# Stato e prospettive di misure a Belle II

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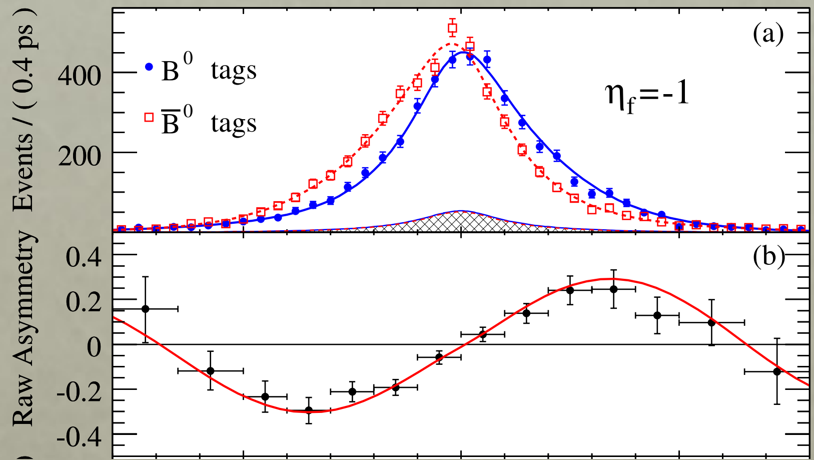
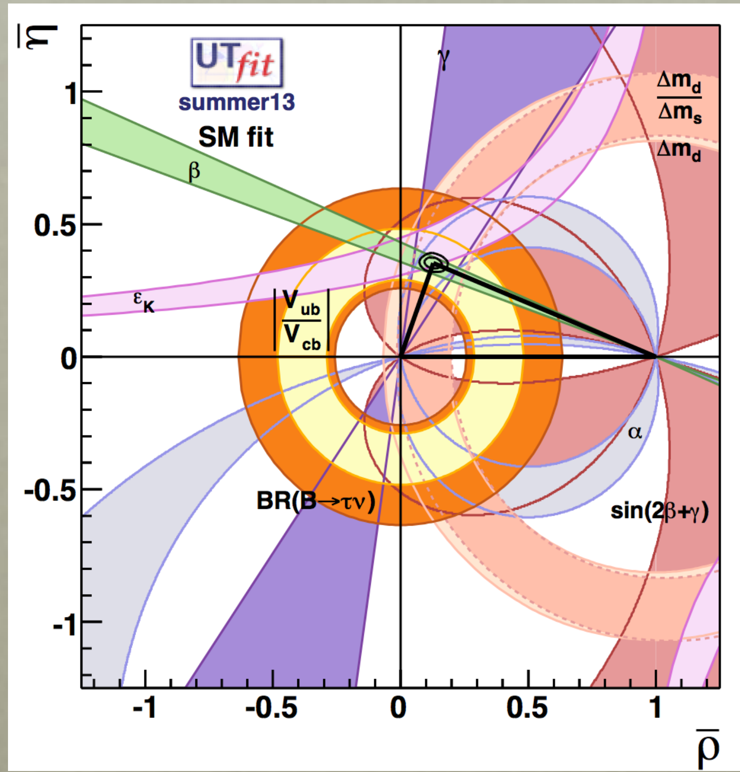
# outline

- Physics motivation
- Status of the project
- Overview of the Physics Program
  - Leptonic and semileptonic decays, FCNC, LFV, CP violation

# The BaBar and Belle B-factories impact in HEP




- Successful experimental program:
  - Established CP violation in B system and the remarkable consistency of the CKM mechanism of the SM

Nobel Prize in Physics In 2008 awarded to Kobayashi and Maskawa

2008

# Frontier Physics : what now?

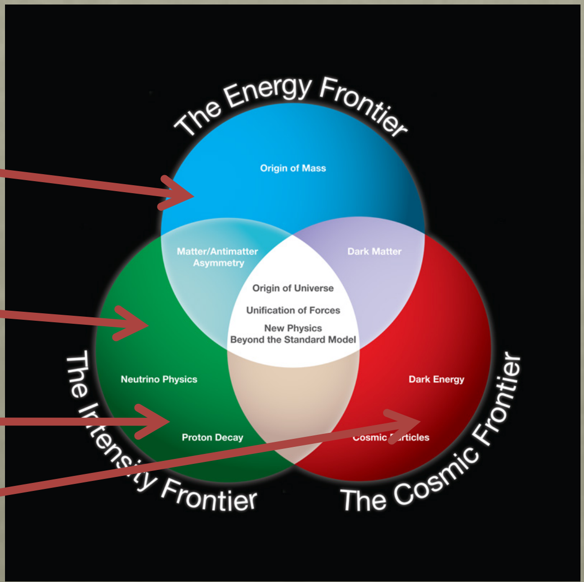
- Despite the experimental efforts, the SM did not break down.
  No compelling evidence of NP.
  - After Higgs discovery, the same story (for now…) in direct searches at LHC
- Option one: Let a Post-Higgs-Depression syndrome bring us down
- Option two: Be aggressive and insist on several frontiers, overlapping and interdependent
  - Also be patient

Direct Searches at LHC

Flavor Physics

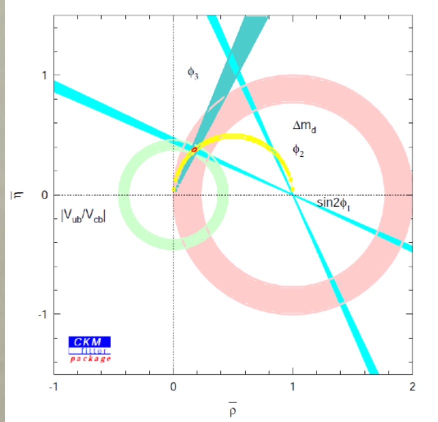
Neutrino Phys.

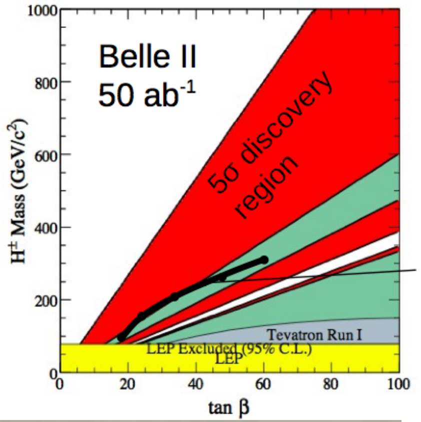
Particles from the cosmo



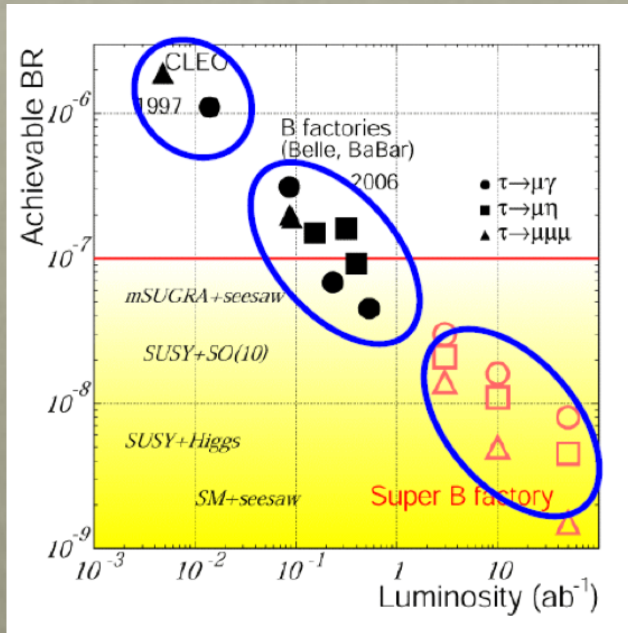
# What is the role of Flavor Physics?

- Quantum effects relate (New) Phyics at high mass scales to lower energy observables.




$$A = A_0 \left[ c_{SM} \frac{1}{M_W^{\,2}} + c_{NP} \frac{1}{\Lambda^2} \right]$$

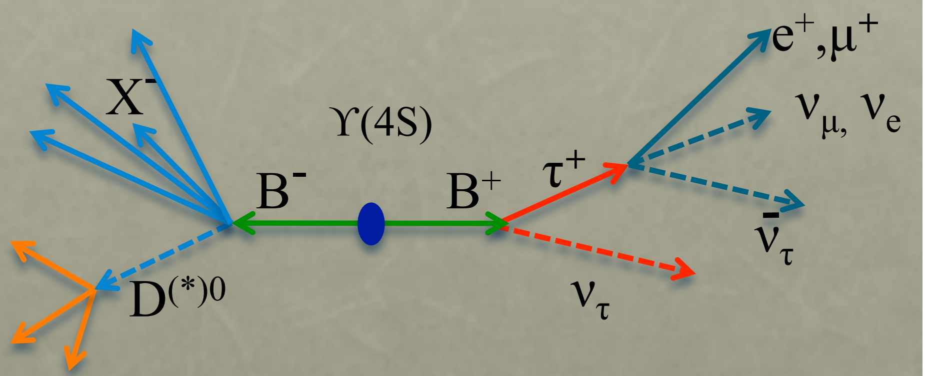



In Flavor Physics detectable in processes where
The SM contribution is absent or well predicted.

Notable examples relevant for Belle II
Lepton Flavor Violation (τ-> μ γ , 3μ, 3e)
Theoretically clean leptonic B decays e lepton univ. Ratios
FCNC b→ s transitions (B → $X_s$ γ, $K^{(*)}$ ν ν)

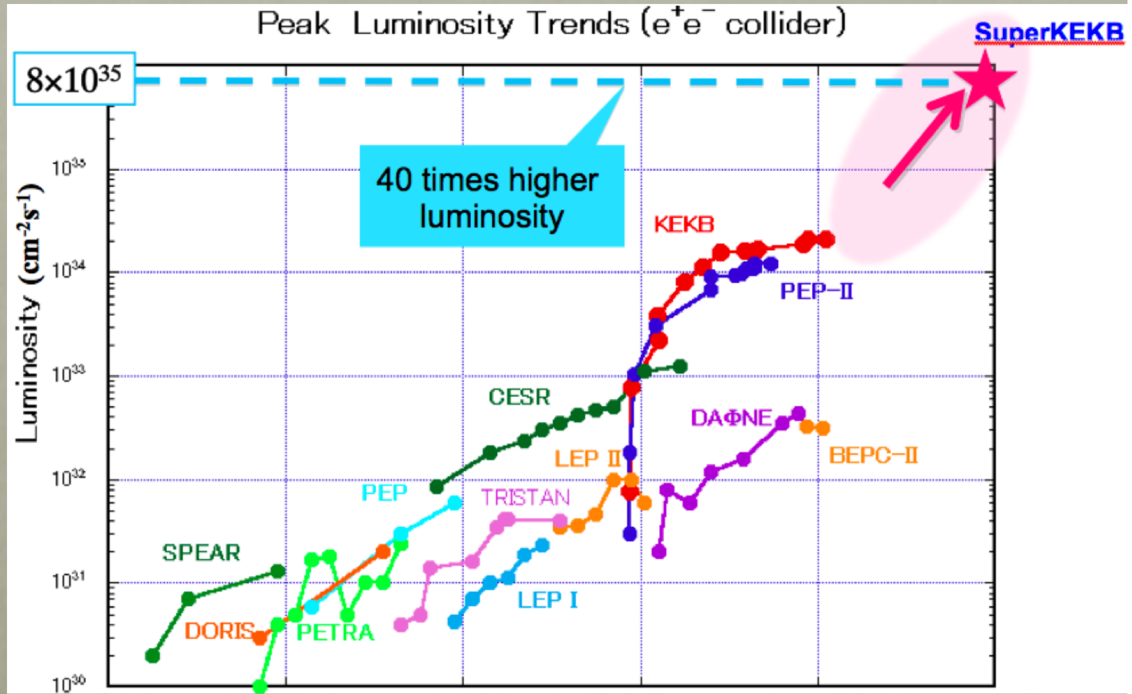
# Unique capabilities of SuperKEKB/Belle II

- Two correlated B mesons at Υ(4S)
- No trigger bias (almost 100% efficiency for multihadron events)
- Excellent efficiency and resolution in tracking as well as in detecting photons, $K_L$, $\pi^0$ and in reconstruction of intermediate resonances
- Very clean (compared to hadron machines) environment permits "full reconstruction" of the event
  - Critical for analysis with weak signatures like leptonic B decays, inclusive analyses…

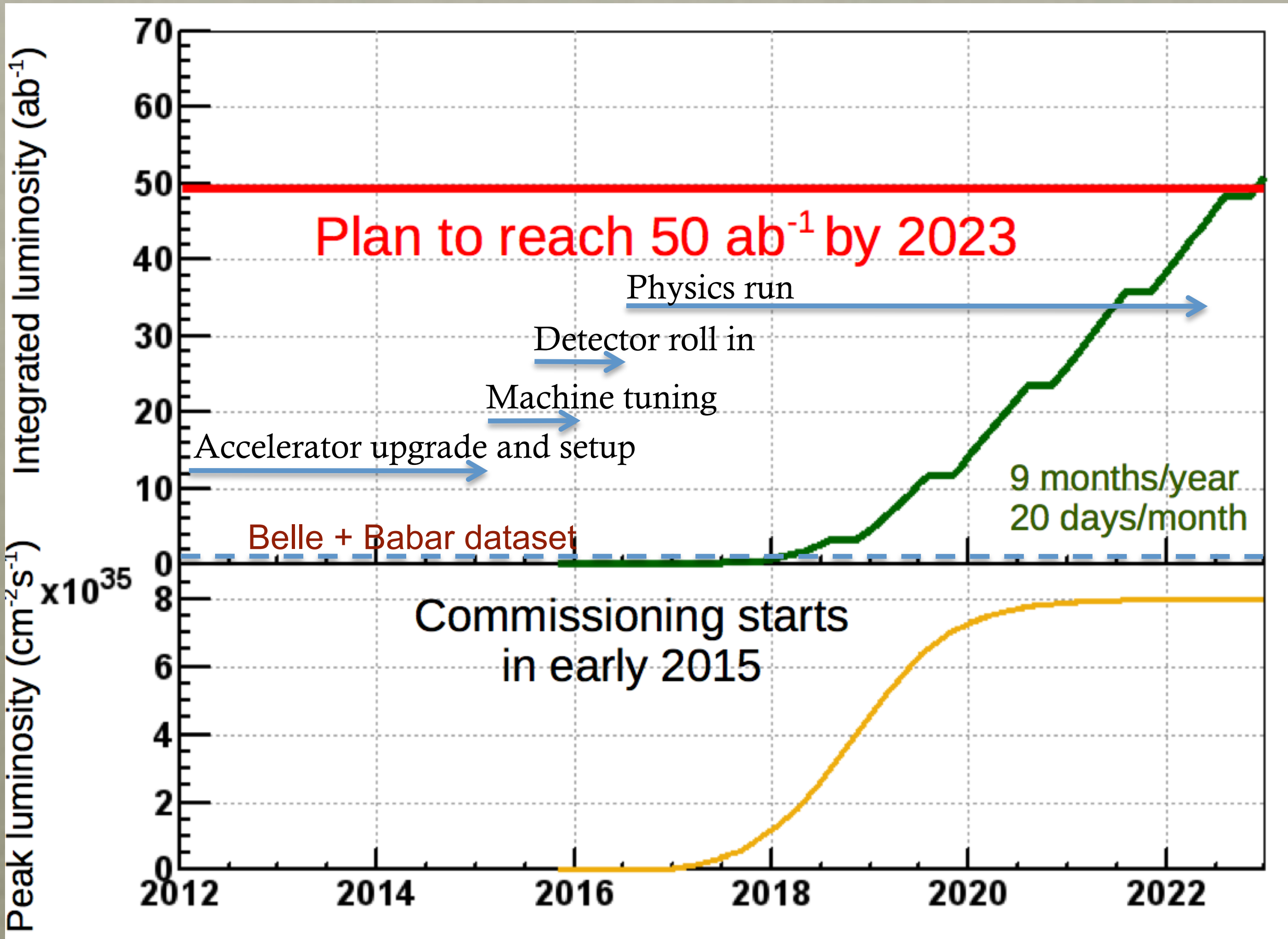


# KEK B accelerator upgrade to SuperKEKB

- 40x better luminosity
- 20x coming from P.Raimondi nano-beams proposal
- 2x Higher beam currents
- Upgrades in many acc. components



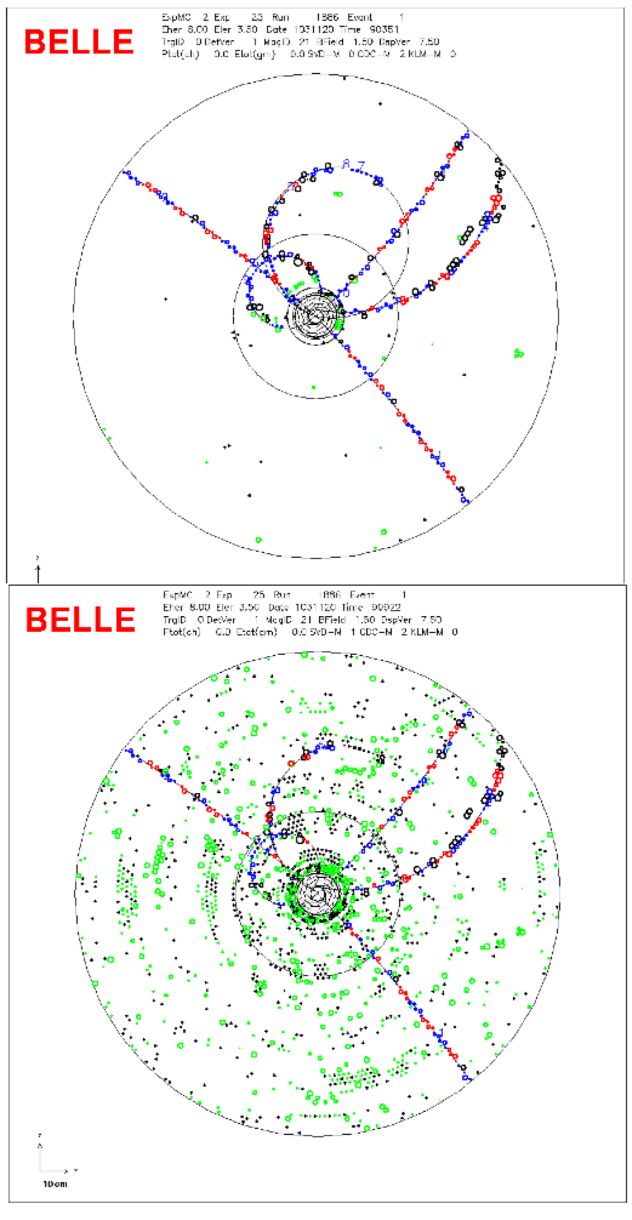

# Luminosity projection

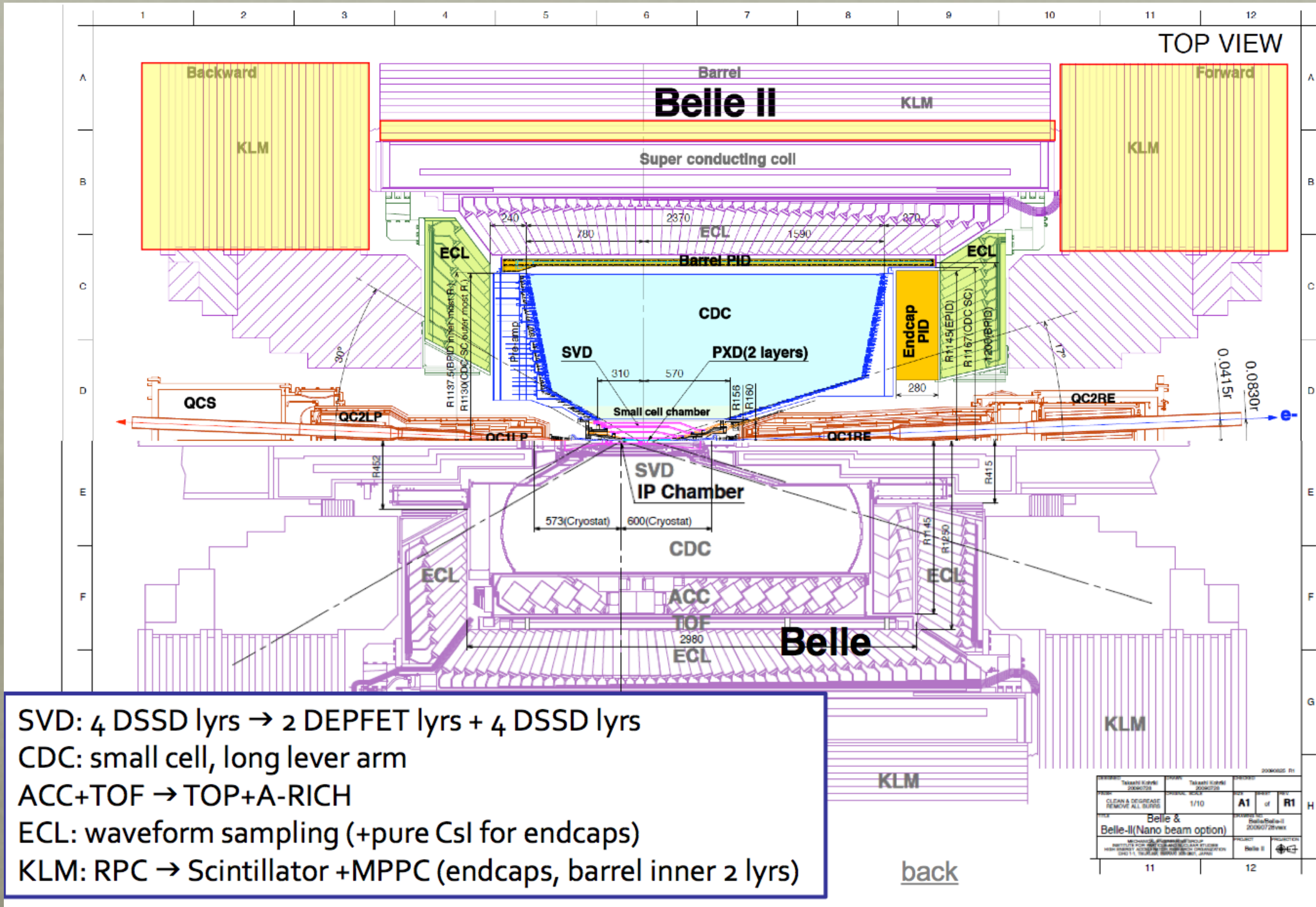


# Detector upgrade

- Changing specifications
  - Larger occupancy
  - Pile-up and fake hits in the EM calorimeter
- Higher event rates
  - DAQ and front end electronics upgrades
- Better performances
  - Better vertex resolution
  - Improved hermeticity (missing energy)
  - Forward PID (kaon ID)
  - Better KL identification

Belle II TDR arXiv:1011.0352

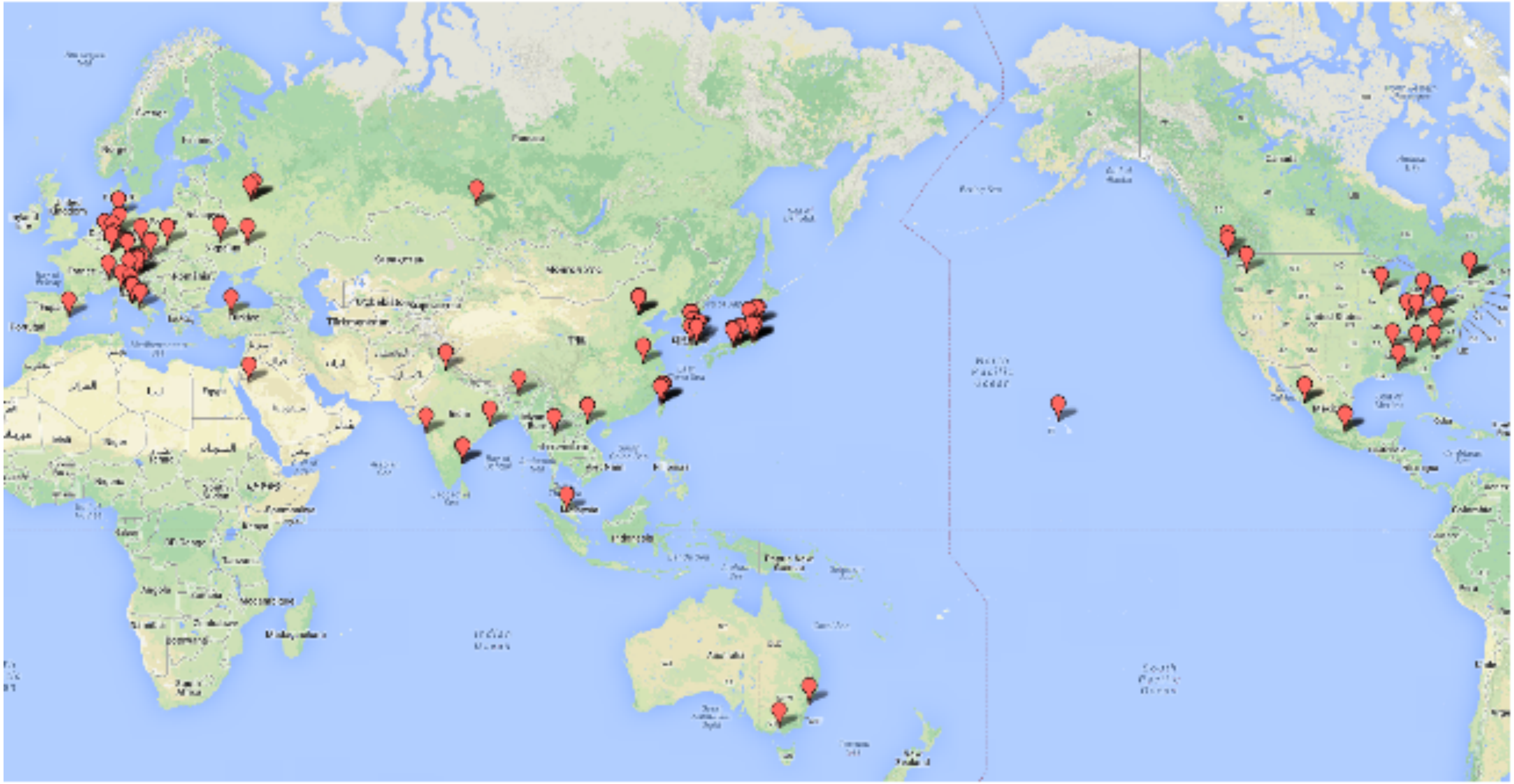





SVD: 4 DSSD lyrs → 2 DEPFET lyrs + 4 DSSD lyrs
CDC: small cell, long lever arm
ACC+TOF → TOP+A-RICH
ECL: waveform sampling (+pure CsI for endcaps)
KLM: RPC → Scintillator +MPPC (endcaps, barrel inner 2 lyrs)

back

# Belle II collaboration



600 collaborators from 97 institutes and 23 countries

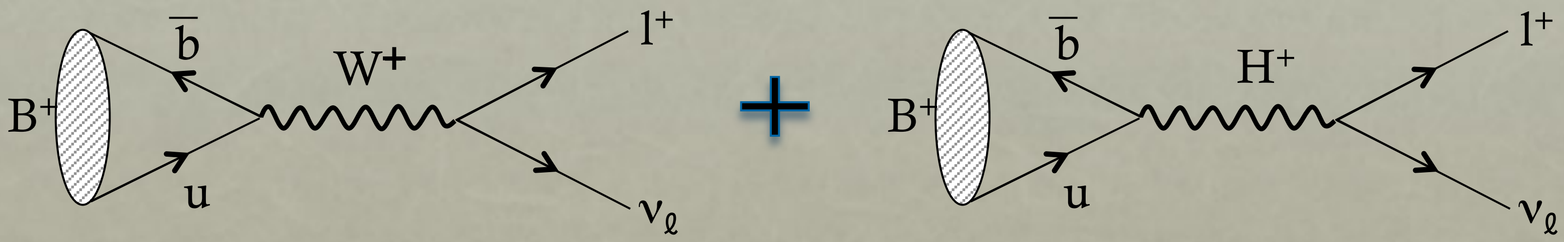
# Physics Program highlights

# |Vub| measurement

- Tension between inclusive and exclusive determinations still here, today
  - Problem in theory? Common exp. systematic effects to understand?
- Belle II will reach 1%-2% accuracy, dominated by systematics
  - The large statistics will allow a systematic survey of exclusive modes
  - Explore in detail the $q^2$ spectrum.

| | Statistical | Systematic (reducible, irreducible) | Total Exp | Theory | Total |
|---|---|---|---|---|---|
| $\|V_{ub}\|$ exclusive (had. tagged) | | | | | |
| 711 $fb^{-1}$ | 5.8 | (2.3, 1.0) | 6.3 | 8.7 (2.0) | 10.8 (6.6) |
| 5 $ab^{-1}$ | 2.2 | (0.9, 1.0) | 2.6 | 4.0 (2.0) | 4.7 (3.3) |
| 50 $ab^{-1}$ | 0.7 | (0.3, 1.0) | 1.3 | 2.0 | 2.4 |
| $\|V_{ub}\|$ exclusive (untagged) | | | | | |
| 605 $fb^{-1}$ | 2.7 | (2.1, 0.8) | 3.5 | 8.7 (2.0) | 9.4 (4.0) |
| 5 $ab^{-1}$ | 1.0 | (0.8, 0.8) | 1.5 | 4.0 (2.0) | 4.2 (2.5) |
| 50 $ab^{-1}$ | 0.3 | (0.3, 0.8) | 0.9 | 2.0 | 2.2 |
| $\|V_{ub}\|$ inclusive | | | | | |
| 605 $fb^{-1}$ (old $B$ tag) | 4.5 | (3.7, 1.6) | 6.0 | 2.5 | 6.5 |
| 5 $ab^{-1}$ | 1.1 | (1.3, 1.6) | 2.3 | 2.5 | 3.4 |
| 50 $ab^{-1}$ | 0.4 | (0.4, 1.6) | 1.7 | 2.5 | 3.0 |

# Leptonic B decays




- Very clean theoretically, hard experimentally (weak signature)
- SM contribution suppressed by helicity
- Sensitive to NP contribution (charged Higgs)

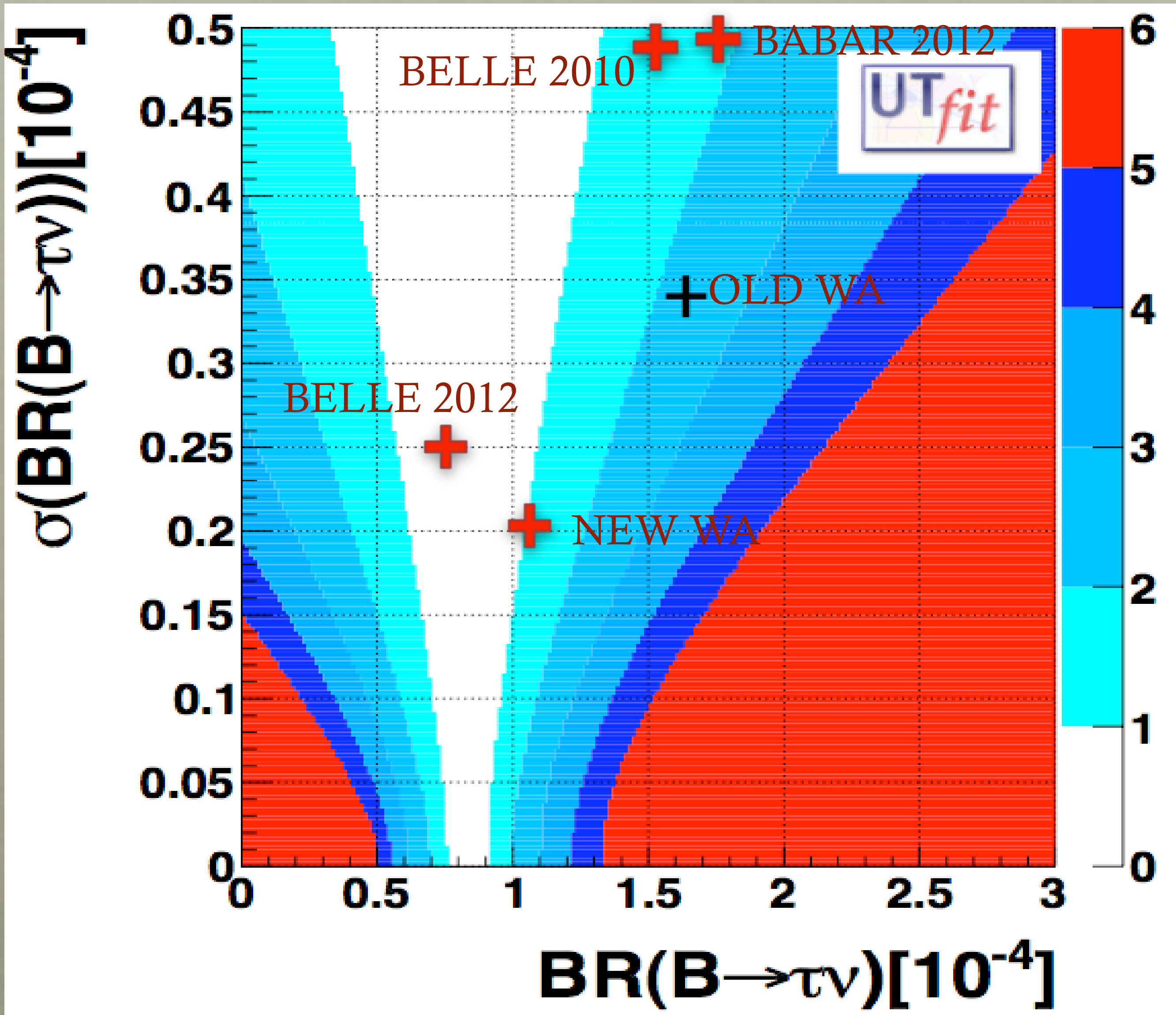
$$\mathcal{B}(B \to l\nu) = \frac{G_F^2 m_B}{8\pi} m_l^2 (1 - \frac{m_l^2}{m_B^2})^2 f_B^2 |V_{ub}|^2 \tau_B$$

$$\mathcal{B}(B \to l\nu)_{2HDM} = \mathcal{B}(B \to l\nu)_{SM} \times (1 - tan^2\beta \frac{m_B^2}{m_H^2})^2$$

Moreover Belle II can test LFU with ratios

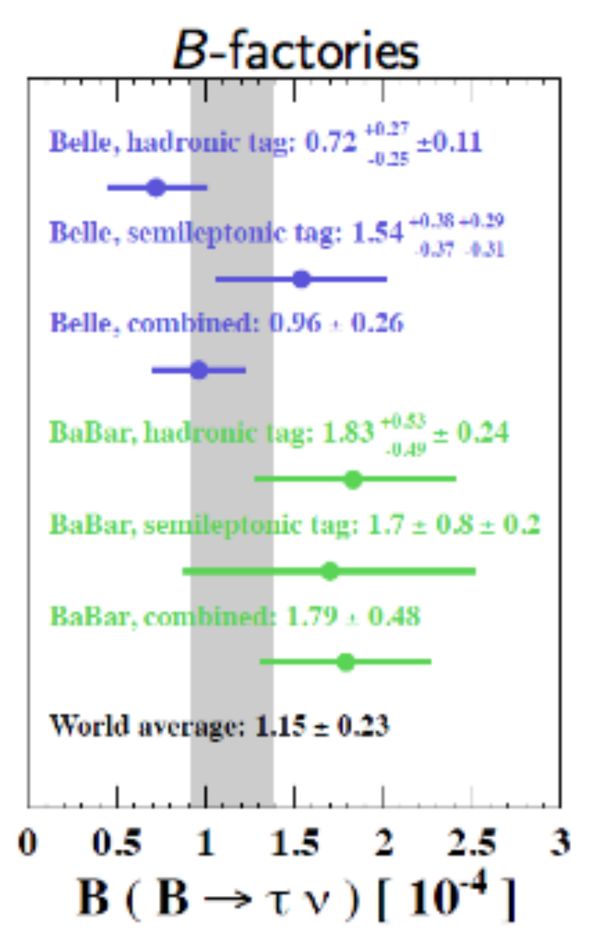
$$R^{\tau\mu} = \frac{\Gamma(B \to \mu\nu)}{\Gamma(B \to \tau\nu)} \qquad R^{\tau e} = \frac{\Gamma(B \to e\nu)}{\Gamma(B \to \tau\nu)}$$

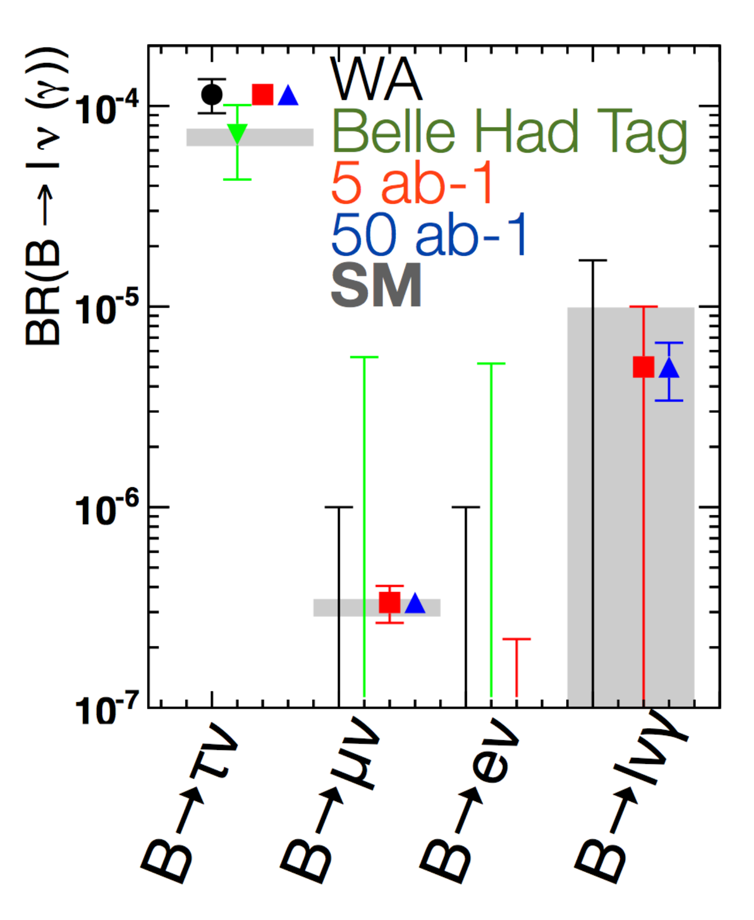
# Current B → τ ν measurements



# B → l ν status and prospects

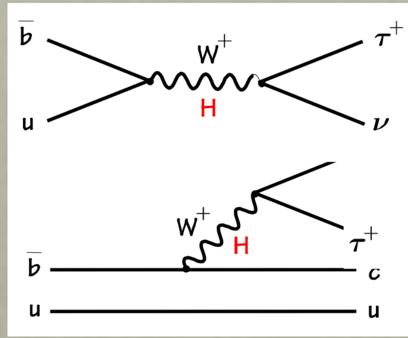
- B→ τν BR expected at 3% (dominated by systematics)
  - How much of the error is reducible?
- Will observe of B → μ ν and B→ e/μ ν γ (assuming SM BR)



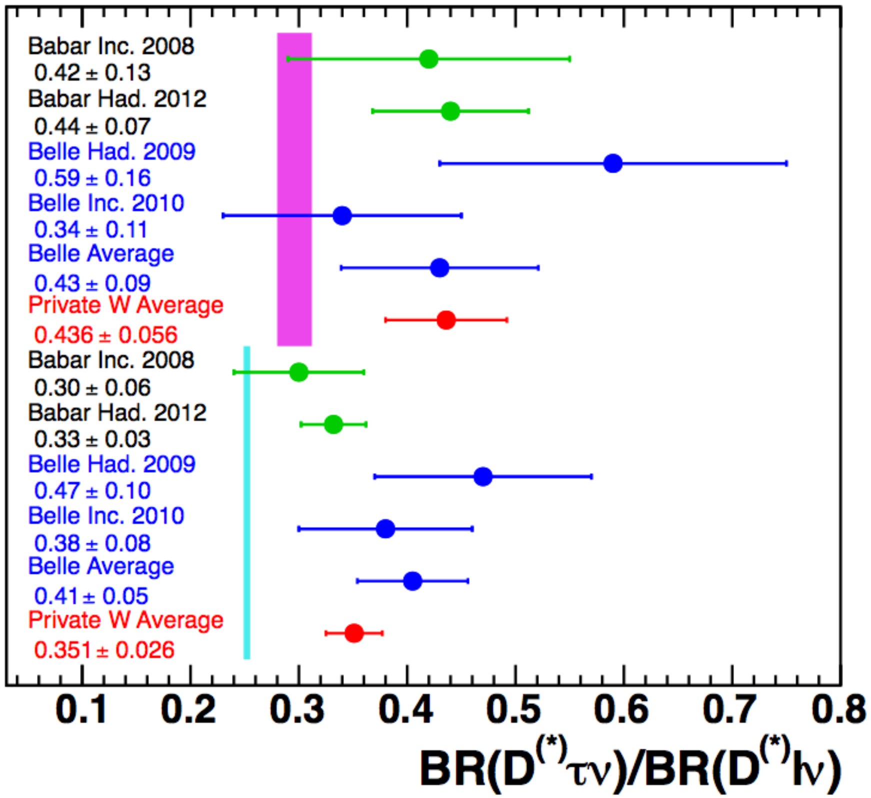



# Semitauonic decays

- SM: tree level b →c semileptonic
- NP from 2HDM extensions
- R(D$^{(*)}$) = BR( B → D$^{(*)}$ τ ν ) / BR( B → D$^{(*)}$ l ν )




**Belle and BaBar measurements exceed SM expectation!**

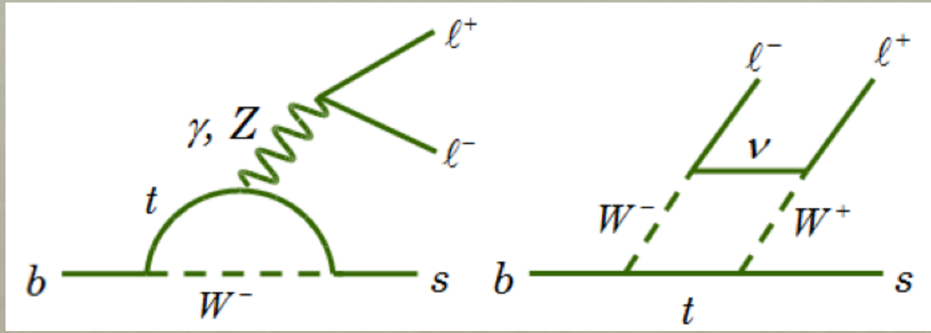



**Belle II projections based on extrapolation of the BaBar result**

| | fb-1 | Statistical | Systematic | Total |
|---|---|---|---|---|
| R(D) | 423 | 13.0 | (9.6, 1.3) | 16.5 |
| | 5000 | 3.8 | (2.8, 1.3) | 5.2 |
| | 50000 | 1.2 | (0.9, 1.3) | **2.5** |
| R(D*) | 423 | 7.0 | (5.5, 1.3) | 9.0 |
| | 5000 | 2.1 | (1.6, 1.3) | 2.9 |
| | 50000 | 0.7 | (0.5, 1.3) | **1.6** |

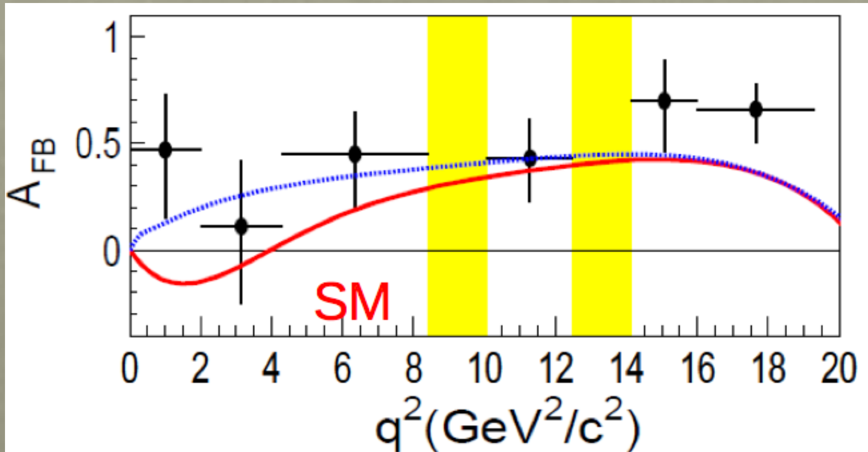
# B → K* l+ l-

- LHC-b will reach a 2% accuracy in the zero crossing of the FB asymmetry $q^2$ distribution in $B \to K^* \mu^+ \mu^-$ decays

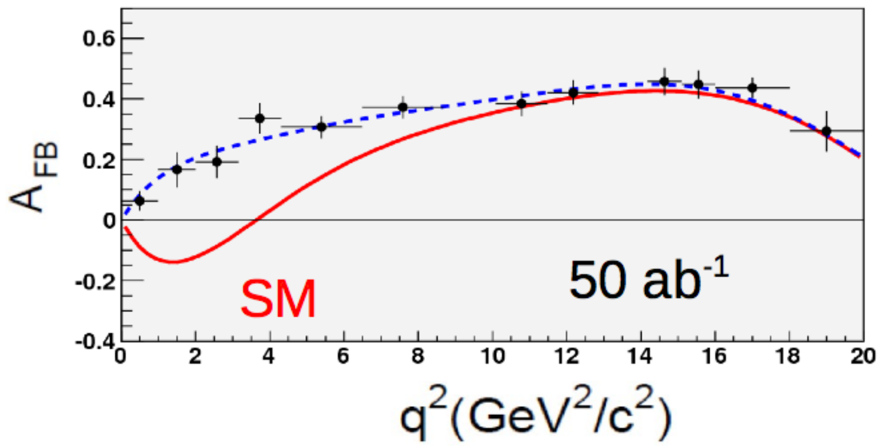



- Belle II: smaller statistics
  - measure $B \to K^* e^+ e^-$
  - Perform an inclusive $B \to X_s l^+ l^-$ analysis

Belle measurement Phys Rev Lett 103 171801 (2009)




Belle II expectation with 50 ab-1



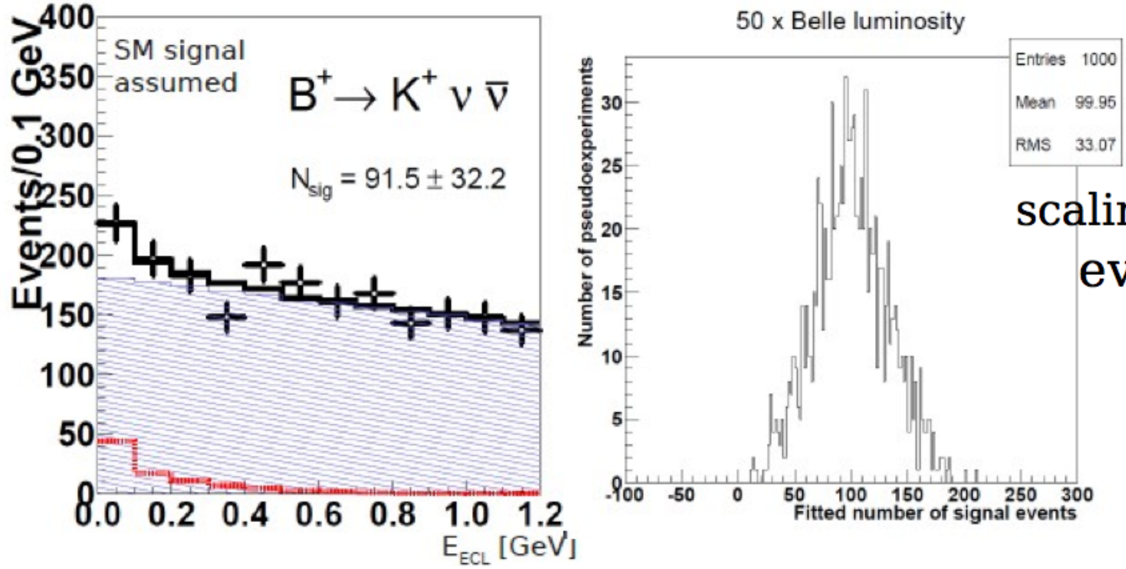
# Inclusive B → X γ

- b → s(d) transitions at quark level with an high energy γ
- Forbidden at tree level in SM, sensitive to charged higgs and new particles in the loop
- Experimental analyses may be on exclusive modes or inclusive.
- Belle/BaBar BR measurements systematically limited except for the tag reconstruction method. Belle II aim at 6% uncertainty.
- CP asymmetry would be new physics. Target Belle II uncertainty $\delta(A_{CP}) = 0.005$

$$A_{CP}(B \to X\gamma) = \frac{N(\overline{B}^0(B^-)\to X\gamma) - N(B^0(B^+)\to X\gamma)}{N(\overline{B}^0(B^-)\to X\gamma) + N(B^0(B^+)\to X\gamma)}$$

## B → h ν ν

- Out of reach of current B-factories. At the edge of the sensitivity also for Belle II.
- Scaling Belle results (with had tag only) we expect 100 $B^+ \to K^+ \nu \nu$, assuming SM BR.
  - 20% accuracy with the full dataset




$B^+ \to K^+ \nu \bar{\nu}$

$N_{sig} \sim 100 \pm 30$

scaling from **new** Belle result

evidence with 50 $ab^{-1}$

(**had.tag only**)

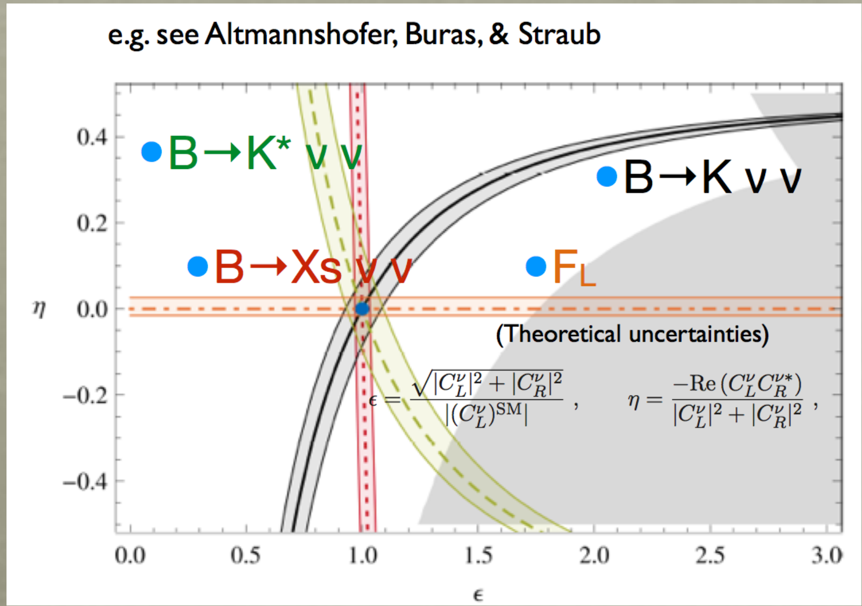
# $B \rightarrow X_s \nu \nu$

- Out of reach of current B-factories. At the edge of the sensitivity also for Belle II.
- Scaling Belle results (with had tag only) we expect 100 $B \rightarrow K^+ \nu \nu$, assuming SM BR.
  - 20% accuracy with the full dataset

- Is $B \rightarrow Xs\ \nu \nu$ possible?
  - Maybe as a sum of exclusive modes

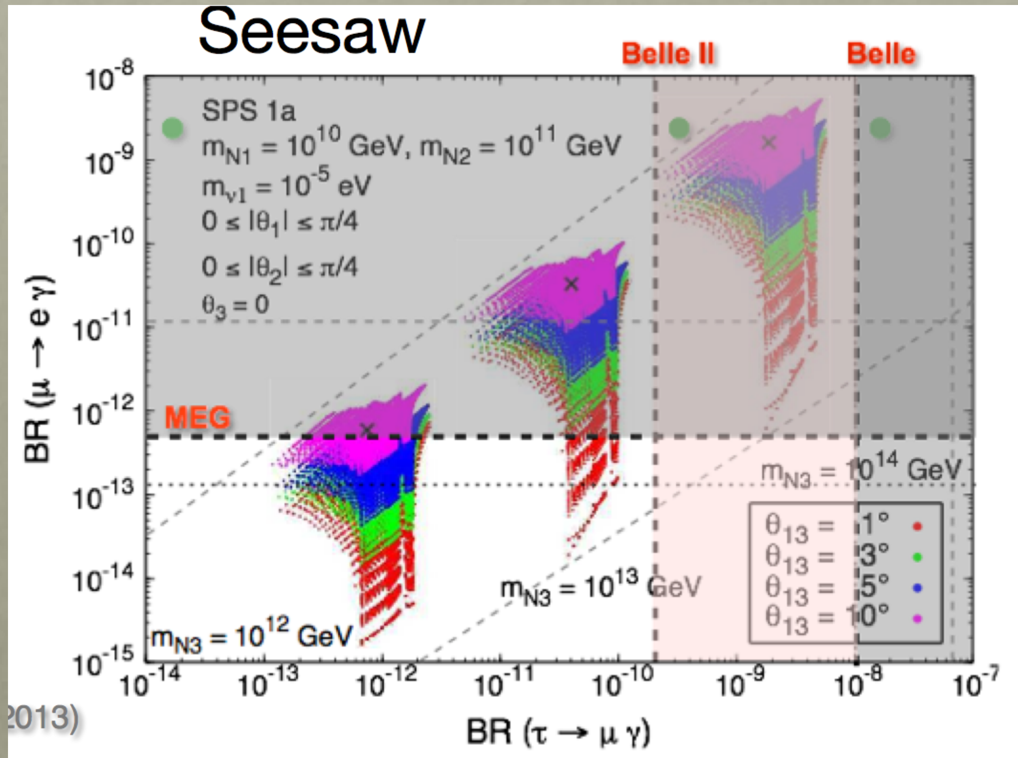
$X_s = K^{\pm}/K_S$ + up to four $\pi$ (at most one $\pi^0$)

[ $K$ ] : $K$, $K_S$
[ $K\pi$ ] : $K\pi$, $K_S\pi$, $K\pi^0$, $K_S\pi^0$
[ $K2\pi$ ] : $K2\pi$, $K_S2\pi$, $K\pi\pi^0$, $K_S\pi\pi^0$
[ $K3\pi$ ] : $K3\pi$, $K_S3\pi$, $K2\pi\pi^0$, $K_S2\pi\pi^0$
[ $K4\pi$ ] : $K4\pi$, $K_S4\pi$, $K3\pi\pi^0$, $K_S3\pi\pi^0$



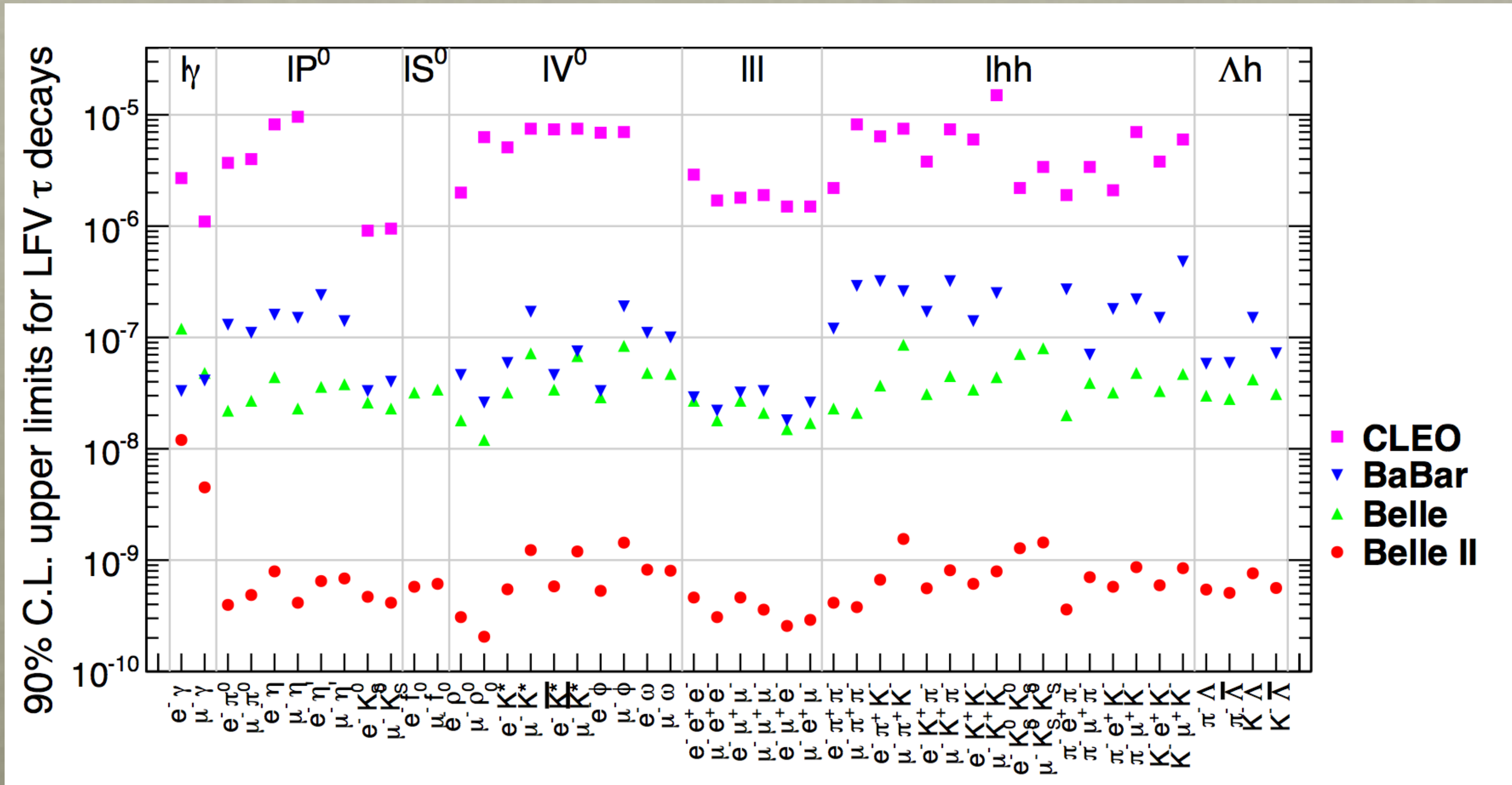
## NP may enhance decays negligible in the SM

- Belle II will collect a huge sample of τ decays
- Will perform a systematic survey of τ physics
- Among the most intersting LFV searches
  - $\tau \to \mu\gamma$
  - $\tau \to 3\mu \,/\, 3e$



# LFV in tau decays

- Almost two order of magnitude improvement expected

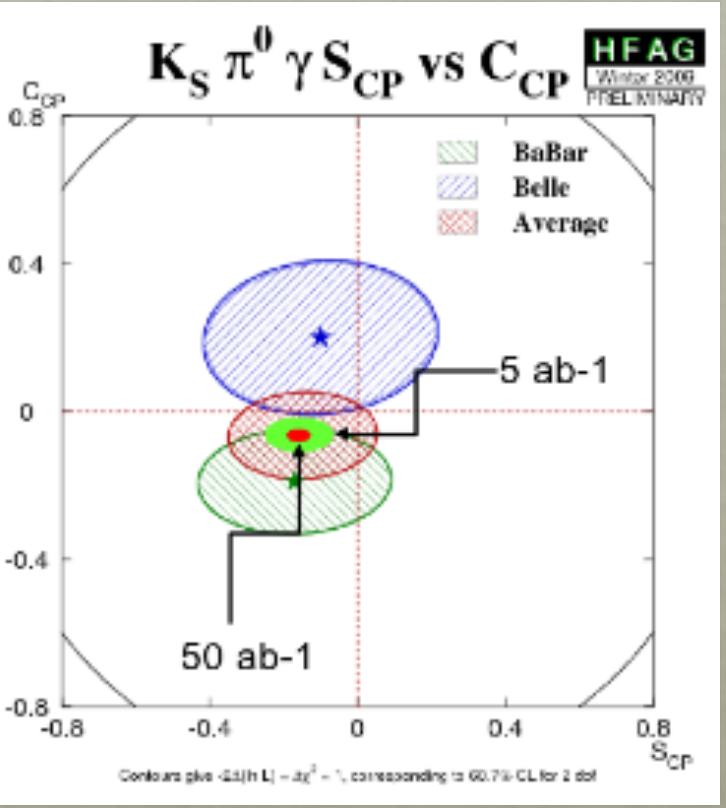


# CP violation

- Time dependent CP asymmetry in $B \rightarrow K^{(*)}\{K_s\pi^0\}\gamma$

$$\mathcal{A}(\Delta t) = S sin(\Delta m \Delta t) + A cos(\Delta m \Delta t)$$

  - SM predicts S = - 0.03
  - Belle II expectation $\sigma_{exp}$ (S) = 0.03 at 50 $ab^{-1}$ (SM level)




- Competitive sensitivity in determination of CKM angle γ with B → D K decays
  - $\sigma_{exp}(\gamma) = 1.5^{o}$ at 50 $ab^{-1}$

# CP violation

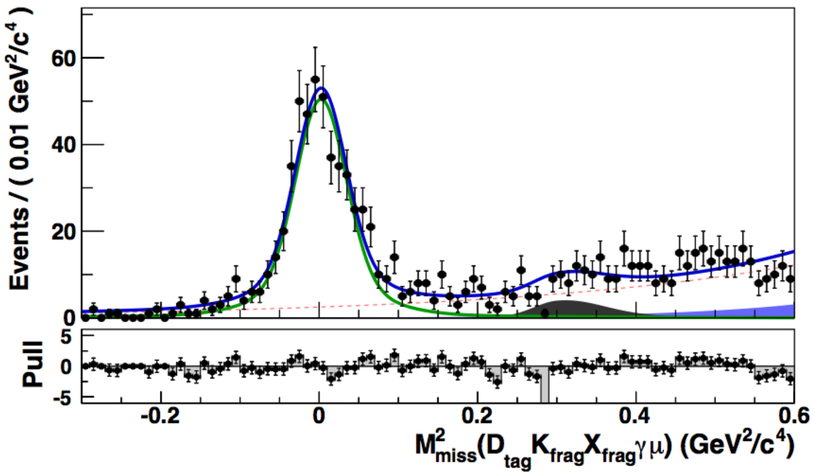
- Belle II can improve up to an order of magnitude the results of BaBar and Belle
  - Expecially relevant for penguin modes
  - Many of them limited by statistics

| Observable | SM theory | Current measurement (early 2013) | Belle II ($50\,\mathrm{ab}^{-1}$) |
|---|---|---|---|
| $S(B \to \phi K^0)$ | 0.68 | $0.56 \pm 0.17$ | $\pm 0.03$ |
| $S(B \to \eta' K^0)$ | 0.68 | $0.59 \pm 0.07$ | $\pm 0.02$ |
| $\alpha$ from $B \to \pi\pi$, $\rho\rho$ | | $\pm 5.4^\circ$ | $\pm 1.5^\circ$ |
| $\gamma$ from $B \to DK$ | | $\pm 11^\circ$ | $\pm 1.5^\circ$ |
| $S(B \to K_S \pi^0 \gamma)$ | $< 0.05$ | $-0.15 \pm 0.20$ | $\pm 0.03$ |
| $S(B \to \rho\gamma)$ | $< 0.05$ | $-0.83 \pm 0.65$ | $\pm 0.15$ |
| $A_{\mathrm{CP}}(B \to X_{s+d}\,\gamma)$ | $< 0.005$ | $0.06 \pm 0.06$ | $\pm 0.02$ |
| $A^d_{\mathrm{SL}}$ | $-5 \times 10^{-4}$ | $-0.0049 \pm 0.0038$ | $\pm 0.001$ |

# Charm Physics

- Based on beam and Recoil tag reconstruction
- Many modes can be studied. Among them
  - $D_s \rightarrow \tau\nu, \mu\nu$
  - $D \rightarrow \nu\nu$ and $\gamma\gamma$ (expected sensitivities $10^{-7}$)

$$e^+e^- \rightarrow c\bar{c} \rightarrow \bar{D}_{\rm tag} X_{\rm frag} D^{(*)}_{\rm recoil}$$




| | Statistical | Systematic reducible | Systematic irreducible | Total |
|---|---|---|---|---|
| $\mathcal{B}(D_s \rightarrow \mu\nu)$ | | | | |
| 913 fb$^{-1}$ | 5.3 | 0.0 | 3.8 | 6.5 |
| 5 ab$^{-1}$ | 2.3 | 1.6 | 0.0-0.9 | 2.9 |
| 50 ab$^{-1}$ | 0.7 | 0.5 | 0.0-0.9 | 0.9-1.3 |
| $\mathcal{B}(D_s \rightarrow \tau\nu)$ | | | | |
| 913 fb$^{-1}$ | 3.7% | 4.4% | 3.5% | 6.8% |
| 5 ab$^{-1}$ | 1.6% | 1.9%-2.3% | 3.5%-2.2% | 3.5%-4.3% |
| 50 ab$^{-1}$ | 0.5% | 0.6%-0.7% | 3.5%-2.2% | 2.3%-3.6% |

# Conclusions

- Belle II Physics program very rich and complementary to LHC-b
  - Unique capabilities of the machine/detector greatly improve the discovery potential
- SuperKEKB upgrade on schedule and will start commissioning at beginning of 2015
- Belle II construction and integration on-going. We expect to roll in late 2016 for first physics run.

# BACKUP

| Observables | Belle (2014) | Belle II 5 $ab^{-1}$ | Belle II 50 $ab^{-1}$ |
|---|---|---|---|
| $\sin 2\beta$ | $0.667 \pm 0.023 \pm 0.012$ | $\pm 0.012$ | $\pm 0.008$ |
| $\alpha$ | | $\pm 2^\circ$ | $\pm 1^\circ$ |
| $\gamma$ | $\pm 14^\circ$ | $\pm 6^\circ$ | $\pm 1.5^\circ$ |
| $S(B \to \phi K^0)$ | $0.90^{+0.09}_{-0.19}$ | $\pm 0.053$ | $\pm 0.018$ |
| $S(B \to \eta' K^0)$ | $0.68 \pm 0.07 \pm 0.03$ | $\pm 0.028$ | $\pm 0.011$ |
| $S(B \to K^0_S K^0_S K^0_S)$ | $0.30 \pm 0.32 \pm 0.08$ | $\pm 0.100$ | $\pm 0.033$ |
| $\|V_{cb}\|$ incl. | $\pm 2.4\%$ | $\pm 1.0\%$ | |
| $\|V_{cb}\|$ excl. | $\pm 3.6\%$ | $\pm 1.8\%$ | $\pm 1.4\%$ |
| $\|V_{ub}\|$ incl. | $\pm 6.5\%$ | $\pm 3.4\%$ | $\pm 3.0\%$ |
| $\|V_{ub}\|$ excl. (had. tag.) | $\pm 10.8\%$ | $\pm 4.7\%$ | $\pm 2.4\%$ |
| $\|V_{ub}\|$ excl. (untag.) | $\pm 9.4\%$ | $\pm 4.2\%$ | $\pm 2.2\%$ |
| $\mathcal{B}(B \to \tau\nu)$ $[10^{-6}]$ | $96 \pm 26$ | $\pm 10\%$ | $\pm 3\%$ |
| $\mathcal{B}(B \to \mu\nu)$ $[10^{-6}]$ | $< 1.7$ | $5\sigma$ | $>> 5\sigma$ |
| $R(D\tau\nu)$ | $\pm 16.5\%$ | $\pm 5.2\%$ | $\pm 2.5\%$ |
| $R(D^*\tau\nu)$ | $\pm 9.0\%$ | $\pm 2.9\%$ | $\pm 1.6\%$ |
| $\mathcal{B}(B \to K^{*+}\nu\overline{\nu})$ $[10^{-6}]$ | $< 40$ | | $\pm 30\%$ |
| $\mathcal{B}(B \to K^{+}\nu\overline{\nu})$ $[10^{-6}]$ | $< 55$ | | $\pm 30\%$ |
| $\mathcal{B}(B \to X_s\gamma)$ $[10^{-6}]$ | $\pm 13\%$ | $\pm 7\%$ | $\pm 6\%$ |
| $A_{CP}(B \to X_s\gamma)$ | | $\pm 0.01$ | $\pm 0.005$ |
| $S(B \to K^0_S \pi^0 \gamma)$ | $-0.10 \pm 0.31 \pm 0.07$ | $\pm 0.11$ | $\pm 0.035$ |
| $\mathcal{B}(B \to X_d\gamma)$ $[10^{-6}]$ | | | |
| $S(B \to \rho\gamma)$ | $-0.83 \pm 0.65 \pm 0.18$ | $\pm 0.23$ | $\pm 0.07$ |
| $\mathcal{B}(B_s \to \gamma\gamma)$ $[10^{-6}]$ | $< 8.7$ | $\pm 0.3$ | |
| $\mathcal{B}(B_s \to \tau^+\tau^-)$ $[10^{-3}]$ | | $< 2$ | |
| $\mathcal{B}(D_s \to \mu\nu)$ | $5.31 \times 10^{-3}(1 \pm 0.053 \pm 0.038)$ | $\pm 2.9\%$ | $\pm(0.9\%$-$1.3\%)$ |
| $\mathcal{B}(D_s \to \tau\nu)$ | $5.70 \times 10^{-3}(1 \pm 0.037 \pm 0.054)$ | $\pm(3.5\%$-$4.3\%)$ | $\pm(2.3\%$-$3.6\%)$ |
| $y_{CP}$ $[10^{-2}]$ | $1.11 \pm 0.22 \pm 0.11$ | $\pm(0.11$-$0.13)$ | $\pm(0.05$-$0.08)$ |
| $A_\Gamma$ $[10^{-2}]$ | $-0.03 \pm 0.20 \pm 0.08$ | $\pm 0.10$ | $\pm(0.03$-$0.05)$ |
| $A_{CP}^{K^+K^-}$ $[10^{-2}]$ | $-0.32 \pm 0.21 \pm 0.09$ | $\pm 0.11$ | $\pm 0.06$ |
| $A_{CP}^{\pi^+\pi^-}$ $[10^{-2}]$ | $0.55 \pm 0.36 \pm 0.09$ | $\pm 0.17$ | $\pm 0.06$ |
| $A_{CP}^{\phi\gamma}$ $[10^{-2}]$ | $\pm 5.6$ | $\pm 2.5$ | $\pm 0.8$ |
| $\tau \to \mu\gamma$ $[10^{-8}]$ | $< 4.5$ | | $< 0.1$ |
| $\tau \to e\gamma$ $[10^{-8}]$ | $< 12.0$ | | |
| $\tau \to \mu\mu\mu$ $[10^{-9}]$ | $< 21.0$ | $< 4.5$ | $< 0.9$ |