Accelerator neutrino interactions in the MINOS Experiment

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Overview of the talk

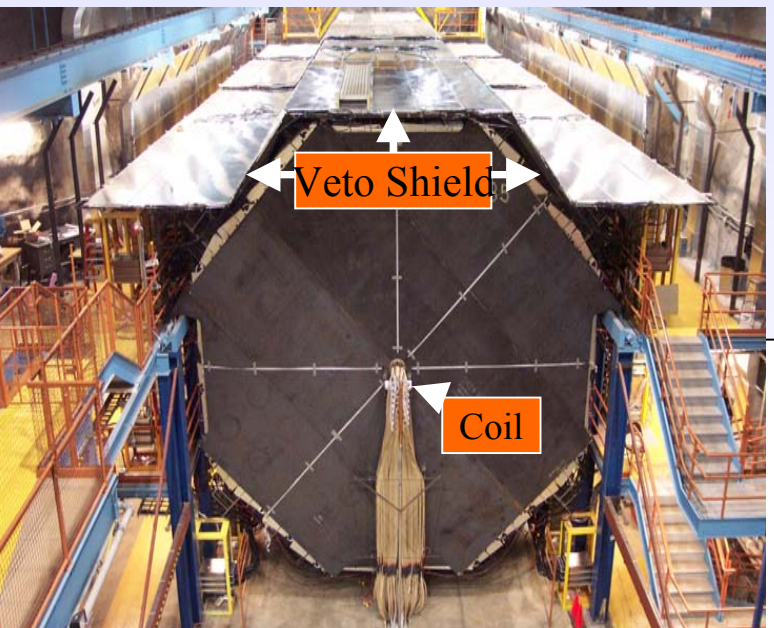
- MINOS experiment
- neutrino interactions
- cuts method of selection
- Range Searching method
- results
- summary

MINOS experiment

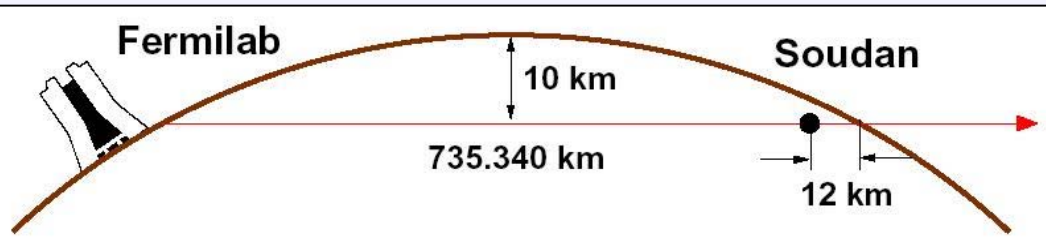
First informations

- **Minos - mythical Greek king of Creta, son of Zeus and Europe**
- **Main Injector Neutrino Oscillation Search- a long-baseline neutrino oscillation experiment**
  - **Neutrinos from the 120 GeV pulsed proton beam on graphite target**
  - **Two detectors (at FermiLab and Soudan)- USA**
  - **The MINOS experiment measures the neutrino oscillation between the detectors**
- **Experiment started in 2005**
- **First results at the beginning of 2006**

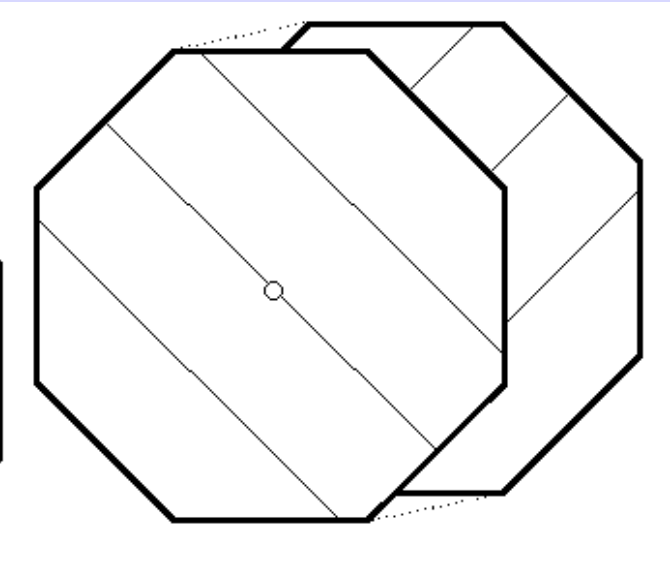
Two underground detectors - Near (ND) and Far Detector (FD)

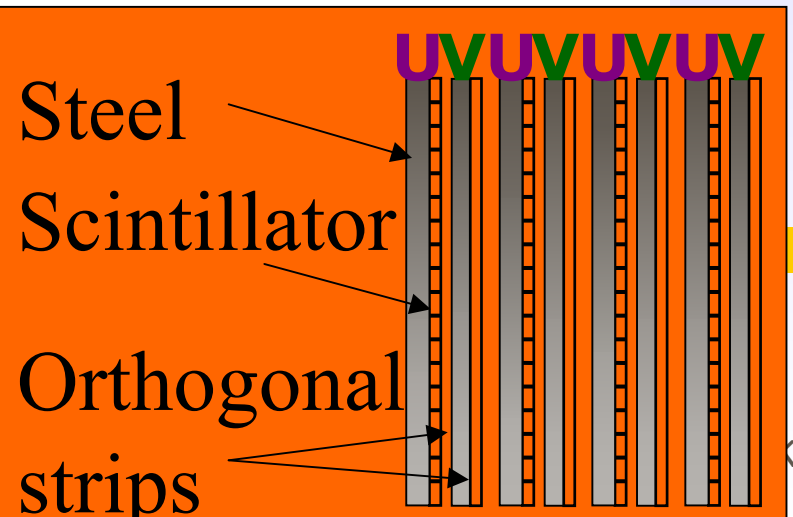


- ND at FNAL, FD at Soudan Mine, 735 km from FNAL
- ND is to measure the beam composition and energy spectrum
- FD is to search for evidence of oscillations between detectors
- FD is ~2x bigger than ND



Detectors construction





- Near & Far detectors are functionally identical
- They share the same basic detector technology and granularity:
  - Iron/Scintillator tracking calorimeters
  - 2.54cm thick magnetized steel planes <B> = 1.2T
  - 1cm thick scintillator planes
  - Alternate planes rotated by ±90^{o} (U,V)
- thanks to this rotation we can find the 3D representation of an event

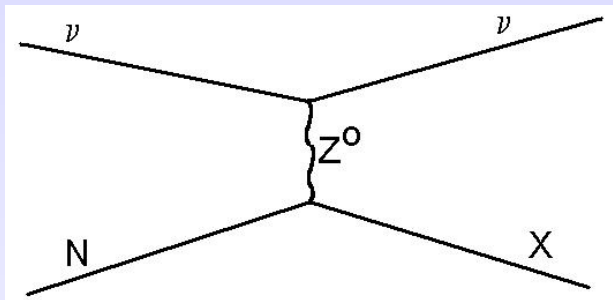

Neutrino interactions

Types of interactions

- Neutral Current (NC) - Z boson exchange

$\nu + N \rightarrow \nu + X$

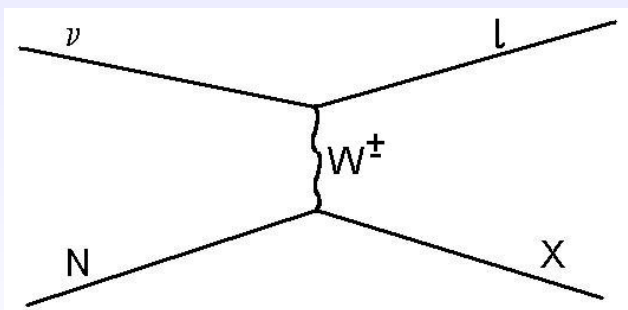
(X - hadronic cascade)



- Charged Current (CC) - W bosons exchange

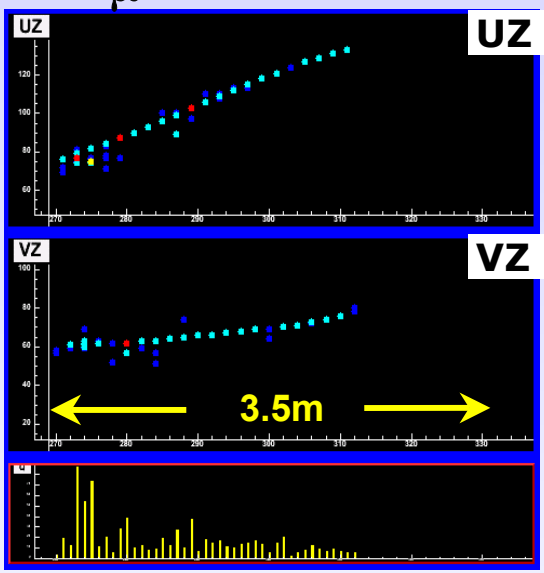
$\nu + N \rightarrow l + X$

(X - hadronic cascade,
l - charged lepton)



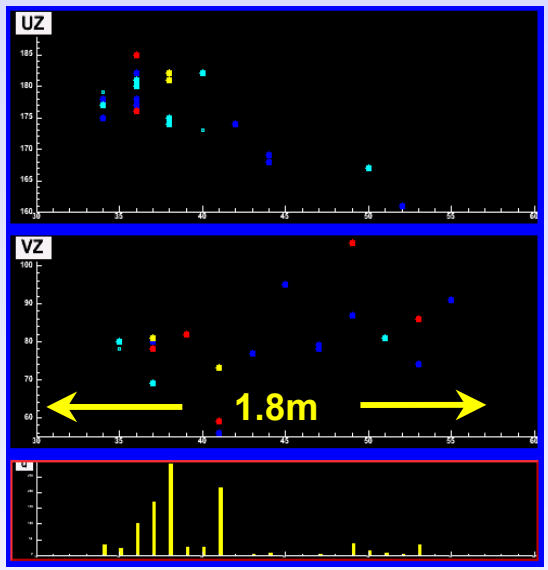
Neutral Current or Charged Current?

ν_μ CC Event



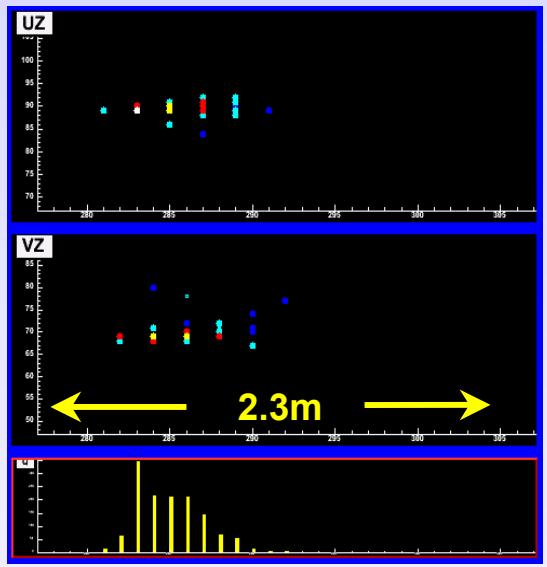
- We have μ with long $\mu-$ track + hadronic shower

NC Event



- short event, often diffuse
- the neutrino is "deflected"!

ν_e CC Event

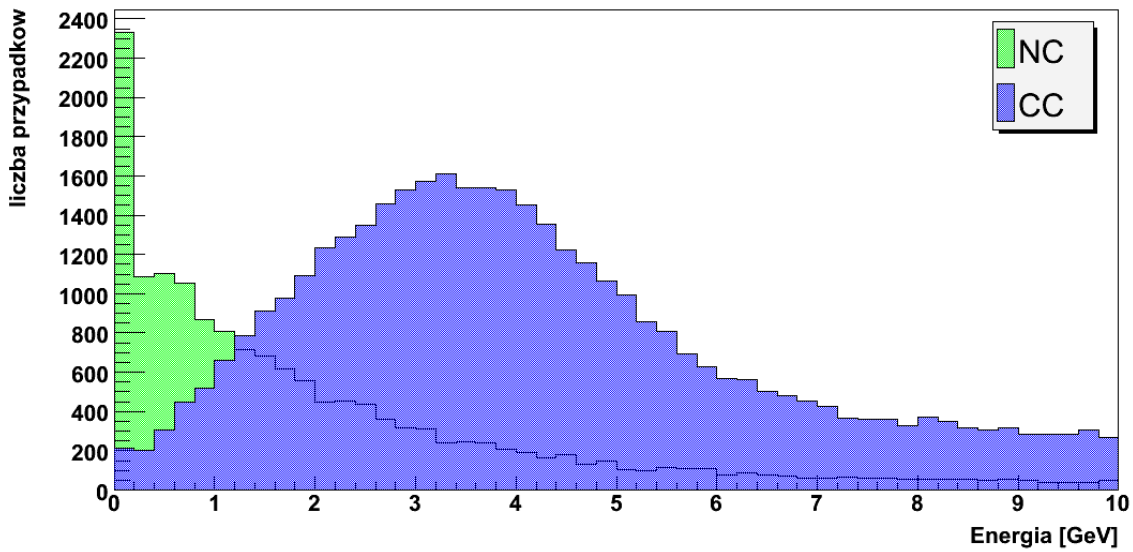


- short, with typical EM shower profile
- no μ !
- No electron track - short radiation length

CC to NC separation

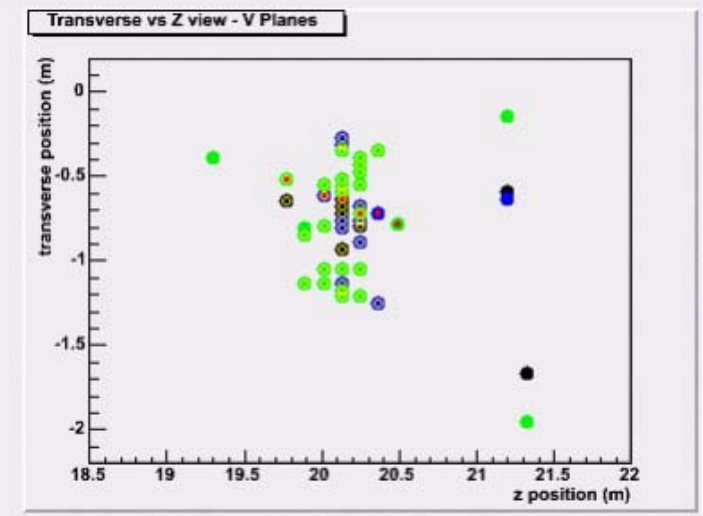
- MINOS can measure oscillations based on muon neutrinos which interact as CC
- It is necessary to separate CC ν_μ from NC events
- the biggest difficulty: low energy events

Events (energy) histogram - based on Monte Carlo events

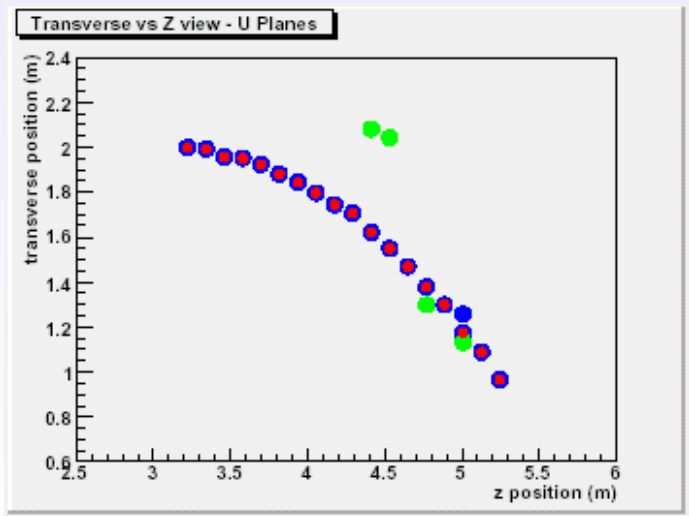


Main goals

- creation a CC from NC Monte Carlo events separation
- analysis of two methods: cuts method and Range Searching
- modifications of the second method



Simple examples of CC ν_μ (right) and NC (left) events



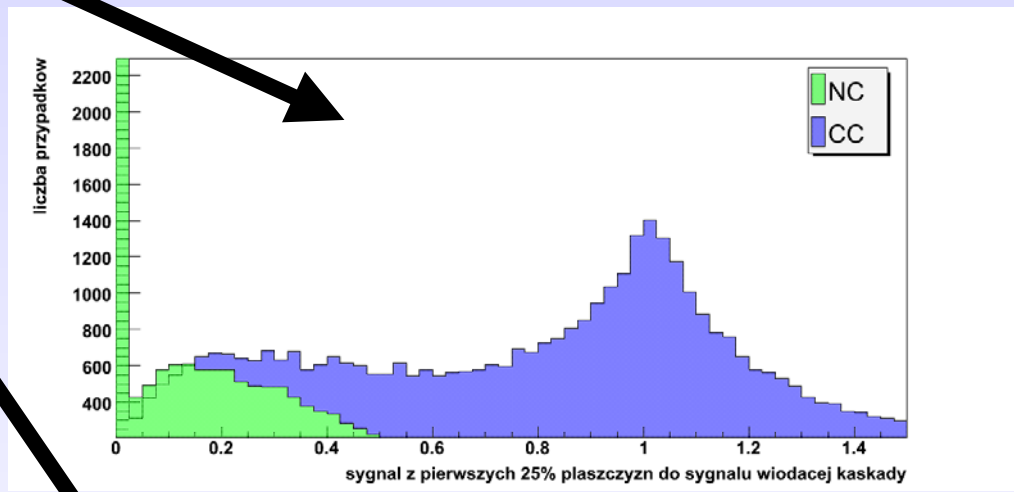

CC/NC Separation
- cuts method

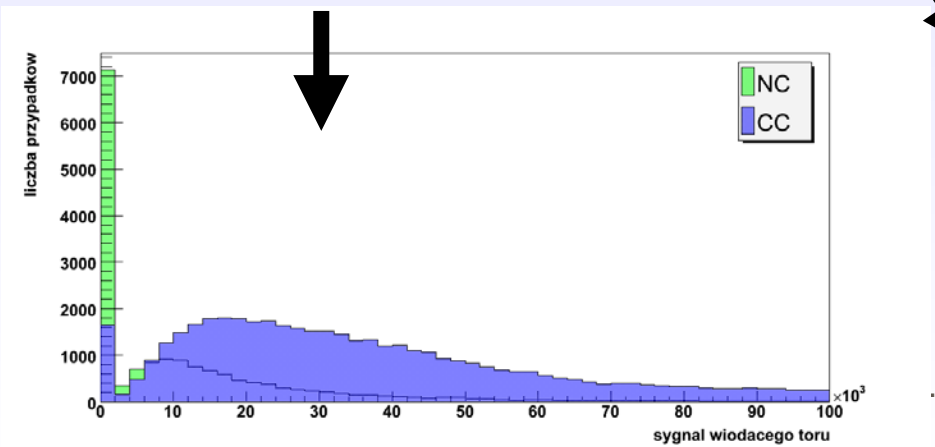
Cuts method

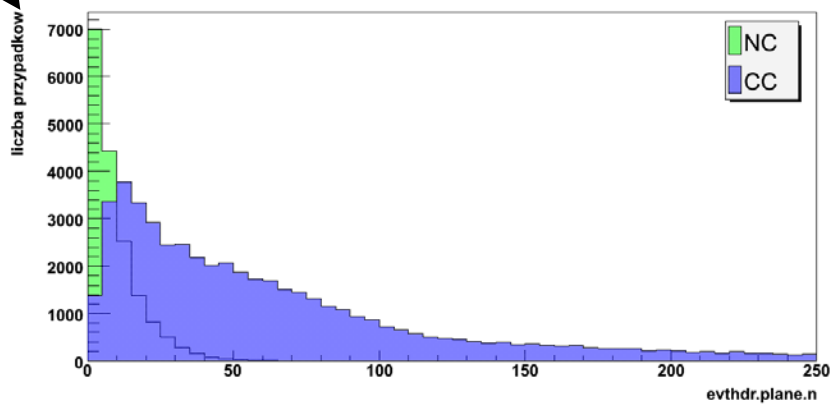
- Simple one-dimensional method of CC/NC separation
- three independent variables from STNP (Standard NTuple) files (ROOT)
- ~70 000 Monte Carlo events

Cuts method - the variables

- Signal from the first 25% active planes to biggest cascade signal
- number of active planes (length of the event)
- signal of the longest reconstructed track



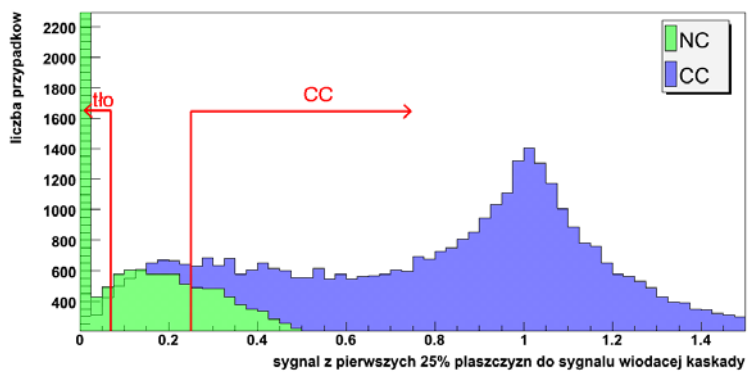




Cuts on variables

- Simple cuts on all variables to separate CC from NC events
- if an event is not clasified in one cut, it is taken by next variable and so on...

an example of one cut →



the results of cuts method will be shown later


CC/NC Separation
-Range Searching method

Range Searching - the algorithm

Overview:

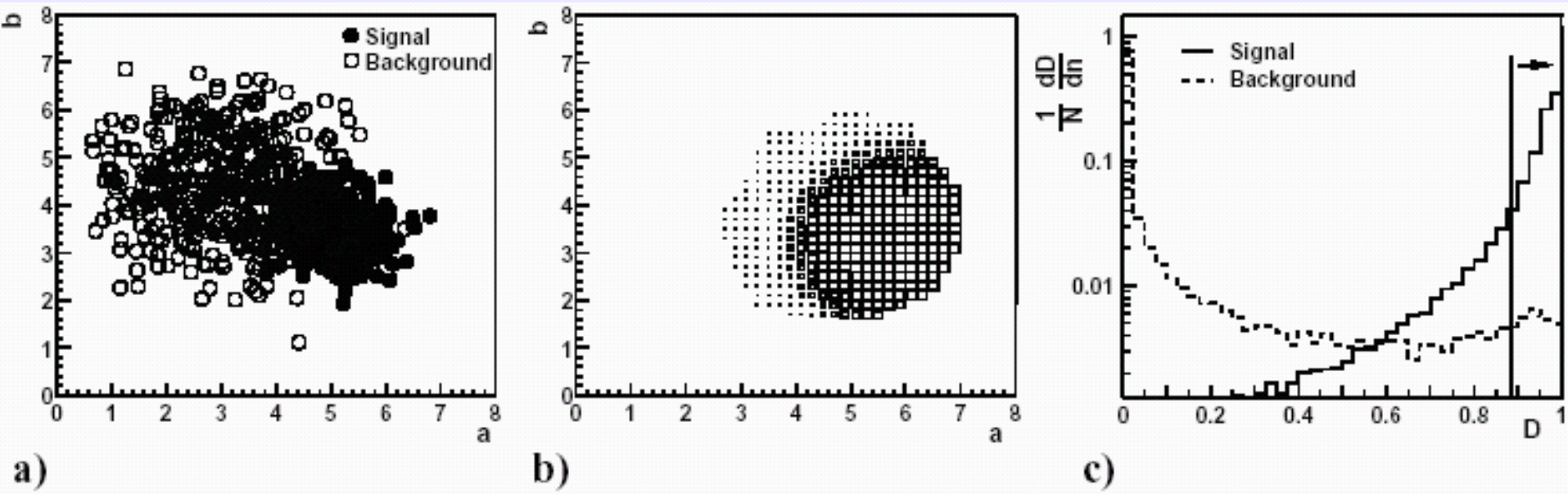
- multi-dimensional method
- creation of the density CC/NC map based on the MonteCarlo model
- one cut on the discriminant variable

Range Searching -first step

- create a model - binary tree contained 220 000 Monte Carlo CC&NC events
- it is necessary to have many thousands of model events -> better density
- each event is described in 3D space by 3 variables - all coordinates are values of the variables
- in this example there are **the same** three variables as in the cuts method

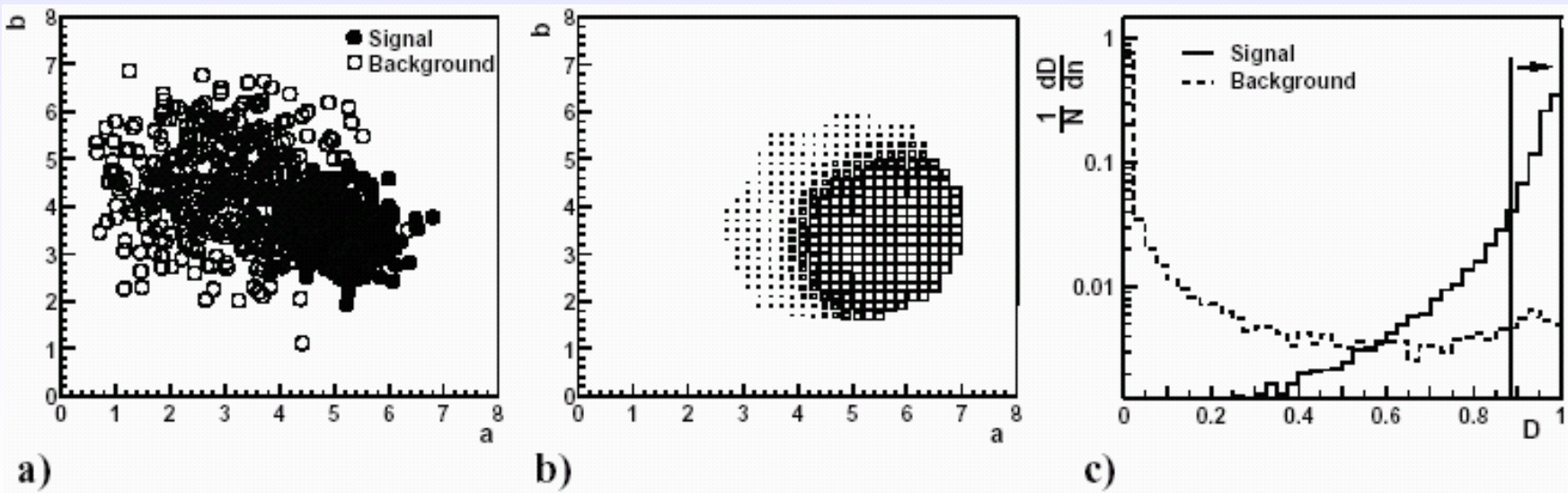
Range Searching - simple 2D example

- example events in 2D variable space to separate signal to background (fig. a)
- algorithm tests the events one by one by comparing the V region around the event



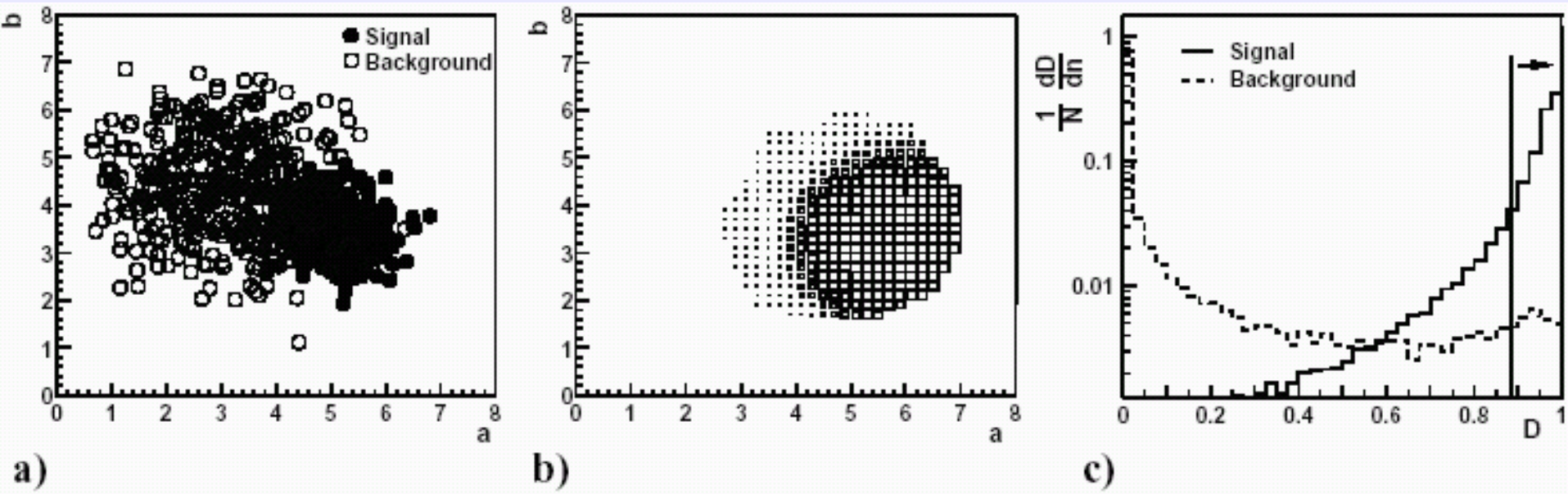
Range Searching - simple 2D example

- V region (volume) around event (being analyzed) is estimated on the basis of the Monte Carlo model
- V contains a certain number of signal (CC) and background (NC) MC events



Range Searching - simple 2D example

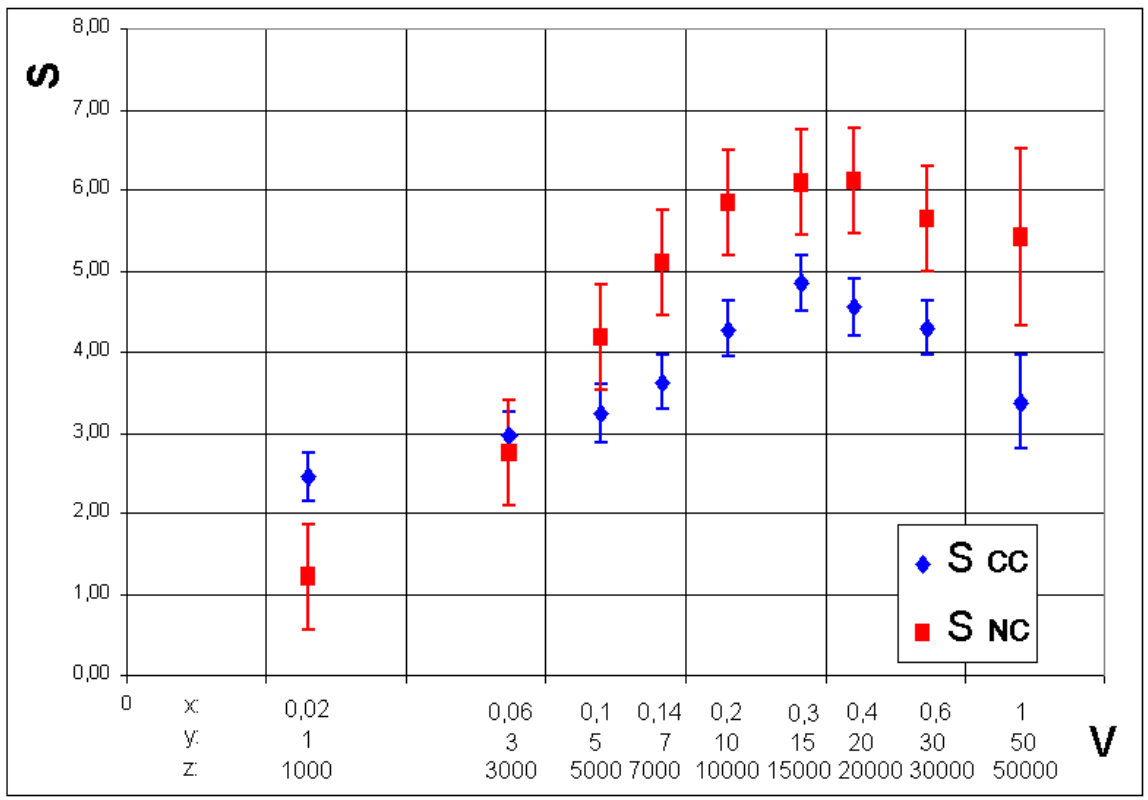
- thanks to number of CC and NC events in V it is possible to find the density D of the events (fig. b)
- this density determines if the event being analyzed is CC or NC
- One cut on D enable to separate CC from NC (fig. c)



Range Searching - real MINOS variables

- After creating a Monte Carlo model, the next step is to find the best volume of V
- V should not contain too small or too large number of events -> worse resolution
- best V: 15% of the characteristic region of variable
- Separation power:

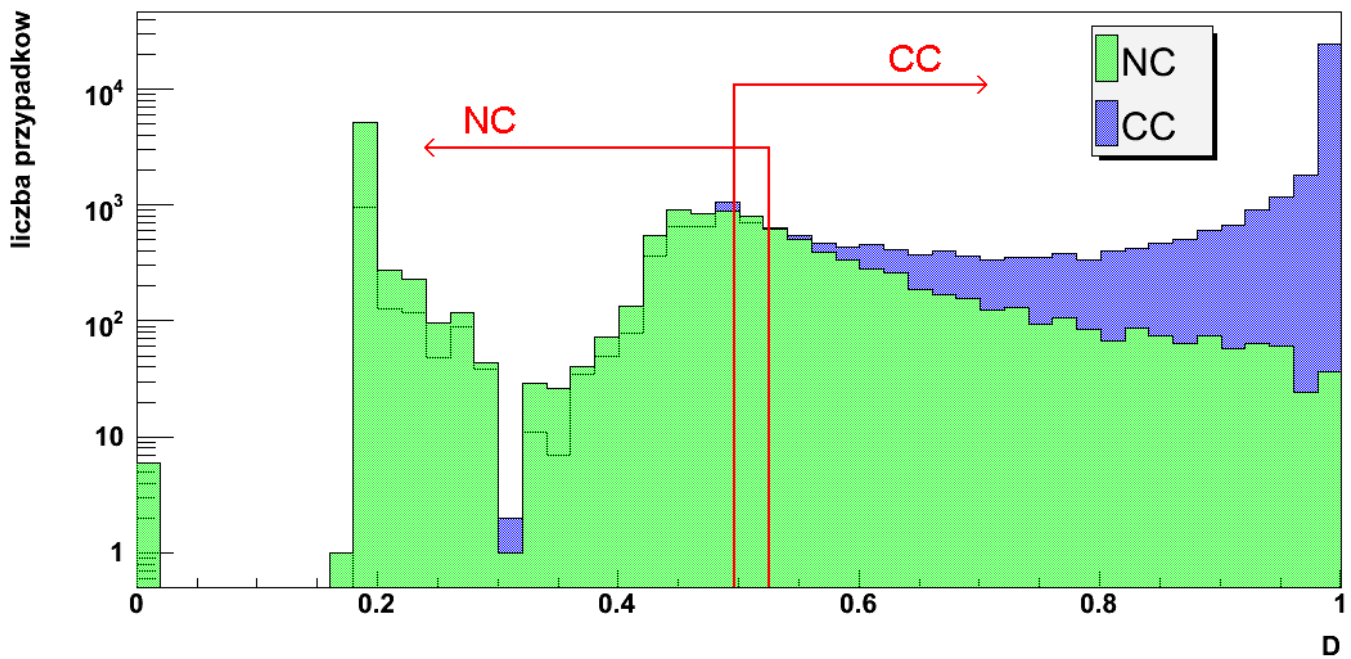
$$S := \frac{\varepsilon_s}{\varepsilon_b} = \frac{\frac{N_{s,\text{selected}}}{N_{s,\text{total}}}}{\frac{N_{b,\text{selected}}}{N_{b,\text{total}}}}$$



Range Searching - discriminant variable D

- by using RS algorithm we can find values of the D variable of all checking events
- one cut can separate CC from NC events

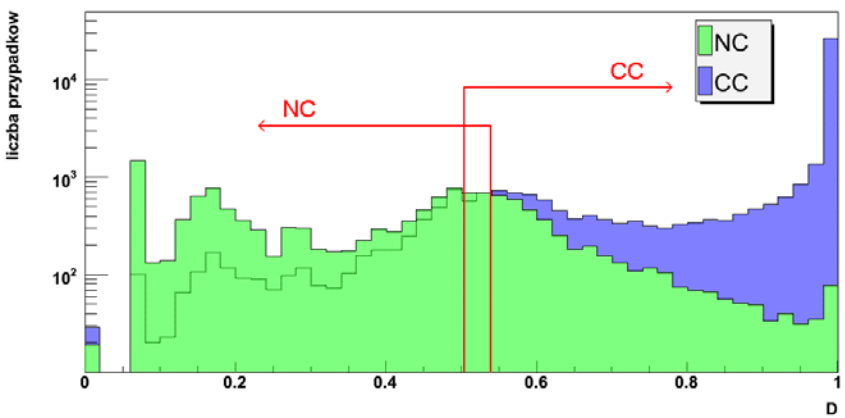
Events (D)

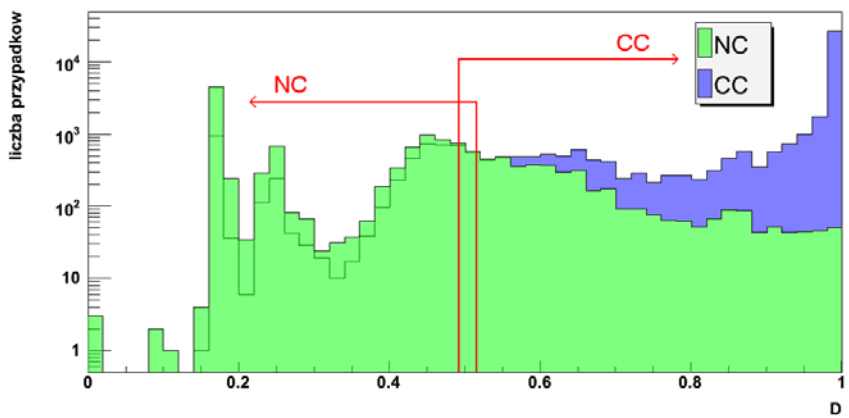


Range Searching - modifications

the use some other groups of variables:

- event length ; track signal to all event signal ; all event signal to event length; (left figure)
- length of the longest track minus length of the biggest cascade ; longest track signal to event length ; number of reconstructed tracks; (right figure)

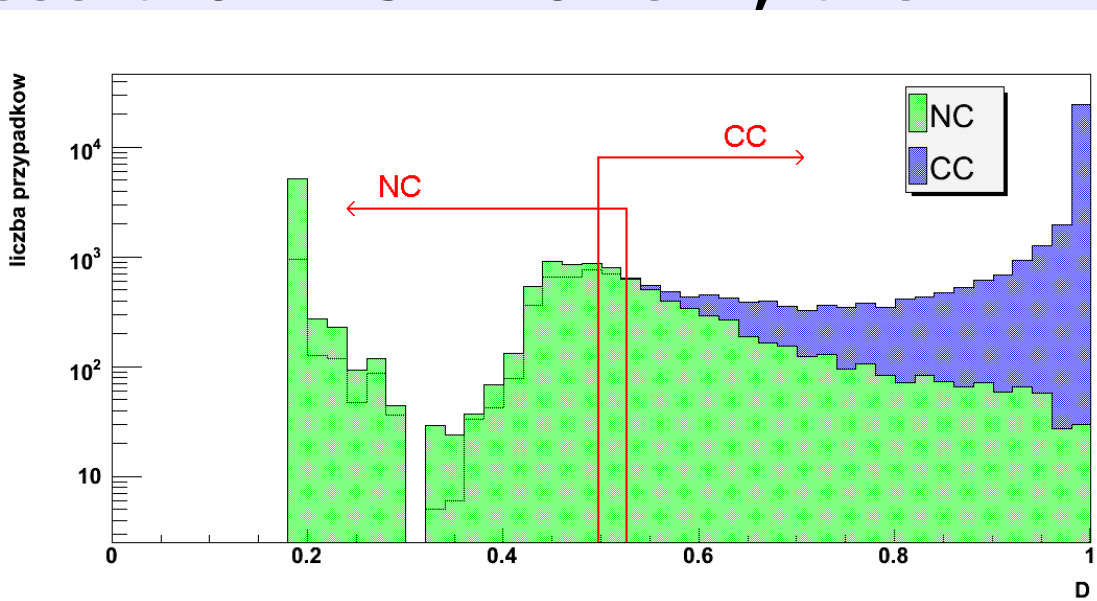




Range Searching - modifications

modification of the original algorithm:

- size of V is changing
- when the signal or background events number are less than 25 in one V, then V increase
- better resolution



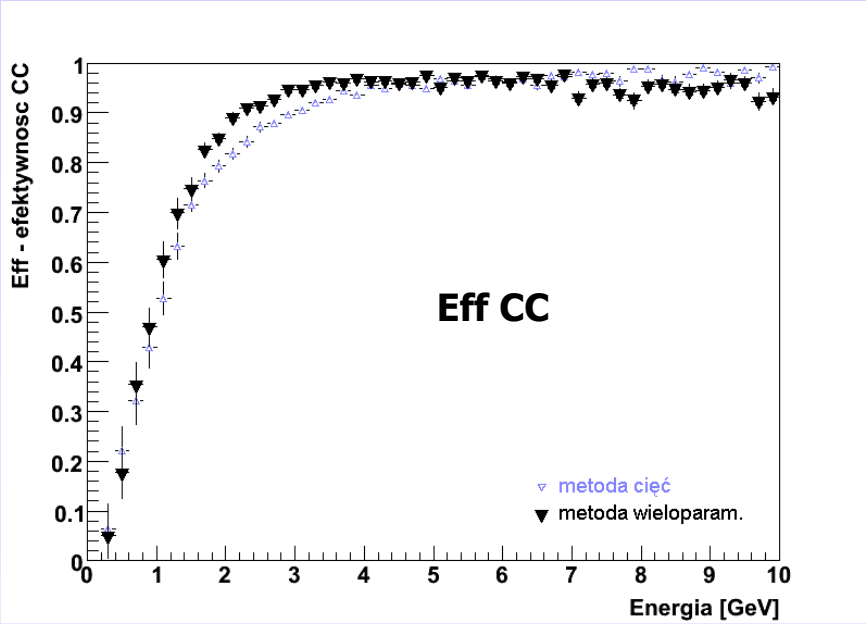

Results of all presented methods

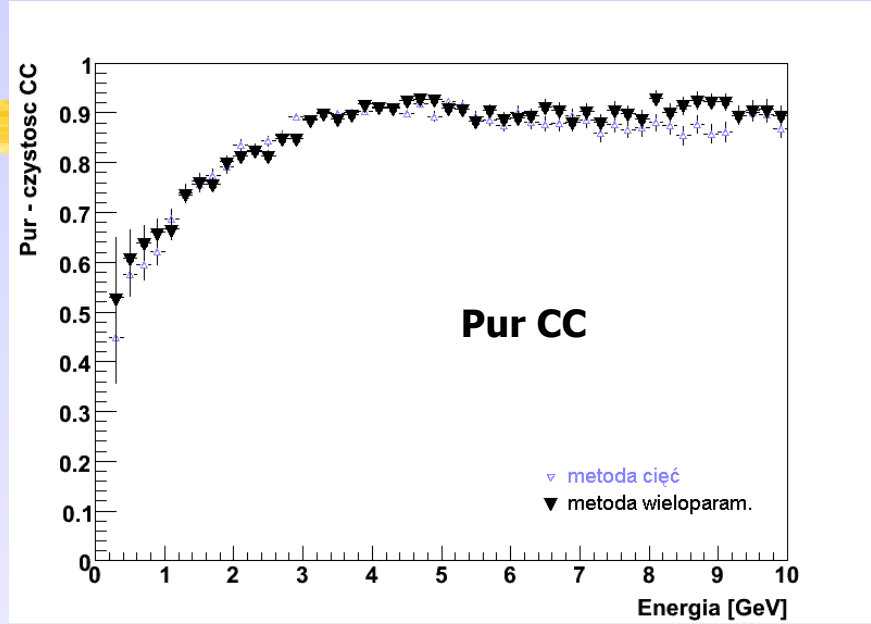
Purity and efficiency of the NC & CC selection

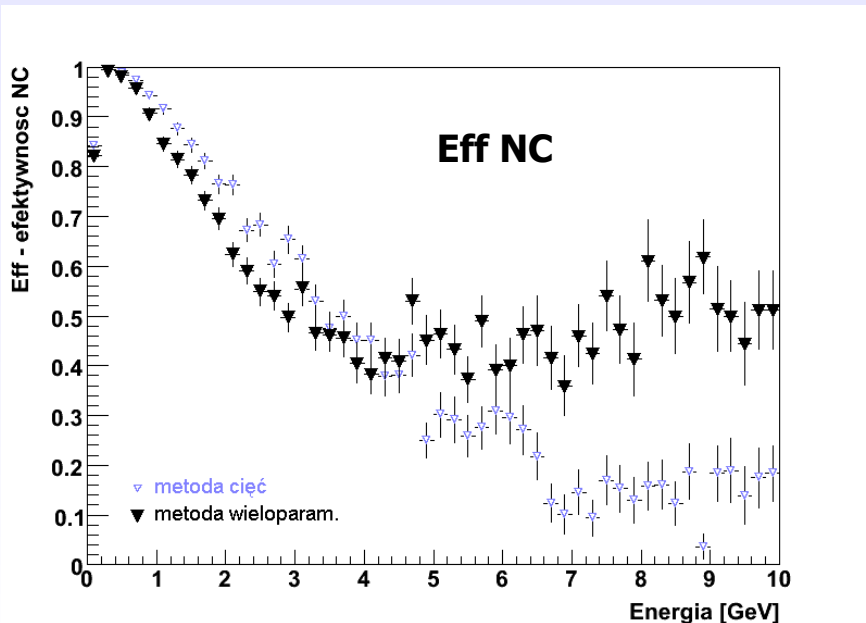
- to check the correctness of the selection, it is necessary to calculate the purity and efficiency of the selection:
- $Pur = N_{true} / (N_{true} + N_{false})$
- $Eff = N_{true} / N_{all}$

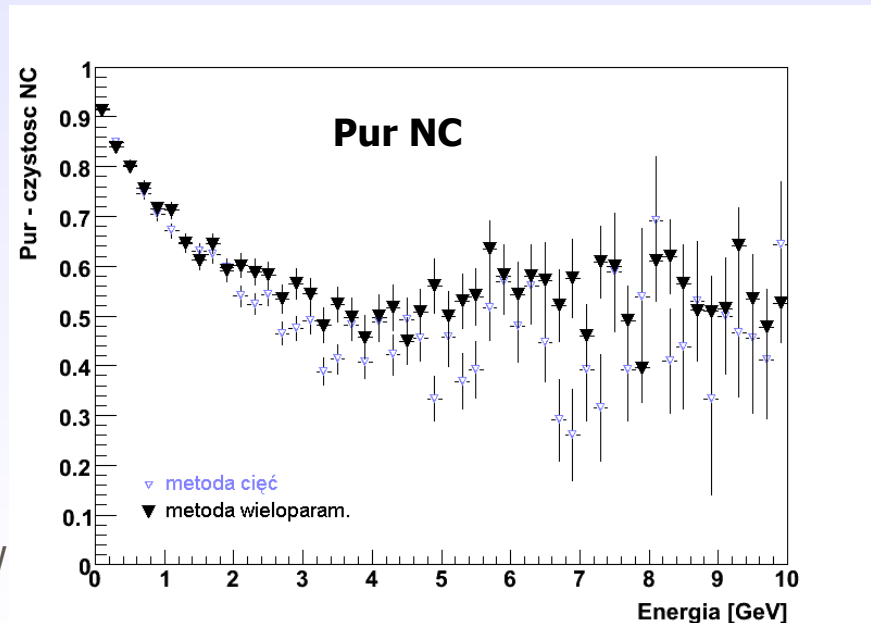
where N_{true} is a number of correctly selected events, N_{false} of incorrectly selected events, N_{all} is the number of all events (CC or NC)

Purity (right figures) and efficiency (left figures) of CC (up fig.) and NC (down fig.) selections. Big black points - Range Searching method. Small violet points - cuts method

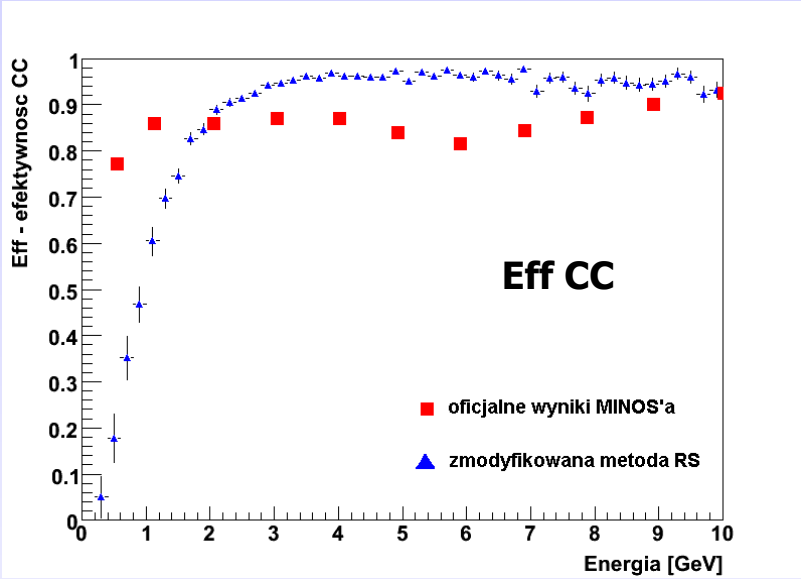


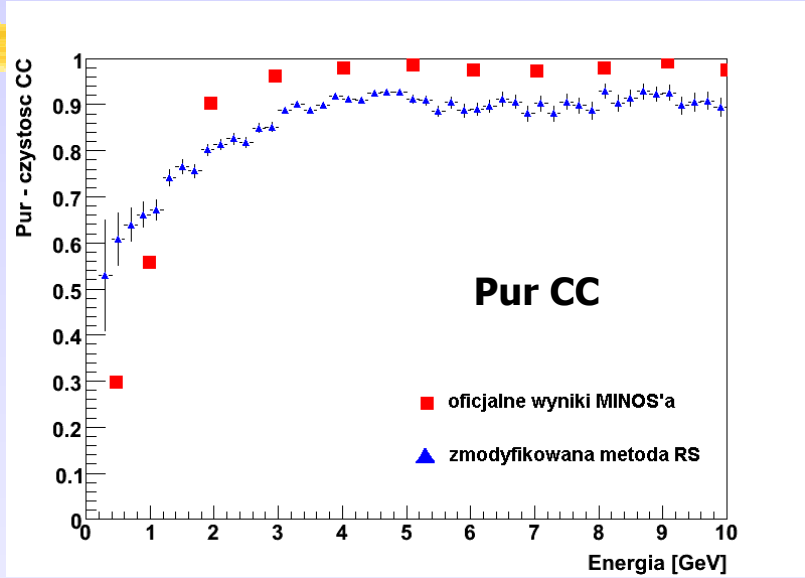


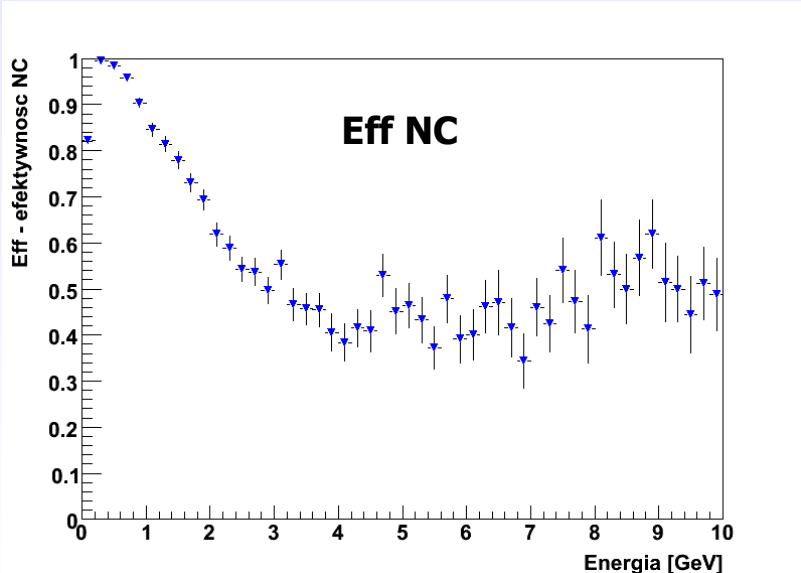


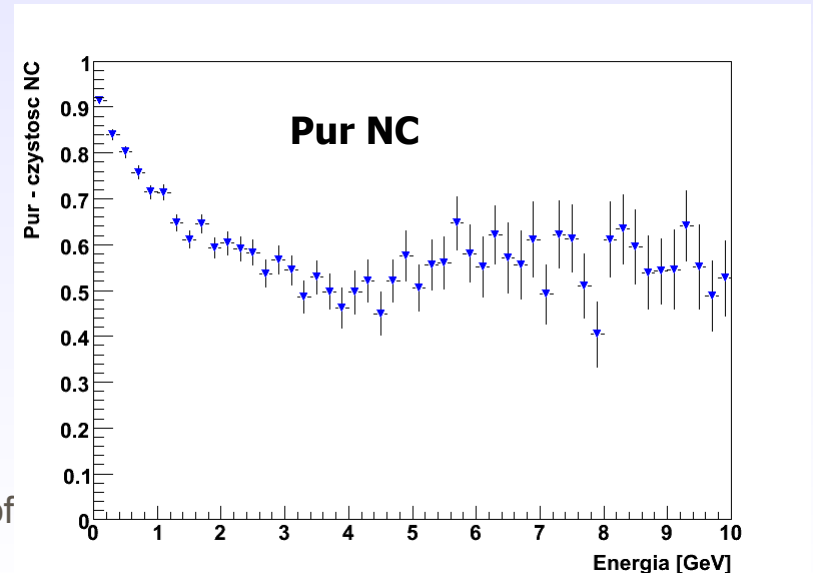


Purity and efficiency. Blue points - modified Range Searching method. Red points (CC only) - official MINOS Pur and EFF. Official MINOS NC selection does not exist yet!









Separation power

- Defined earlier:

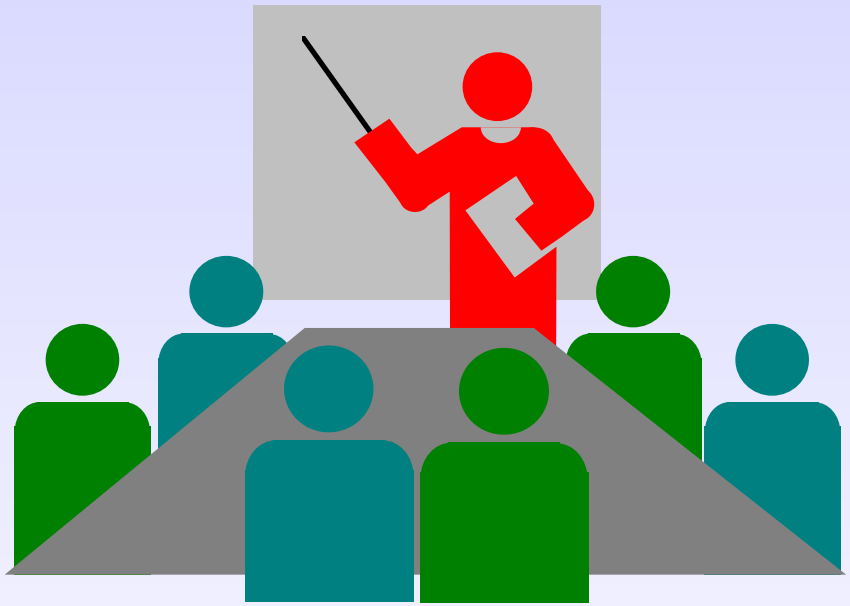
$$S := \frac{\varepsilon_s}{\varepsilon_b} = \frac{\frac{N_{s,\text{selected}}}{N_{s,\text{total}}}}{\frac{N_{b,\text{selected}}}{N_{b,\text{total}}}}$$

	S_{CC}	S_{NC}
Cuts method	$2{,}36 \pm 0{,}04$	$5{,}59 \pm 0{,}07$
Range Searching method	$2{,}65 \pm 0{,}05$	$5{,}85 \pm 0{,}08$
modified RS method	$2{,}68 \pm 0{,}05$	$6{,}02 \pm 0{,}08$
RS method - 1. new variables	$2{,}77 \pm 0{,}09$	$6{,}51 \pm 0{,}14$
RS method - 2. new variables	$2{,}92 \pm 0{,}09$	$6{,}83 \pm 0{,}14$

Summary

- MINOS can measure oscillation based on CC
- good CC from NC separation is necessary
- test of two major separation CC/NC methods: Range Searching better than cuts methods
- Range Searching method can be modified to achieve better results
- **Range Searching can be used in other experiments, in which you need to separate some signal from some background**

THANK YOU!



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