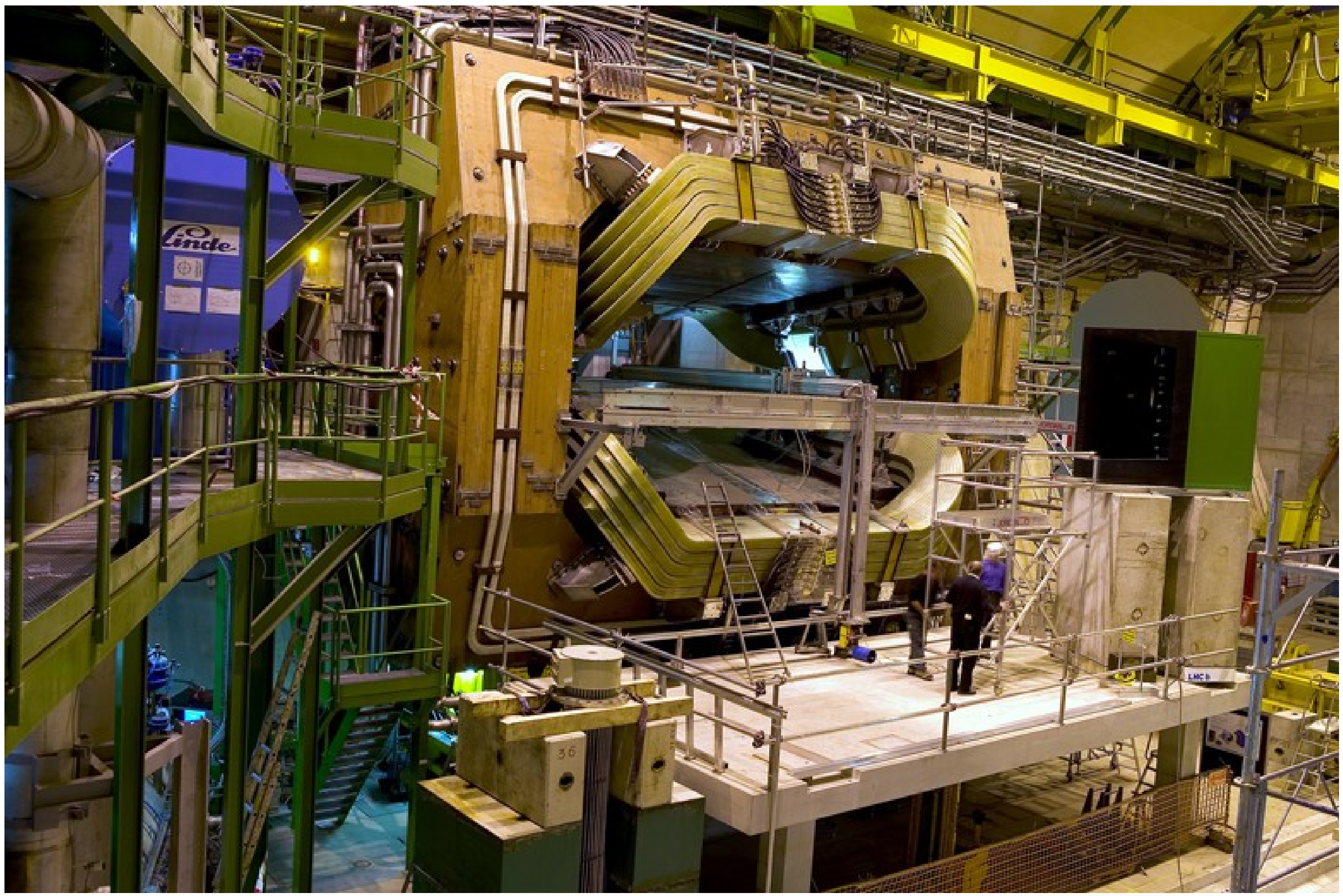
LHCb data analysis: $\Lambda^{0}_{b} \rightarrow \Lambda^{0} + \gamma$ decay for downstream tracks



Arnau Brossa
September 14^{th}, 2016

Outline

- Decay Description

- Samples:
    - Data
    - Monte Carlo
    - Background selection

- Analysis:
    - Preselection cuts
    - MVA's
    - FOM optimization

- “Results”

- Decay recostruction improvement:
    - Leaf-by-leaf method
    - Kalman filter

- Conclusions

Decay:

$$\Lambda^0_b \to \Lambda^0 + \gamma \to \pi^- + p^+$$

Motivation:

- Improve the upper limit for the branching ratio of the Λ_b .

- Constrain new physics from the polarization of the emmited photon.

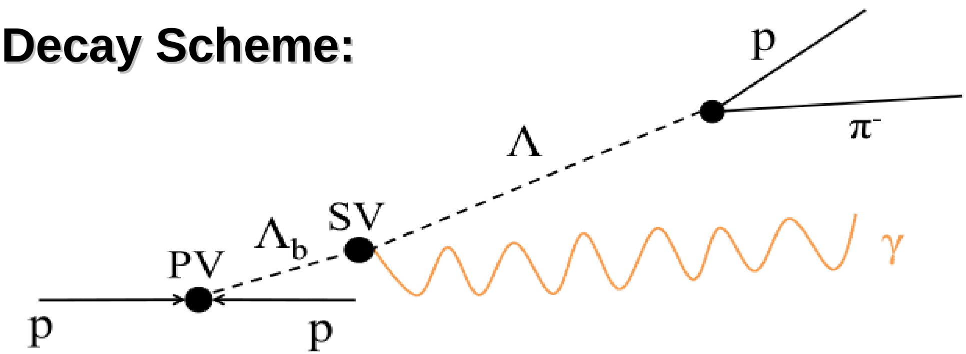
Main issues:

- Impossibility to locate the secondary Vertex (SV)

- Extremely low branching ratio (predicted by the SM)

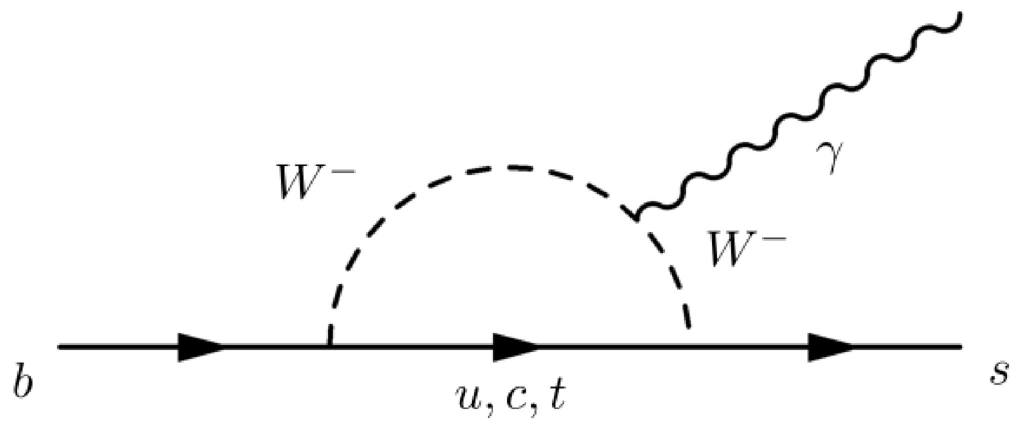
$$B(\Lambda_b^0 \to \Lambda^0 \gamma) \simeq (3-10) \cdot 10^{-5}$$

Decay Scheme:



Penguin diagram:

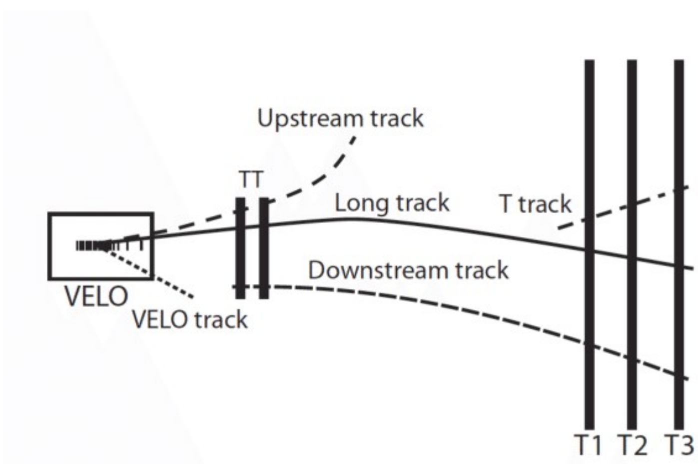
- Electromagnetic penguin process $b \to s\gamma$



Data samples taken in 2011 ($\sqrt{s} = 7\,TeV$) and in 2012 ($\sqrt{s} = 8\,TeV$) by the LHCb.

Long tracks (LL): 44%

Downstream tracks (DD): 56%



Stripping:

Particle	Variable	Cut	
p, π^- tracks	χ^2_{IP} from PV	> 16	
	Min(χ^2/ NDOF) of track fit	< 2	
	Max(χ^2/ NDOF) of track fit	< 3	
	Ghost probability	< 0.4	
π^-	p_{T}	> 300	MeV/c
	Momentum	> 2000	MeV/c
p	p_{T}	> 800	MeV/c
	Momentum	> 7000	MeV/c
Λ^0	$\lvert M_{\Lambda^0}(\mathrm{PDG}) - M_{\Lambda^0}\rvert$	< 20	MeV/c^2
	Vertex χ^2	< 9	
	p_{T}	> 1000	MeV/c
	IP	> 0.05	mm
γ	E_{T}	> 2500	MeV
	Confidence level	> 0.2	
Λ^0_b	$\lvert M_{\Lambda^0_b}(\mathrm{PDG}) - M_{\Lambda^0_b}\rvert$	< 1100	MeV/c^2
	p_{T}	> 1000	MeV/c
	Sum of p_{T} of Λ^0 and γ	> 5000	MeV/c
	χ^2_{MTDOCA}	< 7	

Background cut:

$$\left| M_{\Lambda^0_b}(PDG) - M_{\Lambda^0_b} \right| < 544.0\, MeV/c^2$$

Montecarlo (MC):

-Data generated by PYTHIA, simulating the data from 2012 ($\sqrt{s} = 8\ TeV$)

-Stripping applied too

Background:

Selected from the cut:

$$|M_{\Lambda^0_b}(PDG) - M_{\Lambda^0_b}| > 544.0\ MeV/c^2$$

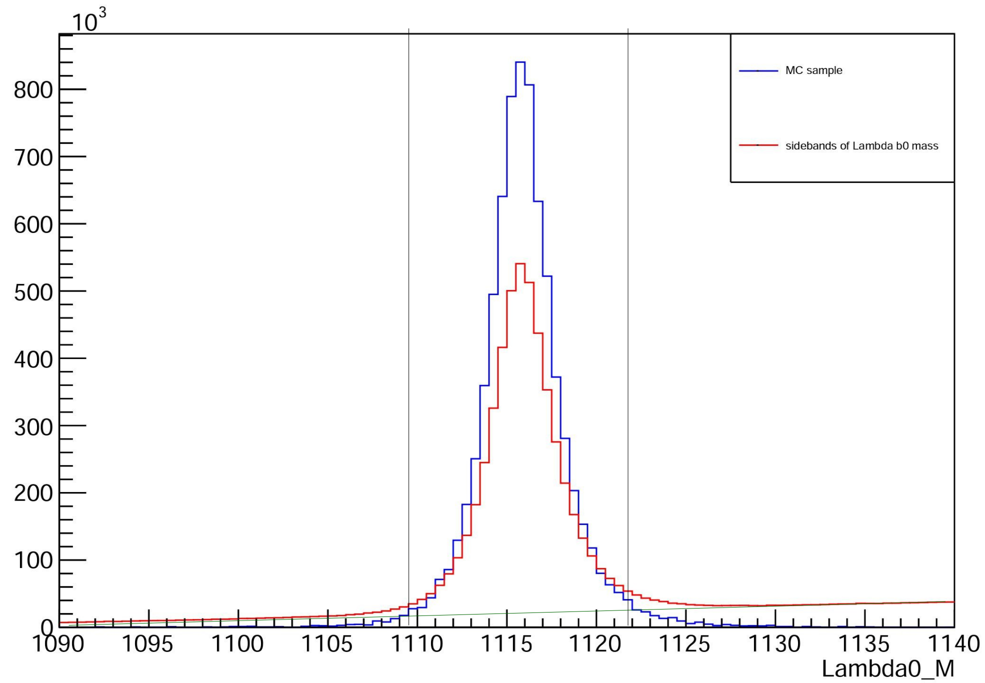
Preselection cuts:

Λ^0 mass sidebands:

$$|M_{\Lambda^0}(PDG) - M_{\Lambda^0}| < 6.5\ MeV/c^2$$

-Linear fit to get the background entries in the mass window.

-"fake" Λ^0's behaviour approximated from the behaviour in the sidebands

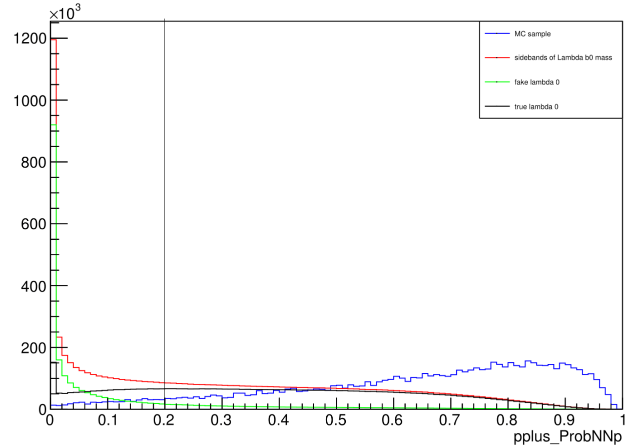


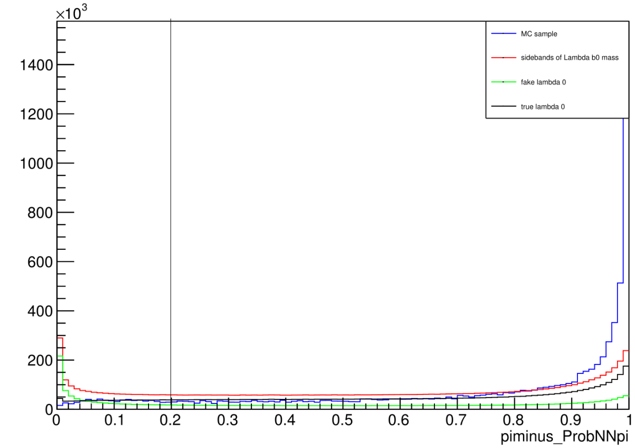
$$\varepsilon_{signal} = 97.24\,\%$$

$$\varepsilon_{background} = 69.59\,\%$$

PID cuts:

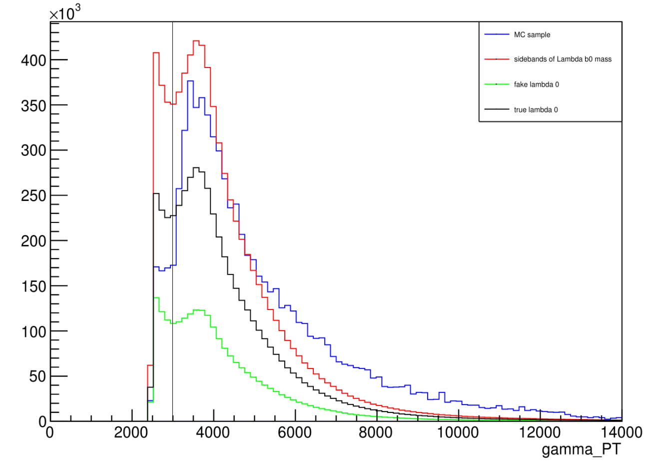
- π^- $PID > 0.2$
- p^+ $PID > 0.2$





γ P_T cut:

- γ $PT > 3000\,MeV$



$$\varepsilon_{signal} = 78.90\,\%$$

$$\varepsilon_{background} = 49.72\,\%$$

Total Events: 2 962 132

Expected Signal Events: 767 (0.025%)

FOM: 0.446

$$FOM = \frac{S}{\sqrt{S+B}}$$

Signal sample (MC): 20 945 events

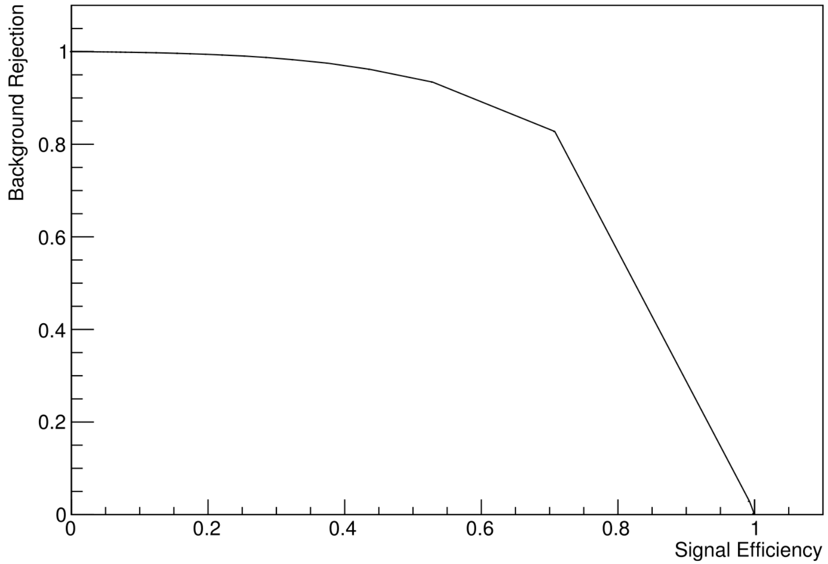
Background sample (Λ_b mass sidebands): 2 609 129 events

Neural Net (NN):

-12 Inputs

-Structure 12:25:1

-1000 Iterations

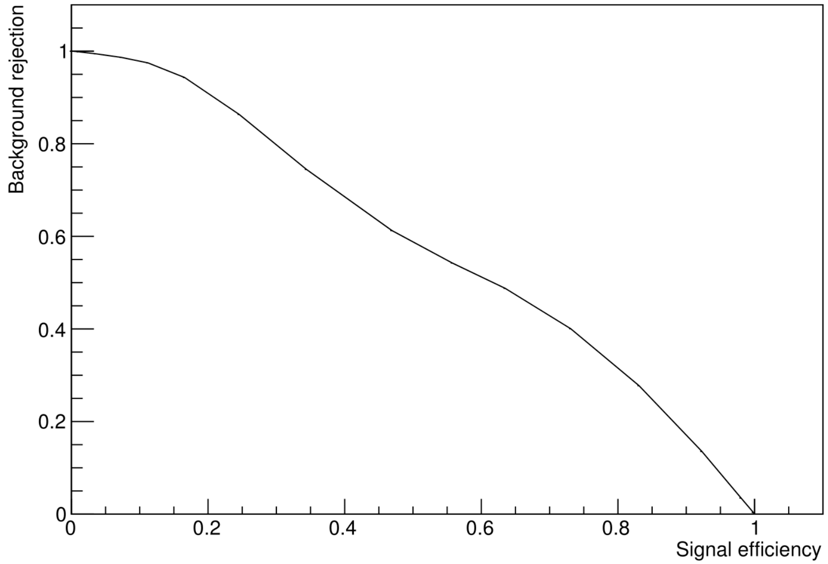


Boosetd Decision Tree (BDT):

-12 Inputs

-1000 trees

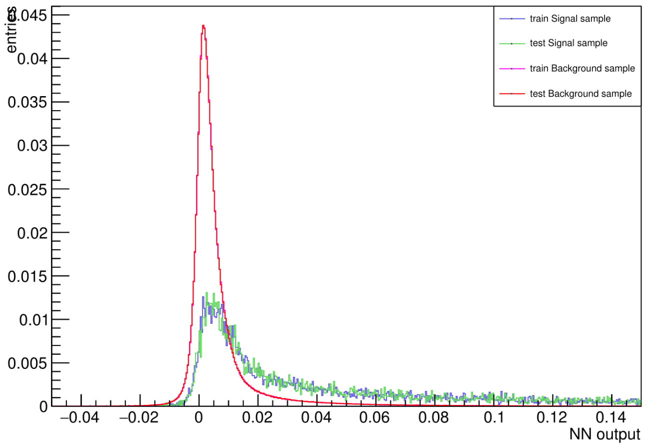
-Max depth: 15



NN study:

-There is no overtraining

-Low separation power expected



FOM optimization:

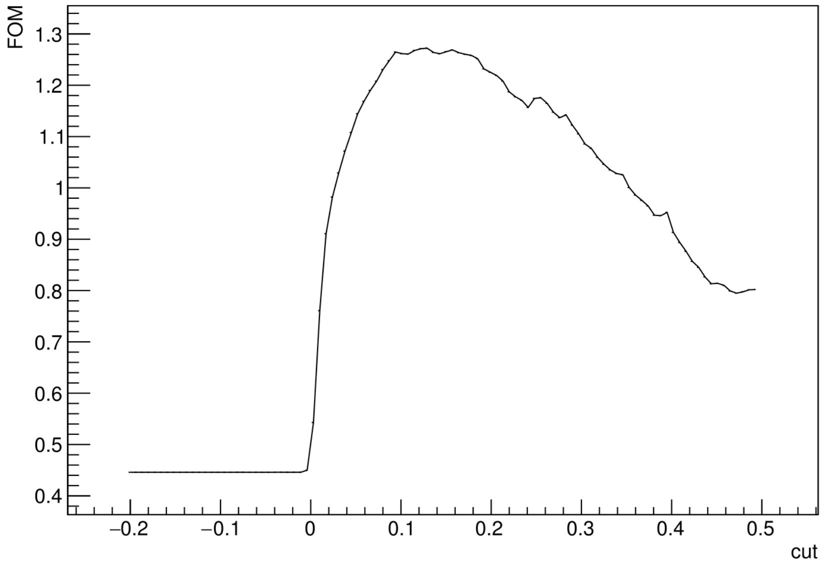
Best Cut: 0.129

$$FOM = \frac{S}{\sqrt{S+B}}$$

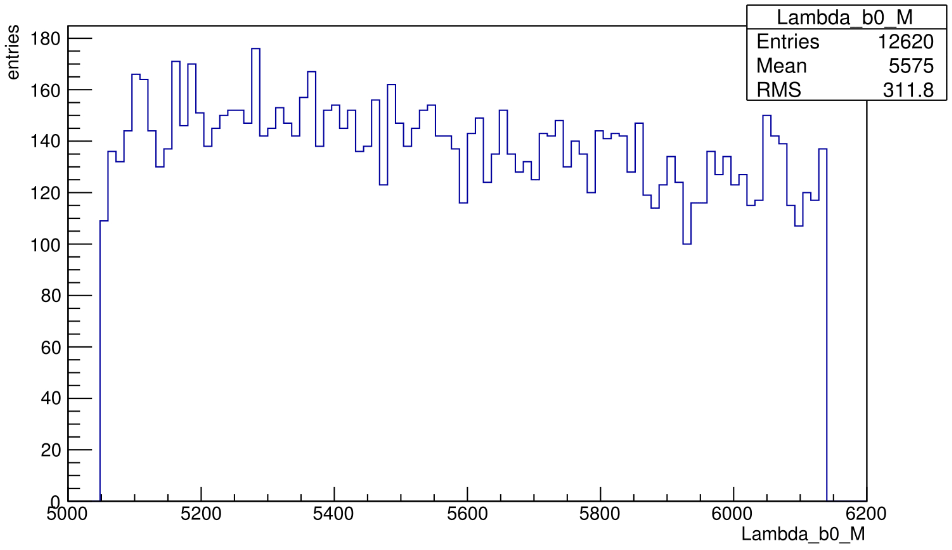
FOM: 1.273

$$\varepsilon_{signal} = 18.62\,\%$$

$$\varepsilon_{background} = 0.50\,\%$$



Λ_b mass:



-Data sample reduced to:

-12 620 events

-143 expected signal events

- 1.13%

- FOM: 1.273

Cut	Background ε	Signal ε
$\lvert M_{\Lambda 0}$ (PDG)-$M_{\Lambda 0} \rvert < 6.5$ MeV/c²	69.59 %	97.24 %
PID/γ PT cuts	49.72 %	78.90 %
NN	0.50 %	18.62%
Total	0.17%	14.29%

And... what now?

- The main problem is the precision of the SV.
- We should try a new reconstruction method.

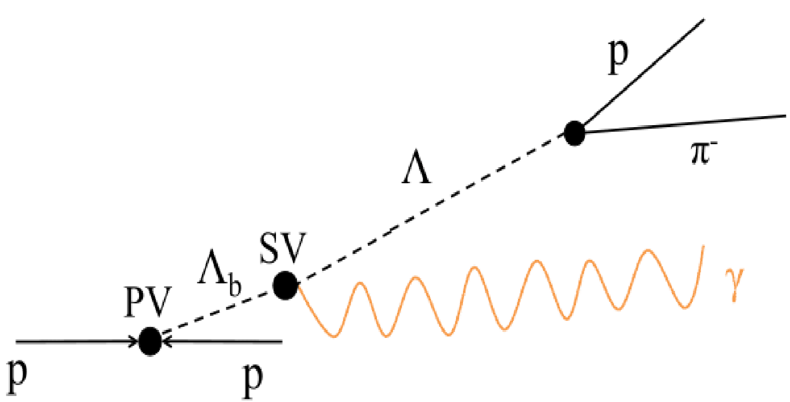
Leaf-by-leaf fitting:

-Step-by-step fit using the daughter tracks in every vertex

-Used by default

-Does not require hypothesis

-Not very useful with multiple decay verices

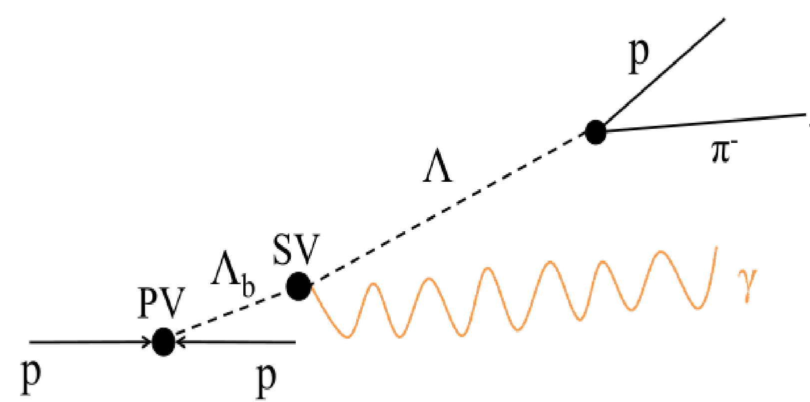


Kalman fitter:

-Least squres fit of a decay chain involving multiple decay vertices

-High computational cost

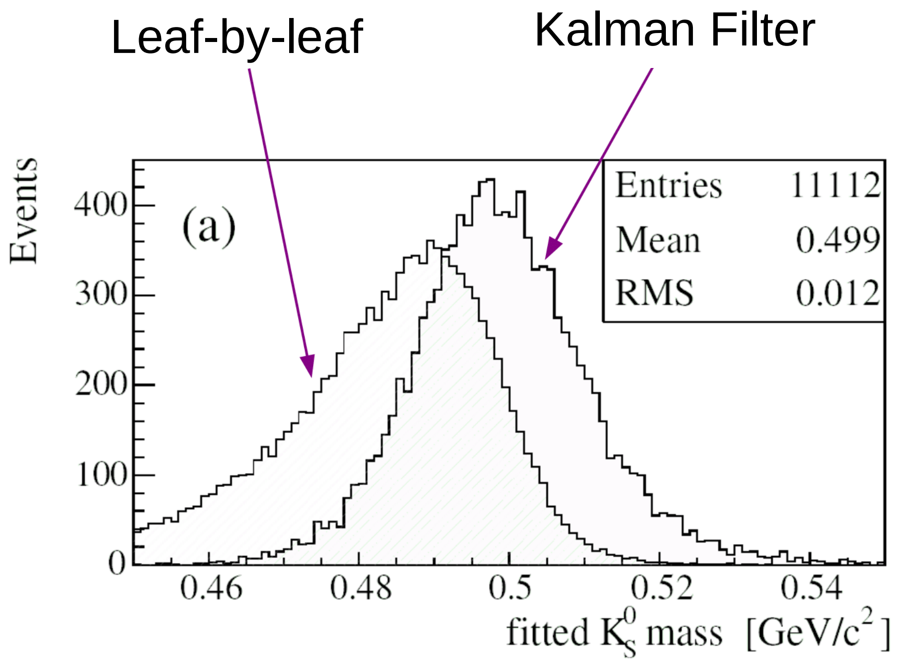
-Requires different hypotesis or constraints depending on the fit



Some examples (not mine).

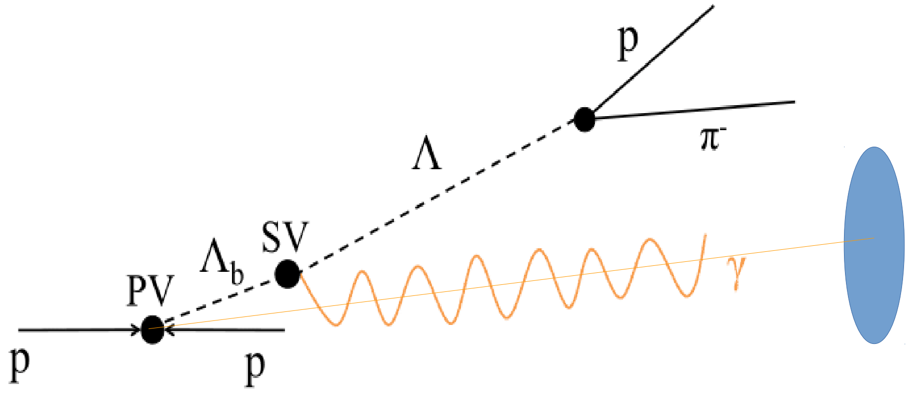
-Fitted K_s^0 mass from the decay:

$$K_s^0 \rightarrow \pi^0 \pi^0$$



http://www.nikhef.nl/~wouterh/topicallectures/TrackingAndVertexing/part6.pdf

In our case:



-We only have the cluster information

-In the Leaf-by-leaf method, the vertex of the photon is set to PV

Further steps:

- Reconstruct all data using the Kalman filter with diferents constraints
- With the new data, apply:
  - Stripping
  - Preselection cuts
  - MVA's

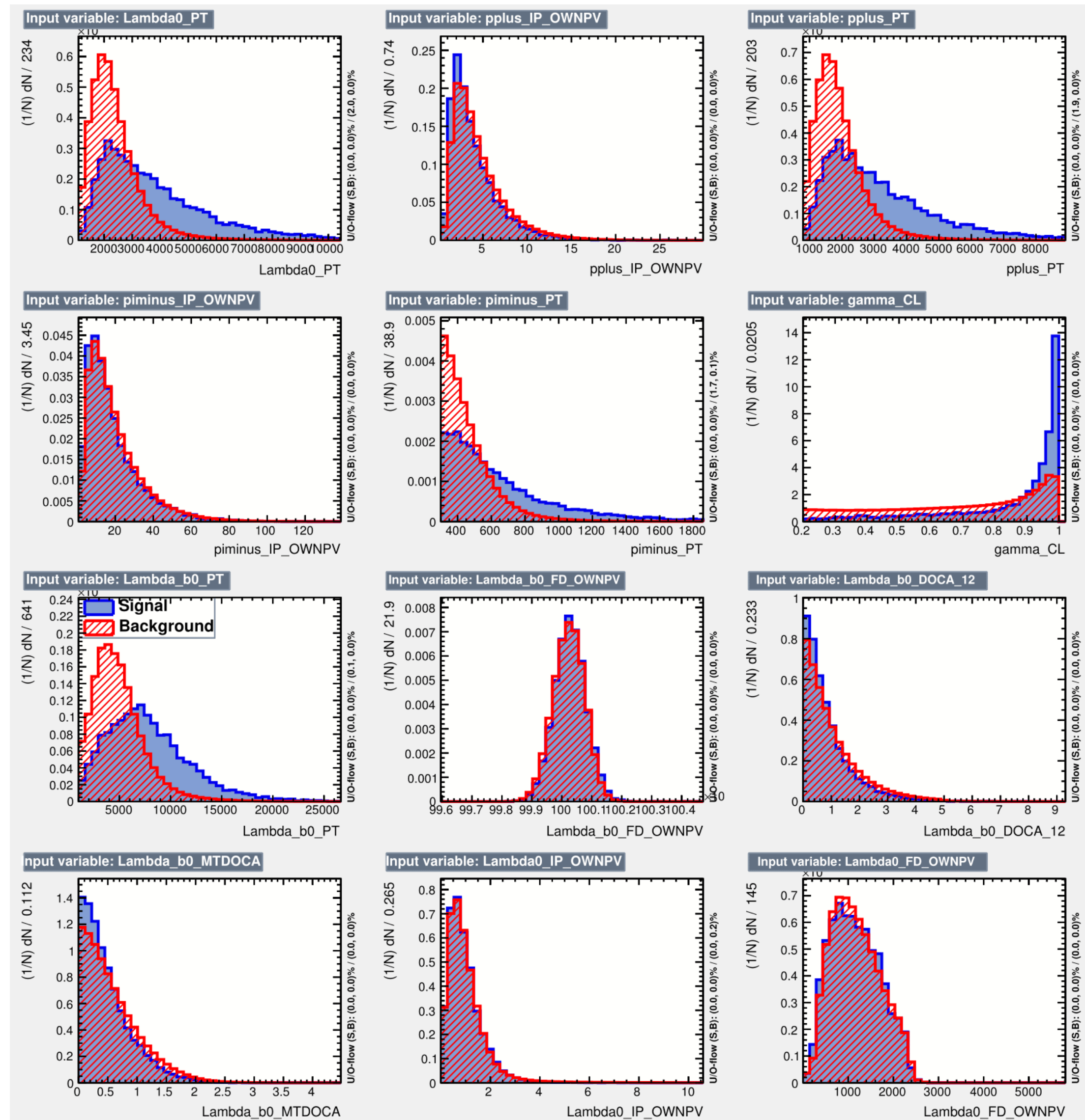
Objectives:

- Obtain a much higher signal/Background ratio
- Use the selected signal to:
  - Improve the upper limit of $B(\Lambda_b{}^0 \rightarrow \Lambda^0 \gamma)$
  - Study the polarization of the resulting photons and the $\Lambda_b{}^0$

Thank you

MVA's input variables:

- Λ^0 PT
- p^+ IP
- p^+ PT
- π^- IP
- π^- PT
- γ CL
- Λ_b^0 PT
- Λ_b^0 FD
- Λ_b^0 DOCA
- Λ_b^0 MTDOCA
- Λ^0 IP
- Λ^0 FD



BACKUP

Introduction:

$$\Lambda^0_b \rightarrow \Lambda^0 + \gamma \rightarrow \pi^- + p^+$$

In the data samples taken 2012 by the LHCb.

LL: 44%

DD: 56%

-low branching ratio

$B(\Lambda_b{}^0 \rightarrow \Lambda^0 \gamma) = 3 - 10 \cdot 10^{-5}$ predicted by SM

$B(\Lambda_b{}^0 \rightarrow \Lambda^0 \gamma) < 1.9 \cdot 10^{-3}$ CDF collaboration (2002)

-Strategy:

- Select the Background sample from the $\Lambda_b{}^0$ mass sidebands.
- Plot the distributions to introduce pre-selection cuts in order to reduce the data sample.
- Select the observables which show the clearest separation power between signal and background.
- Apply a multivariate analysis, studying the performance of a boosted decision tree (BDT) and a Neural net (NN).

Data sample:

Data 2012:

-Post-stripping

-Downstream tracks (DD)

Cuts applied:

$$\left|M_{\Lambda^0_b}(PDG) - M_{\Lambda^0_b}\right| < 544.0\, MeV/c^2$$

$$\left|M_{\Lambda^0}(PDG) - M_{\Lambda^0}\right| < 6.5\, MeV/c^2$$

$$\pi^- \; PID > 0.2$$

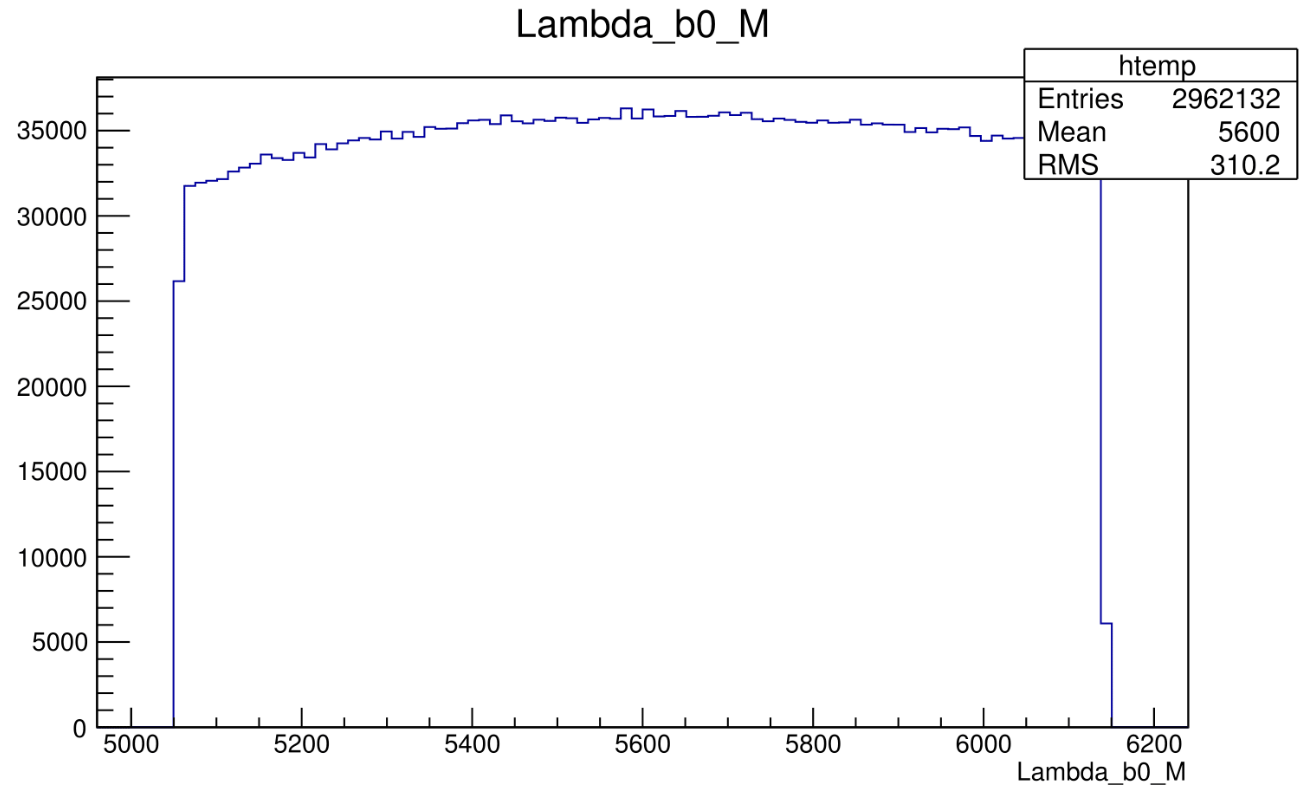
$$p^+ \; PID > 0.2$$

$$\gamma \; PT > 3000\, MeV$$

Total Events: 2962132

Expected Signal Events: 767

FOM: 0.446



MVAs analysis:

Signal sample (MC): 20 945 events

Background sample (Λ_b mass sidebands): 2 609 129 events

Training sample: 1 315 038 events

S: 10 473 events

B: 1 304 565 events

Test sample: 1 315 036 events

S: 10 472 events

B: 1 304 564 events

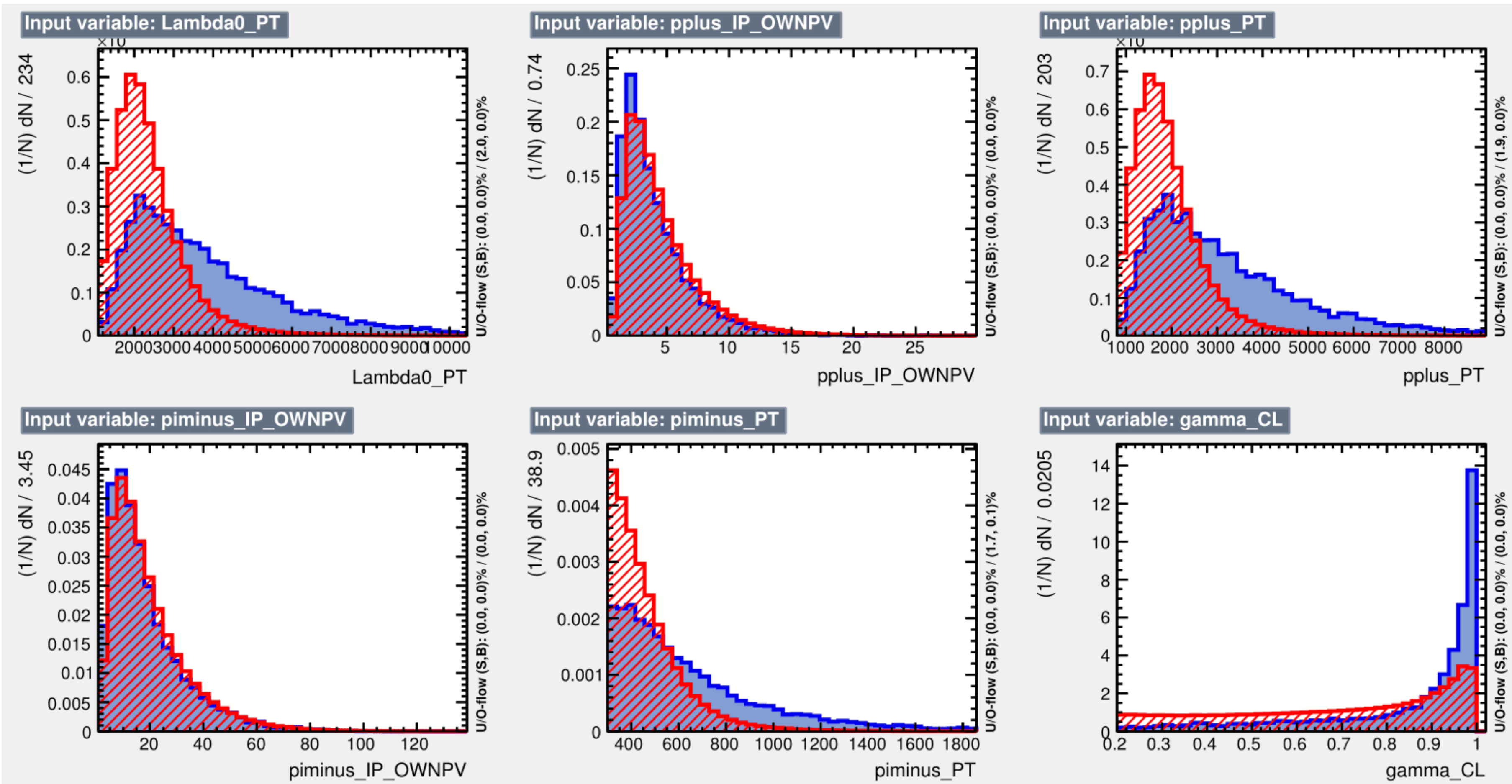
Boosetd Decision Tree (BDT):

-12 Inputs

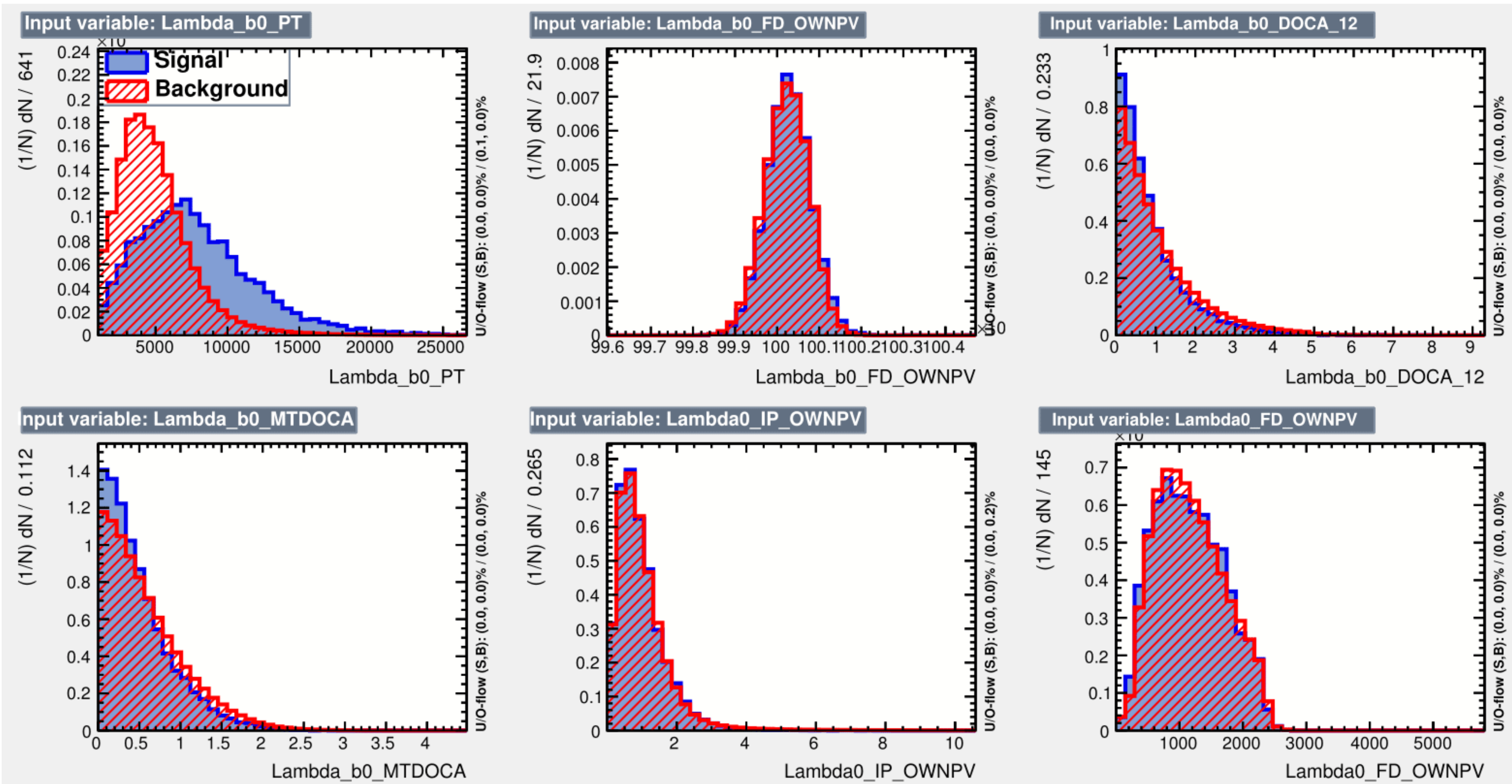
-1000 trees

-Max depth: 15

Input Variables:



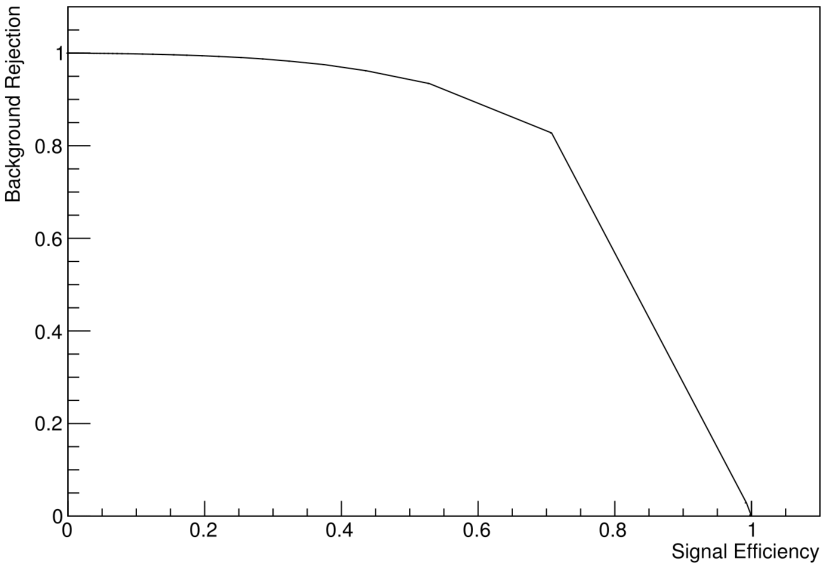
Input Variables:



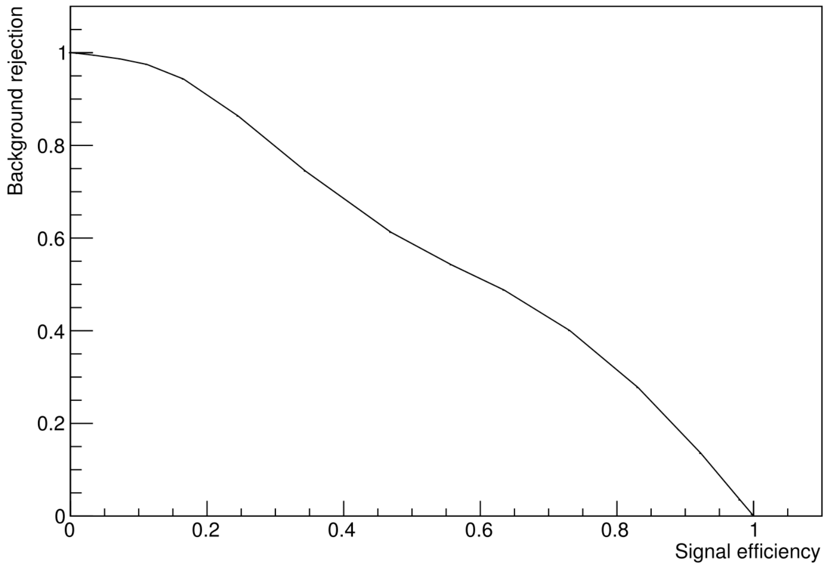
NN and BDT performance.

ROC curves obtained from the test sample.

NN



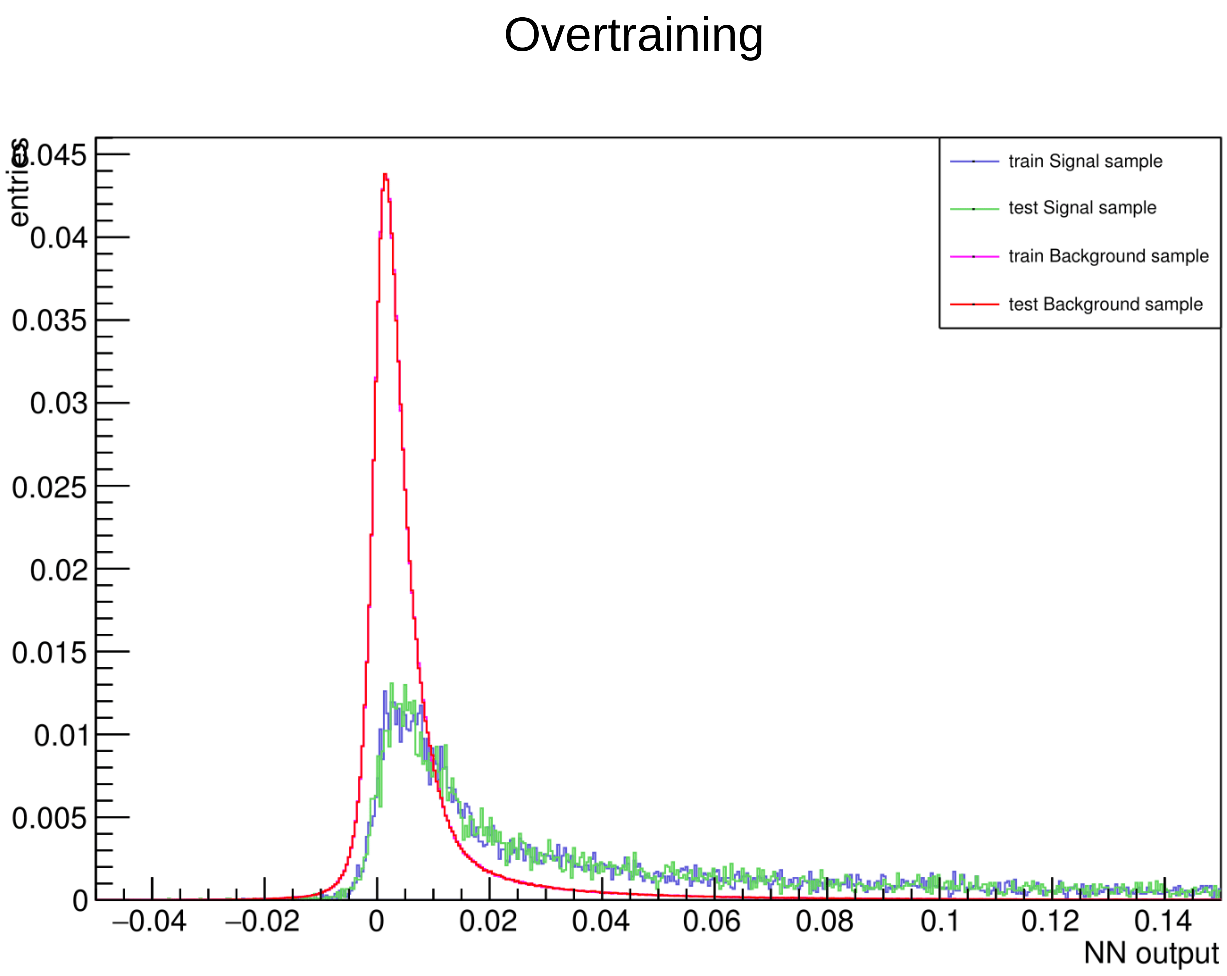
BDT



Overtraining Study.

NN structure: 12:25:1

Iterations: 1000

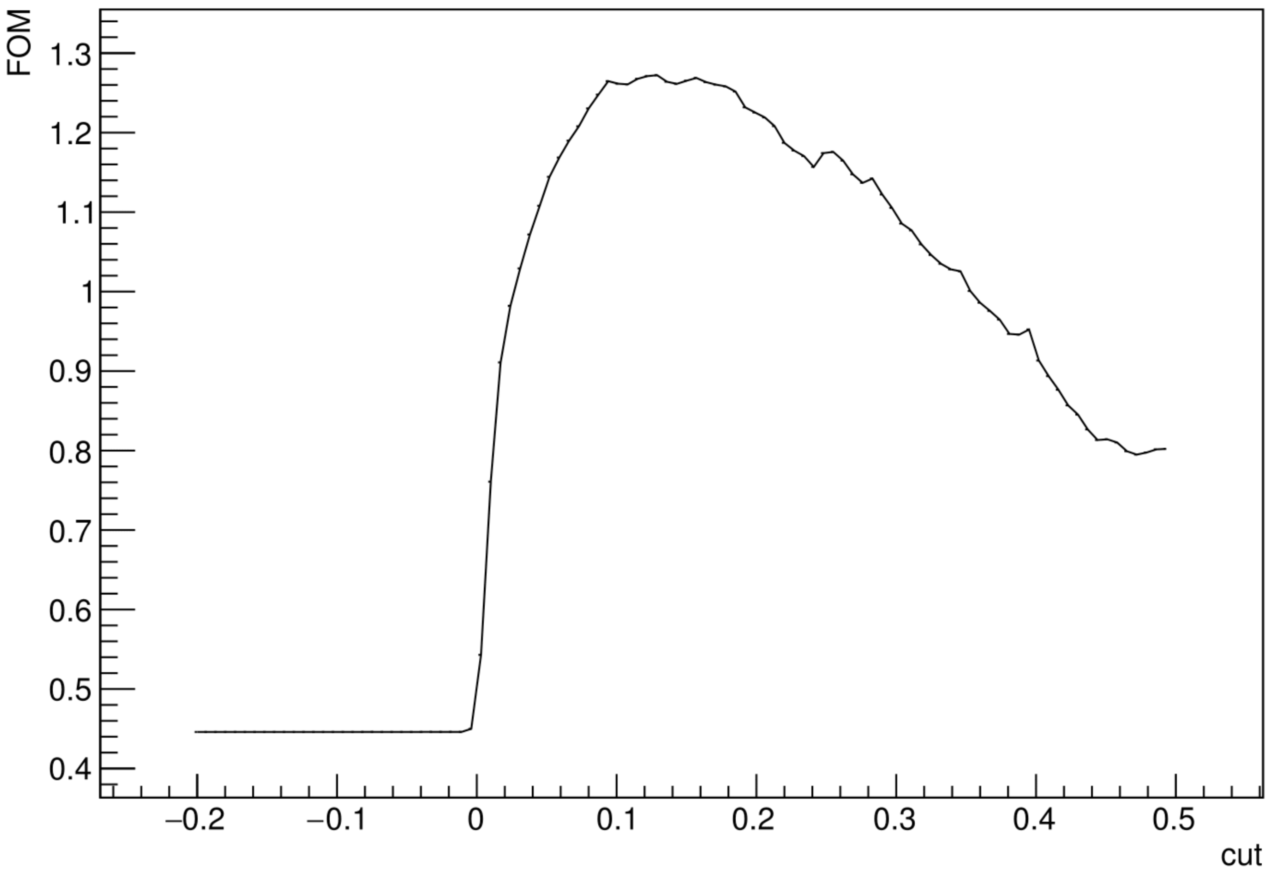


FOM vs NN output cut

$$FOM = \frac{S}{\sqrt{S+B}}$$

- S obtained from the efficiency of the cut in the NN output, and the expected signal events (767)

- B obtained from the data sample after the cut in the NN output (B>>S approximation)



Best Cut: 0.129

Signal Efficiency: 18.62%

FOM: 1.273

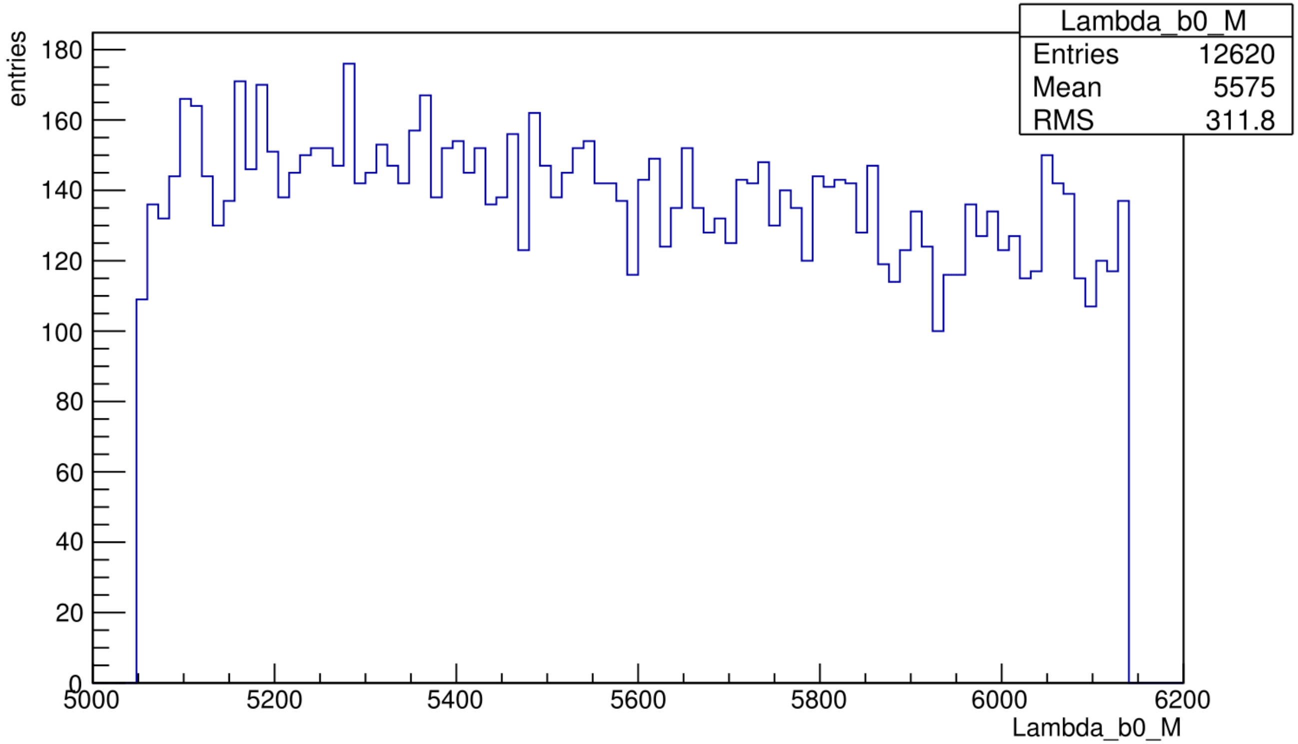
Background Efficiency: 0.50%

Results.

Total Events: 12 620

Expected Signal Events: 143

FOM: 1.273



Recap.

- Cuts applied:

$$\left|M_{\Lambda^0_b}(PDG) - M_{\Lambda^0_b}\right| < 544.0\ MeV/c^2$$

$$\left|M_{\Lambda^0}(PDG) - M_{\Lambda^0}\right| < 6.5\ MeV/c^2$$

$$\pi^- \ PID > 0.2$$

$$p^+ \ PID > 0.2$$

$$\gamma \ PT > 3000\ MeV$$

- MVA analysis:
  Neural Net:
  -NN output > 0.129

-Data sample reduced to:

-12 620 events

-143 expected signal events

- 1.13%

-FOM: 1.273

Cut	Background ε	Signal ε
$\mid M_{\Lambda 0}$ (PDG)-$M_{\Lambda 0}\mid <6.5$ MeV/c²	69.59 %	97.24 %
PID/γ PT cuts	49.72 %	78.90 %
NN	0.50 %	18.62%
Total	0.17%	14.29%

Conclusions.

-The MVA analysis gives a great improvement to our results, even though they are still not conclusive.

-The similarity between the Signal/Background distributions suggest that there can not be major improvement by working further on the MVA analysis.

-Further improvements may come from a better reconstruction of the data sample