Bs decays into charmonium and the extraction of β s

- β s
- Bs->f_0(980) form factors
- Bs decays into charmonium

Wei Wang

INFN, Sezione di Bari

In collaboration with Pietro Colangelo and Fulvia De Fazio

QCD@work Martina Franca July 20-23, 2010

Time-dependent CP Violation in Bs decays

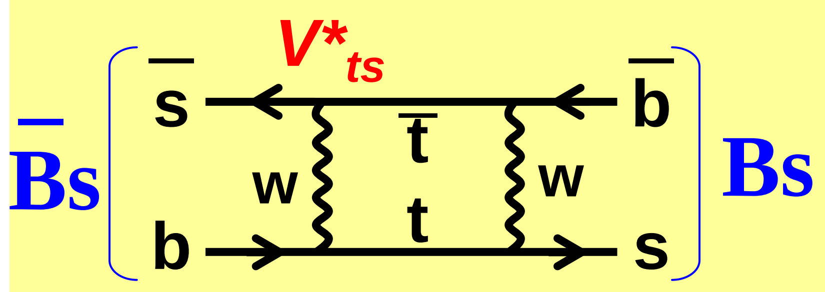
CKM ansatz: CPV is due to a complex phase in the quark mixing matrix

$$V_{n=3} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \simeq \begin{pmatrix} 1-\lambda^2/2 & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1-\lambda^2/2 & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{pmatrix}$$

$\mathcal{O}(\lambda^6)$

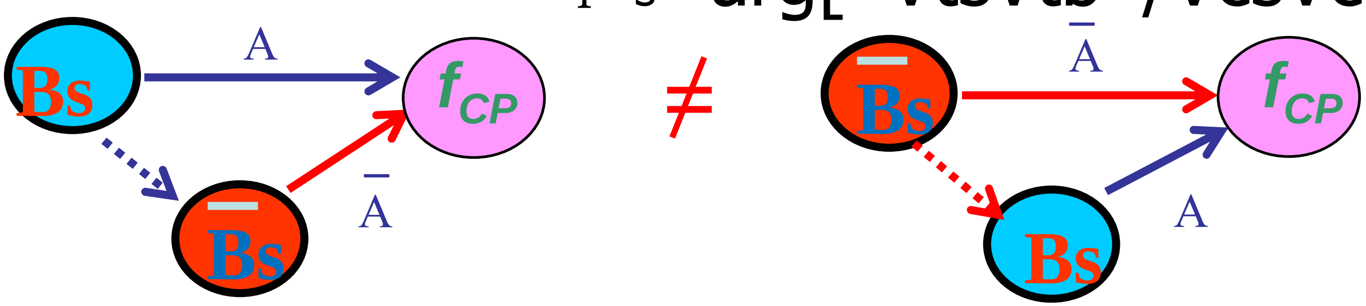
$$\begin{pmatrix} 1-\frac{1}{2}\lambda^2-\frac{1}{8}\lambda^4 & \lambda & A\lambda^3(\rho-i\eta) \\ -\lambda\left[1+\frac{1}{2}A^2\lambda^4(2\rho-1)+iA^2\lambda^4\eta\right] & 1-\frac{1}{2}\lambda^2-\frac{1}{8}\left(4A^2+1\right)\lambda^4 & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2\left[1+\frac{1}{2}\lambda^2(2\rho-1)+i\lambda^2\eta\right] & 1-\frac{1}{2}A^2\lambda^4 \end{pmatrix}$$

Bs-$\overline{\text{Bs}}$ mixing



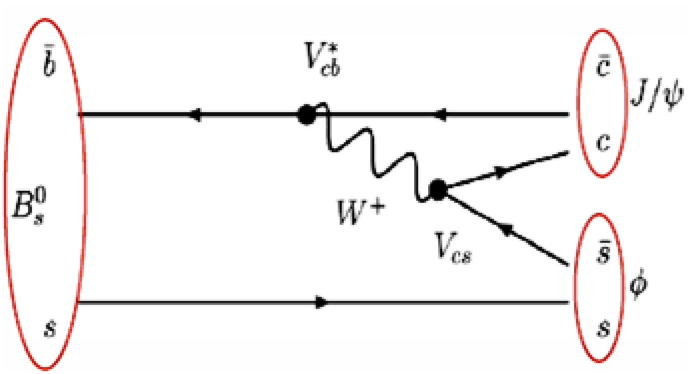
mixing induced CP violation

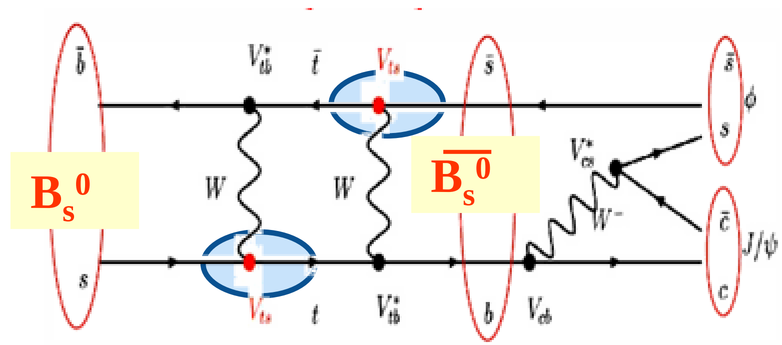
$\beta_s = \arg[-V_{ts}V_{tb}^*/V_{cs}V_{cb}^*]$



ϕ_s from golden mode $B_s \to J/\psi\ \phi$

$B_s(\overline{B}_s) \rightarrow J/\psi(\mu+\mu-)\ \phi(K+K-)$ can proceed directly or through mixing



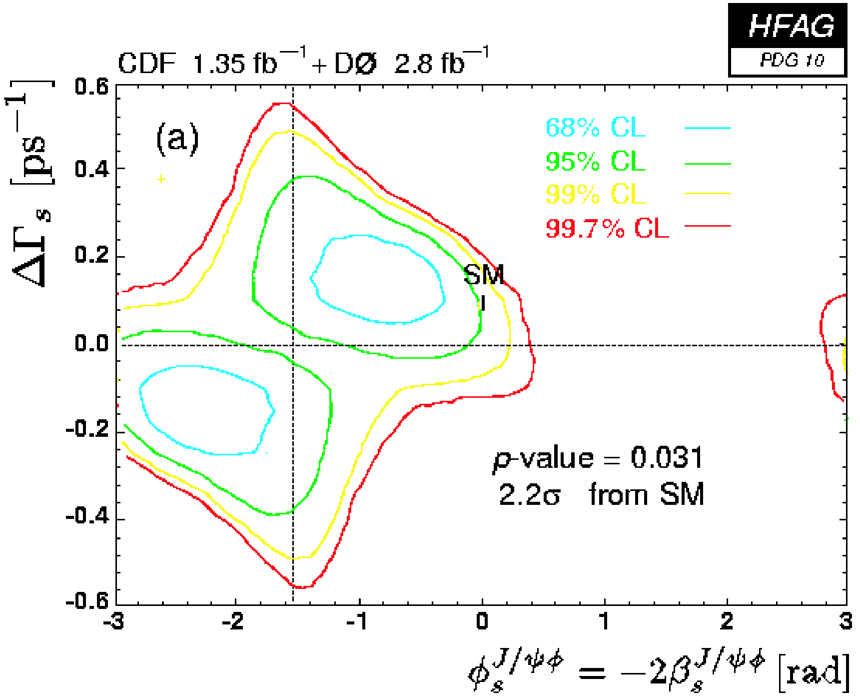


$$A_{CP}(t) = \frac{\Gamma[\overline{B}_s(t) \to f] - \Gamma[B_s(t) \to f]}{\Gamma[\overline{B}_s(t) \to f] + \Gamma[B_s(t) \to f]}$$

$$A_{CP}(t) = \frac{\eta_f sin\phi_s sin(\Delta m_s)t}{cosh(\Delta\Gamma_s t/2) - \eta_f cos\phi_s sinh(\Delta\Gamma_s t/2)}$$

Angular analysis to disentangle different CP-eigenstates

ϕ_s from golden mode $B_s \to J/\psi\ \phi$



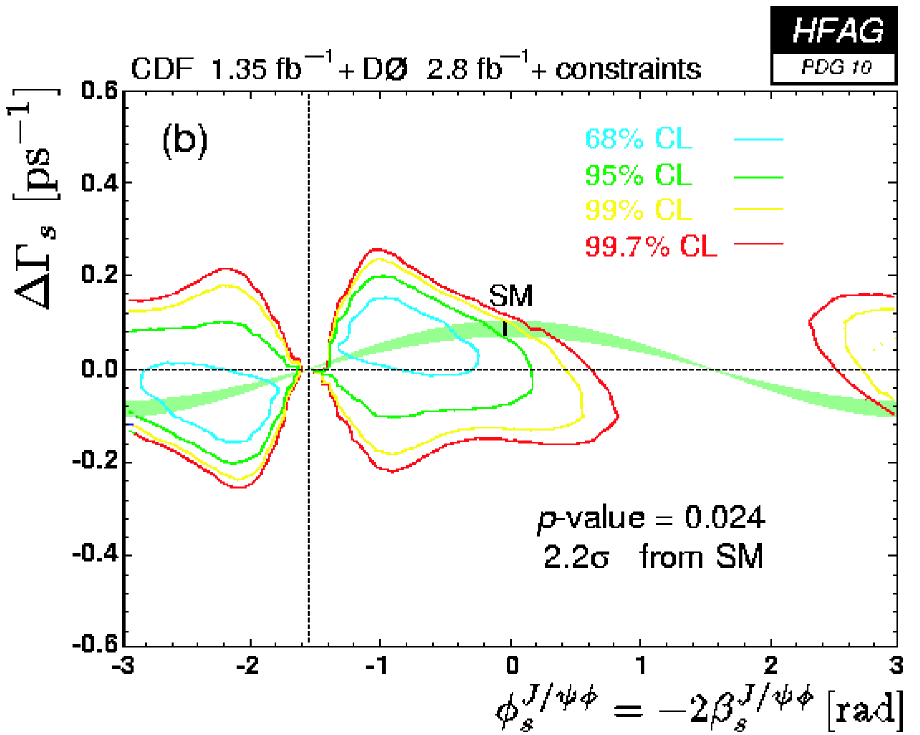
SM: ϕs =-2 β s=-0.04

CDF+D0:[−1.47 ; −0.29] ∪ [−2.85 ; −1.65]
90% CL

First evidence of New Physics?

Uncertainties of the data are still large.

More precise measurement
New channels—cross-check

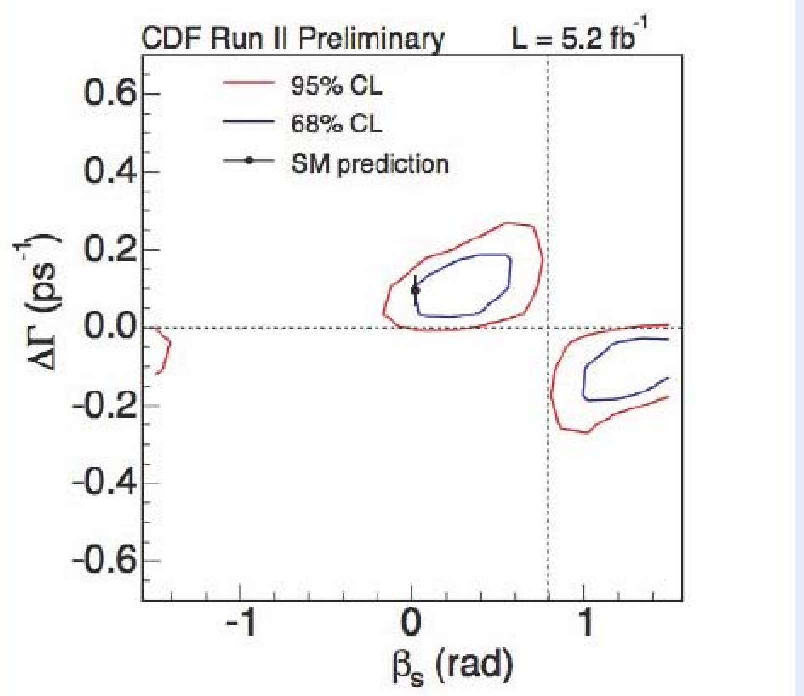


ϕ_s from golden mode $B_s \to J/\psi\ \phi$

New CDF measurement of β_s

68% CL: [0.0, 0.5] U [1.1, 1.5]
95% CL: [-0.1, 0.7] U [0.9, pi/2] U [-pi/2, -1.5]

CDF II Preliminary 5.2fb $^{-1}$

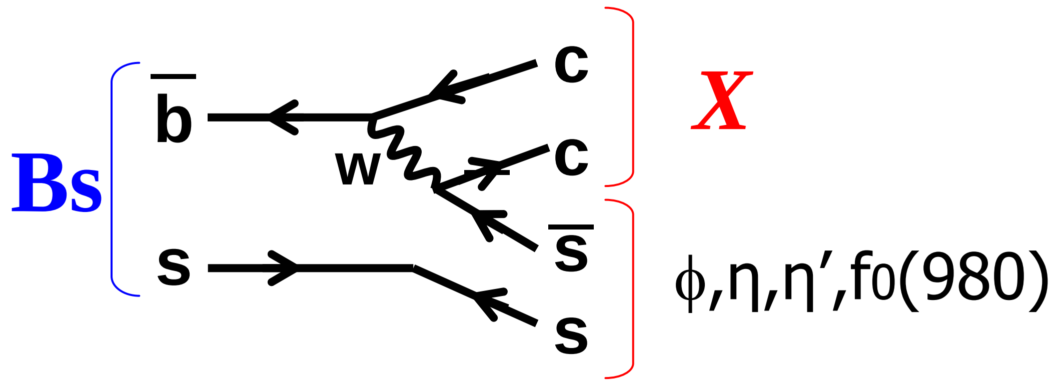


Coverage adjusted 2D likelihood contours for β_s and $\Delta\Gamma$

P-value for SM point: 44% (0.8σ deviation)

$B_s \to X_{c\bar{c}} L$

$b \to c\bar{c}s$ tree



$$X_{c\bar{c}} = J/\psi, \eta_c, \Psi(2S), \eta_c(2S), \chi_{c0,c1,c2}, h_c$$

$$L = \phi, \eta, \eta', f_0(980)$$

Bs->f0 form factors

Form factors are defined as:

$$\langle f_0(p_{f_0})|\bar{s}\gamma_\mu\gamma_5 b|\overline{B_s}(p_{B_s})\rangle = -i\left\{F_1(q^2)\left[P_\mu - \frac{m_{B_s}^2 - m_{f_0}^2}{q^2}q_\mu\right] + F_0(q^2)\frac{m_{B_s}^2 - m_{f_0}^2}{q^2}q_\mu\right\}$$

$$\langle f_0(p_{f_0})|\bar{s}\sigma_{\mu\nu}\gamma_5 q^\nu b|\overline{B_s}(p_{B_s})\rangle = -\frac{F_T(q^2)}{m_{B_s}+m_{f_0}}\left[q^2 P_\mu - (m_{B_s}^2 - m_{f_0}^2)q_\mu\right]$$

We use the LCSR to compute the form factors. Consider a generic correlation function

$$\Pi(p_{f_0}, q) = i\int d^4x e^{iq\cdot x}\langle f_0(p_{f_0})|T\{j_{\Gamma_1}, j_{\Gamma_2}\}|0\rangle$$

Hadron level:

$$\Pi = \frac{\langle f_0(p_{f_0})|j_{\Gamma_1}|\overline{B_s}(p_{B_s})\rangle\langle\overline{B_s}(p_{B_s})|j_{\Gamma_2}|0\rangle}{m_{B_s}^2 - (p_{B_s})^2} + \ldots$$

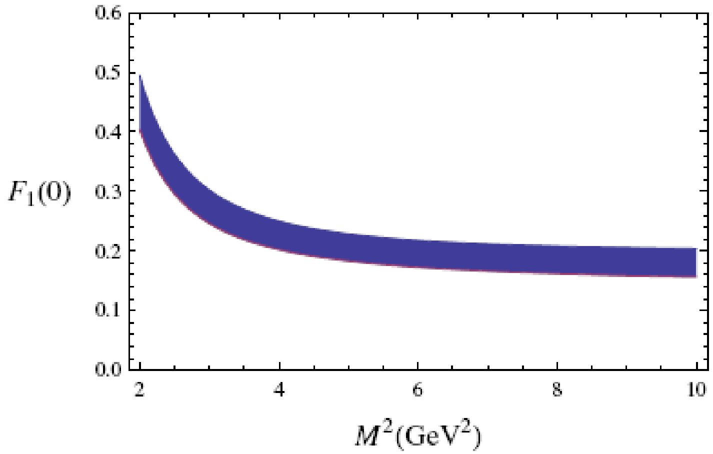
$$\langle\overline{B}_s(p_{B_s})|\bar{b}i\gamma_5 s|0\rangle = \frac{m_{B_s}^2}{m_b + m_s}f_{B_s}$$

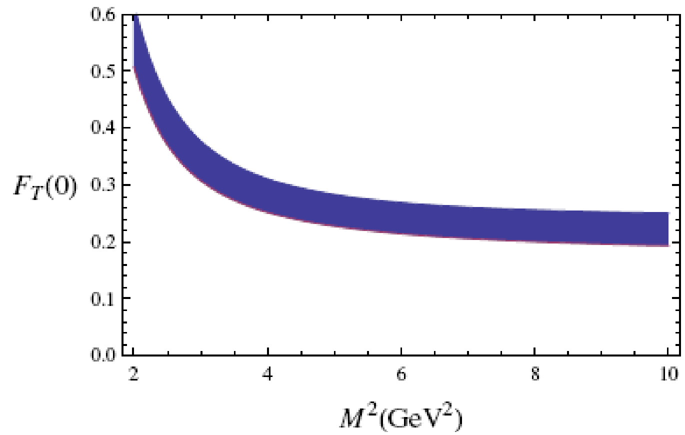
Quark level: Light cone OPE

$$\begin{aligned}&\langle f_0(p_{f_0})|\bar{s}(x)\gamma_\mu s(0)|0\rangle\\ &= \bar{f}_{f_0}p_{f_0\mu}\int_0^1 du e^{iup_{f_0}\cdot x}\Phi_{f_0}(u)\\ &\ldots.\\ \Phi_{f_0}(u) &= 6u(1-u)\sum_{n=1} B_n C_n^{3/2}(2u-1)\\ B_1 &= (-0.78\pm 0.08)\end{aligned}$$

H.Y. Cheng, C.K.Chua, K.C.Yang, PRD73,014017(2006)

Bs->f0 form factors

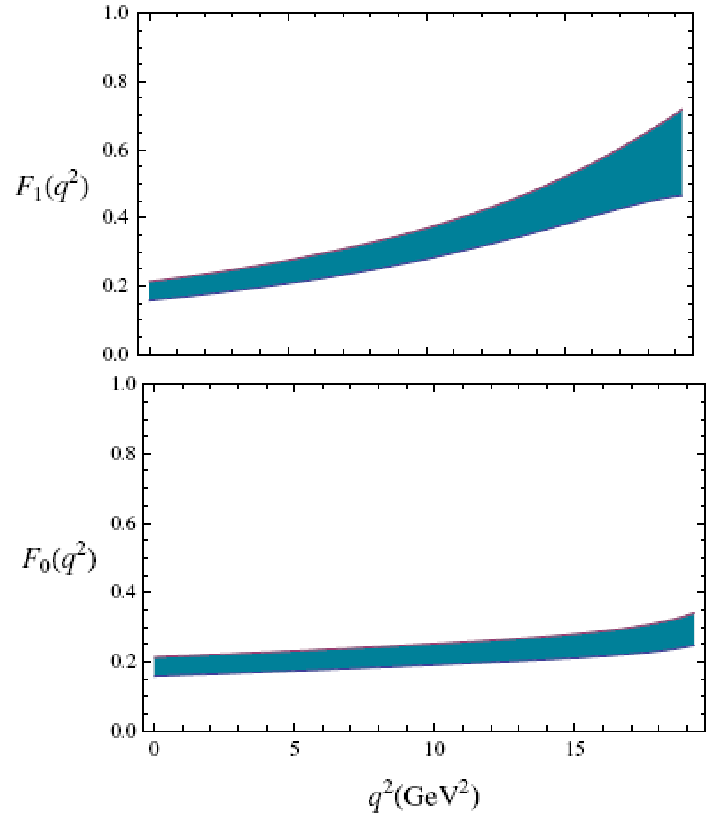




Parameters of the $B_s \to f_0$ form factors by LCSR at the leading order.

	$F_i(q^2=0)$	a_i	b_i	$F_i(q^2_{\max})$
F_1	0.185 ± 0.029	$1.44^{+0.13}_{-0.09}$	$0.59^{+0.07}_{-0.05}$	$0.614^{+0.158}_{-0.102}$
F_0	0.185 ± 0.029	$0.47^{+0.12}_{-0.09}$	$0.01^{+0.08}_{-0.09}$	$0.268^{+0.055}_{-0.038}$
F_T	0.228 ± 0.036	$1.42^{+0.13}_{-0.10}$	$0.60^{+0.06}_{-0.05}$	$0.714^{+0.197}_{-0.126}$

$$F_i(q^2) = \frac{F_i(0)}{1 - a_i q^2/m_{B_s}^2 + b_i (q^2/m_{B_s}^2)^2},$$



P.Colangelo, F. De Fazio, W.W., PRD81:074001,2010

Bs->f0 form factors

NLO B->pi:

G.Duplancic, A.Khodjamirian, T.Mannel, B.Melic and N.Offen, JHEP 0804,014(2008)

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$B_s \to f_0(980)$ transition form factors obtained including an estimate of next-to-leading order corrections

	$F_i(q^2=0)$	a_i	b_i
F_1	0.238 ± 0.036	$1.50^{+0.13}_{-0.09}$	$0.58^{+0.09}_{-0.07}$
F_0	0.238 ± 0.036	$0.53^{+0.14}_{-0.10}$	$-0.36^{+0.09}_{-0.08}$
F_T	0.308 ± 0.049	$1.46^{+0.14}_{-0.10}$	$0.58^{+0.09}_{-0.07}$

$$F_i(q^2) = \frac{F_i(0)}{1 - a_i q^2/m^2_{B_s} + b_i(q^2/m^2_{B_s})^2},$$

30% larger

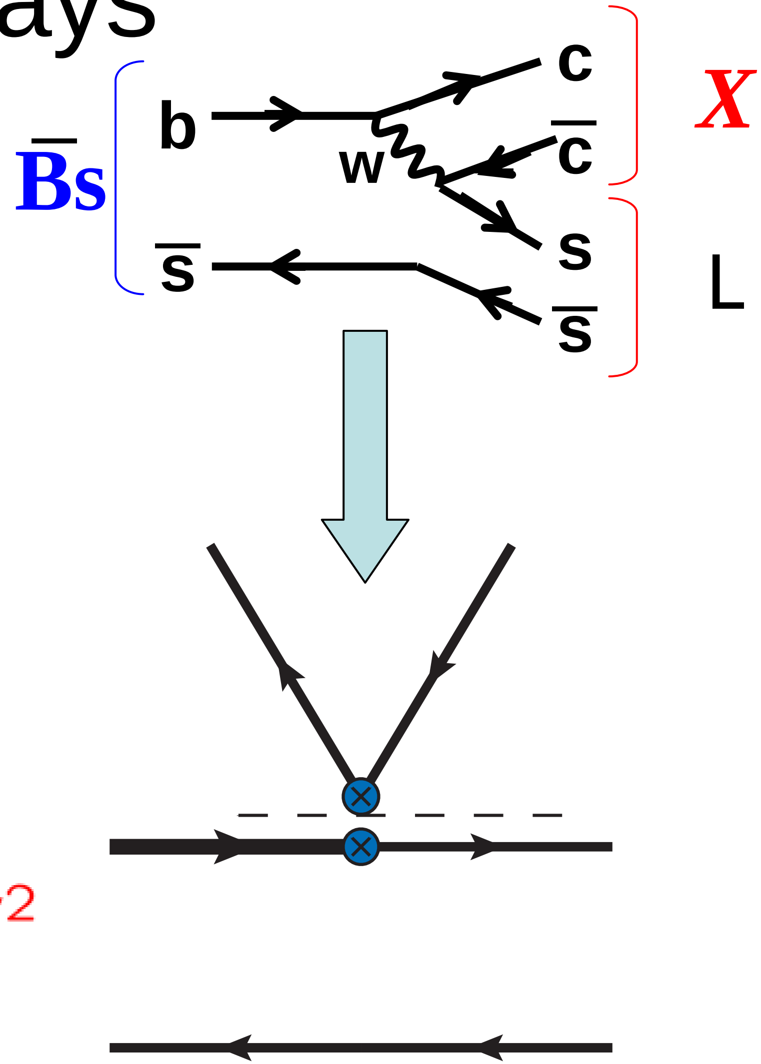
P.Colangelo, F. De Fazio, W.W., PRD81:074001,2010

Bs decays

$$\mathcal{H}_{\rm eff} = \frac{G_F}{\sqrt{2}}\left\{V_{cb}V_{cs}^*[C_1(\mu)O_1 + C_2(\mu)O_2] - V_{tb}V_{ts}^*\left[\sum_{i=3}^{10,7\gamma,8g} C_i(\mu)O_i(\mu)\right]\right\}$$

$$O_1 = \bar{c}\gamma_\mu(1-\gamma_5)c\ \bar{s}\gamma^\mu(1-\gamma_5)b.$$

$$O_2 = \bar{c}\gamma_\mu(1-\gamma_5)b\ \bar{s}\gamma^\mu(1-\gamma_5)c.$$



No annihilation

Factorization assumption:

$$\langle X_{c\bar{c}}L|O|B_s\rangle \sim f_{X_{c\bar{c}}}F^{B_s\to L}\times a_2$$

Color suppressed: a2=C2+C1/3~0.1

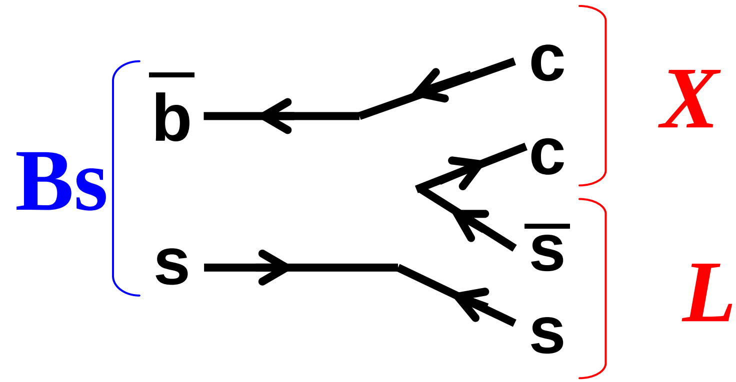
Bs decays

Color suppressed: $a_2 = C_2 + C_1/3$

No annihilation

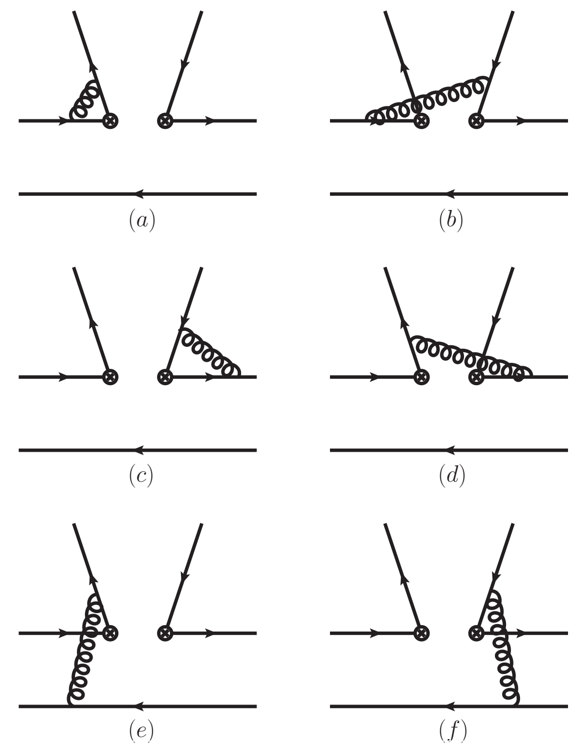
Factorization assumption:

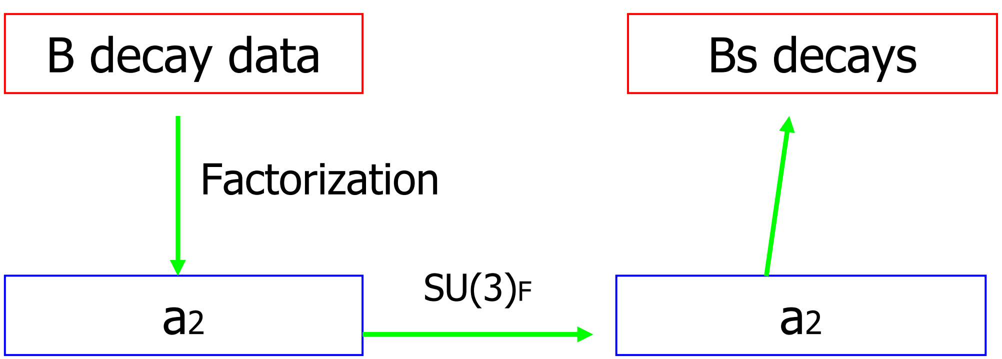
$$\langle X_{c\bar{c}} L | O | B_s \rangle \sim f_{X_{c\bar{c}}} F^{B_s \to L} \times a_2$$



With the inclusion of QCD corrections:

a2 is not universal but channel-dependent.





Bs decays

Channel	a_2^{CDSS}	a_2^{BZ}	Channel	a_2^{CDSS}	a_2^{BZ}
$J/\psi\eta(\eta')$	0.40 ± 0.007	0.26 ± 0.005	$\eta_c\eta(\eta')$	0.36 ± 0.03	0.25 ± 0.02
$J/\psi f_0$	0.40 ± 0.05	0.26 ± 0.035	$\eta_c f_0$	0.36 ± 0.05	0.25 ± 0.04
$\psi(2S)\eta(\eta')$	0.50 ± 0.02	0.31 ± 0.01	$\eta_c(2S)\eta(\eta')$	0.31 ± 0.08	0.21 ± 0.06
$\psi(2S)f_0$	0.50 ± 0.065	0.31 ± 0.04	$\eta_c(2S)f_0$	0.31 ± 0.09	0.21 ± 0.06
Channel	$a_2^{\mathrm{CDSS}} f_{\chi_{c1}}$	$a_2^{\mathrm{BZ}} f_{\chi_{c1}}$	Channel	$a_2^{\mathrm{CDSS}} f_{\chi_{c1}}$	$a_2^{\mathrm{BZ}} f_{\chi_{c1}}$
$\chi_{c1}\eta(\eta')$	0.122 ± 0.006	0.076 ± 0.004	$\chi_{c1}f_0$	0.122 ± 0.016	0.076 ± 0.010
$\chi_{c1}\phi$	—	0.0345 ± 0.006			

in units of GeV

CDSS: Three point QCD sum rules
P.Colangelo, F.De Fazio, P.Santorelli and E.Scrimieri,
PRD53, 3672

BZ: Light cone sum rules
P.Ball and R.Zwicky,
PRD71, 014015; D71, 014029

a2 is not universal

a2(CDSS) is larger than a2(BZ)

the product of a2*f χ_{c1} is used for channels involving χ_{c1}

Bs decays

Channel	CDSS	BZ	Exp.	Channel	CDSS	BZ
$J/\psi\eta$	4.3 ± 0.2	4.2 ± 0.2	3.32 ± 1.02	$\eta_c\eta$	4.0 ± 0.7	3.9 ± 0.6
$J/\psi\eta'$	4.4 ± 0.2	4.3 ± 0.2	3.1 ± 1.39	$\eta_c\eta'$	4.6 ± 0.8	4.5 ± 0.7
$J/\psi f_0$	4.7 ± 1.9	2.0 ± 0.8	< 3.26	$\eta_c f_0$	4.1 ± 1.7	2.0 ± 0.9
$\psi(2S)\eta$	2.9 ± 0.2	3.0 ± 0.2		$\eta_c(2S)\eta$	1.5 ± 0.8	1.4 ± 0.7
$\psi(2S)\eta'$	2.4 ± 0.2	2.5 ± 0.2		$\eta_c(2S)\eta'$	1.6 ± 0.9	1.5 ± 0.8
$\psi(2S)f_0$	2.3 ± 0.9	0.89 ± 0.36		$\eta_c(2S)f_0$	0.58 ± 0.38	1.3 ± 0.8
$J/\psi\phi$	—	16.7 ± 5.7	13 ± 4	$\eta_c\phi$	—	15.0 ± 7.8
$\psi(2S)\phi$	—	8.3 ± 2.7	6.8 ± 3.0			
$\chi_{c1}\eta$	2.0 ± 0.2	2.0 ± 0.2		$\chi_{c1}f_0$	1.88 ± 0.77	0.73 ± 0.30
$\chi_{c1}\eta'$	1.9 ± 0.2	1.8 ± 0.2		$\chi_{c1}\phi$	—	3.3 ± 1.3

Belle, 0912.1434

PDG

$\mathrm{BR}(10^{-4})$

Channel	Theory	Experiment
$J/\psi\phi$	51.3 ± 5.8	54.1 ± 1.7
$\Psi(2S)\phi$	41.0 ± 3.7	
$\chi_{c1}\phi$	43.9 ± 4.4	

$$f_L = \frac{\Gamma_L}{\Gamma_{tot}} (\%)$$

CDSS: Three point QCD sum rules
P.Colangelo, F.De Fazio, P.Santorelli and E.Scrimieri,
PRD53, 3672

BZ: Light cone sum rules
P.Ball and R.Zwicky,
PRD71, 014015; D71, 014029

$B_s \to J/\psi f_0$

$(13 \pm 4) \times 10^{-4}$

- Estimation from Ds decays: $R_{f_0/\phi} = (0.2 - 0.5)$

Stone & Zhang,arXiv:0812.2832; 0909.5442

- Factorization: $\mathcal{B} = (3.1 \pm 2.4) \times 10^{-4}$

P.Colangelo, F. De Fazio, W.W. PRD81,074001

- QCD factorization $\mathcal{B} = (1.3 - 1.7) \times 10^{-4}$

O.Leitner, et. al, 1003.5980

- Factorization+ flavor symmetry: two predictions

$$\mathcal{B} = (4.7 \pm 1.9) \times 10^{-4}; \quad \mathcal{B} = (2.0 \pm 0.8) \times 10^{-4}$$

P.Colangelo, F. De Fazio, W.W. *in preparation*

- Recent experimental data:

$$\mathcal{B}(\mathbf{B_s^0} \to \mathbf{J}/\psi\, \mathbf{f_0}) \times \mathcal{B}(\mathbf{f_0} \to \pi^+\pi^-) < \mathbf{1.63 \times 10^{-4}} \text{ (at 90\% C.L.)}$$

Remi Louvot (Belle) FPCP2010

Theoretical predictions will be tested in the near future.

$B_s \to J/\psi f_0$

- Estimation from Ds decays: $\mathcal{B} = (2-8)\times 10^{-4}$

Stone & Zhang,arXiv:0812.2832; 0909.5442

- Factorization: $\mathcal{B} = (3.1 \pm 2.4)\times 10^{-4}$

P.Colangelo, F. De Fazio, W.W. PRD81,074001

- QCD factorization $\mathcal{B} = (1.3-1.7)\times 10^{-4}$

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P.Colangelo, F. De Fazio, W.W. *in preparation*

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$\mathcal{B}(f_0 \to \pi^+\pi^-) = (50^{+7}_{-9})\%$ BES, PRD72,092002

Theoretical predictions will be tested in the near future.

Nonleptonic B_s Decays into $(\chi_{c0}, \chi_{c2}, h_c)$

Factorization fails:

- vanishing decay constants
- Infrared divergences: see M.Beneke, L. Vernazza, 0810.3575

Assuming SU(3) symmetry for decay amplitudes, the BRs of Bs decays are predicted as (in units of 10^(-4))

Channel	$\mathcal{B}$	Channel	$\mathcal{B}$	Channel	$\mathcal{B}$
$\chi_{c0}\eta$	0.85 ± 0.13	$\chi_{c2}\eta$	< 0.17	$h_c\eta$	< 0.23
$\chi_{c0}\eta'$	0.87 ± 0.13	$\chi_{c2}\eta'$	< 0.17	$h_c\eta'$	< 0.23
$\chi_{c0}f_0$	1.15 ± 0.17	$\chi_{c2}f_0$	< 0.29	$h_c f_0$	< 0.30
$\chi_{c0}\phi$	1.59 ± 0.38	$\chi_{c2}\phi$	$< 0.10(0.62 \pm 0.17)$	$h_c\phi$	(< 1.9)

$B_s \to \chi_{c0}\phi$ may provide a side-check when the number of accumulated data increases.

χ_{c0} decay modes:

$$2(\pi^+\pi^-) + \pi^+\pi^- K^+ K^- + 2(K^+K^-) \sim 4\%$$

Summary

Bs-> f0 form factors in LCSR

- **LO**
- estimate of QCD corrections

Bs decays into charmonium are computed by making use of the SU(3) symmetry.

- **Results of Bs-> J/Ψ (ϕ, η, η′)** are well consistent with the data
- Bs-> J/Ψ f_0 will be tested in the near future and could be helpful for the measurement of β_s
- Bs Decays into χ_{c0} may also be useful

Thank you!

Spare slides

Bs->f0 form factors

TABLE III. $B_s \to f_0(980)$ form factors at $q^2 = 0$. Results evaluated by CLFD/DR [27], PQCD [28] and QCDSR [29] approaches are collected for a comparison.

	CLFD/DR	PQCD	QCDSR	This work
$F_1(0)$	$0.40/0.29^{a}$	$0.35^{+0.09 b}_{-0.07}$	0.12 ± 0.03^{c}	0.185 ± 0.029
$F_T(0)$		$0.40^{+0.10 b}_{-0.08}$	-0.08 ± 0.02^{c}	0.228 ± 0.036

[a]Using $f_{B_s} = 0.259$ GeV.
[b]Using $f_{f_0} = 0.37$ GeV.
[c]Using $f_{f_0} = 0.37$ GeV and $f_{B_s} = 0.209$ GeV.

0.35*0.18/0.37=0.17

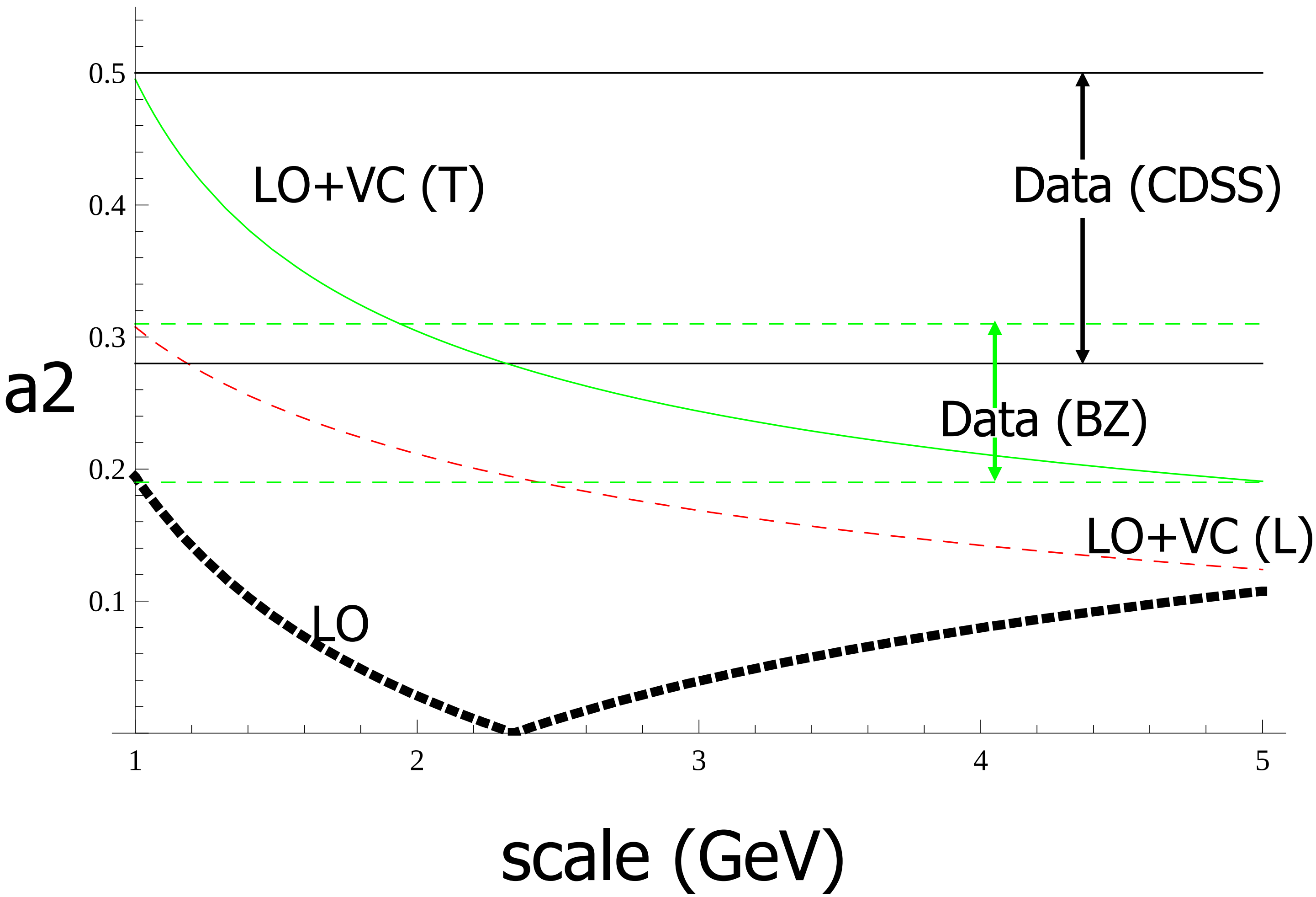
0.40*0.18/0.37=0.19

0.12*0.37/0.18*(0.209/0.231)=0.22

0.08*0.37/0.18*(0.209/0.231)=0.15

[27] B. El-Bennich, O. Leitner, J. P. Dedonder, and B. Loiseau, Phys. Rev. D **79**, 076004 (2009).
[28] R. H. Li, C. D. Lu, W. Wang, and X. X. Wang, Phys. Rev. D **79**, 014013 (2009).
[29] N. Ghahramany and R. Khosravi, Phys. Rev. D **80**, 016009 (2009).

a2:PQCD vs factorization



f0(980), ssbar?

The quark content of f_0 is not uniquely fixed at present. Under the assignment of $\bar{q}q$, this meson might be the mixture of the isosinglet $\bar{n}n$ and $\bar{s}s$ (n=u,d). The mixing angle could be fixed using other experimental data for instance $J/\psi \to \phi f_0$ and $J/\psi \to \omega f_0$:

$$\mathcal{B}(J/\psi \to \phi f_0) = (3.2 \pm 0.9) \times 10^{-4}, \quad \mathcal{B}(J/\psi \to \omega f_0) = (1.4 \pm 0.5) \times 10^{-4},$$

These data indicate a portion of nonstrange content for f_0 and the branching fraction of $B_s \to J/\psi f_0$ might be reduced by roughly 30%. Nevertheless this feature does not limit the power to search for the new physics, since its BR is still large enough to be accessible.