Measurements of Semileptonic B meson decays to Charm and the determination of the CKM matrix element $|V_{cb}|$ at BaBar

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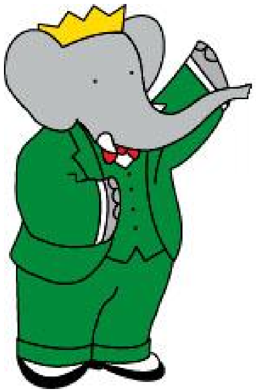
on behalf of
the BaBar collaboration



35^{th} Internatonal Conference on High Energy Physics
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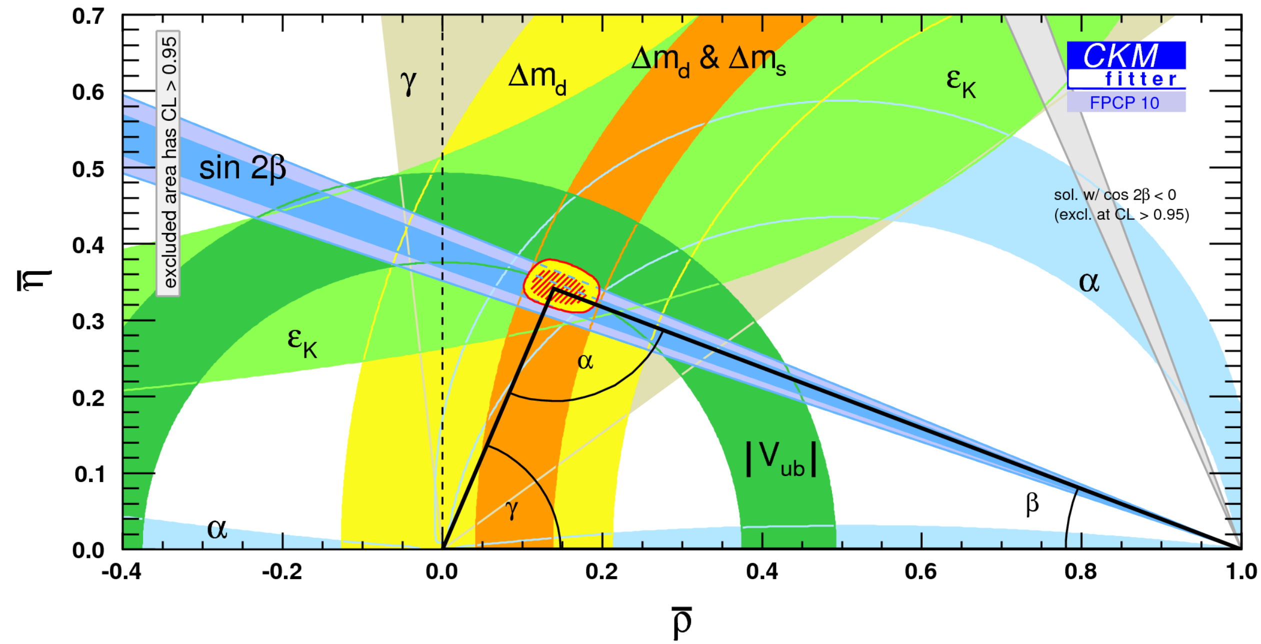
Outline

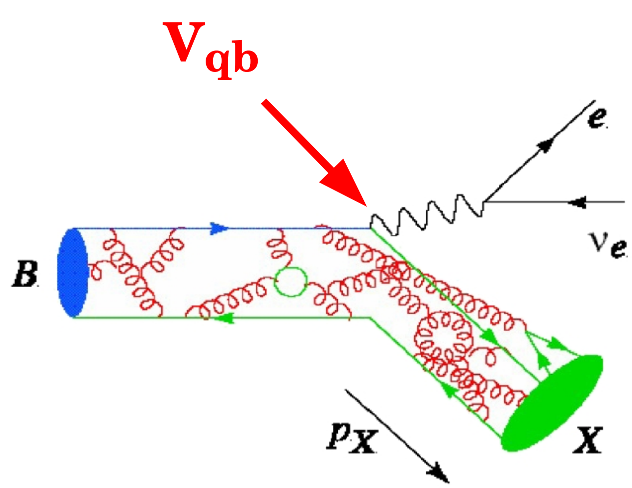
- Inclusive $|V_{cb}|$: measurement of moments
  [PRD **81**, 032003 (2010)]
- Exclusive $|V_{cb}|$: $B \to Dl\nu$ with hadronic tag
  [PRL **104**, 011802 (2010)]
- new
  $\mathcal{B}(B \to D_s^{(*)}Kl\nu)$ measurement

Measure $|V_{cb}|$ and $|V_{ub}|$ to overconstrain the Unitarity Triangle

$$\frac{\delta|V_{cb}|}{|V_{cb}|} \sim 2\%$$



Semileptonic B decays



- leptonic and hadronic current decoupled
- quark decay depends on $|V_{xb}|$, m_b. Perturbative regime
- We see mesons: QCD corrections

<u>Inclusive approach</u>: study distributions from $B \to X_q l\nu$
Theory: OPE

<u>Exclusive approach</u>: focus on single decay channel.
Theory: Form Factors (eg. Lattice QCD)

Inclusive $|V_{cb}|$

Inclusive $|V_{cb}|$

- Total rate described in the context of Heavy Quark Expansion

$$\Gamma(\bar{B} \to X_c \ell \bar{\nu}) = \frac{G_F^2}{192\pi^3} m_b^5 |V_{cb}|^2 (1 + A_{ew}) A^{pert} F\left(r, \frac{\mu_\pi^2}{m_b^2}, \frac{\mu_G^2}{m_b^2}, \ldots\right) \qquad r = \frac{m_c}{m_b}$$

free quark decay

Perturbative corrections (expansion $1/\alpha_s^k$)

non perturbative corrections (expansion $1/m_b^n$)

- non perturbative parameters need to be measured
- OPE relates moments and rates of inclusive distribution to heavy quark parametrs

$$\langle E_\ell^n \rangle_{p_\ell^*} = f^{(n)}(p_\ell^*\ cut, m_b, \mathrm{HQ\ parameters})$$

$$\langle m_X^{2n} \rangle_{p_\ell^*} = g^{(n)}(p_\ell^*\ cut, m_b, \mathrm{HQ\ parameters})$$

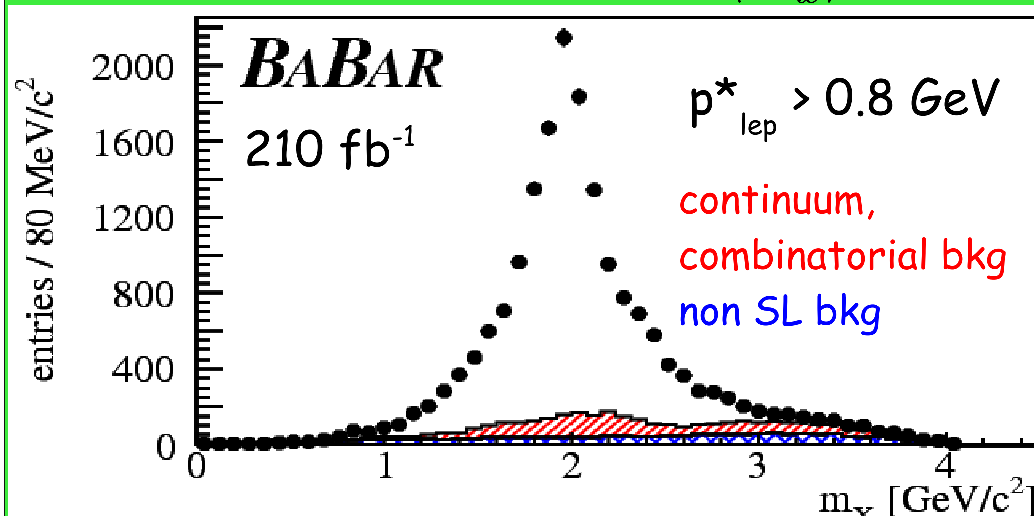
$$\langle E_\gamma^n \rangle_{p_\ell^*} = h^{(n)}(p_\ell^*\ cut, m_b, \mathrm{HQ\ parameters})$$

Calculations available in the "kinetic" (Benson et al. Nucl. Phys. B665:367) and "1S" (Bauer et al., Phys. Rev. D70:094017,2004) mass scheme

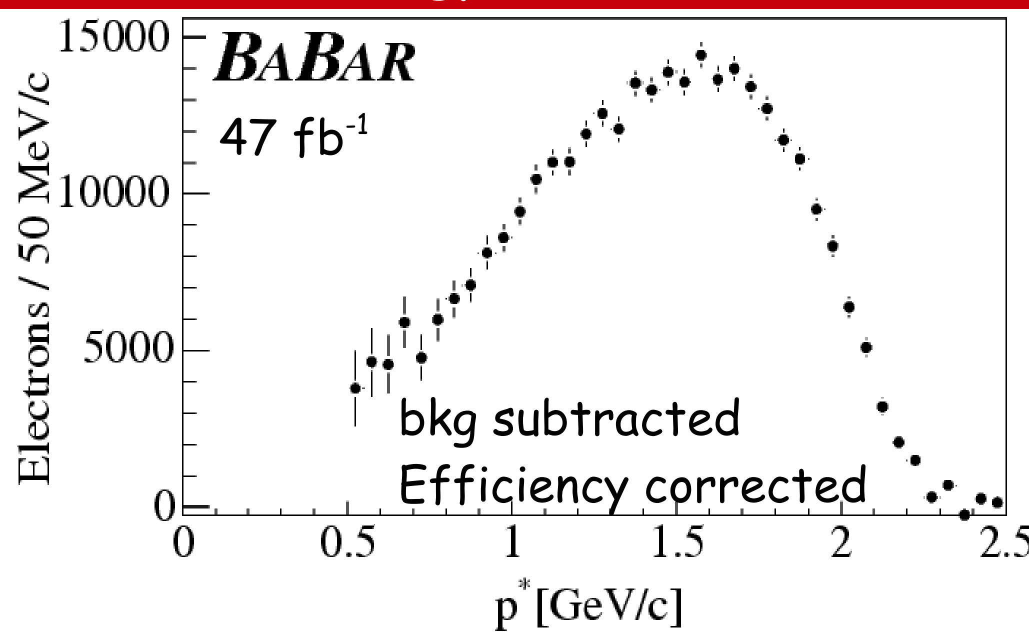
Inclusive $|V_{cb}|$: moments measurements

• Analysis performed reconstructing semileptonic B decays on the recoil of fully reconstructed B meson decays in hadronic mode (low efficiency ~ 0.4%; high purity ~80%)

- Hadronic mass moments $\langle m_x^k \rangle$



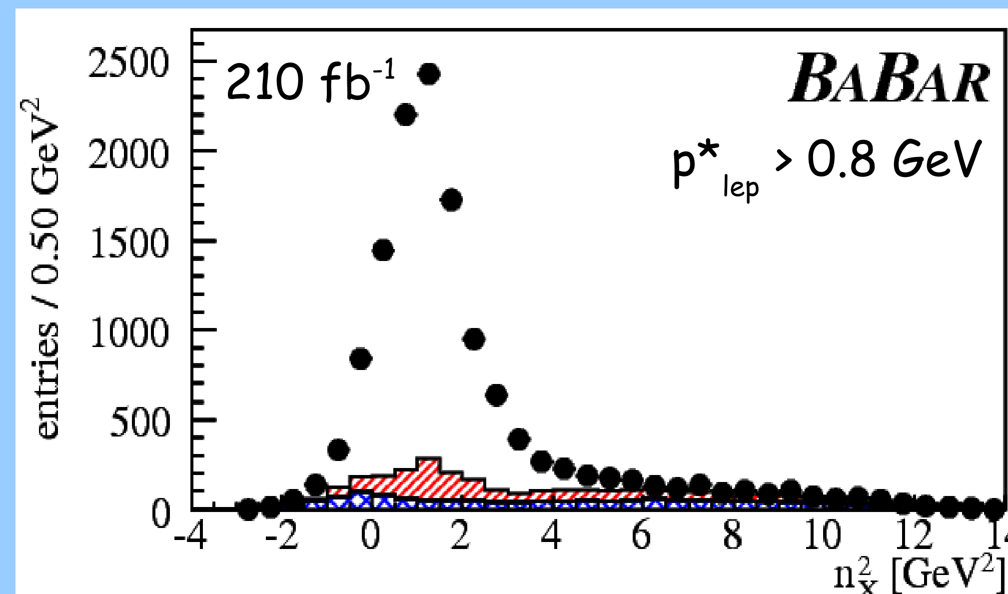
- Electron Energy moments



- Mixed mass and energy moments $\langle n_x^k \rangle$

[Gambino, Uraltsev Eur. Phys. J. C 34, 181 (2004)]

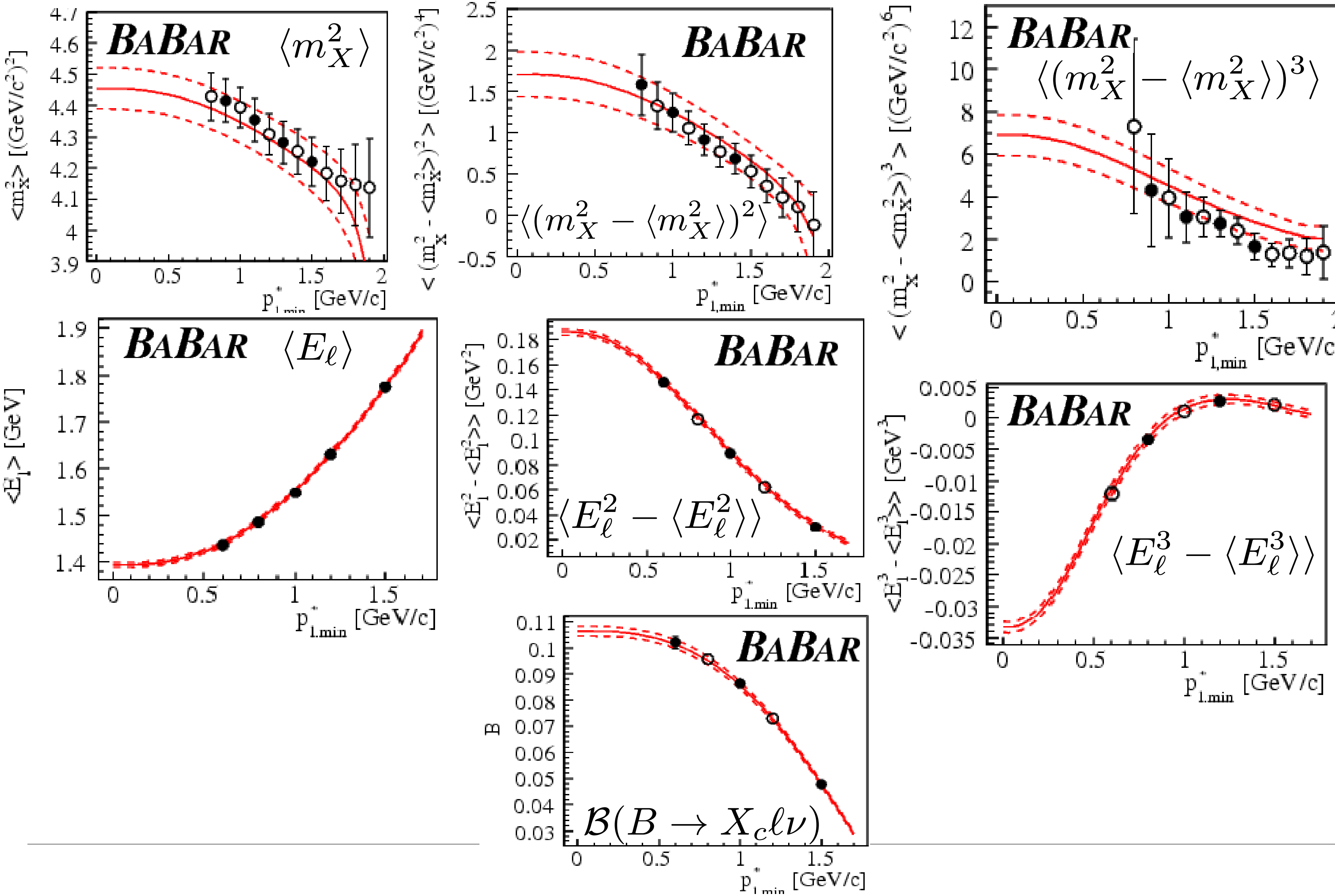
$$n_X^2 = m_X^2 c^4 - 2\tilde{\Lambda} E_X + \tilde{\Lambda}^2$$



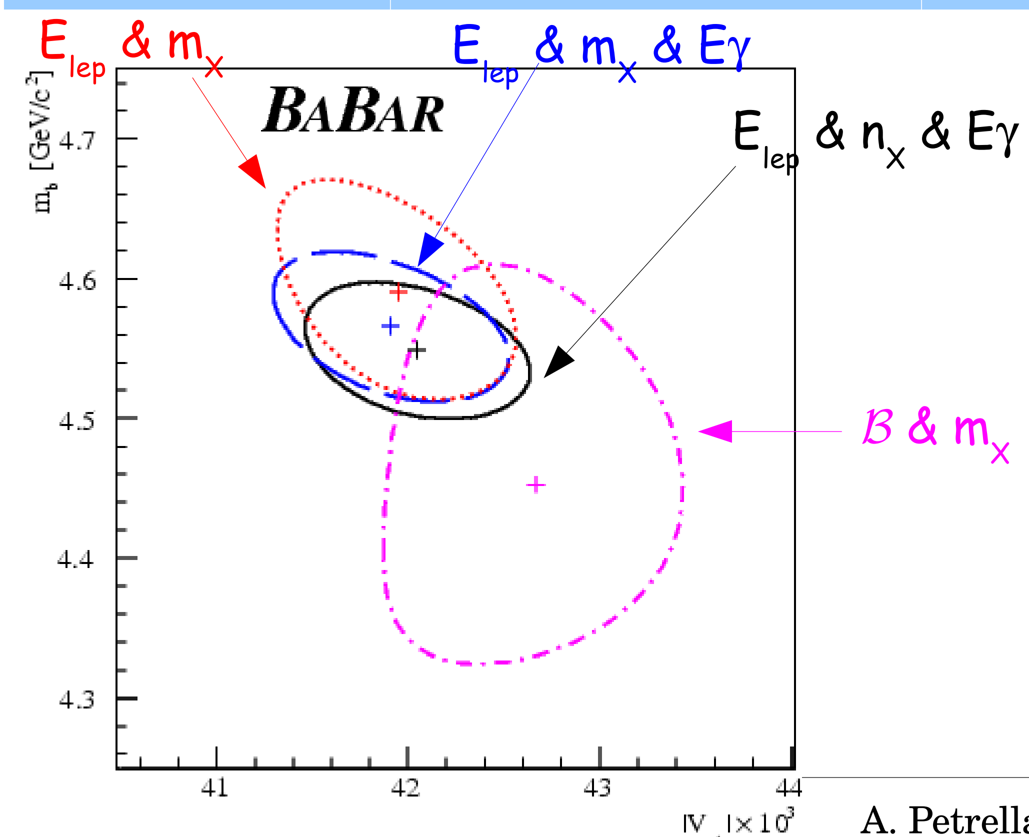
Inclusive $|V_{cb}|$: moments measurements

- Global Fit perfomed with either m_X or n_X and 10 E_{lep} moments and 3 $E\gamma$ moments ($B \rightarrow X_s\gamma$)

external constraint μ^2_G = (0.35 ± 0.07) GeV^2, ρ^3_{LS} = (-0.15 ± 0.10) GeV^3



	Fit with Hadronic mass moments	Fit wit combined mass-energy moments	HFAG Average (end 2009) ($B\rightarrow X_c l\nu$ & $B\rightarrow X_s\gamma$)
$|V_{cb}|$ (10^{-3})	42.05 ± 0.45 ± 0.70	41.91 ± 0.48 ± 0.70	41.85 ± $0.42_{(fit)}$ ± 0.60
m_b (GeV/c^2)	4.549 ± 0.031 ± 0.038	4.556 ± 0.034 ± 0.041	4.591 ± 0.031
$\mathcal{B}(B\rightarrow X_c l\nu)$ (%)	10.64 ± 0.17 ± 0.06	10.64 ± 0.17 ± 0.06	10.55 ± 0.14
χ^2/ndf	10.9 / 28	8.2 / 28	29.7 / 59



- Good agreement of all fit parameters
- Fits in agreement with old determinations and average
- combined mass-energy moment does not give more precise determination
- increased confidence in OPE fits
- $\delta|V_{cb}|/|V_{cb}|$ at ~ 2%

Exclusive $|V_{cb}|$

$B \to Dl\nu$ with Hadronic tag

Exclusive $|V_{cb}|$: B→Dlν with Hadronic tag

- Differential decay rate:

$$\frac{d\Gamma(B \to D\ell\nu)}{dw} = \frac{G_F^2 |V_{cb}|^2}{48\pi^3\hbar} M_D^3 (M_B + M_D)^2 (w^2 - 1)^{3/2} \mathcal{G}^2(w)$$

$\mathcal{G}(w)$ form factor: Caprini et al. Nucl. Phys. B530, 153 (1998)

$$w = \frac{M_B^2 + M_D^2 - q^2}{2 M_B M_D} \qquad q^2 = (p_B - p_D)^2$$

- Experiment measures $\mathcal{G}(1)|V_{cb}|$ and FF slope ρ_D^2

  - Hadronic tag: Neutrino is the only missing particle

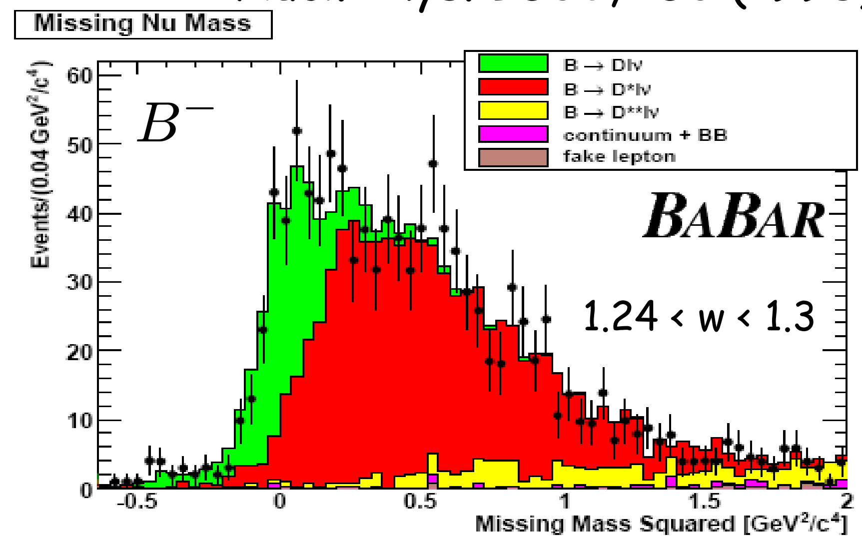
$$m_{miss}^2 = [p_{\Upsilon(4s)} - p_{B_{tag}} - p_D - p_\ell]^2$$

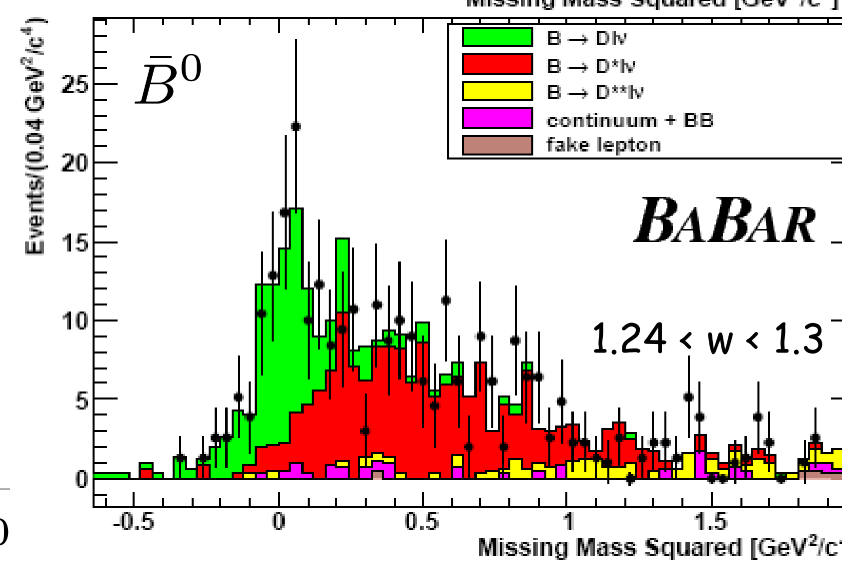
signal side well measured: w resolution ~ 0.01

- Background from D*lν is significant (larger BF, undetected slow π)

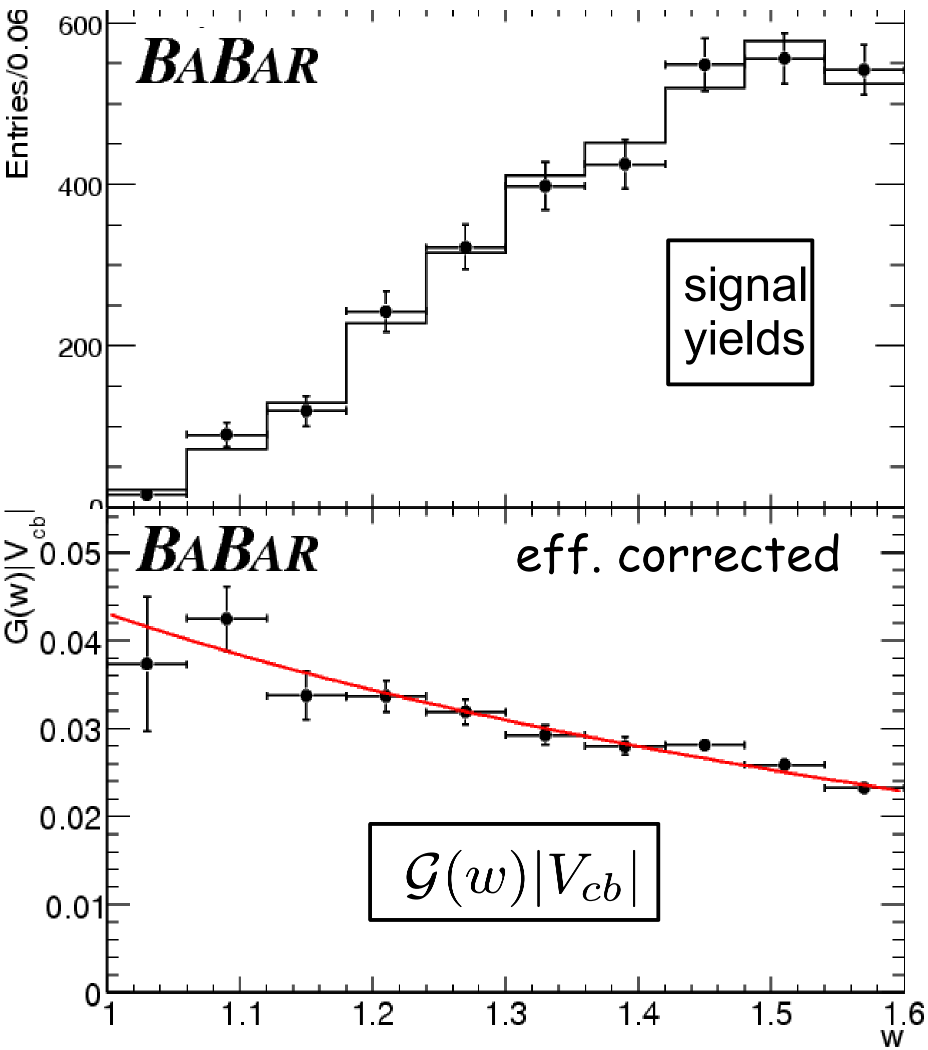
Signal Yields	
	$2147 \pm 69\ B^- \to D^0 \ell \bar{\nu}$
	$1108 \pm 45\ \bar{B}^0 \to D^+ \ell^- \bar{\nu}$

- Inclusive B→Xlν used as normalization sample





χ^2 fit of signal yields in w distribution 1 < w < 1.6



$$\mathcal{B}(\bar{B} \to D\ell\bar{\nu}) = (2.15 \pm 0.06 \pm 0.09)\%$$

$$\mathcal{G}(1)|V_{cb}| = (42.3 \pm 1.9 \pm 1.4) \times 10^{-3}$$

$$\rho_D^2 = 1.20 \pm 0.09 \pm 0.04$$

Unquenched lattice calculation

Okamoto et al. Nucl. Phys. B, Proc Suppl. 140, 461 (2005)

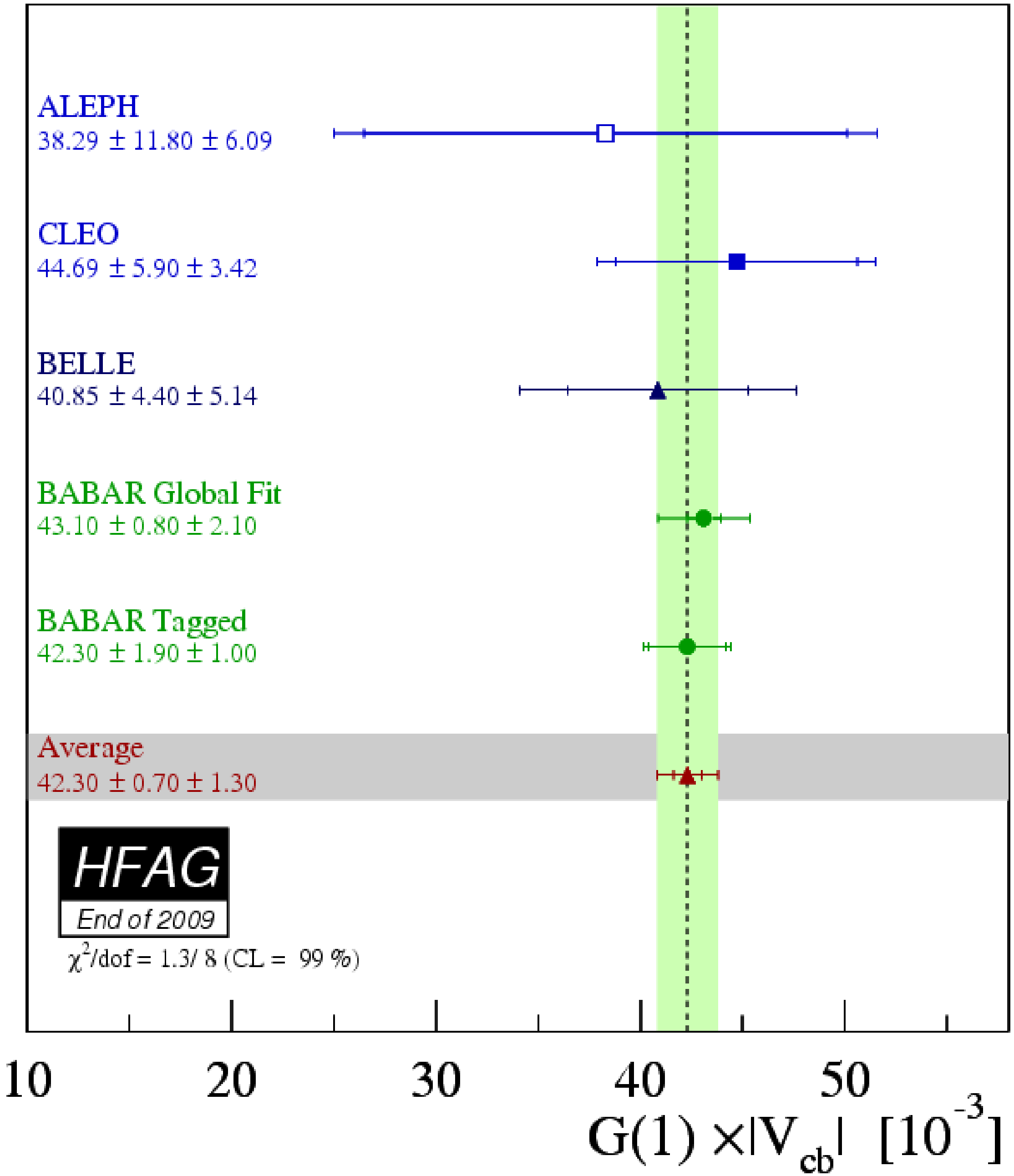
$$|V_{cb}| = (39.2 \pm 1.8 \pm 1.3 \pm 0.9_{FF}) \times 10^{-3}$$

Quenched lattice calculation

Divitiis et al. Phys. Lett. B 655, 45 (2007)

$$|V_{cb}| = (40.9 \pm 1.8 \pm 1.4 \pm 0.7_{FF}) \times 10^{-3}$$

Exclusive $|V_{cb}|$: HFAG averages



Tagged measurement is the most precise in $B \to Dl\nu$ channel

$|V_{cb}| = (39.2 \pm 1.4_{exp} \pm 0.9_{FF})\ 10^{-3}$ (~4%)

$\mathcal{G}(1) = 1.074(18)(16)$

Nucl. Phys. B, Proc Suppl. 140, 461 (2005)

good agreement with $|V_{cb}|$ from exclusive $B \to D^* l\nu$

$|V_{cb}| = (39.1 \pm 0.6 \pm 0.8_{FF})\ 10^{-3}$ (~3%)

$\mathcal{F}(1) = 0.921(13)(20)$

Phys. Rev. D 79, 014506 (2009)

Tension with inclusive measurements

$|V_{cb}| = (41.9 \pm 0.4 \pm 0.6)\ 10^{-3}$ (~2%)

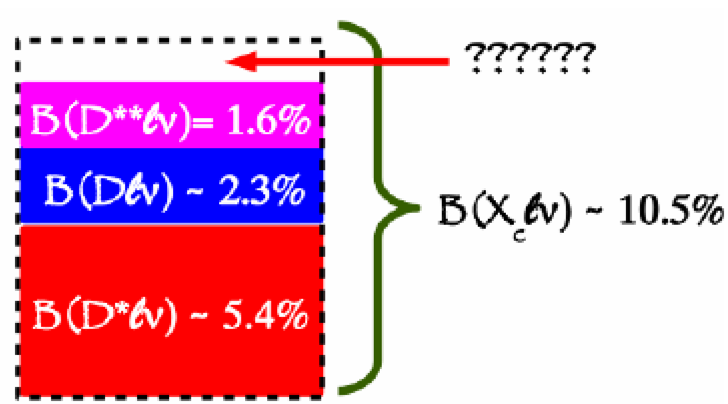
Exclusive determinations 2σ lower than inclusive one

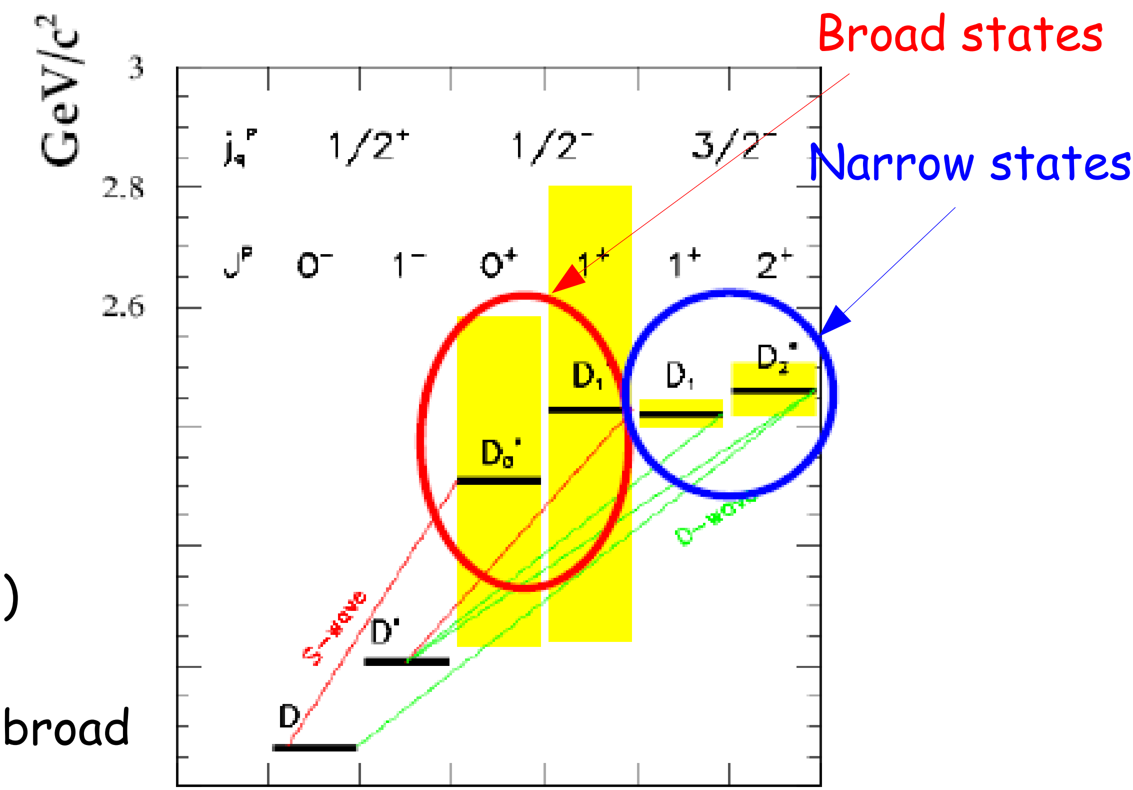
$\mathcal{B}(B \rightarrow D_s^{(*)} K l \nu)$ measurement

$\mathcal{B}(B^- \to D_s^{(*)+} K^- \ell^- \bar{\nu}_\ell)$

Puzzle in exclusive B→ $D^{(*,**)}$lν Branching Fractions:

$$\mathcal{B}(B \to X_c \ell \nu) > \mathcal{B}(B \to D\ell\nu) + \mathcal{B}(B \to D^*\ell\nu) + \mathcal{B}(B \to D^{**}\ell\nu)$$



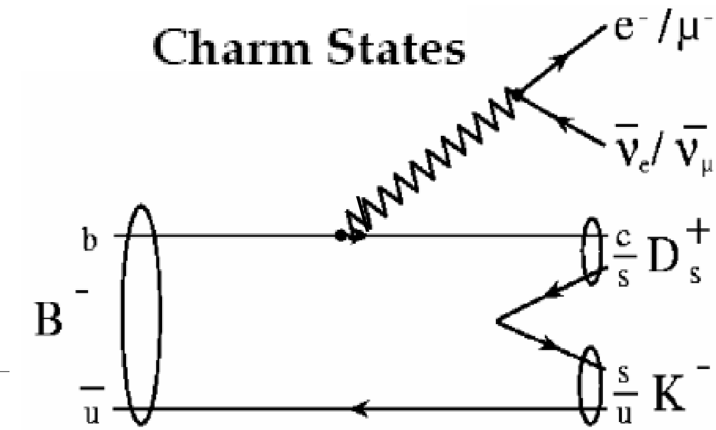


- experimentally: similar rate for broad and narrow (QCD sum rule: narrow >> broad)

- small statistics doesn't allow to separate broad from non resonant

- $B \to D_s^{(*)} K l\nu$ similar to $B \to D^{(*)} \pi l\nu$. Study hadronic mass spectrum above 2.46 GeV/c^2

- $\mathcal{B}(B \to D_s^{(*)} K l\nu)$ expected ~ 10^{-3}



$\mathcal{B}(B^- \to D_s^{(*)+} K^- \ell^- \bar{\nu}_\ell)$

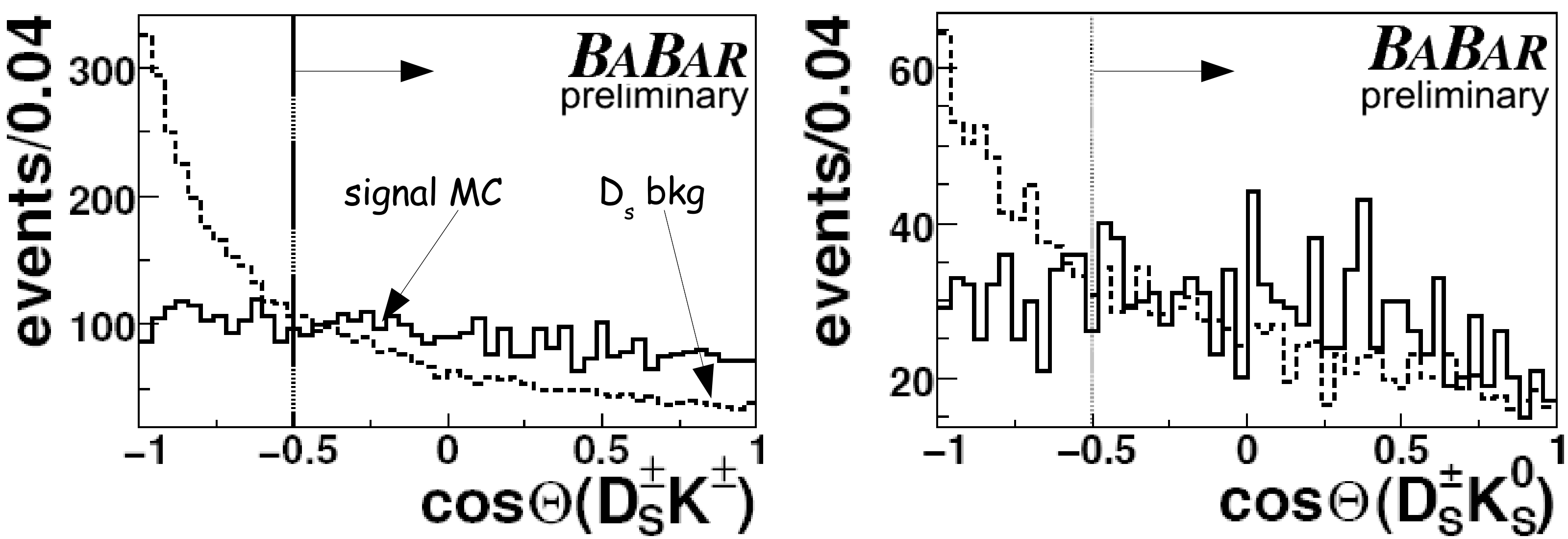
- Exclusive reconstruction

$$D_s \to \phi(K^+K^-)\pi$$
$$D_s \to \bar{K}^{*0}(K^\pm\pi^\mp)K$$
$$D_s \to K_s^0(\pi^+\pi^-)K$$

Feed Forward NN to suppress combinatorial bkg.

- lepton (p_{lep} > 0.8 GeV/c) and Kaon added to D_s candidate
- Bkg from B→DD_s reduced using angular correlation between D_s and D (signal events no correlation)

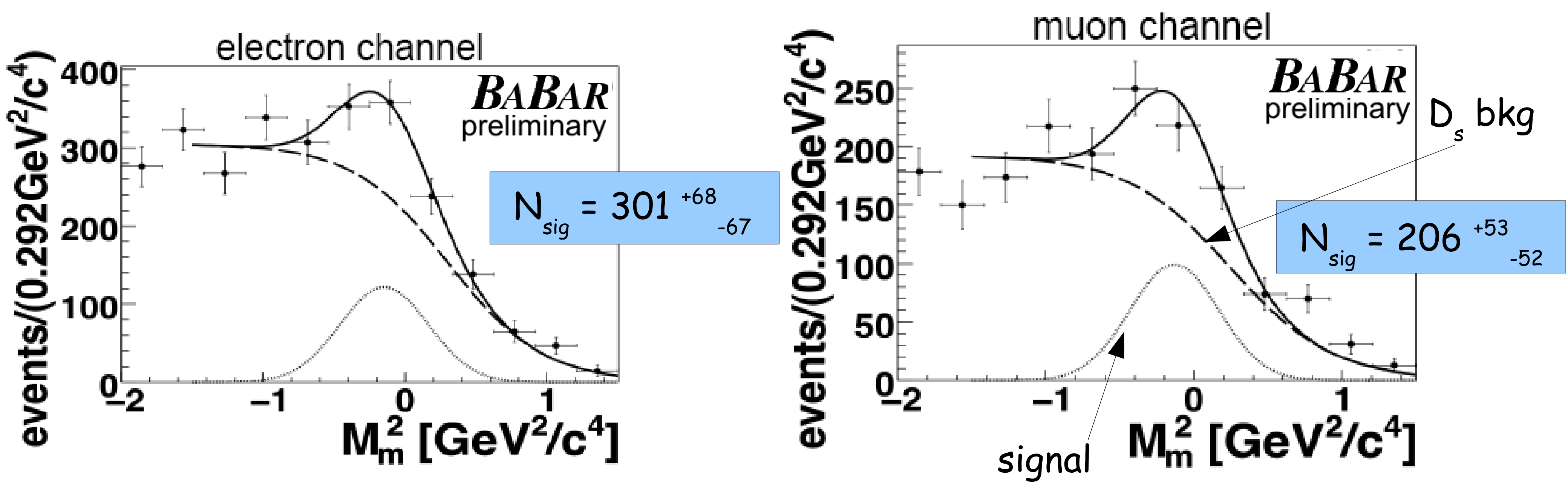
~30% of D_s bkg rejected



$\mathcal{B}(B^- \to D_s^{(*)+} K^- \ell^- \bar{\nu}_\ell)$

- Signal yields extracted via unbinned extended maximum likelihood fit to Missing mass

$$M_m^2 = (E_{beam} - E_Y)^2 - |\vec{p}_Y|^2 = m_\nu^2 \qquad Y = D_s K \ell \text{ candidate}$$



- leading systematic uncertainty: signal MC modelling (~3%- 8% depending on channel)

Signal MC statistics (~2%)

342 fb^{-1}

$$\mathcal{B}(B \to D_s^+ K^- \ell^- \bar{\nu}_\ell) = (6.13^{+1.04}_{-1.03} stat. \pm 0.43_{syst.} \pm 0.51(\mathcal{B}(D_s))) \times 10^{-4}$$

- Result in agreement with ARGUS measurement: $\mathcal{B}(B \to D_s^+ K^- \ell^- \bar{\nu}_\ell) < 5 \times 10^{-3}$
- BR too small to solve the BR puzzle

Conclusions

- Inclusive $|V_{cb}|$ determinations precision at 2% from HQE fits to moments. Consistency check with combined energy-mass moments.

- $B \to Dl\nu$ tagged analyses give the most precise measurement of $\mathcal{G}(1)|V_{cb}|$. $|V_{cb}|$ determinations in agreement among different FF calculations.

- $|V_{cb}|$ determinations with inclusive/exclusive decays differ by ~ 2σ

- First measurement of $\mathcal{B}(B \to D_s^{(*)}Kl\nu)$ decay, **5σ significance**. BR still too small to explain Incl-Excl branching ratio puzzle: more measurements needed.