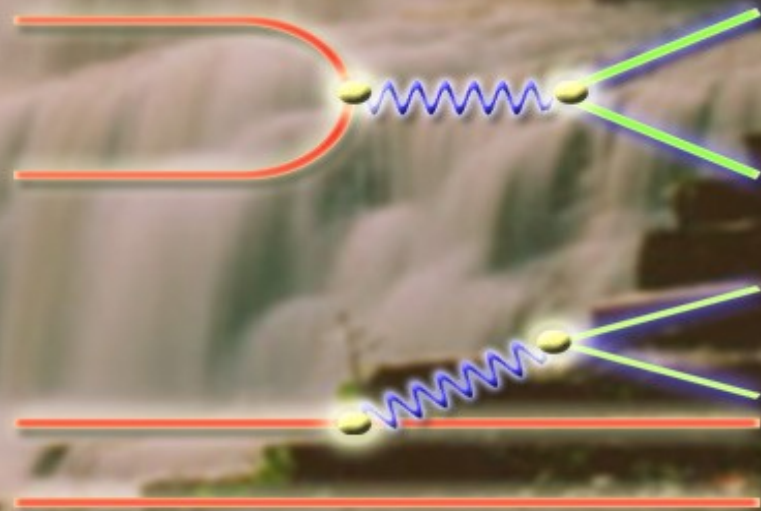


Leptonic & Semileptonic D- and D_s Decays at B-Factories



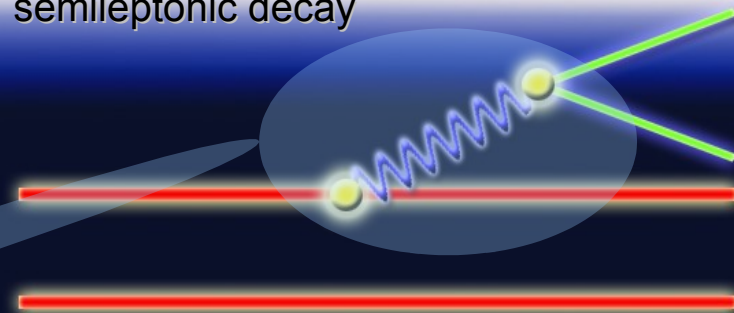
Laurenz Widhalm
HEPHY Vienna
(Belle Collaboration)

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

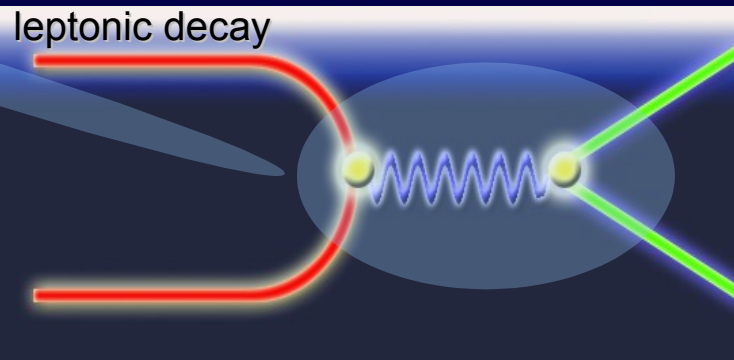
Introduction

leptonic part **easily**
calculable in theory

semileptonic decay



leptonic decay

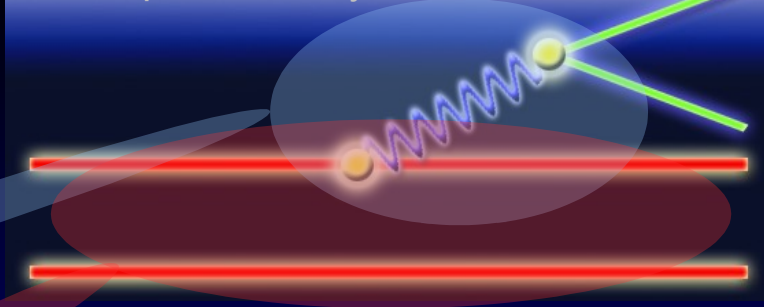


Introduction

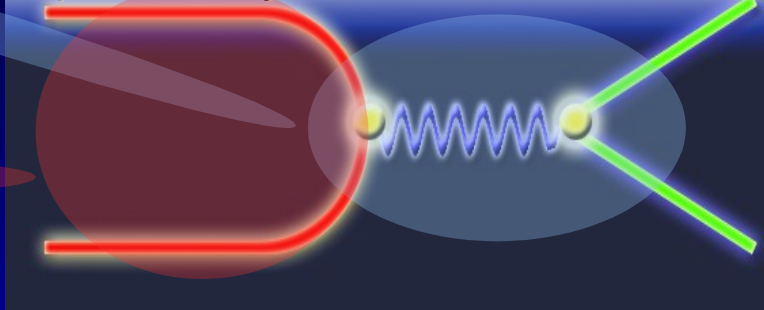
leptonic part **easily calculable** in theory

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

semileptonic decay



leptonic decay



- 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



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

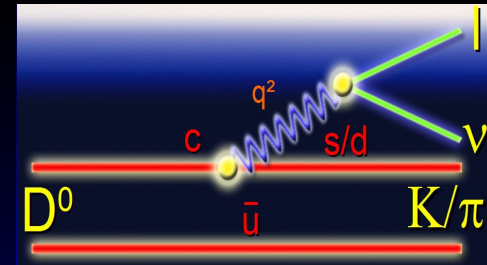
BABAR-PUB-07/015
arXiv:0704.0020 accepted by PRD!



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

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

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



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

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

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

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

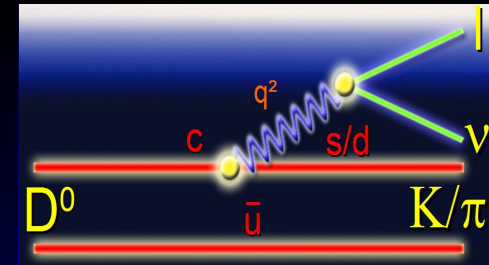
$$\frac{d\Gamma}{dq^2} = \frac{G_f^2 |V_{cq_2}|^2 p_{P'}^3}{24\pi^3} |f_+(q^2)|^2$$

- **various models** that are frequently discussed in literature:

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

- **model-independent:**

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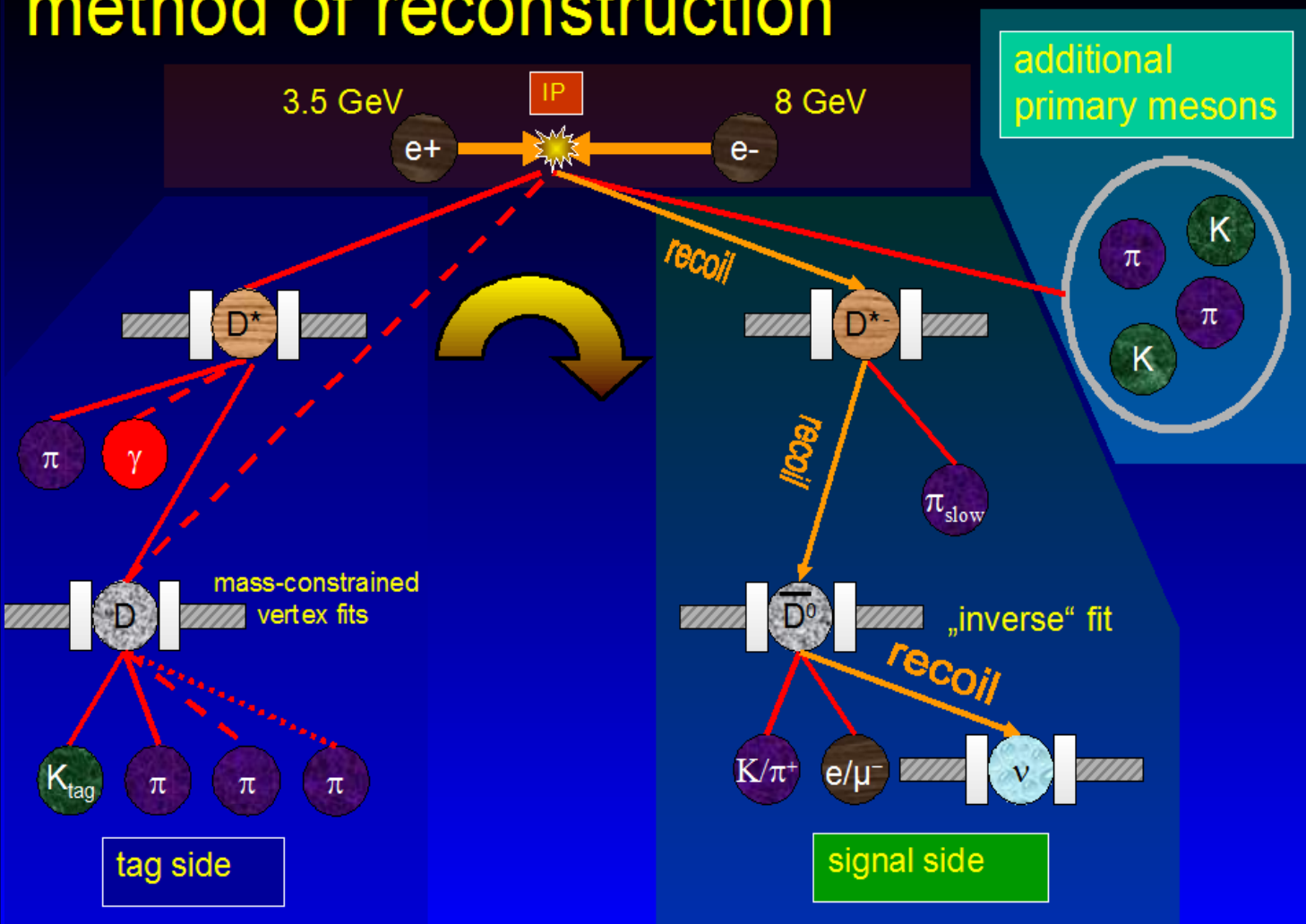


$D^0 \rightarrow K/\pi e/\mu \nu$

tagged, full reconstruction analysis



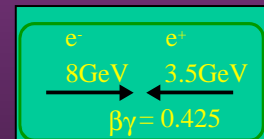
method of reconstruction



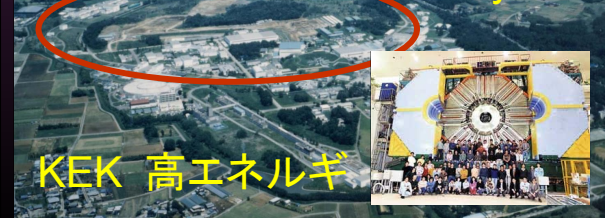
Belle in a nutshell



- 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)



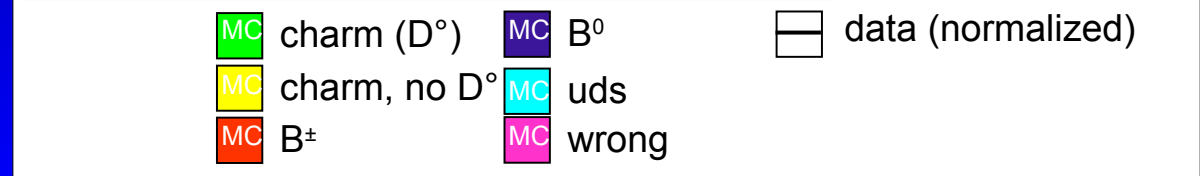
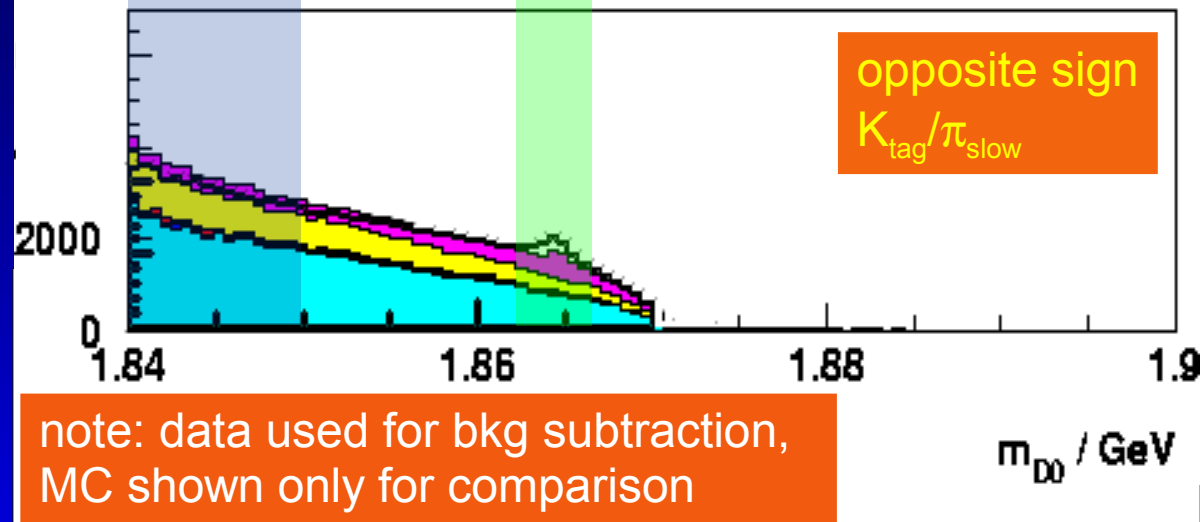
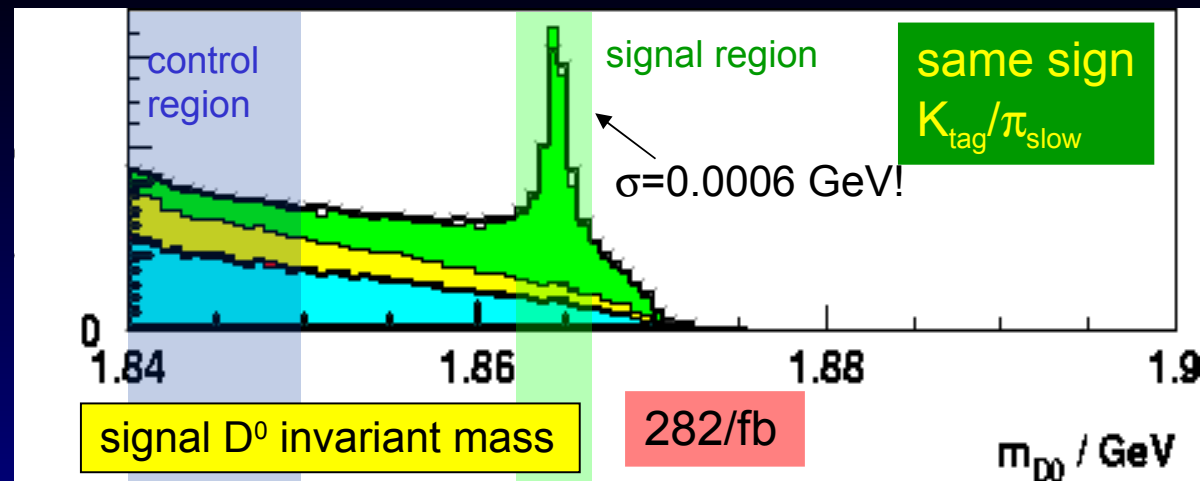
main physics goal: observation of CPV in B meson Decays



D⁰ tags

cuts

- all mass-constr. fits CL > 0.1%
- (released on D⁰ fit for righthand plot)
- same charge $K_{\text{tag}}/\pi_{\text{slow}}$



result

yield

after cuts

95250

background

38789

signal

56461

$\pm 309_{\text{stat}}$

charge correlation
signal subtraction

$\pm 776_{\text{syst}}$

stats bkg sample

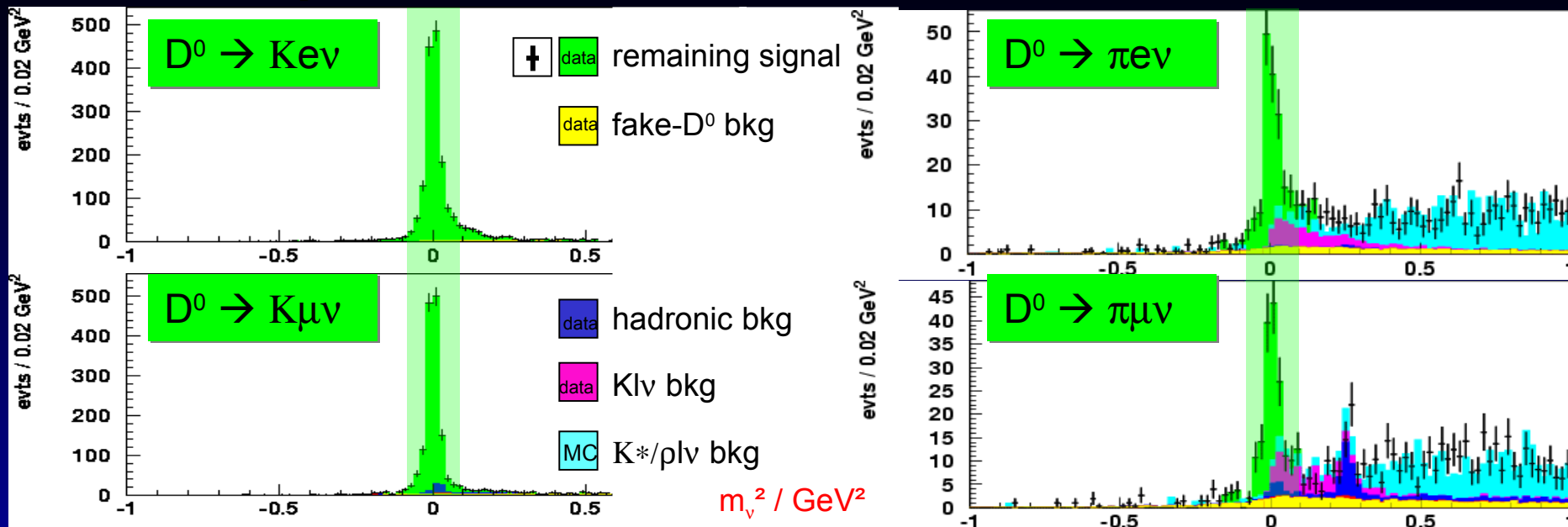
$\pm 233_{\text{syst}}$

$\pm 194_{\text{syst}}$

semileptonic BRs

Phys.Rev.Lett.97:061804,2006

hep-ex/0604049



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

fit results

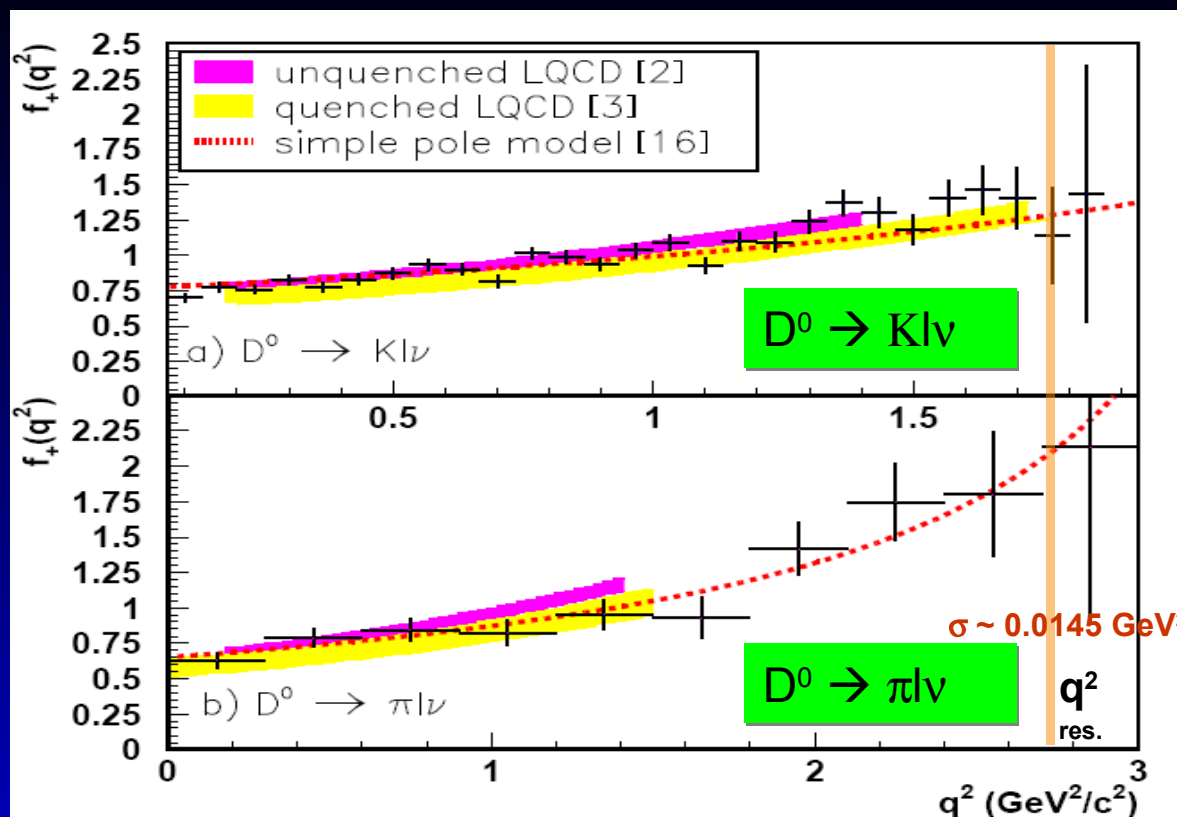
simple pole

	pole mass (GeV)
Klv	$1.82 \pm 0.04_{\text{stat}} \pm 0.03_{\text{syst}}$
πlv	$1.97 \pm 0.08_{\text{stat}} \pm 0.04_{\text{syst}}$

modified pole

(poles fixed at theo. values)

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



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

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

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

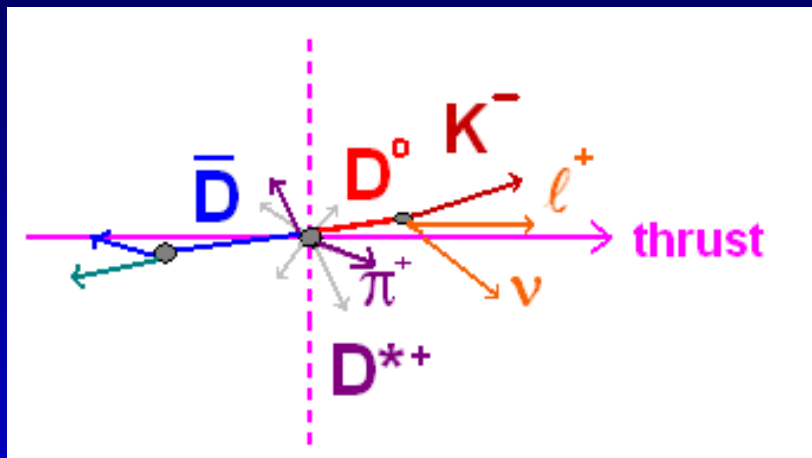
$$\frac{f_+^\pi(0)^2 |V_{cd}|^2}{f_+^K(0)^2 |V_{cs}|^2} = 0.042 \pm 0.003_{\text{stat}} \pm 0.003_{\text{syst}}$$

D⁰ → K e ν

Untagged analysis

- Reconstruct channel $D^{*+} \rightarrow D^0 \pi^+$, $D^0 \rightarrow K^- l^+ \nu$ in $e^+e^- \rightarrow c\bar{c}$ 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, E_{miss} , p_K and p_e



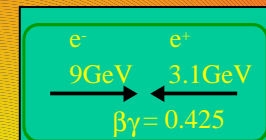
- Reduce the background ← Fisher discriminants ($b\bar{b}$ / $c\bar{c}$ evts)



BaBar in a nutshell

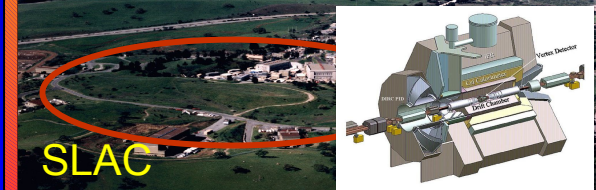


- located at SLAC / USA
- PEP-II Collider



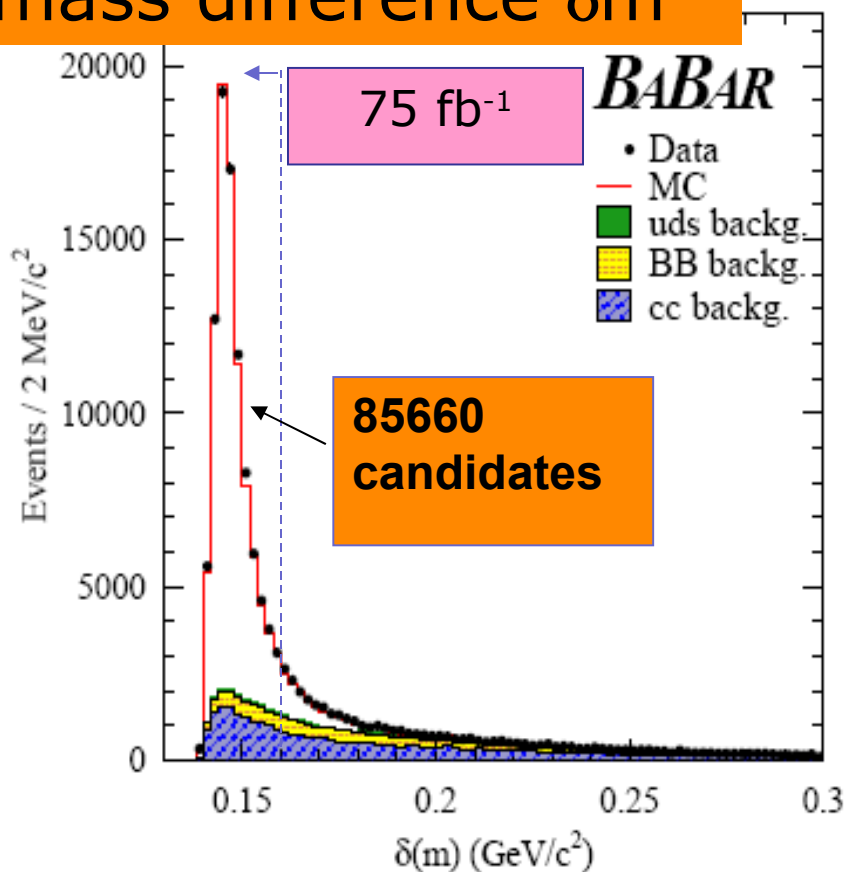
- B-Factory at $\Upsilon(4s)$ resonance
- peak luminosity 12.069 1/nb/s
- integrated luminosity 463 1/fb (as of Jun 2007; only part of it used in presented analyses)

main physics goal: observation of CPV in B meson Decays



signal & control samples

mass difference δm



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

2 control samples:



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



- 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.

branching ratios

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

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

form factors

fit results

z expansion

$$1 + r_1 z + r_2 z^2$$

Kev

$$r_1 = -2.5 \pm 0.2_{\text{stat}} \pm 0.2_{\text{syst}}$$

$$r_2 = 0.6 \pm 6.0_{\text{stat}} \pm 5.0_{\text{syst}}$$

simple pole

pole mass (GeV)

Kev

$$1.884 \pm 0.012_{\text{stat}} \pm 0.015_{\text{syst}}$$

modified pole

(poles fixed at theo. values)

$$f_+(0)$$

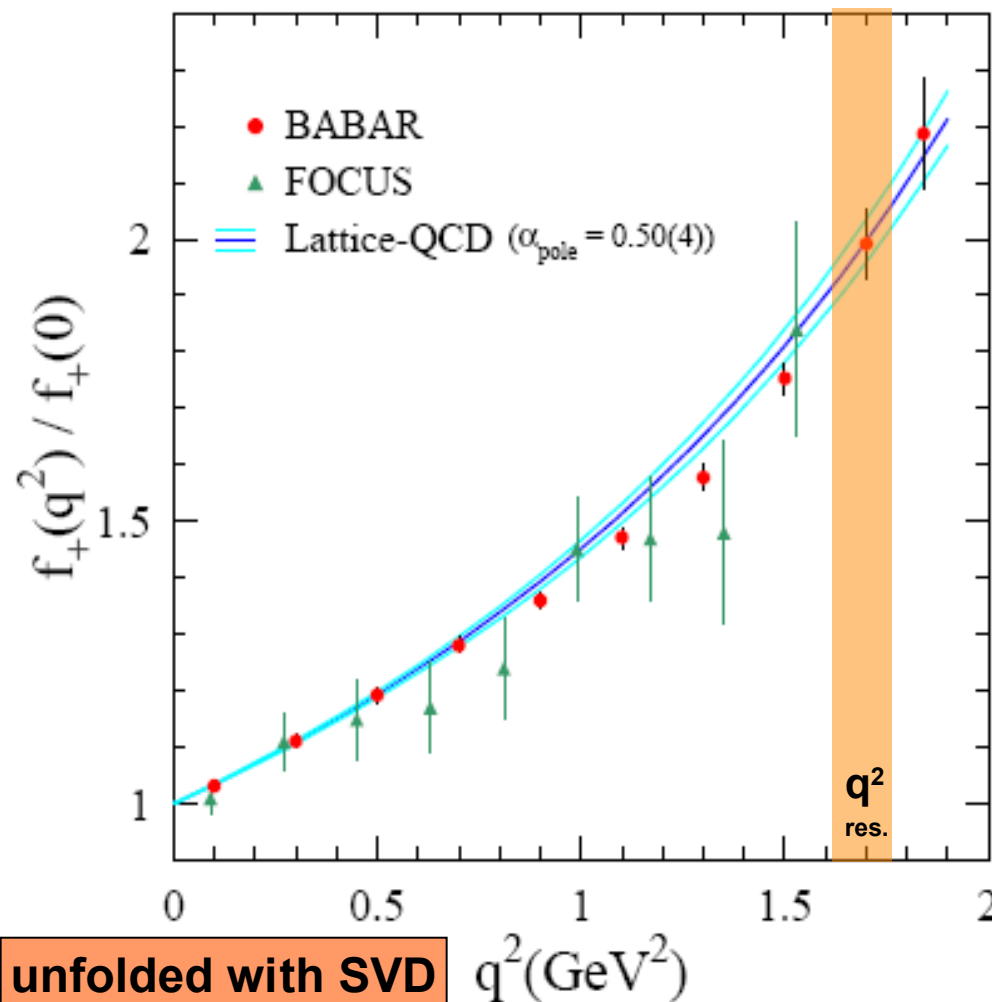
Kev

$$0.727 \pm 0.007_{\text{stat}} \pm 0.005_{\text{syst}} \pm 0.007_{K\pi}$$

$$\alpha$$

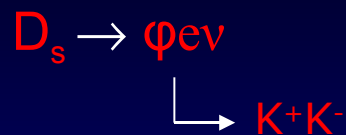
Kev

$$0.377 \pm 0.023_{\text{stat}} \pm 0.029_{\text{syst}}$$



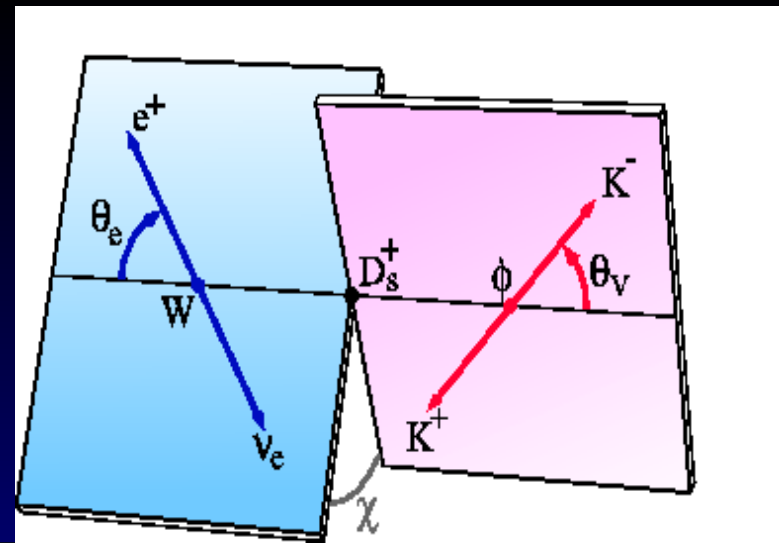
unfolded with SVD

D_s → φ e ν Introduction



4 kinematic variables :
 $q^2, \theta_v, \theta_e, \chi$

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

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

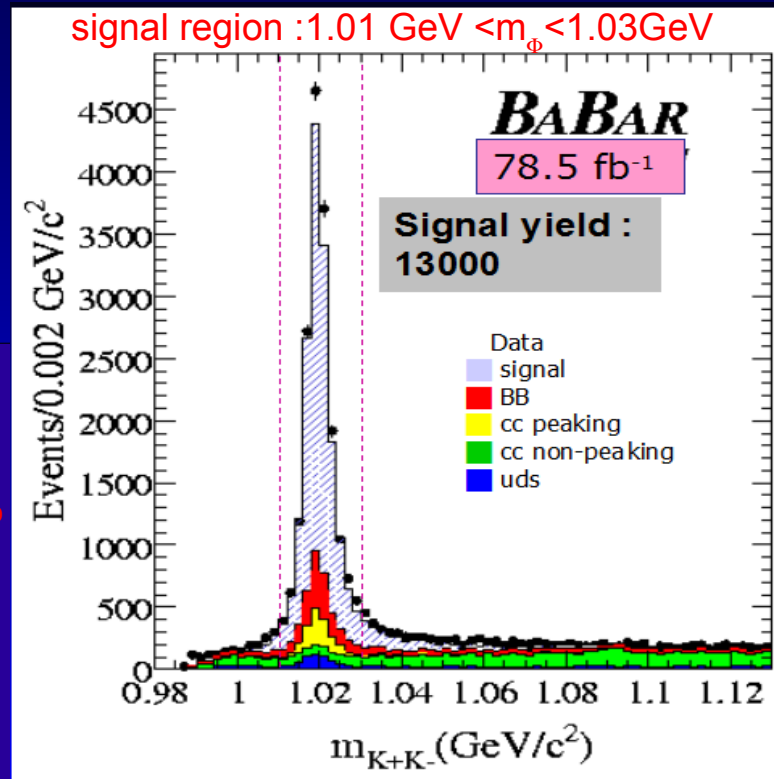
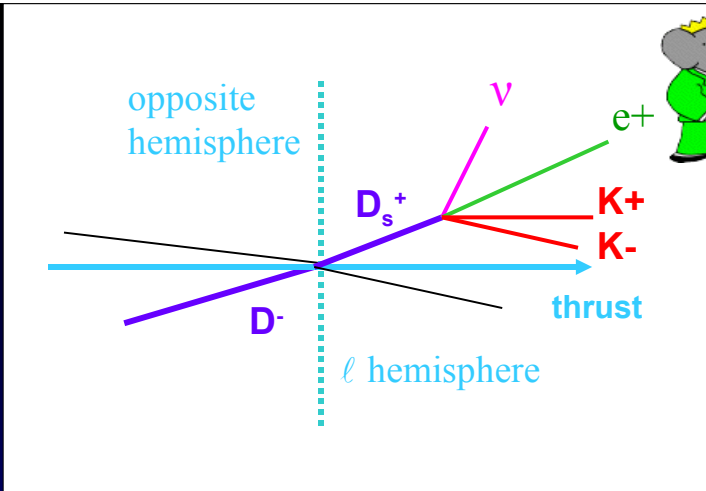
$r_V = V(0)/A_1(0)$ and $r_2 = A_2(0)/A_1(0)$



Event reconstruction

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

- Define 2 hemispheres
take K^+ , K^- , ℓ in the same hemisphere
- Compute D_s direction ($-\mathbf{p}_{\text{all particles} \neq K^+, K^-, \ell}$)
- Compute the missing energy in the ℓ hemisphere
- Fit $\mathbf{p}_{D_s} = \mathbf{p}_{K^+} + \mathbf{p}_{K^-} + \mathbf{p}_{\ell} + \mathbf{p}_{\nu} \rightarrow$ **one constrained fit m_{D_s}**
- Compute kinematic variables : q^2 , θ_{ν} , θ_{ℓ} , χ
- Reduce the background
 \rightarrow **Fisher discriminants**
($b\bar{b}$ and $c\bar{c}$ events)
- control sample $\rightarrow D_s \rightarrow \phi \pi$



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

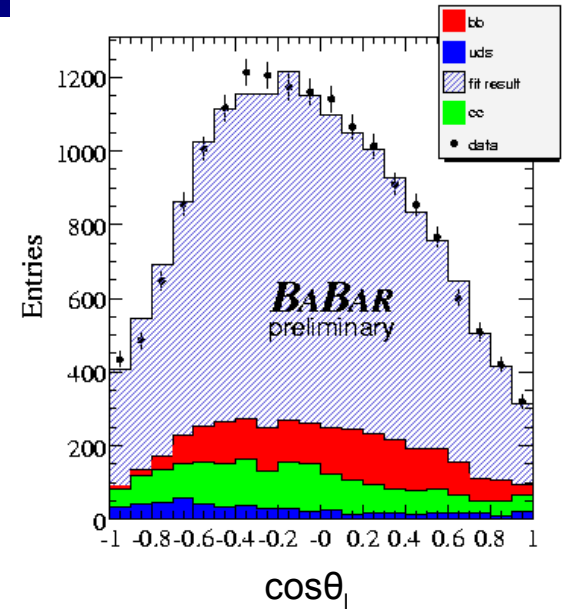
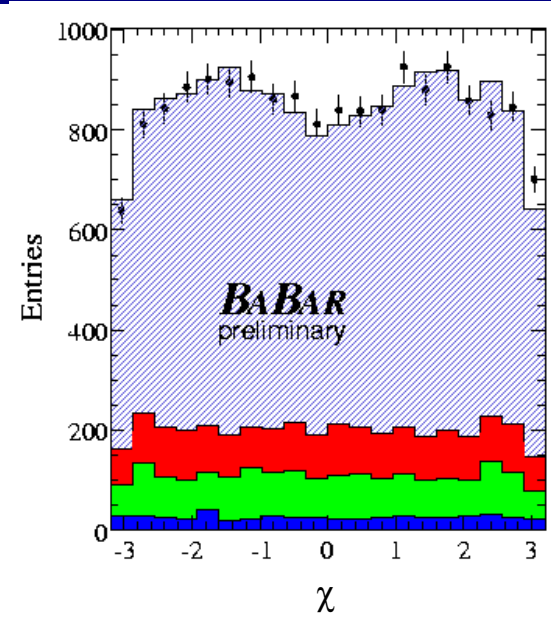
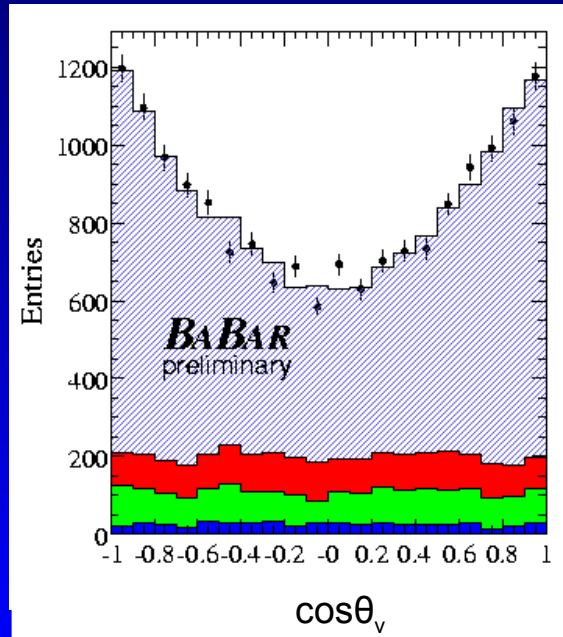
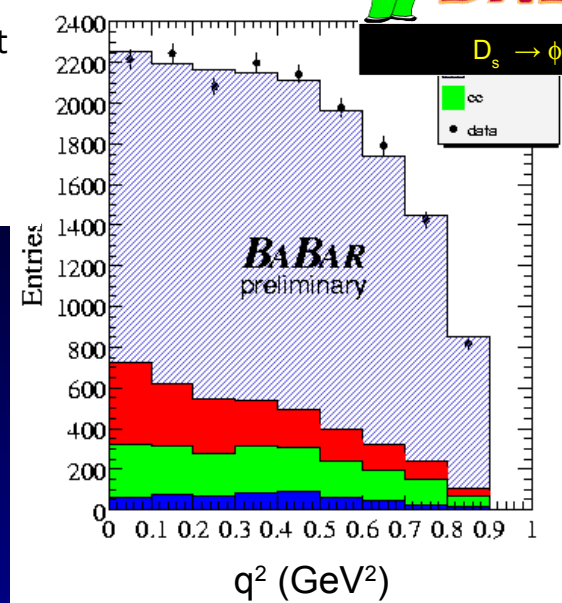
Fitting Procedure

- 5 equal bins for each reconstructed variable
- perform a log-likelihood minimization
- number of bkg events estimated from normalized generic MC (average over $\cos\theta_\nu$ 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



$D_s \rightarrow \phi e \nu$

Data
 fit result
 BB
 CC
 uds

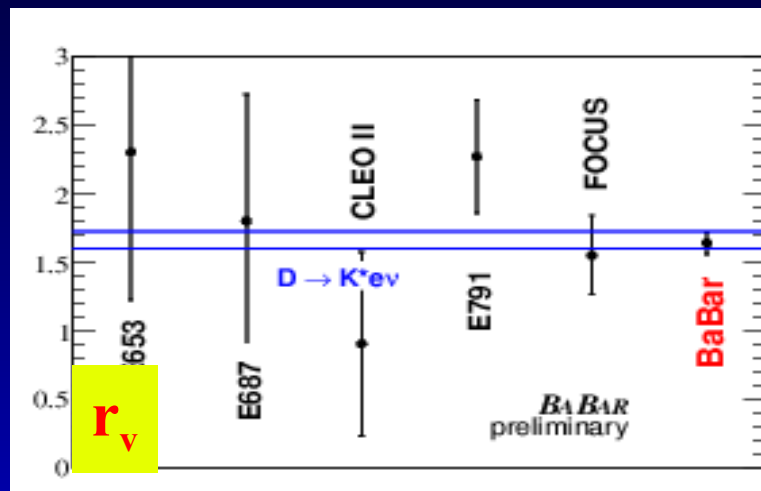
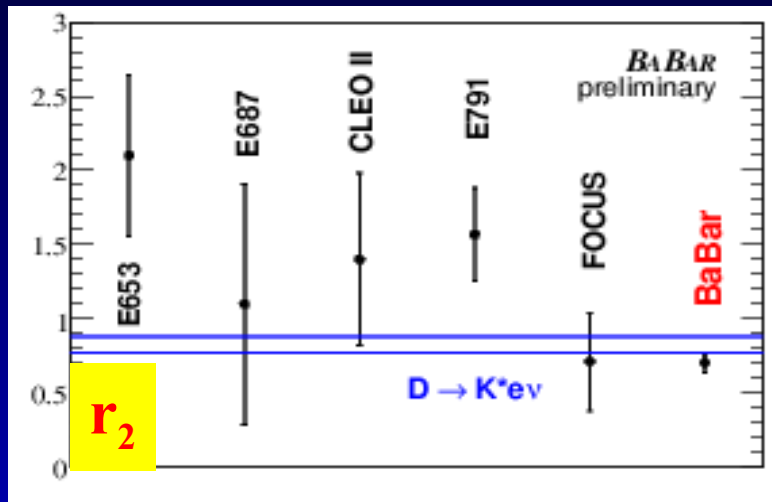


Results

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

$$r_2 = 0.705 \pm 0.056 \pm 0.029$$

$$r_v = 1.636 \pm 0.067 \pm 0.038$$



➔ Same accuracy as $D \rightarrow K^* e \nu$ (FPCP 2006, J.Wiss)

Fixing only the vector pole mass :

$$r_2 = 0.711 \pm 0.111 \pm 0.096$$

$$r_v = 1.633 \pm 0.081 \pm 0.068$$

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

Leptonic Decays



$$D_s \rightarrow \mu \nu$$

Phys.Rev.Lett.98:141801,2007



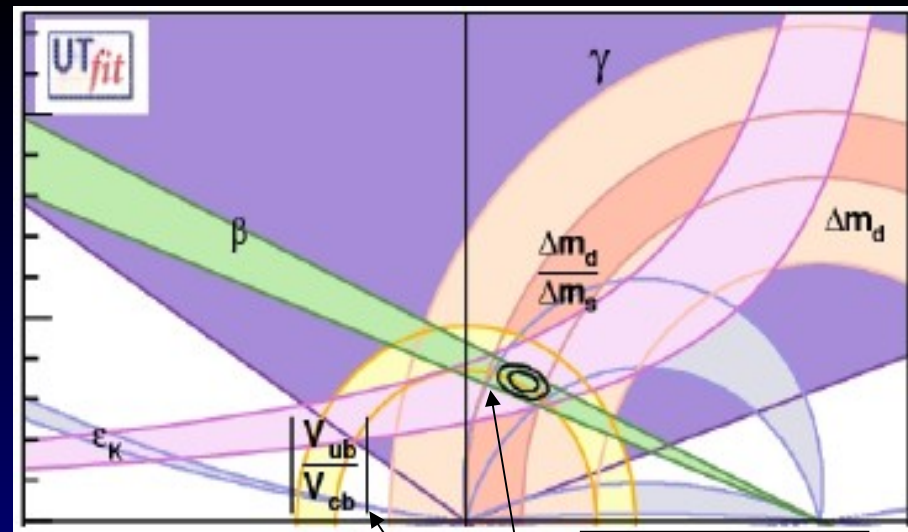
$$D_s \rightarrow \mu \nu$$

preliminary, new 2007 summer result

D_s → μ ν Introduction

Precise knowledge of f_{Bd} and f_{Bs} needed to improve constraints from ΔM_d and ΔM_d/ΔM_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**



theoretical uncertainties

Partial width of M⁺ → l⁺ ν :

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

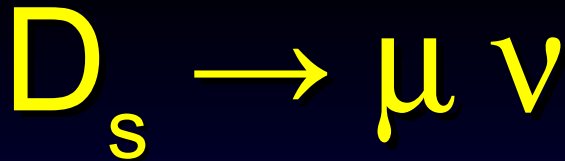
Phase space

CKM Mixing

Helicity Suppression

D_s⁺ → μ⁺ ν is most accessible experimentally :

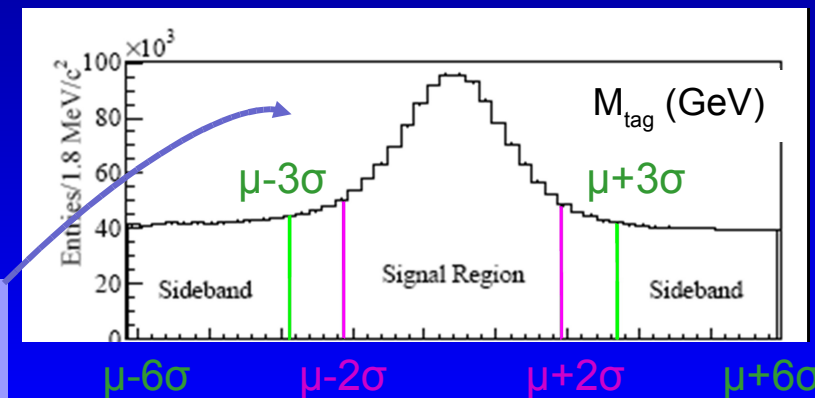
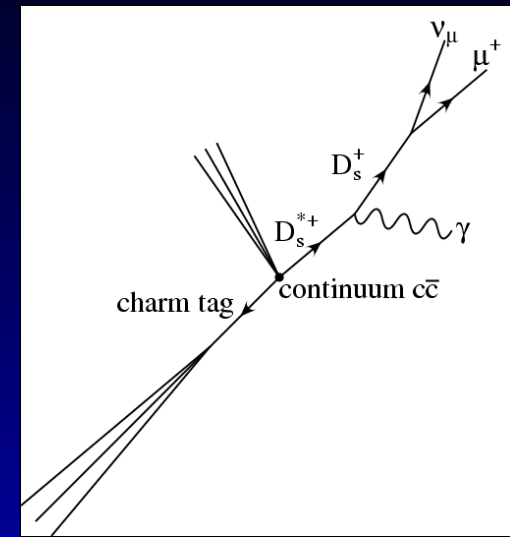
$$\Gamma(D_s^+ \rightarrow \tau^+ \nu_\tau) : \Gamma(D_s^+ \rightarrow \mu^+ \nu_\mu) : \Gamma(D_s^+ \rightarrow e^+ \nu_e) = 10 : 1 : 10^{-5} \quad (\text{BR}(\tau \rightarrow h \nu_\tau) \approx 11\%)$$



tagged, partial
reconstruction
analysis



- 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 \rightarrow muon misidentification by 50%
- Disadvantage
 - Loss in efficiency due to tagging



$5 \cdot 10^5$ 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 $D_s^+ \rightarrow \phi\pi$**

Result :

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

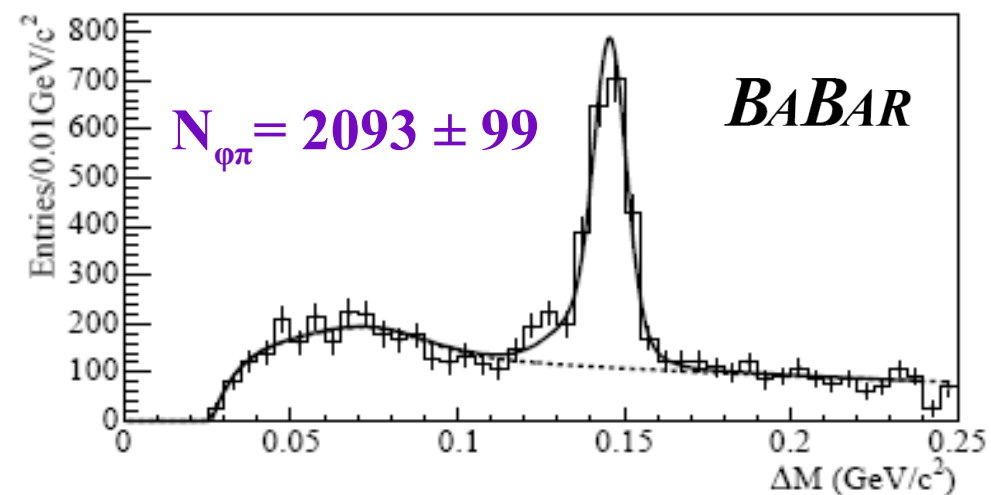
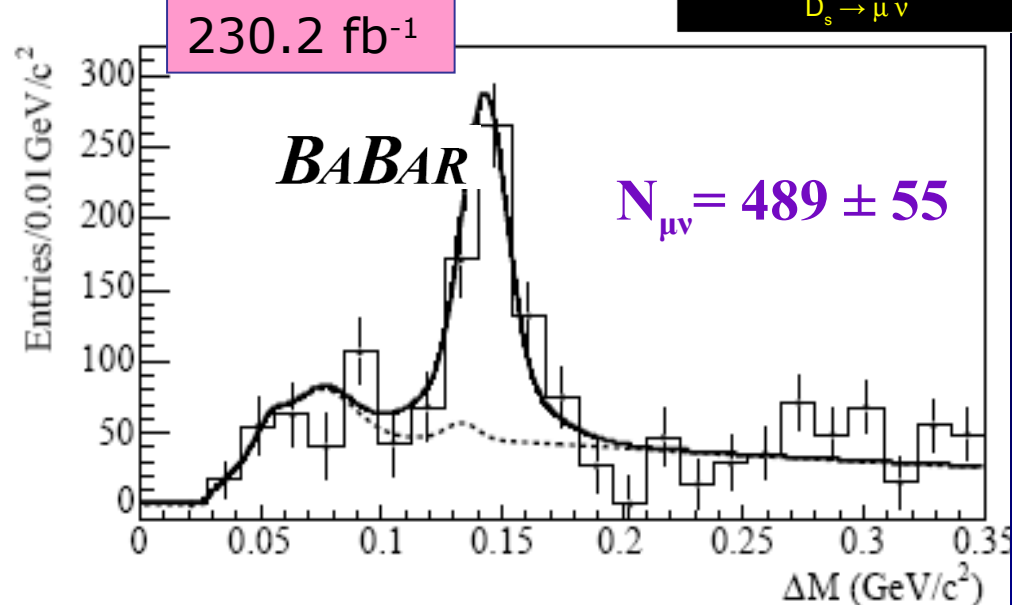
Independent measurement in BaBar :

$$B(D_s^+ \rightarrow \phi\pi) = (4.71 \pm 0.46)\%$$

Phys.Rev.Lett.98:141801,2007



$D_s \rightarrow \mu \nu$



Results

We obtain

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

and

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

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

*Small syst.
uncertainty*

Improvement possible



Using CLEO-c value :

$$f_D = 222.6 \pm 16.7_{\text{stat}}^{+2.8}_{-3.4} \text{ MeV}$$

Phys. Rev. Lett. 95, 251801 (2005)

We obtain

$$f_{D_s} / f_D = 1.27 \pm 0.14 \quad (11\%)$$

Consistent with lattice QCD :

$$f_{D_s} / f_D = 1.24 \pm 0.07 \quad (5.6\%)$$

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

$$D_s \rightarrow \mu \nu$$

new summer 2007 result
preliminary!



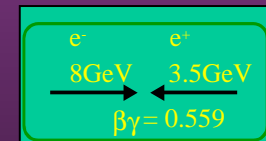
tagged, full
reconstruction
analysis

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

Belle in a
nutshell

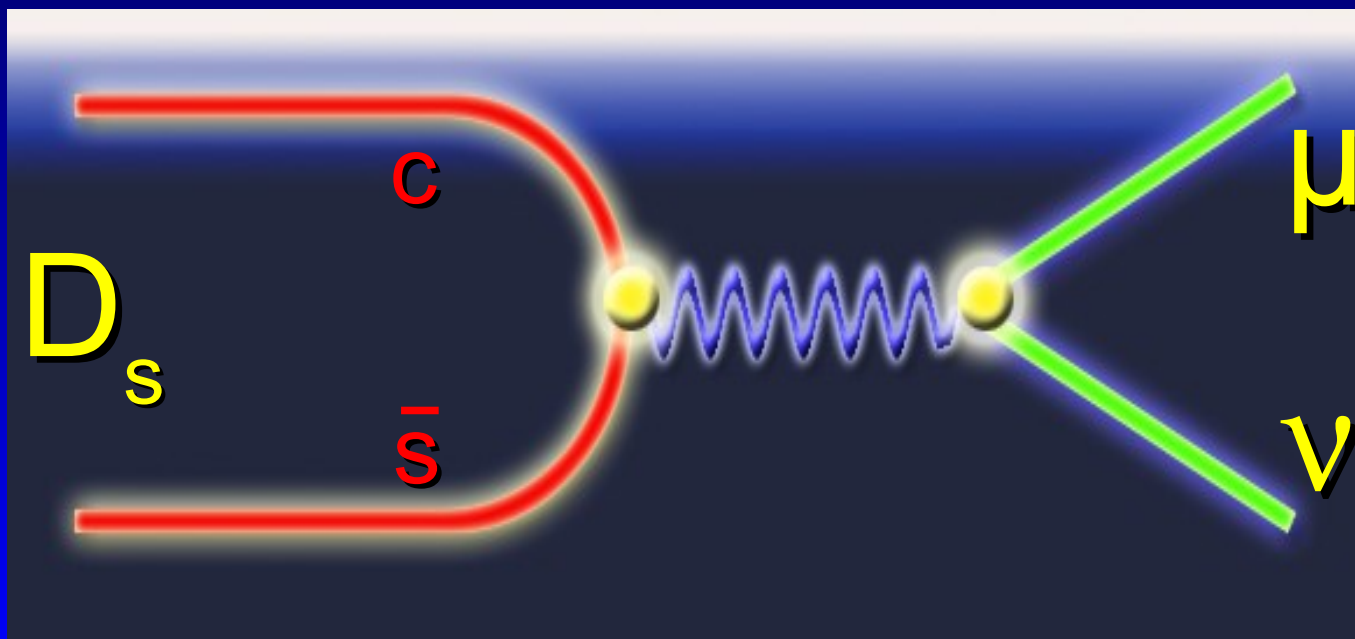
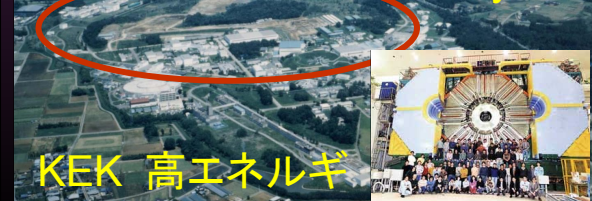


- located at KEK / Japan
- KEKB Collider

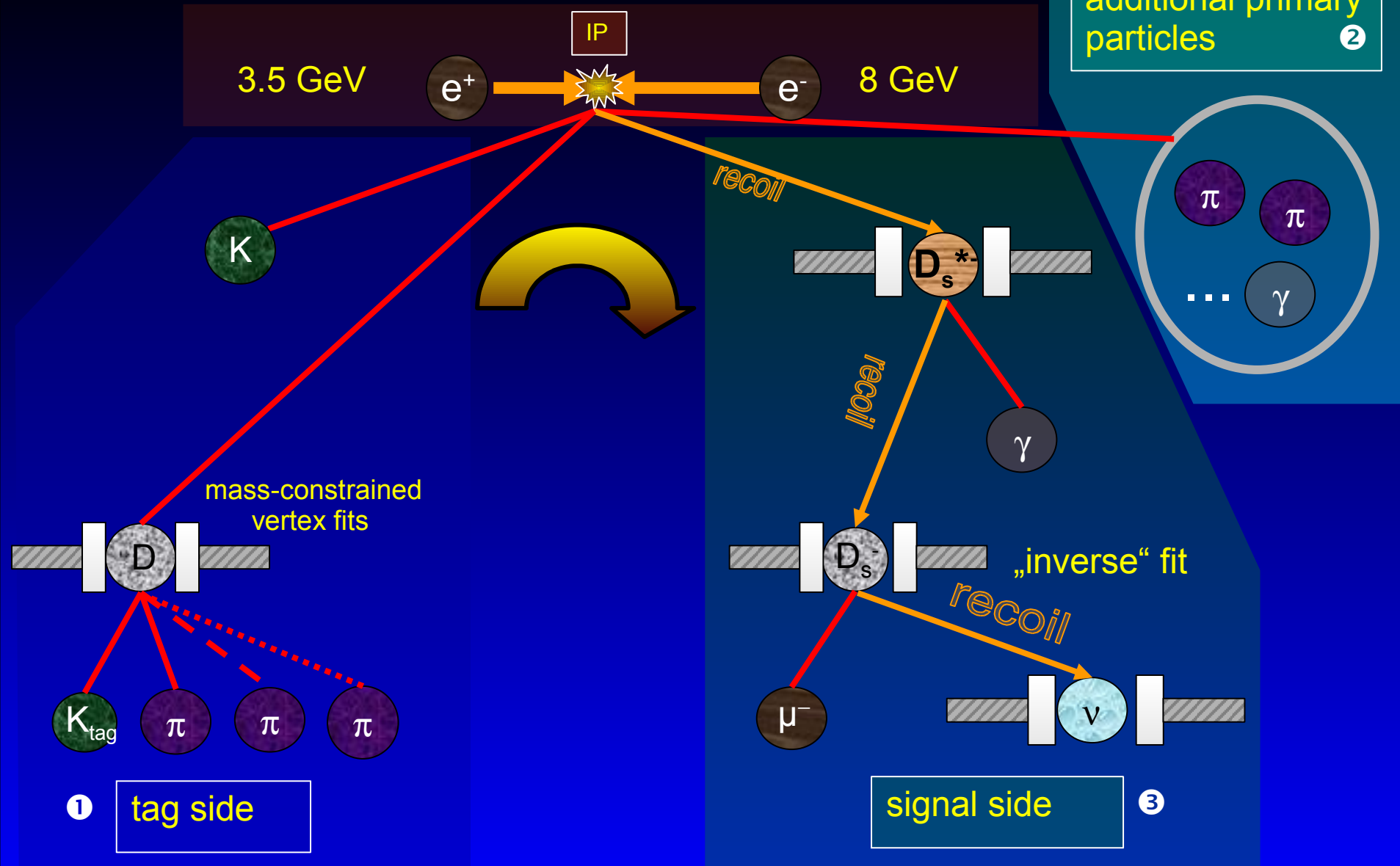


- B-Factory at $\Upsilon(4s)$ resonance
 - peak luminosity 17.118 1/nb/s
 - integrated luminosity 715 1/fb
- (as of Jun 2007; only part of it used in presented analyses)

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

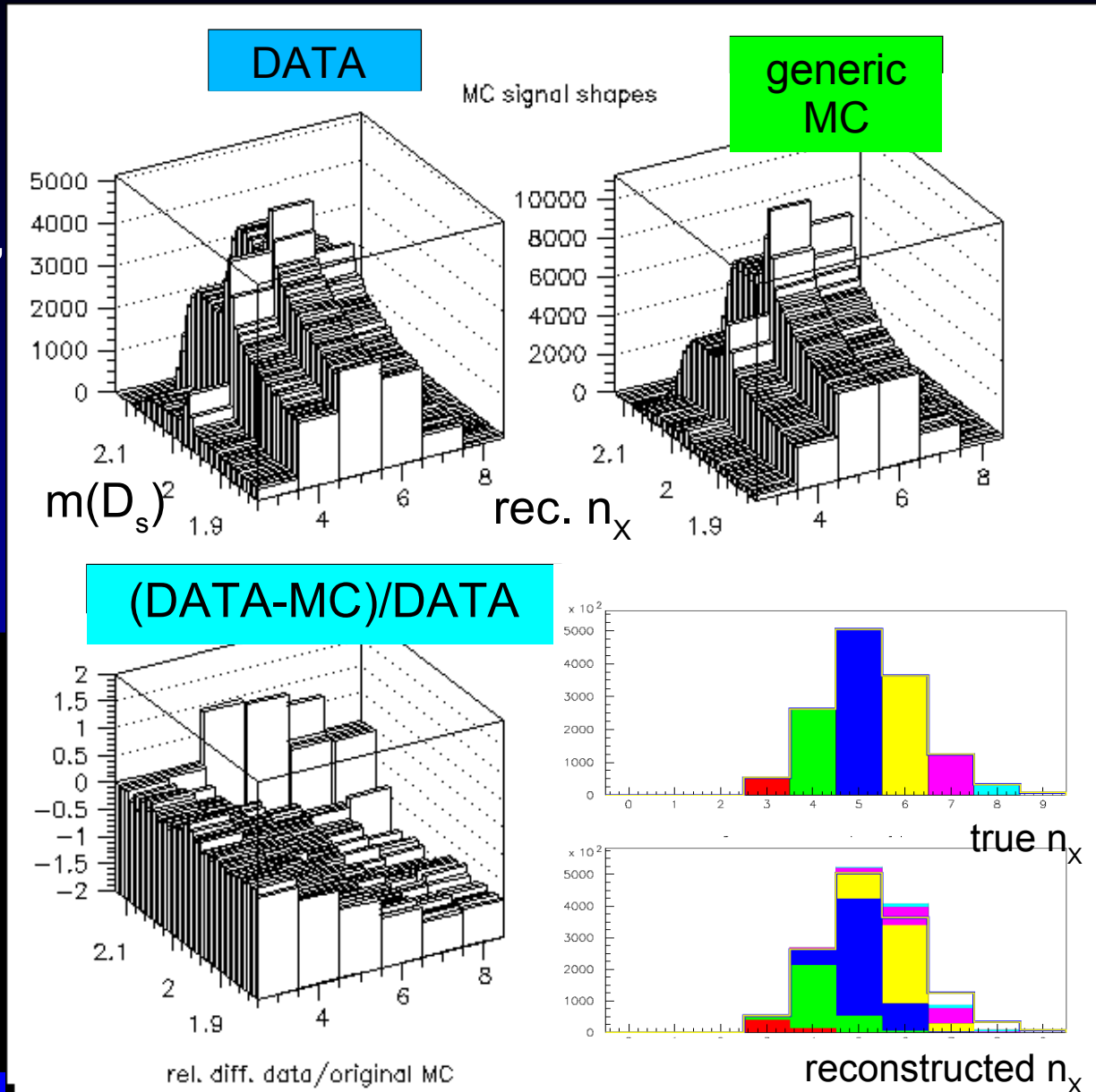
note: the minimal value of n_x is 3 (D, D_s^{*}, K)

Problem:

n_x distribution incorrect in MC and convoluted in reconstruction!

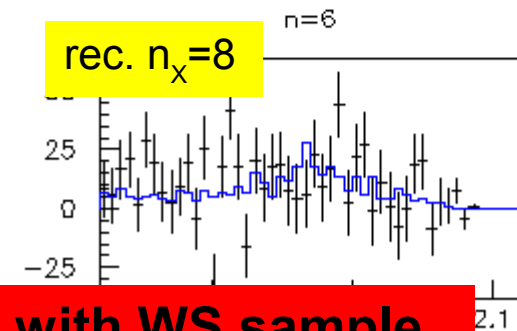
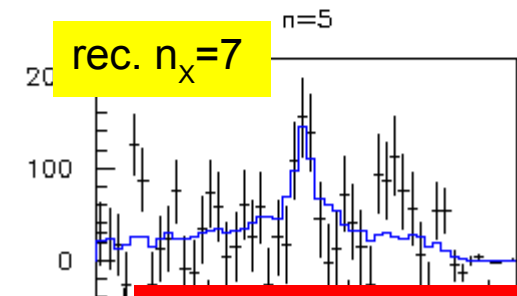
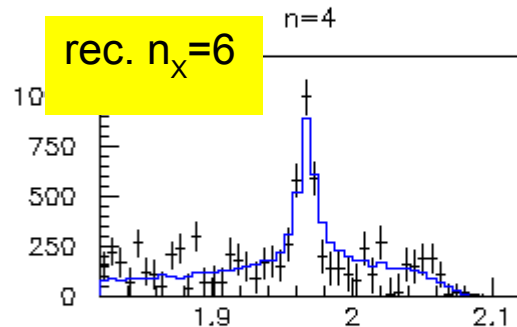
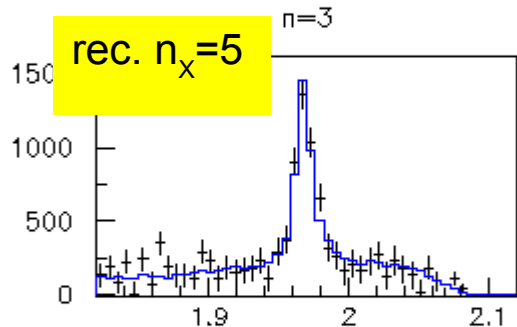
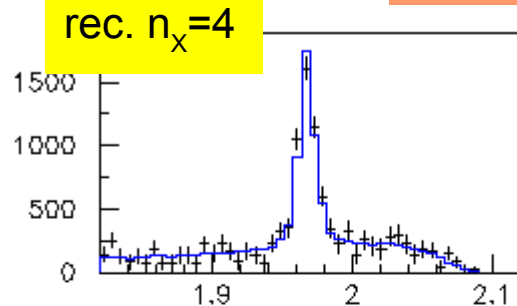
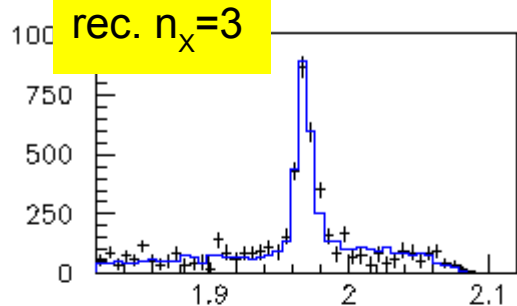
Solution:

fit in bins of true n_x



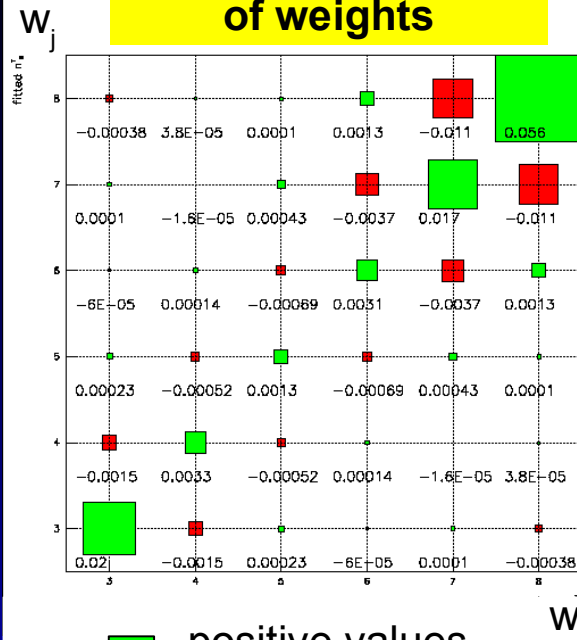
fit of D_s tags

FIT



bkg subtracted with WS sample similar to semileptonic analysis!

correlation matrix of weights



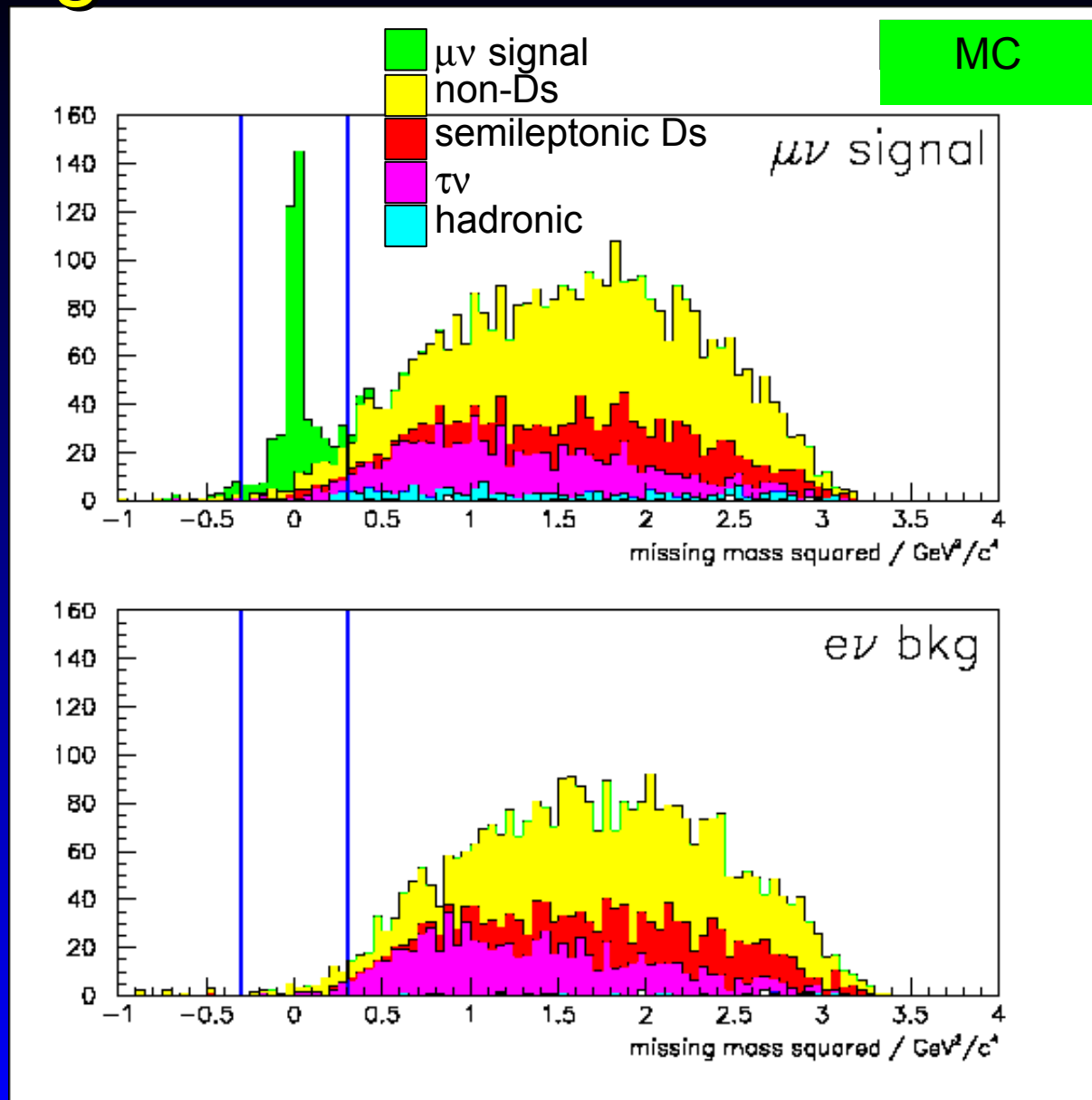
■ positive values
■ negative values

$$N_{D_s}^{\text{rec}} = \sum_{i=1}^6 w_i^{D_s} N_{D_s}^{\text{GMC},i}$$

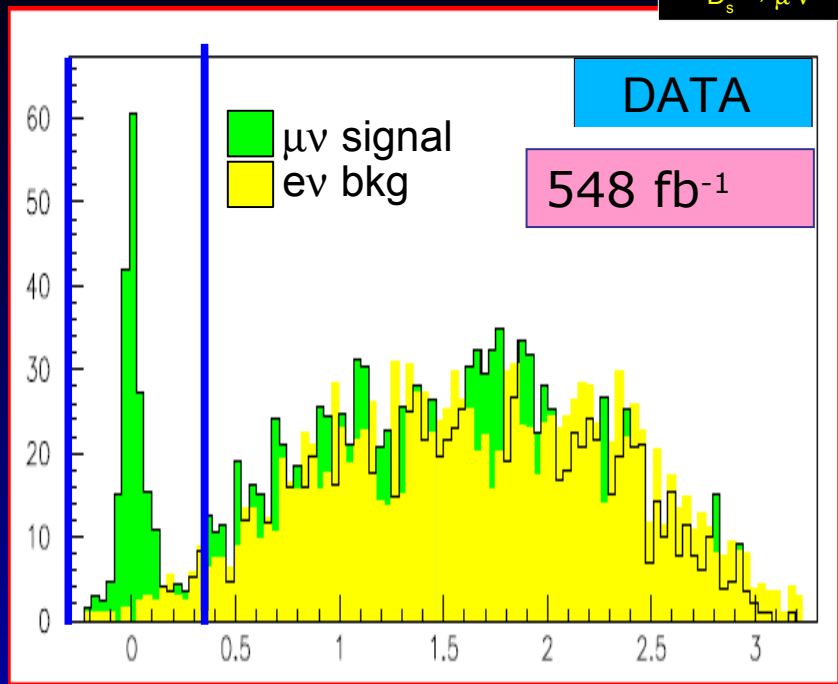
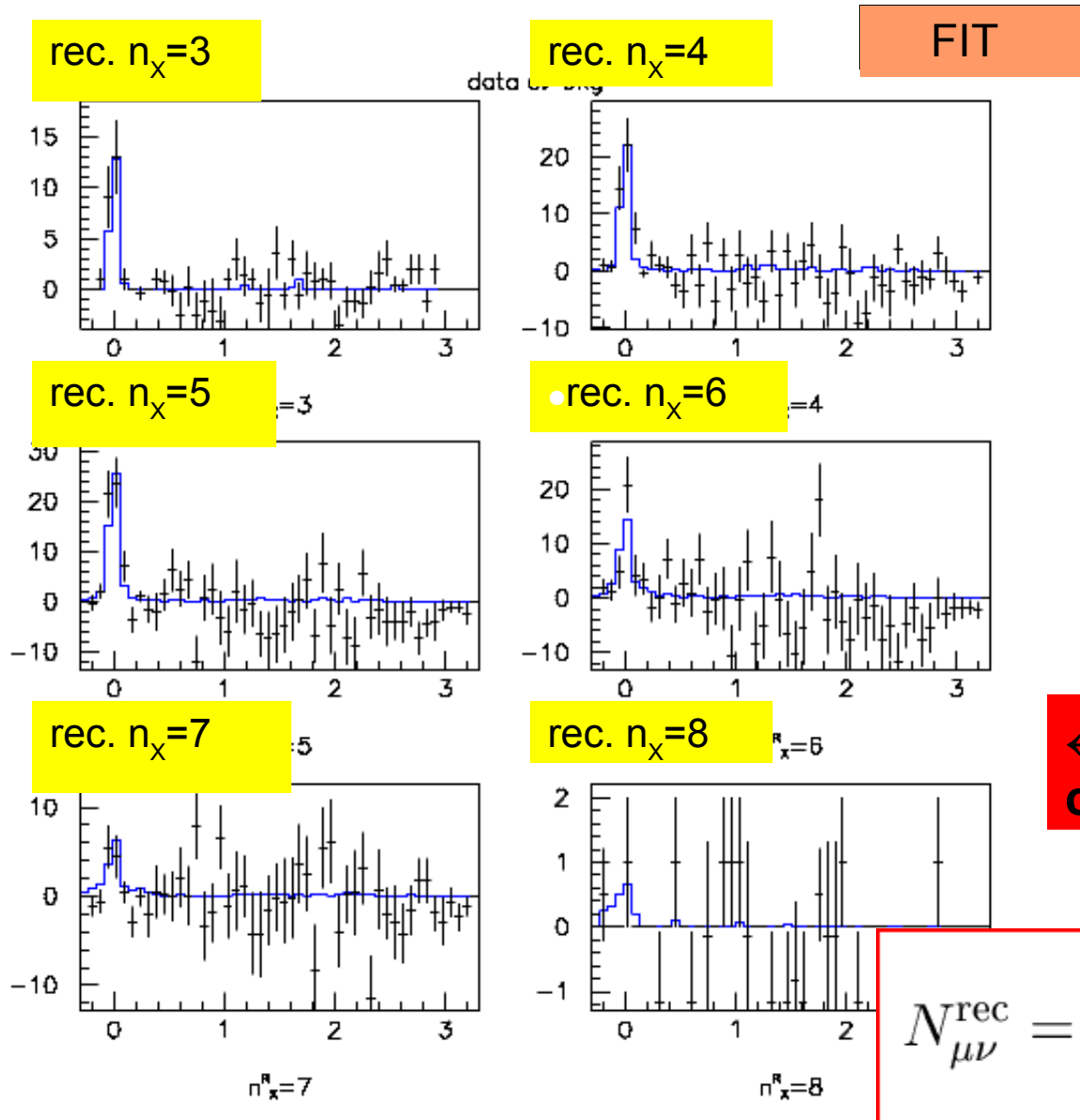
N(D_s tags) =
32100 ± 870_{stat} ± 1210_{syst}

μν signal & background in MC

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



$\mu\nu$ signal yields



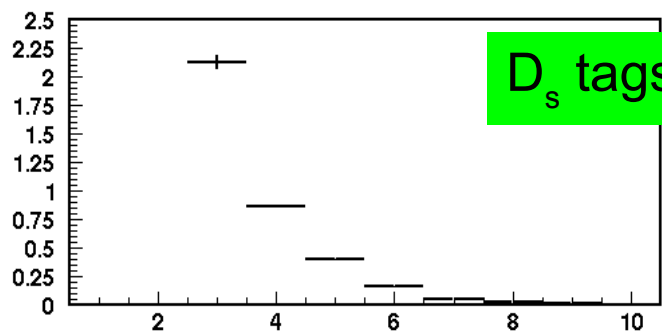
← bkg subtracted using efficiency corrected ev data sample

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

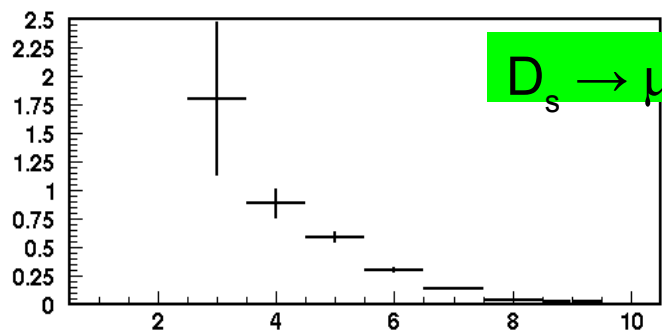
$N(D_s \rightarrow \mu\nu) =$
 $169 \pm 16_{\text{stat}} \pm 8_{\text{syst}}$
 bkg: 30 ± 4

branching ratio & decay constant

efficiency (%)



D_s tags

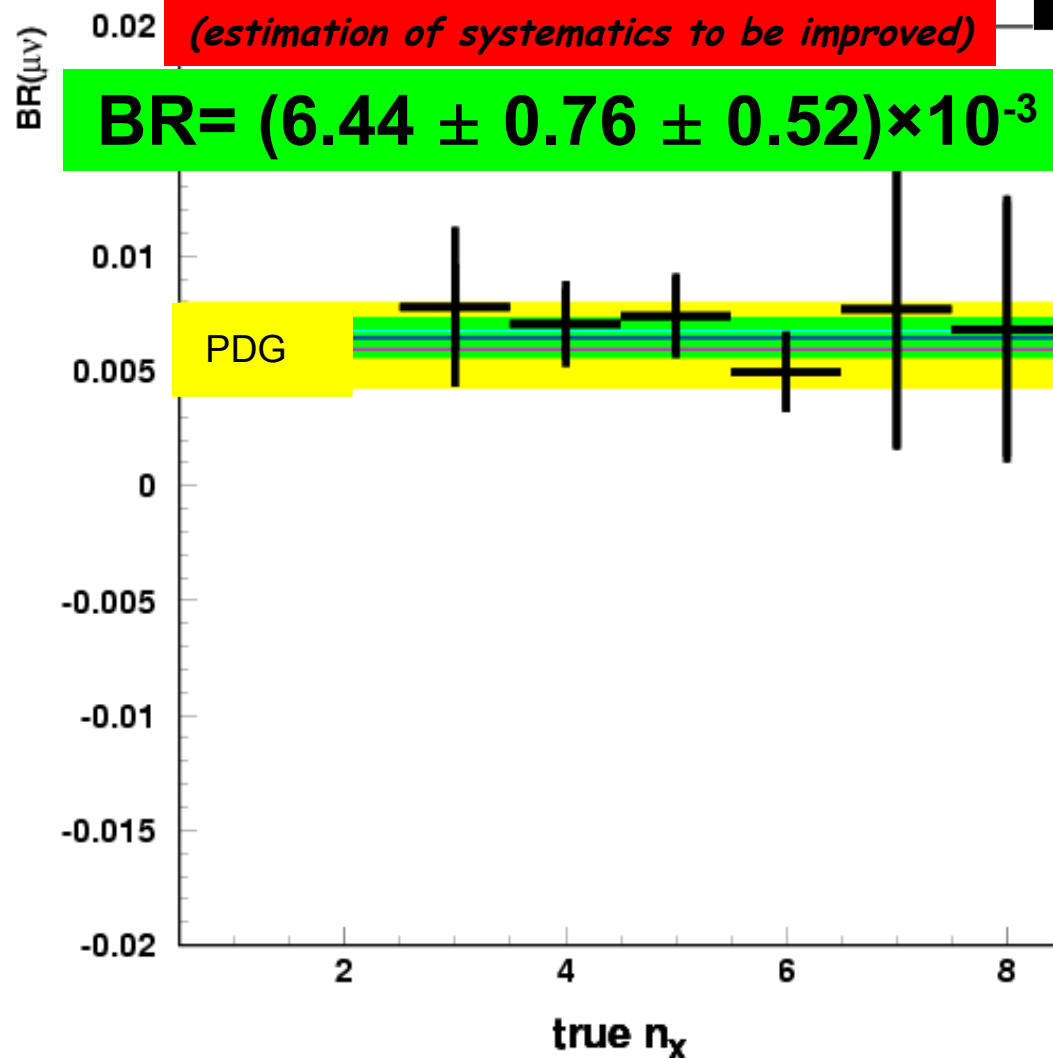


D_s → μν

preliminary




(estimation of systematics to be improved)

BR = (6.44 ± 0.76 ± 0.52) × 10⁻³



f_{D_s} = 275 ± 16_{stat} ± 12_{syst} MeV
(using V_{cs} = 0.9730 from PDG overall fit)

Overview of Results

-  diff. < 1σ
-  1σ < diff. < 2σ
-  diff. > 2σ

theory

D⁰ → K/π e/μ ν

BRs K⁻e⁺ν
K⁻μ⁺ν
π⁻e⁺ν
π⁻μ⁺ν

FF

r₁
r₂

2.112 (D_s^{*})

m_{pole}(K)

2.010 (D^{*})

m_{pole}(π)

0.50 ± 0.04

α(K)

0.44 ± 0.04

α(π)

0.73(3)(7)

f₊(0,K)

0.64(3)(6)

f₊(0,π)



3.522 ± 0.027_{stat} ± 0.045_{syst} ± 0.065_{Kπ} 

-2.5 ± 0.2_{stat} ± 0.2_{syst}

0.6 ± 6.0_{stat} ± 5.0_{syst}

1.884 ± 0.012_{stat} ± 0.015_{syst} GeV 

0.377 ± 0.023_{stat} ± 0.029_{syst} 

0.727 ± 0.007_{stat} ± 0.005_{syst} ± 0.007_{Kπ} 



3.45 ± 0.10_{stat} ± 0.19_{syst}

3.45 ± 0.10_{stat} ± 0.21_{syst}

0.279 ± 0.027_{stat} ± 0.016_{syst}

0.231 ± 0.026_{stat} ± 0.019_{syst}

1.82 ± 0.04_{stat} ± 0.03_{syst} GeV

1.97 ± 0.08_{stat} ± 0.04_{syst} GeV




0.52 ± 0.08_{stat} ± 0.06_{syst}

0.10 ± 0.21_{stat} ± 0.10_{syst}

0.695 ± 0.007_{stat} ± 0.022_{syst}

0.624 ± 0.020_{stat} ± 0.030_{syst}

Overview of Results

-  diff. < 1σ
-  1σ < diff. < 2σ
-  diff. > 2σ

theory

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

fixing m_A & m_V

r_2

$$0.705 \pm 0.056 \pm 0.029$$

r_V

$$1.636 \pm 0.067 \pm 0.038$$

fixing only m_V

r_2

$$0.711 \pm 0.111 \pm 0.096$$

r_V

$$1.633 \pm 0.081 \pm 0.068$$

m_A

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

$$D_s \rightarrow \mu \nu$$

BR $\times 10^3$

249 \pm 3 \pm 16

f_{D_s}

$$6.74 \pm 0.83 \pm 0.26 \pm 0.66$$

$$283 \pm 17 \pm 7 \pm 14 \text{ MeV}$$

$$6.44 \pm 0.76 \pm 0.52$$

$$275 \pm 16 \pm 12 \text{ MeV}$$



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!

Laurenz Widhalm, HEPHY Vienna (Belle Collab.)

Leptonic & semileptonic D / D_s decays
at B-factories  

Charm 2007

Spare

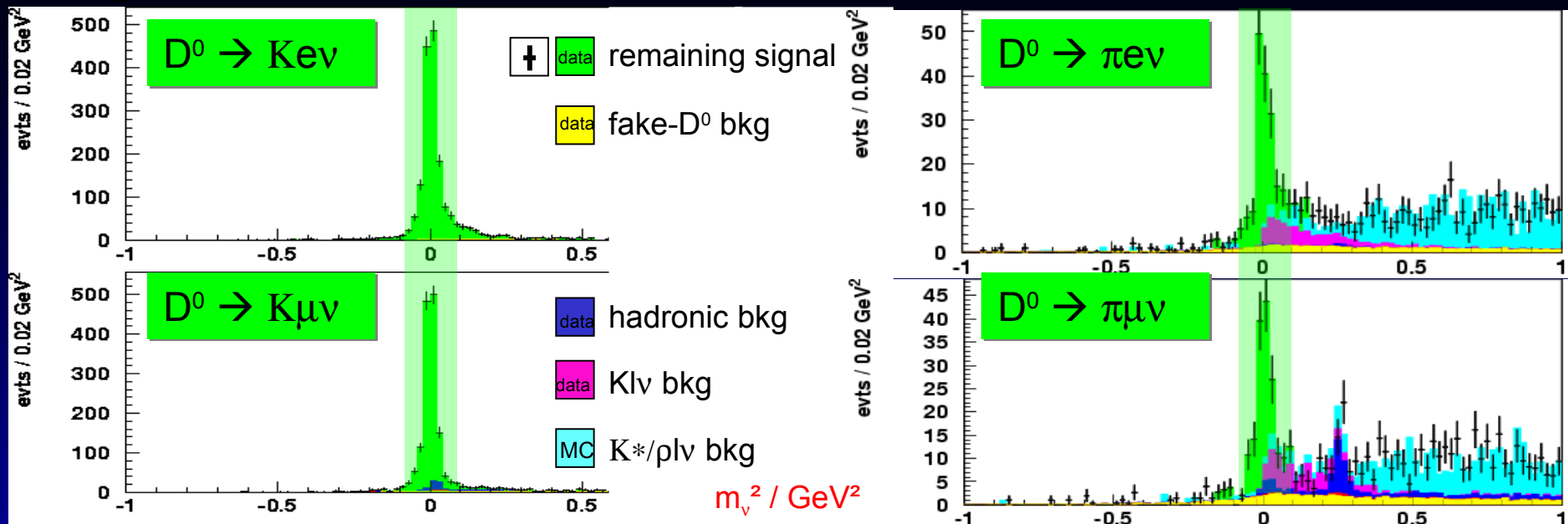
signal

Phys.Rev.Lett.97:061804,2006

hep-ex/0604049



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



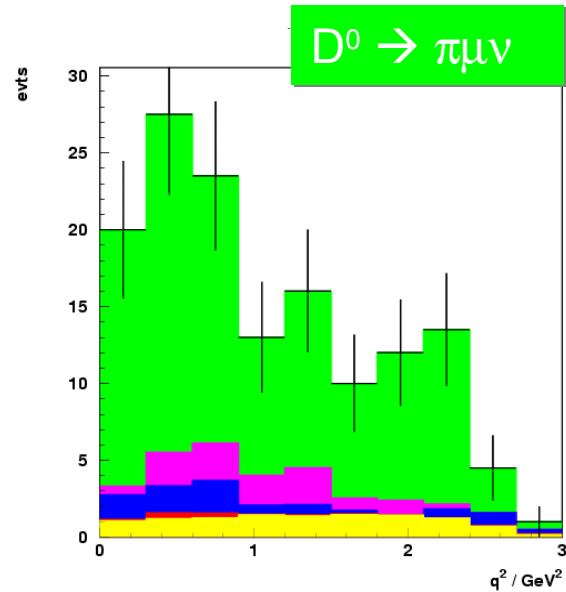
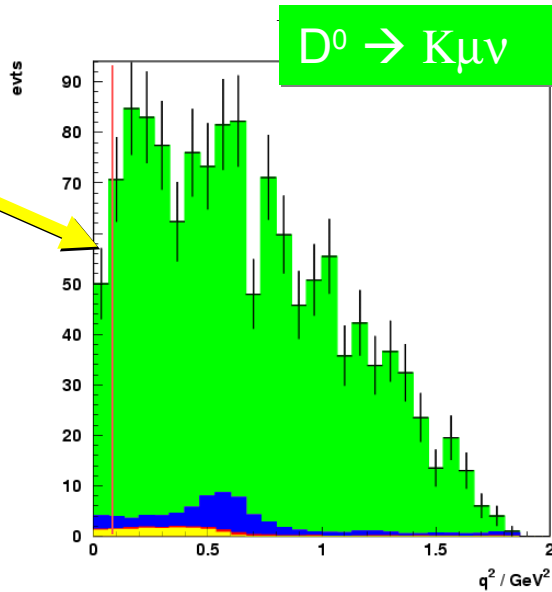
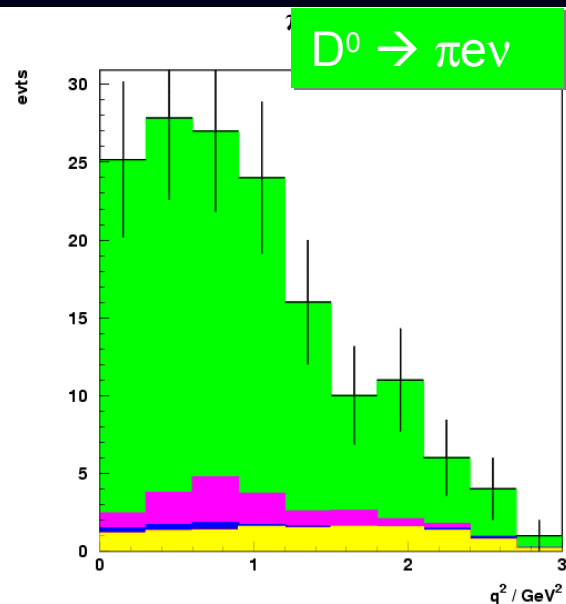
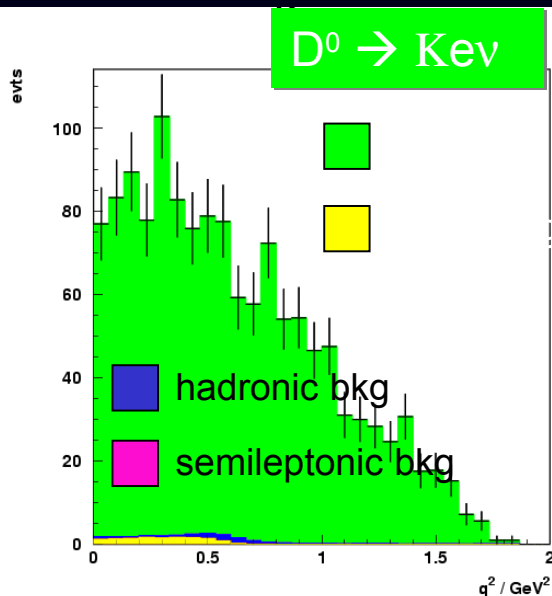
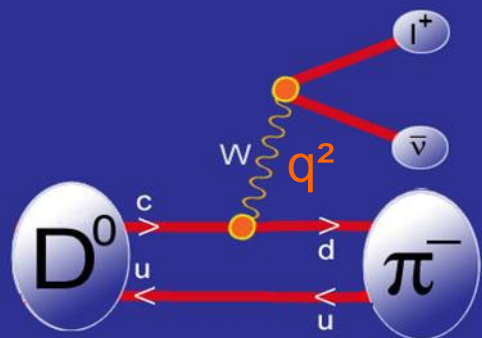
Results (282 fb ⁻¹ of BELLE data)	K e ν	K μ ν	π e ν	π μ ν
signal events	1318 ± 37 _{stat} ± 7 _{syst}	1249 ± 37 _{stat} ± 25 _{syst}	126 ± 12 _{stat} ± 3 _{syst}	106 ± 12 _{stat} ± 6 _{syst}
fake D ⁰ bkg	12.6 ± 2.2	12.2 ± 4.8	12.3 ± 2.2	12.5 ± 4.5
semileptonic bkg*	6.7 ± 2.6	10.0 ± 2.5	11.7 ± 1.2	12.6 ± 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 – q^2 distribution



$\sigma(q^2) = 0.0145 \text{ GeV}^2/c^2$
(width of red line)
→ no unfolding necessary!

background shapes from data

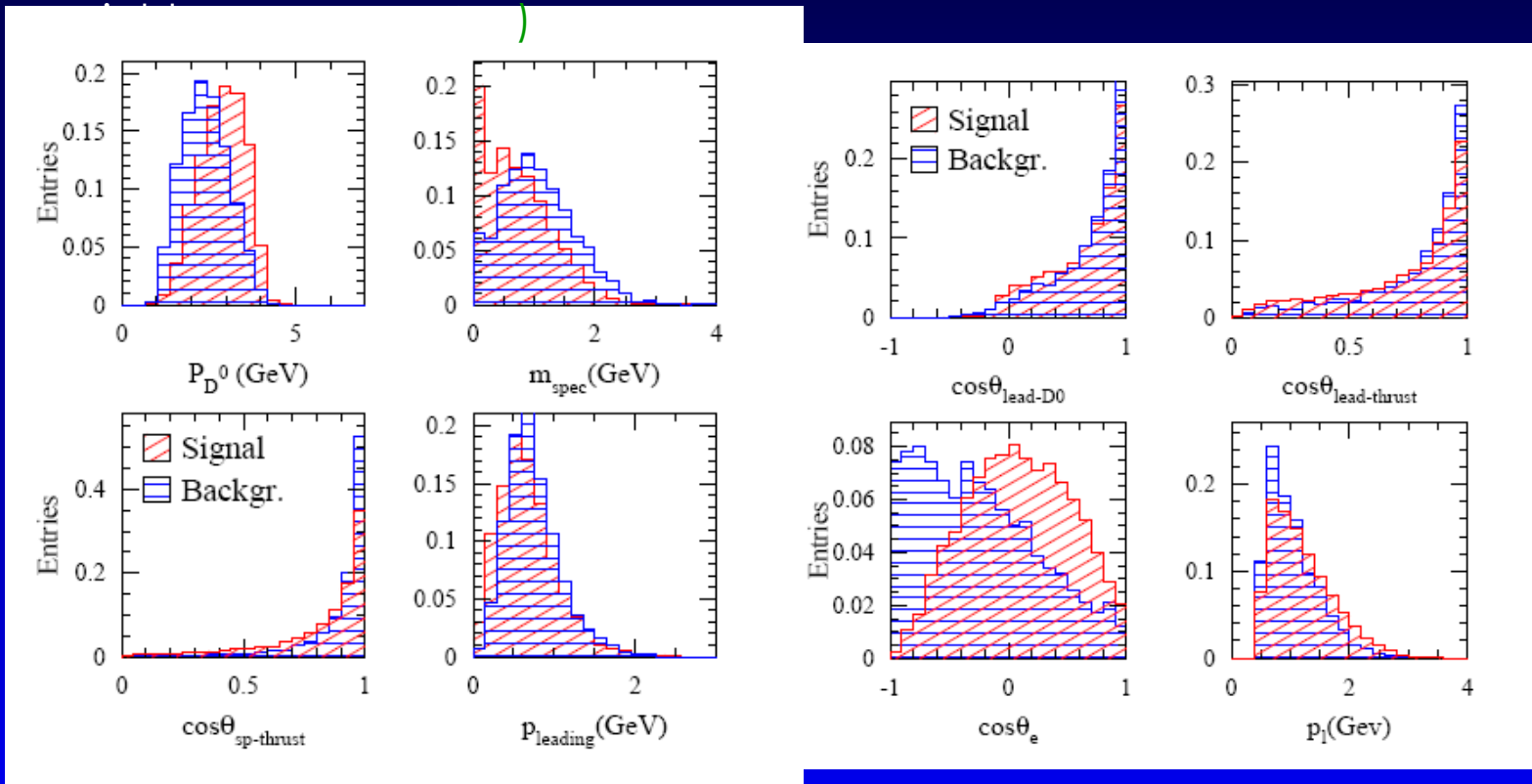
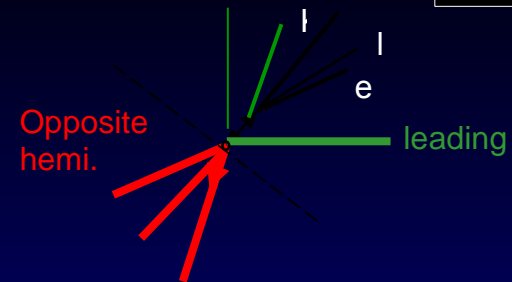


$D^0 \rightarrow K/\pi e \nu$

2 Fisher variables :

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

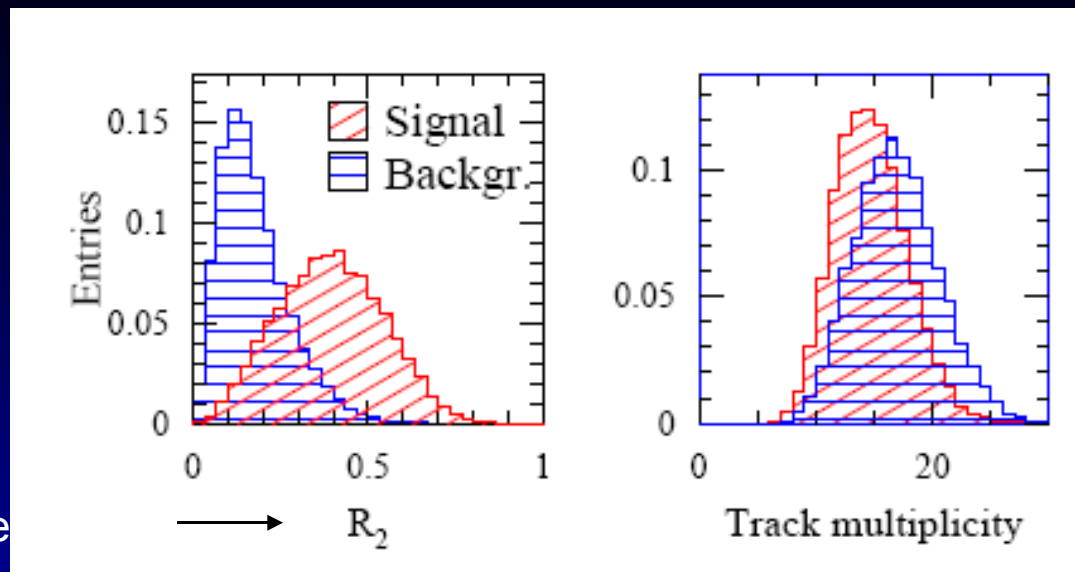
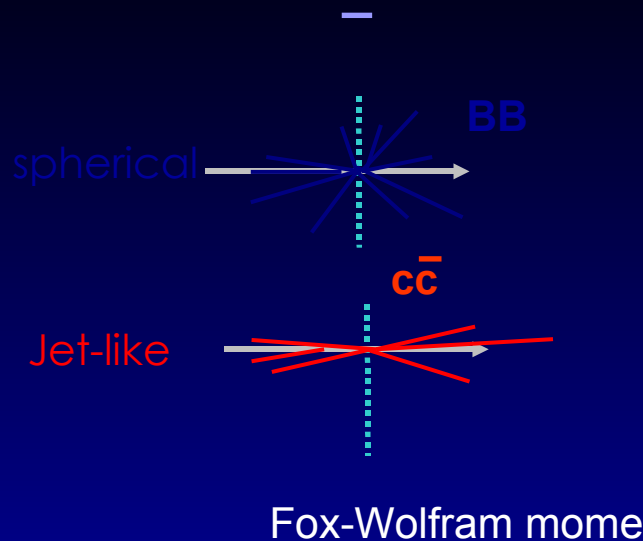
(mass, angular distribution, momentum and angular distribution of the leading particle + kinematic





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

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



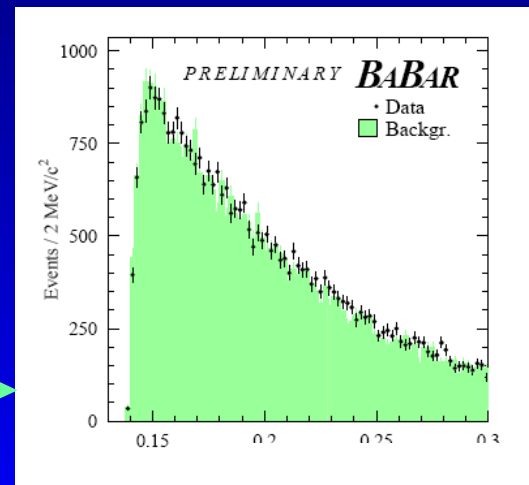
Remaining background composition :

$B^0\bar{B}^0$ 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



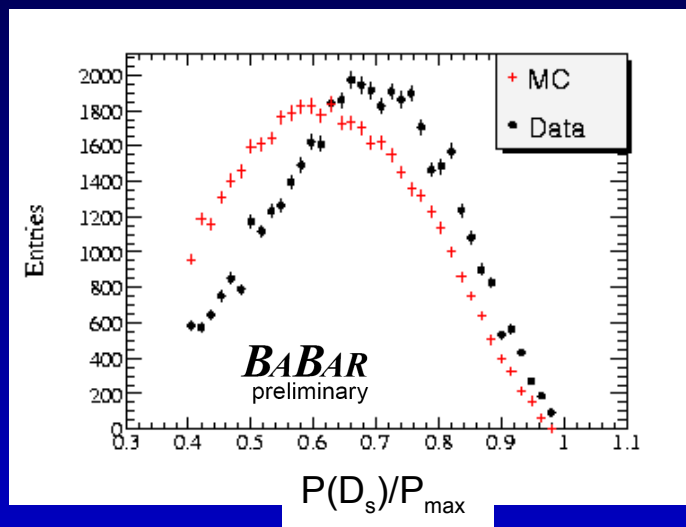


Control Samples

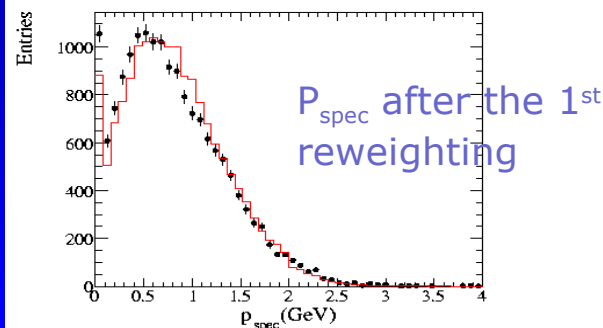
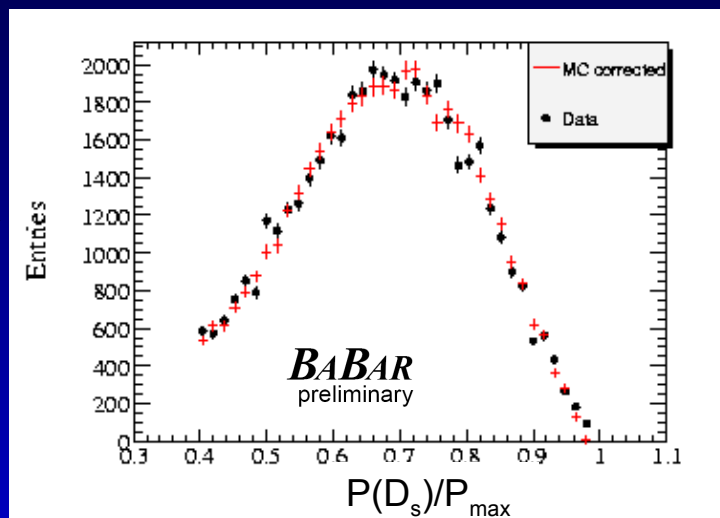
- Use $D_s \rightarrow \phi \pi$ (reconstructed as similar as possible)
- D_s direction and missing energy determination:

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**

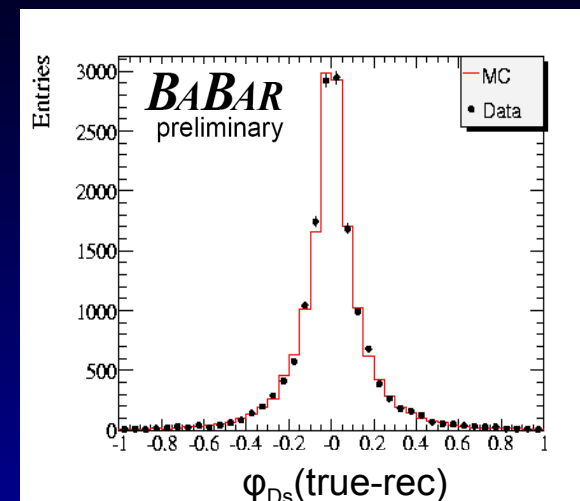
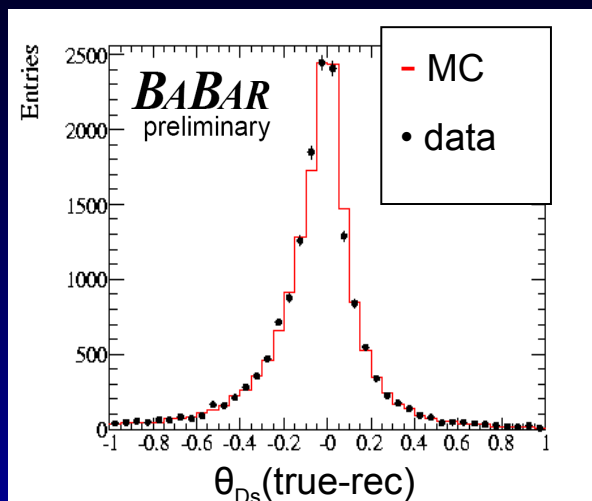


Check other Fisher variables after correction : small discrepancy remains, ex: spect. syst. momentum

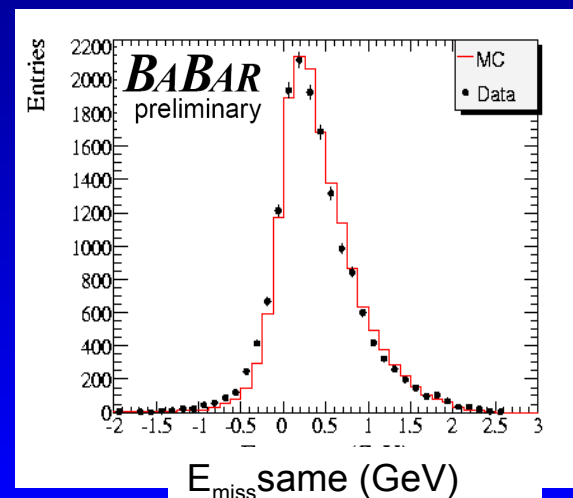
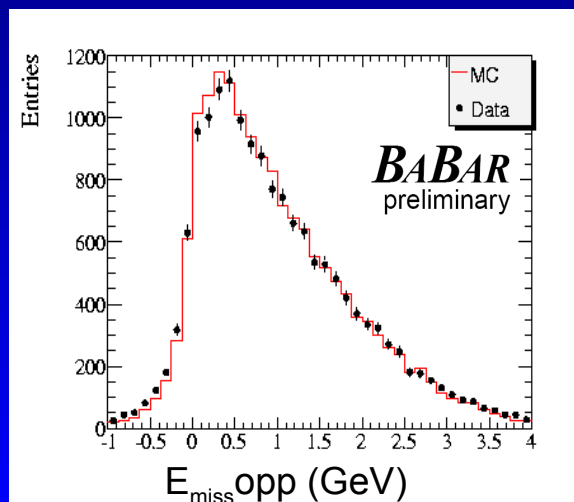
Taken into account in the systematic uncertainties by defining an additional weight on this variable.

Control Samples

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



Missing energy in the 2 hemispheres :



Tagging

- Fully reconstructed D in 13 hadronic decay modes

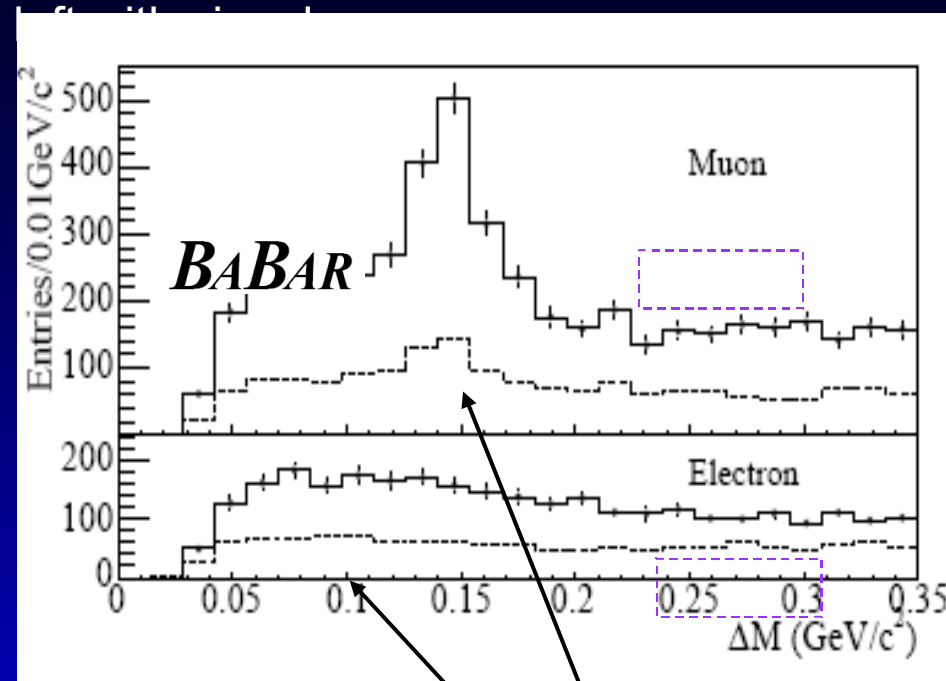
- $D^0 \rightarrow K^-\pi^+, K^-\pi^+\pi^0, K^-\pi^+\pi^+\pi^-$
- $D^+ \rightarrow K^-\pi^+\pi^+(\pi^0), K_S^0\pi^+(\pi^0), K_S^0\pi^+\pi^+\pi^-, K^+K^-\pi^+, K_S^0K^+$
- $D_s^+ \rightarrow K_S^0K^+, \Phi\rho^+$
- $D^{*+} \rightarrow D^0\pi^+, D^0 K_S^0\pi^+\pi^-(\pi^0), K_S^0K^+K^-, K_S^0\pi^0$

Modes allow
identification of
the charm quark
flavour

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

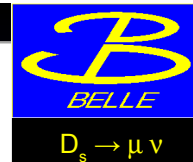
Background

- Signal is a peak in $\Delta M = M_{D_{s^*}} - M_{D_s}$
- 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 \rightarrow 42 %
 \Rightarrow Subtracted using the tag sidebands
- Correct tag but μ from charm semi leptonic decay or τ ($\tau \rightarrow \mu \nu_\mu \nu_\tau$) \rightarrow 26 %
 \Rightarrow Use electron : same decays appear with an e while there is no $D_s^+ \rightarrow e^+ \nu$
 \Rightarrow Take into account differences between μ and e (phase space, Bremsstrahlung, e from conversion)
- Leptonic background
 $cc \rightarrow D_{(s)}^* \rightarrow D_{(s)} \pi^0, D_{(s)} \rightarrow \mu \nu_\mu$
 $cc \rightarrow D_{(s)} \rightarrow \mu \nu_\mu$
- Combinatoric



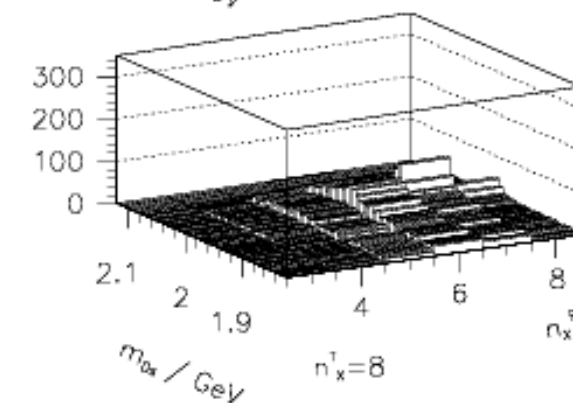
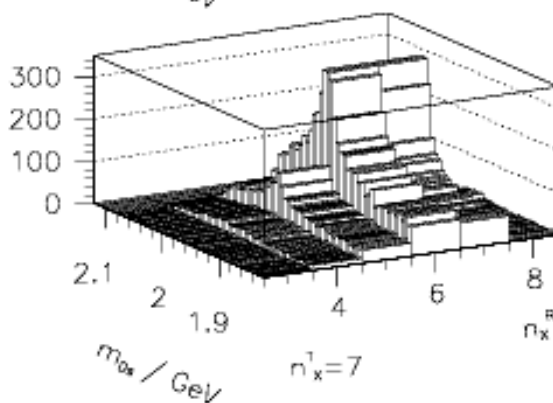
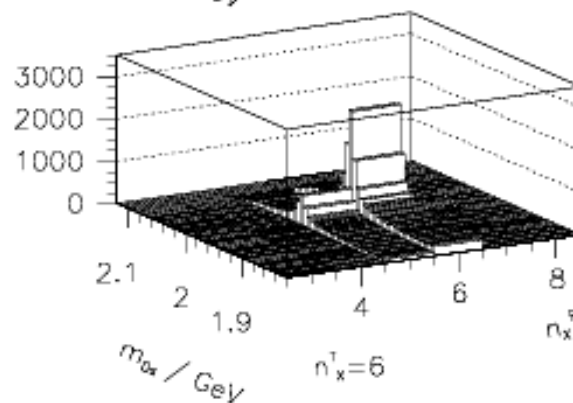
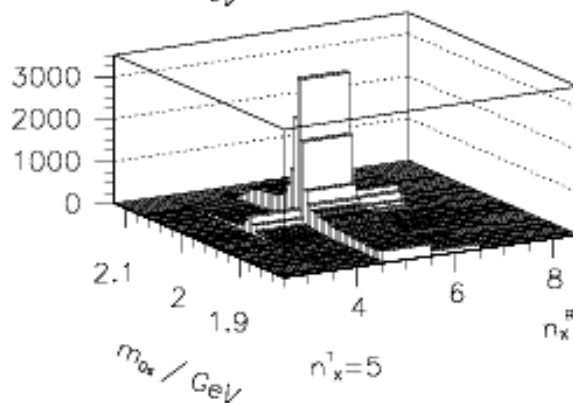
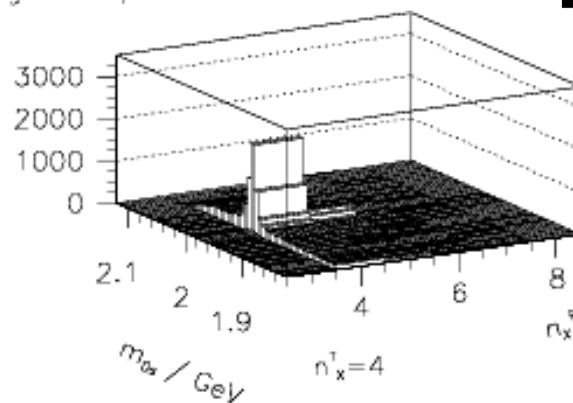
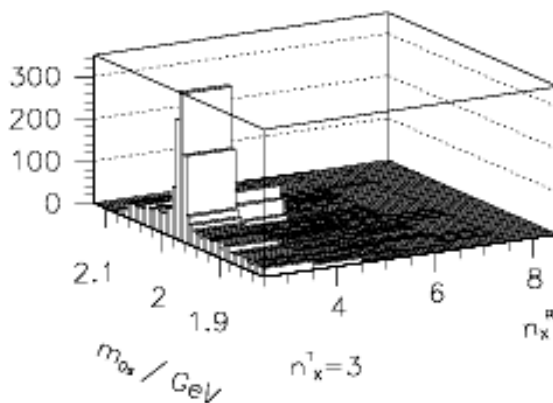
Tag sidebands

Estimated from simulated events



signal shapes used for fit

MC signal shapes





WS bkg shapes used for fit

