XXIV Cracow Epiphany Conference

Advances in Heavy Flavour Physics

IFJ PAN, 9-12 January 2018

Mini review on $|V_{ub}|$, $|V_{cb}|$ @LHCb and B-factories

Marcello Rotondo

Laboratori Nazionali di Frascati

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

$|V_{cb}|$ and $|V_{ub}|$ are determined from leptonic and semileptonic B-hadron decays

They give crucial inputs to CKM fits for indirect search of New Physics

$|V_{ub}|$ opposite to angle β:

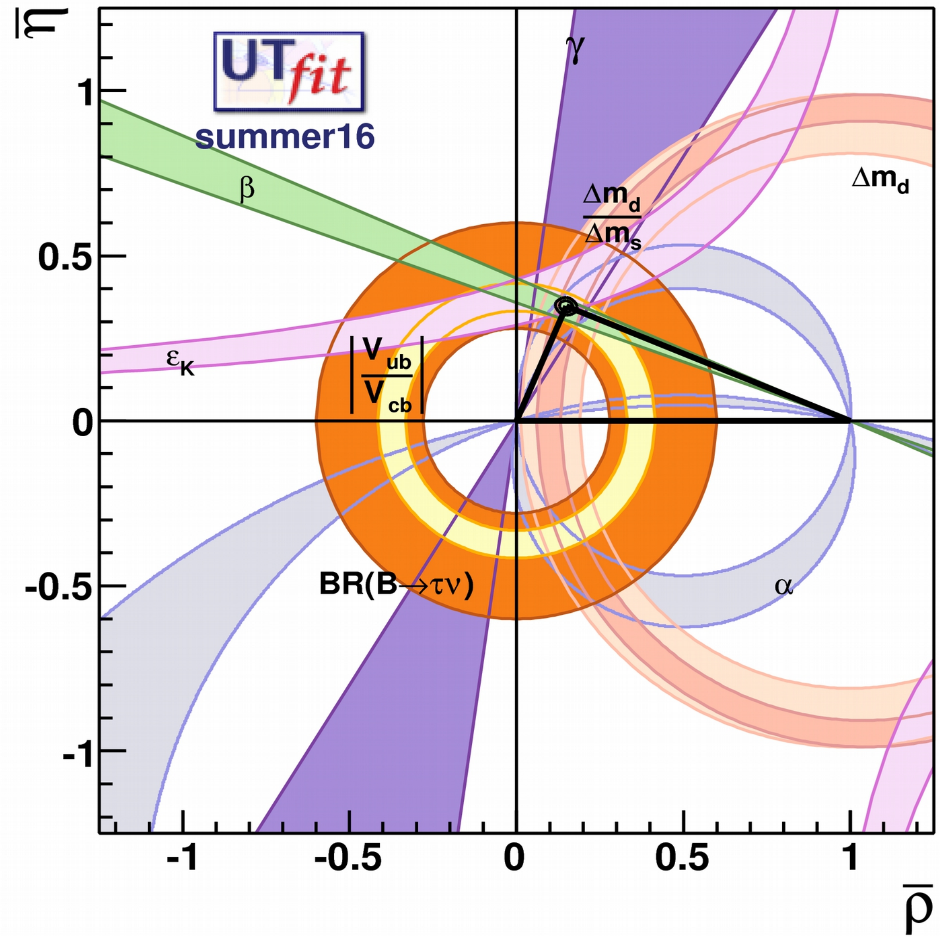
Compare tree-dominated
with loop-dominated processes

Predictions of FCNC processes

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

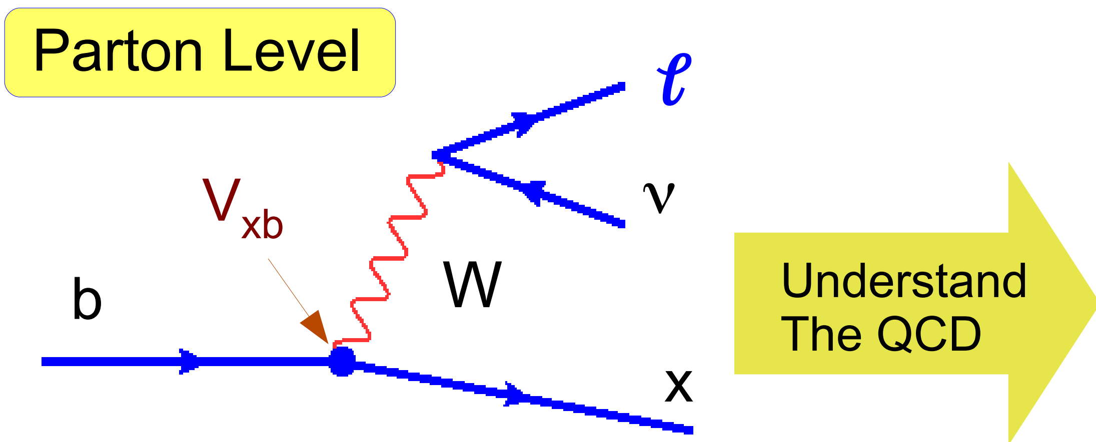
Kaon physics affected by $|V_{cb}|$

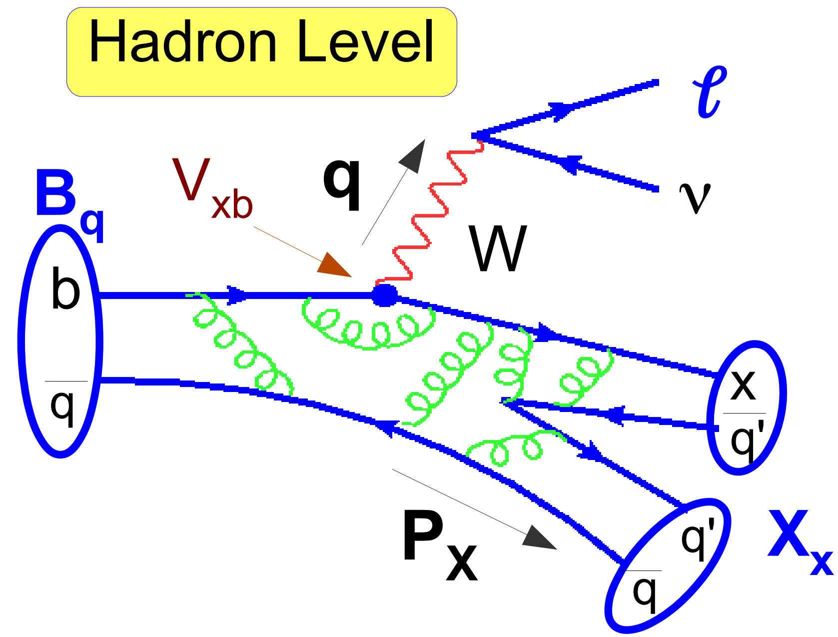
$$\epsilon_K \approx x|V_{cb}|^2 + \ldots$$



R(D)-R(D*) enhanced respect to SM by 4σ! Hints of New Physics at Tree level?
Measurements of $|V_{cb}|$ and $|V_{ub}|$ provide Form-Factors, crucial for SM predictions on R(D)-R(D*) and signal model

Semileptonic Decays: $|V_{xb}|$





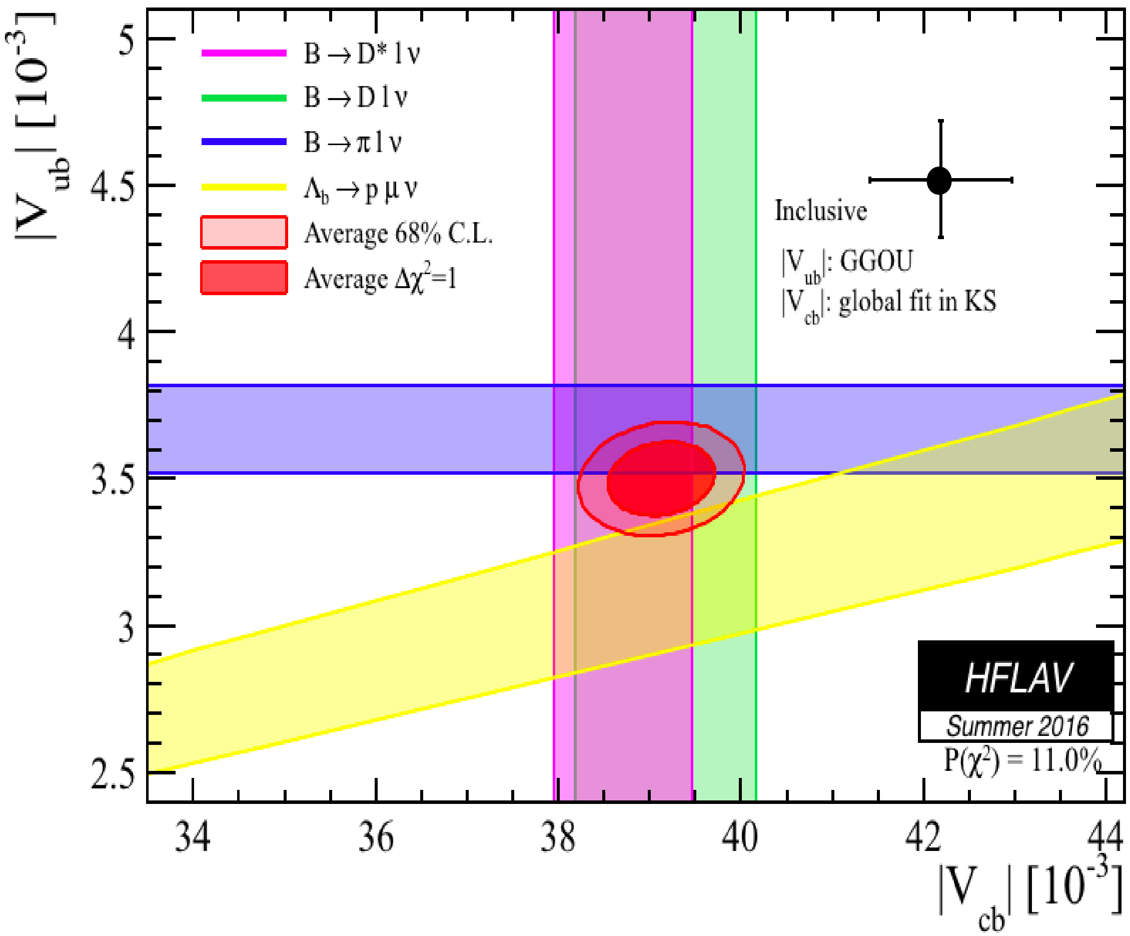
- Inclusive decays $B \to X_u \ell \nu$ or $B \to X_c \ell \nu$
  - QCD corrections to parton level decay rate
  - Operator Production Expansion in α_s and $\Lambda_{QCD}/m_{b,c}$
- Exclusive decays $B \to \pi/\rho \ell \nu$ J $B \to D/D^* \ell \nu$
  - QCD correction parameterized in the Form Factors
  - Lattice-QCD, LCSR

State of the Art

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

Total uncertainties better than 2% for $|V_{cb}|$ and at about 5-6 % for $|V_{ub}|$

For both $|V_{cb}|$ and $|V_{ub}|$ there is a long standing discrepancy between the inclusive and exclusive determinations at ~3σ level



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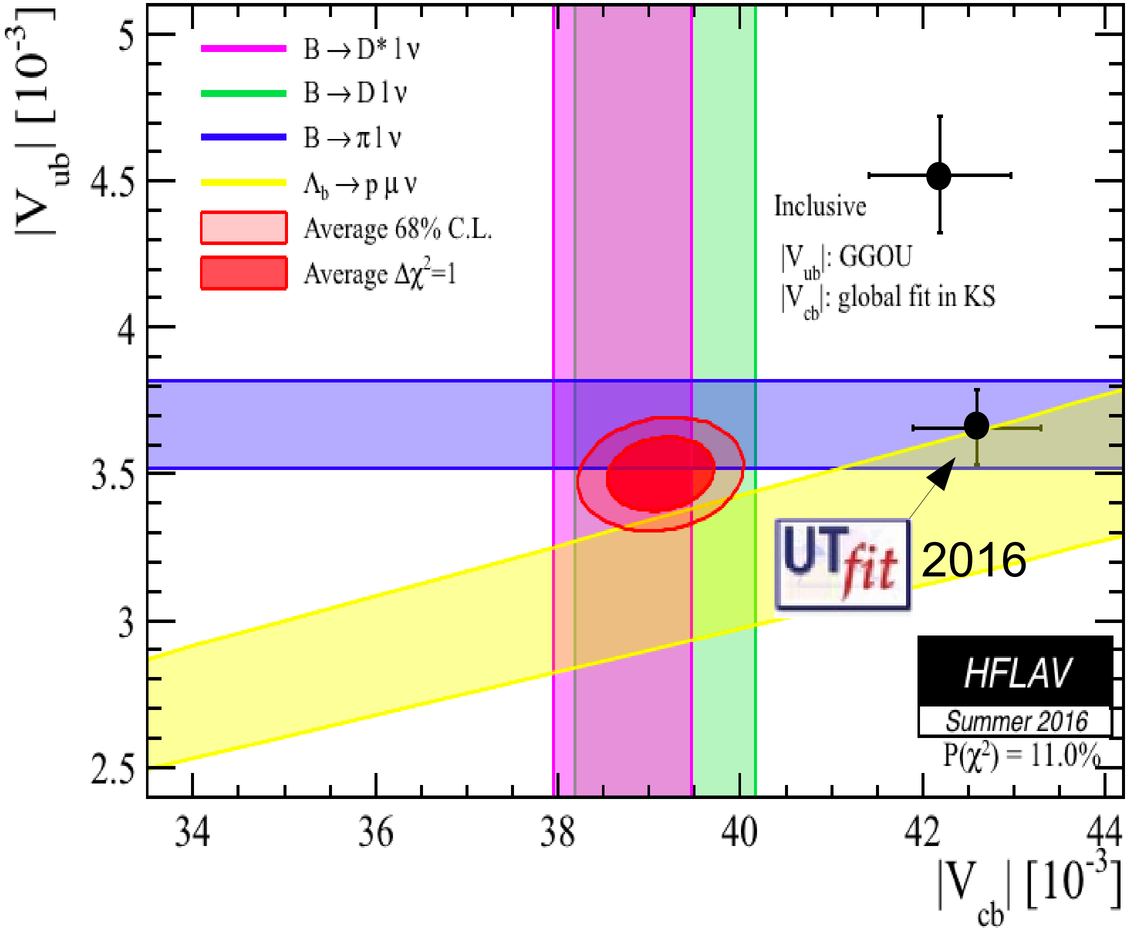
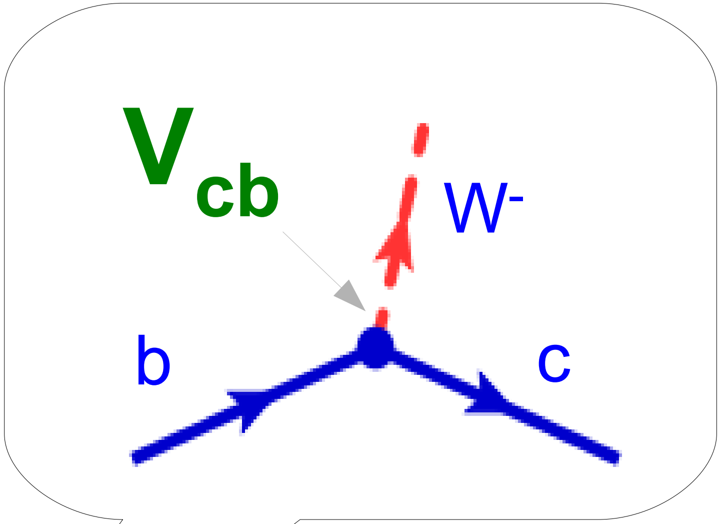


Indirect determinations from CKM fits prefer inclusive $|V_{cb}|$ and exclusive $|V_{ub}|$

$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \begin{pmatrix} d \\ s \\ b \end{pmatrix}$$



$|V_{cb}|$ 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 $|V_{cb}|^2$

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

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 $O(\alpha_O^2 \Lambda_{f \neq \infty}^2 / I_{\cap}^2)$

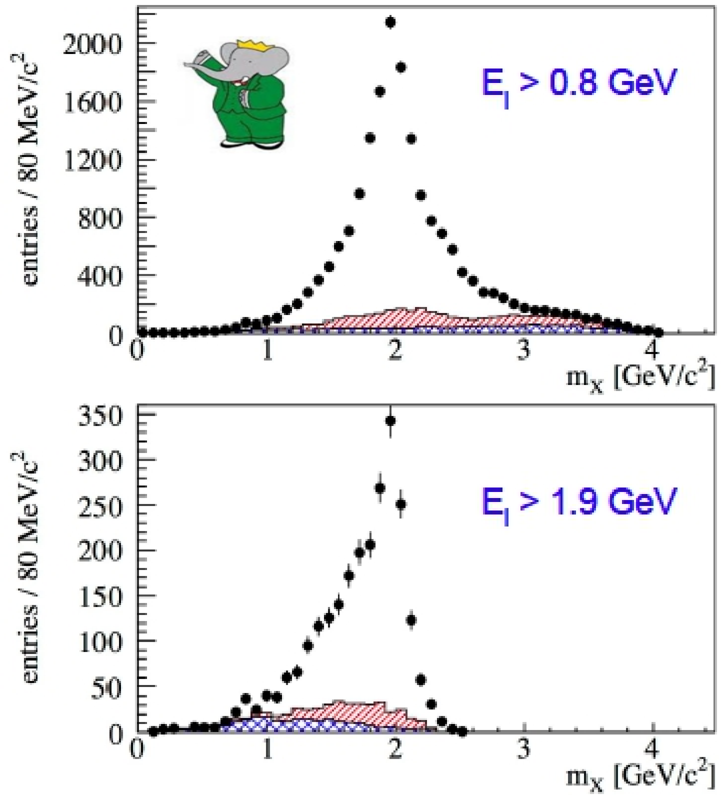
Experiment	Hadron moments $<M^n_X>$	Lepton moments $<E^n_l>$	References
BaBar	n=2 c=0.9,1.1,1.3,1.5 n=4 c=0.8,1.0,1.2,1.4 n=6 c=0.9,1.3 [1]	n=0 c=0.6,1.2,1.5 n=1 c=0.6,0.8,1.0,1.2,1.5 n=2 c=0.6,1.0,1.5 n=3 c=0.8,1.2 [1,2]	[1] Phys.Rev. D81 (2010) 032003 [2] Phys.Rev. D69 (2004) 111104
Belle	n=2 c=0.7,1.1,1.3,1.5 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

$|V_{cb}|$ inclusive

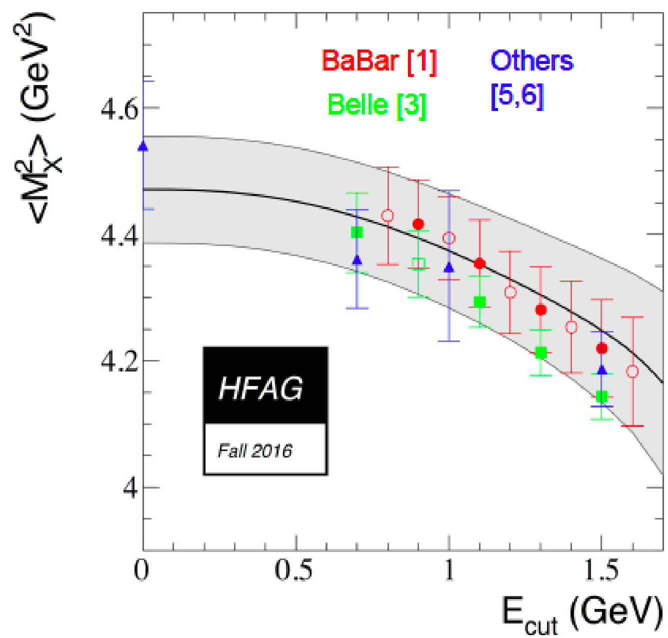
- Moments of the lepton spectrum or invariant mass squared are ideal observables to extract the non perturbative parameters and $|V_{cb}|$

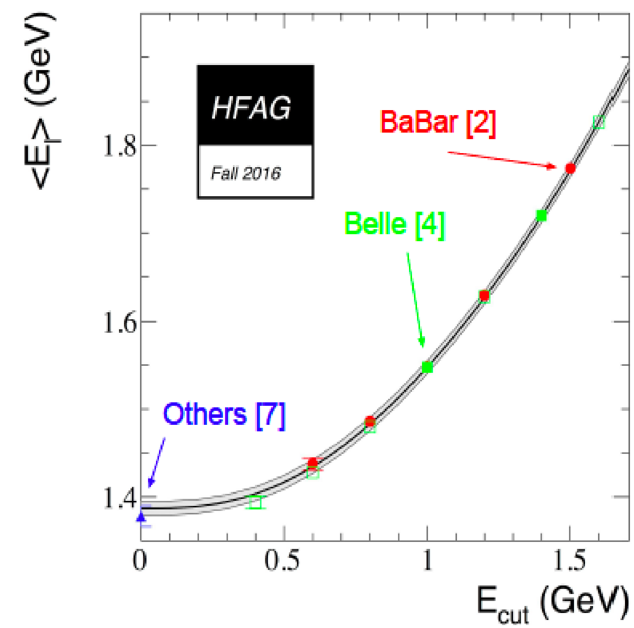
$$\langle E_\ell^n \rangle = \frac{1}{\Gamma_{E_\ell > E_{\rm cut}}} \int_{E_\ell > E_{\rm cut}} E_\ell^n \frac{d\Gamma}{dE_\ell}\, dE_\ell \;,$$

$$\langle m_X^{2n} \rangle = \frac{1}{\Gamma_{E_\ell > E_{\rm cut}}} \int_{E_\ell > E_{\rm cut}} m_X^{2n} \frac{d\Gamma}{dm_X^2}\, dm_X^2$$



Gray bands include theory errors





HFLAV

$Br(B \to X_c lnu)$ (%)	$\|V_{cb}\|$ (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 $m_\ell = 0$

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

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

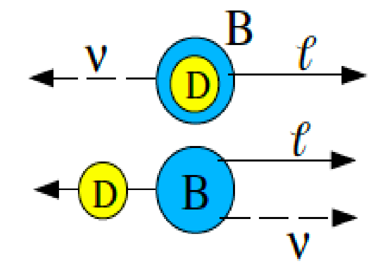
$$\frac{d\Gamma}{dw} = \frac{G_F^2 m_{D^*}^3}{48\pi^3}(m_B - m_{D^*})^2\sqrt{w^2-1}\,\chi(w)\mathcal{F}^2(w)|V_{cb}|^2$$

$B \to D\ell\nu$

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

w=1

w_{max}



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

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

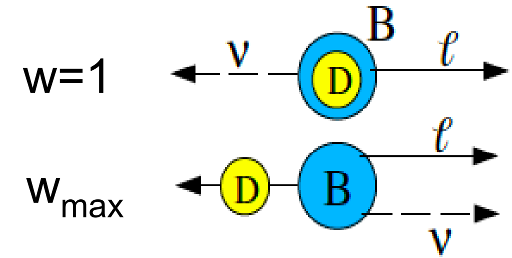
$$\begin{aligned} h_{A_1}(w) &= h_{A_1}(1)\left[1 - 8\rho^2 z + (53\rho^2 - 15)z^2 - (231\rho^2 - 91)z^3\right], \\ R_1(w) &= R_1(1) - 0.12(w-1) + 0.05(w-1)^2 \\ R_2(w) &= R_2(1) + 0.11(w-1) - 0.06(w-1)^2 \end{aligned}$$

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

ct $|V_{cb}|$

Assuming $m_\ell = 0$

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



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

Unquenched lattice FF calculation available only at zero-recoil

2+1+1 lattice calculation from HPQCD
ArXiv:1711.11013, F(1)=0.881 ± 0.022

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

$B \to D \ell \nu$

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

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)

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

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

$$R_1(1) - 0.12(w-1) + 0.05(w-1)^2$$

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

E

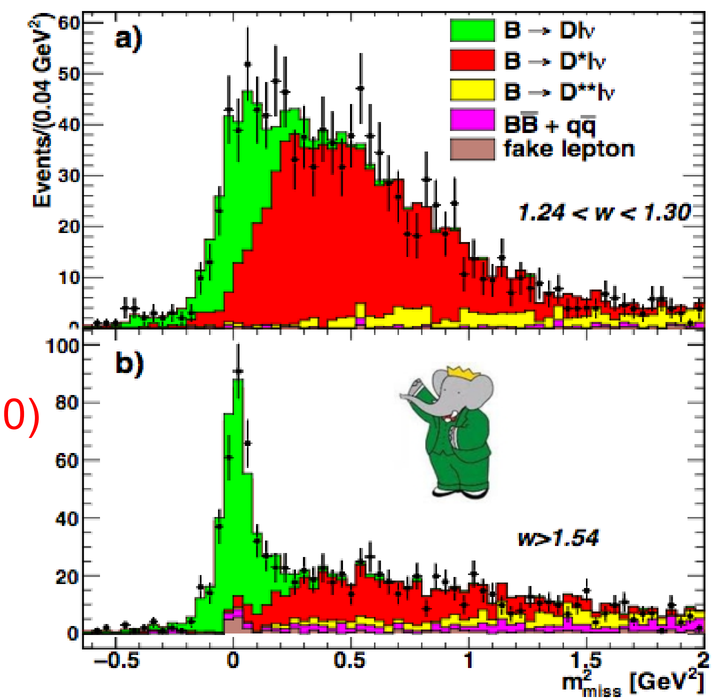
E

Hi

$B \to D\ell\nu$

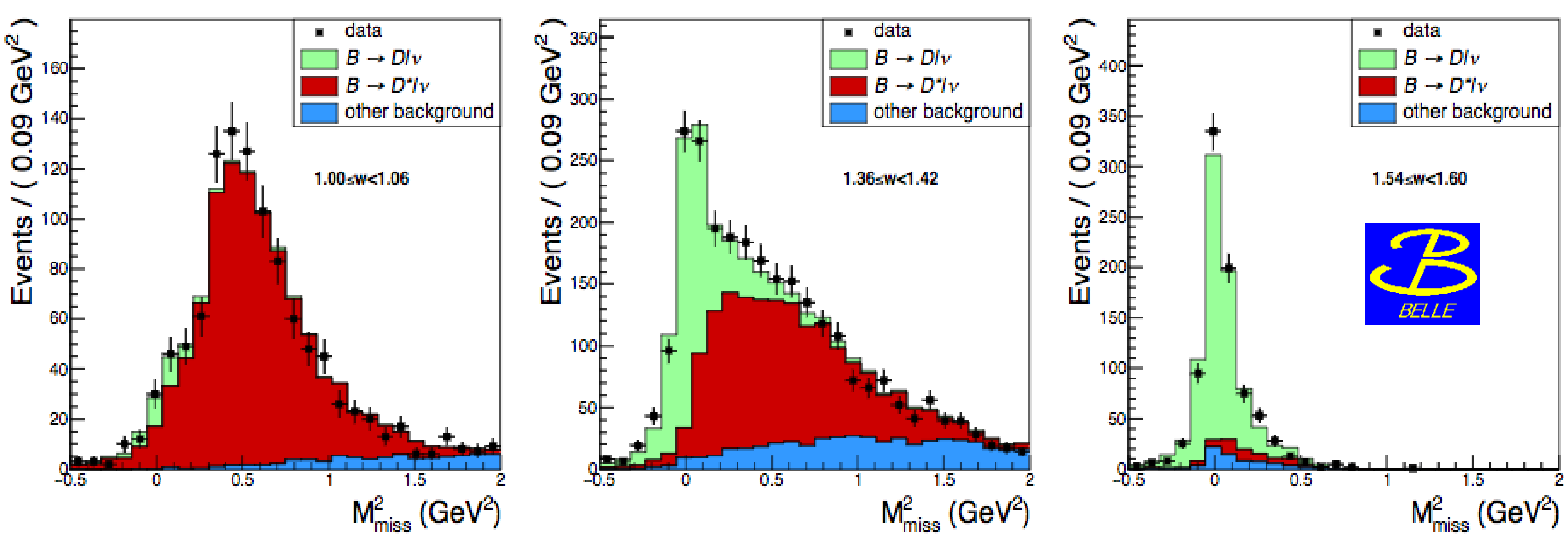
- State of the art performed by BaBar and Belle with hadronic B tagging: improve kinematic resolution and reduce combinatorial backgrounds
- Use both $B \to D^0\ell\nu$ ∈K∫ $B \to D^+\ell\nu$
- Signal extract in 10 bins of w from $M_{miss}{}^2$
- Largest background
  - $B \to D^*\ell\nu$

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

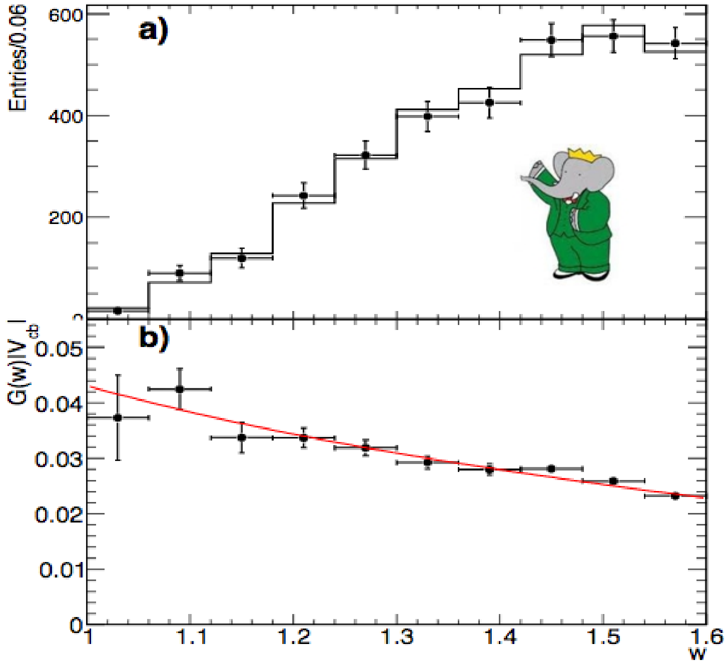


BaBar used 460M $B\bar{B}$
Fit ~3200 signal events
Phys.Rev.Lett.104:011802(2010)

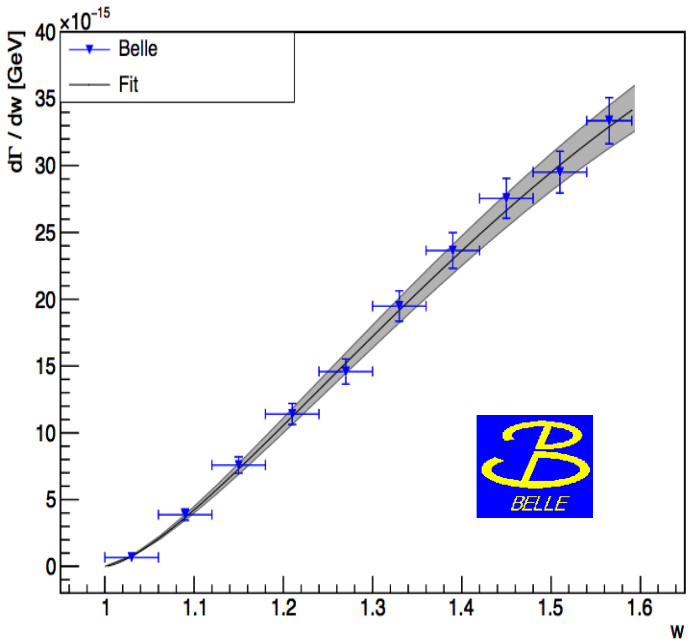
Belle used 771M $B\bar{B}$
Improved Hadronic B Tag based on NeuroBayes
Fit ~17000 signal events
Phys.Rev.D93:032006(2016)



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

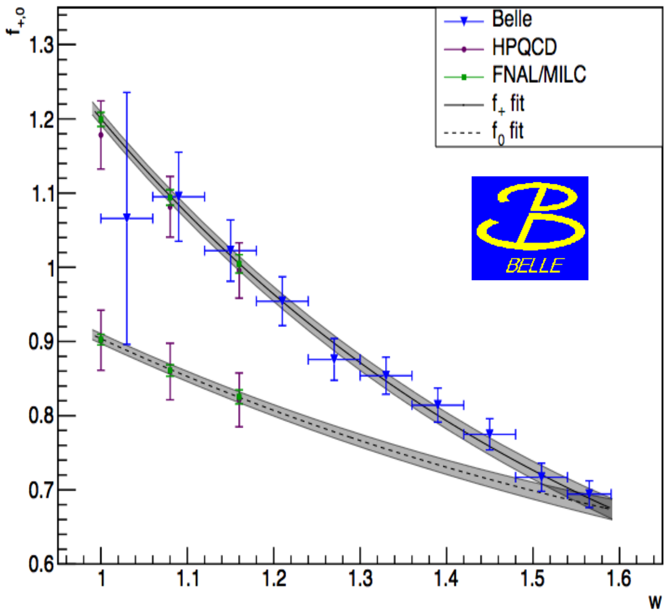


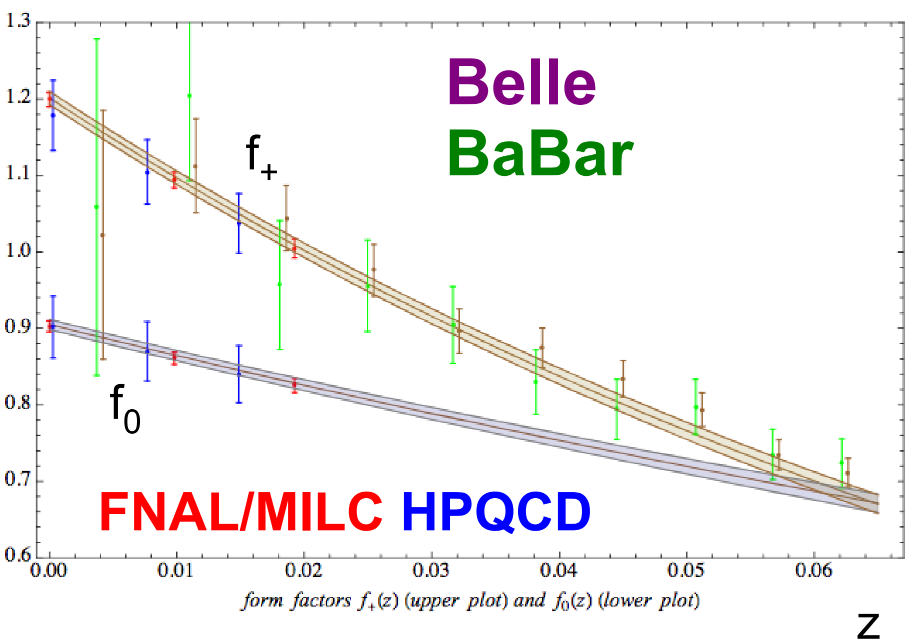
	$B^- \to D^0 \ell^- \bar{\nu}_\ell$	$\overline{B}^0 \to D^+ \ell^- \bar{\nu}_\ell$	$\overline{B} \to D \ell^- \bar{\nu}_\ell$
$\mathcal{G}(1)\lvert V_{cb}\rvert \cdot 10^3$	41.7±2.1 ±1.3	45.6± 3.3±1.6	43.0± 1.9±1.4
ρ^2	1.14± 0.11±0.04	1.29± 0.14±0.05	1.20± 0.09±0.04
ρ_{corr}	0.943	0.950	0.952
χ^2/ndf	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)%



	$B^+ \to \bar{D}^0 e^+ \nu_e$	$B^+ \to \bar{D}^0 \mu^+ \nu_\mu$	$B^0 \to D^- e^+ \nu_e$	$B^0 \to D^- \mu^+ \nu_\mu$	$B \to D \ell \nu_\ell$
$\eta_{\text{EW}}\mathcal{G}(1)\lvert V_{cb}\rvert[10^{-3}]$	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
$\eta_{\text{EW}}\lvert V_{cb}\rvert[10^{-3}]$	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

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	$\eta_{EW}\|V_{cb}\|[10^{-3}]$	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

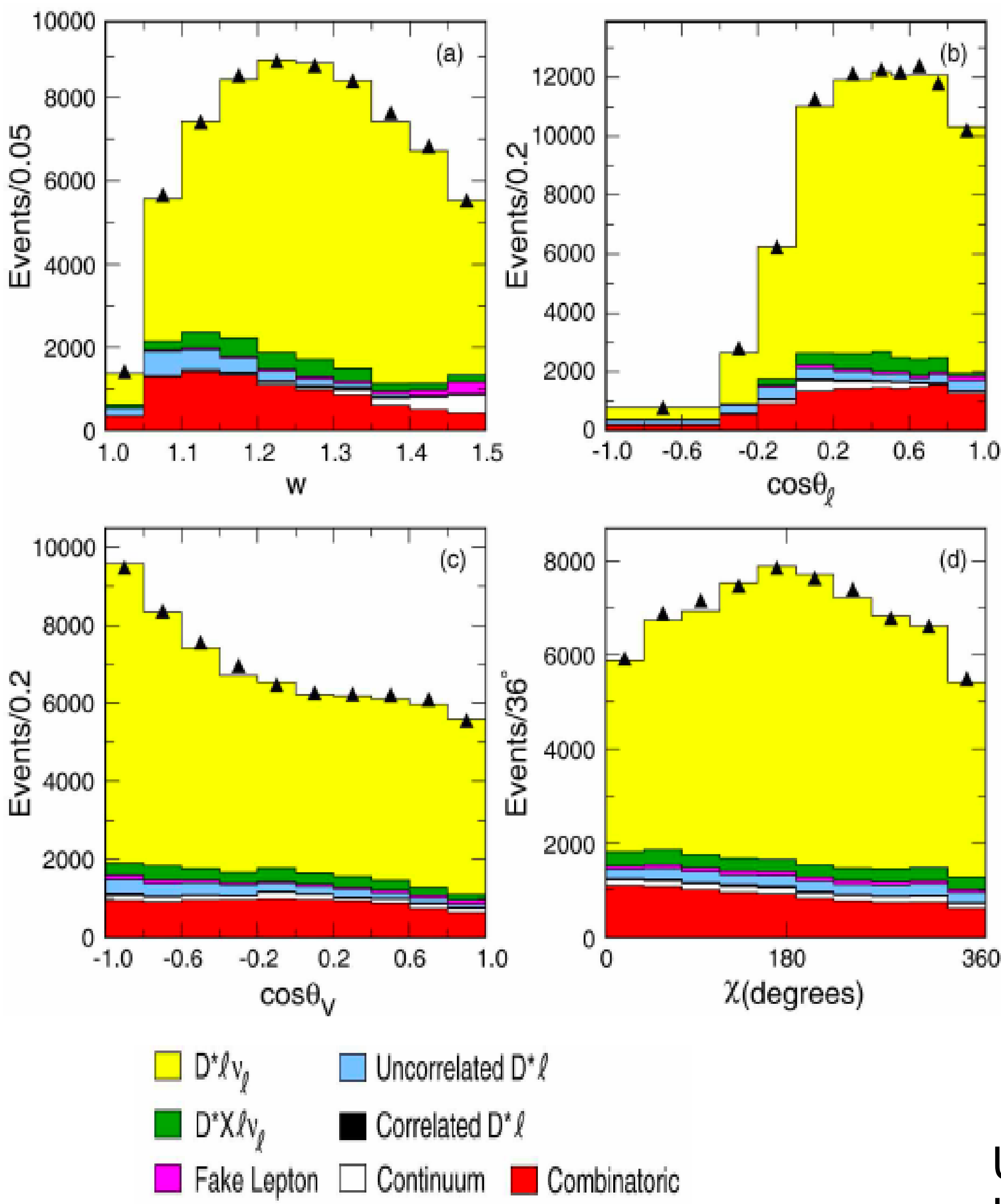
Critical discussion on the FF parameterizations, using both Belle and BaBar data reported in Bigi, Gambino Phys.Rev.D 94,094008(2016)

exp data	lattice data	N,par	$10^3 \times \|V_{cb}\|$	χ^2
all	all	2,BGL	40.62(98)	22.1/26
all	all	3,BGL	40.47(97)	18.2/24
all	all	4,BGL	**40.49(97)**	19.0/22
Belle	all	3,BGL	40.92(1.12)	11.6/14
BaBar	all	3,BGL	40.11(1.55)	12.6/14

BGL and CLN give consistent results. Because of the present accurate Lattice calculation, CLN is no longer a satisfactory parametrization

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

Phys.Rev.D77:032002,2008



- Based on 79fb^{-1}
- Fitter 52.8 K signal events
  - $B^0 \to D^{*-}\ell\nu$ and $D^{*-} \to D^0\pi^-$
  - 3 different D^0 decay modes
  - Fitted the projections, accounting for the proper bin-bin correlations directly from data

CLN parameterization

Subsample	ρ^2	$R_1(1)$	$R_2(1)$	$\mathcal{F}(1)\lvert V_{cb}\rvert \times 10^3$	χ^2/d.o.f.
$K\pi e$	0.971 ± 0.163	1.166 ± 0.182	0.977 ± 0.107	$34.76 \pm 0.61 \pm 0.61$	23.9/24
$K\pi\mu$	1.013 ± 0.175	1.193 ± 0.206	0.922 ± 0.123	$34.55 \pm 0.66 \pm 0.65$	37.9/24
$K\pi\pi\pi e$	1.581 ± 0.151	2.043 ± 0.384	0.405 ± 0.232	$33.30 \pm 1.27 \pm 0.96$	15.6/24
$K\pi\pi\pi\mu$	1.146 ± 0.258	1.156 ± 0.351	0.946 ± 0.197	$34.14 \pm 1.10 \pm 0.98$	28.0/24
$K\pi\pi^0 e$	1.042 ± 0.165	1.217 ± 0.206	0.926 ± 0.118	$34.86 \pm 0.64 \pm 1.46$	26.9/24
$K\pi\pi^0\mu$	1.170 ± 0.155	1.439 ± 0.228	0.838 ± 0.131	$34.38 \pm 0.74 \pm 1.46$	24.8/24

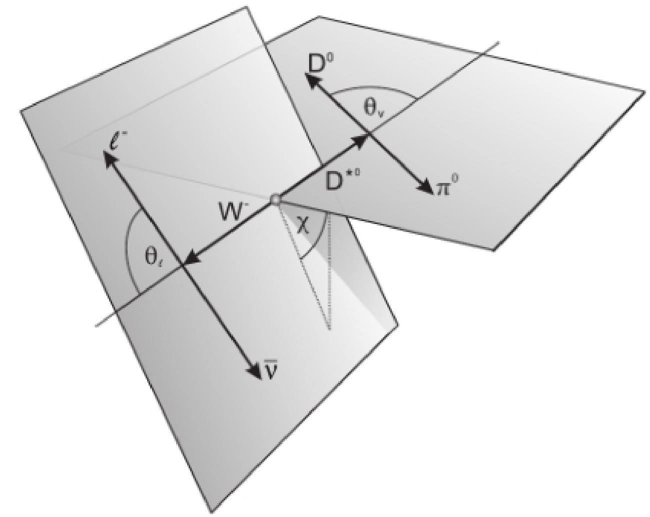
- Very good fit results: $P(\chi^2)$=47%

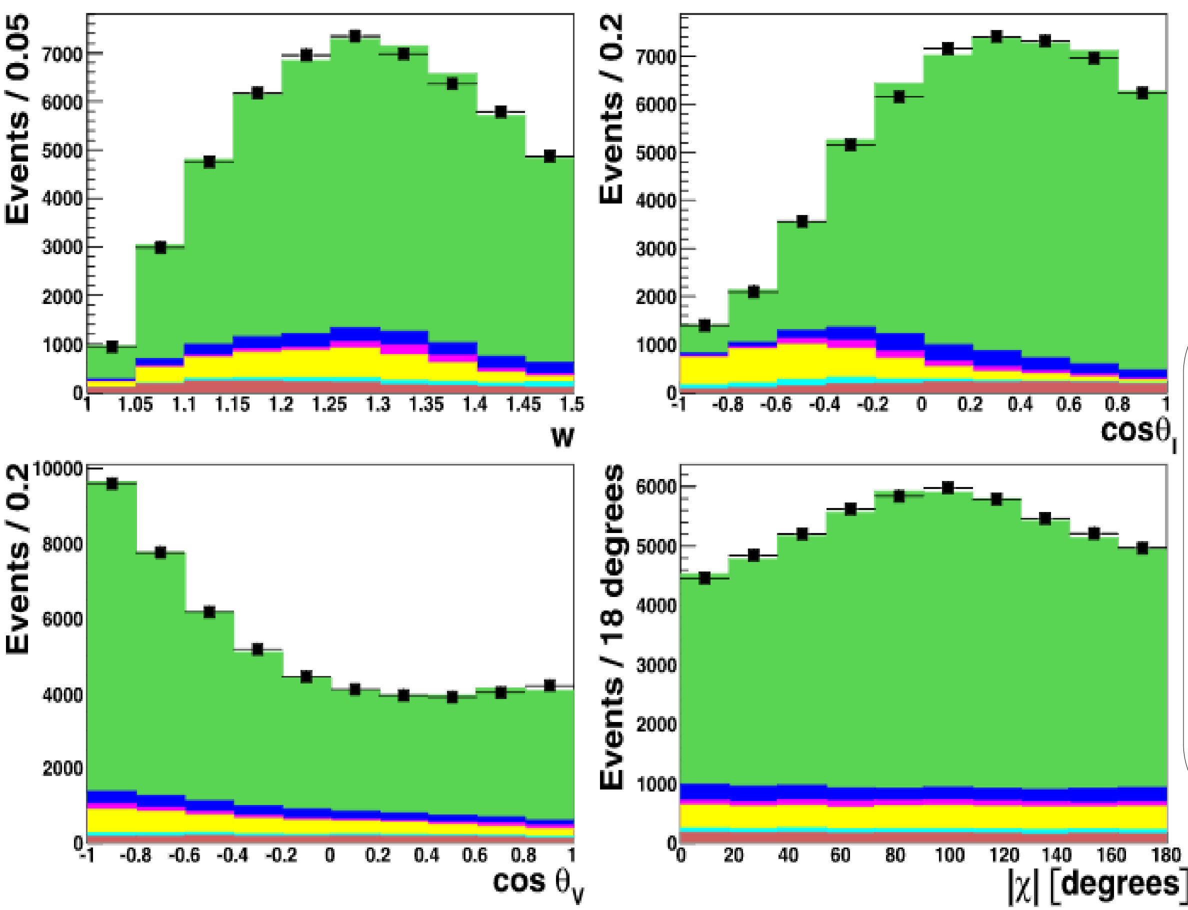
Unfortunately it is not easy to redo this analysis
Hopefully Belle will redo an untagged analysis with model-independent fits

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

Phys.Rev.D82:112007,2010

- Considered neutral B decays, both el. and muons
  - $B^0 \to D^{*-} \ell \nu$ and $D^{*-} \to D^0 \pi^-$ only $D^0 \to K\pi$
- Signal extracted from cosBY and DeltaM
  - 120K events with 711 fb^{-1}
- Fit to projections in w, and decay angles





Fit is performed in various subsamples (run time, lepton energy range, ...) to control efficiencies and backgrounds and than the results averaged

Fit results with the CLN param.

$$\mathcal{F}(1)|V_{cb}| = (34.6 \pm 0.2 \pm 1.0) \times 10^{-3}$$
$$\rho^2 = 1.214 \pm 0.034 \pm 0.009,$$
$$R_1(1) = 1.401 \pm 0.034 \pm 0.018,$$
$$R_2(1) = 0.864 \pm 0.024 \pm 0.008,$$
$$\mathcal{B}(B^0 \to D^{*-} \ell^+ \nu_\ell) = (4.58 \pm 0.03 \pm 0.26)\%.$$

$P(\chi^2)$=47% Very good description of the data

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

- Considered neutral B decays, both el. and muons
  - $B^0 \to D^{*-}\ell\nu$ and $D^{*-} \to D^0\pi^-$ only $D^0 \to K\pi$
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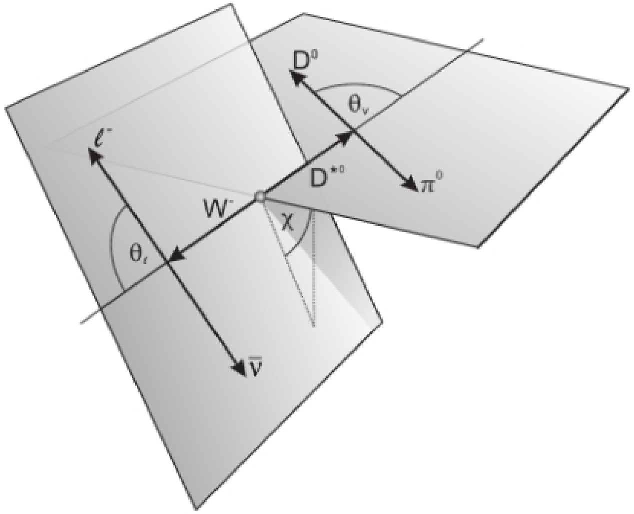
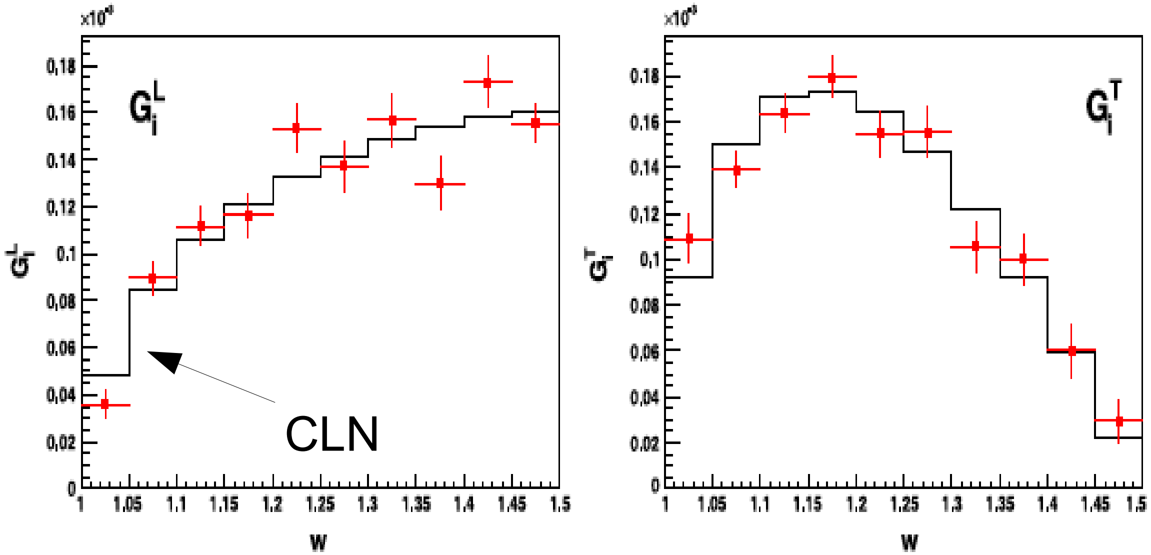




Fit of the helicity functions and predictions from CLN Parameterizations: good consistency

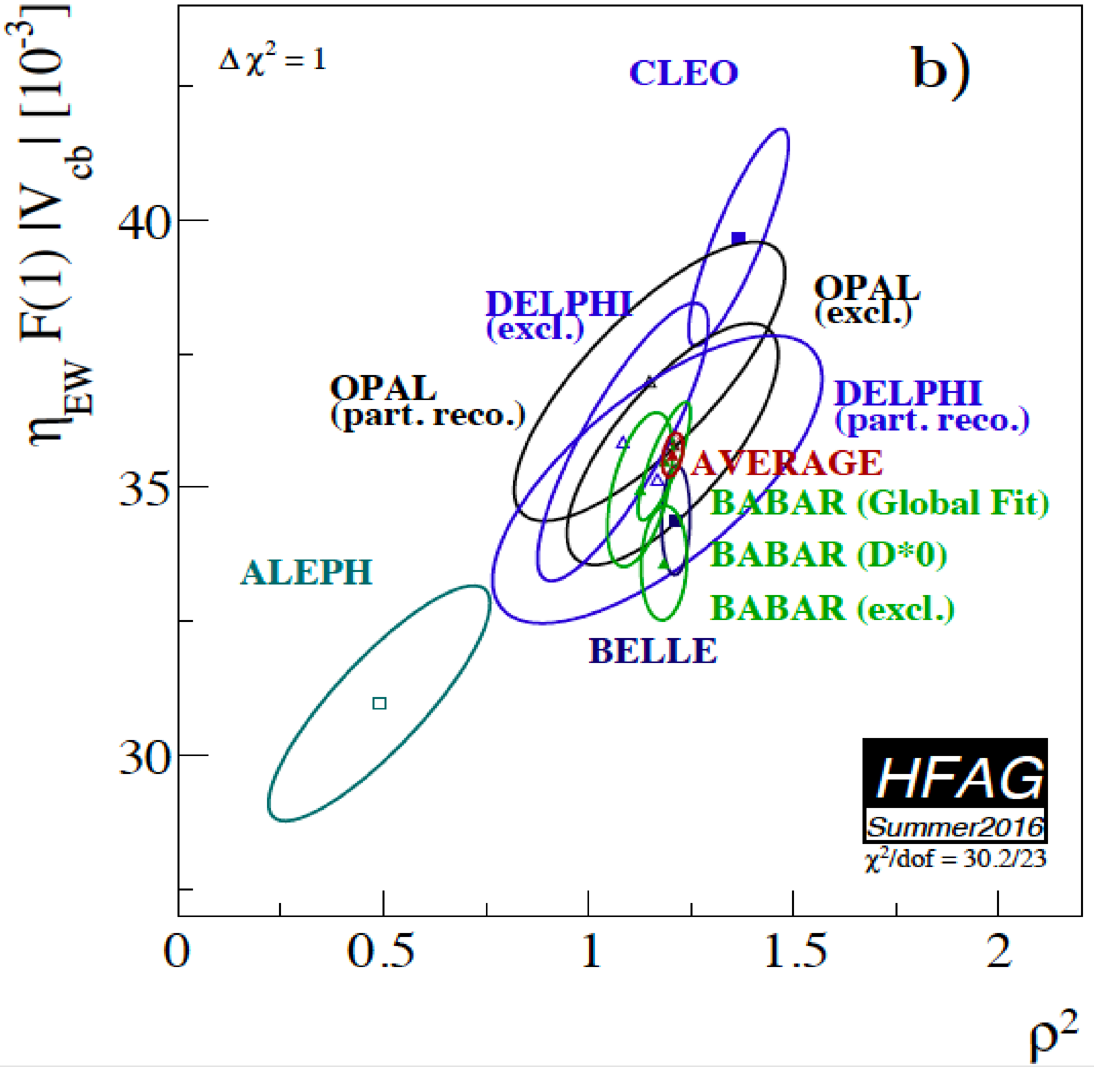
Fit is performed in various subsamples (run time, lepton energy range, ...) to control efficiencies and backgrounds and than the results averaged

Fit results with the CLN param.

$$\begin{aligned} \mathcal{F}(1)|V_{cb}| &= (34.6 \pm 0.2 \pm 1.0) \times 10^{-3} \\ \rho^2 &= 1.214 \pm 0.034 \pm 0.009, \\ R_1(1) &= 1.401 \pm 0.034 \pm 0.018, \\ R_2(1) &= 0.864 \pm 0.024 \pm 0.008, \\ \mathcal{B}(B^0 \to D^{*-}\ell^+\nu_\ell) &= (4.58 \pm 0.03 \pm 0.26)\%. \end{aligned}$$

$P(\chi^2)=47\%$ Very good description of the data

B → D*ℓν: HFLAV average



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

- 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

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

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

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

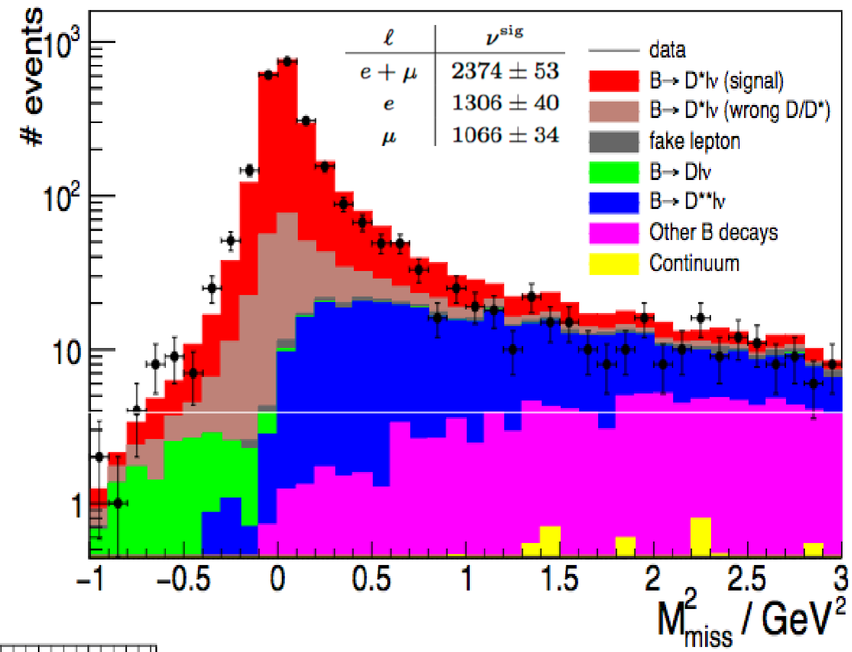
$$|V_{cb}| = (38.71 \pm 0.47_{\rm exp} \pm 0.59_{\rm th}) \times 10^{-3}$$

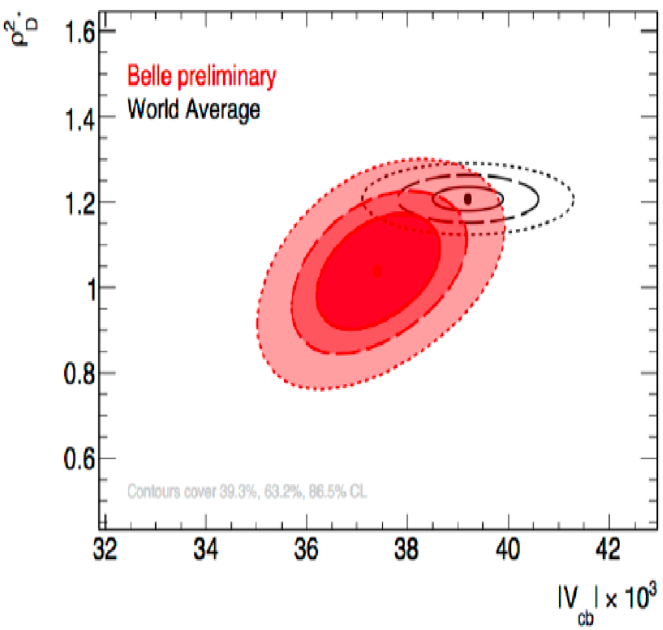
3σ from inclusive determination

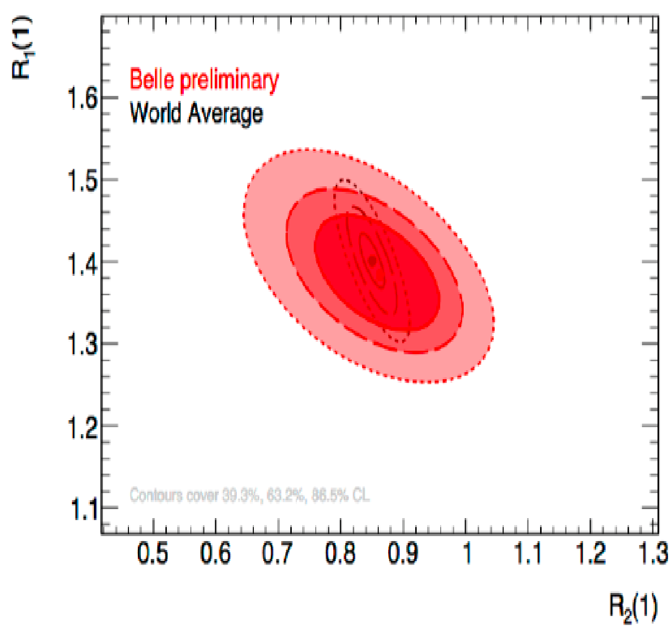
$B \to D^* \ell \nu$: news from Belle

ArXiv:1702.01521v2

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







BF consistent with tWA

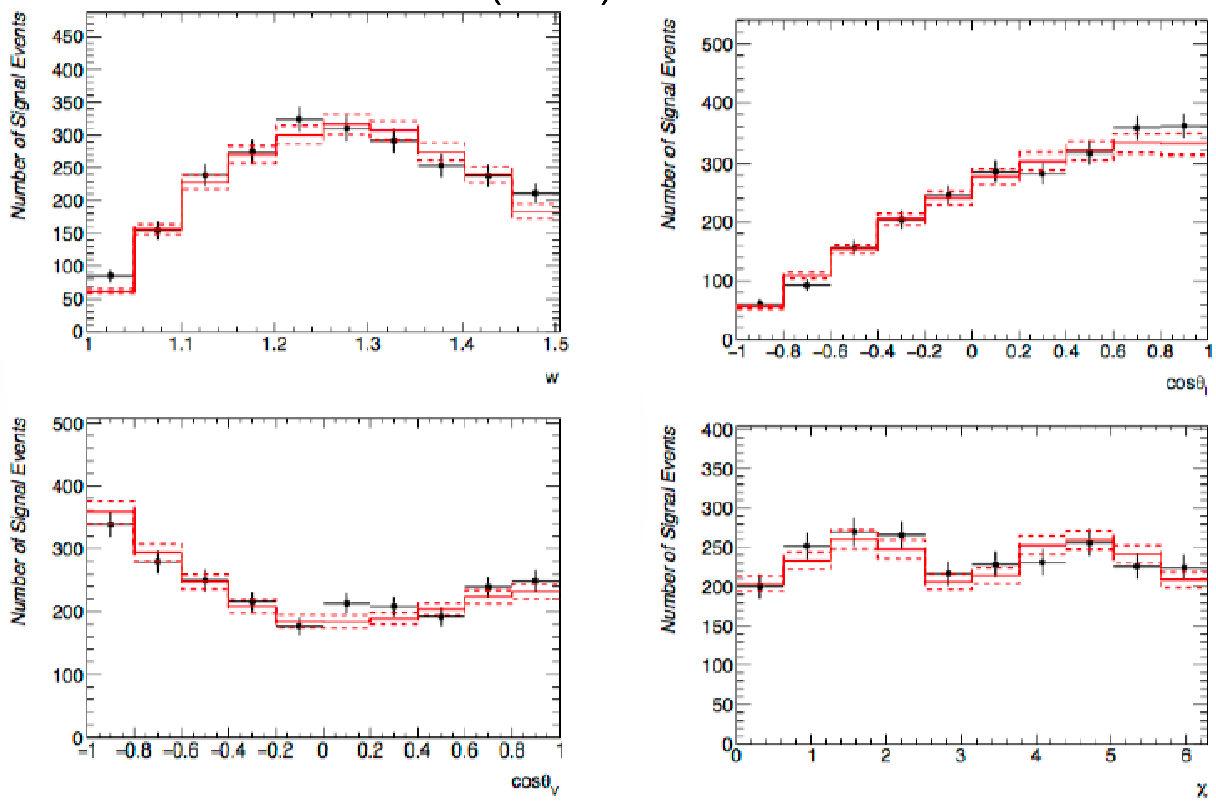
Belle fit with CLN parameterization consistent with world average

Parameter	This result	World Average
$\|V_{cb}\| \times 10^3$	37.4 ± 1.3	39.2 ± 0.7
$\rho^2_{D^*}$	1.03 ± 0.13	1.21 ± 0.03
$R_1(1)$	1.38 ± 0.07	1.40 ± 0.03
$R_2(1)$	0.87 ± 0.10	0.85 ± 0.02

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

ArXiv:1702.01521v2

Belle Fit (CLN) on folded data



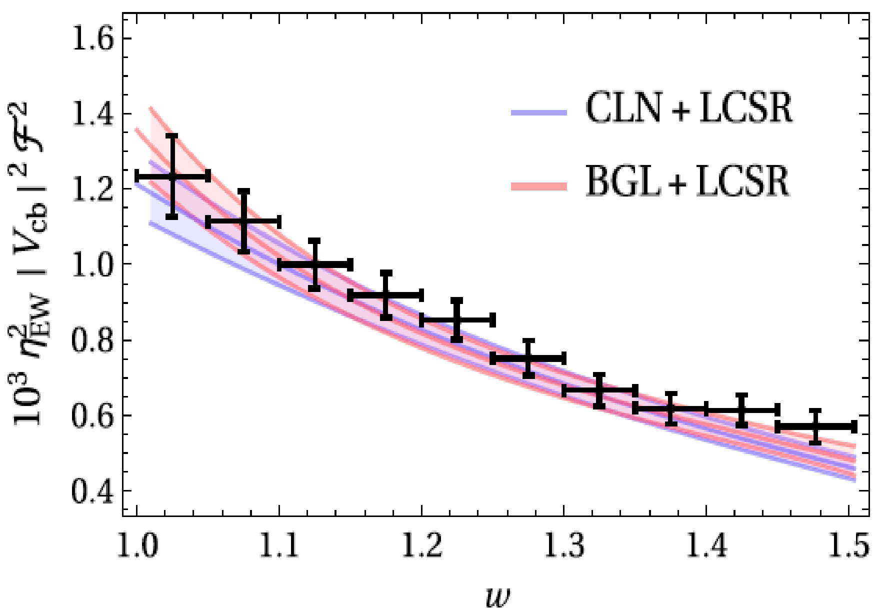
Parameter	folded result	unfolded result
$\lvert V_{cb}\rvert \times 10^3$	37.4 ± 1.3	38.2 ± 1.5
$\rho^2_{D^*}$	1.04 ± 0.13	1.17 ± 0.15
$R_1(1)$	1.38 ± 0.07	1.39 ± 0.09
$R_2(1)$	0.86 ± 0.10	0.91 ± 0.08

- Published for the first time (HEPdata) the unfolded projections 4-D projections and the full correlation matrix: this triggered many interesting discussions on the fit parameterizations

Bernlochner et al. Phys.Rev.D95 (2017) 115008
Bigi at al. Phys.Lett B769 (2017) 441
Grinstein et al Phys.Lett. B771 (2017) 359
Bigi et al. JHEP 1711 (2017) 061
Jaiswal et al JHEP 1712 (2017) 060
Bernlochner et al Phys.Rev.D96 (2017) 091503
Harrison et al arxiv.1711.11013

Model independent analysis

- Bigi, Gambino, Schacht Phys.Lett B 769 (2017) 441: Critical analysis of parameterization

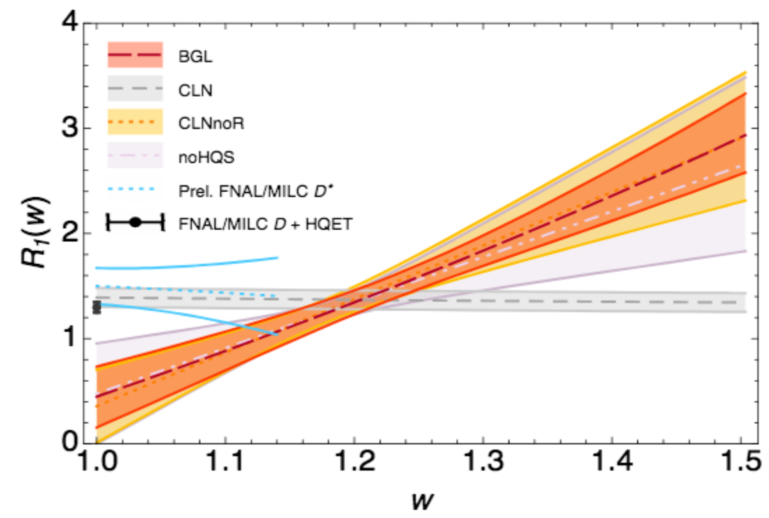


CLN Fit:	Data + lattice	Data + lattice + LCSR
χ^2/dof	34.3/36	34.8/39
$\lvert V_{cb}\rvert$	0.0382 (15)	0.0382 (14)

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

- Similarly in Grinstein, Kobach PLB771 (2017) 359-364, who claimed
  - "strong possibility that the tension between inclusive and exclusive $|V_{cb}|$ …. is due to the use of the CLN parameterization..."

- But some inconsistencies... from Bernlochner et al. PRD96 (2017) 091503 (strong breaking of HQS?)



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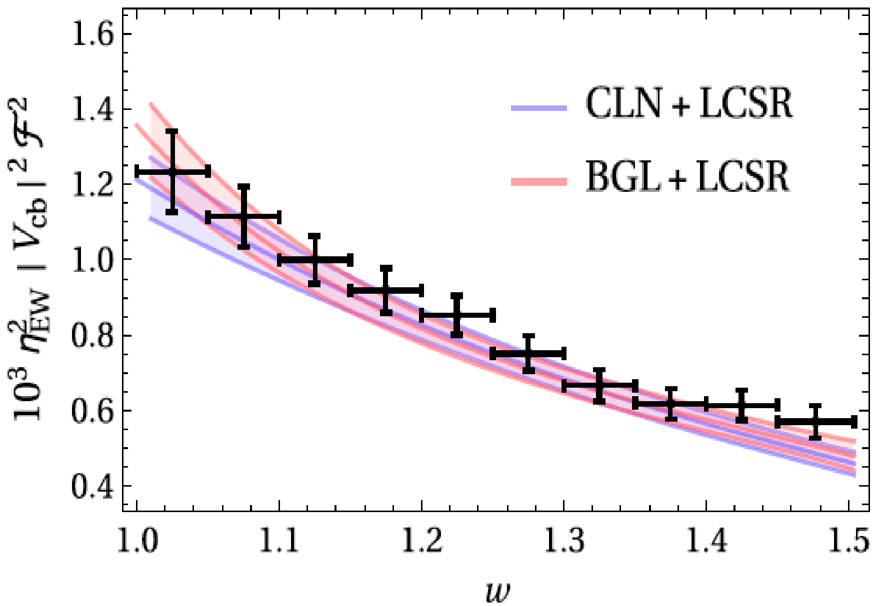
– Bigi, Gambino, Schacht Phys.Lett B 769 (2017) 441: Critical analysis of parameterization



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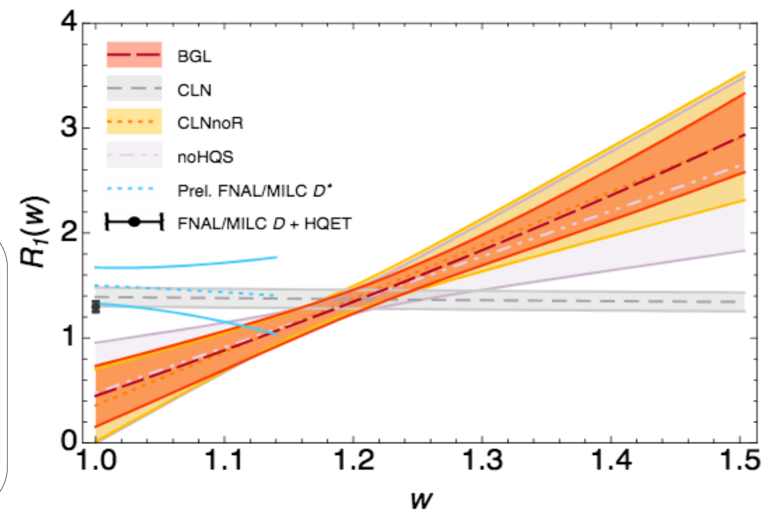
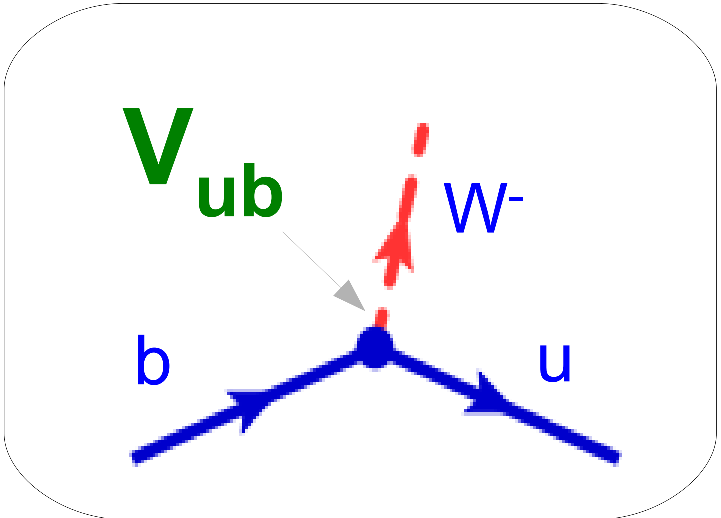
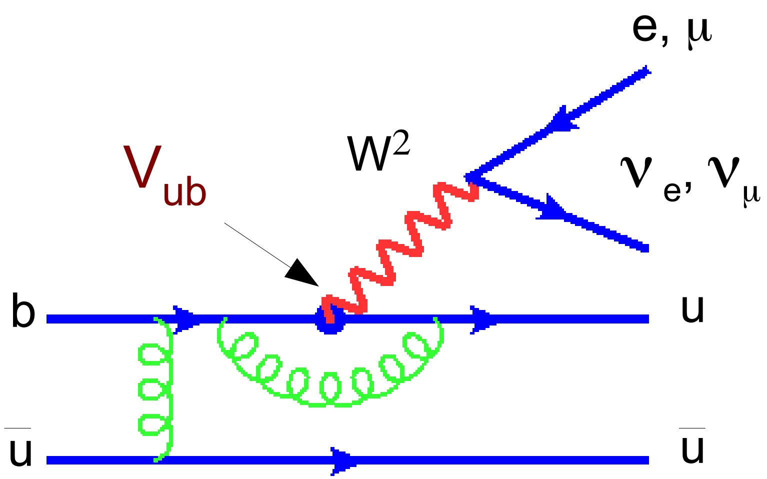


The huge difference between BGL and CLN could just be a "feature" of the Belle unfolded dataset!
We need more data! Bella and Babar data are still available!
LHCb has to enter into this game!



$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \begin{pmatrix} d \\ s \\ b \end{pmatrix}$$

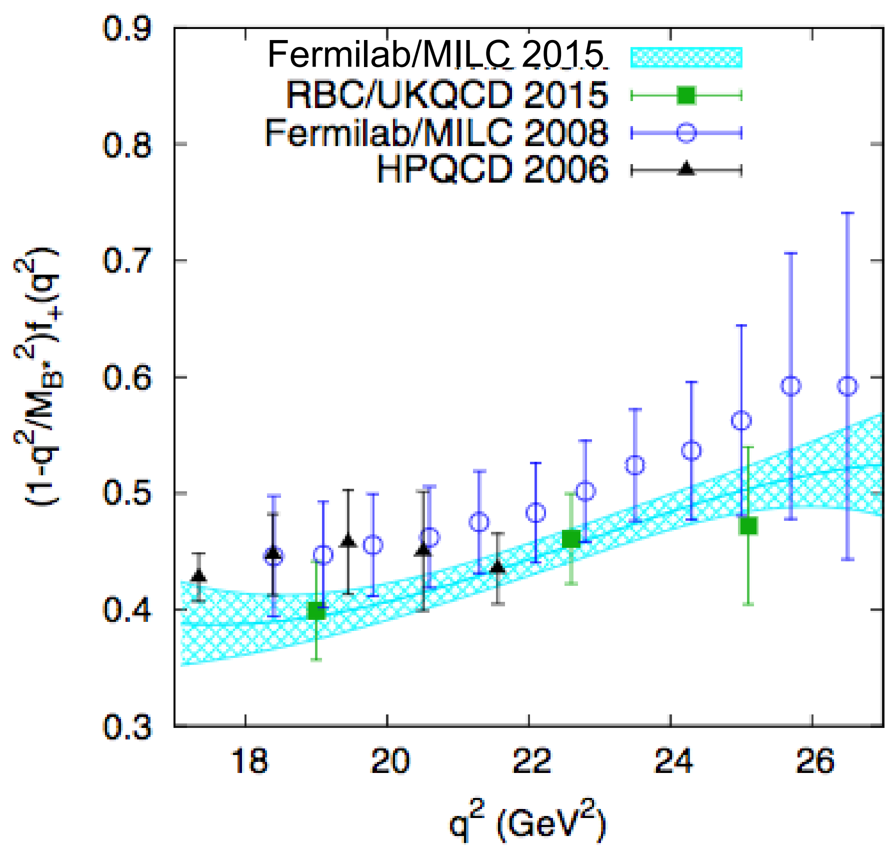
Exclusive $B \to \pi \ell \nu$



- 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



Untagged B→πℓν

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

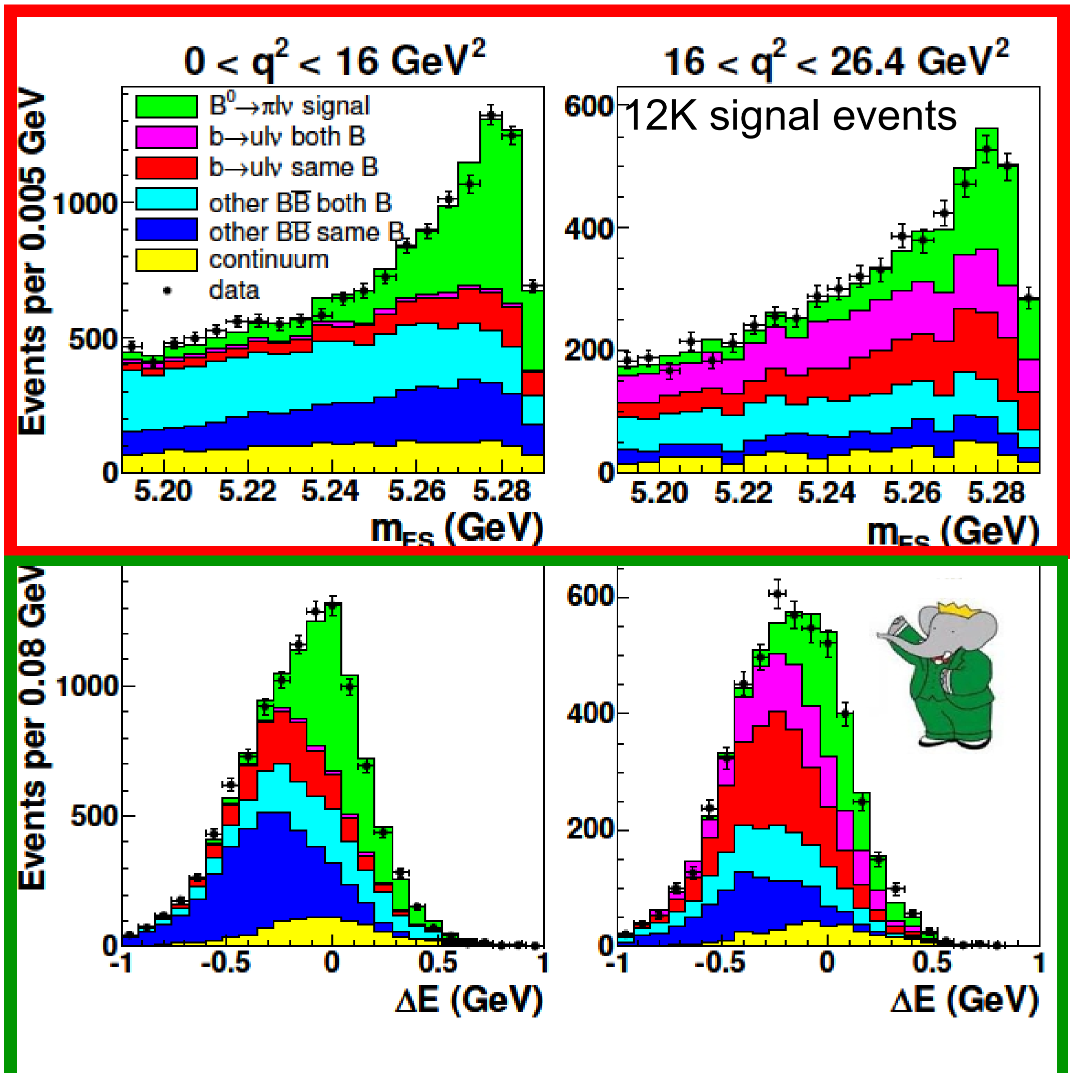
$$m_{ES} = \sqrt{E^{*2}_{beam} - \mathbf{p}^{*2}_{\pi\ell\nu}}$$

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

Phys.Rev.D86(2012) 092004

L=416 fb $^{-1}$
Nsig=12.5K±400

Signal extracted in 12 q^2-bins



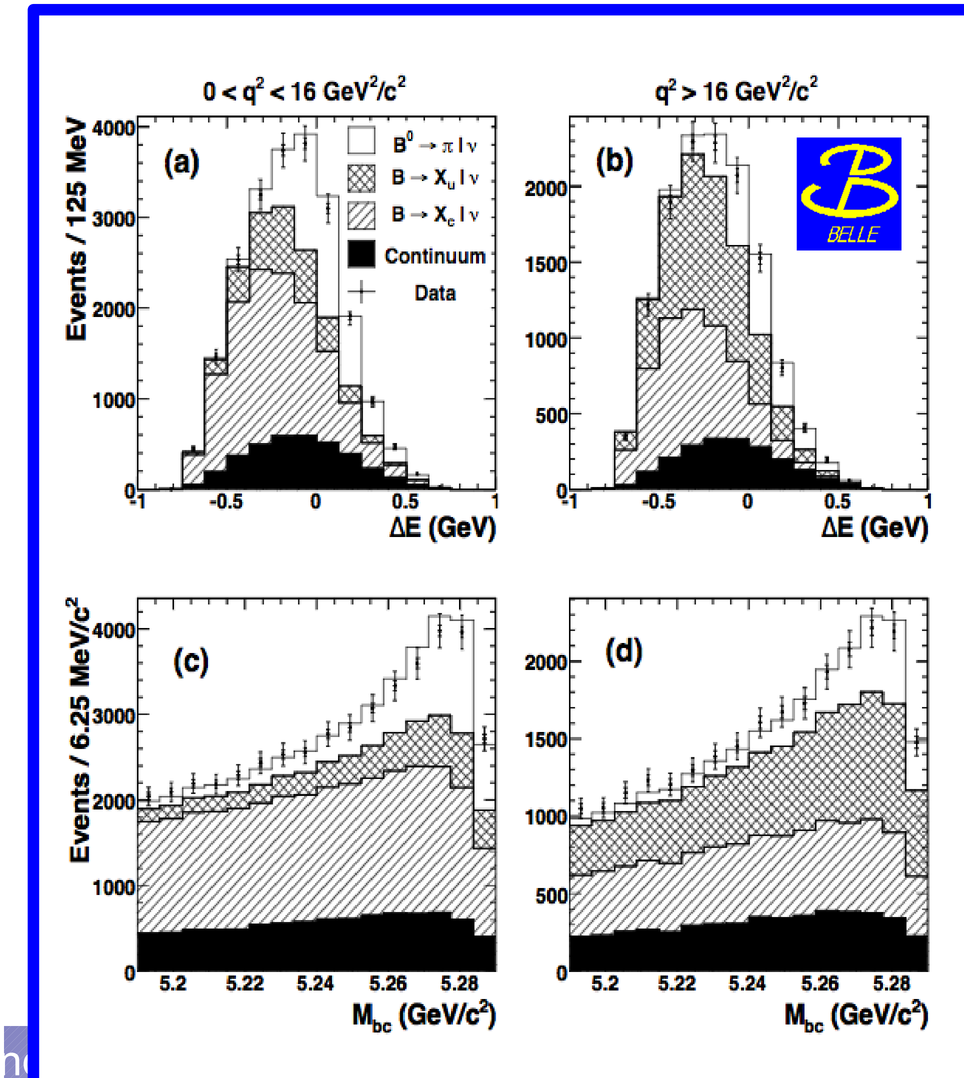
−0.16 < ΔE < 0.20GeV

m_{ES} > 5.268GeV

Phys.Rev.D83(2011) 071101

L=605 fb $^{-1}$
Nsig=21.5K±500

Signal extracted in 13 q^2-bins

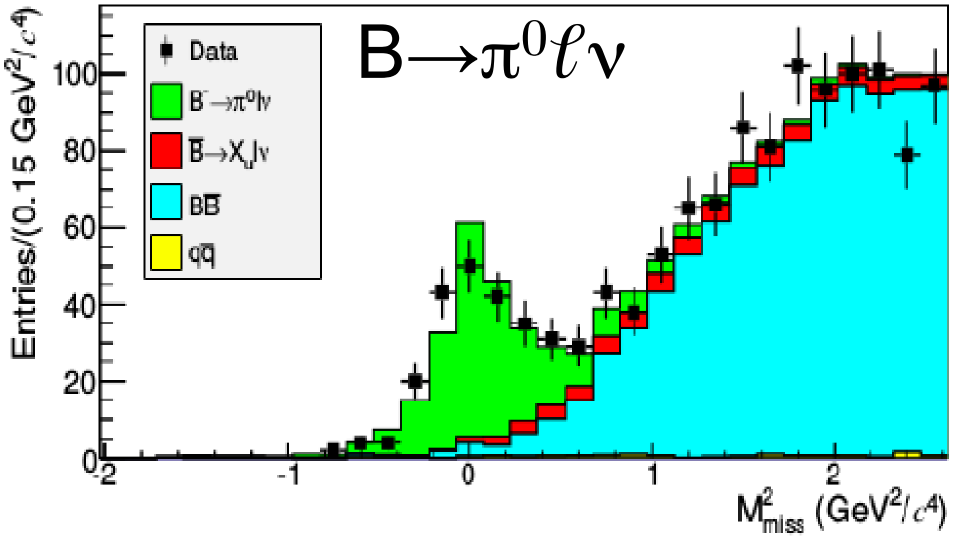


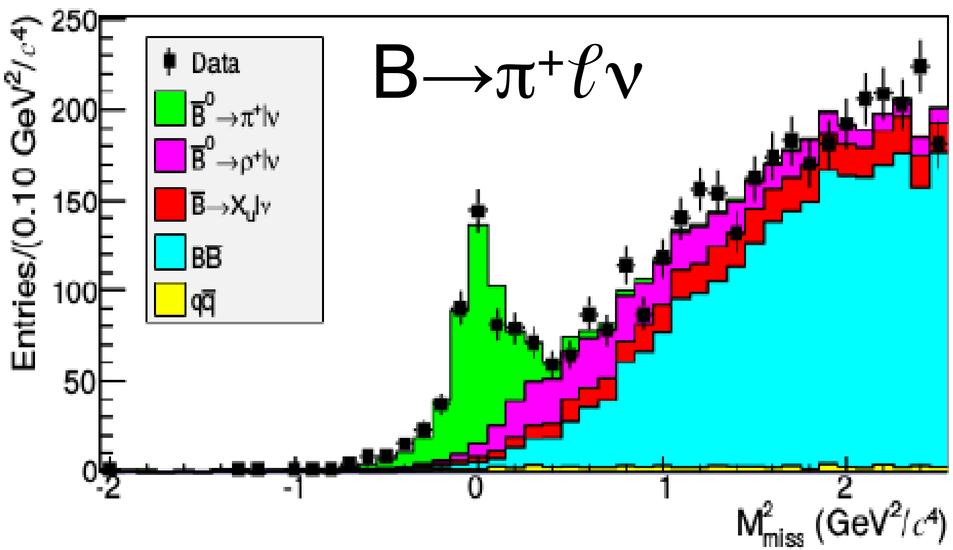
- Using the hadronic tag

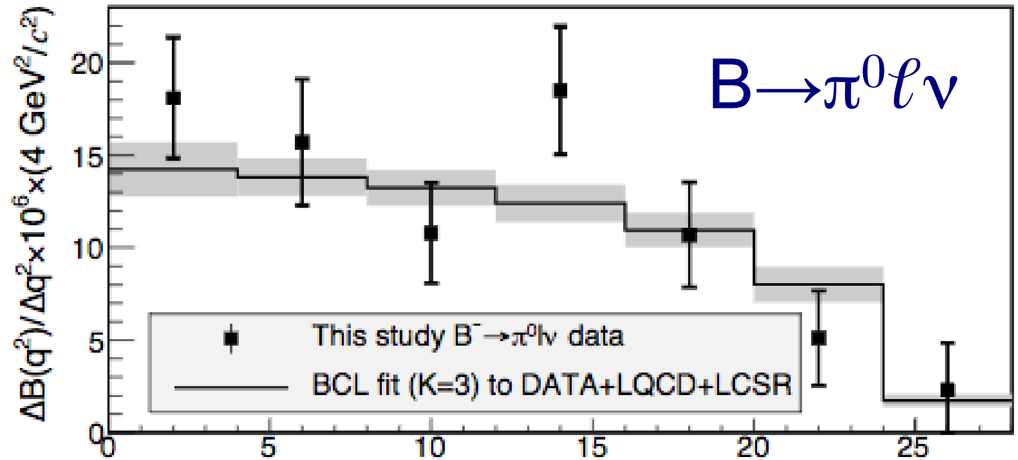
  L=711 fb^{-1}

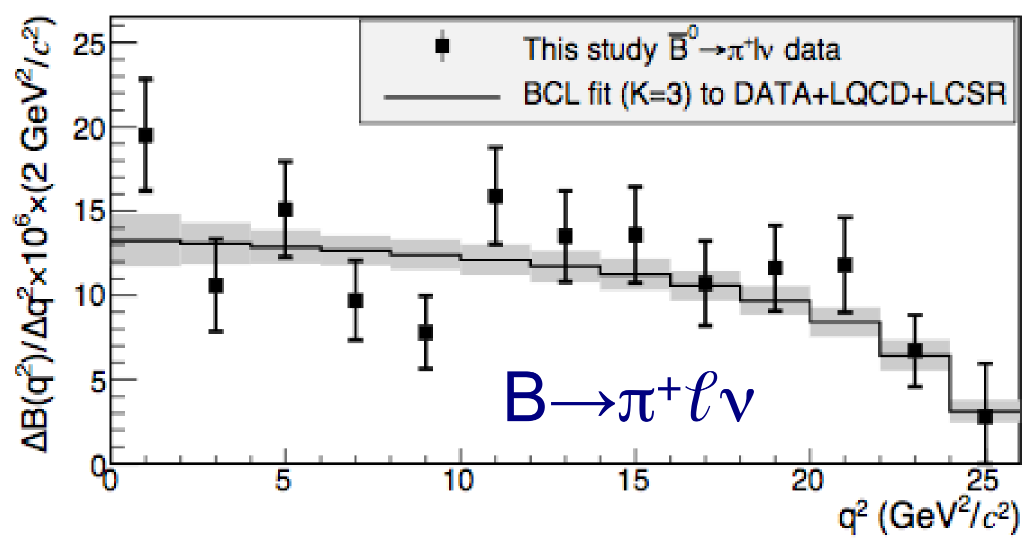
  $N(B\to\pi^{2}\ell\nu) \sim 500$, $N(B\to\pi^{0}\ell\nu) \sim 200$

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



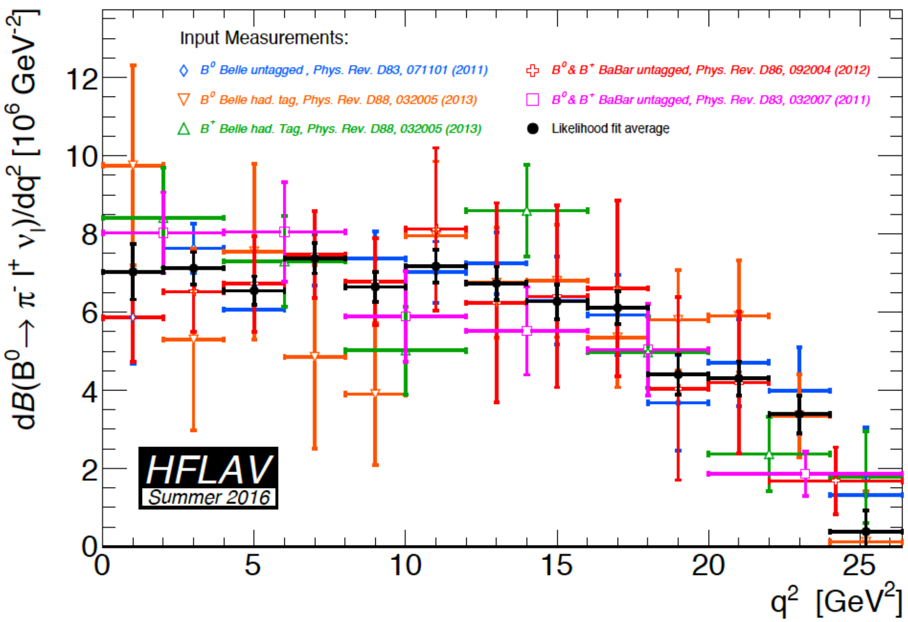




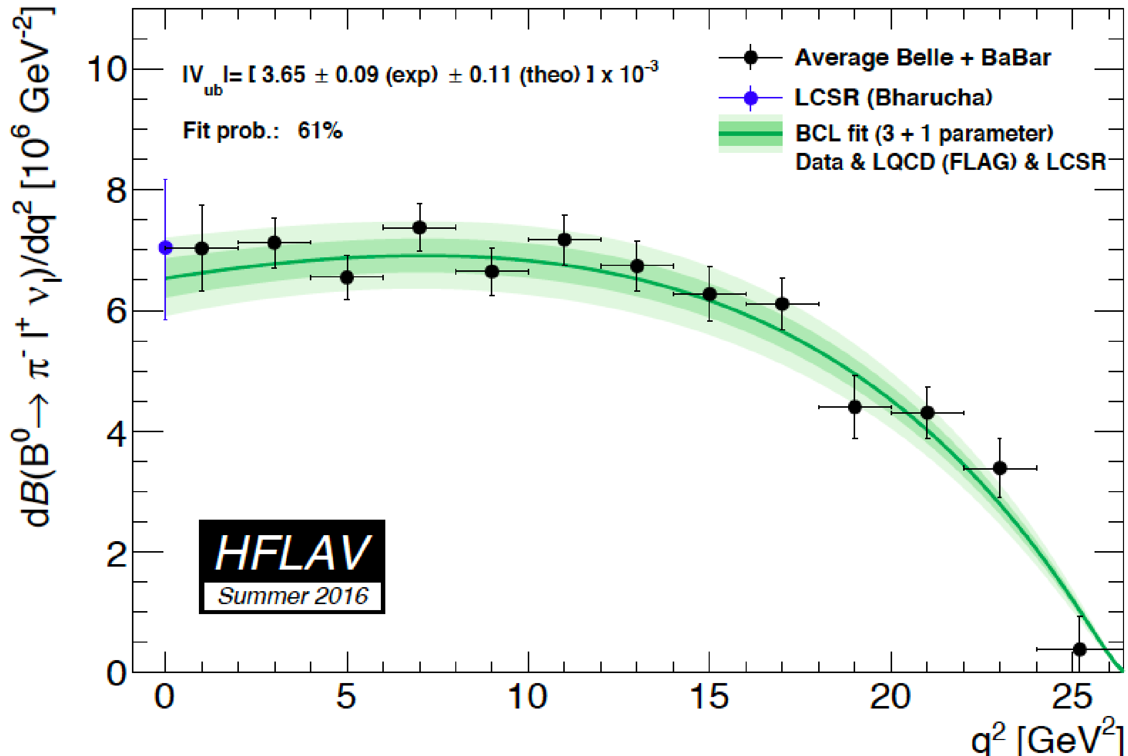


HFLAV average

- 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 at q^2=0
Bharucha, JHEP 1205 (2012) 092



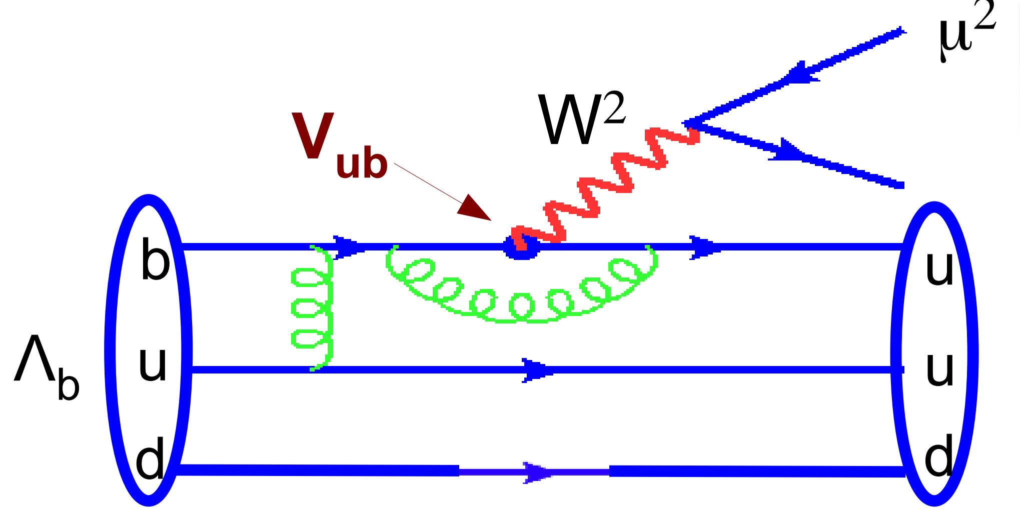
Form Factor parameterization BCL
Bourrely, Caprini, Lellouch, PRD79, 013008 (2009)

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

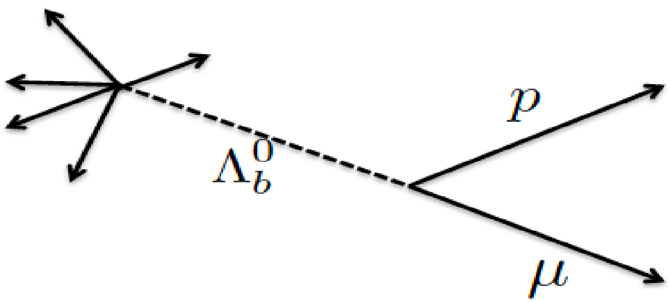
Tot σ ~ 4%!

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

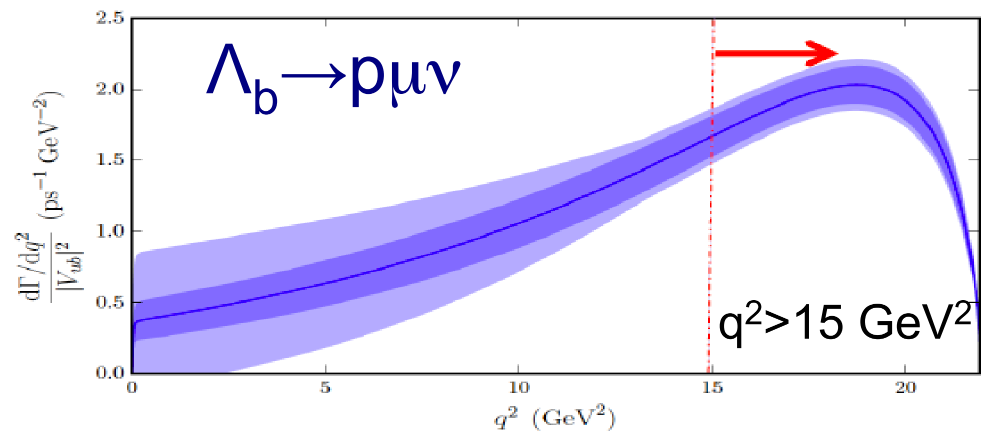


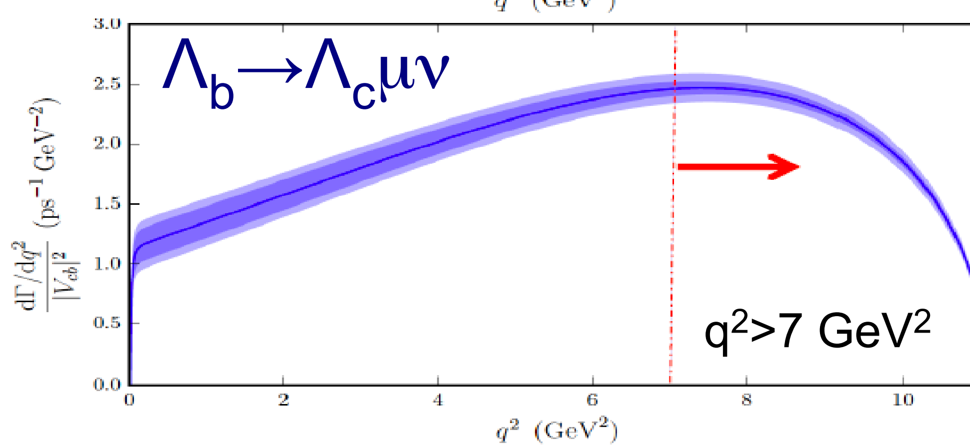
- Kinematic constraints allow the determination of the $p_{\Lambda b}$ (modulo 2-fold ambiguity)
- Large background from $\Lambda_b \to \Lambda_c \mu \nu$
- LHCb determines (in the high q^2 region) the ratio

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

Signal (numerator); Normalization (denominator)

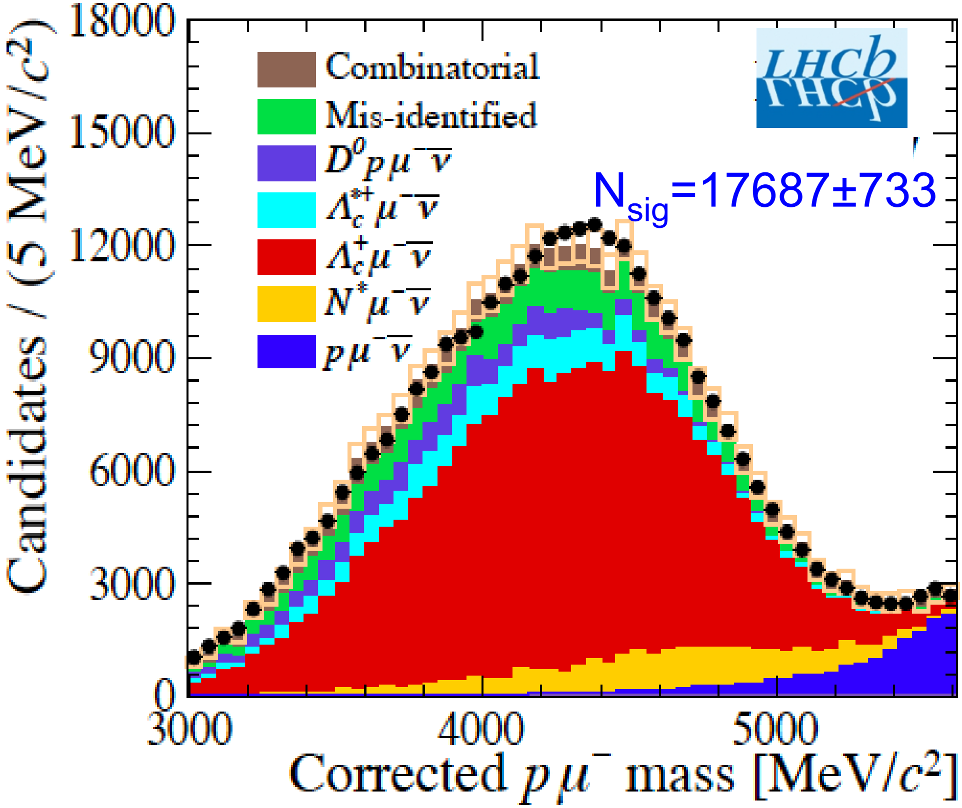
- Precise F.F.calculation on L-QCD
  - Detmold et al PRD92(2015)034503





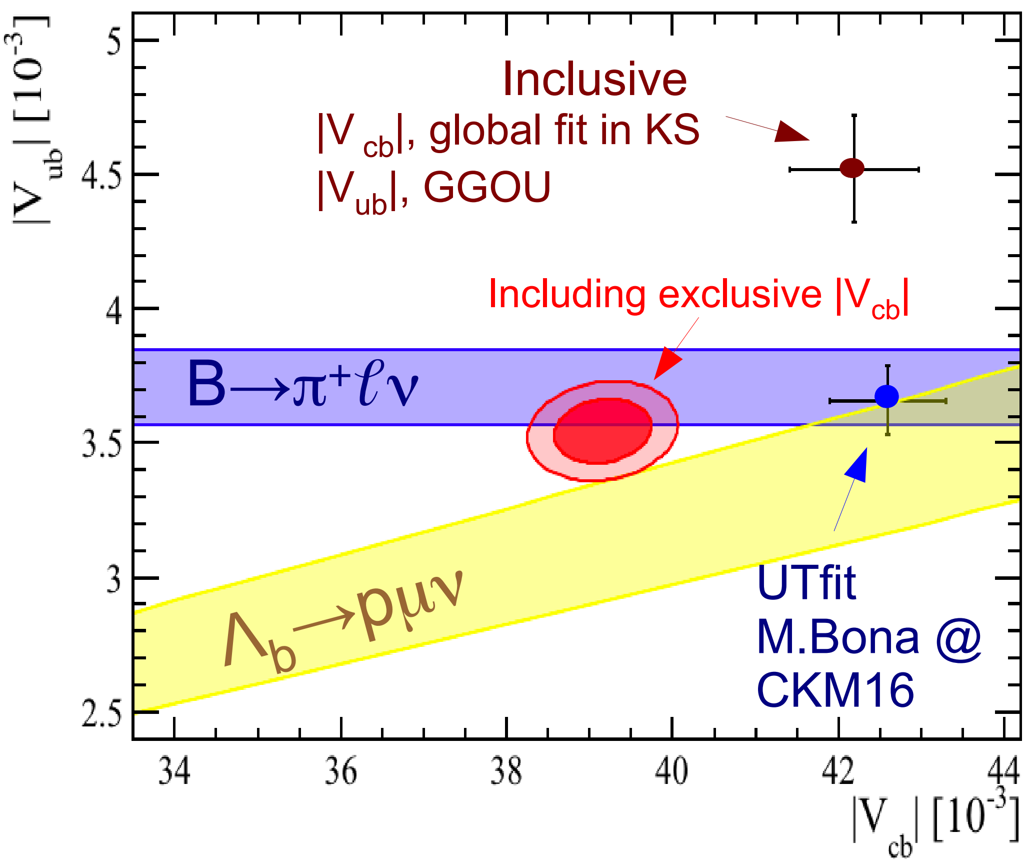
$\Lambda_b \rightarrow p\mu\nu$ signal & $|V_{ub}|$

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



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

σ_{tot}=7%



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

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

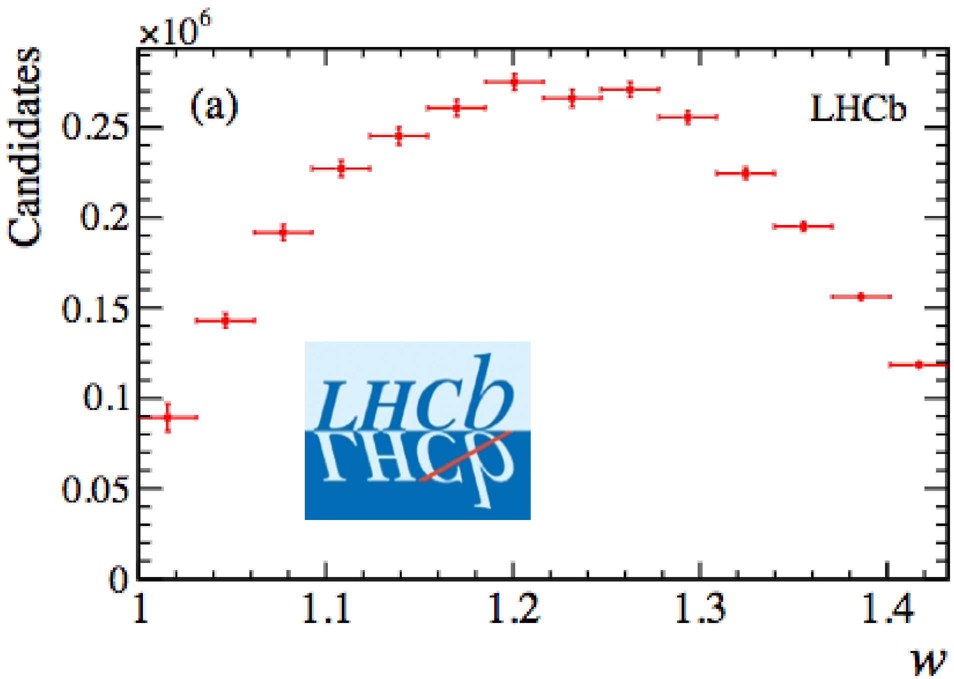
$\Lambda_b \to \Lambda_c \mu\nu$ form factor measurements

- Differential distributions crucial for comparisons with HQET and L-QCD

$$\frac{d\Gamma}{dw} = GK(w)\xi^2(w)$$

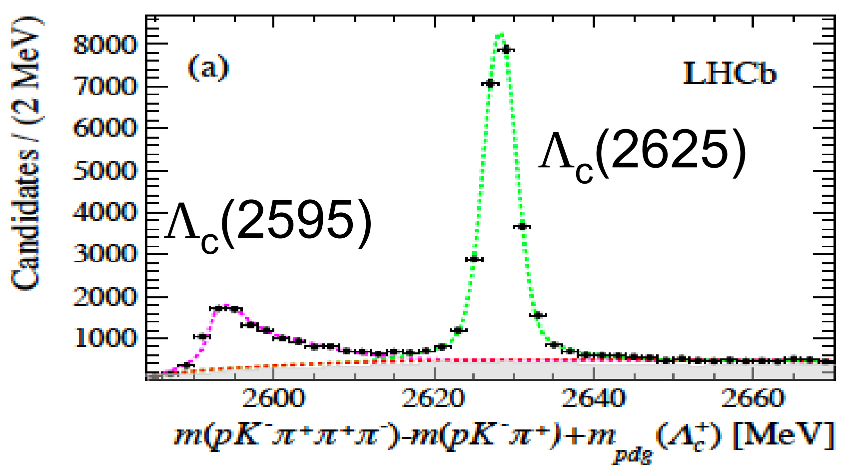
Determination of the Isgur-Wise function $\xi(T)$

- First step to a measurements of exclusive $|V_{cb}|$ (providing a proper normalization channel)



Phys.Rev. D96 (2017) no.11, 112005

Physical backgrounds from $\Lambda_b \to \Lambda_c^* \mu\nu$ (where $\Lambda_c^* \to \Lambda_c\pi\pi$) are not known very well: contributions subtracted from data



$\Lambda_b \to \Lambda_c^* \mu\nu$ decays are interesting "per se"!

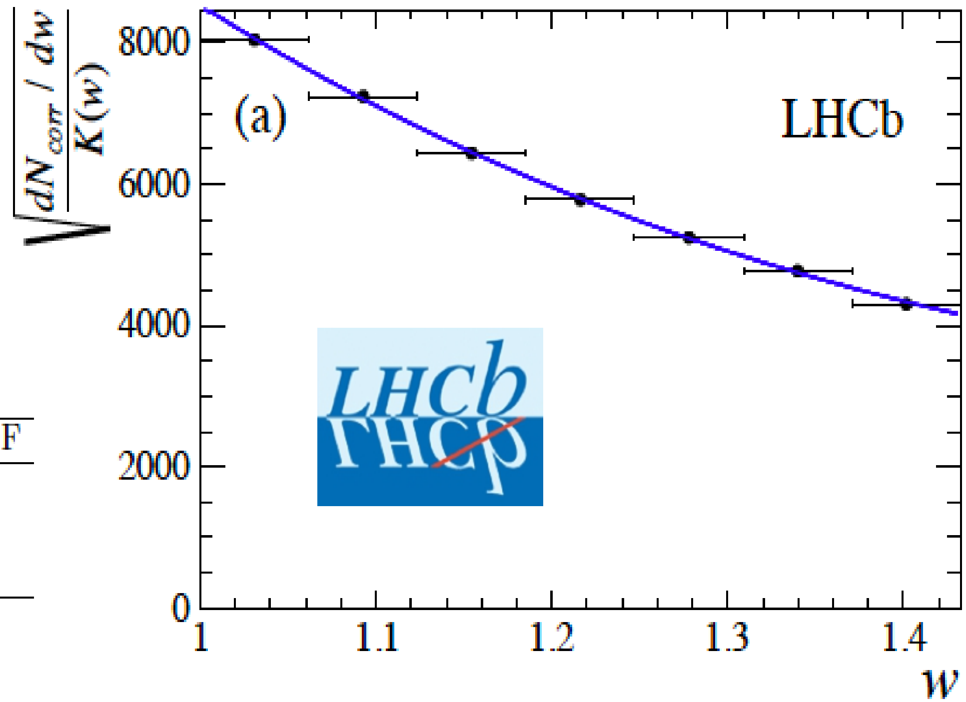
$\Lambda_b \rightarrow \Lambda_c \mu \nu$ form factor measurements

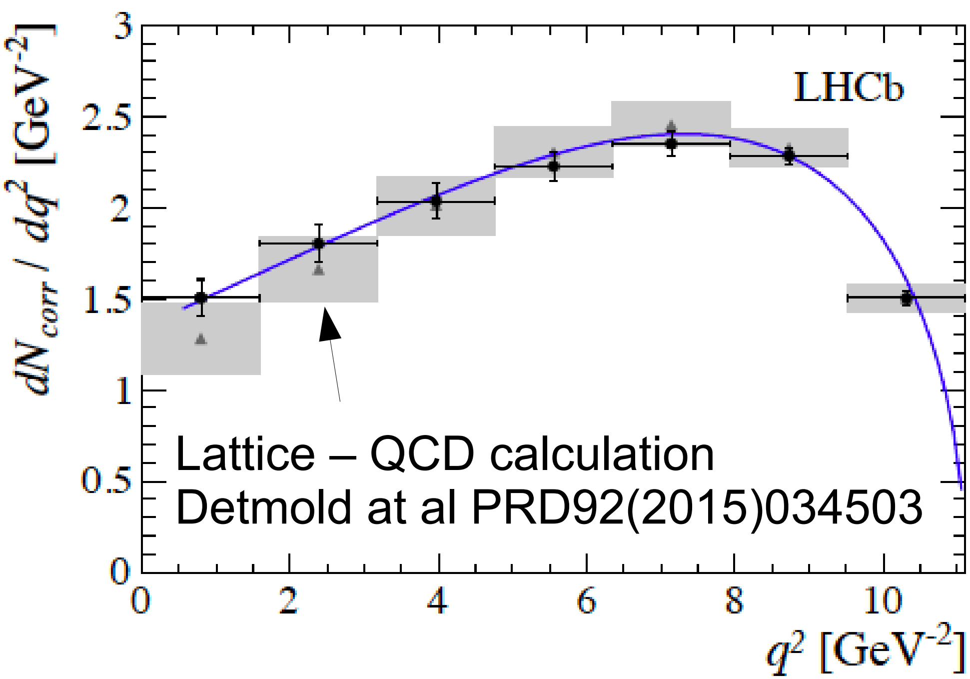
Phys.Rev. D96 (2017) no.11, 112005

- Unfolded and efficiency corrected w spectrum and fit with various ansatz

$$\xi_B(w) = -\rho^2(w-1) + \frac{1}{2}\sigma^2(w-1)^2 + \ldots,$$

Shape	ρ^2	σ^2	correlation coefficient	χ^2/ DOF
Exponential*	1.65 ± 0.03	2.72 ± 0.10	100%	5.3/5
Dipole*	1.82 ± 0.03	4.22 ± 0.12	100%	5.3/5
Taylor series	1.63 ± 0.07	2.16 ± 0.34	97%	4.5/4

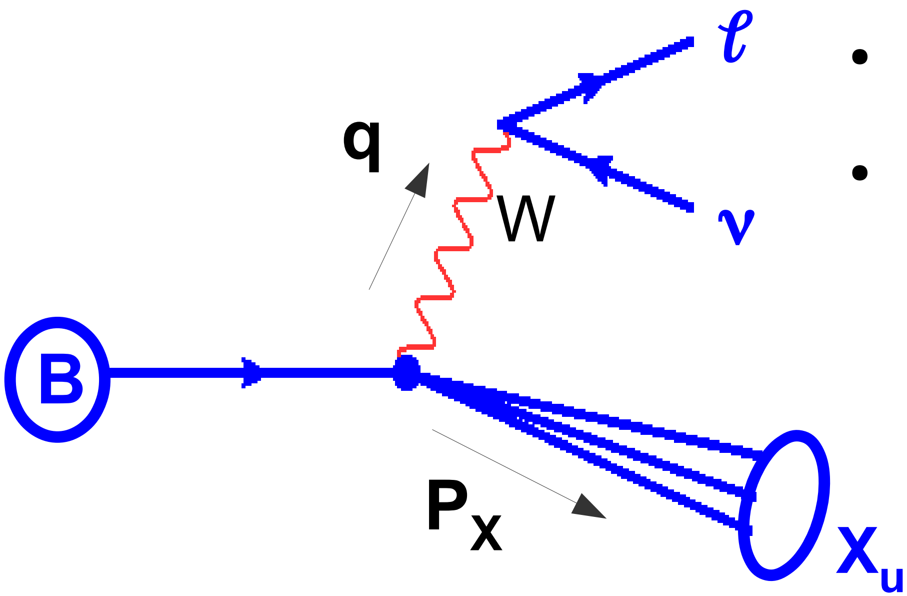




- Comparison with the recent lattice calculation shows good agreement
  - Support the lattice calculation used in the $|V_{ub}|/|V_{cb}|$ measurement
- In future further L-QCD calculations would be really desirable!
- Open the route to measurements of FF in other B-hadrons!

$|V_{ub}|$ from inclusive decays

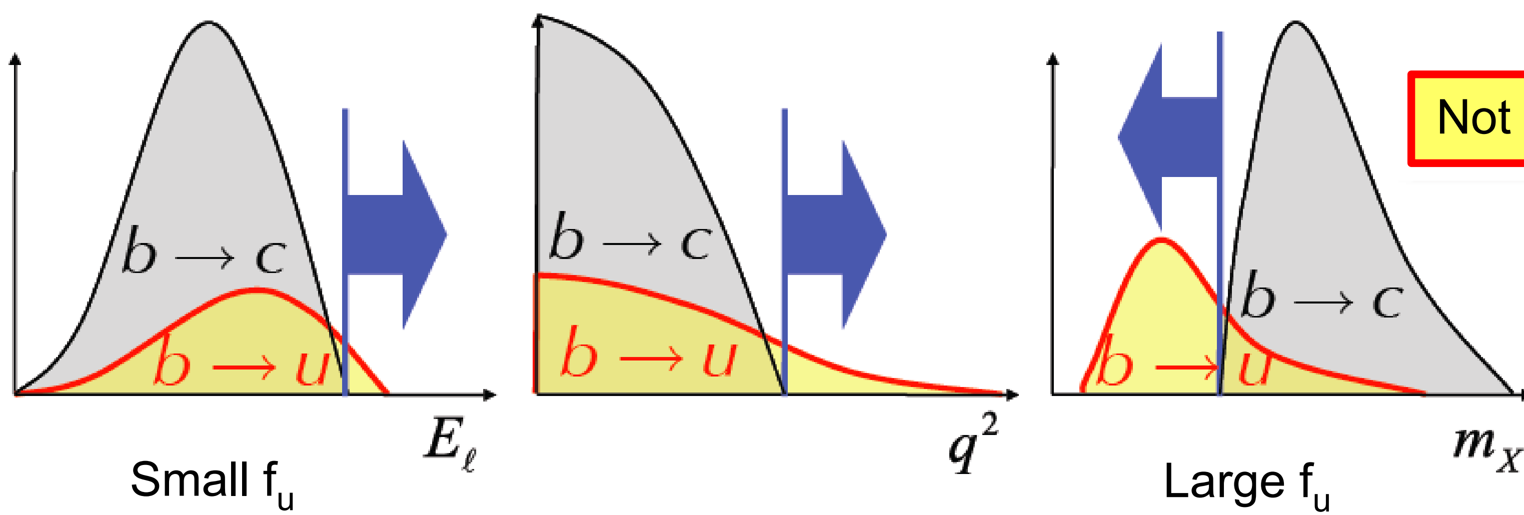
$$\frac{\Gamma(b \to c\ell\nu)}{\Gamma(b \to u\ell\nu)} \approx 50$$



- 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

$|V_{ub}|$ from inclusive decays

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to extract the signal: $m_u << m_c$

d region of phase space (f_u)

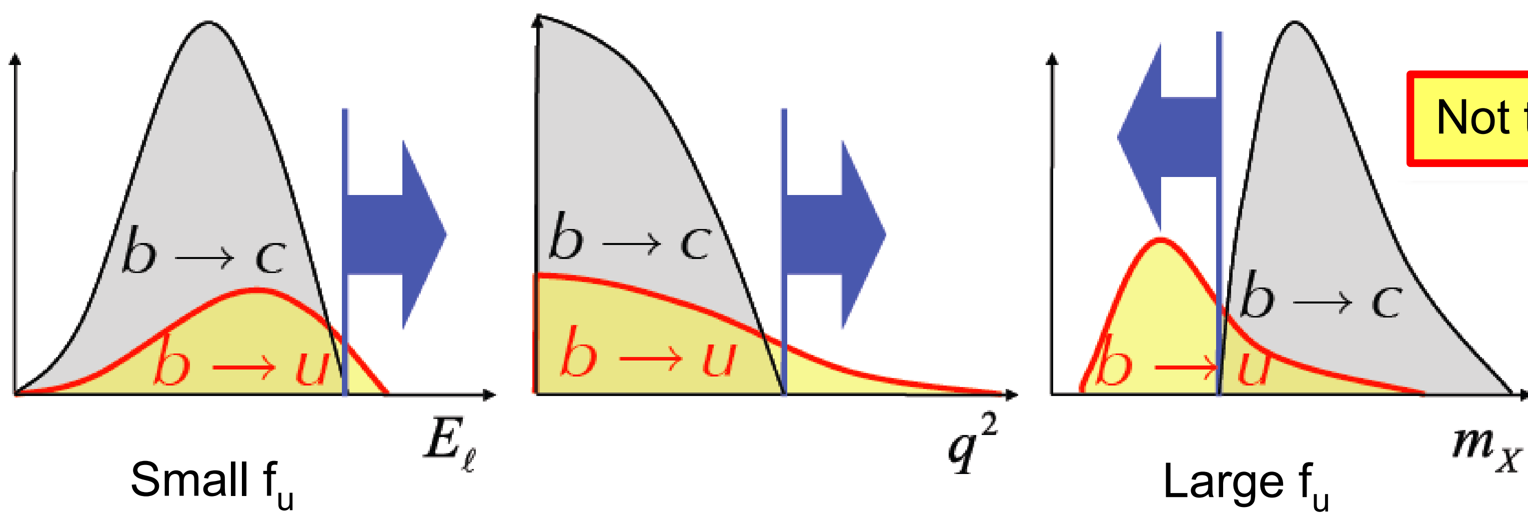
perturbative shape-function needed

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



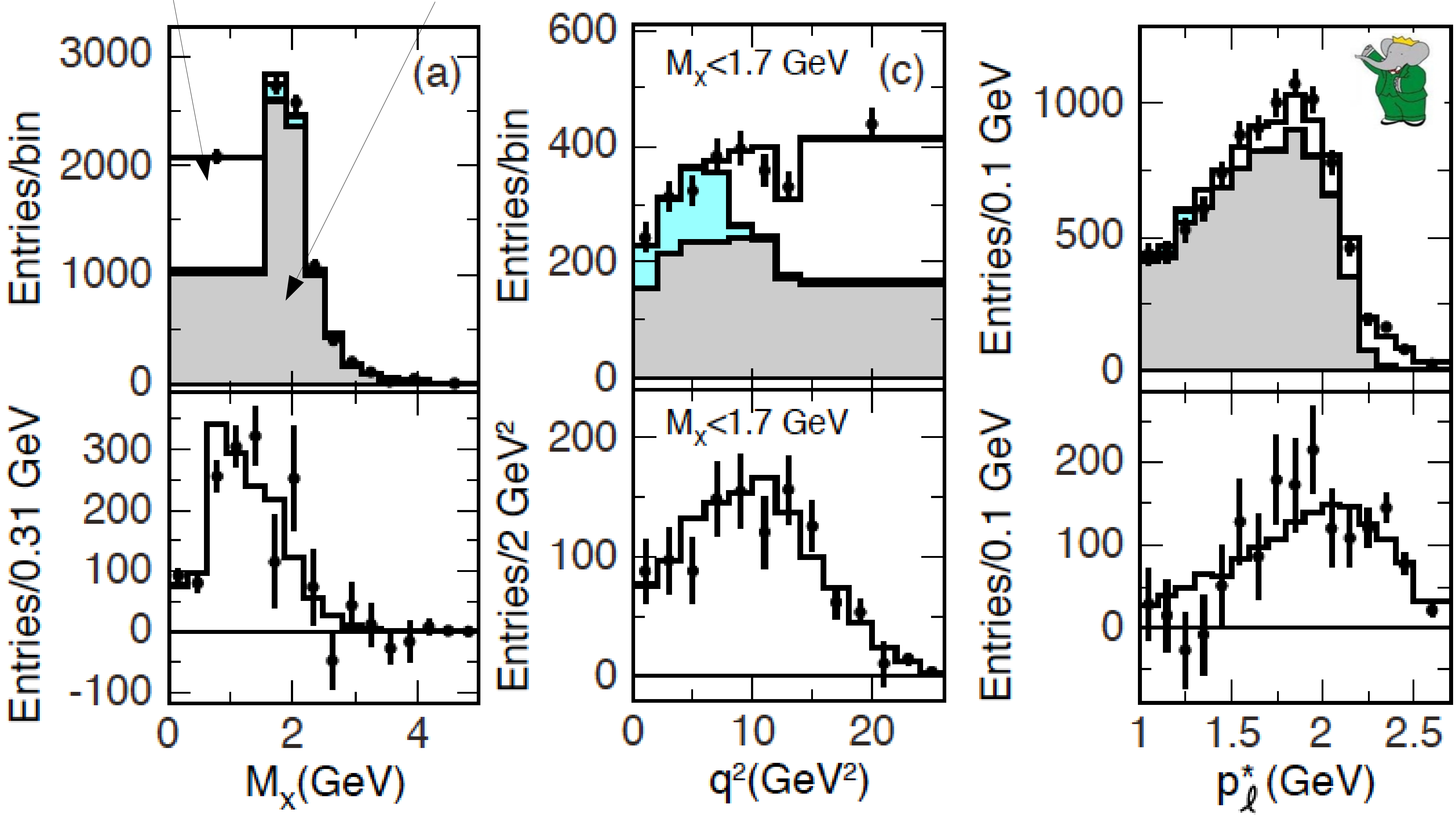
Experimental resolution leads to “irreducible” $b \to c\ell\nu$ contamination
- partially suppressed With K and D* vetos

Fit results in limited regions of phase space

B→$X_u \ell \nu$

B→$X_c \ell \nu$ + 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

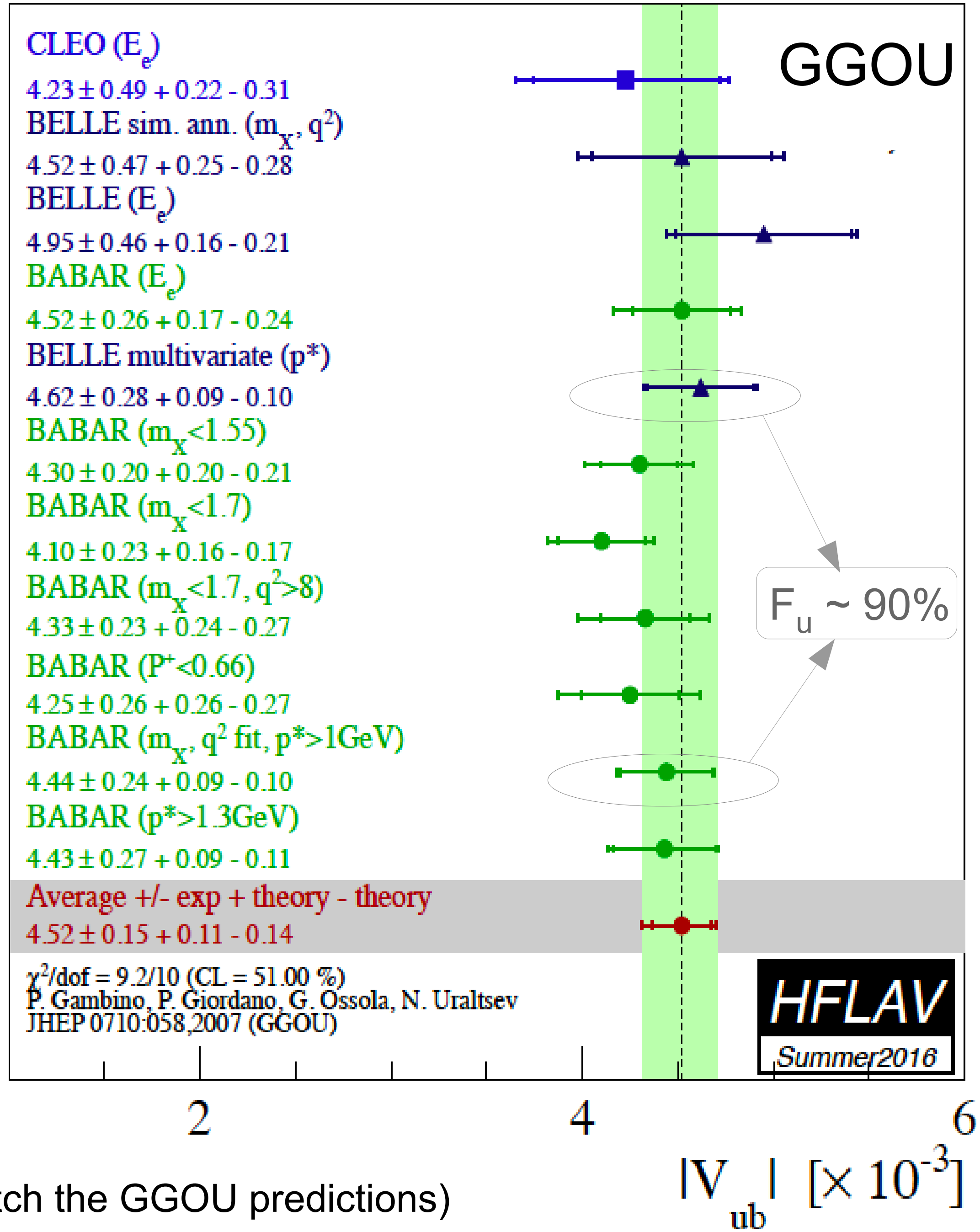
Status of inclusive $|V_{ub}|$

Most recent measurement is dated 2012

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

Framework	$\|V_{ub}\| [10^{-3}]$
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)

New inclusive $|V_{ub}|$

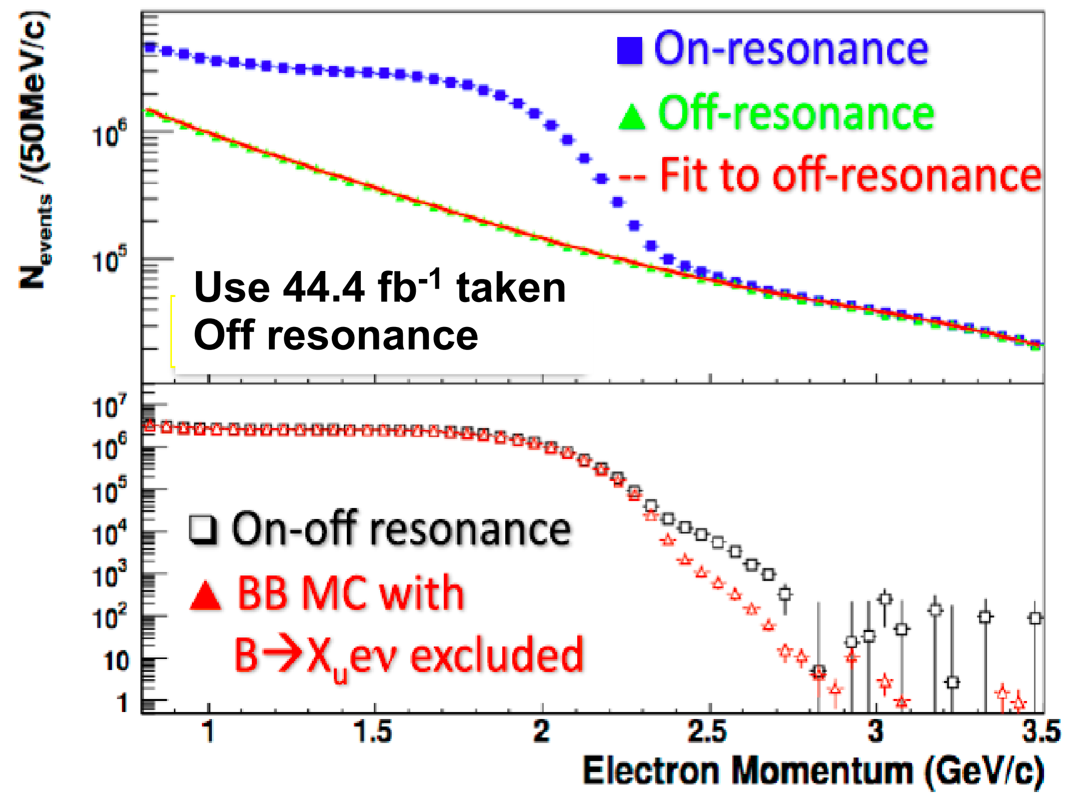
Phys.Rev.D 95, 072001 (2017)

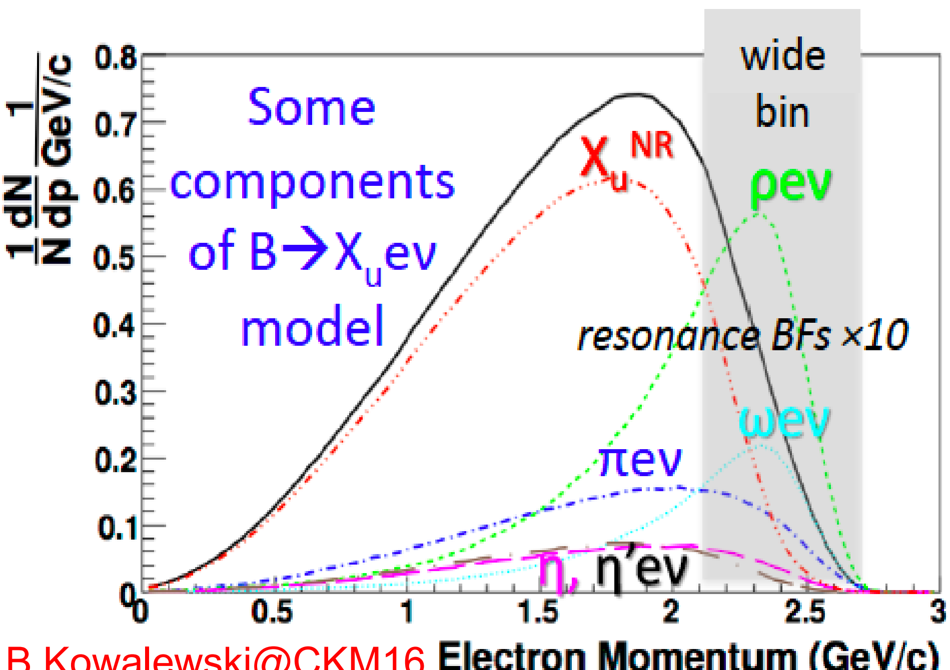
- Inclusive electron spectrum measurement
- Dataset: 467M Y(4S)

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

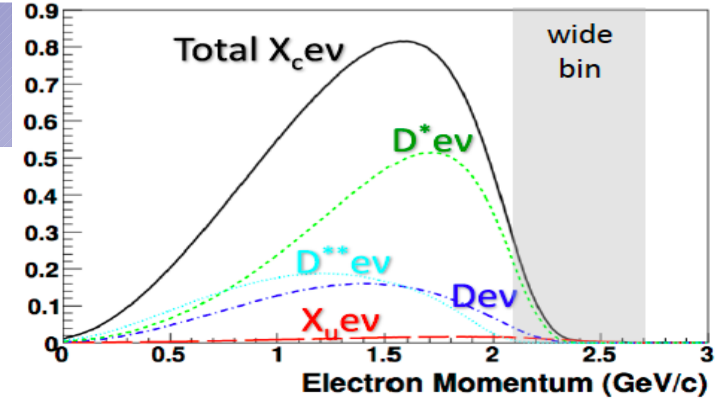




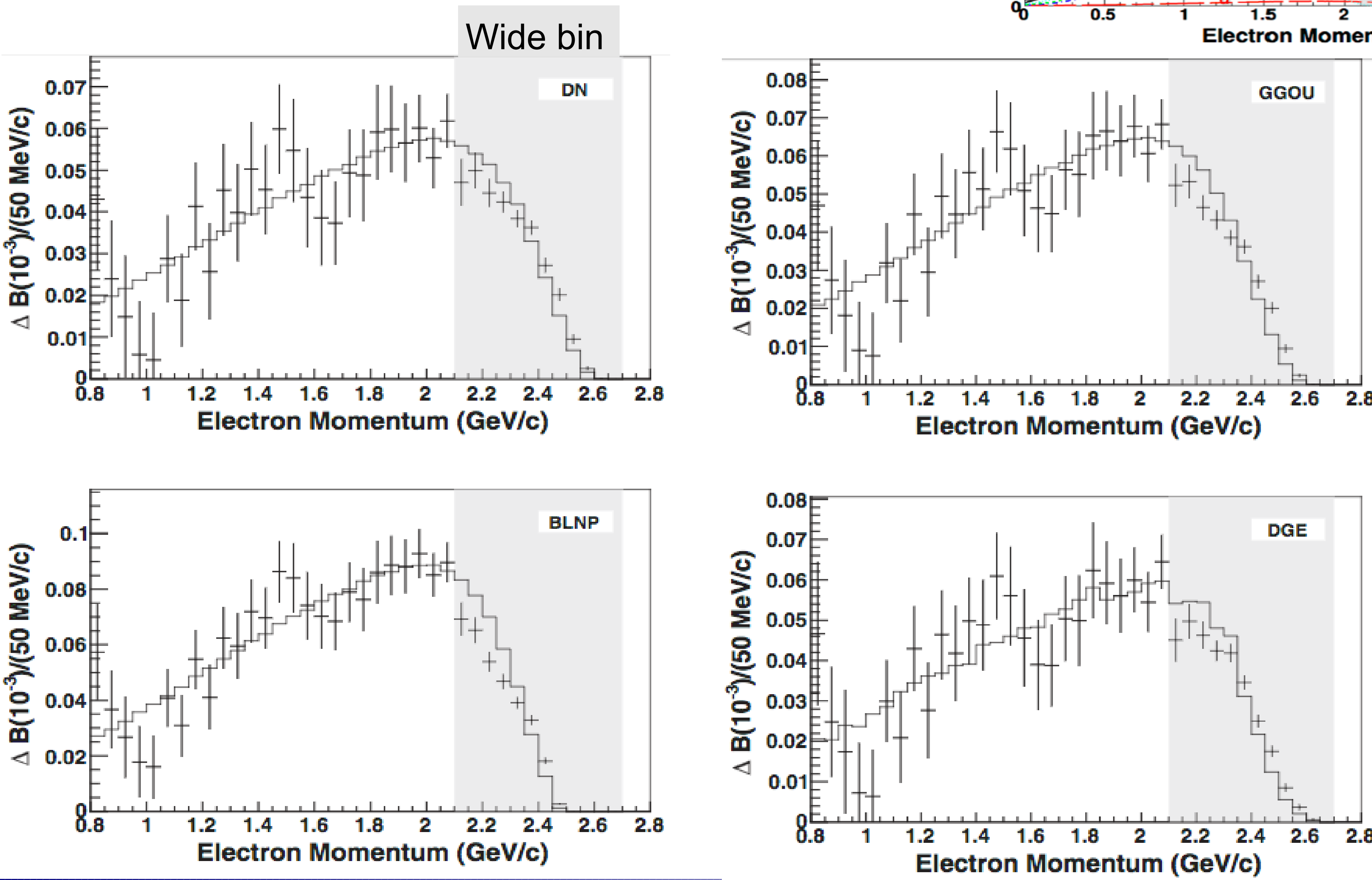
B.Kowalewski@CKM16

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 →$X_u$ev in Y(4S) frame

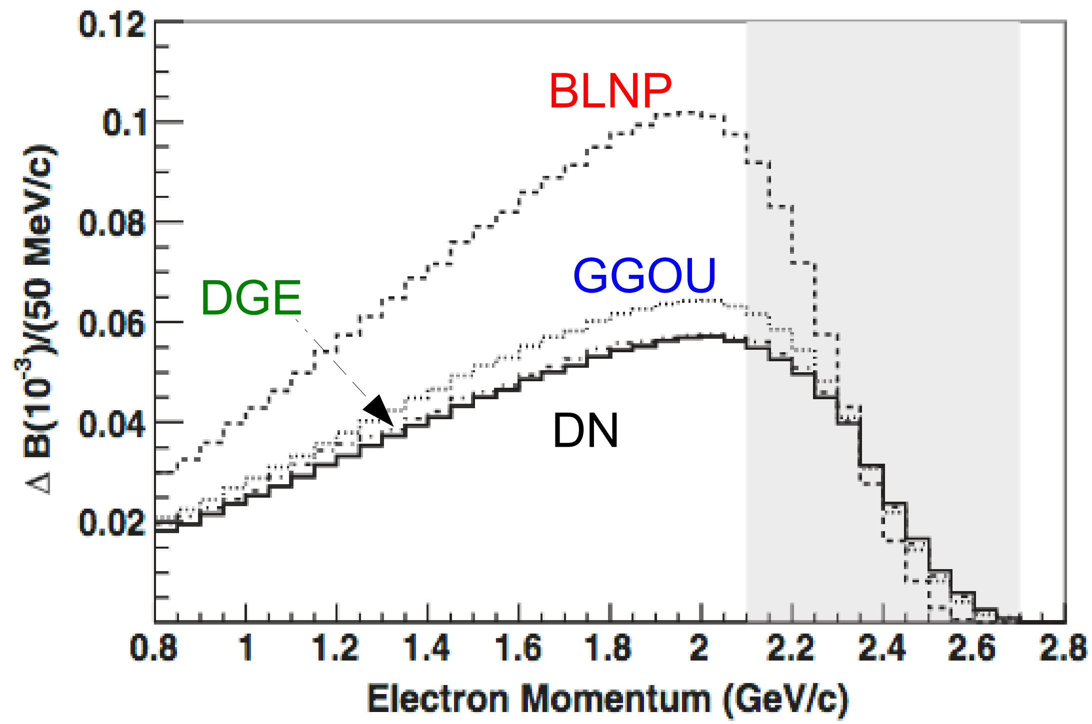


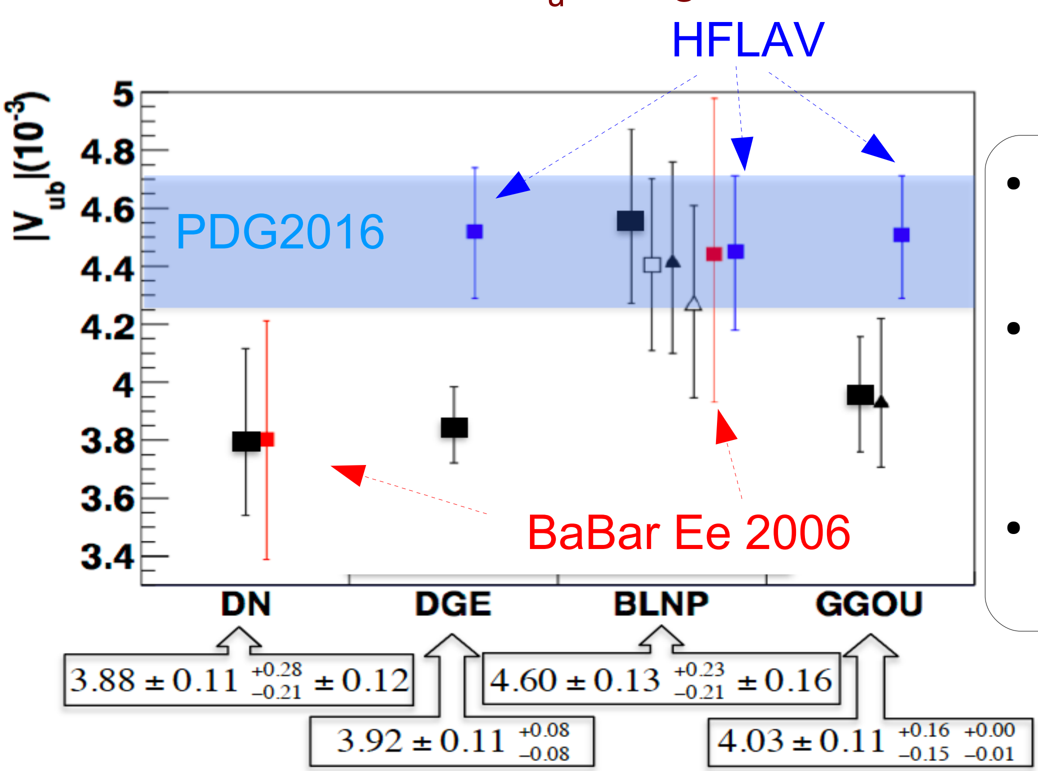
- B→$X_u$ev electron spectra for pe > 0.8 GeV after continuum, B→X_c e v and cascade subtraction



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

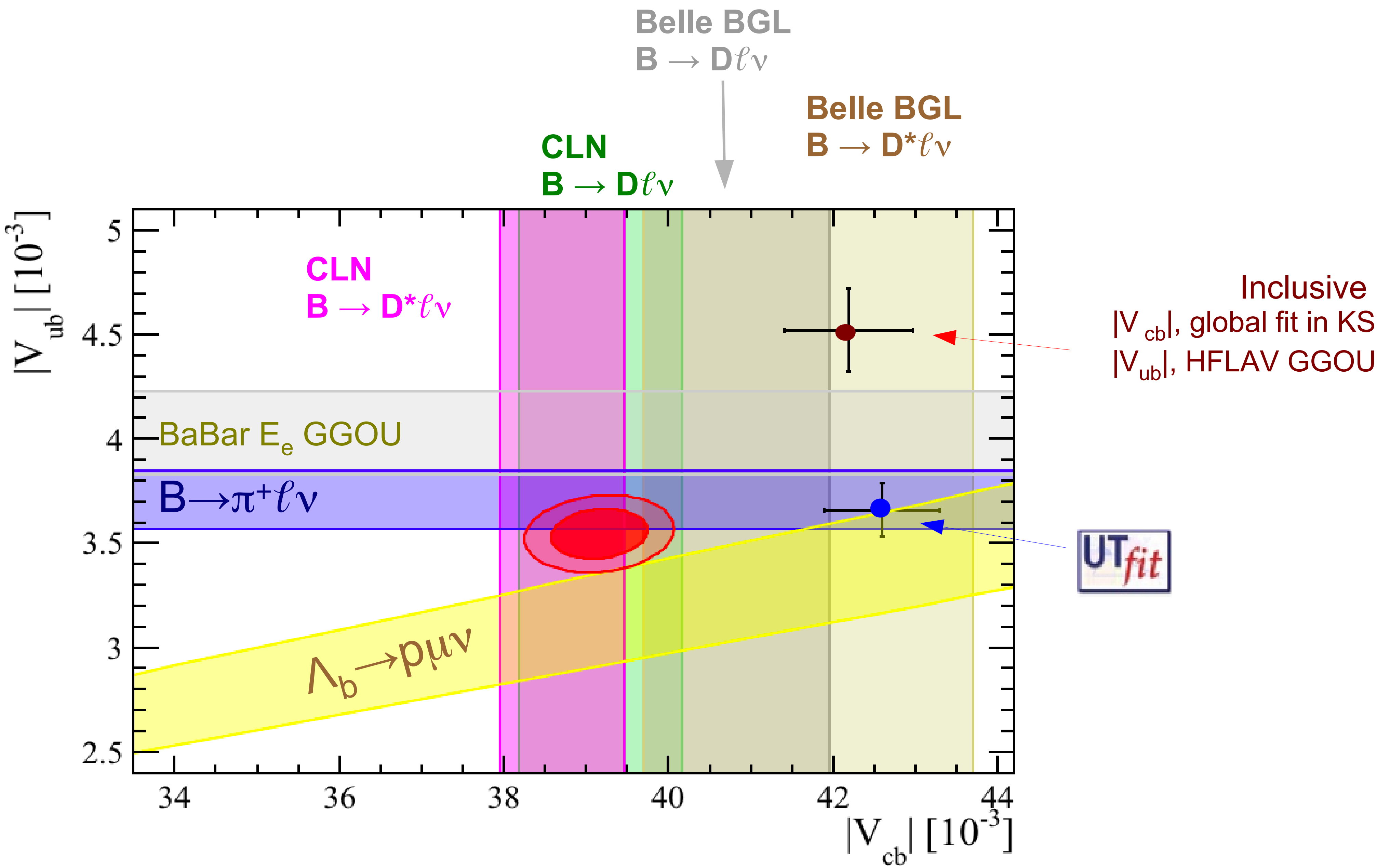
- Highest sensitivity to $B \to X_u e\nu$ in the wide bin 2.1-2.7 GeV
- Models make different predictions for the fractional rate in this bin
  - The normalization of the $B \to X_u e\nu$ is fixed by this bin!
- This dependence on the signal model could impact any measurement that extends in the $B \to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

New global picture ?



Conclusions

- Recently, huge progresses from Lattice and others are on the way!
- Inclusive – Exclusive puzzle cannot be considered solved!
- Unfortunately many published results are based on 10-years old analyses and cannot be easily re-analyzed... nevertheless few results from Belle and BaBar are expected in the coming months!
- Bright future from LHCb (run1+2 & upgrade) and Belle-II!

Conclusione

- Exclusive $|V_{ub}|$
  - huge progressed on lattice
  - LHCb is a new player: opened the route to $B_s \rightarrow K \ell\nu$ (cleanest on Lattice!)
- Inclusive $|V_{ub}|$
  - It is still a puzzle: internally consistent but above CKM fit and exclusive determination
  - 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 $|V_{cb}|$-like from spectra measurements: SIMBA, NNVUB)
- Inclusive $|V_{cb}|$
  - Everything consistent and it gives inputs to $|V_{ub}|$/SF: it would be desirable an update of the 1S scheme framework
- Exclusive $|V_{cb}|$
  - 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

STOP

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
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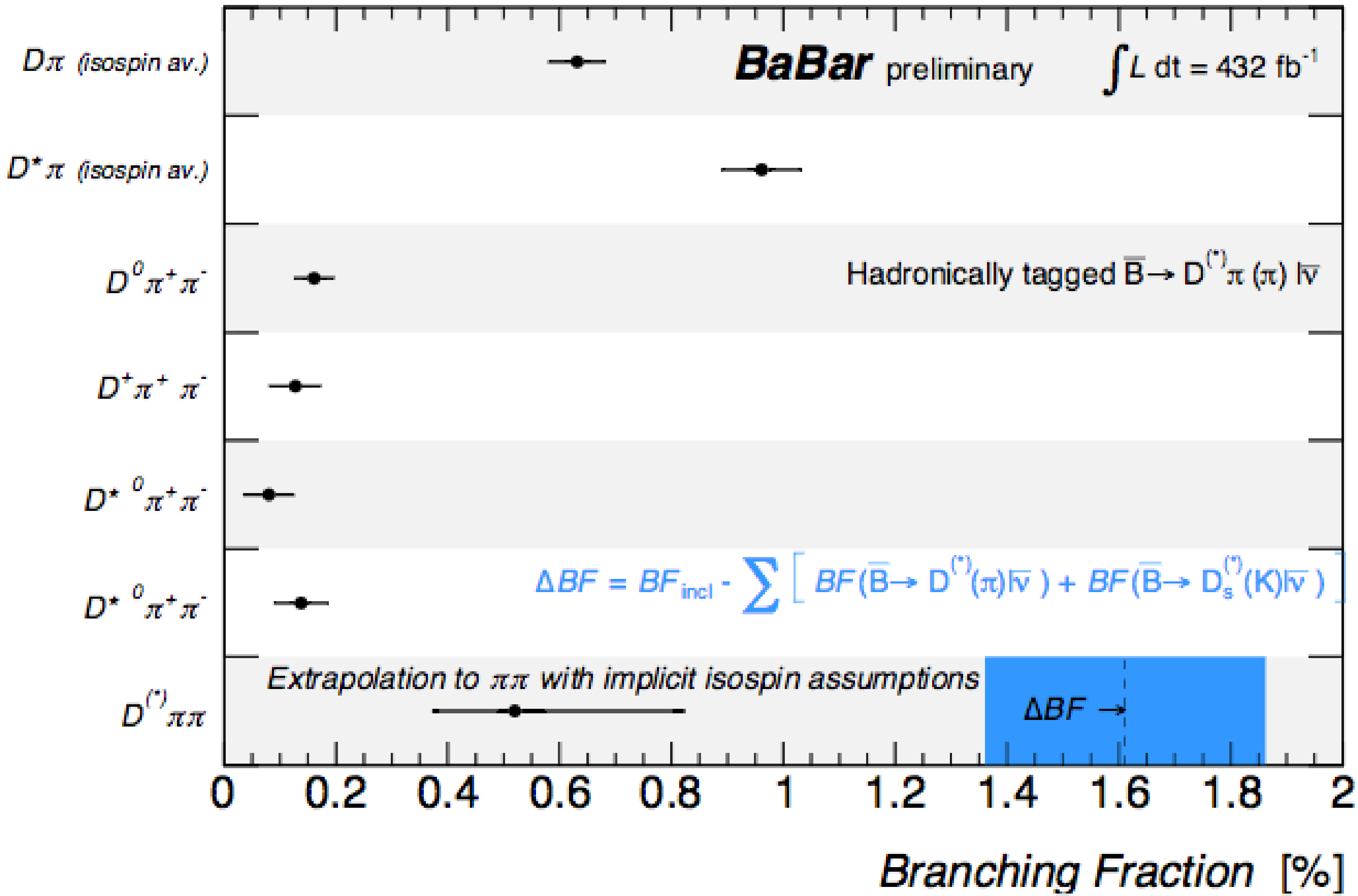
Status of the "gap"



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

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

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