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

- Recent News from Japan
- Tau Lepton Flavor Violation
- The Dark Sector

Excitement and High Stakes in Flavor Physics:
- Connections to the charged Higgs
- Rare B Decays + NP

Flavor Physics, The Next Generation
Belle II/SuperKEKB

Apologies: LHCb was covered in C. Bozzi’s plenary. I have borrowed slides from many excellent physicists and will aim for “a big picture overview” in flavor physics but skip most details.
Belle II in Australia

Melbourne:
(Dr. Phil Urquijo, Assoc. Prof. Martin Sevior, Prof. Geoff Taylor, Prof. Elisabetta Barberio)

- Construction of L3 and software of Belle II silicon detector, Physics Coordination (Urquijo), HLT & L1 menu software (leadership), GRID Computing (leadership of skimming), Governance; Belle measurements of EWP, semileptonic and hadronic B decays; Belle II studies of dark sectors and tau LFV.

Sydney:
Prof. Kevin Varvell, Dr. Bruce Yabsley
- RPC $\mu$ trigger/readout, software;
- Belle measurements of leptonic & semileptonic B decays; B factory legacy book.

Adelaide:
Assoc. Prof. Paul Jackson
- Recently joined on physics analysis and GRID computing.
Feb 2016: First Turns at SuperKEKB (4 GeV e+’s and 7 GeV e-’s)

June 28, 2016  (LER beam current at 1000 mA, HER at 870 mA)

2017: Collisions at the $\Upsilon$(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)
SuperKEKB/Belle II Luminosity Profile

Belle/KEKB recorded $\sim 1000 \text{ fb}^{-1}$. Now change units on y-axis to ab$^{-1}$

“nano-beams” are the key; vertical beam size is 50nm at the IP

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.
Belle II will push many limits below $10^{-9}$; LHCb, CMS and ATLAS have very limited capabilities.

The modes $\tau \to \mu \gamma$ and $\tau \to \mu \, h^+ \, h^-$ provide important constraints on $H \to \mu \tau$.
“Dark Photon” $\rightarrow e^+e^-$ sensitivity

One process used in Belle II is $e^+e^- \rightarrow \gamma A' \rightarrow e^+e^-$

LHCb Talk by G. Onderwater
“Light DM” sensitivity in $e^+e^-\rightarrow\gamma+\text{nothing}$

Signal: mono-photon event

YiMing Zhong et al. (B2TIP) Requires a special new trigger that is being developed for Belle II
“Light DM” sensitivity in $\gamma +\text{nothing}$

Hidden Photon $\rightarrow$ invisible ($m_{A'} > 2 m_\chi$)

see also Izaguirre et al, 2013

BaBar
Belle II projections

the best probe for 100 MeV-10 GeV $A'$
“Light DM” sensitivity in $\gamma$+nothing

Sensitivity increases rapidly with integrated luminosity
“Missing Energy Decays” of the B meson
The BEH boson is now firmly established by experimental results from ATLAS and CMS. *Now planning for future Higgs flavor factory facilities* (e.g. ILC, HL-LHC, CEPC, FCC).

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

Measurements at Belle II and direct searches at hadron colliders take *complementary* approaches to this important question.
Sensitivity to new physics from a charged Higgs

\[
B \to \tau^+ \nu
\]
(Decay with *Large* Missing Energy)

\[
B(B^+ \to \tau^+ \nu_{\tau}) = \frac{G_F^2 m_B}{8\pi} m_{\tau}^2 \left(1 - \frac{m_{\tau}^2}{m_B^2}\right)^2 f_B^2 |V_{ub}|^2 \tau_B
\]

\[
B(B \to \tau \nu) = B_{SM} \times \left(1 - \tan^2 \beta \frac{m_{B^\pm}^2}{m_{H^\pm}^2}\right)
\]


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

(|V_{ub}| taken from indep. measurements.)
Consumer’s Guide to the Charged Higgs

- **Higgs doublet of type I** ($\phi_1$ couples to upper (u-type) and lower (d-type) generations. No fermions couple to $\phi_2$)

- **Higgs doublet of type II** ($\phi_u$ couples to u-type quarks, $\phi_d$ couples to d-type quarks, u and d couplings are different; $\tan(\beta) = v_u/v_d$) [favored NP scenario e.g. MSSM, generic SUSY]

- **Higgs doublet of type III** (not type I or type II; anything goes. “FCNC hell” $\rightarrow$ many FCNC signatures)

Thanks to theorist Xerxes Tata

Talks by Howie Haber, Marcela Carena, Xiao-Gang He at SUSY2016
Why measuring $B^+ \rightarrow \tau^+ \nu$ is non-trivial

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 ($B \rightarrow \tau \nu$) in Data

The clean e+e- environment makes this possible

$$B^+ \rightarrow D^0 \pi^+$$

$$\rightarrow K \pi^- \pi^+ \pi^-$$

$$B^- \rightarrow \tau (\rightarrow e \nu \bar{\nu}) \nu$$
Example: Belle $B \rightarrow \tau \nu$ results with full *reprocessed* data sample and either hadronic or semileptonic tags (PRD 92, 051102 (2015))

- **Hadronic tags:** $63 \pm 22.5$ (3$\sigma$)
- **Semileptonic tags:** $222 \pm 50$ (3.8$\sigma$)

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

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

Currently inclusive $b\rightarrow s\gamma$ rules out $m_{H^+}$ below $\sim 480$ GeV/c$^2$ range at 95% CL (independent of tan$\beta$), M. Misiak et al. (assuming no other NP)

A three-body tale

\[ W^- / H^- \xleftarrow{\tau^-} B\{ \frac{b}{q} \overline{q} \} D^{(*)} \]

\[ \mathcal{R}(D^{(*)})_{2HDM} = \mathcal{R}(D^{(*)})_{SM} + A_{D^{(*)}} \frac{\tan^2 \beta}{m_{H^+}^2} + B_{D^{(*)}} \frac{\tan^4 \beta}{m_{H^+}^4} \]

\[ A_{D^{(*)}} \text{ (GeV}^2\text{)} -3.25 \pm 0.32 -0.230 \pm 0.029 \]
\[ B_{D^{(*)}} \text{ (GeV}^4\text{)} \quad 16.9 \pm 2.0 \quad 0.643 \pm 0.085 \]

\[ R(D^{(*)}) = \frac{\mathcal{B}(B \rightarrow D^{(*)} \tau^- \overline{\nu}_\tau)}{\mathcal{B}(B \rightarrow D^{(*)} \ell^- \overline{\nu}_\ell)} \rightarrow \text{Signal} \]
\[ \text{Normalization (} l = e \text{ or } \mu \text{)} \]

Slide adapted from A. Soffer
Example from a BaBar paper

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

Missing mass variable:

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

$P_l^*$ = momentum of lepton in $B$ rest frame

But wait !!! Now $B \rightarrow D^* \tau \nu$ possible at LHCb.

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

*This was not the end of the “three-body tale” and stimulated much additional experimental and theoretical work.*
It is obvious that we need two orders of magnitude of data to solve these issues related to the charged Higgs.
One more Belle update, March 2016 (Moriond)

Uses semileptonic tagging

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

April 2016:
The WA is now 4.0\(\sigma\) from the SM

arXiv: 1603.06711
Try to distinguish SM and charged Higgs in kinematic distributions.

Both fit well.

Can also constrain other types of NP couplings (e.g. leptoquarks), but need much more data.
Simple message from the world’s flavor physicists:

WE NEED MORE DATA !!!

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

Initial Belle II projections for charged Higgs sensitivity

Credit: Djouadi

Itoh, Sato
Red Hot Flavor Physics

The stakes are getting higher
High Energy Physics History: finding \( NP \) in \( A_{FB} \) (using interference)

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

\( \theta^+ \theta^- \rightarrow \mu^+ \mu^- \)
\( \sqrt{s} \approx 34.5 \text{ GeV} \)

\( \sigma \)

\( \cos \theta \)

\( \sqrt{s} = 34.6 \text{ GeV} \)

QED + Z (Intfr.)
QED + Z (Total)
QED

A fit including the weak interaction (solid line).
The SM forward-backward asymmetry in $b \to s \, l^+ l^-$ arises from the interference between $\gamma$ and $Z^0$ contributions.

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

Note that all the heavy particles of the SM ($W$, $Z$, top) enter in this decay.
More on $A_{FB}(B \rightarrow K^* l^+ l^-)(q^2)$

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

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

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

The “zero-crossing” of $A_{FB}$ depends only on a ratio of form factors and is a clean observable.
B→K*ℓℓ angular variables (skip today)

K* and ℓ⁺ ℓ⁻ helicity angles

Angle φ between *the normals* to the two decay planes.

N.B. Recent LHCb measurements include φ angle data

From http://xxx.lanl.gov/pdf/1606.0091
**B → K*1+1-(q^2) bootcamp (for reference)**

Angular dependence

\[
\frac{1}{d(\Gamma + \Gamma)} \frac{d^3(\Gamma \pm \Gamma)}{d\Omega} = F_L \text{ is the longitudinal polarization fraction.}
\]

\[
\frac{3}{4} \left( 1 - F_L \right) \sin^2 \vartheta_K + F_L \cos^2 \vartheta_K \\
+ \frac{1}{4} \left( 1 - F_L \right) \sin^2 \vartheta_K \cos 2\vartheta_L \\
- F_L \cos^2 \vartheta_K \cos 2\vartheta_L + S_3 \sin^2 \vartheta_K \sin^2 \vartheta_L \cos 2\phi \\
+ S_4 \sin 2\vartheta_K \sin 2\vartheta_L \cos \phi + \\
+ S_7 \sin 2\vartheta_K \sin \vartheta_L \sin \phi
\]

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

Thanks to Rahul Sinha
LHCb $3 fb^{-1}$ results on $B \rightarrow K^* \mu^+\mu^-(q^2)$

Angular Asymmetries based on 2398±57 signal events

“The $P_5'$ measurements are only compatible with the SM prediction at a level of 3.7σ.…..A mild tension can also be seen in the $A_{FB}$ distribution, where the measurements are systematically $\leq 1\sigma$ below the SM prediction in the region $1.1 < q^2 < 6.0$ GeV$^2$”

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

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

Is HEP History repeating itself? [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 “new particles” (bump in some mass spectrum at the LHC) or “new couplings” (flavor physics)

We would be happy to break the Standard Model.

Places where we might find New couplings

\[ b \rightarrow s \gamma (*) : \mathcal{H}_{\Delta F=1}^{SM} \propto \sum_{i=1}^{10} V_{ts}^* V_{tb} C_i Q_i + \ldots \]

\[ Q_7 = \frac{e^2}{g^2} m_b \bar{s} \sigma^{\mu\nu} (1 + \gamma_5) F_{\mu\nu} b \quad \text{[real or soft photon]} \]

\[ Q_9 = \frac{e^2}{g^2} \bar{s} \gamma_\mu (1 - \gamma_5) b \bar{\ell} \gamma_\mu \ell \quad \text{[} b \rightarrow s \mu \mu \text{ via Z/hard } \gamma] \]

\[ Q_{10} = \frac{e^2}{g^2} \bar{s} \gamma_\mu (1 - \gamma_5) b \bar{\ell} \gamma_\mu \gamma_5 \ell \quad \text{[} b \rightarrow s \mu \mu \text{ via Z]} \]

Right-handed currents: \( 1 - \gamma_5 \rightarrow 1 + \gamma_5 \)
A recent example of NP Fits to $B \to s ll$ data

<table>
<thead>
<tr>
<th></th>
<th>$c_7^{NP}$</th>
<th>$c_9^{NP}$</th>
<th>$c_{10}^{NP}$</th>
<th>$c_7^{NP}$</th>
<th>$c_9^{NP}$</th>
<th>$c_{10}^{NP}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$c_9^{NP}$</td>
<td>4.47</td>
<td>0.07</td>
<td>*</td>
<td>1.54</td>
<td>0.92</td>
<td>2.00</td>
</tr>
</tbody>
</table>

Why should I care?

Fits use LCSR at low $q^2$ and lattice form factors at high $q^2$ and all data on $b \to s ll$

These plots mean there are NP coupling(s) in the weak interaction
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 $B \rightarrow K^*$ [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)

→ Use data near $q^2 = q^2_{\text{max}}$ (K* at rest), where symmetry works (Heavy Quark Effective Theory) and constrains ratio of polarizations (no hadronic corrections) → Still find NP
Fit LHCb finely binned angular data at $q^2_{\text{max}}$ (HQET limit)

A. Karan et al. (arXiv: 1603.04355) [R.Sinha group]

Still confirmation and more data is needed to close the case for NP

5σ signal for NP, requires right-handed currents

Contours at 1, 3, 5σ

$r/C_{10} = 0.84$

Data with 1σ, 5σ uncertainties

★ is the SM
Paths to the future:

$A_{FB}(q^2)$ for Inclusive $b \rightarrow s l^+ l^-$

(No form factors)

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

http://arxiv.org/abs/1402.7134

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

<table>
<thead>
<tr>
<th>Mode</th>
<th>$B \times 10^{-6}$</th>
<th>Efficiency $\times 10^{-4}$</th>
<th>$N_{\text{Backg.}}$</th>
<th>$N_{\text{Sig-exp.}}$</th>
<th>Statistical error</th>
<th>Total Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>$B^+ \to K^+\nu\bar{\nu}$</td>
<td>3.98</td>
<td>5.68</td>
<td>21</td>
<td>3.5</td>
<td>23%</td>
<td>24%</td>
</tr>
<tr>
<td>$B^0 \to K^0_S\nu\bar{\nu}$</td>
<td>1.85</td>
<td>0.84</td>
<td>4</td>
<td>0.24</td>
<td>110%</td>
<td>110%</td>
</tr>
<tr>
<td>$B^+ \to K^{*+}\nu\bar{\nu}$</td>
<td>9.91</td>
<td>1.47</td>
<td>7</td>
<td>2.2</td>
<td>21%</td>
<td>22%</td>
</tr>
<tr>
<td>$B^0 \to K^{*0}\nu\bar{\nu}$</td>
<td>9.19</td>
<td>1.44</td>
<td>5</td>
<td>2.0</td>
<td>20%</td>
<td>22%</td>
</tr>
<tr>
<td>$B \to K^*\nu\bar{\nu}$ combined</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>15%</td>
<td>17%</td>
</tr>
</tbody>
</table>

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

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

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

which is 2.6$\sigma$ from unity, 3$\sigma$ if BaBar included.

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

R. Aaij et al. (LHCb collab); PRL 113, 151601 (2014)
We need more data!!

Apologies to Director Akira Kurosawa

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

Signal of ~187 events

Belle I data S. Wehle, DESY, arXiv: 1604.04042
Belle II Detector

**BEAST (Background commissioning detector)**

**EM Calorimeter:**
CsI(Tl), waveform sampling (barrel)
Pure CsI + waveform sampling (end-caps)

**Central Drift Chamber**
He(50%):C₂H₆(50%), small cells, long lever arm, fast electronics

**Beryllium beam pipe**
2cm diameter

**Particle Identification**
Time-of-Propagation counter (barrel)
Prox. focusing Aerogel RICH (fwd)

**KL and muon detector:**
Resistive Plate Counter (barrel outer layers)
Scintillator + WLSF + MPPC (end-caps, inner 2 barrel layers)

**Electrons** (7GeV)

**Positrons** (4GeV)

**Vertex Detector**
2 layers DEPFET + 4 layers DSSD
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)

Incoming track

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

FWD/BWD
Italy
Status: May 20, 2016 all 16 TOP modules were installed into the Belle II structure. Magnetic field mapping on-going then CDC installation in 2nd half of August.
“Full sized” pixel detector module 0

Pixel detector group from many institutes and universities in Germany, also Czech Republic and Spain.
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 with 4 SVD ladders at DESY. (readout full VXD system with beam)

Test full-sized PXD modules in a beam. [Checked 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.
Some Belle II jargon

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

**BEAST PHASE II**: More elaborate inner background commissioning detector. [Full Belle II outer detector](#). Full superconducting final focus. *No vertex detectors. Collisions!*
**HEP world: So when do we start Belle II?**

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

BEAST PHASE II: **Starts in Dec 2017** [damping ring commissioning; First collisions; limited physics without vertex detectors]

Belle II Physics Running: **late Fall 2018** [vertex detectors in]

QCSL at KEK, Dec 2015

QCSR will be at KEK, Nov 2016
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 need much more data.**
• **Time for a Paradigm Shift?**

SuperKEKB Phase I commissioning Feb-June, 2016. 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]. **These facilities will inaugurate a new era of flavor physics and the study of CP violation.**
Backup slides

Australian Belle II Silicon Vertex Detector Construction Team
Total internal reflection of laser light in a TOP module

Cosmic ray in the partially instrumented CDC tracker

Cosmic ray muon in the partially instrumented barrel KLM RPC system

Matched PXD hits from a projected SVD track in the DESY $e^-$ test beam

2 PXD sensors
Beast Phase II & New Triggers

- Update to First-physics report: **BELLE2-NOTE-PH-2015-003** 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 **Trigger Menu (Link)**.

### Triggers

<table>
<thead>
<tr>
<th>Single Photon (γ)</th>
<th>Some Ideas</th>
<th>C-H. Li</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>γ</strong></td>
<td>Cascade: different thresholds with separate pre-scale factors</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Use different pre-scale factors for Barrel and Endcap</td>
<td></td>
</tr>
</tbody>
</table>

| e^+e^-             | two Bhabha triggers, “accept” and “veto” | |
|                    | “accept”: flattening scheme | |
|                    | “veto”: 2D \(\rightarrow\) 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         | dedicated triggers for calibration (CDC,ECL) | |
| γ+μ^-              | dedicated triggers for detectors study (CDC, ECL, KLM) | |
| γ+γ                 | 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 Matching
- More detectors information…….
In $e^+e^-$ scattering at 10-11 GeV, a **critical issue** for vertexing is multiple scattering.

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

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

**Large improvement in $\Delta S(B \rightarrow [K_S\pi^0] \gamma)$**

B decay point reconstruction from the $K_S$ vertex, used in searches for **NP right handed currents**.

Reduce the multiple scattering lever arm; reduce $X_0$ (to preserve intrinsic resolution)
Consumer’s guide to charged Higgs

- **Higgs doublet of type I** ($\phi_1$ couples to upper (u-type) and lower (d-type) generations. No fermions couple to $\phi_2$)

- **Higgs doublet of type II** ($\phi_u$ couples to u type quarks, $\phi_d$ couples to d-type quarks, u and d couplings are different; $\tan(\beta) = v_u/v_d$) [**favored NP scenario** e.g. MSSM, generic SUSY]

- **Higgs doublet of type III** (not type I or type II; anything goes. “FCNC hell” $\rightarrow$ many FCNC signatures)

Thanks to theorist Xerxes Tata

Talks by Howie Haber, Marcela Carena, Xiao-Gang He at SUSY2016
Executive Summary of Detector Construction Status

- **Outer detector**: EKLM, BKLM, TOP are installed; CDC in August; readout and DAQ integration is a lingering concern. *Endcap* ARICH schedule (HV hardware and sparking of HAPDs) may delay Phase II startup by 1 month. *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.
Physics Reach of Belle II and the LHCb upgrade

Competition and complementarity

Gelato flavors in Asakusa

Tofu Gelato?
Belle II dominates here

Tight race

$B \rightarrow \psi K_S$

Belle II ahead

Belle II dominates here

$B \rightarrow \eta' K_S$

Tight race

$B \rightarrow \pi^+ \pi^- \text{ CPV}$
So when do we start Belle II?

BEAST PHASE I: Started in Feb 2016 (Belle II roll-in at the end of the year) and ends this week.

BEAST PHASE II: Starts in Dec 2017 [damping ring commissioning; First collisions; limited physics without vertex detectors]

Belle II Physics Running: late Fall 2018 [vertex detectors in]

QCSL at KEK, Dec 2015
QCSR will be at KEK, Nov 2016
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 ongoing in June-July, then CDC installation in 2nd half of August.
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
- $\Upsilon(3S) \to \pi^+ \pi^- \Upsilon(2S)$ infeasible, but $\Upsilon(6S) \to \pi Z_b \to \pi h_b(nP)$ unaffected

Phase 2
Phase 3

PRELIMINARY

$\Upsilon(6S) \to \pi Z_b$
$Z_b \to \pi h_b(1P)$

$\Upsilon(3S) \to \pi \pi \Upsilon(2S)$
$\Upsilon(3S) \to \pi \pi \Upsilon(1S)$
What happens at $\Upsilon(6S)$?

If $\Upsilon(6S) \approx B^{**}B \Rightarrow \pi$

$\Upsilon(6S)$

$B^{**}$

$B^*$

$B$

$Z_b(10610)$

no way to produce $B^*B^*$ molecule = $Z_b(10650)$
Upsilon(6S) issues

Accessible in $\Upsilon(5, 6S) \rightarrow W_b + \gamma$ — small rate. $W_{b0}$ maybe accessible in $\Upsilon(6S) \rightarrow W_{b0} \pi \pi$.

$I^G(J^P)$:

- $1^+(1^+)$
- $1^-(0^+)$
- $1^-(1^+)$
- $1^-(2^+)$
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

Page, Swanson and Szczepaniak
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 ~2 fb\(^{-1}\) at the Upsilon(4S); verify functionality of Belle II; check B meson reconstruction.

Take remaining ~20 fb\(^{-1}\) at the peak of the Upsilon(6S) (build a unique dataset for strong interaction physics to provide initial early Belle II physics publications.)
More backup material
“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

Belle II Software is in a fairly advanced state (T. Kuhr (LMU) is the Belle II software coordinator)
“Missing Energy Decay” in a Belle II GEANT4 MC simulation

\[ B \rightarrow \tau \nu, \tau \rightarrow e \nu \nu \quad B \rightarrow D \pi, D \rightarrow K \pi \pi \pi \]
SuperKEKB vacuum scrubbing to reduce \textit{LER} beam gas backgrounds in Belle II

LER integrated beam dose $> 100$ A-h

BEAST data shows the LER backgrounds decreasing as vacuum scrubbing proceeds.
SuperKEKB vacuum scrubbing to reduce HER beam gas backgrounds in Belle II

BEAST data shows the HER backgrounds decreasing as vacuum scrubbing proceeds.
April 2016: Large Touschek background observed in the LER

Will need excellent collimators to handle nano-beam backgounds.
Mixing and CP violation in the D system

There is a very strong $y$ signal

However, the $x$ signal is marginal

There is a very strong $y$ signal
**D mixing: Another new physics phase!**

\[ \varphi \sim \frac{2\eta A^2 \lambda^5}{\lambda} \sim O(10^{-3}) \]

CPV in D system negligible in SM

CPV in interf. mix./decay:

\[ \text{Im} \frac{q \overline{A}_f}{p A_f} \equiv (1 + \frac{A_M}{2}) e^{i\varphi} \neq 0; \varphi \neq 0 \]

The existence of D mixing (if \( x \) is non-zero) allows us to look for another poorly constrained new physics phase but this time from up-type quarks.

(c.f. CPV in B\(_s\) mixing)

Current WA sensitivity \( \sim \pm 20^0 \), 50 ab\(^{-1}\) go below 2\(^0\)
CPV in the charged lepton sector

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

BaBar rate anomaly ??

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 $\eta_S$ is given by [12]

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

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 $\tau$ and $\nu_\tau$ and the $u$ and $s$ quarks, respectively (see [5, 12]). The limit $|\Im(\eta_S)| < 0.026$ is therefore equivalent to

$$|\Im(XZ^*)| < 0.15 \frac{M_{H^\pm}^2}{1\text{ GeV}^2/c^4}.$$
Upgraded LHCb detector

Tracking System: NEW DETECTORS!

Muon system: Remove M1. NEW READ-OUT BOARDS!

Calorimeters: Remove SPD/PS – no LO trigger. Operate PMTs at lower gain. NEW READ-OUT!

Ring Imaging Cherenkov detectors: Remove aerogel from RICH1+modify optical system. NEW PHOTON DETECTORS AND READ-OUT!
LHCb Upgrade: *Key Feature* is Trigger-less readout

30 MHz

Full Software Trigger

- Trigger-less read-out.
- Zero suppression in front-ends.
- Full detector data to Full Software Trigger.
- Inelastic collision rate is 30 MHz.

- Low level trigger as throttle.
- Partial information from muon system and calorimeters.

15 to 30 MHz

Full track reconstruction

- Full event reconstruction.
- Run-by-run detector calibration.

1 to 2 MHz

Track fit
RICH particle ID
Inclusive and exclusive selections

20 to 100 kHz

- Perform simplified Kalman track fit.
- Add RICH information.
- Inclusive and exclusive selections.

- 2 – 10 GBytes/s to storage.
B factories: *Check CP violation in $b \rightarrow c$ [ubard] processes*

2015: First joint BaBar-Belle data analysis  

M. Rohrken et al

“Color-suppressed” $B \rightarrow D h$

where $D^0$ is a CP eigenstate and $h^0 = \pi^0, \eta, \omega$

Combining Belle and BaBar datasets, ~1260 signal events, obtain a 5.4σ CP violation signal  

First observation  

$\sin(2\beta_{\text{eff}}) = 0.66 \pm 0.10(\text{stat}) \pm 0.06(\text{sys})$

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. $B \rightarrow J/\psi K_S$)
More backup
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 ➔ 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)
Production testing of readout with single photo-electron laser pulses in Hawaii; electronics resolution $\sim$35ps

All quartz and electronics in hand; now testing and assembling.
DESY contributions to SuperKEKB

An important piece of SuperKEKB

“RVC” = Remote Vacuum Connection

Also SuperKEKB beam background simulation: Synchrotron Radiation (SR)

Karsten Gadow (DESY)
Major DESY contributions to Belle II

Thermal mockup of the vertex detectors/CO\(_2\) 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)

Not a complete list!