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Exclusive charmless semileptonic B decays and $|V_{ub}|$ measurement in BaBar

Torino, 08/01/2003

OUTLINE

- Physics Motivations
  - CKM matrix determination
- Measurement of $|V_{ub}|$
  - Experimental approaches
  - Inclusive Recoil tecnique
  - Exclusive $B \to X_u\, l\, \nu$ decays
- Conclusions

CKM matrix (I)

- Weak processes with quark flavour change couple the boson vector field to the charged weak V-A current, containing elements of the Cabibbo-Kobayashi-Maskawa quark-mixing matrix.

$$\mathcal{J}^\mu = \sum_{i,j} \bar{u}_i \gamma^\mu \frac{1}{2}(1-\gamma_5) V_{ij} d_j$$

$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \begin{pmatrix} d \\ s \\ b \end{pmatrix}$$

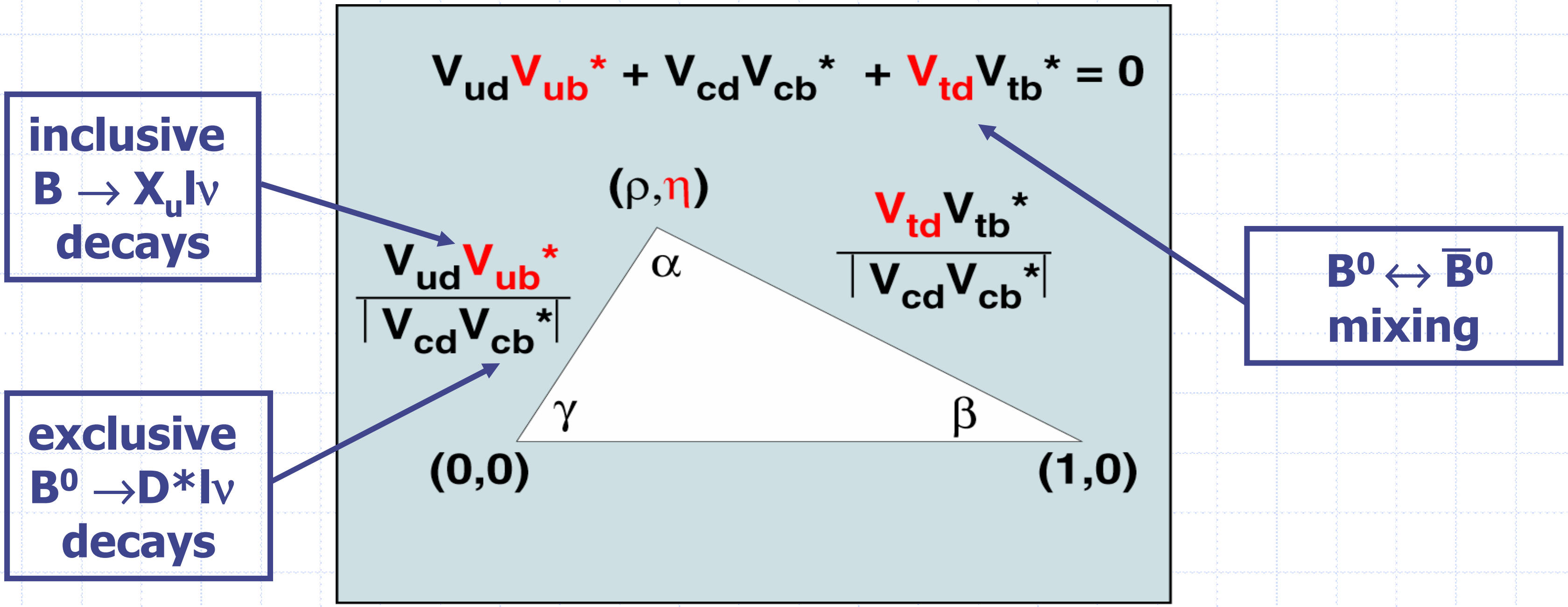
- With 3 quark generations there are 4 real indepedent parameters. The presence of an imaginary phase is responsible for CP violation.

$\lambda = \sin\theta_c \cong 0.22$

$$V = \begin{pmatrix} 1-\frac{1}{2}\lambda^2 & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1-\frac{1}{2}\lambda^2 & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{pmatrix} + \mathcal{O}(\lambda^4)$$

CKM Matrix (II)

- The unitarity of CKM matrix implies relations between its elements which can be expressed as "unitary triangles", whose non-zero area accounts for CP violation.
- In 2001 BaBar established ~~CP~~ in the B sector by measuring sin(2β).



CKM matrix elements

PDG 2002

$\|V_{xy}\|$	Measured value	Total Error (%)	Tecnique
$\|V_{ud}\|$	0.9734 ± 0.0008	< 0.1%	Nuclear β Decays
$\|V_{us}\|$	0.2196 ± 0.0026	~ 1%	K_{e3} Decay ($K^{+(0)} \rightarrow \pi^{0(-)} e^{+} \nu_{e}$)
$\|V_{ub}\|$	0.0036 ± 0.0007	~ 20%	Charmless SL B Decays
$\|V_{cd}\|$	0.224 ± 0.016	~ 7%	Charm production with ν beams
$\|V_{cs}\|$	0.996 ± 0.013	~ 1%	Charm-tagged W Decays
$\|V_{cb}\|$	0.0412 ± 0.0020	~ 5%	Charmed SL B Decays
$\|V_{td}\|$	$\| V_{tb}^{*} V_{td} \| = 0.0083 \pm 0.016$	-	$B_d\bar{B}_d$ Mixing
$\|V_{ts}\|$	$\| V_{td} / V_{ts} \| < 0.24$	-	$B_s\bar{B}_s$ Mixing
$\|V_{tb}\|$	$\|V_{tb}\|^2 / \Sigma_{d,s,b}\|V_{ty}\|^2 = 0.94 \pm 0.31$	-	Semileptonic t Decays

Constraints on the unitary triangle

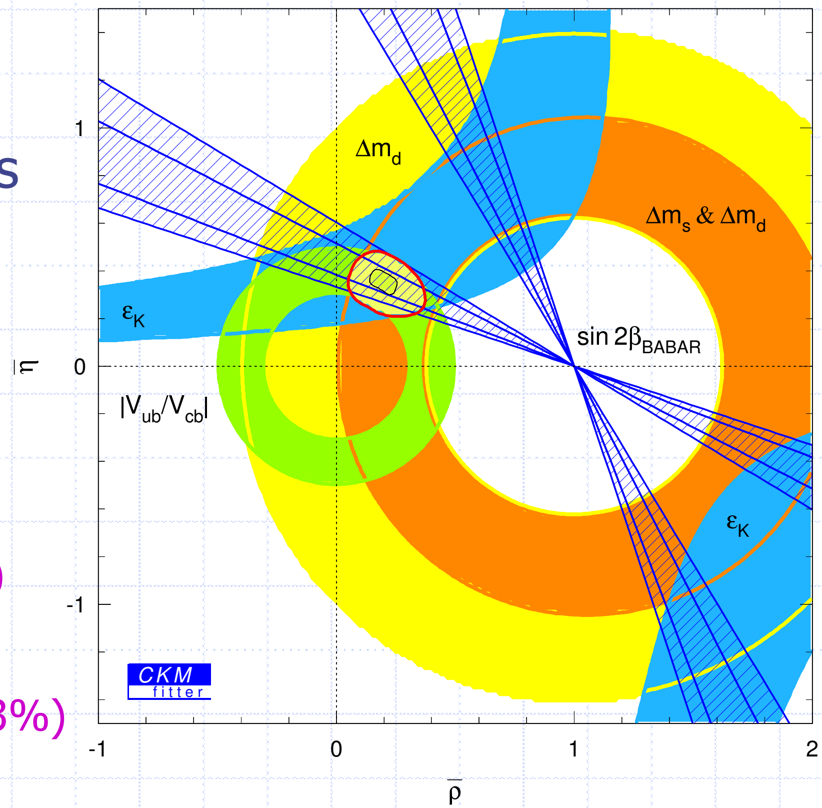
- $|V_{ub}|$ and $|V_{cb}|$ give a constraint on the Unitary Triangle.
- Different experimental approaches exploited Inclusive and Exclusive Semileptonic B decays.
- BaBar improved measurements of $|V_{cb}|$ (published soon) and $|V_{ub}|$.

$|V_{cb}| = (47.4 \pm 1.4 \pm 2.0 \pm 2.1) * 10^{-3}$ (~7%)

(CLEO exclusive – hep-ex/0203032)

$|V_{cb}| = (4.04 \pm 0.09 \pm 0.05 \pm 0.08) * 10^{-2}$ (~3%)

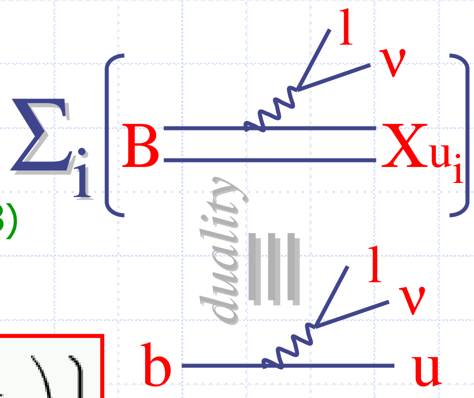
(CLEO inclusive – PRL 87, 251808 (2001))



- $|V_{ub}|$ is the CKM matrix element with biggest uncertainty.

$|V_{ub}|$ from semileptonic B decays

- $|V_{ub}|$ can be extracted from charmless semileptonic B decays.
- Calculation of the total decay rate using OPE:
  - N. Uraltsev, Int. J. Mod. Phys. A 14, 4641 (1999) [arXiv:hep-ph/9905520]
  - I.I. Bigi, R.D. Dikeman and N. Uraltsev, Eur. Phys. J. C 4, 453 (1998) [arXiv:hep-ph/9706520]

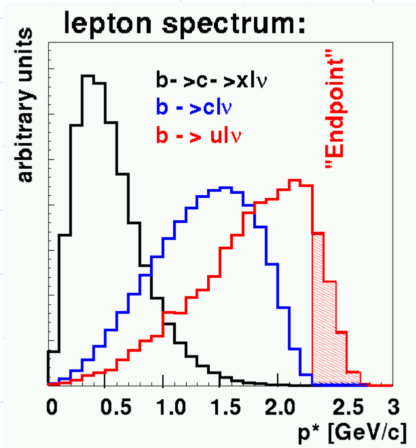


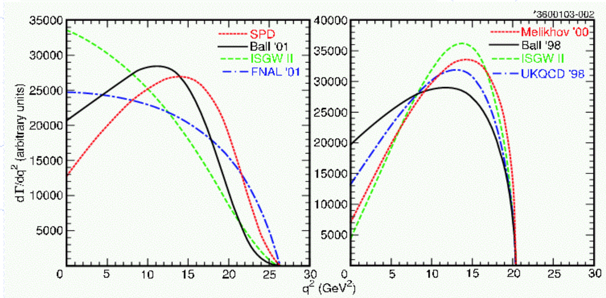
$$\Gamma_{sl}^{b\to u} = \frac{G_F^2 m_b^5}{192\pi^3}|V_{ub}|^2 \left\{ A_0 \left(1 - \frac{\mu_\pi^2 - \mu_G^2}{2m_b^2}\right) - 2\frac{\mu_G^2}{m_b^2} + O\left(\frac{1}{m_b^3}\right) \right\}$$

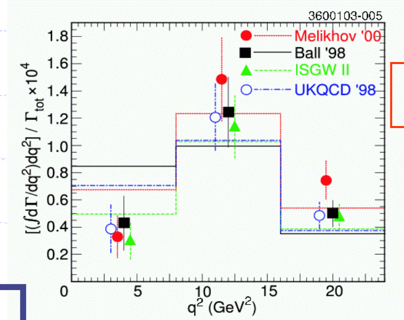
- Hadronization effects and Fermi motion must be taken into account.
- Main background is from $B\to X_c l\nu$ events ($BR(b\to cl\nu)$ = ~60 x $BR(b\to ul\nu)$), can be controlled only in limited regions of phase space (enpoint of the lepton spectrum).

Experimental approaches

- Measure the lepton
  - Basic approach for all analysis
  - Endpoint of lepton spectrum ($p^* > 2.3$ GeV)
  - 10-15% of $b \to u\, l\, \nu$ phase space accepted
  - Shape function information (e.g. from $b \to s\, \gamma$)
- Reconstruct the neutrino kinematics
  - Low experimental efficiency (~5%)
  - Higher phase space acceptance (20-30%)
  - Large background from $b \to c\, l\, \nu$ and continuum
  - Modest ν momentum resolution (σ ~0.5GeV)
  - Dependence from m_b and resonant states modeling
- Reconstruct the other B…



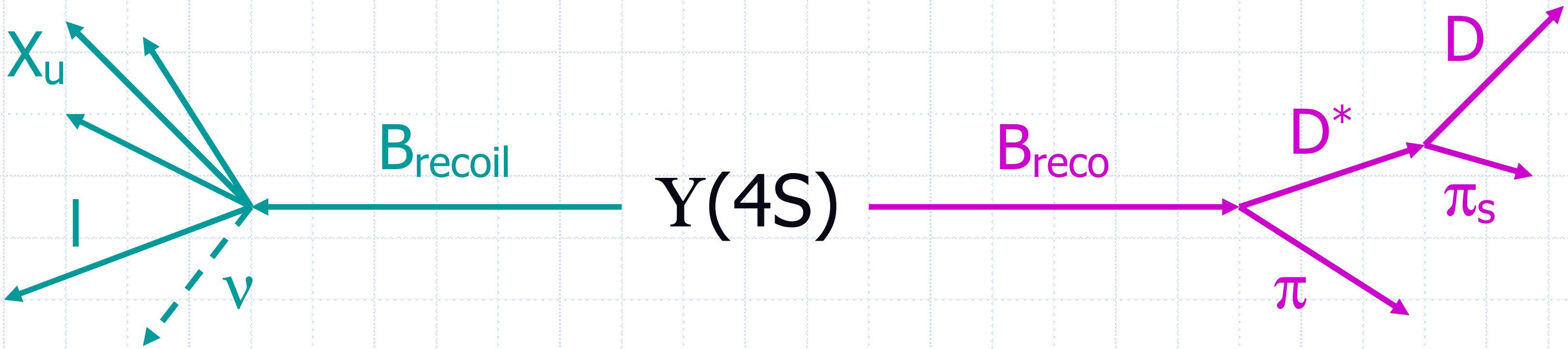




$q^2 = (p_{lep} + p_\nu)^2$

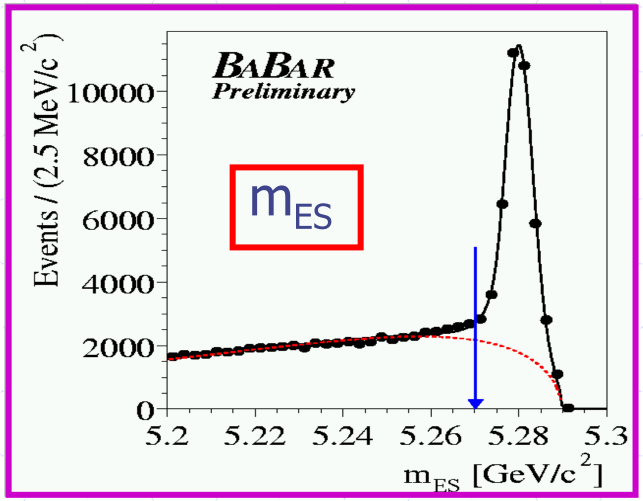
RECOIL tecnique (I)

- This analysis uses $\Upsilon(4S) \rightarrow B\bar{B}$ events in which one B meson is fully reconstructed (B_{reco}) and the semileptonic decay of the recoiling B (B_{recoil}) is identified by the presence of a high energy lepton (e or μ).
- Since there are no missing particles on the B_{reco} side, the rest of the event comes from the B_{recoil}.
- This is equivalent to having a single B beam!



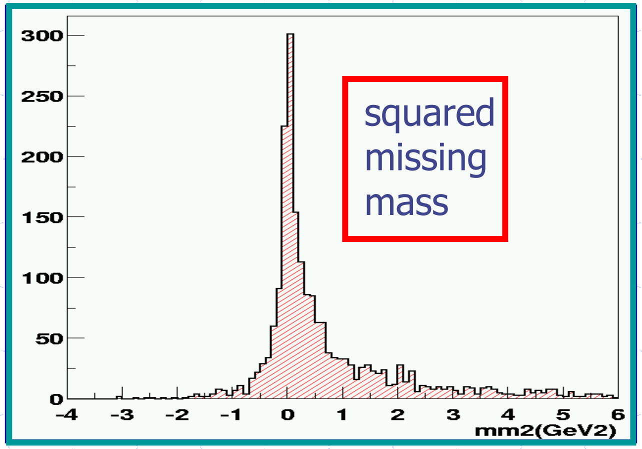
RECOIL tecnique (II)

$$m_{ES} = \sqrt{E^{*2}_{beam} - p^{*2}_{B}}$$



B_{reco}

- Clean sample with small background
- B_{reco} (B_{recoil}) flavor tagging
- Small reconstruction efficiency: ~0.4%



B_{recoil}

- M_x reconstruction
- Lepton charge – B_{reco} flavour correlation
- Missing mass can be determined

Semi-Exclusive B_{reco} reconstruction

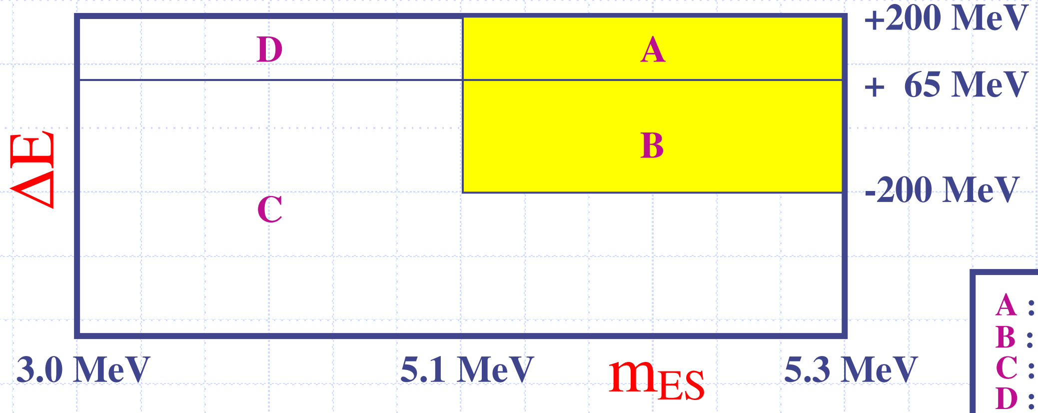
- B_{reco} mesons reconstructed with Semi-Exclusive tecnique:

  $B \rightarrow D(*)\,X$

  $X = n\pi\ mK\ pK_s\ q\pi^0$ $(n+m+p+q<6)$

mode	Branching Fraction (%)
$B \rightarrow D^{*-}X$	22.7 ± 1.6
$B \rightarrow D^{-}X$	24.1 ± 1.9
$B \rightarrow \bar{D}^{*0}X$	26.0 ± 2.7
$B \rightarrow \bar{D}X$	63.5 ± 2.9
$B \rightarrow D_s^{+}X$	10.0 ± 2.5
$B^0 \rightarrow D^{\pm(*)}l\nu$	6.7 ± 0.3
$B^- \rightarrow D^{0(*)}l\nu$	7.7 ± 0.8
$B^0 \rightarrow D^{-(*)}D^{+(*)}$	~ 0.3
$B^0 \rightarrow D^{-(*)}D^{+(*)}K$	~ 1.0
$B^0 \rightarrow D^{-(*)}D_s^{(*)}$	4.8 ± 1.0
$B^+ \rightarrow D^{0(*)}D^{+(*)}$	~ 0.3
$B^+ \rightarrow D^{0(*)}D^{+(*)}K$	~ 1.0
$B^+ \rightarrow D^{0(*)}D_s^{(*)}$	4.8 ± 1.2

- Breco candidates selected in (ΔE , m_{ES}) plane:
  - D modes reconstruted and combined with a h (π or K)
  - Added a couple h^+h^-, a π^0 or a $4h^{\pm}$ system, up to max 7 particles or two neutrals in X.



$$m_{ES} = \sqrt{E^{*2}_{beam} - p^{*2}_{B}}$$

$$\Delta E = E^*_B - E^*_{beam}$$

A : only used as a candidate
B : used as a candidate and as a seed
C : only used as a seed
D : not used

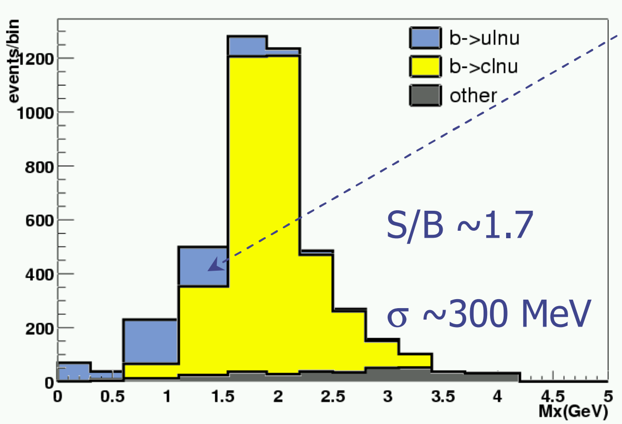
Analysis of B_{recoil}

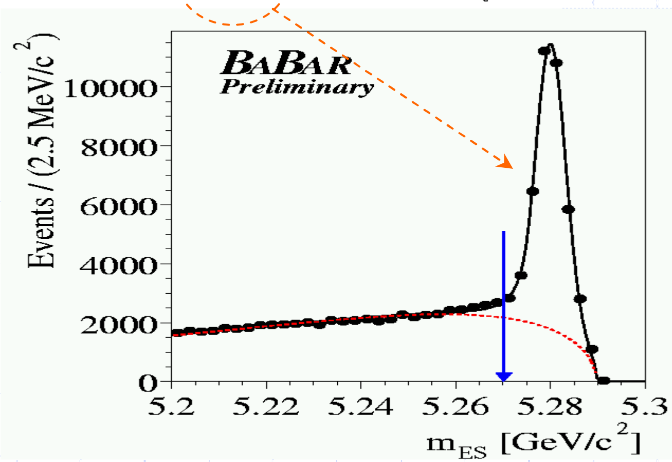
- B_{recoil} selection and reconstruction of the X system in $B \to X_u \, l \, \nu$ (in the region $M_x < 1.55$ GeV/c^2):
  - One and only one lepton with $p^* > 1$ GeV
  - Correlation between lepton charge and B_{reco} flavour (included correction for B^0 mixing)
  - $M_{miss}^2 < 0.5$ GeV^2/c^4
  - Charge conservation: $Q_{tot}=0$
  - Kinematic fit (2-C): improve hadronic mass resolution
- Separate $B \to X_u \, l \, \nu$ in two samples:
  - Signal enriched (veto on $K^{\pm}$ and K_s): used to perform the measurement
  - Signal depleted (no Kaon veto): used as control sample

Extraction of BR(b→ulν)

- Fit on the signal enhanced sample
- Components in the M_x distribution fit: **b->ulν, b->clν, background**
- Signal efficiency ($\varepsilon_{sel}^u\ \varepsilon_{Mx}^u$), B_{reco} efficiency ratio ($\varepsilon_t^u/\varepsilon_t^{sl}$) and lepton efficiency ratio ($\varepsilon_l^u/\varepsilon_l^{sl}$) from MC

$$R_{u/sl} = \frac{\mathcal{B}(B\to X_u\ell\nu)}{\mathcal{B}(B\to X\ell\nu)} = \frac{N_u^{true}}{N_{sl}^{true}} = \frac{N_u/(\varepsilon_{sel}^u \varepsilon_{M_X}^u)}{N_{sl}} \times \frac{\varepsilon_l^{sl}\varepsilon_t^{sl}}{\varepsilon_l^u \varepsilon_t^u}$$

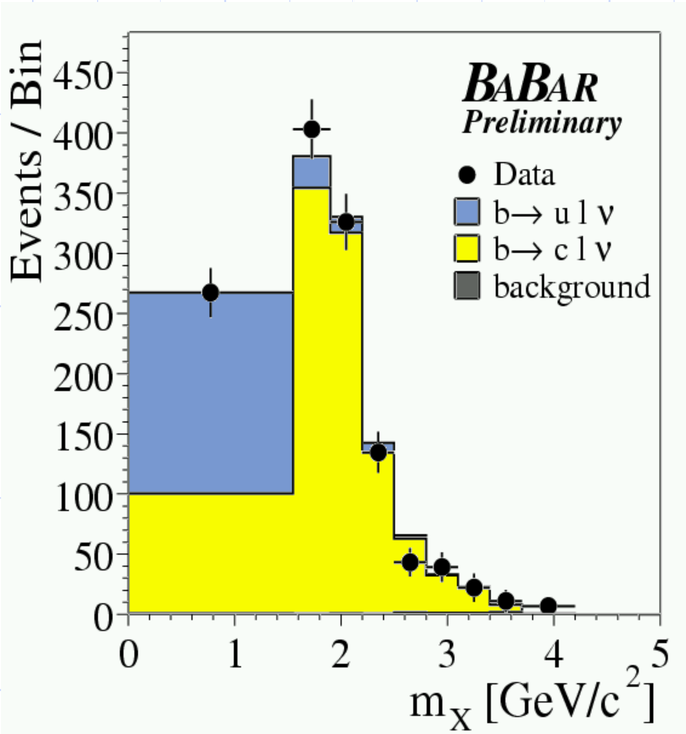


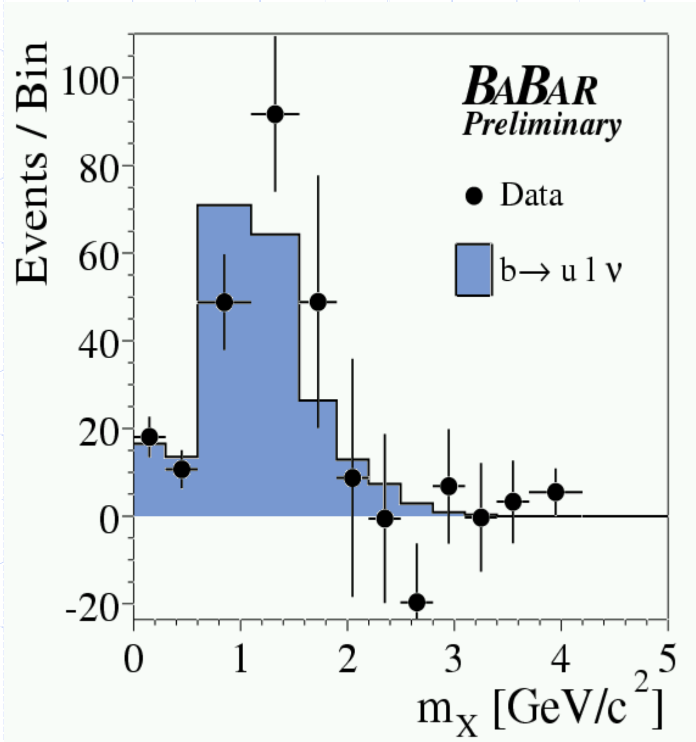


- Multiply by total semileptonic Branching Ratio measured by BaBar:

$$\mathcal{B}(B\to Xe\nu) = (10.87 \pm 0.18 \pm 0.30)\%$$

Inclusive Branching Ratio





82 fb^{-1}

$$R_{u/sl} = \frac{\mathcal{B}(B \to X_u \ell \bar{\nu})}{\mathcal{B}(B \to X \ell \bar{\nu})} = 0.0206 \pm 0.0025(stat) \pm 0.0009(MC\ stat) \pm 0.0023(syst) \pm 0.0036(theo)$$

|Vub| result

Submitted to PRL
hep-ex/0307062

- The measured charmless semileptonic branching ratio is:

$$\mathcal{B}(B \to X_u \ell \bar{\nu}) = (2.24 \pm 0.27(stat) \pm 0.26(syst) \pm 0.39(theo)$$

- |Vub| can be extracted using the relation:

τ_b = 1.608 ± 0.016 ps (PDG02)
m_b = 4.58 ± 0.09 GeV

$$|V_{ub}| = 0.00445 \left(\frac{\mathcal{B}(B \to X_u l \nu)}{0.002} \frac{1.55ps}{\tau_b} \right)^{1/2} \times (1.0 \pm 0.020_{pert} \pm 0.052_{1/m_b^3})$$

- The value for $|V_{ub}|$ from the inclusive data sample (in OPE approximation) is:

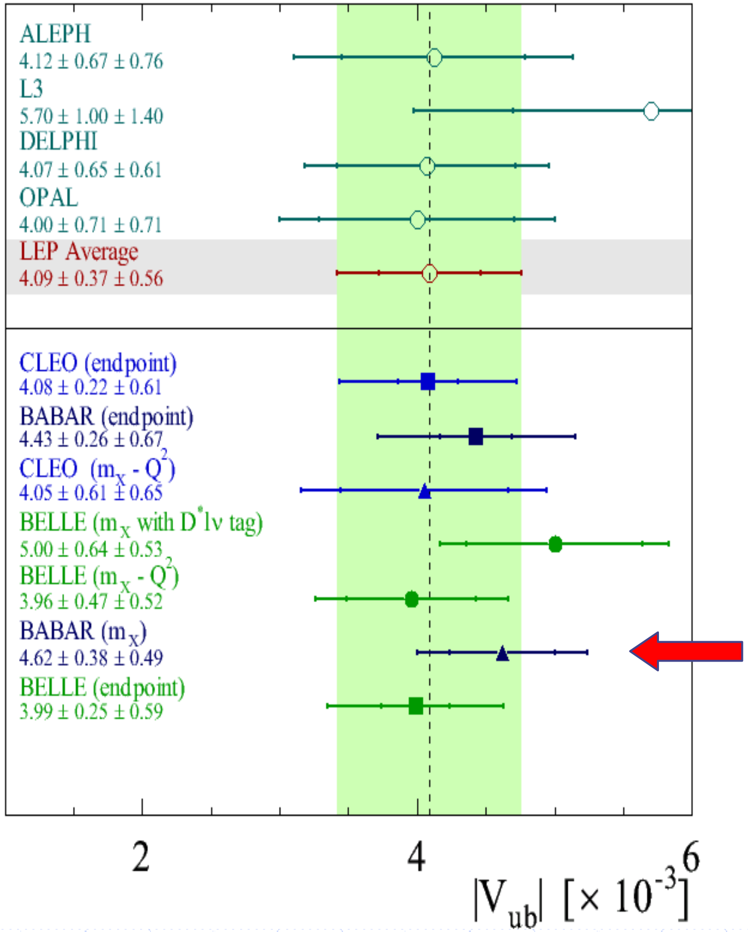
$$V_{ub}| = (4.62 \pm 0.28(stat) \pm 0.27(syst) \pm 0.40(theo) \pm 0.09(pert) \pm 0.24(1/m_b^3)) \times 10^{-3}$$

Summary of $|V_{ub}|$ measurements

- Inclusive recoil tecnique allows for a $|V_{ub}|$ measurement with relative total error better than LEP average.

- Previous BaBar $|V_{ub}|$ measurements
  - Exclusive $B \to \rho e \nu$
    (hep-ex/0301001)
    $|V_{ub}| = (3.29 \pm 0.42_{stat} \pm 0.47_{syst} \pm 0.60_{theo}) * 10^{-3}$
  - Inclusive electron spectrum endpoint
    (hep-ex/0207081)
    $|V_{ub}| = (4.43 \pm 0.29_{stat} \pm 0.25_{exp} \pm 0.50_{fu} \pm 035_{syst}) * 10^{-3}$

- BELLE new result
  - Advanced ν Reconstruction with Hadronic Tags
    (hep-ex/0311048)
    $|V_{ub}| = (4.66 \pm 0.28_{stat} \pm 0.19_{exp} \pm 0.58_{fu} \pm 035_{syst}) * 10^{-3}$

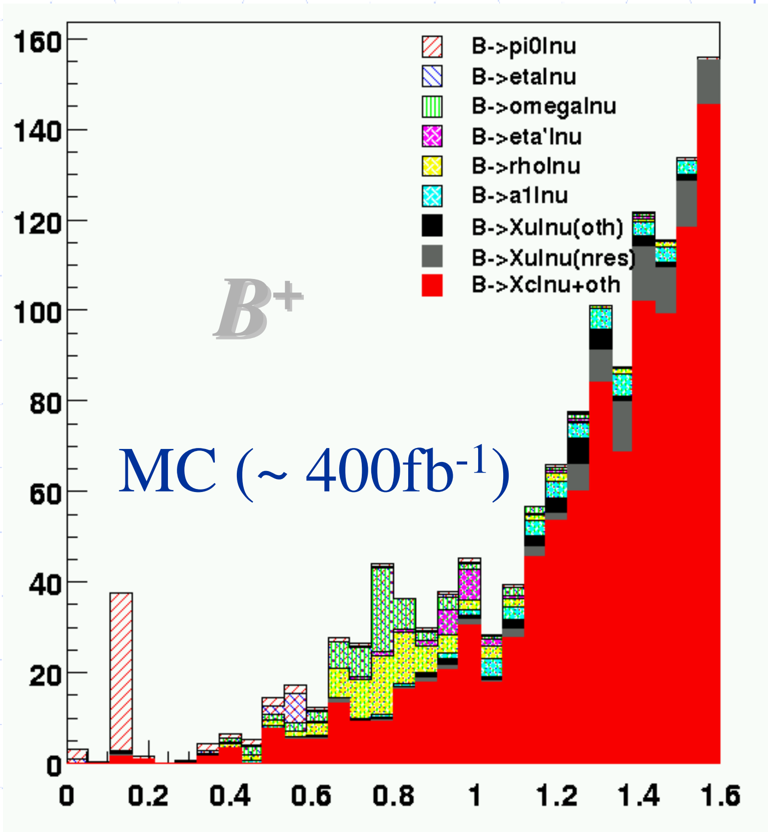


$|V_{ub}|$ from exclusive $B \to X_u\, l\, \nu$ channels

- Advantages of study of exclusive decays using Recoil Tecnique:
  - Reduced Form Factors dependence.
  - Crossfeed and continuum background highly reduced.

- Event selection and purity can be improved by dedicated cuts for each exclusive channel.

- Events are selected in M_x windows.



M_X (GeV)

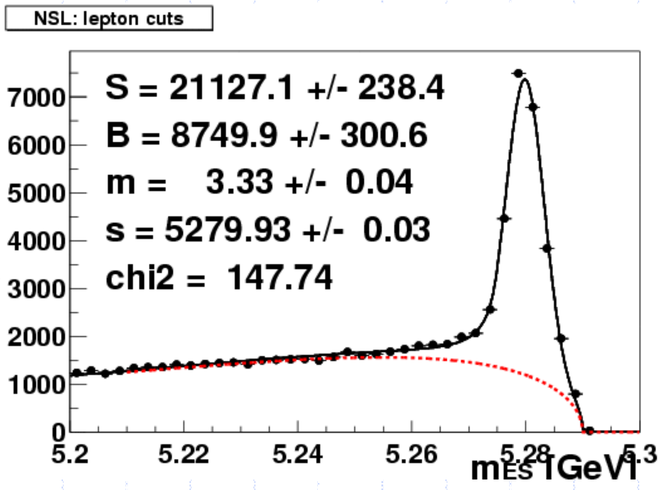
Measurement tecnique

- The observed number of events is normalized to the total number of semileptonic decays B $\rightarrow$ q l ν (q = u,c):

$$R_{x/sl} = \frac{\mathcal{B}(B^{\pm} \rightarrow \pi^0(\rho^0, \omega)\ell\nu)}{\mathcal{B}(b \rightarrow q\ell\nu)} = \frac{(N^{meas}_{excl} - BG_{excl})/\epsilon^{excl}_{sel}}{(N^{meas}_{sl} - BG_{sl})} \times \frac{\epsilon^{sl}_{l}\epsilon^{sl}_{t}}{\epsilon^{excl}_{l}\epsilon^{excl}_{t}}$$

- Additional selection criteria are imposed to each particular exclusive decay.

- The number of data events in the M_X signal region, after all analysis cuts, is obtained by an unbinned maximum likelihood fit to m_{ES}.



Fit result on data (82 fb^{-1})

Parameter	$B^{\pm} \to \pi^0 l\nu$	$B^{\pm} \to \rho^0 l\nu$	$B^{\pm} \to \omega l\nu$
N^{meas}_{excl}	7.0 ± 2.6	12.9 ± 3.6	14.5 ± 4.4
BG_{excl}	0.2 ± 0.2	2.5 ± 1.2	3.3 ± 1.4
ϵ^{excl}_{sel}	0.42 ± 0.04	0.31 ± 0.03	0.20 ± 0.02
$N^{meas}_{sl} - BG_{sl}$	19580 ± 230	19580 ± 230	19580 ± 230
$\frac{\epsilon^{sl}_{l}}{\epsilon^{excl}_{l}}$	0.92 ± 0.06	0.82 ± 0.05	0.76 ± 0.04
$\frac{\mathcal{B}(b\to\pi^0(\rho^0,\omega)\ell\nu)}{\mathcal{B}(b\to q\ell\nu)}$ $[*10^{-3}]$	$0.76 \pm 0.30_{stat}$	$1.41 \pm 0.49_{stat}$	$2.16 \pm 0.84_{stat}$

$$\frac{\mathcal{B}(B^{\pm}\to\pi^0 l\nu)}{\mathcal{B}(B^{\pm}\to X\ell\nu)} = (0.76 \pm 0.30_{stat} \pm 0.07_{MCstat})10^{-3}$$

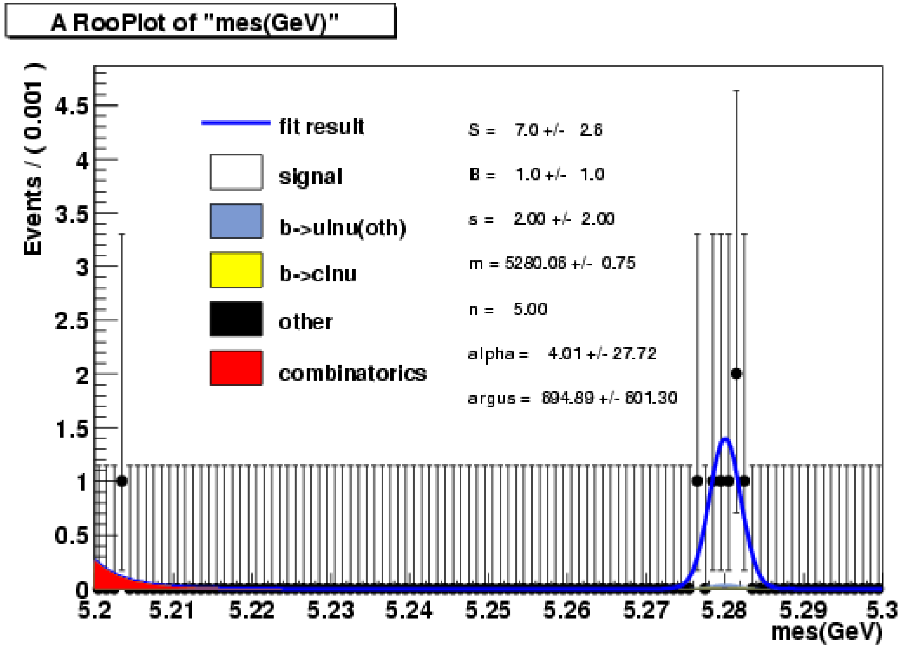
$$\frac{\mathcal{B}(B^{\pm}\to\rho^0 l\nu)}{\mathcal{B}(B^{\pm}\to X\ell\nu)} = (1.41 \pm 0.49_{stat} \pm 0.17_{MCstat})10^{-3}$$

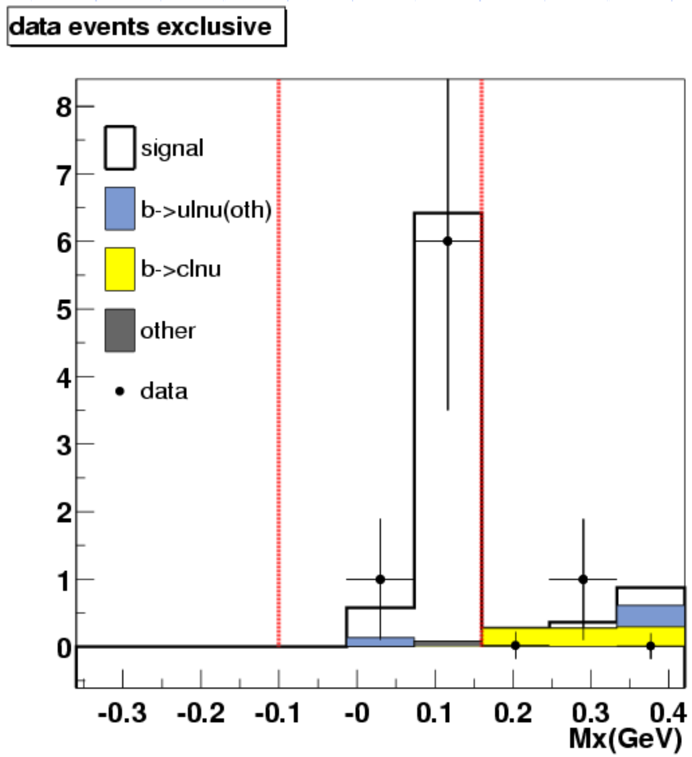
$$\frac{\mathcal{B}(B^{\pm}\to\omega l\nu)}{\mathcal{B}(B^{\pm}\to X\ell\nu)} = (2.16 \pm 0.84_{stat} \pm 0.31_{MCstat})10^{-3}$$

$B^{\pm} \rightarrow \pi^0 l\nu$

Presented at LP03

$$BR(B^{\pm} \rightarrow \pi^0 l\nu) = (0.78 \pm 0.32_{stat} \pm 0.13_{syst}) * 10^{-4}$$

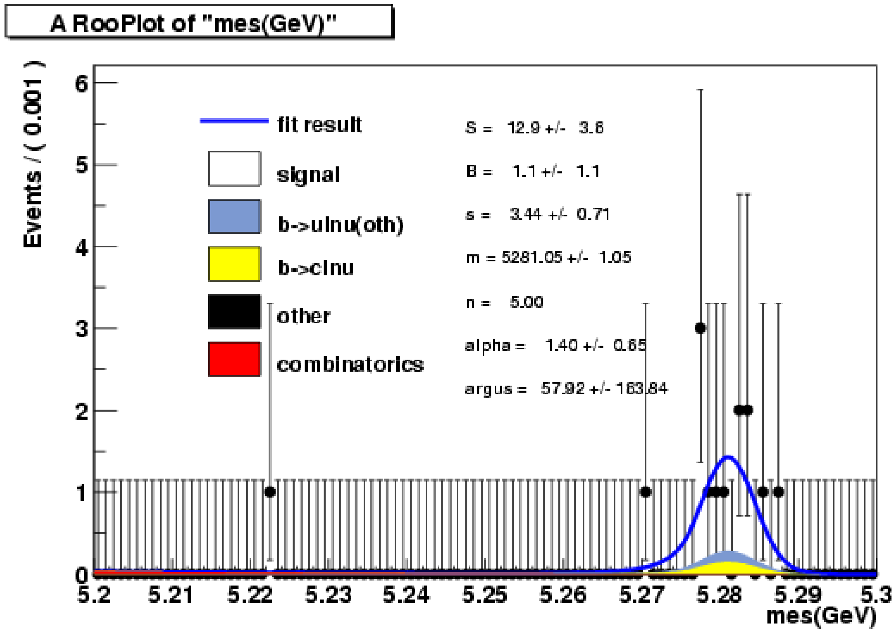


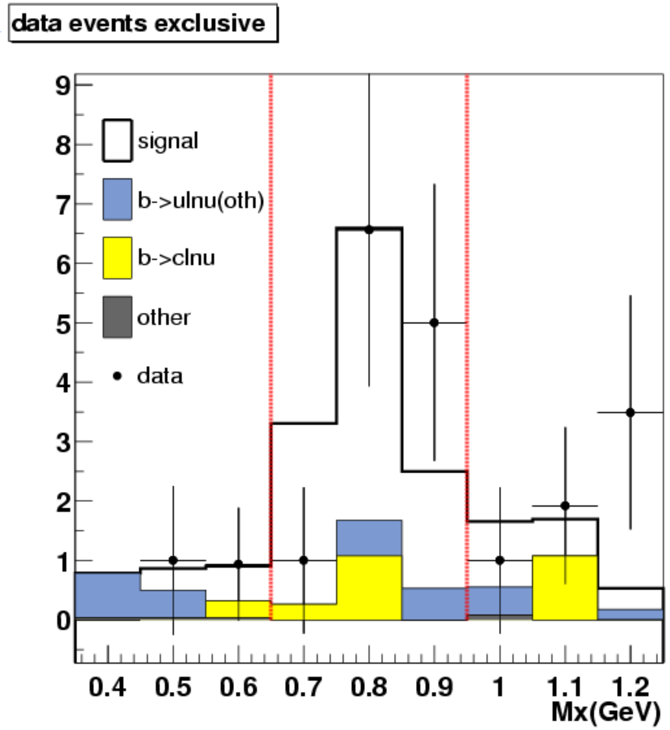


$B^{\pm} \rightarrow \rho^0 l \nu$

Presented at LP03

$$BR(B^{\pm} \rightarrow "\rho^0" l\nu) = (0.99 \pm 0.37_{stat} \pm 0.19_{syst}) * 10^{-4}$$

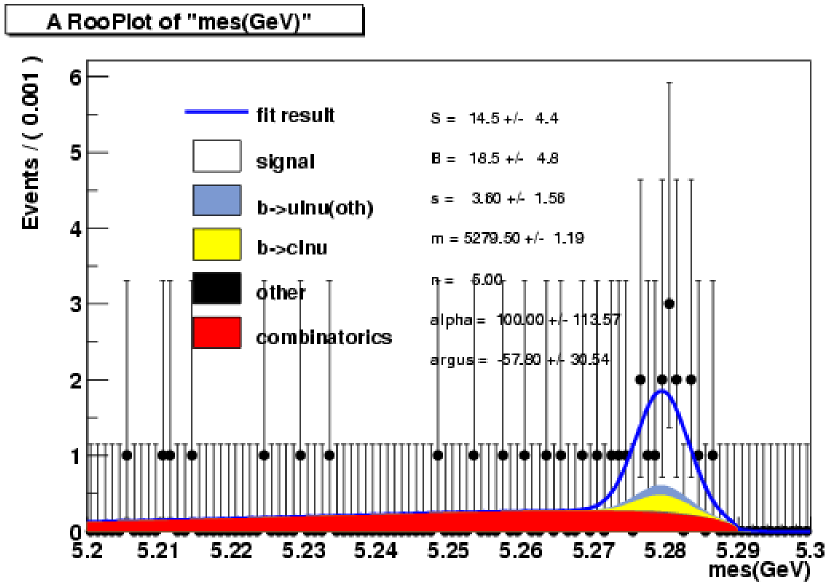


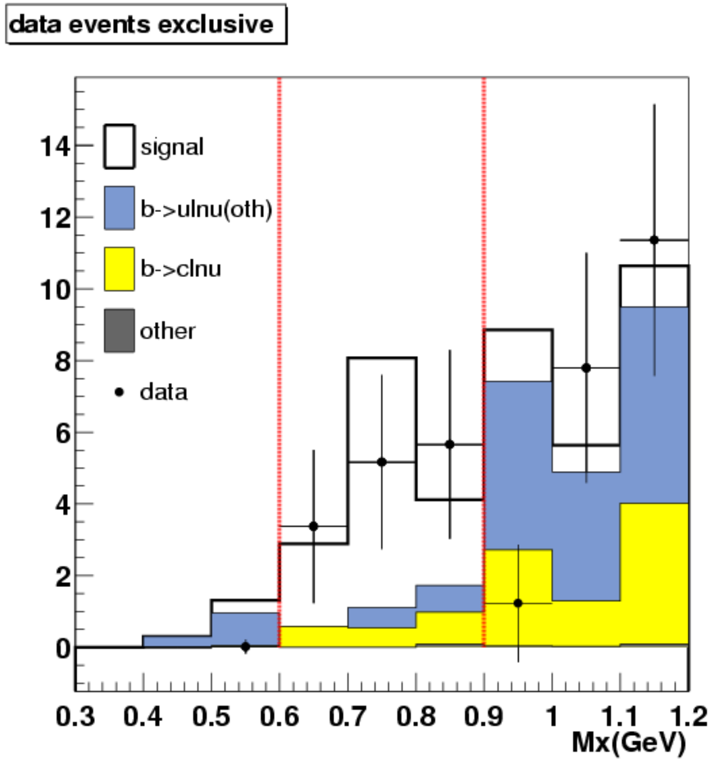


$B^{\pm} \rightarrow \omega l \nu$

Presented at LP03

$$BR(B^{\pm} \rightarrow \omega l \nu) = (2.20 \pm 0.92_{stat} \pm 0.57_{syst}) * 10^{-4}$$

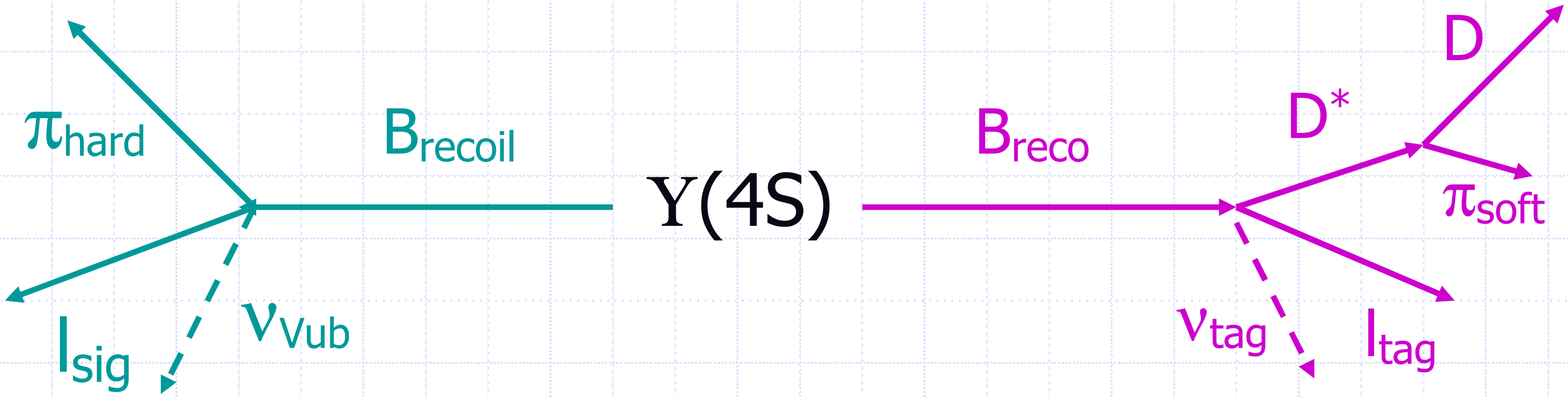




Charmless Exclusive Branching Fractions

Decay	BaBar ($*10^{-4}$)	BELLE ($*10^{-4}$)	CLEO ($*10^{-4}$)
$B^0 \rightarrow \pi^- l^+ \nu$	-	$1.89 \pm 0.15 \pm 0.30$ (2003 - ν Reconstruction)	$1.33 \pm 0.18 \pm 0.13$ (2003 - ν Reconstruction)
$B^+ \rightarrow \pi^0 l^+ \nu$	$0.78 \pm 0.32 \pm 0.13$ (2003 – Recoil)	-	-
$B^0 \rightarrow \rho^- l^+ \nu$	$3.29 \pm 0.42 \pm 0.79$ (2003 - e^- endpoint)	-	$2.17 \pm 0.34 \pm 0.68$ (2003 - ν Reconstruction)
$B^+ \rightarrow \rho^0 l^+ \nu$	$0.99 \pm 0.37 \pm 0.19$ (2003 – Recoil)	$1.44 \pm 0.18 \pm 0.23$ (2002 - ν Reconstruction)	-
$B^+ \rightarrow \omega\, l^+ \nu$	$2.20 \pm 0.92 \pm 0.57$ (2003 – Recoil)	$1.4 \pm 0.4 \pm 0.3$ (2003 - ν Reconstruction)	-
$B^+ \rightarrow \eta\, l^+ \nu$	-	-	$0.85 \pm 0.31 \pm 0.18$ (2002 - ν Reconstruction)
Other Light Mesons ($\eta', a_0, a_1, b_1, f_0, f_1, h_1, \ldots$)	-	-	-

A new method: Partial Reconstruction



- Using a double semileptonic decay with partial reconstruction on B_{reco} side can help improving statistics without increasing background too much.
- This tecnique has been already used in BaBar for $|V_{cb}|$ and B lifetime measurements, using the B_{reco} side as signal side (look @ hep-ex/0308027)
- B_{reco} Side: $\pi_{soft} + l_{tag}$ (partial reconstruction)
- B_{recoil} Side: $\pi_{hard} + l_{sig}$
- Two unseen neutrinos and no D reconstruction (to improve efficiency).
- For signal events all remaining tracks come from D decay, for background events further tracks and clusters are expected.

Conclusions

- Semi-Exclusive reconstruction and recoil tecnique allowed for a precise inclusive measurement of |Vub|.
- Similar tecnique used for exclusive semileptonic decays gives:

$$\begin{cases} \mathcal{B}(B^+ \to \pi^0 l^+ \nu) = (0.78 \pm 0.32_{stat} \pm 0.13_{syst}) \cdot 10^{-4} \\ \mathcal{B}(B^+ \to "\rho^0" l^+ \nu) = (0.99 \pm 0.37_{stat} \pm 0.19_{syst}) \cdot 10^{-4} \\ \mathcal{B}(B^+ \to \omega l^+ \nu) = (2.20 \pm 0.92_{stat} \pm 0.57_{syst}) \cdot 10^{-4} \end{cases}$$

- Measurements with small number of events but low systematics.
- Increasing luminosity and new theoretical effort can help improving these measurements.
- New tecniques (e.g. B_{reco} Partial Reconstruction) also look promising.

Torino Group future tasks

- Update of $B^+ \to (\pi^0, \rho^0, \omega)\ l^+ \nu$ Branching Fractions (with increased luminosity and new theoretical results) expected for summer conferences.
- Study of missing exclusive channels (B^0 and B^+).
- Exploitation of alternative approaches to improve signal efficiency.
- Exclusive measurement of $|V_{ub}|$ (end of 2004?)

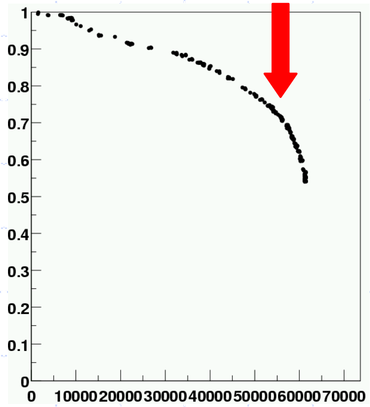
Backup Slides

Selection of B_{reco} candidates

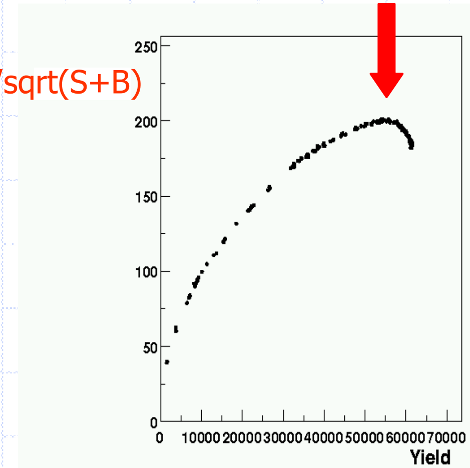
- The selection of the best B_{reco} relies on:
  - reconstructing all possible $B \rightarrow D(*)X$ decay modes
  - resolving the multiple candidates
  - assigning the candidate to the submode with the highest priority (purity and yields)

82 fb^{-1}

purity



S/sqrt(S+B)

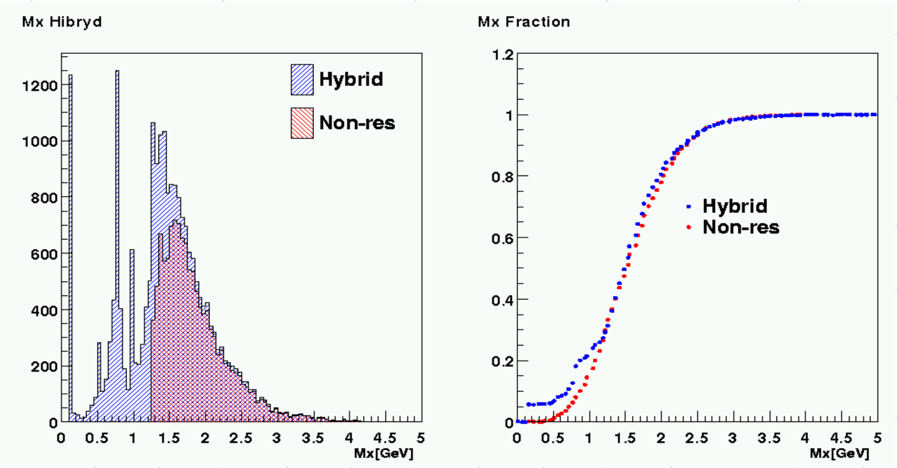


Channel	final pur.> 80%	final pur.> 50%	single mode pur.> 10%	**final selection** (5.4.2)
$B^+ \to D^0 X$	19120 ± 170	54120 ± 370	95204 ± 660	100650 ± 640
$B^0 \to D^+ X$	11070 ± 130	25720 ± 260	55830 ± 480	62960 ± 550
$B^+ \to D^{*0} X$	18600 ± 170	44270 ± 330	75350 ± 580	82660 ± 640
$B^0 \to D^{*+} X$	20670 ± 170	50300 ± 340	55560 ± 390	46380 ± 310
Total B^+	37720 ± 240	98390 ± 500	170560 ± 880	183310 ± 905
Total B^0	31740 ± 210	76020 ± 430	111390 ± 620	109340 ± 630
Total	69460 ± 320	174410 ± 660	281950 ± 1080	292650 ± 1100

Signal MC generation (I)

- Three kinds of signal MC are used for $B \rightarrow X_u l \nu$:

- resonant: contains exclusive $B \rightarrow X_u l \nu$ decays according to measured values and theoretical expectations (ISGW2 model, look @ PRD, 52, 1995 (2783))
- non resonant: the final state hadron is produced with a continuous invariant mass spectrum (above $2m_\pi$) and takes into account the Fermi motion of the quark b inside the B meson (Neubert and De Fazio, JHEP 9906:17 (1999))
- hybrid: mixes the previous ones in agreement with the measured fraction of resonant and non resonant events below a given Mx threshold.

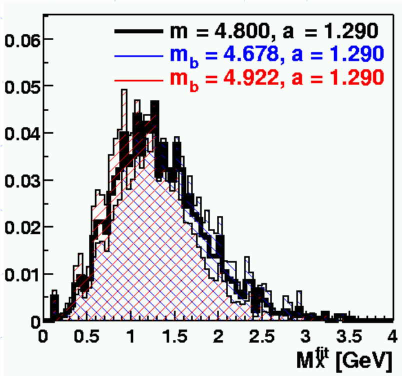


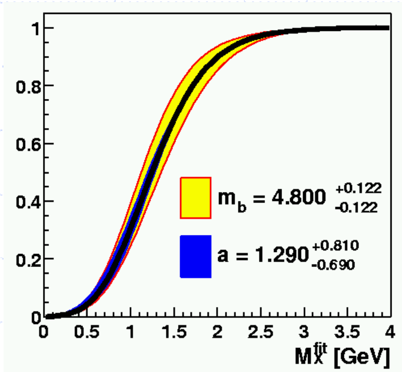
Signal MC generation (II)

mode	BR	hadron mass [GeV]	mode	BR	hadron mass [GeV]
$B^0 \to \pi^- \ell^+ \nu$	$180 \cdot 10^{-6}$	0.13498	$B^+ \to \pi^0 \ell^+ \nu$	$90 \cdot 10^{-6}$	0.13957
			$B^+ \to \eta \ell^+ \nu$	$30 \cdot 10^{-6}$	0.54730
$B^0 \to \rho^- \ell^+ \nu$	$260 \cdot 10^{-6}$	0.7685	$B^+ \to \rho^0 \ell^+ \nu$	$130 \cdot 10^{-6}$	0.7685
			$B^+ \to \omega \ell^+ \nu$	$130 \cdot 10^{-6}$	0.78257
			$B^+ \to \eta' \ell^+ \nu$	$60 \cdot 10^{-6}$	0.95777
$B^0 \to a_0^- \ell^+ \nu$	$14 \cdot 10^{-6}$	0.9835	$B^+ \to a_0^0 \ell^+ \nu$	$7 \cdot 10^{-6}$	0.9835
$B^0 \to a_1^- \ell^+ \nu$	$165 \cdot 10^{-6}$	1.23	$B^+ \to a_1^0 \ell^+ \nu$	$82 \cdot 10^{-6}$	1.23
$B^0 \to a_2^- \ell^+ \nu$	$14 \cdot 10^{-6}$	1.318	$B^+ \to a_2^0 \ell^+ \nu$	$7 \cdot 10^{-6}$	1.318
$B^0 \to b_1^- \ell^+ \nu$	$102 \cdot 10^{-6}$	1.231	$B^+ \to b_1^0 \ell^+ \nu$	$48 \cdot 10^{-6}$	1.231
			$B^+ \to f_0^0 \ell^+ \nu$	$4 \cdot 10^{-6}$	1.000
			$B^+ \to f_0'^0 \ell^+ \nu$	$4 \cdot 10^{-6}$	1.4
			$B^+ \to f_1^0 \ell^+ \nu$	$41 \cdot 10^{-6}$	1.2822
			$B^+ \to f_1'^0 \ell^+ \nu$	$41 \cdot 10^{-6}$	1.4268
			$B^+ \to f_2^0 \ell^+ \nu$	$4 \cdot 10^{-6}$	1.275
			$B^+ \to f_2'^0 \ell^+ \nu$	$4 \cdot 10^{-6}$	1.525
			$B^+ \to h_1^0 \ell^+ \nu$	$24 \cdot 10^{-6}$	1.17
			$B^+ \to h_1'^0 \ell^+ \nu$	$24 \cdot 10^{-6}$	1.40
exclusive	$735 \cdot 10^{-6}$		exclusive	$730 \cdot 10^{-6}$	
inclusive	$616 \cdot 10^{-6}$		inclusive	$616 \cdot 10^{-6}$	
total	$1351 \cdot 10^{-6}$		**total**	$1346 \cdot 10^{-6}$	

Systematic uncertainties

- The Fermi motion of the b quark inside the b meson affects the Mx distribution and the efficiency of the Mx cut.

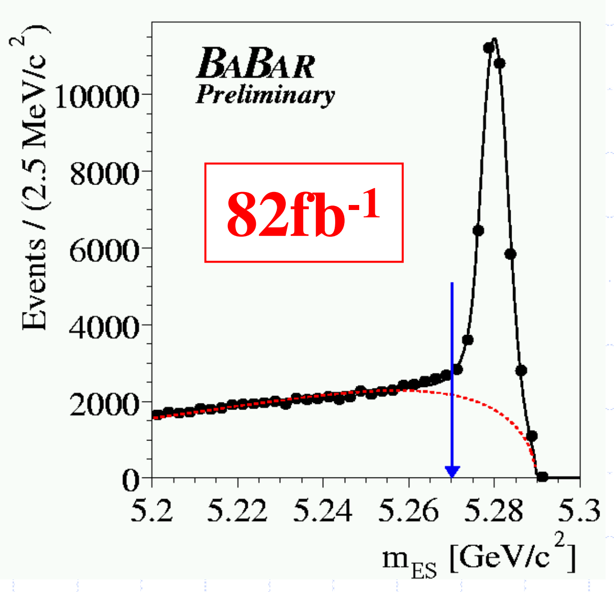




Source	$\Delta R_{u/sl}/R_{u/sl}$ [%]
Data statistics	12.7
MC statistics	4.5
Electron identification	1.0
Muon identification	1.0
$K^{\pm}$ identification	2.3
Tracking efficiency	1.0
Photon resolution	4.7
K_L interactions	1.0
B_{reco} composition, background subtraction	3.8
Binning effects	1.2
$\varepsilon_t^{sl}/\varepsilon_t^{u}$	3.0
Detector systematic error	8.7
$B \to D^{(*,**)} l\bar{\nu} X$ branching fractions	4.0
D branching fractions	1.8
Modeling of $B \to X_c \ell\bar{\nu}$ and $X_c \to Y \ell\bar{\nu}$	4.4
Excl. $b \to u l \nu$ branching fractions	2.7
Incl. $b \to u l \nu$ branching fractions	0.8
Hadronization error	3.0
$s\bar{s}$ popping	3.7
Modeling of $B \to X_u \ell\bar{\nu}$	5.5
m_b dependence	16.0[a]
λ_1 dependence	6.0
Total theoretical error	17.5

Expected yields from MC

- Same tecnique of inclusive analysis.
- Fitted hadronic mass and charged tracks multiplicity are used to separate resonances.
- Using MC estimation, ~170 $B \to X_u l\nu$ events are expected in 82 fb^{-1} of data after all cuts, for M_X<1.55GeV.



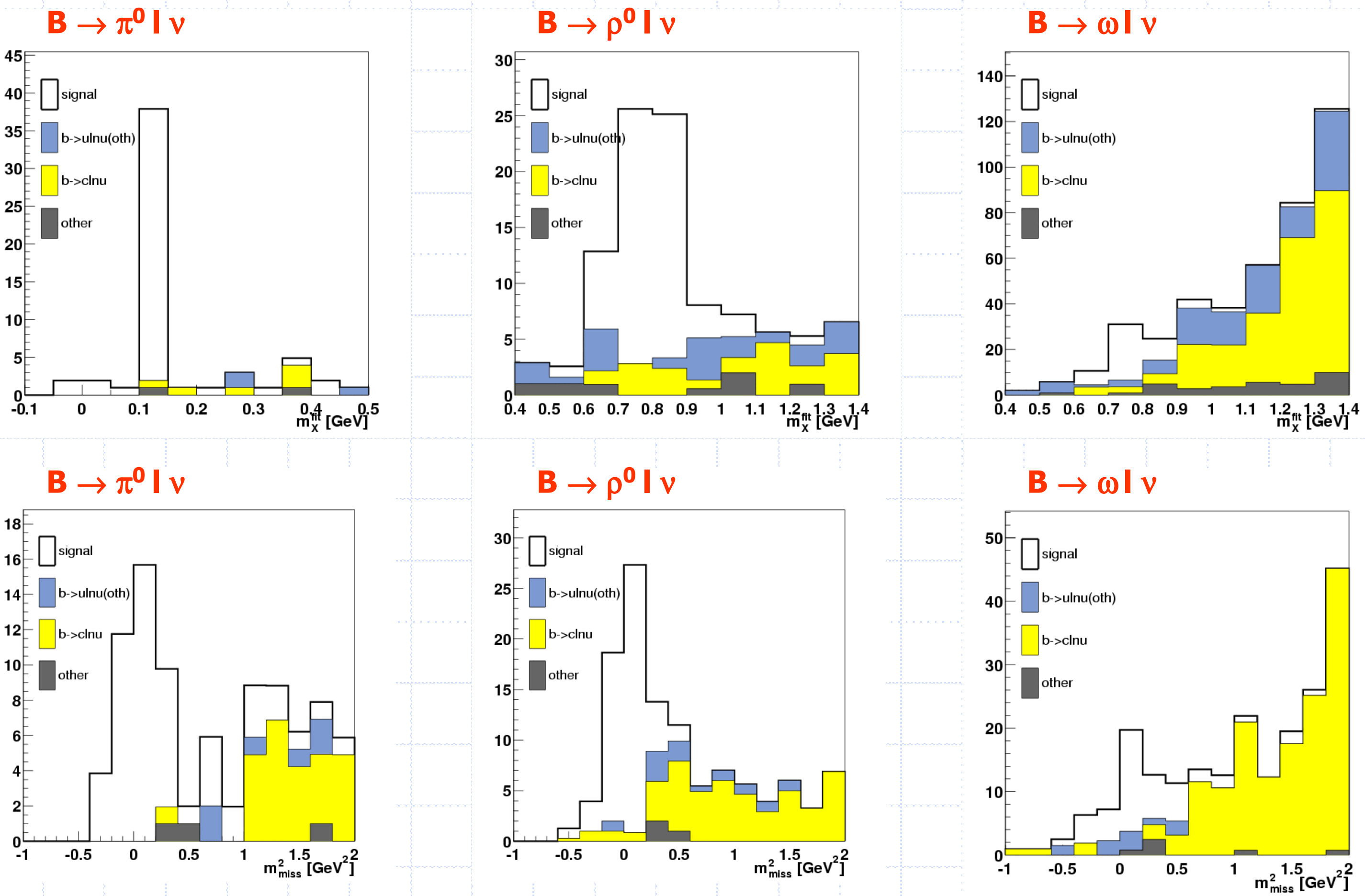
N_{SL}= 32K $B \to X l\nu$ events in data (20.5K B^+,11.5K B^0)

$$N_{B\to\pi^0(\rho,\omega)\ell\nu} \simeq N_{sl}\frac{\mathcal{B}(B\to\pi^0(\rho,\omega)\ell\nu)}{\mathcal{B}(B^\pm\to X\ell\nu)} \simeq 20K\frac{\mathcal{B}(B\to\pi^0(\rho,\omega)\ell\nu)}{0.102}$$

17 $B^+\to\pi^0 l\nu$
25 $B^+\to\rho^0 l\nu$
25 $B^+\to\omega l\nu$
15 $B^+\to a_1 l\nu$

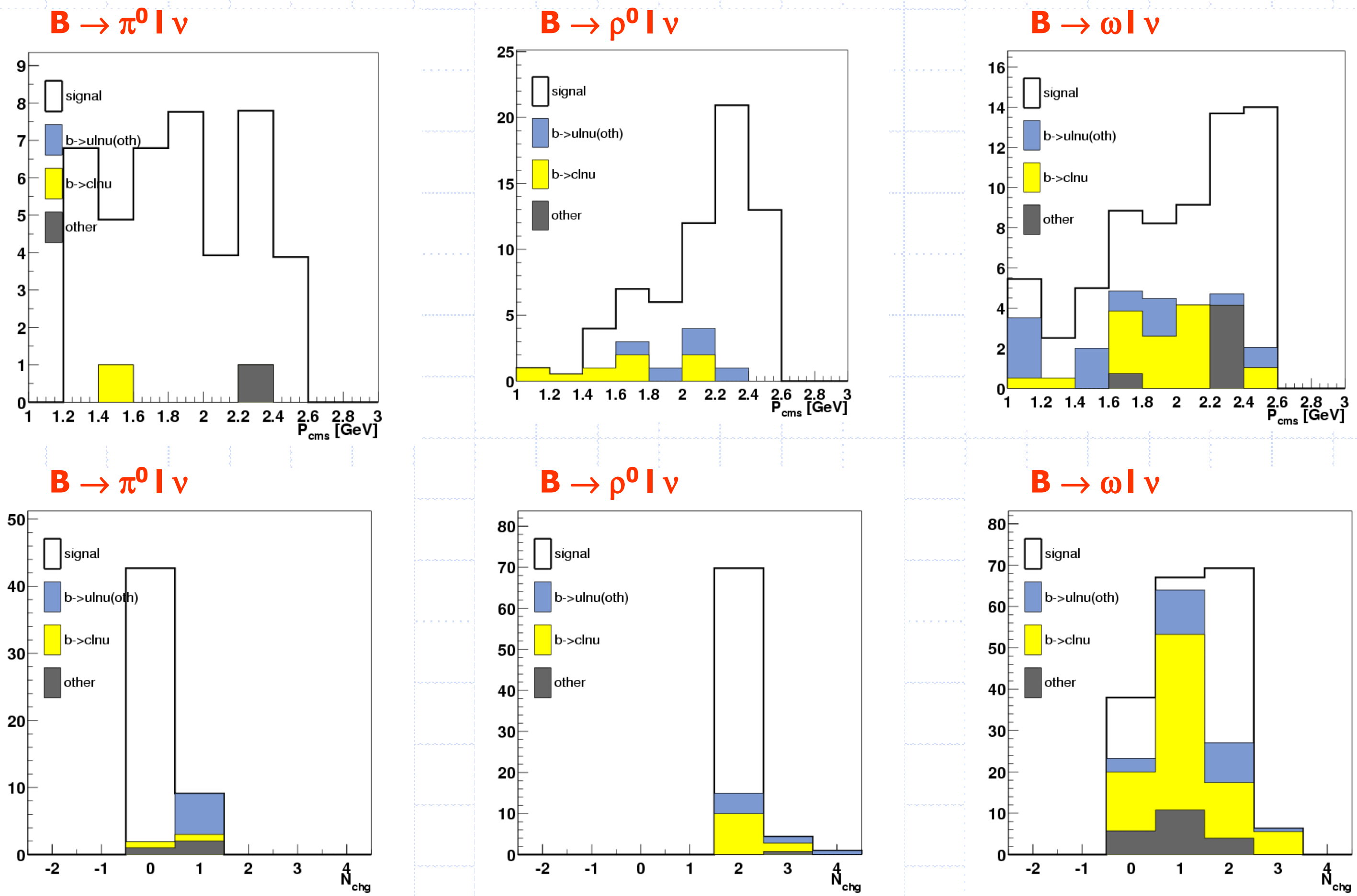
19 $B^0\to\pi^+ l\nu$
27 $B^0\to\rho^+ l\nu$
17 $B^0\to a_1 l\nu$

M_X & M_{miss}^2 for $B^{\pm} \rightarrow (\pi^0,\rho^0,\omega)l\upsilon$



MC
$\sim$240 fb^{-1}

p_l^* & N_{tracks} for $B^\pm \rightarrow (\pi^0, \rho^0, \omega) l \upsilon$



MC
~240 fb⁻¹

Event selection

- Selection cuts are optimized in order to maximize statistical significance:

Selection Criteria	$B \to \pi^0 l \nu$	$B \to \rho^0 l \nu$	$B \to \omega l \nu$	$B \to q l \nu$
B_{reco} candidate	purity cuts	purity cuts	purity cuts	purity cuts
Min. lept. momentum	$p^* > 1.0\ GeV$	$p^* > 1.0\ GeV$	$p^* > 1.0\ GeV$	$p^* > 1.0\ GeV$
Number of leptons	$N_{lepton} = 1$	$N_{lepton} = 1$	$N_{lepton} = 1$	$N_{lepton} > 0$
Lept. Charge - B Flav.	$Q_{b(recoil)} Q_\ell > 0$	$Q_{b(recoil)} Q_\ell > 0$	$Q_{b(recoil)} Q_\ell > 0$	$Q_{b(recoil)} Q_\ell > 0$
Total charge	$Q_{tot} = 0$	$Q_{tot} = 0$	$Q_{tot} = 0$	-
Missing mass sq.	$M^2_{miss} < 0.4\ GeV^2$	$M^2_{miss} < 0.3\ GeV^2$	$M^2_{miss} < 0.6\ GeV^2$	-
Kaon Veto	$N_{K^\pm} + N_{K_S} = 0$	$N_{K^\pm} + N_{K_S} = 0$	$N_{K^\pm} + N_{K_S} = 0$	-
N charged tracks	$N_{chg} = 0$	$N_{chg} = 2$	$N_{chg} = 2$	-
$m_{X\ fit} - m_{X\ chg}$	-	$\Delta M_{chg} < 0.1 GeV$	$\Delta M_{chg} > 0.1 GeV$	-
Lower m_X Cut	$m_X > -0.1$ GeV	$m_X > 0.65$ GeV	$m_X > 0.6$ GeV	-
Upper m_X Cut	$m_X < 0.16$ GeV	$m_X < 0.95$ GeV	$m_X < 0.9$ GeV	-

- "ρ^0" is defined as $\pi^+\pi^-$ in the mass window $0.65 < m_{\pi^+\pi^-} < 0.95$ GeV

Sistematic uncertainties

	Relative Uncertainty on $R_{x/sl}(\%)$		
	$B^{\pm} \to \pi^0 l\nu$	$B^{\pm} \to$ "ρ^0" $l\nu$	$B^{\pm} \to \omega l\nu$
electron id	1.3	4.0	2.5
muon id	0.5	1.3	0.3
$K^{\pm}$ id	0.0	0.3	3.0
tracking efficiency	0.8	4.8	4.4
photon resolution	7.5	5.2	4.1
m_{ES} fit	8.5	11.0	3.7
cross-feed $B^0 \to B^+$	1.5	1.8	2.4
$\epsilon_t^{sl}/\epsilon_t^u$	8.0	8.0	8.0
lepton momentum cut	2.0	4.0	4.0
$B \to Dl\nu X$ and D BRs	0.0	1.0	1.4
$b \to ul\nu$ resonant	0.5	3.2	5.8
$b \to ul\nu$ non-resonant	0.5	6.8	16.4
Total error	14.2	17.1	24.5