Semileptonic D decays and Weak Annihilation

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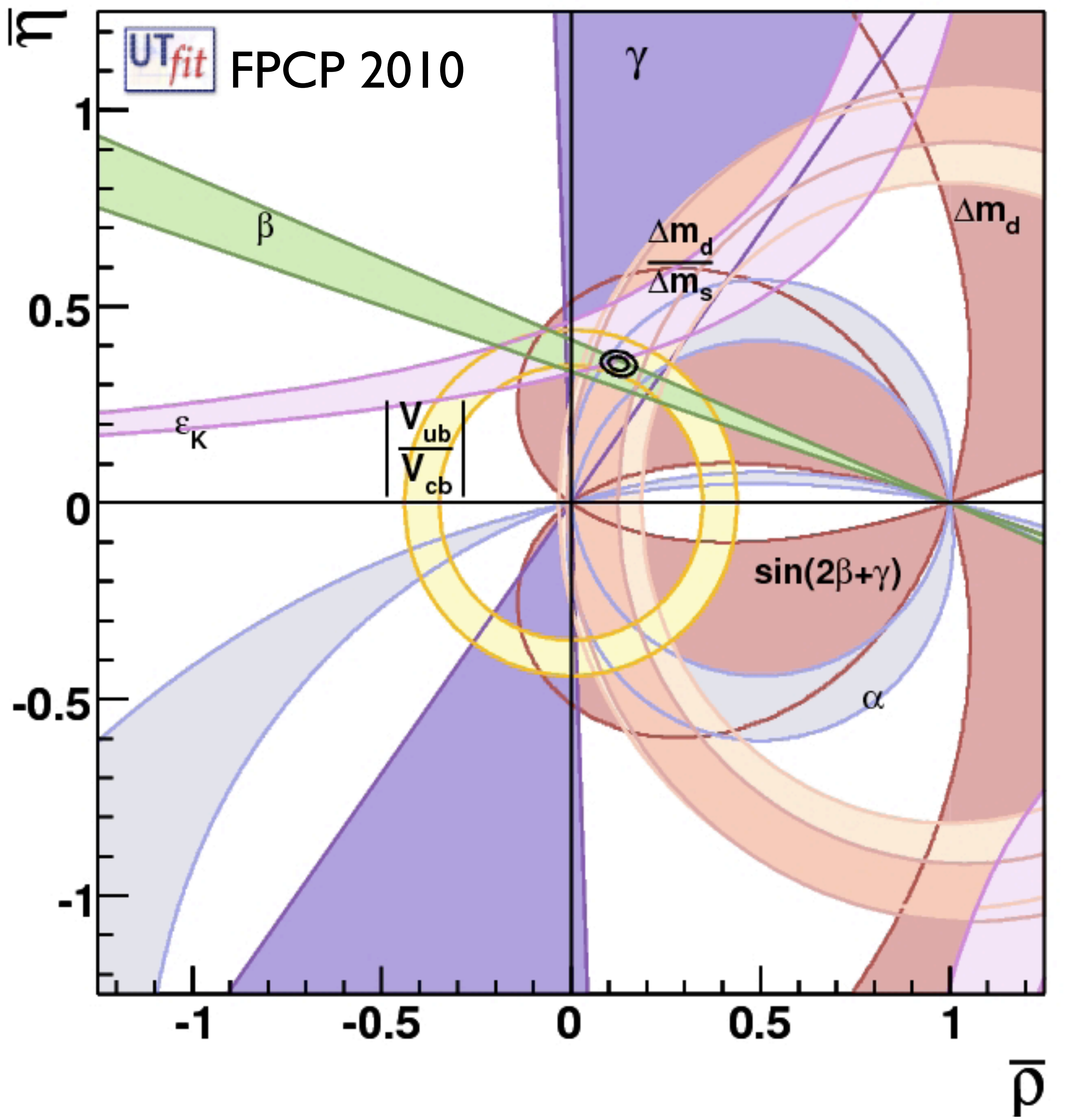
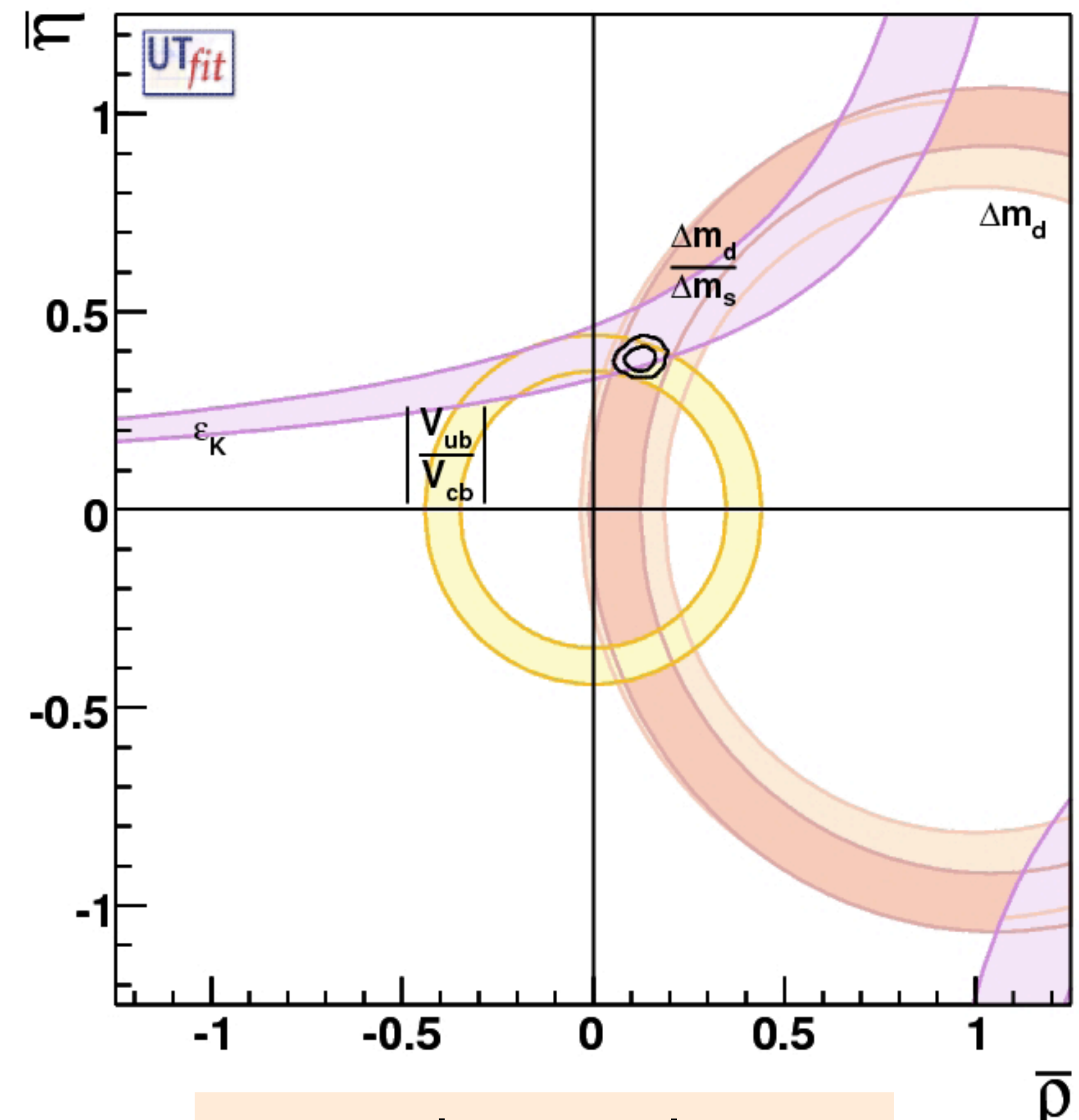
The Unitarity Triangle





$\bar{\rho}$ = 0.130 ± 0.020 $\bar{\eta}$ = 0.355 ± 0.013

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

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

M. Bona UTfit@FPCP 2010

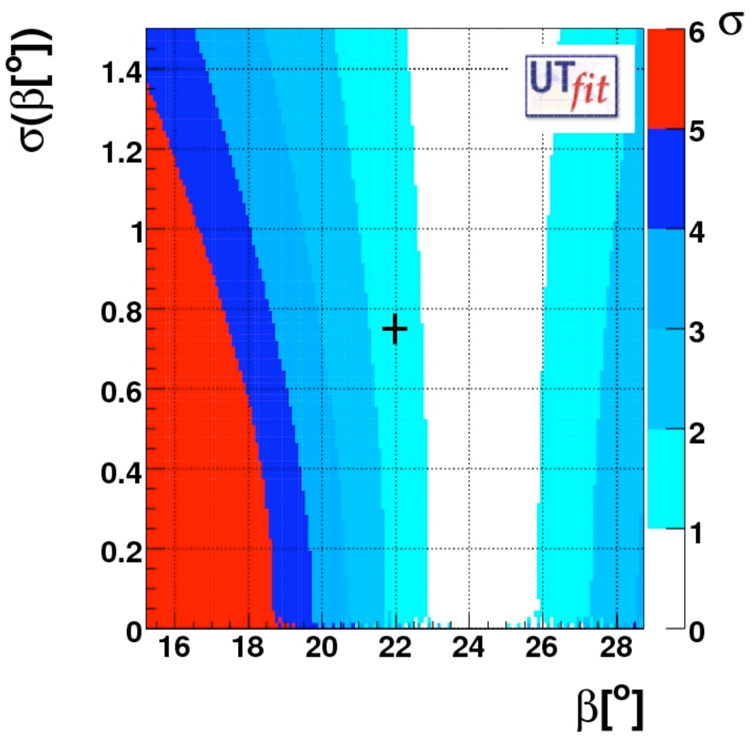
compatibility plots in the SM

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

~2.4σ

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

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

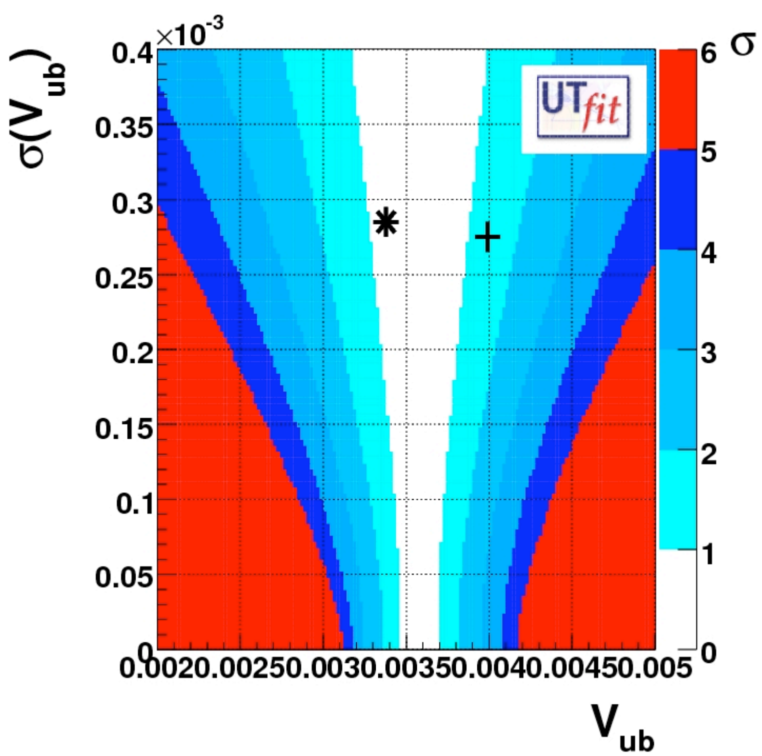


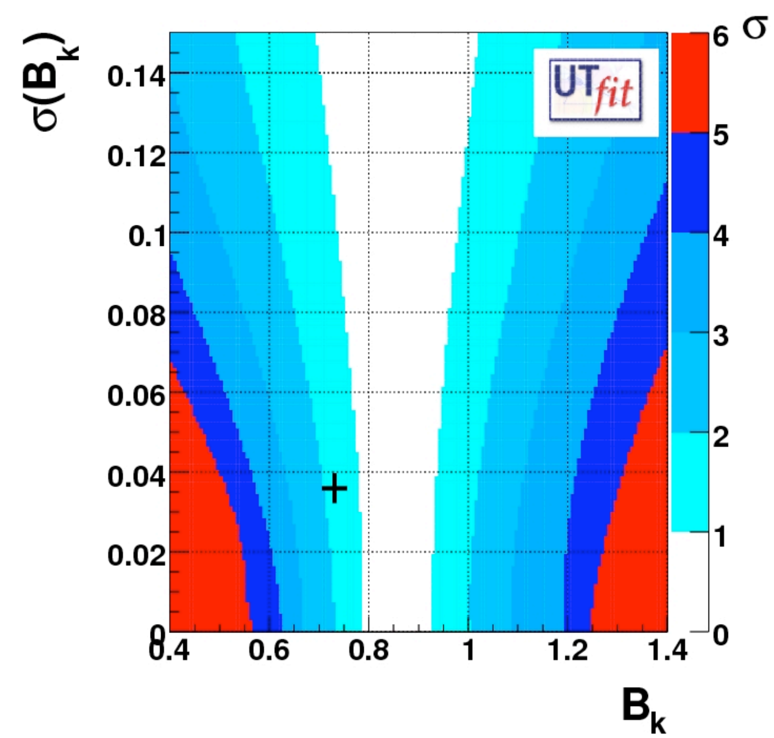
~1.6σ

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

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

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





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

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

! !

<1σ (incl ~1.3σ)

$|V_{ub}|$ in the kinetic scheme -GGOU

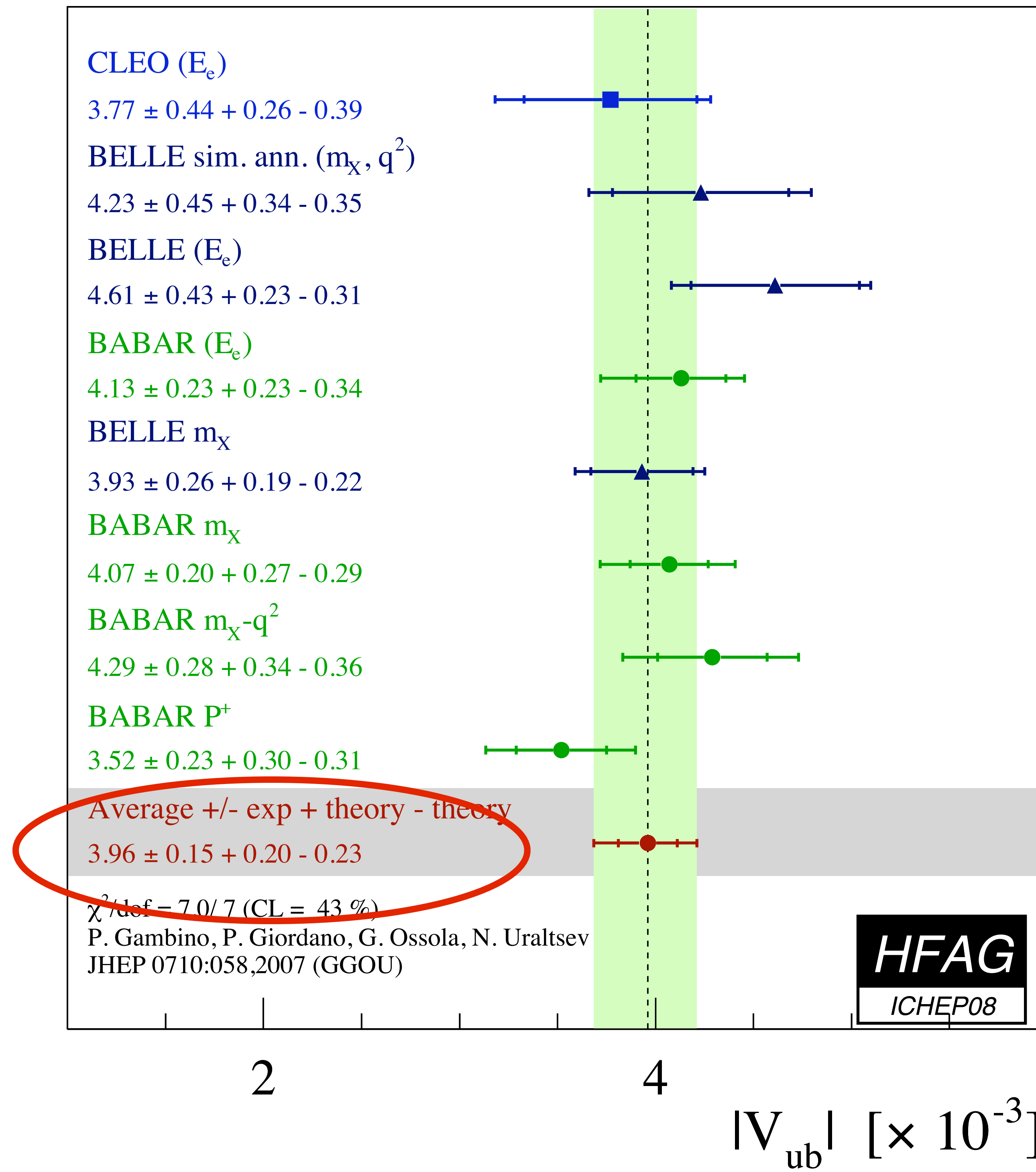
PG,Giordano,Ossola,Uraltsev

Good consistency & small th error.
OPE in a scheme with Wilsonian IR cutoff ~1GeV, all subleading $1/m_b$ and $O(\alpha_s^2\beta_0)$ terms consistently included,
careful treatment of high q^2 tail.

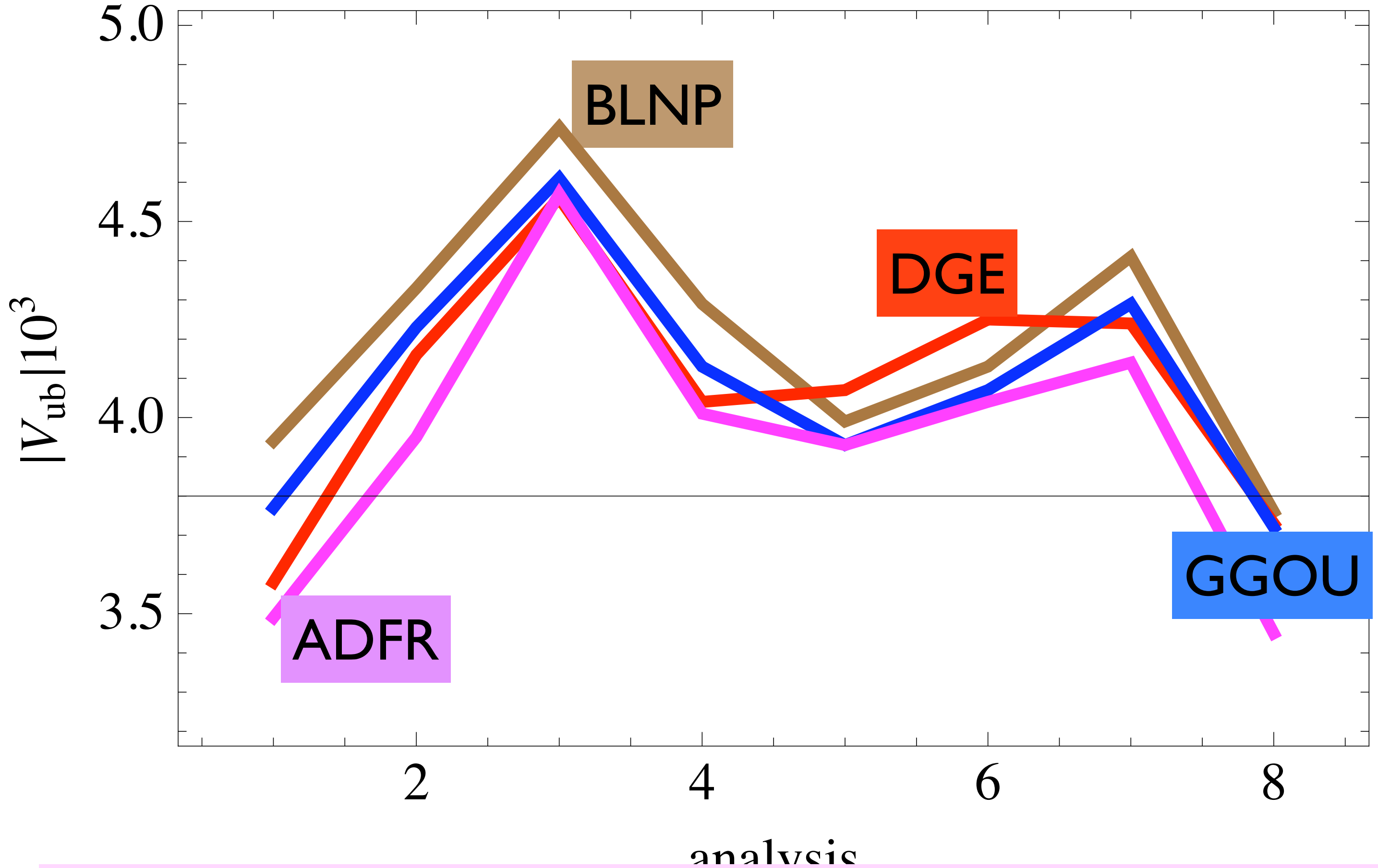
Inputs from global fit to the moments

+6.3-7.0% total error

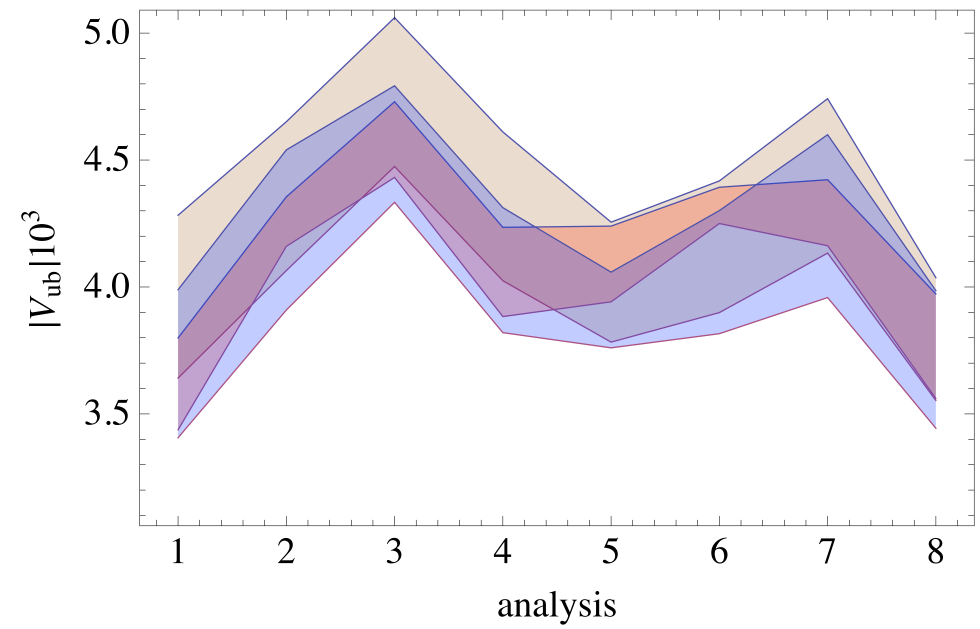
very strong dependence on m_b, twice larger than in total rate

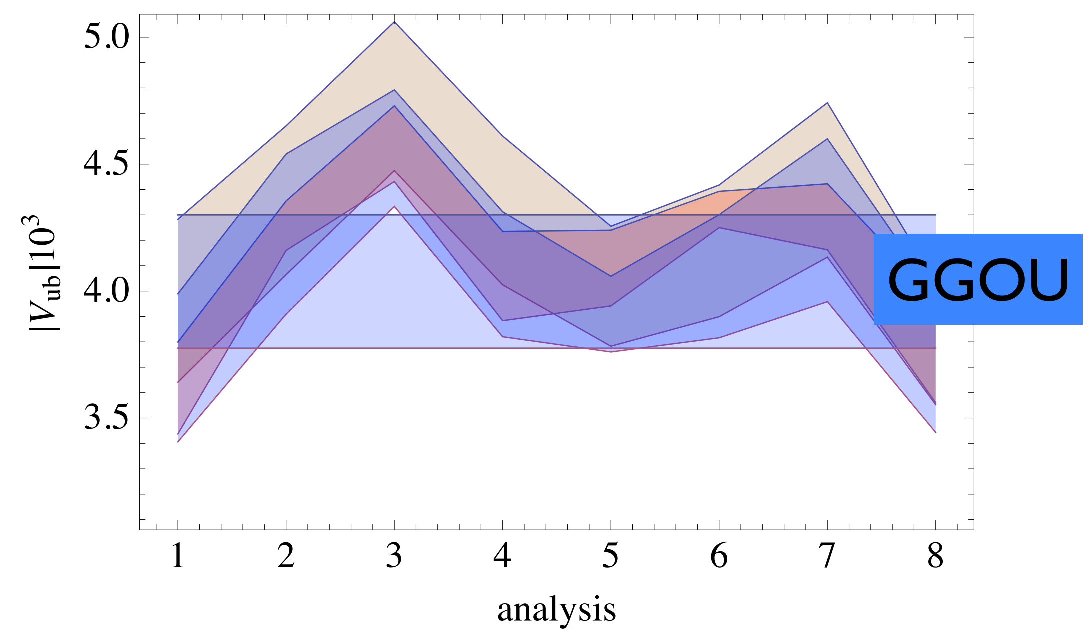


A global comparison arXiv:0907.5386



only theory errors
(without common parametric)





- ✳ common inputs (except ADFR)
- ✳ Overall good agreement **SPREAD WITHIN TH ERRORS!**
- ✳ NNLO BLNP still missing: will push it up a bit
- ✳ Systematic offset of central values: normalization? to be investigated

- *Not all observables are equally clean. eg high q^2 tail is sensitive to WA*
- *More inclusive measurements, less dependence on m_b*
- *Spectra can help discriminate models. Vary the cuts.*
- *Theory errors are partly parametric: m_b dependence is crucial*

HFAG 2010	Average $\|V_{ub}\| \times 10^3$
GGOU	$4.27(16)_{ex}{}^{+15}{}_{-21}$

2009 preliminary Belle Multivariate analysis only $E_l > 1$GeV

$$|V_{ub}| = (4.45 \pm 0.26^{+0.13}_{-0.22}) \times 10^{-3}$$

2.1σ from excl, 2.5σ from UTFit probably a bit less after fit upgrade

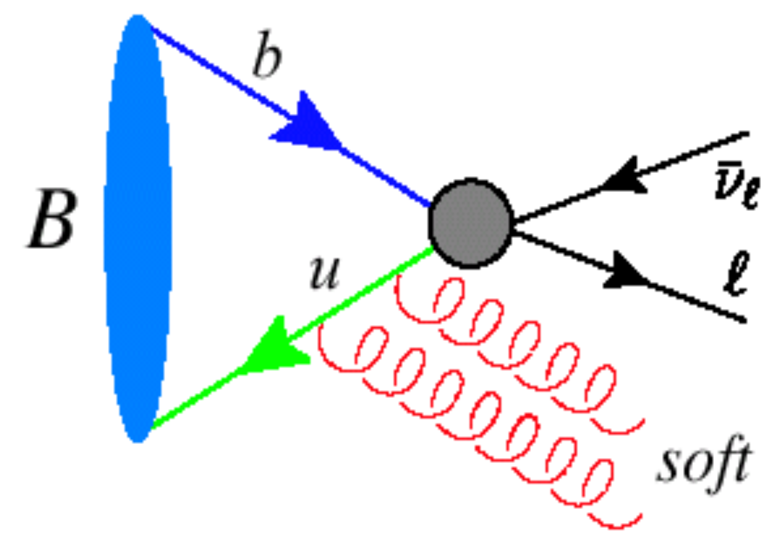
Includes about 90% of the rate: really inclusive measurement, no need for SF. Crucial input m_b, needs to be confirmed!

1.8σ from $B \to \pi l \nu$ (MILC-FNAL)
2.5σ from UTFit (because of sin2β)

NEW PHYSICS? *eg LR models Chen,Nam*

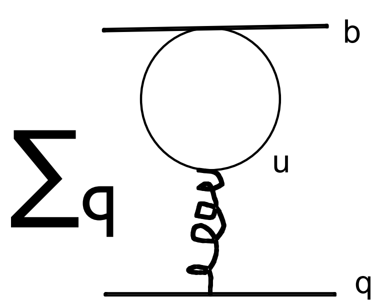
Weak Annihilation

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)

WA in the OPE

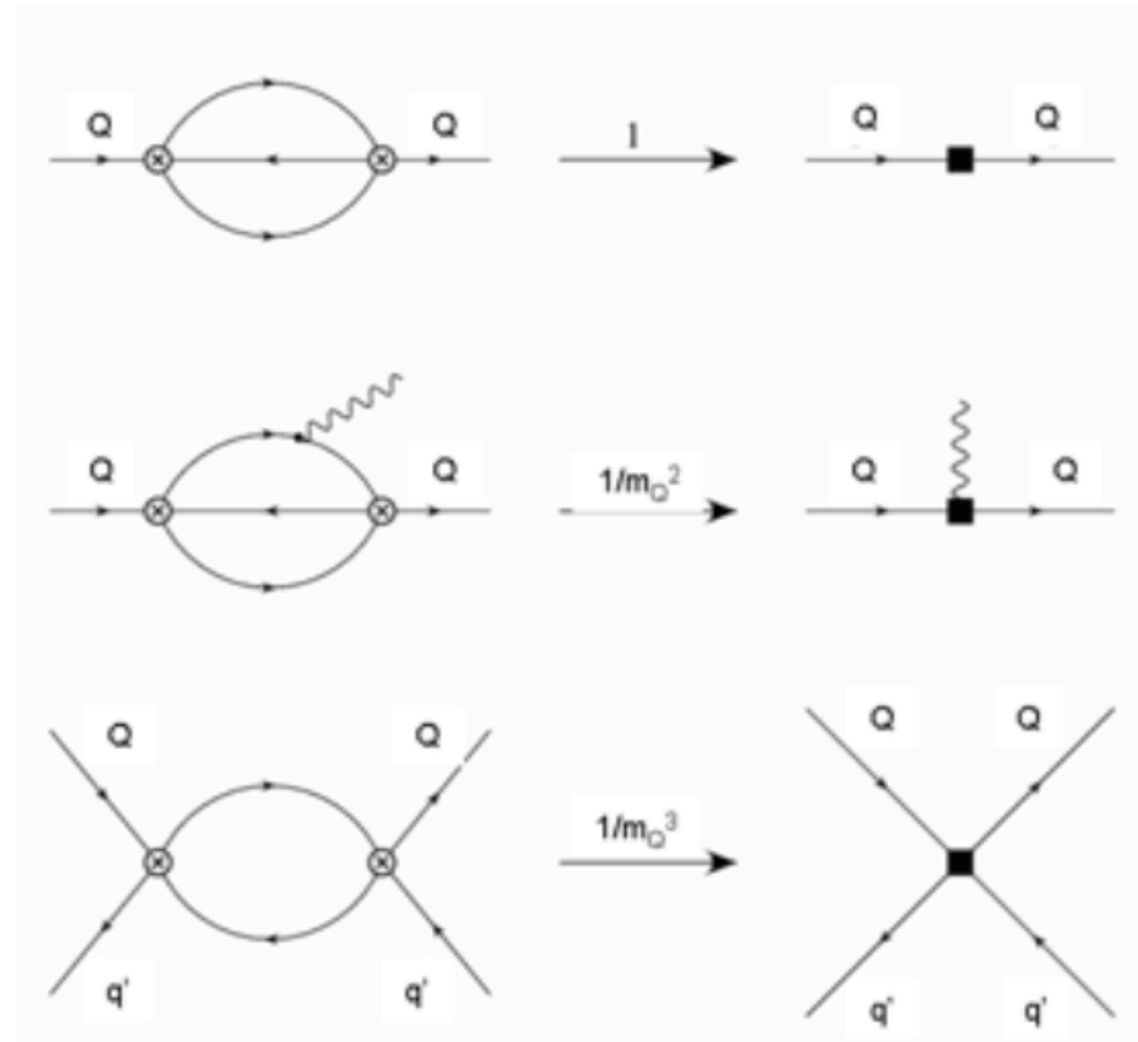
WA appears naturally in the OPE for total rates as a combination of 4-fermion dim-6 op

$$\mathcal{O}_1^{Qq} = \bar{Q}\gamma_\mu(1-\gamma_5)q\,\bar{q}\gamma^\mu(1-\gamma_5)Q$$

$$\mathcal{O}_2^{Qq} = \bar{Q}(1-\gamma_5)q\,\bar{q}(1-\gamma_5)Q$$

Its B meson exp value vanishes in the limit of factorization, but it is enhanced by the coefficient

$$B_{\rm WA}(\mu_{\rm WA}) = \langle B|O_1 - O_2|B\rangle$$



Because of the mixing with Darwin op, the WA m.e. depends on μ_{WA}

$$\delta\Gamma \sim \left[C_{\rm WA}\, B_{\rm WA}(\mu_{\rm WA}) - \left(8\ln\frac{m_b^2}{\mu_{\rm WA}^2} - \frac{77}{6}\right)\frac{\rho_D^3}{m_b^3} + \mathcal{O}(\alpha_s)\right] \qquad C_{\rm WA} = 32\pi^2/m_b^3$$

New Cleo-c results

arXiv:0912.4232

- Recently determined experimentally
  - $$B(D^+ \to Xe\nu) = (16.13 \pm 0.20 \pm 0.33)\%$$ $$B(D^0 \to Xe\nu) = (6.46 \pm 0.17 \pm 0.13)\%$$
  - Similar results for muons
- Very recently results also for D_s decays

$$B(D_s \to Xe\nu) = (6.52\pm, 0.39 \pm 0.15)\%$$

D_s and D_0 rates differ significantly

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

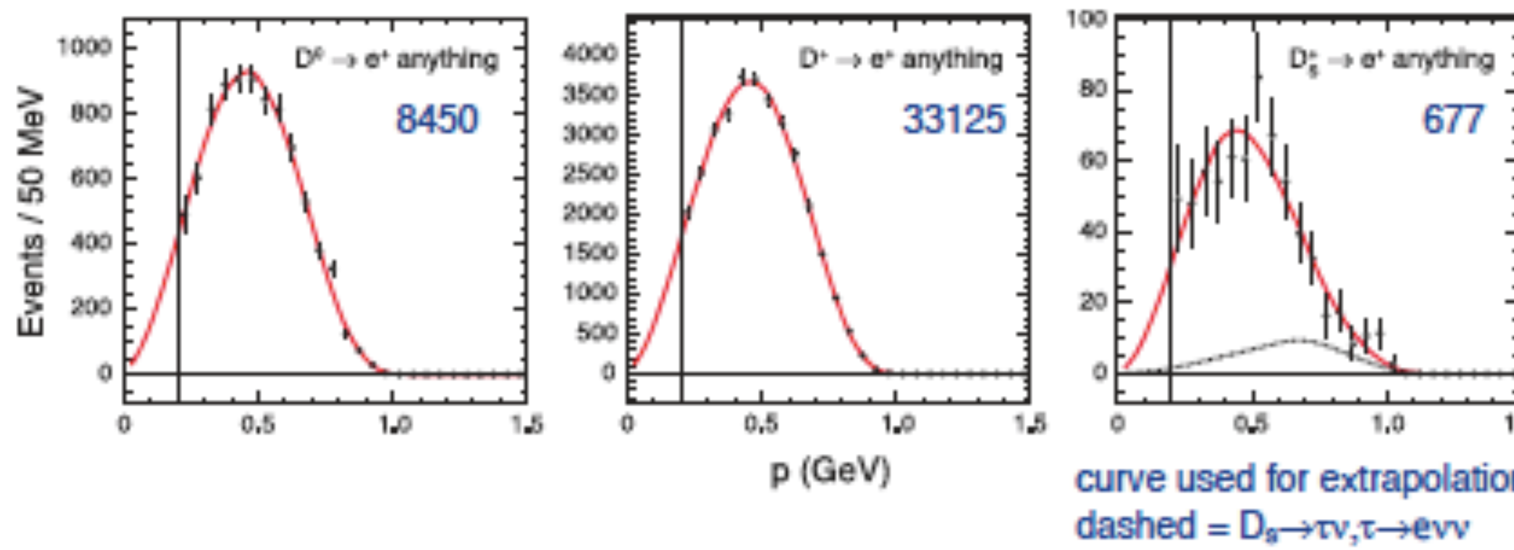
$$\Gamma(D_s^+ \to Xe^+\nu)/\Gamma(D^0 \to Xe^+\nu) = 0.828(57)$$

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

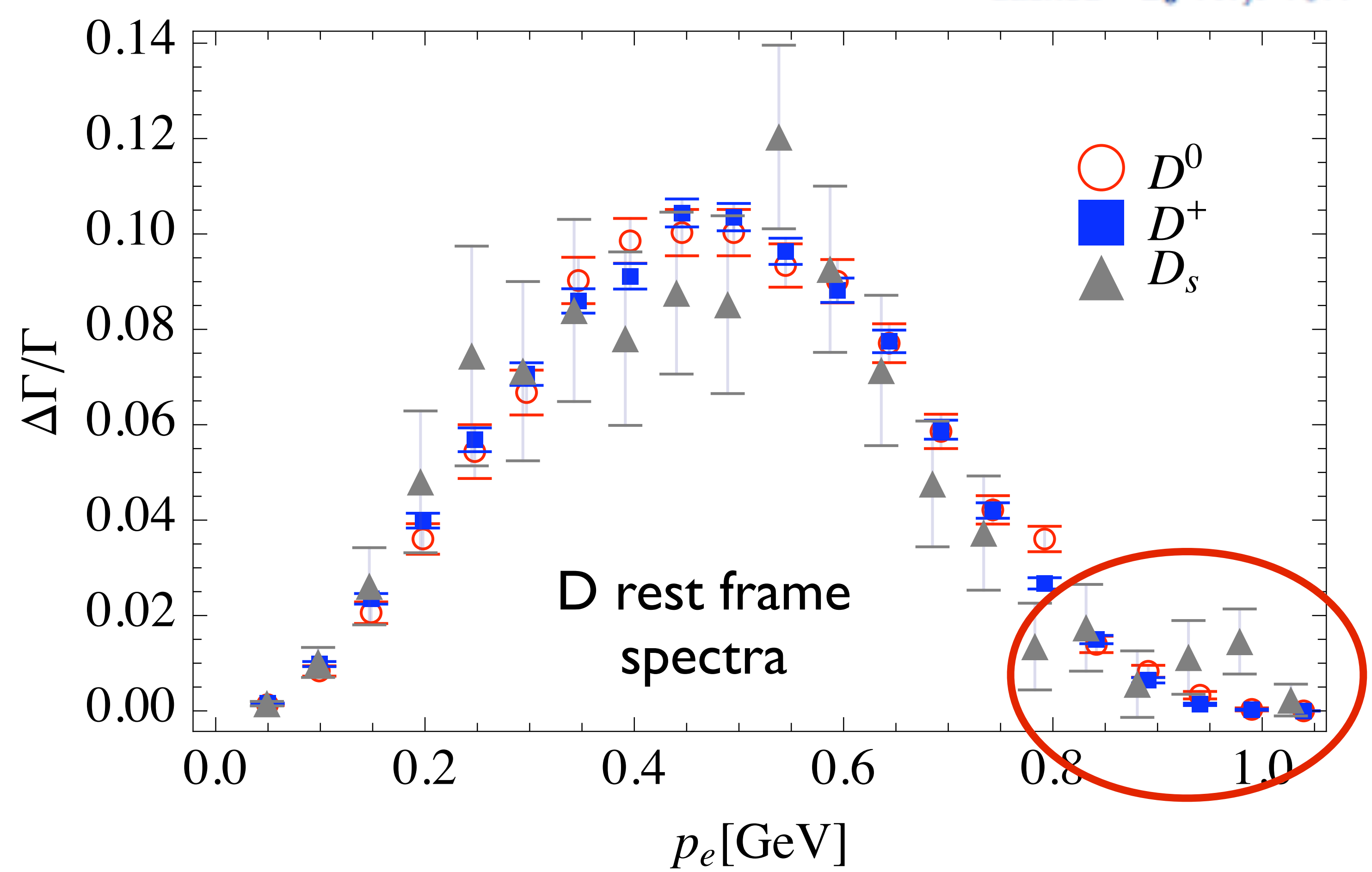
New Cleo-c results (II) arXiv:0912.4232

- Cleo also measured the electron spectra for p>0.2GeV in the lab



- We have extrapolated them to p=0, computed their first moments, and boosted to the D rest frame

- We cannot compute spectra, but moments should follow OPE.



New Cleo-c results (III)

$$\langle E_\ell \rangle^{D^0}_{exp} = 0.459(3)\text{GeV}\,, \qquad \langle E_\ell^2 \rangle^{D^0}_{exp} = 0.240(2)\text{GeV}^2\,,$$
$$\langle E_\ell \rangle^{D^+}_{exp} = 0.455(1)\text{GeV}\,, \qquad \langle E_\ell^2 \rangle^{D^+}_{exp} = 0.236(1)\text{GeV}^2\,,$$
$$\langle E_\ell \rangle^{D_s}_{exp} = 0.456(11)\text{GeV}\,, \qquad \langle E_\ell^2 \rangle^{D_s}_{exp} = 0.239(12)\text{GeV}^2\,,$$

JF Kamenik,PG, arXiv:1004.0114

$$\langle (E_\ell - \langle E_\ell \rangle)^2 \rangle^{D^0}_{exp} = 0.029(2)\text{GeV}^2\,,$$
$$\langle (E_\ell - \langle E_\ell \rangle)^2 \rangle^{D^+}_{exp} = 0.029(1)\text{GeV}^2\,,$$
$$\langle (E_\ell - \langle E_\ell \rangle)^2 \rangle^{D_s}_{exp} = 0.031(12)\text{GeV}^2$$

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

OPE expansion for charm

$$\boxed{\Gamma^{(n)} \equiv \int_0^{(1-r)} \frac{d\Gamma}{dx} x^n dx}$$

Moments

$$x = 2E_e/m_c, \quad r = m_s^2/m_c^2$$

$$= \frac{G_F^2 m_c^5}{192\pi^3}|V_{cs}|^2 \left[f_0^{(n)}(r) + \frac{\alpha_s}{\pi} f_1^{(n)}(r) + \frac{\alpha_s^2}{\pi^2} f_2^{(n)}(r) + \frac{\mu_\pi^2}{m_c^2} f_\pi^{(n)}(r) + \frac{\mu_G^2}{m_c^2} f_G^{(n)}(r) \right.$$
$$\left. + \frac{\rho_{LS}^3}{m_c^3} f_{LS}^{(n)}(r) + \frac{\rho_D^3}{m_c^3} f_D^{(n)}(r) + \frac{32\pi^2}{m_c^3} B_{\rm WA}^{(n)s} \right],$$

- *$O(\alpha_s^2\beta_0)$ pert corrections*
- *$O(1/m_c^3)$ power corrections*

Pole mass scheme, m_c=1.6GeV, μ_{WA}=0.8GeV

$$\Gamma = \Gamma_0 \left[1 - 0.72\,\alpha_s - 0.29\,\alpha_s^2\beta_0 - 0.60\,\mu_G^2 - 0.20\,\mu_\pi^2 + 0.42\,\rho_D^3 + 0.38\,\rho_{LS}^3 + 80 B_{\rm WA}^{(0)} \right],$$

$$\langle E \rangle = \langle E \rangle_0 \left[1 - 0.03\,\alpha_s - 0.03\,\alpha_s^2\beta_0 - 0.07\,\mu_G^2 + 0.20\,\mu_\pi^2 + 1.4\,\rho_D^3 + 0.29\,\rho_{LS}^3 + 135 \bar{B}_{\rm WA}^{(1)} \right]$$

$$\langle E^2 \rangle = \langle E^2 \rangle_0 \left[1 - 0.07\,\alpha_s - 0.05\,\alpha_s^2\beta_0 - 0.14\,\mu_G^2 + 0.52\,\mu_\pi^2 + 3.5\,\rho_D^3 + 0.66\,\rho_{LS}^3 + 204 \bar{B}_{\rm WA}^{(2)} \right]$$

$$\sigma_E^2 = (\sigma_E^2)_0 \left[1 - 0.09\,\alpha_s - 0.05\,\alpha_s^2\beta_0 - 0.14\,\mu_G^2 + 1.7\,\mu_\pi^2 + 9.4\,\rho_D^3 + 1.4\,\rho_{LS}^3 + 641 \bar{B}_{\rm WA}^{(\sigma)} \right],$$

Poor convergence for rates. Moments have smaller pert and power corrections, but are still quite sensitive to WA

OPE expansion for charm

Kinetic scheme, μ=0.5GeV, m_c=1.4GeV, μ_{WA}=0.8GeV

$$\Gamma_{kin} = 1.2(3)10^{-13}\mathrm{GeV}\left\{1 + 0.23\,\alpha_s + 0.18\,\alpha_s^2\beta_0 - 0.79\,\mu_G^2 - 0.26\mu_\pi^2 + 1.45\,\rho_D^3 + 0.56\rho_{LS}^3 + 120 B_{\mathrm{WA}}^{(0)}\right\}$$

$$\langle E_\ell\rangle_{kin} = 0.415(21)\mathrm{GeV}\left\{1 + 0.03\,\alpha_s + 0.02\,\alpha_s^2\beta_0 - 0.09\,\mu_G^2 + 0.26\mu_\pi^2 + 2.7\rho_D^3 + 0.44\rho_{LS}^3 + 203\bar{B}_{\mathrm{WA}}^{(1)}\right\},$$

$$\langle E_\ell^2\rangle_{kin} = 0.192(20)\mathrm{GeV}^2\left\{1 + 0.001\,\alpha_s + 0.02\,\alpha_s^2\beta_0 - 0.18\,\mu_G^2 + 0.68\mu_\pi^2 + 6.6\rho_D^3 + 0.99\rho_{LS}^3 + 307\bar{B}_{\mathrm{WA}}^{(2)}\right\},$$

$$\sigma_{E,kin}^2 = 0.019(2)\mathrm{GeV}^2\left\{1 - 0.53\,\alpha_s - 0.17\,\alpha_s^2\beta_0 - 0.18\mu_G^2 + 2.2\mu_\pi^2 + 17\rho_D^3 + 2.1\rho_{LS}^3 + 961\bar{B}_{\mathrm{WA}}^{(\sigma)}\right\},$$

In kinetic scheme, better convergence for low 0.5<μ<0.8GeV.
D-expectation values related to those in B by heavy quark symmetry
Use B->X_c lν moments fit for m_c and OPE parameters with enlarged errors

$$\Gamma_{\mathrm{WA}}^{(n)}(D^0) \propto \cos^2\theta_c B_{\mathrm{WA}}^{(n),s}(D^0) + \sin^2\theta_c B_{\mathrm{WA}}^{(n),d}(D^0),$$

$$\Gamma_{\mathrm{WA}}^{(n)}(D^+) \propto \cos^2\theta_c B_{\mathrm{WA}}^{(n),s}(D^+) + \sin^2\theta_c B_{\mathrm{WA}}^{(n),d}(D^+),$$

$$\Gamma_{\mathrm{WA}}^{(n)}(D_s) \propto \cos^2\theta_c B_{\mathrm{WA}}^{(n),s}(D_s) + \sin^2\theta_c B_{\mathrm{WA}}^{(n),d}(D_s),$$

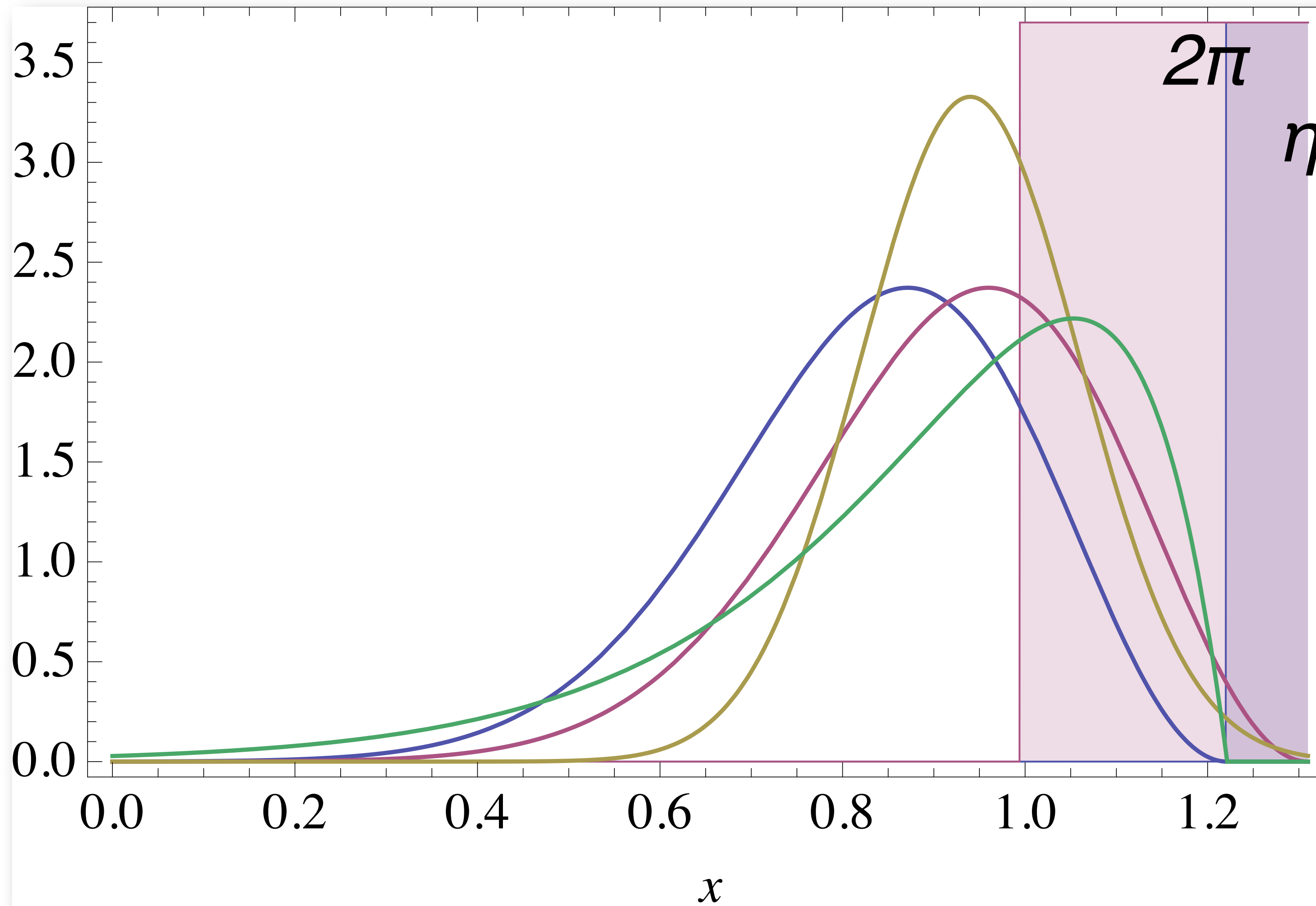
Cabibbo suppressed contributions generally negligible
We can extract the singlet and "valence" contributions

WA dilution

Expect perturbative and non-perturbative smearing of WA. It is both α_s and $1/m_c$ suppressed.

The exclusive upper threshold is 2π or η

The smearing is <u>model dependent</u> and generally dilutes the WA contribution to higher E_l moments, although it is generally a modest effect



$$B_{\rm WA}^{(n),q} = B_{\rm WA}^{q}, \text{ for all } n$$ No dilution

$$B_{\rm WA}^{(1)q} \gtrsim 0.8\, B_{\rm WA}^{(0)q},\ B_{\rm WA}^{(2)q} \gtrsim 0.7\, B_{\rm WA}^{(0)q}$$ our dilution models

Results

JF Kamenik,PG 1004.0114

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

$$\Delta B_{\rm WA}^{(0),s} \equiv B_{\rm WA}^{(0),s}(D_s) - B_{\rm WA}^{(0),s}(D^0) = -0.0014(12)(5)\mathrm{GeV}^3$$

$$\Delta \bar{B}_{\rm WA}^{(1),s} = 0.0000(3)(1)\mathrm{GeV}^3$$

$$\Delta \bar{B}_{\rm WA}^{(2),s} = 0.0000(4)(2)\mathrm{GeV}^3$$

Valence component
always compatible with zero

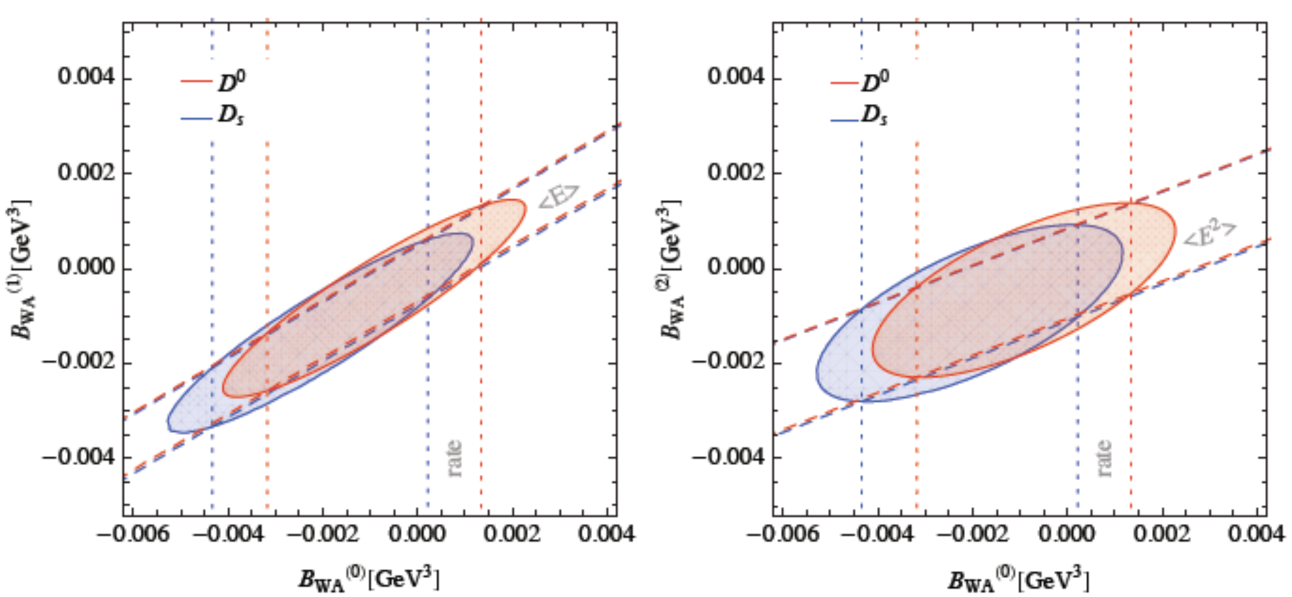
In worst dilution scenario the moments alone give (linearly adding errors)

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

Singlet component

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

equivalent to 30% error on rate



In principle, one can even probe dilution in data by comparing WA contributions to different moments resolution is now insufficient

Implications for V_{ub}

A factor 2.5 in going to B

neglecting running and power corrections

$$B^{bq}_{\rm WA}(\mu_{\rm WA}) = \frac{m_B f_B^2}{m_D f_D^2} B^{cq}_{\rm WA}(\mu_{\rm WA})$$

Singlet component $|B^b_{\rm WA}(\mu_{\rm WA} = 0.8 \mathrm{GeV})| \lesssim 0.006 \mathrm{GeV}^3$

Valence component $-0.004\,\mathrm{GeV}^3 \lesssim \Delta B^b_{\rm WA}(\mu_{\rm WA} = 0.8\mathrm{GeV}) \lesssim 0.002\,\mathrm{GeV}^3$

In GGOU V_{ub} analysis we had max B_{WA}=0.02. Factor 3 improvement.
Max 1% effect on V_{ub} *for most inclusive analyses*
B^0 and B^+ inclusive widths should not differ more than about 1%

Compatible results from widths only in Ligeti, Luke, Manohar, 1003.1351 but moments are cleaner than rates and our errors more conservative

Conclusions

- *OPE seems to work surprisingly well for D decays*
- *We find no evidence for WA, mild indication in the widths*
- *WA uncertainty in inclusive $|V_{ub}|$ is reduced by factor 3*
- *Additional tests possible at Cleo and BES-III*