XIIth Meeting on B Physics
Tensions in Flavour Measurements
Napoli, 22-24 May 2017

Puzzles in $|V_{ub}|$ and $|V_{cb}|$
Towards a solution?

Marcello Rotondo

Laboratori Nazionali fi Frascati

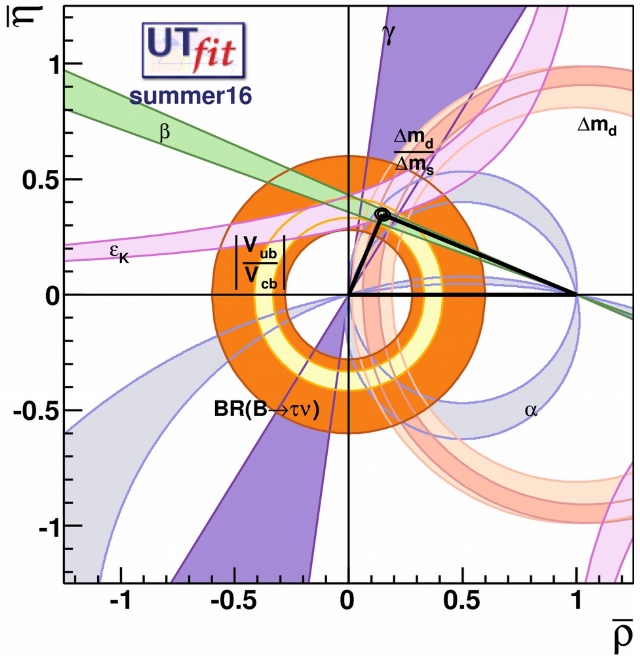
Why $|V_{cb}|$ and $|V_{ub}|$?

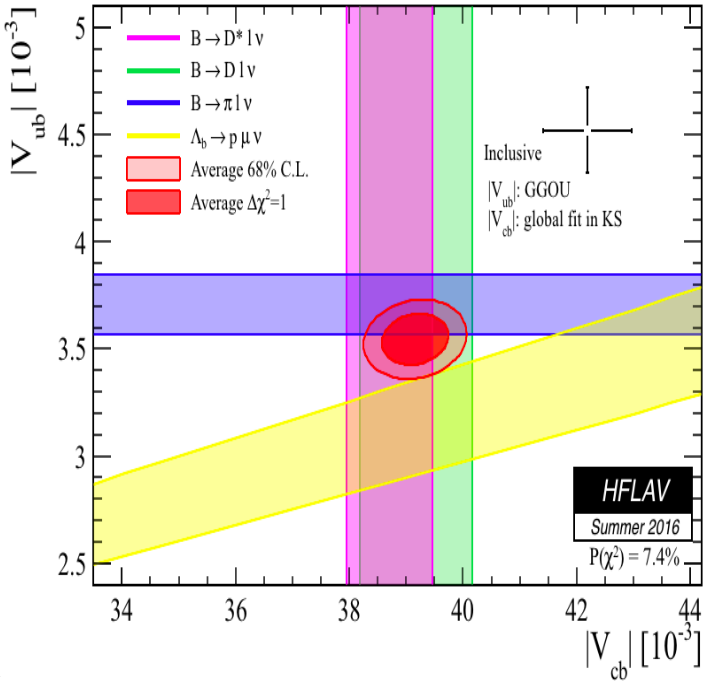
$|V_{xb}|$: crucial inputs
To indirect search of New Physics

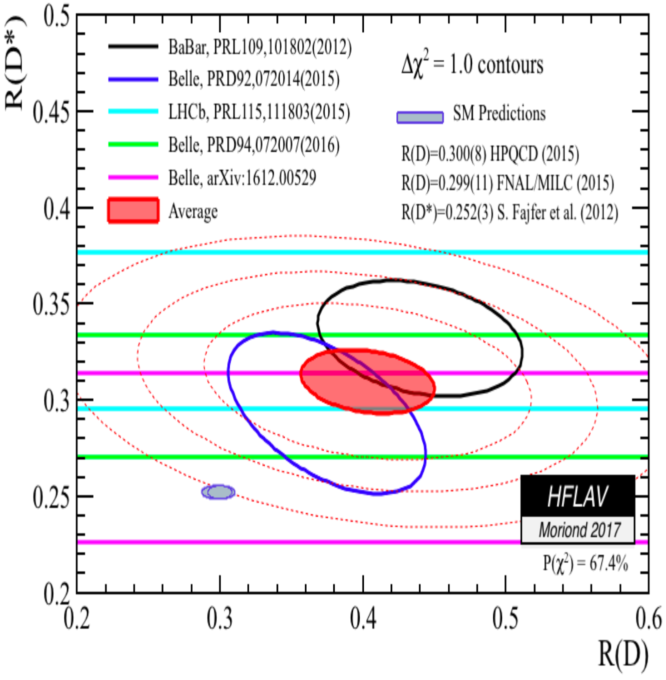
$|V_{cb}|$ and $|V_{ub}|$
discrepancy between different determinations: 3σ effect

$$\frac{\Gamma(B \to D^{(*)}\tau\nu_\tau)}{\Gamma(B \to D^{(*)}\ell\nu_\ell)}$$

Enhanced respect to SM Predictions (~4σ)







Predictions of FCNC processes

$$\propto |V_{tb}V_{ts}| \approx |V_{cb}|^2[1 + O(\lambda^2)]$$

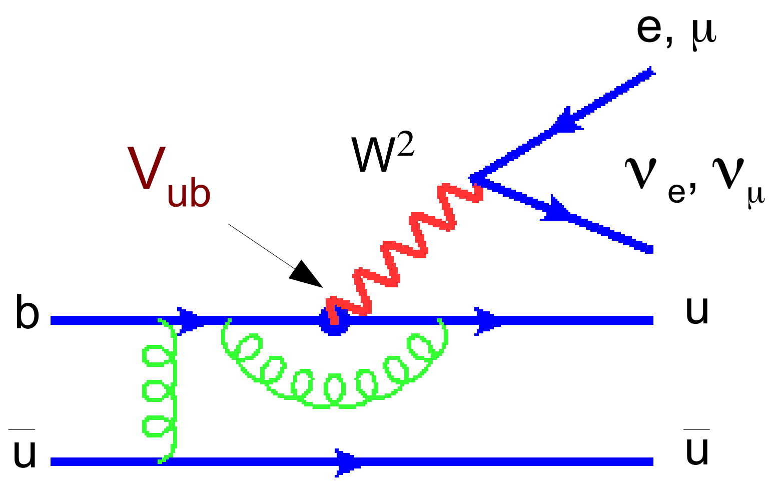
Kaon physics $\epsilon_K \approx x|V_{cb}|^2 + ...$

$|V_{ub}|$ opposite to angle β:
compare Tree with loops

Semileptonic measurements provide Form-Factors, crucial for SM predictions on R(D)-R(D*)

Study of B → D** crucial to constrain backgrounds in $|V_{ub}|$ inclusive $|V_{cb}|$ and R(D)-R(D*) determinations

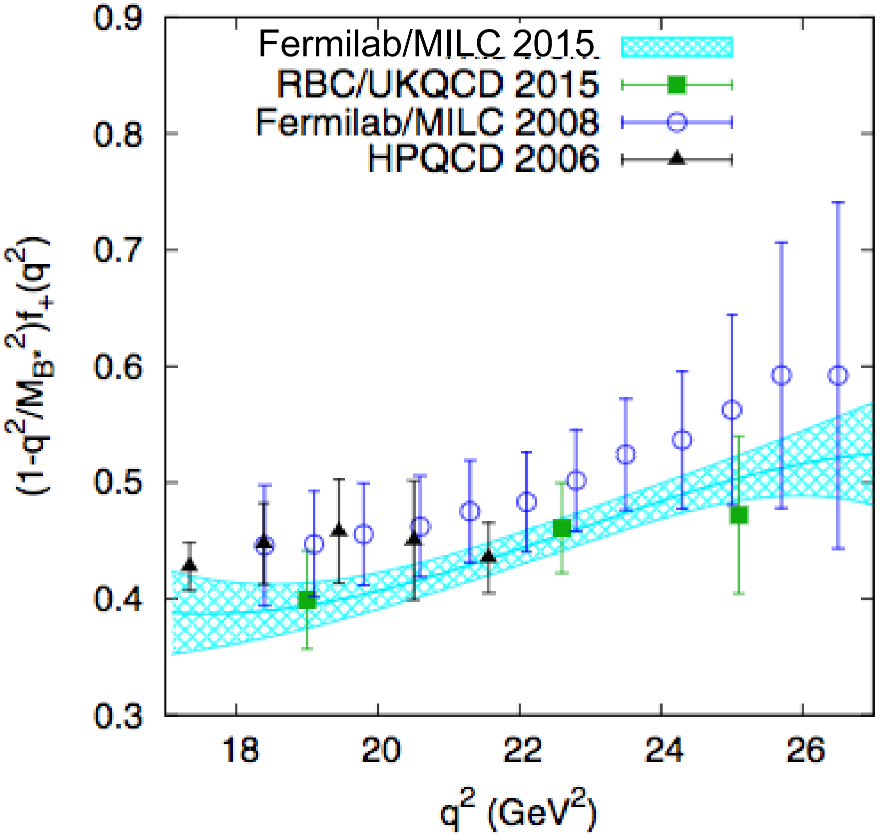
Exclusive $B\to\pi\ell\nu$



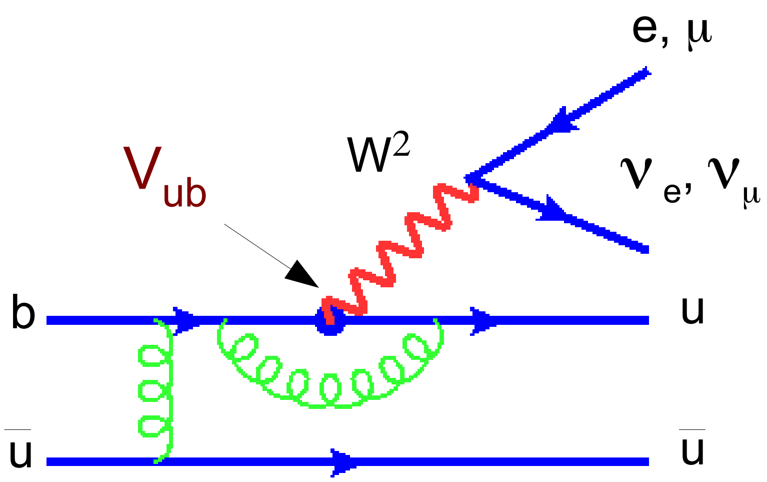
- For massless leptons only one Form Factor

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

- Lattice QCD (UKQCD, FNAL,…)
  - Works at high q^2
  - Unquenched calculations (2+1, 2+1+1)
  - Other mesons (ρ, ω,...) difficult on lattice
- Light Cone Sum Rules
  - Reliable at low q^2
  - Works for both pseudo-scalars and vector decays



Exclusive B→$\pi\ell\nu$



- For massless leptons only one Form Factor

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

- Lattice QCD (HPQCD, FNAL,…)
  - Works at high q^2
  - Unquenched calculations (2+1, 2+1+1)
  - Other mesons (ρ, ω,...) difficult on lattice
- Light Cone Sum Rules
  - Reliable at low q^2
  - Works for both pseudo-scalars and vector decays

Strategies for $|V_{ub}|$ extraction

- Measure ΔBr in regions where theory is reliable

$$|V_{ub}|^2 = \frac{\Delta Br}{\tau_B \Delta\tilde{\Gamma}_{theory}}$$

- Simultaneous fit to data and theory
  - Measure ΔBr in bins of q^2
  - $|V_{ub}|$ and form factor shape from a fit to data and theory
  - Exploiting the recent lattice calculations in many points at high q^2

Untagged B→πℓν

$$m_{ES} = \sqrt{E^{*2}_{beam} - \mathbf{p}^{*2}_{\pi\ell\nu}}$$

$$\Delta E = E^{*}_{\pi\ell\nu} - E^{*}_{beam}$$

- Combined π with a lepton ℓ; the neutrino from the rest of the event

Phys.Rev.D86(2012) 092004

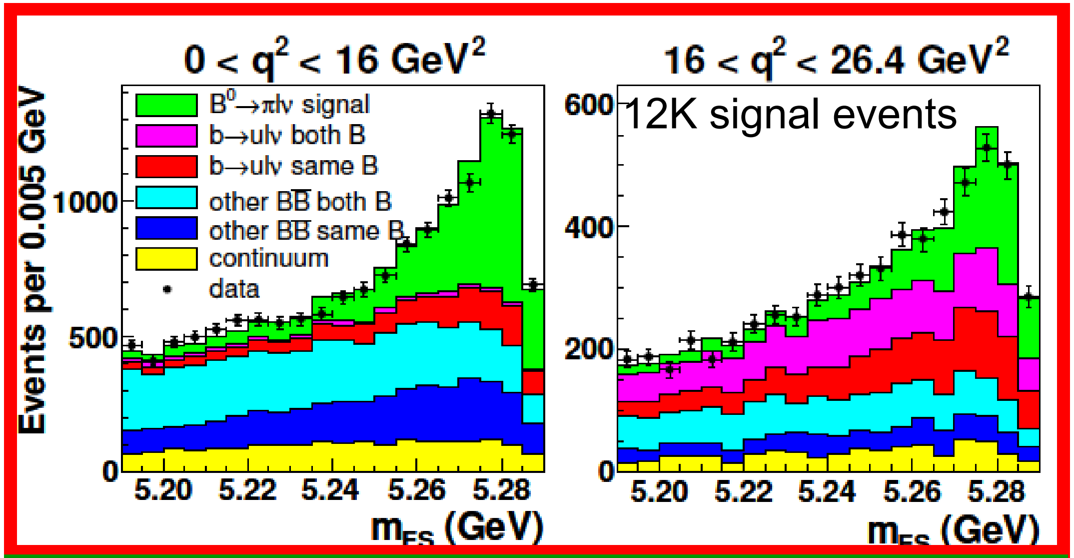
L=416 fb $^{-1}$
Nsig=12.5K±400

Signal extracted in 12 q^2-bins

Phys.Rev.D83(2011) 071101

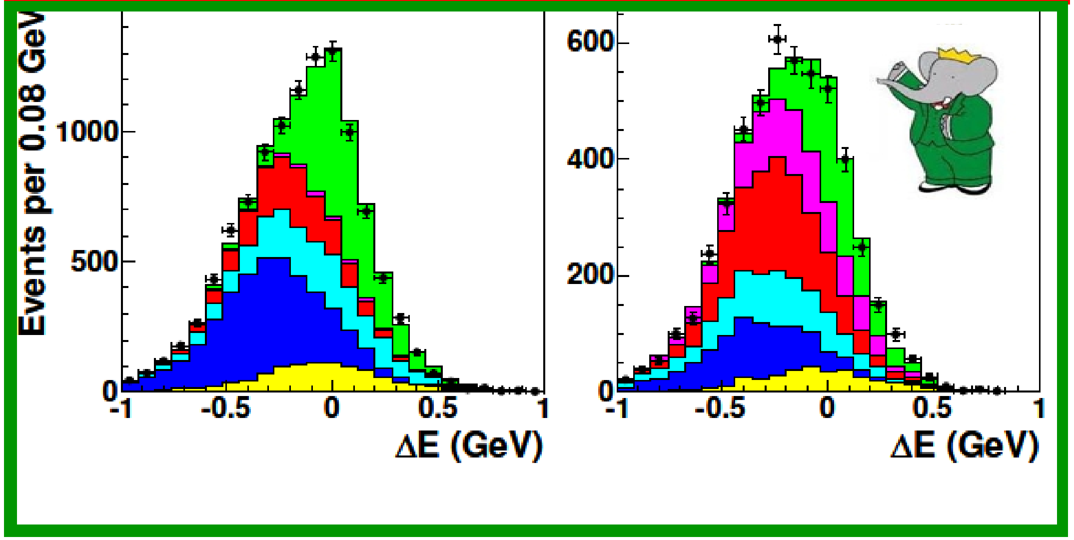
L=605 fb $^{-1}$
Nsig=21.5K±500

Signal extracted in 13 q^2-bins

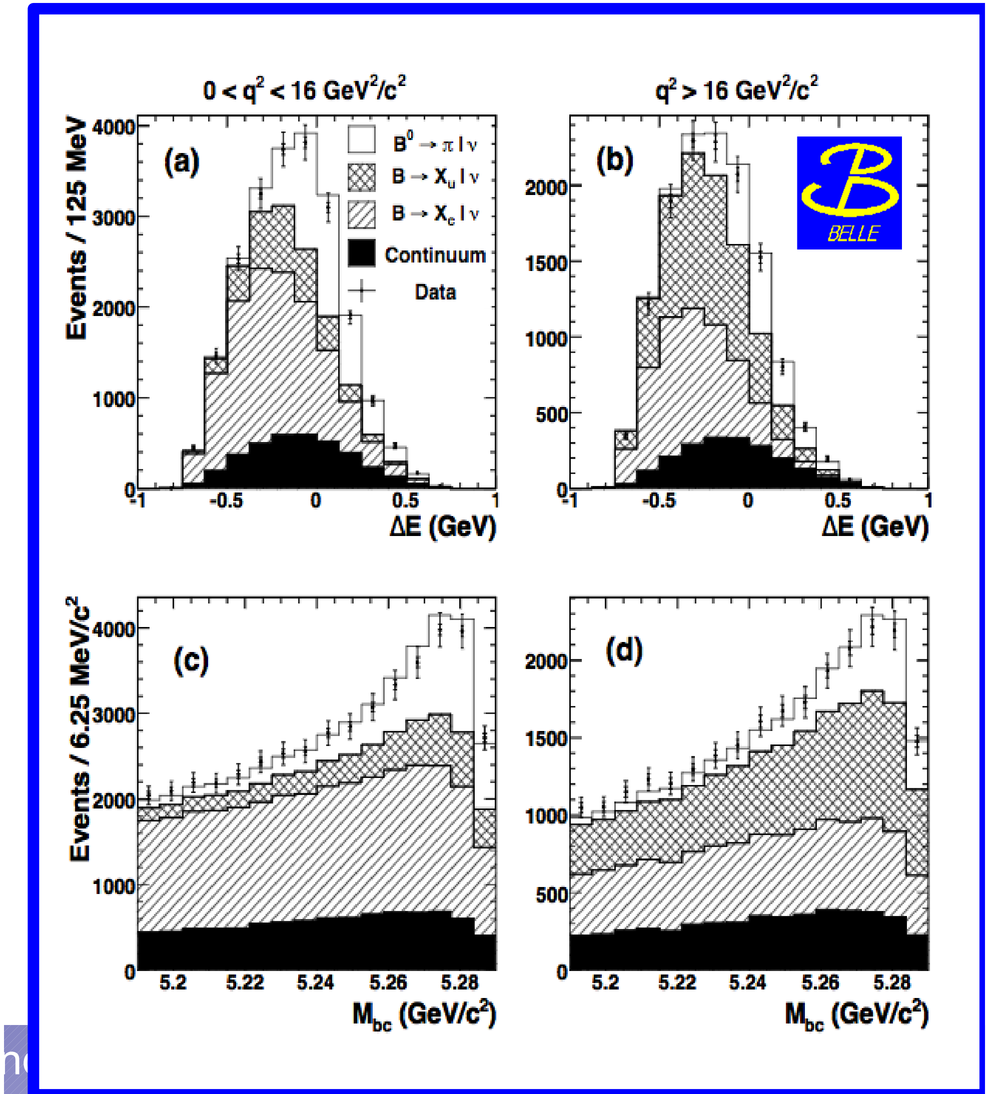


12K signal events

$-0.16 < \Delta E < 0.20$GeV



$m_{ES} > 5.268$GeV



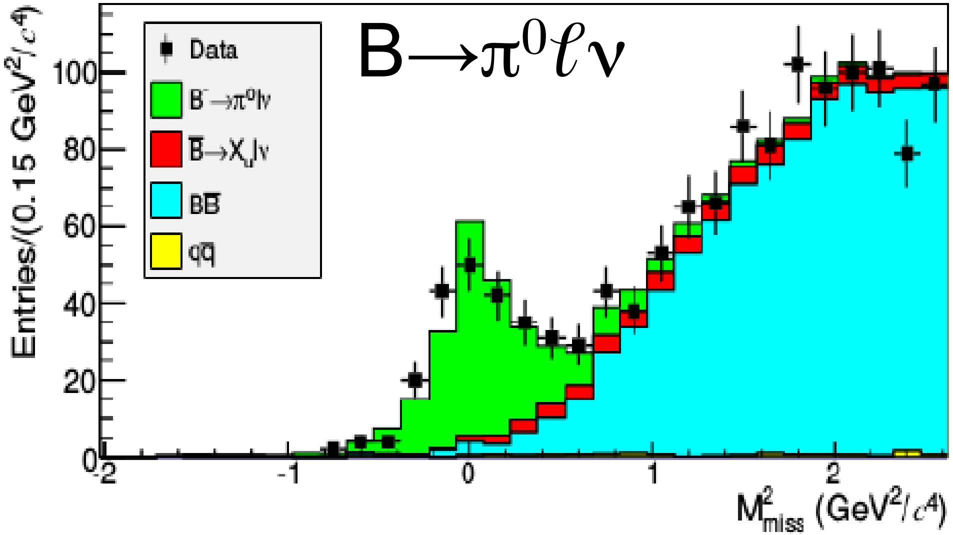
Tagged $B\to\pi\ell\nu$

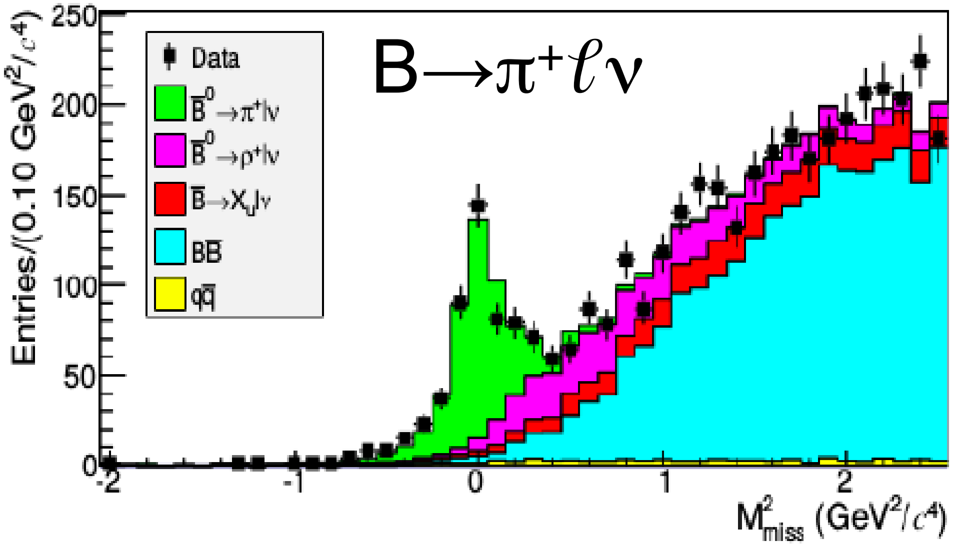
Phys.Rev.D83(2011) 071101

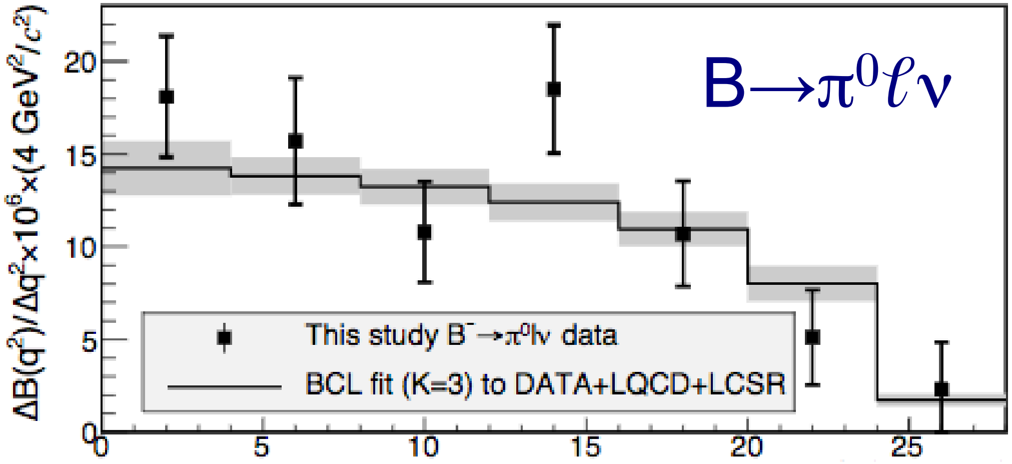
- Using the hadronic tag

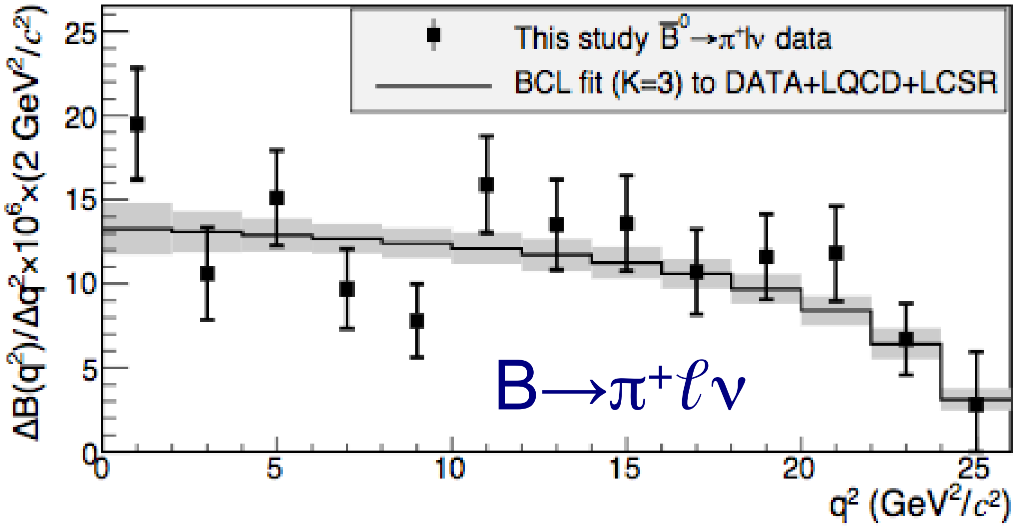
L=711 fb^{-1}
N($B\to\pi^2\ell\nu$) ~ 500, N($B\to\pi^0\ell\nu$) ~ 200

- Reduce combinatorial backgrounds
- Improve kinematic resolution
  - Signal B direction determined by B$_{tag}$



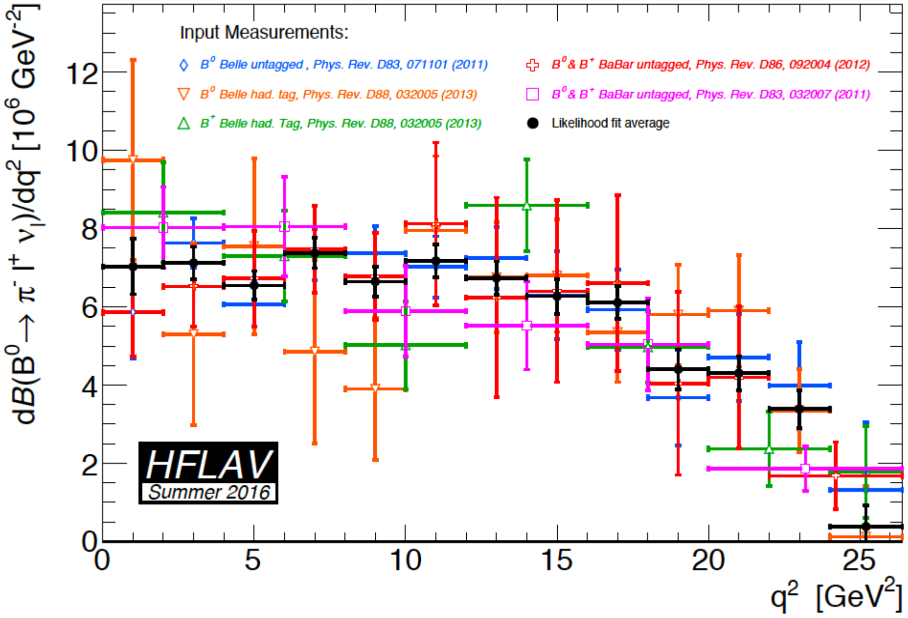




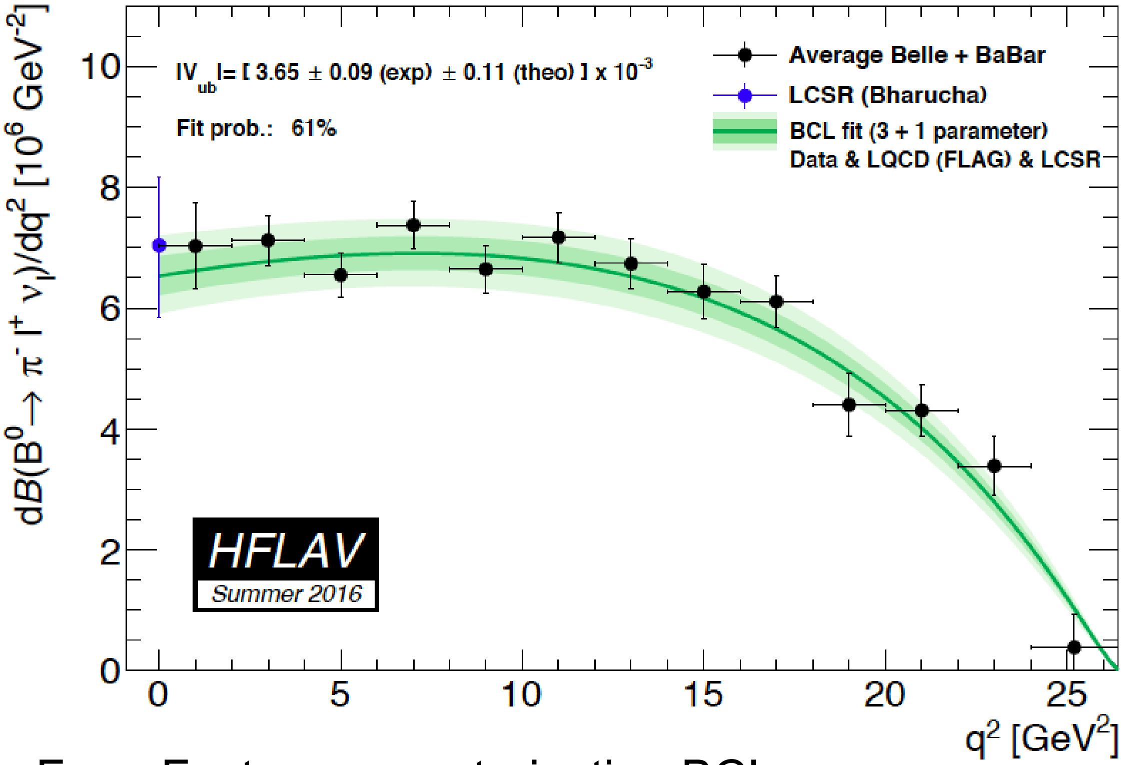


HFLAV average

- Include the most precise measurements
  - Partial Br averaged with a likelihood fit



Theoretical inputs:
- Lattice QCD at high q^2
HFLAG average of FNAL/MILC + HPQCD
Eur.Phys.J. C77 (2017) no.2, 112
- LCSR ta q^2=0
Bharucha, JHEP 1205 (2012) 092



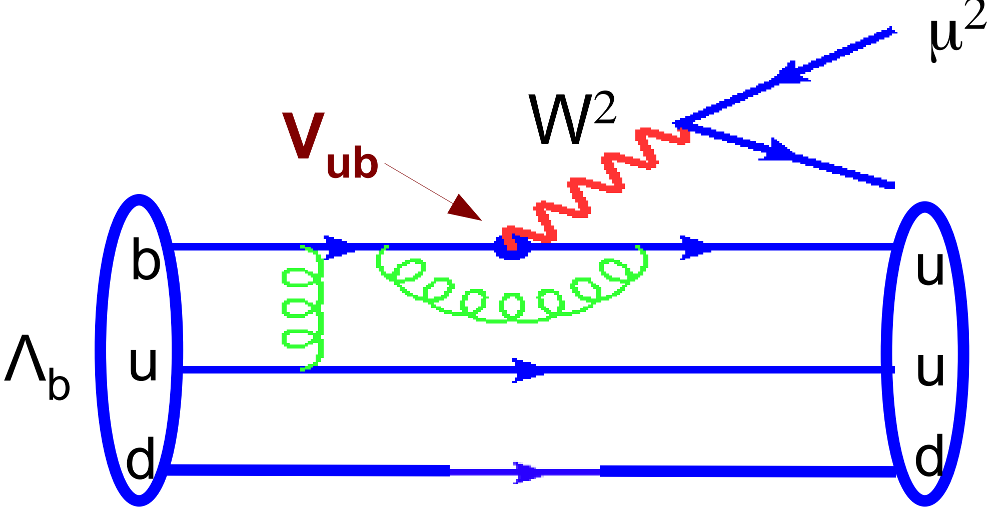
Form Factor parameterization BCL
Bourrely, Caprini, Lellouch, PRD79, 013008 (2009)

$$f_+(q^2, \vec{b}) = \frac{1}{1 - q^2/m^2_{B^*}} \sum_{k=0}^{K} b_k(t_0)\, z(q^2)^k$$

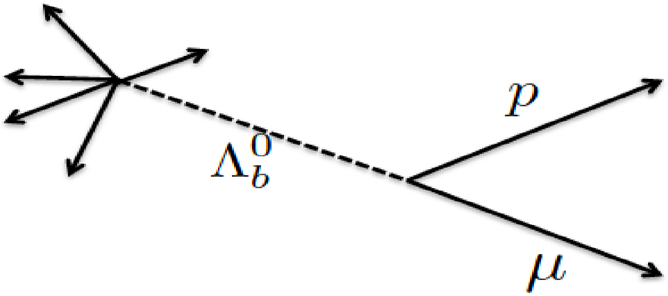
Tot σ ~ 4%!

Parameter	Value
$\lvert V_{ub}\rvert$	$(3.65 \pm 0.14) \times 10^{-3}$
b_1^+	0.421 ± 0.017
b_2^+	-0.390 ± 0.033
b_3^+	-0.650 ± 0.126

$|V_{ub}|$ at LHCb



- B-baryons provide complementary informations to B-mesons
- Copious production of Λ_b



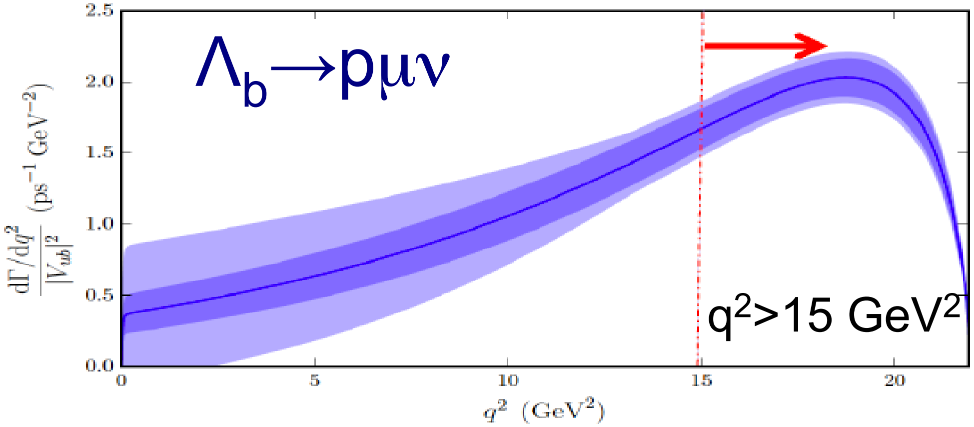
- Kinematic constraints allow the determination of the $p_{\Lambda b}$ (modulo 2-fold ambiguity)
- Large background from $\Lambda_b \rightarrow \Lambda_c \mu\nu$
- LHCb determines (in the high q^2 region) the ratio

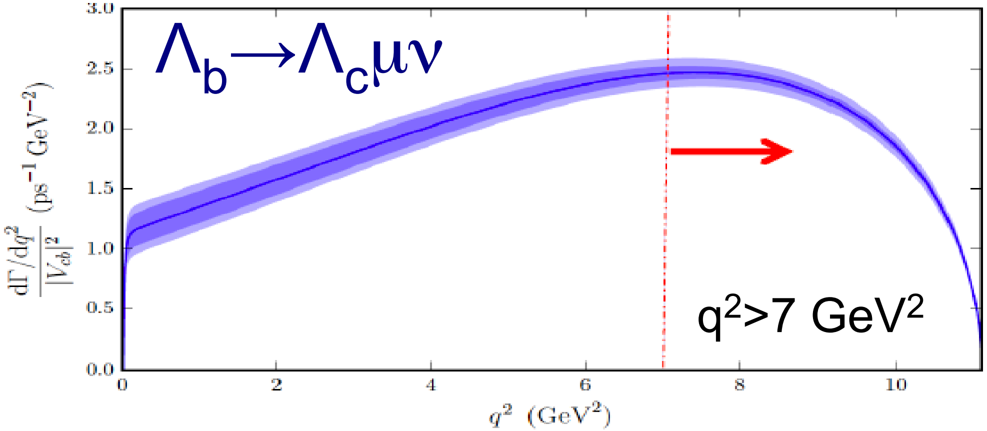
$$R_{exp} = \frac{\mathcal{B}(\Lambda_b \to p\mu\nu)}{\mathcal{B}(\Lambda_b \to \Lambda_c\mu\nu)}$$

Signal

Normalization

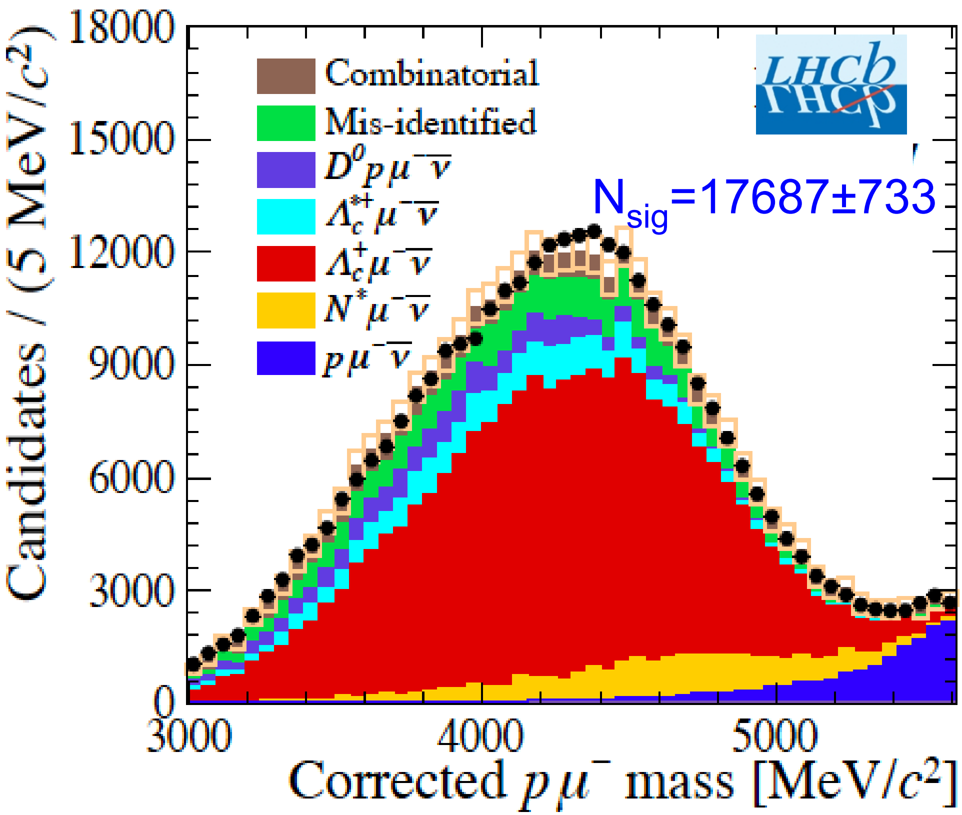
- Precise F.F.calculation on L-QCD
  - Detmold et al PRD92(2015)034503





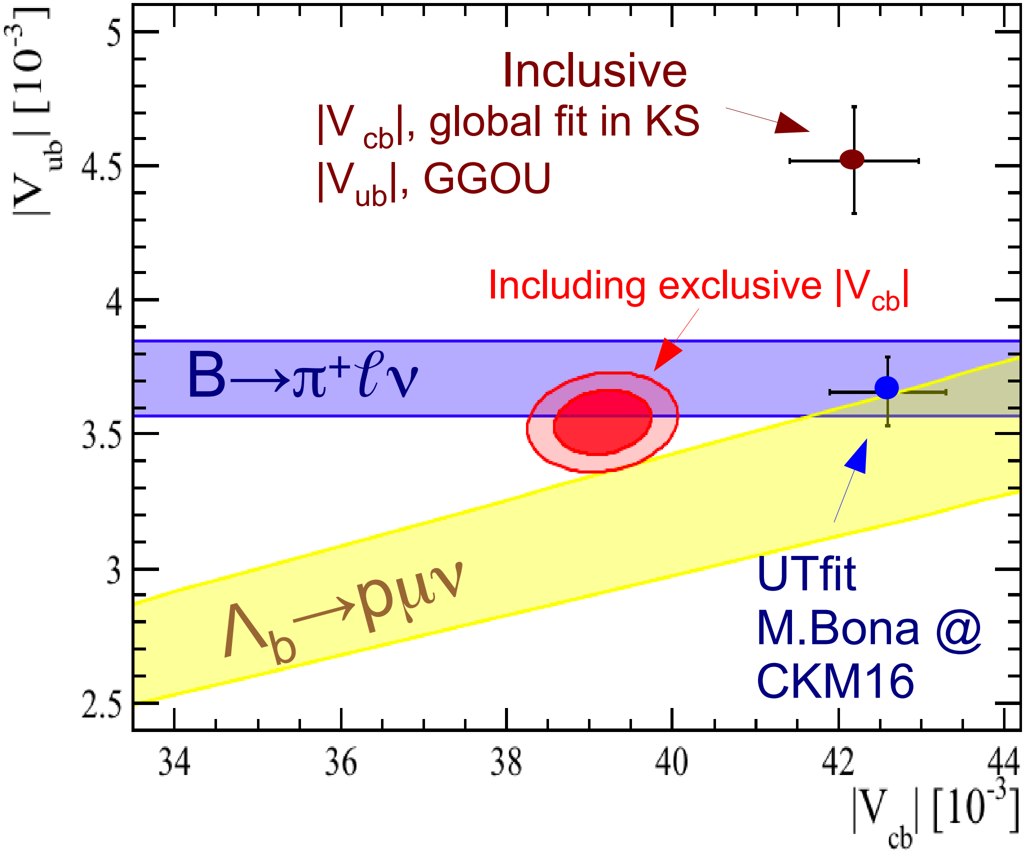
$\Lambda_b \to p\mu\nu$ signal & $|V_{ub}|$

$$M_{corr} = \sqrt{p_\perp^2 + M_{p\mu}^2} + p_\perp$$



$$\frac{|V_{ub}|}{|V_{cb}|} = 0.080 \pm 0.004_{Exp.} \pm 0.004_{F.F.}$$

σ_{tot}=7%

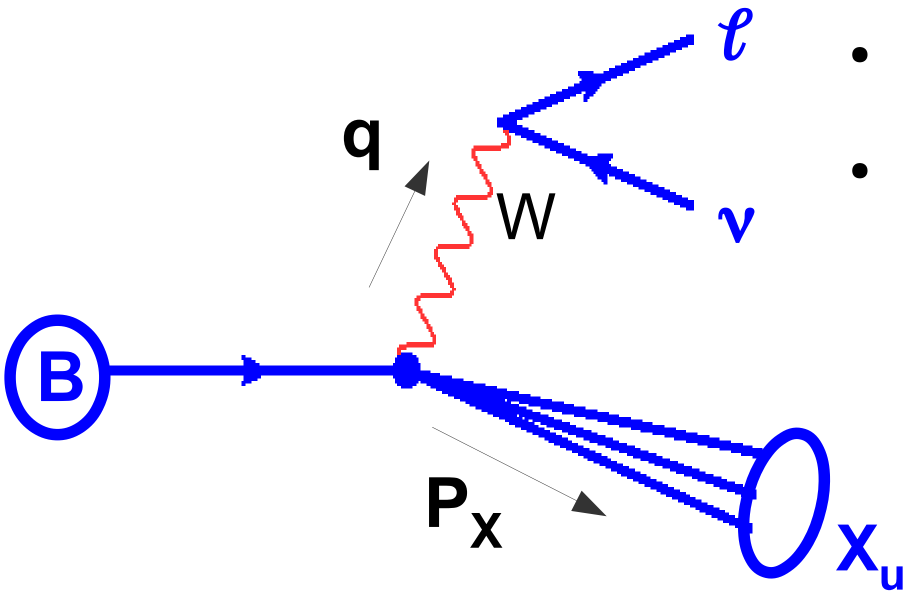


$$R = \frac{\mathcal{B}(\Lambda_b \to p\mu\nu)_{q^2>15\ GeV^2}}{\mathcal{B}(\Lambda_b \to \Lambda_c\mu\nu)_{q^2>7\ GeV^2}} = (0.95 \pm 0.04 \pm 0.07) \times 10^{-2}$$

Systematics dominated by
BF($\Lambda_c \to pK\pi$)=(6.46 ± 0.24)%
HFLAV using BESIII-Belle
measurements

$|V_{ub}|$ from inclusive decays

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



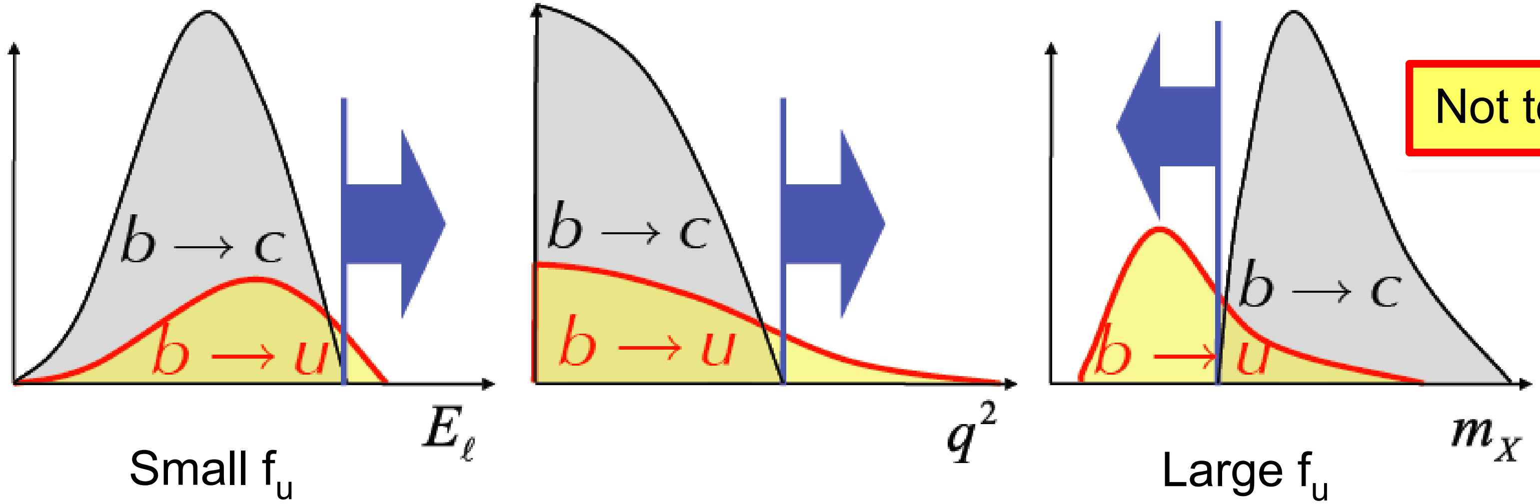
- Large background from $B \to X_c \ell \nu$
- Kinematics to extract the signal: $m_u << m_c$
    - Cut limited region of phase space (f_u)
        - Non perturbative shape-function needed
        - Universal only at leading order in Λ/m_b

E_ℓ = lepton energy

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

M_X = X_u hadronic mass

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



Small f_u

Large f_u

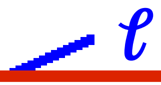
Not to scale!

Experimental resolution leads to “irreducible” $b \to c \ell \nu$ contamination

- partially suppressed With K and D* vetos

$|V_{ub}|$ from inclusive decays

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

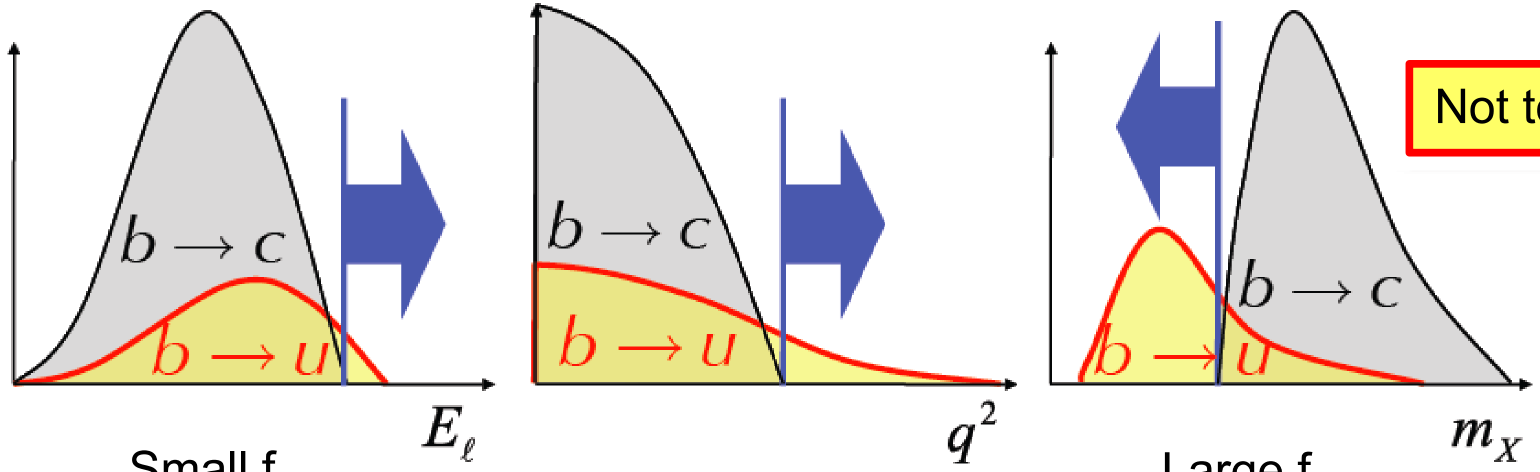


- Large background from B→$X_c\ell\nu$
- to extract the signal: $m_u << m_c$
- d region of phase space (f_u)
- erturbative shape-function needed
- rsal only at leading order in Λ/m_b

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

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

M_X = X_u hadronic mass



Small f_u

Large f_u

Not to scale!

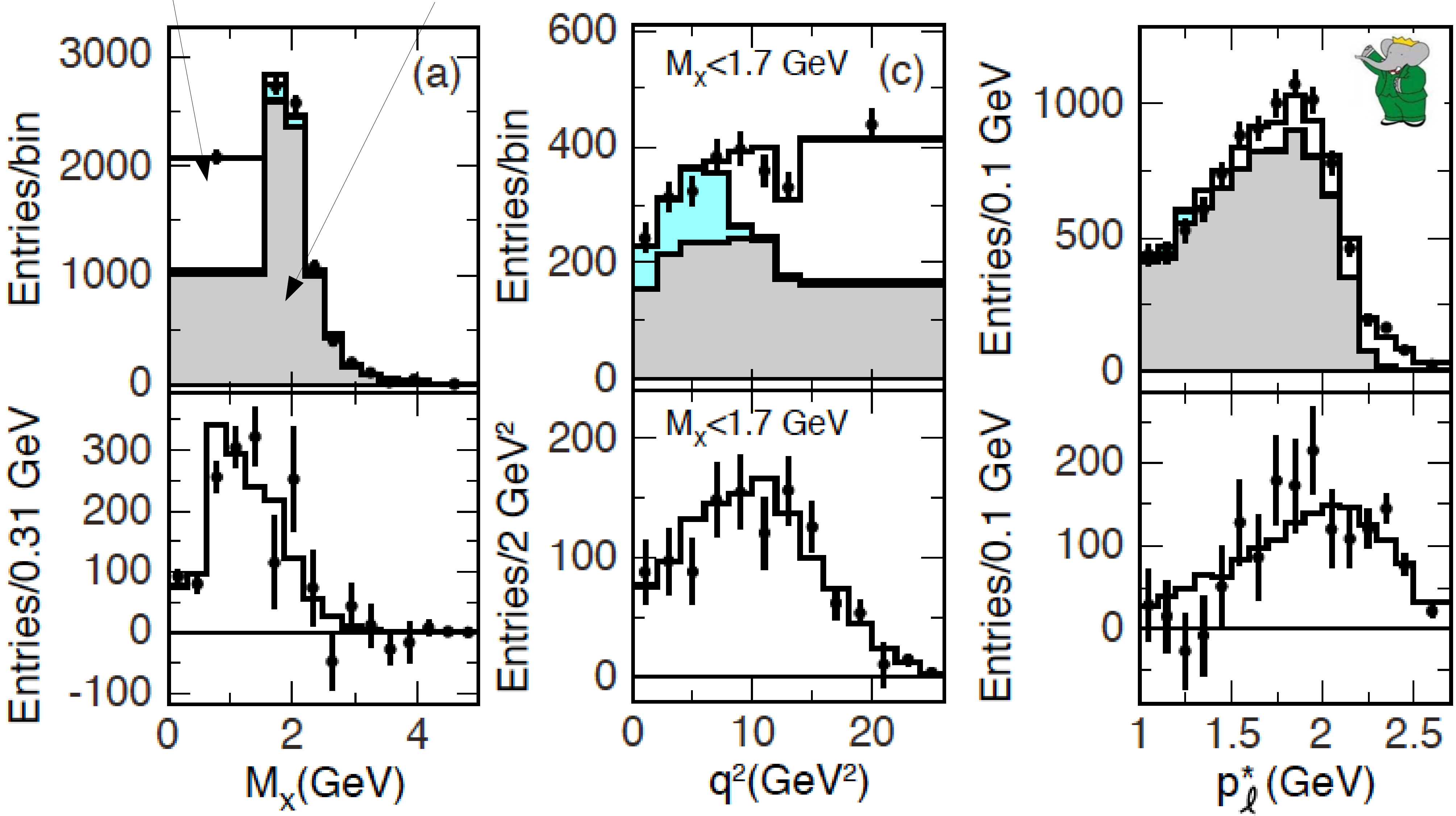
Experimental resolution leads to “irreducible” b→ c$\ell\nu$ contamination
- partially suppressed With K and D* vetos

Fit results in limited regions of phase space

$B \to X_u \ell \nu$

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

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



Phys.Rev. D86 (2012) 032004

Status of inclusive $|V_{ub}|$

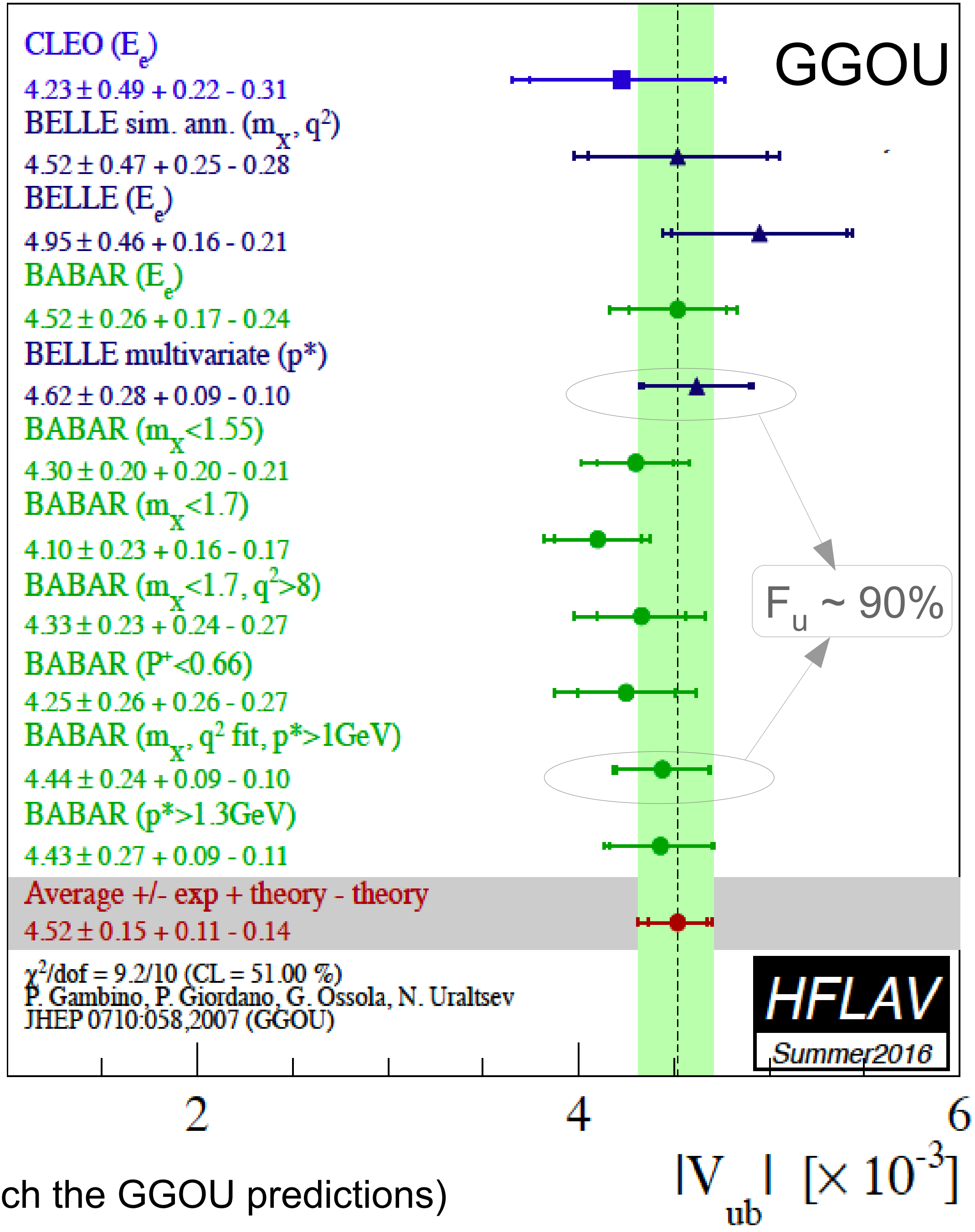
Most recent measurements is dated 2012

- 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)	$4.62 \pm 0.20 \pm 0.29$

- 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

(Belle multivariate, adjust the signal model to match the GGOU predictions)



$F_u \sim 90\%$

New inclusive $|V_{ub}|$

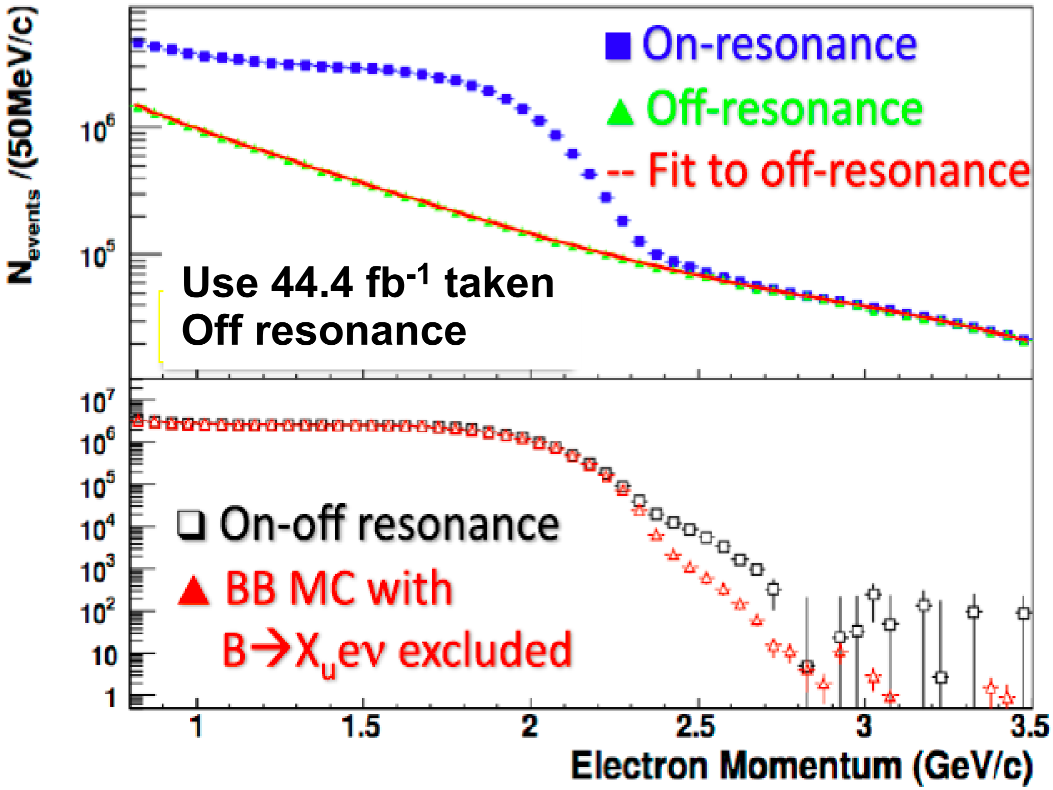
Phys.Rev.D 95, 072001 (2017)

- Inclusive electron spectrum measurement
- Dataset: 467M Y(4S)

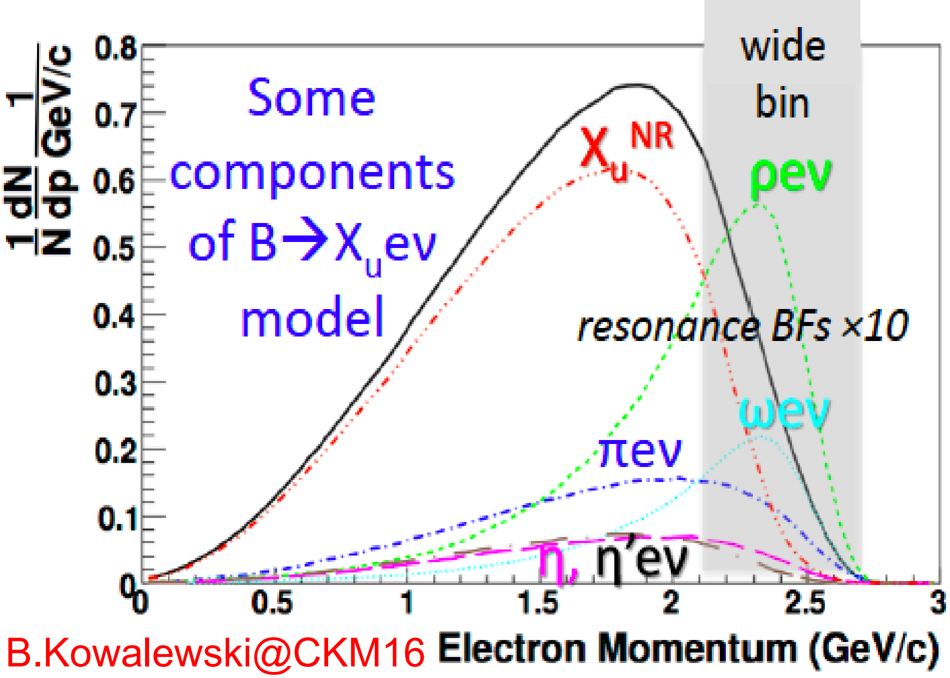
Fit Strategy

- 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

Large statistics: >10^6 events / 50 MeV bin;
statistical uncertainties dominated by continuum subtraction



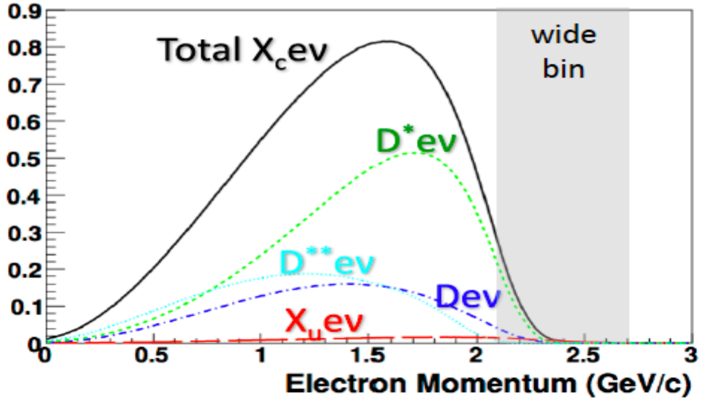
Use 44.4 fb^{-1} taken Off resonance



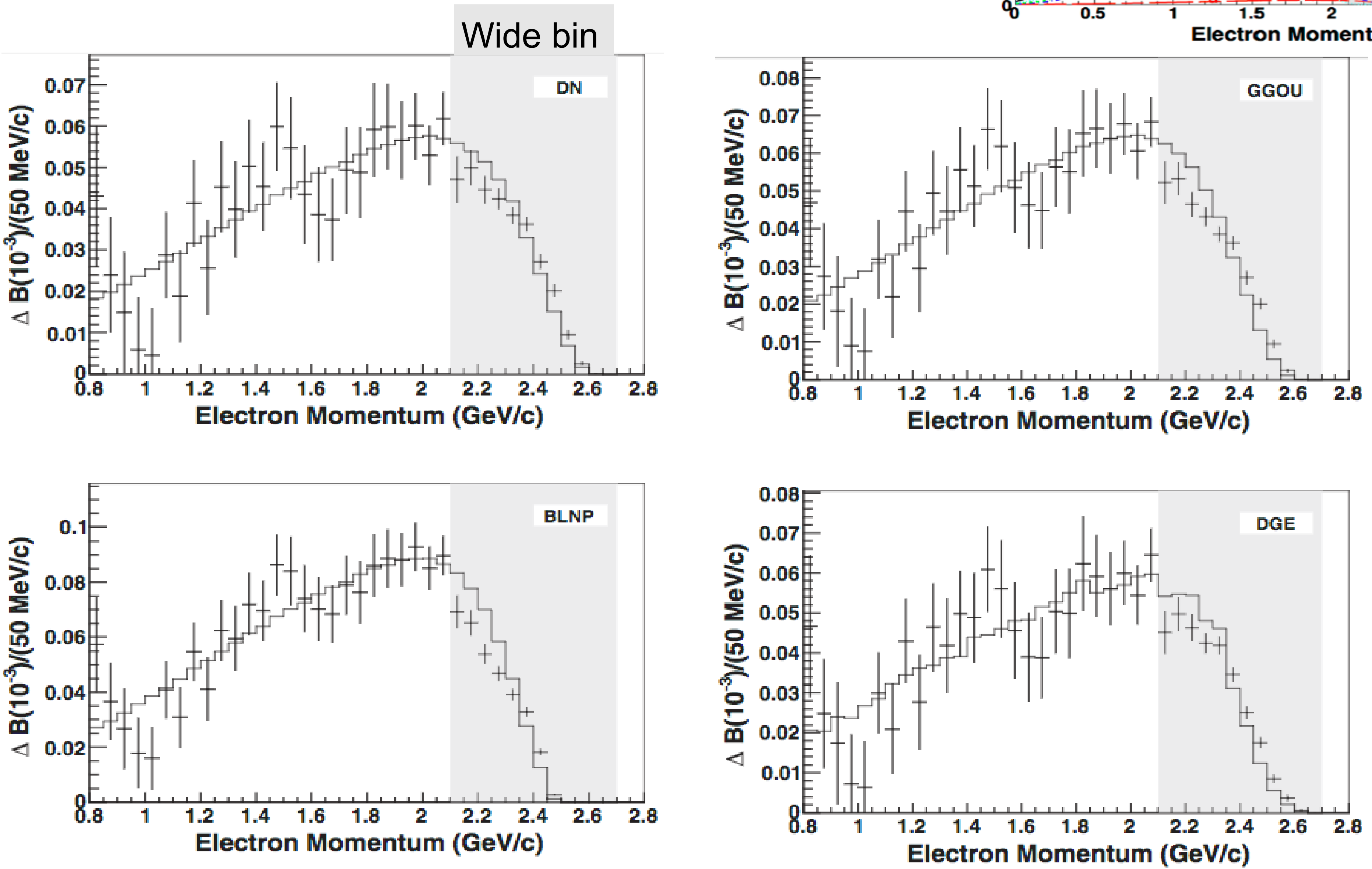
B.Kowalewski@CKM16

Signal model obtained mixing known existing exclusive final states with calculations for $b \to X_u\ e\ \nu$ (Hybrid model). Four different calculations considered for $b \to X_u\ e\ \nu$ Inclusive spectrum

B $\rightarrow X_u e\nu$ in Y(4S) frame

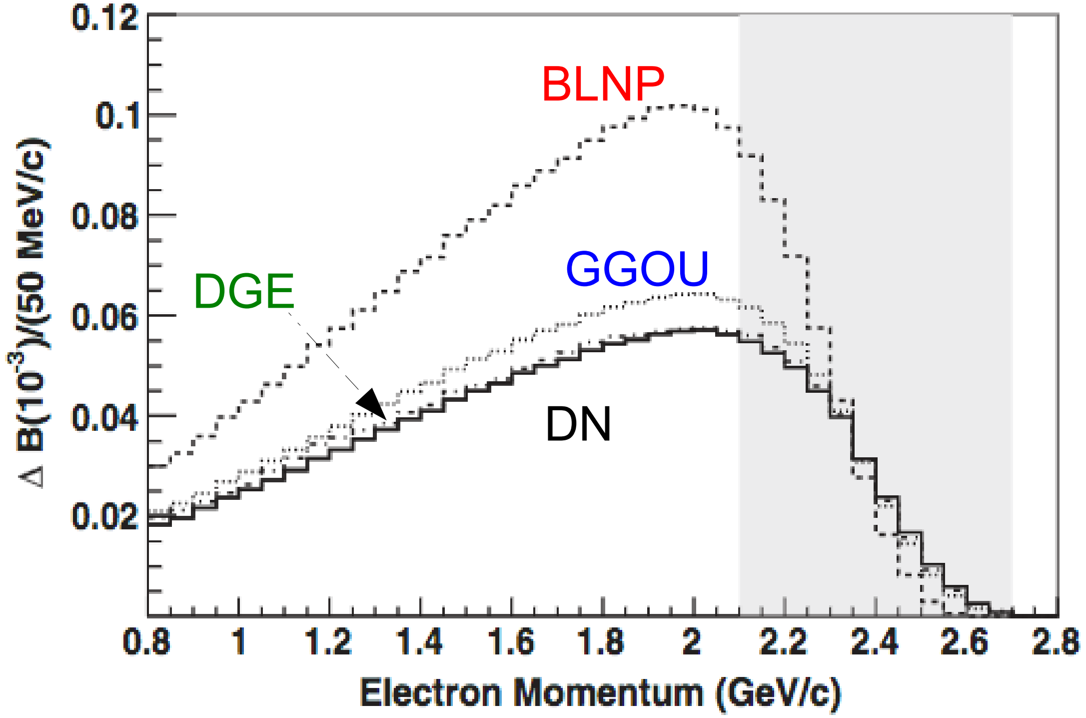


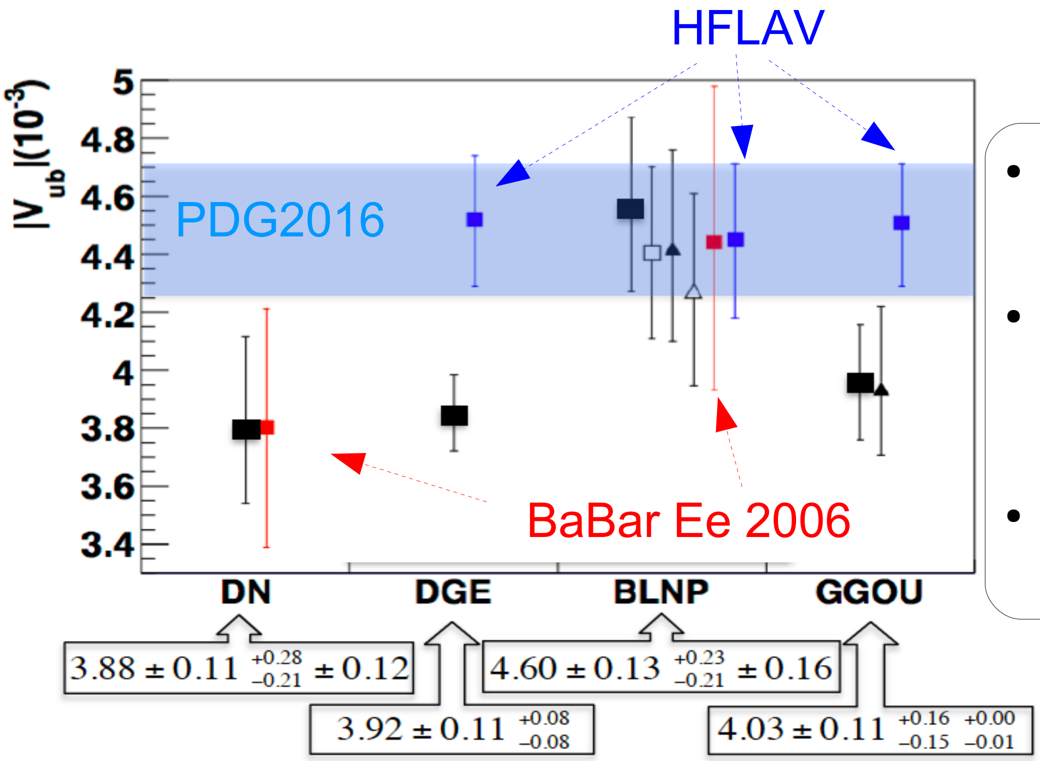
- B→$X_u e\nu$ electron spectra for pe > 0.8 GeV after continuum, B→X_c e ν and cascade subtraction



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 could impact any measurement that extends in the $B \to X_u e \nu$ region

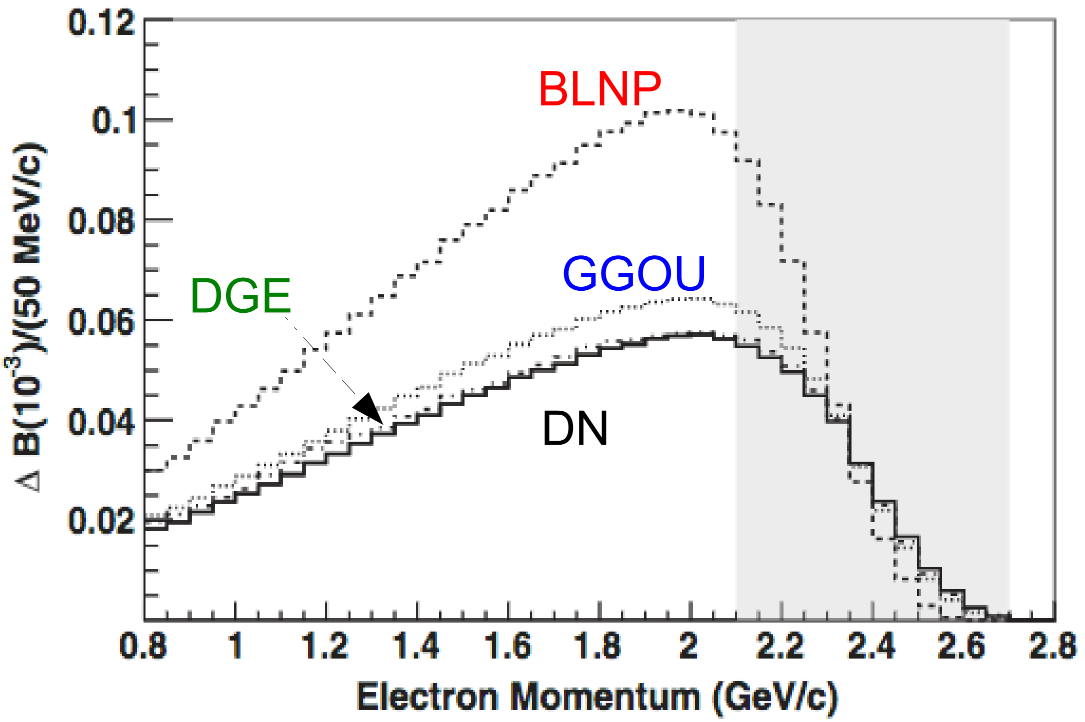


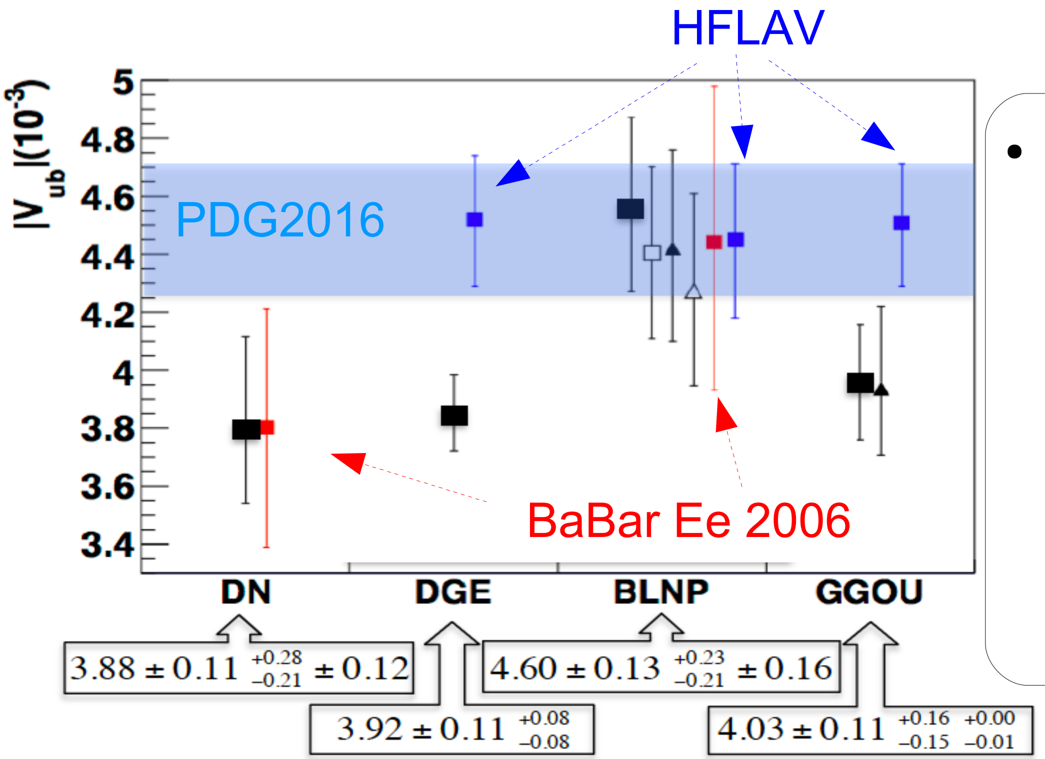


- Results are lower than previous measurement (not for BLNP!)
- How existing analyses would be affected by the signal model is difficult to predict without re-analysing old data!
- The effect could be smaller than the one observed here!

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 impact any measurement that extends in the $B \to X_u e\nu$ region





- In the future it will be crucial to improve
  - Knowledge about $B \to X_c$ composition and kinematics: rates and FFs for D/D*/D**...
  - Constrain the signal model measuring exclusive $B \to n\pi\, e\nu$: up to now resonant and non-resonant contributions are combined in an ad-hoc procedure
  - WA, X_u hadronisation...

$|V_{cb}|$ inclusive

- HQE is the successful tool to include perturbative and non-perturbative QCD corrections that allow to connect measurements of semileptonic B-meson decays to $|V_{cb}|^2$

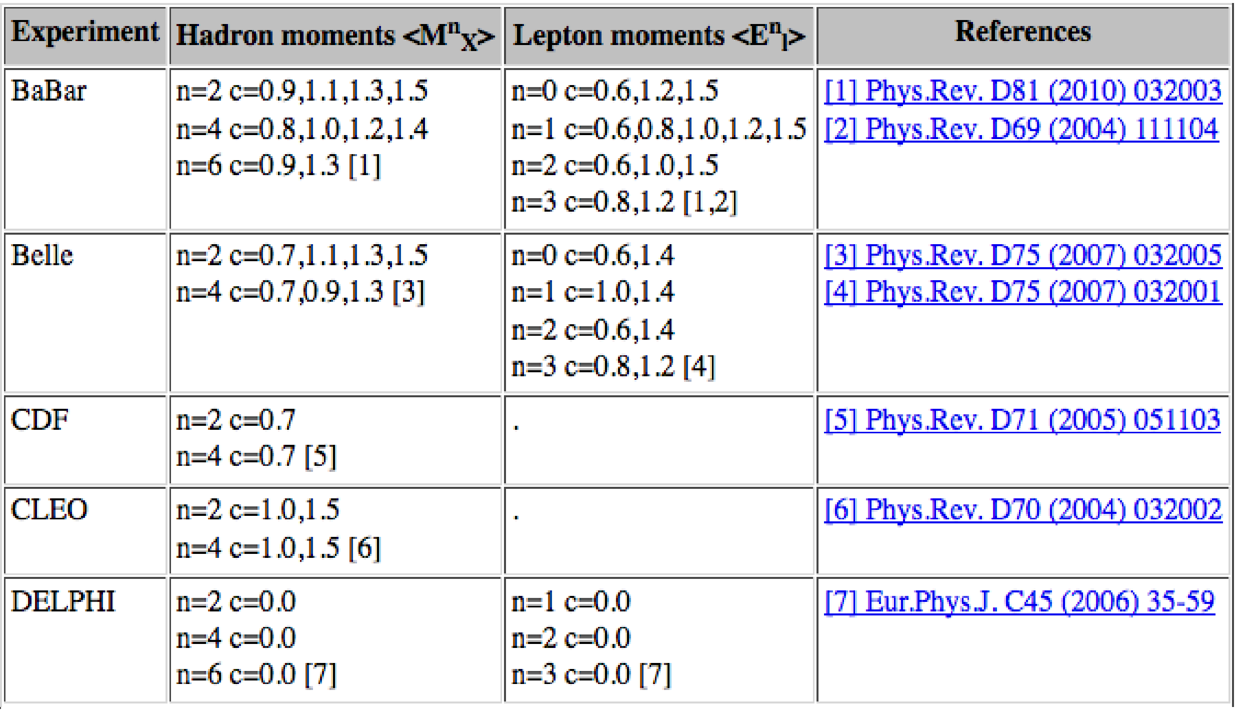
$$\Gamma_{sl} = \Gamma_0 \Big[1 + a^{(1)} \frac{\alpha_s(m_b)}{\pi} + a^{(2,\beta_0)} \beta_0 \Big(\frac{\alpha_s}{\pi}\Big)^2 + a^{(2)} \Big(\frac{\alpha_s}{\pi}\Big)^2 + \Big(-\frac{1}{2} + p^{(1)} \frac{\alpha_s}{\pi}\Big) \frac{\boxed{\mu_\pi^2}}{\boxed{m_b^2}} + \Big(g^{(0)} + g^{(1)} \frac{\alpha_s}{\pi}\Big) \frac{\boxed{\mu_G^2}(m_b)}{\boxed{m_b^2}} + d^{(0)} \frac{\boxed{\rho_D^3}}{\boxed{m_b^3}} - g^{(0)} \frac{\boxed{\rho_{LS}^3}}{\boxed{m_b^3}} + \text{higher orders} \Big]$$

No new experimental results since 2010

Latest fits in Kinetic Scheme:

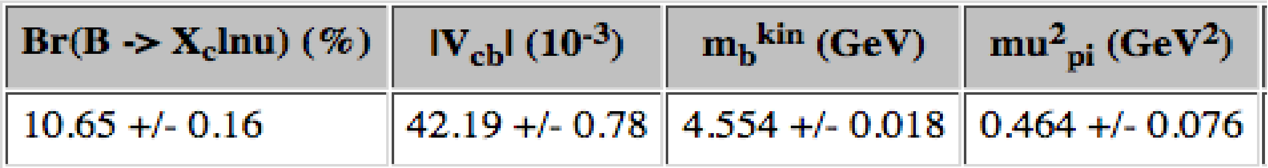
Gambino, Schwanda
PhysRevD 89,014022 (2014)
Include charm-quark mass from sum-rule results (PRD80,074010 (2009))

Alberti, Gambino, Healey, Nandi
PhysRevLett 114,061802 (2015)
- Includes corrections of $O(\alpha_{O}^{2}\Lambda_{f\neq\infty}^{2}/\mathrm{I}\ \cap^{2})$



Experiment	Hadron moments <M^n_X>	Lepton moments <E^n_l>	References
BaBar	n=2 c=0.9,1.1,1.3,1.5 n=4 c=0.8,1.0,1.2,1.4 n=6 c=0.9,1.3 [1]	n=0 c=0.6,1.2,1.5 n=1 c=0.6,0.8,1.0,1.2,1.5 n=2 c=0.6,1.0,1.5 n=3 c=0.8,1.2 [1,2]	[1] Phys.Rev. D81 (2010) 032003 [2] Phys.Rev. D69 (2004) 111104
Belle	n=2 c=0.7,1.1,1.3,1.5 n=4 c=0.7,0.9,1.3 [3]	n=0 c=0.6,1.4 n=1 c=1.0,1.4 n=2 c=0.6,1.4 n=3 c=0.8,1.2 [4]	[3] Phys.Rev. D75 (2007) 032005 [4] Phys.Rev. D75 (2007) 032001
CDF	n=2 c=0.7 n=4 c=0.7 [5]	.	[5] Phys.Rev. D71 (2005) 051103
CLEO	n=2 c=1.0,1.5 n=4 c=1.0,1.5 [6]	.	[6] Phys.Rev. D70 (2004) 032002
DELPHI	n=2 c=0.0 n=4 c=0.0 n=6 c=0.0 [7]	n=1 c=0.0 n=2 c=0.0 n=3 c=0.0 [7]	[7] Eur.Phys.J. C45 (2006) 35-59

HFLAV



Br(B -> X$_c$lnu) (%)	$\lvert V_{cb}\rvert$ (10^{-3})	m$_b^{kin}$ (GeV)	mu$^2_{pi}$ (GeV^2)
10.65 +/- 0.16	42.19 +/- 0.78	4.554 +/- 0.018	0.464 +/- 0.076

Exclusive $|V_{cb}|$ and Form Factors

- $B \to D\ell\nu$ and $B \to D^*\ell\nu$ provide clean way to extract $|V_{cb}|$

Assuming $m_\ell = 0$

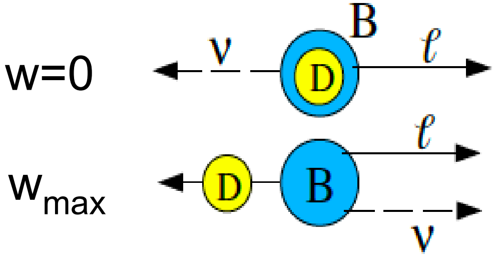
$$w = \frac{m_B^2 + m_D^2 - q^2}{2 m_B m_D}$$

$B \to D^*\ell\nu$

$$\frac{d\Gamma}{dw} = \frac{G_F^2 m_{D^*}^3}{48\pi^3}(m_B - m_{D^*})^2\sqrt{w^2-1}\,\chi(w)\boxed{\mathcal{F}^2(w)}|V_{cb}|^2$$

$B \to D\ell\nu$

$$\frac{d\Gamma}{dw} = \frac{G_F^2 m_D^3}{48\pi^3}(m_B + m_D)^2(w^2-1)^{3/2}\boxed{\mathcal{G}^2(w)}|V_{cb}|^2$$



Form Factor Parameterizations

- BGL Boyd, Grinstein, Lebed Phys.Rev.Lett 74, 4603 (1995)

$$f_i(z) = \frac{1}{P_i(z)\phi_i(z)}\sum_{n=0}^{N} a_{i,n} z^n, \qquad z(w) = \frac{\sqrt{w+1}-\sqrt{2}}{\sqrt{w+1}+\sqrt{2}}$$

Coefficient $a_{i,n}$ free parameters
The analyticity of the OPE assure bounds on the sum of the $a_{i,n}{}^2$

- CLN Caprini, Lellouch, Neubert Nucl.Phys.B530, 153 (1998)

$B \to D\ell\nu$

$$\mathcal{G}(z) = \mathcal{G}(1)(1 - 8\rho^2 z + (51\rho^2 - 10)z^2 - (252\rho^2 - 84)z^3)$$

Higher order coefficient connected with the slope ρ^2

$B \to D^*\ell\nu$

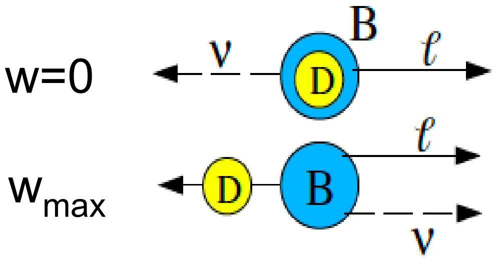
$$\begin{aligned} h_{A_1}(w) &= h_{A_1}(1)\big[1 - 8\rho^2 z + (53\rho^2 - 15)z^2 \\ &\qquad - (231\rho^2 - 91)z^3\big], \\ R_1(w) &= R_1(1) - 0.12(w-1) + 0.05(w-1)^2 \\ R_2(w) &= R_2(1) + 0.11(w-1) - 0.06(w-1)^2 \end{aligned}$$

Exclusive $|V_{cb}|$ and Form Factors

- ct $|V_{cb}|$

Assuming $m_\ell = 0$

$$w = \frac{m_B^2 + m_D^2 - q^2}{2 m_B m_D}$$



E

$V_{cb}|^2$

E

B → D*ℓν

Unquenched lattice FF calculation available only at zero-recoil
MILC/FNAL Phys.Rev.D89, 115404 (2014)
F(1) = 0.906 ± 0.013

Quenched calculation extends to w=1.1
De Vitiis et al, Nucl. Phys.B807 (2009) 373

LCSR at w_{max}
Faller et al. Eur.Phys.J C60(2009) 603

B → Dℓν

Unquenched lattice FF calculation also at moderately large recoil
MILC/FNAL Phys.Rev.D92, 034506 (2015)
HPQCD Phys.Rev.D92, 054510 (2015)

ns

5)

Coefficient $a_{i,n}$ free parameters

The analyticity of the OPE assure bounds on the sum of the $a_{i,n}{}^2$

8)

B → D*ℓν

$$h_{A_1}(1)\left[1 - 8\rho^2 z + (53\rho^2 - 15)z^2 - (231\rho^2 - 91)z^3\right],$$

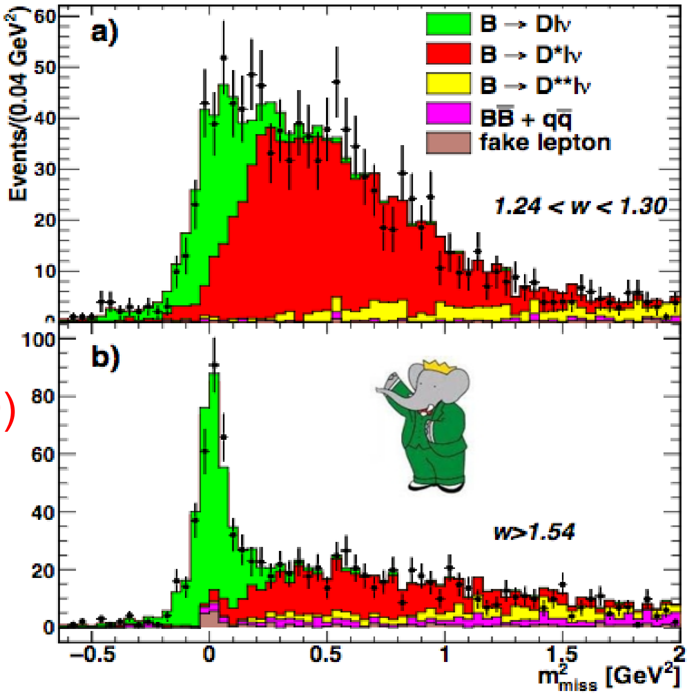
$$R_1(w) = R_1(1) - 0.12(w-1) + 0.05(w-1)^2$$
$$R_2(w) = R_2(1) + 0.11(w-1) - 0.06(w-1)^2$$

Higher order coefficient connected with the slope ρ^2

$B \rightarrow D\ell\nu$

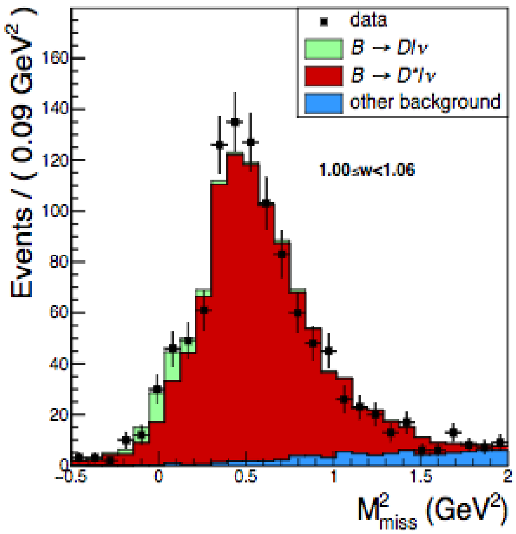
- State of the art performed by BaBar and Belle with hadronic B tagging: improve kinematic resolution and reduce combinatorial backgrounds
- Use both $B \rightarrow D^0\ell\nu$ ∈K∫ $B \rightarrow D^+\ell\nu$
- Signal extract in 10 bins of w from M_{miss}^2
- Largest background
  - $B \rightarrow D^*\ell\nu$

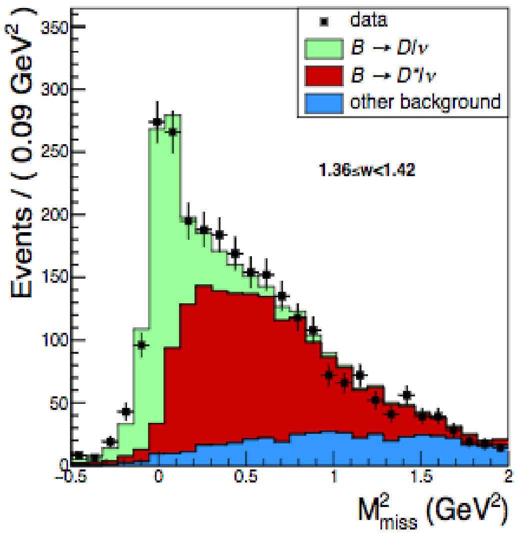
- $B \rightarrow D^0\ell\nu$

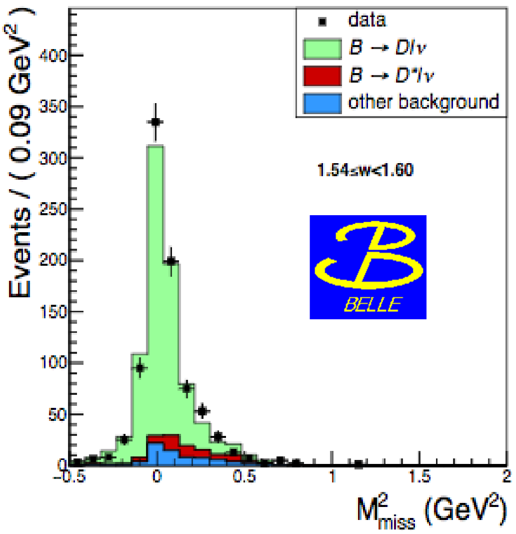


BaBar used 460M $B\bar{B}$
Fit ~3200 signal events
Phys.Rev.Lett.104:011802(2010)

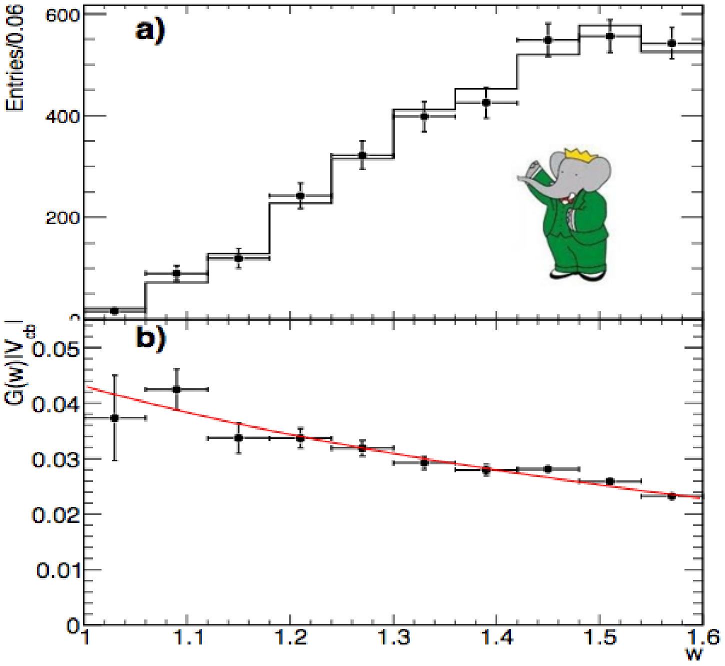
Belle used 771M $B\bar{B}$
Improved Hadronic B Tag based on NeuroBayes
Fit ~17000 signal events
Phys.Rev.D93:032006(2016)

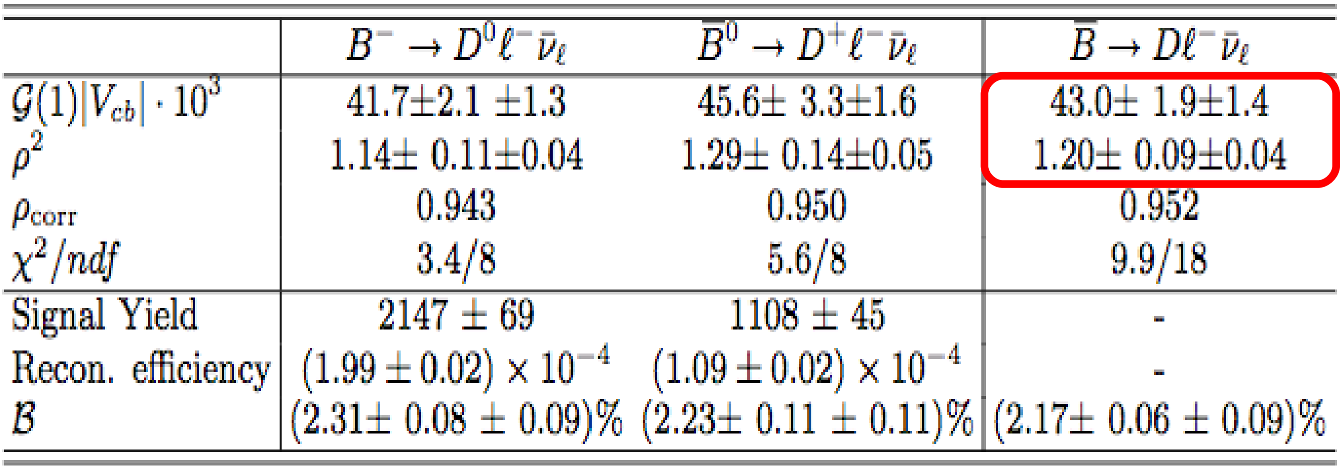




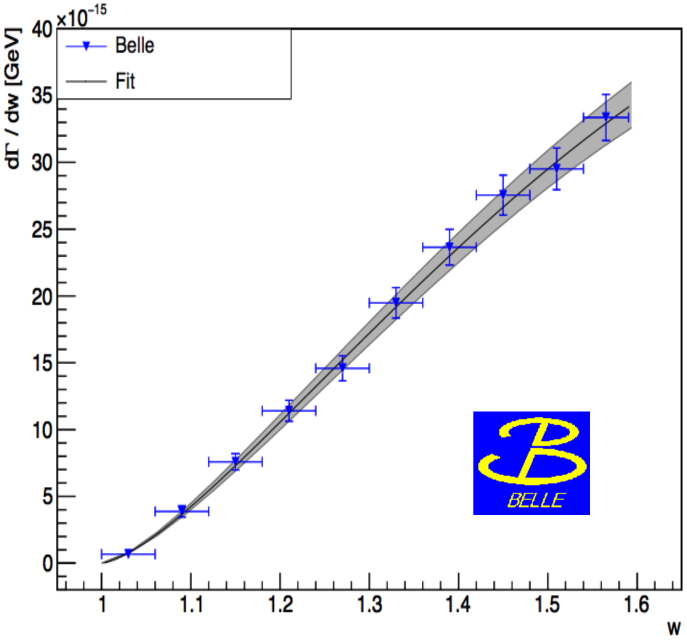


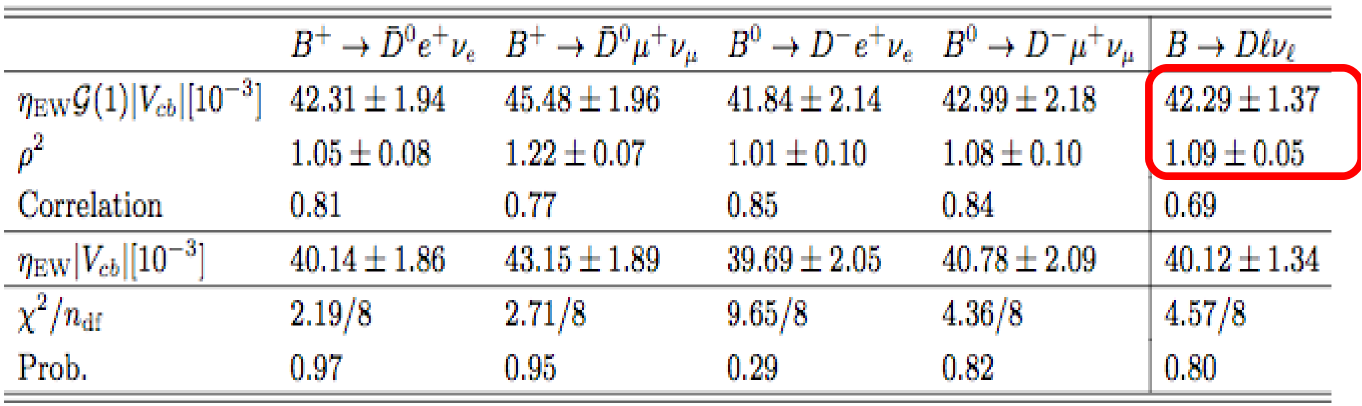
$G(1)|V_{cb}|$: results at B-Factories





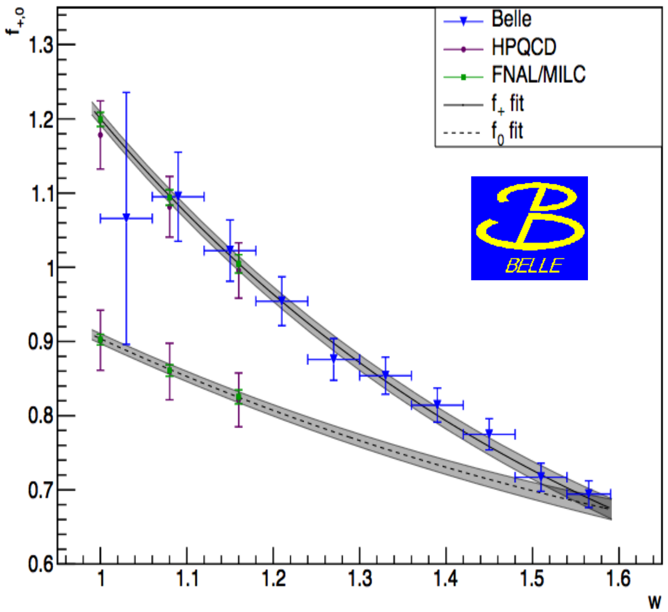
	$B^- \to D^0\ell^-\bar{\nu}_\ell$	$\overline{B}^0 \to D^+\ell^-\bar{\nu}_\ell$	$\overline{B} \to D\ell^-\bar{\nu}_\ell$
$\mathcal{G}(1)\lvert V_{cb}\rvert \cdot 10^3$	41.7±2.1 ±1.3	45.6± 3.3±1.6	43.0± 1.9±1.4
ρ^2	1.14± 0.11±0.04	1.29± 0.14±0.05	1.20± 0.09±0.04
$\rho_{\rm corr}$	0.943	0.950	0.952
χ^2/ndf	3.4/8	5.6/8	9.9/18
Signal Yield	2147 ± 69	1108 ± 45	-
Recon. efficiency	$(1.99 \pm 0.02) \times 10^{-4}$	$(1.09 \pm 0.02) \times 10^{-4}$	-
$\mathcal{B}$	(2.31± 0.08 ± 0.09)%	(2.23± 0.11 ± 0.11)%	(2.17± 0.06 ± 0.09)%





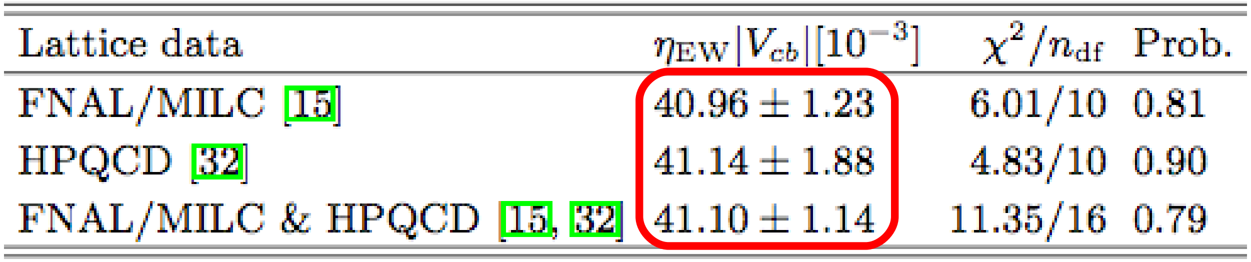
	$B^+ \to \bar{D}^0 e^+\nu_e$	$B^+ \to \bar{D}^0\mu^+\nu_\mu$	$B^0 \to D^- e^+\nu_e$	$B^0 \to D^-\mu^+\nu_\mu$	$B \to D\ell\nu_\ell$
$\eta_{\rm EW}\mathcal{G}(1)\lvert V_{cb}\rvert[10^{-3}]$	42.31 ± 1.94	45.48 ± 1.96	41.84 ± 2.14	42.99 ± 2.18	42.29 ± 1.37
ρ^2	1.05 ± 0.08	1.22 ± 0.07	1.01 ± 0.10	1.08 ± 0.10	1.09 ± 0.05
Correlation	0.81	0.77	0.85	0.84	0.69
$\eta_{\rm EW}\lvert V_{cb}\rvert[10^{-3}]$	40.14 ± 1.86	43.15 ± 1.89	39.69 ± 2.05	40.78 ± 2.09	40.12 ± 1.34
$\chi^2/n_{\rm df}$	2.19/8	2.71/8	9.65/8	4.36/8	4.57/8
Prob.	0.97	0.95	0.29	0.82	0.80

G(1)|V_{cb}|: effect of the parameterization



- Combined fit with Lattice data beyond zero-recoil using BGL parameterization

Series truncated at n=3

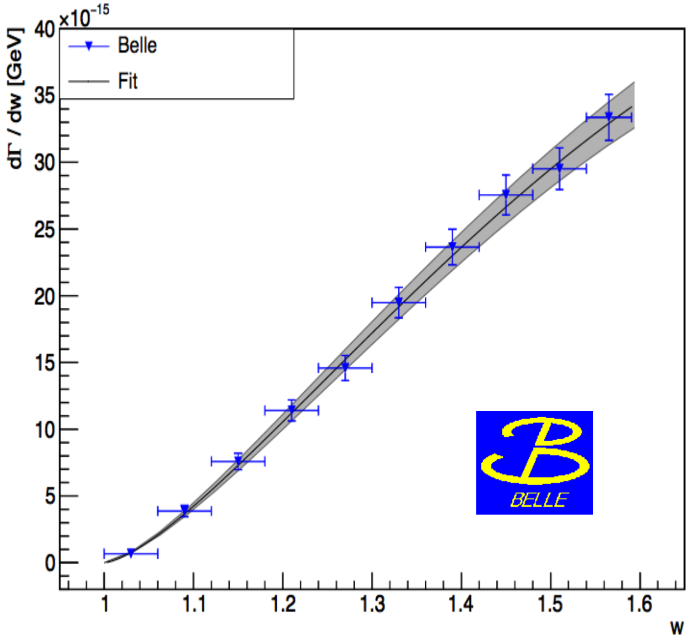


Lattice data	$\eta_{EW}\lvert V_{cb}\rvert[10^{-3}]$	χ^2/n_{df}	Prob.
FNAL/MILC [15]	40.96 ± 1.23	6.01/10	0.81
HPQCD [32]	41.14 ± 1.88	4.83/10	0.90
FNAL/MILC & HPQCD [15, 32]	41.10 ± 1.14	11.35/16	0.79

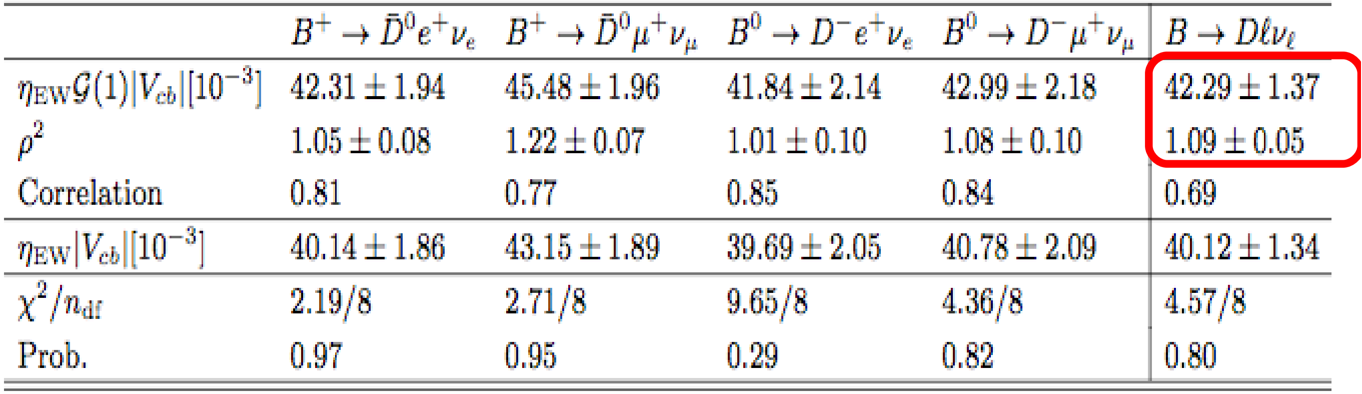
With the most recent FF normalization FNAL/MILC'15 G(1)=1.0541 ± 0.0083

CLN fit: |V_{cb}| = (39.86 +/- 1.33) x 10^{-3}

BGL fit: |V_{cb}| = (40.83 +/- 1.13) x 10^{-3}

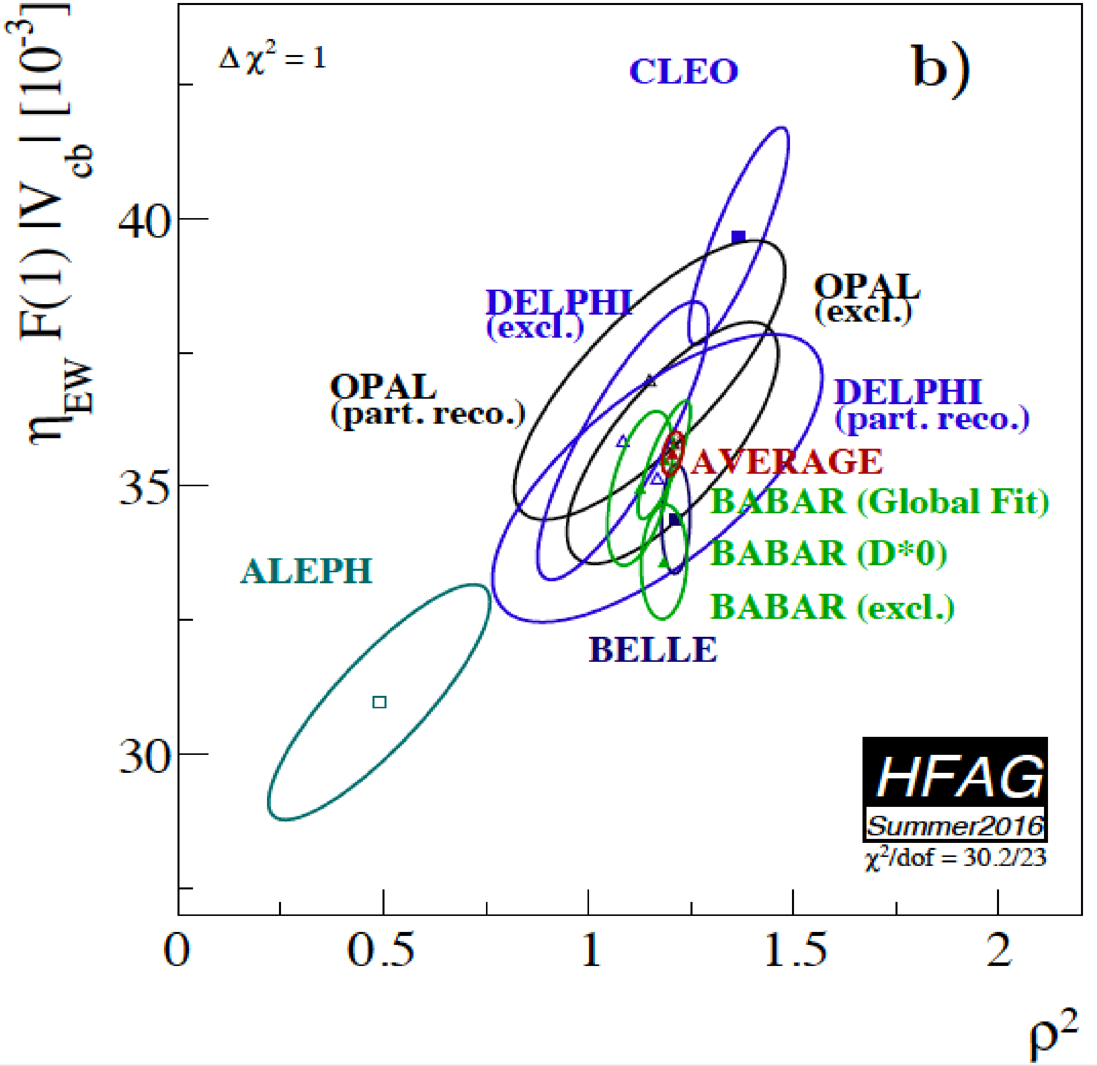


Critical discussion on the FF parameterizations, using both Belle and BaBar data reported in Bigi, Gambino Phys.Rev.D 94,094008(2016)



	$B^+ \to \bar{D}^0 e^+ \nu_e$	$B^+ \to \bar{D}^0 \mu^+ \nu_\mu$	$B^0 \to D^- e^+ \nu_e$	$B^0 \to D^- \mu^+ \nu_\mu$	$B \to D \ell \nu_\ell$
$\eta_{EW}\mathcal{G}(1)\lvert V_{cb}\rvert[10^{-3}]$	42.31 ± 1.94	45.48 ± 1.96	41.84 ± 2.14	42.99 ± 2.18	42.29 ± 1.37
ρ^2	1.05 ± 0.08	1.22 ± 0.07	1.01 ± 0.10	1.08 ± 0.10	1.09 ± 0.05
Correlation	0.81	0.77	0.85	0.84	0.69
$\eta_{EW}\lvert V_{cb}\rvert[10^{-3}]$	40.14 ± 1.86	43.15 ± 1.89	39.69 ± 2.05	40.78 ± 2.09	40.12 ± 1.34
χ^2/n_{df}	2.19/8	2.71/8	9.65/8	4.36/8	4.57/8
Prob.	0.97	0.95	0.29	0.82	0.80

B → D*$\ell\nu$: HFLAV average



- Most recent calculation is from Belle in 2010
- All based on CLN parameterization
- Two are based on a 4-dimensional fit
  - BaBar, Phys.Rev.D77:032002,2008
  - Belle Phys.Rev.D82:112007,2010

$$\begin{aligned} \eta_{\rm EW}\mathcal{F}(1)|V_{cb}| &= (35.61 \pm 0.43) \times 10^{-3} \,, \\ \rho^2 &= 1.205 \pm 0.026 \,, \\ R_1(1) &= 1.404 \pm 0.032 \,, \\ R_2(1) &= 0.854 \pm 0.020 \,, \end{aligned}$$

Only published unquenched calculation available is at zero-recoil from FANL/MILC

Bailey et al., Phys.Rev.D89,114504(2014)

Unfortunately these old data cannot be Re-analysed with a different parameterization

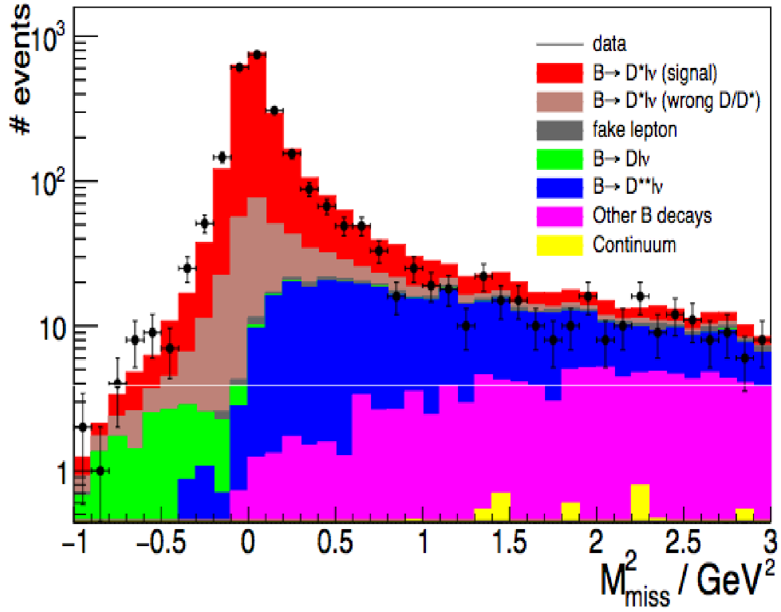
$$\boxed{|V_{cb}| = (38.71 \pm 0.47_{\rm exp} \pm 0.59_{\rm th}) \times 10^{-3}}$$

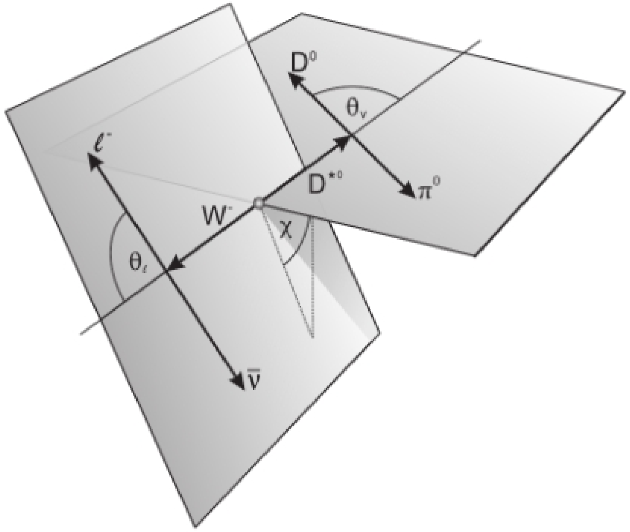
3σ from inclusive determination

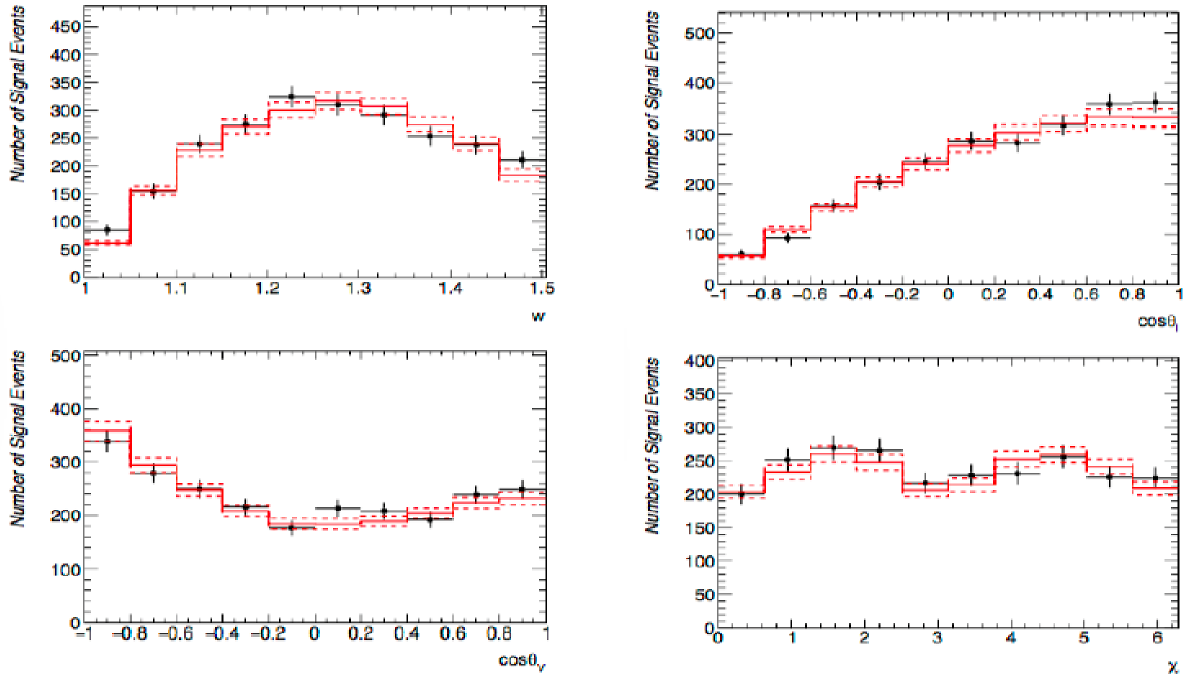
$B \to D^{*}\ell\nu$: news from Belle

ArXiv:1702.01521

- With the hadronic tag, similar to $B \to D$
- Signal extracted from the missing mass distribution by a unbinned maximum likelihood fit
- Yields extracted in 4x10 bins of w and 3 angular variables: statistical correlations determined with bootstrapping technique
- For the first time published the Unfolded distributions



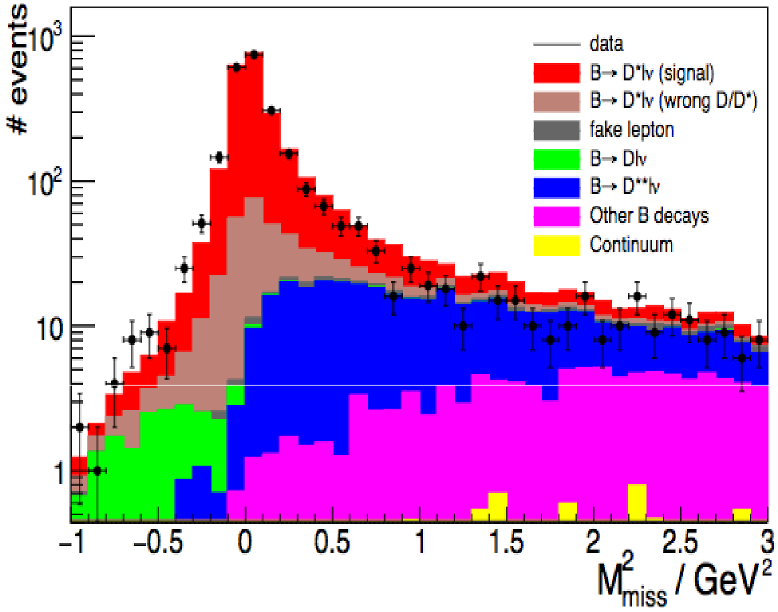




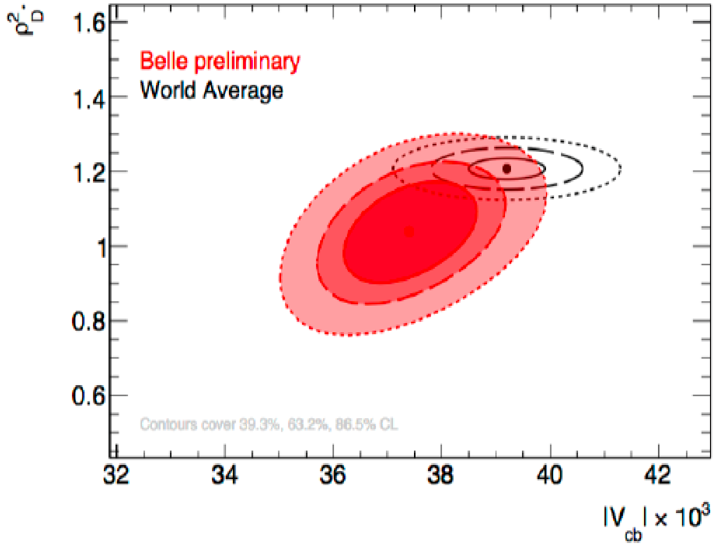
$B \to D^*\ell\nu$: news from Belle

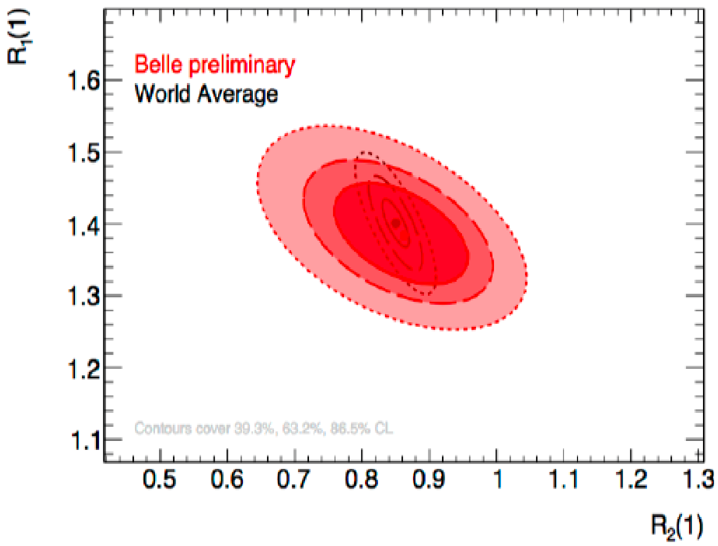
ArXiv:1702.01521

- With the hadronic tag, similar to $B \to D$
- Signal extracted from the missing mass distribution by a unbinned maximum likelihood fit
- Yields extracted in 4x10 bins of w and 3 angular variables: statistical correlations determined with bootstrapping technique
- For the first time published the Unfolded distributions



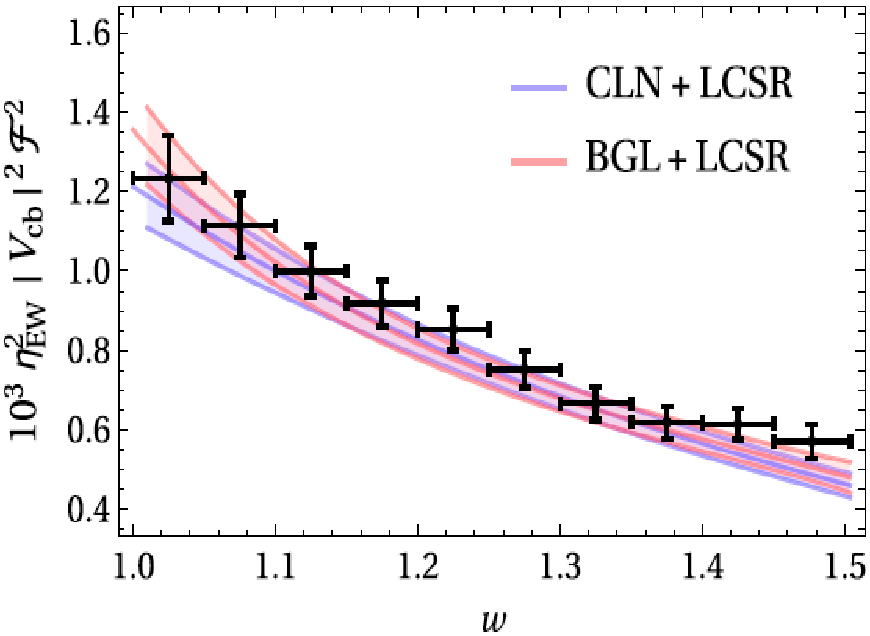
- Belle fit with CLN parameterization consistent with world average

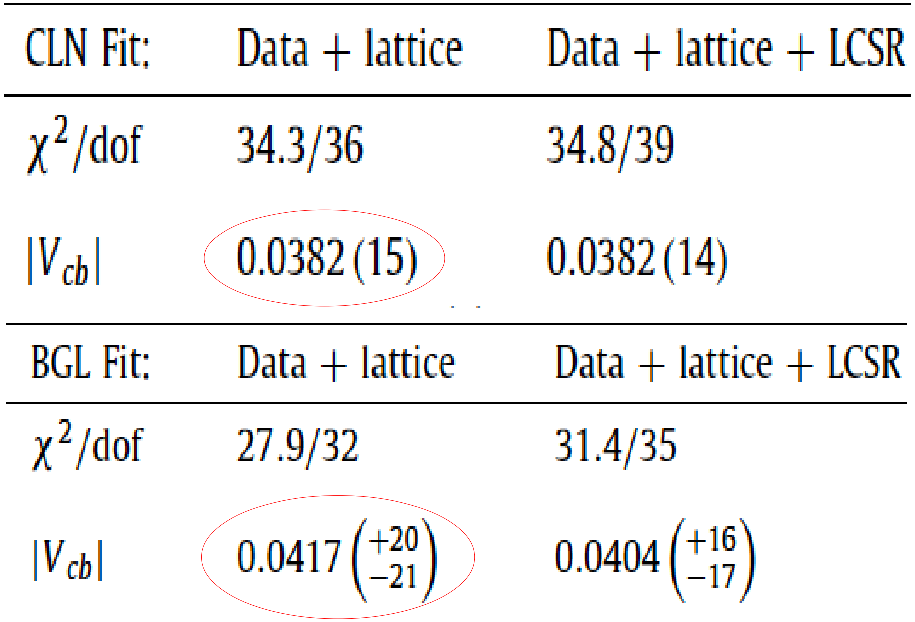




Model independent analysis

- **Bigi, Gambino, Schacht Phys.Lett B 769 (2017) 441:** Critical analysis of parameterization with the Belle data

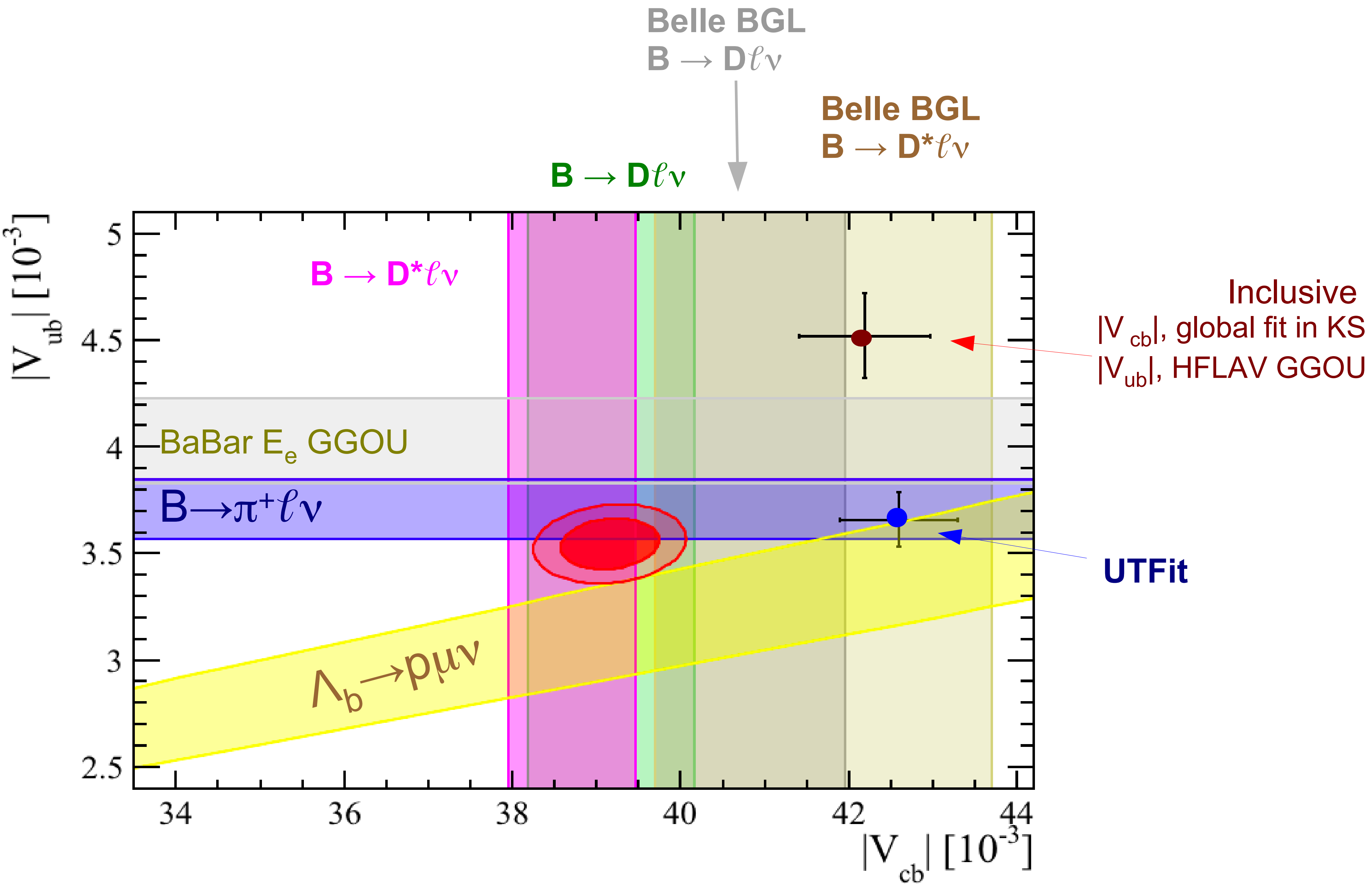




CLN Fit:	Data + lattice	Data + lattice + LCSR
χ^2/dof	34.3/36	34.8/39
$\lvert V_{cb} \rvert$	0.0382 (15)	0.0382 (14)
BGL Fit:	Data + lattice	Data + lattice + LCSR
χ^2/dof	27.9/32	31.4/35
$\lvert V_{cb} \rvert$	$0.0417 \left(^{+20}_{-21}\right)$	$0.0404 \left(^{+16}_{-17}\right)$

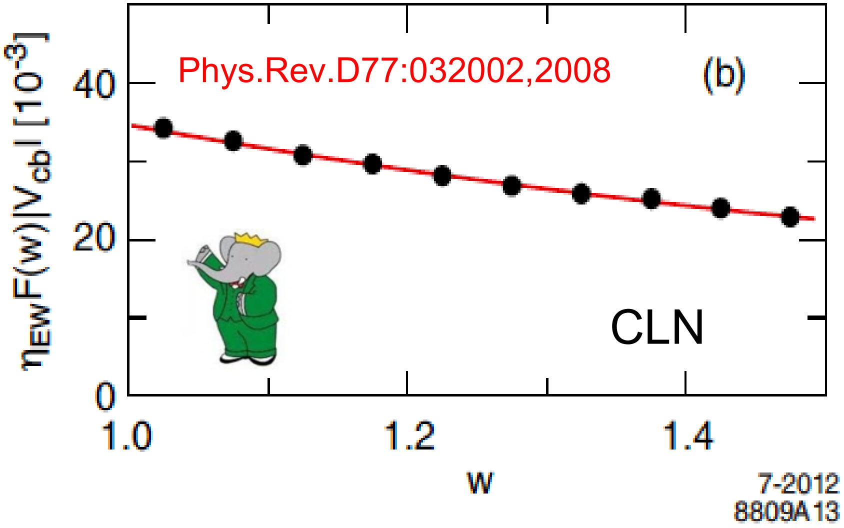
- This result points to a systematic difference between CLN and a model-independent parameterization
- Similar analysis in **Grinstein, Kobach arXiv.1703.0817**, who claimed
  - “strong possibility that the tension between inclusive and exclusive |Vcb| …. is due to the use of the CLN parameterization...”

New global picture ?



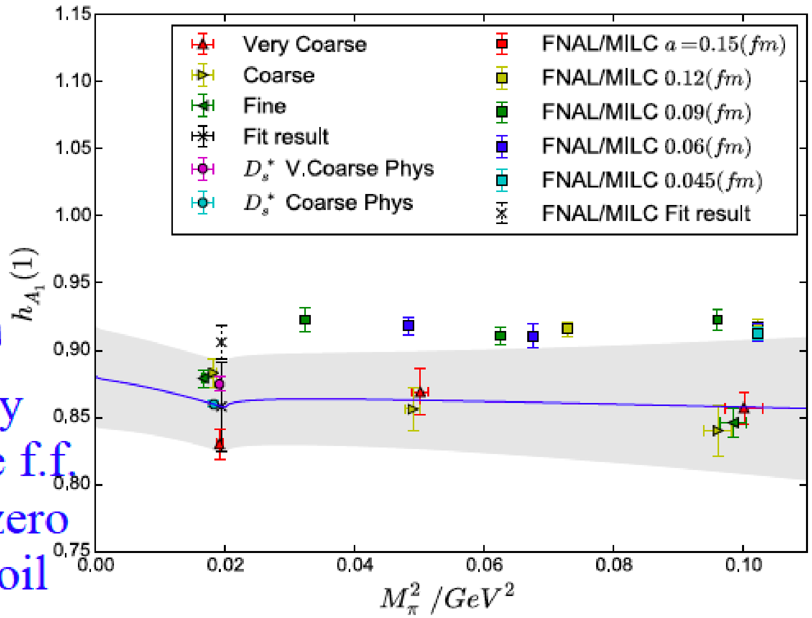
Remarks

- CLN can be affected by underestimated uncertainties
    - An uncertainty of “better than 2%” on the FF quoted in CLN paper, with the increasing precision, cannot be neglected anymore
- It is crucial to move to a model-independent parameterization, CLN is too constrained
    - Unfortunately existing HFLAV average uses measurements based on CLN
- But the difference BGL-CLN of about ~8% on $|V_{cb}|$ from the recent Belle data, cannot be considered the only systematic missed in the existing average that fill the gap with the inclusive: CLN fit well old precise data!



Remarks

- CLN can be affected by underestimated uncertainties
    - An uncertainty of “better than 2%” on the FF quoted in CLN paper, with the increasing precision, cannot be neglected anymore
- It is crucial to move to a model-independent parameterization, CLN is too constrained
    - Unfortunately existing HFLAV average uses measurements based on CLN
- But the difference BGL-CLN of about ~8% on $|V_{cb}|$ from the recent Belle data, cannot be considered the only systematic missed in the existing average that fill the gap with the inclusive: CLN fit well old precise data!



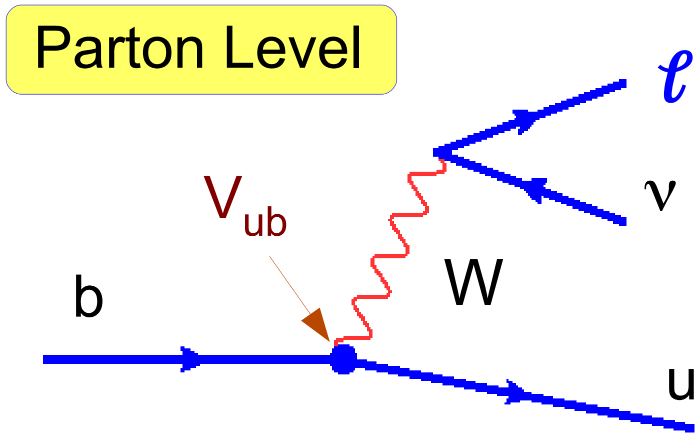
only one f.f. at zero recoil

- We should not neglect that there is only one lattice calculation for F(1)
- Recently HPQCD F(1)=0.862(35) C.Davie at CKM2016
    - Lower than FNAL/MILC!
    - HQSum-Rule, F(1) =0.86(2)
- Calculations at non-zero recoil could be desirable

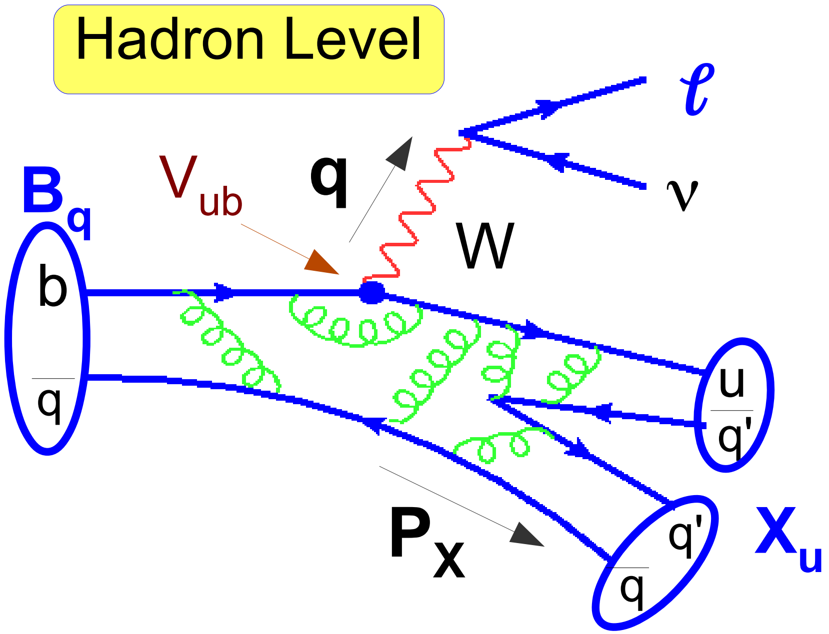
Conclusione

- Exclusive Vub
  - huge progressed on lattice
  - LHCb is a new player: opened the route to $B_s \rightarrow K \ell\nu$ (cleanest on Lattice!)
- Inclusive Vub
  - It is still a puzzle: internally consistent but above CKM fit and exclusive
  - Partial rates that include the b→c region depends on the signal model: crucial to consider this and use the same model for both signal extraction and |Vub|
  - Theory/parameters uncertainties dominate: need to constrain the SF (global fit Vcb-like from spectra measurements: SIMBA, NNVUB)
- Inclusive Vcb
  - Everything consistent and it gives inputs to Vub/SF: it would be desirable an update of the 1S scheme framework
- Exclusive Vcb
  - General agreement to move to model independent FF parameterizations
  - New Lattice-FF calculation for B→D* (even a non-zero recoil) are on the way from MILC/FNAL and HPQCD

Semileptonic Decays



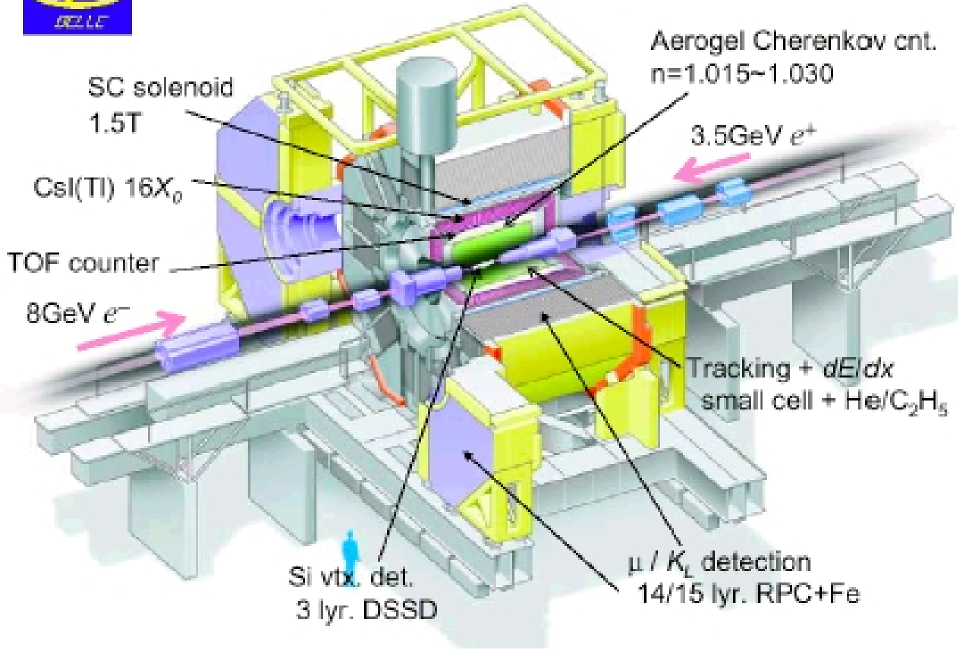
Understand The QCD



- Inclusive decays $B \rightarrow X_u \ell \nu$:
  - QCD corrections to parton level decay rate
  - Operator Production Expansion in α_s and Λ/m_b
- Exclusive decays $B \rightarrow \pi/\rho \ell \nu$:
  - QCD correction parameterized in the Form Factors
  - Lattice-QCD, LCSR

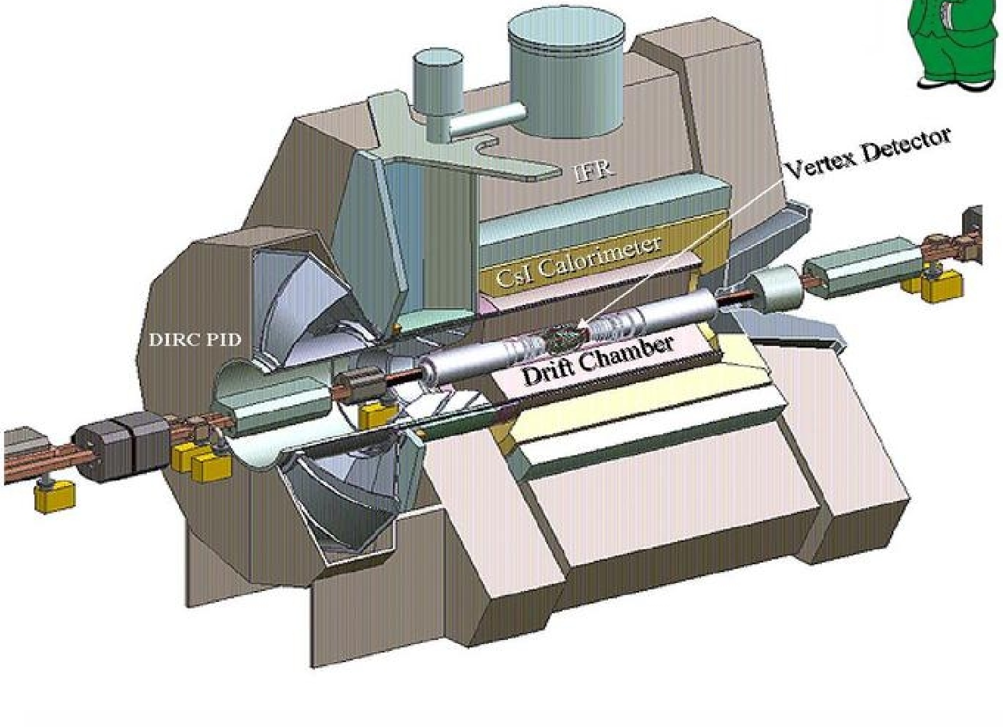
Experiments: B-Factories

Belle Detector



@ KEK Japan: 1999-2009

BaBar Detector



@ SLAC: 1999-2008

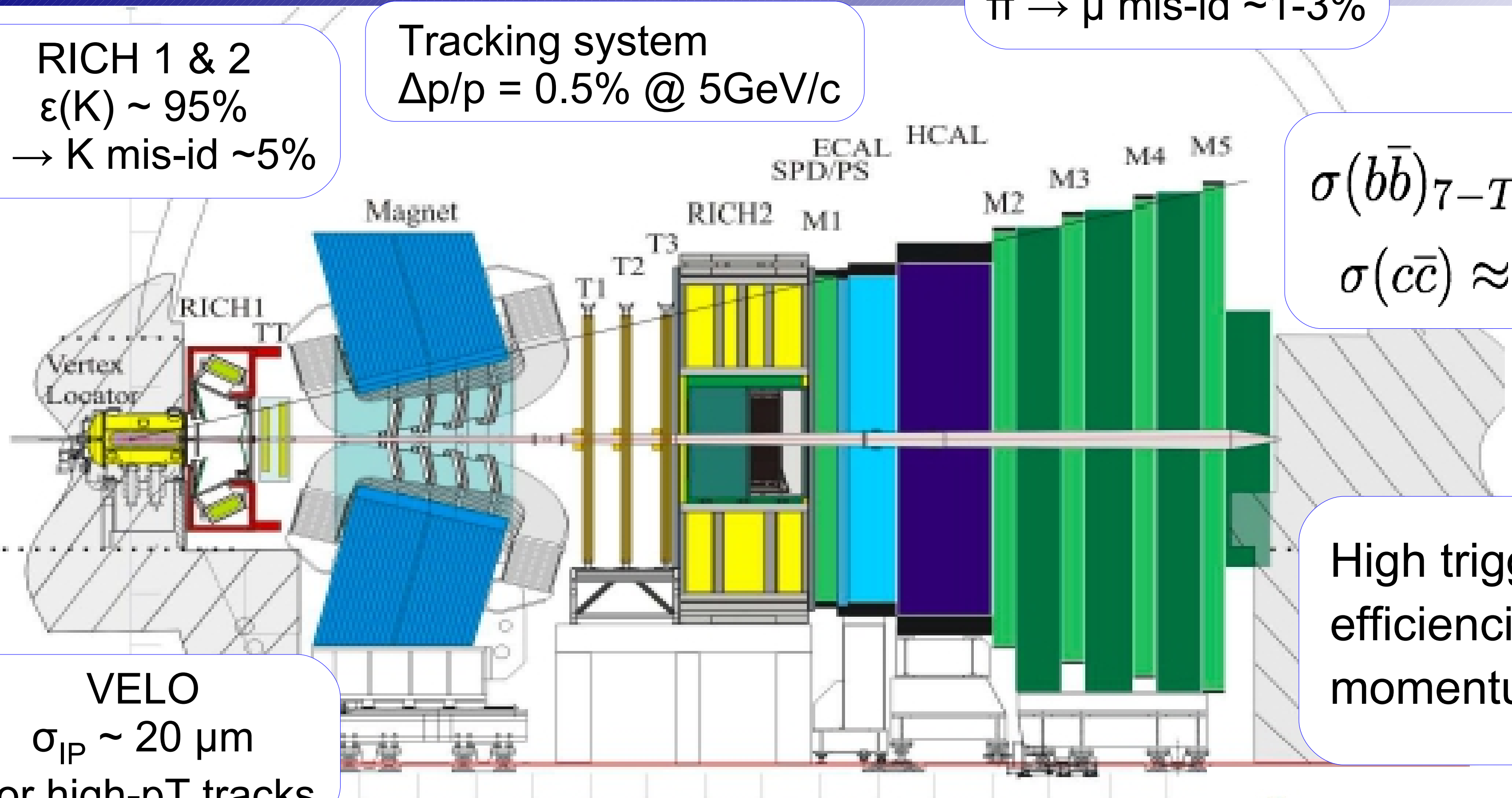
B-Factories: hermetic detectors, low background, access (mainly) at $B^{0/+}$

About (771 + 467)x10^6
e^+e^- → Y(4S) → BB events in the Belle+BaBar data

Belle and KEK is being upgraded

Belle-II aims to collect $50ab^{-1}$ by 2024

The LHCb experiment



RICH 1 & 2
$\varepsilon(K) \sim 95\%$
$\pi \rightarrow K$ mis-id ~5%

Tracking system
$\Delta p/p = 0.5\%$ @ 5GeV/c

Muons
$\varepsilon(\mu) \sim 97\%$
$\pi \rightarrow \mu$ mis-id ~1-3%

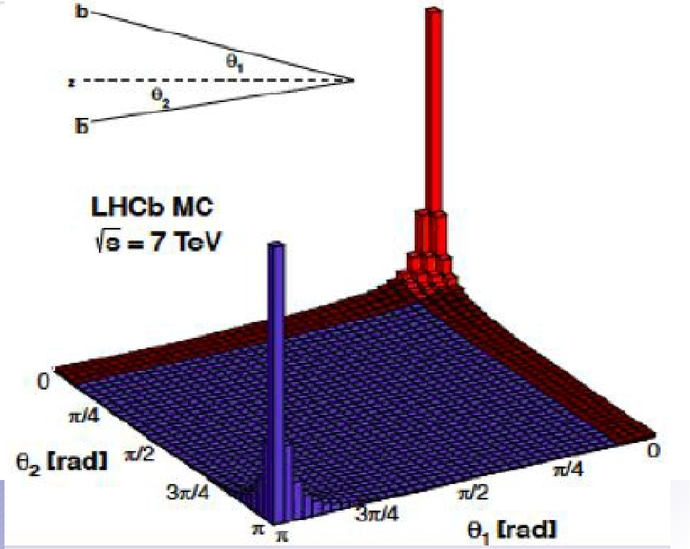
$$\sigma(b\bar{b})_{7-TeV} \approx 290\mu b$$
$$\sigma(c\bar{c}) \approx 20 \times \sigma(b\bar{b})$$

High trigger efficiencies, low momentum thresholds

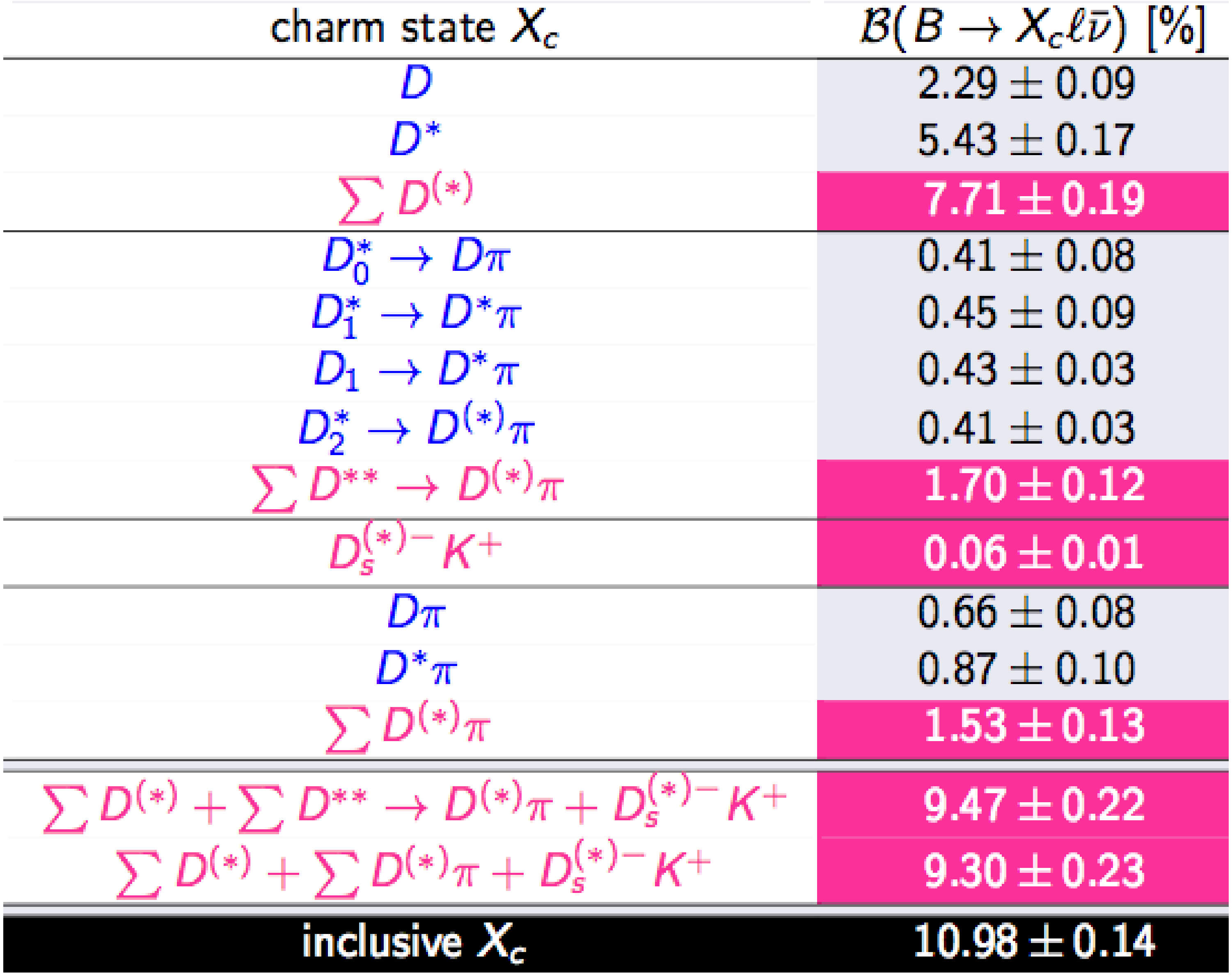
VELO
$\sigma_{IP} \sim 20\ \mu m$
For high-pT tracks

LHCb: forward spectrometer for flavor physics
Excellent tracking and vertexing capabilities.
Excellent PID performances
Access to all hadrons with b- and c-quarks

Collected 3.0 fb^{-1} in 2011-2012



The gap problem

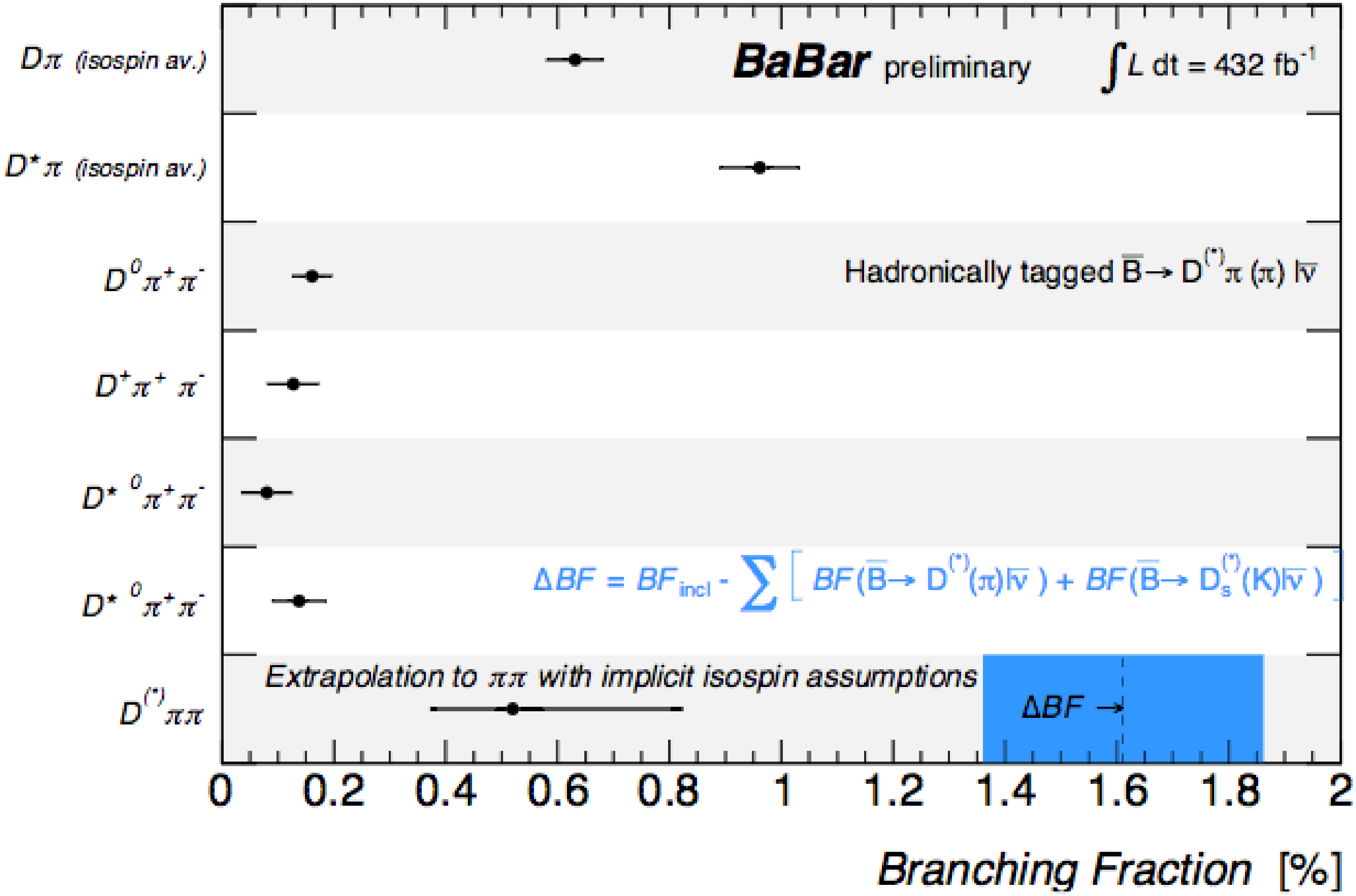


charm state X_c	$\mathcal{B}(B \to X_c \ell \bar{\nu})$ [%]
D	2.29 ± 0.09
D^*	5.43 ± 0.17
$\sum D^{(*)}$	7.71 ± 0.19
$D_0^* \to D\pi$	0.41 ± 0.08
$D_1^* \to D^*\pi$	0.45 ± 0.09
$D_1 \to D^*\pi$	0.43 ± 0.03
$D_2^* \to D^{(*)}\pi$	0.41 ± 0.03
$\sum D^{**} \to D^{(*)}\pi$	1.70 ± 0.12
$D_s^{(*)-} K^+$	0.06 ± 0.01
$D\pi$	0.66 ± 0.08
$D^*\pi$	0.87 ± 0.10
$\sum D^{(*)}\pi$	1.53 ± 0.13
$\sum D^{(*)} + \sum D^{**} \to D^{(*)}\pi + D_s^{(*)-} K^+$	9.47 ± 0.22
$\sum D^{(*)} + \sum D^{(*)}\pi + D_s^{(*)-} K^+$	9.30 ± 0.23
inclusive X_c	10.98 ± 0.14

Inclusive – Σexclusive = (1.51 ± 0.26) %

From T.Lueck
@EPS2015

Status of the “gap”



- gap reduced from $\approx 7\sigma$ to $\approx 3\sigma$

extrapolation to full $\mathcal{B}$ assumed $\Gamma(D^{(*)}\pi^+\pi^-\ell\nu)/\Gamma(D^{(*)}\pi\pi\ell\nu) = 0.50 \pm 0.17$

From T.Lueck
@EPS2015