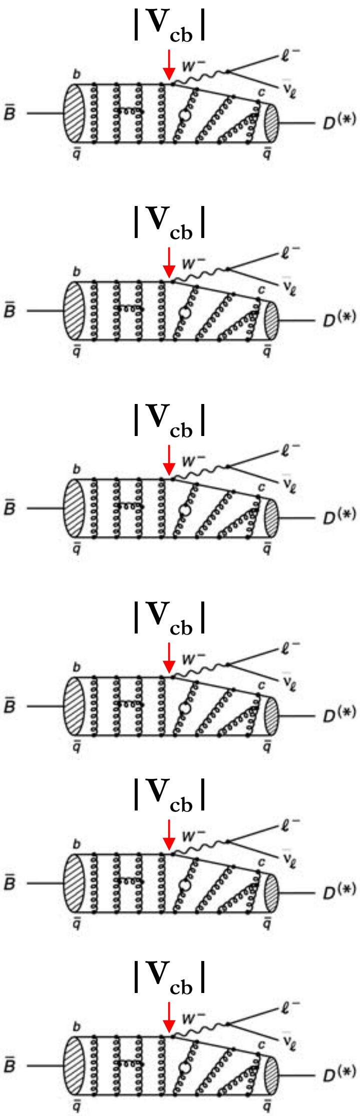
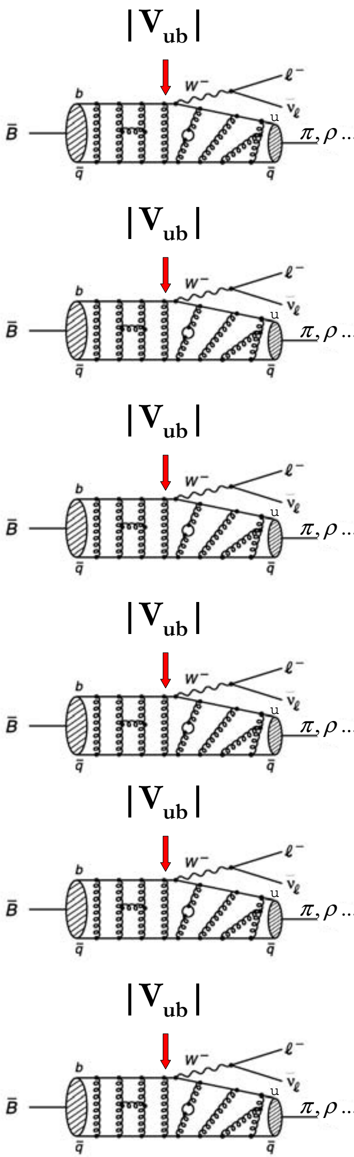


Measurement of $|V_{cb}|$ and $|V_{ub}|$ at



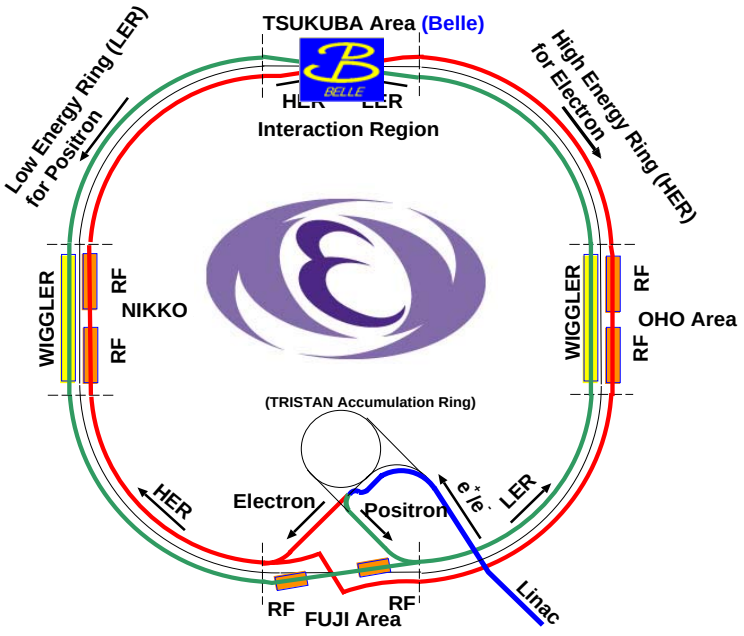
Weak Interactions and Neutrinos 2003

October 7

I. Bizjak, J. Stefan Institute

for Belle collaboration

Belle detector @ KEK-B



Beam energies:

e^+ (HER): 8.0 GeV

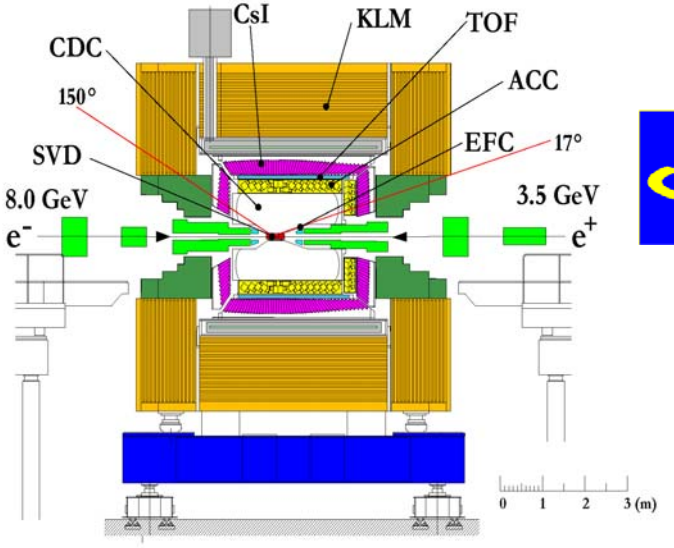
e^- (LER): 3.5 GeV

E_{CM}=10.58 GeV

4 years of data taking:

$L_{max}=10.6 \cdot 10^{33}\ cm^{-2}s^{-1}$

$L_{int}= 158.7 fb^{-1}$ ... 152 million B meson events



SVD: Silicon Vertex Detector
CDC: Central Drift Chamber
CsI: CsI Calorimeter
KLM: K_L and muon detector
TOF: Time of Flight Counter
ACC: Aerogel Cherenkov Counter
EFC: E-M Forward Calorimeter

Measurement of $|V_{cb}|$ and $|V_{ub}|$

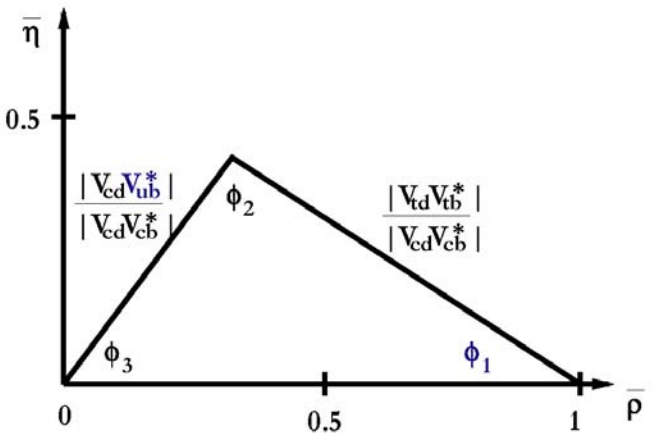
$$V_{CKM} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

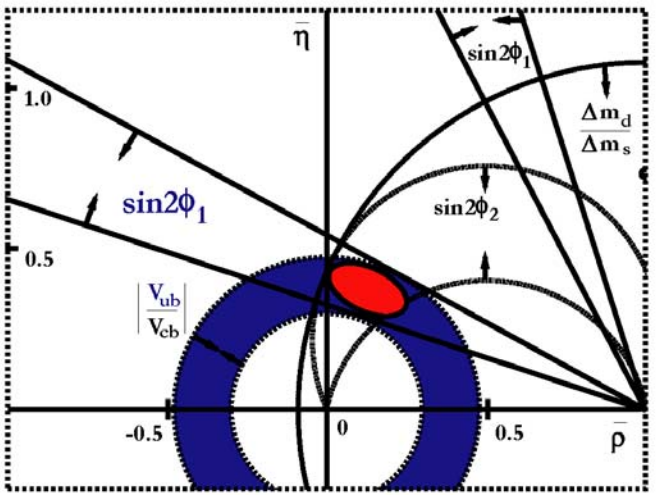
B physics can determine 2/3 real par.

+

complex phase

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





Exclusive $|V_{ub}|$: evidence for $B^+ \to \omega l^+ \nu$

Previous exclusive results:

Br $(B^0 \to \pi^- l^+ \nu) = (1.33 \pm 0.11 \pm 0.21) \cdot 10^{-4}$ (60 fb^{-1})

Br $(B^+ \to \rho^0 l^+ \nu) = (1.44 \pm 0.18 \pm 0.23) \cdot 10^{-4}$ (29 fb^{-1})

Preliminary

$B^+ \to \omega l^+ \nu$

l^+

- Events with single lepton (e or μ)

ν

- Reconstructed neutrino momentum from missing momentum

$$^3p_{miss} = {}^3\Upsilon(4S) - \Sigma\, {}^3p \qquad {}^4p_{miss} = (|p_{miss}|, {}^3p_{miss})$$

$\sigma(p_{miss}) \approx 140 MeV/c$

ω

Fully reconstruct the final state

ω decay reconstruction: $\omega \to \pi^+ \pi^- \pi^0$

Simultaneous fit of the signal

$m(\pi^+ \pi^- \pi^0)$, ΔE, p_l

in three lepton momentum bins

p_l	1.8 – 2.1 GeV/c	2.1 – 2.4 GeV/c	2.4 – 2.7 GeV/c
data	1990	667	75
$B^+ \to \omega l^+ \nu$	41 ± 13	68 ± 21	35 ± 11
$B \to X_u l \nu$	61 ± 28	82 ± 28	21 ± 5
$B \to X_c l \nu$	1743 ± 36	415 ± 14	0
fake, non B	19 ± 3	33 ± 4	3 ± 1
continuum	17 ± 12	61 ± 23	9 ± 9
sum	1881 ± 49	659 ± 44	68 ± 15

Exclusive $|V_{ub}|$: evidence for $B^+ \to \omega l^+ \nu$ (78 fb^{-1})

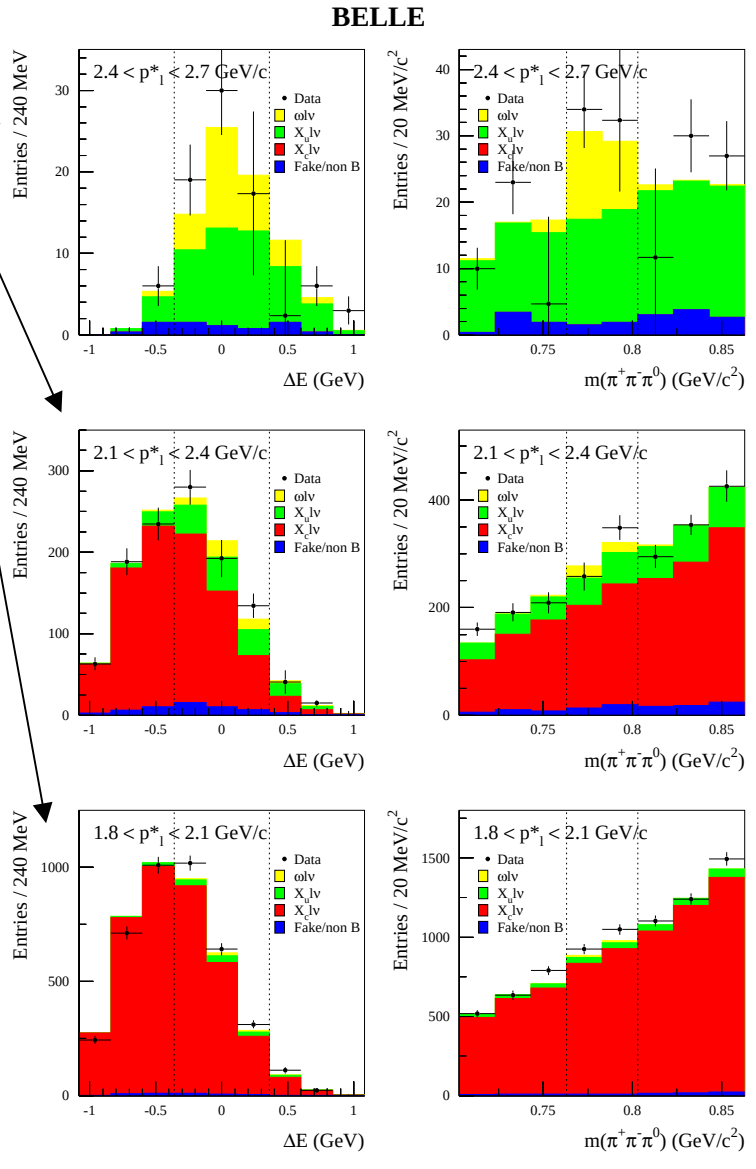
Simultaneous fit of the signal
$m(\pi^+ \pi^- \pi^0)$, ΔE, p_l
in three lepton momentum bins

form-factor	signal yield	$\mathcal{B}(B^+ \to \omega l^+ \nu)$
ISGW2	144 ± 44	$(1.00 \pm 0.31) \cdot 10^{-4}$
UKQCD	145 ± 44	$(1.20 \pm 0.37) \cdot 10^{-4}$
LCSR	176 ± 52	$(1.67 \pm 0.50) \cdot 10^{-4}$
average	$155 \pm 47 \pm 15$	$(1.29 \pm 0.39 \pm 0.28) \cdot 10^{-4}$

Preliminary

stat. sys. model

Br $(B^+ \to \omega l^+ \nu) = (1.3 \pm 0.4 \pm 0.2 \pm 0.3) \cdot 10^{-4}$

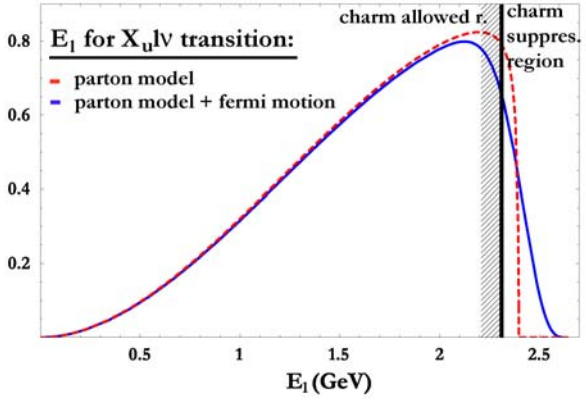


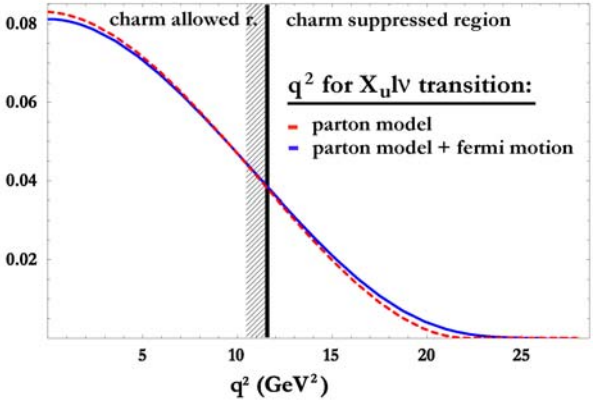
Dominant systematic uncertainty:

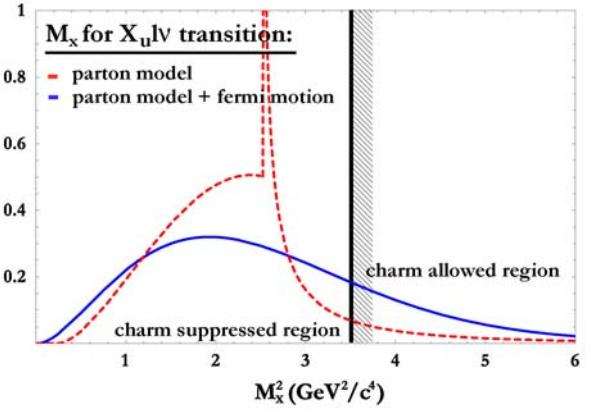
- **B $\to X_u l \nu$ crossfeed ... 14%**
- **Neutrino reconstruct., track&cluster finding ... 9%**

Inclusive $|V_{ub}|$: the variables

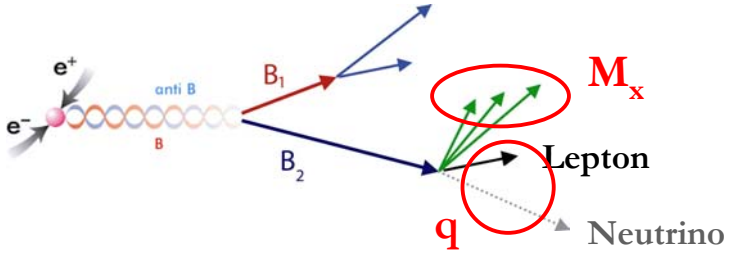
How to suppress $B \to X_c l\nu$, which is approx. 60 times more abundant than $B \to X_u l\nu$?







C.W.Bauer, Z. Ligeti, M. Luke: PLB 479,395 (2000)

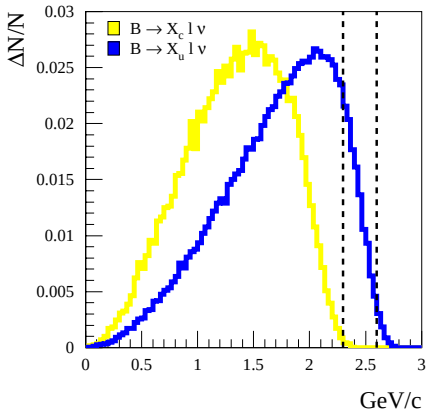


Part of phase space, where b→c is kinematically suppresed

What part of b→u in this phase space

Hadronic invariant mass M_x	$M_x < M_D$	80%
$l^{\pm}\nu$ invariant mass q^2	$q^2 > (m_B - m_D)^2$	20%
Lepton energy E_l	$E_l > \frac{(m_B^2 - m_D^2)}{2m_B}$	10%

Electron spectrum endpoint: the method



✓ Using endpoint of momentum spectrum for $e^{\pm}$

- Measurement region: 2.3 GeV/c < p_e < 2.6 GeV/c (CMS)
- Backg. estim. region: 1.5 GeV/c < p_e < 2.2 GeV/c (CMS)

Deal with large backgrounds:

Non BB backgrounds

- Continuum ($e^+e^- \to qq$)
- QED processes

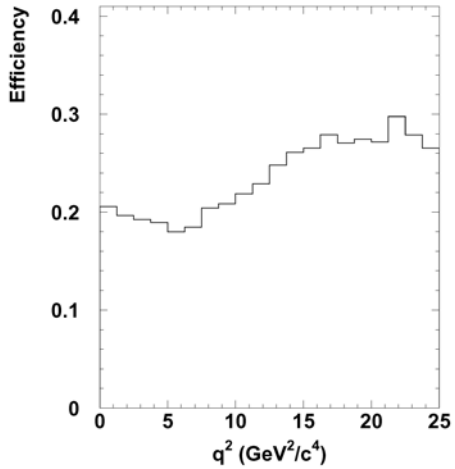
← Fox-Wolfram moments
← Fisher discriminant:
← Thrust axis
← Visible energy
← Charged multiplicity

+ Subtraction of continuum ($8.8fb^{-1}$ of offresonance data)

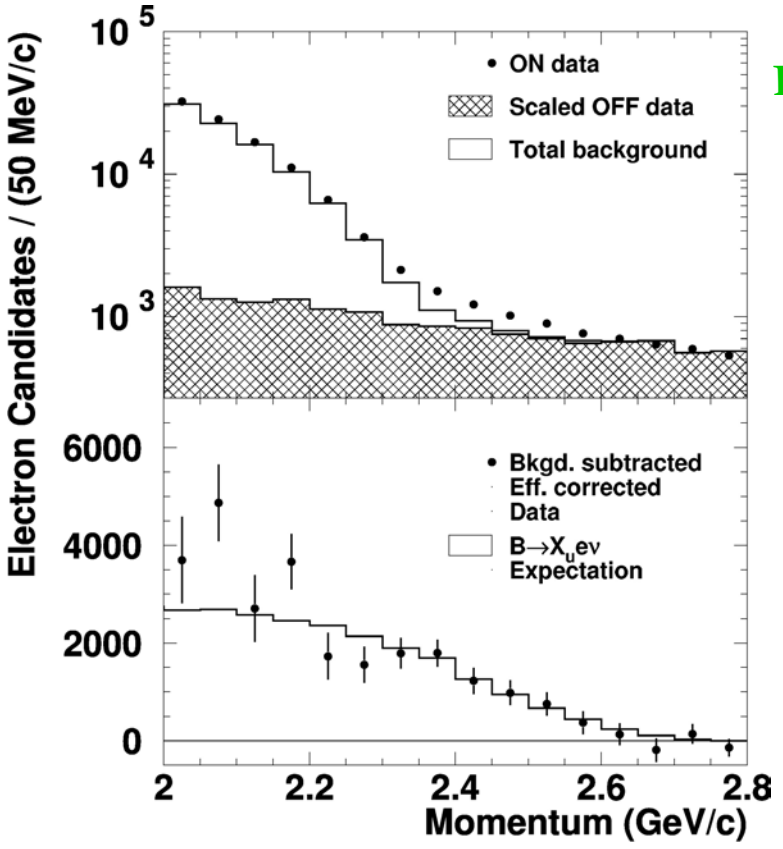
BB backgrounds

- $B \to X_c l\nu$ ← MC simulation:
  - D**eν (ISGW2)
  - D*eν (HQET)
  - Deν (ISGW2)
  - $D^{(*)}\pi$ (Goity-Roberts)
- Leptons from other decays (J/ψ, γ conv.) ← Veto on inv. mass
- Fake electrons ← Estimated using $K_s \to \pi^+\pi^-$

Acceptance of selection requirements as a funct. of q^2



Electron spectrum endpoint: the result (27 fb^{-1})



Partial branching fraction:

$\Delta Br = Br\ (B \to X_u e \nu$: 2.3 GeV/c $< p_e <$ 2.6 GeV/c)

$\Delta Br = (1.18 \pm 0.11 \pm 0.10) \cdot 10^{-4}$ Preliminary

Systematic uncertainty:

Model dependent signal efficiency ... 4.5%

$B \to X_c l \nu$ background estimation ... 4.3%

Extrapolation to whole momentum space:

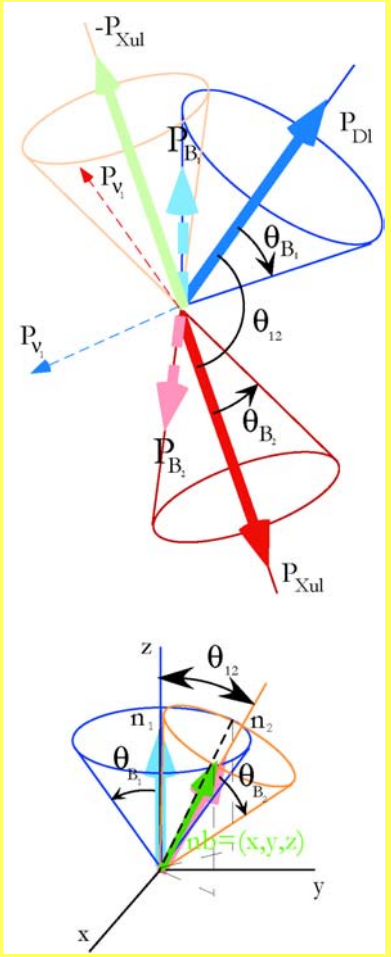
Using $B \to X_s \gamma$ by CLEO [PRL87,251807 (2001)]

$$Br\ (B \to X_u e \nu) = \Delta Br / f_u = (1.60 \pm 0.15^{stat.} \pm 0.14^{sys.} \pm 0.44^{f_u}) \cdot 10^{-4}$$

Preliminary

$$|V_{ub}| = (3.96 \pm 0.18^{stat.} \pm 0.17^{sys.} \pm 0.55^{f_u} \pm 0.22^{theo.}) \cdot 10^{-3}$$

$D^{(*)}l\nu$ tag : the method



- Tag events with both B decaying semileptonically

Tag side → $B \to D^{(*)} l\nu$ & $B \to X l\nu$ ← Signal side

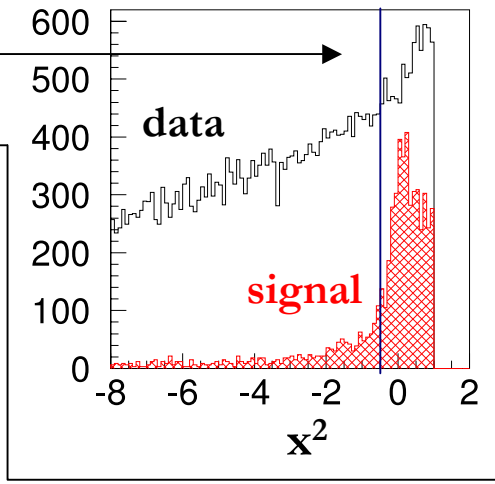
Requrements:

Reconstructed $D^{(*)}$ meson and 2 leptons with opposite charge

Kinematics solvable, if:

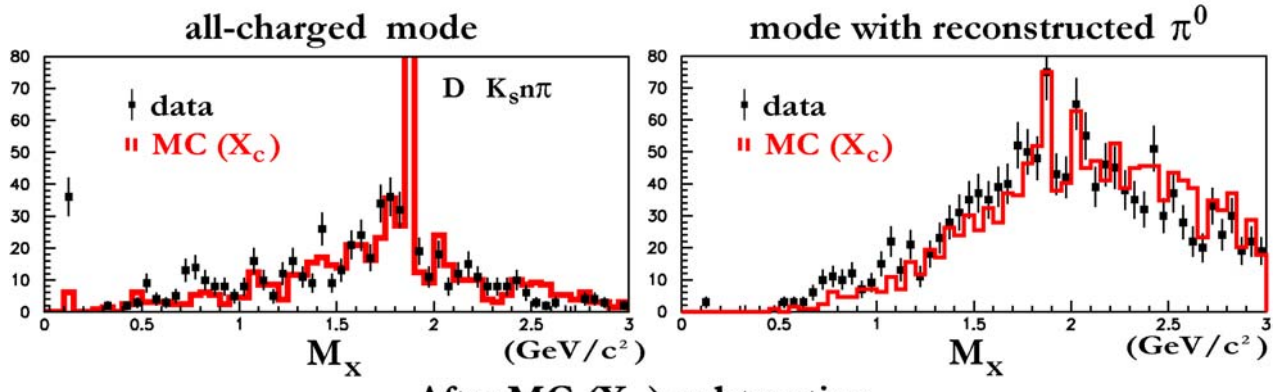
$$x^2 = 1 - (\cos^2\theta_{B1} + \cos^2\theta_{B2} - 2\cos\theta_{B1}\cos\theta_{B2}\cos\theta_{12})/\sin\theta_{12}$$

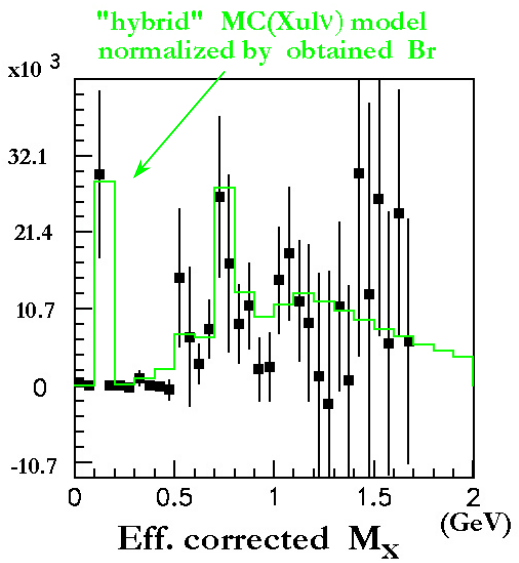
Due to experimental resol. : cut $x^2 > -0.2$



X_u/X_c separation by demanding no detected $K^{\pm}$ on the signal side

$D^{(*)}l\nu$ tag : the result (78 fb^{-1})





$N(B\to X_u l\nu: m_x < 1.5\ GeV/c^2, p_l > 1\ GeV/c, \text{all charged}) = 82 \pm 19$

$N(B\to X_u l\nu: m_x < 1.5\ GeV/c^2, p_l > 1\ GeV/c, \pi^0 \text{ associat.}) = 92 \pm 21$

Preliminary

$$Br(B\to X_u l\nu) = (2.62 \pm 0.63_{stat} \pm 0.23_{sys} \pm 0.05_{b\to c} \pm 0.41_{b\to u}) \cdot 10^{-4}$$

(model)

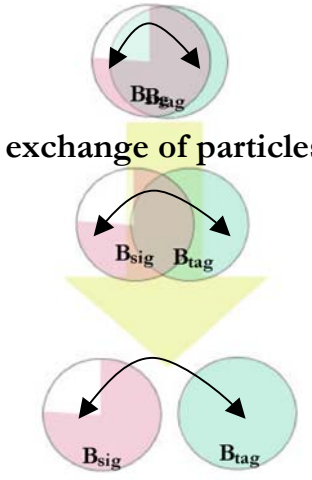
$$|V_{ub}| = (5.0 \pm 0.64_{exp} \pm 0.53_{theo}) \cdot 10^{-3}$$

Advanced ν reconstruction tag : the result (78 fb^{-1})

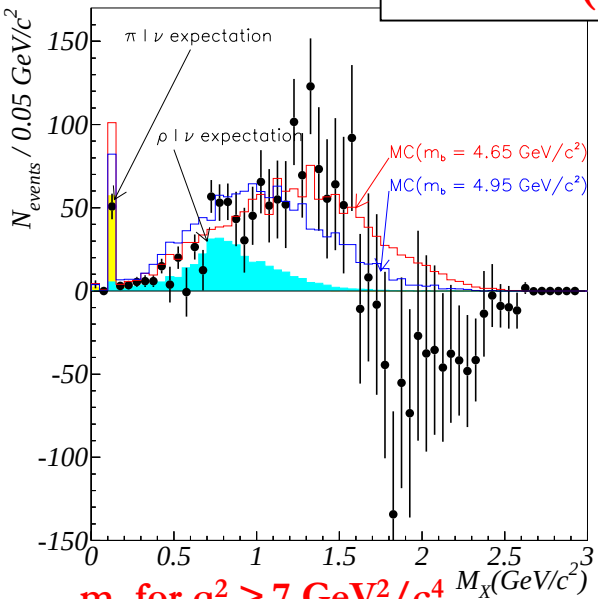
by minimising:

$$W = \frac{\text{PDF(random)}}{\text{PDF(rand.)+PDF(correct)}}$$

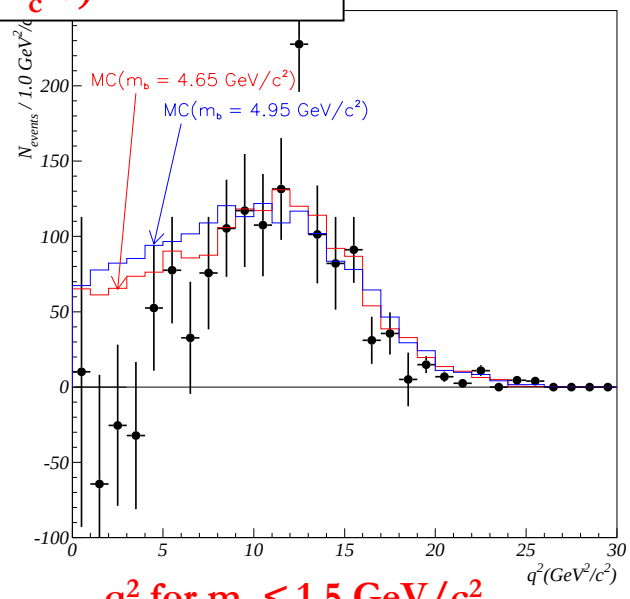
$\text{PDF}(p_B, E_B, M_{miss}, \ldots)$



After MC($X_c l\nu$) subtraction



m_x for $q^2 > 7$ GeV$^2/c^4$



q^2 for $m_x < 1.5$ GeV/c^2

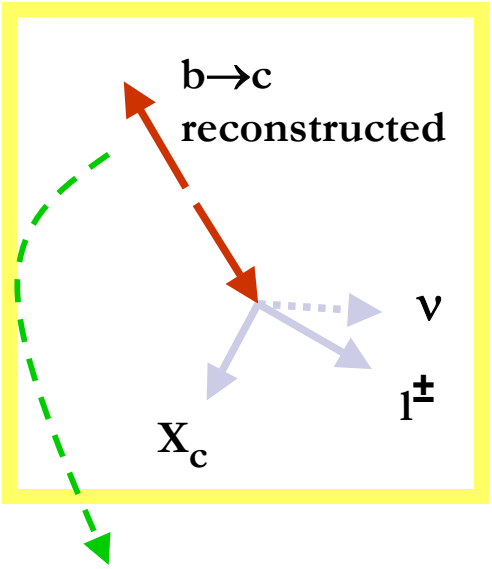
$N(B \to X_u l\nu$: $m_x < 1.5$ GeV/c^2 $q^2 > 7$ GeV$^2/c^4$ $) = 1148 \pm 98$

Preliminary

$$\text{Br}(B \to X_u l\nu) = (1.64 \pm 0.14_{stat} \pm 0.36_{sys} \pm 0.28_{model\ b\to c} \pm 0.22_{model\ b\to u}) \cdot 10^{-4}$$

$$|V_{ub}| = (3.96 \pm 0.47_{exp} \pm 0.52_{theo}) \cdot 10^{-3}$$

B→Xlν using full reconstruction of the other B



- Measuring B flavour/ lepton charge correlation
- Lepton momentum measurement in B rest-frame

- Subtraction of continuum (8.8fb^{-1} of offresonance data)
- Taking into account other background:
  Leptons from J/ψ, γ conv., upper vertex charm
- Numbers corrected for mixing in the B^0 case

Reconstructed channels:

$B^0 \to D^{*+}\pi^- / D^{*+}\rho^- / D^{*+}a_1^- ; D^+\pi^- / D^+\rho^- / D^+a_1^-$

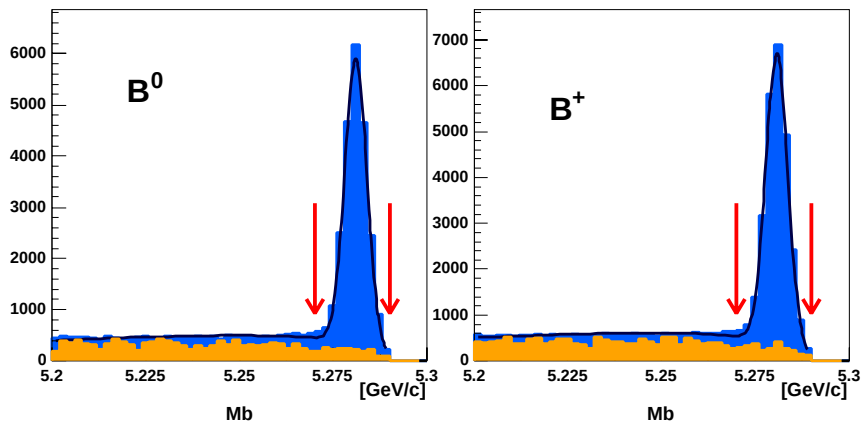
$B^- \to D^{*0}\pi^- / D^{*0}\rho^- / D^{*0}a_1^- ; D^0\pi^-$

($B^- \to D^+\rho^- / D^+a_1^-$ not used due to low purity)

$D^* \to D^0\pi$

$D^0 \to K\pi / K\pi\pi^0 / K\pi\pi\pi / K_s\pi\pi$

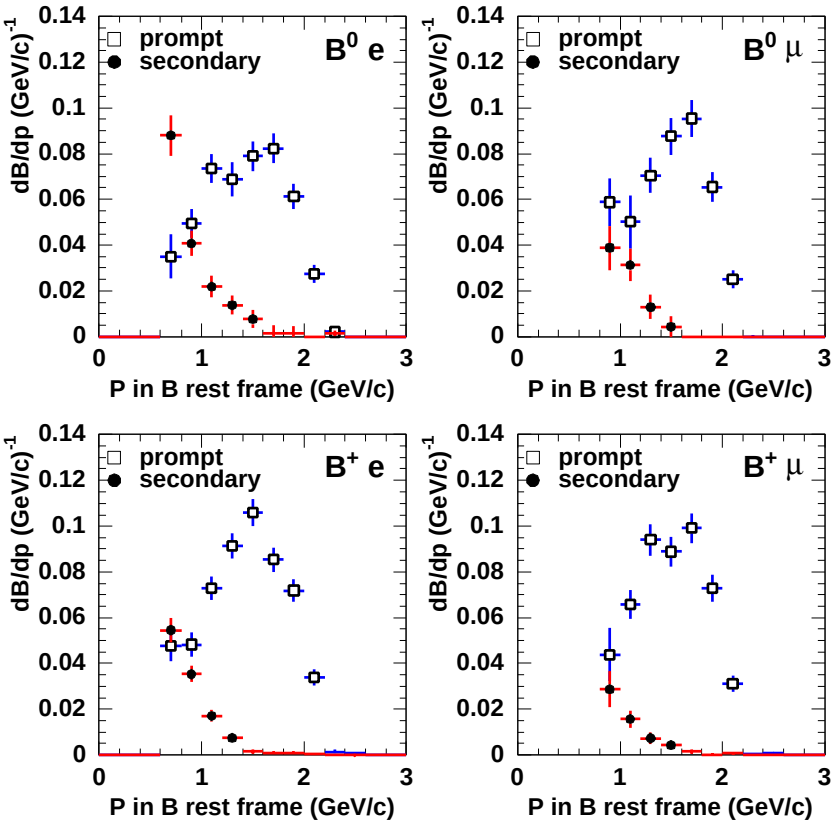
Beam constrained mass: $\sqrt{(E_{beam}, p_B)^2}$



$N(B^0)=21915\pm202$ $N(B^+)=24529\pm227$

B→Xlν using full rec. of the other B: the results (78 fb^{-1})

Lepton momentum in B rest frame



stat. sys.

Br ($B^0 \to Xl\nu$)=(10.32 ± 0.32 ± 0.29)%

Br ($B^+ \to Xl\nu$)=(11.77 ± 0.26 ± 0.32)%

Preliminary

stat. sys.

Br ($B \to Xl\nu$)=(11.19 ± 0.20 ± 0.31)%

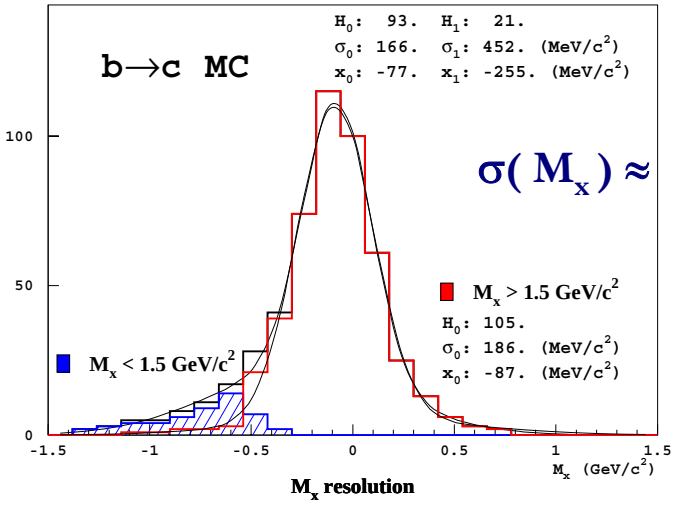
Br (B^+)/Br (B^0)= 1.14 ± 0.04 ± 0.01

Consistent with B^+/B^0 lifetime ratio

Preliminary

$|V_{cb}| = (4.13 \pm 0.07_{exp.} \pm 0.25_{theo.}) \cdot 10^{-2}$

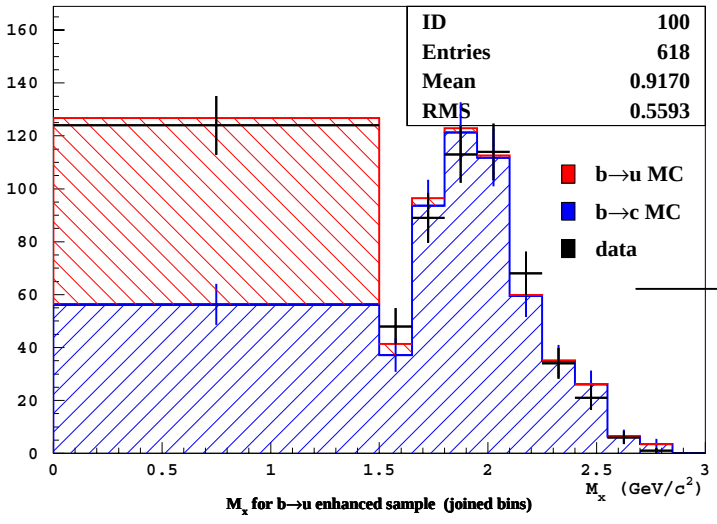
Full reconstruction tag: $|V_{ub}|$ pre-release



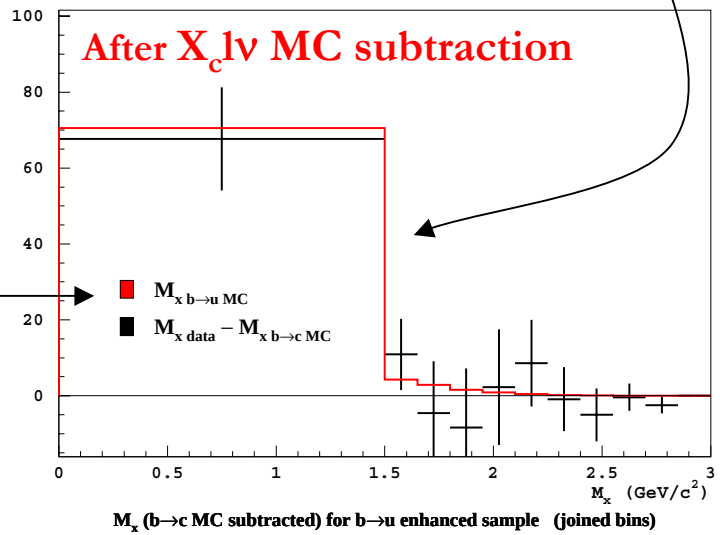
$\sigma(M_x) \approx$ 190MeV

M_x resolution

- Good M_x resolution
- Observed excess of events in the low M_x

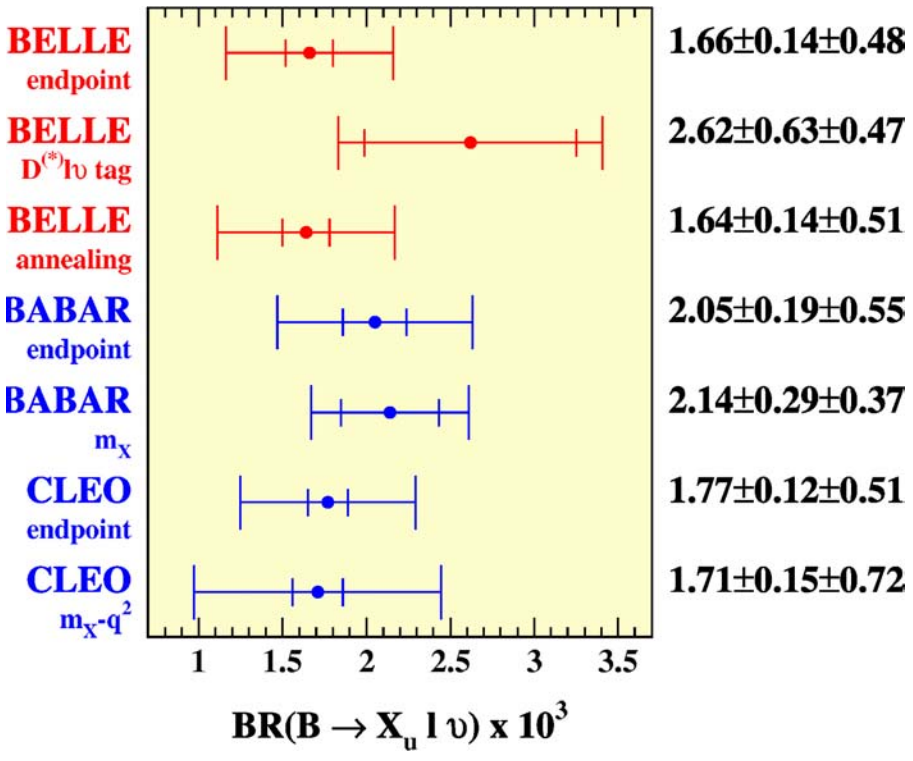


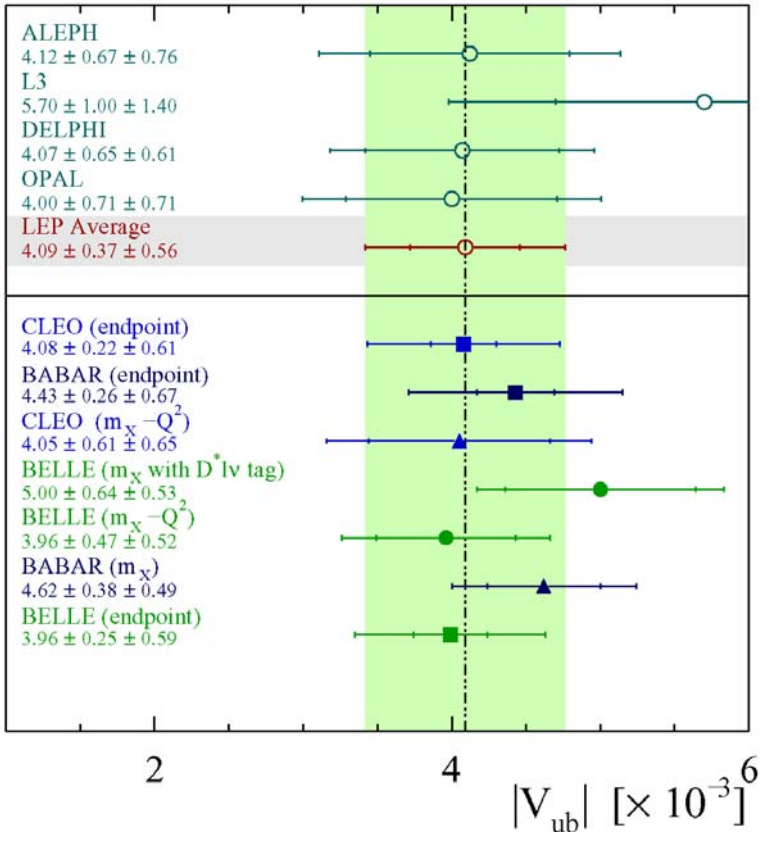
M_x for b→u enhanced sample (joined bins)



M_x (b→c MC subtracted) for b→u enhanced sample (joined bins)

$|V_{ub}|$ Results

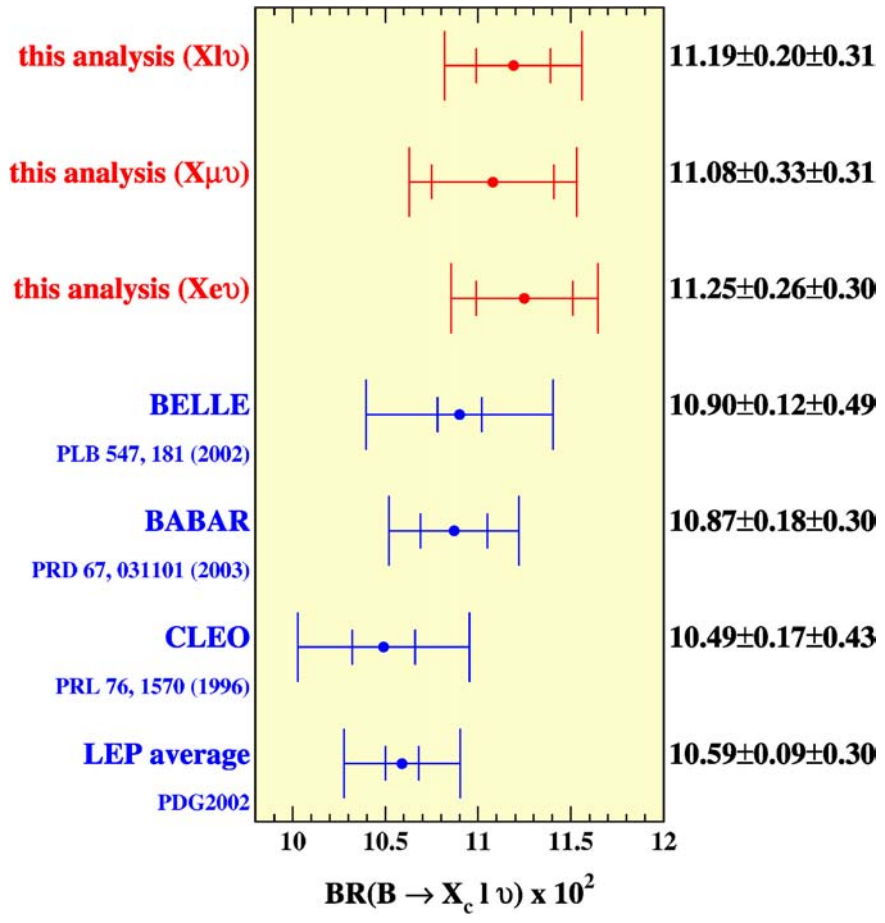


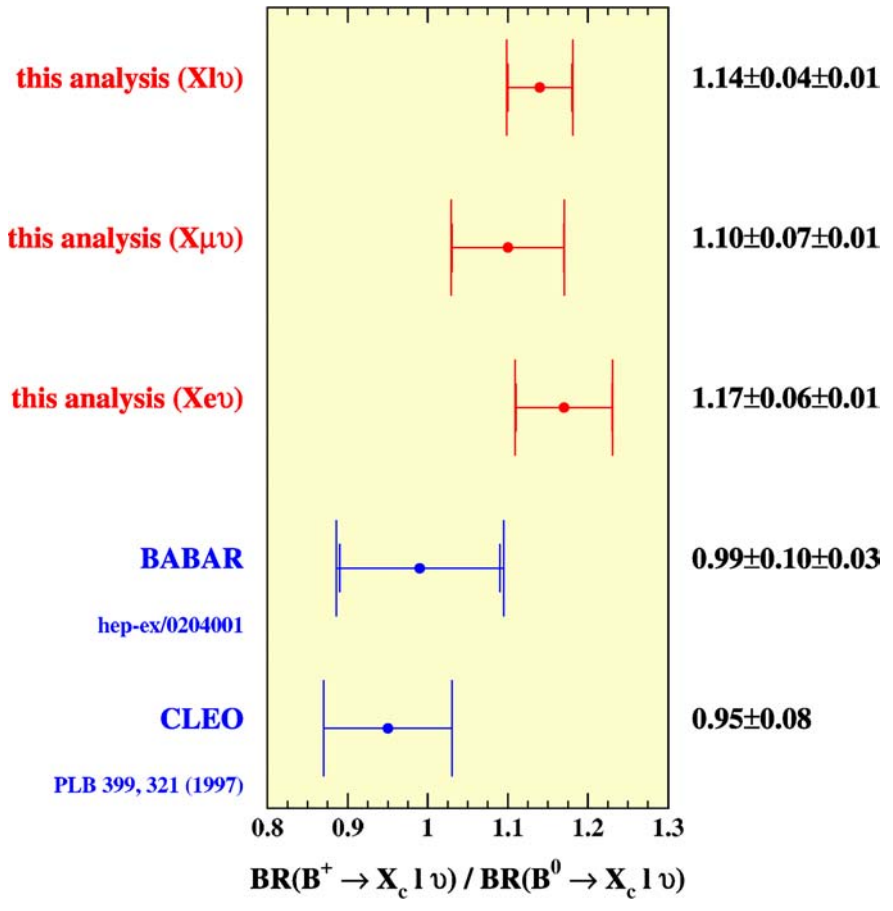


Exclusive:

$Br\ (B^+ \to \omega l^+ \nu) = (1.3 \pm 0.4 \pm 0.2 \pm 0.3) \cdot 10^{-4}$

$|V_{cb}|$ Results





Preliminary

$$|V_{cb}| = (4.13 \pm 0.07_{\text{exp.}} \pm 0.25_{\text{theo.}}) \cdot 10^{-2}$$

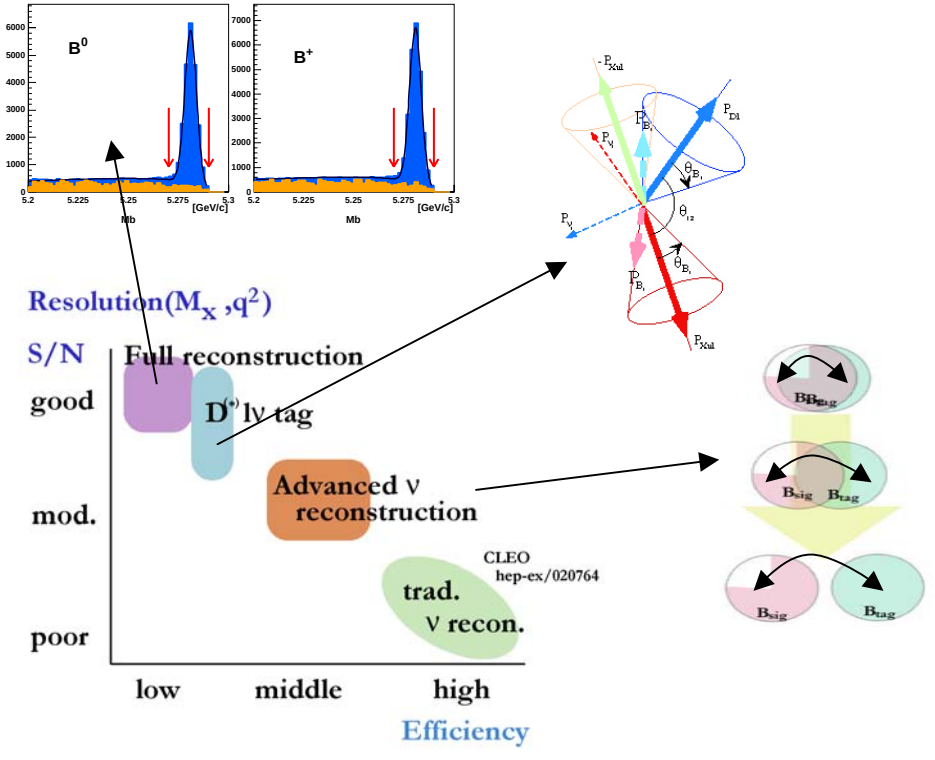
Conclusion

$|V_{ub}|$

Inclusive measurements by using M_x / q^2

Lepton endpoint measurement

Exclusive result for $\omega l^+ \nu$



$|V_{cb}|$

Inclusive measurement on fully recon. sample

Future

Finalise the analyses + use the whole data set

Preliminary number for $|V_{ub}|$ with full reconstruction method out soon