# Search for $B^+ \to K^+\nu\bar{\nu}$ at the Belle II experiment with machine learning techniques

(see also presentation from F. Dattola [T81.3])

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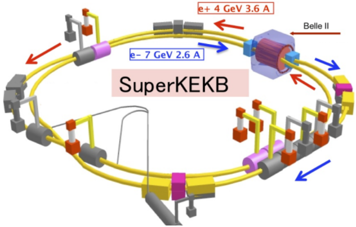
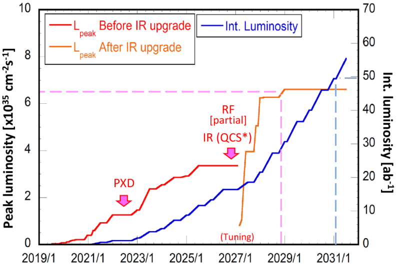
# Outline

1. Introduction
   - The SuperKEKB collider
   - The Belle II detector
2. Search for $B^+ \to K^+\nu\bar{\nu}$
   - Motivation
   - Classifiers
3. Conclusion and outlook

# SuperKEKB

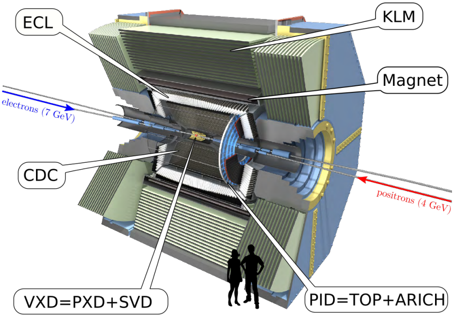
- $e^+e^-$ collider in Tsukuba, Japan.
- $\sqrt{s} = 10.6\,\mathrm{GeV} = \mathrm{m}(\Upsilon(4S))c^2$.
- $\mathrm{BR}(\Upsilon(4S) \to B\bar{B}) > 96\%$.
- $\int_{2019}^{\text{Summer 2020}} L\,\mathrm{d}t \approx 63\,\mathrm{fb}^{-1}$.
- World highest instant. luminosity.
  - $L = 2.4 \times 10^{34}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$ achieved in June 2020.

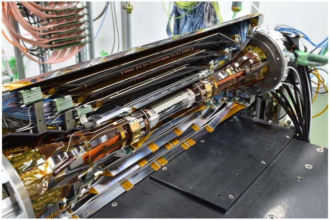


# The Belle II detector

- Pixel Detector (PXD).
- Silicon Vertex Detector (SVD).
- Central Drift Chamber (CDC).
- Calorimeter (ECL).
- Aerogel Ring-Imaging Cherenkov (ARICH).
- Time-Of-Propagation (TOP) counter.
- $K_L^0$ and $\mu$ detection (KLM).

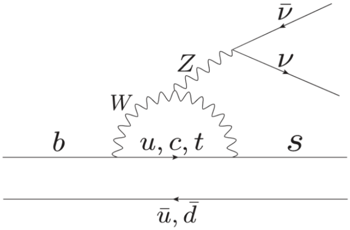


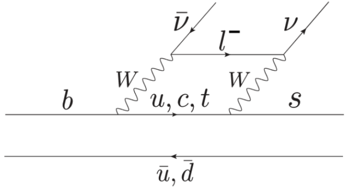
# Outline

# Lowest-order SM quark level diagrams for $b \to s\nu\overline{\nu}$

- Loop




- Box



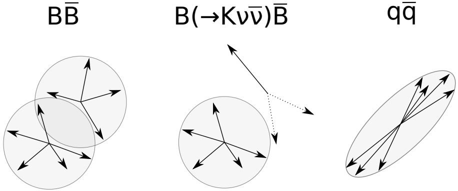

- Advantage of $\nu_\ell\overline{\nu}_\ell$ (over $\ell^+\ell^-$): no virtual photon contribution, thus cleaner theoretical prediction.

# Branching ratio (BR) in the Standard Model and beyond

- Standard Model (SM) prediction:
  - $\mathrm{BR}(B^+ \to K^+ \nu\overline{\nu})_{\mathrm{SM}} = (4.6 \pm 0.5) \times 10^{-6}$ [1606.00916].
- Multiple models beyond the SM constrained by $\mathrm{BR}(B^+ \to K^+ \nu\overline{\nu})$:
  - leptoquarks [1806.05689].
  - axions [2002.04623].
  - dark matter particles [1911.03490].
  - ...

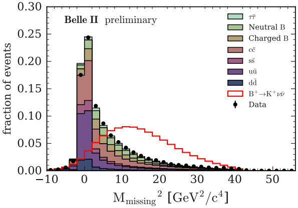
# Signal and background

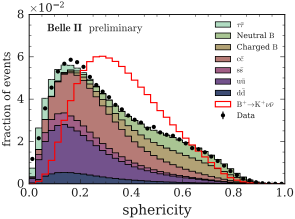
- Signal.
  - $e^+e^- \to \Upsilon(4S) \to B^+(\to K^+\nu\bar{\nu})B^-$.
- Background.
  - Generic $B$-meson decays: $e^+e^- \to \Upsilon(4S) \to B^+B^-$ or $B^0\bar{B}^0$.
  - Continuum events: $e^+e^- \to q\bar{q}$ or $\tau^+\tau^-$ ($q = u, d, s, c$ quarks).

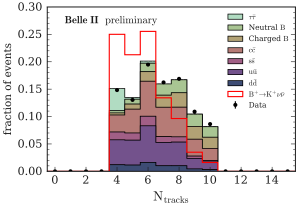


# Features

- $\mathcal{O}(100)$ discriminative features considered.
- Feature selection (parallelised):
  - Iteratively remove variables from the training.
  - Check performance degradation.
- After selection, boosted decision trees (BDT) trained with 51 features.

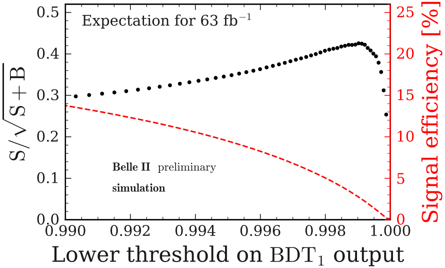


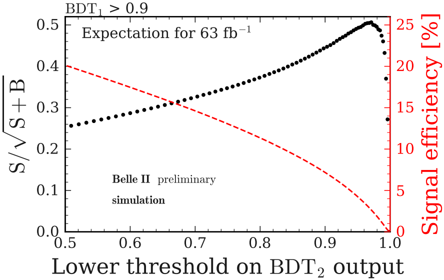



# Training

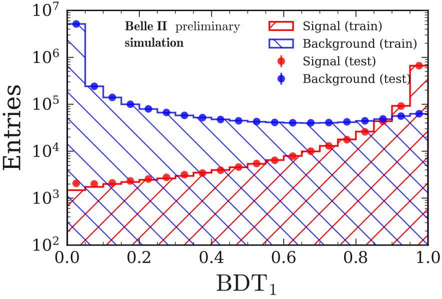
- Manual boosting.
  - Train $\mathrm{BDT}_1$ on $\mathcal{O}(10^7)$ simulated events.
  - Train $\mathrm{BDT}_2$ on $\mathcal{O}(10^7)$ simulated events with $\mathrm{BDT}_1 > 0.9$.

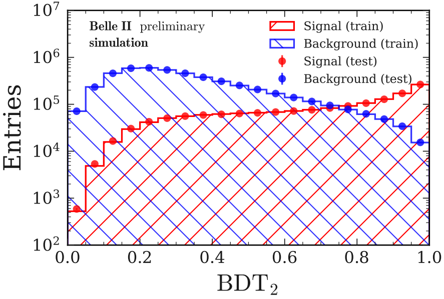


# Overfitting check

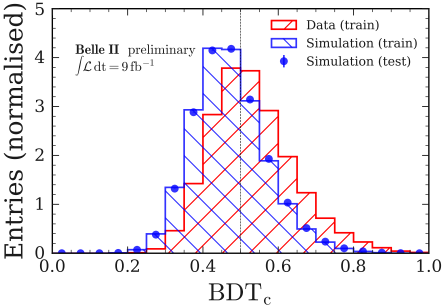
- A bit of overfitting is not problematic as long as the classification behaves the same on simulation and on data.
  - See F. Dattola's presentation [T81.3].



# Simulation reweighting using a classifier [doi:10.1088/1742-6596/368/1/012028]

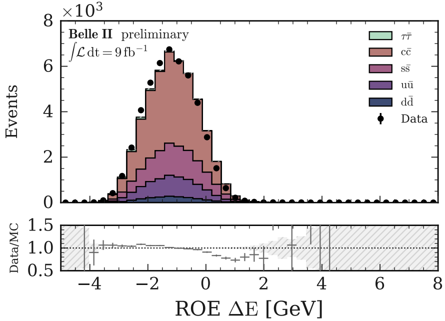
- Data-driven method to correct mismodeling in simulation.
  1. Train a binary classifier ($\mathrm{BDT_c}$) to distinguish simulation *vs* data.
  2. Given the output $p$ of $\mathrm{BDT_c}$, the simulated events are weighted according to $p/(1-p)$.



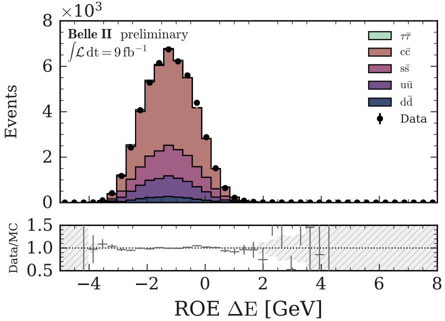
# Simulation reweighting using a classifier [doi:10.1088/1742-6596/368/1/012028]

- This reweighting procedure improves the data-simulation agreement for data collected below the $\Upsilon(4S)$ threshold.

Before reweighting:




After reweighting:



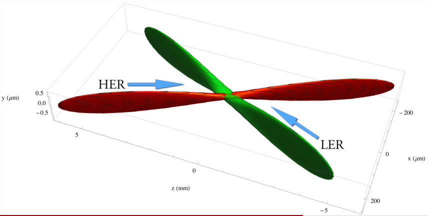
# Conclusion and outlook

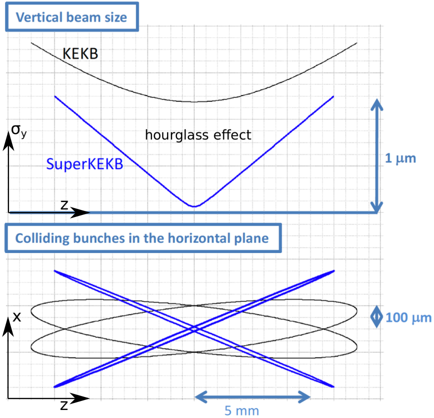
- BDTs are trained to select $B^+ \to K^+ \nu\bar{\nu}$ at Belle II.
- A binary classifier can be used to correct simulation mismodeling.
- Other algorithms, such as neural networks, are currently studied.

Thank you for your attention.

# Nano-beam scheme (idea from Pantaleo Raimondi)

- Goal: $\beta_y^* = 0.3\,\mathrm{mm}$.
- Hourglass effect limited if $\sigma_z^{eff} < \beta_y^*$.
- Half crossing angle:
  - $\phi_x \approx 40\,\mathrm{mrad}$.
- Nominal beam spot parameters:
  - $\sigma_x \approx 10\,\mu\mathrm{m}$.
  - $\sigma_z^{eff} = \frac{\sigma_x}{\sin \phi_x} \approx 0.25\,\mathrm{mm}$.
  - $\sigma_y \approx 50\,\mathrm{nm}$.

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