π^0 and extra energy reconstruction performances

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8th Belle II Italian meeting

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Outline

- New photons and pi0s physics lists in software release-01-00
- Performances of the pi0s in BB generic events in different bkg conditions (phase III BGx0 and BGx1, phase II)
- Dedicated extra clusters and pi0 cleaning against beam background with MVA

New π^0 lists in release-01-00

- Definition of photons and π^0 lists with fixed efficiency (max purity) based on energy, dt99 (time containing 99% of the signal), E1/E9 and invariant mass cuts

https://stash.desy.de/projects/B2/repos/software/browse/analysis/scripts/stdPhotons.py

- Lists optimized for Phase II backgrounds: "pi0eff20", 30, 40, 50, 60. Details in the Torben's talk at the last B2GM:

https://kds.kek.jp/indico/event/25459/session/10/contribution/137/material/slides/0.pdf

- Evaluate efficiency/purity and resolution in generic BB samples in Phase II and Phase III (bgx0 and bgx1)

$$\varepsilon = \frac{n(\gamma\gamma)_{matched\ \&\ sel}}{n(\pi^0)_{truth}}$$

$$P = \frac{n(\gamma\gamma)_{matched\ \&\ sel}}{n(\gamma\gamma)_{sel}}$$

matched: photons coming from pi0 and with $E_{reco} > 50\%\ E_{true}$

sel: selected by the pi0 list (in ECL acceptance)

truth: MC pi0s

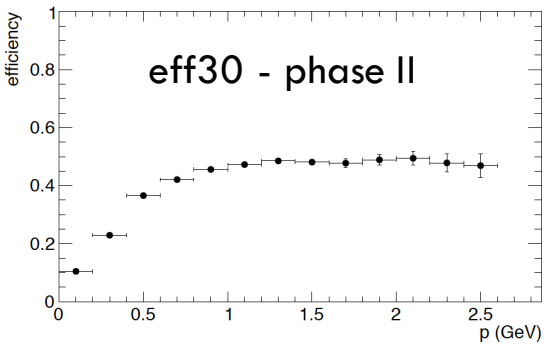
π^0 efficiency and purity

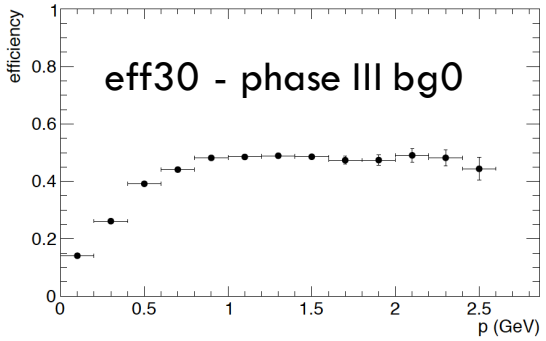
efficiency (%) / purity (%)	eff30	eff40	eff50
Phase II – bg1	26 / 39	36 / 30	63 / 10
Phase III – bg0	29 / 42	41 / 33	61 / 10
Phase III – bg1	19 /30	27 / 18	61 / 4

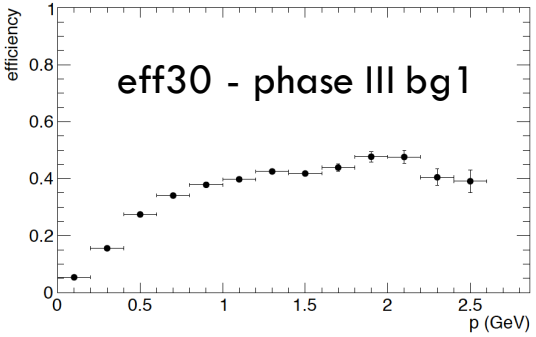
looser cuts

- Phase II and Phase III bg0 have similar performances
- Phase III – bg1: lower efficiency and purity

efficiency vs momentum



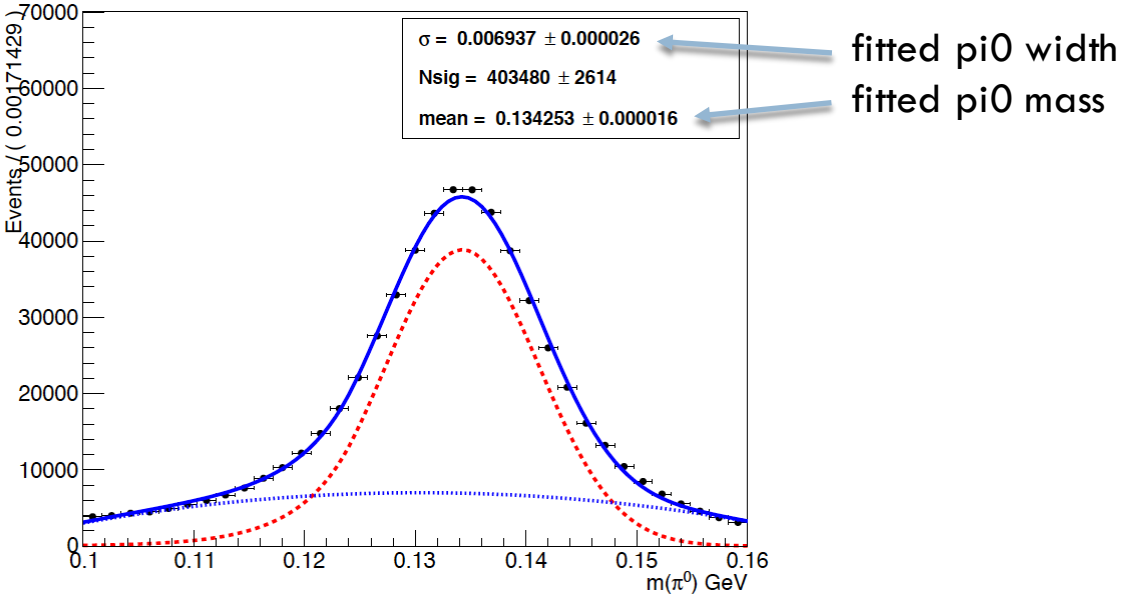




π^0 resolution

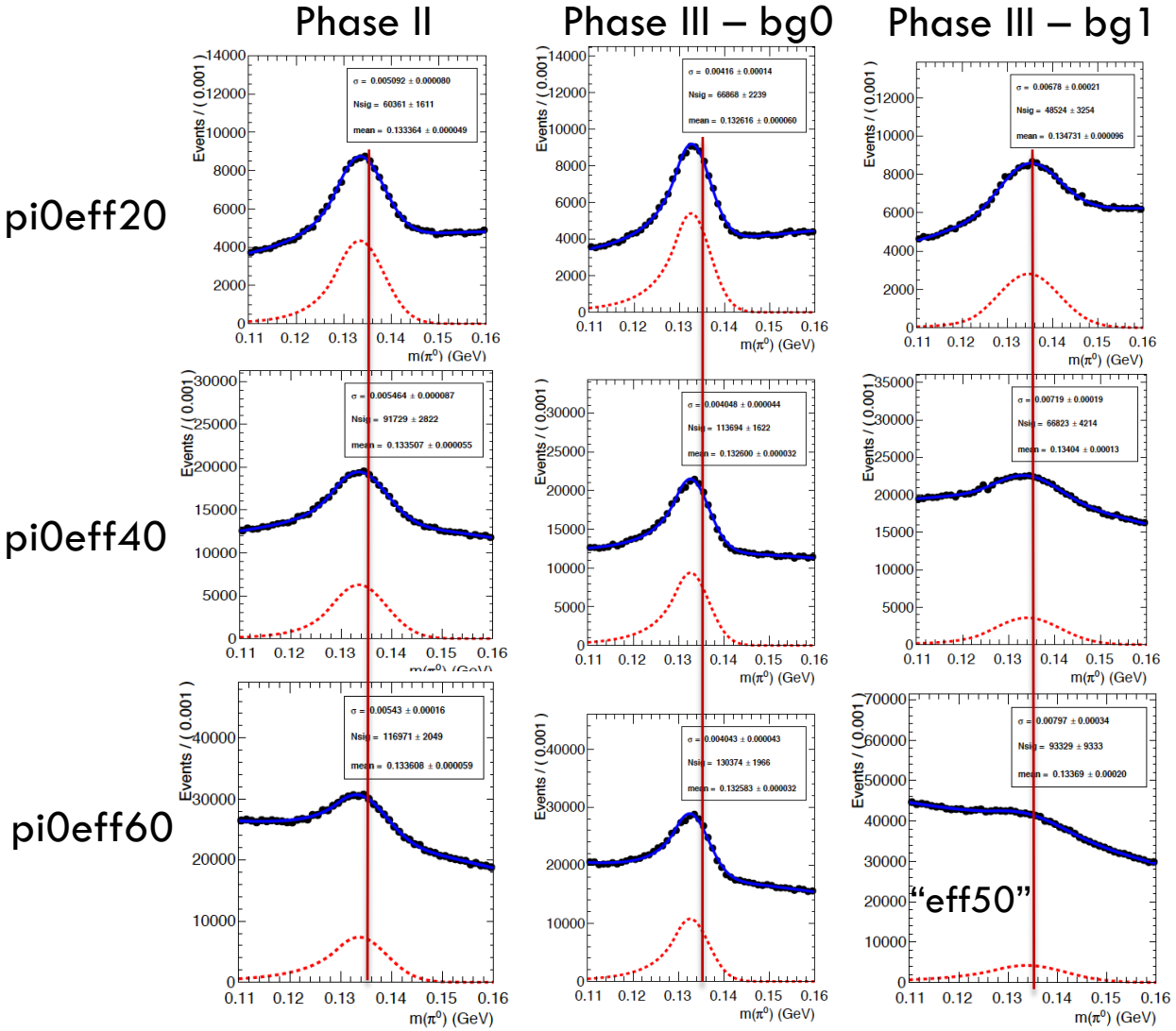
Mass fit with Crystal Ball (signal) + 2nd order Chebyshev polynomial (bkg)

π^0 mass invariant mass (true π^0)



- In the next slide: π^0 resolution for eff20, eff40 and eff60 lists, in Phase II and Phase III (bgx0, bgx1)

π^0 resolution



σ (MeV)	eff20	eff40	eff60
phase II – bg1	5.0	5.5	5.4
phase III – bg0	4.2	4.0	4.0
phase III – bg1	6.8	7.2	8.0 (eff50)

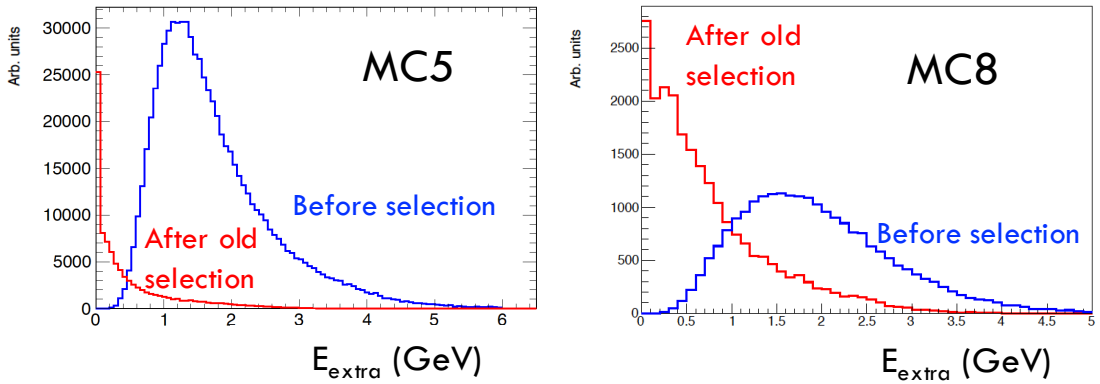
- Reasonable resolution, sensitive to bkg level
- Expected small shift in the central mass value towards lower π^0 mass due to photon low energy tails

Extra clusters and π^0 selection optimization with MVA

Extra clusters cleaning and π^0 selection optimization

- The aim of the study is to reject beam background and clean up the π^0 reconstruction and the E_{extra} distribution for physics studies
- Start from the $B \to \tau\nu$ analysis reconstruction: B-tag reconstruction (with Full Event Interpretation) + 1 track on the signal side (e, μ, π or $\pi\pi^0$)
- Old selection with rectangular cuts on cluster energy and absolute timing can be found here: Physics Pi0 and extra clusters cleaning
  - Problems: it does not take into account the correlations among the cluster variables and it is weak against beam bkg increase -> new MVA classifiers trained for the extra clusters and pi0s

E_{extra} in $B \to \tau\nu$ events with the old selection: worse performance with higher beam background



MVA setup

- Define two photon categories:
  - Beam background photons (photons failing MC matching, no MC photon corresponding to the reconstructed one) as background
  - Physics photons (photons with correct MC ID) as signal

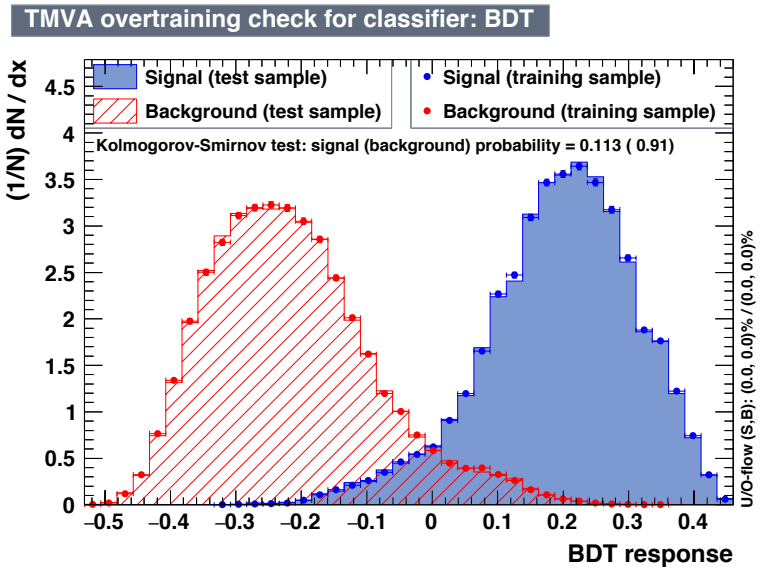
- Consider the following cluster variables: energy, absolute timing, dt99 (time containing 99% of the signal), cluster theta and phi, number of crystals in the cluster, lateral energy distribution (LAT), E1/E9 or E9/E21, and Zernike moments (account for energy distribution in a plane perpendicular to the shower)

- Train a BDT with $B \rightarrow \tau\nu$ events from MC9 production bgx1 (using TMVA)

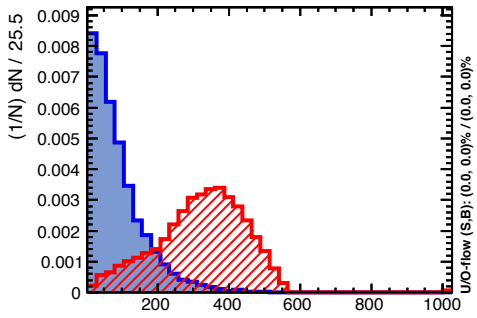
- Optimize / tune the training options in order to get the highest BDT classifier ROC integral with overtraining under control

Extra clusters MVA

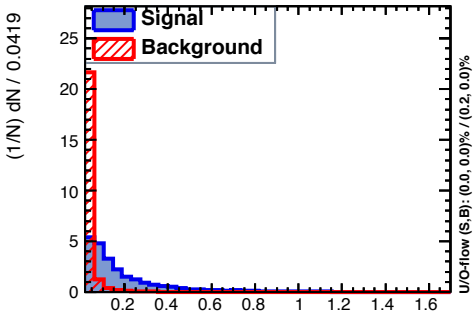
BDT output classifier for signal (physics photons) and background (photons from beam)



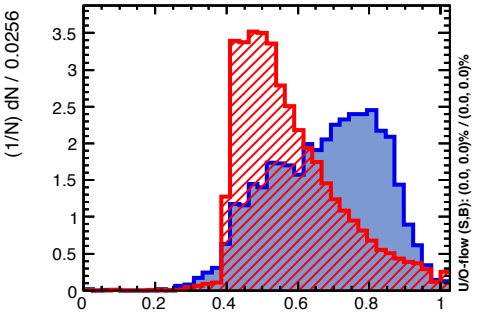
Most important variables



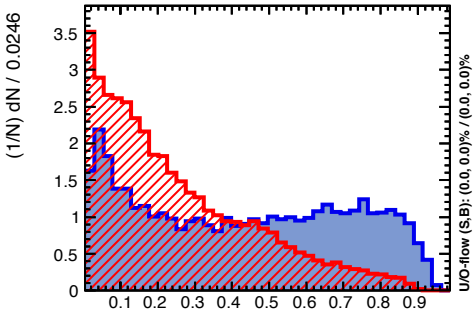
dt99 (ns)



Energy (GeV)



E1 / E9



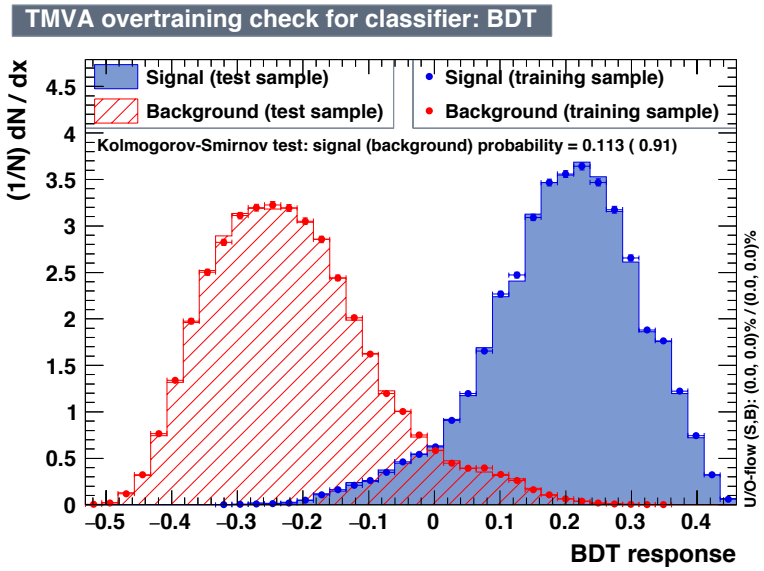
Zernike MVA

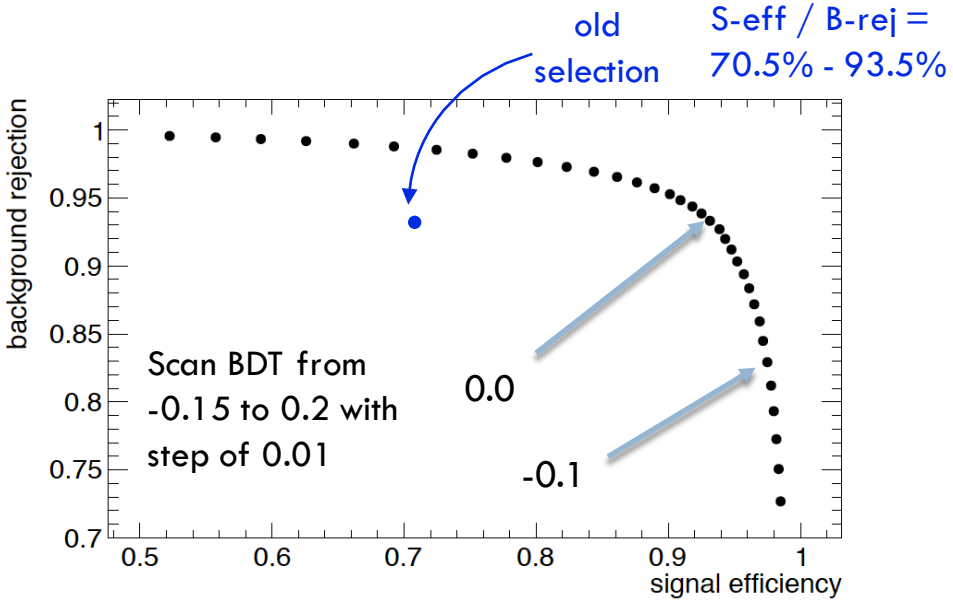
Variables correlation:

- Shower shape variables slightly correlated (E1/E9, Zernike and LAT)
- Some level of correlation between dt99 and the cluster energy

full set of variables and their correlation in the backup slides

Extra clusters MVA: ROC curve





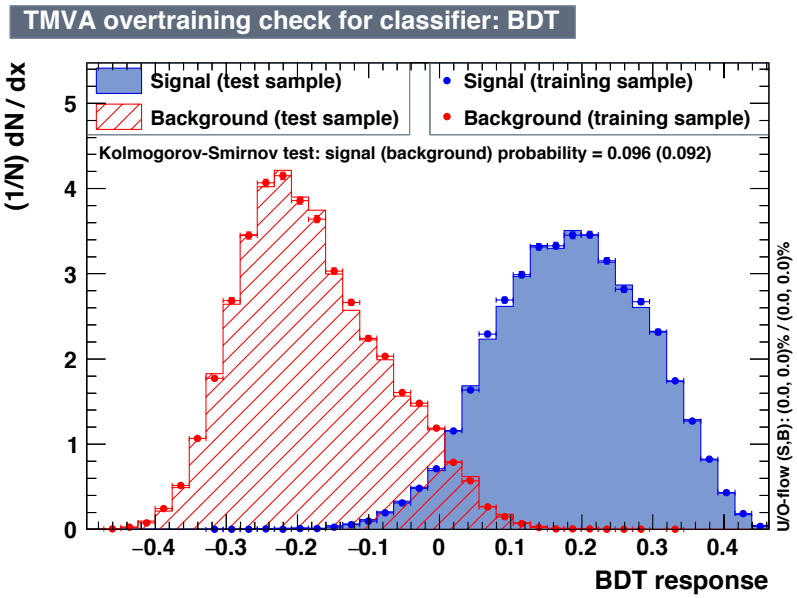
Signal efficiency: N physics photons after BDT cut / Ntot physics photons
Background efficiency: N bkg photons after BDT cut / Ntot bkg photons
Background rejection = 1 - Background efficiency

At same signal efficiency level, we have ε_{bkg}=1.5% with respect to 6.5% of old selection –> ~80% more bkg rejected

To choose the optimal cut point look at the E_{extra} distributions for B–>τν and generic BB (see my talk in the physics session)

π^0 MVA

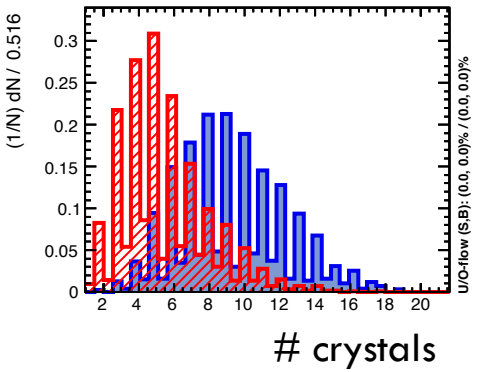
BDT output classifier for signal (physics photons) and background (photons from beam)



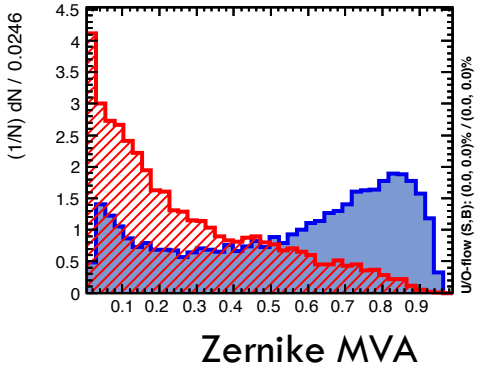
Variables correlation:

- Shower shape variables slightly correlated (E1/E9, Zernike and LAT)
- Number of crystals highly correlated with energy and timing (~60%)

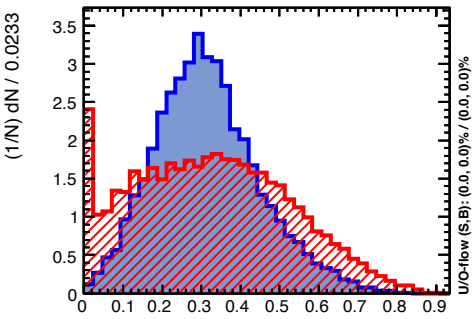
Most important variables



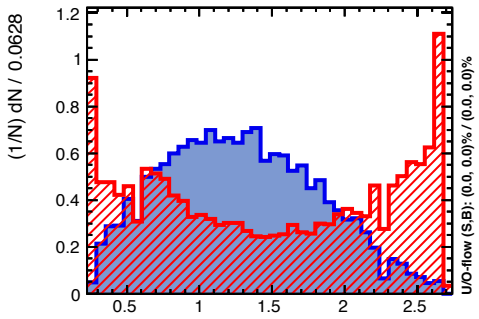
crystals



Zernike MVA



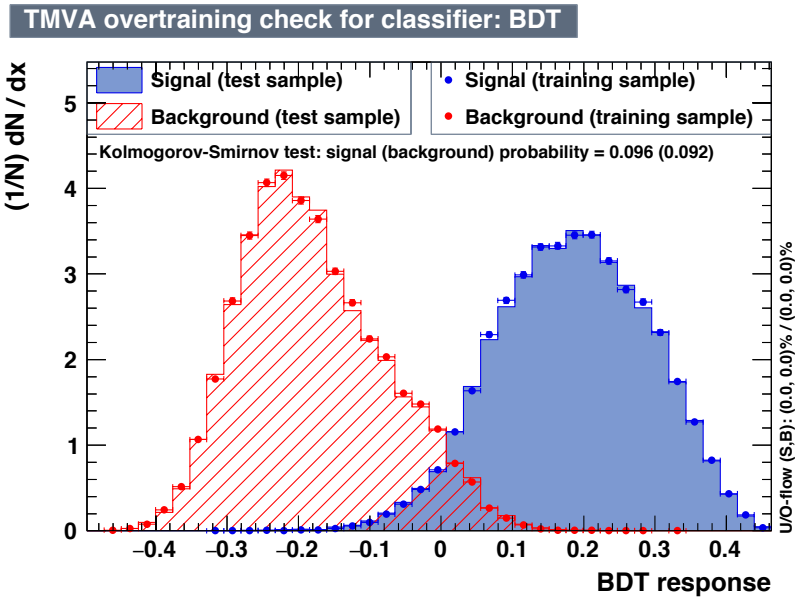
lateral moment



theta

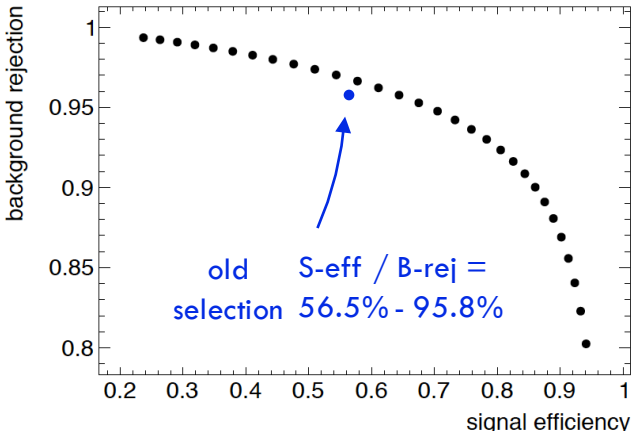
full set of variables and their correlation in the backup slides

π^0 MVA: performances

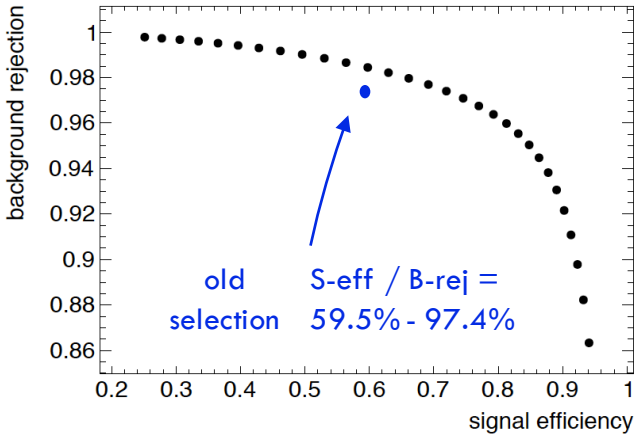


Scan of the BDT from -0.15 to 0.15 with step of 0.01, and plot the signal efficiency vs background rejection

B^+B^- events



$B \to \tau\nu$ events

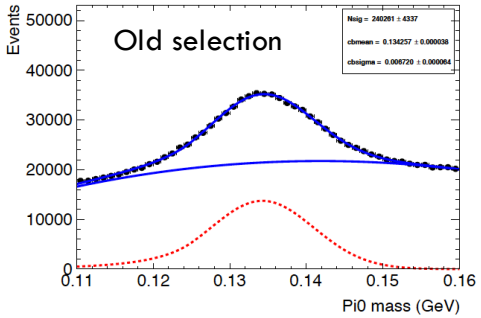


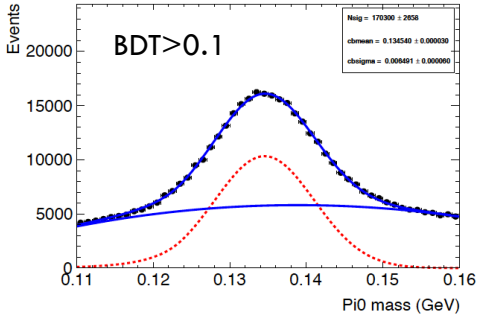
At same signal efficiency level, we have ε_{bkg}=1.5% with respect to 2.6% of old selection –> 40% more bkg rejected

π^0 MVA: resolution

- Crystal ball + 2nd order Chebyshev polynomial fit to the π^0 invariant mass

$B \rightarrow \tau\nu$ events



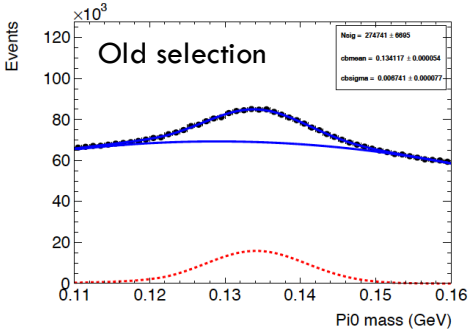


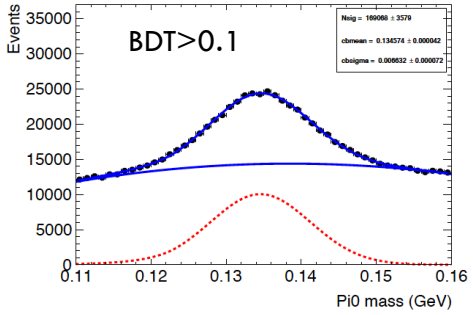
σ (MeV) / peak (MeV)	$B \rightarrow \tau\nu$	BB
Old selection	6.7 / 134.3	6.6 / 134.4
BDT > -0.05	6.8 / 134.2	6.7 / 134.1
BDT > 0.1	6.5 / 134.5	6.6 / 134.6

Impact of the MVA selection

- No sensible effect on the pi0 resolution
- Higher signal efficiency (prev. slide)
- To do: check the impact on the reconstruction of the channel $B \rightarrow \tau\nu \rightarrow (\pi\pi^0\nu)\nu$

BB events





Conclusions

- New π^0 (and photons) physics lists in software release 10: important impact of beam background on performances in Phase III
- π^0 reconstruction is strongly sensitive to kinematics of the particular final state, we need to optimize the selection according to the physics case
- Ad hoc π^0 and extra clusters selection used for $B \to \tau\nu$ and $B \to K^*\nu\nu$ improved with use of MVA: better efficiency and background rejection with stable π^0 resolution (impact on E_{extra} in the physics session)
- To do: understand the possibility to standardise this MVA selection for other analyses usage (easier for extra energy than for π^0)

Backup

Note about MC matching

- Difference between nominal and "measured" efficiency due to the different definitions of mc matching at analysis level and at ecl clusters level
  - at analysis level I simply require that the reconstructed photon has at least 50% of the energy of the true photon ***
  - at ecl cluster level we require that at least 50% of true photon energy is deposited in the crystals belonging to that cluster (crystals can be shared among different clusters)

*** Caveat: the modular analysis MC matching **by default** requires that the fraction of the energy deposited by the MC particle in the crystals belonging to the cluster is at least 20% of the total cluster energy and at least 30% of the true photon energy ⟶ need to be studied and optimized
https://confluence.desy.de/display/BI/Photon+and+ECL+variables

Old photon cuts: summary

Y4S photons

- `E > 58 MeV, abs(clusterTiming) < 18 ns – forward`
- `E > 62 MeV, abs(clusterTiming) < 21 ns – barrel`
- `E > 40 MeV, abs(clusterTiming) < 38 ns – backward`

Extra photons

- `E > 62 MeV, abs(clusterTiming) < 18 ns – forward`
- `E > 60 MeV, abs(clusterTiming) < 20 ns – barrel`
- `E > 56 MeV, abs(clusterTiming) < 44 ns – backward`

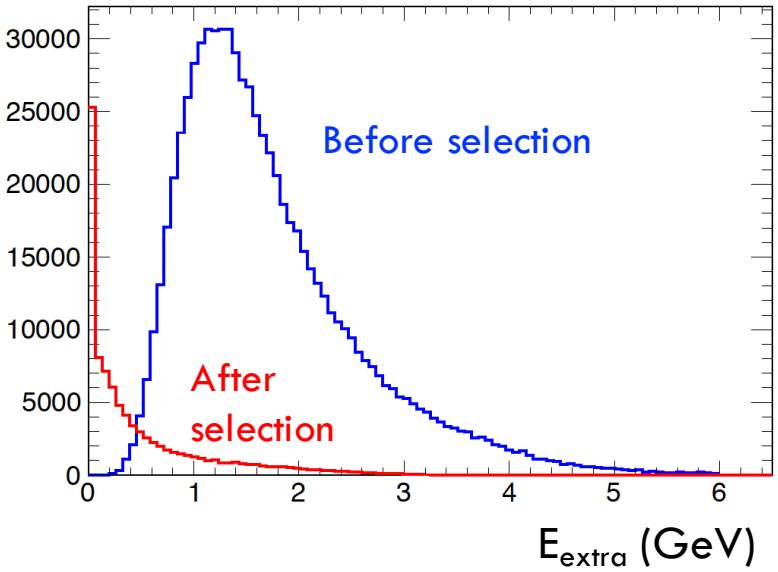
Pi0 efficiency and purity

efficiency (%) / purity (%)	eff20	eff30	eff40	eff50	eff60
Phase II – bg1	14 / 51	26 / 39	36 / 30	63 / 10	68 / 6
Phase III – bg0	16 / 54	29 / 42	41 / 33	61 / 10	66 / 8
Phase III – bg1	11 / 38	19 /30	27 / 18	61 / 4	65 / 1

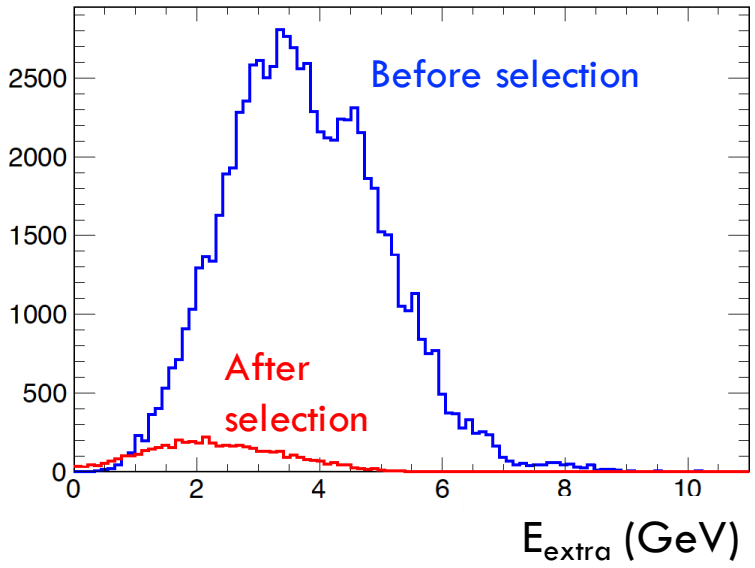
looser cuts

Extra photons cleaning: E_{extra} distribution MC5

signal $B \to \tau\nu$ – BGx1



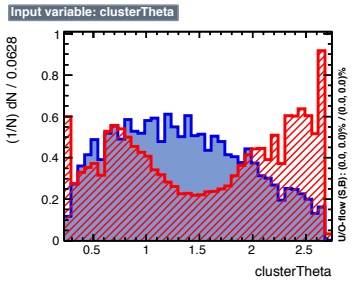
B^+B^- bkg – BGx1

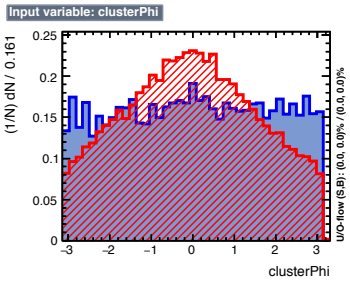


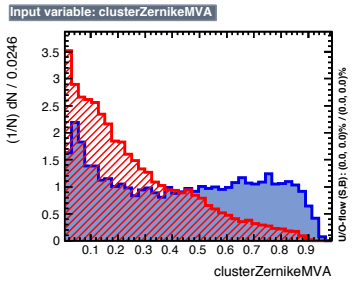
- After cluster cleaning the E_{extra} distribution for signal peaks at zero as expected

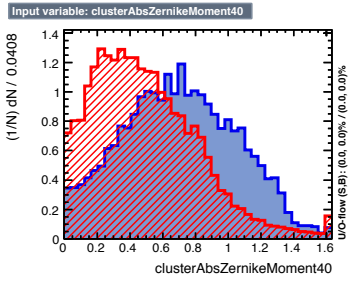
  N.B. no cut on M_{bc} and $|\Delta E|$

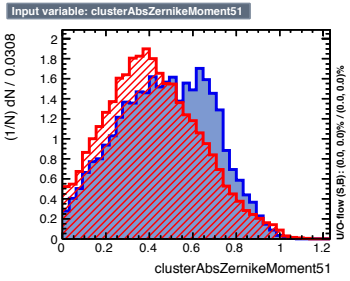
Extra clusters MVA: input variables

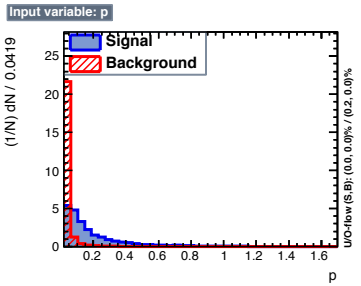


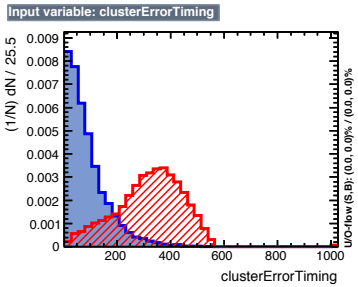


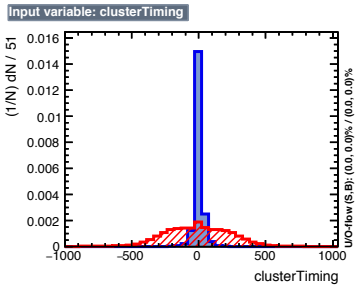


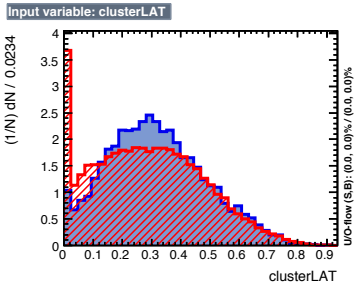


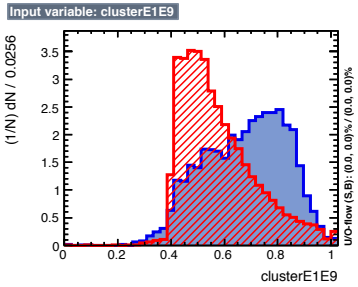


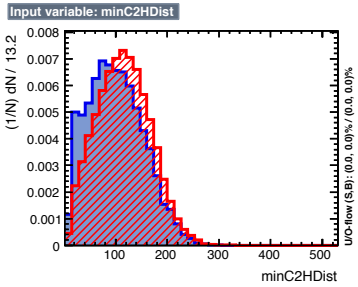










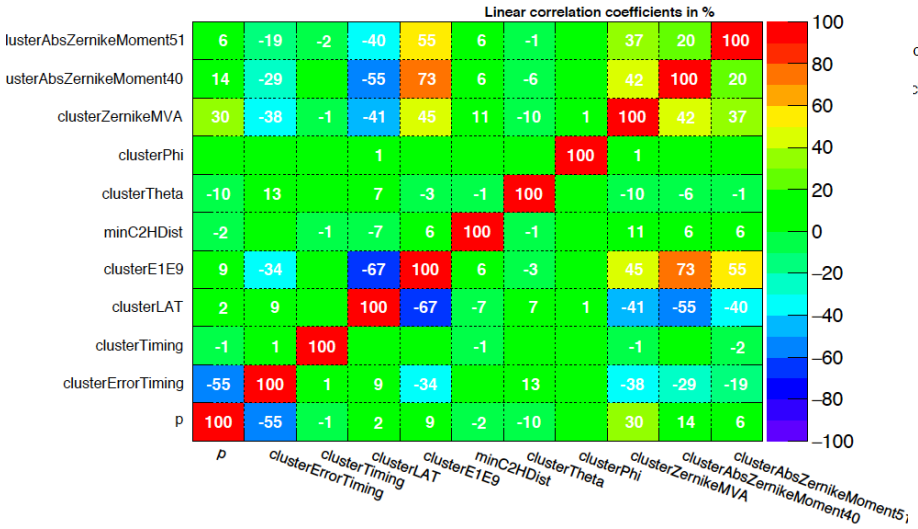


cluster LAT:

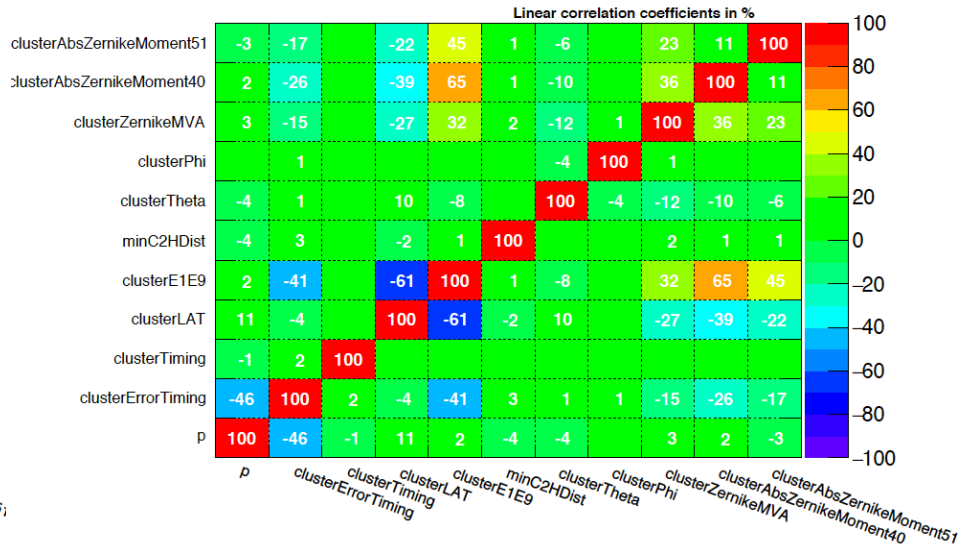
$$S = \frac{\sum_{i=3}^{n} w_i E_i r_i^2}{\sum_{i=3}^{n} w_i E_i + w_0 E_0 r_0^2 + w_1 E_1 r_0^2}$$

Extra clusters MVA: variables correlation

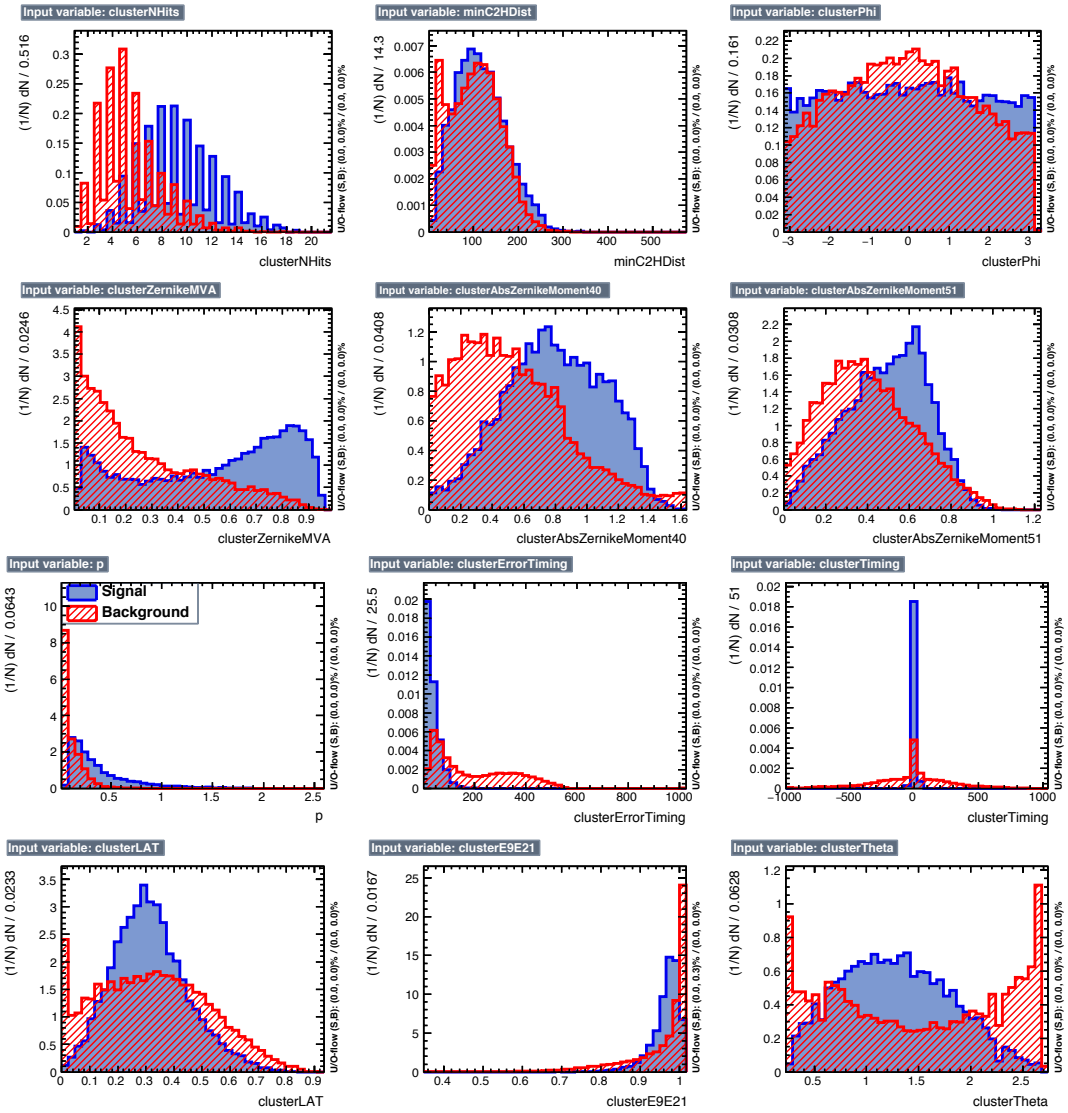
Correlation Matrix (signal)



Correlation Matrix (background)

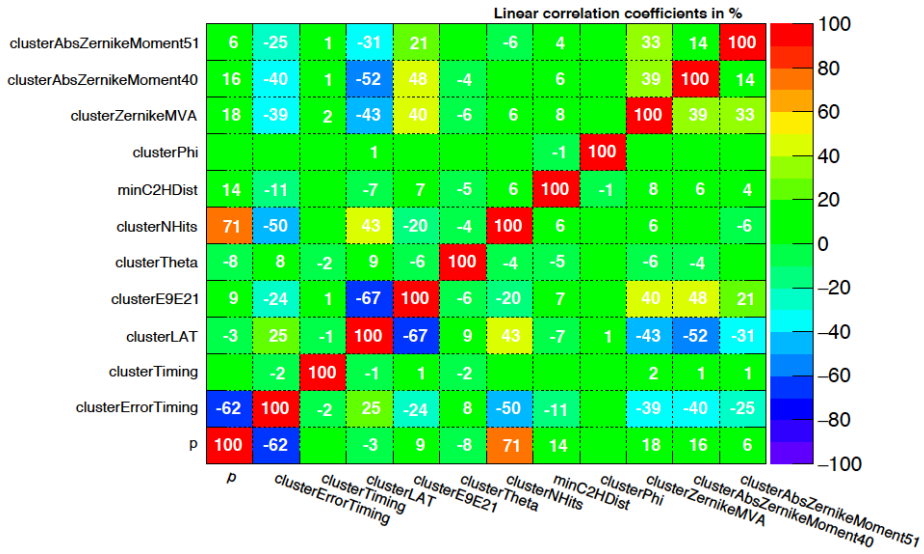


Pi0 MVA

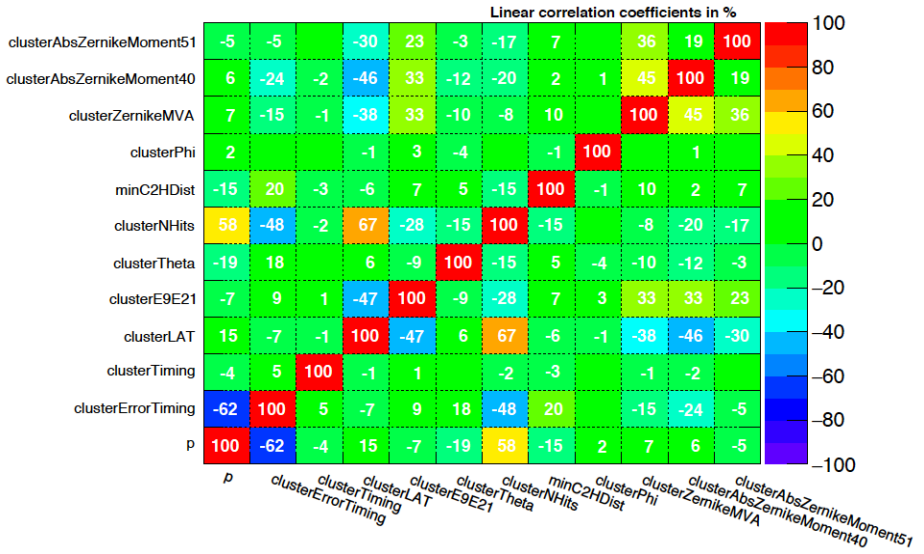

Input variable: clusterNHits
clusterNHits
Input variable: minC2HDist
minC2HDist
Input variable: clusterPhi
clusterPhi
Input variable: clusterZernikeMVA
clusterZernikeMVA
Input variable: clusterAbsZernikeMoment40
clusterAbsZernikeMoment40
Input variable: clusterAbsZernikeMoment51
clusterAbsZernikeMoment51
Input variable: p
Signal
Background
p
Input variable: clusterErrorTiming
clusterErrorTiming
Input variable: clusterTiming
clusterTiming
Input variable: clusterLAT
clusterLAT
Input variable: clusterE9E21
clusterE9E21
Input variable: clusterTheta
clusterTheta

Pi0 MVA: variables correlation

Correlation Matrix (signal)



Correlation Matrix (background)



Systematics

Systematics / real data

- We can use control samples to compare shower shape variables and timing distributions in MC and data.
- Muon pairs / random triggers to study background clusters.
- Hadronic split offs are not so easy.
- But how to put this all together? If cutting on the likelihood in MC gives an efficiency ε, what is the systematic error on ε? Requires much thought.

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