B and Charm semileptonic decays with BaBar

SUSY 2011

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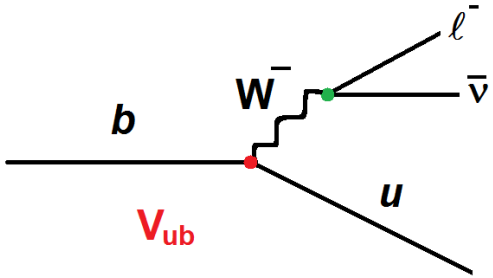
- $B \to D^{(*)}\tau\nu$
- $B \to X_u \ell\nu$
- Charm sl decays

The Mighty Oak Tree by J. Mooth

Introduction

B and charm semileptonic decays are tree level processes involving CKM matrix elements:



$$V_{CKM} \underset{PDG10}{=} \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

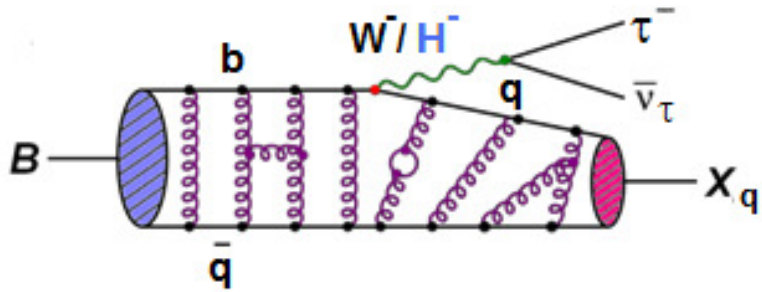
0.00389(44)

0.0406(13)

0.230(11) 1.023(36)

New Physics contributions can only be seen:

→ in semileptonic decays involving τ leptons: coupling ~ $m_b m_\tau \tan\beta^2$



→ $B \to D^{(*)}\tau\nu$

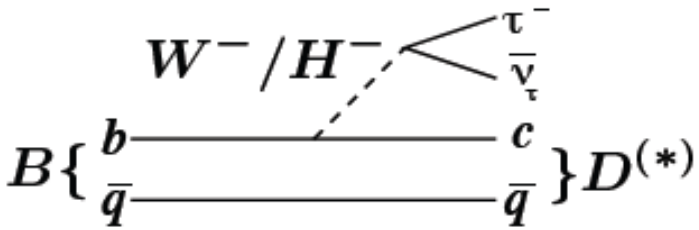
→ by comparing CKM matrix elements in leptonic and semileptonic decays

→ V_{ub}: Inclusive $B \to X_u \ell\nu$, exclusive $B \to \pi\ell\nu$

Note: Must control (by measuring) QCD effects (form factors)

→ Charm semileptonic decays

$B \to D^{(*)}\tau\nu$



- Sensitive to charged-Higgs effects
- Involve form factors which can be measured in $B \to D^{(*)}e/\mu\nu$ decays
- Observables: R(D) and R(D*) ratios

$$R(D^{(*)}) = \frac{\mathcal{B}\left(B \to D^{(*)}\tau\nu_\tau\right)}{\mathcal{B}\left(B \to D^{(*)}\ell\nu_\tau\right)}$$

- can be enhanced by the charged-Higgs ($\tan\beta/m_H$)
- several syst. and theo. uncertainties cancel out

SM predictions:

R(D) = 0.31 $\pm$ 0.02

R(D*) = 0.25 $\pm$ 0.02

[Nierste, Trine, Westhoff PRD78 (08) 015066]

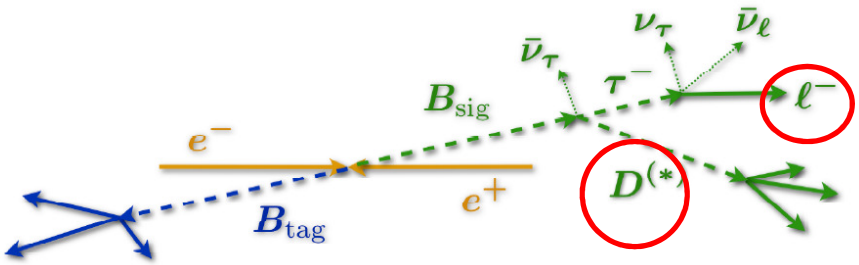
$B \to D^{(*)}\tau\nu$

Analysis procedure:

- Complete BaBar data sample: 426 fb^{-1}
- Improved efficiencies (lepton and Btag)
- Btag fully reconstructed into hadrons
- Bsig: $D^{(*)}$ and lepton (μ, e)
  - 4 signal samples: (D^0, D^+, D^{*0}, D^{*+})$\ell\nu$ (to extract $B \to D^{(*)}\tau\nu$)
  - 4 control samples: (D^0, D^+, D^{*0}, D^{*+})$\pi^0\ell\nu$ (to derive $D^{**}\ell\nu$ bkg)
- 2D unbinned ML fit m_{miss}^2-p^*_ℓ (3x4 par.)
  Yields for:

$B \to (D^0, D^+, D^{*0}, D^{*+})\tau\nu$
$B \to (D^0, D^+, D^{*0}, D^{*+})\ell\nu$
$B \to (D^0, D^+, D^{*0}, D^{*+})\pi^0\ell\nu$ $\longrightarrow$ R(D) and R(D*)

$\tau \to \mu\nu_\mu\nu_\tau$
$\tau \to e\nu_e\nu_\tau$



$m_{miss}^2 = (p_{e+e-} - p_{Btag} - p_{D(*)} - p_\ell)^2$

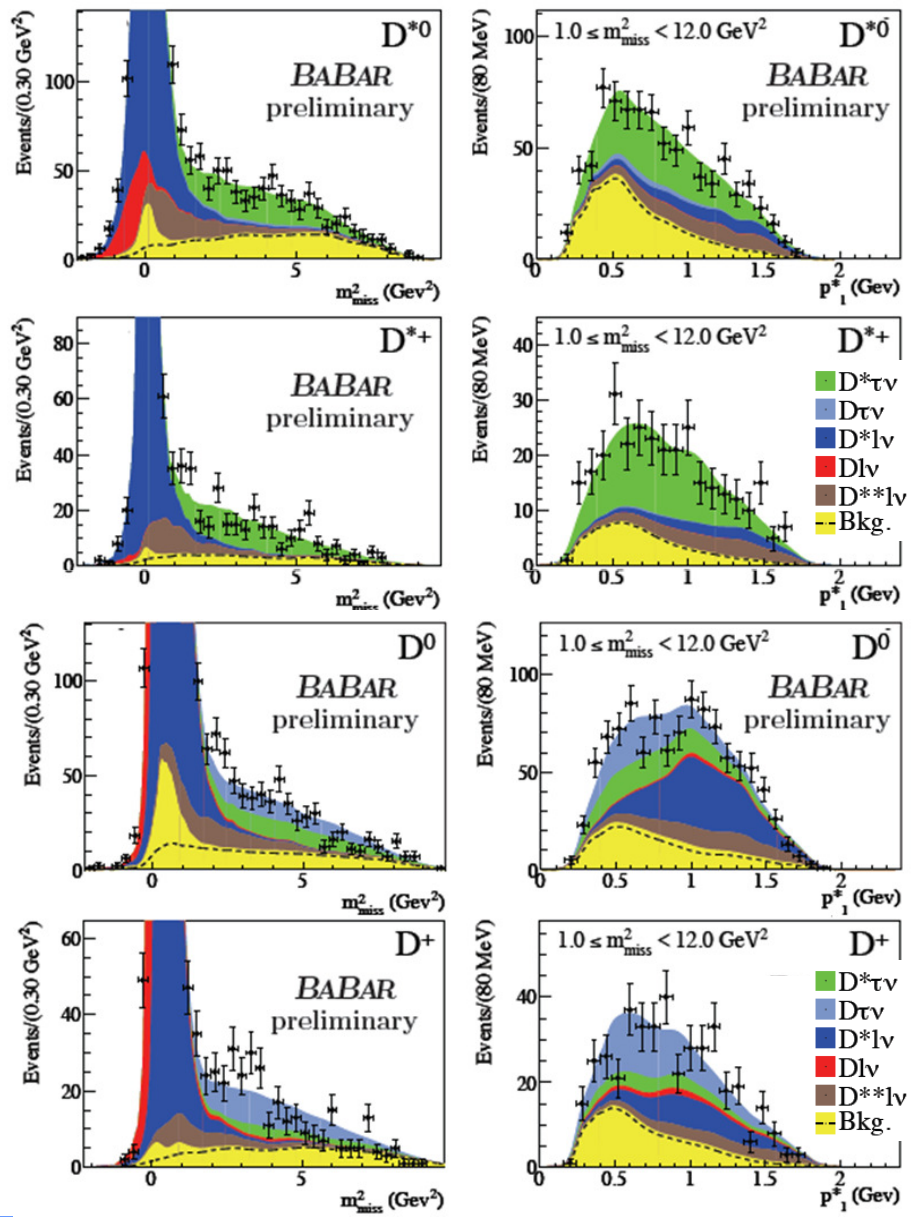
$B \to D^{(*)}\tau\nu$

Fit results (preliminary):

	D^{*0}	D^{*+}	D^* (isospin)
N_{sig}	511 ± 48	220 ± 23	730 ± 50
Signif.	11.9	12.1	17.1
$R(D^*)$	0.314 ± 0.030	0.356 ± 0.038	0.325 ± 0.023

	D^0	D^+	D (isospin)
N_{sig}	226 ± 39	139 ± 21	368 ± 42
Signif.	6.2	7.5	9.6
$R(D)$	0.422 ± 0.074	0.513 ± 0.081	0.456 ± 0.053

→large signal significance (> 5σ) for all channels



Systematics (preliminary):

- Selection cuts: ~6%(D*),~9%(D)
- D** fitted in $D^{(*)}\pi^0\ell\nu$ samples: ~4%(D*), ~5%(D)

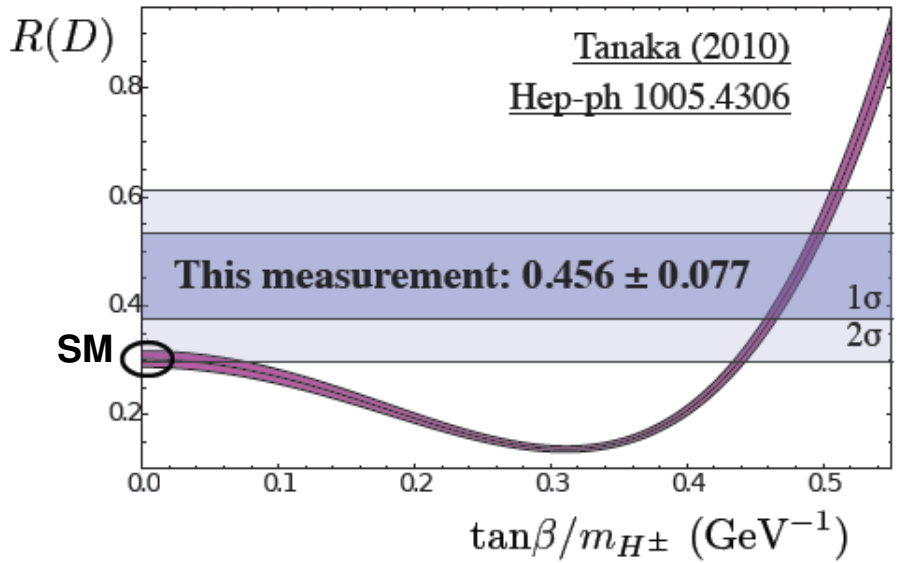
$B \to D^{(*)}\tau\nu$

Results (preliminary):

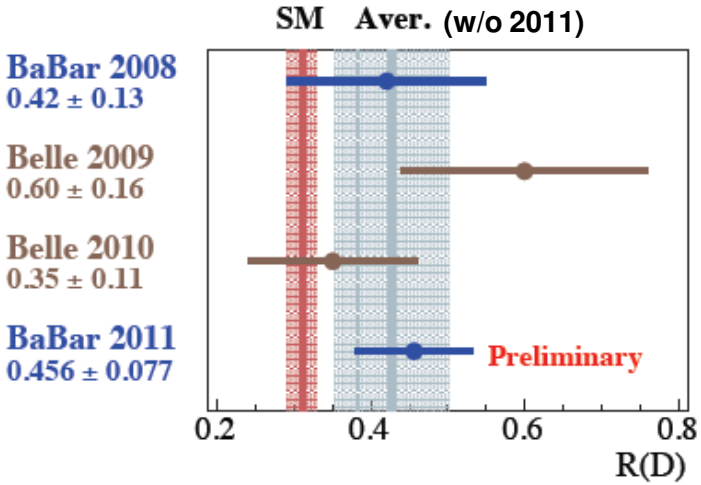
SM predictions:
R(D) = 0.31 ± 0.02
R(D*) = 0.25 ± 0.02

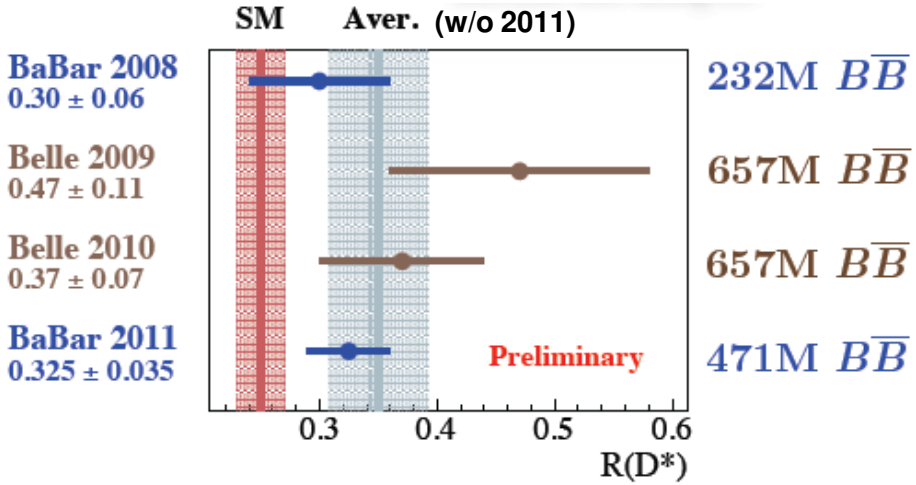
$$R(D) = 0.456 \pm 0.053 \pm 0.056$$
$$R(D^*) = 0.325 \pm 0.023 \pm 0.027$$

1.8σ larger than SM prediction
→ favors large tanβ



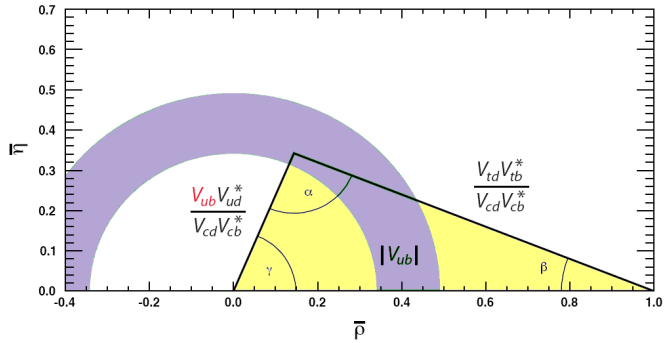
Comparison with previous results:



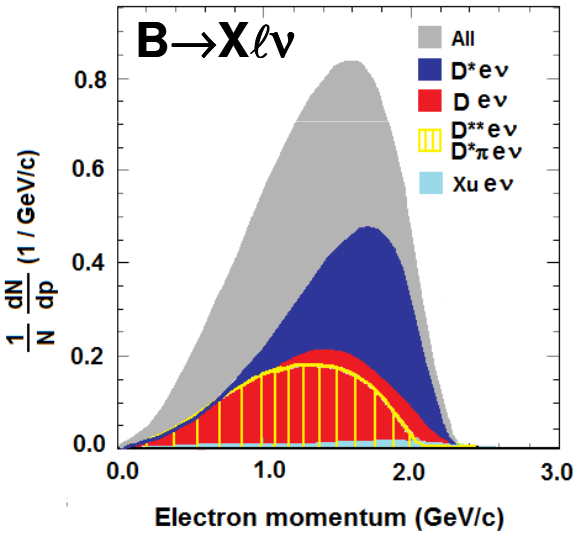


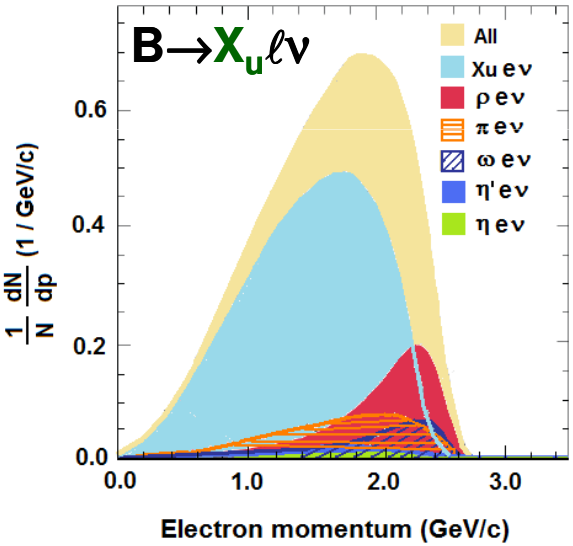
$B \to X_u \ell \nu$

- Charmless semileptonic decays allow us to measure V_{ub}
  → key for the CKM picture: defines the upper UT vertex



- Challenge: suppress charm background $B \to X\ell\nu = B \to X_c\ell\nu + B \to X_u\ell\nu$ (50 : 1)



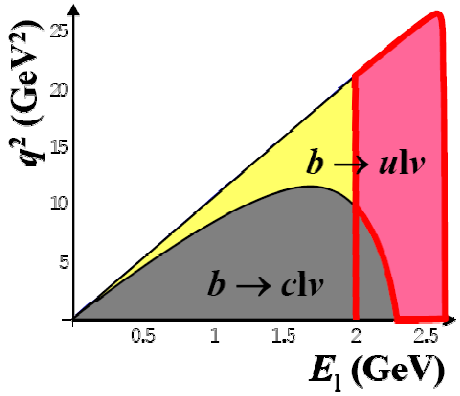


- Two different experimental methods:
  - <u>Inclusive:</u> reconstruct the lepton
  - <u>Exclusive:</u> reconstruct the lepton and the final meson (π,ρ,ω…)

$B \to X_u \ell \nu$

- **Inclusive vs exclusive:**

- **Inclusive:** → Larger statistics, but a lot of charm background
  → Use kinematic variables to suppress as much as possible $b \to c$: E_ℓ, q^2, M_X and $P_+ = E_X - |p_X|$
  → Need shape function from QCD



- **Exclusive:**
  → Smaller statistics but better background rejection
  → Need form factors from QCD

Inclusive $|V_{ub}| \neq$ Exclusive $|V_{ub}|$

~2σ difference since many years ago and V_{ub} from $B \to \tau\nu$ larger than for $B \to \pi\ell\nu$

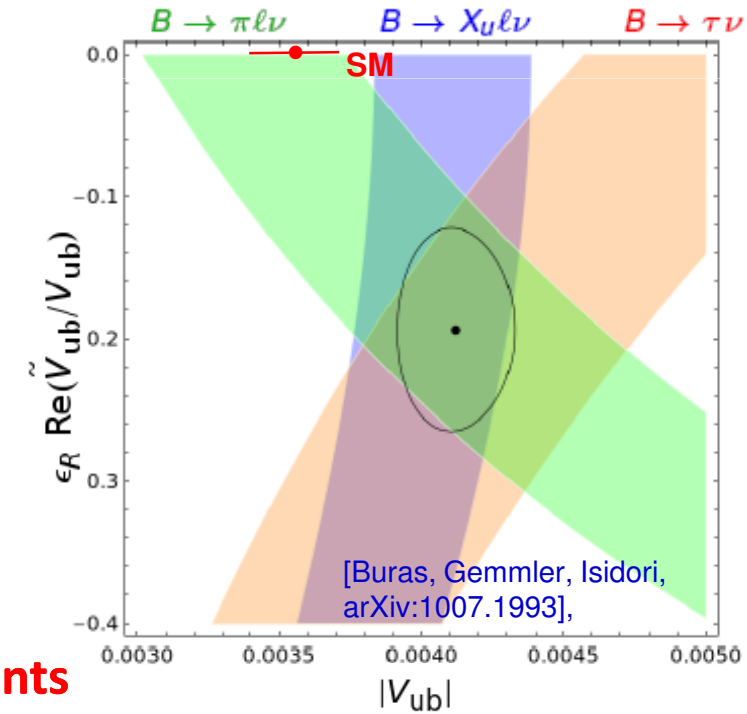
New Physics contribution?

(RH currents modification)

$$|V_{ub}|_{B\to X_u \ell\nu} \longrightarrow \sqrt{|V_{ub}|^2 + \epsilon_R^2 |\widetilde{V}_{ub}|^2}$$

$$|V_{ub}|_{B\to \pi\ell\nu} \longrightarrow |V_{ub} + \epsilon_R \widetilde{V}_{ub}|$$

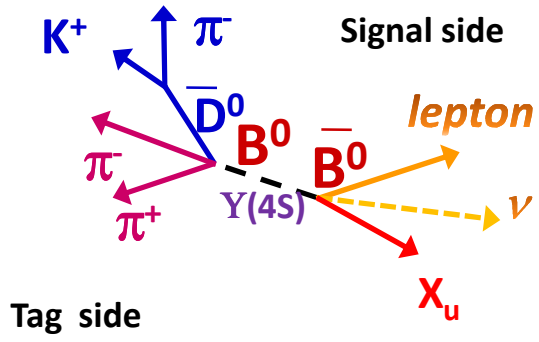
$$|V_{ub}|_{B\to \tau\nu} \longrightarrow |V_{ub} - \epsilon_R \widetilde{V}_{ub}|$$



→ Need to have precise $|V_{ub}|$ measurements

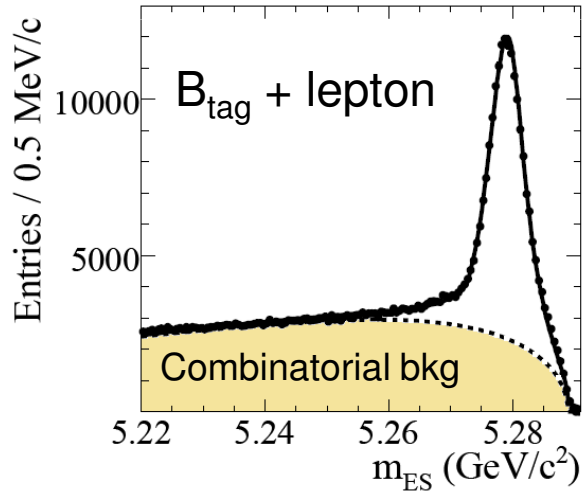
$B \to X_u \ell \nu$: inclusive

Analysis procedure:



- Complete BaBar data sample: 426 fb^{-1}
- Btag fully reconstructed hadronically (ε ~0.3-0.5%)
- A lepton (μ or e) from the Bsig
- X_u from all remaining tracks and neutral clusters
- ν estimated from missing energy and momentum

- Bkg supression:
  - Combinatorial substracted from m_{ES}
  - Charm: $B \to D^* \ell \nu$ partial reconstructed, kaon veto, only 1 lepton $p_\ell^* > 1$ GeV



- Several PS regions: $M_x < 1.55$ GeV, $M_x < 1.7$ GeV
  $p_\ell > 1.0$ GeV, $p_\ell > 1.3$ GeV
  $P_+ < 0.66$ GeV
  $q^2 > 8$ GeV^2

- 2D fit for $\Delta B(B \to X_u \ell \nu)/B(B \to X \ell \nu)$ in q^2-M_x

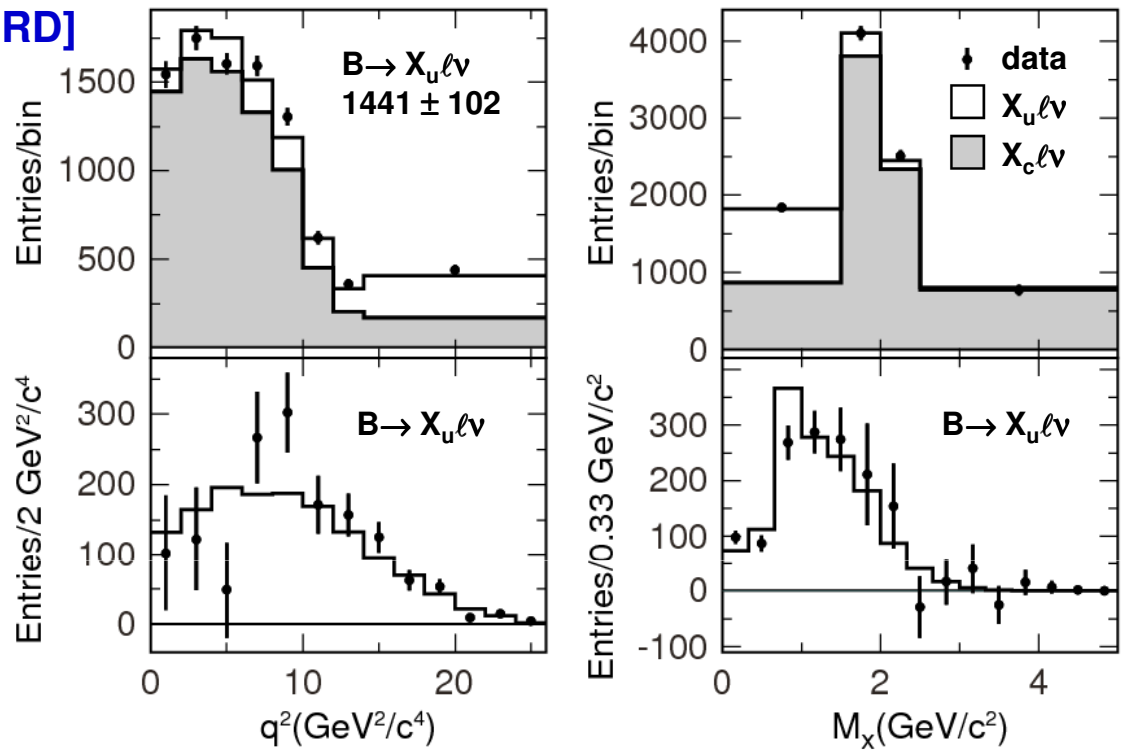
$B \to X_u \ell \nu$: inclusive

[to be submitted to PRD]

Fit results:

- Most precise result : 2D fit q^2-M_x for $p_\ell^* > 1$ GeV
- Fit for $B \to X_c \ell \nu$ bkg and $B \to X_u \ell \nu$ signal yields

$$\mathcal{B}(\overline{B} \to X_u \ell \bar{\nu}) = (1.80 \pm 0.13 \pm 0.15)\ 10^{-3}$$



V_{ub} extraction:

$$|V_{ub}| = \sqrt{\frac{\Delta\mathcal{B}(\overline{B} \to X_u \ell \bar{\nu})}{\tau_B \cdot \Delta\Gamma_{\text{theory}}}}$$

QCD Calculation	$\Delta\Gamma_{theory}$ (ps^{-1})	$\lvert V_{ub}\rvert(10^{-3})$
BLNP	$62.7^{+7.0}_{-5.7}$	$4.27 \pm 0.15 \pm 0.18^{+0.23}_{-0.20}$
DGE	$60.7^{+4.3}_{-3.9}$	$4.34 \pm 0.16 \pm 0.18^{+0.15}_{-0.15}$
GGOU	$62.1^{+4.4}_{-3.1}$	$4.29 \pm 0.15 \pm 0.18^{+0.11}_{-0.14}$
ADFR	$60.2^{+7.8}_{-6.6}$	$4.35 \pm 0.19 \pm 0.20^{+0.15}_{-0.15}$

Average:

$$|V_{ub}| = (4.31 \pm 0.25_{exp} \pm 0.16_{theo})10^{-3}$$

[Bosch *et al.* , PRD 72 (05) 073006]

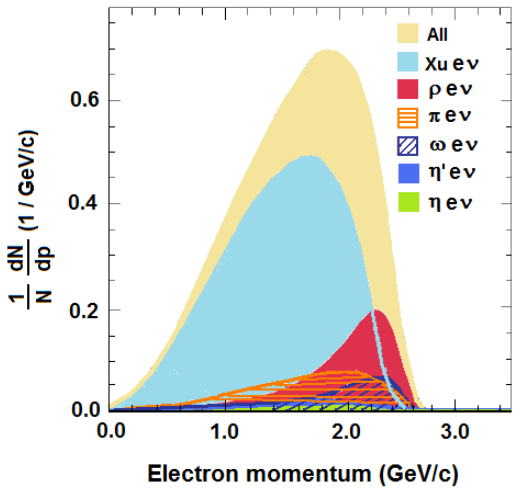
[Andersen et al. , JHEP 0601 (06) 097]

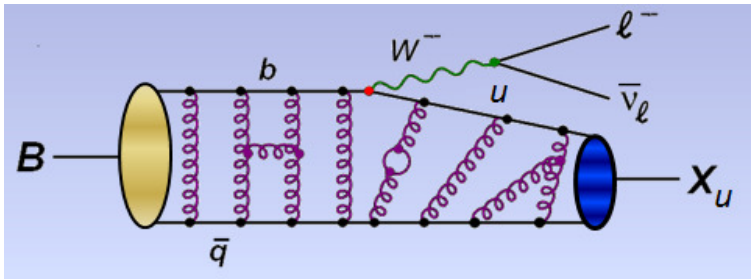
[Gambino et al., JHEP 0710 (07) 058]

[Aglietti et al., EPJ. C 59 (09) 831]

$B \to X_u \ell \nu$: exclusive

- The exclusive B semileptonic decay rate is described as function of form factors:

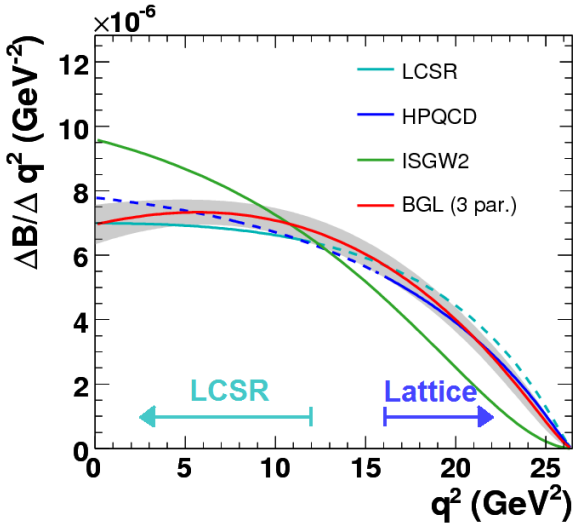


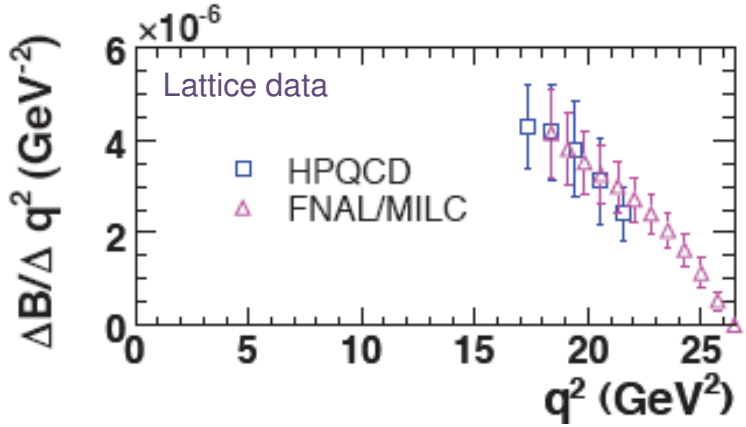


$= \pi, \eta, \eta', \rho, \omega$

$$\frac{d\Gamma(B \to \pi \ell \nu)}{dq^2} = \frac{G_F^2}{24\pi^3} |V_{ub}|^2 p_\pi^3 |f_+(q^2)|^2$$

QCD calculations:





V_{ub} exclusive: $B \to \pi \ell \nu$

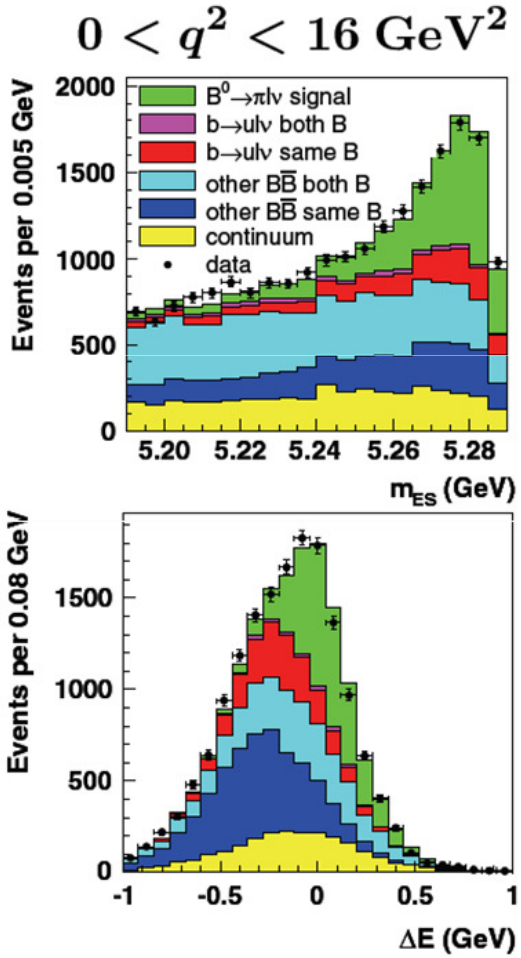
PRD 83 (2011) 052011
PRD 83 (2011) 032007

Analyses procedure:

- BaBar data samples: 423 fb^{-1} , 349 fb^{-1}
- Untagged analyses (high stat., more bkg.), e + μ
- Loose ν reconstruction from full event ($p_\nu = p_{beams} - \Sigma p_i$)
- Background suppression by cuts or NN
- 2D or 3D fit $\Delta E = (P_B P_{beams-} - s/2)/\sqrt{2}$,
  $m_{ES} = [(s/2 + p_B p_{beams-})^2 / E^2_{beams} - p^2_B]^{1/2}$
  $q^2 = (p_\ell + p_\nu)^2 = (p_B - p_\pi)^2$
  to extract the signal yield
- q^2 in 12 or 6 bins

$$\mathcal{B}(B^0 \to \pi^- \ell^+ \nu_\ell) = (1.42 \pm 0.05 \pm 0.07) \times 10^{-4}$$

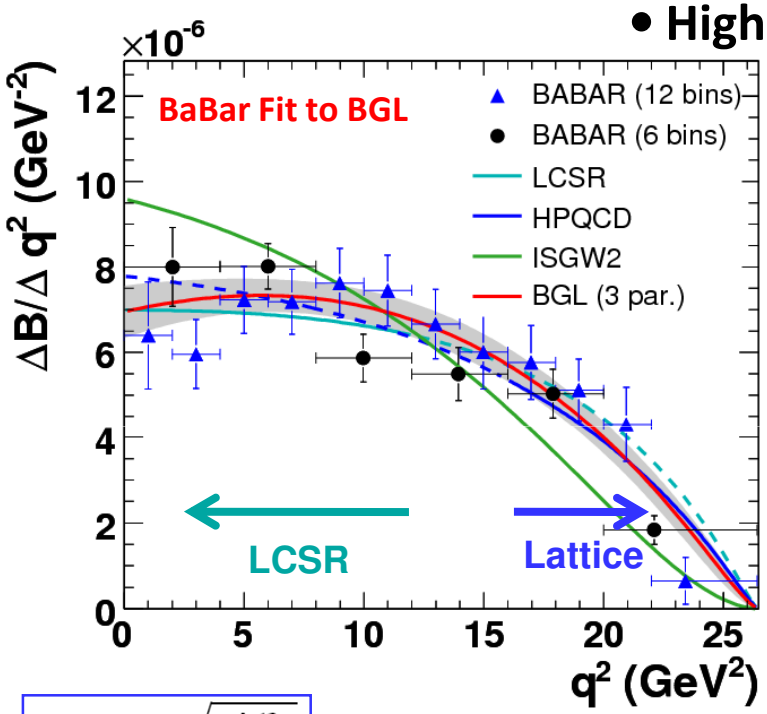
$$\mathcal{B}(B^0 \to \pi^- \ell^+ \nu_\ell) = (1.41 \pm 0.05 \pm 0.07) \times 10^{-4}$$



V_{ub} exclusive: BaBar combined

BaBar combined result:

- Small event overlap of $B^0 \to \pi^- \ell \nu$ (<1%)
- Uncorrelated statistical uncertainties
- Highly correlated systematics

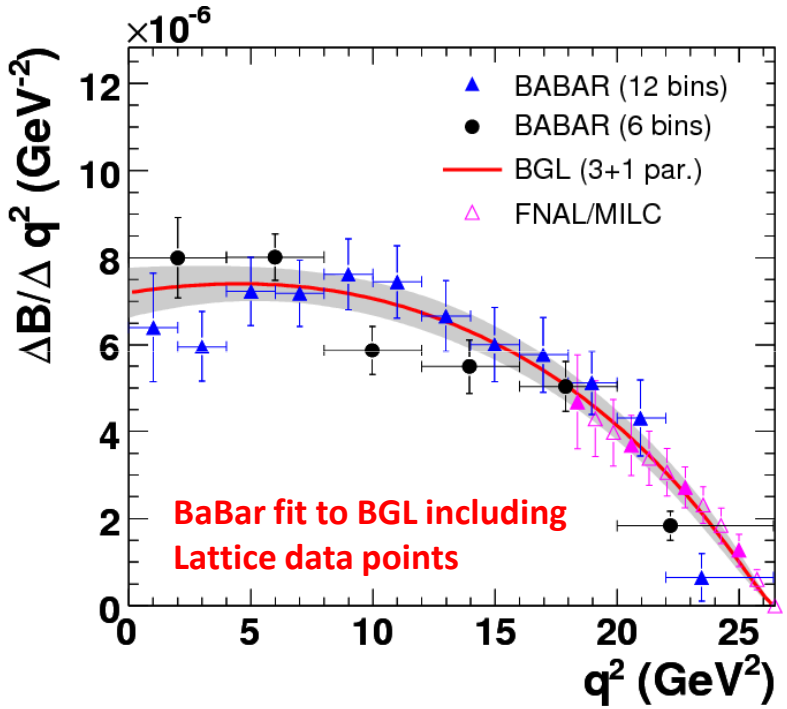


$$|V_{ub}| = \sqrt{\frac{\Delta\mathcal{B}}{\tau_0\,\Delta\zeta}}$$

(ΔB : LCSR $q^2 < 12\,\mathrm{GeV}^2$, LQCD $q^2 > 16\,\mathrm{GeV}^2$)

$\times 10^{-3}$	12 bins	6 bins	Combined
$\lvert V_{ub}\rvert_{\mathrm{HPQCD}}$	3.28 ± 0.20	3.21 ± 0.18	$3.23 \pm 0.16^{+0.57}_{-0.37}$
$\lvert V_{ub}\rvert_{\mathrm{FNAL}}$	3.14 ± 0.18	3.07 ± 0.16	$3.09 \pm 0.14^{+0.35}_{-0.29}$
$\lvert V_{ub}\rvert_{\mathrm{LCSR}}$	3.70 ± 0.11	3.78 ± 0.13	$3.72 \pm 0.10^{+0.54}_{-0.39}$

$f_+(0)|V_{ub}| = (9.4 \pm 0.4) \times 10^{-4}$



$f_+(0)|V_{ub}| = (9.6 \pm 0.4) \times 10^{-4}$

$$|V_{ub}| = (3.13 \pm 0.14 \pm 0.27) \times 10^{-3}$$

(fits from J.Dingfelder and V. Luth)

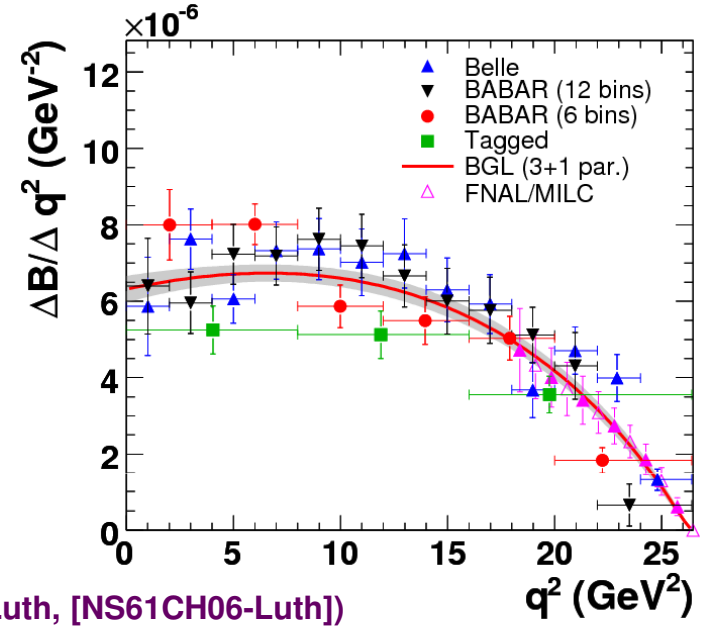
$B \to X_u \ell \nu$

Summary of V_{ub} measurements:

$|V_{ub}| = (3.19 \pm 0.14 \pm 0.27) \times 10^{-3}$

- **Exclusive:** (V. Luth, J. Dingfelder)

Theory	Experiment	q^2 range (GeV^2)	$\Delta\mathcal{B}$ (10^{-4})	$\lvert V_{ub}\rvert$ (10^{-3})
LCSR	BaBar+Belle Untagged+tagged	$0-12$	0.79 ± 0.03	$3.35 \pm 0.06^{+0.36}_{-0.31}$
HPQCD	BaBar+Belle Untagged+tagged	$16-26.4$	0.37 ± 0.03	$3.46 \pm 0.14^{+0.60}_{-0.39}$
FNAL/MILC	BaBar+Belle Untagged+tagged	$16-26.4$	0.37 ± 0.03	$3.31 \pm 0.13^{+0.37}_{-0.30}$
FNAL/MILC	BaBar+Belle Untagged+tagged	$16-26.4$	1.40 ± 0.04	$3.19 \pm 0.14 \pm 0.27$



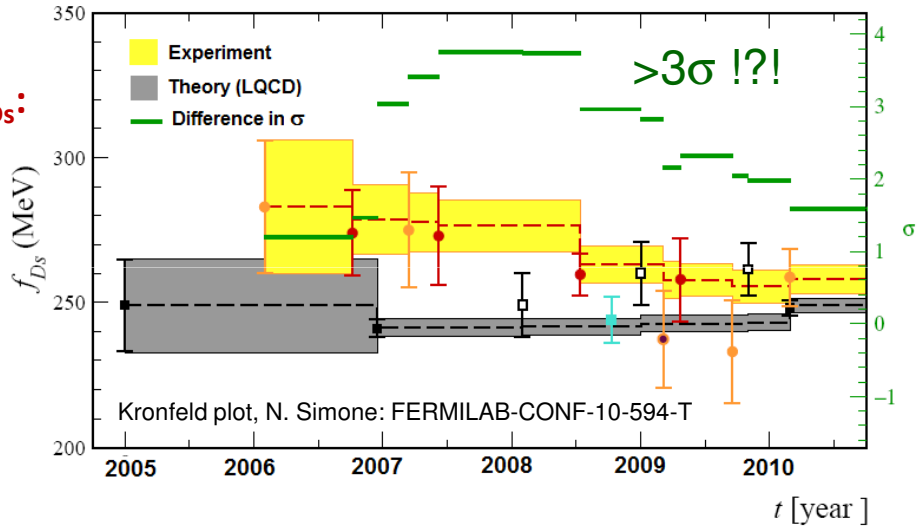
- **Inclusive:** $|V_{ub}| = (4.34 \pm 0.13 \pm 0.15) \times 10^{-3}$ (V. Luth, [NS61CH06-Luth])

Experiment	Selection	$\Delta\mathcal{B}$ (10^{-4})	Vub (10^{-4}) BLNP	Vub (10^{-4}) GGOU	Vub (10^{-4}) DGE
CLEO	$p^*_\ell > 2.2$ GeV	$2.30 \pm 0.15 \pm 0.30$	$4.00 \pm 0.47 \pm 0.34$	$3.81 \pm 0.45^{+0.22}_{-0.39}$	$3.70 \pm 0.43^{+0.30}_{-0.26}$
Belle	$p^*_\ell > 1.9$ GeV	$8.47 \pm 0.37 \pm 1.53$	$4.81 \pm 0.45^{+0.32}_{-0.29}$	$4.65 \pm 0.43^{+0.19}_{-0.30}$	$4.66 \pm 0.43^{+0.26}_{-0.25}$
BaBar	$p^*_\ell > 2.0$ GeV	$5.72 \pm 0.41 \pm 0.51$	$4.35 \pm 0.25^{+0.31}_{-0.30}$	$4.17 \pm 0.24^{+0.20}_{-0.33}$	$4.15 \pm 0.28^{+0.28}_{-0.25}$
BaBar	$p^*_\ell > 2.0$ GeV $s^{max.} > 3.5$ GeV ^{2}	$4.41 \pm 0.42 \pm 0.42$	$4.48 \pm 0.30^{+0.39}_{-0.37}$	—	$4.15 \pm 0.28 \pm 0.30$
Average	Untagged	—	$4.41 \pm 0.17 \pm 0.32$	$4.20 \pm 0.19^{+0.20}_{-0.33}$	$4.16 \pm 0.17^{+0.28}_{-0.25}$
Belle	$M_X \times q^2$, $p^*_\ell > 1.0$ GeV	$19.6 \pm 1.7 \pm 1.6$	$4.45 \pm 0.27^{+0.24}_{-0.21}$	$4.47 \pm 0.27^{+0.11}_{-0.15}$	$4.53 \pm 0.27 \pm 0.15$
BaBar	$M_X \times q^2$, $p^*_\ell > 1.0$ GeV	$18.0 \pm 1.3 \pm 1.5$	$4.27 \pm 0.23^{+0.23}_{-0.20}$	$4.29 \pm 0.24^{+0.11}_{-0.14}$	$4.34 \pm 0.24 \pm 0.15$
Average	Tagged	$18.7 \pm 1.0 \pm 1.1$	$4.35 \pm 0.18^{+0.24}_{-0.21}$	$4.37 \pm 0.18^{+0.11}_{-0.15}$	$4.42 \pm 0.18 \pm 0.15$

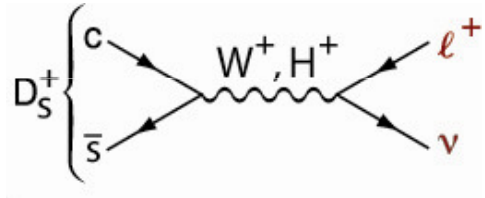
Charm sl decays

- Charm semileptonic decays allow to measure form factors in the charm sector, validating LQCD methods
  - → increase theory precision involving B decays
  - → trust LQCD calculations ensuring possible New Physics signs

Example: the leptonic constant f_{Ds}:



f_{Ds} puzzle:
exp ≠ theo→ contribution from a charged Higgs?

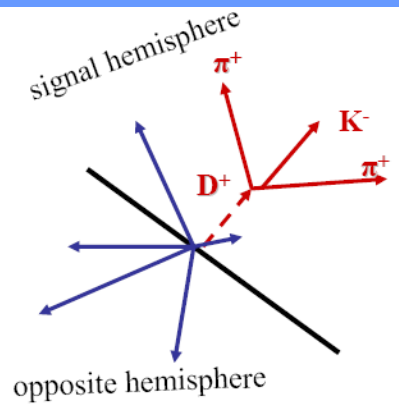


- Several charm semileptonic channels have been studied at BaBar:

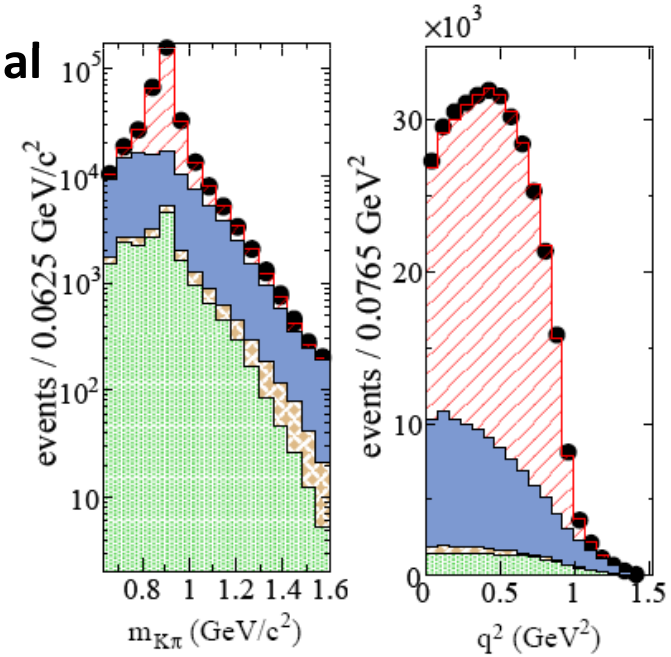
$D \to K e \nu$ [PRD 76, 052005 (2007)]	$f^K_+(q^2)$	
$D_s \to K K e \nu$ [PRD 78, 051101(R) (2008)]	$A_1(q^2), A_2(q^2), V(q^2)$	$\longrightarrow$ $r_2 = A_2(0)/A_1(0)$
$D^+ \to K \pi e \nu$ [PRD 83, 072001 (2011)]	$A_1(q^2), A_2(q^2), V(q^2)$	$r_v = V(0)/A_1(0)$
$D \to \pi e \nu$ soon	$f^\pi_+(q^2)$	

Charm sl decays

Analysis procedure:

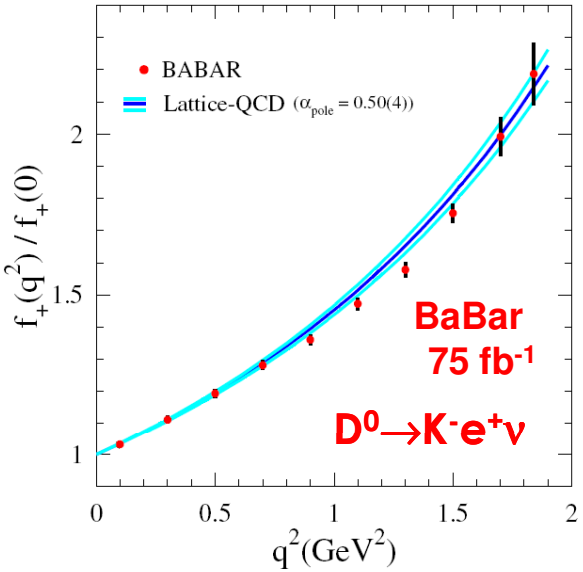


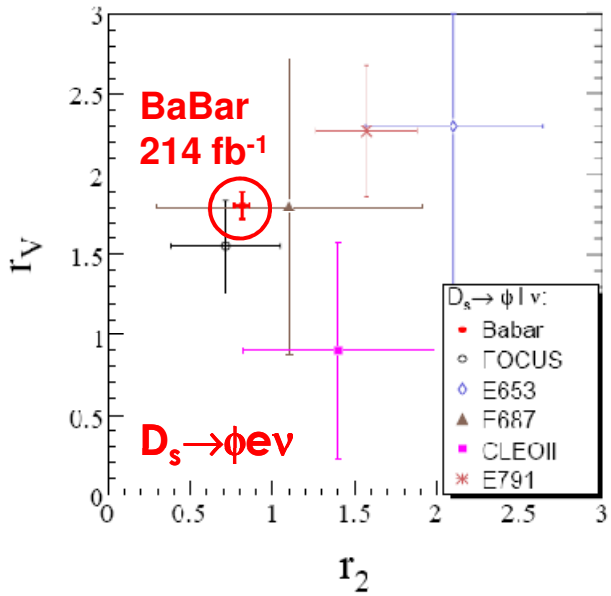
- Partial reconstruction method; $e^+e^- \rightarrow cc$; only electrons
- D* tag in case of $D \rightarrow Ke\nu$, no tag for D_s or D^+ decays
- Compute the $D_{(s)}$ direction from all tracks ≠ signal tracks
- q^2 and angular distributions: kinematic fit with signal tracks momenta and missing energy information
- Background suppression using event shape and topological variables
- Background control, test of the analysis technique and the normalization are obtained from hadronic data samples (ex: $D \rightarrow K\pi$, $D \rightarrow K\pi\pi$)

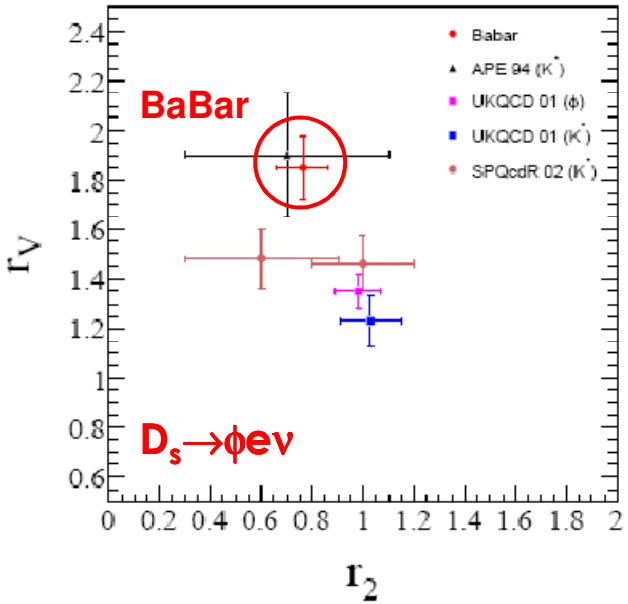


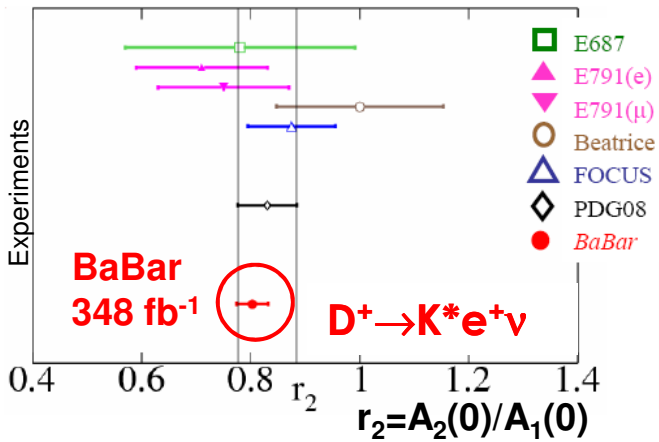
Charm sl decays

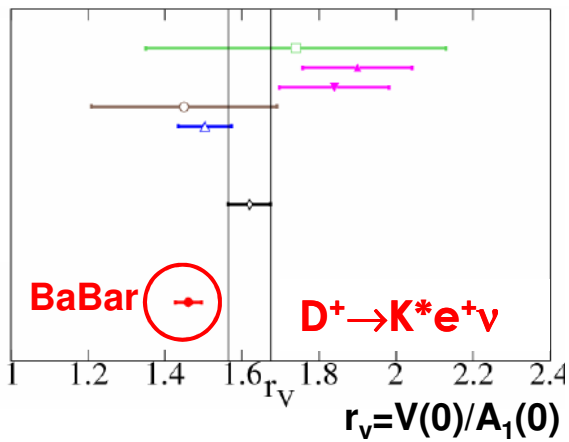
- Quite precise form factor measurements from BaBar→ need LQCD improvements

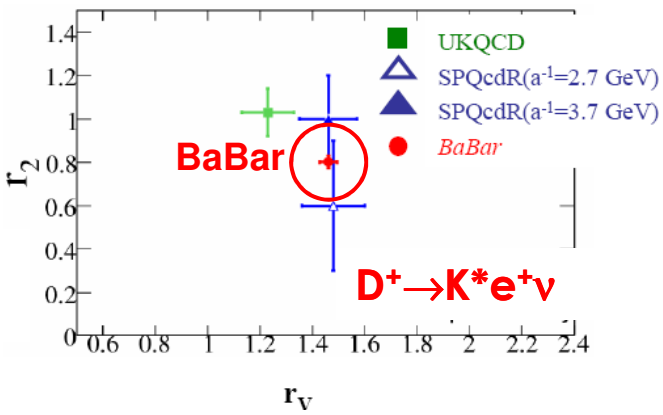












Summary

- $B \to D^{(*)}\tau\nu$

Improved measurements at BaBar
$B \to D^0\tau\nu$ and $B \to D^+\tau\nu$ more than 5σ significance
$R(D^{(*)})$ exceed by $1.8\ \sigma$ the SM values $\to$ favors large $\tan\beta$

- V_{ub}

$|V_{ub}|_{excl.} = (3.19 \pm 0.14 \pm 0.27) \times 10^{-3}$
$|V_{ub}|_{incl.} = (4.34 \pm 0.13 \pm 0.15) \times 10^{-3}$

Despite the experimental and theoretical efforts the discrepancy between exclusive and inclusive measurements remains:
what does it means? what don't we understand?

- Charm Semileptonic form factors

Quite precise results from BaBar for $D \to Ke\nu$, $D_s \to \phi e\nu$, $D \to K^* e\nu$,
form factors allow to check QCD methods: need LQCD improvements