A Decay Tree Fitter for the Belle II Analysis Framework

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Belle II

Introduction

The Belle II experiment at SuperKEKB has recently begun commissioning and is scheduled for first physics in 2017.
Featuring a state-of-the-art Silicon Vertex Detector, it will be used to perform precision measurements of Standard Model and New Physics processes with unprecedented accuracy. At the same time, the Belle dataset ($\sim$1 ab^{-1}) still presents rich possibilities for physics analyses.
In both of these cases, precise reconstruction of decay vertices is a fundamental tool for background separation. We present a global vertexing technique based on a progressive approach and discuss its applications in the context of present and future analyses.
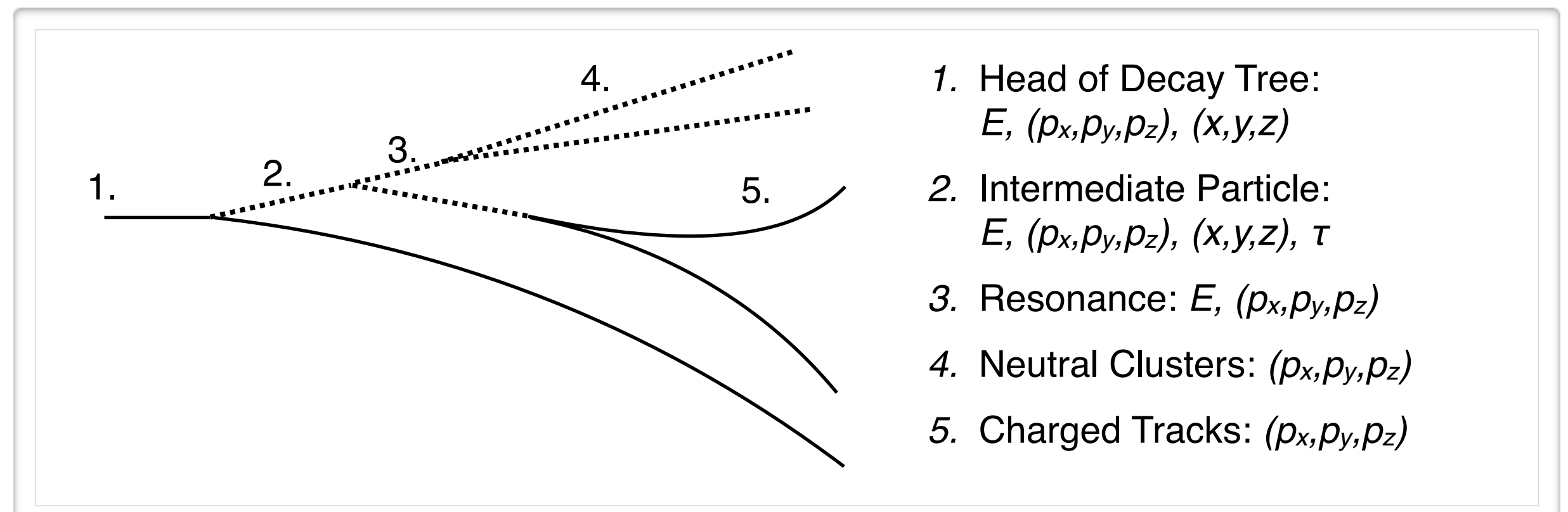
Fitting Decay Trees: Leaf-by-leaf vs Global

We can broadly define two approaches to fitting a particle decay tree:

- Leaf-by-leaf: Vertices are fitted individually, starting from final decay products. Computationally light, but fails when an excessive amount of neutral particles is involved.

- Global: The full decay tree is parametrised and fitted globally. This method is computationally expensive because of the many parameters, but is able to treat underconstrained branches. Such a fit can also provide access to the full covariance matrix of the tree.
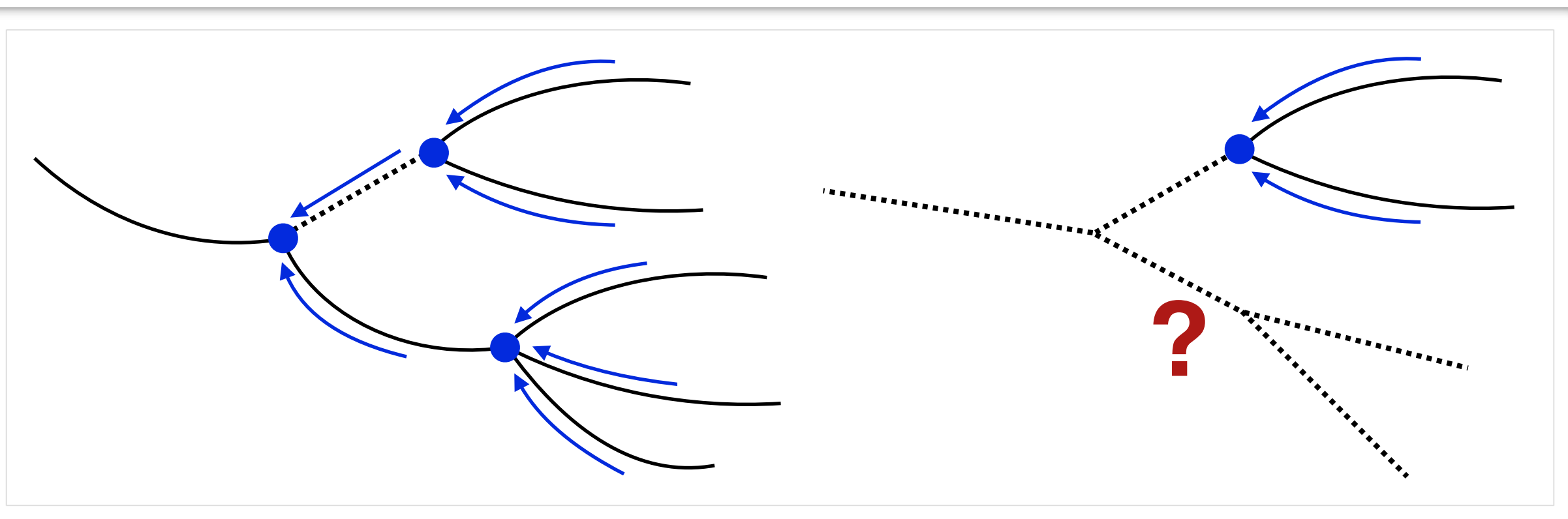
Left: Cascading approach. Vertices with neutral particles (dashed lines) and charged tracks (continuous curves) are fit individually. **Right:** Neutral-rich decay, requiring global treatment.

The TreeFitter Algorithm

The TreeFitter works around the limitations of global fits with a progressive approach, through the use of a Kalman Filter algorithm. This technique was first successfully used in BaBar[1] and is being adapted to the Belle II Analysis Software Framework (BASF2).

In a Kalman Filter, constraints are treated one by one instead of being fitted simultaneously. The contribution of the n-th constraint to the χ^2 fit is computed with a linear projection from the predicted (*running*) parameters, which were obtained from the previous $n-1$ constraints. New running parameters are then calculated.

As the inversion of a large matrix is replaced with the inversion of multiple small matrices, this allows for faster calculations.

This fit can naturally incorporate a variety of constraints in order to improve vertex resolution, such as (but not limited to) track and cluster measurements, interaction point position, particle mass and lifetime.

[1] W. D. Hulsbergen, Nucl.Instrum.Meth. A552 (2005) 566-575

1. Head of Decay Tree:
   $E, (p_x,p_y,p_z), (x,y,z)$
2. Intermediate Particle:
   $E, (p_x,p_y,p_z), (x,y,z), \tau$
3. Resonance: $E, (p_x,p_y,p_z)$
4. Neutral Clusters: (p_x,p_y,p_z)
5. Charged Tracks: (p_x,p_y,p_z)

Above: Parametrisation scheme of a full decay tree. Note the large amount of parameters.

Ordering and Referencing

Since the TreeFitter is based on a linear approximation, it is very sensitive to the ordering of constraints, which should in principle be carefully applied to the filter in order of linearity.

To minimize this dependency, the Kalman algorithm was modified through referencing. Instead of using the *running* value of the parameters to project constraints, the *smoothed* result of the last full iteration is used. This makes the algorithm more stable and improves convergence speed.

Charged Vertexing Performance in Belle II vs Belle

Vertex resolution in Belle II is already significantly improved since Belle. Thanks to the new tracker and vertex detector, preliminary studies predict charged and tag B vertex resolutions at $\sigma_z^{sig} = 25.7$ μm and $\sigma_z^{tag} = 52.7$ μm, compared to $\sigma_z^{sig} = 43$ μm, $\sigma_z^{tag} = 89$ μm for Belle.

The TreeFitter will strongly benefit from these tight constraints, which will impact the vertex fit quality across the whole decay chain.
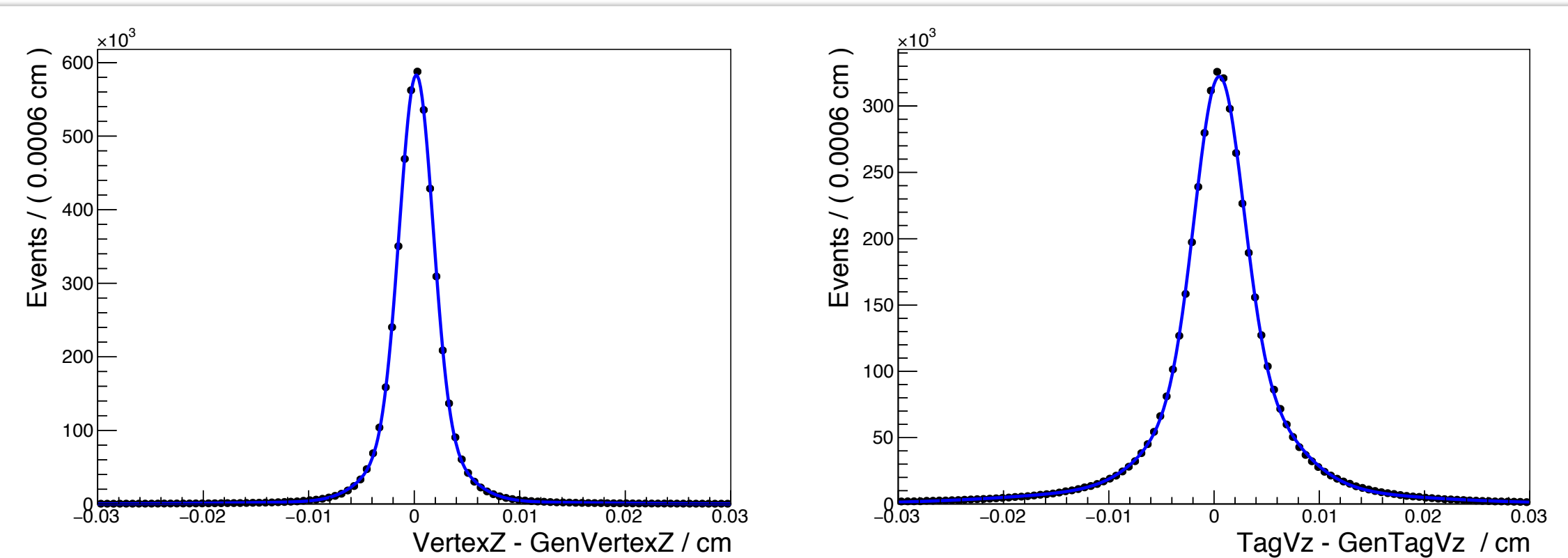
Above: Residual of the decay vertex z position for reconstructed J/$\psi \to \mu\mu$ events **(left)** and for the tag vertex **(right)** in Belle II simulated data (2015 MC5 production).

Physics Prospects

The TreeFitter is uniquely suited to the treatment of modes with neutral or missing particles, thanks to its ability to improve individual vertex resolutions by taking advantage of constraints from the rest of the decay tree.

As an example would be the golden semileptonic modes B $\to$ D$^{(*)}$lv, in which measurements of the CP violating phase V$_{cb}$ show long-standing tensions, and where the B $\to$ D$^{(*)}\tau\nu$ sub-mode displays a 4σ excess that could hint at the existence of new physics. Background rejection in these channels can be greatly improved by any technique allowing to treat the missing neutrino(s).

Additionally, thanks to the global approach providing the full decay covariance matrix, this technique can enable better treatment of errors in time-dependent Dalitz plot analyses. The Belle to Belle II conversion module, recently introduced in BASF2, allows the analysis of Belle data within the Belle II framework, allowing the algorithm to be immediately applied to analyses in Belle.

A functioning version of the TreeFitter is already available in BASF2 and is being tested for performance and bugs.