Measurment of Branching Franction of $B^- \to D^0\pi^-\pi^+\pi^-$

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Outline

SuperKEKB accelerator

- Super KEKB: 4 GeV e^+ and 7 GeV e^- asymmetric collider at KEK, Japan.
- 3 km circumference and 41 mrad crossing angle.
- The center-of-mass energy is close to the mass of $\Upsilon(4S)$, which decays later to $B\overline{B}$ pair.
- A 30-fold increase in Luminosity over Belle, $L = 6x10^{35}\text{cm}^{-2}\text{s}^{-1}$.
- Uses the nano-beam scheme (minimization of vertical beta function); hence doubled current.
- Better performance and can tolerate the much higher level of beam-related backgrounds due to the increase in instantaneous luminosity.
- **Belle II detector** is at the interaction point.

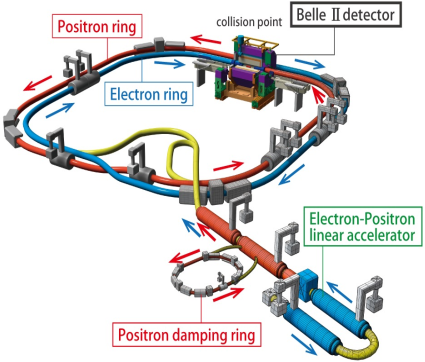
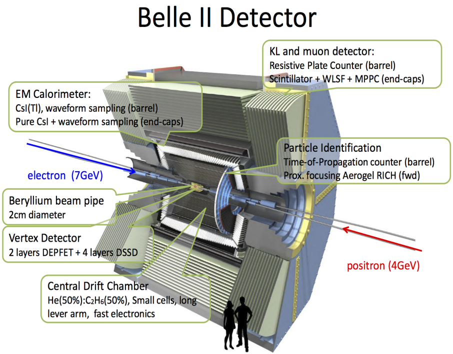


Figure: SuperKEKB accelerator

Belle II detector

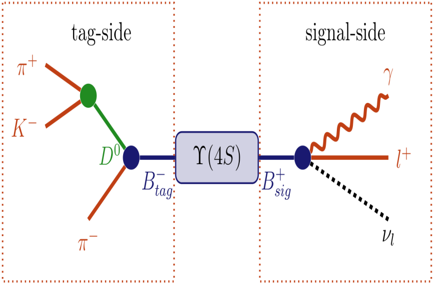
- Vertex detector (PXD+SVD): two layers of pixel detector and four layers of SVD to determine *B* meson decay vertices.
- Central drift chamber (CDC): A large gaseous detector that acts as the principal tracking device.
- Aerogel Ring Imaging Cherenkov Counter (ARICH): Used for particle identification, mainly to distinguish between pions and kaons.
- Time-of-Propagation Counters (TOP): Cerenkov radiation totally internally reflected within quartz bars for particle identification.
- Electromagnetic calorimeter (ECAL): Detects photons and measures their energy and position with thallium-doped caesium iodide crystals.

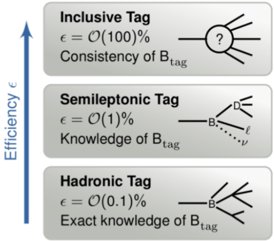


- K-Long and muon detector (KLM): Detects muons and long-lived neutral kaons, and distinguishes between them using scintillators along with RPCs.
- Superconducting Solenoid : Provides a homogeneous magnetic field of 1.5T along the beam axis.

Full Event Interpretation

- Implement tagging, where one B referred to as B_{tag} is exclusively reconstructed using hadronic or semi-leptonic modes.
- The remaining tracks and clusters are then attributed to B_{sig}, on which the search or measurement of a particular decay is done.
- Any missing energy is attributed to the B_{sig}.





Infer momentum and direction of signal B candidate:

$$p_{Bsig} \equiv (E_{Bsig}, \vec{p}_{Bsig}) = \left(\frac{m_{\Upsilon(4S)}}{2}, -\vec{p}_{B\text{tag}}\right)$$

Ideal for decays with neutrinos, missing energy signatures!

Full Event Interpretation

- Final-state particle candidates are selected and corresponding classification methods are trained using the detector information.
- Intermediate particle candidates are reconstructed and a multivariate classifier is trained for each employed decay channel.
- Employs over 200 Boosted Decision Trees to reconstruct more than 10000 B decay modes.

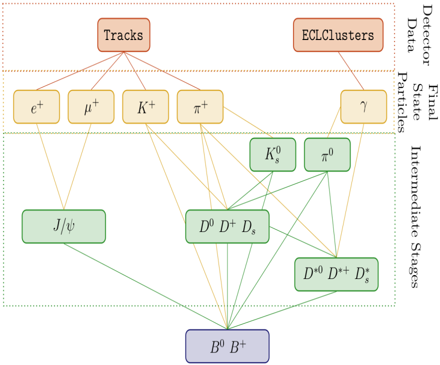
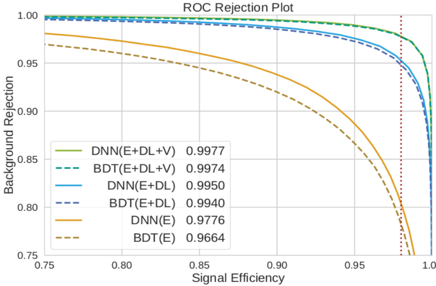


Figure: MVC algorithm with Hierarchal approach

Boosted Decesion Tree

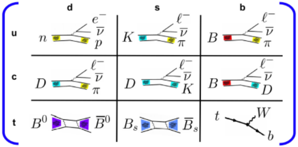
- Boosted Decision Trees (BDTs) are a specific type of a machine learning model used for classification tasks.
- The name decision tree refers to the general structure: the classification is done with a series of "decisions".
- Decisions are logical operations (like ">", "<", "=", etc.) on the input variables of each data point, by the outcome of which the data points are separated into groups.
- The word boosted refers to the specific way the tree is formed: gradient boosting. Gradient boosting means, that a final tree is made by combining a series of smaller trees of a fixed depth.
- The BDT is a supervised machine learning method, i.e. it needs to be trained on a dataset where we know the true class that we are trying to predict (this variable is called the target variable).

- FastBDT is the fastest contestant for small models (depth of the trees <5 and number of trees <300), whereas XGBoost has a slightly better scaling behaviour for large models.
- Used in FEI and to reject continuum background.



Motivation

- Inclusive and exclusive $b \to ul\nu$ and $b \to cl\nu$ transitions are crucial for the determination of the CKM matrix elements $|V_{ub}|$ and $|V_{cb}|$.

V =


- FEI is a powerful technique to reconstruct such decays with missing energy.
- Tag decays include high branching fraction decays like $B^- \to D^0\pi^-\pi^+\pi^-$.

$$\boxed{\mathrm{BF}=(5.6 \pm 2.1) \times 10^{-3}}$$

- However it is not well simulated in MC because of the large uncertainity on the branching fraction.
- Goal is to improve the accuracy of the branching fraction measurement of $B^- \to D^0\pi^-\pi^+\pi^-$.

Formalism & Approach

- The BF measurements are based on the following equations:

$$\mathcal{B}(\mathrm{B}^+ \to \bar{\mathrm{D}}^0\pi^+\pi^-\pi^+) = \frac{N_{sig}}{2 \cdot \varepsilon \cdot L \cdot \sigma_{B^+B^-} \cdot \mathcal{B}(\bar{\mathrm{D}}^0 \to K^+\pi^-)}$$

- Data Set: MC14ri_a inclusive MC (100 fb^{-1})
- **Track selection:**
  - Transverse impact parameter |d0| < 0.2 cm.
  - Longitudinal impact parameter |z0| < 1 cm.
  - Polar angle $\rightarrow 0 < \theta < 126.87$: cosTheta >= -0.6
- Selection on kinematic variables:
  - Mass of D^0 meson: 1.84 < M < 1.89 GeV/c^2
  - Beam constrained mass (M_{bc}) > 5.27 GeV/c^2, defined as

    $$M_{\mathrm{bc}} = \sqrt{E_{\mathrm{beam}}^2 - (\Sigma\vec{p_i})^2}$$
  - Beam-energy Difference $|\Delta E| < 0.15$ GeV, defined as $\Delta E = \Sigma E_i - E_{\mathrm{beam}}$.

Continuum Suppression

- R_2: Ratio of second and zeroth Fox-Wolfram moment.

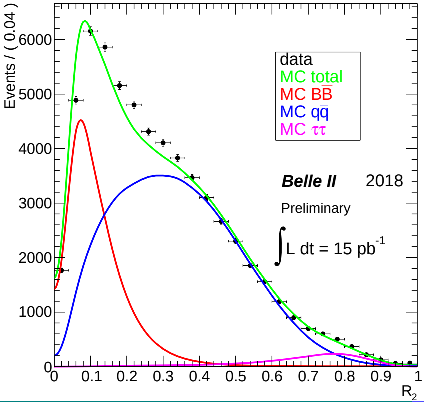
$$H_l = \sum_{ij} |p_i||p_j| P_l(\cos\theta_{ij})$$

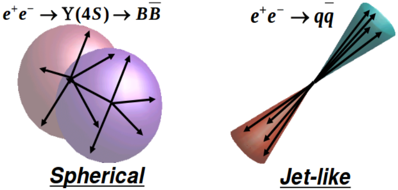
i, j = charged & γ

Momentum of particle i and j

Legendre polynomial

Angle between particle i and j





- Spherical limit: $R_2 \to 0$; jet-like limit: $R_2 \to 1$.
- So we are on $\Upsilon(4S)$ resonance and recording $B\bar{B}$ pairs.

M_{bc}

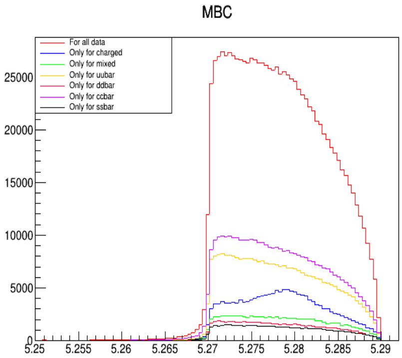


Figure: Plotting M_{bc} for different set

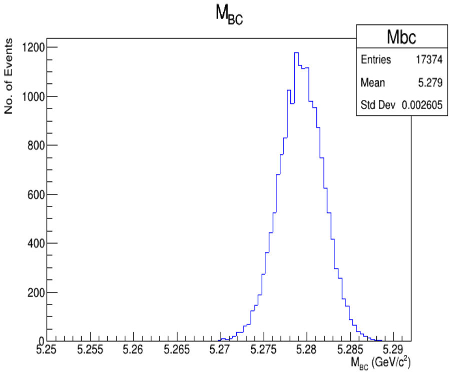


Figure: Plotting M_{bc} for signal

Delta E

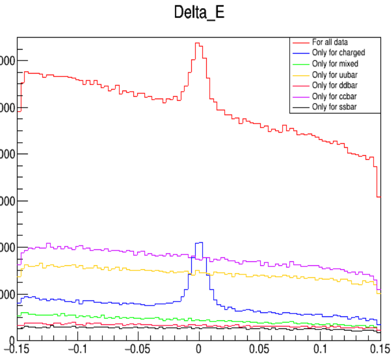


Figure: Plotting $\triangle$E for different set

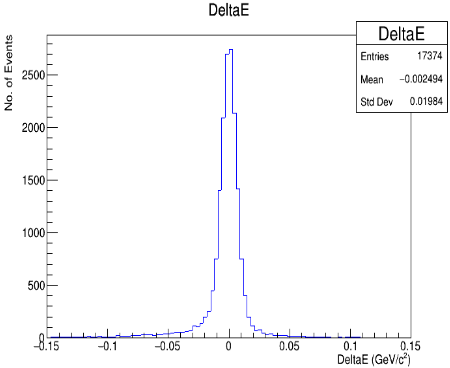


Figure: Plotting $\triangle$E for signal

R2

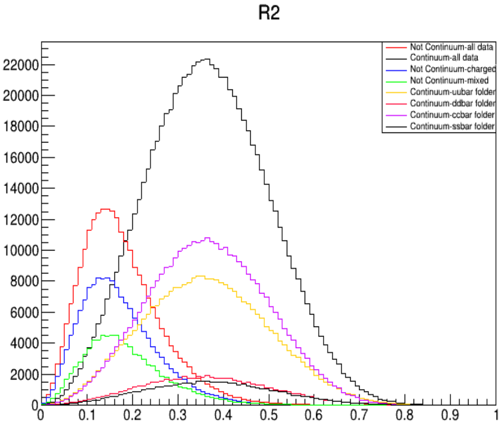
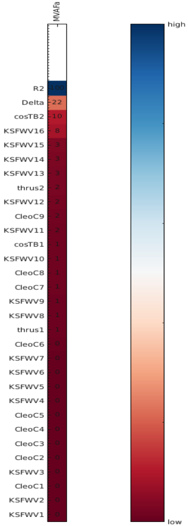
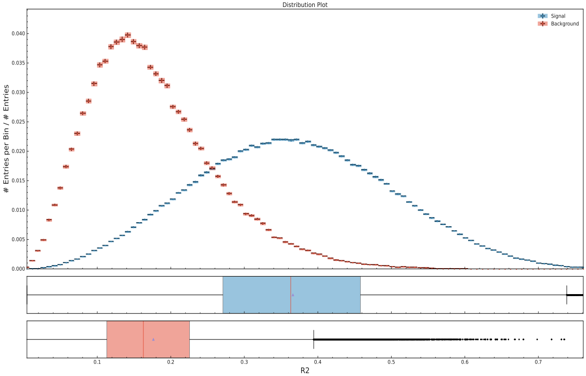


Figure: Plotting R2 for different set



FBDT output of R2 variable



- Future plan:
  - Train FBDT in various way to get better cuts for continuum suppression.
  - Finding all $B\bar{B}$ mesons using Hadronic and Semileptonic tag in FEI.

Reference

- The Belle II Physics Book (KEK Preprint 2018-27)
- The Physics of the B Factories (KEK Preprint 2014-3)
- Observables for the Analysis of Event Shapes in e^+e^- Annihilation and Othere Processes (1978)(7811220, CALT-688680)
- Belle II Software Documentation→ software.belle2.org
- Root Data Analysis Framework user Guide→ https://root.cern/

Thank you!