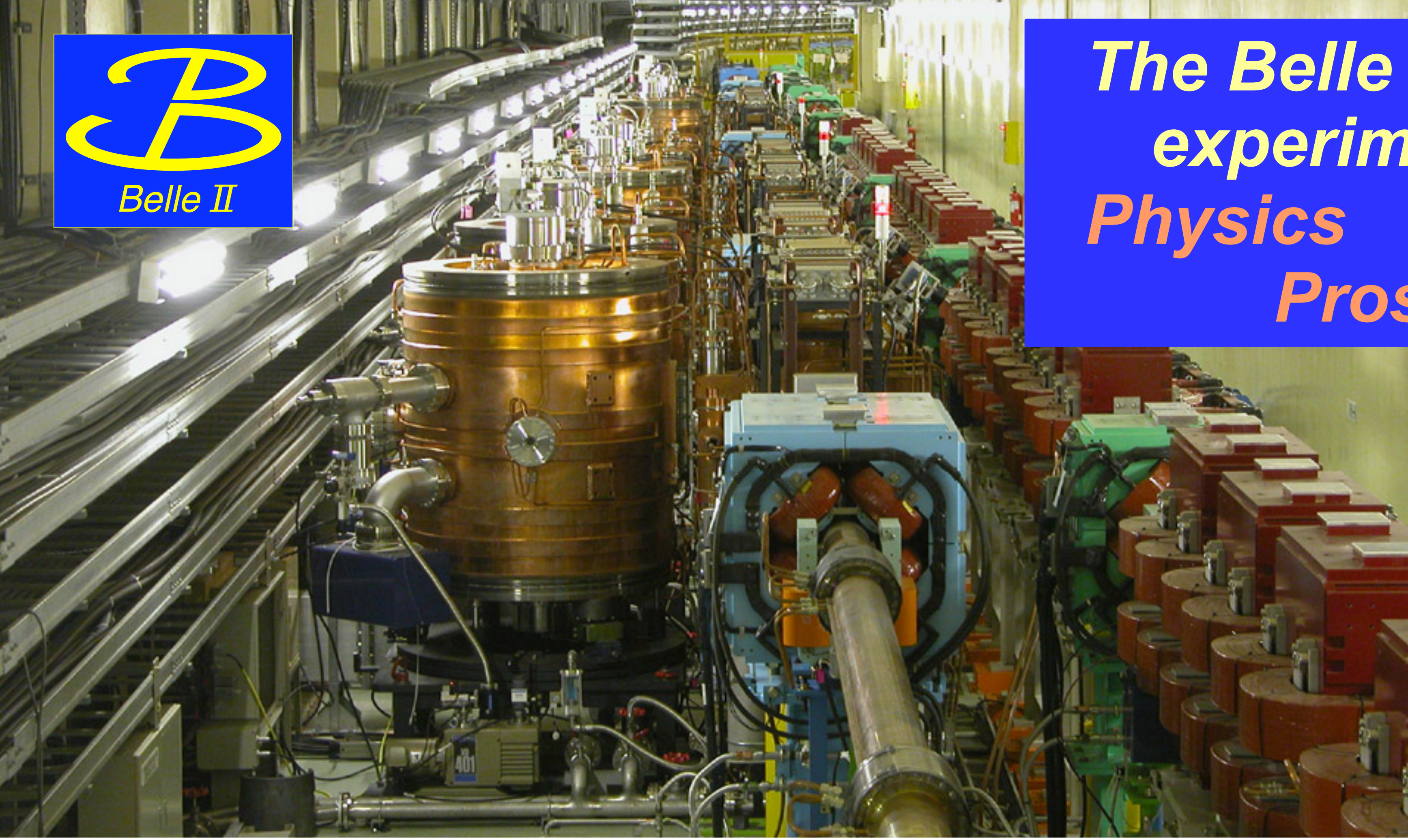

Belle II

The Belle II experiment: Physics Prospects

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Workshop on Tau-Charm at High Luminosity
26-31 May 2013
La Biodola, Isola d'Elba, Italy

- *motivation*
- *KEKB upgrade*
- *Belle II detector upgrade*
- *charm physics potential*
- *τ physics potential*

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.*

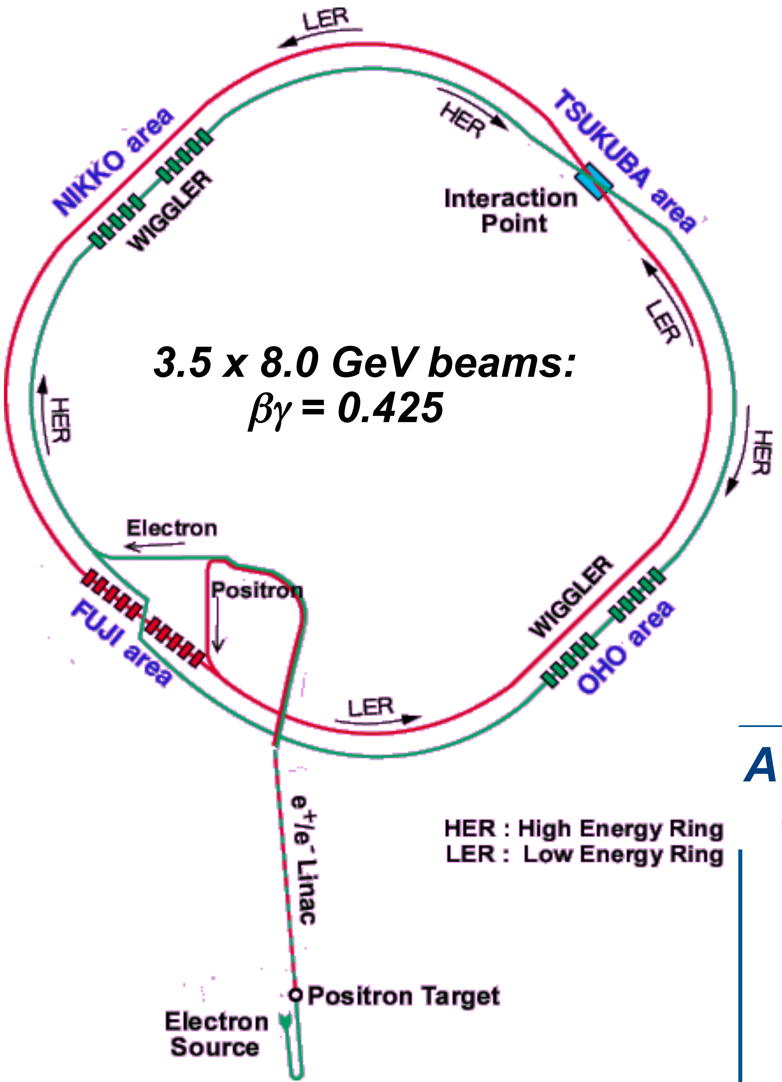
A (super) flavor factory searches for NP by phases, CP asymmetries, inclusive decay processes, rare leptonic decays, absolute branching fractions. There is a wide range of observables with which to confront theory.

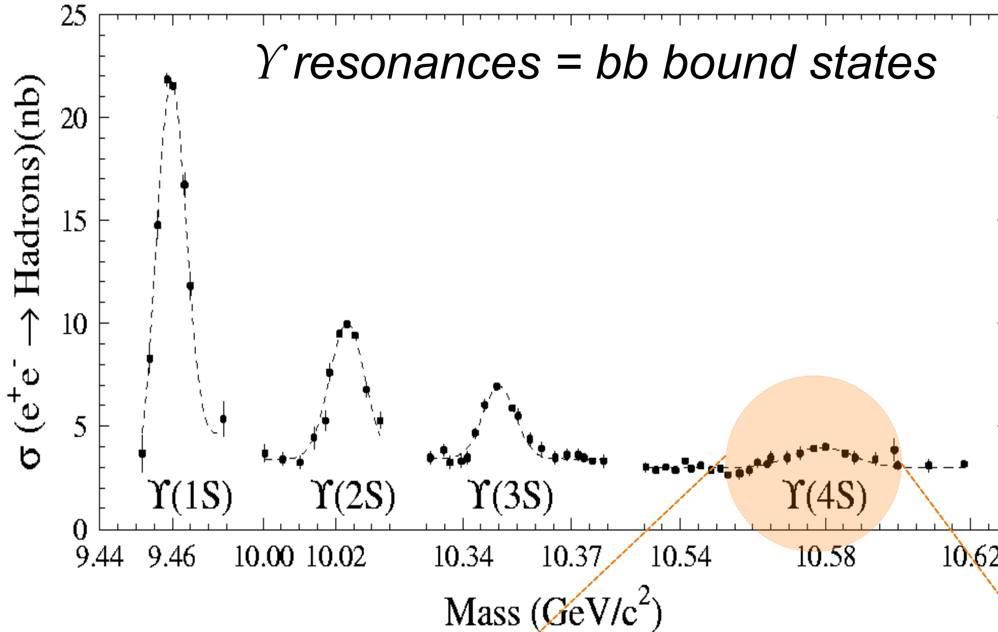
Why an e^+e^- Machine?

- *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.*

Belle and Belle II run at KEKB:

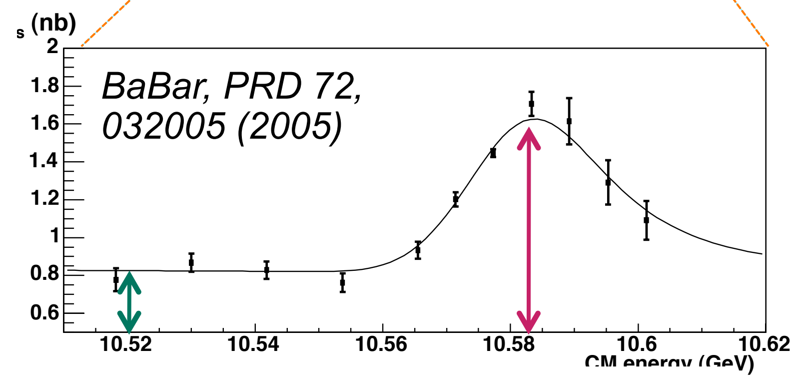
KEKB collider:





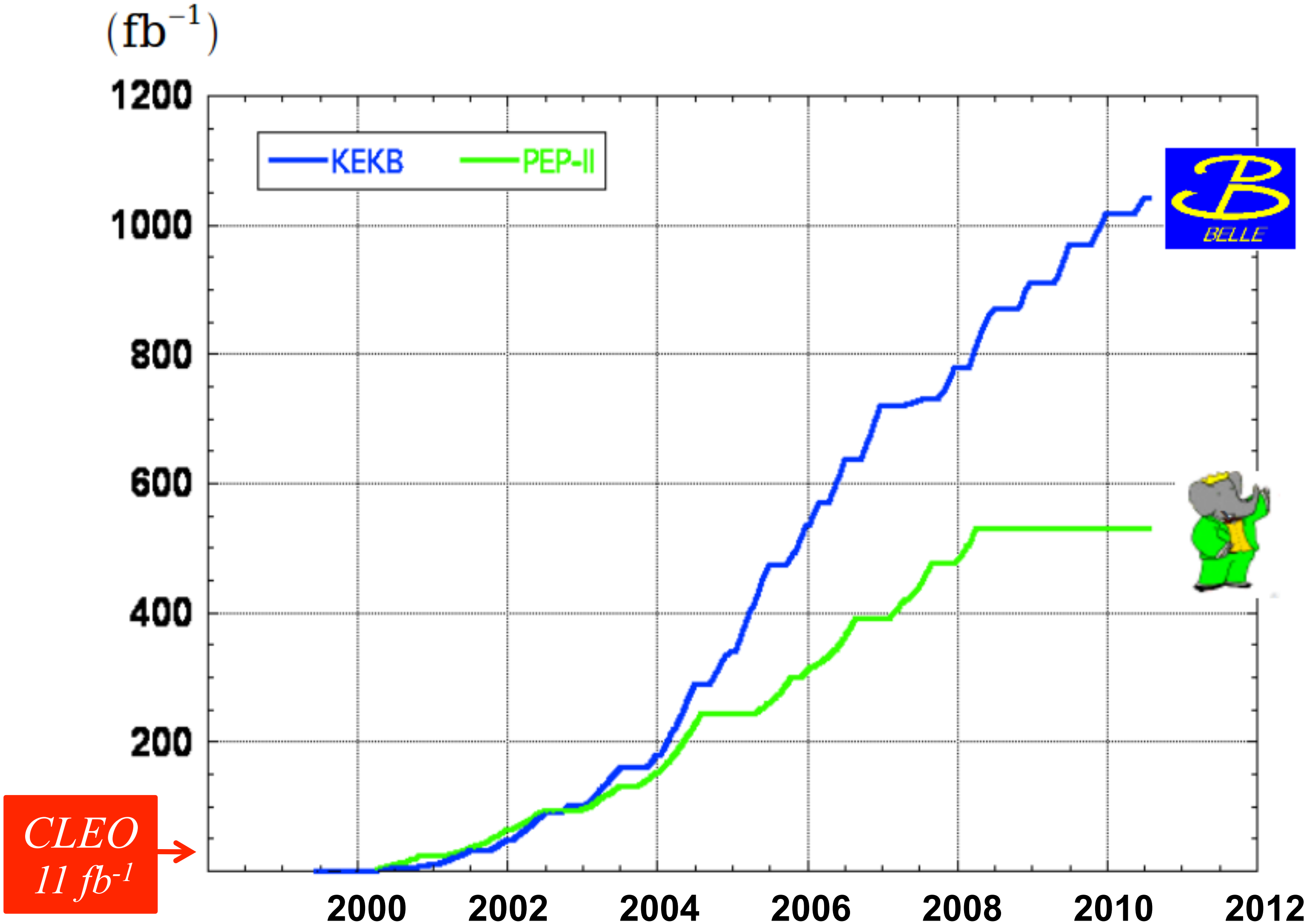
At ϒ(4S) resonance:
($\sqrt{s}$ = 10.579 GeV)

$\sigma(b\bar{b}) \approx 1.1$ nb
$\sigma(c\bar{c}) \approx 1.3$ nb
$\sigma(u\bar{u}) \approx 1.4$ nb
$\sigma(d\bar{d},s\bar{s}) \approx 0.3$ nb



off-resonance *on-resonance*

The Belle + BaBar Era



> 1 ab^{-1}

On resonance:

$\Upsilon(5S)$: 121 fb^{-1}

$\Upsilon(4S)$: 711 fb^{-1}

$\Upsilon(3S)$: 3 fb^{-1}

$\Upsilon(2S)$: 25 fb^{-1}

$\Upsilon(1S)$: 6 fb^{-1}

Off reson./scan:

~ 100 fb^{-1}

~ 550 fb^{-1}

On resonance:

$\Upsilon(4S)$: 433 fb^{-1}

$\Upsilon(3S)$: 30 fb^{-1}

$\Upsilon(2S)$: 14 fb^{-1}

Off resonance:

~ 54 fb^{-1}

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

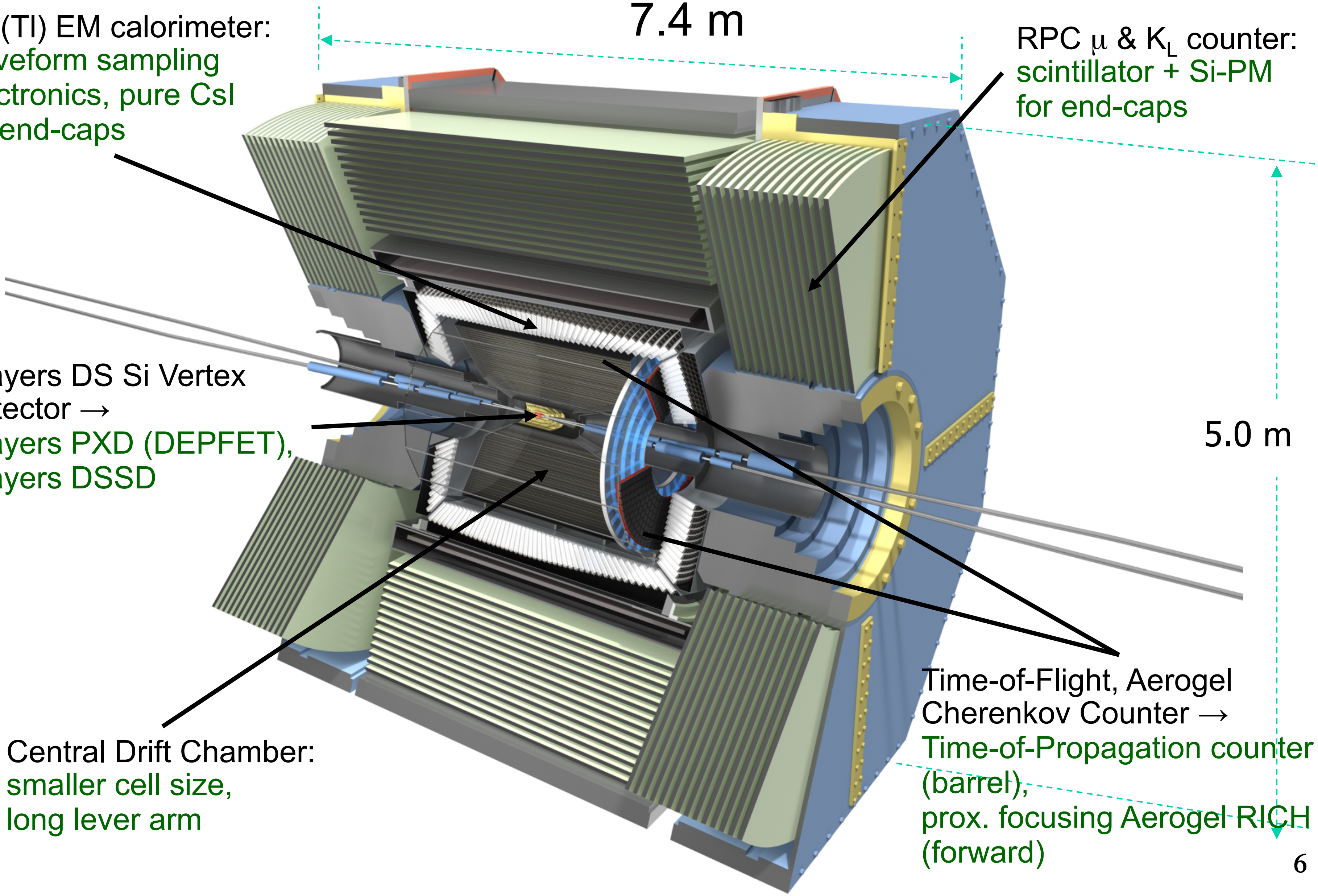
How to achieve L~10^{36}? Super-KEKB

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

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

Two options considered:	***I (current) (amps)***	***β_y (mm)***	***ξ***
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***
KEKB achieved	***1.8/1.45***	***6.5/5.9***	***0.11/0.06***

The Belle II Detector:



Belle II approval + funding status:

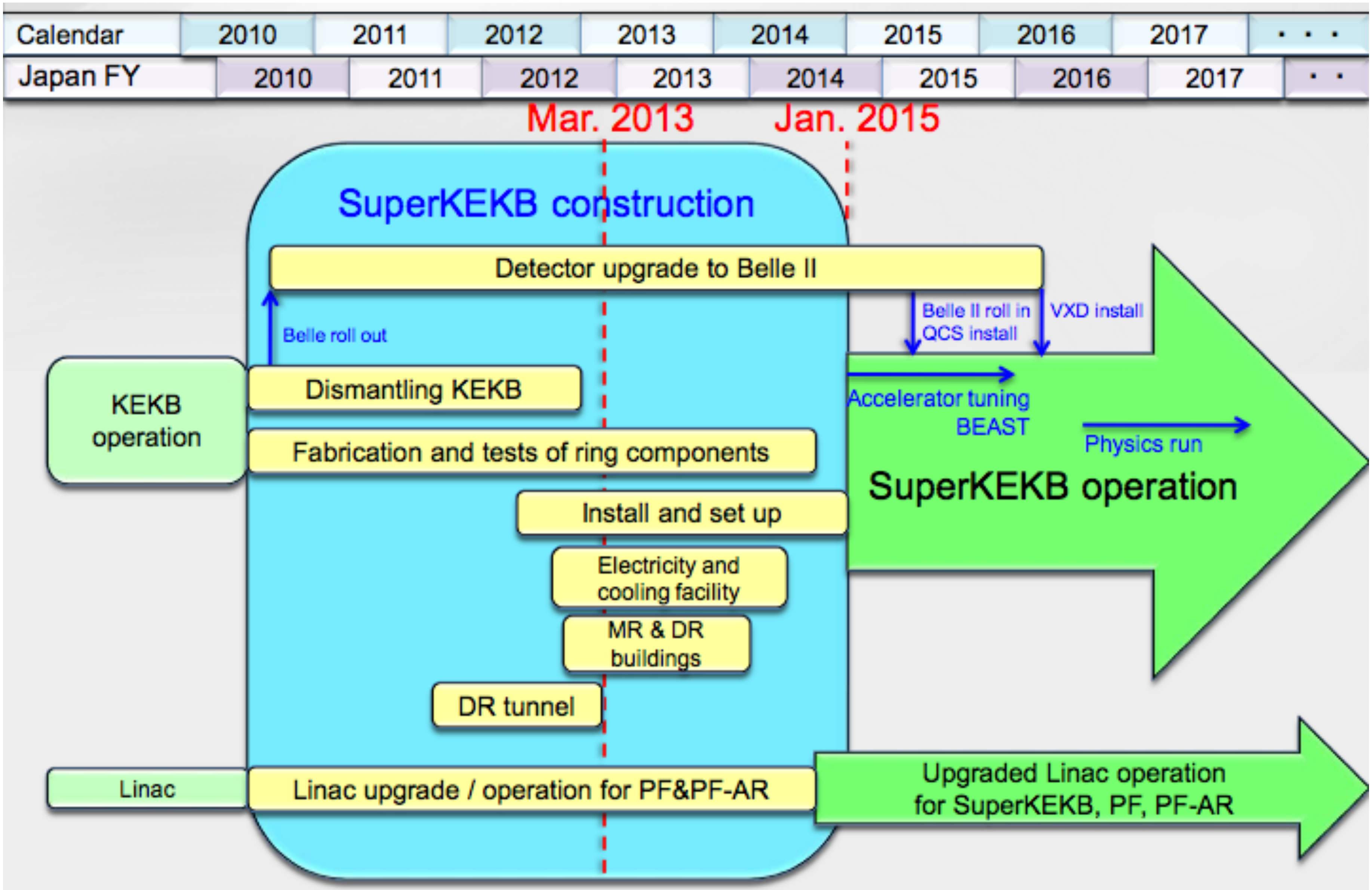
◆ The KEKB upgrade was fully approved by the Japanese government in December 2010. The KEKB groundbreaking ceremony was held in November, 2011. Super-KEKB and Belle-II are priorities of KEK.

◆ KEKB accelerator upgrade fully funded by Japan. Belle II detector half-funded by Japan, half by outside funding agencies. US contribution: quartz optics for barrel imaging time-of-propagation (iTOP) detector, and readout electronics for the iTOP and upgraded barrel muon detector (KLM). The DOE has stated that Belle II is their highest priority project for e^+e^- physics.

◆ Accelerator upgrade on schedule to be completed in 2015; first beams will circulate then. [see details in Sugimoto-san's talk]

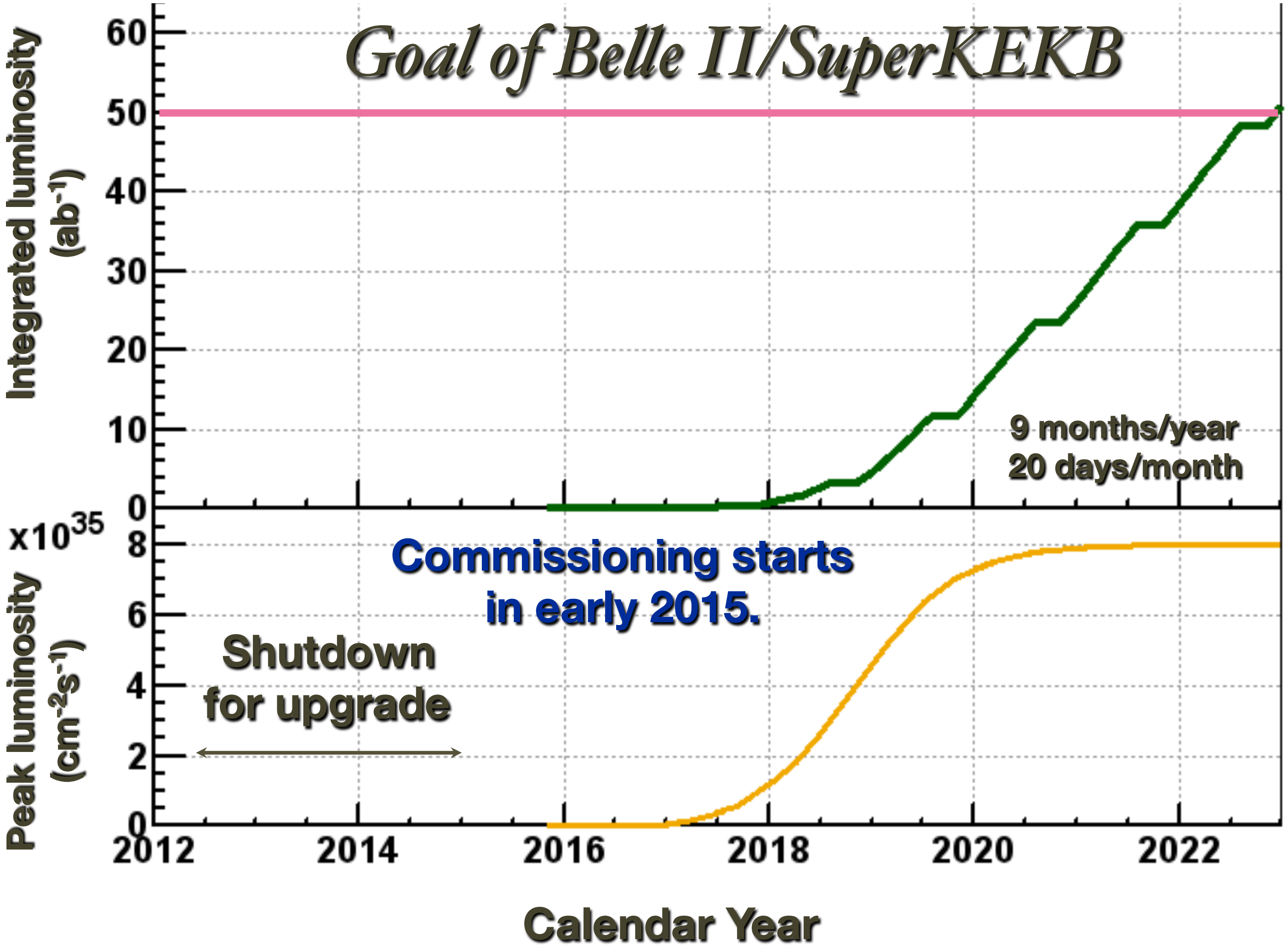
Detector commissioning scheduled to begin in spring, 2016. Numerous institutions have joined – overlap with Belle is ~50%.

SuperKEKB/Belle II Schedule



Luminosity schedule:

- *4-year shut-down for upgrade of the accelerator and detector*
- *Start machine operation in 2015, data-taking in 2016, reach 50 ab^{-1} in ~2022*



The Belle II Collaboration

http://belle2.kek.jp

21 countries/regions, 76 institutions, ~480 collaborators (~200 from Europe)

Broad Physics Program:

B Physics @ Υ(4S)

Observable	B Factories (2 ab^{-1})	Super$B$ (75 ab^{-1})
$\sin(2\beta)$ $(J/\psi\, K^0)$	0.018	0.005 (†)
$\cos(2\beta)$ $(J/\psi\, K^{*0})$	0.30	0.05
$\sin(2\beta)$ (Dh^0)	0.10	0.02
$\cos(2\beta)$ (Dh^0)	0.20	0.04
$S(J/\psi\, \pi^0)$	0.10	0.02
$S(D^+D^-)$	0.20	0.03
$S(\phi K^0)$	0.13	0.02 (∗)
$S(\eta' K^0)$	0.05	0.01 (∗)
$S(K^0_S K^0_S K^0_S)$	0.15	0.02 (∗)
$S(K^0_S \pi^0)$	0.15	0.02 (∗)
$S(\omega K^0_S)$	0.17	0.03 (∗)
$S(f_0 K^0_S)$	0.12	0.02 (∗)
γ $(B \to DK,\, D \to CP$ eigenstates$)$	$\sim 15^\circ$	2.5°
γ $(B \to DK,\, D \to$ suppressed states$)$	$\sim 12^\circ$	2.0°
γ $(B \to DK,\, D \to$ multibody states$)$	$\sim 9^\circ$	1.5°
γ $(B \to DK$, combined$)$	$\sim 6^\circ$	1–2°
α $(B \to \pi\pi)$	$\sim 16^\circ$	3°
α $(B \to \rho\rho)$	$\sim 7^\circ$	1–2° (∗)
α $(B \to \rho\pi)$	$\sim 12^\circ$	2°
α (combined)	$\sim 6^\circ$	1–2° (∗)
$2\beta+\gamma$ $(D^{(*)\pm}\pi^\mp,\, D^\pm K^0_S \pi^\mp)$	20°	5°

Observable	B Factories (2 ab^{-1})	Super$B$ (75 ab^{-1})
$\lvert V_{cb}\rvert$ (exclusive)	4% (∗)	1.0% (∗)
$\lvert V_{cb}\rvert$ (inclusive)	1% (∗)	0.5% (∗)
$\lvert V_{ub}\rvert$ (exclusive)	8% (∗)	3.0% (∗)
$\lvert V_{ub}\rvert$ (inclusive)	8% (∗)	2.0% (∗)
$\mathcal{B}(B \to \tau\nu)$	20%	4% (†)
$\mathcal{B}(B \to \mu\nu)$	visible	5%
$\mathcal{B}(B \to D\tau\nu)$	10%	2%
$\mathcal{B}(B \to \rho\gamma)$	15%	3% (†)
$\mathcal{B}(B \to \omega\gamma)$	30%	5%
$A_{CP}(B \to K^*\gamma)$	0.007 (†)	0.004 († ∗)
$A_{CP}(B \to \rho\gamma)$	~ 0.20	0.05
$A_{CP}(b \to s\gamma)$	0.012 (†)	0.004 (†)
$A_{CP}(b \to (s+d)\gamma)$	0.03	0.006 (†)
$S(K^0_S \pi^0 \gamma)$	0.15	0.02 (∗)
$S(\rho^0\gamma)$	possible	0.10
$A_{CP}(B \to K^*\ell\ell)$	7%	1%
$A^{FB}(B \to K^*\ell\ell)s_0$	25%	9%
$A^{FB}(B \to X_s\ell\ell)s_0$	35%	5%
$\mathcal{B}(B \to K\nu\bar{\nu})$	visible	20%
$\mathcal{B}(B \to \pi\nu\bar{\nu})$	–	possible

Charm mixing and CPV

Mode	Observable	$\Upsilon(4S)$ (75 ab^{-1})	$\psi(3770)$ (300 fb^{-1})
$D^0 \to K^+\pi^-$	x'^2	3×10^{-5}	
	y'	7×10^{-4}	
$D^0 \to K^+K^-$	y_{CP}	5×10^{-4}	
$D^0 \to K^0_S \pi^+\pi^-$	x	4.9×10^{-4}	
	y	3.5×10^{-4}	
	$\lvert q/p\rvert$	3×10^{-2}	
	ϕ	2°	
$\psi(3770) \to D^0\overline{D}^0$	x^2		$(1-2) \times 10^{-5}$
	y		$(1-2) \times 10^{-3}$
	$\cos\delta$		$(0.01-0.02)$

B_s Physics @ Υ(5S)

Observable	Error with 1 ab^{-1}	Error with 30 ab^{-1}
$\Delta\Gamma$	0.16 ps^{-1}	0.03 ps^{-1}
Γ	0.07 ps^{-1}	0.01 ps^{-1}
β_s from angular analysis	20°	8°
$A^s_{\rm SL}$	0.006	0.004
$A_{\rm CH}$	0.004	0.004
$\mathcal{B}(B_s \to \mu^+\mu^-)$	-	$< 8 \times 10^{-9}$
$\lvert V_{td}/V_{ts}\rvert$	0.08	0.017
$\mathcal{B}(B_s \to \gamma\gamma)$	38%	7%
β_s from $J/\psi\phi$	10°	3°
β_s from $B_s \to K^0\bar{K}^0$	24°	11°

+ τ decays, rare D decays, D_{sJ}, X, Y, Z studies, etc.

Physics Landscape:

charm physics:

- D^0-$\bar{D}^0$ Mixing and CP Violation
- Direct CP Violation
- Excited $D_{(s)}$ Mesons
- Semileptonic Decays
- CP and T-violating Asymmetries
- D_s Decay Constant f_{Ds}
- Two-body Hadronic D^0 Decays
- Charm Baryons
- Rare and Forbidden Decays
- X, Y, Z states, charm structure

τ physics:

- hadronic branching fractions
- $\mu\nu$ / $e\nu$ branching fractions (tests of lepton universality)
- $|V_{us}|$ determination
- Lepton-Flavor-Violating (LFV) upper limits

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

	CDF		BELLE	CLEO	LHCb	Belle II	
√		√	√	√	√	√	• **Wrong-sign semileptonic $D^0(t) \to K^+ l^- \nu$** measures x^2+y^2, no DCS contamination
√	√	√	√		√	√	• **Wrong-sign hadronic $D^0(t) \to K^+\pi^-$** measures $x' = x\cos\delta + y\sin\delta$, $y' = y\cos\delta - x\sin\delta$
√		√	√	√	√	√	• **Decays to CP eigenstates: $D^0(t) \to K^+K^-, \pi^+\pi^-$** measures y_{CP} , A_K, A_π
		√	√		√	√	• **Dalitz plot analysis of $D^0(t) \to K^0\pi^+\pi^-$** measures x, y
		√				√	• **Dalitz plot analysis of $D^0 \to K^+\pi^-\pi^0$** measures x'', y''
		√	√		√	√	• **Dalitz plot analysis of $D^0 \to K^0K^+K^-$** measures y_{CP} (CLEO, Belle)
				√			• **Quantum correl. in $e^+e^- \to \psi(3770) \to D^0\bar{D}^0(n\pi^0)$** measures x^2, y, R_D , $\cos\delta$. $\sin\delta$

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

$$\lambda = \frac{q}{p}\frac{\bar{\mathcal{A}}_f}{\mathcal{A}_f} \equiv \left|\frac{q}{p}\right| \sqrt{R_D}\, e^{i(\phi+\delta)}$$

$$\bar{\lambda} = \frac{p}{q}\frac{\mathcal{A}_{\bar{f}}}{\bar{\mathcal{A}}_{\bar{f}}} \equiv \left|\frac{p}{q}\right| \sqrt{\bar{R}_D}\, e^{i(-\phi+\delta)}$$

$$\frac{N(D^0\to f)}{dt} \propto e^{-\bar{\Gamma} t}\left\{R_D + \left|\frac{q}{p}\right|\sqrt{R_D}\,[\,y\cos(\phi+\delta) - x\sin(\phi+\delta)\,]\,(\bar{\Gamma}t) + \left|\frac{q}{p}\right|^2 \frac{(x^2+y^2)}{4}(\bar{\Gamma}\,t)^2\right.$$

$$= e^{-\bar{\Gamma} t}\left\{R_D + \left|\frac{q}{p}\right|\sqrt{R_D}(y'\cos\phi - x'\sin\phi)(\bar{\Gamma}t) + \left|\frac{q}{p}\right|^2 \frac{(x'^2+y'^2)}{4}(\bar{\Gamma}\,t)^2\right\}$$

$$\frac{N(\bar{D}^0\to \bar{f})}{dt} \propto e^{-\bar{\Gamma} t}\left\{\bar{R}_D + \left|\frac{p}{q}\right|\sqrt{\bar{R}_D}y'\cos\phi + x'\sin\phi)(\bar{\Gamma}t) + \left|\frac{p}{q}\right|^2 \frac{(x'^2+y'^2)}{4}(\bar{\Gamma}\,t)^2\right\}$$

$$x' \equiv x\cos\delta + y\sin\delta \qquad\qquad y' \equiv y\cos\delta - x\sin\delta$$

$\lvert q/p\rvert$	CPV in mixing
$A_D \equiv (R_D - \bar{R}_D)/(R_D + \bar{R}_D)$	CPV in the decay amplitude (direct CPV)
ϕ	CPV in mixed/direct interference

No CPV ($R_D = \bar{R}_D$, $|q/p| = 1$, and $\phi = 0$):

$$\frac{dN(D^0\to f)}{dt} \propto e^{-\bar{\Gamma} t}\left\{R_D + \sqrt{R_D}\,y'(\bar{\Gamma}t) + \frac{(x'^2+y'^2)}{4}(\bar{\Gamma}\,t)^2\right\}$$

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

Expected Uncertaintes (B. Golob):

Analysis	Observable	Uncertainty (%)	
		Now ($\sim$1.5 fb^{-1})	$\mathcal{L} = 50$ ab^{-1}
$K_S^0\pi^+\pi^-$	x	0.211	0.10
	y	0.186	0.08
	$\lvert q/p \rvert$	32	9
	ϕ	0.32 rad	0.07 rad
$\pi^+\pi^-$, K^+K^-	y_{CP}	0.217	0.05
	A_Γ	0.248	0.03
	A_{CP}	0.240	0.07
$K^+\pi^-$	x'^2	0.0195	0.009
	y'	0.321	0.16
	A_D	3.5	1.7
	R_D	0.013	0.0015

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

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

Note: *statistical error and some systematics scale by luminosity, e.g., background PDF shapes, best-candidate selection bias, $\pi^{\pm}$ charge bias, etc. Other systematics do not, e.g. alignment, error on luminosity...*

Marko Staric, systematics for $D^0(t) \rightarrow K^+K^-$, $\pi^+\pi^-$ CHARM 2012:

errors do not necessarily (or fully) scale with $\mathcal{L}$

source	Δy_{CP} (%)	ΔA_{Γ} (%)
acceptance	0.050	0.044
SVD misalignments	0.060	0.041
mass window position	0.007	0.009
background	0.059	0.050
resolution function	0.030	0.002
binning	0.021	0.010
sum in quadrature	0.11	0.08

D^0-$\bar{D}^0$ mixing and CPV (global fit via HFAG)

10 parameters: $x, y, \delta, \delta_{K\pi\pi}, R_D, A_D, A_\pi, A_K, |q/p|, \varphi$

41 observables: y_{CP}, A_Γ, $(x, y, |q/p|, \varphi)_{\text{Belle } K^0_S\pi^+\pi^-}$, $(x, y)_{\text{BaBar } K^0_S h^+ h^-}$, $(R_M)_{K\ell\nu}$, $(x'', y'')_{K^+\pi^-\pi^0}$, $(R_D, x^2, y, \cos\delta, \sin\delta)_{\Psi(3770)}$, $(R_D, A_D, x'^{\pm}, y'^{\pm})_{\text{BaBar}}$, $(R_D, A_D, x'^{\pm}, y'^{\pm})_{\text{Belle}}$, $(R_D, x', y')_{\text{CDF}}$, $(R_D, x', y')_{\text{LHCb}}$, $(A_{CP}^K, A_{CP}^\pi)_{\text{BaBar}}$, $(A_{CP}^K, A_{CP}^\pi)_{\text{Belle}}$, $(A_{CP}^K - A_{CP}^\pi)_{\text{CDF}}$, $(A_{CP}^K - A_{CP}^\pi)_{\text{LHCb}(D^*)}$, $(A_{CP}^K - A_{CP}^\pi)_{\text{LHCb}(B\to D^0\mu X)}$

$$R_M = \frac{1}{2}(x^2+y^2)$$

$$2\,y_{CP} = \big(|q/p|+|p/q|\big)y\cos\phi - \big(|q/p|-|p/q|\big)x\sin\phi$$
$$2\,A_\Gamma = \big(|q/p|-|p/q|\big)y\cos\phi - \big(|q/p|+|p/q|\big)x\sin\phi$$

$$x_{K^0\pi\pi} = x$$
$$y_{K^0\pi\pi} = y$$
$$|q/p|_{K^0\pi\pi} = |q/p|$$
$$\text{Arg}\,(q/p)_{K^0\pi\pi} = \phi$$

$$\begin{pmatrix} x'' \\ y'' \end{pmatrix}_{K^+\pi^-\pi^0} = \begin{pmatrix} \cos\delta_{K\pi\pi} & \sin\delta_{K\pi\pi} \\ -\sin\delta_{K\pi\pi} & \cos\delta_{K\pi\pi} \end{pmatrix}\begin{pmatrix} x \\ y \end{pmatrix}$$

$$\begin{pmatrix} x' \\ y' \end{pmatrix} = \begin{pmatrix} \cos\delta & \sin\delta \\ -\sin\delta & \cos\delta \end{pmatrix}\begin{pmatrix} x \\ y \end{pmatrix}$$

$$A_M = \frac{|q/p|^2-|p/q|^2}{|q/p|^2+|p/q|^2}$$

$$x'^{\pm} = \left(\frac{1\pm A_M}{1\mp A_M}\right)^{1/4}(x'\cos\phi \pm y'\sin\phi)$$

$$y'^{\pm} = \left(\frac{1\pm A_M}{1\mp A_M}\right)^{1/4}(y'\cos\phi \mp x'\sin\phi)$$

$$\frac{\Gamma(D^0\to K^+\pi^-)+\Gamma(\overline{D}^0\to K^-\pi^+)}{\Gamma(D^0\to K^-\pi^+)+\Gamma(\overline{D}^0\to K^+\pi^-)} = R_D$$

$$\frac{\Gamma(D^0\to K^+\pi^-)-\Gamma(\overline{D}^0\to K^-\pi^+)}{\Gamma(D^0\to K^+\pi^-)+\Gamma(\overline{D}^0\to K^-\pi^+)} = A_D$$

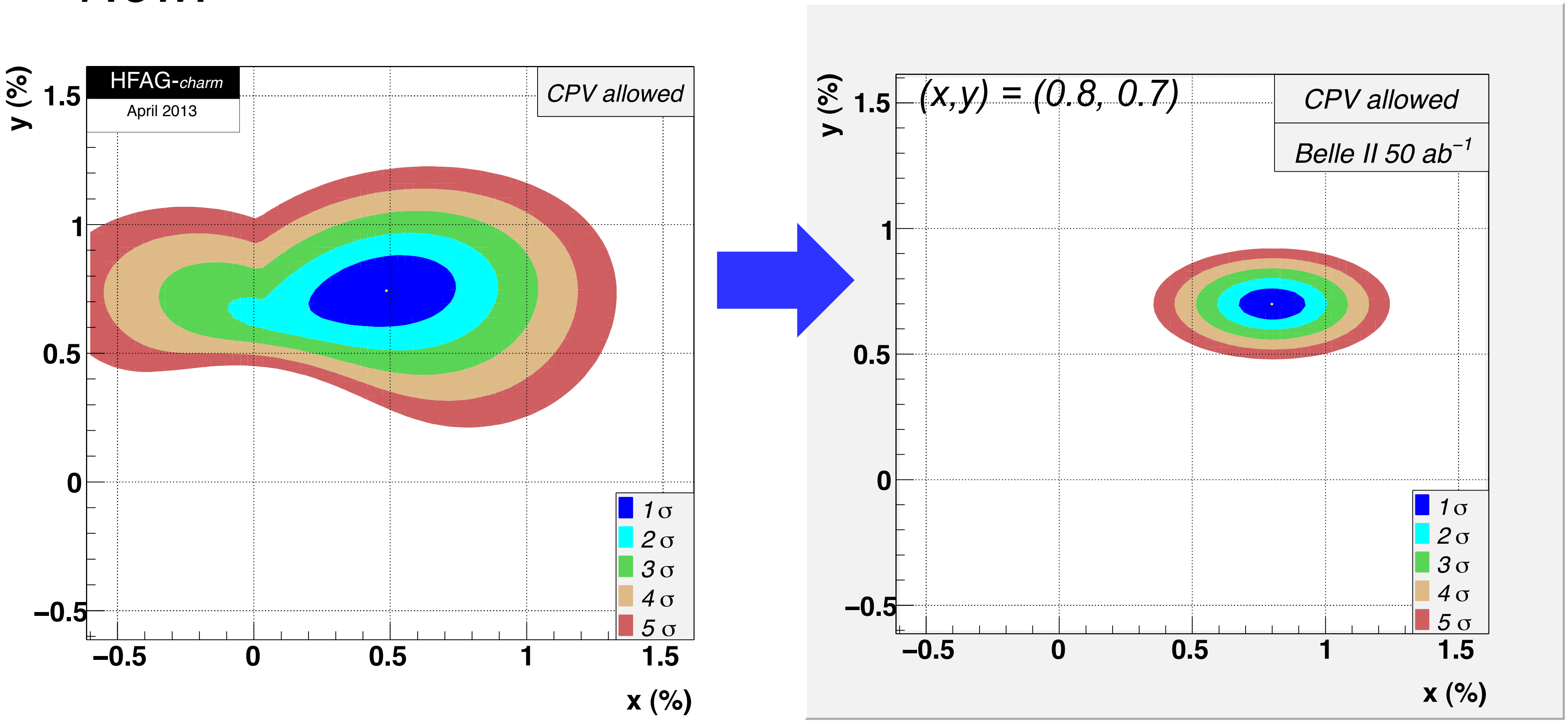
$$\frac{\Gamma(D^0\to K^+K^-)-\Gamma(\overline{D}^0\to K^+K^-)}{\Gamma(D^0\to K^+K^-)+\Gamma(\overline{D}^0\to K^+K^-)} = A_K + \frac{\langle t\rangle}{\tau_D}\mathcal{A}_{CP}^{\text{indirect}}$$

$$\frac{\Gamma(D^0\to \pi^+\pi^-)-\Gamma(\overline{D}^0\to \pi^+\pi^-)}{\Gamma(D^0\to \pi^+\pi^-)+\Gamma(\overline{D}^0\to \pi^+\pi^-)} = A_\pi + \frac{\langle t\rangle}{\tau_D}\mathcal{A}_{CP}^{\text{indirect}}$$

$$2\mathcal{A}_{CP}^{\text{indirect}} = \big(|q/p|+|p/q|\big)x\sin\phi - \big(|q/p|-|p/q|\big)y\cos\phi$$

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

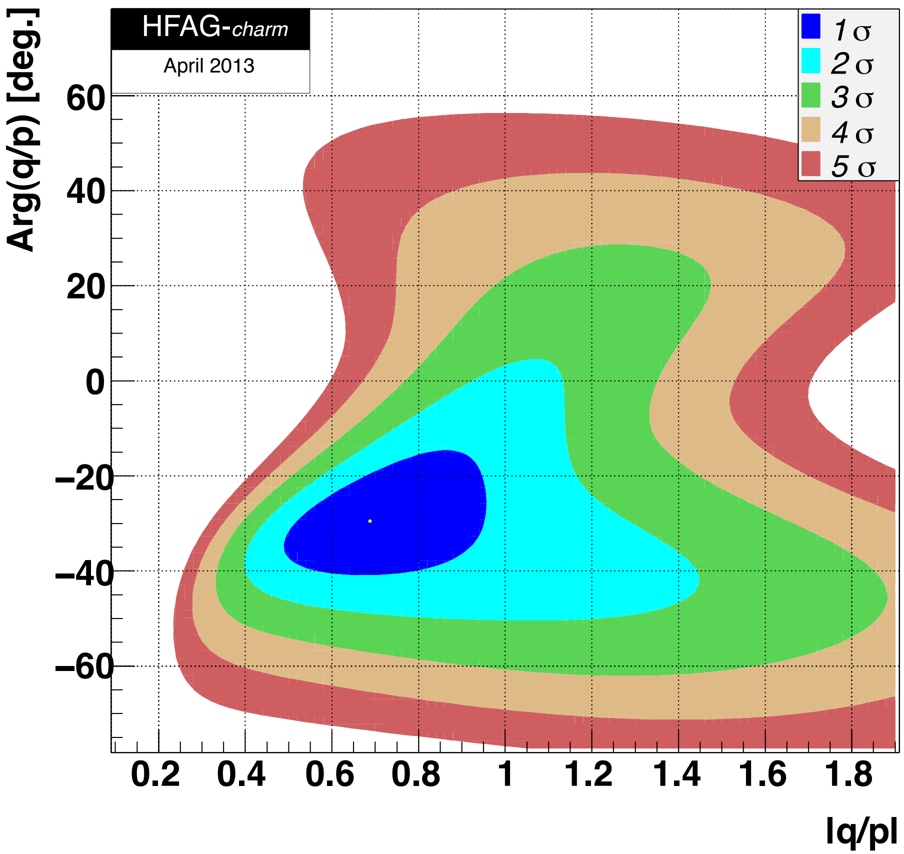
Now: 50 ab^{-1}:



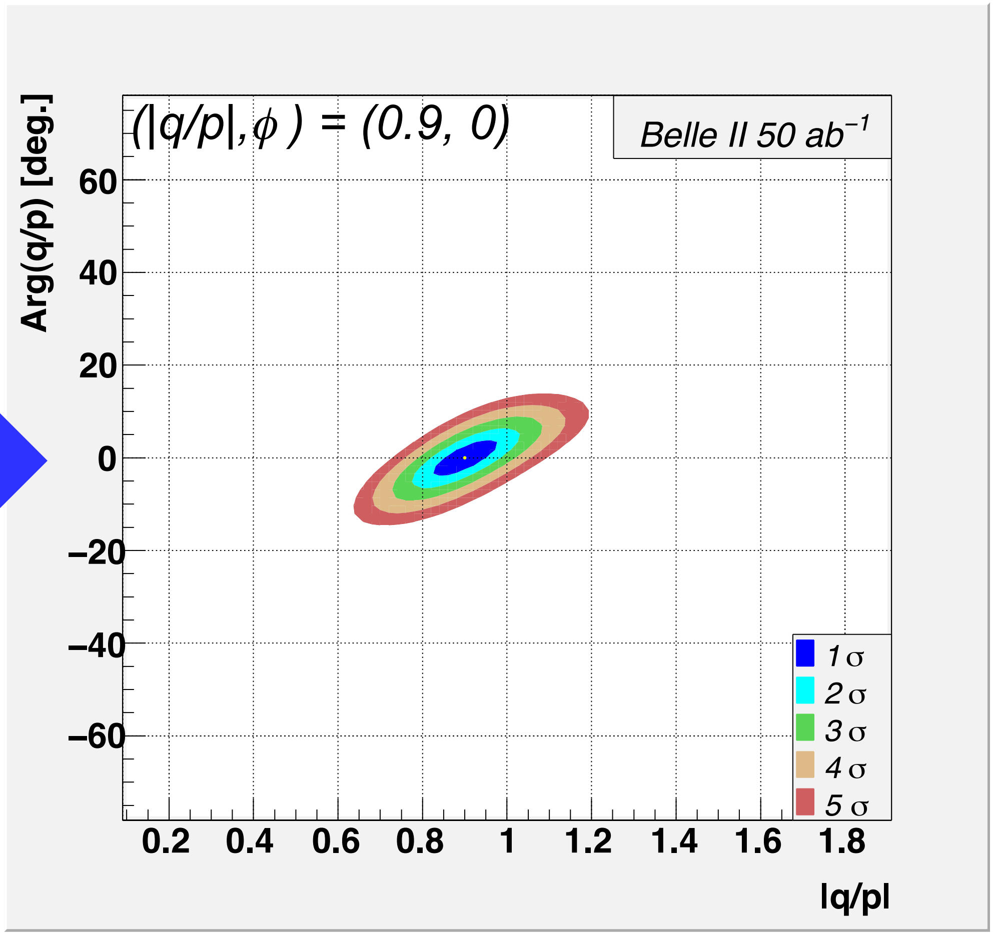
Current measurements of x, y give many constraints on NP models
[see Golowich et al., PRD76, 095009 (2007); 21 models considered, e.g., 2-Higgs doublets, left-right models, little Higgs, extra dimensions, of which 17 give constraints]

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

Now:



50 ab^{-1}:



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

Results:

Parameter	Now	Future (50 ab^{-1})
x (%)	$0.63\,^{+0.19}_{-0.20}$	± 0.08
y (%)	0.75 ± 0.12	± 0.04
δ (°)	$22.1\,^{+9.7}_{-11.1}$	$\pm 3.8°$
R_D (%)	0.3311 ± 0.0081	± 0.003
A_D (%)	-1.7 ± 2.4	± 0.70
$\|q/p\|$	$0.88\,^{+0.18}_{-0.16}$	± 0.05
ϕ (°)	$-10.1\,^{+9.5}_{-8.9}$	$\pm 2.6°$
A_π	0.36 ± 0.25	± 0.07
A_K	-0.31 ± 0.24	± 0.07

Results are conservative:

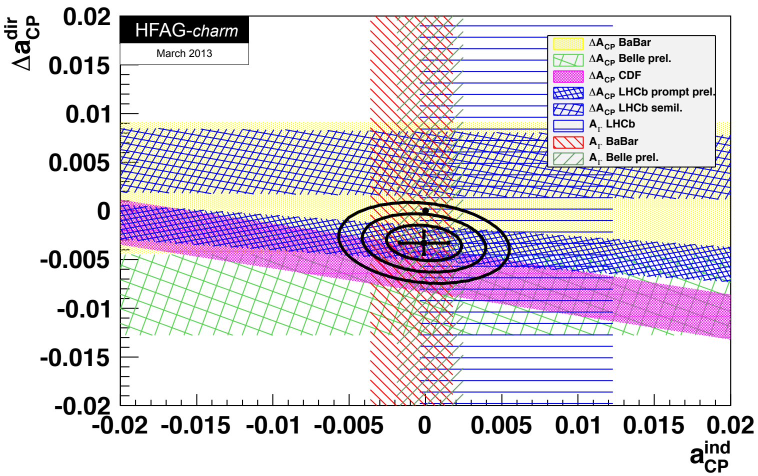
do not include $K^+\pi^-\pi^0$ and $K_S K^+ K^-$ Dalitz plot analyses, $K^+ l \nu$, $\psi(3770)$ results from BES III ...

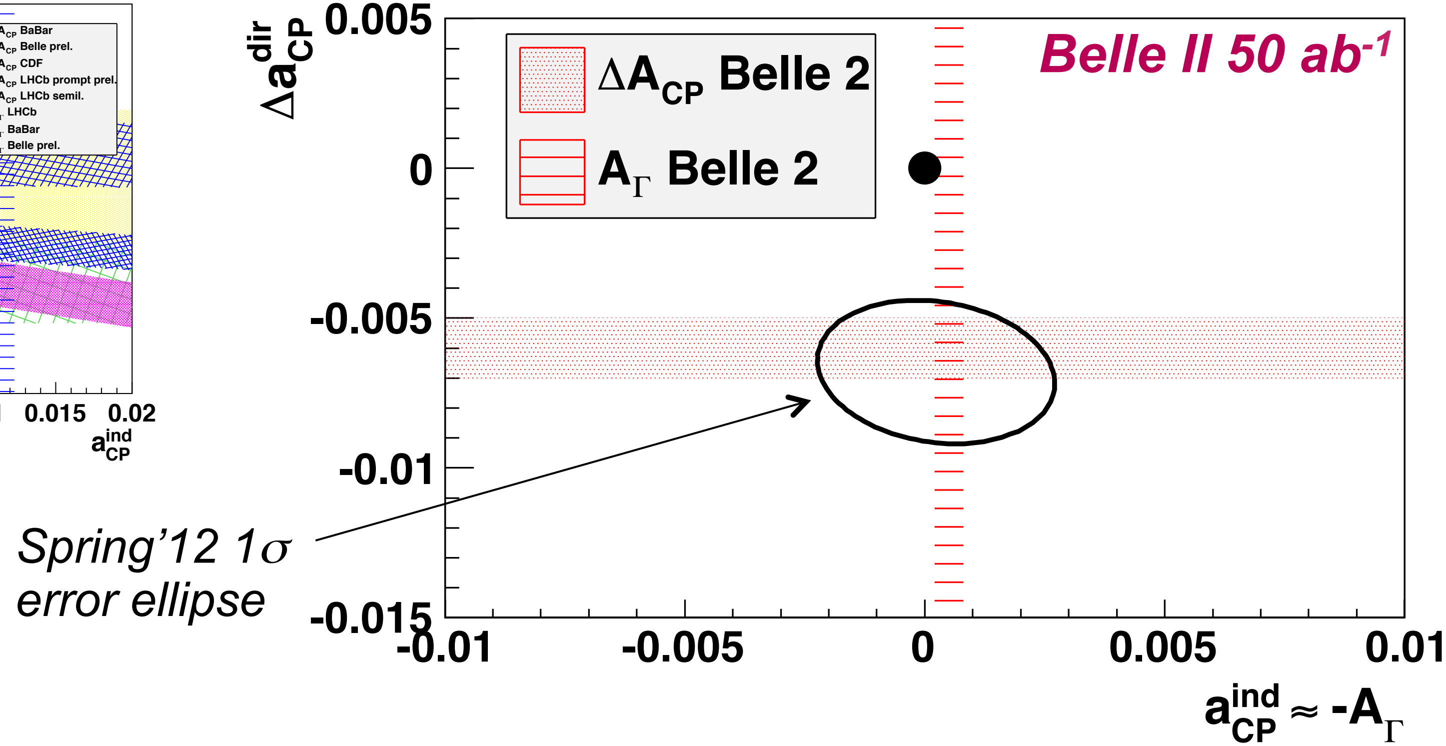
Direct CPV *(courtesy Marco Gersabeck)* :

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

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

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





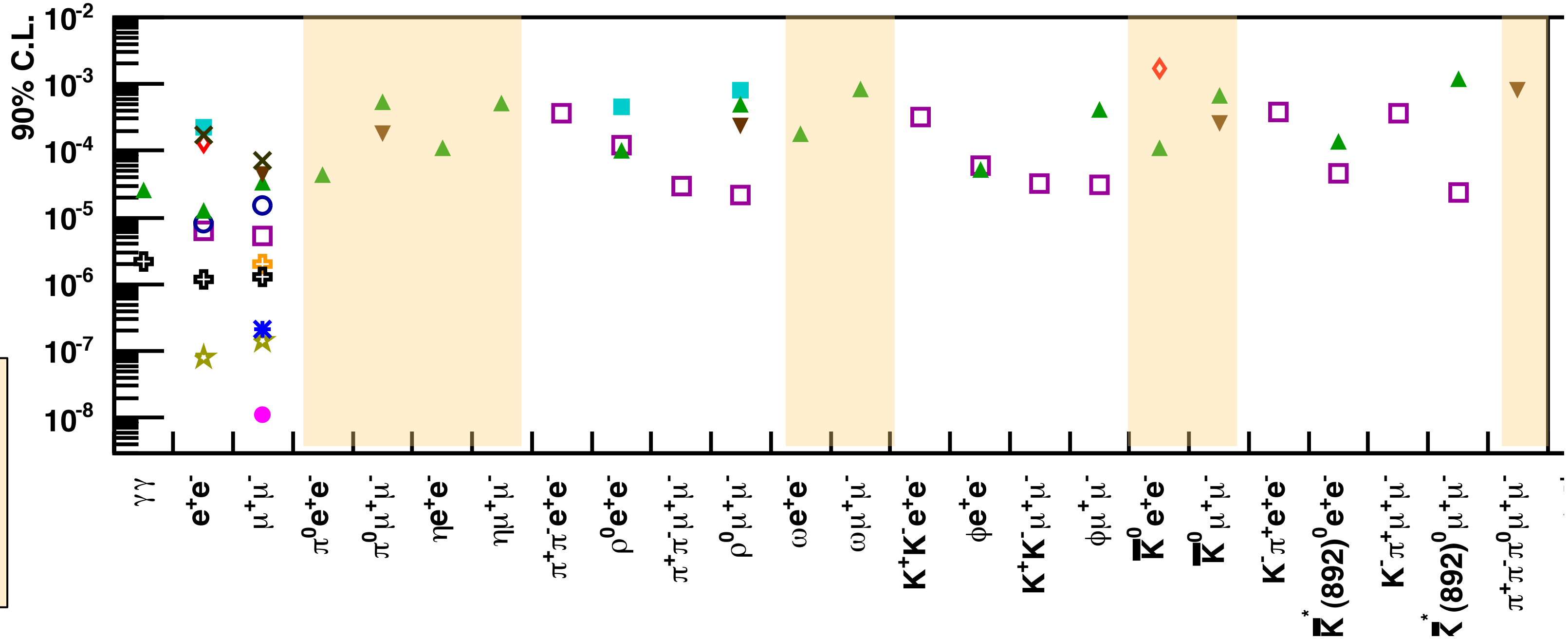
Direct CPV:

Mode	$\mathcal{L}$ [fb^{-1}]	A_{CP} [%]	Belle II with 50 ab^{-1} [%]	
$D^0 \to K^0_S \pi^0$	791	$-0.28 \pm 0.19 \pm 0.10$	± 0.05	
$D^0 \to K^0_S \eta$	791	$+0.54 \pm 0.51 \pm 0.16$	± 0.10	
$D^0 \to K^0_S \eta'$	791	$+0.98 \pm 0.67 \pm 0.14$	± 0.10	
$D^0 \to \pi^+\pi^-$	976	$0.55 \pm 0.36 \pm 0.09$	± 0.07	M. Staric, arXiv:1212.1975
$D^0 \to K^+K^-$	976	$-0.32 \pm 0.21 \pm 0.09$	± 0.05	
$D^0 \to \pi^+\pi^-\pi^0$	532	$+0.43 \pm 1.30$		
$D^0 \to K^+\pi^-\pi^0$	281	-0.6 ± 5.3		
$D^0 \to K^+\pi^-\pi^+\pi^-$	281	-1.8 ± 4.4		
$D^+ \to \phi\pi^+$	955	$+0.51 \pm 0.28 \pm 0.05$	± 0.05	
$D^+ \to \eta\pi^+$	791	$+1.74 \pm 1.13 \pm 0.19$	± 0.20	
$D^+ \to \eta'\pi^+$	791	$-0.12 \pm 1.12 \pm 0.17$	± 0.20	
$D^+ \to K^0_S\pi^+$	977	$-0.024 \pm 0.094 \pm 0.067$	± 0.05	Ko et al., PRL 109, 021601 (2012); 119903 (2012)
$D^+ \to K^0_S K^+$	977	$0.08 \pm 0.28 \pm 0.14$	± 0.10	
$D^+_s \to K^0_S\pi^+$	673	$+5.45 \pm 2.50 \pm 0.33$	± 0.30	
$D^+_s \to K^0_S K^+$	673	$+0.12 \pm 0.36 \pm 0.22$	± 0.10	

Rare/Forbidden Decays:

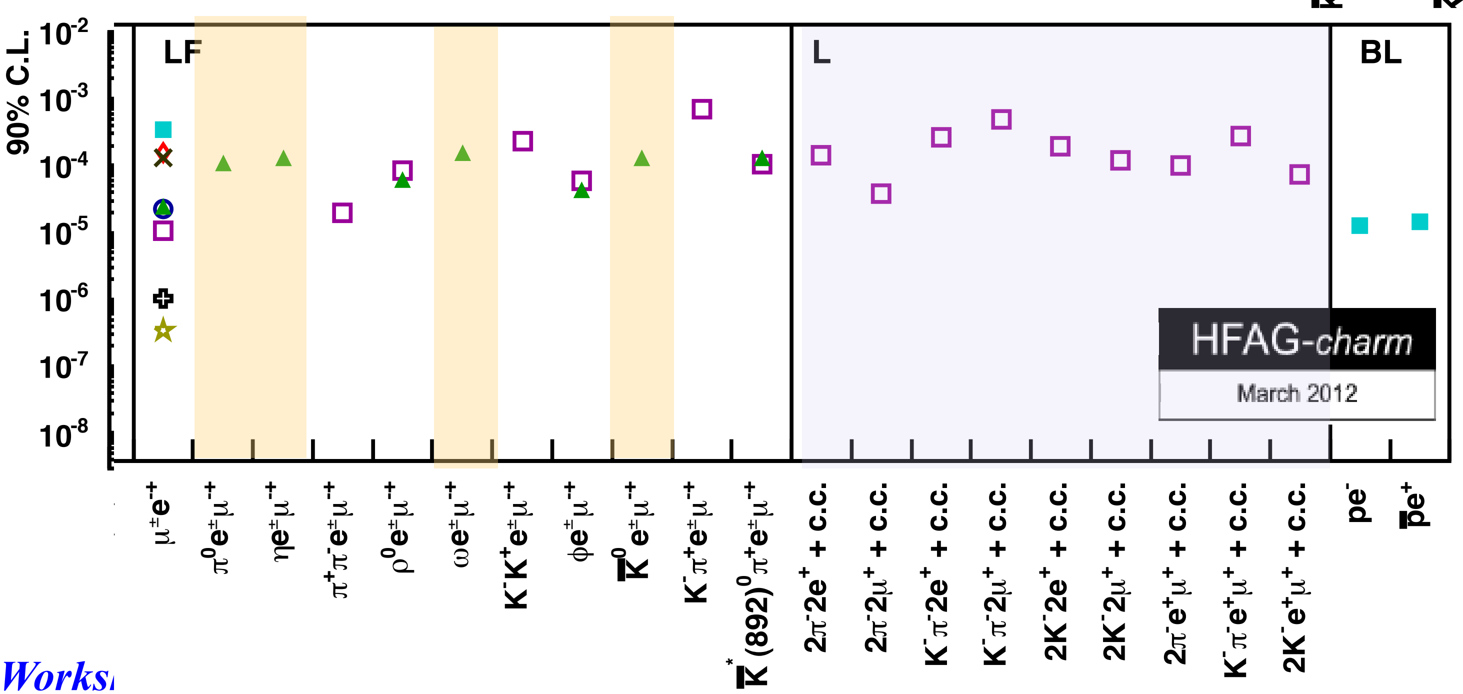
www.slac.stanford.edu/xorg/hfag/charm/ICHEP12/Rare/rare_charm.html

flavor-changing neutral currents



modes containing π^0's *(can only be done @ e^+e^-)*

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



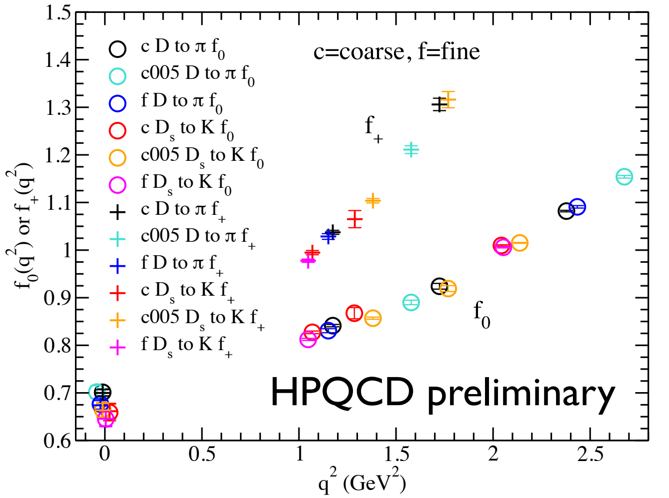
Semileptonic Decays:

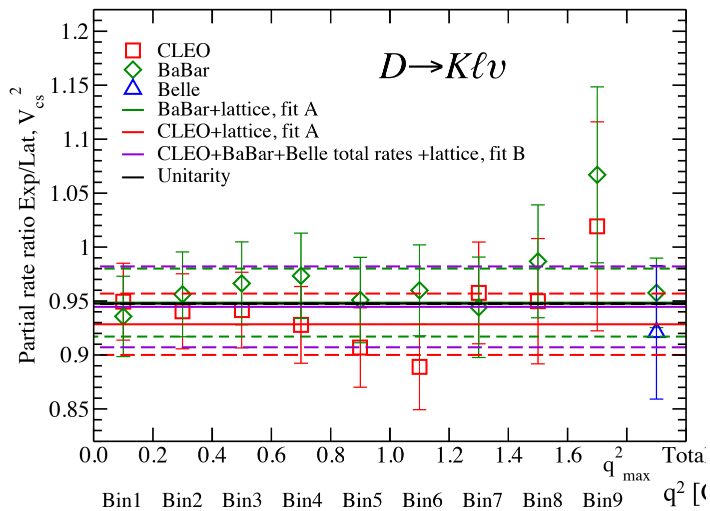
$D \to (K,\pi)\, \ell^+ \nu$:

$$\frac{d\Gamma}{dq^2} = \frac{G_F^2\, p_h^3}{24\pi^3} \left|V_{cs,cd}\right|^2 \left|f_+(q^2)\right|^2$$

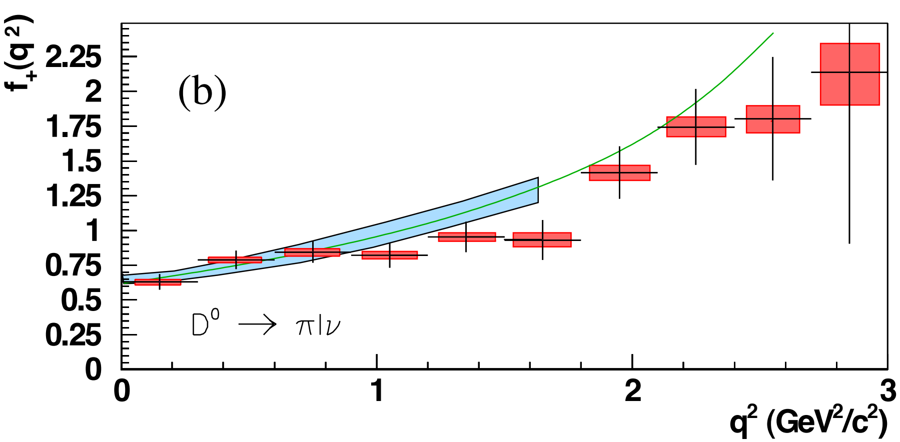
⇒ Take $f_+(q^2)$ form factor from lattice, determine V_{cs} or V_{cd}

Jonna Koponen:
V_{cs} = 0.965(14)





Belle II 5 ab⁻¹ (~2018):



⇒ *expect substantial improvement in measuring q^2 spectrum, should notably improve V_{cs} , V_{cd}*

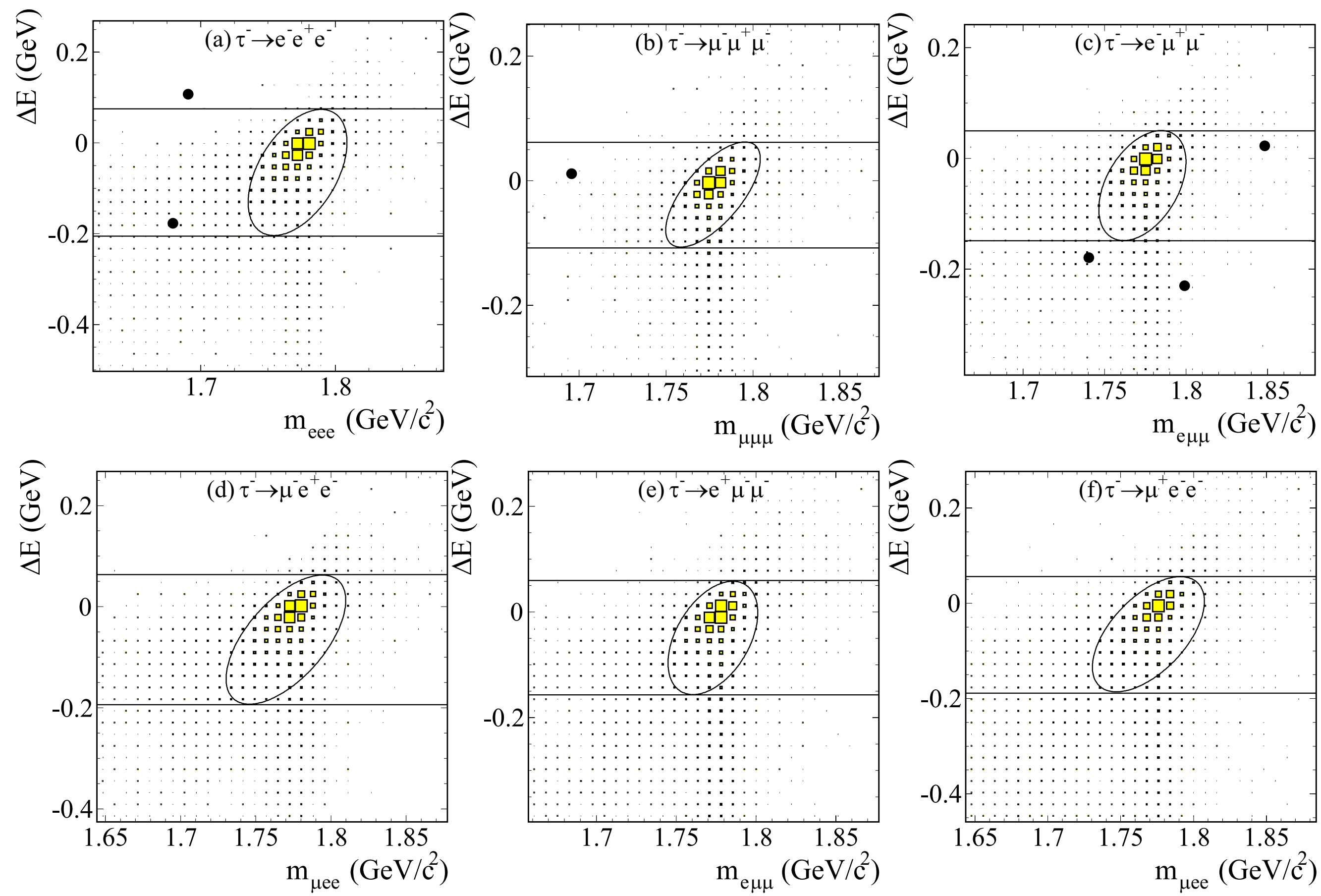
τ Physics at Belle

Belle has searched for and set upper limits on 48 LFV (lepton-flavor-violating) decays, e.g., $\tau^+ \to \ell^+\ell^+\ell^-$

782 fb^{-1} *Hayasaka et al., PLB 687, 139 (2010)*

Modes are especially clean due to good lepton ID and numerous kinematic constraints.

Mode	ε (%)	UL (x10^{-8})
$e^-e^+e^-$	6.0	**2.7**
$\mu^-\mu^+\mu^-$	7.6	**2.1**
$e^-\mu^+\mu^-$	6.1	**2.7**
$\mu^-e^+e^-$	9.3	**1.8**
$\mu^-e^+\mu^-$	10.1	**1.7**
$e^-\mu^+e^-$	11.5	**1.5**



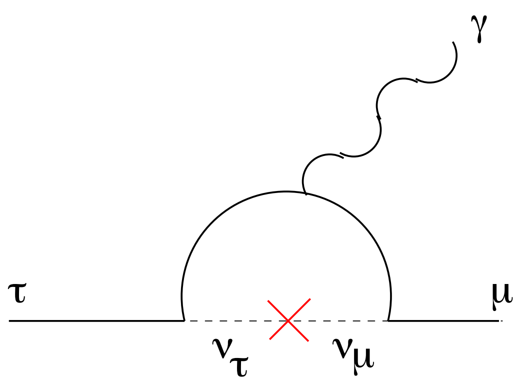
Limits currently at 1-2 x 10^{-8}.
Negligible background ⇒ ideal for Belle II

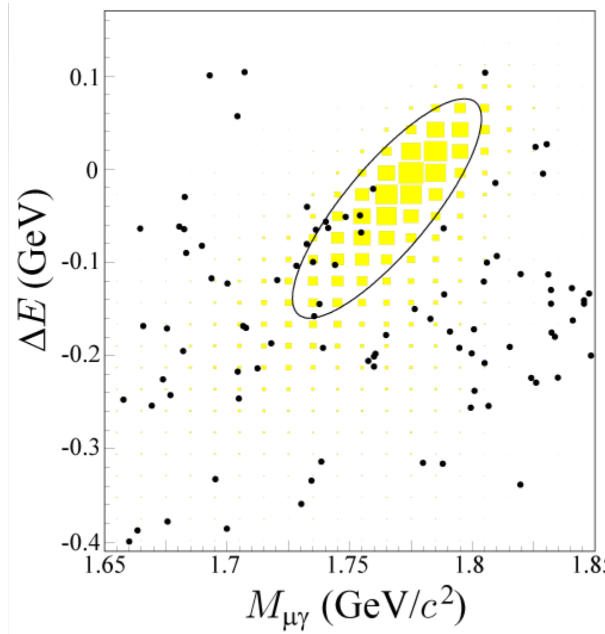
τ Physics at Belle

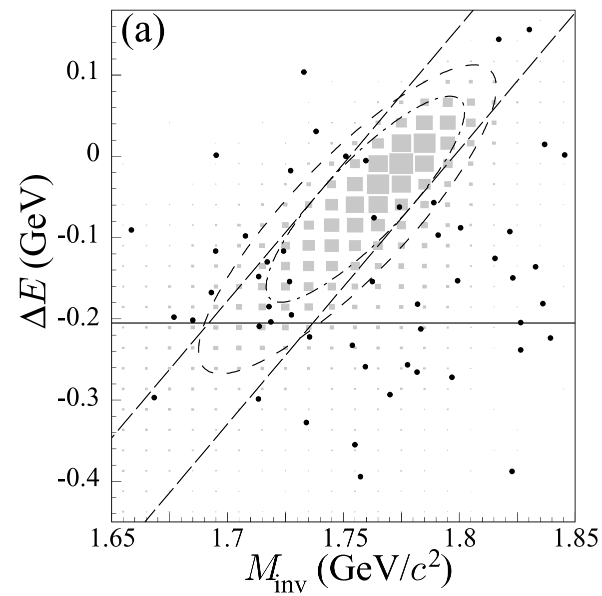
Another mode: $\tau^+ \to \ell^+\gamma$ **545 fb^{-1}** *Hayasaka et al., PLB 666, 16 (2008)*

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

B < 4.5 x 10^{-8} (90% CL)





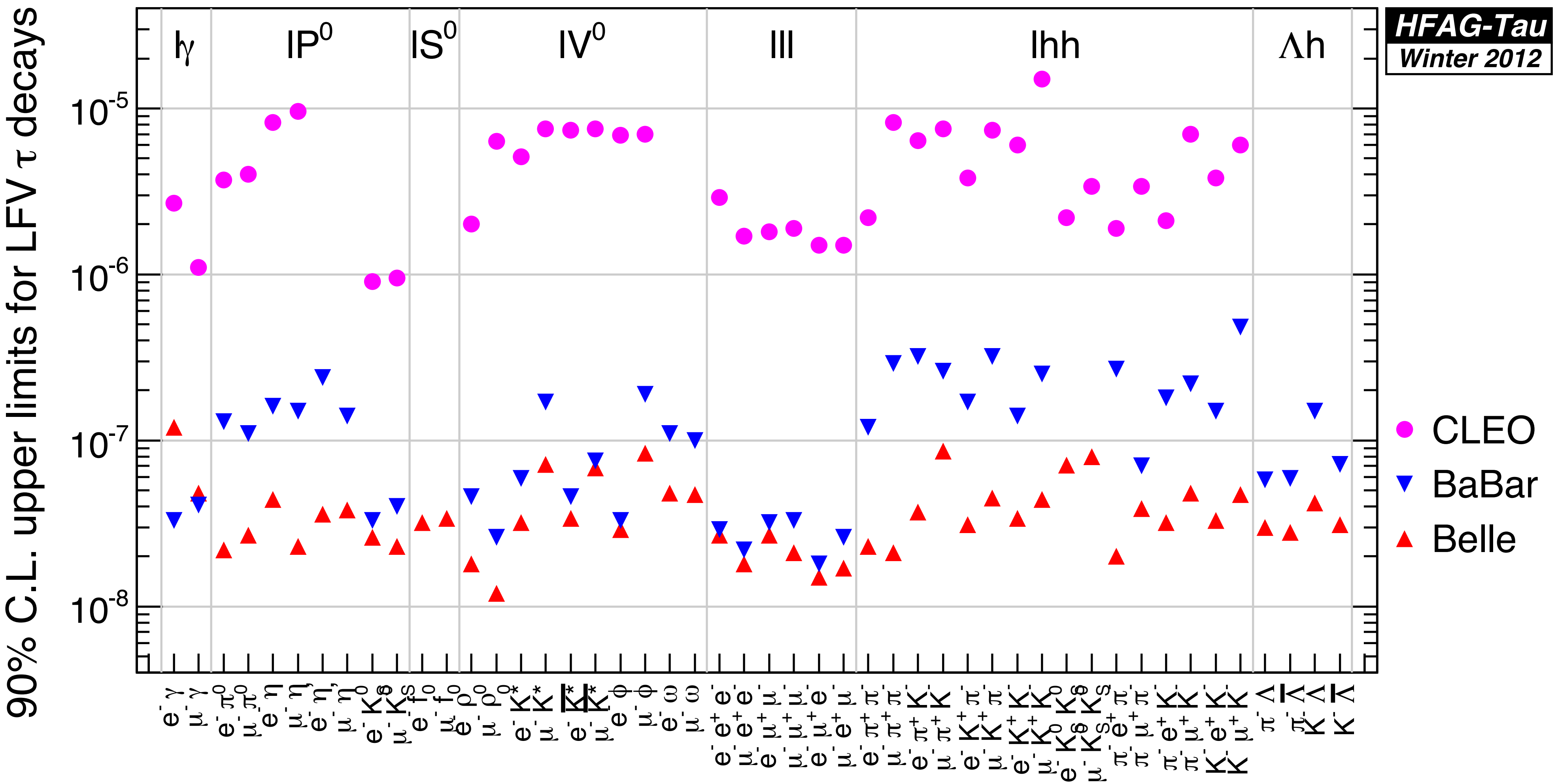


This level of sensitivity begins to probe models of physics beyond the SM:

	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}

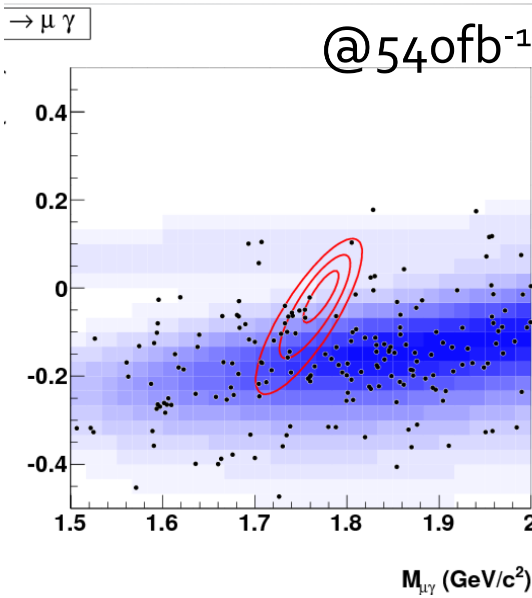
τ Physics at Belle

Belle Upper Limits (48 LFV final states):

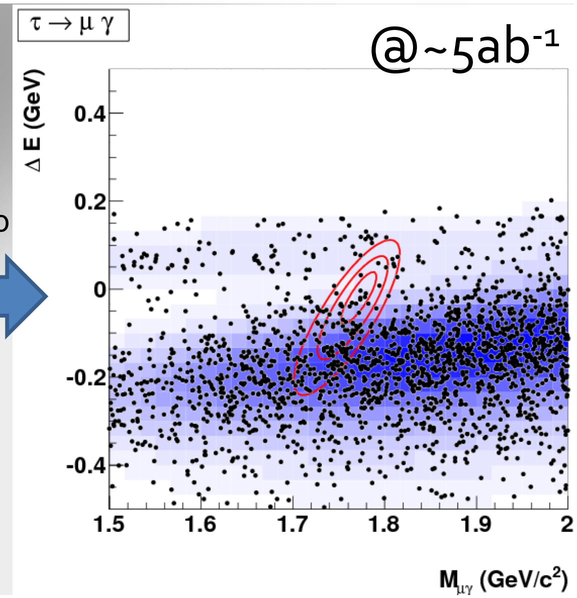


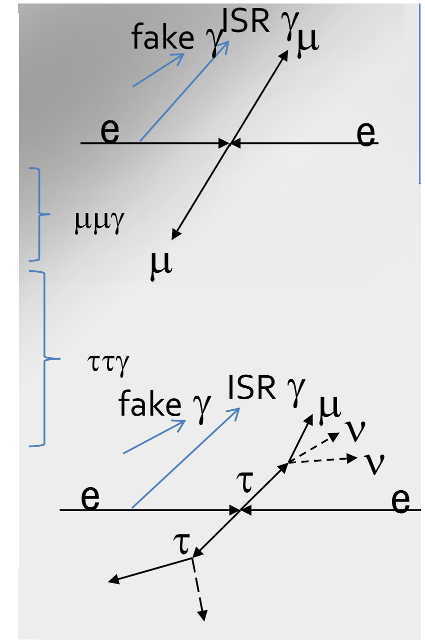
Belle II Prospects for τ

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

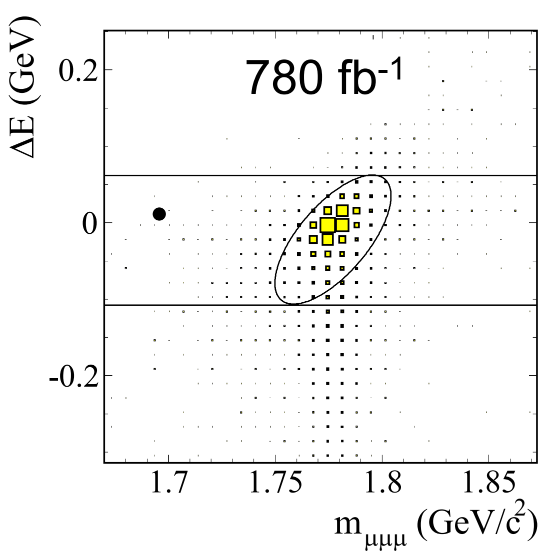


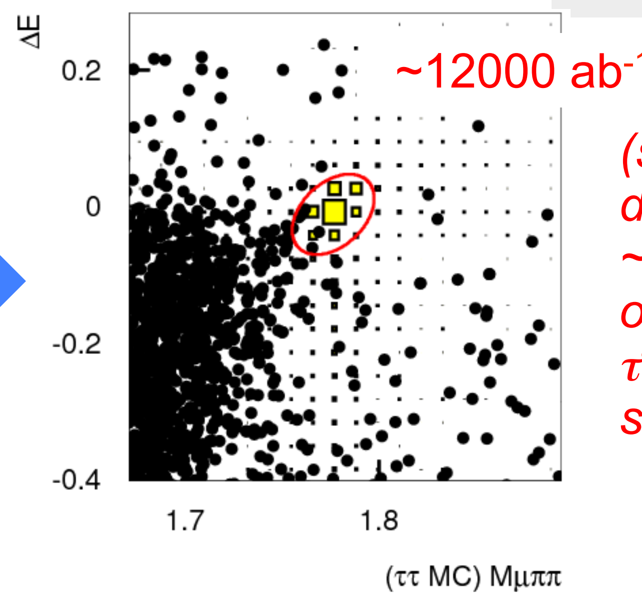
x10





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





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

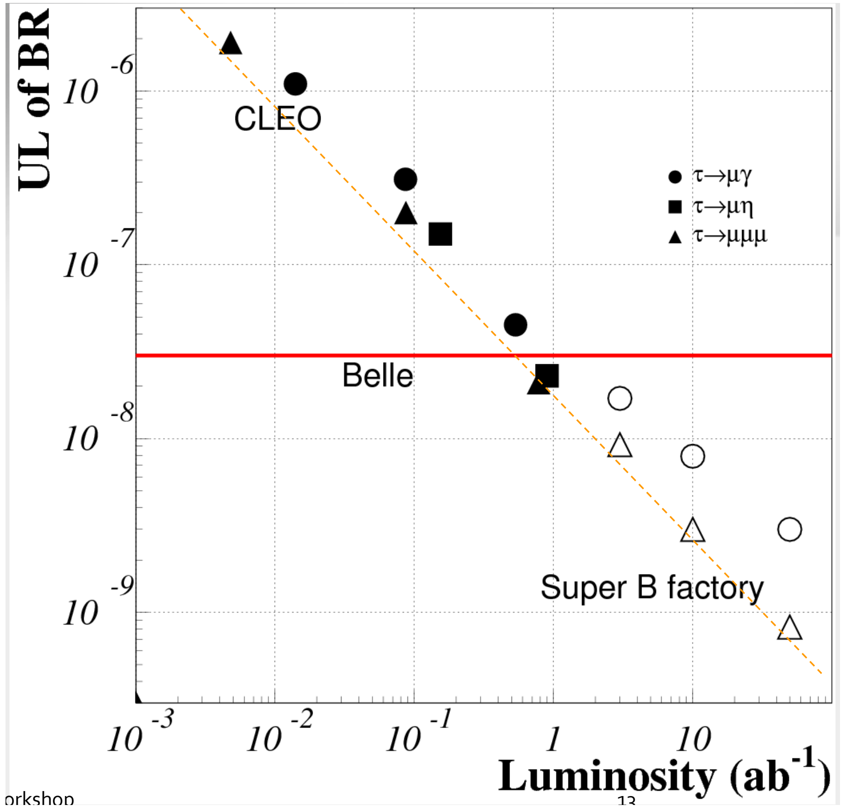
Belle II Prospects for τ

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

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

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

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



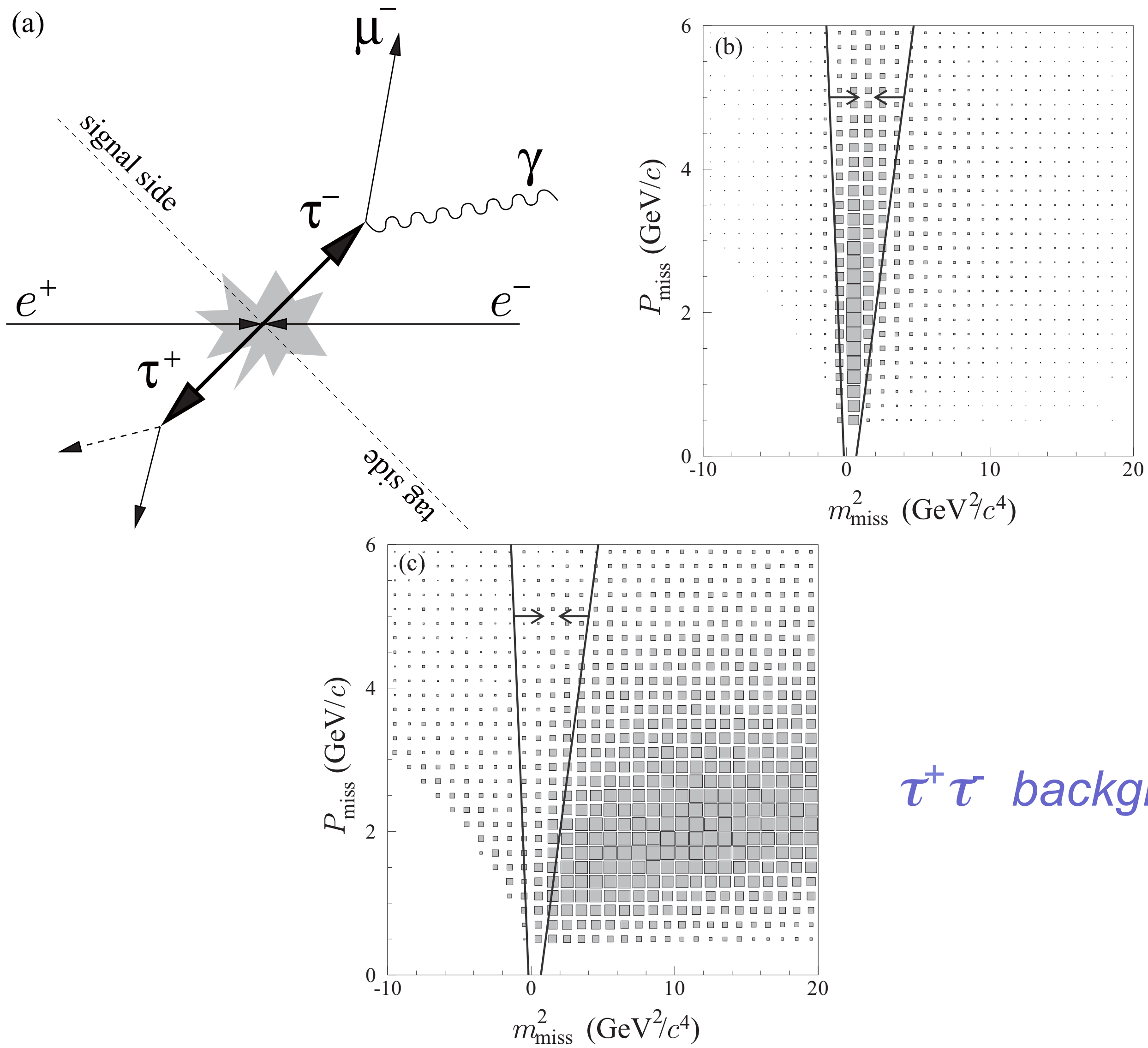
Upper Limits:

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

This probes NP models

	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}

$\tau^+ \to \mu^+\gamma$ Bckgrnd Suppression via kinematics



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

$\tau^+\tau^-$ background

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 project, many detector components and most electronics will be replaced.*

- *A Super B Factory should resolve current flavor puzzles of Belle and Babar, e.g., difference in phase ϕ_1 between b→ s loop diagram and b→ c tree diagram; possible enhanced loop diagram in $B \to K\pi$ decays, etc.*

- *A Super B Factory will have a rich charm physics program: should greatly 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, measurements of charm baryons, etc.*

- *A Super B Factory will have a rich τ physics program; should greatly improve LFV upper limits, constraining (or discovering) new physics. Can also probe CPV in τ decays with ~3 x 10^{-5} precision (scaled from CLEO $\tau^+ \to K_S \pi^+ \nu$ measurement)*

Back-up Slides

The KEKB Machine

Decision: nano-beam option

- For high current scheme, $\xi \propto \sqrt{(\beta^*/\varepsilon)} = 0.3$ looked hard (KEKB achieved 0.1)
- No solution was found for IR design to realize $\beta^*_x = 20$ cm.
- Bunch length could not be reduced to 3mm because of the coherent synchrotron radiation.
- Higher operating costs.

Nano-beams design:

- Small beta function at IP (x 1/20): horiz: 1200→32/25mm vert.: 5.9→0.27/0.42mm beam size 100μm(H) x 2μm(V) → 10μm(H) x 59nm(V)
- Crab waist is considered as an option (but current KEKB machine optics diminishes impact)
- For such small β, two final-Q magnets in both L/R sides are needed
- To put final-Q magnets closer to IP, increase crossing angle 22→ 83 mrad.
- For acceptable dynamic aperture, reduce energy asymmetry to 7 GeV x 4 GeV

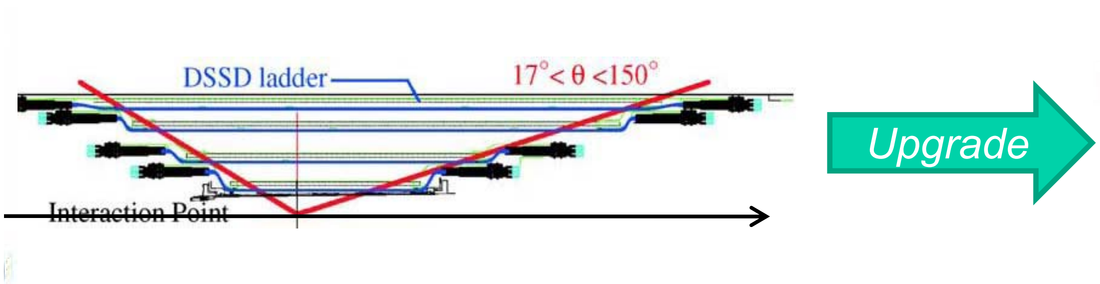
KEKB → SuperKEKB (nano-beam)

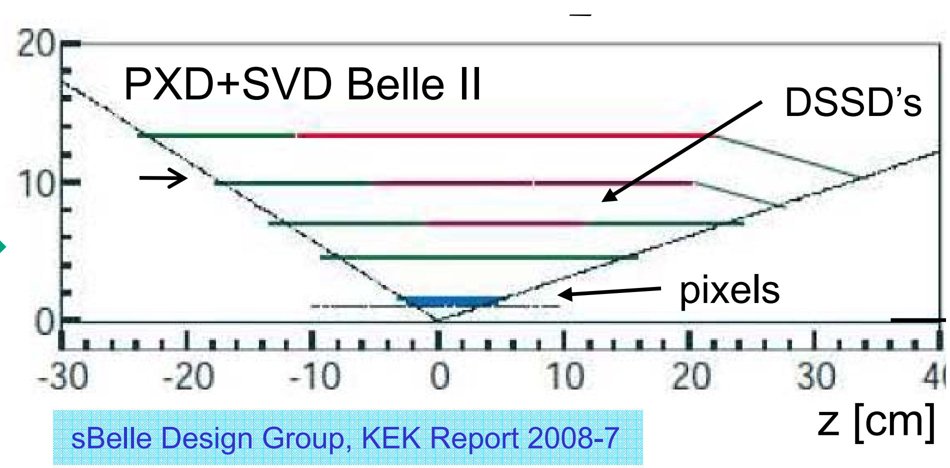
parameters		KEKB LER	KEKB HER	SuperKEKB LER	SuperKEKB HER	units
Beam energy	E_b	3.5	8	4	7	GeV
Half crossing angle	φ	11		41.5		mrad
Horizontal emittance	ε_x	18	24	3.2	4.6	nm
Emittance ratio	κ	0.88	0.66	0.37	0.40	%
Beta functions at IP	β_x^*/β_y^*	1200/5.9		32/0.27	25/0.30	mm
Beam currents	I_b	1.64	1.19	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}		$cm^{-2}s^{-1}$

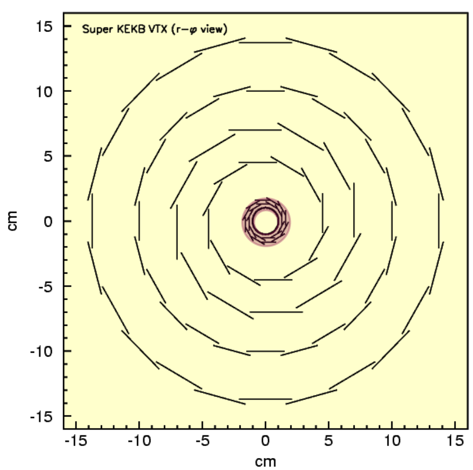
- **Nano-beams and a factor of two more beam current** to increase luminosity
- **Large crossing angle**
- **Change beam energies** to solve the problem of short lifetime for the LER

Belle II Vertex Detector Upgrade

4 layers → 6 layers w/pixels:







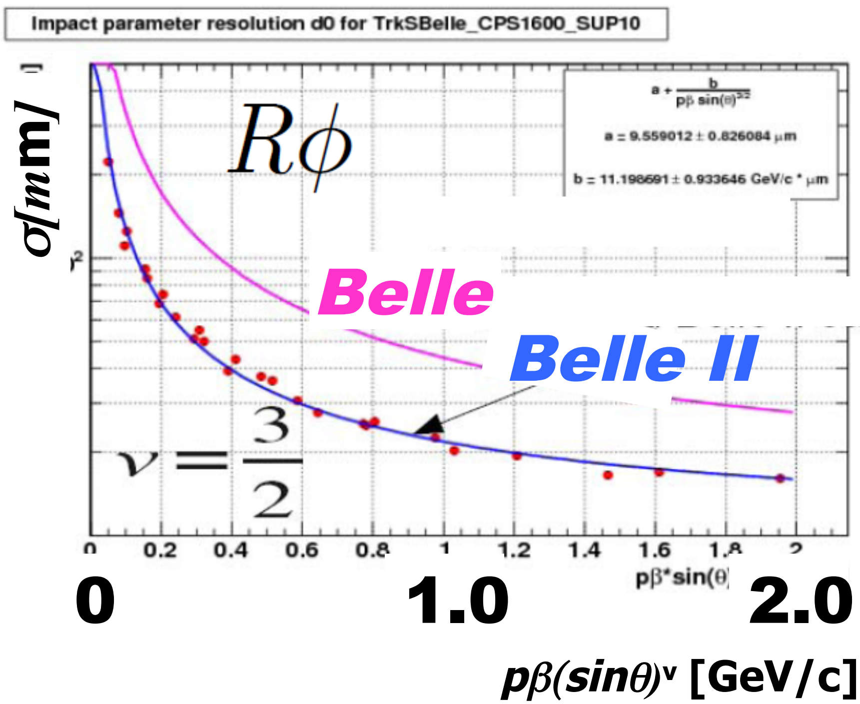
Beam Pipe	**r = 1cm**
DEPFET	
Layer 1	**r = 1.3cm**
Layer 2	**r = 2.2cm**
DSSD	
Layer 3	**r = 3.8cm**
Layer 4	**r = 8.0cm**
Layer 5	**r = 11.5cm**
Layer 6	**r = 14.0cm**

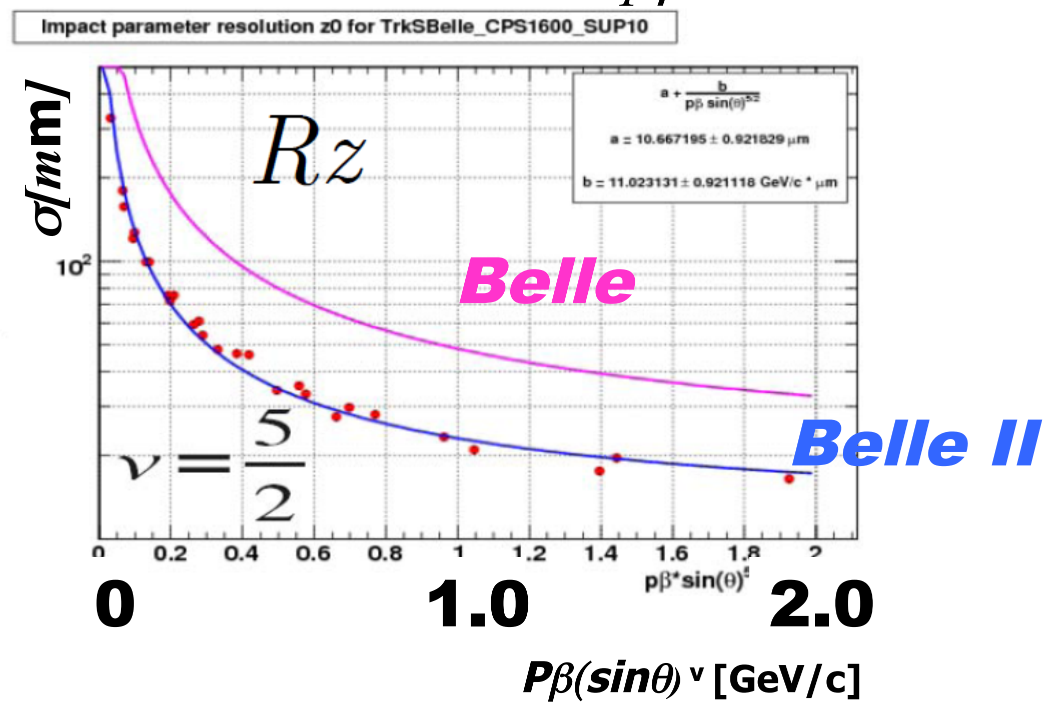
- *Outer radius increases: 8→14 cm*
  ∴ K_S recon. effic. increases ~30%
- *Inner radius decreases 1.5 → 1.3 cm*
  ∴ 25% improv. in vertex resolution
- *Inner 2 layers are DEPFET pixel detectors developed in Germany*
  ∴ greatly reduce occupancy
- *Layers 3-6 readout chip: VA1TA →APV25*
  ∴ reduce occupancies

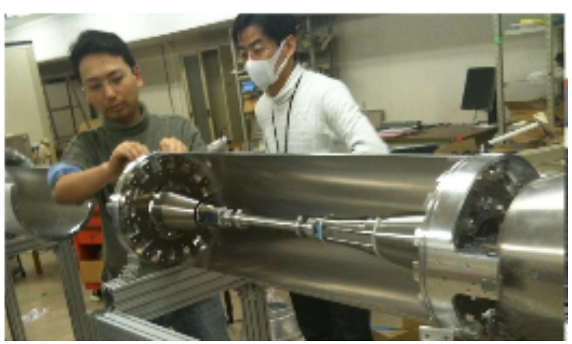
Belle II Vertex Detector Upgrade

Significant improvement in IP resolution:

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





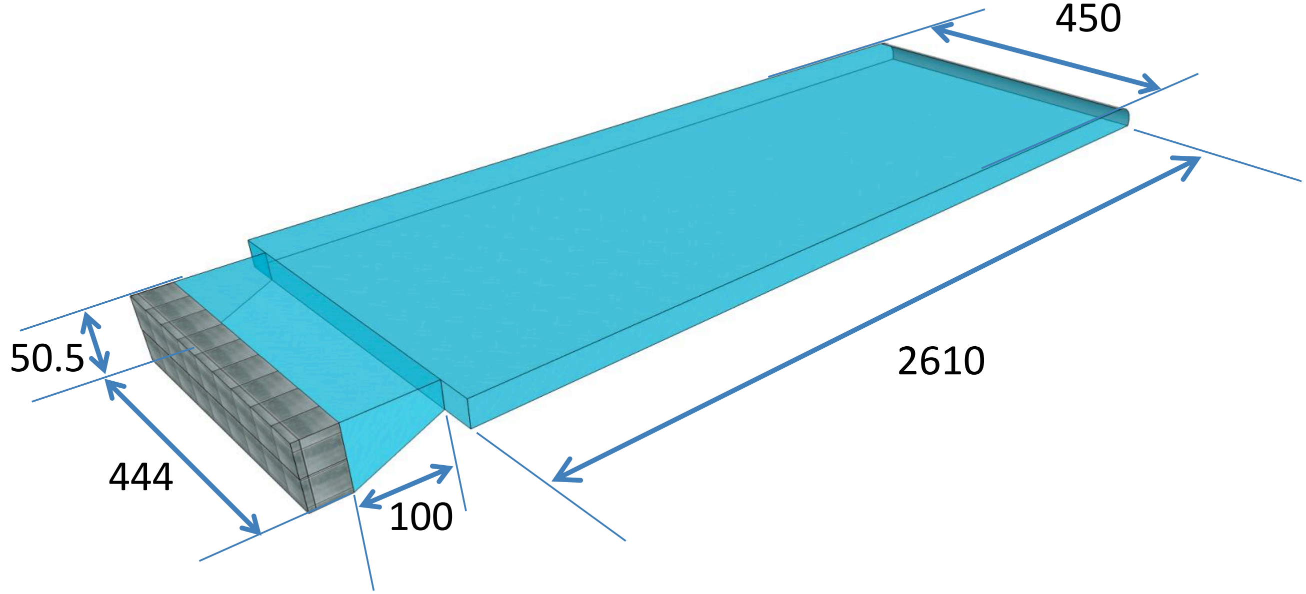


Will improve analyses such as $B \to K_S \pi^0 \gamma$ (decay vertex determined by K_S and IP)

$C_{CP}(K_S\,\pi^0\gamma)$ = -0.07 ±0.12
$S_{CP}(K_S\,\pi^0\gamma)$ = -0.15 ±0.20 → 0.09 (5 fb^{-1})
→ 0.03 (50 fb^{-1})

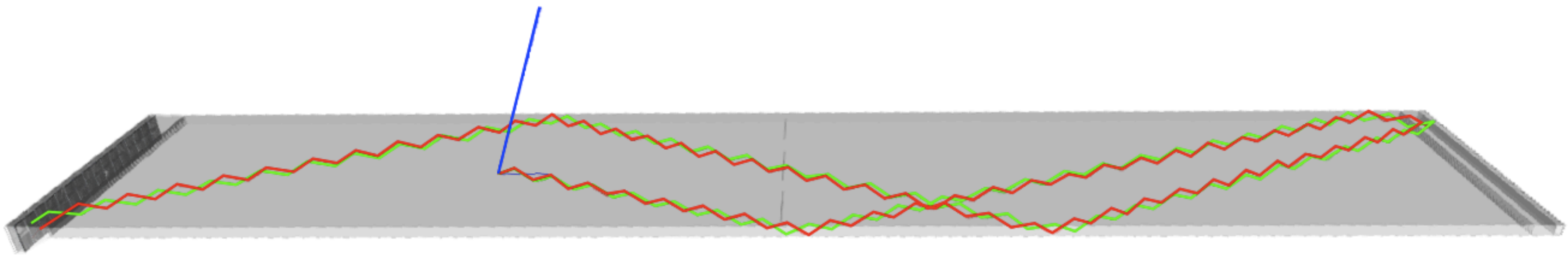
Belle II Detector Upgrade – barrel particle ID

In barrel region we will use an imaging time-of-propagation (iTOP) counter:

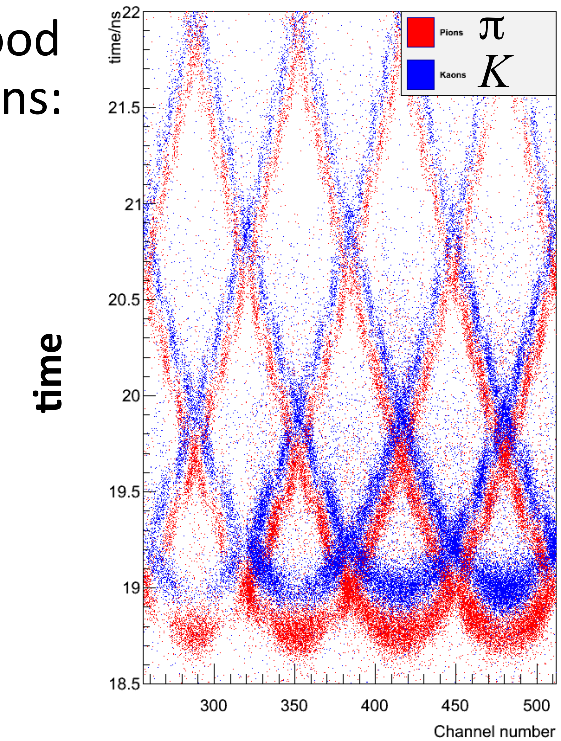


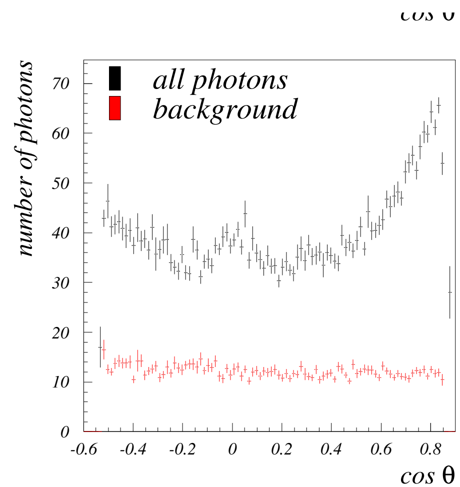
- *Two wide bars of quartz, 125 cm long, are epoxied together to make a "long" bar*
- *A spherical mirror is epoxied to the upstream end, focusing the light at the PMTs attached at the downstream end (note: the focal length is long, ~3.5m)*
- *An "expansion prism" is attached at the downstream end to allow the photons to spread out, improving the imaging and reducing ambiguities.*
- *The PMT array is attached to the expansion wedge.*

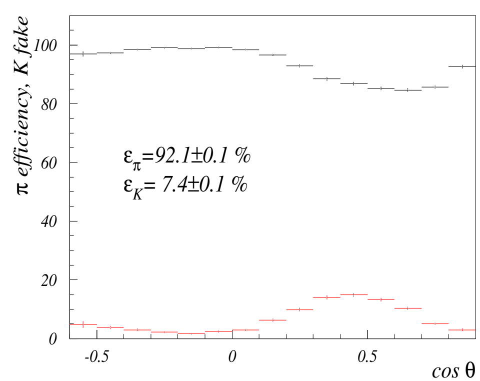
Belle II Detector Upgrade – barrel particle ID



Likelihood Functions:







$B^0 \rightarrow K^+\pi^-$ full simulation results:

N_γ(signal) = 22
N_γ(bkg) = 15

ε_π = 92 % (Belle: 89%)
ε_K = 7.4 % (Belle: 12%)