$D_{s0}^{*}(2317)$ and DK scattering from B_s^0 decays

[M. A., M. Nielsen, E. Oset, Phys. Lett. B 746, 305 (2015)]

Miguel Albaladejo (IFIC, Valencia)

Hadron 2015
Newport News, Sept. 13-18, 2015

In collaboration with:
M. Nielsen (São Paulo)
E. Oset (Valencia)

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Gobierno de España
Ministerio de Economía y Competitividad

Outline

1. Introduction
2. DK scattering and $\bar{B}_s^0 \to D_s^- (DK)^+$
3. Results
4. Summary and Conclusions

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Introduction: basic facts about $D_{s0}^{*\pm}(2317)$

- PDG statements on $D_{s0}^{*\pm}(2317)$:
  - $I(J^P) = 0(0^+)$
  - $M = 2317.8 \pm 0.6$ MeV , $\Gamma < 3.8$ MeV
  - Decays to $D_s^{\pm}\pi^0$

...little information, much speculation...

- Discovered by BABAR[1] , confirmed by others (CLEO, BELLE, FOCUS)[2]
- Mass is 160 MeV below the quark model prediction. Interpretation?
  - $c\bar{s}$ state
  - **two-meson molecular state**
  - K-D mixing
  - four-quark state
  - mixture of two-meson and four quark
- Lattice QCD?

[1] [BABAR Coll., Phys. Rev. Lett.**90**, 242001 (2003); Phys. Rev. **D69**, 031101 (2004)]

[2] [CLEO Coll., Phys. Rev. **D68**, 032002 (2003)] [BELLE Coll., Phys. Rev. Lett. **91**, 262002 (2003)] [FOCUS Coll., hep-ex/0406044]

$D_{s0}^{*\pm}(2317)$ in Lattice QCD

- No state if only $\bar{q}q$ interpolators are used...
- [Mohler, Lang, Leskovec, Prelovsek, Woloshyn, Phys. Rev. Lett. **111**, 222001 (2013)]
  ...but with KD interpolators and with the effective range formula a state 40 MeV below KD threshold is found. Support for molecular nature?
- [Liu, Orginos, Guo, Hanhart, Meissner, Phys. Rev. D **87**, 014508 (2013)]
  Reanalysis of LQCD results for KD scattering lengths are extrapolated to physical pion mass. From Weinberg compositeness condition, a fraction $P_{DK} \simeq 0.7$ is found
- [A. M. Torres, E. Oset, S. Prelovsek and A. Ramos, JHEP 1505,153(2015)]
  Reanalysis of LQCD spectra with EFT in finite volume, using all levels of the simulation. Similar $P_{DK} \simeq 70\%$ is found

Goals of this work: $\bar{B}_s^0 \to D_s^- (DK)^+$

1. **Propose** the measurement of a reaction to confirm $D_{s0}^*(2317)$
2. **Predict** the shape of the DK spectrum in this reaction
3. **Analyze** the sensitivity of this reaction for the different quantities one can extract from it

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DK scattering amplitude

- S-wave, $I = 0$ DK scattering amplitude. In general,

$$T^{-1}(s) = V^{-1}(s) - G(s)$$

$$16\pi^2 G(s) = a(\mu) + \log\frac{m_D m_K}{\mu^2} + \frac{\Delta}{2s}\log\frac{m_D^2}{m_K^2} + \frac{\nu}{2s}\left(\log\frac{s-\Delta+\nu}{-s+\Delta+\nu} + \log\frac{s+\Delta+\nu}{-s-\Delta+\nu}\right),$$

$$\Delta = m_D^2 - m_K^2\,, \quad \nu = \lambda^{1/2}(s, m_D^2, m_K^2)$$

- In terms of phase shift δ, or of the effective range expansion (scattering length a_0 and effective range r_0), it reads:

$$T(s) = -\frac{8\pi\sqrt{s}}{p_K \mathrm{ctg}\delta - i p_K} \simeq -\frac{8\pi\sqrt{s}}{\frac{1}{a_0} + \frac{1}{2} r_0 p_K^2 - i p_K},$$

- In reanalysis of LQCD data: $a_0 = -1.4 \pm 0.6$ fm, $r_0 = -0.1 \pm 0.2$ fm
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DK scattering amplitude: pole and probability

- $D_{s0}^{*\pm}(2317)$ will appear as a pole in T at $s_0 = M^2_{D_{s0}^{*\pm}}$:

$$T(s) = 1/\left(V^{-1}(s) - G(s)\right) = \frac{g^2}{s - s_0} + \text{regular terms}$$

- We have the following exact **sum rule**:

$$\frac{1}{g^2} = \frac{\partial T^{-1}(s)}{\partial s} = \frac{\partial V^{-1}(s)}{\partial s} - \frac{\partial G(s)}{\partial s} \Longrightarrow 1 = \underbrace{-g^2 \frac{\partial G(s)}{\partial s}}_{P_{DK}} + \underbrace{g^2 \frac{\partial V^{-1}(s)}{\partial s}}_{P_{\text{other}}}$$

Two **important results:**

1. P_{DK} is the **probability** of DK in the wave function of D_{s0}^*, and

$$P_{DK} = 1 - \alpha\, g^2 \quad \text{with } \alpha \equiv \frac{\partial V^{-1}(s)}{\partial s}$$

2. At the pole, $V^{-1}(s_0) = G(s_0)$

$$V^{-1}(s) = G(s_0) + \alpha(s - s_0) + \cdots$$

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2. At the pole, $V^{-1}(s_0) = G(s_0)$. Assume $V(s)$ **smooth**:

$$V^{-1}(s) \equiv G(s_0) + \alpha(s - s_0)$$

and hence

$$\boxed{T^{-1}(s) = G(s_0) + \alpha(s - s_0) - G(s)}$$

Cuts and Adler zeroes

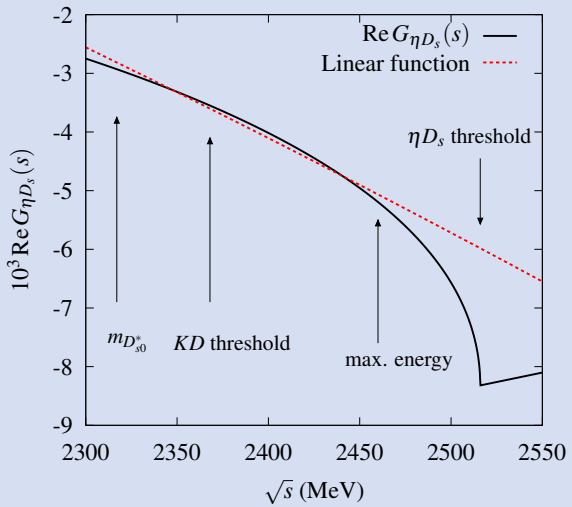
1. About LHC:

- LHC originating from 2π exchange, starting at $\vec{p}_K^{\,2} = -m_\pi^2$.
- It is located between the threshold and the position of the $D_{s0}^*(2317)$ pole.
- It could provide an energy dependence different than the linear one.
- We can rely on previous works that compute 2π exchange potential in similar cases: it is weak and it can be safely neglected.

  [A. Martinez Torres, K. P. Khemchandani and E. Oset, EPJ,A**36**,211(2008)]
  [F. Aceti *et al.*, PR,D**90**,016003(2014)][F. Aceti *et al.*, EPJ,A**50**,103(2014)]

2. ηD_s and linear depedence:

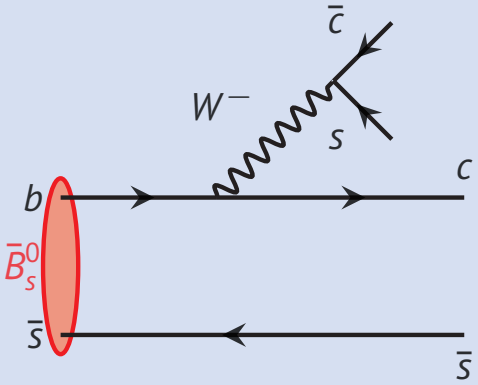
$$V^{(\text{eff})}_{KD,KD}(s) = V_{KD,KD} + V^2_{KD,\eta D_s} G_{\eta D_s}(s)$$



3. Adler zeroes:

- [A. M. Torres, E. Oset, S. Prelovsek and A. Ramos, JHEP **1505**, 153 (2015)]
- Perturbatively, $V(s_0) = 0$, $\sqrt{s_0} \simeq m_D$, which is $m_K \simeq 495$ MeV below threshold.

Differential width $\bar{B}_s^0 \to D_s^- (DK)^+$



- DK state stems from the hadronization of the $c\bar{s}$ pair
- We introduce the following $q\bar{q}$ matrix:

- M satisfies $M^2 = (v\,\bar{v})(v\,\bar{v}) = v \underbrace{(\bar{v}\,v)}_{u\bar{u}+d\bar{d}+\cdots} \bar{v} = M\,(u\bar{u} + d\bar{d} + \cdots)$
- The $q\bar{q}$-matrix M is related to the meson-matrix ϕ:

$$\phi = \begin{pmatrix} \frac{\eta}{\sqrt{3}} + \frac{\pi^0}{\sqrt{2}} + \frac{\eta'}{\sqrt{6}} & \pi^+ & K^+ & \bar{D}^0 \\ \pi^- & \frac{\eta}{\sqrt{3}} - \frac{\pi^0}{\sqrt{2}} + \frac{\eta'}{\sqrt{6}} & K^0 & D^- \\ K^- & \bar{K}^0 & \frac{\sqrt{2}\eta'}{\sqrt{3}} - \frac{\eta}{\sqrt{3}} & D_s^- \\ D^0 & D^+ & D_s^+ & \eta_c \end{pmatrix}$$

- Hadronization proceeds through $(M^2)_{43} \to (\phi^2)_{43} = D^0 K^+ + D^+ K^0 + \cdots$
- The DK pair has $I = 0$

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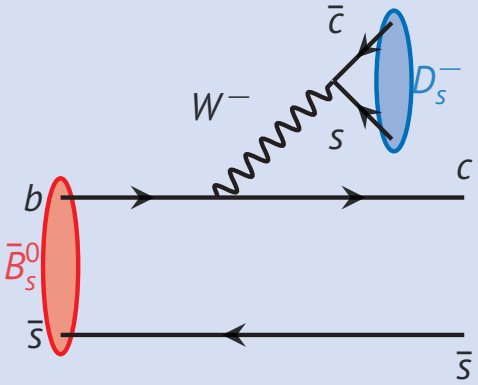

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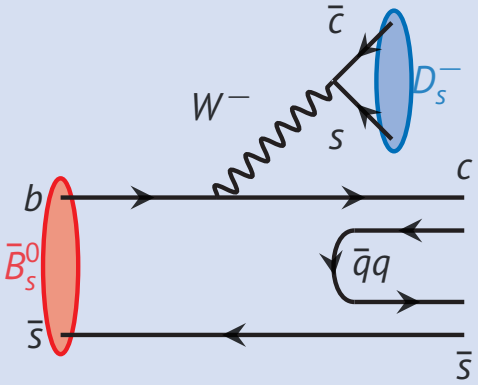

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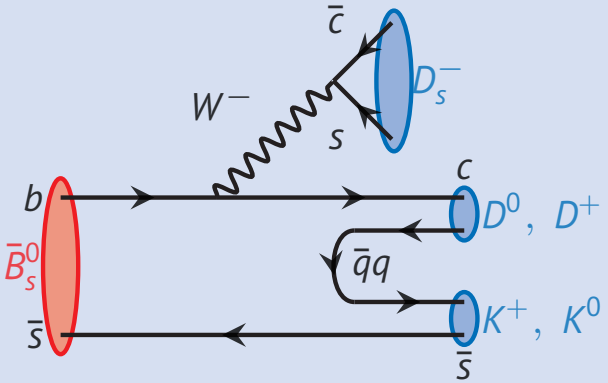

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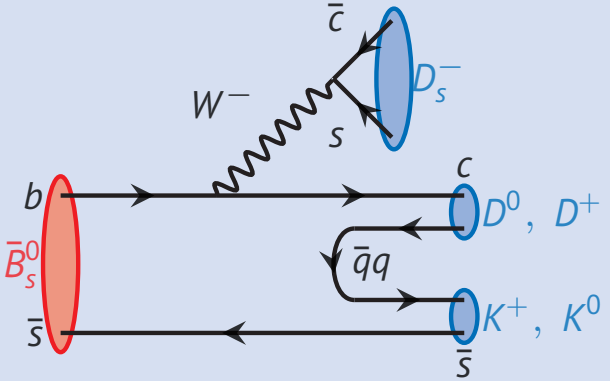

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$$M = v\,\bar{v} = \begin{pmatrix} u \\ d \\ s \\ c \end{pmatrix} \begin{pmatrix} \bar{u} & \bar{d} & \bar{s} & \bar{c} \end{pmatrix} = \begin{pmatrix} u\bar{u} & u\bar{d} & u\bar{s} & u\bar{c} \\ d\bar{u} & d\bar{d} & d\bar{s} & d\bar{c} \\ s\bar{u} & s\bar{d} & s\bar{s} & s\bar{c} \\ c\bar{u} & c\bar{d} & c\bar{s} & c\bar{c} \end{pmatrix}$$

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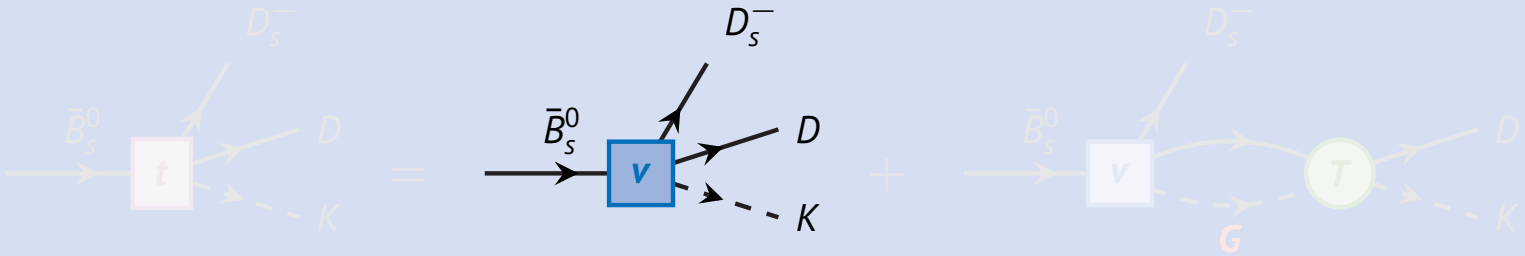
Differential width $\bar{B}_s^0 \to D_s^- (DK)^+$: including DK interaction



- Let V denote the **bare vertex** for the $\bar{B}_s^0 \to D_s^- (DK)^+$ production
- The **full amplitude** is denoted by T
- Relate T and V, that is, bring in **DK interaction T**:

$$T = V + V\,G(s)\,T(s) = V\,(1 + G(s)\,T(s)) = V\frac{T(s)}{V(s)}$$

- Finally, the differential decay width is:

$$\frac{d\Gamma}{d\sqrt{s}} = \frac{1}{32\pi^2 M_{\bar{B}_s^0}^2} p_{D_s^-} p_K \left|T\right|^2 = C p_{D_s^-} p_K \left|\frac{T(s)}{V(s)}\right|^2$$

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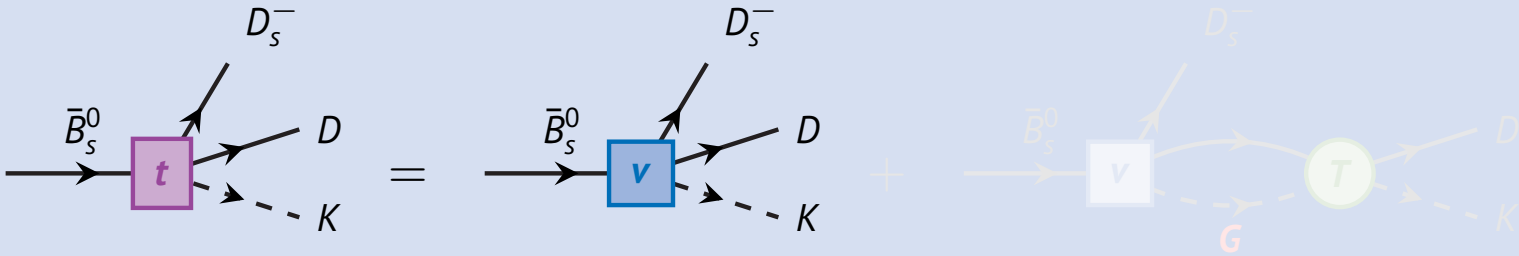

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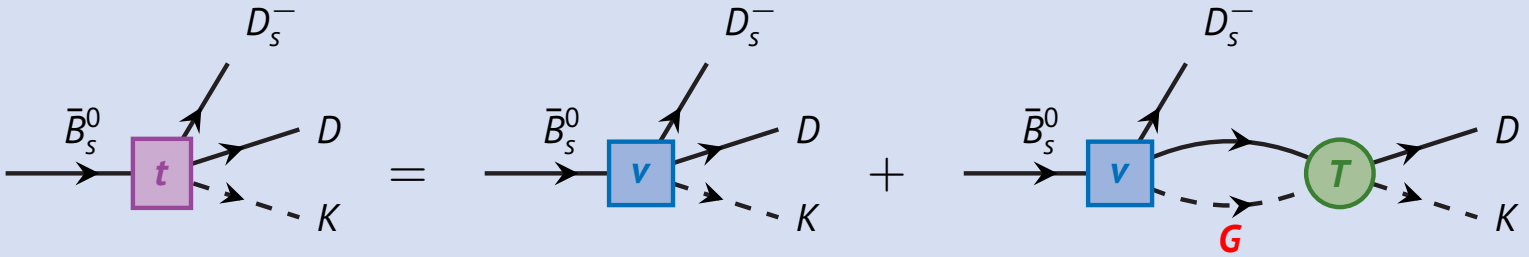

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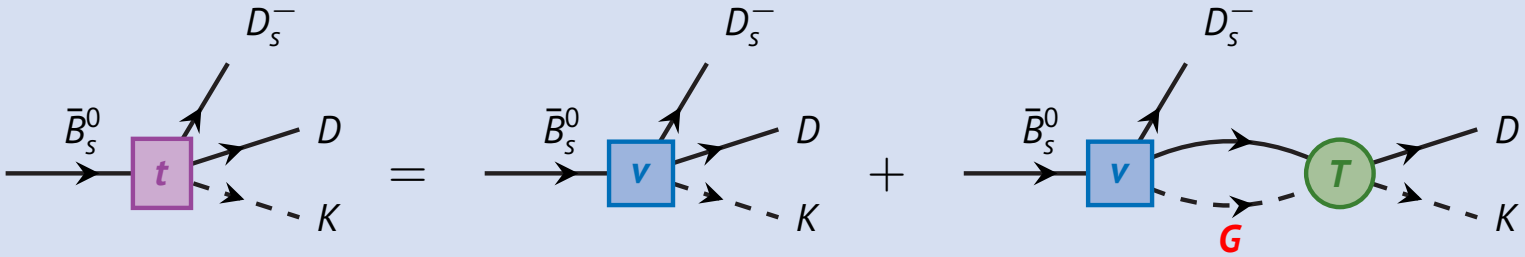

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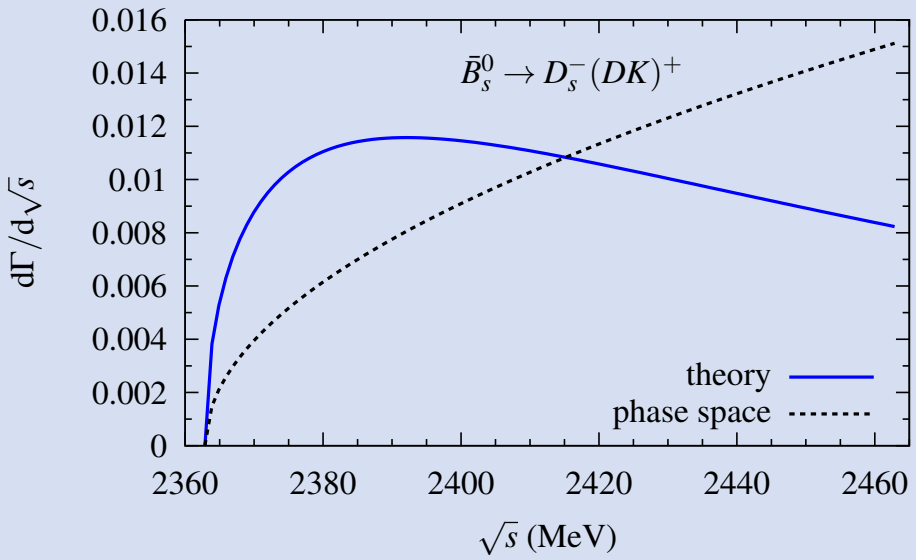
Generating data



Central values	
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M (MeV)	2317.0
$a(\mu)$	-1.30
P_{DK}	0.75

- Values for the parameters: $M = 2317$ MeV, $P_{DK} = 0.75$ which implies $10^3\alpha = 2.06\ \text{GeV}^{-2}$, $a(\mu) = -1.3$ (from previous studies)
- From the theoretical prediction, we construct "synthetic data", which we analyze as "experiment given"
- The central fit is obviously perfect, but we are interested in **errors**
- Monte Carlo: we generate around $2 \cdot 10^3$ random (gaussian distribution) different sets of "experimental data", for which we fit the parameters (and calculate P_{DK}, etc...)
- After the whole run, the central range containing a 68% of each calculated quantity is retained

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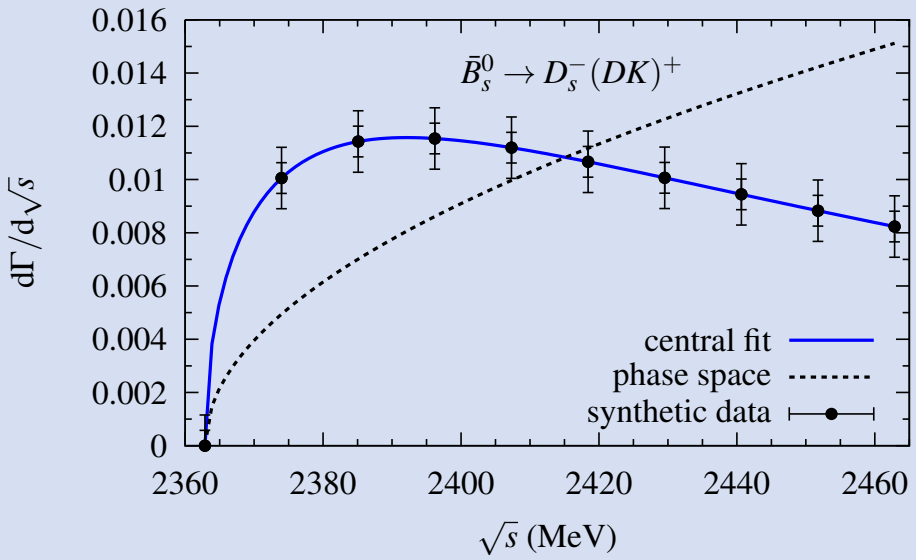

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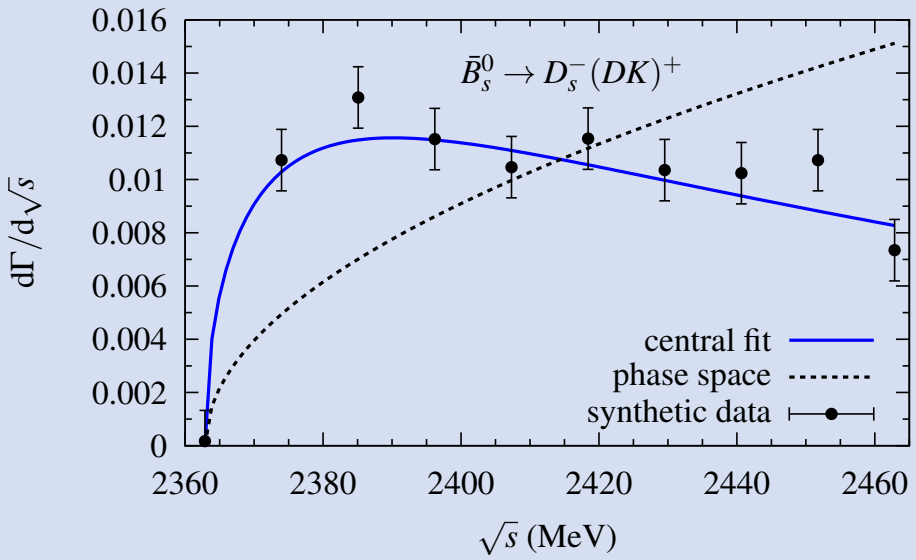
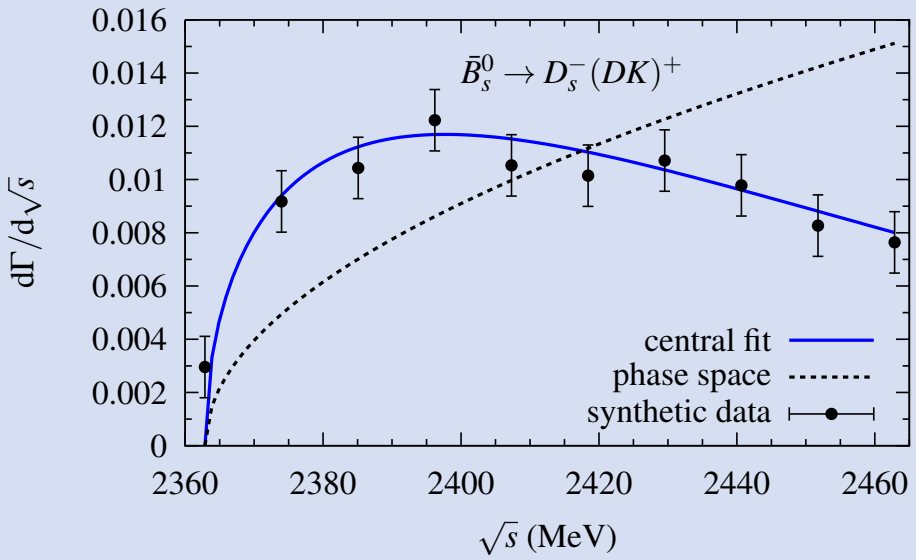


Fitted parameters	
$10^3\ \alpha\ (\text{GeV})^{-2}$	1.82
M (MeV)	2324.9
$a(\mu)$	-1.11
P_{DK}	0.79

- Values for the parameters: $M = 2317$ MeV, $P_{DK} = 0.75$ which implies $10^3\alpha = 2.06\ \text{GeV}^{-2}$, $a(\mu) = -1.3$ (from previous studies)
- From the theoretical prediction, we construct "synthetic data", which we analyze as "experiment given"
- The central fit is obviously perfect, but we are interested in **errors**
- Monte Carlo: we generate around $2 \cdot 10^3$ random (gaussian distribution) different sets of "experimental data", for which we fit the parameters (and calculate P_{DK}, etc...)
- After the whole run, the central range containing a 68% of each calculated quantity is retained

Generating data



Fitted parameters	
$10^3\ \alpha\ (\text{GeV})^{-2}$	1.60
M (MeV)	2267.0
$a(\mu)$	-0.70
P_{DK}	0.71

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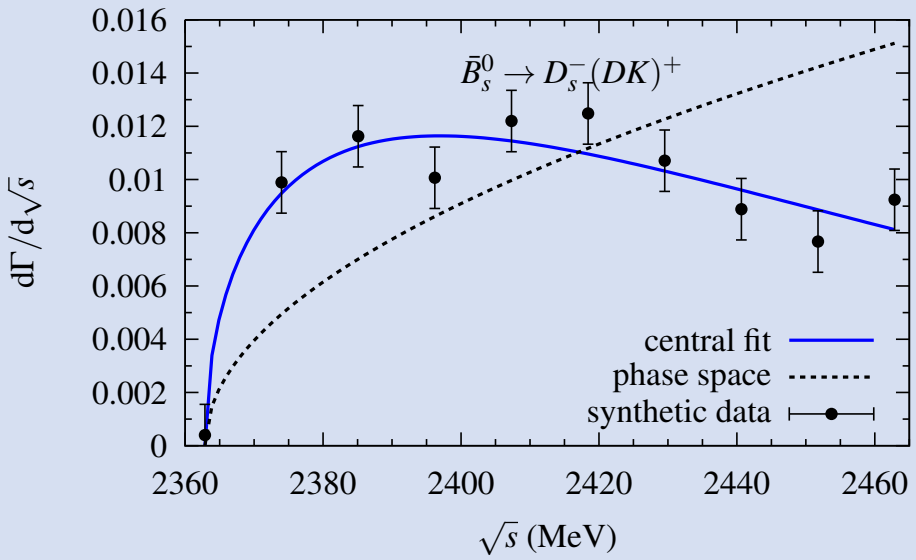

Fitted parameters	
$10^3\ \alpha\ (\text{GeV})^{-2}$	2.32
M (MeV)	2282.2
$a(\mu)$	-0.72
P_{DK}	0.66

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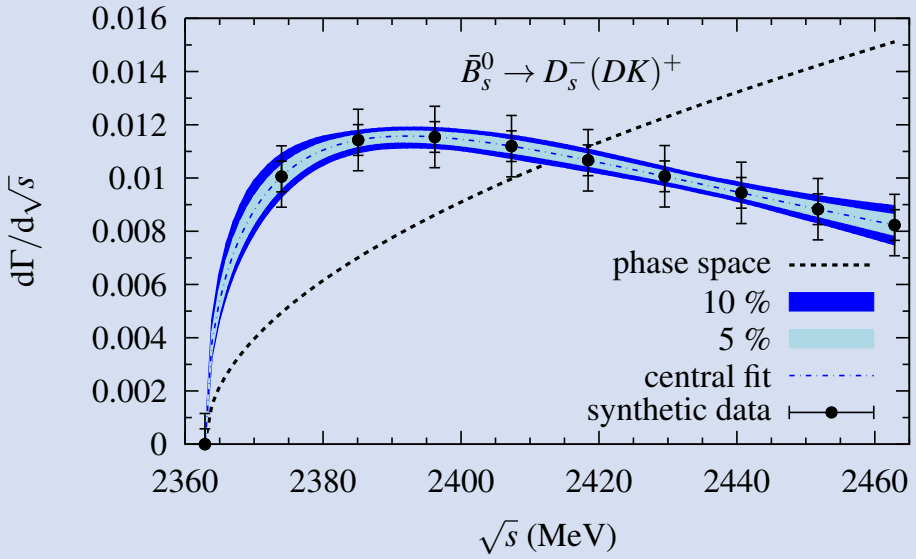
Results



	Central Value	5 %	10 %
$10^3\ \alpha\ (\text{GeV}^{-2})$	2.06	$^{+0.17}_{-0.40}$	$^{+0.10}_{-1.09}$
$M_{D_{s0}^*}$ (MeV)	2317	$^{+14}_{-24}$	$^{+21}_{-73}$
$a(\mu)$	-1.30	$^{+0.15}_{-0.37}$	$^{+0.27}_{-0.49}$
$\lvert g\rvert$ (GeV)	11.0	$^{+1.0}_{-0.6}$	$^{+2.2}_{-1.1}$
a_0 (fm)	-1.0	$^{+0.2}_{-0.2}$	$^{+0.4}_{-0.5}$
r_0 (fm)	-0.14	$^{+0.06}_{-0.03}$	$^{+0.16}_{-0.04}$
P_{DK}	0.75	$^{+0.07}_{-0.06}$	$^{+0.16}_{-0.11}$

- Line shape is very different from a phase space distribution
- Central values of the fit are central values of the theory (obviously...)
- Upper values of M are quite below the threshold ($\sqrt{s} \simeq 2360$ MeV)
- Error in probability P_{DK} is also small, even in the case of a 10% error
- Scattering length in agreement with those obtained in LQCD [A. M. Torres, E. Oset, S. Prelovsek and A. Ramos, JHEP 1505,153(2015)]

$$a_0 = -1.4 \pm 0.6 \text{ fm}$$
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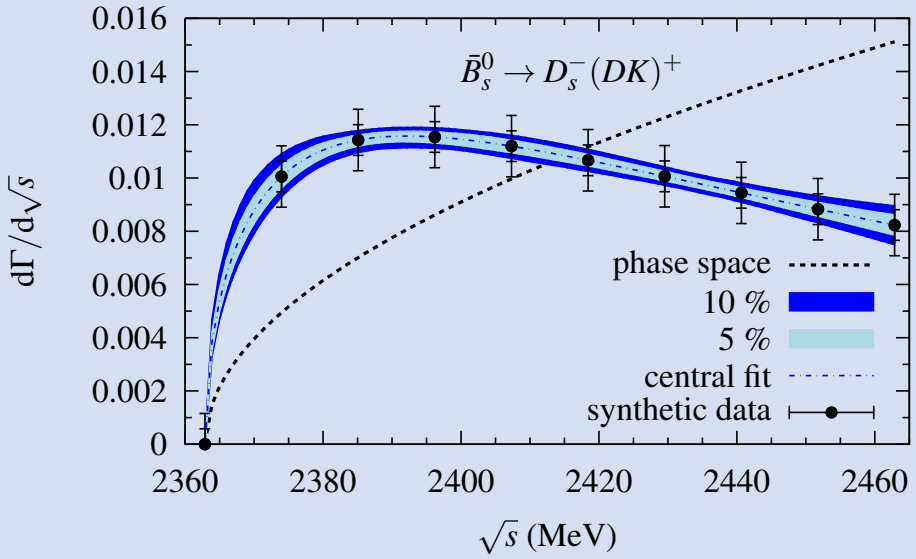
Results



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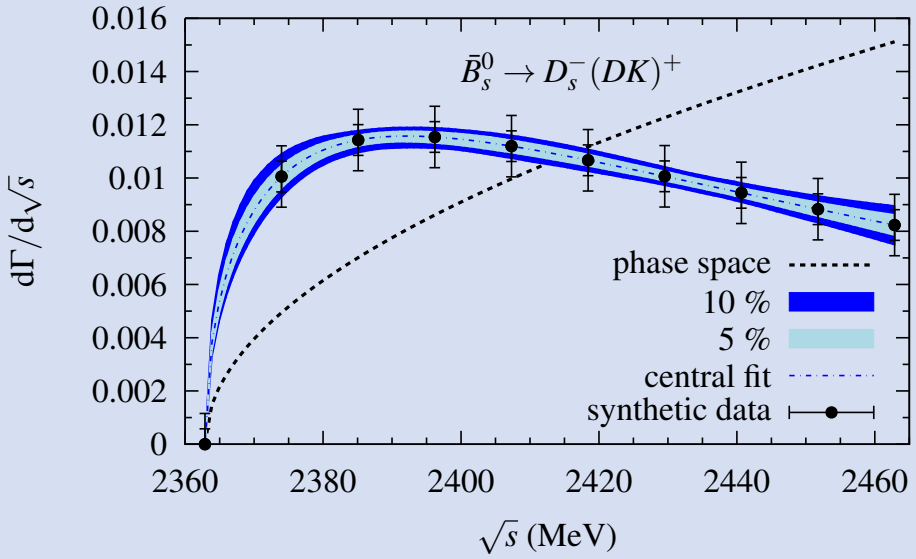

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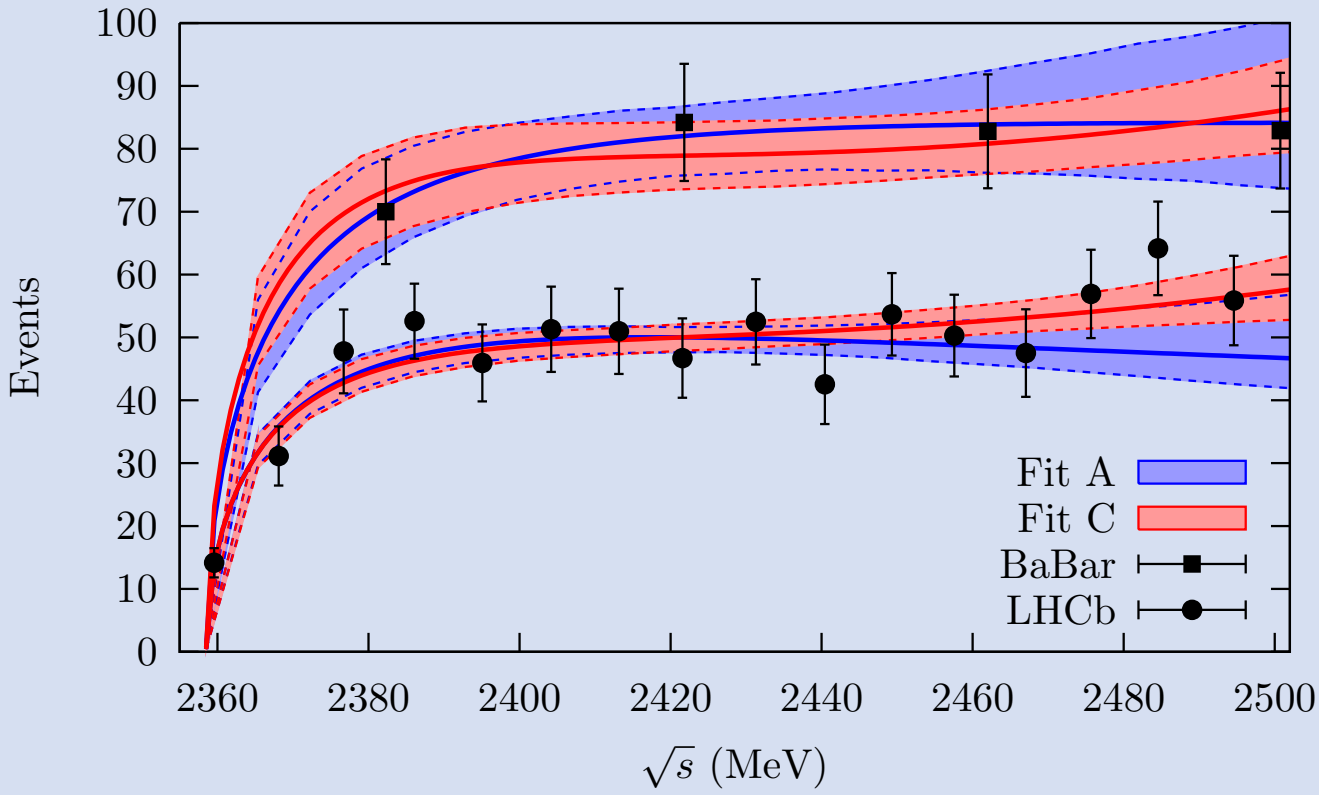
Ongoing work...

We are analysing (real!) data from:

- BABAR: $B^- \to D^0 \left(\bar{D}^0 K^-\right)$
- LHCb: $\bar{B}_s^0 \to \pi^- \left(D^0 K^+\right)$



Outline

1 Introduction

2 DK scattering and $\bar{B}_s^0 \to D_s^- (DK)^+$

3 Results

4 **Summary and Conclusions**

Summary and Conclusions

- We have considered $D_{s0}^*(2317)$ in the KD molecular picture
- Analysis based on this picture and in LQCD give a fraction $P_{DK} \simeq 0.7$
- We investigate the possibility of observing the effects of KD interactions and the D_{s0}^* state in $\bar{B}_s^0 \to D_s^- (DK)^+$ decays
- Synthetic data generated from the theory have been analyzed considering the cases of a 5% or 10% experimental errors
- In both cases, the mass and the DK fraction (P_{DK}) can be obtained with significant accuracy
- Similar work can be (is being) done in other reactions with real data

Thanks for your attention!

$D_{s0}^{*}(2317)$ and DK scattering from B_s^0 decays

[M. A., M. Nielsen, E. Oset, Phys. Lett. B 746, 305 (2015)]

Miguel Albaladejo (IFIC, Valencia)

Hadron 2015
Newport News, Sept. 13-18, 2015

In collaboration with:
M. Nielsen (São Paulo)
E. Oset (Valencia)

CSIC Consejo Superior de Investigaciones Científicas
IFIC Institut de Física Corpuscular
Gobierno de España
Ministerio de Economía y Competitividad