EUROPEAN AI FOR FUNDAMENTAL PHYSICS CONFERENCE
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Reconstruction of Low Mass Vector Mesons(LMVM) using machine learning techniques for CBM Experiment at FAIR SIS100

Presented by: Abhishek Kumar Sharma

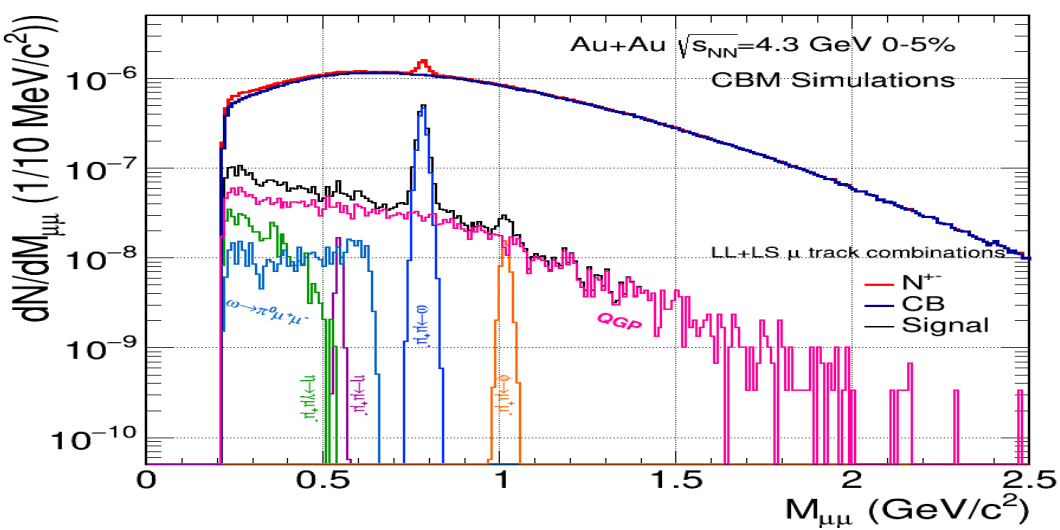
Collaborators: Raktim Mukherjee, Pawan Sharma, Partha Partim Bhaduri, Apar Agarwal, Anand Kumar Dubey, Anna Senger, Subhashish Chattopadhyay

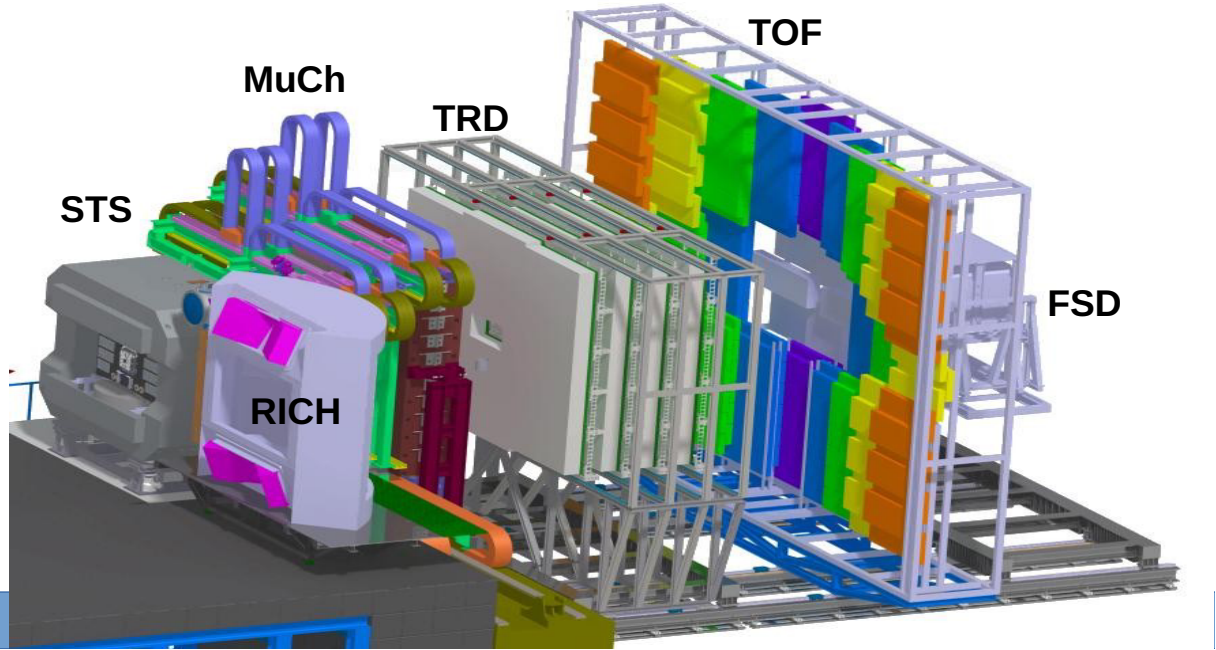
GSI FAIR

CBM

CBM Experiment at FAIR

- The Compressed Baryonic Matter Experiment is situated within the accelerator facility known as Facility for Anti Proton Ion Research (FAIR) in Darmstadt, Germany
- The goal of the CBM experiment is to investigate the phase diagram of strongly interacting matter under conditions characterized by high net baryon densities and moderate temperatures.
- In-medium modification of light vector mesons, hyper-nuclei, charm production and their propagation inside the nuclear matter.
- The particle multiplicity of the particle like ω, η, ϕ, ρ is quite low.
- The precision and rare probes need high statistics with greater efficiency. The signal efficiency obtained through traditional uni-variate cut method is low.
- Therefore the need for multivariate analysis for the dimuon detection is required.

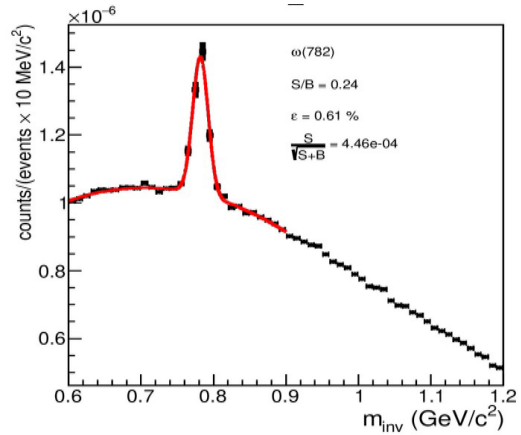




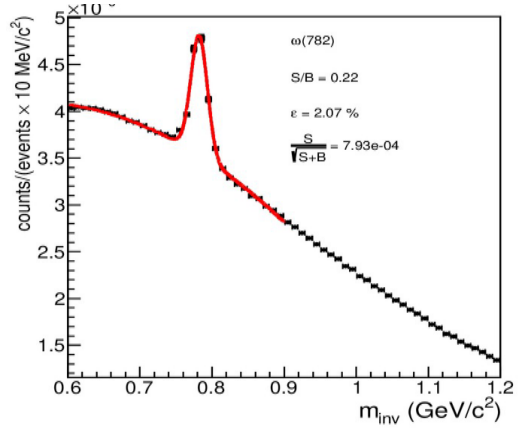
Physics Observables

$\omega \longrightarrow \mu^+ \mu^-$ $\eta \longrightarrow \mu^+ \mu^-$ $\phi \longrightarrow \mu^+ \mu^-$

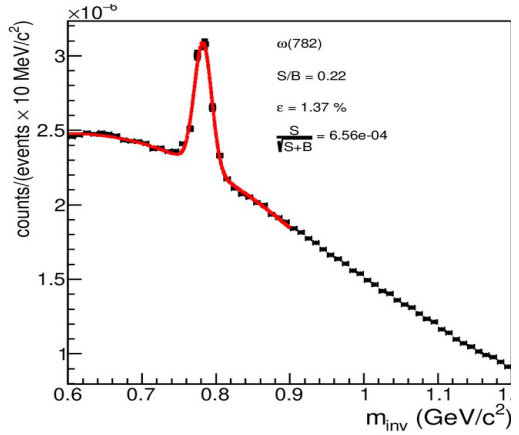
ω meson using manual cuts with efficiency 0.61



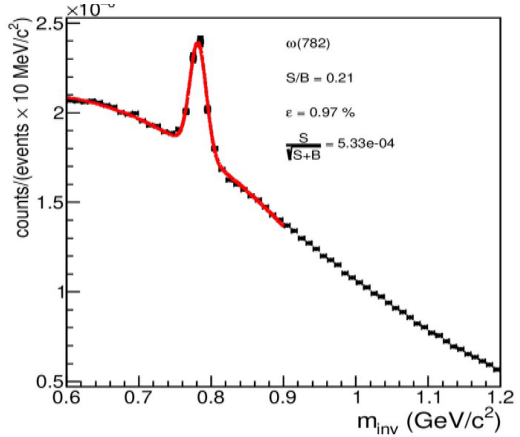
ω meson BDTG @ 0.7 with efficiency increase of 3.39 with same S/B



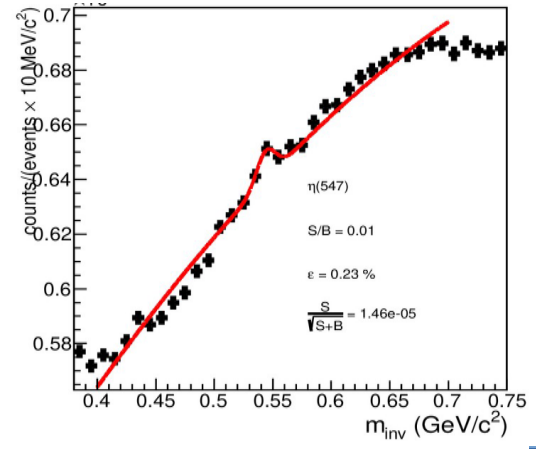
ω meson kNN @ 0.88 with efficiency increase of 2.24 with same S/B



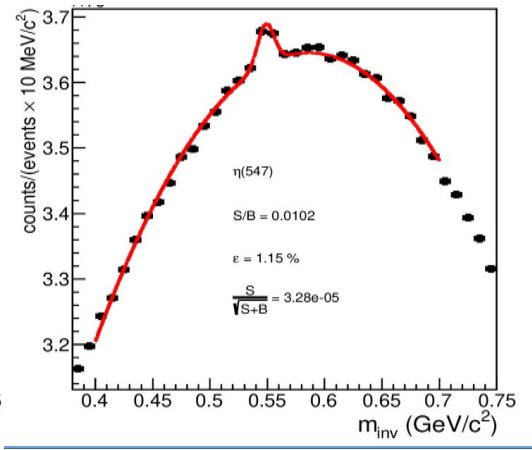
ω meson HMatrix @ 0.18 with efficiency increase of 3.39 with same S/B



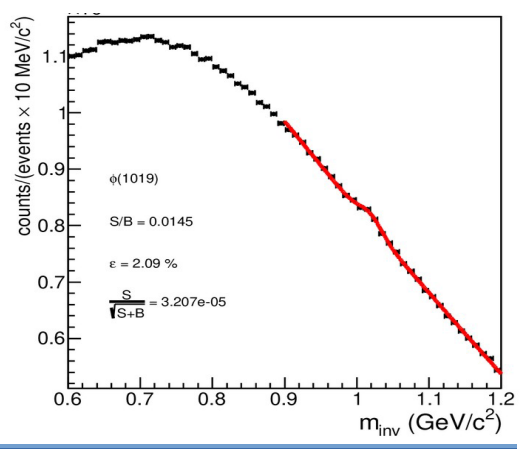
η meson using manual cuts with efficiency 0.23



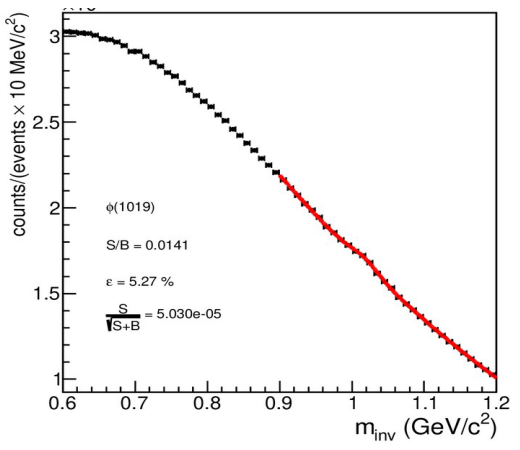
η meson BDTG @ 0.7 with efficiency increase of 5.00 with same S/B



ϕ meson using manual cuts with efficiency 2.09



ϕ meson BDTG @ 0.71 with efficiency increase of 2.52 with same S/B



Comparison Table for Physics Observables

meson	method	S/B ratio	Efficiency(%)	Normalised Significance
$\omega \rightarrow \mu^+\mu^-$	Manual cuts	0.24	0.61	1.00
$\omega \rightarrow \mu^+\mu^-$	BDTG @ 0.65	0.22	2.07	1.77
$\omega \rightarrow \mu^+\mu^-$	kNN @ 0.88	0.22	1.37	1.47
$\omega \rightarrow \mu^+\mu^-$	HMatrix @ 0.18	0.21	0.97	1.19
$\eta \rightarrow \mu^+\mu^-$	Manual cuts	0.01	0.23	1.00
$\eta \rightarrow \mu^+\mu^-$	BDTG @ 0.7	0.01	1.15	2.24
$\phi \rightarrow \mu^+\mu^-$	Manual cuts	0.014	2.09	1.00
$\phi \rightarrow \mu^+\mu^-$	BDTG @ 0.71	0.014	5.27	1.57

- Further investigation of complete dimuon cocktail production and for high mass region for J/ψ production is under progress.
- These ML algorithms can also be used to at the digitization and reconstruction level as well for improving the detector efficiency.

Thank you very much for your Kind Attention !

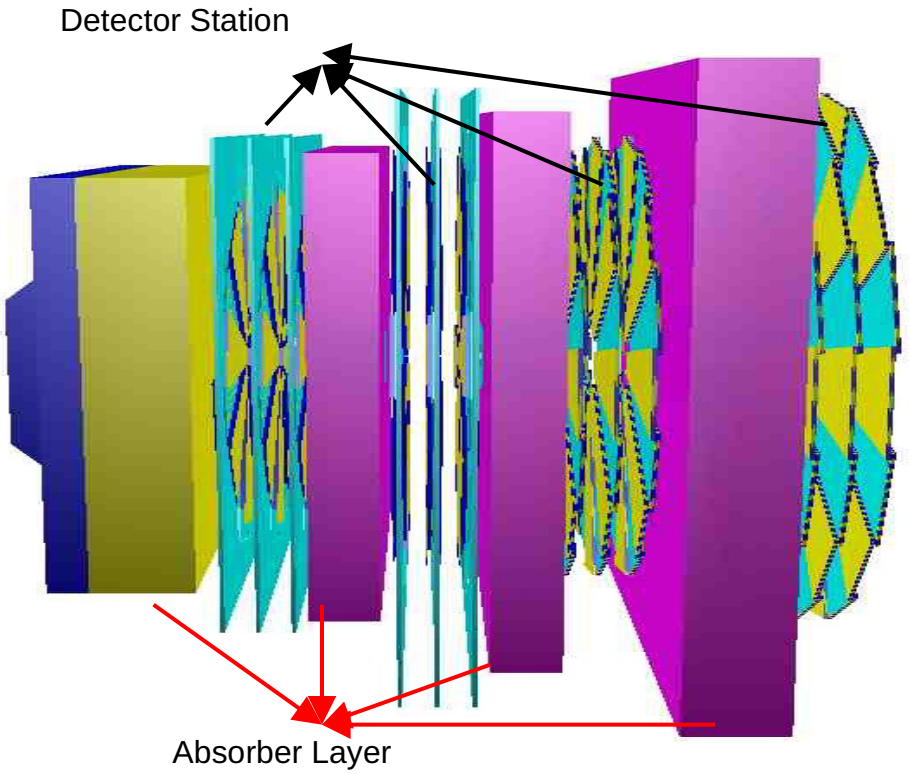
BACK UP

Muon Chamber at CBM

Aim: Study the LMVMs via dimuon decay channel.

$$\omega \longrightarrow \mu^+ \mu^-$$
$$\eta \longrightarrow \mu^+ \mu^-$$
$$\phi \longrightarrow \mu^+ \mu^-$$

MuCh Setup:
Detector Stations: 4
GEM: Station1 & Station 2
RPC: Station 3 & Station 4
Absorbers : 4
Absorber 1: Carbon and Concrete
Absorber 2, 3 & 4: Iron

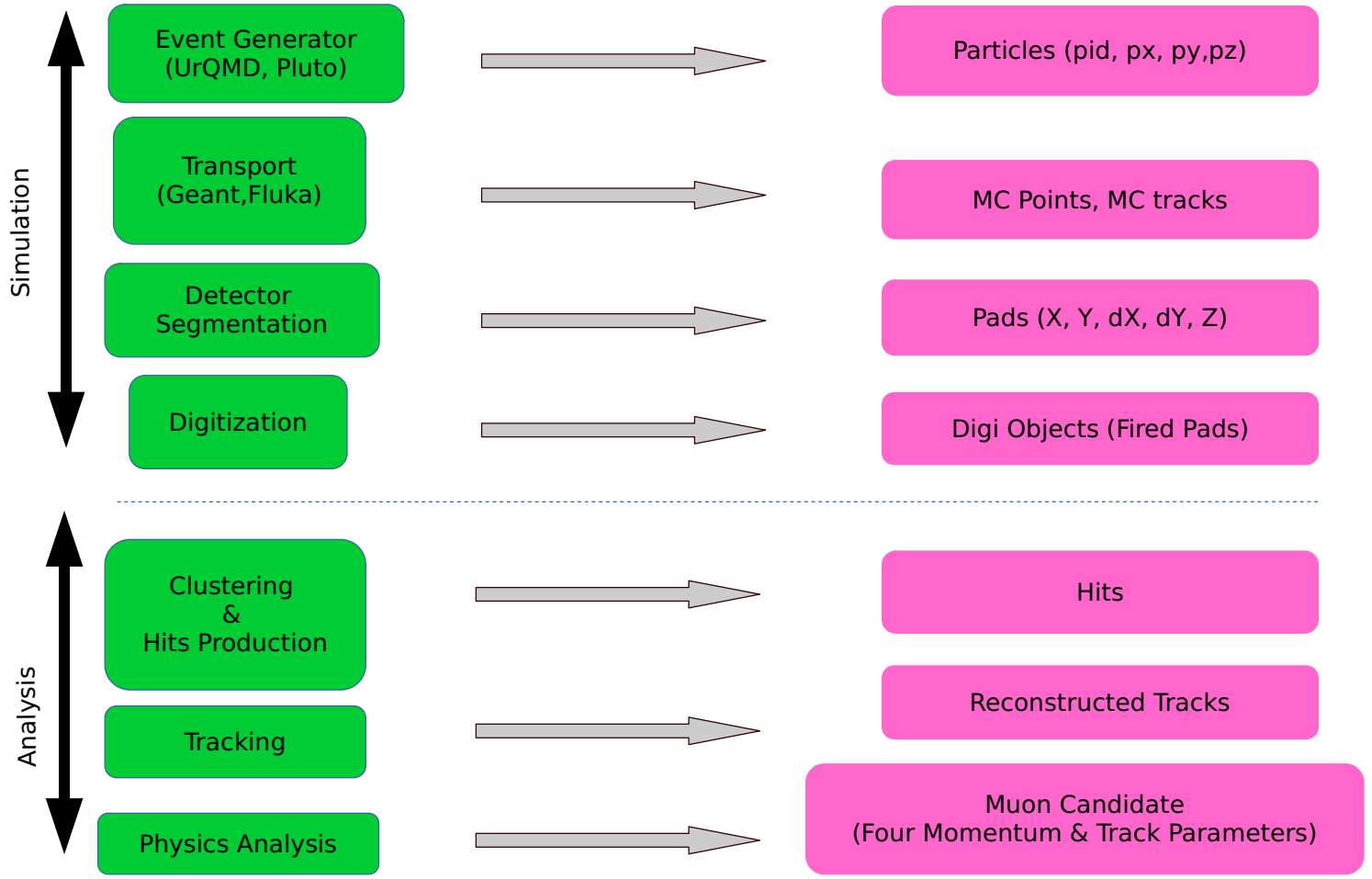


Schematics of CBM MuCh Detector

Basic Simulation Details:

- **Geometry** : v23a
- **Generator** : UrQMD & Pluto
- **Beam & Target system** : AuAu
- **Energy** : 8 AGeV
- **Centrality** : central
- **Setup** : SIS100_muon_lmvm
- **No of Events**: 100k
- **FairSoft** : Apr21p2 & **FairRoot** : 18.6.7
- **Cbmroot**: 21.2.99

Track Reconstruction:

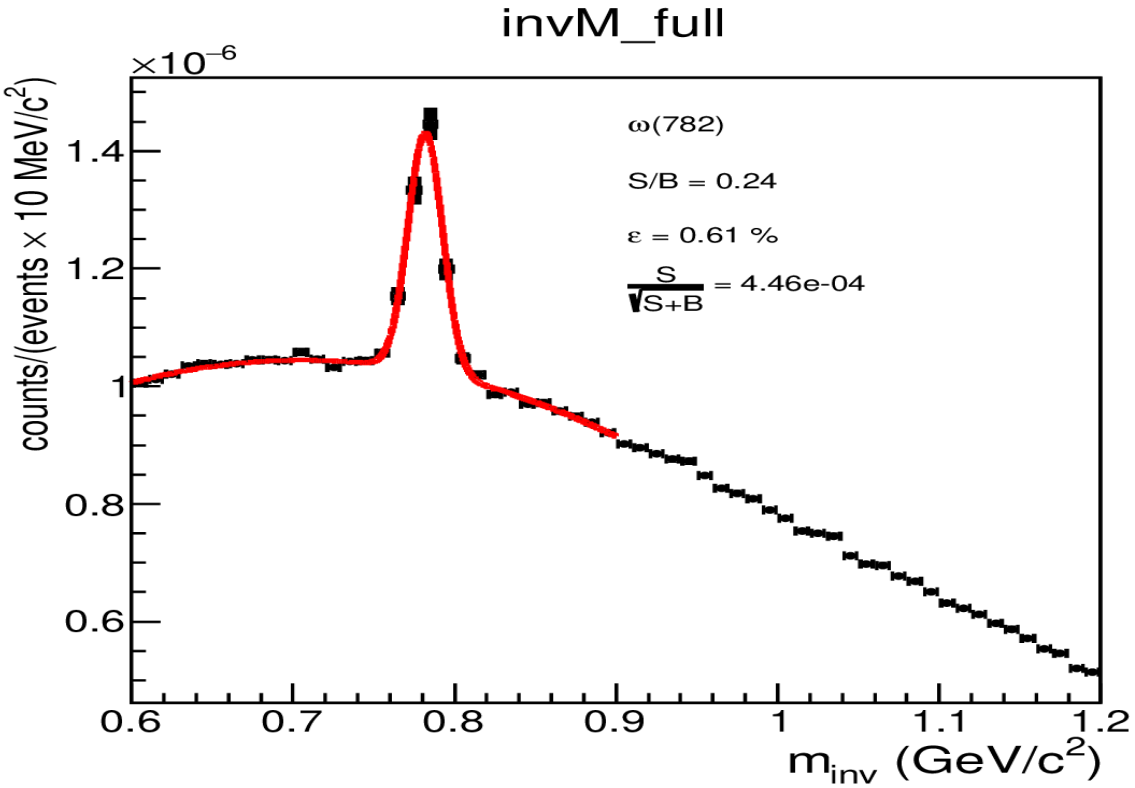


Physics Analysis

Reconstruction of ω meson via dimuon decay channel using Traditional cut Method

$$\omega \longrightarrow \mu^+ \mu^-$$

- Number of MuCh hits ≥ 11,
- Number of STS hits ≥ 7,
- Number of TRD hit ≥ 1,
- Number of TOF hits ≥ 1,
- Chi Sqaure $\chi^2_{MuCh} < 3$,
- Chi Sqaure $\chi^2_{STS} < 2$,
- Chi Sqaure $\chi^2_{vertex} < 2.5$,
- SigmaToFCut=2.



Machine Learning:

Multivariate analysis: The signal efficiency obtained through traditional univariate cut method is quite low, hence the need for multivariate analysis for the dimuon detection.

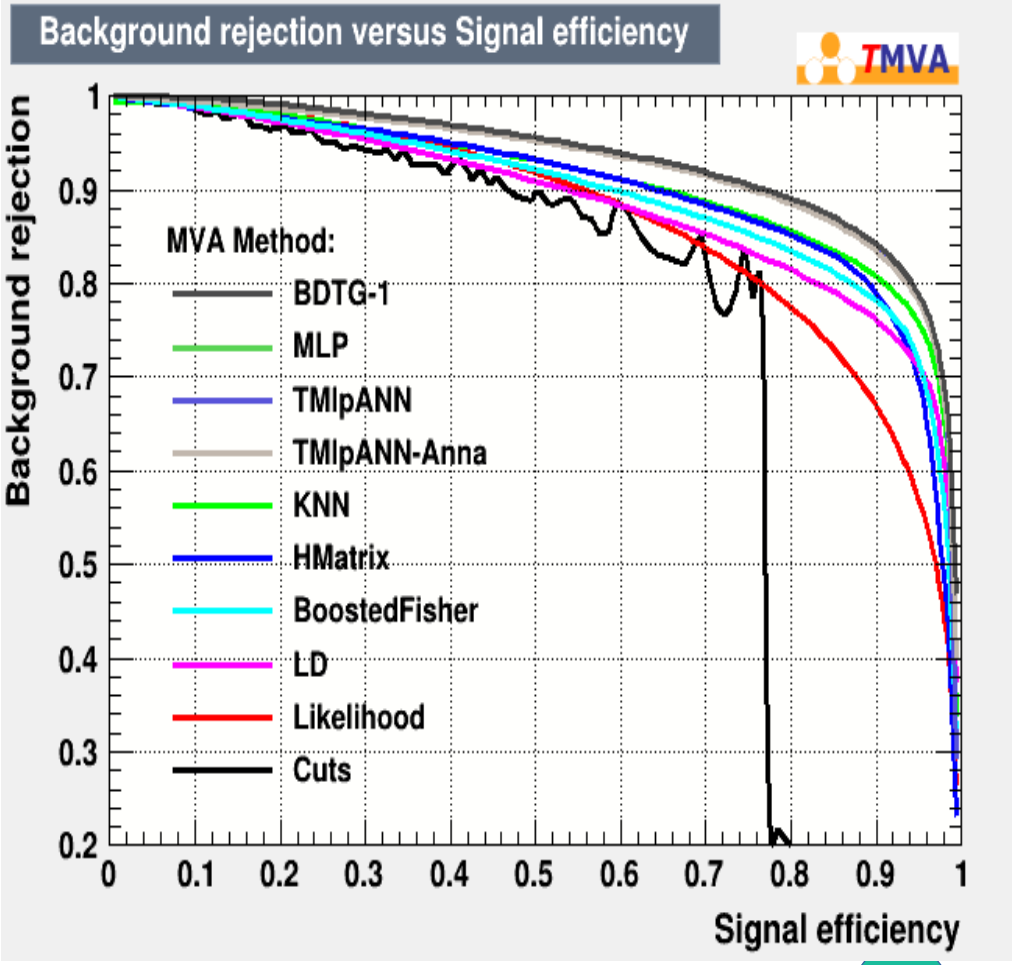
- **The performance of dimuons detection has been enhanced through the utilization of the TMVA root class.**

Models covered using TMVA

- **Boosted decision trees(BDT):** Decision trees facilitate the separation of data across multiple dimensions, by combining multiple univariate cuts on input variables.

- **kNN:** kNN compares an observed event with reference events from a training dataset.

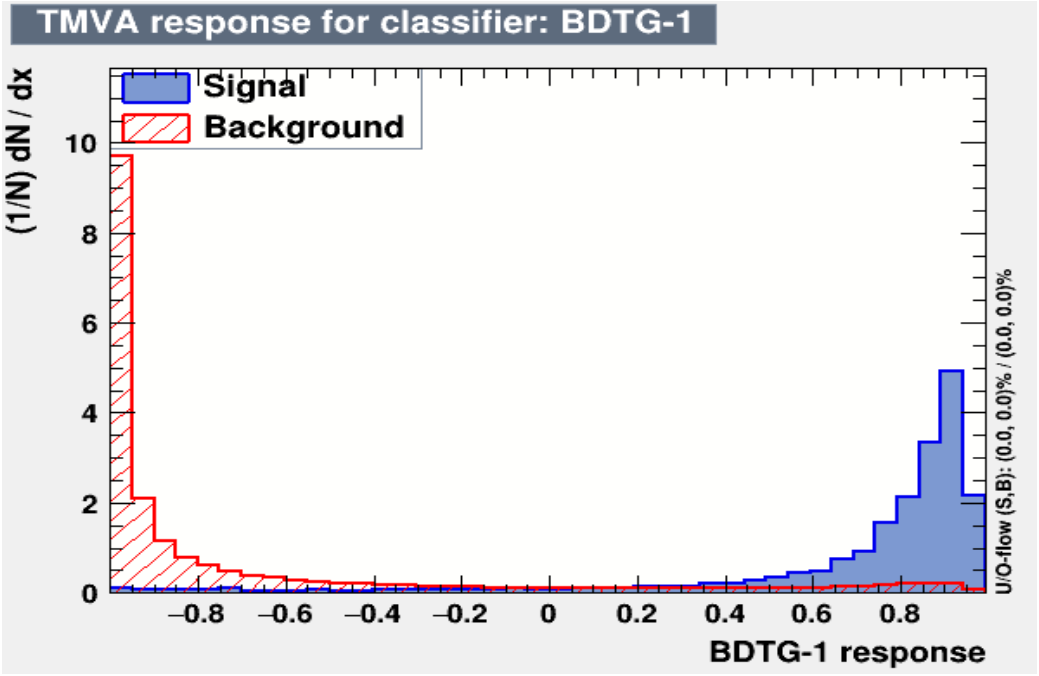
- **Hmatrix:** HMatrix discriminates between classes (e.g., signal and background) of a feature vector, utilizing Gaussian-distributed correlated elements, with the inverse being the HMatrix.



ML: Training data

Signal and background have following variables

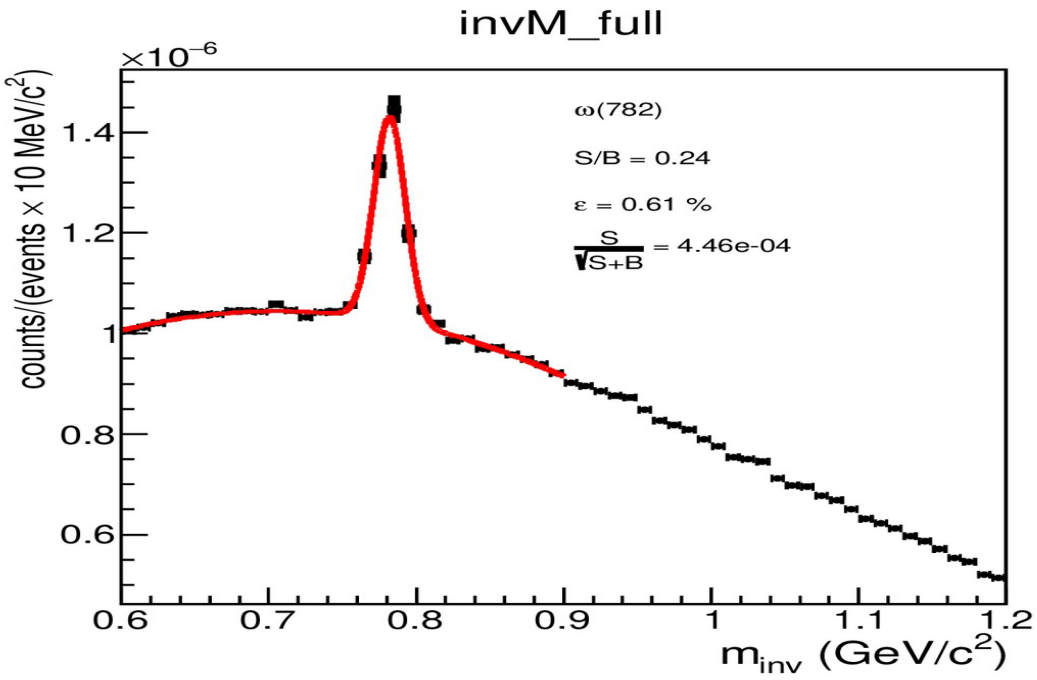
- TOF Mass
- Momentum
- No of MuCh Hits
- No of STS Hits
- No of TRD Hits
- No of TOF Hits
- Chi2Much(χ^2_{MuCh})
- Chi2STS (χ^2_{STS})
- Chi2Vertex(χ^2_{Vertex})



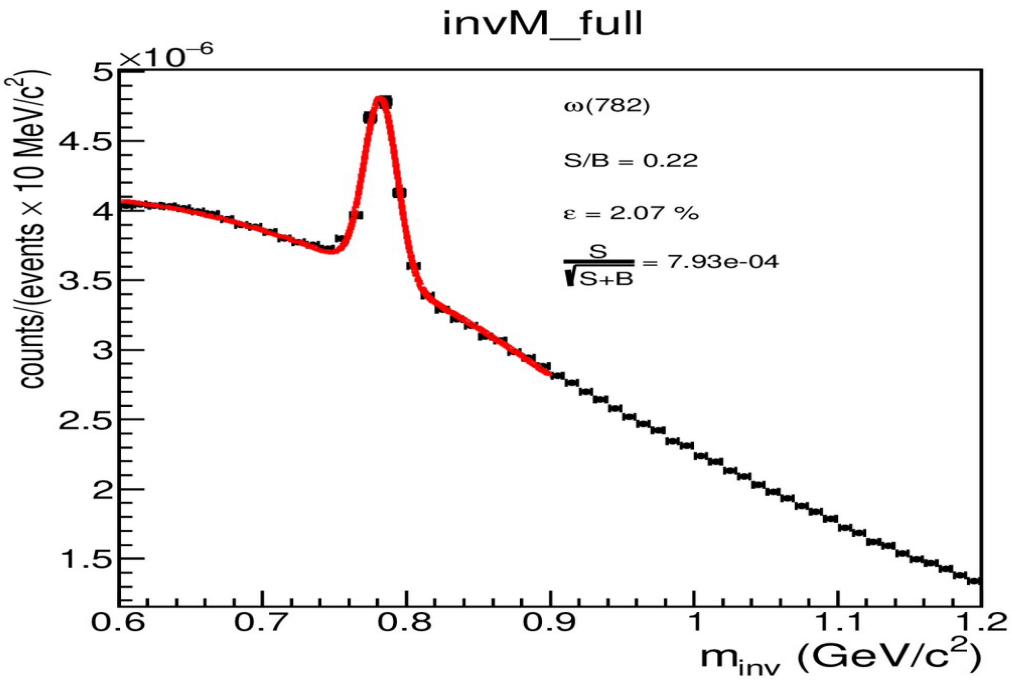
- **Various ML models like BDTG, KNN, Hmatrix have been tested.**
- **Among them BDTG model performs the best.**

Invariant Mass Omega meson($\omega \longrightarrow \mu^+ + \mu^-$)

Manual Selection Cuts



BDTG-1 response cut at 0.65

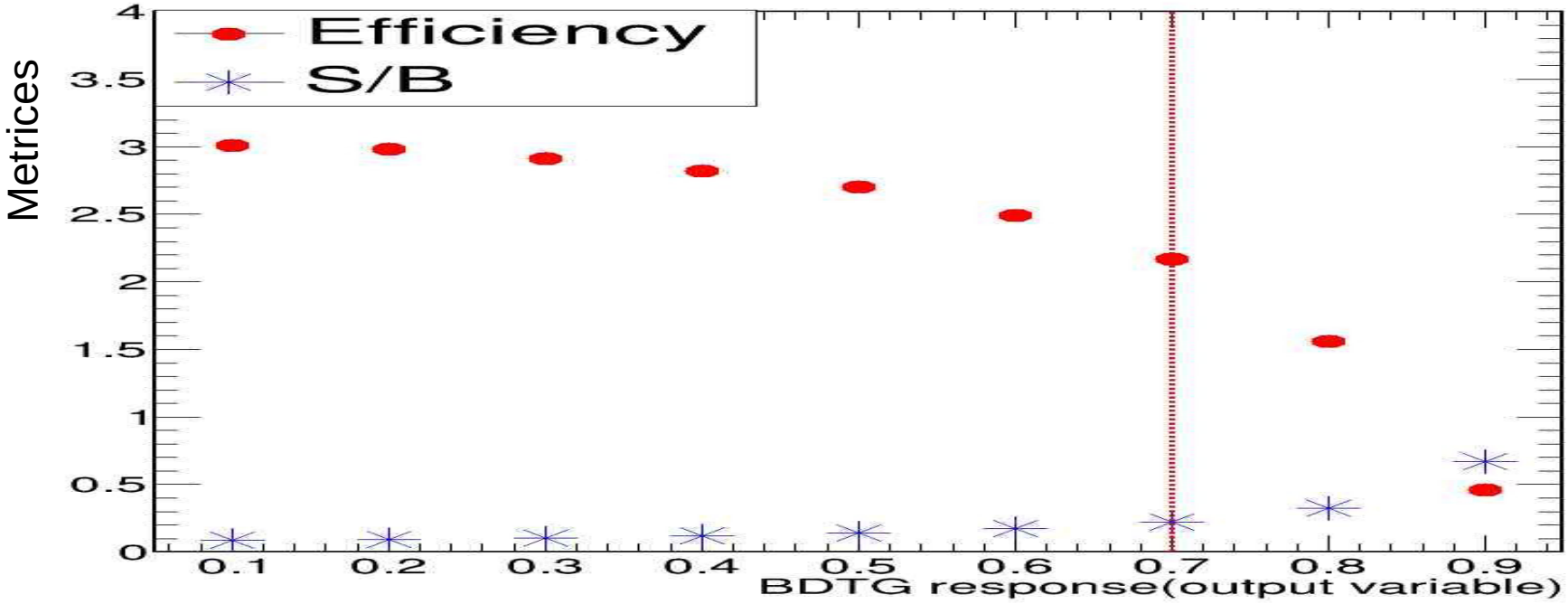


***Following selection cuts were used**: Number of MuCh hits > 11, Number of STS hits > 7, Number of TRD hit > 1, Number of TOF hits > 1, $\chi^2_{MuCh} < 3$, $\chi^2_{STS} < 2$, $\chi^2_{vertex} < 2.5$, SigmaToFCut=2.

***Following selection cuts were used for ML**: Number of MuCh hits > 8, Number of STS hits > 5, Number of TRD hits > 1, Number of TOF hits > 1, $\chi^2_{MuCh} < 20$, $\chi^2_{STS} < 20$, $\chi^2_{vertex} < 20$, SigmaToFCut=2.

For similar S/B ratio(0.22), efficiency with BDTG is 3.4 times more than manual cuts.

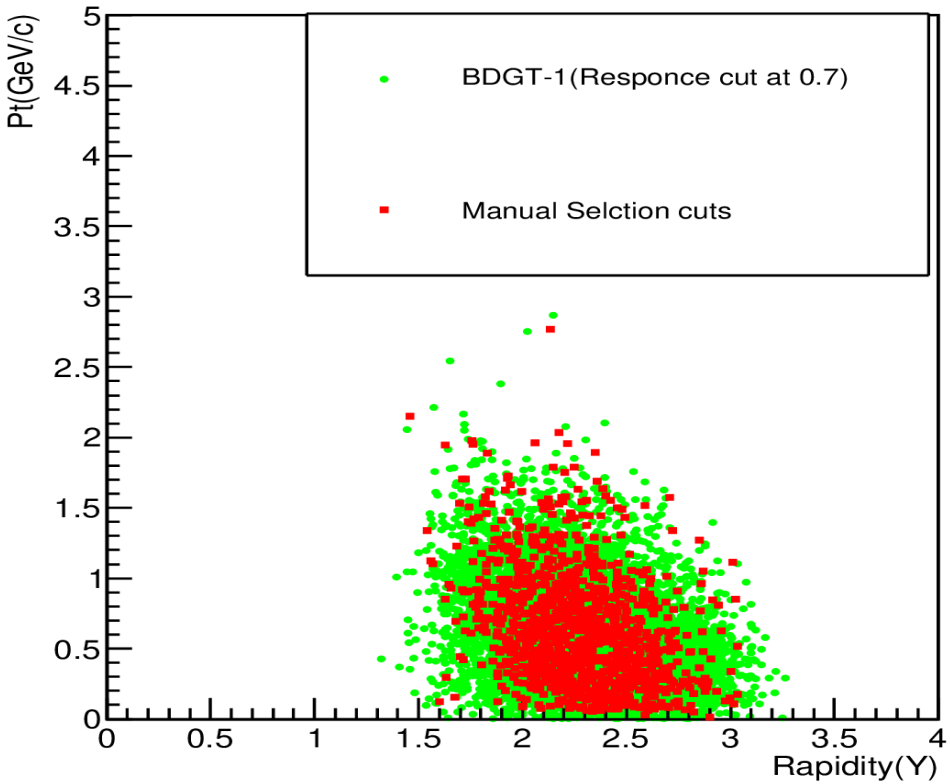
Efficiency & S/B for different BDTG response or output variable



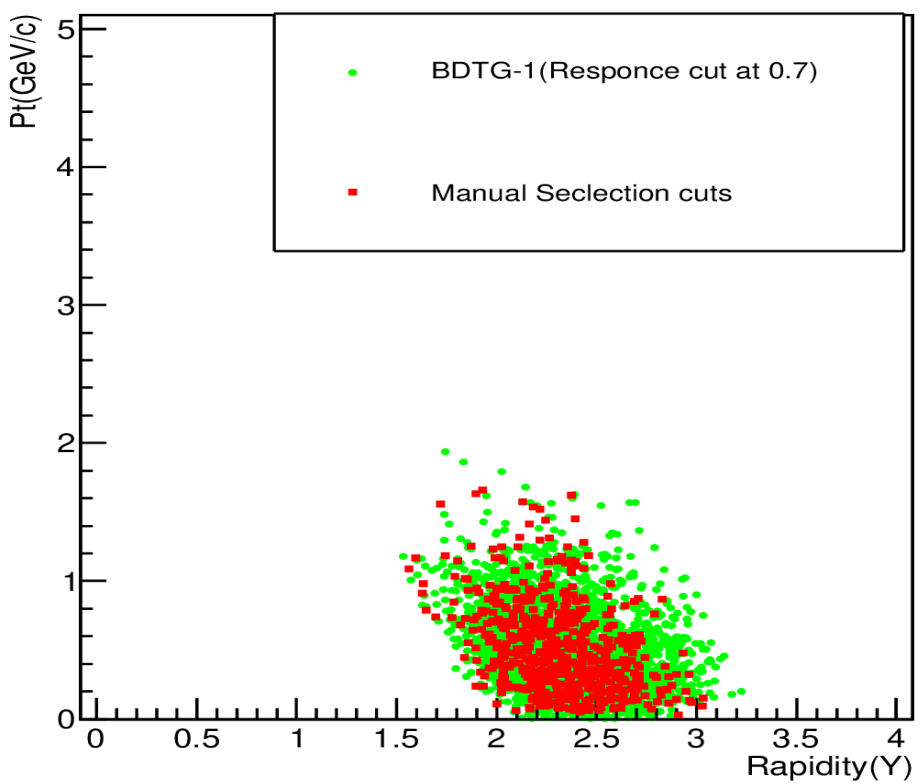
- **Selected response cut on BDTG is 0.7(dashed red line), S/B = 0.22 & eff= 2.07%**

Y-P_t distribution ω meson

Manual selection cuts & BDTG



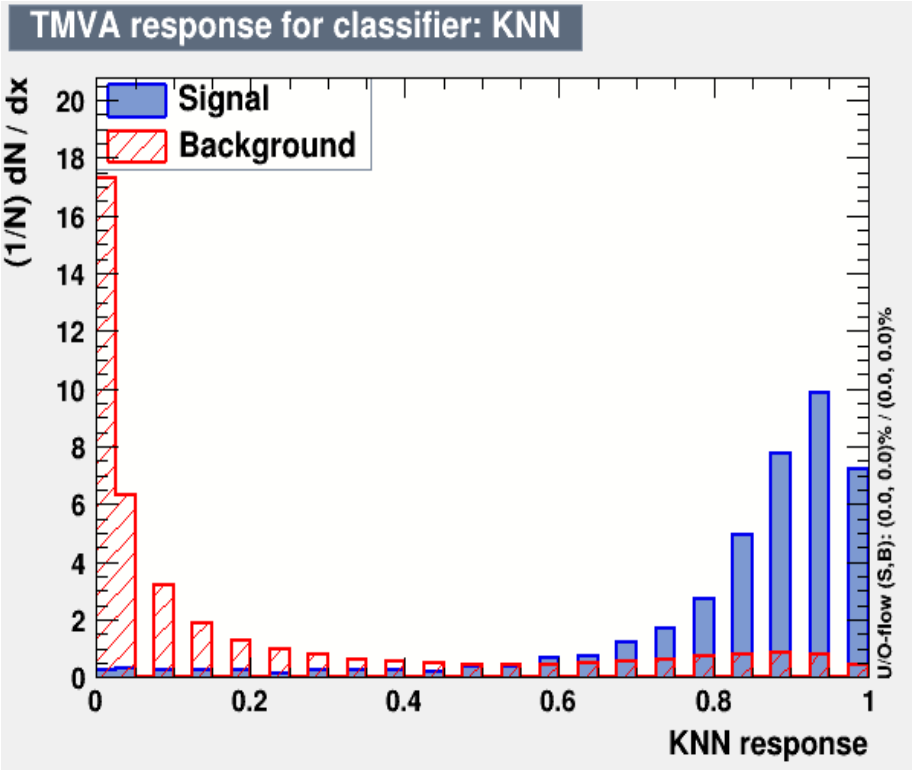
Manual selection cuts & BDTG with TrueMuon cut



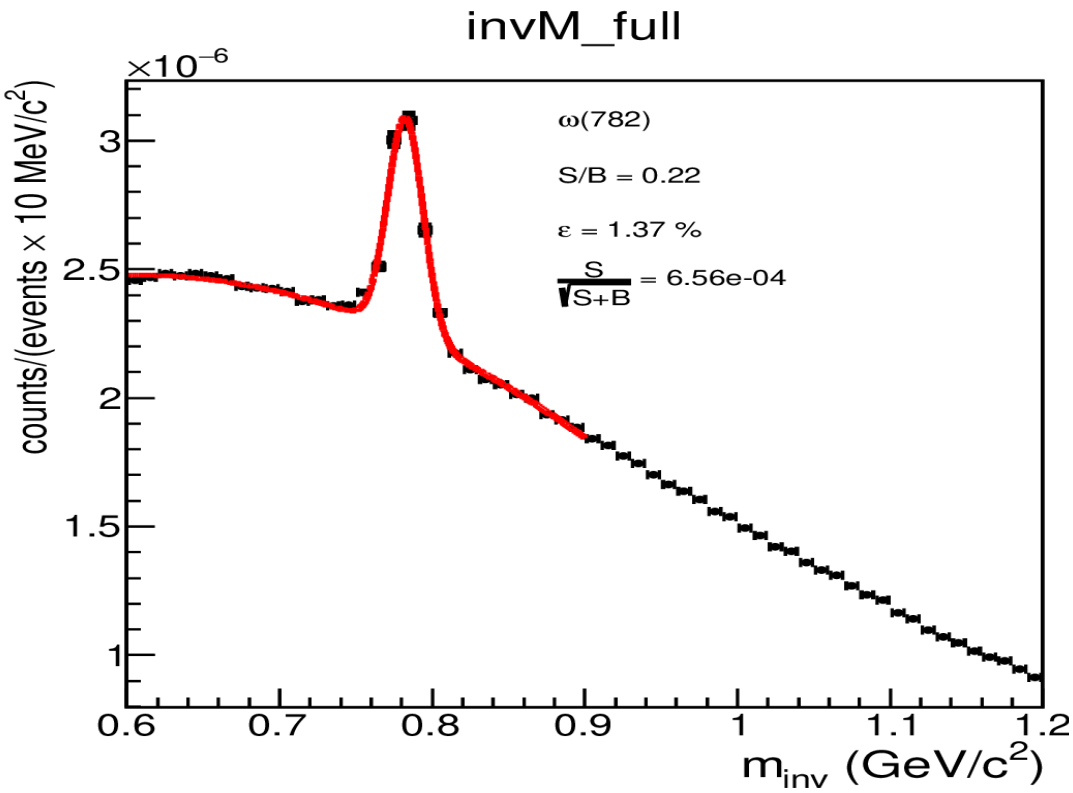
- **Extended phase space coverage with BDTG model in comparison with traditional cut analysis.**
- **The low rapidity values is absent after applying True Muon cuts.**

Invariant mass spectra of Omega using kNN

Separability



kNN(response cut at 0.88)

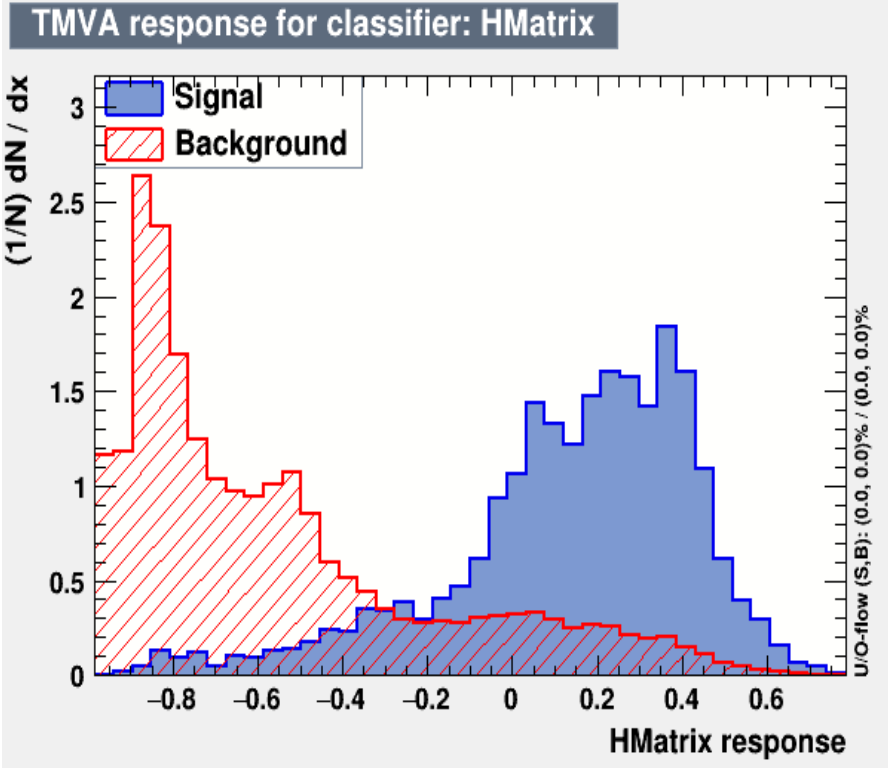


Following selection cuts were used for ML: Number of MuCh hits > 8, Number of STS hits > 5, Number of TRD hits > 1, Number of TOF hits > 1, $\chi^2_{MuCh} < 20$, $\chi^2_{STS} < 20$, $\chi^2_{vertex} < 20$, SigmaToFCut=2.

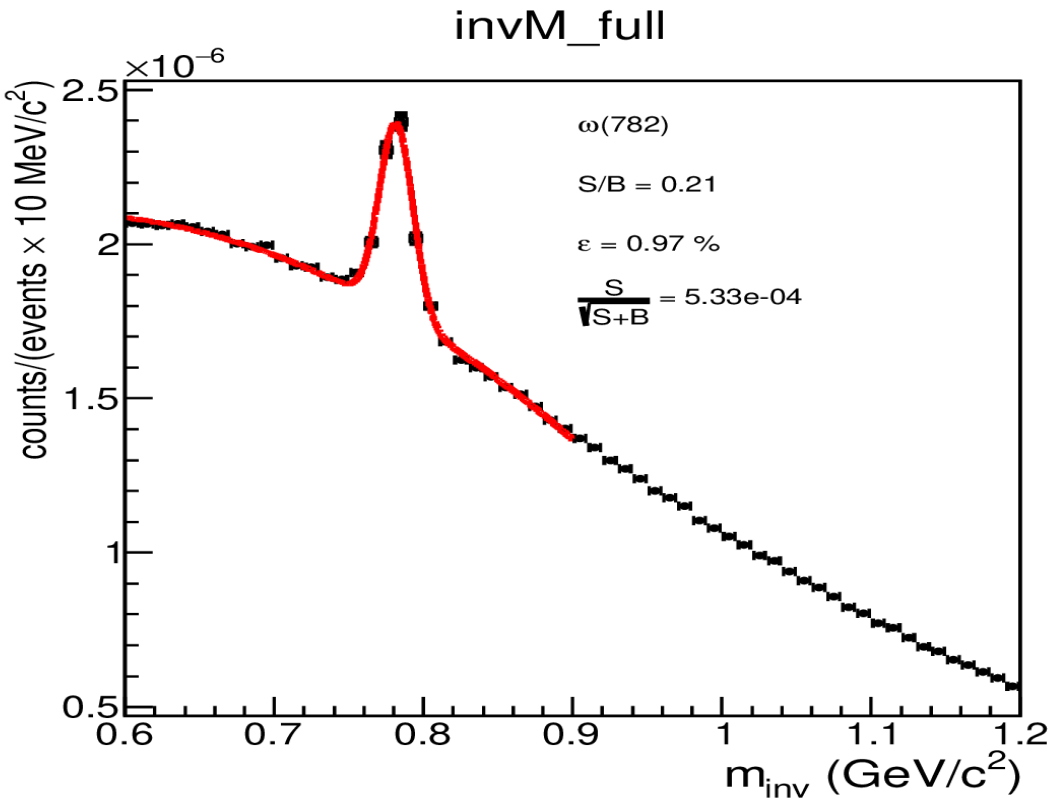
- **For similar S/B ratio(0.22), efficiency with kNN is 2.24 times more than manual cuts**

Invariant mass spectra of Omega using HMatrix

Separability



HMatrix(response cut at 0.18)

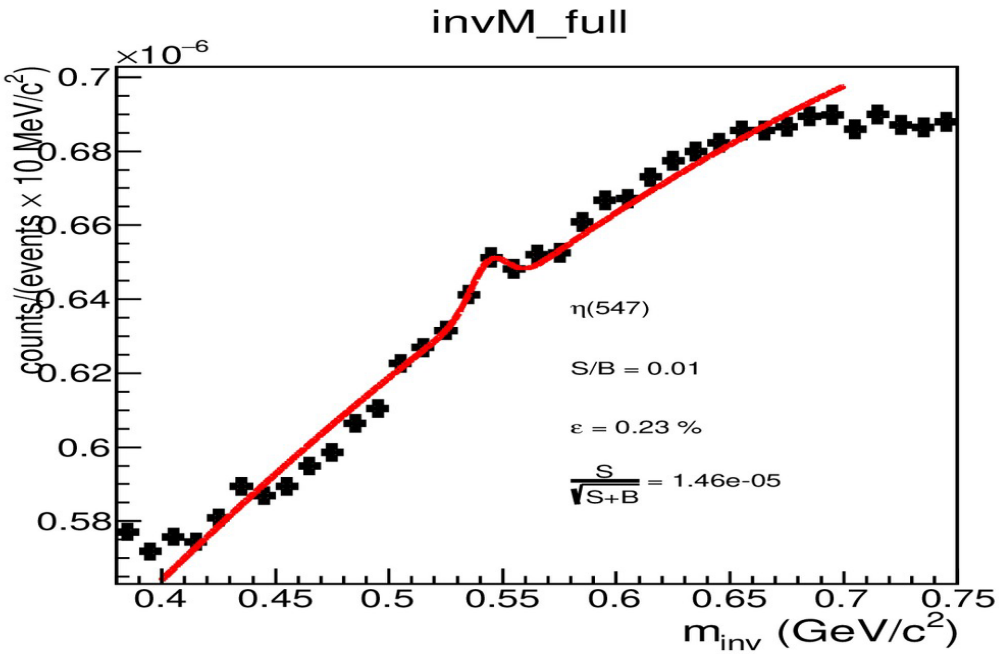


Following selection cuts were used for ML: Number of MuCh hits > 8, Number of STS hits > 5, Number of TRD hits > 1, Number of TOF hits > 1, $\chi^2_{MuCh} < 20$, $\chi^2_{STS} < 20$, $\chi^2_{vertex} < 20$, SigmaToFCut=2.

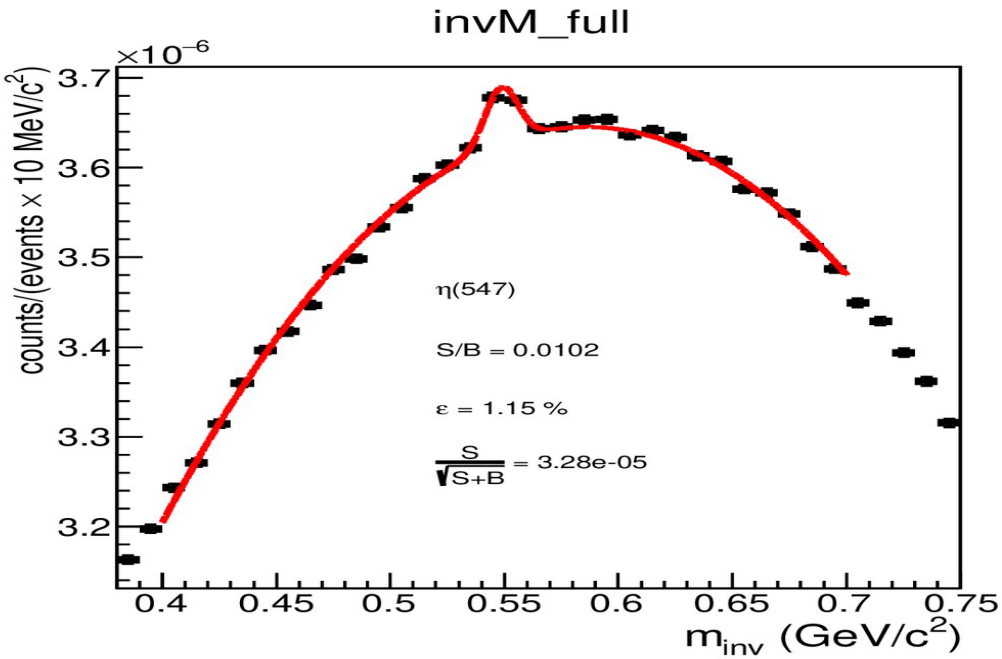
- **For similar S/B ratio(0.21), efficiency with HMatrix is 1.59 times more than manual cuts**

Invariant Mass of Eta meson($\eta \longrightarrow \mu^+ + \mu^-$)

Manual Selection Cuts



BDTG-1 response cut at 0.7



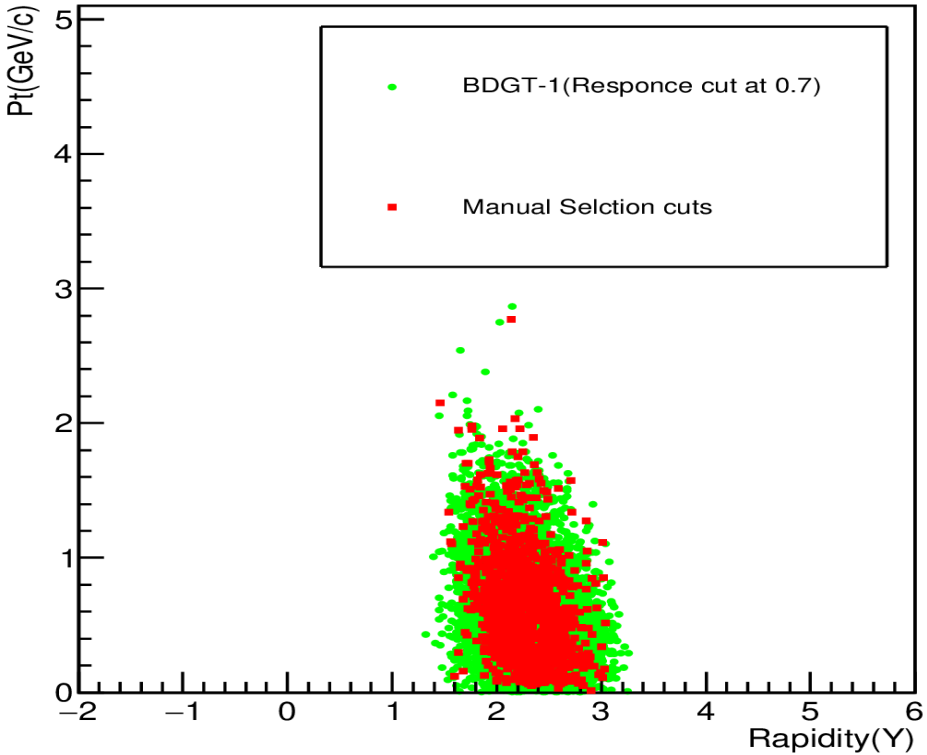
***Following selection cuts were used**: Number of MuCh hits > 11, Number of STS hits > 7, Number of TRD hit > 1, Number of TOF hits > 1, $\chi^2_{MuCh} < 3$, $\chi^2_{STS} < 2$, $\chi^2_{vertex} < 1.1$, SigmaToFCut=2.

***Following selection cuts were used for ML**: Number of MuCh hits > 8, Number of STS hits > 5, Number of TRD hits > 1, Number of TOF hits > 1, $\chi^2_{MuCh} < 20$, $\chi^2_{STS} < 20$, $\chi^2_{vertex} < 20$, SigmaToFCut=2.

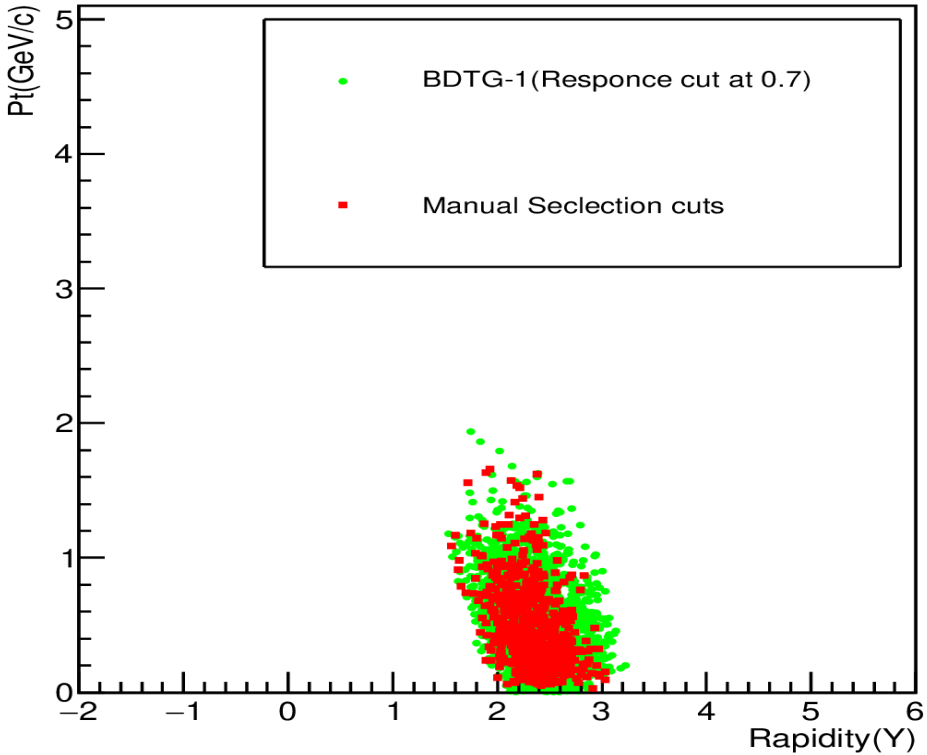
- **For similar S/B ratio(0.01), efficiency with BDTG is 5.0 times more than manual cuts**

Y-P_t distribution η meson

Manual selection cuts & BDTG



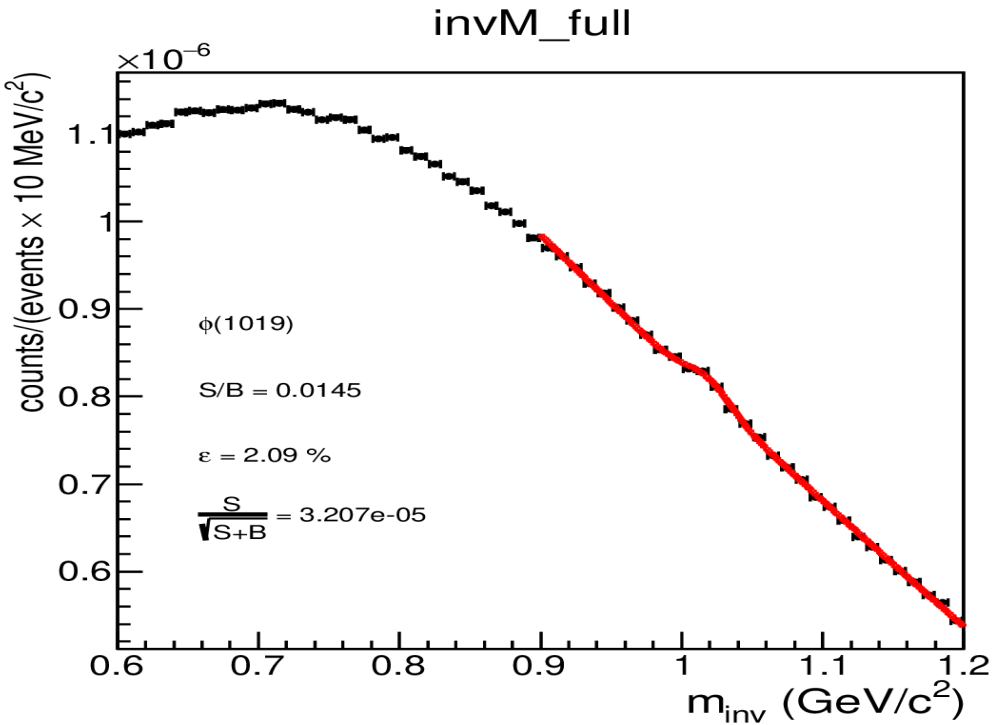
Manual selection cuts & BDTG with TrueMuon cut



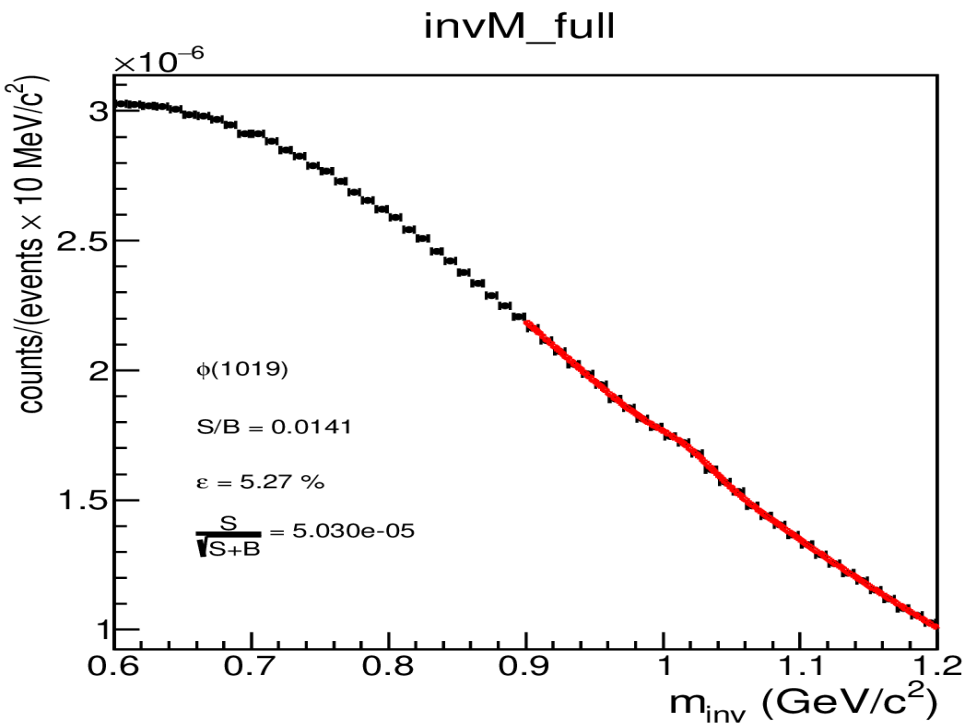
- **Extended phase space coverage with BDTG model in comparison with traditional cut analysis.**
- **The low rapidity values is absent after applying True Muon cuts.**

Invariant Mass Phi Meson ($\phi \longrightarrow \mu^+ + \mu^-$)

Manual Selection Cuts



BDTG-1 response cut at 0.71



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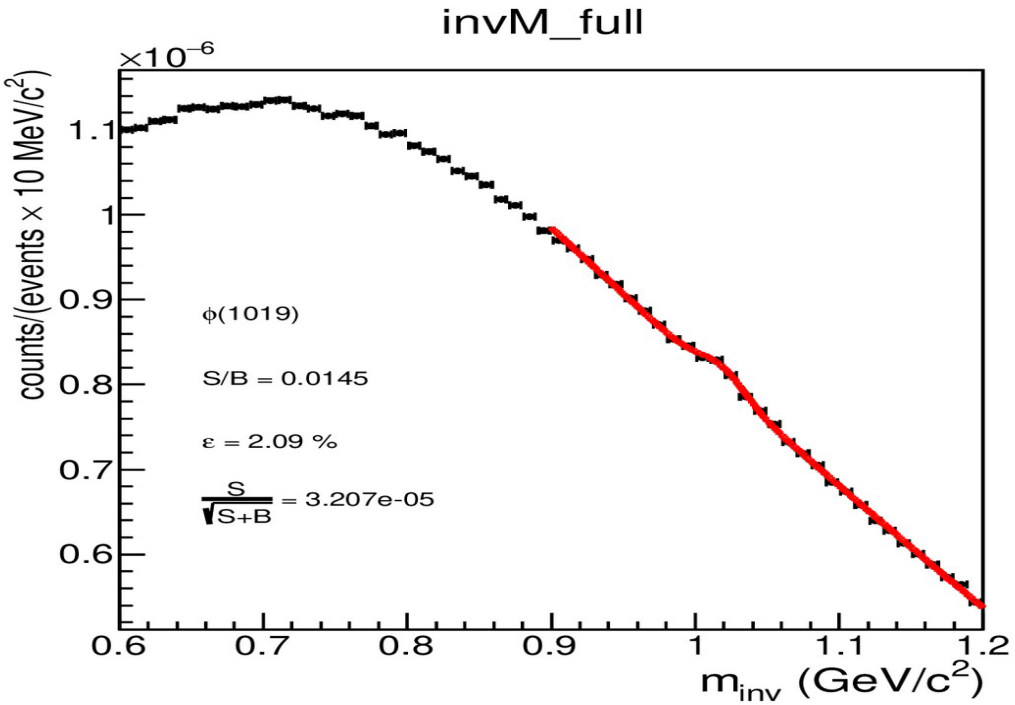
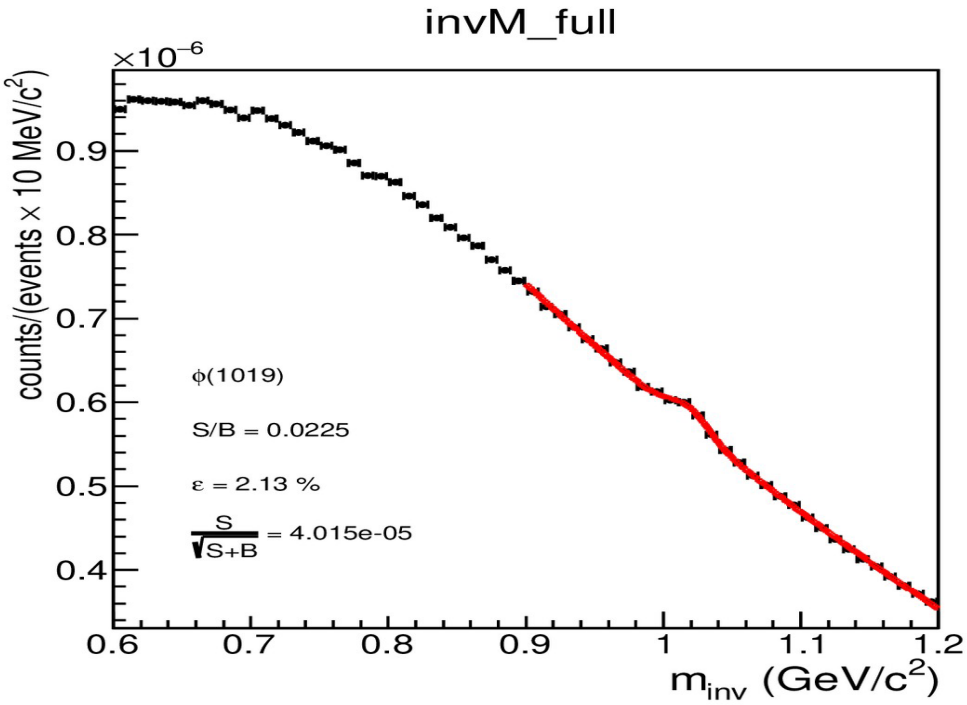
- **For similar S/B ratio(0.01), efficiency with BDTG is 2.52 times more than manual cuts**

Invariant Mass Phi Meson ($\phi \longrightarrow \mu^+ + \mu^-$)

Manual Selection Cuts



BDTG-1 response cut at 0.83



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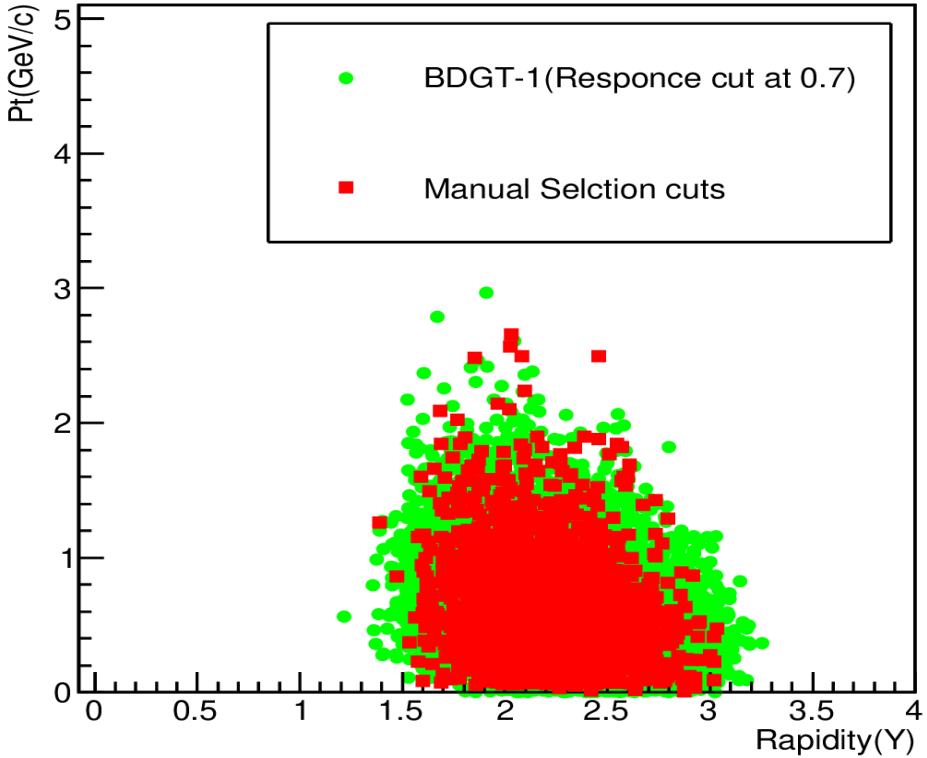
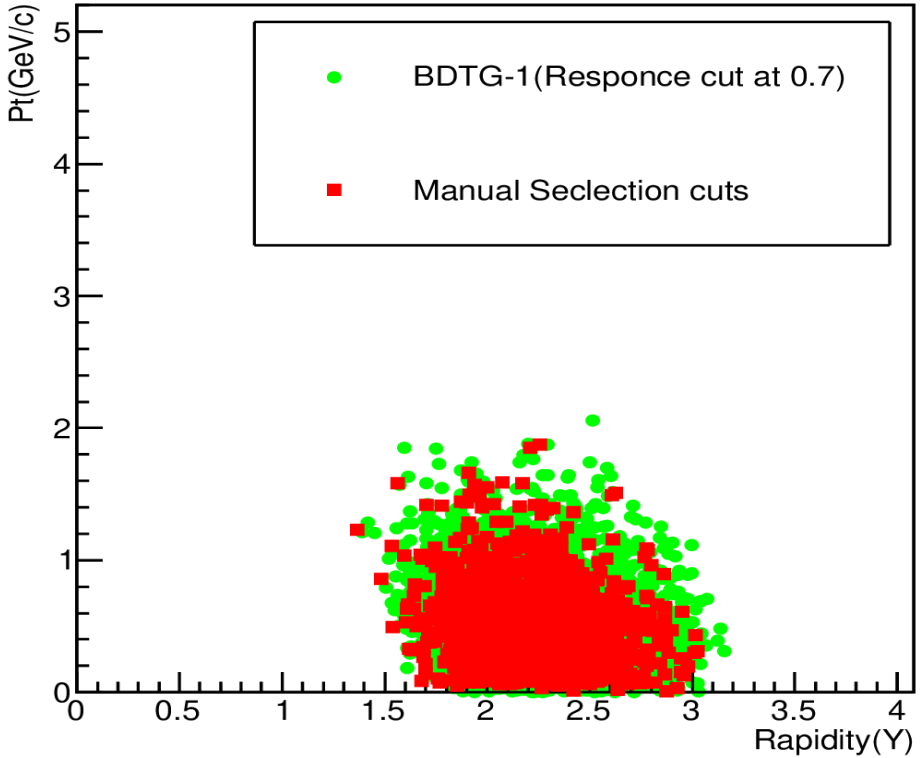
- **For similar efficiency, S/B ratio with BDTG is 1.55 times more than manual cuts**

Y-P_t distribution ϕ meson

Manual selection cuts & BDTG



Manual selection cuts & BDTG with TrueMuon cut



- **Extended phase space coverage with BDTG model in comparison with traditional cut analysis.**
- **The low rapidity values is absent after applying True Muon cuts.**