HANDS-ON SESSION #9

Comparison of background rejection capabilities of two algorithms by using a ROC curve

Colab file: **`E+_9_ROC.ipynb`**

Erasmus+ EU programme

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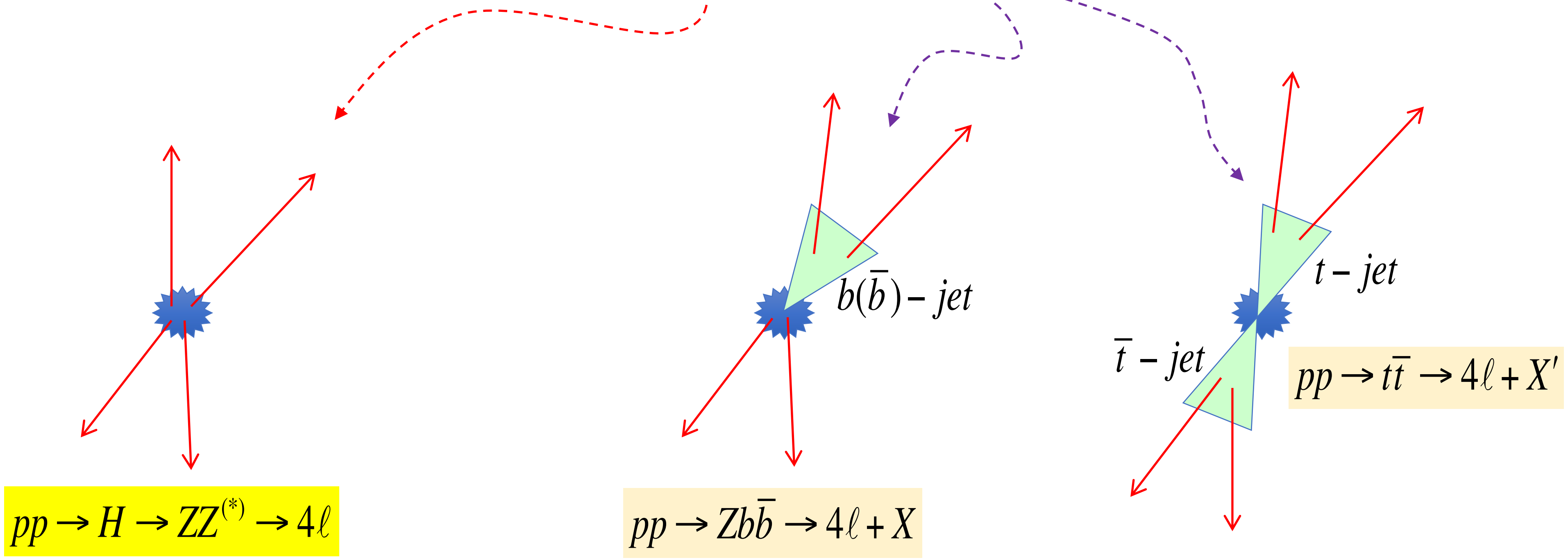
Hands-on exercises will be carried out within a `Jupyter` *Notebook executed in the* `Google Colab` *framework.*

(*) I would like to thank my collaborator **Umit Sozbilir**

PHYSICS CASE - I

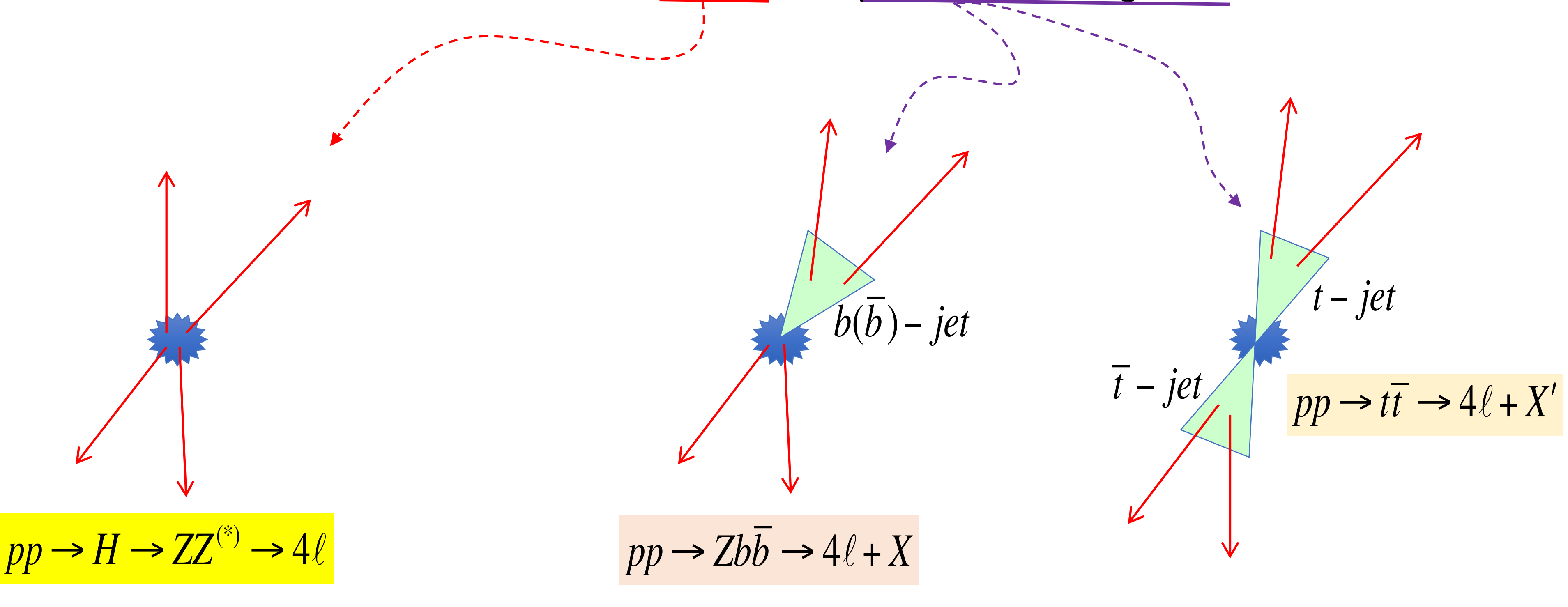
In the optimization of the selection criteria for the “golden” channel $H \to ZZ^* \to 4\ell\ (\ell = 4\mu, 2\mu 2e, 4e)$, we developed - within CMS - several algorithms such as, for instance , those based on the vertexing of the lepton tracks and on the isolation of the tracks, with the aim to extract the signal from the overwhelming backgrounds.

In this exercise let’s discuss an example of comparison of performances of two (slightly) different vertexing algorithms having the aim to reject background (while preserving signal) on the basis of simulated data of signal and backgrounds.
We perform it in the framework of the theory of binary classification.
Practically we will use two different test statistics to discriminate ***signal*** from (2 types of) background:



PHYSICS CASE - II

Practically we will use to different test statistics to discriminate ***signal*** from (2 types of) background:



Final state's signature

4 "prompt" leptons	2 "prompt" +2 "non-prompt" leptons	4 "non-prompt" leptons

We'll investigate the background rejection power of two variables based (in a different way)

… on the displacement of leptons from the primary vertex

TYPICAL INSTALLATION

In this exercise we build a ROC CURVE associated to the variable we want exploit to discriminate signal from backgrounds

Installation

```
!pip install -q condacolab
import condacolab
condacolab.install()
```

```
✨🍰✨ Everything looks OK!
```

```
!conda create -n SDAL python=3.10 -y
!source /usr/local/etc/profile.d/conda.sh && conda activate SDAL

!conda install -c conda-forge root=6.28.10 -y

import os
os.environ["PATH"] = "/usr/local/envs/SDAL/bin:" + os.environ["PATH"]
os.environ["PYTHONPATH"] = "/usr/local/envs/SDAL/lib/python3.10/site-packages"
```

FILES TO IMPORT

We download 3 files (with the 3 simulated data samples, 1 for the signal and 2 for the two backgrounds):

```
# Step 1: Download the Signal H->ZZ->2e2m (mass=150GeV) ROOT file
!wget --no-check-certificate 'https://docs.google.com/uc?export=download&id=1qz0j5-2edlphKObMstg_b48hoS_JJtg3' -O H150_ZZ_4l_10TeV_GEN_HLT_Presel_glb_2e2mu_2e2mu_merged.root

# Step 2: Download the BKG ttbar ROOT file
!wget --no-check-certificate 'https://docs.google.com/uc?export=download&id=10ozujuBRsGJlWBlCH9Kj3SoXpOX3EQoT' -O TT_4l_10TeV_Presel_4l_2e2mu_merged.root

# Step 2: Download the BKG Zbbar->2lbbar ROOT file
!wget --no-check-certificate 'https://docs.google.com/uc?export=download&id=1hGHbEZFDy8a4IOeFCDhSmXXDwiJRuxHX' -O LLBB_4l_10TeV_Presel_4l_2e2mu_merged.root
```

STORAGE MODALITY

```
# MODE options:
# "temp":      use temporary /content space, move .root files to temp data_dir
# "drive_cp":  use Google Drive, copy .root files into Drive
# "drive_use": use Google Drive, assume files already exist there

MODE = "drive_cp"  # ← change to "temp" or "drive_use" if needed

number = 9   # exercise label

import os
if MODE.startswith("drive"):
    from google.colab import drive
    drive.mount('/content/drive/')
    base = "/content/drive/My Drive/Colab Notebooks/"
    data_dir = f"{base}exercise_{number}/"
    plot_dir = f"{base}exercise_{number}/Plots/"
else:
    data_dir = f"/content/exercise_{number}/"
    plot_dir = f"/content/exercise_{number}/Plots/"

os.makedirs(data_dir, exist_ok=True)
os.makedirs(plot_dir, exist_ok=True)

if MODE == "drive_cp":
    !cp *.root "$data_dir"
elif MODE == "temp":
    if any(fname.endswith(".root") for fname in os.listdir()):
        !cp *.root "$data_dir"

if not any(fname.endswith(".root") for fname in os.listdir(data_dir)):
    print("No ROOT files found.")
```

3 modalities to store files (simulated data)

Installing ROOT & configuring - I

```python
import ROOT
from datetime import datetime
from array import array
from ROOT import gROOT

date = datetime.now().strftime("%Y-%m-%d")
```

```python
# -- historically we had many variables
# var1==AllLeptIP3D, Ele(Mu)IP_best(worst), Ele(Mu)SLIP_best(worst), Ele(Mu)STIP_best(worst), LeptIP3D_worst, LeptSTIP_SLIP_worst, etc.
# var2=="", AllLeptIP3D, Ele(Mu)IP_best(worst), Ele(Mu)SLIP_best(worst), Ele(Mu)STIP_best(worst), LeptIP3D_worst, LeptSTIP_SLIP_worst, etc.
# -- the one we compare here are: var1=LeptIP3D_worst, var2=LeptSTIP_SLIP_worst

#ROOT.gROOT.Reset()
#ROOT.gROOT.Clear()

# configuring graphics style
ROOT.gStyle.SetCanvasColor(0)
ROOT.gStyle.SetPadColor(0)
# ROOT.gStyle.SetHistFillColor(0)
# ROOT.gStyle.SetHistLineStyle(1)
# ROOT.gStyle.SetHistLineWidth(1)
# ROOT.gStyle.SetHistLineColor(1)
ROOT.gStyle.SetTitleXOffset(0.9)
ROOT.gStyle.SetTitleYOffset(1.15)
# ROOT.gStyle.SetOptStat(1110)
# ROOT.gStyle.SetOptStat(kFALSE)
ROOT.gStyle.SetOptFit(111)  # In ROOT, 0111 is valid (octal), but in Python, leading zeros are not allowed in decimal numbers.
ROOT.gStyle.SetStatH(0.1)
ROOT.gStyle.SetPadTopMargin(0.09)
ROOT.gStyle.SetPadBottomMargin(0.13)
ROOT.gStyle.SetPadLeftMargin(0.12)
ROOT.gStyle.SetPadRightMargin(0.10)
ROOT.gStyle.SetPadTickX(1)  # To get tick marks on the opposite side of the frame
ROOT.gStyle.SetPadTickY(1)
ROOT.gStyle.SetOptTitle(1)
ROOT.gStyle.SetStatFont(42)
ROOT.gStyle.SetTitleFont(42)
ROOT.gStyle.SetTitleSize(1)

ROOT.gROOT.SetStyle("Plain")  # change of style
ROOT.gStyle.SetNdivisions(10)
ROOT.gStyle.SetCanvasBorderMode(0)
ROOT.gStyle.SetPadBorderMode(0)
# ROOT.gStyle.SetOptLogy(0)

#ROOT.gROOT.ForceStyle()  # force style to be applied
```

```
Welcome to JupyROOT 6.28/10
```

Installing ROOT & configuring - II

```
# opening files in READ mode:
f = [ROOT.TFile(f"{data_dir}H150_ZZ_4l_10TeV_GEN_HLT_Presel_glb_2e2mu_2e2mu_merged.root", "READ"),  # Signal H->ZZ->2e2m (mass=150GeV)
     ROOT.TFile(f"{data_dir}TT_4l_10TeV_Presel_4l_2e2mu_merged.root", "READ"),                      # BKG ttbar
     ROOT.TFile(f"{data_dir}LLBB_4l_10TeV_Presel_4l_2e2mu_merged.root", "READ")]                    # BKG Zbbar->2lbbar

# Define TGraph variables for the signal vs background comparison
gr_h150_TT_vtx = ROOT.TGraph()   # signal vs tt for var1
gr_h150_Zbb_vtx = ROOT.TGraph()  # signal vs Zbb for var1

gr_h150_TT_wrkgPt = ROOT.TGraph()

gr_h150_TT_var2 = ROOT.TGraph()    # signal vs tt for var2
gr_h150_Zbb_var2 = ROOT.TGraph()   # signal vs Zbb for var2
```

TGraph objects to be used later

array of files, in the order: 1) Signal MC (Higgs with $m(H) \equiv 150\, GeV/c^2$)

2) $t\bar{t}$ Bkg MC

3) $Zb\bar{b}$ Bkg MC ($Z \to \ell\bar{\ell}$)

[all characterized by $E_{cms} = \sqrt{s} \equiv 10 TeV$]

DISCRIMINANT VARIABLES

We use two test statistics, denoted in the code as:

```
var1 = "LeptIP3D_worst"
```

```
var2 = "LeptSTIP_SLIP_worst"
```

The exercise aims to compare the performance of these two physical observables in rejecting some background while preserving most of signal by applying a cut.

In the next slides we introduce the meaning of these two variables to understand why they are useful to reject backgrounds.

1st discriminant variable - I

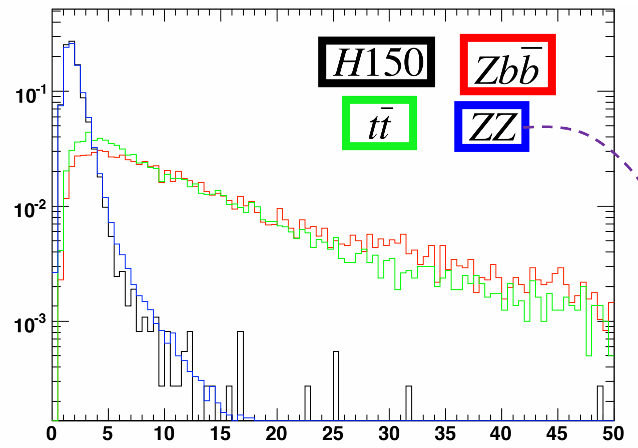
Algorithm: var1 (`LeptIP3D_worst`)

Three-dimensional (IP_{3D}) distance - from the Primary Vertex (PV) - of the point of closest approach to PV for the "back propagated" lepton track is calculated. [Propagators are specific for muons & electrons].

Significance (SIP_{3D}) is obtained by dividing IP_{3D} for the relative uncertainty (by full error computation):

$$SIP_{3D} = \frac{IP_{3D}}{\sigma(IP_{3D})}$$

Normalized SIP_{3D} for the worst lepton (e/μ)

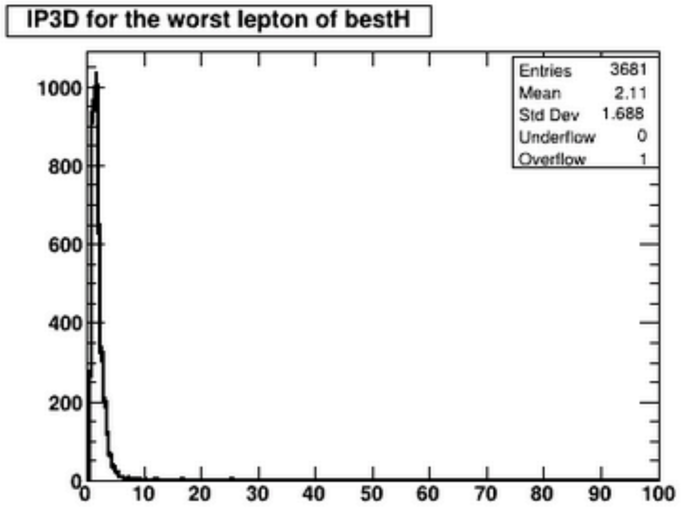


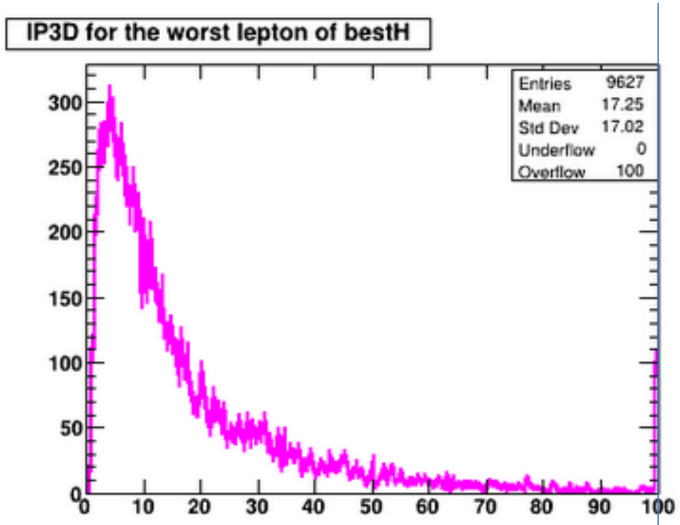
In $Zb\bar{b}$, $t\bar{t}$ and generic multi-jet background events the impact parameters of 2 or 4 leptons (in generic 4-leptons final state) are - in average - naturally larger w.r.t. those of signal.

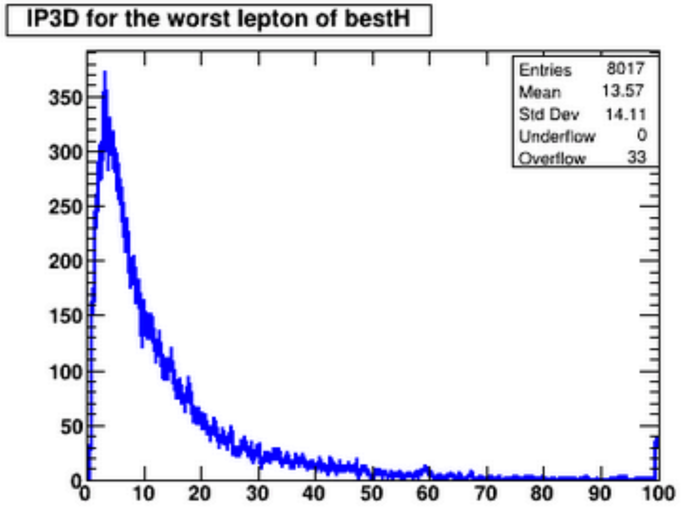
Incoherent $H \to ZZ^{(*)}$ bkg; indistinguishable from signal since it has exactly the same topology the two Z promptly decaying into 2 leptons (cannot be reduced with vertexing or isolation-based variables)

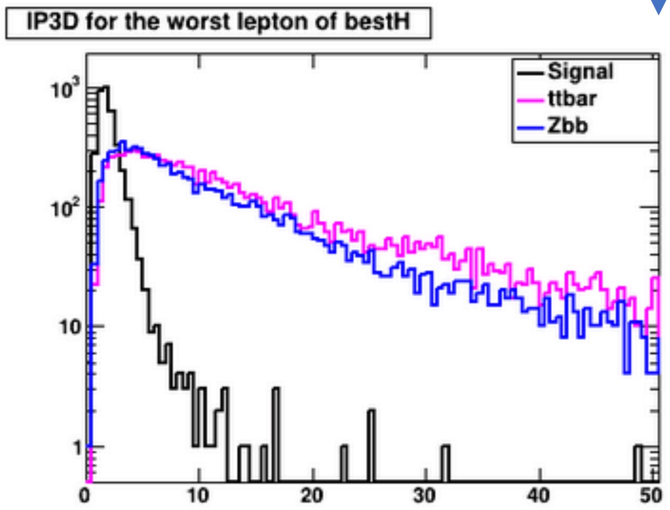
1st discriminant variable - II

The code will produce this kind of plots:









2^{nd} discriminant variable - I

Algorithm: var2 (LeptSTIP_SLIP_worst)

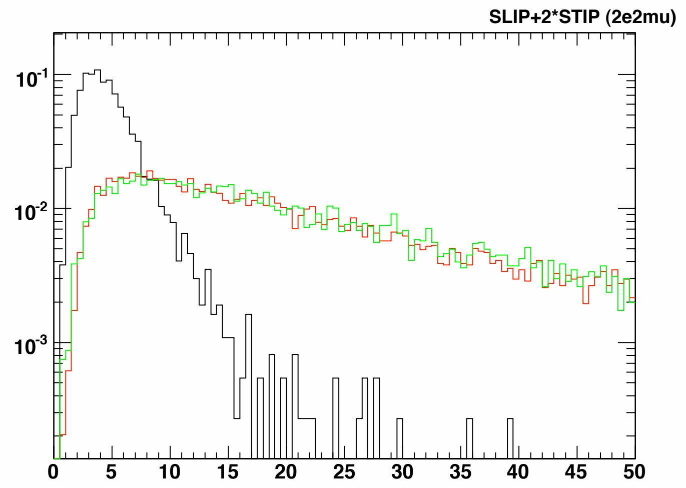
Transverse (TIP) and longitudinal (LIP) distances - from PV - of lepton track, "back-propagated" w.r.t. to PV, are calculated.

[Propagators are specific for muons & electrons].

Significances (STIP, SLIP) are taken by dividing them for the relative uncertainty (by full error computation - correlation included).

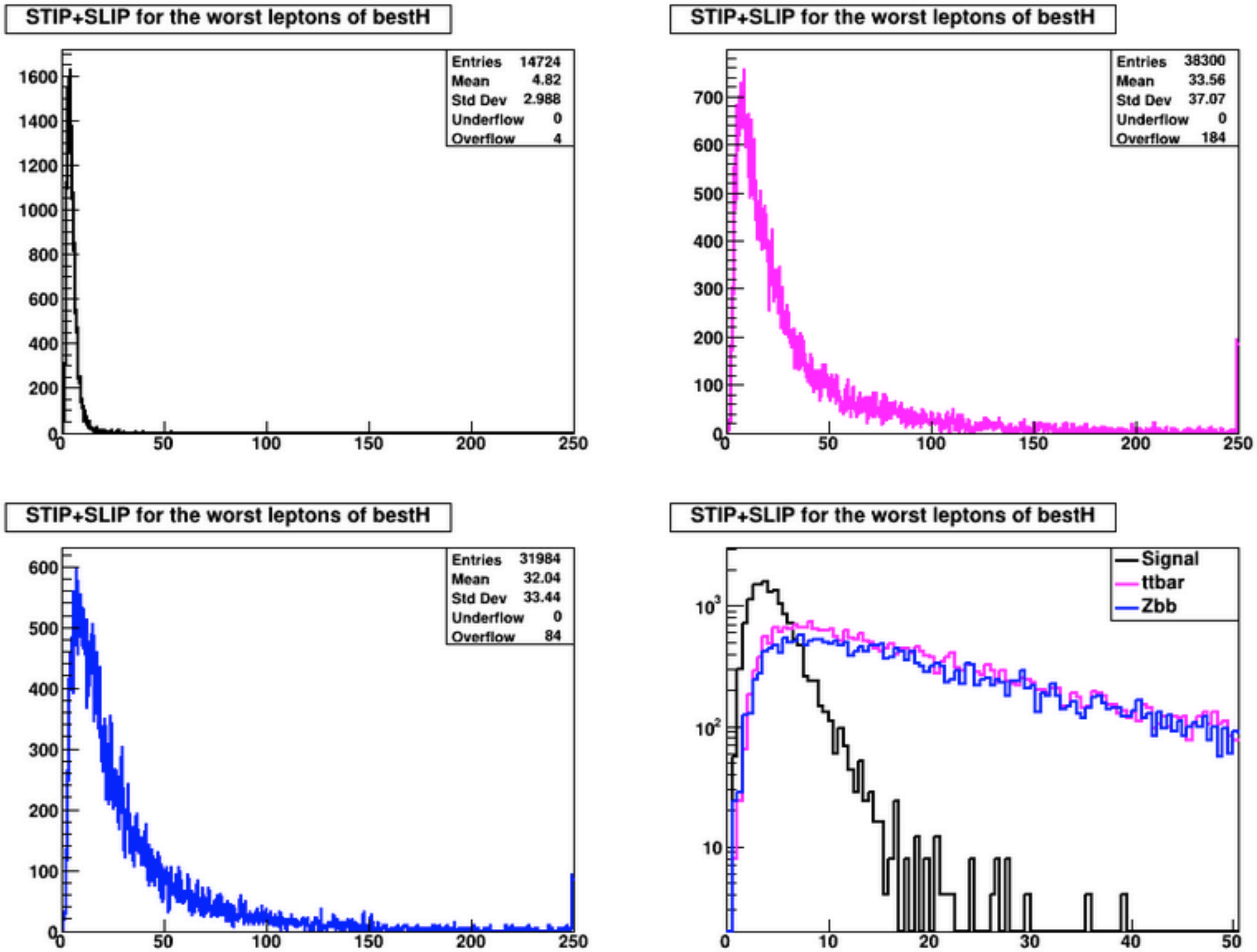
The discriminating observable used here is the following suitable weighted combination of SLIP and STIP:

$$SLIP(4^{th}\,\ell) + 2 * \left[STIP(\ell^+) + STIP(\ell^-) \right] \quad \text{where} \quad \ell^+,\ \ell^- \text{ are from } Z^*$$



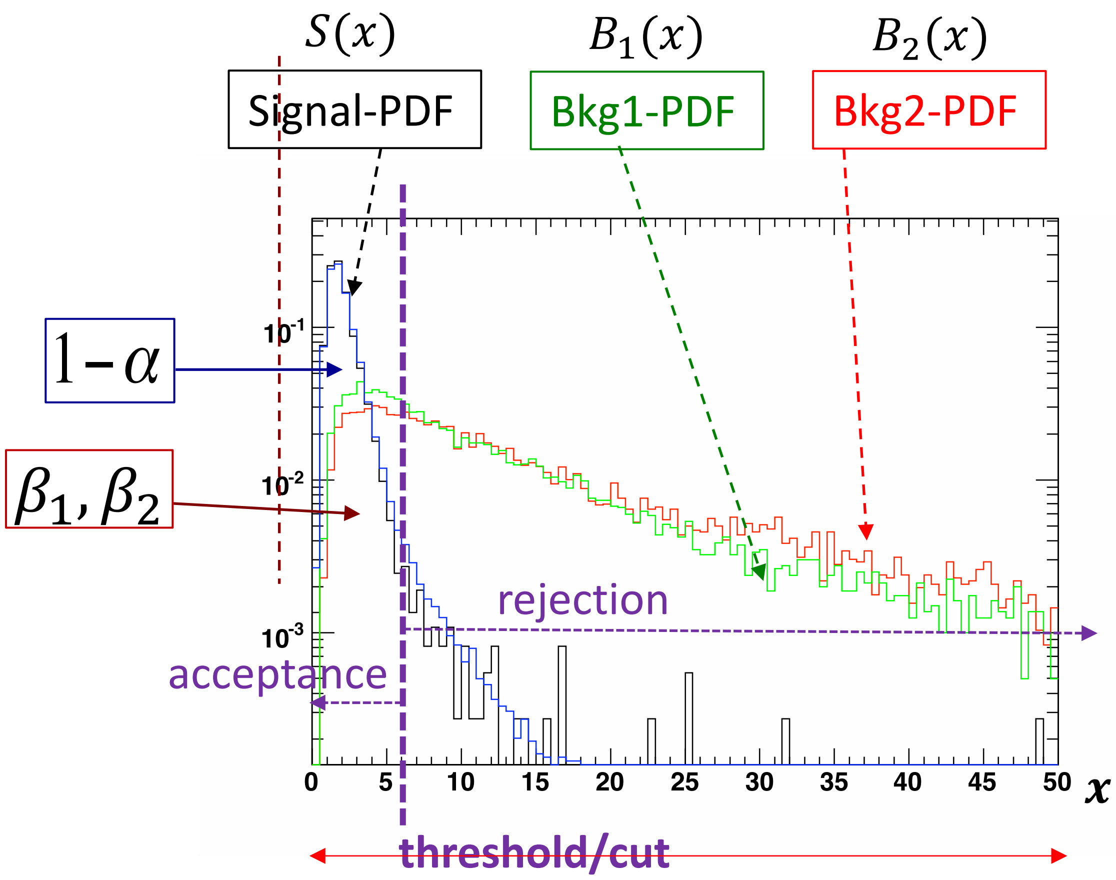
The idea is that the leptons from b-quarks (having tipically higher STIP value) in both relevant backgrounds events - tend likely to mimic the 2 leptons involved in the Z* reconstruction.

2nd discriminant variable - II



Signal-to-background discrimination

The idea (implemented in the code that we will look into in detail in a bit) is the following:



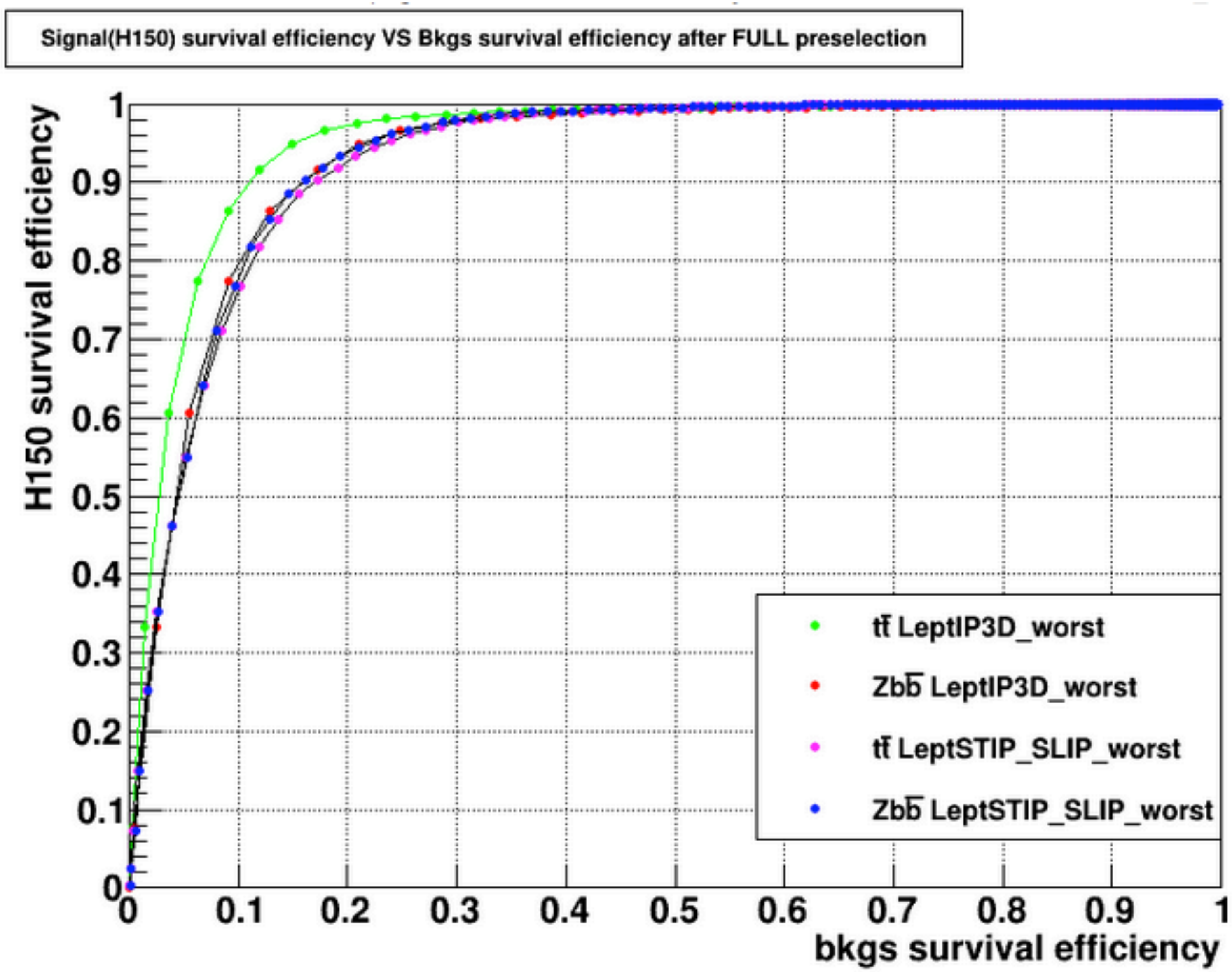
Treat the normalized to unity histogram as an effective p.d.f.;
(normalization is obtained by dividing by the full integral)

$$1-\alpha = 1 - \int_{x_{cut}}^{\infty} S(x)dx$$ ***signal efficiency***

$$\beta_{1,2} = \int_{0}^{x_{cut}} B_{1,2}(x)dx$$ ***backgrounds' contamination***

Vary the cut from 0 to end-of-scale, moving it with a step-size equal to the granularity of the available histogram, and write down the pairs of integral values, $(1-\alpha, \beta_1)$ and $(1-\alpha, \beta_2)$, and plot them on a graph obtaining two ROC curves.

Results: comparison of the ROC curves



The 4 ROC curves are superimposed but the performance comparison of the two algorithms must be done for the same background type:

	var1	var2
- for $t\bar{t}$:	green	vs pink
- for $Zb\bar{b}$:	red	vs blue

var1 is better than var2

var1 and var2 perform similarly

Quantitatively we'll calculate AUC (*Area-Under-the-Curve*):

Comparison	AUC
$t\bar{t}$ vs H150 (LeptIP3D_worst)	0.952161
$Z\bar{b}b$ vs H150 (LeptIP3D_worst)	0.931232
$t\bar{t}$ vs H150 (LeptSTIP_SLIP_worst)	0.928861
$Z\bar{b}b$ vs H150 (LeptSTIP_SLIP_worst)	0.931054

Overall var1 performs better than var2!

1^{st} discriminant variable (code) - I

```python
#-- 1ST VARIABLE [LeptIP3D_worst]
# Define histograms
hVar1 = [ROOT.TH1D() for _ in range(3)]
hVar1Ratio = [ROOT.TH1D() for _ in range(3)]

# Define arrays for integrals and efficiency
TotIntegral1 = [0.0] * 3
PartIntegral1 = [0.0] * 3
Eff1 = [0.0] * 3
IntegralCounts1 = [[0] * 500 for _ in range(3)]  # keep the matrix large for possible rebinning (we will use 200 bins by default)

# Histogram name array
histoname = [''] * 128

# Dummy initialization for nBins1
nBins1 = 200

var1 = "LeptIP3D_worst"

for i in range(3):
    hVar1[i] = f[i].Get(f"h{var1}")

    # ---------- Integrals
    nBins1 = hVar1[i].GetNbinsX()
    print(f"# of bins of hVar1 = {nBins1}")  # by default they are 200

    TotIntegral1[i] = hVar1[i].Integral(1, 201)  # that's why the total integral is obtained integrating over 200 bins

    # Creating histogram for the ratio
    histoname[i] = f"hVarRatio[{i}]"
    hVar1Ratio[i] = ROOT.TH1D(histoname[i], "Partial integral over total", 200, 0., 1.)

    for j in range(1, nBins1 + 1):                     # this is a nested loop
        PartIntegral1[i] = hVar1[i].Integral(1, j)     # partial integral from bin 1 to bin j (till reaching the bin 200))
        Eff1[i] = PartIntegral1[i] / TotIntegral1[i]   # in the j-loop this is a partial ratio updated at each j value
        IntegralCounts1[i][j - 1] = Eff1[i]            # that's why we save it in a ixj matrix and in the following histogram:

        hVar1Ratio[i].Fill(Eff1[i])  # which is not extremely relevant since it saturates to 1 and for the signal it does it very quickly!
```

range(#) --> start from 0 till #-1

Note: in Python loop goes from 0 to #-1 (in C^{++} from 1 to #)

double (nested) loops

matrix 3x200

Integrals: $\begin{cases} i = 0: 1-\alpha \\ i = 1: \beta_1 \\ i = 2: \beta_2 \end{cases}$

1^{st} discriminant variable (code) - II

```python
# configure properly a function to plot with the right stat-box

def add_stats_box(histogram, pad, x1=0.7, y1=0.7, x2=0.9, y2=0.9):
    pad.cd()

    histogram.SetStats(True)

    # Draw with error bars (auto-creates the stats box on the specified pad)
    histogram.Draw("Ehist")
    pad.Update()

    # Grab ROOT's built-in TPaveStats (named "stats")
    stats = histogram.FindObject("stats")

    if stats and isinstance(stats, ROOT.TPaveStats):
        # Re-positioning
        stats.SetX1NDC(x1); stats.SetY1NDC(y1)
        stats.SetX2NDC(x2); stats.SetY2NDC(y2)
        stats.SetOptStat(111110)

        stats.SetTextSize(0.035)
        stats.SetBorderSize(1)
        stats.SetMargin(0.12)
        stats.Draw()
    else:
        print(f"Warning: stats box not found for {histogram.GetName()}")

    pad.Modified()
    pad.Update()
```

passed through interface

Built-in function `isinstance(obj,Class)` that returns a boolean:

- TRUE if `obj` is an instance of `Class` (or its subclass)
- FALSE otherwise

Here it checks that the object we get from `FindObject` (i.e. `stats`) is indeed a TPaveStats object before calling its methods to prevent a crash if it is not.

1st discriminant variable (code) - III

```
# Create the canvas
MyC = ROOT.TCanvas("MyC", "Plots", 900, 700)

# Divide the canvas into 2x2 grid
MyC.Divide(2, 2)
```

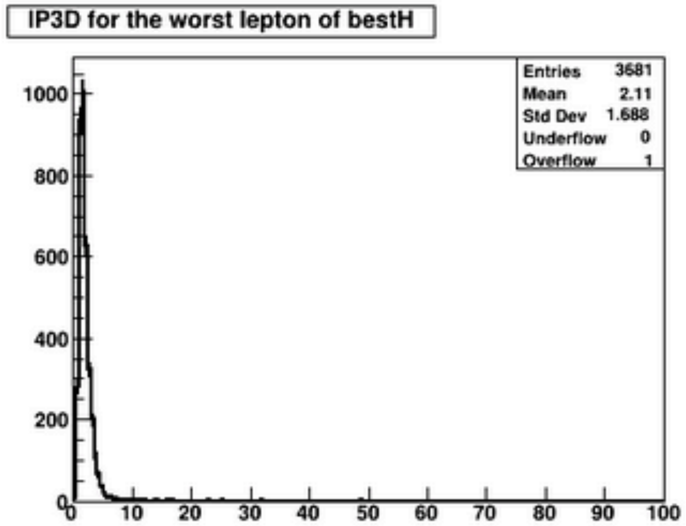
configure for 4 pads (and 4 plots)

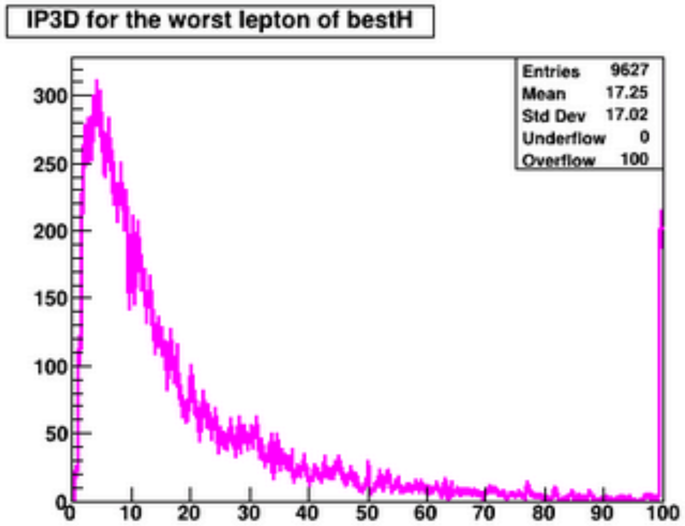
```
# first pad
pad1 = MyC.cd(1)
hVar1[0].SetFillColor(0) # Set fill color to transparent
hVar1[0].SetLineWidth(2)
#hVar1[0].SetAxisRange(0., 50., "X") # Set X-axis range for zoom
add_stats_box(hVar1[0], pad1)    # calling the fucntion here


# second pad
pad2 = MyC.cd(2)
ovflw_bkg1 = hVar1[1].GetBinContent(nBins1 + 1) # Get the overflow bin content
hVar1[1].AddBinContent(nBins1, ovflw_bkg1) # Add overflow content to the last visible bin
hVar1[1].SetLineColor(6) # Set line color (6 corresponds to magenta)
hVar1[1].SetLineWidth(2)
add_stats_box(hVar1[1], pad2)   # calling the function here
# third pad
pad3 = MyC.cd(3)
ovflw_bkg2 = hVar1[2].GetBinContent(nBins1 + 1)
hVar1[2].AddBinContent(nBins1, ovflw_bkg2)
hVar1[2].SetLineColor(4) # Set line color (4 corresponds to blue)
hVar1[2].SetLineWidth(2)
add_stats_box(hVar1[2], pad3)    # calling the function here

# 4. Pad: Overlaying All Histograms with Log Scale
# Clone histograms to preserve the original ones

hVar1_clone = [h.Clone(f"{h.GetName()}_clone") for h in hVar1]

pad4 = MyC.cd(4)
pad4.SetLogy()
```

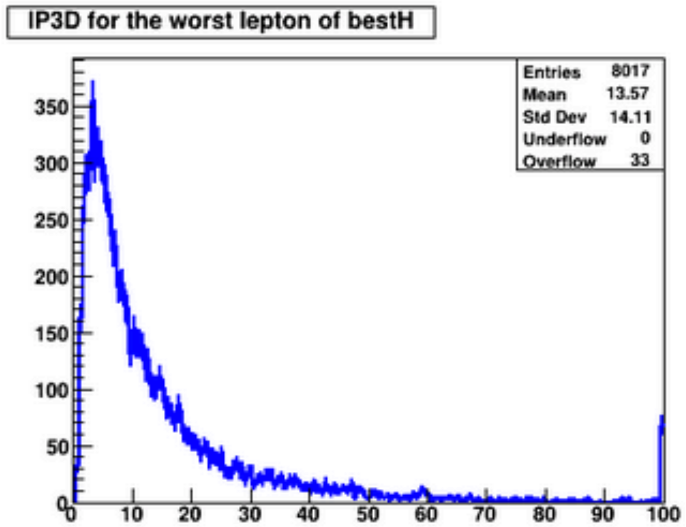
```
# Configure and draw the cloned histograms without stats boxes
hVar1_clone[0].SetStats(False)
hVar1_clone[0].SetLineWidth(2)
hVar1_clone[0].SetAxisRange(0., 50., "X") # Set X-axis range for zoom
hVar1_clone[0].Draw()

hVar1_clone[1].SetStats(False)
hVar1_clone[1].SetLineWidth(2)
hVar1_clone[1].Draw("same")

hVar1_clone[2].SetStats(False)
hVar1_clone[2].SetLineWidth(2)
hVar1_clone[2].Draw("same")

# Create and configure the legend (optinal)
legend = ROOT.TLegend(0.7, 0.75, 0.9, 0.9)
legend.AddEntry(hVar1_clone[0], "Signal", "l")
legend.AddEntry(hVar1_clone[1], "ttbar", "l")
legend.AddEntry(hVar1_clone[2], "Zbb", "l")
legend.Draw()

MyC.Update()

MyC.Draw()
MyC.SaveAs(f"{plot_dir}Histo{var1}_{date}.png")
```

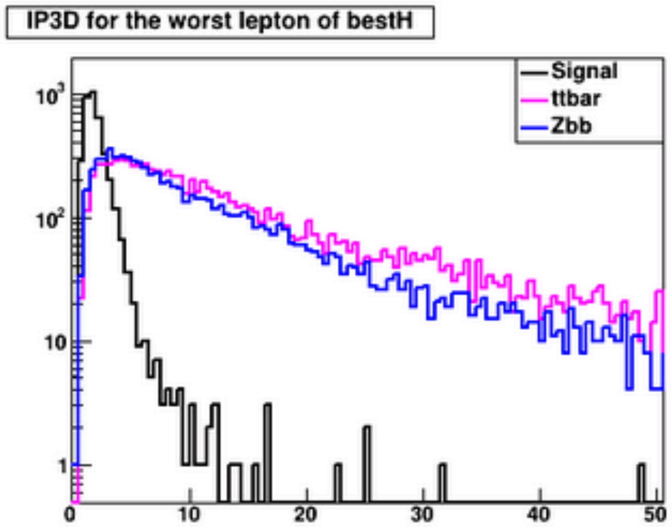
1^{st} discriminant variable (code) - IV

Info in <TCanvas::Print>: png file /content/drive/My Drive/Colab Notebooks/exercise_9/Plots/HistoLeptIP3D_worst_2025-05-03.png has been created









just superimposed

2nd discriminant variable (code) - I

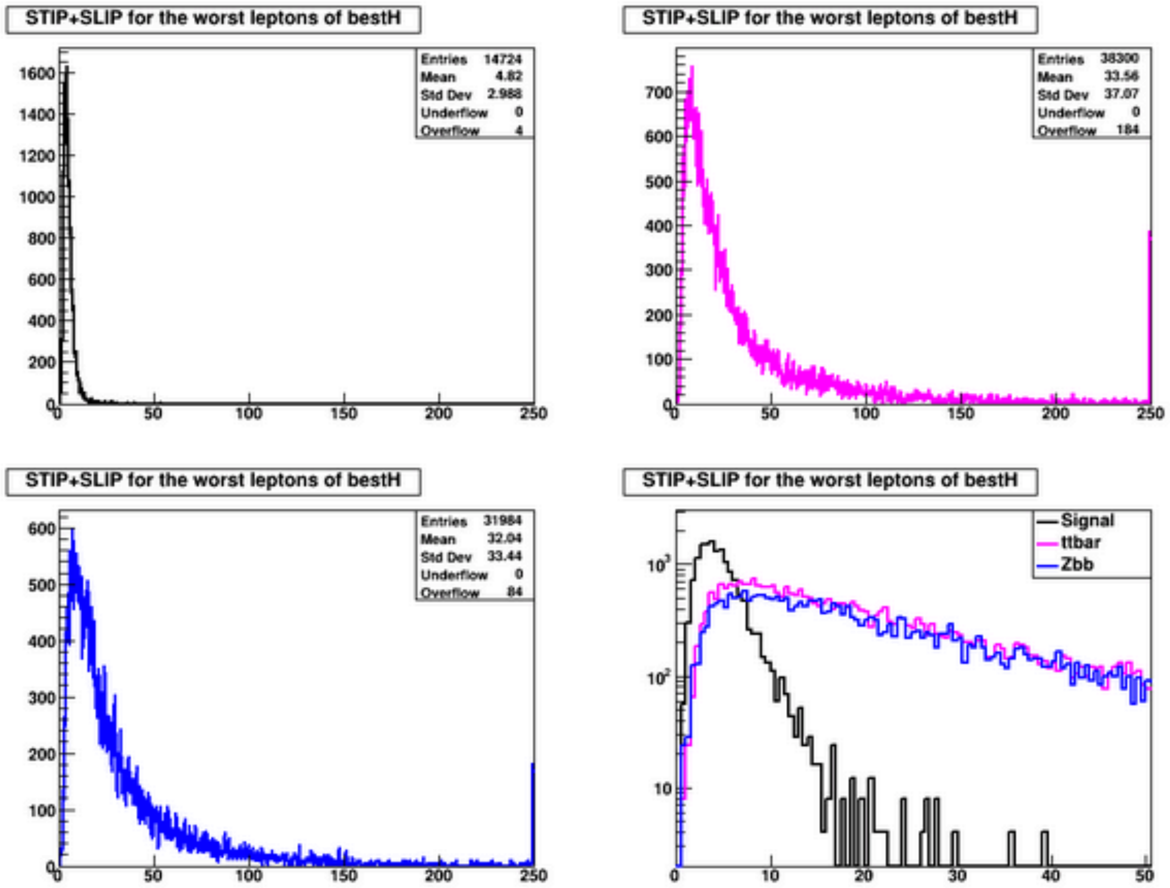
Same logic applied for var2

```
# do the same for VARIABLE-2
var2 = "LeptSTIP_SLIP_worst"

hVar2 = [ROOT.TH1D() for _ in range(3)]
hVar2Ratio = [ROOT.TH1D() for _ in range(3)]

TotIntegral2 = [0.0] * 3
PartIntegral2 = [0.0] * 3
Eff2 = [0.0] * 3
IntegralCounts2 = [[0] * 500 for _ in range(3)]  # keep matrix large for possible rebinning

histoname2 = [''] * 128

nBins2 = 100 #just a dummy inizialization

for i in range(3):
    hVar2[i] = f[i].Get(f"h{var2}")

    #  Integrals
    nBins2 = hVar2[i].GetNbinsX()
    print(f"# of bins of hVar2 = {nBins2}")  # by default they are 500
    #
    TotIntegral2[i] = hVar2[i].Integral(1, 501)  # that's why the total integral is obtained integrating over 500 bins
    #
    histoname2 = f"hVar2Ratio[{i}]"
    hVar2Ratio[i] = ROOT.TH1D(histoname2, "Partial integral over total", 500, 0., 1.)
    #
    for j in range(1, nBins2 + 1):
        PartIntegral2[i] = hVar2[i].Integral(1, j)  # partial integral from bin 1 to bin j (till reaching the bin 200))
        Eff2[i] = PartIntegral2[i] / TotIntegral2[i]  # in the j-loop this is a partial ratio updated at each j value
        IntegralCounts2[i][j - 1] = Eff2[i]           # that's why we save it in a ixj matrix and in the following histogram:

        hVar2Ratio[i].Fill(Eff2[i])  # which is not extremely relevant since it saturates to 1 and for the signal this happens very quickly!
```

2^{nd} discriminant variable (code) - II

```python
MyC.Clear()

MyC.Divide(2, 2)

# 1. Pad - Signal (hVar2[0])
pad1_hVar2 = MyC.cd(1)
hVar2[0].SetFillColor(0)
hVar2[0].SetLineWidth(2)
#hVar2[0].SetAxisRange(0., 50., "X")
add_stats_box(hVar2[0], pad1_hVar2)

# 2. Pad - TTbar (hVar2[1])
pad2_hVar2 = MyC.cd(2)
ovflw_bkg21 = hVar2[1].GetBinContent(nBins2 + 1)
hVar2[1].AddBinContent(nBins2, ovflw_bkg21)
hVar2[1].SetLineColor(6)
hVar2[1].SetLineWidth(2)
add_stats_box(hVar2[1], pad2_hVar2)

# 3. Pad - Zbb (hVar2[2])
pad3_hVar2 = MyC.cd(3)
ovflw_bkg22 = hVar2[2].GetBinContent(nBins2 + 1)
hVar2[2].AddBinContent(nBins2, ovflw_bkg22)
hVar2[2].SetLineColor(4)
hVar2[2].SetLineWidth(2)
add_stats_box(hVar2[2], pad3_hVar2)

# 4. Pad -  now superimpose the 3 components
pad4_hVar2 = MyC.cd(4)
pad4_hVar2.cd()
pad4_hVar2.SetLogy()

hVar2_clone = [h.Clone(f"{h.GetName()}_clone") for h in hVar2]

hVar2_clone[0].SetStats(False)
hVar2_clone[0].SetLineWidth(2)
hVar2_clone[0].SetAxisRange(0., 50., "X")
hVar2_clone[0].Draw()

hVar2_clone[1].SetStats(False)
hVar2_clone[1].SetLineWidth(2)
hVar2_clone[1].Draw("same")

hVar2_clone[2].SetStats(False)
hVar2_clone[2].SetLineWidth(2)
hVar2_clone[2].Draw("same")

legend = ROOT.TLegend(0.7, 0.75, 0.9, 0.9)
legend.AddEntry(hVar2_clone[0], "Signal", "l")
legend.AddEntry(hVar2_clone[1], "ttbar", "l")
legend.AddEntry(hVar2_clone[2], "Zbb", "l")
legend.Draw()

pad4_hVar2.Update()

MyC.SaveAs(f"{plot_dir}Histo_{var2}_{date}.png")

MyC.Draw()
```

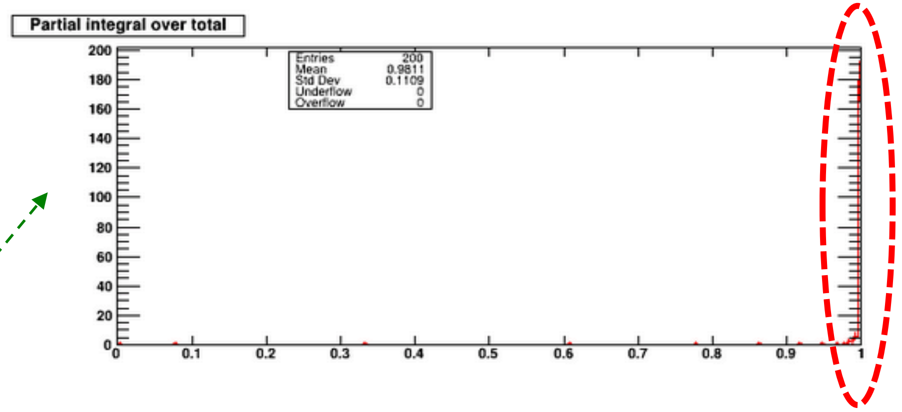
```
Info in <TCanvas::Print>: png file /content/drive/My Drive/Colab Notebooks/exercise_9/Plots/Histo_LeptSTIP_SLIP_worst_2025-05-03.png has been created
```

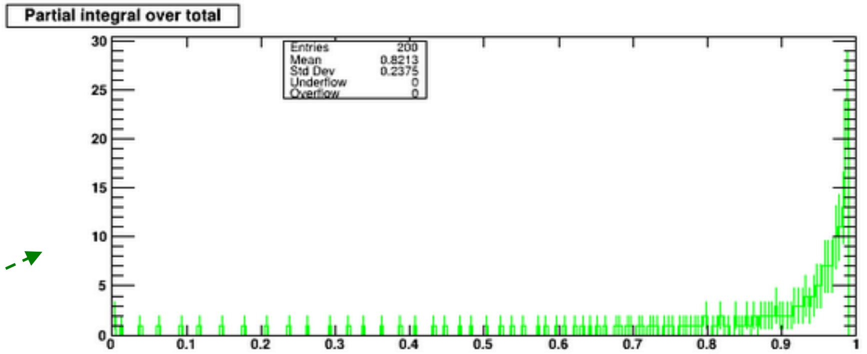


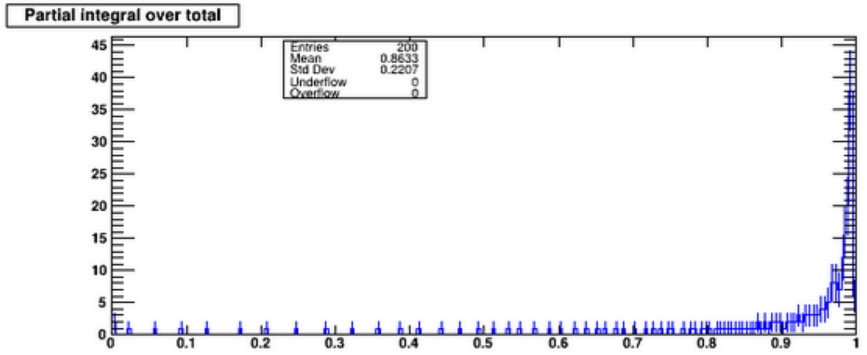
just superimposed

2nd discriminant variable - III

```python
# Now draw ratios  PartIntegral[i]/TotIntegral[i]
# but not extremely relevant since they saturate to 1 and for the signal this happens very quickly!
#
def add_legend_label_strict(pad, label, x1=0.1, y1=0.8, x2=0.2, y2=0.9):
    pad.cd()
    legend = ROOT.TLegend(x1, y1, x2, y2)
    legend.SetFillColor(0)
    legend.SetTextSize(0.05)
    legend.AddEntry("", label, "")
    legend.Draw()
    pad.Update()

canvas_integral = ROOT.TCanvas("Integral_Ratios", "Integral Ratios", 700, 900)

canvas_integral.SetGridx(True)
canvas_integral.SetGridy(True)
canvas_integral.Divide(0, 3)

stat_box_x1 = 0.30
stat_box_y1 = 0.75
stat_box_x2 = 0.45
stat_box_y2 = 0.90

# Pad 1
padR1 = canvas_integral.cd(1)
hVar1Ratio[0].SetLineColor(2)
add_stats_box(hVar1Ratio[0], padR1, stat_box_x1, stat_box_y1, stat_box_x2, stat_box_y2)
#hVar1Ratio[0].SetTitle("Signal")
add_legend_label_strict(padR1, "signal")

# Pad 2
padR2 = canvas_integral.cd(2)
hVar1Ratio[1].SetLineColor(3)
add_stats_box(hVar1Ratio[1], padR2, stat_box_x1, stat_box_y1, stat_box_x2, stat_box_y2)
#hVar1Ratio[1].SetTitle("t#bar{t}")
add_legend_label_strict(padR2,"t#bar{t}")

# Pad 3
padR3 = canvas_integral.cd(3)
hVar1Ratio[2].SetLineColor(4)
add_stats_box(hVar1Ratio[2], padR3, stat_box_x1, stat_box_y1, stat_box_x2, stat_box_y2)
#hVar1Ratio[2].SetTitle("Zb#bar{b}")
add_legend_label_strict(padR3, "Zb#bar{b}")

canvas_integral.Update()
canvas_integral.Draw()
canvas_integral.SaveAs(f"{plot_dir}Integral-over-Total_{var1}_{date}.png")
```







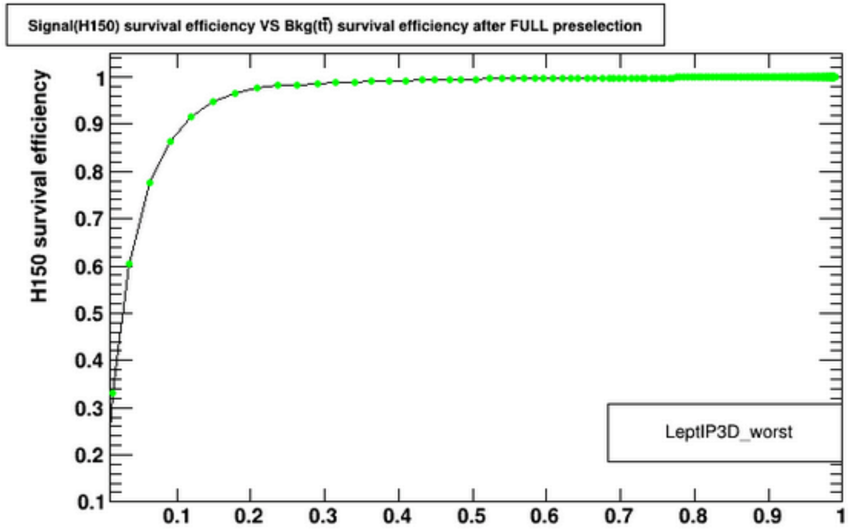
ROC curves for 1st discriminant variable (code) - I

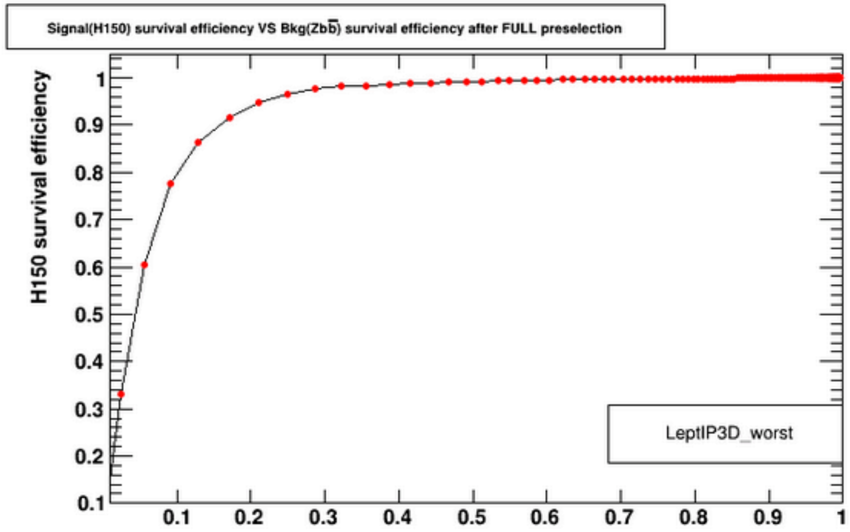
```
# Draw ROC curve for each bkg - 1 VARIABLE

canvas_scatter = ROOT.TCanvas("scatter_canvas", "Canvas Scatter", 700, 900)
# VARIABLE-1 vs Bkgs scatter plots
canvas_scatter.Divide(0, 2)
canvas_scatter.SetGridx()
canvas_scatter.SetGridy()


# Pad 1: H150 vs t#bar{t}
scat_pad_1 = canvas_scatter.cd(1)
hframe1 = ROOT.TH2F(
    "hframe1",
    "Signal(H150) efficiency VS Bkg(t#bar{t}) survival prob. after FULL preselection",
    100, 0.01, 1.0, 100, 0.1, 1.05
)
hframe1.SetStats(False)

hframe1.Draw()
hframe1.SetYTitle("H150 efficiency")
hframe1.SetXTitle("t#bar{t} survival efficiency")
#hframe1.GetXaxis().SetNdivisions(505)

x_tt = array('d', IntegralCounts1[1][:nBins1])
y_tt = array('d', IntegralCounts1[0][:nBins1])
gr_h150_TT_vtx = ROOT.TGraph(nBins1, x_tt, y_tt)
gr_h150_TT_vtx.SetMarkerColor(3)
gr_h150_TT_vtx.SetMarkerSize(0.6)
gr_h150_TT_vtx.SetMarkerStyle(20)
gr_h150_TT_vtx.Draw("LP")

txt1 = ROOT.TLegend(0.65, 0.2, 0.9, 0.3)
txt1.SetTextFont(42)
txt1.SetFillColor(0)
txt1.SetTextSize(0.035)
txt1.AddEntry("", var1, "")
txt1.Draw()
```

```
# Pad 2: H150 vs Zb#bar{b}
scat_pad_2 = canvas_scatter.cd(2)
hframe2 = ROOT.TH2F(
    "hframe2",
    "Signal(H150) efficiency VS Bkg(Zb#bar{b}) survival prob. after FULL preselection",
    100, 0.01, 1.0, 100, 0.1, 1.05
)
hframe2.SetStats(False)
hframe2.Draw()
hframe2.SetYTitle("H150 efficiency")
hframe2.SetXTitle("Zb#bar{b} survival efficiency")

x_zbb = array('d', IntegralCounts1[2][:nBins1])
y_zbb = array('d', IntegralCounts1[0][:nBins1])
gr_h150_Zbb_vtx = ROOT.TGraph(nBins1, x_zbb, y_zbb)
gr_h150_Zbb_vtx.SetMarkerColor(2)
gr_h150_Zbb_vtx.SetMarkerSize(0.6)
gr_h150_Zbb_vtx.SetMarkerStyle(20)
gr_h150_Zbb_vtx.Draw("LP")

txt2 = ROOT.TLegend(0.65, 0.2, 0.9, 0.3)
txt2.SetTextFont(42)
txt2.SetFillColor(0)
txt2.SetTextSize(0.035)
txt2.AddEntry("", var1, "")
txt2.Draw()

canvas_scatter.Update()
canvas_scatter.Draw()
canvas_scatter.SaveAs(f"{plot_dir}scatt-effic_H150-vsBkgs_{var1}_{date}.png")
canvas_scatter.Clear()
canvas_scatter.Close()
```

ROC curves for 1st discriminant variable (code) - II

Info in <TCanvas::Print>: png file /content/drive/My Drive/Colab Notebooks/exercise_9/Plots/scatt-effic_H150-vsBkgs_LeptIP3D_worst_2025-05-03.png has been created





AUC for 1st discriminant variable (code) - II

```
# First, define a helper to pad the ROC endpoints to (0,0) and (1,1).

import numpy as np

def closed_curve(x, y):
    #Pad the ROC curve with (0,0) and (1,1) so the trapezoidal integration
    #covers the full [0,1] range of background vs. signal efficiencies.
    x_full = np.concatenate(([0.0], x, [1.0]))
    y_full = np.concatenate(([0.0], y, [1.0]))
    return x_full, y_full

# Use closed_curve to prepare the full ROC arrays
x_tt_full_var1,  y_tt_full_var1  = closed_curve(x_tt,  y_tt)
x_zbb_full_var1, y_zbb_full_var1 = closed_curve(x_zbb, y_zbb)

# Then compute the AUC via numpy.trapezoid
auc_tt_var1  = np.trapezoid(y_tt_full_var1,  x_tt_full_var1)
auc_zbb_var1 = np.trapezoid(y_zbb_full_var1, x_zbb_full_var1)

print(f"AUC_tt̄_vs_H150 for {var1} (np.trapezoid) = {auc_tt_var1:.4f}")
print(f"AUC_Zb̄b_vs_H150 for {var1} (np.trapezoid) = {auc_zbb_var1:.4f}")
print("\n")

# Alternatively, you can use sklearn's implementation that also relies on the trapezoidal rule:

from sklearn.metrics import auc as sklearn_auc

# Compute AUC via sklearn for var1
auc_tt_var1_sk   = sklearn_auc(x_tt_full_var1,  y_tt_full_var1)
auc_zbb_var1_sk  = sklearn_auc(x_zbb_full_var1, y_zbb_full_var1)

print(f"AUC_tt̄_vs_H150 for {var1} (sklearn) = {auc_tt_var1_sk:.4f}")
print(f"AUC_Zb̄b_vs_H150 for {var1} (sklearn) = {auc_zbb_var1_sk:.4f}")
```

```
AUC_tt̄_vs_H150 for LeptIP3D_worst (np.trapezoid) = 0.9522
AUC_Zb̄b_vs_H150 for LeptIP3D_worst (np.trapezoid) = 0.9312


AUC_tt̄_vs_H150 for LeptIP3D_worst (sklearn) = 0.9522
AUC_Zb̄b_vs_H150 for LeptIP3D_worst (sklearn) = 0.9312
```

result

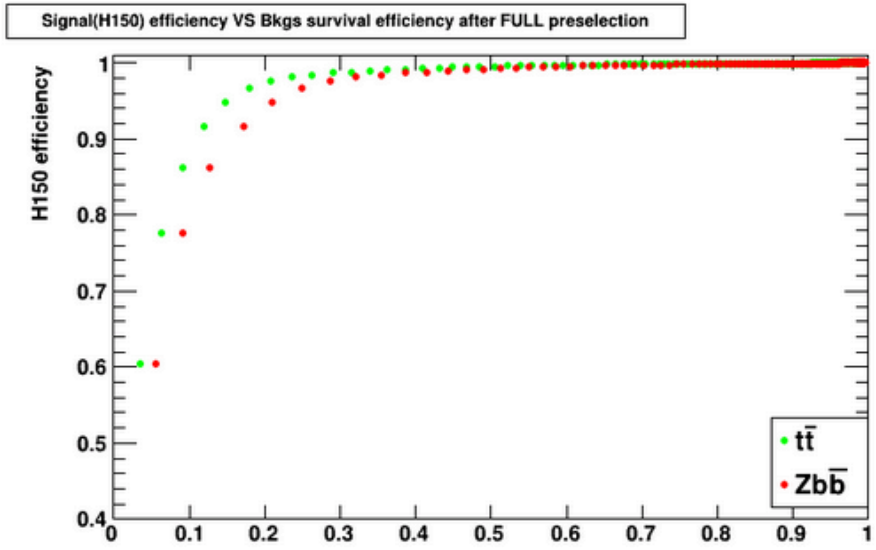
Use trapezoidal rule to calculate the AUC !

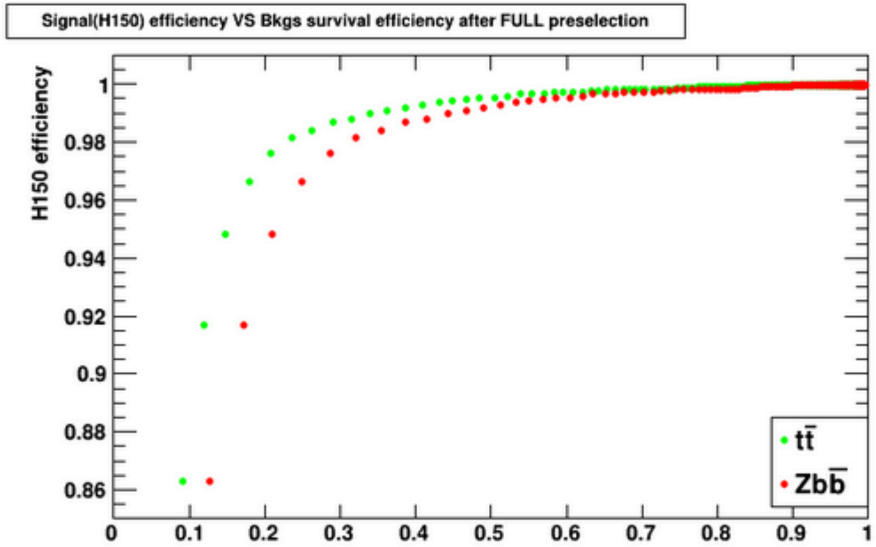
[using either **numpy** or **sklearn**]

Superimpose ROC curves for 1st discriminant variable (code)

```python
canvas_scatter_2 = ROOT.TCanvas("scatter_canvas_2", "Canvas Scatter 2", 700, 900)
canvas_scatter_2.SetGridx()
canvas_scatter_2.SetGridy()
canvas_scatter_2.Divide(0,2)
canvas_scatter_2.cd(1)
hframe3 = ROOT.TH2F(
    "hframe3",
    "Signal(H150) efficiency VS Bkgs survival efficiency after FULL preselection",
    100,0.,1.,100, 0.4,1.01 #we set the lower limit to 0.4 to make the plot more readable
)
hframe3.SetStats(0)
hframe3.SetYTitle("H150 efficiency")
hframe3.SetXTitle("bkgs survival efficiency")

hframe3.Draw()

gr_h150_TT_vtx.Draw("P")
gr_h150_Zbb_vtx.Draw("Psame")

leg4 = ROOT.TLegend(.8,.15,.9,.3)
#leg4.SetTextFont(42)
leg4.SetFillColor(0)
leg4.SetTextSize(0.05)
leg4.AddEntry(gr_h150_TT_vtx,"t#bar{t}", "P")
leg4.AddEntry(gr_h150_Zbb_vtx,"Zb#bar{b}", "P")
leg4.Draw()
#Zoom
canvas_scatter_2.cd(2)
hframe4 = ROOT.TH2F("hframe4",
    "Signal(H150) efficiency VS Bkgs survival efficiency after FULL preselection",
    100,0.,1.,100,0.85,1.01 #we set the lower limit to 0.85 to make the plot more readable
)
hframe4.SetStats(0)
hframe4.Draw()

hframe4.SetYTitle("H150 efficiency")
hframe4.SetXTitle("bkgs survival efficiency")

gr_h150_TT_vtx.Draw("P")
gr_h150_Zbb_vtx.Draw("Psame")

leg5 = ROOT.TLegend(.8,.15,.9,.3)
#leg5.SetTextFont(42)
leg5.SetFillColor(0)
leg5.SetTextSize(0.05)
leg5.AddEntry(gr_h150_TT_vtx,"t#bar{t}", "P")
leg5.AddEntry(gr_h150_Zbb_vtx,"Zb#bar{b}", "P")
leg5.Draw()

canvas_scatter_2.Update()
canvas_scatter_2.Draw()
canvas_scatter_2.SaveAs(f"{plot_dir}scatt-effic_H150-vsBkgs-overlap_{var1}_{date}.png")
```

```
Info in <TCanvas::Print>: png file /content/drive/My Drive/Colab Notebooks/exercise_9/
```





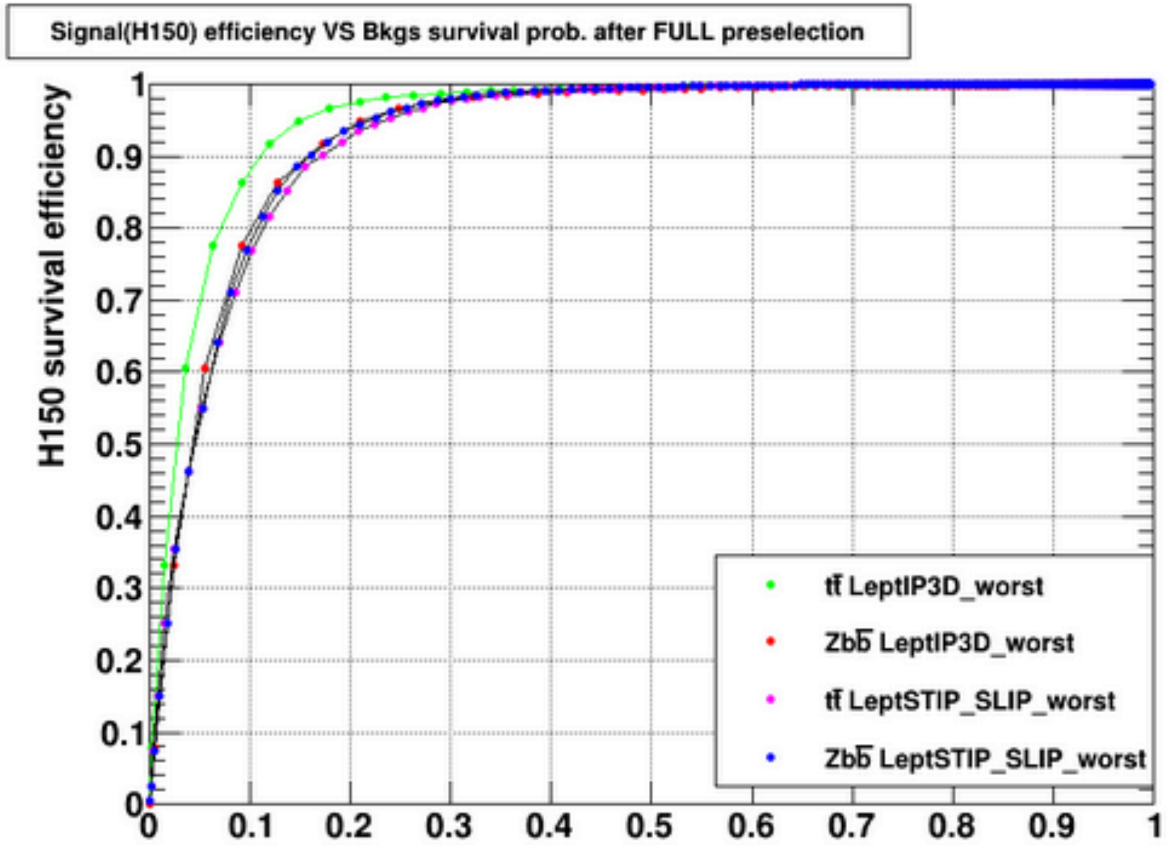
Superimpose ROC curves for both discriminant variables (code) - I

```python
logscale = False

canvas_scat_eff = ROOT.TCanvas("scatter_efficiency", "Scatter Efficiency", 800, 600)

ymin = 1e-6
ymax = 2.2 if logscale else 0.999999

ROOT.gStyle.SetOptStat(0)
ROOT.gPad.SetGridx()
ROOT.gPad.SetGridy()
hframe6 = ROOT.TH2F(
    "hframe6",
    "Signal(H150) efficiency VS Bkgs survival prob. after FULL preselection",
    100, 0.000001, 0.999999,
    100, ymin, ymax
)
hframe6.SetStats(0)
hframe6.Draw()
if logscale:
    canvas_scat_eff.SetLogy()

hframe6.SetXTitle("bkgs efficiency")
hframe6.SetYTitle("H150 survival efficiency")

x_values_TT_var2 = array('d', IntegralCounts2[1])
y_values_TT_var2 = array('d', IntegralCounts2[0])

x_values_Zbb_var2 = array('d', IntegralCounts2[2])
y_values_Zbb_var2 = array('d', IntegralCounts2[0])

length_TT_var2 = len(x_values_TT_var2)
length_Zbb_var2 = len(x_values_Zbb_var2)

gr_h150_TT_var2 = ROOT.TGraph(length_TT_var2, x_values_TT_var2, y_values_TT_var2)
gr_h150_TT_var2.SetMarkerColor(6)
gr_h150_TT_var2.SetMarkerSize(0.7) #0.65
gr_h150_TT_var2.SetMarkerStyle(20) #21

gr_h150_Zbb_var2 = ROOT.TGraph(length_Zbb_var2, x_values_Zbb_var2, y_values_Zbb_var2)
gr_h150_Zbb_var2.SetMarkerColor(4)
gr_h150_Zbb_var2.SetMarkerSize(0.7) #0.65
gr_h150_Zbb_var2.SetMarkerStyle(20) #21

x_values_TT_vtx = array('d', IntegralCounts1[1])
y_values_TT_vtx = array('d', IntegralCounts1[0])
length_TT_vtx = len(x_tt)

x_values_Zbb_vtx = array('d', IntegralCounts1[2])
y_values_Zbb_vtx = array('d', IntegralCounts1[0])
length_Zbb_vtx = len(x_zbb)
```

```python
gr_h150_TT_vtx = ROOT.TGraph(length_TT_vtx, x_tt, y_tt)
gr_h150_TT_vtx.SetMarkerColor(3)
gr_h150_TT_vtx.SetMarkerSize(0.6)
gr_h150_TT_vtx.SetMarkerStyle(20)

gr_h150_Zbb_vtx = ROOT.TGraph(length_Zbb_vtx, x_zbb, y_zbb)
gr_h150_Zbb_vtx.SetMarkerColor(2)
gr_h150_Zbb_vtx.SetMarkerSize(0.6) #0.65
gr_h150_Zbb_vtx.SetMarkerStyle(20) #21

gr_h150_TT_vtx.SetLineColor(3)
gr_h150_TT_vtx.Draw("LP")
#gr_h150_Zbb_vtx.SetLineColor(2)
gr_h150_Zbb_vtx.Draw("LP same")
gr_h150_TT_var2.Draw("LP same")
gr_h150_Zbb_var2.Draw("LP same")

leg6 = ROOT.TLegend(0.56, 0.15, 0.9, 0.4)
leg6.SetFillColor(0)
leg6.SetTextSize(0.03) #default: 0.05
leg6.AddEntry(gr_h150_TT_vtx, f"t#bar{{t}} {var1}", "P")
leg6.AddEntry(gr_h150_Zbb_vtx, f"Zb#bar{{b}} {var1}", "P")
leg6.AddEntry(gr_h150_TT_var2, f"t#bar{{t}} {var2}", "P")
leg6.AddEntry(gr_h150_Zbb_var2, f"Zb#bar{{b}} {var2}", "P")
leg6.Draw()

canvas_scat_eff.Update()
canvas_scat_eff.Draw()

if not logscale:
    canvas_scat_eff.SaveAs(f"{plot_dir}linear_scatt-effic_H150-vsBkgs-overlap-{var1}-{var2}_{date}.png")
else:
    canvas_scat_eff.SaveAs(f"{plot_dir}log_scatt-effic_H150-vsBkgs-overlap-{var1}-{var2}_{date}.png")

canvas_scat_eff.Clear()
canvas_scat_eff.Close()
```

Superimpose ROC curves for both discriminant variables (code) - II

Info in <TCanvas::Print>: png file /content/drive/My Drive/Colab Notebooks/exercise_9/Plots/linear_scatt-effic_H150-vsBkgs-overlap-LeptIP3D_worst-LeptSTIP_SLIP_worst_2025-05-03.png



Calculate AUC for both discriminant variables (code)

```python
# Use closed_curve to prepare the full ROC arrays
x_tt_full_var2,  y_tt_full_var2  = closed_curve(x_values_TT_var2,  y_values_TT_var2)
x_zbb_full_var2, y_zbb_full_var2 = closed_curve(x_values_Zbb_var2, y_values_Zbb_var2)

# Then compute the AUC via numpy.trapezoid
auc_tt_var2  = np.trapz(y_tt_full_var2,  x_tt_full_var2)
auc_zbb_var2 = np.trapz(y_zbb_full_var2, x_zbb_full_var2)

print(f"AUC_tt̄_vs_H150 for {var2} (np.trapz) = {auc_tt_var2:.4f}")
print(f"AUC_Zb̄b_vs_H150 for {var2} (np.trapz) = {auc_zbb_var2:.4f}")
print("\n")

# Compute AUC via sklearn for var1
auc_tt_var2_sk   = sklearn_auc(x_tt_full_var2,  y_tt_full_var2)
auc_zbb_var2_sk  = sklearn_auc(x_zbb_full_var2, y_zbb_full_var2)

print(f"AUC_tt̄_vs_H150 for {var2} (sklearn) = {auc_tt_var2_sk:.4f}")
print(f"AUC_Zb̄b_vs_H150 for {var2} (sklearn) = {auc_zbb_var2_sk:.4f}")
```

```
AUC_tt̄_vs_H150 for LeptSTIP_SLIP_worst (np.trapz) = 0.9289
AUC_Zb̄b_vs_H150 for LeptSTIP_SLIP_worst (np.trapz) = 0.9311

AUC_tt̄_vs_H150 for LeptSTIP_SLIP_worst (sklearn) = 0.9289
AUC_Zb̄b_vs_H150 for LeptSTIP_SLIP_worst (sklearn) = 0.9311
```

```python
import pandas as pd

# Build a tidy table of just the sklearn AUC results for both var1 and var2
auc_data = {
    "Comparison": [
        f"tt̄ vs H150 ({var1})",
        f"Zb̄b vs H150 ({var1})",
        f"tt̄ vs H150 ({var2})",
        f"Zb̄b vs H150 ({var2})"
    ],
    "AUC": [
        auc_tt_var1_sk,
        auc_zbb_var1_sk,
        auc_tt_var2_sk,
        auc_zbb_var2_sk
    ]
}

pd.DataFrame(auc_data)
```

	Comparison	AUC
0	tt̄ vs H150 (LeptIP3D_worst)	0.952161
1	Zb̄b vs H150 (LeptIP3D_worst)	0.931232
2	tt̄ vs H150 (LeptSTIP_SLIP_worst)	0.928861
3	Zb̄b vs H150 (LeptSTIP_SLIP_worst)	0.931054

Background	"LeptIP3D_worst"	"LeptSTIP_SLIP_worst"
$t\bar{t}$	0.9522	0.9288
$Zb\bar{b}$	0.9312	0.9311