SUMMARY OF WG2:
Semileptonic & Rare Decays

participants: 22 theorists
13 experimentalists

↙ lots of room for more!

What can we learn?

① FCNC decays

ex: $B \to K^* \mu^+ \mu^-$

- new physics
- measure form factors for $B \to \rho e \bar{\nu}$

② Semileptonics

- Vub, Vcb (but will presumably do better at e^+e^- machines)
- testing Heavy Quark Expansion (particularly in $\Lambda_b \to \Lambda_c e \bar{\nu}$)

③ Radiative decays

(ex: $B_s \to \varphi \gamma$)

- competitive?

① FCNC's

MODES:

$B \to K^{(*)} \ell^+ \ell^-, \ \varphi \ell^+ \ell^-$

$\quad \to X_s \ell^+ \ell^-$

$B_{d,s} \to \mu^+ \mu^-$

$B \to K^* e\mu, \ e\mu$ ("tooth fairy modes")

$b \to s \ell^+ \ell^-$: additional constraints on new physics over $b \to s \gamma$

EXCLUSIVE: $B \to K^{(*)} \ell^+ \ell^-, \ \varphi \ell^+ \ell^-$

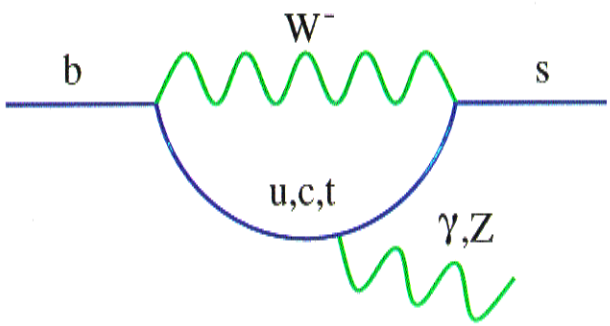
- expect $\mathcal{O}(10^2)$ events

GOALS: $\frac{d\Gamma}{dm_{\ell\ell}}$, $\frac{d\Gamma}{dE_\ell}$, $M_{\ell\ell}^0$ (forward-backward asymmetry - less model dependent?)

$\Rightarrow$ extract form factors, combine with CLEO measurement of $B \to \rho \ell \nu$ via $SU(3)$ to measure $|V_{ub}|$

FCNCs Induced at One Loop

- In the SM, Flavor Changing Neutral Currents (FCNCs) are forbidden at tree level. For instance, $b \to s$ transitions can only occur starting at one loop:



- These transitions are sensitive to heavy physics in the loop. For instance, in the SM $b \to s$ is dominated by the top-W loop. => Test of the SM.

- Physics beyond the SM contributing to the loop could give large deviations. E.g.: In SUSY, contributions from charged scalars, gauginos and squarks could lead to deviations of $\mathcal{O}(1)$.

$B \to X_s \ell^+ \ell^-$

- More complexity: γ-penguin + Z-penguin + box diagrams. Short distance is now determined by C_7 plus C_9 and C_{10}, where

$$\mathcal{O}_9 = \frac{e^2}{16\pi^2} (\bar{s}_L \gamma_\mu b_L)(\bar{\ell}\gamma^\mu \ell)$$
$$\mathcal{O}_{10} = \frac{e^2}{16\pi^2} (\bar{s}_L \gamma_\mu b_L)(\bar{\ell}\gamma^\mu \gamma_5 \ell)$$

- Additional observables. Dilepton mass distribution, angular distributions (e.g. forward-backward asymmetry for leptons). More handles to disentangle new physics. For instance: sgn(C_7) not known from $B \to X_s \gamma$.

- Theoretically clean. Similar sources of uncertainty as from $B \to X_s \gamma$ (renormalization scale and scheme dependence, initial state Fermi motion, ...).

- Theoretical prediction:
  $Br^{\rm th.}(B \to X_s \ell^+ \ell^-) \simeq (6 - 8) \times 10^{-6}$.
  Experimental bounds:
  $Br^{\rm exp.}(B \to X_s \ell^+ \ell^-) < 5.7 \times 10^{-5}$.

Exclusive vs. Inclusive Decays

- Inclusive Modes: $B \to X_s\gamma$, $B \to X_s\ell^+\ell^-$, ...
  - Theoretically cleaner. They have small theoretical uncertainties mostly from perturbative QCD and other controlled approximations such as the HQET and the OPE.
  - Experimentally more challenging. Need clean detector environment for precise measurements.
- Exclusive Modes: $B \to K^*\gamma$, $B \to K^*\mu^+\mu^-$, ...
  - Large theoretical uncertainties from hadronic form-factors. The stuff of Lattice calculations. Symmetries and related tricks may help in *some* cases.
  - Cleaner experimental signals, especially at hadron colliders.

$B \to \mu\mu K^{(*)}$ results

At 90% C.L.:

- $Br(B^+ \to \mu^+\mu^- K^+) < 5.2 \times 10^{-6}$
- $Br(B^0 \to \mu^+\mu^- K^{*0}) < 4.0 \times 10^{-6}$
- CLEO has limits, at $\sim 9 \times 10^{-6}$

Run II triggers

Studying possible triggers. Current plan:

- one CMP with $p_T > 3$ GeV$/c$
  other anywhere with $p_T > 1.5$ GeV$/c$
- or two anywhere with displaced (SVT) track

Food for thought (*W. Wester*)

- inclusive search $B \to \mu\mu X$, where X is:
  - one or more tracks
  - displaced vertex

$B \to K^* \ell^+ \ell^-$

- Hadronic uncertainties large from various form-factors. Almost all observables affected but these large theoretical errors.

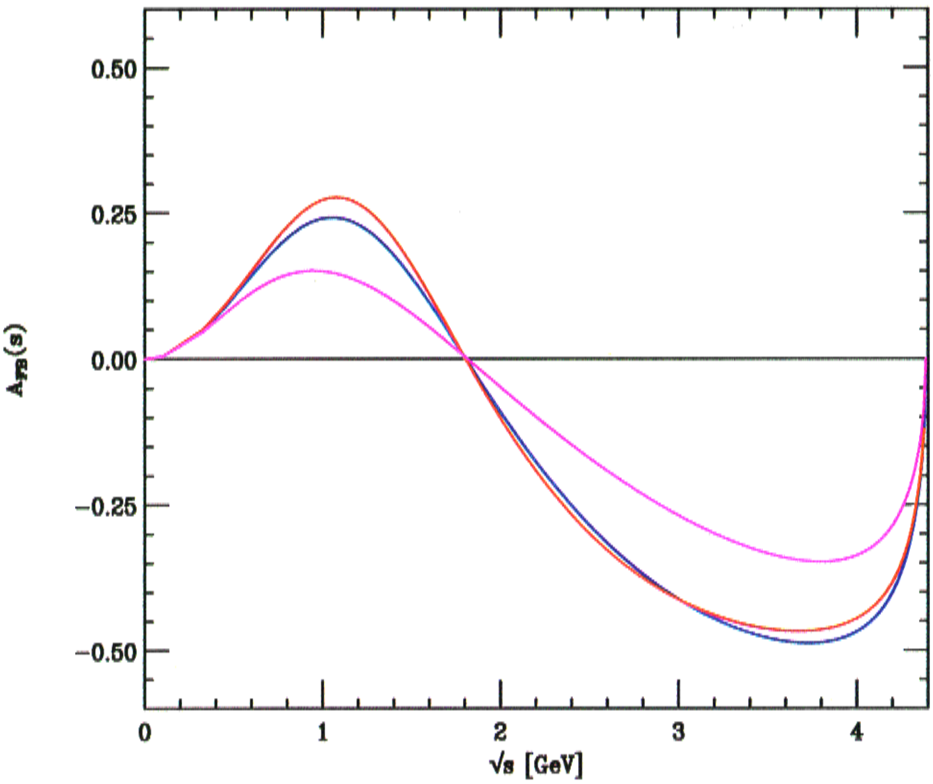
- Hope:

  - Lattice calculations of weak transition matrix elements => predictions for form-factors.
  - Heavy Quark Spin Symmetry: relates the $B \to K^* \ell^+ \ell^-$ form-factors to the semileptonic form-factors in $B \to \rho \ell \nu$.
  - Forward-backward asymmetry zero: $A_{FB}(m_{\ell\ell})$ has a zero in the SM. The value of $m_{\ell\ell}$ for which $A_{FB}(m_{\ell\ell}) = 0$ (seems to be) free of hadronic uncertainties.

- May be best rare B mode at Tevatron: Clean signal and largest branching ratio.
  $Br^{\text{th.}}(B \to K^* \ell^+ \ell^-) \simeq (1 - 5) \times 10^{-6}$

- Current limits: $Br^{\text{exp.}}(B \to K^* \ell^+ \ell^-) < 10^{-5}$ from CLEO, CDF.

∗ The ratio R_V is very stable across models!



⟶ BSW*: Bauer, Stech and Wirbel, Z. Phys. C29, 637 (1985); Stech, Phys. Lett. B354, 447 (1995).

⟶ LCSR: Ball and Braun, Phys. Rev. D55, 5561 (1997).

⟶ MNS: Melikhov, Nikitin and Simula, Phys. Lett. B410, 210 (1997).

INCLUSIVE: $B \to X_s \ell^+ \ell^-$

- theoretically clean (model-independent)
- DØ has already placed limits based on high invariant mass region (3.9 GeV < $m_{\ell^+\ell^-}$ < 4.4 GeV)

Current limit: < 4.2×10^{-5} (CLEO)
SM: $6-8 \times 10^{-6}$

Run II: expect $\mathcal{O}(10^3)$ events

NB: Physics background : signal is 100 : 1 (with only invariant mass cuts) - need to study!
- strong competition from CLEO
- need strategies beyond cutting on lepton inv't mass (vertexing, impact parameter, pseudo-reconstruction...)

THEORY: OPE may break down in high inv't mass region - (like $B \to X_u \ell \nu$ near endpoint)
- may need shape f'n analysis (underway)

② Semileptonics

- exclusive modes are understood via HQET
- major ~~ca~~ capability is study of

$\underbrace{\Lambda_b \to \Lambda_c \ell \bar{\nu}}$

all form factors are related to a single universal function, <u>including</u> $1/M_b$ corrections

Exp't: goal is to measure form factors
- need to reconstruct ν (cdf: 3D vertexing)
- need q^2 spectrum (need large sample)
- absolute or relative normalization?

Theory: determine the useful observables

<u>MESONS:</u> $B \to D^{(*)} \ell \nu$ - validate techniques

$B_c \to J/\psi \ell \nu$ (test NRQCD)

③ Radiative Penguins

$$B \to K^* \gamma$$
$$B_s \to \phi \gamma$$

- CDF is planning dedicated triggers for these modes
- $B \to K^* \gamma$ also accessible at e^+e^-; not clear Tevatron will be competitive

$$B \to X_s \gamma$$

- inclusive mode is more difficult than $B \to X_s \mu^+ \mu^-$
- BTeV will study