

Decadimenti semileptonici del B e misura di $|V_{ub}|$

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Outline

- Motivazioni fisiche per la misura di $|V_{ub}|$
- Tecniche sperimentali
- Misure inclusive
- Misure esclusive
- Conclusioni

$|V_{ub}|$ e triangolo di unitarietà

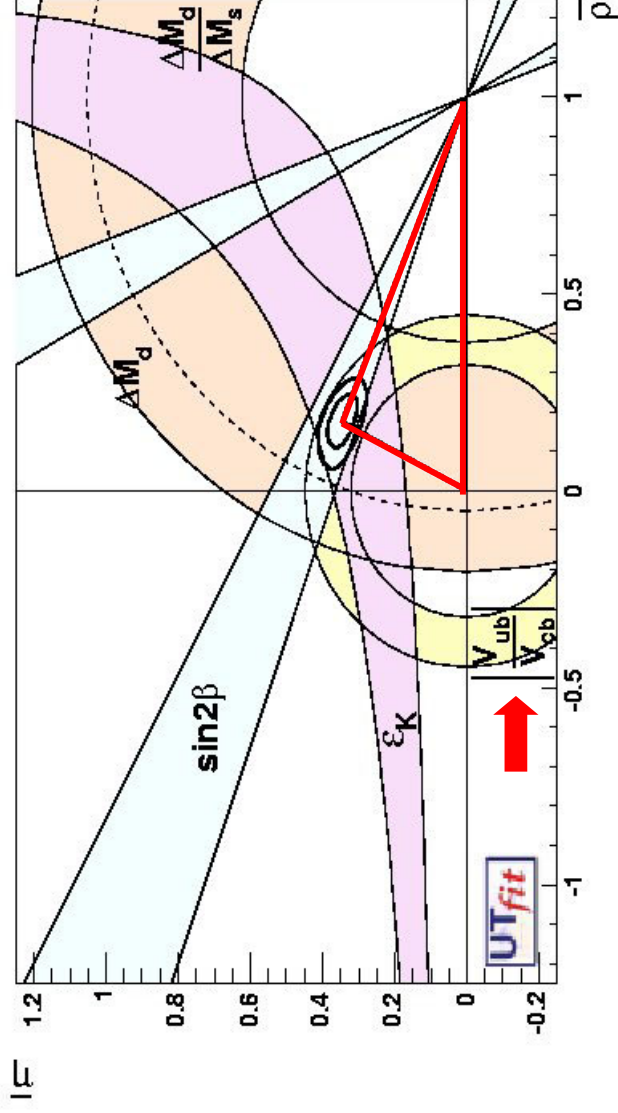
- Matrice di Cabibbo-Kobayashi-Maskawa (mixing dei quark):

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

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

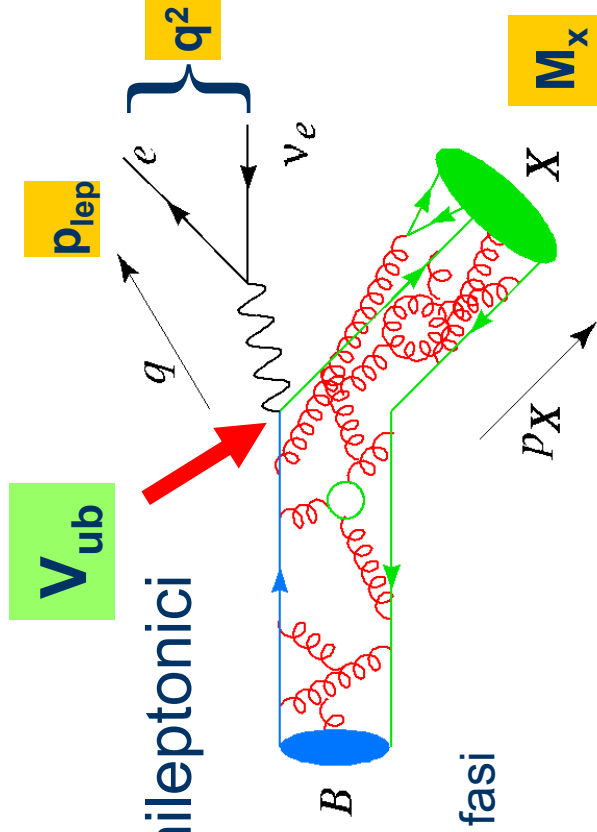
- $|V_{ub}|$ pone dei vincoli sul vertice del Triangolo Unitario.

- HFAG 2004:
 $\sigma(|V_{cb}|) / |V_{cb}| \sim 5\%$
- Misura precisa di $|V_{ub}|$ cruciale per testare il Modello Standard.



$|V_{ub}|$ dai canali semileptonici

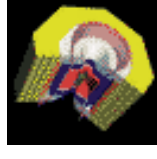
- Estrazione diretta di $|V_{ub}|$ dai decadimenti semileptonici senza *charm* del mesone B
- Fondo dominante da eventi semileptonici contenenti *charm*



$$BR(b \rightarrow c | \nu) \cong 60 * BR(b \rightarrow u | \nu)$$

- studiare regioni limitate dello spazio delle fasi

- Diversi approcci sperimentali
 - endpoint dello spettro del leptone (BaBar, BELLE, CLEO)
 - ricostruzione cinematica del neutrino (BELLE, CLEO)
 - tecnica del rinculo (BaBar)



Misure inclusive di $|V_{ub}|$

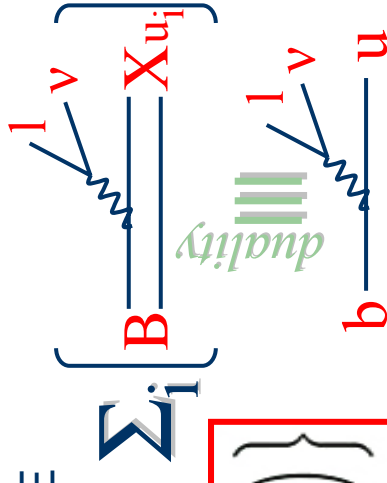
Estrazione di $|V_{ub}|$ da $BR(b \rightarrow u l \nu)$

- Estrazione di $|V_{ub}|$ dal BR semileptonico inclusivo charmless:

- ampiezza totale di decadimento predetta da HQET e OPE

Uraltsev, Int. J. Mod. Phys. A14:4641 (1999)

Bigi, Dikeman, Uraltsev, Eur. Phys. J. C4:453 (1998)



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

- sviluppo in potenze di $1/m_b$ e operatori locali relativi alle proprietà del quark b: μ_π^2 (energia cinetica) e μ_G^2 (accoppiamento cromomagnetico con spin gluone)

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

Uraltsev, Hoang,
Ligeti, Manohar
CKM 2002

- incertezze teoriche da adronizzazione, assunzione dualismo quark-adroni, massa del quark b, moto di Fermi del b nel mesone B

Misure inclusive: ENDPOINT (1)

● Endpoint dello spettro del leptone

$$\sigma(|V_{ub}|) / |V_{ub}| \sim 15 \%$$

- limite cinematico per eventi con *charm* ($p_{lep}^* > 2.3 \text{ GeV}$)
- estrazione eventi di segnale in intervallo di momento Δp
- *shape function* (da HQET) descrive proprietà del quark b dentro il mesone B
- stessa *shape function* (al 1° ordine) per tutte le transizioni del b in quark leggeri
- frazione $f_u(\Delta p)$ dello spettro di p_{lep}^* contenuta in Δp derivata dallo spettro di energia del fotone in $B \rightarrow X_s \gamma$

$$f_u(\Delta p) \sim 7.4 \% \quad (2.3 < p_{lep}^* < 2.6 \text{ GeV})$$

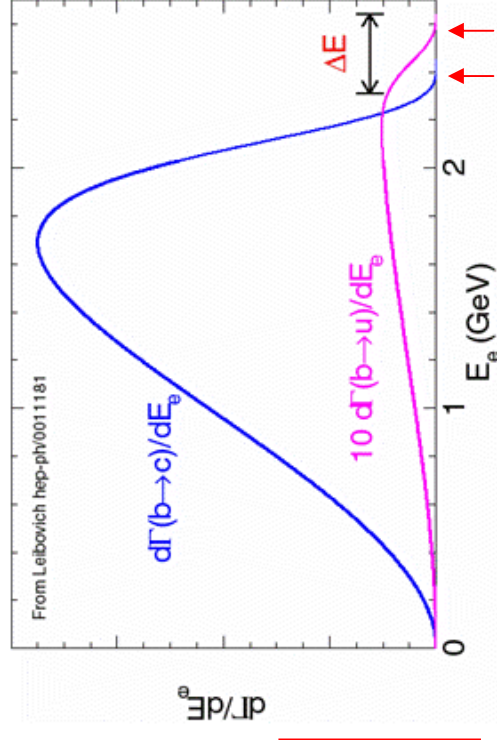
CLEO, PRL 88: 231803,2002

- estrapolazione al BR totale:

$$\mathcal{B}(B \rightarrow X_u e \nu_e) = \frac{\Delta \mathcal{B}(B \rightarrow X_u e \nu_e)(2.3 < \frac{p_{CM}^e}{\text{GeV}/c} < 2.6)}{f_u}$$

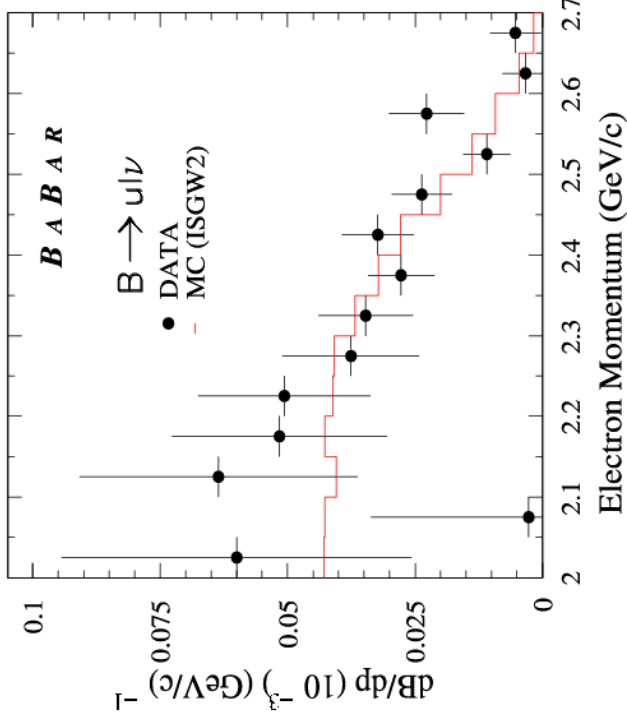
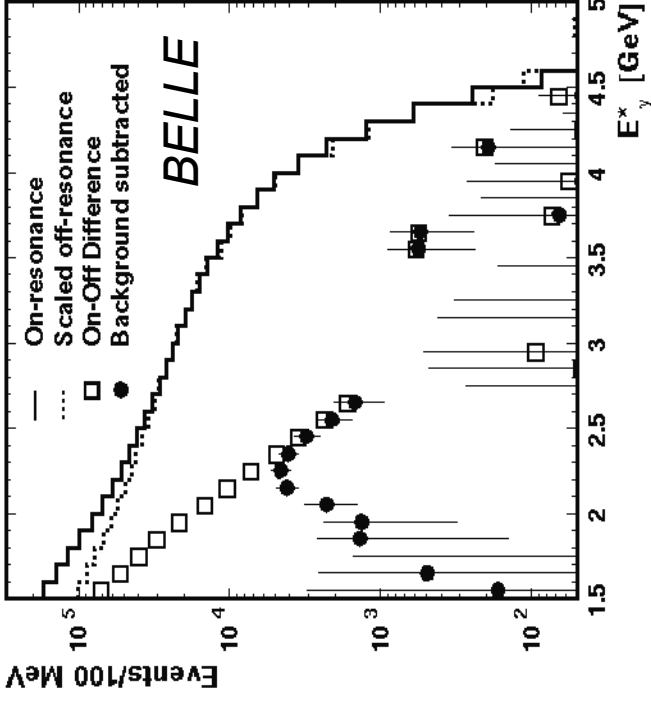
De Fazio, Neubert
JHEP 06, 017 (1999)

Leibovich, Low, Rothstein
PRD 61, 053006 (2000)



Misure inclusive: ENDPOINT (2)

hep-ex/0403004



CLEO
PRL 88:231803 (2002)
BaBar
hep-ex/0207081
BELLE
EPS HEP 2003

	$\Delta Br(B \rightarrow X_u e \nu) (*10^{-4})$	$ V_{ub} (*10^{-3})$
CLEO	$1.43 \pm 0.10 \pm 0.13$	$4.27 \pm 0.24_{exp} \pm 0.17_{OPE} \pm 0.47_{fu} \pm 0.34_{sy}$
BaBar	$1.52 \pm 0.14 \pm 0.14$	$4.43 \pm 0.29_{exp} \pm 0.25_{OPE} \pm 0.50_{fu} \pm 0.35_{sy}$
BELLE	$1.19 \pm 0.11 \pm 0.10$	$3.99 \pm 0.17_{exp} \pm 0.22_{OPE} \pm 0.45_{fu} \pm 0.32_{sy}$

Misure inclusive: RICOSTRUZIONE ν (1)

- Ricostruzione cinematica del neutrino:

$$\sigma(|V_{ub}|) / |V_{ub}| \sim 22\%$$

- selezione eventi con leptone di alto momento ($p_{lep}^* > 1 \text{ GeV}$)

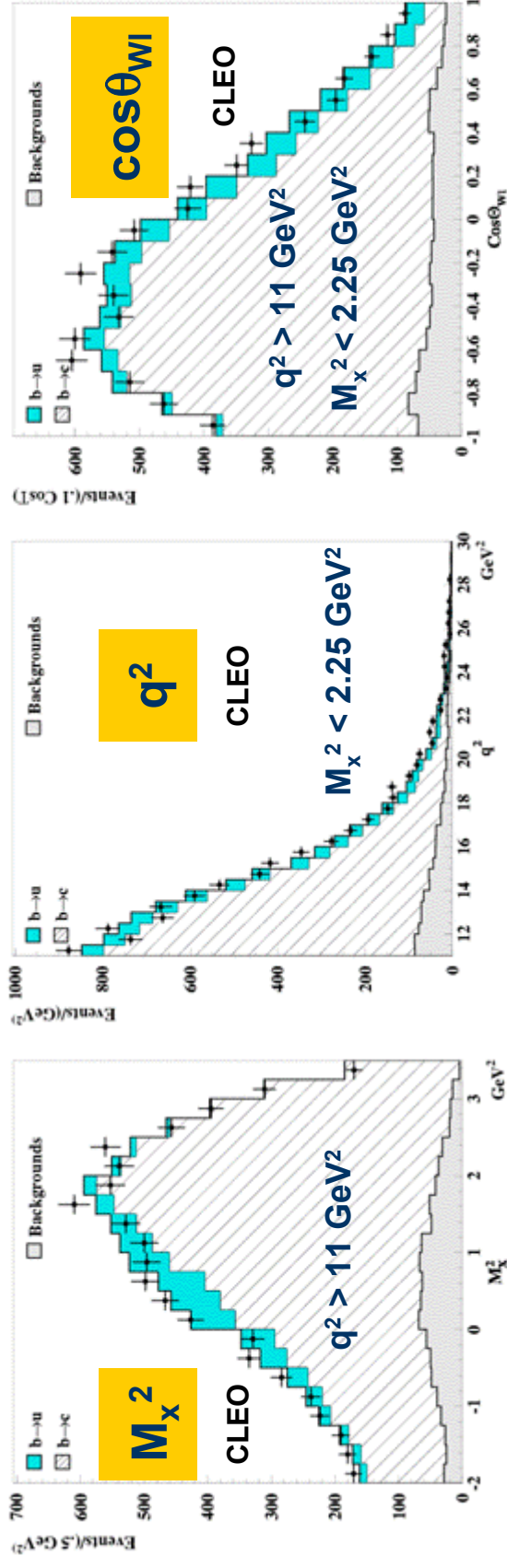
- *missing momentum* ($\sigma \sim 120 \text{ MeV}$) con B considerato a riposo

- ΔBR in regione di alto q^2 e bassa M_X (alta sensitività del fit)

hep-ex/0207064

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

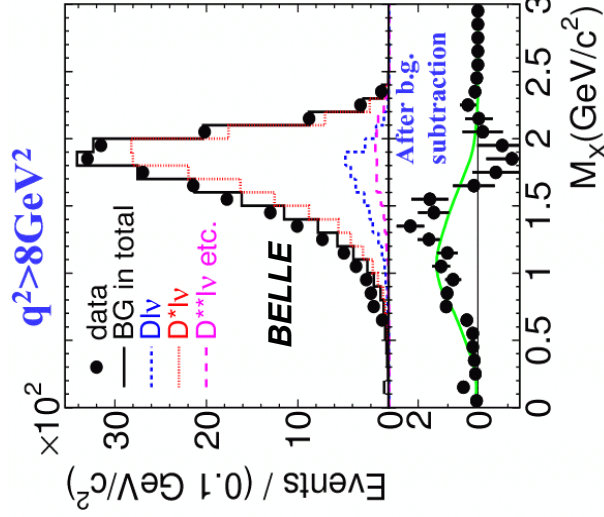
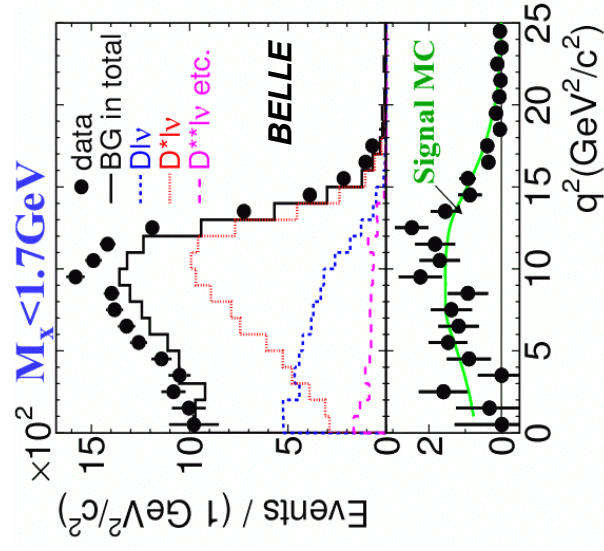
$$|V_{ub}| = (4.05 \pm 0.18_{exp} \pm 0.58_{syst} \pm 0.25_{b \rightarrow c} \pm 0.21_{b \rightarrow u} \pm 0.56_{theo}) * 10^{-3}$$



Misure inclusive: RICOSTRUZIONE ν (2)

- Ricostruzione di M_X e q^2 con *simulated annealing*:
 - selezione candidati con minore m_{miss}^2 e p_{miss} nella regione di accettazione
 - algoritmo basato su *simulated annealing* consente la separazione dei prodotti di decadimento dei due B per selezionare la migliore combinazione $X\nu$
 - ΔBR da eventi di segnale in $M_X < 1.7 \text{ GeV}^2$, $q^2 > 8 \text{ GeV}^2$

$$|V_{ub}| = (4.66 \pm 0.28_{\text{stat}} \pm 0.35_{\text{syst}} \pm 0.17_{b \rightarrow c} \pm 0.08_{b \rightarrow u} \pm 0.58_{\text{theo}}) * 10^{-3}$$



$$\sigma(|V_{ub}|) / |V_{ub}| \sim 16 \%$$

PRL 92, 181801 (2004)

Simulated annealing
S. Kirkpatrick et al.,
Science 220, No. 4598 (1983)



Misure inclusive: RECOIL (1)

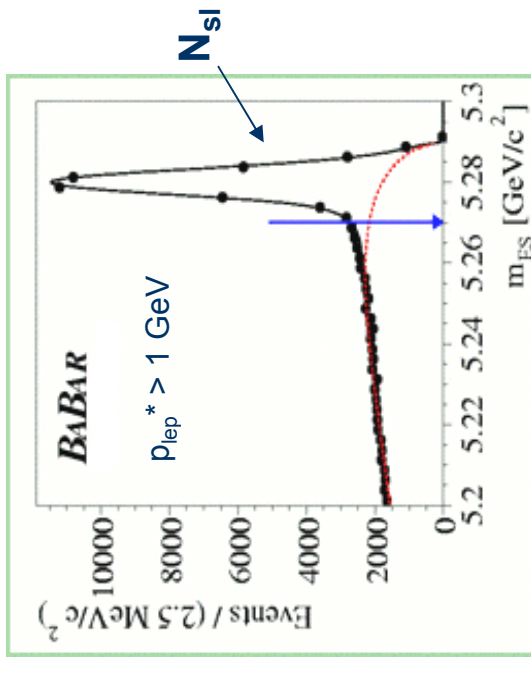
- Eventi con un B completamente ricostruito
- B di rinculo decade semileptonicamente
- Selezione degli eventi:
 - leptone di alto momento ($p_{lep}^* > 1 \text{ GeV}$)
 - $M_x < 1.55 \text{ GeV}$ (accettanza $\sim 70\%$)
 - $m_{miss}^2 < 0.5 \text{ GeV}^2$, veto su K e K_s
 - efficienza di ricostruzione $\sim 10^{-3}$, S/B ~ 2
- Misura del rapporto di BR:
 - riduzione incertezze sistematiche
 - correzioni per efficienza: ϵ_{sel} , ϵ_{M_x} (finestra di M_x), ϵ_l (taglio su p_{lep}^*), ϵ_t (ricostruzione adronica del B)

$$R_{u/sl} = \frac{B(B \rightarrow X_u \ell \nu)}{B(B \rightarrow X \ell \nu)} = \frac{N_u^{true}}{N_{sl}^{true}} = \frac{N_u / (\epsilon_{sel}^u \epsilon_{M_x}^u)}{N_{sl}} \times \frac{\epsilon_l^{sl} \epsilon_t^{sl}}{\epsilon_l^u \epsilon_t^u}$$

$$B \rightarrow D^{(*)} X$$

$$X = n\pi mK pK_s q\pi^0$$

$$(n+m+p+q < 6)$$



$$BR(B \rightarrow X | \nu) =$$

$$(10.87 \pm 0.18 \pm 0.30)\%$$

BaBar, PRD 67:031101 (2003)

Misure inclusive: RECOIL (2)

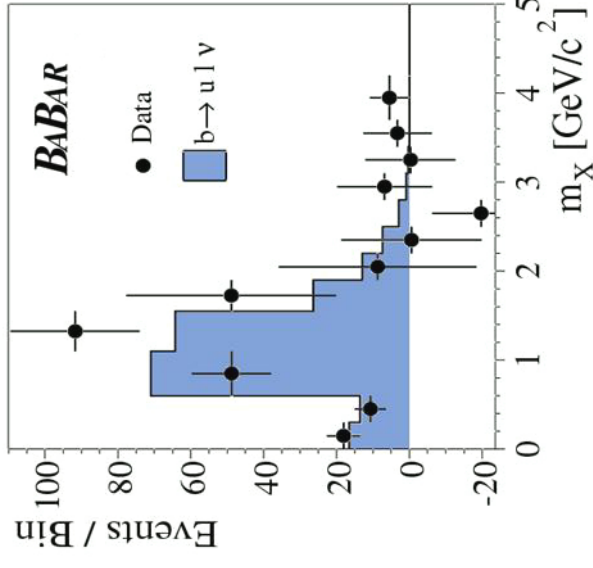
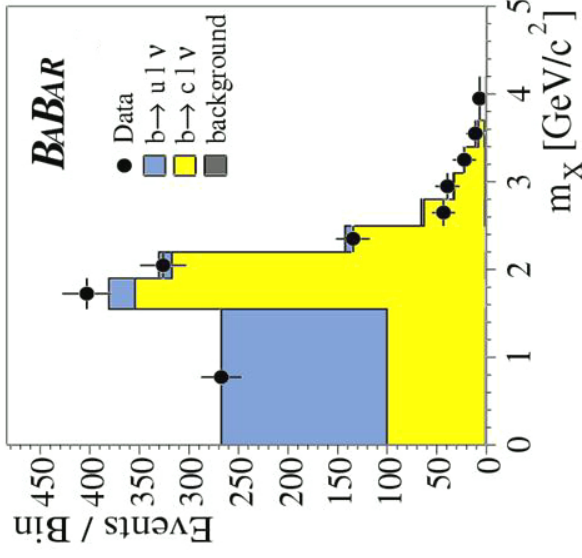
- Eventi di segnale estratti dal fit a M_x
- BR semileptonico inclusivo *charmless*:

$$\mathcal{B}(\bar{B} \rightarrow X_u \ell \bar{\nu}) = (2.24 \pm 0.27 \pm 0.26 \pm 0.39) \times 10^{-3}$$

PRL 92, 071802 (2004)

$$\sigma(|V_{ub}|) / |V_{ub}| \sim 13\%$$

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



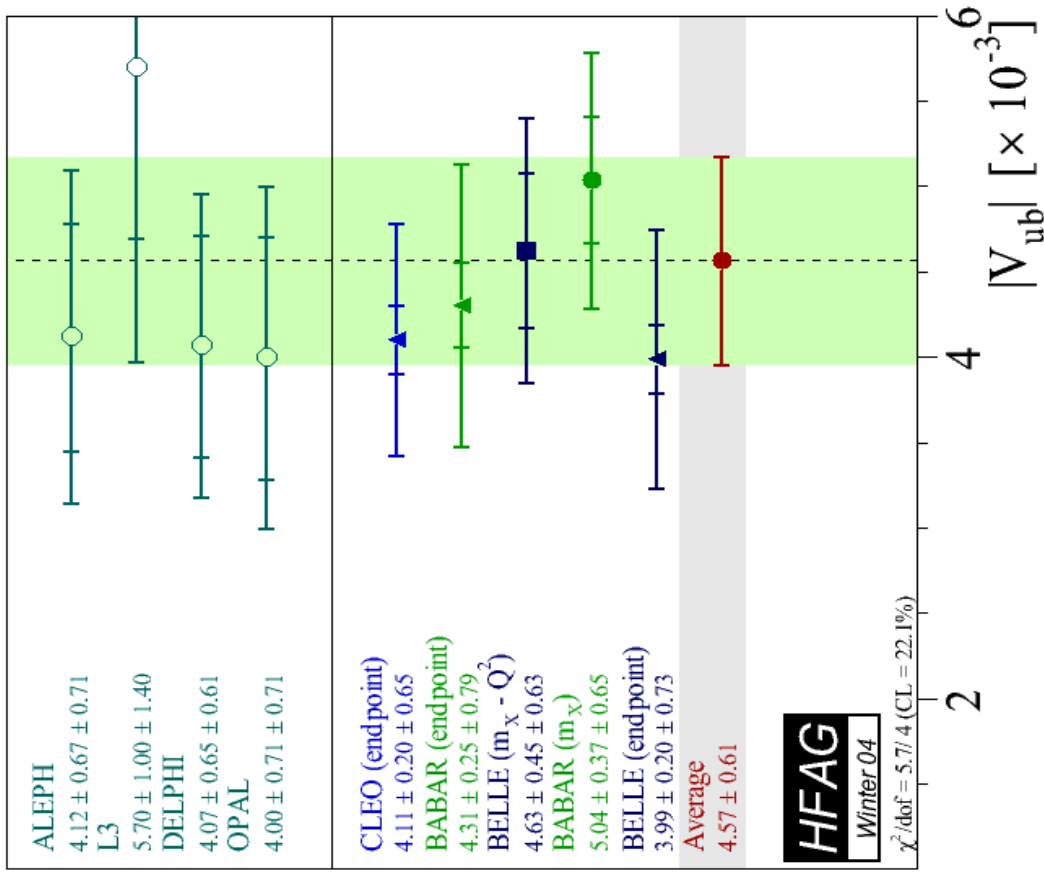
Misure inclusive di $|V_{ub}|$

- Media mondiale inclusiva:
 - diverse tecniche sperimentali
 - correlazione errori
 - misure scalate ad un set comune di parametri e relativi errori

- Media calcolata solo con risultati delle *B-factories*:

$$|V_{ub}| = (4.57 \pm 0.61) \cdot 10^{-3}$$

$$\sigma(|V_{ub}|) / |V_{ub}| \sim 13 \%$$



Misure esclusive di $|V_{ub}|$

Estrazione di $|V_{ub}|$ da $B \rightarrow (\pi, \rho, \omega, \eta, \dots) | \nu$

- Estrazione di $|V_{ub}|$ dai BR esclusivi *charmless*

- ampiezza di decadimento differenziale con Fattori di Forma (corrente adronica)
- 1 solo Fattore di Forma necessario per decadimenti in pseudoscalari ($\pi | \nu, \eta | \nu$),
3 per decadimenti in pseudovettoriali ($\rho | \nu$)

$$\frac{d\Gamma(B^0 \rightarrow S^- \ell^+ \nu)}{dy d \cos \theta_{W\ell}} = |V_{ub}|^2 \frac{G_F^2 k_S^3 M_B^2}{32\pi^3} \sin^2 \theta_{W\ell} |f_1(q^2)|^2$$

$$y = q^2 / M_B^2$$

$$\theta_{W\ell} = \text{angolo } (W^*, \ell)$$

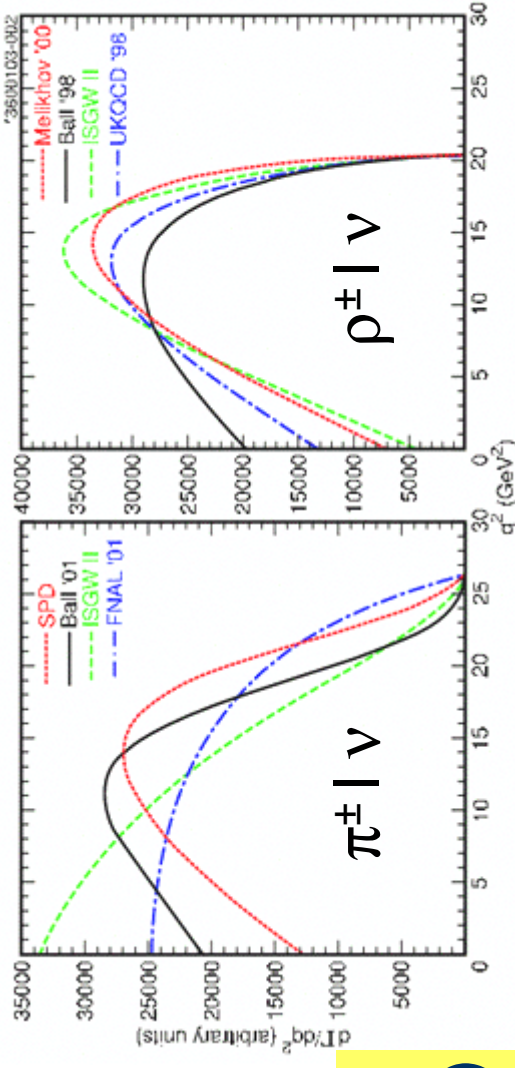
$$k_S = \text{impulso } \pi, \rho, \omega, \eta, \dots$$

$$f_1(q^2) = \text{Fattore di Forma}$$

- integrare su tutto il range di q^2
- incertezze da normalizzazione dei Fattori di Forma (Γ_{FF})
- solo alcuni canali misurati

$$|V_{ub}|^2 =$$

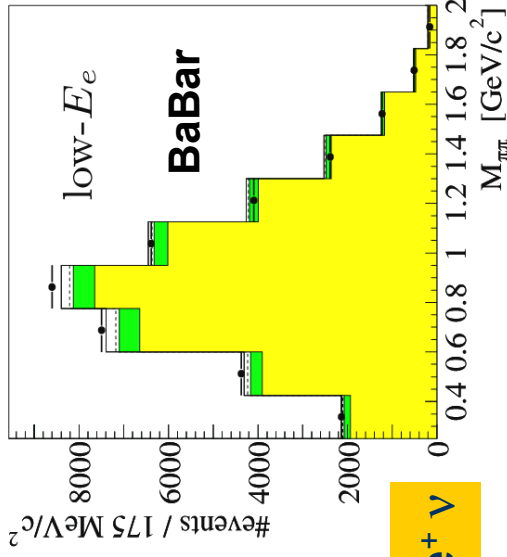
$$BR(B \rightarrow (\pi, \rho, \omega, \eta, \dots) | \nu) / (\Gamma_{FF} * \tau_B)$$



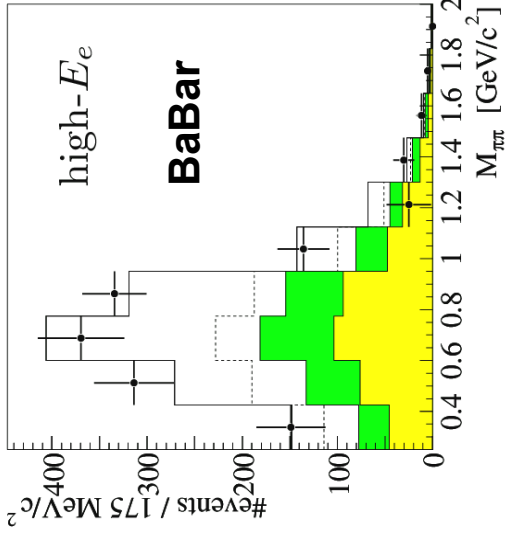
Misure esclusive: ENDPOINT

- Endpoint spettro del leptone:
 - selezione eventi con un leptone di alto momento ($p_{lep}^* > 2 \text{ GeV}$)
 - segnale in $2.3 < p_{lep}^* < 2.7 \text{ GeV}$, fondo V_{cb} in $2 < p_{lep}^* < 2.3 \text{ GeV}$
 - ricostruzione esclusiva della risonanza (e.g. $\rho^- \rightarrow \pi^0 \pi^-$)
 - *missing momentum*, estrazione segnale da fit a M_x

$$|V_{ub}| = (3.64 \pm 0.22_{stat} \pm 0.25_{syst} + 0.39_{+0.39} - 0.56_{-0.56} \text{ theo}) * 10^{-3}$$



$$B^0 \rightarrow \rho^- e^+ \nu$$



$$\sigma(|V_{ub}|) / |V_{ub}| \sim 18 \%$$

PRL 90, 181801 (2003)

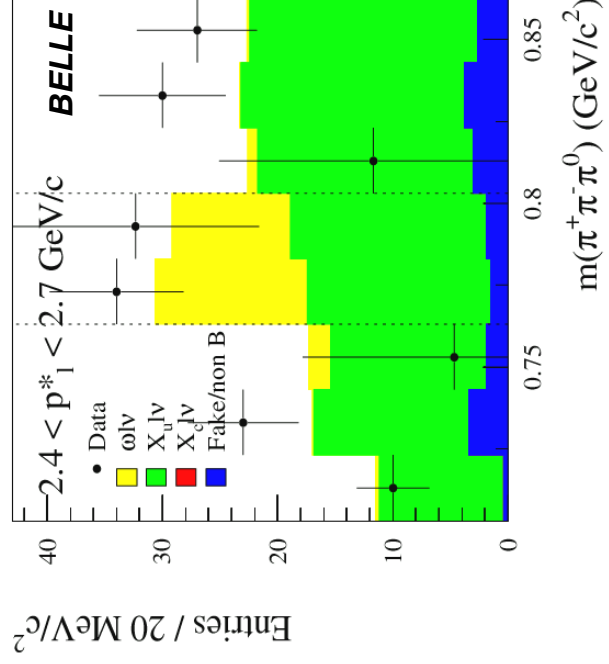
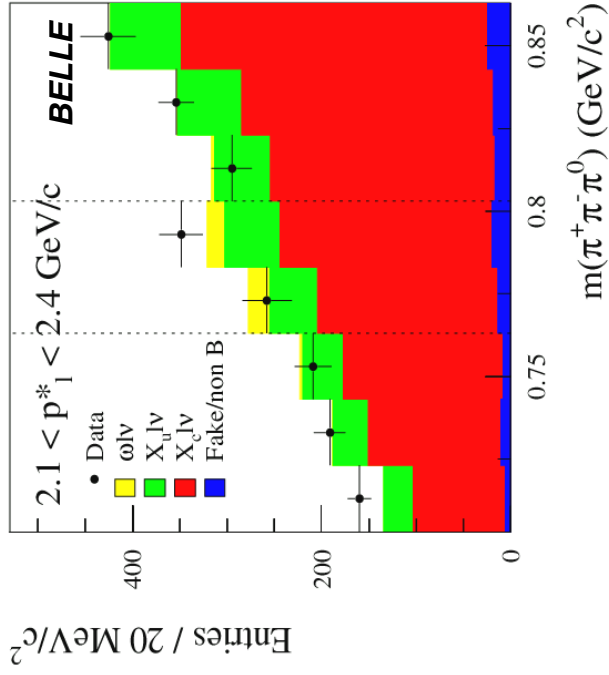


Misure esclusive: RICOSTRUZIONE ν (1)

- Ricostruzione cinematica del neutrino:

- selezione eventi con un leptone di alto momento ($p_{lep}^* > 1 \text{ GeV}$)
- ricostruzione stato finale risonanza (e.g. $\omega \rightarrow \pi^+ \pi^- \pi^0$)
- *missing momentum* ($\sigma \sim 150 \text{ MeV}$) compatibile con ipotesi neutrino

$$BR(B^+ \rightarrow \omega l^+ \nu) = (1.3 \pm 0.4_{stat} \pm 0.2_{syst} \pm 0.3_{flu}) * 10^{-4}$$

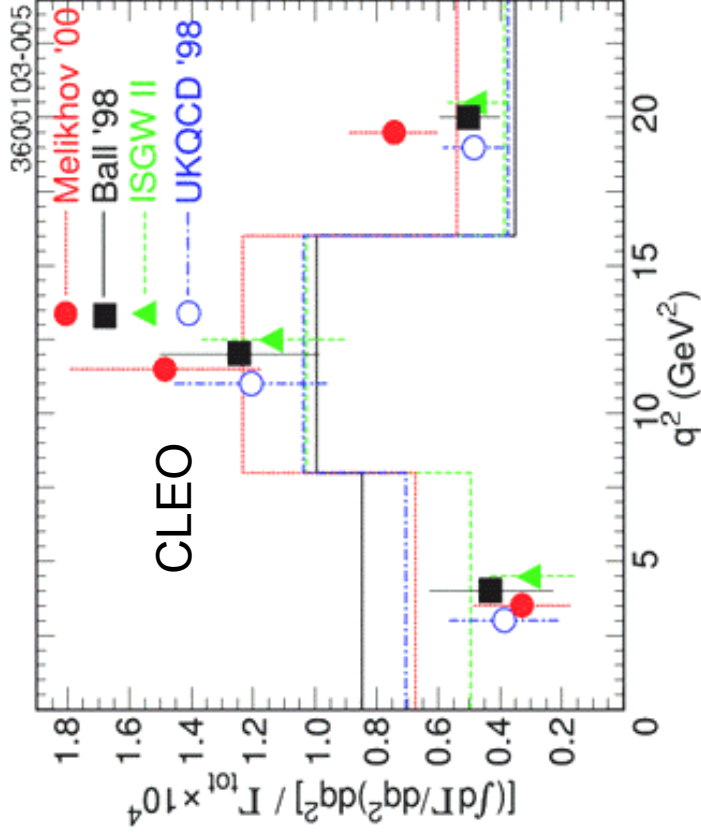


hep-ex/0402023

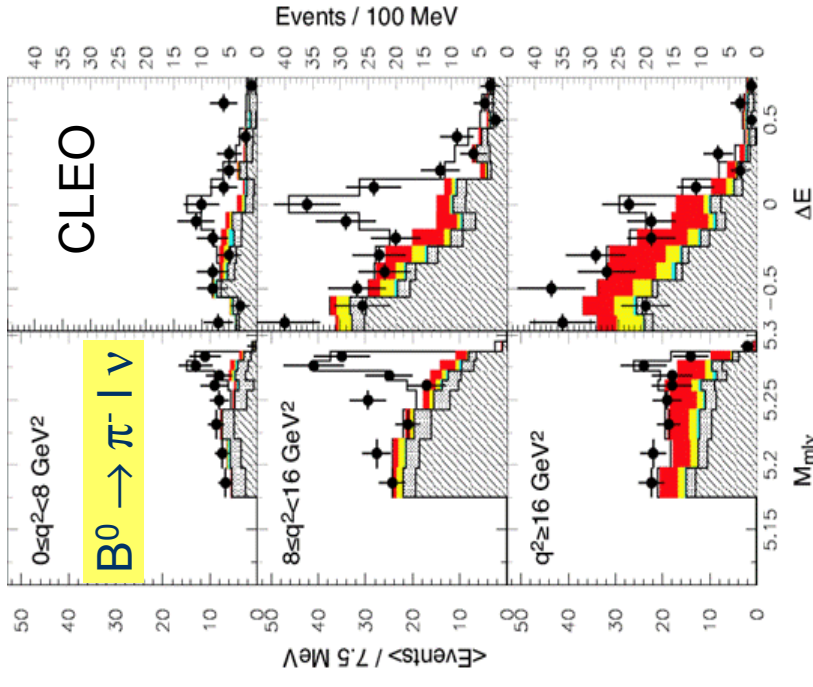


Misure esclusive: RICOSTRUZIONE ν (2)

- Estrazione del BR in intervalli di q^2



- estrazione di $|V_{ub}|$ su tutto il range di q^2



$$\sigma(|V_{ub}|) / |V_{ub}| \sim 18 \%$$

ICHEP2002

$$|V_{ub}| = (3.32 \pm 0.21_{stat} \pm 0.19_{syst} \pm 0.55_{\pi V} \pm 0.12_{\rho V} \pm 0.071_{b \rightarrow u}) * 10^{-3}$$

Misure esclusive: RECOIL

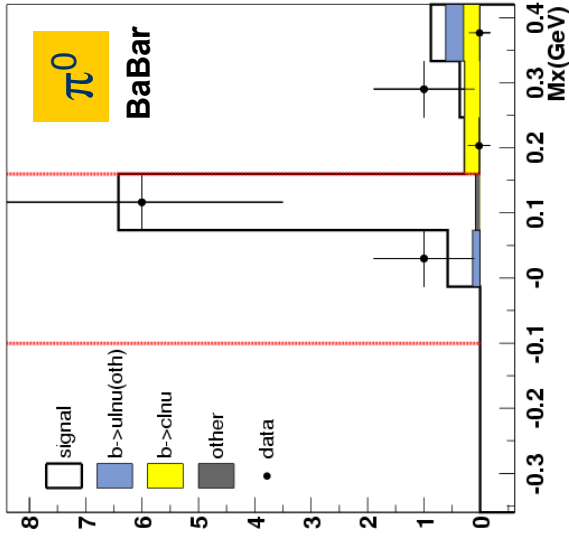
$$\left\{ \begin{aligned} \mathcal{B}(B^+ \rightarrow \pi^0 l^+ \nu) &= (0.78 \pm 0.32_{stat} \pm 0.13_{syst}) \cdot 10^{-4} \\ \mathcal{B}(B^+ \rightarrow \rho^0 l^+ \nu) &= (0.99 \pm 0.37_{stat} \pm 0.19_{syst}) \cdot 10^{-4} \\ \mathcal{B}(B^+ \rightarrow \omega l^+ \nu) &= (2.20 \pm 0.92_{stat} \pm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

" ρ^0 " is $\pi^+\pi^-$ with $0.65 < m_{\pi^+\pi^-} < 0.95$ GeV

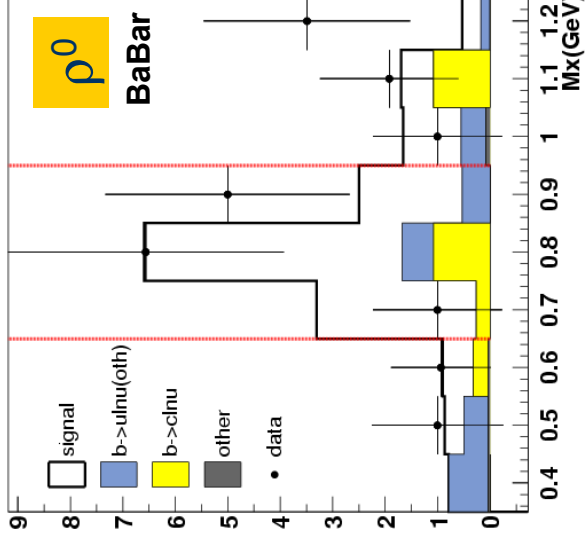


LP2003

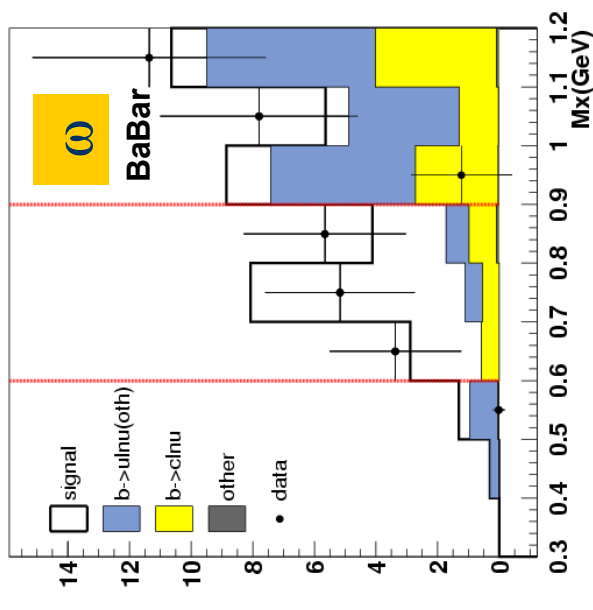
data events exclusive



data events exclusive



data events exclusive



Overview dei BR esclusivi

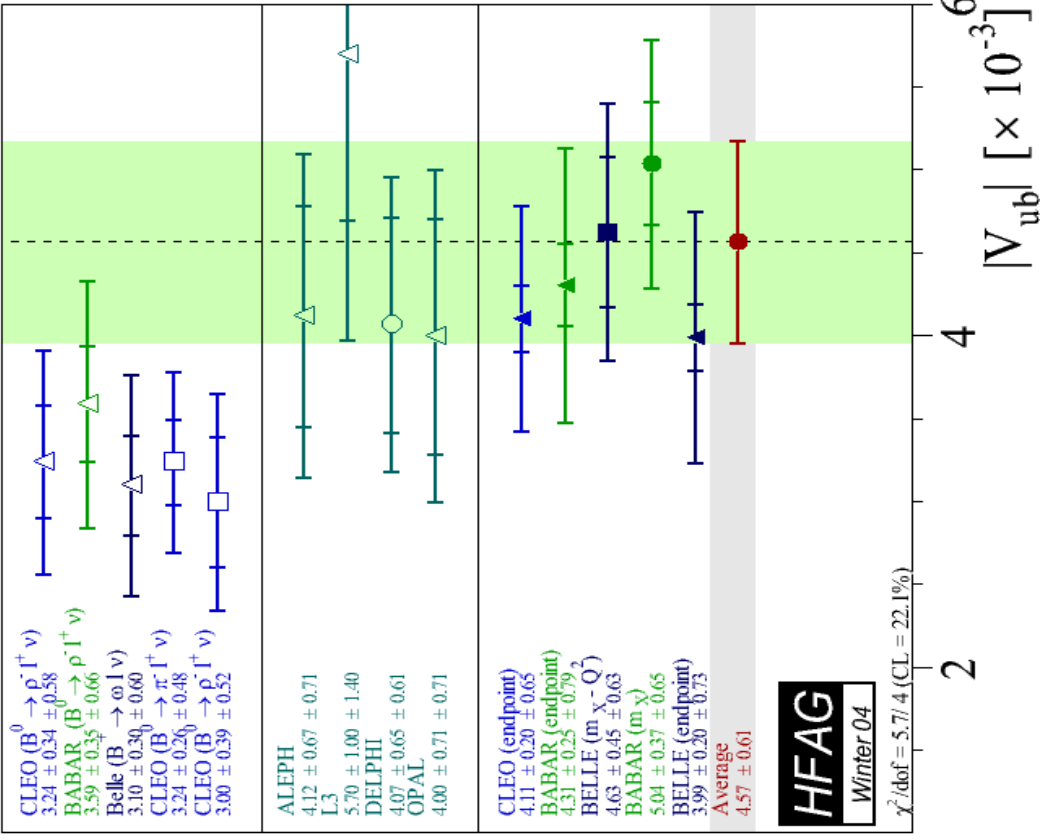
Decay	BaBar (*10 ⁻⁴)	BELLE (*10 ⁻⁴)	CLEO (*10 ⁻⁴)
$B^0 \rightarrow \pi^- l^+ \nu$	-	$1.89 \pm 0.15 \pm 0.30$ (2002 – Ricostruzione ν)	$1.33 \pm 0.18 \pm 0.13$ (2003 – Ricostruzione ν)
$B^+ \rightarrow \pi^0 l^+ \nu$	$0.78 \pm 0.32 \pm 0.13$ (2003 – Recoil)	-	-
$B^0 \rightarrow \rho^- l^+ \nu$	$3.29 \pm 0.42 \pm 0.47 \pm 0.55$ (2003 - endpoint)	-	$2.17 \pm 0.34 + 0.47 - 0.54$ (2003 – Ricostruzione ν)
$B^+ \rightarrow \rho^0 l^+ \nu$	$0.99 \pm 0.37 \pm 0.19$ (2003 – Recoil)	$1.44 \pm 0.18 \pm 0.23$ (2002 – Ricostruzione ν)	-
$B^+ \rightarrow \omega l^+ \nu$	$2.20 \pm 0.92 \pm 0.57$ (2003 – Recoil)	$1.3 \pm 0.4 \pm 0.2 \pm 0.3$ (2004 – Ricostruzione ν)	-
$B^+ \rightarrow \eta l^+ \nu$	-	-	$0.84 \pm 0.31 \pm 0.16$ (2003 – Ricostruzione ν)
Altri mesoni leggeri ($\eta', a_0, a_1, b_1, f_0, f_1, h_1, \dots$)	-	-	-

Misure inclusive ed esclusive di $|V_{ub}|$

$B^0 \rightarrow \pi^- l^+ \nu$
 $B^0 \rightarrow \rho^- l^+ \nu$
 $B^+ \rightarrow \omega l^+ \nu$

Misure inclusive

- Accordo tra le misure inclusive entro gli errori
- Misure esclusive al di sotto della media inclusiva
- Discussioni in corso per calcolo della media esclusiva



Conclusioni

$$|V_{ub}| = (4.57 \pm 0.61) \cdot 10^{-3} \quad \sigma(|V_{ub}|) / |V_{ub}| \sim 13 \%$$

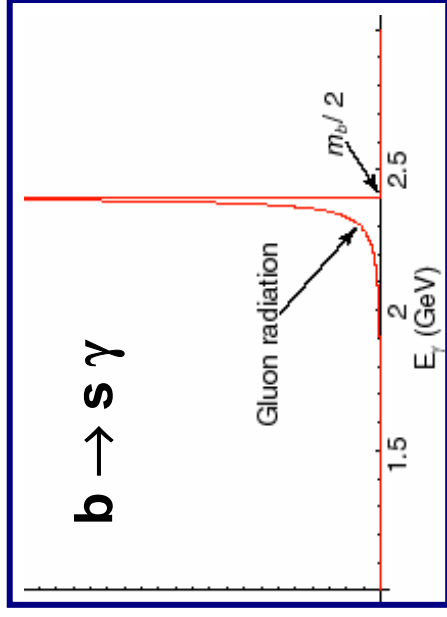
- Molte misure risultano oramai limitate da incertezze sistematiche e teoriche.
- Elevata luminosità raggiunta dalle *B-factories* rende promettente lo studio dei canali esclusivi.
 - estate 2004: BaBar $\sim 200 \text{ fb}^{-1}$, BELLE $\sim 250 \text{ fb}^{-1}$
- A breve nuovi studi dei *BR* di *B* $\rightarrow (\pi, \rho, \omega, \eta, \eta', a_0, \dots) |V$ permetteranno nuove misure di $|V_{ub}|$ e inoltre l'estrazione di informazioni sui fattori di forma.

BACKUP

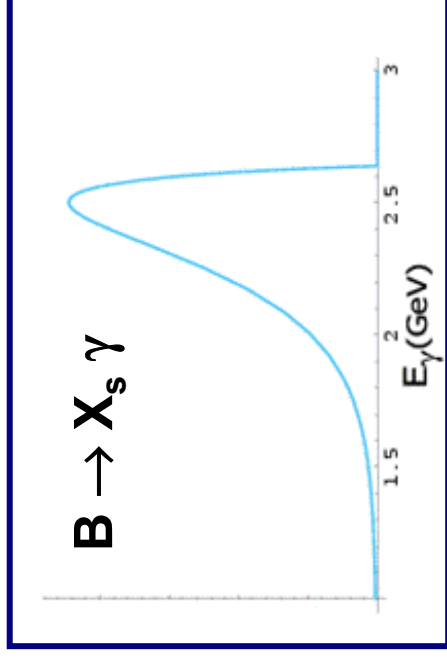


Shape Function

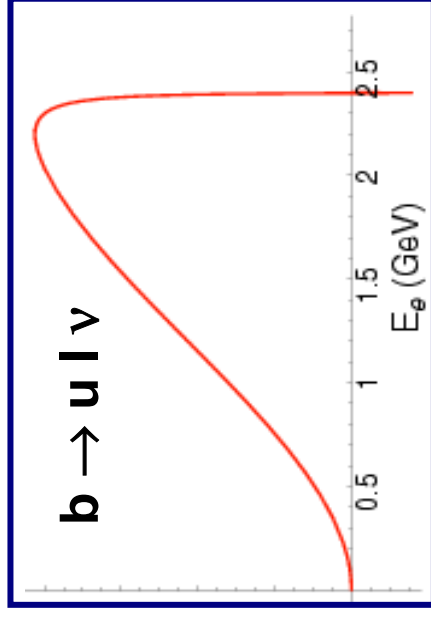
- *Shape function* (da LCSR) descrive *smearing* dello spettro osservato (a livello adronico) rispetto allo spettro a livello partonico.
- Al 1° ordine in Λ_{QCD}/m_b STESSA *shape function* per tutte le transizioni $b \rightarrow \text{light quark}$ ($b \rightarrow s \gamma \Rightarrow B \rightarrow X_s \gamma e b \rightarrow u l \nu \Rightarrow B \rightarrow X_u l \nu$).



CONVOLUZIONE
con shape function



Frazione di spettro
 $b \rightarrow u l \nu$ sopra 2.2 GeV:
 0.13 ± 0.03



Simulated annealing (BELLE)



Novel X_u reconstruction by Belle -2
Separation of two B meson decays

Simulated Annealing Method -1

- 6 discriminants are used
 - $p^*_B, E^*_B, \cos \theta^*_B, N_{ch}$ of the associated B in CMS
 - $Q_B \times Q_l, M_{MM}^2(E^*_B, M_B)$ of associated B are fixed to known values
- Using MC simulation, calculate PDFs for correct X_{lv} combinations and random X_{lv} combinations
- Calculate W with two likelihoods $L(\text{correct})$ and $L(\text{random})$

$$W \equiv \frac{L(\text{random})}{L(\text{random}) + L(\text{correct})}$$

- The most likely candidate combination is found by minimizing W using an approximate iterative algorithm based on simulated annealing

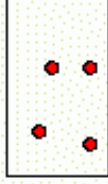
Simulated annealing (BELLE)



Simulated Annealing -2

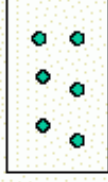
One iteration

Initial state



Random config.

X



B_{assoc}

W_{old}

Move random one particle between X and Bassoc



W_{new}

If $W_{new} < W_{old}$, keep new configuration, $W_{new} \Rightarrow W_{old}$

If $W_{new} > W_{old}$, keep new configuration with probability of $\exp\{-1000(W_{new}-W_{old})/W_{old}\}$, otherwise keep old configuration

Repeat this process until all particles are moved at least once and only once

In total 500 iterations are used

Recoil Technique (BaBar)

Selection Criteria	$N_{\pi^0}^{meas}$ $B \rightarrow \pi^0 l \nu$	$N_{\rho^0}^{meas}$ $B \rightarrow \rho^0 l \nu$	N_{ω}^{meas} $B \rightarrow \omega l \nu$	N_{sl}^{meas} $B \rightarrow q l \nu$
B_{reco} candidate	purity cuts	purity cuts	purity cuts	purity cuts
Min. lept. momentum	$p^* > 1.0 \text{ GeV}$	$p^* > 1.0 \text{ GeV}$	$p^* > 1.0 \text{ GeV}$	$p^* > 1.0 \text{ GeV}$
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.	$M_{miss}^2 < 0.4 \text{ GeV}^2$	$M_{miss}^2 < 0.3 \text{ GeV}^2$	$M_{miss}^2 < 0.6 \text{ GeV}^2$	-
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	$N_{chg} = 0$	$N_{chg} = 2$	$N_{chg} = 2$	-
$m_X \text{ fit} - m_X \text{ chg}$	-	$\Delta M_{chg} < 0.1 \text{ GeV}$	$\Delta M_{chg} > 0.1 \text{ GeV}$	-
Lower m_X Cut	$m_X > -0.1 \text{ GeV}$	$m_X > 0.65 \text{ GeV}$	$m_X > 0.6 \text{ GeV}$	-
Upper m_X Cut	$m_X < 0.16 \text{ GeV}$	$m_X < 0.95 \text{ GeV}$	$m_X < 0.9 \text{ GeV}$	-

