Neutrinos & the MINOS Experiment

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WF PW 2007

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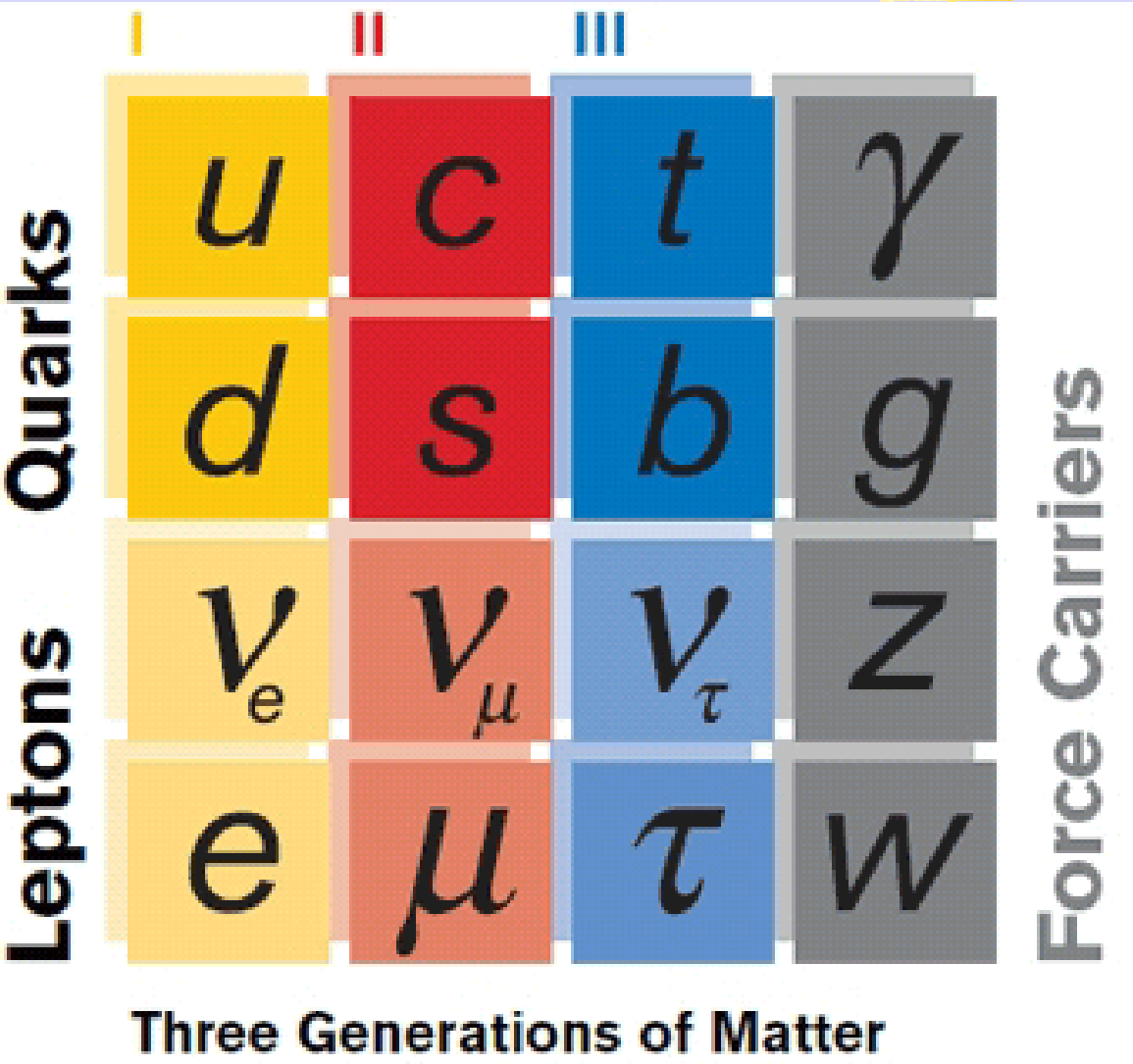
UW

Overview of the talk

- neutrino theory
- neutrino beam & MINOS experiment
- software analysis
- neutrino events
- first results of event selection
- summary


A little bit of theory

Standard model



- there are 3 generations of neutrinos
- neutrinos are non-charged leptons
- neutrinos have a very low mass
- neutrinos are not visible!
- we can detect them thanks to particle collisions

Theory

- in many neutrino experiments scientists proved that neutrinos can oscillate into each other (for ex. K2K experiment)
- the neutrino „flavour” is changing during their travel
- $\nu_\mu <-> \nu_\tau <-> \nu_e <-> \nu_\mu$ etc.

Theory

The approximate formula describing oscillations is:

$$\mathbf{P(\nu_\alpha \rightarrow \nu_\beta) = \sin^2 2\theta \sin^2(1.27\, \Delta m^2\, L/E)}$$

where L (source to detector distance) and E (neutrino energy) are experimental parameters

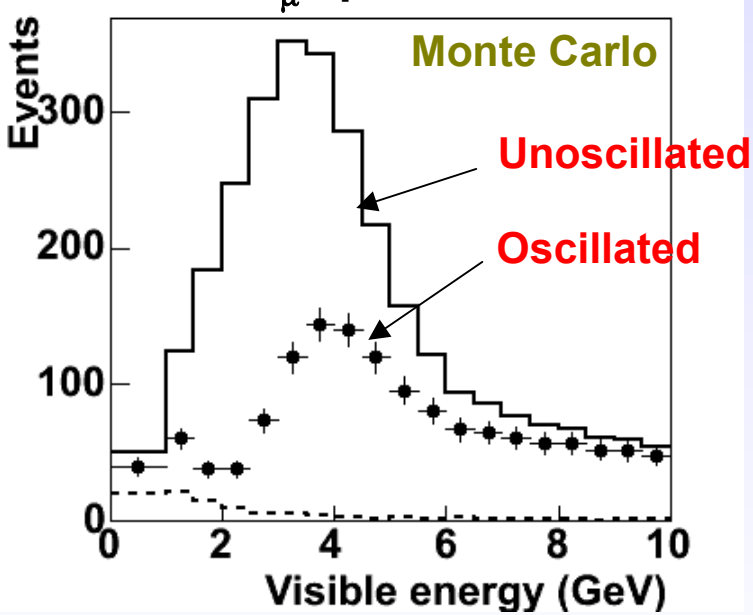
2θ (mixing angle) and Δm^2 (mass squared difference) are oscillation parameters

Example of a ν_μ disappearance measurement

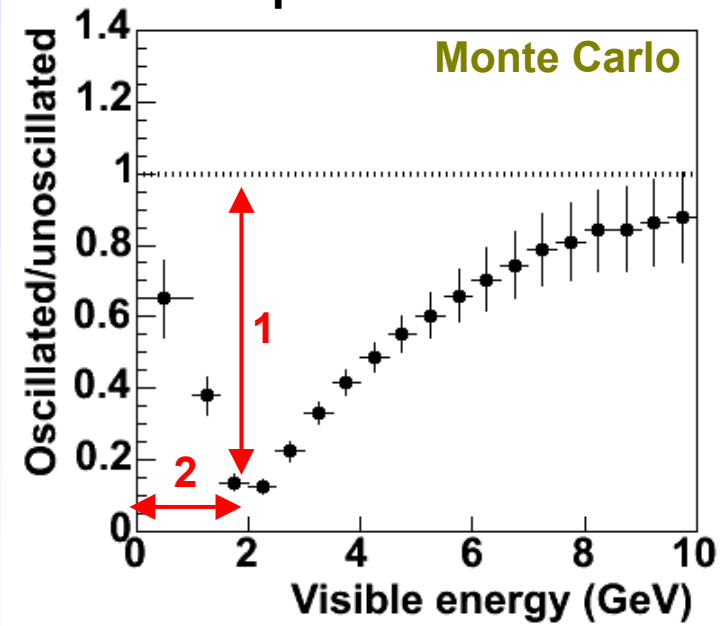
- Look for a deficit of ν_μ events at FD

$$P(\nu_\mu \rightarrow \nu_\mu) = 1 - \underset{1}{\sin^2 2\theta} \sin^2(1.267 \underset{2}{\Delta m^2} L/E)$$

ν_μ spectrum



spectrum ratio




MINOS Experiment

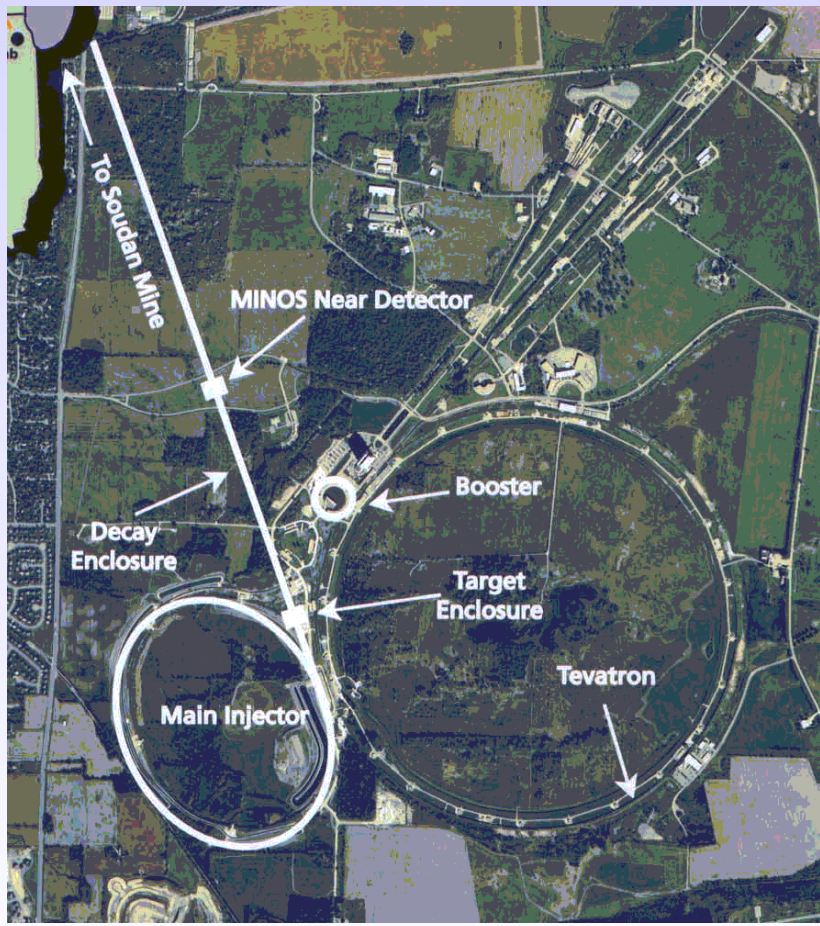
First informations

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


Beam production

Production of the beam

- Fermi National Laboratory near Chicago
- 120 GeV protons from the Main Injector accelerator
- time between pulses - 2s (design parameter)
- length of the pulse = 10μs
- 2.5×10^{13} protons/pulse

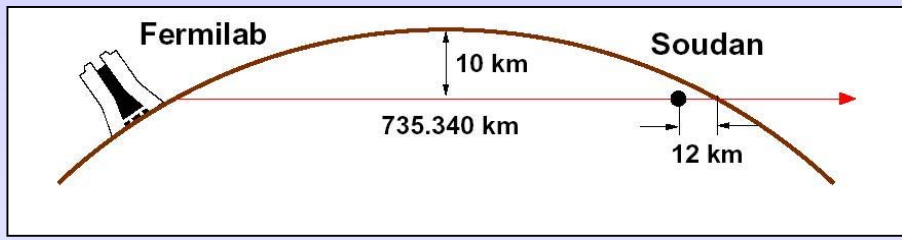


Producing the neutrino beam - the scheme

Proton beam collides with a graphite target. As a result there are many short-life particles (pions, kaons, etc.), which decay into muons (and ν). Muons decay into muon neutrinos. In such a way the neutrino beam is formed.

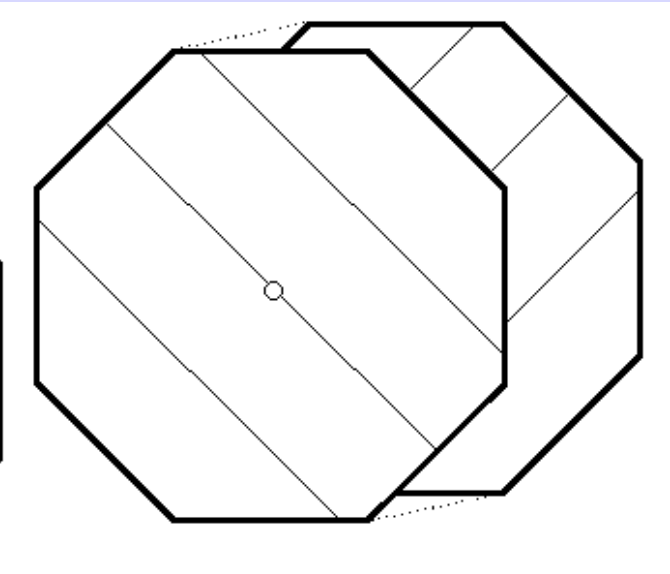
MINOS long-baseline experiment detectors

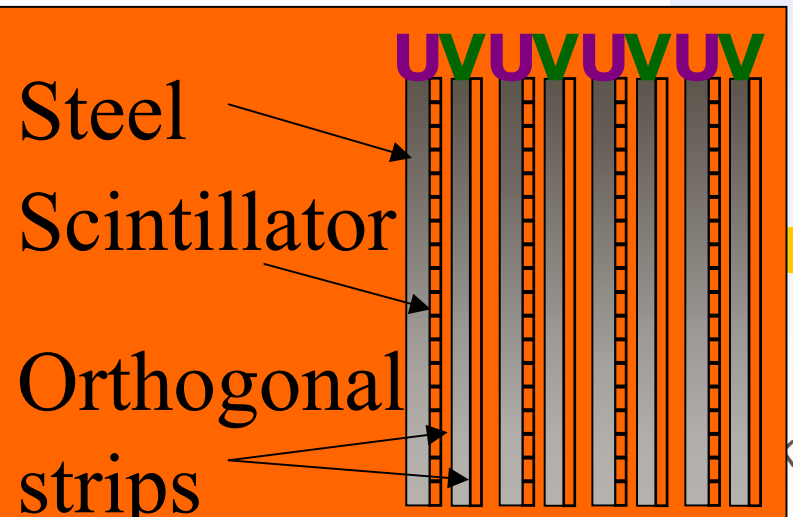
Why „long-baseline” experiment?



- neutrino beam travels from Fermilab to the Near Detector (ND) at Fermilab and to the Far Detector (FD) in the Soudan Mine (Minnesota)
- long distance between detectors => neutrino oscillations

Detectors construction



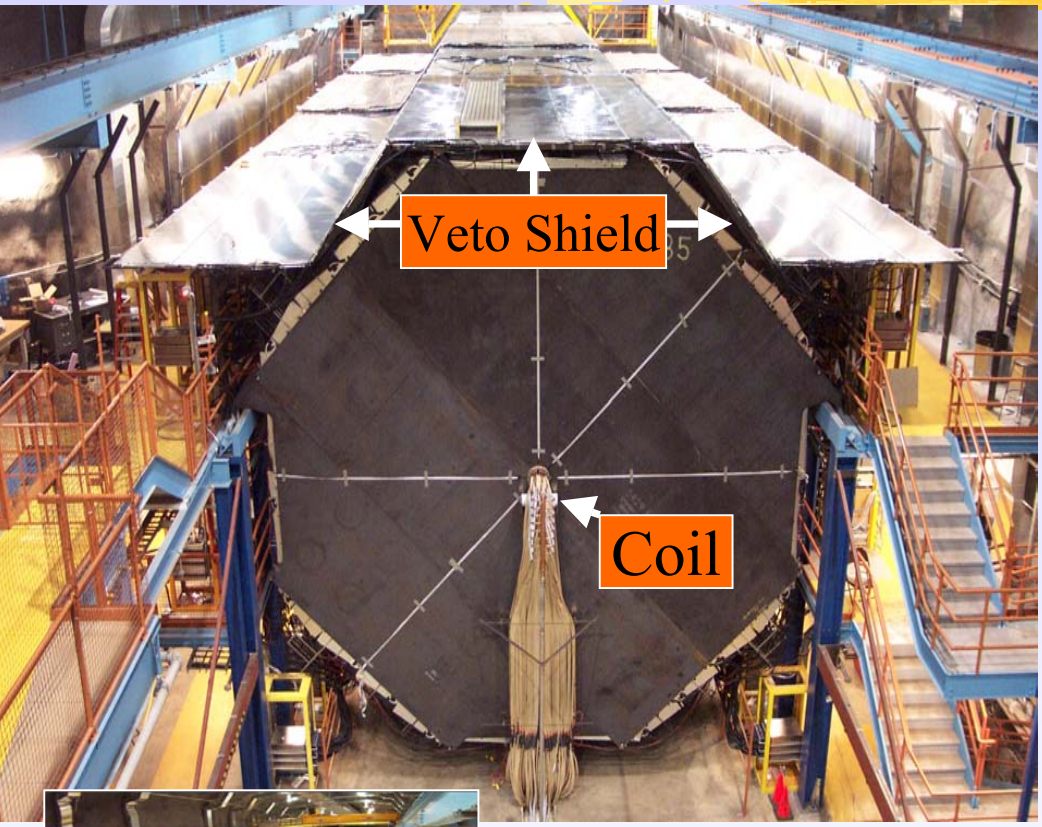


- Near & Far detectors are functionally identical
- They share the same basic detector technology and granularity:
  - Iron/Scintillator tracking calorimeters
  - 2.54cm thick magnetized steel planes <B> = 1.2T
  - 1cm thick scintillator planes
  - Alternate planes rotated by ±90^{o} (U,V)
- thanks to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

MINOS Near Detector (ND)

- Located at FNAL
- 1040m from the target
- 103m underground
- mass 980 tons
- 3.8m x 4.8m x 16m
- 282 steel + 153 scintillator planes
- ND is to measure the beam composition and energy spectrum

MINOS Far Detector (FD)

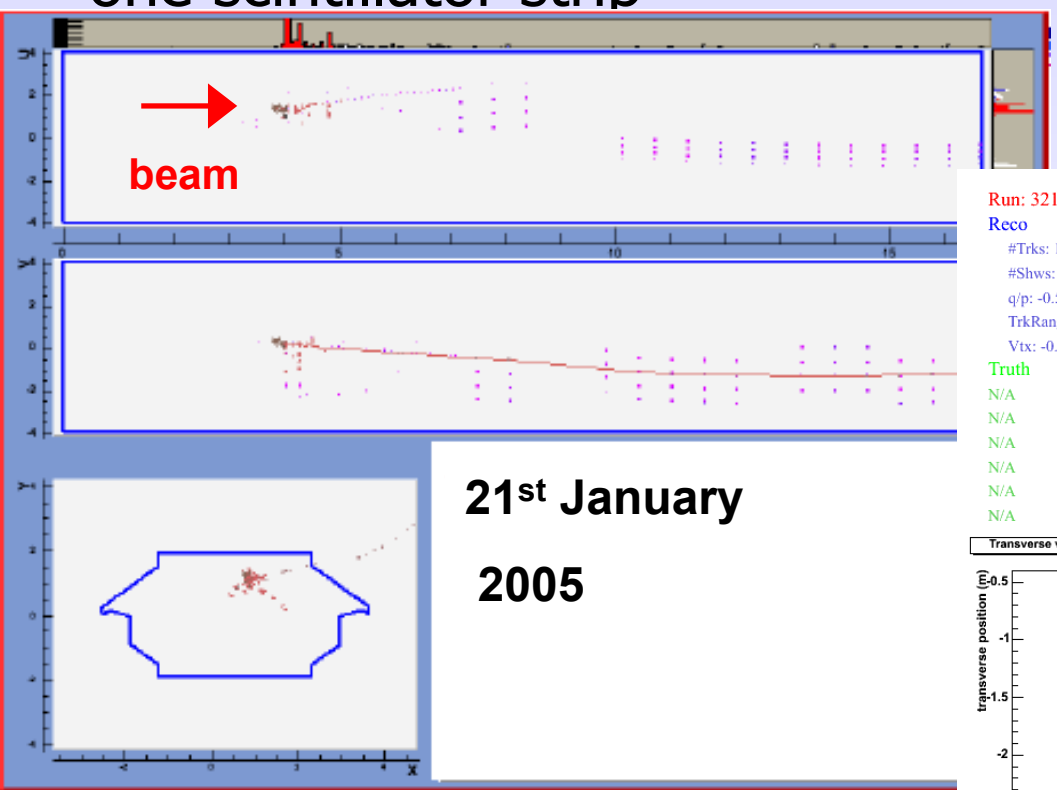


- 735 km from the target
- 705m underground
- 5.4 kton mass
- 8m x 8m x 30m
- 484 scintillator planes
- veto shield for cosmic ray rejection in atmospheric ν analysis
- FD to search for evidence of oscillations


Software analysis

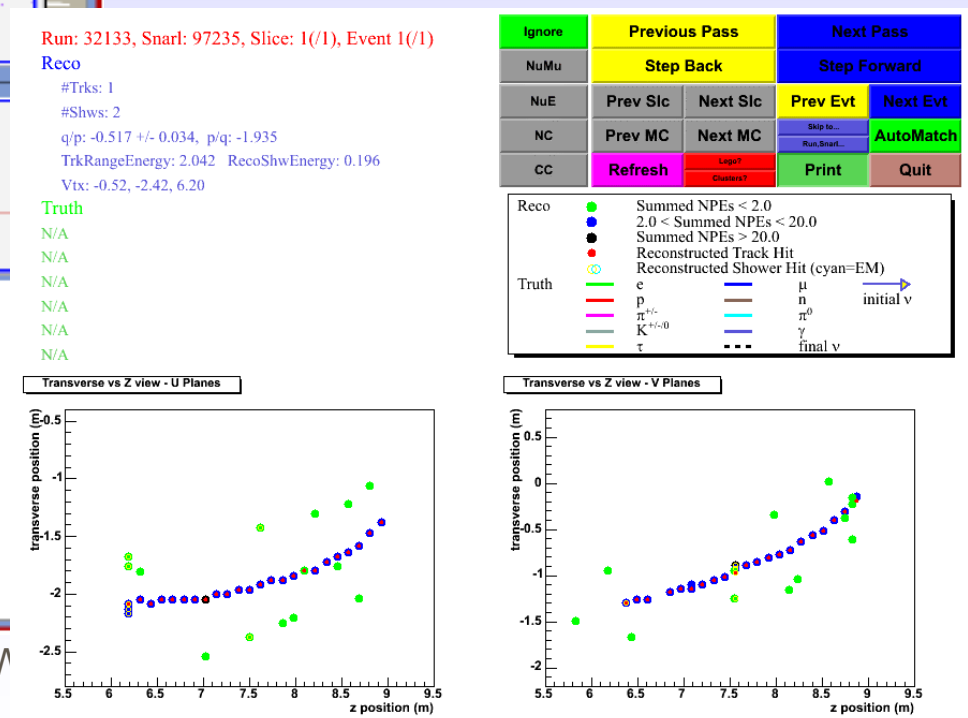
How you can see the signal

In the picture you can see a track of the muon in ND as the result of the neutrino interaction. Each point is a signal from one scintillator strip



21st January

2005

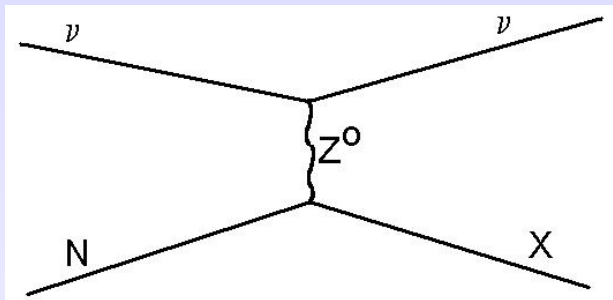


Types of interactions

- Neutral Current (NC) - Z boson exchange

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

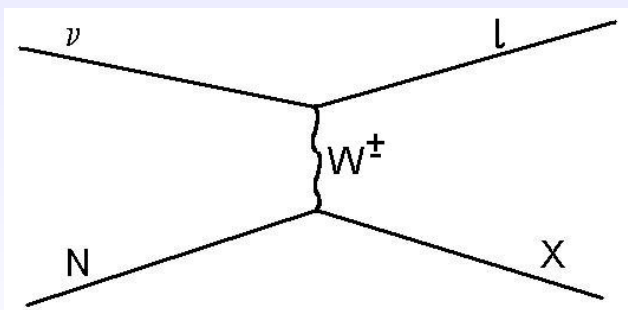
(X - hadronic cascade)



- Charged Current (CC) - W bosons exchange

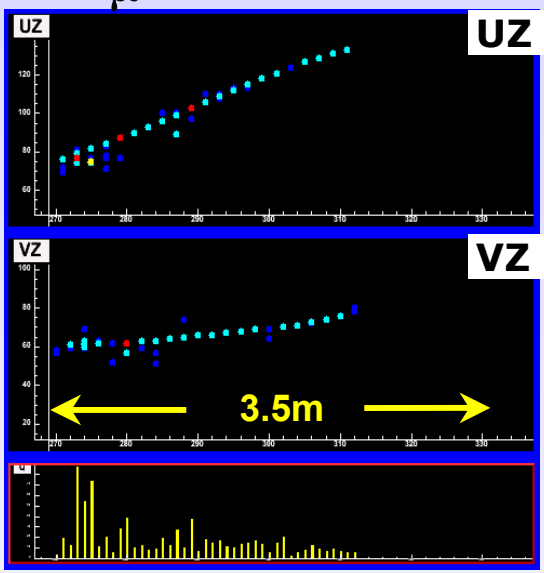
$\nu + N \rightarrow l + X$

(X - hadronic cascade,
l - charged lepton)



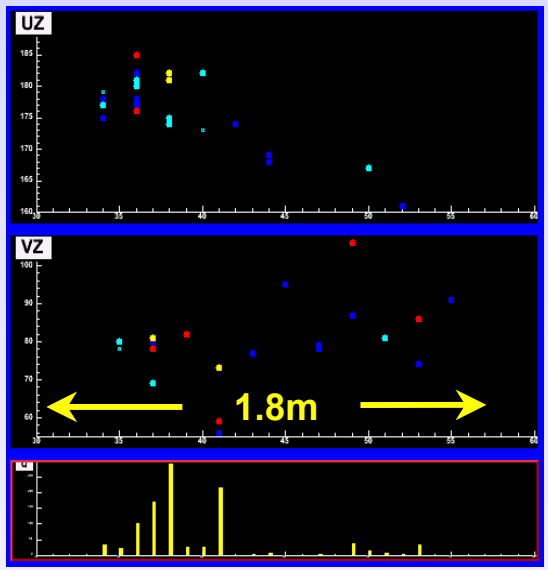
Neutral Current or Charged Current?

ν_μ CC Event



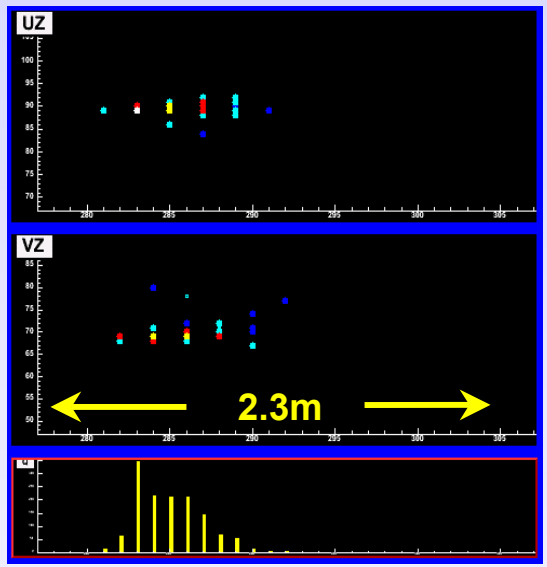
- We have μ with long μ track+ hadronic shower

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


Data analysis and my first results (Far Detector)

Data structure

- ROOT TTree (NTuple)
- MC or Data
- There is 1000 to 5000 neutrino events in one file
- many variables in each event
- tree structure - branches and leaves

Some variables - examples - ‘evthdr’ branch

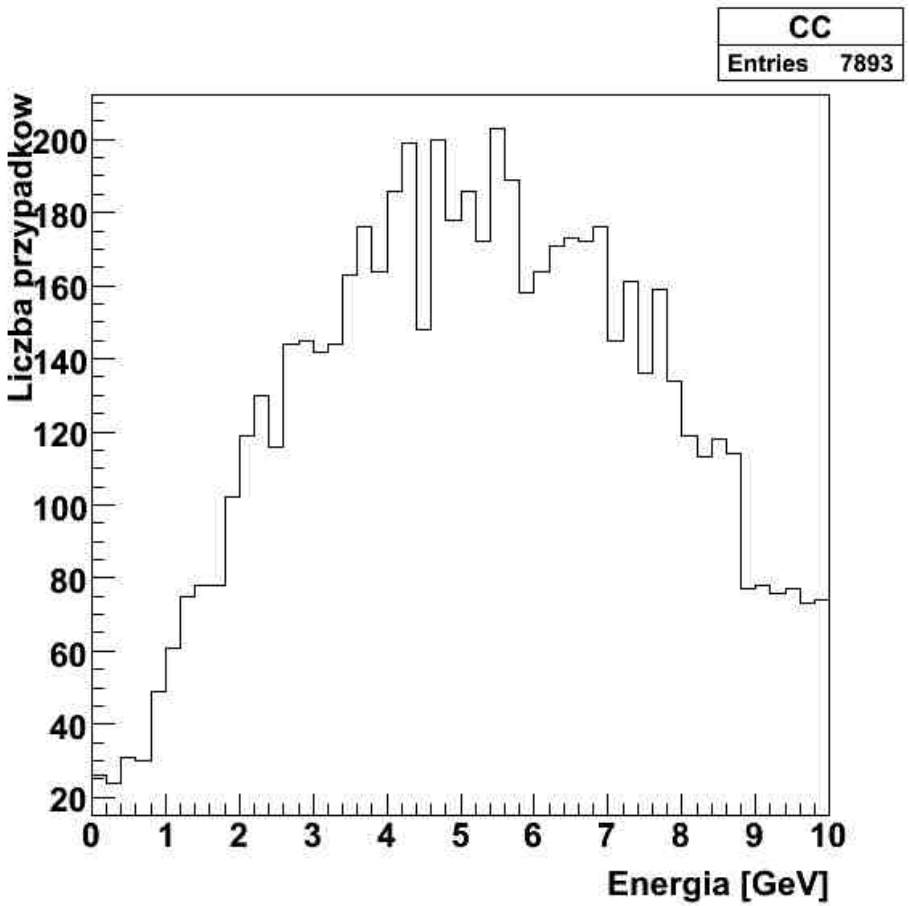
- **evthdr.ph.sigcor** – pulse height of the event (visible energy)
- **evthdr.ntrack** – number of reconstructed tracks in the event
- **evthdr.nshower** – numer of recontructed hadronic cascades in the event
- **evthdr.planeall.n** – number of active scintillator planes (total lenght of the event)

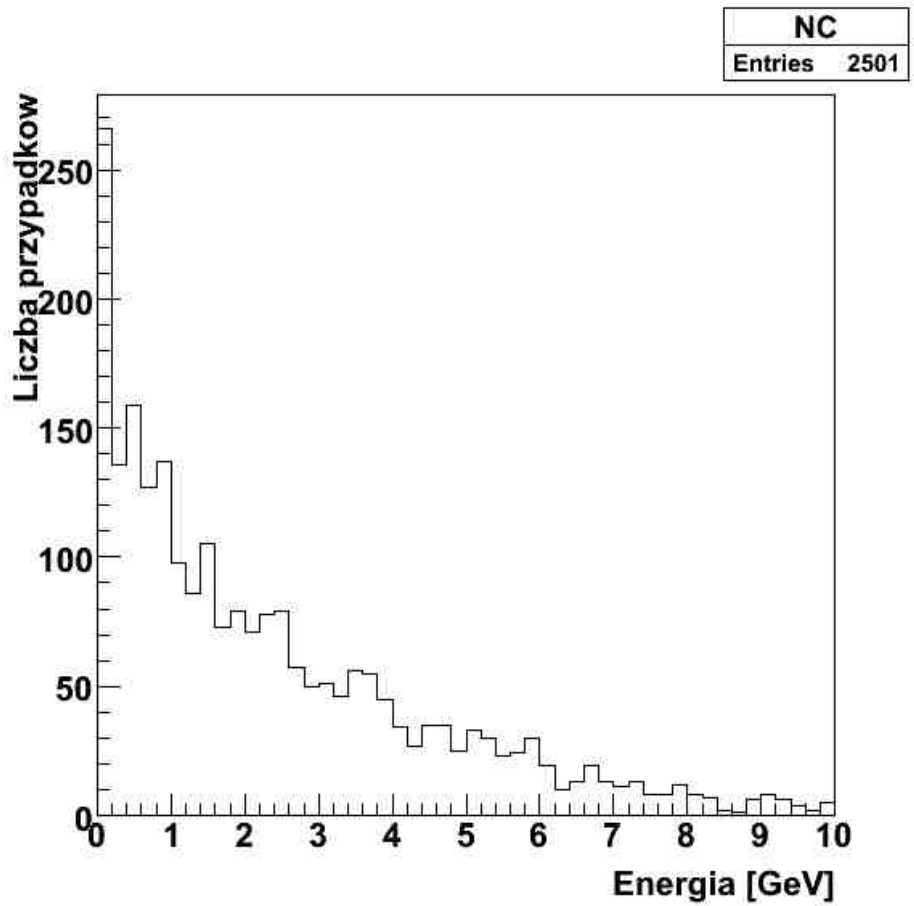
One important MC variable

- **mc.iaction**

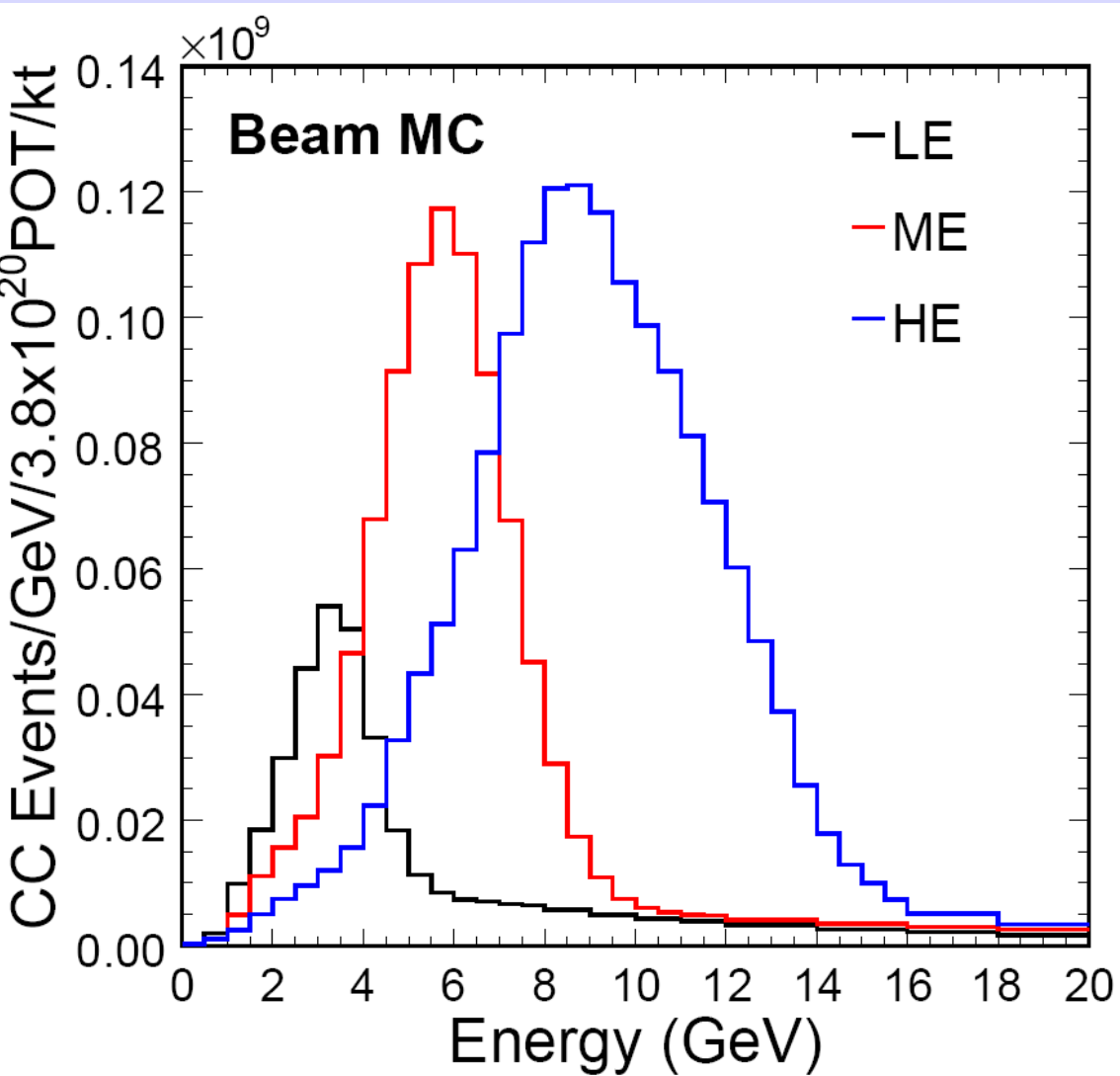
- 'mc' branch
- = 1 when there is a CC event
- = 0 when there is a NC event
- thanks to that we can compare the distributions for the NC and CC events...

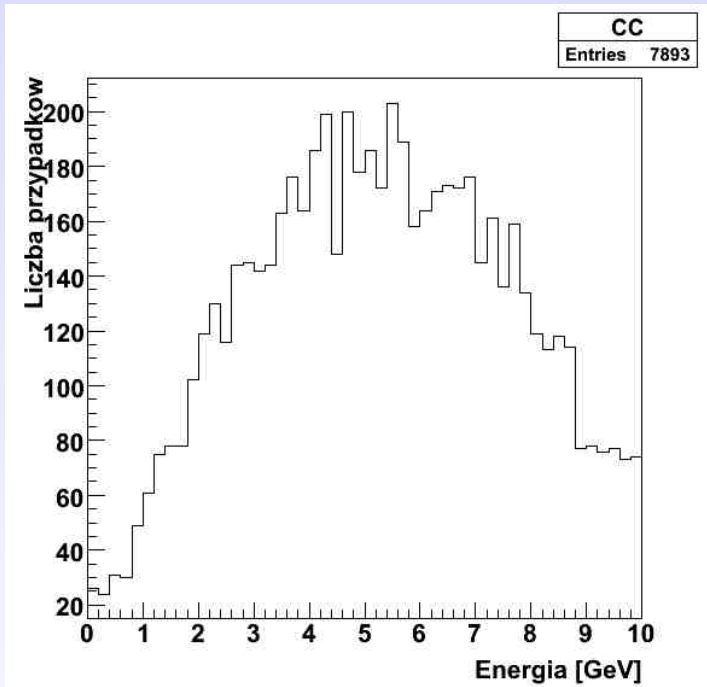
NC & CC event distributions Monte Carlo simulation





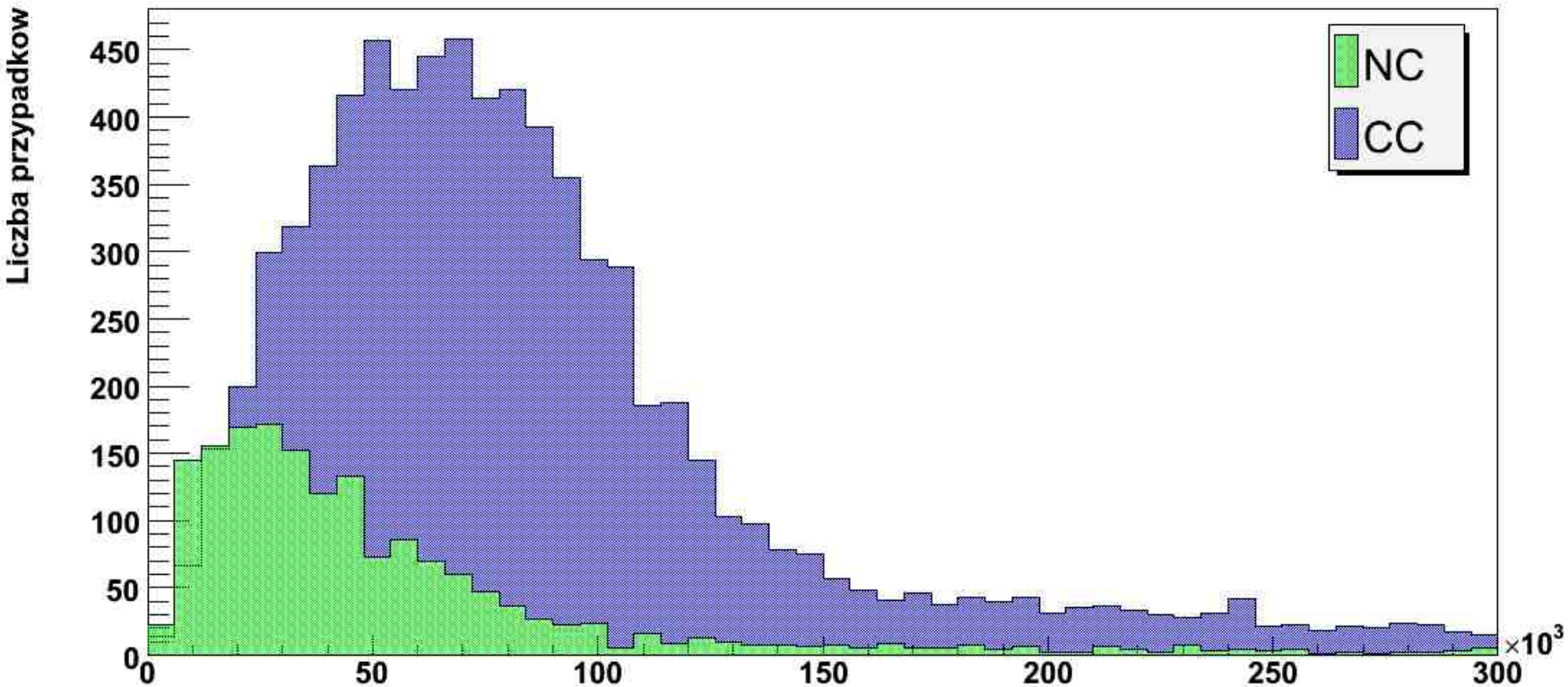
Medium-energy beam





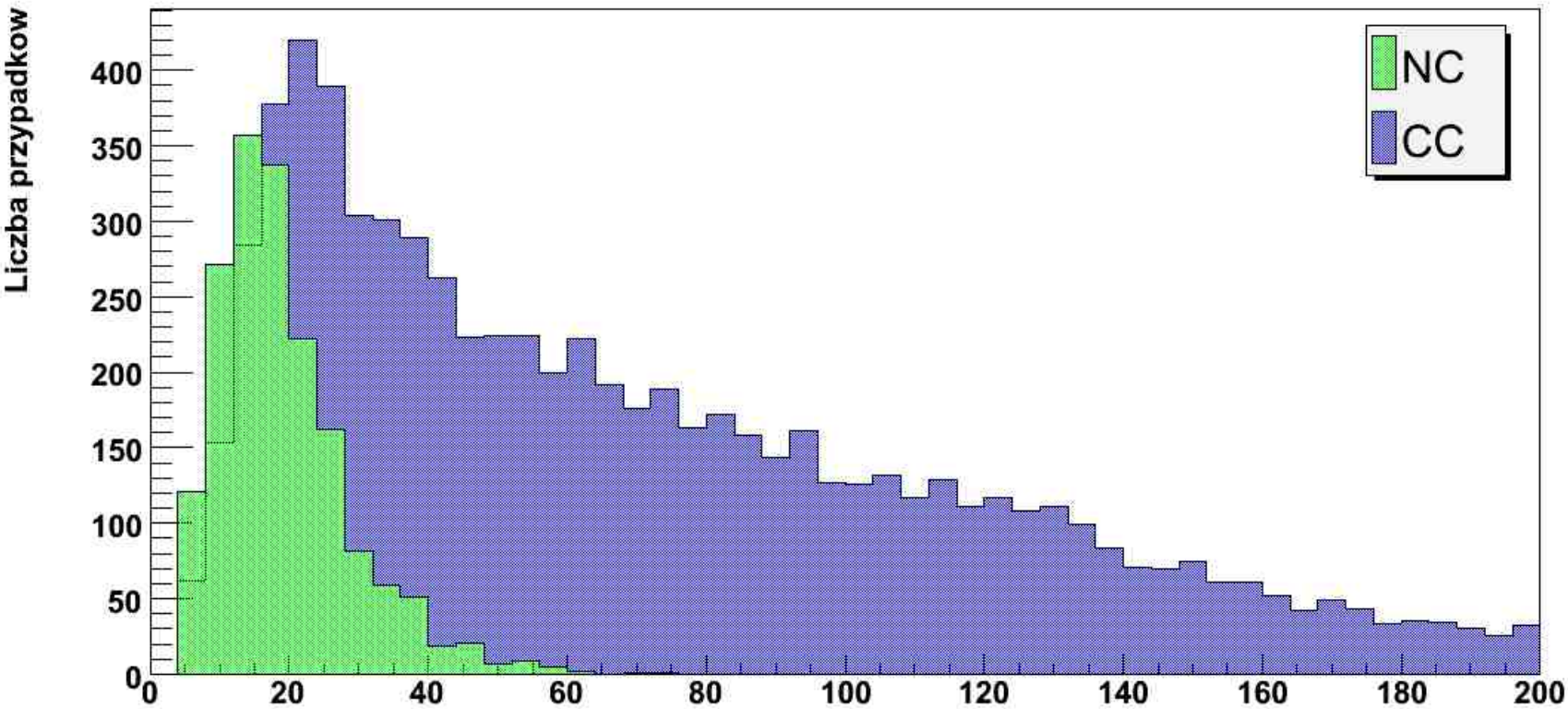

Some examples of variables' distributions

evthdr.ph.sigcor variable NC & CC comparison



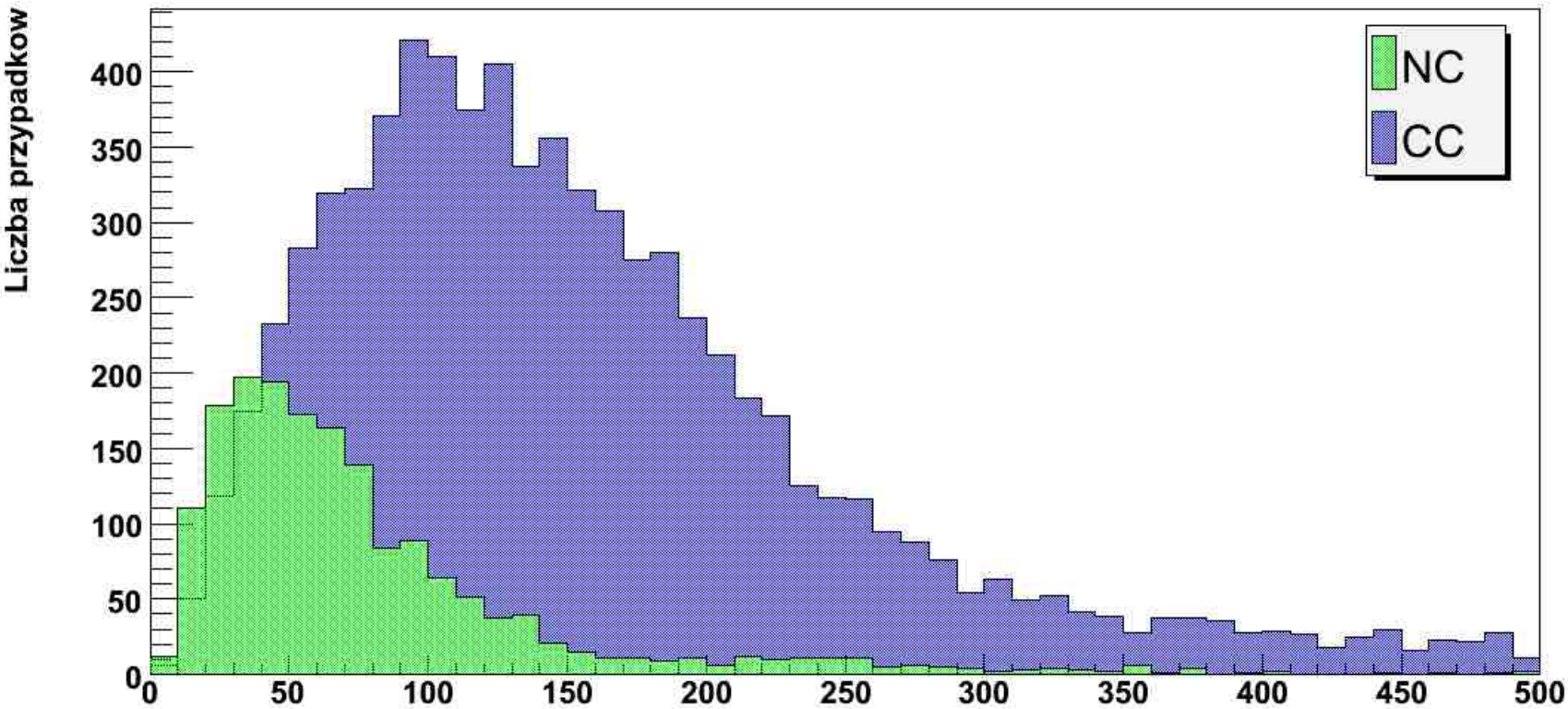
evthdr.ph.sigcor (visible energy)

evthdr.planeall.n variable NC & CC comparison



evthdr.planeall.n (event lenght)

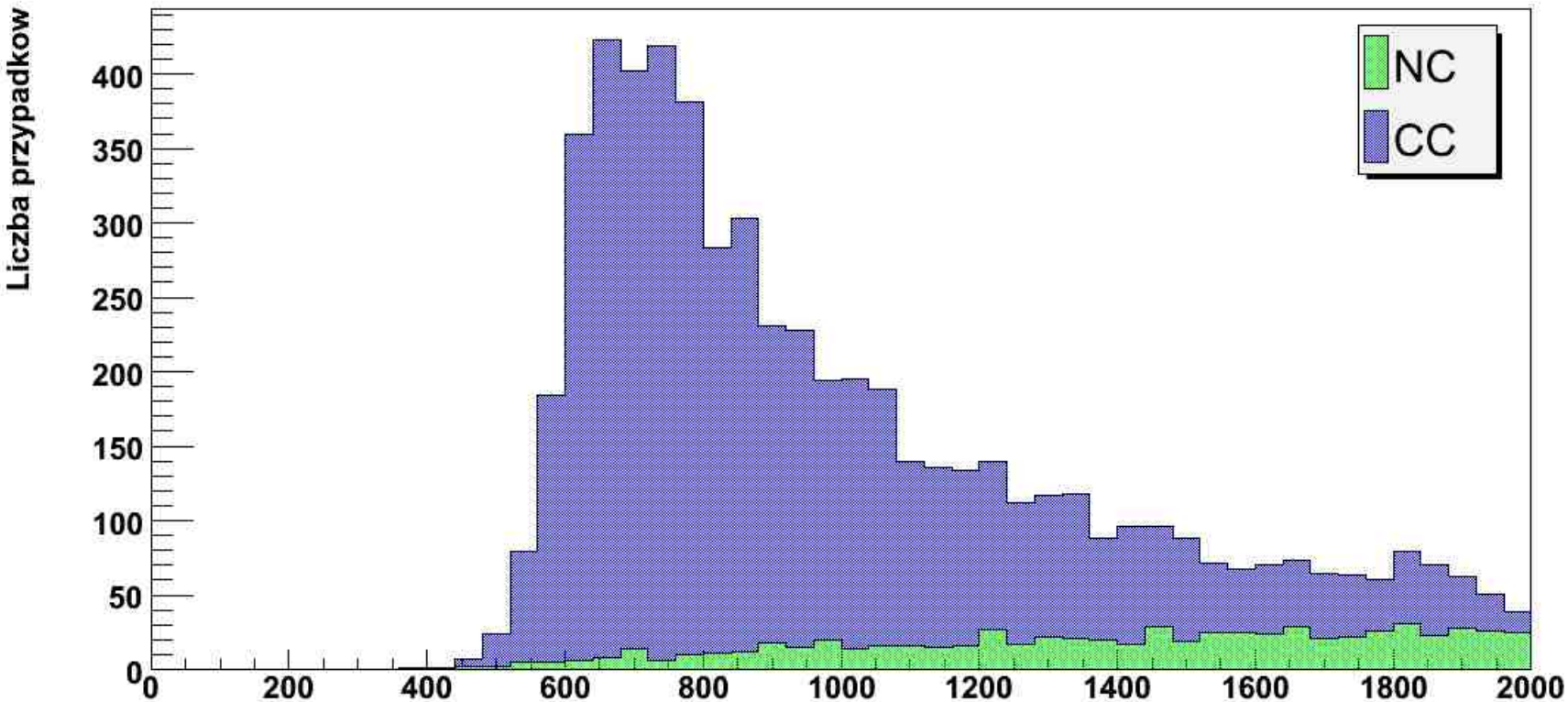
evthdr.nstrip variable NC & CC comparison



evthdr.nstrip (number of strips)

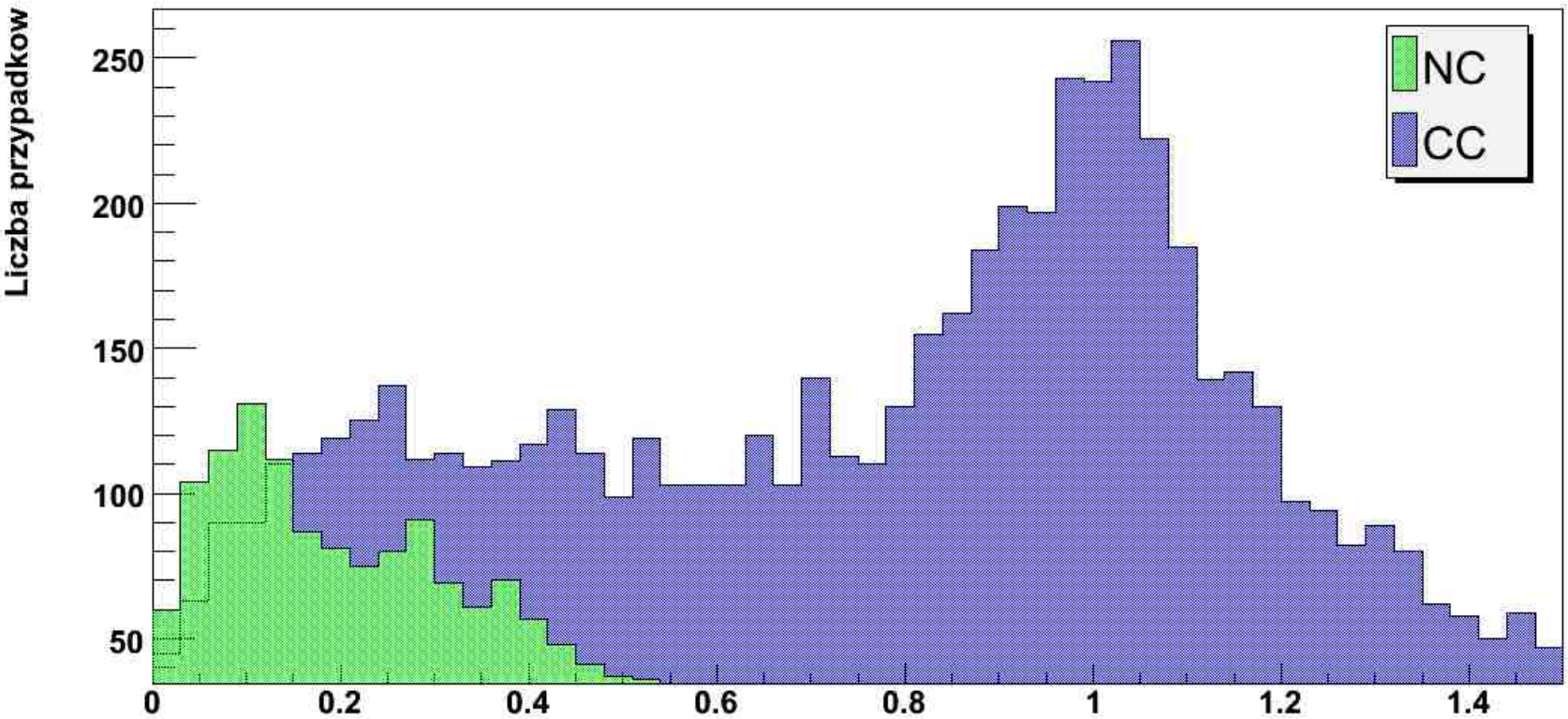
evthdr.ph.sigcor/evthdr.planeall.n variable

NC & CC comparison



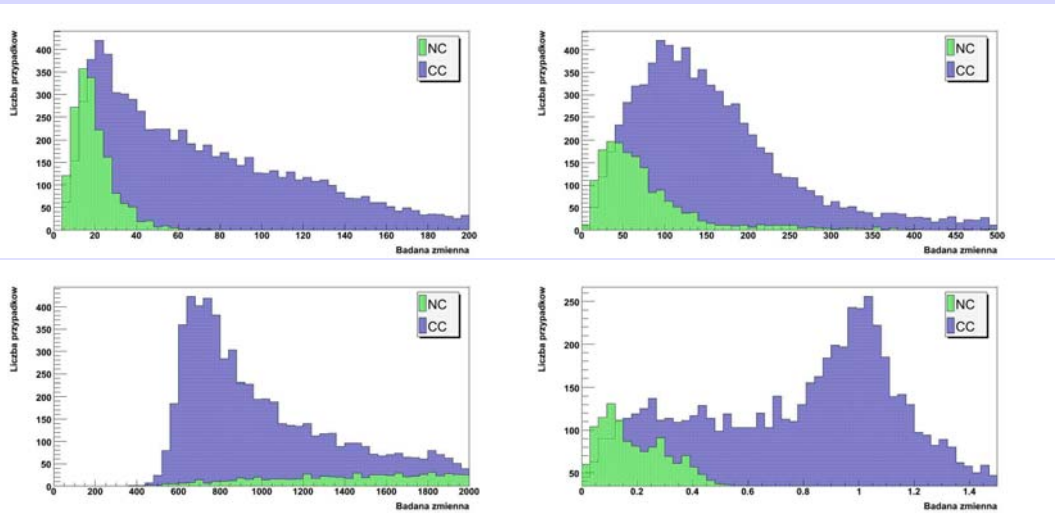
evthdr.ph.sigcor/evthdr.planeall.n (energy / event lenght)

NC & CC comparison



energy in the first x planes (x=1/4) / energy of the main shower

NC & CC selection alghoritm



- Thanks to cuts on variables alghoritm can separate CC from NC events

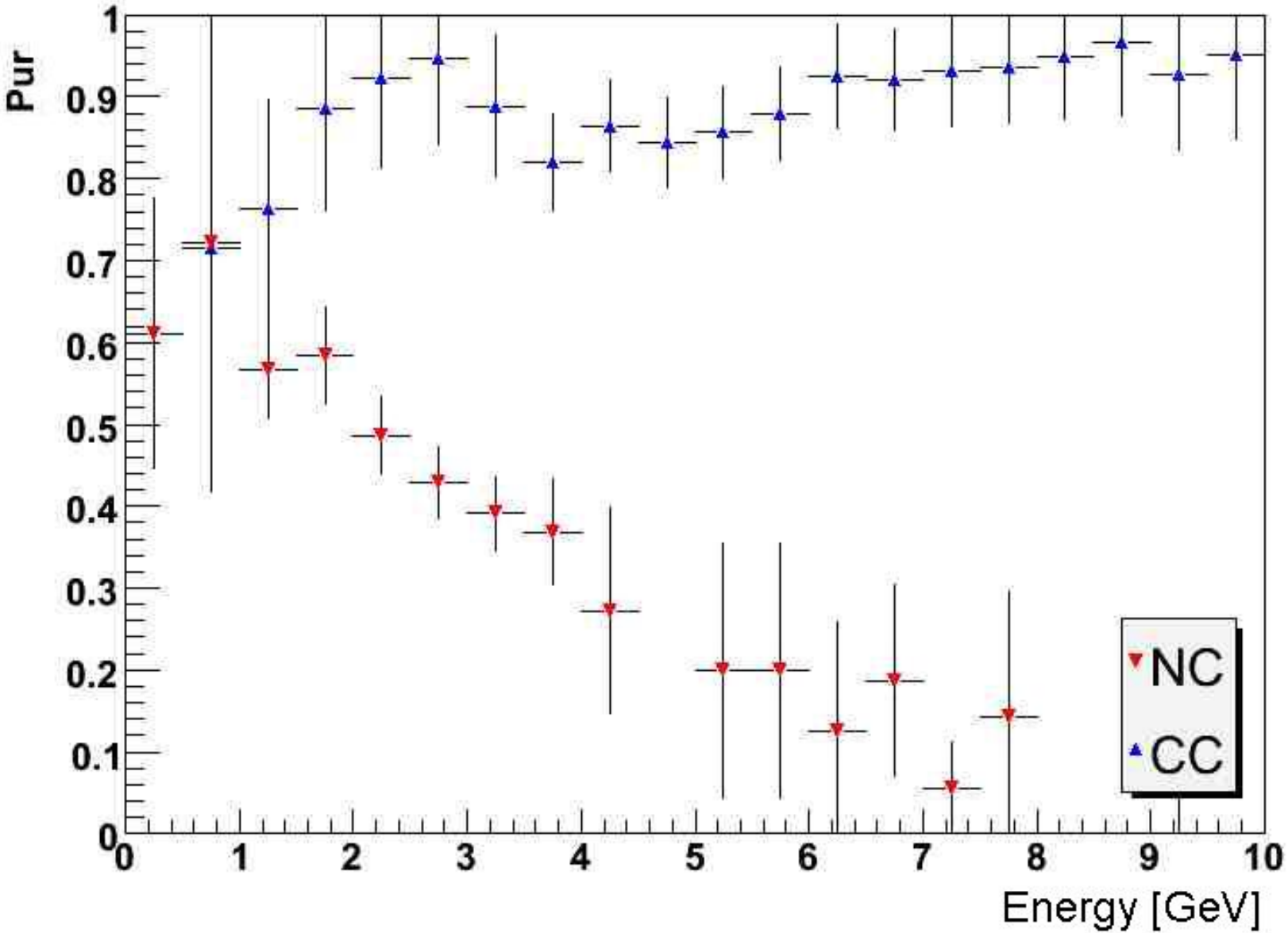
- We have candidates for NC and CC events

Purity and efficiency of the NC & CC selection

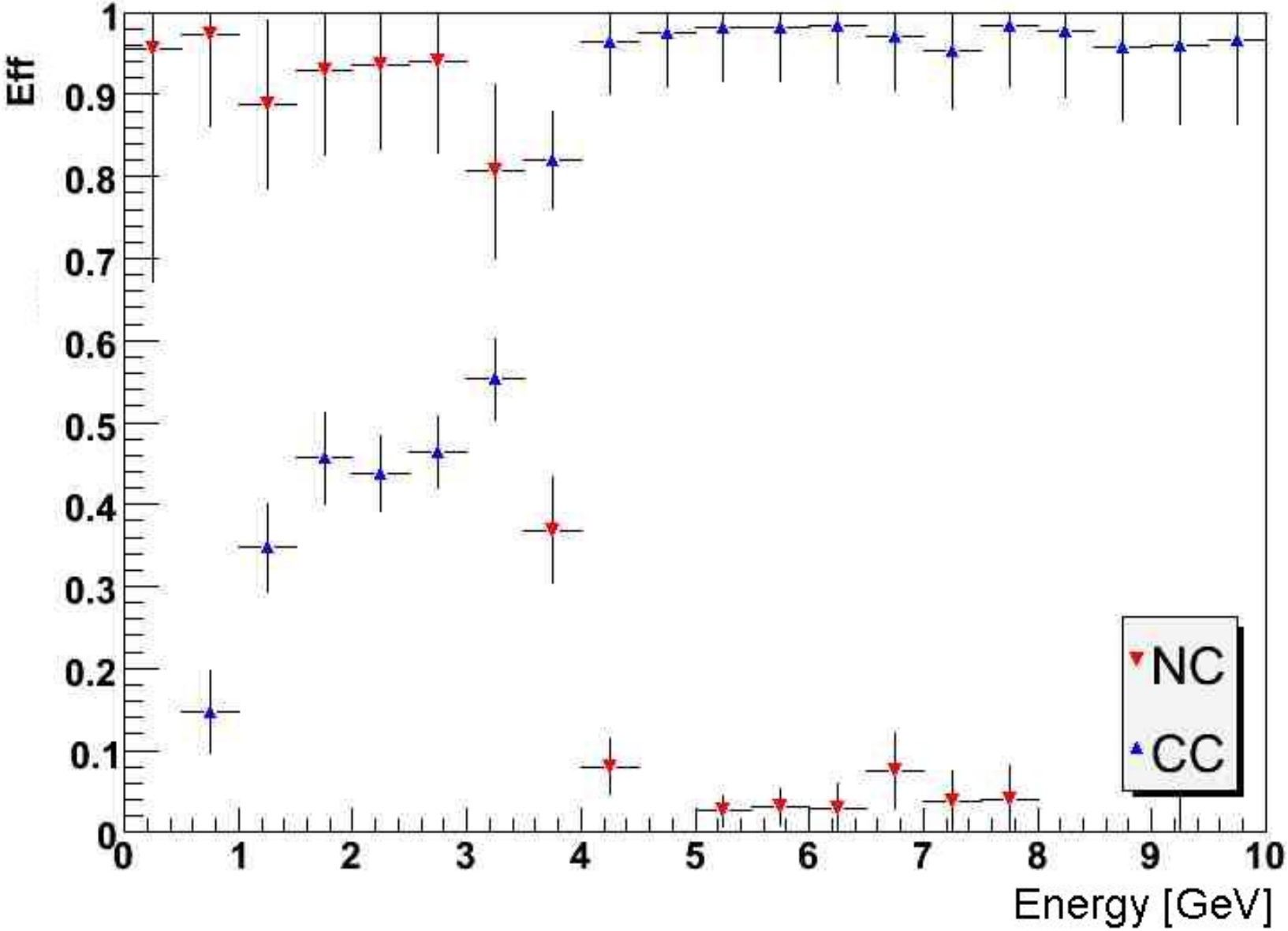
- To check the correctness of the selection, it is necessary to calculate the purity and efficiency of the selection:
- $Pur = N_{true} / (N_{true} + N_{false})$
- $Eff = N_{true} / N_{all}$

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

Purity ‘Pur’



Efficiency „Eff’



Near future...

- better NC & CC selection
- better Pur & Eff histograms
- add new NC & CC variables to this selection
- use more events to check the selection alghoritm
- make my alghoritm better and better...

Summary

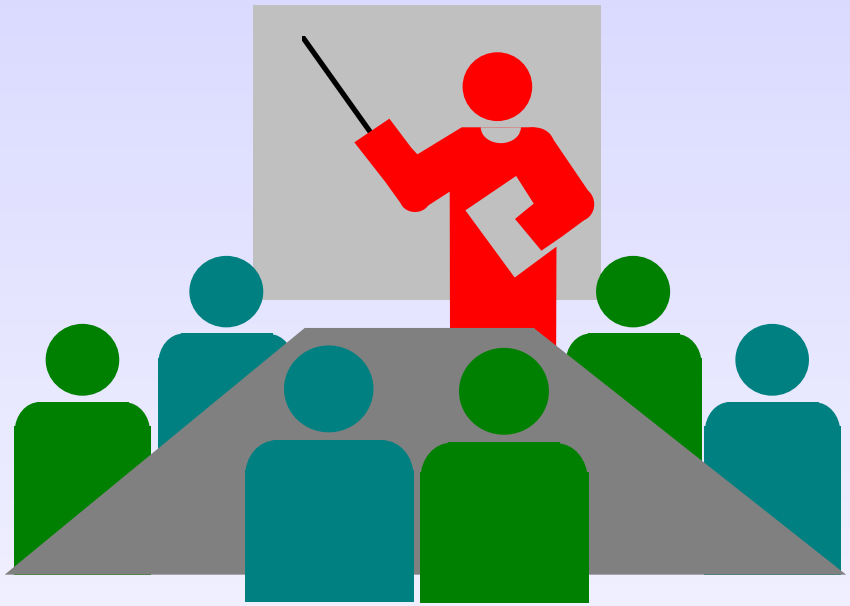
- MINOS is a new neutrino experiment in USA
- the main goal is to test the neutrino oscillation hypothesis and measure the oscillation parameters
- it is necessary to have selected NC and CC events
- the selection must be as good as possible

References

- www-numi.fnal.gov

- **especially**:
- www-numi.fnal.gov/talks/results093e18.html
- www-numi.fnal.gov/talks/results127e18.html
- beaker.astro.indiana.edu/brebel/powerpoint/minos_overview.ppt

THANK YOU!



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