Time dependent CP violation analysis setup in BelleII

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Time dependent CP violation is a powerful tool to both perform precise measurement of the unitary triangle and to look for new physics beyond the standard model.

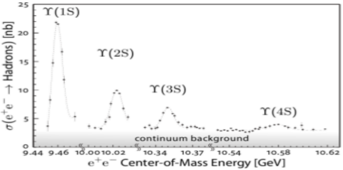
Within B2TIP Work Package 3, several analysis are being developed in order to:

- estimate the sensitivity of the experiments in these analysis
- to asses the readiness of the BelleII software and analysis tool, as well train the analysis facilities (including the physicist), in a full scale exercise.

I will briefly report on progress done on three of these analysis:

- $B \to J/\psi K_s$ as benchmark for TD analysis
- two charmless channels:
  - $B \to \phi K^0$ one of the cleanest charmless hadronic channel;
  - $B \to \eta' K^0$ an other charmless channel, possibly more sensitive.

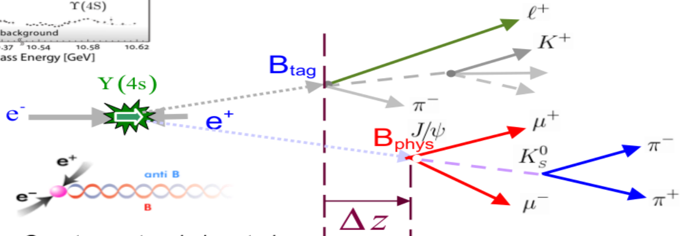
Time dependent measurements



- Y(4S) is the first resonance just above the $B\bar{B}$ production threshold
- Only $B\bar{B}$ pairs are produced, and are at rest in the Y(4S) frame

$$\Delta t = \frac{\Delta z}{\beta \gamma c}$$

Resolution on Δt will be dominated by the resolution of the tagging side vertex



Quantum entangled neutral B meson pair production

Belle ~ 200 µm
Belle II ~ 130 µm

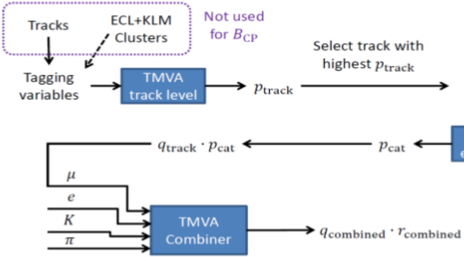
Δt probability parametrization $\mathcal{P}(\Delta t, q) = \frac{e^{-|\Delta t|/\tau_{B^0}}}{4\tau_{B^0}} \left[1 + q\left(\mathcal{A}_{CP} \cos \Delta m_d \Delta t + \mathcal{S}_{CP} \sin \Delta m_d \Delta t\right)\right]$

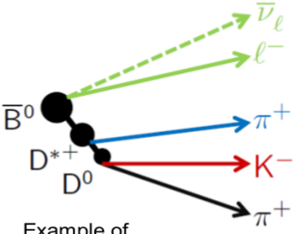
NB: $\beta\gamma_{Belle2(Belle)} = 0.28(0.425)$

$$Asym = \frac{\Gamma(B^0 \to X_{CP} - \Gamma\bar{B}^0 \to X_{CP}}{\Gamma B^0 + \Gamma \bar{B}^0} = \mathcal{A}\cos(\Delta m \Delta t) + \mathcal{C}\sin()$$

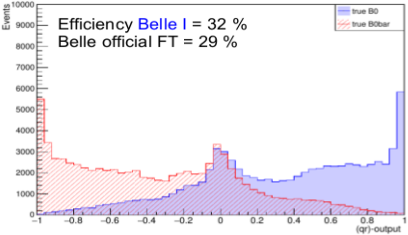
Need to tag flavour of B_{tag}, CP state of B_{phys}, and then fit $P(\Delta t, q)$ to data to extract A_{cp} and S_{cp}

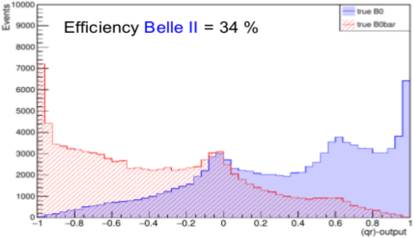
Flavour tagging





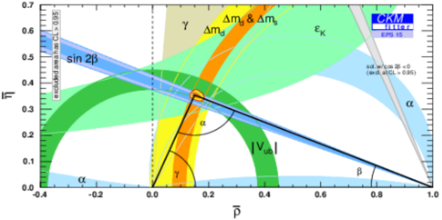
Example of signatures





$B^0 \to J/\psi K^0$: Belle status

$B^0 \to J/\psi K^0$ is a tree level process $b \to c$, $\mathcal{A}$ directly related to $\sin(2\phi_1)$



- $\sin(2\phi_1)$ will remain the most precise measurement on the Unitarity Triangle parameters
- In Belle II the measurement will be dominated by systematics
  - Effort concentrated in understand and reducing them

$$\sigma_{\text{total}}^{\sin 2\beta} = \sqrt{(0.023^2 + 0.010^2) \times 0.711/\mathcal{L}_{\text{int}} + 0.007^2}$$

Belle measurement statistical error

Belle measurement reducible systematic error

Belle measurement non reducible systematic error

Integrated luminosity used in Belle measurement

Belle II expected integrated luminosity

	Statistical	Systematic (reducible, irreducible)	Total
$\sin 2\beta$			
711 fb^{-1}	0.023	(0.010, 0.007)	0.026
5 ab^{-1}	0.009	(0.004, 0.007)	0.012
50 ab^{-1}	0.003	(0.001, 0.007)	0.008
$\mathcal{A}$			
711 fb^{-1}	0.016	(0.010, 0.011)	0.022
5 ab^{-1}	0.006	(0.004, 0.011)	0.013
50 ab^{-1}	0.002	(0.001, 0.011)	0.011

$B^0 \to J/\psi K^0$: Belle systematics

Phys. Rev. Lett. 108 171802 (2012)

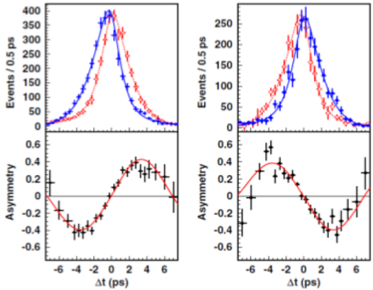


FIG. 2 (color online). The background-subtracted Δt distribution (top) for $q = +1$ (red) and $q = -1$ (blue) events and asymmetry (bottom) for good tag quality ($r > 0.5$) events for all CP-odd modes combined (left) and the CP-even mode (right).

TABLE II. CP violation parameters for each $B^0 \to f_{CP}$ mode and from the simultaneous fit for all modes together. The first and second errors are statistical and systematic uncertainties, respectively.

Decay mode	$\sin 2\phi_1 = -\xi_f \mathcal{S}_f$	$\mathcal{A}_f$
$J/\psi K_S^0$	$+0.670 \pm 0.029 \pm 0.013$	$-0.015 \pm 0.021^{+0.045}_{-0.023}$
$\psi(2S) K_S^0$	$+0.738 \pm 0.079 \pm 0.036$	$+0.104 \pm 0.055^{+0.047}_{-0.027}$
$\chi_{c1} K_S^0$	$+0.640 \pm 0.117 \pm 0.040$	$-0.017 \pm 0.083^{+0.046}_{-0.026}$
$J/\psi K_L^0$	$+0.642 \pm 0.047 \pm 0.021$	$+0.019 \pm 0.026^{+0.017}_{-0.041}$
All modes	$+0.667 \pm 0.023 \pm 0.012$	$+0.006 \pm 0.016 \pm 0.012$

Source	Irreducible	Error on $\mathcal{S}$	Error on $\mathcal{A}$
Vertexing	X	±0.007	±0.007
Δt resolution		±0.007	±0.001
Tag-side interference	X	±0.001	±0.008
Flavor tagging		±0.004	±0.003
Possible fit bias		±0.004	±0.005
Signal fraction		±0.004	±0.002
Background Δt PDFs		±0.001	< 0.001
Physics parameters		±0.001	< 0.001
Total		±0.012	±0.012

Irreducible systematic errors:

- Vertexing (without detector upgrade)
- Tag-side interference
  - More sophisticated treatment will be considered

New vertex detector and reconstruction algorithm

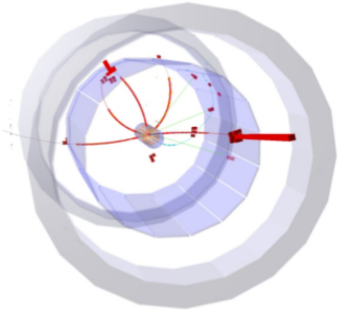
- 40 times increase of luminosity → higher background
- Lower boost → smaller separation between the B mesons

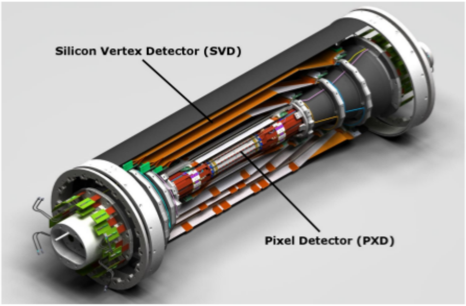
→ Pixel detector needed

Most suited technology : DEPFET

- Innermost detector system as close as possible to IP
- Highly granular pixel sensors provide most accurate 2D position information

- Reconstruction of primary and secondary vertices of short-lived particles
- Decay of particles is typical in the order of 100μm from the IP



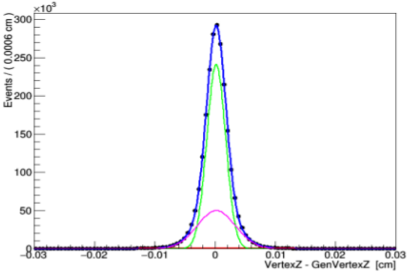


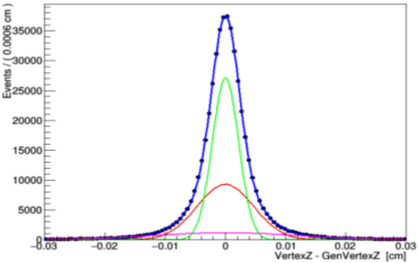
Δz resolution (signal side)

Two vertex fitters used in Belle II for kinematic vertex fits

- Kfit : used in Belle
- RAVE: a CMS tool, see https://rave.hepforge.org/)

$J/\psi \rightarrow \mu\,\mu$





Belle II

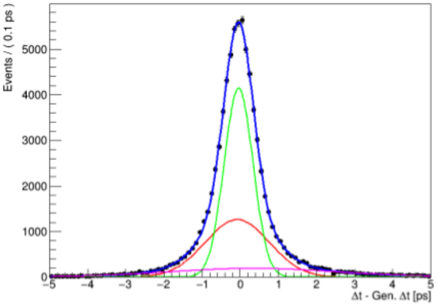
- Shift = 2.0 μm
- Resolution = 21.6 μm

Belle MC + basf2

- Shift = 0.17 μm
- Resolution = 43 μm

Comparison of the same (new) vertex algorithm for BelleII (simulation) and Belle (porting data to B2 format and use B2 reconstruction software)

Improvement of the Δt resolution

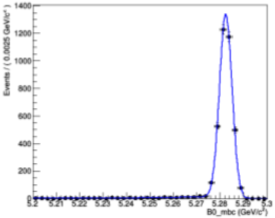


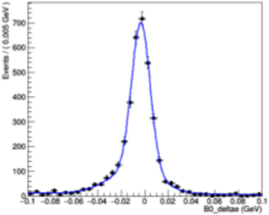
- Δt resolution depends on tag and signal side, as well as boost;

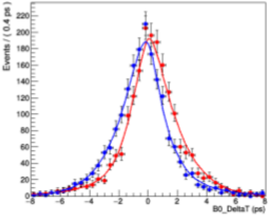
Belle : reso=0.92 ps

BelleII : reso=0.79 ps

- in spite of lower boost at BelleII, the Δt resolution is better in BelleII

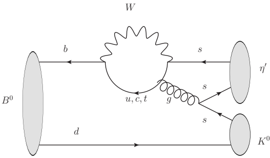


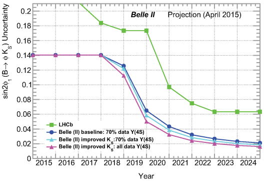


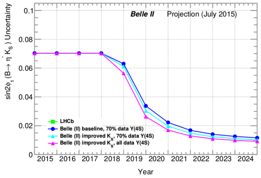


Charmless decay

- TDCPV also in charmless $b \to s$ decay. Here only:
  - $B^0 \to \phi K^0$
  - $B^0 \to \eta' K^0$
- in general the BR is much lower than the $b \to c$
- $S_{\eta' K^0} = \sin 2\phi_1^{eff}$ 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;
- competition from LHCb in the case of ϕ, not for η', due to the presence of neutrals.







Comparison of the two channels

Common issue (and tools)

- vertexing;
- background from continuum;
- multidimensional likelihood fit to extract results.

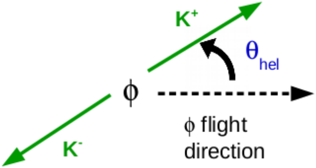
$B^0 \to \eta' K^0$

- larger BR $\sim 10x$
- Complex final states: $\eta' \to \eta\pi\pi$, $\eta \to \gamma\gamma/\pi\pi$ or $\eta' \to \rho\gamma$
- Combinatorics can be tricky, especially in presence of beam background (neutrals)
- vertexing slightly better thanks to multiple π

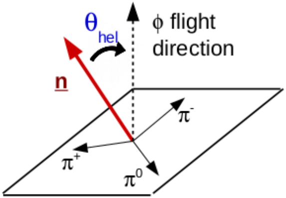
$B^0 \to \phi K^0$

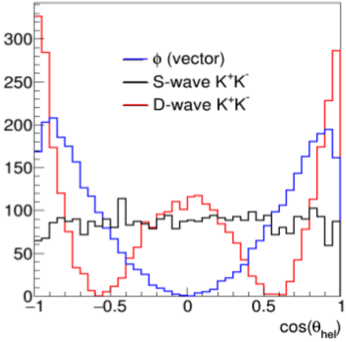
- one of the "Old Superstars" (A.J.Buras);
- Best published results using a complex Dalitz analysis
- A simpler quasi two-body decay used here
- Simple final state $\phi \to KK$ or $\phi \to 3\pi$ (not used at BaBar/Belle)
- Good channel for commissioning: vertexing, PID, flavour-tagging, ...
- Presence of scalar, non resonant, KK S-wave

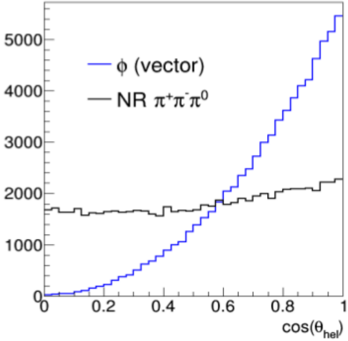
Helicity angles for $B^0 \to \phi K^0$



The angles are measured in the ϕ rest frame

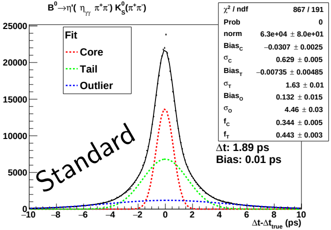


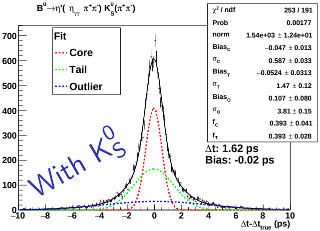


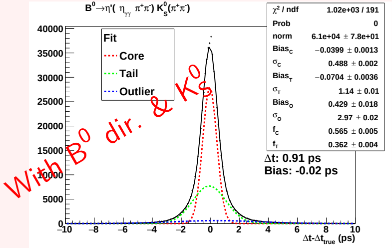


Vertexing improvement $B^0 \to \eta'(\eta \to \gamma\gamma)\pi^+\pi^-$

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







With beamspot (x, y) & K^0_S:

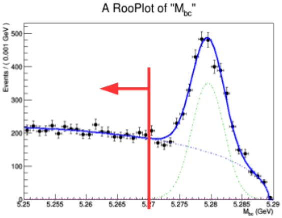
No efficiency loss

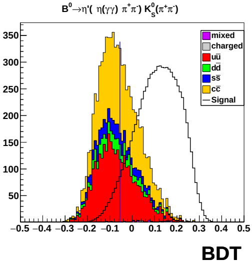
important improvement in Δt resolution

$1.89 \to 1.62 \to 0.91\ ps$

Background

- **Continuum:** from $e^+e^- \to u\bar{u}, d\bar{d}, s\bar{s}, c\bar{c}$ events. Will be modeled on data from side bands: now from MC
    - Easy to deal with exploiting the diffent topology between $B\bar{B}$ events (central) and continuum (jet-like)
    - Several variables, sensitive to the event topology are combined in a multivariate discriminator (which can handle the correlations among the variables);
- **Peaking:** actual B decay containing real η, η', ϕ, or K_0. From cocktail MC.





Likelihood fit

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

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

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

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

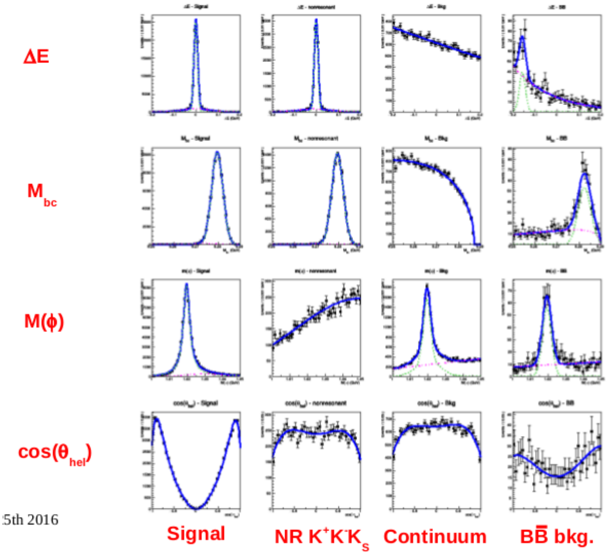
variables (x_k) used, in addition to Δt

- M_{bc}
- ΔE
- Helicity (for ϕ)
- Cont. Suppr.

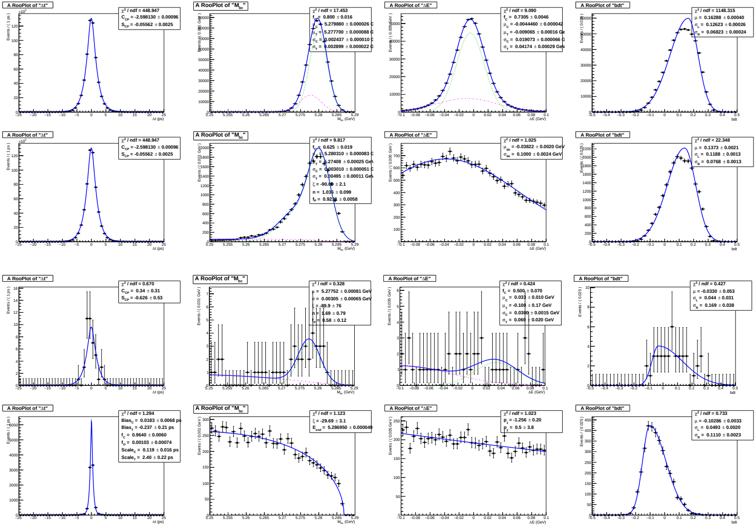
Parameters:

- effective tagging efficiency: $Q = \epsilon(1-2w)^2 = 0.34$
  - $w = 0.21$, $\Delta w = 0.02$
- Δt resolution as shown previously (convoluted)
- τ, Δm from PDG

ML fit example $\phi(K^{\pm})K_S(\pi^{\pm})$



PDF fit results examples



Signal

SxF

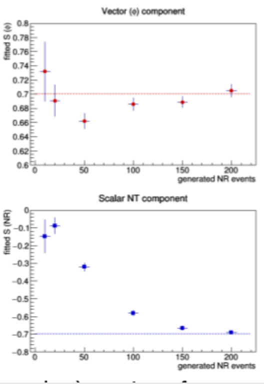
Peaking bkgnd

Continuum

ΔT M_{bc} ΔE CS variable

Toy studies

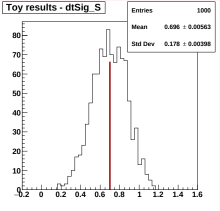
Estimate the capability to deal with the NR s-wave ϕ



No bias, provided enough $\mathcal{O}(100)$ event for each component are available

Estimate the sensitivity for a given luminosity scenario η'

- Yield estimated for $L = 300\ \text{fb}^{-1}$. $N_{sig} = 390$
- input CP pars: S=0.7 C=0.0



Par	Bias	RMS
S (0.7)	0.696 ± 0.005	0.178
C (0.0)	0.005 ± 0.004	0.13
nSig	390.7 ± 0.8	24.7

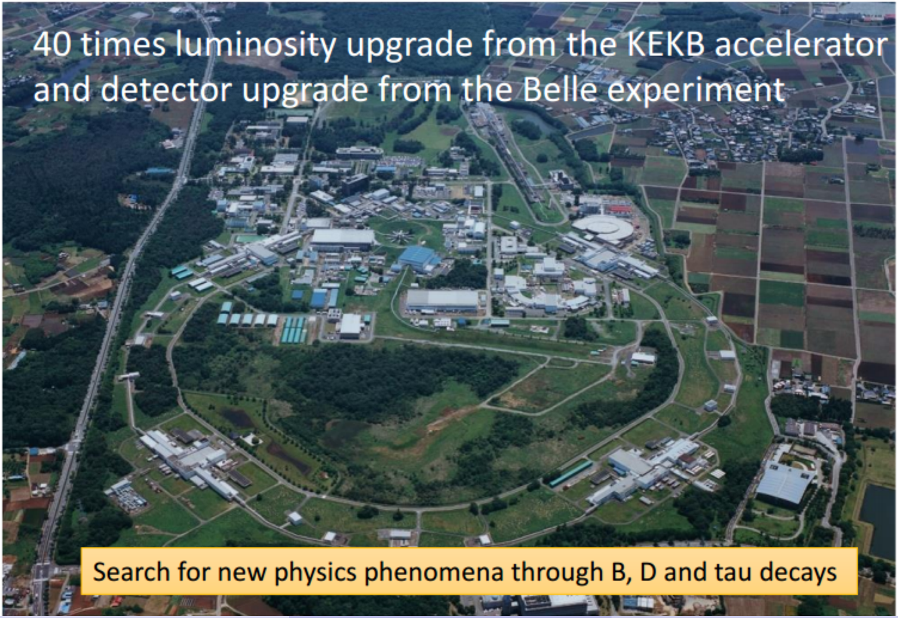
Conclusions

- B2TIP is very useful to develop and test the full chain of an analysis exercise;
- good progress in basic as well advanced reconstruction and analysis tools;
- no show stoppers so far, the resolution and sensitivity is in the right ball park;
- writing of the documentation is in progress as well;
- still a long road, but we'll be ready for the data taking.

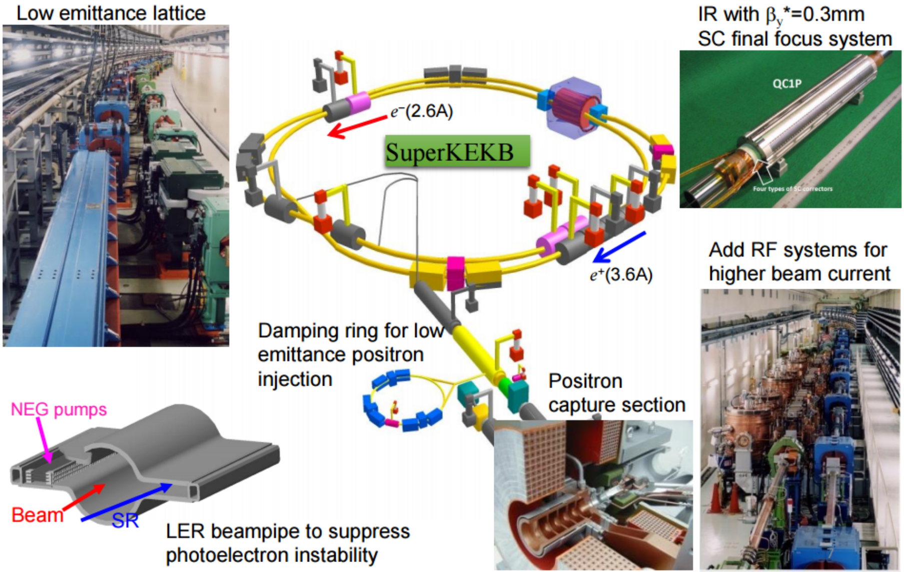
thanks for your attention

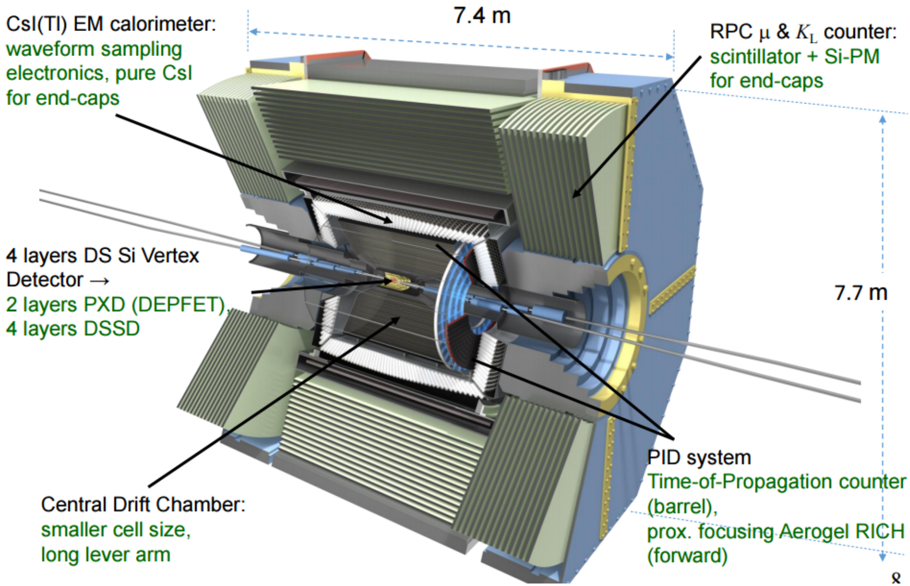
Additional or backup slides

SuperKEKb


40 times luminosity upgrade from the KEKB accelerator
and detector upgrade from the Belle experiment
Search for new physics phenomena through B, D and tau decays

SuperKEKb


Low emittance lattice
IR with β_y^*=0.3mm
SC final focus system
QC1P
Four types of SC correctors
e^-(2.6A)
SuperKEKB
e^+(3.6A)
Add RF systems for
higher beam current
Damping ring for low
emittance positron
injection
Positron
capture section
NEG pumps
Beam
SR
LER beampipe to suppress
photoelectron instability

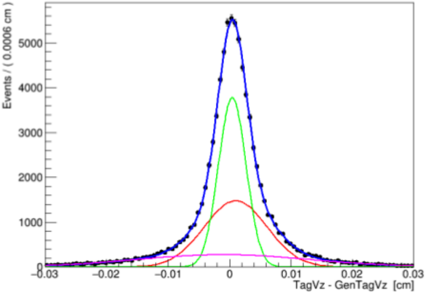

7.4 m
CsI(Tl) EM calorimeter:
waveform sampling
electronics, pure CsI
for end-caps
RPC μ & K_L counter:
scintillator + Si-PM
for end-caps
4 layers DS Si Vertex
Detector →
2 layers PXD (DEPFET),
4 layers DSSD
7.7 m
Central Drift Chamber:
smaller cell size,
long lever arm
PID system
Time-of-Propagation counter
(barrel),
prox. focusing Aerogel RICH
(forward)
8

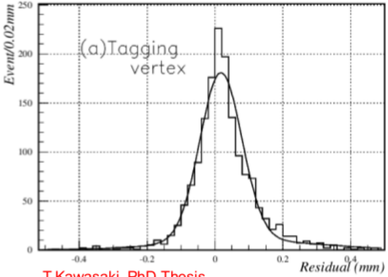
Golden Mode Proposal

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





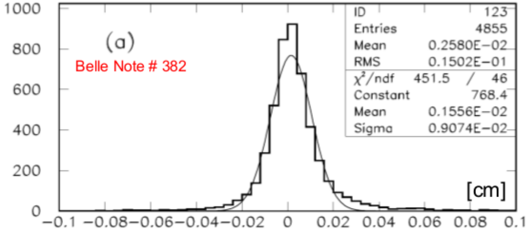
T.Kawasaki, PhD Thesis

Belle II

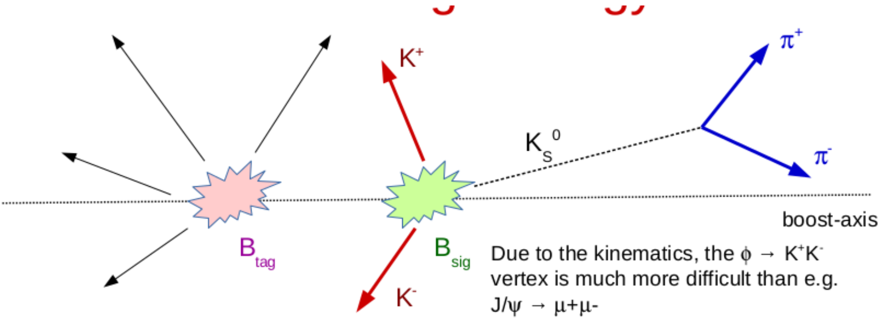
- Shift = 3.8 μm
- Resolution = 56 μm

Belle

- Shift = 29 μm
- Resolution = 89 μm



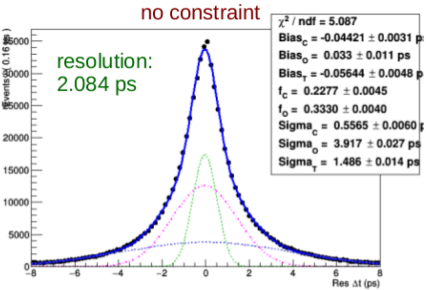
Vertexing strategy

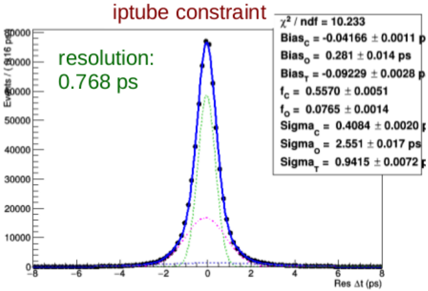


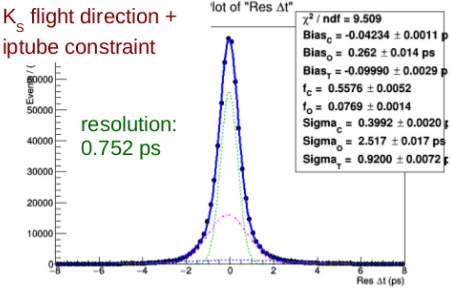
Different strategies to determine the B_{sig} decay vertex:

- 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.

Δt resolution for ϕK^0





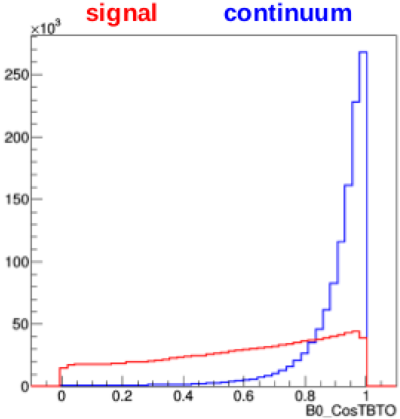


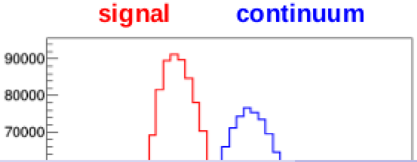
The quoted resolution is the weighted average of the gaussians' widths

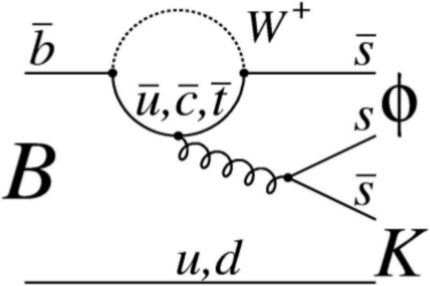
May 25th 2016

9

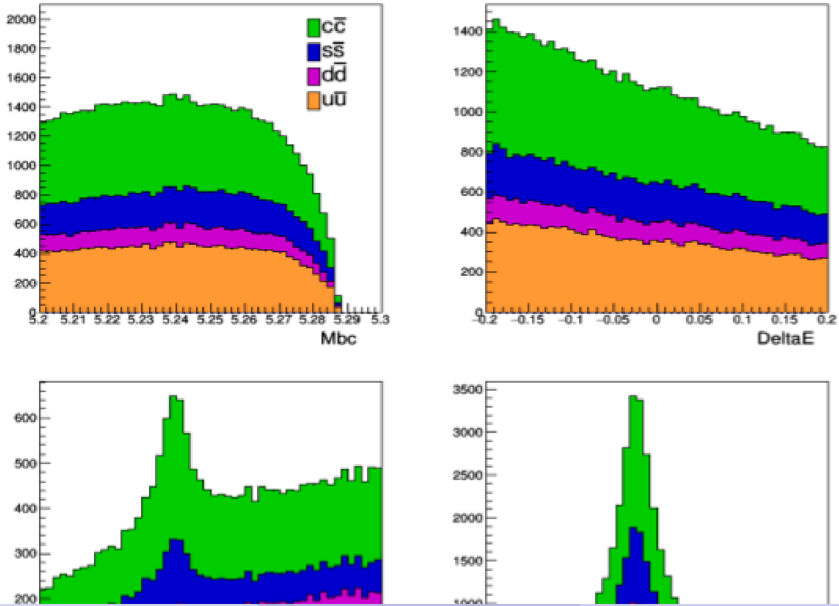
continuum suppression





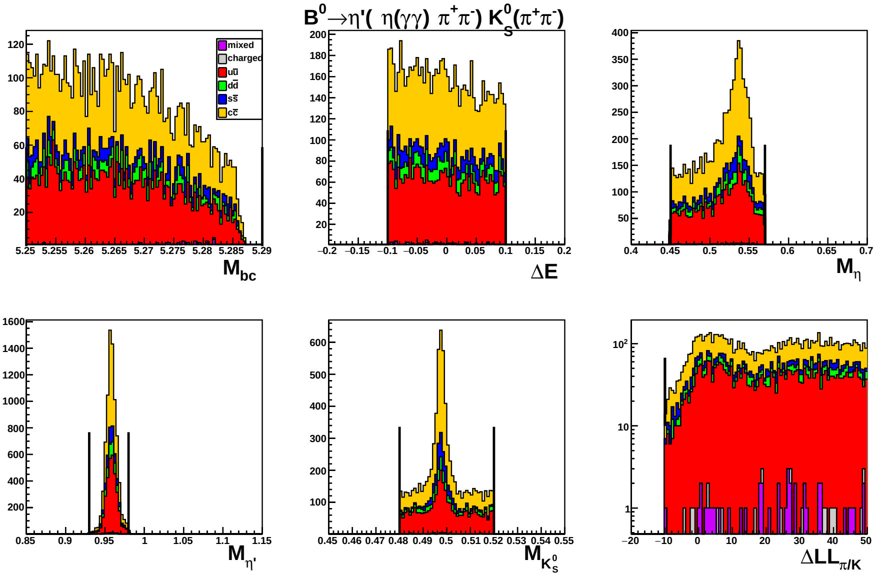


continuum Background distribution (ϕK^0)



Background distributions

Best candidates, after selections



Bibliography I