Determination of the asymmetry observables in $B_s \to D_s h$ decays

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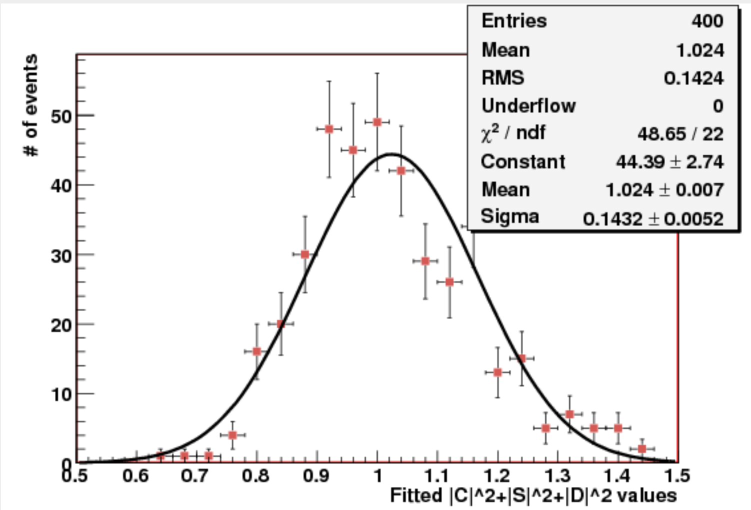
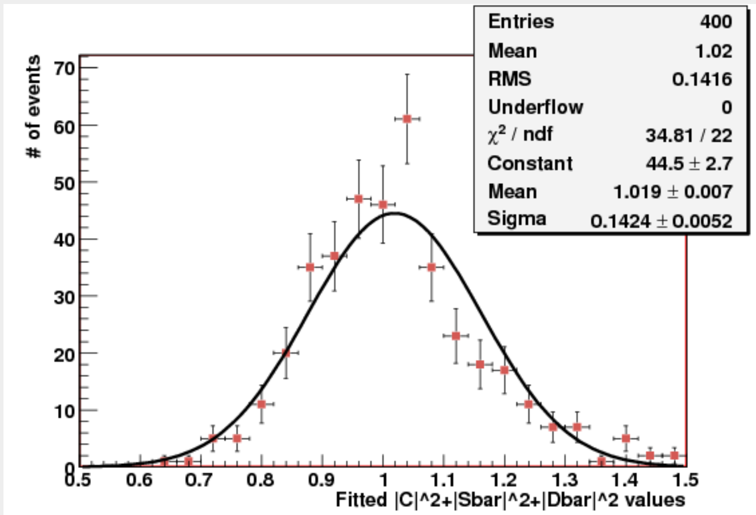
LHCb CP Measurements WG, CERN, 22 May 2008





Physics with $B_s \to D_s h$ decays

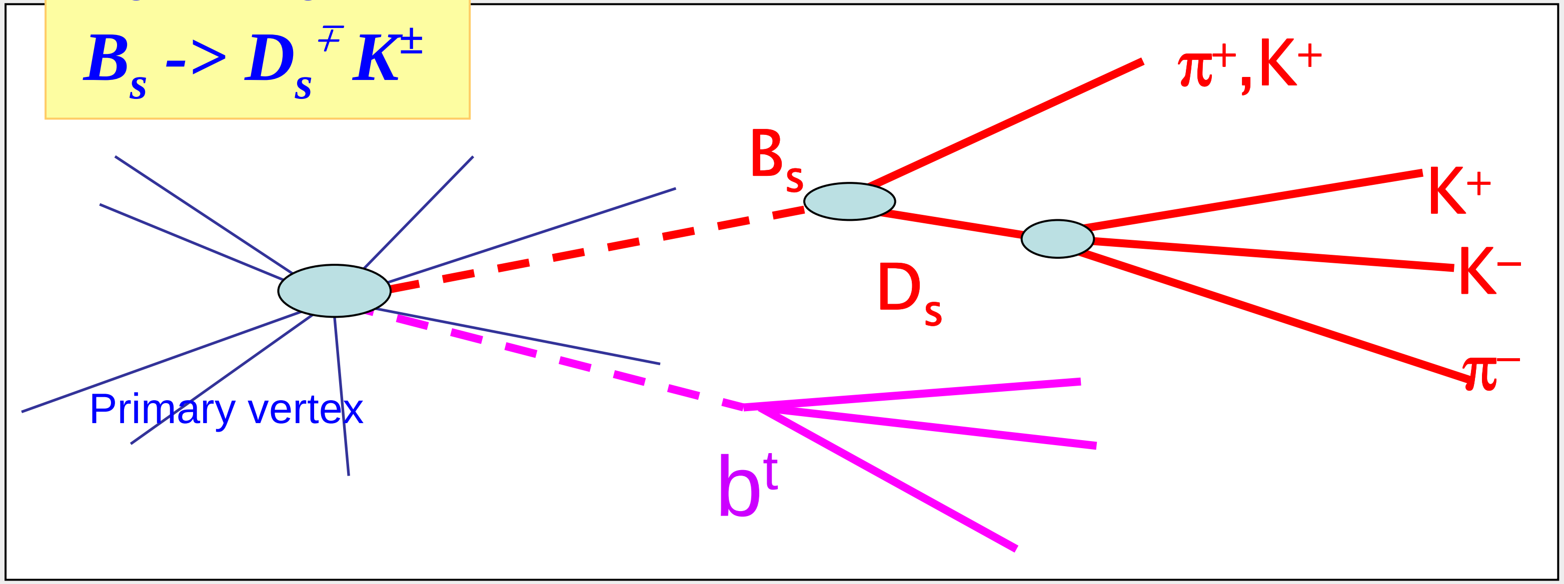
Decay topology

Topology of both decays

Is very similar

$B_s \longrightarrow D_s^- \pi^+$

$B_s \text{ -> } D_s^{\mp} K^{\pm}$



Decay diagrams

$B_s \to D_s\, \pi$ MODE:

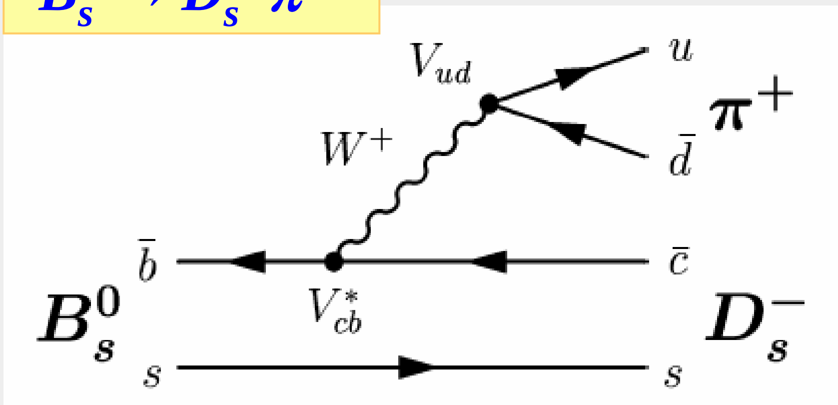
- Flavour-specific decay
  (2 decay amplitudes only)

$B_s \to D_s\, K$ MODE:

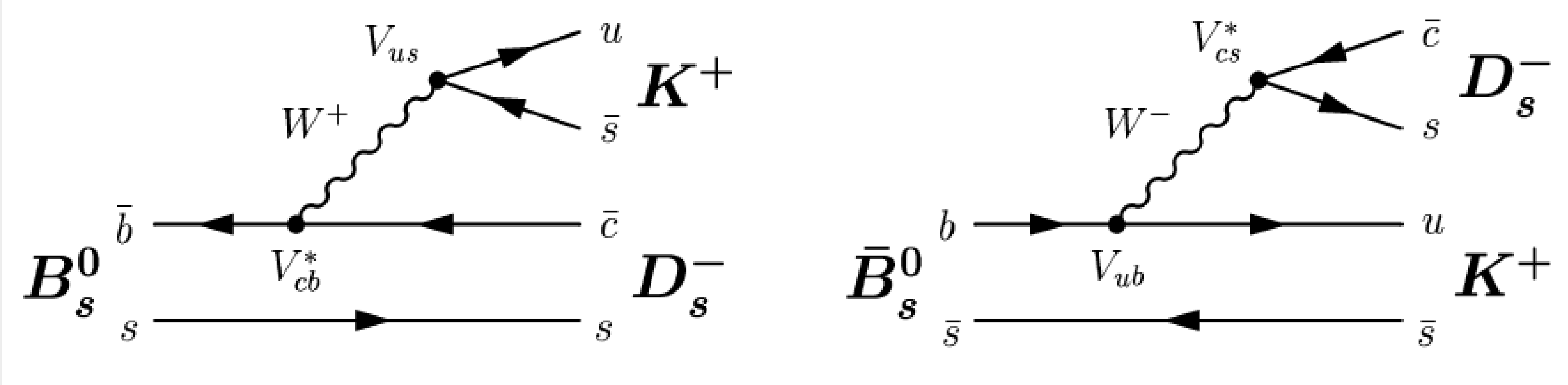
- 4 decay amplitudes of interest:
  B_s, $\bar{B}_s$ -> $D_s^+K^-$, $D_s^-K^+$
  $\to$ 2 time-dependent asymmetries
  for the 2 possible final states

- Ratio of amplitudes of order 1
  $\to$ large interference and
  asymmetry expected

$B_s \to D_s^-\, \pi^+$



B_s -> $D_s^{\mp} K^{\pm}$



Decay rate equations

$$\Gamma_{B\to f}(t) = |A_f|^2 \left(1+|\lambda_f|^2\right) \frac{e^{-\Gamma t}}{2} \cdot \left(\cosh \tfrac{\Delta\Gamma}{2} t + D_f \sinh \tfrac{\Delta\Gamma}{2} t + C_f \cos \Delta m_s t - S_f \sin \Delta m_s t\right)$$

$$\Gamma_{\overline{B}\to f}(t) = |A_f|^2 \left|\frac{p}{q}\right|^2 \left(1+|\lambda_f|^2\right) \frac{e^{-\Gamma t}}{2} \cdot \left(\cosh \tfrac{\Delta\Gamma}{2} t + D_f \sinh \tfrac{\Delta\Gamma}{2} t - C_f \cos \Delta m_s t + S_f \sin \Delta m_s t\right)$$

Asymmetry observables

$$C_f \equiv A_{CP}^{dir} = \frac{1-|\lambda_f|^2}{1+|\lambda_f|^2} \quad , \quad S_f \equiv A_{CP}^{mix} = \frac{2\,\mathrm{Im}(\lambda_f)}{1+|\lambda_f|^2} \quad , \quad D_f \equiv A_{CP}^{\Delta\Gamma} = \frac{2\,\mathrm{Re}(\lambda_f)}{1+|\lambda_f|^2}$$

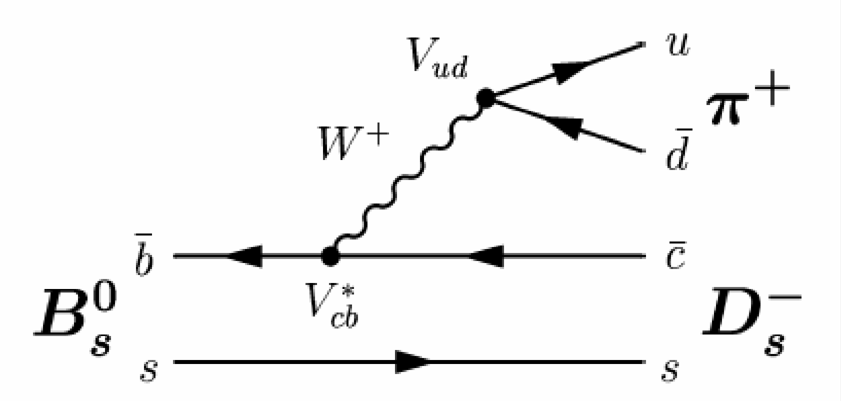
$$\lambda_f = \frac{q}{p}\frac{\overline{A}_f}{A_f}$$

For charge conjugate final states:

B → Bbar , f → fbar, $\lambda_f \to \bar{\lambda}_{\bar{f}}$, $A_f \to \bar{A}_{\bar{f}}$,p/q → q/p

$B_s \to D_s\, \pi$ decays

- **Single decay diagram**



- **One diagram means**

$$\lambda_f = \bar{\lambda}_{\bar{f}} = 0 \quad \left(\left| A_{\bar{f}} \right| = \left| \bar{A}_f \right| = 0 \right)$$

leading to

$$C_f = 1 \quad , \quad S_f = 0 \quad , \quad D_f = 0$$

(2 unique equations)

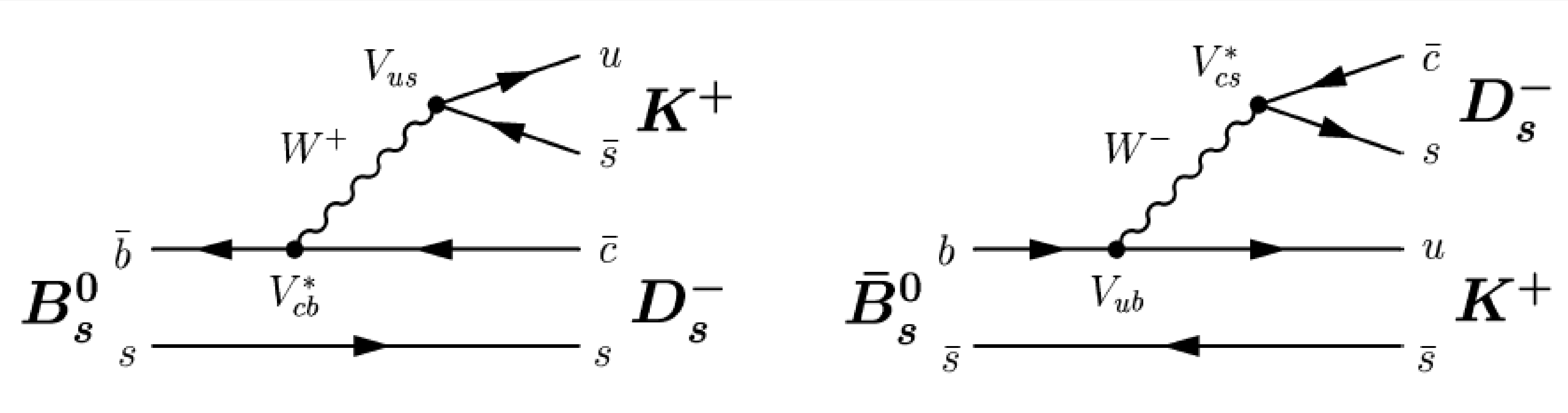
- **Parameters to measure:**

  Δm_s, $\Delta \Gamma_s$

- We assume |p/q|=1

$B_s \to D_s$ K decays

- **Non-flavour specific decay**



- **Non-trivial time dependence:**

$$|\lambda_f| = |\bar{\lambda}_{\bar{f}}|$$

$$C_f \neq 0 \quad , \quad S_f \neq 0 \quad , \quad D_f \neq 0$$

- **Parameters to measure:**

  different « sets » are possible …

$B_s \to D_s K$: measurement of γ

- **Sensitivity to γ via**

$$\gamma + \phi_s = \left[\arg(\bar{\lambda}_{\bar{f}}) - \arg(\lambda_f)\right]/2$$
$$\Delta_{T1/T2} = \left[\arg(\bar{\lambda}_{\bar{f}}) + \arg(\lambda_f)\right]/2$$

- **With a fit to the 3 parameters**

$$|\lambda_f| \quad , \quad \arg(\lambda_f) \quad , \quad \arg(\bar{\lambda}_{\bar{f}})$$

- **Not the aim of the present study**
- **Full details in the LHCb note 2007-041**

- $\Delta_{T1/T2}$ represents the strong phase between the 2 contributing diagrams
- ϕ_s is the B_s mixing phase

$B_s \to D_s K$: measurement of the asymmetry observables

Study presented

- **Direct fit to the asymmetry observables**

$$C_f\,(=C_{\bar{f}}) \quad , \quad S_f \quad , \quad D_f \quad , \quad S_{\bar{f}} \quad , \quad D_{\bar{f}}$$

- **No model dependence in this 5-parameter fit!**

- **A 3-parameter fit is also possible using the constraints**

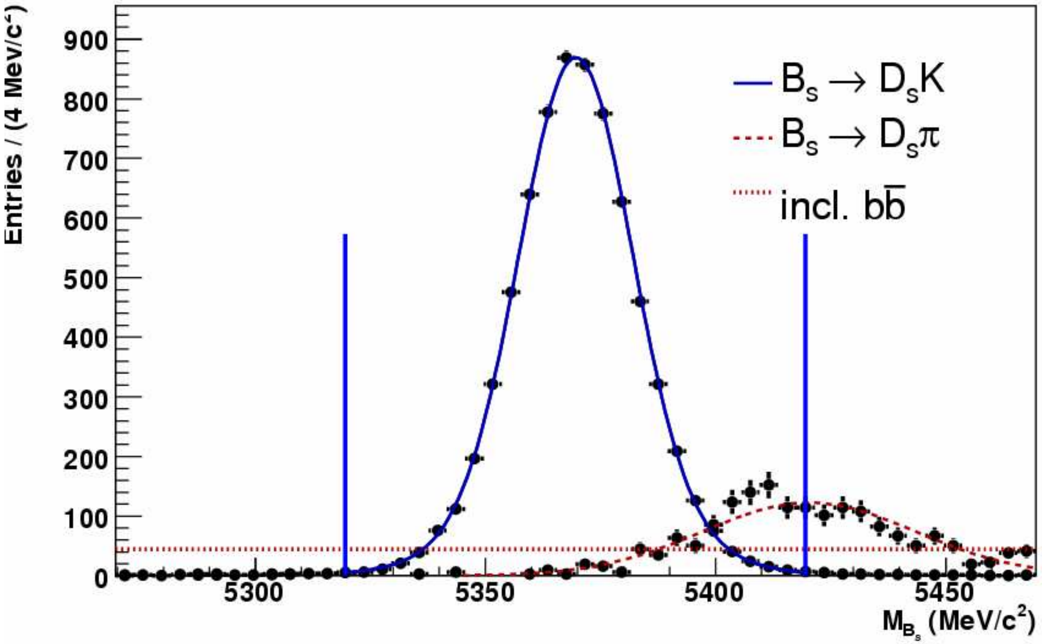
$$C_f^2 + S_f^2 + D_f^2 = 1 \qquad C_{\bar{f}}^2 + S_{\bar{f}}^2 + D_{\bar{f}}^2 = 1 \qquad C_f = C_{\bar{f}}$$

DC04 results on $B_s \rightarrow D_s h$ decays

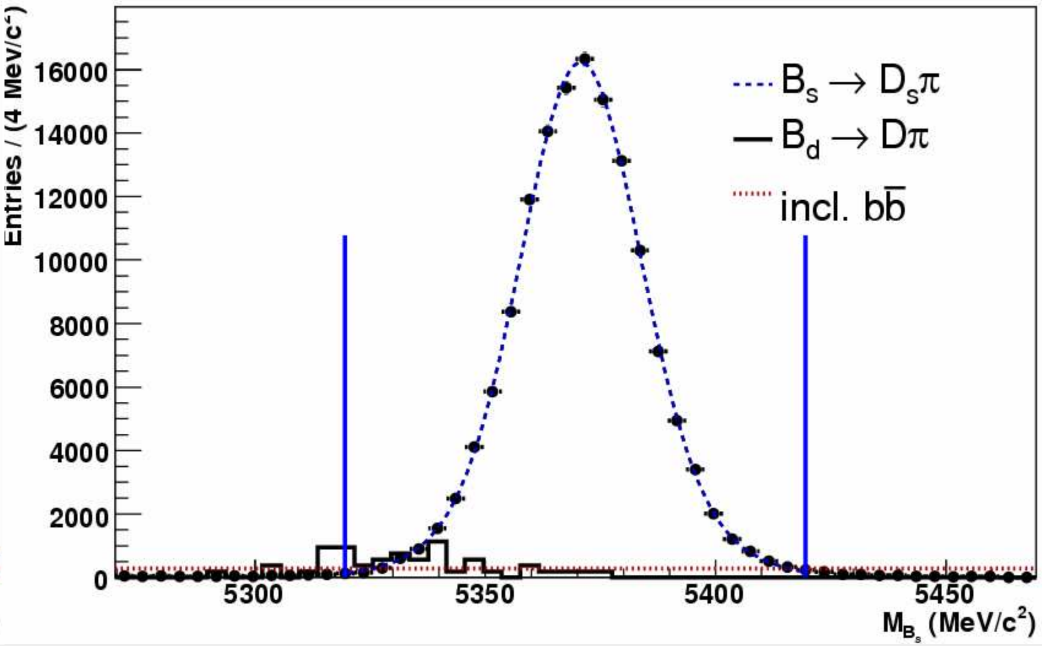
Borel & Nicolas, LHCb note 2007-017

Event selection

$B_s \to D_s K$: B_s reconstructed mass
signal and main background



$B_s \to D_s \pi$: B_s reconstructed mass
signal and main background



B_s mass resolution ~14 MeV

Borel & Nicolas, LHCb note 2007-017

Signal yields & background contamination

Event yields for $2fb^{-1}$ (defined as 1 year)	
$B_s \to D_s^- \pi^+$	140k ± 0.67k (stat.) ± 40k (syst.)
$B_s \to D_s^{\mp} K^{\pm}$	6.2k ± 0.03k (stat.) ± 2.4k (syst.)

Results for B/S ratios, no trigger applied		
Channel	B/S at 90% CL (bb combinatorial)	B/S at 90% CL (bb specific)
$B_s \to D_s^- \pi^+$	[0.014,0.05] C.V 0.027±0.008	[0.08,0.4] C.V 0.21±0.06
$B_s \to D_s^{\mp} K^{\pm}$	[0,0.18] C.V 0.0	[0.08,3] C.V 0.7±0.3

(central values used for sensitivity studies)

Borel & Nicolas, LHCb note 2007-017

Sensitivity studies

Toy MC sensitivity study to asymmetry observables

- Simultaneous $B_s \rightarrow D_s\pi$ and $B_s \rightarrow D_sK$ fit: correlations taken into account
- All 6 decay rate equations included: 6 PDFs
- Complete fit allows to obtain Δm_s and the mistag rate as well
- Toy in mass and propertime. Includes:
  - ✓ smearing due to mis-tagging
  - ✓ propertime acceptance function
  - ✓ per-event propertime error
  - ✓ background (rough estimation/description)
- Fit done with tagged $B_s \rightarrow D_s\pi$ and $B_s \rightarrow D_sK$ events
- 400 “experiments” each time,

  each for 5 years of nominal LHCb data taking

Toy MC: likelihood description

Likelihood function

$$L_{B_s^0\to f}\left(\vec{\alpha},\vec{\beta}\right)=\prod_i^{B_s^0\to D_s\pi}\Pr ob\left(\tau_{rec},\Delta\tau_{rec}\middle|\vec{\alpha},S_{sig},S_{bg},\omega\right)\times\prod_i^{B_s^0\to D_sK}\Pr ob\left(\tau_{rec},\Delta\tau_{rec}\middle|\vec{\beta},S_{sig},S_{bg},\omega\right)$$

with $\vec{\alpha}=(\Gamma_s,\Delta m_s,\Delta\Gamma_s)$, $\vec{\beta}=\left(\lambda_f,\bar{\lambda}_{\bar{f}},\Gamma_s,\Delta m_s,\Delta\Gamma_s\right)$

acceptance function

resolution function: proper time per-event error, with signal scale factor

$$\Pr ob\left(\tau_{rec},\Delta\tau_{rec}\middle|\vec{\alpha},S_{sig},S_{bg},\omega\right)=$$

$$\int_0^\infty\left\{\left[\left(1-f_{bg}\right)M_{sig}(m_{rec})\Gamma_{sig}\left(t\middle|\vec{\alpha},\omega\right)\right]\cdot A(t)\cdot G_{sig}\left(t-\tau_{rec},\Delta\tau_{rec},S_{sig}\right)\right.$$

$$\left.+\left[f_{bg}M_{bg}(m_{rec})\Gamma_{bg}(t)\right]\cdot A(t)\cdot G_{bg}\left(t-\tau_{rec},\Delta\tau_{rec},S_{bg}\right)\right\}\cdot dt$$

signal proper time including mistagged events

bg proper time

resolution function: proper time per-event error, with bg scale factor

signal reconstructed B_s mass

bg reconstructed B_s mass

Toy MC: input parameters

- Using experiment-related parameters/results from DC04 selection results (LHCb-note 2007-017)
- Physics parameters:

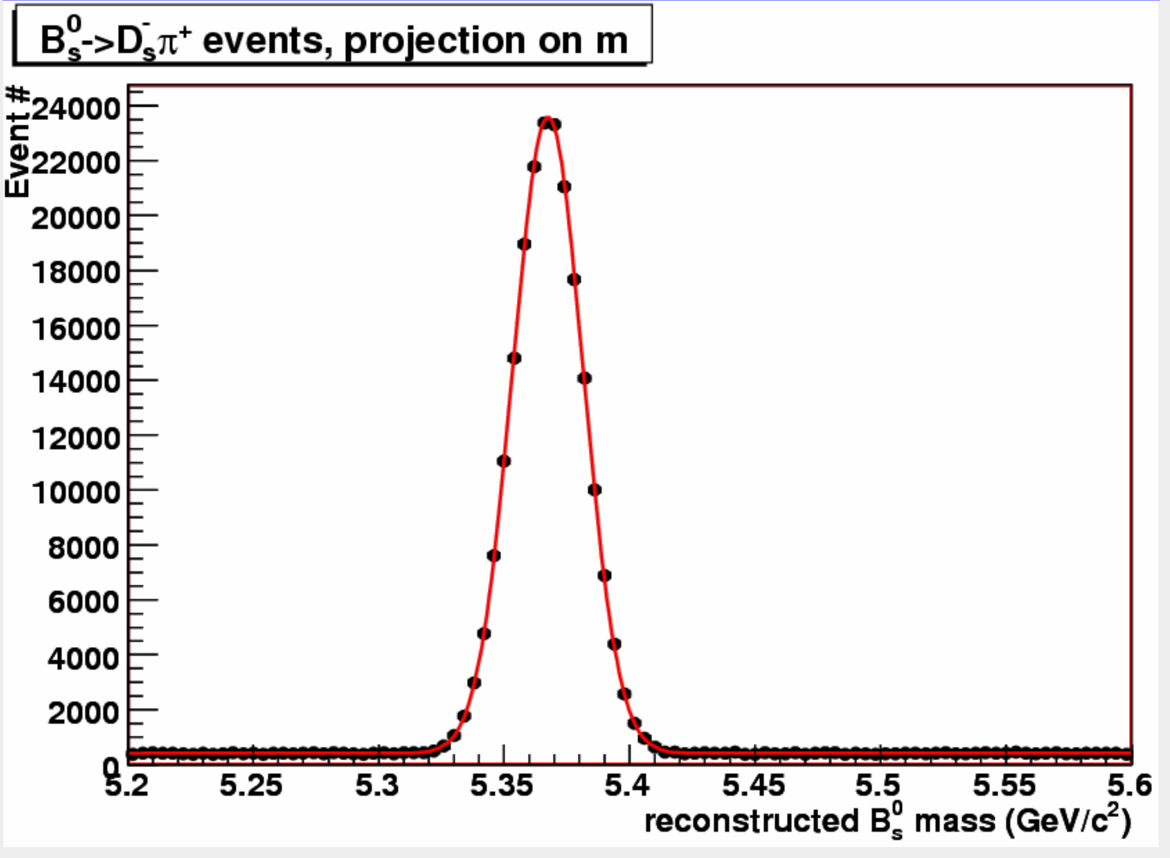
  those agreed upon by WG

- $\Delta_{T1/T2}=0$, $(\gamma+\varphi_s)=60°$

Parameter	Input value
$\Delta\Gamma/\Gamma$	0.1
Δm_s	17.5 ps^{-1}
ω	0.328
$\lvert\lambda_f\rvert$	0.37
$Arg(\lambda_f) = \Delta_{T1/T2}+(\gamma+\varphi_s)$	60°= 1.047 rad
$Arg(\lambda bar_{fbar}) = \Delta_{T1/T2}-(\gamma+\varphi_s)$	-60°= -1.047 rad
Event yield (1y) $D_s\pi$ Event yield (1y) DsK	140K 6.2K
B/S ratio for $D_s\pi$ B/S ratio for DsK	0.2 0.7
ε_{tag}	0.5812
$\sigma(m_{Bs})$	14MeV

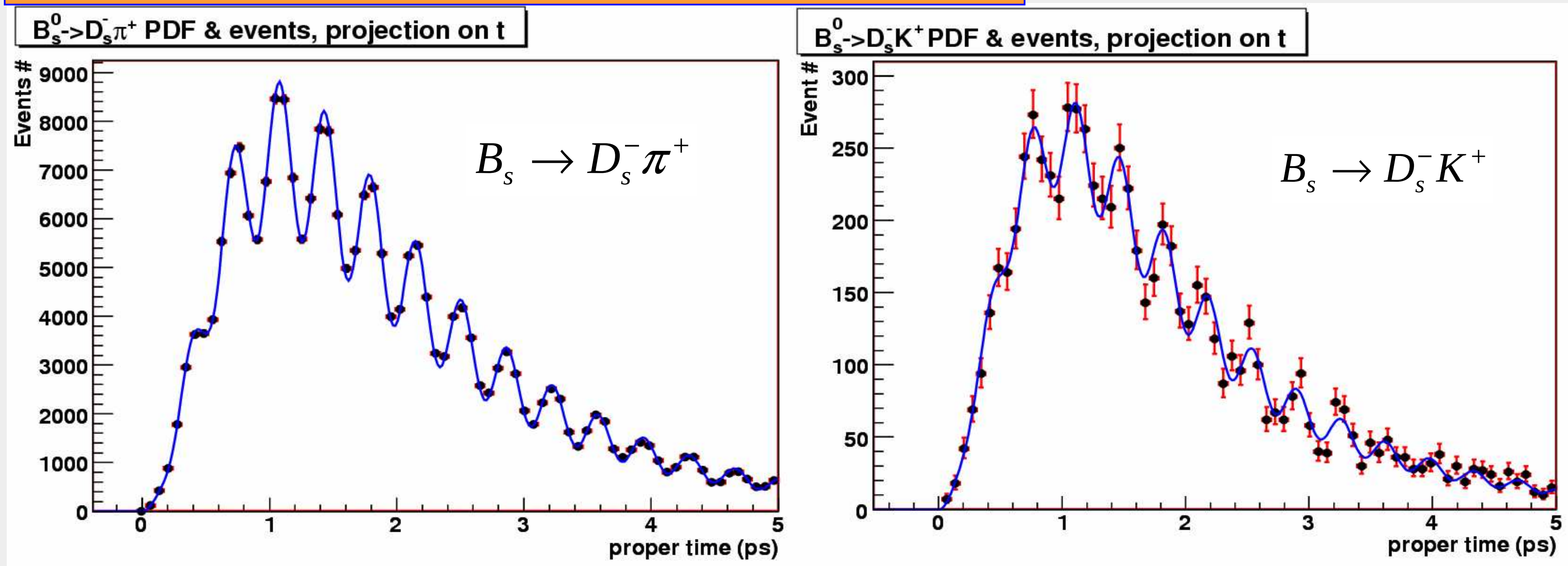
Toy MC: description in mass

Signal & background, 5-year statistics



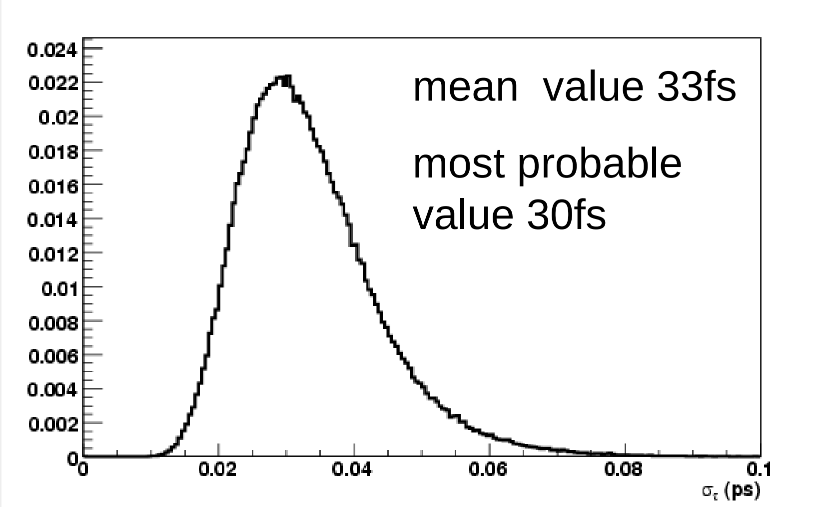
Toy MC: description in propertime

Combined sample, tagged events, 5-year statistics

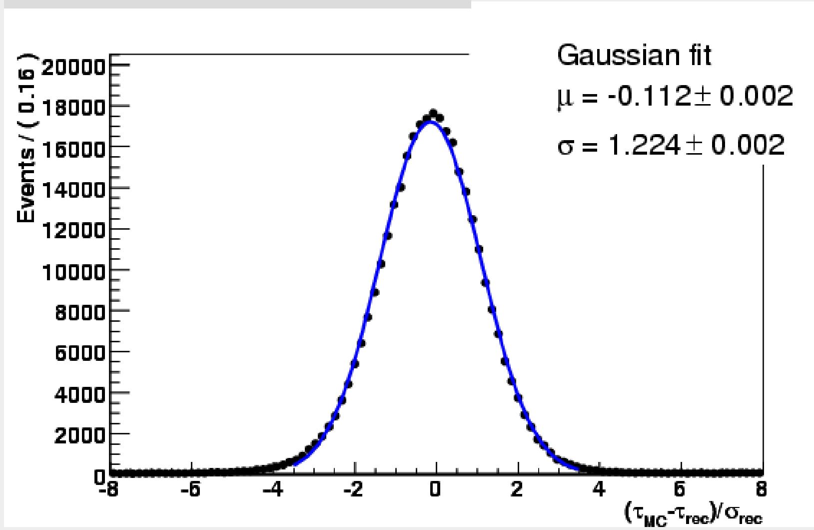


Toy MC: description in propertime

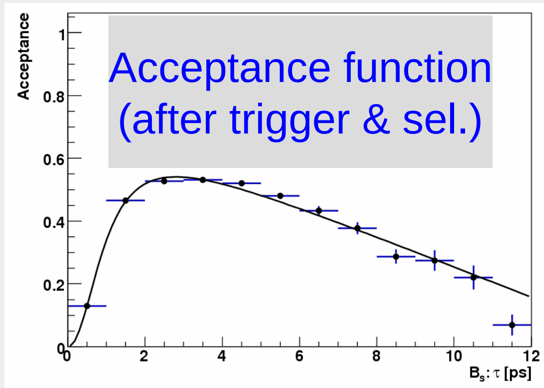
Proper time per-event error distribution



Proper time error pull



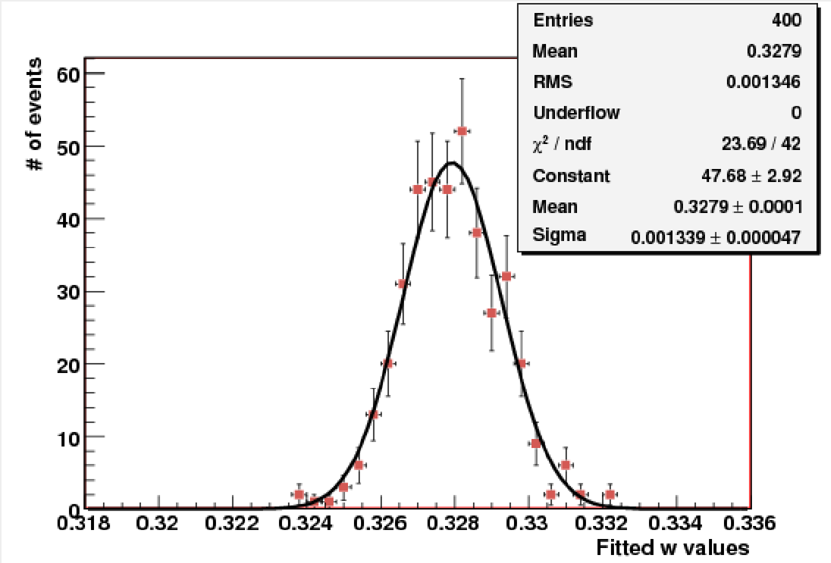
- **Proper time error distribution**
  - Parameterization for proper time error and scale correction due to the pull sigma value
- **Acceptance function after triggers and offline selection**

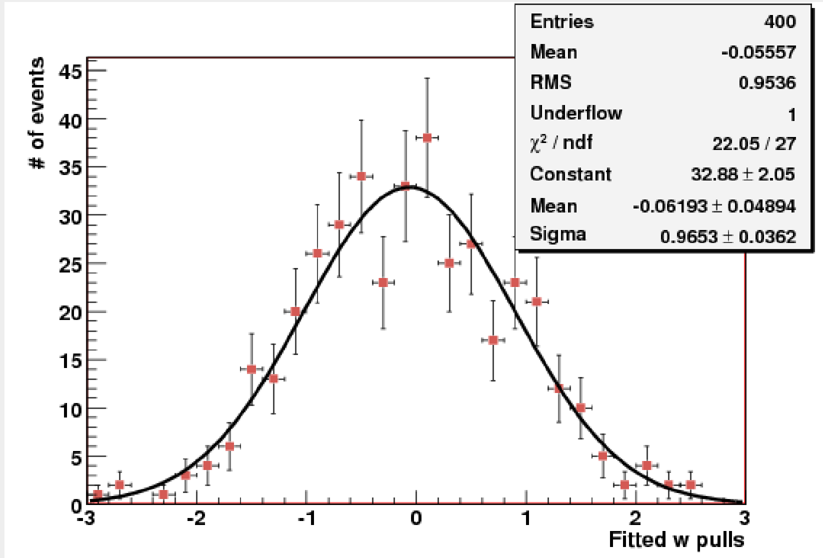


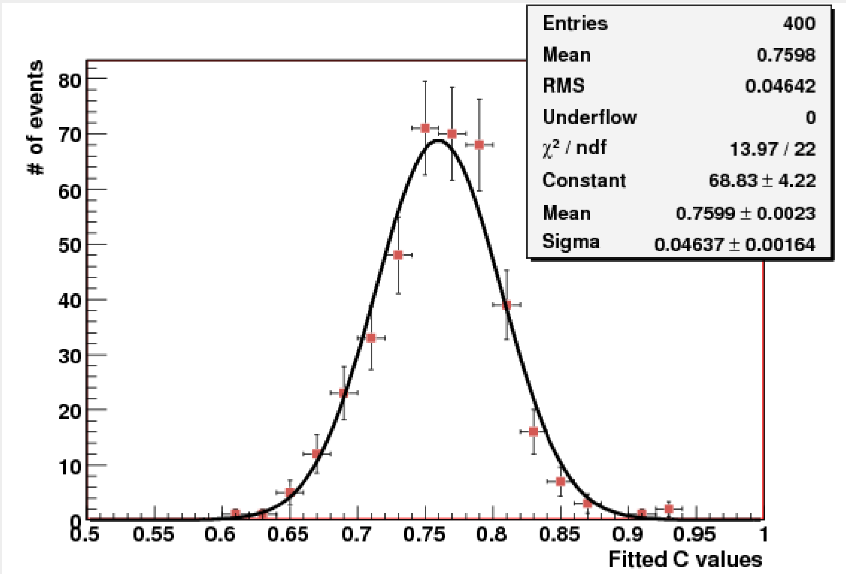
Borel & Nicolas, LHCb note 2007-017

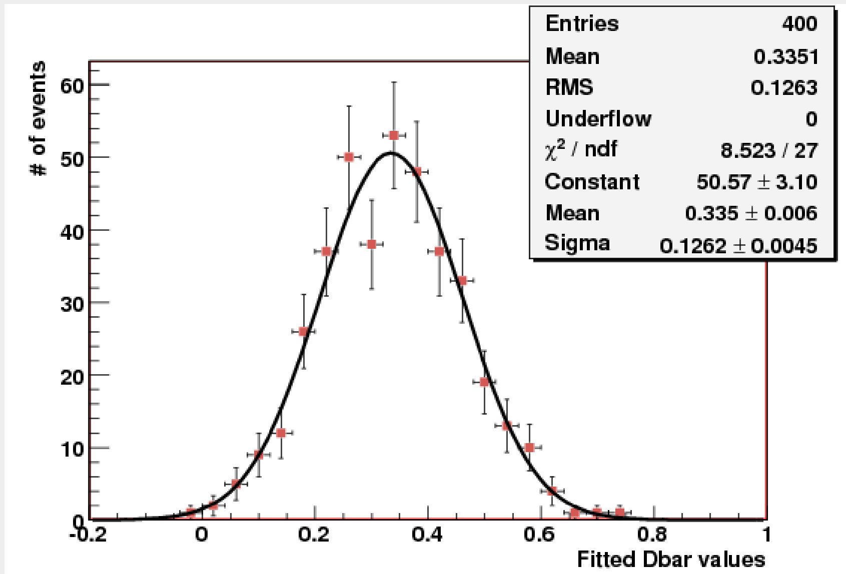
Toy MC results

Fit without constraint on C, S and D (1/3)









Fit without constraint on C, S and D (2/3)

Variable	Input value	Fit value	+/-	error (5y)	Fit value	+/-	error (1y)
C	0.759	0.760	+/-	0.046	0.760	+/-	0.104
D	0.325	0.328	+/-	0.119	0.328	+/-	0.267
Dbar	0.325	0.335	+/-	0.126	0.335	+/-	0.282
S	0.564	0.568	+/-	0.063	0.568	+/-	0.141
Sbar	-0.564	-0.559	+/-	0.065	-0.559	+/-	0.144
dM	17.500	17.500	+/-	0.003	17.500	+/-	0.007
w	0.328	0.328	+/-	0.001	0.328	+/-	0.003

Asymm. obs. 1-year resolutions ~15-30%

Variable	Pull mean	Pull sigma
C	-0.00	1.02
D	-0.02	0.99
Dbar	0.03	1.04
S	0.04	1.05
Sbar	0.10	1.06
dM	0.06	1.02
w	-0.06	0.97

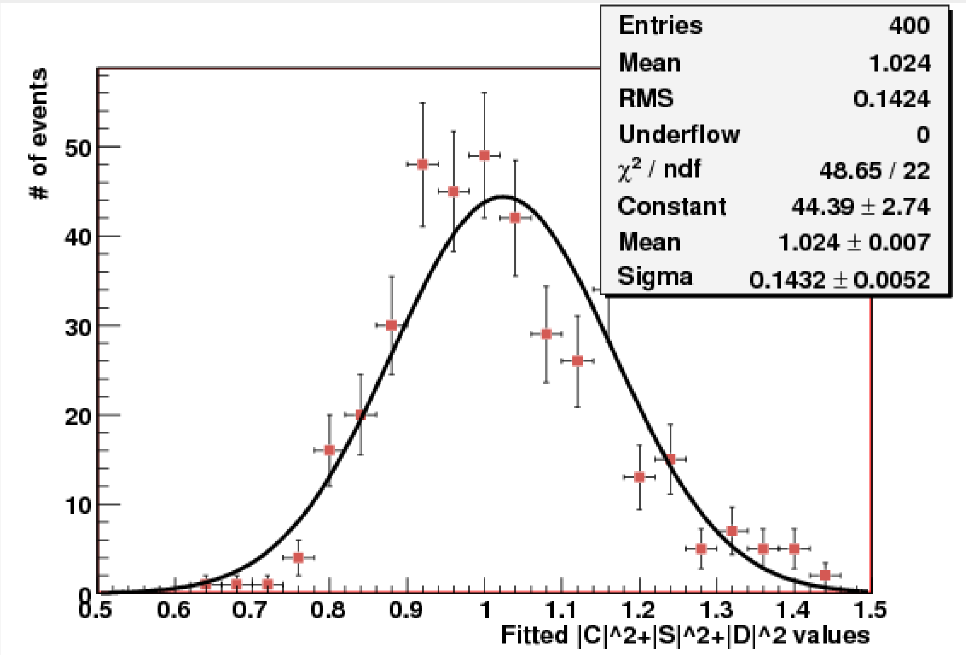
- **Global correlations of asymm. obs. typically ~0.2**

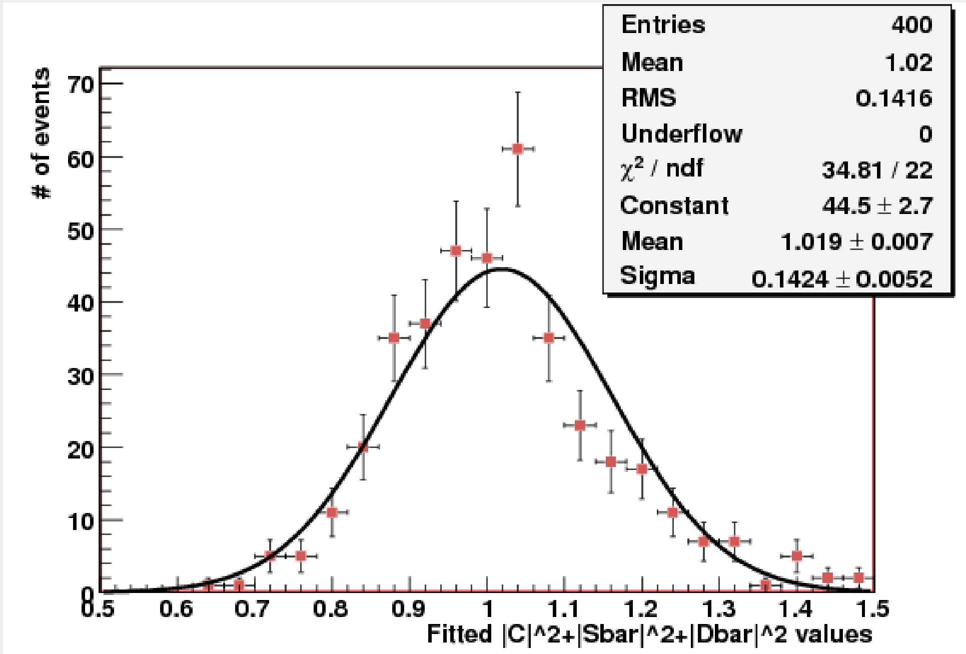
Fit without constraint on C, S and D (3/3)

❖ What about the relations

$$C_f^2 + S_f^2 + D_f^2 = 1 \qquad C_f^2 + S_{\bar{f}}^2 + D_{\bar{f}}^2 = 1$$

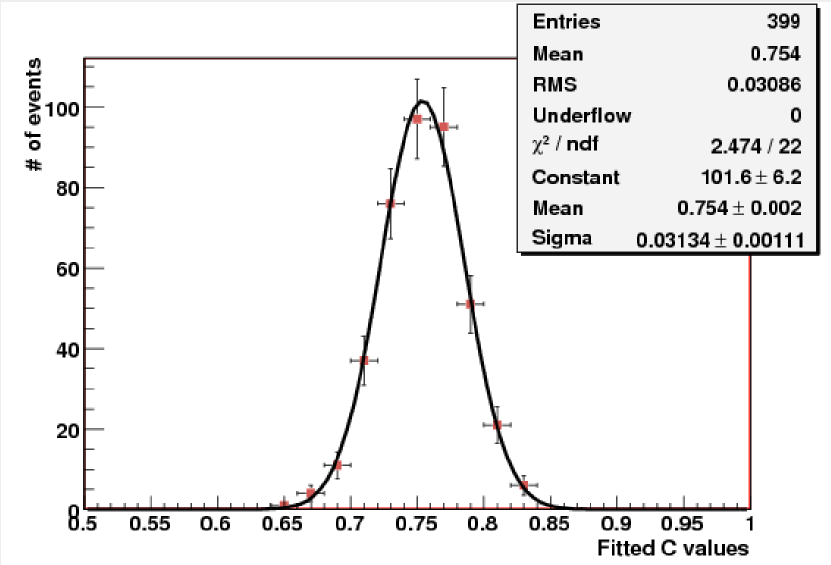
not used in the fit? How are they predicted …?

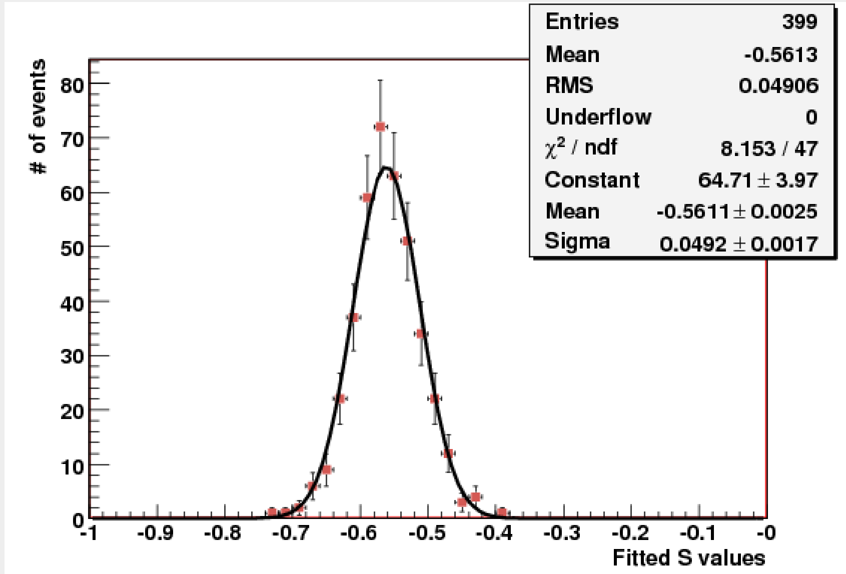


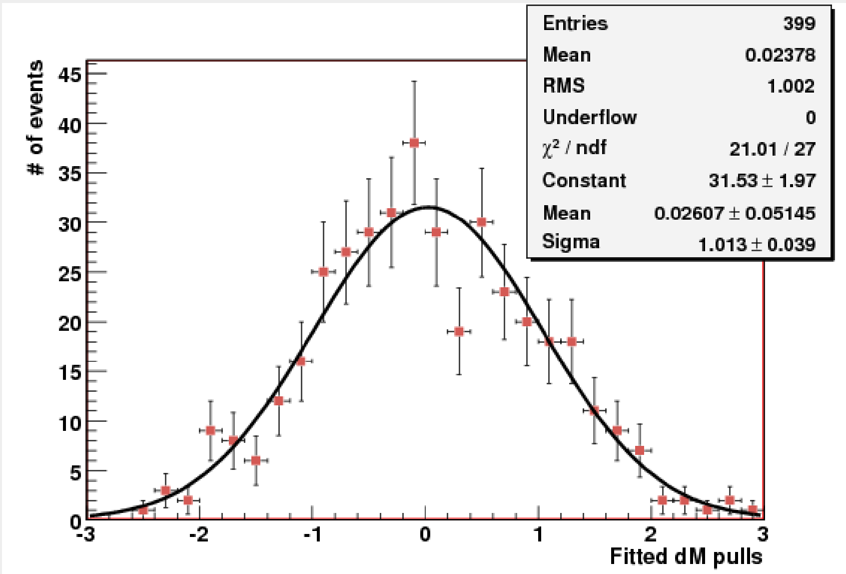


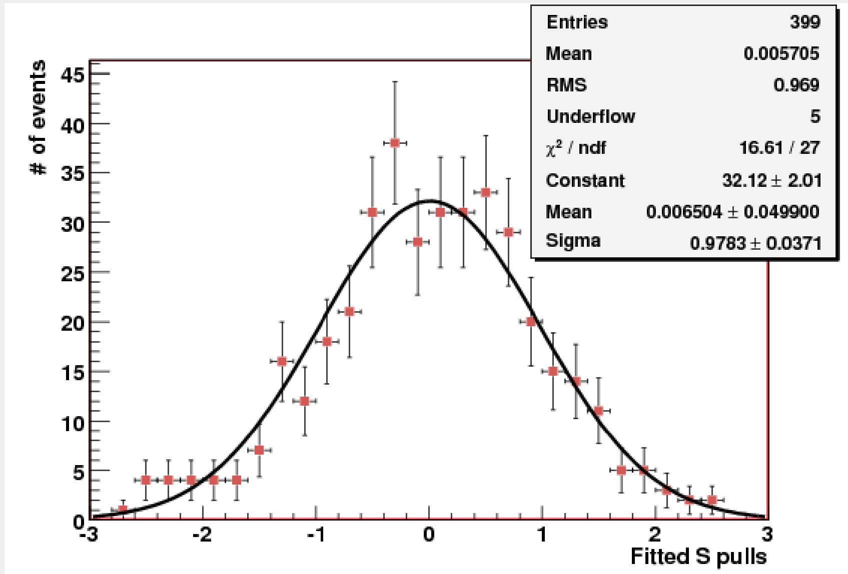
⇒ **Nice check that the fit is working well!**

Fit with constraint on C, S and D (1/3)









Fit with constraint on C, S and D (2/3)

Variable	Input value	Fit value	+/-	error (5y)	Fit value	+/-	error (1y)
C	0.759	0.754	+/-	0.031	0.754	+/-	0.070
S	-0.564	-0.561	+/-	0.049	-0.561	+/-	0.110
Sbar	0.564	0.565	+/-	0.045	0.565	+/-	0.101
dM	17.500	17.500	+/-	0.003	17.500	+/-	0.007
w	0.328	0.328	+/-	0.001	0.328	+/-	0.003

The errors on the asymmetry observables are smaller by ~20-30% compared to the unconstrained case

Variable	Pull mean	Pull sigma
C	-0.15	0.94
S	0.01	0.98
Sbar	0.01	0.87
dM	0.03	1.01
w	-0.10	1.01

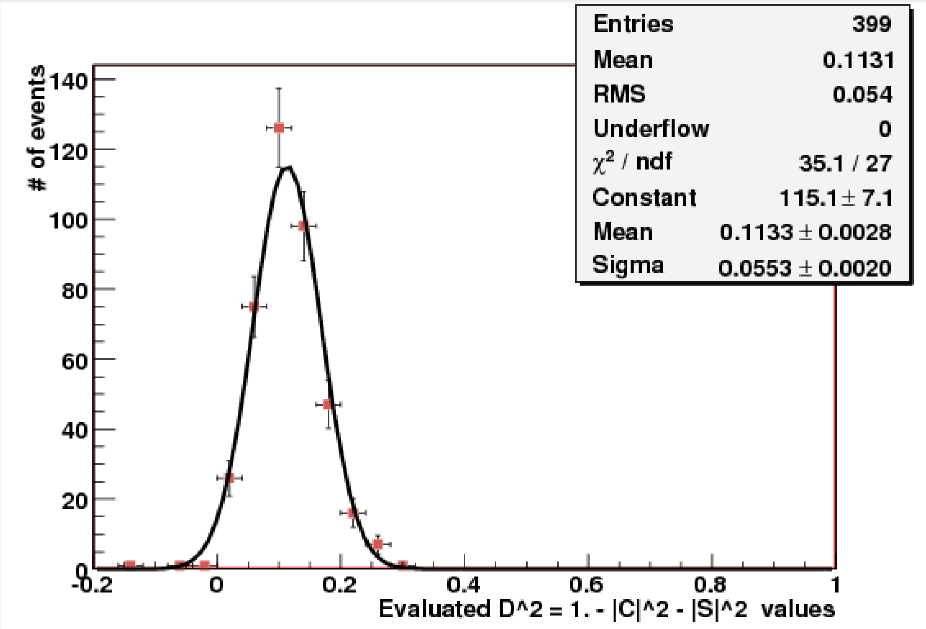
❖ **Global correlations of asymm. obs. typically ~0.5-0.6**

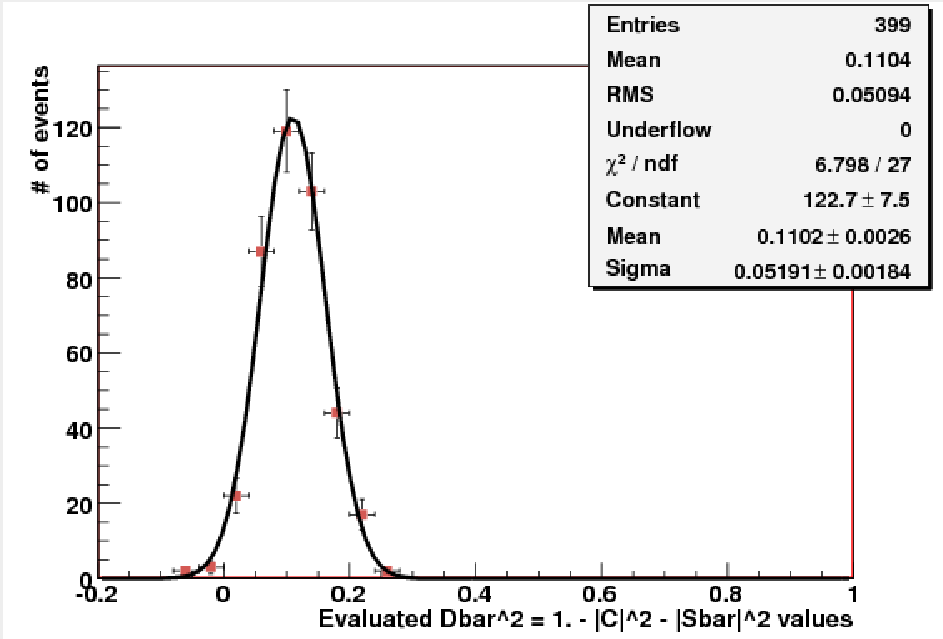
Fit with constraint on C, S and D (3/3)

❖ **The sensitivity on the D's can be obtained from the constraints**

$$C_f^2 + S_f^2 + D_f^2 = 1 \qquad C_{\bar{f}}^2 + S_{\bar{f}}^2 + D_{\bar{f}}^2 = 1$$

used in the fit:





⇒ **We obtain Gaussian distributions centered around the correct value with a resolution ~30% better compared to the unconstrained fit result**

Outlook

- Alternative fit to $B_s \rightarrow D_s h$ decays presented
- Fits directly the asymmetry observables

- Model-independent fit possible
- Results can serve as input to other analyses

- Some "robustness" studies have also been done
- To be presented asap