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# **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

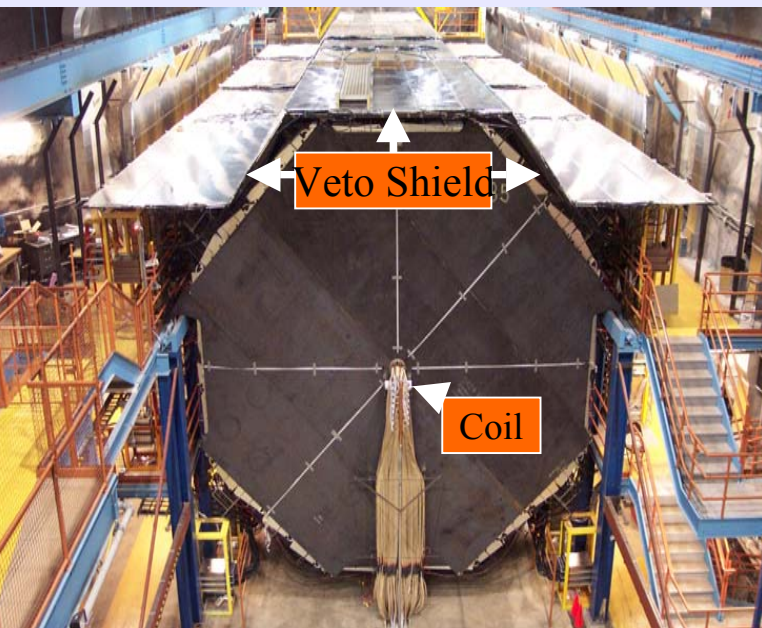


# **MINOS** **experiment**

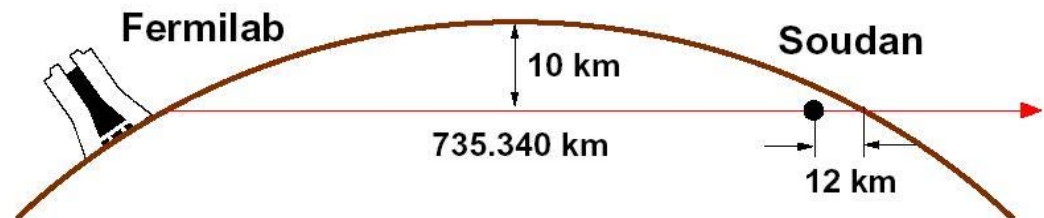
# First informations

- **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

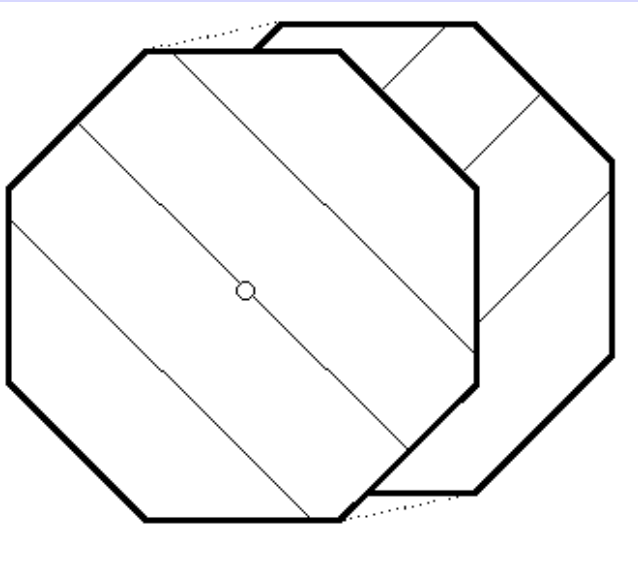
# Two underground detectors - Near (ND) and Far Detector (FD)



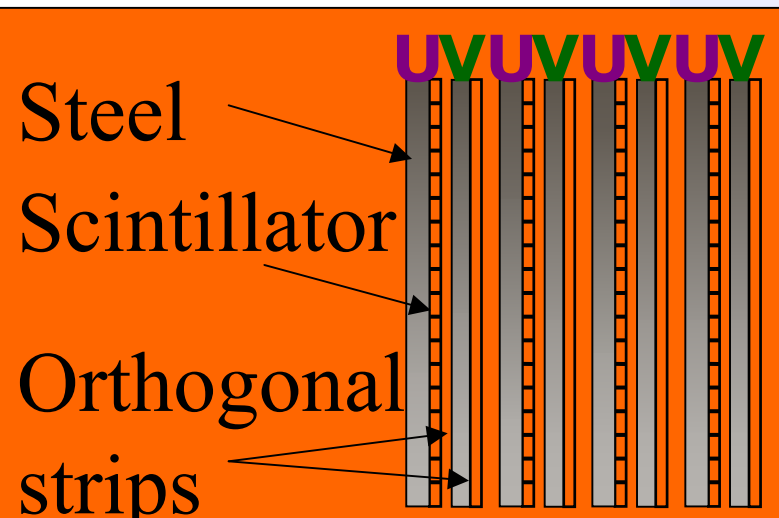
- ND at FNAL, FD at Soudan Mine, 735 km from FNAL
- ND is to measure the beam composition and energy spectrum
- FD is to search for evidence of oscillations between detectors
- FD is  $\sim 2x$  bigger than ND



# 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  $\langle B \rangle = 1.2T$
  - 1cm thick scintillator planes
  - Alternate planes rotated by  $\pm 90^\circ$  (U,V)
- thanks to this rotation we can find the 3D representation of an event

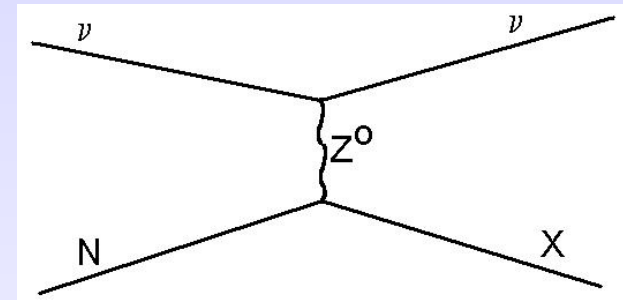
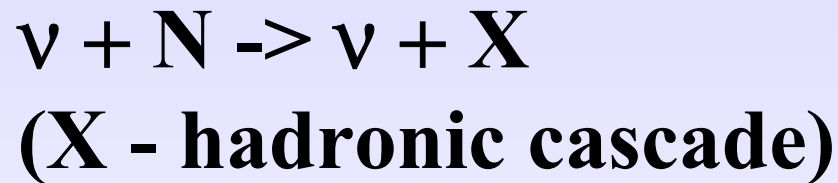




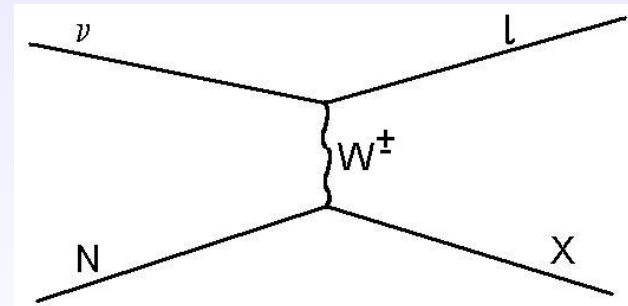
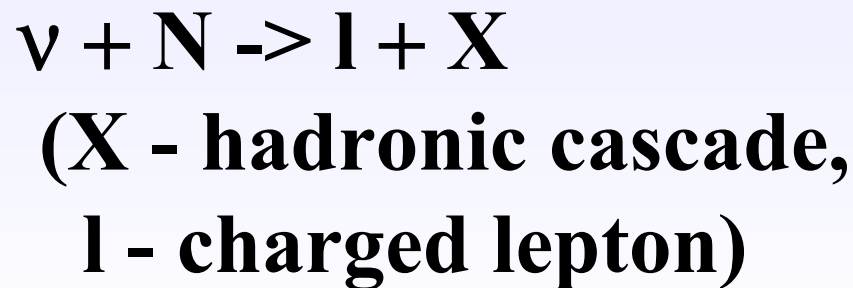
# Neutrino interactions

# Types of interactions

- Neutral Current (NC) - Z boson exchange



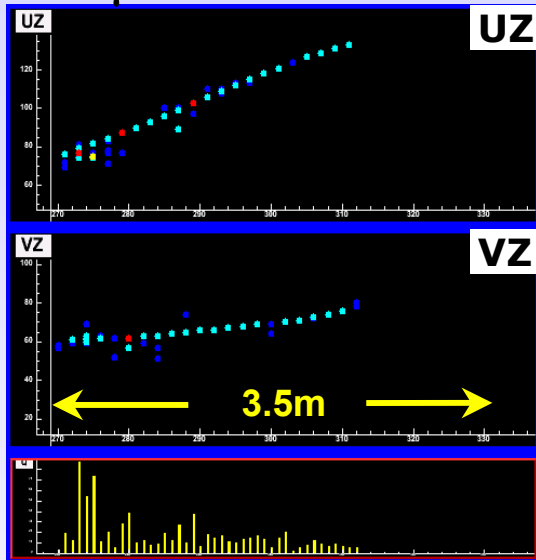
- Charged Current (CC) - W bosons exchange



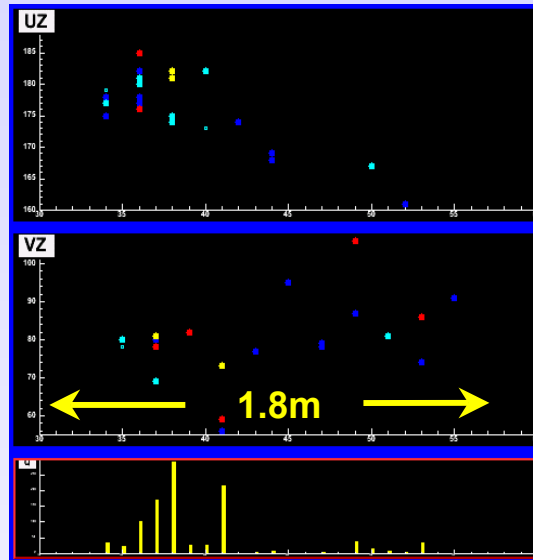


# Neutral Current or Charged Current?

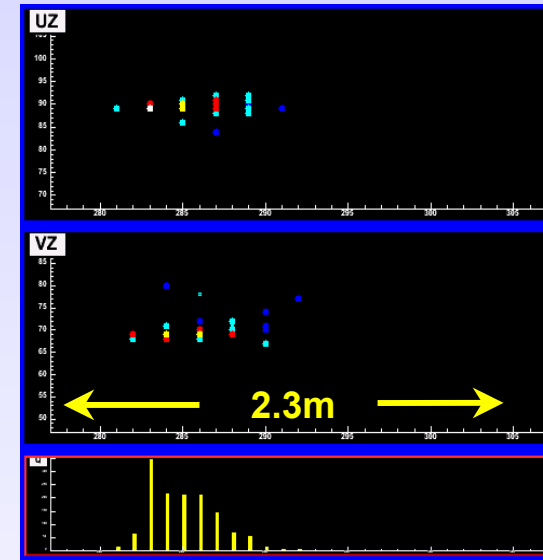
$\nu_{\mu}$  CC Event



NC Event



$\nu_e$  CC Event



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

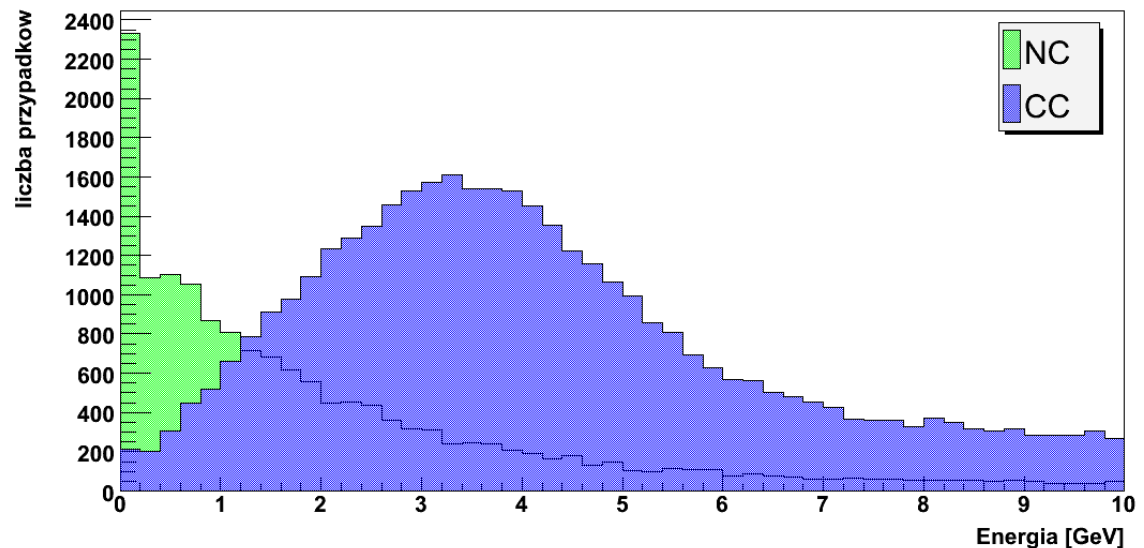
- short event, often diffuse
- the neutrino is “deflected”!

- short, with typical EM shower profile
- no  $\mu$  !
- No electron track - short radiation length

# CC to NC separation

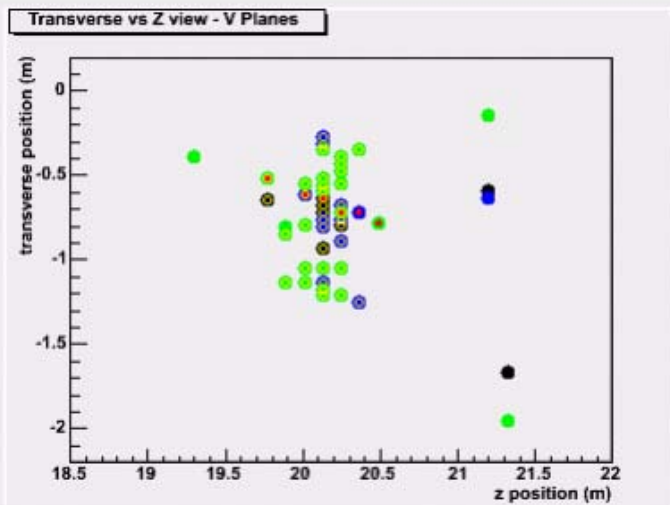
- MINOS can measure oscillations based on muon neutrinos which interact as CC
- It is necessary to separate CC  $\nu_\mu$  from NC events
- the biggest difficulty: low energy events

**Events (energy)  
histogram  
- based on  
Monte Carlo  
events**



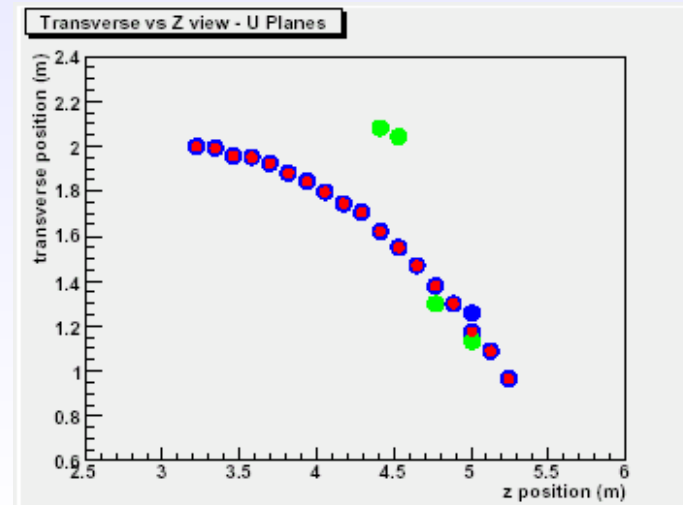
# Main goals

- 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  $\nu_\mu$  (right)  
and NC (left)  
events

Krzysztof W. Fornalski





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# **CC/NC Separation - cuts method**

# Cuts method



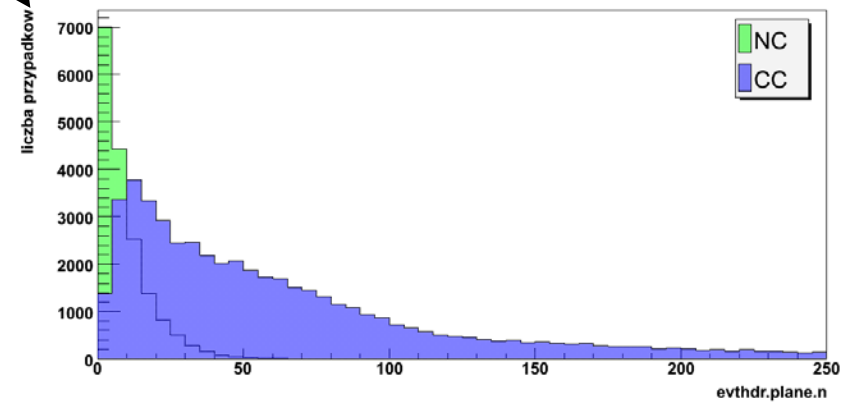
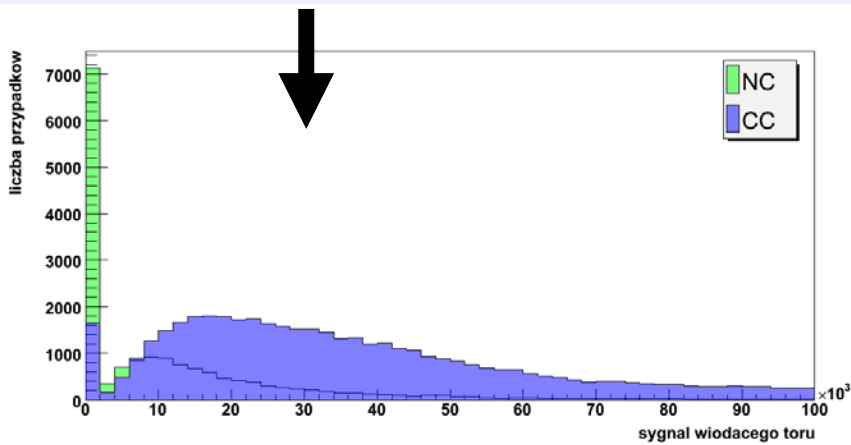
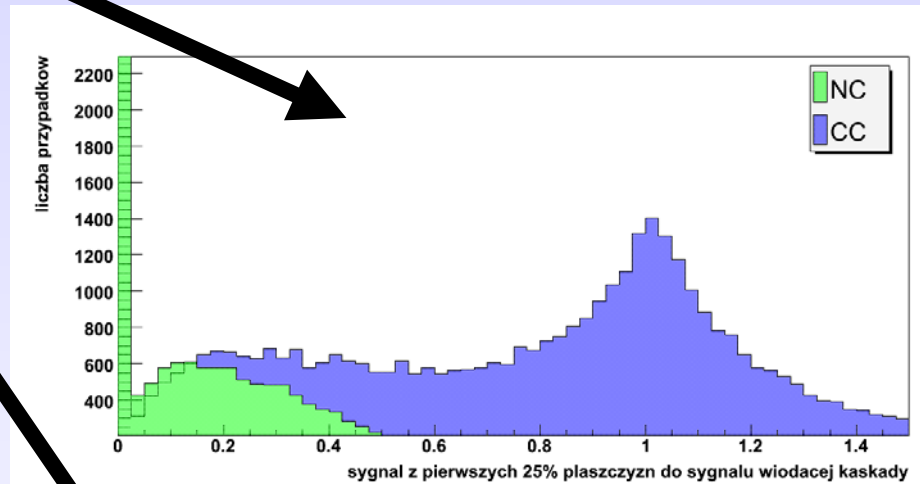
- Simple one-dimensional method of CC/NC separation
- three independent variables from STNP (Standard NTuple) files (ROOT)
- $\sim 70\,000$  Monte Carlo events

# Cuts method - the variables

- Signal from the first 25% active planes to biggest cascade signal

- number of active planes (length of the event)

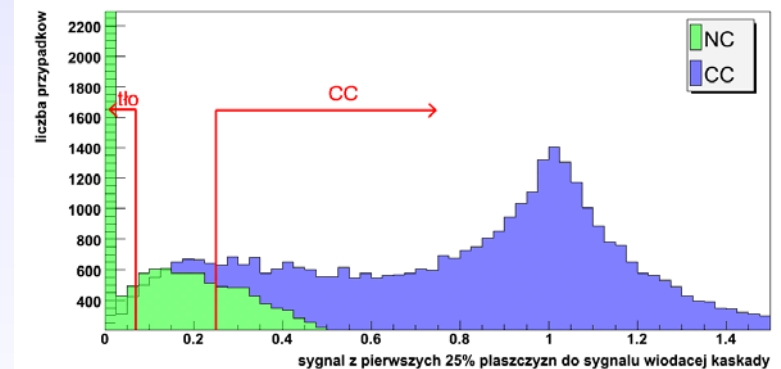
- signal of the longest reconstructed track



# Cuts on variables

- Simple cuts on all variables to separate CC from NC events
- if an event is not classified 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



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# **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

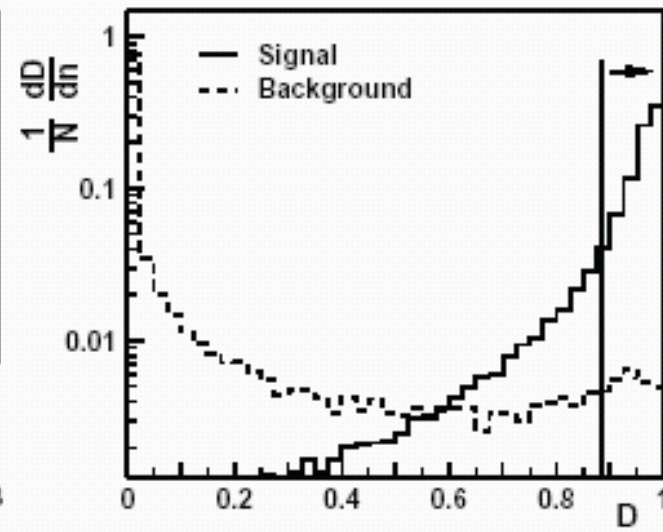
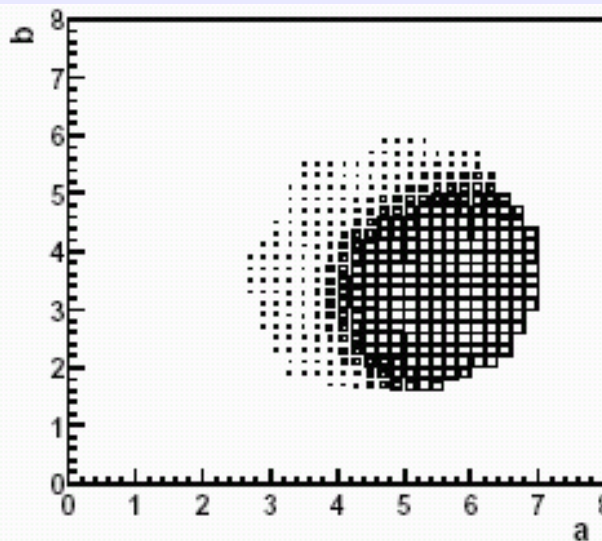
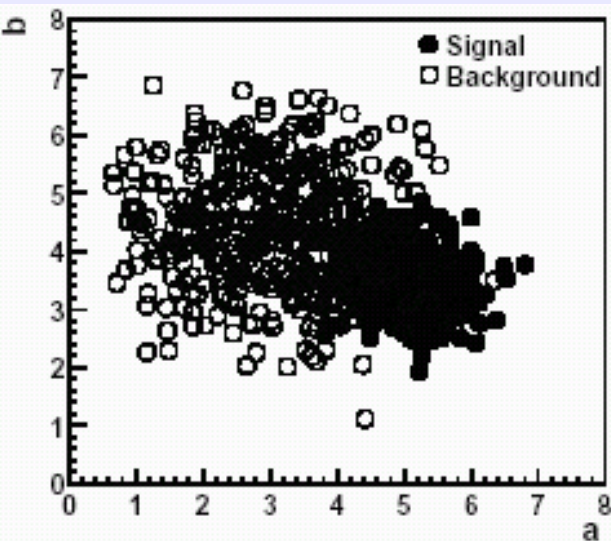
# Range Searching

## -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

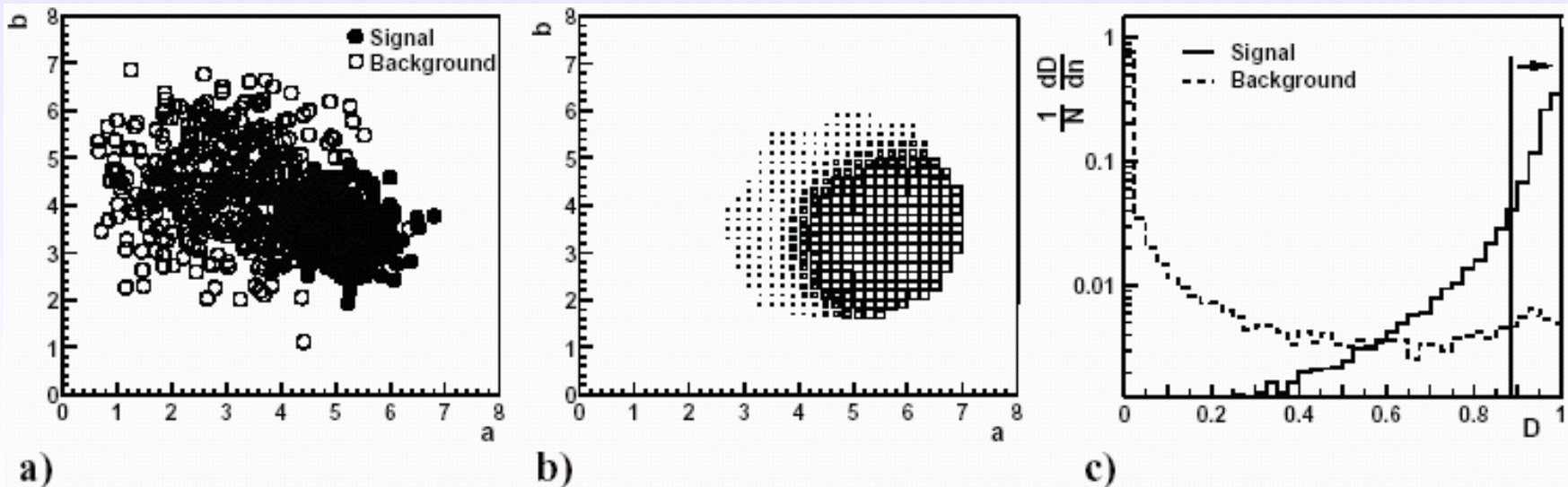
# Range Searching - simple 2D example

- 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

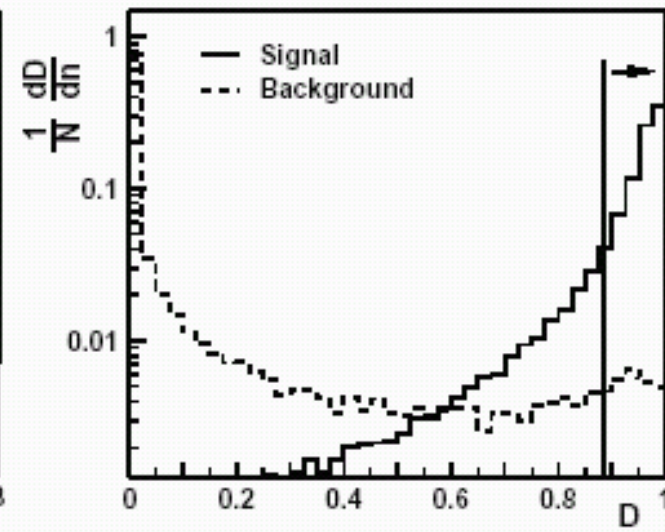
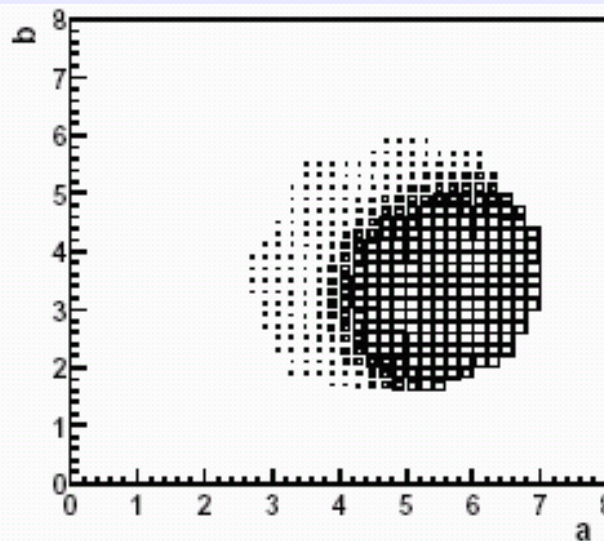
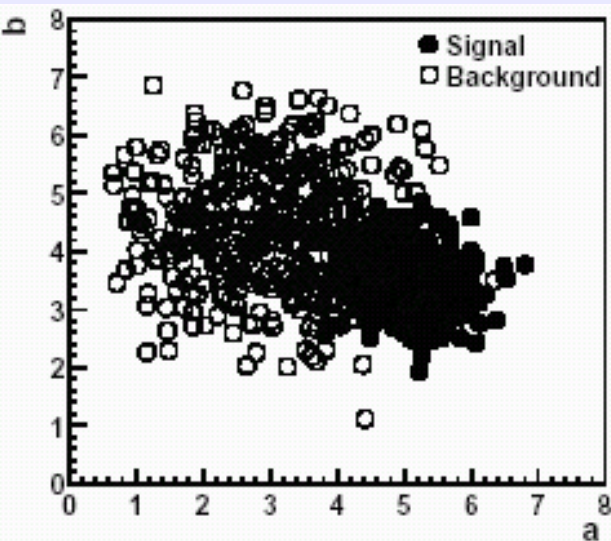
- V region (volume) around event (being analyzed) is estimated on the basis of the Monte Carlo model
- V contains a certain number of signal (CC) and background (NC) MC events



# 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)



a)

b)

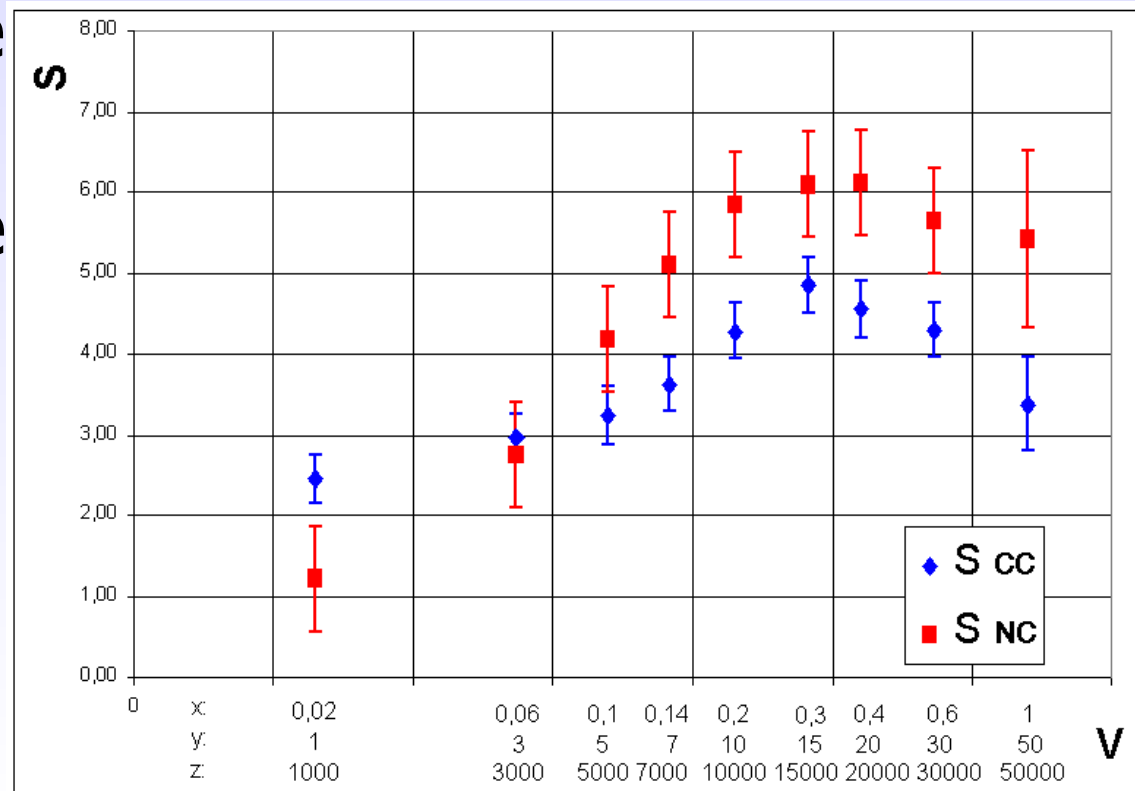
c)

# 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:

$$S := \frac{\epsilon_s}{\epsilon_b} = \frac{N_{s,\text{selected}}}{N_{s,\text{total}}} \frac{N_{b,\text{total}}}{N_{b,\text{selected}}}$$

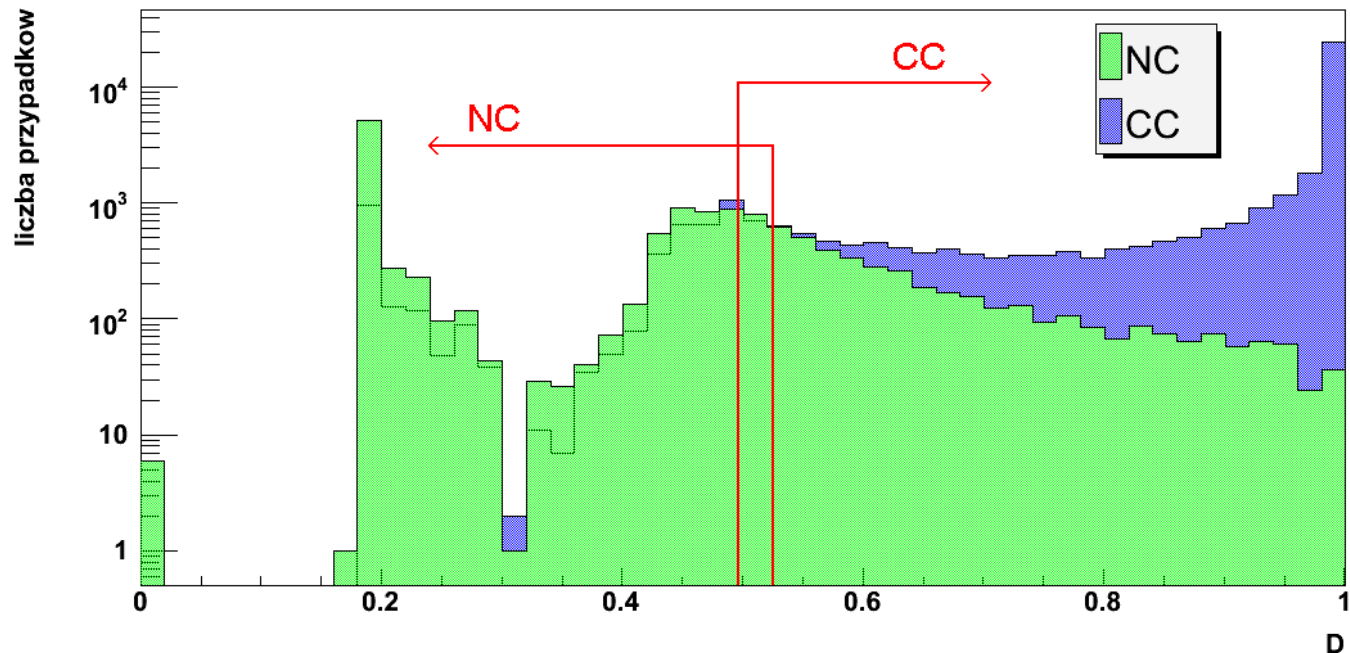


# Range Searching

## - 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

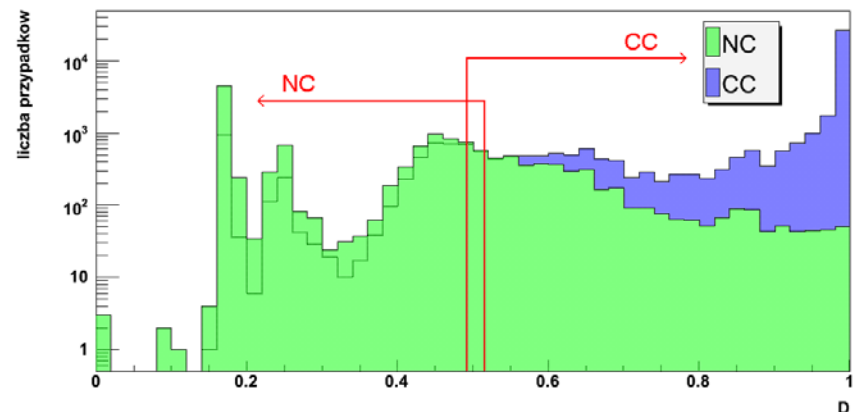
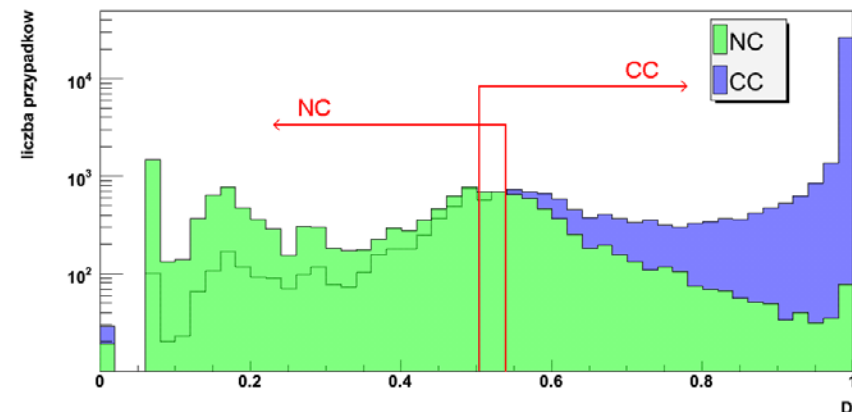
Events (D)



# 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)

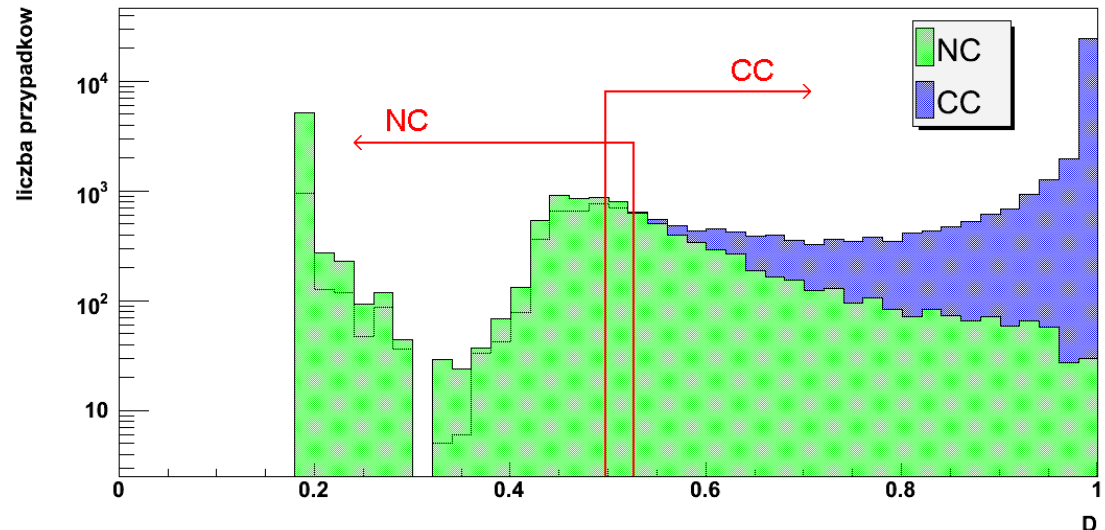




# Range Searching - modifications

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





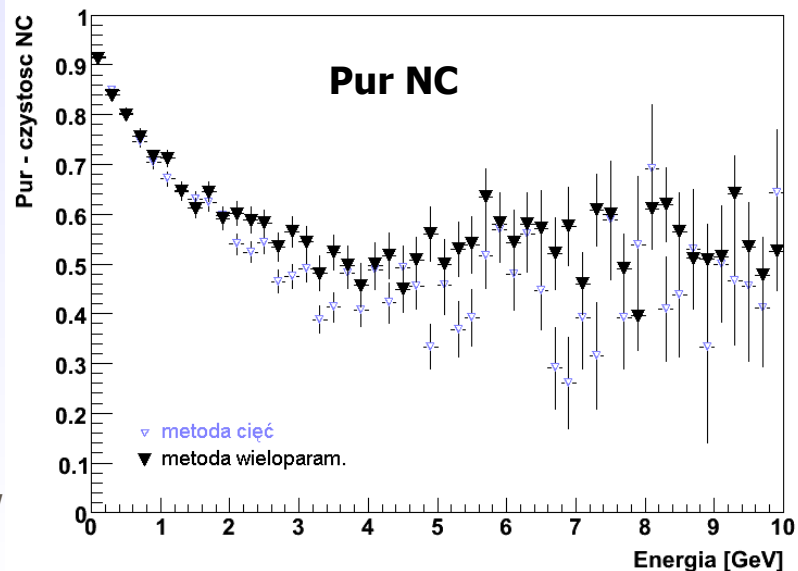
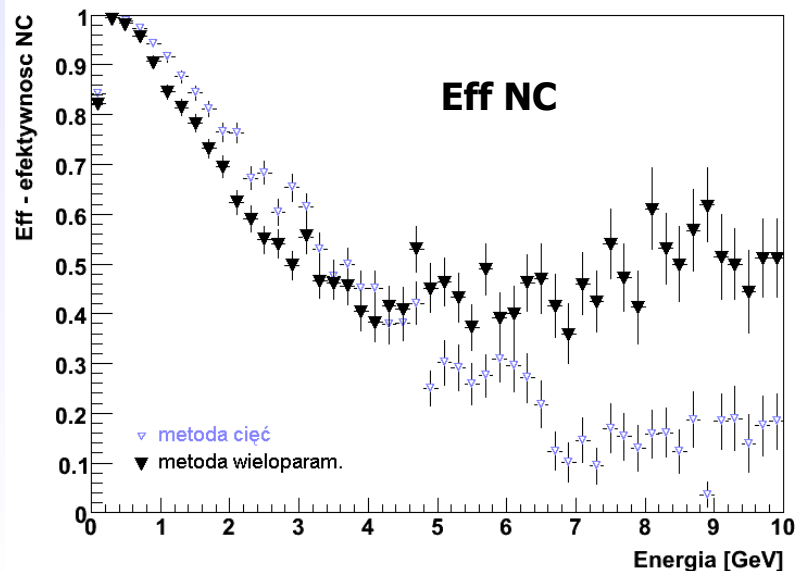
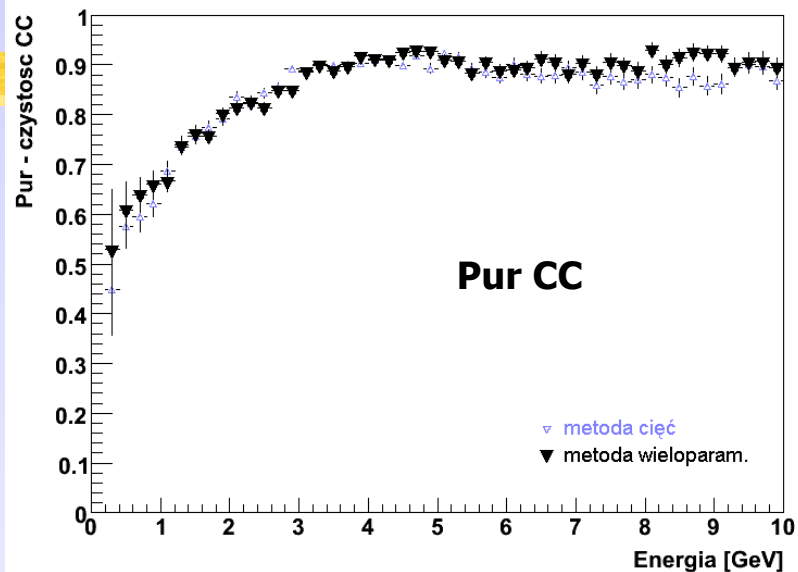
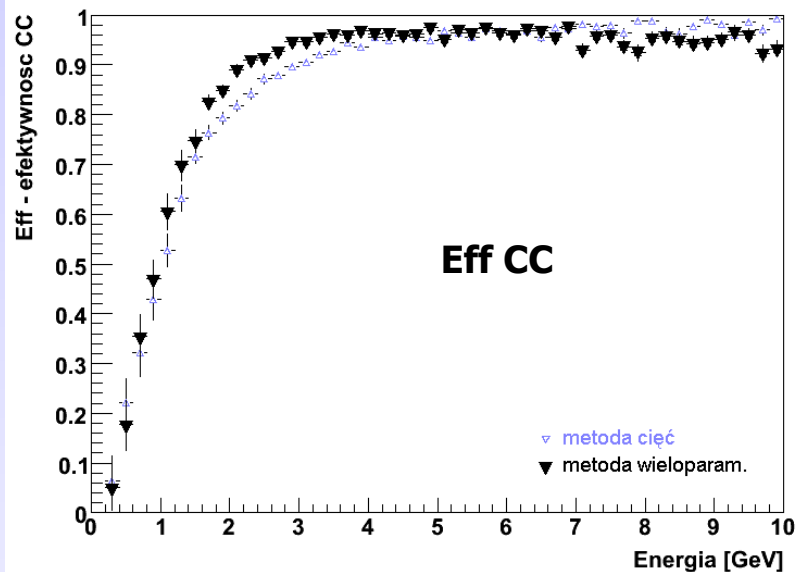
# **Results of all presented methods**

# Purity and efficiency of the NC & CC selection

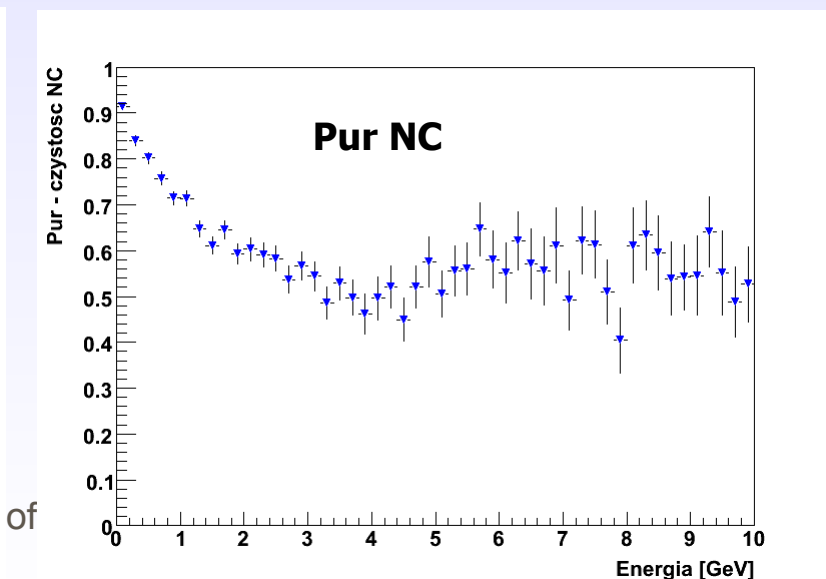
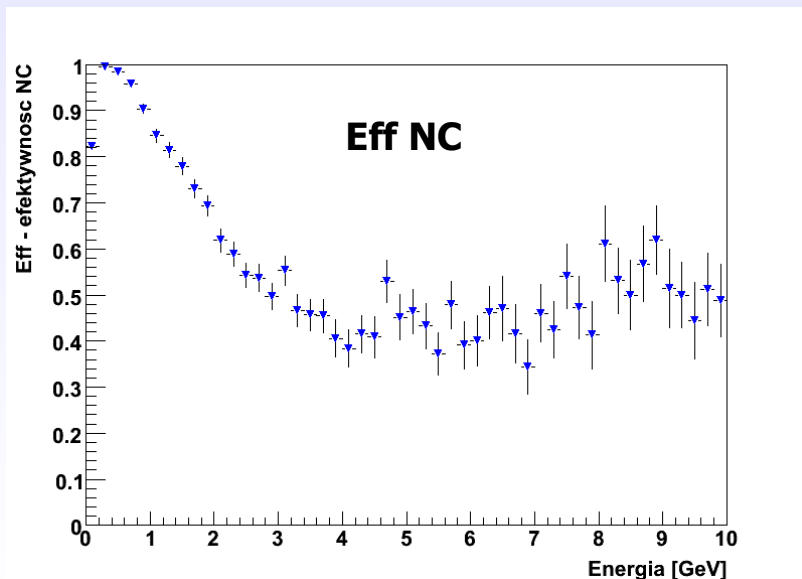
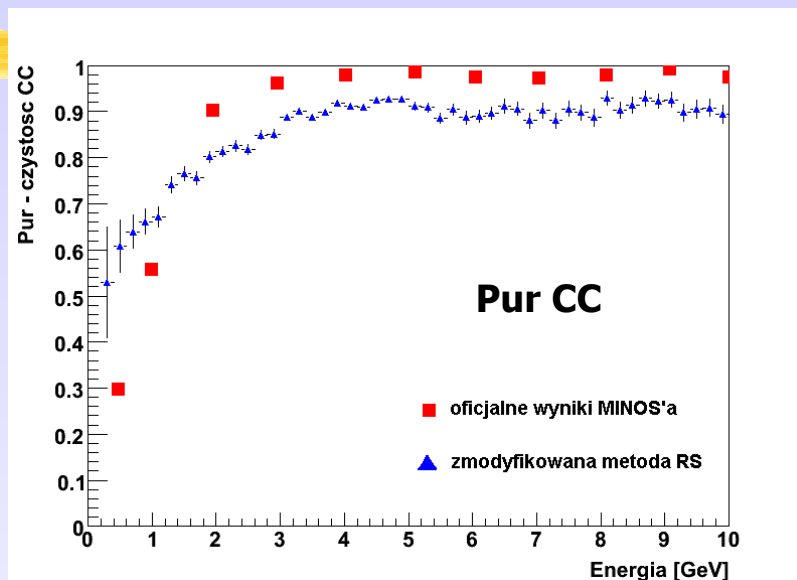
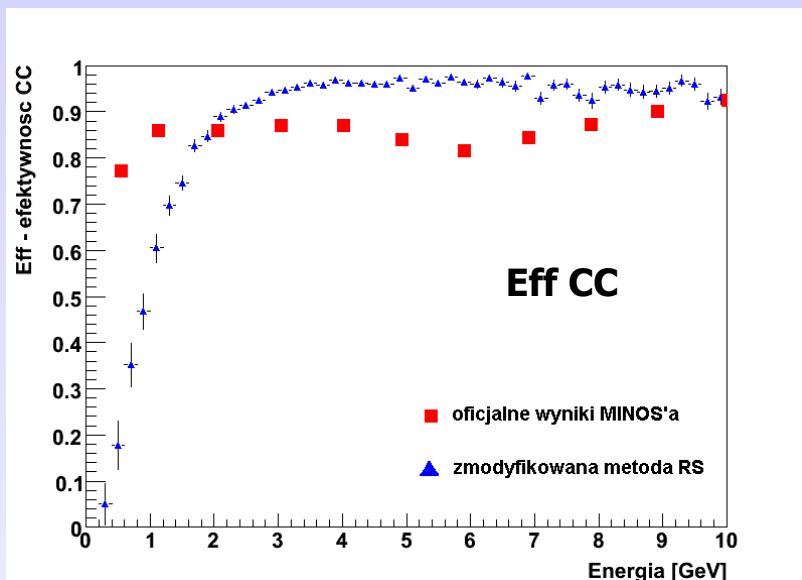
- to check the correctness of the selection, it is necessary to calculate the purity and efficiency of the selection:
- $\text{Pur} = N_{\text{true}} / (N_{\text{true}} + N_{\text{false}})$
- $\text{Eff} = N_{\text{true}} / N_{\text{all}}$

where  $N_{\text{true}}$  is a number of correctly selected events,  $N_{\text{false}}$  of incorrectly selected events,  $N_{\text{all}}$  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!



of

# Separation power

■ Defined earlier:

$$S := \frac{\epsilon_s}{\epsilon_b} = \frac{\frac{N_{s,\text{selected}}}{N_{s,\text{total}}}}{\frac{N_{b,\text{selected}}}{N_{b,\text{total}}}}$$

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