Status report $B^0 \to \eta' K^0_S$

First look at $\eta' \to \rho^0 \gamma$ mode

S. Lacaprara, A.Mordá

INFN - Padova

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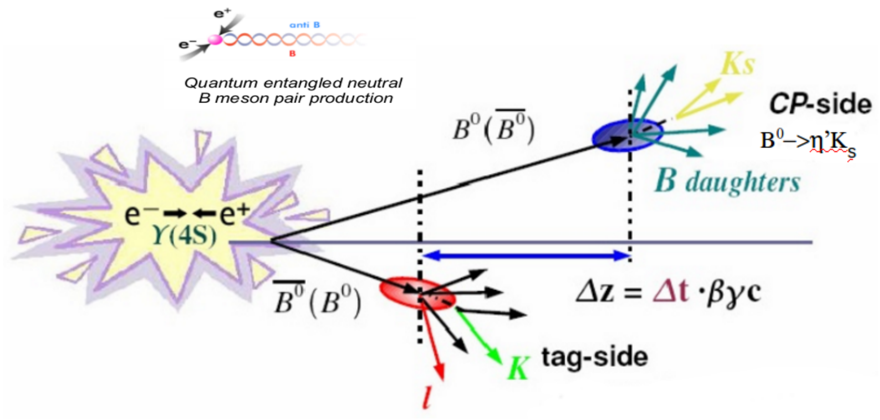
Outlook

- TD CPV in $B^0 \to \eta'(\to \rho^0\gamma)K_S^0$
  - remind of motivation
  - the $\eta' \to \rho^0\gamma$ final state
  - skim & reconstruction efficiencies
  - selection & efficiency
  - time resolution
- latest results for B2TIP

Time Dependent CP Violation using $\eta' K_0$ final state (slide ©S.Lacaprara)



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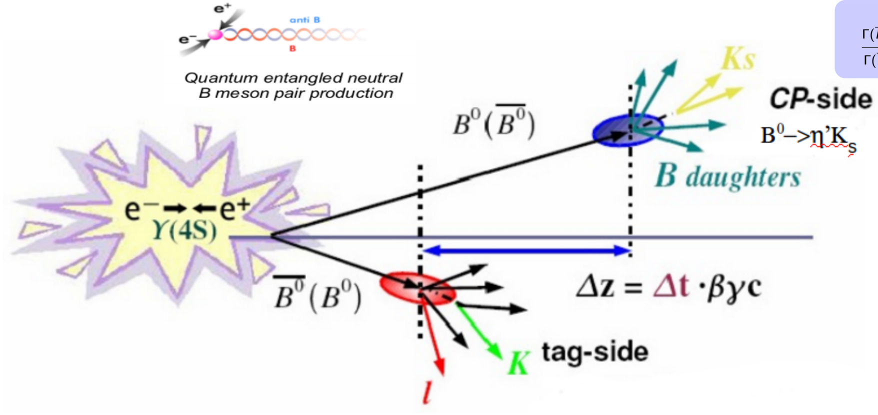
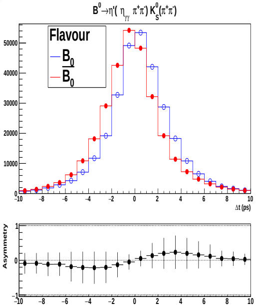


$$Asym_{CP}(t) = \frac{\Gamma(\overline{B}(t) \to f_{CP};t) - \Gamma(B(t) \to f_{CP};t)}{\Gamma(\overline{B}(t) \to f_{CP};t) + \Gamma(B(t) \to f_{CP};t)}$$



$$\Delta t \text{ probabilty parametrization: } \mathcal{P}(\Delta t, q) = \frac{e^{-\Delta t/\tau_{B^0}}}{4\tau_{B^0}} \left[1 + q\left(\mathcal{A}_{CP}\cos\Delta m_d \Delta t + \mathcal{S}_{CP}\sin\Delta m_d \Delta t\right)\right]$$

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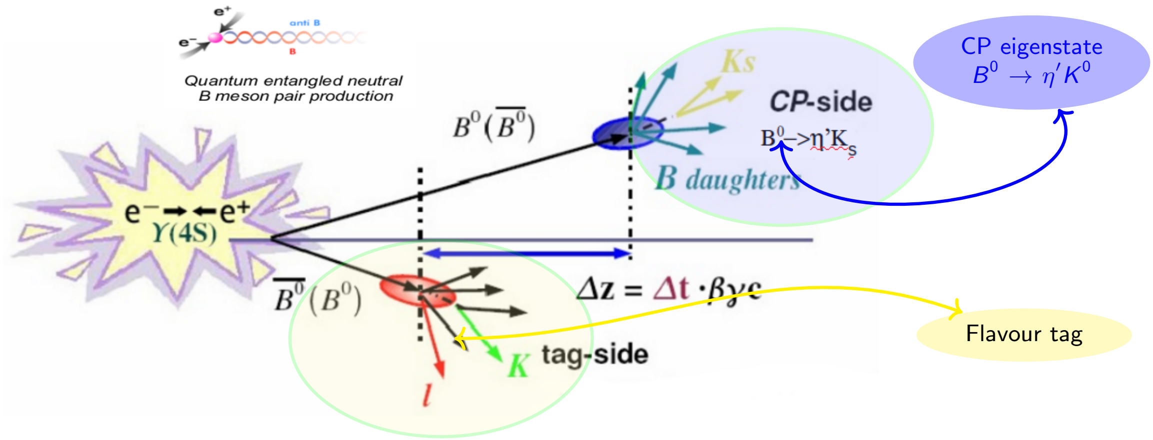

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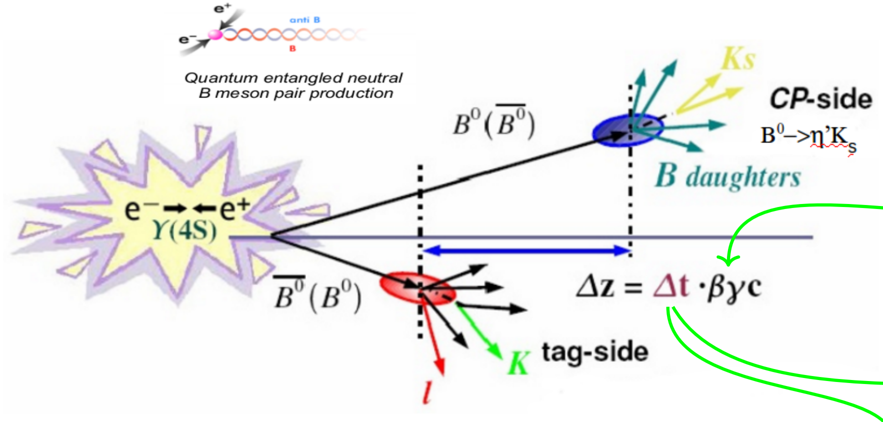
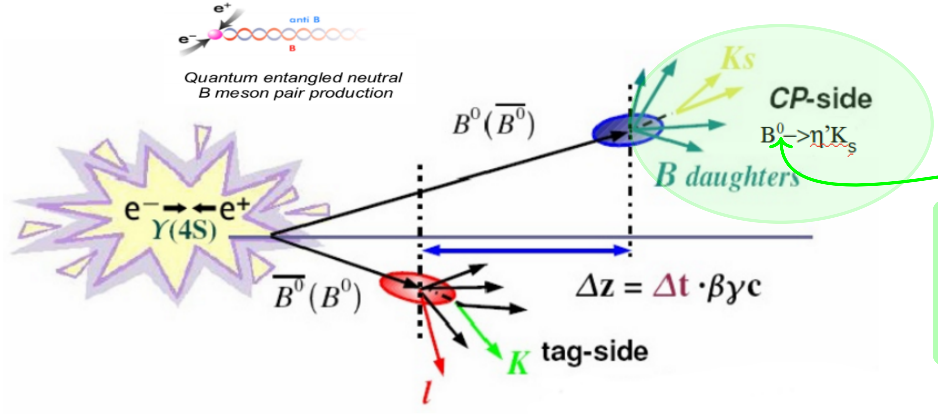


$\beta\gamma$ = 0.28(0.45) Belle2(Belle)

Δt probabilty parametrization: $\mathcal{P}(\Delta t, q) = \frac{e^{-\Delta t/\tau_{B^0}}}{4\tau_{B^0}}\left[1 + q\left(\mathcal{A}_{CP}\cos\Delta m_d \Delta t + \mathcal{S}_{CP}\sin\Delta m_d\Delta t\right)\right]$

Time Dependent CP Violation using $\eta' K_0$ final state (slide ©S.Lacaprara)



Signal:

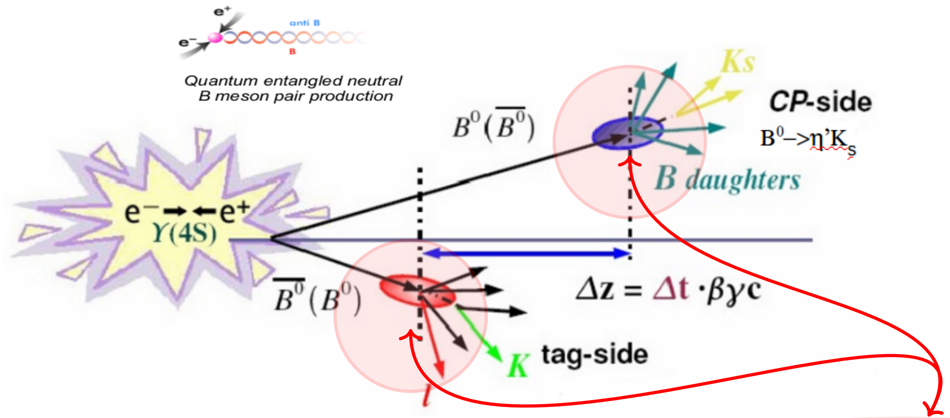
$K_S^0 \rightarrow \pi^+\pi^-$

$\eta' \rightarrow \rho^0\gamma/\eta\pi^+\pi^-$

$\eta \rightarrow 2\gamma/3\pi$

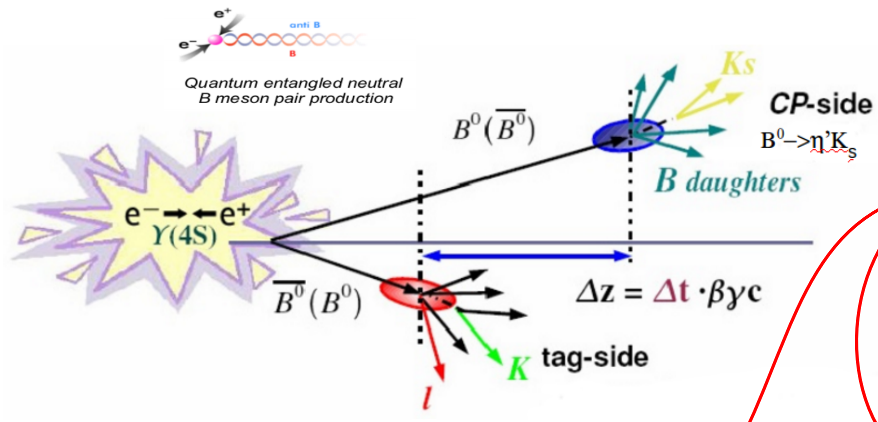
$\rho^0 \rightarrow \pi^+\pi^-$

Time Dependent CP Violation using $\eta' K_0$ final state (slide ©S.Lacaprara)



Signal and Tag-side
vertex resolution

Time Dependent CP Violation using $\eta' K_0$ final state (slide ©S.Lacaprara)



- backgrounds:
  - $q\bar{q}$
  - $b\bar{b}$
  - mis-reco sig (sxf)
- ML fit to extract the phys params
- ...

Δt probabilty parametrization: $\mathcal{P}(\Delta t, q) = \frac{e^{-\Delta t/\tau_{B^0}}}{4\tau_{B^0}}\left[1 + q\left(\mathcal{A}_{CP}\cos\Delta m_d \Delta t + \mathcal{S}_{CP}\sin\Delta m_d \Delta t\right)\right]$

The $\eta' \to \rho(\to \pi^+\pi^-)\gamma$

The following decay channels have been fully studied for the B2TIP:

- $\eta_{\gamma\gamma}K^0_S(\pm)$: $B^0 \to \eta'(\to \eta(\to \gamma\gamma)\pi^+\pi^-)K^0_S(\to \pi^+\pi^-)$
- $\eta_{3\pi}K^0_S(\pm)$: $B^0 \to \eta'(\to \eta(\to \pi^+\pi^-\pi^0)\pi^+\pi^-)K^0_S(\to \pi^+\pi^-)$
- total $\mathcal{BR}(\eta' K^0_S \to \textit{final state}) \sim 11\%$

A preliminary study has been done also for

- $\eta_{\gamma\gamma}K^0_S(00)$: $B^0 \to \eta'(\to \eta(\to \gamma\gamma)\pi^+\pi^-)K^0_S(\to \pi^0\pi^0)$
- rising the total $\mathcal{BR}(\eta' K^0_S \to \textit{final state}) \sim 14\%$
- need still some work and has not been finalized for B2TIP
- we'd like to wait for a more stable framework for the π^0 reconstruction

Today we'll present a preliminary analysis chain set up for

$$B^0 \to \eta'(\to \rho^0(\to \pi^+\pi^-)\gamma)K^0_S(\to \pi^+\pi^-)$$

- no π^0 reconstruction
- $\mathcal{BR}(\eta' \to \pi^+\pi^-\gamma) = 0.291$
- includes a non-resonant $\eta' \to \pi^+\pi^-\gamma$ contribution (not measured)
- gives by far the most abundant yield:

mode	$\mathcal{BR}$ (%)
$\eta'_{\gamma\gamma}K^0_S(\pm)$	5.8
$\eta'_{3\pi}K^0_S(\pm)$	4.9
$\eta'_{\gamma\gamma}K^0_S(00)$	2.9
$\eta'_{\rho\gamma}K^0_S(\pm)$	10.1

skim & reconstruction efficiencies

Studies based on **release-00-08-00** & MC8 production campaign

Analyzed beam background samples

Full **BG1 MC8 signal sample** production (1.6 Mevts)

Generic background samples studied: **uubar, ccbar, charged, mixed**. Missing: **ddbar, ssbar**

Standard particle lists used:

- gamma:good
- pi-:all
- K_S0:mdst

Skim selection

- $\rho^0 \to \pi^+\pi^-$ with $0.400 < M_{\rho^0} < 1.1$ GeV
- $\eta' \to \rho^0\gamma$ with $0.200 < M_{\eta'} < 1.5$ GeV
- $B^0 \to \eta' K_S^0$ with $M_{bc} > 5.0$ GeV & $|\Delta E| < 0.5$ GeV

Impact of beam background (on top of 1 Kevt):

	BG0	BG1
ε	0.64	0.54

- expected drop
- (very!) roughly $\sim$ 4% drop for each charged track
- to be compared with $\sim$ 8% of rel-00-07-01 (computed with $\eta'_{\gamma\gamma}$ channel)

skim & reconstruction efficiencies

Reconstruction:

- vertex rave for ρ^0, K_S^0
- massKFit for η'
- vertex rave with IPtube constraint for B^0

Skim & reconstruction efficiencies:

	Skim	Reco	Skim $\otimes$ Reco
Sig	0.54	0.85	0.46
$u\bar{u}$	0.06	0.41	0.023
$c\bar{c}$	0.09	0.42	0.038
charged	0.0058	0.24	0.0015
mixed	0.0075	0.30	0.0023

Efficiencies of missing $q\bar{q}$ modes expected to be at the same level

Average multiplicity $\sim$ 4.5 cands/evt

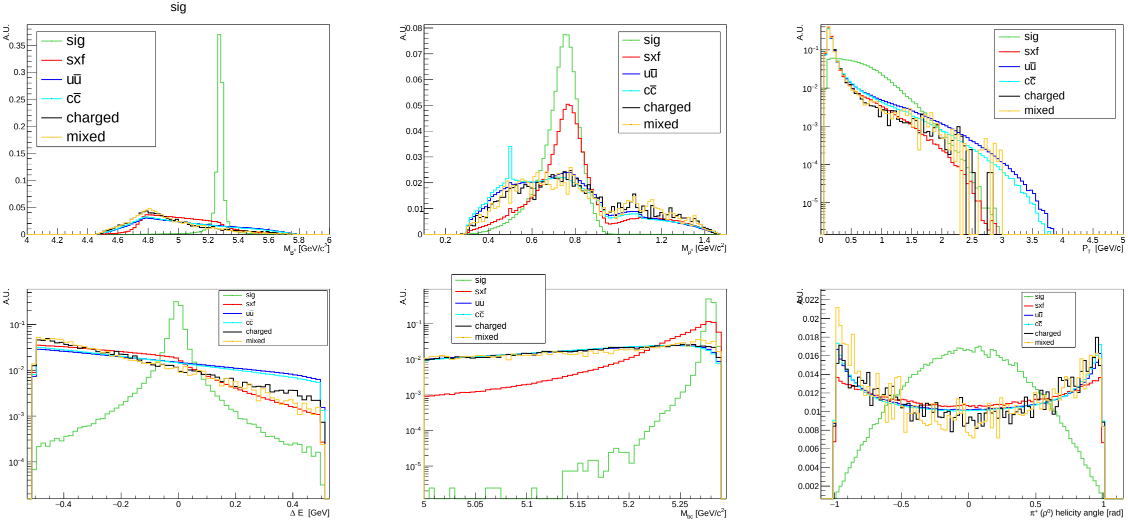
Fraction of reco events containing a true signal $\sim$ 0.75

Most of the signal misreco events are due to bad η' reco:

- in 0.95 of all wrong events
- mismatched γ is responsible for 0.47
- wrong ρ^0 reco causes the remaining 0.53

Need further study to figure out the reason

Variable distributions



Selection criteria

Efficiencies for studied samples:

	ε
sig	0.27
$u\bar{u}$	$\sim 2.0 \cdot 10^{-3}$
$c\bar{c}$	$\sim 2.7 \cdot 10^{-3}$
mixed	$\sim 8.2 \cdot 10^{-5}$
charged	$\sim 1.4 \cdot 10^{-4}$

Requirements on reconstructed candidates:

Variable	Requirement
M_{B^0}	[5,5.6] GeV
$M_{K^0_S}$	[0.44,0.55] GeV
M_{ρ^0}	[0.3,0.95] GeV
P_γ	$>$ 0.15 GeV
$\lvert\Delta E\rvert$	[-0.4,0.4] GeV
M_{bc}	[5.25,5.3] GeV
$\lvert\theta_{hel}\rvert$	$<$ 0.9
DLLKaon	$>$ -10
$\pi^\pm$ (ρ^0) TrPval	$>$ 0.01

- For signal there are as many true as sxf candidates
- Overall a too high background rate (compare with $\varepsilon^{generic}_{\gamma\gamma,3\pi} \sim \mathbf{10^{-6}}$)
- Need to go to a ''NLO'' refinement of selection criteria

The sig efficiency reasonably matches the values we extrapolated for B2 from Belle & BaBar (for the B2TIP):

	ε
B2 measured	0.27
B2 estimated	0.29
Belle	0.291
BaBar	0.285

Channel	ε
$\eta'(\eta_{\gamma\gamma}\pi^\pm)K_S^{(\pm)}$	23.0 %
$\eta'(\eta_{3\pi}\pi^\pm)K_S^{(\pm)}$	8.0 %

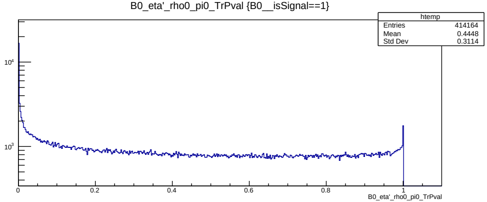
N.B. for $\eta_\gamma\gamma$ and $\eta_{3\pi}$ a dedicated strategy to deal with sxf was applied!

Selection criteria - $\pi^{\pm}$ TrPval cut efficiency

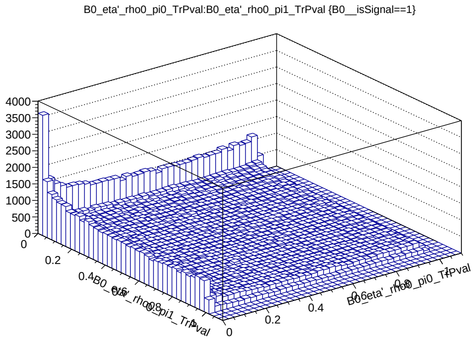
A not well understood behavior is seen when changing the requirement on $\pi^{\pm}$ (ρ^0) TrPval:

$\pi^{\pm}$ (ρ^0) TrPval	ε^{sig}
0.001	0.270
0.075	$\sim$ 0.216
0.1	$\sim$ 0.210

π^{+} TrPval (true signal, before selection)



(π^{+}, π^{-}) TrPval (true signal, before selection)



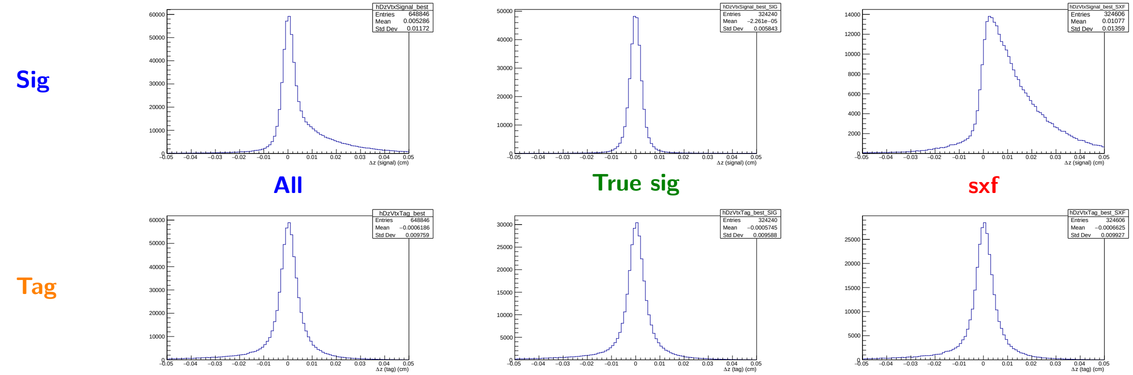
The same behavior is observed on the $\eta_{\gamma\gamma}$ mode

Vertex resolution - ΔZ Tag and Sig side

B^0 vertex fitted with the $\pi^{\pm}$ from ρ^0 decay (ok, plus K_S^0 & IPtube)

Resolution on the vertex expected to be in the same ballpark of $\eta_{\gamma\gamma}$

Distribution of $\Delta Z \equiv Z_{B^0(sig,tag)} - Z^{truth}_{B^0(sig,tag)}$



A bug fix make the shoulder seen in ΔZ reasonable: it's not in the tag side, but in the signal side and for sxf

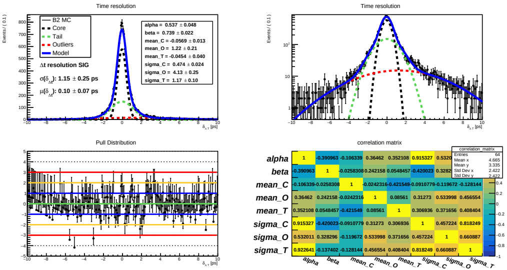
Time resolution with beam background

The time resolution is computed looking at $\delta_{\Delta T} \equiv \Delta T - \Delta T^{Truth}$ and fitting with the following $\mathcal{PDF}$:

$$\mathcal{PDF} = \alpha \cdot \mathcal{G}_C(\mu_C, \sigma_C) + (1-\alpha) \cdot [\beta \cdot \mathcal{G}_T(\mu_T, \sigma_T) + (1-\beta) \cdot \mathcal{G}_O(\mu_O, \sigma_O)]$$

superposition of a core ($\mathcal{G}_C(\mu_C, \sigma_C)$), a tail ($\mathcal{G}_T(\mu_T, \sigma_T)$), and an outlier ($\mathcal{G}_O(\mu_O, \sigma_O)$)

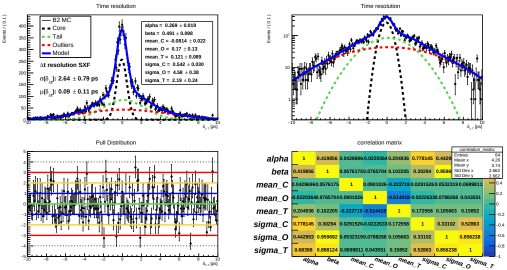
true signal



$\sigma(\delta_{\Delta T})$=1.15 ± 0.25 ps

$\mu(\delta_{\Delta T})$=0.10 ± 0.07 ps

sxf



$\sigma(\delta_{\Delta T})$=2.64 ± 0.79 ps

$\mu(\delta_{\Delta T})$=0.09 ± 0.11 ps

Time resolution with beam background

true signal

$\boldsymbol{\sigma(\delta_{\Delta T})=1.15 \pm 0.25}$ **ps**

$\mu(\delta_{\Delta T})=0.10 \pm 0.07$ ps

sxf

$\sigma(\delta_{\Delta T})=2.64 \pm 0.79$ ps

$\mu(\delta_{\Delta T})=0.09 \pm 0.11$ ps

A bias in $\delta_{\Delta T}$ is observed, both for true signal and sxf $\rightarrow$ improve fit procedure(?)

The error on σ & μ is quite large (only a part of the available stat has been used for fit)

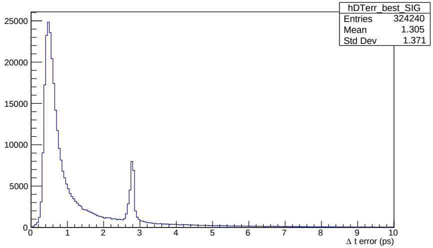
Comparison with time resolution of the $\eta_{\gamma\gamma}$ and $\eta_{3\pi}$

Channel	True	SxF	All
$\eta'(\eta_{\gamma\gamma}\pi^{\pm})K_S^{(\pm)}$	1.22 ps	2.87 ps	1.45 ps
$\eta'(\eta_{3\pi}\pi^{\pm})K_S^{(\pm)}$	1.17 ps	2.36 ps	1.50 ps
$\eta'_{\rho^0\gamma}K_S^{(\pm)}$	1.15 ps	2.64 ps	—

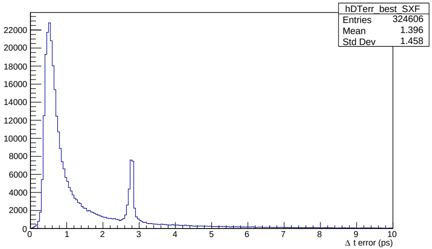
Error on ΔT

- a new tool computes the error on ΔT event-by-event (available in the head of basf2)
- can be used as a weight in the ML fit
- applied *out-of-the-box*
- needs a bit more of investigation

true signal



sxf



Analysis of systematics in $B^0 \to \eta' K^0$ for B2TIP

The current measurement by Belle divides the sources of systematics uncertainties for S in two classes:

- irreducible: vertexing (± 0.014), tag-side interference (± 0.001)
- reducible: Δt resolution, signal fraction, background Δt pdf, flavour tagging, fit bias, ± 0.038 (sum in quadrature).

Source of improvement:

- reducible systematics will scale with the luminosity (evaluated via control samples & MC simulation)
- vertex related systematics, tracking and alignment algorithm possibly reduced by a factor two thanks to improved Pixel Vertex detector
- ...but, differently from $b \to c$, expected background level higher for $b \to s$ modes

Two scenario have been considered:

- vertex related systematics are reduced (**optimistic**)
- no improvement in vertex related systematics (**pessimistic**)

L (ab^{-1})	stat. (10^{-2})	syst. (10^{-2})	total (10^{-2})
5	2.7	**2.1** (**1.7**)	**3.4** (**3.2**)
50	0.85	**1.8** (**1.3**)	**2.0** (**1.5**)

For $B^0 \to \eta' K^0$ systematic $\sim$ statistical uncertainty on S for $L = $ **10** (**20**) ab^{-1}

$B^0 \to \eta' K^0$ is the first $b \to q\bar{q}s$ mode for which statistical $\sim$ systematic uncertainties

Conclusions ...

- an analysis chain has been set up for the $\eta' \to \rho^0\gamma$ final state
- is the channel with the higher yield (accounting for almost all the $\eta_{\gamma\gamma}$ & $\eta_{3\pi}$)
- the efficiency of the preliminary selection well matches the one estimated for the B2TIP
- the level of background & sxf is too high $\to$ need a refinement of the selection

• an estimation of the systematic uncertainty has been presented

& prospects ...

- add the $d\bar{d}$ & $s\bar{s}$ bkg samples
- refine the selection criteria
- define the strategy to deal with sxf
- finalize the sensitivity studies with toys MC

Backup

Efficiencies

Table: Expected yields of continuum and peaking ($B\bar{B}$) events passing the selection for the different channels. The equivalent luminosity of the generic MC sample used is 1 ab^{-1}. The continuum background yield is before any cut on the continuum suppression variable (BDT)

Channel	Continuum	$B\bar{B}$	B^+B^-
$\eta'(\eta_{\gamma\gamma}\pi^{\pm})K_S^{(\pm)}$	16413	1834	57
$\eta'(\eta_{3\pi}\pi^{\pm})K_S^{(\pm)}$	4508	304	13

Estimated resolution

Table: The estimated resolutions from toy MC studies for CP-violating S_f and A_f parameters for an integrated luminosity of 1 and 5 ab^{-1} for different channels.

Channel	yield	$\sigma(S_f)$	$\sigma(A_f)$
	1 ab^{-1}		
$\eta'(\eta_{\gamma\gamma}\pi^{\pm})K_S^{(\pm)}$	969	0.13	0.08
$\eta'(\eta_{\gamma\gamma}\pi^{\pm})K_S^{(00)}$	215	0.27	0.17
$\eta'(\eta_{3\pi}\pi^{\pm})K_S^{(\pm)}$	283	0.25	0.16
$\eta'(\rho\gamma)K_S^{(\pm)}$	2100	0.06	0.07
$\eta'(\rho\gamma)K_S^{(00)}$	320	0.10	0.17
K_S modes	3891	0.065	0.040
K_L modes	1546	0.17	0.11
$K_S + K_L$ modes	5437	0.060	0.038
	5 ab^{-1}		
$\eta'(\eta_{\gamma\gamma}\pi^{\pm})K_S^{(\pm)}$	4840	0.06	0.04
$\eta'(\eta_{\gamma\gamma}\pi^{\pm})K_S^{(00)}$	1070	0.12	0.09
$\eta'(\eta_{3\pi}\pi^{\pm})K_S^{(\pm)}$	1415	0.11	0.08
$\eta'(\rho\gamma)K_S^{(\pm)}$	10500	0.04	0.03
$\eta'(\rho\gamma)K_S^{(00)}$	1600	0.10	0.07
K_S modes	19500	0.028	0.021
K_L modes	7730	0.08	0.05
$K_S + K_L$ modes	27200	0.027	0.020