Rare non-hadronic B Decays
Status, Prospects, and Pipe Dreams

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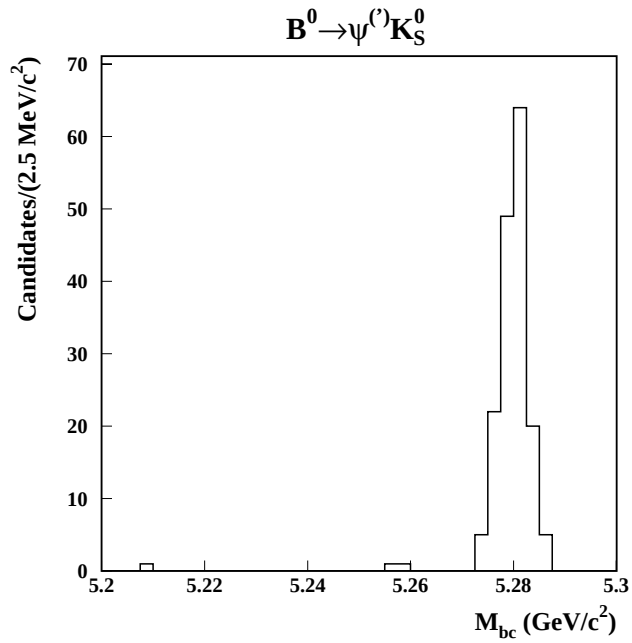
- $b \to s/d\ l^+l^-$
- exclusive $b \to s/d\ \gamma$ using γ conversions
- $B \to \tau\nu$
- $b \to s\nu\bar{\nu}$
- $B \to l^+l^-$
- $B \to \gamma\gamma$

@

- CLEO, BaBar, Belle, LEP
- CDF
- BTeV, LHC

$B \to J/\psi K_s^0$ — a "standard candle"

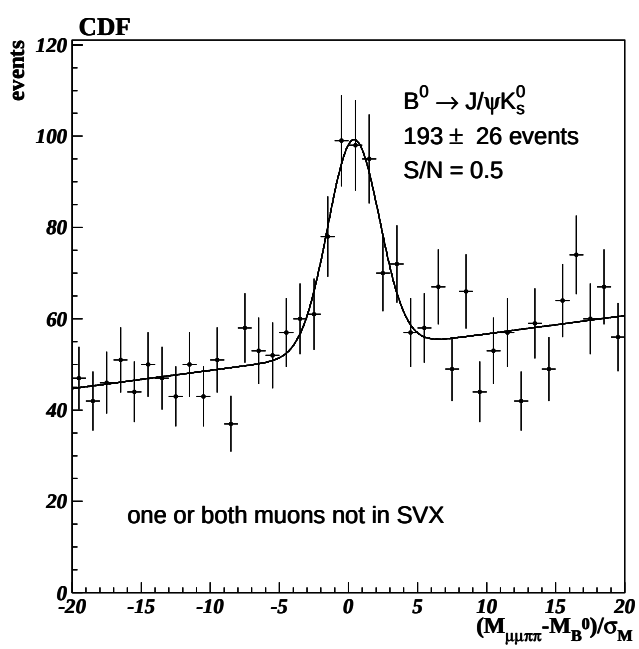


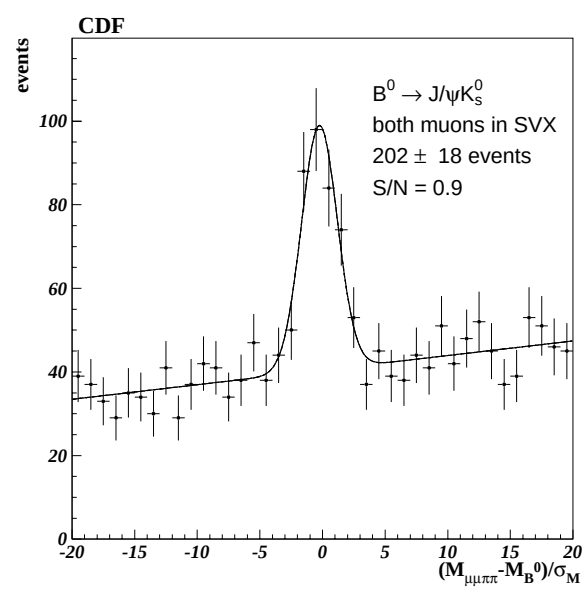
$10 fb^{-1}$ @ $\Upsilon(4S)$

$\to \sim 150 J/\psi K_s^0$

$88 pb^{-1}$ @ CDF Run I

$\to \sim 400 J/\psi K_s^0$





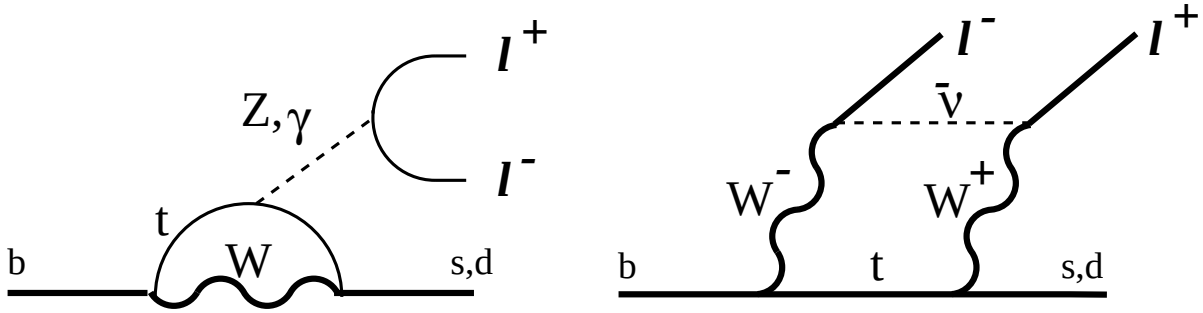
Three Generations of B Experiments

Three different "Operating environments"

	Start	$J/\psi K_s^0$/year	Today	$\sim$ 2004	$\sim$ 2008
CLEO	1999	300	150	$\sim$ 1K	
BaBar	1999	450		$\sim$ 1.5K	
Belle	1999	$\sim$ 1.5K		$\sim$ 1.5K	
N.G. $\Upsilon(4S)$	$\sim$ 2004	$\sim$ 5K			$\sim$ 20K
CDF	2001	$\sim$ 7.5K	200/400	$\sim$ 15K	$\sim$ 150K
BTeV	2005	$\sim$ 109K			$\sim$ 200K
LHCb	2005	$\sim$ 150K			$\sim$ 300K

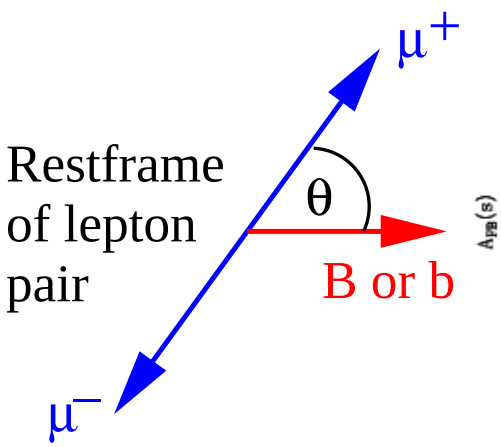
Don't take these numbers too serious !!!

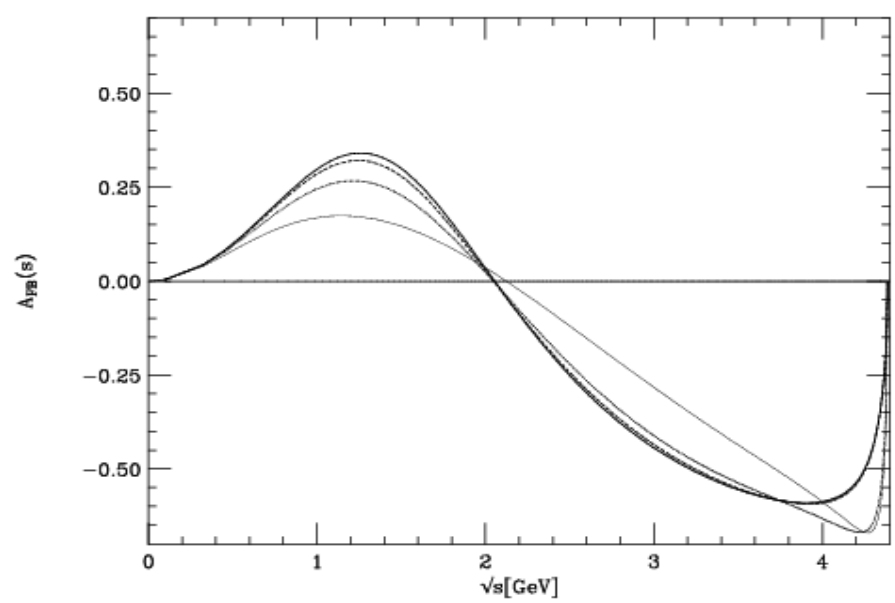
$b \to s/d\ l^+l^-$



Theoretically clean signatures

- inclusive rate
- inclusive forward-backward asymmetry ($A_{fb}(m_{ll})$)
- $B \to V l^+ l^-$: m_{ll} for which $A_{fb}(m_{ll}) = 0$





CLEO $b \to sl^+l^-$ Phys. Rev. Lett.80:2289,1998

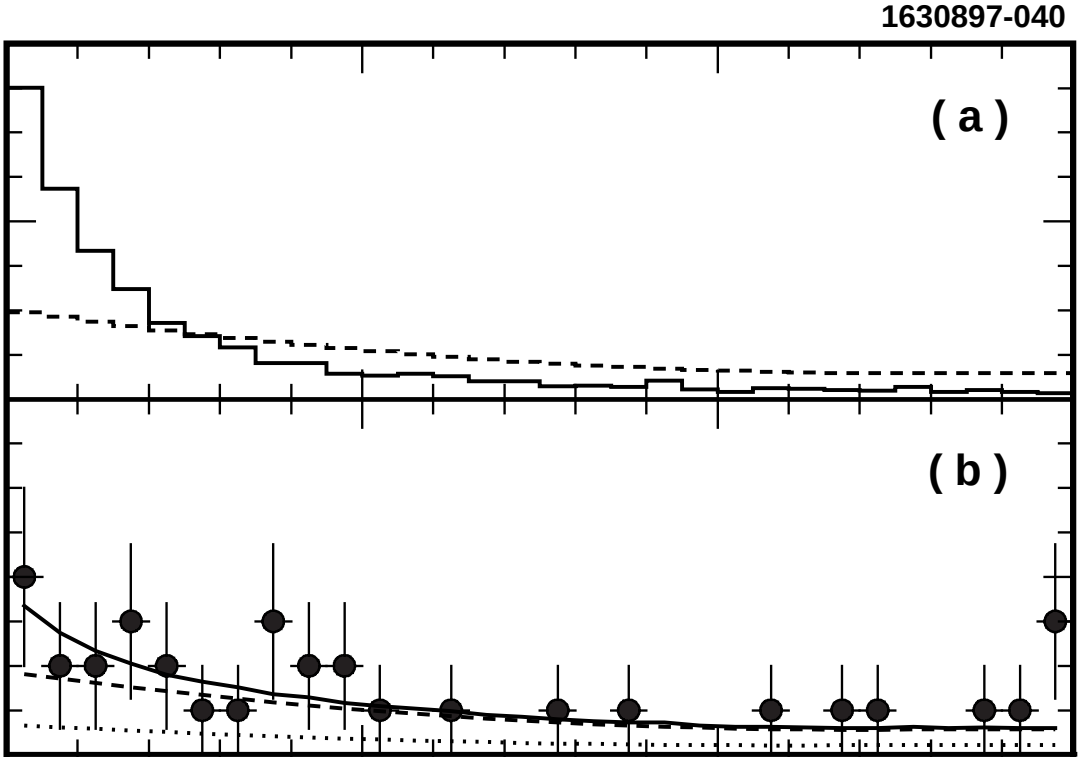
- Uses $3.3 \times 10^6 B\bar{B}$, i.e. 1/3 of CLEO dataset.
- analysis similar to $b \to s\gamma$
  - $X_s = K + 0 - 4\pi$ with $\leq 1\pi^0$
  - CL of K (dE/dx) $\geq 5\%$, 3σ consistency for TOF
  - choose candidate/event which minimizes χ^2 of TOF, dE/dx, M_B, $(E_B - E_{beam})$, m_{π^0}, $m_{K^0_s}$
  - suppress continuum bkg using event shape.
  - $m_{X_s} \leq 1.8$GeV to suppress $B\bar{B}$ bkg.
- $m_{l^+l^-}$ exclude ψ, ψ' for $e^+e^-, \mu^+\mu^-$.
- determine yield by fit of χ^2_B to on+off resonance data.

$$\chi^2_B \equiv \left(\frac{M_B - 5.279\ GeV}{\sigma_{M_B}}\right)^2 + \left(\frac{E_B - E_{beam}}{\sigma_{\Delta E}}\right)^2$$

	$X_s e^+e^-$	$X_s \mu^+\mu^-$	$X_s \mu^+e^-$
fit yield	7 ± 7	1 ± 7	-18 ± 10
eff.	$(5.2 \pm 1.1)\%$	$(4.5 \pm 1.8)\%$	$(7.3 \pm 2.0)\%$

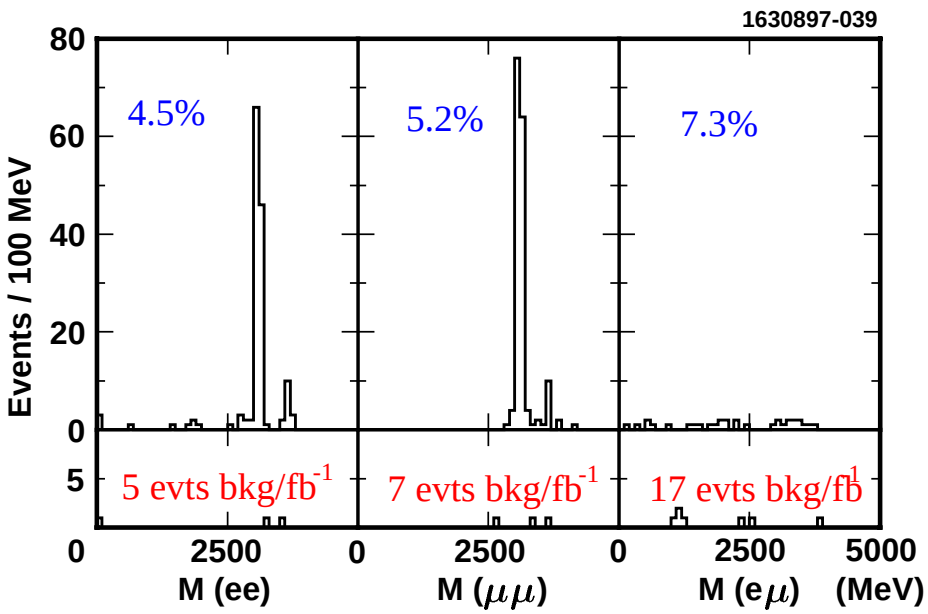
CLEO $b \to sl^+l^-$ Phys. Rev. Lett.80:2289,1998

E.g. $B \to X_s e^+ e^-$



$$\mathcal{B}(b \to s\mu^+\mu^-) < 5.8 \times 10^{-5}, \ \mathcal{B}(b \to se^+e^-) < 5.7 \times 10^{-5}$$
$$\mathcal{B}(b \to se^+\mu^-) < 2.2 \times 10^{-5}, \ \mathcal{B}(b \to sl^+l^-) < 4.2 \times 10^{-5}$$

Future Prospects based on CLEO 1998



Efficiencies

Expected bkg/fb^{-1}

	Theory	Yield/100 fb^{-1}	bkg/100fb^{-1}
$b \to sl^+l^-$	6×10^{-6}	~ 30 evts	500 evts

Improvements in detector and/or analysis technique needed.
RICH, SVX, smart graduate students.

Exclusive Decays: $B \to K^{(*)} l^+ l^-$

Theory Predictions

Kl^+l^-	$\sim$	$0.2 - 0.9 \times 10^{-6}$
$K^*\mu^+\mu^-$	$\sim$	$1 - 4 \times 10^{-6}$
$K^*e^+e^-$	$\sim$	$1 - 6 \times 10^{-6}$

Experimental Results

$K^+\mu^+\mu^-$	$<$	5.2×10^{-6}	CDF 1999
$K^{*0}\mu^+\mu^-$	$<$	4.0×10^{-6}	CDF 1999
$K^+\mu^+\mu^-$	$<$	9.7×10^{-6}	CLEO 1998
$K^0\mu^+\mu^-$	$<$	21×10^{-6}	CLEO 1998
$K^{*+}\mu^+\mu^-$	$<$	33×10^{-6}	CLEO 1998
$K^{*0}\mu^+\mu^-$	$<$	9.5×10^{-6}	CLEO 1998
$K^+e^+e^-$	$<$	11×10^{-6}	CLEO 1998
$K^0e^+e^-$	$<$	17×10^{-6}	CLEO 1998
$K^{*+}e^+e^-$	$<$	28×10^{-6}	CLEO 1998
$K^{*0}e^+e^-$	$<$	14×10^{-6}	CLEO 1998
Kl^+l^-	$<$	7.0×10^{-6}	CLEO 1998
$K^*l^+l^-$	$<$	6.8×10^{-6}	CLEO 1998

CDF $B \to K^{(*)}\mu^+\mu^-$

- Trigger Requirements
  - Level 1: 2μ track segments
  - Level 2: ≥ 1 track match in central tracker
  - Level 3: refined track match for both μ

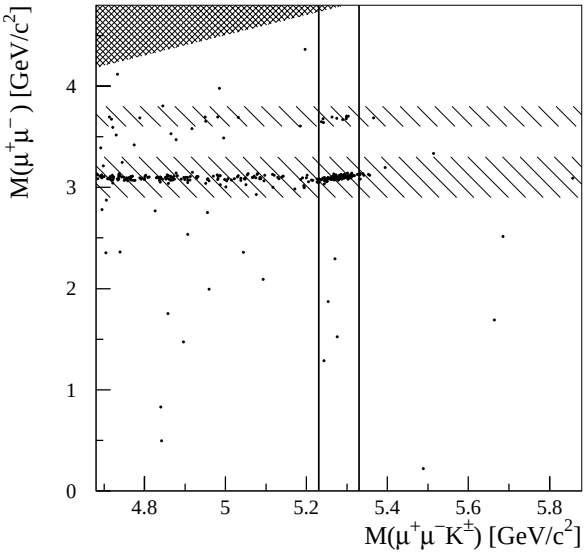
    $\to$ $p_T > 1.5 - 3\text{GeV}$
- Measure yield ratio $K^{(*)}\mu^+\mu^-/K^{(*)}J/\psi(\to \mu^+\mu^-)$
- only efficiency ratio from Monte Carlo
- $p_T > 2\text{GeV}$ for K^+ or K^*, $p_T > 6\text{GeV}$ for B
- $K^{0*} \to K^+\pi^-$ with m_{K^*} within $\pm 2\Gamma$
- Isolation requirement
- flight distance cut

  $\to$ eff. $B \to K^+\mu^+\mu^-$ (excl. trigger) $= 79\%$

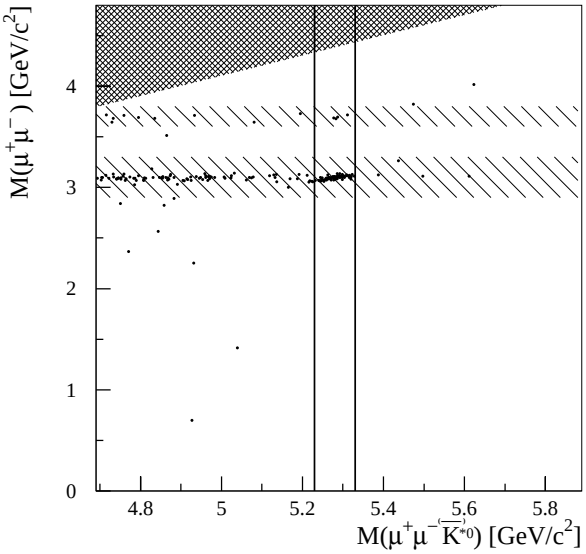
  $\to$ eff. $B \to K^{*0}\mu^+\mu^-$ (excl. trigger) $= 65\%$
- syst. err. dominated by $\mathcal{B}$ and yield of normalization modes

  $\to$ statistics limited (of course).

CDF $B \to K^{(*)}\mu^+\mu^-$



$$\mathcal{B}(B \to K^+\mu^+\mu^-) < 5.2 \times 10^{-6} \text{ @ } 90\% \textbf{ CL}$$



$$\mathcal{B}(B \to K^{*0}\mu^+\mu^-) < 4.0 \times 10^{-6} \text{ @ } 90\% \textbf{ CL}$$

CDF projections for Run II

- Theory prediction: $1 - 4 \times 10^{-6}$
- expected bkg level 0.9×10^{-6}

  $\rightarrow$ S/B > 1 even for pessimistic assumptions

- improvements in trigger thresholds + geometric acceptance
- small increase in beam energy
- add di-electron trigger
- factor 23 in luminosity $(2fb^{-1}/88pb^{-1})$
- Expect yield increase by factor ~ 50 for Run II.

  $\rightarrow$ expect $30 - 120$ signal evts on ~ 25 evts bkg.

Observation of $B \rightarrow K^* l^+ l^-$ expected.
m_{ll} for which $A_{fb}(m_{ll}) = 0$
maybe measurable in CDF Run IIb.
Expect $O(10^4)$ event yield @ LHCb + BTeV.

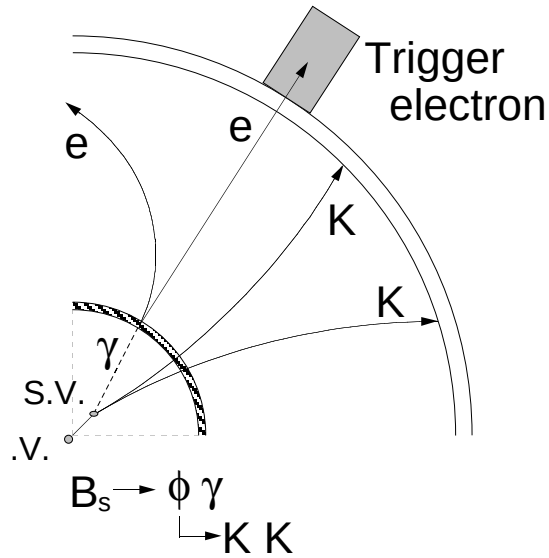
$B \to K^* l^+ l^-$ @ $\Upsilon(4s)$

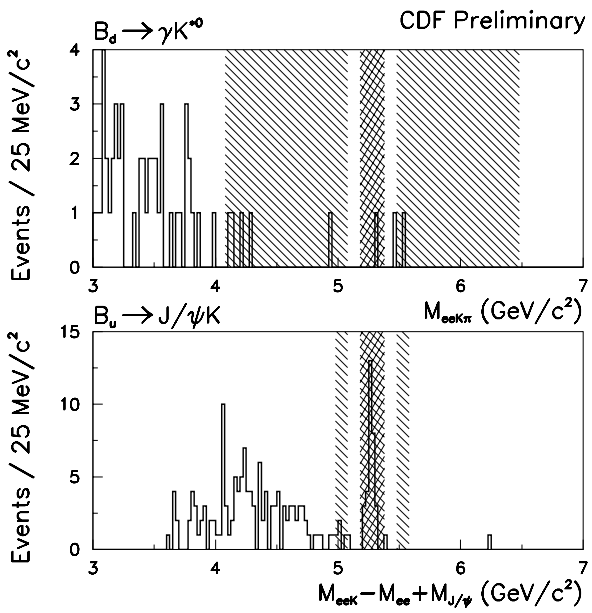
- CLEO (estimate based on ICHEP98 result)
  - $\sim$ 50 evts bkg per mode for $100 fb^{-1}$
  - average eff. 6.4% $\times 10^8$ $B's$ $\times 1 - 4 \times 10^{-6} = 6 - 25$ signal evts expected per mode.
  - detector and/or analysis improvements needed (RICH, SVX, smart students).
- BaBar book (estimate based on Monte Carlo):
  - $\sim$ 10(36) evts bkg for $K^{*0}(K^{*+})$
  - average eff. 9% $\times 10^8$ $B's$ $\times 1 - 4 \times 10^{-6} = 9 - 36$ signal evts expected per mode.

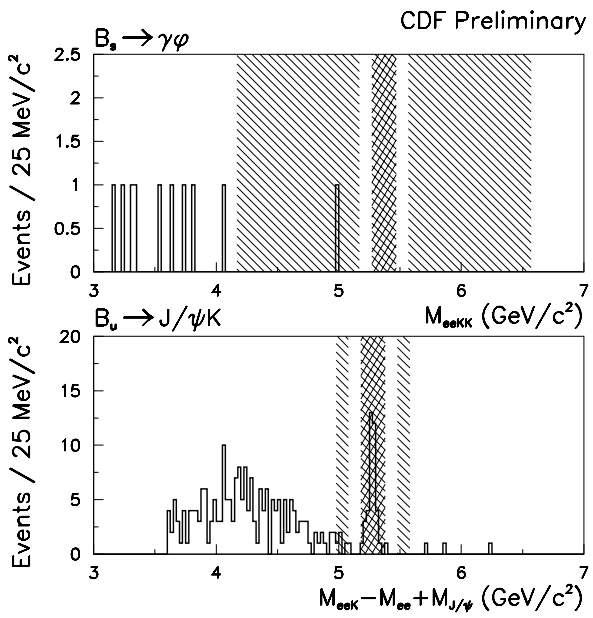
Observation of $B \to K^* l^+ l^-$ with $100 fb^{-1}$ within reach.
m_{ll} for which $A_{fb}(m_{ll}) = 0$
maybe measurable with N.G. experiment(s).

$B \to K^*\gamma$ with γ conversions @ CDF

Excl. reconstr. of
$B_d \to K^{*0}\gamma \to (K^+\pi^-)(e^+e^-)$
$B_s \to \phi\gamma \to (K^+K^-)(e^+e^-)$
eff. for conversions = 7%
8 GeV incl. electron trigger
secondary vtx cut
B isolation cut







$\mathcal{B}(B_d \to K^{*0}\gamma) < 1.7 \times 10^{-4}$

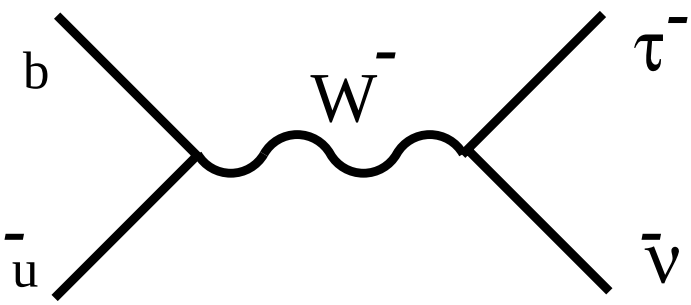
$\mathcal{B}(B_s \to \phi\gamma) < 2.2 \times 10^{-4}$

CDF projections for $b \to s\gamma$ in Run II

- Trigger
  - 1 electron (> 4GeV)
  - 2 tracks ($p_T > 1.5$GeV)
  - 1 of the tracks with large impact parameter ($p_T > 2$GeV)
- $\sigma_{M_B} = 30$MeV $\to 3\sigma$ $B_s - B_d$ separation.
- 1000 evts/$2fb^{-1}$ $B \to K^{*0}\gamma$ yield expected
- 900 evts/$100fb^{-1}$ $B \to K^{*0}\gamma$ @ $\Upsilon(4s)$
- 400 evts/$100fb^{-1}$ $B \to K^{*+}\gamma$ @ $\Upsilon(4s)$

$\Upsilon(4s) \sim$ **CDF**

$B \to \tau\nu$



$$\mathcal{B}(B \to \tau\nu) = \frac{G_F^2}{8\pi}\tau_B m_\tau^2 m_B (1 - \frac{m_\tau^2}{m_B^2})^2 \times |V_{ub}|^2 f_B^2$$
$$\sim 4 - 10 \times 10^{-5}$$

Experimental Status (90% CL)

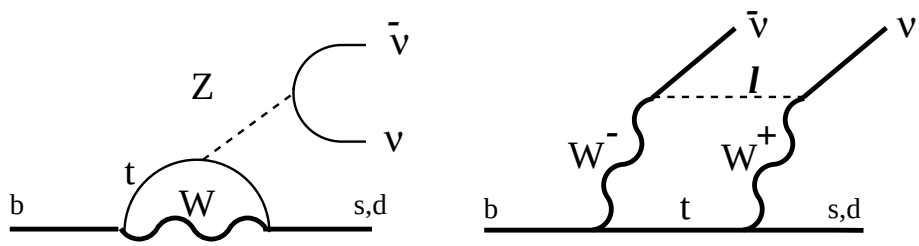
L3 1996	$<$	5.7×10^{-4}	no future
ALEPH 1996	$<$	16×10^{-4}	no future
CLEO 1995	$<$	22×10^{-4}	bkg limited
CLEO 1992	$<$	130×10^{-4}	eff. limited

Prospects for $B \to \tau\nu$

Two CLEO analyses in public domain:

- 1992 Summer Conference paper:
  - 716 ± 123 out of 10^6 B's fully reconstructed $\to$ eff. $\sim 0.1\%$
  - no candidate $B \to \tau\nu$ found
  - $\mathcal{B}(B \to \tau\nu) < 1.3\%$ @ 90% CL
  - $\to$ scales like 1/luminosity
  - Needs factor 260 more luminosity
- PRL 75, 785 (1995)
  - no signal on top of gigantic background
  - 4.1% eff., $2.2 \times 10^6 B\bar{B}$'s used in analysis
  - $\mathcal{B}(B \to \tau\nu) < 0.22\%$ @ 90% CL
  - $\to$ scales like $1/\sqrt{\text{luminosity}}$
  - Need factor 2000 more luminosity !!!
- Work currently in progress:
  - improve 1992 efficiency by factor 10
  - unclear when this becomes bkg limited
  - see few signal on (hopefully) few bkg with CLEO III

Observation of $b \to s\nu\bar{\nu}$ — a pipe dream ?



Theoretically clean signatures

- inclusive rate
- inclusive rate vs $m_{\nu\bar{\nu}}$

Experimental pipe dream @ $\Upsilon(4s)$

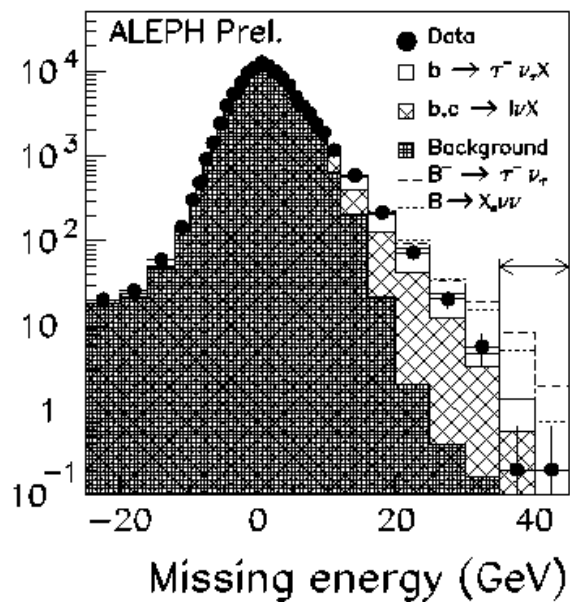
- fully reconstruct cleanly 1% of all B decays.
- reconstruct $K^{(*)}$ and nothing else in the event with eff. 10%

  $\to p_B, p_{K^{(*)}} \to m_{\nu\bar{\nu}}$ are known.
- Hoped for yield: $4 \times 10^{-5} \times 0.3 \times 0.1\% \times 10^8 B's \sim 1$ event

Experimental Status of $b \to s\nu\bar{\nu}$

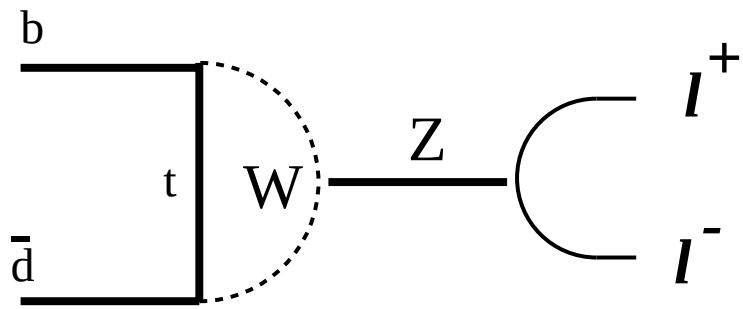
$b-$tag in opposite hemisphere
$\to$ eff. 50%, purity 80%
same side lepton veto

Count events with large E_{miss}
no distinction between $B \to \tau\nu$ and $b \to s\nu\bar{\nu}$.
$\mathcal{B}(b \to s\nu\bar{\nu}) < 7.7 \times 10^{-4}$ @ 90% CL



DELPHI: $\mathcal{B}(B_d \to K^{*0}\nu\bar{\nu}) < 1.0 \times 10^{-3}$
DELPHI: $\mathcal{B}(B_s \to \phi\nu\bar{\nu}) < 5.4 \times 10^{-3}$

Status of search for $B \to l^+l^-$



$$\mathcal{B}(B_s \to \mu^+\mu^-) \propto m_\mu^2 |V_{ts}|^2 f_{B_s}^2$$
$$\sim 4 \times 10^{-9}$$

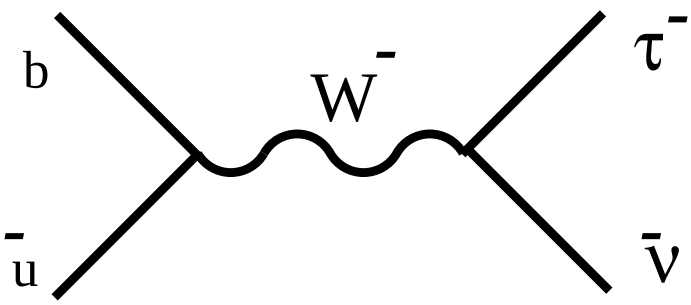
Experimental Status (UL @ 90% CL $\times 10^6$)

	$B_{d(s)} \to e^+e^-$	$B_{d(s)} \to \mu^+\mu^-$	$B_{d(s)} \to e^+\mu^-$
L3 1996	14(54)	10(38)	16(41)
CLEO 1993	5.9	5.9	5.9
CDF 1998/97		0.86(2.6)	3.5(6.1)

CLEO: $\mathcal{B}(B_d \to e^+(\mu^+)\tau^-) < 5.3(8.3) \times 10^{-4}$

ATLAS, CMS, LHC-b expect to measure $B_s \to \mu^+\mu^-$ to 15%

Status of search for $B \to \gamma\gamma$



Experimental Status (90% CL)

	B_d	B_s
L3 1995	$< 3.9 \times 10^{-5}$	$< 14.8 \times 10^{-5}$
Theory	$O(10^{-8})$	$O(10^{-7})$

Summary and Conclusions

- Many theoretically clean signatures.
- at present only $B \to K^{*0}\mu^+\mu^-$ limit from CDF near SM expectations.
- Next Generation Experiments
  - $b \to sl^+l^-$ @ $\Upsilon(4s)$ (maybe).
  - $B \to K^*l^+l^-$ @ CDF and (maybe) @ $\Upsilon(4s)$.
  - $B \to \tau\nu$ @ $\Upsilon(4s)$ (maybe).
- Next-to-Next Generation Experiments
  - $B \to K^*\nu\bar{\nu}$ @ $\Upsilon(4s)$ (probably not).
  - m_{ll} for which $A_{fb} = 0$ in $B \to V\ l^+l^-$
  - $B_s \to \mu^+\mu^-$