Charm semileptonic decays with the *B* factories

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for the BaBar collaboration

$D^0 \to K^- e^+ \nu_e$	*BaBar* [PRD **76**, 052005 (2007)]
$D^0 \to K^- l^+ \nu_e$	Belle [PRL **97**, 061804 (2006)]
$D^0 \to \pi^- l^+ \nu_e$	Belle [PRL **97**, 061804 (2006)]
$D_s^+ \to K^- K^+ e^+ \nu_e$	*BaBar* [PRD **78**, 051101(R) (2008)]
$D^+ \to K^- \pi^+ e^+ \nu_e$	*BaBar* [preliminary, aiming PRD]

Lattice QCD Meets Experiment Workshop 2010, Fermilab, 26/27 April 2010

Introduction

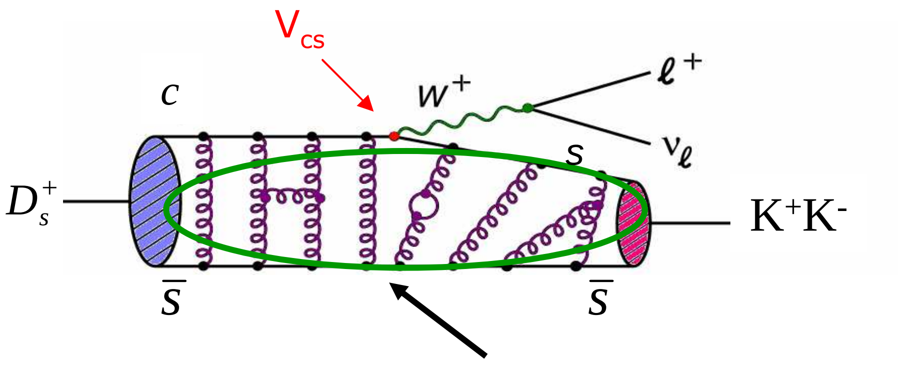
Decay rate:

$$d\Gamma \propto |V_{ij}|^2 \times FF^2$$

- Charm: V_{cs} well known thanks to CKM unitarity $\longrightarrow$ we can measure precisely FF
- validate lattice QCD computation
- Apply this method to the B sector to improve the determination of $|V_{ub}|$

Example: $D_s^+ \longrightarrow K^-K^+e^+\nu$

$$q^2 = (P_l + P\nu)^2 = (P_P - P_{P'})^2$$



Strong interaction effects parameterized by FF

- Pseudoscalar l ν decay : one form factor, angular distribution known
- 2 pseudoscalars l ν decay : 3 helicity states, 5 kinematic variables

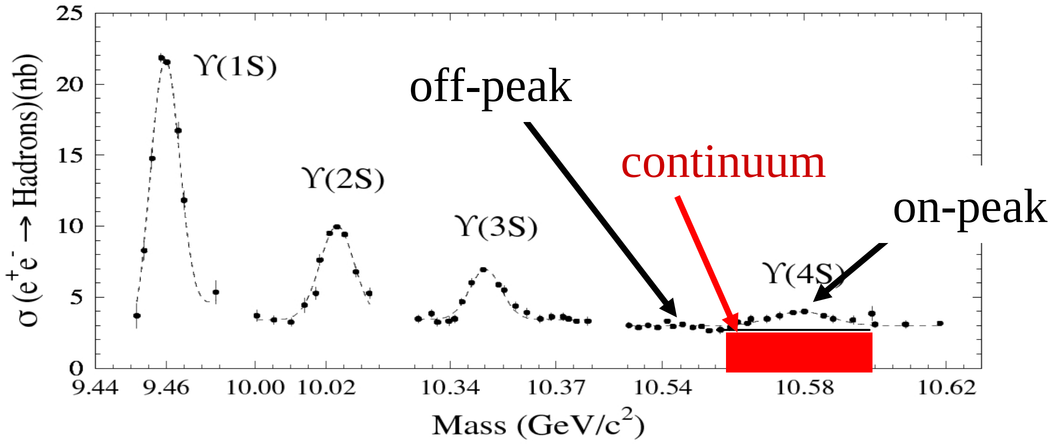
$D^0 \longrightarrow K^-e^+\nu$ ⟵ **Babar results** ⟶ **$D^+ \longrightarrow K^-\pi^+e^+\nu$** **$D_s^+ \longrightarrow K^-K^+e^+\nu$**

$D^0 \longrightarrow K^-l^+\nu$ **$D^0 \longrightarrow \pi^-l^+\nu$** ⟵ **Belle results**

Isolation of D semileptonic decays in *BaBar*

e^+e^- collisions @Υ**(4S)** CM energy.
Other processes are present:
events from lighter quark pair production
($e^+e^- \to q\bar{q}$, called **continuum events**)

- **use D from <u>continuum</u>.**



These are jet-like events and allow for a better reconstruction of the missing ν as compared to D's from B decays

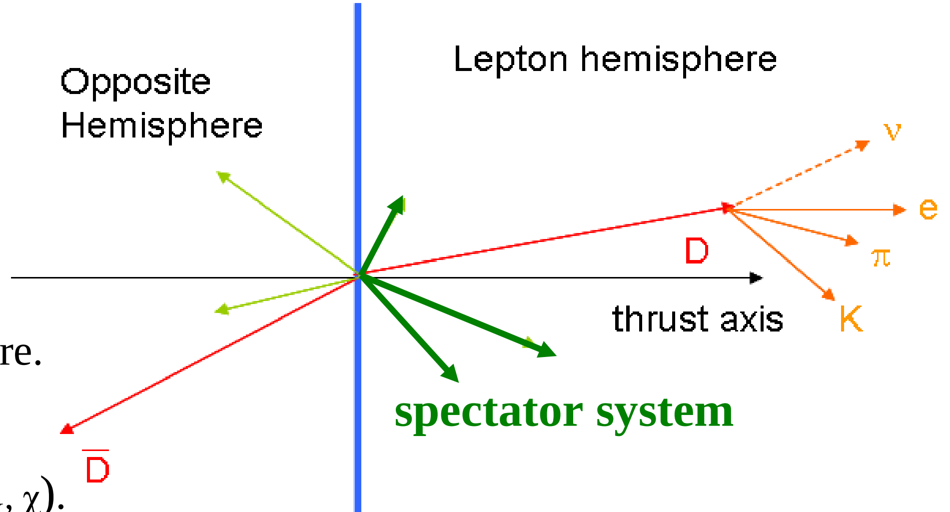
Event reconstruction

Ex. for $D^+ \to K^- \pi^+ e^+ \nu$

define two hemispheres.

- select K^-, π^+, e^+ in the same hemisphere.
- compute the D^+ direction ($-\vec{p}_{\text{all tracks}\neq K,\pi,e}$).
- compute the missing energy in the lepton hemisphere.
- mass constraint fit $\vec{p}_{D^+} = \vec{p}_{K^-} + \vec{p}_{\pi^+} + \vec{p}_{e^+} + \vec{p}_\nu$.
- compute kinematical variables ($m_{K\pi}$, q^2, $\cos\theta_e$, $\cos\theta_K$, χ).

→ **large statistics**
→ **non negligible background**
→ **poor resolution on most kinematic variables**

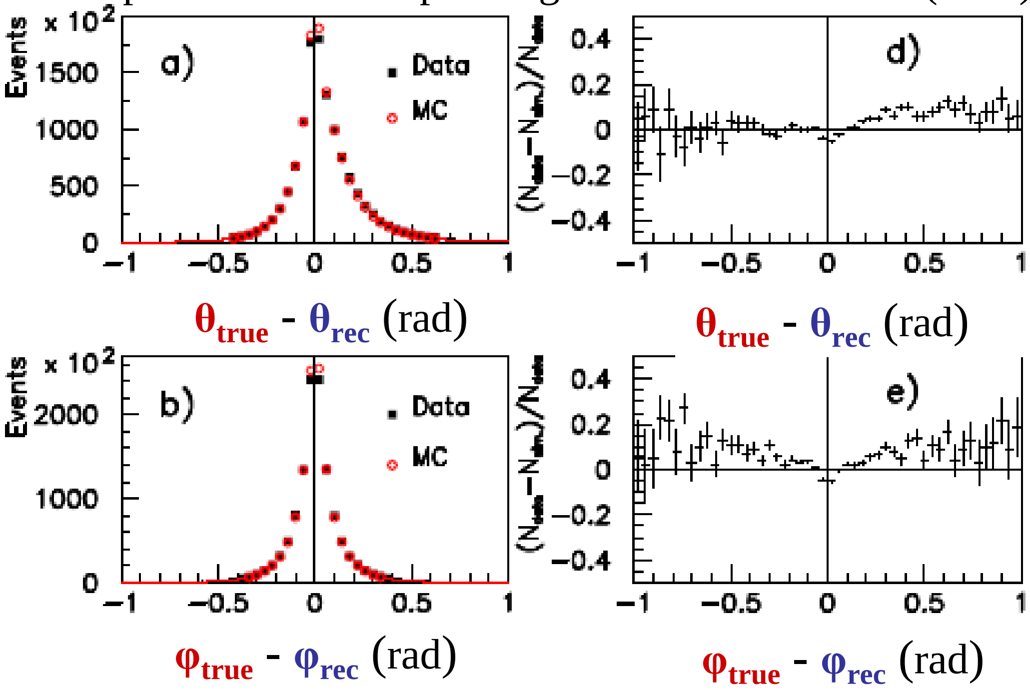


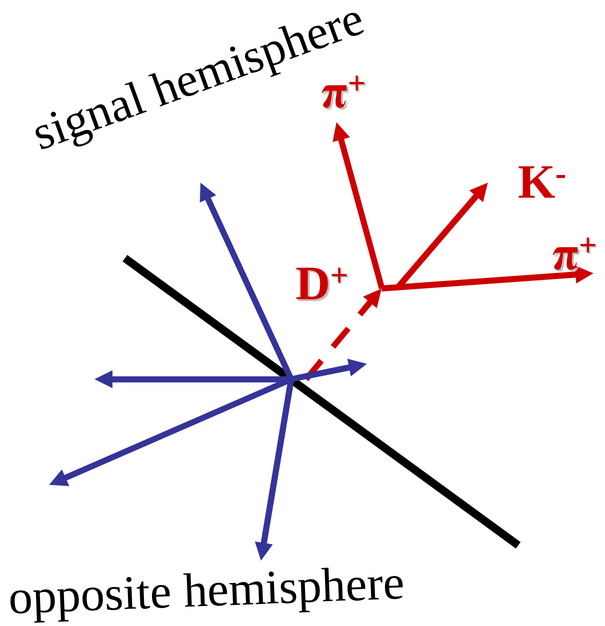
Derive resolution and background estimates from data

Control of mass constrained fit inputs

Ex. for $D^+ \to K^- \pi^+ e^+ \nu$

D^+ direction and missing energy in the signal hemisphere are determined using $K^- \pi^+ \pi^+$ (**=true**) , and compared with corresponding determination in SL (**=rec**) for data and MC.





Corrections found as function of the missing energy in the opposite hemisphere.

→ ***Input variables to the mass constrained fit***

Charm background in *BaBar*

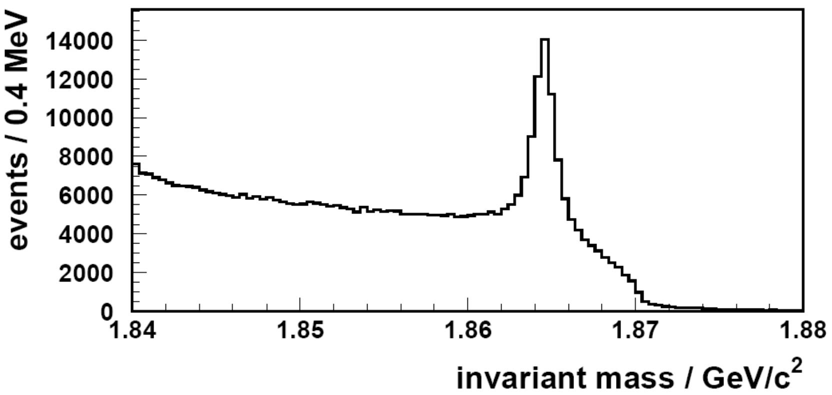
- Data-MC comparison in hadronic D decays into charged particles used to:

  improve simulation of particle production associated with c-mesons

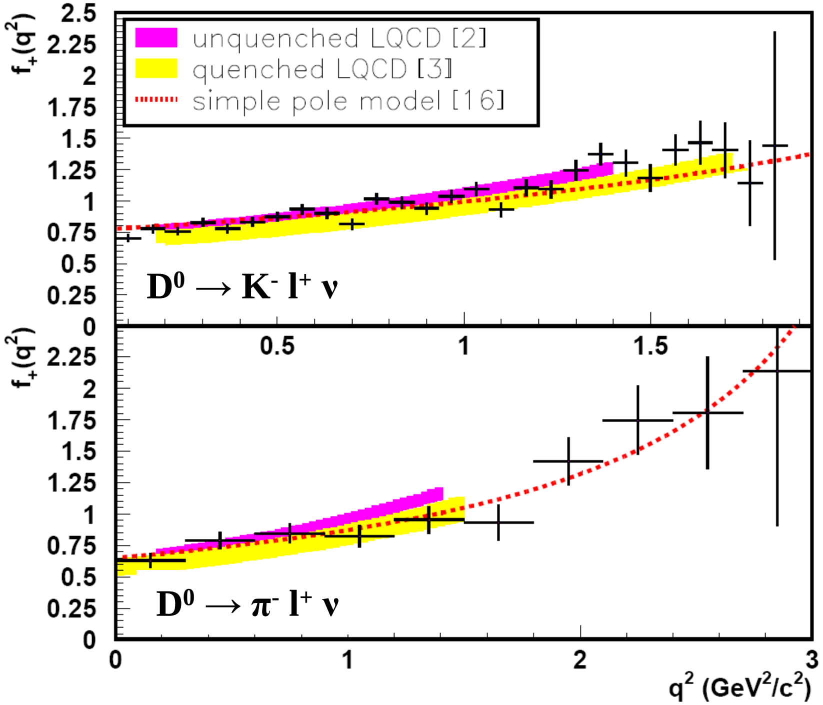
- Correction to MC of $c\bar{c}$: semileptonic decay models
  hadronization of c-quarks

Belle approach: $e^+e^- \to D^{(*)}_{tag} D^{*-}_{sig} X$

- signal D^0 is tagged using reconstruction of all other particles,
- **positive** : high resolution on decay kinematic variables, allows absolute BR measurements, low background
- **negative** : low efficiency, systematics not negligible, applies to D^0 only(?)

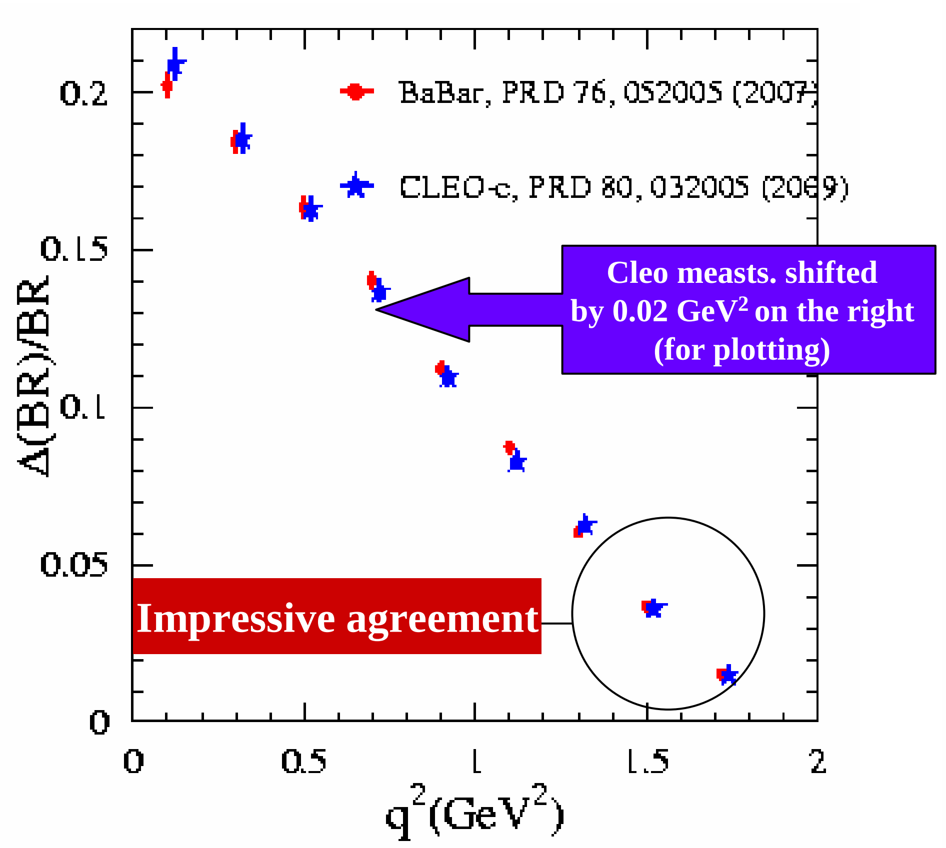


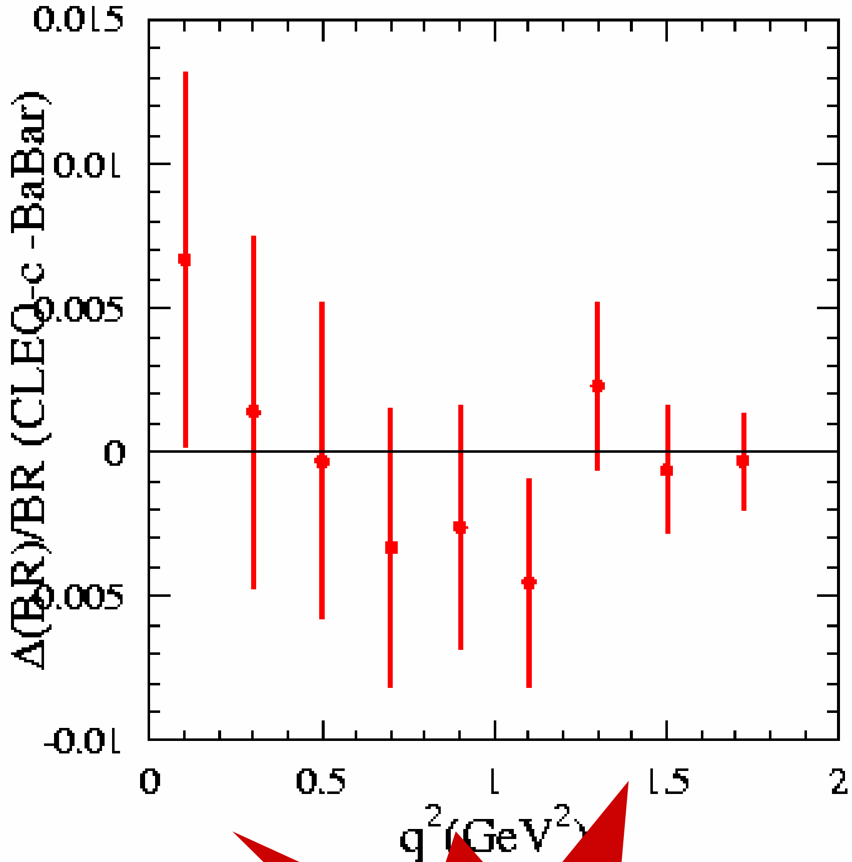
56461±309±830 D^0 tagged
from 282 fb^{-1}



$D^0 \rightarrow K^- e^+ \nu_e$

Signal events : 74 000





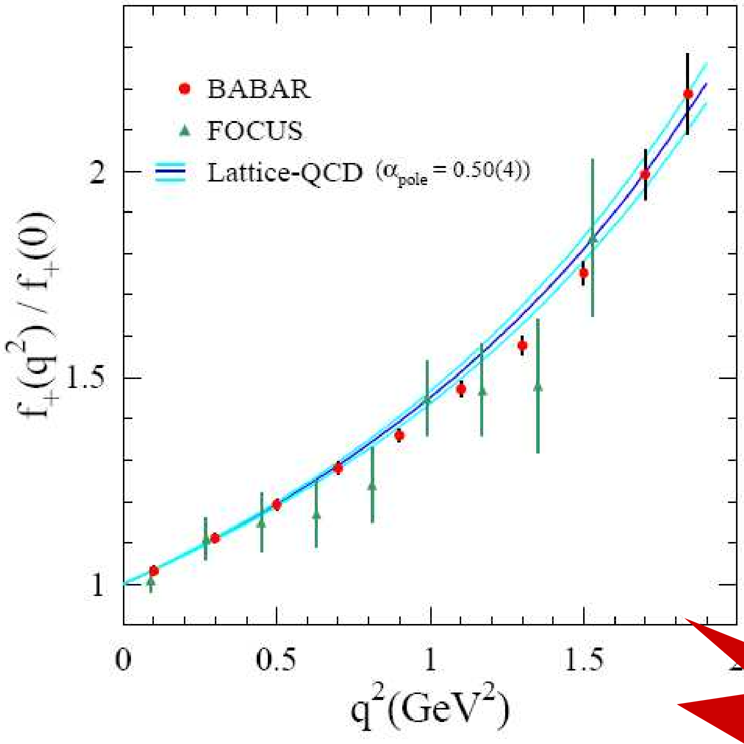
-CLEO-c and BaBar measurements agree,
our uncert. is similar to final CLEO-c (818 pb^{-1})

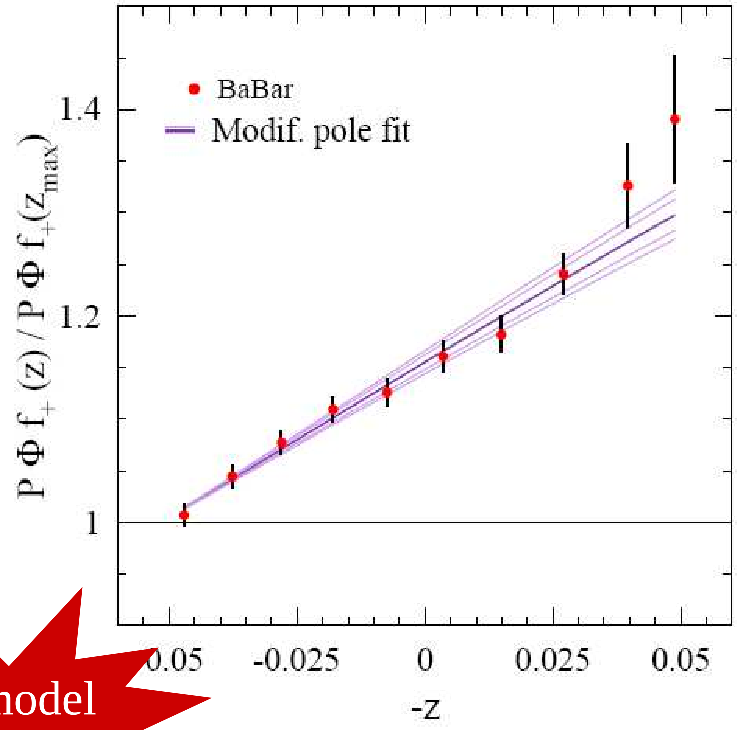
-Only 1/6 of BaBar stat. (75 fb^{-1}) was. used

needs
better radiative
simulations.

$D^0 \to K^- e^+ \nu_e$

Form factor variation





BK model agrees

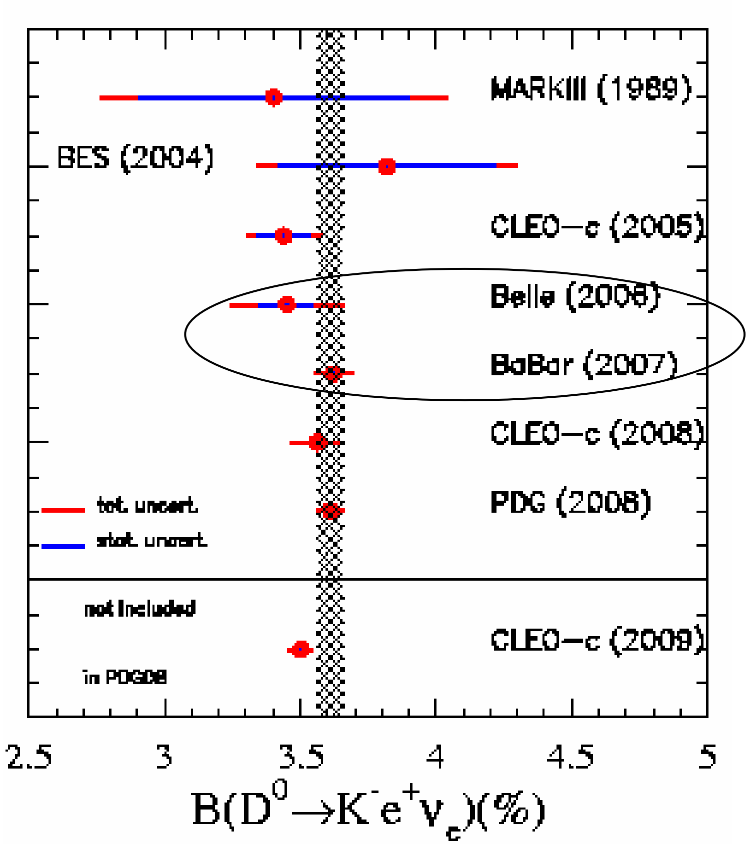
Theoretical ansatz	Unit	Parameters	χ^2/NDF	Expectations [χ^2/NDF]
z expansion		$r_1 = -2.5 \pm 0.2 \pm 0.2$	5.9/7	
		$r_2 = 0.6 \pm 6. \pm 5.$		
Modified pole		$\alpha_{pole} = 0.377 \pm 0.023 \pm 0.029$	6.0/8	
Simple pole	GeV/c^2	$m_{pole} = 1.884 \pm 0.012 \pm 0.015$	7.4/8	2.112 [243/9]
ISGW2	GeV^{-2}	$\alpha_I = 0.226 \pm 0.005 \pm 0.006$	6.4/8	0.104 [800/9]

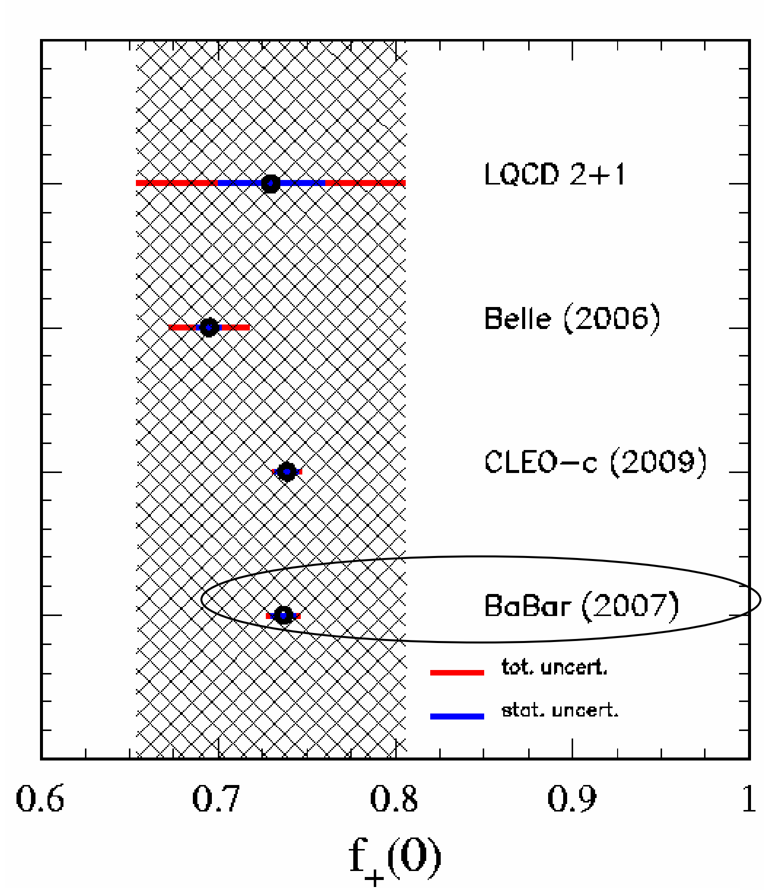
$\alpha_{pole} < (m_{Ds*} / m_{Ds*'})^2 \sim 0.6$

M_{pole}, ISGW, default values excluded

$D^0 \to K^- e^+ \nu_e$

Rate



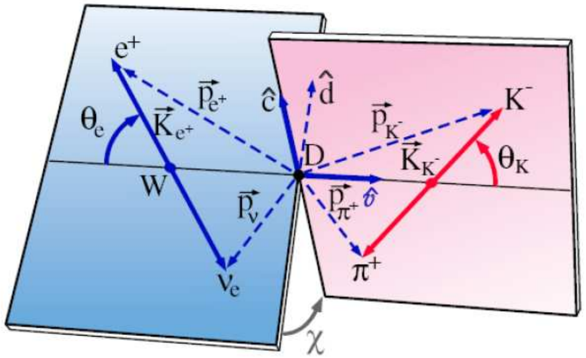


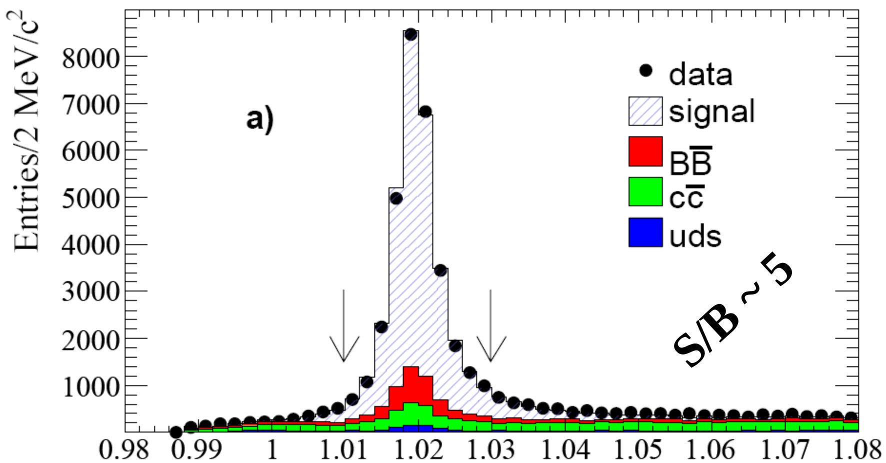
α_{pole}= **0.38 (2) (3)** BaBar
α_{pole}= **0.30 (3) (1)** CLEO-c
[α_{pole}= **0.21 (4) (3)** CLEO-c 281pb^{-1}]
α_{pole}= **0.52 (8) (6)** Belle
α_{pole}= **0.50 (4) (7)** LQCD

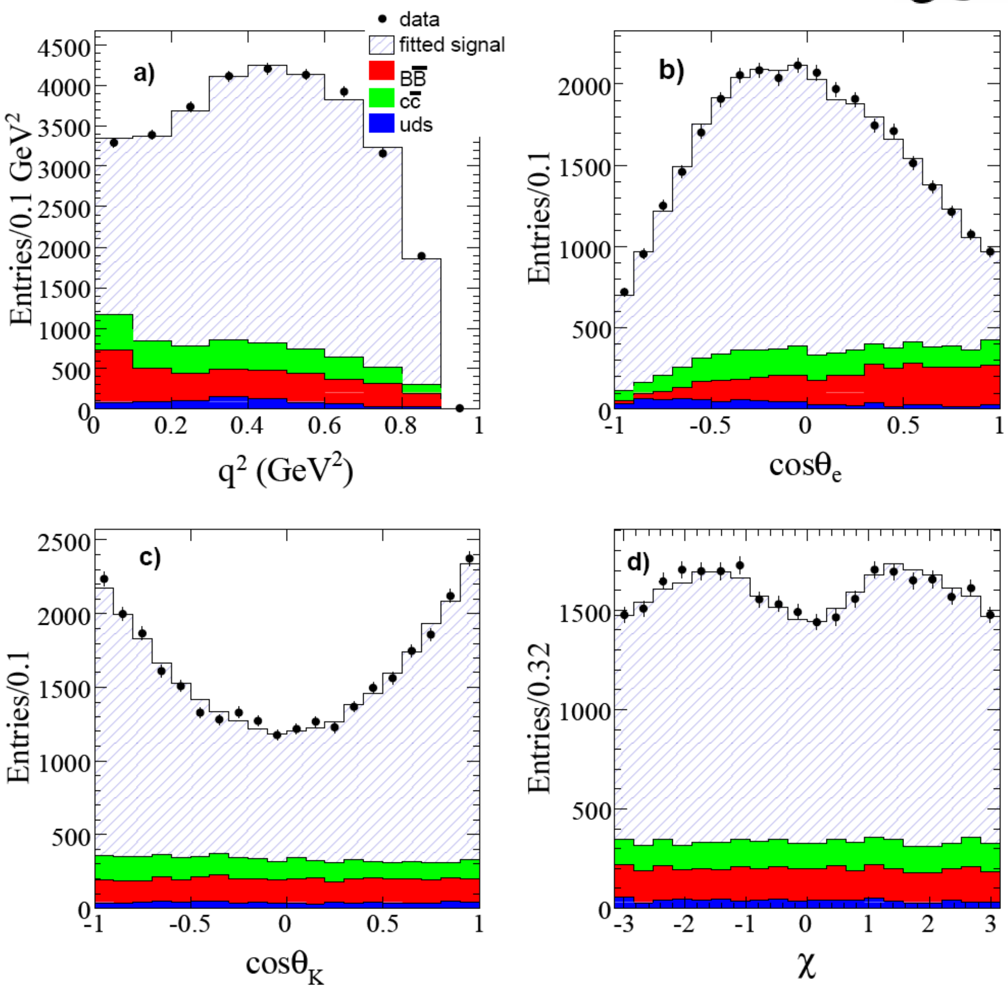
$$f_+(q^2) = \frac{f_+(0)}{\left(1 - \frac{q^2}{m^2_{D_s^*}}\right)\left(1 - \alpha_{\rm pole}\frac{q^2}{m^2_{D_s^*}}\right)}$$

$D_s \rightarrow K^- K^+ e^+ \nu_e$

- About 10% of D-meson are D_s
- **25000** signal events from 214 fb^{-1} analyzed (**50 times** more statistics than FOCUS, CLEO-c has ~**106** φ eν decays)
- **4D** fit in the φ meson region





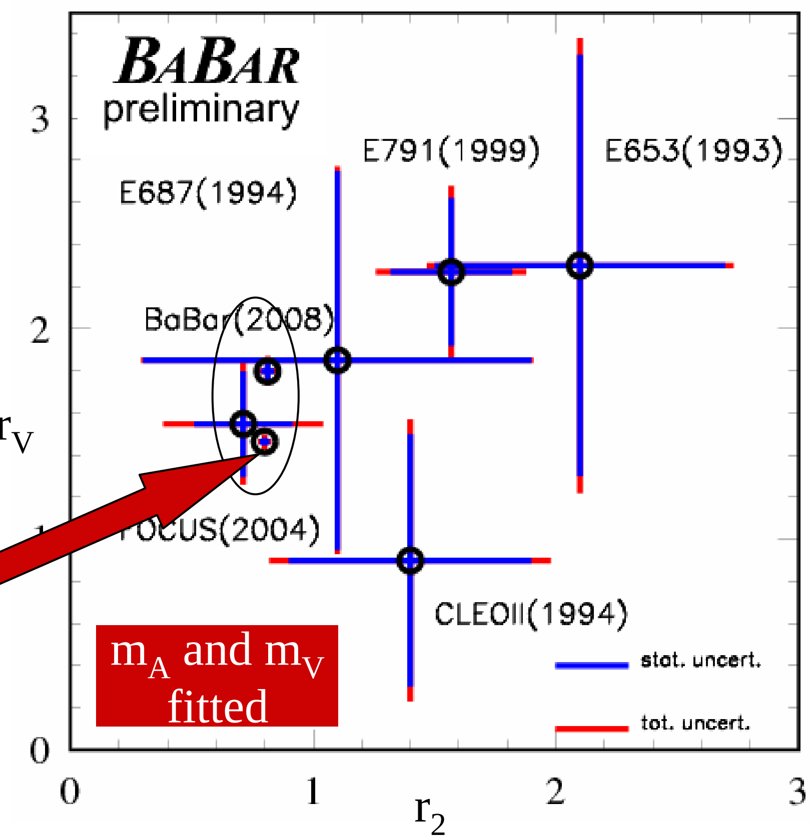


$D_s \to K^- K^+ e^+ \nu_e$

Form factors

- Accurate determination of $D_s \to \phi e\nu$ decay characteristics (first measurement of q^2 variation for the axial vector form factor **m_A=2.3±0.2±0.2 GeV/c^2**,

- Br normalized to $D_s \to K^+K^-\pi^+$;
- Extraction of form factors normalization at q^2=0 : **$A_1(0)$=0.607±0.011±0.019±0.018**



$D^+ \to \overline{K}^{*0} e^+ \nu_e$

	$D^+_s \to \varphi e^+ \nu$	$D^+ \to \overline{K}^{*0} e^+ \nu$
$A_1(0)$	0.61±0.03	0.62±0.01
r_2	0.76±0.10	0.80±0.03
r_V	1.85±0.11	1.46±0.04

preliminary

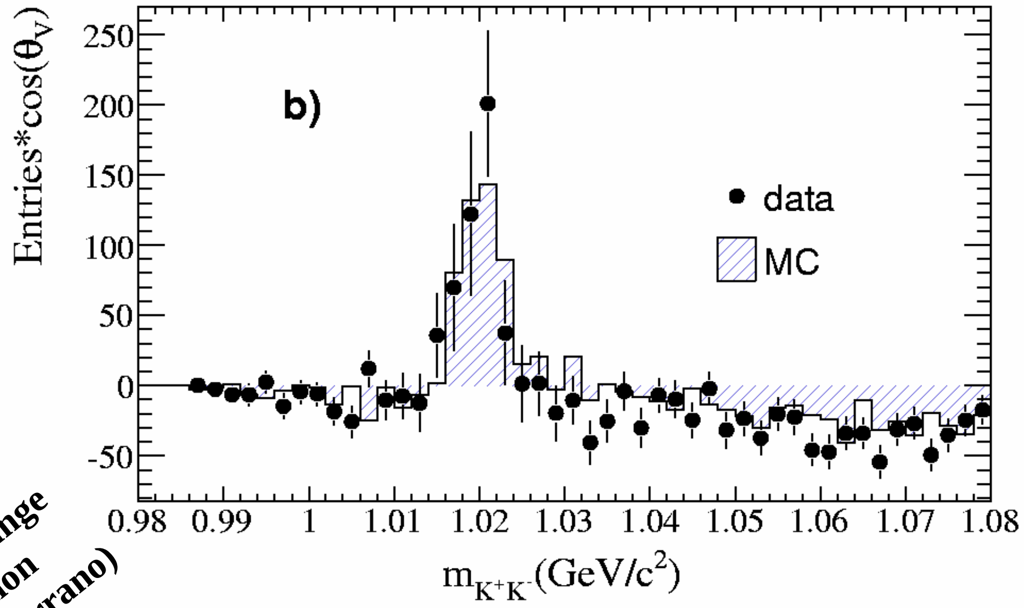
m_A fitted
m_V fixed

3σ?

flavour indep. of $D \to V e^+ \nu$

$D_s \rightarrow K^- K^+ e^+ \nu_e$

S-wave



first S-wave signal in D_s sl. decays ($>5\sigma$)

r_0=15.1±2.6±1.0 GeV^{-1}
(S-wave relative amplitude)

within [1.01,1.03] GeV/c²

total mass range extrapolation (PhD. J. Serrano)

$$\frac{BR(D_s \rightarrow f_0 e^+ \nu_e) \times BR(f_0 \rightarrow K^+K^-)}{BR(D_s \rightarrow K^+K^- e^+ \nu_e)} = 0.23^{+0.12}_{-0.08} \pm 0.03\%$$

$$\frac{BR(D_s \rightarrow f_0 e^+ \nu_e)}{BR(D_s \rightarrow \phi e^+ \nu_e)} = 4.7^{+2.5}_{-1.6} \pm 0.6\%.$$

$$\frac{BR(D^+ \rightarrow K^- \pi^+ e^+ \nu)_S}{BR(D^+ \rightarrow K^- \pi^+ e^+ \nu)_P} = \mathbf{5.79 \pm 0.16 \pm 0.15\ \%}$$

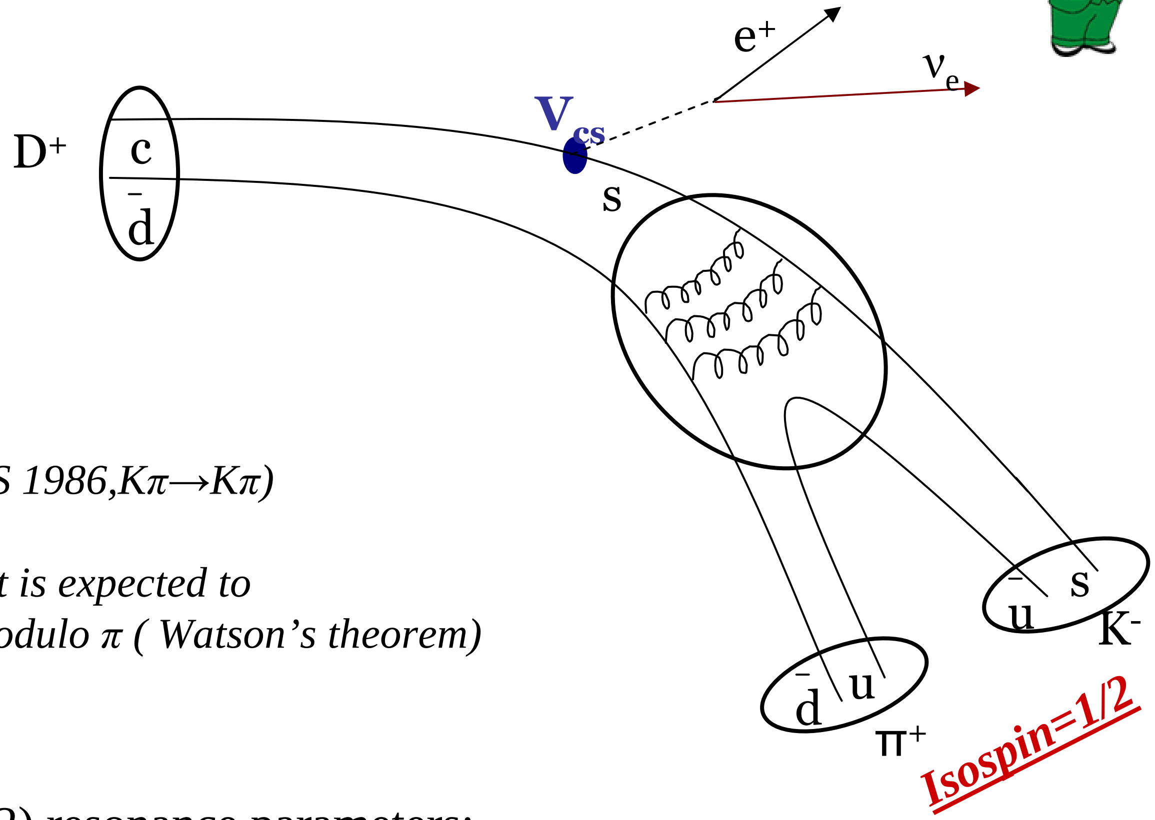
CLEO-c
$17 \pm 3^{+4}_{-2}$ %

Direct measurement of the S-wave component in the φ region

*[PRD **81**, 052007 (2010)]*

$D^+ \rightarrow K^- \pi^+ e^+ \nu_e$ (NEW preliminary results)

Study the hadronic $K\pi$ system without accompanying hadrons



- $K\pi$ system in S wave.
  - phase variation with $m_{K\pi}$;

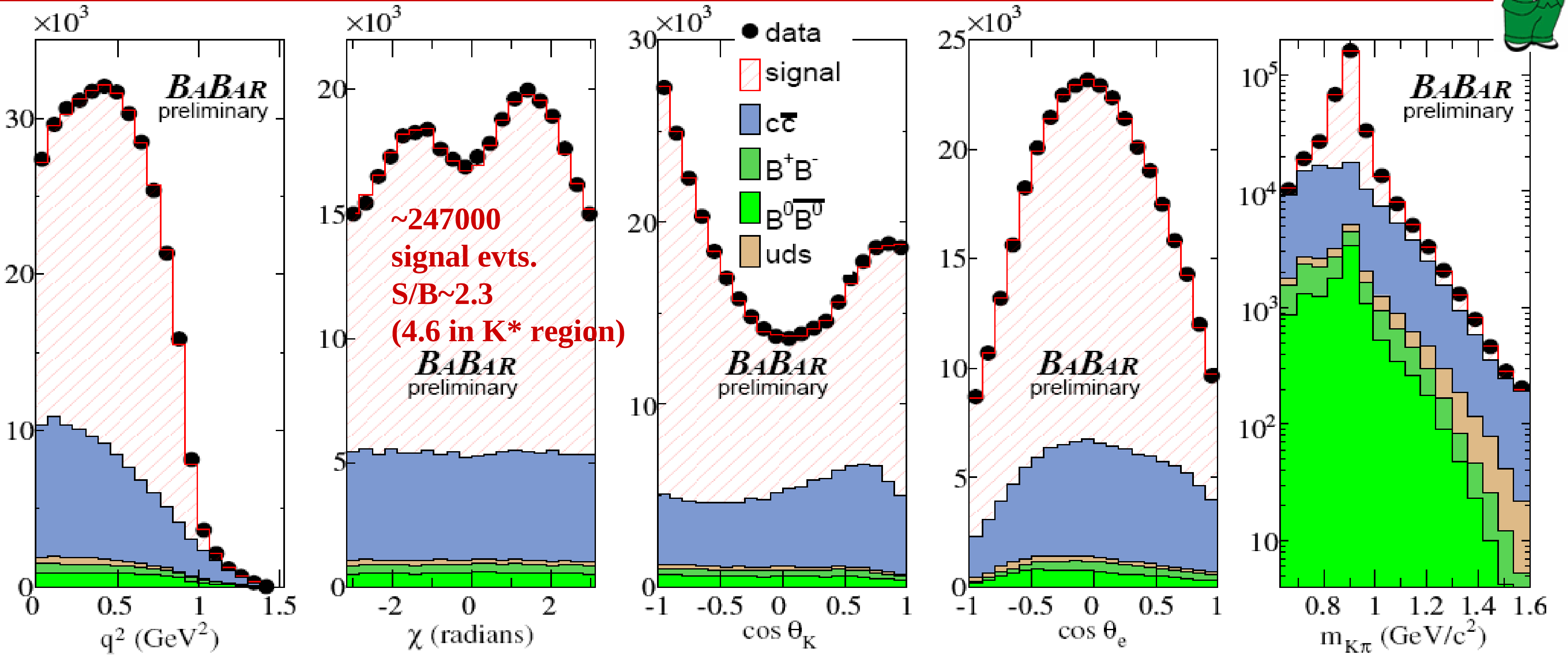
Present experimental results (LASS 1986,$K\pi \rightarrow K\pi$) still need validation.
Phase of the $K\pi$ S-wave component is expected to be the same as in $K\pi$ scattering, modulo π (Watson's theorem) in the elastic regime

- $K\pi$ system in P wave.
  - precise determination of $K^{*0}(892)$ resonance parameters;
  - determination of form factor parameters *(compare with LQCD);*
  - search for possible higher mass state contributions;

- understand the D semileptonic exclusive decays (missing exclusive states in B semileptonic decays).

Using 347.5 fb^{1}
Fit in 5D in all phase space, first time in this decay

$D^+ \to K^- \pi^+ e^+ \nu_e$

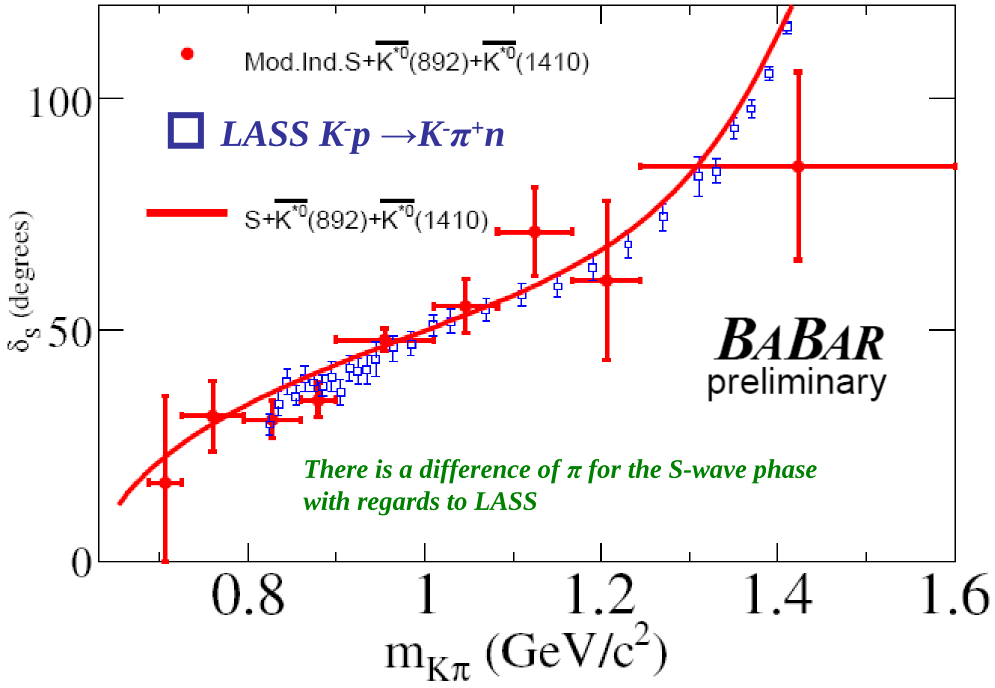


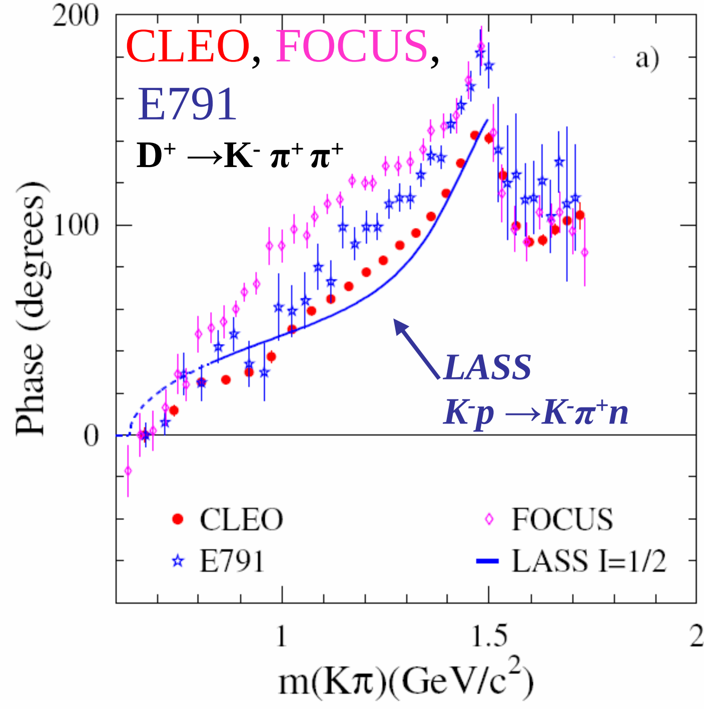
$$\mathcal{B}(D^+ \to K^-\pi^+e^+\nu_e) = (4.04 \pm 0.03 \pm 0.04 \pm 0.09) \times 10^{-2}$$

Component	S+K*(892) (%)	S+K*(892) + K*(1410) (%)	S+K*(892) + K*(1410) + D(%)
S-wave	5.62 ± 0.14 ± 0.13	5.79 ± 0.16 ± 0.15	5.69 ± 0.16 ± 0.15
P-wave	94.38	94.21	94.12
K*(892) K*(1410)	94.38 0	94.11 ± 0.74 ± 0.75 0.33 ± 0.13 ± 0.19	94.41 ± 0.15 ± 0.20 0.16 ± 0.08 ± 0.14
D-wave	0	0	0.19 ± 0.09 ± 0.09

$D^+ \rightarrow K^- \pi^+ e^+ \nu_e$

S-wave phase



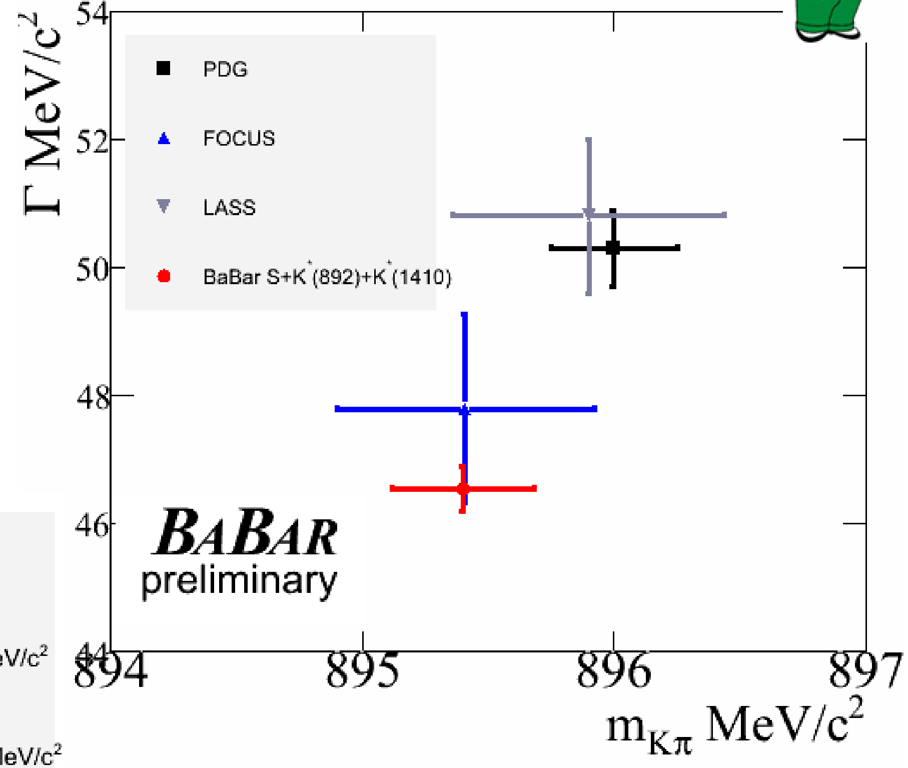


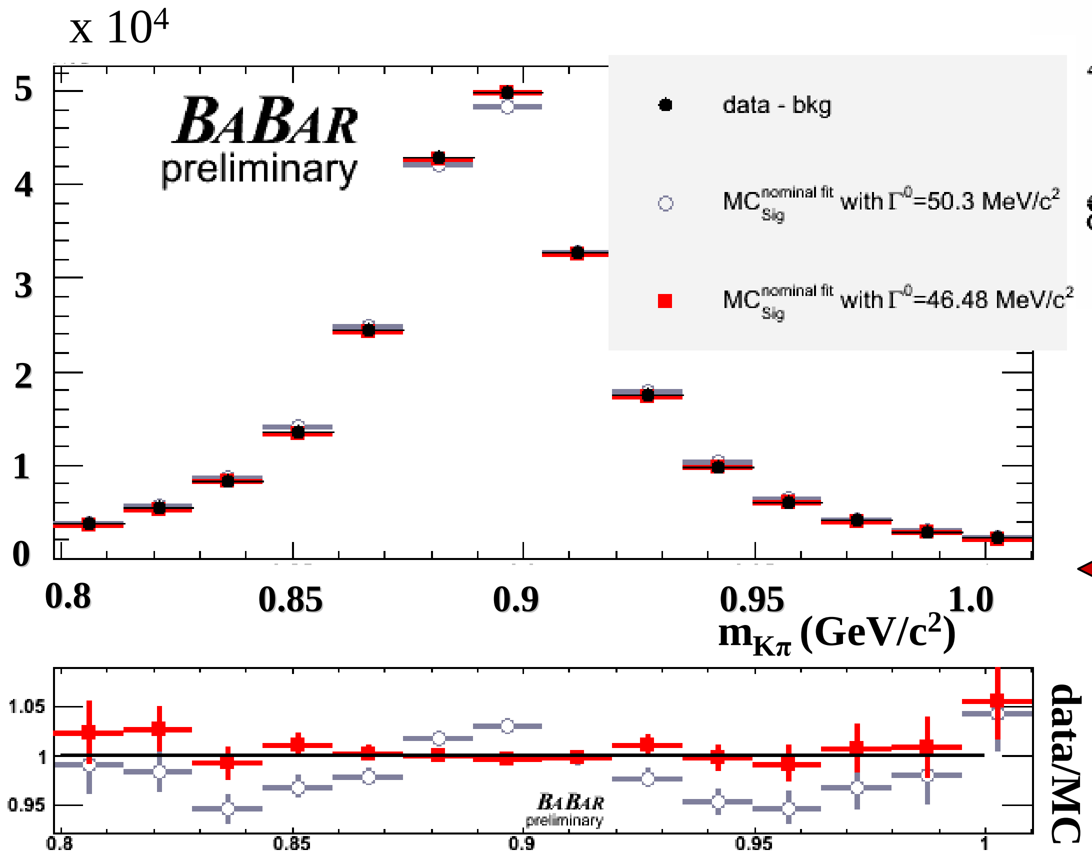
- Watson's theorem : same phase variation (modulo π) with regards to Kπ scattering in the elastic regime
- We find agreement with results from Kπ scattering experiment (LASS) (difference of π)
- This may help understanding the effect of the spectator π in $D^+ \rightarrow K^- \pi^+ \pi^+$ experiments

$D^+ \rightarrow K^- \pi^+ e^+ \nu_e$

K*(892) mass and width:

- Measurement of the $K^*(892)$ width is quite different from LASS and from the PDG average



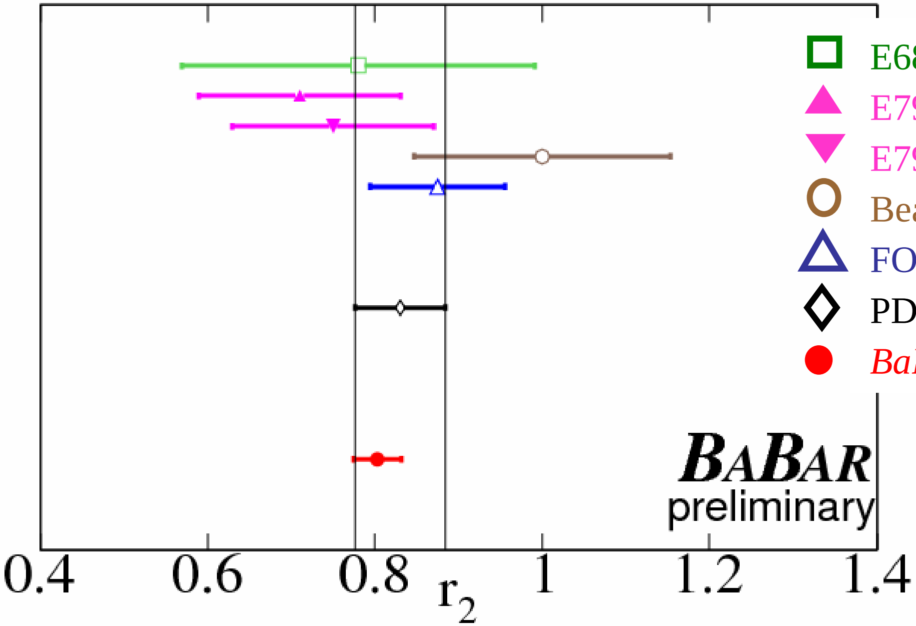


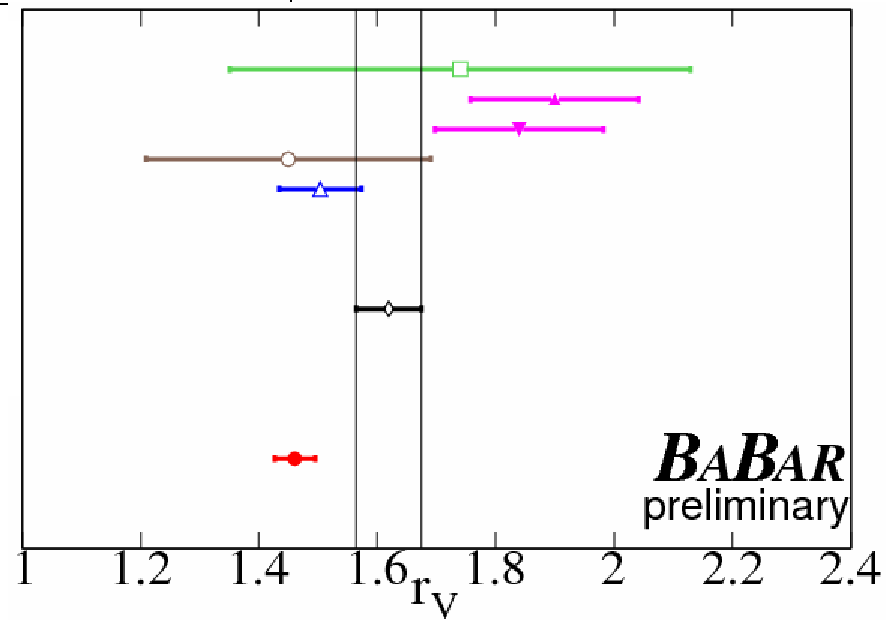
Fitting BaBar data keeping the K* width fixed at the PDG value gives a poor agreement with data

$D^+ \to K^- \pi^+ e^+ \nu_e$

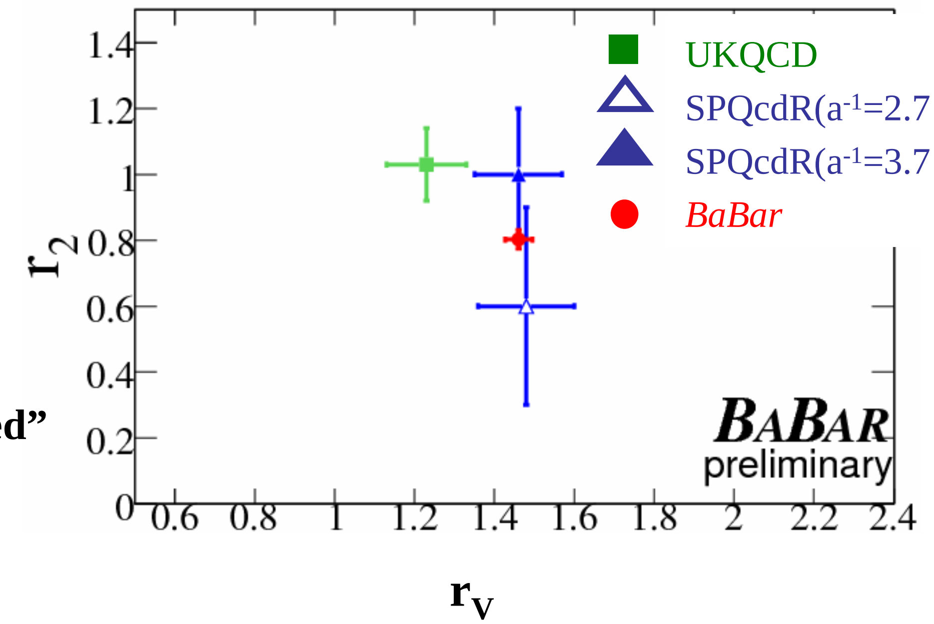
Form factors

Comparison with other experiments





Comparison with LQCD



"quenched" approximation

would be nice to have "unquenched" results

Expected value for m_A close to **$m(D_{s1})$~2.5 GeV/c^2**.
(found **2.63± 0.10± 0.10 GeV/c^2**)

Conclusions

- BaBar and CLEO-c agree on the rate and on the FF q^2 variation for $D^0 \to K^- e^+ \nu$. These are reference values for LQCD.

- Accurate measurements of decay rate and FF q^2 variation for $Ds \to \varphi e^+ \nu$ and $D^+ \to \overline{K}^{*0} e^+ \nu$. Similar values are obtained for $A_1(0)$ and r_2, some difference seen on r_V.

- First measurement of the axial-vector FF q^2 variation.

- The S-wave component is about 5% in both decays.
  Complementary information to CLEO-c on the S-wave in D_s sl. decays.
  Some discrepancy observed in $D_s \to f_0 e^+ \nu$ with CLEO-c

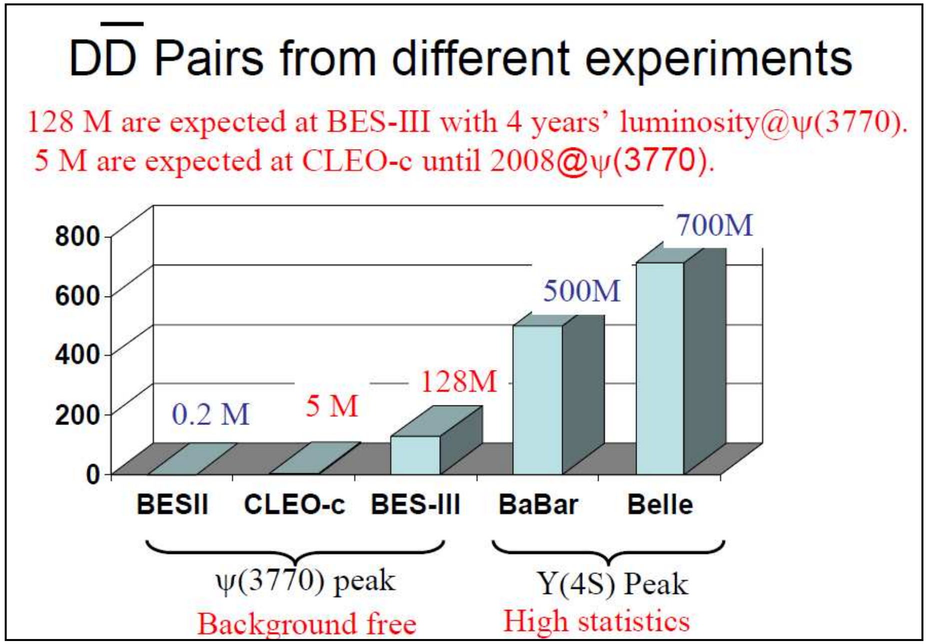
- Measurements of the $K\pi$ S-wave phase agree with LASS ($+\pi$)

- Detailed measurements of the K^{*0} mass distribution

- Low limits placed on $K^*(1410)$ and $K_2^*(1430)$ contributions in the $K^- \pi^+$ final state.

Other experiments

• BES-III (e^+e^-) :



Data taking started

• LHCb (pp) : lot of charm, from B decays and prompt but analysis not easy in an hadronic environment

First data coming

• SuperB (e^+e^-) :

First data in 2015 ?

- at the Υ(4S), 15 ab^{-1} per year (~ 30x Babar statistics)
- at the Ψ(3770), 1.5 ab^{-1} per year → 2 months of data taking=300xCLEO-c

Future

- Present accuracy on hadronic FF is already much higher than LQCD evaluations

- Other sl D decay channels can be measured at B-factories using present data: $D^0 \rightarrow \pi^- e^+ \nu$, $D_s \rightarrow \eta/\eta' e^+ \nu$, $\Lambda_c \rightarrow \Lambda e^+ \nu$, … (manpower?)

- To obtain higher accuracy, operating at threshold is better: low background, high resolution on kinematic variables, possibility to measure radiated photons, access rare decay modes, control of detector performances using J/ψ decays, …

- This favours the possibility to run a Super-flavour factory at charm threshold.