Developments in semileptonic B decays

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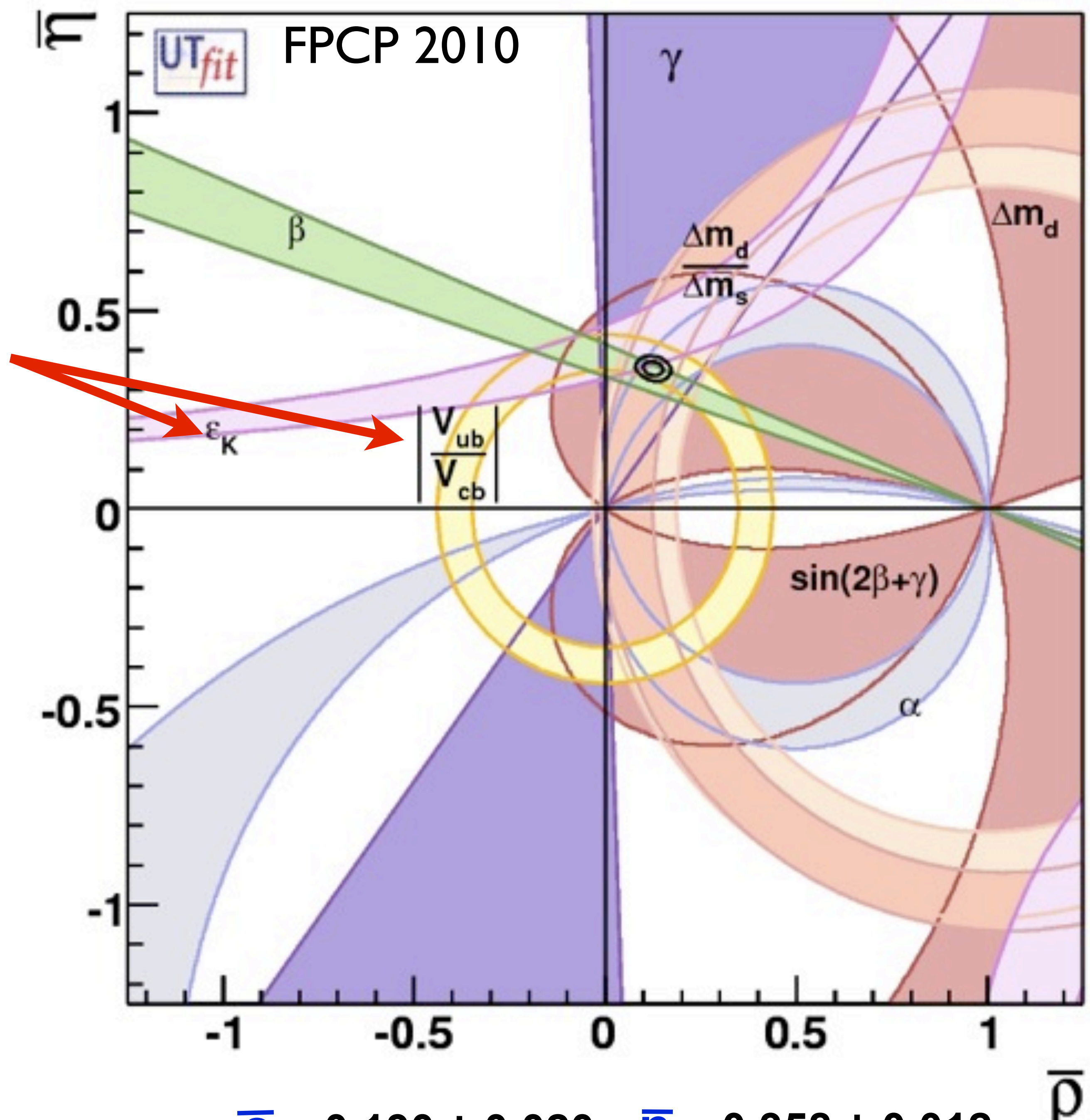
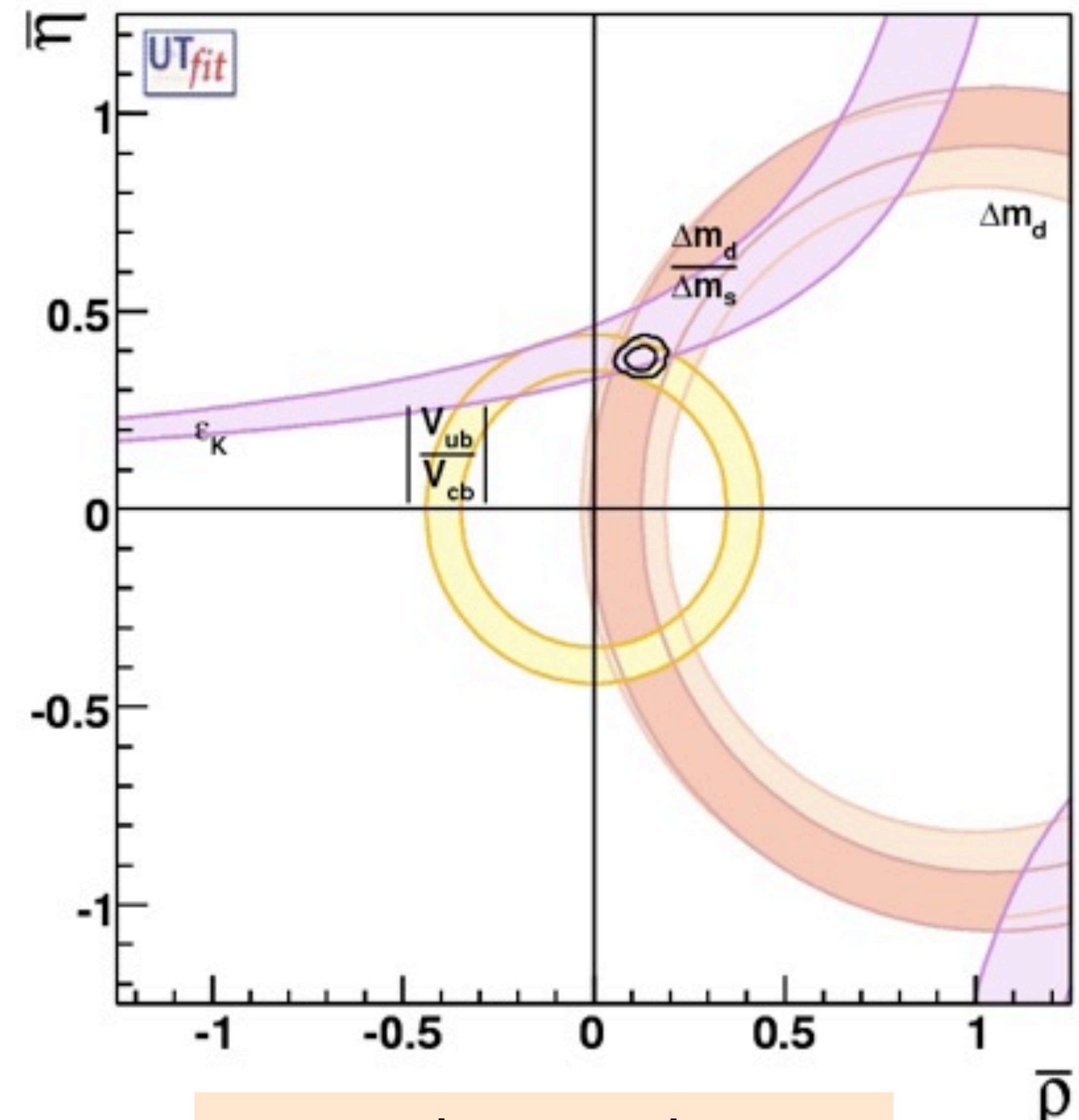
The UT and V_{ub}, V_{cb}



$\bar{\rho}$ = 0.130 ± 0.020 $\bar{\eta}$ = 0.358 ± 0.012

$\sin 2\beta_{charmonium} = 0.655 \pm 0.024$



without angles
UTfit inputs:
ξ=1.24(3) B_K=0.731(36)

recent results B_K=0.72(3)

getting to 5% accuracy

Tensions in the UTfit

compatibility plots in the SM

measure the agreement of a single measurement with the indirect determination from the fit using all the other inputs

$\sin 2\beta_{exp} = 0.655 \pm 0.024$

$\sin 2\beta_{UTfit} = 0.753 \pm 0.034$

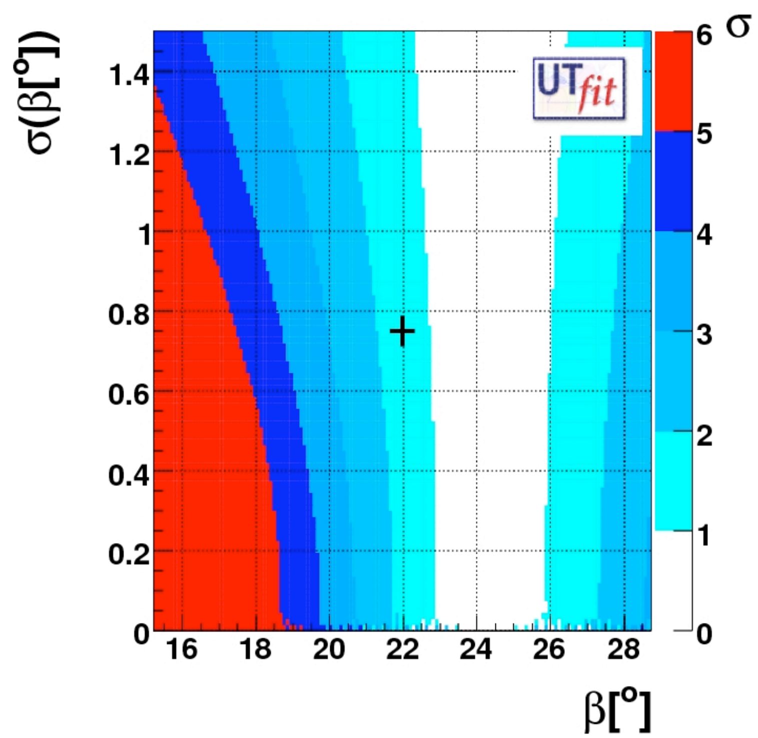
$$\left|\frac{V_{ub}}{V_{cb}}\right|_{incl} = 0.101 \pm 0.006$$

$$\left|\frac{V_{ub}}{V_{cb}}\right|_{excl} = 0.084 \pm 0.008$$

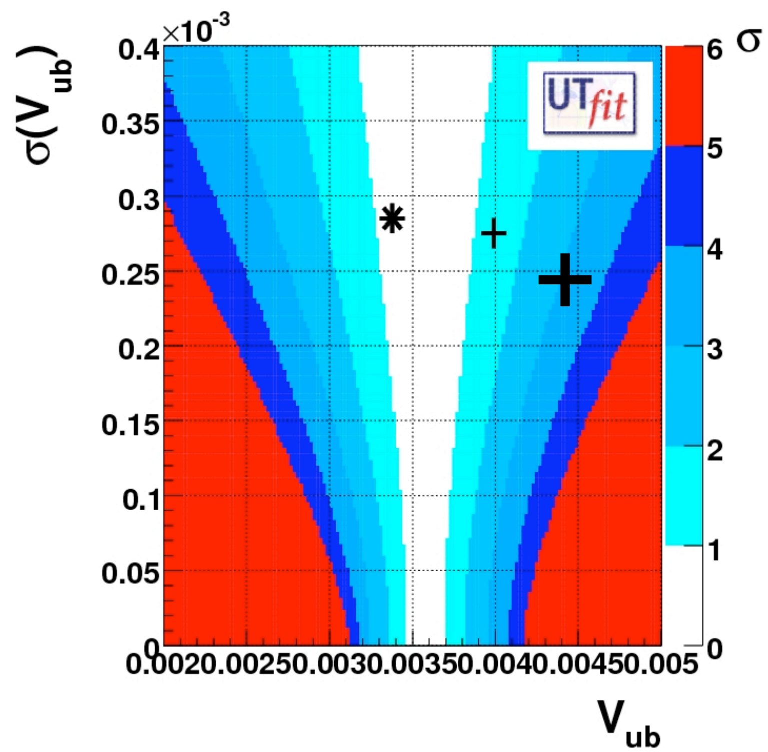
$B_{K_{exp}} = 0.731 \pm 0.036$

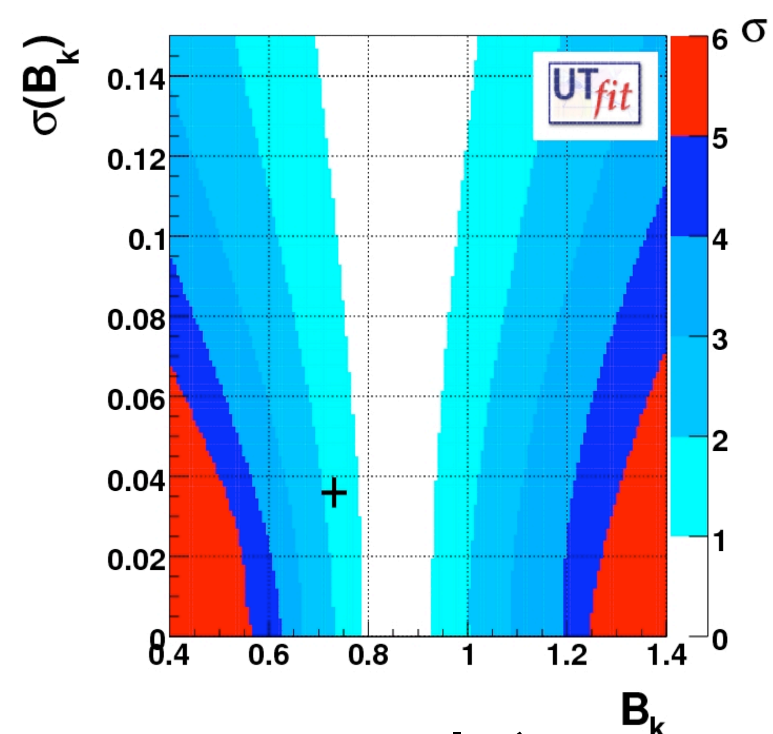
$B_{K_{UTfit}} = 0.855 \pm 0.069$

$B_{K_{nolattice}} = 0.869 \pm 0.079$



~2.4σ





~1.6σ

$Vub_{exp} = (37.2 \pm 2.1) \cdot 10^{-4}$

$Vub_{UTfit} = (35.8 \pm 1.1) \cdot 10^{-4}$

<1σ (incl ~2.5σ)

M. Bona
UTfit@FPCP 2010

The total s.l. width in the OPE

$$\Gamma[\bar{B} \to X_c e \bar{\nu}] = \frac{G_F^2 m_b^5}{192\pi^3} |V_{cb}|^2 g(r) \left[1 + \frac{\alpha_s}{\pi} p_c^{(1)}(r,\mu) + \frac{\alpha_s^2}{\pi^2} p_c^{(2)}(r,\mu) \right.$$

$$- \frac{\mu_\pi^2}{2m_b^2} + \left(\frac{1}{2} - \frac{2(1-r)^4}{g(r)}\right) \frac{\mu_G^2 - \frac{\rho_{LS}^3 + \rho_D^3}{m_b}}{m_b^2}$$

$$r = \frac{m_c^2}{m_b^2}$$

$$\left. + \left(8 \ln r - \frac{10r^4}{3} + \frac{32r^3}{3} - 8r^2 - \frac{32r}{3} + \frac{34}{3}\right) \frac{\rho_D^3}{g(r)\, m_b^3}\right]$$

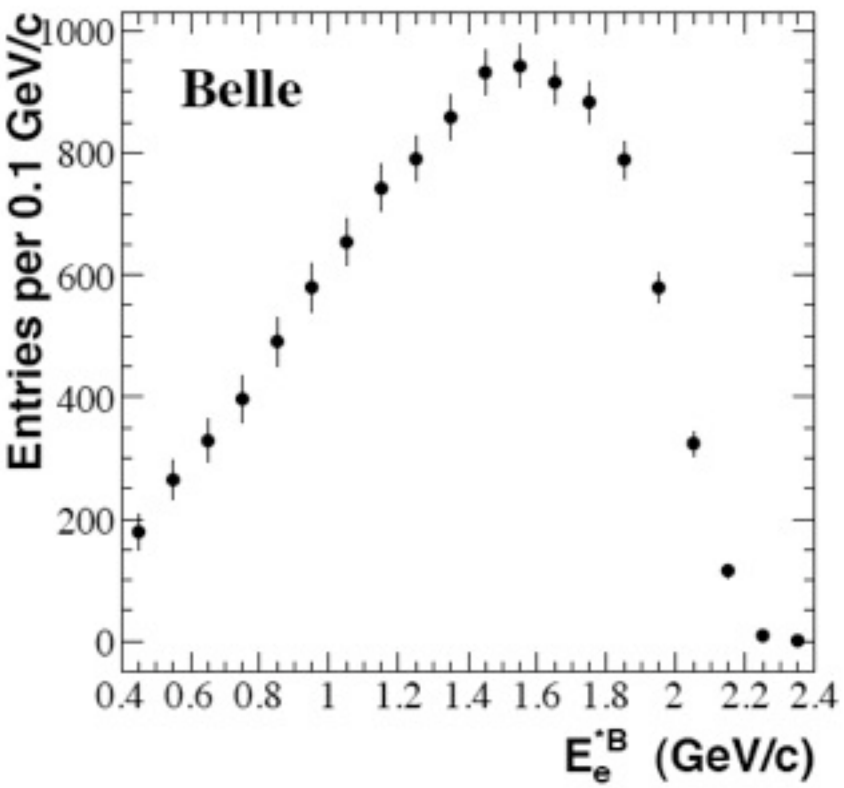
$$+ O(\alpha_s \frac{\mu_{\pi,G}^2}{m_b^2}) \quad + O(\frac{1}{m_b^4})$$

OPE valid for inclusive enough measurements, away from perturbative singularities ➠ moments

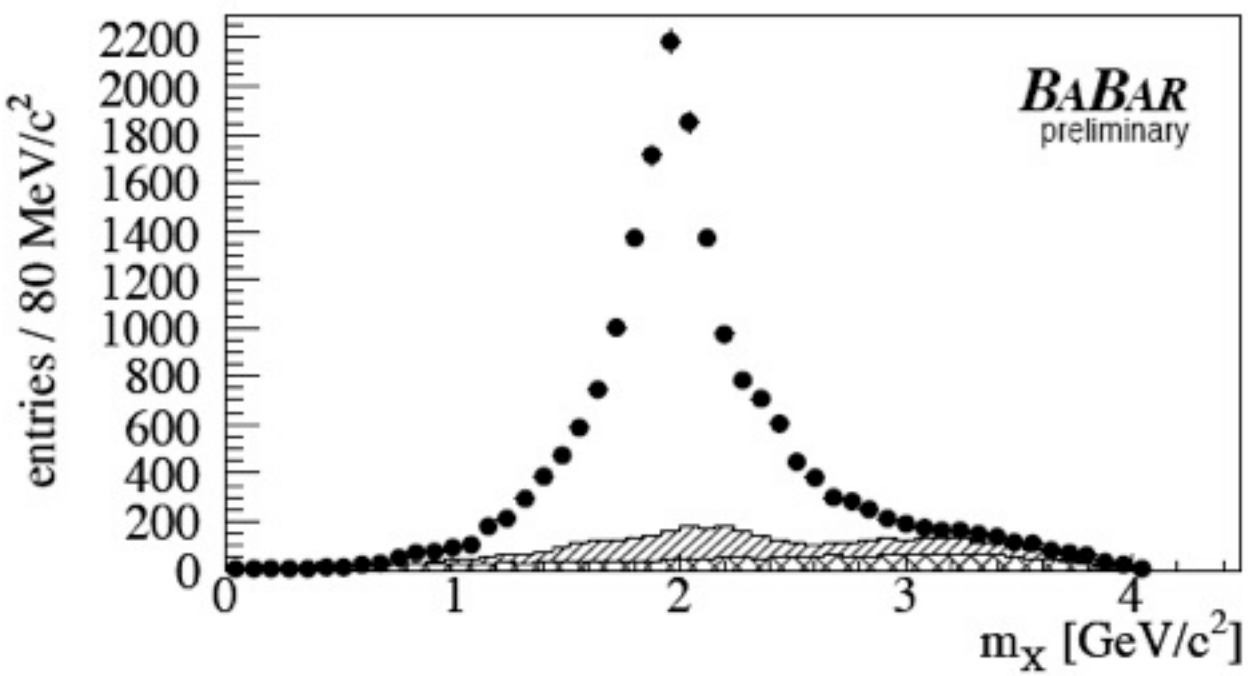
Present implementations include all terms through $O(\alpha_s^2 \beta_0, 1/m_b^3)$: $m_{b,c}$, $\mu^2_{\pi,G}$, $\rho^3_{D,LS}$ 6 parameters

Fitting OPE parameters to the moments

E_l spectrum



m_X spectrum



*Total **rate** gives $|V_{cb}|$, global **shape** parameters (moments of the distributions) tell us about B structure, m_b and m_c*

OPE parameters describe universal properties of the B meson and of the quarks → useful in many applications

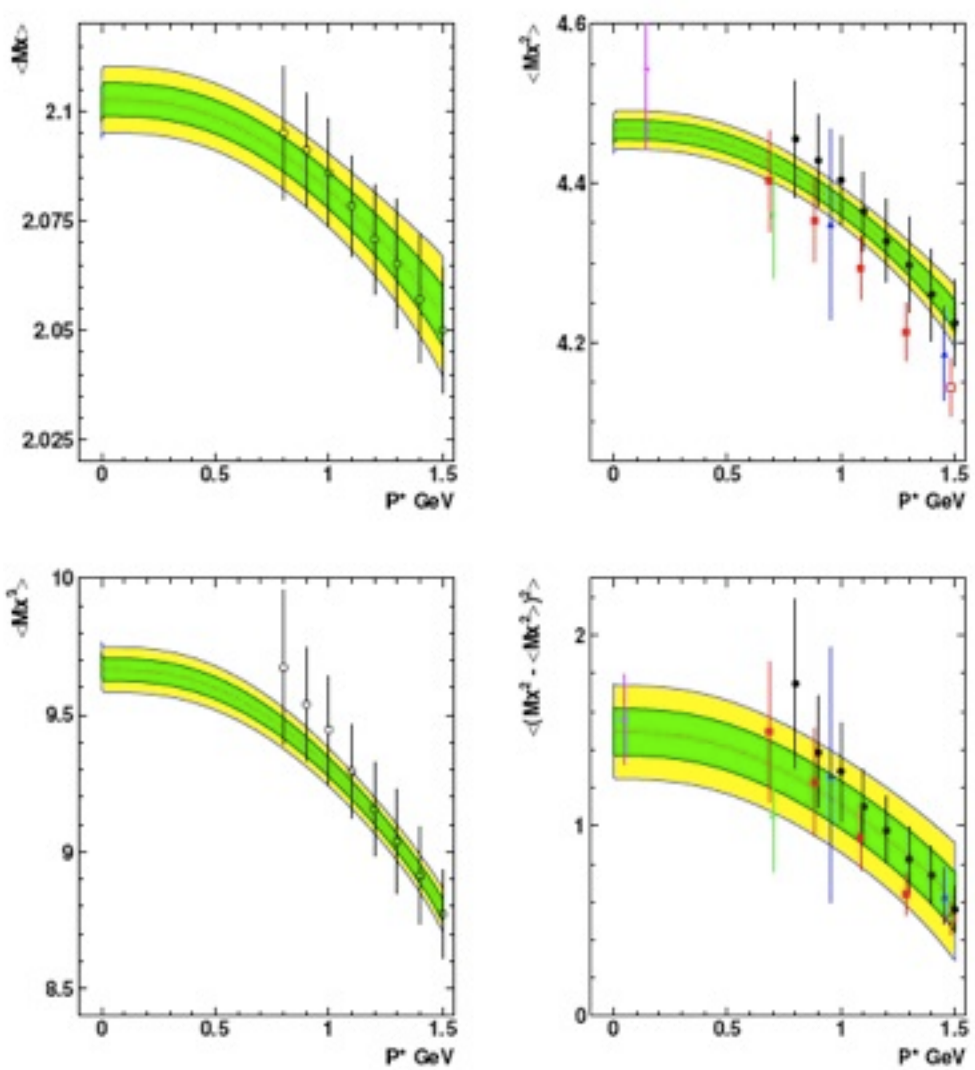
Global HFAG fit (kinetic scheme)

Inputs	$\|V_{cb}\|\ 10^3$	m_b^{kin}	χ^2/ndf
b→c & b→sγ	41.85(44)(58)	4.590(31)	29.7/59
b→c only	41.68(48)(58)	4.646(47)	24.2/48

Based on PG, Uraltsev, Benson et al

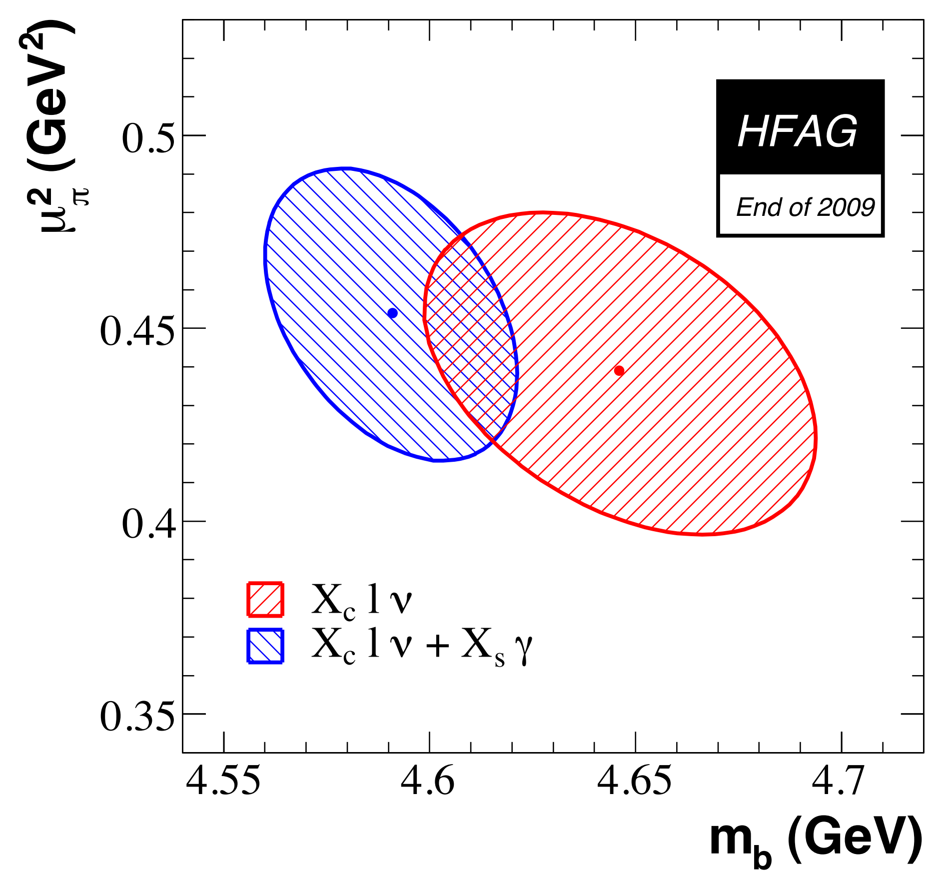
***In the kinetic scheme** the contributions of gluons with energy below $\mu \approx 1$GeV are absorbed in the OPE parameters*

Here *scheme* means also a number of different assumptions, inclusion of different data, and a recipe for theory errors



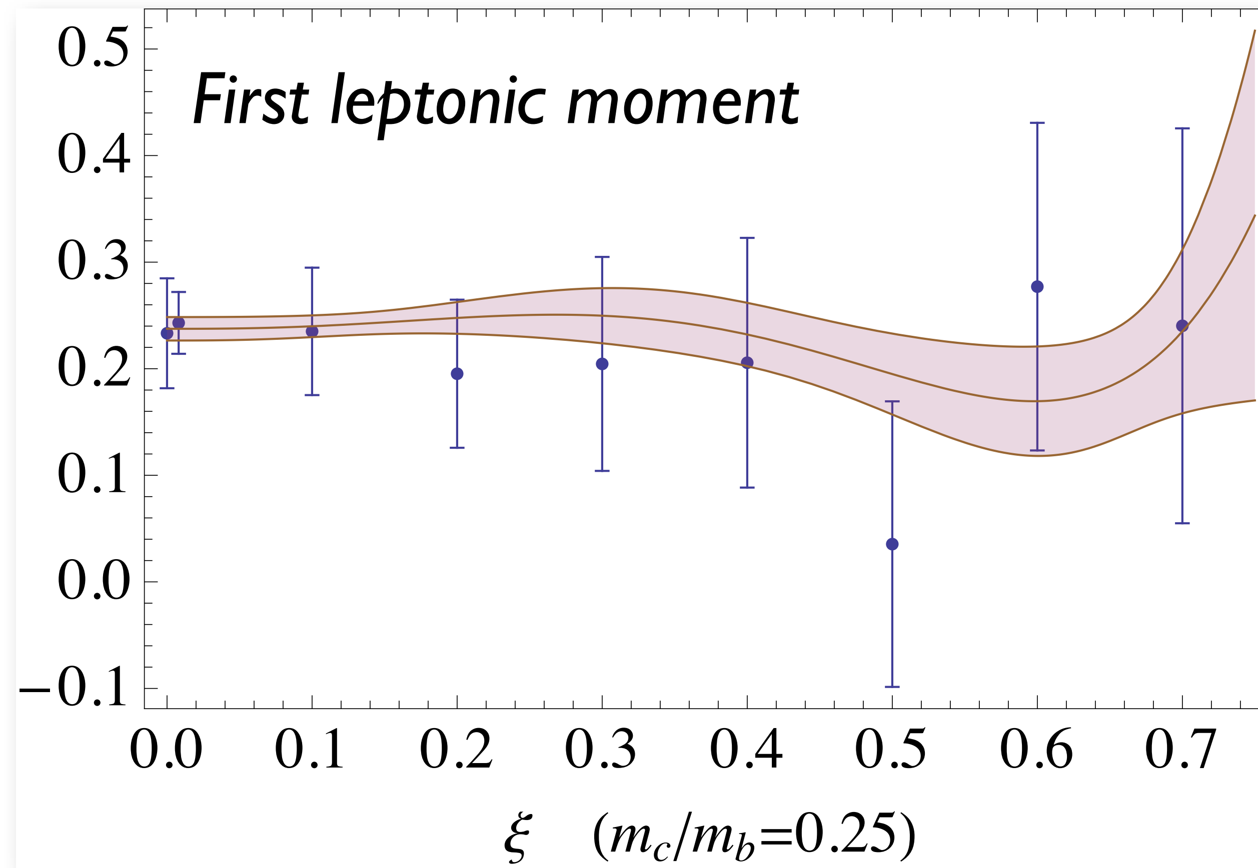
Very close result for $|V_{cb}|$ in 1S scheme

Bauer Ligeti Luke Manohar Trott



OPE at NNLO

- ✳ Complete 2loop corrections to width and moments with cuts are now known, either in expansion m_c/m_b or numerically
  Biswas-Melnikov, Pak, Czarnecki
- ✳ Minor corrections to BLM, residual th error on V_{cb} O(0.5%).
- ✳ Competitive with pert corrections to power suppressed terms. $O(1/m_b^3)$ corrections ~3% in width, to have 1% accuracy we may need to compute through $O(\alpha_s/m_b^3)$



Available NNLO corrections have non-negligible uncertainty important in higher moments

Preliminary NNLO results

	ℓ_1	ℓ_2	ℓ_3	R^*
	$\mu=0$			
tree	1.5426	0.0848	-0.0010	0.8003
$O(\alpha_s)$	1.5398	0.0835	-0.0010	0.8009
$O(\beta_0\alpha_s^2)$	1.5343	0.0818	-0.0009	0.7992
$O(\alpha_s^2)$	1.5357(2)	0.0821(8)	-0.0014(25)	0.7992(1)
	$\mu=1\text{GeV}$			
$O(\alpha_s)$	1.5455	0.0858	-0.0003	0.8029
$O(\beta_0\alpha_s^2)$	1.5468	0.0868	0.0005	0.8035
$O(\alpha_s^2)$	1.5470(2)	0.0866(8)	-0.0001(25)	0.8031(1)
$\delta\alpha_s=0.04$	0.0011	0.0005	0.0003	0.0005
GU error	0.0113	0.0051	0.0022	

E_{cut}=1GeV, m_c/m_b=0.25

	ℓ_1	ℓ_2	ℓ_3	R^*
	$\mu=1\text{GeV}$, $m_c^{\overline{\text{MS}}}(2\text{GeV})$			
tree	1.5536	0.0873	-0.0013	0.8058
$O(\alpha_s)$	1.5502	0.0869	-0.0003	0.8056
$O(\beta_0\alpha_s^2)$	1.5540	0.0884	0.0004	0.8073
$O(\alpha_s^2)$	1.5528(3)	0.0880(9)	-0.0006(26)	0.8061(1)
	$\mu=1\text{GeV}$, $m_c^{\overline{\text{MS}}}(3\text{GeV})$			
tree	1.5748	0.0922	-0.0020	0.8159
$O(\alpha_s)$	1.5613	0.0894	-0.00043	0.8118
$O(\beta_0\alpha_s^2)$	1.5629	0.0904	0.00042	0.8125
$O(\alpha_s^2)$	1.5578(4)	0.0892(13)	-0.0014(40)	0.8093(2)

	$\langle M_X^2\rangle$	
	on-shell	$\mu=1\text{GeV}$
tree	4.452	4.452
$O(\alpha_s)$	4.563	4.426
$O(\beta_0\alpha_s^2)$	4.701	4.404
$O(\alpha_s^2)$	4.682(1)	4.424(1)

Small corrections, within theory errors. NNLO code in any scheme almost finished, will allow for a more precise determination of masses etc

$O(\alpha_s/m_b^2)$ effects in $B\to X_s\gamma$

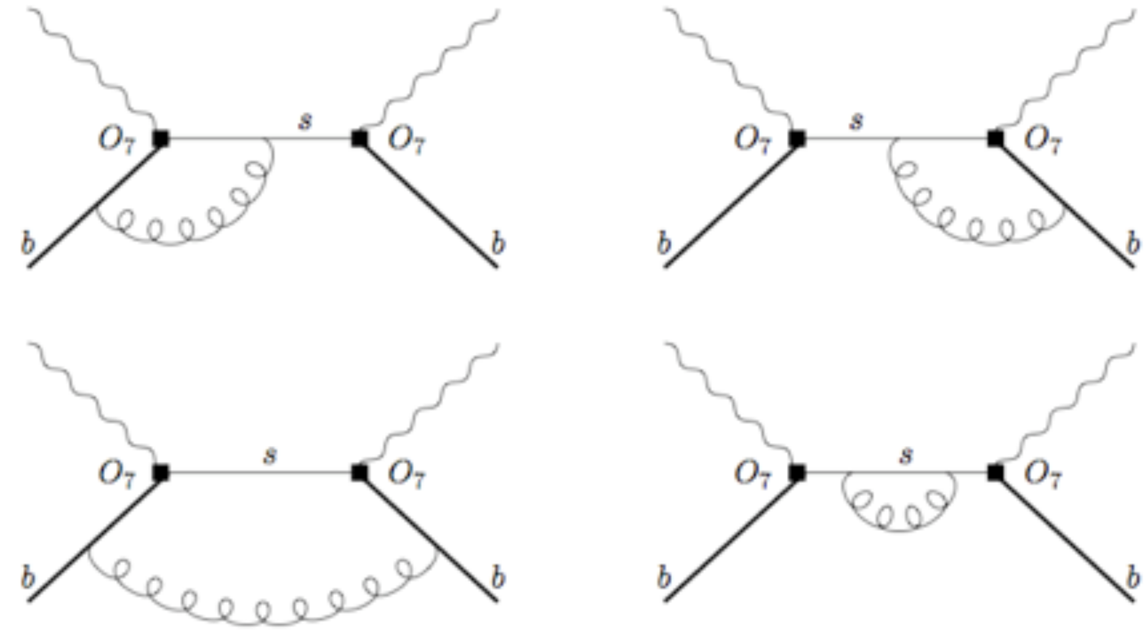
Ewerth,Nandi,PG arXiv:0911.2175

$$T\{\bar b(x)\sigma_{\mu\nu}P_L s(x)\bar s(0)\sigma_{\alpha\beta}P_R b(0)\} =$$

$$c_{\dim 3}O_{\dim 3} + \frac{1}{m_b}c_{\dim 4}O_{\dim 4} + \frac{1}{m_b^2}c_{\dim 5}O_{\dim 5} + \ldots$$

$$O_b^\mu = \bar b\gamma^\mu b, \qquad O_2^{\mu\nu} = \bar b_v \frac{1}{2}\{iD^\mu, iD^\nu\}b_v\,,$$

$$O_1^\mu = \bar b_v iD^\mu b_v, \qquad O_3^{\mu\nu} = \bar b_v \frac{g_s}{2}G^{a\mu}{}_\alpha\sigma^{\alpha\nu}T^a b_v\,,$$



One-loop matching onto local operators with HQET fields in dim reg

$$\frac{d\Gamma_{77}}{dz} = \Gamma_{77}^{(0)}\left[c_0^{(0)} + c_{\lambda_1}^{(0)}\frac{\lambda_1}{2m_b^2} + c_{\lambda_2}^{(0)}\frac{\lambda_2(\mu)}{2m_b^2} + \frac{\alpha_s(\mu)}{4\pi}\left(c_0^{(1)} + c_{\lambda_1}^{(1)}\frac{\lambda_1}{2m_b^2} + c_{\lambda_2}^{(1)}\frac{\lambda_2(\mu)}{2m_b^2}\right)\right]$$

$\lambda_{1,2}$ are HQET analogues of $\mu^2_{\pi,G}$

The NLO effect 10-20% in coefficients of first few moments,
leading to $\delta m_b \sim 10$MeV, $\delta\mu_\pi^2 \sim 0.04\text{GeV}^2$
Extension to semileptonic case almost complete:
$O(\alpha_s\mu^2_\pi/m_b^2)$ to moments known numerically Becher,Boos,Lunghi

Higher power corrections

Mannel,Turczyk,Uraltsev **1009.4622**
see also Bigi,Mannel,Turczyk,Uraltsev
Bigi,Uraltsev,Zwicki

Proliferation of non-pert parameters: for ex at $1/m_b^4$

$$
\begin{aligned}
2M_B m_1 &= \langle ((\vec{p})^2)^2 \rangle \\
2M_B m_2 &= g^2 \langle \vec{E}^2 \rangle \\
2M_B m_3 &= g^2 \langle \vec{B}^2 \rangle \\
2M_B m_4 &= g \langle \vec{p} \cdot \mathrm{rot}\, \vec{B} \rangle
\end{aligned}
$$

$$
\begin{aligned}
2M_B m_5 &= g^2 \langle \vec{S} \cdot (\vec{E} \times \vec{E}) \rangle \\
2M_B m_6 &= g^2 \langle \vec{S} \cdot (\vec{B} \times \vec{B}) \rangle \\
2M_B m_7 &= g \langle (\vec{S} \cdot \vec{p})(\vec{p} \cdot \vec{B}) \rangle \\
2M_B m_8 &= g \langle (\vec{S} \cdot \vec{B})(\vec{p})^2 \rangle \\
2M_B m_9 &= g \langle \Delta(\vec{\sigma} \cdot \vec{B}) \rangle
\end{aligned}
$$

can be estimated by Ground State Saturation

$$\frac{\delta\Gamma_{1/m^4} + \delta\Gamma_{1/m^5}}{\Gamma} \approx 0.013 \qquad \frac{\delta V_{cb}}{V_{cb}} \approx +0.4\%$$

after inclusion of the corrections in the moments. While this might set the scale of effect, not yet clear *how much it depends on assumptions on expectation values.*

Exclusive decays: $B \to D^* l\nu$

At zero recoil, where rate vanishes, the ff is

$$\mathcal{F}(1) = \eta_A(1 + \delta_{1/m^2})$$

Recent progress in the measurement of slopes and shape parameters Despite extrapolation, exp error is only ~2%

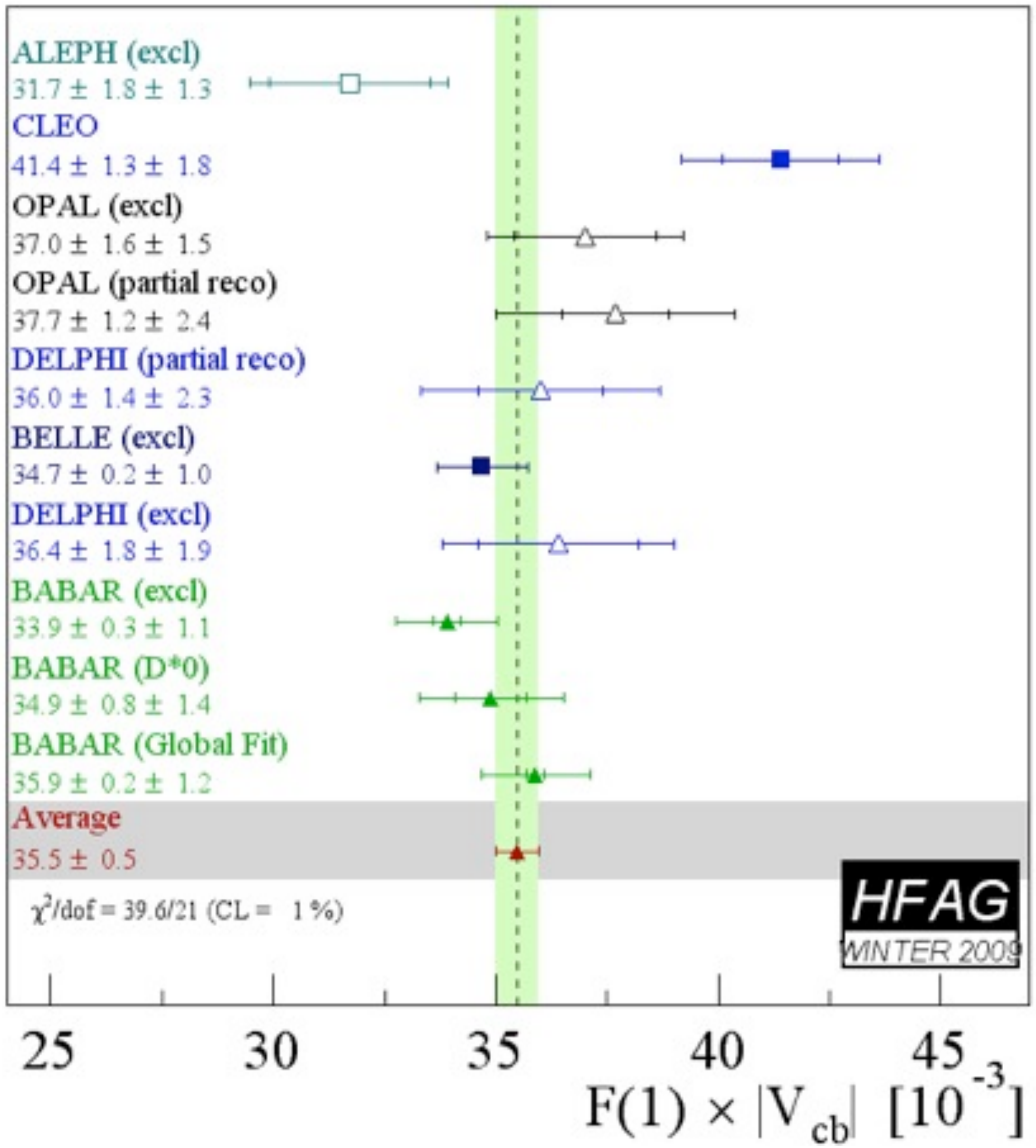
Main problem is the ff F(1): cannot be experimentally determined or constrained

New unquenched Lattice QCD (only group):
F(1) =0.908(17) Laiho et al 2010

$$|V_{cb}|=39.1(1.1)(0.7)\times 10^{-3}$$

~1.8σ from inclusive determination

2.5% error



Promising alternative: w dependence, only quenched de Divitiis et al

$B \to D l\nu$ gives consistent result with larger errors $|V_{cb}|=39.1(1.4)(1.3)\times 10^{-3}$

Fits are not only for V_{cb}...

- Results of fits to semileptonic & radiative moments are crucial input in inclusive $|V_{ub}|$ determination (mostly m_b and μ_π^2) and in normalizing $B\to X_s\gamma$ and $B\to X_s l^+l^-$
- b quark mass determinations from e^+e^- have recently improved significantly: how do they compare with fits? do we understand/ trust theory errors?
- Work in progress to implement new corrections, to use additional inputs (masses) in the fits, to control problems due to highly correlated theoretical inputs, to understand better various uncertainties. Role of radiative moments equivalent to loose PDG m_b constraint. C.Schwanda, PG

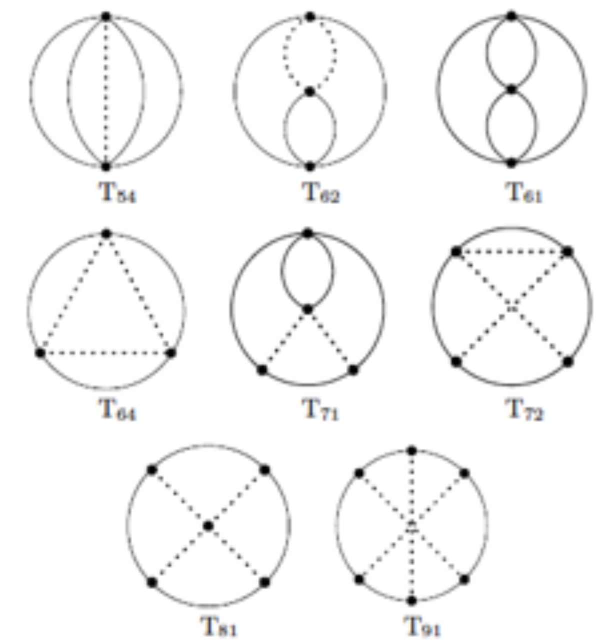
c,b masses from SVZ sumrules

$$R(s) = 12\pi\, \mathrm{Im}\left[\Pi(q^2 = s + i\epsilon)\right] \qquad \left(-q^2 g_{\mu\nu} + q_\mu q_\nu\right)\Pi(q^2) \equiv i\int dx\, e^{iqx}\langle T j_\mu(x) j_\nu(0)\rangle$$

Taylor expansion: $\Pi_Q(q^2) = Q_Q^2 \frac{3}{16\pi^2}\sum_{n\geq 0}\bar{C}_n z^n$

with $z = q^2/(4m_Q^2)$ and $m_Q = m_Q(\mu)$ the $\overline{\mathrm{MS}}$ mass.

$$\bar{C}_n = \bar{C}_n^{(0)} + \frac{\alpha_s}{\pi}\bar{C}_n^{(1)} + \left(\frac{\alpha_s}{\pi}\right)^2 \bar{C}_n^{(2)} + \left(\frac{\alpha_s}{\pi}\right)^3 \bar{C}_n^{(3)} + \dots$$



Boughezal, Czakon, Schutzmeier (2006)
Kuhn, Steinhauser, Sturm (2006)

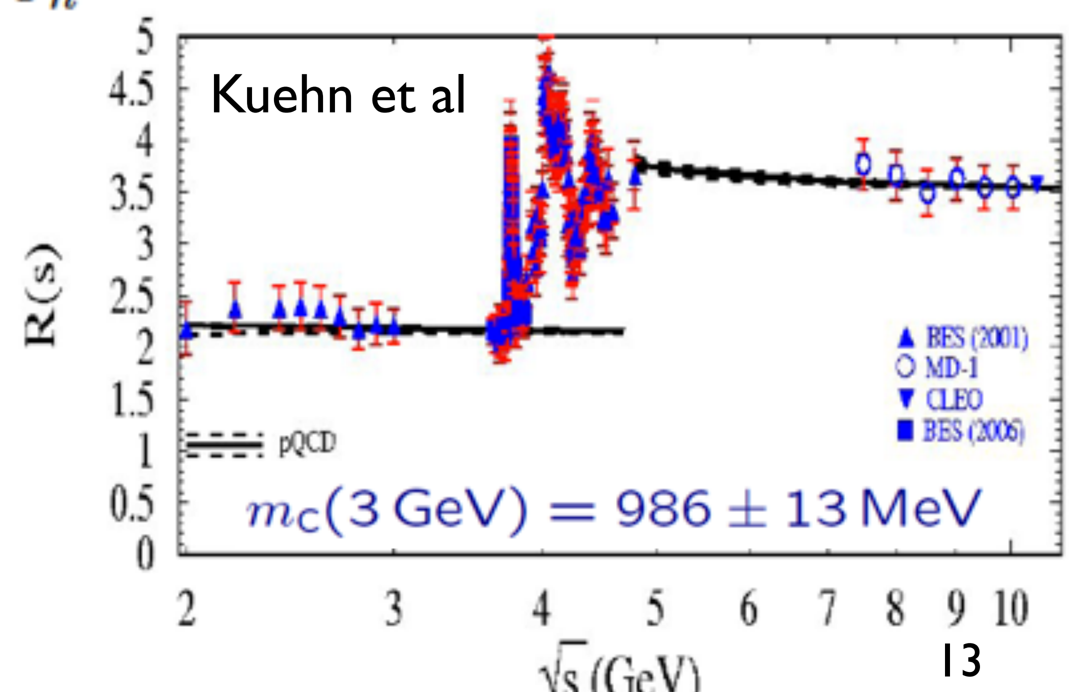
Relation to measurements

$$\mathcal{M}_n^{\mathrm{th}} \equiv \frac{12\pi^2}{n!}\left(\frac{d}{dq^2}\right)^n \Pi_c(q^2)\Big|_{q^2=0} = \frac{9}{4}Q_c^2\left(\frac{1}{4m_c^2}\right)^n \bar{C}_n$$

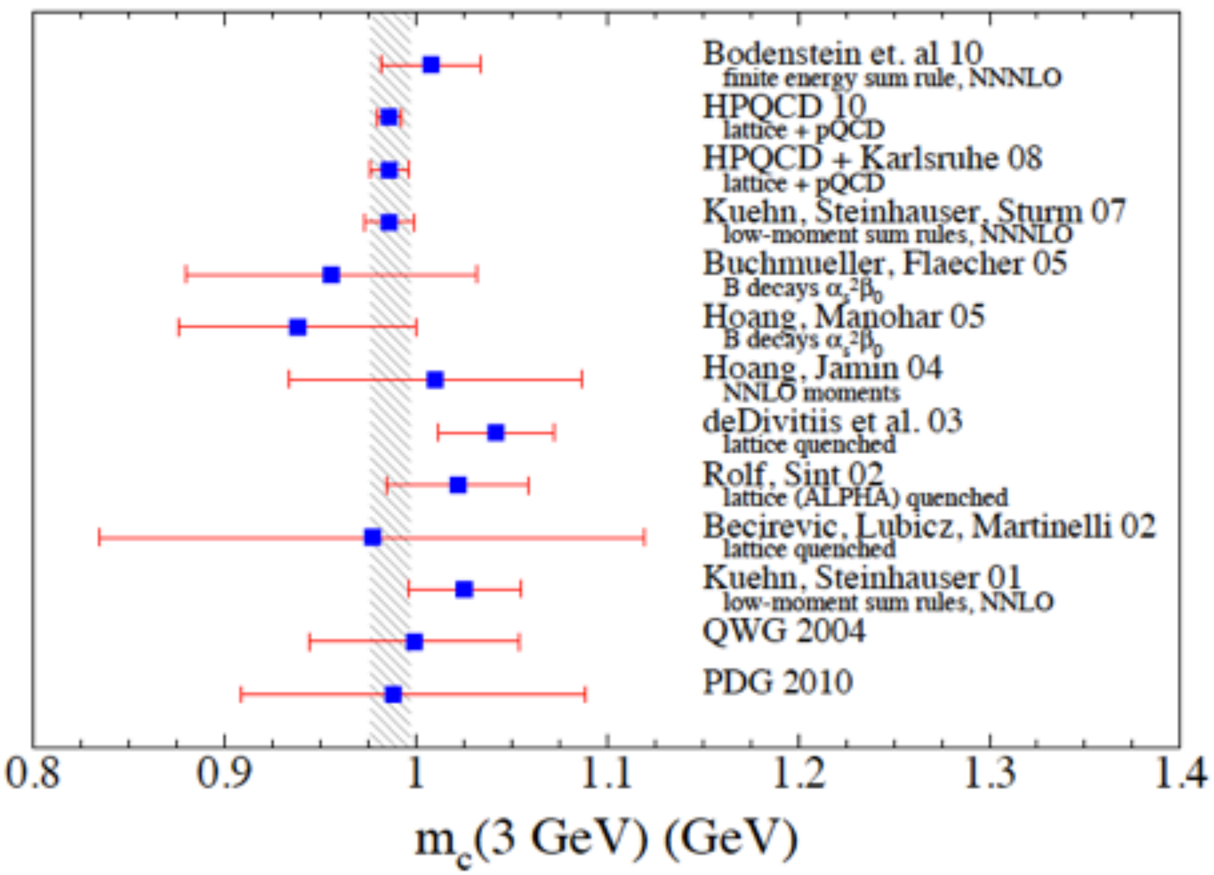
$$\Pi_c(q^2) = \frac{q^2}{12\pi^2}\int ds\, \frac{R_c(s)}{s(s-q^2)} + \text{subtraction}$$

$$\Rightarrow \mathcal{M}_n^{\mathrm{exp}} = \int \frac{ds}{s^{n+1}} R_c(s) = \mathcal{M}_n^{\mathrm{th}}$$

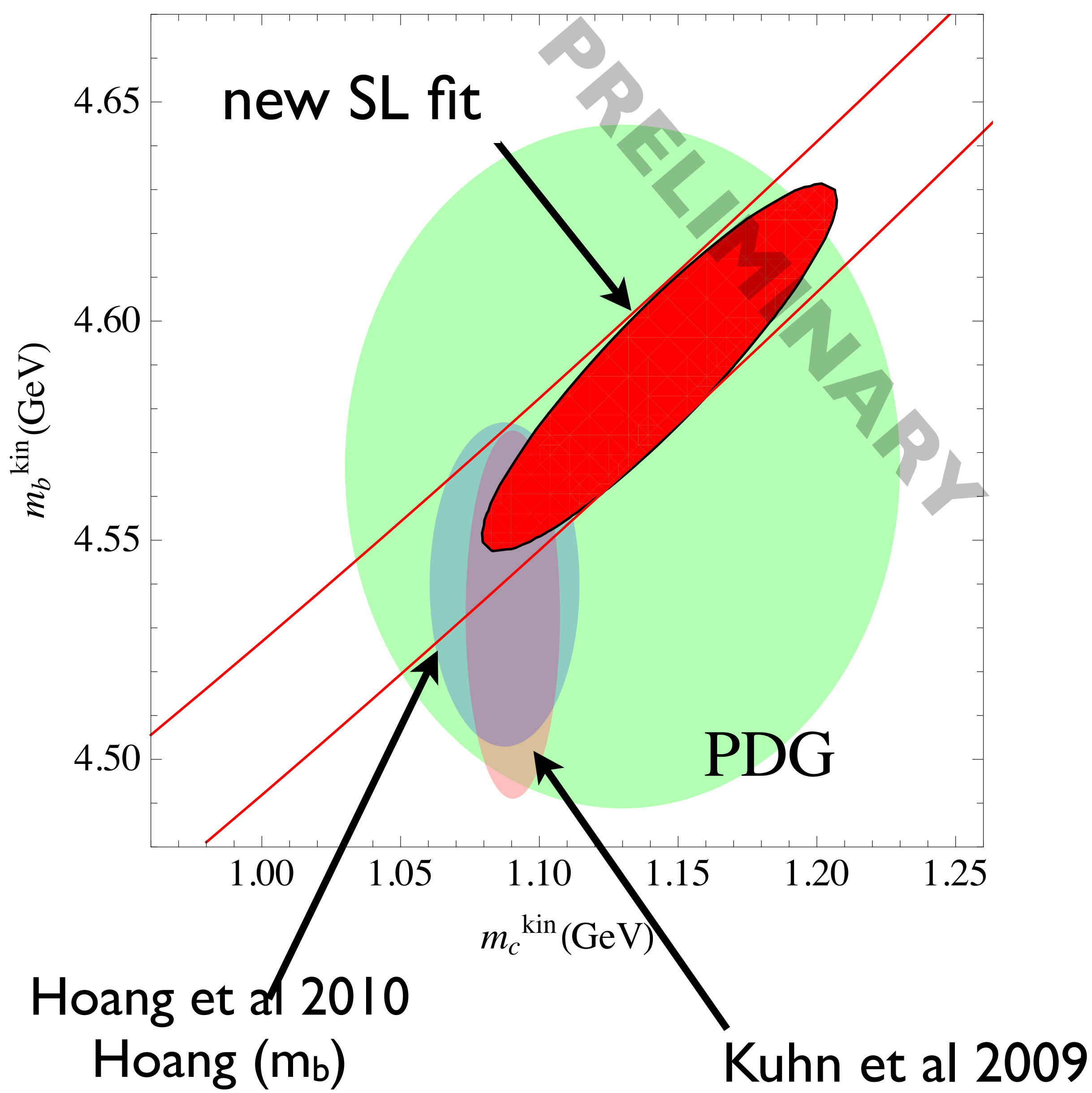
moments can also be *measured* on the lattice!



Using mass determinations



Recent sum rules determinations converted to kin scheme



Comparisons and combinations for $m_{b,c}$ penalized by changes of scheme.

Direct fit to m_c(3GeV) with Karlsruhe constraint on m_c leads to

m_b^{kin}=4.535(21)GeV

➨*$m_b(m_b)$=4.165(45)GeV Consistent!*

The total B→X$_u$lν width in the OPE

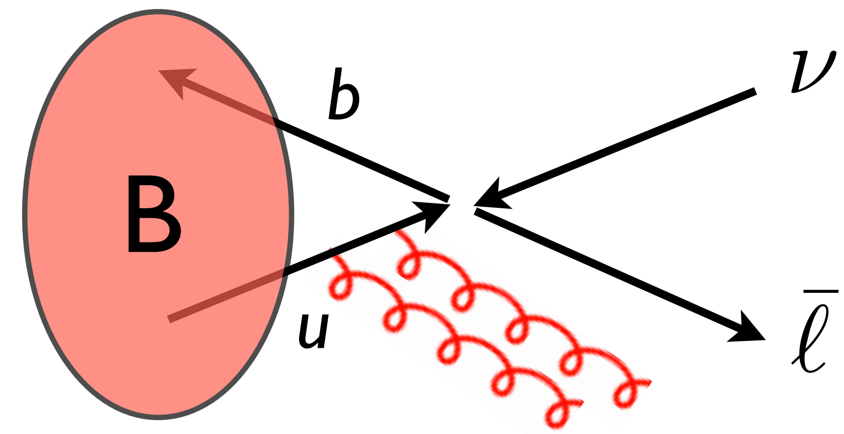
$$
\begin{aligned}
\Gamma[\bar B \to X_u e \bar\nu] \;=\; & \frac{G_F^2\, m_b^5}{192\pi^3}|V_{ub}|^2 \left[1 + \frac{\alpha_s}{\pi} p_u^{(1)}(\mu) + \frac{\alpha_s^2}{\pi^2} p_u^{(2)}(r,\mu) - \frac{\mu_\pi^2}{2m_b^2} - \frac{3\mu_G^2}{2m_b^2} \right. \\
& \left. + \left(\frac{77}{6} + 8\ln\frac{\mu_{\rm WA}^2}{m_b^2}\right)\frac{\rho_D^3}{m_b^3} + \frac{3\rho_{LS}^3}{2m_b^3} + \frac{32\pi^2}{m_b^3} B_{\rm WA}(\mu_{\rm WA}) \right] \\
& + O\!\left(\alpha_s \frac{\mu_{\pi,G}^2}{m_b^2}\right) + O\!\left(\frac{1}{m_b^4}\right)
\end{aligned}
$$

Weak Annihilation

Life could be relatively easy with the total width...

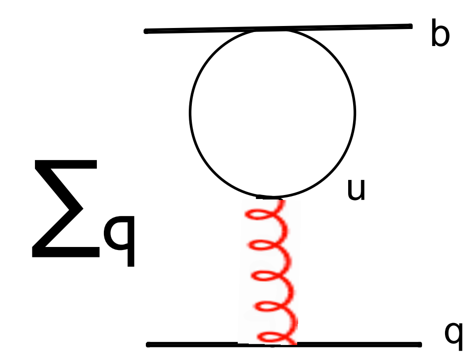
Weak Annihilation

Spectator dependent non-pert contribution localized at max E_l (or max q^2)
Bigi, Uraltsev 1993



In principle affects B^+ only but WA mixes with Darwin operator at O(1).
Isosinglet component can be as large as isotriplet

Difficult to study on the lattice, can be constrained experimentally Rosner et al [Cleo coll]



WA may pollute all present inclusive determinations of V_{ub} and more severely the less inclusive ones (E_l endpoint, high q^2)

D_s and D_0 rates differ significantly, (Cleo-c arXiv:0912.4232)

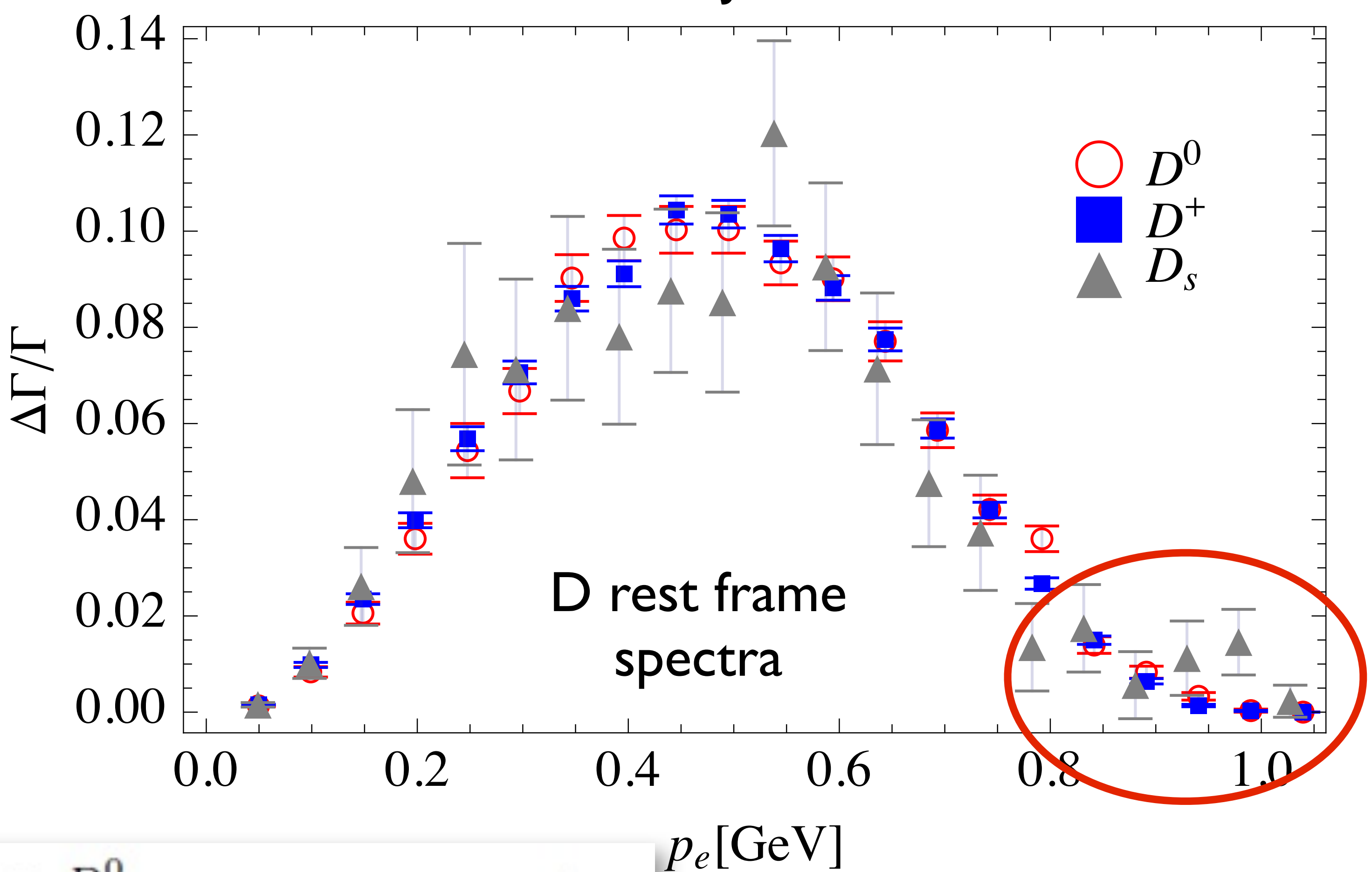
$$\Gamma(D^+ \to Xe^+\nu)/\Gamma(D^0 \to Xe^+\nu) = 0.985(28)$$
$$\Gamma(D_s^+ \to Xe^+\nu)/\Gamma(D^0 \to Xe^+\nu) = 0.828(57)$$

Valence WA Cabibbo suppressed in D^+, absent in D^0, is it a sign of WA?
Bigi,Mannel,Turczyk,Uraltsev 0911.3322 Ligeti,Luke,Manohar 1003.1351

Cleo-c electron spectra

JF Kamenik,PG, arXiv:1004.0114

- *Cleo also measured the electron spectra for p>0.2GeV. We extrapolated them to p=0, computed their first moments, and boosted to the D rest frame*
- *Moments should follow OPE, but are less sensitive to power and pert corrections than widths*



$$\langle E_\ell \rangle_{exp}^{D^0} = 0.459(3)\mathrm{GeV}\,, \qquad \langle E_\ell^2 \rangle_{exp}^{D^0} = 0.240(2)\mathrm{GeV}^2\,,$$

$$\langle E_\ell \rangle_{exp}^{D^+} = 0.455(1)\mathrm{GeV}\,, \qquad \langle E_\ell^2 \rangle_{exp}^{D^+} = 0.236(1)\mathrm{GeV}^2\,,$$

$$\langle E_\ell \rangle_{exp}^{D_s} = 0.456(11)\mathrm{GeV}\,, \qquad \langle E_\ell^2 \rangle_{exp}^{D_s} = 0.239(12)\mathrm{GeV}^2\,,$$

Moments

No evidence for spectator effects! Is there really evidence for WA?

SU(3) violation in charm

- Decay constants on the lattice:

  f_D=260(10)MeV vs f_{Ds}=217(10)MeV Bazavov et al

- Hyperfine splittings $\Delta^{hf}_{D_q} = 3(m^2_{D^*_q} - m^2_{D_q})/4 \approx \mu^2_G$

$$\Delta^{hf}_{D^+} = 0.409(1)\mathrm{GeV}^2\,, \qquad \Delta^{hf}_{D^0} = 0.413(1)\mathrm{GeV}^2\,, \qquad \Delta^{hf}_{D_s} = 0.440(2)\mathrm{GeV}^2$$

- SU(3) violation can be as large as 20%. Widths get much larger power corrections than moments and this might partially explain the observed width difference without WA

Results and implications J Kamenik,PG 1004.0114

Allowing for 20% SU(3) violation in the OPE parameters

$$\Delta B_{\rm WA}^{(0),s} \equiv B_{\rm WA}^{(0),s}(D_s) - B_{\rm WA}^{(0),s}(D^0)$$

$$\Delta B_{\rm WA}^{(0),s} = 0.0000(12)(3)\,{\rm GeV}^3$$

Valence component
always compatible with zero

$$B_{\rm WA}^{s} = -0.0003(25)\,{\rm GeV}^3$$

Singlet component

In worst dilution scenario from the moments alone (linearly adding errors)
equivalent to 30% error on rate

A factor ~2.5 in going to B: $|B_{\rm WA}^{b}(\mu_{\rm WA} = 0.8{\rm GeV})| \lesssim 0.006\,{\rm GeV}^3$ *Singlet*

$$-0.004\,{\rm GeV}^3 \lesssim \Delta B_{\rm WA}^{b}(\mu_{\rm WA} = 0.8{\rm GeV}) \lesssim 0.002\,{\rm GeV}^3$$ *Valence*

Max 1% effect on V_{ub} *for most inclusive analyses*
B^0 and B^+ inclusive widths should not differ more than about 1%

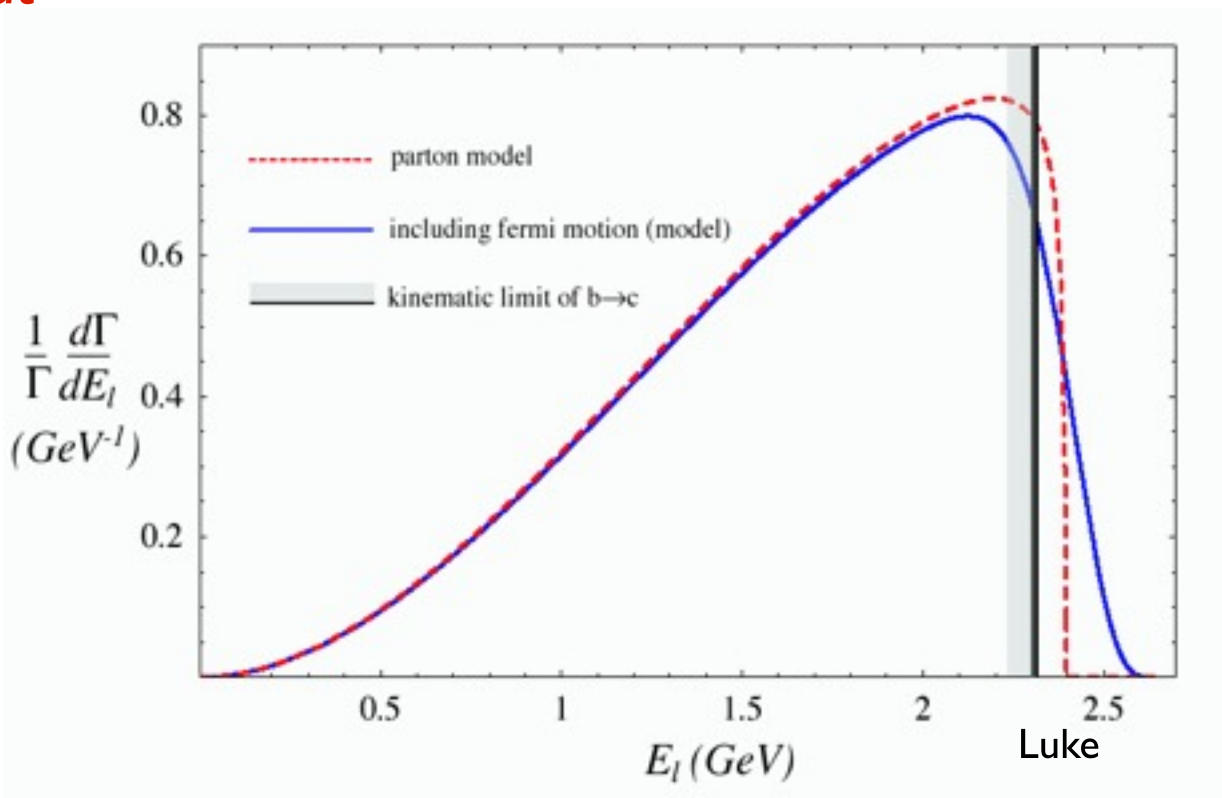
The problems with cuts

Experiments generally need kinematic cuts to avoid the ~100x larger $b \to cl\nu$ background:

$m_X < M_D$ $E_l > (M_B^2 - M_D^2)/2M_B$ $q^2 > (M_B - M_D)^2$ ...

The cuts destroy convergence of the OPE that works so well in b→c. OPE expected to work only away from pert singularities

Rate becomes sensitive to *local* b-quark wave function properties like Fermi motion Dominant non-pert contributions can be resummed into a **SHAPE FUNCTION** f(k+)

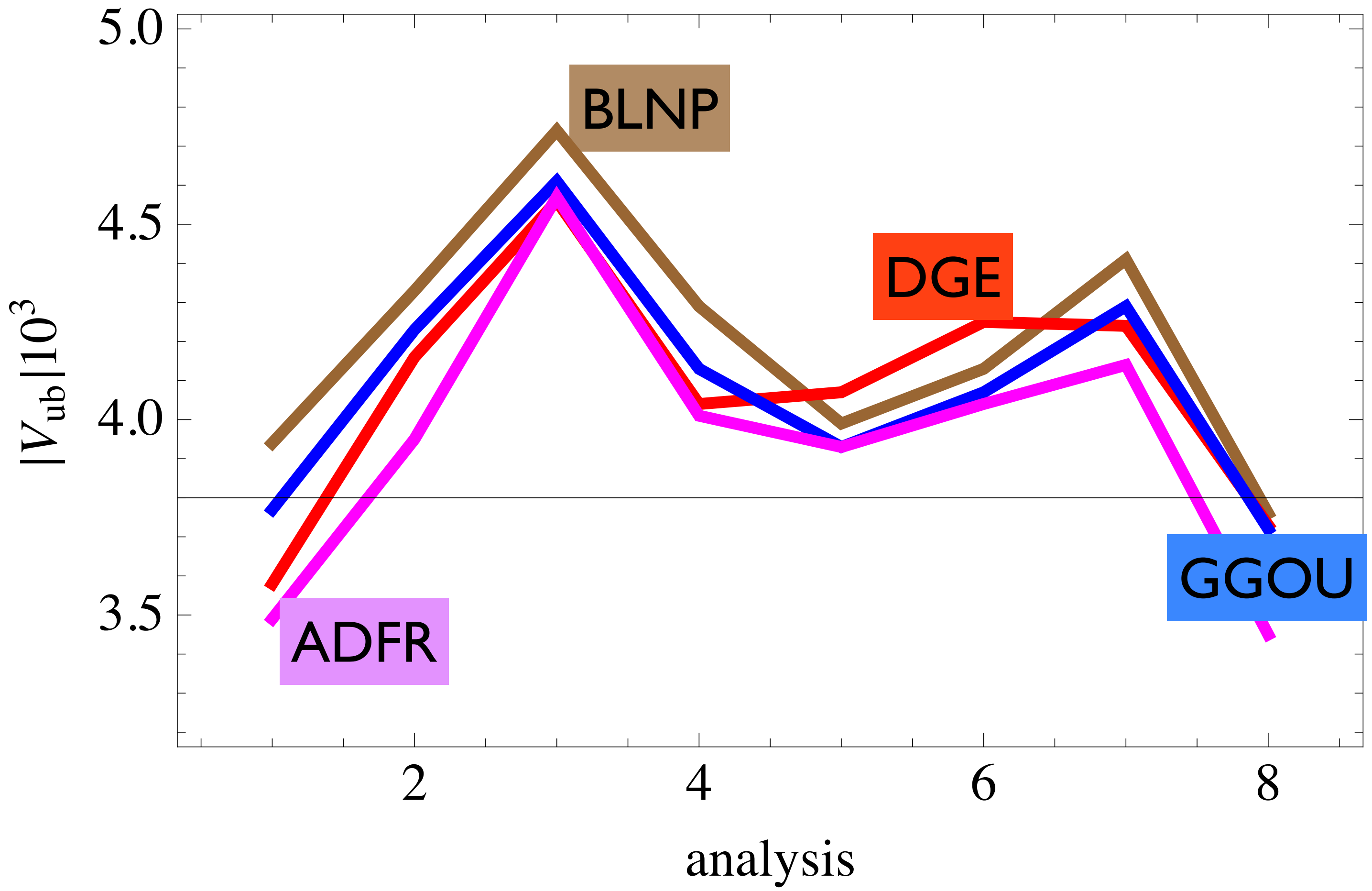


How to access the SF?

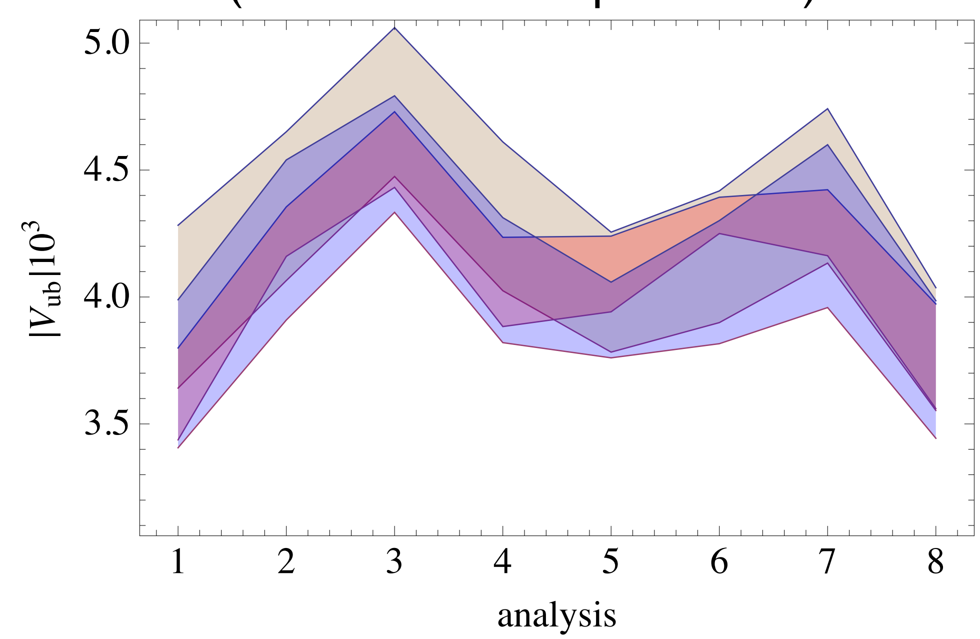
Prediction *based* on resummed pQCD DGE, ADFR	OPE constraints + parameterization without/with resummation GGOU, BLNP

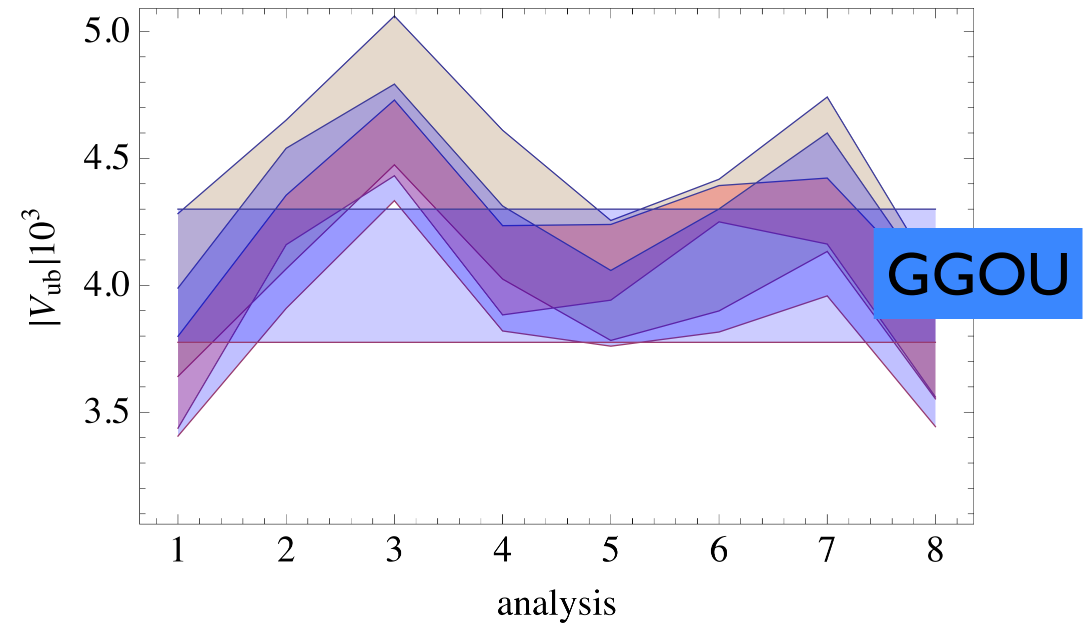
SIMBA fits radiative data for leading SF & m_b, parameterizes subleading only. No V_{ub} yet Bernlocher et al

A global comparison 0907.5386, Phys Rept



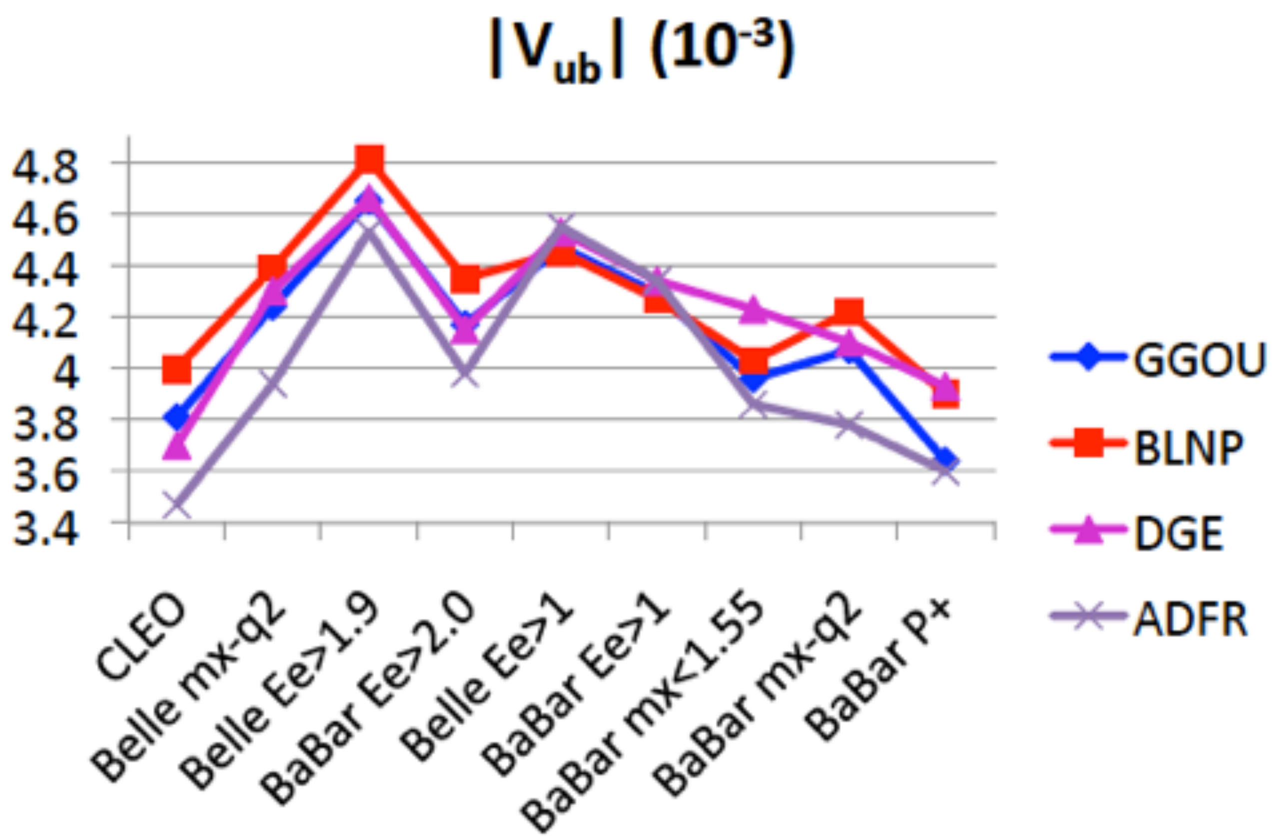
only theory errors
(without common parametric)





- ✳ Overall good agreement with common inputs SPREAD WITHIN TH ERRORS
- ✳ Recent BLNP at NNLO (in SF region) Asatrian,Greub, Neubert,Pecjak,Bonciani,Ferroglia Beneke,Huber, Li, Bell *Strong impact in BLNP (+10%), not yet included, unlikely in other approaches. $O(\alpha_s^2)$ calculation in the full phase space necessary*
- ✳ *Not all observables are equally* clean.

Inclusive $|V_{ub}|$ averages



HFAG 2010	Average $\|V_{ub}\| \times 10^3$
DGE	$4.44(16)_{ex}{}^{+18}_{-17}$
BLNP	$4.31(16)_{ex}{}^{+22}_{-23}$
GGOU	$4.33(16)_{ex}{}^{+15}_{-22}$

2.1σ from $B \to \pi l \nu$ (MILC-FNAL)
2.5σ from UTFit (because of sin2β)

Belle+Babar multivariate analysis, $E_l > 1$ GeV

$$|V_{ub}| \approx (4.35 \pm 0.18^{+0.13}_{-0.17}) \times 10^{-3}$$

Includes about 90% of the rate: really inclusive measurement, no need for SF. Crucial input m_b, needs to be confirmed!

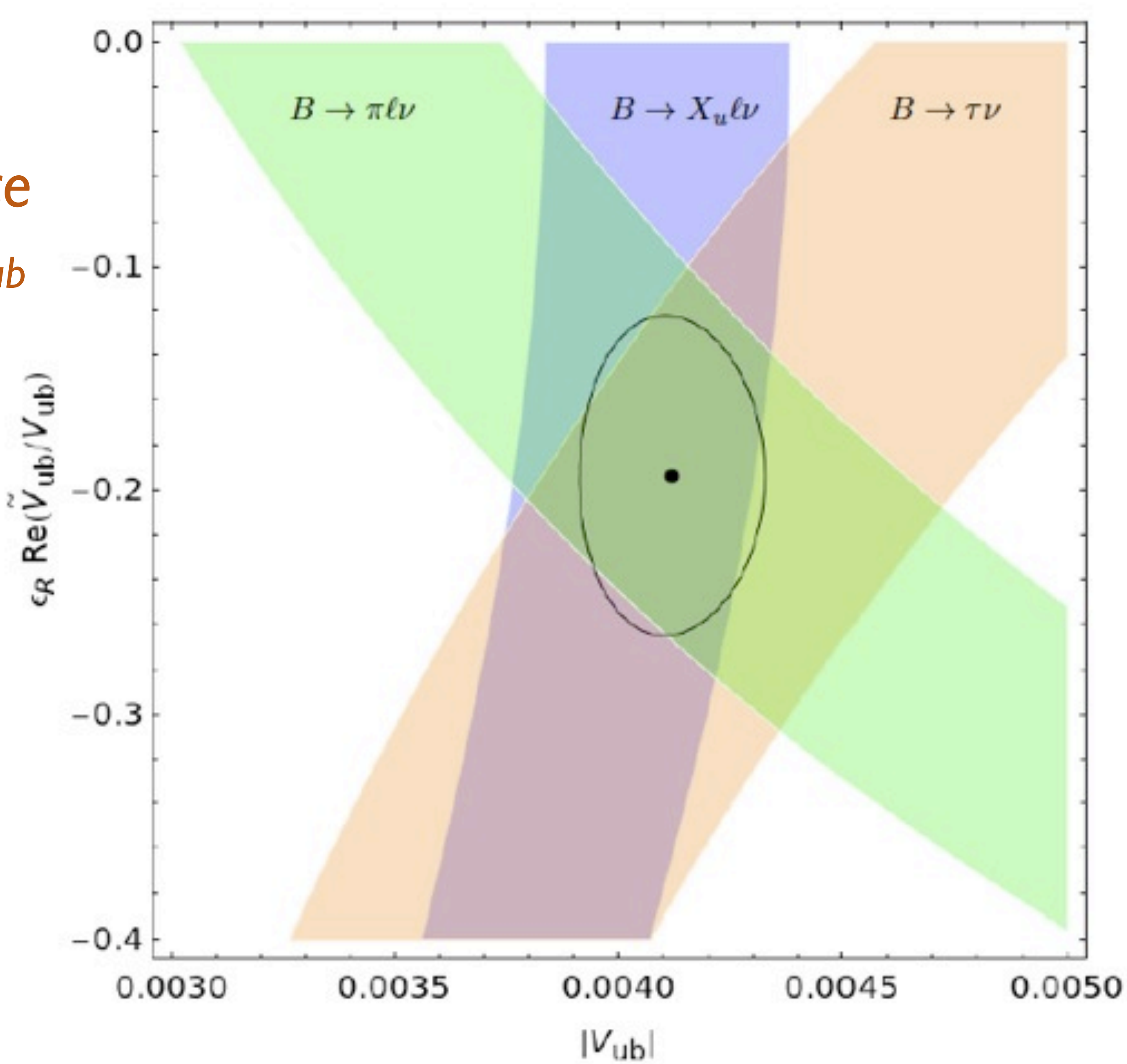
- **7-8% total error**
- More inclusive measurements, less dependence on m_b

New physics?

LR models can explain a difference between inclusive and exclusive V_{ub} determinations *Chen,Nam*

Also in MSSM *Crivellin*

BUT the RH currents affect predominantly the exclusive V_{ub}, making the conflict between V_{ub} and sin2β (ψK_S) stronger...



Buras, Gemmler, Isidori 1007.1993

Conclusions

- *Semileptonic B decays provide us with a lot of information: V_{cb}, V_{ub}, constraints on $m_{b,c}$ (consistent with sum rules)*
- *Slow but steady progress in inclusive $|V_{cb}|$, NNLO and higher power corrections, good prospects for th error reduction*
- *Some tension persists between exclusive and inclusive $|V_{cb}|$*
- *Inclusive V_{ub} moves slightly up, ~2σ clash with exclusive one and UT fit, but latest results should be described by local OPE.*

experimental problem or new physics?