DRAFT - Track finding with the Belle II drift chamber

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Abstract

In this paper, we describe a track finding algorithm, that is intended to be used with the Belle II drift chamber. The algorithm is designed balancing the requirements of a high efficiency to find charged particles and a good track parameter resolution, a low rate of wrong or multiple found tracks, and a reasonable demand on CPU resources. The algorithm is optimized for the Belle II drift chamber, that was designed with the requirement, that the physics performance of the Belle II experiment must be at least as good as the Belle experiment, despite a less hospital environment in terms of beam background. The results of the newly developed algorithm are compared with an adaption of the algorithm used in the Belle experiment to the Belle II drift chamber.

The main purpose of the Belle II experiment [1], currently being set up in Tsukuba, Japan, is the analysis of e^+e^--collisions with beams of 4 GeV and 7 GeV energy respectively. At the design luminosity of the SuperKEKB accelerator of 8×10^{35} cm^{-2}s^{-1}, which is 40 times the peak luminosity reached by KEKB, which fed the Belle experiment, we expect the creation of about 1000 $\Upsilon(4S)$ per second and a larger rate of other processes, that are, however, less challenging for the tracking. The $\Upsilon(4S)$ decays with more than 96% probability into a pair of either B^+B^- or $B^0\overline{B}^0$ mesons. Sufficiently long living decay products of the B mesons reach the drift chamber (CDC) after crossing a beam pipe of paraphine cooled beryllium, and a 6 layer silicon vertex detector (VXD) with 2 layers of DEPFET technology based pixel sensors with a thickness of 75 μm and 4 layers of strip sensors with a thickness of 320 μm. Three of the strip layers have slanted sensors in the forward region, with only 300 μm thickness. The additional material for services and structure means, a single orthogonal crossing of a strip layer equals about 0.6% of a radiation length, while a pixel layer amounts to about 0.2%. Going radially outwards, the overlap of sensors within one layer of VXD is in the order of 10%. Both, the VXD and the CDC have encasements made of carbon with the thickness of the inner wall of the CDC being about 500 μm. The radius of the inner (outer) wall of the CDC is 16 (113) cm. Assuming spherical coordinates with the z-axis along the higher energetic incoming electrons, the CDC covers the full ϕ range and θ between

17°and 150°. Outside the CDC particle identification detectors and a calorimeter provide dense material where many of the charged particles are absorbed. A solenoid provides a magnetic field of about 1.5 T, that is fairly homogeneous around the IP, and varies in the order of 1% in the CDC volume.

The inner volume of the CDC contains about 50.000 sense and field wires,

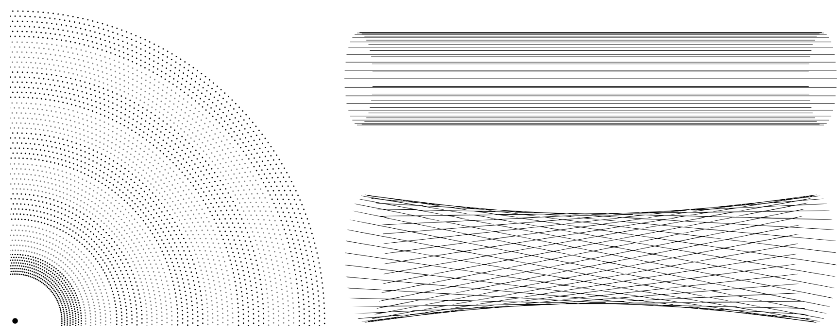


Figure 1: Left: Quadrant of slice of r-ϕ projection of the drift chamber. The innermost superlayer contains 8 layers, the following ones each 6. Right: Visualization of Stereo Wires relative to Axial Wires. The skew is exaggerated.

defining drift cells with a size of about 2 cm. The sense wires are arranged in layers, where 6 or 8 adjacent layers are combined in a so-called superlayer, as seen in figure 1. The outer 8 superlayers consist of six layers with 160 to 384 wires. The innermost superlayer has 8 layers with 160 wires in smaller (half-size) drift cells to cope with the increasing background towards smaller radii. The superlayers are alternate between axial ("A") orientation, aligned with the solenoidal magnetic field (z-axis), and stereo ("U", "V") orientation. Stereo wires are skewed by an angle between 45.4 and 74 mrad in positive and negative direction. The direction changes sign between U and V layers, with a total superlayer configuration of AUAVAUAVA. By combining the information of axial and stereo wires (the space point resolution of the drift chamber is about 120 m), it is possible to reconstruct a full 3D track.

Explain the time-based measurement principle of the CDC

Description of event characteristics:

- track multiplicities(about 11) and number of hits in the CDC.
  Heat Map of Hits vs. Track Multiplicity in the pure Y(4S) event.

- typical momentum (spheric events with momentum distribution... boost of ...)
  Plot of momentum spectra in the multiplicity bins from Viktor's thesis.

- Chemistry of events

- Share of tracks, that have substantial life time mothers ($K_S, \Lambda, \Sigma, ...$)

- backgrounds and source of them (e.g. higher beam current, Touschek,...) + average of total number of background hits + "event display" of typical background only event.

- Plots of drift time distribution for pure Y(4S) (in layer 2) and electric field simulation

1 Structure and Algorithms of the CDC Track Finding

The Belle II Experiment developed the `basf2` framework which is based on C++ and allows to implement reconstruction algorithms as modules which are loosely coupled and transfer data only via a common exchange container, named `DataStore`. This allows to split the reconstruction task as a chain of independent and interchangeable modules. The CDC Track Finding takes full advantage of this model and structures the required processing steps in modules which can be developed and optimized independant of each other.

To achieve the best possible track finding efficiency two complementary methods are employed and their output is combined and filtered to arrive at the final list of found tracks.

Description of actual track finding algorithm in the CDC.

- Reconstruction Framework, Structure and Modules

- Global CDC Tracking Approach: fast Quad Tree implementation and optimizations

  Schematic of Quad Tree search in Legendre Space

- Stereo Hit Finding and combination

- Local CDC Tracking Approach: Segment building and combination

- Combination of local and global tracks and quality filters

- Runtime Characterization and application on HLT

Particle type	Average fraction
$\pi^{\pm}$	72.8%
$K^{\pm}$	14.9%
$e^{\pm}$	5.8%
$\mu^{\pm}$	4.7%
$p^{\pm}$	1.8%

Table 1: Fraction of particles in generic $\Upsilon(4S)$ events (the average of 30k events).

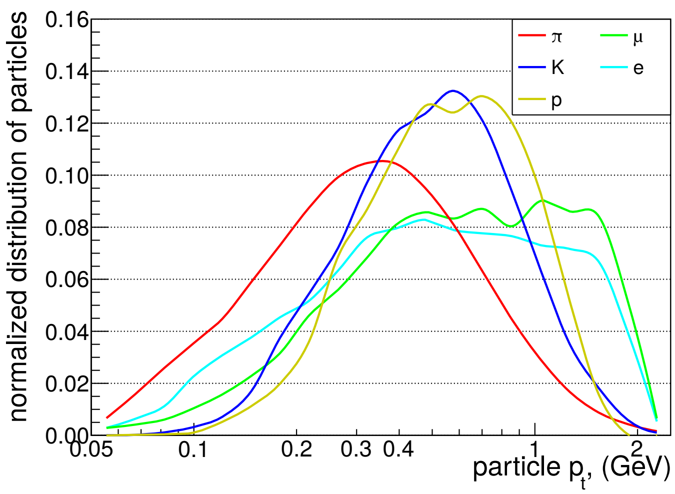


Figure 2: Transverse momentum of the generated particles. Only primary particles are taken into account.

Efficiency and fake rate of the CDC track finding

- Definition of found track.
- Heat Map of single Track finding efficiency for momentum vs. theta. Including line at minimum p_t needed for being found without material and for different species. (+-)
- Effiency vs. p_t for Y(4S) events with different amounts of background (+)
- Effiency vs. p_t for Y(4S) events with track multiplicity bins. (+)
- Efficiency dependence on d_0 (+)

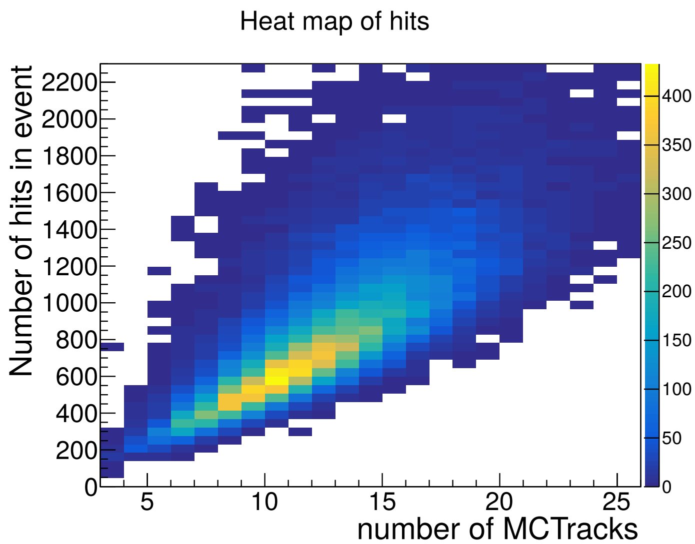
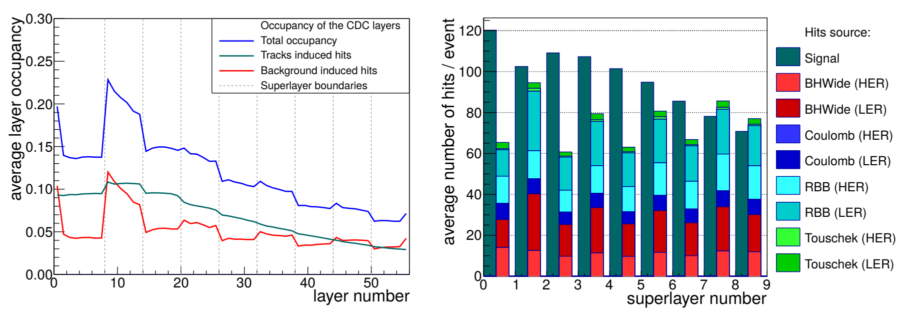


Figure 3: Heat map of hits vs event multiplicity (no background).



(a) Occupancy of the CDC layers.

(b) Average distribution of the hits in events by superlayers.

Figure 4: Average load of the CDC.

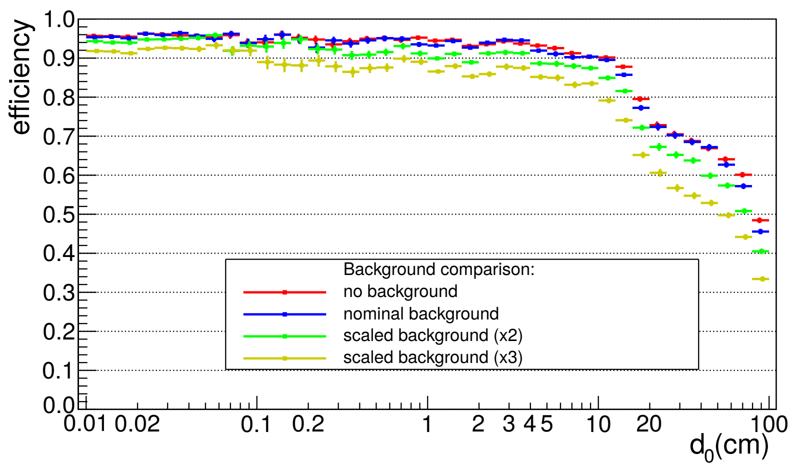
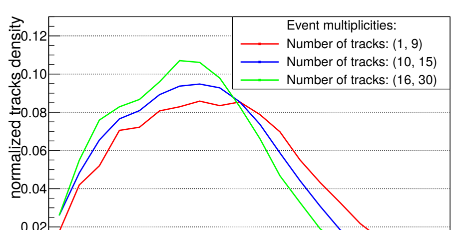
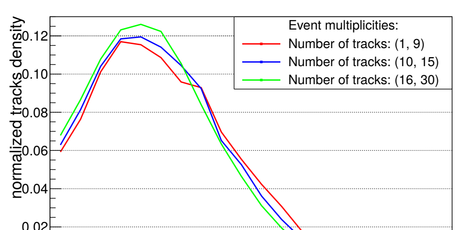


Figure 5: Efficiency in bins of the track impact parameter. Simulation without background is compared to nominal background and scaled background simulation.



(a) Prompt tracks



(b) Non-prompt tracks

Figure 6: Probability to get a track with the given p_t.

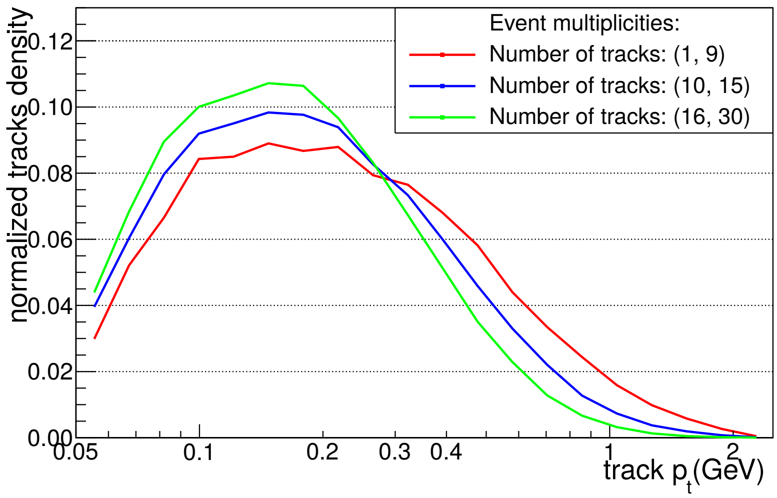
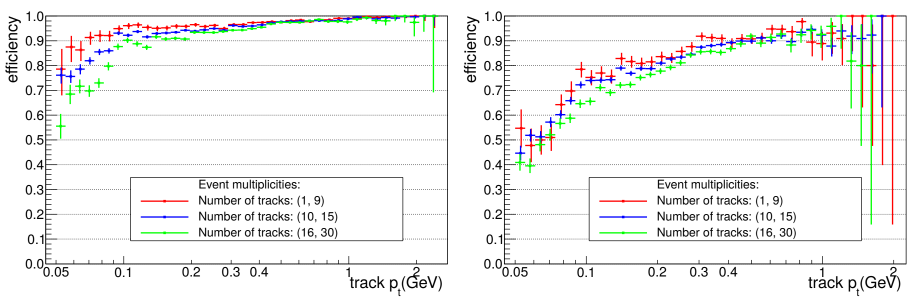


Figure 7: Probability to get a track with the given p_t. All tracks are considered.



(a) Prompt tracks

(b) Non-prompt tracks

Figure 8: Efficiency in bins of the track transverse momentum of prompt (a) and non-prompt (b) tracks. Different event multiplicities are compared. Prompt tracks are defined as tracks whith $d_0 < 1$ cm.

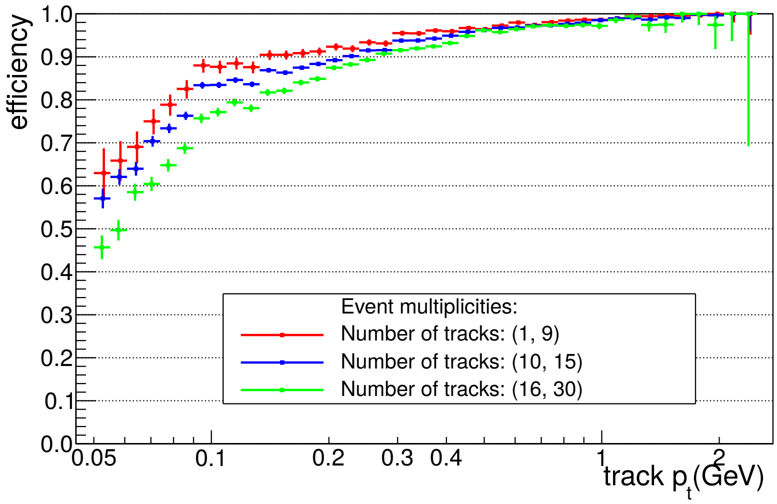
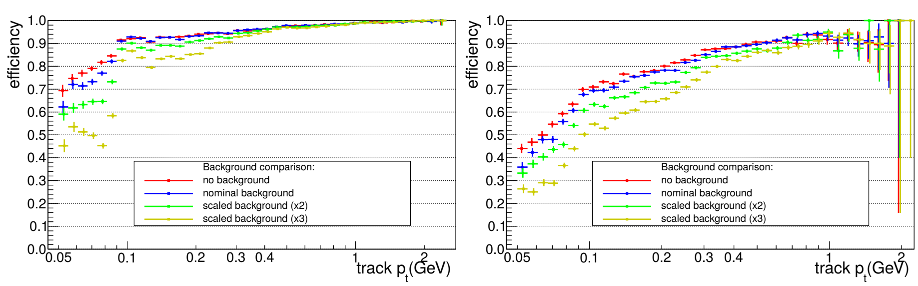


Figure 9: Efficiency in bins of the track transverse momentum. Different event multiplicities are compared, all tracks are considered.



(a) Prompt track candidates (b) Non-prompt track candidates

Figure 10: Efficiency in bins of the track transverse momentum of prompt (a) and non-prompt (b) tracks. Simulation without background is compared to nominal background and scaled background simulation. Prompt tracks are defined as tracks whith $d_0 < 1$ cm.

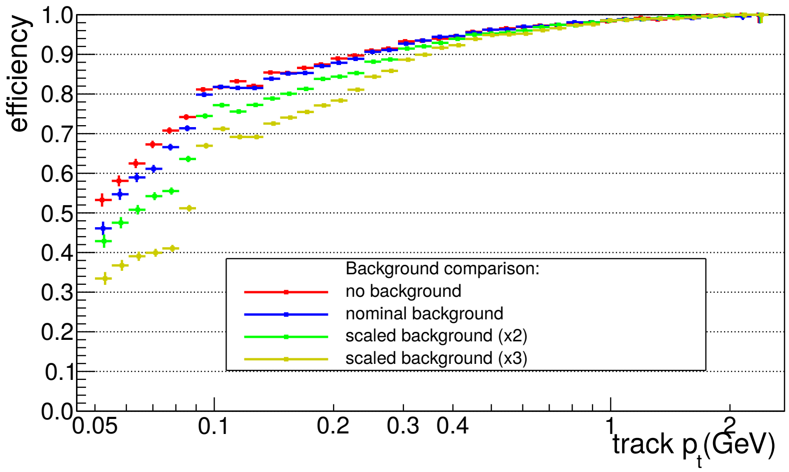


Figure 11: Efficiency in bins of the track transverse momentum. Simulation without background is compared to nominal background and scaled background simulation, all tracks are considered.

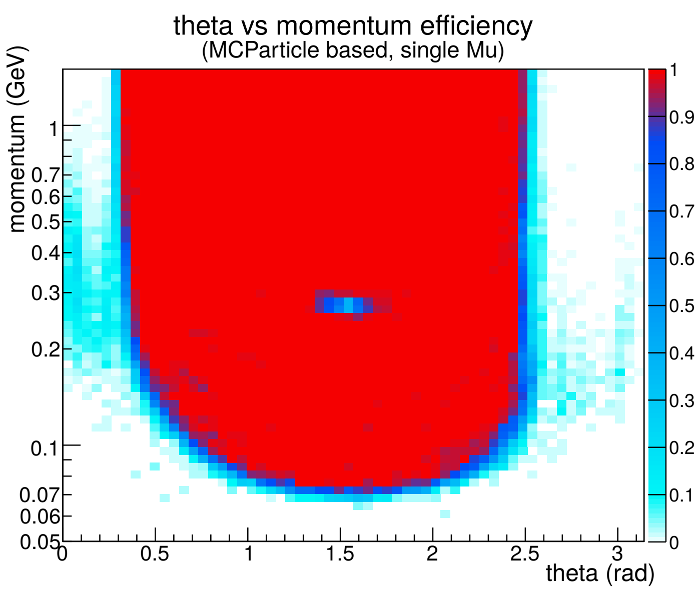


Figure 12: Heat map of single track finding efficiency. Momentum and a polar angle of the simulated particle (μ) are considered.This plot needs to be rechecked, the efficiencies outside of the detector acceptance and the low efficiency at Momentum 275 MeV need ot be understood.

References

[1] T. Abe et al., *Belle II Technical Design Report*, KEK-REPORT-2010-1, arXiv:1011.0352v1 [physics.ins-det] (2010).