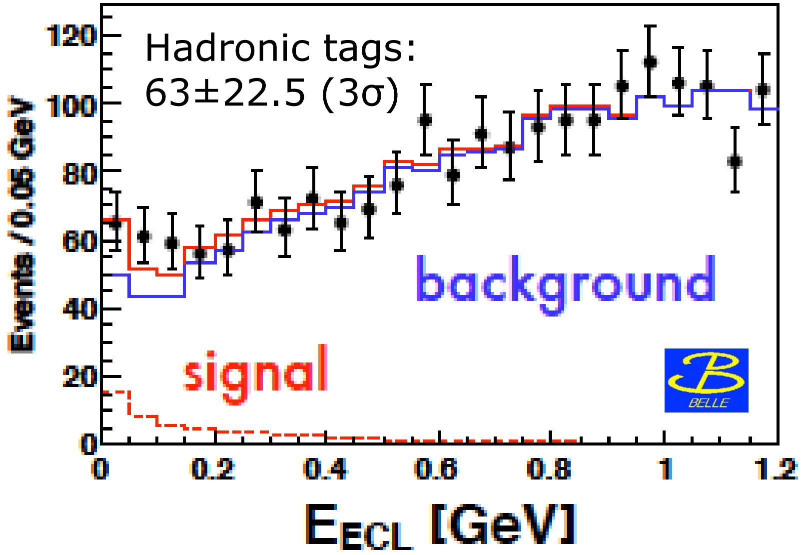
BEAST Phase 2: ~May 2017
- Belle II rolled in.
- VXD BEAST Assembly
- BEAST detectors in dock space and around QCS
- **BEAST DAQ & Belle DAQ**

A Belle II task force has been looking into opportunities for physics during BEAST Phase 2.

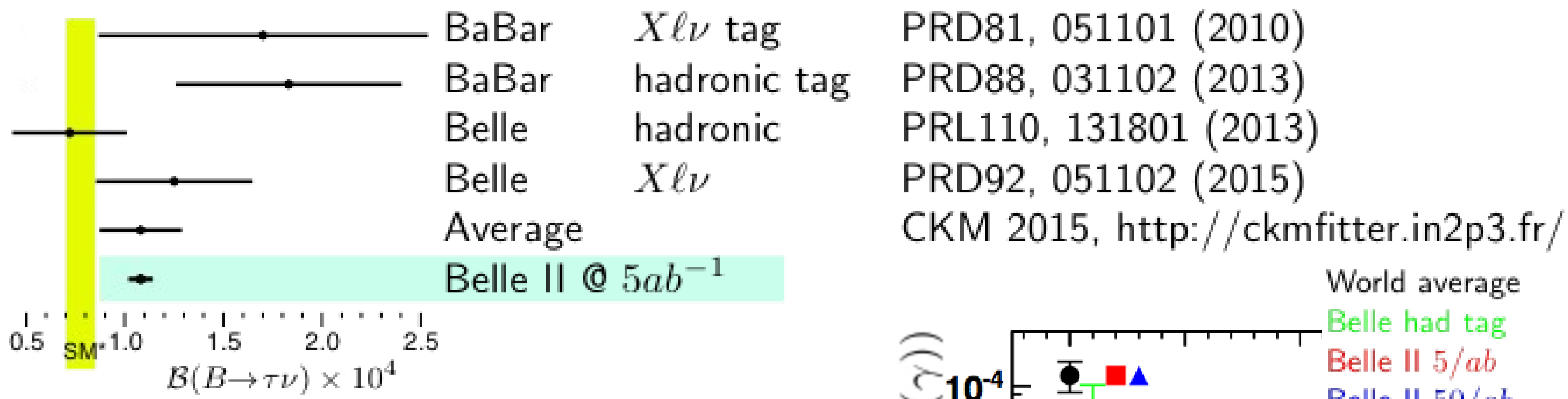
$\mathcal{B}(B \rightarrow \tau\nu)$



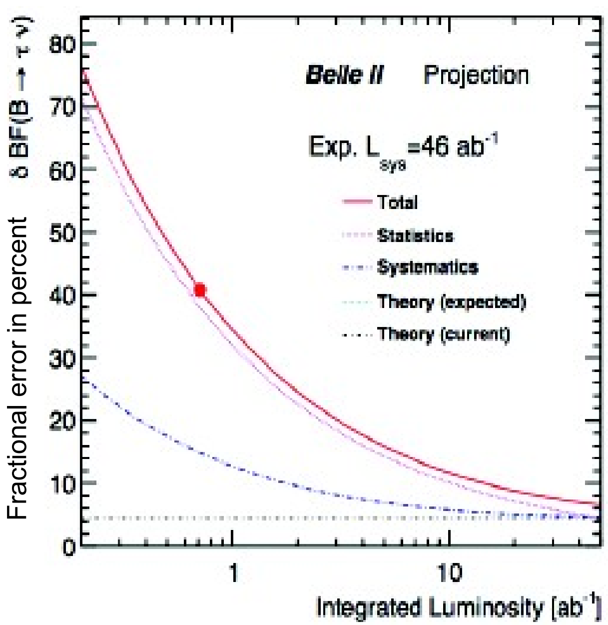


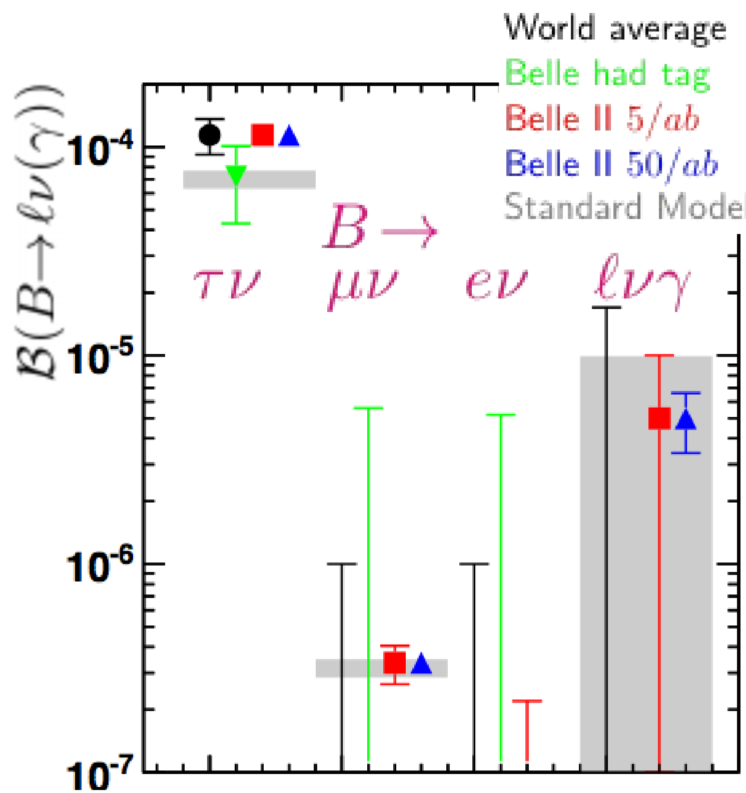


E_{ECL} is calorimeter energy not associated with the daughters of the $\Upsilon(4S)$.
Ultimately the signal is the small excess above projected background at low E_{ECL}.
Challenging for the instrumentation at the B factories.
(Much more challenging at LHCb.)



30% precision at Belle → <5% precision at Belle II





Belle, B→ μ ν , e ν (Had) PRD91, 052016 (2015)
Belle, B→ l ν gamma Preliminary (2014 B2TiP)

*See slide 4.

Two Higgs Doublets Models (2HDMs)

- Extend the SM
- Face problem of FCNC's at tree-level
- Resolved by introducing discrete symmetries
  - type I by having all q couple to Φ_2.
  - type II by up-type RH (u_R) quarks couple to Φ_2.
- Broken $\mathcal{Z}_2$ symmetry in type III allows some tree-level FCNC

Some Details from M. Staric, CHARM2015 talk

Prospects for charm at Belle II

- Belle measurements extrapolated to 50 ab^{-1}
- Systematic uncertainties primarily scale with integrated luminosity, with two exceptions:
  - t-dependent Dalitz: model related systematics (resonance parameters - masses, widths, form factors, angular dependence etc.)
  - A_{CP} of modes with K^0_s: asymmetry of $K^0/\overline{K}^0$ interactions in material (PRD 84, 111501 (2011)), $\sigma_{\rm irred} \approx 0.02\%$
- Extrapolation:

$$\sigma_{BelleII} = \sqrt{(\sigma^2_{stat} + \sigma^2_{sys})\frac{\mathcal{L}_{Belle}}{50\ \mathrm{ab}^{-1}} + \sigma^2_{\rm irred}}$$

Detector performance improvements are not included in the extrapolation (detailed MC studies are on the way)

Mixing and indirect CPV

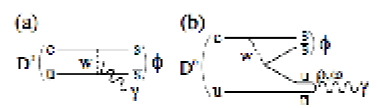
$D^0 \to K^{(*)-}\ell^+\nu$	492 fb^{-1}	50 ab^{-1}
R_M	$(1.3 \pm 2.2 \pm 2.0) \times 10^{-4}$	$\pm 0.3 \times 10^{-4}$
$D^0 \to K^+K^-, \pi^+\pi^-$	976 fb^{-1}	50 ab^{-1}
y_{CP}	$(1.11 \pm 0.22 \pm 0.11)\%$	$\pm 0.04\%$
A_Γ	$(-0.03 \pm 0.20 \pm 0.08)\%$	$\pm 0.03\%$
$D^0 \to K^+\pi^-$	400 fb^{-1}	50 ab^{-1}
x'^2	$(1.8 \pm 2.2 \pm 1.1) \times 10^{-4}$	$\pm 0.22 \times 10^{-4}$
y'	$(0.06 \pm 0.40 \pm 0.20)\%$	$\pm 0.04\%$
A_M	0.67 ± 1.20	± 0.11
$\lvert\phi\rvert$	0.16 ± 0.44	± 0.04
$D^0 \to K^0_s\pi^+\pi^-$	921 fb^{-1}	50 ab^{-1}
x	$(0.56 \pm 0.19 \pm 0.06 \pm 0.08)\%$	$\pm 0.08\%$
y	$(0.30 \pm 0.15 \pm 0.06 \pm 0.04)\%$	$\pm 0.05\%$
$\lvert q/p\rvert$	$0.90 \pm 0.16 \pm 0.04 \pm 0.06$	± 0.06
ϕ	$-0.10 \pm 0.19 \pm 0.04 \pm 0.07$	± 0.07

$$|q/p| = 1 + \tfrac{1}{2}A_M \Rightarrow \delta|q/p| = \tfrac{1}{2}\delta A_M$$

Time-integrated measurements (A_{CP})

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
$D^0 \to \pi^0\pi^0$	966	$-0.03 \pm 0.64 \pm 0.10$	± 0.09
$D^0 \to K^0_s\pi^0$	966	$-0.21 \pm 0.16 \pm 0.07$	± 0.03
$D^0 \to K^0_s\eta$	791	$+0.54 \pm 0.51 \pm 0.16$	± 0.07
$D^0 \to K^0_s\eta'$	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
$D^+ \to K^0_s\pi^+$	977	$-0.36 \pm 0.09 \pm 0.07$	± 0.03
$D^+ \to K^0_s K^+$	977	$-0.25 \pm 0.28 \pm 0.14$	± 0.05
$D^+_s \to K^0_s\pi^+$	673	$+5.45 \pm 2.50 \pm 0.33$	± 0.29
$D^+_s \to K^0_s K^+$	673	$+0.12 \pm 0.36 \pm 0.22$	± 0.05

Direct CPV in $D^0 \to \phi\gamma, \rho^0\gamma$



- Direct CPV in radiative decays can be enhanced to exceed 1% (G. Isidori and J. F. Kamenik, PRL 109, 171801 (2012))
  - $D^0 \to \phi\gamma$: A_{CP} up to 2%
  - $D^0 \to \rho^0\gamma$: A_{CP} up to 10%
- $D^0 \to \phi\gamma$: first observation by Belle with 78 fb^{-1} (PRL 92, 101803 (2004))
  - measured yield: $27.6^{+7.4+0.5}_{-6.5-1.0}$ $\Rightarrow$ relative error on yield 25% (as would be the error on A_{CP})
- A_{CP} sensitivity at 50 ab^{-1}: $\approx 1\%$

P. Urquijo [B2-1]

Belle uncertainties and Belle II projections

	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
	$S(B \to K^0_S K^0_S K^0_S)$	$0.30 \pm 0.32 \pm 0.08$ [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.	$37.5 \cdot 10^{-3}(1 \pm 3.0\%_{\text{ex.}} \pm 2.7\%_{\text{th.}})$ [10]	1.8%	1.4%
	$\lvert V_{ub}\rvert$ incl.	$4.47 \cdot 10^{-3}(1 \pm 6.0\%_{\text{ex.}} \pm 2.5\%_{\text{th.}})$ [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
	$S(B \to K^0_S \pi^0 \gamma)$	$-0.10 \pm 0.31 \pm 0.07$[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
	$A_{CP}(D^0 \to K^0_S\pi^0)$ [10^{-2}]	$-0.21 \pm 0.16 \pm 0.09$ [62]	0.08	0.03
Charm Mixing	$x(D^0 \to K^0_S\pi^+\pi^-)$ [10^{-2}]	$0.56 \pm 0.19 \pm {}^{0.07}_{0.13}$ [50]	0.14	0.11
	$y(D^0 \to K^0_S\pi^+\pi^-)$ [10^{-2}]	$0.30 \pm 0.15 \pm {}^{0.05}_{0.08}$ [50]	0.08	0.05
	$\lvert q/p\rvert(D^0 \to K^0_S\pi^+\pi^-)$	$0.90 \pm {}^{0.16}_{0.15} \pm {}^{0.08}_{0.06}$ [50]	0.10	0.07
	$\phi(D^0 \to K^0_S\pi^+\pi^-)$ [°]	$-6 \pm 11 \pm {}^{4}_{5}$ [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