Belle II Physics and Construction Status Tom Browder (University of Hawai'i at Manoa)



1st TOP module arriving at Tsukuba Hall



1st DEPFET pixel plane

<u>Complex phases in the weak</u> <u>interaction</u>: V_{td} and V_{ts} and associated CPV asymmetries <u>Excitement and High Stakes in</u> <u>Flavor Physics:</u>

-Connections to the <u>charged Higgs</u> -Rare B Decays + <u>NP</u>

Flavor Physics, The Next Generation: <u>Belle II/SuperKEKB</u>

Apologies: I have borrowed slides from many excellent physicists and will aim for "a big picture overview" In flavor physics but skip most details. *BEAST results will be covered by Nakayama-san.* Feb 2016: First Turns at SuperKEKB (4 GeV e+'s and 7 GeV e-'s)



June 13, 2016 (LER beam current at 908 mA, HER at 828 mA) 2017: Collisions at the Y(4S) will produce pairs of QM entangled (B-anti B) mesons

First new particle collider since the LHC (*intensity frontier* rather than energy frontier; e⁺ e⁻ rather than p p)

L. Wolfenstein (1923-2015)

Three Angles: $(\varphi_1, \varphi_2, \varphi_3)$ or (β, α, γ)



Big Questions: Are determinations of angles consistent with determinations of the sides of the triangle ? Are angle determinations from loop and tree decays consistent ?

Time-dependent CP violation is "<u>A Double-Slit experiment</u>" with particles and antiparticles

QM interference between two diagrams



Measures the <u>phase</u> of V_{td} or equivalently the <u>phase</u> of B_d —anti B_d mixing.



Measurement of $\sin(2\varphi_1)/\sin(2\beta)$ in B→Charmonium K⁰ modes

Overpowering evidence for CP violation (matter-antimatter asymmetries). >>>> The phase of V_{td} is in good agreement with Standard Model expectations. This is the phase of B_d mixing.

News from Utah, April 2016: APS Panofsky Prize for *Experimental Particle Physics* Awarded to <u>Steve Olsen</u>, Dave Hitlin, Jonathan Dorfan, and <u>Fumihiko Takasaki</u>

"Founding Fathers of the B Factory Experiments"



Front row 2008 Physics Nobelists: T. Maskawa, M. Kobayashi



Results from Global Fits to Data (CKMFitter Group)





Results on the phase of B_s -anti B_s mixing (i.e. phase of V_{ts}) [use $B_s \rightarrow J/\psi \phi$; $J/\psi \pi \pi$ modes]



B_c Mixing Phase

(Includes the most recent LHCb prelim result, gives WA of -33 ±33 mrad)

"Missing Energy" Decays

2 Accelerators Find Particles That May Break Known Laws of Physics

The LHC and the Belle experiment have found particle decay patterns that violate the Standard Model of particle physics, confirming earlier observations at the BaBar facility

By Clara Moskowitz | September 9, 2015 | Véalo en español

Democracy suffers a blow-in particle physics

Three independent B-meson experiments suggest that the charged leptons may not be so equal after all.

Steven K. Blau 17 September 2015

The BEH boson is now firmly established by experimental results from ATLAS and CMS. *Now planning for future Higgs <u>flavor factory</u> facilities (e.g ILC, HL-LHC, CEPC, FCC).*

Does the GP (Brout-Englert-Higgs particle) have a "brother" i.e. the charged Higgs ?

Y. Nambu, 1921-2015

Measurements at Belle II and direct searches at hadron colliders take *complementary* approaches to this important question.

$B \rightarrow \tau \nu$

(Decay with Large Missing Energy)

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

The B meson decay constant, determined by the B wavefunction at the origin

 $(|V_{ub}|$ taken from indep. measurements.)

Consumer's guide to charged Higgs

- <u>Higgs doublet of type I</u> (φ₁ couples to upper (u-type) and lower (d-type) generations. No fermions couple to φ₂)
- <u>Higgs doublet of type II</u> (ϕ_u couples to u type quarks, ϕ_d couples to d-type quarks, u and d couplings are different; tan(β) = v_u/v_d) [favored NP scenario_e.g. MSSM, generic SUSY]
- <u>Higgs doublet of type III</u> (not type I or type II; anything goes. "FCNC hell"→many FCNC signatures)

Why measuring $B^+ \rightarrow \tau^+ v$ is non-trivial

Most of the sensitivity is from tau modes with 1-prongs.

The experimental signature is rather difficult: B decays to a single charged track + nothing

(This may be hard at a hadron collider)

Example of a Missing Energy Decay $(B \rightarrow \tau v)$ *in <u>Data</u>*

The clean e+e- environment makes this possible

But we need to keep the beam-related backgrounds under control

Example: Belle $B \rightarrow \tau v$ results with full *reprocessed* data sample and either hadronic or semileptonic tags (PRD 92, 051102 (2015))

With the full B factory statistics only "evidence". No single observation from either Belle or BaBar.

The horizontal axis is the "Extra Calorimeter Energy"

Complementarity of e+ e- factories and LHC

(Slide adapted from A. Bevan)

The current combined $B \rightarrow \tau \upsilon$ limit places a stronger constraint than direct searches from LHC exps. for the next few years.

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

Currently inclusive $b \rightarrow s\gamma$ rules out m_{H^+} below ~480 GeV/c² range at 95% CL (independent of tan β), M. Misiak et al. (assuming no other NP)

http://arxiv.org/abs/1503.01789

Slide adapted from A. Soffer

Example from a BaBar paper

Signals in $B \rightarrow D^{(*)} \tau \nu$ (489±63, 888±63)

Missing mass variable:

 $m_{miss}^{2} = p_{miss}^{2} = (p[e^+e^-] - p_{tag}^{-} - p_{D(*)}^{-} - p_{I})^{2}$

 P_{I}^{*} = momentum of lepton in B rest frame

But wait !!! Now possible at LHCb.

Production of B meson pairs at threshold is critical to the separation of backgrounds from the missing energy/ momentum signal.

FIG. 1. (Color online) Comparison of the data and the fit projections for the four $D^{(*)}\ell$ samples. The insets show the $|p_{\ell}^{*}|$ projections for $m_{\text{miss}}^{2} > 1 \text{ GeV}^{2}$, which excludes most of the normalization modes. In the background component, the region above the dashed line corresponds to charge cross-feed, and the region below corresponds to continuum and $B\overline{B}$.

BaBar collaboration, Phys. Rev. Lett. 109, 101802 (2012)

"However, the combination of R(D) and R(D*) excludes the type II 2HDM charged Higgs boson with a 99.8% confidence level for any value of $tan(\beta)/m_{H^+}$ "

In other words, found NP but *killed* the 2HDM NP model.

Apres Nagoya: World Averages for R(D) and R(D*)

It is *obvious* that we <u>need two orders of magnitude of data</u> to solve these issues related to the <u>charged Higgs</u>.

One more Belle update, March 2016 (Moriond)

Talk by P. Goldenzweig (Karlsruhe)

Uses semileptonic tagging

 $\mathcal{R}(D^*) = 0.302 \pm 0.030(\text{stat}) \pm 0.011(\text{syst})$

Last Belle update, March 2016 http://arxiv.org/abs/1603.06711

Try to distinguish SM and charged Higgs in kinematic distributions.

Can also constrain other types of NP couplings (e.g. leptoquarks), *but need much more data*

Credit: Djouadi

Simple message from the world's flavor physicists:

With apologies to Herodotus, Thucydides, Sparta, Persia...

Initial Belle II projections for charged Higgs sensitivity

Red Hot Flavor Physics

The stakes are getting higher

High Energy Physics History: finding NP in A_{FB} (using interference)

a fit including the weak interaction (solid line).

Conclusion: There is a Z boson at higher energy even though colliders of the time did not have enough \sqrt{s} to produce it

$A_{FB}(B \rightarrow K^* l^+ l^-)(q^2)$

The SM forward-backward asymmetry in $b \rightarrow s l^+ l^-$ arises from the <u>interference</u> between γ and Z^0 contributions.

$$A_{FB}(B \to K^* \ell^+ \ell^-) = -C_{10}\xi(q^2) \left[Re(C_9)F_1 + \frac{1}{q^2}C_7F_2 \right]$$

Ali Mannel Morozumi PLB273 505 (1991)

Note that all the heavy particles of the SM (W, Z, top) enter in this decay.

More on $A_{FB}(B \rightarrow K^* l^+ l^-)(q^2)$

Can in effect

 A_{FB} depends on $q^2 = M^2(l^+l^-)$

$$A_{FB}(B \to K^* \ell^+ \ell^-) = -C_{10} \xi(q^2) \left[Re(C_9) F_1 + \frac{1}{q^2} C_7 F_2 \right]$$

Ali, Mannel, Morezumi, PLB273, 505 (1991)

The "zero-crossing" of A_{FB} depends only on a ratio of form factors and is a *clean* observable.

$B \rightarrow K^* | |$ angular variables

K^{*} and I⁺ I⁻ helicity angles

> Angle ϕ between <u>the normals</u> to the two decay planes.

N.B. Recent LHCb measurements include φ angle data

From http://xxx.lanl.gov/pdf/ 1606.00916v1

$B \rightarrow K^* l^+ l^- (q^2)$ bootcamp (for reference)

Angular dependence

(-) means the _____ term is only in $\Gamma - \Gamma$

Thanks to Rahul Sinha

$$\frac{1}{d(\Gamma + \overline{\Gamma})/dq^2} \frac{d^3(\Gamma + \overline{\Gamma})}{d\overline{\Omega}} = F_L \text{ is the longitudinal polarization fraction.}}$$

$$\int_{-F_L}^{3} \frac{4}{(1 - F_L)\sin^2 \vartheta_K} + F_L \cos^2 \vartheta_K + F_L \cos^2 \vartheta_K + \frac{1}{4}(1 - F_L)\sin^2 \vartheta_K \cos 2\vartheta_L + S_3 \sin^2 \vartheta_K \sin^2 \vartheta_L \cos 2\varphi + S_4 \sin 2\vartheta_K \sin 2\vartheta_L \cos \varphi + \frac{1}{4}(1 - F_L)\sin^2 \vartheta_K \sin 2\vartheta_L \cos \varphi + \frac{1}{4}(1 - F_L)\sin^2 \vartheta_K \sin 2\vartheta_L \cos \varphi + \frac{1}{4}(1 - F_L)\sin^2 \vartheta_K \sin 2\vartheta_L \sin \varphi + \frac{1}{4}(1 - F_L)\sin^2 \vartheta_K \sin 2\vartheta_L \sin \varphi + \frac{1}{4}(1 - F_L)\sin^2 \vartheta_K \sin 2\vartheta_L \sin \varphi + \frac{1}{4}(1 - F_L)\sin^2 \vartheta_K \sin^2 \vartheta_L \sin \vartheta_L \sin \varphi + \frac{1}{4}(1 - F_L)\sin^2 \vartheta_K \sin^2 \vartheta_L d^2 u^2 \vartheta_L d^2 u^$$

Introduce $P_{4,5} = S_{4,5}/sqrt[F_L(1-F_L)]$ to reduce/eliminate dependence on form factors

LHCb 3fb⁻¹ results on $B \rightarrow K^* \mu^+ \mu^- (q^2)$

Angular Asymmetries based on 2398±57 signal events

"The P₅' measurements <u>are only compatible with the SM</u> prediction at a level of 3.7σA mild tension can also be seen in the A_{FB} distribution, where the measurements are systematically <=1 σ below the SM prediction in the region $1.1 < q^2 < 6.0 \text{ GeV}^2$ " Blank regions are the J/ ψ a

Theory from http://arxiv.org/abs/1510.04329

Blank regions are the J/ ψ and ψ' vetos

R. Aaij et al., JHEP 1602, 104 (2016)
Recent LHCb results on $B \rightarrow K^* \mu^+ \mu^- (q^2)$

<u>Is HEP History repeating itself</u>? [But be sure this is not a tricky SM form factor effect.]

Why does NP appear first in this mode (and not others) ?





Possible answer: All the heavy particles of the SM (t, W, Z) and maybe NP (except the Higgs) appear here. Sensitive to NP via interference (linear effects and many types of couplings).

NP could mean "<u>new</u> <u>particles</u>" (bump in some mass spectrum at the LHC) or "<u>new</u> <u>couplings</u>" (flavor physics)



We would be happy to break the Standard Model.

Places where we might find New couplings $b \rightarrow s\gamma(^*) : \mathcal{H}_{\Delta F=1}^{SM} \propto \sum_{i=1}^{10} V_{ts}^* V_{tb} C_i Q_i + \dots$ $Q_7 = \frac{e}{g^2} m_b \, \bar{s} \sigma^{\mu\nu} (1 + \gamma_5) F_{\mu\nu}^{i=1} b$ [real or soft photon] $Q_9 = \frac{e^2}{g^2} \bar{s} \gamma_\mu (1 - \gamma_5) b \, \bar{\ell} \gamma_\mu \ell$ [$b \rightarrow s\mu\mu \text{ via } Z/\text{hard } \gamma$] $Q_{10} = \frac{e^2}{g^2} \bar{s} \gamma_\mu (1 - \gamma_5) b \, \bar{\ell} \gamma_\mu \gamma_5 \ell$ [$b \rightarrow s\mu\mu \text{ via } Z$]





<u>Right-handed currents</u>: $1 - \gamma_5 \rightarrow 1 + \gamma_5$

A recent example of NP Fits to $B \rightarrow s 11$ data



L. Hofer et al., **Moriond March** 2016

Fits use LCSR at low q² and lattice form factors at high q^2 and all data on $b \rightarrow s \parallel l$

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Theory issues on $B \rightarrow K^* \mu^+ \mu^- (q^2)$

→ Check dependence on light-cone form factors (some checks already done by Lattice QCD groups)

→Can tails of large B→K* [c-cbar] or non-factorizable effects produce the anomalies found in the angular distributions ? (If all non-perturbative effects float with arbitrary normalization in the fit then the data can explained, http://lanl.arxiv.org/abs/1512.07157)

Major concern

→ Use data near $q^2 = q_{max}^2$ (K* at rest), where symmetry works (Heavy Quark Effective Theory) and constrains ratio of polarizations (no hadronic corrections)→ <u>Still find NP</u>



1603.04355) [R.Sinha group]

needed to close the case for NP



Paths to the future: $A_{FB}(q^2)$ for <u>Inclusive</u> b \rightarrow s l⁺ l⁻

No form factors

Precise result useful for NP diagnosis but Belle II only (see http://arxiv.org/abs/ 1503.04849)

http://arxiv.org/abs/1402.7134 To appear in PRD.

TABLE II. Fit results for the four q^2 bins. For \mathcal{A}_{FB} , the first uncertainty is statistical and the second uncertainty is systematic. $\mathcal{A}_{\rm FB}$ values predicted by the SM [4, 7] are also shown with systematic uncertainties. For the signal yields, only statistical uncertainties are shown. The uncertainties of α and β are due to the statistical uncertainties of the MC.

		1st bin	2nd bin	3rd bin	4th bin
q^2 range $[{\rm GeV}^2/c^2]$	$ \begin{array}{c} (B \to X_s e^+ e^-) \\ (B \to X_s \mu^+ \mu^-) \end{array} $	[0.2, 4.3]	[4.3,7.3] [4.3,8.1]	[10.5,11.8] [10.2,12.5]	[14.3, 25.0]
$\mathcal{A}_{\mathrm{FB}}$		$0.34 \pm 0.24 \pm 0.02$	$0.04 \pm 0.31 \pm 0.05$	$0.28 \pm 0.21 \pm 0.01$	$0.28 \pm 0.15 \pm 0.01$
$\mathcal{A}_{\rm FB}$ (theo	ory)	-0.11 ± 0.03	0.13 ± 0.03	0.32 ± 0.04	0.40 ± 0.04
$N_{ m sig}^{ee}$		45.6 ± 10.9	30.0 ± 9.2	25.0 ± 7.0	39.2 ± 9.6
$N_{\rm sig}^{\mu\mu}$		43.4 ± 9.2	23.9 ± 10.4	30.7 ± 9.9	62.8 ± 10.4
α^{ee}		1.289 ± 0.004	1.139 ± 0.003	1.063 ± 0.003	1.121 ± 0.003
$\alpha^{\mu\mu}$		2.082 ± 0.010	1.375 ± 0.003	1.033 ± 0.003	1.082 ± 0.003
β		1.000	1.019 ± 0.003	1.003 ± 0.000	1.000

TABLE I: Projections for the statistical uncertainties on the $B \to K^{(*)} \nu \bar{\nu}$ branching fractions.

Mode	$B [10^{-6}]$	Efficiency Belle	$\begin{array}{c} N_{\mathrm{Backg.}} \\ 711 \ \mathrm{fb}^{-1} \end{array}$	$\begin{array}{c} N_{\rm Sig-exp.} \\ 711 \ {\rm fb}^{-1} \end{array}$	$\begin{array}{c} N_{ m Backg.} \\ 50 \ { m ab}^{-1} \end{array}$	$\begin{array}{c} N_{\mathrm{Sig-exp.}} \\ 50 & \mathrm{ab^{-1}} \end{array}$	Statistical error	Total Error
		$[10^{-4}]$	Belle	Belle	Belle II	Belle II	50 ab^{-1}	
$B^+ \rightarrow K^+ \nu \bar{\nu}$	3.98	5.68	21	3.5	2960	245	23%	24%
$B^0 \to K^0_{ m S} \nu \bar{\nu}$	1.85	0.84	4	0.24	560	22	110%	110%
$B^+ \rightarrow K^{*+} \nu \bar{\nu}$	9.91	1.47	7	2.2	985	158	21%	22%
$B^0 \to K^{*0} \nu \bar{\nu}$	9.19	1.44	5	2.0	704	143	20%	22%
$B \to K^* \nu \bar{\nu}$ combined							15%	17%

Ans: Verify hint of lepton universality breakdown at Belle II (good electron eff)

Control region gives R_K consistent with unity. Interesting, low q^2 region gives:

 $R_K = 0.745^{+0.090}_{-0.074}$ (stat) ± 0.036 (syst).

which is 2.6o from unity, 3o if BaBar included.

R. Aaij et al. (LHCb collab); PRL 113, 151601 (2014)

According to http://xxx.lanl.gov/abs/ 1605.07633, no significant SM radiative corrections



"We need more data !!"





Apologies to Director Akira Kurosawa

To find out whether there are NP couplings in the weak interaction





N.B. To realize this steep turn-on, requires close cooperation between Belle II and SuperKEKB [and *international collaboration* on the accelerator].

This plot assumes a *full* and *stable* operation funding profile.

Physics Reach of Belle II and the LHCb upgrade

Competition and complementarity



Gelato flavors in Asakusa



Tofu Gelato ?



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Belle II Detector



Outer Detector



Scintillator based endcap KLM was installed as well as *two-scintillator-based layers* in the barrel KLM. Barrel RPC (resistive plate chambers) were retained. *Readout is new*.

Barrel Particle Identification

A GEANT4 event display of a 2 GeV pion and kaon interacting in a TOP [time of propagation] quartz bar. (Japan, US, Slovenia, Italy)



Vertexing/Inner Tracking



Beampipe r= 10 mm DEPFET pixels (Germany, Czech Republic, Spain...) Layer 1 r=14 mm Layer 2 r= 22 mm DSSD (double sided silicon detectors) Layer 3 r=38 mm (Australia) Layer 4 r=80 mm (India) Layer 5 r=115 mm (Austria) Layer 6 r=140 mm (Japan)

+Poland (software), Korea

Belle II at Tsukuba Hall



First TOP module arriving at Tsukuba Hall

Update: May 20, 2016 all 16 TOP modules were installed into the Belle II structure. Magnetic field mapping then CDC installation in 2nd half of August.



May 2016:TOP in Belle II structure



CDC (Central Drift Chamber)

In e⁺ e⁻ scattering at 10-11 GeV, a <u>critical issue</u> for vertexing is multiple scattering.

Belle: r(beampipe) 2 cm \rightarrow 1.5 cm Belle II: r(beampipe) 1cm

Improved resolution and nano-beams will open new possibilities for vertex analysis

Reduce the multiple scattering lever arm; reduce X₀ (to preserve intrinsic resolution)





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"Full sized" pixel detector module 0



Pixel detector group from many institutes and universities in Germany, also Czech Republic and Spain. 75 μm thick



April 2016: Belle II VXD beam test at DESY

(DESY provides the infrastructure and facilities for this critical beam test)



April 2016: Two *full-sized* Belle II DEPFET pixel detector modules at DESY (readout full system with beam)



Working examples of L3, L4, L5, L6 SVD ladders



Test full-sized PXD modules in a beam. [Measure efficiency and S/N].

Test the integrated PXD-SVD system. This includes ROI (region of interest) extrapolation from the SVD tracker to the PXD, which is needed to reduce the *large data volume*. 55



For reference: PXD schedule and milestones





<u>Belle II at IPMU in 柏の葉, Japan</u>

Constructing two layers of the Belle II SVD detector in the Production on clean room on the 1st floor. Dr T. Higuchi is the L6 leader.

Japan (Layer 6) and India/Tata Institute (Layer 4)





⁹⁰Sr Source Test [2] (SBW990)





L4 mechanical prototype

For reference: Ladder production schedule

						2016	2017											2018				
		Q2	Q3		Q4	Q1		Q2	Q3		Q4		Q1		Q2		Q3		Q	4	(Q1
	Name	4 5 6	7 8	9 10	11 12	1 2	3 4	5 6	7 8	9	10 11	12 1	2	3 4	5	6	7 8	9	10 1	1 12	1	2 3
110	FW/BW: Full site qualification (CBQ)	- i	Aay 29																			
111	FW/BW: Class A production		40%						FW/B	W: Clas	s A produ	ction		1								
112	FW/BW production completed								🗳 Jul 1	8					Гюс		τ Γ\	A / /		1		
113															EIIC	υ		/ / /	BVV			
114	L3: Class C+B assembly	100%			L3: Class C+E	3 assembly									nro	d	icti	on.				
120	L3: Full site qualification (CBQ)			•	Oct 29										pro	uu		011.	•			
121	L3: Bridge re-production					0%	L3: Brid	ge re-pro	duction						Lul	วก	16					
122	L3: Class C ladder					0% 🖻	L3: Clas	s C ladder							Jui	zυ	TO					
123	L3: Class A production					0%	-	L3:	Class A pro	duction	•											
124	L3: Ladder production completed							🔶 M	ay 27													
125																						
126	L4: Class C+B assembly			70%	-L4:	Class C+B a	assembly	!														
127	L4: Full site qualification (QCB)					0% 🍒	L4: Full	site qualif	fication (QC	B)												
128	L4: Class A production					1	0%								L4:	Class /	A produ	ction				
129	L4: 1st halft completed (5+1 spare)									-0%)	L4: 1st h	alft com	pleted ((5+1 sp	are)							
130	L4: Ladder production completed														🔶 Ma	iy 12						
131																	(
132	L5: Class C+B assembly (L5.903, L5.904)		L5: Class	C+B assem	bly (L5.903,	L5.904)												Fn	do	of I 6	ົວ	
133	L5: Full site qualification (QCB)		A 🔶	Aug 6																		
134	L5: L5.001 (class B batch 0), L5.905		100% 📩	-L5	: L5.001 (cla	ss B batch (0), L5.90	15										pro	odi	ıcti	on	:
135	L5: Class A production				10%									L5: C	ass A pro	ductio	on					
136	L5: 1st half completed (6+1 spare)					Ч—	:		- 0%)	L5: 1st	half comp	leted (6	+1 spare	e)				Se	p. 2	201	7	
137	L5: Ladder production completed													Mar	10				•			
138																						/
139	L6: Class C+B production			70%		6: Class C+ E	B produc	tion														
140	L6: Full site qualification (QBC)					0% 📩	-L G : Full	site quali	fication (QE	IC)								V				
141	L6: Class A production					(0%											l	L6: Clas	s A proc	luction	1
142	L6: 1st halft completed (8+2spare)											— X	Jan 24	4								
143	L6: Ladder production completed																	é	Sep 25			

To be updated next week at the Belle II general meeting

For reference: Integration schedule

				2017	,									2018	В											2019			
		Q4			Q1		Q2		Q	3		Q4			Q1			Q2			Q3			Q4			Q1		
	Name	11	12	1	2 3	4	5	6	7 8	3	9 10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4
141	L6: Class A production										L6:	Class	A pro	ductio	n														
142	L6: 1st halft completed (8+2spare)			→◆	Jan 24																								
143	L6: Ladder production completed										🔶 Se	p 25																	
144																													
145	▲ SVD assembly			0%									- 5	VD as	semb	oly													
146	Ladder mount 1st half shell			0%		📥 La	idder r	mour	nt 1st ha	alf sl	hell							\square											
147	Ladder mount 2nd half shell							C)% 📥		Įa	dder I	noun	t 2nd	half s	shell			SV	Dr	ea	dv	: D)ec	: 20	017	7		
148	Finish ladder mount				Δ						e 🔶	Oct 2															J		
149	SVD commissioning										0%		SVD (ommi	ission	ning													
150	SVD ready for integration		S	tar	t of	lad	lde	r					٦ 🔶	ec 8	_		: 												
151																													
152	4 VXD integration & commissioning		n	າວເ	int:					0)% 🦰			:						:			VXD	integ	ratio	n & co	mmis	sioni	ng
153	PXD arrives at KEK				201	÷					- 🔶 C	Oct 3																	
154	PXD final tests at B4			ep	201	1					0% 🏝	- PXE) fina	tests	at B4	4													
155	VXD integration											_)% 🝆			۷	XD	ntegr	ation										
156	VXD commissioning / cosmic run														0	1% 🚈	:			VXD	comm	ission	ing /	cosm	nic rui	n			
157	VXD installation							_											0%	*		- +	XD i	nstalla	ation				
158									<u> </u>	\																			
159	4 KEKB operation schedule			/Χ[) int	eg	rati	ior	ן:		0%									:		i	KE	КВ ор	erati	on sch	edule		
160	Beast phase 2					-0					0%	5		:			Be	ast ph	ase 2										
161	Transition phase 2 to phase 3			roi	n De	ec.	201	L /]						0%							Trar	nsitio	n pha	se 2 to	o phas	e 3	
162	Start of physics runs		_																			4) Oc	t 2					

To be updated next week at the Belle II general meeting

SVD ladder production status

- <u>Pisa (FW/BW)</u> 85% (66%) of the backward (forward) sub-assemblies completed as of Jun 6, 2016
- Melbourne (L3) start of class A production delayed by L3 bridge reproduction delays, bond machine troubles and L3 cooling studies – to start after the June B2GM
- <u>TIFR (L4</u>) one class A ladder completed (out of 10), assembly of second one started on June 13, 2016
- <u>HEPHY (L5</u>) third class A ladder (out of 12) to be completed on June 17, 2016
- <u>Kavli IPMU (L6)</u> first class A ladder (out of 16) will be completed on June 15, 2016

Executive Summary of Detector Construction Status

- <u>Outer detector</u>: EKLM, BKLM, TOP are installed; CDC in August; readout and DAQ integration is a lingering concern. Delay in *endcap* ARICH schedule (HV hardware and sparking of HAPDs) may impact Phase II startup schedule. *Roll-in* of outer detector by Christmas.
- Inner detector: SVD production has started; some technical surprises; concerns about L6 schedule and manpower; PXD production is gearing up. Problems with SVD-PXD readout/DAQ integration revealed by April 2016 DESY beam test. Tests of CO₂ cooling and RVC (Remote Vacuum Connection) on track in Germany but need to be integrated at Tsukuba Hall in 2017.
- Overall, Belle II construction and integration are on-track but the schedule is tight. The Belle II collaboration is fully mobilized and performed well for the outer detector.

Some Belle II jargon

<u>BEAST PHASE I</u>: Simple background commissioning detector (diodes, diamonds TPCs, crystals...). No final focus. Only *single* beam background studies possible [started in Feb 2016].

See talk by H. Nakayama-san for results and details.

Recommendations:



- R4: Formalize how the Belle II collaboration will help the SuperKEKB accelerator group turn-on and commission more quickly.
- R5: Finalize the design and technical scope of the BEAST II detector so that as much as possible can be studied during the Phase 1 and 2 accelerator commissioning periods.

<u>BEAST PHASE II</u>: More elaborate inner background commissioning detector. <u>Full Belle II outer</u> <u>detector</u>. Full superconducting final focus. *No vertex detectors.*

Belle II Schedule



HEP world: When do we start Belle II ?

BEAST PHASE I: Started in Feb 2016 (Belle II roll-in at the end of the year)

BEAST PHASE II: Starts in ~Nov

2017 [incl. first collisions;

limited physics without vertex detectors]

Belle II Physics Running: Fall

2018 [vertex detectors in]



QCSL at KEK, Dec 2015

Conclusions

- Flavor physics is exciting and fundamental. Did we just find NP via new weak interaction couplings ?
- Flavor could be the path for the future of HEP but we <u>need much more data.</u>
- Time for a Paradigm Shift ?

SuperKEKB commissioning started in February. Belle II rolls in at the end of the year. First collisions in fall 2017. Belle II physics runs in 2018 [and the LHCb upgrade in ~2021]. <u>These facilities will</u> <u>inaugurate a new era of flavor physics and the study of CP violation.</u>

 The Committee believes that SuperKEKB needs to be the top priority of the KEK Tsukuba campus in the next few years if the commissioning and operation are to be successful in a timely fashion.

2015 ARC Recommendation

7) Belle II and SuperKEKB management teams should jointly develop the run objectives and parameters for the early physics running in SuperKEKB Phase 2 commissioning by fall 2015. In light of the delays caused by the budget shortfall, every effort should be made to take physics data as soon as possible, preferably during Phase 2 commissioning.



R. Mussa athttps://indico.hep.pnnl.gov/event/0/session/24/contribution/QWG 201686/material/slides/1.pdf

Upsilon(5S)/(6S) energy region





FIG. 1: (colored online) Cross sections for the $e^+e^- \rightarrow h_b(1P)\pi^+\pi^-$ (top) and $e^+e^- \rightarrow h_b(2P)\pi^+\pi^-$ processes as a function of c.m. energy. Points with error bars are the data, red solid curves are the fit results.

Issues for special Upsilon(nS) runs

Lack of vertex detector diminishes low p_T track reconstruction

• $\Upsilon(3S) \rightarrow \pi^+ \pi^- \Upsilon(2S)$ infeasible, but $\Upsilon(6S) \rightarrow \pi Z_b \rightarrow \pi h_b(nP)$ unaffected



Early Physics at Belle II – Bryan Fulsom (PNNL) B2TIP Pitt WG7 – 2016 05 23

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17

A. E. Bondar, M. B. Voloshin Phys. Rev. D 93, 094008 (2016)

Upsilon(6S) issues

What happens at $\Upsilon(6S)$?

R. Mizuk@B2TIP, Krakow



no way to produce B^*B^* molecule = $Z_b(10650)$



Hunting for (b bbar g) "QCD hybrids"

Tetraquark (4-quark) states such as the Z(4430) first seen by Belle in 2003 Pentaquark (5-quark) states first observed by LHCb in 2015



TABLE VI. 10.7 GeV $b\bar{b}$ hybrid decay modes (MeV).

			alt	10.9 GeV hybrid	standard	IKP	reduced
2^{-+}	<i>B</i> * <i>B</i>	Р	.1	0	.5	3	44
1^{-+}	B^*B	Р	.1	0	.5	3	44
0 ⁻⁺	B^*B	Р	.5	0	2	13	177
1	B^*B	Р	.2	0	1.2	7	88
2+-	B^*B	D	.08	.05	.25	1	22
1^{+-}	B*B	S	.02	.1	.2	5	13
	B^*B	D	.02	.02	.15	.6	12
1++	B^*B	S	.01	.05	.25	2	7
	<i>B*B</i>	D	.1	.05	.5	1	24

Page, Swanson and Szczepaniak Phys. Rev D. 59, 034016 (1999)

Review of Phase II recommendations

installed in the detector, which will complete the detector packages. A successful Phase 2 beam run is crucial for early advancement of the ultimate particle physics program. Phase 3 of the accelerator commissioning will begin when the Belle detector is complete.

7) Belle II and SuperKEKB management teams should jointly develop the run objectives and parameters for the early physics running in SuperKEKB Phase 2 commissioning by fall 2015. In light of the delays caused by the budget shortfall, every effort should be made to take physics data as soon as possible, preferably during Phase 2 commissioning.

Latest Proposal:

Once collisions are established, record $\sim 2 \text{ fb}^{-1}$ at the Upsilon(4S); verify functionality of Belle II; check B meson reconstruction.

<u>Take remaining ~20 fb⁻¹ at the peak of the Upsilon(6S)</u> (build a unique dataset for strong interaction physics to provide initial early Belle II physics publications.)

Backup slides


More backup material





HAPD Status



- We recently found that "getter reactivation" cures the large pulse problem in the magnetic field.
 - Among 11 HAPDs with getter reactivation, large pulse (dead time) disappeared for 10 HAPDs.
 - ✓ 5 HAPDs are confirmed to keep low dead time after one month.
 - ✓ Getter activation is done during standard HAPD production process, so reactivation is likely to be harmless.
 - > HPK is now doing illumination (aging) test for one reactivated HAPD.





Construction Status







- HV board and most of other parts were delivered recently.
- Mounting HAPD modules (HAPD + FE) started end of May.
- Now, 18 modules are mounted.
- Merger boards, and readout cables will be mounted soon.
- Target: one sector (1/6) in June.
- Installation of one sector will take one week.
- We plan to install sensor modules (HAPD + read-out) in the full detector in July.



Construction Status



 Structure for both aerogel side and HAPD side are ready in Tsukuba B4.



Aerogel side



HAPD side



- Aerogel tiles for 5 cells were installed for the container.
- Target: inner most cells before B2GM.

S. Korpar, S. Nishida et al

Reminder: SVD ladder structure



SVD Classification scheme <u>Class A</u> production, useable for the final detector <u>Class B</u>, electrically working but some lower quality components <u>Class C</u> Mechanically accurate but not electrically working Slide from last two B2GM's !!

Belle II DAQ

Current major Belle II challenge is readout integration of <u>outer detectors [still a key issue at this B2GM]</u>



Large numbers of FPGAs on front-end; large number of CPUs.

Complexity of firmware and interfaces is problematic.

"Missing Energy Decay" in a Belle II GEANT4 MC simulation Signal $B \rightarrow K \nu \nu$ tag mode: $B \rightarrow D\pi$; $D \rightarrow K\pi$

Zoomed view of the vertex region in r--phi

View in r-z



→Belle II Software is in a fairly advanced state (T. Kuhr / (LMU) is the Belle II software coordinator)

G. Caria

"Missing Energy Decay" in a Belle II GEANT4 MC simulation

 $B \rightarrow \tau \nu, \tau \rightarrow e \nu \nu$ $B \rightarrow D \pi, D \rightarrow K \pi \pi \pi$



BEAST Phase I Highlight

SuperKEKB vacuum scrubbing to reduce *LER* beam gas backgrounds in Belle II

LER integrated beam dose > 100 A-h



SuperKEKB vacuum scrubbing to reduce HER beam gas backgrounds in Belle II



BEAST data shows the HER backgrounds decreasing as vacuum scrubbing proceeds.

BEAST Phase I Highlight

April 2016: Large Touschek background observed in the LER



→Will need excellent collimators to handle nano-beam backgounds.

Innovative Technologies in Belle II

Pixelated photo-sensors play a central role



MCP-PMTs in the iTOP HAPDs in the ARICH SiPMs in the KLM, DEPFET pixels



Waveform sampling with precise timing is "saving our butts". Front-end custom ASICs (Application Specific Integrated Circuits) for all subsystems \rightarrow a 21st century HEP experiment.

Pixel detector [3 custom German ASICs: DCD, DHP, Switcher] KL/muon detector (TARGETX ASIC) Electromagnetic calorimeter

(New waveform sampling backend with good timing) iTOP particle identification (IRSX ASIC) Aerogel RICH (KEK custom ASIC) Central Drift Chamber (KEK custom ASIC) SVD (APV2.5 readout chip adapted from CMS)

Highlights of Belle II construction

SuperKEKB hardware is being finalized.



BEAST PHASE I beampipe installed



Final Belle II SVD ladder in CERN beam in June (working well !)



(a) CDC arriving at Tsukuba Hall; (b) first cosmics with partly instrumented electronics (6 layers)

Rare B Decays

Two event displays



J. Albrecht

LHC found the rarest B decay; $B_s \rightarrow \mu + \mu$ -



N. B. Here and in $b \rightarrow s l^+ l^-$ all the heavy particles of the SM enter as virtual particles in the Feynman diagrams

Skip today LHCb Update: full dataset: 3fb-1 Improved BDT Expected sensitivity: 5.0 or PRL 111 (2013) 101805 Candidates / (44 MeV/c²) LHCb BDT>0.7 Significance: 4.0σ 5000 5500 $m_{\mu^+\mu^-}$ [MeV/c²] $BR(B_s \rightarrow \mu^+ \mu^-) = (2.9^{+1.1}_{-1.0}) \times 10^{-9}$ $BR(B^0 \rightarrow \mu^+ \mu^-) = (3.7^{+2.4}_{-2.1}) \times 10^{-10}$ $BR(B^0 \rightarrow \mu^+ \mu^-) < 7 \times 10^{-10} @ 95\% CL$





Tau Lepton Flavor Violation



Example of the decay topology





Belle II will push many limits below 10⁻⁹; LHCb has very limited capabilities.

Mixing and CP violation in the D system



D mixing: Another new physics phase !



Current WA sensitivity $\sim \pm 20^{\circ}$, 50 ab⁻¹ go below 2°

CPV in the charged lepton sector

 There is mixing in the neutrino (neutral lepton) sector. CP violation is possible too.

BaBar rate anomaly ??



FIG. 2. (a) Measured CP violation asymmetry after background subtraction (squares). The vertical error bars are the statistical error and systematic errors added in quadrature. The CP asymmetry measured in the control sample is indicated by the blue triangles (statistical errors only) and the inverted red triangles show the expected asymmetry for $\Im(\eta_S) = 0.1 \ [\Re(\eta_S) = 0]$. (b) Expanded view (the vertical scale is reduced by a factor of five).

Can we explore at Belle II ?

Theoretical predictions for $\Im(\eta_S)$ can be given in context of a MHDM with three or more Higgs doublets [4, 5]. In such models η_S is given by [12]

$$\eta_S \simeq \frac{m_\tau m_s}{M_{H^\pm}^2} X^* Z \tag{10}$$

if numerically small terms proportional to m_u are ignored. Here, $M_{H^{\pm}}$ is the mass of the lightest charged Higgs boson and the complex constants Z and X describe the coupling of the Higgs boson to the τ and ν_{τ} and the u and s quarks, respectively (see [5, 12]). The limit $|\Im(\eta_S)| < 0.026$ is therefore equivalent to

$$|\Im(XZ^*)| < 0.15 \frac{M_{H^{\pm}}^2}{1 \,\mathrm{GeV}^2/c^4}.$$
 (11)

M. Bischofberger et al, Phys. Rev. Lett. 107, 131801 (2011)

Beast Phase II & New Triggers

- Update to First-physics report: <u>BELLE2-NOTE-PH-2015-003</u> Y(2S), Y(3S), Y(6S), Scan proposals
- Beast Phase II Physics Task Force formed to study physics with this configuration (B. Fulsom).
- Belle Y(1S) decay data used for Pythia 8 MC tuning in Belle II (U. Tamponi).



 HLT & L1 Trigger Menu under design. Evolving <u>Trigger Menu (Link)</u>.



Triggers		Some Ideas C-H. Li
Single Photon (γ)		 Cascade: different thresholds with separate pre-scale factors Use different pre-scale factors for Barrel and Endcap
e+e-		 two Bhabha triggers, "accept" and "veto" "accept" : flattening scheme "veto": 2D→3D ECL Bhabha is being investigated salvage: retain a pre-scaled sample of physics triggers without veto
μ+μ-		independent CDC and KLM triggers for luminosity systematics
γγ		reduce pre-scale to 10 instead of 100
γ+ 2 trks	γ e+e -[hlt]	dedicated triggers for calibration (CDC,ECL)
	γμ+μ-	dedicated triggers for detectors study (CDC, ECL, KLM)
	γh^+h^-	 high efficiency for all γ energies and h⁺h⁻ invariant masses one high energy cluster in ECL, one track in opposite hemisphere
Additional trigger information		CDC-TOP-ECL-KLM MatchingMore detectors information



LHCb Upgrade: Key Feature is Trigger-less readout



B factories: *Check CP violation in b* \rightarrow *c [ubar d] processes*

2015: First joint BaBar-Belle data analysis M. Rohrken et al



where D^0 is a CP eigenstate and $h^0=\pi^0$, η , ω

Combining Belle and BaBar datasets, ~1260 signal events, obtain a 5.4 σ CP violation signal \rightarrow First observation sin(2 β_{eff})=0.66±0.10(stat)±0.06(sys)



Phase of V_{td} again

Conclusion: CP violation in b \rightarrow c ubar d modes is the same as in b \rightarrow c cbar s modes (e.g. B \rightarrow J/ ψ K_S)

More backup

Belle II iTOP at Fuji Hall/Hawaii







Module 04 assembly at Fuji Hall

Production testing of readout with single photo-electron laser pulses in Hawaii; electronics resolution ~35ps

All quartz and electronics in hand; now testing and assembling.

DESY contributions to SuperKEKB









Major DESY contributions to Belle II

Thermal mockup of the vertex detectors/CO₂ cooling

(many initial results, on-going)

Precise mapping of the 1.5 T B field of the Belle II superconducting solenoid (starts June 2016)



Software Alignment of Belle II detectors (standard Belle II package)

GRID computing and Collaborative Computing Services for Belle II (starts summer 2016)