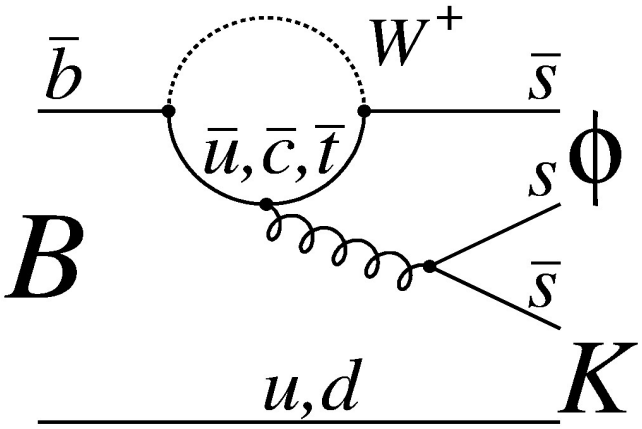
Study of the sensitivity of the $B^0 \to \phi K^0$ time dependent CP analysis

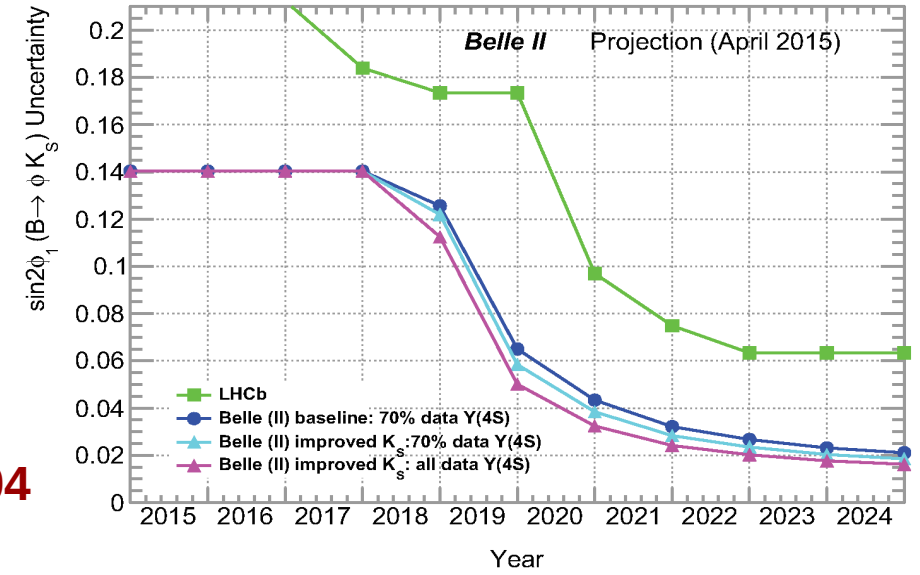


S. Lacaprara, A. Gaz,
University of Padova & INFN

Belle II Italia, Frascati 21 may 2015

Motivations

- $B^0 \rightarrow \phi K^0$ is one of the “Old Superstars” (A.J.Buras);
- Time-dependent CP asymmetry is little affected by “wrong-phase amplitudes”, so it's expected to be tightly related to $\sin 2\beta_{\psi K0}$ (and V_{ub});
- The errors will be dominated by the statistical uncertainty for very long, so the initial progress will be quick, as soon as we have more data than BaBar and Belle;
- There will be competition with LHCb:



P. Urquijo
BELLE2-NOTE-PH-2015-004

- Padova is involved in the activities of the TOP, this is a good channel to commission/check PID performance on signal reconstruction and B flavor tagging.

Outline

- Analysis strategy;
- Computing resources;
- Signal Monte Carlo;
- Δt resolution;
- Backgrounds:
  - Combinatorial;
  - Peaking;
- Multidimensional fit;
- What's missing;
- To do list, conclusions.

Most of what I'll show today is done using `build-2015-05-01`

Analysis strategy

- The ultimate sensitivity in BaBar and Belle was reached with a Dalitz Plot analysis of $K^+K^-K_S$;

BaBar: PRD 85, 112010 (2012)
Belle: PRD 82, 073011 (2010)

- We propose to start with a simpler quasi-two body approach, restricting the K^+K^- invariant mass range around the ϕ mass;
- We can separate the vector (ϕ) component from the scalar (mostly f_0 and non-resonant) using the helicity angle of the ϕ decay products;
- We started considering the channels:

1) $\phi\,(K^+K^-)$ $K_S\,(\pi^+\pi^-)$
2) $\phi\,(K^+K^-)$ $K_S\,(\pi^0\pi^0)$
3) $\phi\,(\pi^+\pi^-\pi^0)$ $K_S\,(\pi^+\pi^-)$
4) $\phi\,(K^+K^-)$ K_L

In the past this mode has not been used. With higher statistics and better background suppression, it could give a significant contribution

- Today I'll mostly focus on $\phi \rightarrow K^+K^-$, $K_S \rightarrow \pi^+\pi^-$.

Computing resources

So far we used a variety of resources:

- Signal MC production: as of now it is not centrally provided, we (Belle II Pd) have a quota at the local INFN Cloud, and can dedicate some virtual machines to the production of signal MC: we can generate ~18k events/(core day);

- To run on generic ($B\bar{B}$ and continuum) MC, we need to use the grid:
  - Not very user friendly and sometimes unstable;
  - Now it is optimized for MC production, so the limit on #events per job is somewhat inconvenient for analyzing existing MC;

- The analysis of the flat root files can then proceed on our local resources.

Selection

Main selection cuts:

- $M_{bc} > 5.25$;
- $|\Delta E| < 0.2$;
- $1.00 < M(K^+K^-) < 1.04$;
- $0.42 < M(\pi^+\pi^-) < 0.58$;
- $d_0(K^\pm) < 0.05$;
- $z_0(K^\pm) < 0.2$;
- At least one PXD hit for each $K^\pm$;
- PIDk(K) > 0.5;
- PIDpi(π) > 0.5;
- VtxPvalue(K_S, ϕ, B) > 0.0001.

Objects:

$K^\pm$: `stdLooseK`

$\pi^\pm$: `stdLoosePi`

Vertexing:

K_S, ϕ: `vertexKFit`

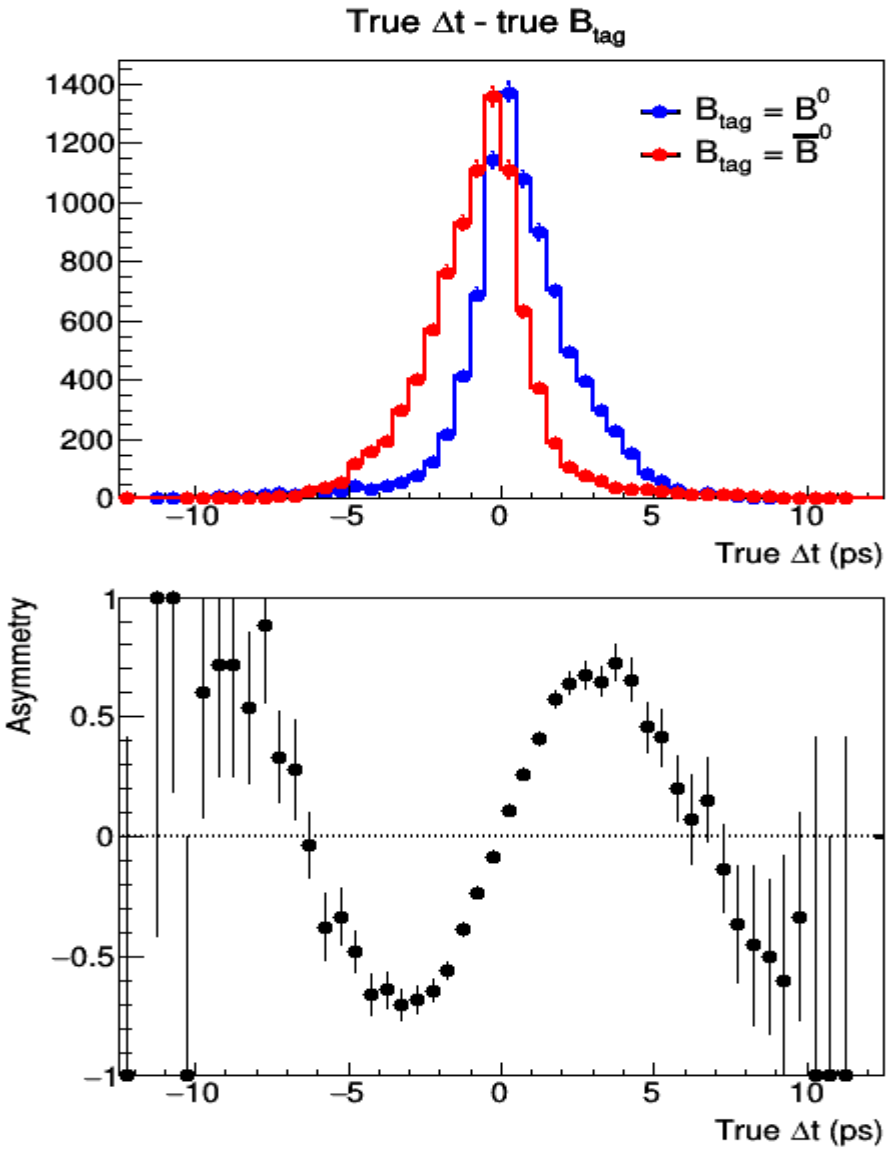
B: `vertexRave`

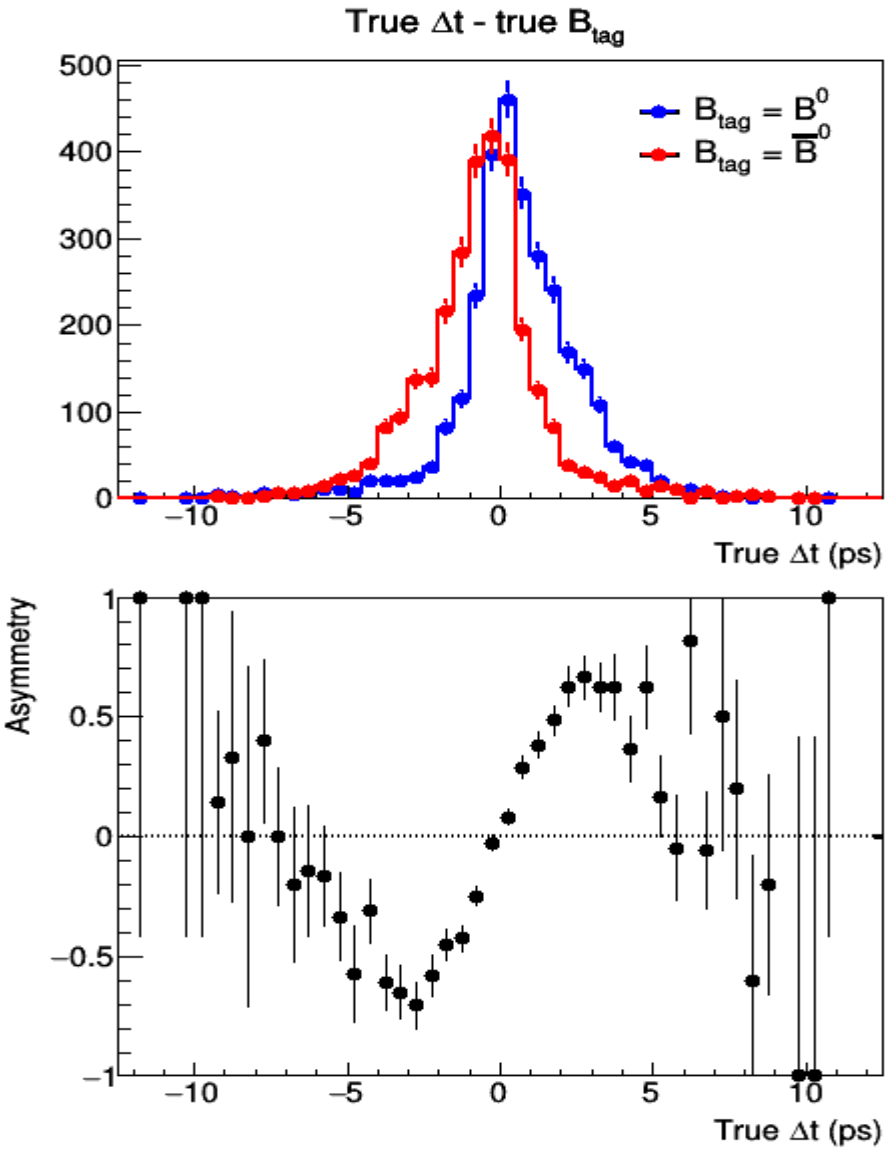
Signal efficiency ε = 22.5%
Candidate multiplicity = 1.0086

(it was ε ~ 40% in BaBar)

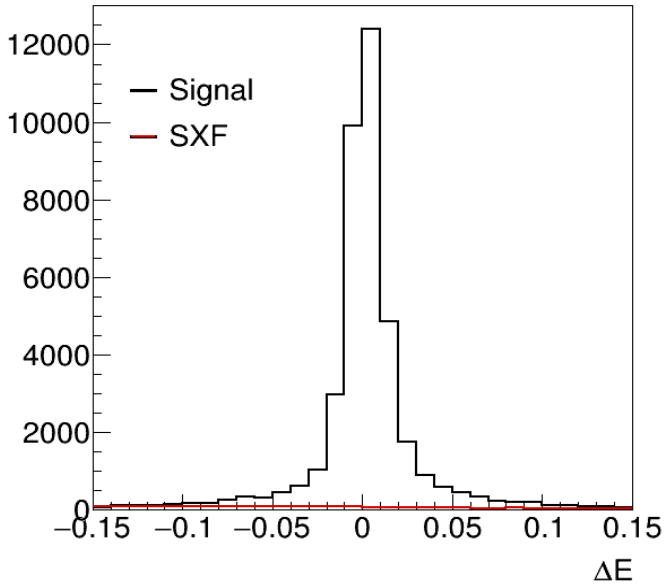
Signal MC

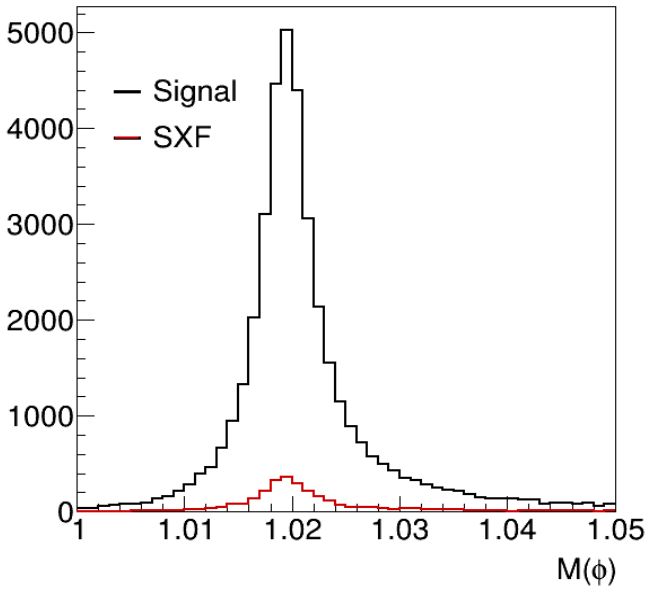
Generated 100k events of $B \rightarrow \phi(KK)\, K_S(\pi^+\pi^-)$ and $B \rightarrow \phi(\pi^+\pi^-\pi^0)\, K_S(\pi^+\pi^-)$

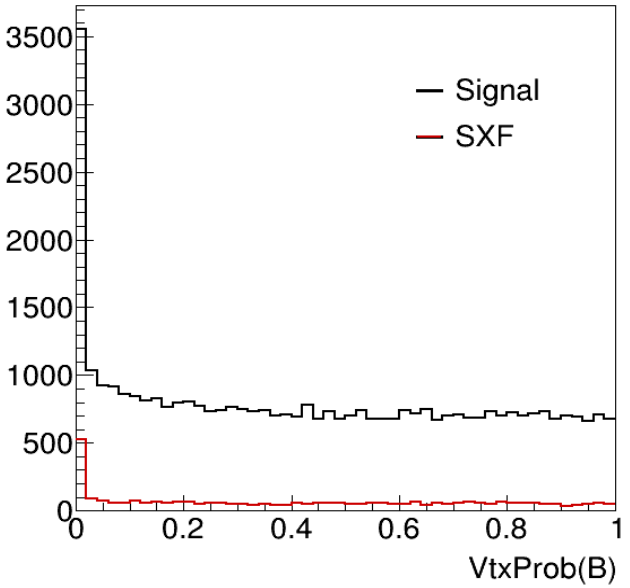


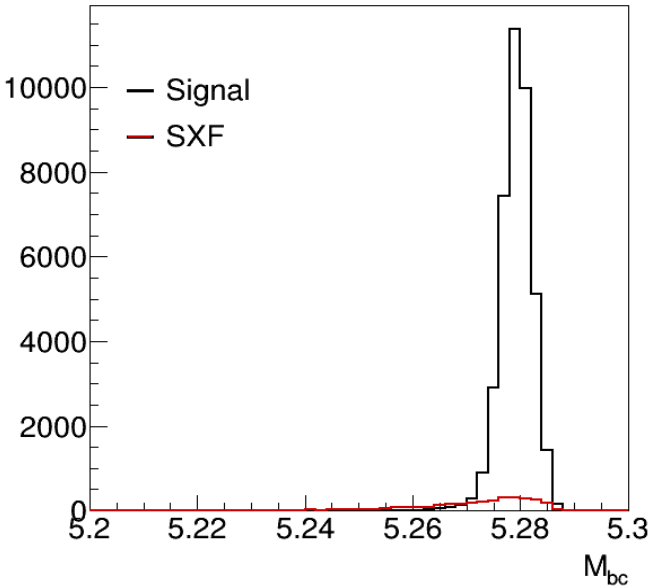


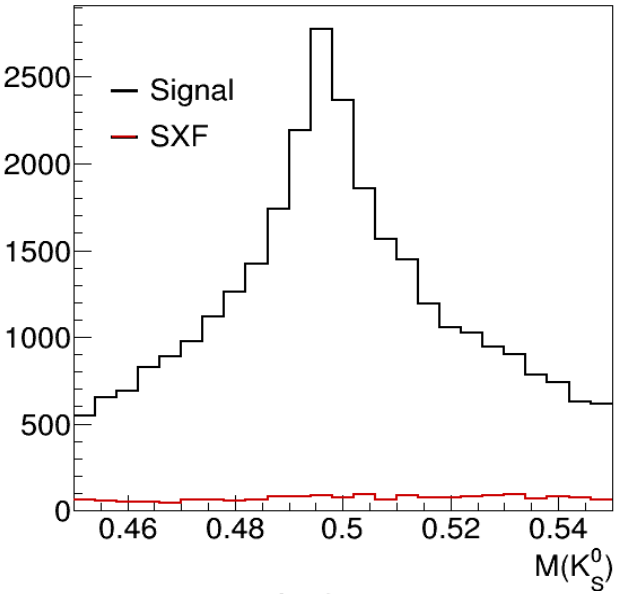
Signal MC – $\phi(KK)$ $K_S(\pi^+\pi^-)$

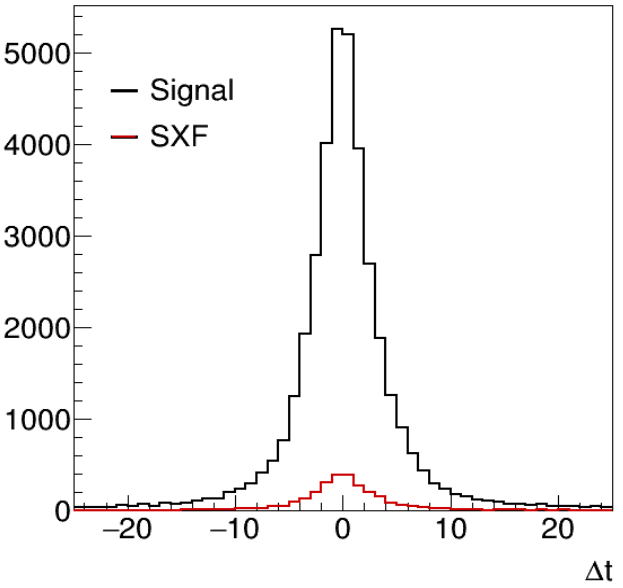




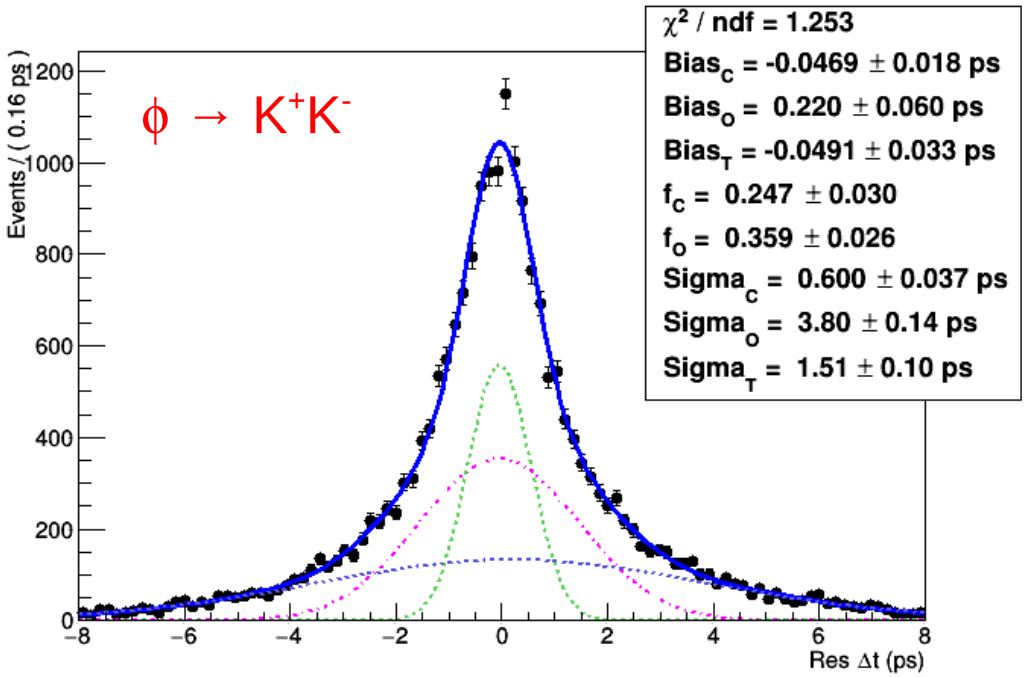


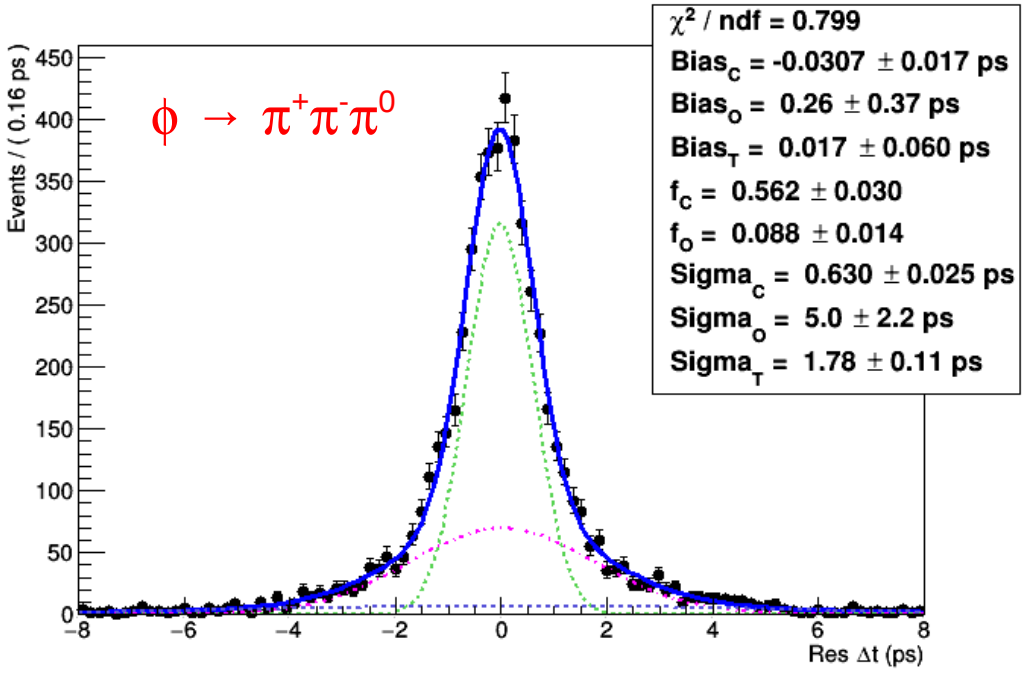


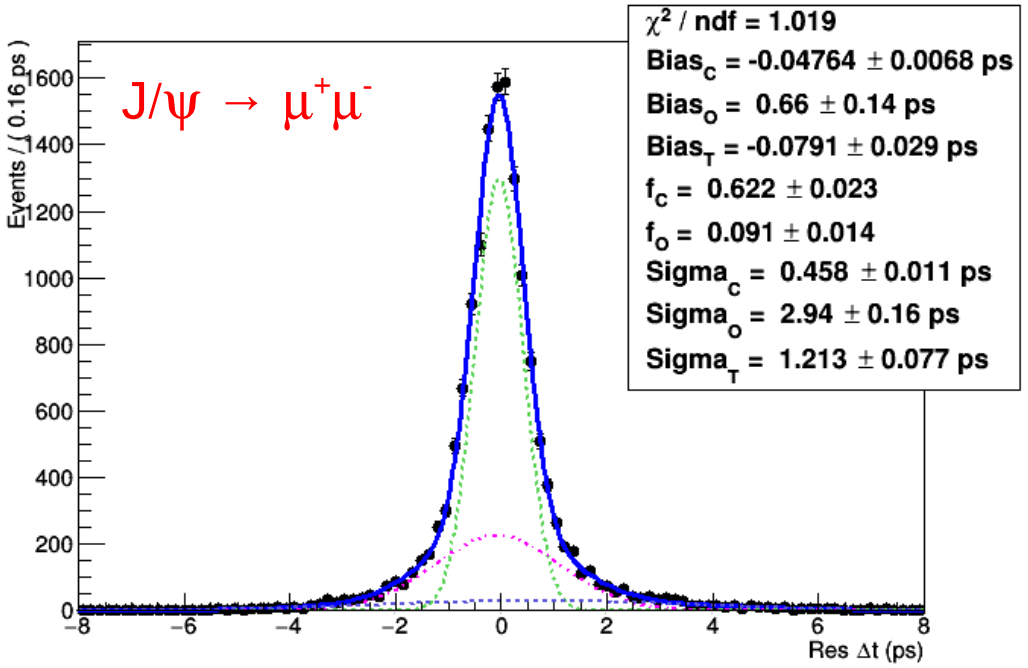




Δt resolution







C = "core"
T = "tail"
O = "outlier"

Background overview

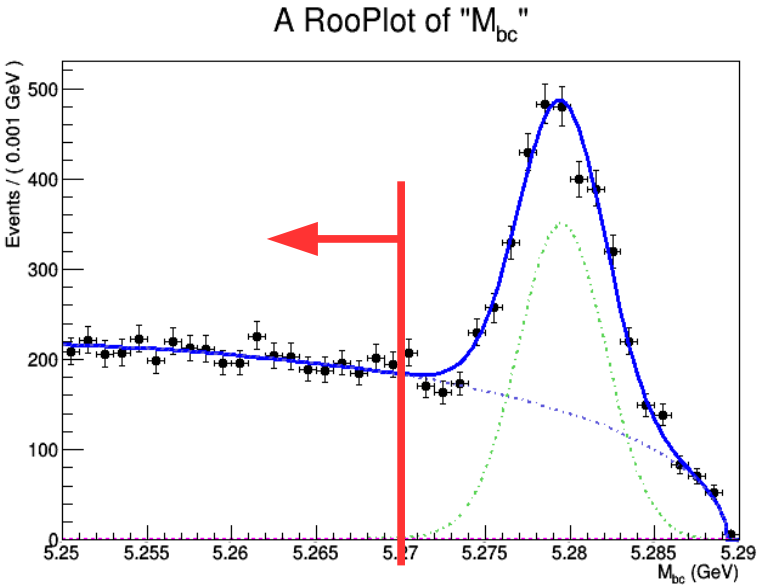
Two main background components:

- Combinatorial: dominated by continuum events.

  On a real analysis, this is taken from the data on M_{bc} or ΔE sidebands.

  For preliminary studies, I ran on a small (few %'s of what's available) amount of version 3.5 generic MC.

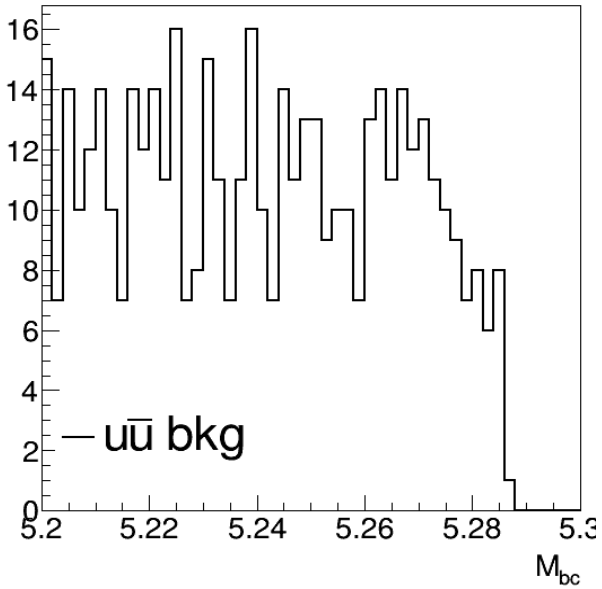
  Continuum suppression non yet applied;

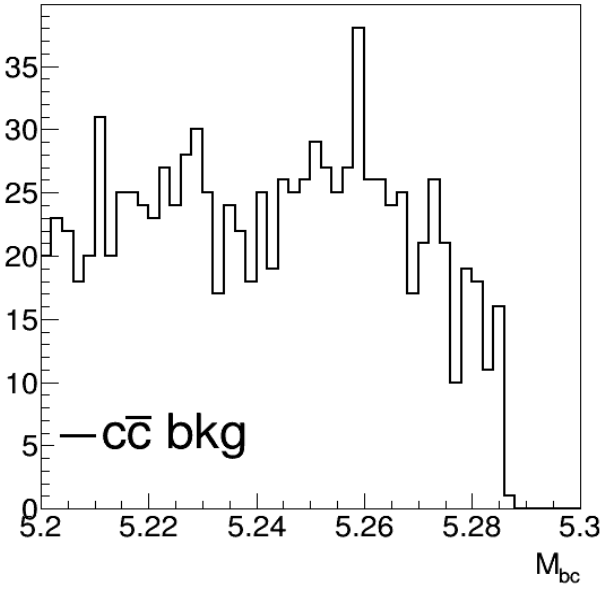


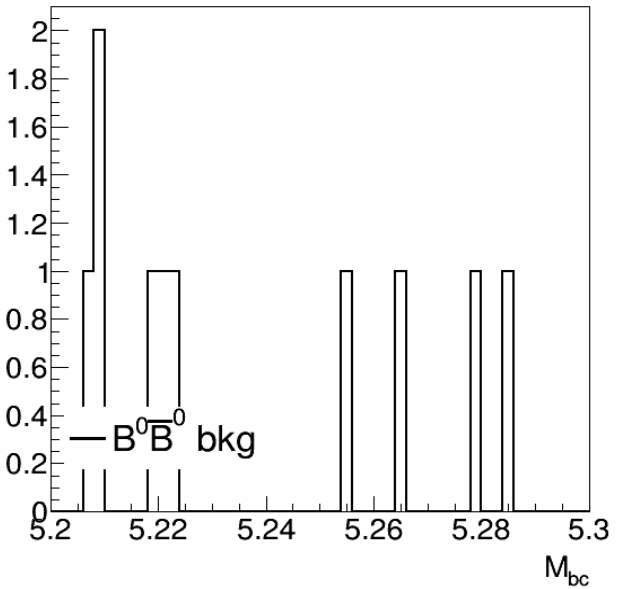
- Peaking: typically it contains events from (charmless) B decays, which peak in one or more of the variables used in the analysis (M_{bc}, ΔE, $M(\phi)$, …). It is modeled from a MC cocktail containing the modes that have a non negligible probability of passing the selection.

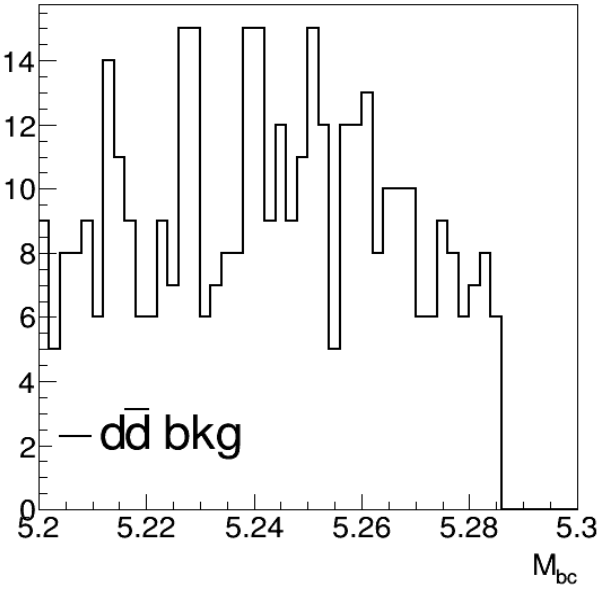
  Not yet studied.

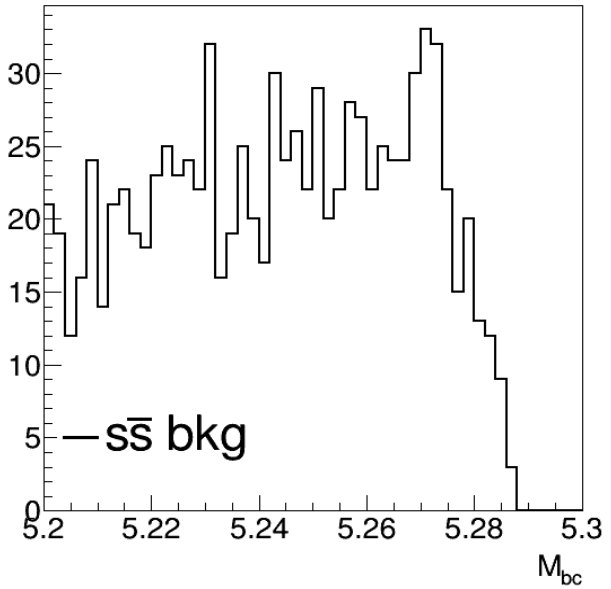
Combinatorial background: M_{bc}

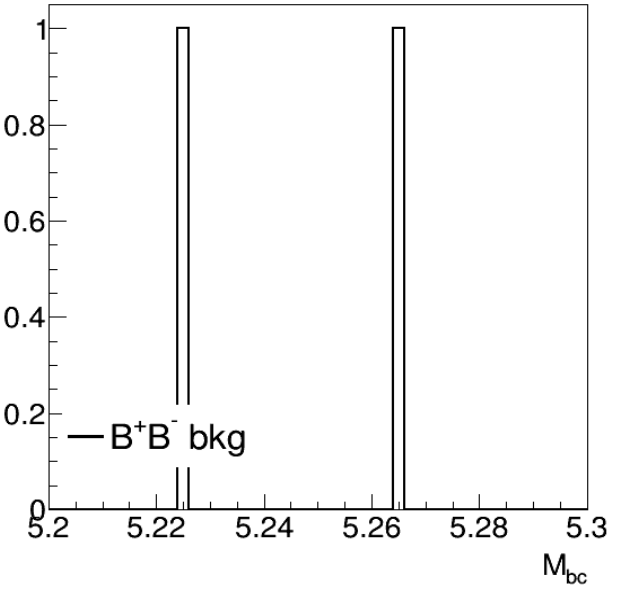




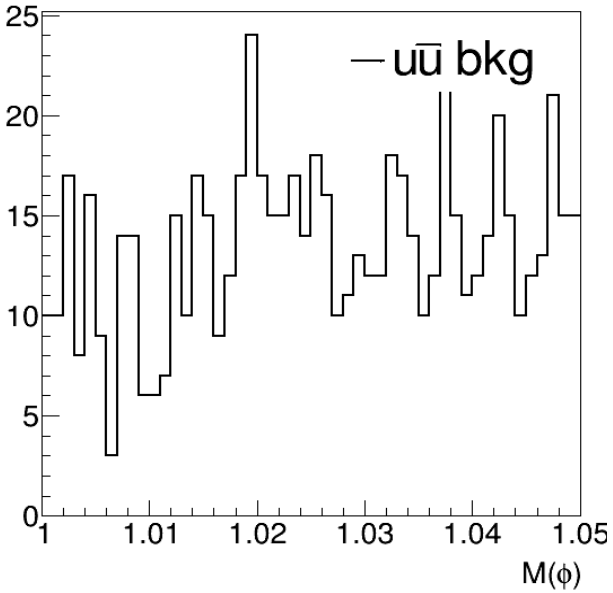


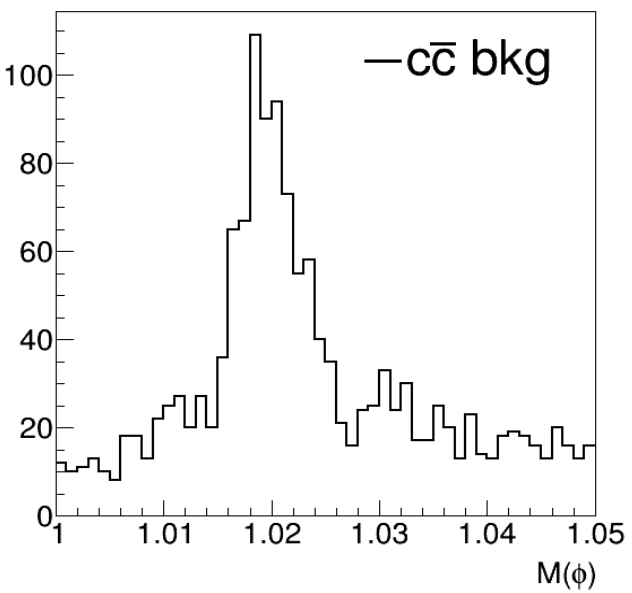


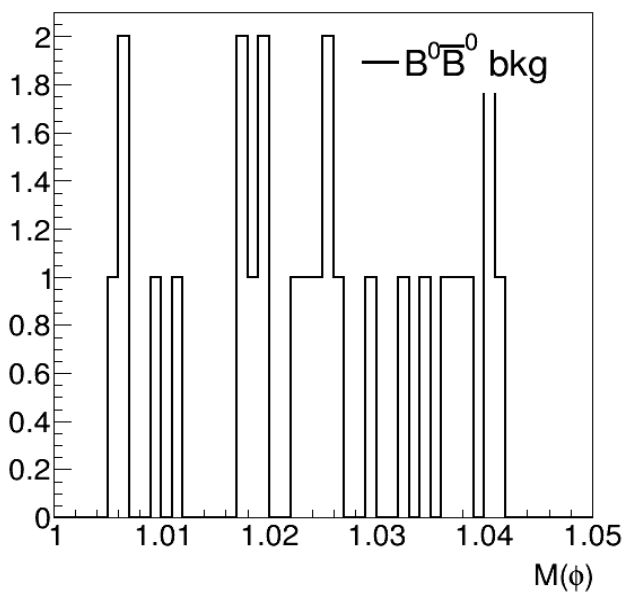


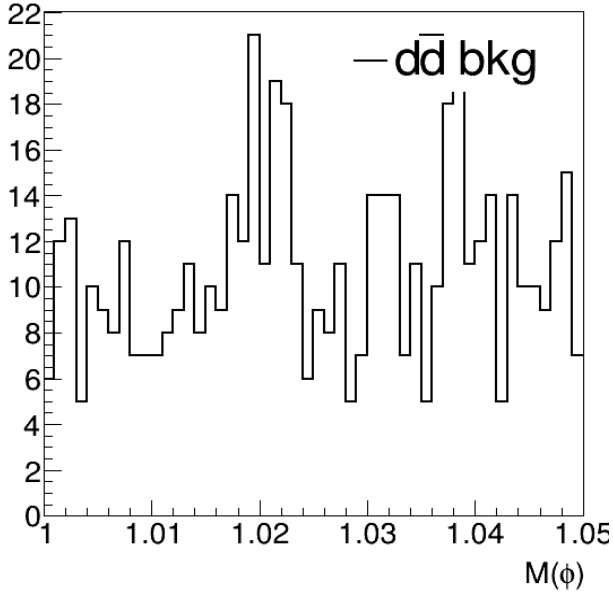


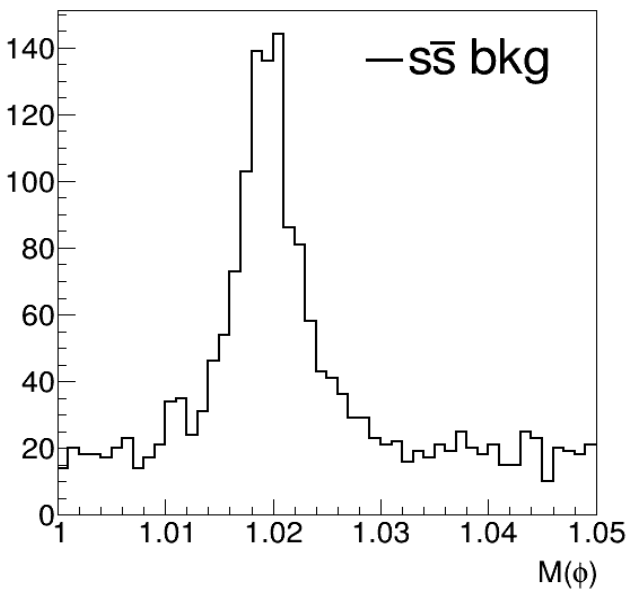
Combinatorial background: M(ϕ)

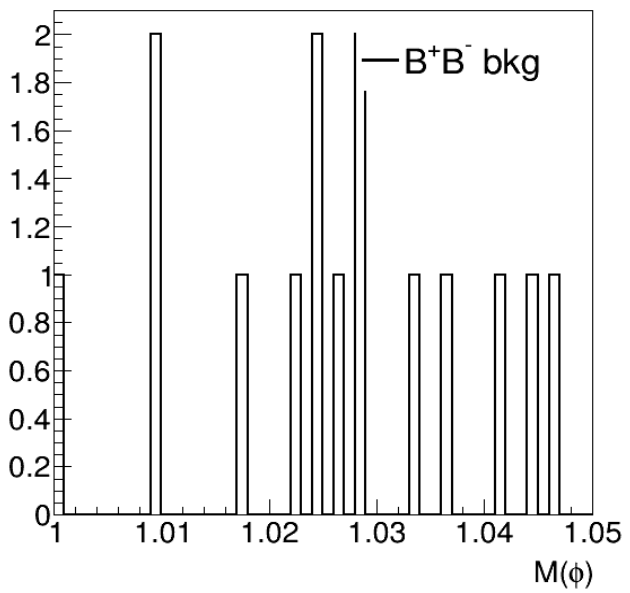












Multidimensional fit

- The extraction of the parameters of interest (mostly S and C), is done performing a multi-dimensional maximum likelihood fit, using the variables:
  - Δt;
  - ΔE;
  - M_{bc};
  - $M(\phi)$;
  - ϕ helicity; (not yet implemented)
  - Continuum suppression variable; (not yet used)
  - ...

The pdf is of the form:

$$\mathcal{P}_j^i \equiv \underbrace{\mathcal{T}_j\left(\Delta t^i, \sigma_{\Delta t}^i, \varphi^i\right)}_{\text{time dependent part}} \cdot \prod_k \underbrace{\mathcal{Q}_{k,j}(x_k^i)}_{\text{time integrated}}$$

- Right now we are using the old package RooRarFit, updated to cope with the newer version of ROOT/RooFit.

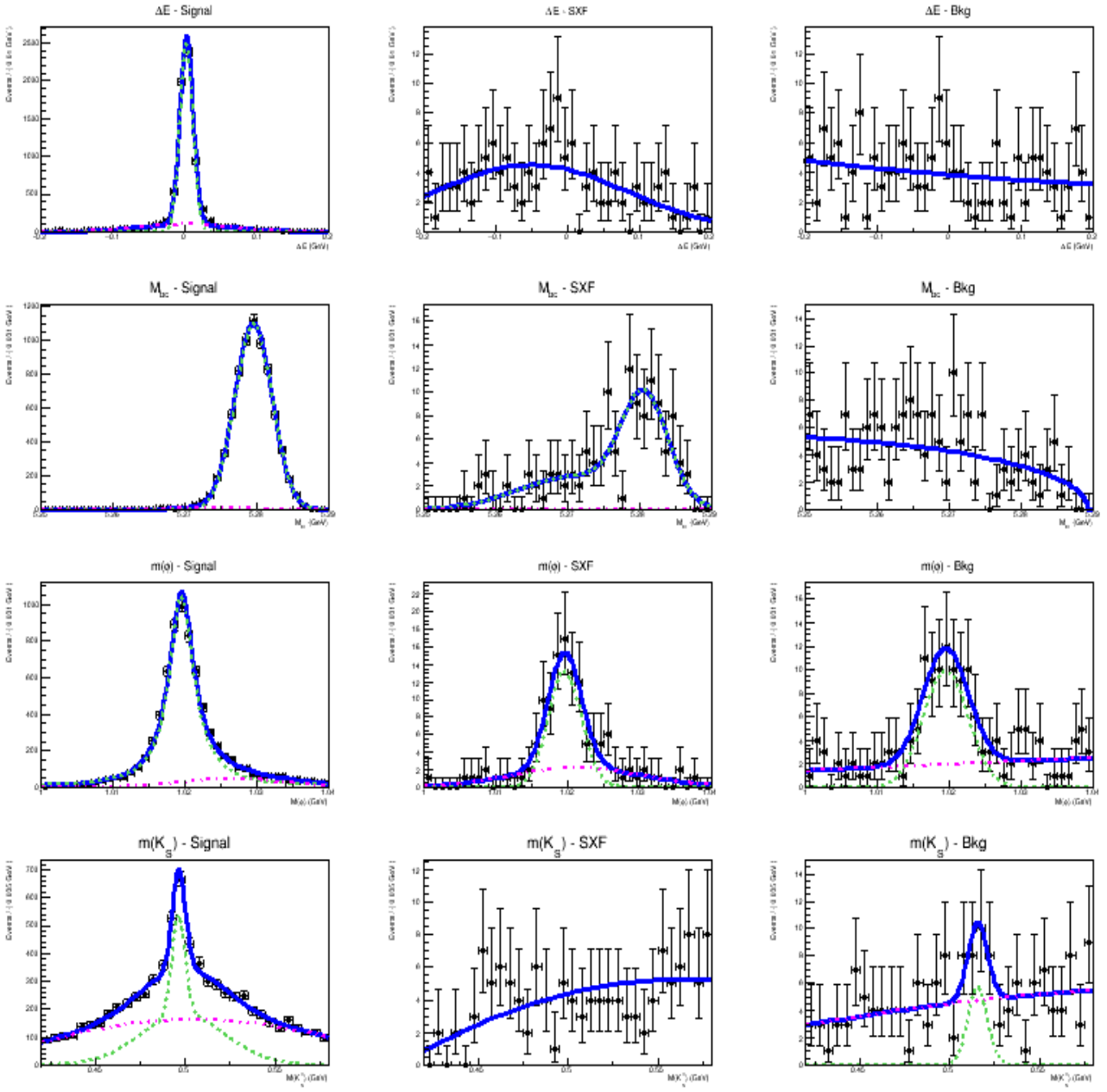
Multidimensional fit

ΔE

M_{bc}

$M(\phi)$

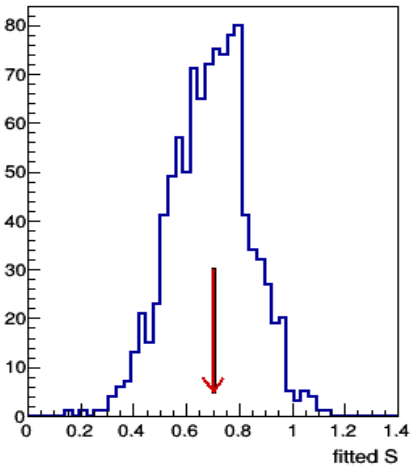
$M(K_S)$

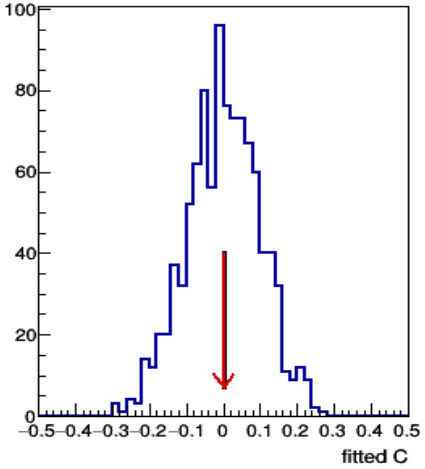


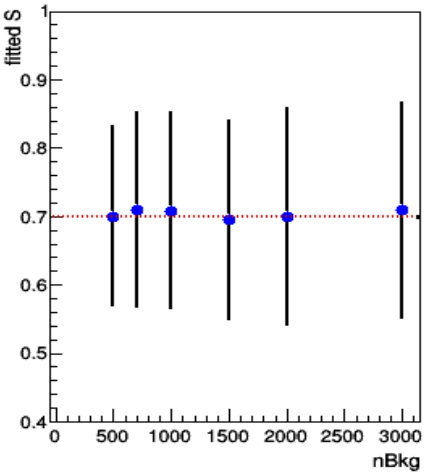
Signal **SXF** **Combinatorial Bkg.**

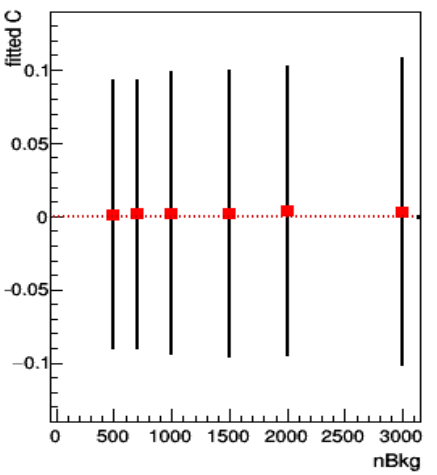
Toy studies

- We started testing the fitting machinery using toy experiments;
- We embed 250 signal (and 12 SXF) events in a variable number of combinatorial background events, generated from their pdf's;
- We check that the fit is stable and unbiased, and that the dependence of the errors on S and C on the number of background events is mild;
- The results are not very realistic, because the modeling of the combinatorial background is sketchy and the peaking background is missing...
- However, we are not yet exploiting all the information in the analysis, so this looks encouraging.





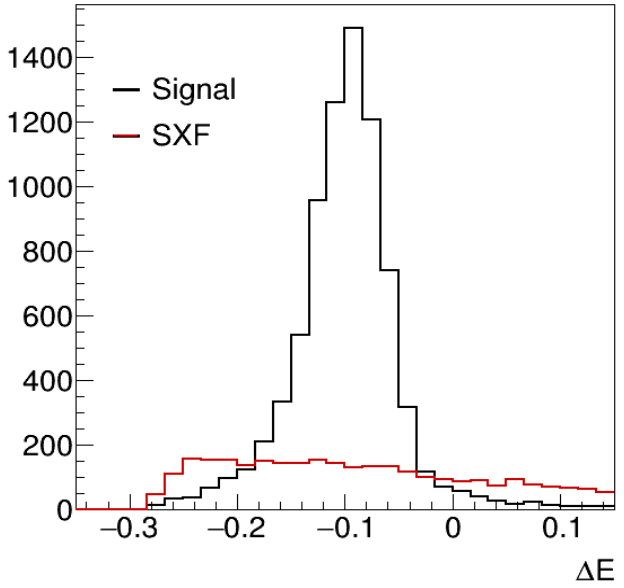


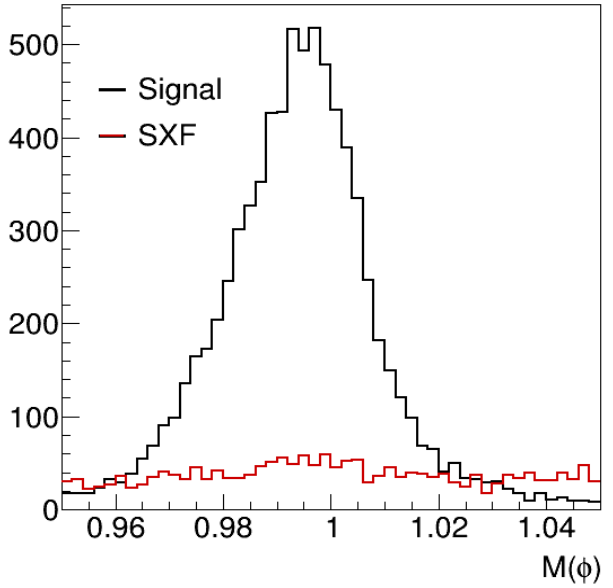


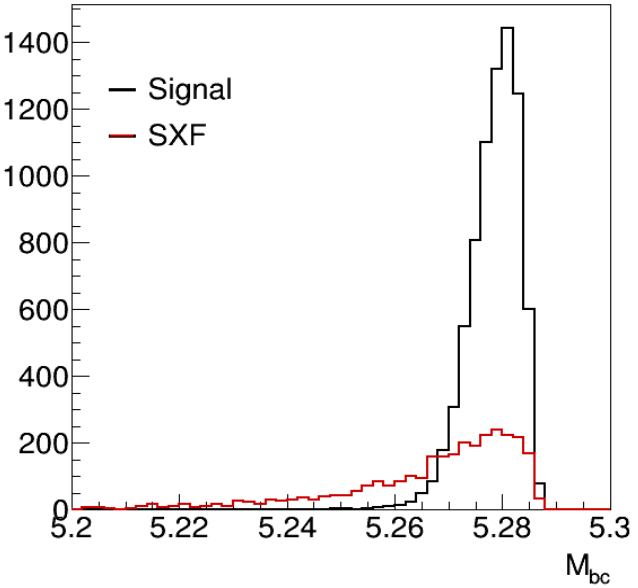
A look at $\phi \rightarrow \pi^+\pi^-\pi^0$

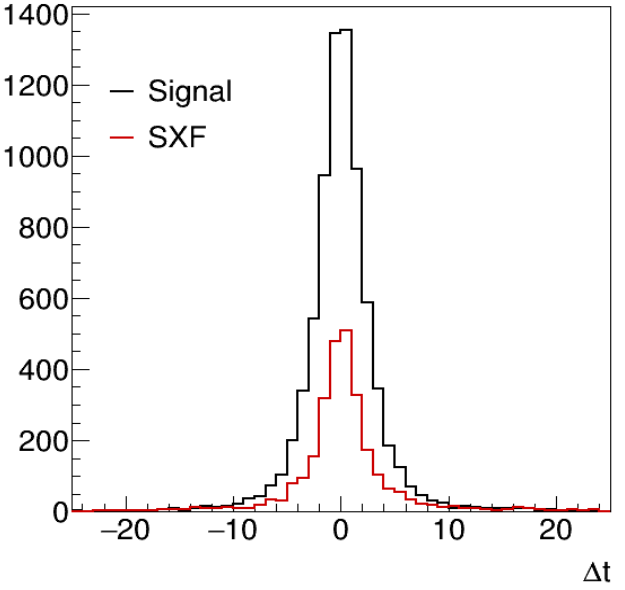
Compared to $\phi \rightarrow K^+K^-$, we have:

- Lower efficiency;
- Higher SXF fraction;
- Pretty large bias on ΔE and $M(\phi)$.





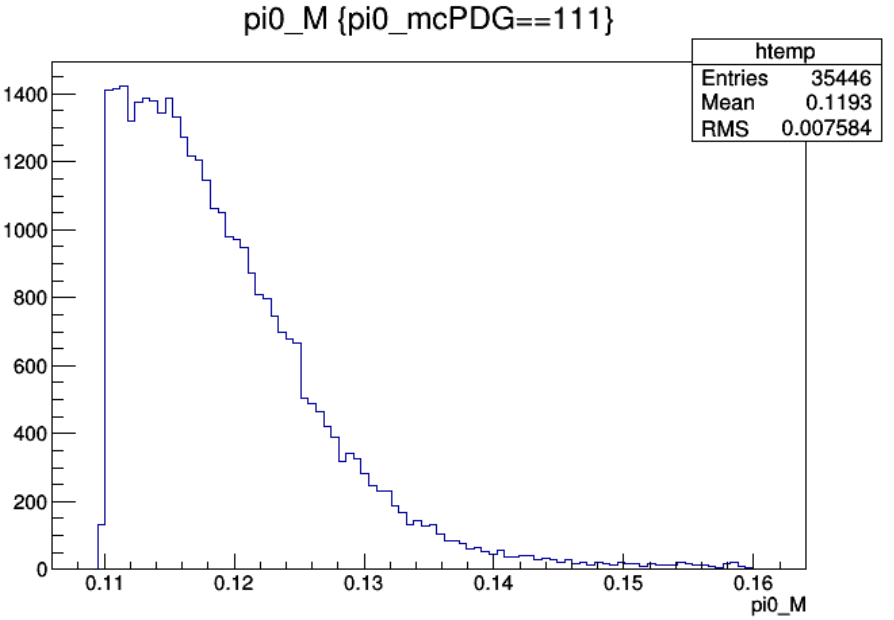




What's missing

- I just used `pi0:good` from `stdPi0()`.

  Evident calibration issue (unless there is some recipe that I need to apply in order to correct this effect)



- K^0_L also are problematic: there is no particle list provided yet. For the time being the recommendation is to identify the (endcap) KLM clusters with at least 2 hits, not matched with any track.

To do list

- Implement the ϕ helicity infrastructure;
- Study the non-resonant $K^+K^-K^0$ component;
- Optimize continuum suppression;
- Run on all the relevant generic ($B\bar{B}$ and continuum) MC as soon as it is produced with the new release;
- Identify and include the most relevant peaking background modes;
- …

- Provide a realistic estimate of the sensitivity of the analysis with an integrated luminosity of 0.3-1.0 ab^{-1};
- Spin-off: measure direct CP asymmetry in $B^+ \rightarrow \phi K^+$, which is interesting because it could be connected to the $B \rightarrow K\pi$ puzzle. It will be challenging to control the detector related asymmetries in the early phases of the experiment.

Conclusions / outlook

- The time dependent CP analysis of $B^0 \rightarrow \phi K^0$ has started;
- We are still in the very early stages, but things so far look encouraging;
- The reconstruction/analysis tools are in reasonable shape, quite a bit of work is needed especially on the neutrals;
- We plan to have a realistic estimate of the Belle II sensitivity on these channels in a few months time scale;
- Help is welcome!

Backup Slides

Δt resolution

Comparison of Δt resolutions, on different $B \rightarrow X K_S$ channels:

Channel	RMS ($\Delta t_{reco} - \Delta t_{true}$)
$J/\psi \rightarrow \mu^+\mu^-$	1.192
$\phi \rightarrow \mu^+\mu^-$	1.297
$J/\psi \rightarrow K^+K^-$	1.365
$\phi \rightarrow \pi^+\pi^-\pi^0$	1.622
$\phi \rightarrow K^+K^-$	2.661

build-2015-02-09

Selection efficiency breakdown

	# events	Efficiency	Rel. efficiency	Cand. multiplicity
Generated	100000			
Reconstructed	43079	43.1%	43.1%	1.0482
M_{bc} cut	42717	42.7%	99.2%	1.0431
ΔE cut	41925	41.9%	98.1%	1.0346
$M(\phi)$ cut	39039	39.0%	93.1%	1.0313
$M(K_S)$ cut	36007	36.0%	92.2%	1.0256
$d_0(K)$ cut	35011	35.0%	97.2%	1.0250
$z_0(K)$ cut	33844	33.8%	96.6%	1.0250
K PXD hits cut	29406	29.4%	86.9%	1.0247
PID(K)	26085	26.1%	88.7%	1.0252
PID(π)	24491	24.5%	93.9%	1.0251
K_S VtxProb	22821	22.8%	93.2%	1.0087
ϕ VtxProb	22525	22.5%	98.7%	1.0086
B VtxProb	22515	22.5%	99.9%	1.0086

Peaking backgrounds

- Some of the modes considered in the old analyses:

$$B^0 \to K^+\pi^- K^0$$
$$B^0 \to \pi^+\pi^- K^0$$
$$B^0 \to f^0 K^0$$
$$B^0 \to a^0 K^0$$
$$B^0 \to \phi K^{*0}, K^{*0} \to K^0\pi^0$$
$$B^+ \to \phi K^{*+}, K^{*+} \to K^0\pi^+$$