# Measuring $B_s \rightarrow \Phi\Phi$ Polarization Amplitudes

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# Goal of presentation

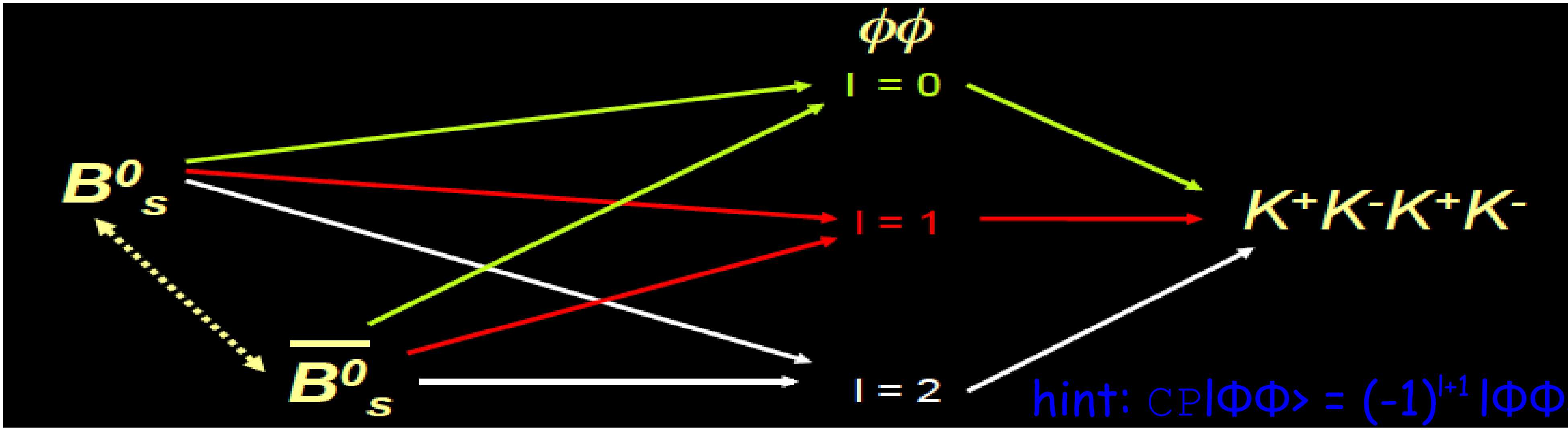
Show the status of the polarization analysis for

$B_s \longrightarrow \Phi\Phi$

Topics:

1. Recall some definitions...
2. Strategy;
3. Time-integated analysis (projections, tests)
4. Current issues with sculpting detector
5. Conclusions

# Polarization Amplitudes




$|\Phi\Phi\rangle$ is a 2 vectors state of:

$$\left.\begin{array}{l}\left.\begin{array}{l}|\langle B|\Phi\Phi\rangle_{l=0}|^2 \sim |A_0|^2 \\ |\langle B|\Phi\Phi\rangle_{l=2}|^2 \sim |A_{//}|^2\end{array}\right\} \text{CP-even (short-lived,light)} \\ \\ |\langle B|\Phi\Phi\rangle_{l=1}|^2 \sim |A_\perp|^2 \quad \text{CP-odd (long-lived, heavy)}\end{array}\right\} \text{admixture}$$

-> an angular analysis is required to disentangle them

# The choice of basis

$|\Phi\Phi\rangle$ is an identical bosons state

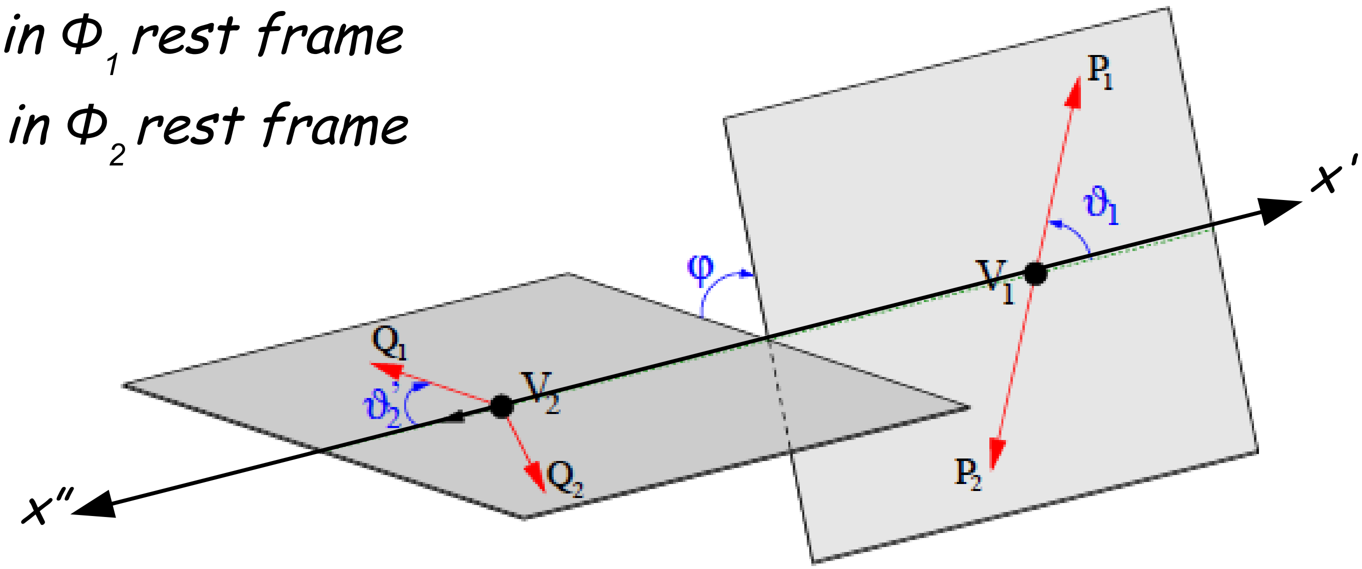
-> it must be treated symmetrically (Bose statistics)

**Helicity Basis $\omega = (\theta_1, \theta_2, \varphi)$**

*$x'$ ($x''$) : $\mathbf{p}_{\Phi 1}$ ($\mathbf{p}_{\Phi 2}$) direction in B rest frame*

*$\Theta_1$ : in $\Phi_1$ rest frame*

*$\Theta_2$ : in $\Phi_2$ rest frame*




Legend

$V_{1/2} = \Phi$

$P_{1/2} = K^{+/-}$

# Angular distribution

Differential angular decay distribution:
It contains both B and Bbar terms: we perform an untagged analysis (no care if the initial state is B or Bbar) -> sum B and Bbar terms; the results is:

$$\frac{d^4P(\vec{\omega},t)}{d^3\omega dt} = \mathcal{L}\left(|A_0|^2, |A_\parallel|^2, \Re(A_0^* A_\parallel), \vec{\omega}\right)\mathcal{U}\left(\Gamma_L, \phi_s, t\right) + \mathcal{H}\left(|A_\perp|^2, \vec{\omega}\right)\mathcal{V}\left(\Gamma_H, \phi_s, t\right)$$

Angular functions

time evolution

Comments:

- The distribution **doesn't factorize** in time and angular variables...
- We assume **to be in SM** (neglects CP violation):

fix $\phi_s = 0$

# Expected precision

CDF Note 8501, B → VV angular analysis

| | $B_d \to J/\psi K^{*0}$ | $B_d \to \phi K^{*0}$ |
|---|---|---|
| Yield | $934 \pm 24$ | $59 \pm 9$ |
| $\lvert A_0 \rvert^2$ | $0.572 \pm 0.026 \pm 0.018$ | $0.571 \pm 0.097 \pm 0.050$ |
| $\lvert A_\perp \rvert^2$ | $0.220 \pm 0.032 \pm 0.016$ | $0.206 \pm 0.089 \pm 0.045$ |
| $arg\{A_\parallel\}$ | $2.75 \pm 0.23 \pm 0.06$ | $2.97 \pm 0.52 \pm 0.26$ |
| $arg\{A_\perp\}$ | $2.99 \pm 0.15 \pm 0.02$ | $2.77 \pm 0.37 \pm 0.37$ |
| $\lvert A_\parallel \rvert^2$ | $0.207 \pm 0.032 \pm 0.007$ | $0.223 \pm 0.077 \pm 0.054$ |

In our $B_s \to \Phi\Phi$ samples we have about a factor 4 in the events number then we expect a factor ½ in the statistical uncertainties

~ 4-5%

# Strategy

## 1st : Time-Integrated Analysis

Our hypothesis: the statistics uncertainity is bigger than the systematic induced by the time integration (remember the non-factorization form of the distribution):

$O(\frac{\Delta\Gamma}{\Gamma})\sim 10\%$ where $\Gamma = \frac{\Gamma_L + \Gamma_H}{2}$ and $\Delta\Gamma = \Gamma_H - \Gamma_L$

## 2nd : Time-Dependent Analysis

...this must be done if our hypothesis is not correct, or if there are non-trivial complications due to the time evolutions

Unbinned Maximum Likelihood fit

# Time-integrated fit

Input event variables:

- Mass $m$;
- Angles $\omega=(\theta_1,\theta_2,\varphi)$

The p.d.f.:

$$P = (1 - f_{bgk})\ Mass(Signal)\ Ang(Signal) + f_{bgk}\ Mass(Bkg) Ang(Bkg)$$

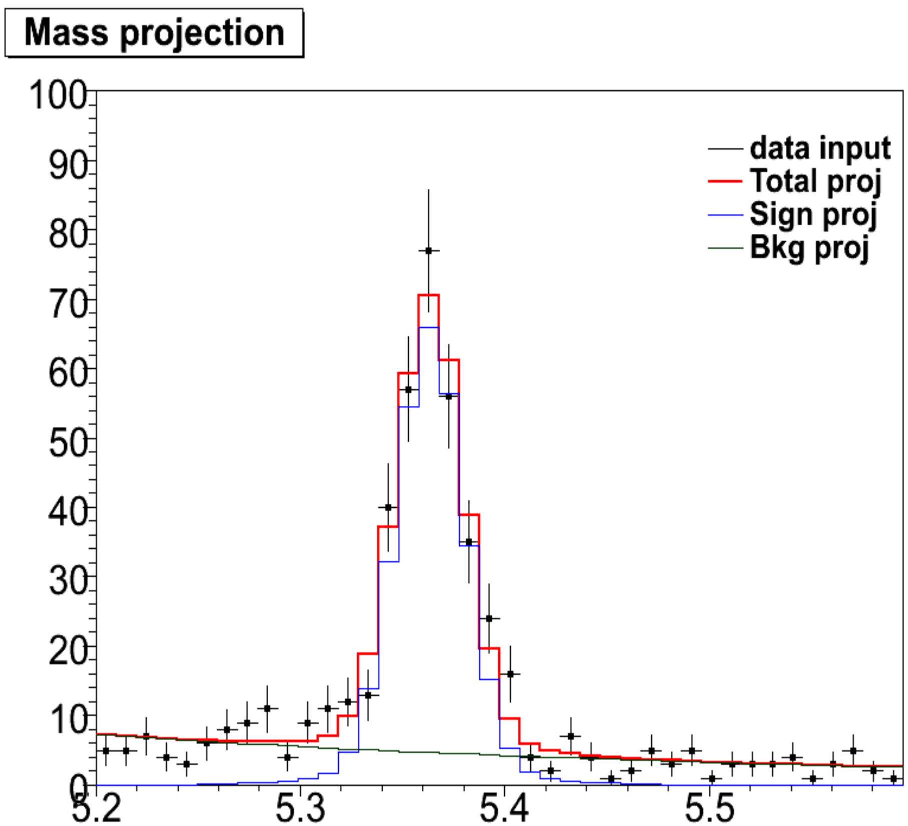
The fit parameters:

| | *Signal* | *Background* |
|---|---|---|
| *Mass* | $M_B$, $\sigma$ | $f_{bgk}$, slope |
| *Angular* | $\lvert A_0\rvert^2, \lvert A_0\rvert^2, \delta$ | $F_1, F_2, F_3$ |

# Time-integrated fit

- Mass(*Signal*) double gaussian function
- Mass(*Bkg*) exponentially decreasing function

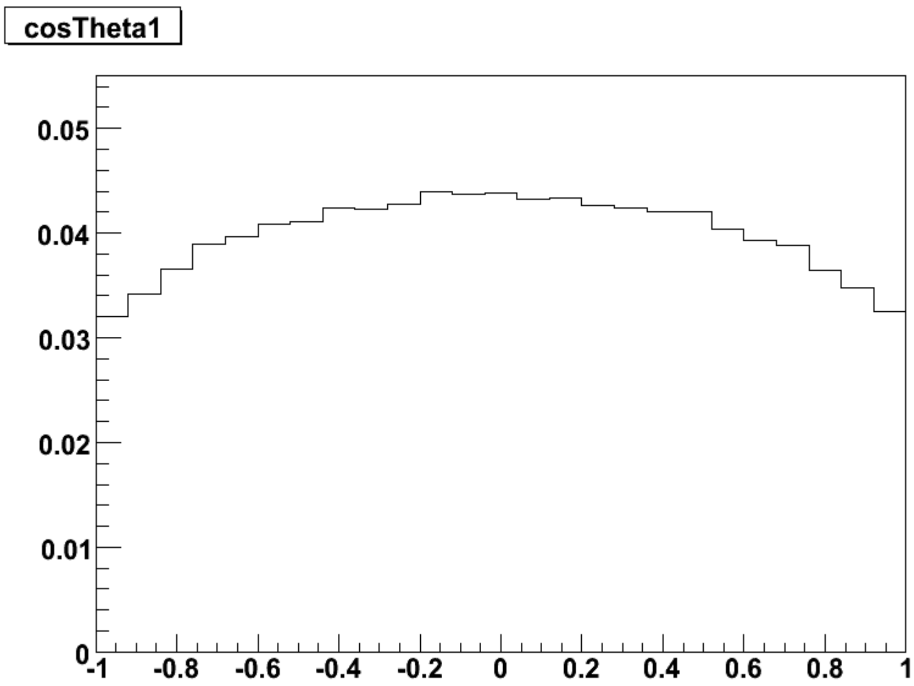
| | Fit resuts | BR fit |
|---|---|---|
| $M_B$ (GeV) | 5.364(1) | 5.364(1) |
| $\sigma$ | 0.016(1) | 0.017(1) |
| $f_{bgk}$ | 0.38(3) | 0.39(3) |
| slope | 2.7(7) | 2.5(7) |

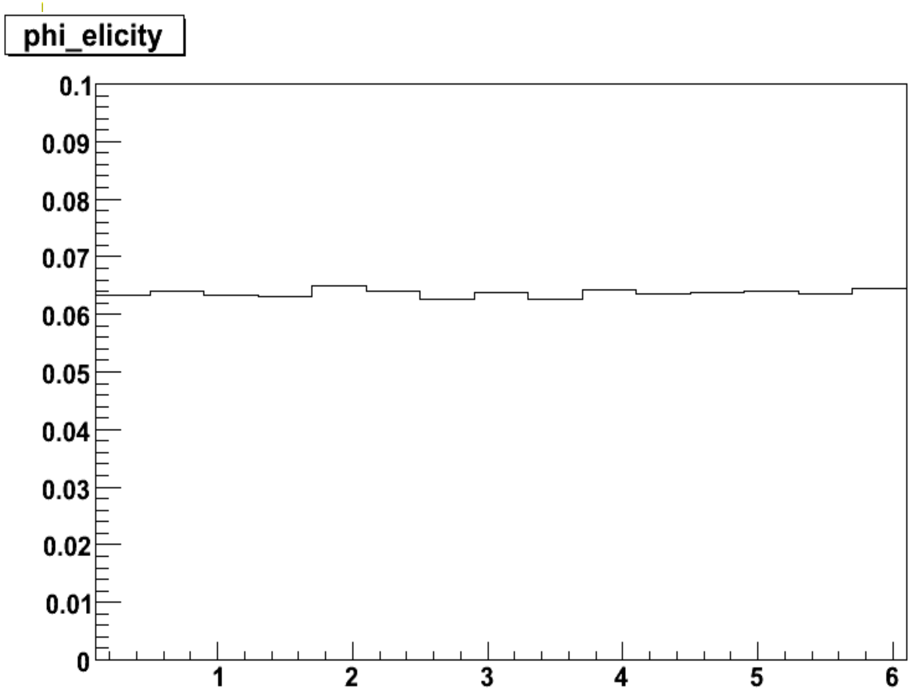


# Time-integrated fit

- Ang(*Signal*) : $\dfrac{d^3P(\vec{\omega})}{d^3\omega}$ **ε(ω)**

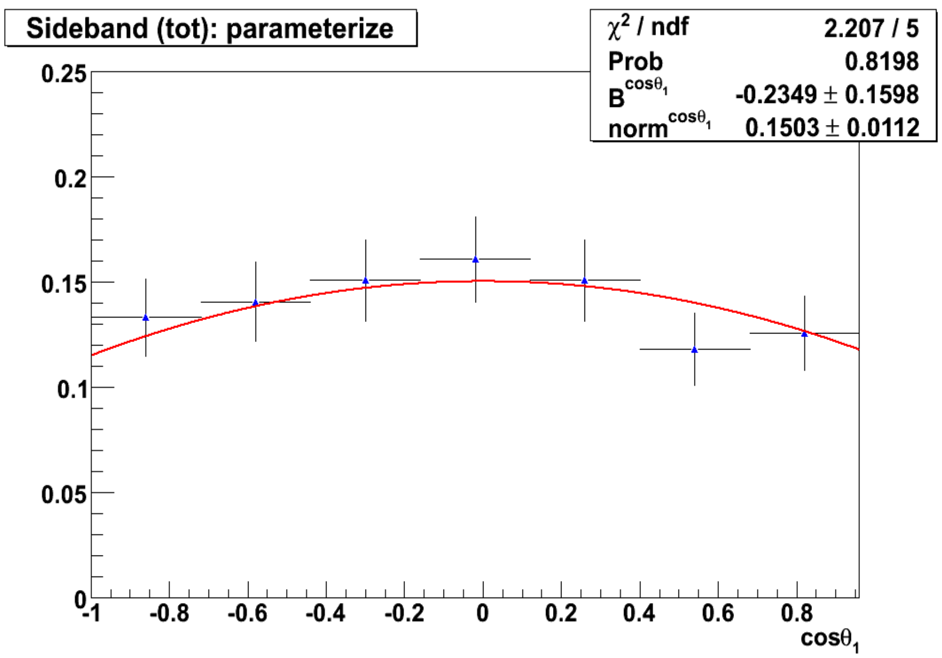
**ε(ω)** **detector sculpting** on angular variables:
3D histo of helicity angles from non polarized MC (flat generated)

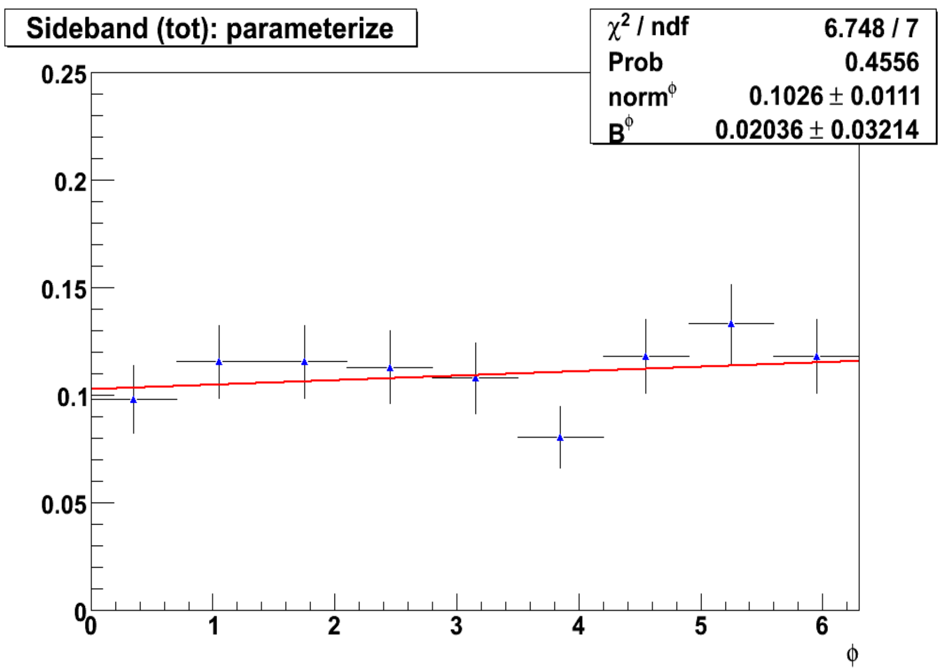


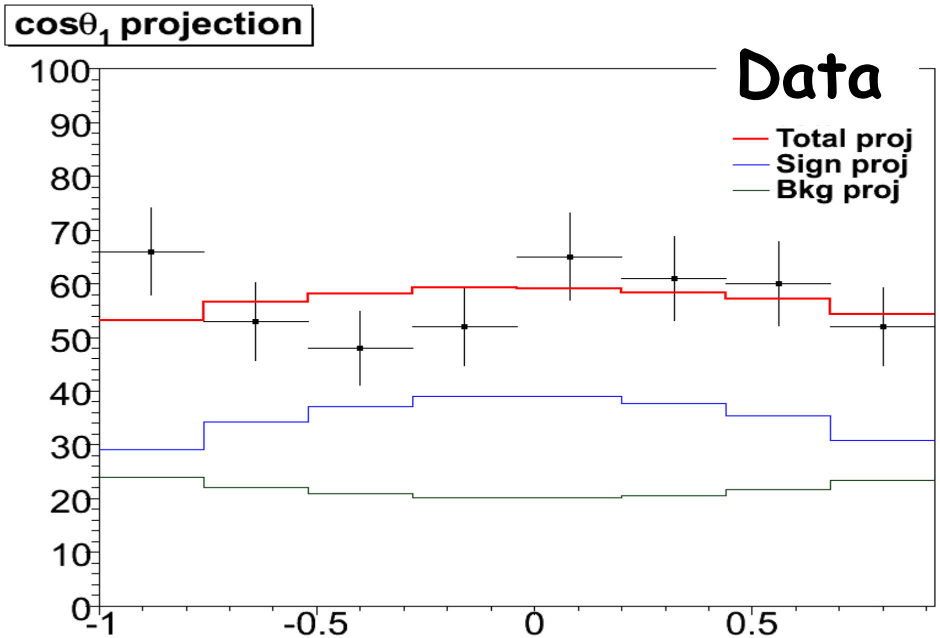
# Time-integrated fit

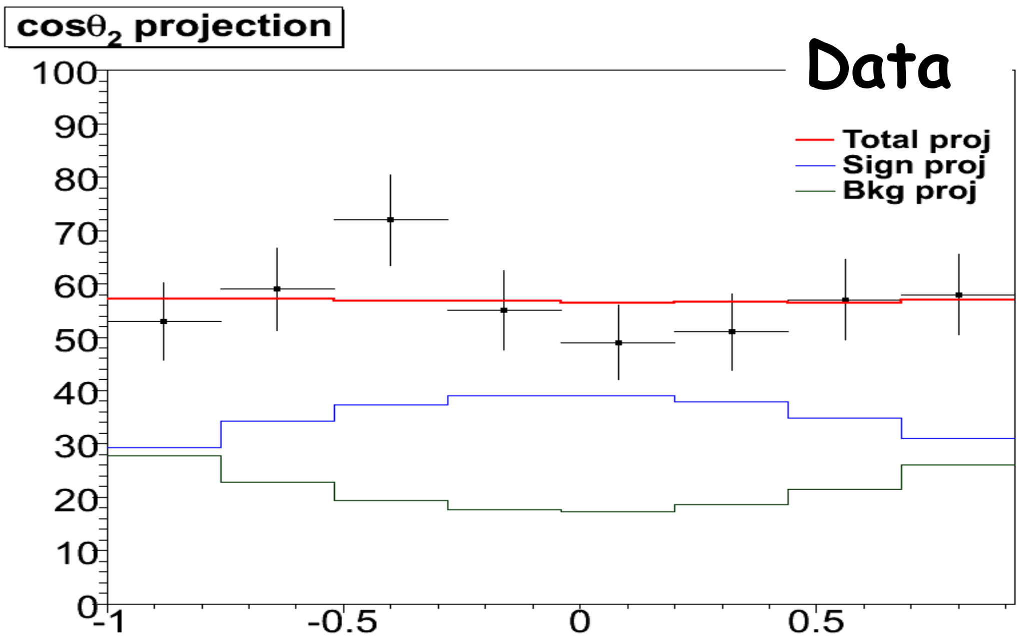
- Ang(*Bkg*) modeled from the events of the Bs mass sideband regions

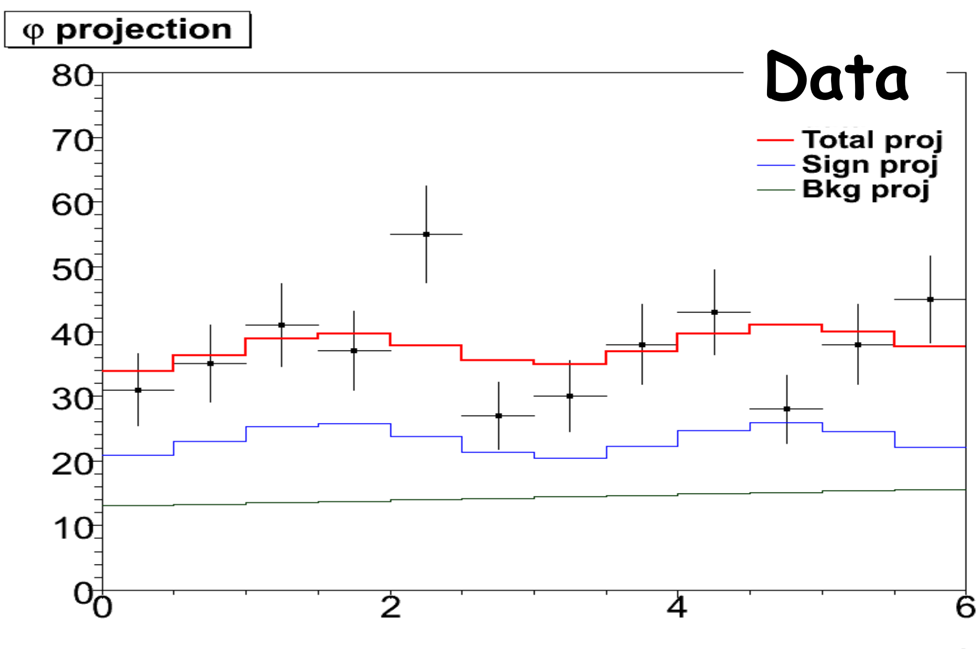


# Time-integrated fit




The amplitudes statistical uncertainty is of about 4%

# Fit Tests

Purpose:

- To validate the correctness of its implementation;
- investigate the likelihood behavior;
- detect any potential fit biases;

Tests already performed:

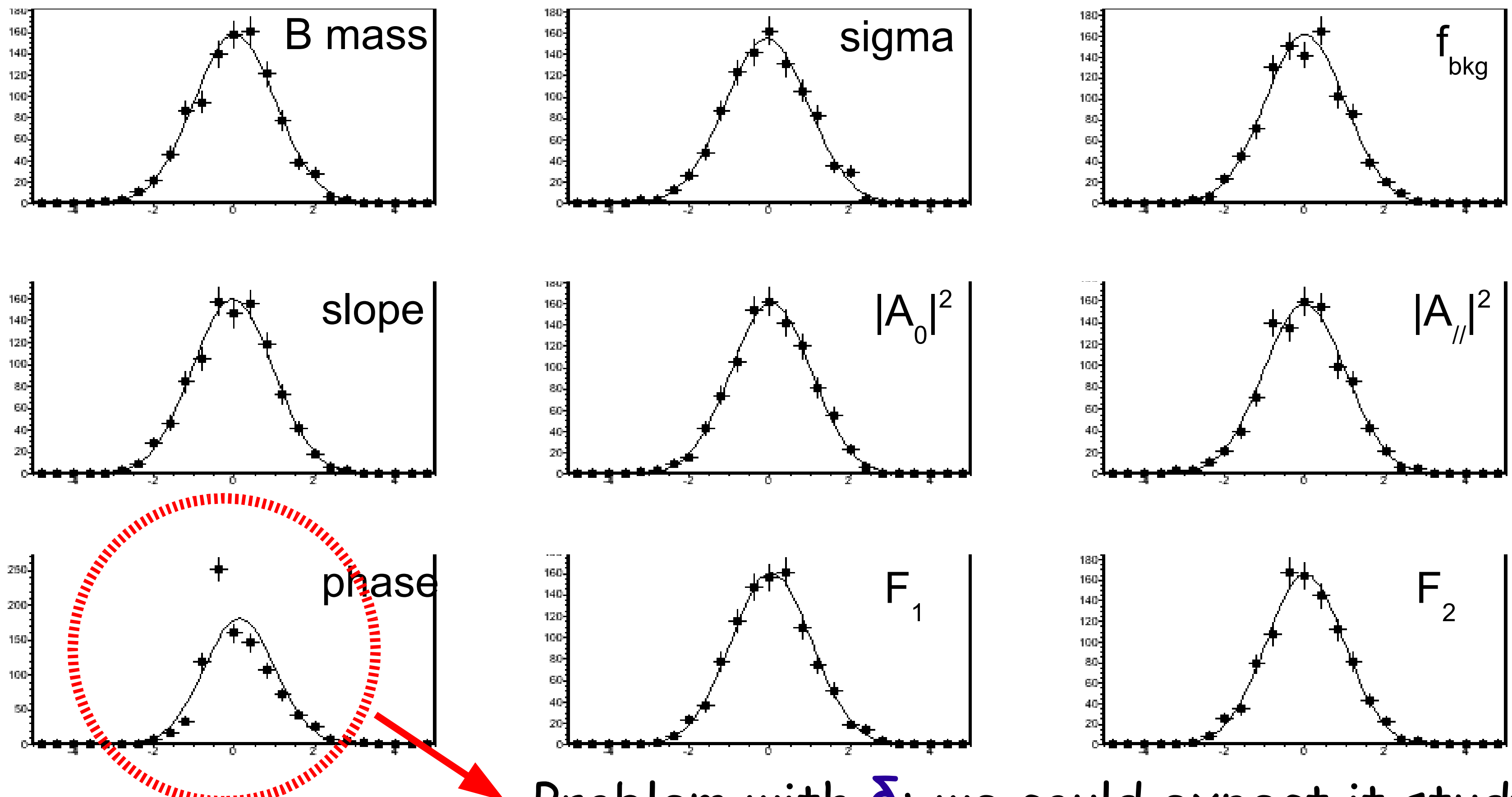
√ Pulls distributions;

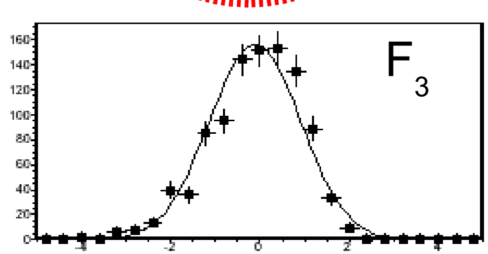
√ Use $B_s \to J/\psi\, \Phi$ as control sample: do the same fit and compare the results with the published ones;

√ Fit the realistic MC;

# Fit Tests

Pulls distributions **OK**

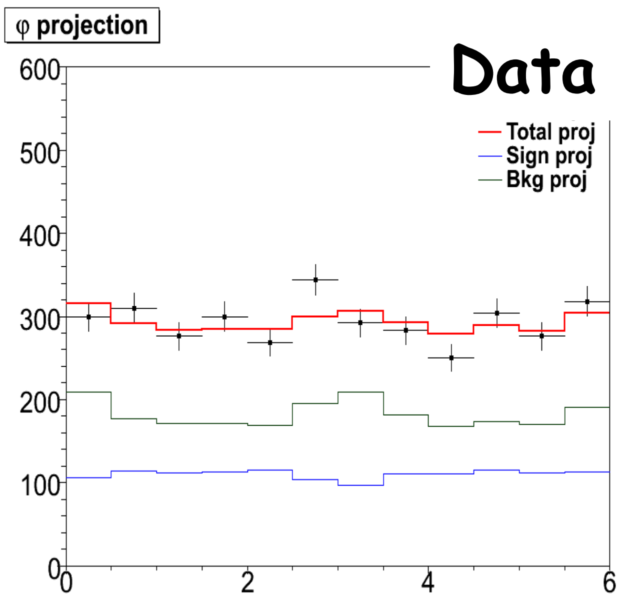


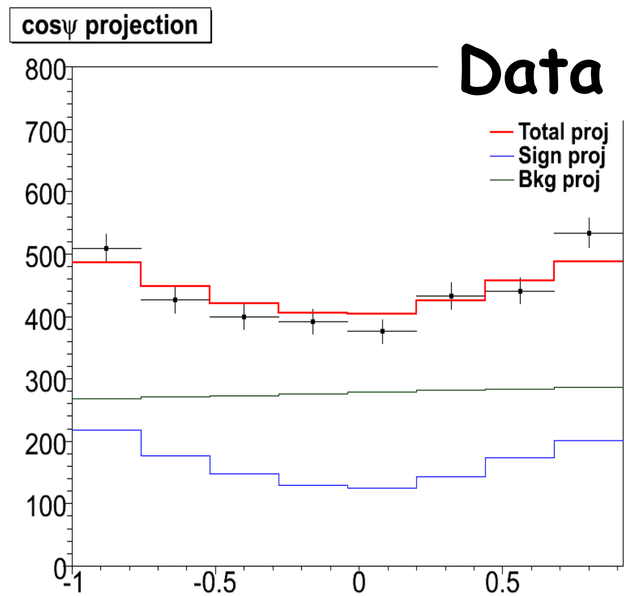



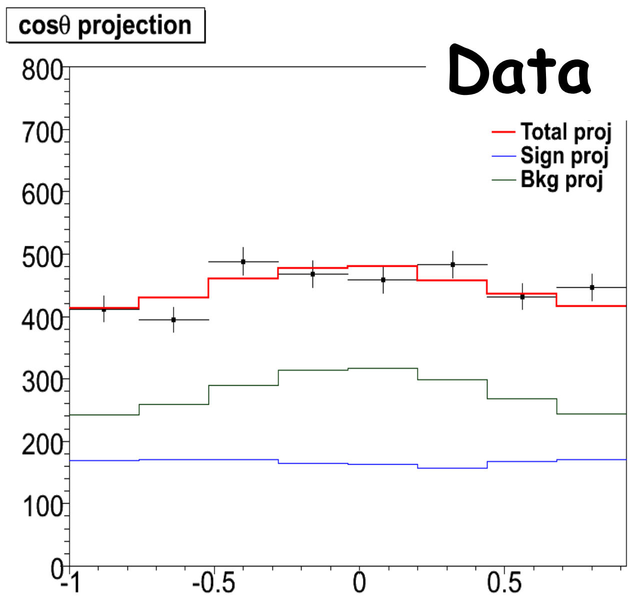

Problem with $\delta$: we could expect it studying previous similar analysis... increasing the statistic in toyMC experiments the problem disappear.

# Fit Tests

$B_s$ -> $J/\psi\ \Phi$ fit OK



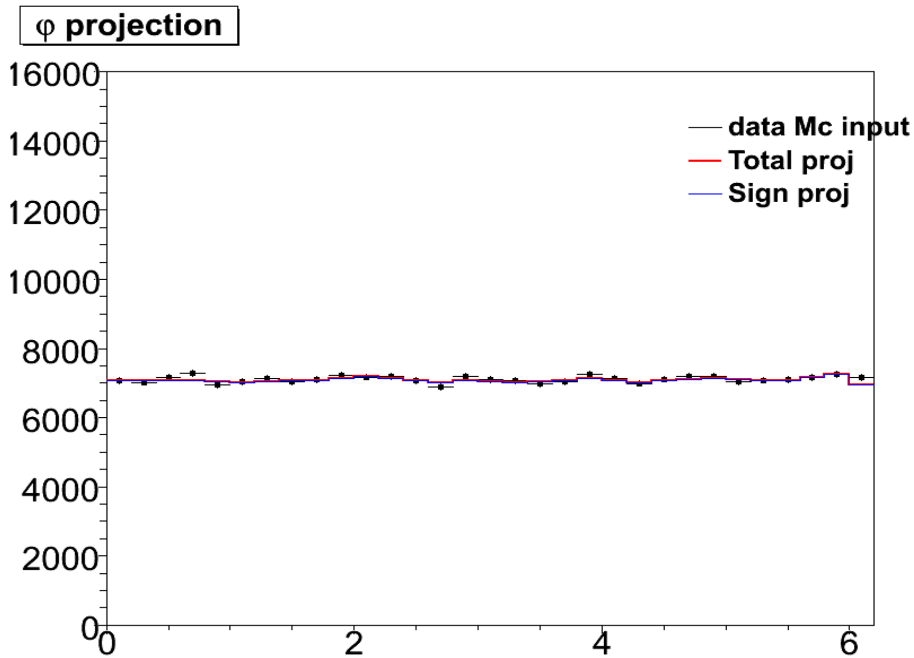

| | Fit resuts | Published result* |
|---|---|---|
| $\lvert A_0\rvert^2$ | 0.54(2) | $0.531(29)_{stat}(07)_{syst}$ |
| $\lvert A_{//}\rvert^2$ | 0.25(3) | $0.239(29)_{stat}(11)_{syst}$ |
| $\delta$ | 0.0(3) | $0.230(26)_{stat}(09)_{syst}$ |

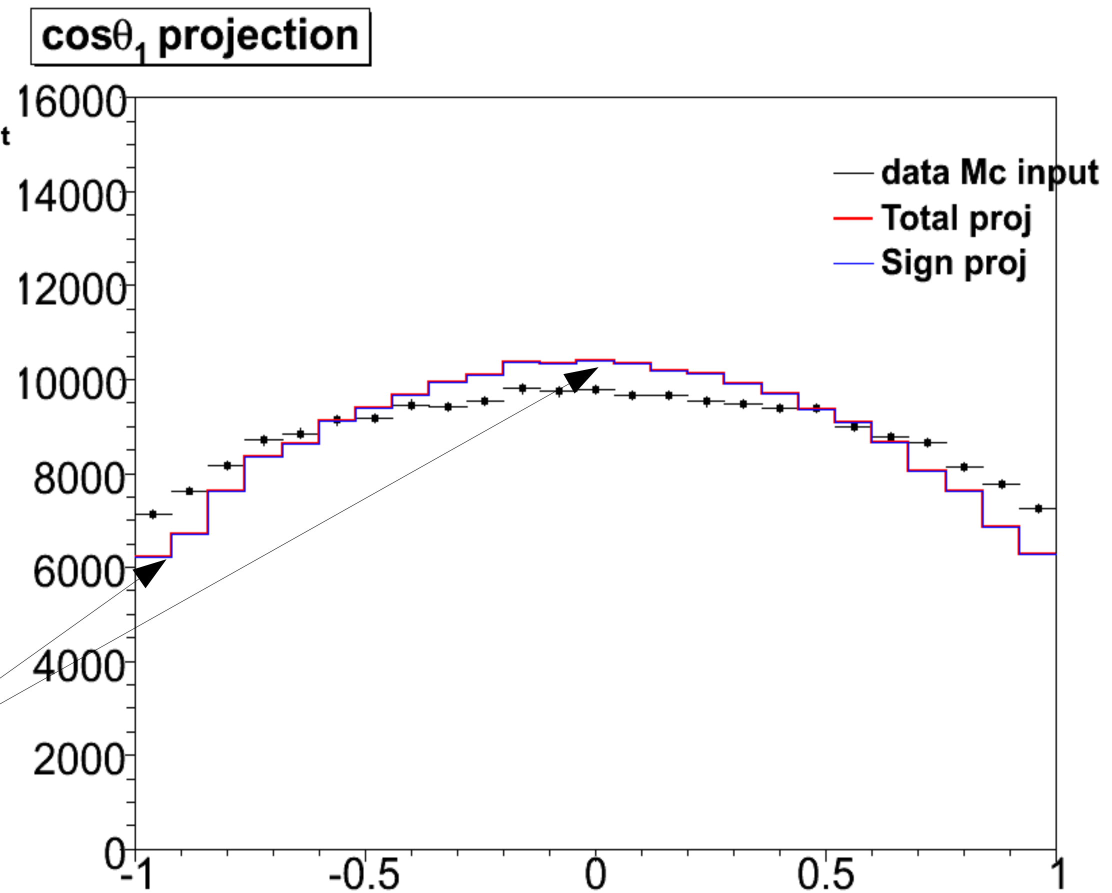
*Measurement of Lifetime and Decay-Width Difference in B0(s) --> J/psi phi Decays
T. Aaltonen et al., The CDF Collaboration, Phys. Rev. Lett. 100, 121803 (2008).

# Time-integrated fit

Fit the realistic MC:

The sample has 220 000 signal events generated flat (about 1000 times of events in our data samples)

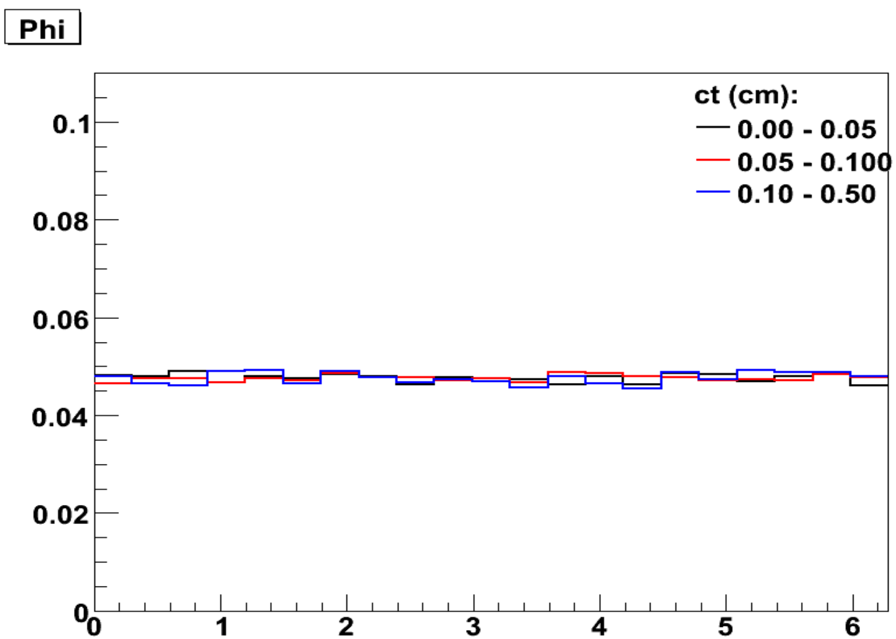


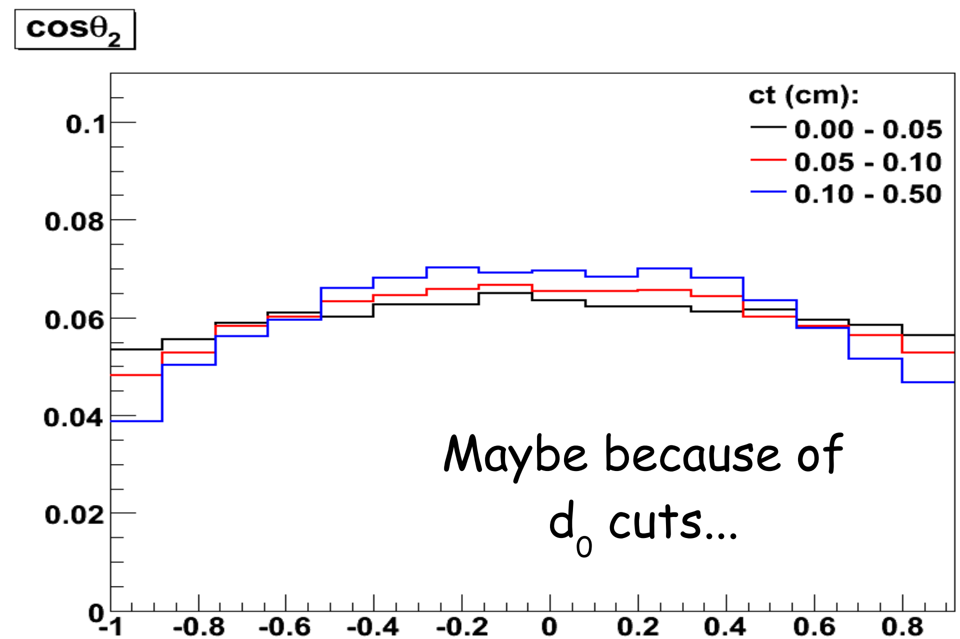




Problem with $\cos\theta_{1/2}$ projections!

# Why???

In the time-integrated fit there is the implicit assumptions that the angular sculpting of the detector is time indipendent.
But, if we divide the sculpting in slice of cτ ...




| | Fit resuts | Generated | Δ |
|---|---|---|---|
| $\|A_0\|^2$ | 0.320(1) | 0.333 | 1% |
| $\|A_{//}\|^2$ | 0.355(1) | 0.333 | 2% |
| δ | 1.572(5) | 1.571 | |

# ...and then?

A solution is to implement the time-dependent fit:
we have to introduce also the t of the event as input fit variables

This deals with the time dependent angular distribution

$$\frac{d^4P(\vec{\omega},t)}{d^3\omega dt} \quad \varepsilon(\omega,t)$$

and automatically eliminates the systematic uncertainty from time integration.

We have to find a feasible way to deal with cτ dependences of the sculpting.
A solution is to bin the 3D histogram sculpting in slice of cτ
But pay attention! In this way the p.d.f becomes a conditional probability...

$$\varepsilon(\omega,t) \longrightarrow \varepsilon(\omega|t)$$

We are still working with this "appealing" conceptual business!

# Conclusions

> the time integrated analysis is almost completely understood

> the time dependent fit is in progress...

> we have to introduce the reflections in the bkg p.d.f

> we have to study the systematics:

- S-wave under peak signal
- CP violation dependences
- Phase bias in the fit results
- trigger effects
- ...