9-е Черенковские чтения
Новые методы в экспериментальной ядерной физике и физике частиц

Научно-образовательный центр
НЕВОД

Пространственное распределение черенковского излучения каскадных ливней в воде

Spatial distribution of Cherenkov radiation from cascade showers in water

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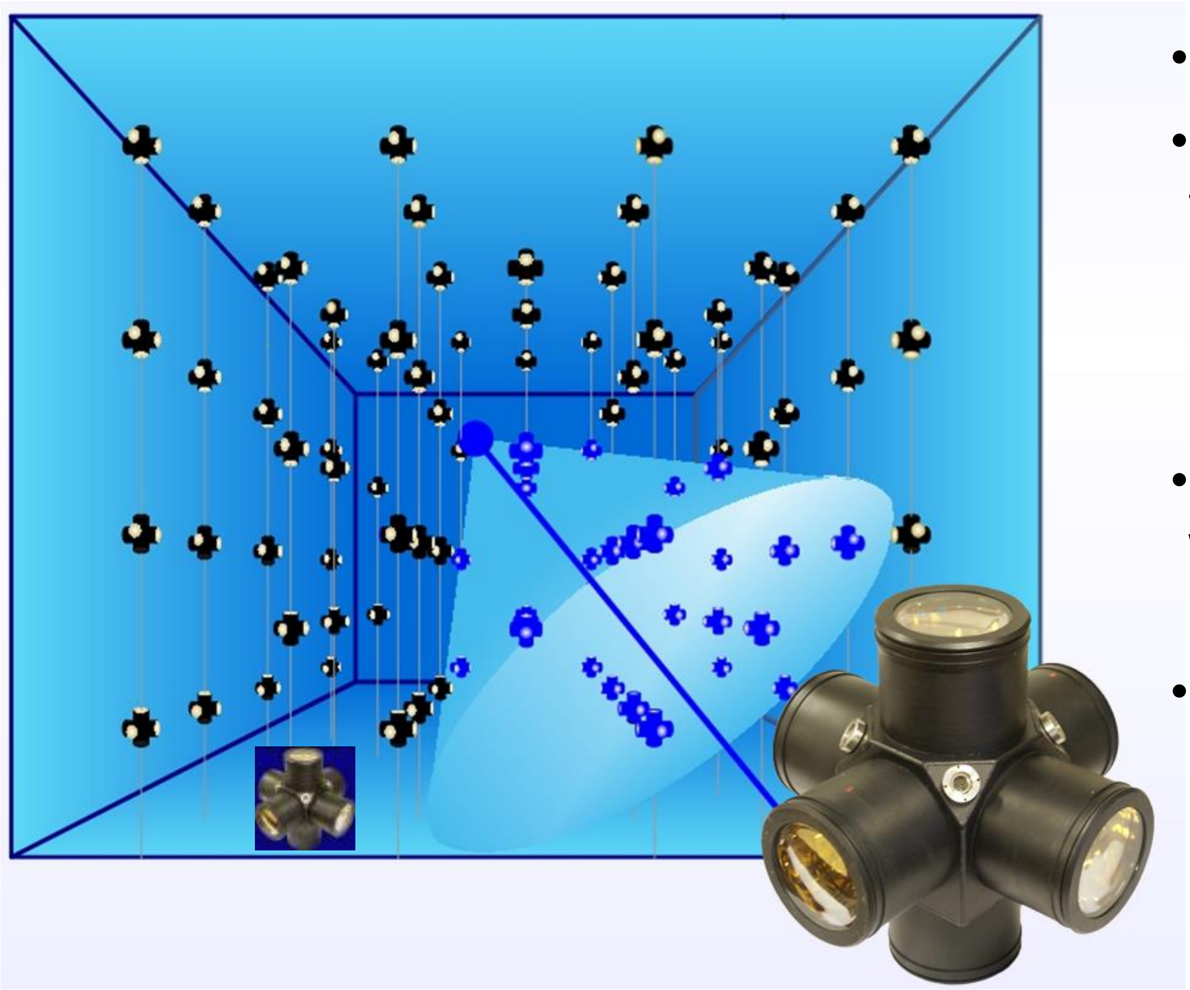
Introduction

- Cherenkov water detectors are widely used for investigating the ultrahigh-energy muons and neutrinos (IceCube, ANTARES, Baikal);
- The energy of these particles is estimated through cascade showers;
- The topical experimental task is to investigate the distribution of the Cherenkov light from cascade showers in water;
- Large-scale detectors with long distances between the measuring modules are limited to obtain the detailed picture of light;
- In the present work, the light distribution from cascades is studied with the Cherenkov detector having the dense lattice of detecting modules.

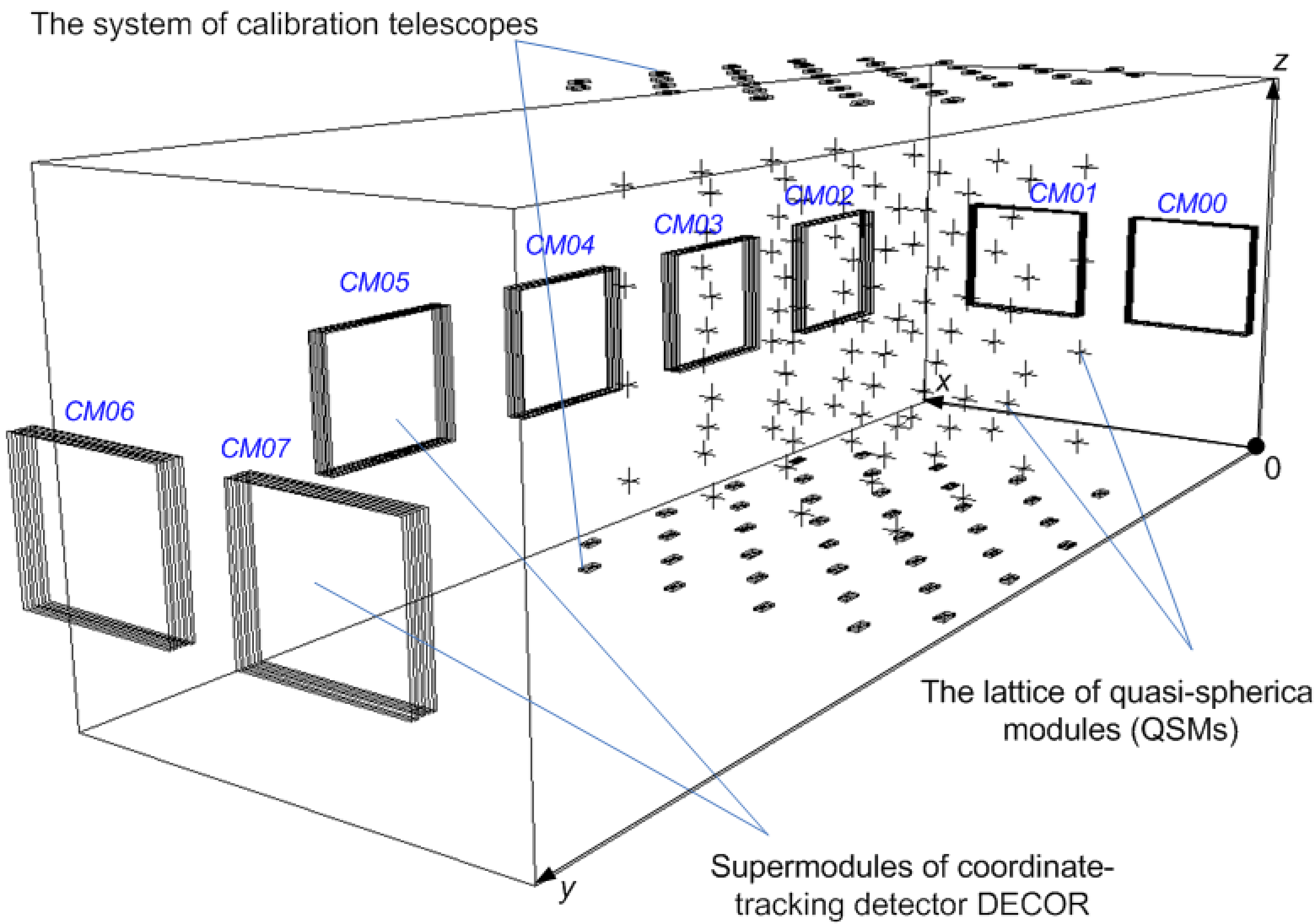
Cherenkov water detector NEVOD



- 2000 m^3 volume;
- the detecting system is formed as a spatial lattice of 91 quasi-spherical modules (QSM), placed in 25 strings (the step is 2 x 2 x 2.5 m^3);
- each QSM has six PMTs with flat cathodes, directed along the coordinate axes;
- the dynamic range for each PMT is 1–10^5 ph.e.

The small step of the spatial lattice and the wide dynamic range allow the detector to measure the full cascade curve in individual events.

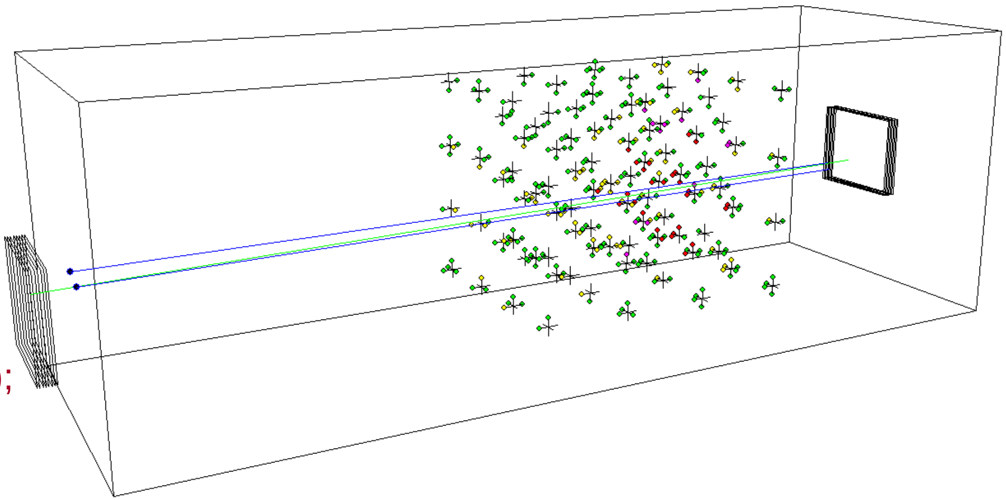
Experimental complex NEVOD



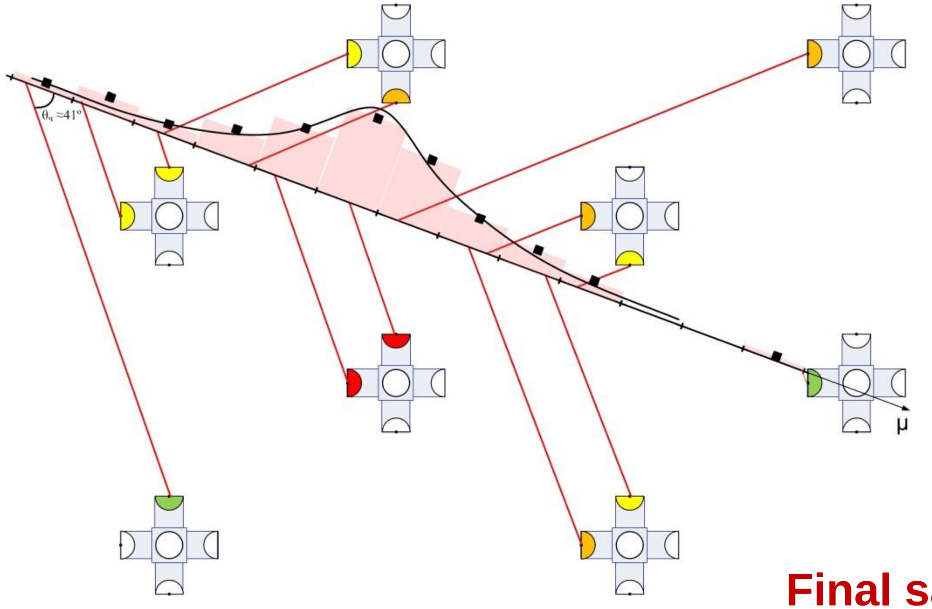
Selection of cascade showers and reconstruction of their parameters

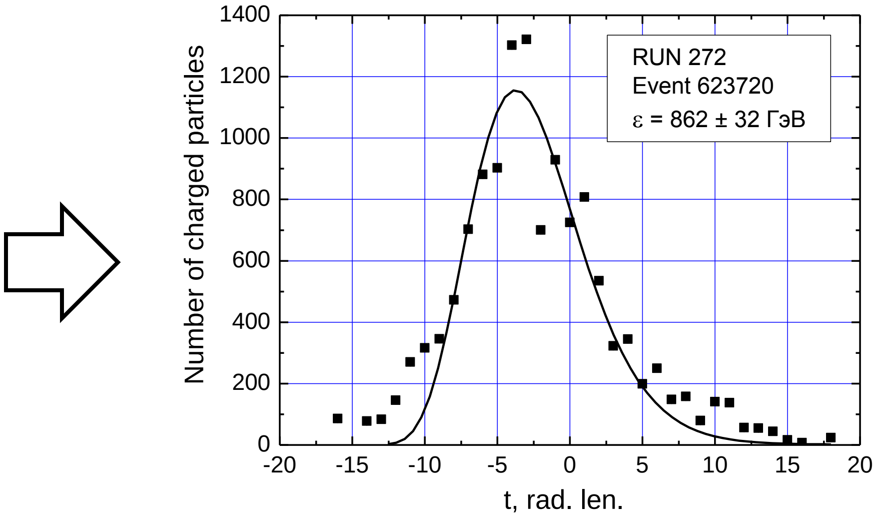
The cascades produced by nearly horizontal muons were investigated (zenith angles are 85º÷90º).

The tracks were reconstructed by means of coordinate detector DECOR.



O.Saavedra at al., J. Phys.: Conf . Ser. 409 (2013);
S.S.Khokhlov et al., Bull. RAS. Phys. 77 (2013).





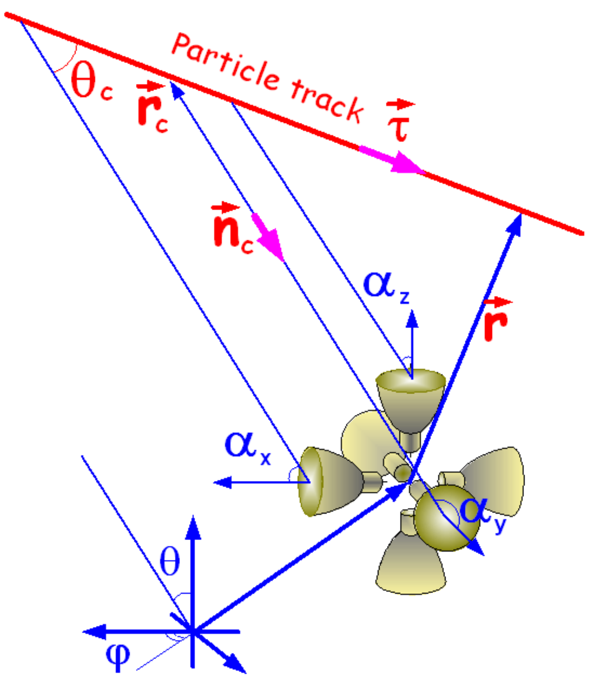
Final sample: 522 events with reconstructed energies from 100 GeV to 500 GeV

Response of the quasi-spherical module

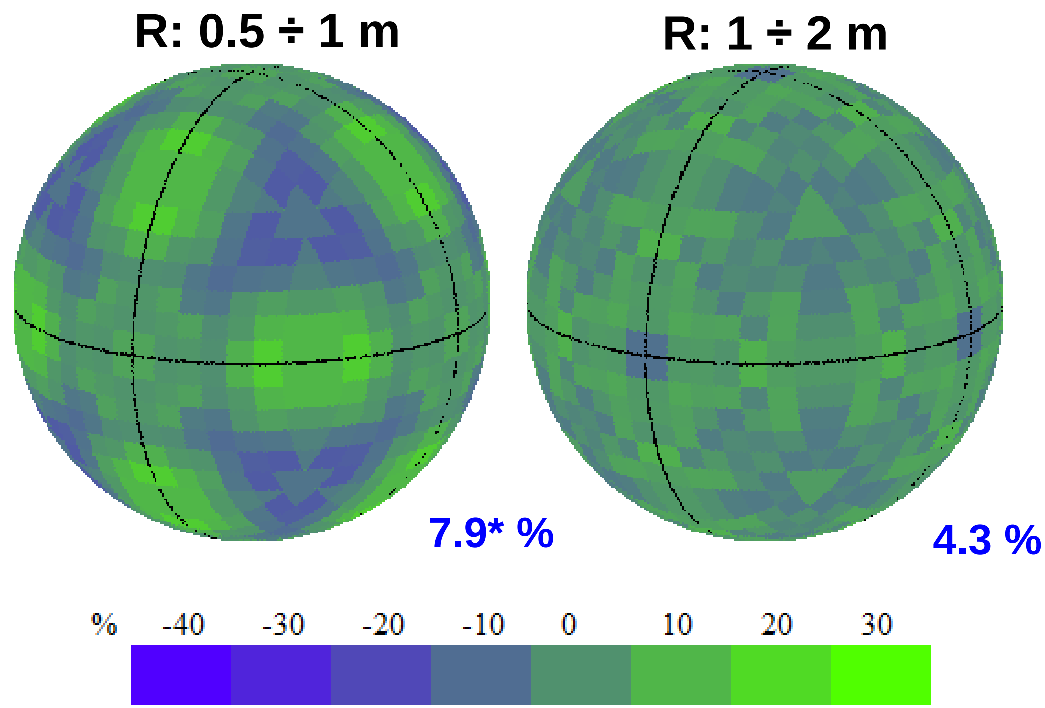
$$A_1(R,\alpha) = \frac{C \cdot \cos\alpha}{r} \cdot \exp(-\frac{r}{l})$$

$$B = \sqrt{\sum A_i^2}$$

(square root of the squared amplitudes of PMTs)



$$\cos^2\alpha_x + \cos^2\alpha_y + \cos^2\alpha_z = 1$$



* rms-deviation from the mean value of B

Distribution of light from the cascade showers

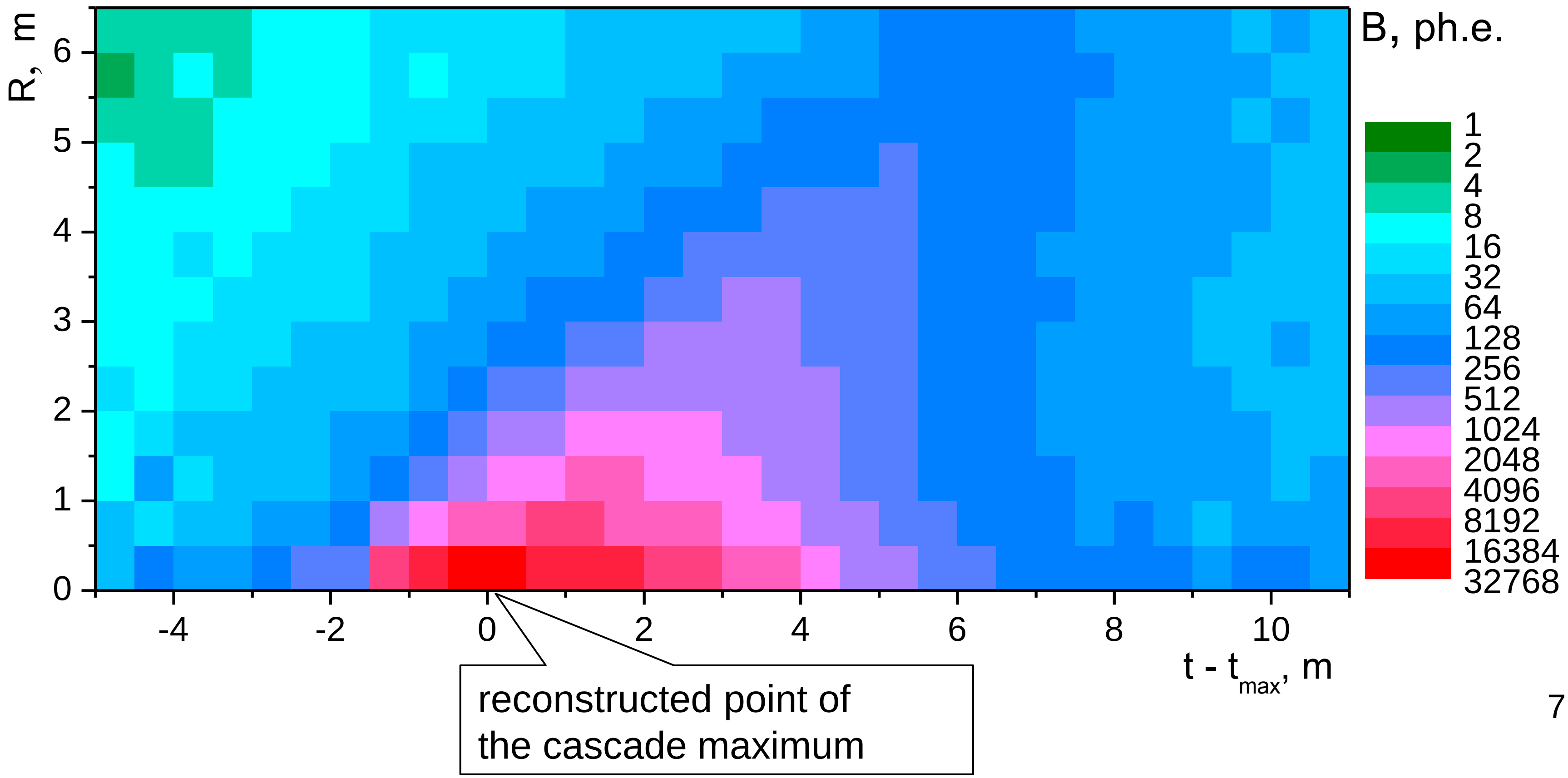
The responses of the modules in all events are normalized to reconstructed energy values:

$$B = \frac{\varepsilon_0}{\varepsilon}\sqrt{\sum A_i^2}$$

where ε_0 is the normalizing energy of 200 GeV (close to the average energy of showers in the sample);

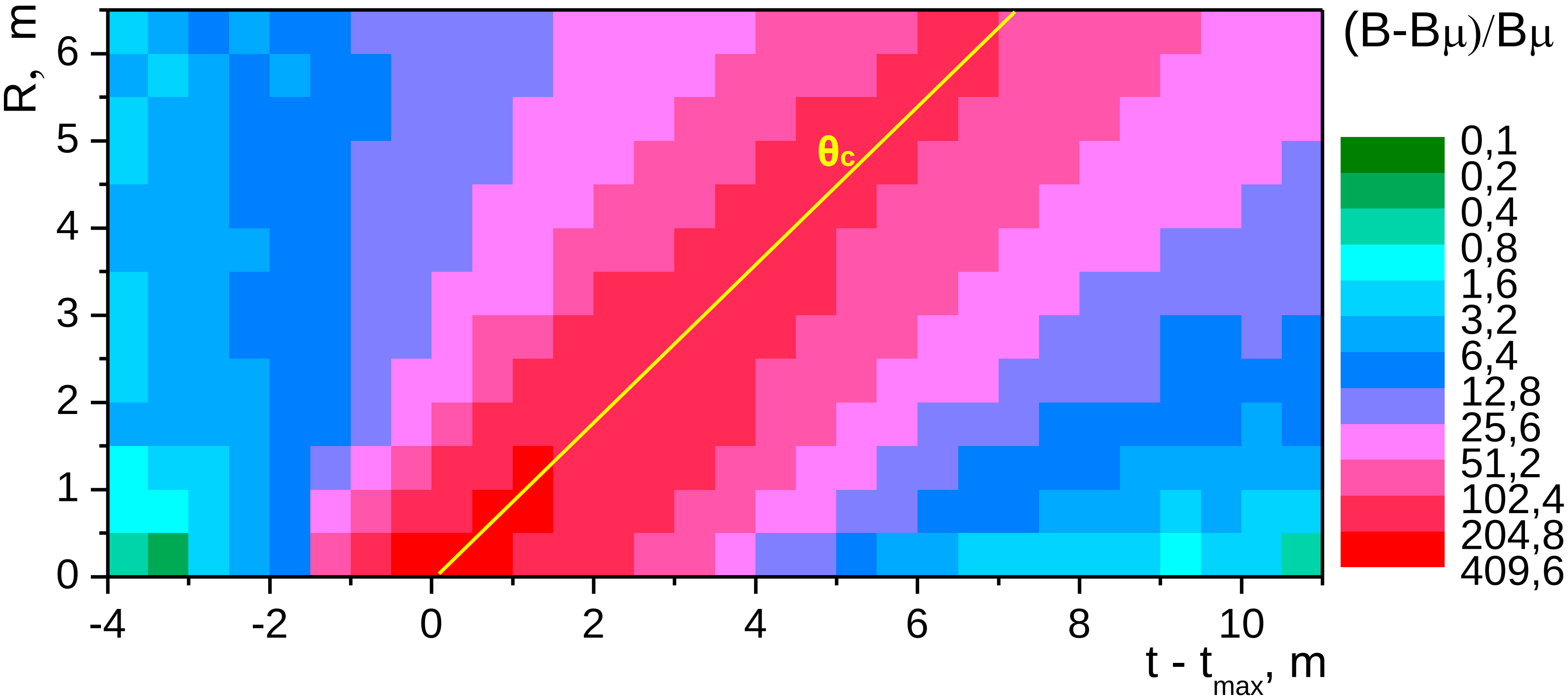
ε is the reconstructed energy of the shower in the event;

A_i is the amplitude of i-th PMT in QSM (in photoelectrons, ph.e.).



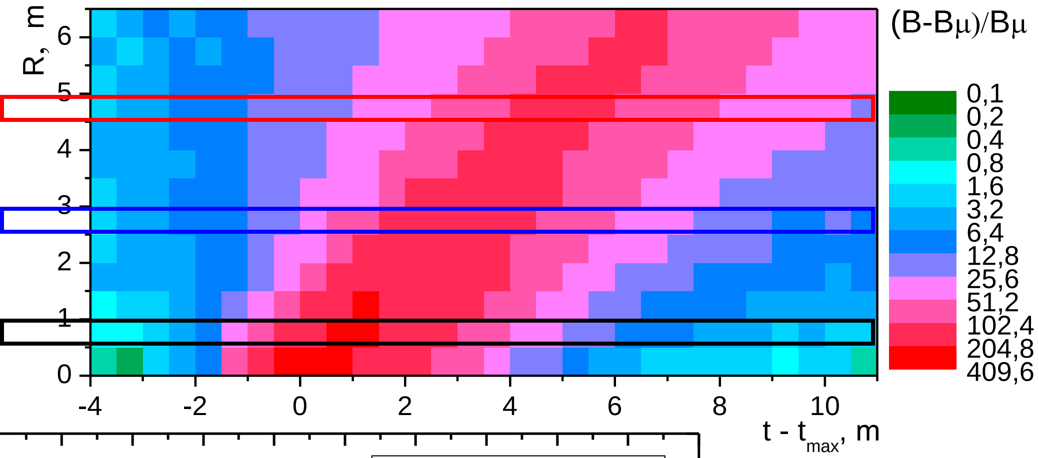
Compensation of light attenuation

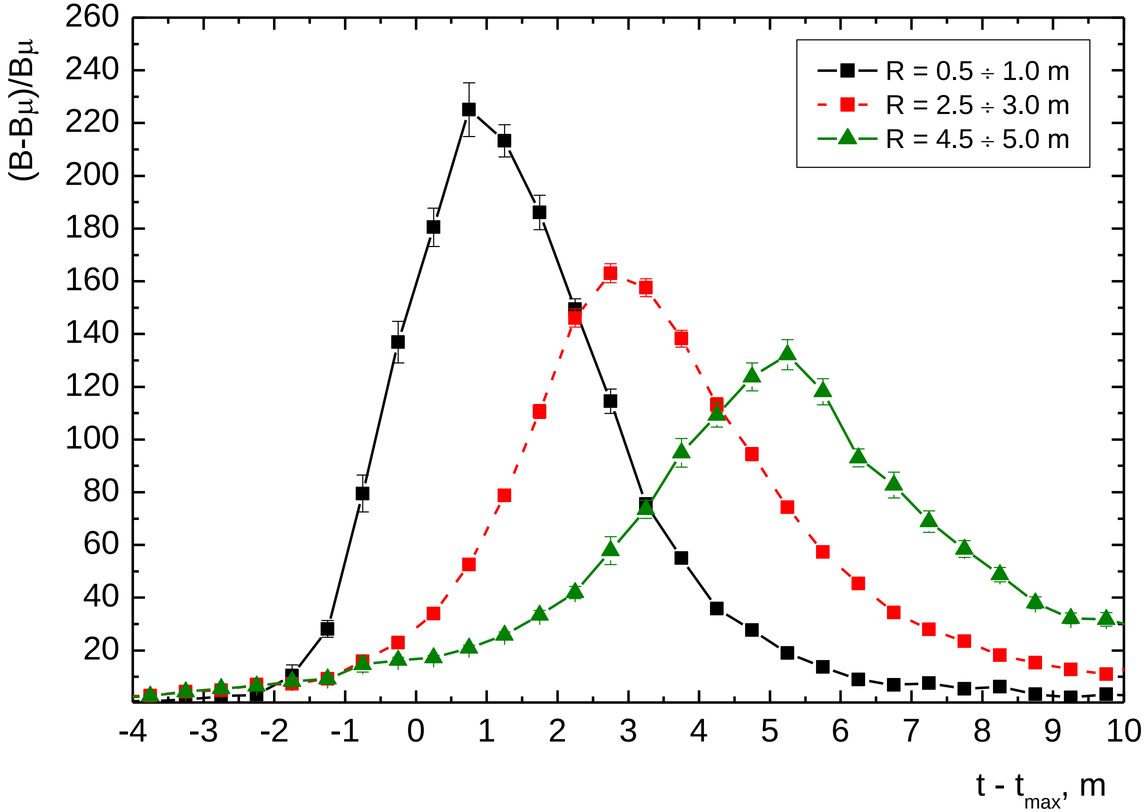
Since the parameters of the light attenuation are the same for cascades and for single muons, it is reasonable to consider the ratio of light intensity for cascades (*B*) to the intensity measured for events with single muons (B_μ):



Influence of scattering of cascade particles

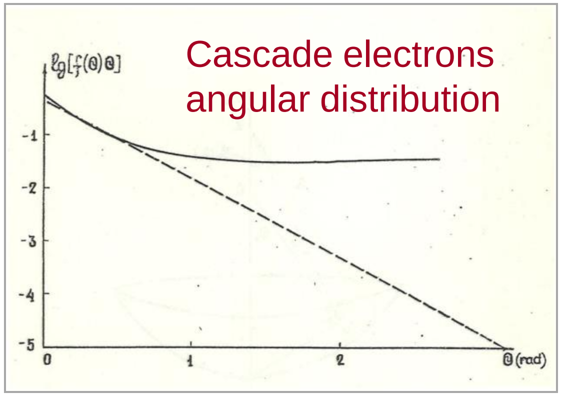
The longitudinal profiles of $(B\text{-}B_\mu)/B_\mu$ value at different distances from the axis





The profiles become wider with increasing distance from the axis of the shower.

Models of cascade particles scattering



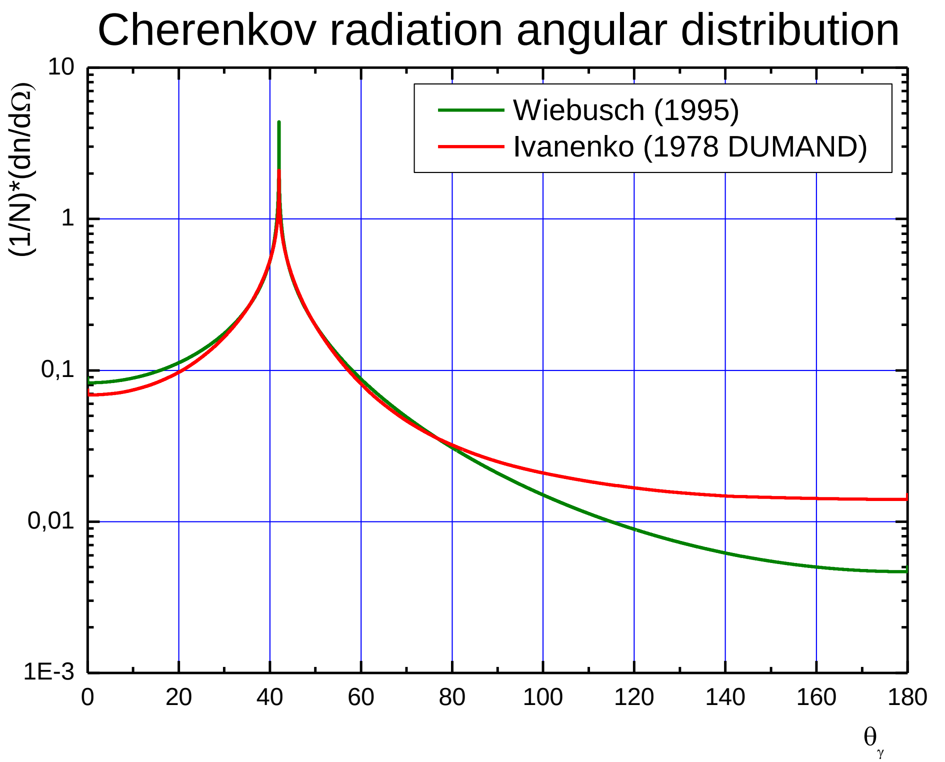
1. Analitical solution of cascade equations (*I.P. Ivanenko et al. / Proc. of the 1978 DUMAND Summer Workshop*).

2. Approximation (*M.G. Aarsten et al. / Nucl. Instr. And Meth. in Phys. Res. A711 (2013)*) of MC simulation with GEANT 3 (*C.H. Wiebusch / Ph.D. Thesis, Physikalische Institute, RWTH Aachen, 1995*).

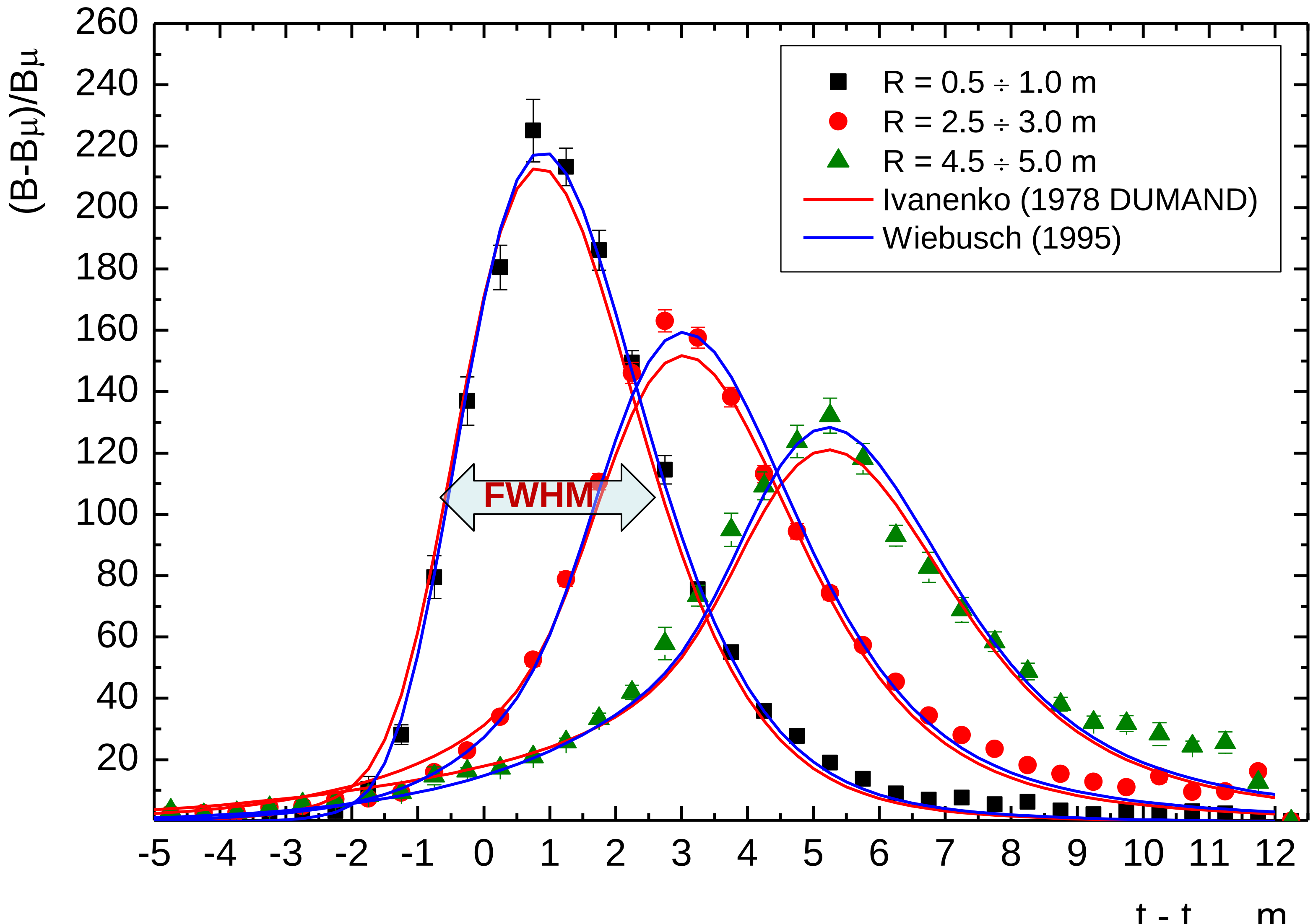
Calculation with assumption:

photons are emitted at the same angle to the track of electron

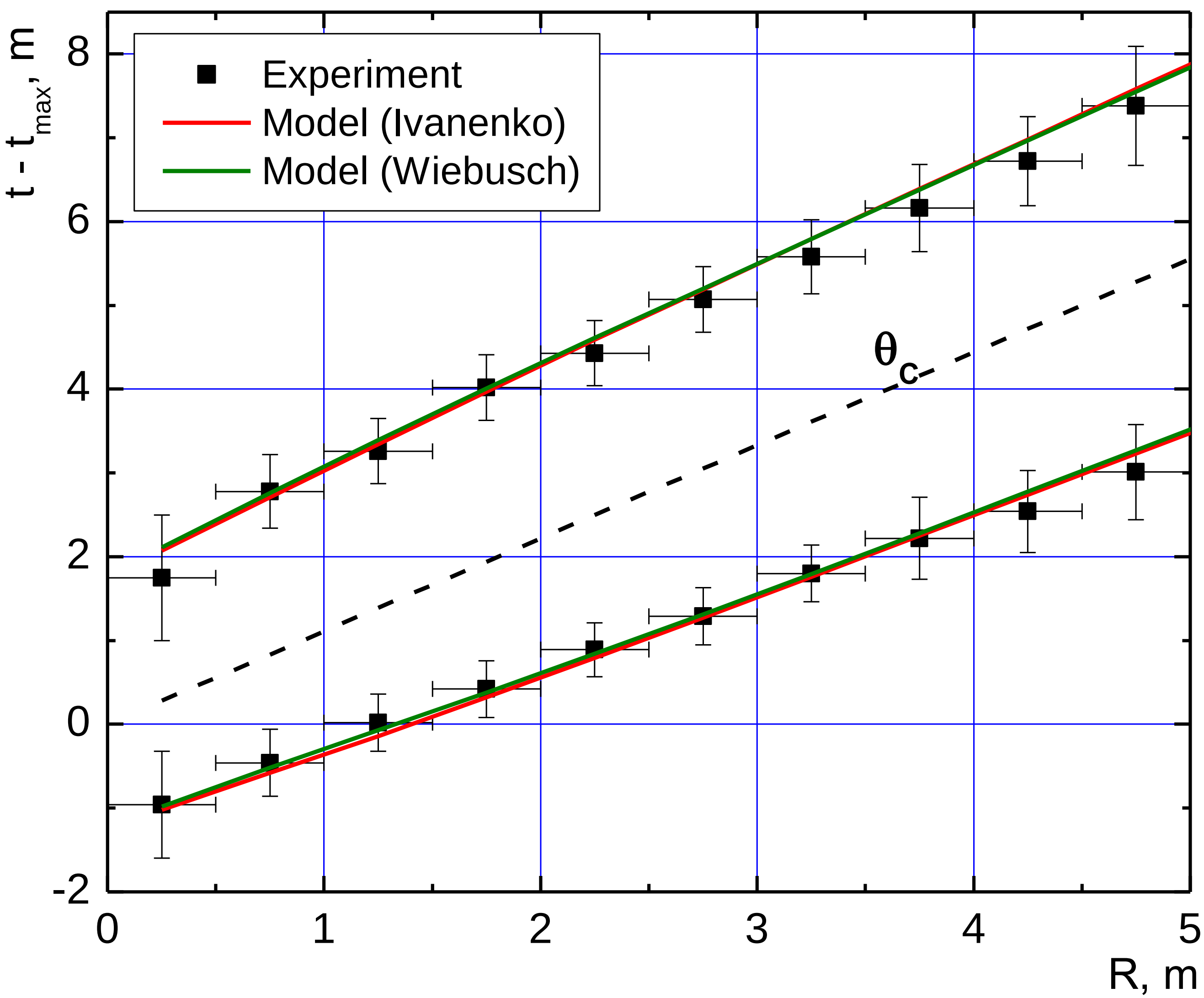
θc = arrcos(1/n)



Experimental and calculated longitudinal profiles of Cherenkov radiation spatial distribution



Comparison of experimental data with calculations



Conclusions

- For the first time, the spatial distribution of Cherenkov light from high energy cascade showers generated by muons in water has been experimentally measured at NEVOD CWD.
- The results show a good directivity of the light from the cascades at the angle close to the angle of Cherenkov radiation in water ($\approx 42^\circ$).
- The preliminary comparison shows the consent of experimental data (based on a sample of about 500 cascade events with reconstructed energies 100-500 GeV) with models.

Thank you for your attention!