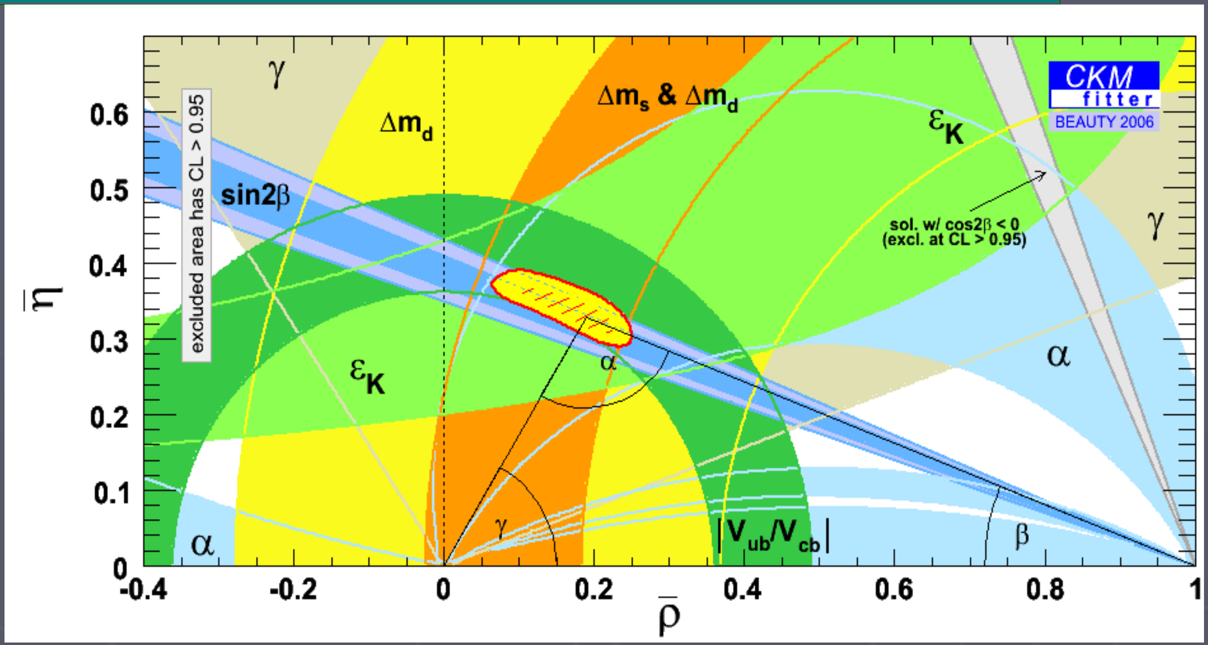
# Exclusive $B \rightarrow X_u l \nu$ decays with BaBar

Benoit VIAUD
Université de Montréal
On behalf of the BaBar collaboration

# Why $|V_{ub}|$ with exclusive decays ??




> Most precise $|V_{ub}|$ measurements to date: inclusive $B \to X_u l\nu$

- "Tension" with constraints from UT angles (e.g. sin2β) .
- Large uncertainty on $|V_{ub}|$ from theory !

  $\Gamma(b \to cl\nu) = 50\times\Gamma(b \to ul\nu)$ -> tight kinematical cuts

  -> difficult treatment of the Fermi motion of the b inside the B.

=> Need an alternative approach: exclusive decays !

# $|V_{ub}|$ from Exclusive $B \to X_u l\nu$ Decays ($X_u = \pi, \rho, \eta, \eta', \ldots$)

> Theory: more difficult to describe a specific final state an inclusive one

$$|V_{ub}| = \sqrt{\Delta B / \tau_B \Gamma_{thy}}$$

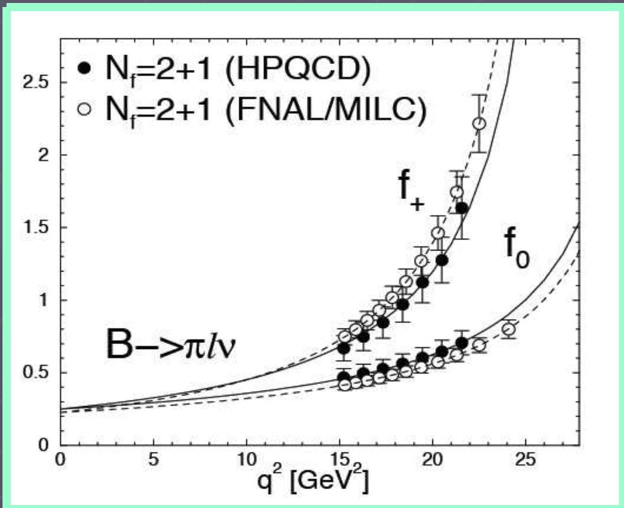
$$\Gamma_{thy} = \frac{G_F^2}{24\pi^3} \int_{q^2_{min}}^{q^2_{max}} \left| f_+(q^2) \right|^2 p_\pi^3 \, dq^2$$

Evaluation of the $f_+(q^2)$ Form Factor (FF): Need theo. calculations

- LQCD ($q^2 > 16$ GeV$^2$): HPQCD[1], FNAL[2]
- LCSR ($q^2 < 16$ GeV$^2$): Ball-Zwicky[3]
- quark model : ISGW2 [4]
- Extrapolation to the full $q^2$ range:

Ex: Becirevic-Kaidalov (BK) parameterization

$$f^+(q^2, \alpha) = \frac{f_0}{(1 - q^2/m^2_{B^*})(1 - \alpha q^2/m^2_{B^*})}.$$




-> unquenched LQCD / LCSR: $\sigma_{th}$ now down to ~12% !! ( >16 / <16 GeV$^2$ )

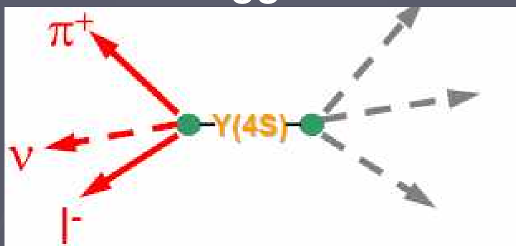
-> But need more to reach the same precision as inclusive decays.

Experiments can help -> constraint on the FF shape

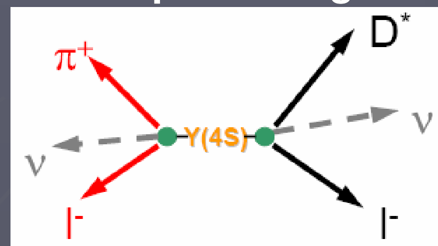

[1] Gulez & al, hep-lat/0601021
[2] Okamoto & al, hep-lat/0409116
[3] Ball & al, hep-ph/0406232
[4] Scora & al, hep-ph/9503486

# Tagged and untagged analyses

**Untagged**




**Semileptonic tag**




*tag side: $B \to D^{(*)} l \nu$

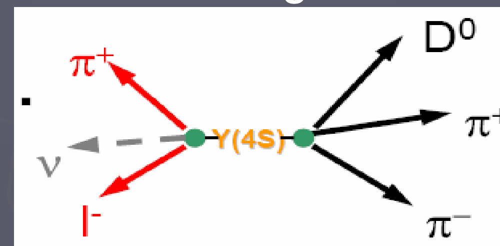
$D^0 \to K^-(\pi^+, 3\pi\pi\pi, \pi^+\pi^0)$, $K^0_s \pi^+\pi^-$;

$D^+ \to K^- 2\pi$;

$D^{(*+)} \to D^{+/0}\pi^{0/+}$

*tag-B kinematics incomplete: 2 $\nu$

**Hadronic tag**




*tag side: $B \to D^{(*)} + (\pi^\pm, K^\pm)$, full reco. (~1000 modes)

*Well defined event : full knowledge of kinematics, charge, flavor.

*Only one neutrino : precise reconstruction of $m^2_{miss}$, $q^2$

High signal statistics,

More sensitive to

Background simulation

clean sample

Purity +

+ Efficiency

# B→πlν, Hadronic and semileptonic Tags

Once a BB event is tagged by finding a $B_{tag}$ …

- Select B→π lν signal in the recoil of $B_{tag}$:
  - Only one π-l pair, $p_e(p_\mu) > 0.5(0.8)$ GeV
  - No other tracks, small residual energy
- B→π lν extracted in 3 $q^2$ bins

hadr. tag:

-$q^2=(p_l+p_{miss})^2$, $p_{miss}= p_{Y(4S)}-p_{Btag}- p_\pi - p_l=p_\nu$

-$m_{ES}$ fit in $m^2_{miss}$ bins to subtract combinatorics/ non BB

-$N_{sig}$ = (data – Backgrounds from MC),

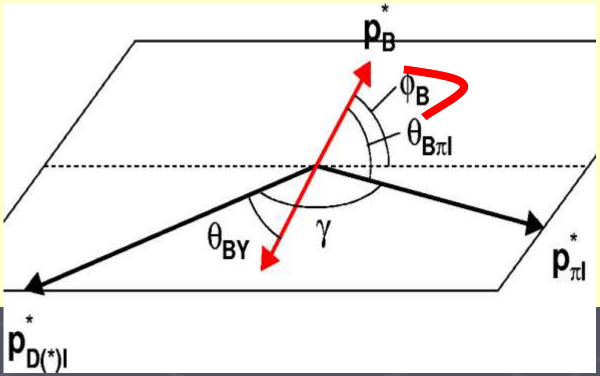
MC rescaled with $m^2_{miss}$ sideband

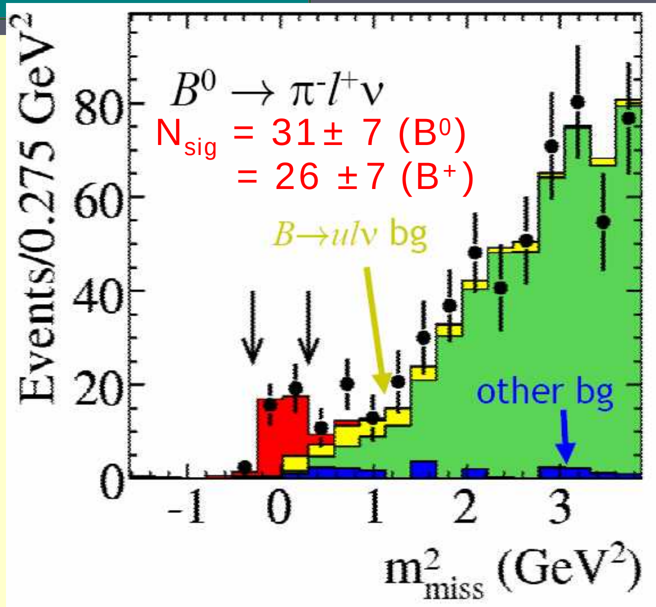
½-lep. tag:

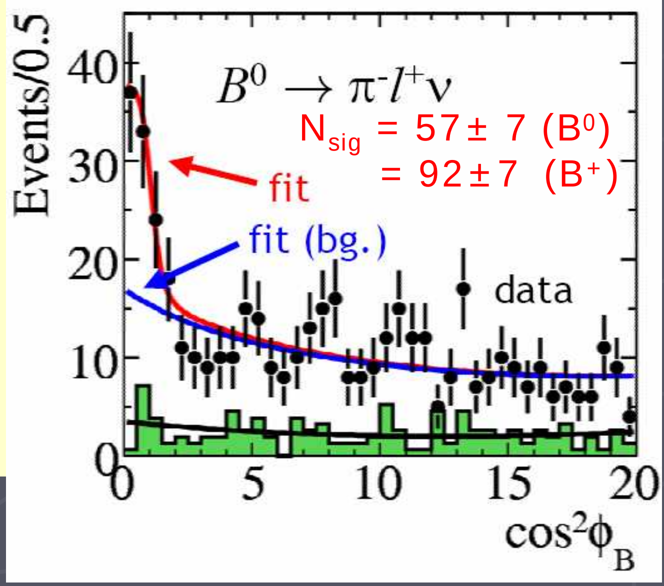
-$q^2=(m_B- E_\pi)^2 -|p_\pi|^2$ ( hypo: B at rest in Y(4S) frame)

-Fit to $\cos^2\Phi_B$

(<1 for clean signal events where only the ν are undetected)

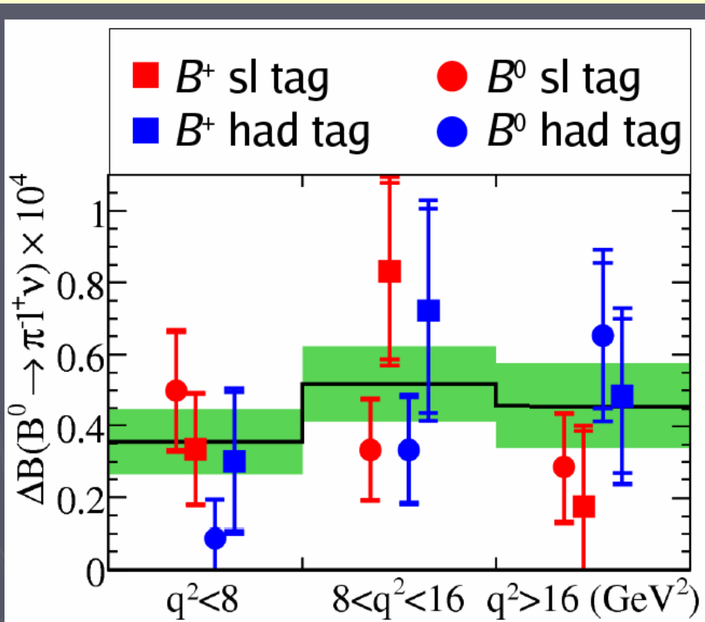


# Combine Hadronic & Semileptonic Tags, $B^+$ & $B^0$

- weighted averages + isospin symmetry: $\Gamma(B^0 \to \pi^- l^+ \nu) = 2\Gamma(B^+ \to \pi^0 l^+ \nu)$




| $\Delta BF(q^2 > 16)$ | $\Delta BF(q^2 < 16)$ | Total BF |
|---|---|---|
| $0.46 \pm 0.10 \pm 0.06$ | $0.87 \pm 0.13 \pm 0.06$ | $\boxed{1.33 \pm 0.17 \pm 0.11}$ |

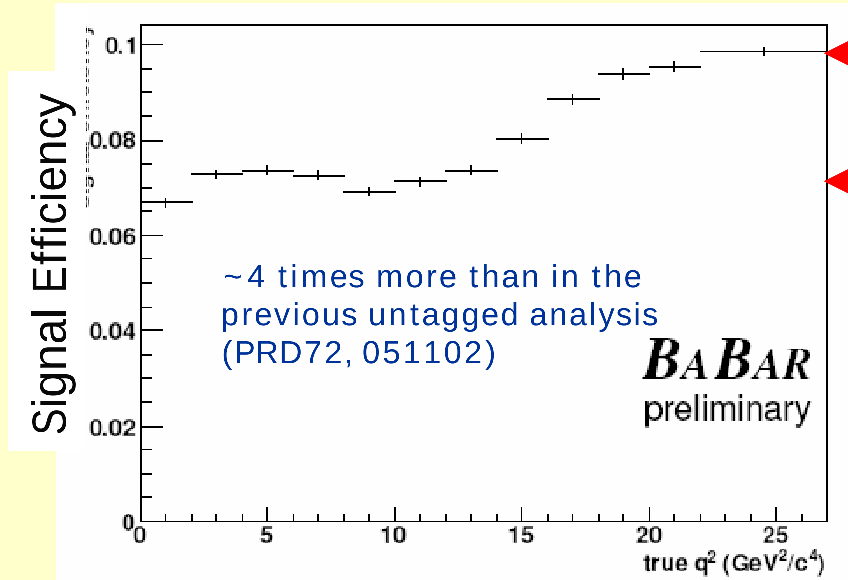
| | $q^2$ (GeV$^2$) | $\Delta\zeta$ (ps$^{-1}$) | $\lvert V_{ub}\rvert$ ($10^{-3}$) |
|---|---|---|---|
| LCSR | $< 16$ | $5.44 \pm 1.43$ | $3.2 \pm 0.2 \pm 0.1^{+0.5}_{-0.4}$ |
| HPQCD | $> 16$ | $1.46 \pm 0.35$ | $4.5 \pm 0.5 \pm 0.3^{+0.7}_{-0.5}$ |
| FNAL | $> 16$ | $1.83 \pm 0.50$ | $4.0 \pm 0.5 \pm 0.3^{+0.7}_{-0.5}$ |

- Limited by statistics !
- Largest systematics:
  - hadronic: $m_{ES}$ fit, neutral and $\mu$ reconstruction
  - 1/2leptonic: Btag efficiency, $\cos^2\Phi_B$ shape for backgrounds
  - both: BF & FF of semileptonic backgrounds

# Untagged $B^0 \to \pi^- l^+ \nu$, loose $\nu$-reconstruction

206 $fb^{-1}$ , hep-ex/06xxxxx

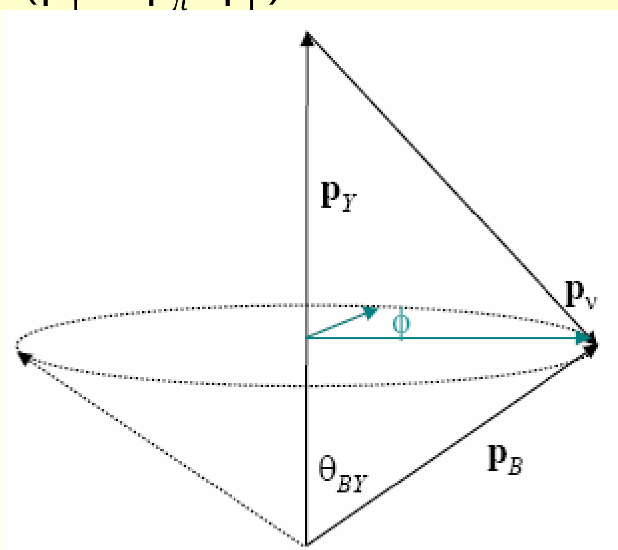
- Novel technique ! No tight $\nu$-reconstruction cuts : Signal Yield + Purity -
  - **π-l** pair (tight identification criteria)
  - Cuts optimized as a function of $q^2$




9.8%

6.7%

$q^2 = (p_B - p_\pi)^2$ :
"Y-average frame" method
($p_Y = p_\pi + p_l$ )




In the Y(4S) frame:
$|p_B|$ = nominal from 4-mom. conservation
+
average over arbitrary azimuth
Φ, Φ+90°, Φ+180°, Φ+270°

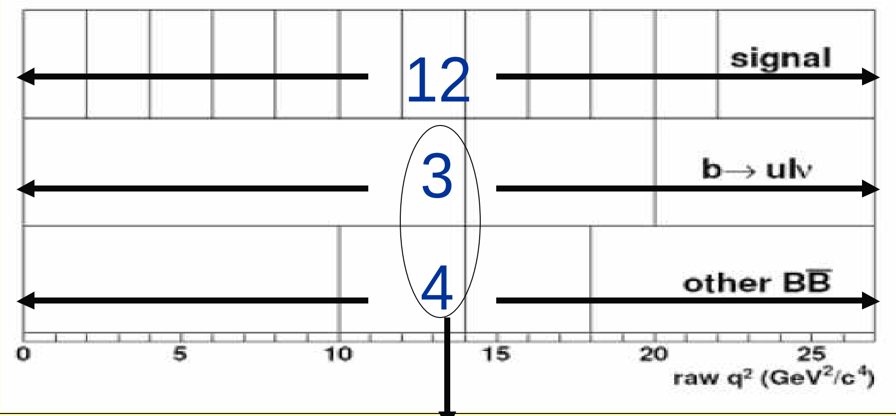
$\sigma$ =0.53 $GeV^2$
Corrected by an unfolding procedure

# $B^0 \to \pi^- l^+ \nu$, loose $\nu$, Signal Yield Extraction

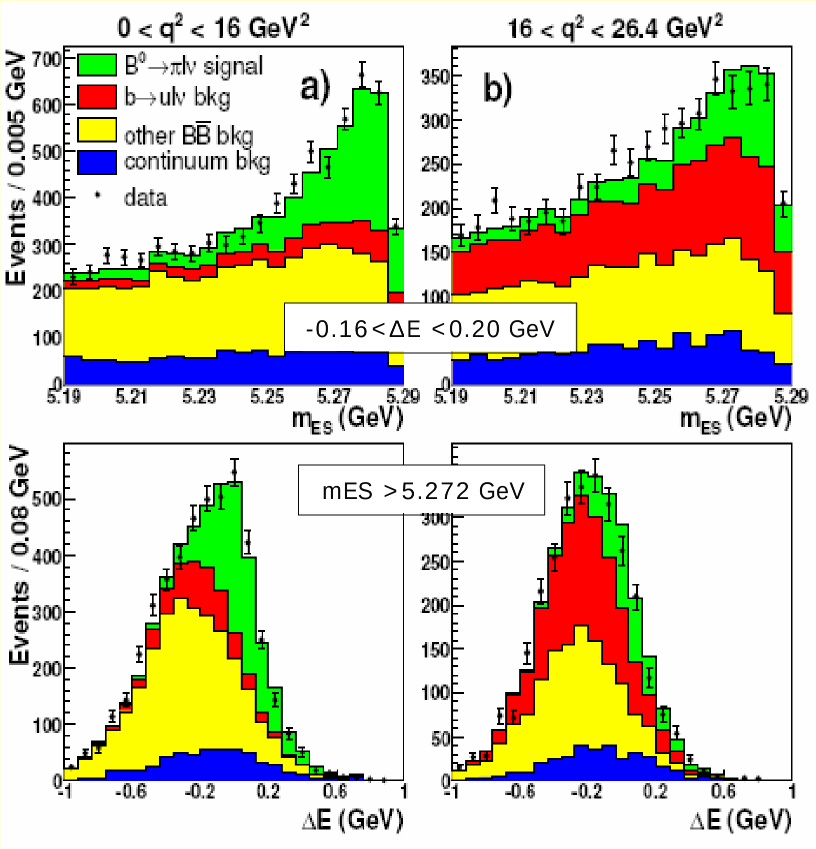
- 2+1 ($\Delta E, m_{ES}$ ; $q^2$) extended binned max. likelihood fit

$m_{ES} = \sqrt{s/4 - |\mathbf{p}_B|^2}$ $\Delta E = E_B - \sqrt{s}/2$

- Finds **19** scaling factors to be applied to MC histograms to fit data




Fit the background normalization as a function of $q^2$
-> Reduce syst. error from BF & FF

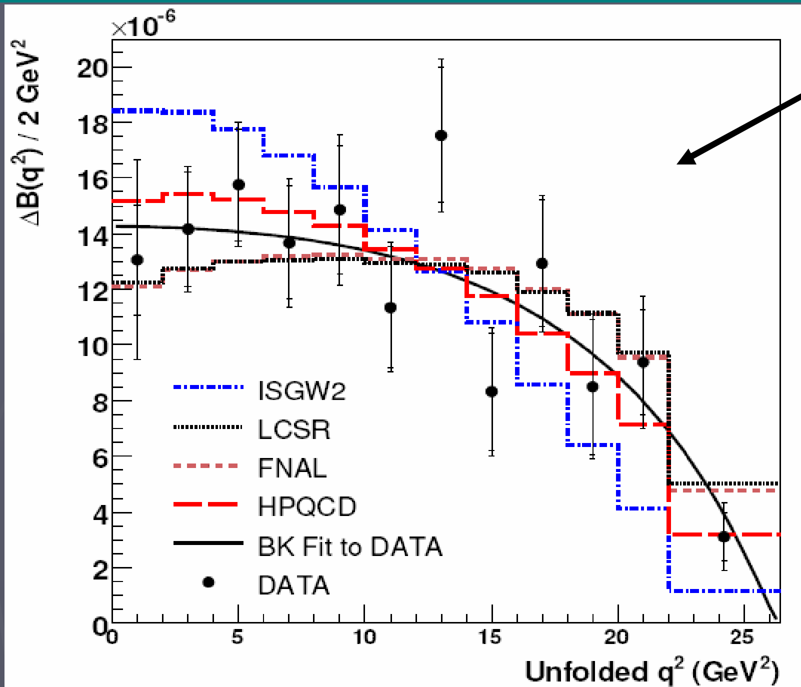



- Continuum fixed, corrected to match the off-resonance data control sample ($27 fb^{-1}$)

- Signal Yields: 367 to 523 depending on $q^2$
  Total = 5072

$\chi^2$ = 423 for 389 d.o.f

# Results: $|V_{ub}|$ & Form Factors




-ΔBF in 12 $q^2$ bins,
stat. & syst cov. mat. also measured

$$BF = 1.46 \pm 0.07_{stat} \pm 0.08_{syst}$$

-BK fit to the data:

$\alpha = 0.52 \pm 0.05 \pm 0.03$

$|V_{ub} f_+(0)| = (9.6 \pm 0.3 \pm 0.2) \times 10^{-4}$

-Data/th. Calculations comparison, $P(\chi^2)$

| | | | |
|---|---|---|---|
| BK fit | 0.65 | HPQCD | 0.67 |
| FNAL | 0.45 | LCSR | 0.41 |
| ISGWII | 0.0006 -> incompatible with data ! | | |

| | $q^2$ (GeV$^2$) | $\Delta\zeta$ (ps$^{-1}$) | $\|V_{ub}\|$ ($10^{-3}$) |
|---|---|---|---|
| HPQCD | $> 16$ | $1.46 \pm 0.35$ | $4.1 \pm 0.2 \pm 0.2\ ^{+0.6}_{-0.4}$ |
| FNAL | $> 16$ | $1.83 \pm 0.50$ | $3.7 \pm 0.2 \pm 0.2\ ^{+0.6}_{-0.4}$ |
| LCSR | $< 16$ | $5.44 \pm 1.43$ | $3.6 \pm 0.1 \pm 0.1\ ^{+0.6}_{-0.4}$ |
| ISGW2 | 0-26.4 | $9.6 \pm 4.8$ | $3.2 \pm 0.1 \pm 0.1\ ^{+1.3}_{-0.6}$ |

Dominant systematics: detector effects and continuum description

# Prospects: $|V_{ub}|$ at Babar with 1/ab (end of 2008)

> Reduction of systematic uncertainties

- improved track and neutral reconstruction
- better knowledge of $b \to u l \nu$ backgrounds (BF and FF)
- systematics based on data/MC comparisons (loose-$\nu$ : continuum, tagged analyses: $\cos^2\Phi_B$ shape) might be reduced with higher statistics.

Combined with ~5 times more statistics:

Expected uncertainties, in terms of $B^0 \to \pi^- l^+ \nu$ (Combine Hadr. & ½ leptonic Tags, B+ & B0 )

| method | $N_{sig}$ | $\sigma_{BF\text{-}stat}$(%) | $\sigma_{BF\text{-}syst}$ (%) | $\sigma_{BF\text{-}tot}$ (%) | $\sigma_{\lvert Vub \rvert}$ (%) Full $q^2$ range | $\sigma_{\lvert Vub \rvert}$ (%) $q^2$>16 GeV$^2$ |
|---|---|---|---|---|---|---|
| Hadronic tag | $B^+$ 130<br>$B^0$ 150 | 6(13) | 6(8) | 8.5(15) | 4 (7.5) | 7(13) |
| ½ leptonic tag | $B^+$ 450<br>$B^0$ 280 | | | | | |
| untagged | 25000 | 2.5(5) | 4(5) | 4.5(7.5) | 2.5(3.2) | 4(7) |

$$|V_{ub}| = (4.1 \pm \underline{0.3}\,^{+0.6}_{-0.4}) \times 10^{-3} \to (x.x \pm \underline{0.1}\,^{+0.6}_{-0.4}) \times 10^{-3}$$

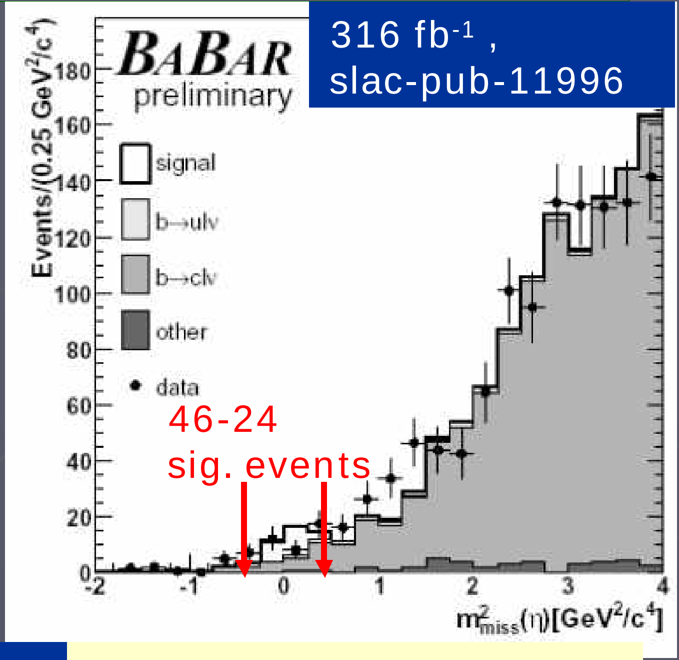
Full $q^2$ range

Which reduction can we expect here ???

# Other Channels: $B \to (\eta, \eta', \rho) l \nu$

- B->(η, η') lν with a hadronic tag
  - analogous to B->πlν
  - $\eta \to \gamma\gamma$, $\pi^+\pi^-\pi^0$, $\pi^0\pi^0\pi^0$ / $\eta' \to \rho^0\gamma$ ($\rho^0 \to \pi^+\pi^-$), $\eta\ \pi^+\pi$
  - VERY LOW statistics

$$\mathcal{B}(B^+ \to \eta l^+ \nu) = (0.84 \pm 0.27_{\text{stat}} \pm 0.21_{\text{syst}}) \times 10^{-4}$$
$$\mathcal{B}(B^+ \to \eta' l^+ \nu) < 1.3 \times 10^{-4} (90\%\text{CL})$$




316 fb$^{-1}$, slac-pub-11996

- Ready soon: B->ηlν , untagged analysis

318 fb$^{-1}$

- Ready soon: B->ρlν , untagged analysis 318 fb$^{-1}$
  - In 3 $q^2$ bins
  - Even with 1/ab, will be difficult to extract the full 4-D $\frac{d\Gamma}{dq^2 d\cos\theta_\ell \cos\theta_V d\chi}$ rate ($5^4$ bins !)

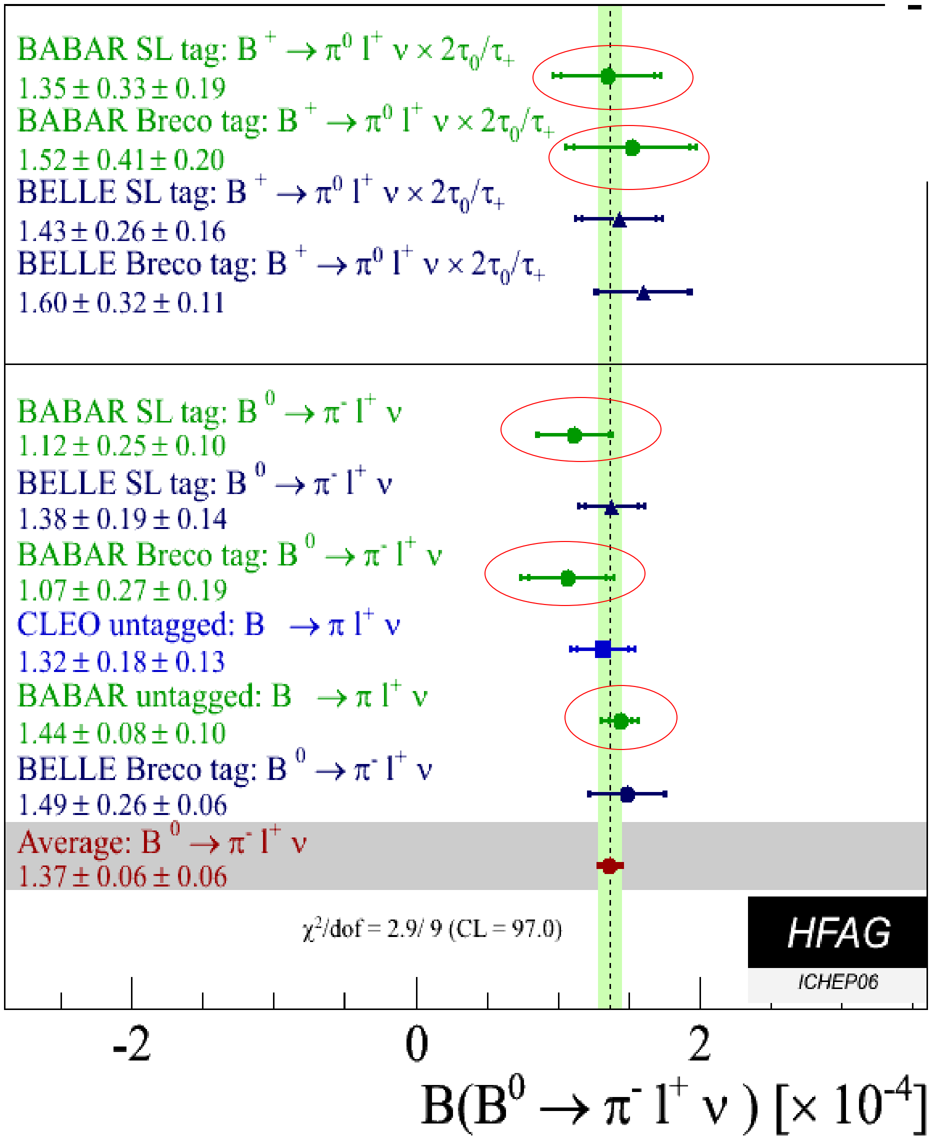
  Would need help from th. : integrate over the angles ? FF ratios ?

- These measurements will yield a nice improvement of the experimental knowledge of these channels. Theoretical progress needed to fully take advantage of this ($|V_{ub}|$ extraction, constraints on FF,...)
  - Existing model: Ball-Zwicky [3] (not for η') ; Nothing (?) from LQCD...
  - Something new by the end of 2008 ??

# Also on the way: D→(π,K)lν

- Test of FF calculations
- $|V_{ub}|$ from $$\frac{d\Gamma(B\to\pi\ell\nu)/dw}{d\Gamma(D\to\pi\ell\nu)/dw}=\left|\frac{V_{ub}}{V_{cd}}\right|^2\left(\frac{M_B}{M_D}\right)\left|\frac{f_+^{B\to\pi}}{f_+^{D\to\pi}}\right|^2 \qquad w=\frac{M^2+m_\pi^2-q^2}{2Mm_\pi}$$

# Summary




- 3 Analyses:
  - 2 measurements of BF(B-> $\pi l \nu$)
  - 2 measurements of $|V_{ub}|$

Loose neutrino (with HPQCD):

$|V_{ub}| = (4.1 \pm 0.2 \pm 0.2^{+0.6}_{-0.4}) \times 10^{-3}$

World Average (HFAG, HPQCD )

$|V_{ub}| = (3.93 \pm 0.26^{+0.6}_{-0.4}) \times 10^{-3}$

Babar, End of 2008 ?

$|V_{ub}| = (4.1 \pm 0.1^{+x.x}_{-x.x}) \times 10^{-3}$

Precision similar to inclusive $|V_{ub}|$ ??

$|V_{ub}| = (4.49 \pm 0.19 \pm 0.27) \times 10^{-3}$

Average (HFAG, BNLP)

# Back-up

# Theoretical side: on going work…

> Extend FF calculations to the full $q^2$ range

- moving NRQCD
  - non relativistic description of the b quark in a moving frame of reference (instead of B frame). B and $\pi$ in opposite directions.

$$p_b = m_b u + k\,; \quad u = 4\text{-velociy of B} = p_B / m_B = \gamma(1, \vec{v})$$

K.Y Wong, LAT06

exact treatment

Discretize this (k is small)

- parameterization of the FF shape (Becher & Hill, hep-ph/0509090 ; Ball hep-ph/0611108, …)

$$f(t) = \frac{1}{P(t)\phi(t,t_0)} \sum_{k=0}^{\infty} a_k(t_0)\, z(t,t_0)^k$$

Accounts for B* pole.

Calculable function to make $a_k$s look simple.

$$z(t,t_0) = \frac{\sqrt{t_+ - t} - \sqrt{t_+ - t_0}}{\sqrt{t_+ - t} + \sqrt{t_+ - t_0}}$$

( $t = q^2 = (p_H - p_L)^2$, $t_+ = (m_H + m_L)^2$, $t_- = (m_H - m_L)^2$).

Unitarity -> $\sum_{k=0}^{n_A} a_k^2 \leq 1$

Heavy quarks, B($\pi l \nu$) in powers of $\Lambda_{QCD}/m_B$ -> $\sum_{k=0}^{\infty} a_k^2$ of order $(\Lambda/m_b)^3$

Theoretical constraints + shape from data -> very precise knowledge of the shape.

# Theoretical side: on going work...

> Potential reduction of theoretical uncertainties: on going work in LQCD

- improved matching between LQCD and continuum QCD (2-loops calculations or fully non-perturbative)
- improved extrapolation to physical light quark masses ($\chi_{PT}$)
- smaller lattice spacings
- various types of actions (in addition to improved staggered AsqTad action, presently used by the FNAL and HPQCD calculations we use).
- What else ??

=> We need $\sigma_{th}$ to drop from ~13% to ~6% to reach a precision similar to inclusive $B \to X_u l\nu$ decays:

Exclusive, end 2008 ??

$$|V_{ub}| = (x.x \pm 0.1^{+0.3}_{-0.2}) \times 10^{-3}$$

Inclusive (Average from HFAG, BNLP)

$$|V_{ub}| = (4.49 \pm 0.19 \pm 0.27) \times 10^{-3}$$

Can we hope it will be so by the end of 2008 ??

# Leading systematics ( % ) (detector and Continuum)

| $q^2$ bins ($GeV^2$) | 0-2 | 12-14 | 22-26.4 | q2<16 | q2>16 | Total |
|---|---|---|---|---|---|---|
| Trk eff | 1.6 | 1.8 | 9.2 | 1.9 | 1.8 | 1.1 |
| $\gamma$ eff | 4.7 | 3.5 | 7.0 | 2.9 | 1.7 | 1.9 |
| $K^0_L$ & neutrons | 0.9 | 1.6 | 2.8 | 1.2 | 1.4 | 1.3 |
| PID | 7 | 2.6 | 7.0 | 2.6 | 3.6 | 2.9 |
| Tot Detector & $K^0_L$ | 8.6 | 5.0 | 13.8 | 4.5 | 4.6 | 3.9 |
| Continuum Yield | 7 | 0.6 | 4 | 1.0 | 1.6 | 1.0 |
| Continuum shape | 20.3 | 1.5 | 10.2 | 2.6 | 3.2 | 2.3 |
| Total | 23.7 | 7.1 | 27 | 6.3 | 7.8 | 5.7 |

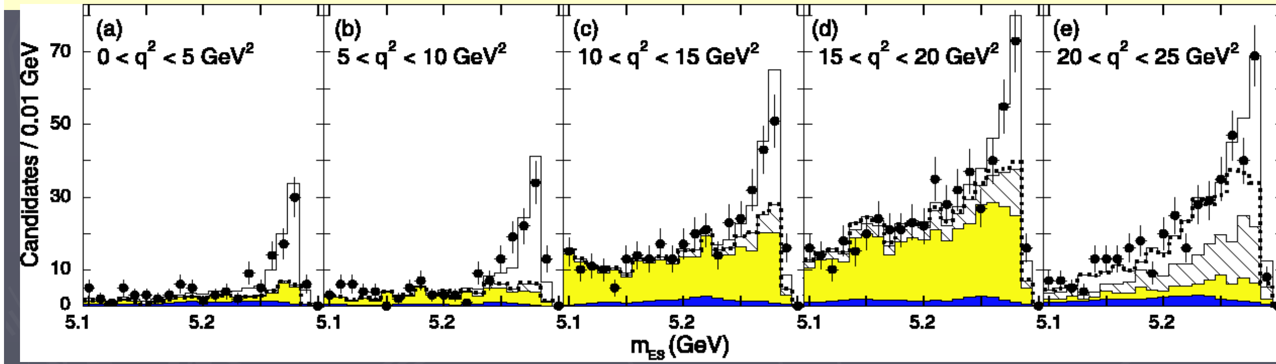
# ④Untagged B->π(ρ)lν, ν-reconstruction

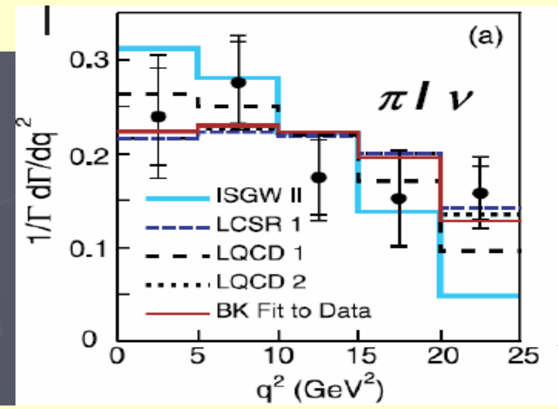
**76 fb$^{-1}$**, **hep-ex/0507003**
**PRD-RC 72, 051102 (2005)**

- Neutrino reconstruction from full event.
  - $|m^2_{miss}/2E_{miss}|<0.4$ GeV : Improves recons. of
  - kinem. cuts on $p_l$, $p_h$ : b->clν suppression
  - topological cuts: ee->qq suppression

$$q^2 = (p_l + p_\nu)^2 \quad \Delta E = E_B^* - \sqrt{s}/2 \quad m_{ES} = \sqrt{s/4 - |\vec{p}_B^{\,*}|^2}$$

- B-> **$\pi^+$,$\pi^0$, $\rho^+$, $\rho^0$ ,lν yields from max-LH fit to ΔE ×$m_{ES}$ in 5 (3) bins of $q^2$.**
  - 4 modes simultaneously, assumes isospin symmetry




$$\mathcal{B}(B^0 \to \pi^- \ell^+ \nu) = (1.38 \pm 0.10_{stat} \pm 0.16_{syst} \pm 0.08_{FF\ shape}) \times 10^{-4}$$

$$\mathcal{B}(B^0 \to \rho^- \ell^+ \nu) = (2.14 \pm 0.21_{stat} \pm 0.48_{syst} \pm 0.28_{FF\ shape}) \times 10^{-4}$$

- Syst. Error dominated by ν–reconstruction (tracks/neutrals) and background models.

BK fit to B->πlν data :

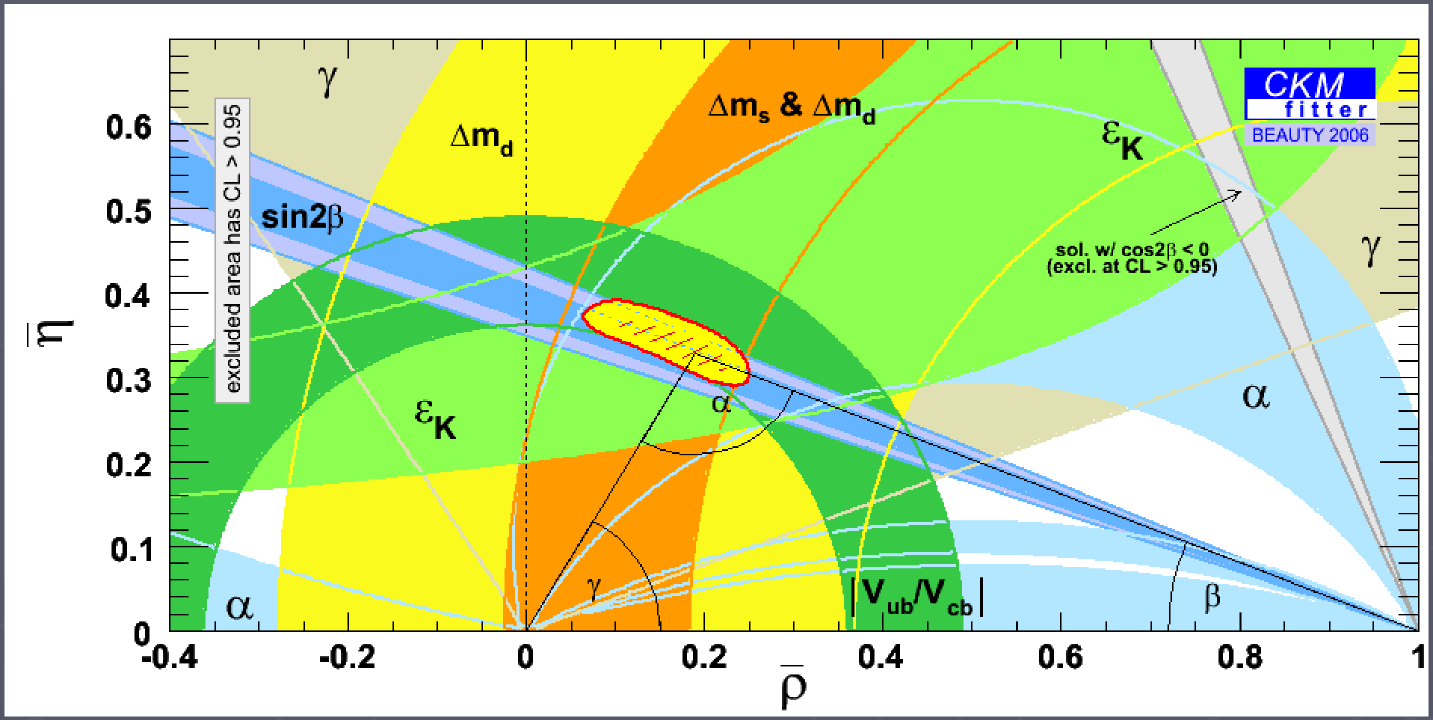
**α = 0.61±0.09**

(HPQCD : **α = 0.42**, FNAL **α = 0.62** )

- $|V_{ub}|$ with B->πlν + FNAL extrapolated to full range with BK:

$$|V_{ub}| = (3.82 \pm 0.14_{stat} \pm 0.22_{syst} \pm 0.11_{FF}\ {}^{+0.88}_{-0.52}{}_{LQCD}) \times 10^{-3}$$

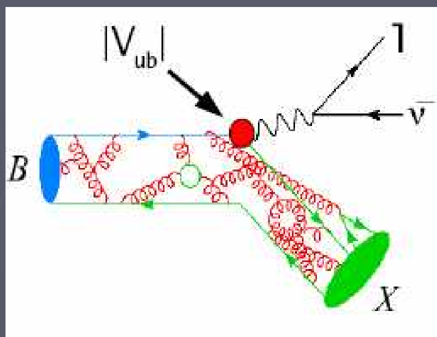
# $|V_{ub}|$




- Precise measurements of $|V_{ub}|$ yield a stringent constraint on the description of CP violation by the Standard Model.
- Complementary to sin2**β**

# $|V_{ub}|$ from $B \to X_u l \nu$ Decays

- Full decay rate: clean access to $|V_{ub}|$ (OPE+HQE: $\sigma_{th} < 5\%$ !)




$$\Gamma(B \to X_u l \upsilon) = \frac{G_F^2 |V_{ub}|^2 m_b^5}{192\pi^3}\left[1 - \frac{\mu_\pi^2}{2m_b^2} + \frac{\mu_G^2}{2m_b^2} + O\left(\frac{\alpha_s}{\pi}\right)\right]$$

$$|V_{ub}| = 0.00424\sqrt{\frac{B(B \to X_u l \nu)}{0.002}\,\frac{1.61\,ps}{\tau_B}}\left(1 \pm 0.020_{OPE} \pm 0.022_{HQE}\right)$$

<u>BUT</u>: difficult to measure: $\Gamma(b \to cl\nu) = 50 \times \Gamma(b \to ul\nu)$ !!

- <u>1st approach</u>: Inclusive selection, tight cuts (e.g. $E_l > E_{cut}$ )
  - $|V_{ub}|$ from partial BF: $|V_{ub}| = (\Delta BF/\Delta\zeta \ldots)$ = x.xx±x.xx (world ave)
  - Most precise approach up to now, but <u>large contribution from $\sigma_{th}$</u>.

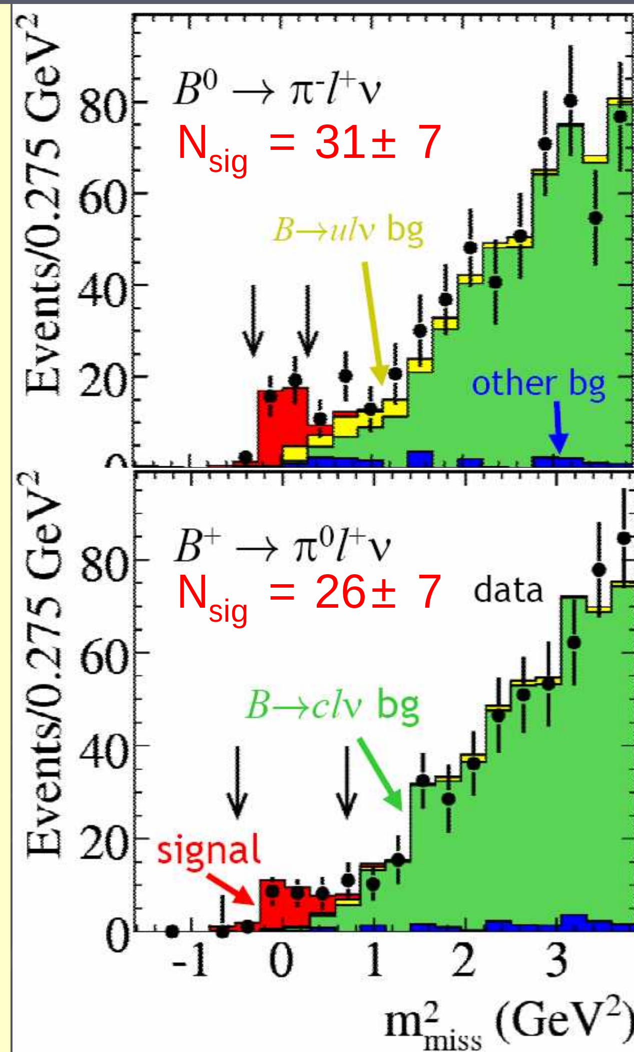
  $\Delta\zeta$ sensitive to the Fermi motion of the b inside the B (difficult to evaluate)

  -> good to have an alternative approach...

- <u>2nd approach</u>: Exclusive decays

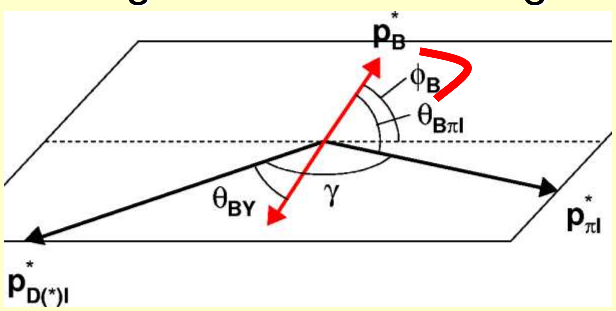
# B› πlν , Hadronic Tag

- Tag BB event with $B_{tag}$: fully reconstructed hadronic decay
- Select B› π lν signal in the recoil of $B_{tag}$:
  - one π l pair : $p_e(p_\mu)$ > 0.5(0.8) GeV
  - No other tracks, $E_{res}$ small
- Full reco. of $B_{tag}$ =>precise ν reconstruction
  - $\Delta E$, $m_{ES}$, , $p_{miss} = p_{Y(4S)} - p_{Btag} - p_\pi - p_l$ , $m^2_{miss}$
  - $q^2=(p_l+p_\nu)^2=(p_l+p_{miss})^2$
- B› π lν extracted in 3 $q^2$ bins
  - $m_{ES}$ fit in $m^2_{miss}$ bins to subtract combinatorics/non BB events
  - other backgrounds: MC, rescaled with $m^2_{miss}$ sideband
- ΔBF(B› π lν ) from the ratio of B-> π lν yields to B->Xlν yields + BF(B->Xlν ): $\sigma_{syst}$ ˘

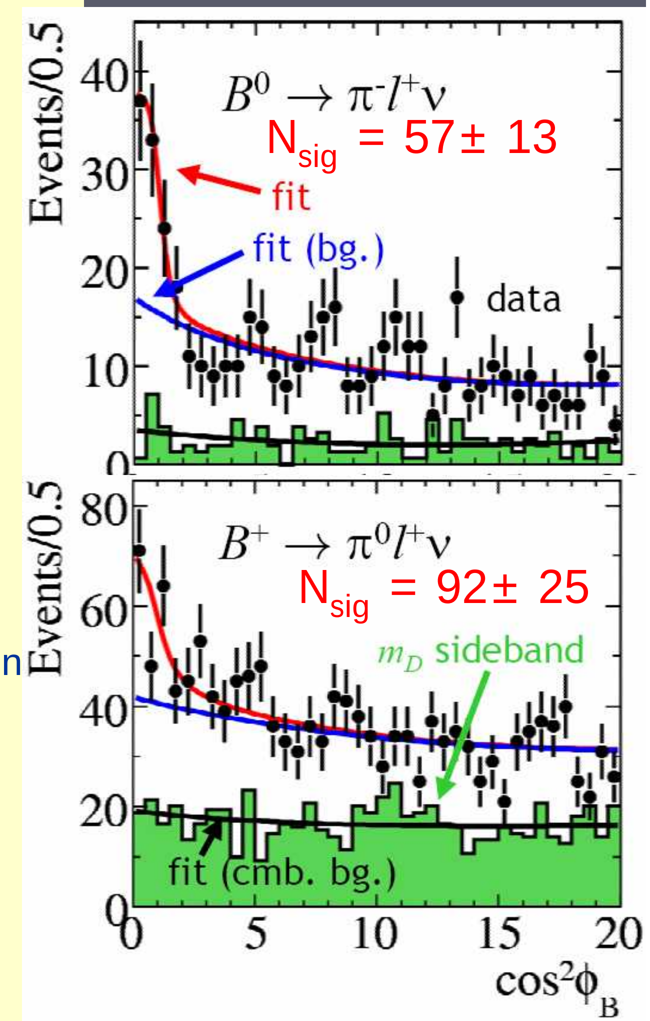


# B› πlν , semileptonic Tag

- Tag BB event with $B_{tag}$: B->D(*)lν
  - $D^0 \to K^-(\pi^+, 3\pi\pi\pi, \pi^+\pi^0)$, $K^0_s\,\pi^+\pi^-$ ; $D^+ \to K^-\,2\pi$ ; $D^{(*+)} \to D^{+/0}\pi^{0/+}$
  - $m_D$ , $|p_l|$ > 0.8 GeV, Dl vertex,...
- Select B› π lν signal in the recoil of $B_{tag}$:
  - one π l pair : $p_l$ >0.8 GeV
  - no other tracks, $E_{res}$ small
- $q^2 = (m_B - E_\pi)^2 - |p_\pi|^2$ (assume B at rest in Υ(4S) frame)
- Signal extraction: global event topology, 3 $q^2$ bins




Fit to $\cos^2\Phi_B$ :
- simultaneous to data and MC,
- $M_D$ sideband included to constrain combinatorial background




- ΔBF(B› π lν ): ε from MC +data control samples
  - events with 2 non-overlapping $B_{tag}$'s

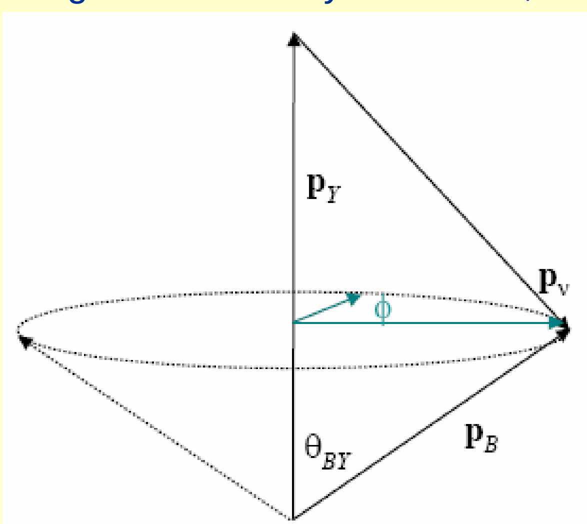
# ⑤ Untagged $B^0 \to \pi^- l^+ \nu$, loose $\nu$-reconstruction

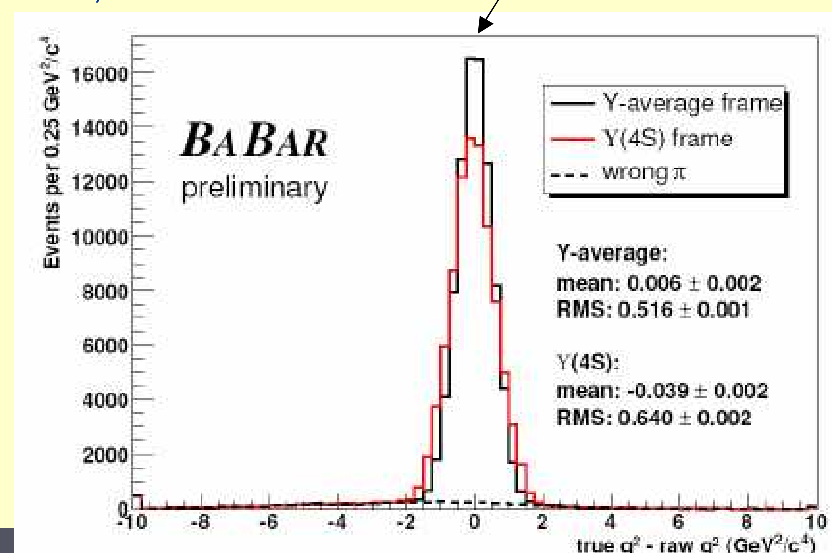
- Novel technique ! No tight $\nu$-reconstruction cuts : Signal Yield ^ Purity ˇ
  - $\pi l$ pair: tight $\pi$ and l ID criteria, $|p_{e(\mu)}|>0.5(1)$ GeV, $|\cos\theta_{BY}|<1$
  - Topology cuts to reduce non BB events.
  - Cuts optimized as a function of $q^2$: Angle between Y and rest of event thrust axes, $p_{miss}$ polar angle and $m^2_{miss}$ , W helicity angle
  - Signal efficiency from 6.7 % to 9.8 % (depending on $q^2$)
- $q^2=(p_B-p_\pi)^2$ with the "Y-average frame" method

  average over arbitrary azimuth Φ, Φ+90°, Φ+180°, Φ+270°

$\sigma$ =0.53 GeV²

Corrected by an unfolding procedure



# B› πlν , Hadronic and semileptonic Tags

$N_{sig}$ = 26± 7

Once a BB event is tagged by finding a $B_{tag}$ ...

- Select B› π lν signal in the recoil of $B_{tag}$:
  - Only one π-l pair, No other tracks, small residual energy
- B› π lν extracted in 3 $q^2$ bins

hadr. tag:

-$q^2=(p_l+p_{miss})^2$, $p_{miss}= p_{Y(4S)}-p_{Btag}- p_\pi - p_l=p_\nu$

-$m_{ES}$ fit in $m^2_{miss}$ bins to subtract combinatorics/ non BB

-other backgrounds: MC, rescaled with $m^2_{miss}$ sideband

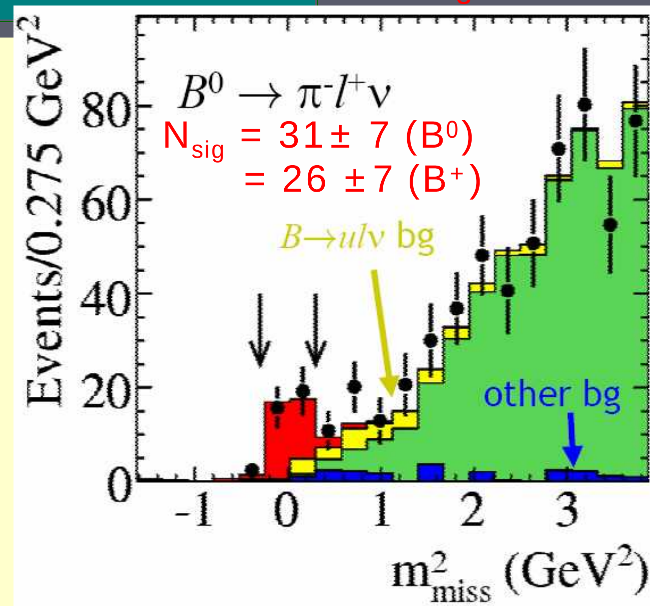
-ΔBF(B› π lν ) from the ratio of B-> π lν yields to B->Xlν yields + BF(B->Xlν ): $\sigma_{syst}$ ˘

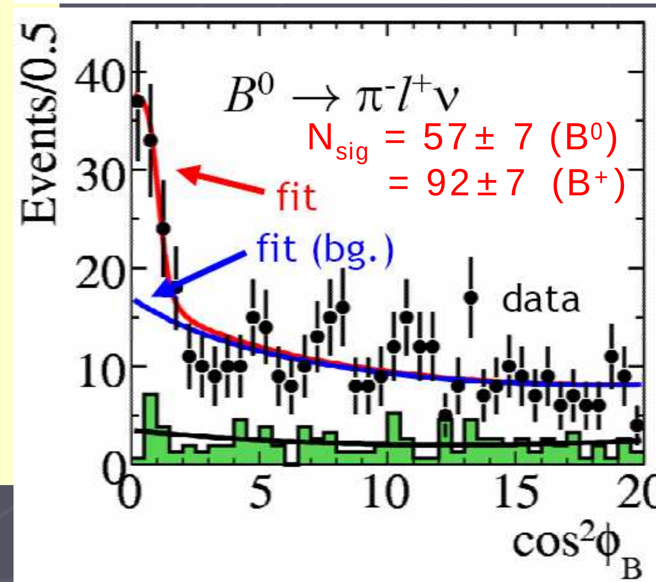
½-lep. tag:

-$q^2=(m_B- E_\pi)^2 -|p_\pi|^2$ ( hypo: B at rest in Y(4S) frame)

-Fit to $\cos^2\Phi_B$

-ΔBF(B› π lν ): efficiency from MC & data control samples (events with 2 non-overlapping $B_{tag}$'s)



# few definitions...

$$m_{\rm ES} = \sqrt{s/4 - |\mathbf{p}_B|^2} \quad \Delta E = E_B - \sqrt{s}/2$$

$$\cos\theta_{BY} = (2E_B E_Y - m_B^2 - m_Y^2)/(2|\mathbf{p}_B||\mathbf{p}_Y|)$$

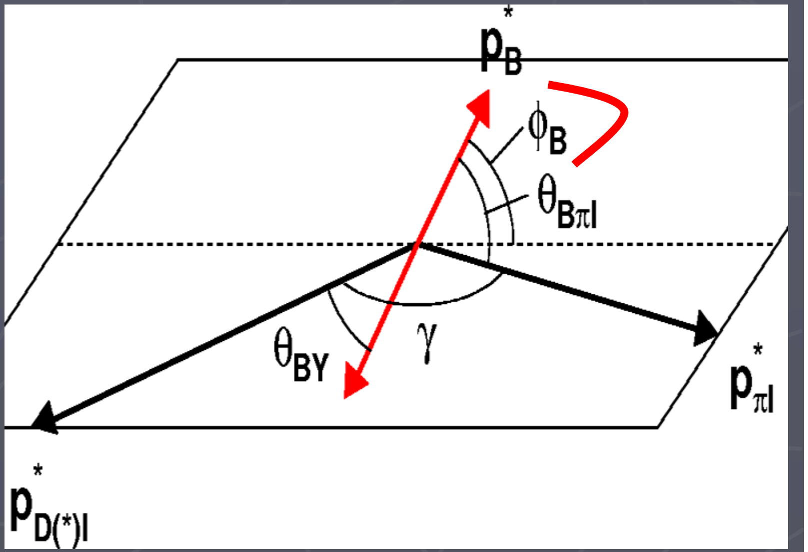
$$\cos^2\phi_B = \frac{\cos^2\theta_{BY} + \cos^2\theta_{B\pi\ell} + 2\cos\theta_{BY}\cos\theta_{B\pi\ell}\cos\gamma}{\sin^2\gamma}$$

In the Y(4S) frame:

$E_B$, $p_B$ = nominal values of the B energy and momentum, from 4-mom. conservation

$p_Y = p_\pi + p_l$

$|\cos\theta_{BY}|$ and $|\cos^2\Phi_B| < 1$ if the ν's are the only undetected particles...



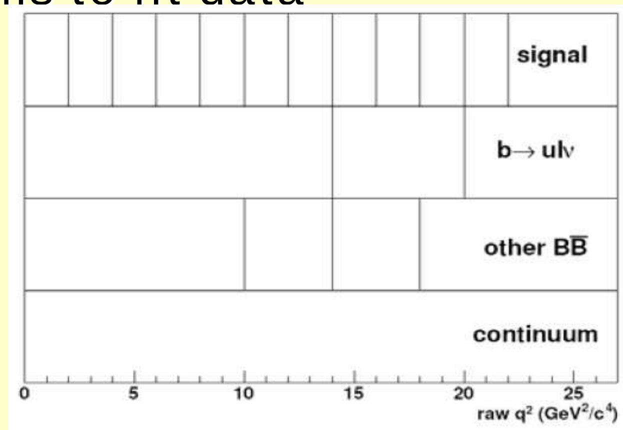
# $B^0 \to \pi^- l^+ \nu$, loose $\nu$, Signal Yield Extraction

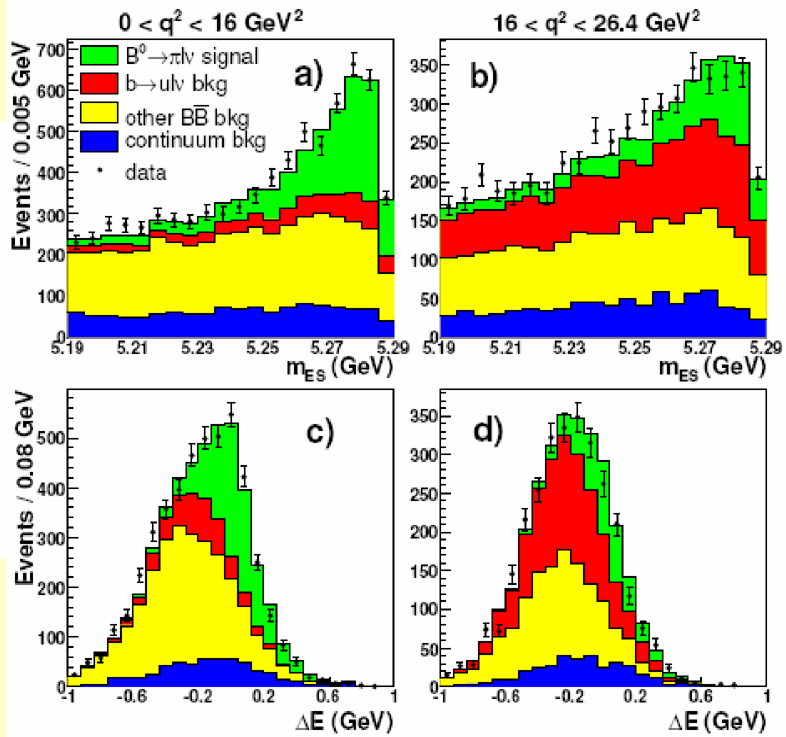
- 2+1 ($\Delta E, m_{ES}$ ; $q^2$) extended binned max. likelihood fit

$$m_{ES} = \sqrt{s/4 - |\mathbf{p}_B|^2} \qquad \Delta E = E_B - \sqrt{s}/2$$

- Finds 19 scaling factors to be applied to MC histograms to fit data
  - Signal (12 bins)
  - b->ulv (3 " ")
  - other BB (4 " ")

Reduce syst. error from BF & FF




- Continuum fixed, corrected to match the off-resonance data control sample (27fb$^{-1}$)

- Signal Yields

| $q^2$ bins (GeV$^2$) | 0-2 | 2-4 | 4-6 | 6-8 | 8-10 | 10-12 | 12-14 | 14-16 | 16-18 | 18-20 | 20-22 | 22-26.4 | $q^2<16$ | $q^2>16$ | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Fitted yield | 366.6 | 462.9 | 499.5 | 451.8 | 436.4 | 391.0 | 522.7 | 333.6 | 458.0 | 355.4 | 364.8 | 428.8 | 3464.6 | 1606.9 | 5071.5 |

$\chi^2$ = 423 for 389 d.o.f

# Results: Relative Errors on ΔBF($q^2$)

| $q^2$ bins (GeV$^2$) | 0-2 | 2-4 | 4-6 | 6-8 | 8-10 | 10-12 | 12-14 | 14-16 | 16-18 | 18-20 | 20-22 | 22-26.4 | $q^2$<16 | $q^2$>16 | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Fit error | 15.2 | 14.4 | 12.8 | 14.8 | 15.4 | 19.2 | 13.9 | 25.2 | 17.6 | 28.5 | 20.2 | 27.7 | 5.3 | 10.3 | 4.8 |
| Trk eff | 1.6 | 1.7 | 1.3 | 3.1 | 3.8 | 1.3 | 1.8 | 7.1 | 2.3 | 1.7 | 2.2 | 9.2 | 1.9 | 1.8 | 1.1 |
| $\gamma$ eff | 4.7 | 1.3 | 2.6 | 5.0 | 3.6 | 3.2 | 3.5 | 3.1 | 3.0 | 3.5 | 3.8 | 7.0 | 2.9 | 1.7 | 1.9 |
| $K_L^0$ & neutrons | 0.7 | 0.6 | 0.7 | 1.0 | 1.2 | 1.2 | 1.2 | 1.3 | 2.0 | 1.5 | 1.1 | 2.2 | 0.5 | 1.0 | 0.6 |
| PID | 7.0 | 2.5 | 2.1 | 1.9 | 0.7 | 2.7 | 2.6 | 2.5 | 2.6 | 3.4 | 2.9 | 7.0 | 2.6 | 3.6 | 2.9 |
| Continuum yield | 7.0 | 0.5 | 0.6 | 0.2 | 0.9 | 1.0 | 0.6 | 0.8 | 0.6 | 1.9 | 1.1 | 4.0 | 1.0 | 1.6 | 1.0 |
| Continuum $q^2$ | 20.1 | 1.5 | 1.0 | 1.0 | 1.7 | 1.8 | 1.5 | 2.0 | 1.5 | 3.3 | 4.0 | 8.7 | 2.4 | 1.9 | 1.8 |
| Continuum $m_{ES}$ | 1.1 | 0.3 | 0.1 | 0.1 | 0.1 | 0.1 | 0.3 | 0.6 | 0.3 | 0.6 | 0.7 | 1.0 | 0.2 | 0.5 | 0.2 |
| Continuum $\Delta E$ | 3.0 | 1.6 | 0.5 | 1.0 | 1.5 | 0.2 | 0.1 | 1.2 | 0.6 | 1.8 | 3.8 | 5.2 | 1.0 | 2.5 | 1.4 |
| $b \to u\ell\nu$ BF | 1.2 | 1.4 | 0.7 | 0.7 | 1.0 | 1.4 | 1.1 | 1.8 | 1.7 | 3.6 | 10.4 | 12.1 | 0.9 | 3.4 | 1.2 |
| SF param | 0.4 | 0.5 | 0.3 | 0.5 | 0.1 | 0.1 | 0.1 | 0.4 | 0.4 | 4.1 | 5.7 | 14.9 | 0.2 | 2.1 | 0.7 |
| $B \to \rho\ell\nu$ FF | 1.3 | 0.7 | 1.8 | 1.1 | 0.8 | 1.1 | 1.2 | 3.2 | 0.5 | 3.3 | 1.3 | 4.3 | 0.9 | 0.8 | 0.6 |
| $B^0 \to \pi^-\ell^+\nu$ FF | 0.4 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.8 | 0.7 | 0.7 | 1.1 | 3.5 | 0.5 | 1.3 | 0.7 |
| FSR | 0.7 | 1.5 | 2.2 | 1.9 | 2.6 | 2.7 | 2.2 | 0.6 | 2.5 | 2.0 | 1.3 | 1.1 | 1.9 | 1.8 | 1.9 |
| $b \to c\ell\nu$ BF | 1.8 | 2.1 | 1.1 | 2.2 | 4.6 | 1.2 | 2.4 | 2.2 | 1.3 | 2.5 | 1.7 | 2.2 | 0.9 | 1.0 | 0.8 |
| $B \to D^*\ell\nu$ FF | 0.7 | 1.1 | 0.1 | 1.6 | 3.1 | 0.8 | 1.4 | 1.0 | 0.9 | 1.2 | 0.6 | 2.7 | 0.7 | 0.4 | 0.6 |
| $B \to D\ell\nu$ FF | 1.7 | 1.2 | 0.7 | 0.3 | 2.2 | 0.4 | 0.1 | 0.7 | 0.6 | 0.9 | 0.4 | 0.7 | 0.1 | 0.4 | 0.2 |
| $\Upsilon(4S) \to B^0\bar{B}^0$ BF | 2.1 | 2.5 | 1.5 | 1.5 | 1.3 | 1.7 | 1.6 | 1.2 | 1.6 | 1.0 | 2.4 | 1.9 | 1.7 | 1.7 | 1.7 |
| $D \to X\ell\nu$ BF | 2.3 | 2.8 | 1.1 | 1.3 | 1.6 | 1.1 | 1.1 | 0.9 | 0.6 | 0.9 | 1.0 | 0.8 | 0.4 | 0.5 | 0.3 |
| $D \to K_L^0$ BF | 0.6 | 1.7 | 2.3 | 1.5 | 2.0 | 2.3 | 1.0 | 4.2 | 1.8 | 3.9 | 1.0 | 1.7 | 1.1 | 1.0 | 1.1 |
| B counting | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 |
| Signal MC stat error | 1.5 | 1.7 | 1.6 | 1.9 | 1.6 | 1.9 | 1.4 | 1.8 | 1.4 | 1.6 | 1.3 | 1.5 | 0.5 | 0.6 | 0.4 |
| Total syst error | 23.7 | 7.0 | 6.2 | 8.1 | 9.6 | 7.3 | 7.1 | 11.0 | 7.0 | 11.0 | 14.9 | 27.0 | 6.3 | 7.8 | 5.7 |
| Total error | 28.2 | 16.1 | 14.2 | 16.9 | 18.2 | 20.5 | 15.6 | 27.5 | 19.0 | 30.6 | 25.1 | 38.7 | 8.2 | 12.9 | 7.5 |

-Dominant syst. errors: Detector effects, Continuum description

-Fit of the backgrounds yields in several $q^2$ bins (thanks to high statistics due to loose ν ) => reduced systematic error due backgrounds BF and FF.