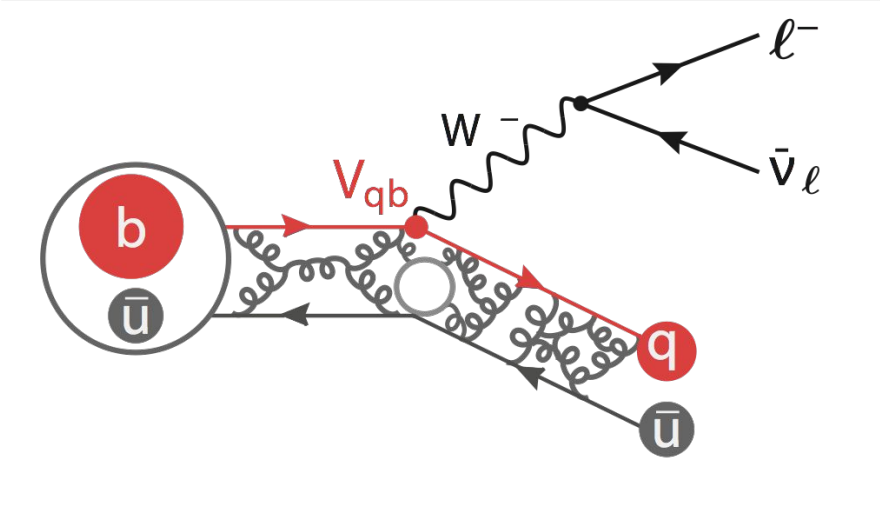
Phase II Physics Discussion



Meeting Introduction

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Meeting Scope

Discuss possible physics measurements for Phase II data taking

Main goal of such measurements:

- Show that we can carry out physics with Belle II
  - Should be simple enough to have a quick turn-around-time
  - Ideally provides a measurement of a branching fraction we can convert into N_{BB}
  - Highlights performance aspect
  - Test all the tools and chains to show we are ready for Phase III
- Unclear at this point in time on what $\sqrt{s}$ we will run and how much data will be recorded
  - $L = O(20 +/- 20\ fb^{-1})$
  - Likely driven by accelerator and detector crews need to commission the beam and detector

Proposed measurements: inclusive semileptonic *BFs*

- Inclusive SL BF to light leptons is large (~ 20%); not much data needed to carry out a reasonable measurement.

√s	**Measurement**
Y(4S)	BF($B \to X\, l\, \nu$)
Y(5S)	BF($B_s \to X\, l\, \nu$)
Y(6S)	BF($B_s \to X\, l\, \nu$)

Measurement of the inclusive semileptonic *BF* at √s = Y(4S)

Inclusive SL BF to light leptons is large (~ 20%)

→ Not much lumi needed to carry out a reasonable measurement

→ E.g. CLEO measurement used 9.4/fb plus 4.5/fb off-resonance data

https://arxiv.org/pdf/hep-ex/0403053.pdf

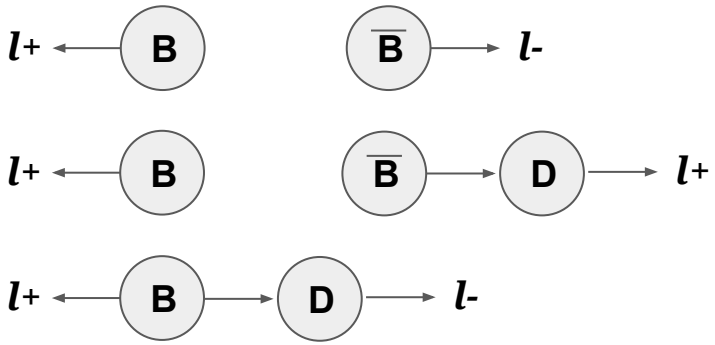
- Many aspects of detector performance needs to be understood well, e.g.
  - Performance of Lepton ID and mis-identification efficiencies crucial
  - Efficiency of selection cuts, in case one wants to revert the measurement to a N_{BB}

Proposed Analysis strategy (based on hep-ex/0403053)

Use semileptonic double tagging to select signal events

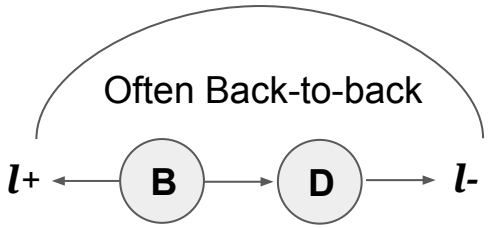
- Select events with a high-momentum (tag) lepton with e.g. $p_l > 1.4$ GeV/c
- In events with tags, search for accompanying (signal) electrons or muons with a minimum momentum of e.g. 0.6 GeV/c
  - Neglecting Mixing this produces *three* categories of events:

Category
Primary Events
Opposite *B* secondary Events
Same *B* secondary Events

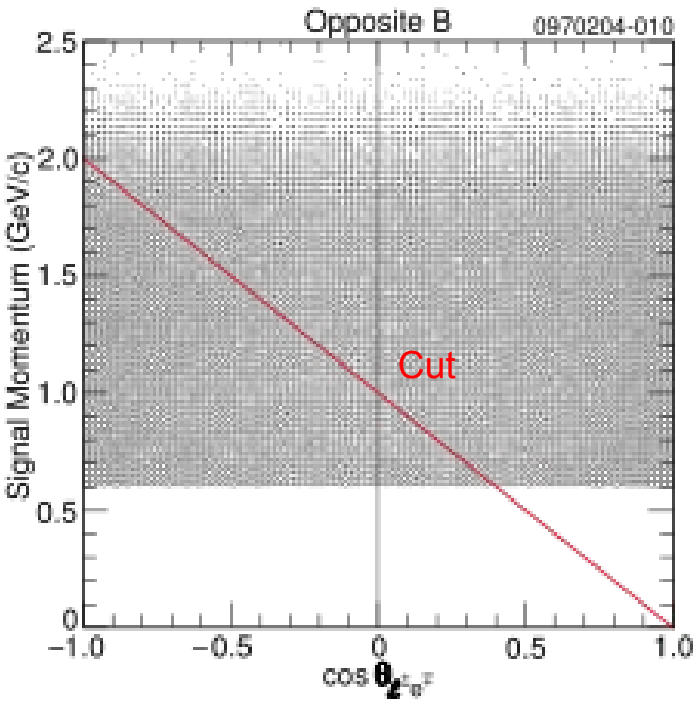


Reduction of same *B* Secondary Events

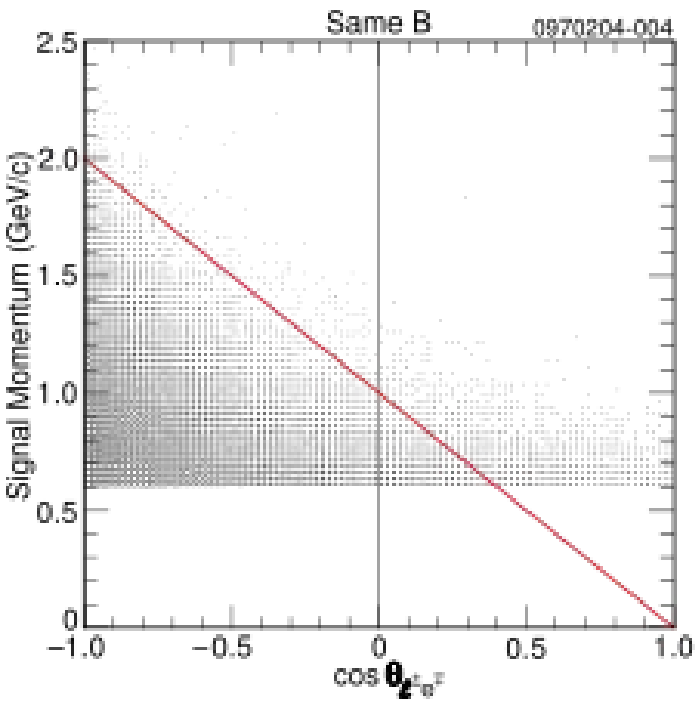
Category
Same *B* secondary Events



Signal



Same *B* secondary Events



Primary and secondary decay spectra

The measured spectra are connected to the differential branching fractions of primary and secondary decays as:

Secondary decays (bkg)

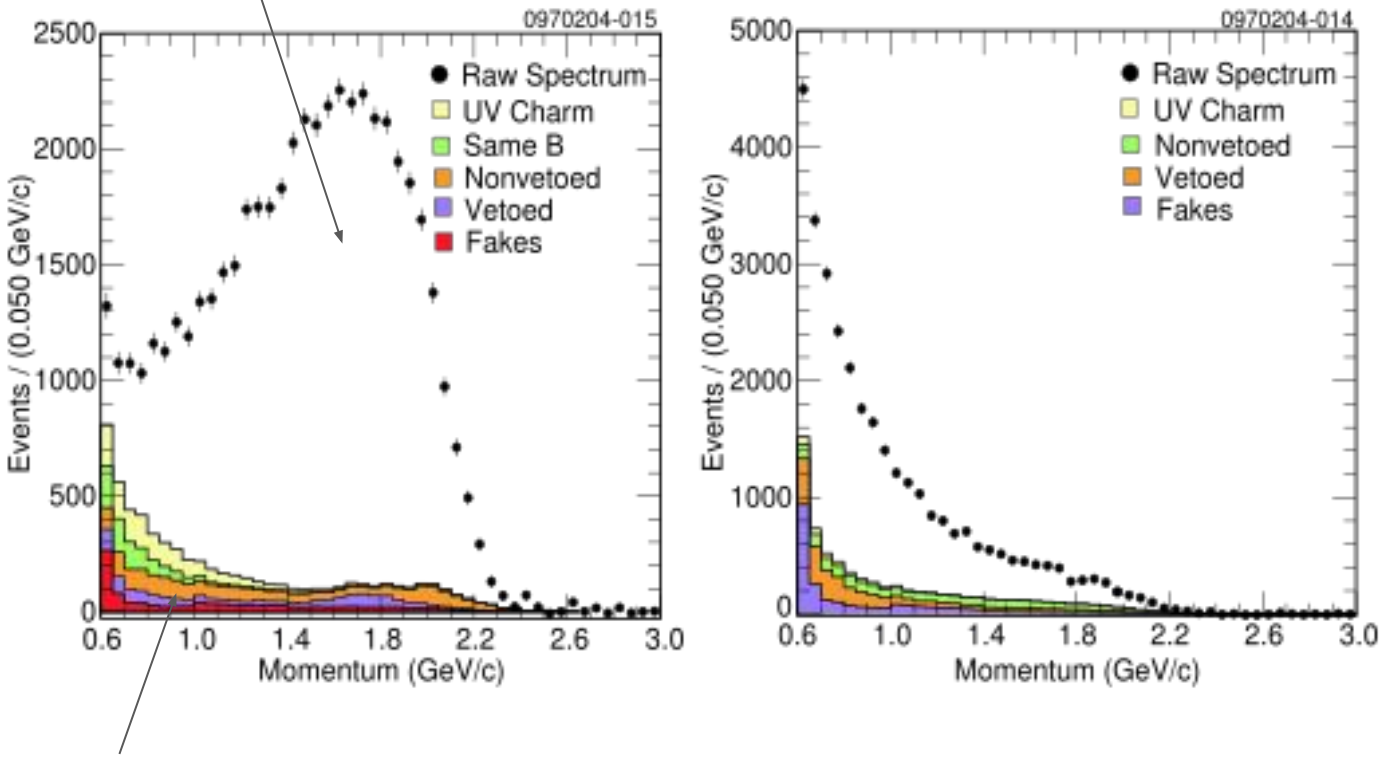
Primary decays (signal)

$$\frac{dN(\ell^{\pm}e^{\mp})}{dp} = N_{\ell}\,\eta(p)\,\epsilon(p)\left[\frac{d\mathcal{B}(b)}{dp}(1-\chi) + \frac{d\mathcal{B}(c)^{oppB}}{dp}\chi\right]$$

$$\frac{dN(\ell^{\pm}e^{\pm})}{dp} = N_{\ell}\,\eta(p)\left[\frac{d\mathcal{B}(b)}{dp}\chi + \frac{d\mathcal{B}(c)^{oppB}}{dp}(1-\chi)\right]$$

Factor that accounts for mixing: $\chi = f_{00}\,\chi_d$

Primary and secondary decays



Other backgrounds

Important Ingredients

Need to have a good understanding of several performance related issues

- Lepton PID Performance and Mis-ID
  - Need data-driven auxiliary measurements to validate performance
    - Lepton mis-ID rates of pions, kaons, and protons

$$K_S \to \pi^+\pi^- \qquad D^* \to D \to K\pi \qquad \Lambda \to p\pi$$

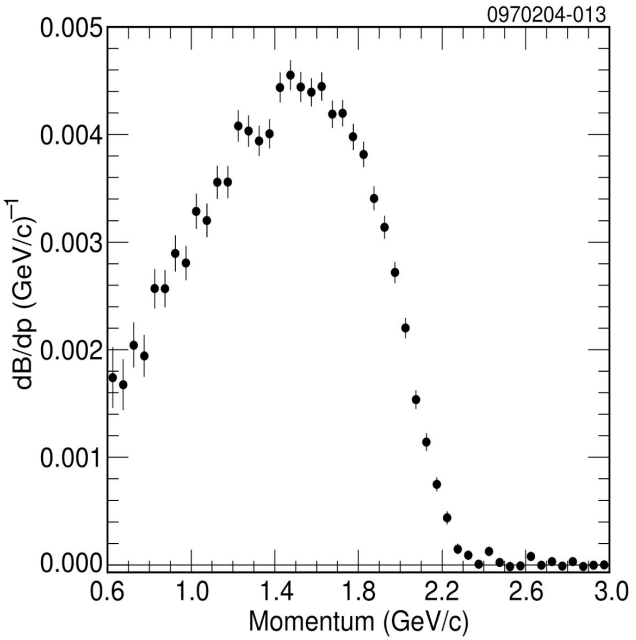
    - Electron ID and track-selection performance could be studied with radiative Bhabha events
      - Could be done via ‘embedding’ into generic MC events or an orthogonal data sample of BB events
      - Or by correcting the event topology, angular distributions, etc. in another fashion

Conversion of measured yields in BFs

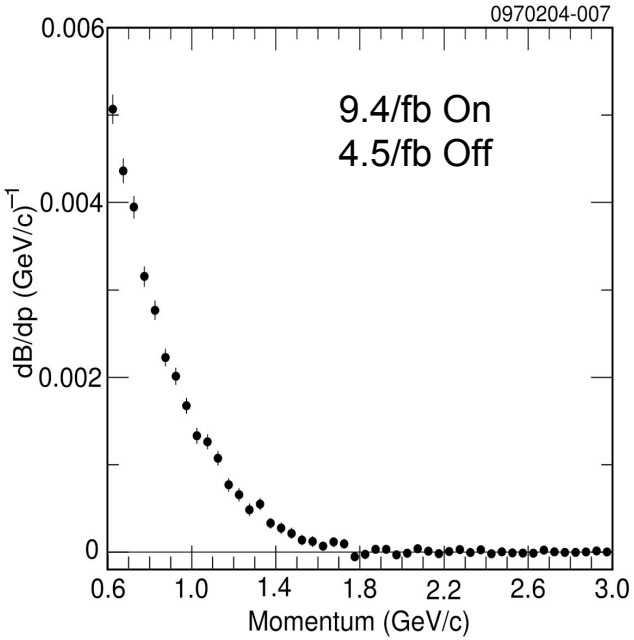
$$\frac{d\mathcal{B}(b)}{dp} = \frac{1}{(1-[\Delta(p)+1]\,\chi)}\frac{1}{N_\ell\,\eta(p)}\left[\frac{[1-\chi\Delta(p)]}{\epsilon(p)}\frac{dN(\ell^\pm e^\mp)}{dp} - \chi\Delta(p)\frac{dN(\ell^\pm e^\pm)}{dp}\right]$$

$$\frac{d\mathcal{B}(c)}{dp} = \frac{1}{(1-[\Delta(p)+1]\,\chi)}\frac{1}{N_\ell\,\eta(p)}\left[\frac{\chi}{\epsilon(p)}\frac{dN(\ell^\pm e^\mp)}{dp} - (1-\chi)\frac{dN(\ell^\pm e^\pm)}{dp}\right]$$

Signal



Secondary Decays



Normalization

The CLEO measurement extracted the BF by counting the number of tags

- I.e. how many events have a tag lepton with or without a second signal lepton
  - BF: Fraction of tagged events that has a signal side lepton from a primary decay

$$\frac{d\mathcal{B}(b)}{dp} = \frac{1}{(1-[\Delta(p)+1]\,\chi)} \frac{1}{N_\ell\,\eta(p)} \left[\frac{[1-\chi\Delta(p)]}{\epsilon(p)} \frac{dN(\ell^\pm e^\mp)}{dp} - \chi\Delta(p) \frac{dN(\ell^\pm e^\pm)}{dp} \right]$$

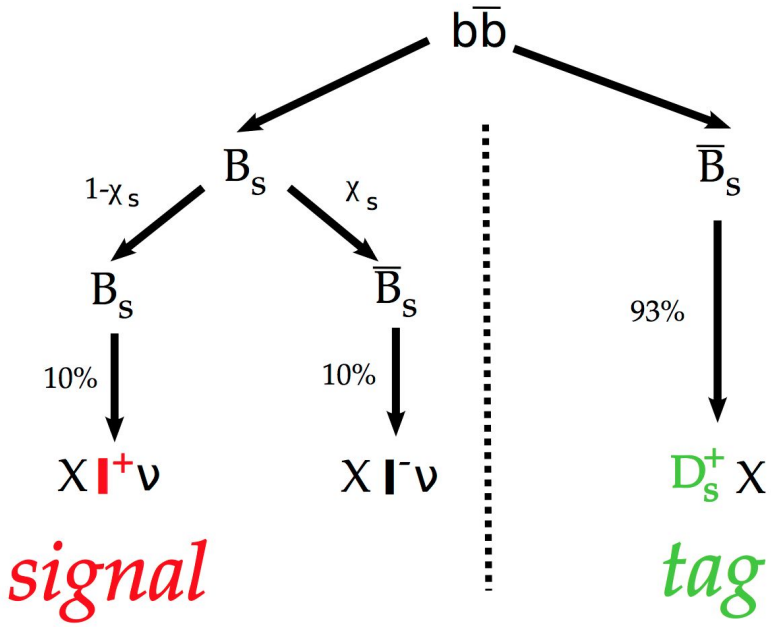
Number of tags

- To convert this information into the number of BB-pairs, we would need to determine (from simulation) the efficiency of selecting a tag
  -

Measurement of the inclusive semileptonic *BF* at √s = Y(5S) or Y(6S)

Separation of $B\overline{B}$ and $B_s\overline{B}_s$ contributions important; tag Ds meson

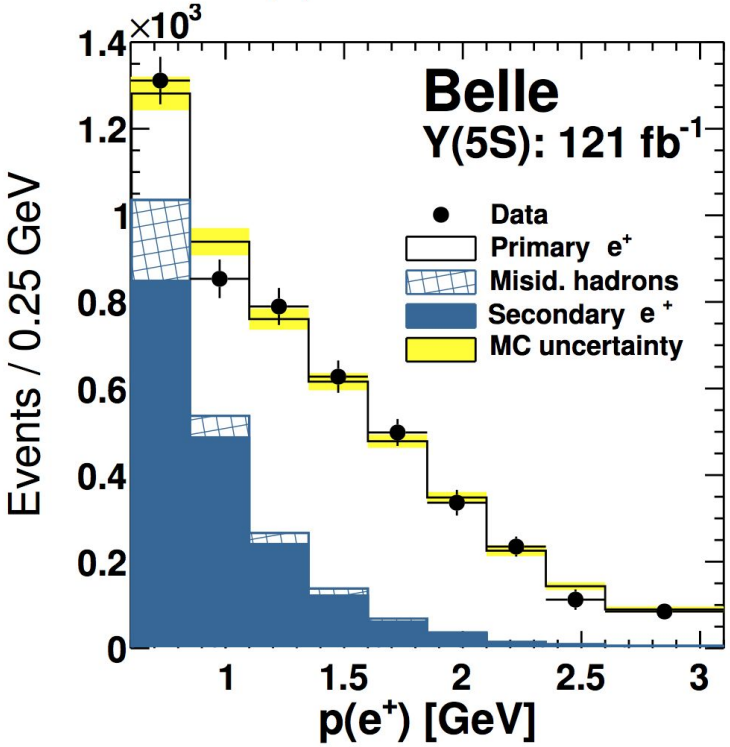
https://arxiv.org/pdf/1212.6400.pdf



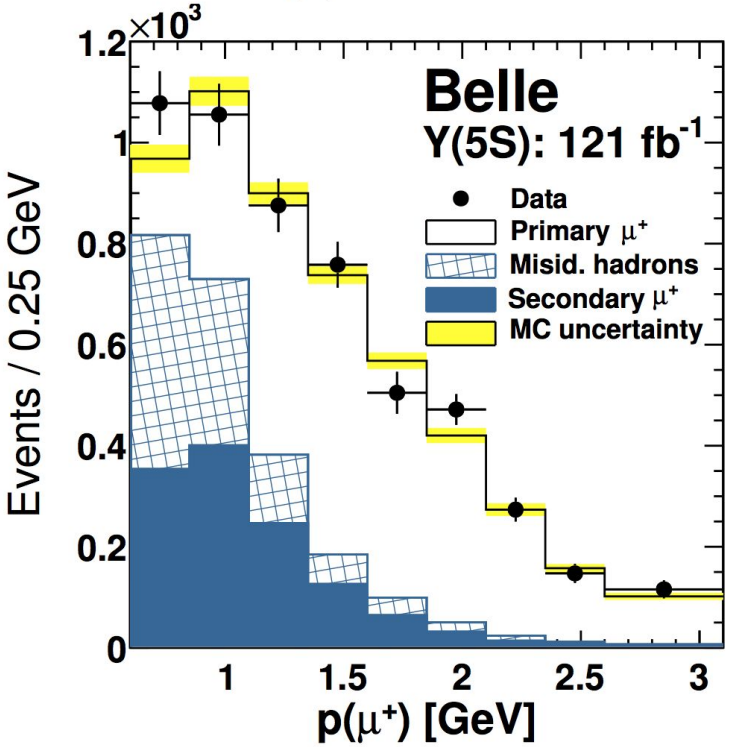
$$\mathcal{R} = \frac{\mathcal{N}_{D_s^+\ell^+}}{\mathcal{N}_{D_s}},$$

$$\mathcal{R} = \frac{\mathcal{N}_{D_s^+\ell^+}}{\mathcal{N}_{D_s}} = \frac{\mathcal{N}_{D_s^+\ell^+}(B_s) + \mathcal{N}_{D_s^+\ell^+}(B)}{\mathcal{N}_{D_s}(B_s) + \mathcal{N}_{D_s}(B)}.$$

(a) Electrons



(b) Muons



$$\mathcal{R}_\ell = \frac{\mathcal{N}_{D_s^+\ell^+}}{\mathcal{N}_{D_s}} = \frac{N_{\text{primary}}}{N_{D_s}} \cdot \frac{\epsilon_{K^+K^-\pi^+}(D_s)}{\epsilon_{K^+K^-\pi^+}(D_s^+\ell^+)} \cdot$$

BF determination

$$\mathcal{B}(B_s \to X\ell\nu) = \frac{[\mathcal{N}_{D_s}(B_s) + \mathcal{N}_{D_s}(B)] \cdot \mathcal{R}_\ell - \mathcal{N}_{D_s^+\ell^+}(B)}{\chi_s \cdot \mathcal{N}_{D_s}(B_s)}.$$

BF obtained by combining measured ratio with external measurements

Parameter	Value	$\lvert\Delta\mathcal{B}/\mathcal{B}\rvert$ [%]
$f_u = \mathcal{B}(\Upsilon(5S) \to B^+X)/2$	[36.1 ± 3.2] % [77]	0.8
$f_d = \mathcal{B}(B)\Upsilon(5S) \to B^0X/2$	[38.5 ± 4.2] % [77]	0.6
f_s	[19.9 ± 3.0] %	2.4
$\mathcal{B}(B_s \to D_s^\pm X)$	[93 ± 25] %	4.4
$\mathcal{B}(B^+ \to D_s^+ X)$	[7.9 ± 1.4] %	2.2
$\mathcal{B}(B^0 \to D_s^+ X)$	[10.3 ± 2.1] %	1.7
$\mathcal{B}(B^0 \to D_s^- X)$	[1.5 ± 0.8] % [114]	1.1
$\mathcal{B}(B^+ \to D_s^- X)$	[1.1 ± 0.4] %	0.9
$\mathcal{B}(B^0 \to X\ell^+\nu_\ell)$	[10.33 ± 0.28] %	0.4
$\mathcal{B}(B^+ \to X\ell^+\nu_\ell)$	[10.99 ± 0.28] %	0.1
$F_{B^*\bar{B}^*}$	[38.1 ± 3.4] %	0.1
$F_{B^*\bar{B}}$	[13.7 ± 1.6] %	0.1
$F_{B\bar{B}}$	[5.5 ± 1.6] %	0.0
$F'_{B^*\bar{B}^*\pi}$	[5.9 ± 7.8] % [77]	0.1
$F'_{B^*\bar{B}\pi}$	[41.6 ± 12.1] % [77]	0.2
$F'_{B\bar{B}\pi}$	[0.2 ± 6.8] % [77]	0.0
x_d	0.771 ± 0.008	0.1
χ_s	0.500 ± 0.001	0.2

$$\begin{aligned}
\mathcal{N}_{D_s}(B_s)/N_{b\bar{b}} &= 2 \cdot f_s \cdot \mathcal{B}(B_s \to D_s X), \\
\mathcal{N}_{D_s}(B)/N_{b\bar{b}} &= 2 \cdot f_d \cdot \mathcal{B}(B^0 \to D_s X) + 2 \cdot f_u \cdot \mathcal{B}(B^+ \to D_s X)
\end{aligned}$$

$$\begin{aligned}
\mathcal{N}_{D_s^-\ell^-}(B)/N_{b\bar{b}} = {} & \\
& 2 \cdot \tfrac{f_d}{f_{u,d}} \cdot \underbrace{\left[F_{B\bar{B}} + F_{B^*\bar{B}^*} + \tfrac{1}{3}(f_{u,d} - F_2) \cdot (F'_{B\bar{B}\pi} + F'_{B^*\bar{B}^*\pi}) + (f_{u,d} - F_2) \cdot (1 - F'_3)\right] \cdot \left\{\chi_d^{(-)} \cdot \mathcal{B}(B^0 \to D_s^+ X) + \left(1 - \chi_d^{(-)}\right) \cdot \mathcal{B}(B^0 \to D_s^- X)\right\} \cdot \mathcal{B}(B^0 \to X\ell^+\nu_\ell)}_{B^{0(*)}B^{\bar{0}(*)} \text{ pairs, } C \text{ even}} \\
& + 2 \cdot \tfrac{f_d}{f_{u,d}} \cdot \underbrace{\left[F_{B^*\bar{B}} + \tfrac{1}{3}(f_{u,d} - F_2) \cdot F'_{B^*\bar{B}\pi}\right] \cdot \left\{\chi_d^{(+)} \cdot \mathcal{B}(B^0 \to D_s^+ X) + \left(1 - \chi_d^{(+)}\right) \cdot \mathcal{B}(B^0 \to D_s^- X)\right\} \cdot \mathcal{B}(B^0 \to X\ell^+\nu_\ell)}_{B^0\bar{B}^0 \text{ pairs, } C \text{ odd}} \\
& + 2 \cdot \tfrac{f_u}{f_{u,d}} \cdot \underbrace{\left[F_2 + \frac{1}{3}(f_{u,d} - F_2) \cdot F'_3 + (f_{u,d} - F_2) \cdot (1 - F'_3))\right] \cdot \mathcal{B}(B^+ \to D_s^- X) \cdot \mathcal{B}(B^+ \to X\ell^+\nu_\ell)}_{B^{-(*)}B^{-(*)} \text{ pairs}} \\
& + \underbrace{\left[\tfrac{2}{3} \cdot (f_{u,d} - F_2) \cdot F'_3\right] \cdot \left(\left\{\chi_d^{(-)} \cdot \mathcal{B}(B^0 \to D_s^+ X) + \left(1 - \chi_d^{(-)}\right) \cdot \mathcal{B}(B^0 \to D_s^- X)\right\} \cdot \mathcal{B}(B^+ \to X\ell^+\nu_\ell) + \left\{\chi_d^{(-)} \cdot \mathcal{B}(B^+ \to D_s^+ X) + \left(1 - \chi_d^{(-)}\right) \cdot \mathcal{B}(B^+ \to D_s^- X)\right\} \cdot \mathcal{B}(B^0 \to X\ell^+\nu_\ell)\right)}_{B^{+(*)}B^{0(*)} \text{ and } B^{-(*)}B^{\bar{0}(*)} \text{ pairs}}.
\end{aligned}$$

(7.1

Which groups would be interested in contributing?

Ideally we would tackle this as a **group effort;** could be the first SL Belle II result

- Group work will ensure quick turn-around-time once we have data
- Preparation needs to start in early 2017
  - Need to optimize selection and implement auxiliary measurements to cross check PID performance and other aspects
  - Auxiliary measurements will be useful beyond the measurement of the inclusive *BF* and the SL working group
    - Good preparation to ensure physics readyness for Phase III
- Y(4S) data is fairly straightforward; Y(5S) & Y(6S) measurements a bit more involved as one has to deal with BB backgrounds
  - Factor of 2-4 less data than CLEO still would make a reasonable Y(4S) measurement
  - Off-resonance data would be nice to have, but could also subtract continuum with MC
    - Can go beyond kinematic endpoint of lepton spectrum to validate subtraction or derive correction function