Charm semileptonic decays at BaBar

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LNF spring school

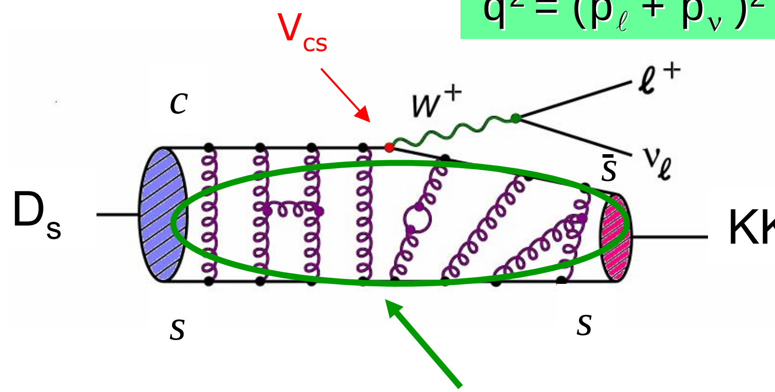
Charm semileptonic decays

Motivations :

➢ Charm semileptonic decays provide an important way to test lattice QCD predictions through form factor measurements.

➢ Techniques validated in the charm sector can then be used in the B sector to improve the accuracy on CKM parameters determination.

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



➢ Pseudoscalar $\ell\ \nu$ decay : one form factor, angular distribution known

- $D^0 \to K^- e^+ \nu$
- $D_s \to \eta/\eta' e\nu$
- $D^0 \to \pi^- e^+ \nu$

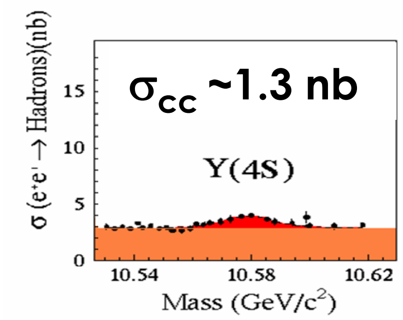
➢ Vector $\ell\ \nu$ decay : 3 helicity states, 5 kinematic variables

- $D_s^+ \to \varphi e^+ \nu$
- $D \to K\pi e\nu$

BaBar vs CLEO-c

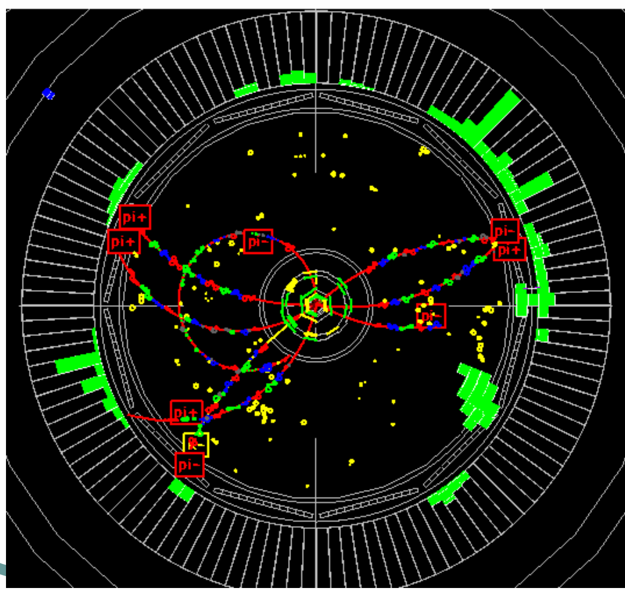
- Large integrated luminosity

$400\ fb^{-1}$

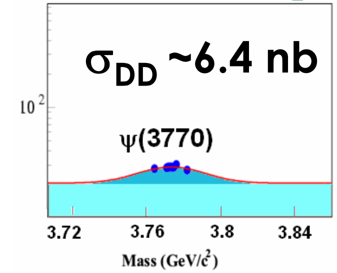


- fragmentation (D, D_s, Λ_c, …)
- main challenge : background control

$c\bar{c}$

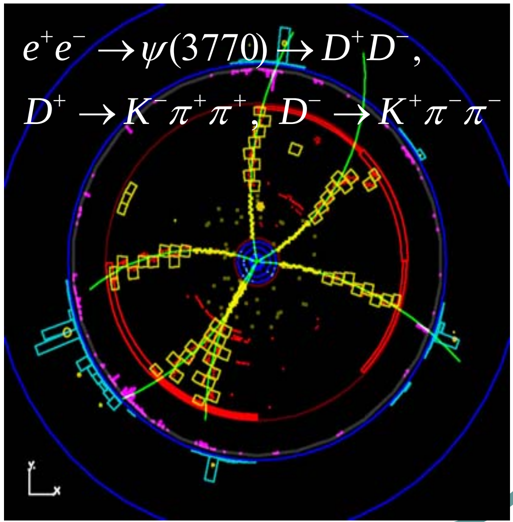


- Pure $D\bar{D}$, no additional particles
- less background



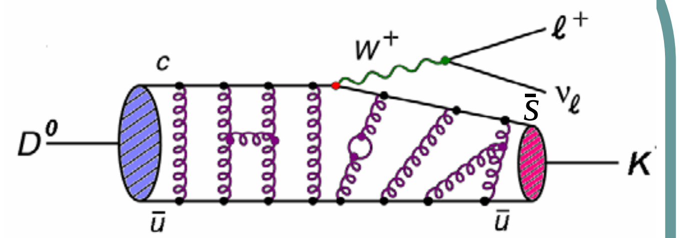
- low statistics : 281 pb^{-1} $D\bar{D}$

  314 pb^{-1} $D_s^*D_s$



D→Keν

☆ If the lepton is massless, the decay rate depends on one (vector) ff :



$$\frac{d\Gamma}{dq^2} = \frac{G_f^2 |V_{q_1 q_2}|^2 p_{P'}^3}{24\pi^3} |f_+(q^2)|^2$$

The measured ff can be compared with different theoretical models and test LQCD determination of the parameter involved :

- **Simple pole mass** : suppose that the decay is governed by the spectroscopic pole. The measured parameter is the "effective pole mass" m_{pole}.

$$\left|f_+(q^2)\right| = \frac{f_+(0)}{1 - \frac{q^2}{m_{pole}^2}}$$

Spectroscopic mass pole, mD_s^* for Keν

(1^- $c\bar{s}$ state)

- **Modified pole mass** (B&K): add an effective pole to take into account higher resonances. Measure α_{pole}.

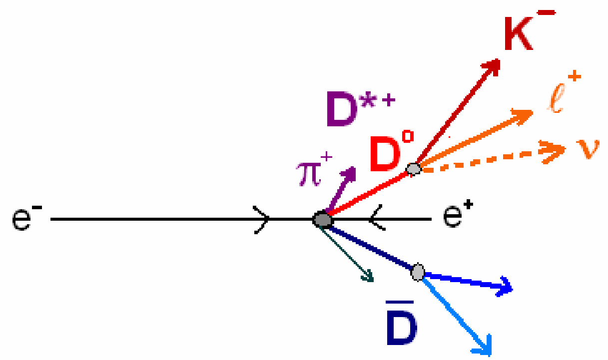
$$\left|f_+(q^2)\right| = \frac{f_+(0)}{\left(1 - \frac{q^2}{m_{D_s^*}^2}\right)\left(1 - \frac{\alpha_{pole} q^2}{m_{D_s^*}^2}\right)}$$

- **ISGW2** (model used in the simulation)

- **Taylor expansion**

Analysis overview

- Untagged analysis



- Reconstruct the decay channel

$D^{*+} \to D^0 \pi^+, \quad D^0 \to K^- \ell^+ \nu$

in $e^+e^- \to c\bar{c}$ continuum events

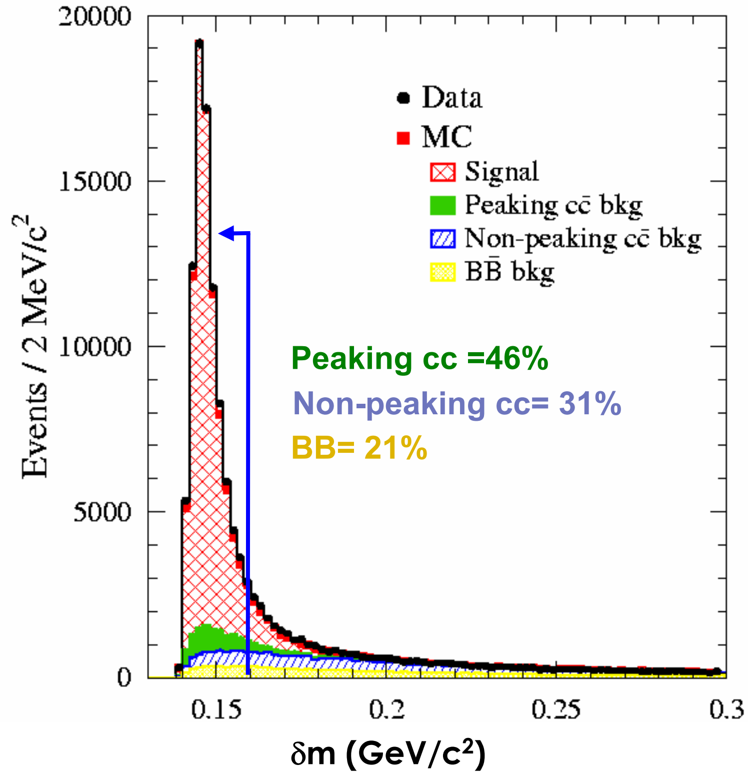
$\Upsilon(4S)$ rest frame : *jet-like* events

- Determine $q^2 = (p_D - p_K)^2 = (p_\ell + p_\nu)^2$ ← two constrained fits (m_{D0}, m_{D^*})
- Reduce the background ← Fisher analyses to separate signal from bkg
- Extract the form factor ← Unfolding
- methods validation ← Control samples

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

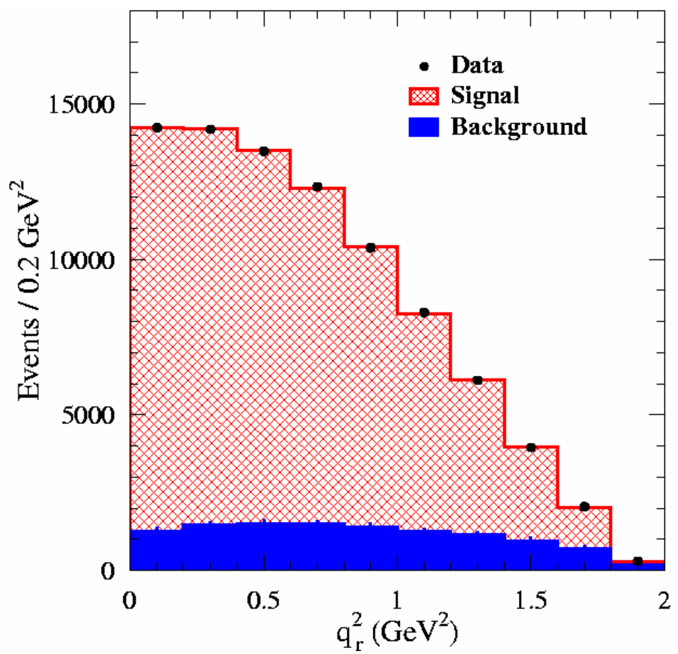
Decay characterisics

☆ Mass difference distribution



$\delta m = m(K^- \ell^+ \nu \pi^+) - m(K^- \ell^+ \nu)$ after the fit with 1 constraint on m_D

☆ q^2 distribution



$q^2 = (p_D - p_K)^2$
after the fit with 2 constraints: m_{D^*} and m_D

85000 events (13% bkg)

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

Results

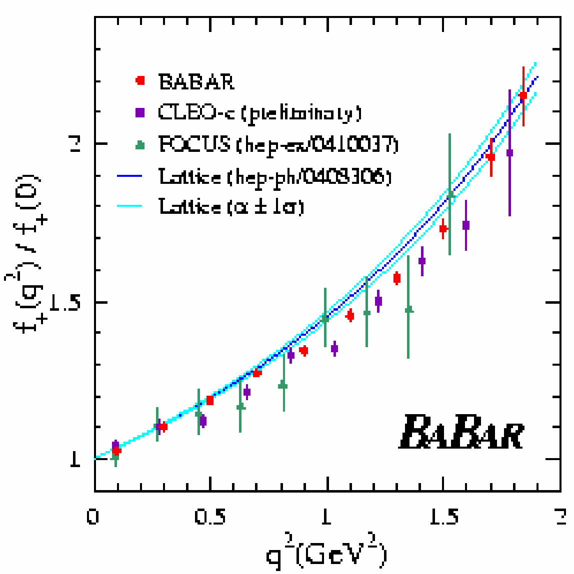
experiment	stat	$m_{pole}(GeV/c^2)$	α_{pole}
CLEO-c	281 pb^{-1}	$1.97 \pm 0.02 \pm 0.01$	$0.21 \pm 0.04 \pm 0.03$
FOCUS	13k evts	$1.93 \pm 0.05 \pm 0.03$	$0.28 \pm 0.08 \pm 0.07$
Belle	282 fb^{-1}	$1.82 \pm 0.04 \pm 0.03$	$0.52 \pm 0.08 \pm 0.06$
BaBar	75 fb^{-1}	$1.884 \pm 0.012 \pm 0.015$	$0.38 \pm 0.02 \pm 0.03$

preliminary

hep-ex/0410037

hep-ex/0604049

arXiv:0704.0020



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

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

- same accuracy as CLEO-c
- Pole mass below $m_{D^*_s}$ (=**2.112 GeV**), we exclude the simple pole mass model
- α measurement lower than lattice QCD value: **α = 0.50 ± 0.04** hep-ph/0408306
  - Disagreement between values from BaBar and CLEO-c ⇒ has to be clarified !

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

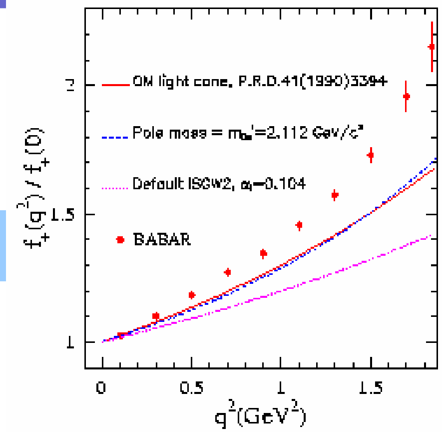
Results

☆ **Other models:**

ISGW2

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

$\alpha_I = 0.222 \pm 0.005 \pm 0.006\ \mathrm{GeV}^{-2}$



▶ Disagreement with predicted value $\alpha_I = 0.104\ \mathrm{GeV}^{-2}$
We exclude this model

Taylor expansion

$$F(t) = \frac{1}{P(t)\phi(t,t_0)} \sum_{k=0}^{\infty} a_k(t_0)\, z(t,t_0)^k \qquad t \equiv q^2$$

$a_1/a_0 = -2.5 \pm 0.2 \pm 0.2$

$a_2/a_0 = 2 \pm 6 \pm 4$

▶ One parameter is enough to describe the FF shape

☆ **Branching fraction:** (Relative to $D \to K\pi$)

$$R_D = \frac{BR(D^0 \to K^- e^+ \nu_e)_{\mathrm{data}}}{BR(D^0 \to K^- \pi^+)_{\mathrm{data}}}$$

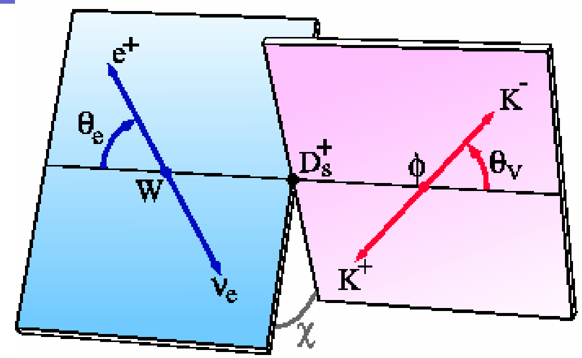
$BR(D^0 \to K^- e^+ \nu_e(\gamma))$ = $(3.522 \pm 0.027 \pm 0.045 \pm 0.065)\%$

$f_+(0) = 0.727 \pm 0.008 \pm 0.005 \pm 0.007$

Lattice: $f_+(0) = 0.73 \pm 0.03 \pm 0.07$

$D_s \to \varphi e \nu$
$\quad \hookrightarrow K^+K^-$

4 kinematic variables :
q^2 , θ_V, θ_l, χ



Decay rate : (assuming $m_\ell = 0$)

$$\frac{d^4\Gamma}{dq^2 d\cos\theta_V d\cos\theta_e d\chi} \propto p_{KK} q^2 \left| (1+\cos\theta_e)\sin\theta_V e^{i\chi} H_+ - (1-\cos\theta_e)\sin\theta_V e^{-i\chi} H_- - 2\sin\theta_e \cos\theta_V H_0 \right|^2$$

Helicity ff :

$$H_\pm(q^2) = (M_D + m_{KK}) A_1(q^2) \mp 2\frac{M_D p_{KK}}{M_D + m_{KK}} V(q^2)$$

$$H_0(q^2) = \frac{1}{2m_{KK}\sqrt{q^2}} \left[(M_D^2 - m_{KK}^2 - q^2)(M_D + m_{KK}) A_1(q^2) - 4\frac{M_D^2 p_{KK}^2}{M_D + m_{KK}} A_2(q^2) \right]$$

pole dominance parametrization:

$$A_i(q^2) = \frac{A_i(0)}{1 - q^2/M_A^2} \qquad V(q^2) = \frac{V(0)}{1 - q^2/M_V^2}$$

Two parameters are usually measured : ratios of the ff at $q^2 = 0$

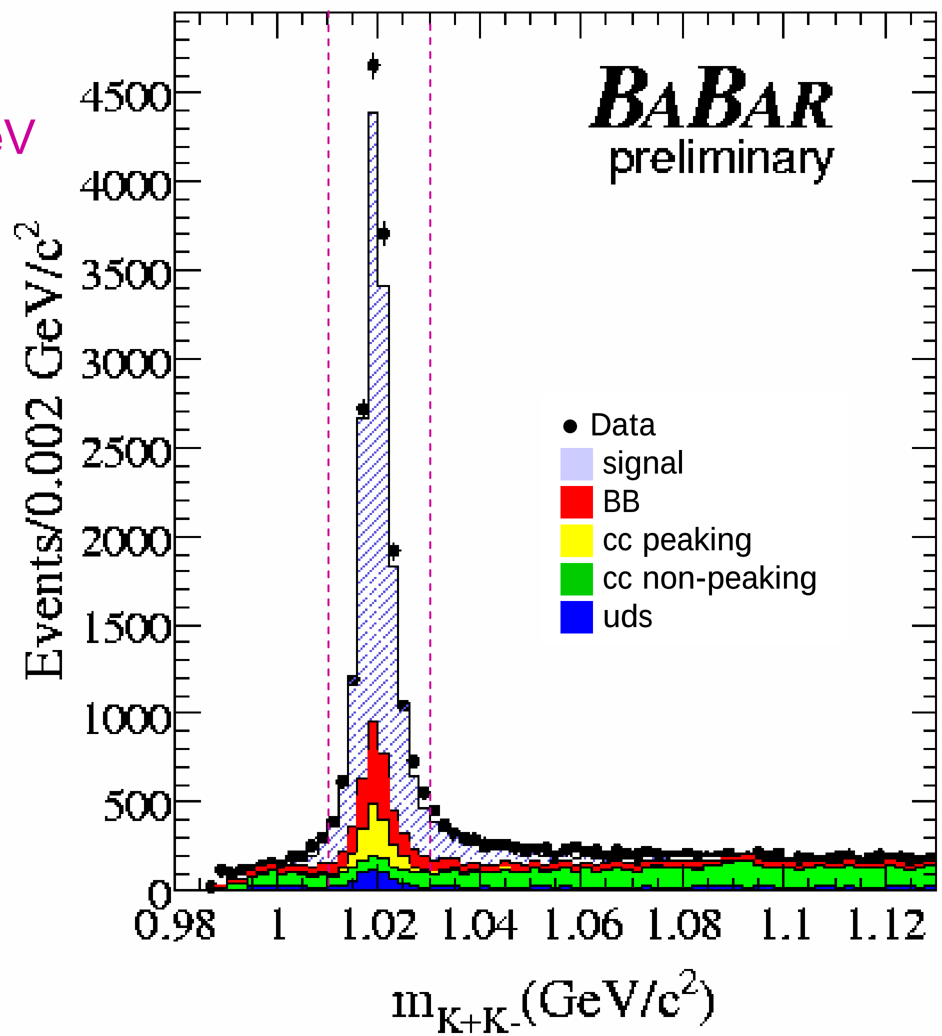
$$r_V = V(0)/A_1(0) \quad \text{and} \quad r_2 = A_2(0)/A_1(0)$$

$D_s^+ \to \varphi e^+ \nu$

Decay characteristics

signal region :

1.01 GeV <mφ<1.03GeV



78.5 fb^{-1}

Signal yield : 13000

Background composition :

B^0B^0 evts = 23%

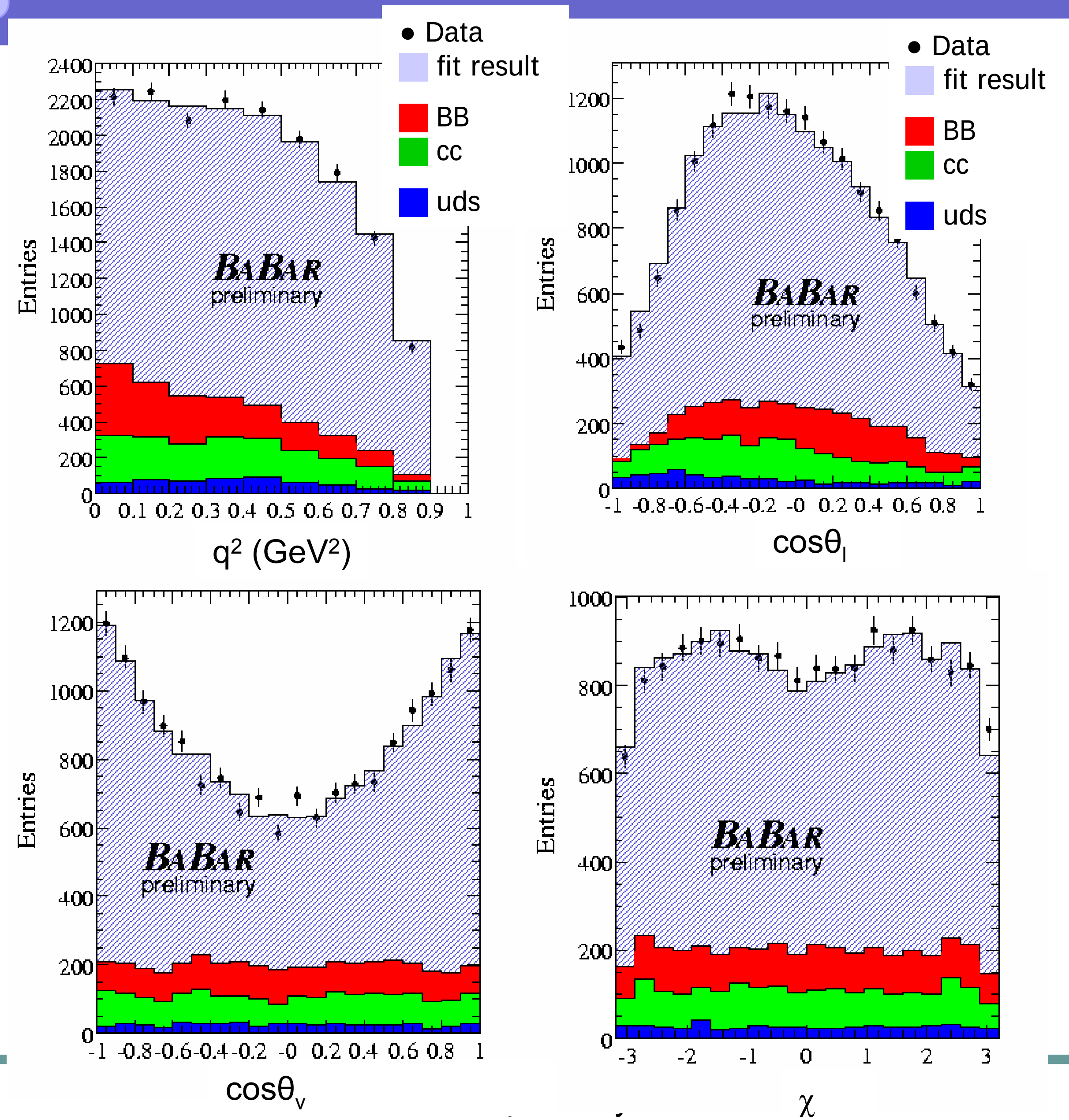
B^+B^- evts = 22%

uds evts = 14%

$c\bar{c}$ = 41%

$D_s^+ \to \varphi e^+ \nu$

Results



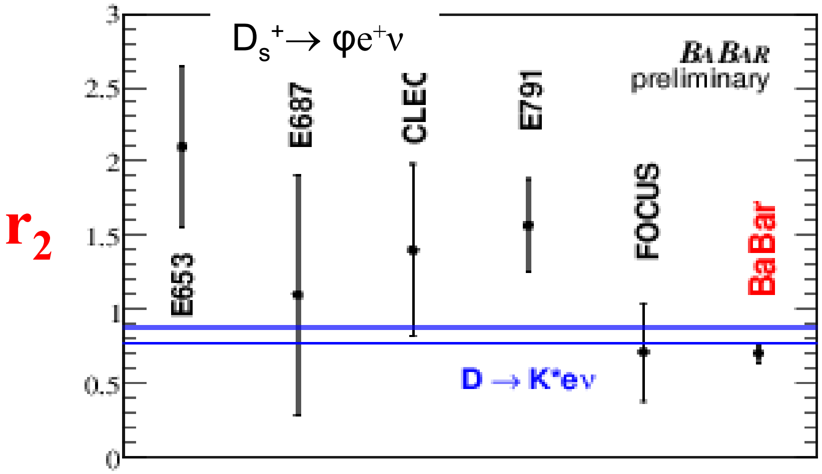
Results

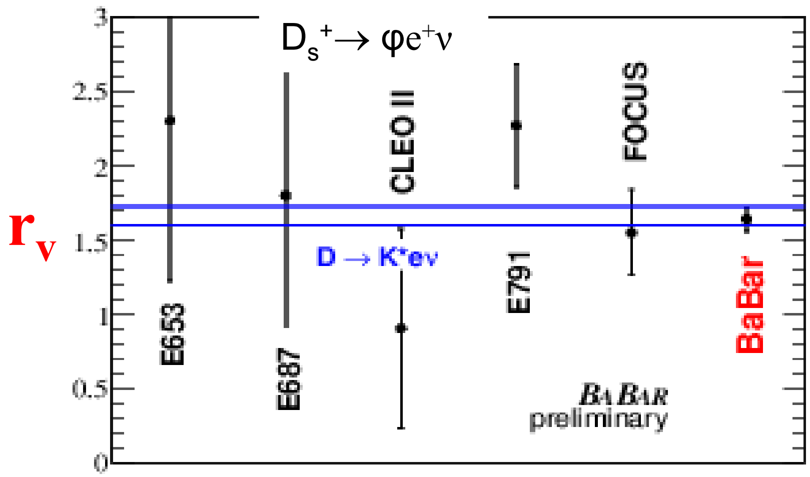
Hep-ex:0607085

★ Form factor ratios at $q^2=0$ (fixing $m_A = 2.5\,GeV/c^2$ and $m_V = 2.1\,GeV/c^2$) :

$\boxed{r_2 = 0.705 \pm 0.056 \pm 0.029}$

$\boxed{r_V = 1.636 \pm 0.067 \pm 0.038}$





→ Same accuracy as world average $D \to K^* e \nu$ and similar values

★ Fixing only the vector pole mass :

$\boxed{r_2 = 0.711 \pm 0.111 \pm 0.096}$

$\boxed{r_V = 1.633 \pm 0.081 \pm 0.068}$

$\boxed{m_A = 2.53^{+0.54}_{-0.35} \pm 0.054\ GeV/c^2}$

Conclusion

BaBar is not only a B factory !

- $D \to K e \nu$ form factor : First study of the Babar potential in charm sl decays

  Very successful, measurement much more precise than lattice

  Open a large perspective in ff measurements in BaBar …

- $D_s \to \varphi e \nu$ form factors : Much more precise than previous experiments

Still a lot of interesting measurement that we can do :

- ff in $D \to \pi l \nu$ and $D \to K \pi l \nu$
- Enlarge KK mass in $D_s \to \varphi e \nu$ to study 0^+ states
- S wave in $D \to K \pi l \nu$
- Charm baryons,....

BACK UP

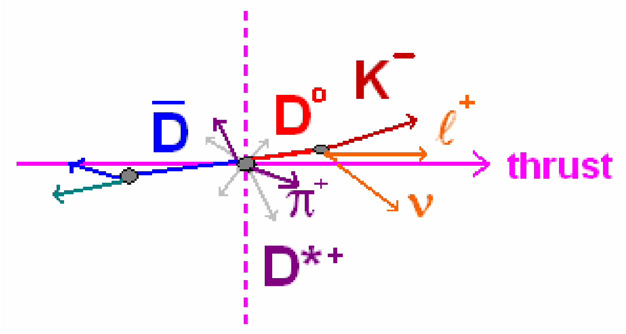
$D^0 \to K^- e^+ \nu$

Event reconstruction

- **Define two hemispheres:**
  - take soft π^+, K^- and ℓ^+ in the same hemisphere

Cuts
- p^*_ℓ , p_ℓ > 0.5 GeV
- $p^*_{\pi+}$ < 0.4 GeV
- $\cos\theta_{thrust}$ < 0.6

Υ(4S) rest frame : *jet-like* events



- **Compute D direction** $(-\, p_{\text{all particles} \neq K,\ell})$
- **Compute the missing energy in the ℓ hemisphere**
- **Fit $p_D = p_K + p_\ell + p_\nu$**
  - From p_K, p_ℓ, computed E_{miss} and D^0 direction
  - Constraints using m_D and m_{D^*} (1c or 2c fit)

- **Compute $q^2 = (p_D - p_K)^2$**

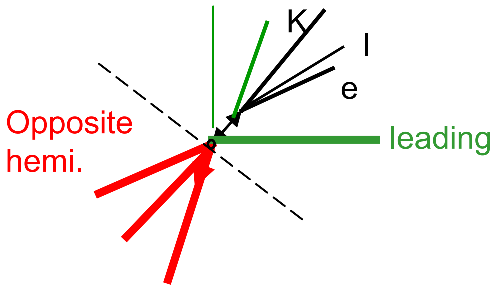
$D^0 \to K^- e^+ \nu$

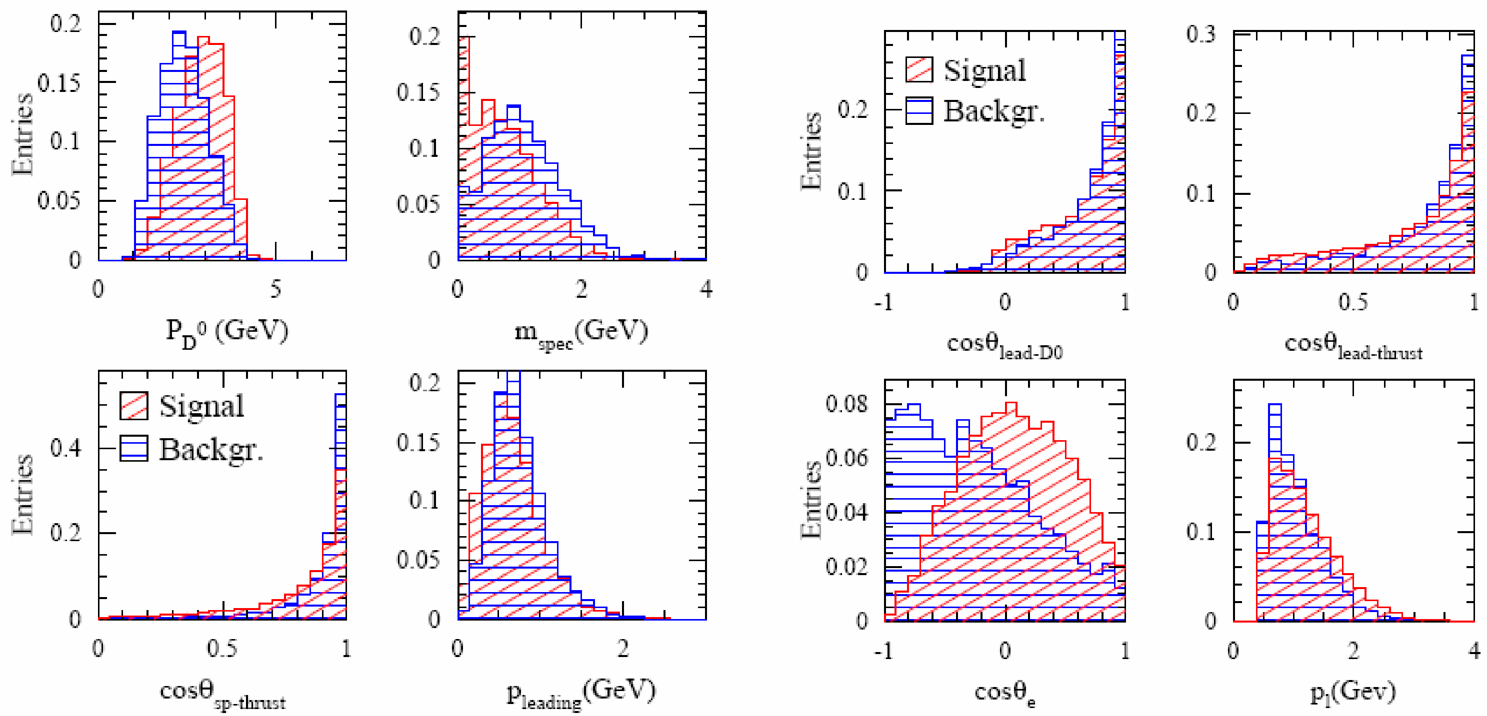
Background rejection

2 Fisher variables :

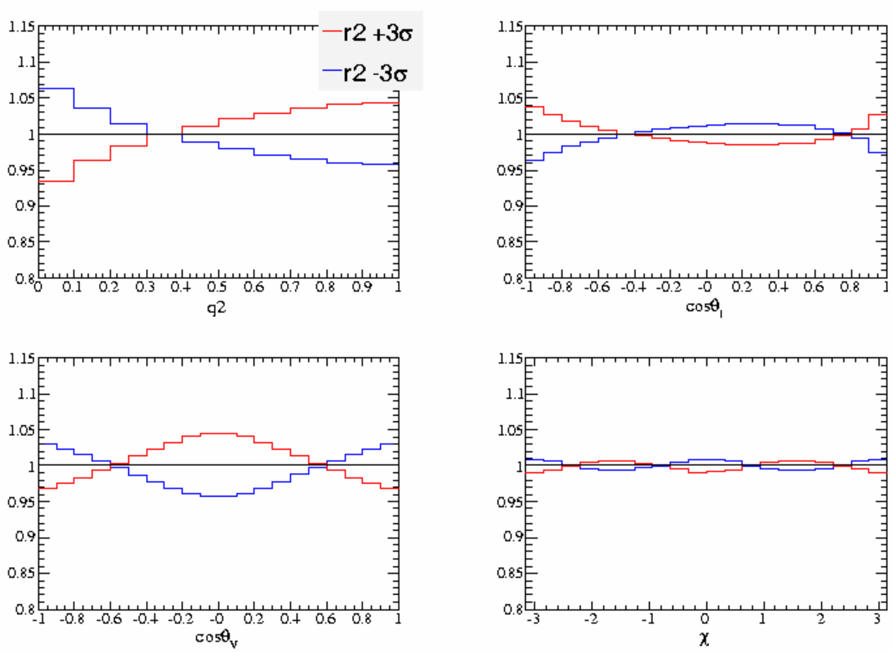
- **$c\bar{c}$ background:** Spectator system variables

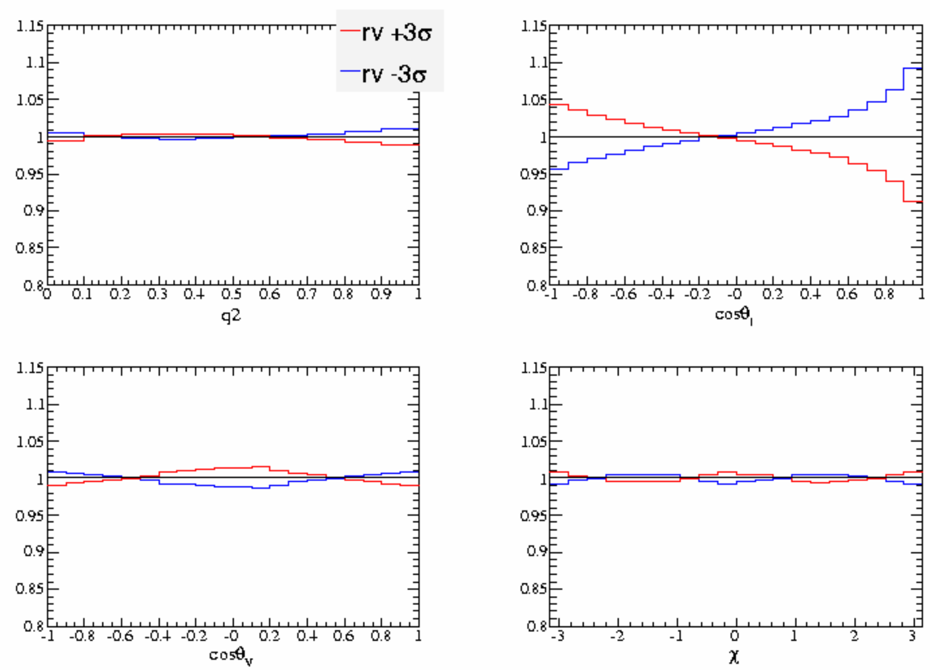
(mass, angular distribution, momentum and angular distribution of the leading particle + kinematic variables: p_D, p_ℓ, $\cos\vartheta_{W\ell}$)





Parameter sensitivity

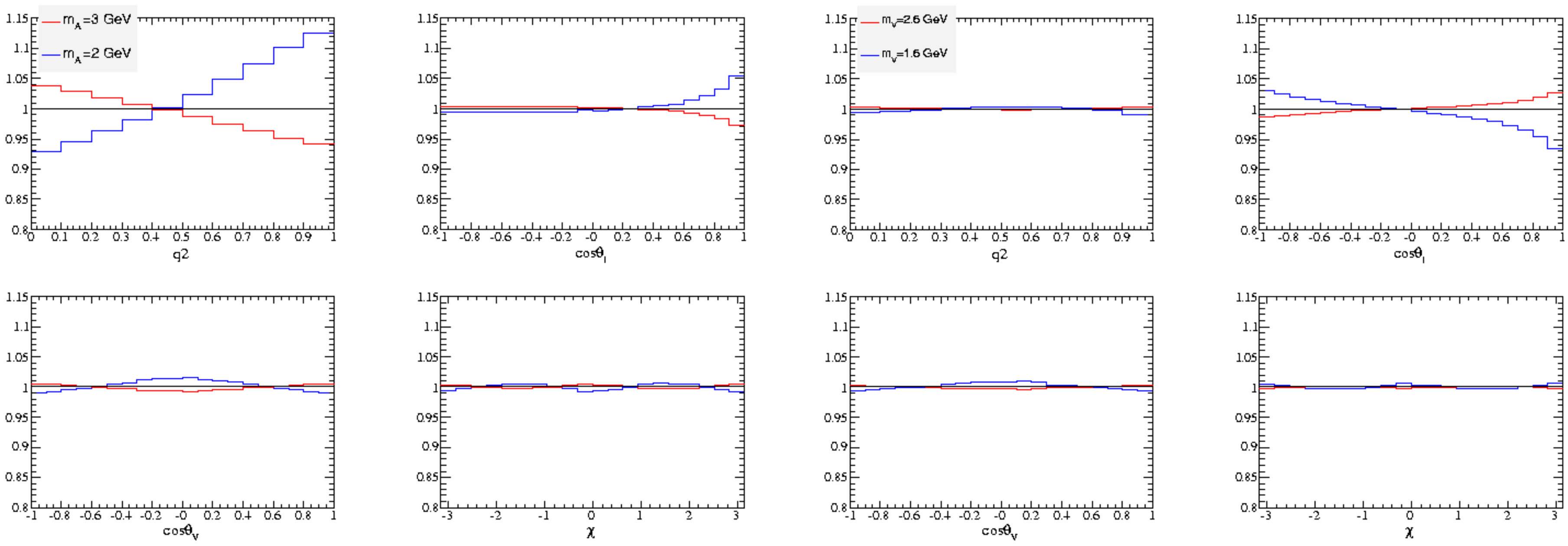




r2 sensitivity

rV sensitivity

Parameter sensitivity



mA sensitivity

mV sensitivity