Sensitivity estimation for $H \rightarrow s\bar{s}$ search with machine learning

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Motivation for $H \rightarrow s\bar{s}$ Search

Higgs mechanism

In the SM, Higgs boson coupling is proportional to particle's mass

The measurements are ongoing

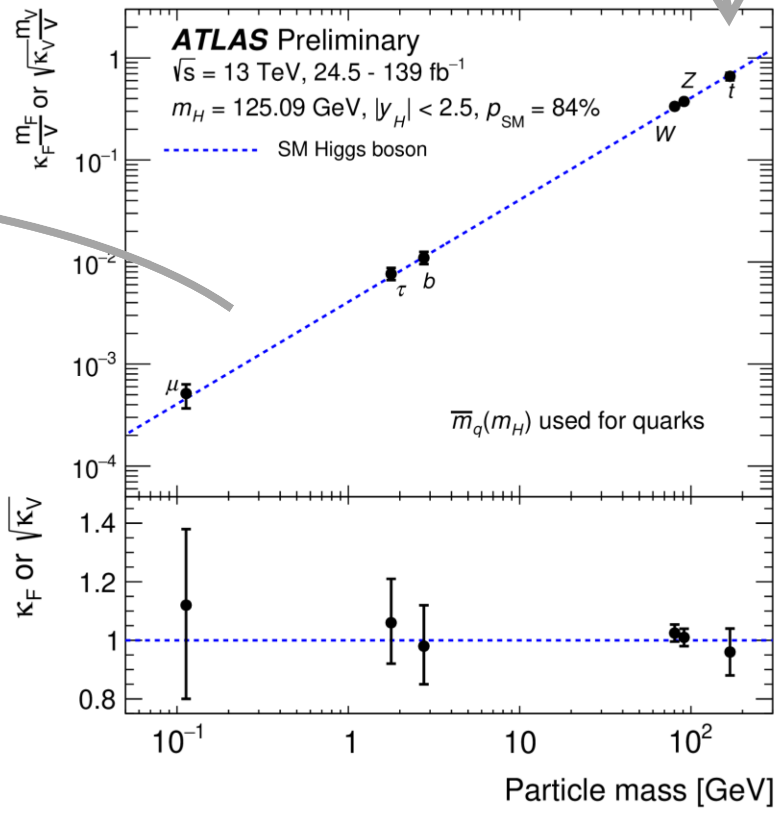
-Weak boson

-3rd-generation charged fermion

For 2nd-generation charged fermion

-μ	HL-LHC
-*charm*	ILC
-*strange*	??

→**Focus on *s*!!**



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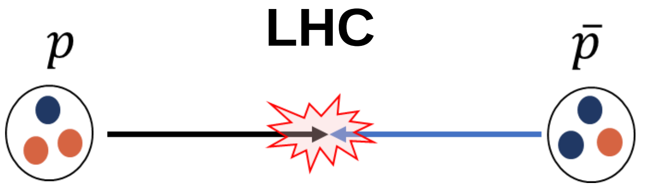
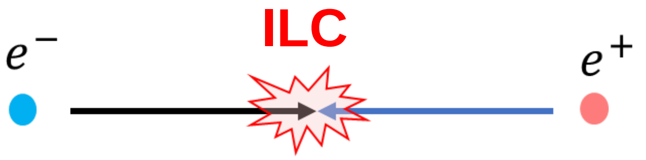
Higgs Production and Decays Focused on

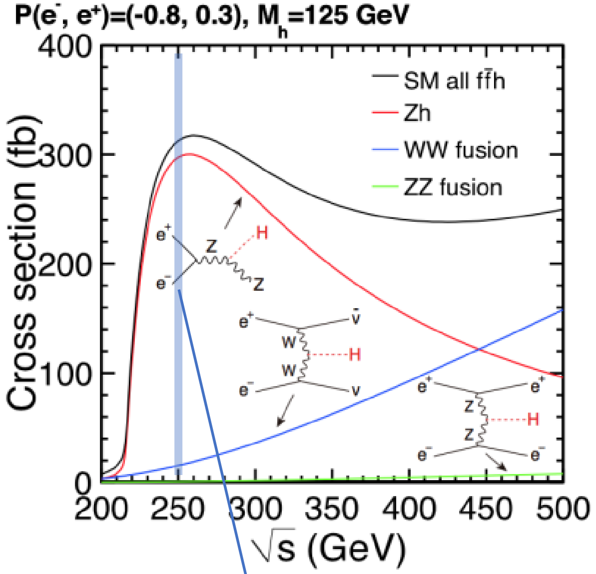
As the first step of $H \to s\bar{s}$ search, study with truth not through detector simulation



Strange jet is difficult to be identified



High jet identification performance



Suppose $H \to b\bar{b}, c\bar{c}$ are separable

Consider $H \to gg$

- Branching ratio: ~100 times $H \to s\bar{s}$
- Jet shape is similar

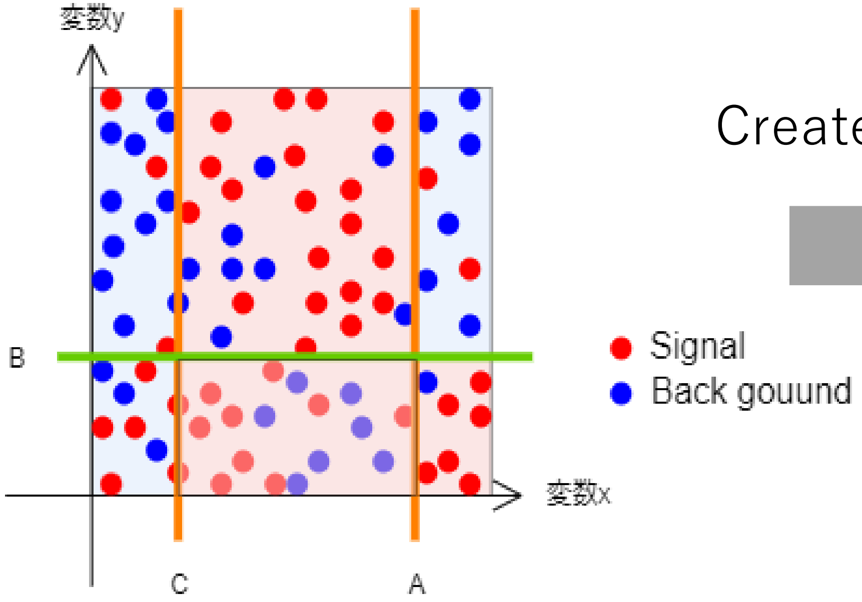
Experiments
ILC

Higgs production
ZH

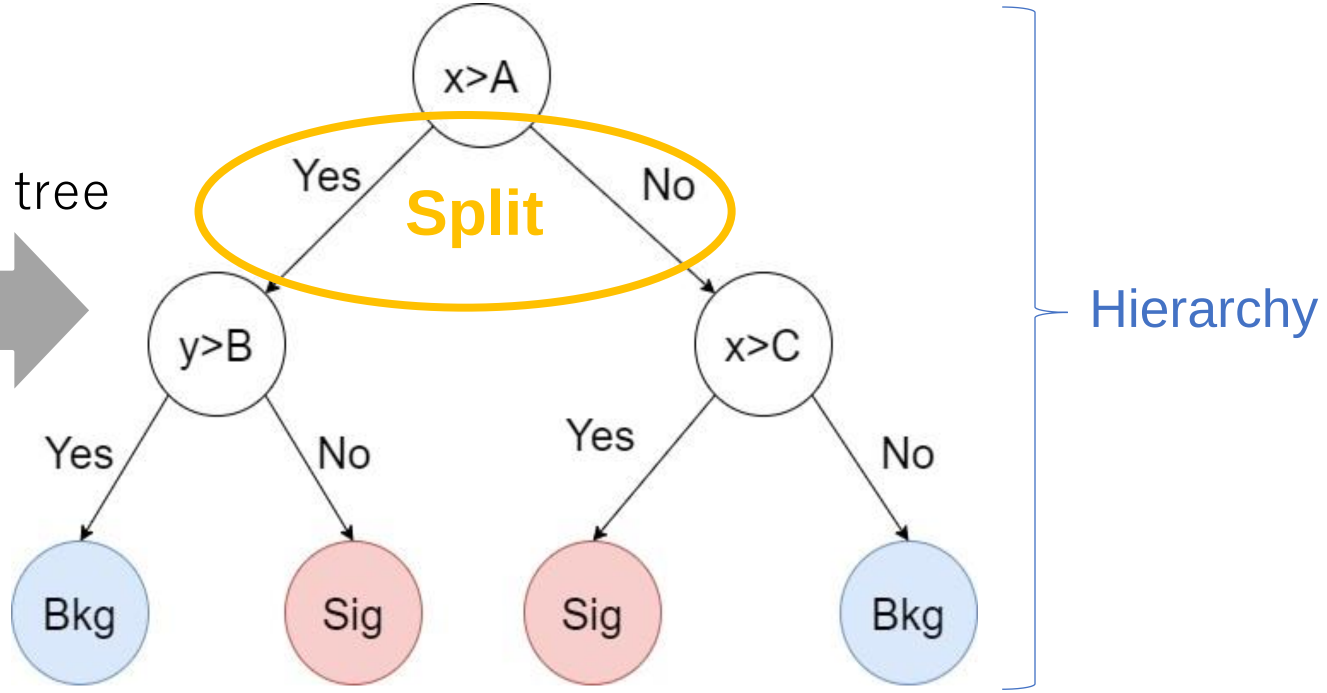
Signature: high pt muon

Signal: $H \to s\bar{s}$
Background: $H \to gg$

Boosted Decision Tree (BDT)



Create decision tree



Combination of multiple decision trees with better discrimination performance

BDT

Significance

$$(\text{Significance}) \equiv \frac{\boldsymbol{S}}{\sqrt{\boldsymbol{S}+\boldsymbol{B}}}$$

S= $\boldsymbol{\sigma(e^+e^- \to ZH) \times Br(Z \to \mu^-\mu^+) \times Br(H \to s\bar{s}) \times L \times \varepsilon_{sig}}$

B $= \boldsymbol{\sigma(e^+e^- \to ZH) \times Br(Z \to \mu^-\mu^+) \times Br(H \to gg) \times L \times \varepsilon_{bkg}}$

L:Integrated luminosity= 2000 fb^{-1} (10 year,250 GeV)

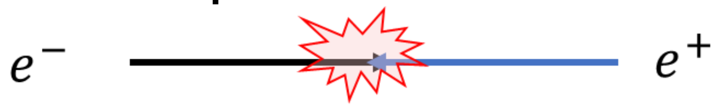
σ: cross section

Br: Branching ratio

The goal :Estimation of the significance

Flow

Sample Generation



$\sqrt{s}$=250 GeV

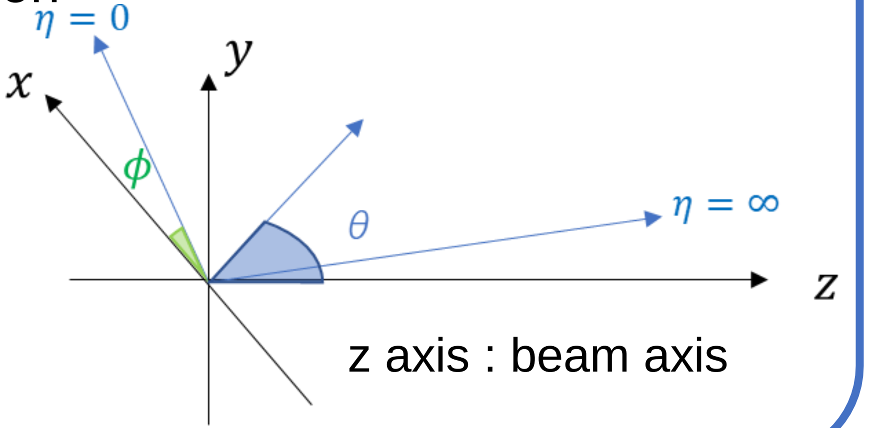
→ **Separation between $H \to s\bar{s}$ and $H \to gg$ with BDT**

→ **Significance estimation**

Assume ILC

- -Only ZH production
- -Truth flag
- -Signal: $H \to s\bar{s}$
- -Background: $H \to gg$

Direction



Input variables

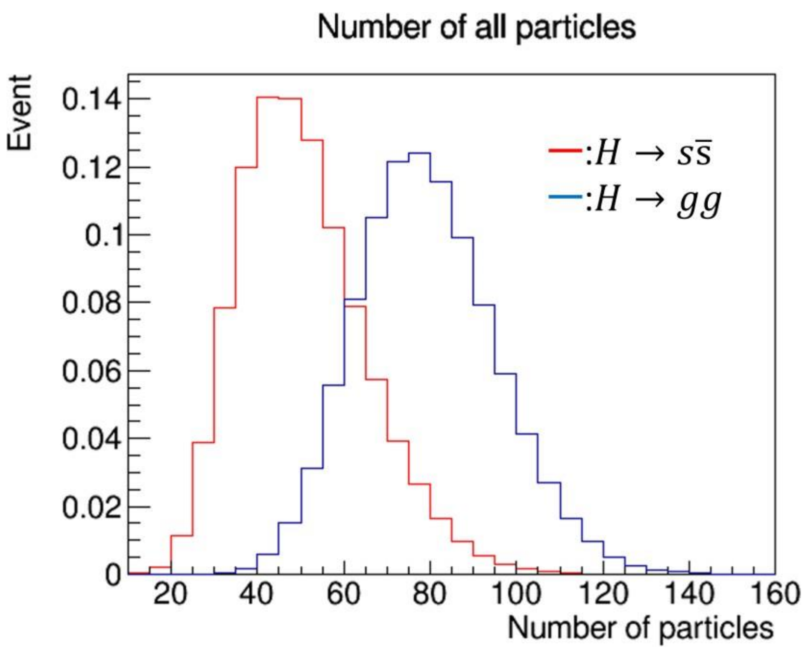
- -Number of particles
- -Number of kaons
- -Energy sum

Variables for the BDT

Obtained from final state particles by event

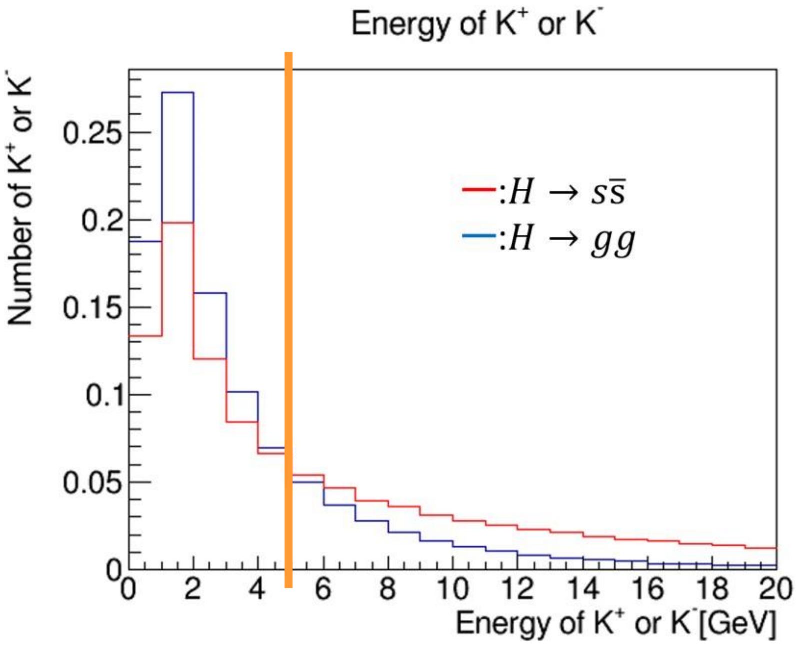
①Total number of particles

difference due to color charge



②Total number of K^+, K^- with energies greater than 5 GeV

s jets contain more K^+, K^-



Variables for the BDT

Obtained from final state particles by event

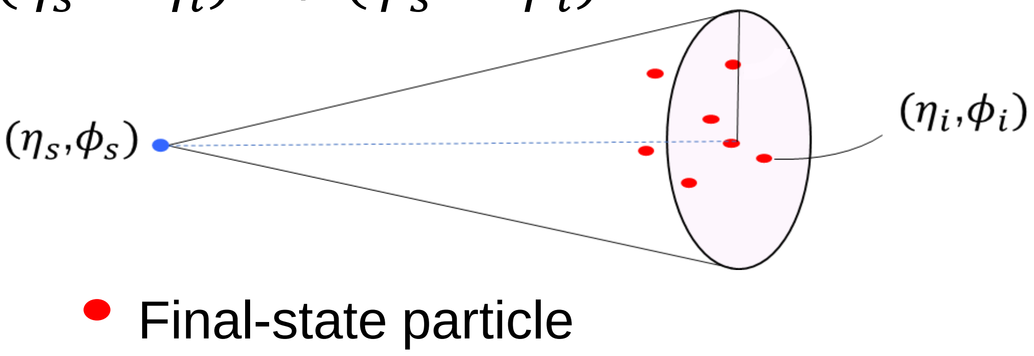
③$E(\Delta R)$:Sum of energies in cone

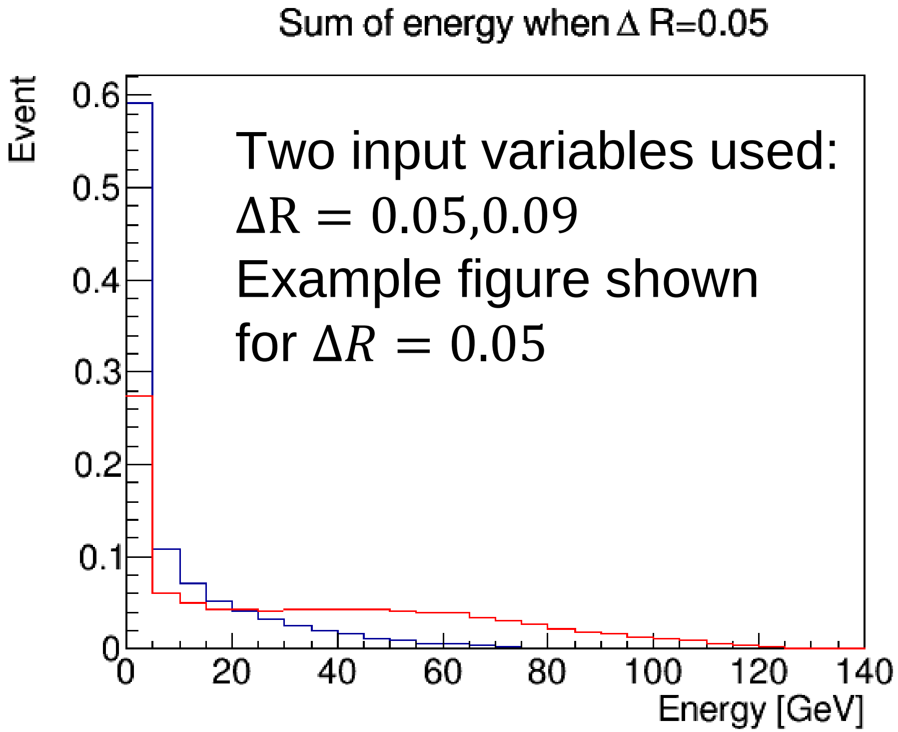
Difference due to jet shape (difference due to color charge)

$$\mathbf{E(\Delta R)} = \mathbf{E}_{\bar{s}}(\Delta R) + \mathbf{E}_{s}(\Delta R)$$

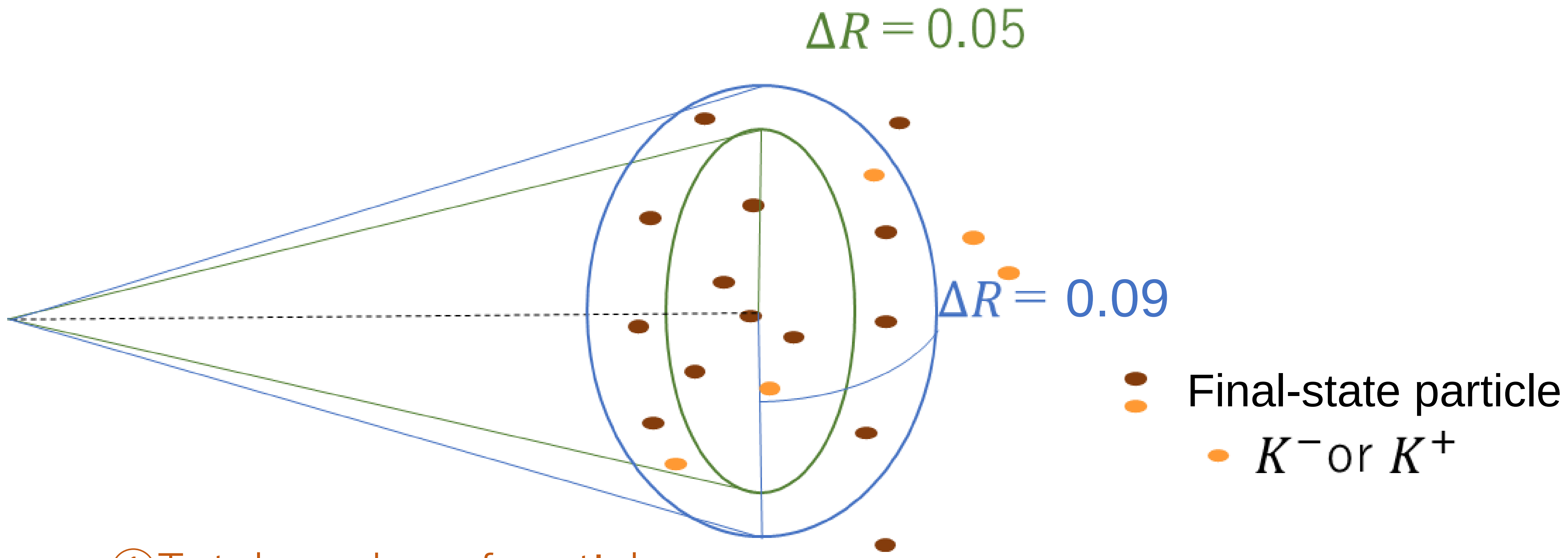
E_s ($E_{\bar{s}}$): sum of energies in s ($\bar{s}$) jet cone

$$\Delta R = \sqrt{(\eta_s - \eta_i)^2 + (\phi_s - \phi_i)^2}$$



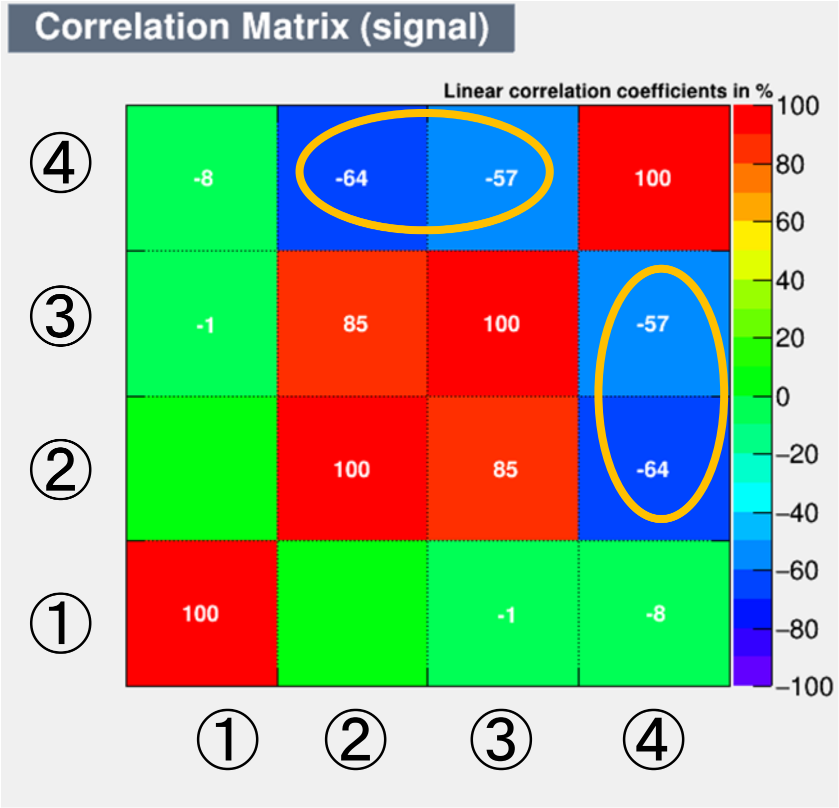


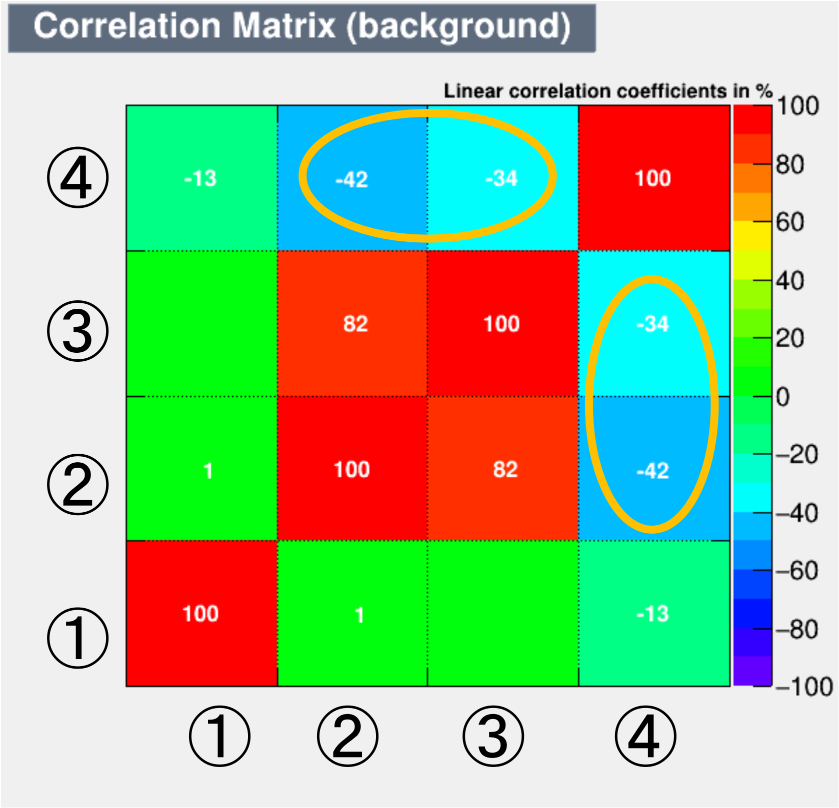
Summary of Variables



①Total number of particles
②Total number of K^+, K^- with energies greater than 5 GeV
③Sum of energy in the cone at ΔR=0.05
④Sum of energy in the cone at ΔR=0.09

Correlations Matrices





① Total number of K^{+}, K^{-} with energies greater than 5 GeV

② Sum of energy in the cone at ΔR=0.09

③Sum of energy in the cone at ΔR=0.05

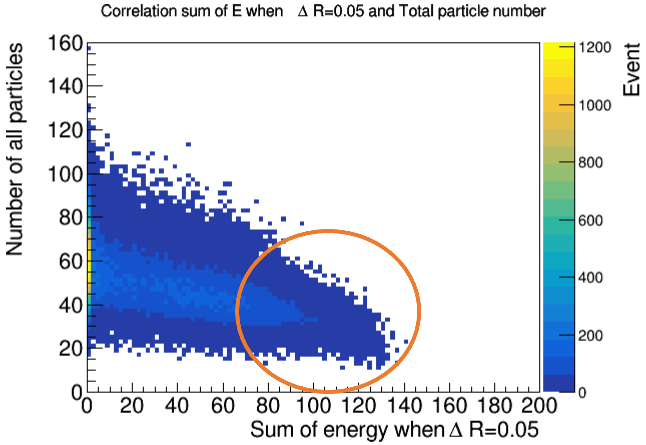
④ Total number of particles

Different correlations among ②, ③ and ④
for signal and background

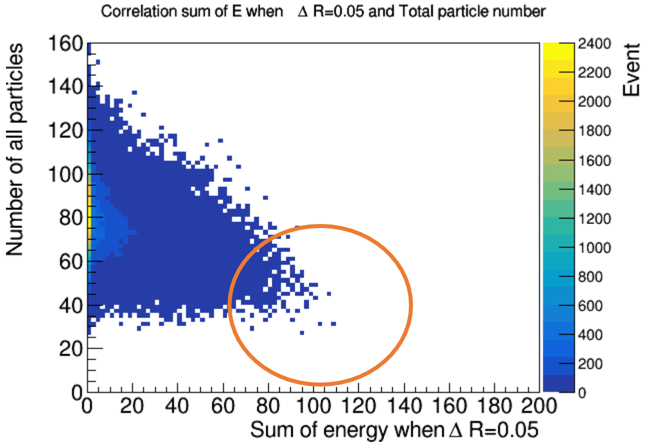
Difference between Energy and Particles Counts

$\Delta R = 0.05$

$H \rightarrow s\bar{s}$

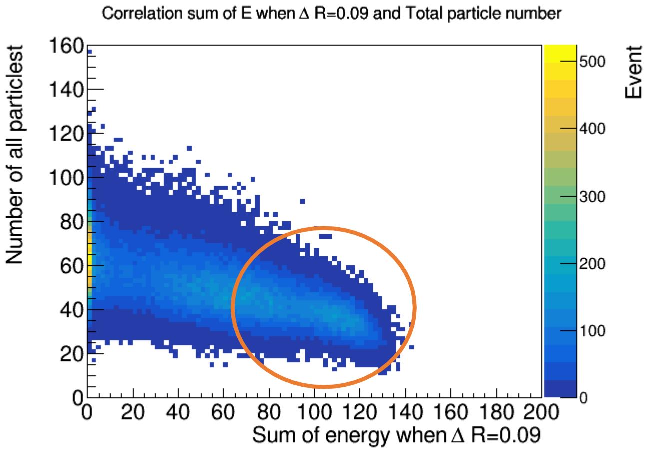


$H \rightarrow gg$

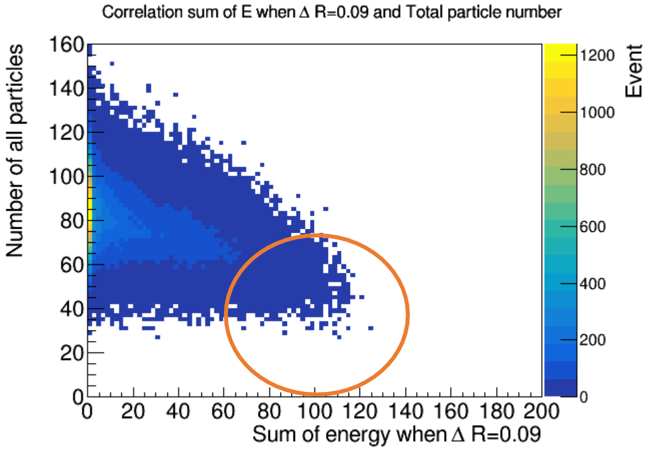


$\Delta R = 0.09$

$H \rightarrow s\bar{s}$



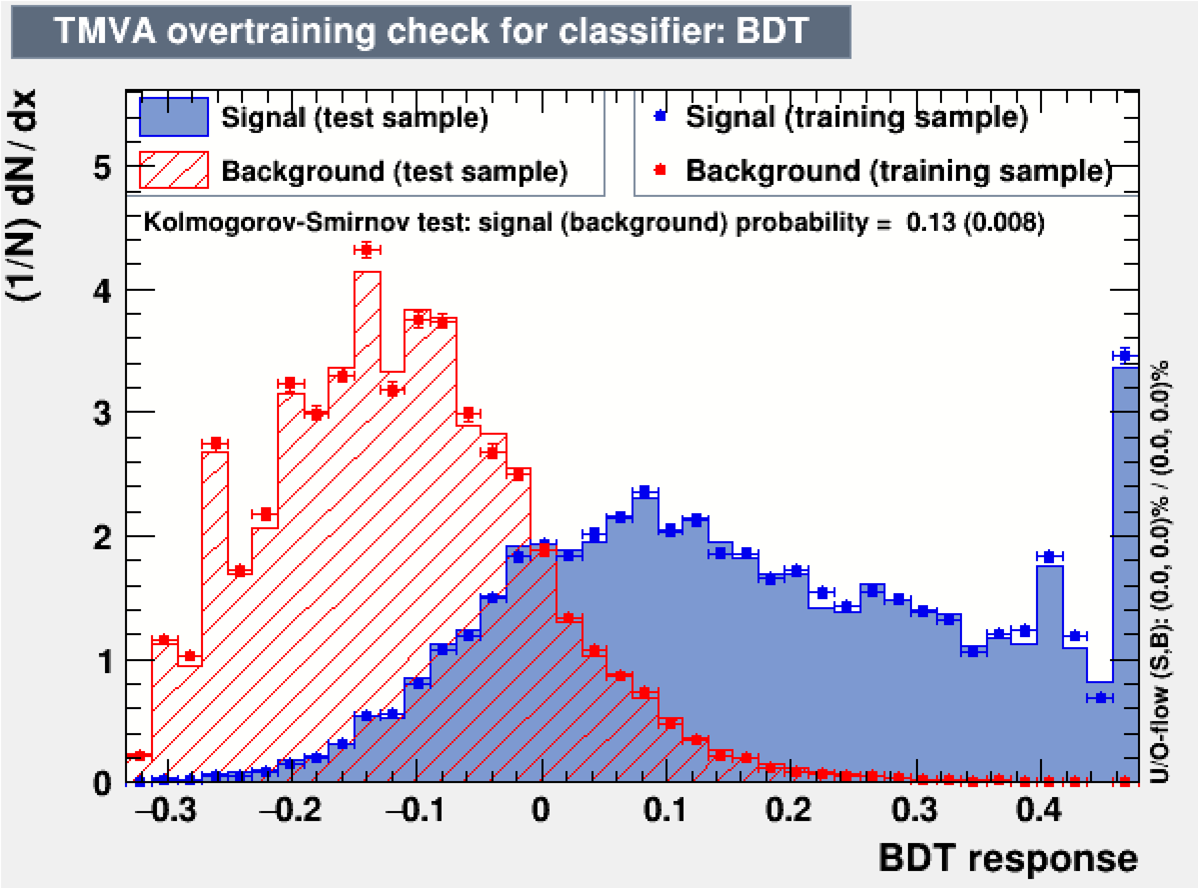
$H \rightarrow gg$



BDT can consider difference in correlation

BDT Response

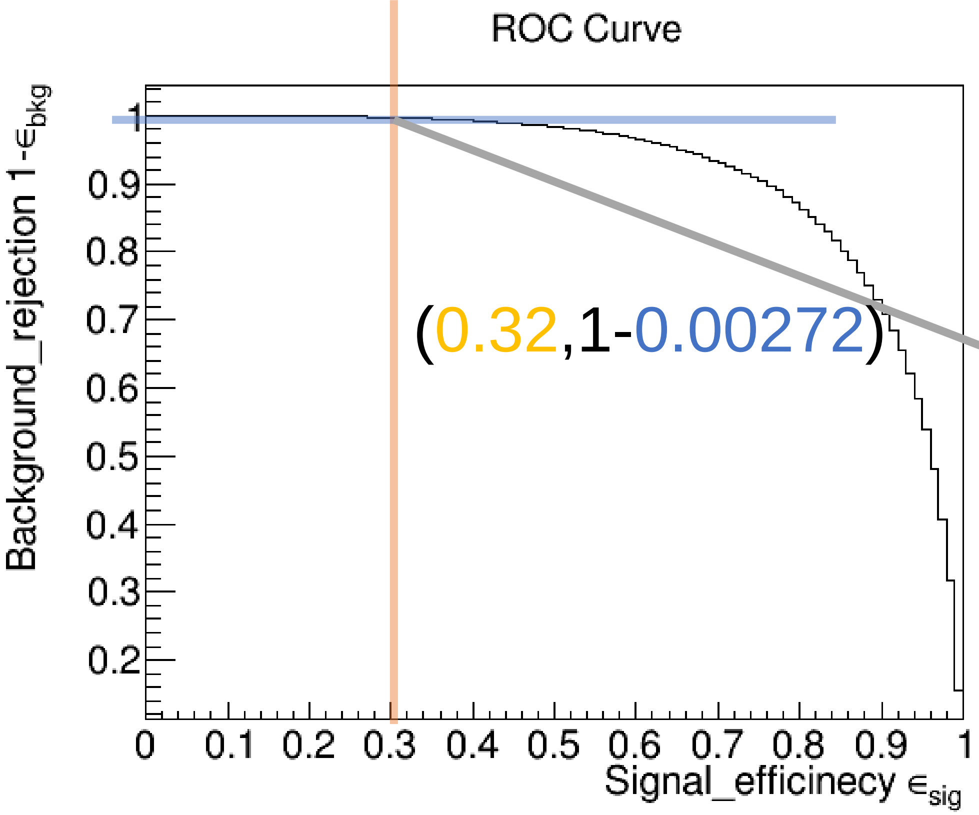
Signal (background) events have values closer to 1 (-1)



Significance Estimation

Using Receiver Operating Characteristic (ROC) curve

I obtain ε_{sig} and ε_{bkg} which is required to obtain significance



For the integrated luminosity 2000 fb^{-1},
the maximum significance is **1.2σ**

Summary

As the first step in $H \rightarrow s\bar{s}$ search

-Separation between $H \rightarrow s\bar{s}$ and $H \rightarrow gg$ was performed with BDT

-Using truth information, for the integrated luminosity 2000 fb^{-1}, the maximum significance is **1.2σ**

Back up

Optimized Cone Size and Number

Optimized number of E(ΔR)

Comparison

-BDT input: Fixed ①,②

Changing number of E(ΔR)

-ΔR:0.05-2.0 (0.01 step)

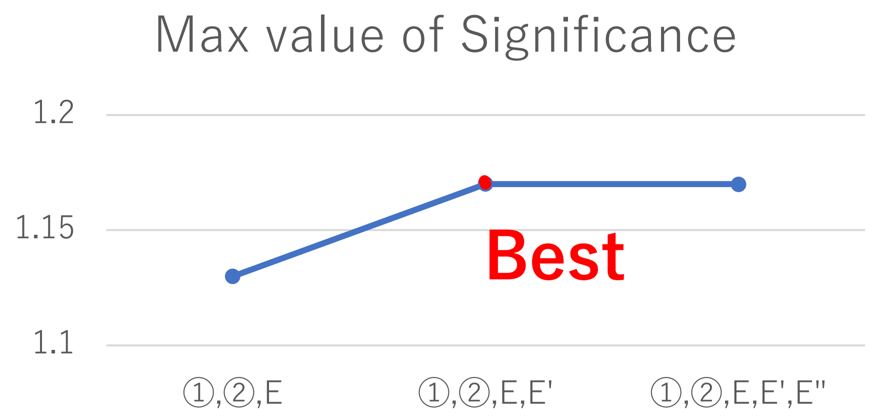
①Total number of particles

②Total number of K^+, K^- with energies greater than 5 GeV

Ex.When Input two E(ΔR)

BDT input:①,②,E(ΔR),E(ΔR')

Result



The optimal combination of E(ΔR) is $\Delta R = (0.05, 0.09)$

Discrimination Index

Significance

$$\frac{\sigma(e^+e^- \to ZH) \times Br(Z \to \mu^-\mu^+) \times Br(H \to s\bar{s}) \times L \times \varepsilon_{sig}}{\sqrt{\sigma(e^+e^- \to ZH) \times Br(Z \to \mu^-\mu^+) \times L \times \{Br(H \to s\bar{s}) \times \varepsilon_{sig} + Br(H \to gg) \times \varepsilon_{bkg}\}}}$$

L:Integrated luminosity

$\sigma(e^+e^- \to ZH)$:Cross section

$Br(H \to gg)$, $Br(H \to s\bar{s})$, $Br(Z \to \mu^-\mu^+)$:Branching Ratio

ε_{sig}:Signal efficiency

ε_{bkg}:Background efficiency

※Each constant is a value that takes ILC into account.

※BDT Output

Constants used for Significance

- L: Integrated luminosity

  $2000\ \mathrm{fb}^{-1}$ (10 year, 250 GeV)
- $\sigma(e^+e^- \to ZH)$: Cross section

  300 fb
- $\mathrm{Br}(H \to gg)$, $\mathrm{Br}(H \to s\bar{s})$, $\mathrm{Br}(Z \to \mu^-\mu^+)$: Branching Ratio

  $\mathrm{Br}(H \to gg) = \mathbf{8.187 \times 10^{-2}}$

  $\mathrm{Br}(H \to s\bar{s}) = \mathbf{5.05753 \times 10^{-4}}$

  $\mathrm{Br}(Z \to \mu^-\mu^+) = \mathbf{3.36 \times 10^{-2}}$

Ability to Identify Single Variable

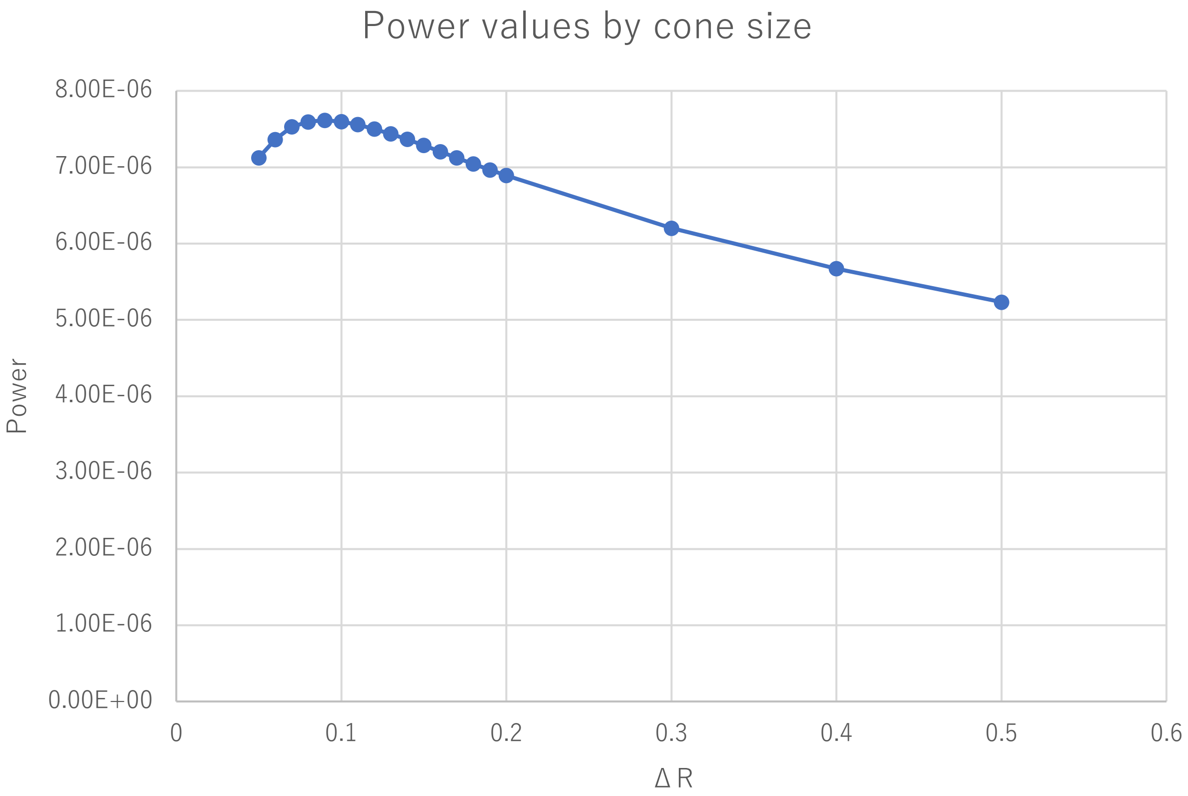
Power : indicator of the identification accuracy of a single variable

$$\text{power} \equiv \frac{\left|M_{sig} - M_{bkg}\right|}{\sqrt{\sigma_{sig}^2 + \sigma_{bkg}^2}}$$

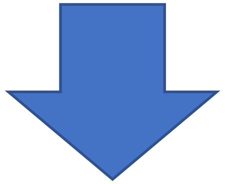
σ_{sig} :Standard deviation of a variable with signal events
M_{sig}:Mean of a variable with signal events
σ_{bkg} :Standard deviation of a variable with background events
M_{bkg}:Mean of a variable with background events

Variables with higher values have higher discriminative power

Ability to identify single variable

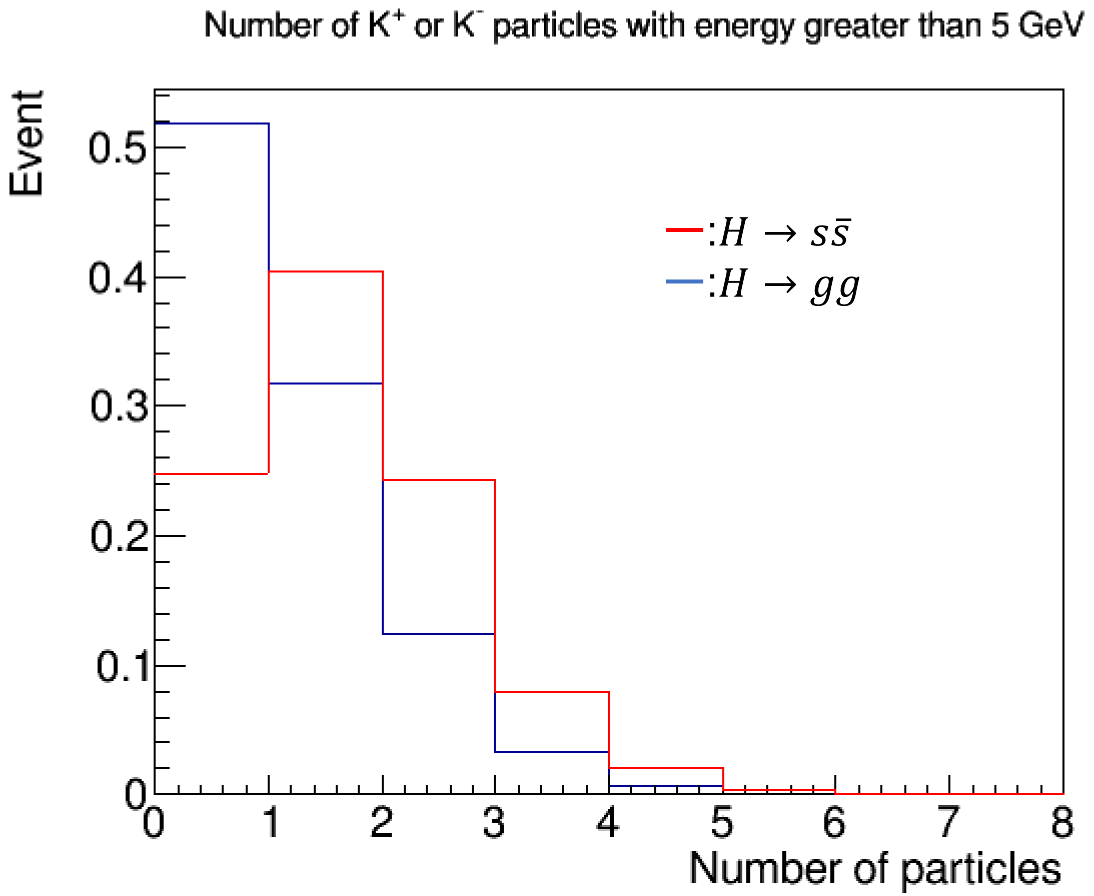


When $\mathbf{\Delta R = 0.09}$,
Power value was highest

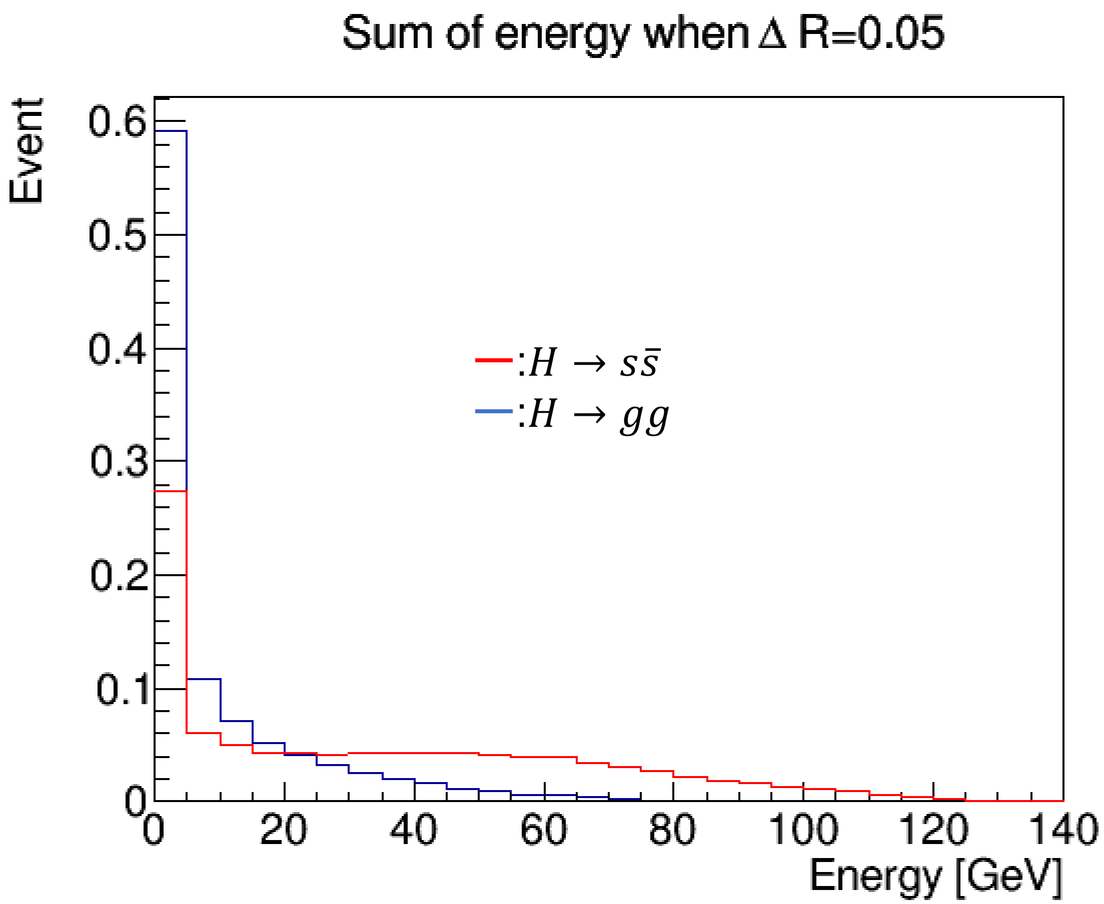


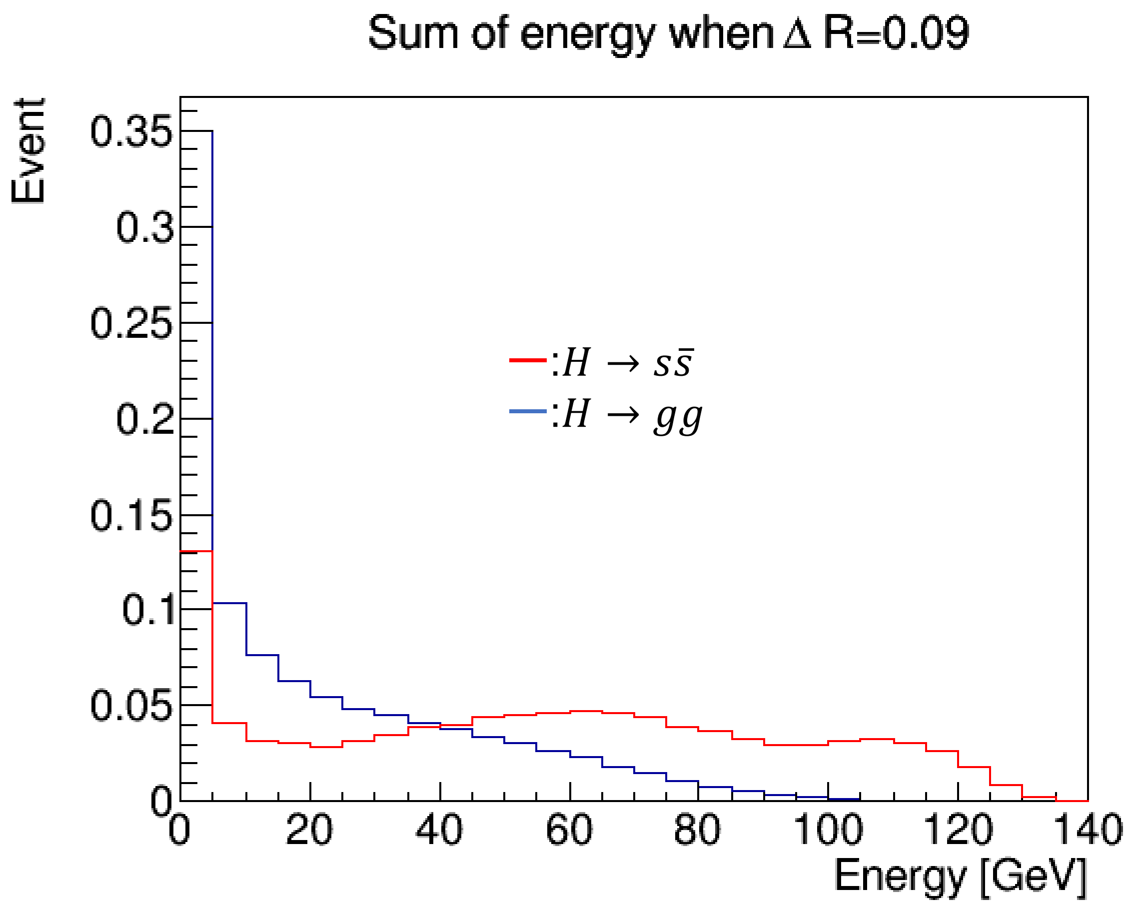
Best discriminating ability of single variable is at **0.09**

K^-, K^+ that are E ≥ 5 GeV per event



Sum of energy in cone





Kaon Energy Comparison

Focusing on the final state particles of each of $H \rightarrow s\bar{s}$ and $H \rightarrow gg$

①Total number of particles

②Sum of energy in the cone at ΔR=0.05

③Sum of energy in the cone at ΔR=0.09

④Total number of K^+, K^- with energy greater than 5 GeV

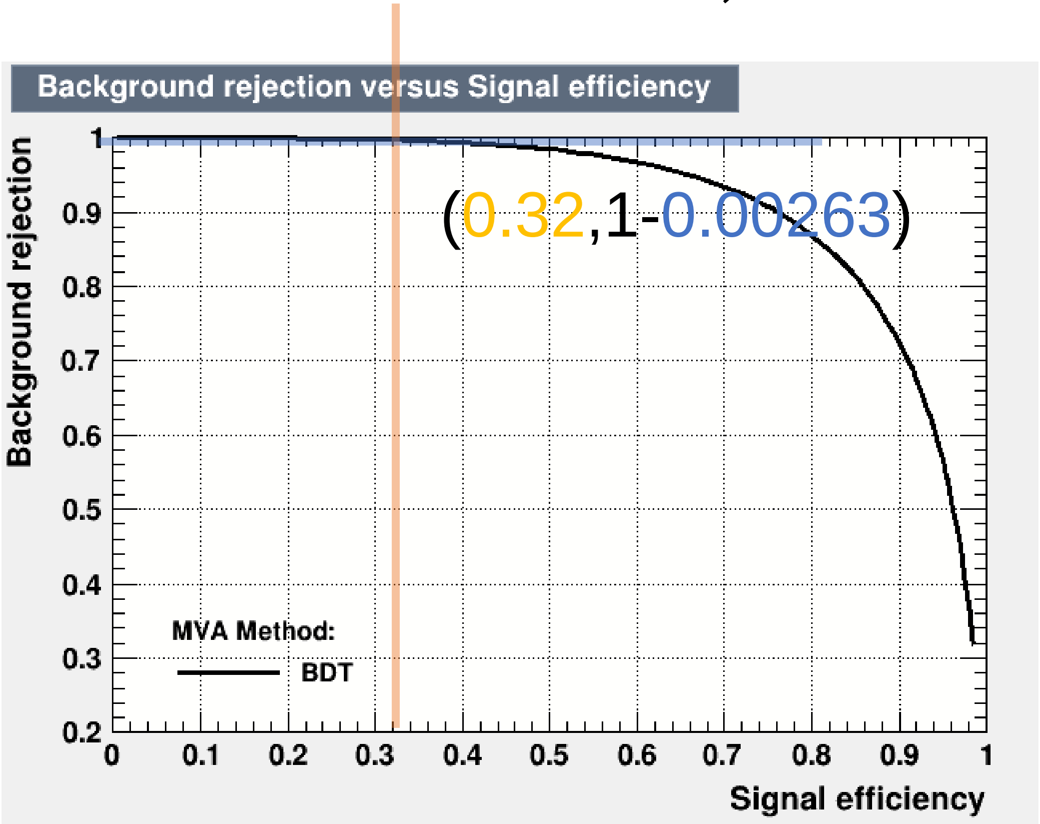
⑤**Total number of K^+, K^- with energy less than 5 GeV**

①-⑤ and ①-③ and ①-③+⑤ as input variables,

BDTs were created and compared

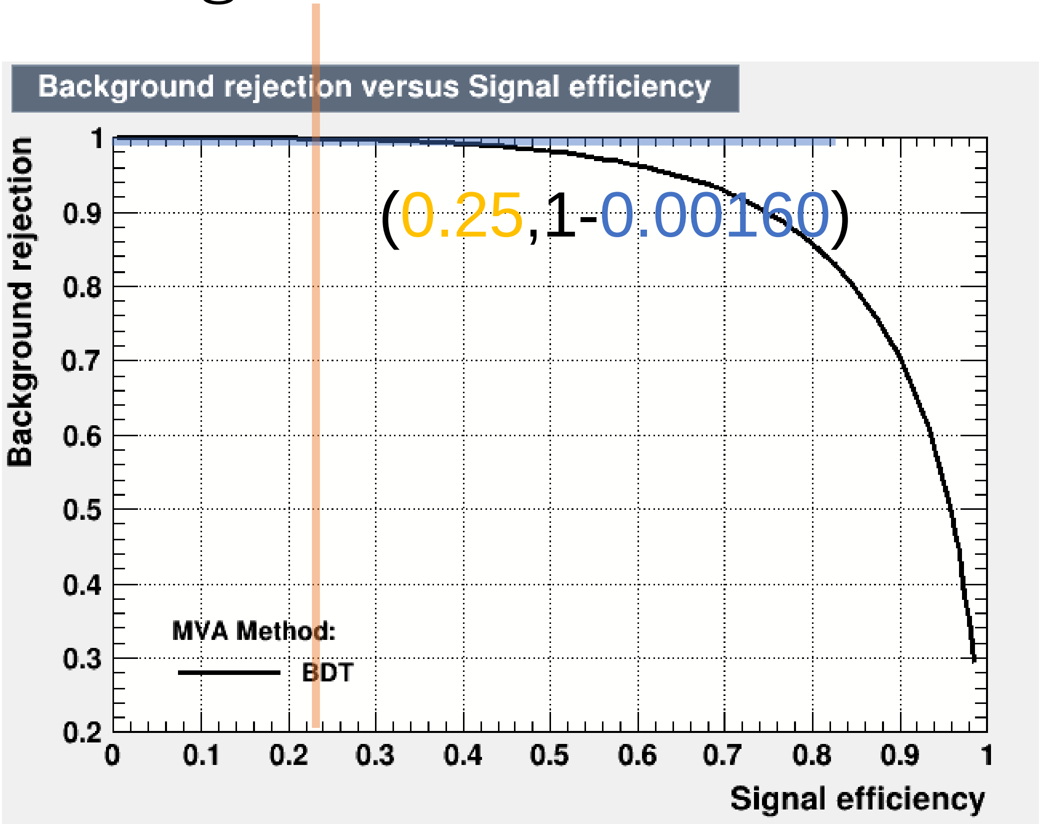
Result

Add E≦5 GeV K^{+}, K^{-}



Max Significance:1.19

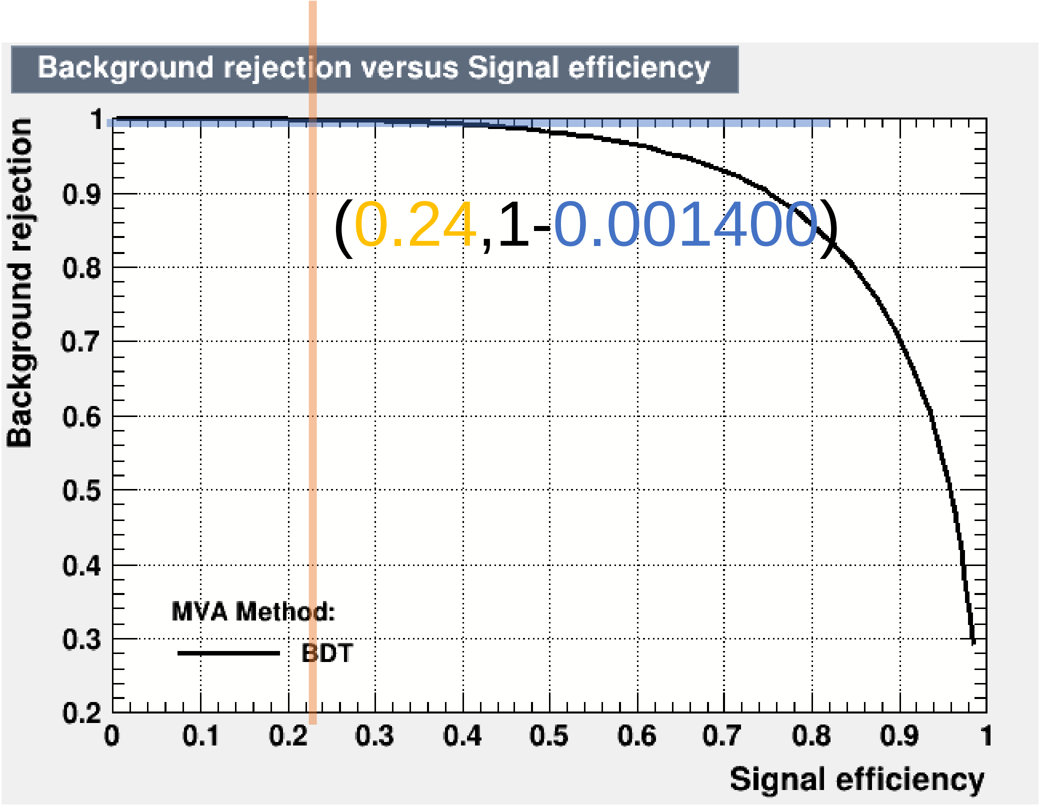
Excluding variables related to K^{+}, K^{-}



Max Significance:1.12

Result

Add E≦5 GeV K^+, K^- but exclude E≧5 GeV K^+, K^-



Max Significance:1.12σ