Status of $B_0 \to \eta' K_0$

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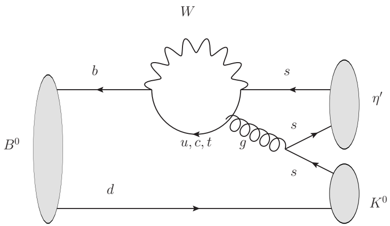
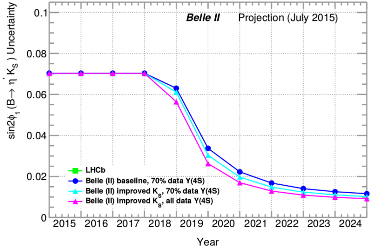
Charmless decay

TDCPV in charmless $b \to s$ decay

- the BR is much lower than the $b \to c$ $B \to J/\psi K_s$
- also, vertex resolution is generally worse due to lower q of B^0 decay
- $S_{\eta' K^0} = \sin 2\phi_1^{eff}$ tightly related to $\sin 2\phi_1$ measured in $b \to cs\bar{s}$ decay
- identical if only penguin diagram were present. Not so: $\Delta S_{\eta' K^0} \approx \pm 0.03, 0.05$
- new physics can enter in the loop, shifting $\Delta S_{\eta' K^0}$ more than SM expectation
- errors are statistically dominated, so far: fast improvement with first data;
- no competition from LHCb for η', due to the presence of neutrals.





Decay channels

many decay channels available $B^0 \to \eta' K^0$

decay channel		
$\eta' \to \rho^0(\to \pi^+\pi^-)\gamma$	BR=29%	not yet
$\eta' \to \eta\pi^+\pi^-$	43%	today
$\searrow \eta \to \gamma\gamma$	40%	$\eta_{\gamma\gamma}$
$\searrow \eta \to \pi^+\pi^-\pi^0$	23%	$\eta_{3\pi}$
$K^0_S \to \pi^+\pi^-$	69%	today
$K^0_S \to \pi^0\pi^0$	31%	just started
K^0_L		not yet
$B_0 \to \eta'(\to\eta_{\gamma\gamma}/\eta_{3\pi}\pi^+\pi^-)K^0_S(\to\pi^+\pi^-)$	BR=19%	

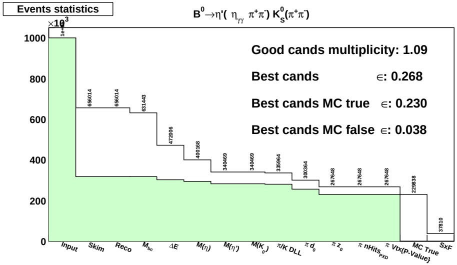
- Not all final state studied in time for B2TIP report
- final states considered so far in red
- not yet (ρ^0, $K^0_S \to \pi^0\pi^0$, K^0_L)
  - π^0 reconstruction eff still quite low
  - K^0_L reconstruction not yet available
  - $\rho^0\gamma$ not yet
- educated guess in final sensitivity for the missing channels

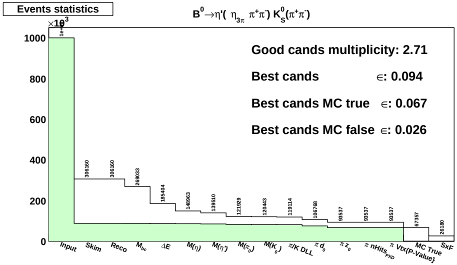
What's new wrt last B2GM

- Release 00.07.01
- Move to MC6 dataset: full BGx1 analysis
- Efficiency of the signal w/ and w/o machine background understood;
- BDT for signal cross feed (SxF) included in the ML fit;
- Accept multiple candidates per event;
  - particularly useful for $\eta_{3\pi}$, where cands multiplicity is high;
  - increase of efficiency for true signal yield, at the cost of more SxF;
  - the SxF BDT allows for separation of signal and SxF on a statistical basis on the ML fit;
- study sensitivity obtained using different number of candidates per event $\eta_{3\pi}$.
- $\mathcal{S}_{CP}$ sensitivity with toys.
- Educated extrapolation to other $B^0 \to \eta' K^0$ and penguin $b \to s\bar{q}q$ modes.
- Documented in B2TIP report
- First look to effect of beam-background on Flavor Tagging

Impact of machine background on signal efficiency

channel	BGx0 ϵ %	BGx0 SxF%	BGx0 cands/ev	BGx1 ϵ %	BGx1 SxF %	BGx1 cands/ev
$B^0 \to \eta'(\eta_{\gamma\gamma}\pi^\pm)K^0_S\ (\to \pi^+\pi^-)$	30.1	2.3	1.06	23.0	3.8	1.09
$B^0 \to \eta'(\eta_{3\pi}\pi^\pm)K^0_S(\to \pi^+\pi^-)$	15.1	3.0	1.45	6.7	2.6	2.71





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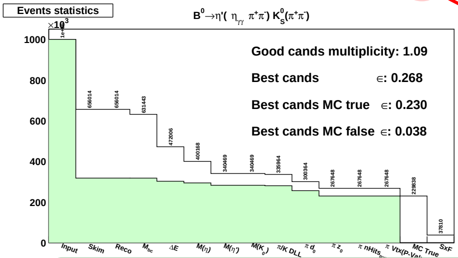

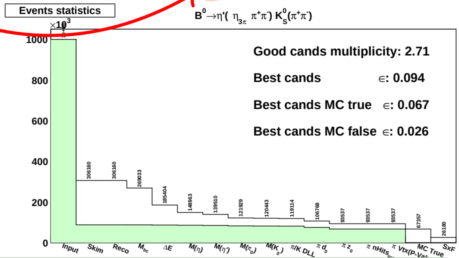

Important drop of efficiency passing from BGx0 to BGx1

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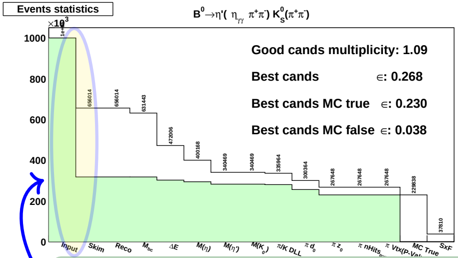

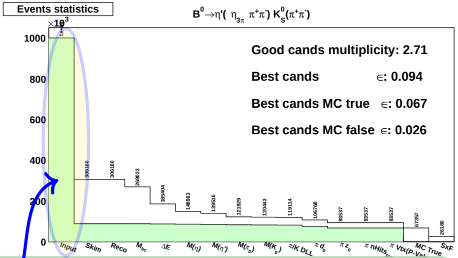

Important drop of efficiency passing from BGx0 to BGx1

- Reconstruction efficiency accounts for almost all eff drop
- Acceptance for signal is about: $\sim$ 50%

Impact of machine background on signal efficiency

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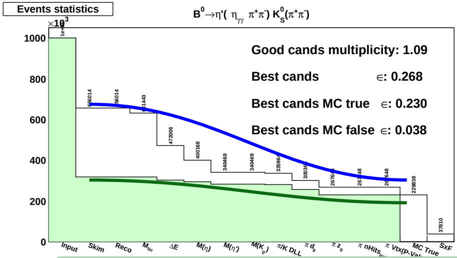
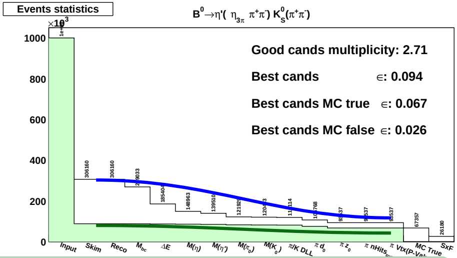


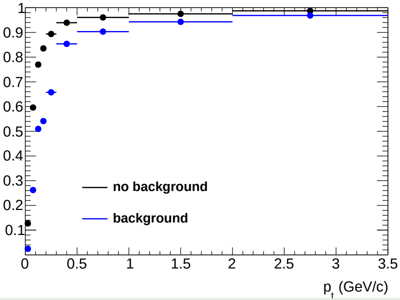


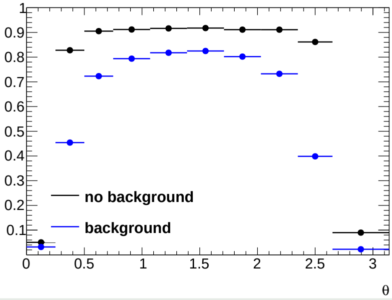
Important drop of efficiency passing from BGx0 to BGx1

- Reconstruction efficiency accounts for almost all eff drop
- Acceptance for signal is about: $\sim$ 50%
- Signal selections mostly reduce SxF (and background)
- optimization for signal efficiency at the cost of SxF increase.

Tracking efficiency without and with machine background

From B2TIP report (draft): Belle2 Performances





- About 8% loss for track (nb rel 00,07.01)
- $B^0 \to \eta'(\eta_{\gamma\gamma}\pi^{\pm})K^0_S\ (\to \pi^+\pi^-)$ has 4 charged tracks: $\sim$ 30% drop, $30 \to 23.0$

  In good agreement with what observed in $B^0 \to \phi(\to K^+K^-)K_S(\to \pi^+\pi^-)$
- $B^0 \to \eta'(\eta_{3\pi}\pi^{\pm})K^0_S(\to \pi^+\pi^-)$ has 6 charged tracks: $\sim$ 50% drop, $15.1 \to 6.7$
  - Some gain possible with fine tuning selections, but mostly is reconstuction;
- likely to improve with better reconstruction algorithms: to be checked with rel 8

Signal cross feed

Issue

- machine background increases also fraction of signal cross feed
- Signal is selected but a wrong set of tracks or photons are used to build the decay chain
  - BGx0→BGx1

$\eta_{\gamma\gamma}$: SxF/Signal=2.3% $\rightarrow$ 16.5%

$\eta_{3\pi}$: SxF/Signal=5.8% $\rightarrow$ 27%

Origin

mis−Reco ⇒	$\frac{\text{wrong } \eta'}{\text{tot SXF}}$	$\frac{\text{wrong } \eta}{\text{wrong } \eta'}$	$\frac{\text{wrong } \pi^0}{\text{wrong } \eta}$
$\eta_{\gamma\gamma}K_S^{\pm}$	99.0 %	78.1 %	− − −
$\eta_{3\pi}K^{\pm}$	99.9 %	98.7 %	82.03%

As expected, in most of the cases the problem is in the neutrals $\eta, \pi^0 \rightarrow \gamma\gamma$

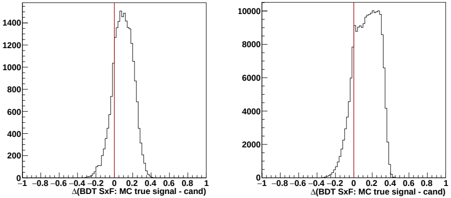
Loosening selection criteria improves signal efficiency but worsen the problem

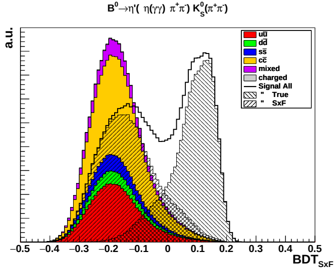
Solutions explored so far

- improve the choice of best candidate in events with multiple ones
- inizial choice based on best $\Pi(P_{vertex})$ or χ^2 of invariant masses in the decay chain
- try a multivariate approach

SxF BDT

- The behavior is good, true signal has the best BDT in most of the cases
- Separation between signal and SxF is good
- Background (continuum and peaking) is well separated as well
- Choose the candidate with the highest BDT





But ...

In spite of all this, the actual improvement in Sxf contamination is marginal: few % at most!

$\eta_{\gamma\gamma}$: SxF/Signal=16.5% $\to$ 15%

$\eta_{3\pi}$: SxF/Signal=27% $\to$ 25%

true signal vs SxF separation possible

Improve efficiency by multiple candidates

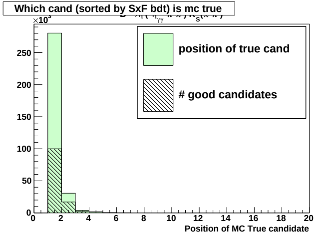
- The SxF BDT not able to select the *one* best candidate...
- ...but helps discriminating if a candidate is true signal or not;
- to avoid further drop in the true signal efficiency we accept more than one candidate per event

$\eta_{\gamma\gamma}$ can take all candidates, low multiplicity per event

$\eta_{3\pi}$ many true candidates are the next to best BDT

- this will significantly increase SxF as well
- include SxF BDT in the ML to separate the two sources

$\mathrm{B}^0 \to \eta'(\eta_{\gamma\gamma}\pi^{\pm})\mathrm{K}^0_S$



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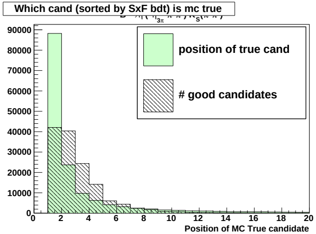
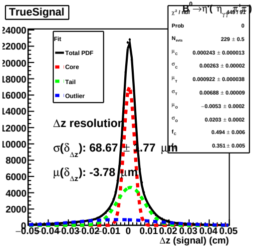
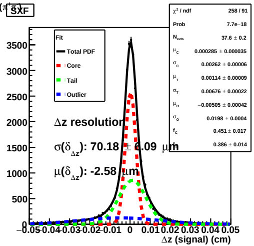


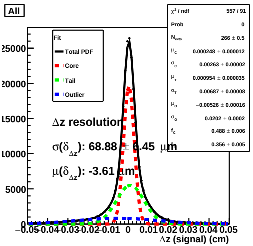
$\eta_{3\pi}$: efficiencies and SxF

candidates	1	2	all
True signal efficiency	6.7	8.1	9.6
SxF efficiency	2.3	6.0	28.6

Vertex resolution: True signal, SxF, all. $B^0 \to \eta'(\eta_{\gamma\gamma}\pi^\pm)K^0_S$







True Signal

SxF

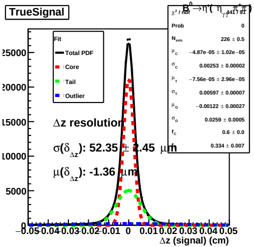
All

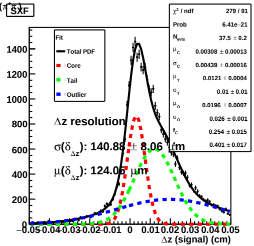
Signal side

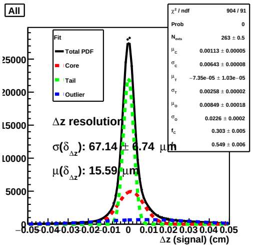
True $\sigma = 69\ \mu m$

SxF $\sigma = 70\ \mu m$

All $\sigma = 69\ \mu m$







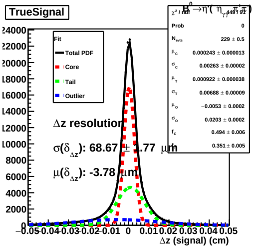
Tag side

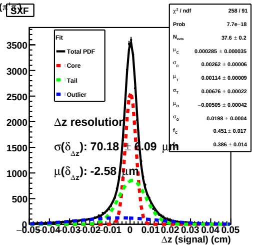
True $\sigma = 52\ \mu m$

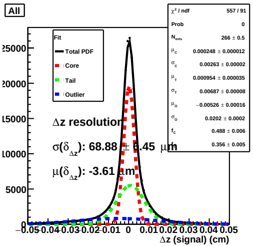
SxF $\sigma = 141\ \mu m$

All $\sigma = 67\ \mu m$

Vertex resolution: True signal, SxF, all. $B^0 \to \eta'(\eta_{\gamma\gamma}\pi^{\pm})K^0_S$



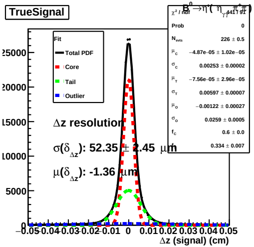


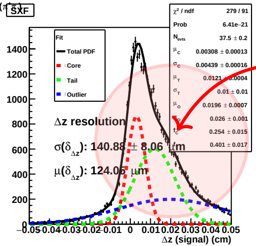


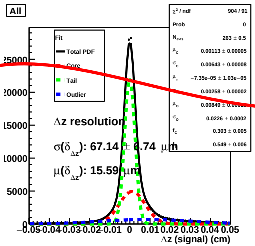
True Signal

SxF

All







Signal side

True $\sigma = 69\ \mu m$

SxF $\sigma = 70\ \mu m$

All $\sigma = 69\ \mu m$

Tag side

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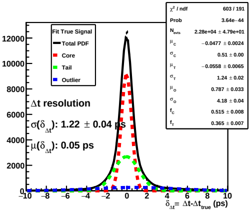
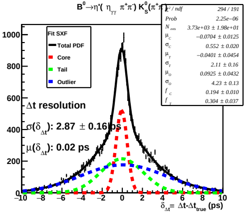
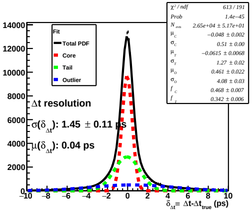
Δt resolution







True Signal

SxF

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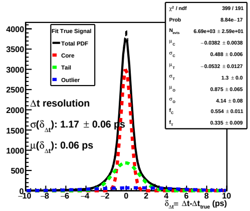
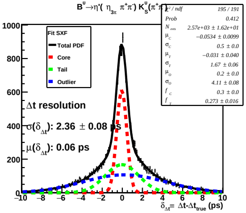
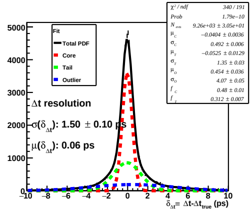






Non negligible impact of BGx1 on Δt resolution

$\eta_{\gamma\gamma}$(BGx1)

True $\sigma = 1.22\ ps$

SxF $\sigma = 2.87\ ps$

All $\sigma = 1.45\ ps$

True (BGx0)

$\sigma = 0.91\ ps$

$\eta_{3\pi}$(BGx1)

True $\sigma = 1.17\ ps$

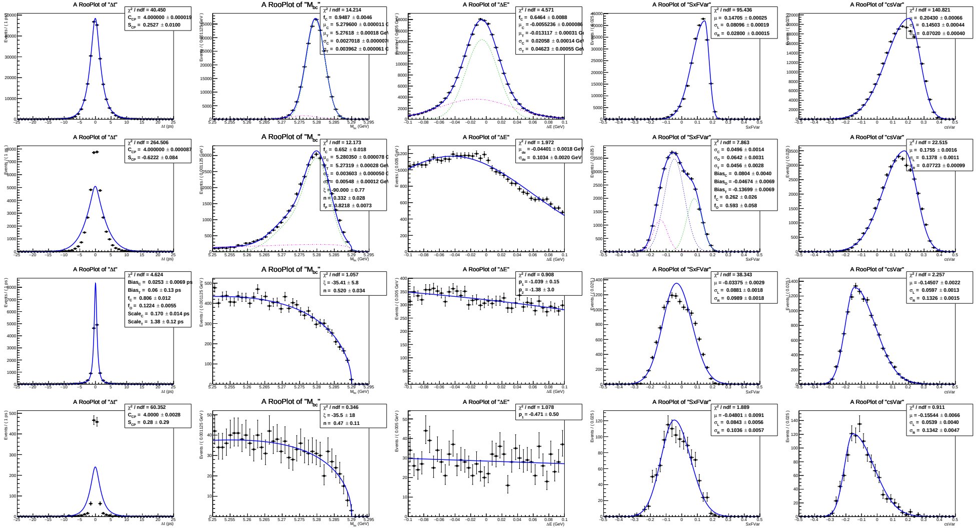
SxF $\sigma = 2.36\ ps$

All $\sigma = 1.50\ ps$

True (BGx0)

$\sigma = 0.88\ ps$

ML fit $B^0 \to \eta'(\eta_{\gamma\gamma}\pi^{\pm})K^0_S$



Signal

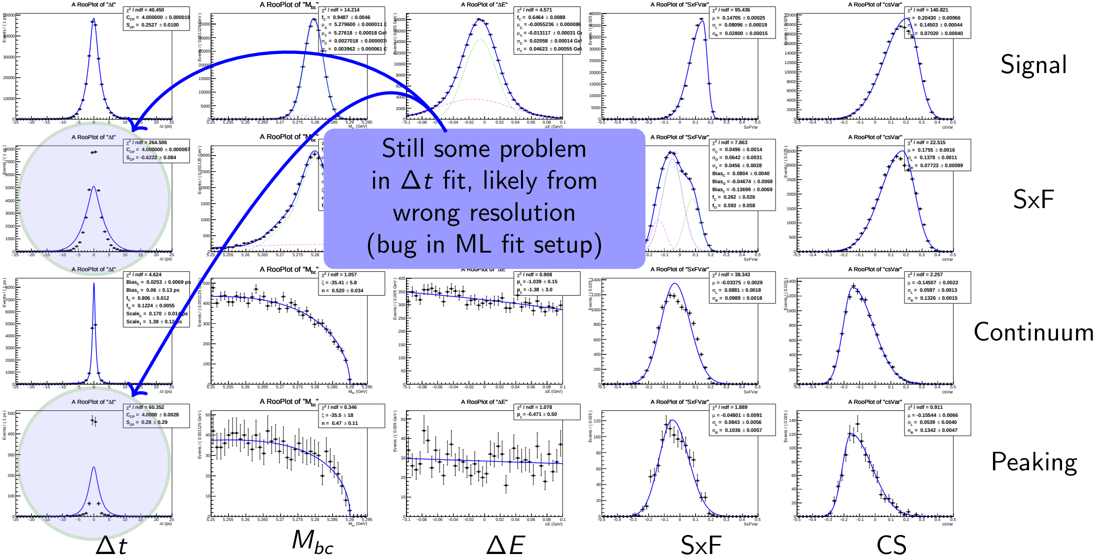
SxF

Continuum

Peaking

Δt | M_{bc} | ΔE | SxF | CS

ML fit $B^0 \to \eta'(\eta_{\gamma\gamma}\pi^{\pm})K^0_S$



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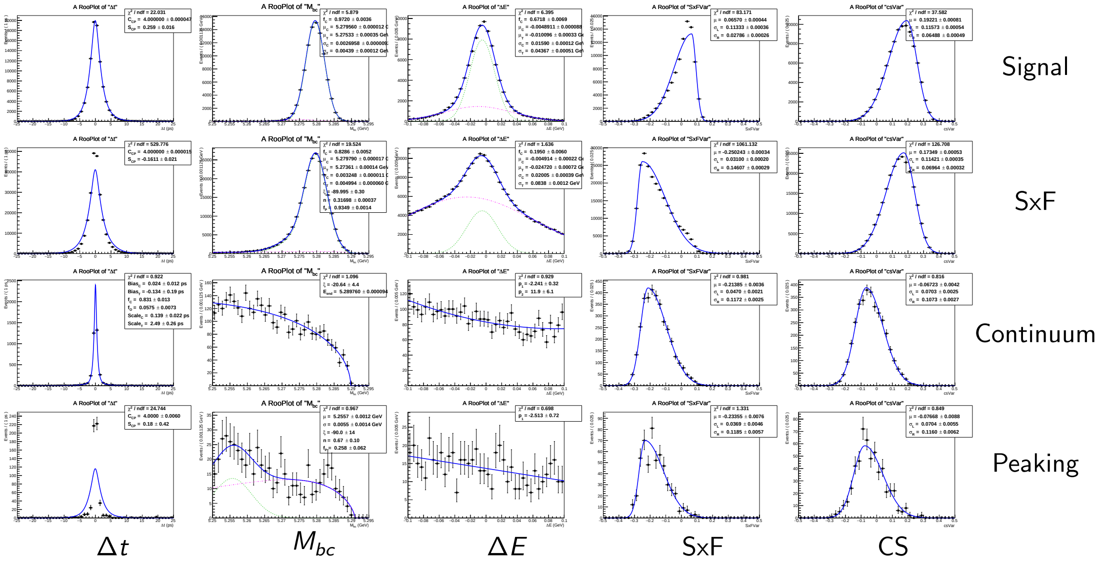
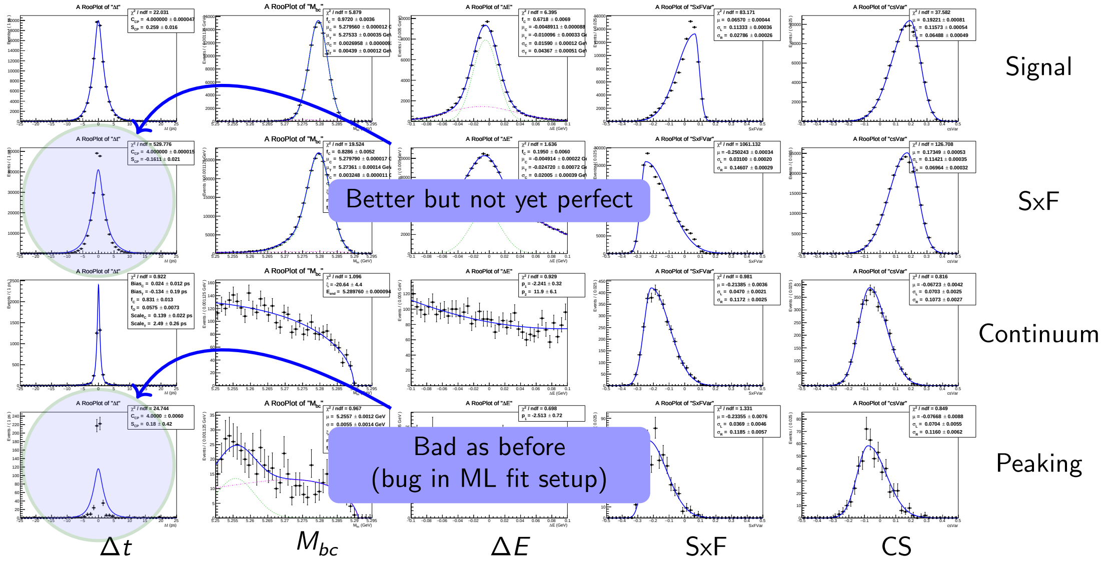
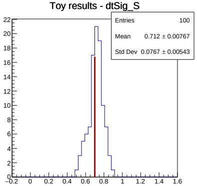
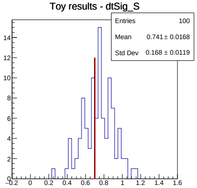


ML fit $B^0 \to \eta'(\eta_{3\pi}\pi^\pm)K_S^0$



Toys and projection





Channel	yield	$\sigma(S)$	$\sigma(C)$
	$1\ ab^{-1}$		
$\eta(2\gamma)K^0_S(\pi^\pm)$	969	0.13	0.08
$\eta(3\pi)K^0_S(\pi^\pm)$	283	0.25	0.16
	$5\ ab^{-1}$		
$\eta(2\gamma)K^0_S(\pi^\pm)$	4840	0.06	0.04
$\eta(3\pi)K^0_S(\pi^\pm)$	1415	0.11	0.08

Non negligible bias on $\mathcal{A}(C)_{CP}$ under investigation

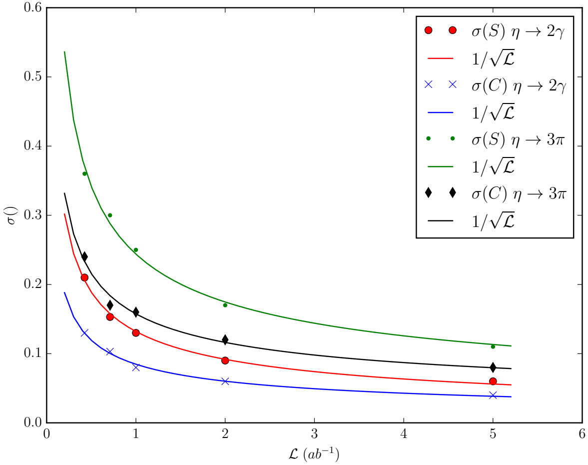
Missing channel

- $K^0_S \to 2\pi^0$, $\eta' \to \rho\gamma$, and K^0_L
- Use educated extrapolation

Efficiencies (%) comparison			
Channel	Belle 2	Belle	BaBar
$\eta(2\gamma)K^0_S(\pi^\pm)$	23.0	21.9	26.04
$\eta(3\pi)K^0_S(\pi^\pm)$	8.1	7.1	11.5

Resolution vs Luminosity

- The correct dependence $\sigma(S, C) \sim \frac{1}{\sqrt{\mathcal{L}}}$ has been checked
- considered scenario up to $\mathcal{L}$=5 ab^{-1}
- for higher luminosity $\sigma_{stat} \sim \sigma_{syst}$



Extrapolating to missing channels & other $b \to sq\bar{q}$ penguin modes

Statistical uncertainty on S and C ($\sigma(S, C)$) has the following dependence

$$\sigma(S, C) \sim \frac{\mathcal{C}}{\sqrt{\text{Yield}^{sig}}} = \frac{\mathcal{C}}{\sqrt{\mathcal{N}^{sig}\epsilon_{sig}}}$$

where

- $\mathcal{C}$ is a function of the vertex resolution, depending (at $\mathcal{O}(1)$) from number of charged tracks from B^0 decay vertex;
- ϵ_{sig} is the total efficiency for reconstruction and selection of signal candidate events

For each missing channel Y:

- a benchmark channel X (studied for Belle2, *i.e.* $B \to \eta'(\eta_{(\gamma\gamma,3\pi)})K_S(\pi^+\pi^-)$) is used, according to the number of charged tracks in the final state (in order to have similar $\mathcal{C}$)
- $\epsilon_Y^{B2} = r \cdot \epsilon_X^{B2}$ with $r \equiv \frac{\epsilon_Y^{B,BaBar}}{\epsilon_X^{B,BaBar}}$ from Belle [Belle(2014)] or BaBar [BABAR(2009)]
- compute $\sigma_Y(S, C)$ by rescaling

$$\sigma_Y(S, C) \simeq \sigma_x(S, C)\sqrt{\frac{\text{Yield}_Y}{\text{Yield}_X}}$$

Extrapolating to missing channels & other $b \to sq\bar{q}$ penguin modes

Summary of $B^0 \to \eta' K^0$

Channel	yield	$\sigma(S)$	$\sigma(C)$
$1\ ab^{-1}$			
$\eta(2\gamma)K^0_S(\pi^\pm)$	969	0.13	0.08
$\eta(2\gamma)K^0_S(2\pi^0)$	215	0.27	0.17
$\eta(3\pi)K^0_S(\pi^\pm)$	283	0.25	0.16
$\rho(\pi^\pm)K^0_S(\pi^\pm)$	2100	0.06	0.07
$\rho(\pi^\pm)K^0_S(2\pi^0)$	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
$5\ ab^{-1}$			
$\eta(2\gamma)K^0_S(\pi^\pm)$	4840	0.06	0.04
$\eta(2\gamma)K^0_S(2\pi^0)$	1070	0.12	0.09
$\eta(3\pi)K^0_S(\pi^\pm)$	1415	0.11	0.08
$\rho(\pi^\pm)K^0_S(\pi^\pm)$	10500	0.04	0.03
$\rho(\pi^\pm)K^0_S(2\pi^0)$	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

Other $b \to sq\bar{q}$ penguin mode

Channel	Benchmark channel	efficiency ratio
$1\ ab^{-1}$		
$\omega(\pi^+\pi^-\pi^0)K^0_S(\pi^\pm)$	$\eta'(\eta_{\gamma\gamma}\pi^+\pi^-)K^0_S(\pi^\pm)$	BaBar
$\pi^0 K^0_S(\pi^\pm)$	$\pi^0 K^0_S(\pi^\pm)\gamma$	BaBar

Results:

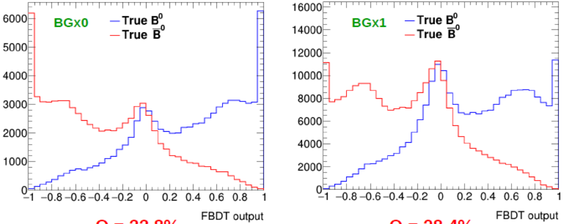
Channel	yield	$\sigma(S)$	$\sigma(C)$
$1\ ab^{-1}$			
$\omega(\pi^+\pi^-\pi^0)K^0_S(\pi^\pm)$	334	0.14	0.11
$\pi^0 K^0_S(\pi^\pm)$	1140	0.20	0.23
$5\ ab^{-1}$			
$\omega(\pi^+\pi^-\pi^0)K^0_S(\pi^\pm)$	1670	0.06	0.05
$\pi^0 K^0_S(\pi^\pm)$	5700	0.09	0.10

Impact of beam background on Flavour tagging - From A.Gaz

- Flavor tagging based on the output of a Multivariate classifier (FastBDT)
- tagging efficiency defined as (w mis-tag probability, ε efficiency)

$$Q = \varepsilon(1-2w)^2$$

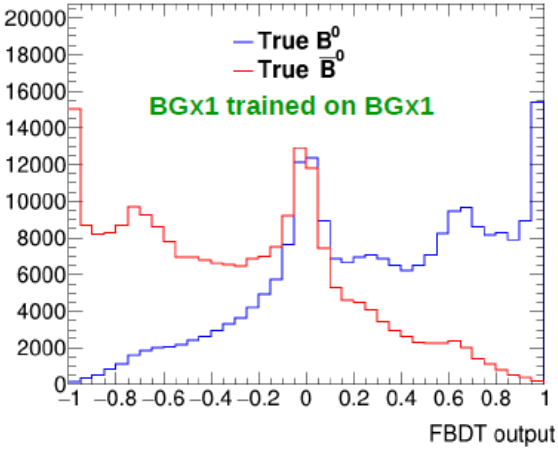
- Flavor tagger trained on $B^0 \to J/\psi(\to \mu^+\mu^-)K_S$ without beam background
- drop of performances when classifying events with beam-background **$Q = 33.8\%$ → $Q = 28.4\%$**



Q = 33.8% Q = 28.4%

- performances are partially recovered once classifier is trained on beam-background sample

Sample	Training sample	Q (%)
BKG0	BKG0	33.8
BKG1	BKG0	28.4
BKG1	BKG1	30.4



Summary and outlook

- Full analysis chain finalized for $\eta'(\eta_{(\gamma\gamma,3\pi)})K_S(\pi^+\pi^-)$
  - new original strategies have been explored (dedicated SXF study, multiple candidates)
  - with current framework Belle2 efficiency is between Belle and BaBar for both channels
- ML fit tuning;
  - Still some remaining issues:
  - migration between continuum and peaking background is seen
  - still failing to properly fit Δt distribution for peaking (possibly related);
  - Bias seen for A in toys ($\mathcal{A}_{CP} = -0.1$), S is fine
- Sensitivity for modes not studied obtained with educated extrapolation
- Included in B2TIP report (draft)
  - Working Group 3 (WG3), chapter 9: "Time Dependent CP Violation of B mesons and the determination of ϕ_1" ,
  - chapter mostly completed (missing introduction, summary, . . .)
- First look at effects of beam-background on flavor tagging presented
- We'd like to have a B2 note with more complete documentation for future reference;

Additional stuff

Additional or backup slides

Selection

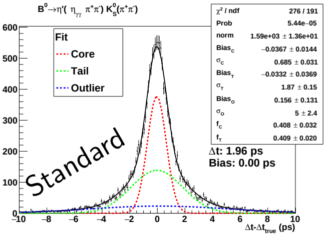
candidate selection: main cuts

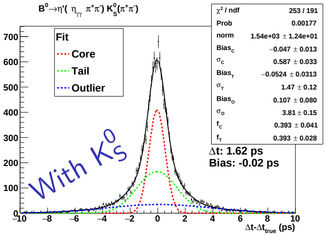
- Reconstruct decay chain with mass constrains for π^0, η, η', K^0_S,
  - vertex only (w/o mass) for B^0 (more later)
    - π^0, $\eta_{\gamma\gamma}$:
      - $0.06 < E_\gamma < 6\,\text{GeV}$, $E_9/E_{25} > 0.75$
      - $M(\pi^0) \in [100, 150]\,\text{MeV}$
      - $M(\eta_{\gamma\gamma}) \in [0.52, 0.57]\,\text{GeV}$;
    - $\eta' \to \eta_{\gamma\gamma}\pi^+\pi^-$:
      - $d_0(\pi^\pm) < 0.08\text{mm}$; $z_0(\pi^\pm) < 0.1\text{mm}$;
      - N $\text{hits}_{PXD}(\pi^\pm) > 1$, PID
      - $M(\eta') \in [0.93, 0.98]\,\text{GeV}$;
    - $\eta' \to \eta_{3\pi}\pi^+\pi^-$:
      - $M(\eta') \in [0.93, 0.98]\,\text{GeV}$;
    - $K^0 \to \pi^+\pi^-$:
      - $M(K^0_S \to \pi^+\pi^-) \in [0.48, 0.52]\,\text{GeV}$;
    - $B^0 \to \eta'(\to \eta_{\gamma\gamma}\pi^+\pi^-)K^{0+-}_S$
      - $M_{bc} > 5.25\,\text{GeV}$;
      - $|\Delta E| < 0.1\,\text{GeV}$;
    - $B^0 \to \eta'(\to \eta_{3\pi}\pi^+\pi^-)K^{0+-}_S$
      - $|\Delta E| < 0.15\,\text{GeV}$;

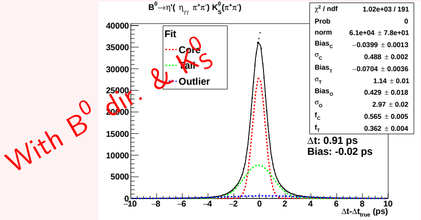
if $N_{cands} > 1$, select that with best reduced χ^2 for η, η', K^0_S inv. masses

Vtx reco and Δt resolution: $\eta_{\gamma\gamma}$ channel

1. Fit the B_0 vertex from charged tracks; ($\pi^{\pm}$ from $\eta' \rightarrow \eta\pi^{\pm}$)
2. add also constraint from reconstructed K_S^0 direction; ($K_S^0 \rightarrow \pi^+\pi^-$)
3. add also constraint from B^0 boost direction, transverse plane only.







With beamspot (x, y) & K_S^0:

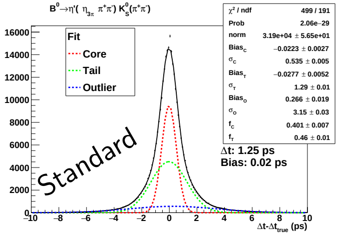
No efficiency loss

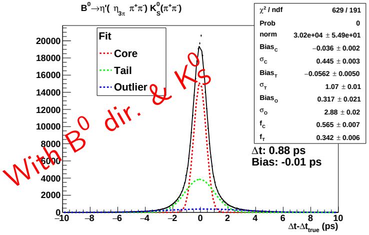
important improvement in Δt resolution

$1.89 \rightarrow 1.62 \rightarrow 0.91$ *ps*

Vtx reconstruction for $B^0 \to \eta'(\to \eta_{3\pi}\pi^+\pi^-)K^{0+-}_S$

Standard reconstruction uses four charged tracks:
$\pi^{\pm}$ from $\eta' \to \eta\pi^{\pm}$ and $\eta \to \pi^{\pm}\pi^0$





With B^0 dir. & K^0_S:

No efficiency loss

$1.25 \to 0.88$ *ps*

In both cases, Δt resolution better than in Belle, in spite of lower boost

Backgrounds

- **Combinatorial**: from continuum background $e^+e^- \to u\bar{u}, d\bar{d}, s\bar{s}, c\bar{c}$
  - evaluated from M_{bc} side bands on real data
  - now from MC production: **NB: still w/o machine background!**
  - use Continuum Suppression variable
    - multivariate variables sensitive to event topology
    - central (signal) vs jet-like (continuum)
    - past issues w/ variables “fixed”
- **Peaking**: any other B decays possibly with real η' and/or K^0_S
  - evaluated from MC of generic $\mathrm{B}^0\overline{\mathrm{B}}^0$, $\mathrm{B}^+\mathrm{B}^-$
    - actual $\mathrm{B}^0 \to \eta' \mathrm{K}^0$ removed.
- Current results based on BGx0 production, namely w/o machine background
  - impact of machine background under study
  - signal w/ machine background already produced
- Next table numbers before Continuum Suppression cut

Background reduction (before CS cut)

Sample	$u\bar{u}$	$d\bar{d}$	$s\bar{s}$	$c\bar{c}$	contiuum	$B^0\overline{B}^0$	B^+B^-
Input ev (M)	1284	321	306	1063	2974	2160	2070
$B^0 \to \eta'(\to \eta_{\gamma\gamma}\pi^+\pi^-)K_S^{0\,+-}$							
ϵ_{sel} $(\cdot 10^{-6})$	2.69	3.06	2.40	3.62	3.0	0.11	0.038
ev for 300 fb^{-1}	1247	369	275	1445	3335	13	6
$B^0 \to \eta'(\to \eta_{3\pi}\pi^+\pi^-)K_S^{0\,+-}$							
ϵ_{sel} $(\cdot 10^{-6})$	0.34	0.54	0.17	1.50	0.76	0.14	0.02
ev for 300 fb^{-1}	166	65	20	597	847	24	3

- Background reduction better for $\eta_{3\pi}$ than for $\eta_{\gamma\gamma}$

$\eta_{\gamma\gamma}$ mostly $u\bar{u}$ and $c\bar{c}$

$\eta_{3\pi}$ mostly $c\bar{c}$

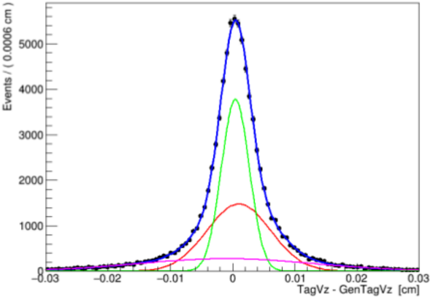
- peaking background is small
  - analyzed whole 5 ab^{-1} dataset from MC5
- preliminary study on w/ machine background shows similar rates

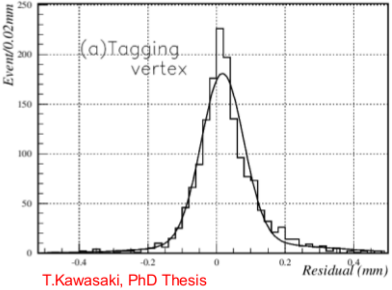
Golden Mode Proposal

Golden modes proposal

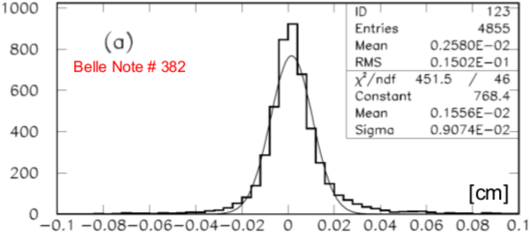
- Time dependent CP asymmetry in $B_d \to J/\psi K_S$
- Time dependent CP asymmetry in $B_d \to \phi K_S$, $B_d \to \eta' K_S$, $B_d \to \pi^0 K_S$, $B_d \to K_S K_S K_S$
- Time dependent CP asymmetry in $B_d \to K_S \pi^0 \gamma$
- Time dependent CP asymmetry in $B_d \to \pi\pi$, $B_d \to \pi\rho$, $B_d \to \rho\rho$

Δz resolution Tag Side

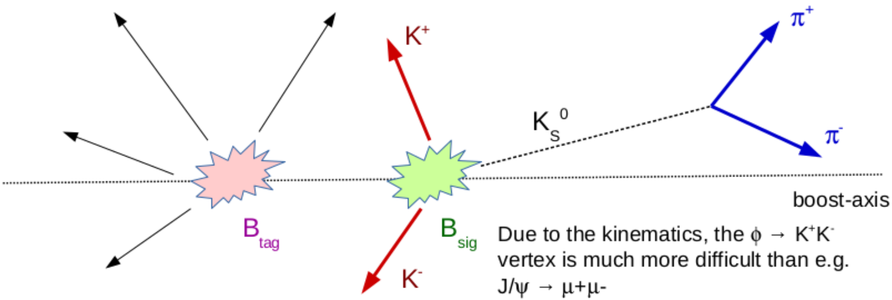




Belle II
- Shift = 3.8 µm
- Resolution = 56 µm



Belle
- Shift = 29 µm
- Resolution = 89 µm



Due to the kinematics, the $\phi \rightarrow K^+K^-$ vertex is much more difficult than e.g. $J/\psi \rightarrow \mu+\mu-$

Different strategies to determine the B_{sig} decay vertex:

- Simply use the tracks from “prompt decays”;
- Add also a kinematical constraint:
  - `ipprofile`: beamspot constraint (all three axes);
  - `iptube`: constraint just on the plane transverse to boost, useful for B-physics;
- Can use also the K^0_S flight direction.

Intro

- A more detailed description of the Yield estimate
- Comparison with Belle and BaBar
- including the educated extrapolation for missing channels:
  - using $K^0_S \to \pi^+\pi^-$vs$K^0_S \to \pi^0\pi^0$Belle/BaBar ratio
  - as well as K^0_S to K^0_L
- plus $\eta' \to \rho^0\gamma K^0_S$

$N_{B\overline{B}}$

Expected yield for integrated lumi L [fb^{-1}]

- $\sigma(e^+e^- \to \Upsilon(4s)) = 1.1\ nb$
- $BR(\Upsilon(4s) \to B^0\overline{B}^0) = .486$
- $N_{B\overline{B}} = L \cdot \sigma$
- $N_{B^0\overline{B}^0} = L \cdot \sigma \cdot BR$
- $N_{B^0} = 2 \cdot N_{B^0\overline{B}^0}$

L [ab^{-1}]	$N_{B\overline{B}}$ [10^6]	$N_{B^0\overline{B}^0}$ [10^6]
0.425(BaBar)	468	232
0.701 (Belle)	771	382
1	1100	546
5	5500	2728
50	55000	27280

Branching ratio

- $BR(\mathrm{B}^0 \to \eta' \mathrm{K}^0) = 6.6 \cdot 10^{-5}$
- $BR(\eta' \to \eta\pi^+\pi^-) = 0.429$
- $BR(\eta' \to \rho\gamma) = 0.291$
- $BR(\eta \to \gamma\gamma) = 0.3941$
- $BR(\eta \to \pi^+\pi^-\pi^0) = 0.3268$
- $BR(\rho \to \pi^+\pi^-) = 1$

- $\mathrm{K}^0_S/\mathrm{K}^0_L$ in $\mathrm{K}^0 = 0.5$
- $BR(\mathrm{K}^0_S \to \pi^+\pi^-) = 0.6920$
- $BR(\mathrm{K}^0_S \to \pi^0\pi^0) = 0.3069$

Channel $\mathrm{B}^0 \to$	BR $[\cdot 10^{-6}]$
$\eta' \to \eta_{\gamma\gamma}\pi^+\pi^-$	
$\eta' \mathrm{K}^0_S(\to \pi^+\pi^-)$	$3.86 \cdot 10^{-6}$
$\eta' \mathrm{K}^0_S(\to \pi^0\pi^0)$	$1.71 \cdot 10^{-6}$
$\eta' \mathrm{K}^0_L$	$5.58 \cdot 10^{-6}$
$\eta' \to \eta_{\pi^+\pi^-\pi^0}\pi^+\pi^-$	
$\eta' \mathrm{K}^0_{S\,\pi^+\pi^-}$	$3.20 \cdot 10^{-6}$
$\eta' \mathrm{K}^0_L$	$4.63 \cdot 10^{-6}$
$\eta' \to \rho_{\pi^+\pi^-}\gamma$	
$\eta' \mathrm{K}^0_{S\,\pi^+\pi^-}$	$2.85 \cdot 10^{-6}$
$\eta' \mathrm{K}^0_{S\,\pi^0\pi^0}$	$1.26 \cdot 10^{-6}$

Signal Efficiency

Channel $B^0 \to$	Eff % Belle2	Eff (Belle) [Belle(2014)]	Eff (BaBar) [BABAR(2009)]
	$\eta' \to \eta_{\gamma\gamma}\pi^+\pi^-$		
$\eta' K^0_S(\to \pi^+\pi^-)$	23.0	21.9	26.4
$\eta' K^0_S(\to \pi^0\pi^0)$	$11.5^\star$	7.9	13.2
$\eta' K^0_L$	-	19.4	14.9
	$\eta' \to \eta_{\pi^+\pi^-\pi^0}\pi^+\pi^-$		
$\eta' K^0_{S_{\pi^+\pi^-}}$	8.1	7.1	11.5
$\eta' K^0_L$	-	6.0	7.0
	$\eta' \to \rho_{\pi^+\pi^-}\gamma$		
$\eta' K^0_{S_{\pi^+\pi^-}}$	-	27.8	32.5
$\eta' K^0_{S_{\pi^0\pi^0}}$	-	7.2	15.1

Note

* very preliminary

The effiency used for the expected yields (next page) for the channels not studied yet are taken as an average of that of Belle and BaBar

Signal Yield vs Luminosity and comparison with Belle/BaBar

L [ab^{-1}] ($N_{B\bar{B}}$)	0.425 (468M)		0.701 (771M)		1 (1100M)	5 (5500M)
Channel $B^0 \to$	B2	[BABAR(2009)]	B2	[Belle(2014)]	B2	B2
$\eta' \to \eta_{\gamma\gamma}\pi^+\pi^-$						
$\eta' K^0_S(\to \pi^+\pi^-)$	412	472	679	648	969	4840
$\eta' K^0_S(\to \pi^0\pi^0)$	91	105	151	104	215	1070
$\eta' K^0_L$	520	386	850	829	1200	6100
$\eta' \to \eta_{\pi^+\pi^-\pi^0}\pi^+\pi^-$						
$\eta' K^0_{S\,\pi^+\pi^-}$	120	171	198	174	283	1415
$\eta' K^0_L$	137	169	223	213	320	1600
$\eta' \to \rho_{\pi^+\pi^-}\gamma$						
$\eta' K^0_{S\,\pi^+\pi^-}$	894	1005	1474	1411	2100	10500
$\eta' K^0_{S\,\pi^0\pi^0}$	140	206	223	162	320	1600
All K^0_S	1654	1959	2728	2519	3891	19500
All K^0_L	657	556	1084	1042	1546	7730
All	2311	2515	3811	3541	5437	27200

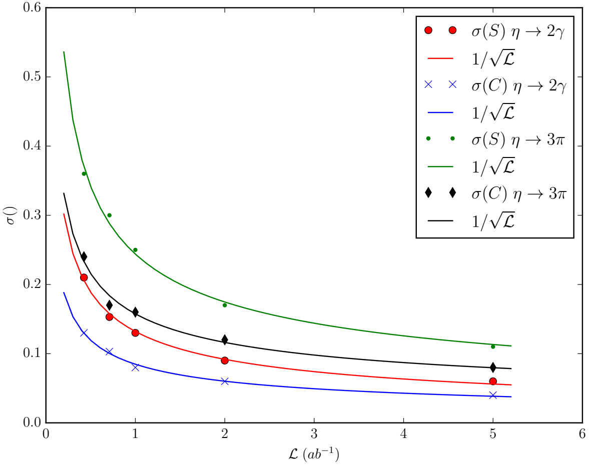
Estimated sensitivity (and comparison with Belle/BaBar)

L [ab^{-1}] ($N_{B\bar{B}}$)	0.425 (468M)				0.701 (771M)			
Channel $B^0 \rightarrow$	σ_S	σ_C	σ_S	σ_C	σ_S	σ_C	σ_S	σ_C
$\eta' \rightarrow \eta_{\gamma\gamma}\pi^+\pi^-$	B2		[BABAR(2009)]		B2		[Belle(2014)]	
$\eta' K^0_S(\rightarrow \pi^+\pi^-)$	0.21	0.13	0.17	0.11	0.15	0.10	0.15	0.10
$\eta' K^0_S(\rightarrow \pi^0\pi^0)$	0.45	0.28	0.34	0.30	0.26	0.17	*0.21	*0.18
$\eta' K^0_L$	0.19	0.14	0.22	0.16	0.11	0.09	n.a.	
$\eta' \rightarrow \eta_{\pi^+\pi^-\pi^0}\pi^+\pi^-$								
$\eta' K^0_{S\,\pi^+\pi^-}$	0.36	0.24	0.26	0.20	0.30	0.20	0.26	0.18
$\eta' K^0_L$	0.33	0.28	0.36	0.25	0.20	0.17	n.a.	
$\eta' \rightarrow \rho_{\pi^+\pi^-}\gamma$								
$\eta' K^0_{S\,\pi^+\pi^-}$	0.10	0.12	0.12	0.09	0.08	0.07	0.09	0.07
$\eta' K^0_{S\,\pi^0\pi^0}$	0.26	0.22	0.33	0.26	0.21	0.18	*0.21	*0.18
All K^0_S	0.100	0.063	0.08	0.06	0.071	0.045	0.074	0.052
All K^0_L	0.165	0.13	0.18	0.13	0.21	0.14	0.21	0.14
All	0.086	0.056	0.08	0.06	0.067	0.043	0.07	0.049

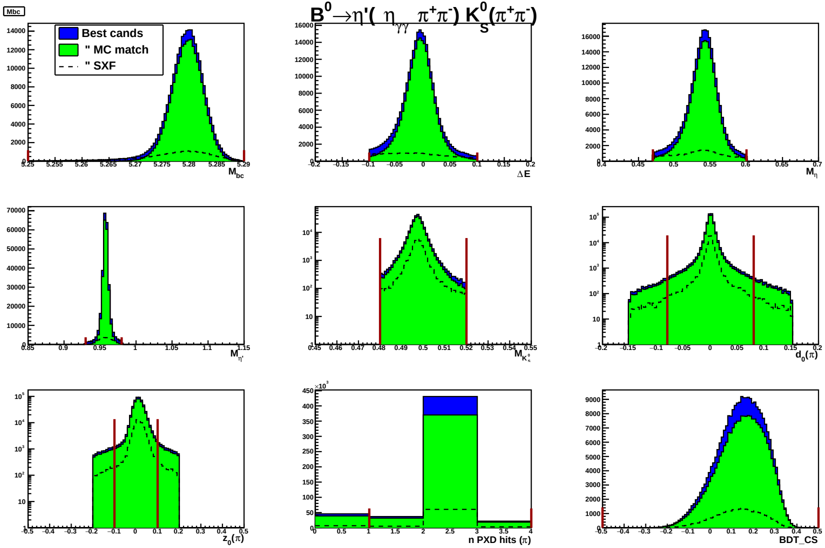
Estimated sensitivity

L [ab^{-1}] ($N_{B\bar{B}}$)	1 (1100M)		2 (2200M)		5 (5500M)	
Channel $B^0 \to$	σ_S	σ_C	σ_S	σ_C	σ_S	σ_C
$\eta' \to \eta_{\gamma\gamma}\pi^+\pi^-$						
$\eta' K^0_S(\to \pi^+\pi^-)$	0.13	0.08	0.09	0.06	0.06	0.04
$\eta' K^0_S(\to \pi^0\pi^0)$	0.27	0.17			0.12	0.09
$\eta' K^0_L$	0.12	0.09			0.06	0.04
$\eta' \to \eta_{\pi^+\pi^-\pi^0}\pi^+\pi^-$						
$\eta' K^0_{S\,\pi^+\pi^-}$	0.25	0.16	0.17	0.12	0.11	0.08
$\eta' K^0_L$	0.22	0.18			0.10	0.08
$\eta' \to \rho_{\pi^+\pi^-}\gamma$						
$\eta' K^0_{S\,\pi^+\pi^-}$	0.06	0.07			0.04	0.03
$\eta' K^0_{S\,\pi^0\pi^0}$	0.10	0.17			0.10	0.07
All K^0_S	0.065	0.040			0.028	0.02
All K^0_L	0.17	0.111			0.08	0.05
All	0.060	0.038			0.027	0.020

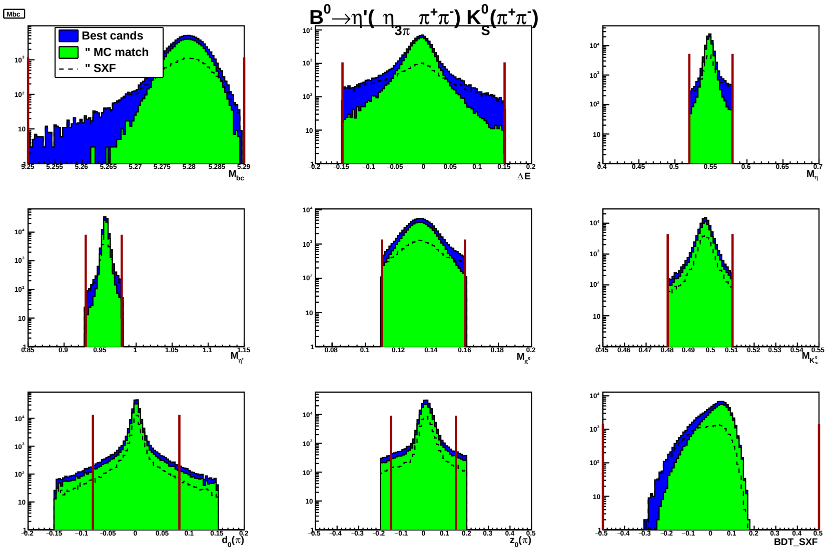
Resolution vs Luminosity



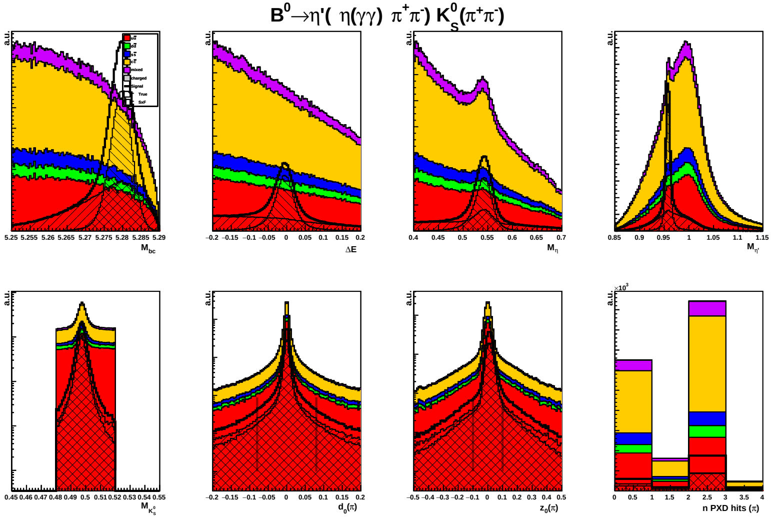
Distribution for Signal



Distribution for Signal

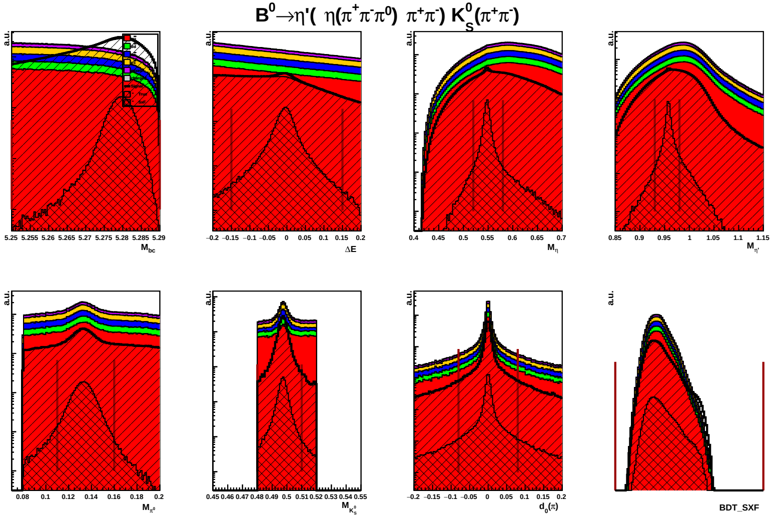


Distribution for Signal and Background



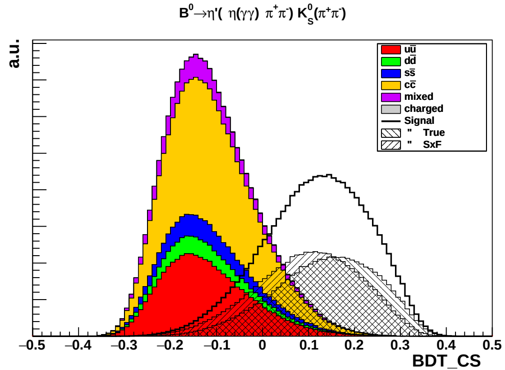
- Black: signal
  - True \\
  - SxF //
  - All candidates!
- Colors: background
- No major differences for Signal and Background distribution from BGx0 to BGx1

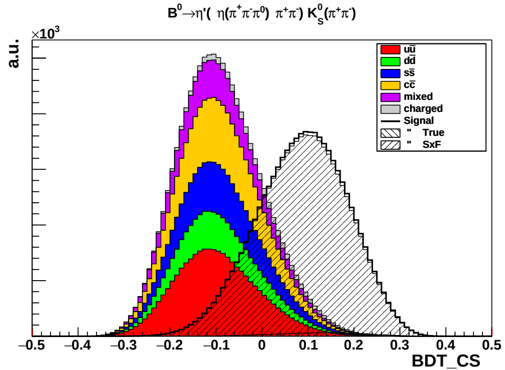
Distribution for Signal and Background



- Black: signal
  - True \\
  - SxF //
  - All candidates!
- Colors: background
- Signal shown with all good candidates
  - multiplicity 2.7 cand/ev

Plot with all candidates





Channel	Continuum	$B\bar{B}$	B^+B^-
$\eta(2\gamma)K^0_S(\pi^\pm)$	16413	1834	57
$\eta(3\pi)K^0_S(\pi^\pm)$	4508	304	13

Likelihood fit

Multi dim. extended maximum likelihood fit to extract S and A.

Pdf is of the form: $\mathcal{P}_j^i = \underbrace{\mathcal{T}_j\left(\Delta t^i, \sigma^i_{\Delta t}, \eta^i_{CP}\right)}_{\text{time-dep part}} \prod_k \underbrace{\mathcal{Q}_{k,j}(x^i_k)}_{\text{time integrated}}$

time-dependent part, taking into account mistag rate ($\eta_f = \pm 1$ is CP state):

$$f(\Delta t) = \frac{e^{-|\Delta t|/\tau}}{4\tau}\left\{1 \mp \Delta w \pm (1-2w) \times \left[-\eta_f S_f \sin(\Delta m \Delta t) - A_f \cos(\Delta m \Delta t)\right]\right\}$$

variables (x_k) used, in addition to Δt

- M_{bc}
- ΔE
- Cont. Suppr.
- SxF BDT new

Parameters:

- effective tagging efficiency: $Q = \epsilon(1-2w)^2 = 0.33$
  - $w = 0.21$, $\Delta w = 0.02$
- Δt resolution as shown previously (convoluted)
- τ, Δm from PDG

[Belle(2014)] Belle. Measurement of time-dependent cp violation in $b_0 \to \eta' k_0$ decays. *Journal of High Energy Physics*, 2014(10):165, 2014. doi: 10.1007/JHEP10(2014)165. URL http://dx.doi.org/10.1007/JHEP10%282014%29165.

[BABAR(2009)] BABAR. Measurement of time dependent *cp* asymmetry parameters in B^0 meson decays to ωK_S^0, $\eta' K^0$, and $\pi^0 K_S^0$. *PRD*, 79:052003, 2009. doi: 10.1103/PhysRevD.79.052003. URL http://link.aps.org/doi/10.1103/PhysRevD.79.052003.