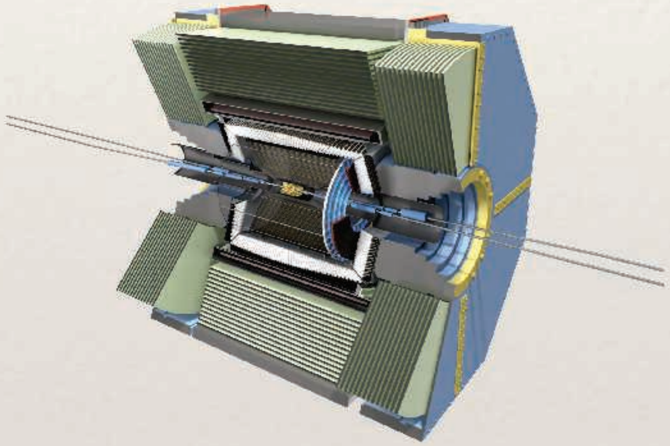
The Belle II experiment



Accelerator, detector, physics prospects and schedule

Ivan Heredia de la Cruz

for the Belle II Collaboration

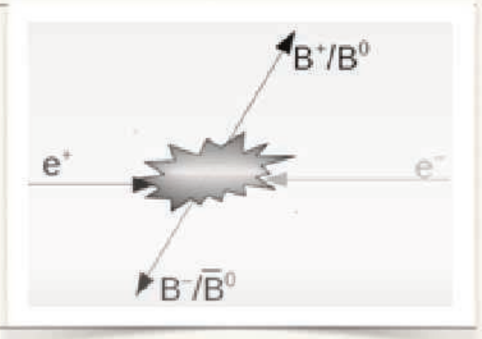
CINVESTAV/CONACyT

November 2015, MWPF2015, Mazatlan, Mexico

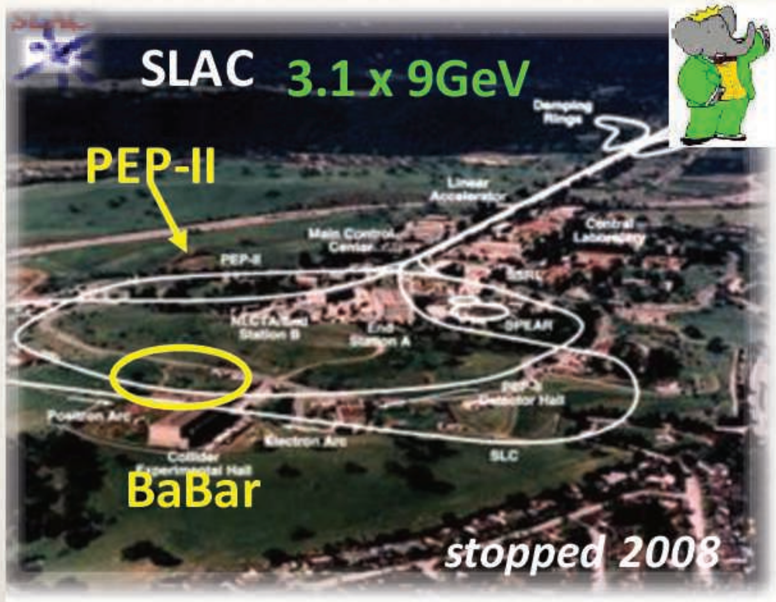
Overview

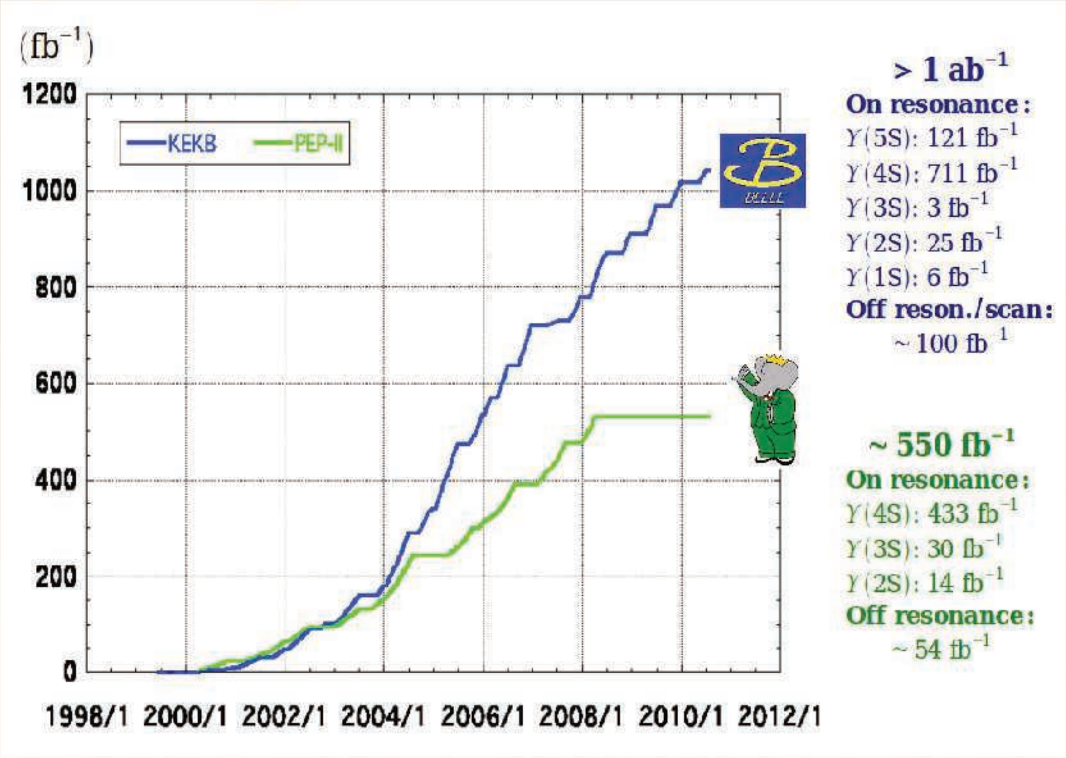
- B-factories (achievements)
- Belle II motivation
  - Search for new physics
  - B-factories advantages
- SuperKEKB
- The Belle II detector
- Physics examples at Belle II
- Plans
- Summary

B-factories



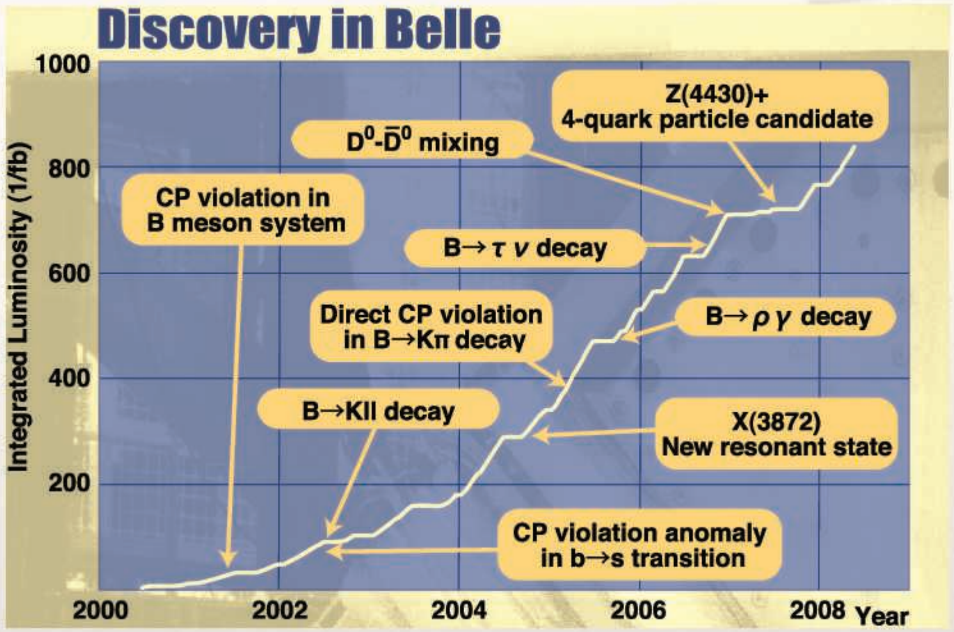
- PEP-II@SLAC (KEKB@KEK):
  - e^+e^- asymmetric collisions at BaBar (99-08) & Belle (99-10).
  - 1st. generation of B-factories.
- KEKB reached world highest lumi, ~$2\times10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}$ (2x design).
- Collisions at $E_{CM} = m(\Upsilon(nS))$:
  - Mainly at $\Upsilon(4S) = 10.58$ GeV.
  - Also off-resonance scan.
  - $L \sim 0.5\ (1)\ \mathrm{ab}^{-1}$ @BaBar (Belle):
    - ~772M $B\bar{B}$, ~900M $\tau\bar{\tau}$ @Belle.
- @ Belle > 450 papers + ongoing.

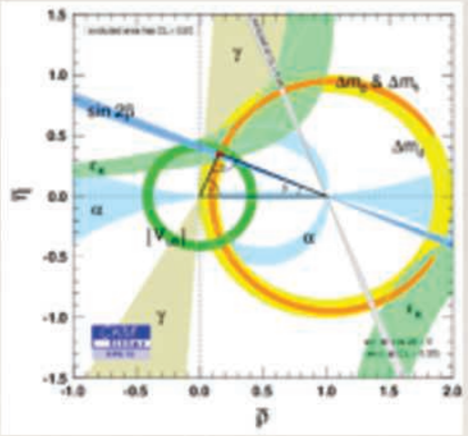




B-factories achievements

- Observation and precise measurements of CPV in B decays + discovery of direct CPV.
- Observation of mixing in charm.
- Studies on rare B decays.
- Searches for rare τ decays.
- Discovery of many new states, including $q\bar{q}$-like X(3872), $Z(4430)^+$.
- Constrains on new physics, e.g. using B→(D*)τν, b→sγ, b→sℓℓ.
- Direct searches for light-H and dark-γ.
- **Measurement of the Unitary Triangle (UT) parameters** (sides and angles).
  - Experimental confirmation of KM-mechanism (Nobel Prize in Physics 2008).

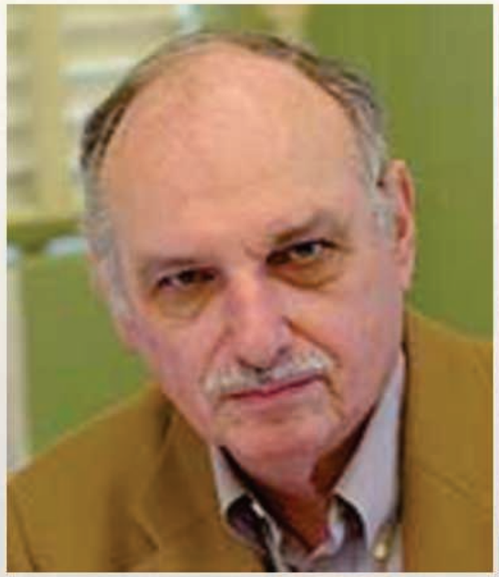




Makoto Kobayashi   Toshihide Maskawa

"For the discovery of the origin of the broken symmetry which predicts the existence of at least three families of quarks in nature"

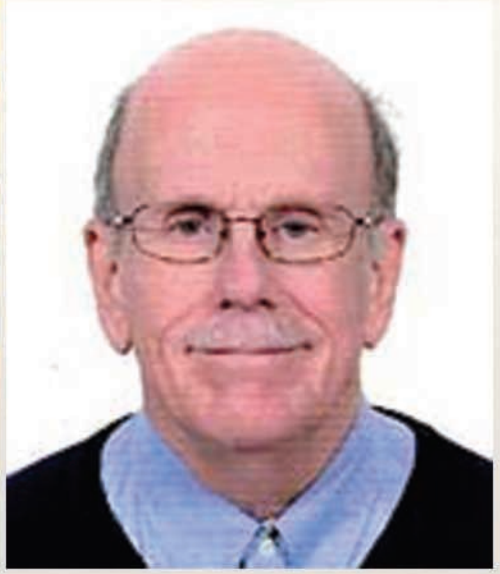
W.K.H. Panofsky Prize 2016 (APS)



David Hitlin

Fumihiko Takasaki

Jonathan Dorfan



Stephen L Olsen

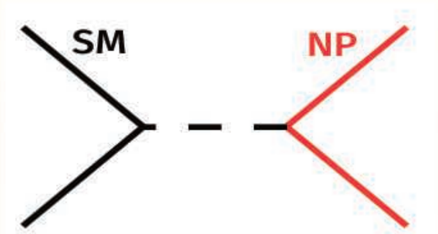
To B-factory founders:

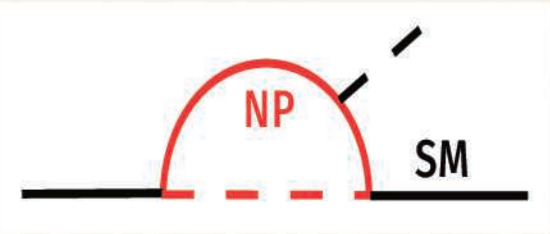
"For leadership in the BaBar and Belle Experiments, which established the violation of CP symmetry in B-meson decay, and furthered our understanding of quark mixing and quantum chromodynamics."

So, why Belle II?

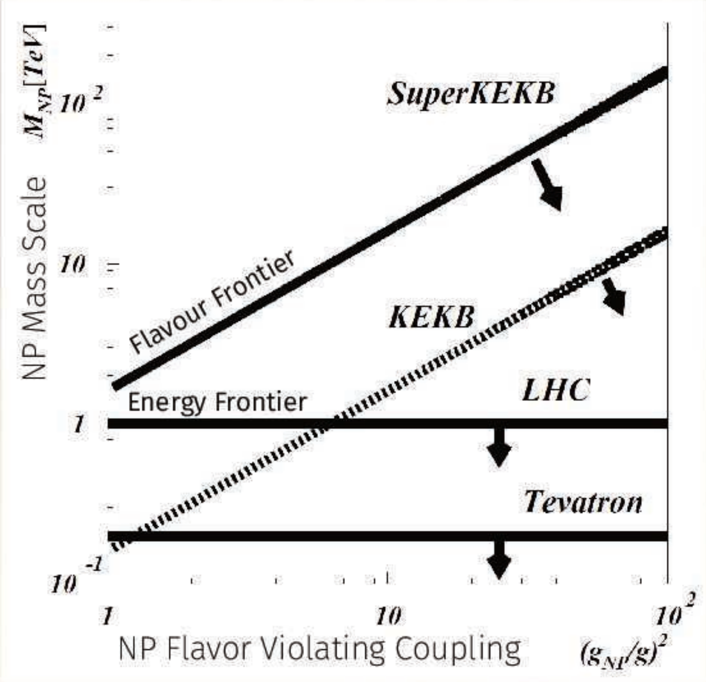
Searching for New Physics (NP)

- *Two approaches* at colliders:
  - Energy frontier: direct production of new particles, limited by beam energy (CMS & ATLAS @LHC).
  - Flavor (intensity) frontier: reveal NP virtual particles in loops (B-factories, LHCb), could test up to 100 TeV ⇒ **SuperKEKB!**





- *Complementarity*:
  - If NP at LHC, effects will emerge in B, D & τ decays.
  - If not, flavor measurements at **Belle-II** will provide unique ways to find NP.
- *Belle-II vs. LHCb:*
  - LHCb specializes in decays to clean final states (e.g. $B \to \mu\mu$) + large production (10^6 x Belle) + bottom baryons.
  - Initial state energy in Belle-II will be well defined ⇒ easy to handle inclusive decays ($B \to X_s \ell\ell$), decays to neutrals particles ($B \to K_s K_s K_s$, $B \to \tau\nu$) + more in a moment!.



Physics at (Super) B factories

SM

- **B and D decays:** access to (almost all) CKM matrix elements (& phases).

BSM

- **B and D decays:**
  - mixing (box), CPV (penguins, etc.), rare decays (FCNC)
- **Tau leptons:**
  - LFV & LNV.
- **Direct search for light particles:**
  - sterile neutrino, dark photons, light Higgs, axions…

- Test models such as SUSY, *Z′*, Little Higgs or 2HDM, hidden dark sector, etc?

QCD

- **Hadron spectroscopy:**
  - quarkonium, charm and light mesons & baryons
- **γγ-physics:**
  - γγ-width, form factors.

- Inputs to QCD models and $(g\text{-}2)_\mu$.

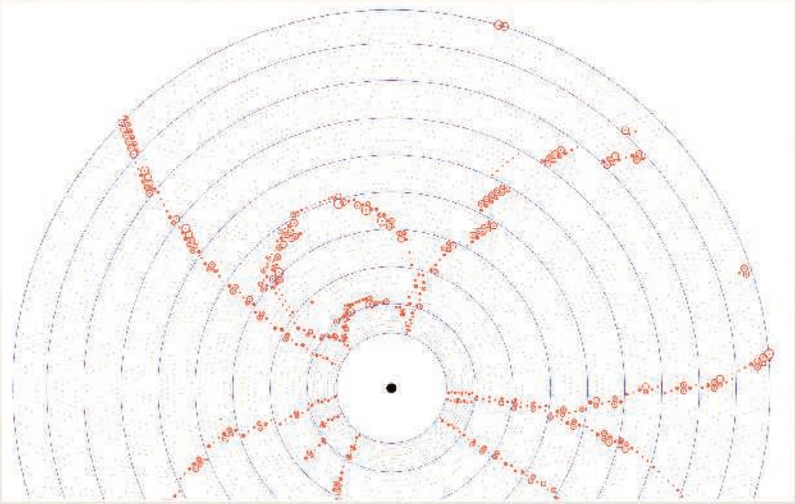
QCD exotics

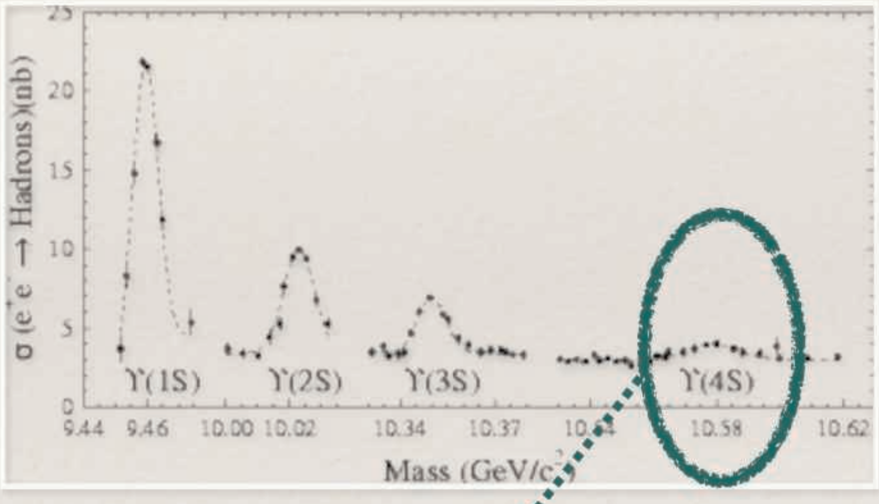
- **Quarkonium-like exotic states**
  - Charmonium, bottomonium

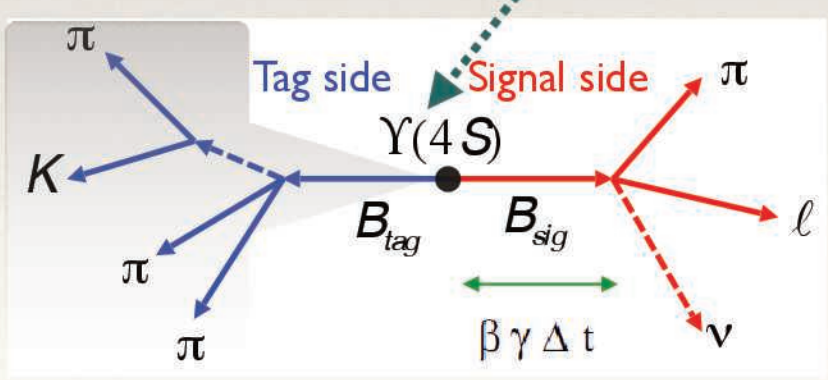
- Spectroscopy beyond standard quark model: tetra/penta-quarks, glueballs, hybrids, molecules, etc.

Unique features in B factory

- Low bkgs. → easier detection of neutrals (γ, hadrons).
- Low track multiplicities (~10) and detector occupancy:
  - High B, D & τ reco efficiency.
  - Low trigger bias → smaller corrections and syst. uncert. in measurements, e.g. Dalitz analyses.
- E_{CM} can be adjusted for (or off-) Υ(nS) resonances.
  - Bottomonium spectroscopy, B_s @ Υ(5S), etc.
- Reconstruction of a B-meson (B_{tag}) constrains flavor of the other (B_{sig}) and its 4-momentum, $p(B_{sig}) = -p(B_{tag})$:
  - Detected particles not from B_{tag} must come from B_{sig}:
    - Inclusive measurements (absolute BR).
    - Missing energy channels, e.g. B→(D*)τν.
    - Tagging power > 30% (compare to 2% for LHCb).
- Asymmetric beams → boosted $B\bar{B}$ → time dep. CPV.



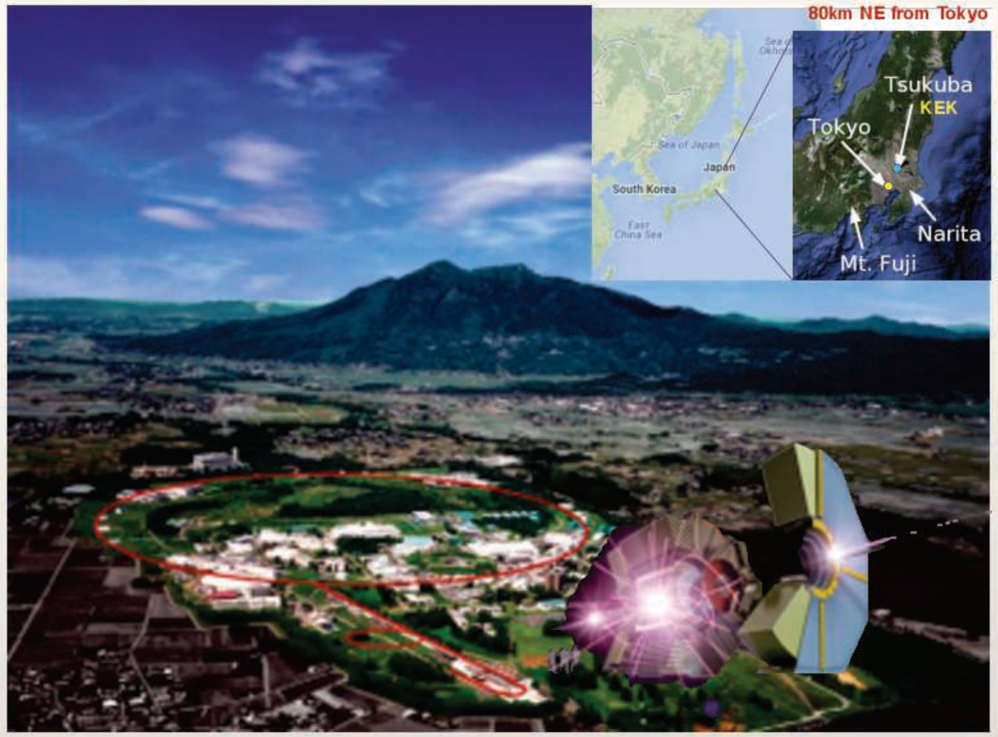


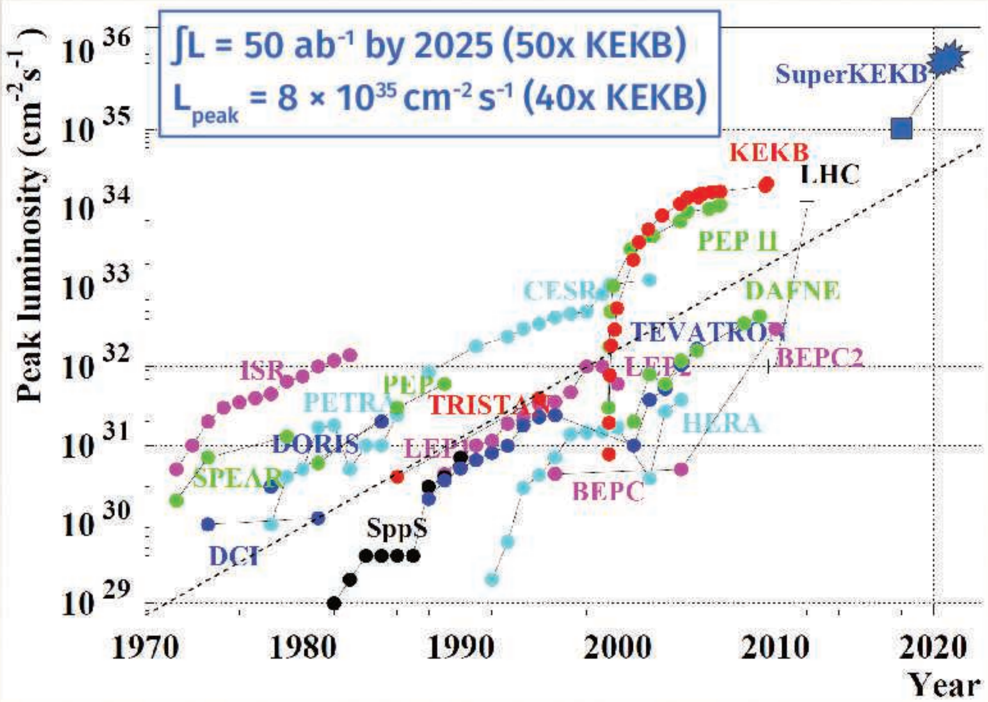


SuperKEKB

- Located at KEK (High Energy Accelerator Research Organization), Tsukuba, Japan.
- Last generation B factory:
  - Major upgrade to KEKB.
- $e^+e^- \to \Upsilon(4S) \to B\bar{B}$ mainly.
- Will deliver 50ab^{-1} to Belle-II (50x KEKB).
- Peak lumi will be 8×10^{35} cm^{-2} s^{-1} (40x KEKB).

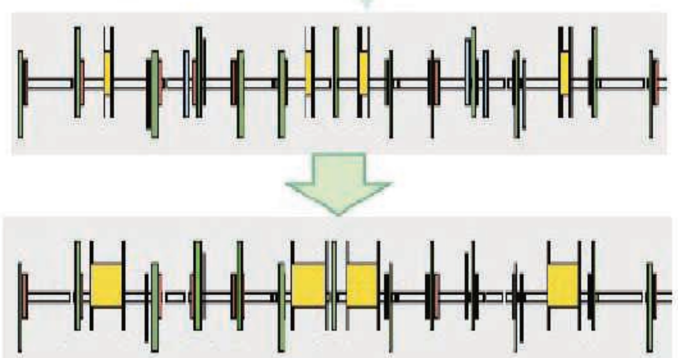
Channel	Belle	BaBar	Belle II (per year)
$B\bar{B}$	7.7×10^8	4.8×10^8	1.1×10^{10}
$B_s^{(*)}\bar{B}_s^{(*)}$	7.0×10^6	–	6.0×10^8
$\Upsilon(1S)$	1.0×10^8		1.8×10^{11}
$\Upsilon(2S)$	1.7×10^8	0.9×10^7	7.0×10^{10}
$\Upsilon(3S)$	1.0×10^7	1.0×10^8	3.7×10^{10}
$\Upsilon(5S)$	3.6×10^7	–	3.0×10^9
$\tau\tau$	1.0×10^9	0.6×10^9	1.0×10^{10}



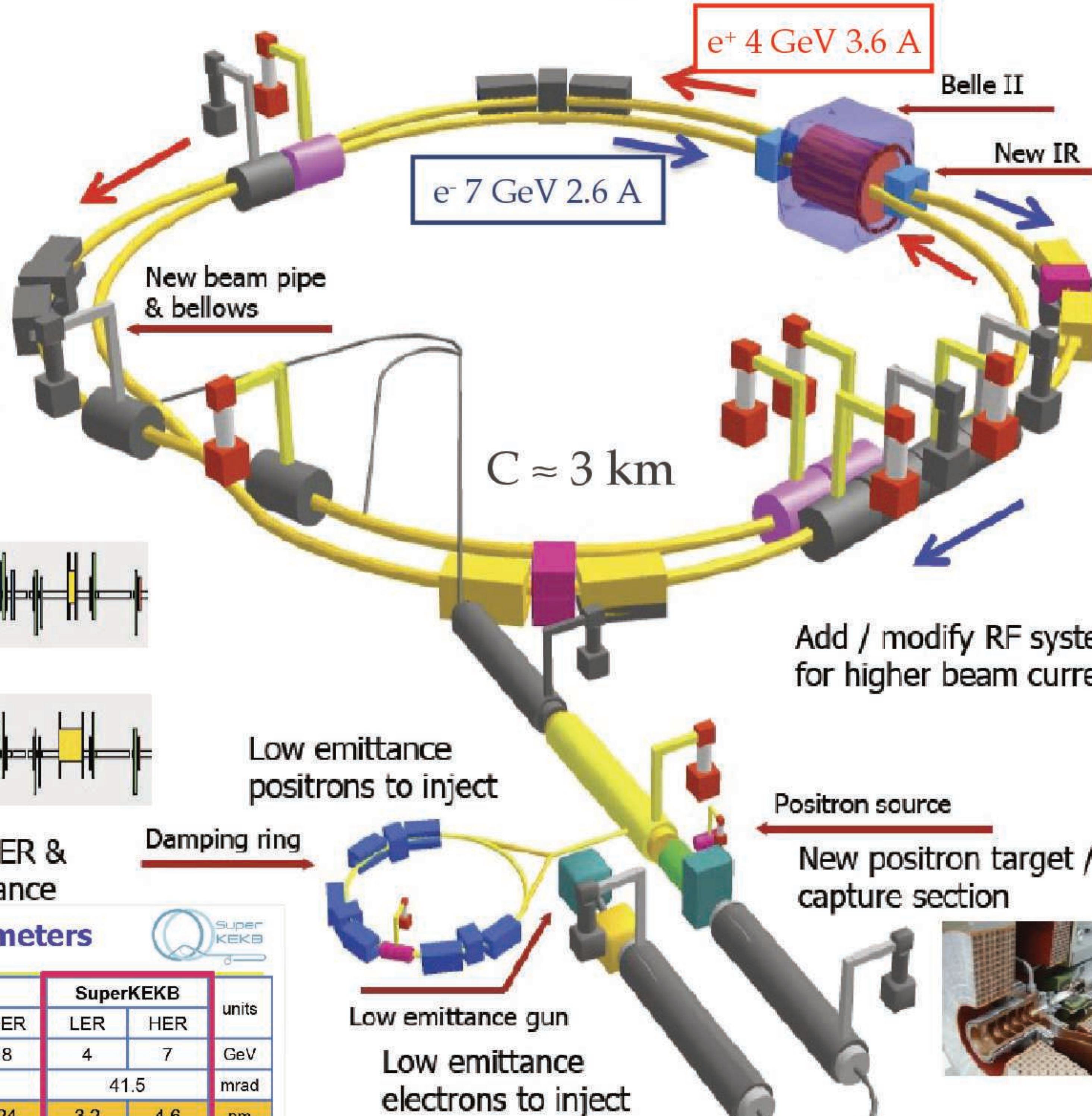


KEKB to SuperKEKB

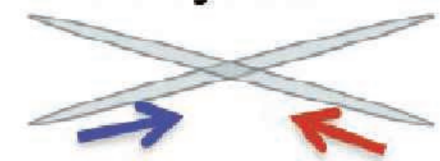
Replace short dipoles with longer ones (LER)



Redesign the lattices of HER & LER to squeeze the emittance



Colliding bunches



New superconducting /permanent final focusing quads near the IP

Add / modify RF systems for higher beam current

New positron target / capture section

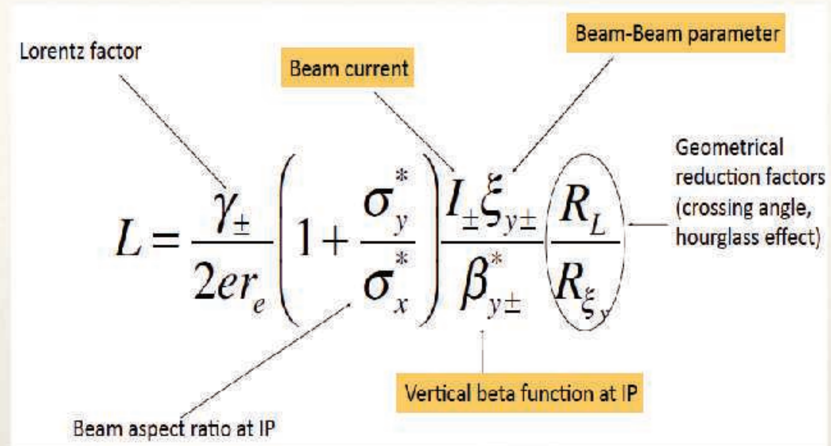
Machine design parameters

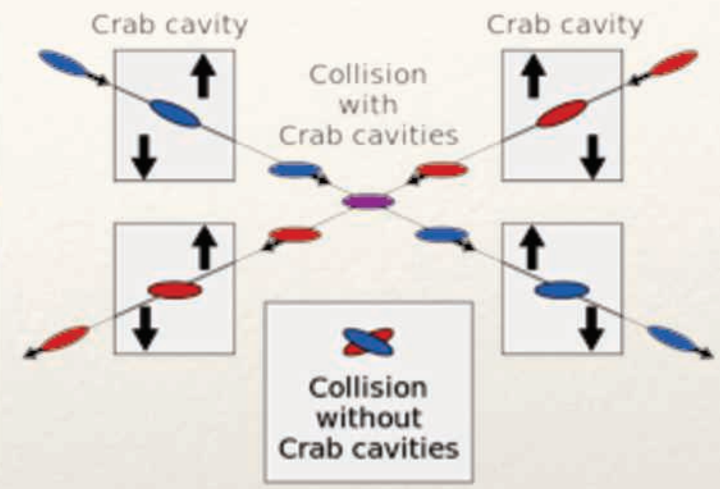
parameters		KEKB LER	KEKB HER	SuperKEKB LER	SuperKEKB HER	units
Beam energy	E_b	3.5	8	4	7	GeV
Half crossing angle	φ	11		41.5		mrad
Horizontal emittance	ε_x	18	24	3.2	4.6	nm
Emittance ratio	κ	0.88	0.66	0.37	0.40	%
Beta functions at IP	β_x^*/β_y^*	1200/5.9		32/0.27	25/0.30	mm
Beam currents	I_b	1.64	1.19	3.60	2.60	A
beam-beam parameter	ξ_y	0.129	0.090	0.0881	0.0807	
Luminosity	L	2.1×10^{34}		8×10^{35}		$cm^{-2}s^{-1}$

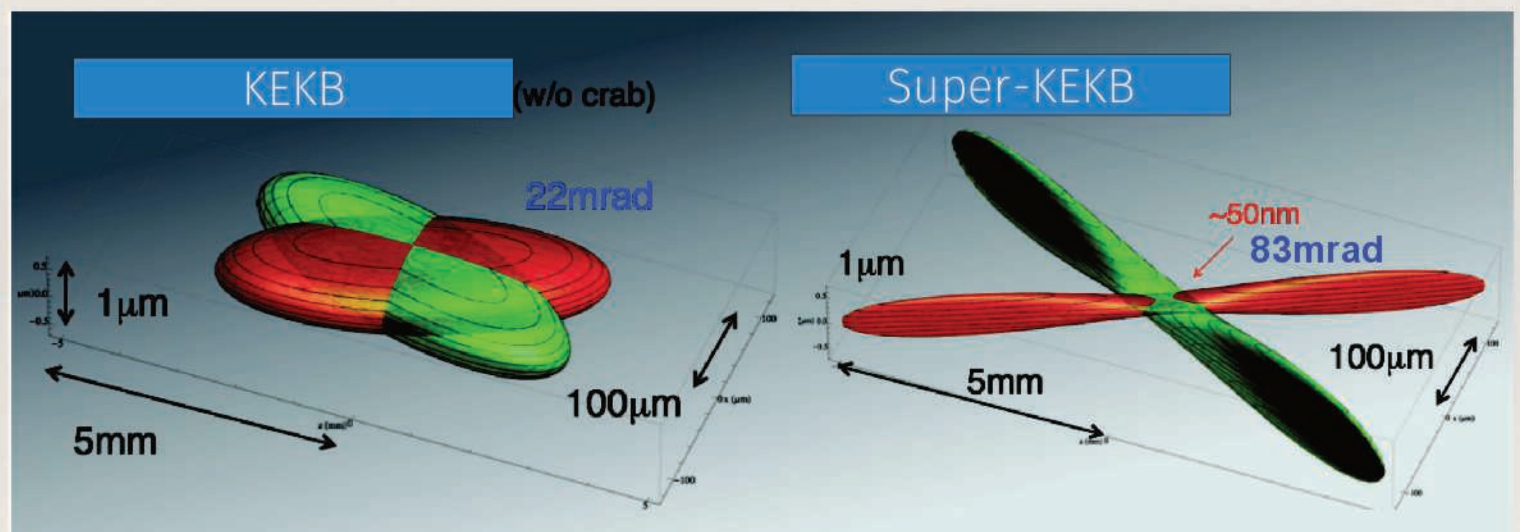
40x luminosity increase!

Luminosity increase

- Reduced in beam-spot size (1/20 x β^*_y) by using nano-beams:
  - Superconducting focusing quads near IP.
- Beam currents increased by 2.
- Large crossing angle ($2\phi \sim 83$ mrad).
  - Avoids long-range beam-beam collisions.
  - Crab cavities imparts transverse kick to restore head-on collisions.
- Higher energy of positron beam (LER) to increase its lifetime ($\beta\gamma = 0.425 \rightarrow 0.28$, TOF $\rightarrow$ hermeticity).





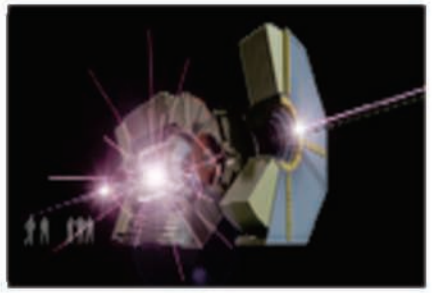


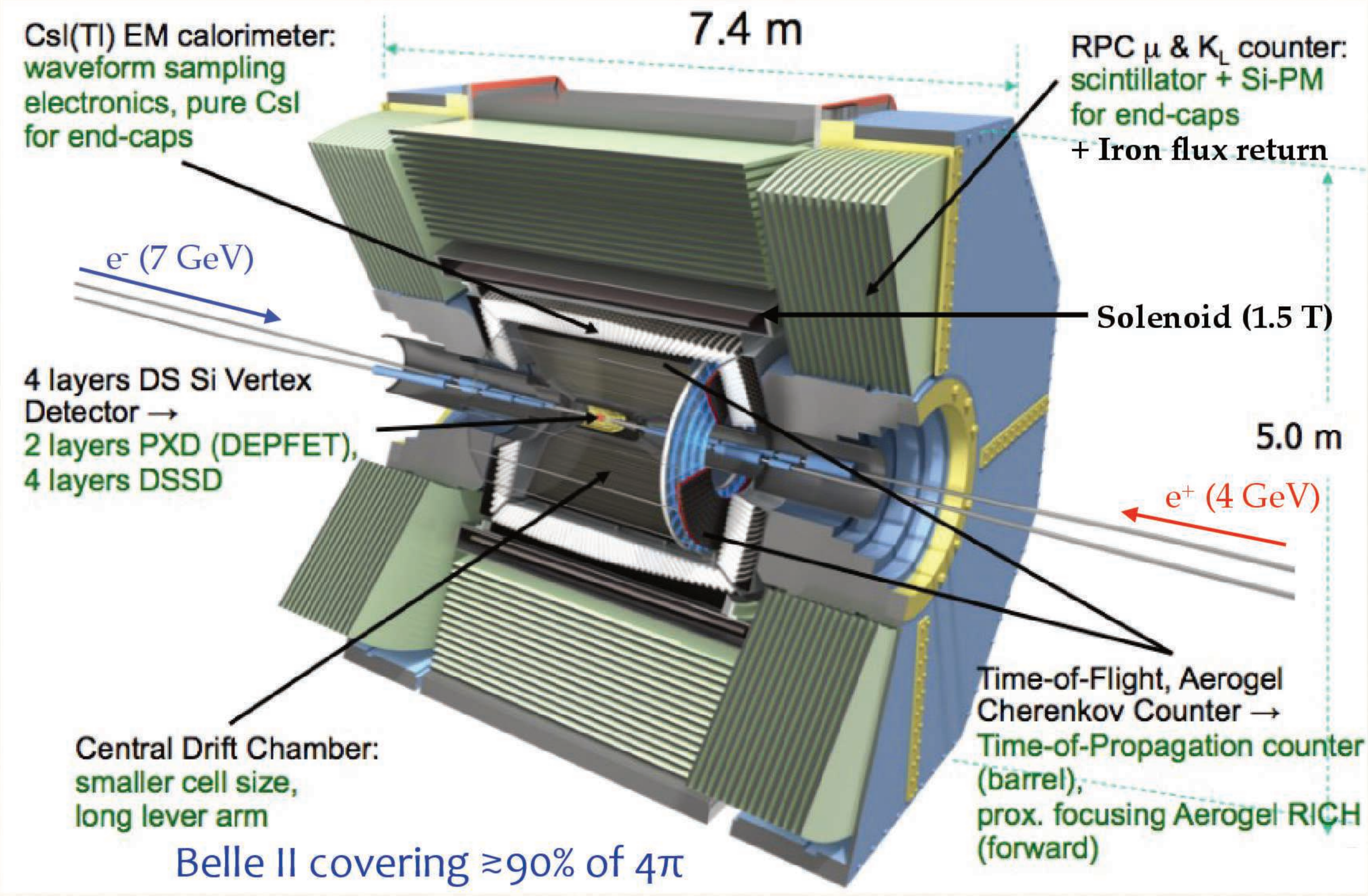
	E (GeV) LER/HER	β^*_y (mm) LER/HER	β^*_x (cm) LER/HER	φ (mrad)	I (A) LER/HER	L ($cm^{-2}s^{-1}$)
KEKB	3.5/8.0	5.9/5.9	120/120	11	1.6/1.2	2.1 x 10^{34}
SuperKEKB	4.0/7.0	0.27/0.30	3.2/2.5	41.5	3.6/2.6	80 x 10^{34}

factor 20 factor 2-3

The Belle-II detector at SuperKEKB

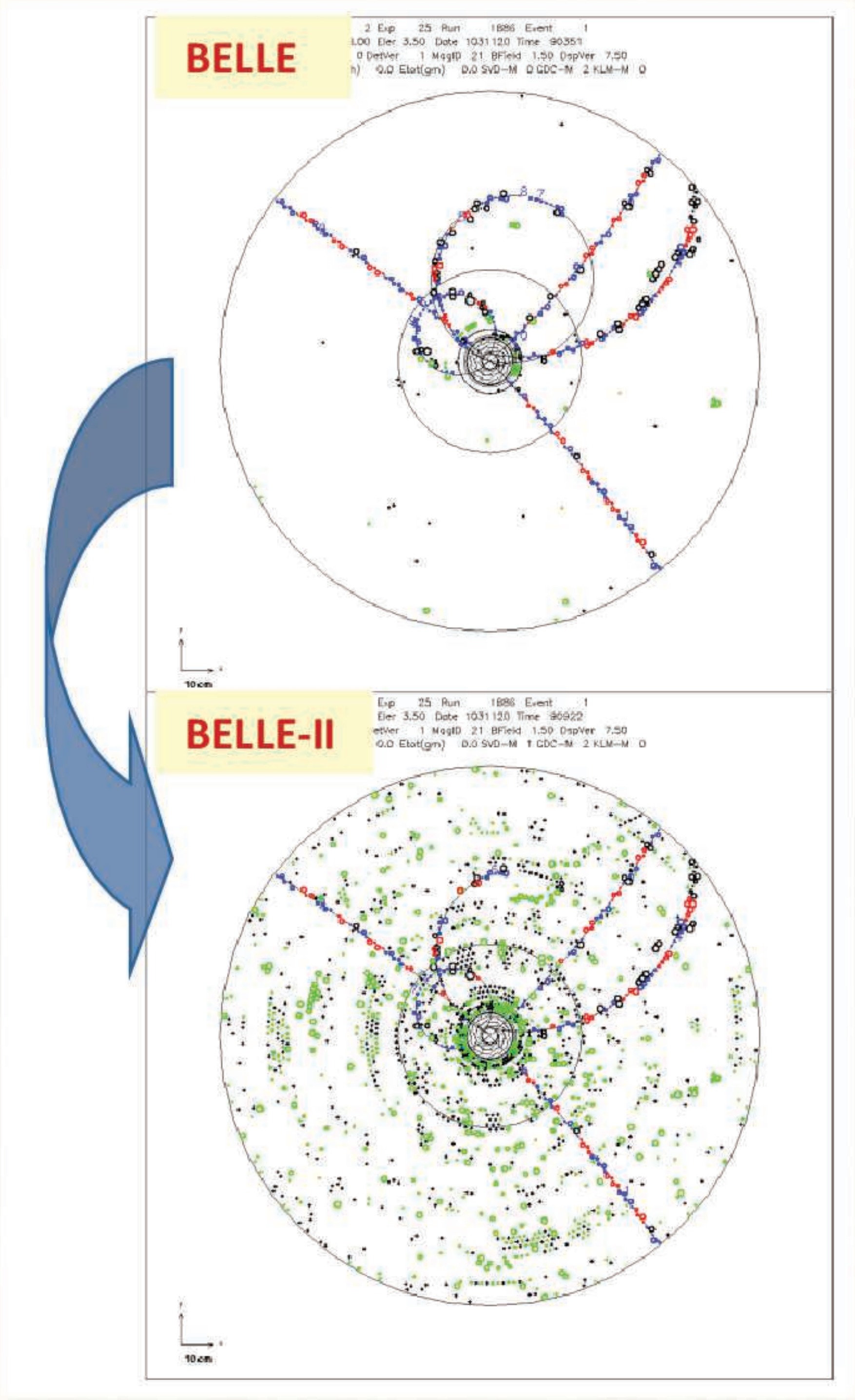
The Belle-II detector





From Belle to Belle-II

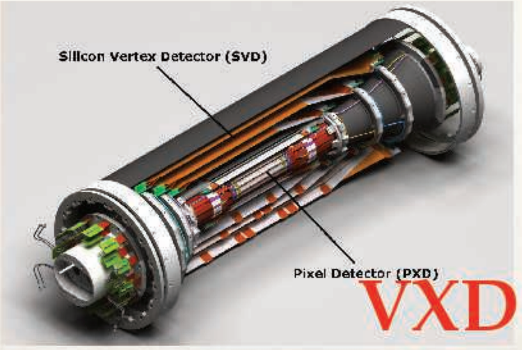
- Several sub detectors upgraded or replaced for improved performance at higher luminosity: backgrounds (occupancy, fake hits, radiation damage) and event rates (0.5→30KHz).
- Larger tracker (SVD & CDC):
  - Improve IP and SV resolution, increase K^0_S (+30%) and π^0 efficiency, better flavor tagging, …
- Smaller beam pipe (1.5→1.0 cm), PXD closer to IP:
  - Improve IP_z resolution (~60 → ~20 μm).
- Upgraded TOP & ARICH:
  - Better K/π separation, flavor tag., bkg rejection, …
- Improved hermeticity (PID & μ-ID in endcaps).
- Improved trigger, DAQ & algorithms.



Tracking system

- Vertex Detector (VXD):
  - precise meas. of IP and SV of short lived particles.
- Central Drift Chamber (CDC):
  - complements VXD for charged track reconstruction and measurement of long-lived particles.
- Average multiplicity in Υ(4S) event:
  - 11 charged tracks, 5 neutral pions, 1 neutral kaon.
- Soft charged tracks spectrum.

Tracker =



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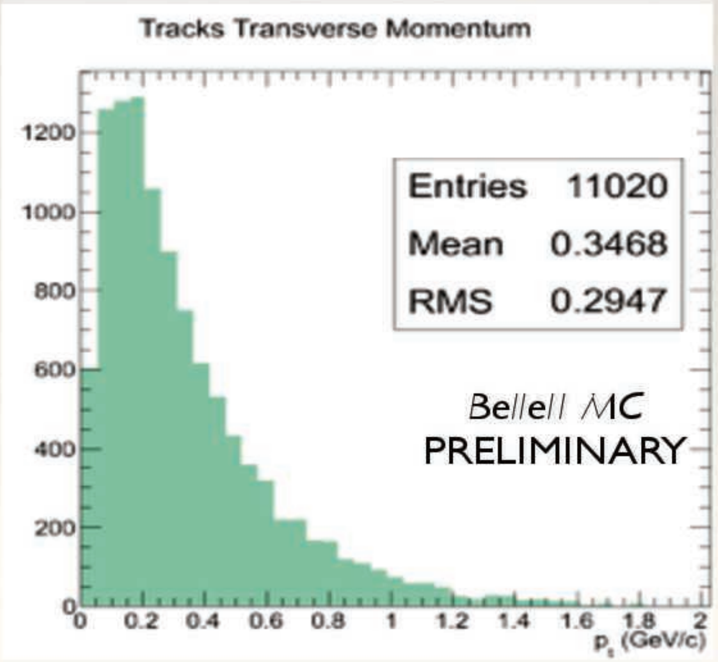
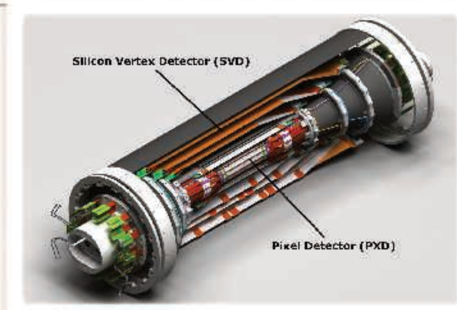
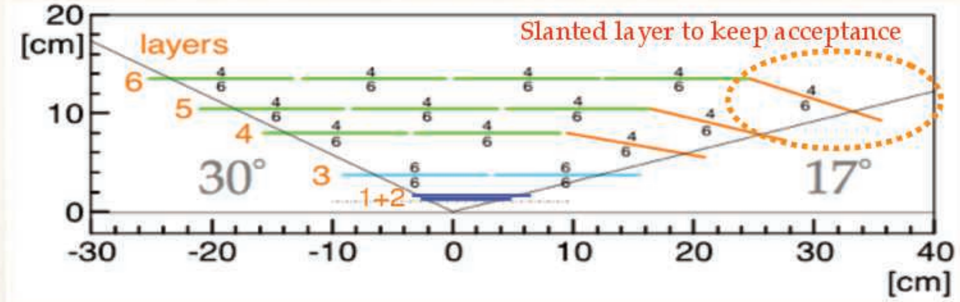


Vertex detector (VXD)



- PXD & SVD complementary to reach expected precision on vertexing and tracking.



Pixel Detector (PXD)

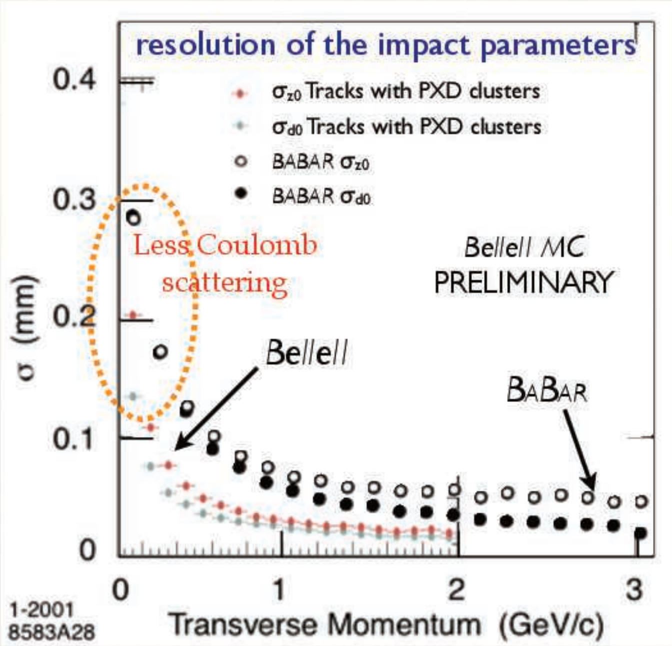
2 layers of DEPFET pixels (layers 1 & 2)

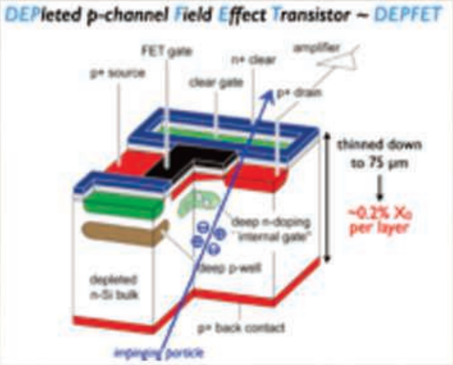
- innermost layer very close to IP (r = 1.4 cm)
- very low material budget (~0.2% X_0)
- excellent spatial granularity ($\sigma \lesssim 15$ μm)

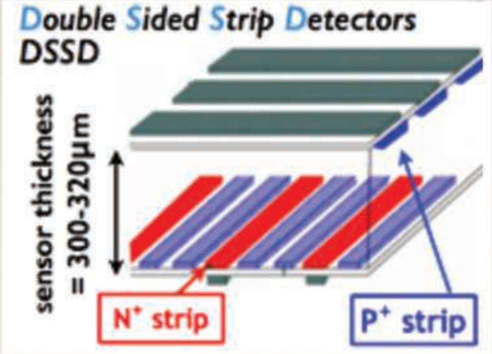
Silicon Vertex Detector (SVD)

4 layers of double sided silicon strip detector (layers 3 to 6)

- excellent timing (σ ~ 2-3 ns)
- low material budget (~0.8% X_0)
- larger outer radius (r = 14 cm)

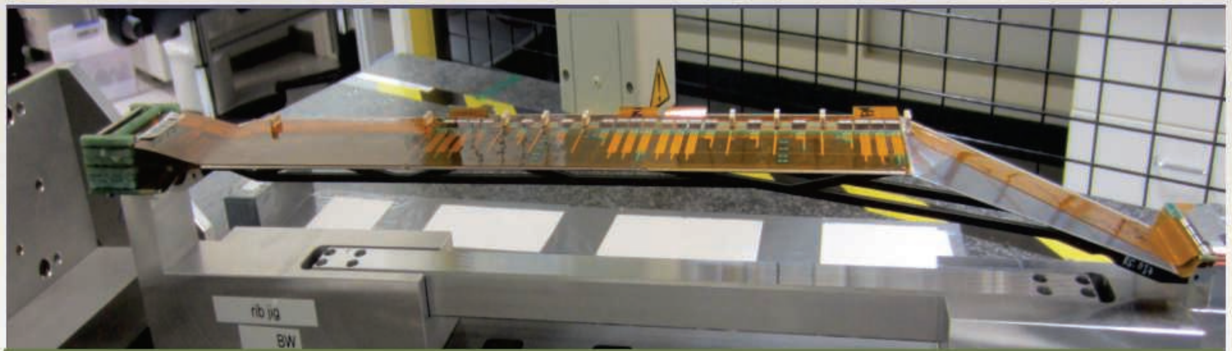






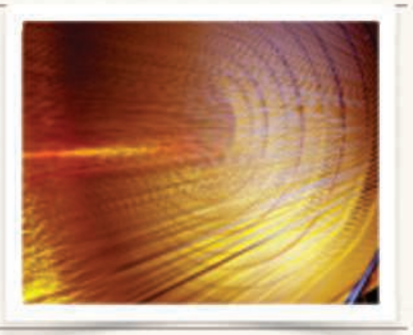
Air cooling sufficient, radiation tolerant!

PXD sensors in production

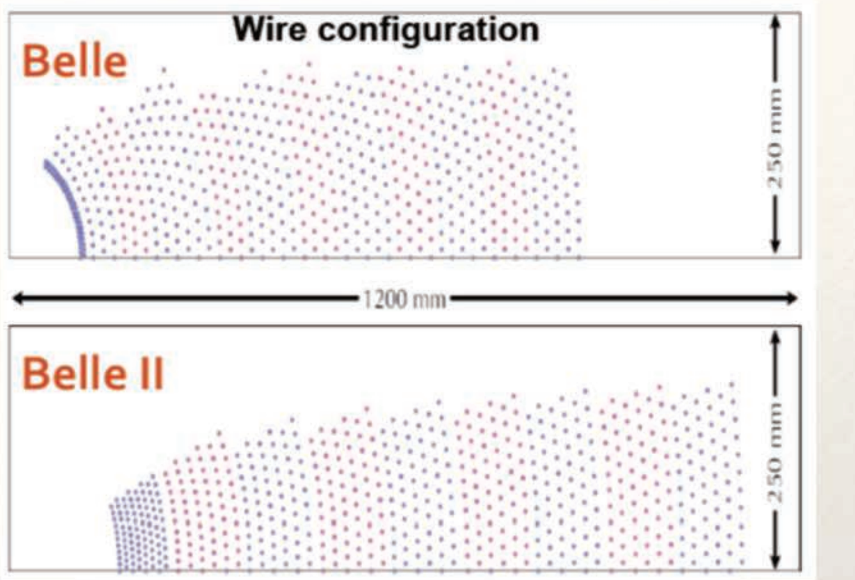


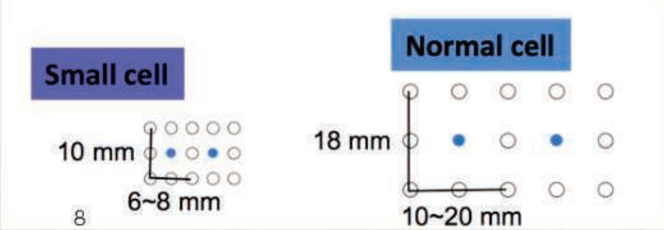
March 23, 2015. First working DSSD ladder completed

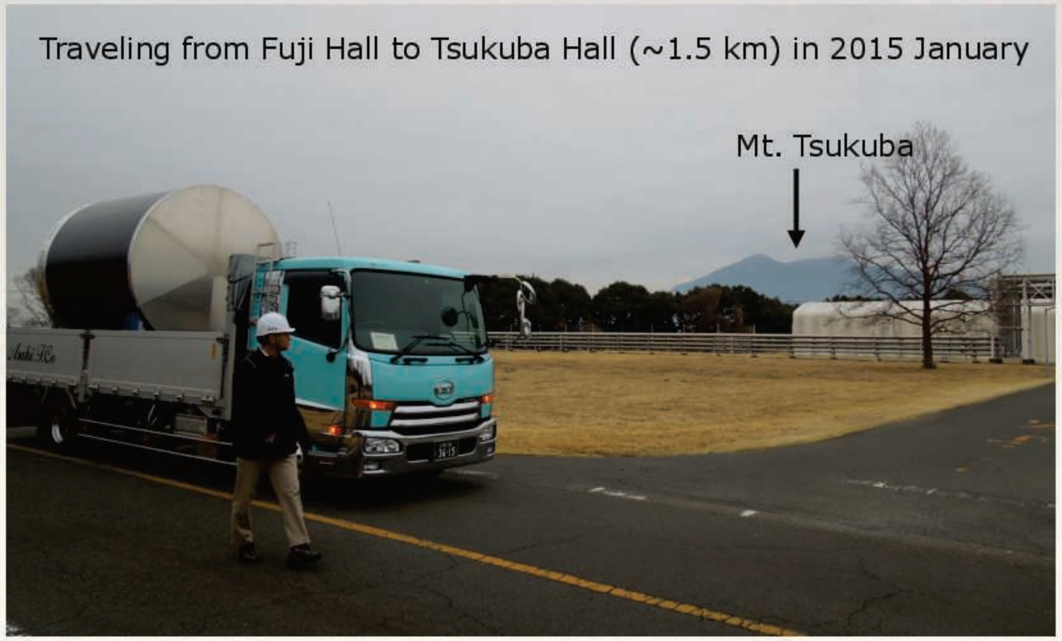
Central Drift chamber (CDC)

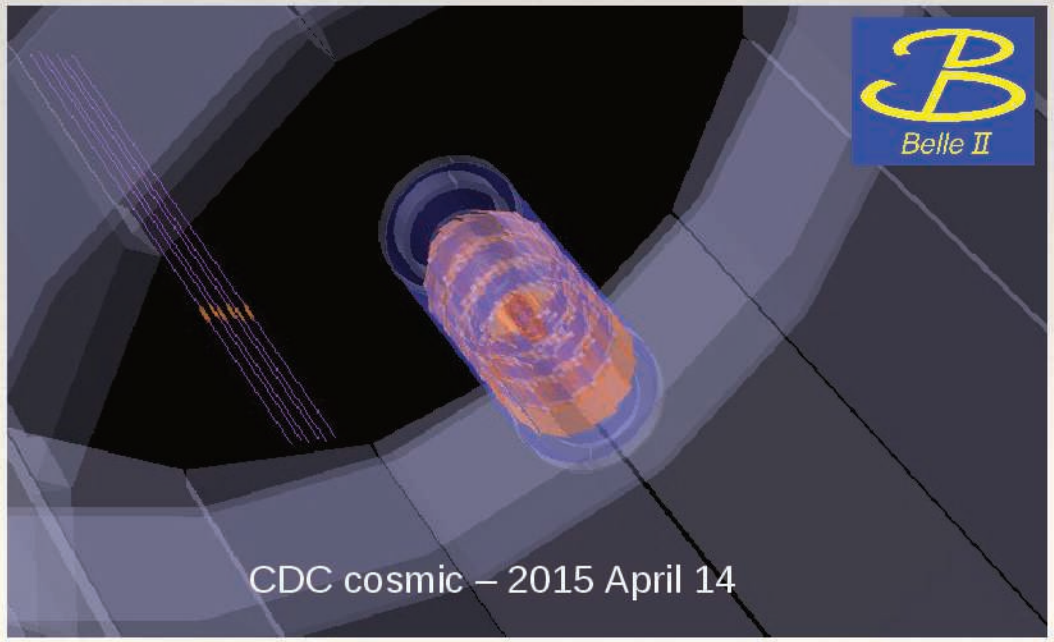


- 14336 drift cells with sense wires allow better (w.r.t. Belle) charged track reco. and dE/dx PID.
  - Spatial resolution ~ 100 μm.
- 56 concentric layers 16.8 - 111.1 cm (Belle: 50 layers, 8.8-86.3 cm), in 9 superlayers alternating axial/stereo.
- Smaller cell size in the innermost layers.
- Stringing completed in January 2014.
- Commissioning with cosmic rays during 2015.

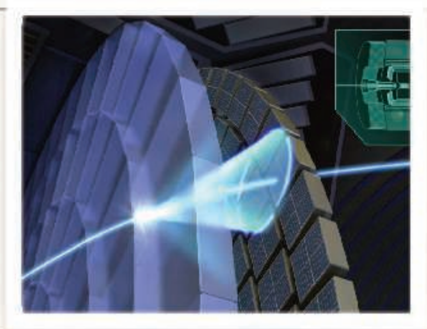




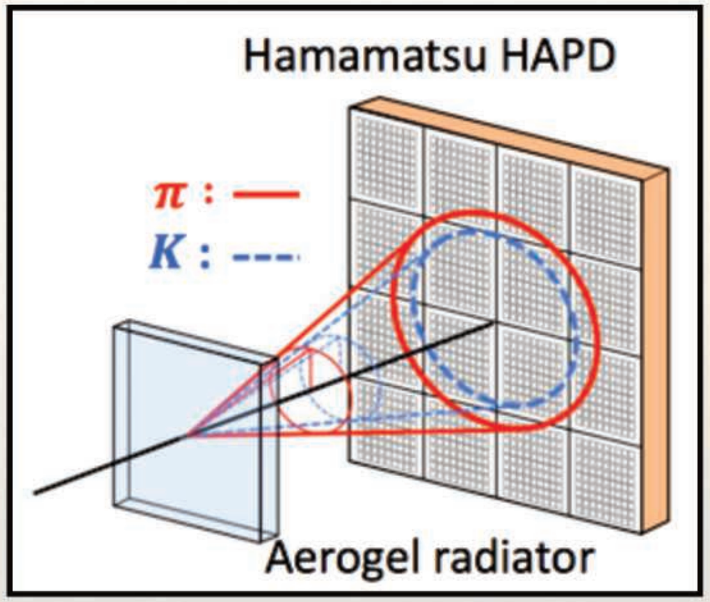


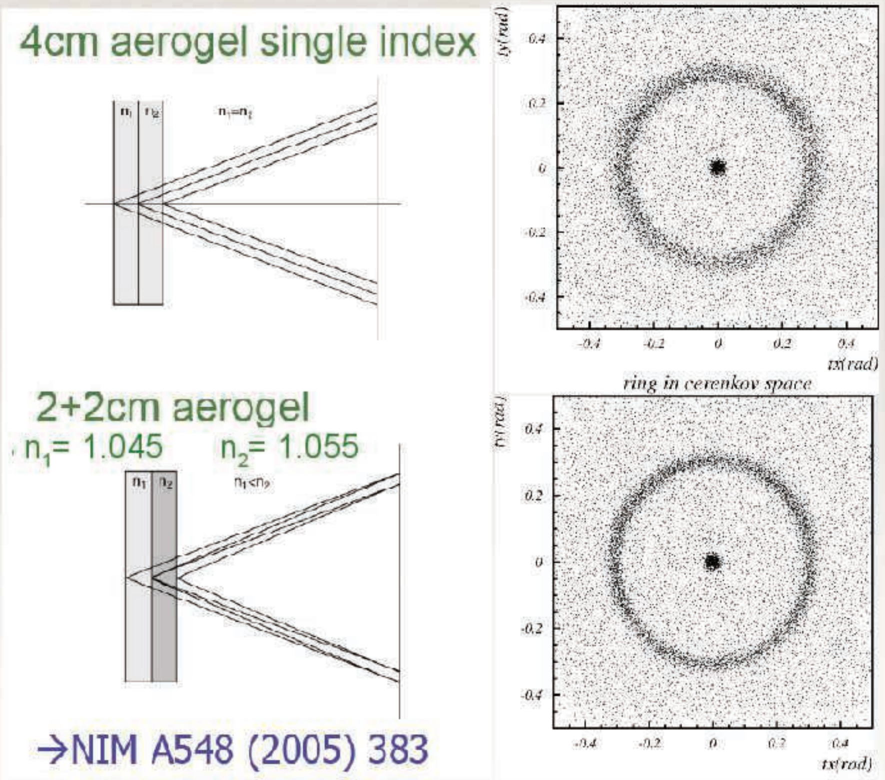


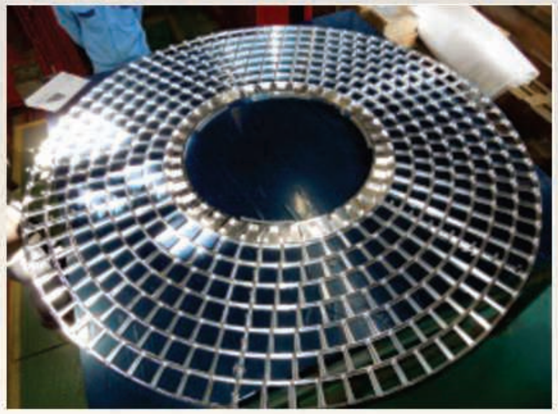
Aerogel Ring Imaging Cherenkov (A-RICH)



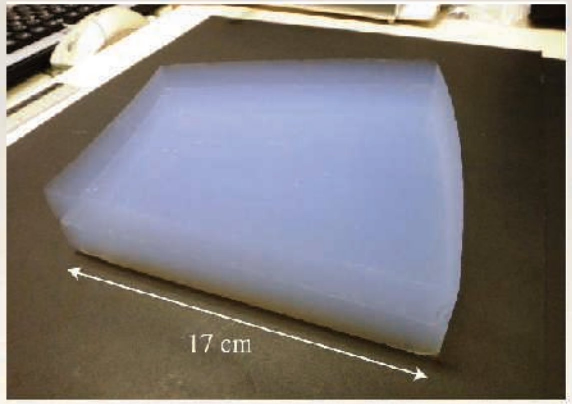
- A-RICH allows PID in forward region.
- Radiator with two layers of aerogel (different *n*) for increasing photon yield (overlapped rings).
- 420 Hybrid Avalanche Photo Detectors (HAPD) with 144 channels.
- Mechanical structure production is already completed.



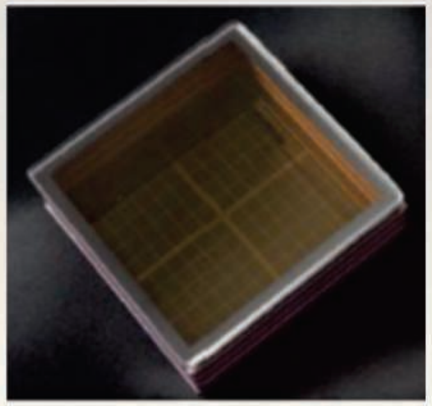




Structure



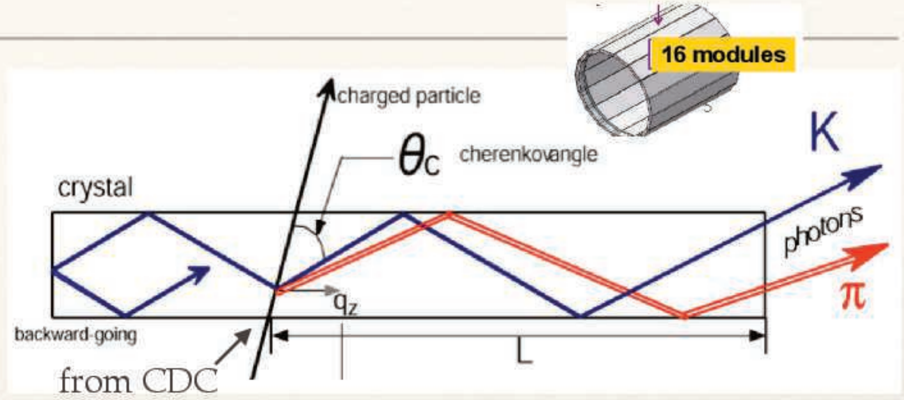
Aerogel

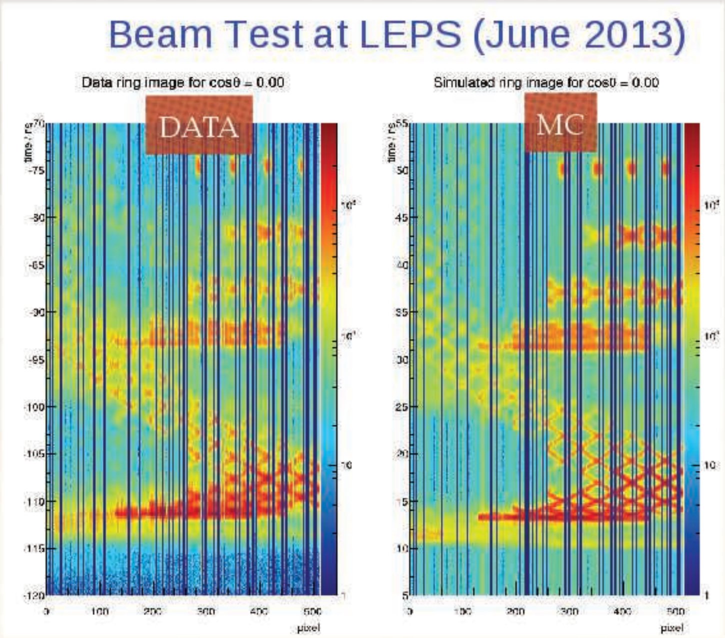


HAPD

Time of Propagation (TOP) counter

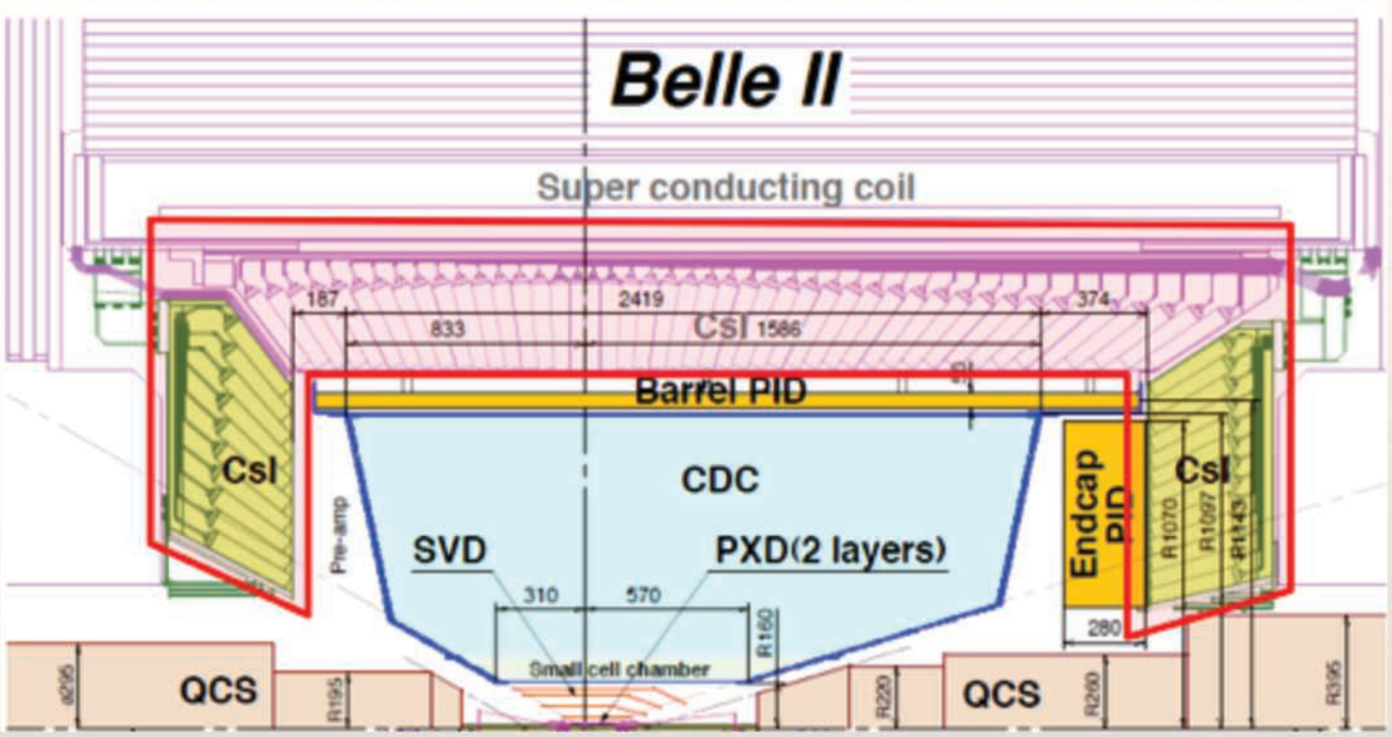
- 16 modules in barrel region (10 cm btw. CDC & ECL).
- Module = 2 quartz bars (20mm x 45cm x 200cm) + array of photo-detectors (+ mirror + extension prism).
- Both, t_{TOP} & detection angle (PMT channel) of photon are needed for PID ("image" in space-time).
- Micro Channel Plate (MCP) PMTs for ultra-fast and high sensitivity photon detection, ~50 ps resolution.
- Beam test in 2013:
    - Good Data-MC agreement.
    - 93% K ID eff., 4% π misID prob. (Belle 88% /9%), good up to 4 GeV.
- 10 of 16 modules already built, 3-weeks/module.
- Commissioning w/ cosmics rays is ongoing.
- Installation in Belle II in summer 2016.

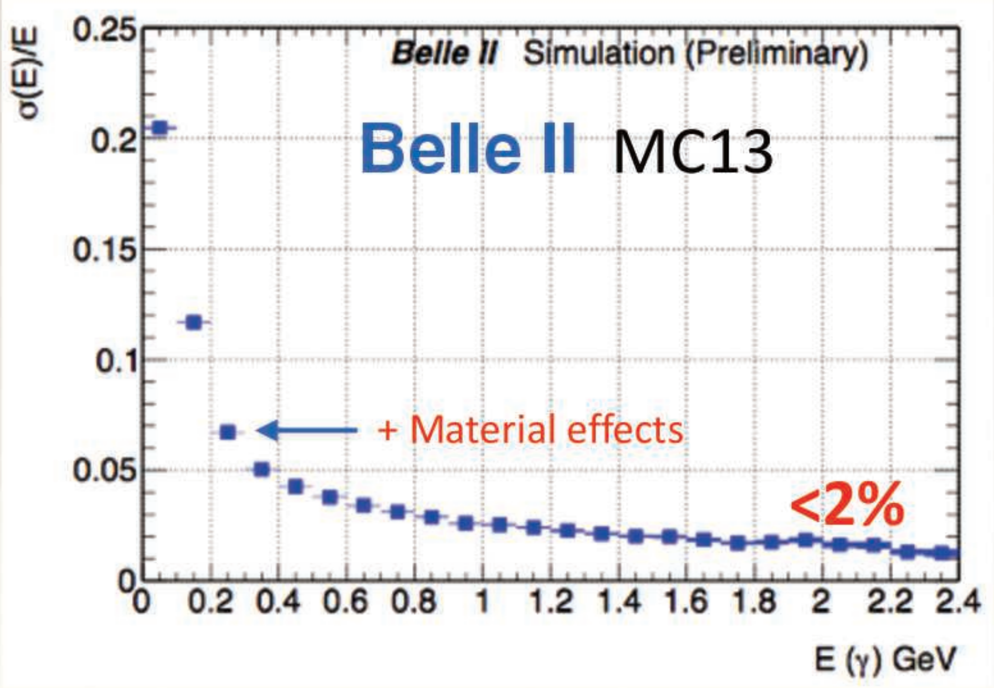




Electromagnetic Calorimeter (ECL)

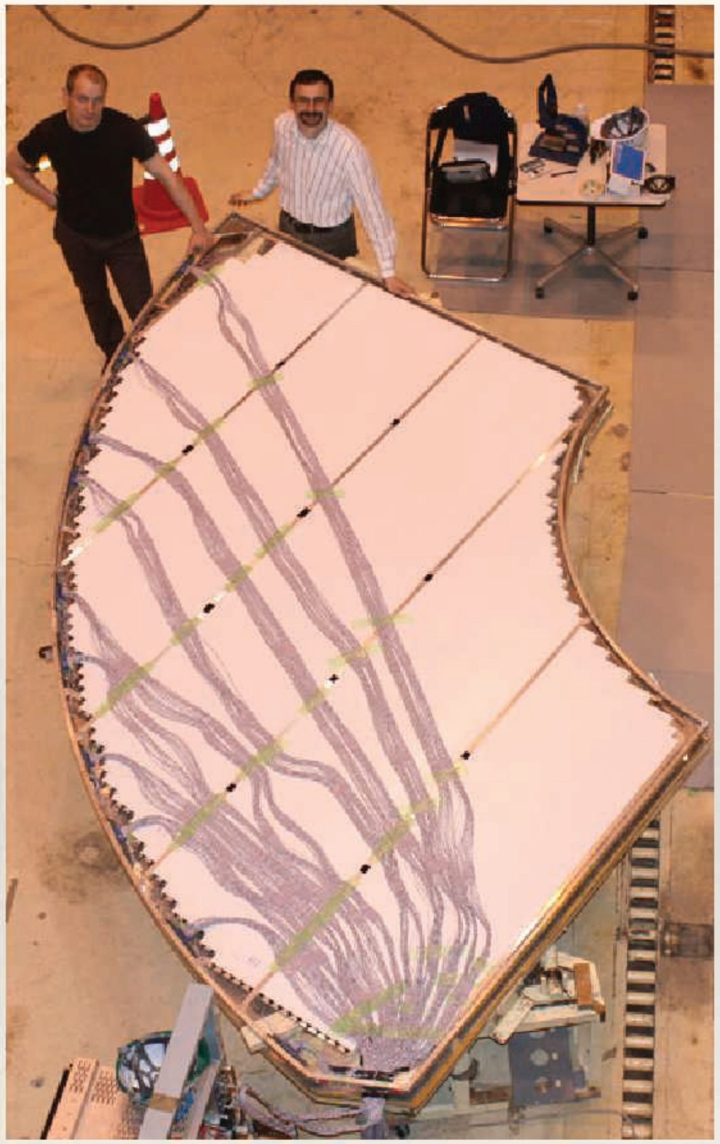
- Upgraded Belle calorimeter to compensate for larger backgrounds.
    - Barrel: CsI(Tl) crystals + faster readout (electronics for waveform sampling)
    - Endcaps: CsI crystals + faster readout.
- Cosmic rays test is ongoing.

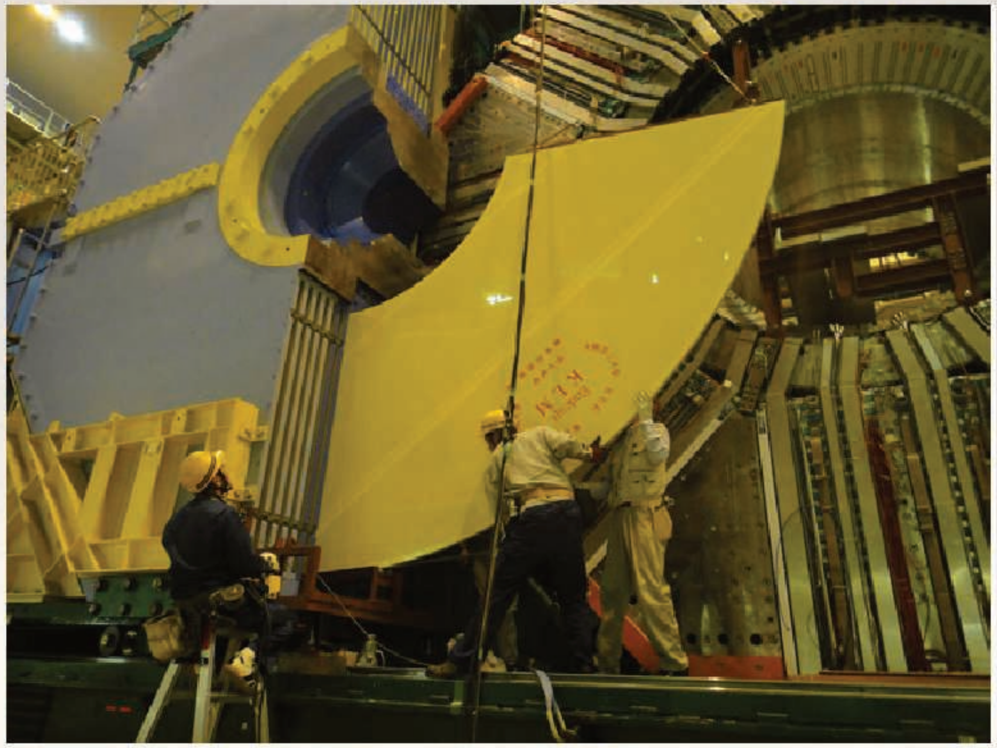




K_L and μ detector (KLM)

- Alternating layers of:
  - Active detectors: RCPs (barrel) or scintillators (new in Belle II to handle bkg., in 2-innermost barrel layers and endcaps).
  - Absorptive iron (flux return) plates, where K_L's can shower hadronically.





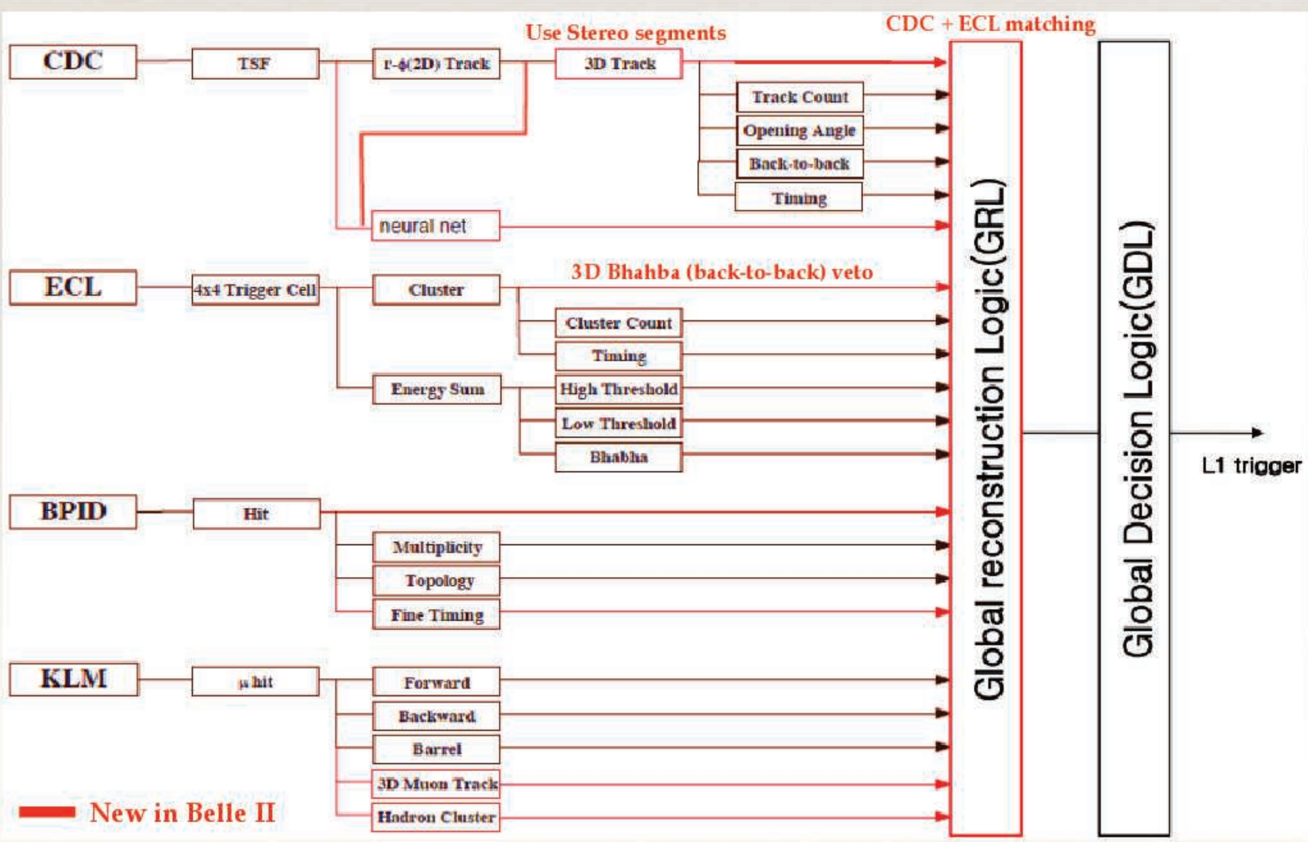
- Installation completed (2014).
- Taking cosmics.

Trigger

- Must handle high luminosity of SuperKEKB:
  - Physics rate ~15-20kHz (Bhabha & γγ pre-scaled x 100).
  - High beam-induced bkgs. (Touschek).
  - Rates an order higher than Belle.

Physics process	Cross section (nb)	Rate (Hz)
$\Upsilon(4S) \to B\bar{B}$	1.2	960
$e^+e^- \to$ continuum	2.8	2200
$\mu^+\mu^-$	0.8	640
$\tau^+\tau^-$	0.8	640
Bhabha ($\theta_{\rm lab} \geq 17°$)	44	350 [a]
$\gamma\gamma$ ($\theta_{\rm lab} \geq 17°$)	2.4	19 [a]
2γ processes [b]	~ 80	~ 15000
Total	~ 130	~ 20000

[a] The rate is pre-scaled by a factor of 1/100.
[b] $\theta_{\rm lab} \geq 17°$, $p_t \geq 0.1\mathrm{GeV}/c$



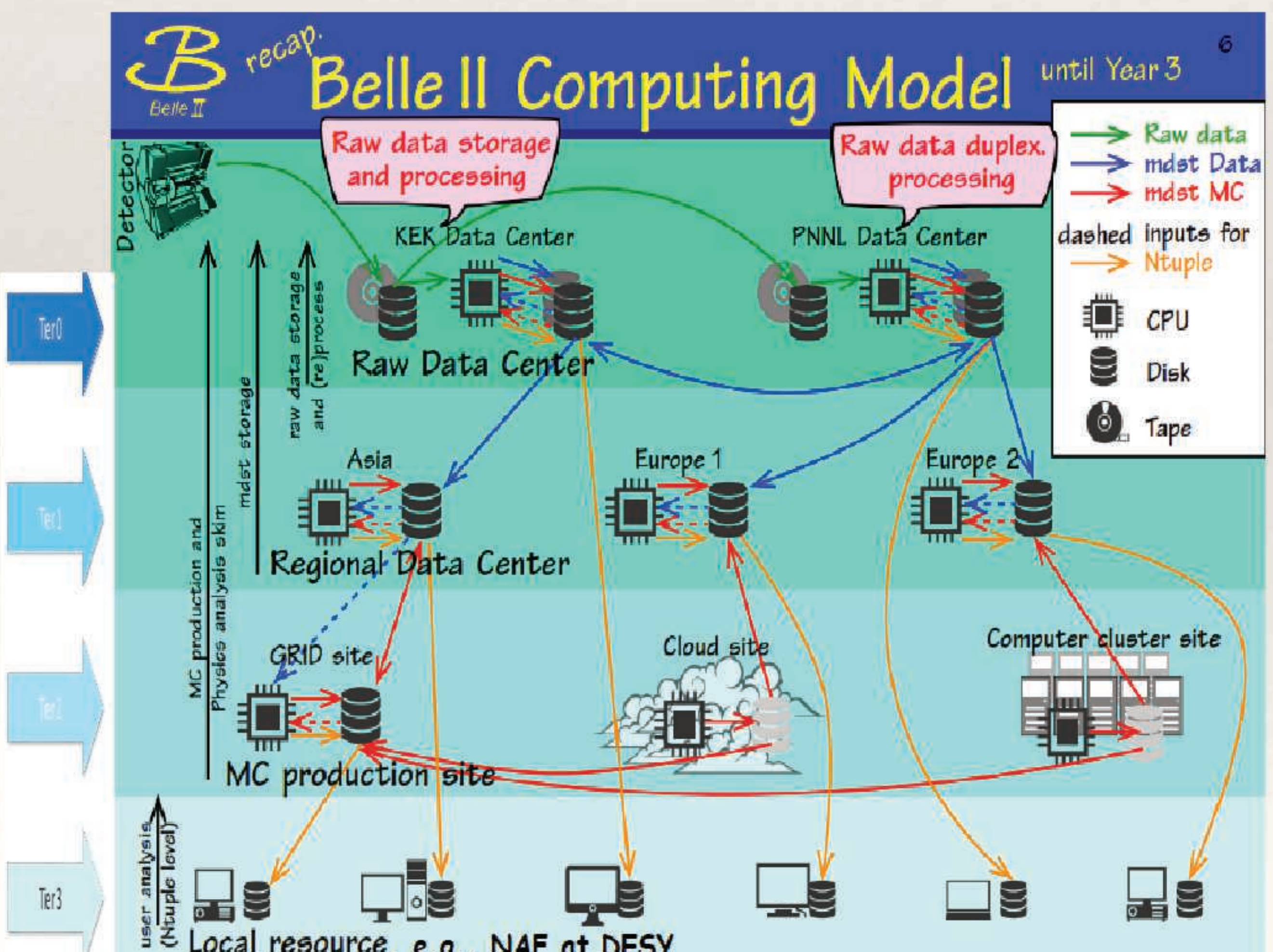
- HWare (L1) + SWare (HLT) trigger:
  - L1 readout rate: 30 kHz (in 5 μs).
  - Event Builder (EB) merges pieces from all detectors (no PXD), before HLT.
  - HLT → 3-10 KHz.
  - Eff. > 99% for $B\bar{B}$.

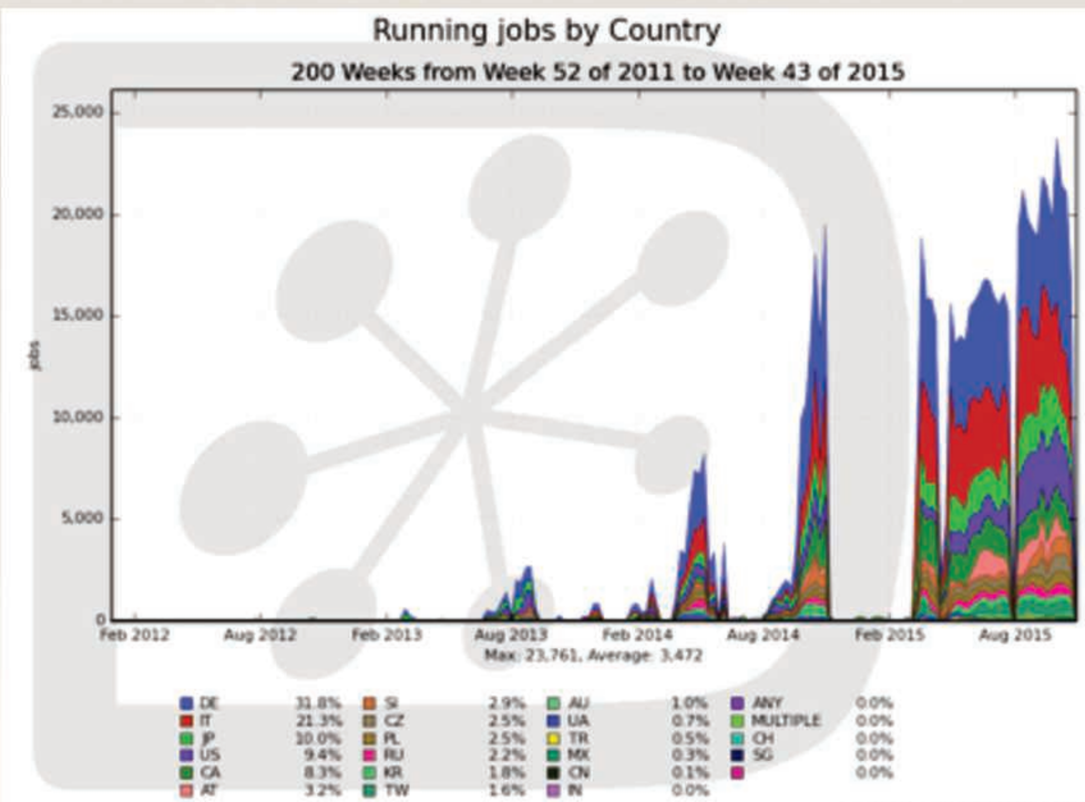
DAQ and Computing

- PDX-info ~1MB/evt ⇒ EB saves only PXD-hits matched to SVD & CDC tracks.
- Final event size ~ 200 kB ⇒ ~ 1.5 GB/s.
- Trigger & DAQ ready by May 2017.

	Hardware Trigger rate	Physics output rate	event size
Belle	500 Hz	90 Hz	40 kB
Belle II	30 kHz	3-10kHz	200kB (max)
ATLAS		0.2kHz	1.6MB

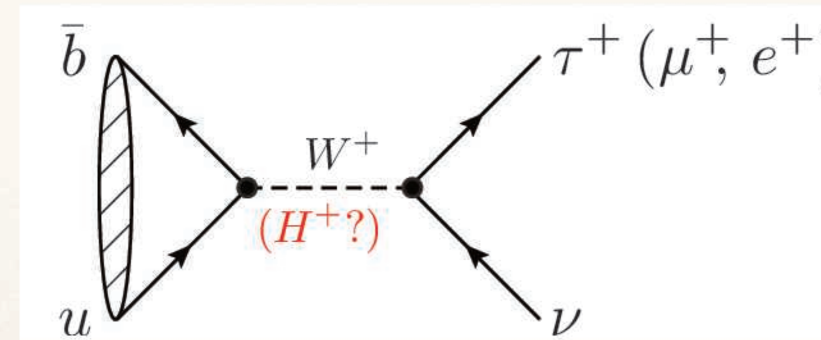
- Grid computing by 17 countries, up to ~20k simult. jobs (160 kHS, 10% nominal).





Physics case 1: B → $\ell\nu_\ell$

- Does nature have multiple Higgs bosons?
- SM vs. BSM:



Measurable via other modes
Phase space
Lattice QCD

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

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

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

2HDM-II [Hou, PRD 48, 2342, (1993)]

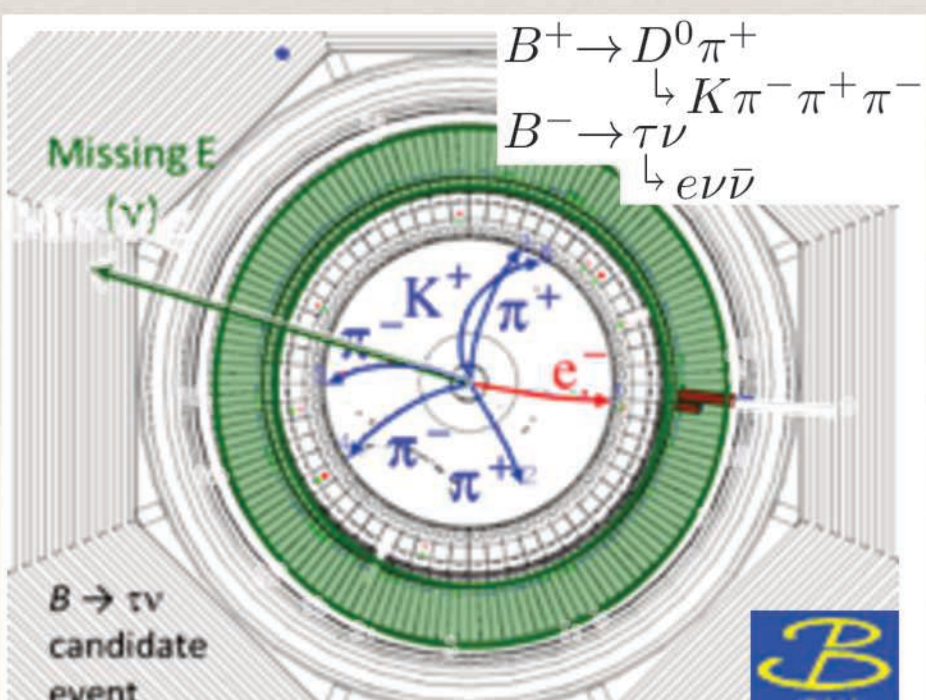
$$\mathcal{B}(B \to \tau\nu) = \mathcal{B}_{\rm SM} \times r_H,$$

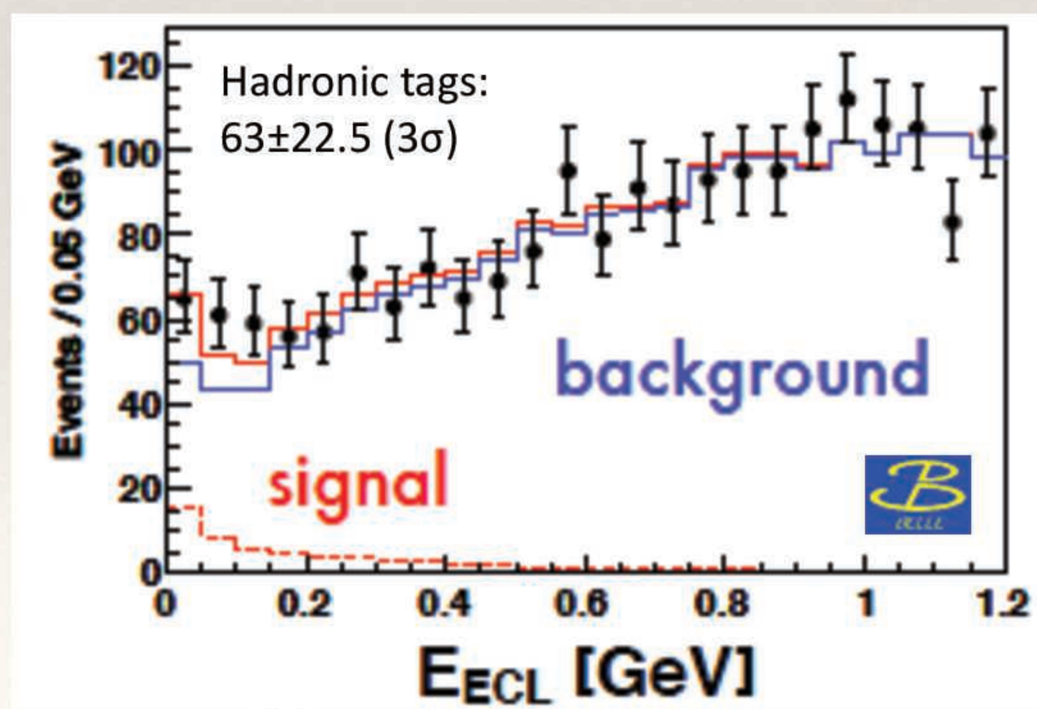
$$r_H = \left(1 - \tan^2\beta \frac{m_B^2}{m_{H^\pm}^2}\right)^2$$

SUSY [Akeroyd, Recksiegel, J. Phys. G29, 2311 (2003)]

$$r_H = \left(1 - \frac{m_B^2}{m_{H^+}^2} \frac{\tan^2\beta}{1 + \tilde{\epsilon}_0 \tan\beta}\right)^2$$

$\tan\beta$ = ratio of VEVs

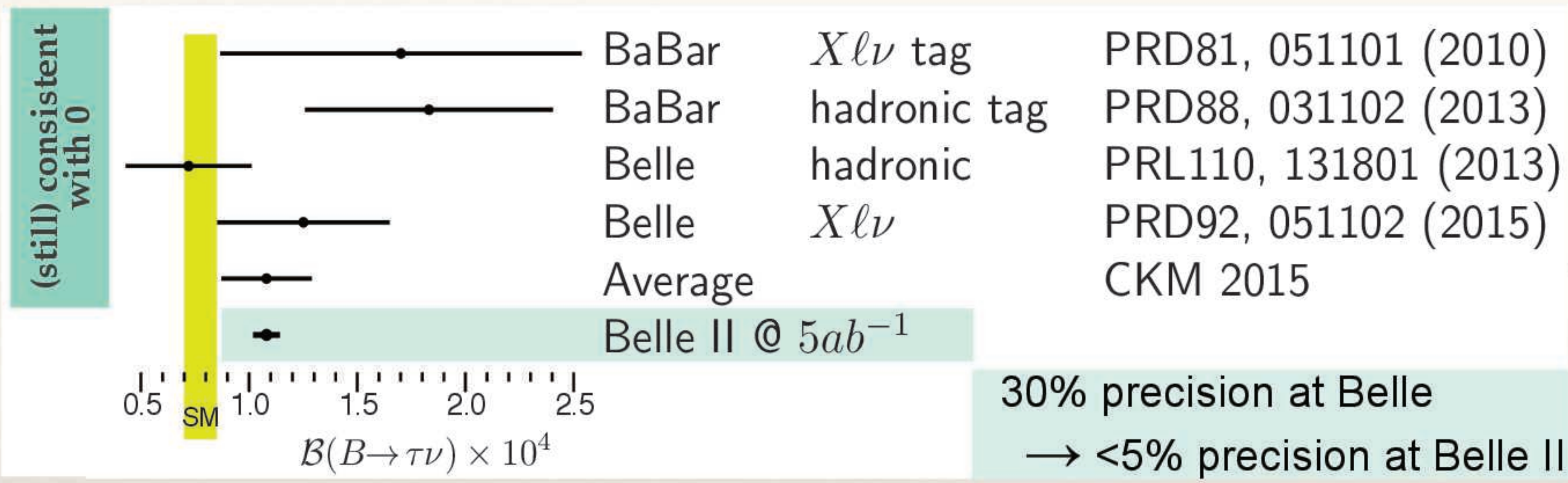




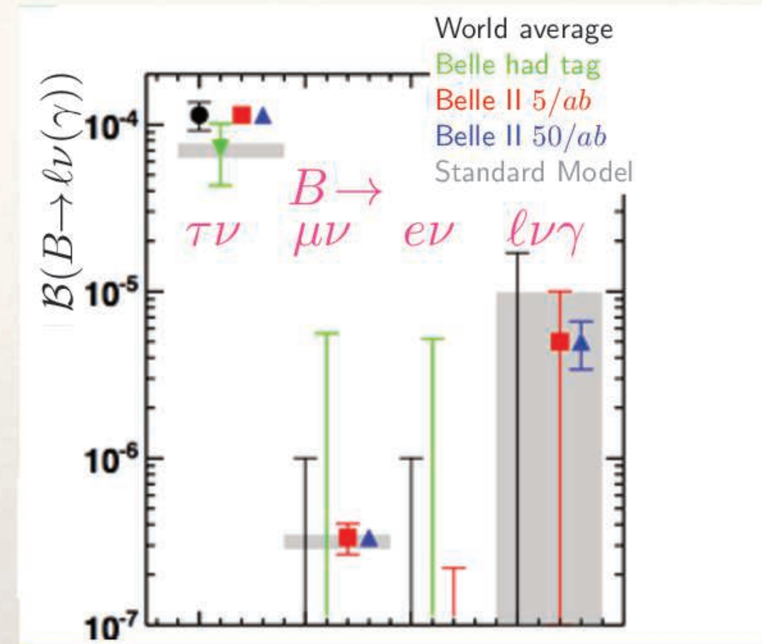
E_{ECL} = calorimeter energy not associated with B_{tag} (deposited electron energy if signal)

B → $\ell\nu_\ell$ (II)

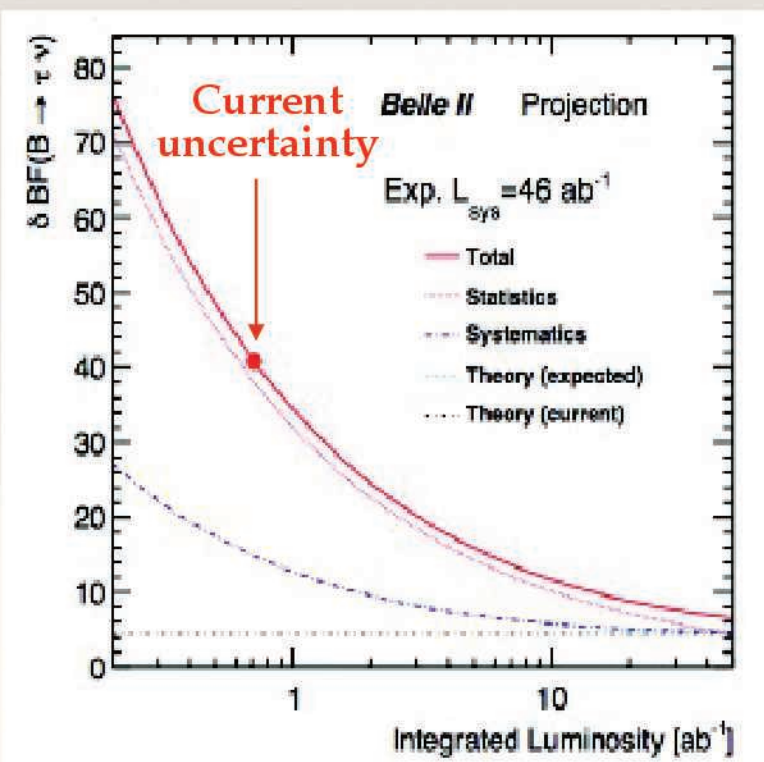
- Belle II has potential to observe B → $\ell\nu_\ell$ during first years.



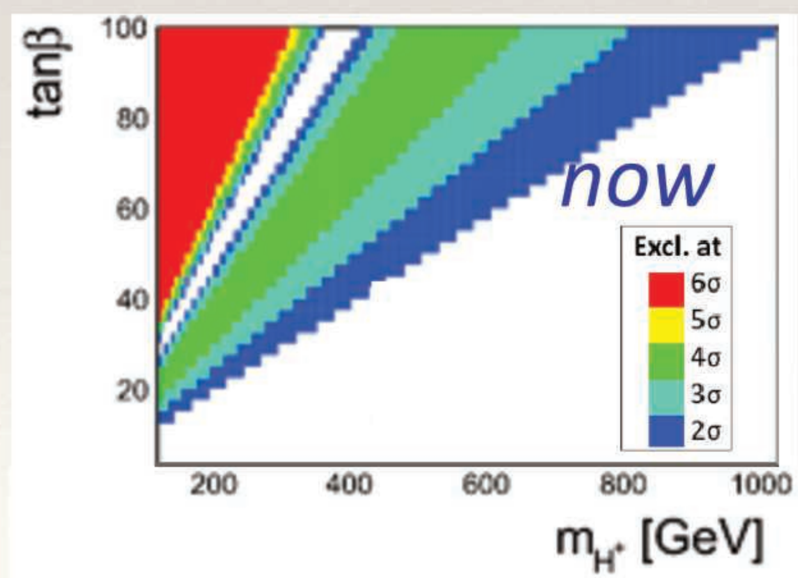
30% precision at Belle
⟶ <5% precision at Belle II

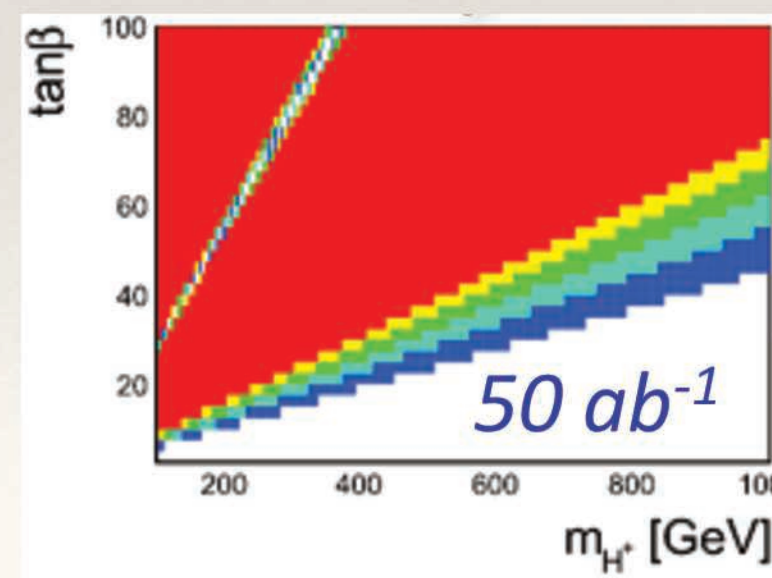


Belle, B→ μ v , e v (Had) arXiv:1406.6356
Belle, B→ l v gamma Preliminary (2014 B2TiP)



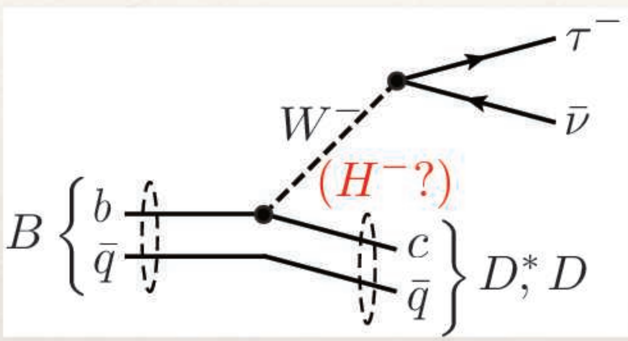
- And constrain charged Higgs models.





Physics case 2: $B \to D^{(*)} \ell \nu_\ell$

- Charged Higgs models constrained through lepton universality violation (LUV) tests.

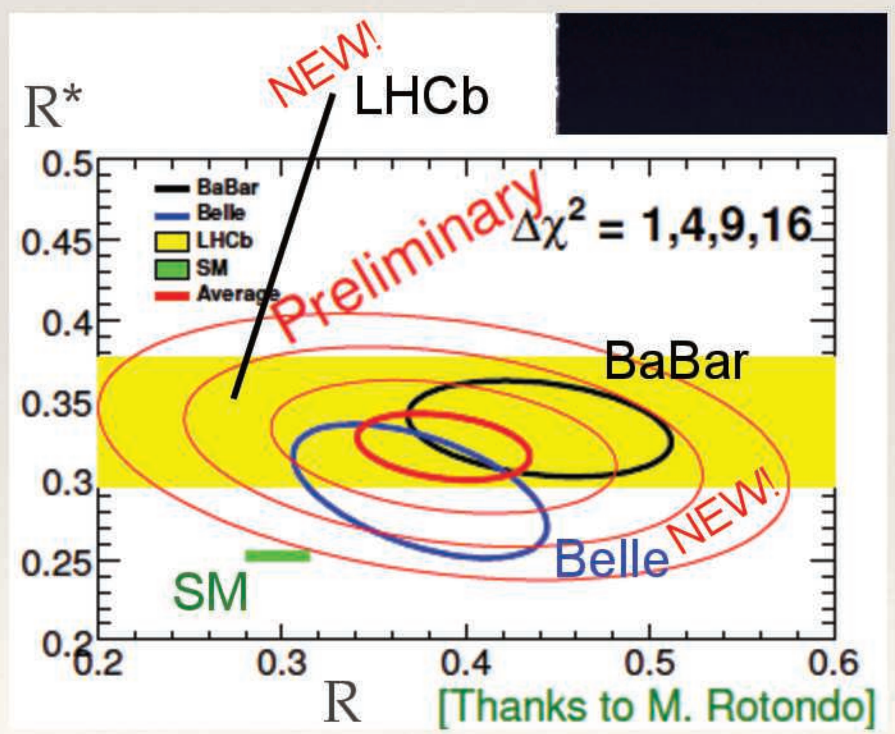


$$R(D^*) \equiv \frac{\mathcal{B}\left(\bar{B} \to D^* \tau \bar{\nu}\right)}{\mathcal{B}\left(\bar{B} \to D^* \ell \bar{\nu}\right)} \qquad \ell = e$$

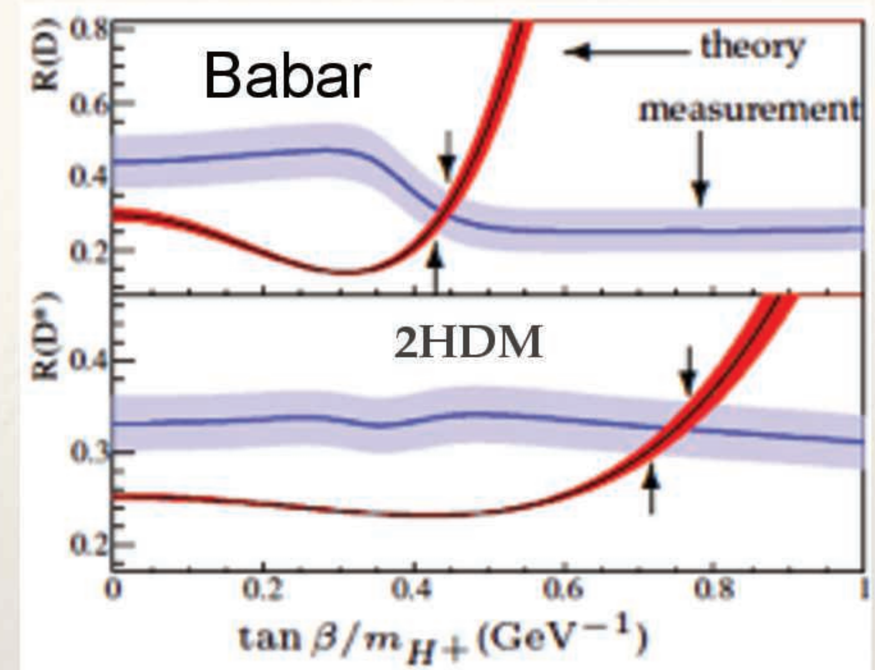
or

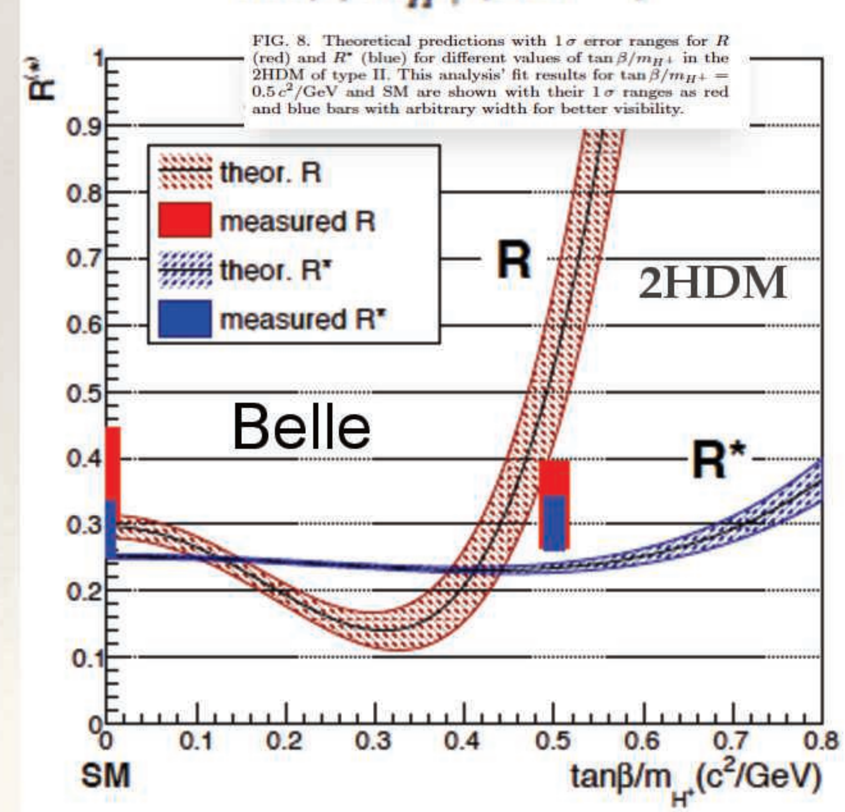
$$R(D) \equiv \frac{\mathcal{B}\left(\bar{B} \to D \tau \bar{\nu}\right)}{\mathcal{B}\left(\bar{B} \to D \ell \bar{\nu}\right)} \qquad \ell = \mu$$

- BaBar: inconsistent values of $\tan\beta/m_{H+}$ for R and R* ⇒ 2HDM excluded?
- Belle: agreement at ~ 0.5 GeV^{-1}.
- LHCb consistent w/ BaBar, Belle & SM.



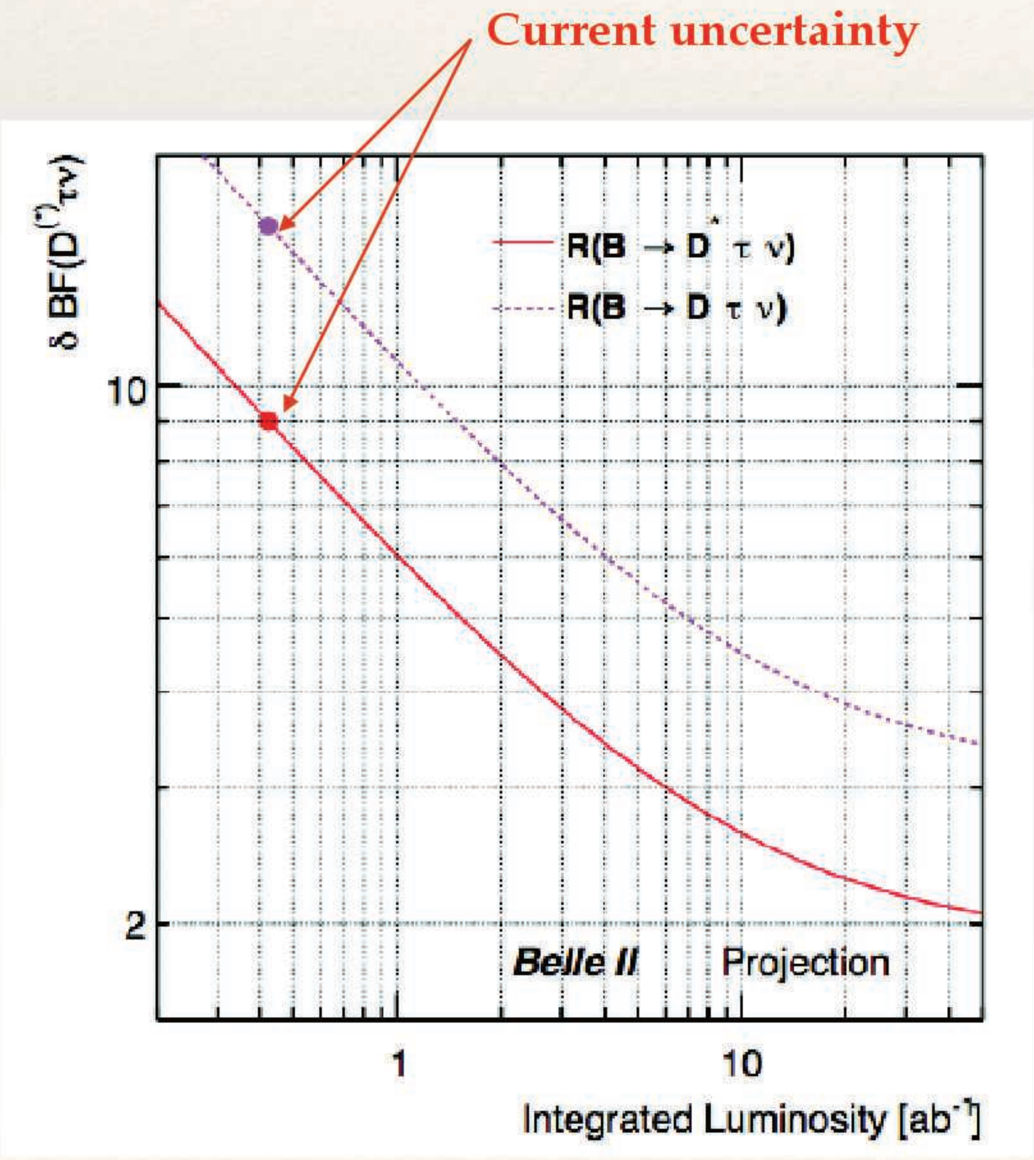
~4σ tension!

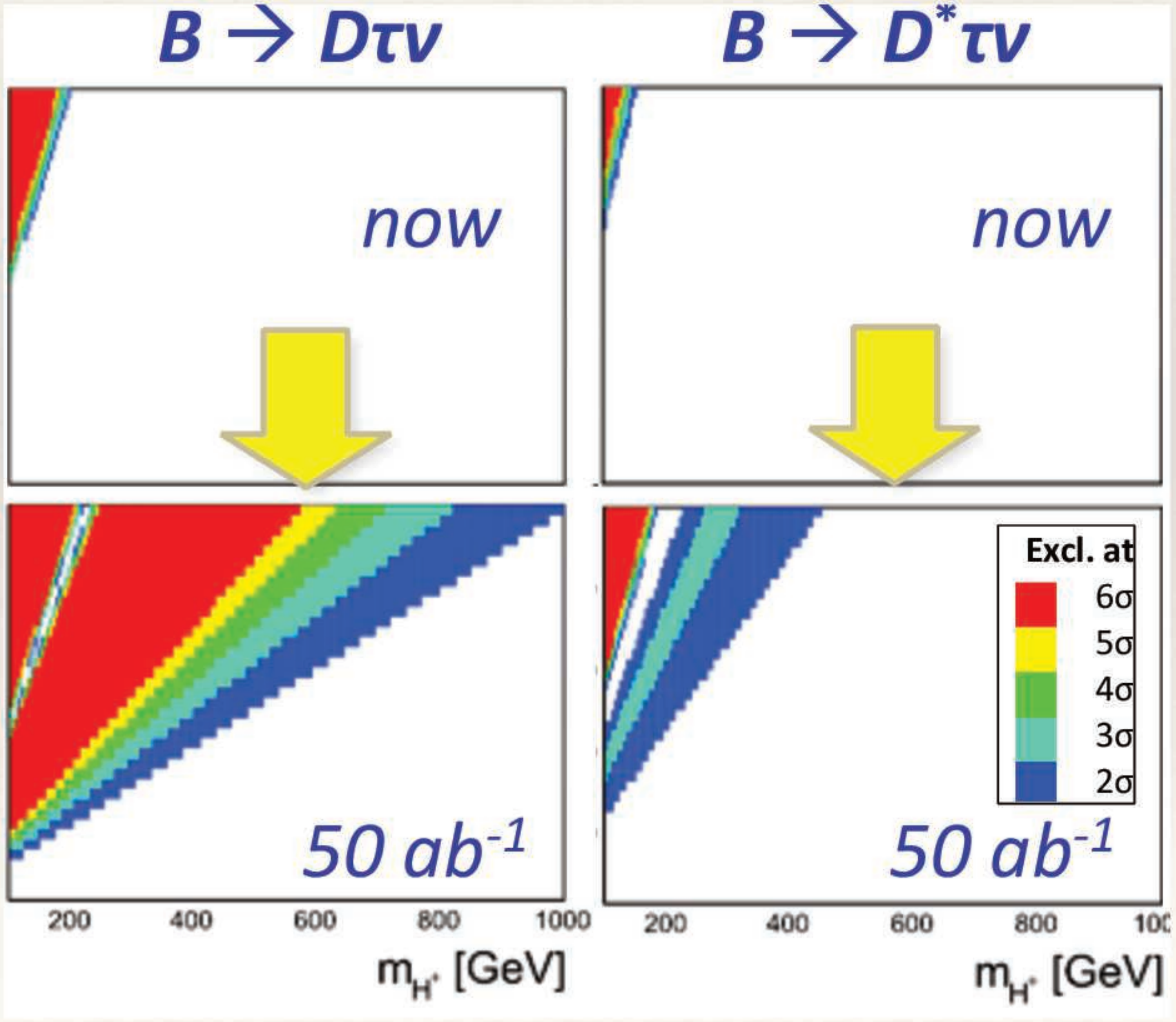




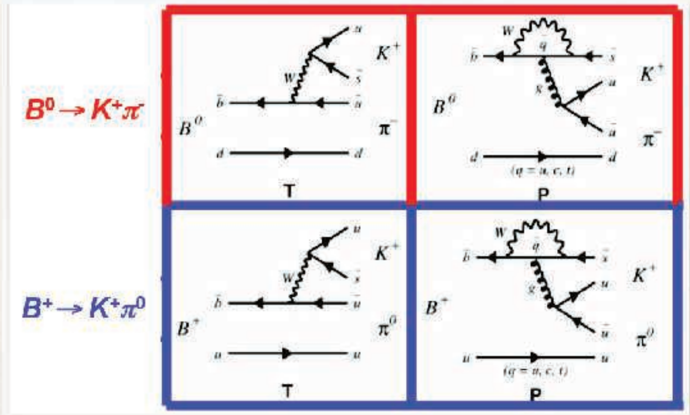
$B \to D^{(*)} \ell \nu_\ell$ (II)

- Belle II could potentially resolve btw. SM & 2HDM-II or constrain charged Higgs models.





Physics case 3: Direct CPV in B→Kπ



- Tension in differences btw. CP asymmetries (ΔA ~ 0 in SM):

$$\Delta A \equiv A_{CP}^{B^0\to K^+\pi^-} - A_{CP}^{B^+\to K^+\pi^0} = -0.122 \pm 0.022 \text{ (HFAG 2013)}$$

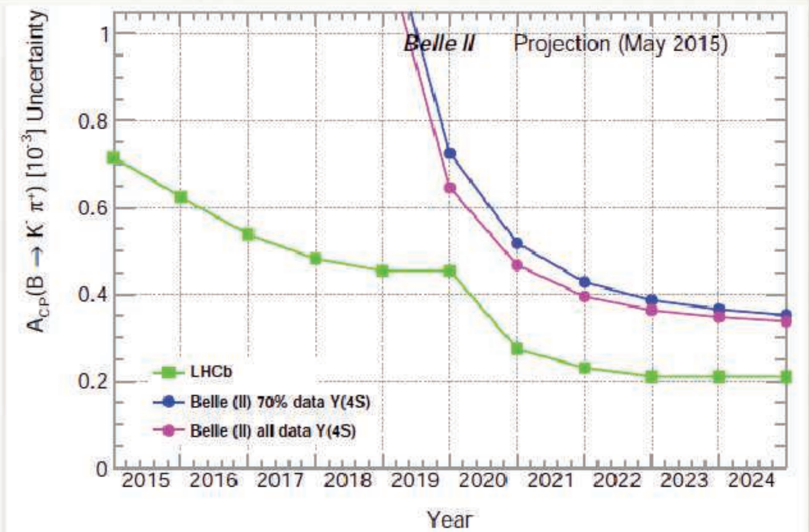
NP or hadronic effects?

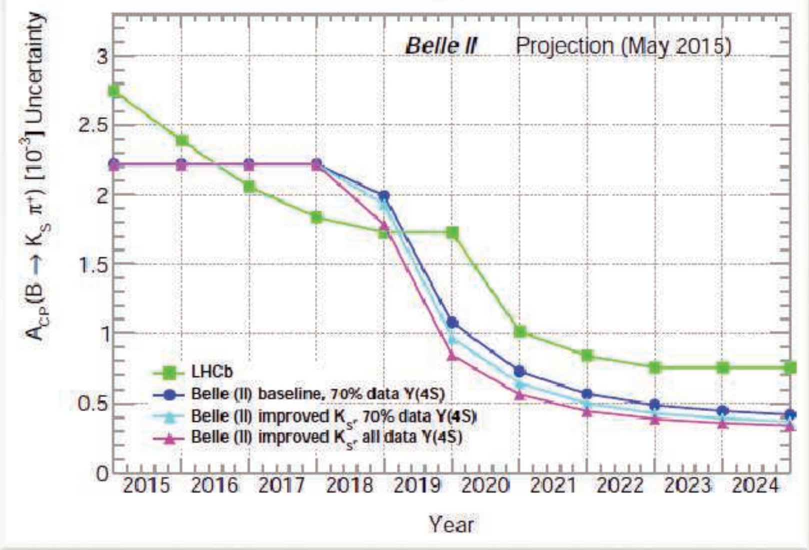
- Model independent sum rule to test SM ($I_{k\pi} \approx 0$ in SM):
  - Need neutral modes (full isospin analysis), where Belle II has better sensitivity than LHCb.

M. Gronau, PLB 627 (2005) 82, D. Atwood, A. Soni, PRD 58 (1998) 036005

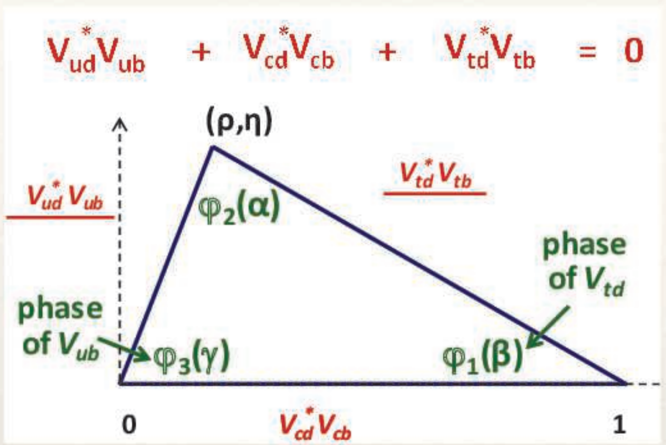
$$I_{K\pi} \cdot \mathcal{B}(B^0 \to K^+\pi^-) = A_{CP}^{K^+\pi^-} \cdot \mathcal{B}(B^0 \to K^+\pi^-) + A_{CP}^{K^0\pi^-} \cdot \mathcal{B}(B^+ \to K^0\pi^-)\frac{\tau_{B^0}}{\tau_{B^+}} - 2A_{CP}^{K^0\pi^0} \cdot \mathcal{B}(B^0 \to K^0\pi^0) + 2A_{CP}^{K^+\pi^0} \cdot \mathcal{B}(B^+ \to K^+\pi^0)\frac{\tau_{B^0}}{\tau_{B^+}}$$

Scenario	$A^{K^0\pi^0}$ Value	Stat.	(Red., Irred.)	$I_{K\pi}$
Belle	0.14	0.13	(0.06, 0.02)	0.27 ± 0.14
Belle + $B \to K^0\pi^0$ at Belle II 5 ab^{-1}		0.05	(0.02, 0.02)	0.27 ± 0.07
Belle II 50 ab^{-1}		0.01	(0.01, 0.02)	0.27 ± 0.03

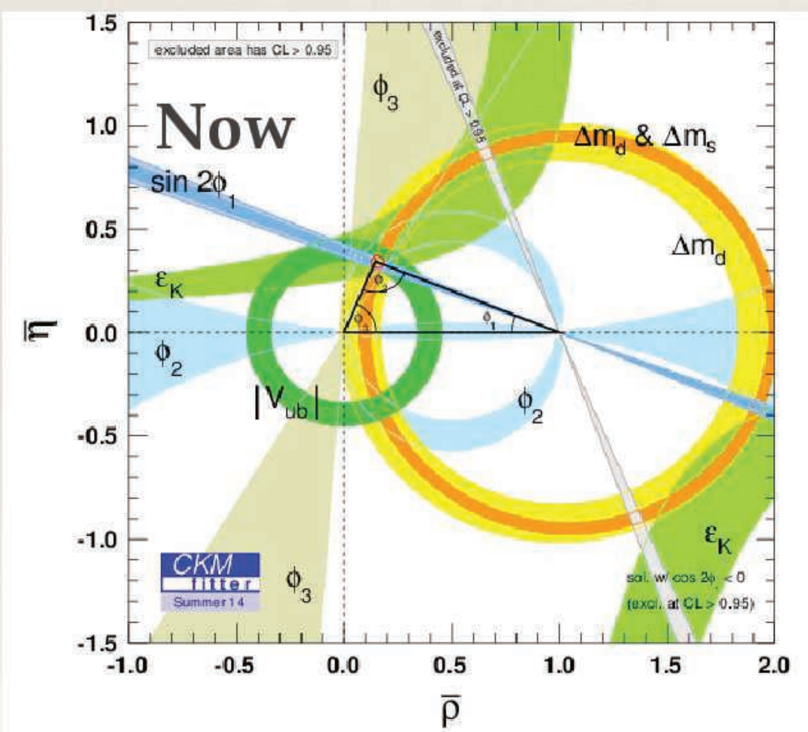




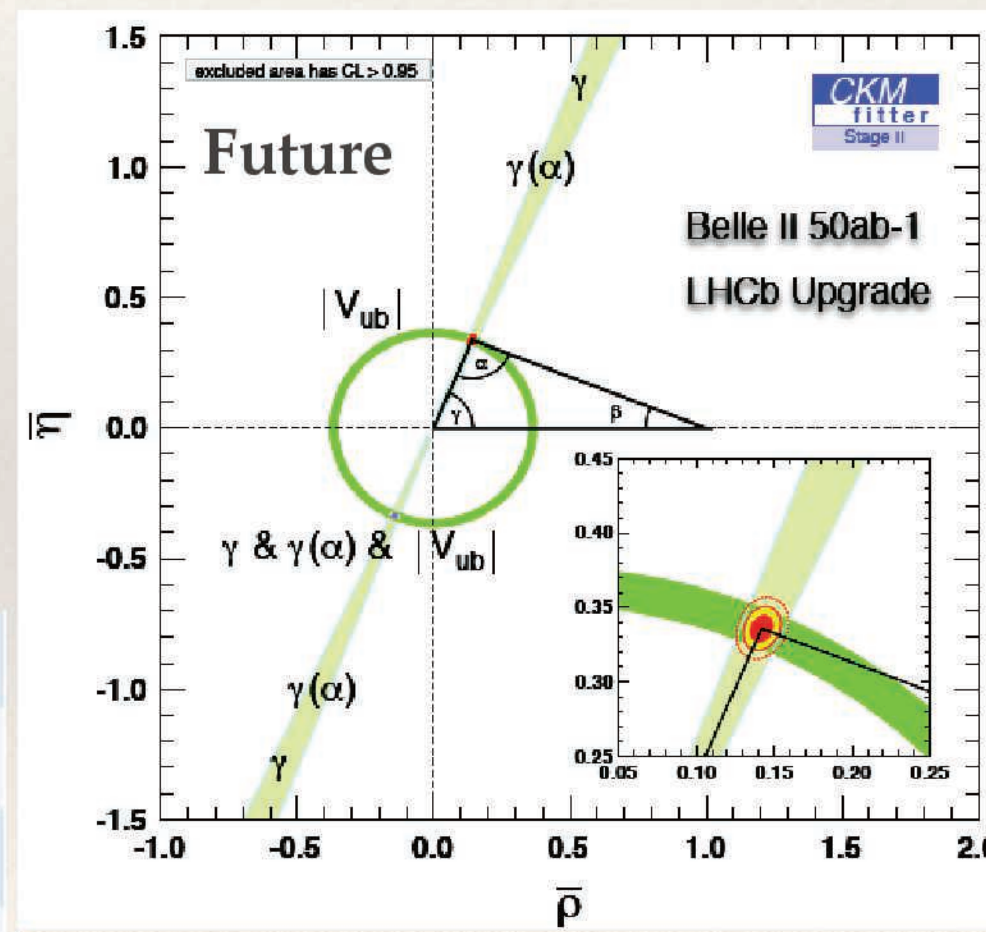
Physics case 4: Unitary Triangle



- Belle II will further over-constrain the Unitary Triangle (UT).



UT 2014		Belle II
α	4° (WA)	1°
β	0.8° (WA)	0.2°
γ	8.5° (WA) 14°(Belle)	1-1.5°

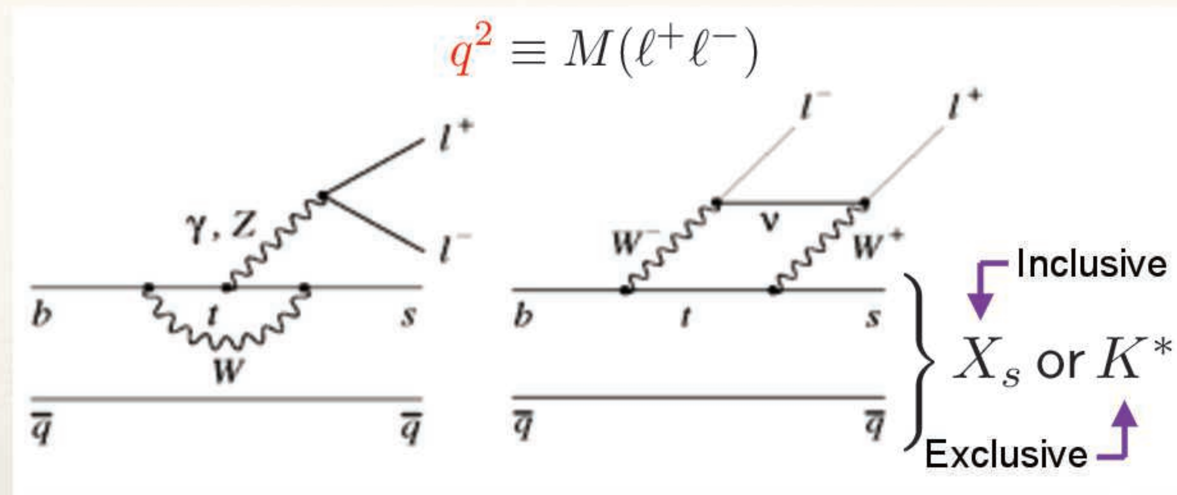


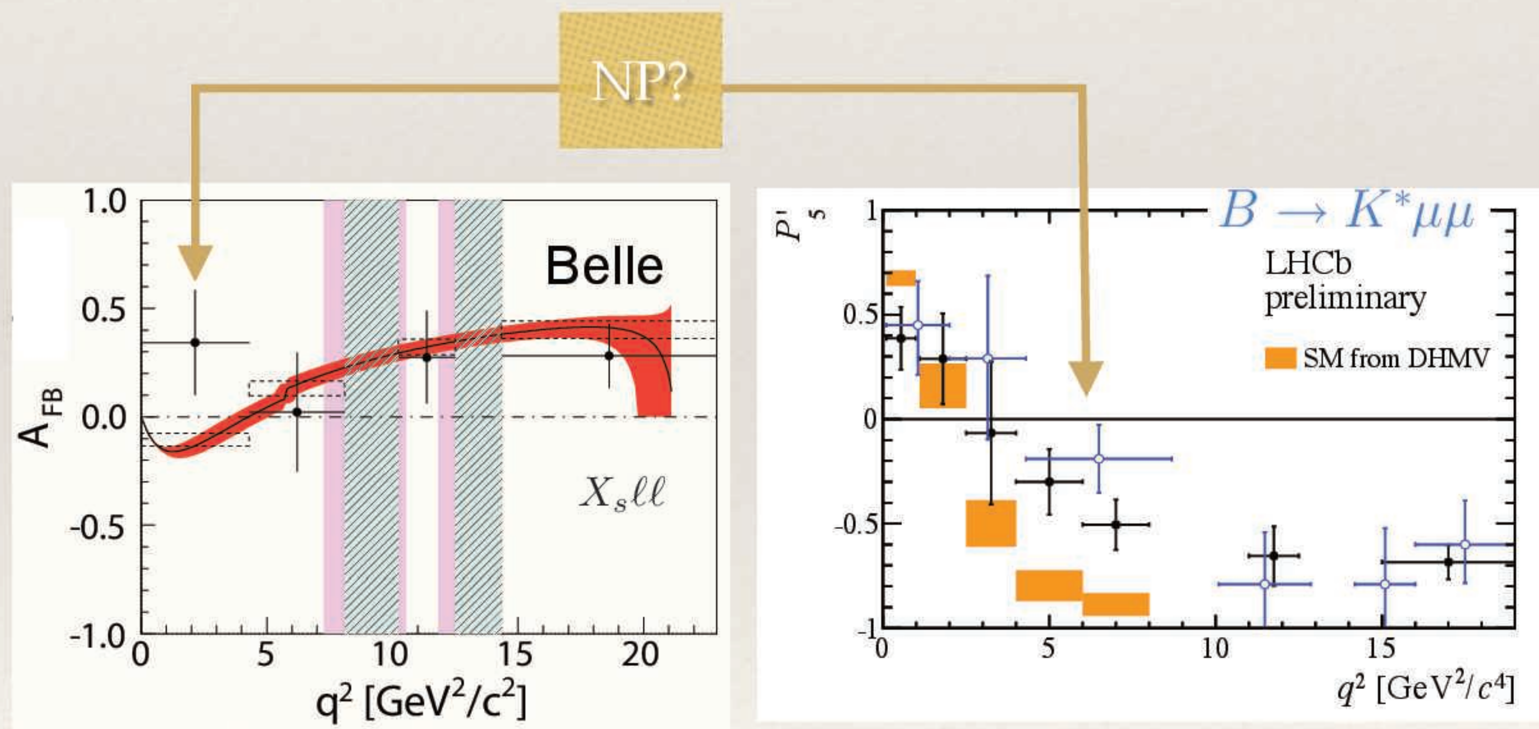
Test of the CKM mechanism for CPV at the percent level!

Physics case 5: Inclusive $b \to s\ell^+\ell^-$

- FCNC process with many observables exposed to NP:

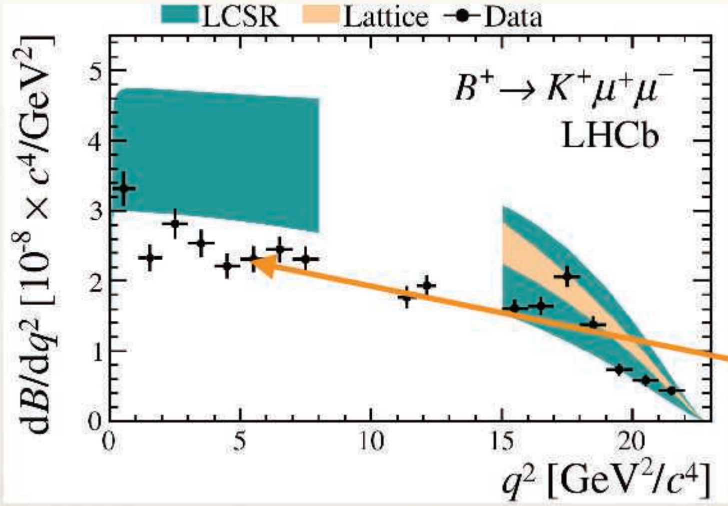
Observable	$K^*\ell\ell$	$X_s\ell\ell$	LHCb	BaBar	Belle	Belle II projection
$d\Gamma/dq^2$	✓	✓	✓	✓		✓
A_{FB}	✓	✓	✓		✓	✓
q_0^2	✓	✓	✓			✓
F_L	✓		✓			
S_3	✓		✓			
S_3	✓		✓			
$S_4,\ P_4'$	✓		✓			
$S_5,\ P_5'$	✓		✓			
P_6'	✓		✓			
S_7	✓		✓			
$S_8,\ P_8'$	✓		✓			
S_9	✓		✓			
A_9	✓		✓			
A_T^2	✓		✓			
A_T^{Re}	✓		✓			
A_{CP}	✓	✓		✓		

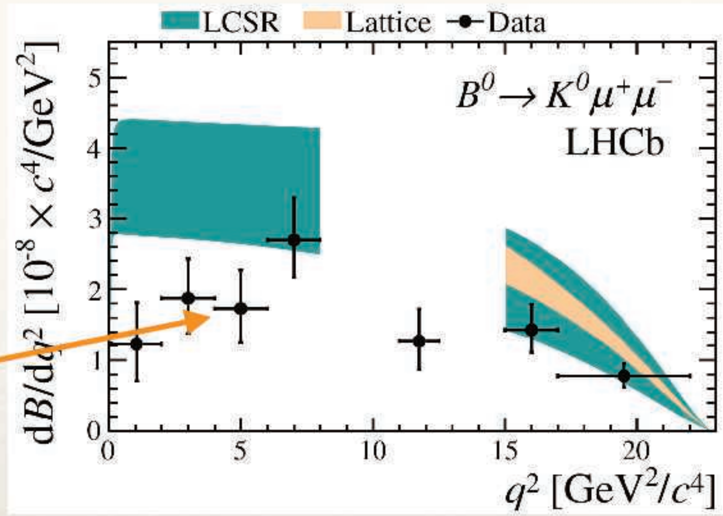




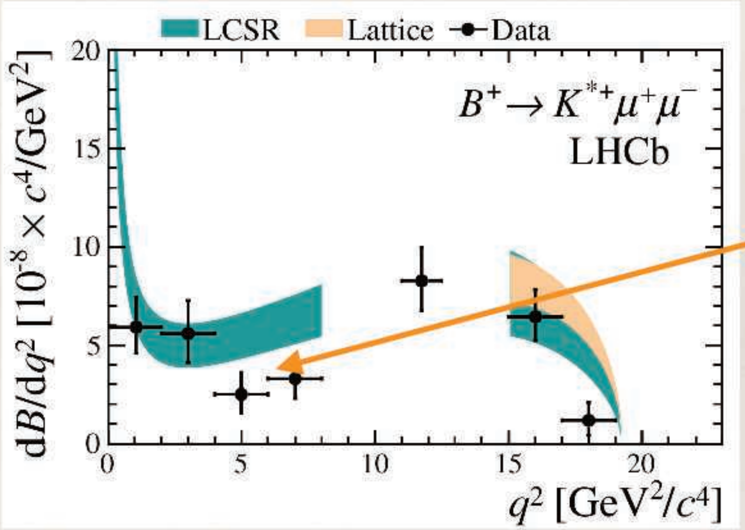
New LHCb: Tension confirmed (3fb⁻¹), 2 bins deviate 2.8s from SM!

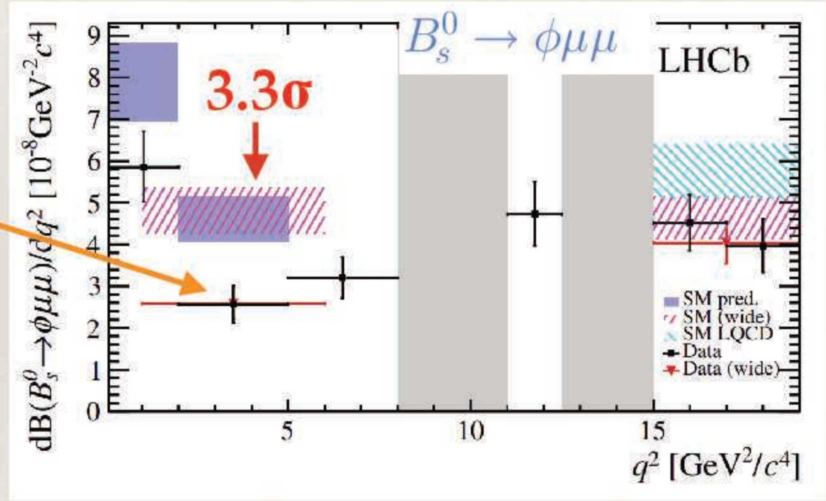
$b \to s\ell^+\ell^-$ (II)





LHCb results consistently smaller than SM prediction (despite its precision)





2.6 σ

[redacted]

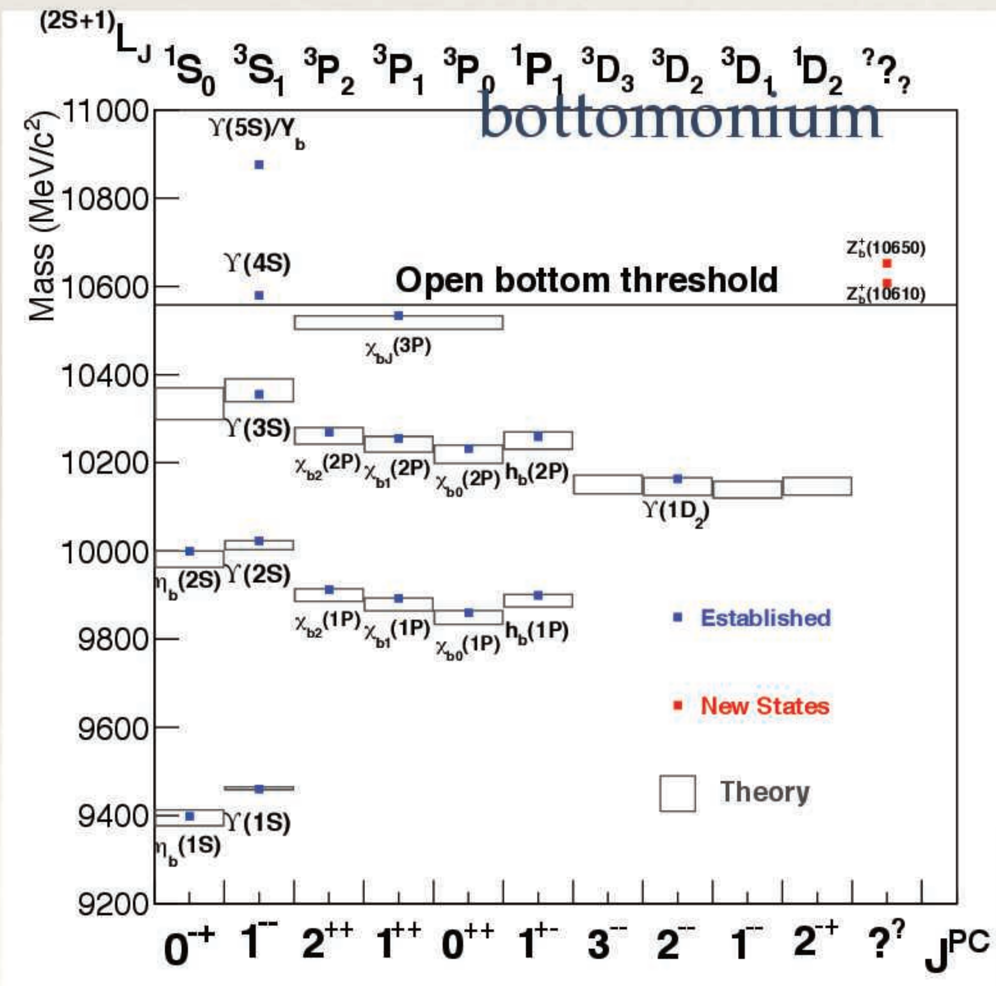
Lepton non-universality?

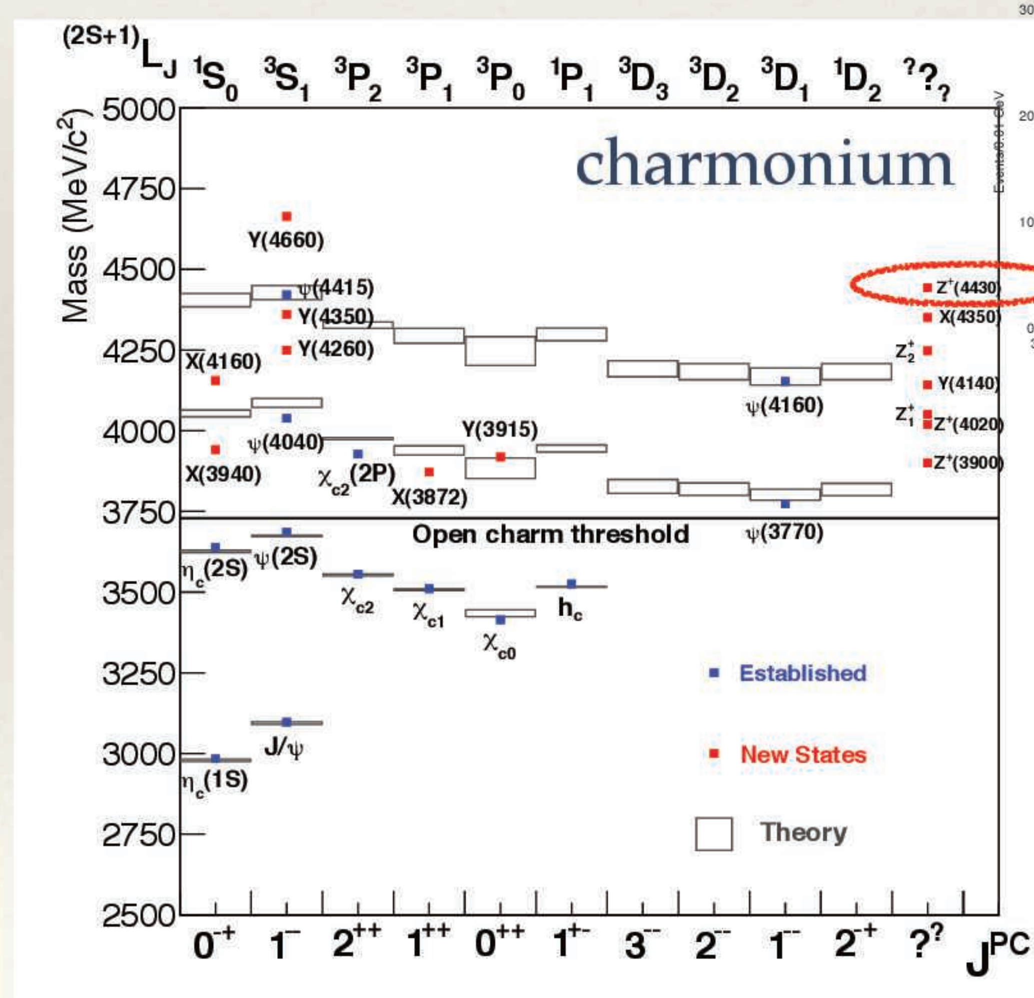
arXiv:1510.04239v1

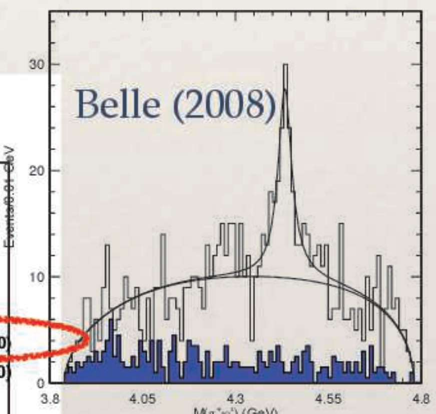
Too many anomalies in electroweak penguins. NP modifying $C_9^{(\prime)}$?
Belle II must act quickly!

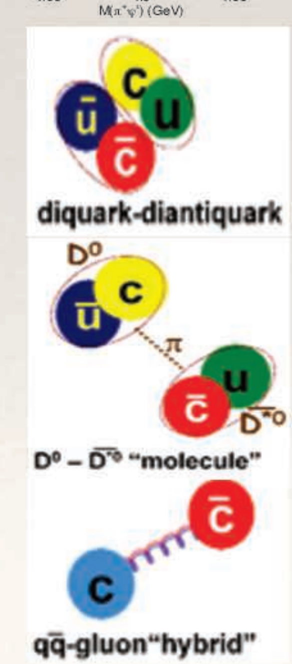
Physics case 6: Quarkonium

- Observe and characterize (m, J, P, Br(X→f), etc.) $c\bar{c}$ and $b\bar{b}$ hadrons.
- Belle/BaBar (/BESIII/LHCb/…) found many states that do not fit the mass spectra predicted by the standard quark model: tetraquarks, molecules, hybrids, glueballs, … ?



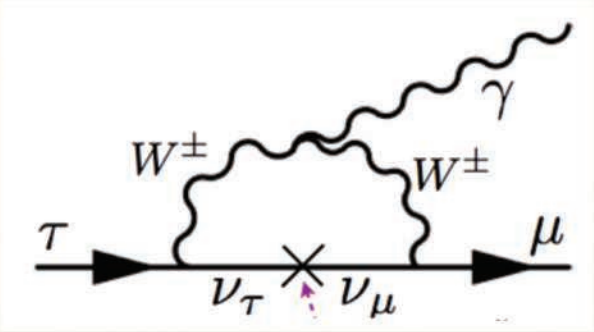


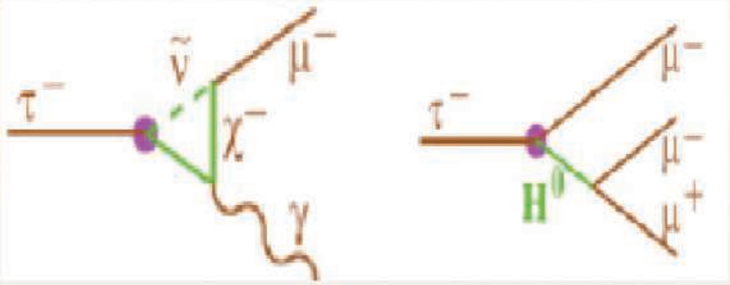




Physics case 7: lepton flavor violation

- Are there sources of BSM lepton flavor violation (LFV)?
  - Highly suppressed in SM: BF ~ 10^{-40} ($\tau \to \ell\gamma$) to 10^{-14} ($\tau \to \ell\ell\ell$) ⇒ **clean null test of SM.**
  - Slight excess (~2.5σ) of $H \to \tau\mu$ at CMS!
  - NP scenarios: BF ~ 10^{-10} to 10^{-7} :
  - BF ratios can discriminate btw. NP models.
- Belle II: **Sensitivity** for LFV BFs are over **100 x Belle for cleanest channels ($\tau \to 3\ell$)** and **10x for other** due to irreducible bkg.





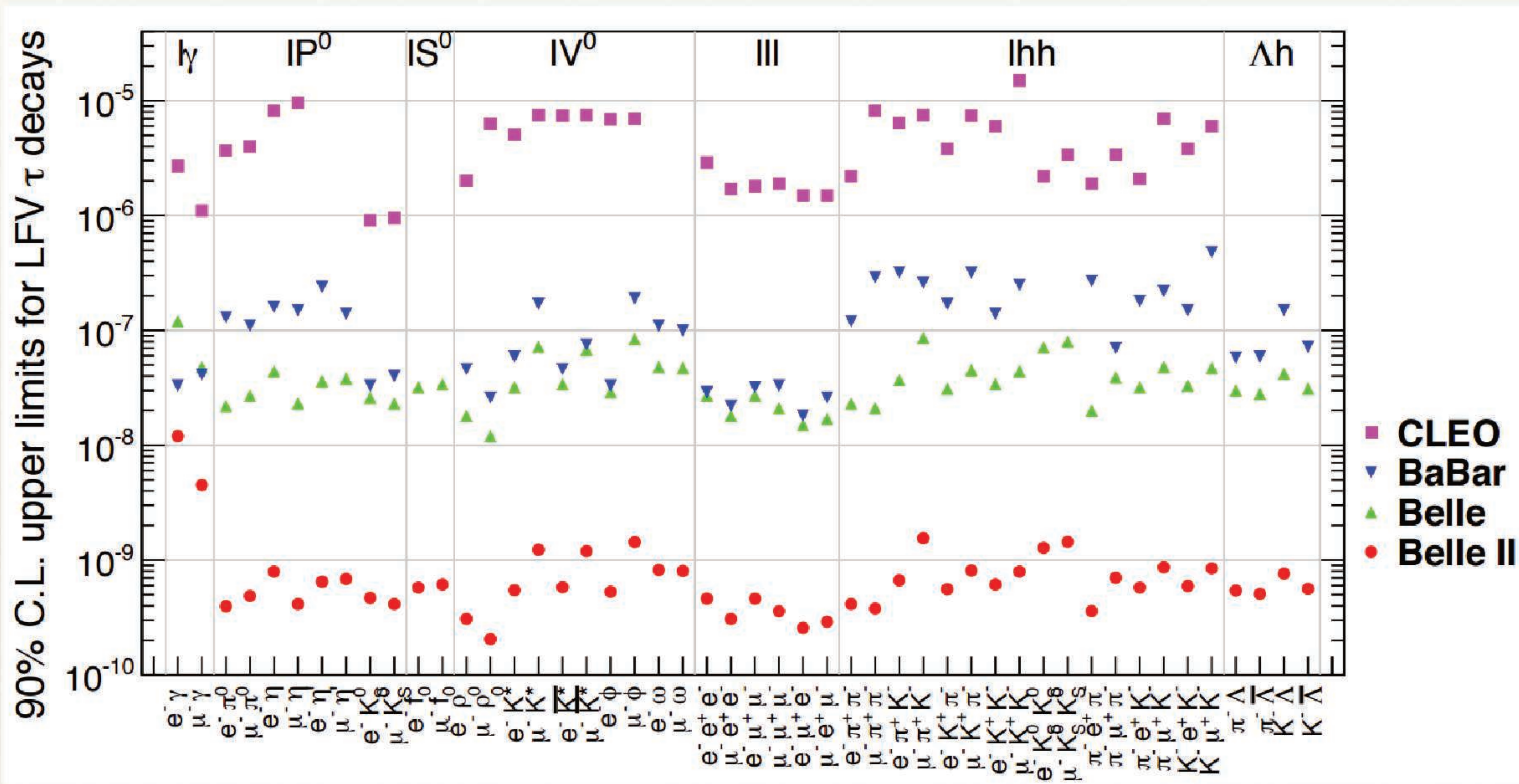
	reference	$\tau \to \mu\gamma$	$\tau \to \mu\mu\mu$
SM + heavy Maj ν_R	PRD 66(2002)034008	10^{-9}	10^{-10}
Non-universal Z'	PLB 547(2002)252	10^{-9}	10^{-8}
SUSY SO(10)	PRD 68(2003)033012	10^{-8}	10^{-10}
mSUGRA+seesaw	PRD 66(2002)115013	10^{-7}	10^{-9}
SUSY Higgs	PLB 566(2003)217	10^{-10}	10^{-7}

Ratio of Tau LFV decay BF: discrimination of NP models
JHEP 0705, 013(2007), PLB54 252 (2002)

	SUSY+GUT (SUSY+Seesaw)	Higgs mediated	Little Higgs	non-universal Z' boson
$\left(\frac{\tau \to \mu\mu\mu}{\tau \to \mu\gamma}\right)$	~2×10^{-3}	0.06~0.1	0.4~2.3	~16
$\left(\frac{\tau \to \mu ee}{\tau \to \mu\gamma}\right)$	~1×10^{-2}	~1×10^{-2}	0.3~1.6	~16
Br($\tau \to \mu\gamma$) @Max	$<10^{-7}$	$<10^{-10}$	$<10^{-10}$	$<10^{-9}$

C. Cecchi

LFV τ decays

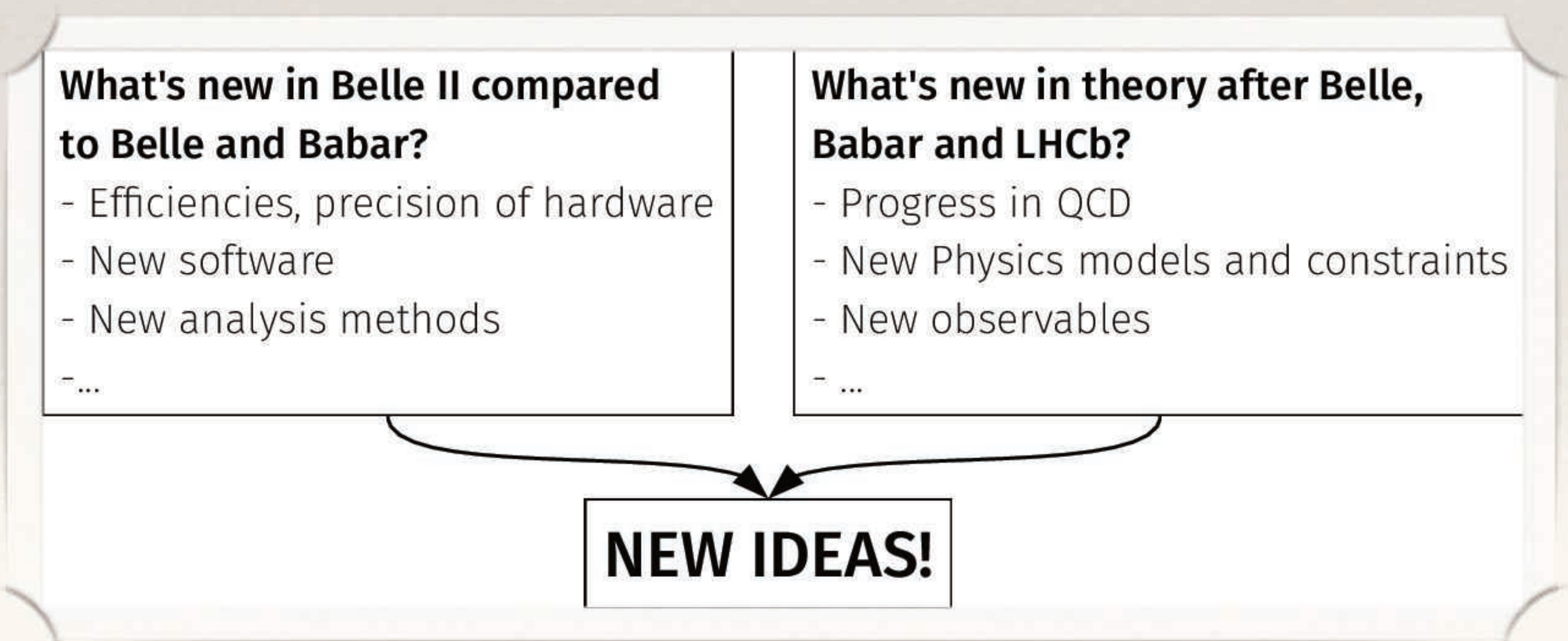


48 modes searched at B-factories!

Need help from theorists to relate them to NP

Belle II Theory Interface Platform (B2TIP)

- Joint theory-experiment effort to study potential impacts of the Belle-II program.
  - Eight physics WGs + “New Physics” WG.
  - Identify important observables to be measured at Belle II, precision, impact on our understating of the theory (SM & BSM), etc.
  - KEK Green Report by the end of 2016.
  - 2 workshops a year, next in May 23-26 2016, Pittsburg.



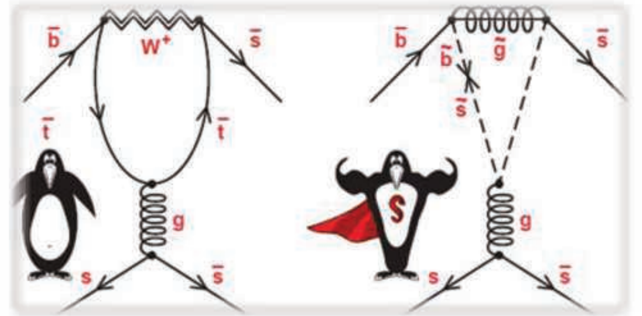
Summary of Belle II physics

	Observables	Belle (2014)	Belle II 5 ab^{-1}	Belle II 50 ab^{-1}	$\mathcal{L}_s$ [ab^{-1}]
UT angles	$\sin 2\beta$	$0.667 \pm 0.023 \pm 0.012$	± 0.012	± 0.008	6
	α		$\pm 2°$	$\pm 1°$	
	γ	$\pm 14°$	$\pm 6°$	$\pm 1.5°$	
	$S(B \to \phi K^0)$	$0.90^{+0.09}_{-0.19}$	± 0.053	± 0.018	>50
	$S(B \to \eta' K^0)$	$0.68 \pm 0.07 \pm 0.03$	± 0.028	± 0.011	>50
	$S(B \to K^0_S K^0_S K^0_S)$	$0.30 \pm 0.32 \pm 0.08$	± 0.100	± 0.033	44
UT sides	$\|V_{cb}\|$ incl.	$\pm 2.4\%$	$\pm 1.0\%$		< 1
	$\|V_{cb}\|$ excl.	$\pm 3.0\%$	$\pm 1.8\%$	$\pm 1.4\%$	< 1
	$\|V_{ub}\|$ incl.	$\pm 6.5\%$	$\pm 3.4\%$	$\pm 3.0\%$	2
	$\|V_{ub}\|$ excl. (had. tag.)	$\pm 10.8\%$	$\pm 4.7\%$	$\pm 2.4\%$	20
	$\|V_{ub}\|$ excl. (untag.)	$\pm 9.4\%$	$\pm 4.2\%$	$\pm 2.2\%$	3
Missing E decays	$\mathcal{B}(B \to \tau\nu)$ [10^{-6}]	96 ± 26	$\pm 10\%$	$\pm 5\%$	46
	$\mathcal{B}(B \to \mu\nu)$ [10^{-6}]	< 1.7	5σ	$>> 5\sigma$	>50
	$R(B \to D\tau\nu)$	$\pm 16.5\%$	$\pm 5.6\%$	$\pm 3.4\%$	4
	$R(B \to D^*\tau\nu)$	$\pm 9.0\%$	$\pm 3.2\%$	$\pm 2.1\%$	3
	$\mathcal{B}(B \to K^{*+}\nu\bar{\nu})$ [10^{-6}]	< 40		$\pm 30\%$	>50
	$\mathcal{B}(B \to K^+\nu\bar{\nu})$ [10^{-6}]	< 55		$\pm 30\%$	>50
Rad. & EW penguins	$\mathcal{B}(B \to X_s\gamma)$ [10^{-6}]	$\pm 13\%$	$\pm 7\%$	$\pm 6\%$	< 1
	$A_{CP}(B \to X_s\gamma)$		± 0.01	± 0.005	8
	$S(B \to K^0_S\pi^0\gamma)$	$-0.10 \pm 0.31 \pm 0.07$	± 0.11	± 0.035	> 50
	$S(B \to \rho\gamma)$	$-0.83 \pm 0.65 \pm 0.18$	± 0.23	± 0.07	> 50
	C_7/C_9 $(B \to X_s\ell\ell)$	~20%	10%	5%	
	$\mathcal{B}(B_s \to \gamma\gamma)$ [10^{-6}]	< 8.7	± 0.3		
	$\mathcal{B}(B_s \to \tau^+\tau^-)$ [10^{-3}]		< 2		

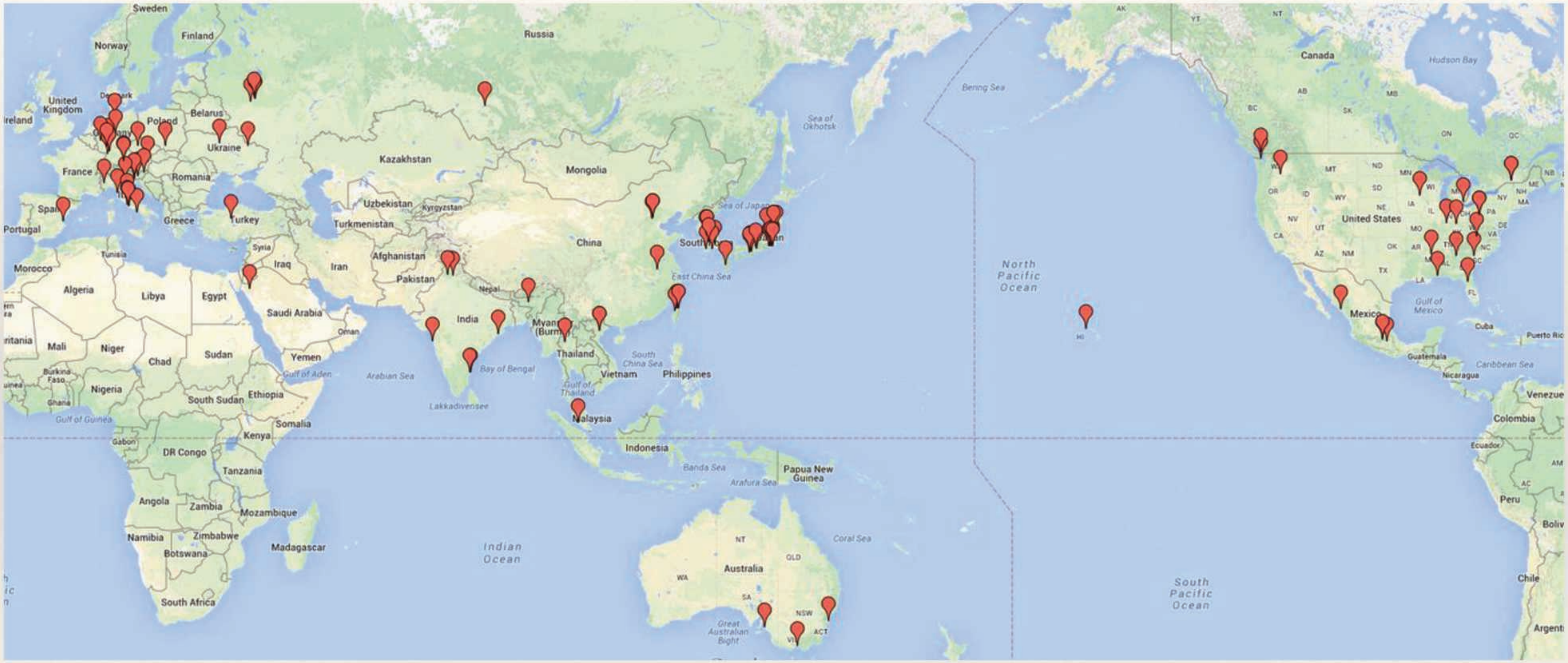
	Observables	Belle (2014)	Belle II 5 ab^{-1}	Belle II 50 ab^{-1}	$\mathcal{L}_s$ [ab^{-1}]
Charm	$\mathcal{B}(D_s \to \mu\nu)$	$5.31 \times 10^{-3}(1 \pm 0.053 \pm 0.038)$	$\pm 2.9\%$	$\pm(0.9\%\text{-}1.3\%)$	> 50
	$\mathcal{B}(D_s \to \tau\nu)$	$5.70 \times 10^{-3}(1 \pm 0.037 \pm 0.054)$	$\pm(3.5\%\text{-}4.3\%)$	$\pm(2.3\%\text{-}3.6\%)$	3-5
	y_{CP} [10^{-2}]	$1.11 \pm 0.22 \pm 0.11$	$\pm(0.11\text{-}0.13)$	$\pm(0.05\text{-}0.08)$	5-8
	A_Γ [10^{-2}]	$-0.03 \pm 0.20 \pm 0.08$	± 0.10	$\pm(0.03\text{-}0.05)$	7 - 9
	$A_{CP}^{K^+K^-}$ [10^{-2}]	$-0.32 \pm 0.21 \pm 0.09$	± 0.11	± 0.06	15
	$A_{CP}^{\pi^+\pi^-}$ [10^{-2}]	$0.55 \pm 0.36 \pm 0.09$	± 0.17	± 0.06	> 50
	$A_{CP}^{\phi\gamma}$ [10^{-2}]	± 5.6	± 2.5	± 0.8	> 50
	$x^{K_S\pi^+\pi^-}$ [10^{-2}]	$0.56 \pm 0.19 \pm {}^{0.07}_{0.13}$	± 0.14	± 0.11	3
	$y^{K_S\pi^+\pi^-}$ [10^{-2}]	$0.30 \pm 0.15 \pm {}^{0.05}_{0.08}$	± 0.08	± 0.05	15
	$\|q/p\|^{K_S\pi^+\pi^-}$	$0.90 \pm {}^{0.16}_{0.15} \pm {}^{0.08}_{0.06}$	± 0.10	± 0.07	5-6
	$\phi^{K_S\pi^+\pi^-}$ [°]	$-6 \pm 11 \pm {}^{4}_{5}$	± 6	± 4	10
	$A_{CP}^{\pi^0\pi^0}$ [10^{-2}]	$-0.03 \pm 0.64 \pm 0.10$	± 0.29	± 0.09	> 50
	$A_{CP}^{K^0_S\pi^0}$ [10^{-2}]	$-0.10 \pm 0.16 \pm 0.09$	± 0.08	± 0.03	> 50
	$Br(D^0 \to \gamma\gamma)$ [10^{-6}]	< 1.5	$\pm 30\%$	$\pm 25\%$	2
Tau		$\tau \to \mu\gamma$ [10^{-9}]	< 45	< 14.7	< 4.7
		$\tau \to e\gamma$ [10^{-9}]	< 120	< 39	< 12
		$\tau \to \mu\mu\mu$ [10^{-9}]	< 21.0	< 3.0	< 0.3

BELLE2-NOTE-0021

4.1 Physics case: CP asymmetry in b→s
[$\phi_{1,c\bar{c}s}$ (tree) vs. $\phi_{1,q\bar{q}s}$ (gluonic penguins)]

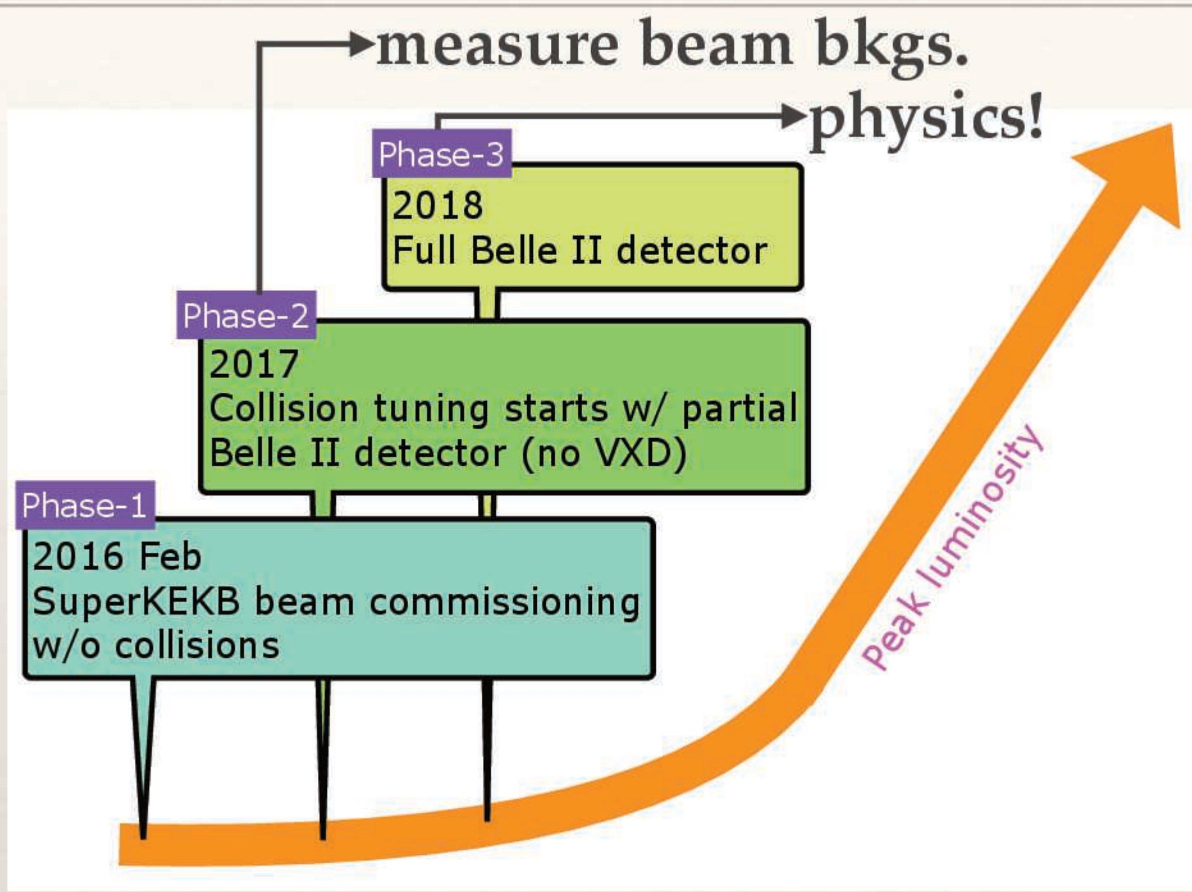


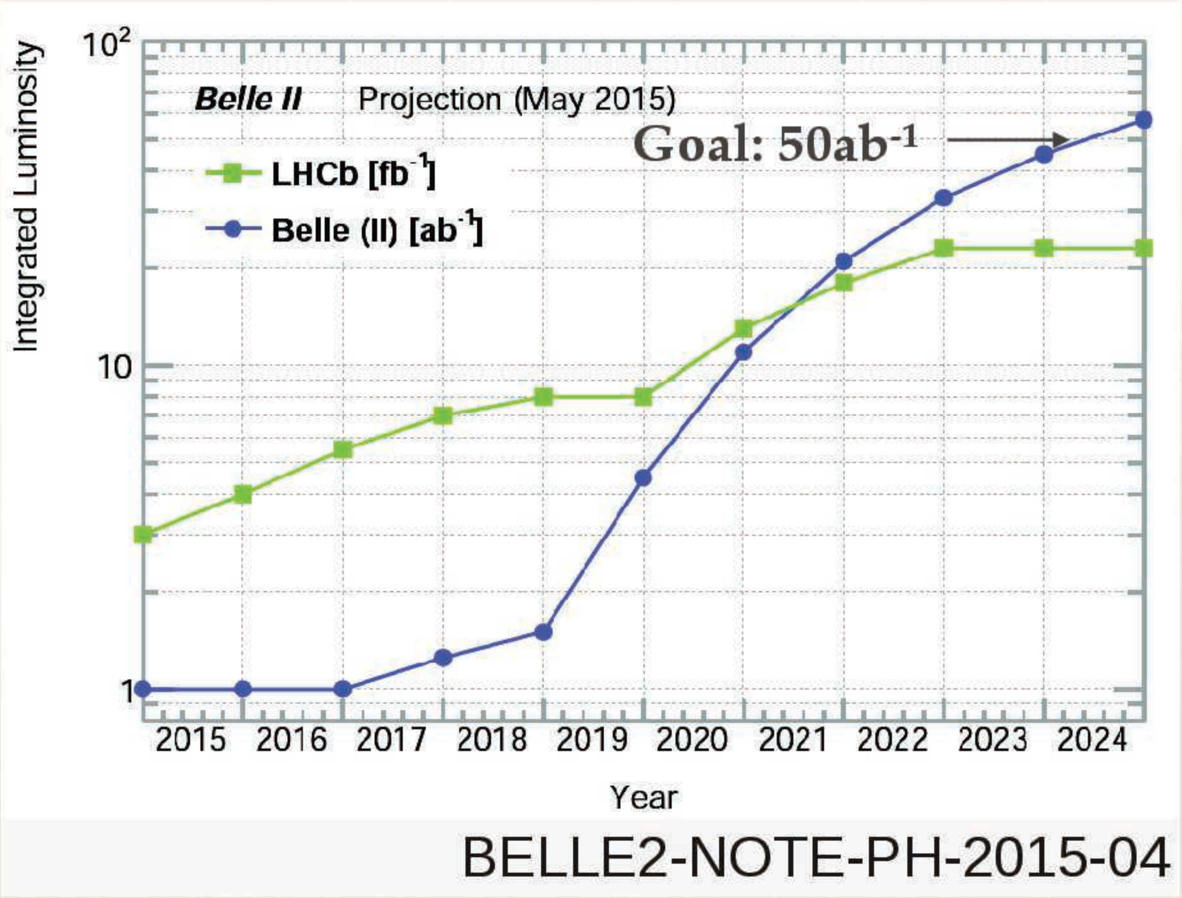
The Belle II Collaboration

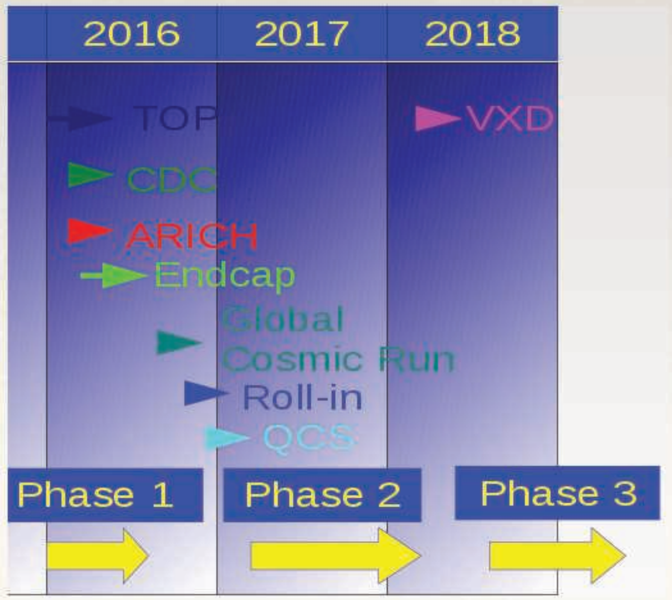


638 colleagues, 98 institutions, 23 countries/regions

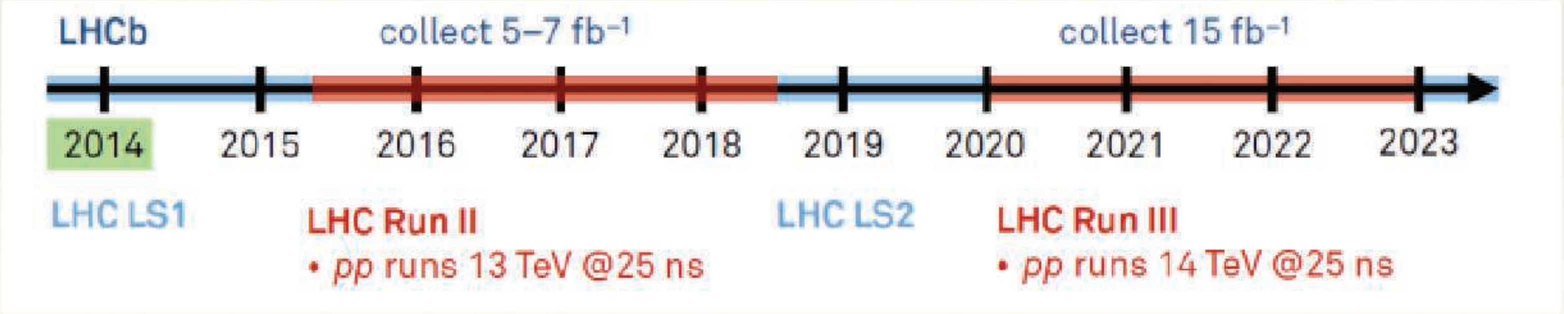
Plans







- LHCb "nearest competitor" in some processes.



Summary

- Rich and successful physics program at the B-factories.
- Many unresolved issues, hints of new physics (?):
  - We will need both, Belle II and the LHC experiments, to investigate them.
  - Many B physics anomalies can be only resolved at Belle II.
- Belle II is more than Belle with higher luminosity; there are also many improvements in detector, trigger, reconstruction, analysis techniques, etc. to reach beyond.
- Belle II will start operations soon, first data in 2017 (non-B measurements) and full quality physics data in 2018.

Students and colleagues are welcome!

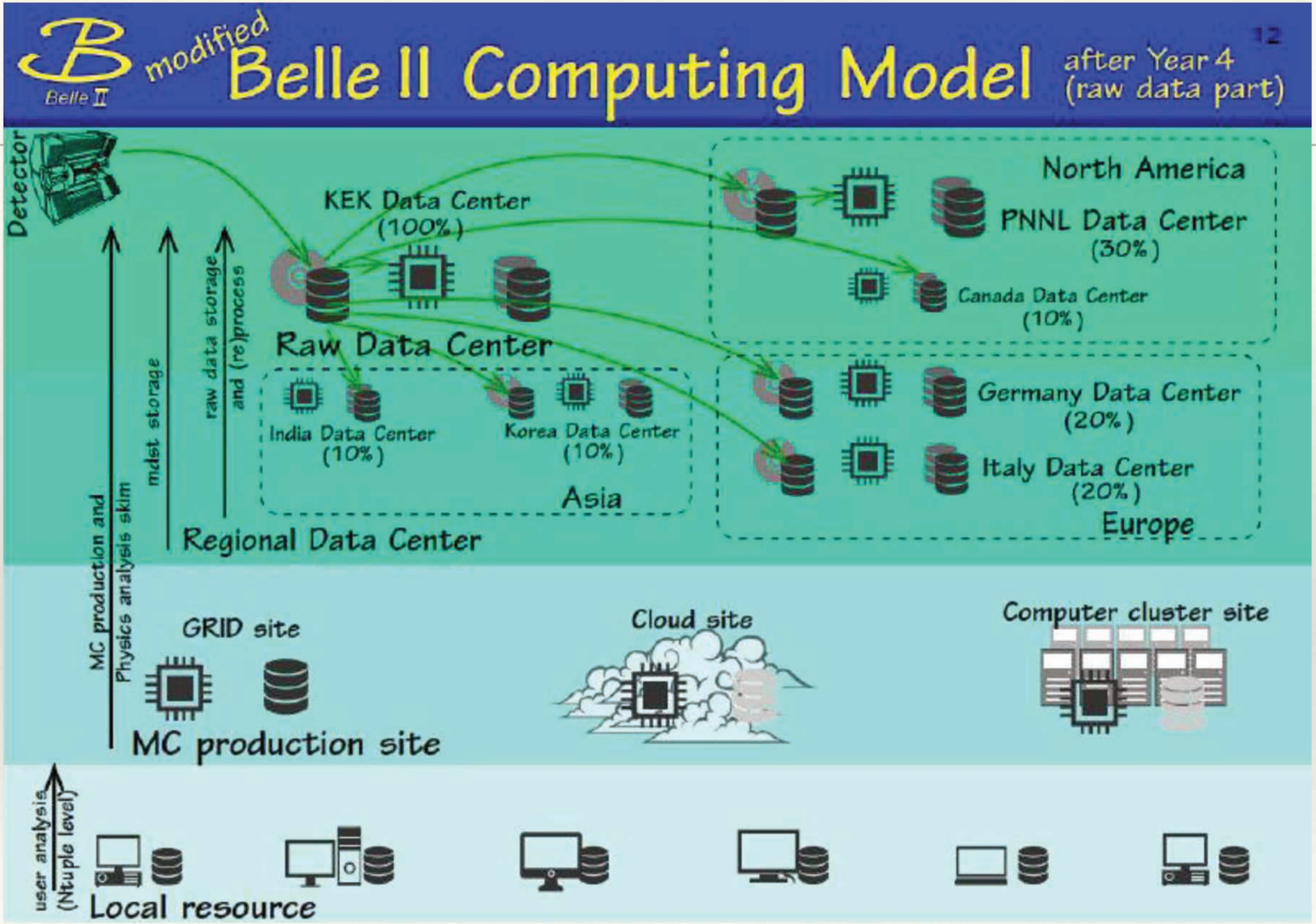
Backup

Golden modes (vs. LHCb)

TABLE XLI: Expected errors on several selected flavour observables with an integrated luminosity of 5 ab^{-1} and 50 ab^{-1} of Belle II data. The current results from Belle, or from BaBar where relevant (denoted with a †) are also given. Items marked with a ‡ are estimates based on similar measurements. Errors given in % represent relative errors.

	Observables	Belle or LHCb*	Belle II		LHCb	
		(2014)	5 ab^{-1}	50 ab^{-1}	8 fb^{-1} (2018)	50 fb^{-1}
UT angles	$\sin 2\beta$	$0.667 \pm 0.023 \pm 0.012 (0.9^\circ)$	0.4°	0.3°	0.6°	0.3°
	α [°]	85 ± 4 (Belle+BaBar)	2	1		
	γ [°] $(B \to D^{(*)} K^{(*)})$	68 ± 14	6	1.5	4	1
	$2\beta_s(B_s \to J/\psi\phi)$ [rad]	$0.07 \pm 0.09 \pm 0.01^*$			0.025	0.009
Gluonic penguins	$S(B \to \phi K^0)$	$0.90^{+0.09}_{-0.19}$	0.053	0.018	0.2	0.04
	$S(B \to \eta' K^0)$	$0.68 \pm 0.07 \pm 0.03$	0.028	0.011		
	$S(B \to K^0_S K^0_S K^0_S)$	$0.30 \pm 0.32 \pm 0.08$	0.100	0.033		
	$\beta_s^{\rm eff}(B_s \to \phi\phi)$ [rad]	$-0.17 \pm 0.15 \pm 0.03^*$			0.12	0.03
	$\beta_s^{\rm eff}(B_s \to K^{*0} \bar{K}^{*0})$ [rad]	–			0.13	0.03
Direct CP in hadronic Decays	$\mathcal{A}(B \to K^0 \pi^0)$	$-0.05 \pm 0.14 \pm 0.05$	0.07	0.04		
UT sides	$\lvert V_{cb} \rvert$ incl.	$41.6 \cdot 10^{-3}(1 \pm 2.4\%)$	1.2%			
	$\lvert V_{cb} \rvert$ excl.	$37.5 \cdot 10^{-3}(1 \pm 3.0\%_{\rm ex.} \pm 2.7\%_{\rm th.})$	1.8%	1.4%		
	$\lvert V_{ub} \rvert$ incl.	$4.47 \cdot 10^{-3}(1 \pm 6.0\%_{\rm ex.} \pm 2.5\%_{\rm th.})$	3.4%	3.0%		
	$\lvert V_{ub} \rvert$ excl. (had. tag.)	$3.52 \cdot 10^{-3}(1 \pm 10.8\%)$	4.7%	2.4%		
Leptonic and Semi-tauonic	$\mathcal{B}(B \to \tau\nu)$ $[10^{-6}]$	$96(1 \pm 26\%)$	10%	5%		
	$\mathcal{B}(B \to \mu\nu)$ $[10^{-6}]$	< 1.7	20%	7%		
	$R(B \to D\tau\nu)$ [Had. tag]	$0.440(1 \pm 16.5\%)^\dagger$	5.6%	3.4%		
	$R(B \to D^*\tau\nu)^\dagger$ [Had. tag]	$0.332(1 \pm 9.0\%)^\dagger$	3.2%	2.1%	...	
Radiative	$\mathcal{B}(B \to X_s\gamma)$	$3.45 \cdot 10^{-4}(1 \pm 4.3\% \pm 11.6\%)$	7%	6%		
	$A_{CP}(B \to X_{s,d}\gamma)$ $[10^{-2}]$	$2.2 \pm 4.0 \pm 0.8$	1	0.5		
	$S(B \to K^0_S \pi^0 \gamma)$	$-0.10 \pm 0.31 \pm 0.07$	0.11	0.035		
	$2\beta_s^{\rm eff}(B_s \to \phi\gamma)$	–			0.13	0.03
	$S(B \to \rho\gamma)$	$-0.83 \pm 0.65 \pm 0.18$	0.23	0.07		
	$\mathcal{B}(B_s \to \gamma\gamma)$ $[10^{-6}]$	< 8.7	0.3	–		
Electroweak penguins	$\mathcal{B}(B \to K^{*+}\nu\bar{\nu})$ $[10^{-6}]$	< 40	< 15	30%		
	$\mathcal{B}(B \to K^{+}\nu\bar{\nu})$ $[10^{-6}]$	< 55	< 21	30%		
	C_7/C_9 $(B \to X_s\ell\ell)$	~20%	10%	5%		
	$\mathcal{B}(B_s \to \tau\tau)$ $[10^{-3}]$	–	< 2	–		
	$\mathcal{B}(B_s \to \mu\mu)$ $[10^{-9}]$	$2.9^{+1.1*}_{-1.0}$			0.5	0.2

	Observables	Belle or LHCb*	Belle II		LHCb	
		(2014)	5 ab^{-1}	50 ab^{-1}	2018	50 fb^{-1}
Charm Rare	$\mathcal{B}(D_s \to \mu\nu)$	$5.31 \cdot 10^{-3}(1 \pm 5.3\% \pm 3.8\%)$	2.9%	0.9%		
	$\mathcal{B}(D_s \to \tau\nu)$	$5.70 \cdot 10^{-3}(1 \pm 3.7\% \pm 5.4\%)$	3.5%	2.3%		
	$\mathcal{B}(D^0 \to \gamma\gamma)$ $[10^{-6}]$	< 1.5	30%	25%		
Charm CP	$A_{CP}(D^0 \to K^+K^-)$ $[10^{-4}]$	$-32 \pm 21 \pm 9$	11	6		
	$\Delta A_{CP}(D^0 \to K^+K^-)$ $[10^{-3}]$	3.4^*			0.5	0.1
	A_Γ $[10^{-2}]$	0.22	0.1	0.03	0.02	0.005
	$A_{CP}(D^0 \to \pi^0\pi^0)$ $[10^{-2}]$	$-0.03 \pm 0.64 \pm 0.10$	0.29	0.09		
	$A_{CP}(D^0 \to K^0_S\pi^0)$ $[10^{-2}]$	$-0.21 \pm 0.16 \pm 0.09$	0.08	0.03		
Charm Mixing	$x(D^0 \to K^0_S\pi^+\pi^-)$ $[10^{-2}]$	$0.56 \pm 0.19 \pm {}^{0.07}_{0.13}$	0.14	0.11		
	$y(D^0 \to K^0_S\pi^+\pi^-)$ $[10^{-2}]$	$0.30 \pm 0.15 \pm {}^{0.05}_{0.08}$	0.08	0.05		
	$\lvert q/p \rvert (D^0 \to K^0_S\pi^+\pi^-)$	$0.90 \pm {}^{0.16}_{0.15} \pm {}^{0.08}_{0.06}$	0.10	0.07		
	$\phi(D^0 \to K^0_S\pi^+\pi^-)$ [°]	$-6 \pm 11 \pm {}^{4}_{5}$	6	4		
Tau	$\tau \to \mu\gamma$ $[10^{-9}]$	< 45	< 14.7	< 4.7		
	$\tau \to e\gamma$ $[10^{-9}]$	< 120	< 39	< 12		
	$\tau \to \mu\mu\mu$ $[10^{-9}]$	< 21.0	< 3.0	< 0.3		



modified
Belle II Computing Model
after Year 4
(raw data part)
Belle II
Detector
KEK Data Center
(100%)
Raw Data Center
North America
PNNL Data Center
(30%)
Canada Data Center
(10%)
India Data Center
(10%)
Korea Data Center
(10%)
Asia
Germany Data Center
(20%)
Italy Data Center
(20%)
Europe
raw data storage
and (re)process
mdst storage
MC production and
Physics analysis skim
Regional Data Center
GRID site
Cloud site
Computer cluster site
MC production site
user analysis
(Ntuple level)
Local resource

LFV current best limits