Optimization of the B meson vertex resolution for the Belle II experiment

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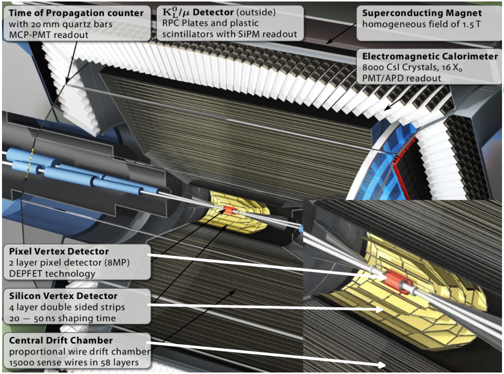
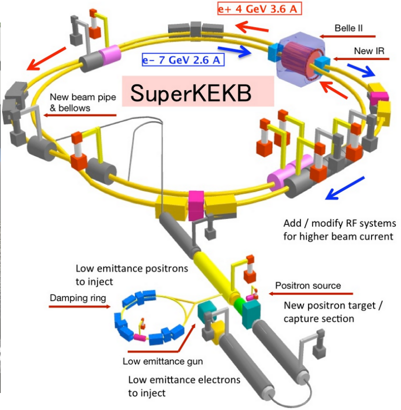
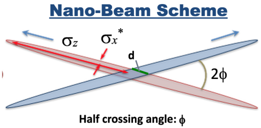
Belle II experiment at SuperKEKB





New Tracking System

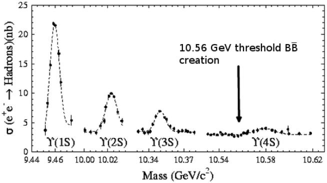
- Pixel Vertex Detector (PXD)
- Silicon Vertex Detector (SVD)
- Central Drift Chamber (CDC)

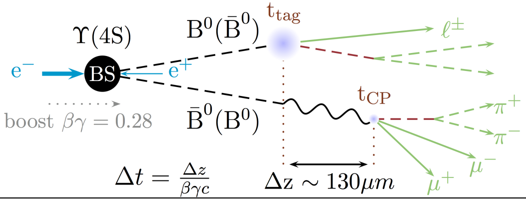


Instantaneous luminosity

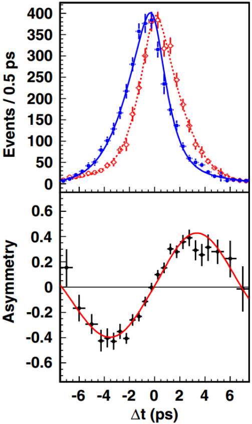
- KEKB: $2 \times 10^{34}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$
- SuperKEKB: $8 \times 10^{35}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$

CP violation and time dependent analysis





$\Upsilon(4s) \to B^0\bar{B}^0 \to f_{CP} f_{tag}$; $f_{CP} \to J/\psi K_S, f_{tag} \to$ all modes

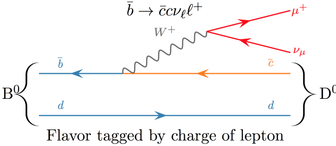


Asymmetry in the $B/\bar{B}$ decay to f_{CP}

$$\mathcal{A}_{CP} = \frac{\Gamma(\bar{B}^0 \to f_{CP}, \Delta t) - \Gamma(B^0 \to f_{CP}, \Delta t)}{\Gamma(\bar{B}^0 \to f_{CP}, \Delta t) + \Gamma(B^0 \to f_{CP}, \Delta t)} =$$
$$A_{CP}\cos(\Delta m_d \Delta t) + S_{CP}\sin(\Delta m_d \Delta t)$$

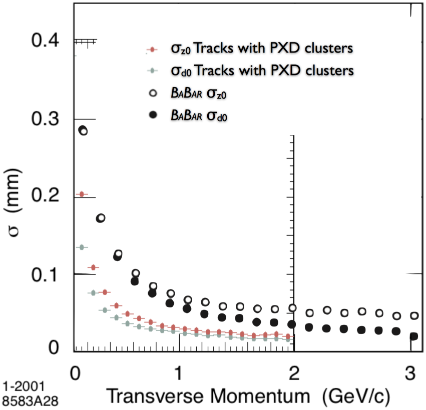
- A_{CP}: direct $\not{C}\not{P}$; S_{CP}: mixing induced $\not{C}\not{P}$

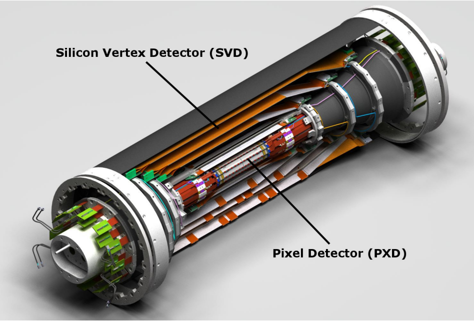
- Kinetic reconstruction
  →CP side
- Flavour ID
  →tag side



* PRL 108, 171802 (2012)

Pixel Vertex Detector - Importance of good resolution





What is the contribution of the Vertex resolution?

- **Time-dependent analysis** depend on the good measurement of **Δt** - obtained from Δz
- Belle: B_{tag} resolution (89 μm) ∼ 30% **worse** than B_{CP} resolution (63 μm)
- B_{tag} **resolution** depends heavily on the fitting **algorithm**.
- The **contribution** for Δz that needs to be specially **optimized** is the $\mathbf{B_{tag}}$ **vertex**

Vertex resolution of the CP side

$$B^0(\bar{B}^0) \rightarrow f_{CP} = [J/\psi \rightarrow \mu^+\mu^-]K_S$$

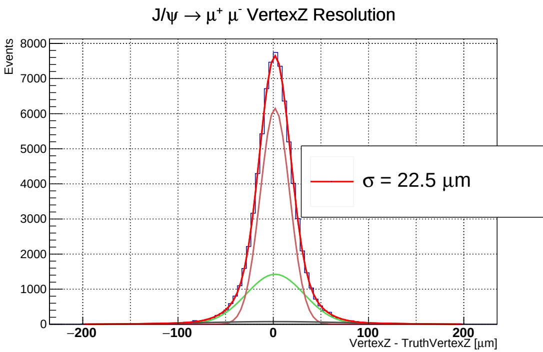
Legend

- Resolution distr. = vertex - MC vertex
- **3 Gaussian fit** with std. dev σ
- Resolution = weighted avg. σ

Observations

- μ tracks $\geq$ **1 PXD hit**
- Resolution **improvement** from Belle (63 µm) - **factor 2.7**
- Small **Shift** of 1.8 µm (under investigation)

Belle II simulation using PXD

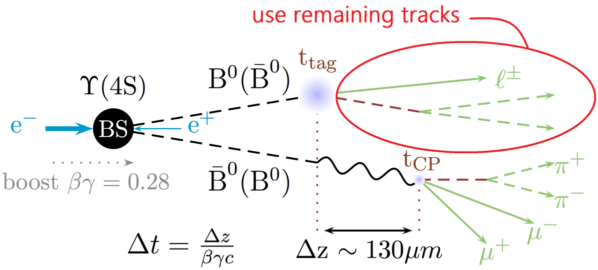


B_{tag} Vertex Fitting Standard Algorithm

How is the fit performed?

1. B_{tag} vertex fit uses the **tracks remaining** after the reconstruction of the CP side
2. **No** B_{tag} reconstruction is peformed (**loss of statistics**)
3. Algorithm: **RAVE** Adaptive Vertex Fit (AVF)* with spatial constraints

* : W. Waltenberger, R. Frühwirth and P. Vanlaer: **Adaptive Vertex Fitting**. CERN-CMS-NOTE-2008-033 (Jul 2008)



Standard fitting algorithm and spatial constraint

RAVE Adaptive Vertex Fit (AVF) with constraints

All tracks are used and **weighted** following two criteria:

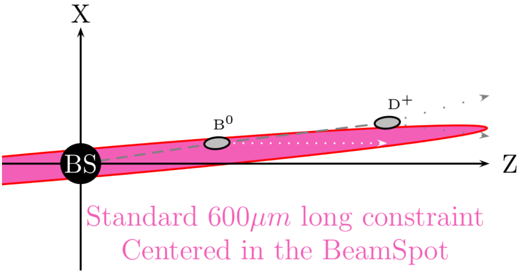
1. **Outlying** and isolated **tracks** are **down-weighted**
2. Tracks weighted according their **position** with respect to the **constraint**

Weighting works **iteratively**

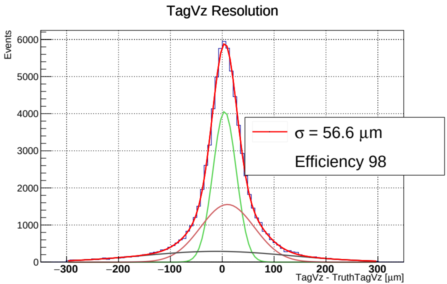
What is the constraint?

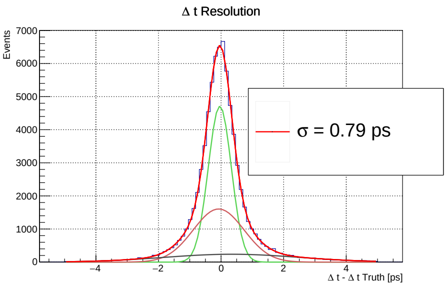
A **spatial constraint** is defined within which the B is expected to decay

- **Ellipsoid** of 600 μm long axis
- Centered in the **Beam Spot**
- Along the **boost direction**



Belle II B_{tag} vertex Resolution - Standard algorithm





In comparison with BELLE:

- **Resolution** = 89 μm - **factor 1.5**

In comparison with BELLE:

- **Resolution** = 0.92 ps - **factor 1.2**
- Lower factor → Lower Boost!

Improvement in the B_{tag} vertex resolution lower than for B_{CP}

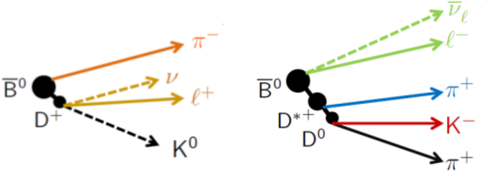
Dominated by the algorithm! PXD precision not fully used.

Can we do better than this? New algorithm

New Algorithm: Using Flavor Tagging Information

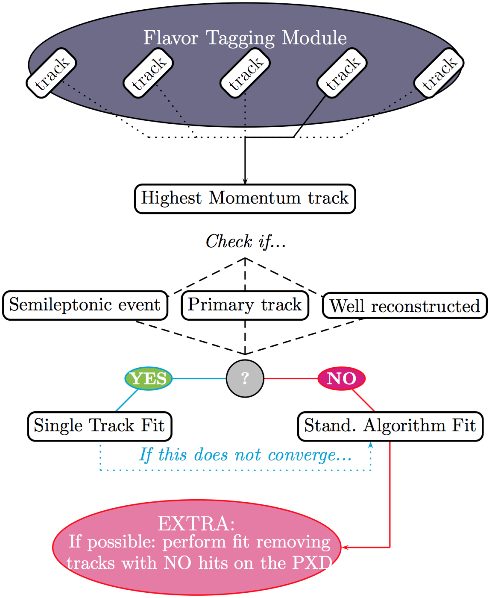
Flavor Tagging Algorithm:

- Take all the **remaining** tracks after the reconstruction of the **CP side**.
- Find the tracks best suited for **Flavor Tagging**
- Extract **probabilistic** information from those tracks
  - **Prob**. of being a **daughter** from B_{tag}
  - **Prob**. of belonging to a given **decay mode**/category
- Finally return a **parameter** $\in [-1, 1]$ that reflects how good the **flavor** can be identified
- **Flavor id. crucial to measure** $\not{C}\not{P}$

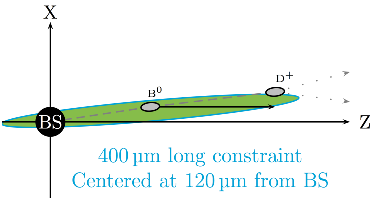


Categories	Targets
Electron	e^-
(Intermediate Electron)	e^+
Muon	μ^-
(Intermediate Muon)	μ^+
KinLepton	e^-
Kaon	K^-
KaonPion	K^-, π^+
SlowPion	π^+
FastPion	π^-
MaximumP	ℓ^-, π^-
FSC	ℓ^-, π^+
Lambda	Λ
Total= 10 (12)	

New Algorithm: Single Track Fit (STF)



Constraint of New Algorithm

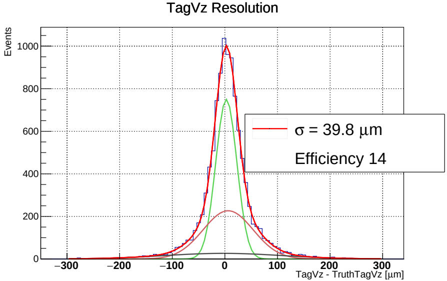


Why do we move the constraint?

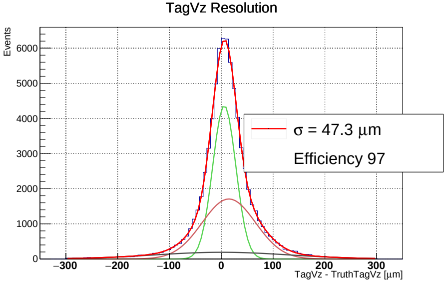
Secondary tracks are **not used** in the fit, and therefore:

- **Constraint** centred at the BS is no longer down weighting secondary tracks
- B-meson **decays** in average $\sim$ 120 μm
- If the **constraint** remains centred at BS, **large bias** appears ($\sim$15 μm)

Events with successful single track fit



All events



In comparison with Belle:

Resolution = 89 µm

- Single Track Fit **Factor 2.2**
- STF + Standard Alg. **Factor 1.9**

In comparison with Standard Algorithm:

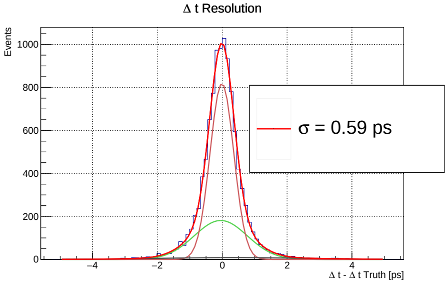
Resolution = 56 µm

- Single Track Fit **Factor 1.4**
- STF+ Standard Alg. **Factor 1.2**

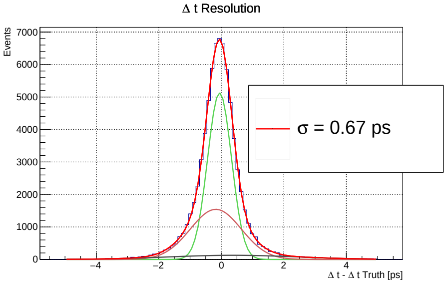
- Single Track Fit **triggered** ∼ 15% of all B_{tag} cases
- Resolution **improvement** with respect to Belle almost reached **CP side**.
  - **CP side - factor 2.8**
  - **Tag side - factor 2.2** (Single Track Fit) , **factor 1.9** (Combined)

New algorithm: Δt distribution

Events with successful single track fit



All events



In comparison with Belle:

Resolution = 0.92 ps

- Single Track Fit **Factor 1.6**
- SFT + Standard Alg. **Factor 1.4**

In comparison with Stand. alg.:

Resolution = 0.78 ps

- Single Track Fit **Factor 1.3**
- SFT + Standard Alg. **Factor 1.2**

- Single Track Fit **triggered** $\sim$ 15% of all B_{tag} cases
- Resolution **improvement** with respect to Belle almost reached **CP side**.
  - **CP side - factor 2.8**
  - **Tag side - factor 2.2** (Single Track Fit) , **factor 1.9** (Combined)

Summary

Vertex resolution and optimization using PXD

- B_{CP} **Vertex resolution** (23 μm): improved a **factor 2.7** with respect to Belle (63 μm).
- B_{tag} **Vertex resolution** with **Standard Algorithm** (57 μm): improved a **factor 1.5** with respect to Belle (89 μm).
- Improvement in **Tagged side** do not scale as in **Reconstructed side**
- **New algorithm** performs a **single track fit** with higher resolution (39 μm) with 15% efficiency, improvement by a **factor 2.2** with respect to Belle.
- B_{tag} **Vertex resolution** with **Standard Algorithm** + Single Track Fit (47 μm): improved a **factor 1.9** with respect to Belle (89 μm).

Outlook

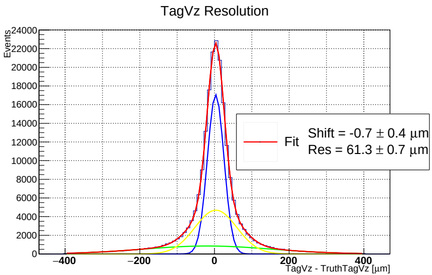
- Understand the small **shift** on the **CP side** vertex
- Improve the **single track selection criteria** in order to increase the efficiency.
- **Improve** the B_{tag} vertex fit **constraint**'s parameters to reduce the **bias** in the **resolution**

THANKS FOR YOUR ATTENTION!

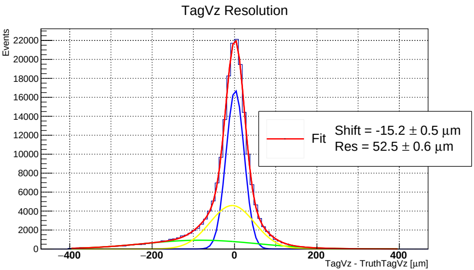
Preliminary analysis - semileptonic decay

$$\boxed{B_{tag} \rightarrow \mu^- \bar{\nu}_\mu D^{(*)+}}$$ and conjugate

USING ALL TRACKS



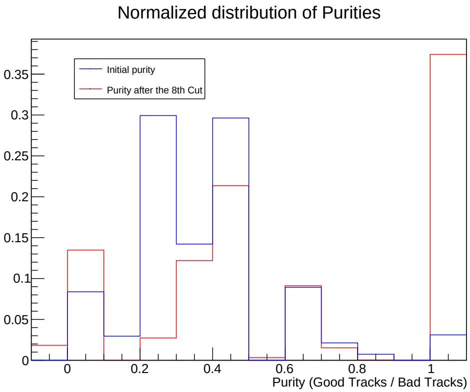
USING MC MATCHED MUONS



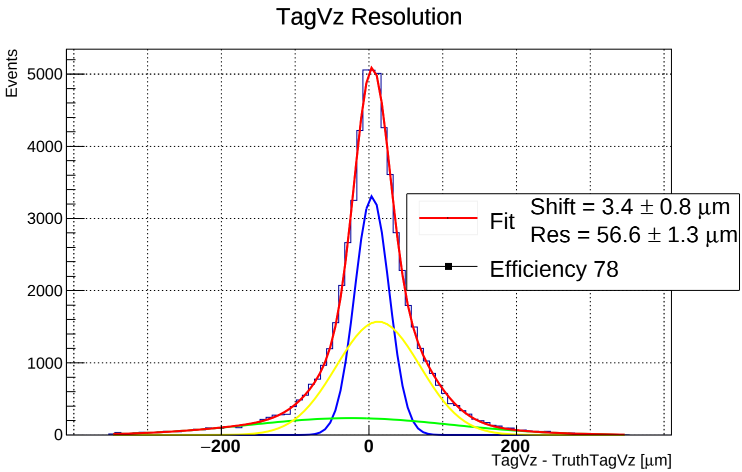
$B_{tag} \to \text{generic}$

Purity analysis

- Perform several **cuts** on the variables of the **tracks**
- Compare with **Monte Carlo** information
- Aim: Kill the **bad** ones and keep the **good** ones!
- **High purity acquainted** after selection



B_{tag} Vertex Resolution after cutting



B_{tag} Vertex Resolution using only tracks not coming from B