Inclusive $|V_{ub}|$: Experimental Results & Prospects

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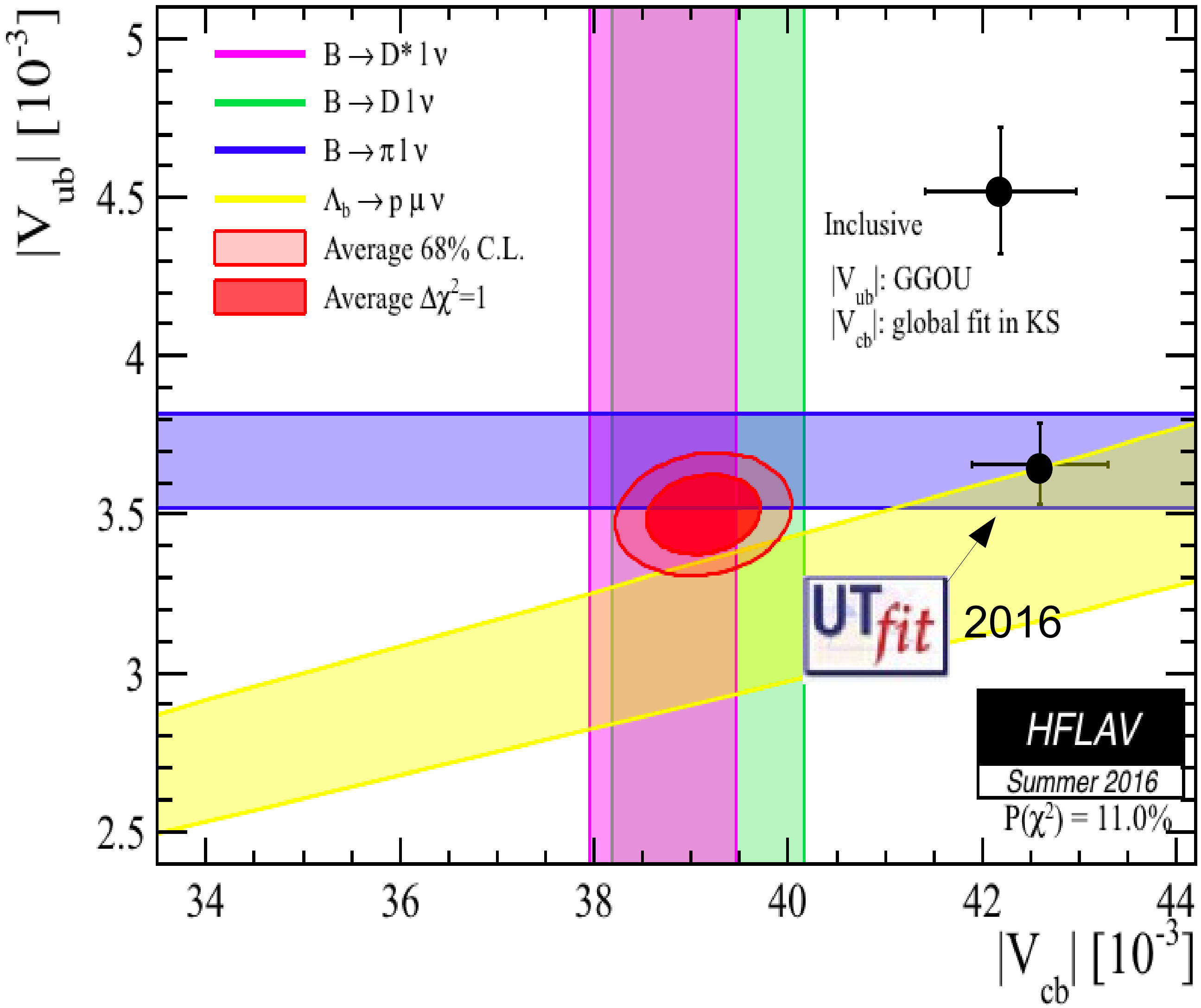
Introduction

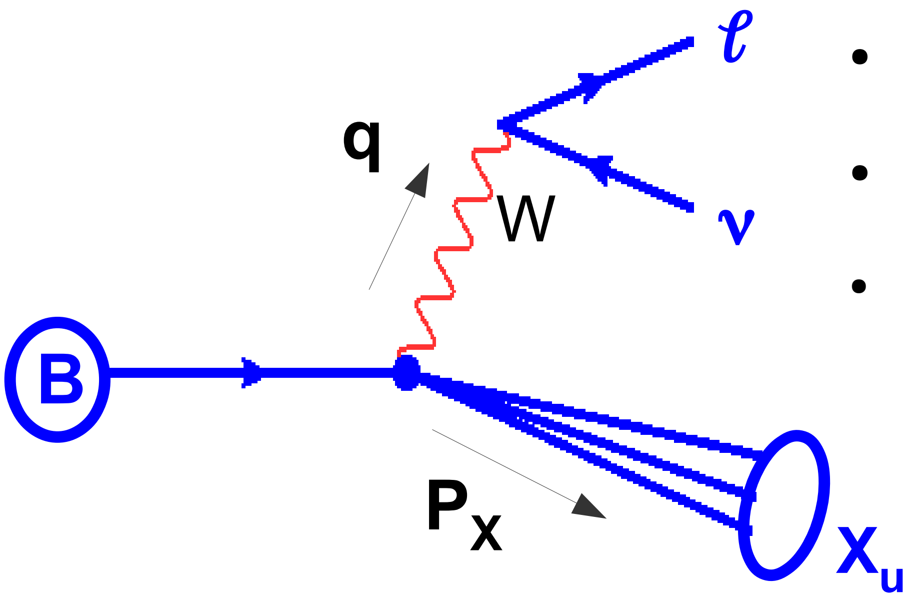
Heavy Flavor Averaging Group
Eur.Phys.J. C77 (2017) no.12, 895

- Large discrepancy with exclusive Vub and CKM fit results
- Critical understanding of the error budgets and possible source of biases are needed
- Some of the source of backgrounds can be constrained from data



$|V_{ub}|$ from inclusive decays

$$\frac{\Gamma(b \to c\ell\nu)}{\Gamma(b \to u\ell\nu)} \approx 50$$



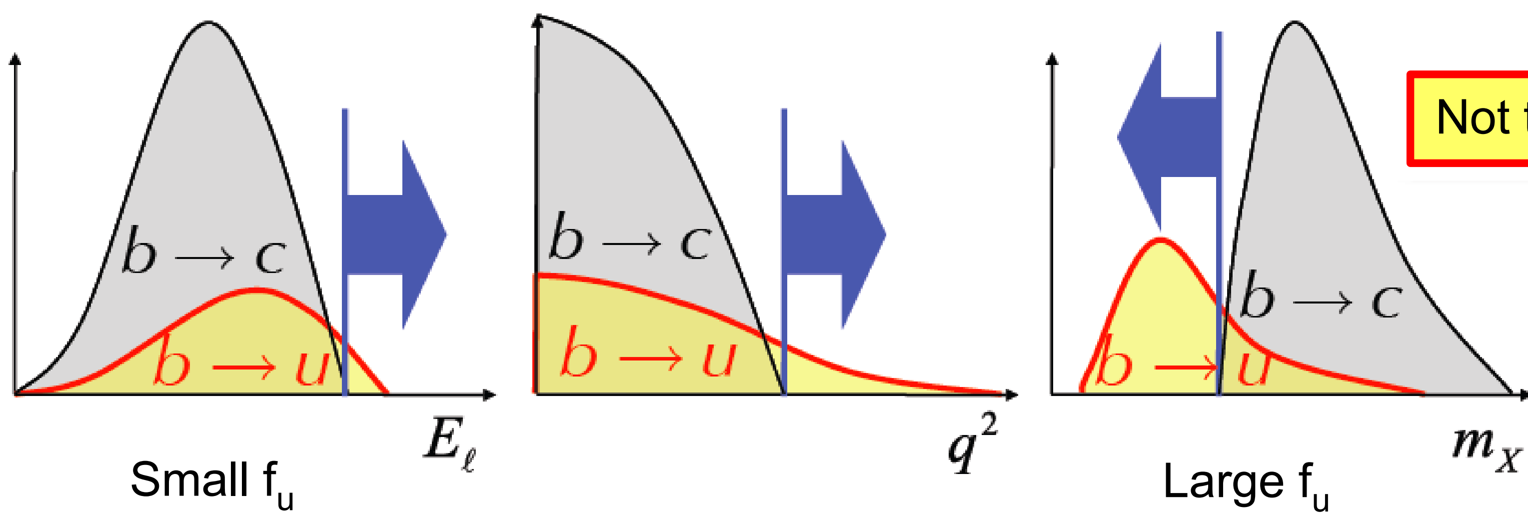
- Large background from $B \to X_c \ell \nu$
- Kinematics to extract the signal: $m_u << m_c$
- Cut limited region of phase space (f_u)
  - Non perturbative shape-function needed
  - Universal only at leading order in Λ/m_b

E_ℓ = lepton energy

$q^2 = (P_B - P_X)^2 = (P_\ell - P_\nu)^2$

M_X = X_u hadronic mass

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



Not to scale!

Experimental resolution leads to “irreducible” $b \to c \ell \nu$ contamination
- partially suppressed With K and D* vetos

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DN De Fazio, Neubert JHEP9905,017 (1999)
Claimed in BLNP to be superseeded
BLNP Bosh, Lange, Neubert, Paz,
Nulc.Phys.B699,335(2004)
GGOU Gambino, Giordano, Ossola, Uraltsev,
JHEP908 10, 058 (2007)
DGE Andersen, Gardi, JHEP 0601, 097 (2006)
ADFR Aglietti, Di Ludovico, Ferrara, Ricciardi
EPJC, Vol. 59 (2009)
BLL Bauer, Ligeti, Luke Phys. Rev. D64,113004 (2001)
Only valid in the mx-q[2] two-dimensions cut

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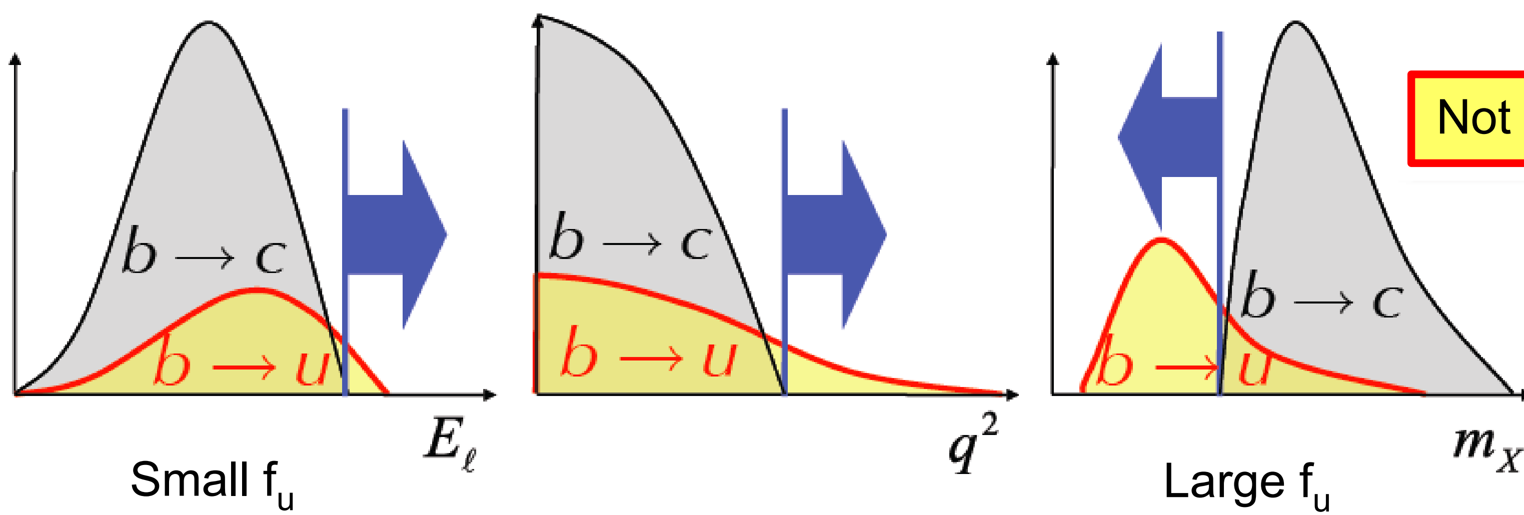

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B

- Avoid the large background
- Avoid regions more sensitive to the Shape Function
- Avoid Weak Annihilation
- We look at many kinematic regions and look for consistencies

E_ℓ

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$M_X = X_u$ hadronic mass

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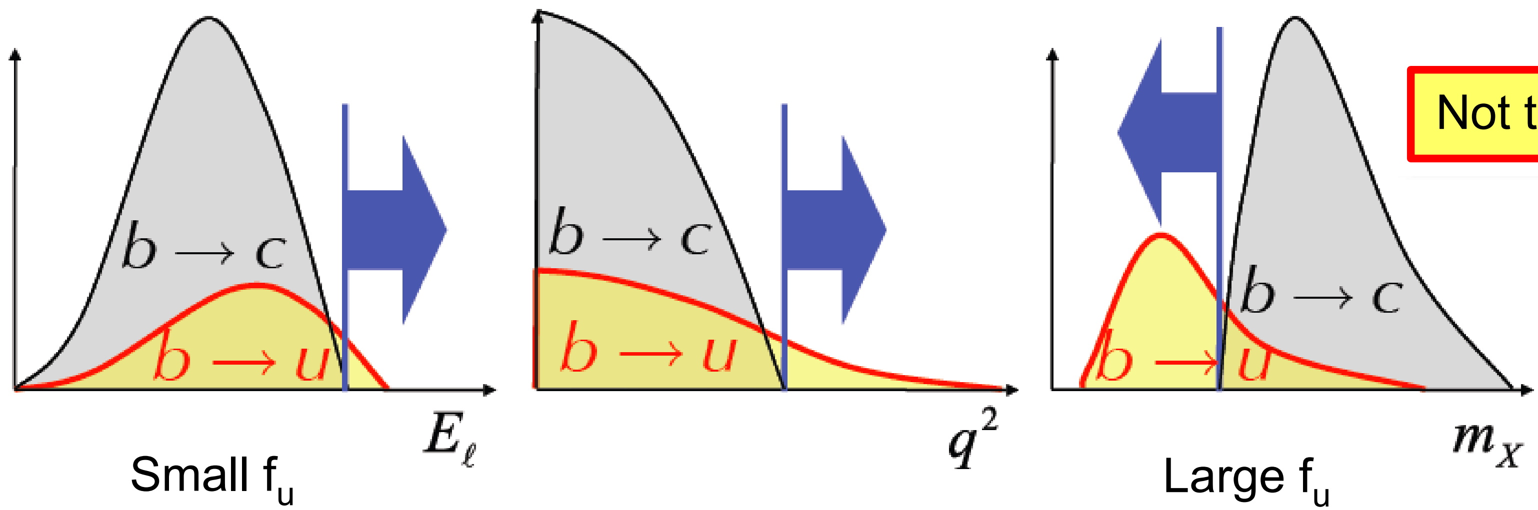

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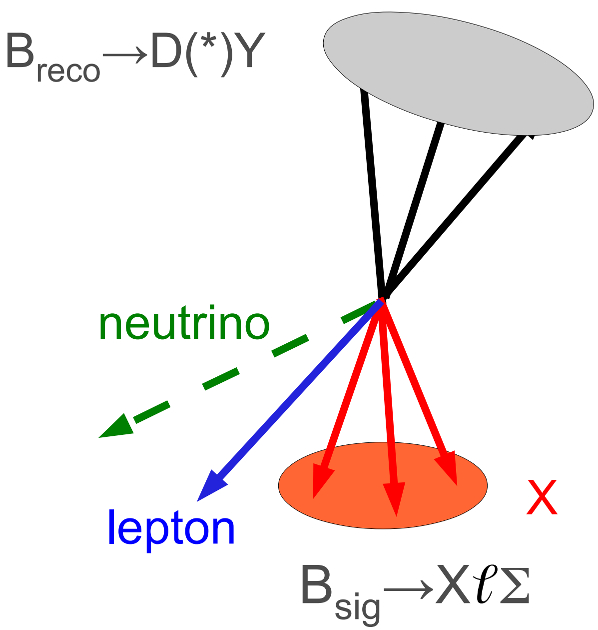
Analyses techniques

- Some observables are accessible from untagged measurements
  - Energy lepton spectrum
  - q^2: from lepton and event missing momentum (neutrino reconstruction)

- Other observables (M_x, $P_+ = E_x - |P_x|$) require the B-hadron tagging to reduce background and have enough kinematic information to separate signal from background



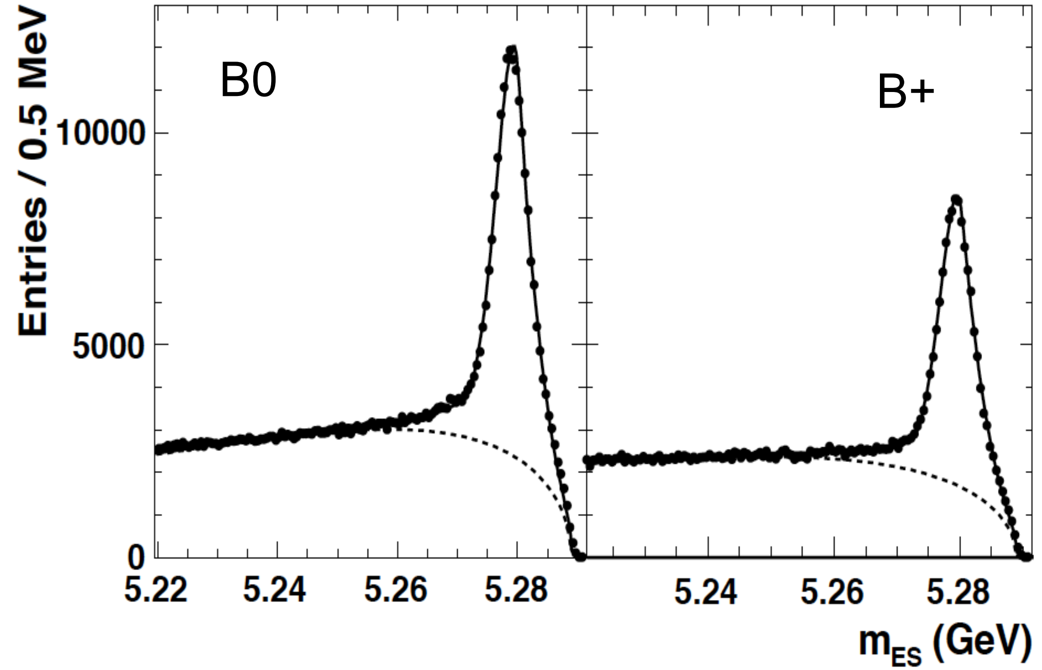
- Identify B momentum, B charge

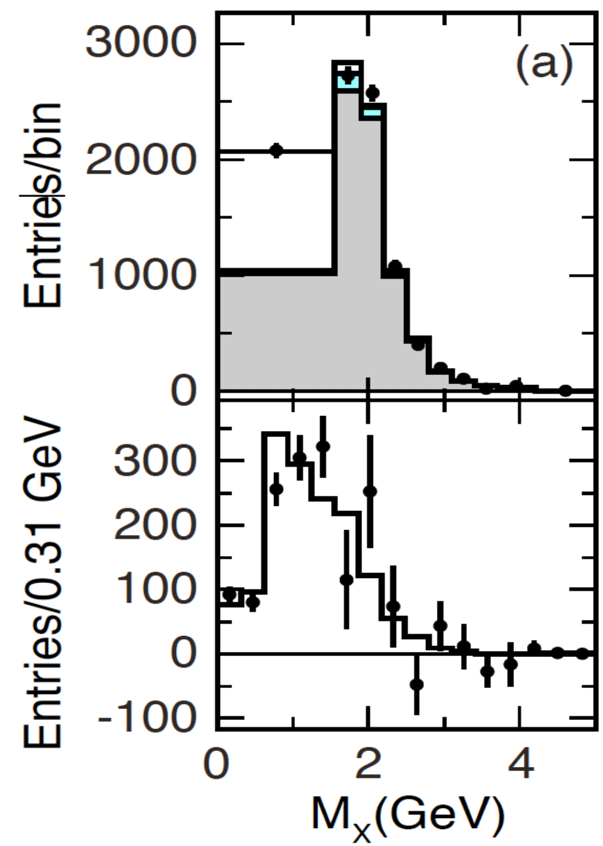
- $p_{miss} = p_{\div(4S)} | \; p_{reco} 2 \; p_X \; 2 \; p_{\text{ lepton}}$
- X: all remaining particles

Hadronic Tagging

- Reconstruct a B
- High momentum lepton
- Veto on Kaons, require total charge Q=0, D* rejected using soft pions (charged and neutrals), require a small MM2
- The combinatorial and the continuum are subtracted using the fit to the mES in bins of the variable considered, or using the MC
- Fit to the various kinematic quantities to determine the signal yields

$$\frac{\Delta B(X_u \ell \nu)}{B(X \ell \nu)} = \frac{N_{b\to u}}{N_{X\ell\nu}} \cdot \frac{F}{\epsilon_{sel}}$$



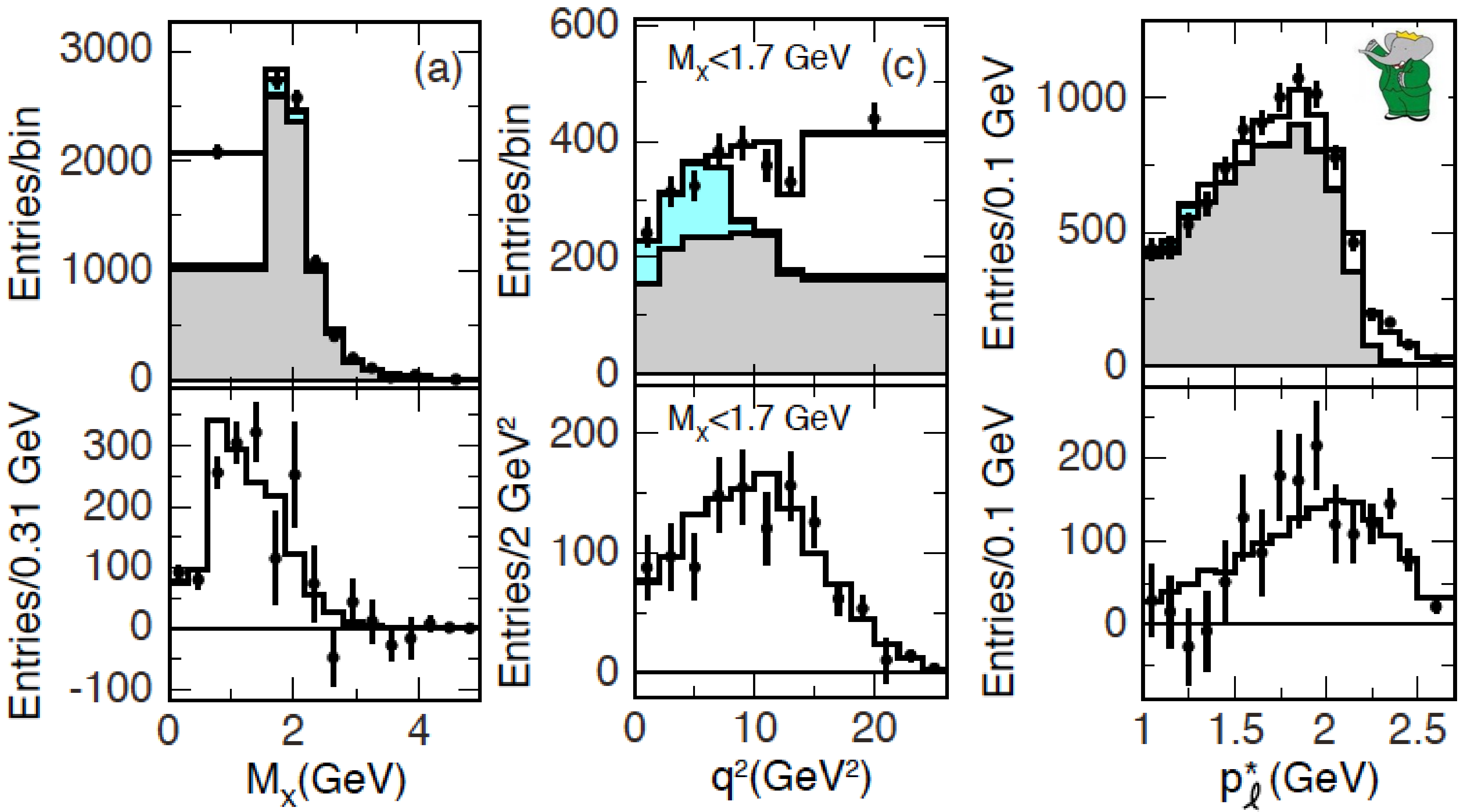


$B \to X_u \ell \nu$

$B \to X_c \ell \nu$ + cascades + fake ℓ

Fit results in limited regions of phase space

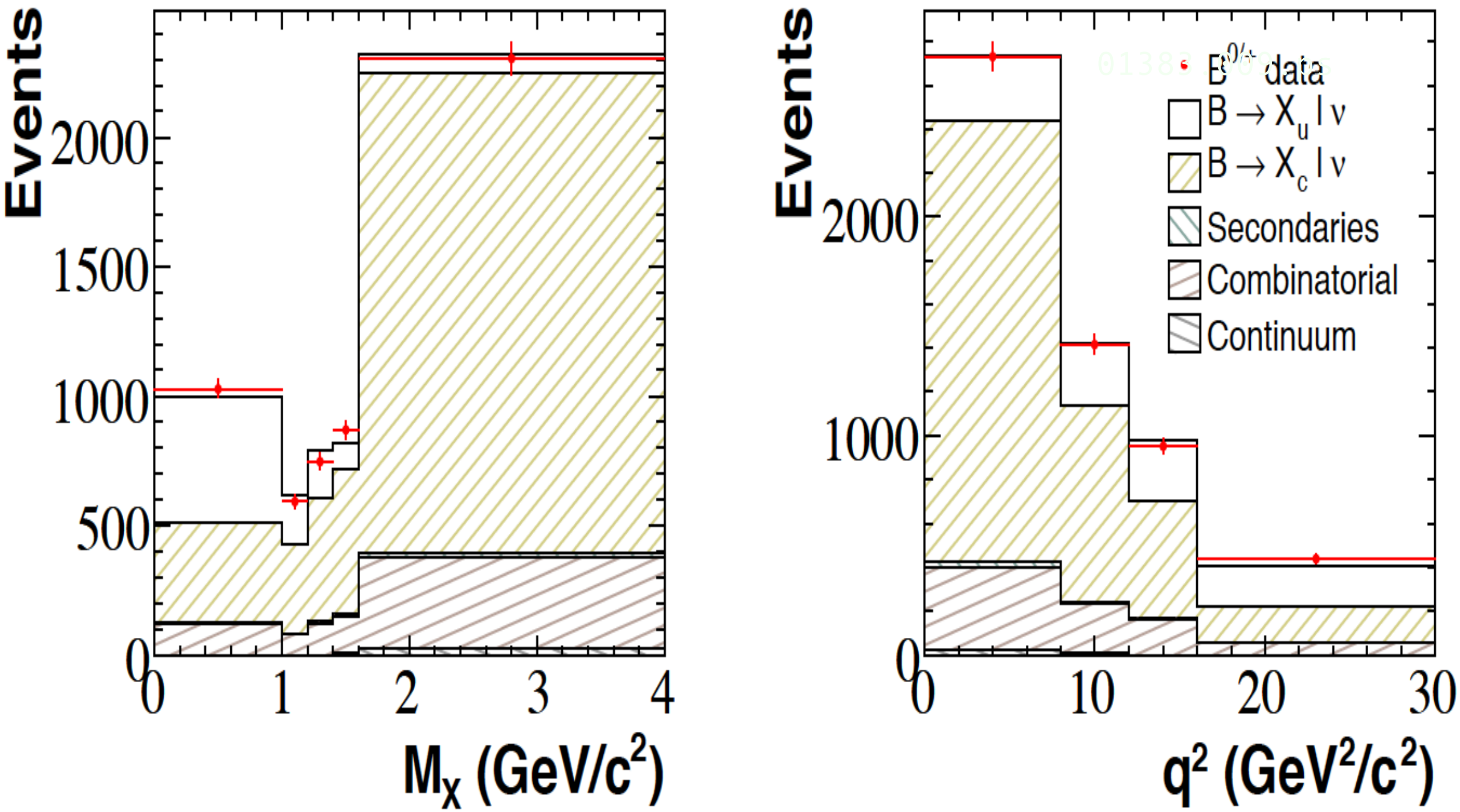
BABAR PRD.86:032004,2012



Into the b $\rightarrow$ c region

- Thanks to a better understanding of the B→Xc backgrounds, could it be possible to extract B→ Xu in the "almost" full phase space
- Theoretical uncertainties strongly reduced fu ~ 90% Babar obtained very similar results

BELLE PRL 104:021801,2010



Similar results from BaBar

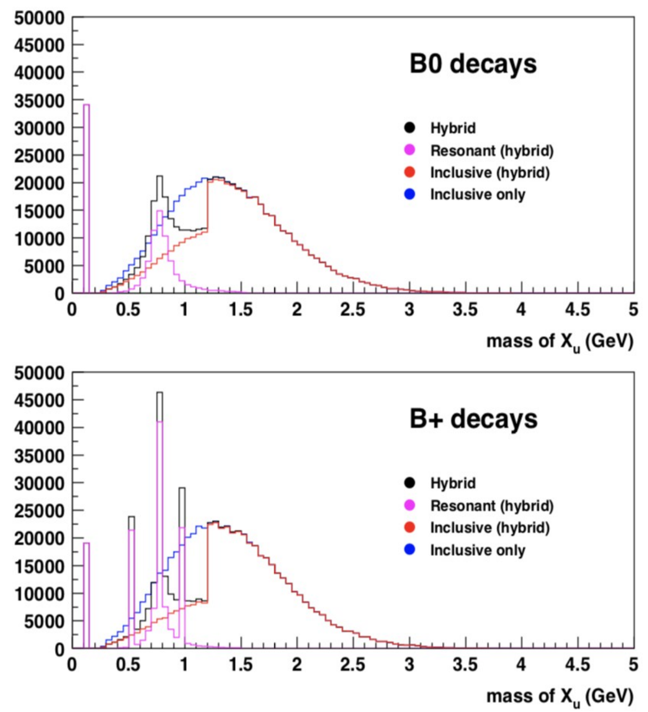
BABAR PRD.86:032004,2012

Into the b → c region

BELLE PRL 104:021801,2010

$p_\ell^{*B} > 1.0$ GeV	$\Delta\mathcal{B}/\mathcal{B}$ (%)
$\mathcal{B}(D^{(*)}\ell\nu)$	1.2
$(D^{(*)}\ell\nu)$ form factors	1.2
$\mathcal{B}(D^{**}e\nu)$ & form factors	0.2
$B \to X_u\ell\nu$ (SF)	3.6
$B \to X_u\ell\nu$ ($g \to s\bar{s}$)	1.5
$\mathcal{B}(B \to \pi/\rho/\omega\ell\nu)$	2.3
$\mathcal{B}(B \to \eta,\ \eta'\ell\nu)$	3.2
$\mathcal{B}(B \to X_u\ell\nu)$ un-meas.	2.9
Cont./Comb.	1.8
Sec./Fakes/Fit.	1.0
PID/Reconstruction	3.1
BDT	3.1
Systematics	8.1
Statistics	8.8

- B → Dlν and D*lν are described by CLN with parameters from HFLAV
- Resonant B→D**lν using LLSW
- Goity-Roberts for non-resonant
- Signal model is an hydrid mix of exclusive and inclusive contributions



- Unmeasured resonances modeled with ISGW2
- Inclusive part uses De Fazio-Neubert SF parameterization
- The inclusive part is varies to have same moments of q^2 and Mx of the GGOU model
- Gluon-splitting simulated by PYTHIA (about 12% of the signal)

Systematics

BABAR PRD.86:032004,2012

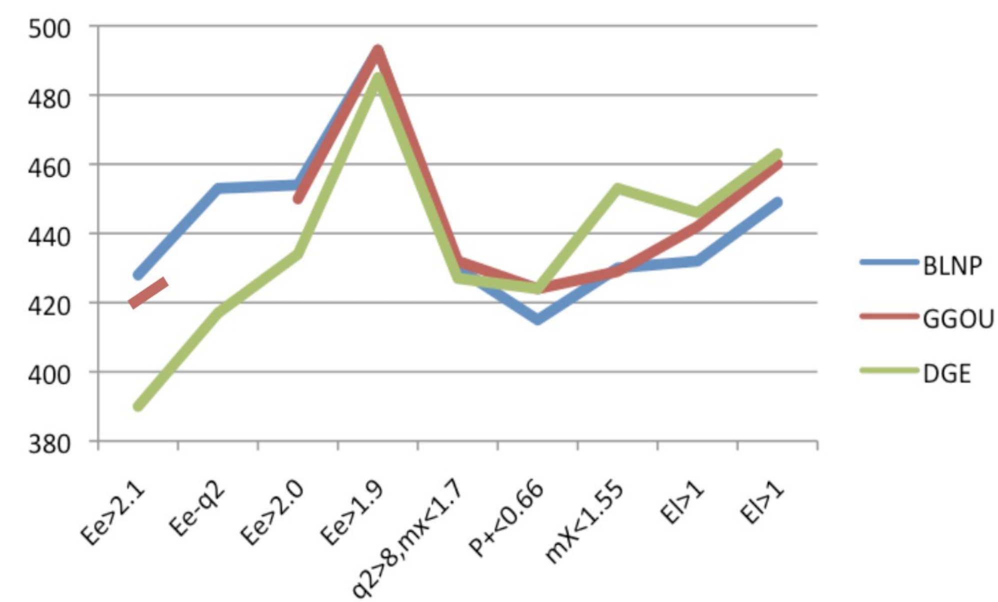
Phase space restriction	$M_X < 1.55$ GeV	$M_X < 1.70$ GeV	$P_+ < 0.66$ GeV	$M_X < 1.70$ GeV, $q^2 > 8$ GeV^2	$M_X - q^2$	$p^*_\ell > 1.0$ GeV	$p^*_\ell > 1.3$ GeV
Data statistical uncertainty	7.1	8.9	8.9	8.0	7.1	9.4	8.8
MC statistical uncertainty	1.3	1.3	1.3	1.6	1.1	1.1	1.2
Detector effects							
Track efficiency	0.4	1.0	1.1	1.7	0.7	1.2	1.0
Photon efficiency	1.3	2.1	4.0	0.7	1.0	0.9	0.9
π^0 efficiency	1.2	0.9	1.1	0.9	0.9	2.9	1.1
Particle identification	1.9	2.4	3.3	2.9	2.3	2.9	2.2
K_L production/detection	0.9	1.3	1.1	2.1	1.6	1.3	0.6
K_S production/detection	0.8	1.4	1.7	2.1	1.2	1.3	0.3
Signal simulation							
Shape function parameters	2.0	1.3	1.2	0.7	5.4	6.4	6.6
Shape function form	1.2	1.6	2.6	1.2	1.5	1.1	1.1
Exclusive $\overline{B} \to X_u \ell \bar{\nu}$	0.6	1.3	1.6	0.7	1.9	5.3	3.4
$s\bar{s}$ production	1.2	1.6	1.1	1.0	2.7	3.1	2.4
Background simulation							
B semileptonic branching ratio	0.9	1.4	1.5	1.4	1.0	0.8	0.7
D decays	1.1	0.6	1.1	0.6	1.1	1.6	1.5
$B \to D \ell \nu$ form factor	0.5	0.5	1.3	0.4	0.4	0.1	0.2
$B \to D^* \ell \nu$ form factor	0.7	0.7	0.9	0.7	0.7	0.7	0.7
$B \to D^{**} \ell \nu$ form factor	0.8	0.9	1.3	0.4	0.9	1.0	0.3
$B \to D^{**}$ reweighting	0.5	1.4	1.5	1.0	1.9	0.4	1.5
m_{ES} background subtraction							
m_{ES} background subtraction	2.0	2.7	1.9	2.6	1.9	2.0	2.5
combinatorial backg.	1.8	1.8	2.6	1.8	1.0	2.1	0.5
Normalization							
Total semileptonic BF	1.4	1.4	1.4	1.4	1.4	1.4	1.4
Total systematic uncertainty	5.5	6.7	8.3	6.6	8.4	11.0	9.3
Total experimental uncertainty	9.0	11.1	12.2	10.4	11.0	14.4	12.8

Status of inclusive $|V_{ub}|$

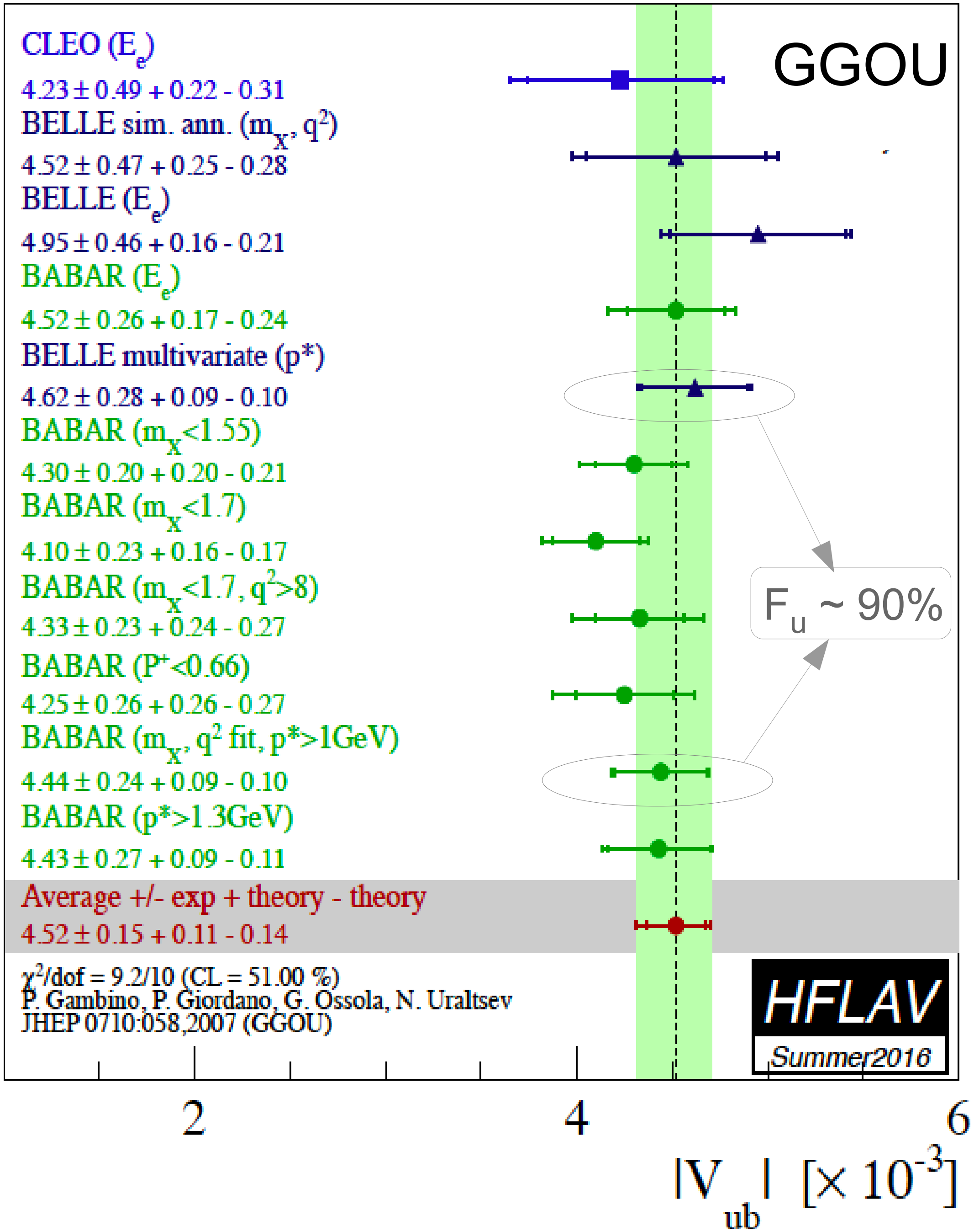
Most recent measurement is dated 2012

- Consistency between difference acceptance regions
- Calculations agree with each other

Framework	$\lvert V_{ub}\rvert[10^{-3}]$
BLNP	$4.44 \pm 0.15^{+0.21}_{-0.22}$
DGE	$4.52 \pm 0.16^{+0.15}_{-0.16}$
GGOU	$4.52 \pm 0.15^{+0.11}_{-0.14}$
ADFR	$4.08 \pm 0.13^{+0.18}_{-0.12}$
BLL (m_X/q^2 only)	$4.62 \pm 0.20 \pm 0.29$



B Kowalewski @ CKM16



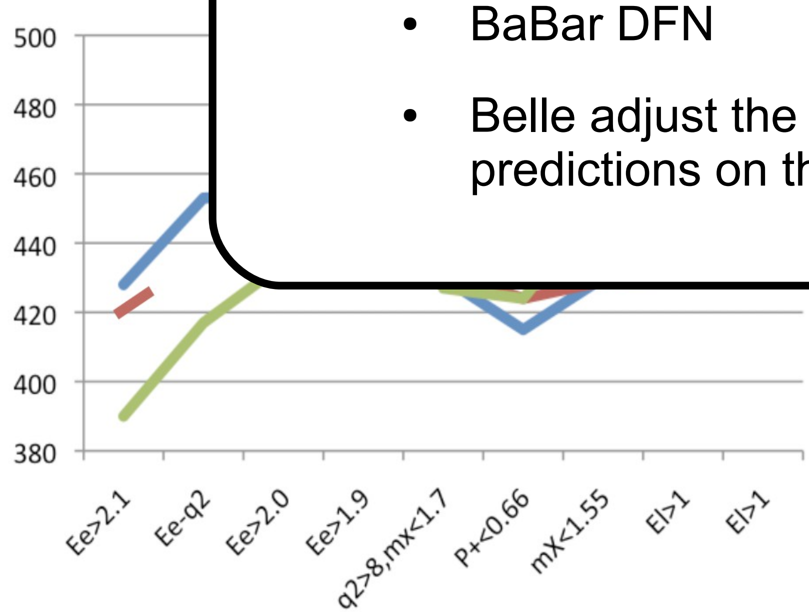
Status of inclusive $|V_{ub}|$

Most recent measurements is dated 2012

- Consi… accep…
- Calcu…

Framew…
BLNP DGE GGOU ADFR BLL $(m$…

- Correlated uncertainties
  - HQE parameters m_b, m_μ^2: from Global Fit for inclusive $|V_{cb}|$
  - Common experimental tools: EvtGen, JETSET X_u hadronisation, $b\to c\ell\nu$
- $|V_{ub}|$ is calculated from partial rates measured with only one signal model
  - BaBar DFN
  - Belle adjust the signal model to match the GGOU predictions on the q2 and mx moments



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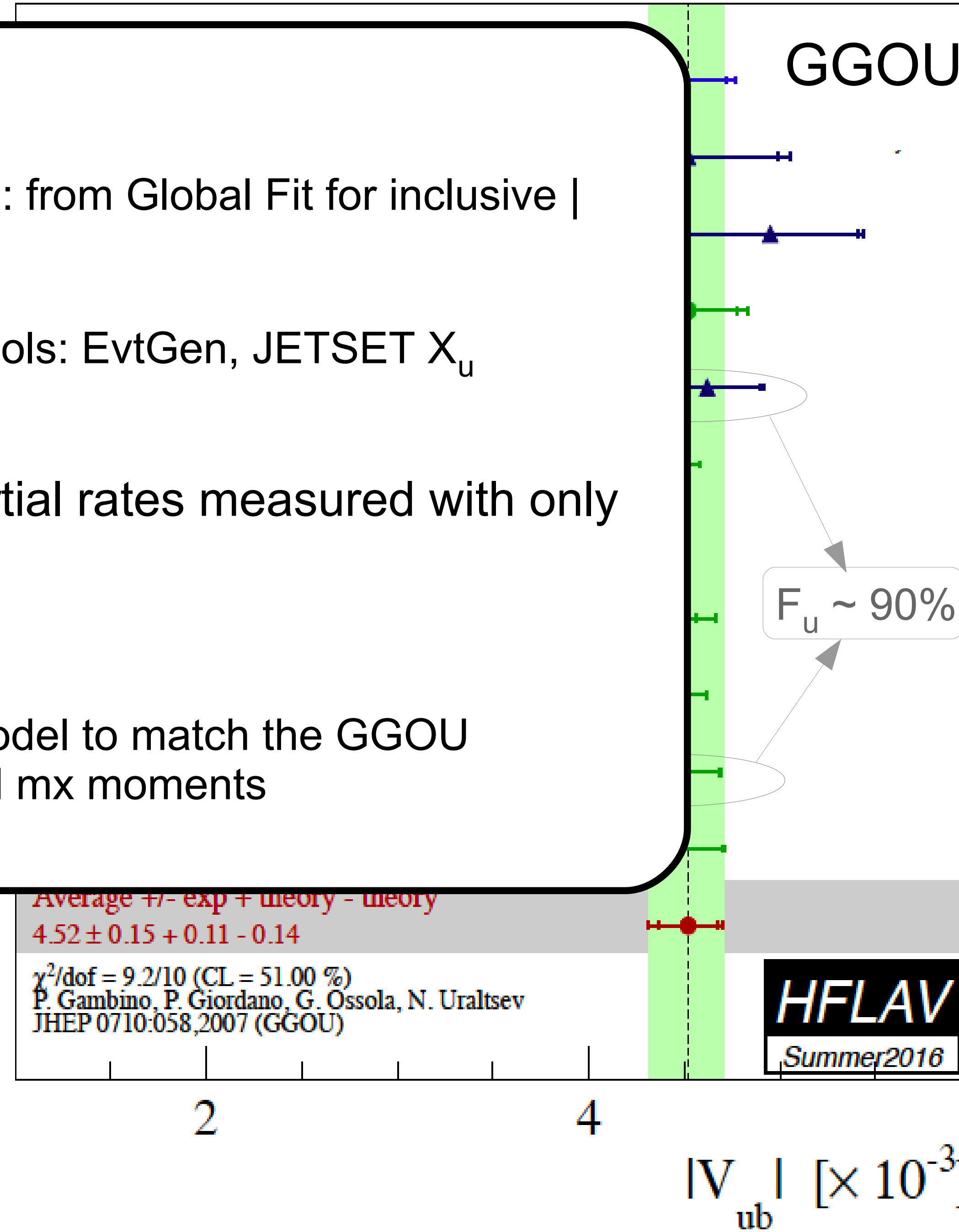


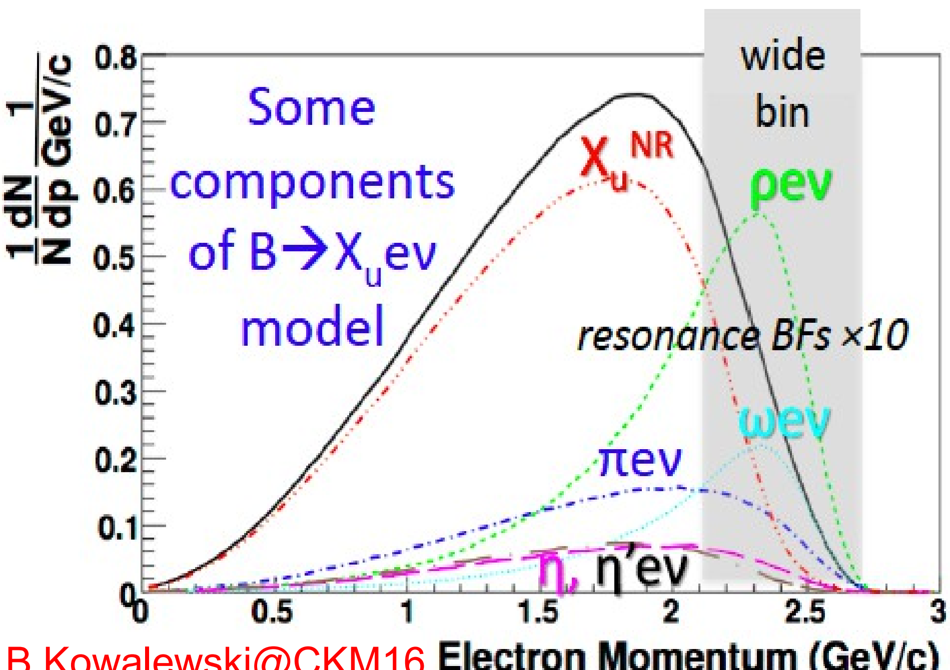
New study of lepton end-point

Phys.Rev.D 95, 072001 (2017)

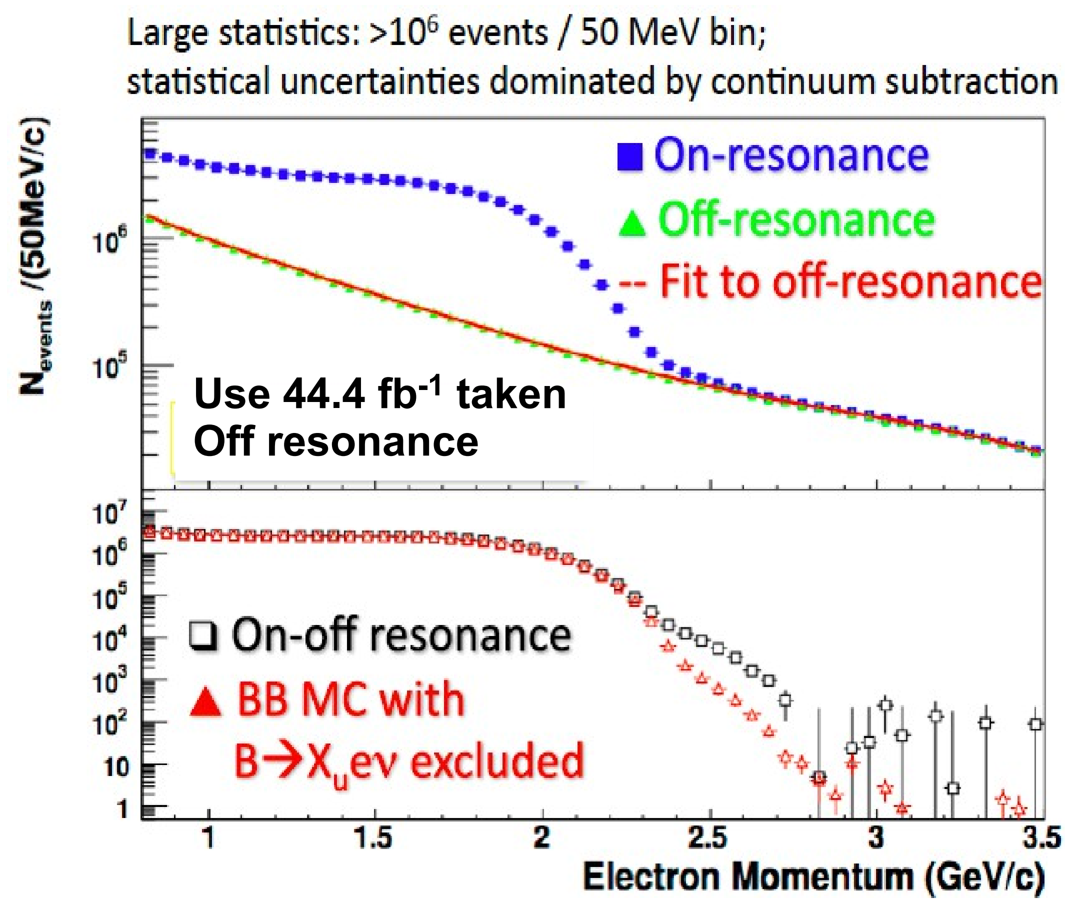
- Inclusive electron spectrum measurement

Fit Strategy

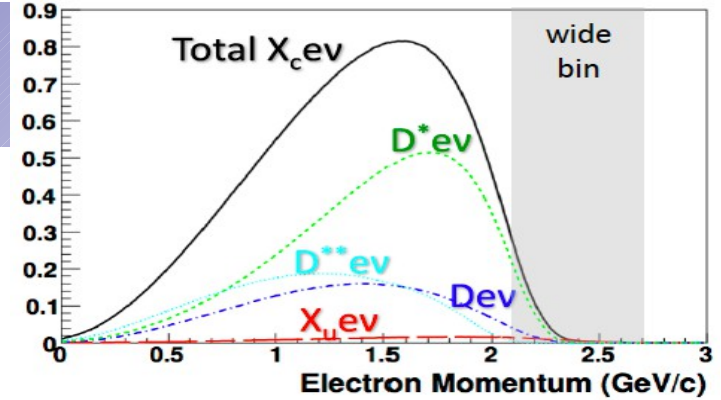
- Fit simultaneously on-Y(4S) and off-Y(4S)
    - 5 separate $b \to c$ components
    - Secondary leptons $b \to c \to e$
    - $b \to X_u e \nu$
- Spectrum range [p_{min}, 2.7] GeV, p_{min} from 0.8 GeV



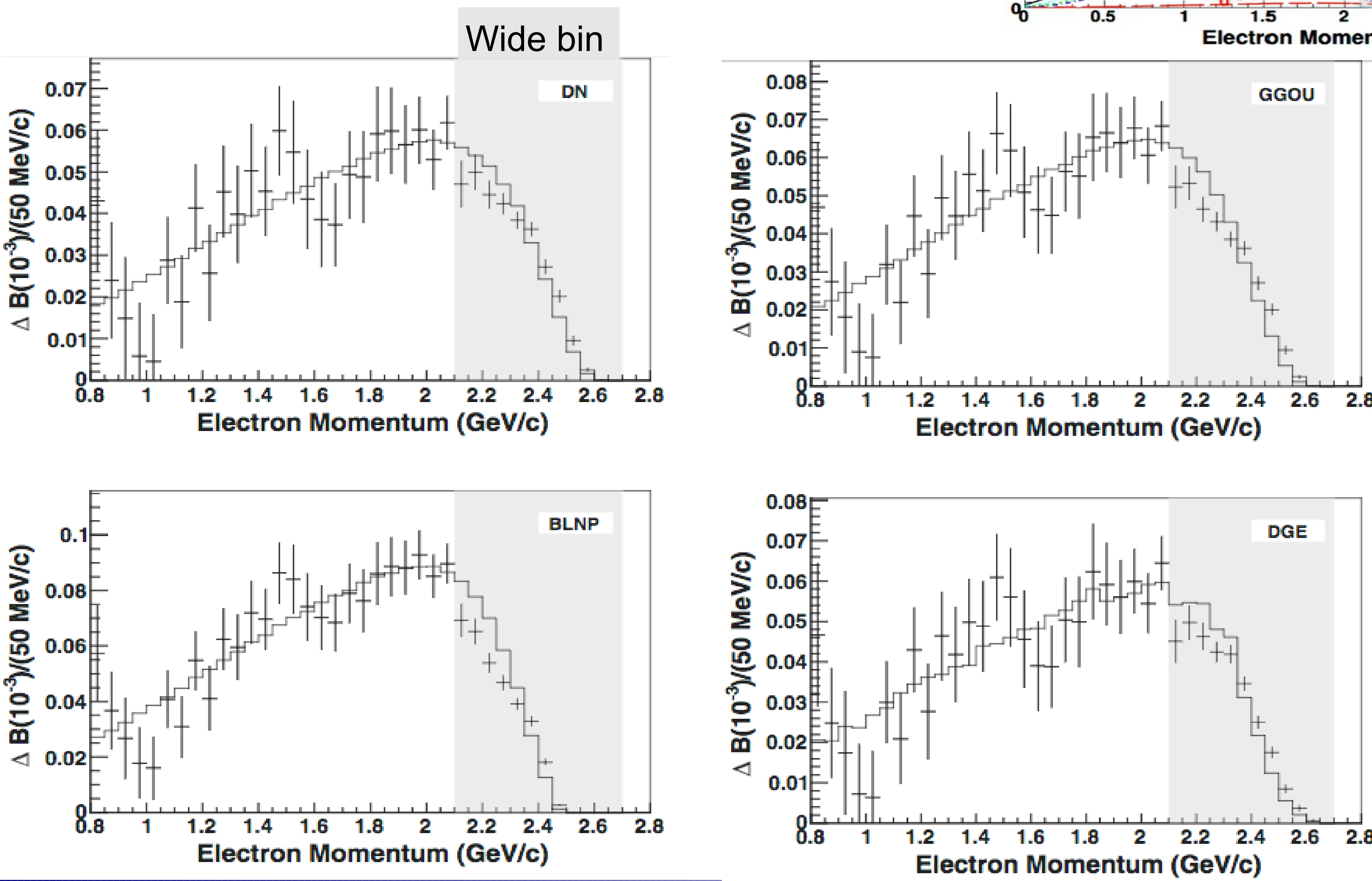
- Dataset: 467M Y(4S)



$B \to X_u e\nu$ in $\Upsilon(4S)$ frame

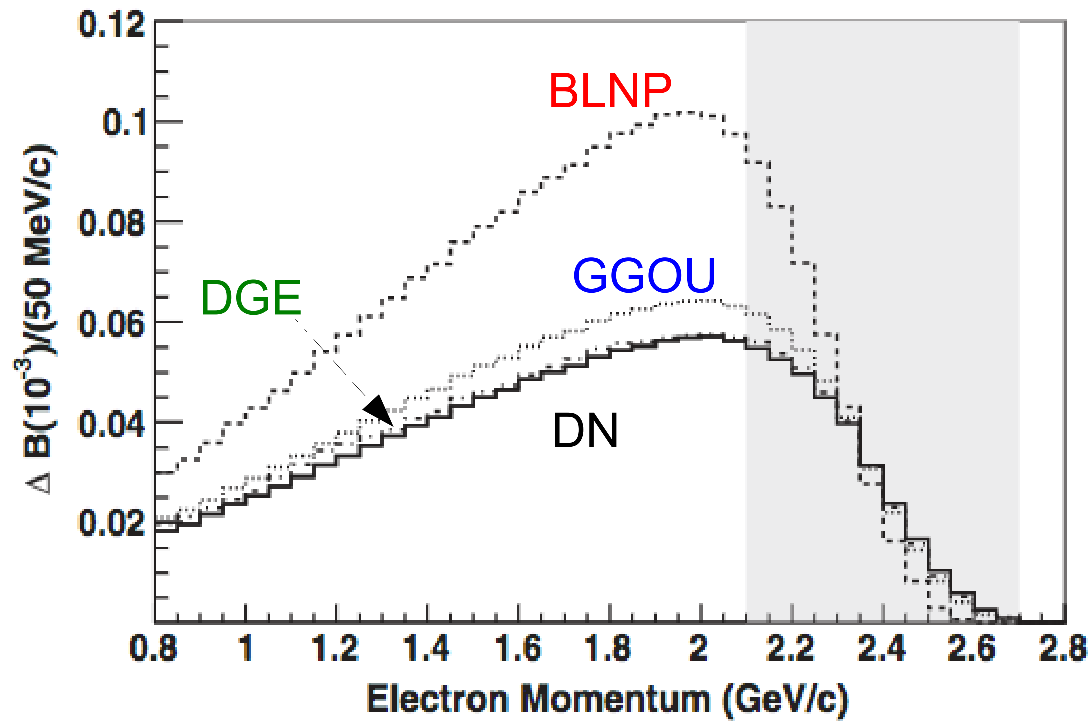


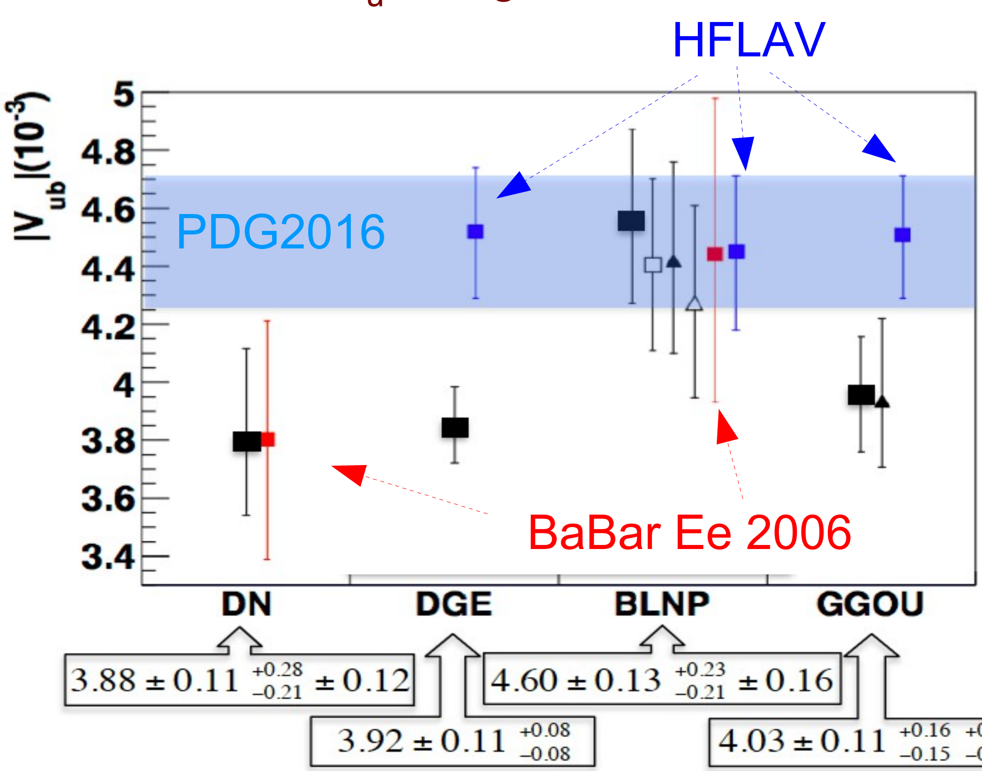
- $B \to X_u e\nu$ electron spectra for pe > 0.8 GeV after continuum, $B \to X_c\, e\, \nu$ and cascade subtraction



Results on total rate and $|V_{ub}|$

- Highest sensitivity to $B \to X_u e\nu$ in the wide bin 2.1-2.7 GeV
- Models make different predictions for the fractional rate in this bin
  - The normalization of the $B \to X_u e\nu$ is fixed by this bin!
- This dependence on the signal model can impact measurement that extends in the $B \to X_u e\nu$ region





- Results are lower than previous measurement (not for BLNP!)
- The effect observed in this study, could be smaller in other analyses that look into other observables

Required improvements

- Future extraction of |Vub| from inclusive B → Xu decays, would require measurements of the signal spectra (SIMBA, Florian's talk)
  - The challenge is to extract spectra that are independent from the underlying signal model
- Future measurements should also give informations on the signal model itself:
  - Tune the Hybrid to mix exclusive states with inclusive
  - JETSET/PYTHIA for the hadronisation of the u-quark
    - Hadronisation parameters have been tuned on high pT events from LEP!
    - Xu multiplicity affects the signal efficiency
    - Gluon→ss splitting
- Not to mention obviously the requirements imporvements on B→Xc and Xc → l decays

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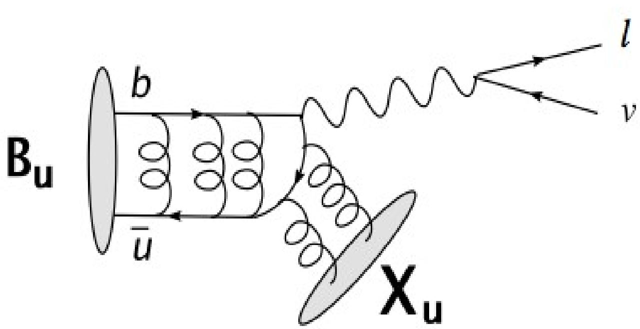
Weak Annihilation is small: dedicated measurements would be desired



CLEO q^2 spectrum
PRL96,121801 (2006)

$$\frac{|\Gamma_{WA}|}{.\,\Gamma_u} < 7.4\% \ at\ 90\% C.L.$$

BaBar from B^0->Xu^+
Arxiv:0708.1753

$$\frac{|\Gamma_{WA}|}{\Gamma_u} < \frac{3.8\%}{f_{WA}(2.3-2.6)} \ at\ 90\% C.L.$$

Nucl.Phys. B840 (2010) 424-437
From Ds decays: contribution on the total rate < 2%

Ongoing measurements in Belle

info from F. Bernlochner and P. Urquijo

- Ongoing measurement in Belle: prototype of measurements that will be done in Belle-II
- Mx, q^2 spectrum measurements
- Signal Fragmentation:
  - Studying exclusive channels B $\rightarrow$ X l v
    - X = $\pi\pi^0$, 2π, $2\pi\pi^0$...
  - Production of ss-quarks
    - Untagged B$\rightarrow$KK l nu is ongoing
    - This is a channel that could be accessible at LHCb: study the KK mass till the B$\rightarrow$D(KK) l v, feasible ?
  - Hadronic Tagged B$\rightarrow\pi\pi$ l nu is ongoing
- Weak Annihilation:
  - Study with high statistics the q^2 spectrum separately for B^0 and B^+