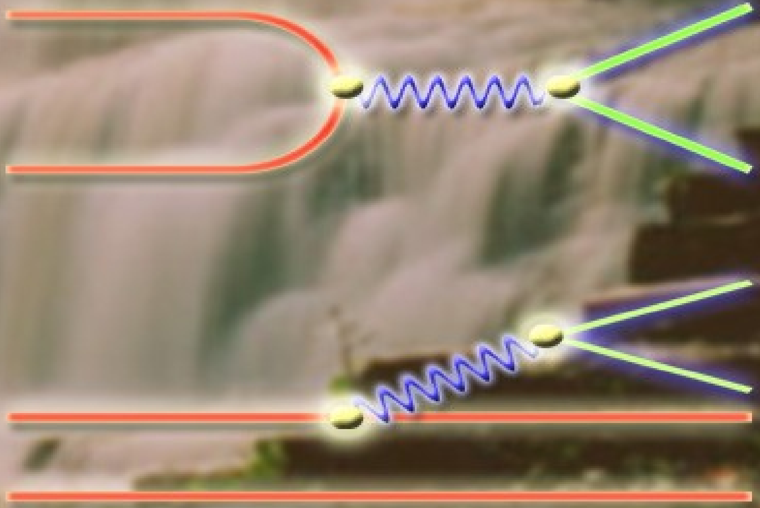
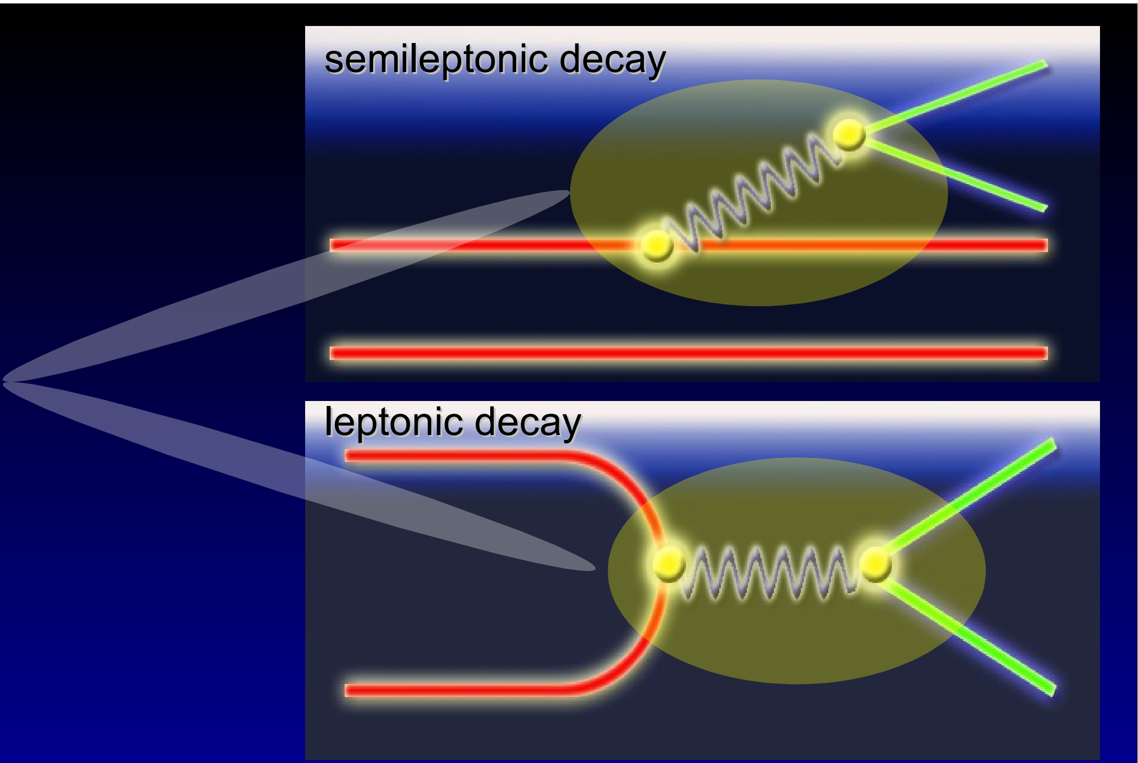
Leptonic & Semileptonic D- and D_s Decays *at B-Factories*



Laurenz Widhalm
HEPHY Vienna
(Belle Collaboration)

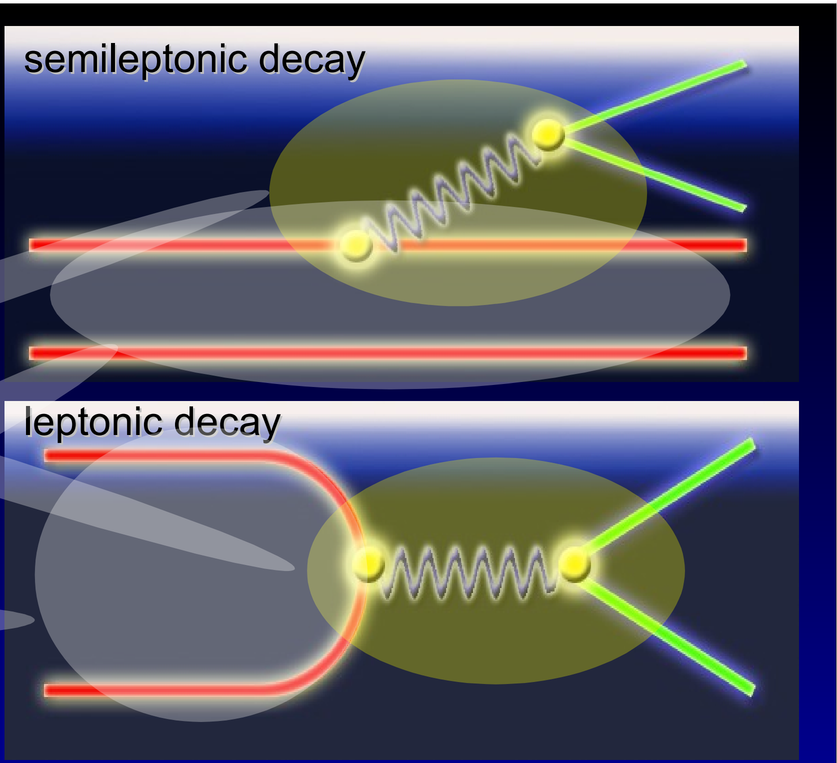
thanks to Arantza Oyanguren, Justine Serrano & Paul Jackson (all BaBar) for their help and material!

Introduction



leptonic part easily calculable in theory

Introduction



leptonic part easily calculable in theory

hadronic part described by decay constant (leptonic decays) or form factors (semileptonic decays)

- calculation of these constants/functions requires non-perturbative QCD (not *that* easy...)
- measurement of these quantities in the charm sector important to check / tune calculations in the B-sector

Semileptonic Decays

$D^0 \rightarrow K/\pi\ e/\mu\ \nu$

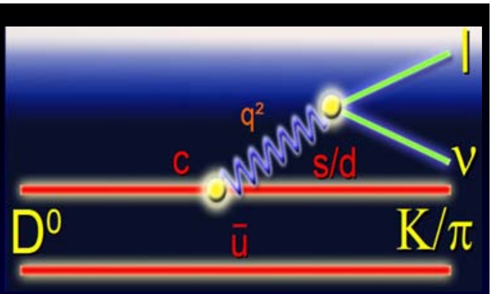
Phys.Rev.Lett.97:061804,2006
hep-ex/0604049

$D^0 \rightarrow K\ e\ \nu$

BABAR-PUB-07/015
arXiv:0704.0020 accepted by PRD!

$D_s \rightarrow \phi\ e\ \nu$

$D^0 \rightarrow K/\pi\ e/\mu\ \nu$ Introduction

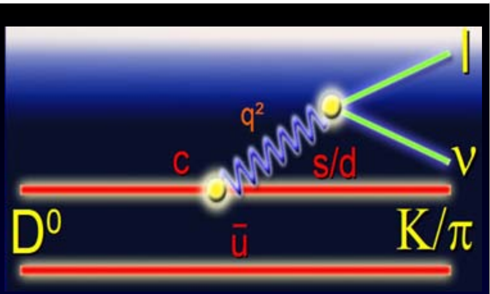


- in principle, two form factors $f^+(q^2)$ and $f^-(q^2)$

$$\frac{d\,\Gamma(D \to P\ell^+\nu_\ell)}{d\,q^2} = \frac{G_F^2\,|V_{CKM}|^2}{384\,\pi^3\,m_D^3}\,\frac{\sqrt{\lambda(q^2,m_D^2,m_P^2)}}{q^6}\,(q^2-m_\ell^2)^2\ \cdot$$

$$\left\{ |f_+(q^2)|^2\left[(2q^2+m_\ell^2)\,\lambda(q^2,m_D^2,m_P^2)\ +\ 3\,m_\ell^2\,(m_D^2-m_P^2)^2\right] + 3\,q^2\,m_\ell^2\left[2\,Re(f_+(q^2)f_-^*(q^2))\,(m_D^2-m_P^2)\ +\ |f_-(q^2)|^2\,q^2\right]\right\}$$

$D^0 \rightarrow K/\pi\ e/\mu\ \nu$ Introduction



- in principle, two form factors $f^+(q^2)$ and $f^-(q^2)$
- kinematically only $f^+(q^2)$ relevant, $f^-(q^2)$ suppressed by m_l^2

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

- various models that are frequently discussed in literature:

simple pole	$f_+(q^2) = \frac{\Omega}{1-q^2/m^2}$	$\Omega \equiv f_+(0)$ m......pole mass $= m\ D^*_s \approx 2.11$ GeV ($Kl\nu$) $= m\ D^* \approx 2.01$ GeV ($\pi l\nu$)
modified pole *D. Becirevic, A.B. Kaidalov, PLB 478, 417 (2000)*	$f_+(q^2) = \frac{\Omega}{(1-q^2/m^2)\ (1-\alpha q^2/m^2)}$	$\alpha_{\text{theor.}} \approx 0.50$ ($Kl\nu$) ≈ 0.44 ($\pi l\nu$)
ISGW2 *N. Isgur and D. Scora, Phys. Lett. B 592 1(2004)*	$f_+(q^2) = \frac{\Omega}{(1-\alpha(q^2-q^2\text{max}))^2}$	

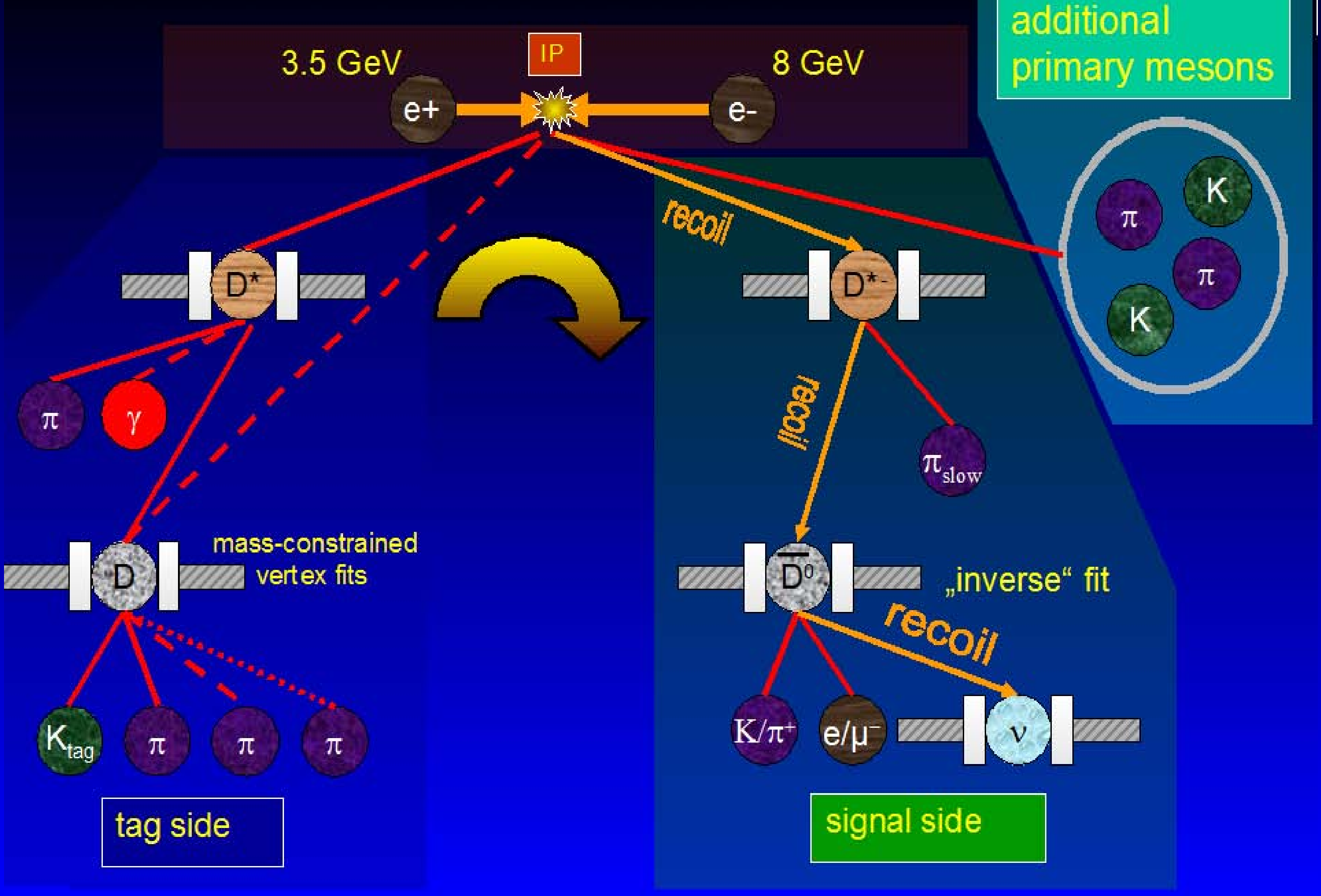
- model-independent:

z-expansion *R. J. Hill, hep-ph/0606023*	$f_+(q^2) = c\ \Sigma a_k z^k \quad z:=f(q^2)$

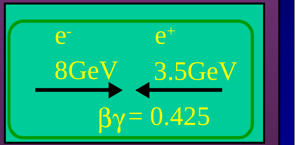
$D^0 \to K/\pi\ e/\mu\ \nu$

tagged, full reconstruction analysis

method of reconstruction



Belle in a nutshell



- located at KEK / Japan
- KEKB Collider
- B-Factory at $\Upsilon(4s)$ resonance
- peak luminosity 17.118 1/nb/s
- integrated luminosity 715 1/fb

(as of Jun 2007; only part of it used in presented analyses)

main physics goal: observation of CPV in B meson Decays

D^0 tags

Phys.Rev.Lett.97:061804,2006 hep-ex/0604049

BELLE

$D^0 \to K/\pi\ e/\mu\ \nu$

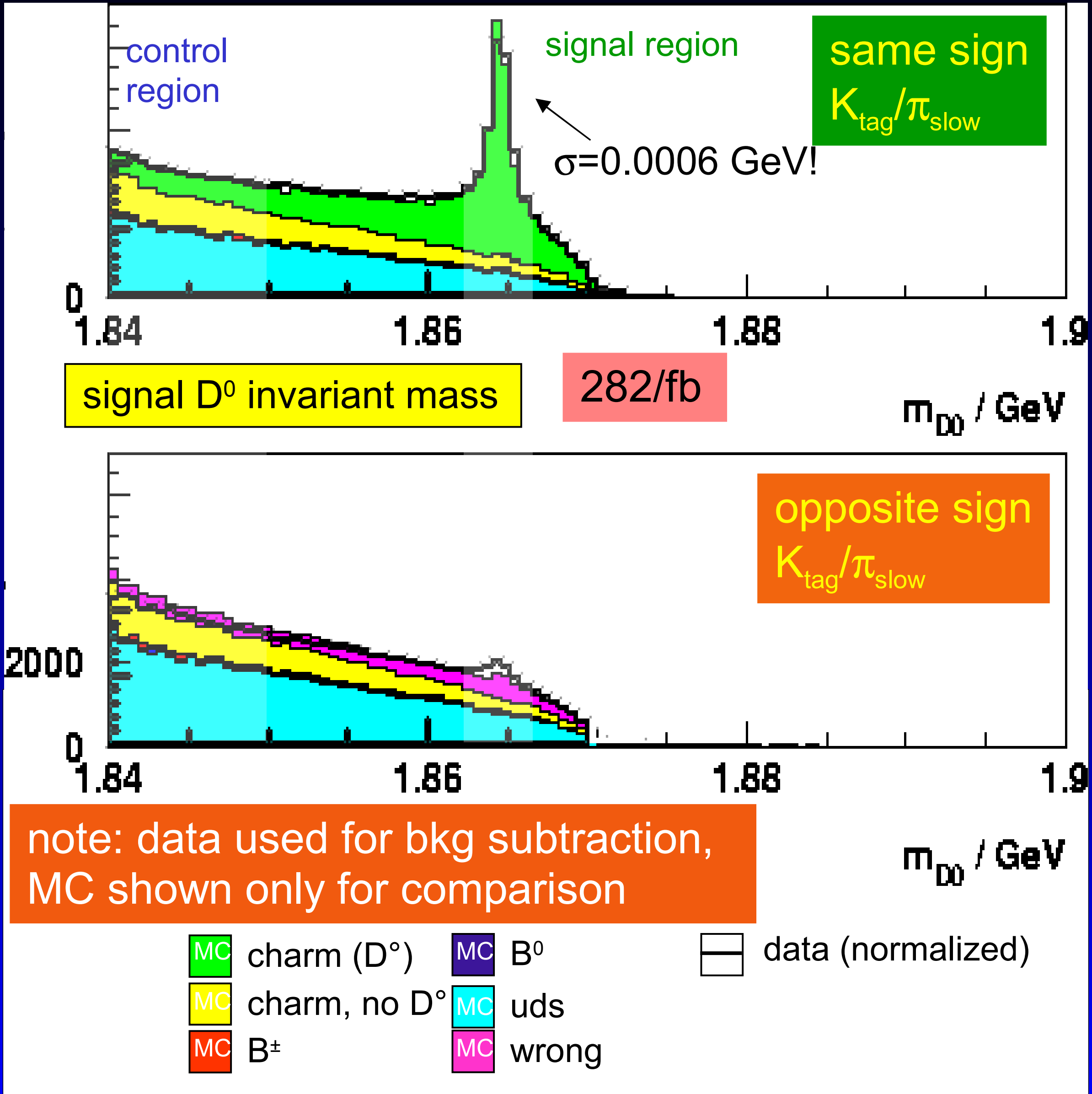
cuts

- all mass-constr. fits CL >0.1%

(released on D^0 fit for righthand plot)

- same charge K_{tag}/π_{slow}

result	yield
after cuts	95250
background	38789
signal	56461
	± 309_{stat}
charge correlation	± 776_{syst}
signal subtraction	± 233_{syst}
stats bkg sample	± 194_{syst}



signal D^0 invariant mass

282/fb

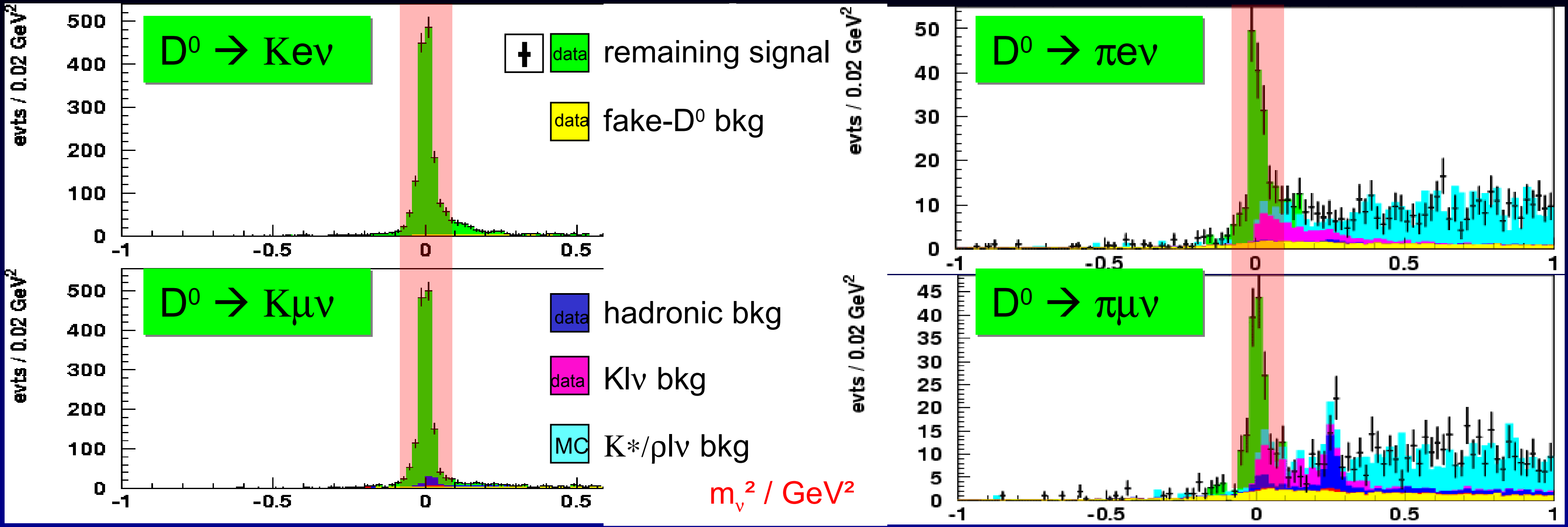
note: data used for bkg subtraction, MC shown only for comparison

semileptonic BRs

Phys.Rev.Lett.97:061804,2006 hep-ex/0604049

BELLE

$D^0 \to K/\pi\ e/\mu\ \nu$



BRs (%)	this analysis	PDG (incl. this result)
$K^-e^+\nu$	$3.45 \pm 0.10_{stat} \pm 0.19_{syst}$	3.50 ± 0.09
$K^-\mu^+\nu$	$3.45 \pm 0.10_{stat} \pm 0.21_{syst}$	3.27 ± 0.13
$\pi^-e^+\nu$	$0.279 \pm 0.027_{stat} \pm 0.016_{syst}$	0.280 ± 0.017
$\pi^-\mu^+\nu$	$0.231 \pm 0.026_{stat} \pm 0.019_{syst}$	0.236 ± 0.024

- absolute branching ratios (ratio to total number of recoil D^0 tags)
- efficiency correction, further corrected for bias due to differences data/MC

(1.9%±3.9%)

form factors

Phys.Rev.Lett.97:061804,2006 hep-ex/0604049

$D^0 \rightarrow K/\pi\ e/\mu\ \nu$

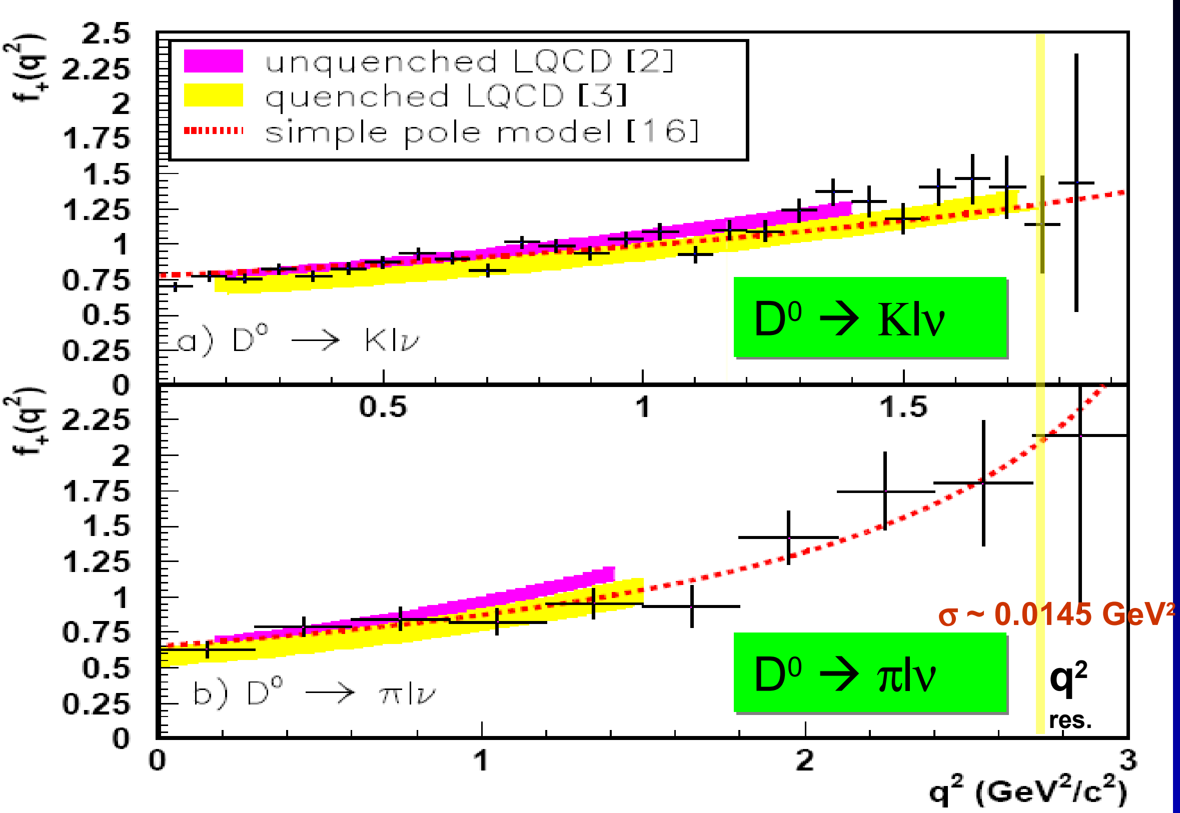
fit results

simple pole

	pole mass (GeV)
Klν	$1.82 \pm 0.04_{stat} \pm 0.03_{syst}$
πlν	$1.97 \pm 0.08_{stat} \pm 0.04_{syst}$

modified pole
(poles fixed at theo. values)

	$f_+(0)$
Klν	$0.695 \pm 0.007_{stat} \pm 0.022_{syst}$
πlν	$0.624 \pm 0.020_{stat} \pm 0.030_{syst}$
	α
Klν	$0.52 \pm 0.08_{stat} \pm 0.06_{syst}$
πlν	$0.10 \pm 0.21_{stat} \pm 0.10_{syst}$



[2] C. Aubin *et al.*, (Fermilab Lattice Collaboration, MILC Collaboration
ration), Phys. Rev. Lett. **94**, 011601 (2005).

[3] A. Abada, D. Becirevic, P. Boucaud, J. P. Leroy, V. Lubicz and F.
619, 565 (2001).

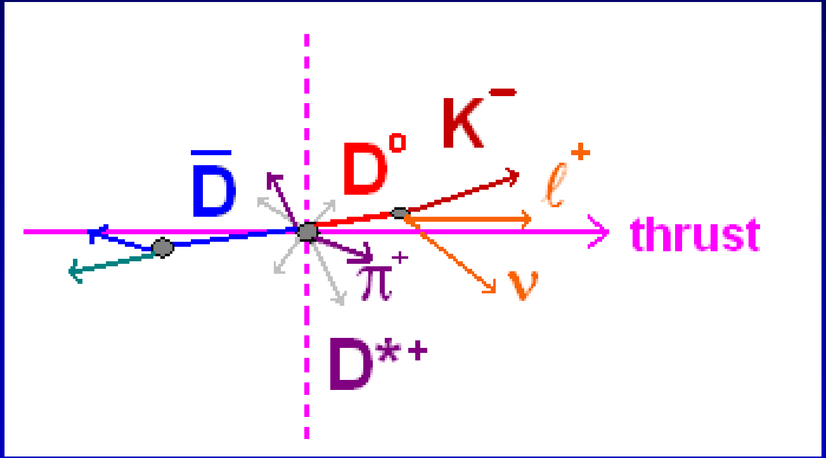
[16] G. Amoros, S. Noguera, J. Portoles, Eur. Phys. J. **C27**, 243 (2003).

$$\frac{f_+^{\pi}(0)^2|V_{cd}|^2}{f_+^{K}(0)^2|V_{cs}|^2} = 0.042 \pm 0.003_{\rm stat} \pm 0.003_{\rm syst}$$

$D^0 \to K\, e\, \nu$

Untagged analysis

- Reconstruct channel $D^{*+} \to D^0\pi^+$, $D^0 \to K^- \ell^+ \nu$ in $e^+e^- \to c\bar{c}$ continuum
- Determine $q^2 = (p_D - p_K)^2 = (p_e + p_\nu)^2$:
  - define 2 hemispheres (soft π, K and e in same)
  - D direction = opposite to all seen part. but K & e
  - E_{miss} in e-hemisphere
  - fit p_D using D direction, Emiss, p_K and p_e)

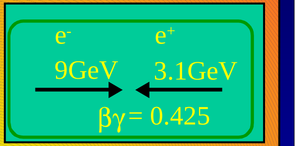


- Reduce the background ← **Fisher discriminants ($b\bar{b}$ / $c\bar{c}$ evts)**

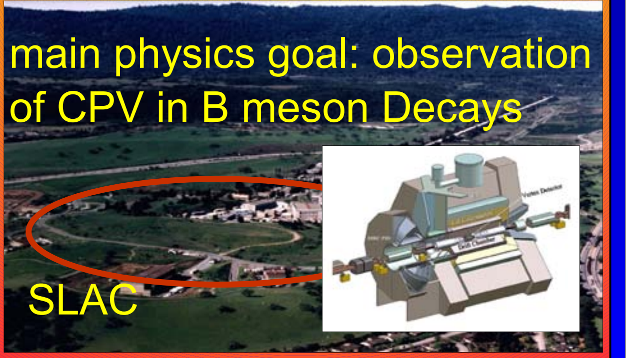
BaBar in a nutshell

- located at SLAC / USA
- PEP-II Collider
- B-Factory at Υ(4s) resonance
- peak luminosity 12.069 1/nb/s
- integrated luminosity 463 1/fb

(as of Jun 2007; only part of it used in presented analyses)



main physics goal: observation of CPV in B meson Decays

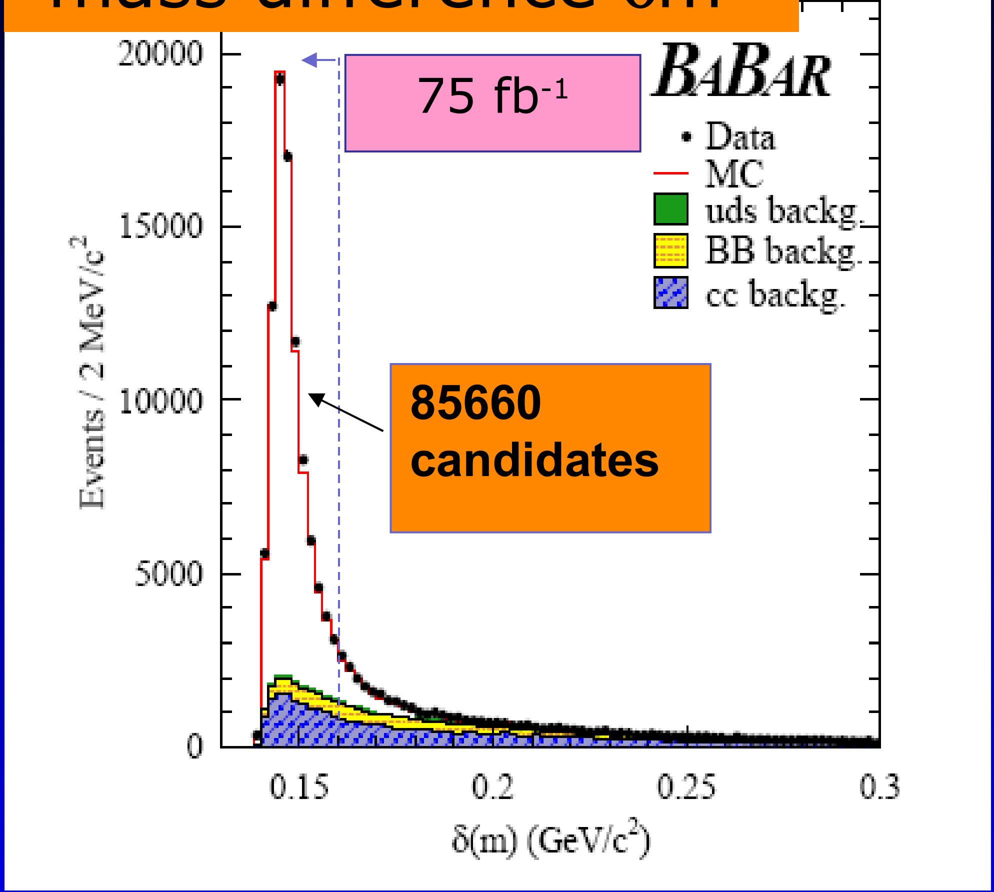


BABAR-PUB-07/015 arXiv:0704.0020

$D^0 \rightarrow K/\pi\, e\, \nu$

signal & control samples

mass difference δm



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

2 control samples:

- **$D^{*+} \rightarrow D^0\pi^+$, $D^0 \rightarrow K^-\pi^+$**

- **control of the Fisher bb and cc variables**
- **control of missing energy and p_D resolution**

- **$D^{*+} \rightarrow D^0\pi^+$, $D^0 \rightarrow K^-\pi^+\pi^0$ $(\pi^0 \rightarrow \gamma\gamma)$**

Treat the π^+ as the e^+ and the π^0 as the ν to check :

- **Reconstruction efficiency**
- **q^2 and angular resolution from data**

Define a parametrization of the differences to take into account possible biases.

BABAR-PUB-07/015 arXiv:0704.0020

BABAR

$D^0 \to K/\pi\, e\, \nu$

branching ratios

- ratio to BR($D^0 \to K\pi$), using world average of (3.80 ± 0.07)%
- efficiency correction

BR (%)	this analysis	PDG (incl. Belle result)
$K^-e^+\nu$	$3.522 \pm 0.027_{stat} \pm 0.045_{syst} \pm 0.065_{BR(K\pi)}$	3.50 ± 0.09

form factors

BABAR-PUB-07/015 arXiv:0704.0020

BABAR

$D^0 \to K/\pi\ e\ \nu$

fit results

z expansion

	$1+r_1z + r_2z^2$
Keν	$r_1 = -2.5 \pm 0.2_{stat} \pm 0.2_{syst}$ $r_2 = 0.6 \pm 6.0_{stat} \pm 5.0_{syst}$

simple pole

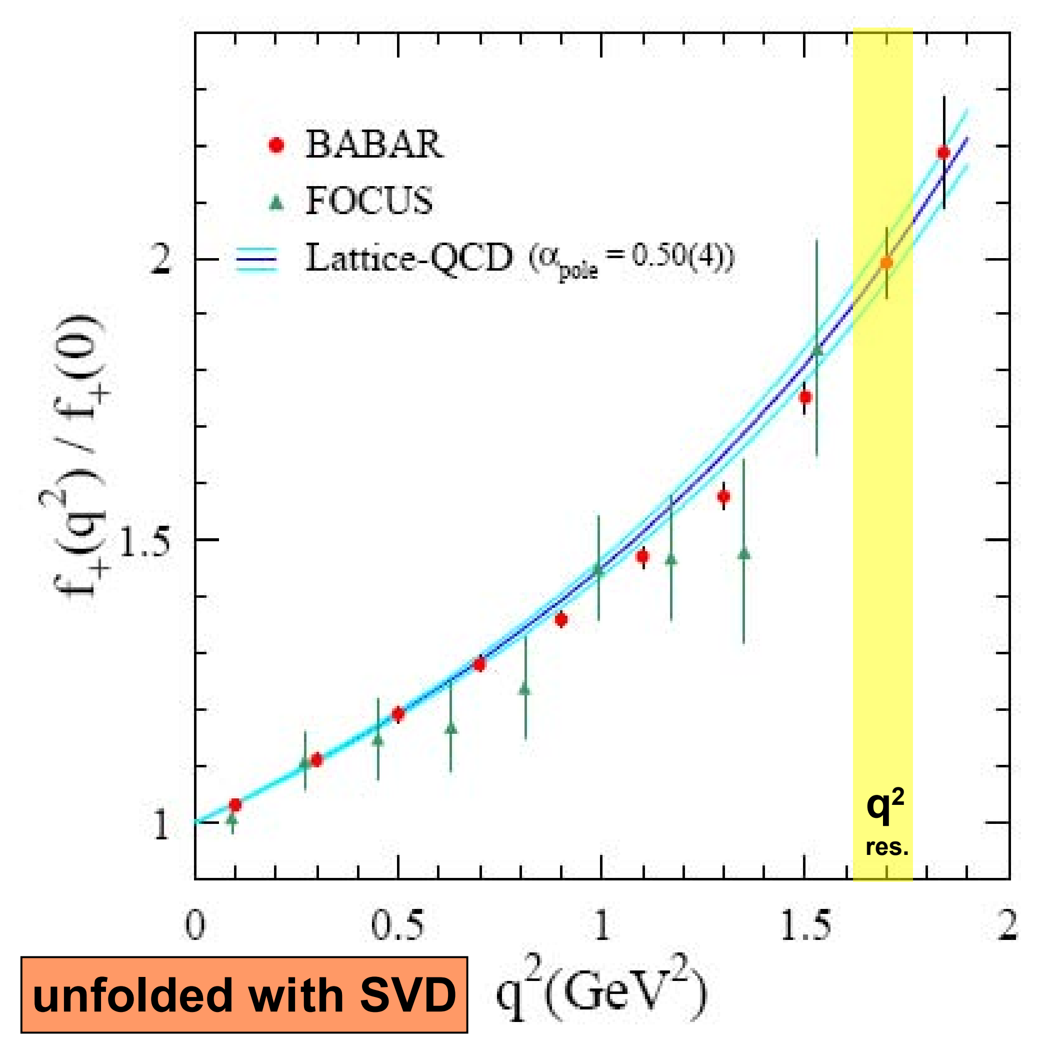
	pole mass (GeV)
Keν	$1.884 \pm 0.012_{stat} \pm 0.015_{syst}$

modified pole

(poles fixed at theo. values)

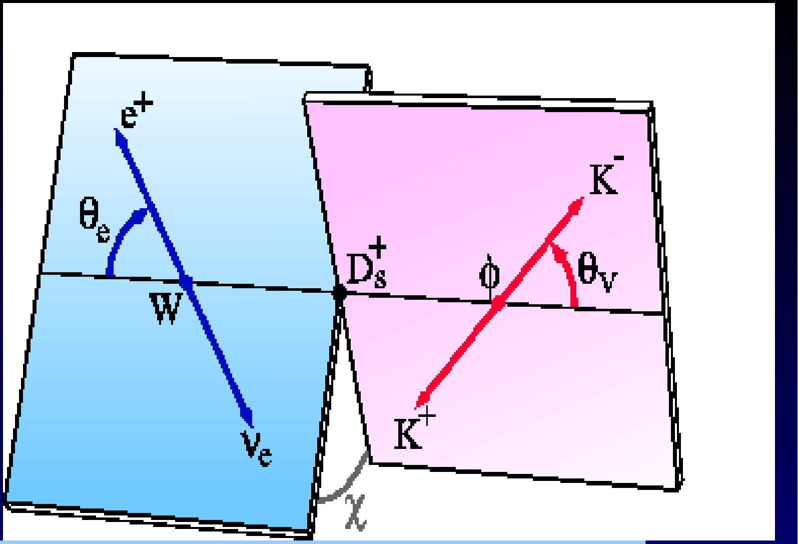
	$f_+(0)$
Keν	$0.727 \pm 0.007_{stat} \pm 0.005_{syst} \pm 0.007_{Kpi}$

	α
Keν	$0.377 \pm 0.023_{stat} \pm 0.029_{syst}$



unfolded with SVD

$D_s \rightarrow \phi e \nu$ Introduction



$D_s \rightarrow \varphi e \nu$

$\quad \hookrightarrow K^+K^-$

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 :

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

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

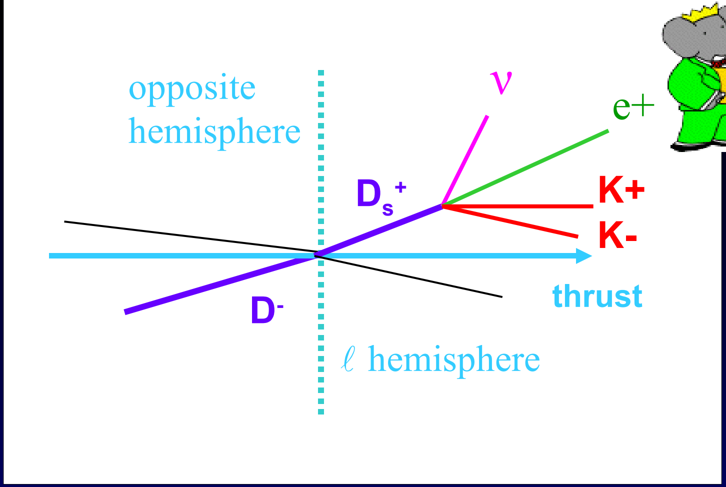
pole dominance parametrization: $\mathrm{A}_i(q^2) = \frac{\mathrm{A}_i(0)}{1 - q^2/M_A^2}$ $\quad \mathrm{V}(q^2) = \frac{\mathrm{V}(0)}{1 - q^2/M_V^2}$

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

$r_V = \mathrm{V}(0)/\mathrm{A}_1(0)$ and $r_2 = \mathrm{A}_2(0)/\mathrm{A}_1(0)$

Event reconstruction

*same method as for $D \to K e \nu$ but without D**



- Define 2 hemispheres

take K^+, K^- , ℓ in the same hemisphere

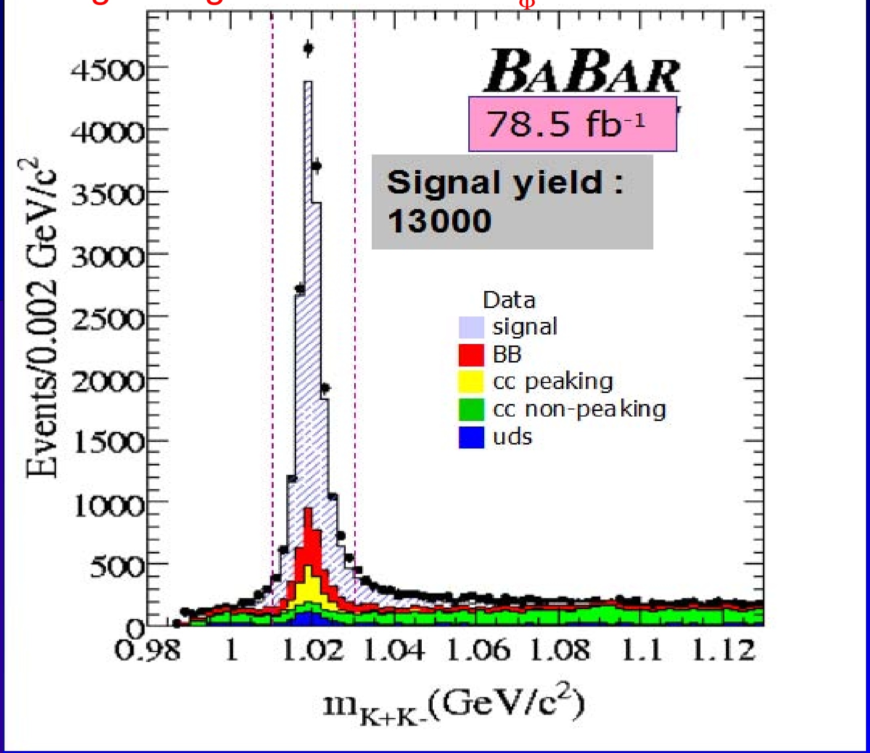
- Compute D_s direction $(-\, p_{\text{all particles} \neq K+,K-,l})$
- Compute the missing energy in the ℓ hemisphere
- Fit $p_{Ds} = p_{K+} + p_{K-} + p_\ell + p_\nu$ → **one constrained fit m_{Ds}**
- Compute kinematic variables : q^2 , θ_V, θ_l, χ

- **Reduce the background**
  → Fisher discriminants (b$\bar{b}$ and c$\bar{c}$ events)

- **control sample → $D_s \to \varphi\pi$**

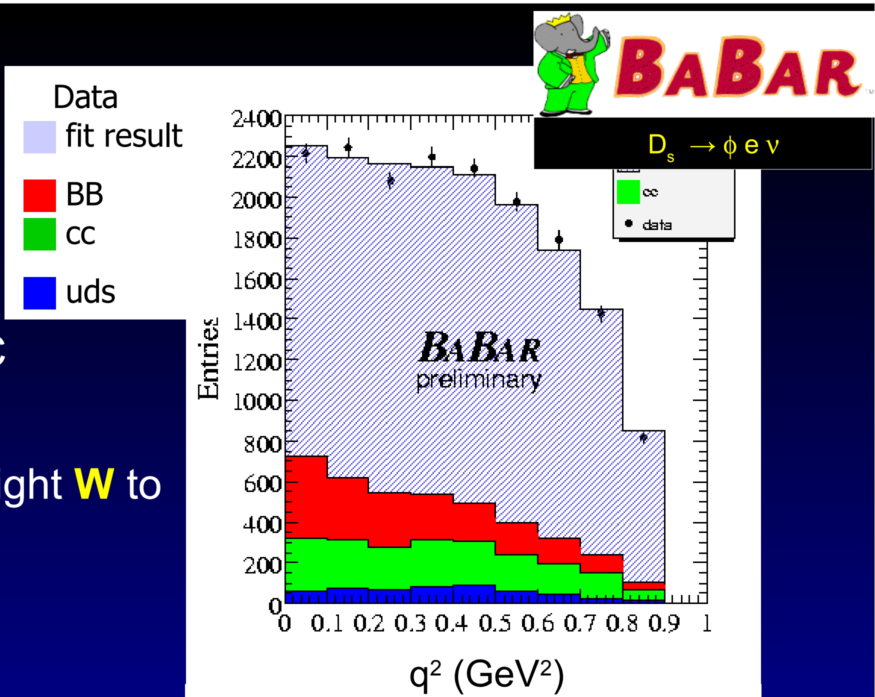
Background composition:
B^0B^0 evts = 23%
B^+B^- evts = 22%
uds evts = 14%
c$\bar{c}$ = 41%

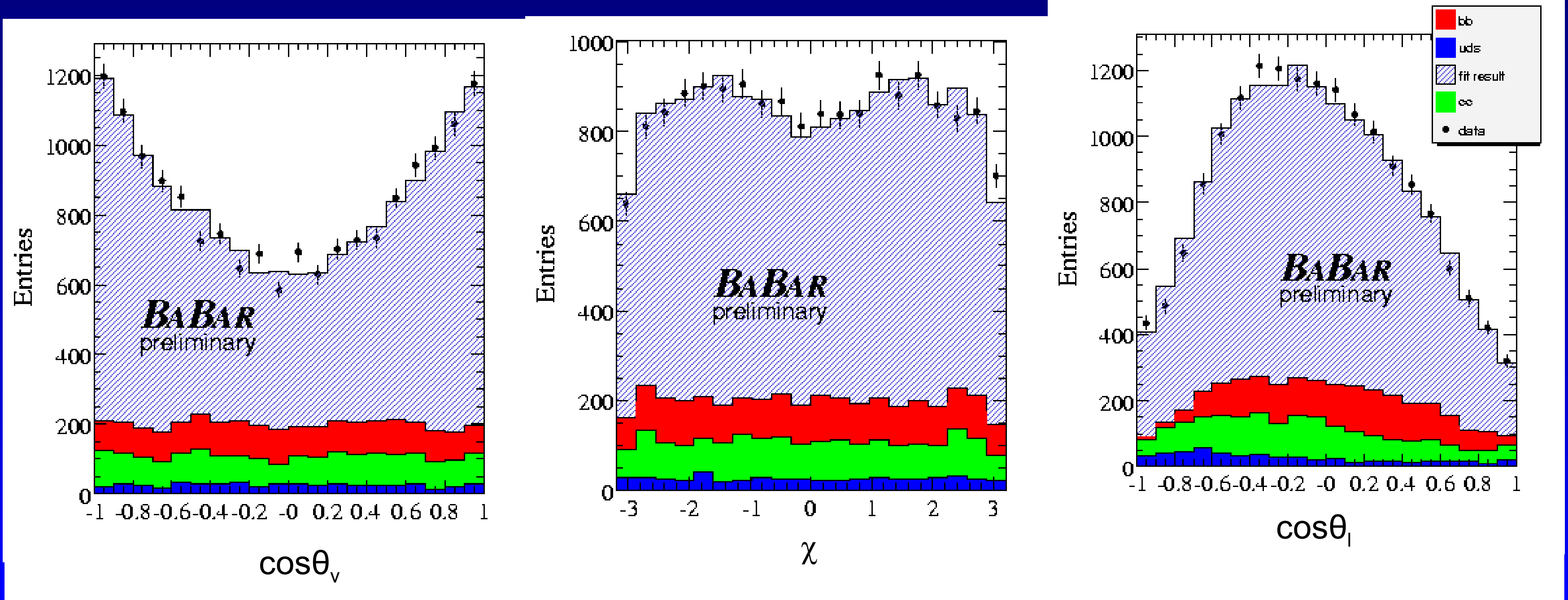
signal region :1.01 GeV <m_Φ<1.03GeV



Fitting Procedure

- 5 equal bins for each reconstructed variable
- perform a log-likelihood minimization
- number of bkg events estimated from normalized generic MC (average over cosθ_v and χ assuming a flat distribution)
- number of signal events expected deduced by applying a weight **W** to MC signal events generated according to phase space
- fitting procedure has been checked on toy simulations





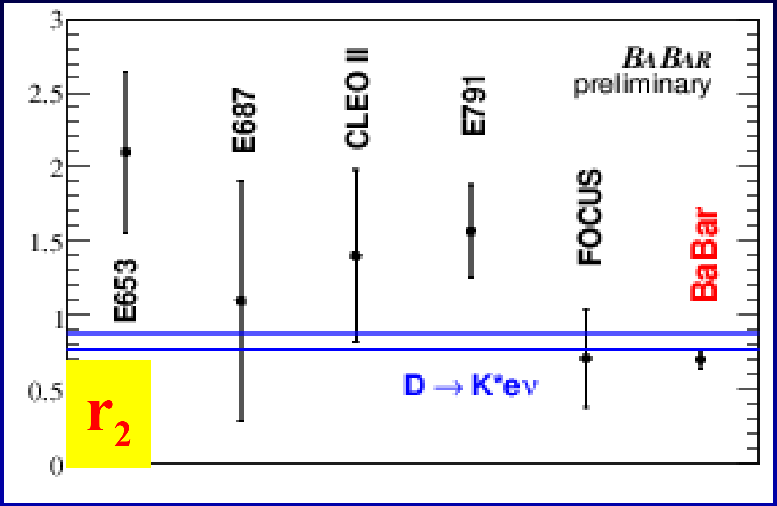
BABAR
$D_s \to \phi e \nu$

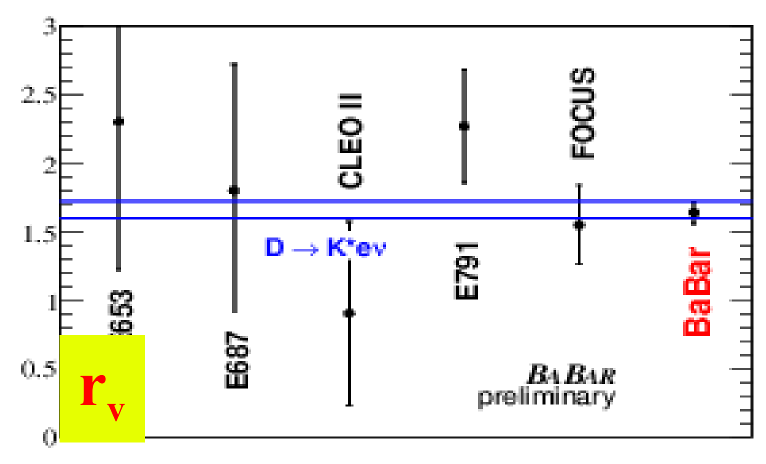
Results

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

$r_2 = 0.705 \pm 0.056 \pm 0.029$

$r_v = 1.636 \pm 0.067 \pm 0.038$





Same accuracy as D→K*eν (FPCP 2006, J.Wiss)

Fixing only the vector pole mass :

$r_2 = 0.711 \pm 0.111 \pm 0.096$

$r_v = 1.633 \pm 0.081 \pm 0.068$

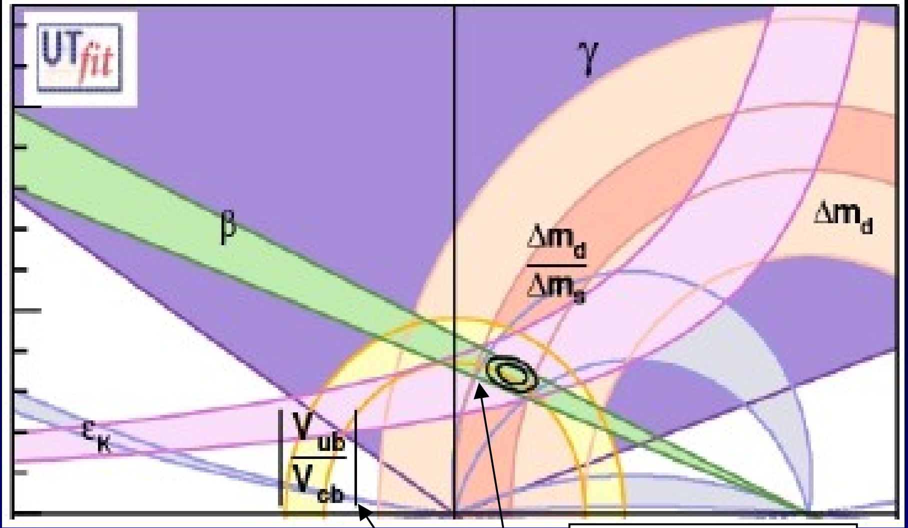
$m_A = 2.53^{+0.54}_{-0.35} \pm 0.054 GeV/c^2$

Leptonic Decays

BABAR $D_s \rightarrow \mu\,\nu$ Phys.Rev.Lett.98:141801,2007

BELLE $D_s \rightarrow \mu\,\nu$ *preliminary, new 2007 summer result*

$D_s \to \mu\,\nu$ Introduction



theoretical uncertainties

Precise knowledge of f_{Bd} and f_{Bs} needed to improve constraints from ΔM_d and $\Delta M_d / \Delta M_s$

In LQCD similar techniques are used to calculate b and c decay constant ⇒ experimental measurements of f_{Ds} and f_D can be used as a test of lattice QCD

Partial width of $M^+ \to l^+ \nu$:

$$\Gamma = \frac{G_F^2}{8\pi} \left|V_{Qq}\right|^2 f_M^2 \, M_M m_l^2 \left(1 - \frac{m_l^2}{M_M^2}\right)^2$$

Phase space

CKM Mixing

Helicity Suppression

$D_s^+ \to \mu^+ \nu$ is most accessible experimentally :

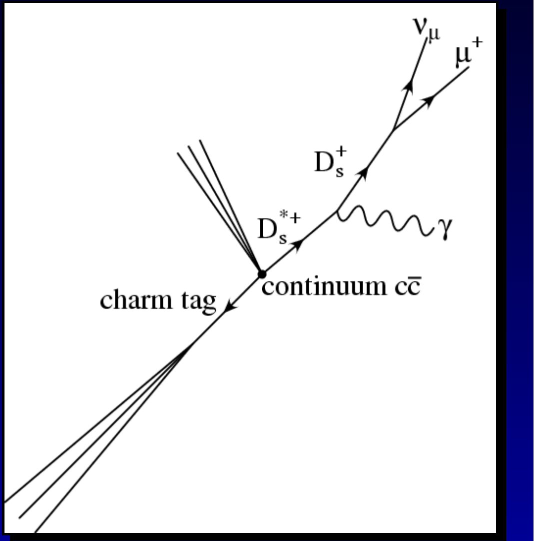
$\Gamma(D_s^+ \to \tau^+ \nu_\tau) : \Gamma(D_s^+ \to \mu^+ \nu_\mu) : \Gamma(D_s + \to e^+ \nu_e) = 10 : 1 : 10^{-5}$ (BR($\tau \to h\nu_\tau$) ≈ 11%)

$D_s \rightarrow \mu\ \nu$

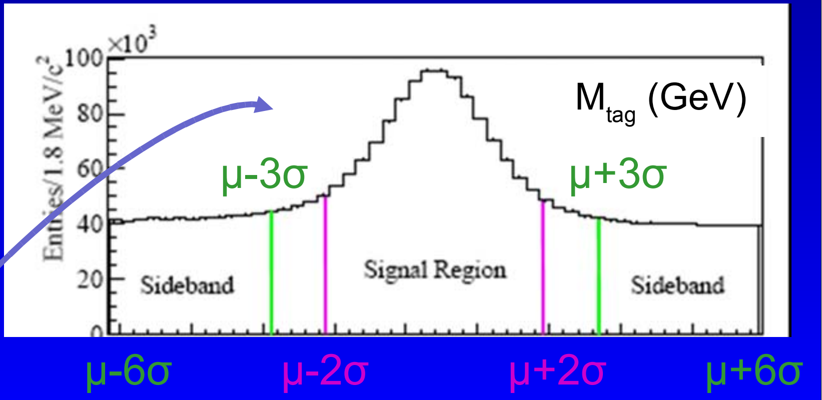
tagged, partial reconstruction analysis

BABAR

- Identify cc events: Charm -Tagging
  - Reconstruct charm mesons D^0, D^+, D_s^+, and D^{*+} using hadronic decay modes – the 'tag'
  - High tag momentum above the kinematic limit from B decays
- Search for $D_s^{*+} \rightarrow \gamma D_s^+ \rightarrow \gamma\mu^+\nu$ in recoil
- Advantages:
  - tag momentum reduces uds, BB, $\tau\tau$ backgrounds
  - tag direction improves fit to missing neutrino and the ΔM resolution
  - knowledge of tag's charm reduces pion→muon misidentification by 50%
- Disadvantage
  - Loss in efficiency due to tagging



5.10^5 events with a muon in the recoil after bkg subtraction



Signal Yield

- Yield extraction :
  - remove fake tag bkg by bin-by-bin subtraction μ tag sideband from μ tag signal region
  - same for electrons
  - then subtract e from μ to remove semileptonic and τ bkg
  - Binned χ^2 fit
- Normalize to $D_s^+ \to \varphi\pi$

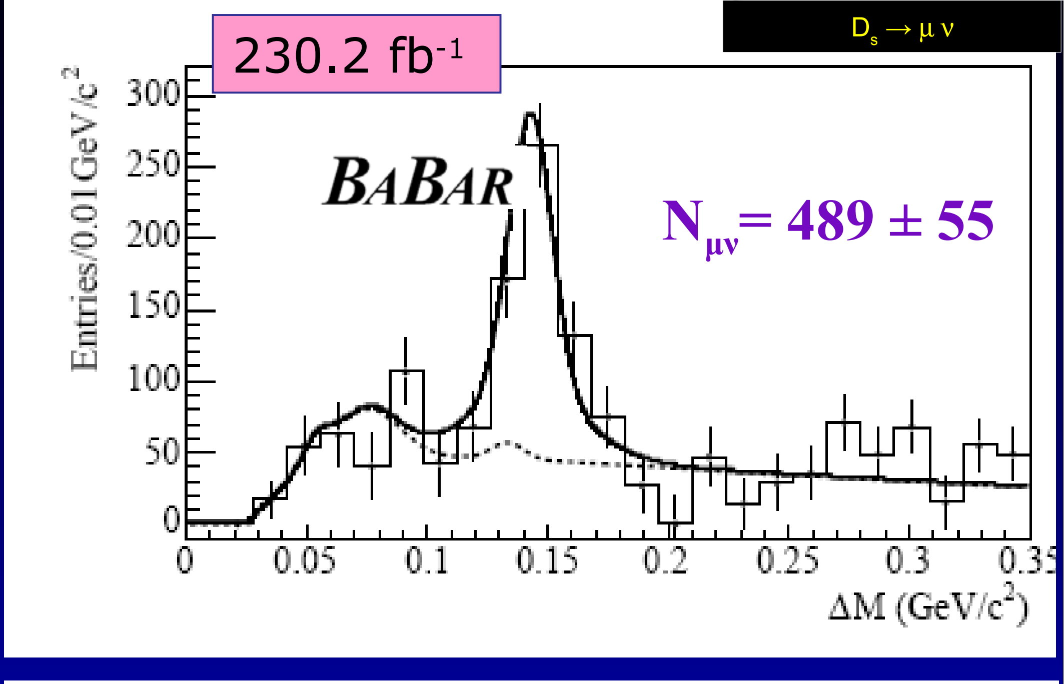
Result :

$$\frac{\Gamma\left(D_s^+ \to \mu^+ \nu_\mu\right)}{\Gamma\left(D_s^+ \to \phi\pi\right)} = 0.143 \pm 0.018 \pm 0.006$$

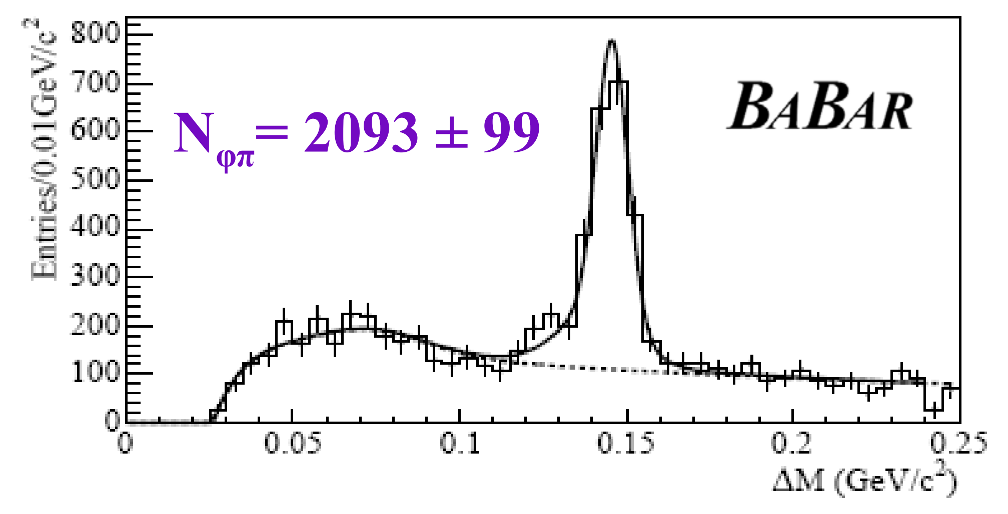
Independent measurement in BaBar :

$$B\left(D_s^+ \to \phi\pi\right) = (4.71 \pm 0.46)\%$$

Phys.Rev.Lett.98:141801,2007


$D_s \to \mu\nu$

230.2 fb^{-1}



Results

Phys.Rev.Lett.98:141801,2007

BABAR

$D_s \rightarrow \mu\,\nu$

We obtain $B(D_s^+ \rightarrow \mu^+ \nu_\mu) = (6.74 \pm 0.83 \pm 0.26 \pm 0.66) \times 10^{-3}$

and $f_{D_s} = 283 \pm 17_{\mathrm{stat}} \pm 7_{\mathrm{syst}} \pm 14_{D_s \rightarrow \phi\pi}$ MeV

Improvement possible (Babar: 1ab^{-1})

Small syst. uncertainty

Improvement possible

☆ Using CLEO-c value : $f_D = 222.6 \pm 16.7_{stat}{}^{+2.8}_{-3.4}{}_{syst}$ MeV Phys. Rev. Lett. 95, 251801 (2005)

We obtain $f_{Ds} / f_D = 1.27 \pm 0.14$ (11%)

Consistent with lattice QCD : $f_{Ds} / f_D = 1.24 \pm 0.07$ (5.6%)

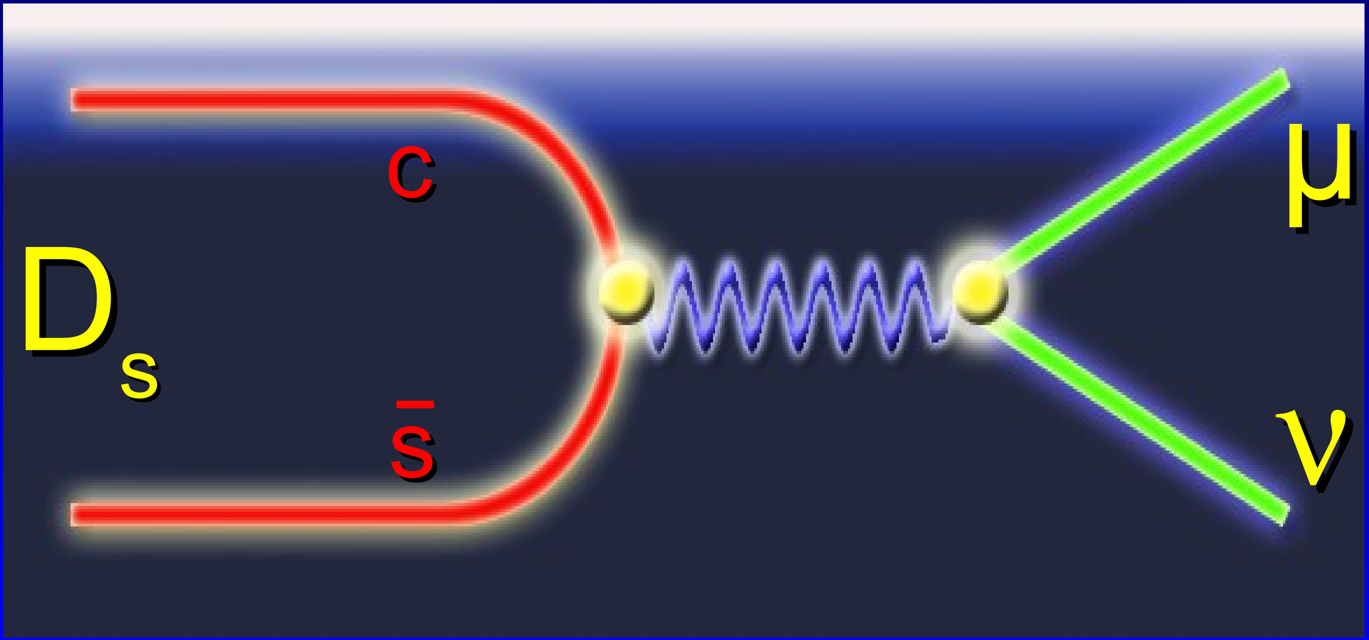
Phys. Rev. Lett. 95, 122002 (2005)

$D_s \to \mu \nu$

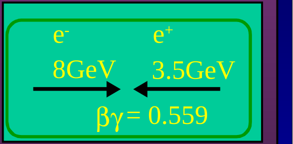
new summer 2007 result preliminary!

tagged, full reconstruction analysis

analysis technique very similar to $D \to K/\pi\, l\nu$ analysis



Belle in a nutshell

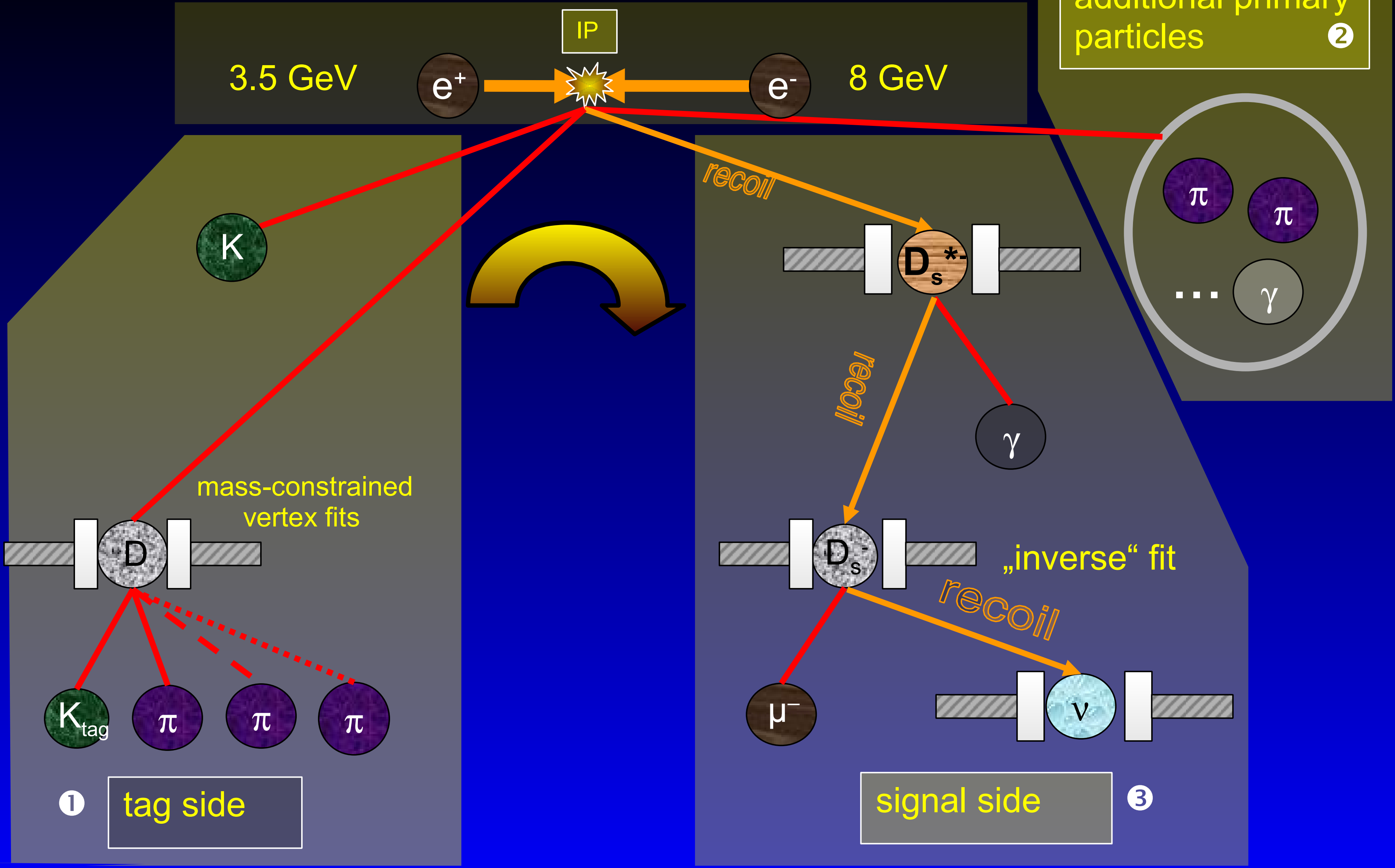


- located at KEK / Japan
- KEKB Collider
- B-Factory at $\Upsilon(4s)$ resonance
- peak luminosity 17.118 1/nb/s
- integrated luminosity 715 1/fb

(as of Jun 2007; only part of it used in presented analyses)

main physics goal: observation of CPV in B meson Decays

reconstruction method



n_X distribution

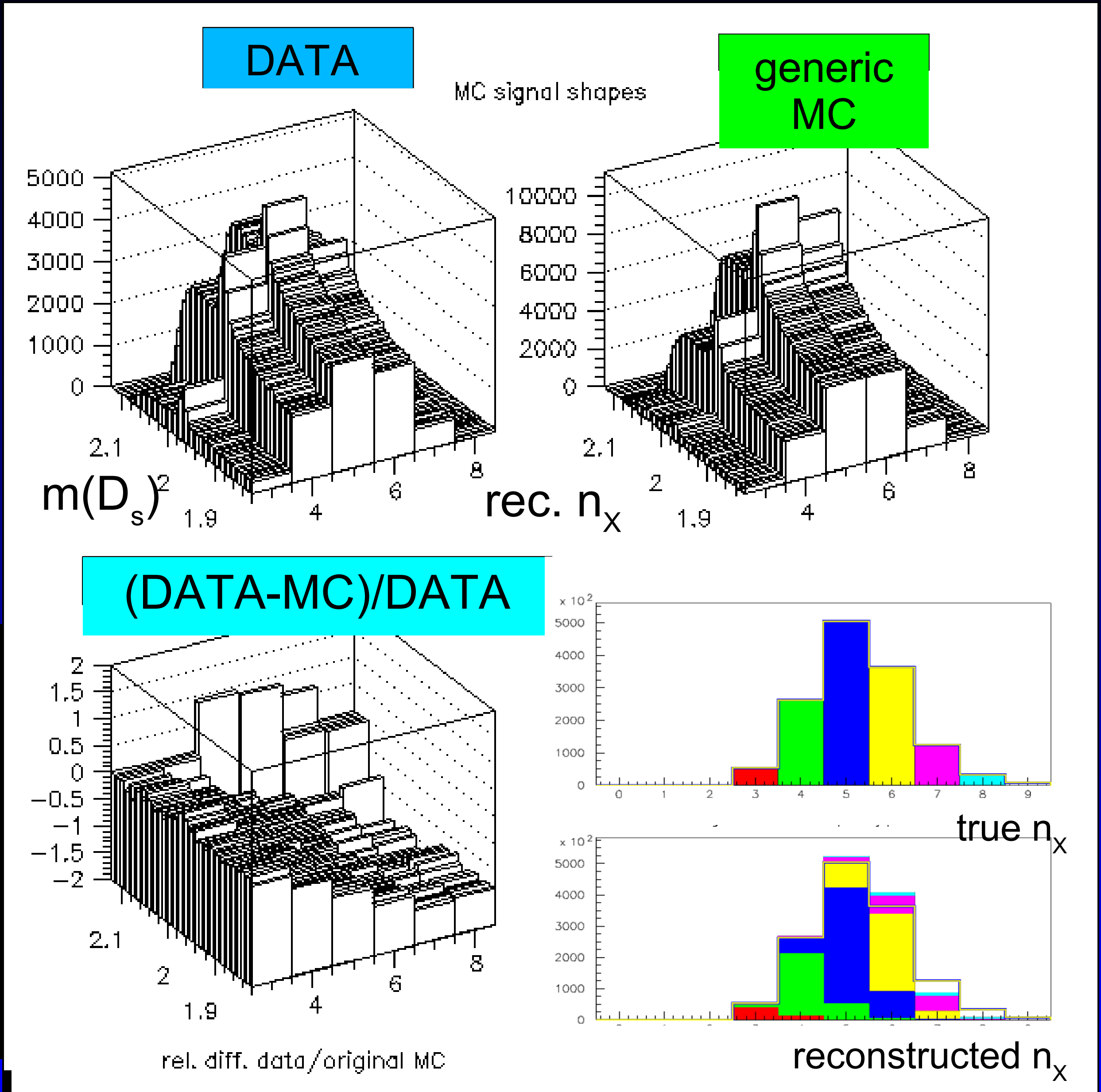
definition of n_x:

n_X = number of primary particles, i.e. the D, the D_s^*, the primary K and an arbitrary number of pions and gammas

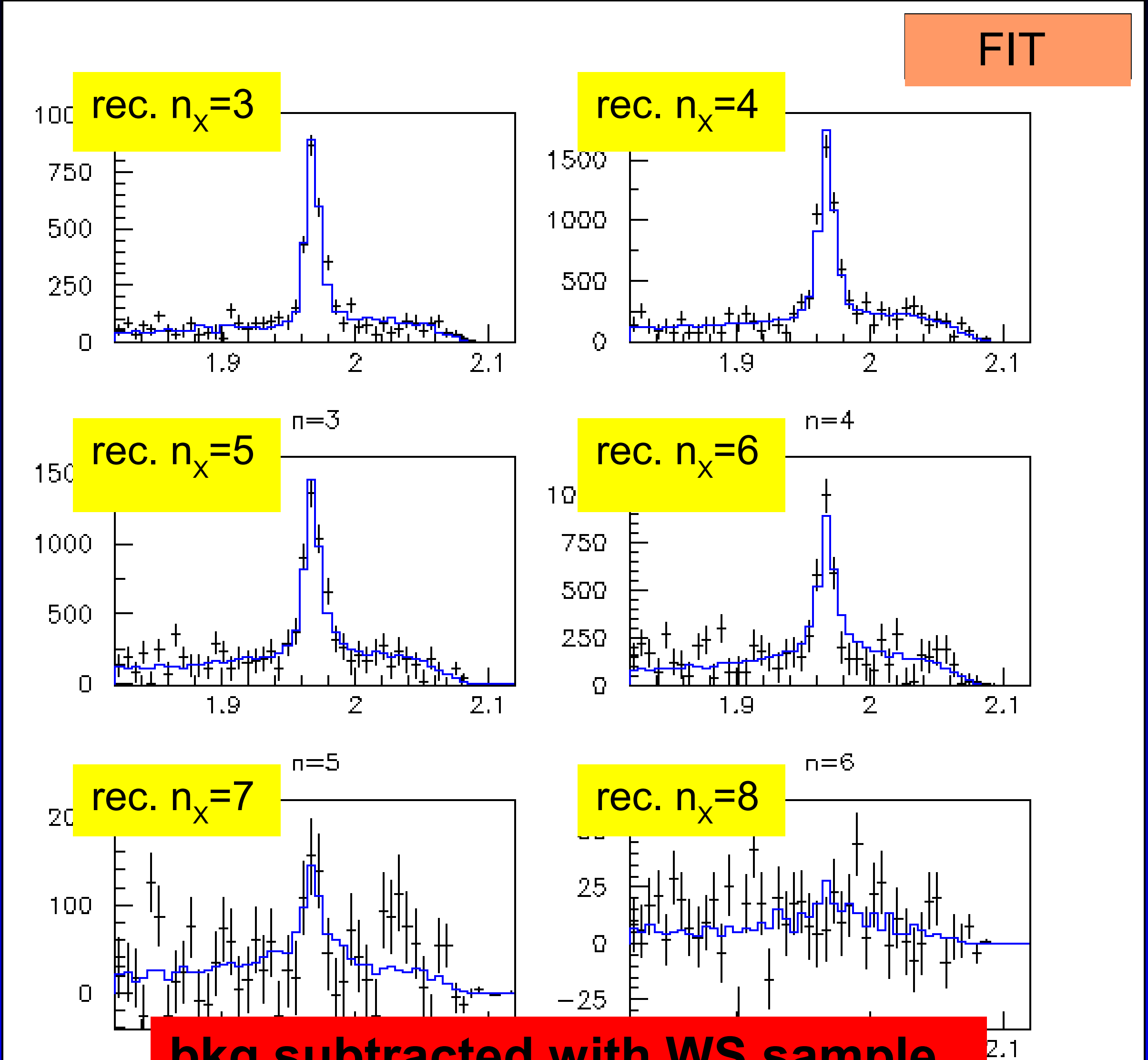
note: the minimal value of n_X is 3 (D, D_s^*, K)

Problem:
n_x distribution incorrect in MC and convoluted in reconstruction!

Solution:
fit in bins of true n_X

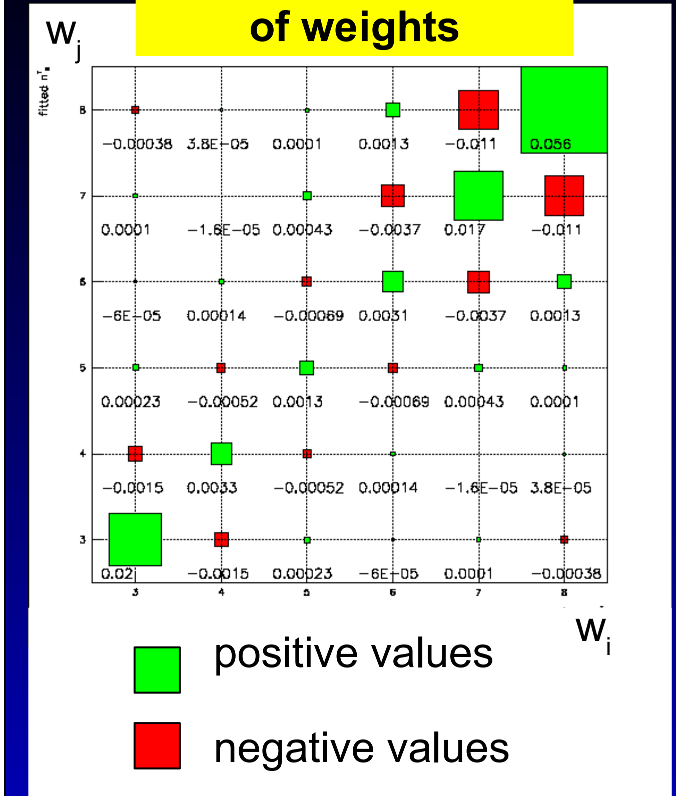


fit of D_s tags



bkg subtracted with WS sample similar to semileptonic analysis!

correlation matrix of weights



	3	4	5	6	7	8
8	−0.00038	3.8E−05	0.0001	0.0013	−0.011	0.056
7	0.0001	−1.6E−05	0.00043	−0.0037	0.017	−0.011
6	−6E−05	0.00014	−0.00069	0.0031	−0.0037	0.0013
5	0.00023	−0.00052	0.0013	−0.00069	0.00043	0.0001
4	−0.0015	0.0033	−0.00052	0.00014	−1.6E−05	3.8E−05
3	0.02	−0.0015	0.00023	−6E−05	0.0001	−0.00038

🟩 positive values

🟥 negative values

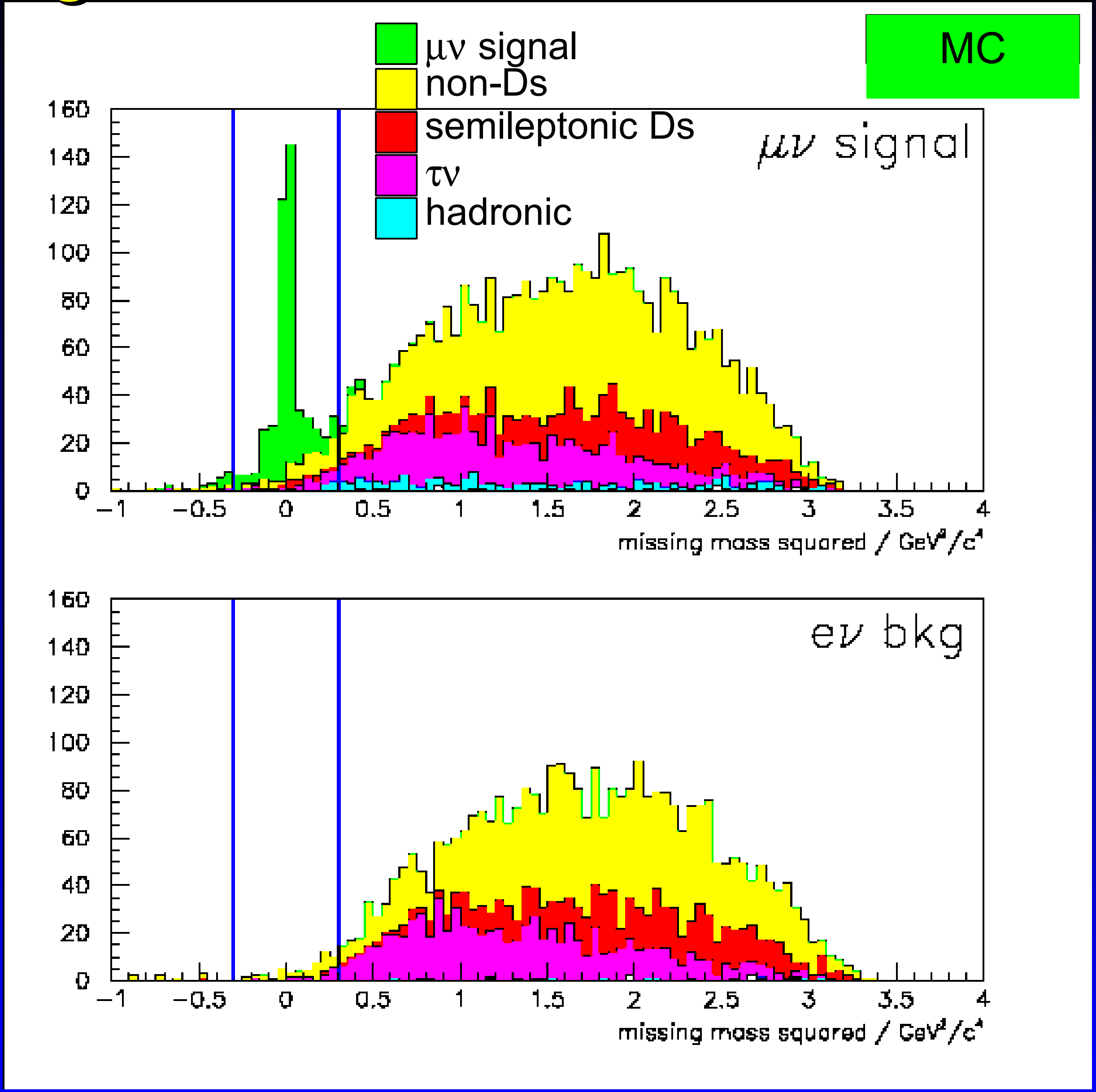
$$N^{\mathrm{rec}}_{D_s} = \sum_{i=1}^{6} w_i^{\mathrm{D_s}} N^{\mathrm{GMC,i}}_{D_s}$$

N(D_s tags) =

$32100 \pm 870_{\mathrm{stat}} \pm 1210_{\mathrm{syst}}$

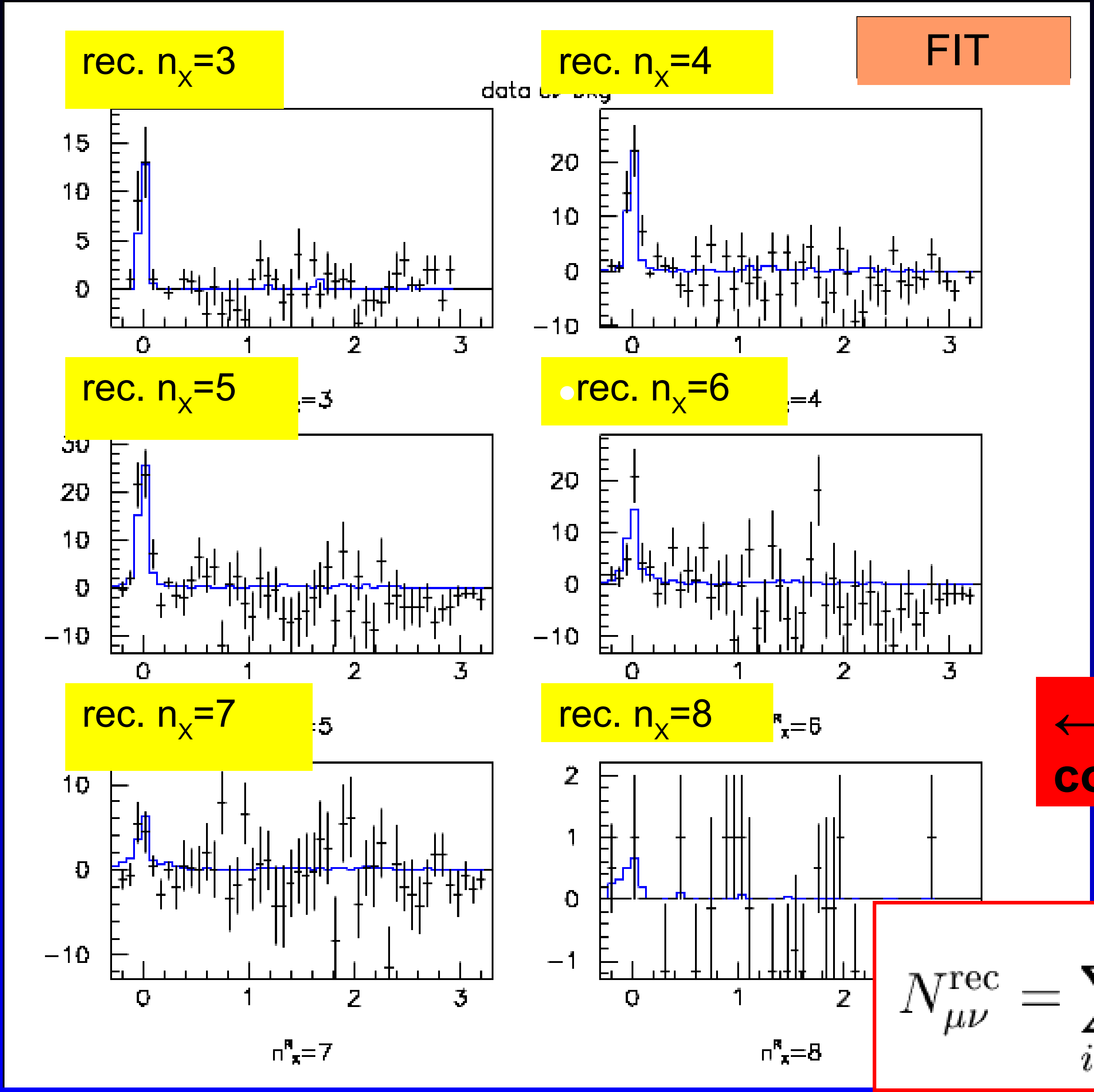
μν signal & background in MC

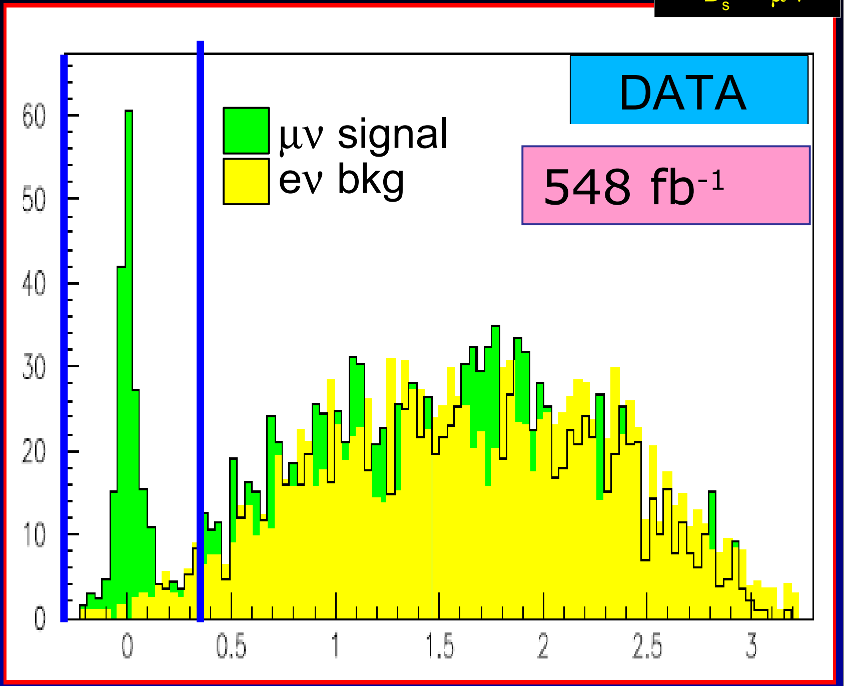
- get shape of background from data by exchanging the muon by an electron („eν shape“)
- use this as model for the background in the fit
- correct for e/μ efficiency differences



μν signal yields

$D_s \to \mu\nu$





← bkg subtracted using efficiency corrected eν data sample

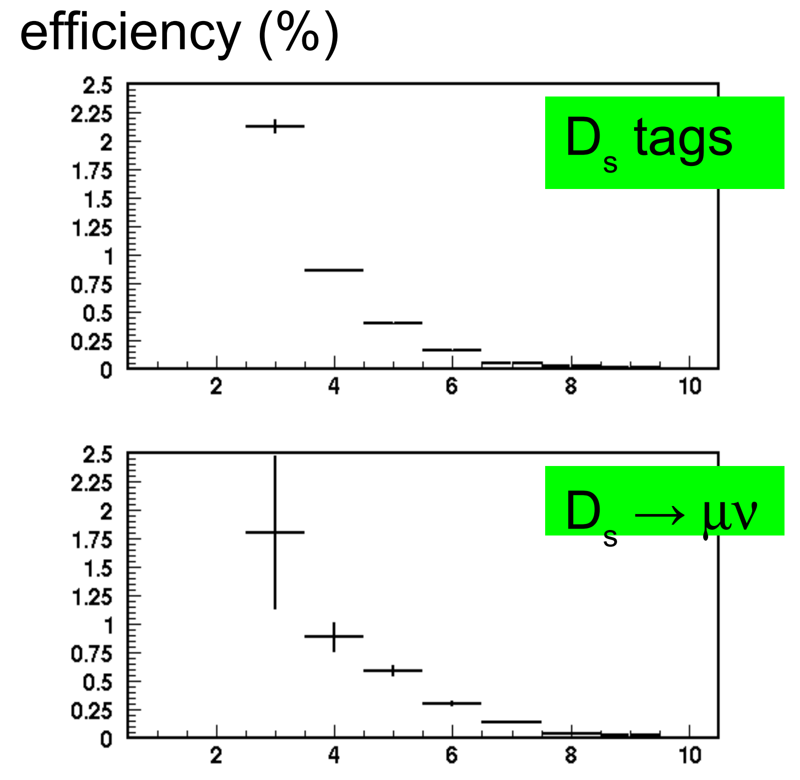
$$N_{\mu\nu}^{\mathrm{rec}} = \sum_{i=1}^{6} w_i^{\mu\nu} N_{\mu\nu}^{\mathrm{SMC,i}}$$

$N(D_s \to \mu\nu)$ =

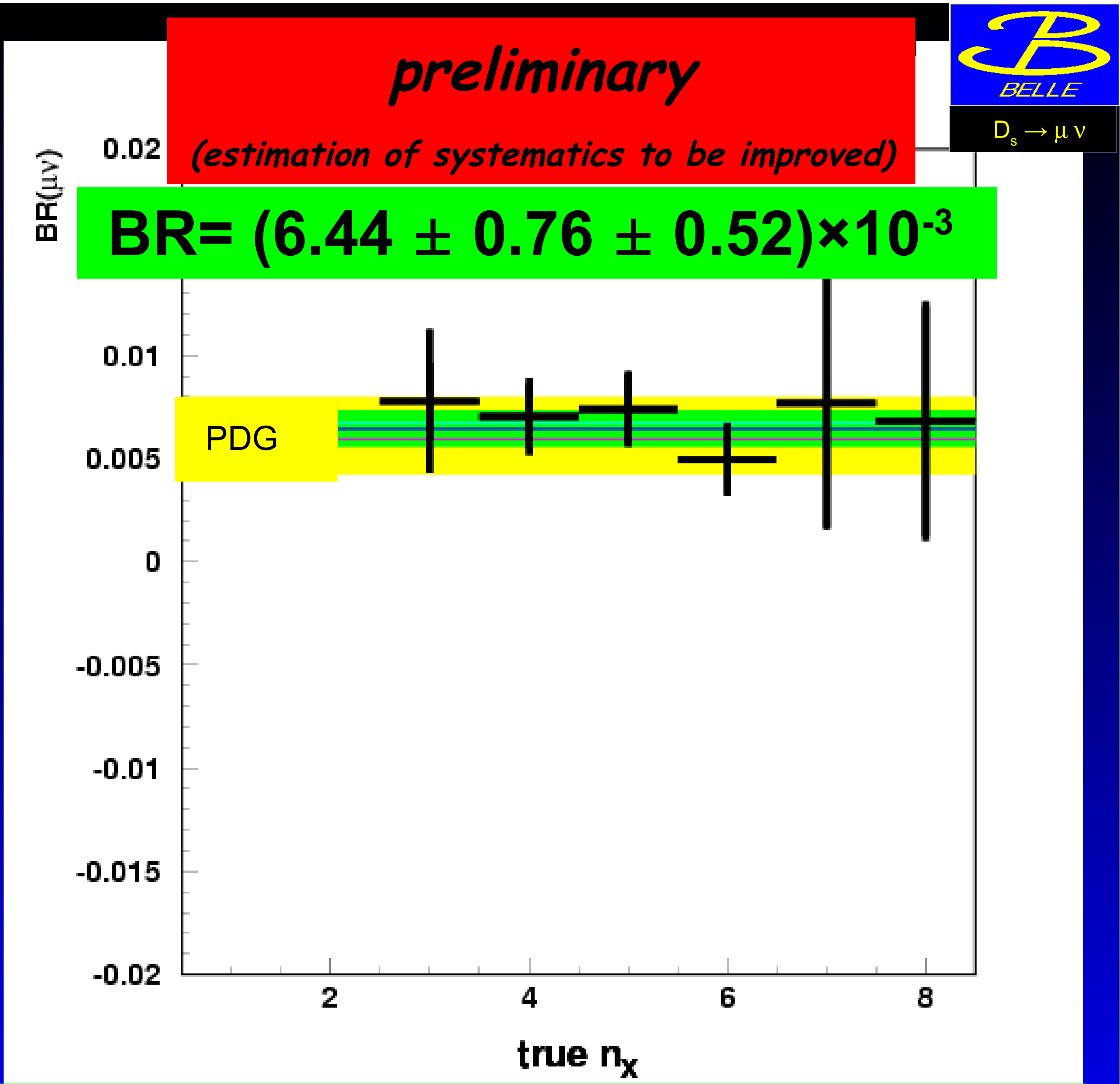
$169 \pm 16_{stat} \pm 8_{syst}$

bkg: 30 ± 4

branching ratio & decay constant



$D_s \to \mu\,\nu$



preliminary

(estimation of systematics to be improved)

$BR = (6.44 \pm 0.76 \pm 0.52) \times 10^{-3}$

$f_{Ds} = 275 \pm 16_{stat} \pm 12_{syst}$ MeV

(using $V_{cs} = 0.9730$ from PDG overall fit)

Overview of Results

🟢 diff. < 1σ
🟡 1σ < diff. < 2σ
🔴 diff. > 2σ

$D^0 \to K/\pi\ e/\mu\ \nu$

theory			BABAR		BELLE
	BRs	$K^- e^+ \nu$	$3.522 \pm 0.027_{stat} \pm 0.045_{syst} \pm 0.065_{K\pi}$	🟢	$3.45 \pm 0.10_{stat} \pm 0.19_{syst}$
		$K^- \mu^+ \nu$			$3.45 \pm 0.10_{stat} \pm 0.21_{syst}$
		$\pi^- e^+ \nu$			$0.279 \pm 0.027_{stat} \pm 0.016_{syst}$
		$\pi^- \mu^+ \nu$			$0.231 \pm 0.026_{stat} \pm 0.019_{syst}$
	FF	r_1	$-2.5 \pm 0.2_{stat} \pm 0.2_{syst}$		
		r_2	$0.6 \pm 6.0_{stat} \pm 5.0_{syst}$		
2.112 (D_s^*)		$m_{pole}(K)$	$1.884 \pm 0.012_{stat} \pm 0.015_{syst}$ GeV	🟡	$1.82 \pm 0.04_{stat} \pm 0.03_{syst}$ GeV
2.010 (D*)		$m_{pole}(\pi)$			$1.97 \pm 0.08_{stat} \pm 0.04_{syst}$ GeV
0.50 ± 0.04		$\alpha(K)$	$0.377 \pm 0.023_{stat} \pm 0.029_{syst}$	🟡	$0.52 \pm 0.08_{stat} \pm 0.06_{syst}$
0.44 ± 0.04		$\alpha(\pi)$			$0.10 \pm 0.21_{stat} \pm 0.10_{syst}$
0.73(3)(7)		$f_+(0,K)$	$0.727 \pm 0.007_{stat} \pm 0.005_{syst} \pm 0.007_{Kpi}$	🟡	$0.695 \pm 0.007_{stat} \pm 0.022_{syst}$
0.64(3)(6)		$f_+(0,\pi)$			$0.624 \pm 0.020_{stat} \pm 0.030_{syst}$

Overview of Results

🟢 diff. < 1σ
🟡 1σ < diff. < 2σ
🔴 diff. > 2σ
theory

		BABAR	BELLE
$D_s \rightarrow \phi e \nu$			
fixing m_A & m_V	r_2	0.705 ± 0.056 ± 0.029	
	r_v	1.636 ± 0.067 ± 0.038	
fixing only m_V	r_2	0.711 ± 0.111 ± 0.096	
	r_v	1.633 ± 0.081 ± 0.068	
	m_A	$2.53^{+0.54}_{-0.35}$ ± 0.054 GeV/c²	
$D_s \rightarrow \mu \nu$			
	BR ×10³	6.74 ± 0.83 ± 0.26 ± 0.66	🟢 6.44 ± 0.76 ± 0.52
249±3±16	f_{Ds}	283 ± 17 ± 7 ± 14 MeV	275 ± 16 ± 12 MeV

Summary

- both BaBar and Belle could help to improve various measurements in leptonic & semileptonic decays:
    - decay constants measured with accuracy similar to LQCD precision (statistically limited)
    - FF normalization already more accurate than LQCD (again statistically limited)
    - hints of differences between measurement and theory in FF q^2 dependency; needs better measurement at high q^2 (where statistics are low)
- methods complement each other (full reconstruction / lower statistics / better resolution vs partial reconstruction / higher statistics / worse resolution)
- results are in good to fair agreement within B-factories
- important (and competitive) complement of results achieved at $D_{(s)}D_{(s)}$ threshold

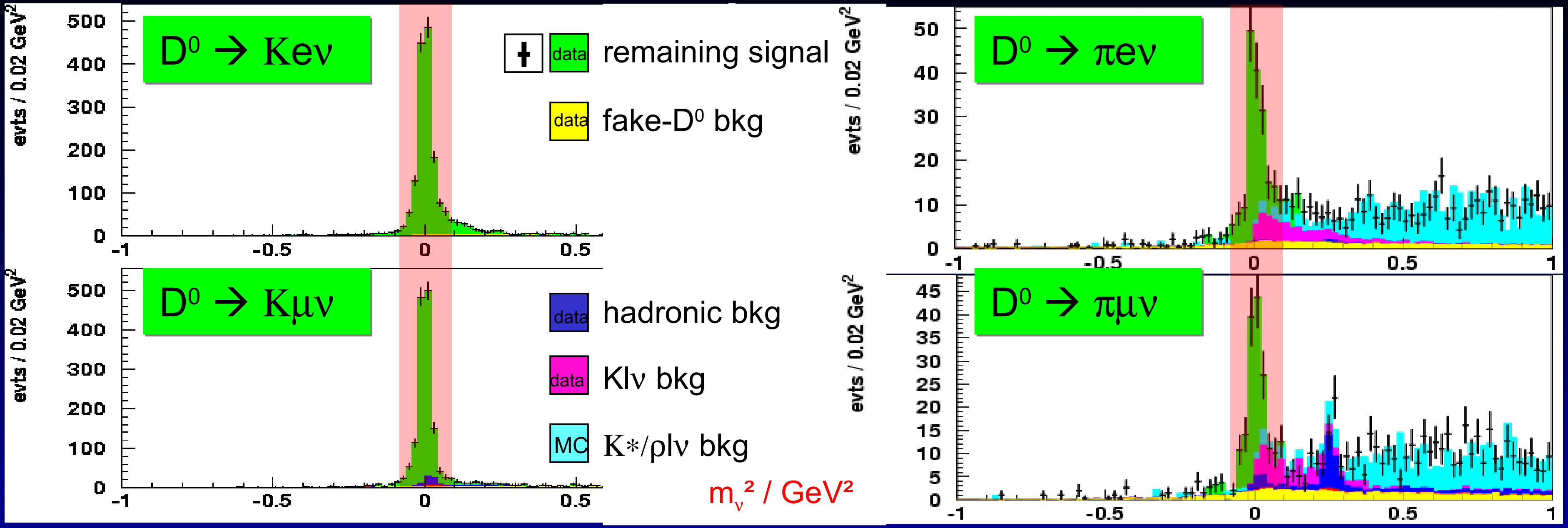
thanks to Arantza Oyanguren, Justine Serrano & Paul Jackson (all BaBar) for their help and material!

Spares

signal

Phys.Rev.Lett.97:061804,2006 hep-ex/0604049

$D^0 \to K/\pi\ e/\mu\ \nu$



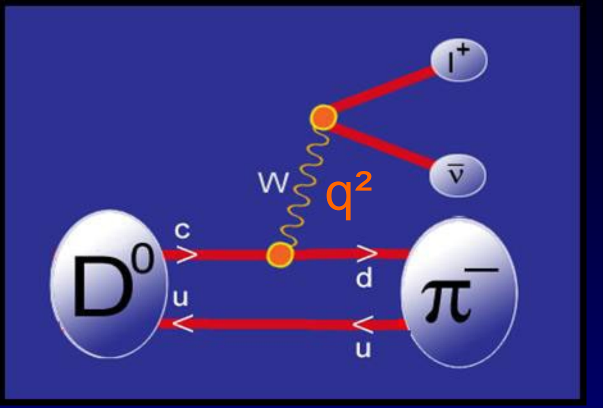
Results (282 fb⁻¹ of BELLE data)	$K e \nu$	$K \mu \nu$	$\pi e \nu$	$\pi \mu \nu$
signal events	1318 $\pm 37_{stat} \pm 7_{syst}$	1249 $\pm 37_{stat} \pm 25_{syst}$	126 $\pm 12_{stat} \pm 3_{syst}$	106 $\pm 12_{stat} \pm 6_{syst}$
fake D⁰ bkg	12.6 ± 2.2	12.2 ± 4.8	12.3 ± 2.2	12.5 ± 4.5
semileptonic bkg*	6.7 ± 2.6	10.0 ± 2.5	11.7 ± 1.2	12.6 ± 1.9
hadronic bkg**	11.9 ± 5.6	62.1 ± 23.9	1.8 ± 0.7	9.7 ± 3.7

* error dominated by MC stats

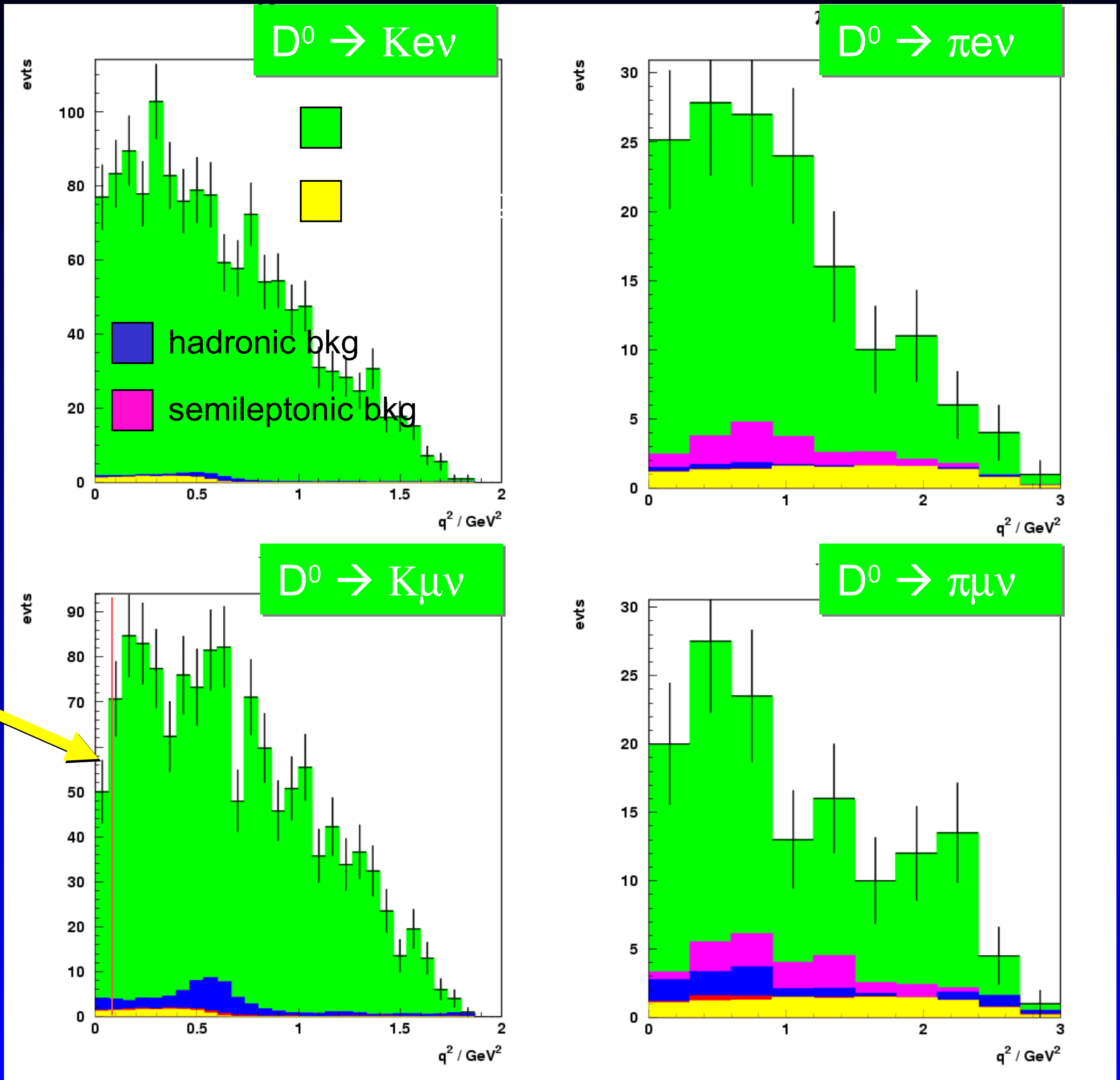
** error dominated by fit errors & bias special bkg sample

Form Factors – q² distribution

BELLE
$D^0 \to K/\pi\ e/\mu\ \nu$



σ(q²) = 0.0145 GeV²/c²
(width of red line)
→ no unfolding necessary!



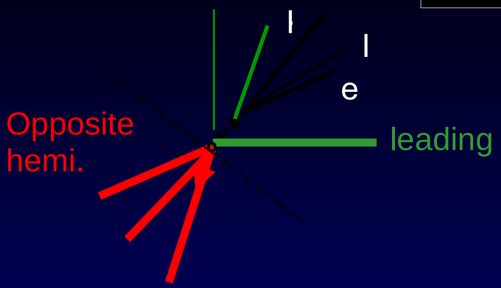
background shapes from data

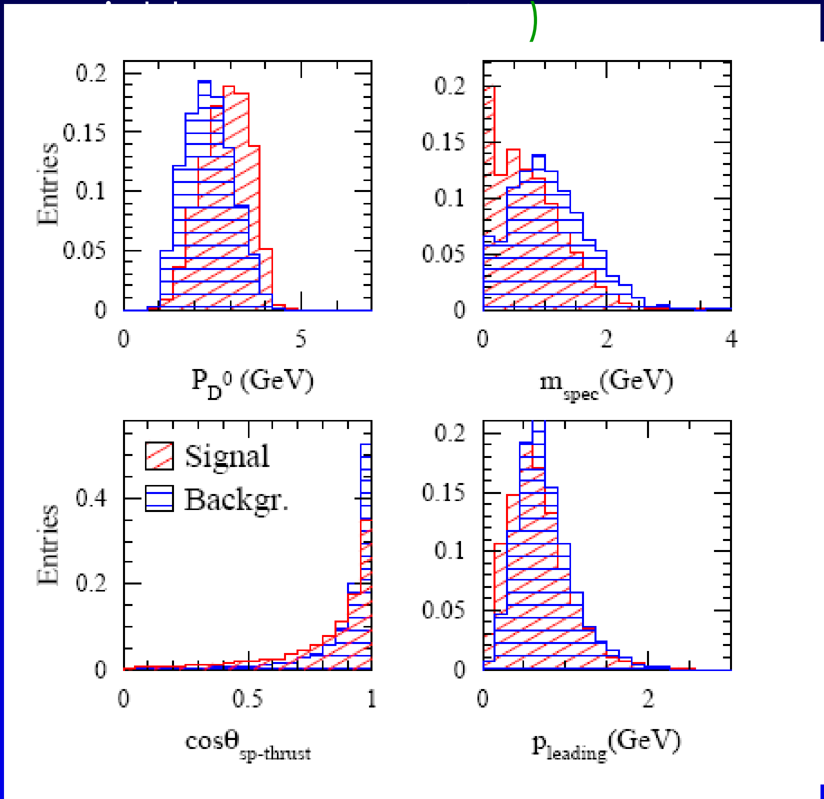
$D^0 \rightarrow K/\pi\, e\, \nu$

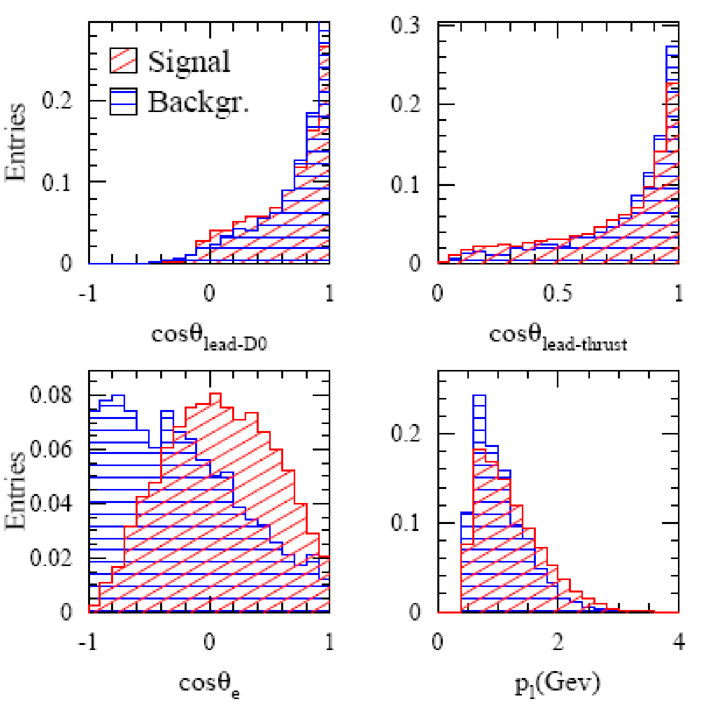
2 Fisher variables :

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

(mass, angular distribution, momentum and angular distribution of the leading particle + kinematic)

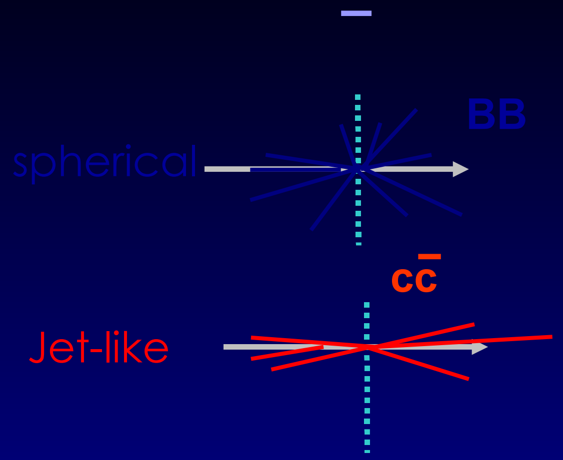




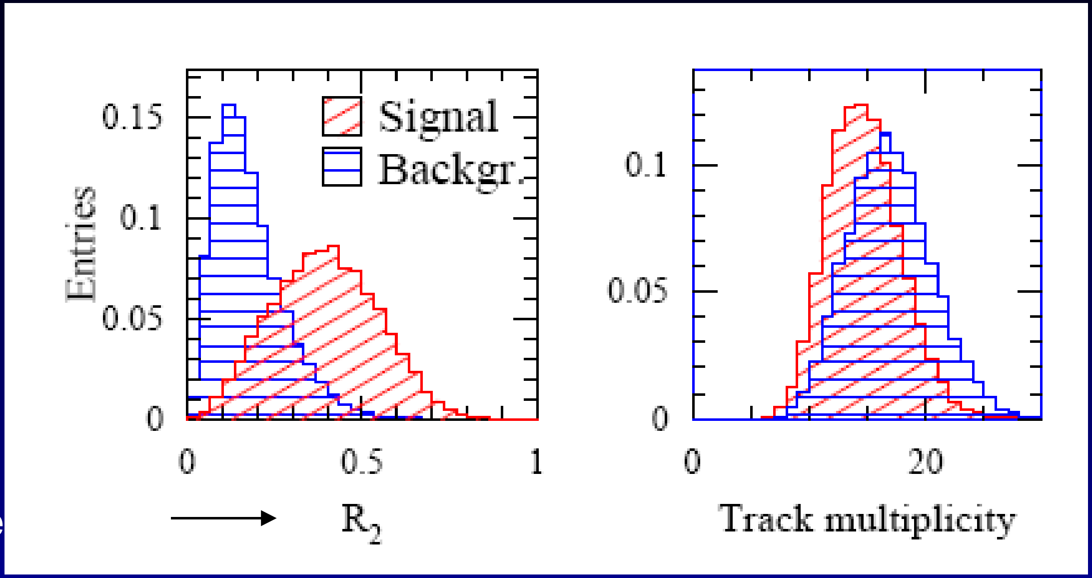


BABAR
$D^0 \rightarrow K/\pi\, e\, \nu$

- **$b\bar{b}$ events rejection:** Event shape variables



Fox-Wolfram mome



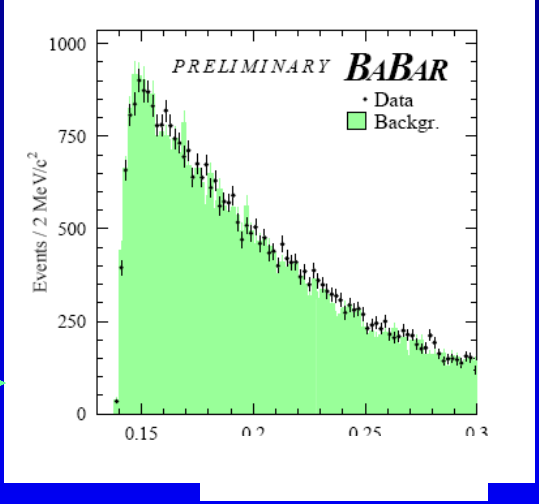
Remaining background composition :

B^0B^0 evts = 17% B^+B^- evts = 7%   uds evts = 3%

Peaking cc = 48%
(real D*, with for ex : $D^0 \rightarrow K^-\pi^0 e\nu$ or $D^0 \rightarrow K^-\pi^0\pi^+$)

Non-peaking cc = 25%

check data/MC agreement with wrong sign events



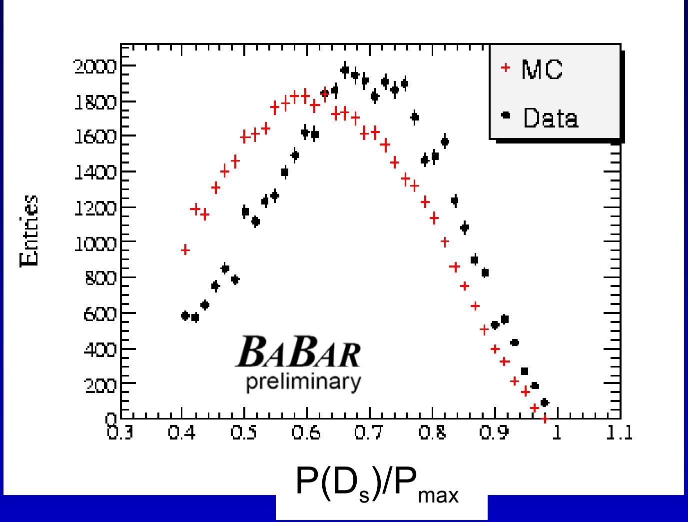
Control Samples

$D_s \to \phi e \nu$

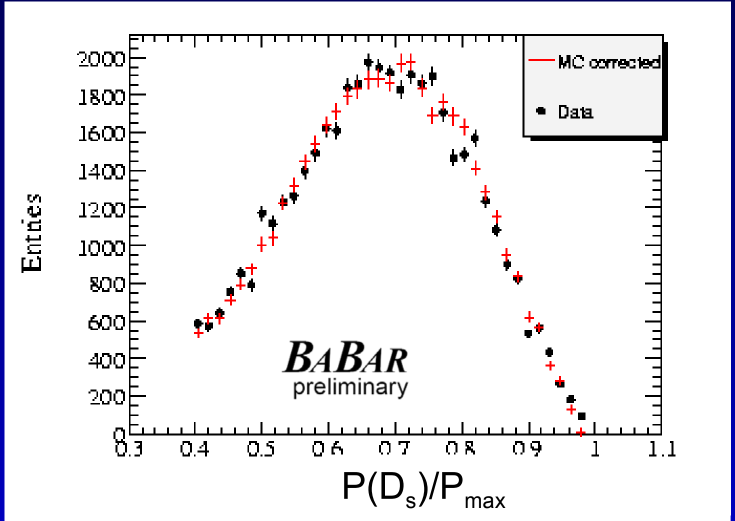
- Use $D_s \to \phi\pi$ (reconstructed as similar as possible)
- D_s direction and missing energy determination:

Define a parametrization of the differences to take into account possible biases.

- Fisher variables : Large disagreement data/MC observed in the fragmentation distribution

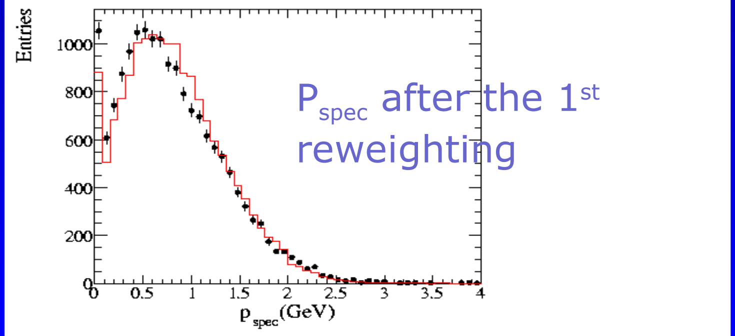


simulated events after reweighting



Check other Fisher variables after correction : small discrepancy remains, ex: spect. syst. momentum

Taken into account in the systematic uncertainties by defining an additional weight on this variable.

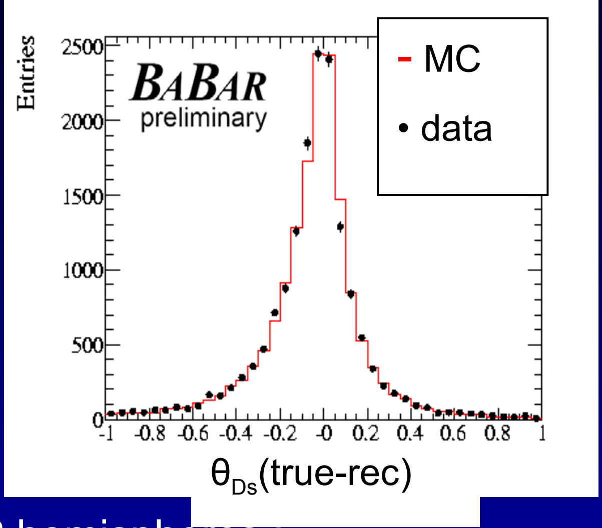


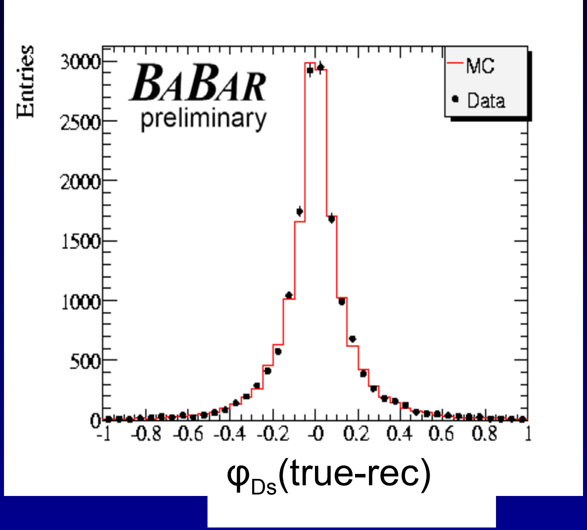
P_{spec} after the 1st reweighting

Control Samples

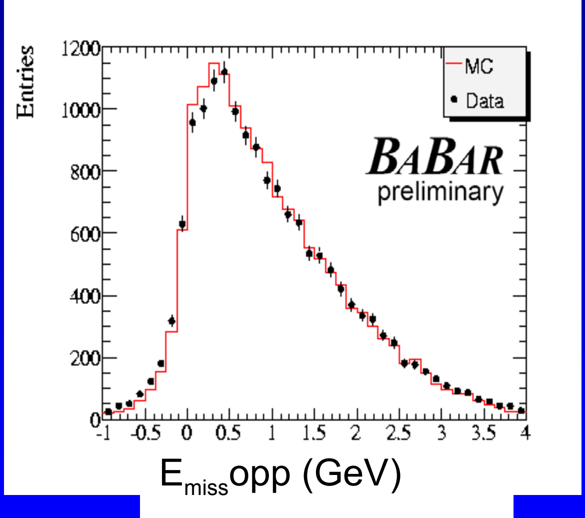
BABAR
$D_s \rightarrow \phi e \nu$

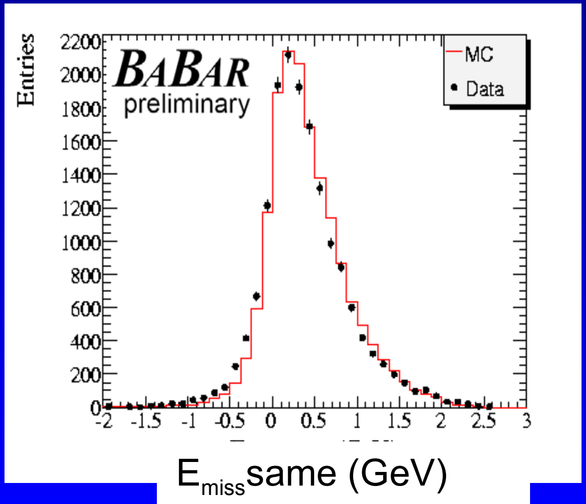
D_s direction determined using all the other tracks in the event is compared to its real value :





Missing energy in the 2 hemispheres :





Phys.Rev.Lett.98:141801,2007

$D_s \to \mu \nu$

Tagging

- Fully reconstructed D in 13 hadronic decay modes

- $D^0 \to K^-\pi^+, K^-\pi^+\pi^0, K^-\pi^+\pi^+\pi^-$
- $D^+ \to K^-\pi^+\pi^+(\pi^0), K_S^0\pi^+(\pi^0), K_s^0\pi^+\pi^+\pi^-, K^+K^-\pi^+, K_S^0K^+$
- $D_S^+ \to K_S^0K^+, \Phi\rho^+$
- D^{*+} $D^0\pi^+$, D^0 $K_S^0\pi^+\pi^-(\pi^0), K_S^0K^+K^-, K_S^0\pi^0$

Modes allow identification of the charm quark flavour

- Tag momentum above 2.35 GeV/c to remove D from B decays

Phys.Rev.Lett.98:141801,2007

BABAR

$D_s \to \mu\,\nu$

Background

- Signal is a peak in $\Delta M = M_{Ds*}-M_{Ds}$
- Tagging removes bb, uds, and $\tau\tau$ background, and cc background
- Identify kinematic quantities which distinguish signal
- Fake charm tag from uds, bb, $\tau\tau$, cc → 42 %

  ⇒ Subtracted using the tag sidebands
- Correct tag but μ from charm semi leptonic decay or τ ($\tau \to \mu\nu_\mu\nu_\tau$) → 26 %

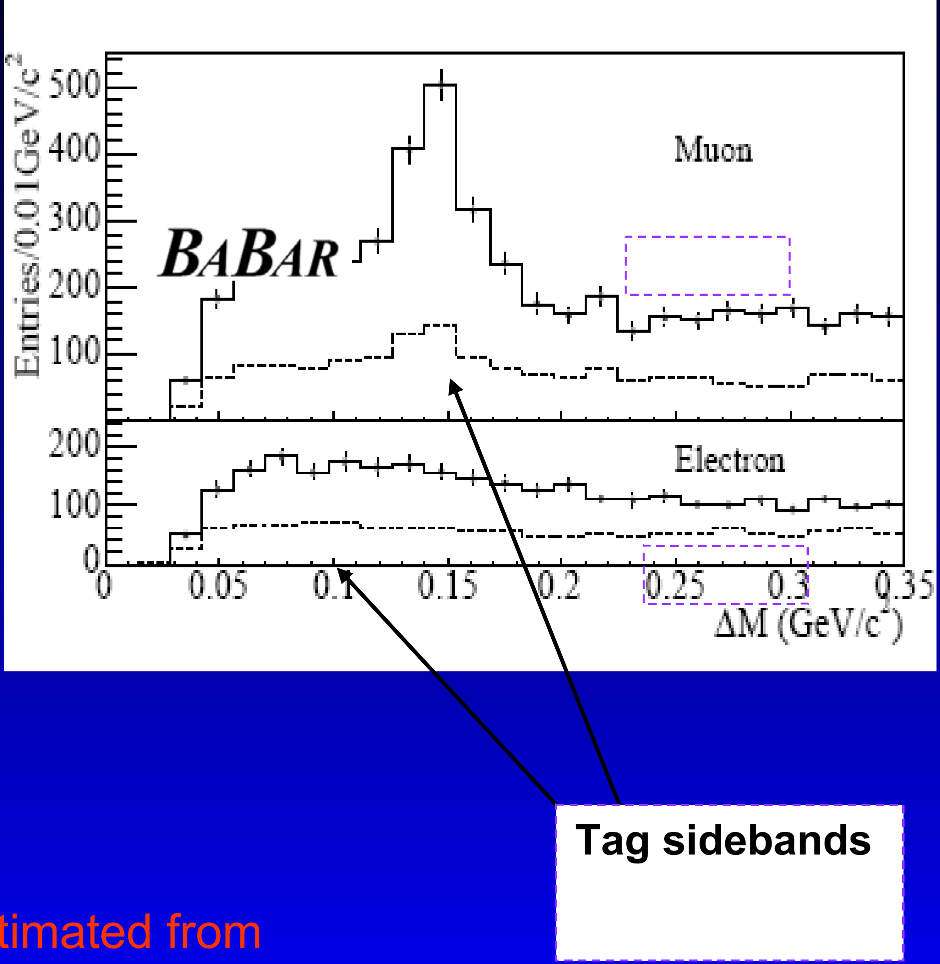
  ⇒ Use electron : same decays appear with an e while there is no $D_s^+ \to e^+\nu$

  ⇒ Take into account differences between μ and e (phase space, Bremsstrahlung, e from conversion)
- Leptonic background

  cc → $D_{(s)}^* \to D_{(s)}\pi^0,\ D_{(s)} \to \mu\nu_\mu$

  cc → $D_{(s)} \to \mu\nu_\mu$
- Combinatoric

Estimated from simulated events

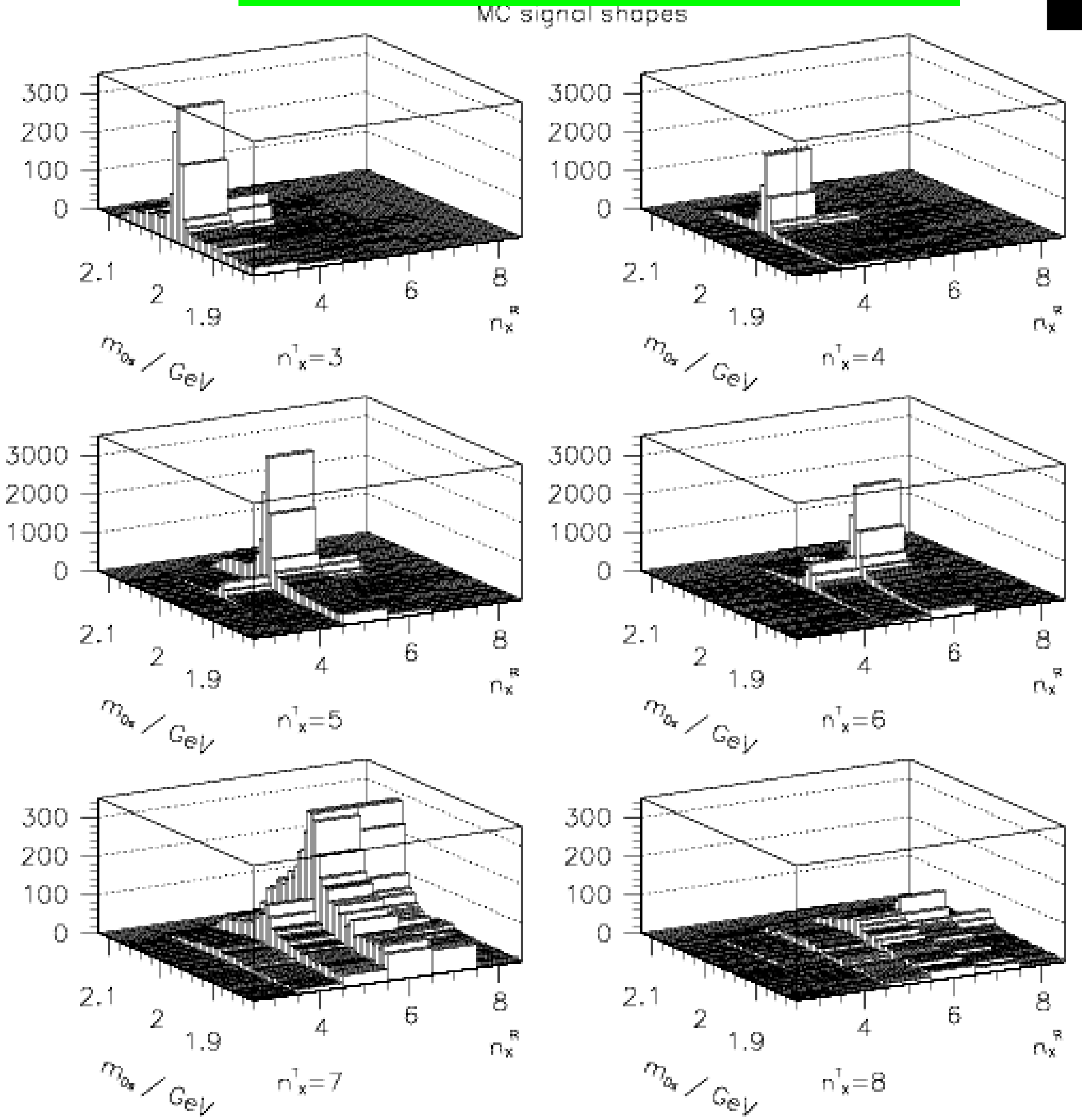


Tag sidebands

BELLE

$D_s \rightarrow \mu \nu$

signal shapes used for fit



WS bkg shapes used for fit

$D_s \to \mu\nu$