# Physics Prospects at Belle II

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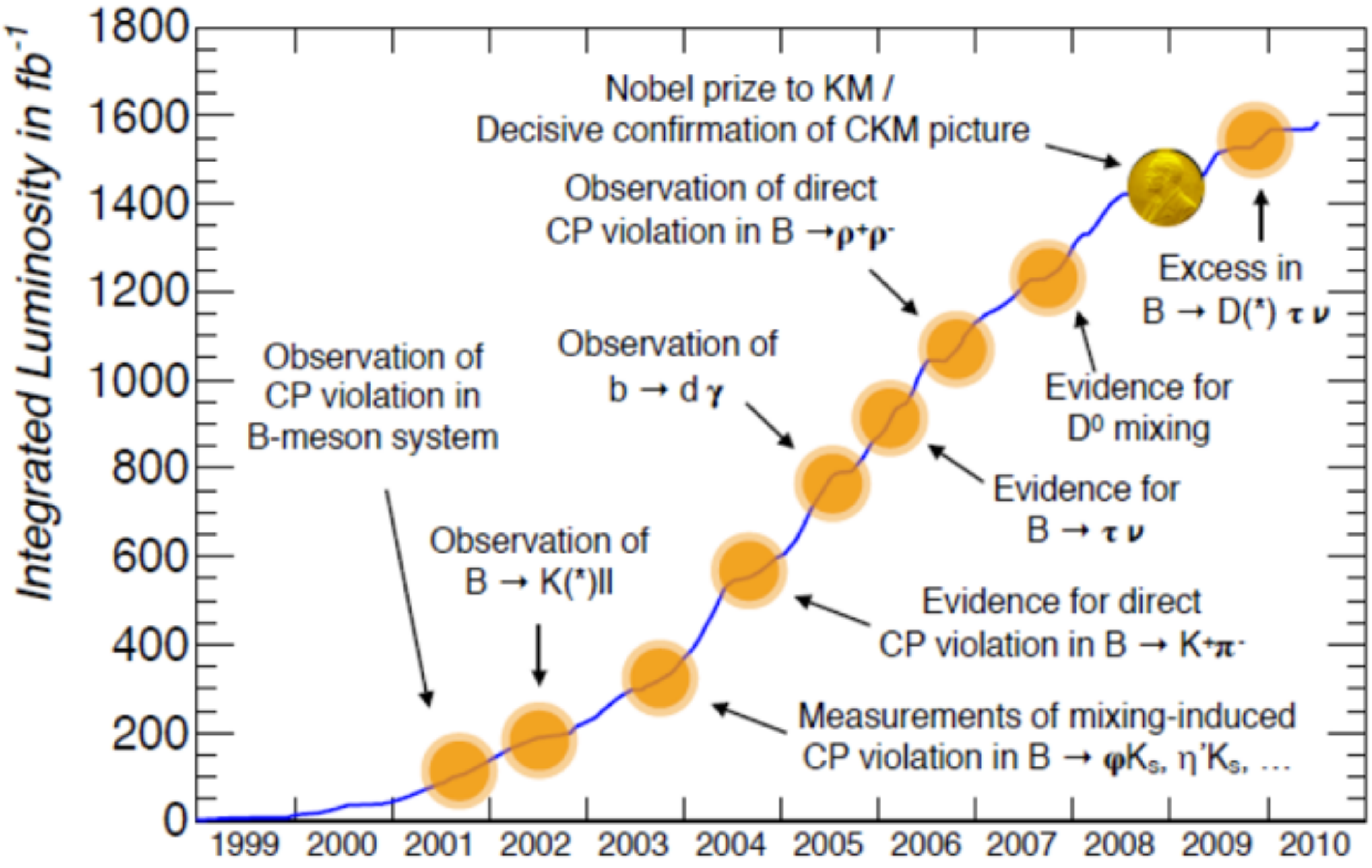
BEACH 2016 - Fairfax, VA

# B factories

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 CPV source in the SM



**$> 1$ $ab^{-1}$**

**On resonance:**

$\Upsilon(5S)$: 121 $fb^{-1}$
$\Upsilon(4S)$: 711 $fb^{-1}$
$\Upsilon(3S)$: 3 $fb^{-1}$
$\Upsilon(2S)$: 25 $fb^{-1}$
$\Upsilon(1S)$: 6 $fb^{-1}$

**Off reson./scan:**

~ 100 $fb^{-1}$

**513.7 ± 1.8 $fb^{-1}$**

**On resonance:**

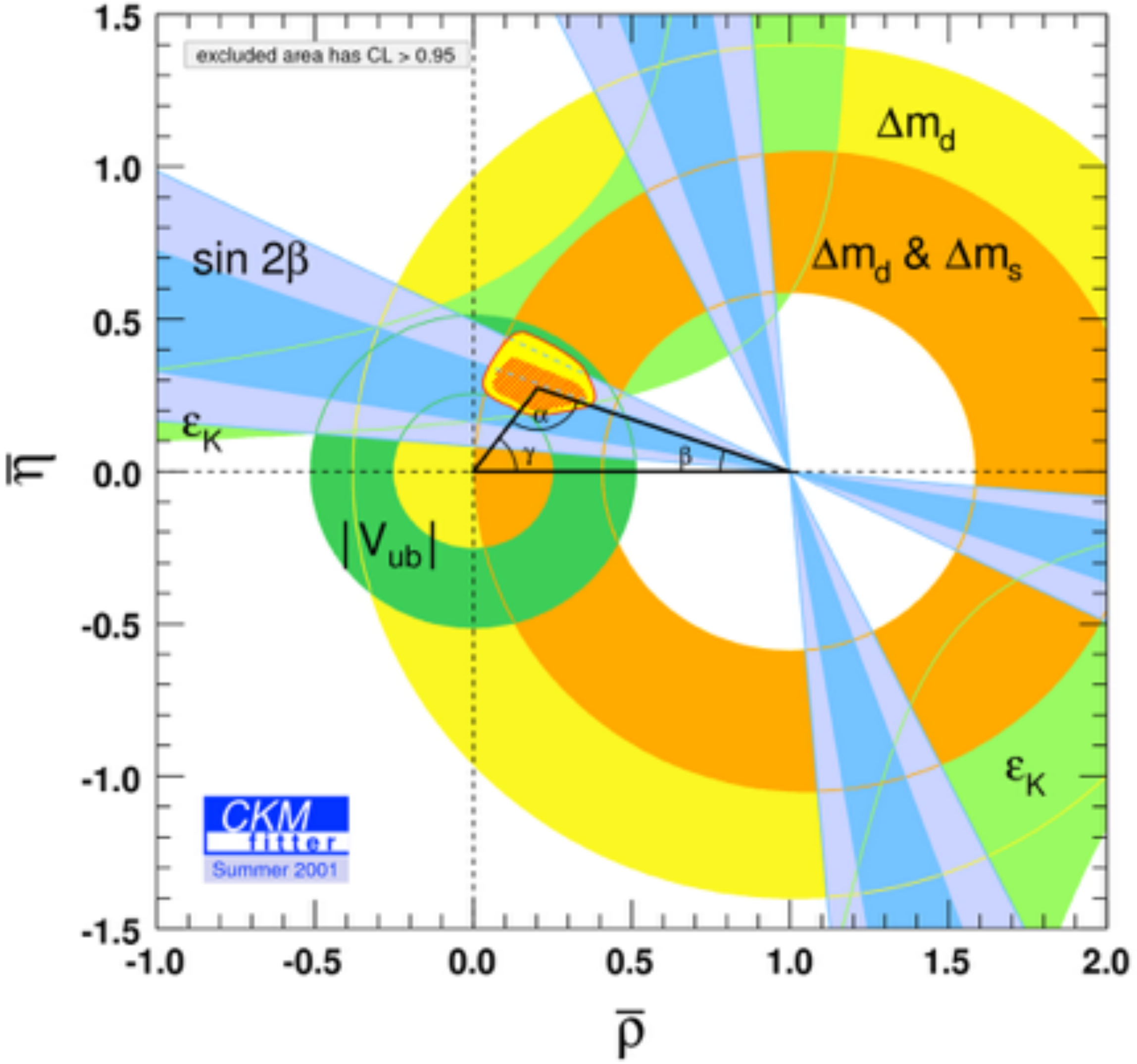
$\Upsilon(4S)$: 424 $fb^{-1}$, 471 M
$\Upsilon(3S)$: 28 $fb^{-1}$, 122 M
$\Upsilon(2S)$: 14 $fb^{-1}$, 99 M

**Off resonance:**

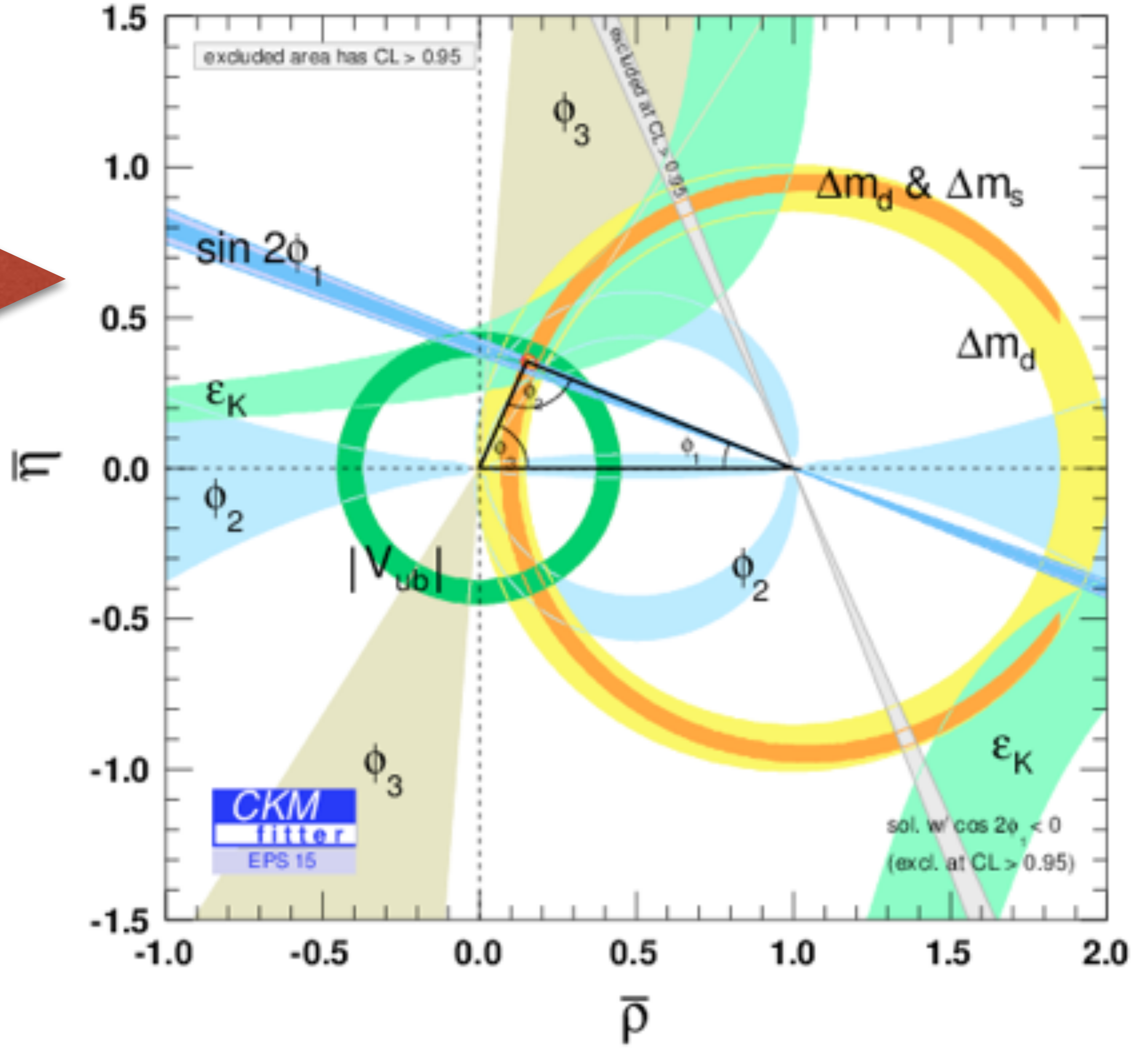
48 $fb^{-1}$

# 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

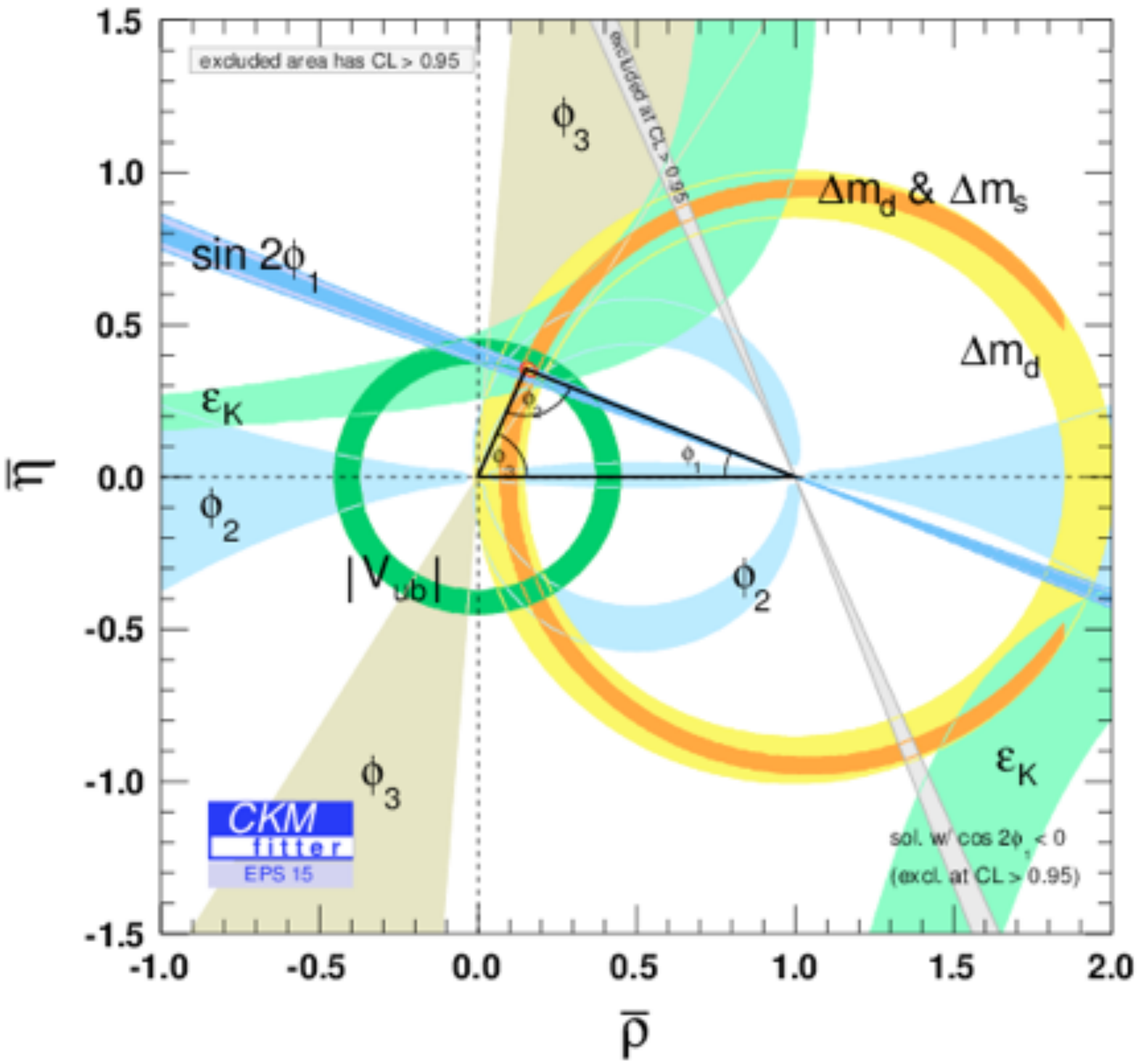


State of the art:
EPS-HEP **2015** conference

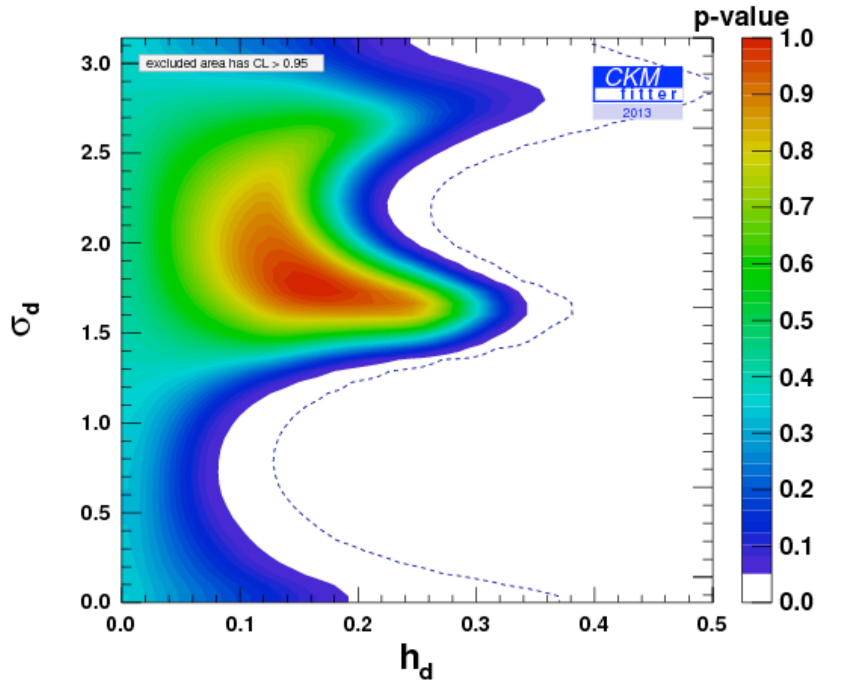


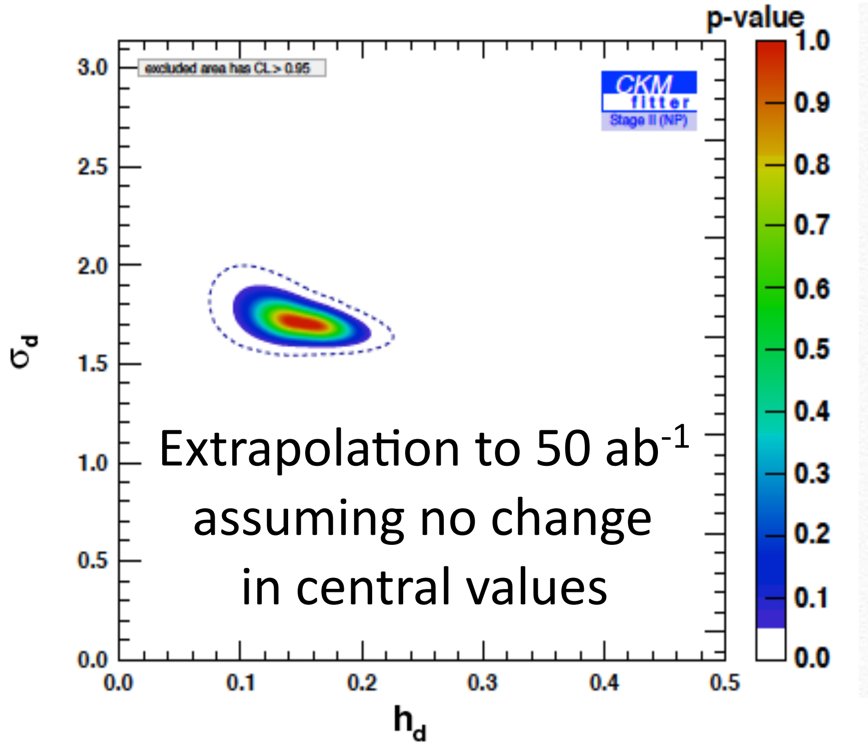
Excellent agreement between SM and results from B-factories and LHCb

# Results from global fits to data



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





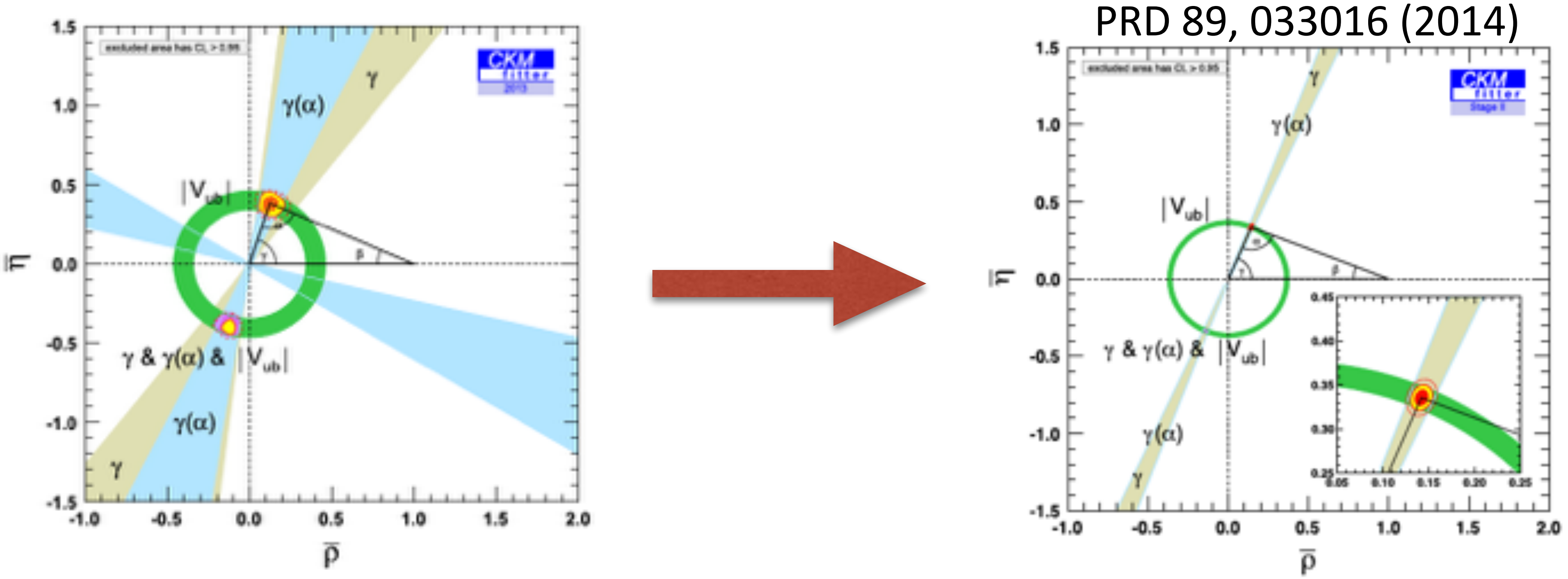
Extrapolation to 50 $ab^{-1}$
assuming no change
in central values

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

- There is still room for new physics contributions (FCNC, LFV, B → τ 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

# Prospects for New Physics (NP) at Belle II

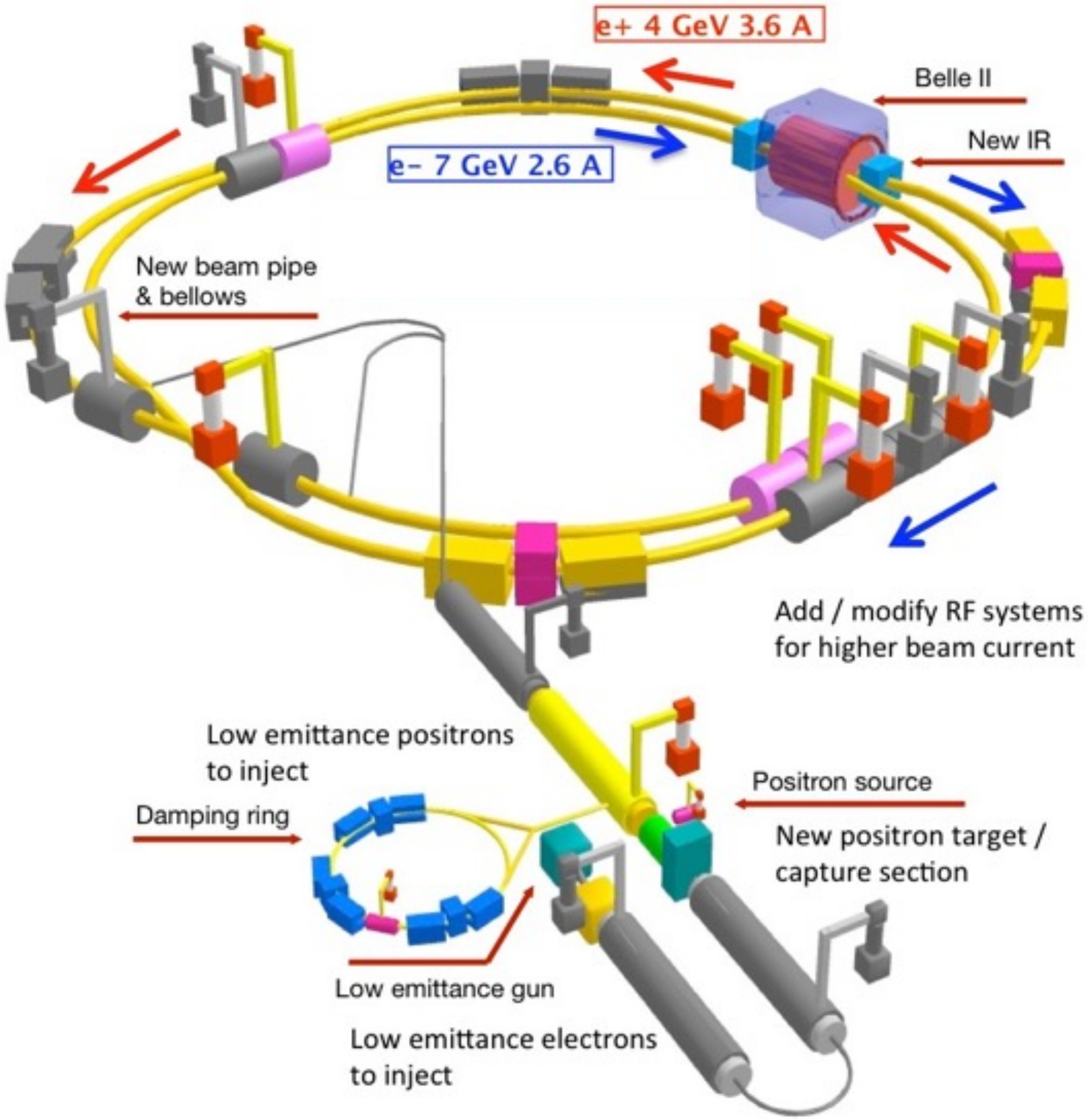
- Search for NP in the flavor sector at the intensity frontier
    - Flavor physics provides a probe for beyond the TeV scale
- Signatures of new particles or processes observed through measurements of suppressed flavor physics reactions or from deviations from SM predictions
    - An observed discrepancy can be interpreted in terms of NP models
    - Need significantly more data to make this possible



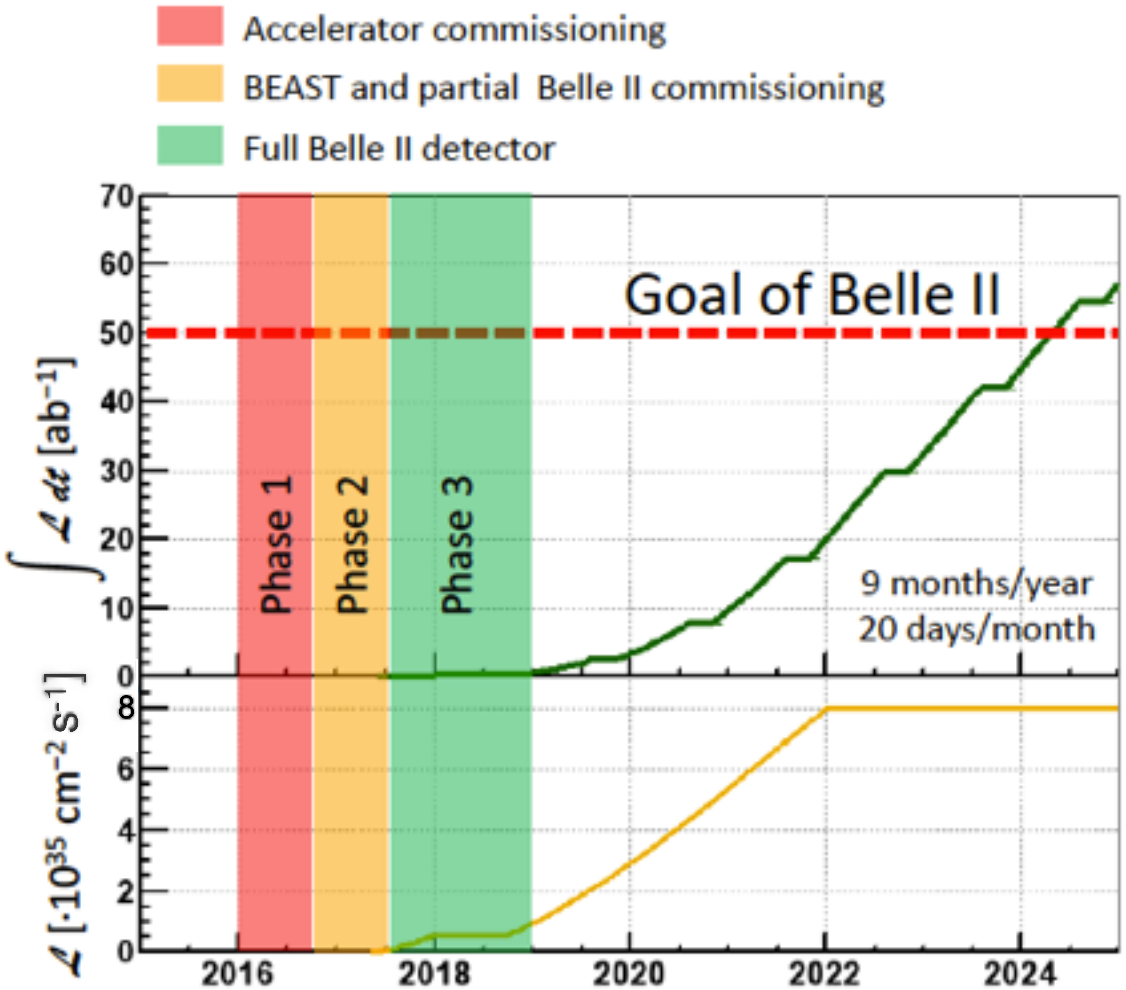
PRD 89, 033016 (2014)

- Belle II physics program much more than just CKM
    - Dark sector searches, Lepton Flavor Violation (LFV), QCD exotics, etc.

# SuperKEKB



*gray - recycled, color - new

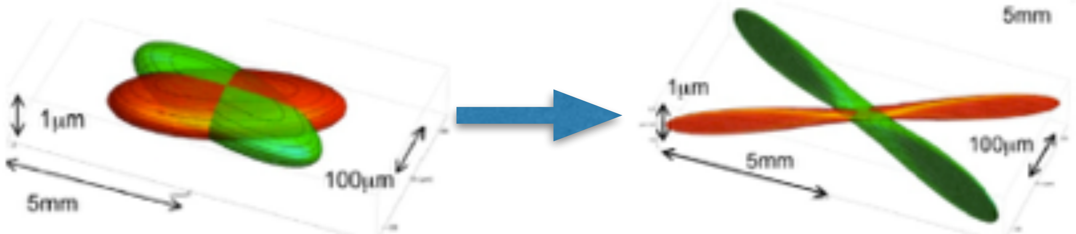


Feb 2016: First Turns at SuperKEKB
(4 GeV $e^+$ and 7 GeV $e^-$)

June 2016: (LER beam current 850 mA, HER at 770 mA)

# SuperKEKB nanobeams

To get 40x luminosity of Belle



Reduce beam size to a few 100 atomic layers!

Lorentz factor

Beam current

Beam-Beam parameter

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

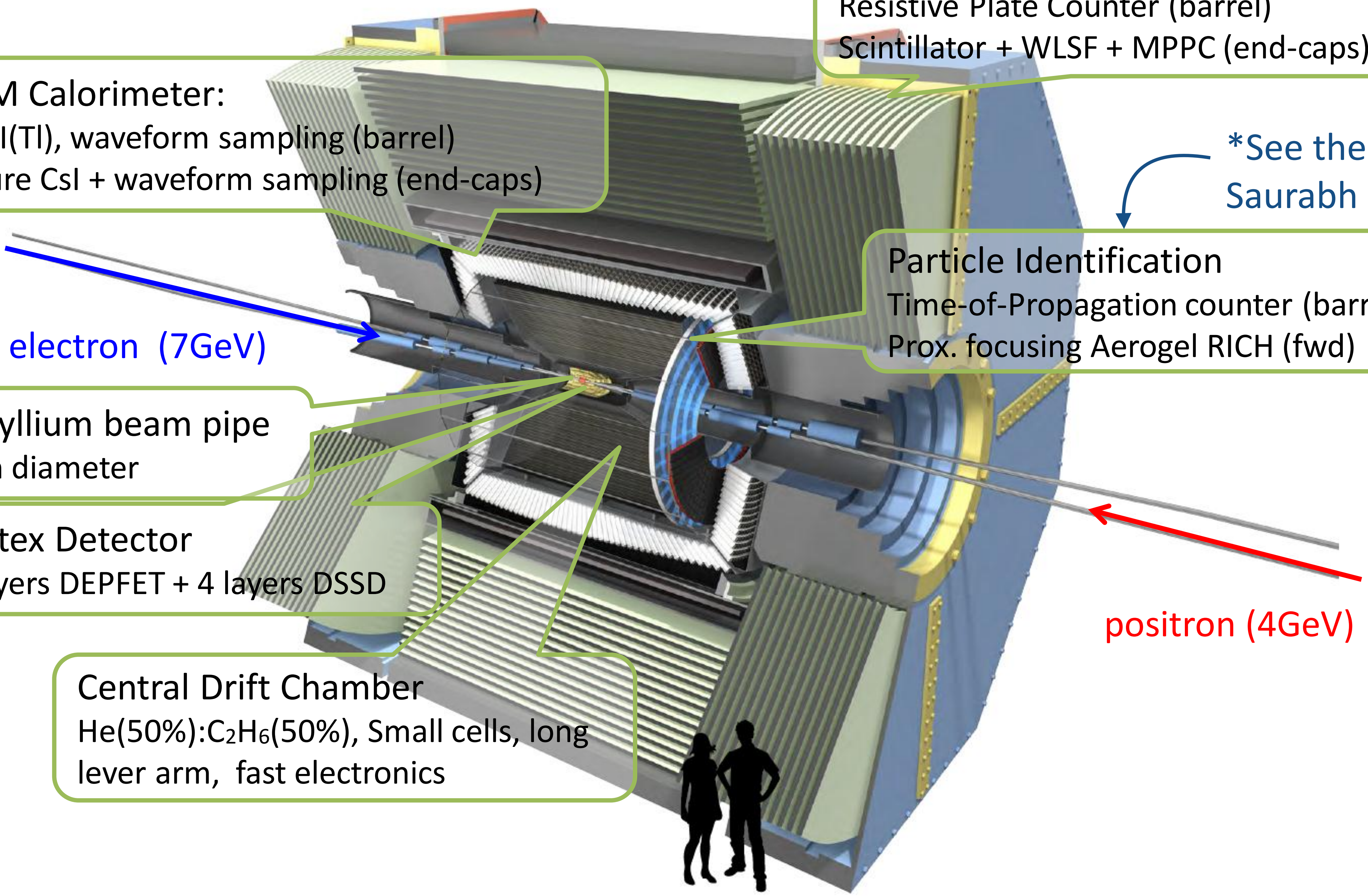
Geometrical reduction factors (crossing angle, hourglass effect)

Beam aspect ratio at IP

Vertical beta function at IP

| Parameter | | KEKB | | SuperKEKB | | units |
|---|---|---|---|---|---|---|
| | | LER | HER | LER | HER | |
| beam energy | $E_b$ | 3.5 | 8 | 4 | 7 | GeV |
| CM boost | $\beta\gamma$ | 0.425 | | 0.28 | | |
| half crossing angle | $\phi$ | 11 | | 41.5 | | mrad |
| horizontal emittance | $\varepsilon_x$ | 18 | 24 | 3.2 | 4.6 | nm |
| emittance ratio | $\kappa$ | 0.88 | 0.66 | 0.37 | 0.40 | % |
| beta-function at IP | $\beta_x^*/\beta_y^*$ | 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 | $\xi_y$ | 129 | 90 | 0.881 | 0.0807 | |
| beam size at IP | $\sigma_x^*/\sigma_y^*$ | 100/2 | | 10/0.059 | | μm |
| Luminosity | $\mathcal{L}$ | 2.1 x $10^{34}$ | | 8 x $10^{35}$ | | $cm^{-2}s^{-1}$ |

# Belle II detector



KL and muon detector:
Resistive Plate Counter (barrel)
Scintillator + WLSF + MPPC (end-caps)

EM Calorimeter:
CsI(Tl), waveform sampling (barrel)
Pure CsI + waveform sampling (end-caps)

*See the talk by Saurabh Sandilya

Particle Identification
Time-of-Propagation counter (barrel)
Prox. focusing Aerogel RICH (fwd)

Beryllium beam pipe
2cm diameter

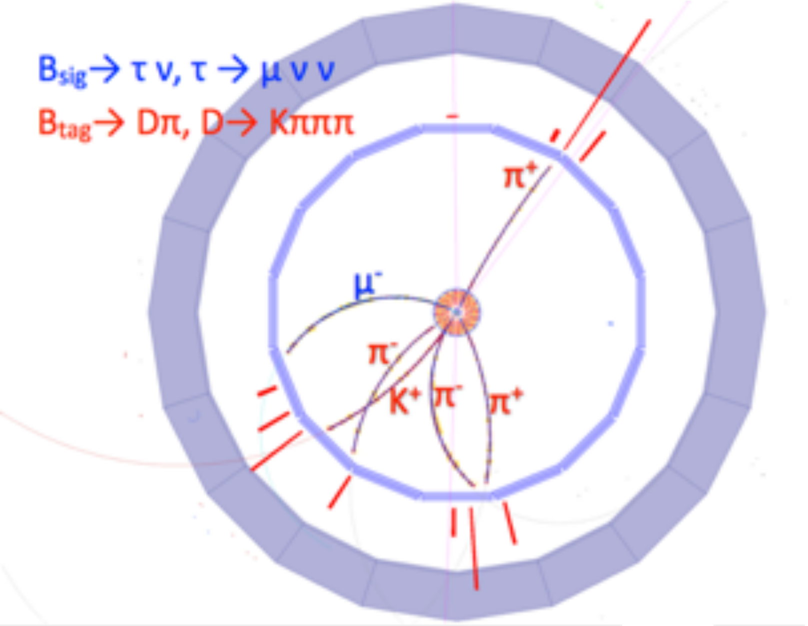
Vertex Detector
2 layers DEPFET + 4 layers DSSD

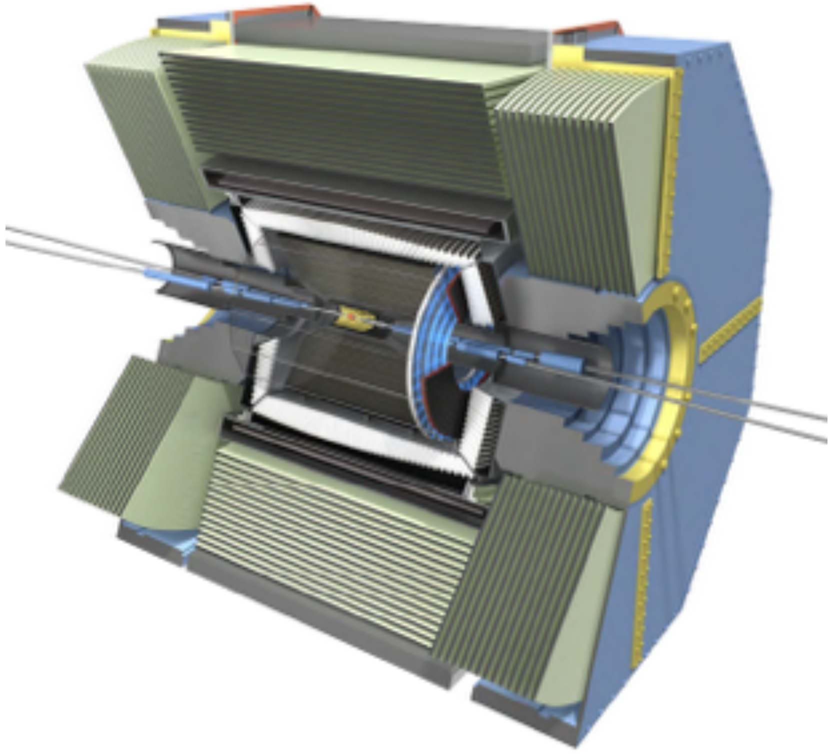
Central Drift Chamber
He(50%):$C_2H_6$(50%), Small cells, long lever arm, fast electronics

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

# Advantages of SuperKEKB and Belle II

- Very clean sample of quantum correlated $B^0\bar{B}^0$ pairs
- Low background environment
  → efficient reconstruction of neutrals ($\pi^0$, η, …)
- High 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)
- Dalitz plot analyses, missing mass analyses straightforward
- Large sample of τ leptons for measurements of rare decays and searches for LFV
- Systematics quite different than those of LHCb
  → NP seen by one experiment should be confirmed by the other
- Ultimate goal: 50 ab$^{-1}$ data sample



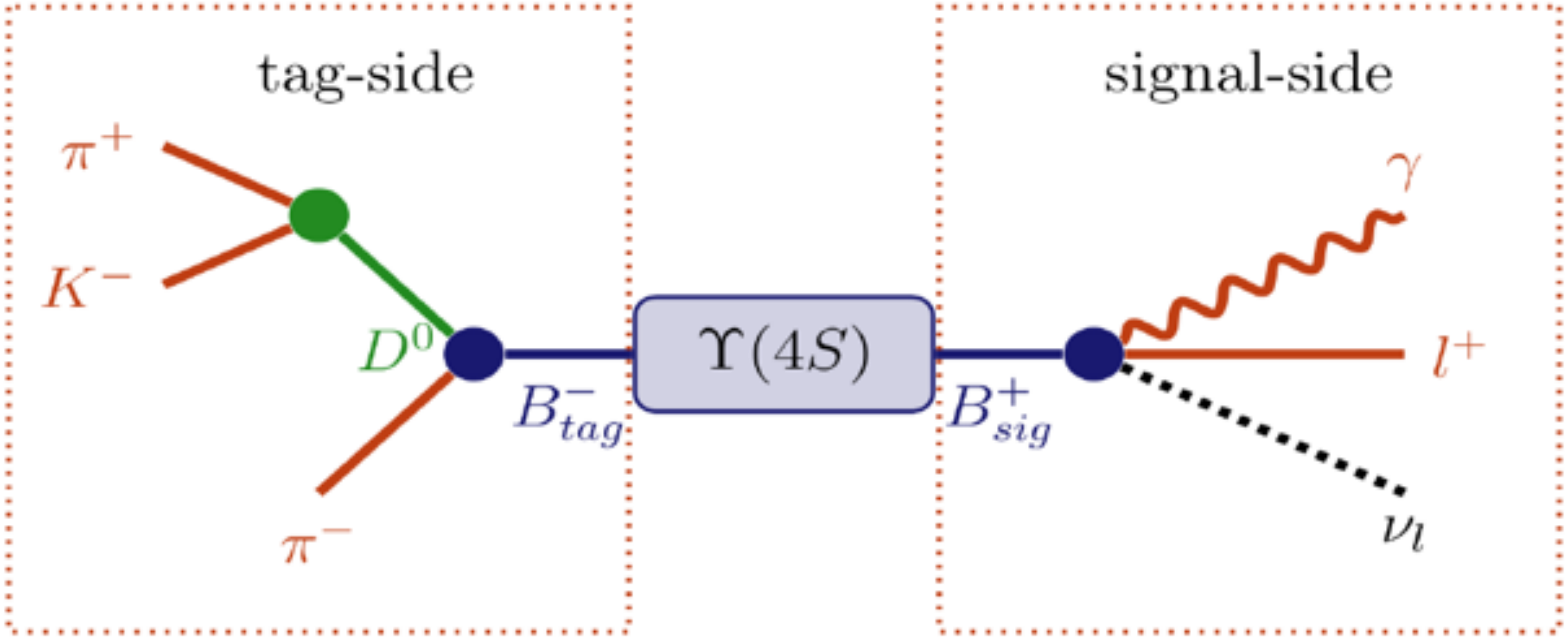


# Full reconstruction tagging

- 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

Full reconstruction:
($\varepsilon \approx$ 0.1-0.3%)

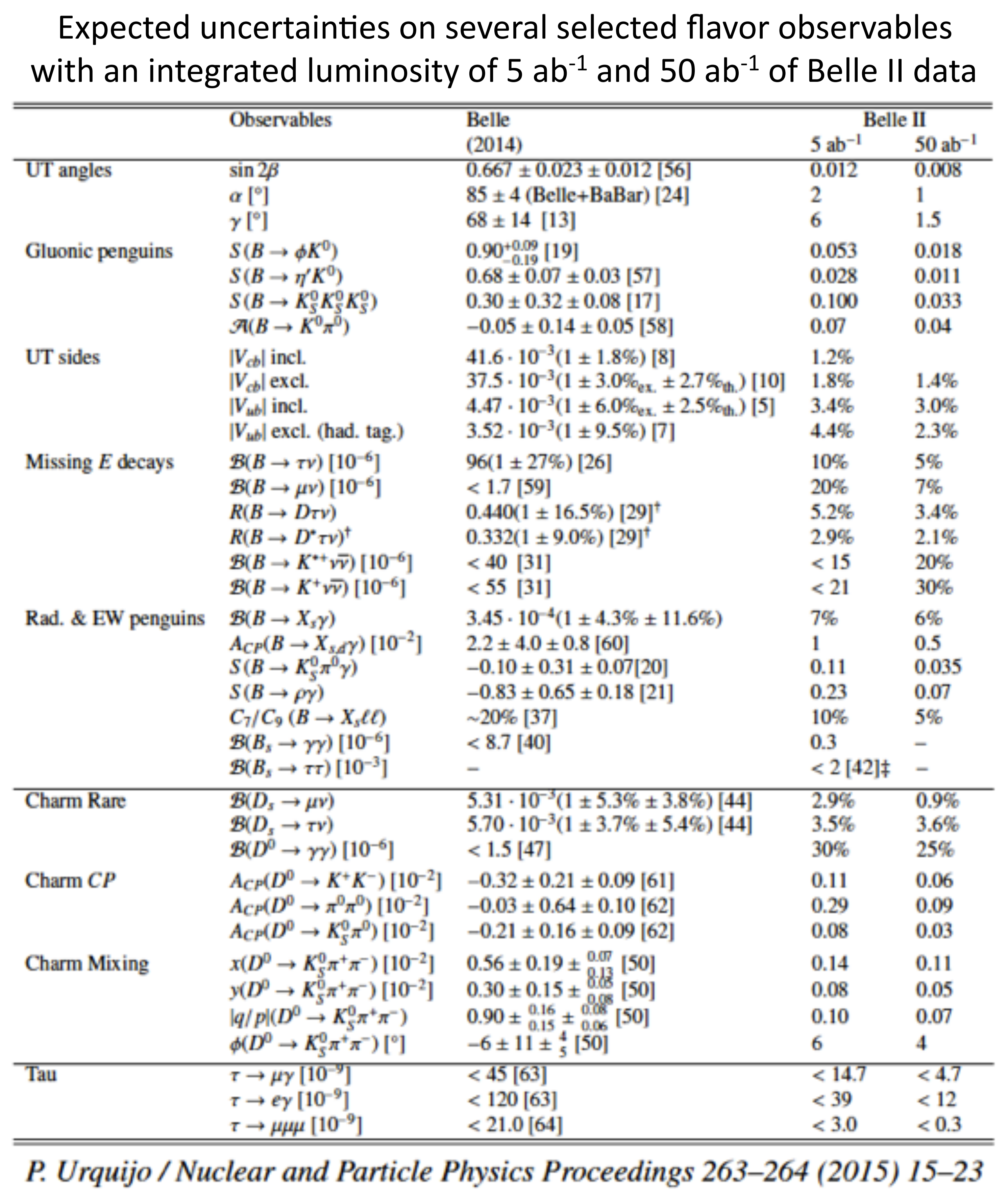
Signal side:
B → X$\ell\nu$ - Precise meas. of $|V_{ub}|$
B → τν - Search for NP
B → Kνν - Search for NP



- 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 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



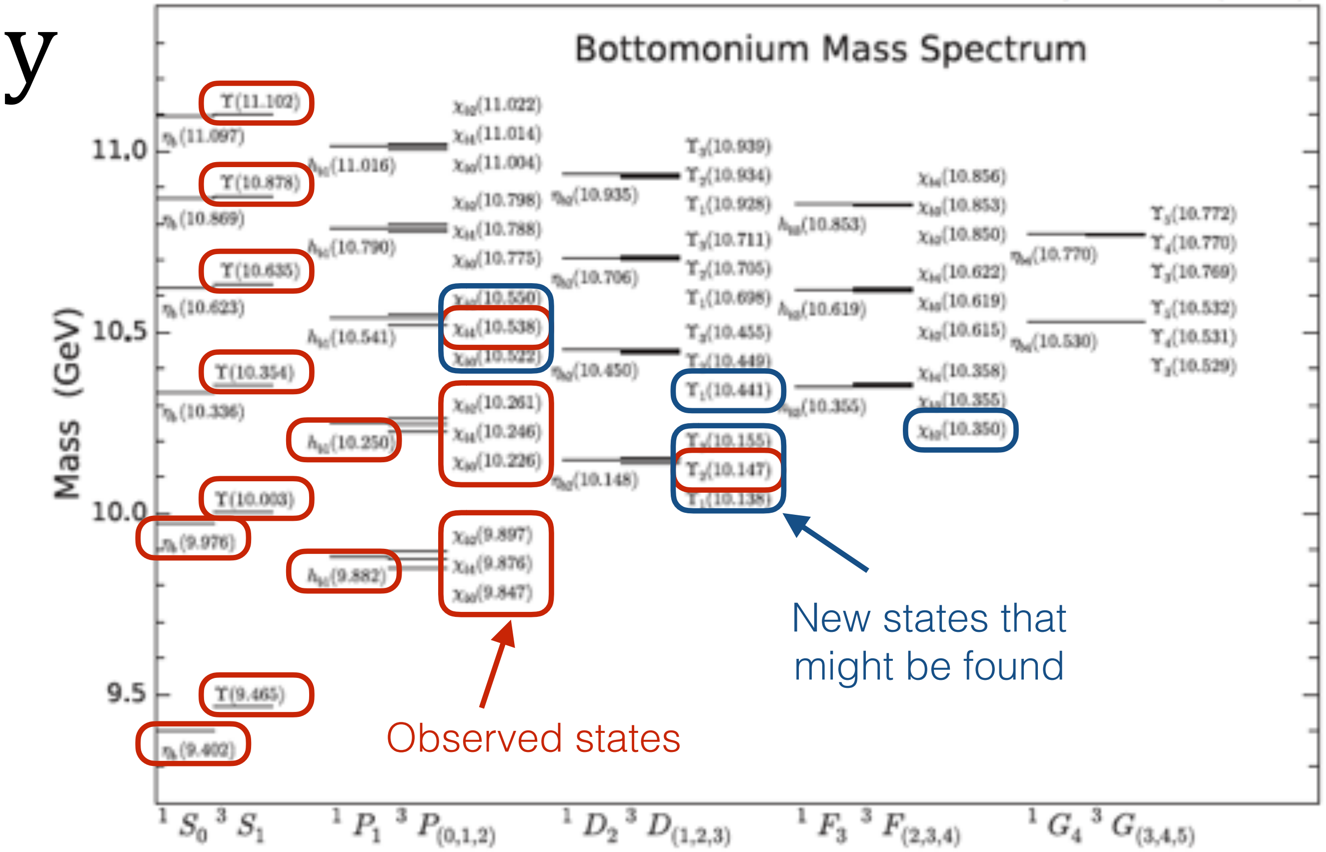
Expected uncertainties on several selected flavor observables with an integrated luminosity of 5 $ab^{-1}$ and 50 $ab^{-1}$ of Belle II data

| | Observables | Belle | Belle II | |
|---|---|---|---|---|
| | | (2014) | 5 $ab^{-1}$ | 50 $ab^{-1}$ |
| UT angles | $\sin 2\beta$ | $0.667 \pm 0.023 \pm 0.012$ [56] | 0.012 | 0.008 |
| | $\alpha$ [°] | $85 \pm 4$ (Belle+BaBar) [24] | 2 | 1 |
| | $\gamma$ [°] | $68 \pm 14$ [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 | $\|V_{cb}\|$ incl. | $41.6 \cdot 10^{-3}(1 \pm 1.8\%)$ [8] | 1.2% | |
| | $\|V_{cb}\|$ excl. | $37.5 \cdot 10^{-3}(1 \pm 3.0\%_{ex.} \pm 2.7\%_{th.})$ [10] | 1.8% | 1.4% |
| | $\|V_{ub}\|$ incl. | $4.47 \cdot 10^{-3}(1 \pm 6.0\%_{ex.} \pm 2.5\%_{th.})$ [5] | 3.4% | 3.0% |
| | $\|V_{ub}\|$ 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]$^{\dagger}$ | 5.2% | 3.4% |
| | $R(B \to D^* \tau\nu)^{\dagger}$ | $0.332(1 \pm 9.0\%)$ [29]$^{\dagger}$ | 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 |
| | $\|q/p\|(D^0 \to K_S^0 \pi^+ \pi^-)$ | $0.90 \pm {}^{0.16}_{0.15} \pm {}^{0.08}_{0.06}$ [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

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

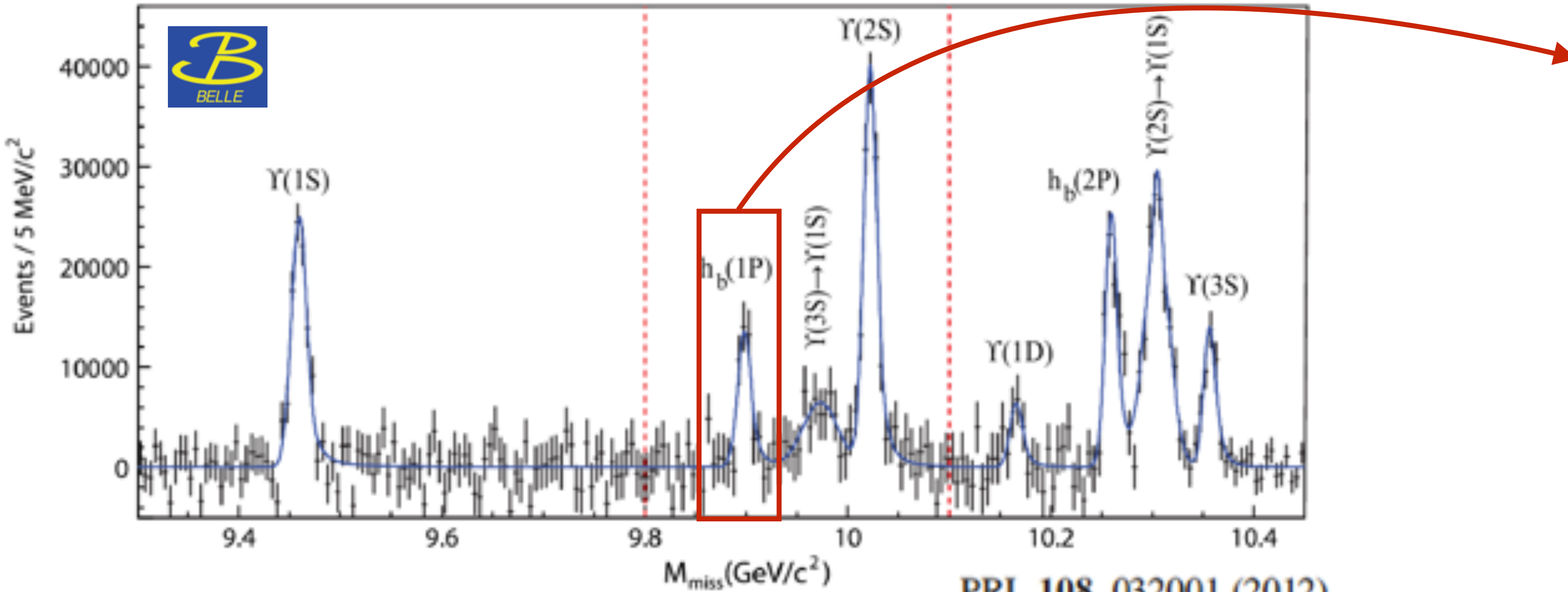


New states that might be found

Observed states

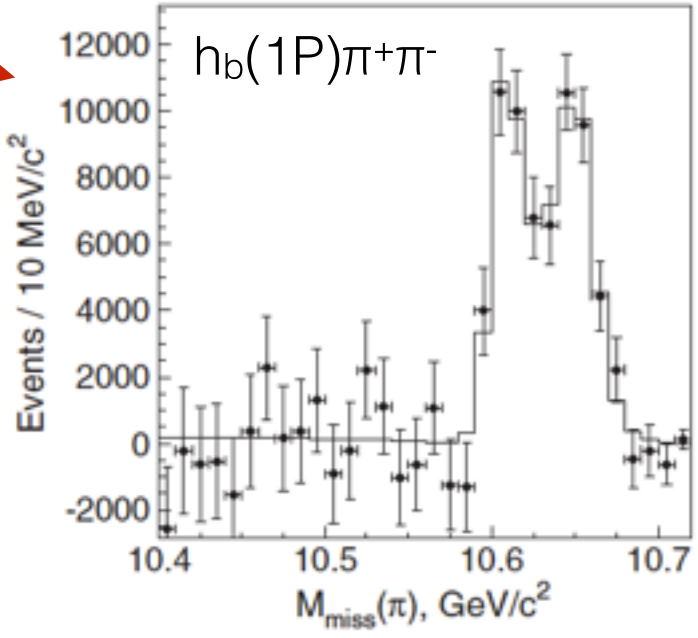
- Considerable progress recently in Lattice QCD
- Belle II has the opportunity to search for missing states
- Clean environment
  - Search for new states inclusively
  - Reconstruct a single resonance and search the recoiling system

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



PRL **108,** 032001 (2012)

$Z_b(10610)$ and $Z_b(10650)$



PRL **108,** 122001 (2012)

# XYZ Spectroscopy (a subset)

X(5568)

$P_c(4380)$
$P_c(4450)$

2015

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

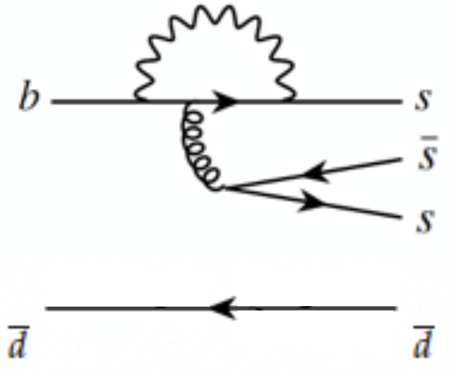
X(3872)

- 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!

# Are there new CP violating phases?

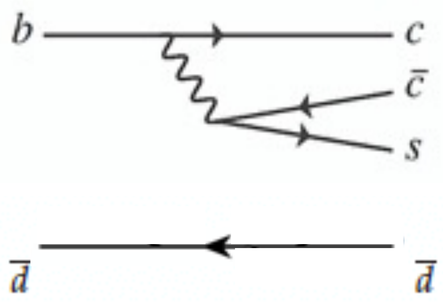
- Most theories involving NP include additional CP-violating phases
  - Some allow large deviations from SM predictions for B meson decays
- Search for new sources of CPV by comparing mixing-induced CP asymmetries in penguin transitions with tree-dominated modes
- Time-dependent CPV in b → s decays such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

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

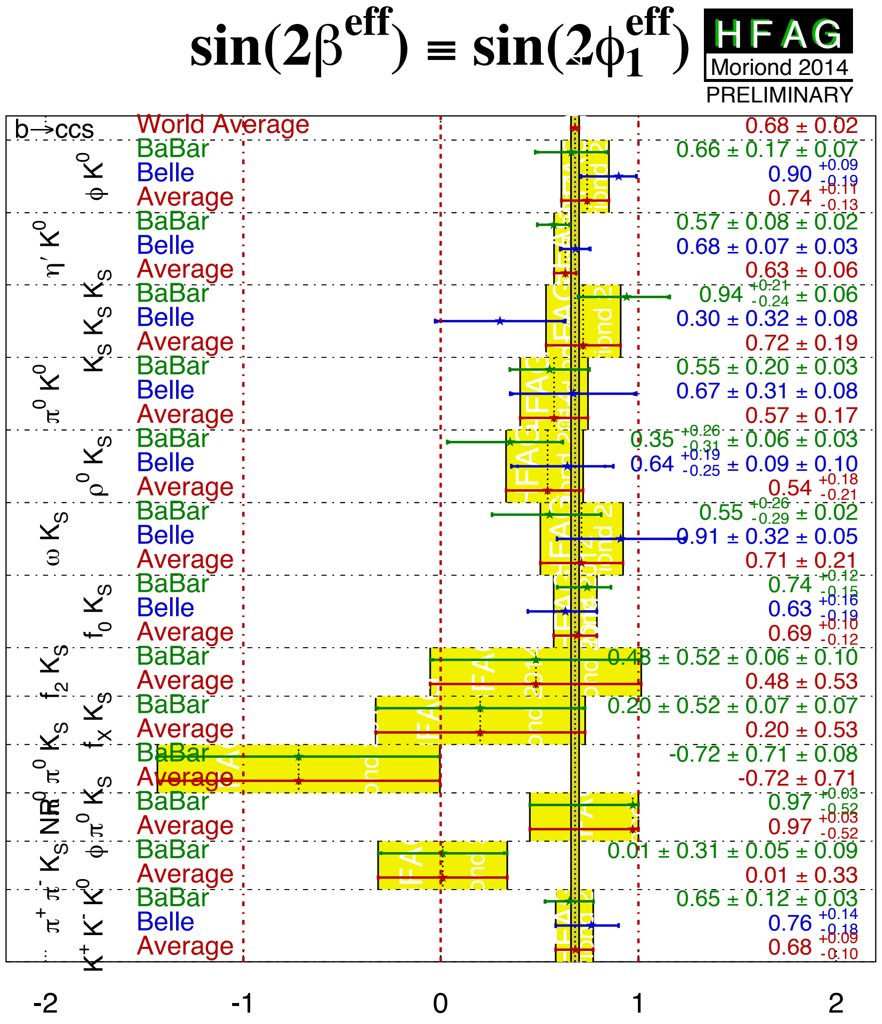


SM:
$|S_{b\to c} - S_{b\to s}| \simeq 0$

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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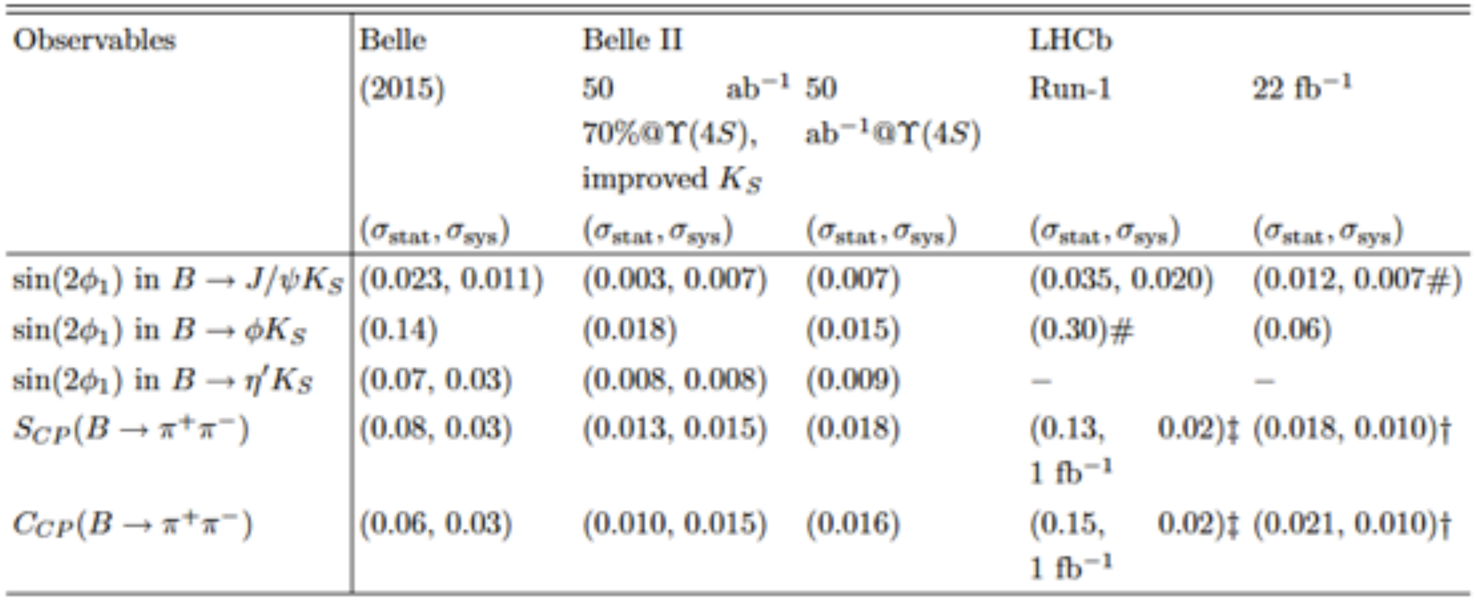
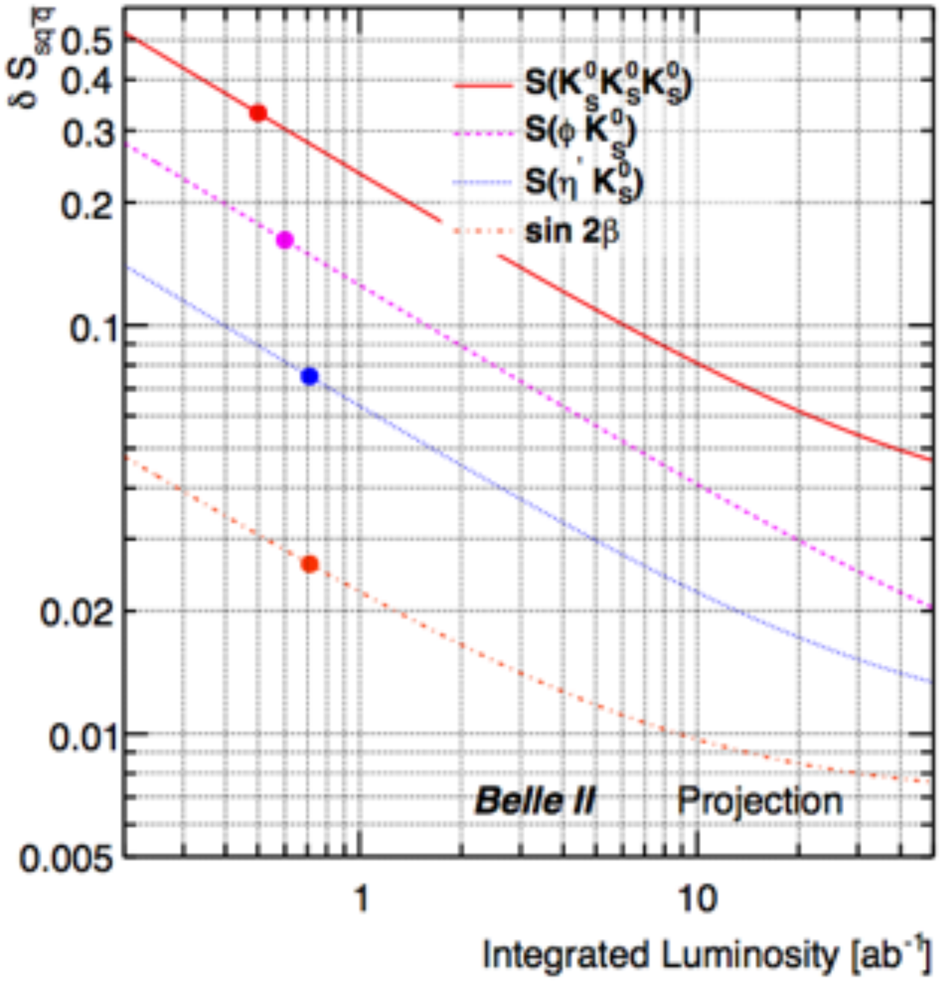


| Observables | Belle | Belle II | | LHCb | |
|---|---|---|---|---|---|
| | (2015) | 50 $ab^{-1}$ 70%@$\Upsilon(4S)$, improved $K_S$ | 50 $ab^{-1}$@$\Upsilon(4S)$ | Run-1 | 22 $fb^{-1}$ |
| | $(\sigma_{stat}, \sigma_{sys})$ | $(\sigma_{stat}, \sigma_{sys})$ | $(\sigma_{stat}, \sigma_{sys})$ | $(\sigma_{stat}, \sigma_{sys})$ | $(\sigma_{stat}, \sigma_{sys})$ |
| $\sin(2\phi_1)$ in $B \to J/\psi K_S$ | (0.023, 0.011) | (0.003, 0.007) | (0.007) | (0.035, 0.020) | (0.012, 0.007#) |
| $\sin(2\phi_1)$ in $B \to \phi K_S$ | (0.14) | (0.018) | (0.015) | (0.30)# | (0.06) |
| $\sin(2\phi_1)$ in $B \to \eta' K_S$ | (0.07, 0.03) | (0.008, 0.008) | (0.009) | – | – |
| $S_{CP}(B \to \pi^+\pi^-)$ | (0.08, 0.03) | (0.013, 0.015) | (0.018) | (0.13, 0.02)‡ 1 $fb^{-1}$ | (0.018, 0.010)† |
| $C_{CP}(B \to \pi^+\pi^-)$ | (0.06, 0.03) | (0.010, 0.015) | (0.016) | (0.15, 0.02)‡ 1 $fb^{-1}$ | (0.021, 0.010)† |



0.033

0.018

0.011

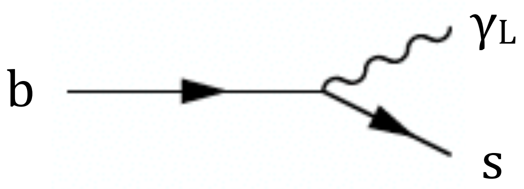
0.008

# Other probes for NP

- Radiative and electroweak processes
  - $\underbrace{b \to s\gamma\ (B \to K^*\gamma)}_{\text{Starts at one-loop order}}, \underbrace{b \to d\gamma\ (B \to \rho\gamma, \omega\gamma),\ b \to s\ell\ell\ (B \to K(^*)\ell\ell)}_{\text{Suppressed by two orders of magnitude}}$

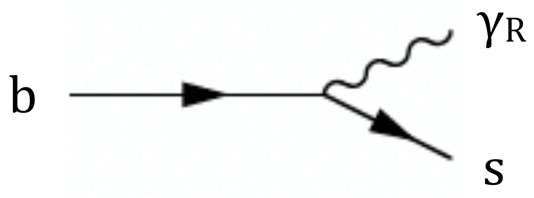
- NP contribution could be different for each process
  - Always one-loop or higher in $b \to s(d)\gamma$, but may be tree level in $b \to s(d)\ell\ell$
- For example helicity-changing NP models and $B^0 \to K_S \pi^0 \gamma$

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



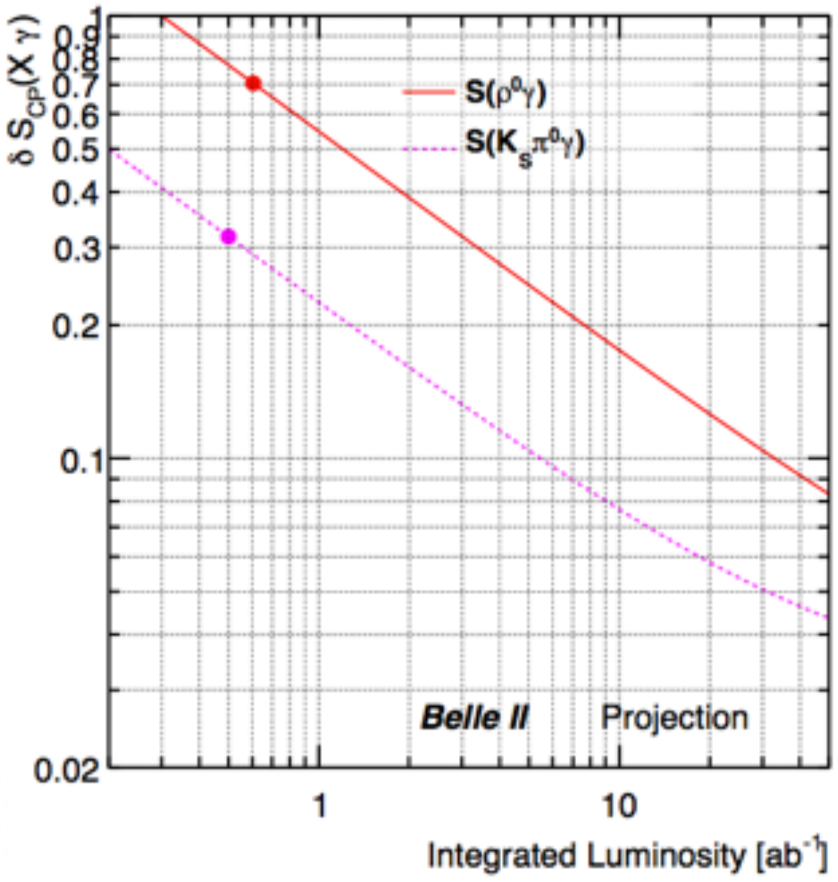
Standard Model

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



Left-Right symmetric model

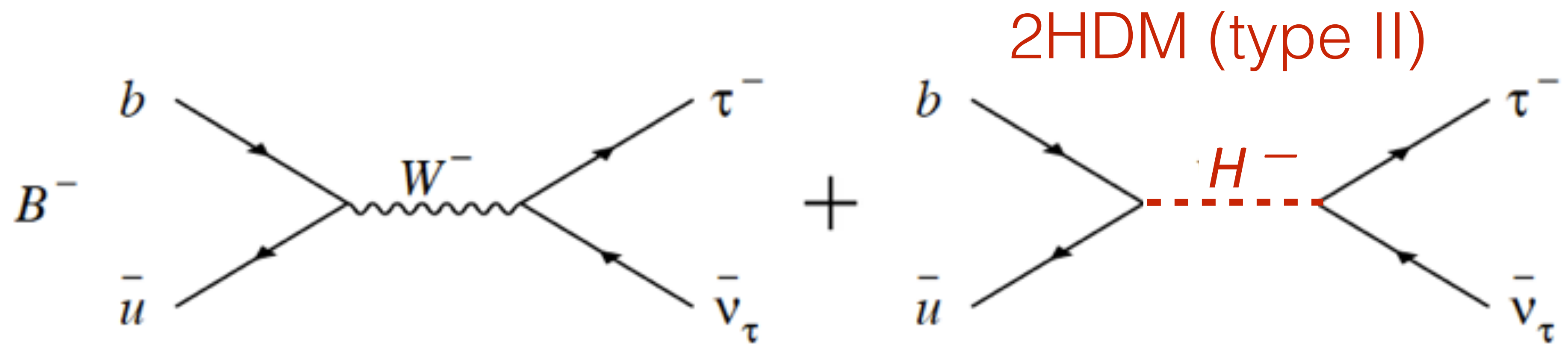
$$S^{LR}_{K_S\pi^0\gamma} = 0.67\cos(2\beta) \sim 0.5$$



0.07

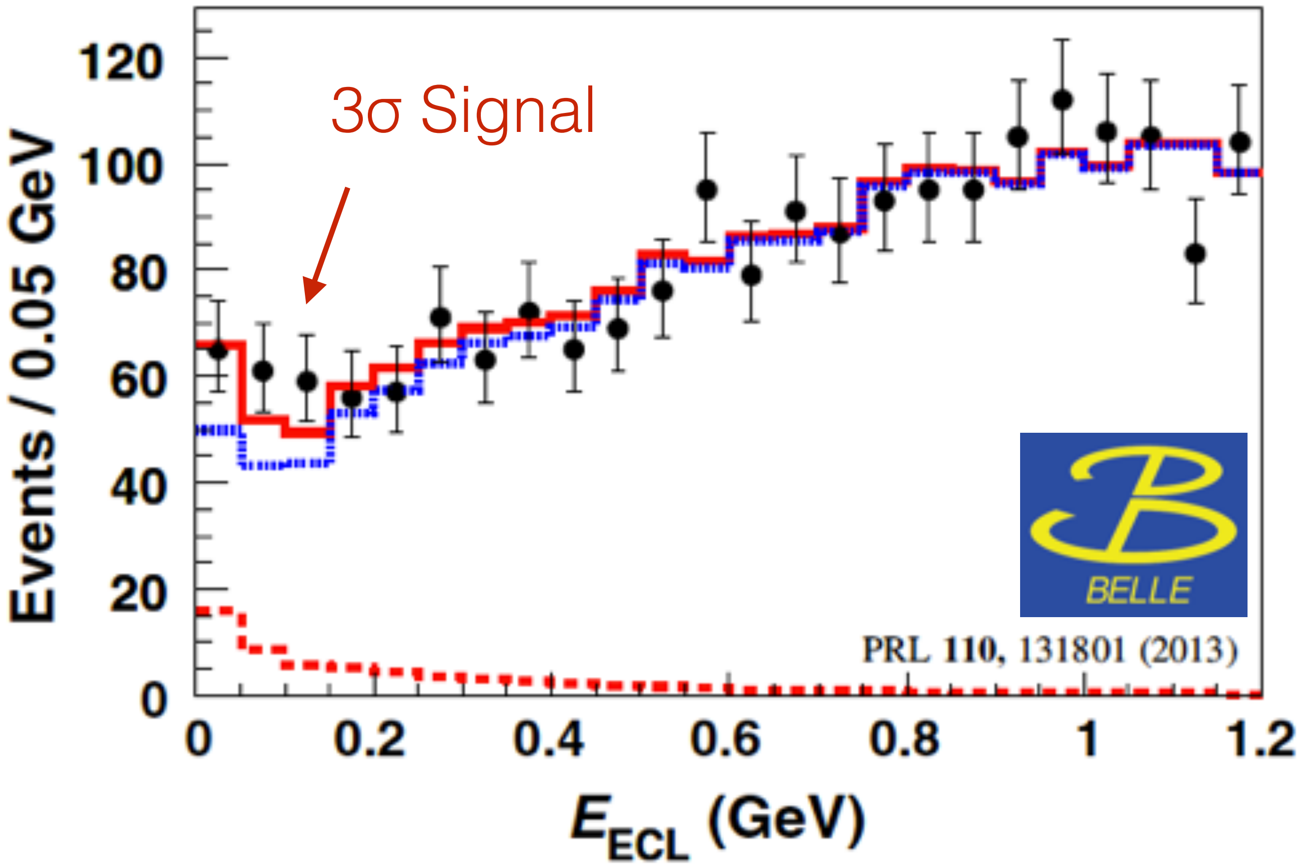
0.035

# Leptonic B decays



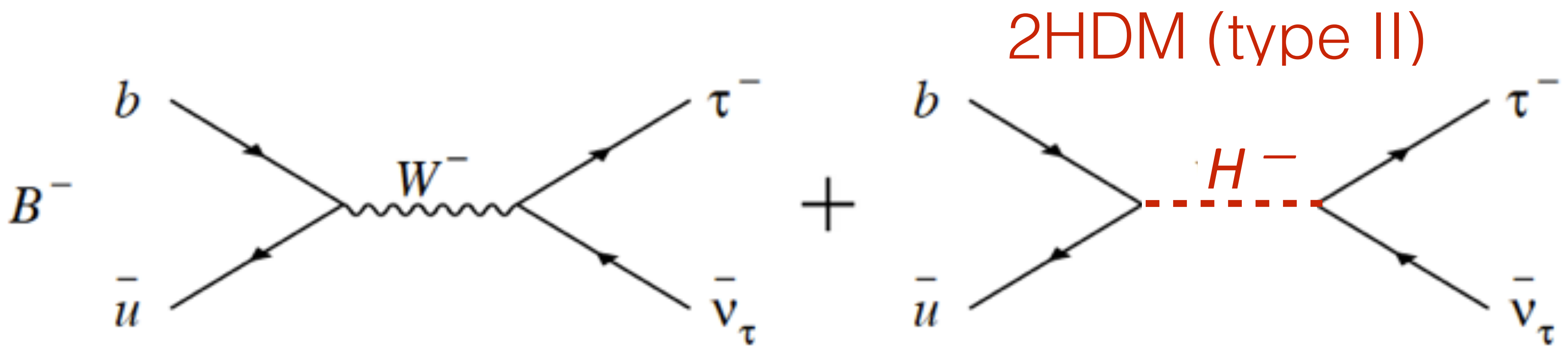
$$\underbrace{\mathcal{B}(B\to\ell\nu)=\frac{G_F^2 m_B m_\ell^2}{8\pi}\left(1-\frac{m_\ell^2}{m_B^2}\right)^2 f_B^2|V_{ub}|^2\tau_B}_{B^{SM}} \times \underbrace{\left(1-m_B^2\frac{\tan^2\beta}{m_{H^\pm}^2}\right)^2}_{r_H}$$

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



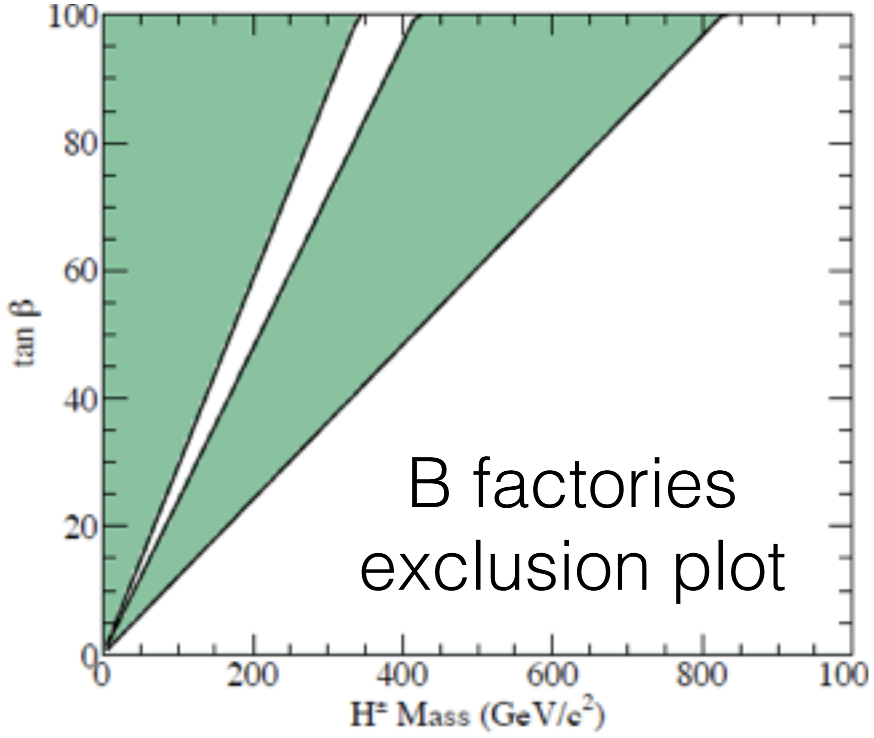
PRL 110, 131801 (2013)

# Leptonic B decays

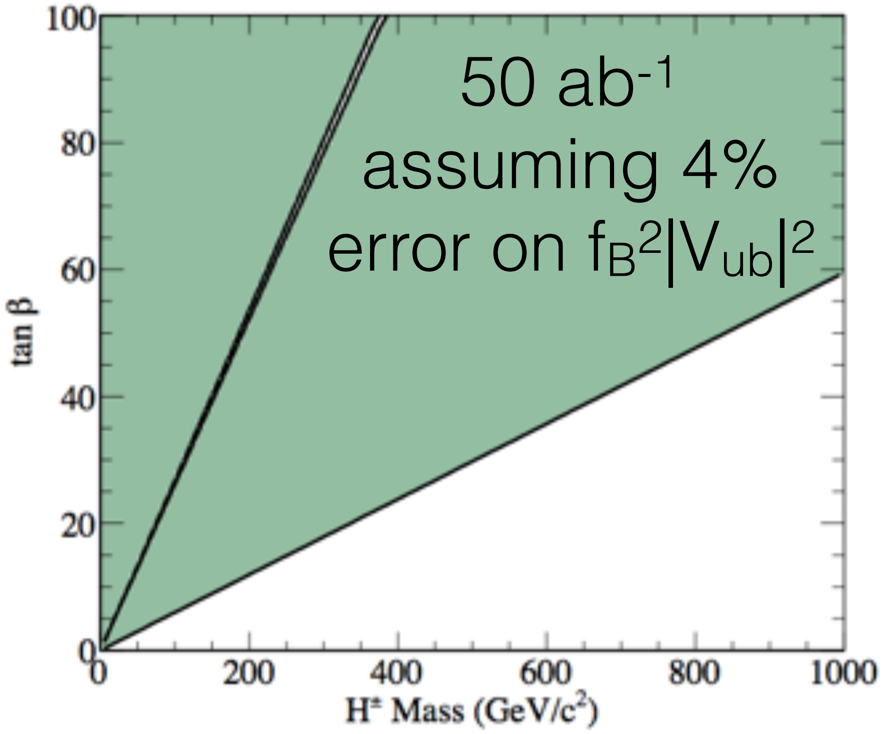


$$\mathcal{B}(B\to\ell\nu)=\frac{G_F^2 m_B m_\ell^2}{8\pi}\left(1-\frac{m_\ell^2}{m_B^2}\right)^2 f_B^2|V_{ub}|^2\tau_B \times \left(1-m_B^2\frac{\tan^2\beta}{m_{H\pm}^2}\right)^2$$

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

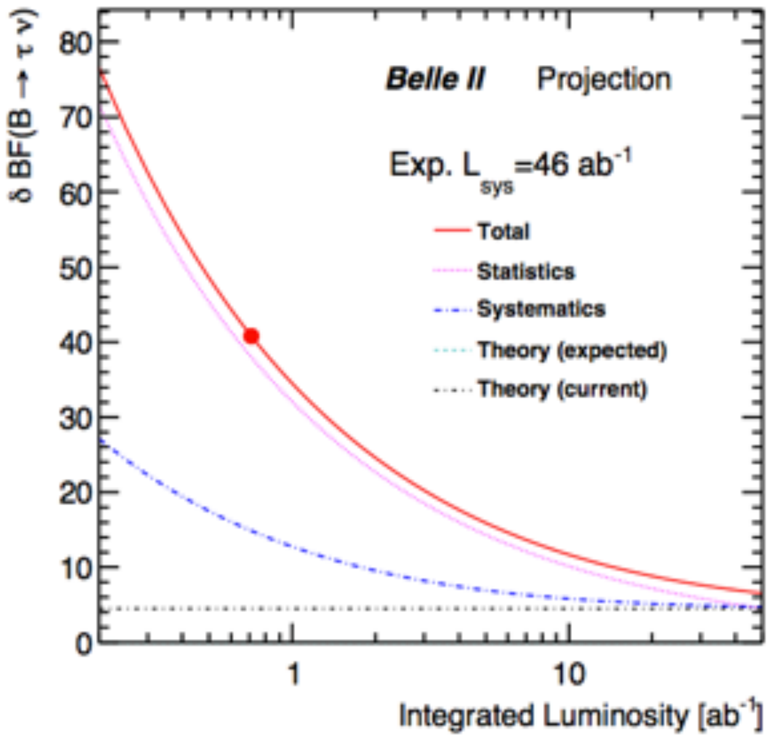


B factories exclusion plot



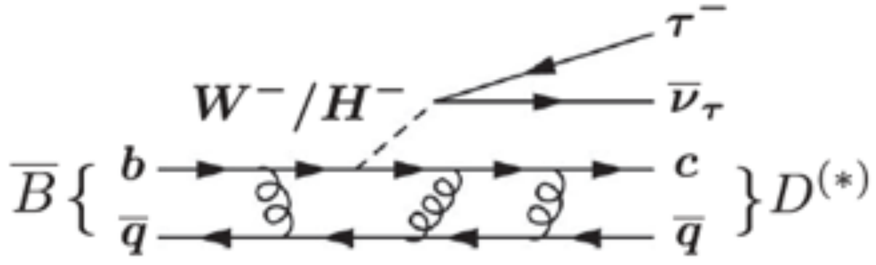
50 $ab^{-1}$ assuming 4% error on $f_B^2|V_{ub}|^2$

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



# Semileptonic B decays

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

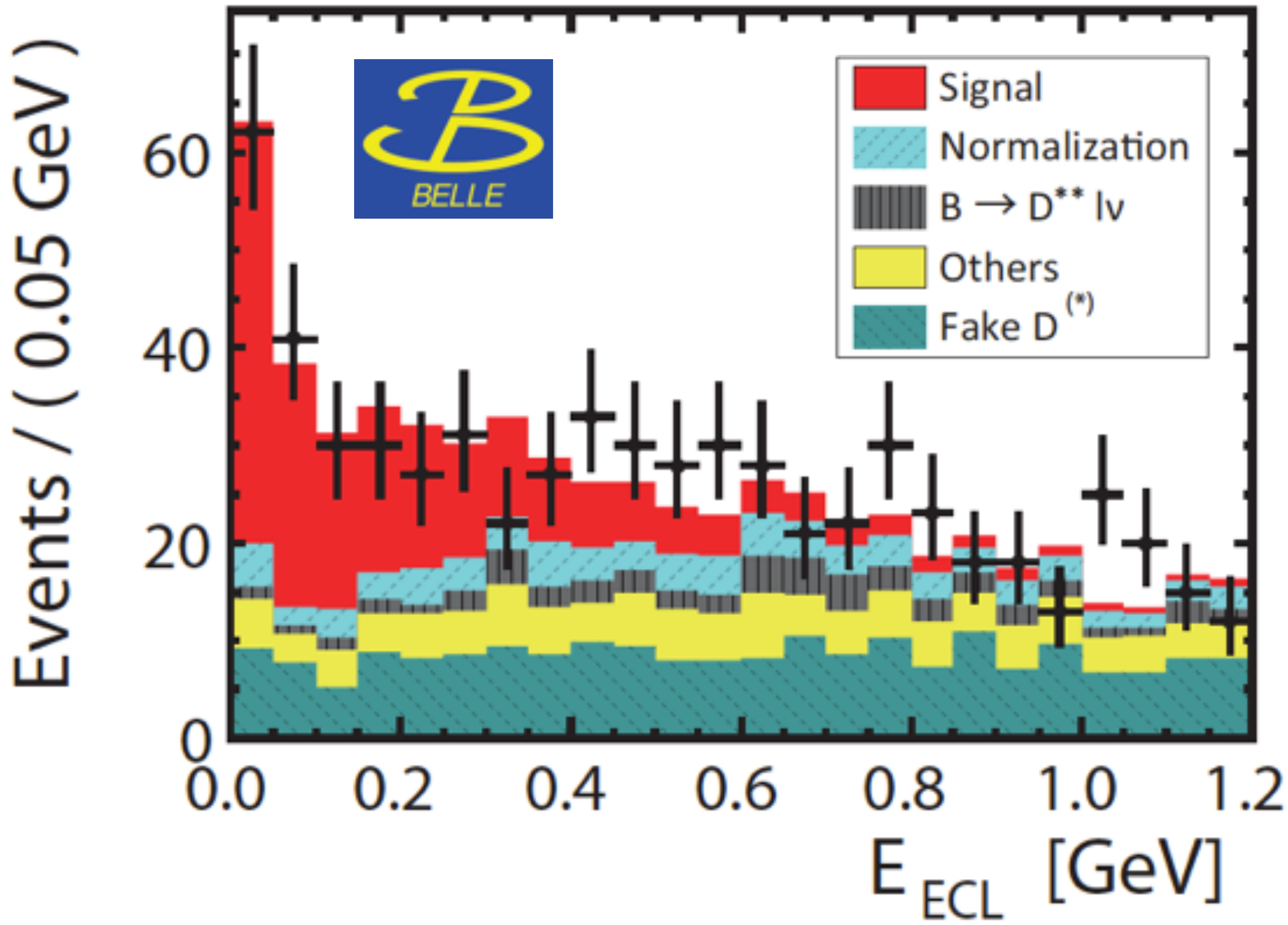


2HDM:

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

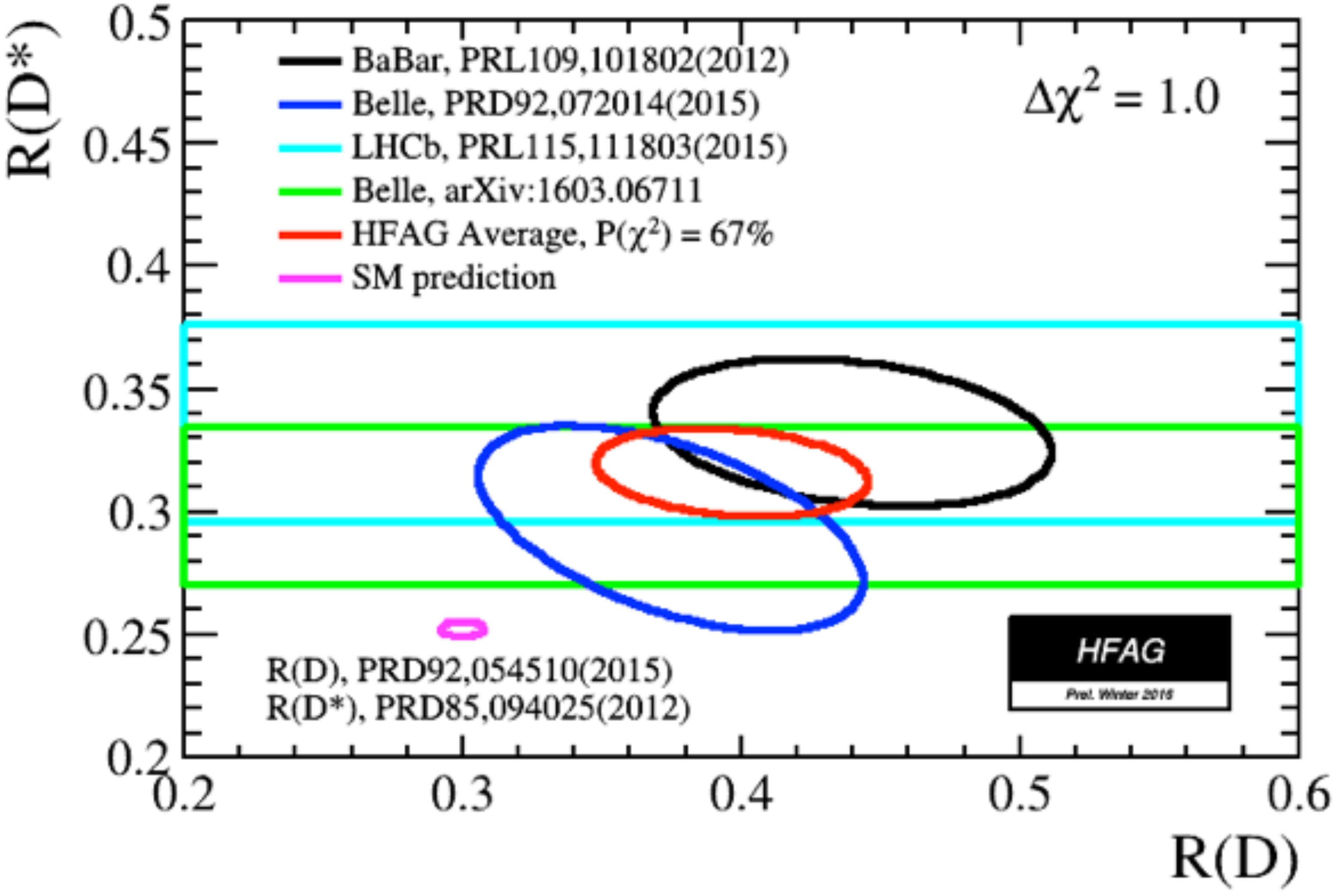
- Decays involving electrons and muons less sensitive to non-SM contributions
  - Measure CKM elements $|V_{cb}|$ and $|V_{ub}|$
- Decays involving τ also sensitive to additional amplitudes
  - Search for NP
  - Experimentally challenging

arxiv1603.06711:Belle-CONF-1602

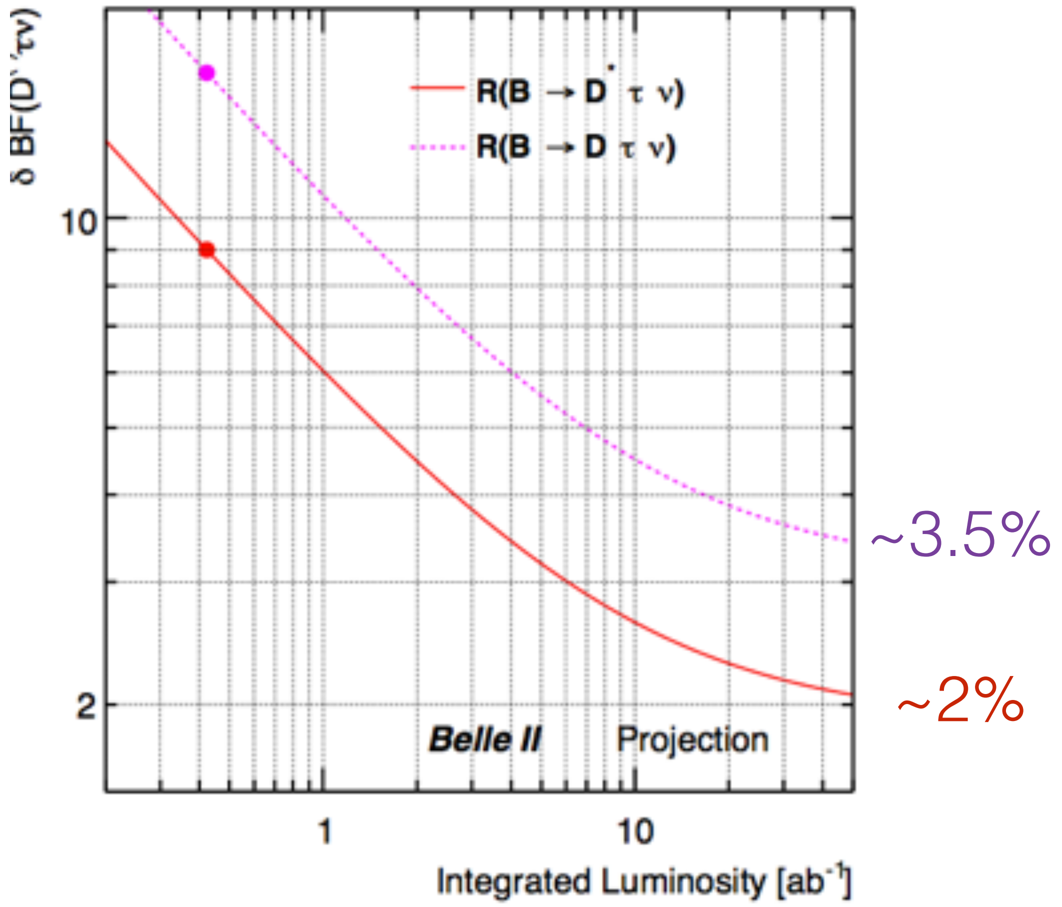


# Flavor anomaly in R(D) and R(D*)

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



- Combined significance of 4.0σ disagreement with SM
- Not compatible with type II 2HDM, could be accommodated by more general charged Higgs of NP



~3.5%

~2%

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

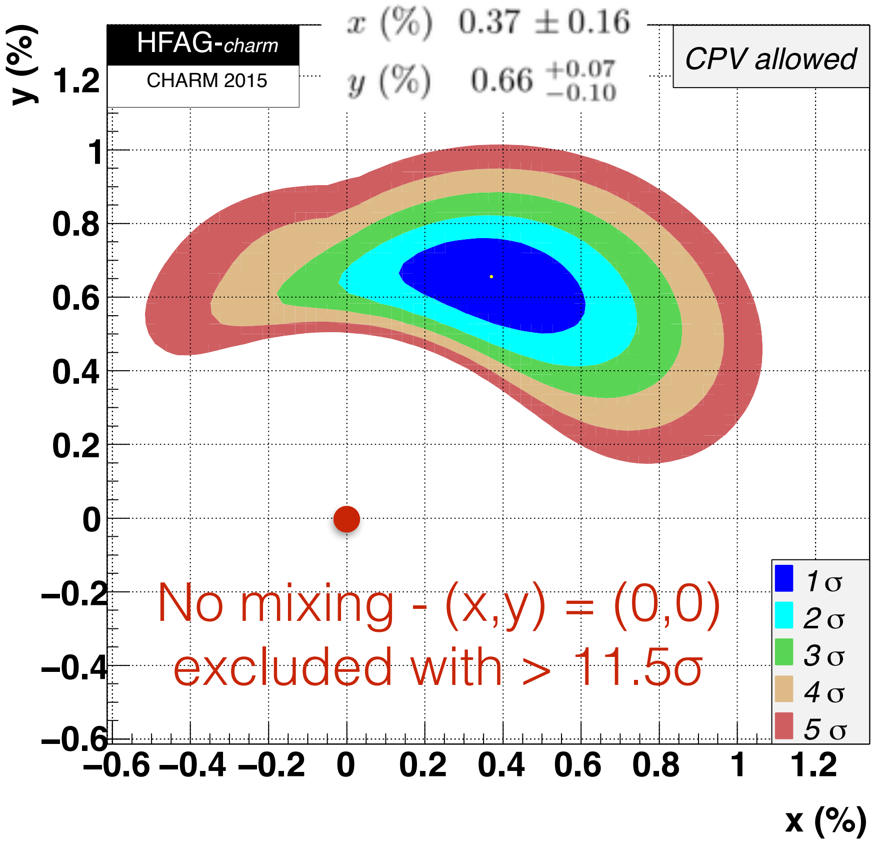
# CPV in $D^0$-$\bar{D}^0$ mixing

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

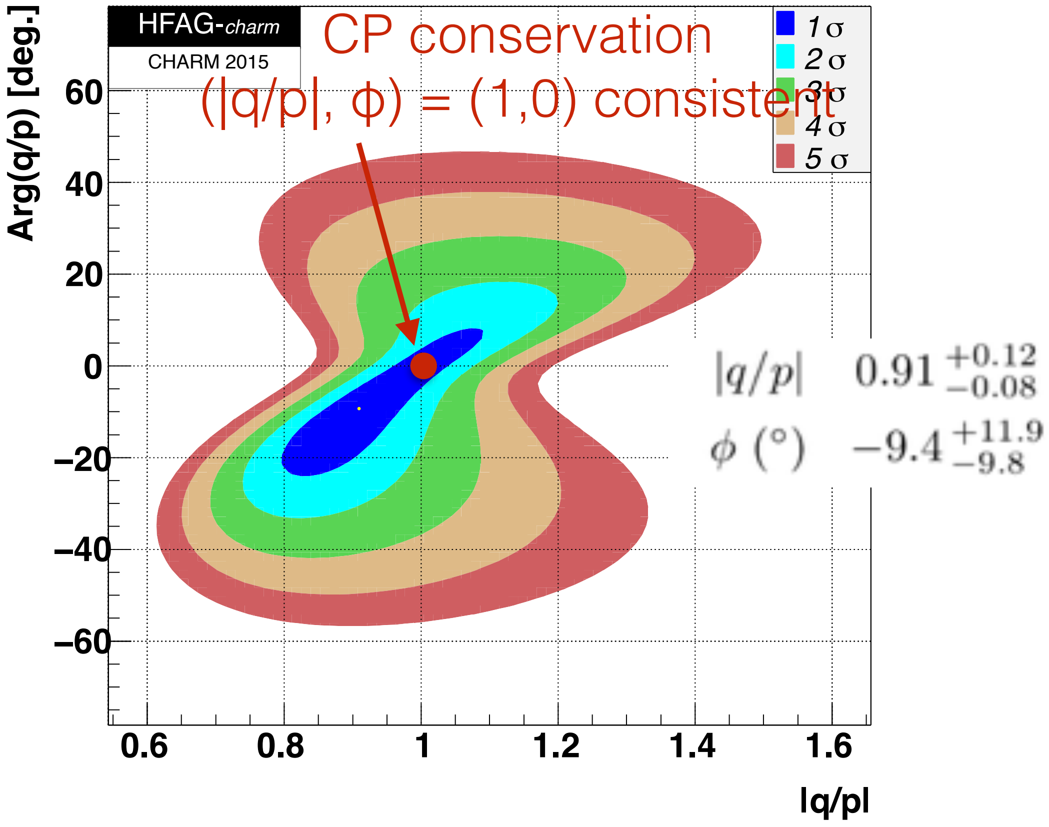
$$D_{\substack{1\\2}} = pD^0 \pm q\bar{D}^0$$

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

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



No mixing - (x,y) = (0,0) excluded with > 11.5σ



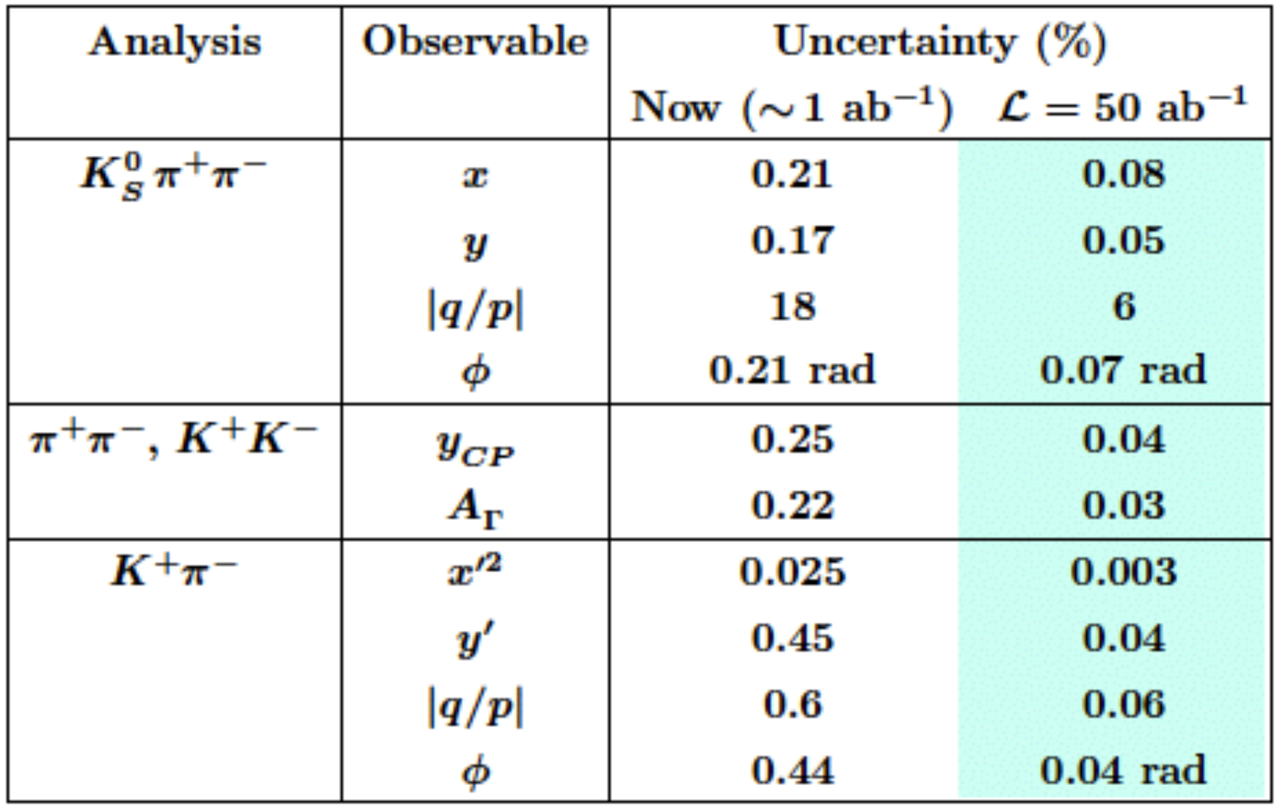
CP conservation

(|q/p|, ϕ) = (1,0) consistent

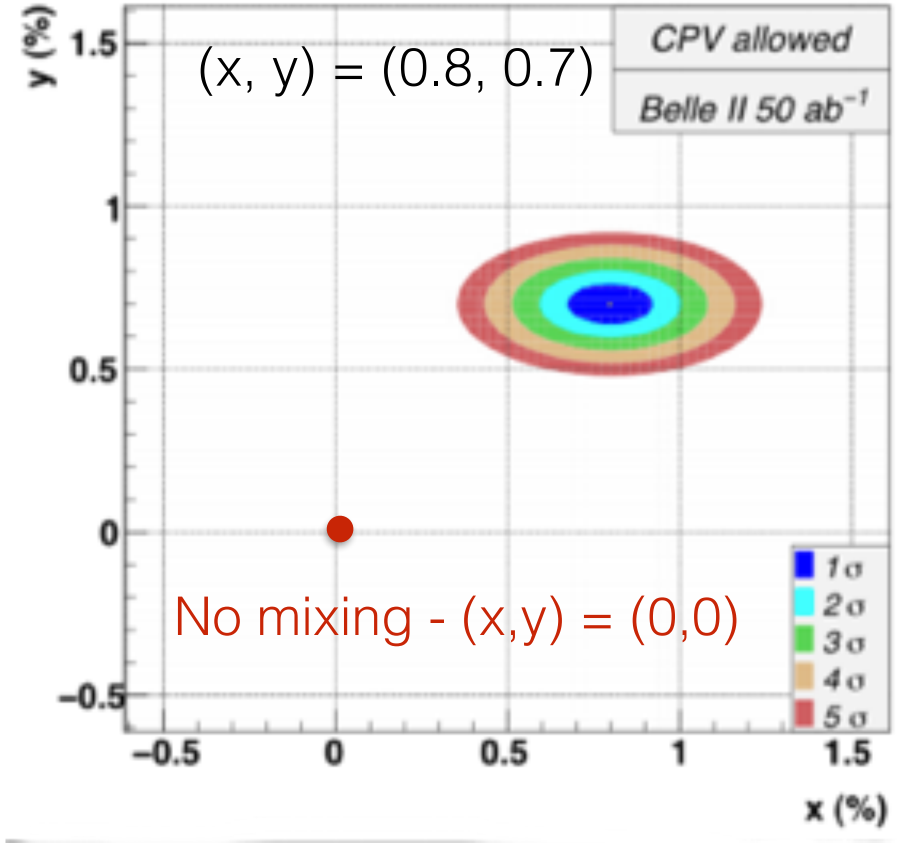
# CPV in $D^0$-$\bar{D}^0$ mixing

- 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)

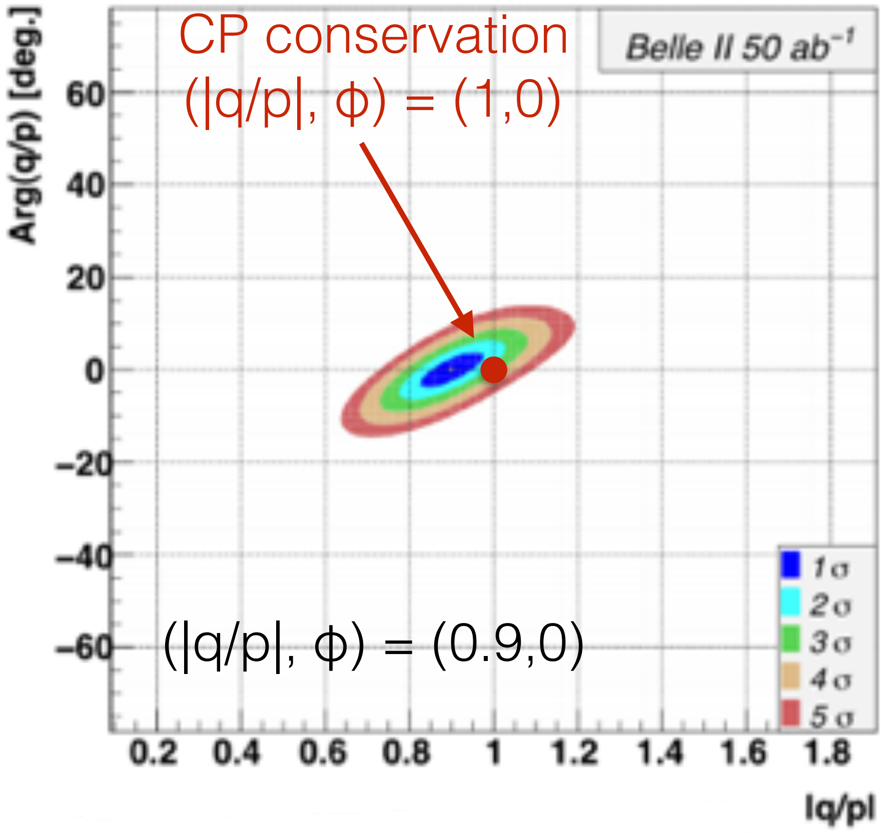


| Analysis | Observable | Uncertainty (%) | |
|---|---|---|---|
| | | Now ($\sim$1 ab$^{-1}$) | $\mathcal{L} = 50$ ab$^{-1}$ |
| $K^0_S\pi^+\pi^-$ | $x$ | 0.21 | 0.08 |
| | $y$ | 0.17 | 0.05 |
| | $\|q/p\|$ | 18 | 6 |
| | $\phi$ | 0.21 rad | 0.07 rad |
| $\pi^+\pi^-$, $K^+K^-$ | $y_{CP}$ | 0.25 | 0.04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



(x, y) = (0.8, 0.7)

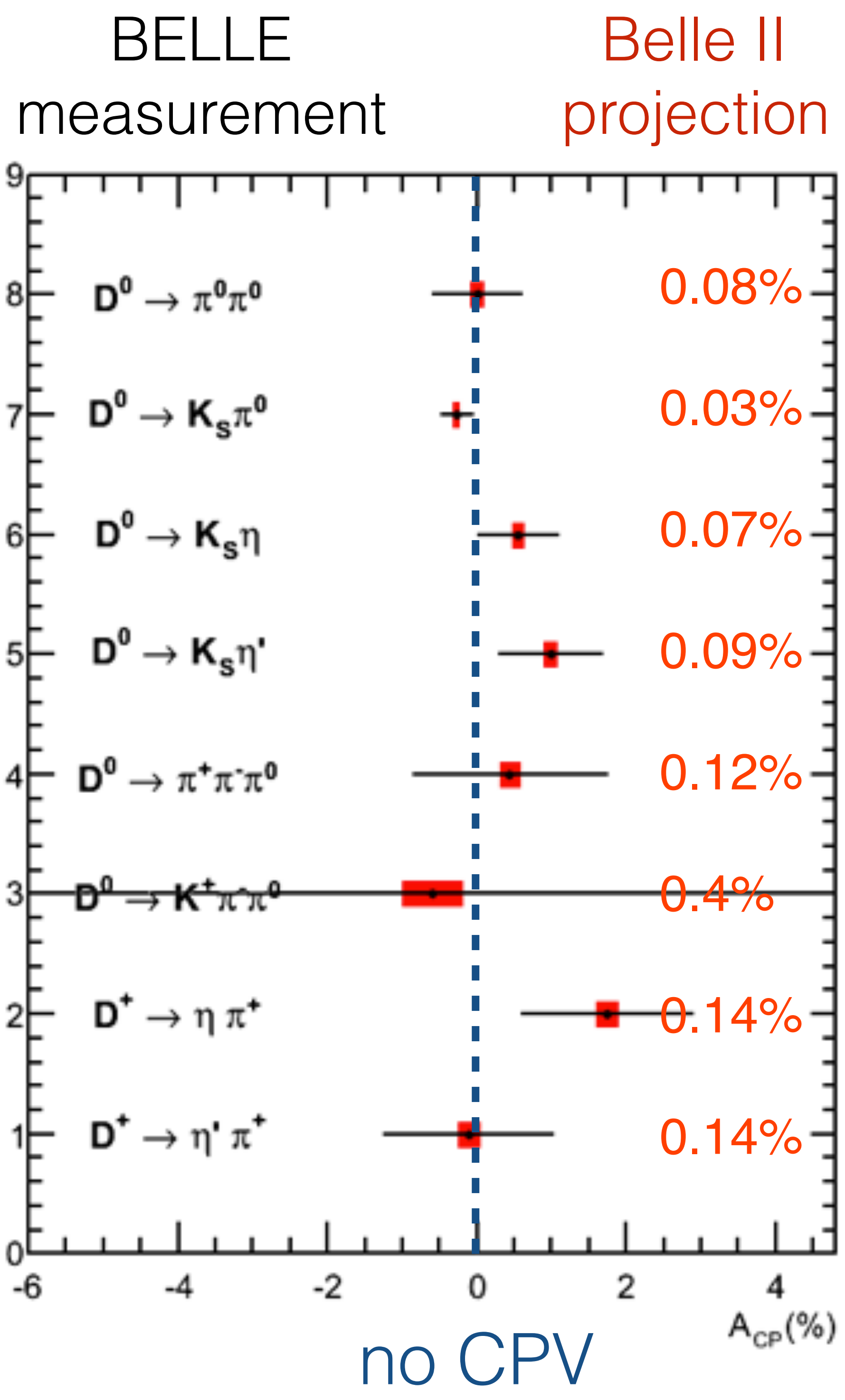
No mixing - (x,y) = (0,0)



CP conservation
(|q/p|, ϕ) = (1,0)

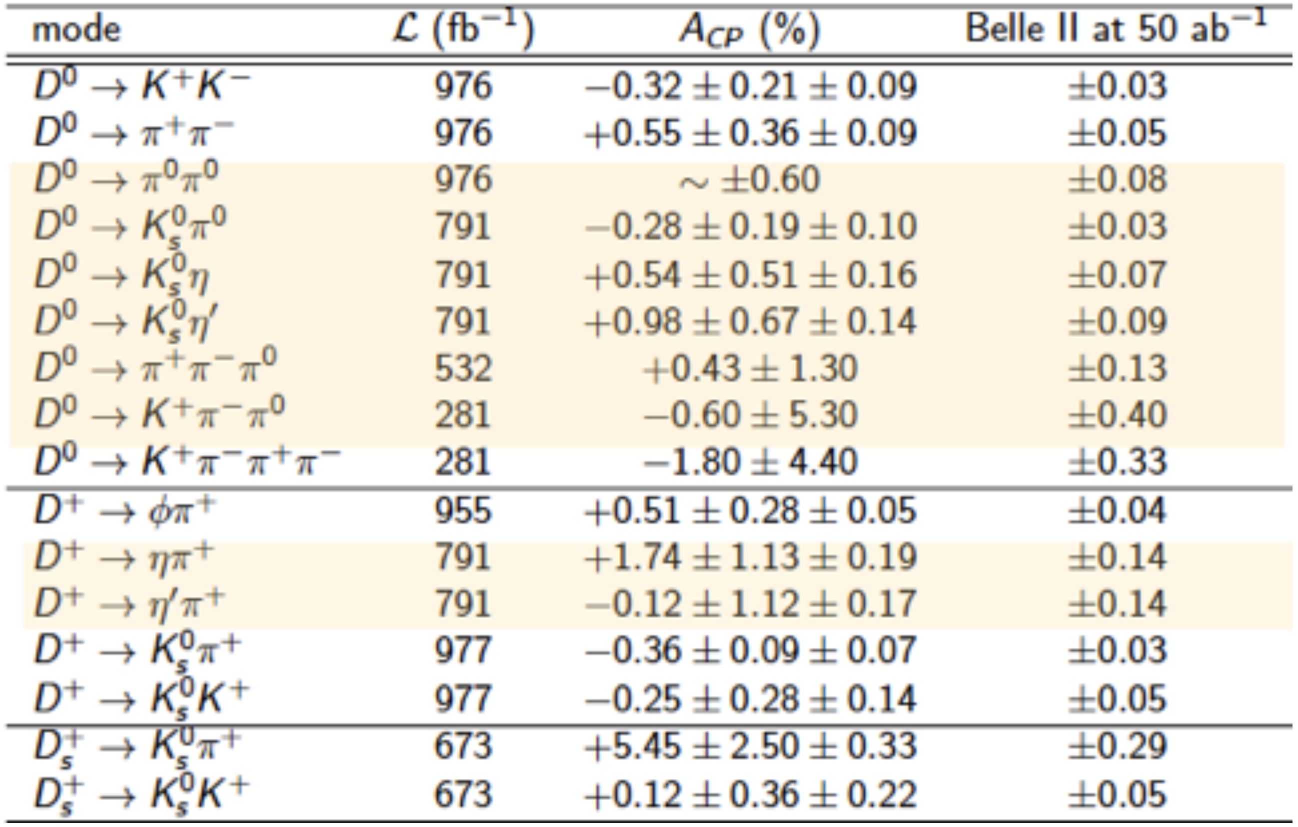
(|q/p|, ϕ) = (0.9,0)

# 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

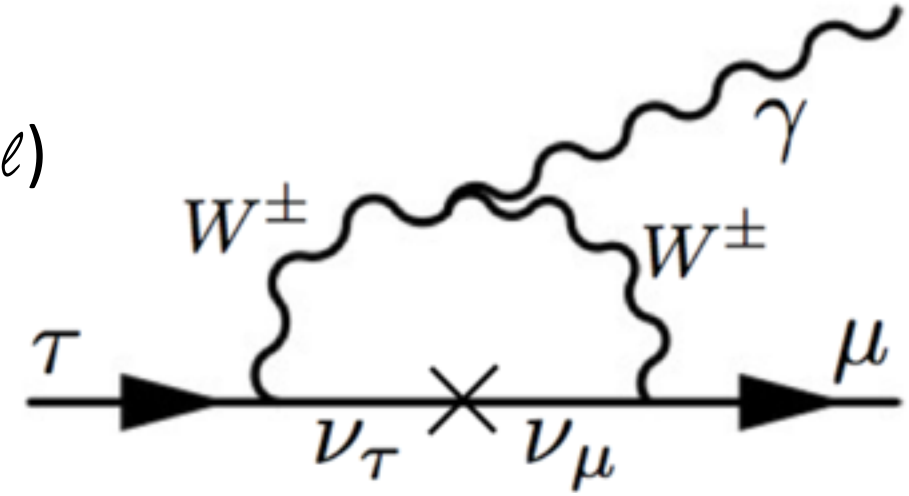


| mode | $\mathcal{L}$ (fb$^{-1}$) | $A_{CP}$ (%) | Belle II at 50 ab$^{-1}$ |
|---|---|---|---|
| $D^0 \to K^+K^-$ | 976 | $-0.32 \pm 0.21 \pm 0.09$ | $\pm0.03$ |
| $D^0 \to \pi^+\pi^-$ | 976 | $+0.55 \pm 0.36 \pm 0.09$ | $\pm0.05$ |
| $D^0 \to \pi^0\pi^0$ | 976 | $\sim \pm0.60$ | $\pm0.08$ |
| $D^0 \to K_s^0\pi^0$ | 791 | $-0.28 \pm 0.19 \pm 0.10$ | $\pm0.03$ |
| $D^0 \to K_s^0\eta$ | 791 | $+0.54 \pm 0.51 \pm 0.16$ | $\pm0.07$ |
| $D^0 \to K_s^0\eta'$ | 791 | $+0.98 \pm 0.67 \pm 0.14$ | $\pm0.09$ |
| $D^0 \to \pi^+\pi^-\pi^0$ | 532 | $+0.43 \pm 1.30$ | $\pm0.13$ |
| $D^0 \to K^+\pi^-\pi^0$ | 281 | $-0.60 \pm 5.30$ | $\pm0.40$ |
| $D^0 \to K^+\pi^-\pi^+\pi^-$ | 281 | $-1.80 \pm 4.40$ | $\pm0.33$ |
| $D^+ \to \phi\pi^+$ | 955 | $+0.51 \pm 0.28 \pm 0.05$ | $\pm0.04$ |
| $D^+ \to \eta\pi^+$ | 791 | $+1.74 \pm 1.13 \pm 0.19$ | $\pm0.14$ |
| $D^+ \to \eta'\pi^+$ | 791 | $-0.12 \pm 1.12 \pm 0.17$ | $\pm0.14$ |
| $D^+ \to K_s^0\pi^+$ | 977 | $-0.36 \pm 0.09 \pm 0.07$ | $\pm0.03$ |
| $D^+ \to K_s^0K^+$ | 977 | $-0.25 \pm 0.28 \pm 0.14$ | $\pm0.05$ |
| $D_s^+ \to K_s^0\pi^+$ | 673 | $+5.45 \pm 2.50 \pm 0.33$ | $\pm0.29$ |
| $D_s^+ \to K_s^0K^+$ | 673 | $+0.12 \pm 0.36 \pm 0.22$ | $\pm0.05$ |

*(table by Marko Staric)*

# Lepton Flavor Violation

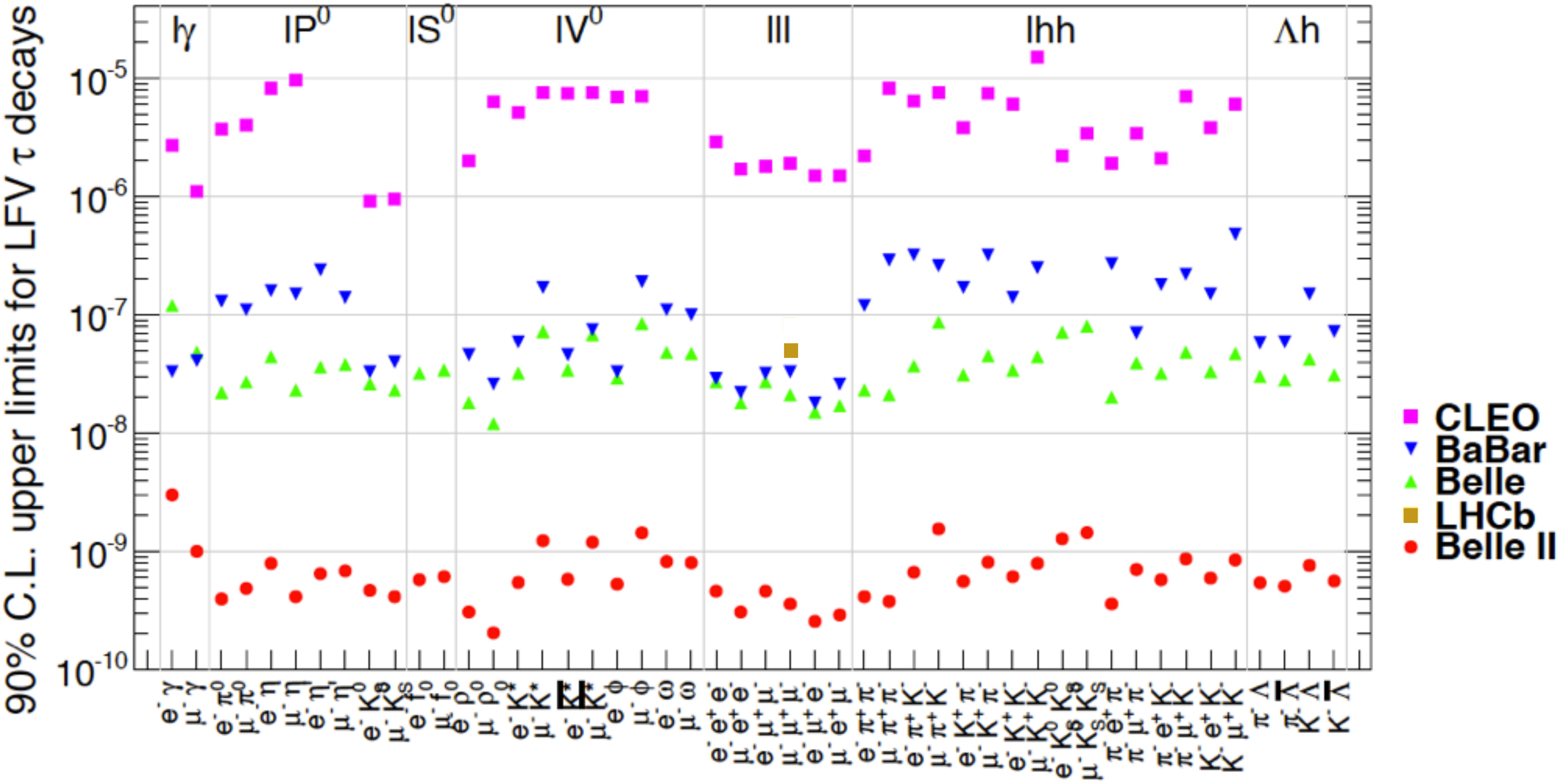
- Highly suppressed in the SM
  - BF on the order of $10^{-40}$ ($\tau \to \ell\gamma$) to $10^{-54}$ ($\tau \to \ell\ell\ell$)
- Clean probes for NP effects
  - May induce LFV at one-loop
- τ decays uniquely studied at B-factories
  - Hadron machines not competitive - trigger and track $p_T$ limiting



| | reference | $\tau \to \mu\gamma$ | $\tau \to \mu\mu\mu$ |
|---|---|---|---|
| SM + heavy Maj $\nu_R$ | PRD 66(2002)034008 | $10^{-9}$ | $10^{-10}$ |
| Non-universal Z' | PLB 547(2002)252 | $10^{-9}$ | $10^{-8}$ |
| SUSY SO(10) | PRD 68(2003)033012 | $10^{-8}$ | $10^{-10}$ |
| mSUGRA+seesaw | PRD 66(2002)115013 | $10^{-7}$ | $10^{-9}$ |
| SUSY Higgs | PLB 566(2003)217 | $10^{-10}$ | $10^{-7}$ |

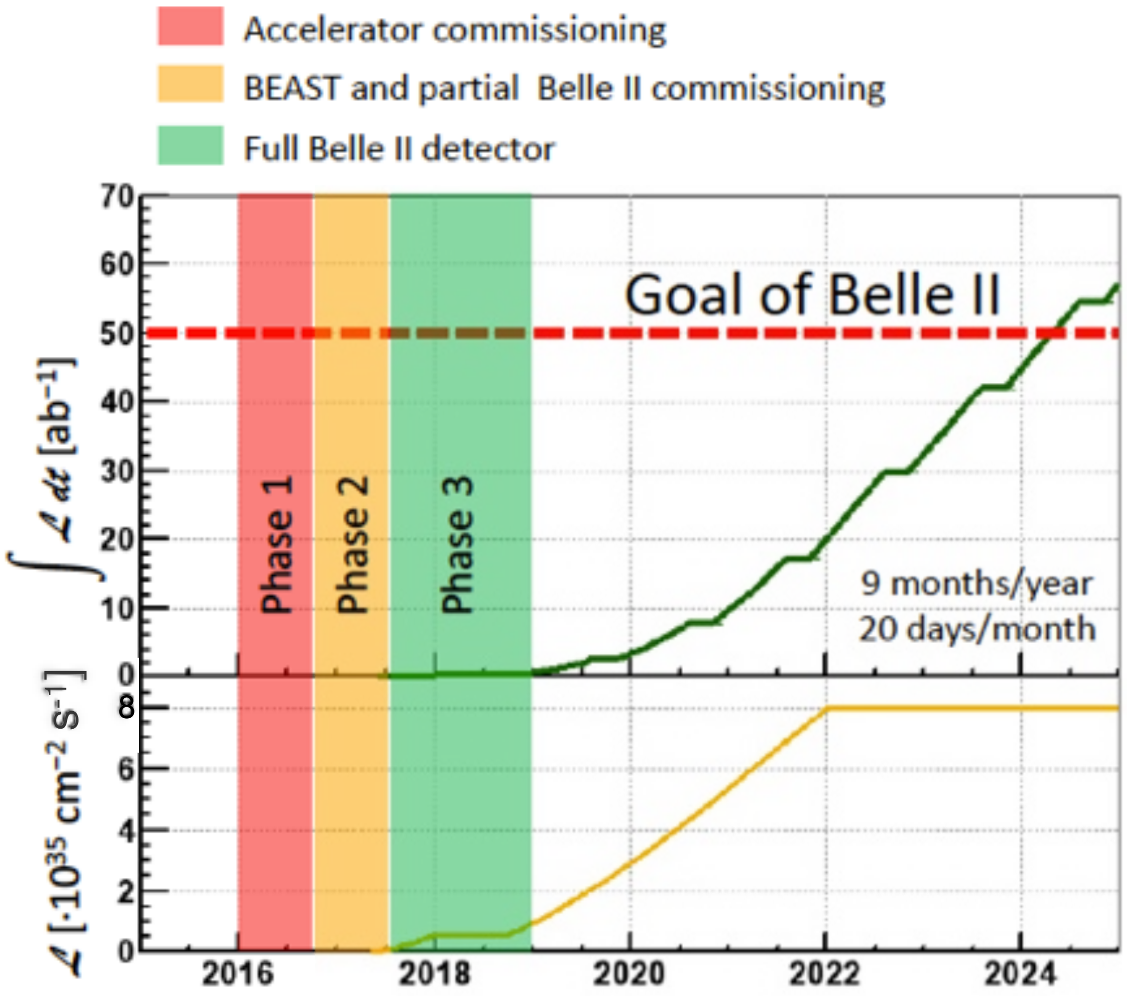
# Lepton Flavor Violation

- Belle II can access LFV decay rates over 100 times smaller than Belle for the cleanest channels!



# Tentative Schedule

- Construction/Installation ongoing
- “BEAST” Phase 1: Started in Feb 2016 (Belle II roll-in at the end of the year)
  - Simple background commissioning detector (diodes, TPCs, crystals). No final focus. Only single beam background studies possible
- “BEAST” Phase 2: Starts in Nov 2017
  - More elaborate inner background commissioning detector. Full Belle II outer detector. Full superconducting final focus. No vertex detectors.
  - Commissioning/physics(?)
- Phase 3 / Run 1: Fall 2018
  - Full detector, ~300 $fb^{-1}$



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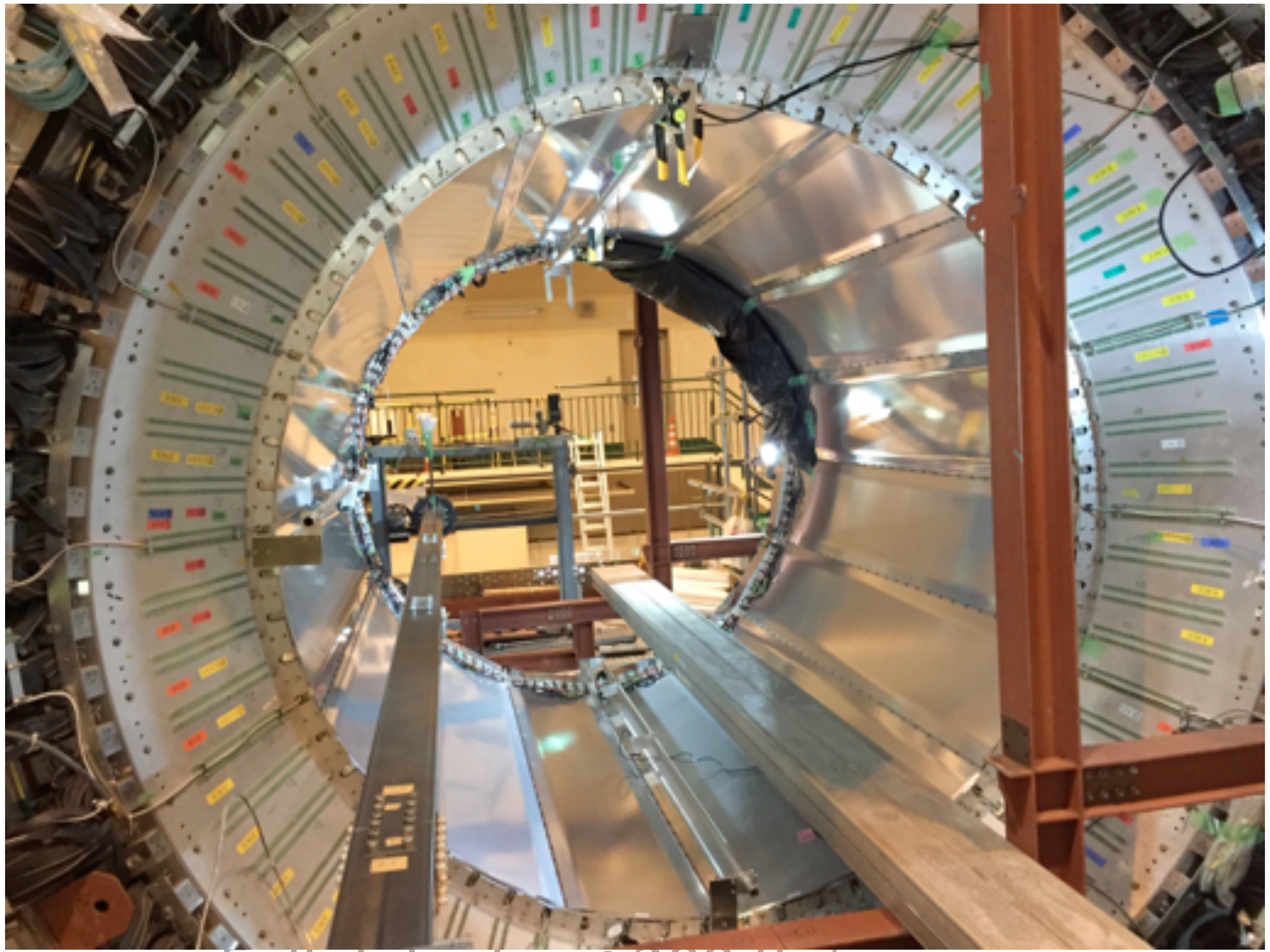

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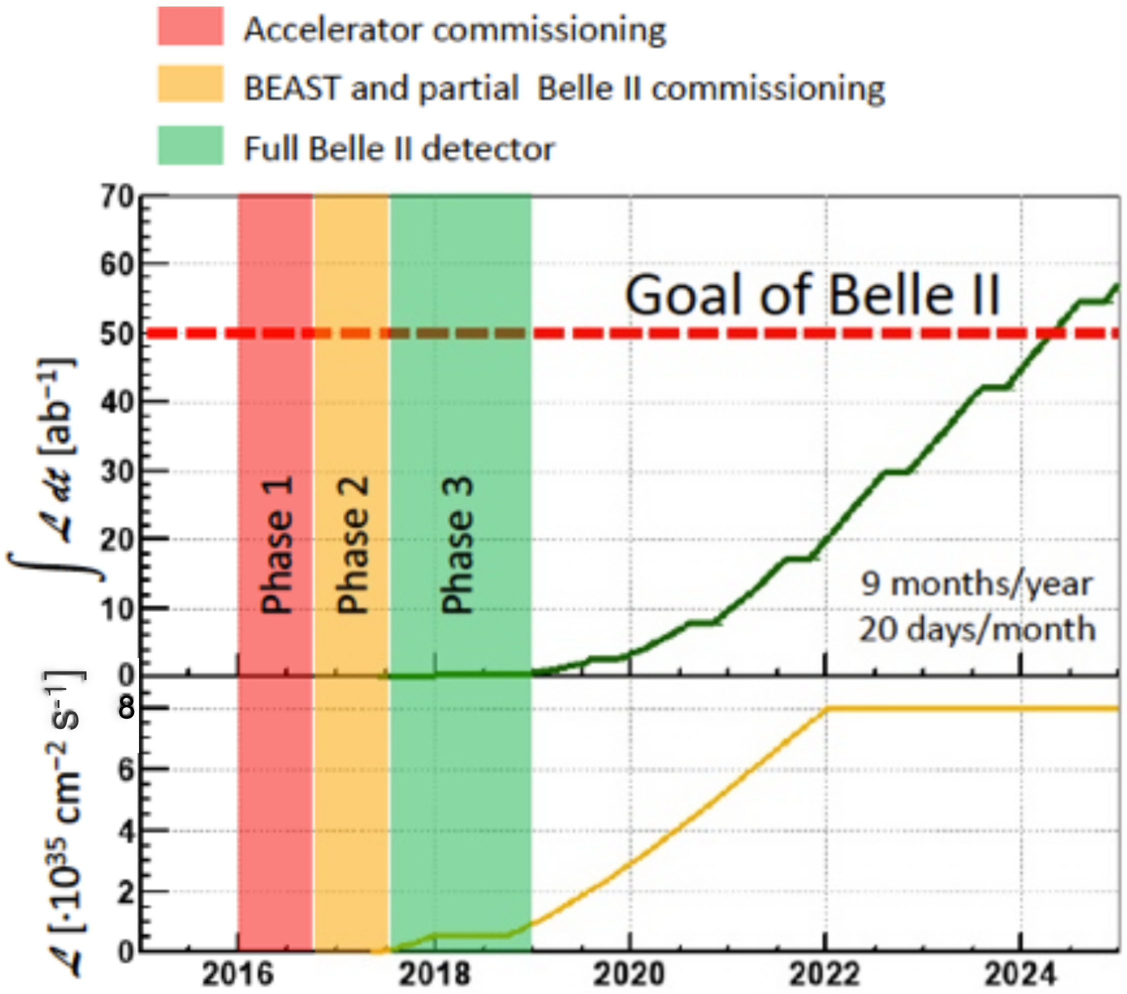
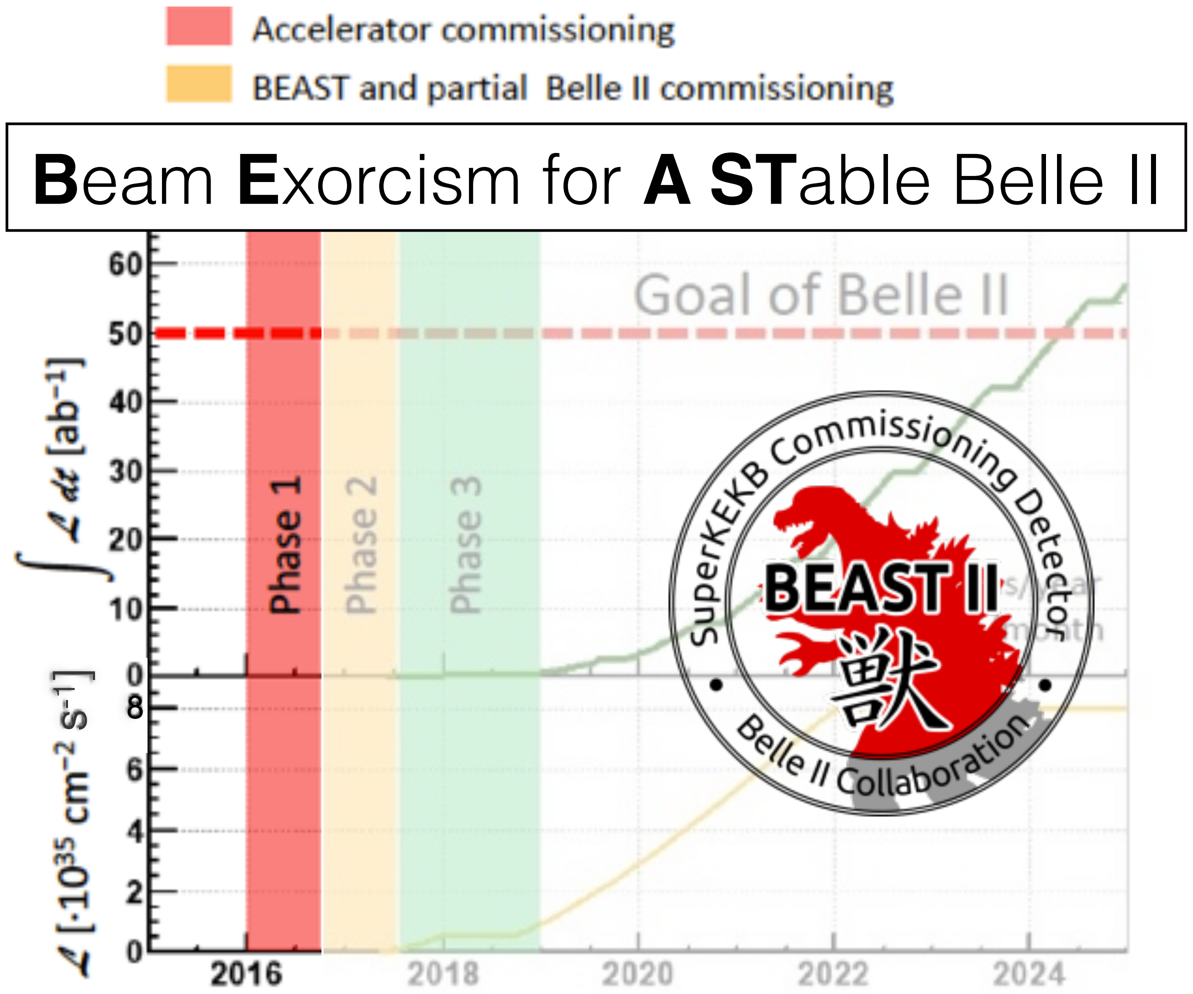


TOP detector installed in Belle II structure (May 2016)!

Magnetic field mapping then CDC installation in the summer

# Tentative Schedule



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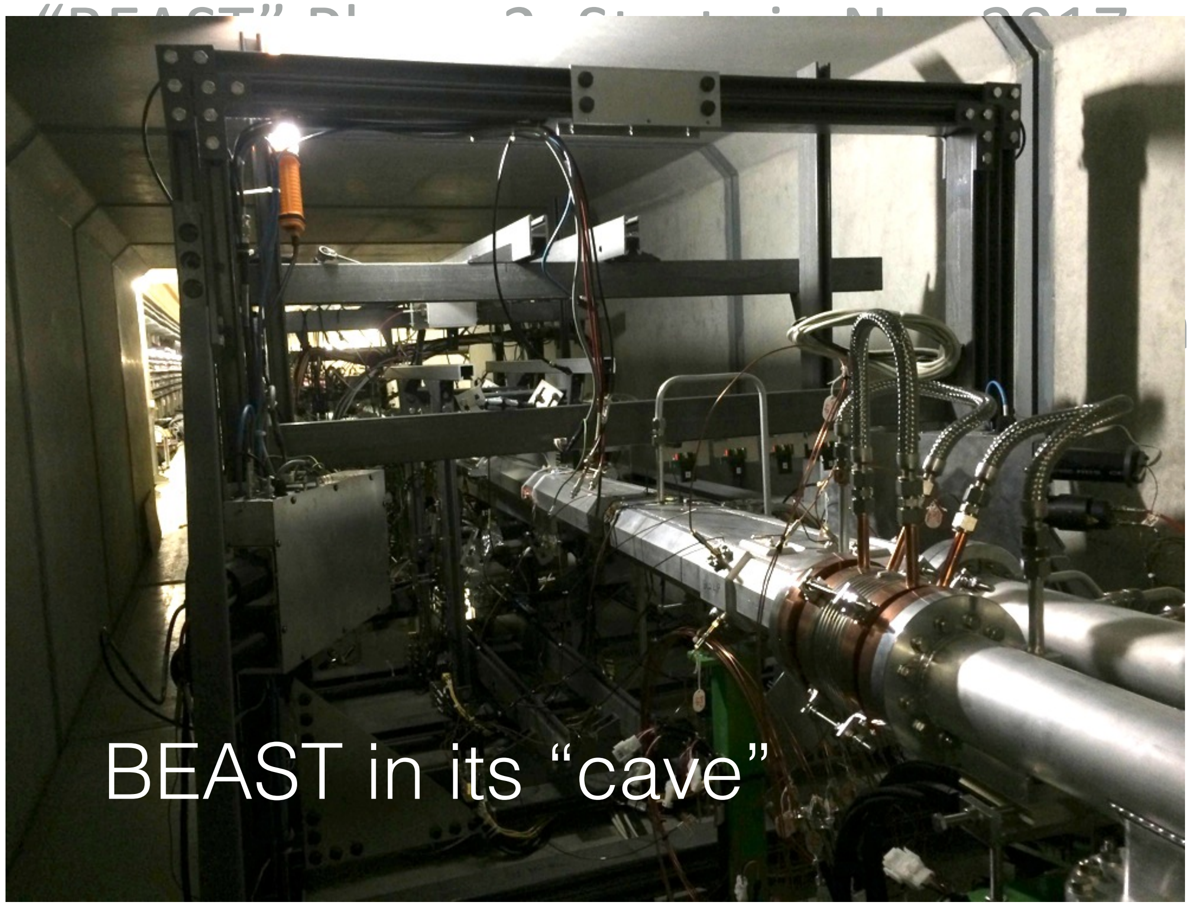
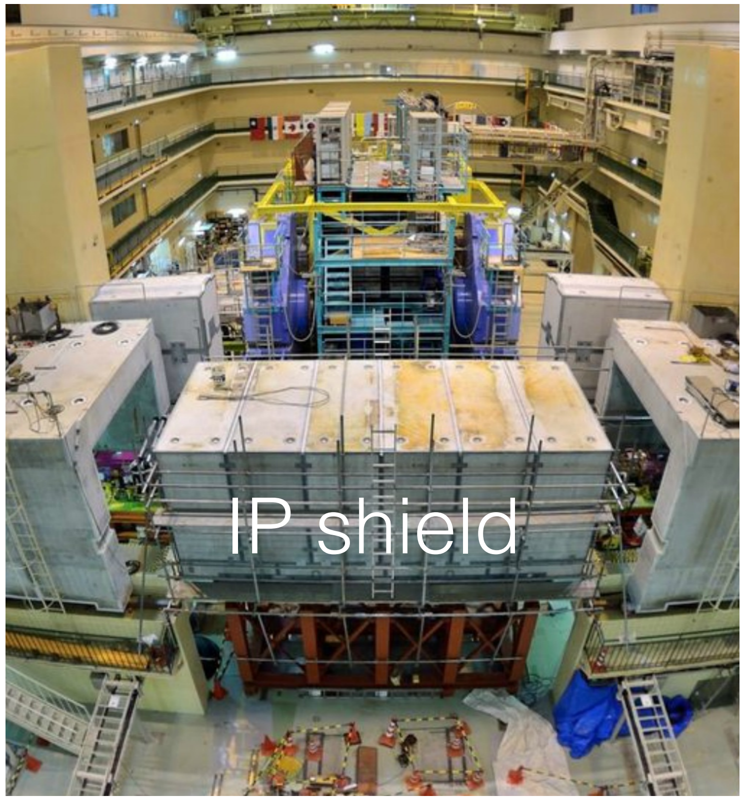

BEAST in its “cave”


IP shield

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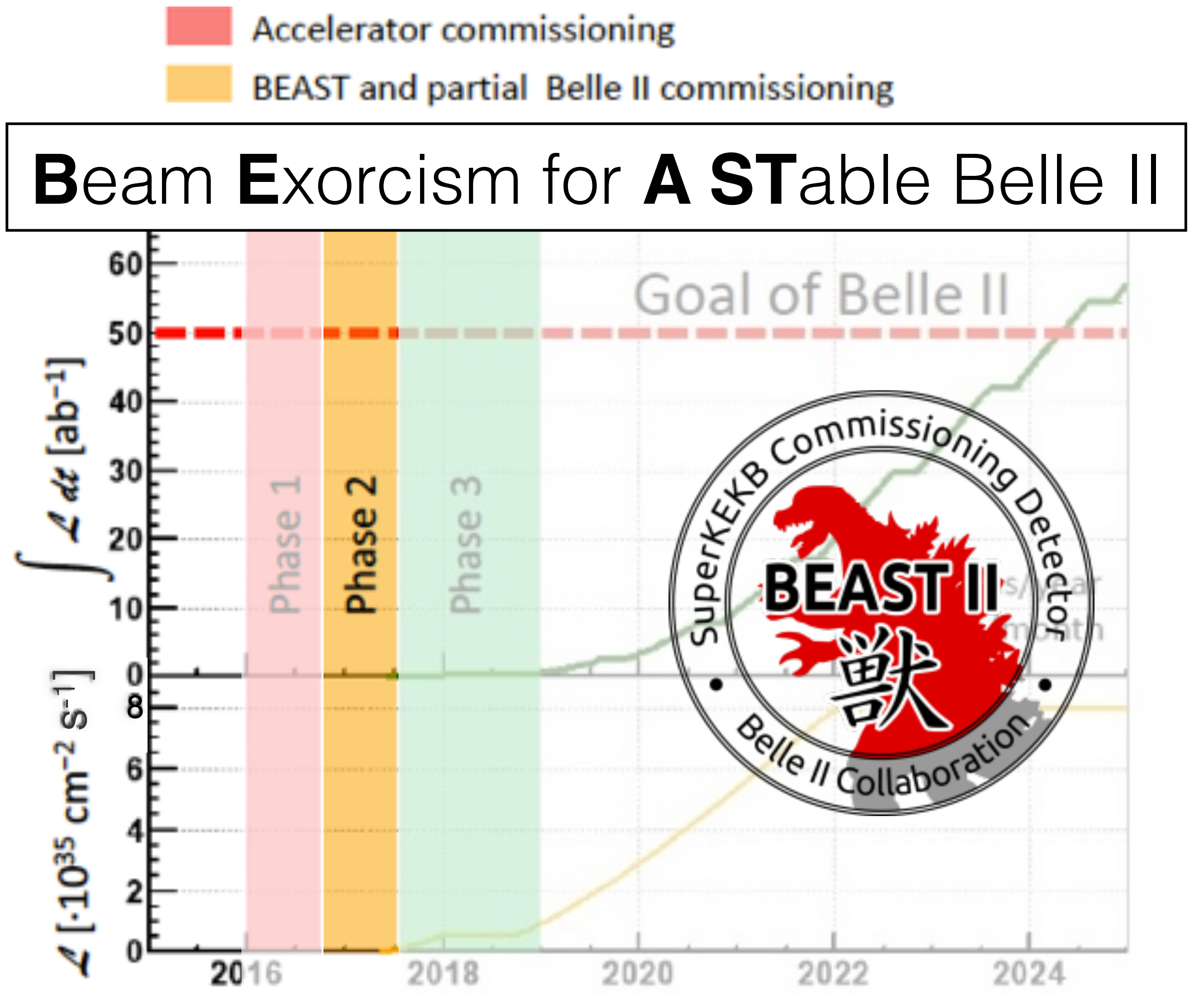
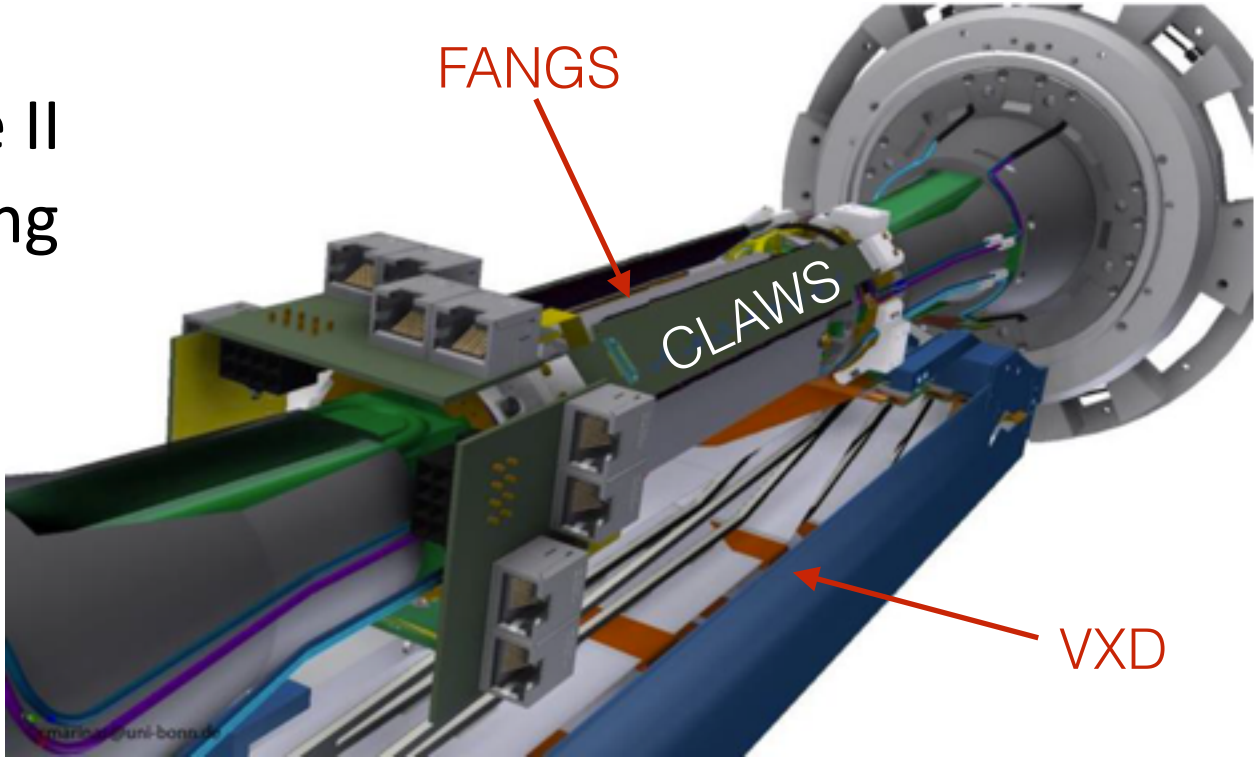


**B**eam **E**xorcism for **A ST**able Belle II



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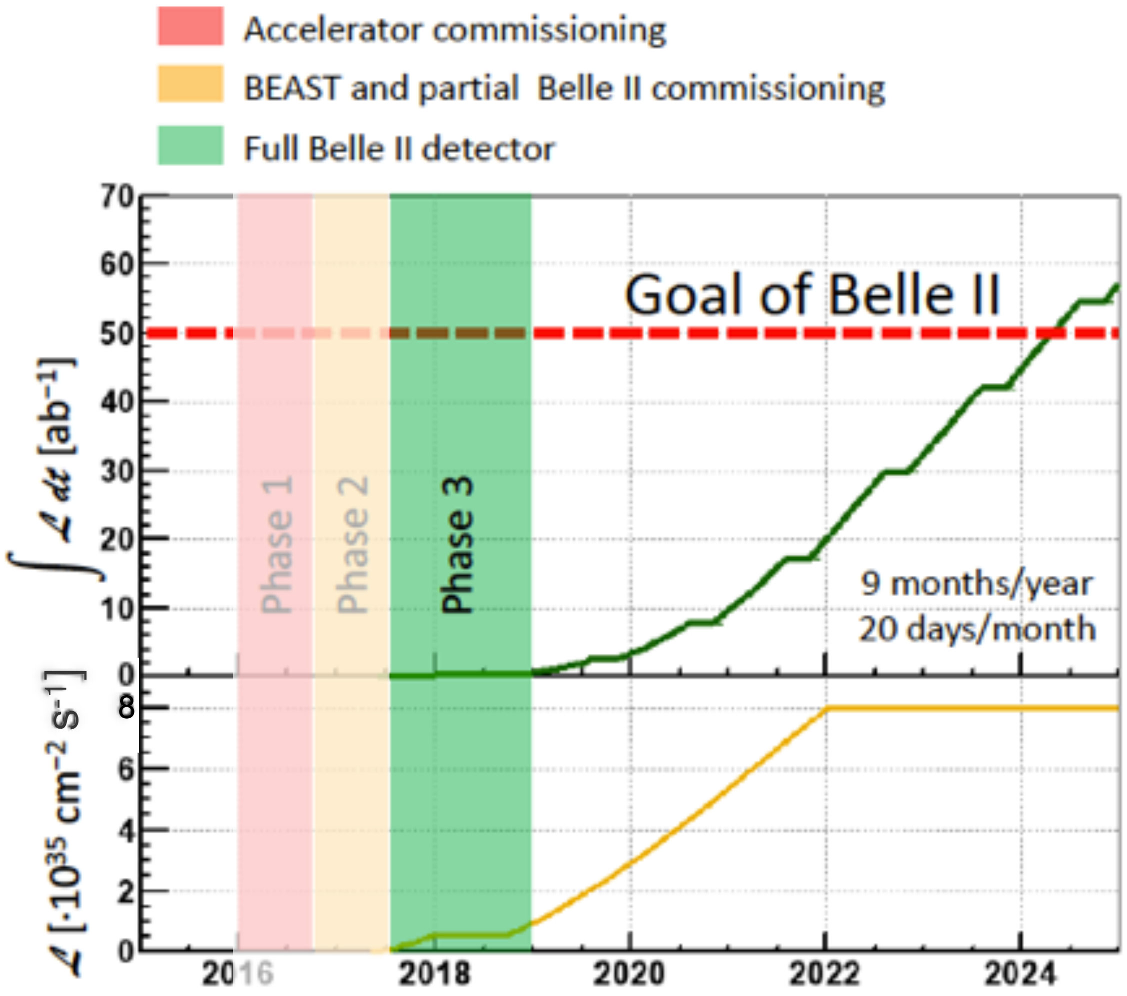
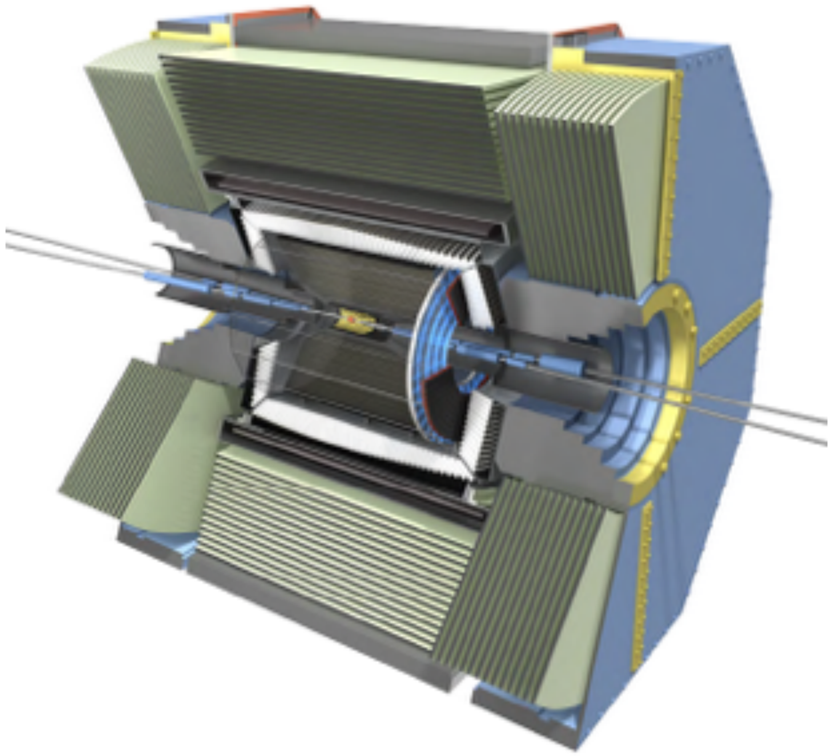
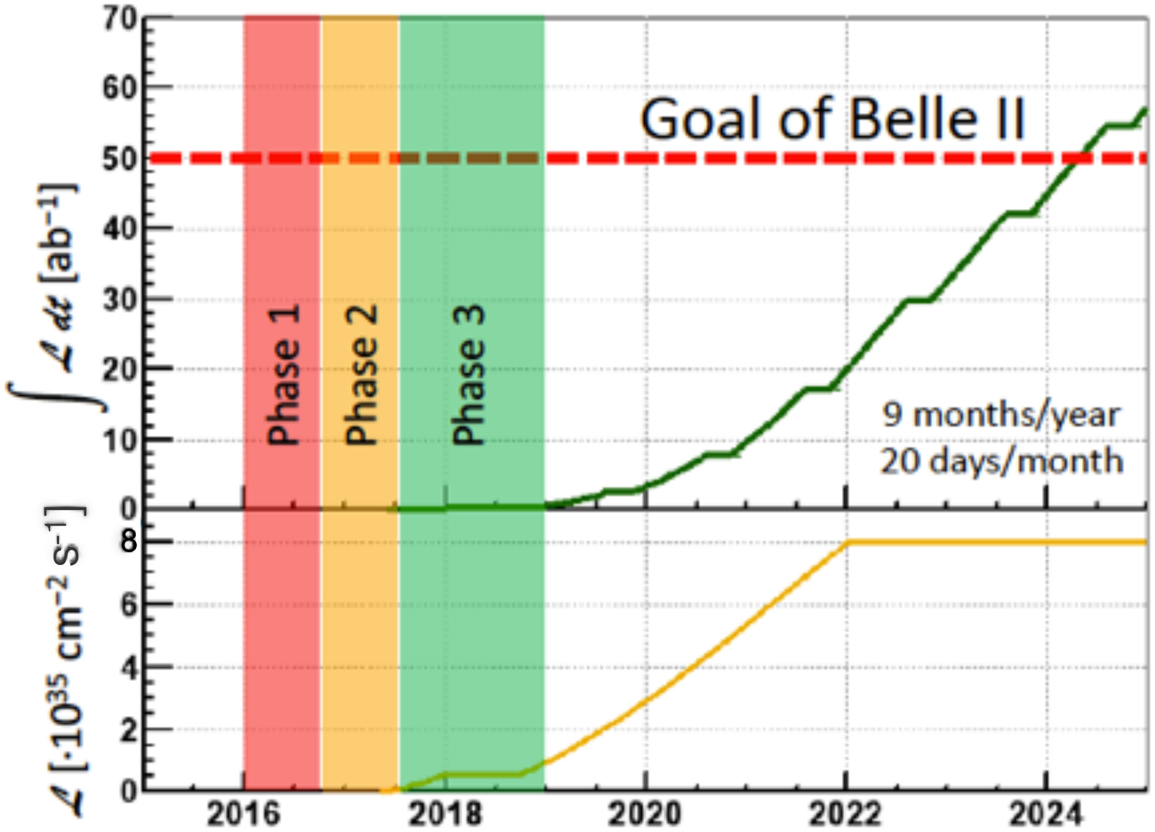




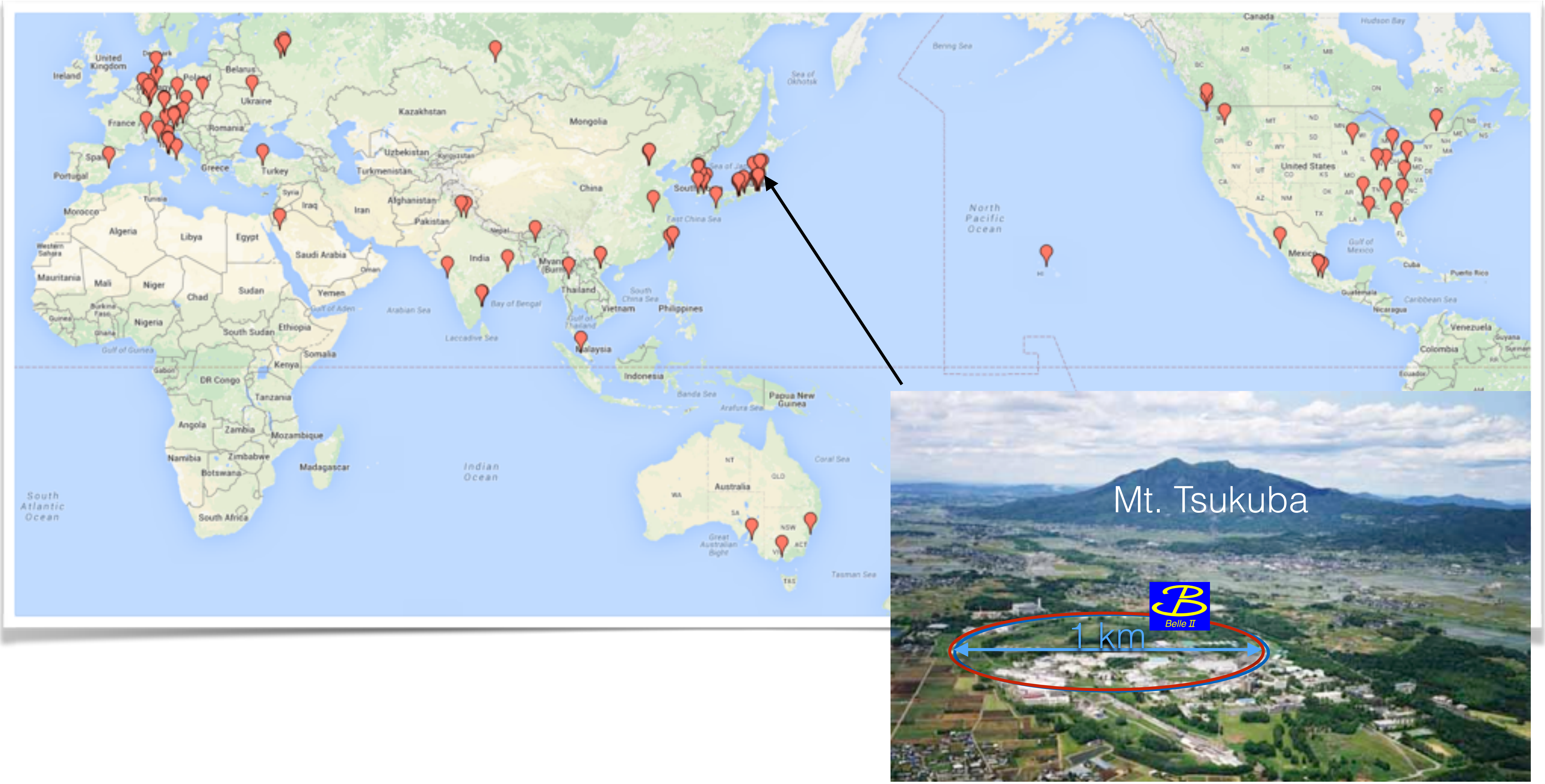
# Summary

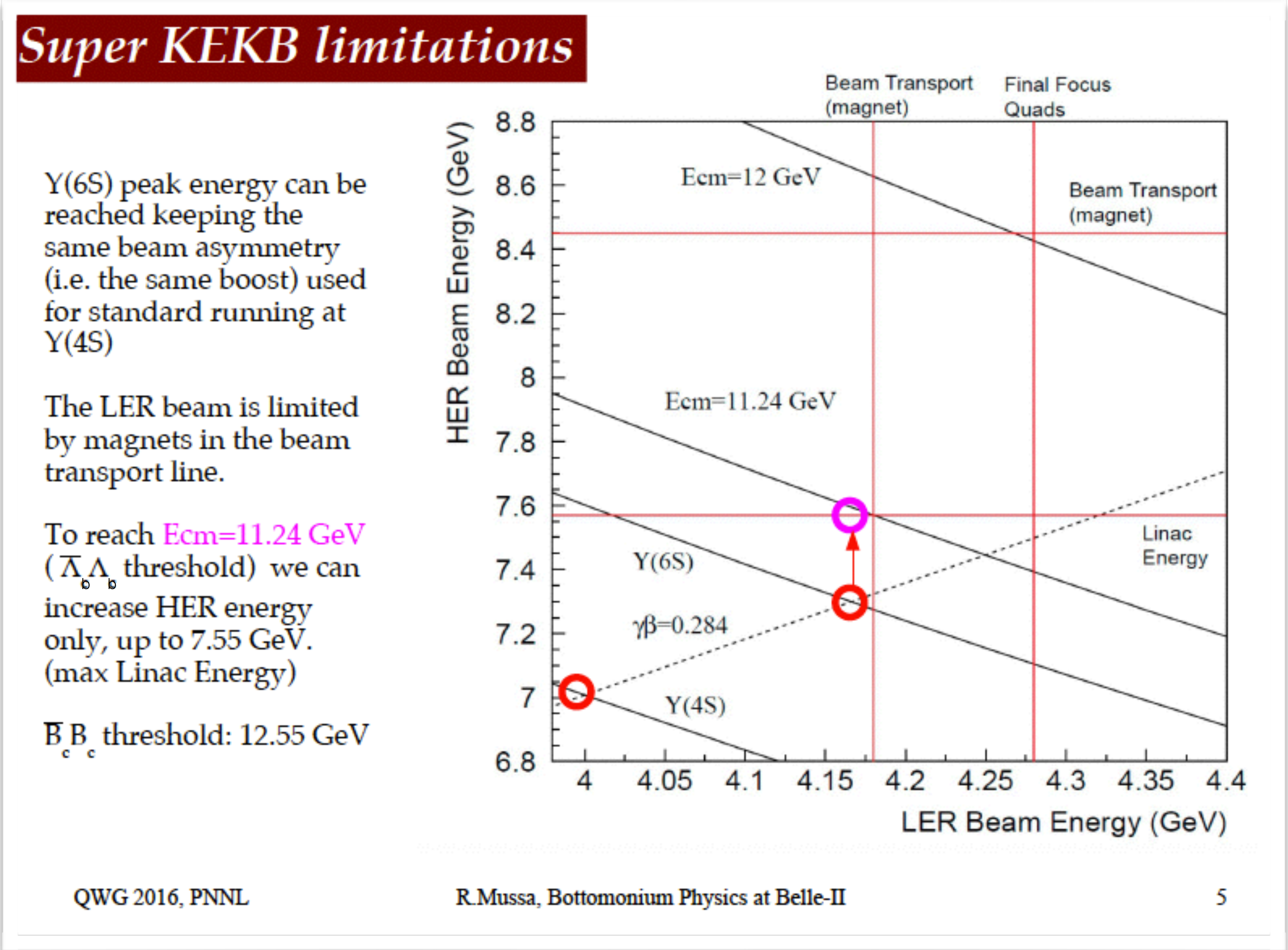
- Major upgrade at KEK represents an essentially new experiment
  - Many detector components and electronics replaced, software and analysis also improved
- Belle II has a rich physics program, complementary to existing experiments and energy frontier program
- SuperKEKB commissioning ongoing!
- First physics possible as early as 2017, full detector running in 2018



# The Belle II Collaboration

615 colleagues, 98 institutions, 23 countries/regions





# 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.

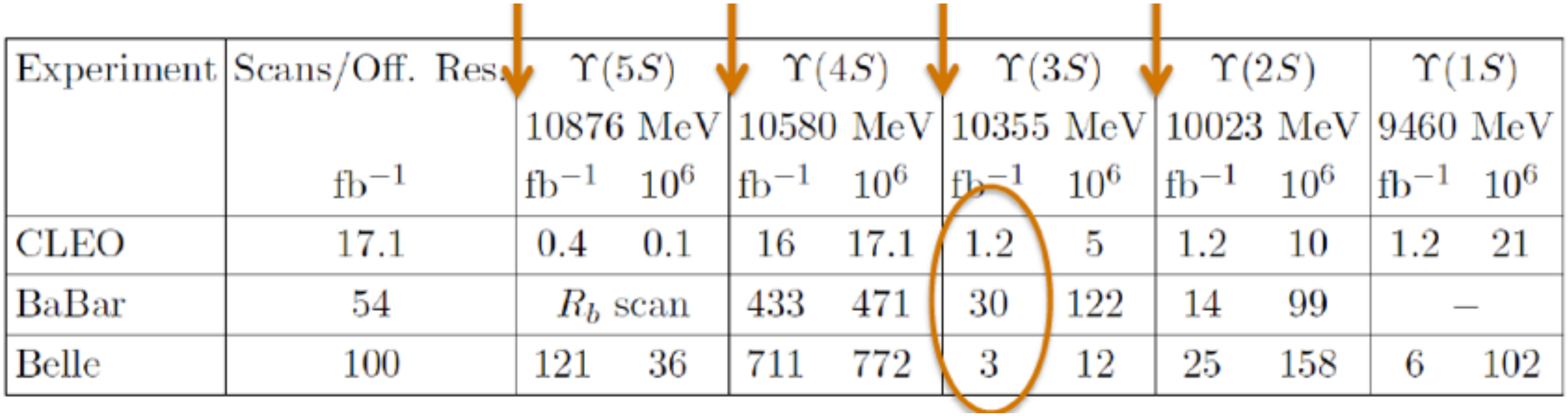
To reach Ecm=11.24 GeV ( $\bar{\Lambda}_b\Lambda_b$ threshold) we can increase HER energy only, up to 7.55 GeV. (max Linac Energy)

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

QWG 2016, PNNL R.Mussa, Bottomonium Physics at Belle-II 5

# First Physics

| Energy | Outcome | Lumi (fb$^{-1}$) | Comments |
|---|---|---|---|
| $\Upsilon$(1S) On | N/A | 60+ | -No interest identified<br>-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<br>-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 $\gamma$ | 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 |