Semileptonic B decays at the Belle experiment

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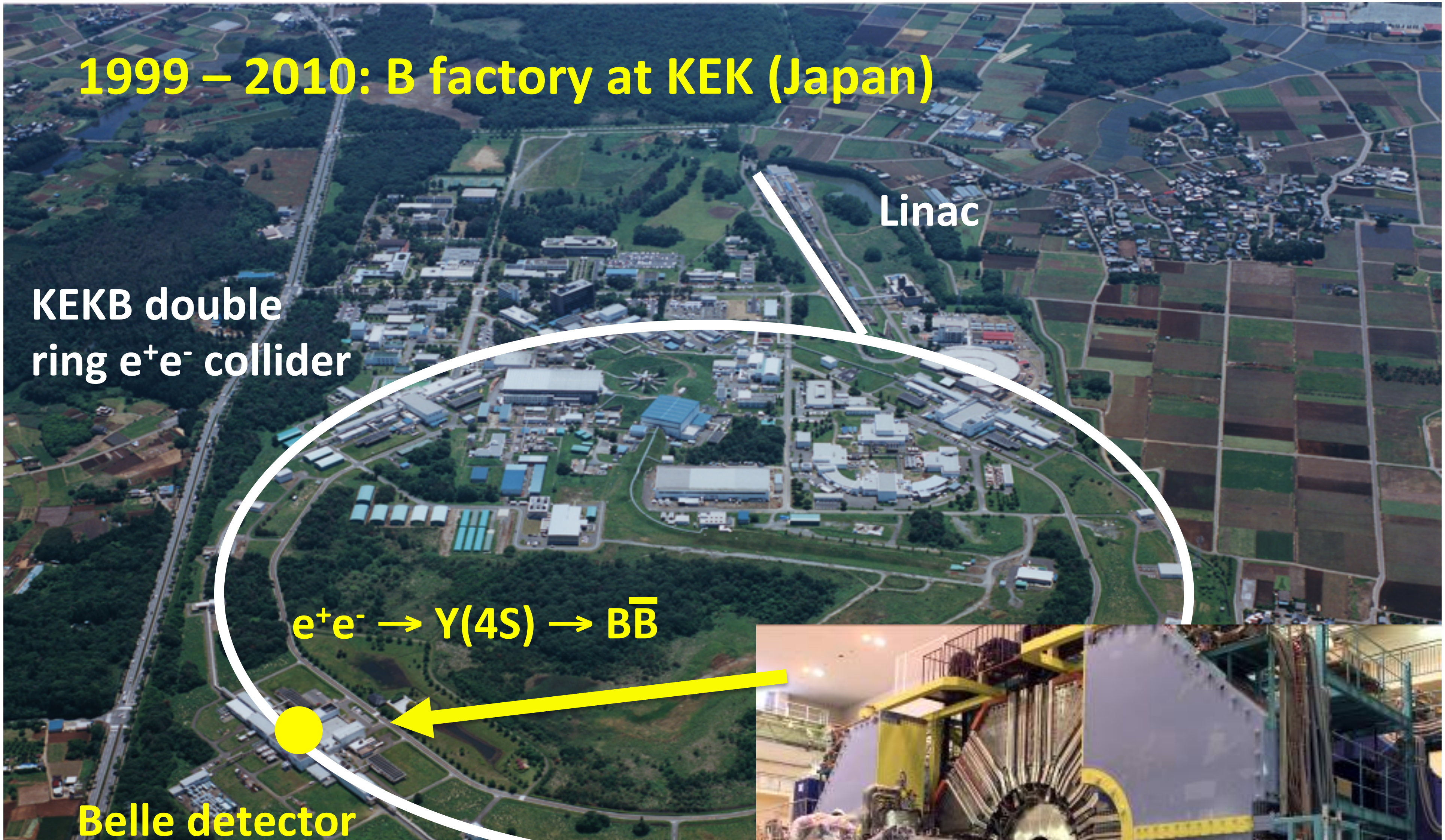
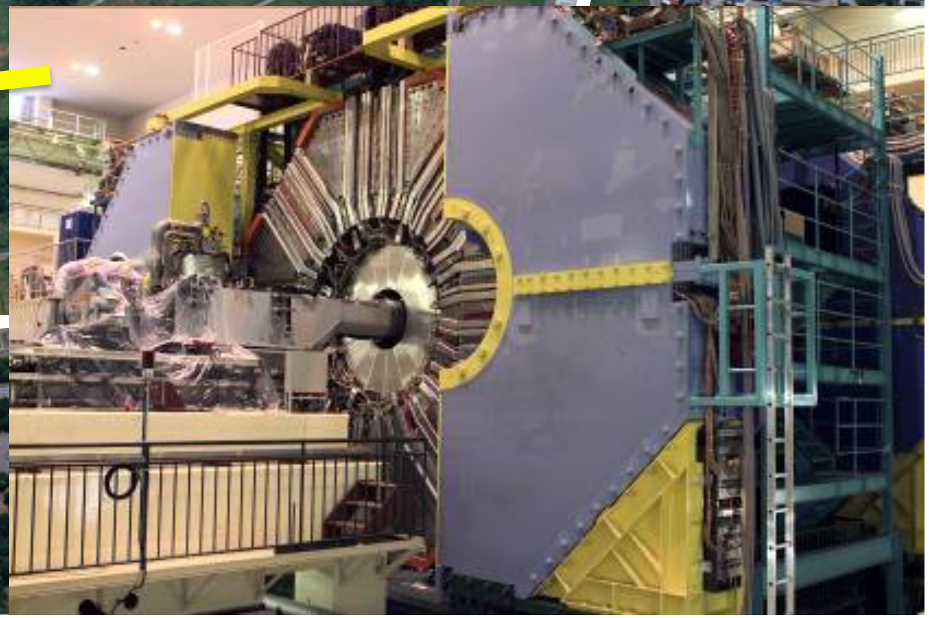
Outline of this talk

- A short introduction to the Belle experiment at KEK
- Measurements of semileptonic B decays at the B factories and determination of $|V_{cb}|$ and $|V_{ub}|$
- The Belle II upgrade
- Prospects for semileptonic B decays at Belle II

The Belle experiment at KEK

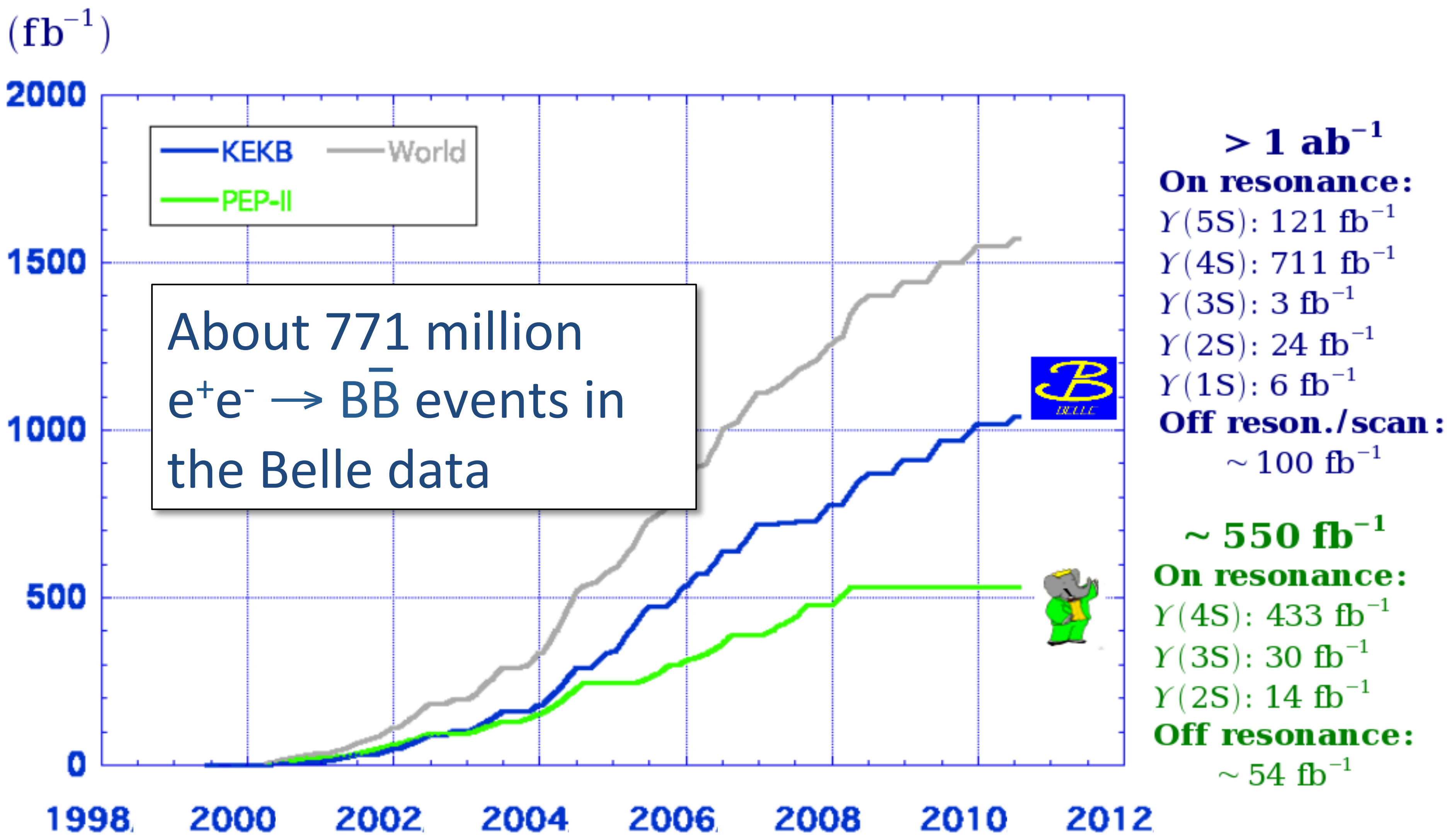
1999 – 2010: B factory at KEK (Japan)



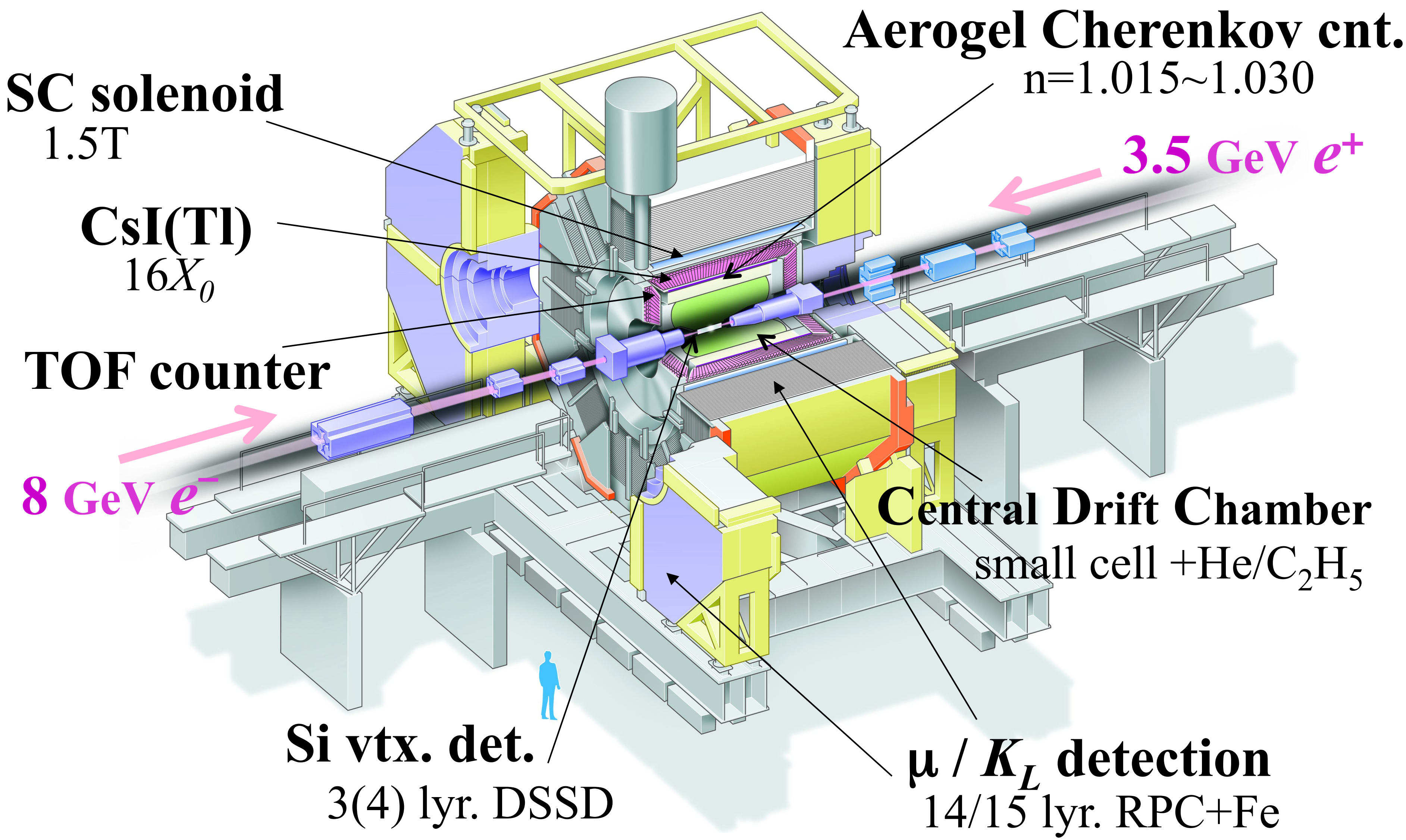


- World largest B meson sample ~771 million BB events
- ~400 Belle physics publications

Luminosity at B factories



About 771 million $e^+e^- \rightarrow B\bar{B}$ events in the Belle data



Lepton ID efficiency ~90%

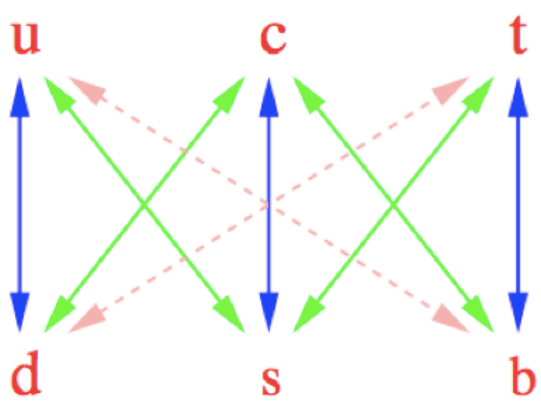
Fake rate ~0.1% (electrons), ~1% (muons)

Cabibbo-Kobayashi-Maskawa quark mixing

$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} = \mathbf{V} \begin{pmatrix} d \\ s \\ b \end{pmatrix}$$

$$V_{\rm CKM} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

$$\mathbf{V}\,\mathbf{V}^{\dagger} = \mathbf{V}^{\dagger}\,\mathbf{V} = 1$$



- W couples to the weak eigenstates
- Charged current processes can change quark flavour
- CKM matrix elements appears at the quark-W vertex

$$-\mathcal{L}_{W^{\pm}} = \frac{g}{\sqrt{2}}\,\overline{u_{Li}}\,\gamma^{\mu}\,(V_{\rm CKM})_{ij}\,d_{Lj}\,W_{\mu}^{+} + \text{h.c.}$$

The main goal of the B factories was…

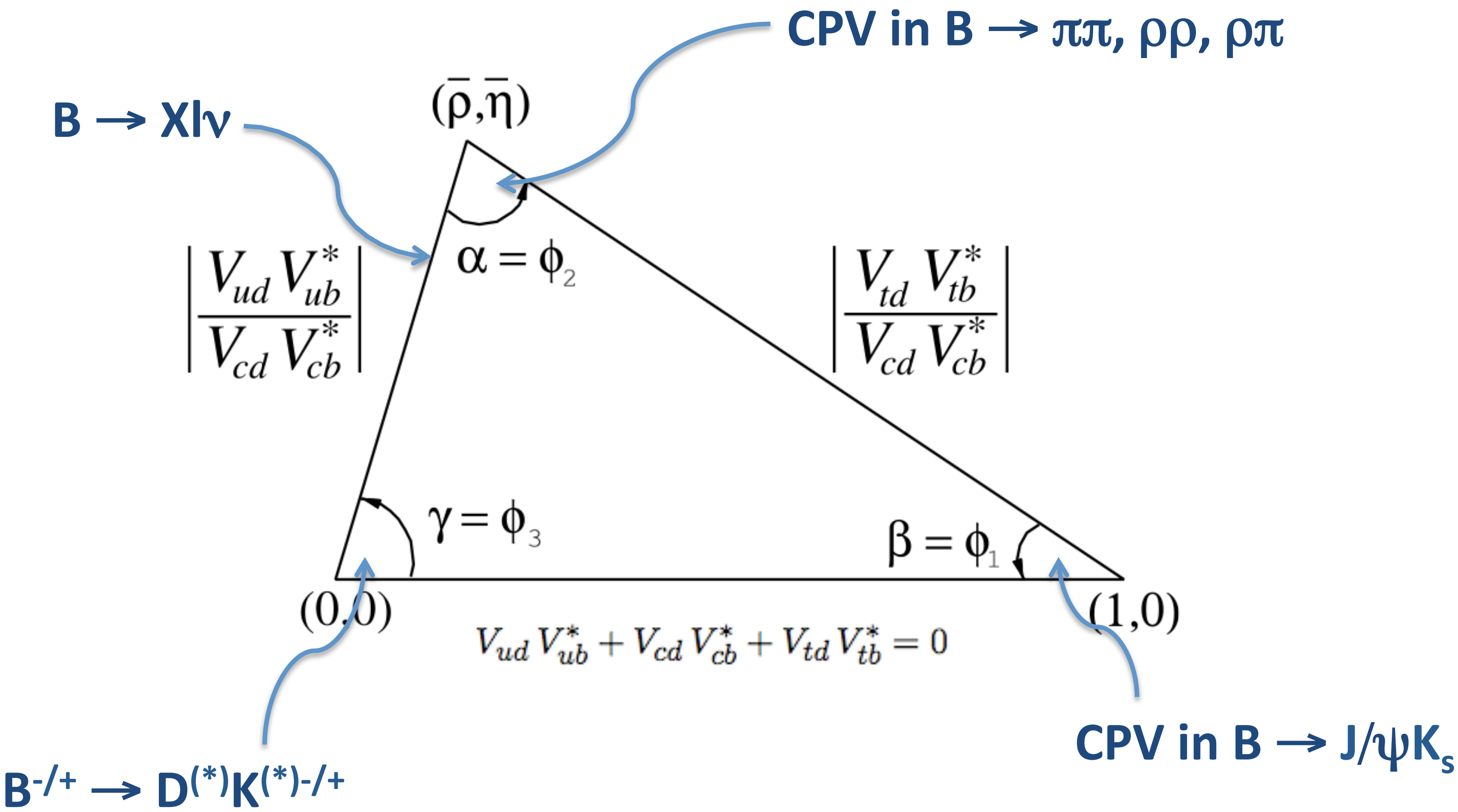
… to confirm the CKM mechanism, as established by M. Kobayashi and T. Maskawa in the year 1973

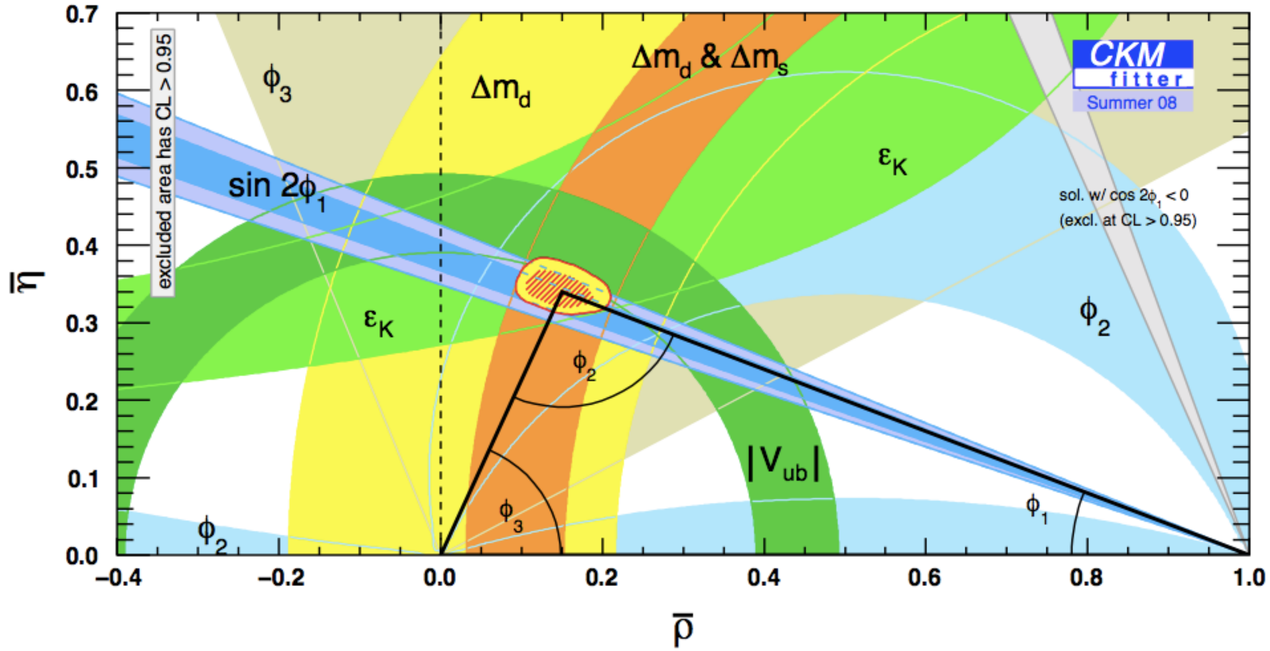
Wolfenstein parametrization of V_{CKM}

$$V_{\mathrm{CKM}} = \begin{pmatrix} 1-\frac{1}{2}\lambda^2-\frac{1}{8}\lambda^4 & \lambda & A\lambda^3(\rho-i\eta) \\ -\lambda+\frac{1}{2}A^2\lambda^5[1-2(\rho+i\eta)] & 1-\frac{1}{2}\lambda^2-\frac{1}{8}\lambda^4(1+4A^2) & A\lambda^2 \\ A\lambda^3[1-(1-\frac{1}{2}\lambda^2)(\rho+i\eta)] & -A\lambda^2+\frac{1}{2}A\lambda^4[1-2(\rho+i\eta)] & 1-\frac{1}{2}A^2\lambda^4 \end{pmatrix}$$

- V_{CKM} contains not only coupling constants of weak transitions
- But also a complex phase, responsible for all CP-violating phenomena in the SM

The CKM unitarity triangle



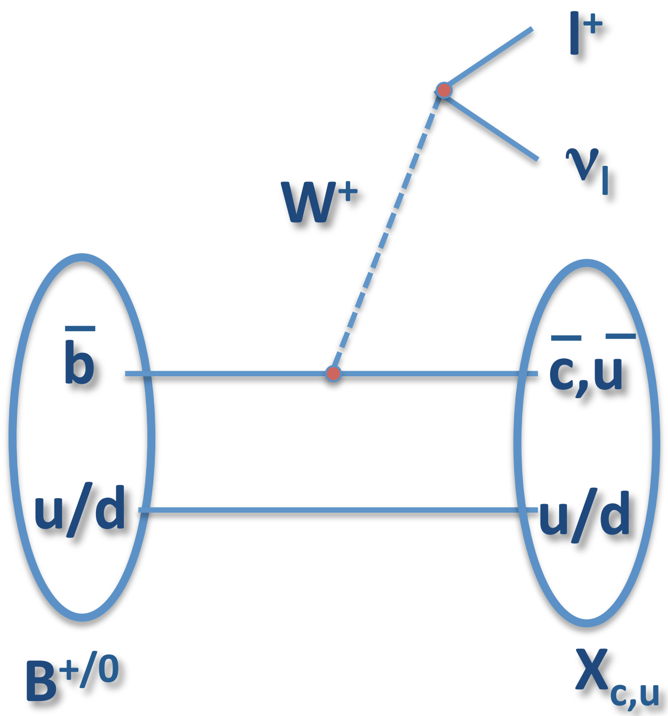


0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
−0.4
−0.2
0.0
0.2
0.4
0.6
0.8
1.0
$\bar{\eta}$
$\bar{\rho}$
excluded area has CL > 0.95
ϕ_3
Δm_d
Δm_d & Δm_s
CKM fitter
Summer 08
ε_K
sin $2\phi_1$
sol. w/ cos $2\phi_1$ < 0
(excl. at CL > 0.95)
ε_K
ϕ_2
ϕ_2
ϕ_3
$|V_{ub}|$
ϕ_1
ϕ_2

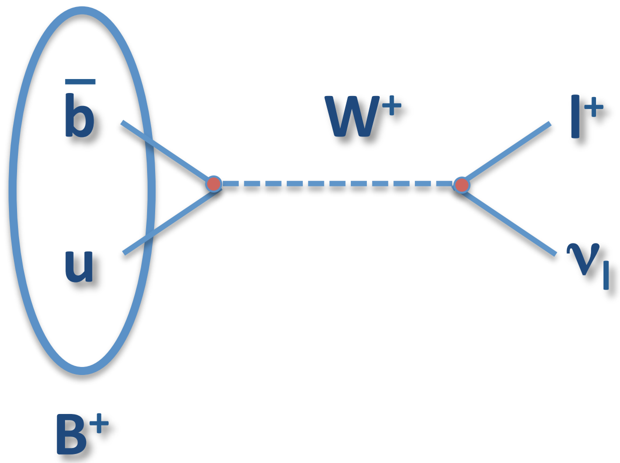
Makoto Kobayashi

Review of semileptonic B decays

Semileptonic B decay

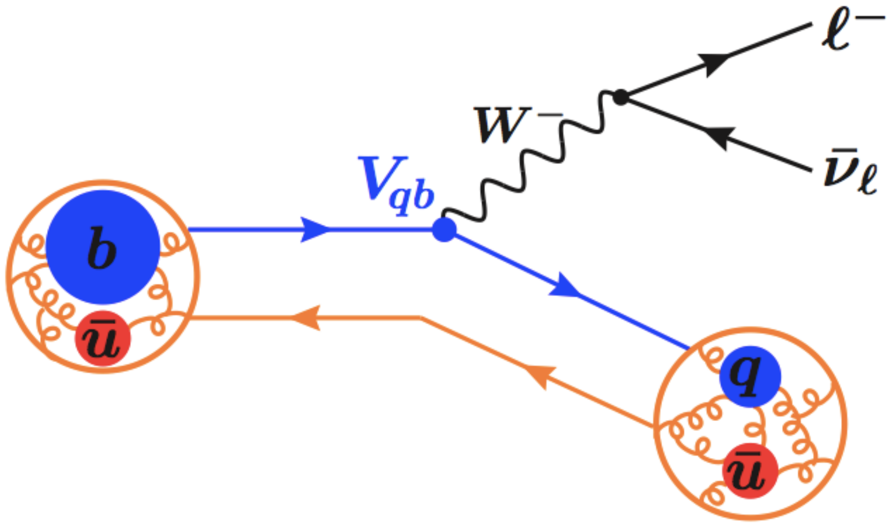


Leptonic B decay



Why study semileptonic B decays…

… because they are the best way to measure the CKM matrix elements $|V_{cb}|$ and $|V_{ub}|$, two fundamental parameters of the SM



$$d\Gamma \propto G_F^2 |V_{qb}|^2 \left| L_\mu \langle X | \bar{q} \gamma_\mu P_L b | B \rangle \right|^2$$

$|V_{cb}|$ from exclusive decays

$$w = \frac{P_B \cdot P_{D^{(*)}}}{m_B m_{D^{(*)}}} = \frac{m_B^2 + m_{D^{(*)}}^2 - q^2}{2 m_B m_{D^{(*)}}}$$

$B \rightarrow D^* l \nu$

$$\frac{d\Gamma}{dw} = \frac{G_F^2 m_{D^*}^3}{48\pi^3} (m_B - m_{D^*})^2 \sqrt{w^2 - 1}\, \chi(w) \mathcal{F}^2(w) |V_{cb}|^2$$

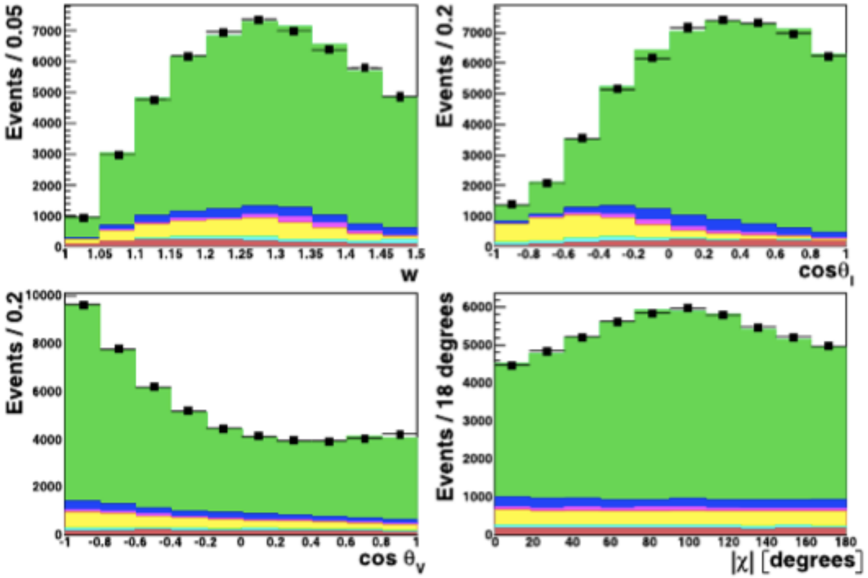
$B \rightarrow D l \nu$

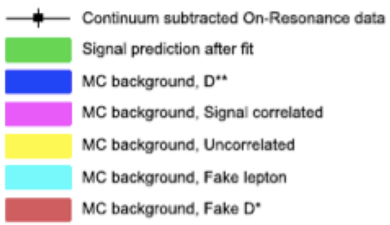
$$\frac{d\Gamma}{dw} = \frac{G_F^2 m_D^3}{48\pi^3} (m_B + m_D)^2 (w^2 - 1)^{3/2} \mathcal{G}^2(w) |V_{cb}|^2$$

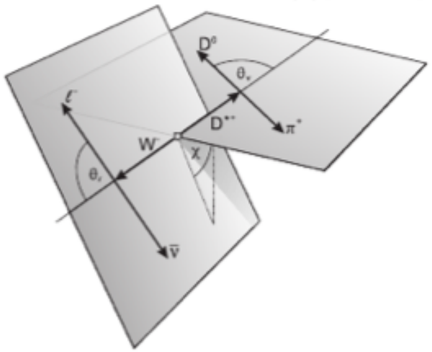
- Theory input: Form factors F(1) and G(1) at zero recoil (w=1) from lattice QCD calculations
- Experimental method: Measure the differential width $d\Gamma$ as a function of w and extrapolate to zero recoil (typically assuming a parameterization of the form factors)

$B^0 \to D^{*-} l^+ \nu$ at Belle

[W. Dungel, CS, PRD 82, 112007 (2010)]







- 711/fb of Belle Υ(4S) data
- About 120,000 reconstructed $B^0 \to D^{*-} l^+ \nu$ decays
- Fit in 40 bins of w, $\cos\theta_l$, θ_V and χ to obtain HQET F.F. parameters
- Dominant experimental systematics: tracking

$$
\begin{aligned}
\mathcal{F}(1)|V_{cb}| &= (34.6 \pm 0.2 \pm 1.0) \times 10^{-3} \\
\rho^2 &= 1.214 \pm 0.034 \pm 0.009 \\
R_1(1) &= 1.401 \pm 0.034 \pm 0.018 \\
R_2(1) &= 0.864 \pm 0.024 \pm 0.008 \\
\chi^2/ndf &= 138.8/155
\end{aligned}
$$

$|V_{cb}|$ from inclusive decays

$B \to X l \nu$

$$\Gamma = \frac{G_F^2 m_b^5}{192\pi^3}|V_{cb}|^2\left(1 + \frac{c_5(\mu)\langle O_5\rangle(\mu)}{m_b^2} + \frac{c_6(\mu)\langle O_6\rangle(\mu)}{m_b^3} + \mathcal{O}\left(\frac{1}{m_b^4}\right)\right)$$

- Based on the Operator Product Expansion (OPE)
- $\langle O_i \rangle$: hadronic matrix elements (non-perturbative)
  c_i: coefficients (perturbative)
- Parton-hadron duality → the hadronic ME depend only on the initial state

	Kinetic scheme [JHEP 1109 (2011) 055]	1S scheme [PRD70, 094017 (2004)]
O(1)	m_b, m_c	m_b
$O(1/m^2_b)$	μ^2_π, μ^2_G	λ_1, λ_2
$O(1/m^3_b)$	ρ^3_D, ρ^3_{LS}	ρ_1, τ_{1-3}

Moments of the E_l and M^2_X spectrum

Also other observables in B → Xlν can be expanded into an OPE with the same heavy quark parameters, e.g.,

- The n[th] moment of the (truncated) lepton energy spectrum

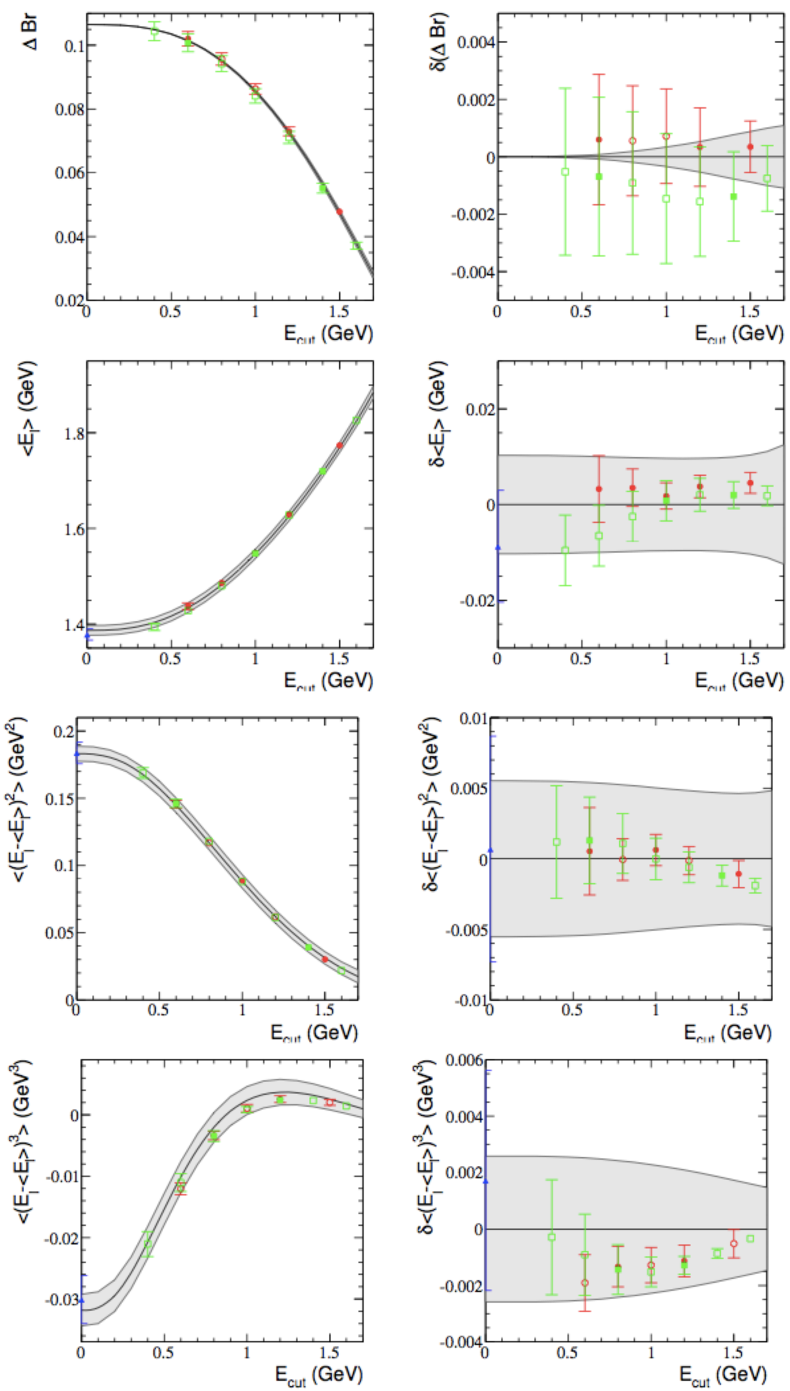
$$R_n(E_{\rm cut},\mu) = \int_{E_{\rm cut}} (E_\ell - \mu)^n \, \frac{{\rm d}\Gamma}{{\rm d}E_\ell}\, {\rm d}E_\ell\,, \quad \langle E_\ell^n \rangle_{E_{\rm cut}} = \frac{R_n(E_{\rm cut},0)}{R_0(E_{\rm cut},0)}$$

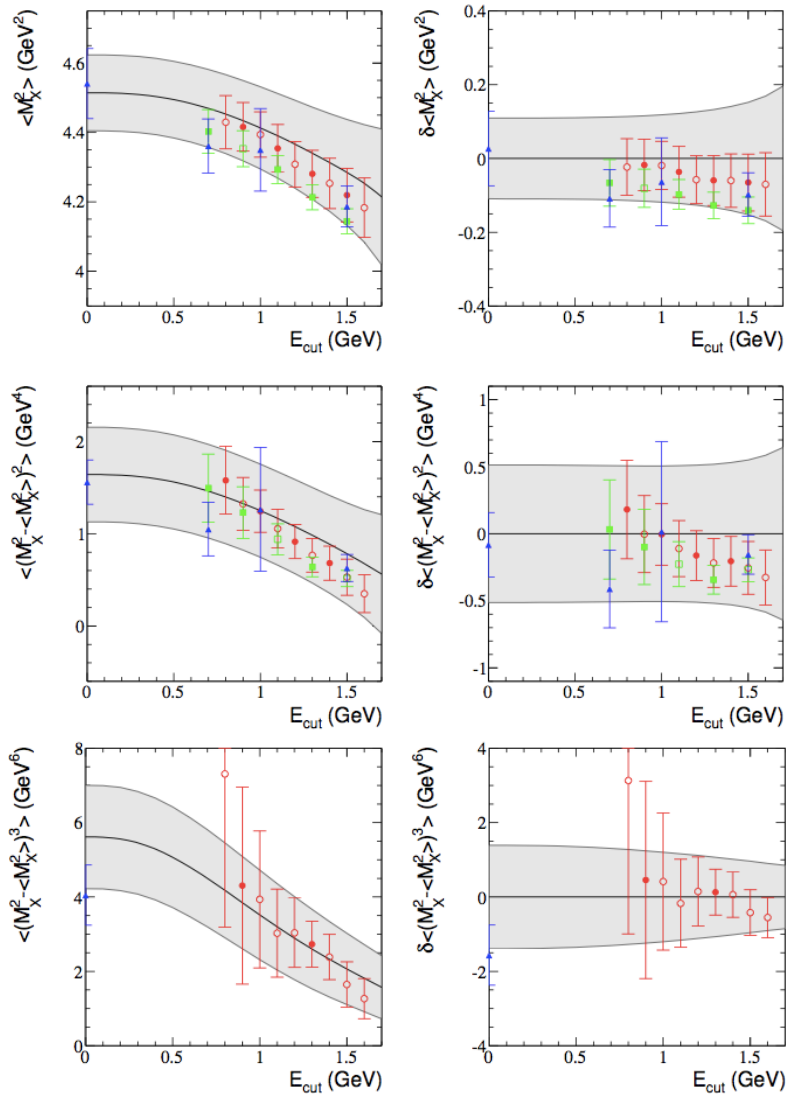
- The n[th] moment of the (truncated) M^2_X spectrum

$$\langle m_X^{2n} \rangle_{E_{\rm cut}} = \frac{\displaystyle\int_{E_{\rm cut}} (m_X^2)^n \, \frac{{\rm d}\Gamma}{{\rm d}m_X^2}\, {\rm d}m_X^2}{\displaystyle\int_{E_{\rm cut}} \frac{{\rm d}\Gamma}{{\rm d}m_X^2}\, {\rm d}m_X^2}$$

Master plan:

- Measure the quark masses and heavy quark parameters using moments
- Substitute them in the formula of the semileptonic width
- Determine $|V_{cb}|$ from the semileptonic branching fraction

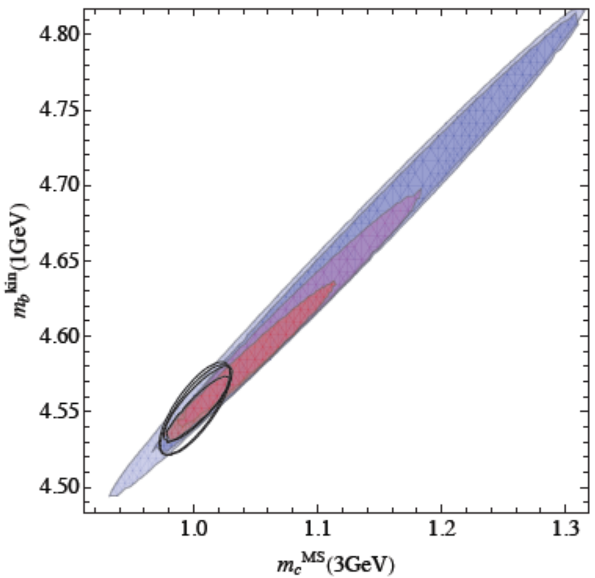




- Analysis in the kinetic scheme with 50 moments from BaBar, Belle, CDF, CLEO and DELPHI

[P. Gambino, CS, Phys.Rev.D89, 014022 (2014)]

Global fit (kinetic scheme) [Phys.Rev.D89, 014022 (2014)]



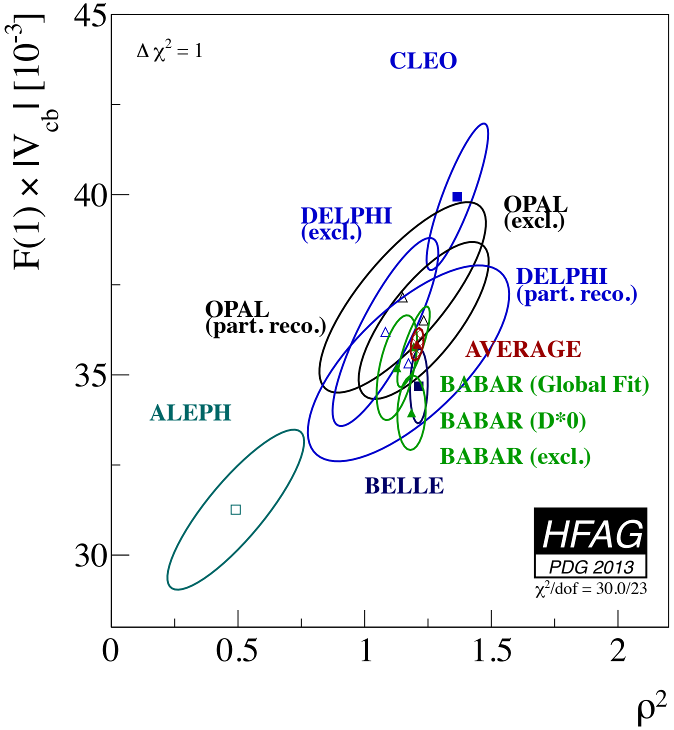
th. corr. scenario	m_b^{kin}	m_c	μ_π^2	ρ_D^3	μ_G^2	ρ_{LS}^3	$BR_{c\ell\nu}$(%)	$10^3\,\lvert V_{cb}\rvert$
D [11]	4.541	0.987	0.414	0.154	0.340	-0.147	10.65	42.42
$\overline{m}_c$(3GeV)	0.023	0.013	0.078	0.045	0.066	0.098	0.16	0.86
A [11]	4.540	0.987	0.454	0.167	0.234	-0.078	10.45	41.85
$\overline{m}_c$(3GeV)	0.014	0.013	0.035	0.022	0.040	0.085	0.13	0.74
B [11]	4.542	0.987	0.457	0.184	0.290	-0.135	10.51	42.15
$\overline{m}_c$(3GeV)	0.017	0.013	0.056	0.035	0.056	0.095	0.14	0.77
C [11]	4.539	0.987	0.415	0.155	0.336	-0.147	10.65	42.45
$\overline{m}_c$(3GeV)	0.022	0.013	0.073	0.043	0.066	0.098	0.16	0.86
D [11]	4.538	0.986	0.415	0.153	0.336	-0.145	10.65	42.46
$\overline{m}_c$(3GeV), m_b	0.018	0.012	0.078	0.045	0.064	0.098	0.16	0.84
D [13]	4.549	0.996	0.413	0.154	0.339	-0.146	10.65	42.40
$\overline{m}_c$(3GeV)	0.029	0.026	0.078	0.045	0.066	0.098	0.16	0.87
D [11]	4.548	1.092	0.428	0.158	0.344	-0.146	10.66	42.24
m_c^{kin}	0.023	0.020	0.079	0.045	0.066	0.098	0.16	0.85
D [11]	4.553	1.088	0.428	0.155	0.328	-0.139	10.67	42.42
$\overline{m}_c$(2GeV), m_b	0.018	0.013	0.079	0.045	0.064	0.098	0.16	0.83

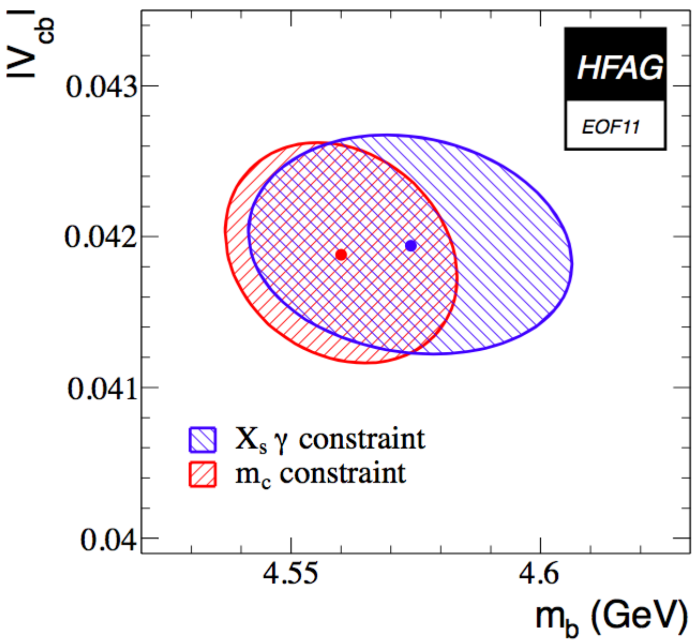
$\overline{m}_c(3\,\mathrm{GeV})$	$m_b^{kin}(1\,\mathrm{GeV})$	$\overline{m}_b(\overline{m}_b)$
0.986(13) [11]	4.541(23)	4.171(38)
0.986(6) [12]	4.540(20)	4.170(36)
0.994(26) [13]	4.549(29)	4.179(42)

[11] K. G. Chetyrkin, J. H. Kuhn, A. Maier, P. Maierhofer, P. Marquard, M. Steinhauser and C. Sturm, Phys. Rev. D **80** (2009) 074010 [arXiv:0907.2110 [hep-ph]].

[12] I. Allison *et al.* [HPQCD Collaboration], Phys. Rev. **D78**, 054513 (2008) [arXiv:0805.2999 [hep-lat]]; C. McNeile, C. T. H. Davies, E. Follana, K. Hornbostel and G. P. Lepage,[HPQCD Collaboration] Phys. Rev. D **82** (2010) 034512 [arXiv:1004.4285 [hep-lat]].

[13] B. Dehnadi, A. H. Hoang, V. Mateu and S. M. Zebarjad, JHEP **1309** (2013) 103 [arXiv:1102.2264 [hep-ph]].





$|V_{cb}|$

Exclusive ($D^*l\nu$)

$|V_{cb}| = (39.48 +/- 0.50_{exp} +/- 0.74_{th}) \times 10^{-3}$
$F(1) = (0.908 +/- 0.017)$ [arXiv:1011.2166]

Inclusive (kinetic)

$|V_{cb}| = (41.88 +/- 0.73) \times 10^{-3}$

HFAG preprint [arXiv:1207.1158]

- Exclusive and inclusive agree at the level of ~2 sigma

$B \to D^{**} l \nu$ mystery

Charm state X_c	$\mathcal{B}(B^+ \to X_c \ell^+ \nu)$
D	(2.31 ± 0.09) %
D^*	(5.63 ± 0.18) %
$\sum D^{(*)}$	**(7.94 ± 0.20) %**
$D_0^* \to D\pi$	(0.41 ± 0.08) %
$D_1^* \to D^*\pi$	(0.45 ± 0.09) %
$D_1 \to D^*\pi$	(0.43 ± 0.03) %
$D_2^* \to D^{(*)}\pi$	(0.41 ± 0.03) %
$\sum D^{**} \to D^*\pi$	**(1.70 ± 0.12) %**
$D\pi$	(0.66 ± 0.08) %
$D^*\pi$	(0.87 ± 0.10) %
$\sum D^*\pi$	**(1.53 ± 0.13) %**
$\sum D^{(*)} + \sum D^*\pi$	**(9.47 ± 0.24) %**
$\sum D^{(*)} + \sum D^{**} \to D^{(*)}\pi$	**(9.64 ± 0.23) %**
Inclusive X_c	**(10.92 ± 0.16) %**

broad states $(0.86 \pm 0.12)\%$

narrow states $(0.84 \pm 0.04)\%$

- Inclusive-exclusive gap of (1.45 +/- 0.29)%
- 1/2 vs. 3/2 puzzle
- Belle II might clarify the situation by measuring $B \to D^{(*)} n\pi l \nu$

Sascha Turczyk
CKM 2012 workshop

Determination of $|V_{ub}|$

Exclusive
$B \to \pi l \nu$

$$\frac{d\Gamma(B^0 \to \pi^- \ell^+ \nu)}{dq^2} = \frac{G_F^2}{24\pi^3}|V_{ub}|^2 p_\pi^3 |f_+(q^2)|^2$$

- Form factor f_+ from lattice QCD [PRD73, 074502; PRD79, 054507] or from QCD sum rules [PRD83, 094031; PRD 71, 014015]

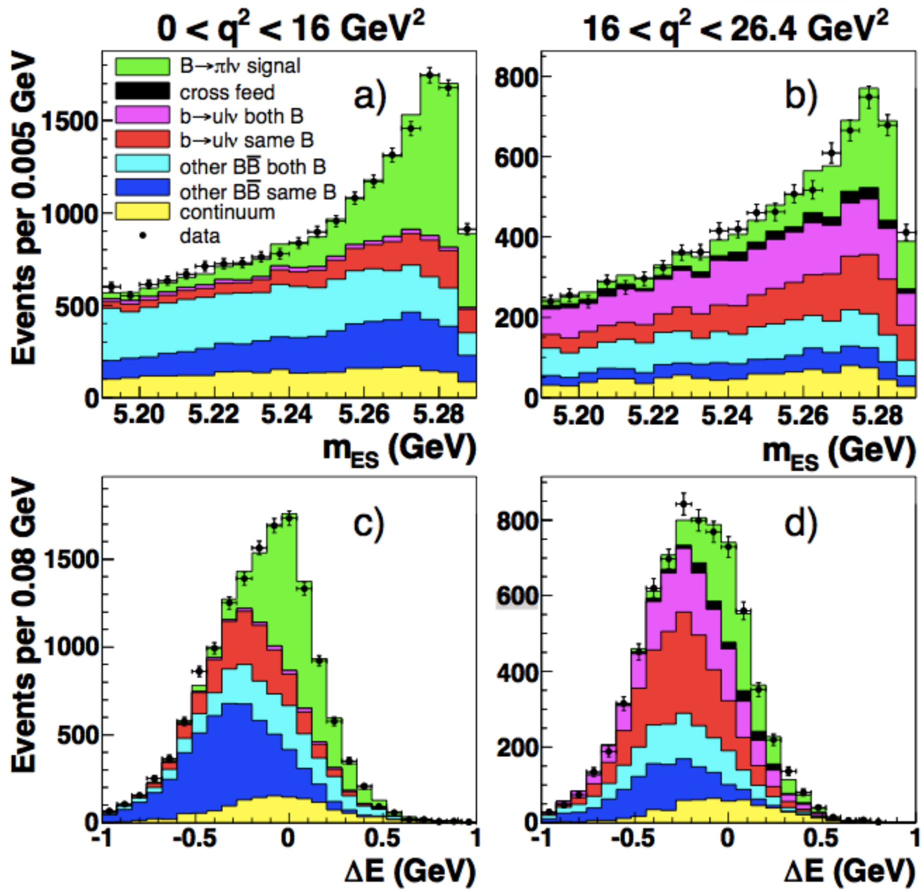
Inclusive
$B \to X_u l \nu$

- Also based on the OPE [NPB699, 335; JHEP01, 097; JHEP10, 058]
- Experimental selections can comprise the convergence of the OPE → shape function

B → πlν untagged

[PRD 86, 092004 (2012)]

- 416/fb of BaBar Y(4S) data
- Reconstruct only πe/πμ, infer neutrino momentum from p_{miss} (loose neutrino reconstruction technique)
- About 12,000 signal events, S/N ~0.1
- Partial branching fractions obtained in 12 q^2 bins
- Systematics: detector effects, b → u background



$$m_{ES} = \sqrt{E^{*2}_{beam} - \mathbf{p}^{*2}_{\pi\ell\nu}}$$
$$\Delta E = E^{*}_{\pi\ell\nu} - E^{*}_{beam}$$

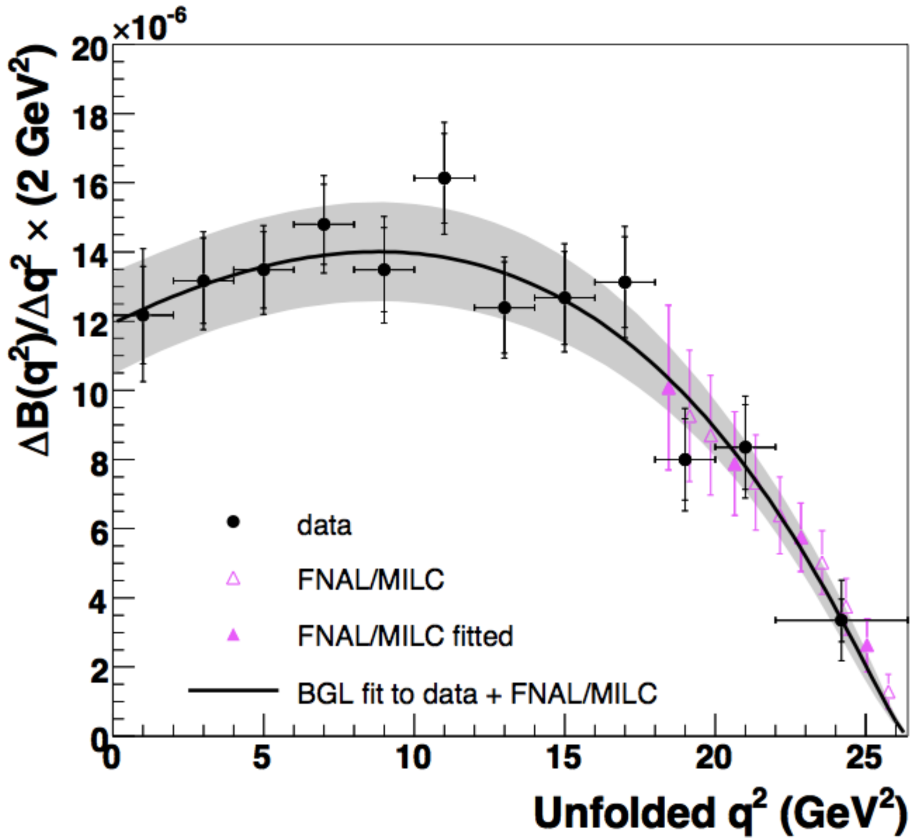
B → πlν untagged

[PRD 86, 092004 (2012)]

- FF parameterization: Boyd-Grinstein-Lebed

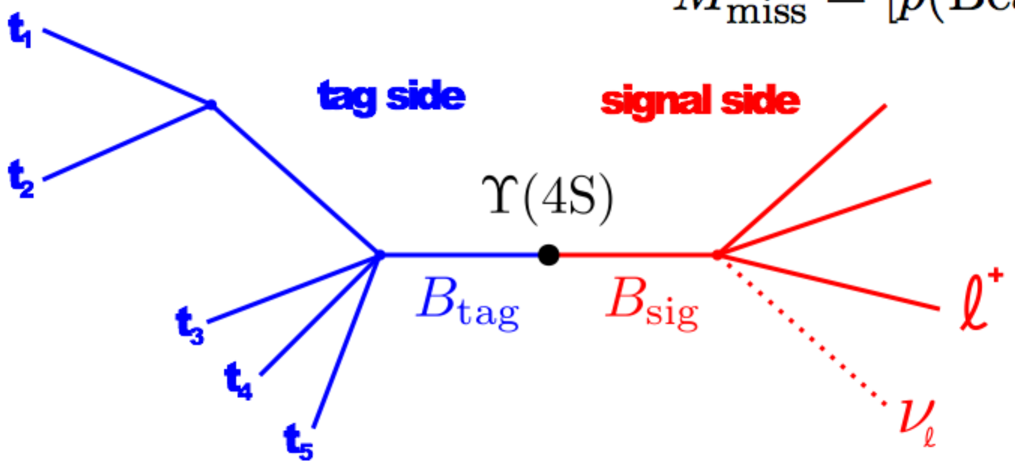
$$f_+(q^2) = \frac{1}{\mathcal{P}(q^2)\phi(q^2, q_0^2)} \sum_{k=0}^{k_{max}} a_k(q_0^2)[z(q^2, q_0^2)]^k \qquad z(q^2, q_0^2) = \frac{\sqrt{m_+^2 - q^2} - \sqrt{m_+^2 - q_0^2}}{\sqrt{m_+^2 - q^2} + \sqrt{m_+^2 - q_0^2}}$$

- Combined fit with FNAL/MILC lattice data yields $|V_{ub}| =$ $(3.25 +/- 0.31) \times 10^{-3}$
- Alternative extractions of $|V_{ub}|$ (using LCSR/LQCD in regions of q^2) consistent with the combined fit

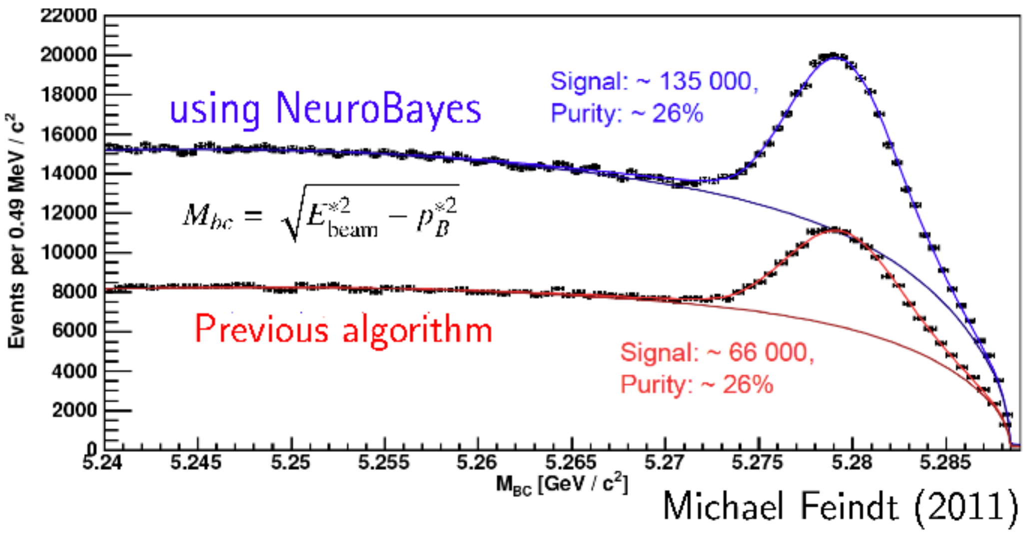


New Belle hadronic tag

$$M^2_{\text{miss}} = [p(\text{Beam}) - (p(B_{\text{tag}}) + p(\text{visible}))]^2$$



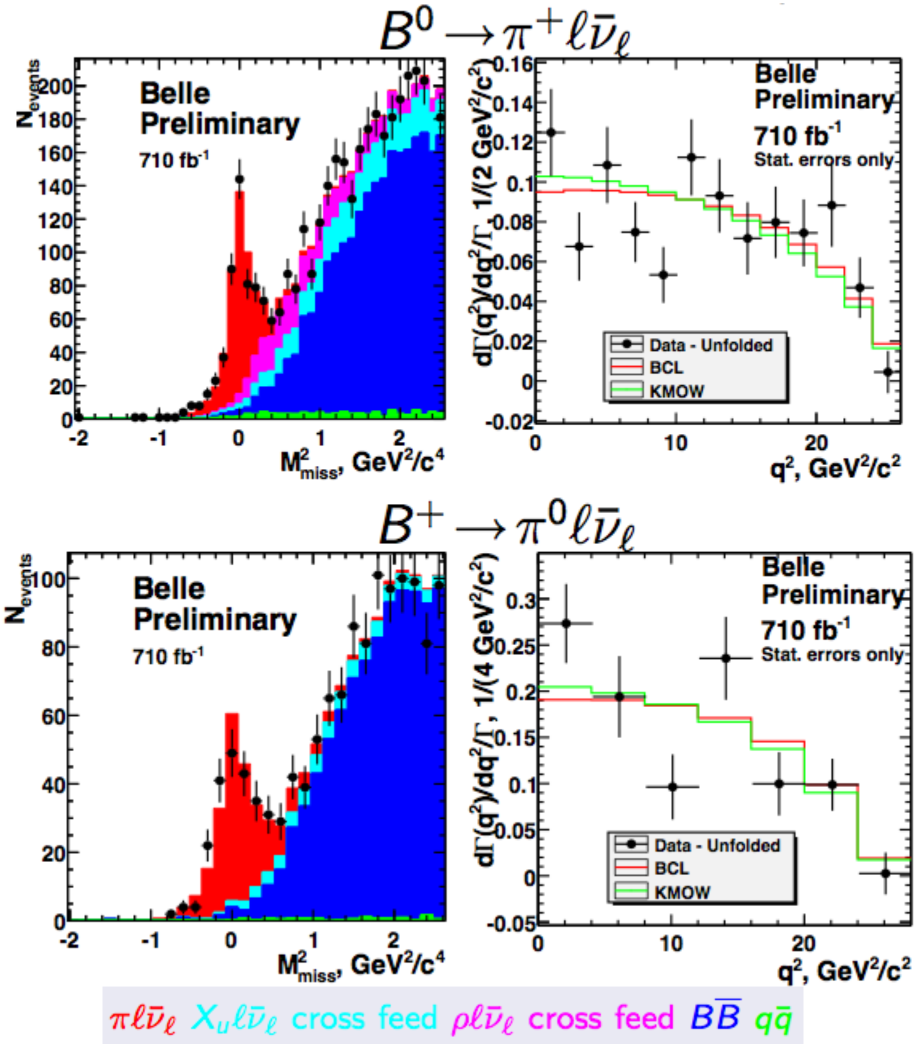
[NIM A654, 432 (2011)]



- New hadronic tag based on Neurobayes
- 2-3x statistical gain over previous analyses

$B \to \pi l \nu$ with hadronic tag

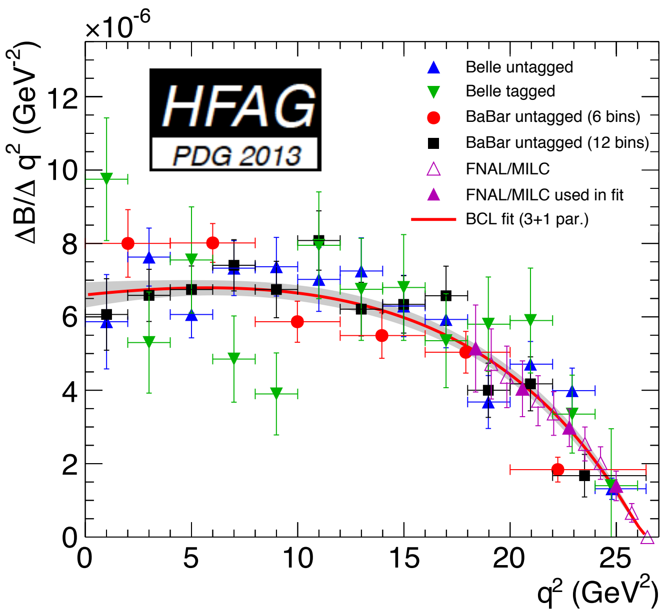
[PRD 88, 032005 (2013)]

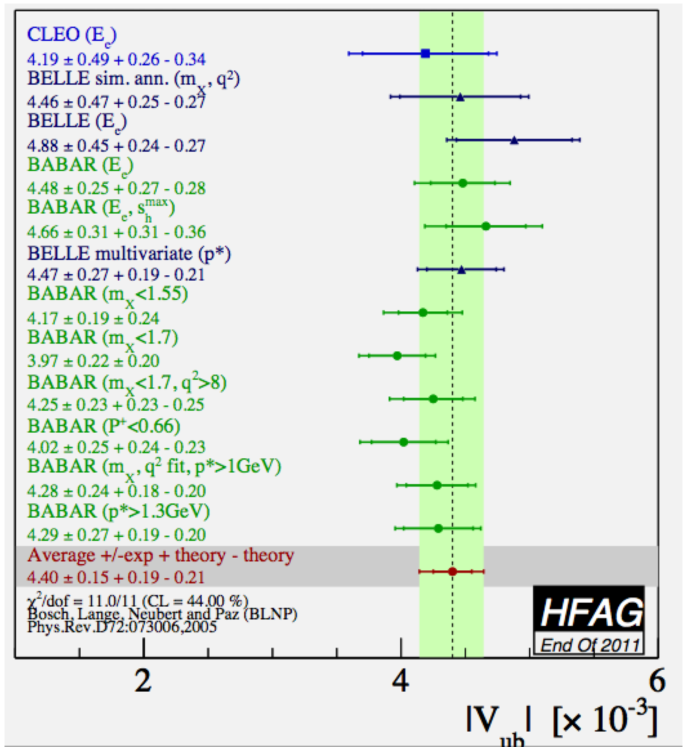


- 703/fb of Belle Y(4S) data
- Hadronic tag
- Yield extracted from M^2_{miss} in 13 (7) bins of q^2 for $B^0 \to \pi^+ l \nu$ ($B^+ \to \pi^0 l \nu$)
- Main systematics: tag calibration

X_u	Yield	$\mathcal{B} \times 10^4$
π^+	461 ± 28	$1.49 \pm 0.09 \pm 0.07$
π^0	230 ± 22	$0.80 \pm 0.08 \pm 0.04$

X_u	Theory	q^2, GeV/c^2	$\lvert V_{ub} \rvert \times 10^3$
π^0	LCSR1	< 12	$3.30 \pm 0.22 \pm 0.09^{+0.35}_{-0.30}$
	LCSR2	< 16	$3.62 \pm 0.20 \pm 0.10^{+0.60}_{-0.40}$
	HPQCD	> 16	$3.45 \pm 0.31 \pm 0.09^{+0.58}_{-0.38}$
	FNAL/MILC	> 16	$3.30 \pm 0.30 \pm 0.09^{+0.36}_{-0.30}$
π^+	LCSR1	< 12	$3.38 \pm 0.14 \pm 0.09^{+0.36}_{-0.32}$
	LCSR2	< 16	$3.57 \pm 0.13 \pm 0.09^{+0.59}_{-0.39}$
	HPQCD	> 16	$3.86 \pm 0.23 \pm 0.10^{+0.66}_{-0.44}$
	FNAL/MILC	> 16	$3.69 \pm 0.22 \pm 0.09^{+0.41}_{-0.34}$





$|V_{ub}|$

Exclusive (BCL fit)

$|V_{ub}| = (3.28 +/- 0.29) \times 10^{-3}$

Inclusive (BLNP)

$|V_{ub}| = (4.40 +/- 0.15_{exp} +/- 0.20_{th}) \times 10^{-3}$

HFAG preprint [arXiv:1207.1158]
+ web updates

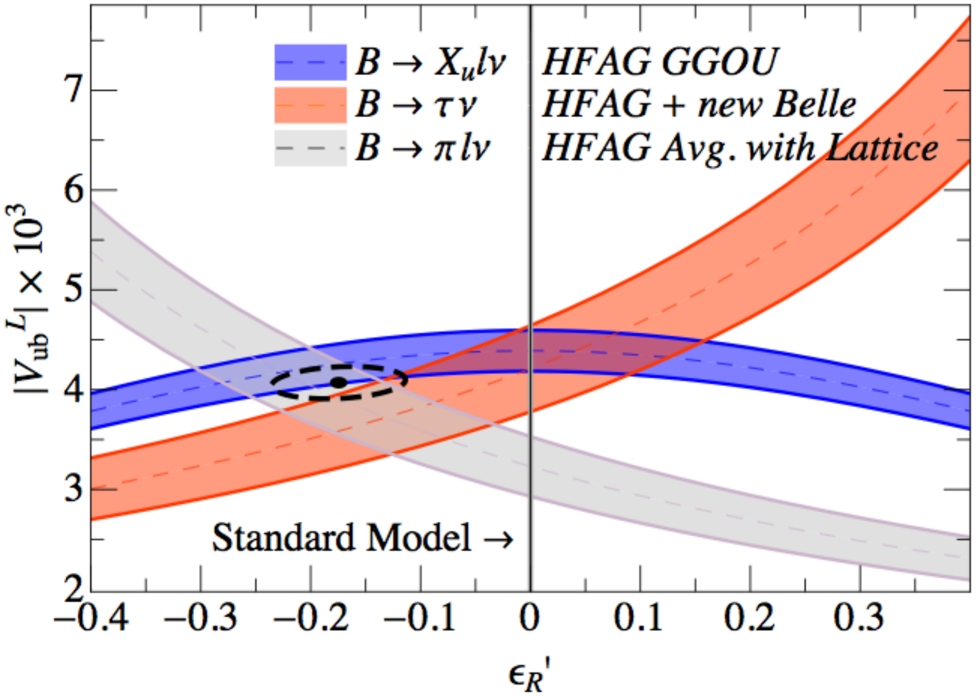
- Exclusive and inclusive agree at the level of ~3 sigma

Right-handed currents

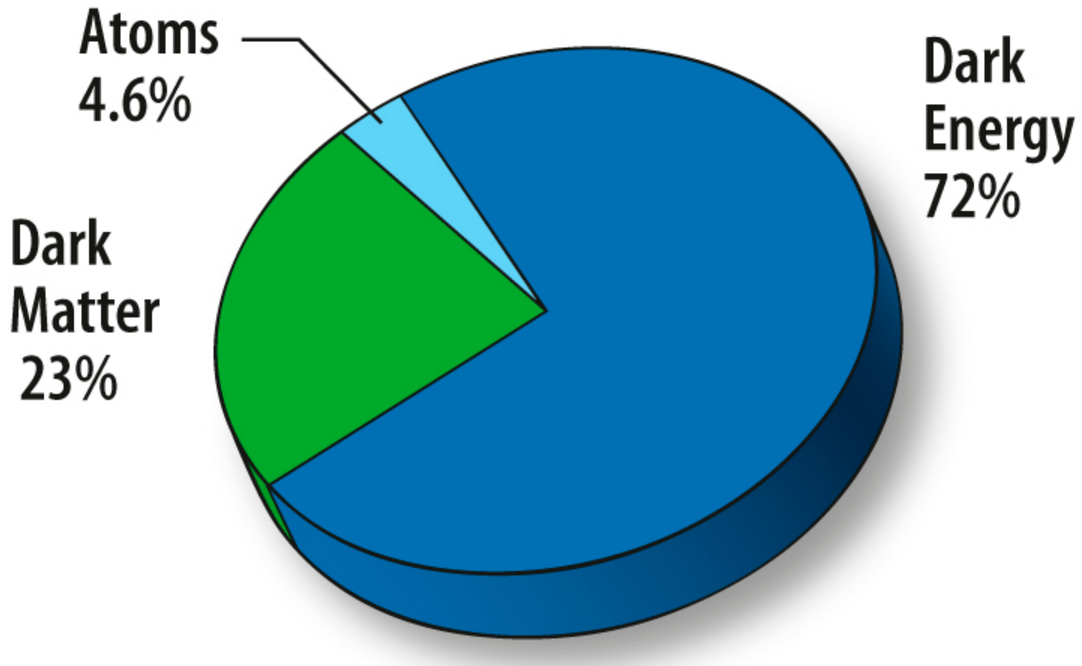
- Add right-handed currents ($|V_{ub}|=|V_{ub}^L|$)
  - $B \rightarrow \pi l \nu$ goes as $|V_{ub}^L+V_{ub}^R|^2$
  - $B \rightarrow \tau \nu$ goes as $|V_{ub}^L-V_{ub}^R|^2$
  - $B \rightarrow X_u l \nu$ goes as $|V_{ub}^L|^2+|V_{ub}^R|^2$
- Can fit the data with ~17% RHC contribution

Florian Bernlochner
CKM 2012 workshop

Proposed by
[hep-ph/0505166]
[arXiv:0907.2461]
[arXiv:1007.1993]



The Belle II upgrade



© NASA/WMAP

Extensions to the Standard Model

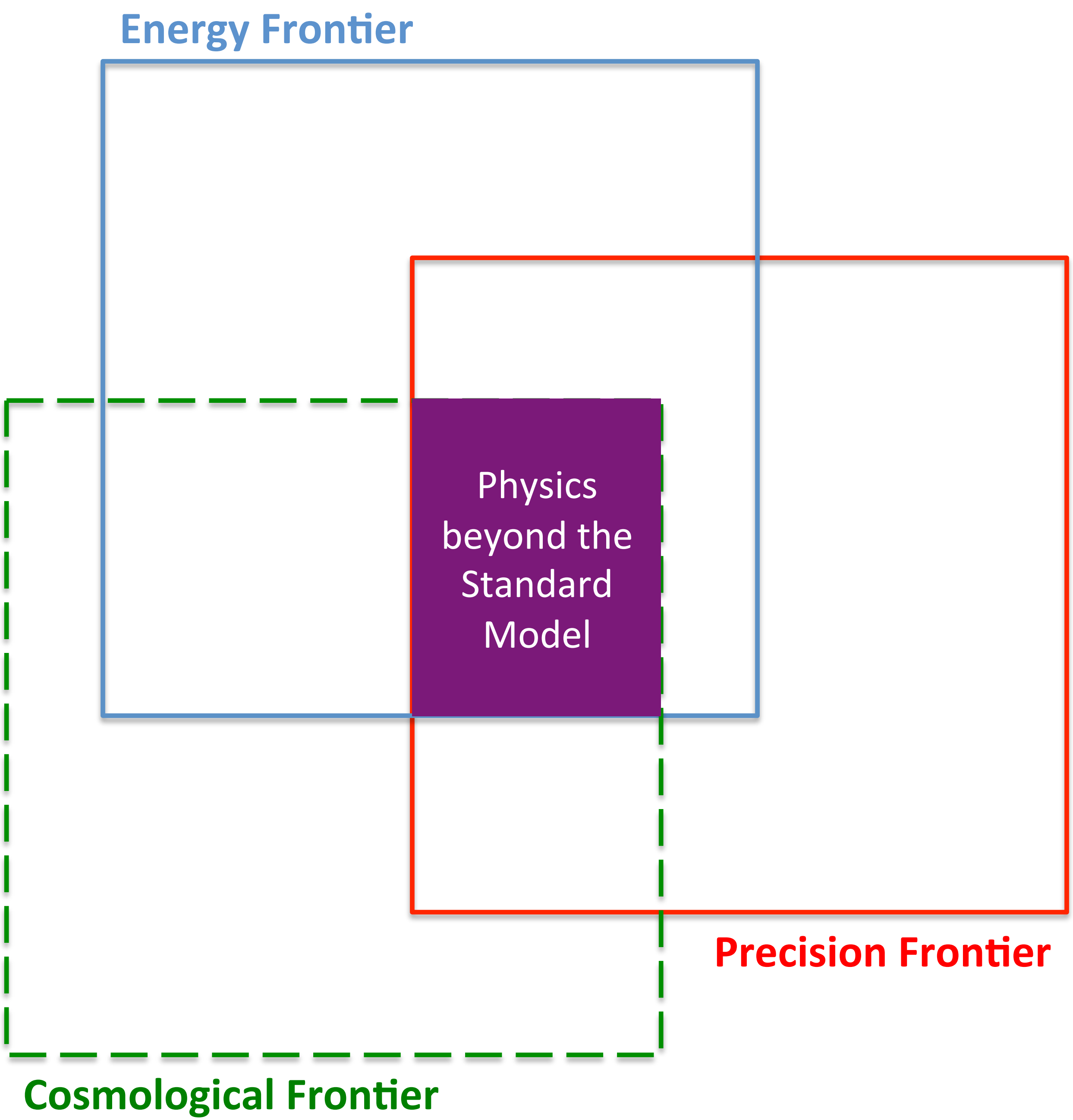
Supersymmetry

Large Extra Dimensions

Technicolor

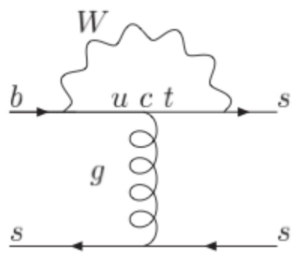
Little Higgs

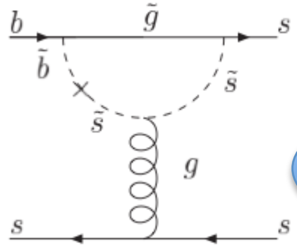
GRAND UNIFICATION


Energy Frontier
Physics beyond the Standard Model
Precision Frontier
Cosmological Frontier

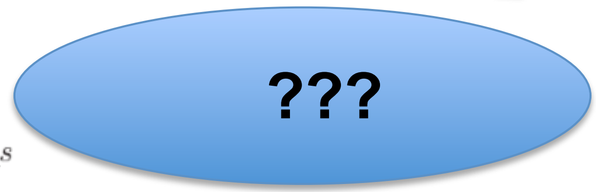
Belle II search channels for NP

Flavor changing neutral currents (virtual contributions of new, heavy particles in loops)





Precision test of CKM unitarity (search for new CP violating phases)

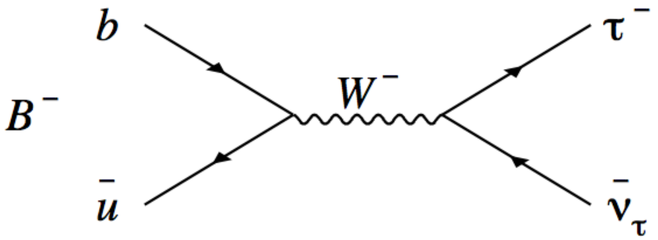


Search for the charged Higgs boson in B → τ nu and B → D(*) τ nu decays

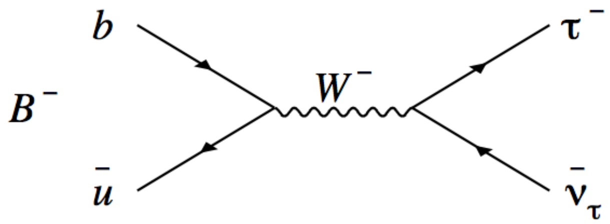
Search for lepton flavor violation in B and tau decays (SUSY breaking mechanism, right-handed neutrino couplings)

Search for the charged Higgs boson with $B^+ \to \tau^+ \nu$

Standard model

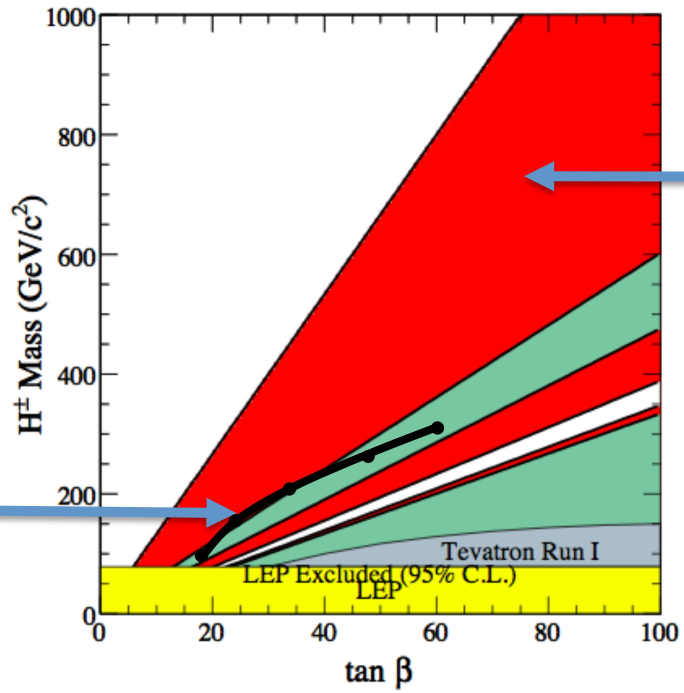


Type II Higgs doublet models



$$\mathcal{B}(B^- \to \tau^- \bar{\nu}) = \mathcal{B}_{\rm SM} \times r_H \quad r_H = \left(1 - \tan^2\beta \frac{m_{B^-}^2}{m_{H^-}^2}\right)^2$$

W.S.Hou,
PRD 48, 2342 (1993)



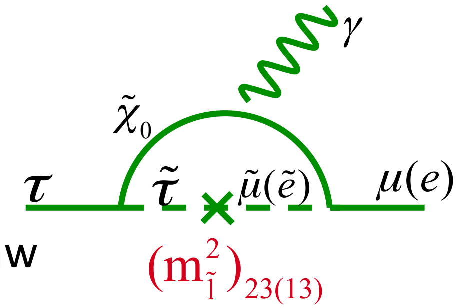
Belle II 5σ H^+ discovery (50/ab)

14 TeV ATLAS 5σ H^+ discovery (30/fb)

arXiv:0901.0512 [hep-ex]

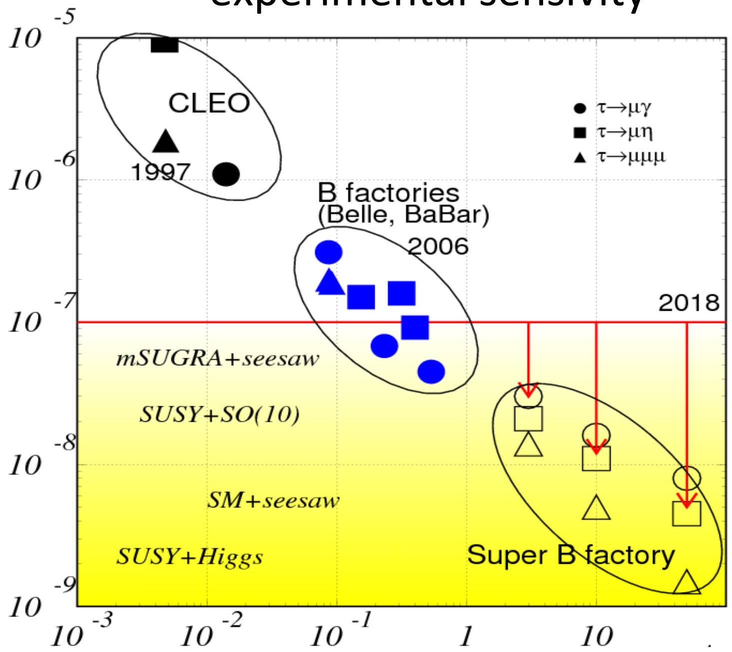
τ lepton flavor violation

τ → lγ

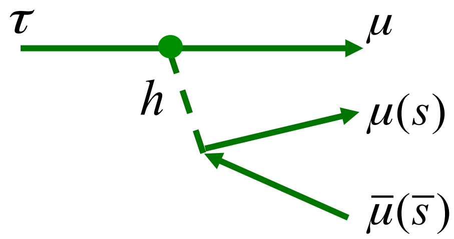


- SUSY + seesaw
- Large LFV

experimental sensivity



τ → 3l, lη



- Neutral Higgs mediated decay
- Important when M_{SUSY} >> EW scale

mode	Br(τ → μγ)	Br(τ → 3l)
mSUGRA + seesaw	10^{-7}	10^{-9}
SUSY + SO(10)	10^{-8}	10^{-10}
SM + seesaw	10^{-9}	10^{-10}
Non-universal Z'	10^{-9}	10^{-8}
SUSY + Higgs	10^{-10}	10^{-7}

The full range of τ LFV modes is only accessible at a Super B factory!

Belle II physics sensitivity

[arXiv:1002.5012[hep-ex]]

Observable	Belle 2006 ($\sim$0.5 ab^{-1})	SuperKEKB (5 ab^{-1})	SuperKEKB (50 ab^{-1})	†LHCb (2 fb^{-1})	†LHCb (10 fb^{-1})
Leptonic/semileptonic B decays					
$\mathcal{B}(B^+ \to \tau^+\nu)$	3.5σ	10%	3%	-	-
$\mathcal{B}(B^+ \to \mu^+\nu)$	†† $< 2.4\mathcal{B}_{SM}$	4.3 ab^{-1} for 5σ discovery		-	-
$\mathcal{B}(B^+ \to D\tau\nu)$	-	8%	3%	-	-
$\mathcal{B}(B^0 \to D\tau\nu)$	-	30%	10%	-	-
LFV in τ decays (U.L. at 90% C.L.)					
$\mathcal{B}(\tau \to \mu\gamma)$ [10^{-9}]	45	10	5	-	-
$\mathcal{B}(\tau \to \mu\eta)$ [10^{-9}]	65	5	2	-	-
$\mathcal{B}(\tau \to \mu\mu\mu)$ [10^{-9}]	21	3	1	-	-
Unitarity triangle parameters					
$\sin 2\phi_1$	0.026	0.016	0.012	$\sim$0.02	$\sim$0.01
ϕ_2 ($\pi\pi$)	11°	10°	3°	-	-
ϕ_2 ($\rho\pi$)	$68° < \phi_2 < 95°$	3°	1.5°	10°	4.5°
ϕ_2 ($\rho\rho$)	$62° < \phi_2 < 107°$	3°	1.5°	-	-
ϕ_2 (combined)		2°	$\lesssim 1°$	10°	4.5°
ϕ_3 ($D^{(*)}K^{(*)}$) (Dalitz mod. ind.)	20°	7°	2°	8°	
ϕ_3 ($DK^{(*)}$) (ADS+GLW)	-	16°	5°	5-15°	
ϕ_3 ($D^{(*)}\pi$)	-	18°	6°		
ϕ_3 (combined)		6°	1.5°	4.2°	2.4°
$\|V_{ub}\|$ (inclusive)	6%	5%	3%	-	-
$\|V_{ub}\|$ (exclusive)	15%	12% (LQCD)	5% (LQCD)	-	-
$\bar{\rho}$	20.0%		3.4%		
$\bar{\eta}$	15.7%		1.7%		

From KEKB to SuperKEKB

$$L = 8\times 10^{-35}\left[cm^{-2}s^{-1}\right] \propto \frac{I_{e\pm}\xi_{\pm y}}{\beta_y^*}.$$

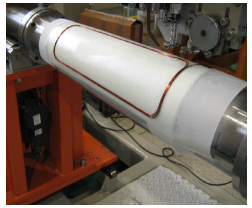
Take advantage of existing items

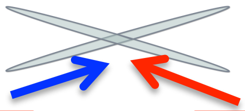
- **the KEKB tunnel,**
- **the KEKB components**
  as much as possible!

Build new beam line Tsukuba section

New QCS magnet for Nano-beam scheme

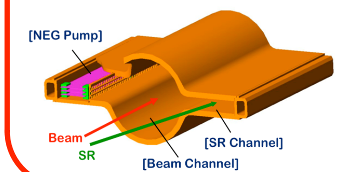
New superconducting / permanent final focusing quads near the IP

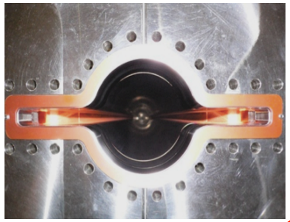




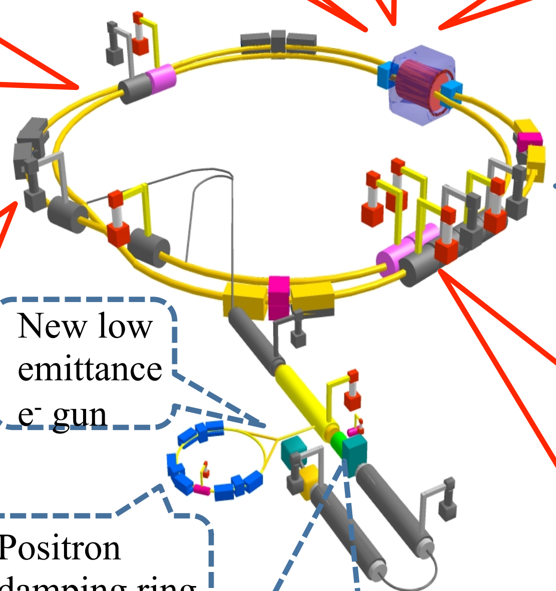
New beam pipe& bellows

TiN-coated beam pipe with antechambers



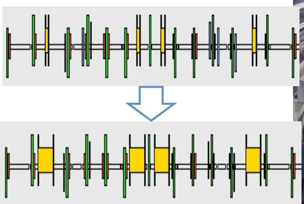


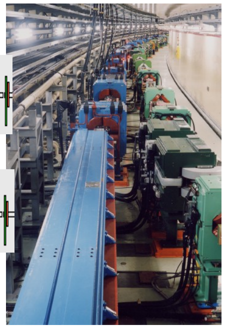
New design for Near-IR



Add / modify RF systems for higher beam current

Main ring arc and straight section:
Redesign the lattices of both rings to reduce the emittance





Main ring arc section:

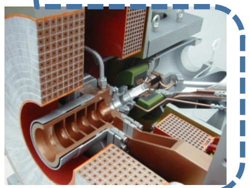
LER: Replace all main dipoles

HER: Preserve the present cells

New low emittance e^- gun

Positron damping ring

New e^+ source



New and re-use wiggler magnets are mixed:

Oho section (LER&HER)

Nikko section (LER)

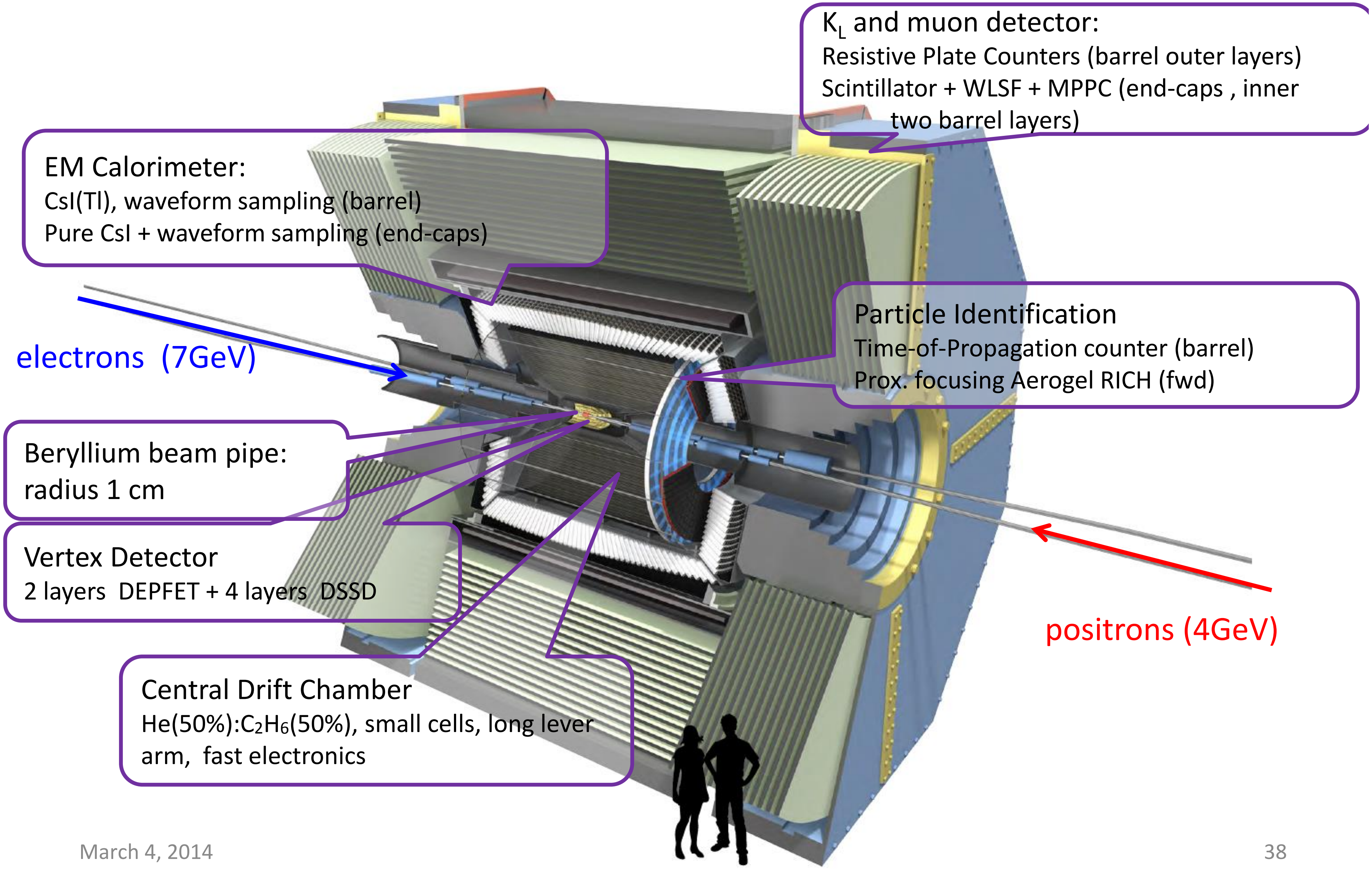
Compare the Parameters for KEKB and SuperKEKB

	KEKB Design	KEKB Achieved : with crab	SuperKEKB Nano-Beam
Energy (GeV) (LER/HER)	3.5/8.0	3.5/8.0	4.0/7.0
β_y^* (mm)	10/10	5.9/5.9	0.27/0.30
β_x^* (mm)	330/330	1200/1200	32/25
ε_x (nm)	18/18	18/24	3.2/5.3
$\varepsilon_y/\varepsilon_x$ (%)	1	0.85/0.64	0.27/0.24
σ_y(μm)	1.9	0.94	0.048/0.062
ξ_y	0.052	0.129/0.090	0.09/0.081
σ_z (mm)	4	6 - 7	6/5
I_{beam} (A)	2.6/1.1	1.64/1.19	3.6/2.6
$N_{bunches}$	5000	1584	2500
Luminosity (10^{34} cm^{-2} s^{-1})	1	2.11	80

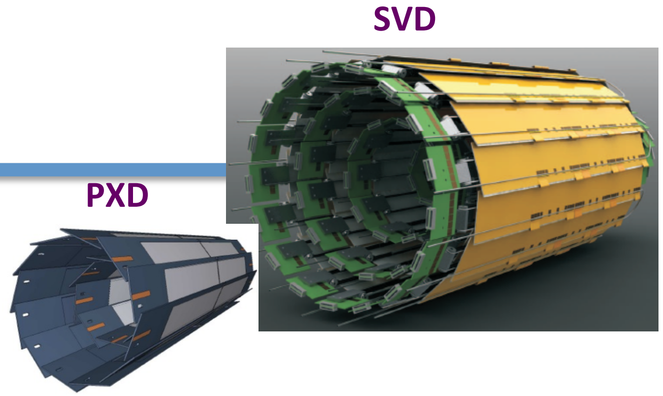
Nano-beams are the key (vertical spot size is ~50nm !!)

This is not a typo

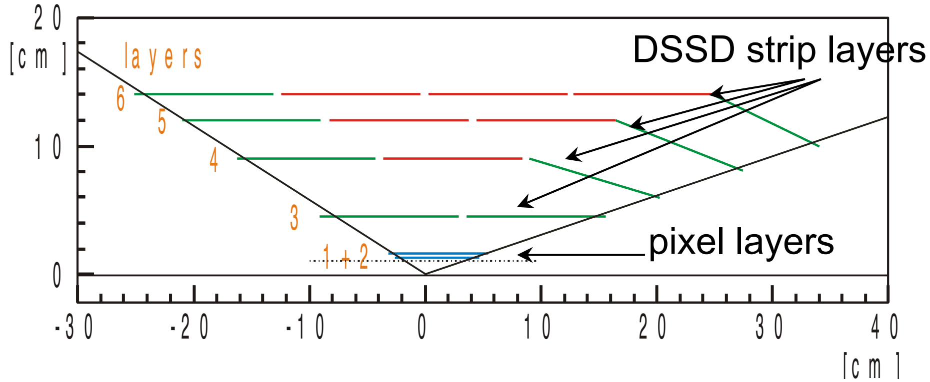
Belle II Detector



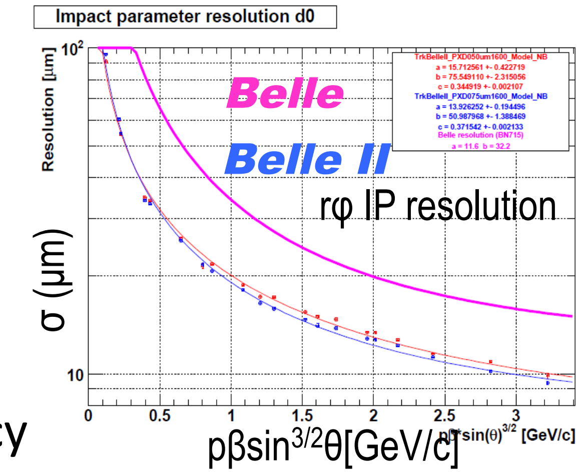
Inner tracking (PXD, SVD)

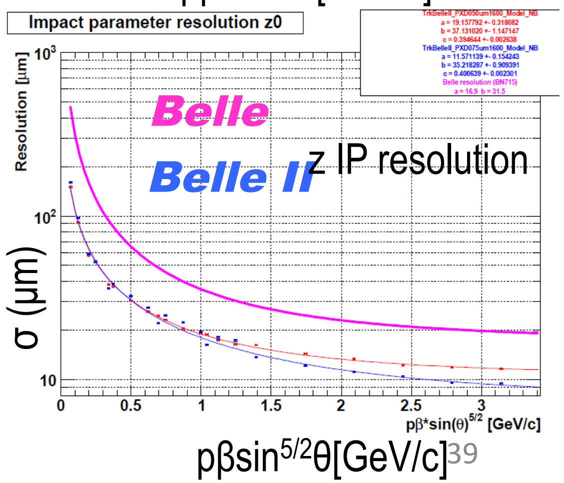


- PXD + SVD in Belle II (in Belle only strip layers)



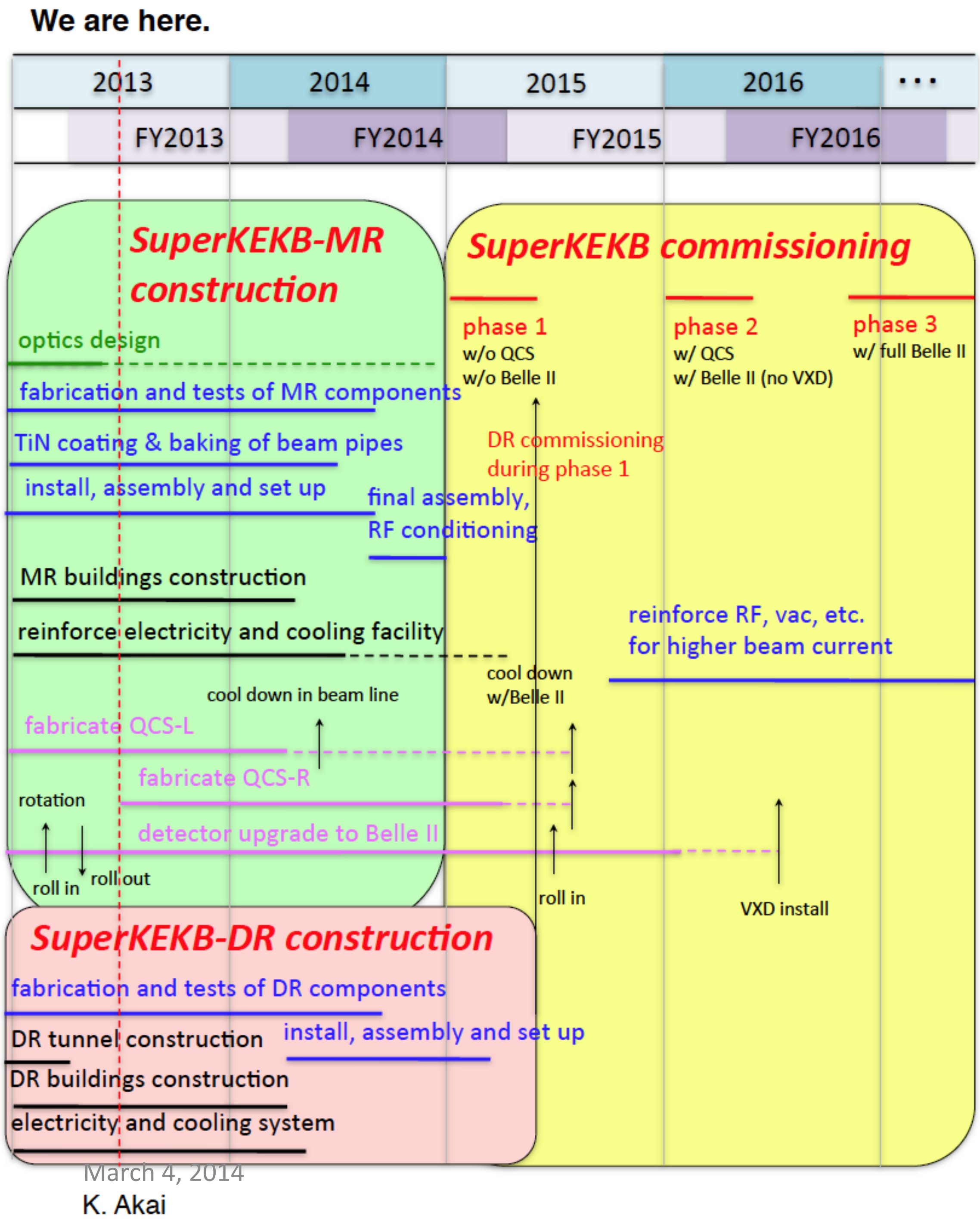
- Pixels in novel DEPFET technology: thin (75μm) sensors give little multiple scattering, close to the IR
- Fast strip readout with APV25 chip (50 ns), low occupancy
- Improved IP resolution and low momentum tracking ($p_T < 100$MeV), 30% larger eff. of $K_s \rightarrow \pi^+\pi^-$ with vertex info





Mechanical mockup of pixel detector

DEPFET sensor



<u>Phase I:</u>

w/o QCS and Belle II

Jan-May, 2015

<u>Phase II:</u>

with QCS and Belle II

Partial TOP,

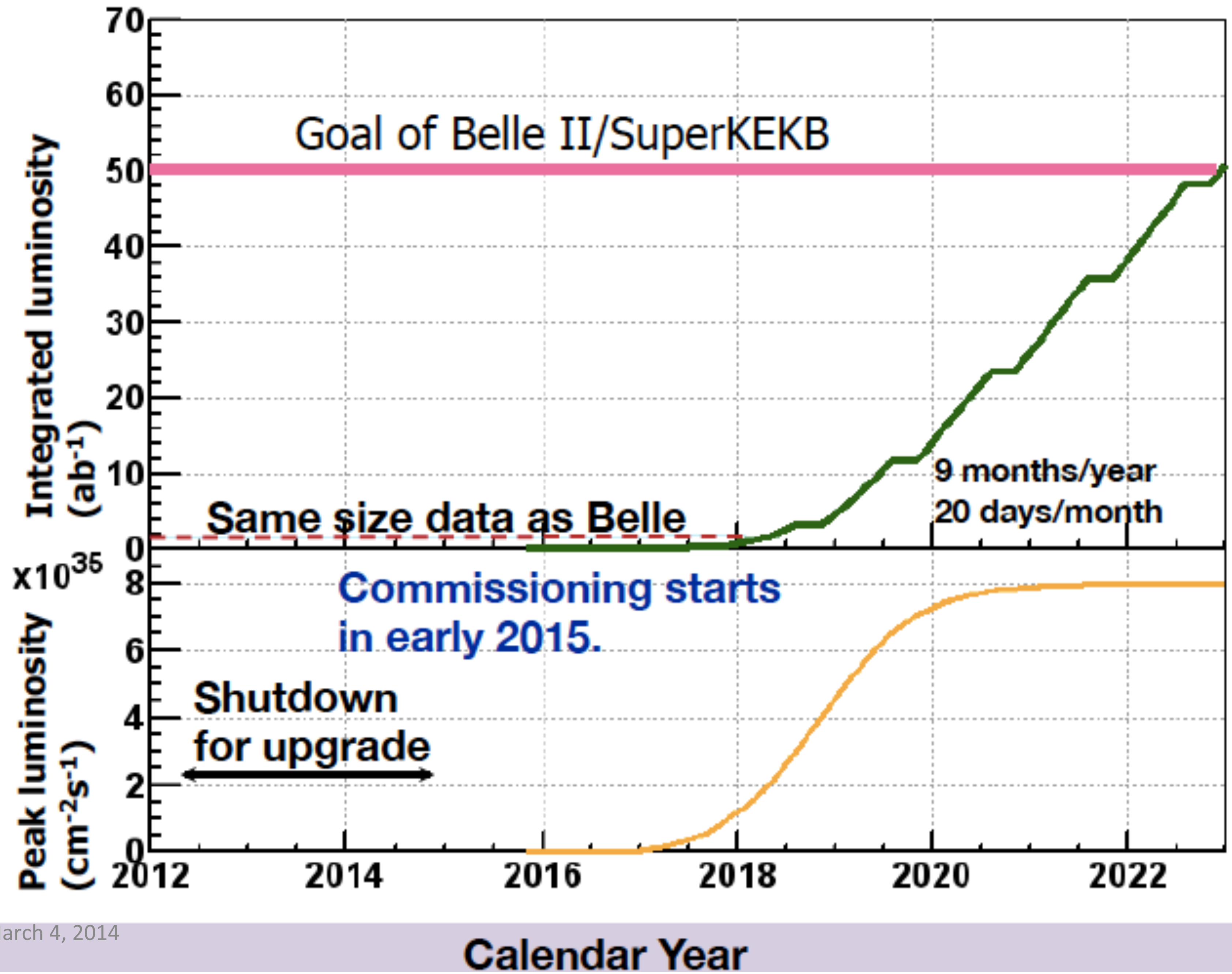
w/o vtx detectors

Feb-June, 2016

<u>Phase III:</u>

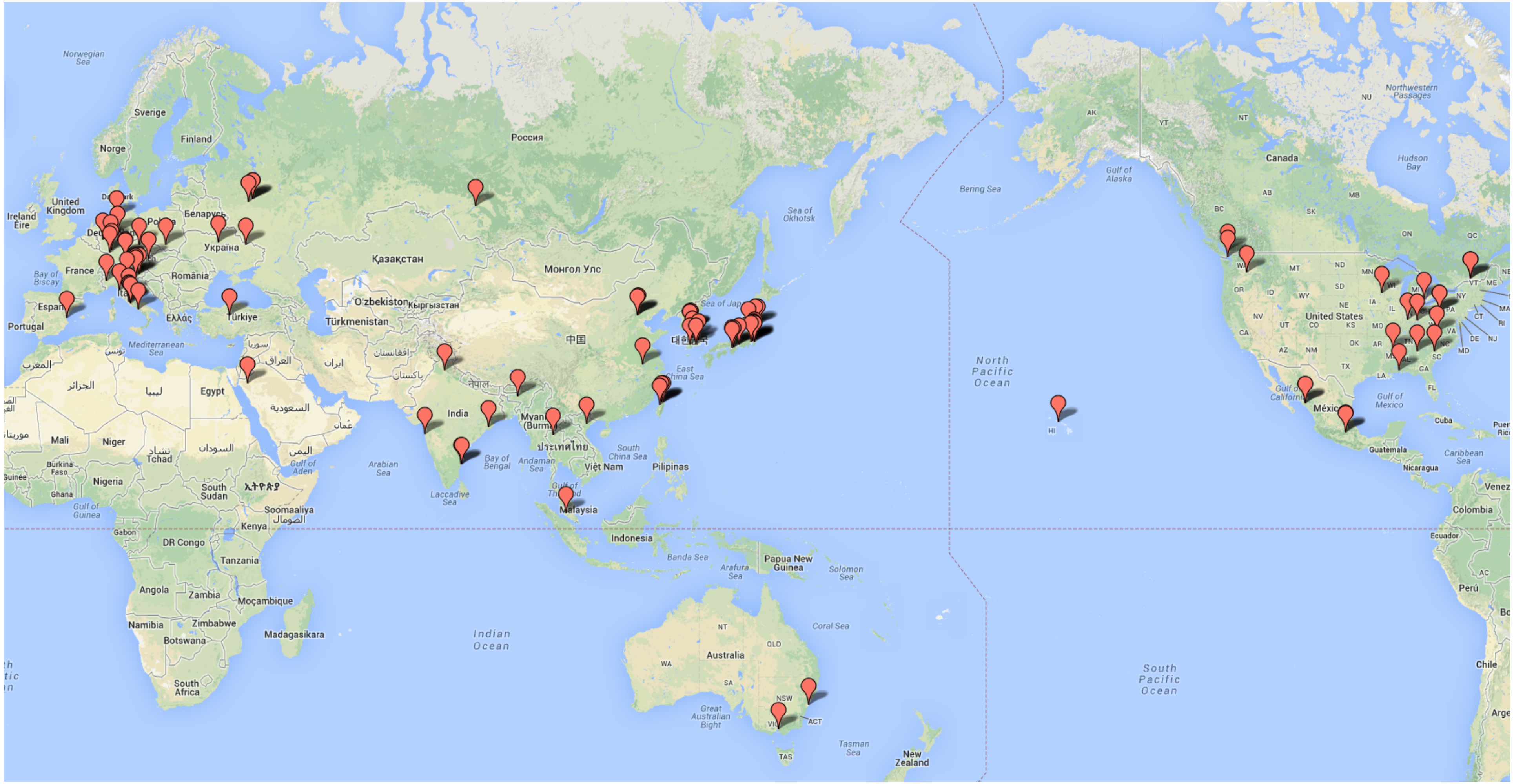
Physics Run with full Belle II

Starts Oct 2016



Goal of Belle II/SuperKEKB
Integrated luminosity (ab-1)
70
60
50
40
30
20
10
0
9 months/year
20 days/month
Same size data as Belle
x10^35
8
6
4
2
0
Commissioning starts
in early 2015.
Shutdown
for upgrade
Peak luminosity (cm-2s-1)
2012
2014
2016
2018
2020
2022
Calendar Year

Belle II map (as of Nov 2013)



<table><tr><td>23 countries/regions, 97 institutions</td></tr></table>

~580 collaborators,
~220 from Europe

Prospects for semileptonic B decays

General comment

- Two aims at Belle II
  - Reduce the uncertainties on $|V_{cb}|$ and $|V_{ub}|$
  - Understand the reason of the discrepancy between inclusive and exclusive (or firmly establish it $\rightarrow$ NP)
- Strategy
  - Use only the theoretically/experimentally cleanest methods
  - Provide consistency checks for theory/experiment

Prospects for $|V_{cb}|$ at Belle II

- Tagged measurement of $B \to D^{*} l\nu$ and $B \to D l\nu$ will yield $|V_{cb}|$ with a similar level of precision
- Fit with lattice data at different kinematic points?

Expected relative uncertainty in $|V_{cb}|$ from $B \to D^{*} l\nu$

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

lattice prospects from
http://www.usqcd.org/documents/13flavor.pdf

Prospects for $|V_{ub}|$ exclusive at Belle II

- The tagged measurement of $B \to \pi l \nu$ reaches a similar precision than the untagged one

Expected relative uncertainty in $|V_{ub}|$ from $B \to \pi l \nu$

Sample	Stat	Syst	Th	Total	
605/fb	2.7	2.2	8.7	9.4	untagged
5/ab	0.9	1.1	4.0	4.2	untagged
50/ab	0.3	0.8	2.0	2.2	untagged
711/fb	5.8	2.5	8.7	10.8	tagged
5/ab	2.2	1.3	4.0	4.7	tagged
50/ab	0.7	1.0	2.0	2.4	tagged

lattice prospects from
http://www.usqcd.org/documents/13flavor.pdf

Prospects for $|V_{ub}|$ inclusive at Belle II

- We can measure inclusive observables in $b \rightarrow u$ and confirm the theory description (similar to $b \rightarrow c$)

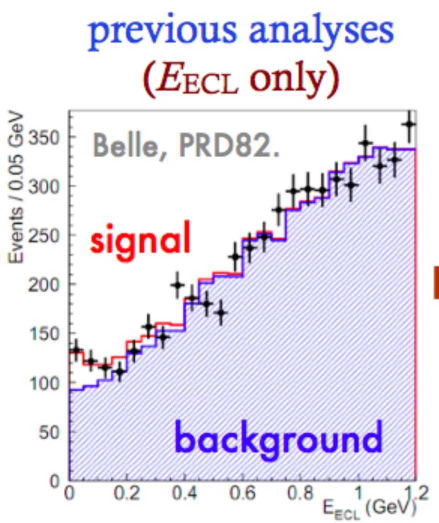
Expected relative uncertainty in $|V_{ub}|$ inclusive

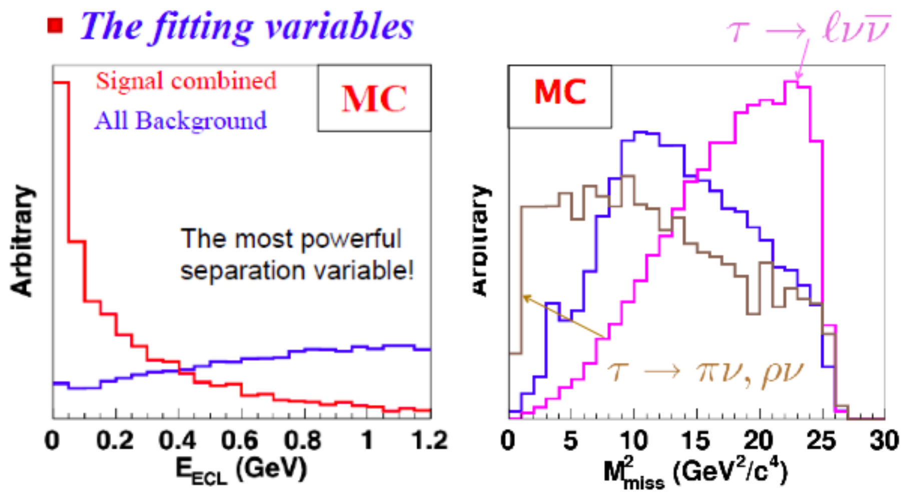
Sample	Stat	Syst	Th	Total
605/fb	4.5	4.1	4.5	7.6
5/ab	1.6	2.6	4.5	5.4
50/ab	0.5	2.3	4.5	5.1

Measurement of $B \rightarrow \tau\nu$

[PRL 110, 131801 (2013)]

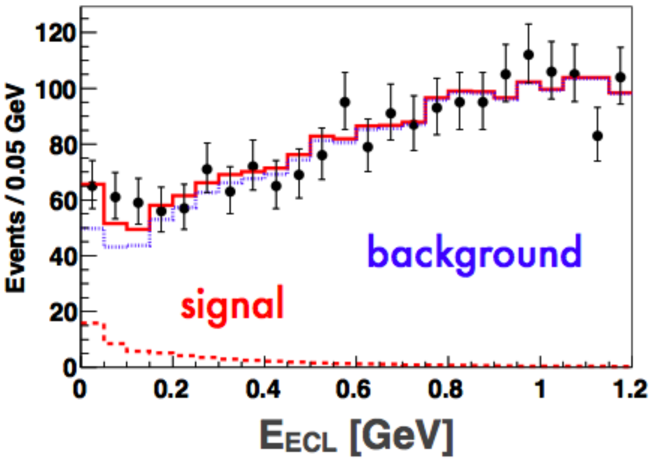
- 703/fb of Y(4S) data
- 4 signal tau modes: $\tau \rightarrow e\nu\nu, \mu\nu\nu, \pi\nu, \rho\nu$
- New hadronic tag (sample x3 compared to 2006 analysis)
- 2d fit to E_{ECL} and M^2_{miss} (2006: E_{ECL} only)
  - Improve sensitivity by 20%
  - More robust against peaking backgrounds



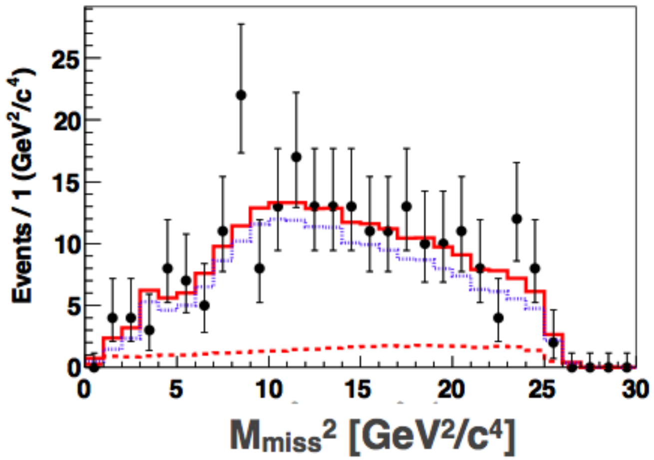


Measurement of B → τν

[PRL 110, 131801 (2013)]



(Projection for all M_{miss}^2 region.)



(Projection for E_{ECL} < 0.2 GeV)

- Signal yield:
  62 +23/-22 +/- 6
  (3σ including systematics)
- Br(B → τν) =
  (0.72 +0.27/-0.25 +/- 0.11) x 10^{-4}

- Current analysis ~3 sigma evidence
- At Belle II, we expect to measure $|V_{ub}|$ from B → τν at the level of 3-5%

SUMMARY

Summary

- Semileptonic B decays have allowed to determine the CKM matrix elements $|V_{cb}|$ and $|V_{ub}|$ to the level of 1-2% and 6-10%, respectively
- However, there is a long-standing discrepancy between inclusive and exclusive measurements of $|V_{cb}|$ and $|V_{ub}|$
- At Belle II we can address this issue with new experimental methods and provide crucial cross checks to confirm the OPE/lattice description

LOC: Schwanda, Abele, Hoang
http://ckm2014.hephy.at/

ckm2014.hephy.at

CKM wiki pages KEK user support system

Home | Venue | Working Groups | Program | Social Events | Registration | Contributions | Travel | Contact

The ***International Workshop on the CKM Unitarity Triangle (CKM2014)*** takes place between **Monday, 8th and Friday, 12th September 2014** at the *Faculty of Electrical Engineering and Information Technology of the Vienna University of Technology*.

The CKM series is a well-established meeting in the field of quark-flavour physics and provides a venue to both experimentalists and theorists. On the experimental side, we bridge borders between neutron, kaon, charm and B-meson physics. The theory programme tries to cover a wide range of approaches. We will discuss how the combination of experiment and theory can allow searches for physics beyond the Standard Model and consider the interplay of the quark-flavour field with high-pT searches for new physics.

Similar to previous editions, the workshop will be a culmination of the efforts of different working groups. There will also be opening and summary plenary sessions.

Submenu

- Committees / Contact
- Deadlines
- Venue
- Poster
- Previous Workshops

Important deadlines not to be missed

Go to "http://ckm2014.hephy.at/"

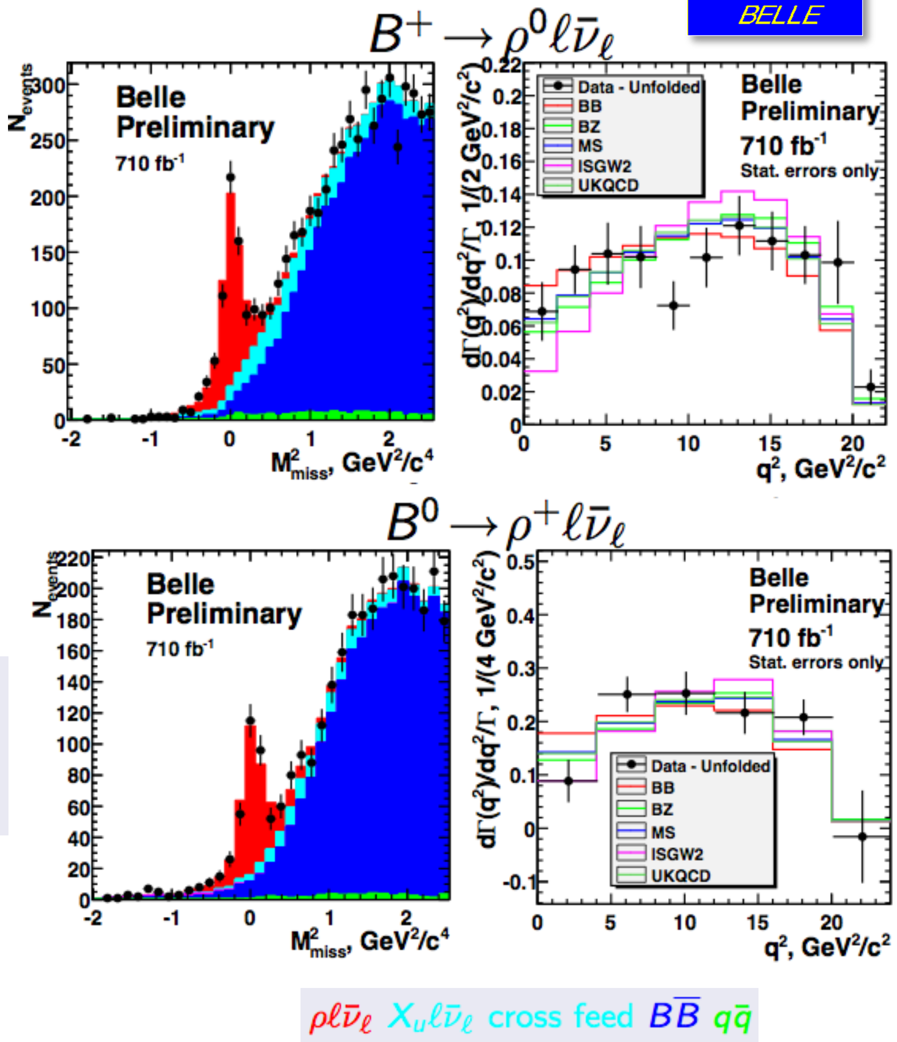
BACKUP

$B \to \rho l\nu$ with hadronic tag

PRD 88, 032005 (2013)

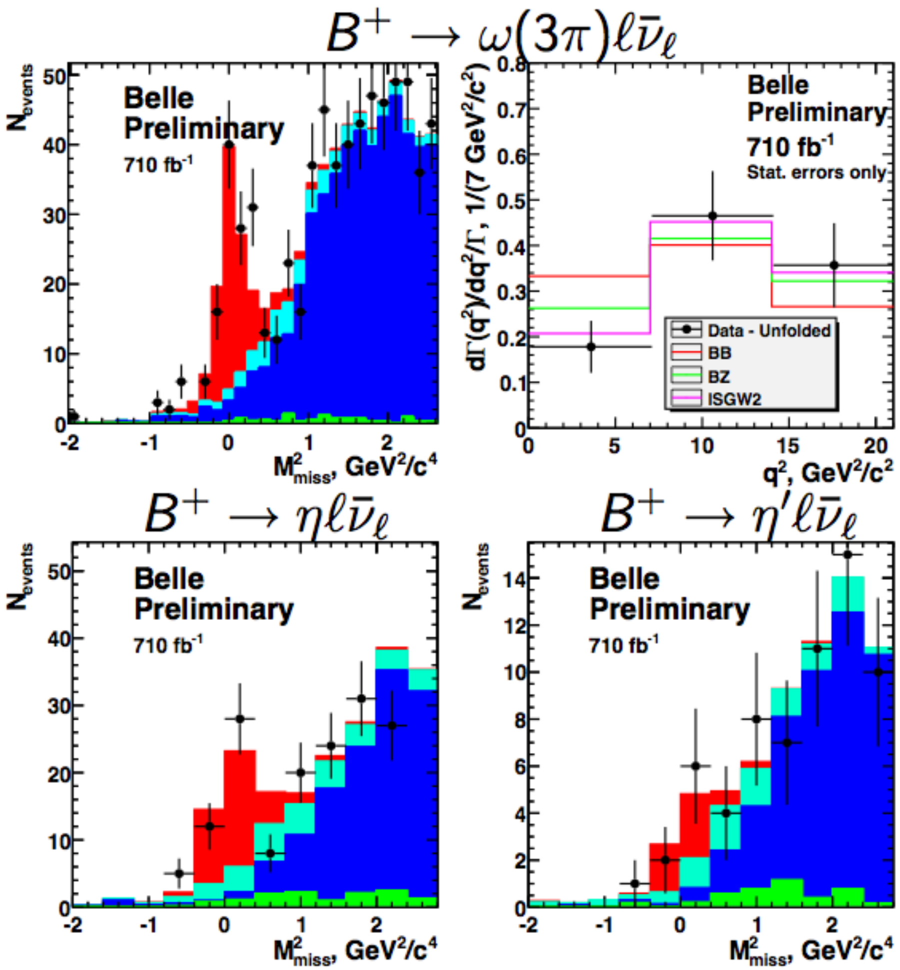
- 703/fb of Belle Y(4S) data
- Hadronic tag
- Yield extracted from M^2_{miss} in 11 (6) bins of q^2 for $B^+ \to \rho^0 l\nu$ ($B^0 \to \rho^+ l\nu$)

X_u	Yield	$\mathcal{B} \times 10^4$
ρ^+	338±28	$3.17 \pm 0.27 \pm 0.18$
ρ^0	632±35	$1.86 \pm 0.10 \pm 0.09$



$B^+ \to \omega l\nu$ and $B^+ \to \eta^{(\prime)} l\nu$

PRD 88, 032005 (2013)



Signal $X_u\ell\bar{\nu}_\ell$ cross feed $B\bar{B}$ $q\bar{q}$

X_u	Yield	$\mathcal{B} \times 10^4$
ω	99±15	$1.09 \pm 0.16 \pm 0.08$
η	39±11	$0.42 \pm 0.12 \pm 0.05$
η'	6.1±4.7	< 0.57 @ 90% CL

- 703/fb of Belle Y(4S) data

$$\frac{d^2\Gamma}{dq^2 d\chi} = a_\chi(q^2) + b_\chi^c(q^2)\cos\chi + b_\chi^s(q^2)\sin\chi + c_\chi^c(q^2)\cos 2\chi + c_\chi^s(q^2)\sin 2\chi$$

$$a_\chi(q^2) = \frac{G_F^2|V_{cb}|^2}{384\pi^4 m_B^3} q^2 \left(1 - \frac{m_\ell^2}{q^2}\right)^2 \sqrt{\lambda_{D^*}(q^2)} \times \Bigg\{ [|H_+|^2 + |H_-|^2 + |H_0|^2] \left(1 + \frac{m_\ell^2}{2q^2}\right) + \frac{3}{2}\frac{m_\ell^2}{q^2}|H_t|^2 \Bigg\}$$

$$c_\chi^c(q^2) = -\frac{G_F^2|V_{cb}|^2}{384\pi^4 m_B^3} q^2 \left(1 - \frac{m_\ell^2}{q^2}\right)^3 \sqrt{\lambda_{D^*}(q^2)} \times \mathcal{R}e\,[H_+ H_-^*]$$

$$c_\chi^s(q^2) = -\frac{G_F^2|V_{cb}|^2}{384\pi^4 m_B^3} q^2 \left(1 - \frac{m_\ell^2}{q^2}\right)^3 \sqrt{\lambda_{D^*}(q^2)} \times \mathcal{I}m\,[H_+ H_-^*]$$

- $b_\chi^{c,s}(q^2) = 0$ unless there is interference with $(D\pi)_S$ amplitude [interesting!!!]
- Two NEW NP-sensitive observables:

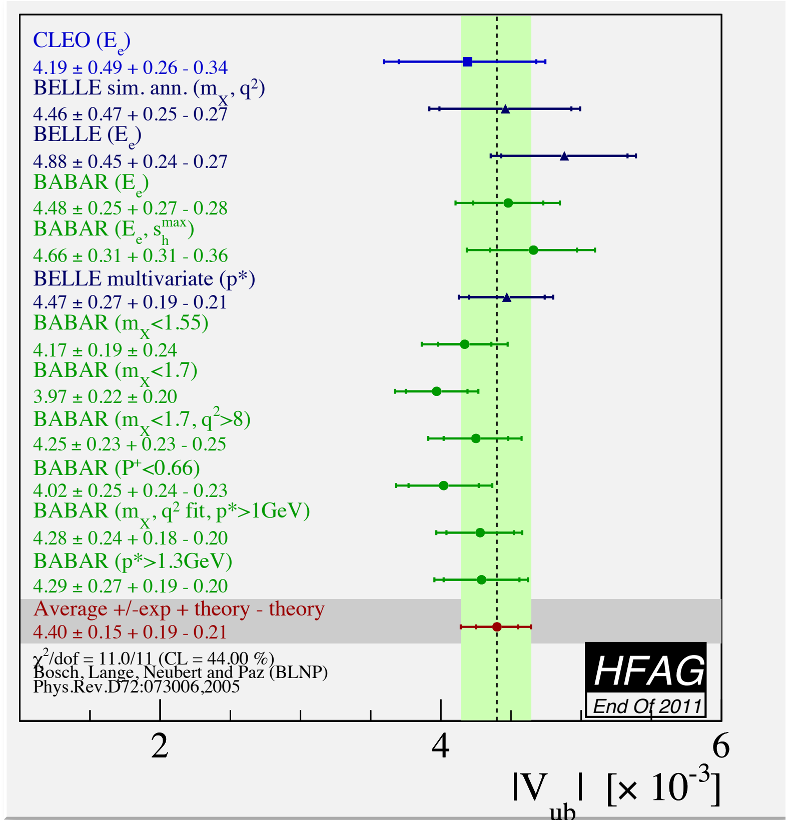
$$C_\chi^{(\ell)}(q^2) = \frac{c_\chi^c(q^2)}{a_\chi(q^2)}, \qquad S_\chi^{(\ell)}(q^2) = \frac{c_\chi^s(q^2)}{a_\chi(q^2)}.$$

Issues in $|V_{cb}|$

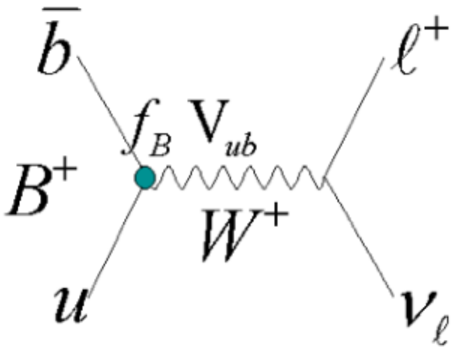
- $|V_{cb}|$ exclusive mainly comes from $B^0 \rightarrow D^{*-} l^+ \nu$
  - $|V_{cb}|$ from $B^+ \rightarrow D^{*0}$bar $l^+ \nu$, $B^0 \rightarrow D^- l^+ \nu$ and $B^+ \rightarrow D^0$bar $l^+ \nu$ is considerably less precise
  - Measurements of $B^0 \rightarrow D^{*-} l^+$ nu by different experiments are consistent but could be affected by common systematics (slow pion tracking)
- F(w) and G(w) form-factors
  - Calculated only at a single kinematic point (zero recoil w=1) – can lattice predict the F.F. shape also in B decays?
  - Precise calculation of F(1) available only from a single lattice group (FNAL MILC)
  - Discrepancy with sum rule calculations (~1 sigma)
- Radiative and EW corrections?

Issues in $|V_{ub}|$

- $|V_{ub}|$ exclusive comes exclusively from $B \to \pi l \nu$
  - No precise F.F. calculations for $B \to \rho l \nu$ or other modes
  - Lattice and sum rule calculations of the F.F. apply to different q^2 regions and don't provide a mutual cross-check
  - Can we claim that lattice predicts the F.F. shape?
- $|V_{ub}|$ inclusive
  - Dominant experimental systematics: $b \to u$ signal modelling – how well do we understand light quark fragmentation?
  - 5 theoretical frameworks but none of them provides a (convincing) internal cross-check



Leptonic B decays



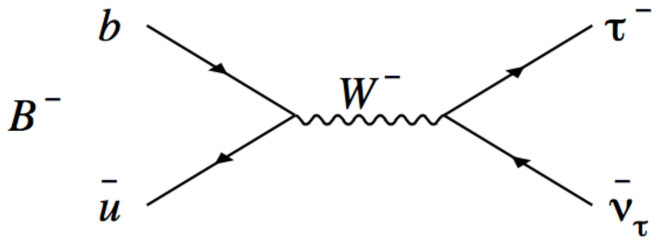
$$\Gamma(B^+ \to \ell^+ \nu_\ell) = \frac{G_F^2 m_B m_\ell^2}{8\pi} \left(1 - \frac{m_\ell^2}{m_B^2}\right)^2 f_B^2 |V_{ub}|^2$$

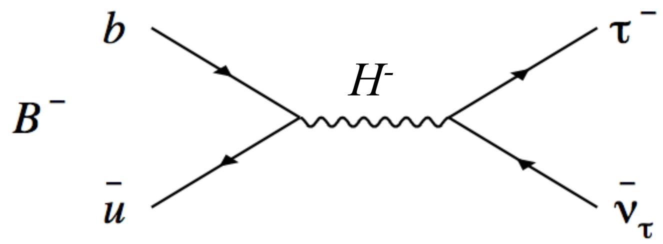
$$\mathcal{B}(B \to e\nu)_{SM} \sim 10^{-11}$$
$$\mathcal{B}(B \to \mu\nu)_{SM} \sim 3.5 \times 10^{-7}$$
$$\mathcal{B}(B \to \tau\nu)_{SM} \sim 10^{-4}$$

- Helicity suppression $\Gamma(e\nu) << \Gamma(\mu\nu) << \Gamma(\tau\nu)$
- Very clean theoretically,
  might be affected by NP (2HDM, lepto-quark)
- $B \to e\nu$ and $B \to \mu\nu$ are also experimentally clean but beyond the reach of Belle
- $B \to \tau\nu$ has 2-3 neutrinos in the final state and kinematics cannot be fully reconstructed
  (high background measurement)

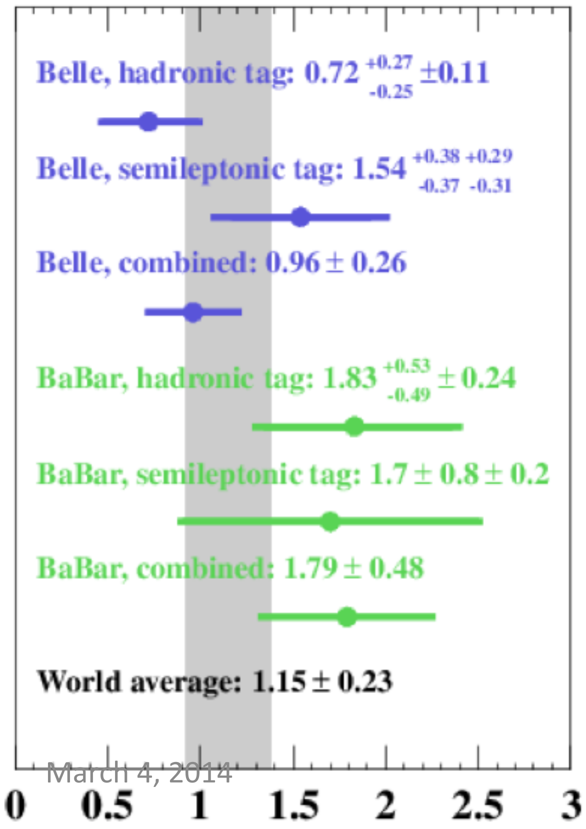
Search for the charged Higgs in B → τν

SM





2HDM
Type II



(10^{-4})

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

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

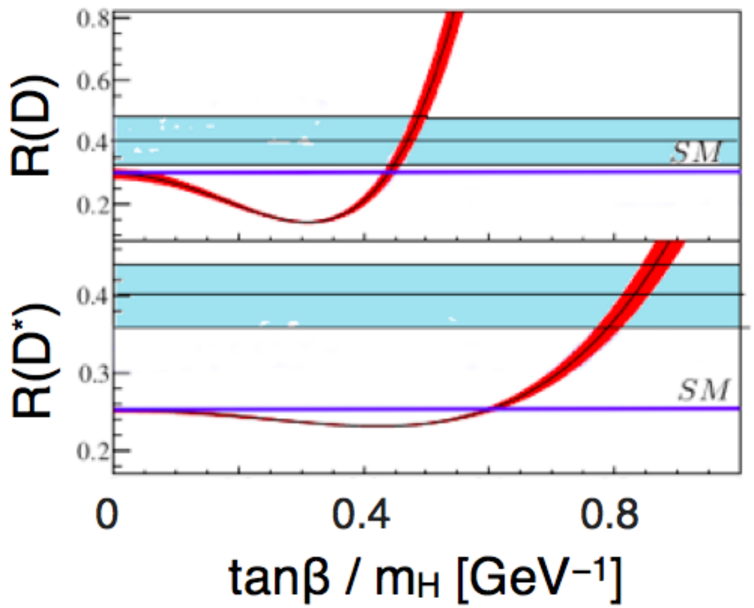
W.S.Hou,
PRD 48, 2342 (1993)

- SM expectation
  - Br(B → τν) = (1.20 +/- 0.25) x 10^{-4}
- UT fit result
  - Br(B → τν) = (0.72 +0.12/-0.08) x 10^{-4}

2HDM Type II effect in $B \to D^{(*)}\tau\nu$

- Observables
  - $R(D^*) = Br(D^*\tau\nu)/Br(D^*l\nu)$
  - $R(D) = Br(D\tau\nu)/Br(Dl\nu)$

Belle $D^{(*)}\tau\nu$ average



BaBar [PRL 109, 101802]