MVA approach to π^0 discrimination in superbeam experiments with LENA

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„To achieve the possible, we must attempt the impossible again and again!“

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Based loosely on *Hermann Hesse*

Outline

- Motivation
- Approach to Problem & Simulation
- MVA parameters
- Preliminary basic MVA results with BDTs
- Summary & Outlook

Motivation

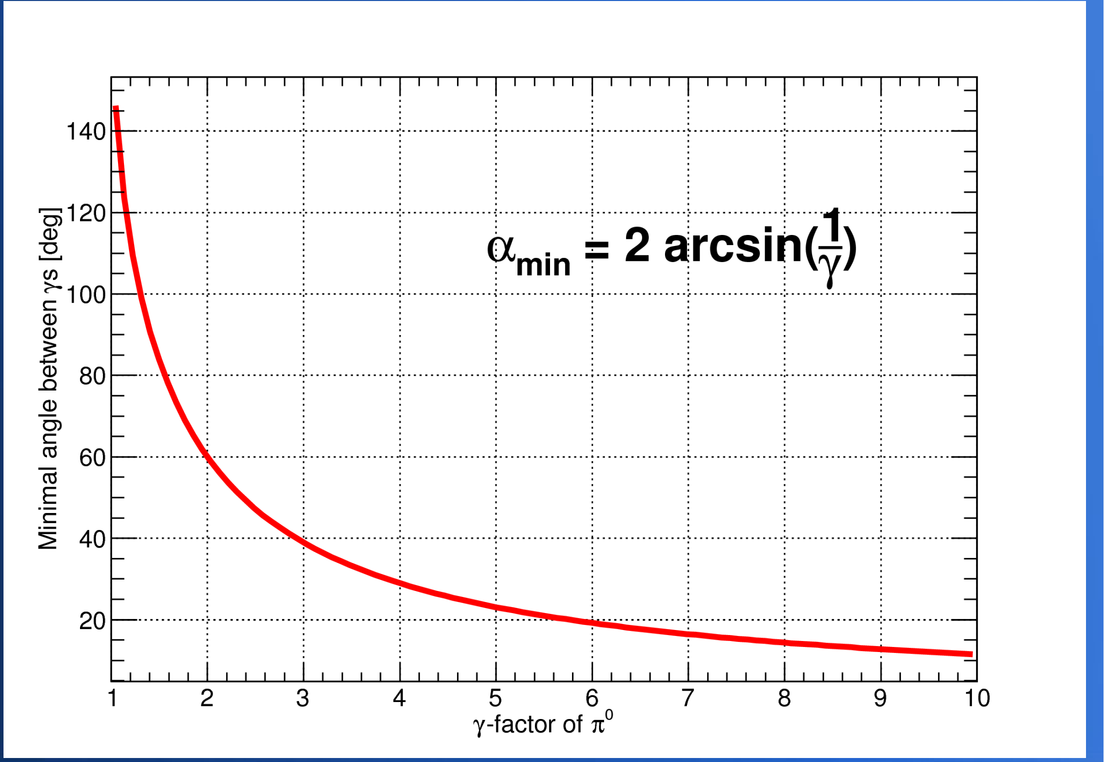
- π^0 's (m ~ 135 MeV) represent a disturbing and dangerous background to $\nu_\mu \rightarrow \nu_e$ ($\bar{\nu}_\mu \rightarrow \bar{\nu}_e$) oscillation search in (super)beam experiments
- π^0 's are created by NC interactions of neutrinos with the target nuclei
  - $\nu + N \rightarrow \nu + \Delta \rightarrow \nu + N + \pi^0$ (resonant)
  - $\nu + A \rightarrow \nu + A + \pi^0$ (coherent)
- Instantaneous ($\tau_{\pi 0} \sim 8 \cdot 10^{-17}$ s) decay of π^0 produces:
  - $\pi^0 \rightarrow \gamma\ \gamma$ (98,8 %)
  - $\pi^0 \rightarrow \gamma + e^+ + e^-$ (1,2 %)

Motivation (II)

- **If only one of the γs becomes detected or the γs cannot be separated, an electron-event is faked!**
- It is a known problem:

  LAr → good spatial resolution to separate γs

  Cherenkov detectors (*MiniBooNE, SK*)
  → fit on visible Cherenkov ring(s)



Approach to Problem

- **What can be done with liquid scintillator?**
  - Fit particle tracks on basis of likelihood analysis
  - Find (weak) discriminating parameters and perform MVA
  - Any other idea?

Approach to Problem

- **What can be done with liquid scintillator?**
  - Fit particle tracks on basis of likelihood analysis
  - <u>Find (weak) discriminating parameters and perform MVA</u>
  - Any other idea?
- Only basic analysis done so far:
  - Simplified (simulation) cases used for MVA
  - “Can one find discriminating parameters for MVA?”
  - NO physics / statistics input (cross-sections etc.)

Simulation

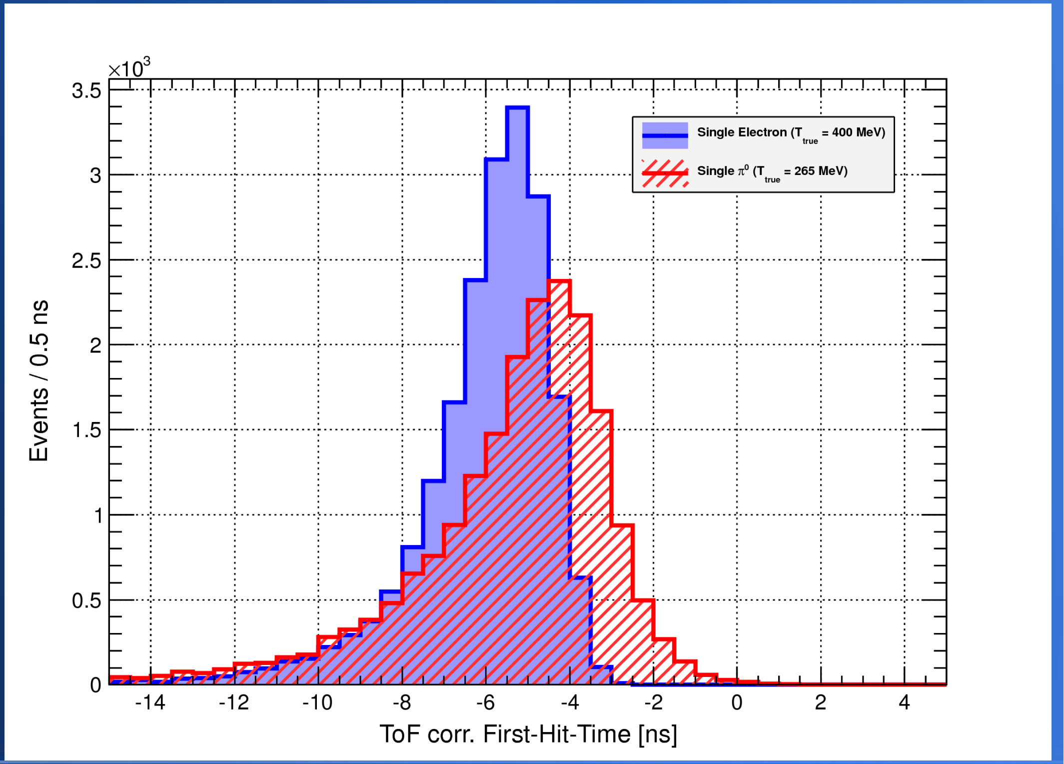
- Geant4 simulation from Munich
  - PXE scintillator, LY: 2000 photons / MeV (20%)
  - 13472 20” PMTs, 1 ns time resolution, 100% QE
- Uniform spectra of
  - 235k e^- (T_{true} : 50 – 1000 MeV)
  - 210k π^0 (T_{true} : 0 – 865 MeV)
- Direct simulation of particles:
  → no “real” neutrino interaction vertices
  → start from centre of detector, momentum in -x direction

MVA parameters

- We are looking for parameters to characterize an event, which differ for π^0 (the γs) and e^- and are ideally uncorrelated.
  - **ToF corrected first-hit time**
  - Parameters from first-hits pulse
    - Relative, maximal pulse height
    - Pulse width
    - Pulse rise & fall
    - Mean time
  - Parameters from “pulse evolution”

ToF corr. first-hit time

- ToF correction with respect to the barycenter
  (Algorithm by D. Hellgartner)
- 20k e^- (T_{true} = 400 MeV) & π^0 (T_{true} = 265 MeV)
- Likely to be an unstable parameter:
  → influence of prim. vertex
  → inclination of track towards central axis
- Further investigation needed



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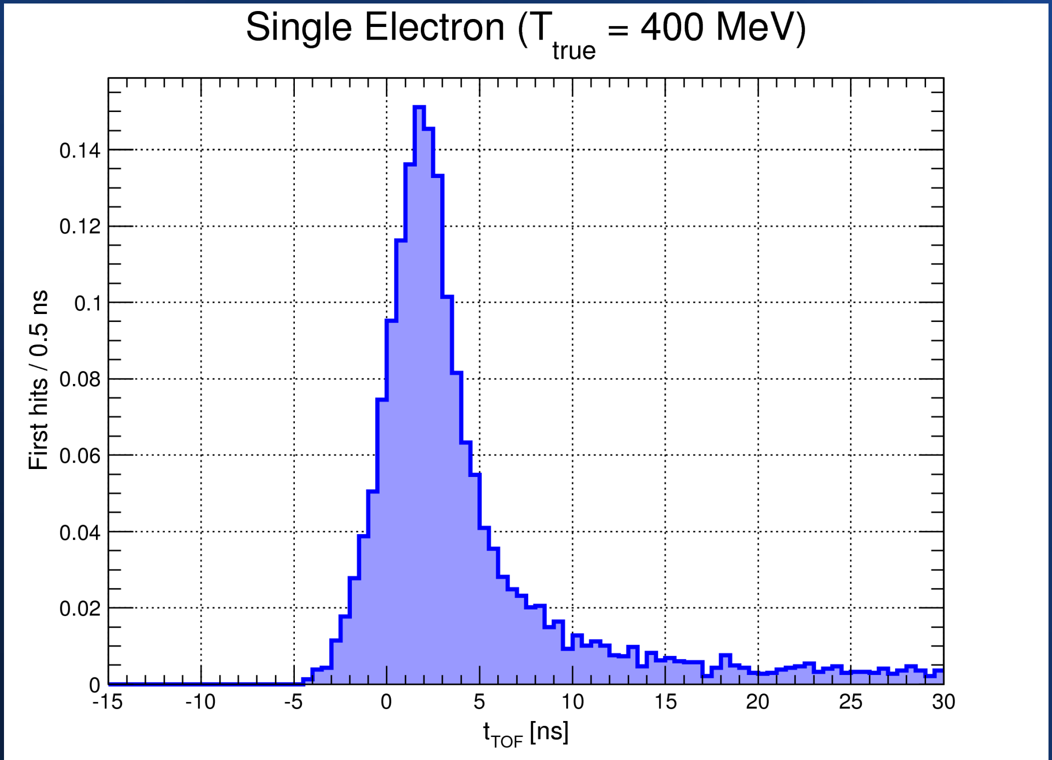
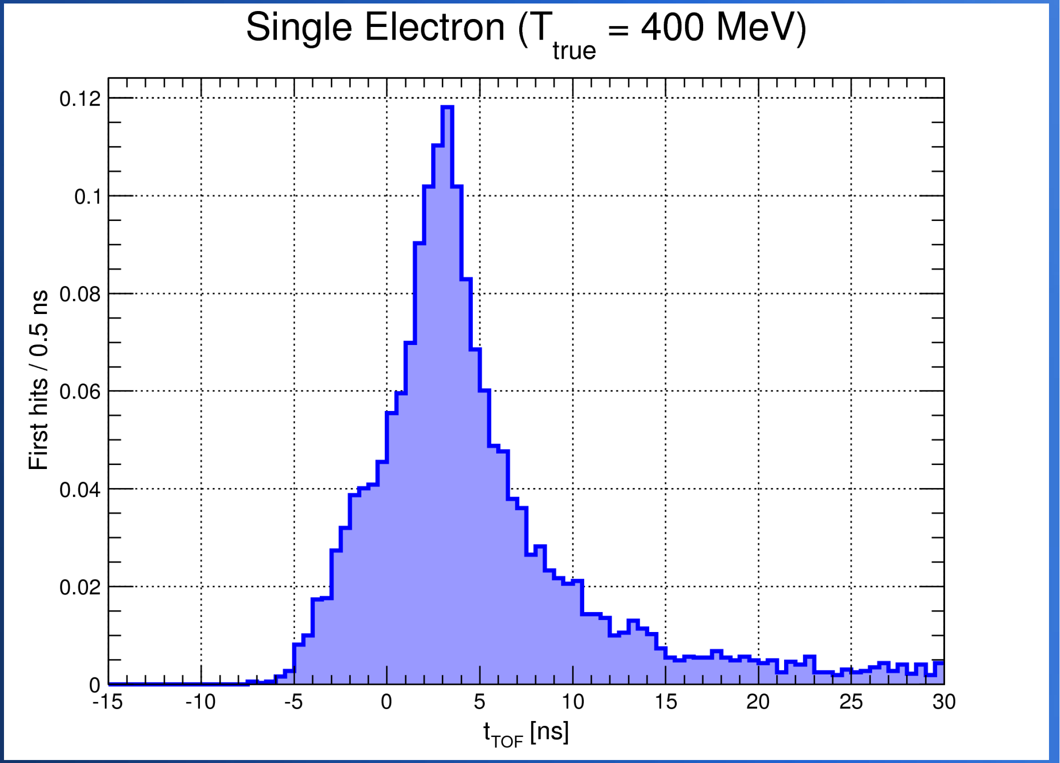
ToF corr. First-hits pulse

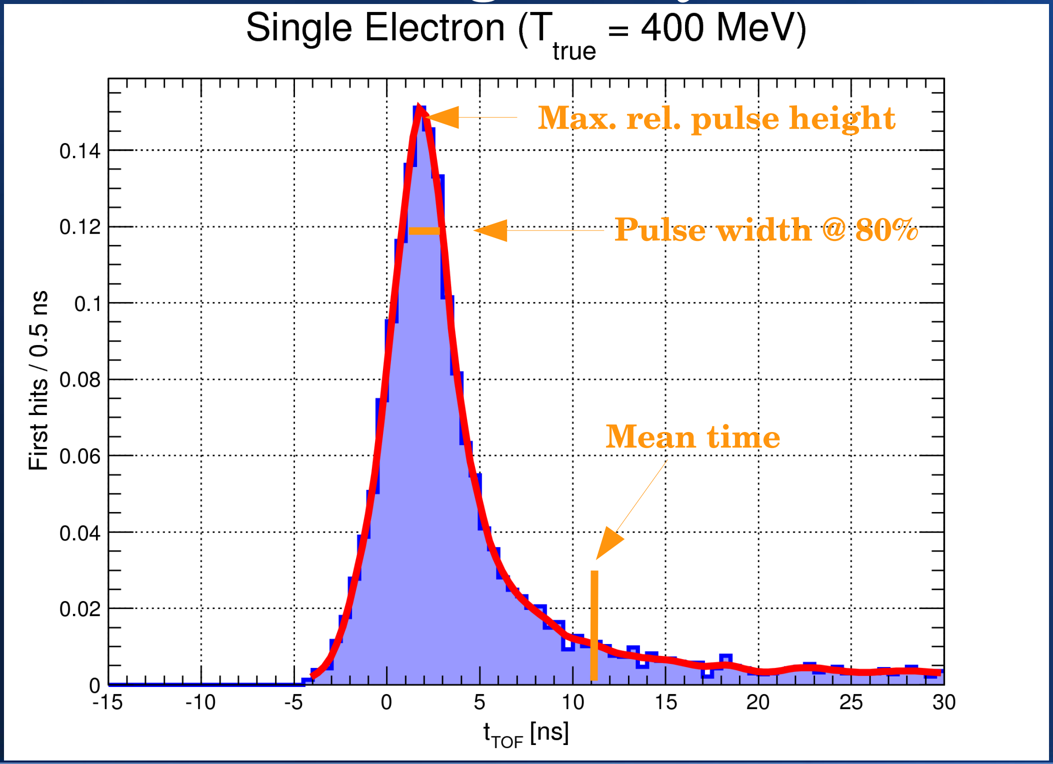
- How to determine the parameters from the pulse shape without binning the data and / or doing a parametrized fit (model?)?

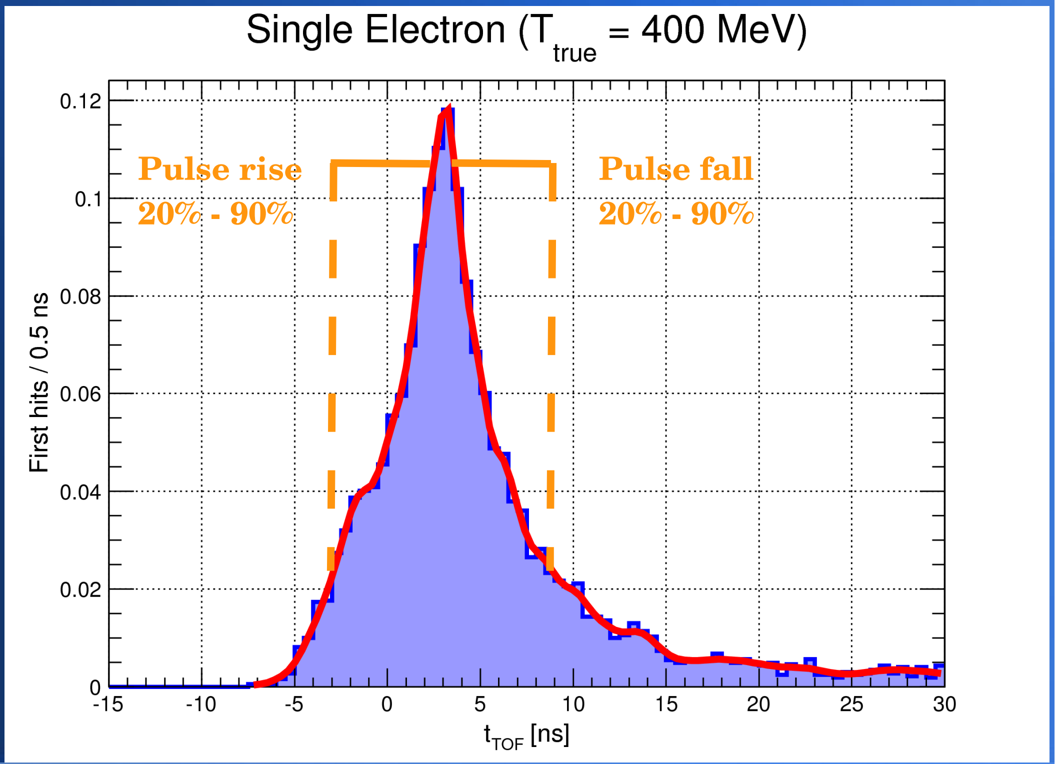




ToF corr. First-hits pulse

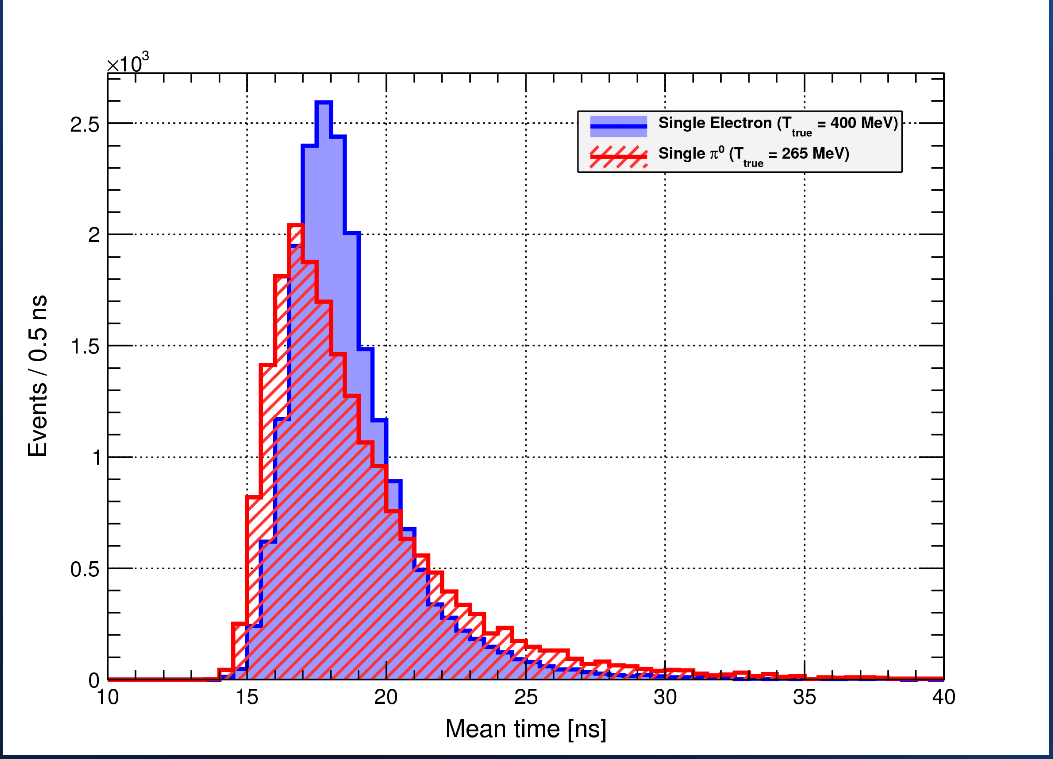
- Solution: "**A**daptive **K**ernel **D**ensity **E**stimation"
  ("***Kernel estimation in high-energy physics***" – K. S. Cranmer [hep-ex/0011057])
- Disadvantage: Very slow fit!

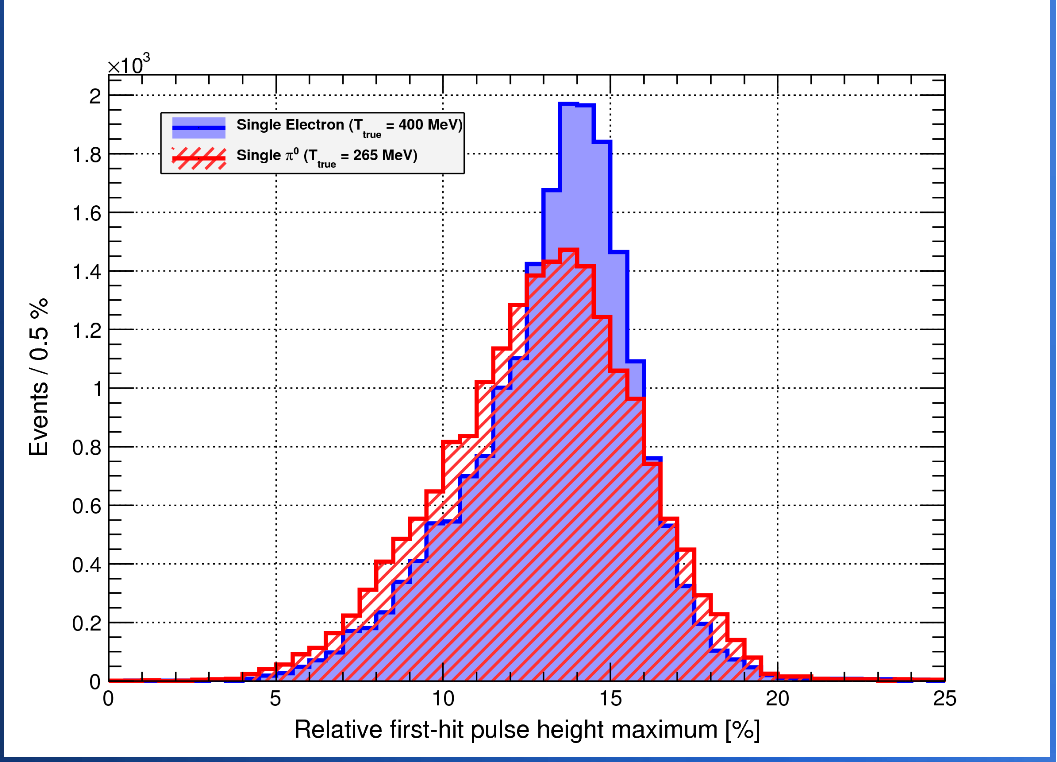




Mean time / max. rel. pulse height

- 20k e$^-$ (T_{true} = 400 MeV) & π^0 (T_{true} = 265 MeV)
- Mean time (left) & max. relative pulse height (right)





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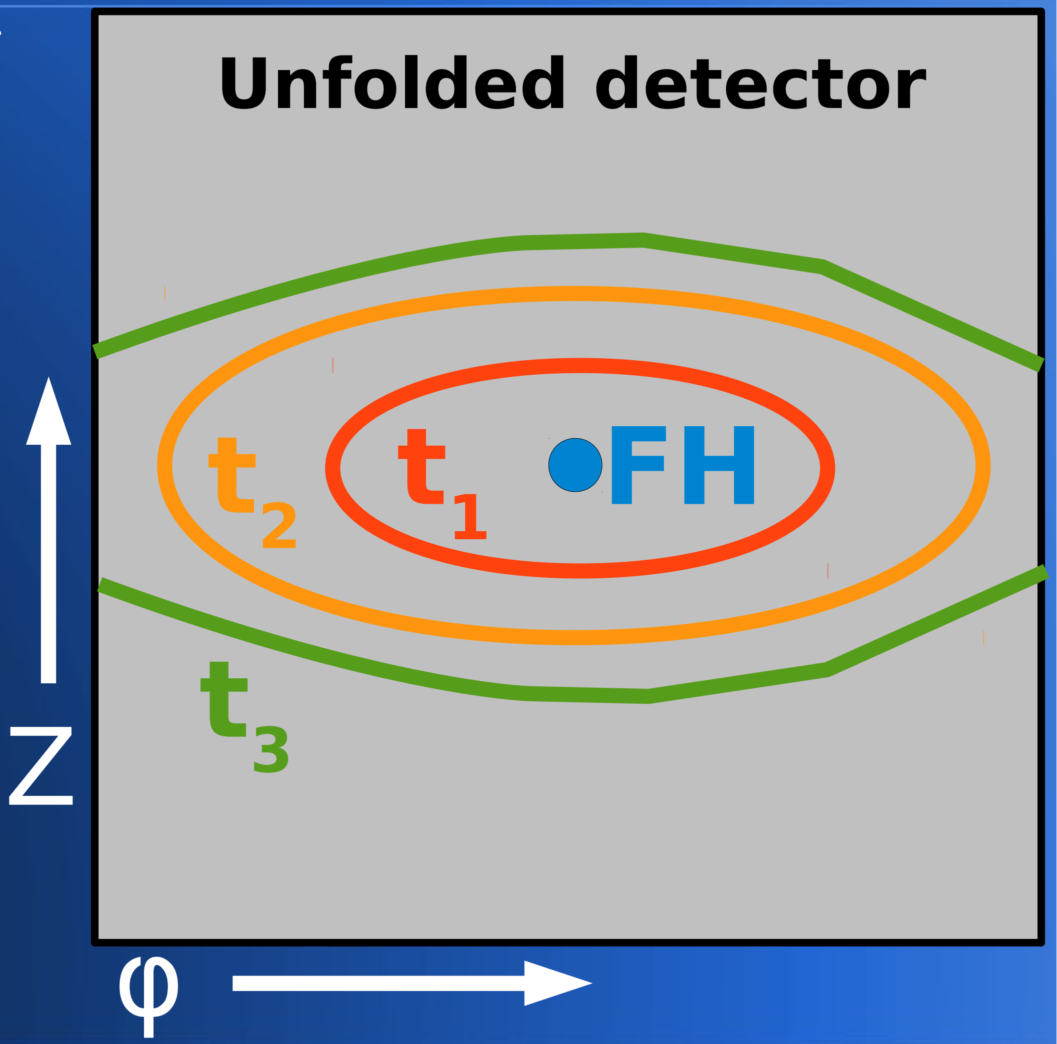
  - **Parameters from “pulse evolution”**

First-hits pulse evolution

- **Idea:** one expects, that two γs activate the PMTs faster than a single electon → parametrize the evolution of the first-hits pulse along phi- and z-axis.
- **Implementation:** use standard deviation (s.d.) of phi and z distribution of first-hits at different times

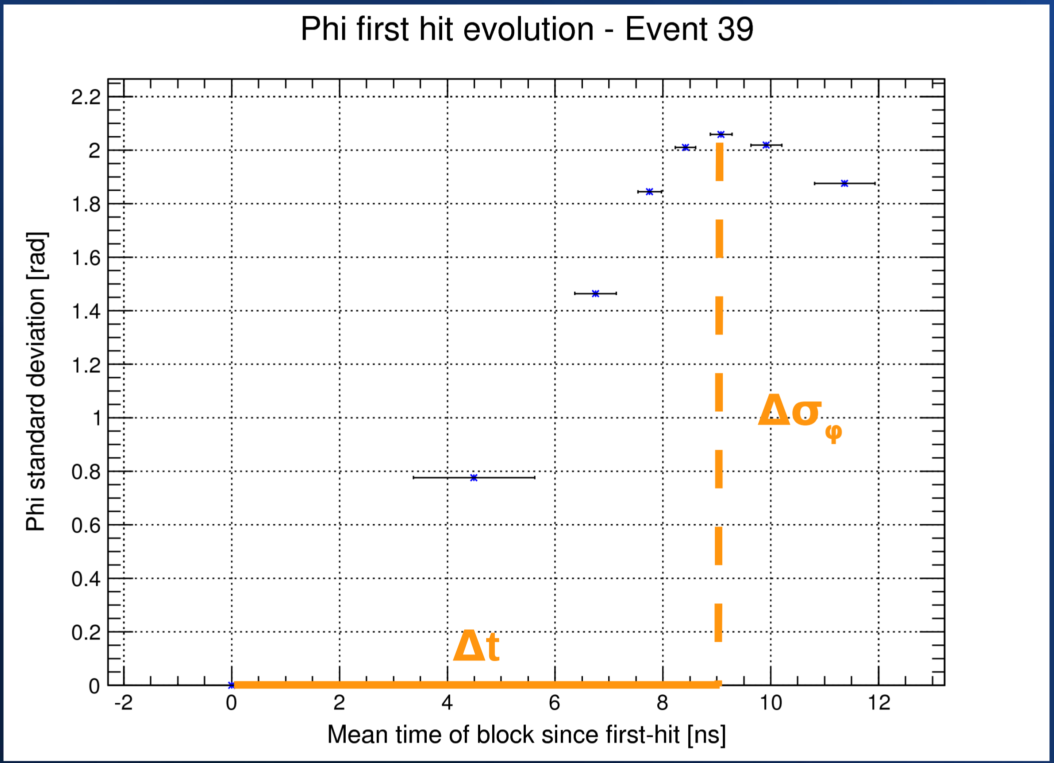
First-hits pulse evolution II

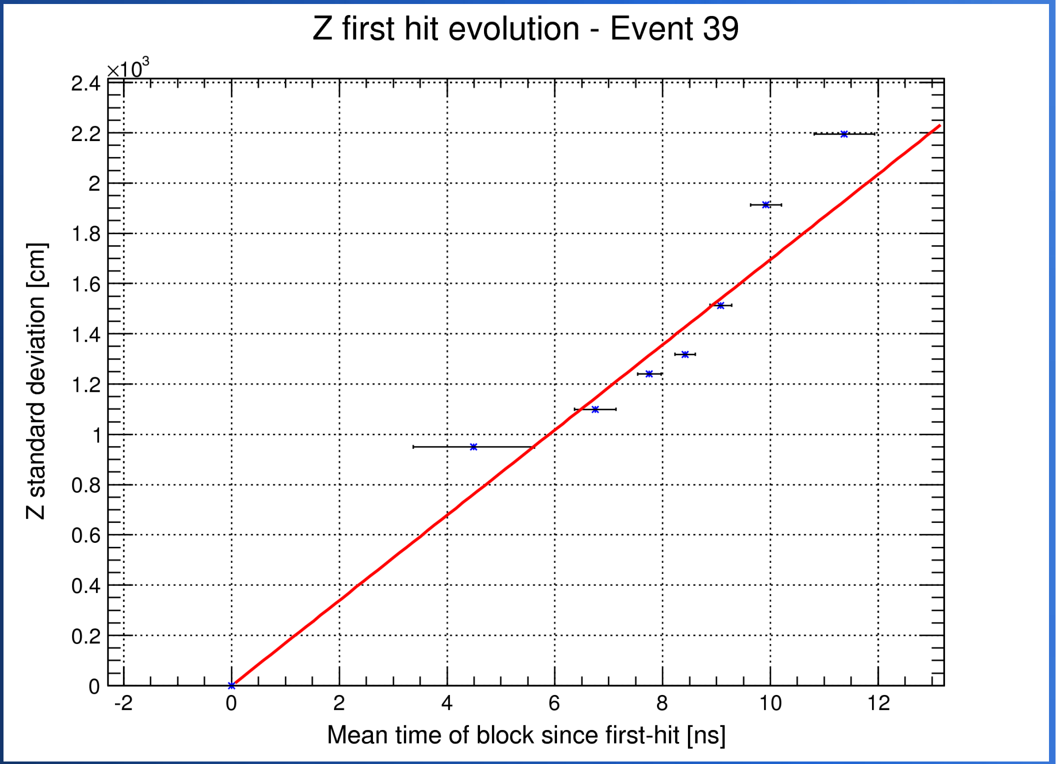
- → Build blocks of first-hits containing approximately 10% of the pulse, e.g. t_2 - t_1 (enough statistics per block)
- → For each block evaluate mean time and s.d. (correction for first-hit position)
- → Linear approximation to time evolution of block-wise s.d.



First-hits pulse evolution III

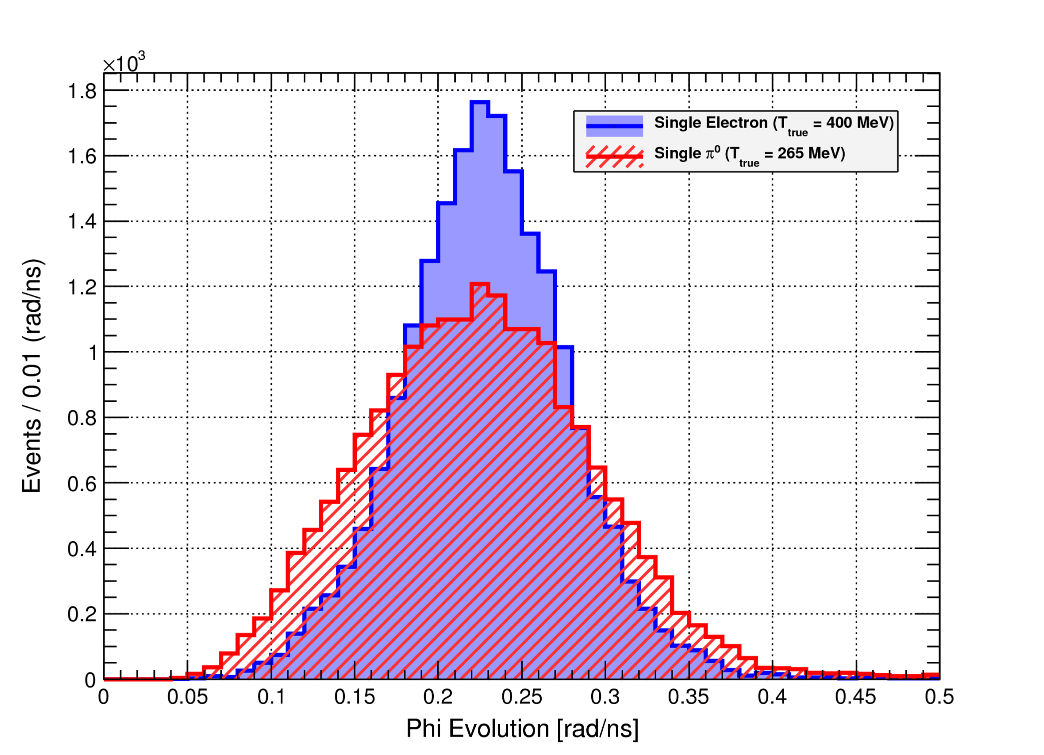
- Use slope of linear approximation as parameter for MVA
- Electron event: E_{true} = 573 MeV @ E_{estim} = 569 MeV

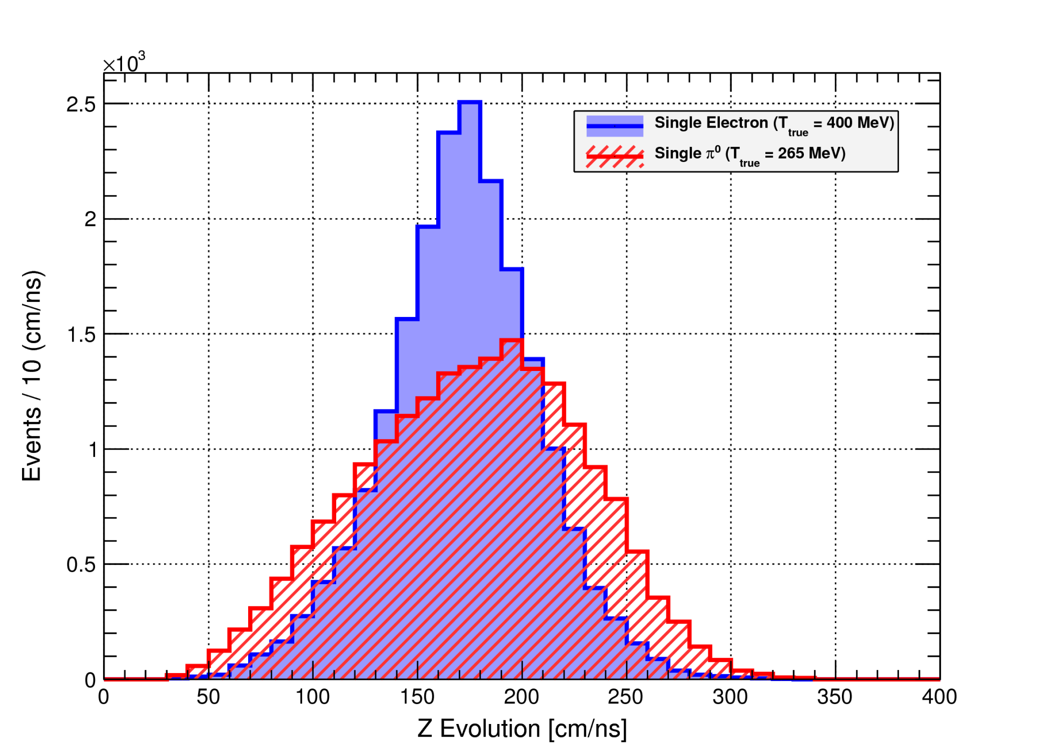




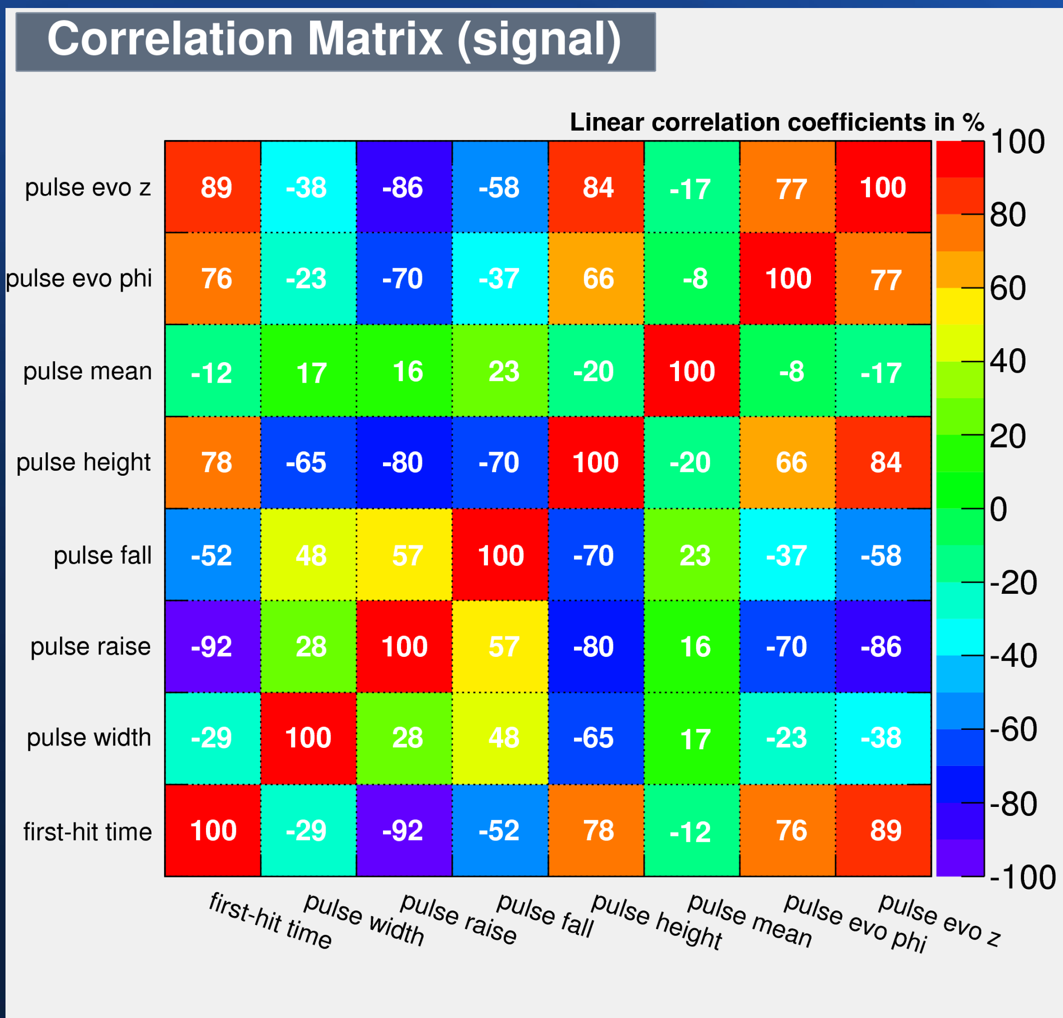
First-hits pulse evolution IV

- 20k e$^-$ (T_{true} = 400 MeV) & π^0 (T_{true} = 265 MeV)
- Phi-evolution (left) & Z-evolution (right)





Parameter correlations

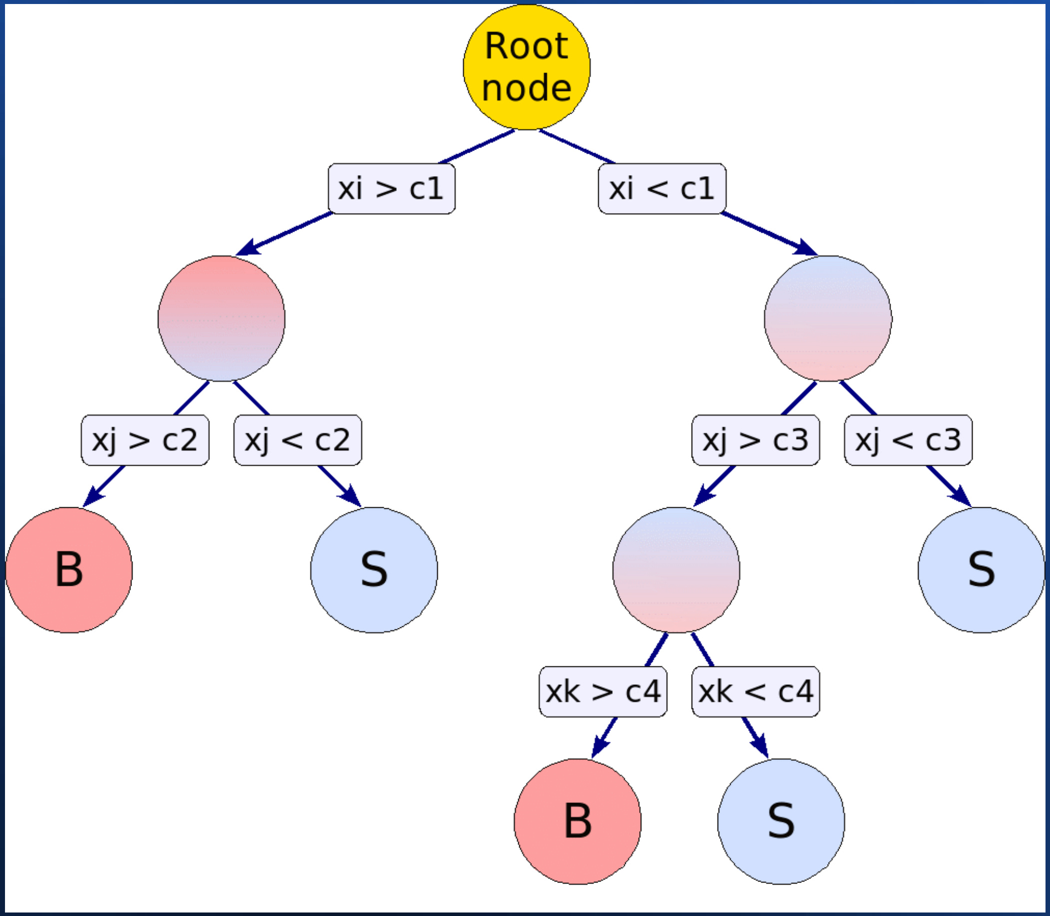


- Linear correlation coefficients for signal events
- Decorrelation techniques can be applied
- Potential to improve result by reducing / combining MVA parameters

MVA with BDT

- Use ***Boosted Decision Tree*** (BDT) for multivariate analysis
- BDTs are also used by the MiniBooNE experiment for particle identification
- Implementation of BDTs from **TMVA** in **ROOT** analysis framework
- **A lot of parameters, which can be tuned for optimization!**
- **One can also test other methods like *Neural Networks***

MVA with BDT II



[From TMVA4 manual]

- Binary decision tree (sequence of cuts)

  → vulnerable to statistical fluctuations in training sample

  → build several trees (forest) with different cut-values, cut-ordering etc. and classify by majority vote
- Boosting: increase weight of falsely identified events when growing next tree

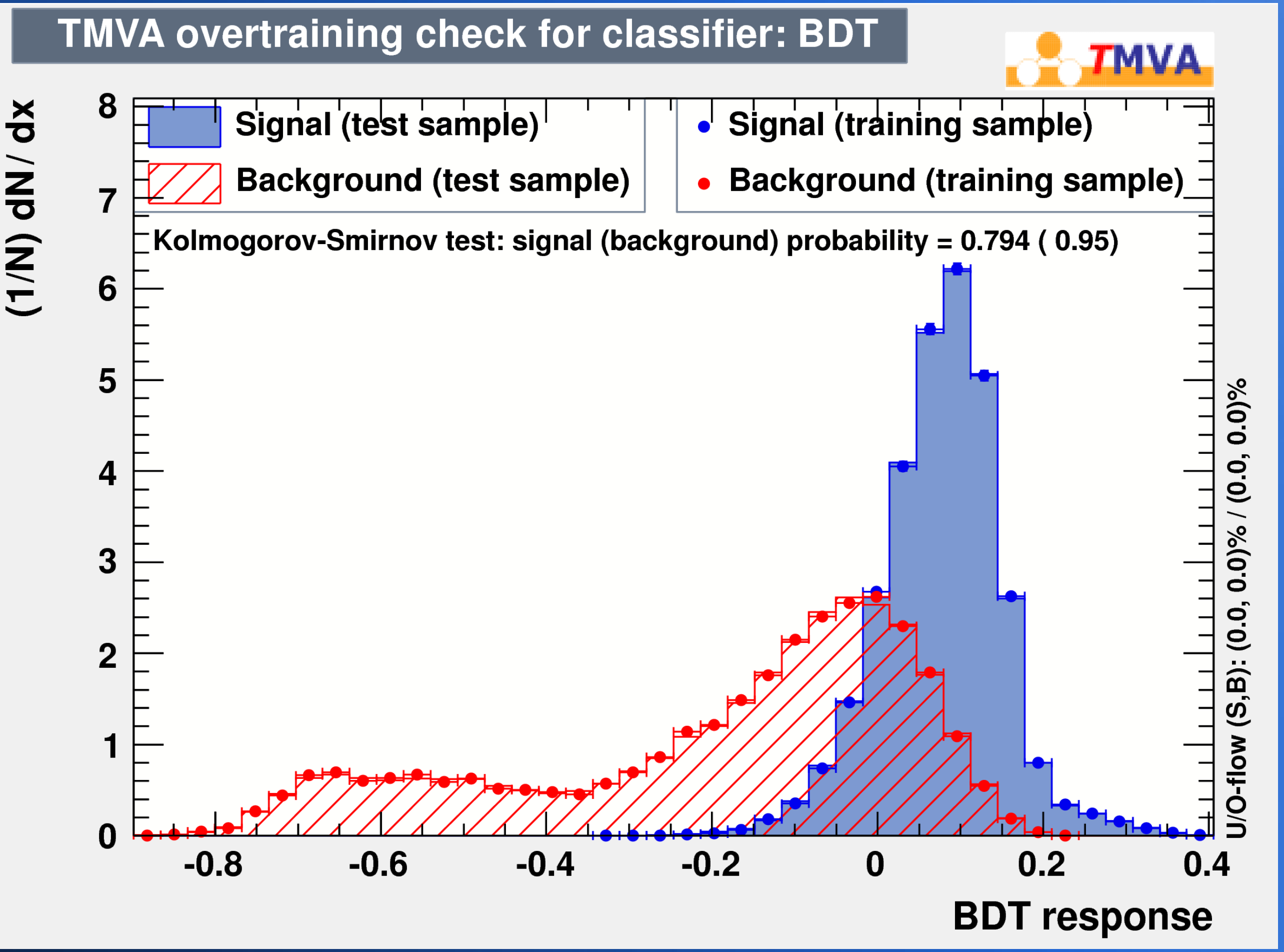
MVA with BDT III

- Standard configuration (from TMVA test files) of BDTs, which differs for different types of boosting etc.
- NO purification of the training / test samples
  $\rightarrow \pi^0 \rightarrow \gamma + e^+ + e^-$ (1,2 %) included!
- With these adjustments and under the consideration of the simplified conditions one finally gets...

… ***drum roll*** …

MVA output

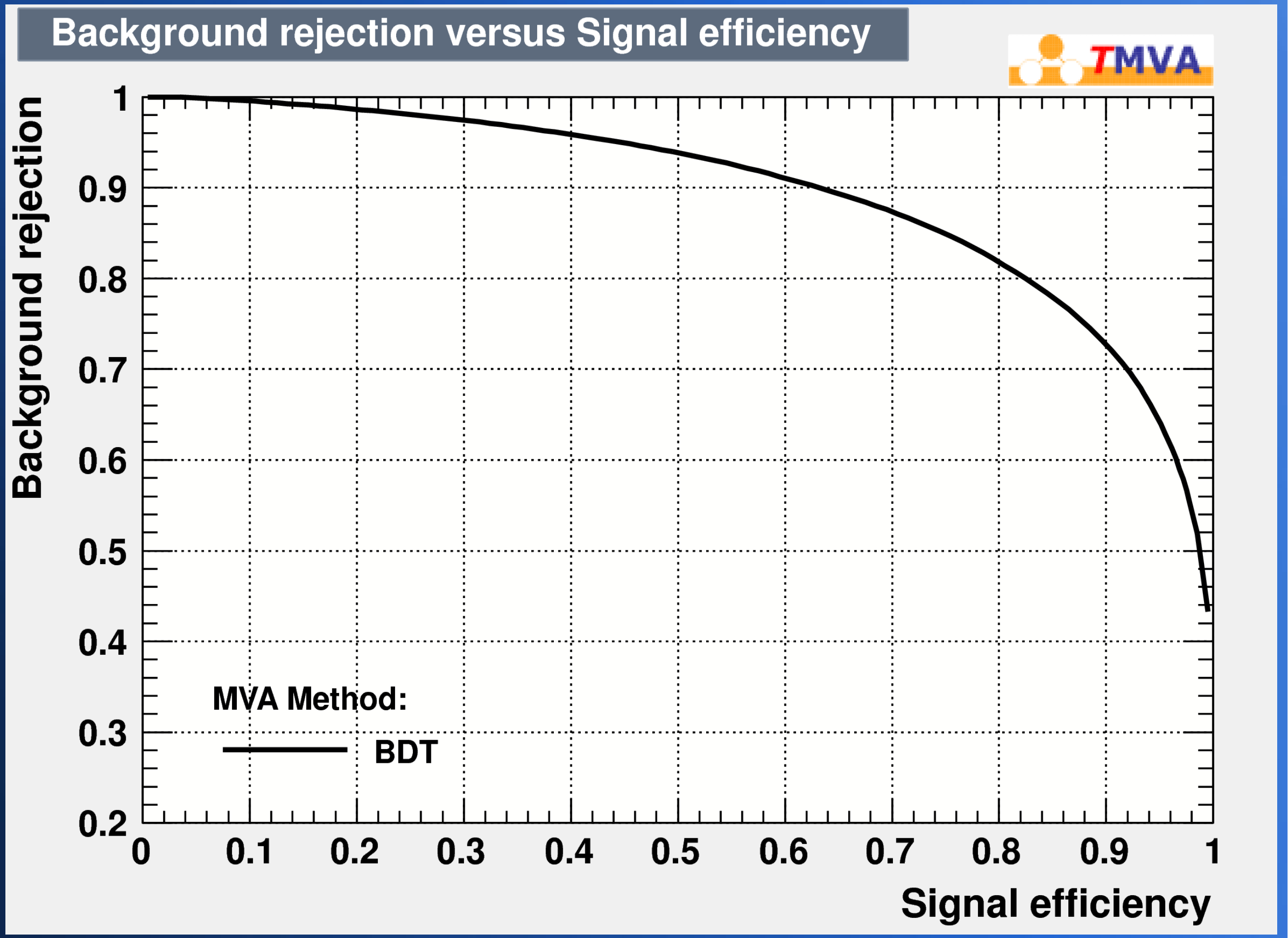
- BDT classifier output
- Kolomogorov-Smirnov test to identify overtraining



MVA output

- BDT background rejection vs. signal efficiency
- Signal efficiency landmarks

@ 30% Bkg. : 92%
@ 10% Bkg. : 63%
@ 1% Bkg. : 17%



Summary & Outlook

- First analysis of LENA's π^0 - discrimination capability with BDTs yields encouraging results for a simplified approach
- (Weak) discriminating parameters could be found, which show some correlation and thus offer potential for optimization
- MVA done with standard configuration of BDTs and allows further improvement
- Nevertheless, a more detailed study on LENA's π^0 - discrimination capability is necessary, including more realistic conditions (primary neutrino interaction vertex, electronics etc.), which are expected to have negative as well as positive impacts on discrimination ability

Thank you for your kind attention!