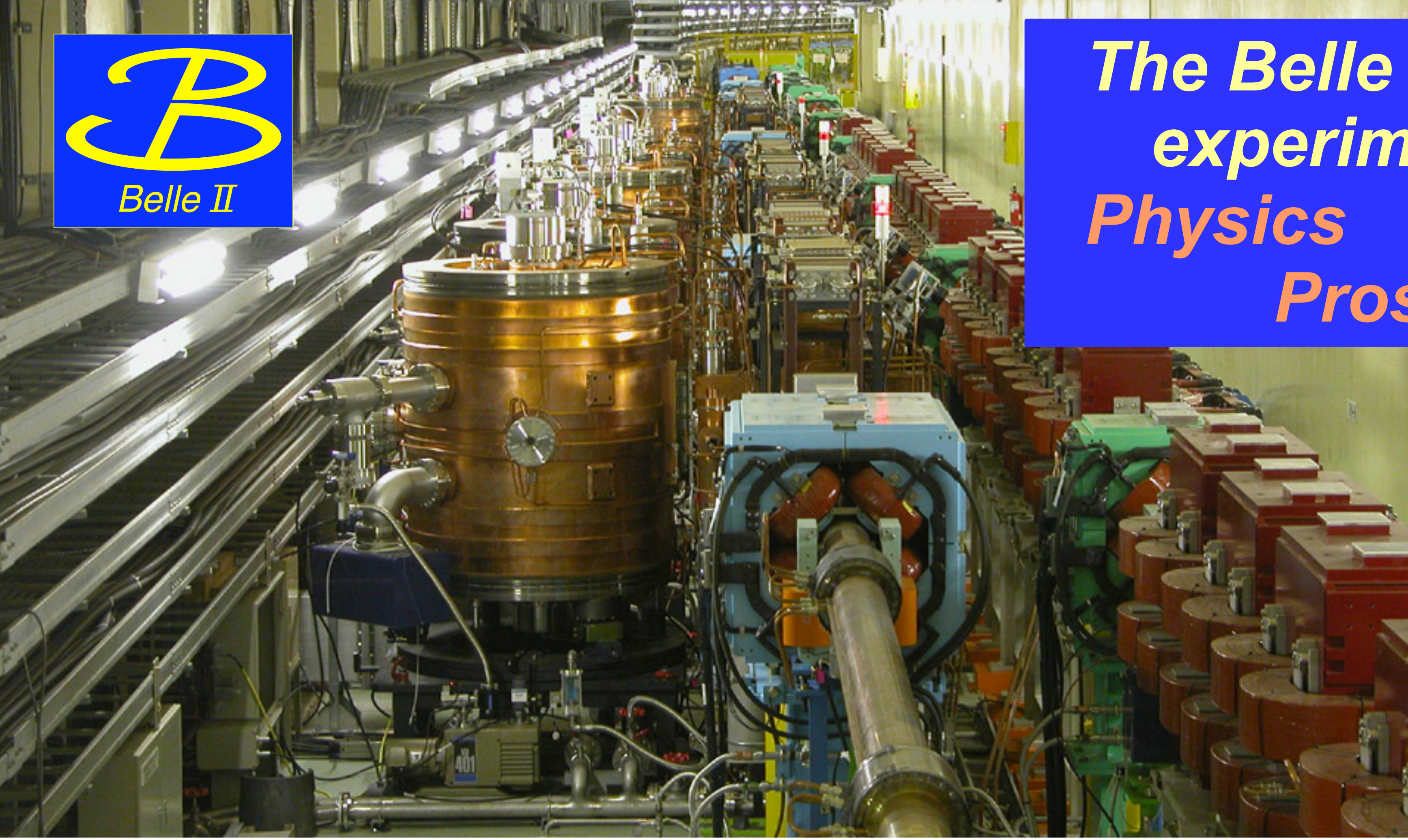

The Belle II experiment: Physics Prospects

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12th Workshop on Flavour Physics and CP Violation
29 May 2014
Marseille, France

- *motivation*
- *upgrading Belle/KEKB → Super B Factory*
- *physics program*
- *projected sensitivities*
- *detector/accelerator status*

Motivation:

Why a flavor factory in the LHC Era?

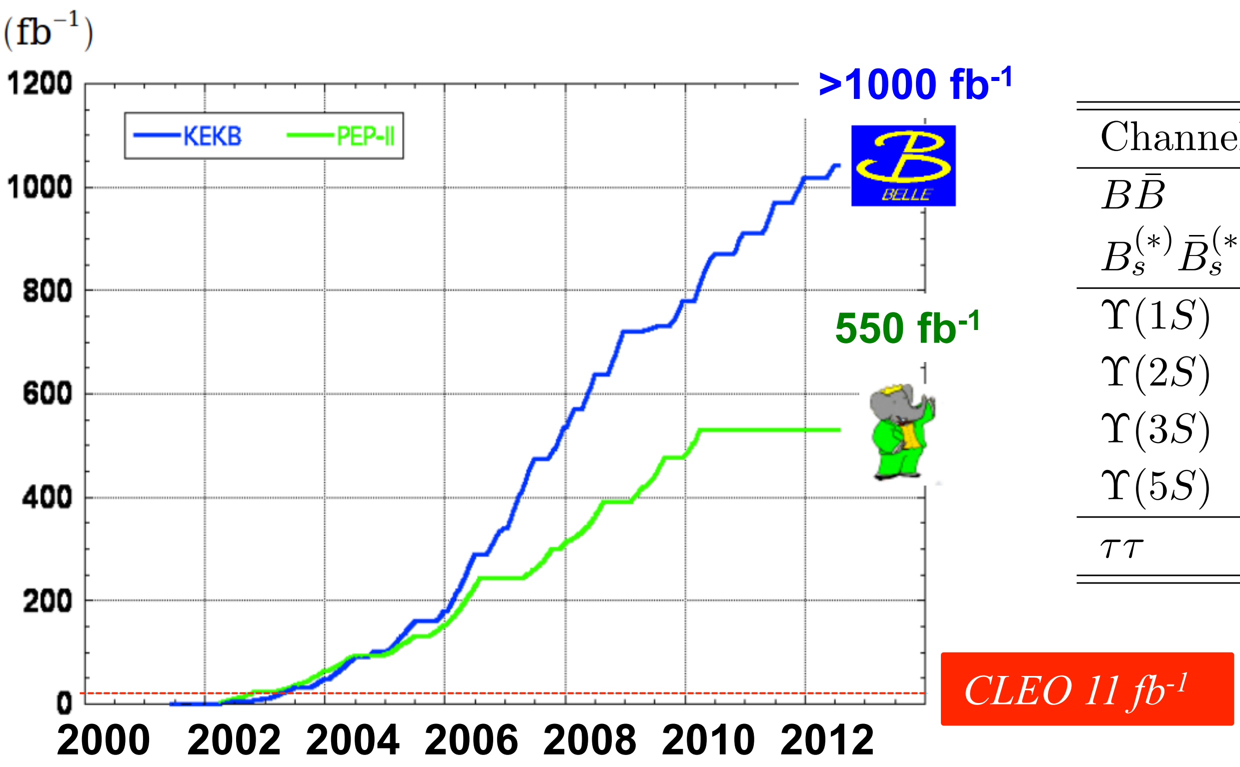
- *A flavor factory studies processes that occur at 1-loop in the SM but may be O(1) in NP: FCNC, neutral meson mixing, CP violation. These loops probe energy scales that cannot be accessed directly (even at the LHC).*
- *If supersymmetry is found at the LHC, a crucial question will be: how is it broken. By studying flavor couplings, a flavor factory can address this.*

A (super) flavor factory searches for NP by phases, CP asymmetries, inclusive decay processes, rare leptonic decays, absolute branching fractions. There is a wide range of observables with which to confront theory.

Why an e^+e^- Machine?

- *Low backgrounds, high trigger efficiency, excellent γ and π^0 recontruction (and thus η, η', ρ+, etc. reconstruction), high flavor-tagging efficiency with low dilution, many control samples to study systematics*
- *Due to low backgrounds, negligible trigger bias, and good kinematic resolutions, Dalitz plots analyses are straightforward. Absolute branching fractions can be measured. Missing energy and missing mass analyses are straightforward.*
- *systematics quite different from those at LHCb. If true NP is seen by one of the experiments, confirmation by the other would be important.*

The Belle + BaBar Era



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}

Belle-II Goal: *40 x present = 4 x 10^{10} BB pairs* ***...but how to do it?***

How to achieve $L \sim 10^{36}$? Super-KEKB

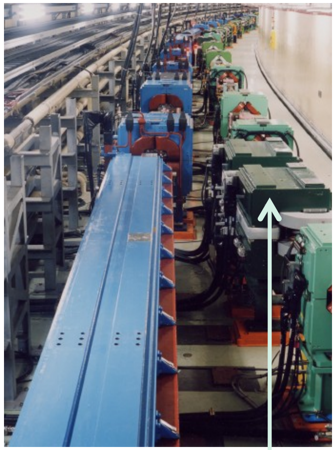
$$L = \frac{\gamma_\pm}{2er_e}\left(1+\frac{\sigma_y^*}{\sigma_x^*}\right)\frac{I_\pm \xi_{y\pm}}{\beta_{y\pm}^*}\left(\frac{R_L}{R_{\xi_y}}\right)$$

- Lorentz factor ($\gamma_\pm$)
- Beam current ($I_\pm$)
- Beam-Beam parameter ($\xi_{y\pm}$)
- Geometrical reduction factors (crossing angle, hourglass effect) (R_L/R_{ξ_y}) ***(0.8-1.0)***
- Vertical beta function at IP ($\beta_{y\pm}^*$)
- Beam aspect ratio at IP (σ_y^*/σ_x^*) ***(0.01-0.02)***

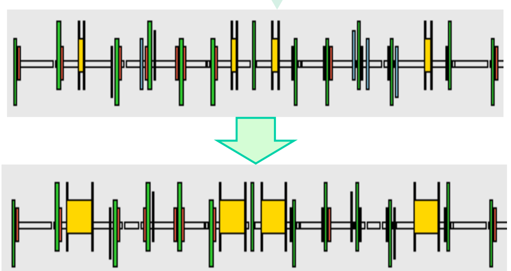
Two options considered:	I (current) (amps)	β_y (mm)	ξ
KEKB achieved	1.8/1.45	6.5/5.9	0.11/0.06
High current	9.4/4.1	3/6	0.3/0.51
→ chosen: Nano-beam (Raimondi for SuperB)	3.6/2.6	0.27/0.30	0.09/0.08

beam size: *100 μm(H) x 2 μm(V) → 10 μm(H) x 59 nm(V)*

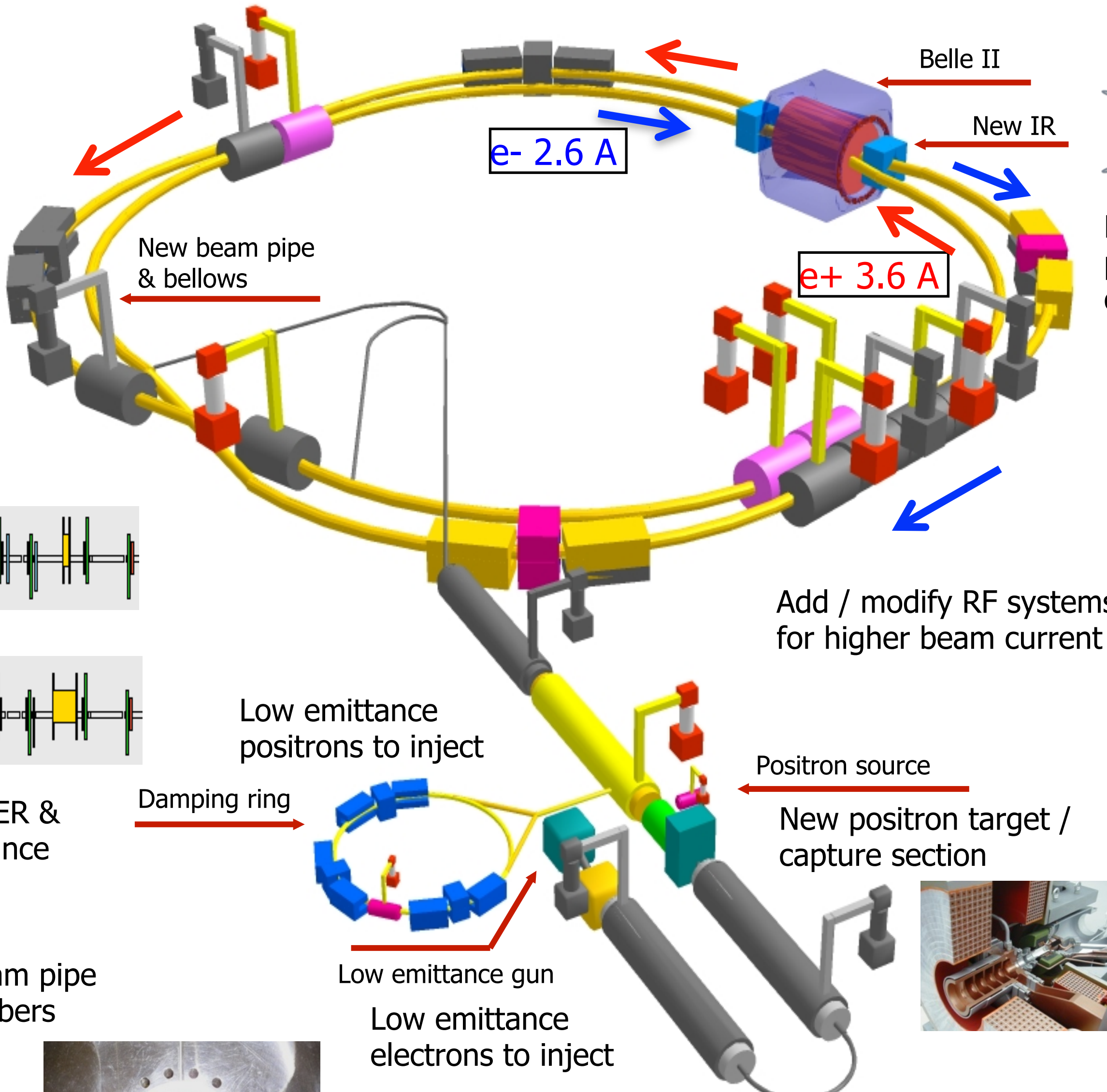
KEKB → SuperKEKB (nano-beam)



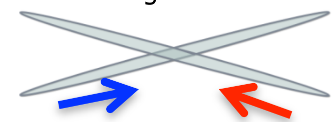
Replace short dipoles with longer ones (LER)



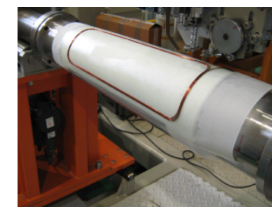
Redesign the lattices of HER & LER to squeeze the emittance



Colliding bunches



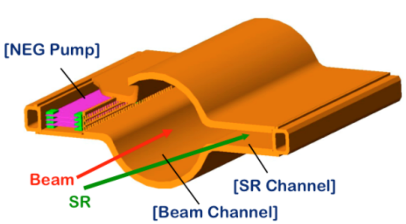
New superconducting / permanent final focusing quads near the IP

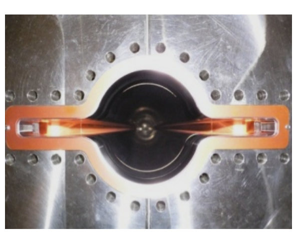


Add / modify RF systems for higher beam current

New positron target / capture section

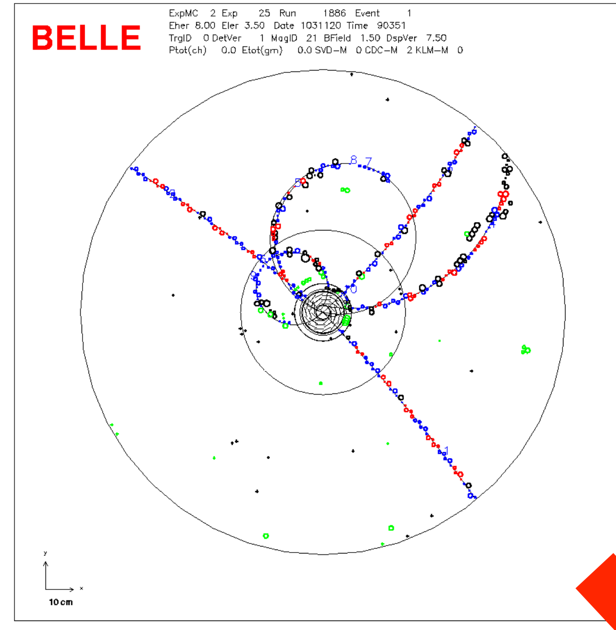
TiN-coated beam pipe with antechambers





To get 40x higher luminosity

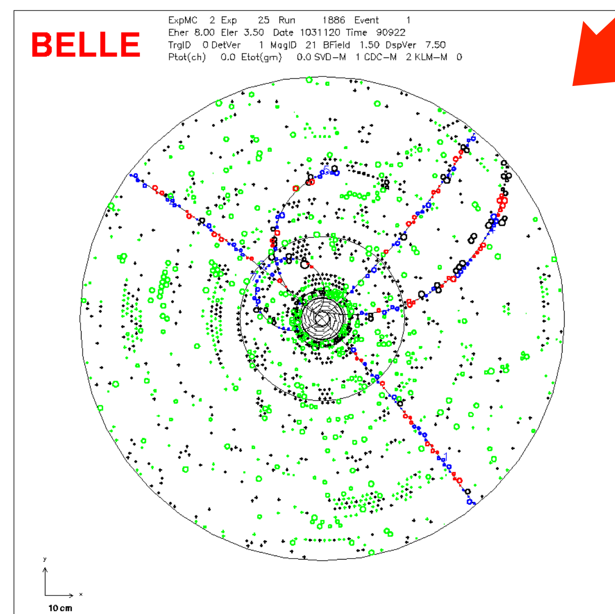
Detector Upgrade:



Challenges:

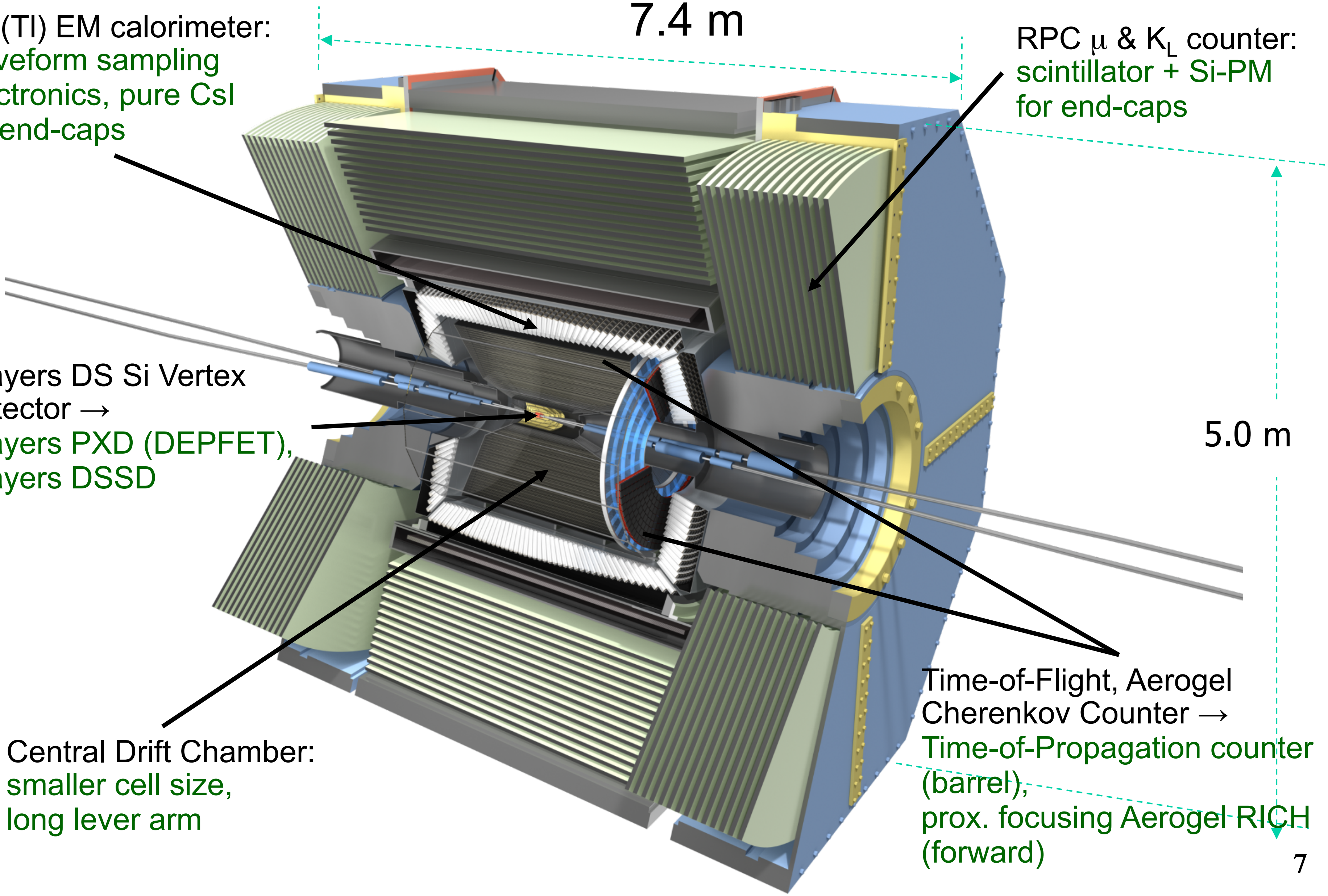
Higher background (×20), higher event rate (×10)
- radiation damage and occupancy
- fake hits and pile-up noise in the EM

Targeted improvements:
- Increase hermiticity
- Increase K_S efficiency
- Improve IP and secondary vertex resolution
- Improve π/K separation
- Improve π^0 efficiency
- Add PID in endcaps
- Add μ ID in endcaps



Detector Choices:
- SVD: 4 DSSD lyrs → 2 DEPFET lyrs + 4 DSSD lyrs
- CDC: small cell, long lever arm
- ACC+TOF → imaging "TOP"+Aerogel RICH
- ECL: waveform sampling
- KLM: RPC → Scintillator +SiPM (end-caps)

The Belle II Detector:



7

Broad Physics Program I:

arXiv:1002.5012 (Belle II)
see also: arXiv:1008.1541 (SuperB)

errors.

	Observables	Belle (2014)	Belle II 5 ab^{-1}	Belle II 50 ab^{-1}
UT angles	$\sin 2\beta$	$0.667 \pm 0.023 \pm 0.012$ [64]	0.012	0.008
	α [°]	85 ± 4 (Belle+BaBar) [24]	2	1
	γ [°]	68 ± 14 [13]	6	1.5
Gluonic penguins	$S(B \to \phi K^0)$	$0.90^{+0.09}_{-0.19}$ [19]	0.053	0.018
	$S(B \to \eta' K^0)$	$0.68 \pm 0.07 \pm 0.03$ [65]	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
	$\mathcal{A}(B \to K^0 \pi^0)$	$-0.05 \pm 0.14 \pm 0.05$ [66]	0.07	0.04
UT sides	$\|V_{cb}\|$ incl.	$41.6 \cdot 10^{-3}(1 \pm 1.8\%)$ [8]	1.2%	
	$\|V_{cb}\|$ excl.	$37.5 \cdot 10^{-3}(1 \pm 3.0\%_{\rm ex.} \pm 2.7\%_{\rm th.})$ [10]	1.8%	1.4%
	$\|V_{ub}\|$ incl.	$4.47 \cdot 10^{-3}(1 \pm 6.0\%_{\rm ex.} \pm 2.5\%_{\rm th.})$ [5]	3.4%	3.0%
	$\|V_{ub}\|$ excl. (had. tag.)	$3.52 \cdot 10^{-3}(1 \pm 8.2\%)$ [7]	4.7%	2.4%
Missing E decays	$\mathcal{B}(B \to \tau\nu)$ [10^{-6}]	$96(1 \pm 27\%)$ [26]	10%	3%
	$\mathcal{B}(B \to \mu\nu)$ [10^{-6}]	< 1.7 [67]	20%	7%
	$R(B \to D\tau\nu)$	$0.440(1 \pm 16.5\%)$ [29]†	5.2%	2.5%
	$R(B \to D^*\tau\nu)^\dagger$	$0.332(1 \pm 9.0\%)$ [29]†	2.9%	1.6%
	$\mathcal{B}(B \to K^{*+}\nu\bar{\nu})$ [10^{-6}]	< 40 [30]	< 15	30%
	$\mathcal{B}(B \to K^{+}\nu\bar{\nu})$ [10^{-6}]	< 55 [30]	< 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}]	$2.2 \pm 4.0 \pm 0.8$ [68]	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% [36]	10%	5%
	$\mathcal{B}(B_s \to \gamma\gamma)$ [10^{-6}]	< 8.7 [42]	0.3	–
	$\mathcal{B}(B_s \to \tau\tau)$ [10^{-3}]	–	< 2 [44]‡	–

covered in this talk

Broad Physics Program II: arXiv:1002.5012 (Belle II)

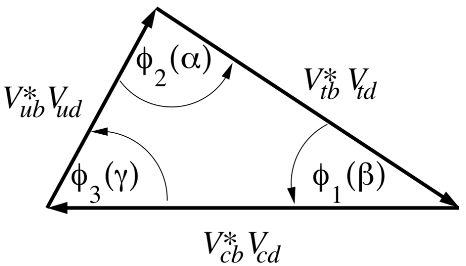
	Observables	Belle (2014)	Belle II 5 ab^{-1}	Belle II 50 ab^{-1}
Charm Rare	$\mathcal{B}(D_s \to \mu\nu)$	$5.31 \cdot 10^{-3}(1 \pm 5.3\% \pm 3.8\%)$ [46]	2.9%	0.9%
	$\mathcal{B}(D_s \to \tau\nu)$	$5.70 \cdot 10^{-3}(1 \pm 3.7\% \pm 5.4\%)$ [46]	3.5%	3.6%
	$\mathcal{B}(D^0 \to \gamma\gamma)$ [10^{-6}]	< 1.5 [49]	30%	25%
Charm CP	$A_{CP}(D^0 \to K^+K^-)$ [10^{-2}]	$-0.32 \pm 0.21 \pm 0.09$ [69]	0.11	0.06
	$A_{CP}(D^0 \to \pi^0\pi^0)$ [10^{-2}]	$-0.03 \pm 0.64 \pm 0.10$ [70]	0.29	0.09
	$A_{CP}(D^0 \to K_S^0\pi^0)$ [10^{-2}]	$-0.21 \pm 0.16 \pm 0.09$ [70]	0.08	0.03
Charm Mixing	$x(D^0 \to K_S^0\pi^+\pi^-)$ [10^{-2}]	$0.56 \pm 0.19 \pm {}^{0.07}_{0.13}$ [52]	0.14	0.11
	$y(D^0 \to K_S^0\pi^+\pi^-)$ [10^{-2}]	$0.30 \pm 0.15 \pm {}^{0.05}_{0.08}$ [52]	0.08	0.05
	$\lvert q/p\rvert(D^0 \to K_S^0\pi^+\pi^-)$	$0.90 \pm {}^{0.16}_{0.15} \pm {}^{0.08}_{0.06}$ [52]	0.10	0.07
	$\phi(D^0 \to K_S^0\pi^+\pi^-)$ [$^\circ$]	$-6 \pm 11 \pm {}^{4}_{5}$ [52]	6	4
Tau	$\tau \to \mu\gamma$ [10^{-9}]	< 45 [71]	< 4.6	< 0.5
	$\tau \to e\gamma$ [10^{-9}]	< 120 [71]	< 12	< 1.2
	$\tau \to \mu\mu\mu$ [10^{-9}]	< 21.0 [72]	< 4.5	< 0.5

+ rare D decays, D_{sJ}/X/Y/Z studies, additional B_s studies at Υ(5S), etc.

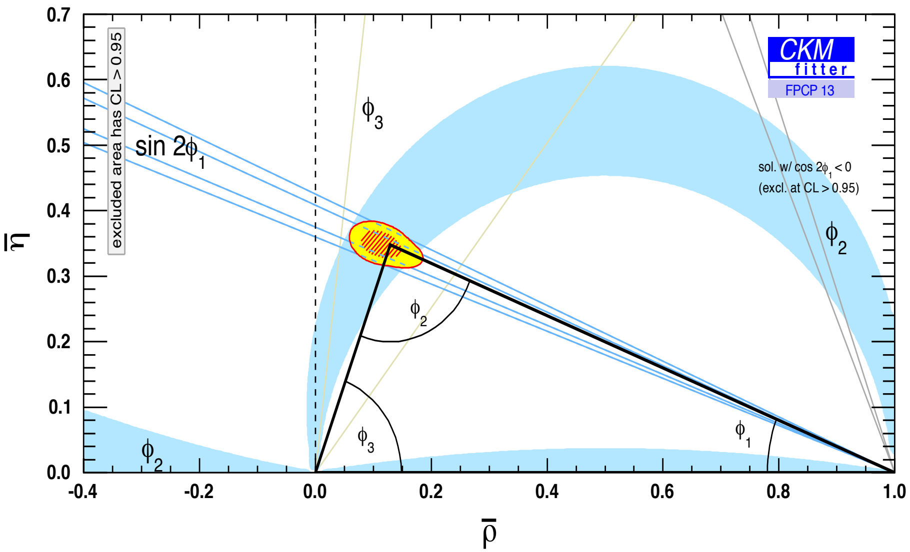
Constraining the CKM Unitarity Triangle:

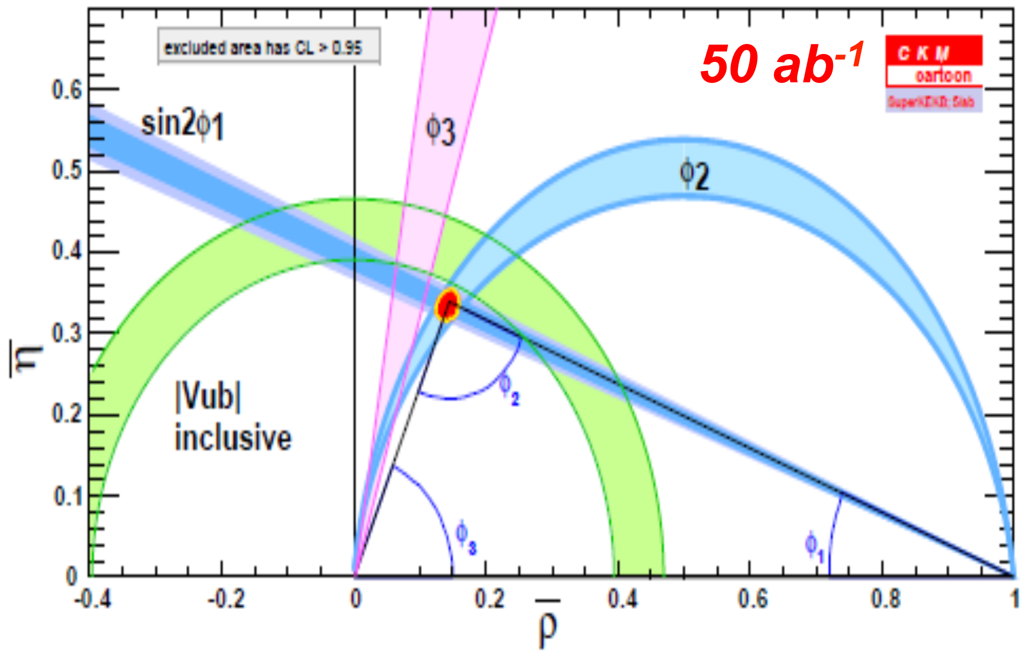
A main physics goal is to substantially reduce the uncertainties on the CKM UT triangle

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

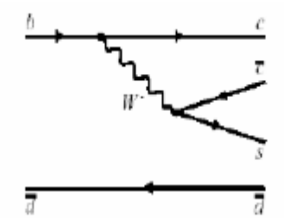


1.2 ab⁻¹

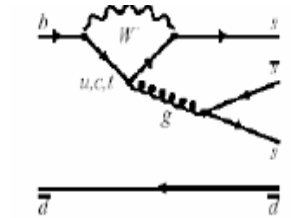




Comparing Tree and Penguin ϕ_1 (β)

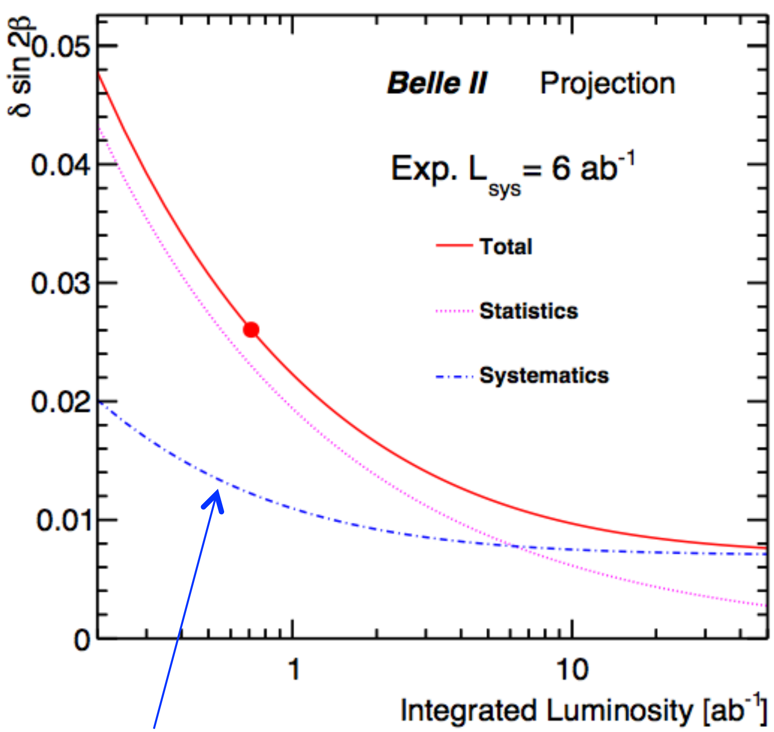


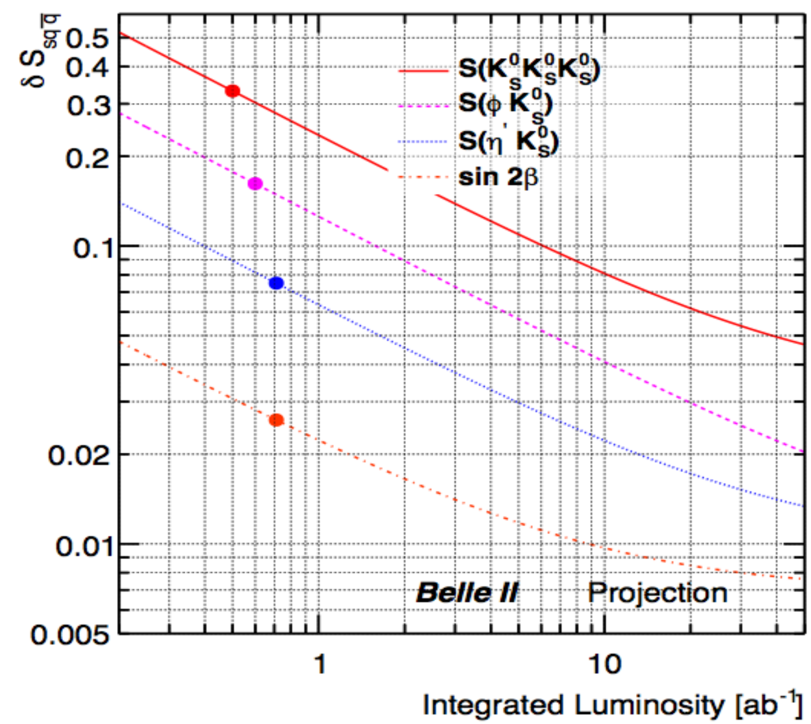
$B^0 \to J/\psi\, K^0$



$B^0 \to \phi\, K^0$
$B^0 \to \eta'\, K^0$
$B^0 \to K^0 K^0 K^0$

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





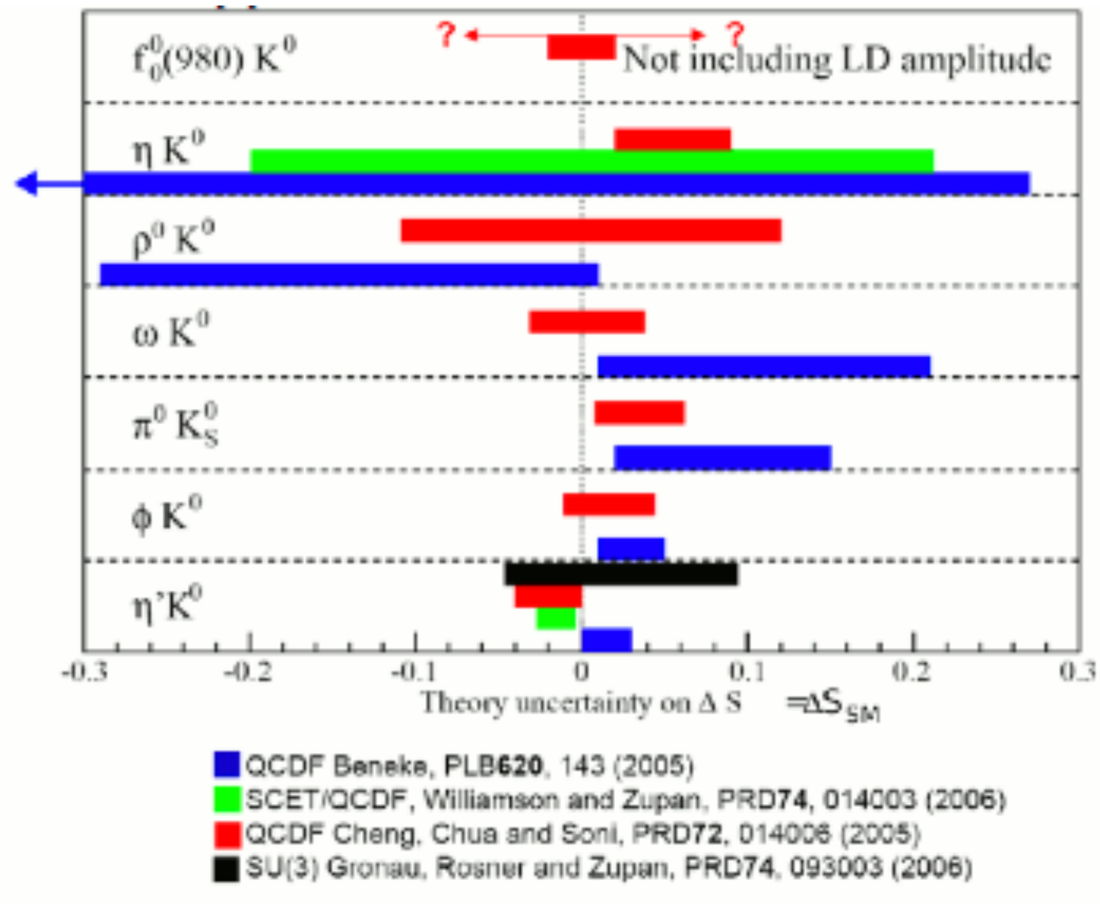
dominated by vertex resolution, which will improve: 61 → ~18 μm

Prospect $\delta(S_{b\to s}) \sim 0.012$ @ 50ab^{-1}

Comparing Tree and Penguin ϕ_1 (β)

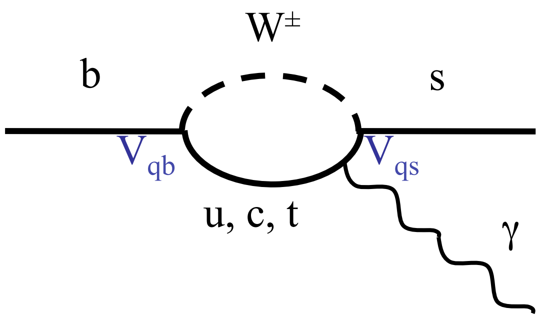
Prospect	$\delta(S_{b\to s})$ ~ 0.012 @ 50ab^{-1}

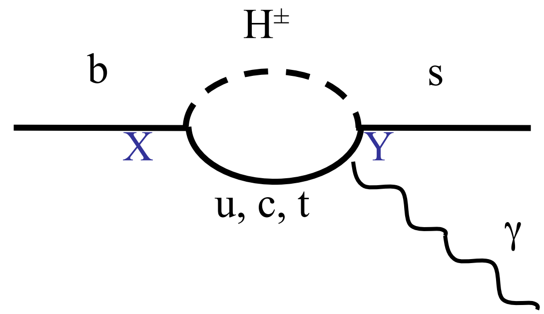
This precision is good enough to distinguish different theory models



Radiative decays $b \to s\gamma$, $b \to d\gamma$ plus $b \to sl^+l^-$

1-loop suppressed in SM ⇒ esp. sensitive to NP:





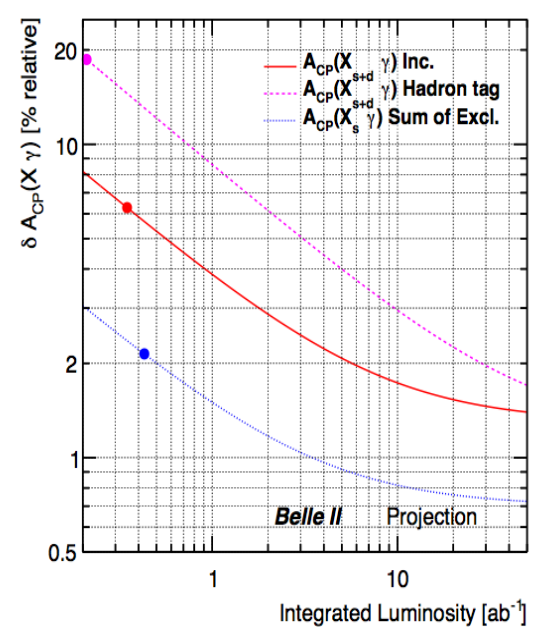
Many observables that probe new physics:

(inclusive: John Walsh's talk
exclusive: A. Ishikawa's talk)

- *inclusive $B \to X_s\gamma$, $B \to X_d\gamma$, and $B \to X_s l^+l^-$ branching fractions*
- *forward-backwards asymmetry and q^2 dependence in $B \to X_s l^+l^-$*
- *direct CPV in $B \to X_s\gamma$*

- *exclusive $B \to K^*\gamma$ and $B \to \rho\gamma$ branching fractions*
- *forward-backwards asymmetry and q^2 dependence in $B \to K^* l^+l^-$*
- *direct CPV in $B^+ \to K^{*+}\gamma$*
- *time-dependent CPV in $B^0 \to K^{*0}\gamma$, $B^0 \to \rho^0\gamma$*

- *photon polarization with photon conversion*
- *lepton flavor dependence in $b \to sl^+l^-$*

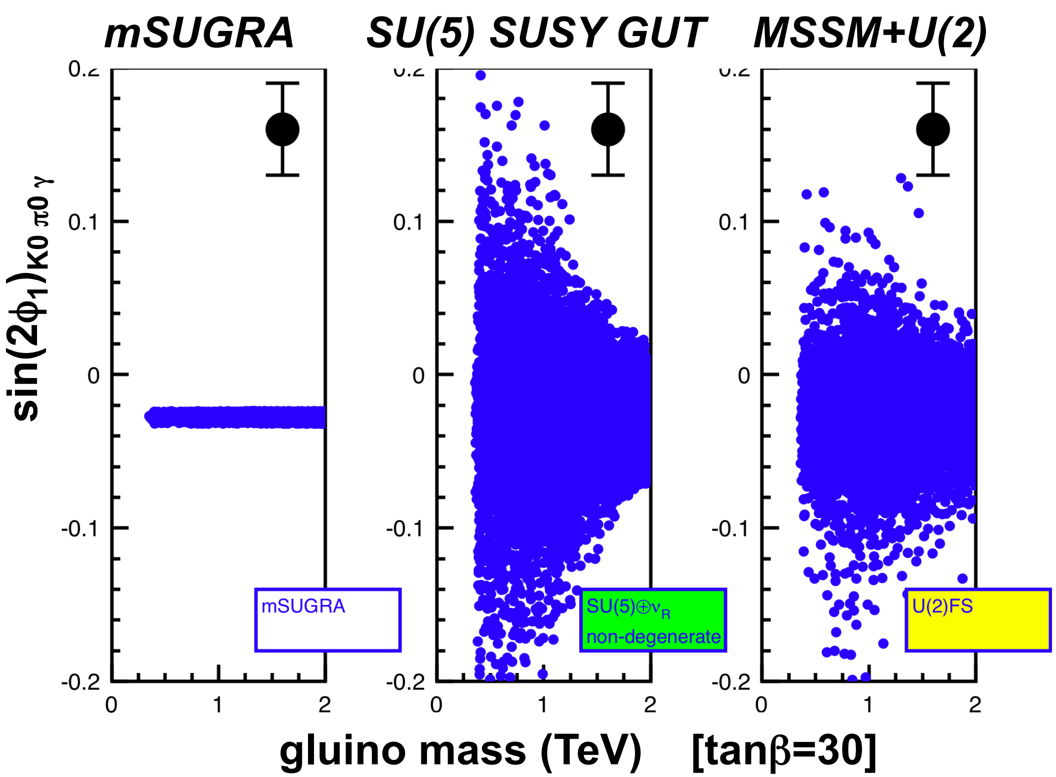


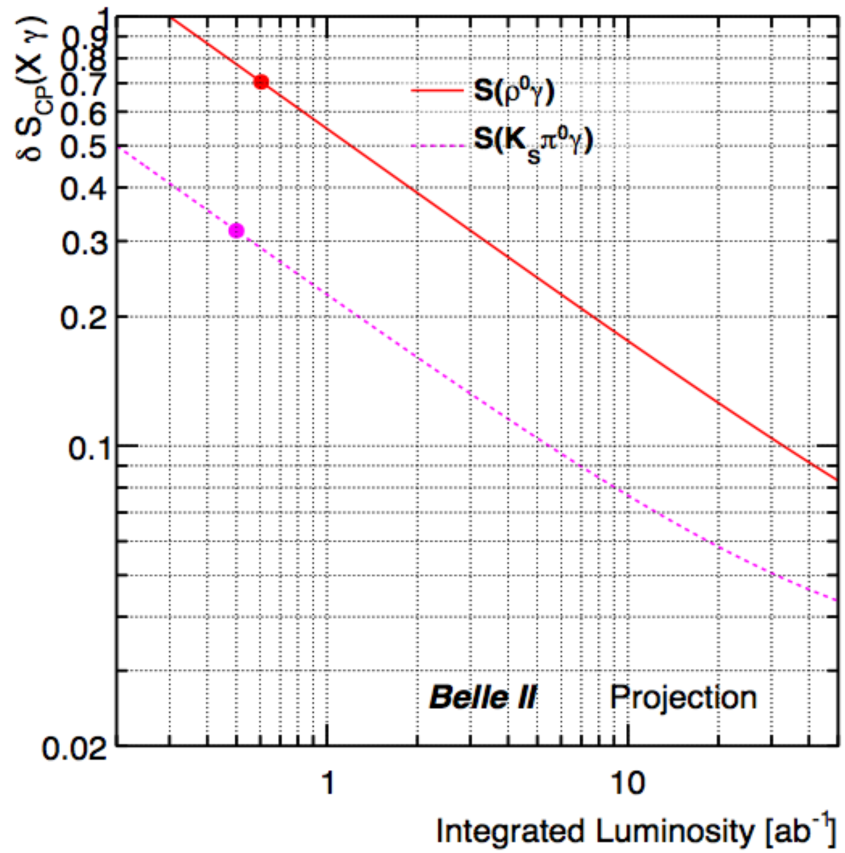
Example: mixing induced CPV in $B \to K_s \pi^0 \gamma$

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

- *value of S sensitive to NP, S~ -0.03 -0.5*
- *value of S can discriminate among SUSY-breaking mechanisms*

Buchalla et al., EPJC 57, 309 (2008); arXiv:0801.1833





Constraining a charged Higgs via $B \to X_s\gamma$

2 Higgs doublet models:

Type II charged Higgs amplitude constructively interferes with SM amplitude, raising BR

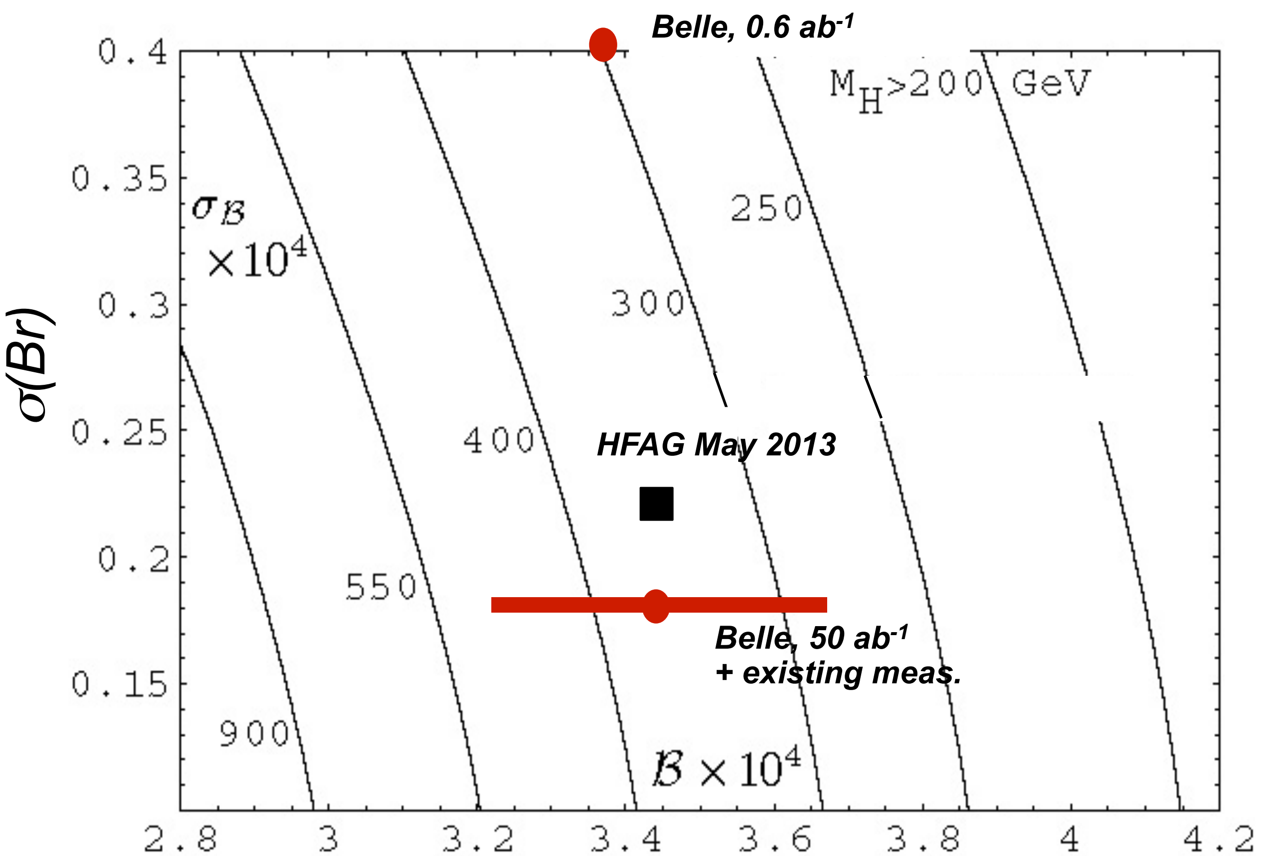
⇒ 95% C.L. lower limit on m(H±), all tanβ

Misiak et al., PRL 98, 022002 (2007)

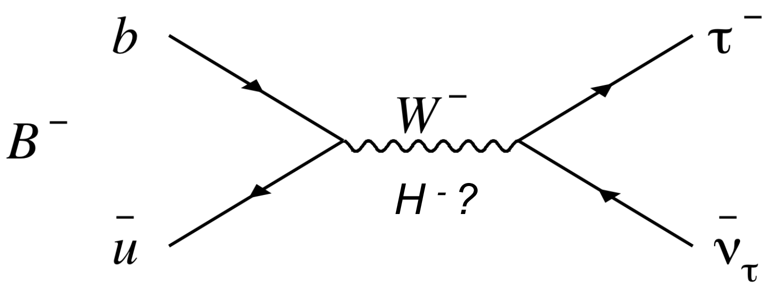
Type	λ_{UU}	λ_{DD}	λ_{LL}
I	$1/\tan\beta$	$1/\tan\beta$	$1/\tan\beta$
II	$1/\tan\beta$	$-\tan\beta$	$-\tan\beta$
III	$1/\tan\beta$	$-\tan\beta$	$1/\tan\beta$
IV	$1/\tan\beta$	$1/\tan\beta$	$-\tan\beta$

Current HFAG WA
$\mathcal{B}(B \to X_s\gamma) = (3.43 \pm 0.22) \times 10^{-4}$
⇒
$m_{H+} > 350$ GeV (95% CL) for all tanβ

Belle II can potentially improve this to $m_{H+} > 500$ GeV
(depending on central value)



Constraining a charged Higgs via $B^+ \to \tau^+\nu$



Hara et al., PRD 82, 071101(R) (2010)
[605 fb^{-1} , semilept tag]] (3.6σ evidnce)
Hara et al., PRL 110 131801 (2013)
[772 fb^{-1} , full recon tag] (3.0σ evidnce)

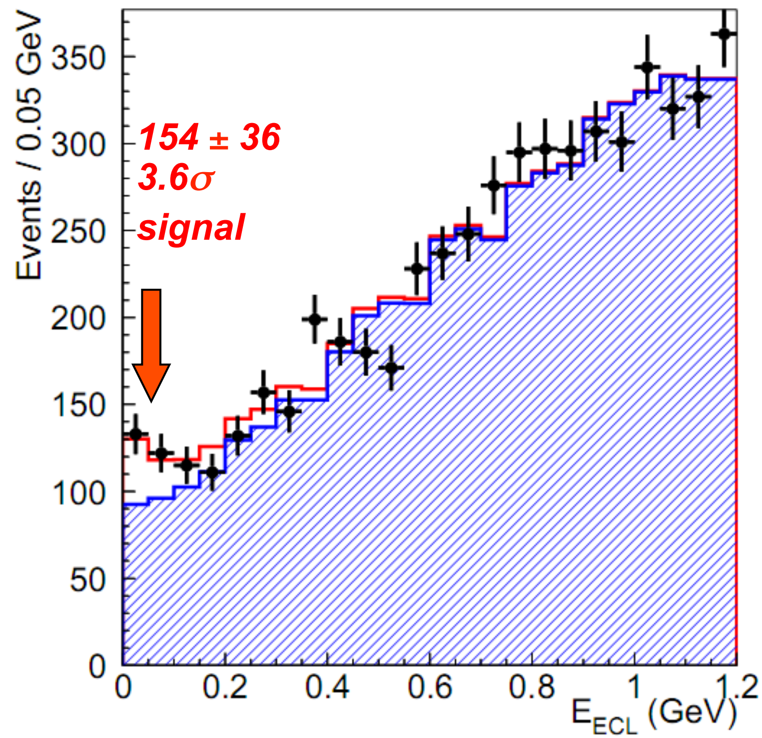
Aubert et al., PRD 77 011107(R)(2008); PRD 81, 051101(R), 2010
[418 fb^{-1}] (2.8σ excess)

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

Very challenging to isolate: two ν's in final state.

- *use fully reconstructed hadronic and semileptonic decays on tagging side*

- *signal side is $\tau \to \mu\nu\nu$, $e\nu\nu$, $\pi\nu$ (1 charged track). Yield is obtained by fitting the ECL (electromagnetic calorimeter energy) distribution: peak near zero indicates $\tau \to \ell\nu\nu$, $\pi\nu$ decay.*



$\mathcal{B}(B \to \tau^+\nu) = (1.14 \pm 0.22) \times 10^{-4}$ (HFAG 2013)

Measuring a charged Higgs: $B^+ \to \tau^+ \nu$

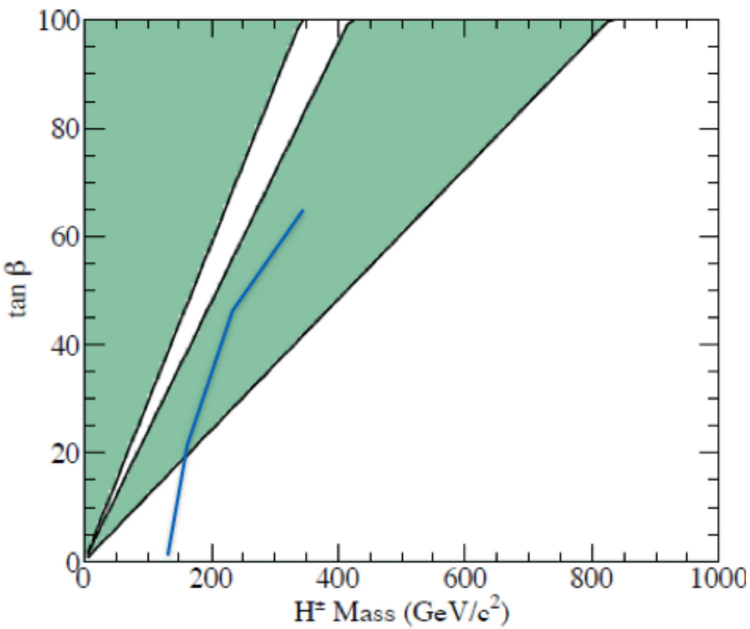
Using f_B = (191 ± 9) MeV (HPQCD, PDG12), |Vub| = (4.15 ± 0.49) x 10^{-3} (PDG12)
one obtains $\mathcal{B}_{SM}$ = (1.11 ± 0.28) x 10^{-4}

2-Higgs doublet model:

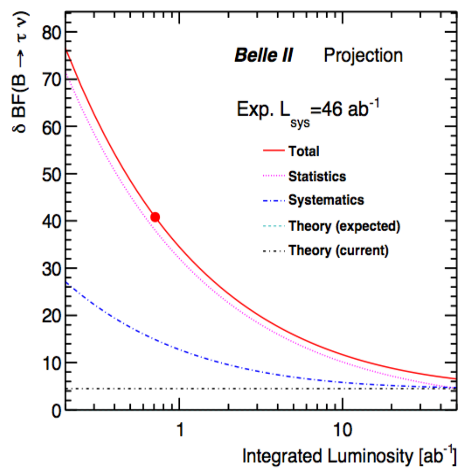
$$\mathcal{B}(B^+ \to \tau^+ \nu) = \mathcal{B}_{SM} \cdot \left(1 - m_B^2 \frac{\tan^2\beta}{m_H^2}\right)$$

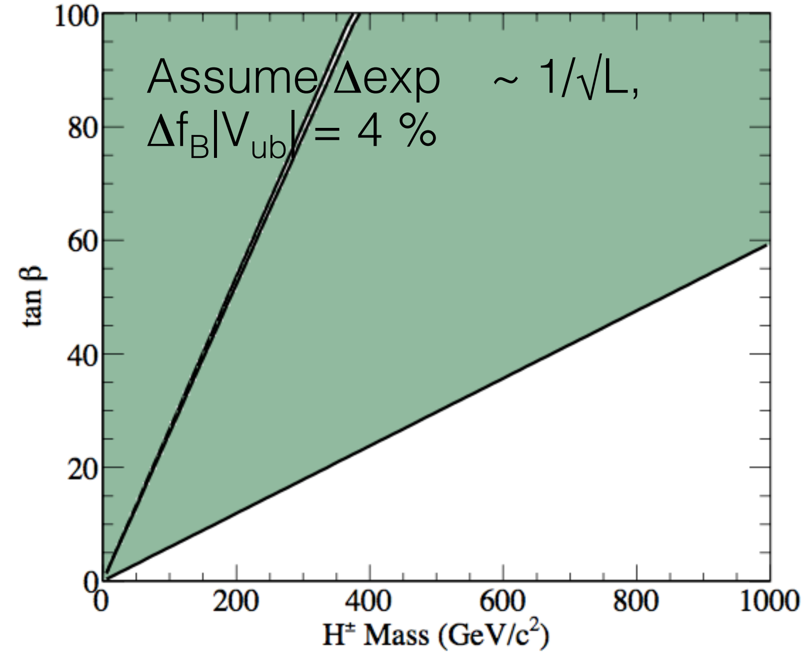
⇒ *lack of a signal constrains tanβ and m_H*

will greatly improve in 50 ab^{-1}:

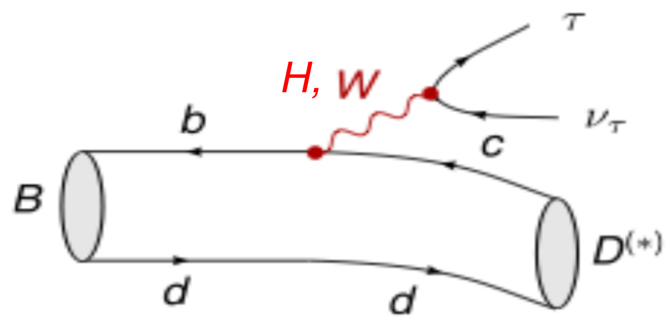


B-factories exclusion plot





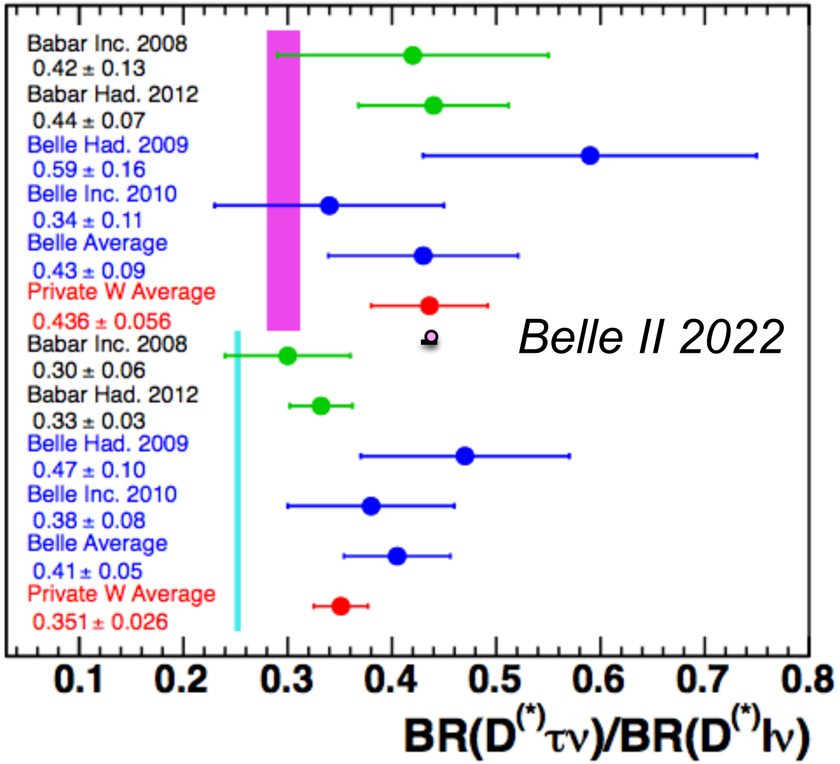
Measuring a charged Higgs: $B \to D^{(*)}\tau^+\nu$

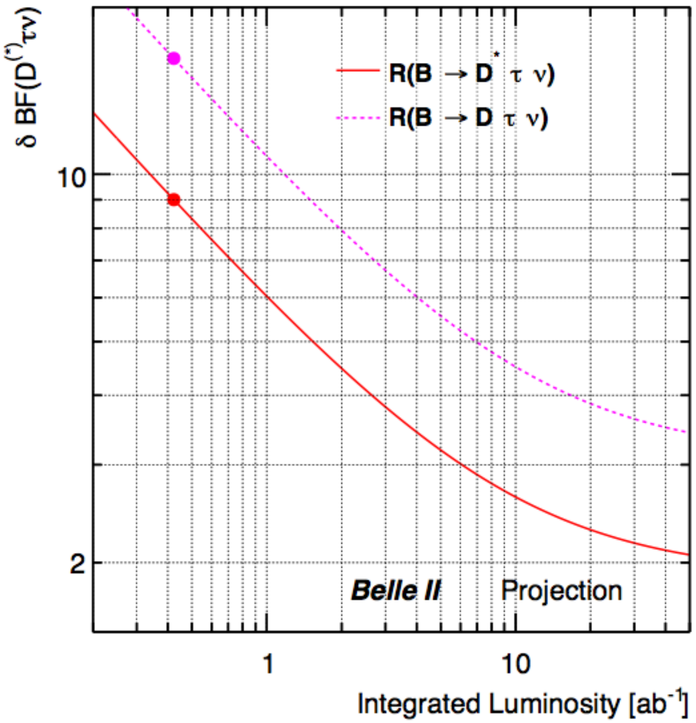


2-Higgs doublet model:

$$\mathcal{B}(B \to D^{(*)}\tau\nu) \propto \mathcal{B}_{SM} \cdot m_W \left(\frac{\tan\beta}{m_H}\right)$$

current $B \to D^{(*)}\ell^+\nu$ is > 4σ above SM (SM) .
Belle II should resolve this discrepancy.





Measuring $|V_{cb}|$ and $|V_{ub}|$

Christoph Schwanda (FPCP14):

There is currently a 3σ discrepancy between exclusive and inclusive measurements for ***both*** *$|V_{cb}|$ and $|V_{ub}|$. Belle II should resolve this.*

Exclusive ($D^*l\nu$) **$|V_{cb}|$ x 1000**

Lattice QCD [PoS LATTICE2010, 311 (2010)]	0.908 +/- 0.017	39.54 +/- 0.50_{exp} +/- 0.74_{th}
Lattice QCD [arXiv:1403.0635]	0.920 +/- 0.013	39.04 +/- 0.49_{exp} +/- 0.56_{th}

Exclusive ($Dl\nu$)

Lattice QCD [NPPS 140, 461-463 (2005)]	1.081 +/- 0.024	39.44 +/- 1.42_{exp} +/- 0.88_{th}

Inclusive 42.42 +/- 0.86 [PRD 89, 014022 (2014)]

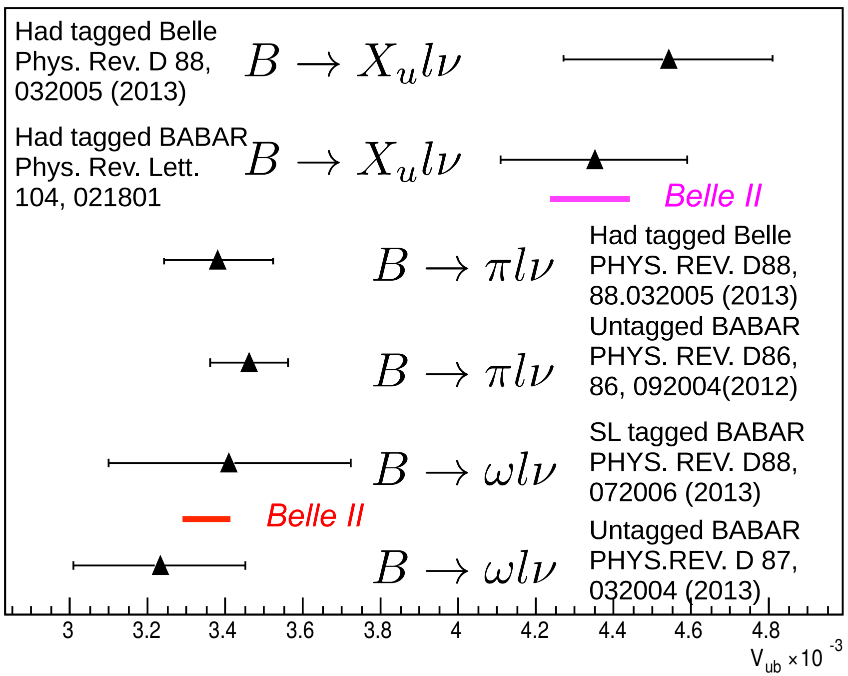
Sample	Stat	Syst	Th	Total
711/fb	0.6	3.0	1.8	3.6
5/ab	0.2	1.5	1.5	2.2
50/ab	0.1	1.1	1.0	1.5

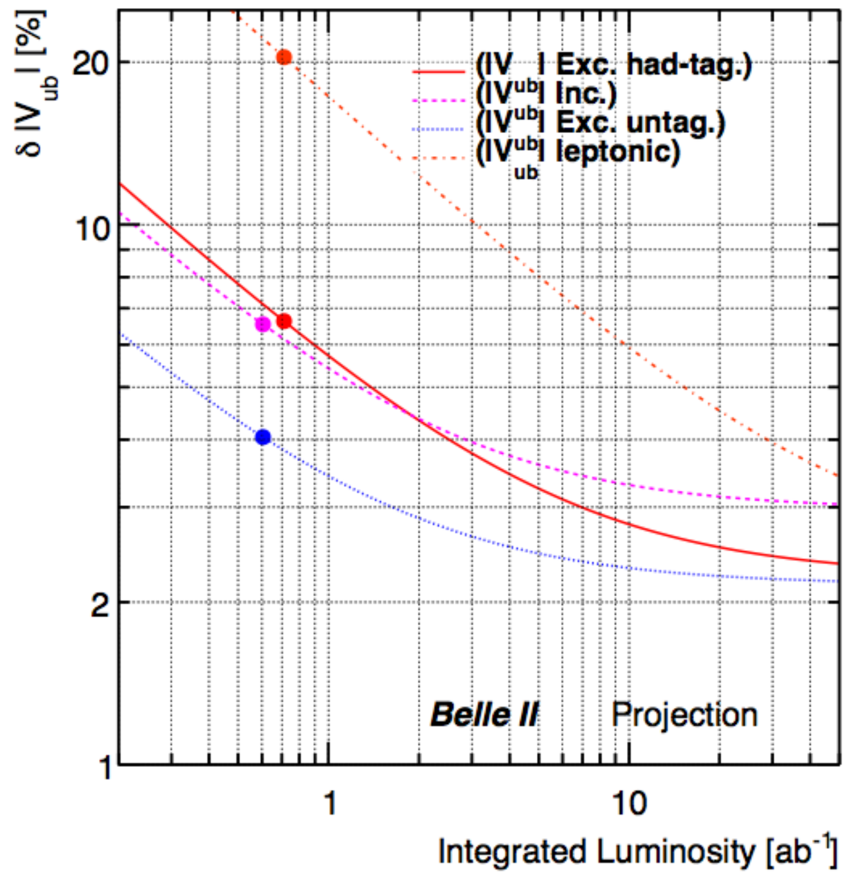
$2.7\sigma \rightarrow 6.6\sigma$

Measuring $|V_{cb}|$ and $|V_{ub}|$

3σ discrepancy between exclusive and inclusive measurements for $|V_{ub}|$.

Alexander Ermakov (FPCP14):



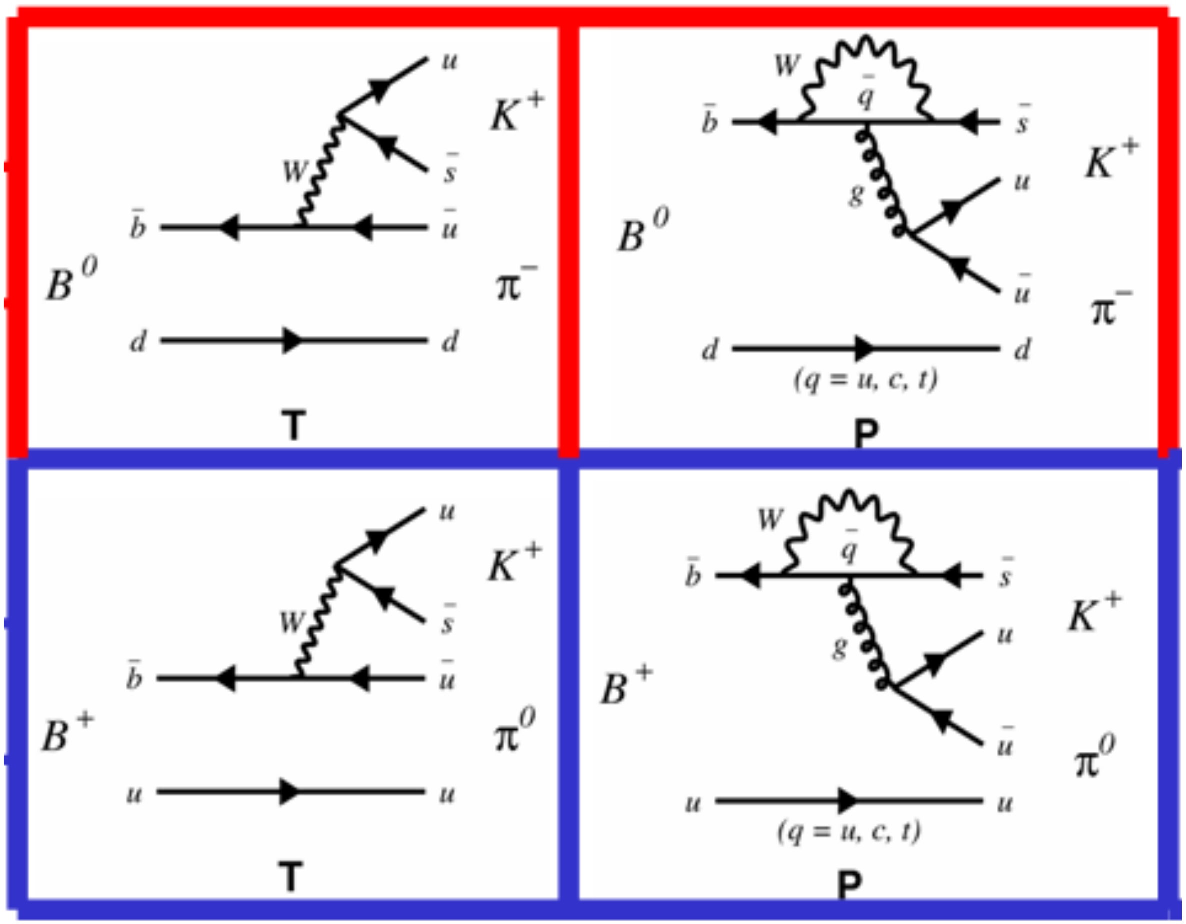


Measuring direct CPV with $B \to K\pi$

$$A_{CP} \equiv \frac{\Gamma(\bar{B} \to \bar{f}) - \Gamma(B \to f)}{\Gamma(\bar{B} \to \bar{f}) + \Gamma(B \to f)} \propto \sin\Delta\phi \, \sin\Delta\delta$$

$B^0 \to K^+\pi^-$

$B^+ \to K^+\pi^0$

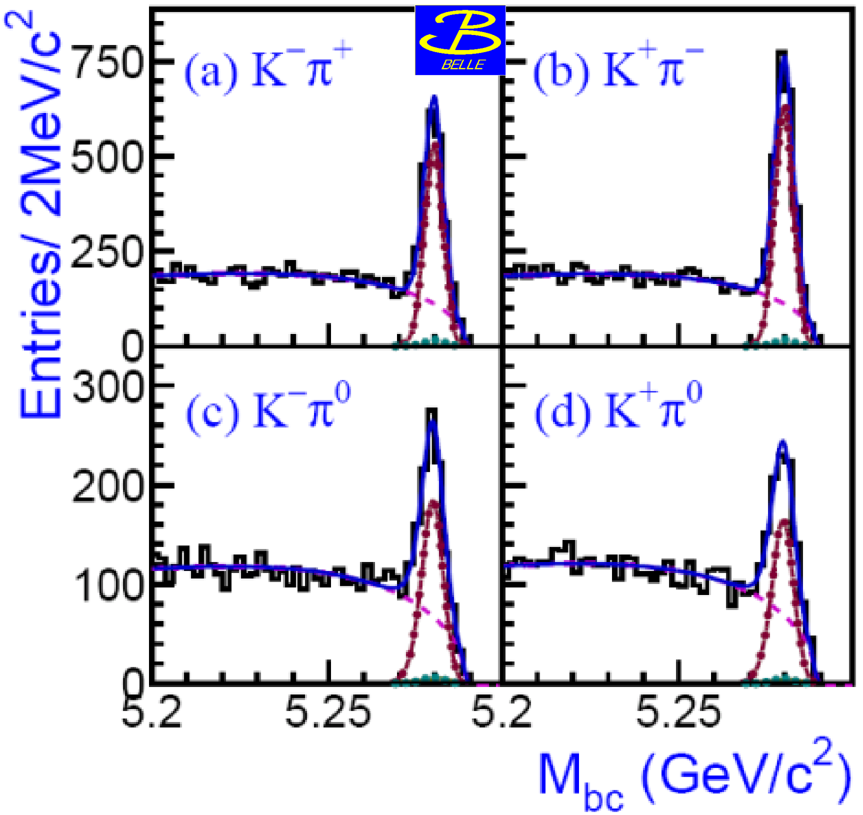


diagrams identical except for "spectator" quark

⇒ strong and weak phases are the same, A_{CP} should be the same…

Measuring direct CPV with $B \to K\pi$

But they are not: *(Belle, Nature 452, p332, 2008):*



$B^0 \to K^+\pi^-$

$B^+ \to K^+\pi^0$

$A_{CP}(K^+\pi^-)$ =

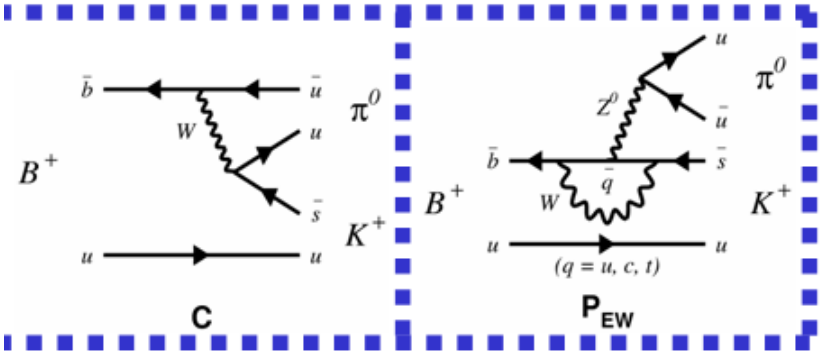
- -0.069 ± 0.016 (Belle)
- -0.107 ± 0.017 (Babar)
- -0.083 ± 0.013 (CDF)
- -0.080 ± 0.008 (LHCb)

$A_{CP}(K^+\pi^0)$ =

- $+0.043 \pm 0.024$ (Belle)
- $+0.030 \pm 0.040$ (Babar)

$A_{CP}(K^+\pi^-) - A_{CP}(K^+\pi^0) = -0.122 \pm 0.022$

(5.6σ difference from zero)



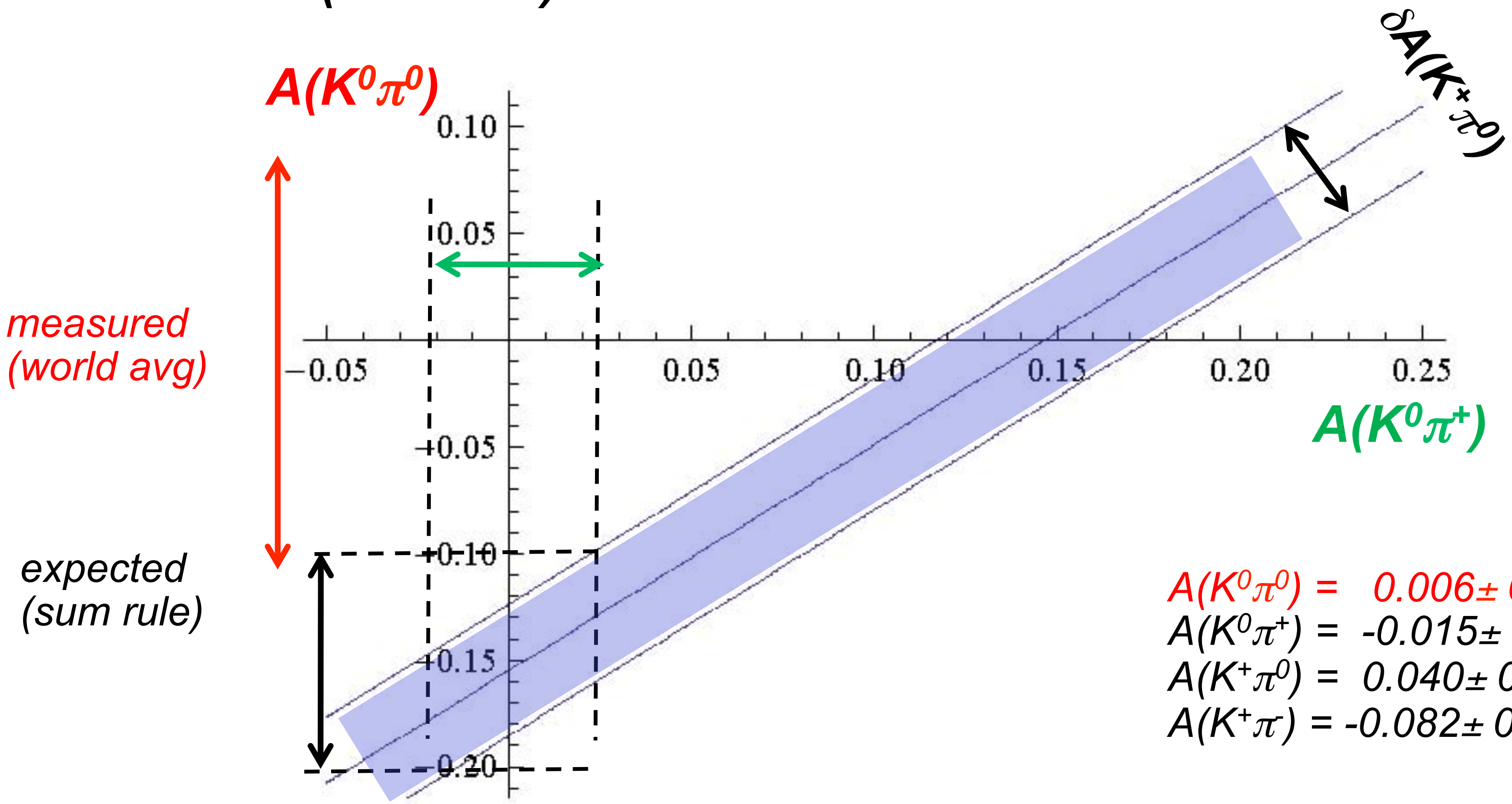
Measure A_{CP} in the $K\pi$ system: now

``Model independent" sum rule for all four modes:

Gronau, PLB 627, 82 (2005); Atwood & Soni, PRD 58, 036005 (1998):

$$\mathcal{A}_{CP}(K^+\pi^-) + \mathcal{A}_{CP}(K^0\pi^+)\frac{\mathcal{B}(K^0\pi^+)}{\mathcal{B}(K^+\pi^-)}\frac{\tau_0}{\tau_+} = \mathcal{A}_{CP}(K^+\pi^0)\frac{2\mathcal{B}(K^+\pi^0)}{\mathcal{B}(K^+\pi^-)}\frac{\tau_0}{\tau_+} + \mathcal{A}_{CP}(K^0\pi^0)\frac{2\mathcal{B}(K^0\pi^0)}{\mathcal{B}(K^+\pi^-)}$$

B factories now (~1.4 ab^{-1}):

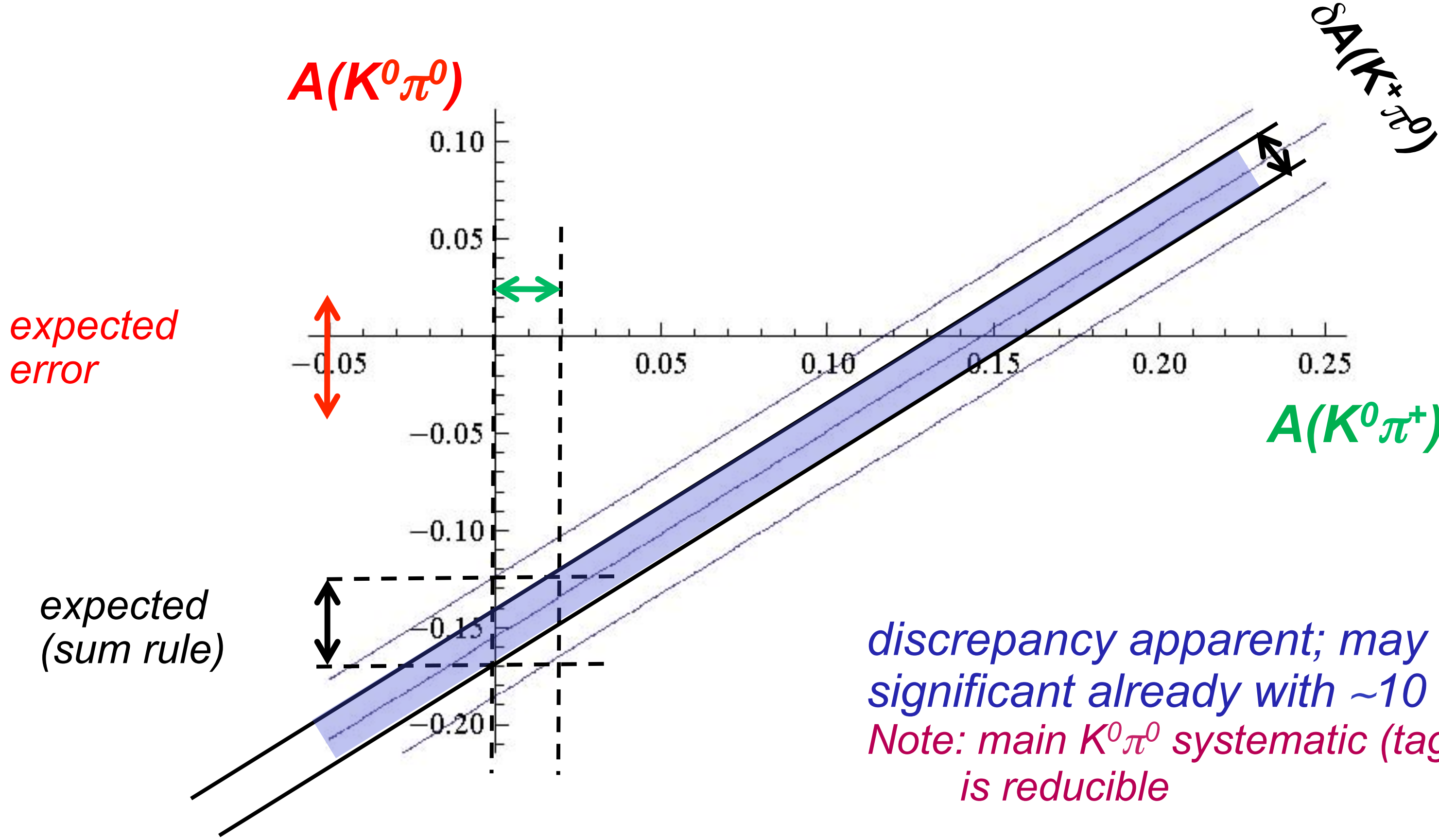


$A(K^0\pi^0)$ = 0.006± 0.06
$A(K^0\pi^+)$ = -0.015± 0.019
$A(K^+\pi^0)$ = 0.040± 0.021
$A(K^+\pi^-)$ = -0.082± 0.006

Measure A_{CP} in the $K\pi$ system: Belle II

$$\mathcal{A}_{CP}(K^+\pi^-) + \mathcal{A}_{CP}(K^0\pi^+)\frac{\mathcal{B}(K^0\pi^+)}{\mathcal{B}(K^+\pi^-)}\frac{\tau_0}{\tau_+} = \mathcal{A}_{CP}(K^+\pi^0)\frac{2\mathcal{B}(K^+\pi^0)}{\mathcal{B}(K^+\pi^-)}\frac{\tau_0}{\tau_+} + \mathcal{A}_{CP}(K^0\pi^0)\frac{2\mathcal{B}(K^0\pi^0)}{\mathcal{B}(K^+\pi^-)}$$

B factory at 50 ab^{-1}, with today's central values:



discrepancy apparent; may be significant already with ~10 ab^{-1}

Note: main $K^0\pi^0$ systematic (tag-side interference) is reducible

D^0-$\bar{D}^0$ mixing and CPV:

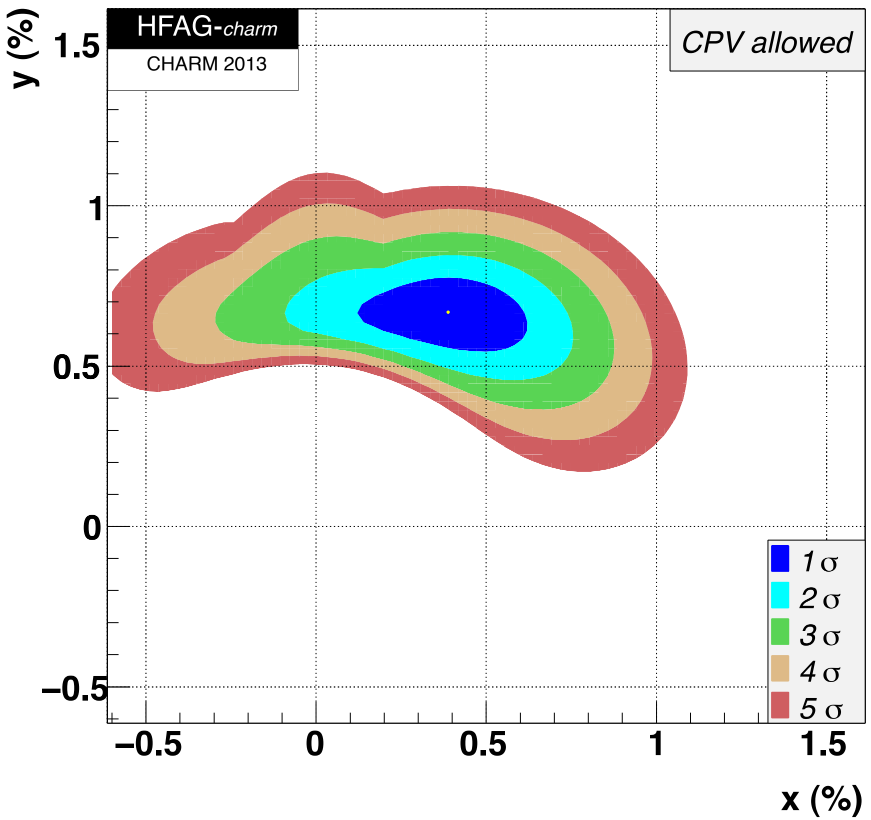
Expected Uncertaintes *(M. Staric, KEK FFW14)*:

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

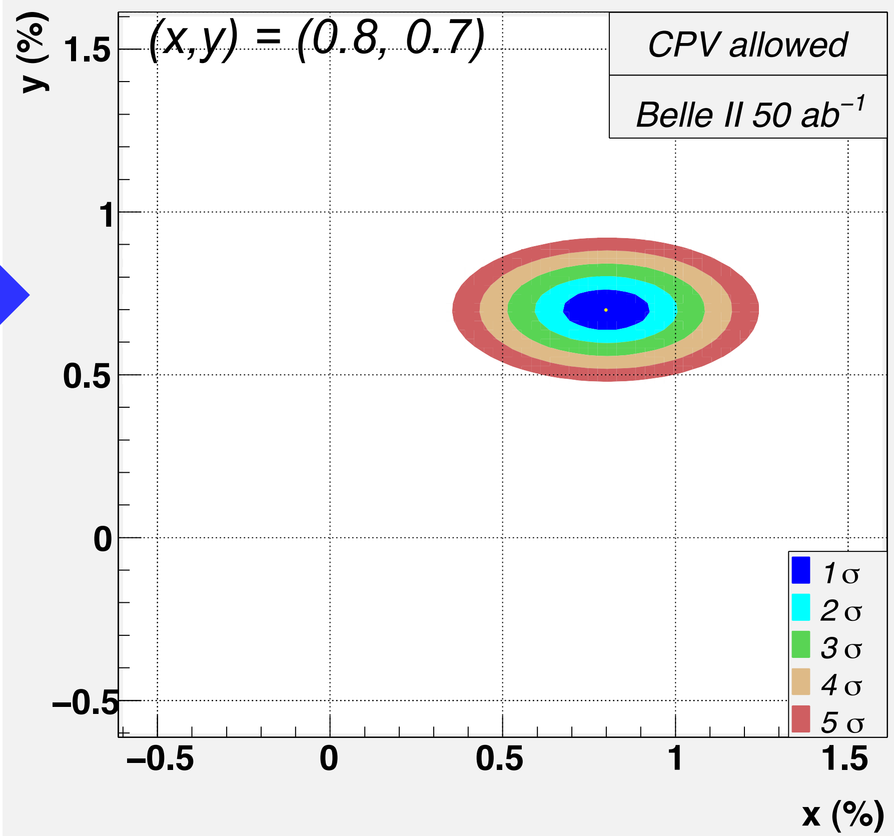
Note: *statistical error and some systematics scale by luminosity, but other systematics do not.*

CPV search in the D^0-$\bar{D}^0$ system:

Now:



50 ab^{-1}:

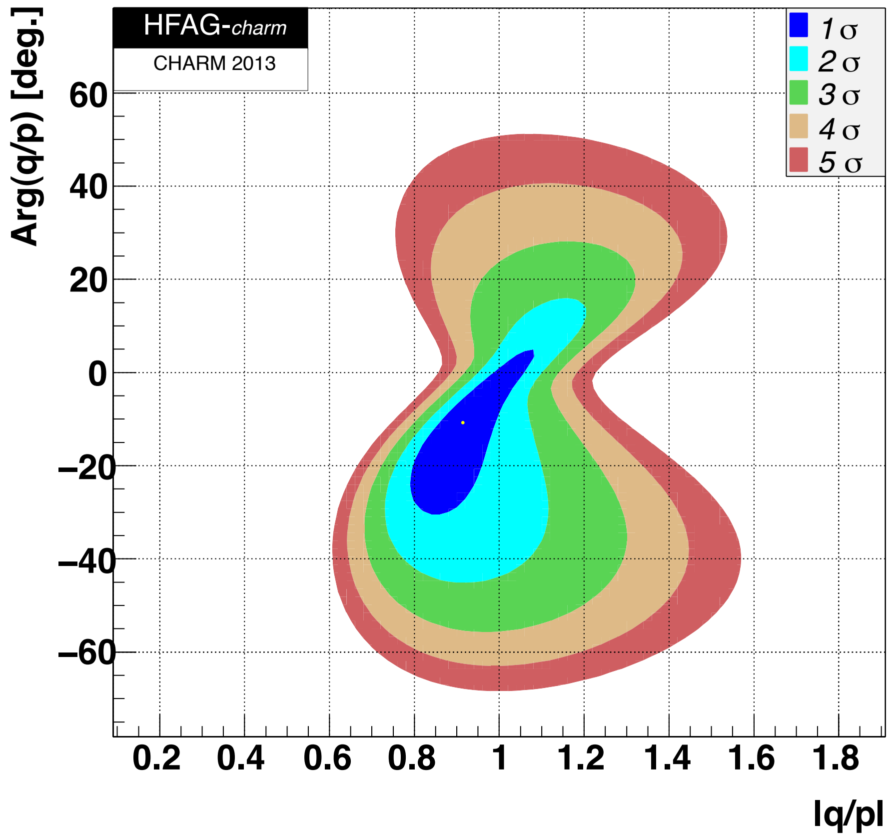


Current measurements of x, y give many constraints on NP models

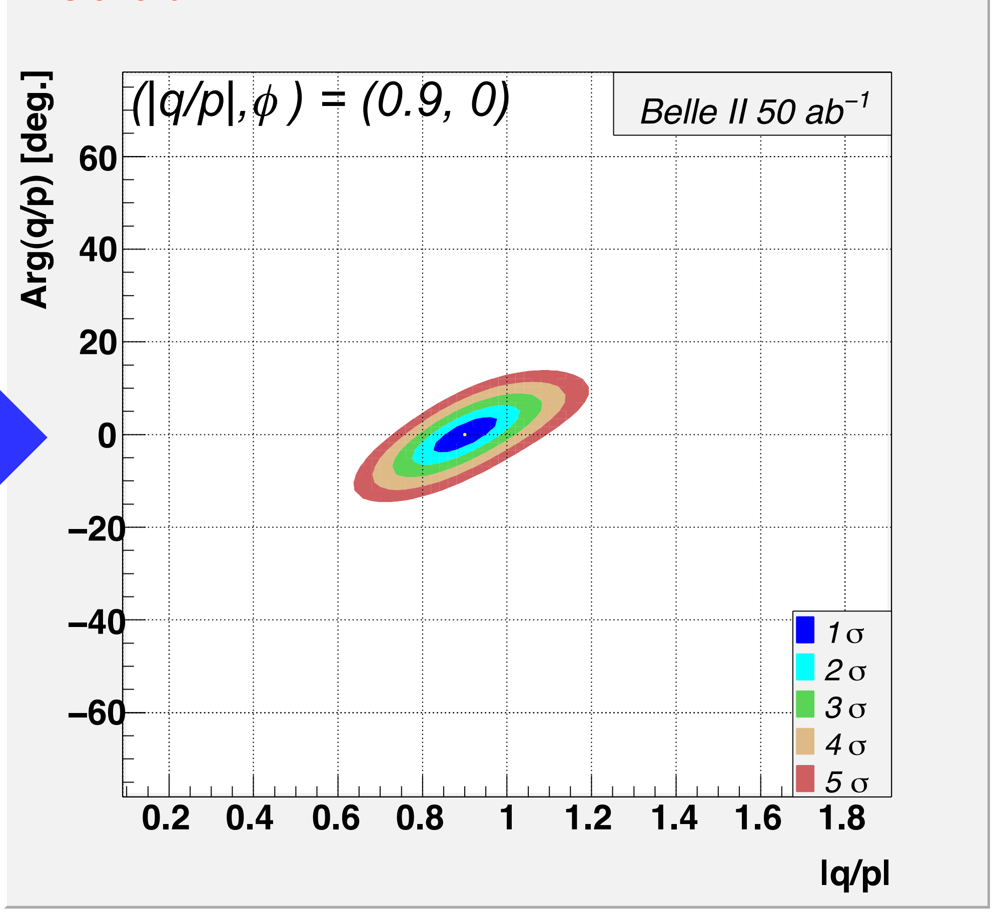
[see Golowich et al., PRD76, 095009 (2007); 21 models considered, e.g., 2-Higgs doublets, left-right models, little Higgs, extra dimensions, of which 17 give constraints]

CPV search in the D^0-$\bar{D}^0$ system:

Now:



50 ab^{-1}:



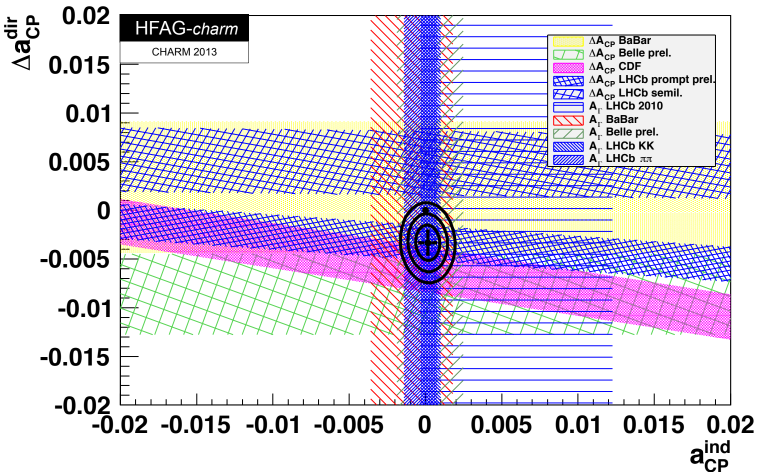
Note: *LHCb will dominate most of these measurements, but Belle II should be competitive in y_{CP} and possibly in x'^2, y', $|q/p|$, ϕ (see Staric, KEK FFW14). If LHCb sees new physics, it would be important for Belle II to independently confirm.*

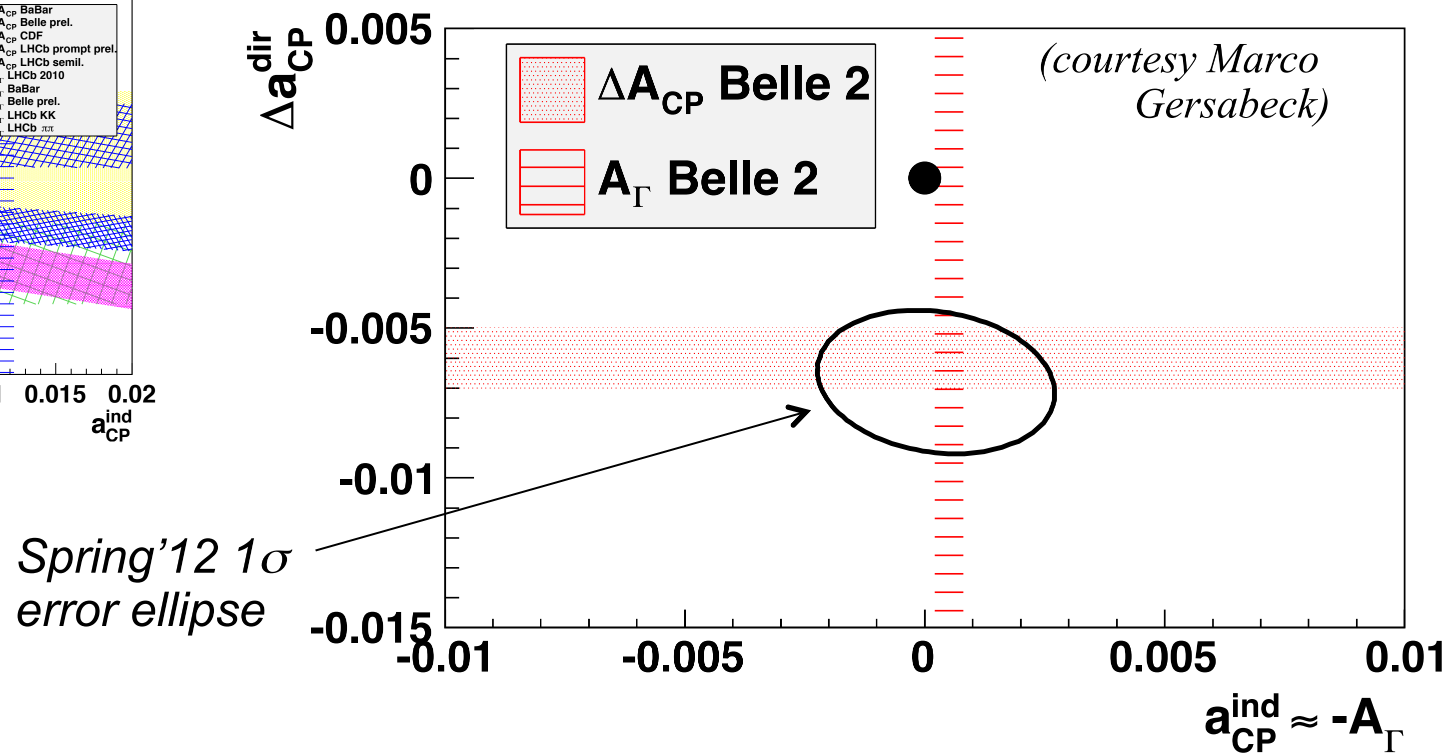
Direct CPV:

$$A_\Gamma \equiv \frac{\tau(\overline{D}^0 \to f) - \tau(D^0 \to f)}{\tau(\overline{D}^0 \to f) + \tau(D^0 \to f)} \approx -a_{CP}^{\rm ind}$$

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

$$\Delta A_{CP} \equiv A_{CP}(K^+K^-) - A_{CP}(\pi^+\pi^-) = \left(1 + y\cos\phi\frac{\overline{\langle t\rangle}}{\tau}\right)\Delta a_{CP}^{\rm dir} + \left(\frac{\Delta\langle t\rangle}{\tau}\right) a_{CP}^{\rm ind}$$





Direct CPV:

(table by Marko Staric)

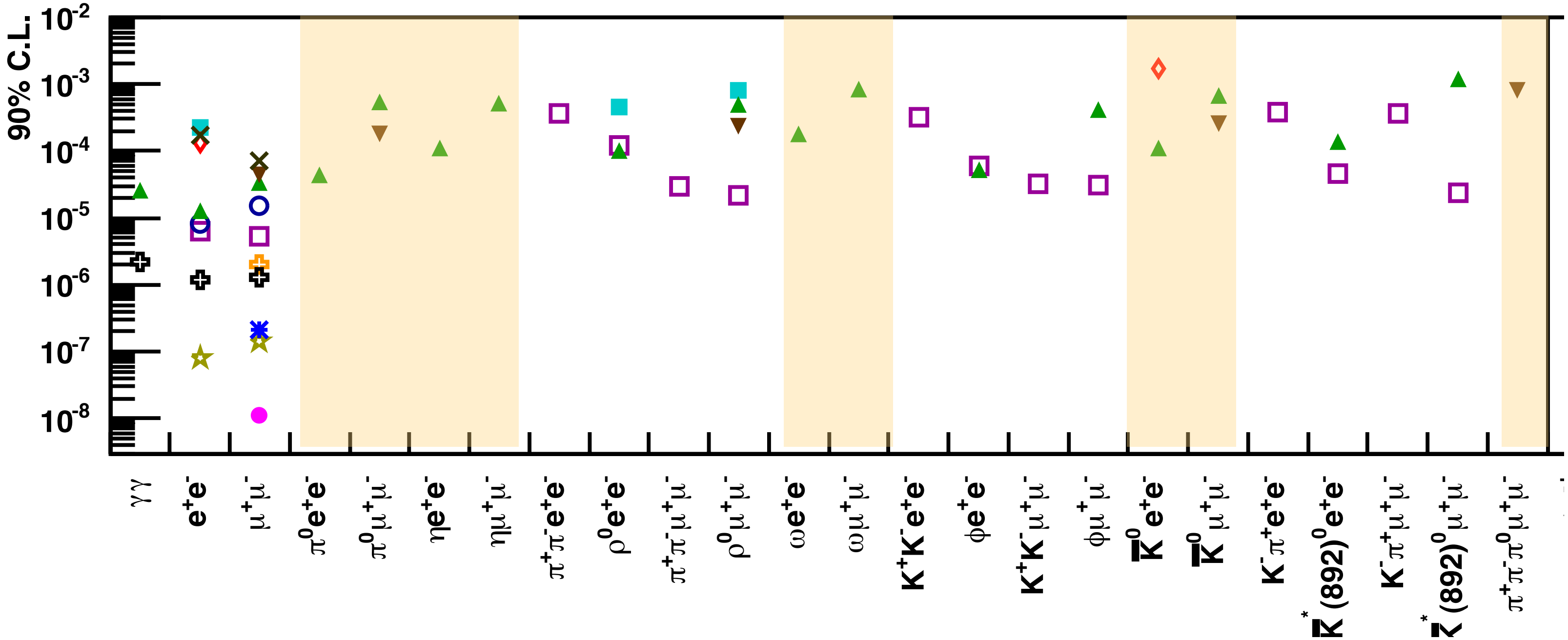
mode	$\mathcal{L}$ (fb^{-1})	A_{CP} (%)	Belle II at 50 ab^{-1}
$D^0 \to K^+K^-$	976	$-0.32 \pm 0.21 \pm 0.09$	± 0.03
$D^0 \to \pi^+\pi^-$	976	$+0.55 \pm 0.36 \pm 0.09$	± 0.05
$D^0 \to \pi^0\pi^0$	976	$\sim \pm 0.60$	± 0.08
$D^0 \to K_s^0\pi^0$	791	$-0.28 \pm 0.19 \pm 0.10$	± 0.03
$D^0 \to K_s^0\eta$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

***modes with π^0's** (easier @ e^+e^-)*

Rare/Forbidden Decays:

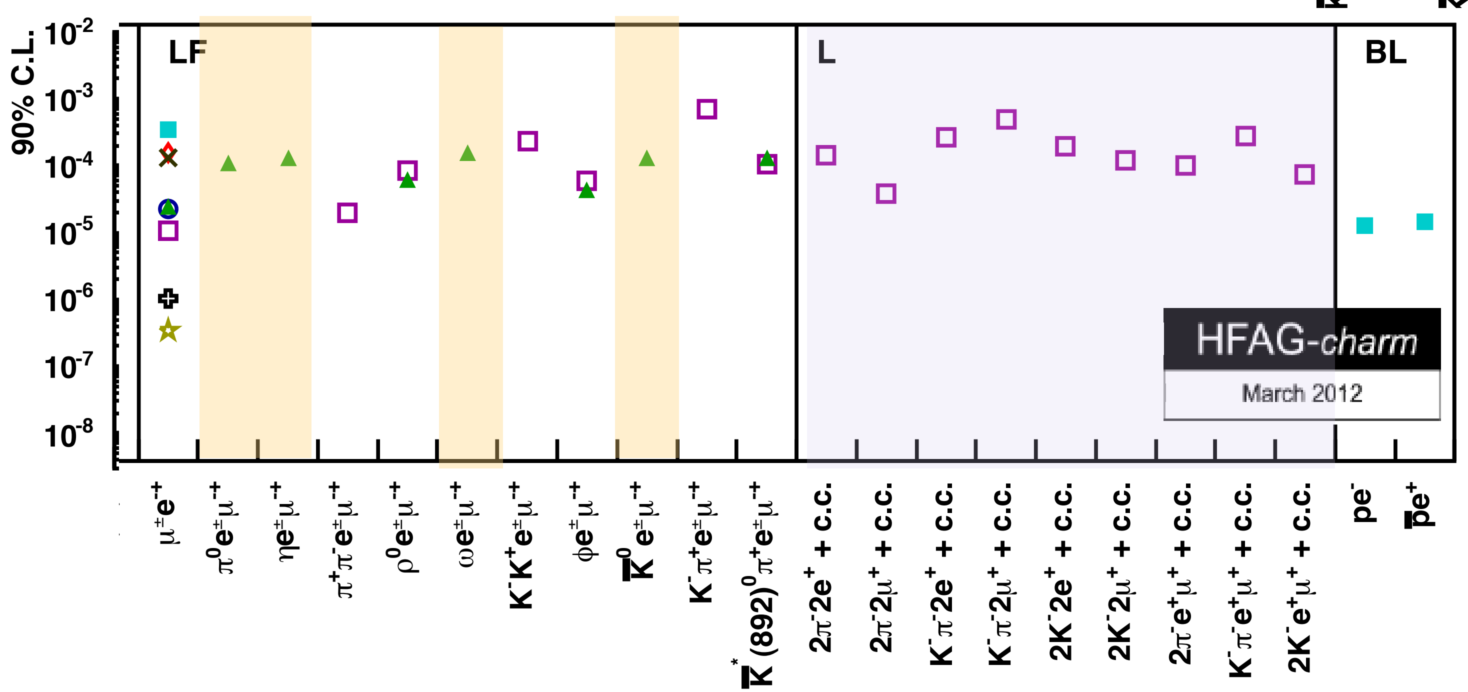
www.slac.stanford.edu/xorg/hfag/charm/ICHEP12/Rare/rare_charm.html

flavor-changing neutral currents



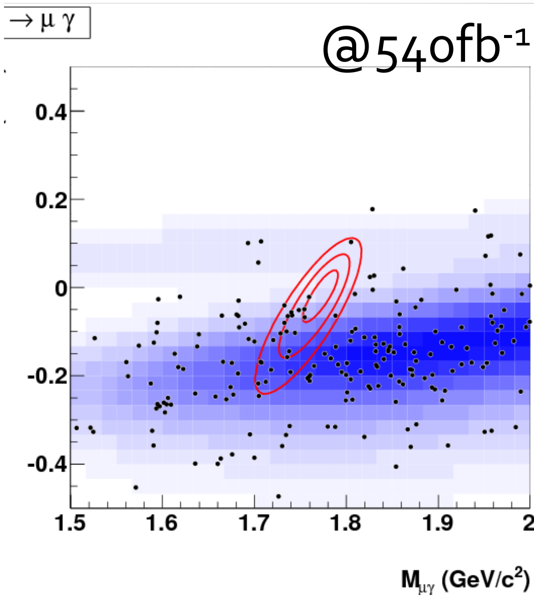
***modes with π^0's** (easier @ e^+e^-)*

lepton-flavor violating; lepton-number violating; baryon +lepton number violating

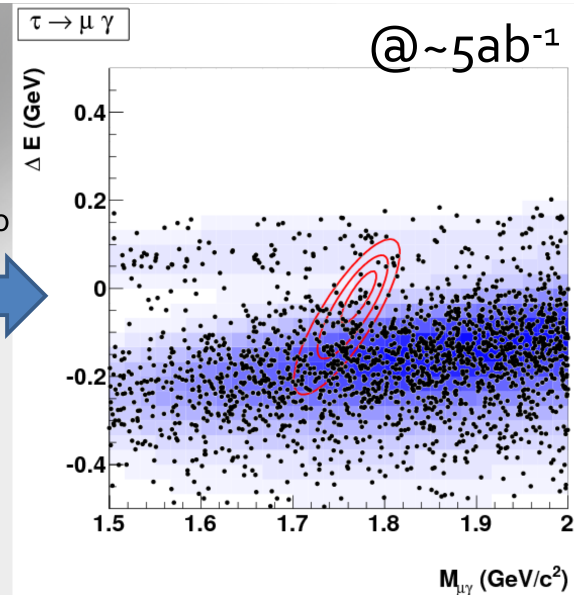


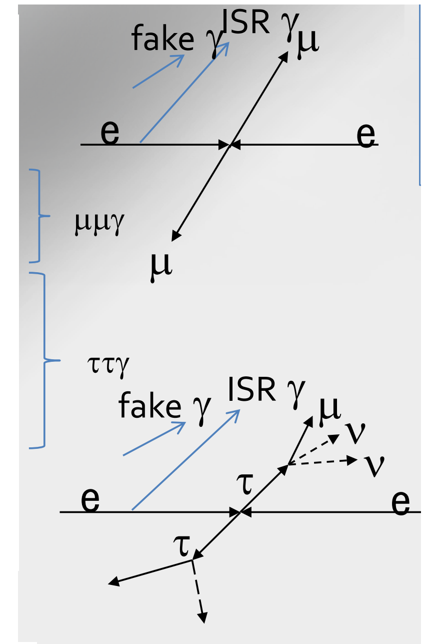
Belle II Prospects for τ

$\tau^+ \to \mu^+\gamma$

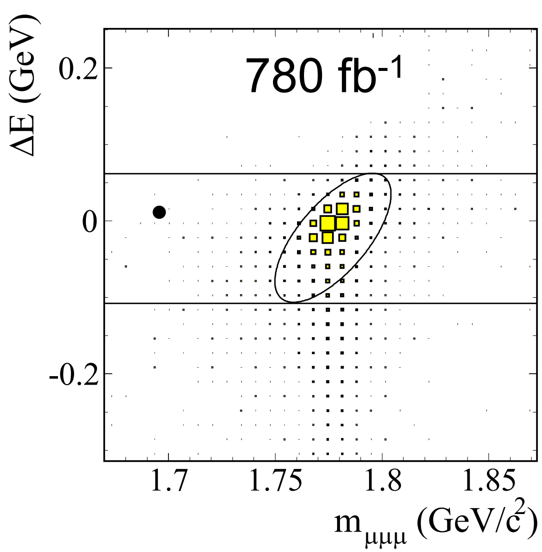


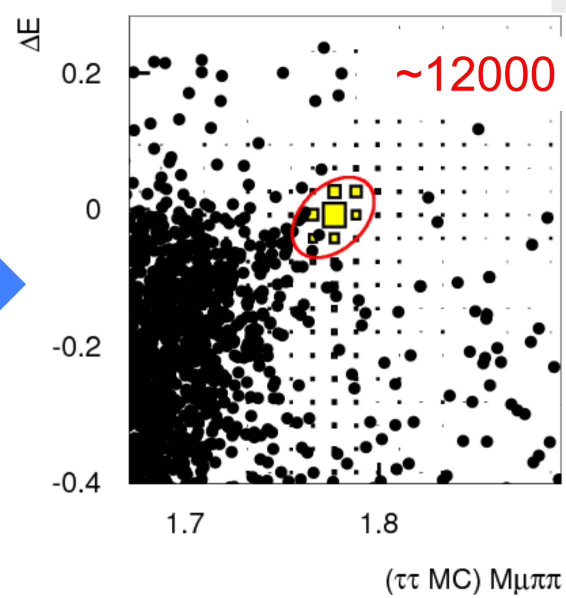
x10





$\tau^+ \to \mu^+\mu^+\mu^-$





(shows distribution of ~70 events, obtained from $\tau^+ \to \pi^+\pi^+\mu^-$ sample)

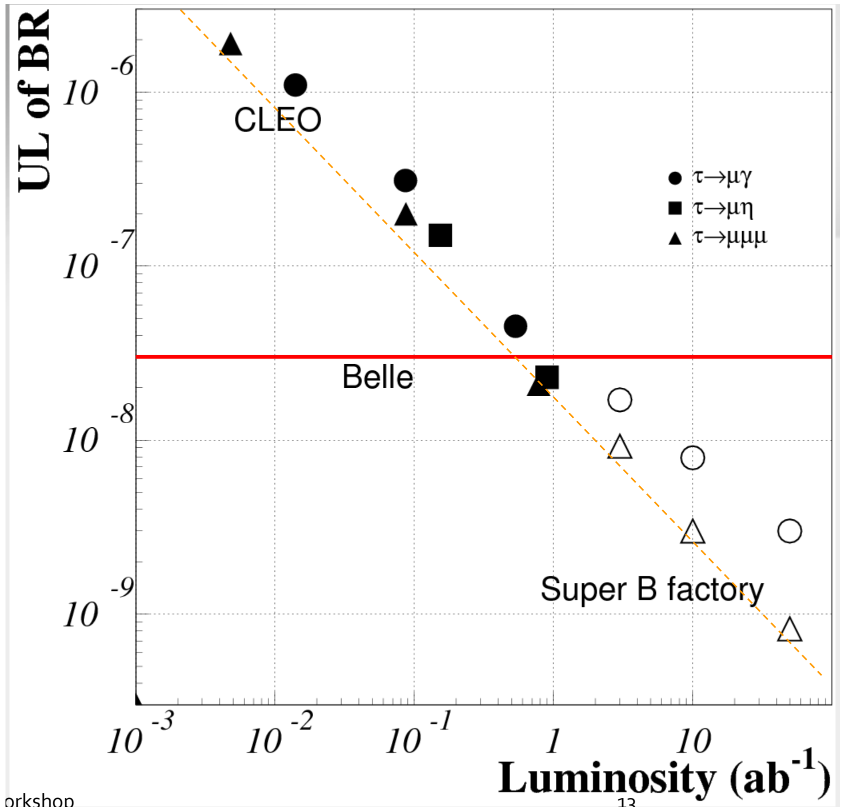
Belle II Prospects for τ

$\tau^+ \to \mu^+ \gamma$

upper half of signal ellipse dominated by
$ee \to \mu\mu\ \gamma_{ISR}$
⇒ possible to reduce
⇒ sensitivity scales with $\sqrt{\mathcal{L}}$

$\tau^+ \to \mu^+ \mu^+ \mu^-$

very clean, essentially background-free up to 50 ab^{-1}
⇒ sensitivity scales linearly with $\mathcal{L}$



Upper Limits:

$\sigma(ee \to \tau\tau) = 0.92$ nb
⇒ 4.6 x 10^{10} $\tau^+\tau^-$ in 50 ab^{-1}
⇒ $B(\tau^+ \to \mu^+\gamma) < \sim 10^{-9}$
⇒ $B(\tau^+ \to \mu^+\mu^-\mu^+) < \sim 10^{-10}$

This probes NP models

	reference	τ→μγ	τ→μμμ
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}

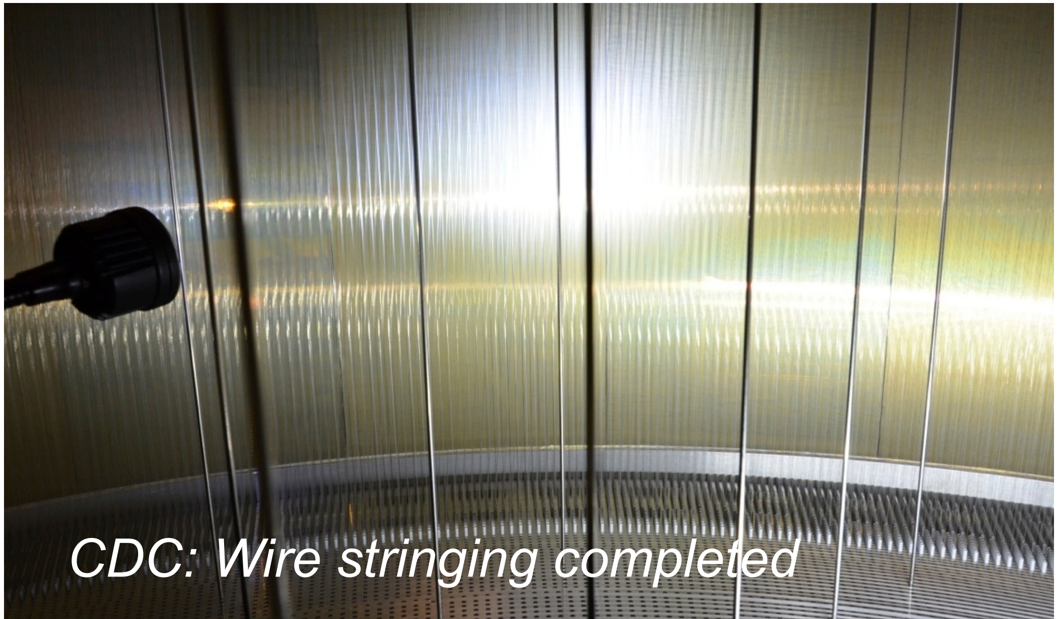
SuperKEKB construction status:

Magnets have been installed:

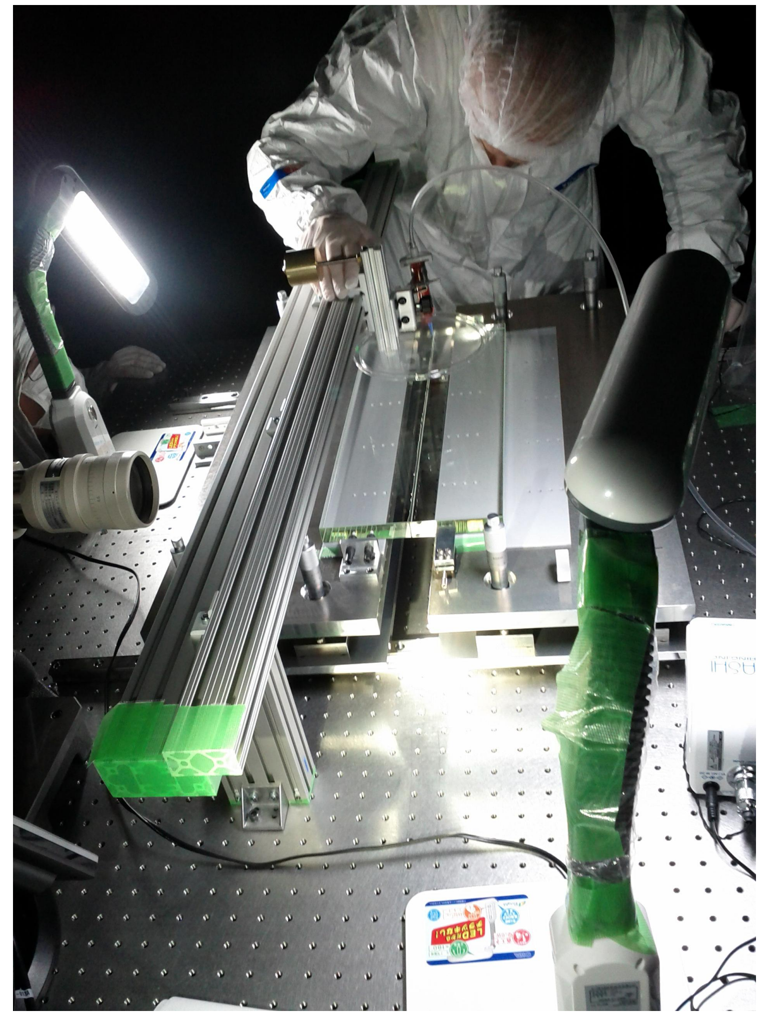
D2(Oho-side)

D1(Nikko-side)

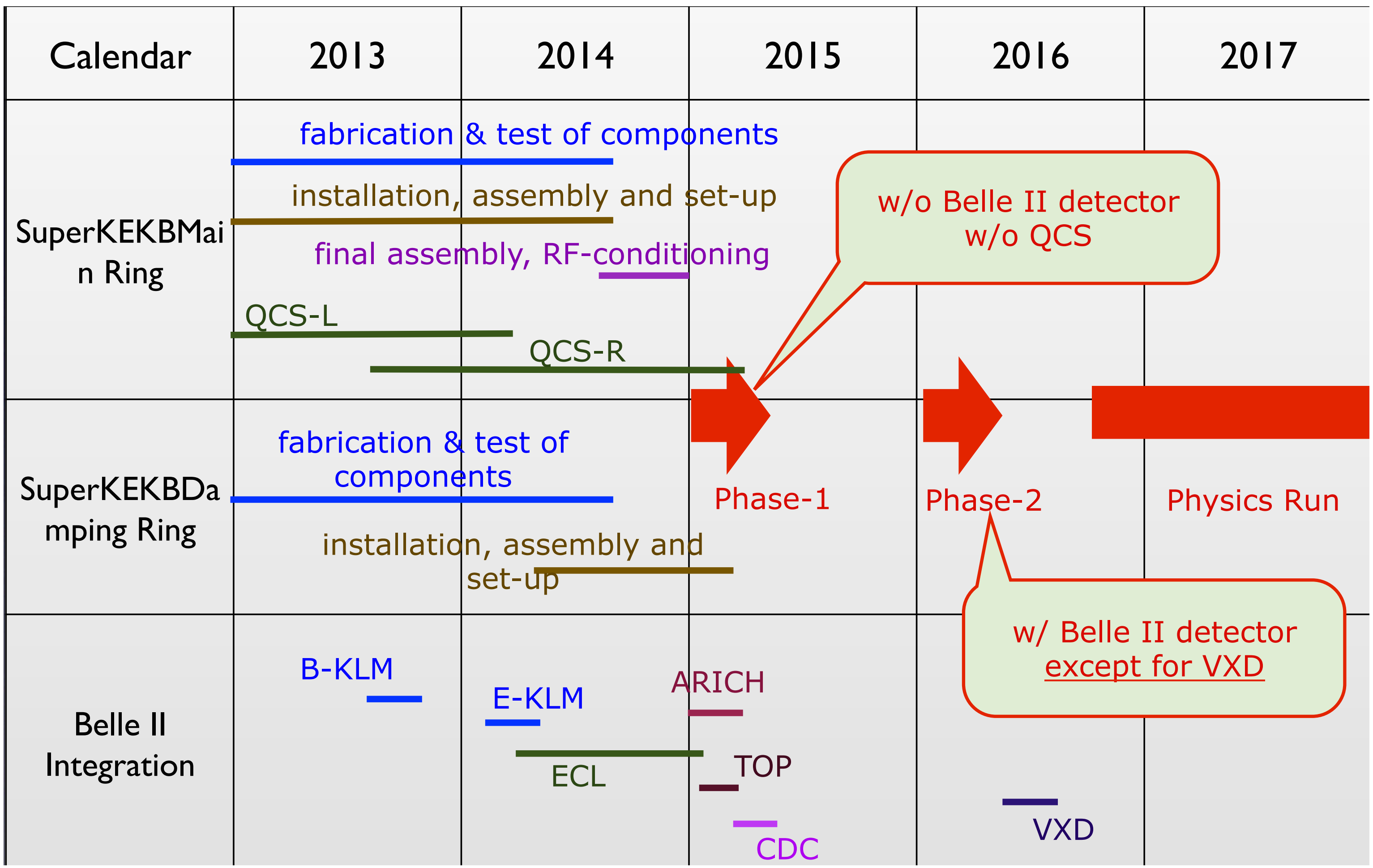
Belle II construction status:



iTOP optics assembly



Belle II installation schedule:



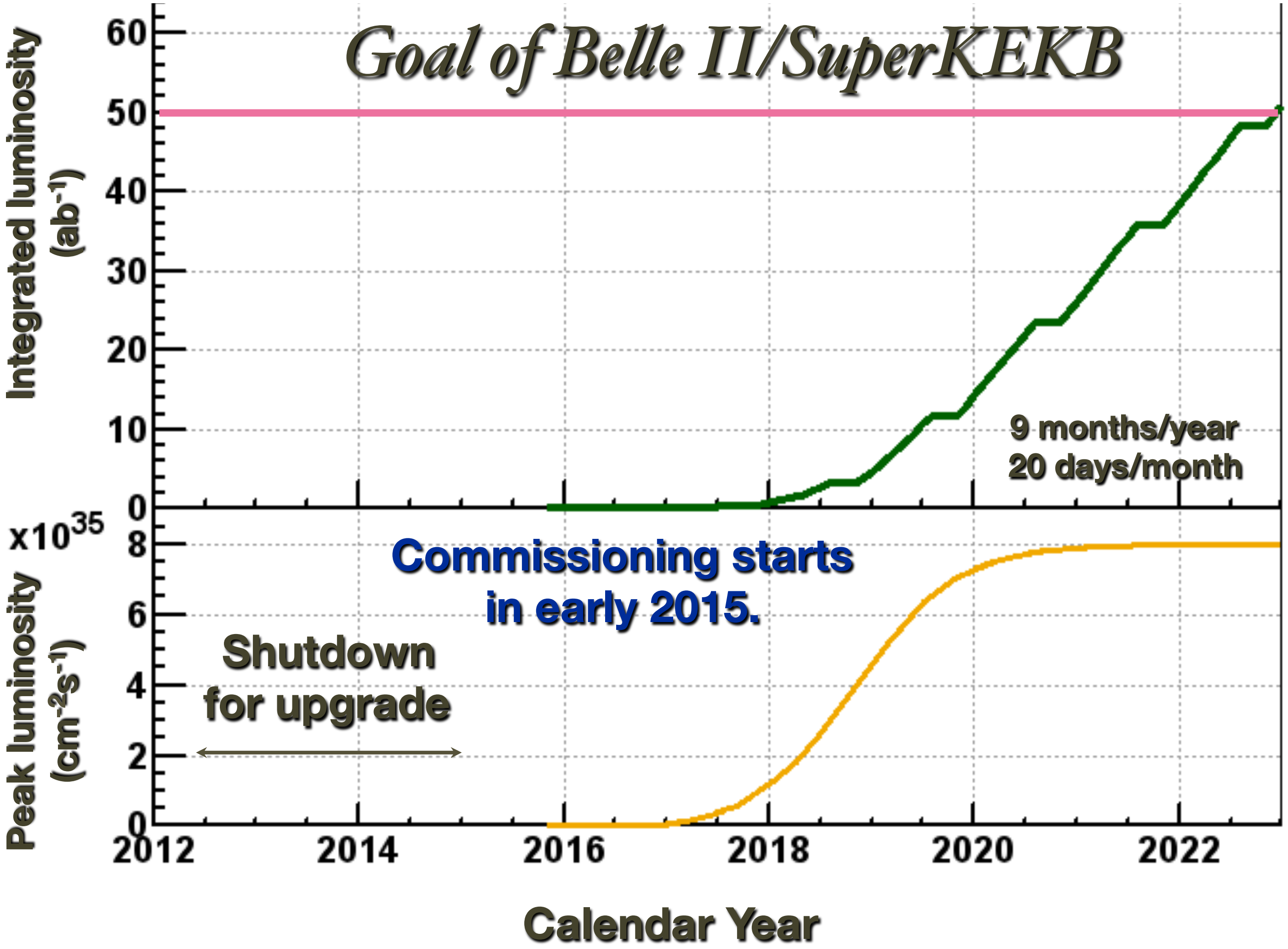
2015:
KEKB commissioning

2016:
Belle detector commissioning

2017
first physics data

Luminosity schedule:

- 4-year shut-down for upgrade of the accelerator and detector
- Start machine operation in 2015, data-taking in 2017, reach 50 ab^{-1} in ~2023



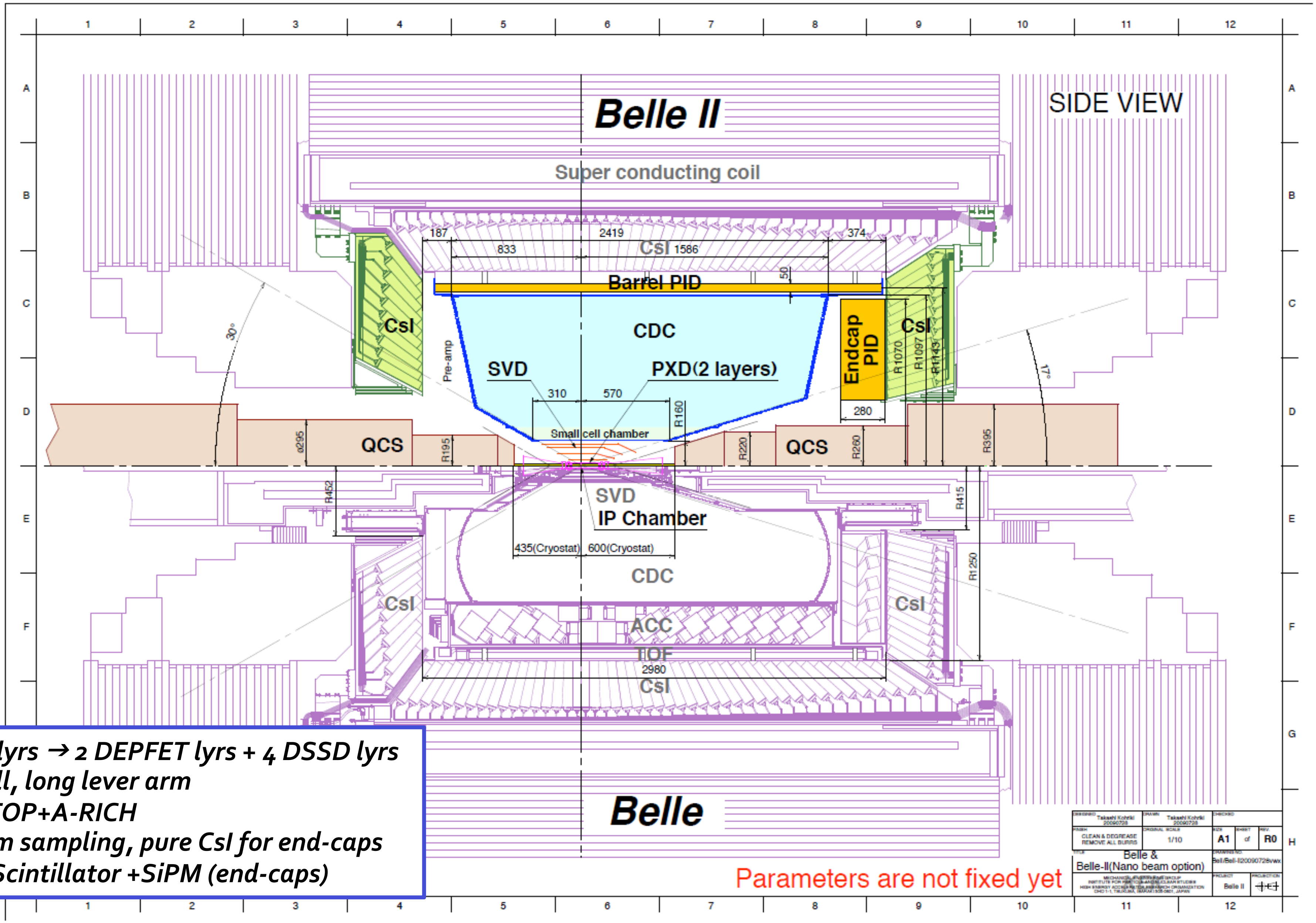
Summary

- *B factories have proven to be an excellent tool for flavour physics, producing a wealth of physics results, having reliable long-term operation, and having constant improvement of performance.*
- *Major upgrade at KEK in 2010-16 → Super B factory: $\mathcal{L}$ x 40. Essentially a new experiment, many detector components and most electronics will be replaced.*
- *Belle II should resolve current flavor puzzles of Belle and Babar, e.g., difference in phase ϕ_1 between $b \to s$ loop and $b \to c$ tree diagrams; possible enhanced EW penguin in $B \to K\pi$ decays, exclusive vs. inclusive values for $|V_{ub}|$, $|V_{cb}|$, etc.*
- *Belle II can identify new CP phases responsible for baryogenesis of our matter universe, can search for/constrain charged Higgs, flavor-changing couplings for MSSM, etc.*
- *Belle II will have a rich charm and tau physics program: should improve precision of mixing/CPV parameters, direct CP asymmetries, precision of V_{cd}, V_{cs} from semileptonic decays, decay constants f_D, f_{Ds}, reduce limits on rare and forbidden decays, etc.*

many of the final states studied are complementary to those studied at LHCb

Back-up Slides

Belle II detector compared to Belle



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 end-caps*
KLM: RPC → *Scintillator +SiPM (end-caps)*

Measuring Supersymmetry

Buchalla et al., arXiv:0801.1833, and references therein

In supersymmetric models, many parameters to tune.

For simplest scenario, "minimal supersymmetric standard model" MSSM, rotate fields such that flavor-changing terms appear as off-diagonal elements in the mass matrix, normalize by the mean mass to yield dimensionless "mass insertion terms" :

$$(\delta^d_{23})_{LR} \equiv \frac{[\Delta M^d_{23}]_{LR}}{\tilde{m}_q}$$

Francesco Forti:

LHCb, SuperB

LHC, ILC - HE frontier

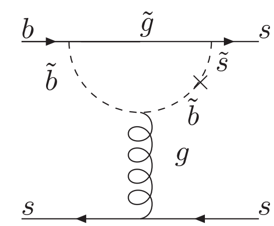
$$M^2_{\tilde{d}} \approx \begin{pmatrix} m^2_{\tilde{d}_L} & m_d(A_d-\mu\tan\beta) & (\Delta^d_{12})_{LL} & (\Delta^d_{12})_{LR} & (\Delta^d_{13})_{LL} & (\Delta^d_{13})_{LR} \\ & m^2_{\tilde{d}_R} & (\Delta^d_{12})_{RL} & (\Delta^d_{12})_{RR} & (\Delta^d_{13})_{RL} & (\Delta^d_{13})_{RR} \\ & & m^2_{\tilde{s}_L} & m_s(A_s-\mu\tan\beta) & (\Delta^d_{23})_{LL} & (\Delta^d_{23})_{LR} \\ & & & m^2_{\tilde{s}_R} & (\Delta^d_{23})_{RL} & (\Delta^d_{23})_{RR} \\ & & & & m^2_{\tilde{b}_L} & m_b(A_b-\mu\tan\beta) \\ & & & & & m^2_{\tilde{b}_R} \end{pmatrix}$$

and similarly for $M^2_{\tilde{u}}$

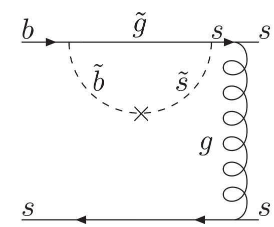
Gluino contribution to the Wilson coefficient for $b \to s\gamma$:

$$C^{\tilde{g}}_{7\gamma} = \frac{\alpha_s \pi \sqrt{2}}{6 G_F V^*_{ts} V_{tb} m^2_{\tilde{q}}} \times \left[(\delta^d_{23})_{LR} \frac{m_{\tilde{g}}}{m_b} \frac{8}{3} M_1(x) + (\delta^d_{23})_{LL} \left(\frac{8}{3} M_3(x) + (\delta^d_{33})_{LR} \frac{m_{\tilde{g}}}{m_{\tilde{b}}} \frac{8}{3} M_a(x) \right) \right]$$

where $x = m^2_{\tilde{g}}/m^2_{\tilde{q}}$ and $M_{(1,3,a)}$ are loop functions.



(c)

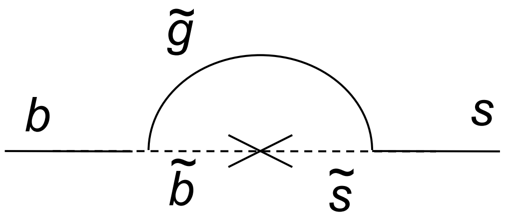


(f)

Gabbiani et al., Nucl.Phys. B477, 321 (1996)
Hisano & Shimizu, PRD 70, 093001 (2004)

Measuring Supersymmetry

Buchalla et al., EPJ.C57:309 (2008), arXiv:0801.1833



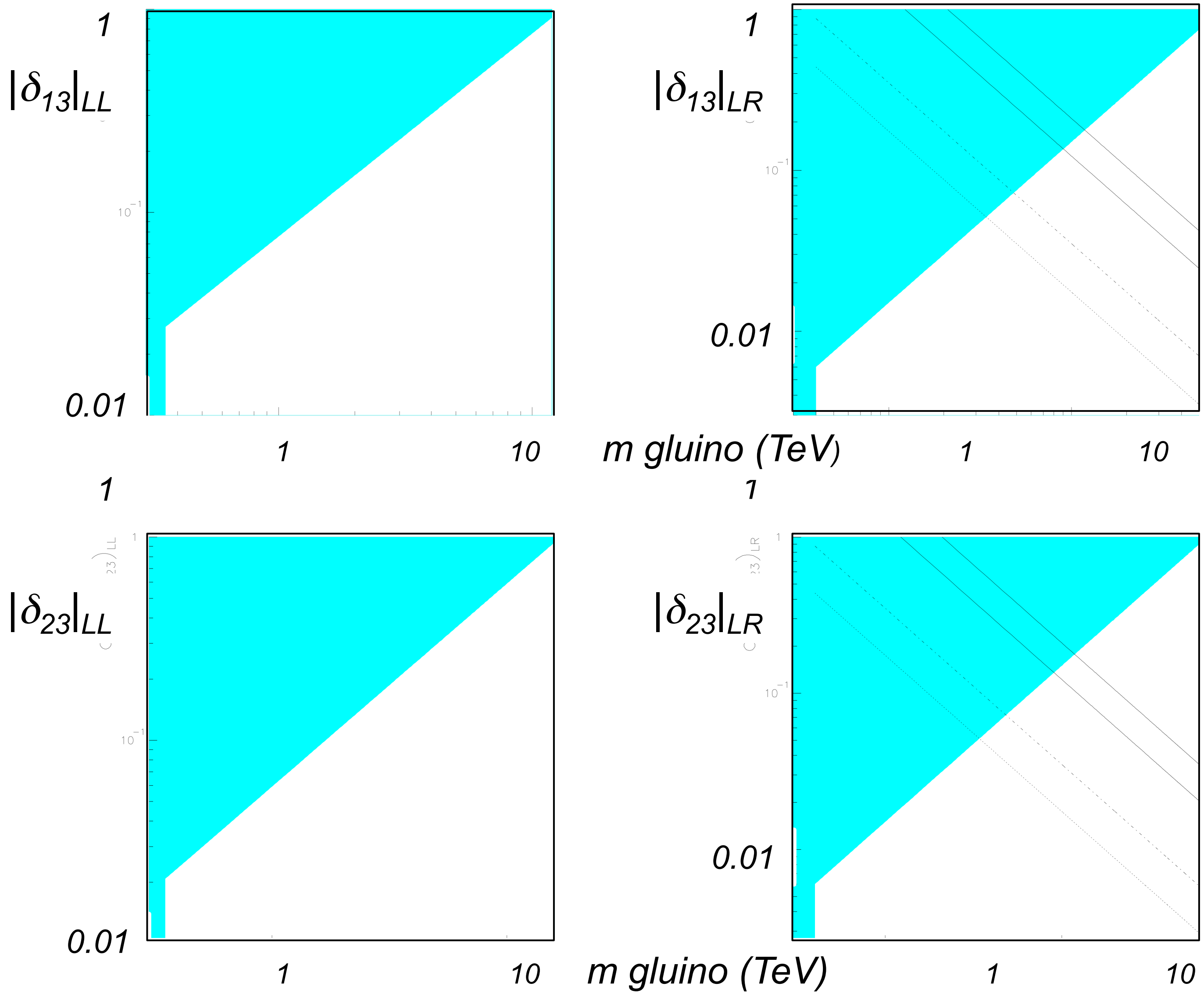
Observables sensitive to this extra loop contribution:

$B(b \to s\gamma)$, $A_{CP}(b \to s\gamma)$,

$B(b \to sll)$, $A_{CP}(b \to sll)$,

Δm_{Bs}

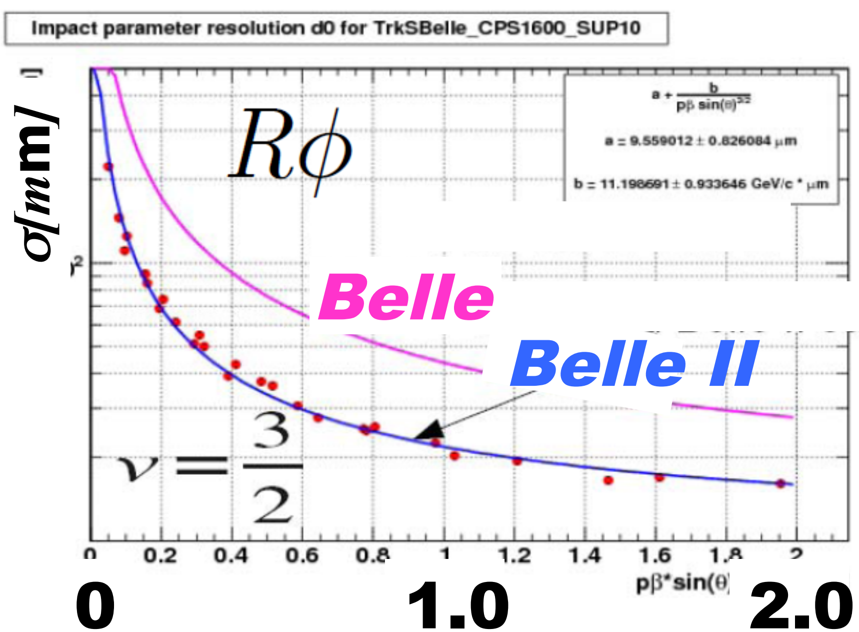
Plots (50 ab^{-1}) show regions of parameter space where the above experimental measurements allow δ to be measured nonzero with 3σ significance

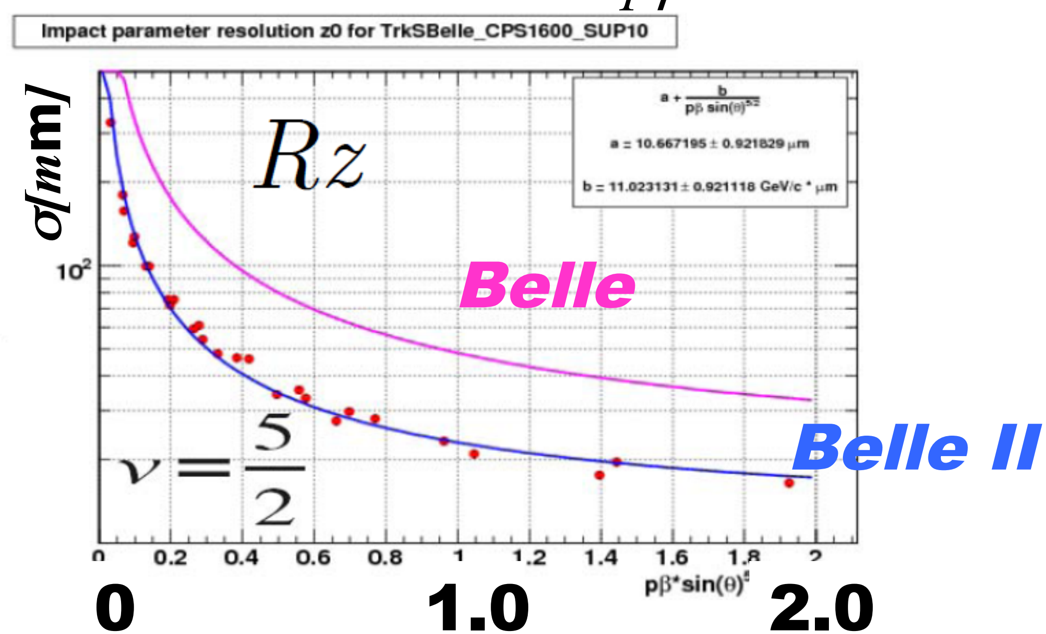


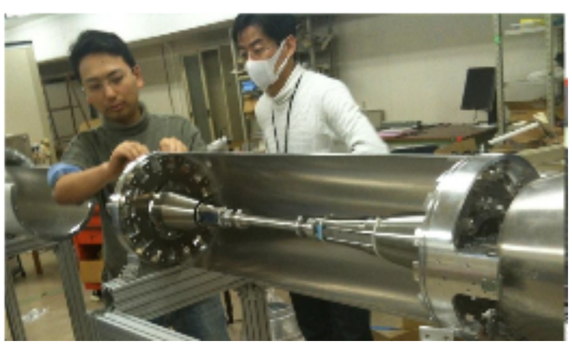
Belle II Vertex Detector Upgrade

Significant improvement in IP resolution:

$$\sigma = a + \frac{b}{p\beta \sin^{\nu}\theta}$$







Will improve analyses such as $B \to K_S \pi^0 \gamma$ (decay vertex determined by K_S and IP)

$C_{CP}(K_S\,\pi^0\gamma) = -0.07 \pm 0.12$

$S_{CP}(K_S\,\pi^0\gamma) = -0.15 \pm 0.20 \to$ 0.10 (5 fb^{-1})

$\to$ 0.04 (50 fb^{-1})