

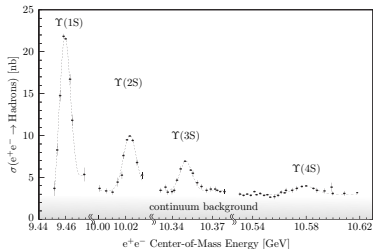
The flavor tagging module for the Belle II Experiment

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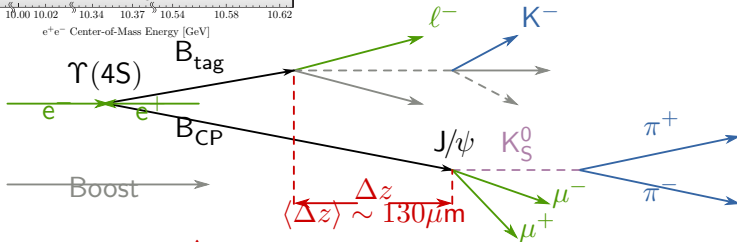
July 10, 2015

- 1 Why flavor tagging?
- 2 Tagger Scheme
- 3 Results
- 4 Outlook





- $\Upsilon(4S)$ above $B\bar{B}$ prod. threshold
 $\Rightarrow B\bar{B}$ at rest in the $\Upsilon(4S)$ frame
- $\sim 48\%$ are $B^0\bar{B}^0$ $q_{B^0,\bar{B}^0} = 1, -1$



- With $\Delta t = \frac{\Delta z}{\langle \beta \gamma \rangle c} \Rightarrow$

$$\mathcal{P}^{\text{Sig}}(\Delta t, q) = \frac{e^{-|\Delta t|/\tau_{B^0}}}{4\tau_{B^0}} [1 + q(\mathcal{A}_{CP} \cos(\Delta m \Delta t) + \mathcal{S}_{CP} \sin(\Delta m \Delta t))]$$

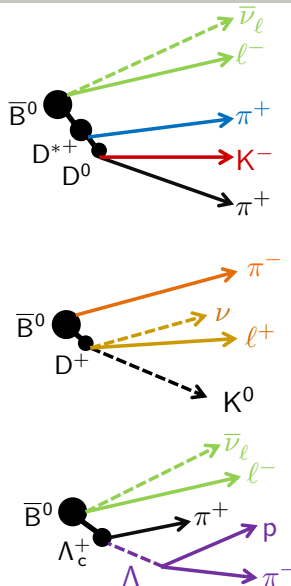
- Only a fraction ε of events is able to be tagged (decays without signatures), and
- a fraction w of them is wrongly classified $\Rightarrow$

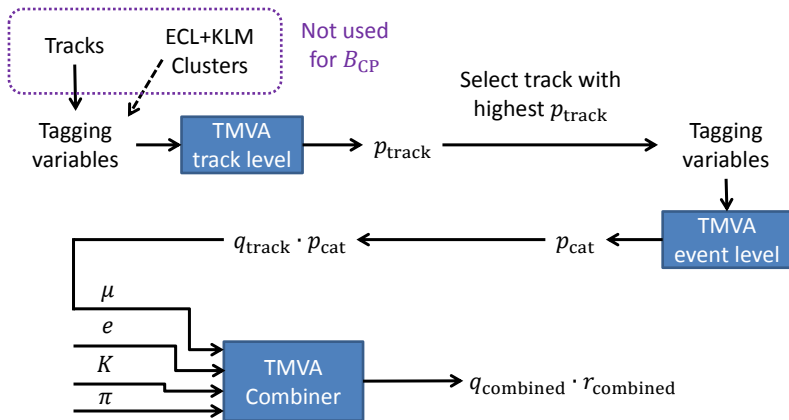
$$\begin{aligned}\mathcal{P}^{\text{Obs}}(\Delta t, q, \varepsilon, w) &= \varepsilon \cdot \left[(1 - w) \cdot \mathcal{P}^{\text{Sig}}(\Delta t, q) + w \cdot \mathcal{P}^{\text{Sig}}(\Delta t, -q) \right] \\ &= \frac{e^{-|\Delta t|\tau_{B^0}}}{4\tau_{B^0}} \varepsilon \left[1 + q(1 - 2w) (\mathcal{A}_{CP} \cos(\Delta m \Delta t) + \mathcal{S}_{CP} \sin(\Delta m \Delta t)) \right] \\ &= \frac{e^{-|\Delta t|\tau_{B^0}}}{4\tau_{B^0}} \varepsilon \left[1 + q \cdot r (\mathcal{A}_{CP} \cos(\Delta m \Delta t) + \mathcal{S}_{CP} \sin(\Delta m \Delta t)) \right]\end{aligned}$$

- Statistical significance $\sim r\sqrt{\varepsilon}$

$\Rightarrow$ Efficiency for several events: $\varepsilon_{\text{Eff}} = r^2 \varepsilon$

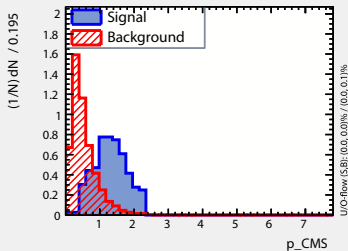
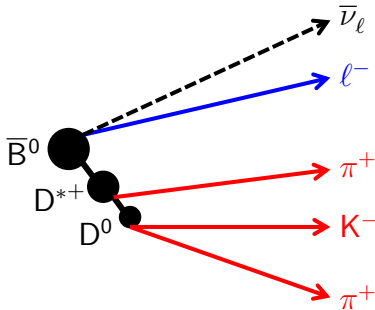
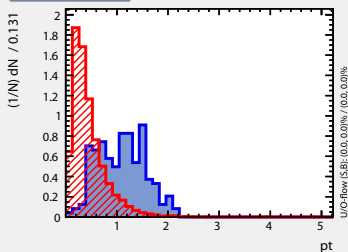
Categories	Targets
Electron	e^-
(Intermediate Electron)	e^+
Muon	μ^-
(Intermediate Muon)	μ^+
KinLepton	e^-
Kaon	K^-
KaonPion	K^-, π^+
SlowPion	π^+
FastPion	π^-
MaximumP	ℓ^-, π^-
FSC	ℓ^-, π^+
Lambda	Λ
Total= 10 (12)	





■ TMVA Multivariate Method 'FastBDT'

$p \hat{=}$ probability

Input variable: p_{CMS} Input variable: pt 

■ E.g. $\cos(\theta)$, d_0 , z_0 , E_W^{90}

Combines all event level outputs:

⇒ 10 Inputs: $q_{\text{track}} \cdot p_{\text{Cat}} \in [-1, 1]$ of each Category

⇒ Output: $y_{\text{Out}} = (q \cdot r)_{\text{Output}} = (q \cdot r)_{\text{Combined}} \in [-1, 1]$

Methods Explored:

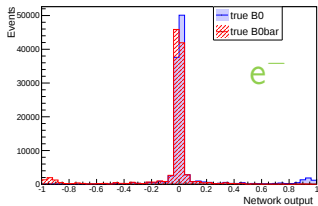
- TMVA ‘FastBDT’
- FANN Multiple Layer Perceptron (MLP)

Training sample (500 MC kEvents):

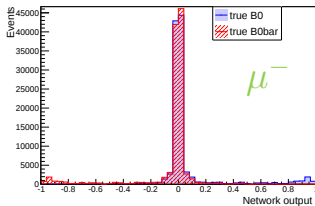
- $\Upsilon(4S) \rightarrow B_1^0 B_2^0 \rightarrow$
 $B_1 \rightarrow J/\Psi K_S^0 \quad B_2 \rightarrow \text{generic}$



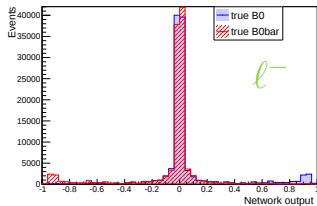
Electron category input



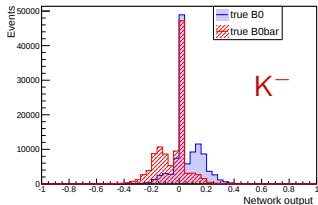
Muon category input



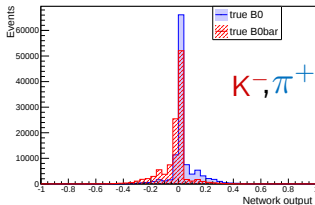
KinLepton category input



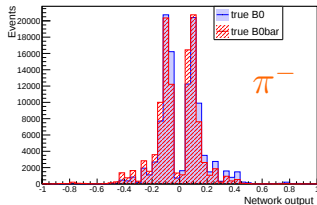
Kaon category input



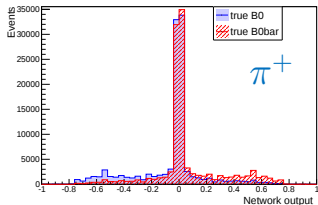
KaonPion category input



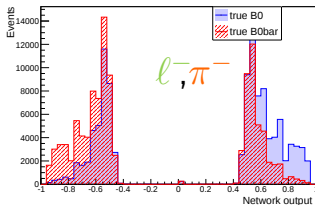
FastPion category input



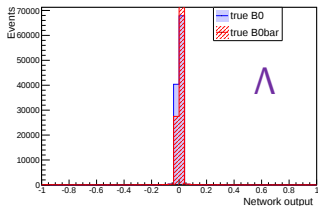
SlowPion category input



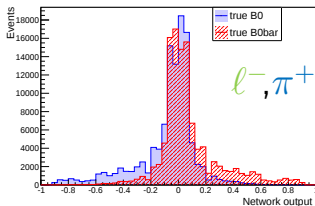
MaximumP category input

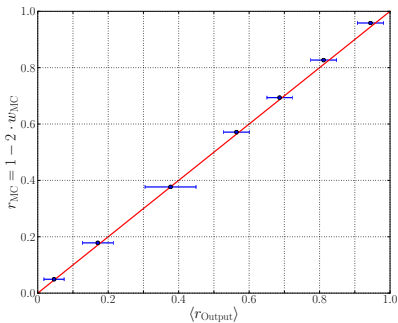
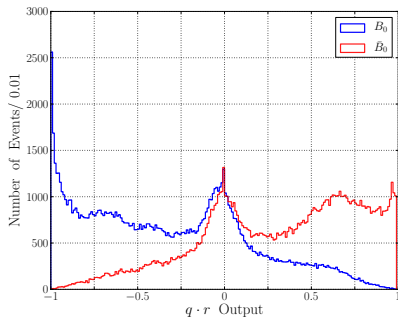


Lambda category input

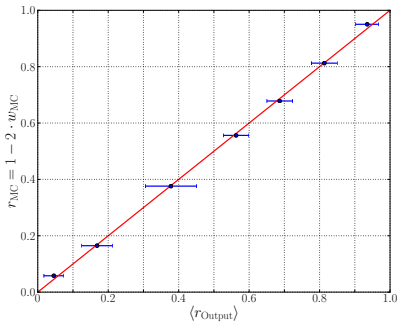
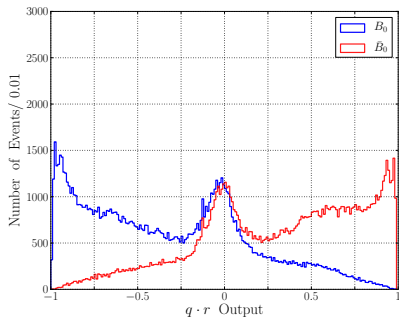


FSC category input

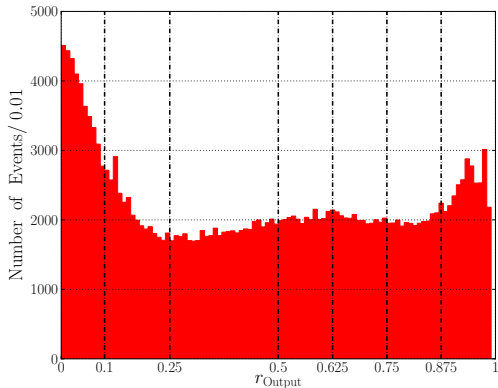




Total Efficiency = 31.3 %



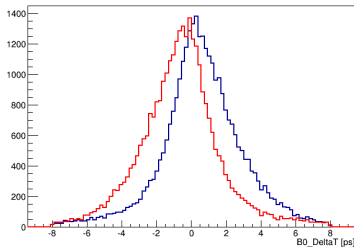
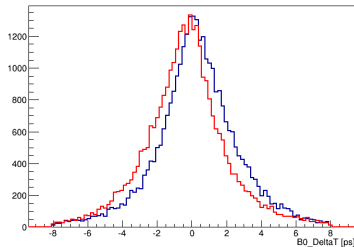
Total Efficiency = 31.6 %



- Binning $\Rightarrow$ correction with real data!
- Efficiency:

$$\epsilon_{\text{Eff}} = \sum_i \epsilon_i \cdot \langle r_i \rangle^2$$

- $r_{\text{MC}} = 1 - 2 \cdot w_{\text{MC}}$
- Calibration: r_{MC} linear to r_{Output}

MC Analysis of $B_{CP} \rightarrow J/\psi K_S^0$ a) q from MCb) q tagged (Total Effcy. = 34 %) B^0 $\bar{B}^0$ Impact on $\mathcal{P}(\Delta t, q, r)$:

$$\mathcal{P}^{\text{Obs}}(\Delta t, q) = \frac{e^{-|\Delta t|\tau_{B^0}}}{4\tau_{B^0}} \varepsilon [1 + q \cdot r (\mathcal{A}_{CP} \cos(\Delta m \Delta t) + \mathcal{S}_{CP} \sin(\Delta m \Delta t))]$$



- A good Flavor Tagging is indispensable for the Study of time dependent CP Violation.
- Up to now: Flavor Tagging Interface for Belle II reaches a slightly better efficiency ($\sim 34\%$) than its predecessors. (Belle $\sim 29\%$, BaBar $\sim 33\%$)
- Still several studies to be made: Comparison and optimization of methods, categories, variables etc.
- Challenge: the development and the accuracy of the Flavor tagging is coupled to the whole software development.



Category	Actual ϵ [%]	BaBar ϵ [%]
Electron	5.33	6.09
Muon	5.40	4.27
KinLepton	5.94	2.83
Kaon	19.06	19.74
KaonPion	13.46	10.23
SlowPion	6.11	5.70
FastPion	2.39	–
MaximumP	12.55	11.19
FSC	11.49	6.26
Lambda	1.781	0.29

a) Inputs $(q \cdot p)_k \hat{=} (q \cdot p)_{\text{Cat}}$

b) Target $\hat{=} q_{\text{MC}}$

■ One Hidden Layer (Kolmogorov)

⇒ Hidden layer: $n_{\text{hidden}} = 3 \cdot n_{\text{input}}$

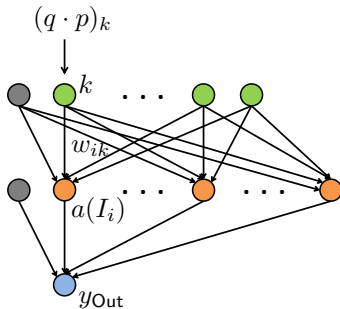
⇒ Activation function

$$a_i = \tanh(I_i) \in [-1, 1]$$

⇒ Input: $I_i = \sum_{k=0}^{n_{\text{input}}} w_{ik} (q \cdot p)_k$

■ Training Sample = ~ 110 kEvents

⇒ Output neuron: $y_{\text{Out}} = (q \cdot r)_{\text{Combined}}$



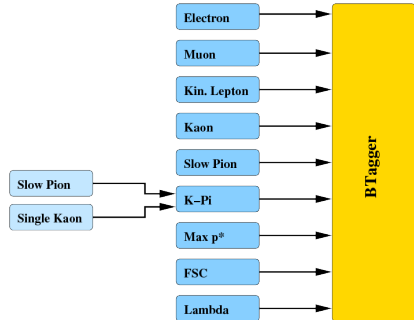
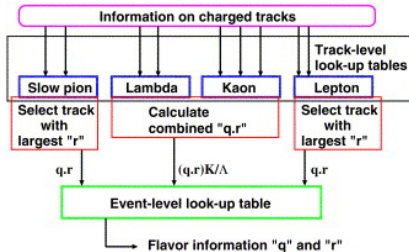
Training:

■ Cost function = MSE

■ Training Algorithm = BP

■ NCycles = ~ 2000

■ Monitoring = True



⇒ Each step: Trained neural network (NN) or other TMVA method.