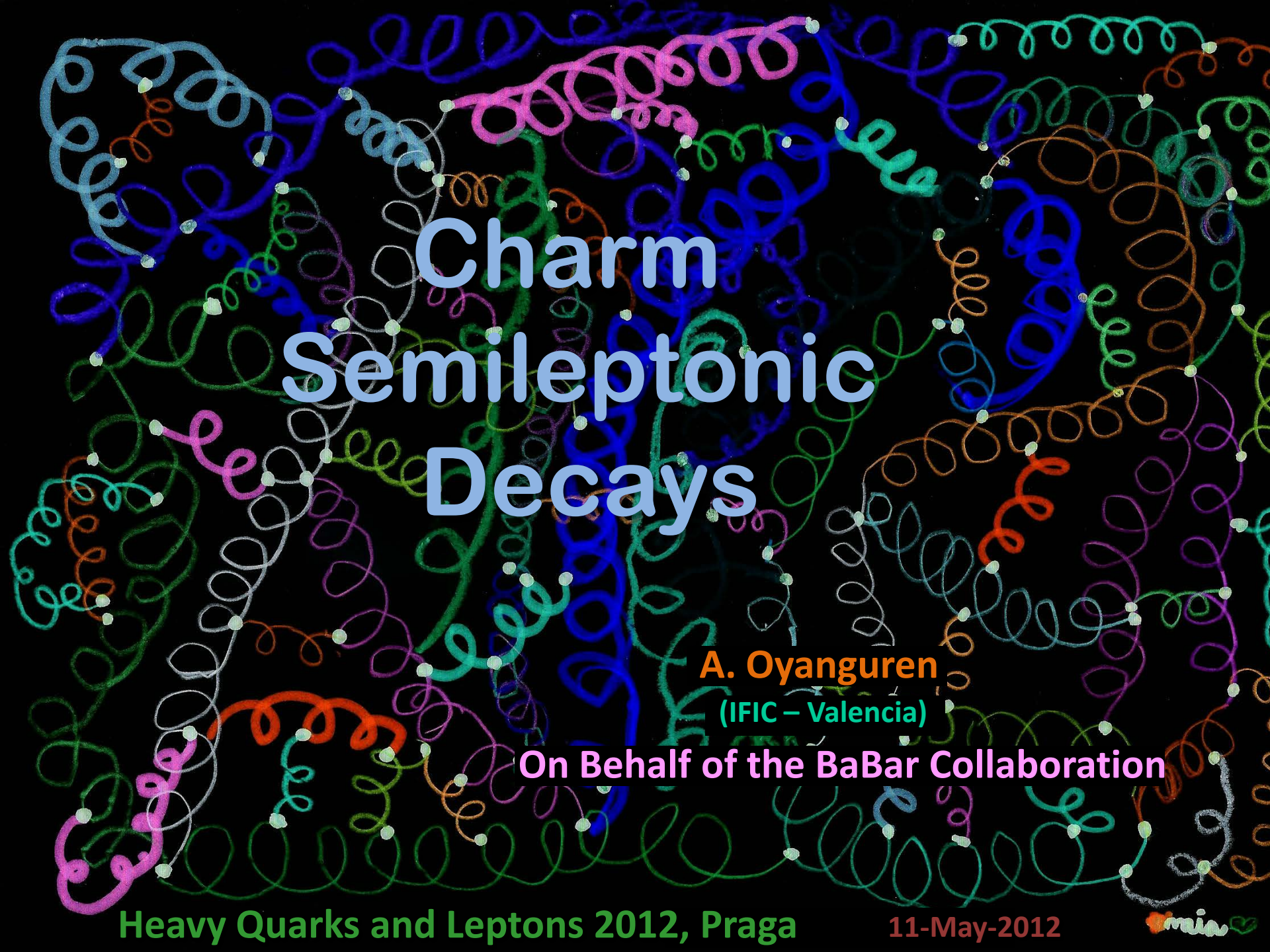


A. Oyanguren

(IFIC – Valencia)

On Behalf of the BaBar Collaboration

Heavy Quarks and Leptons 2012, Praga 11-May-2012

Outline

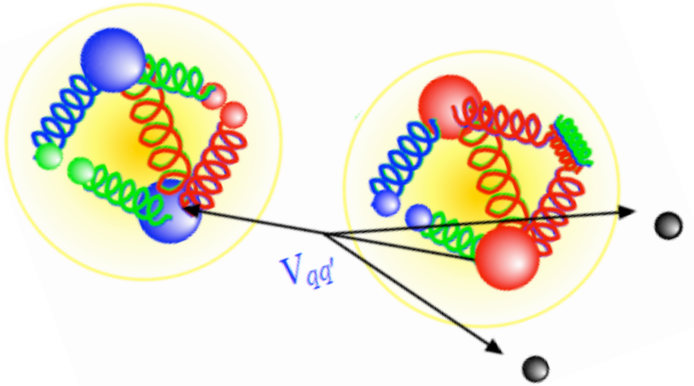
- Motivation
- Experiments and methods
- Pseudoscalar decays: $D \to P\ell\nu$ (P=K,π,η…)
- Vector decays: $D_{(s)} \to V\ell\nu$ (V=K*,ρ, ϕ, …)
- S-wave systems
- Conclusions

Motivation

- Understand (by measuring) non-perturbative QCD

  → Expressed in terms of form factors (for semileptonic decays)

  → Computed by Lattice-QCD



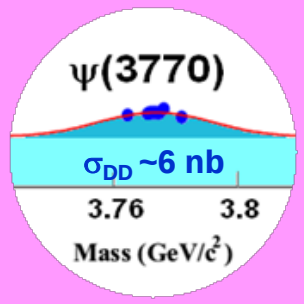
Outcome:

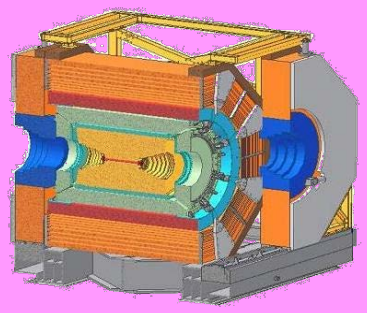
- Validation for the B sector (avoiding fake New Physics hints!)
- Study of $J^P=0^+$ states (S-wave systems) in a non-hadronic environment

Experiments

and data:

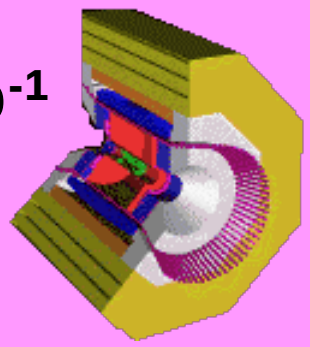
BES III 3 fb^{-1}

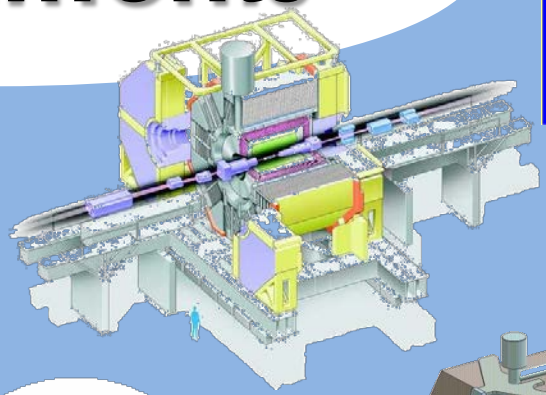




CLEOc

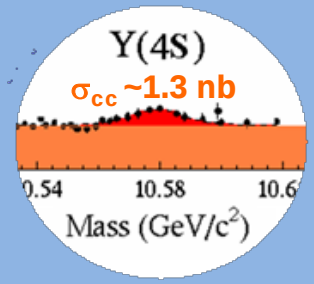
0.82 fb^{-1}

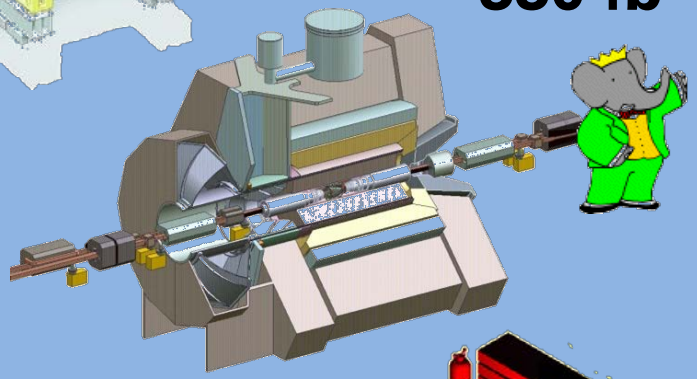




>1ab^{-1}

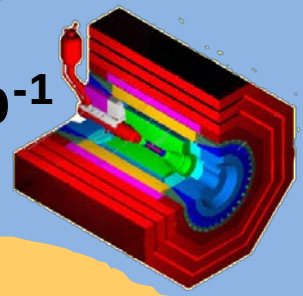
550 fb^{-1}





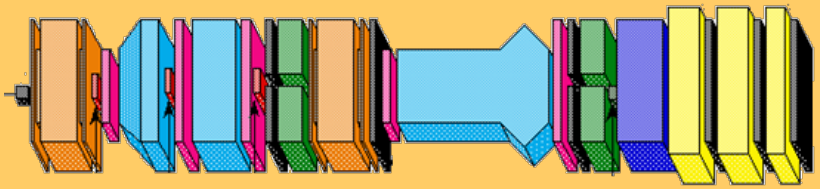
7 fb^{-1}

CLEO III



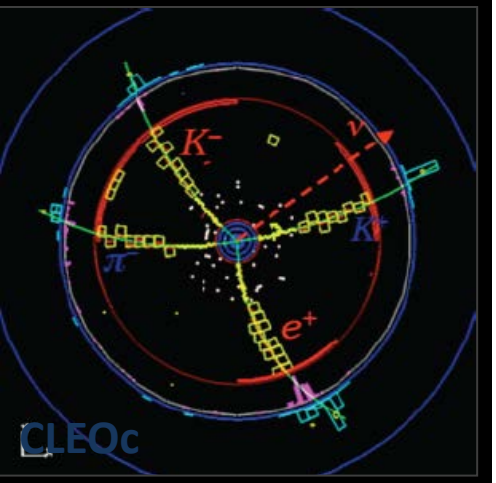
~1M cc

γ+BeO

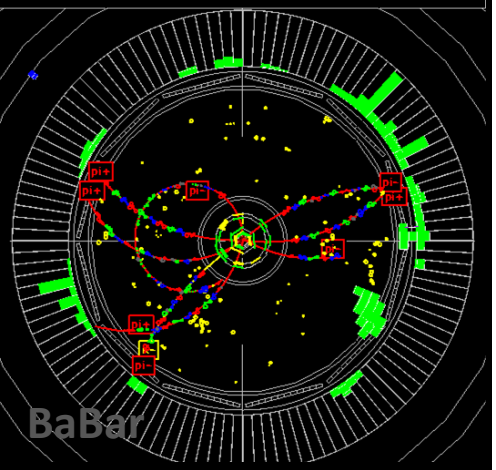


Methods

@ $\psi(3770)\rightarrow D\bar{D}$



@ $\Psi(4s)$ $(c\bar{c})$



- **FOCUS**: Reconstruct the $D^*\rightarrow D\pi$, and the D in the semimuonic channel (or $D\rightarrow K\pi\mu\nu_\mu$)

- **CLEOc & BES III** :

  - Tagged: Full reconstruction: one D in a hadronic channel, the other in the semileptonic channel (only the ν is missing)

  - Untagged (CLEOc): lepton + hadron from the D, E_{miss} of the event = E_ν

- **BaBar**: (untagged) Partial reconstruction of $c\bar{c}$ events, the $D^*\rightarrow D\pi$ and the D in the $Ke\nu$ channel (or the $D_{(s)}\rightarrow Ve\nu_e$). $D_{(s)}$ direction and E_ν from the rest of the event

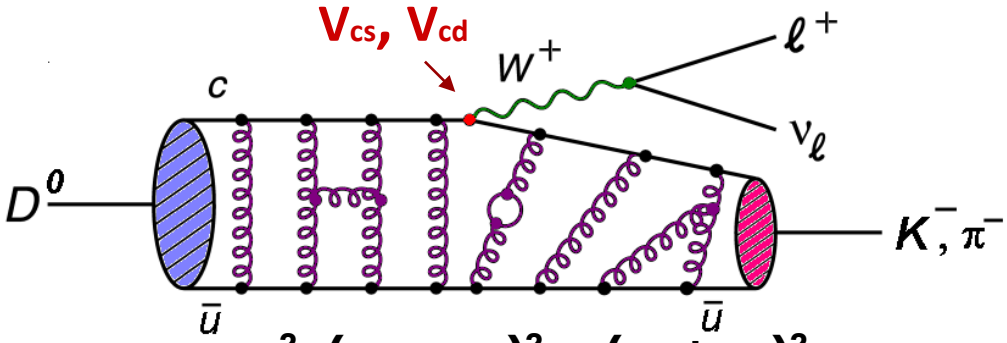
- **BELLE**: (tagged) Full reconstruction of $c\bar{c}$ events including hadronization particles, one D into hadrons, the other in the sl channel, only ν is missing

D→Pℓν

- **Cabibbo favoured D→Kℓν and suppressed D→πℓν**
- **Only one form factor in the differential decay width $f_+(q^2)$:**

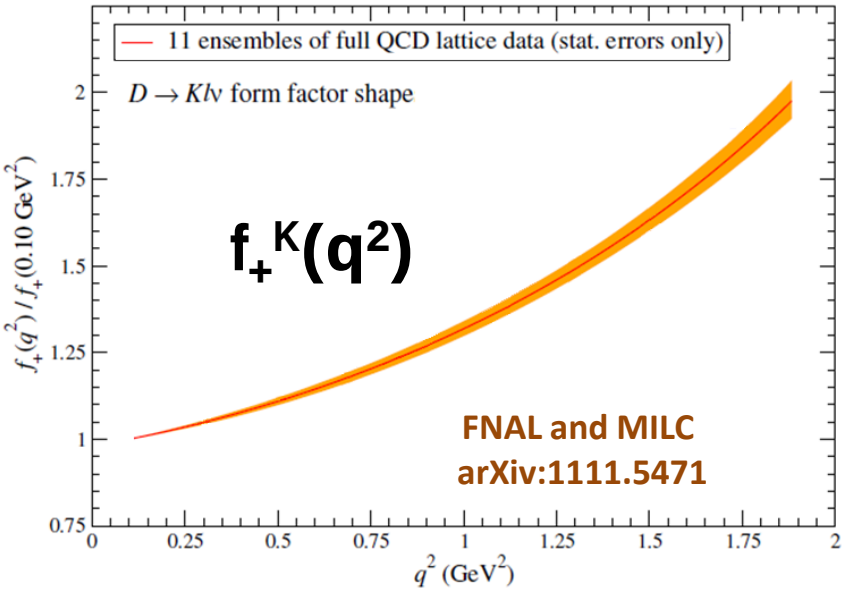
$$\frac{d\Gamma}{dq^2} = \frac{G_f^2 |V_{q_1q_2}|^2 p_{P'}^3}{24\pi^3} |f_+(q^2)|^2$$

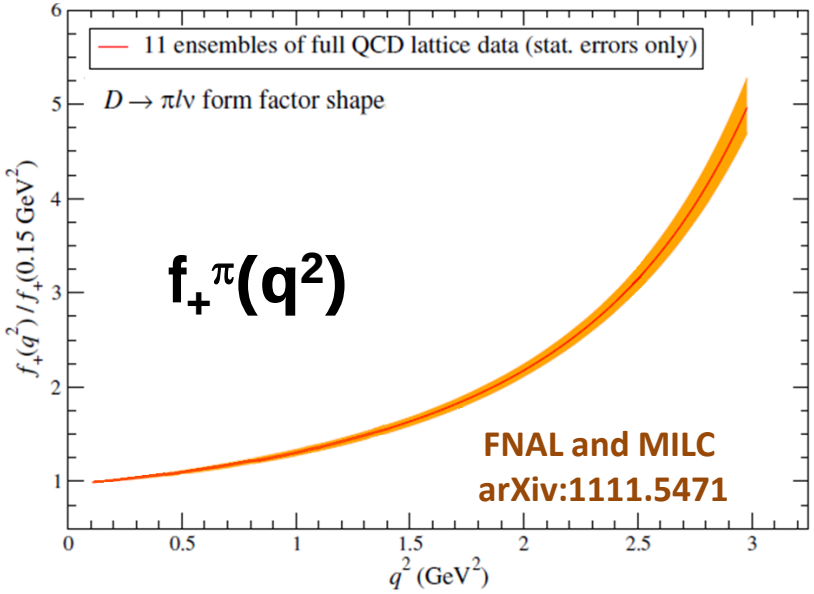
- **Known angular distribution → $\sin^2(\theta_\ell)$**



$q^2=(p_D - p_P)^2 = (p_\ell + p_\nu)^2$

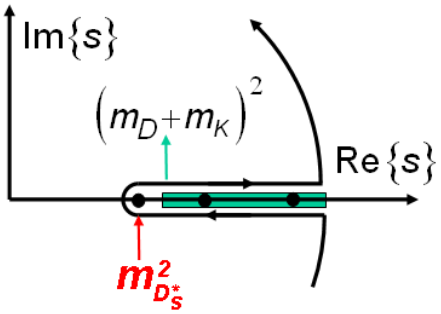
- **New Lattice QCD computations:**





Form factors

Pole dominance: D_s^*



Simple pole

$$f_+(q^2) = \frac{f_+(0)}{1 - \frac{q^2}{m^2_{\rm pole}}}$$

Model prediction:
D→K m_{D^*s} = 2.112 GeV/c²
D→π m_{D^*} = 2.010 GeV/c²

Modified pole

$$f_+(q^2) = \frac{f_+(0)}{\left(1 - \frac{q^2}{m^2_{D_s^*}}\right)\left(1 - \alpha_{\rm pole}\frac{q^2}{m^2_{D_s^*}}\right)}$$

Lattice computation:
D→K α_{pole}= 0.50(4)(7)
D→π α_{pole}= 0.44(4)(7)

ISGW2

$$f_+^{\rm ISGW2}(q^2) = \frac{f_+(q^2_{max})}{(1 + \alpha_I(q^2_{max} - q^2))^2}$$

Model prediction:
D→K, D→π
α_I ~ 0.1 GeV^{-2}

Series expansion

$$F(t) = \frac{1}{P(t)\phi(t,t_0)}\sum_{k=0}^{\infty} a_k(t_0)\, z(t,t_0)^k$$

$t \equiv q^2$ $\qquad$ $|z| << 1$

No model predictions

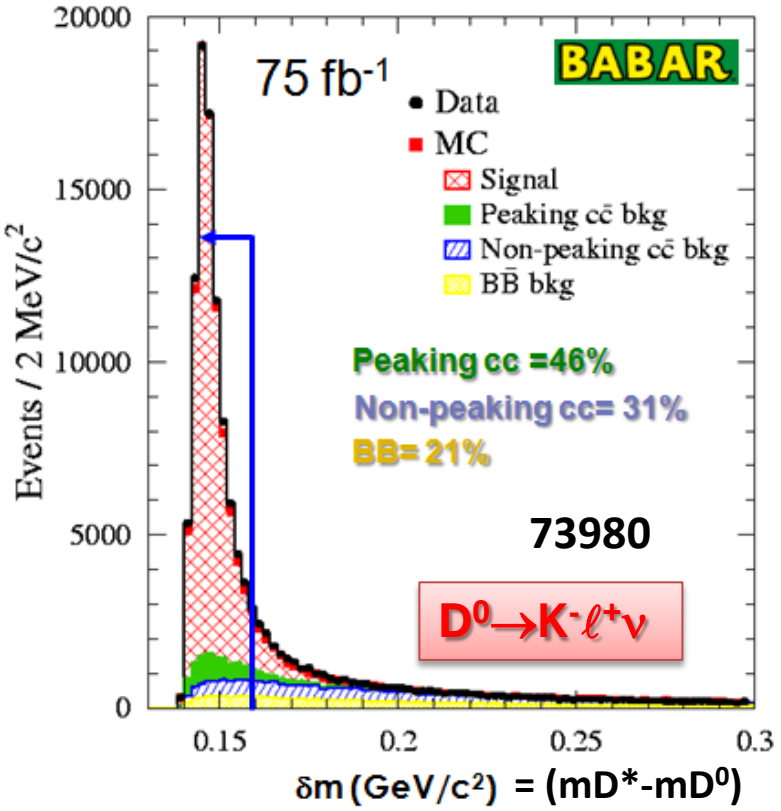
$r_1 = a_1/a_0$
$r_2 = a_2/a_0$

$D \to P \ell \nu$

@ B-factories:

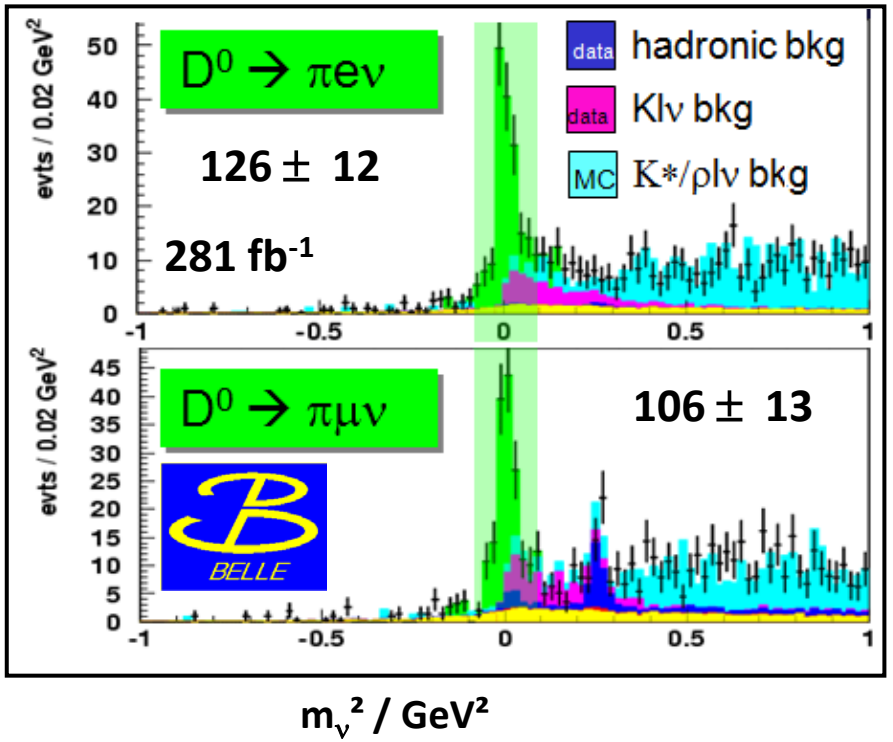
(Analysis with ~ 1/7 BaBar stat.)

PRD 76 (2007) 052005



(Analysis with ~ ¼ Belle stat.)

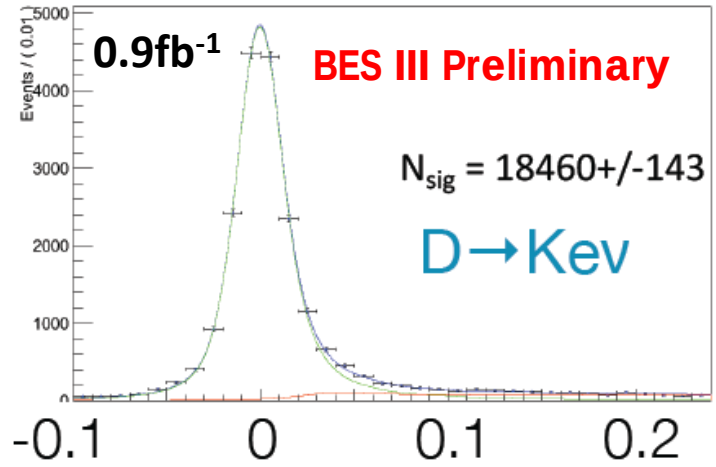
PRL 97 (2006) 061804

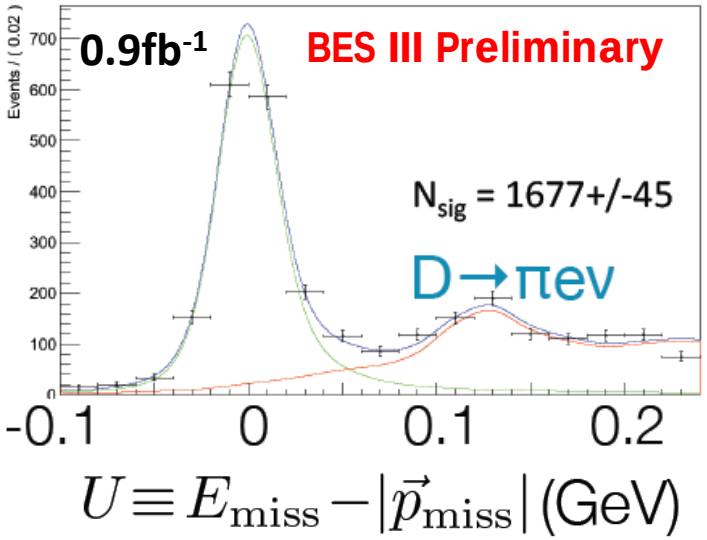


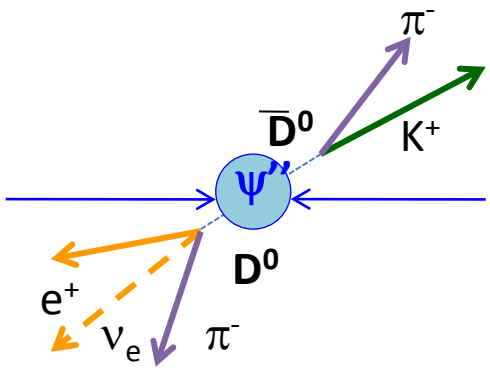
D→Pℓν

@ threshold:

- **NEW results from BES III (1/3 total stat.):**

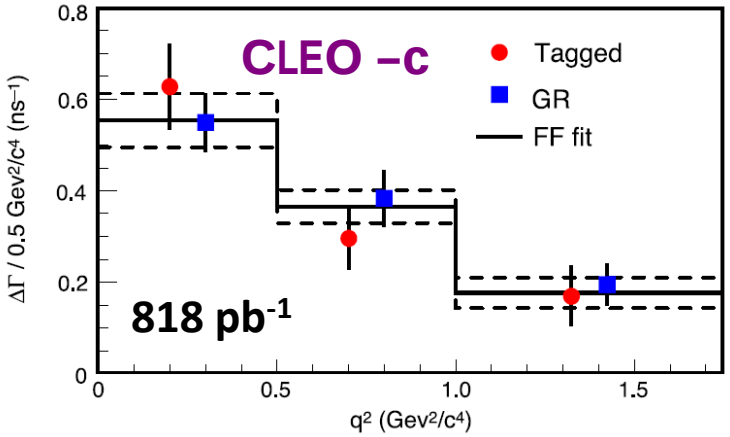






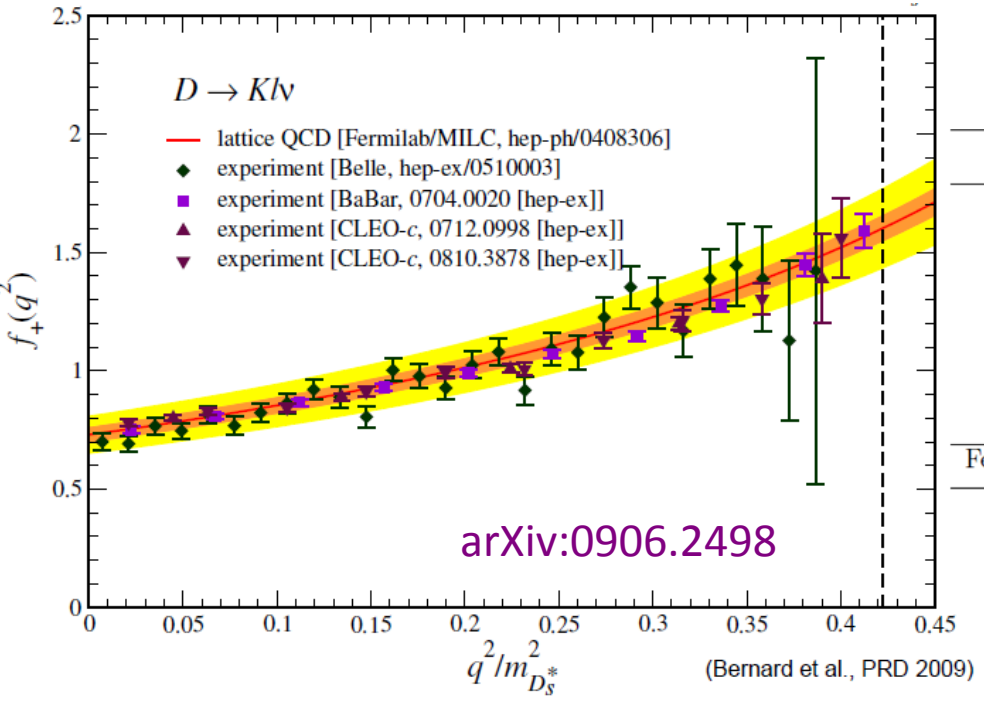
- **CLEO –c also reconstruct the D+ →(η,η')eν$_e$ using tagged and untagged (GR) methods**

PRD 84 (2011) 032001



D→Kℓν

- **Results on form factors:**



$D \to K\ell\nu$ Expt.	$m_{\rm pole}$ (GeV/c^2)	$\alpha_{\rm BK}$
CLEO III	$1.89 \pm 0.05^{+0.04}_{-0.03}$	$0.36 \pm 0.10^{+0.03}_{-0.07}$
FOCUS	$1.93 \pm 0.05 \pm 0.03$	$0.28 \pm 0.08 \pm 0.07$
BELLE	$1.82 \pm 0.04 \pm 0.03$	$0.52 \pm 0.08 \pm 0.06$
BaBar	$1.889 \pm 0.012 \pm 0.015$	$0.366 \pm 0.023 \pm 0.029$
CLEO-c (tagged)	$1.93 \pm 0.02 \pm 0.01$	$0.30 \pm 0.03 \pm 0.01$
CLEO-c (untagged, D^0)	$1.97 \pm 0.03 \pm 0.01$	$0.21 \pm 0.05 \pm 0.03$
CLEO-c (untagged, D^+)	$1.96 \pm 0.04 \pm 0.02$	$0.22 \pm 0.08 \pm 0.03$
BESIII (prel)	$1.943 \pm 0.025 \pm 0.003$	$0.265 \pm 0.045 \pm 0.006$
Fermilab lattice/MILC/HPQCD	–	$0.50 \pm 0.04 \pm 0.07$

Simple pole *Modified pole*

m_{pole} far from theoretical Expectations m_{Ds*} =2.112 GeV

α_{pole}<1 as expected Contributions from other states

→ High precision measurements
→ Agreement ?

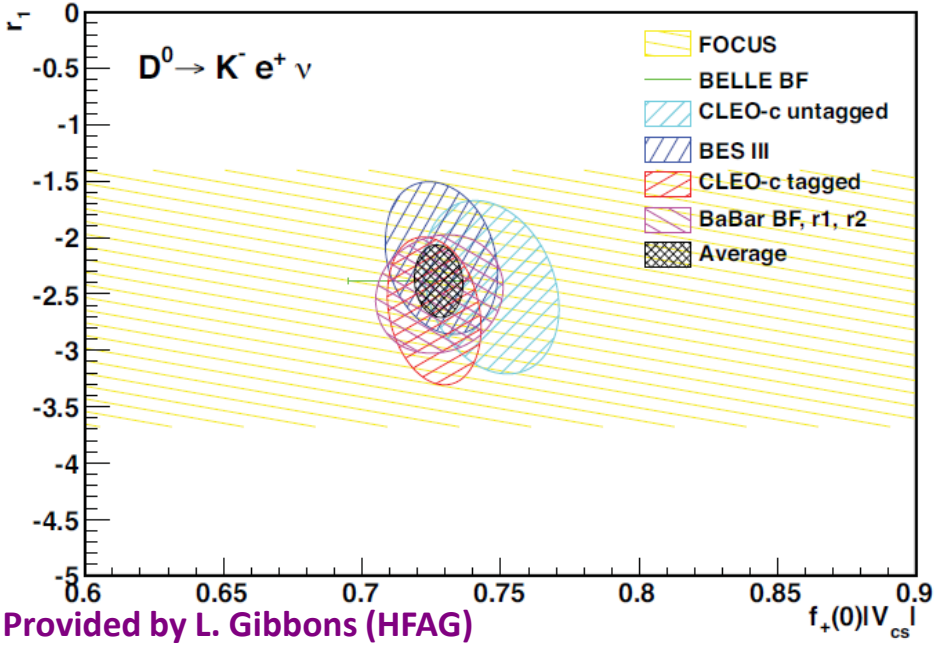
D→Kℓν

- **Results on form factors:**

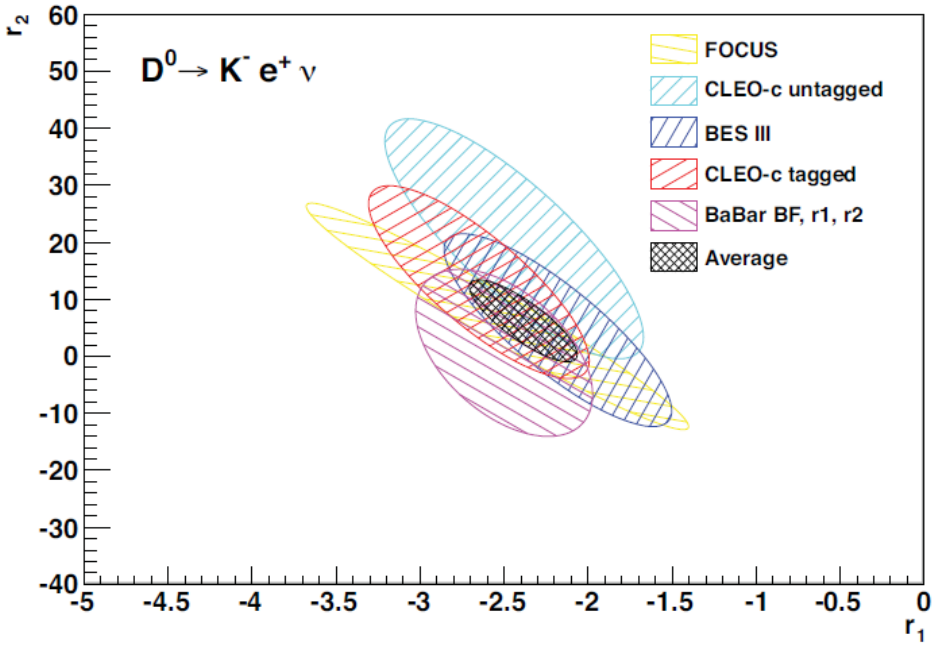
Series expansion

Expt. $D \to K\ell\nu$	mode	r_1	r_2	ρ
CLEO III		$0.2^{+3.6}_{-3.0}$	-89^{+104}_{-120}	-0.99
FOCUS		-2.54 ± 0.75	$7 \pm \pm 13$	-0.97
BaBar		$-2.5 \pm 0.2 \pm 0.2$	$2.5 \pm 6.0 \pm 5.0$	-0.64
CLEO-c (tagged)	$D^0 \to K^-$	$-2.65 \pm 0.34 \pm 0.08$	$13 \pm 9 \pm 1$	-0.82
CLEO-c (tagged)	$D^+ \to \overline{K}^0$	$-1.66 \pm 0.44 \pm 0.10$	$-14 \pm 11 \pm 1$	-0.82
CLEO-c (untagged)	$D^0 \to K^-$	$-2.4 \pm 0.4 \pm 0.1$	$21 \pm 11 \pm 2$	-0.81
CLEO-c (untagged)	$D^+ \to \overline{K}^0$	$-2.8 \pm 6 \pm 2$	$32 \pm 18 \pm 4$	-0.84
BES III		$-2.18 \pm 0.36 \pm 0.05$	$5 \pm 9 \pm 1$	
Combined		-2.39 ± 0.17	6.2 ± 3.8	-0.82

Physics interpretation?

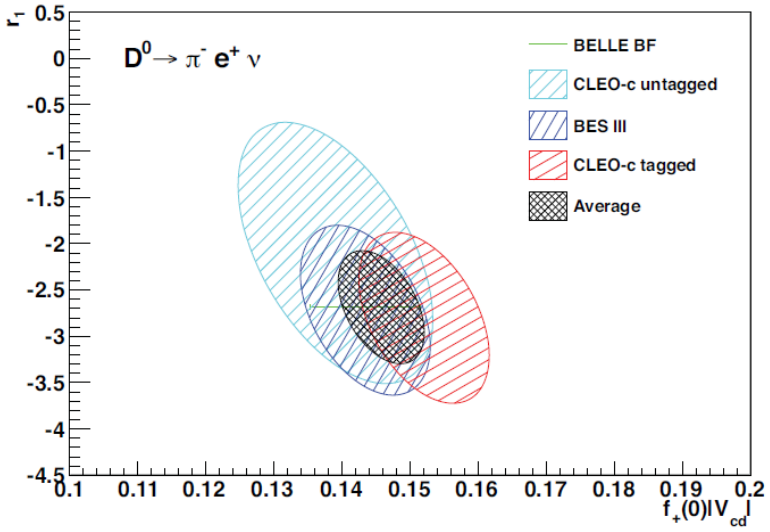


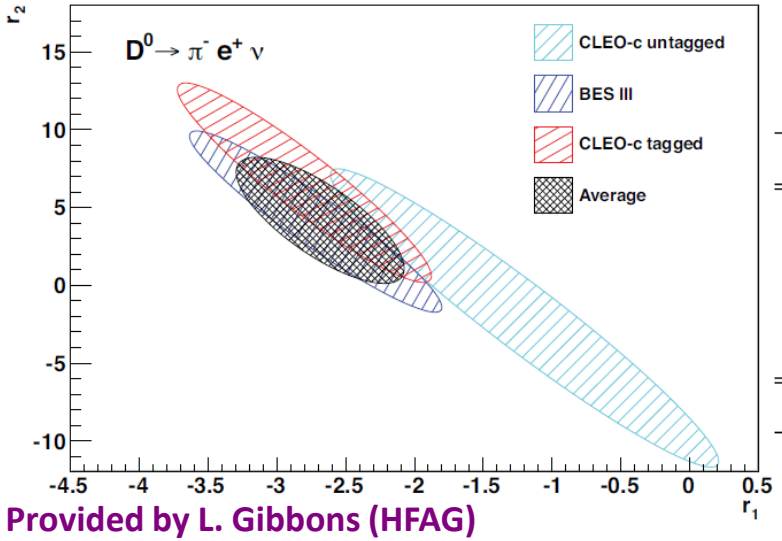
Provided by L. Gibbons (HFAG)



$D \to \pi \ell \nu$

- **Results on form factors:**





Provided by L. Gibbons (HFAG)

$D \to \pi \ell \nu$ Expt.	$m_{\rm pole}$ (GeV/c^2) *Simple pole*	$\alpha_{\rm BK}$ *Modified pole*
CLEO III	$1.86^{+0.10+0.07}_{-0.06-0.03}$	$0.37^{+0.20}_{-0.31} \pm 0.15$
FOCUS	$1.91^{+0.30}_{-0.15} \pm 0.07$	–
BELLE	$1.97 \pm 0.08 \pm 0.04$	$0.10 \pm 0.21 \pm 0.10$
CLEO-c (tagged)	$1.91 \pm 0.02 \pm 0.01$	$0.21 \pm 0.07 \pm 0.02$
CLEO-c (untagged, D^0)	$1.87 \pm 0.03 \pm 0.01$	$0.21 \pm 0.05 \pm 0.03$
CLEO-c (untagged, D^+)	$1.97 \pm 0.07 \pm 0.02$	$0.22 \pm 0.08 \pm 0.03$
BESIII (prel)	$1.876 \pm 0.023 \pm 0.004$	$0.315 \pm 0.071 \pm 0.012$
Fermilab lattice/MILC/HPQCD	–	$0.44 \pm 0.04 \pm 0.07$

$m_{\rm pole}$ far from theoretical expectations m_{D^*} =2.010 GeV

$\alpha_{\rm pole}$<1 as expected Info from contributions from other states

Series expansion

Expt. $D \to \pi \ell \nu$	mode	r_1	r_2	ρ
CLEO-c (tagged)	$D^0 \to \pi^+$	$-2.80 \pm 0.49 \pm 0.04$	$6 \pm 3 \pm 0$	-0.94
CLEO-c (tagged)	$D^+ \to \pi^0$	$-1.37 \pm 0.88 \pm 0.24$	$-4 \pm 5 \pm 1$	-0.96
CLEO-c (untagged)	$D^0 \to \pi^+$	$-2.1 \pm 7 \pm 3$	$-1.2 \pm 4.8 \pm 1.7$	-0.96
CLEO-c (untagged)	$D^+ \to \pi^0$	$-0.2 \pm 1.5 \pm 4$	$-9.8 \pm 9.1 \pm 2.1$	-0.97
BES III		$-2.73 \pm 0.48 \pm 0.08$	$4 \pm 3 \pm 1$	
Combined		-2.69 ± 0.32	4.18 ± 2.16	-0.95

D→Pℓν

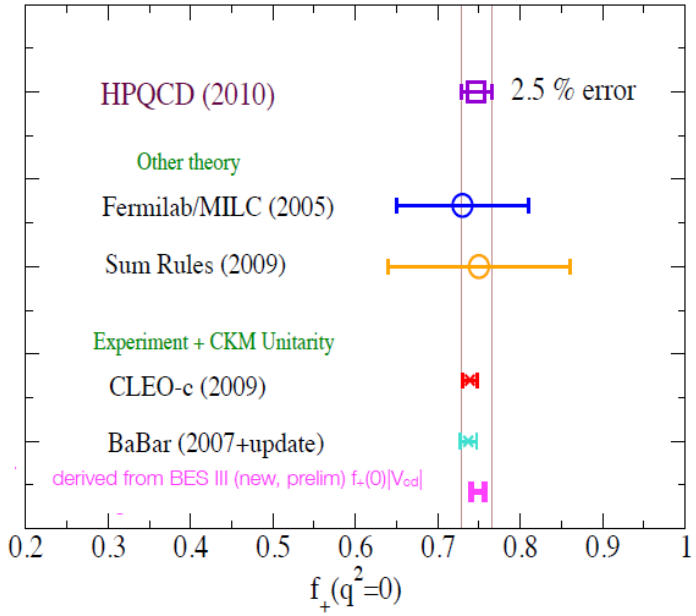
- **Form factor normalization:**

D→K

Experiment	$f_+^K(0)\|V_{cs}\|$
E691 (1989)	$0.69 \pm 0.05 \pm 0.05$
CLEOII (1993)	$0.76 \pm 0.01 \pm 0.04$
E687 (1995)	$0.69 \pm 0.03 \pm 0.03$
BESII (2004)	$0.78 \pm 0.04 \pm 0.03$
Belle (2006) *	$0.692 \pm 0.007 \pm 0.022$
BABAR (2007) *	$0.714 \pm 0.007 \pm 0.007$
CLEO-c (2008)(untagged) *	$0.747 \pm 0.009 \pm 0.009$
CLEO-c (2009) (tagged) *	$0.719 \pm 0.006 \pm 0.005$
BESIII (2012)(prel.) *	$0.729 \pm 0.008 \pm 0.007$
Combined fit *	0.728 ± 0.005
HPQCD	0.727 ± 0.018

(HFAG prel.)

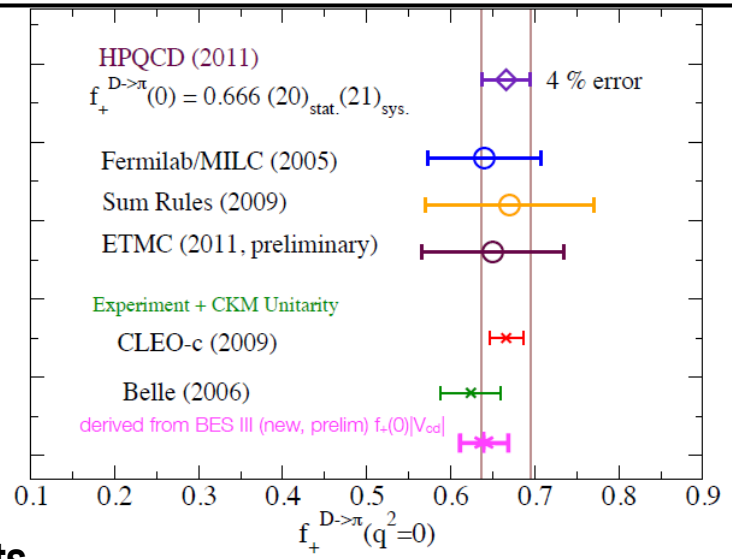
Experimental accuracy below 1% !



D→π

Experiment	$f_+^\pi(0)\|V_{cd}\|$
CLEOII (1995)	$0.163 \pm 0.031 \pm 0.011$
E687 (1996)	$0.160 \pm 0.018 \pm 0.004$
BESII (2004)	$0.164 \pm 0.032 \pm 0.014$
CLEOIII (2005) *	$0.139^{+0.011\ +0.009}_{-0.013\ -0.006}$
FOCUS (2005)	$0.137 \pm 0.008 \pm 0.008$
Belle (2006) *	$0.140 \pm 0.004 \pm 0.007$
CLEO-c (2008)(untagged) *	$0.139 \pm 0.007 \pm 0.003$
CLEO-c (2009) (tagged) *	$0.150 \pm 0.004 \pm 0.001$
BESIII (2012)(prel.) *	$0.144 \pm 0.005 \pm 0.002$
Combined fit *	0.146 ± 0.003
HPQCD	0.150 ± 0.007

(HFAG prel.)

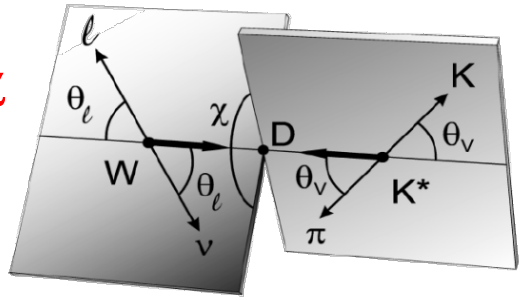


Good agreement between lattice and experiments

$D \to K\pi\ell\nu$

- The decay rate depends on 5 variables: m_V, q^2, θ_ν, θ_ℓ, χ
  For vector decays ($D \to K^*$) two form factor ratios are introduced:

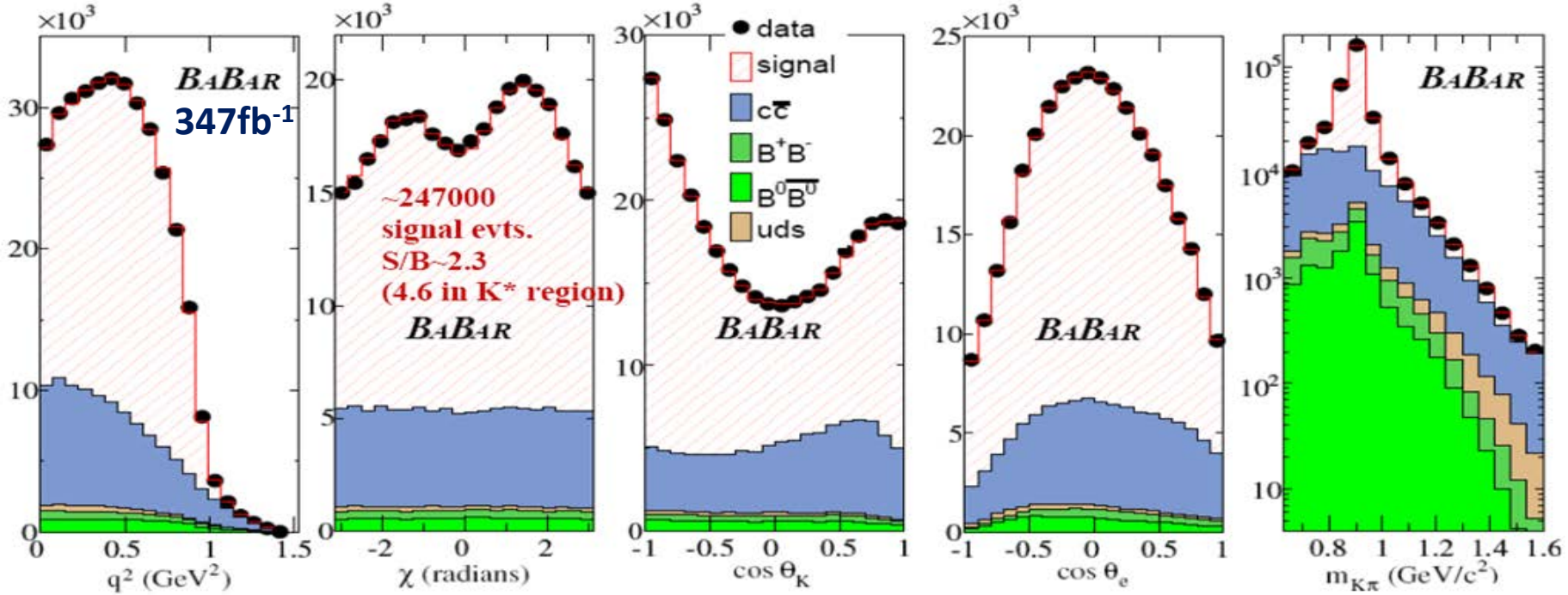
$$r_2 \equiv A_2(0)/A_1(0) \qquad r_v \equiv V(0)/A_1(0)$$



$A_1(q^2)$, $A_2(q^2)$, and $V(q^2)$ shapes: single pole or Fajfer and Kamenik PRD 72, 034029 (2005)

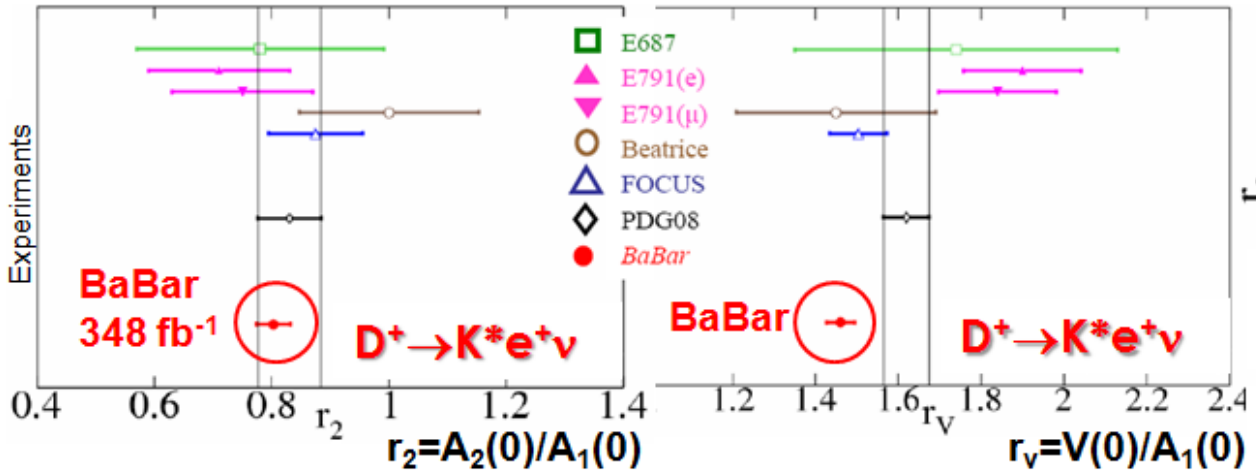
- Sensitive to the $K\pi$ S-wave ($J^P=0^+$)

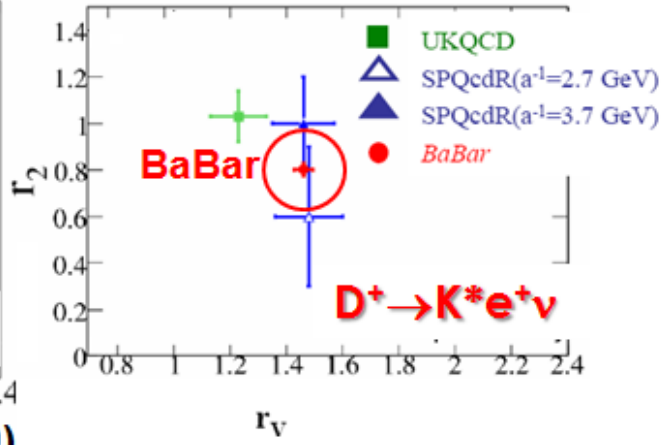
@ Babar: PRD 83 (2011) 072001



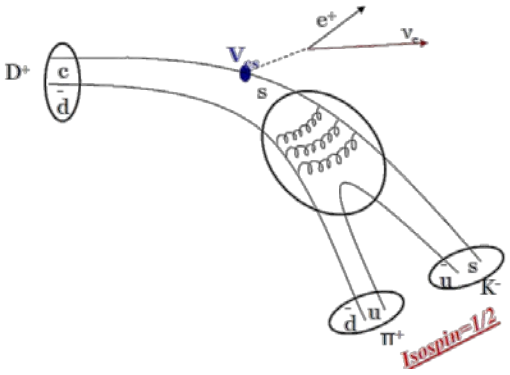
D→Kπℓν

- **Form factors mesurement:**





- **Detailed mesurement of the D→Kπℓν channel:**

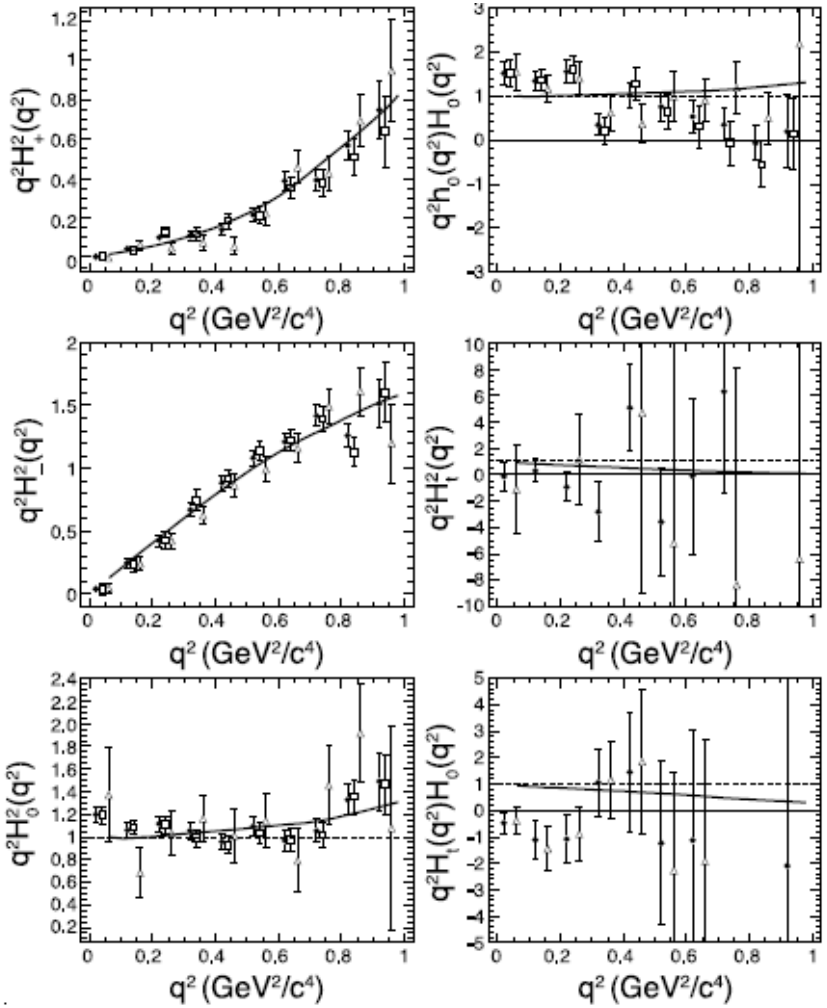


Measurement	BaBar result
$m_{K^*(892)^0}(\ MeV/c^2)$	$895.4 \pm 0.2 \pm 0.2$
$\Gamma^0_{K^*(892)^0}(\ MeV/c^2)$	$46.5 \pm 0.3 \pm 0.2$
$r_{BW}(\ GeV/c)^{-1}$	$2.1 \pm 0.5 \pm 0.5$
r_V	$1.463 \pm 0.017 \pm 0.031$
r_2	$0.801 \pm 0.020 \pm 0.020$
$m_A(\ GeV/c^2)$	$2.63 \pm 0.10 \pm 0.13$
$\mathcal{B}(D^+ \to K^-\pi^+e^+\nu_e)(\%)$	$4.04 \pm 0.03 \pm 0.04 \pm 0.09$
$\mathcal{B}(D^+ \to K^-\pi^+e^+\nu_e)_{\overline{K}^{*0}}(\%)$	$3.80 \pm 0.04 \pm 0.05 \pm 0.09$
$\mathcal{B}(D^+ \to K^-\pi^+e^+\nu_e)_{S-wave}(\%)$	$0.234 \pm 0.007 \pm 0.007 \pm 0.005$
$\mathcal{B}(D^+ \to \overline{K}^*(1410)^0e^+\nu_e)(\%)$	$0.30 \pm 0.12 \pm 0.18 \pm 0.06$ (< 0.6 at 90% C.L.)
$\mathcal{B}(D^+ \to \overline{K}^*_2(1430)^0e^+\nu_e)(\%)$	$0.023 \pm 0.011 \pm 0.011 \pm 0.001$ (< 0.05 at 90% C.L.)

$D \to K\pi\ell\nu$

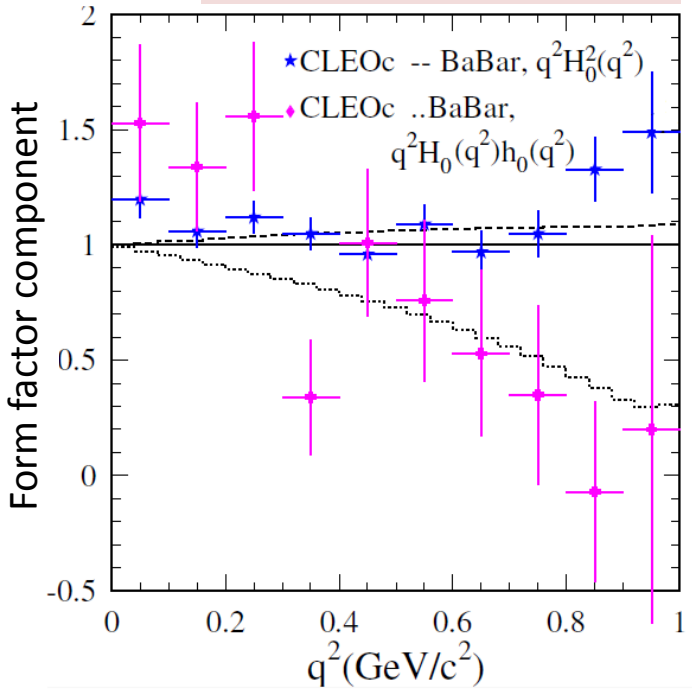
@ CLEO-c: **Measure the q^2 dependence of helicity form factors in $D \to K\pi\ell\nu$**

PRD81,112001 (2010)



- **Comparison with BaBar results:**

PRD 83 (2011) 072001

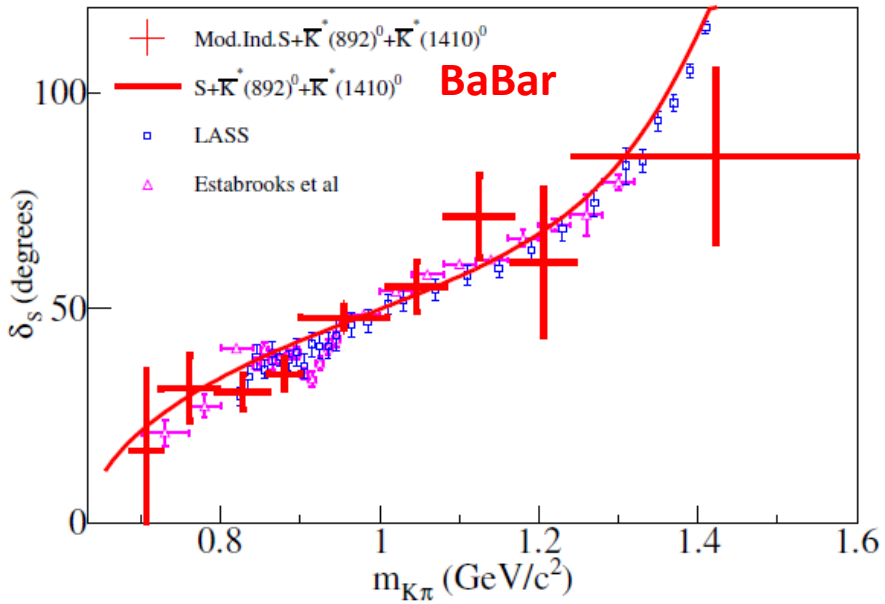


Good agreement

Kπ S-wave

- **S-wave contribution @ BaBar:** $(5.79 \pm 0.16 \pm 0.15)\%$

PRD 83 (2011) 072001



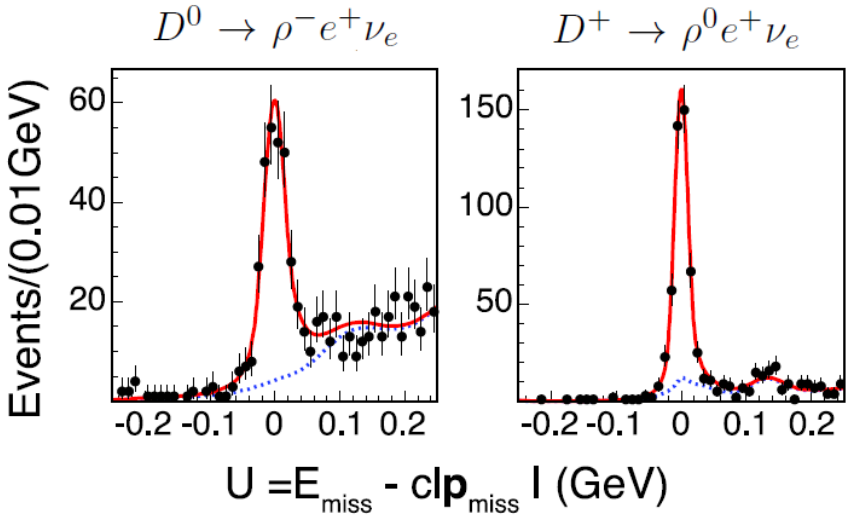
- **Same phase variation in D→Kπℓν decays and Kπ scattering in the elastic regime (Watson's theorem) → BaBar and LASS agree well**

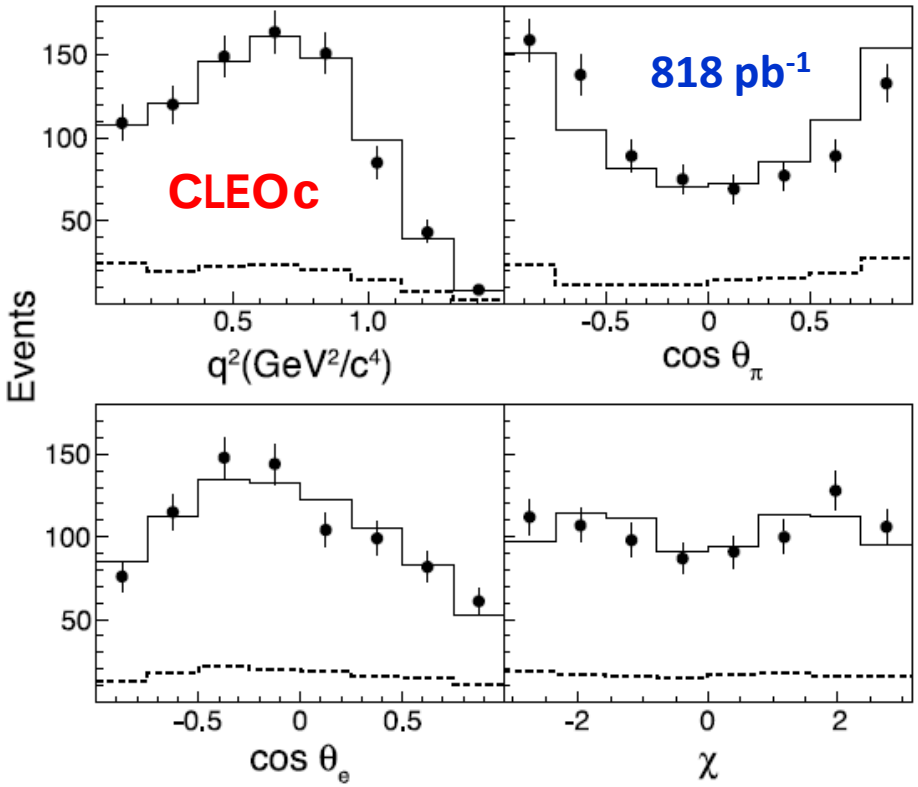
- **Helpful to understand the effect of the spectator π in $D^+ \to K^- \pi^+ \pi^+$**

D→ρℓν

@ CLEOc : arXiv:1112.2884 [hep-ex]

- With full reconstruction also measure the suppressed decay D→ ρeν (ρ→ππ)



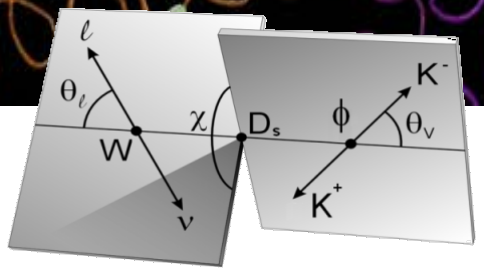


$$V(0)/A_1(0) = 1.48 \pm 0.15 \pm 0.05$$
$$A_2(0)/A_1(0) = 0.83 \pm 0.11 \pm 0.04$$

$$A_1(0) = 0.56 \pm 0.01^{+0.02}_{-0.03}$$
$$A_2(0) = 0.47 \pm 0.06 \pm 0.04$$
$$V(0) = 0.84 \pm 0.09^{+0.05}_{-0.06}$$

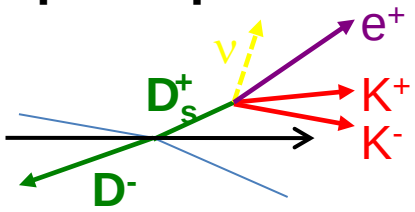
In agreement with Fajfer and Kamenik

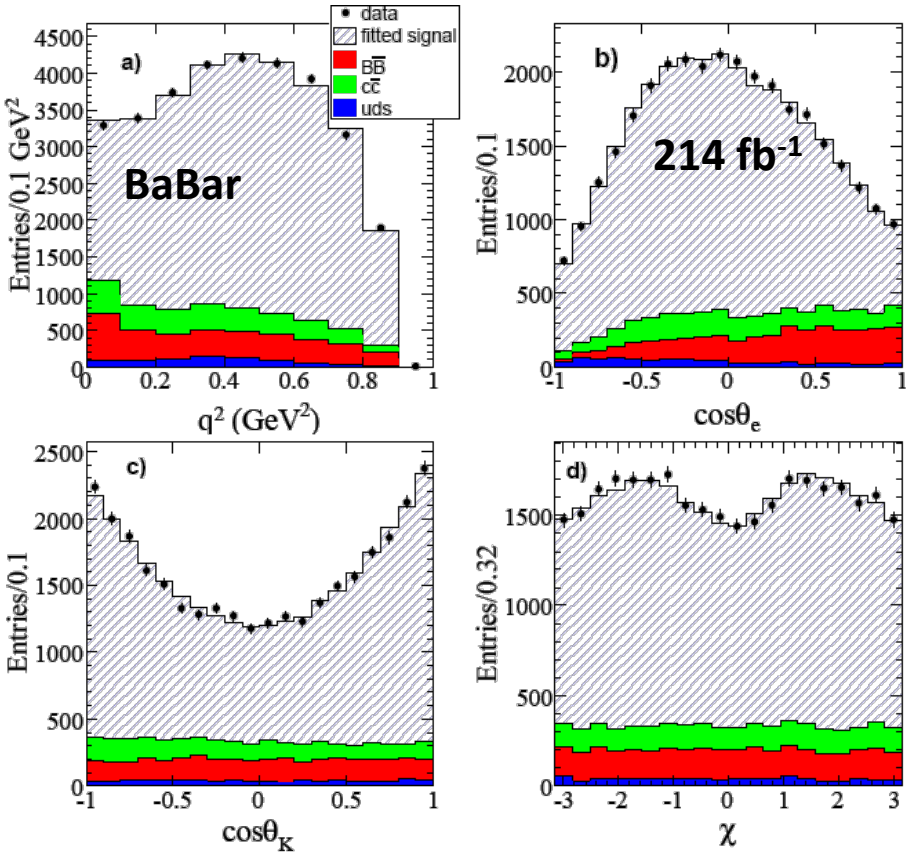
$D_s \to \phi \ell \nu$



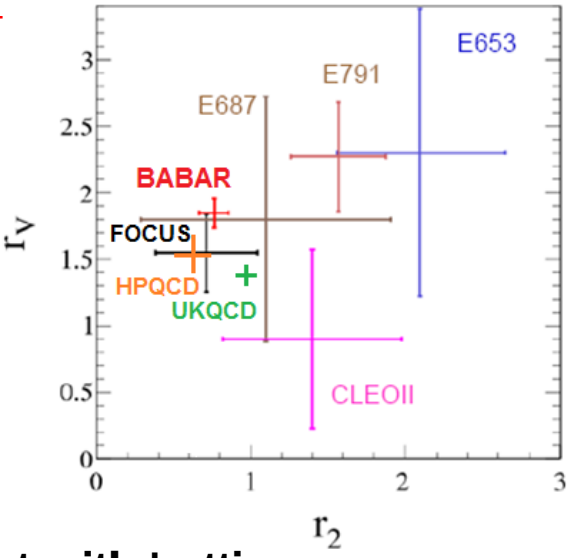
- @ BaBar same reconstruction technique as previous analyses (~1/2.5 BaBar stat.)

PRD78 (2008) 051101 (RC)





Determination of form factors:



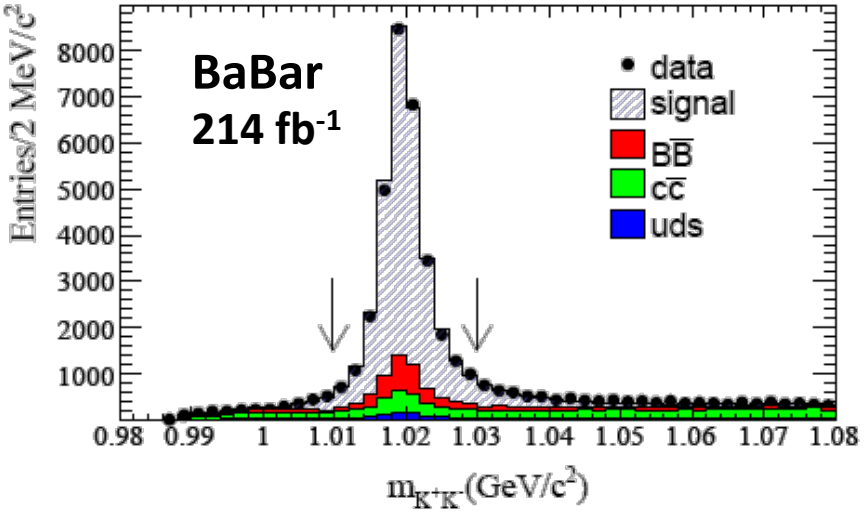
In agreement with Lattice:

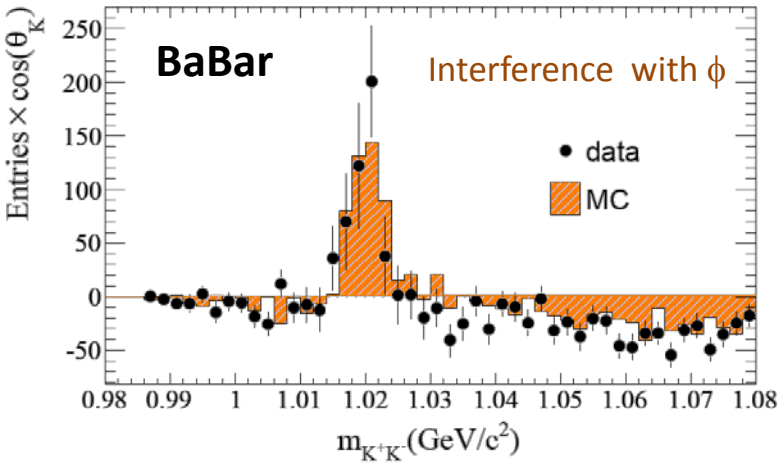
	HPQCD 2011	BaBar 2008	UKQCD 2001
$A_1(0)$	0.594(22)	0.607(11)(19)(18)	0.63(2)
Local $A_1(0)$	0.603(20)	–	–
$V(0)$	0.903(67)	1.122(85)*	0.85(4)
$A_0(0)$	0.686(17)	–	0.63(2)
$A_2(0)$	0.401(80)	0.463(61)*	0.62(5)
r_V	1.52(12)	1.849(60)(95)	1.35(7)*
r_2	0.62(12)	0.763(71)(65)	0.98(8)*

KK S-wave

- First evidence of a S-wave:
  Small contribution (0.22% in the ϕ region)

PRD78 (2008) 051101 (RC)





Important for β_s measurements:

→ Expected contribution of the S-wave in the Bs→J/ψ KK channel below 1% (in the same Δm).

This in agreement with D0, CDF and LHCb observations

- For D→$\phi\ell\nu$, $\mathcal{B}(D_s^+ \to \phi e^+ \nu_e) = (2.61 \pm 0.03 \pm 0.08 \pm 0.15) \times 10^{-2}$

$D_s \to f_0 \ell \nu$

PRD 80 (2009) 052009

@ CLEOc (4176 MeV):

- **D→KK$\ell\nu$ and D→$\pi\pi\ell\nu$ using the full reconstruction method**

In addition to the ϕ, they also observe the f_0 (980) (→$\pi\pi$) (0^+ state)

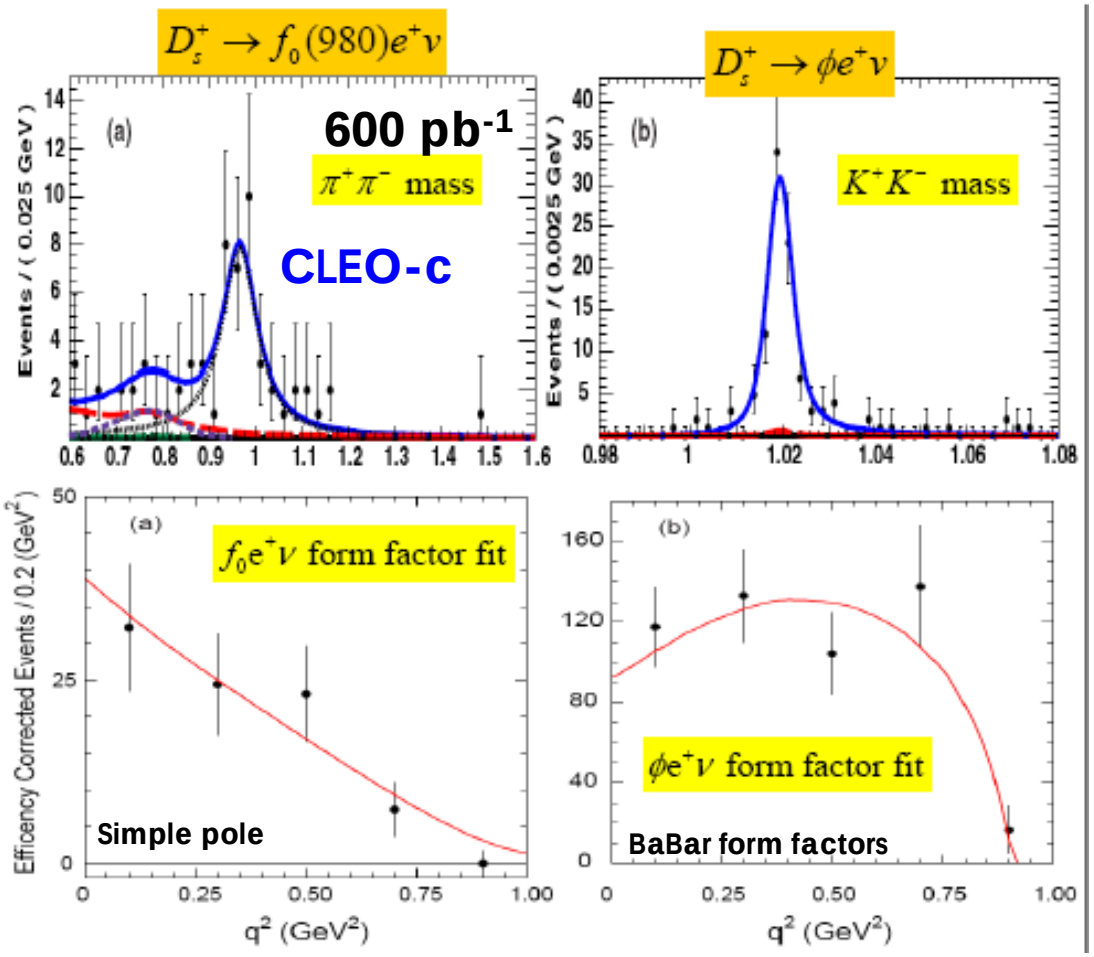
$$\mathcal{B}(D_s^+ \to f_0(980)e^+\nu)\mathcal{B}(f_0 \to \pi^+\pi^-) = (0.20 \pm 0.03 \pm 0.01)\%.$$

$$\mathcal{B}(D_s^+ \to \phi e^+\nu) = (2.36 \pm 0.23 \pm 0.13)\%$$

The ratios of the decay rates at q^2=0:

$$R_{f/\phi} = (42 \pm 11)\%$$

Important to measure CPV in the Bs→J/ψ f_0 channel



Conclusions

- Many results in different channels
- New data coming @ BESIII
- Only partial data analyzed at B-factories
- $|V_{cs}| f_+^K(0)$ accuracy at 1%
- $|V_{cd}| f_+^\pi(0)$ accuracy at 2%
- Precise Lattice results to be compared with, in agreement with experiments
- Important informations on the S-wave systems


Thank you
Special thanks to P. Roudeau and L. Gibbons for the averages
and to my 5-year-old daughter Maia for the background picture
mia