



# Time dependent CP violation study in the decay channel $B^0 \rightarrow K_S^0 \pi^0 \gamma$

Alberto Martini  
University of Pisa - Belle II Pisa Group

6th BelleII Italian meeting  
Roma Sapienza, 14 December 2016



UNIVERSITÀ DI PISA

# OUTLINE

- Motivations
- Reconstruction of  $B_{\text{sig}}$  and relative decay chain
- $B_{\text{tag}}$  vertex reconstruction and tagging procedure
- Conclusion and prospects

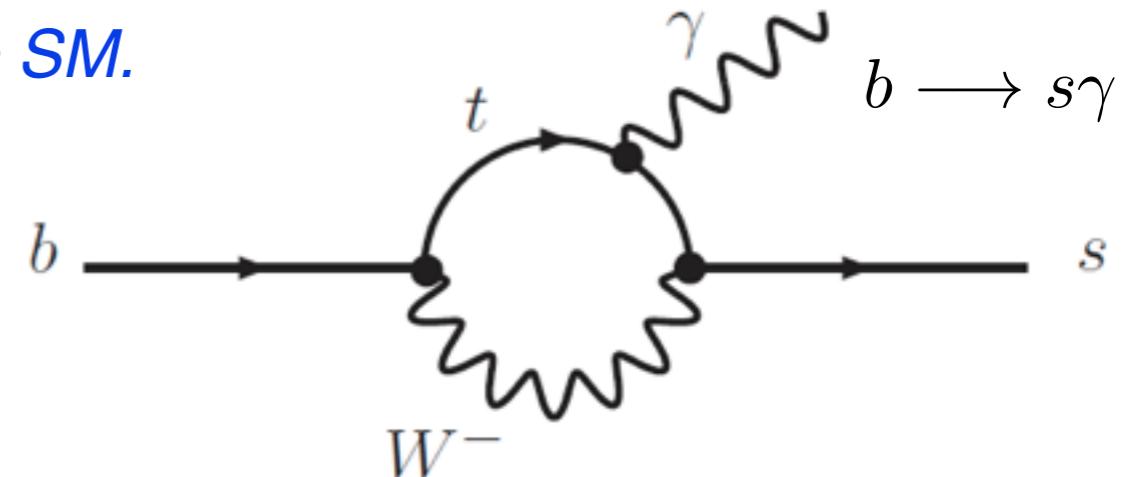


# Motivation

**Aim:** Evaluation of sensitivity of the parameters S and C in the decay channel  $B^0 \rightarrow K_S^0 \pi^0 \gamma$

*Sensitivity to contributions from physics beyond the SM.*

The photon helicity is predominantly left handed  
(right handed) in  $b \rightarrow s\gamma$  ( $\bar{b} \rightarrow \bar{s}\gamma$ ) in the SM.



In  $B^0 \rightarrow (K_S^0 \pi^0)\gamma$  the interference between mixing  $B^0 - \bar{B}^0$  and direct decay is suppressed.



Evidences of CPV asymmetry means new physics.

**Measurements done up to now:** <http://www.slac.stanford.edu/xorg/hfag/triangle/moriond2016/index.shtml#bsgamma>

- Babar:
  - 467 million  $\Upsilon(4S) \rightarrow B\bar{B}$  decays  $\rightarrow S_{K_S^0 \pi^0 \gamma} = -0.17 \pm 0.26 \pm 0.03$  and  $C_{K_S^0 \pi^0 \gamma} = -0.19 \pm 0.14 \pm 0.03$
- Belle:
  - 535 million  $\Upsilon(4S) \rightarrow B\bar{B}$  decays  $\rightarrow S_{K_S^0 \pi^0 \gamma} = -0.10 \pm 0.31 \pm 0.07$  and  $C_{K_S^0 \pi^0 \gamma} = 0.20 \pm 0.20 \pm 0.06$

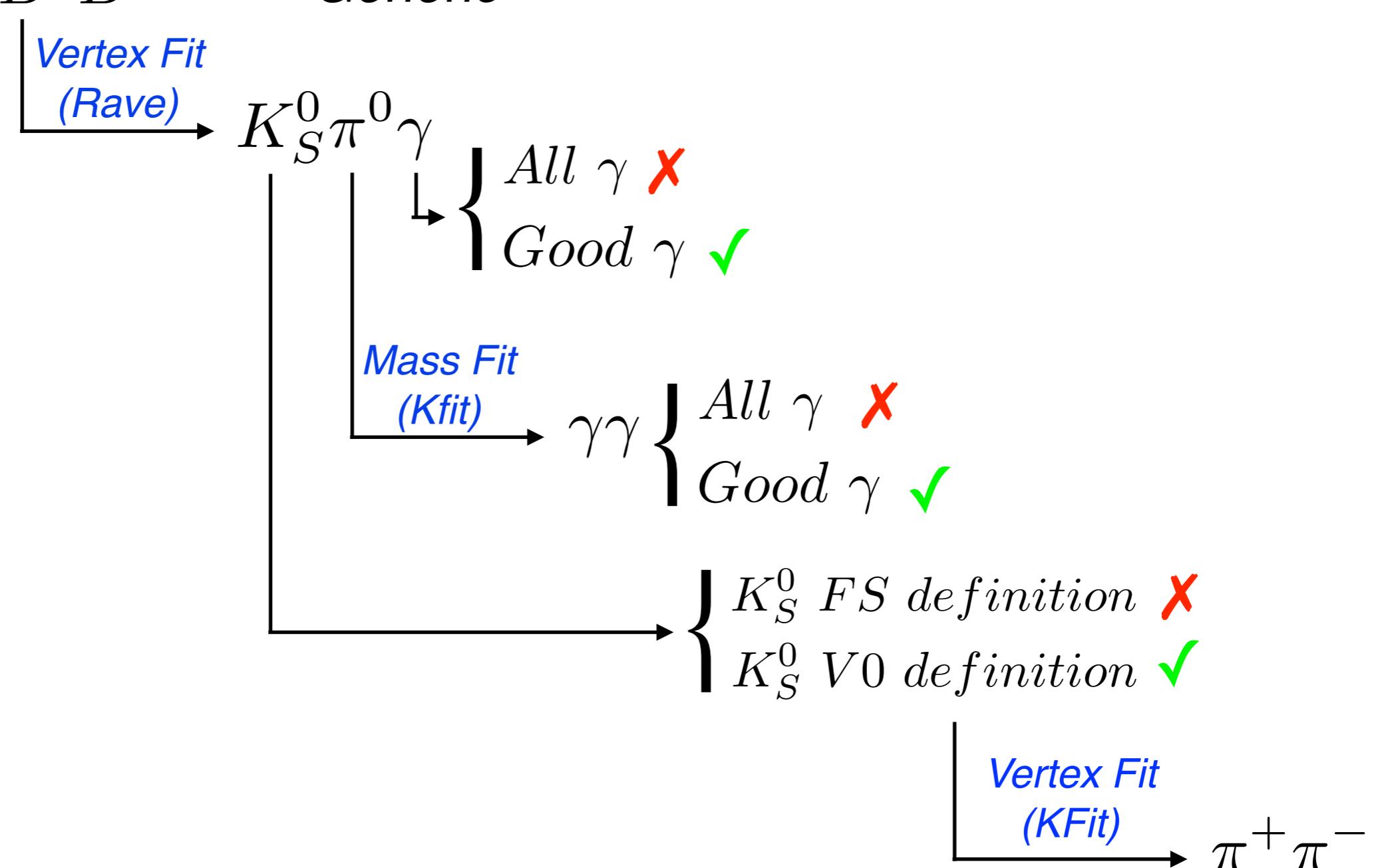


# Event reconstruction

Generated and reconstructed 10000 signal events  $\Upsilon(4S) \rightarrow B\bar{B}$  of  $B^0/\bar{B}^0$  decaying into  $K_S^0\pi^0\gamma$  with release version: 00-07-01. *No machine background.*

## Reconstructed decay chain

$\Upsilon(4S) \rightarrow B^0\bar{B}^0 \longrightarrow \text{Generic}$



# Efficiency studies on a pure sample of data

Efficiency defined as:

$$\varepsilon^{reco} = \frac{\# Matched\ reconstructed\ particles}{\# Generated\ particles}$$

Purity defined as:

$$\varepsilon^{purity} = \frac{\# Matched\ reconstructed\ particles}{\# Reconstructed\ particles}$$

Efficiencies studies done on pure signal sample: Generated and reconstructed 10000 events of  $\Upsilon(4S) \rightarrow B\bar{B}$  with  $B_{sig} \rightarrow K_S^0\pi^0\gamma$  and the other  $B^0$  decays into:  $B^0 \rightarrow \nu\bar{\nu}$

	Ks	$\pi^0$	$\gamma^*$	$B^0_{sig}$
$\varepsilon^{reco}$ (%)	58.6	53.7	87.4	26.2

For the next studies I generated and reconstructed 10000 events of  $\Upsilon(4S) \rightarrow B\bar{B}$  with  $B_{sig} \rightarrow K_S^0\pi^0\gamma$  and the other  $B^0$  decays generic.



\*gamma definition: (<https://confluence.desy.de/display/BI/Physics+Pi0Reco>)

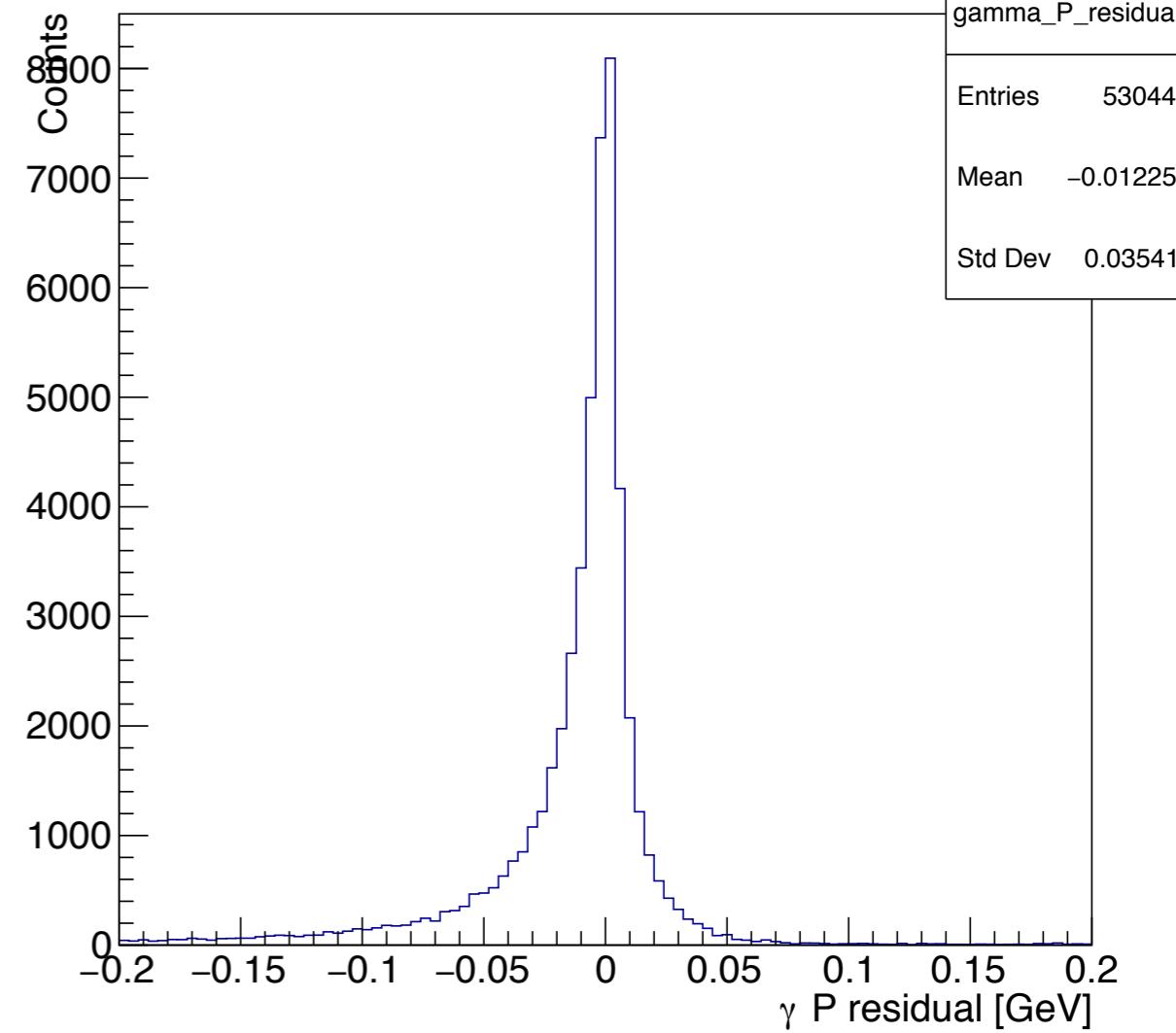
# Reconstruction of $\gamma$

$\gamma$  P residual

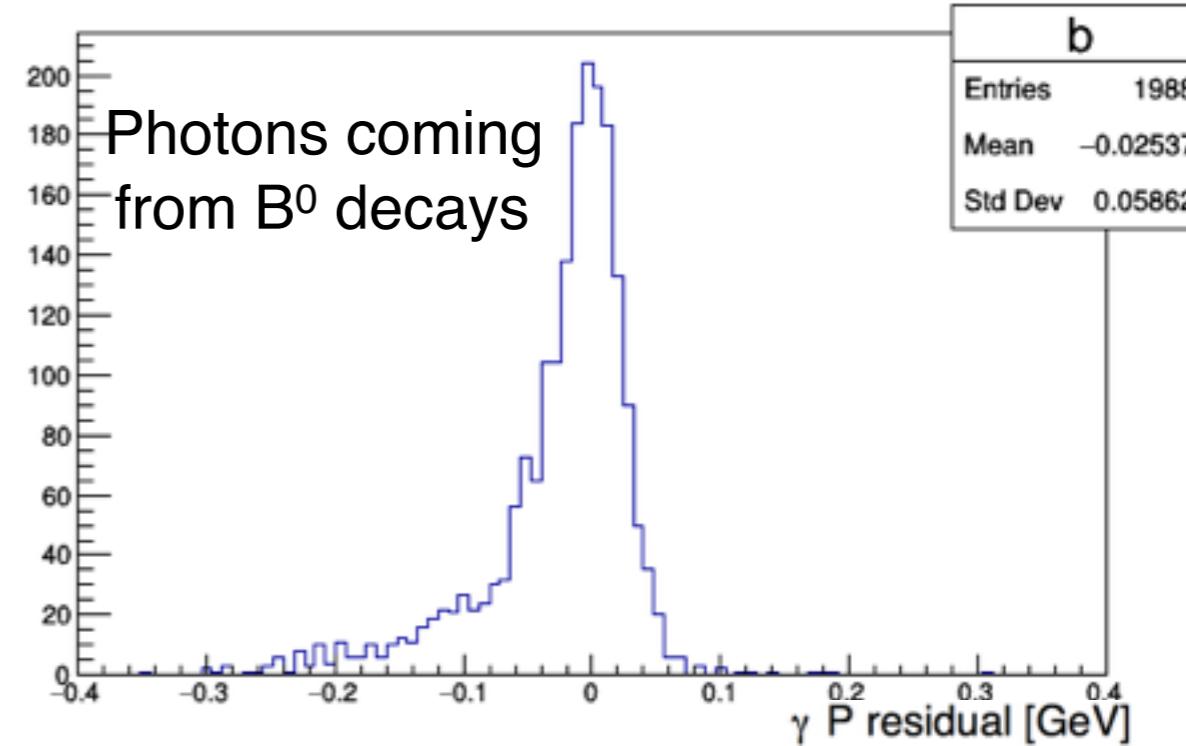
## Selection cuts

(depending from detected area (<https://confluence.desy.de/display/BI/Physics+Pi0Reco>))

- $E \geq 90$  MeV
- $\text{minC2HDist} \geq 40$  cm
- $E9/E25 \geq 0.75$



**Long negative tail that affected also  
the reconstruction of  $\pi^0$  and  $B^0$**

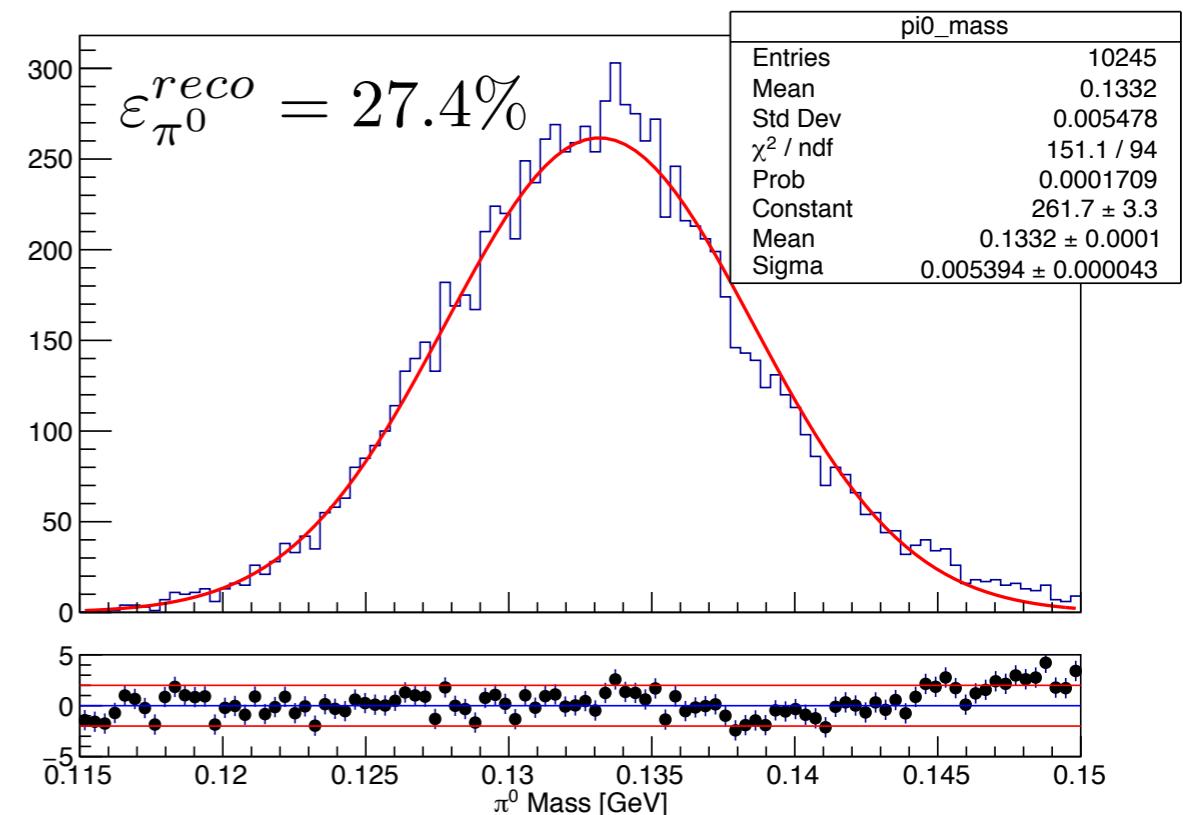


# Reconstruction of $\pi^0 \rightarrow \gamma\gamma$

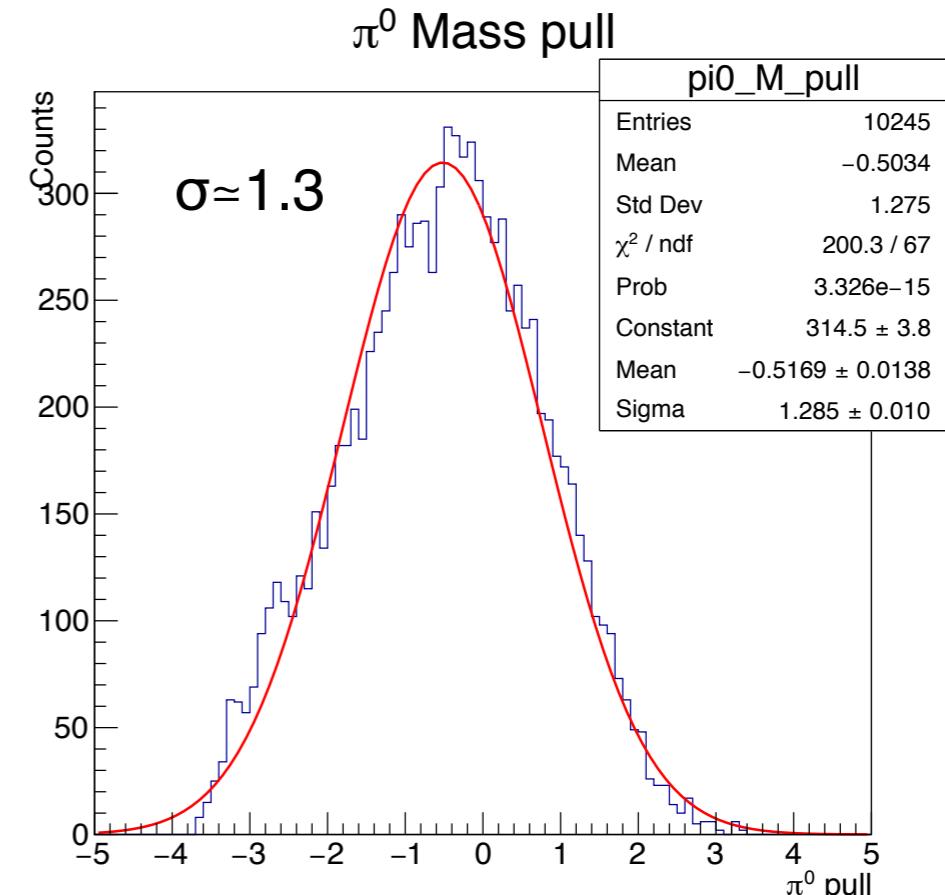
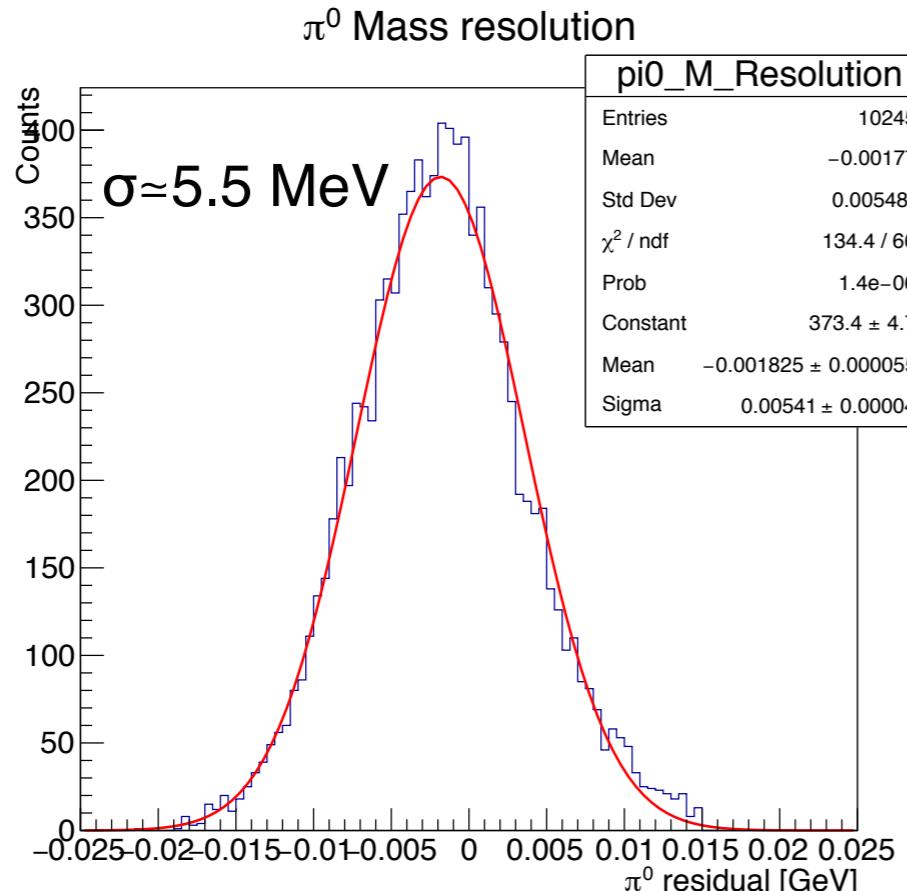
**Correctly reconstructed  $\pi^0$**

## Selection cuts

- Good photons list used
- Mass cut  $0.11 \text{ GeV} < M_{\pi^0} < 0.150 \text{ GeV}$
- Mass Fit with p-value  $>1\%$  (*Kfit*)



## Small bias on residuals and pull distributions:

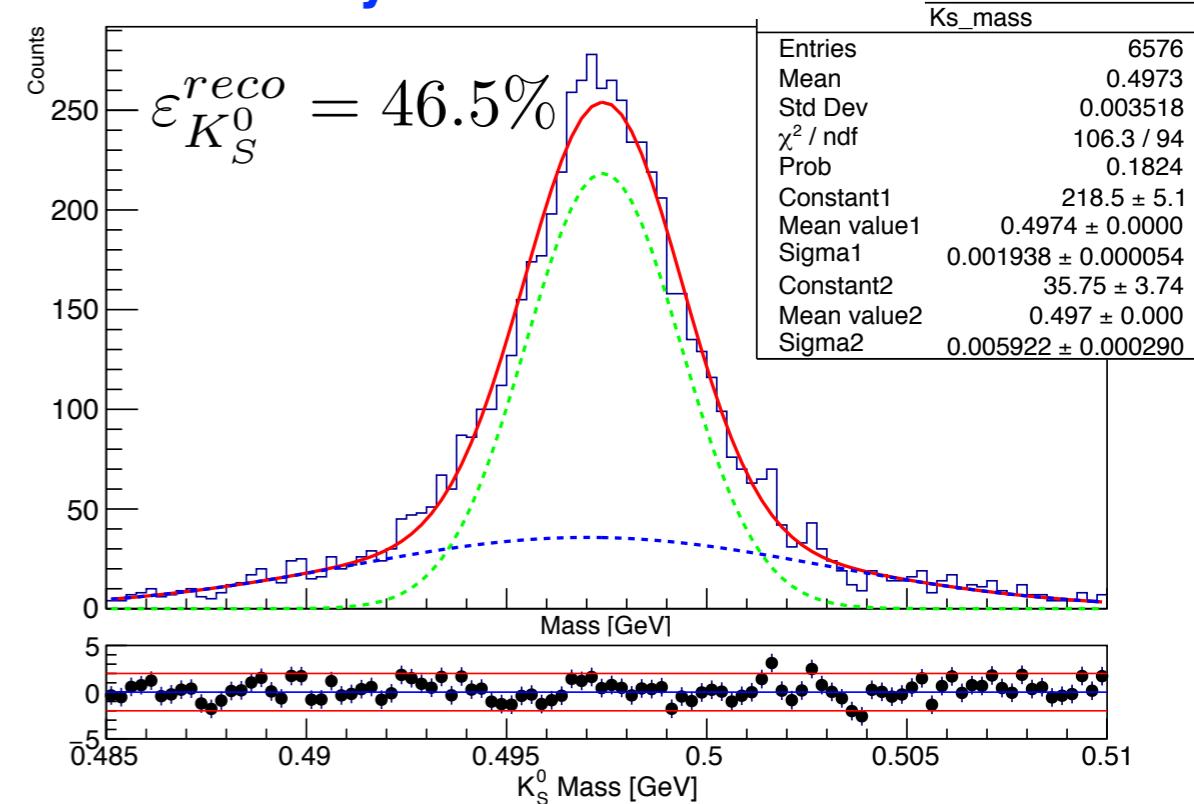


# Reconstruction of $K_S^0 \rightarrow \pi^+ \pi^-$

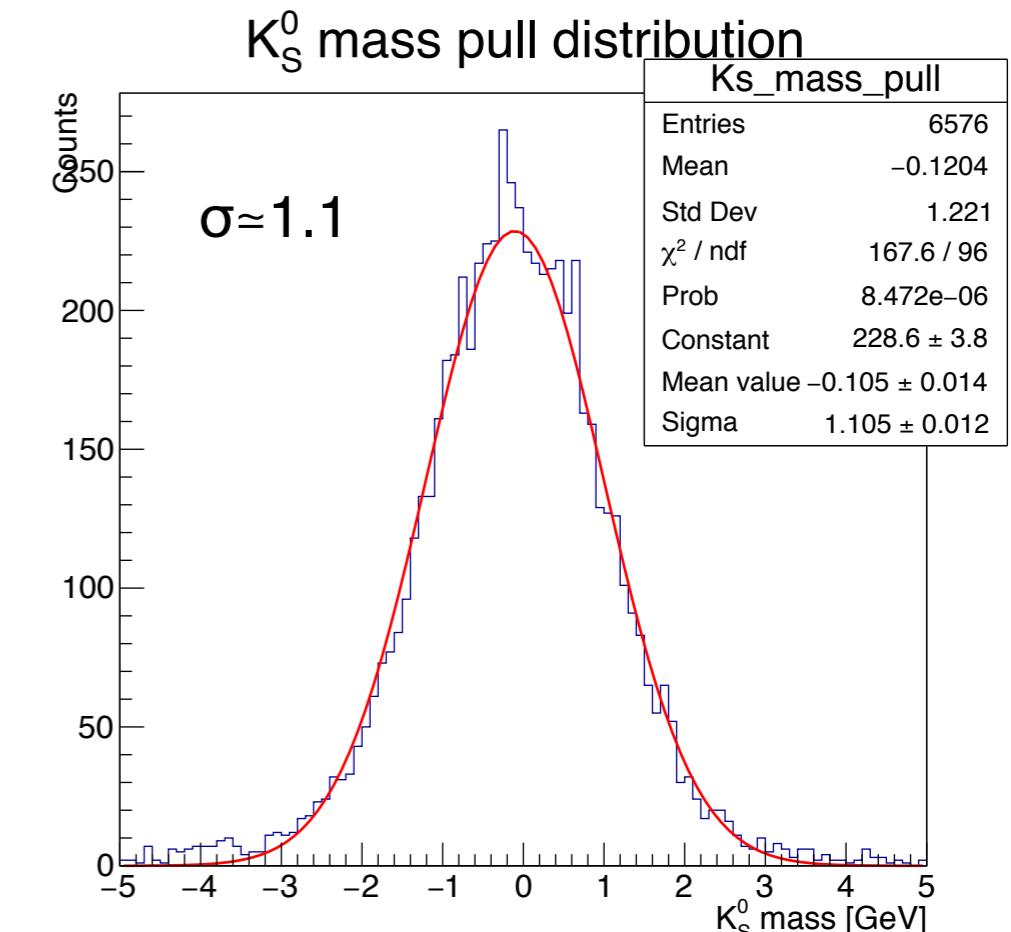
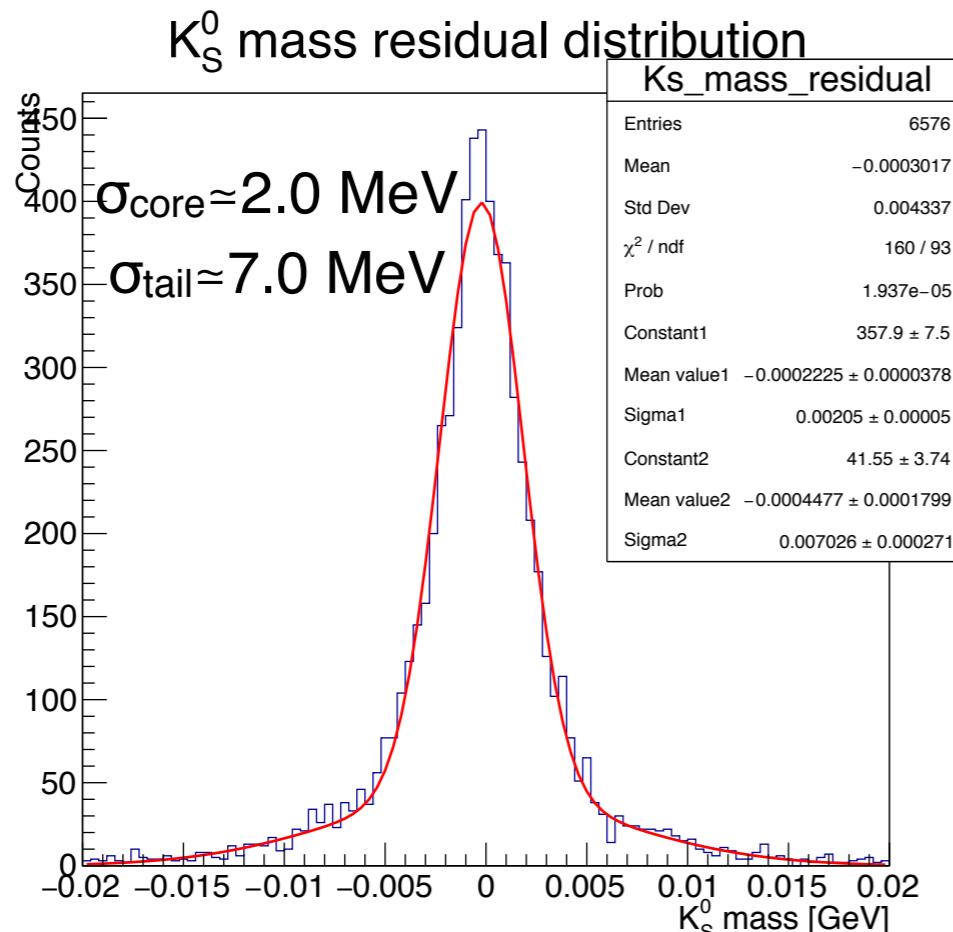
## Selection cuts

- Use V0 objects
- Mass cut  $0.4 \text{ GeV} < M_{K_S^0} < 0.6 \text{ GeV}$
- Vertex Fit (KFit) with p-value  $> 1\%$

## Correctly reconstructed Ks



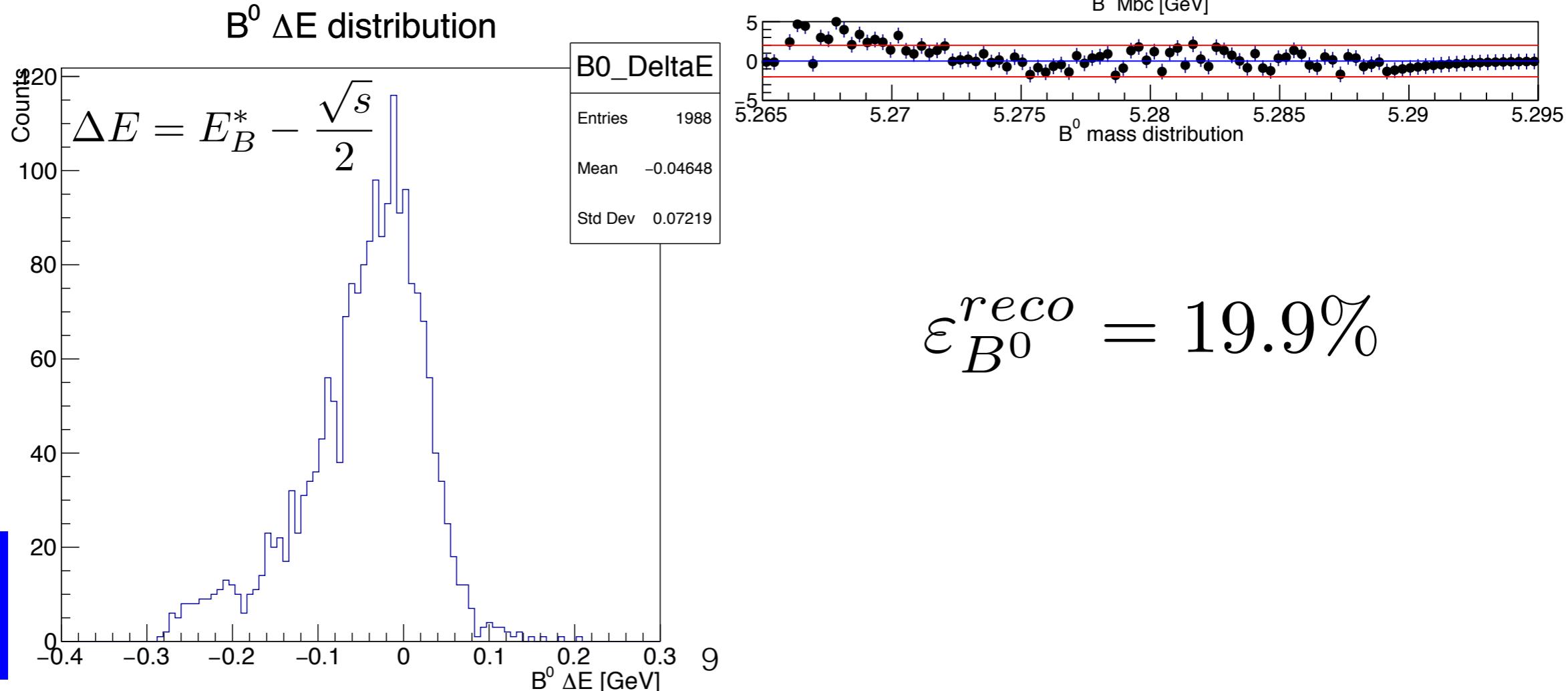
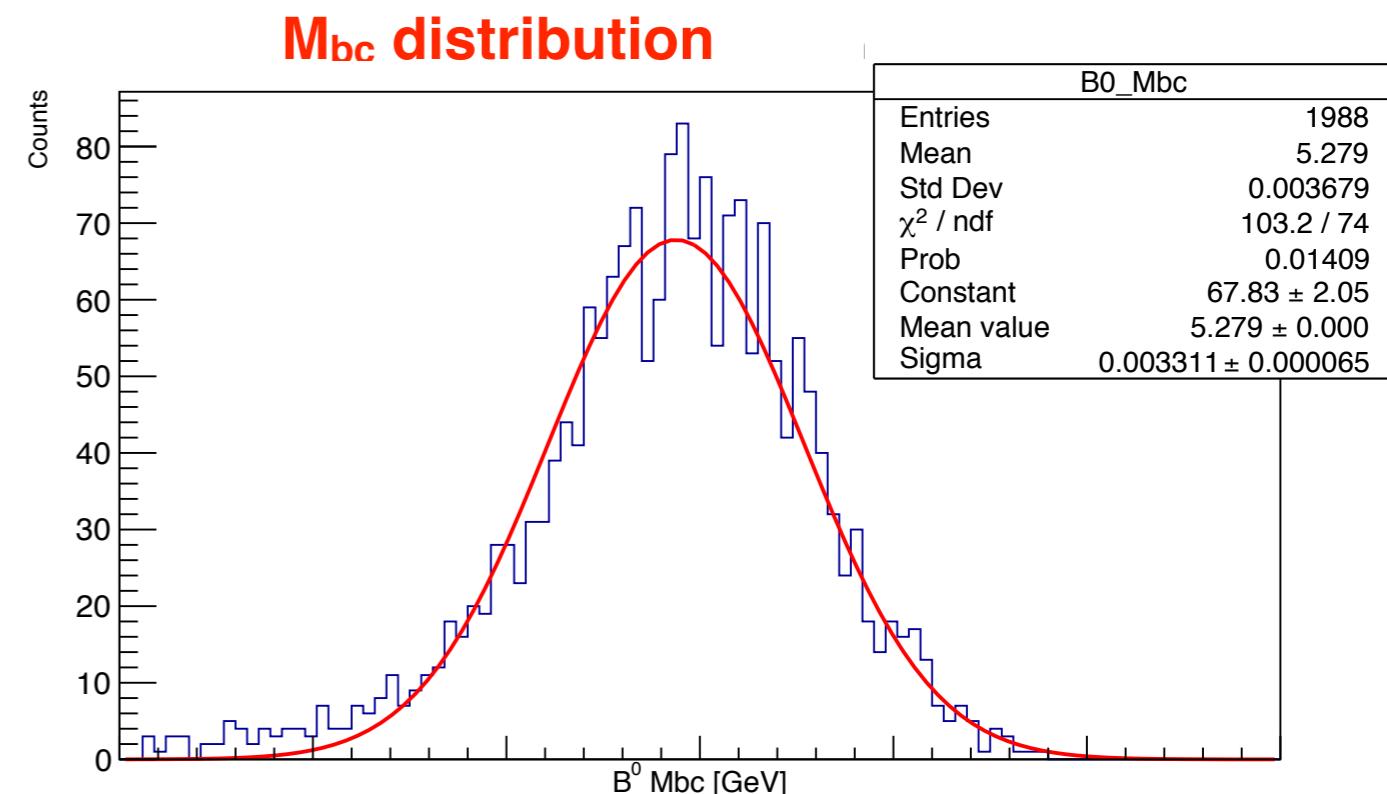
Small bias on residuals and pull distributions:



# Reconstruction of $B^0$ decay: $B^0 \rightarrow K_S^0 \pi^0 \gamma$

## Selection cuts

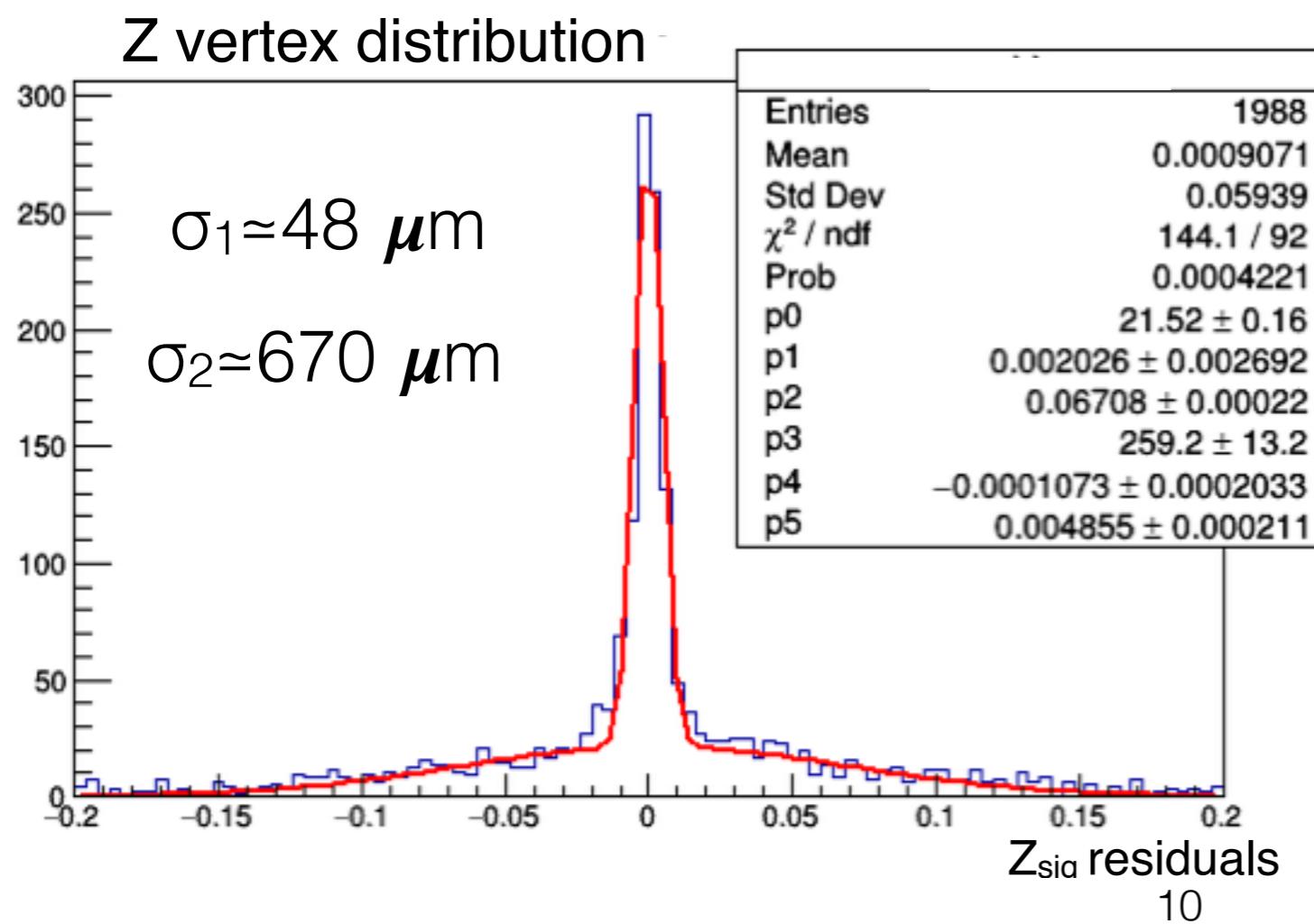
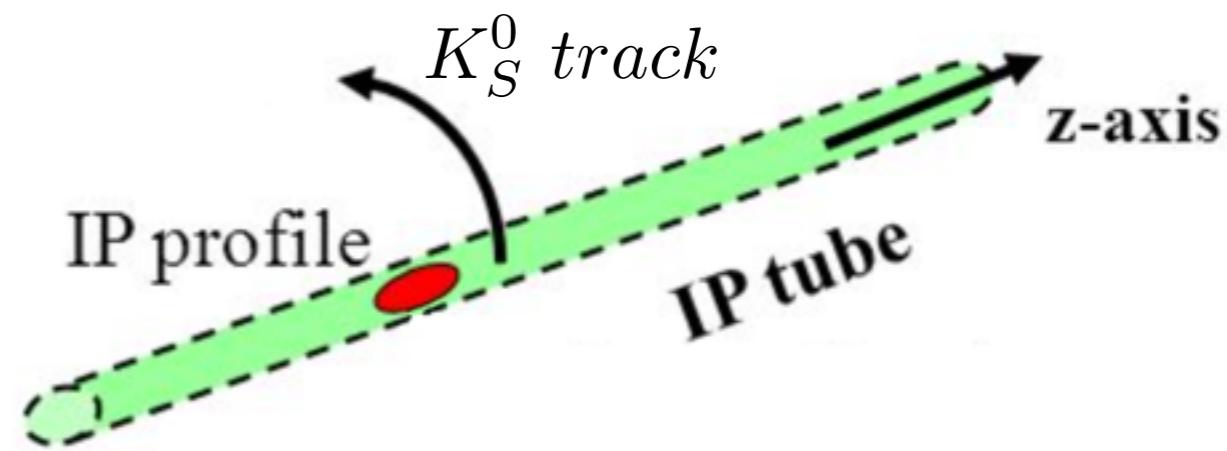
- Mass cut  $5.0 \text{ GeV} < M_{B^0} < 5.5 \text{ GeV}$
- Vertex Fit (Ravefit) with p-value  $> 1\%$   
IP tube constraint (“iptube” option).



# $B^0_{\text{sig}}$ vertex reconstruction

## IP-Tube constraint

In order to reconstruct the  $B^0$  vertex I need the track information coming from the  $K_S^0$  and an additional constraint (iptube). The iptube is defined as an ellipse placed around the boost direction with transversal dimensions equal to the beam spot:  $\sigma_x \approx 6 \mu\text{m}$   $\sigma_y \approx 42 \text{ nm}$ .  $\sigma_z \approx 2\text{cm}$

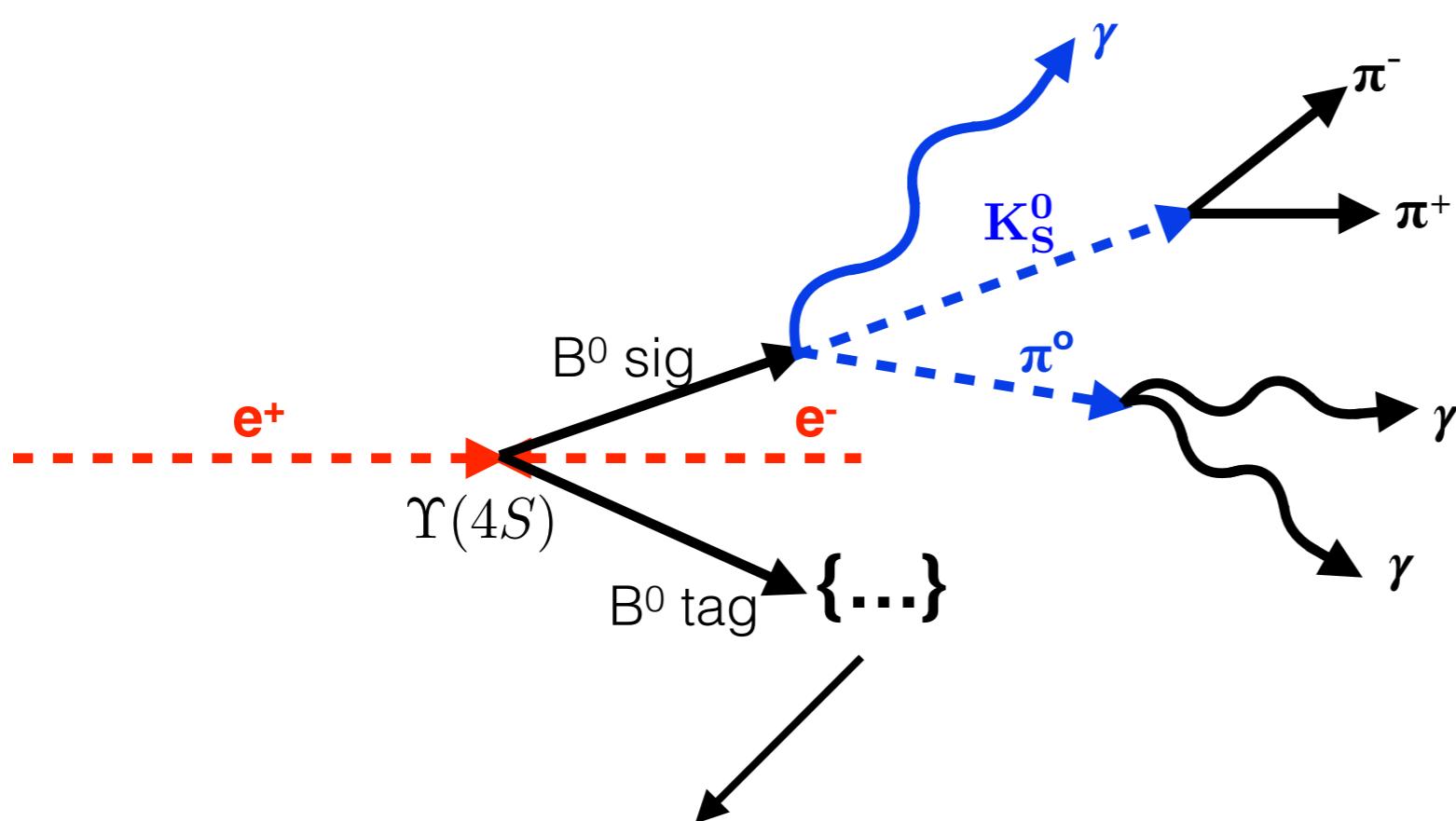


Considering the small x-y dimensions of the iptube constraint, is possible that some  $B^0$  that have large transverse flight distance are not well fitted. I will check it changing the transversal dimension of the tube, in order to explain these long tails.

# $B^0_{\text{tag}}$ vertex reconstruction

I need to reconstruct also the  $B_{\text{tag}}$  vertex and perform the flavour tagging in order to:

- Reconstruct the z distance between the signal  $B^0$  and tag  $B^0$  vertices ( $\Delta z$ ).  
It is necessary to obtain the  $\Delta t$  distribution;
- Know the flavour of the signal  $B^0$  (*information not used yet*).



$B_{\text{tag}}$  decays generically  
in all decay modes.

## $B_{\text{tag}}$ vertex process:

- Takes all tracks in the event.  
 $K_S$  daughters excluded due to long  $K_S$  live time;
- Performs a weighted fit to all tracks considering the primary tracks with an higher weight and secondary (coming from D decays) with a lower weight.

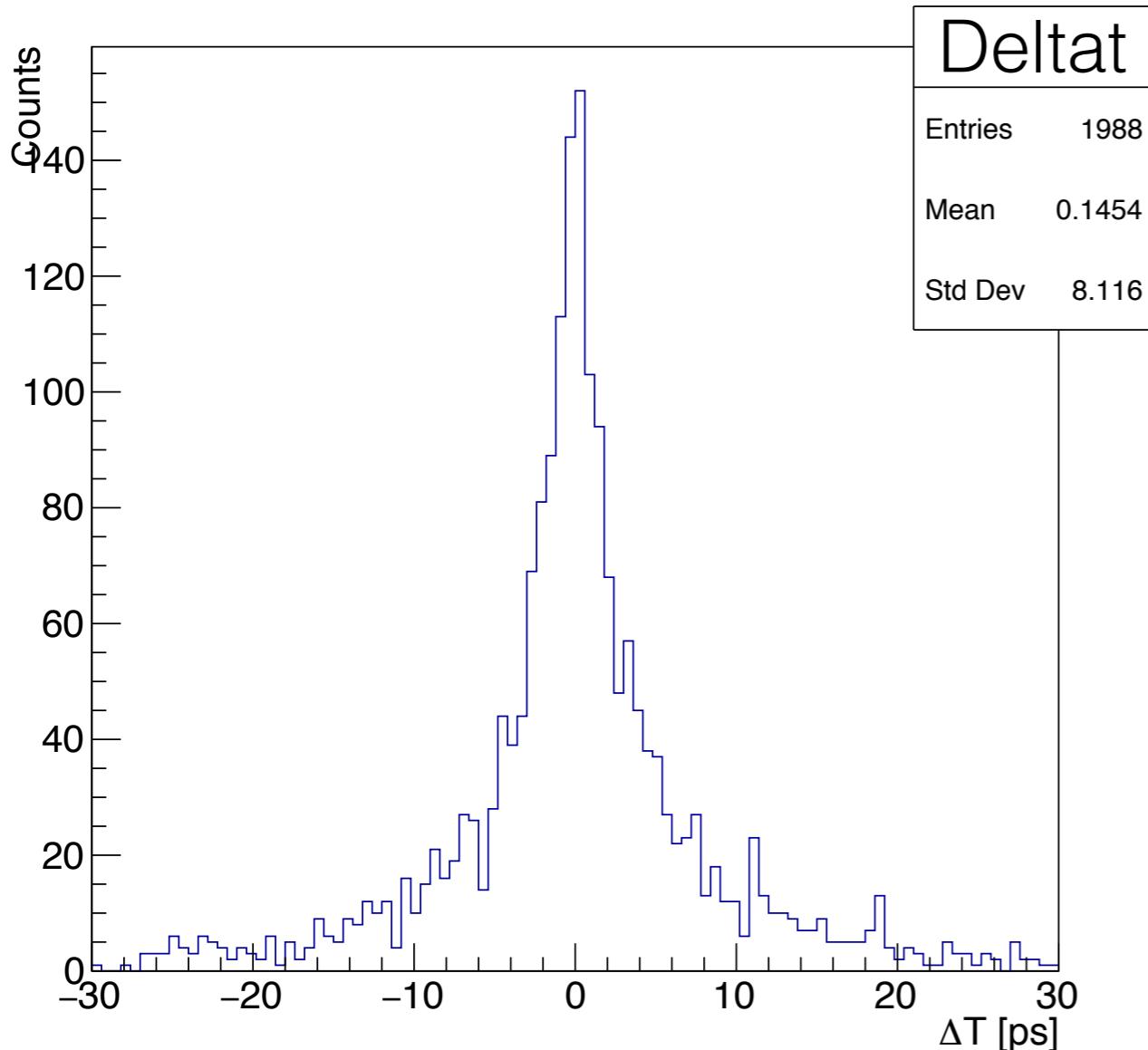
# $\Delta t$ resolution results

For what concerns the vertex procedure for the Btag, the efficiency is almost 100%.

This efficiency is calculated considering the number of failed vertex fit processes.

Using the information of  $\Delta z$  it's possible to obtain the  $\Delta t$  distribution and resolution plots:

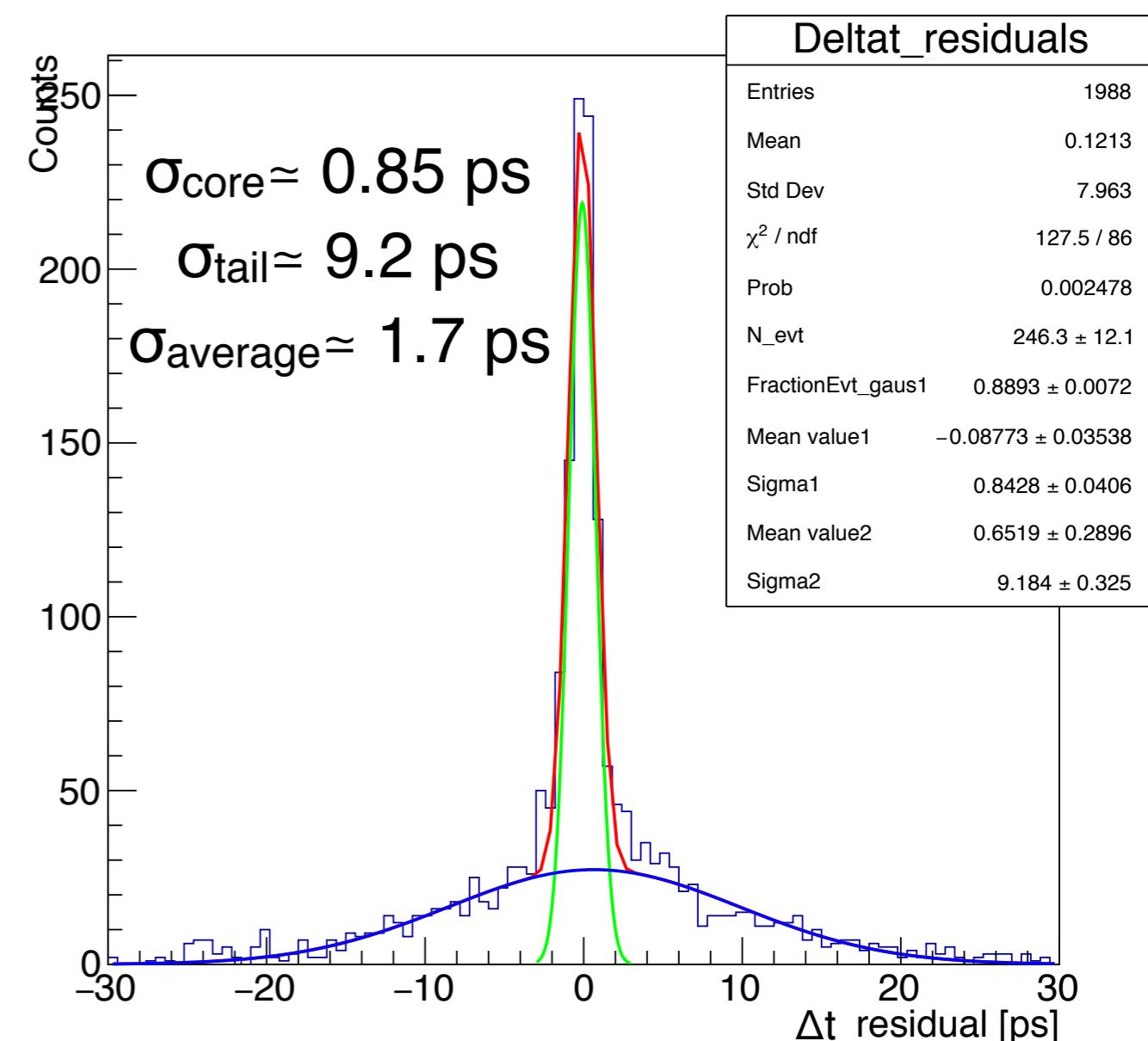
$\Delta t$  distribution between  $B^0$  vertices



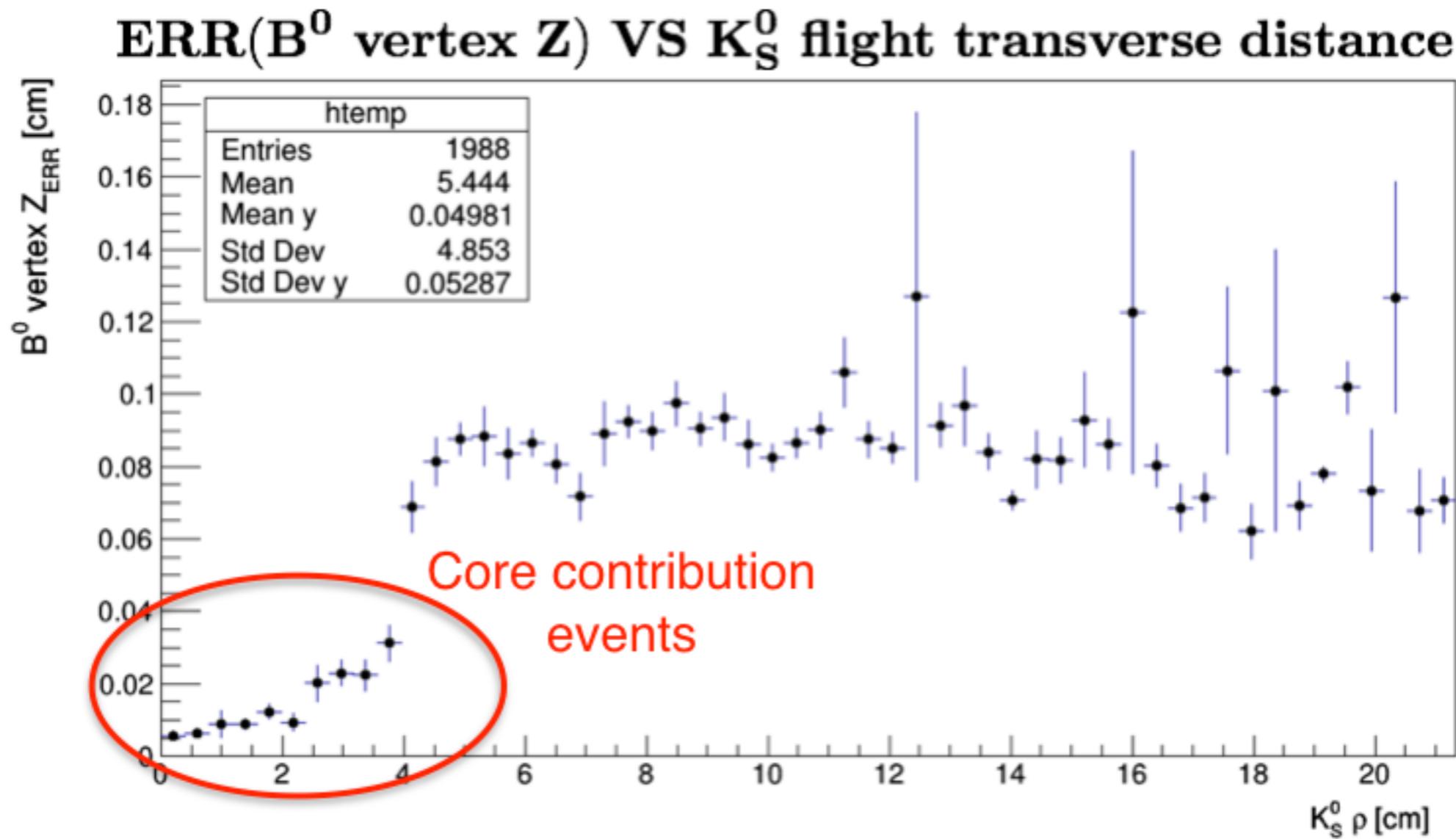
12

$$\text{Residual} = \Delta t_{reco} - \Delta t_{truth}$$

*Distribution fitted with the sum of 2 gaussians*



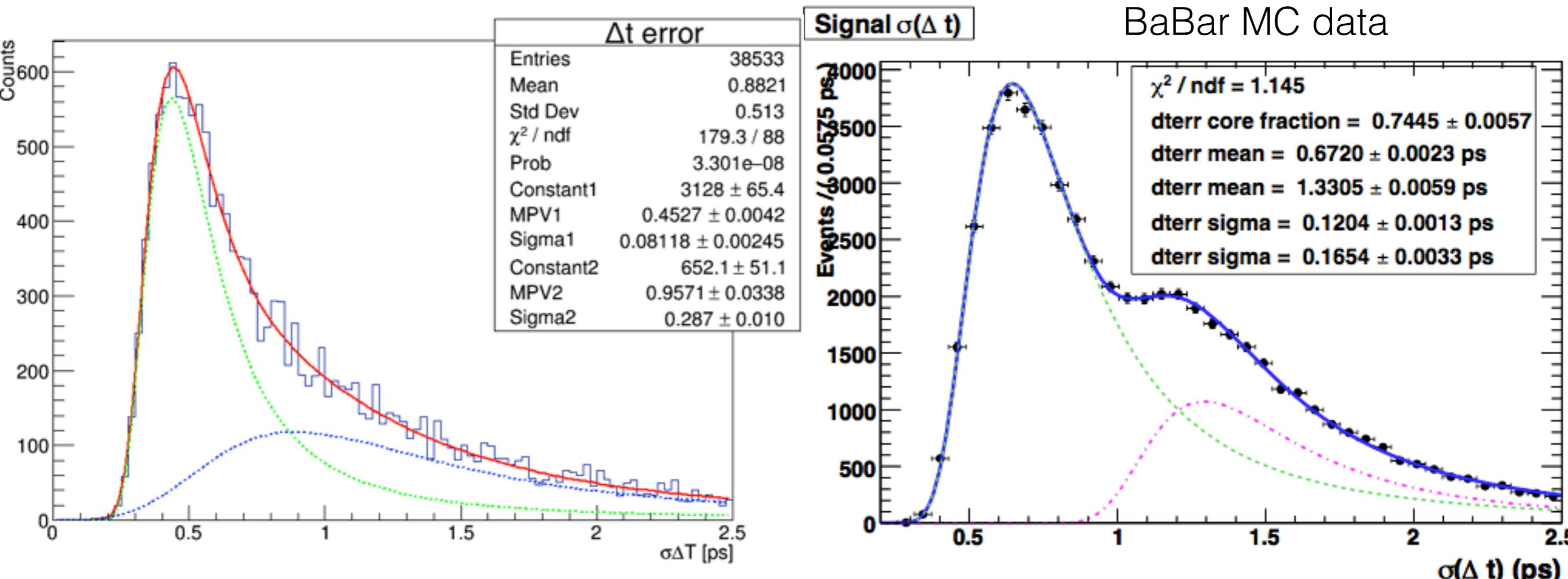
# $\Delta t$ contributions origins



The  $K_s$  that decay before layer 3 ( $\rho < 3.8$  cm) provide a better reconstruction of the  $B_{\text{sig}}$  vertex. The events inside the red circle belong to the core gaussian of the  $\Delta t$  distribution shown in the previous slide.

# $\Delta t$ Error distribution

*Fitted with the sum of 2 Landau distributions*



$$\sigma_1 \approx 0.08 \text{ ps}$$

$$\sigma_2 \approx 0.29 \text{ ps}$$

$$\sigma_1 \approx 0.12 \text{ ps}$$

$$\sigma_2 \approx 0.16 \text{ ps}$$

Comparison with BaBar results:  $\sigma$  values are similar.

# Conclusions and next steps

- Reconstruction of  $B^0 \rightarrow K_S^0 \pi^0 \gamma$ ,  $B_{\text{tag}}$  vertexing,  $B_{\text{sig}}$  vertexing using ipTube constraint and flavour discrimination done. 
- $\Delta t$  resolution result seems acceptable. Known tail contribution origins. 

## Next Steps:

- In order to complete my thesis work I am going to evaluate the sensitivity on C and S through toys MC, using the numbers of selection efficiency of Belle/BaBar.
- I planned to complete my contribution for the B2Tip as soon as possible, adding the results shown in these slides.

*Thank  
you*



# BACKUP SLIDES

# Differences between V0 and FS definition of $K_S^0$

## FS method

Use the  $\pi^\pm$  available after reconstruction, at mDST level

Extrapolate the 5 helix parameters at the POCA (Point Of Closest Approach)

Starting point of the offline vertex fit is POCA

For particles decaying outside the pipe, contributions coming from multiple scattering with the VXD layers are wrongly considered

## V0 method

Use gentFit tracks: helix + hit informations

Perform vertex fit using hit informations and obtain TrackFitResults

Extrapolate the 5 helix parameters at the vertex point

Starting point of the offline vertex fit is the vertex position

For particles decaying outside the pipe, contributions coming from multiple scattering with the VXD layers are correctly not considered

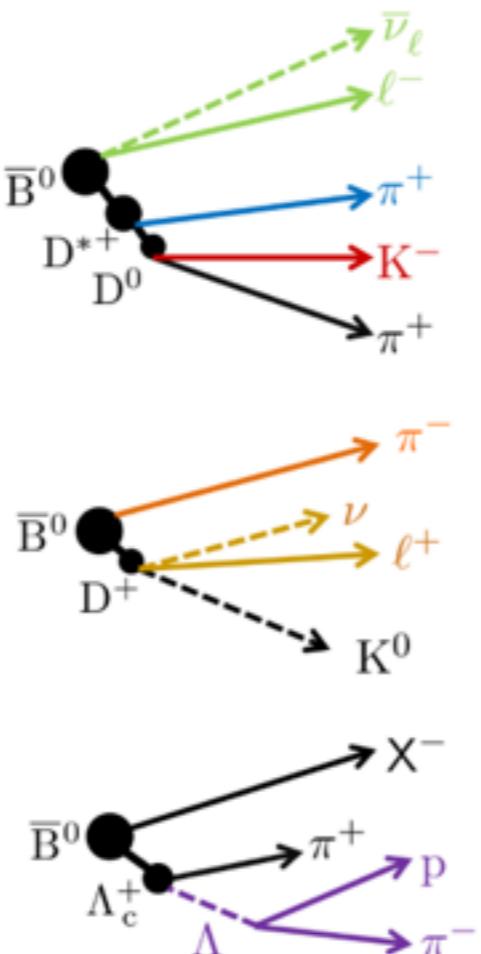
O  
N  
L  
I  
N  
E  
  
O  
F  
F  
L  
I  
N  
E

# $B^0$ flavour tagging

The different signatures of flavour specific decay channels can be grouped into, up to now, 13 categories:

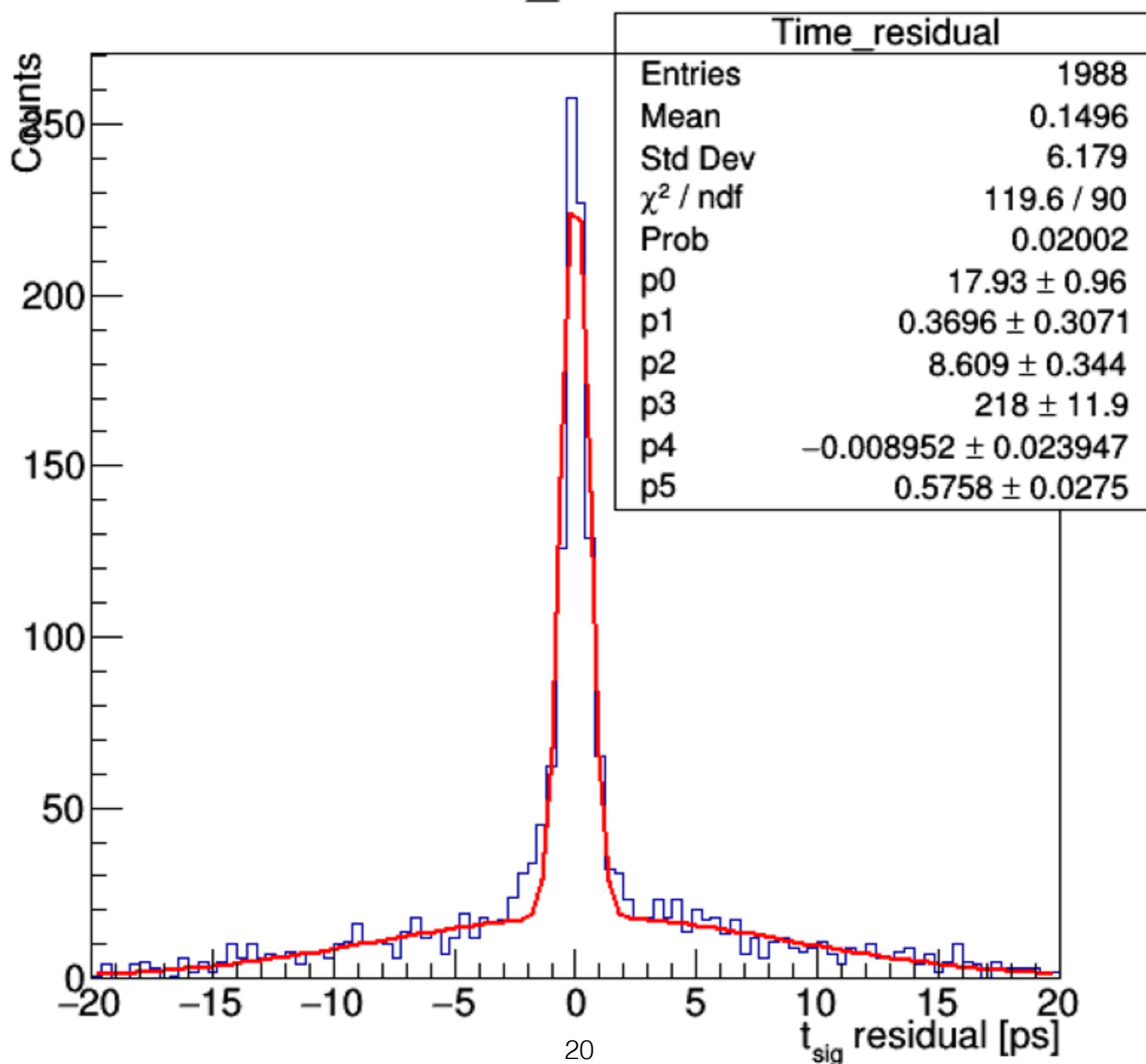
Tag vertex process:

Categories	Targets
Electron	$e^-$
Intermediate Electron	$e^+$
Muon	$\mu^-$
Intermediate Muon	$\mu^+$
KinLepton	$e^-$
Intermediate KinLepton	$\ell^+$
Kaon	$K^-$
KaonPion	$K^-, \pi^+$
SlowPion	$\pi^+$
FastPion	$\pi^-$
MaximumP	$\ell^-, \pi^-$
FSC	$\ell^-, \pi^+$
Lambda	$\Lambda$
Total= 13	



- Track level: tracks in the ROE are fitted and put inside lists according to previous mass hypothesis. Several kinetic flavour tagging variables are calculated for each track and taken as inputs for a multivariate method. Each category has its own multivariate method that gives as output the probability of the tracks to be the right ones in their categories (RightTrack).
- Event level: it calculates the probability of the category to be the RightCategory (assuming the track as RightTrack) using again the flavour tagging variables.
- Combiner level: it selects the tracks with the highest RightTrack probability and uses the product qp (charge and RightCategory probability) as input to the combiner. The multivariate analysis of the combiner gives us the product qr where q=flavour and r=dilution factor=1-2ω (ω=mistag probability)

# Time\_residual



# $\Delta t$ reisudlas VS $\Delta t$

