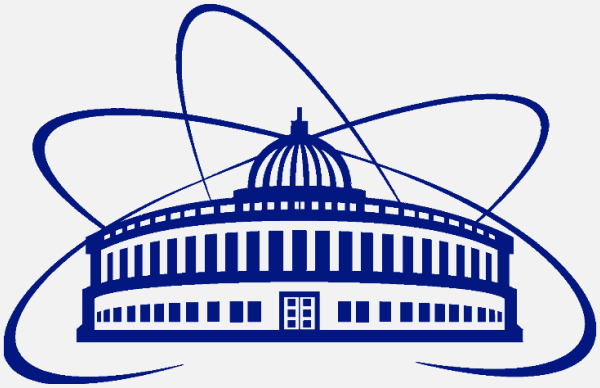


Joint Institute of Nuclear Research

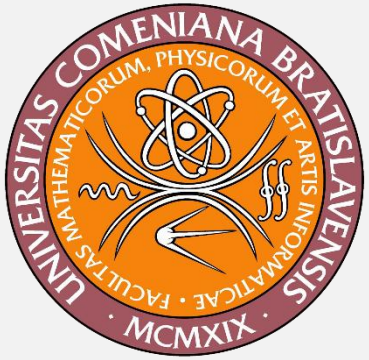
International Summer Practice 2018 Stage 2

Time and charge calibration of the optical modules in the Baikal GVD telescope

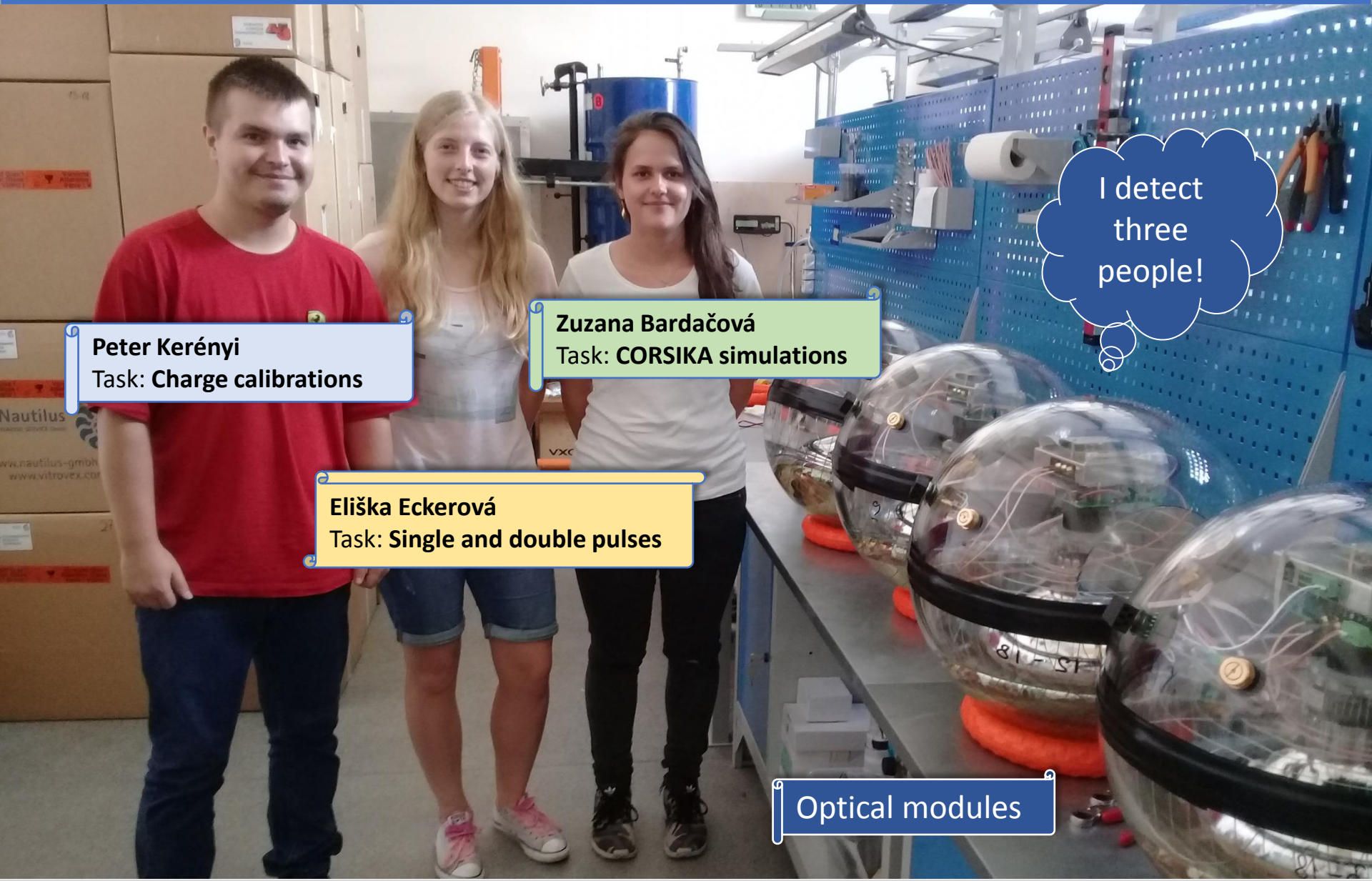
Students: **Peter Kerényi**
Zuzana Bardačová
Eliška Eckerová

Affiliation: Comenius University
Slovakia

Supervisors: Rastislav Dvornický
Lukáš Fajt

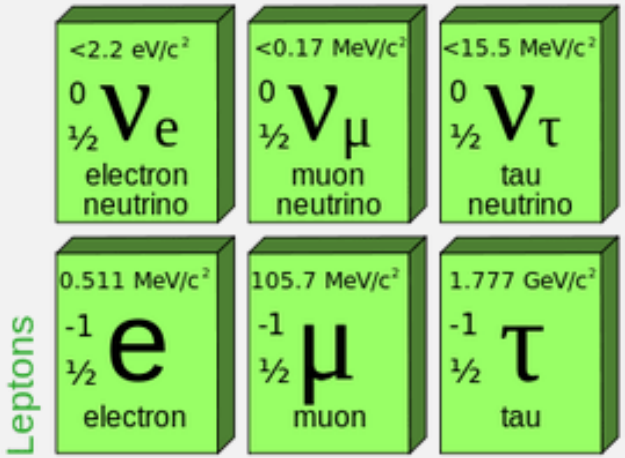


The crew…


I detect three people!
Peter Kerényi
Task: Charge calibrations
Zuzana Bardačová
Task: CORSIKA simulations
Eliška Eckerová
Task: Single and double pulses
Optical modules

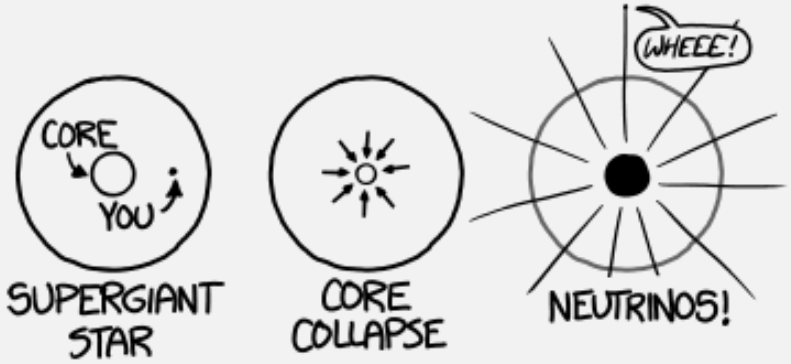
About neutrinos...

- Neutral leptons of three generations: ν_e, ν_μ, ν_τ
- Oscillation between flavour states
- Interaction via weak force
- Low probability of interaction with matter
- Impossibility of direct detection

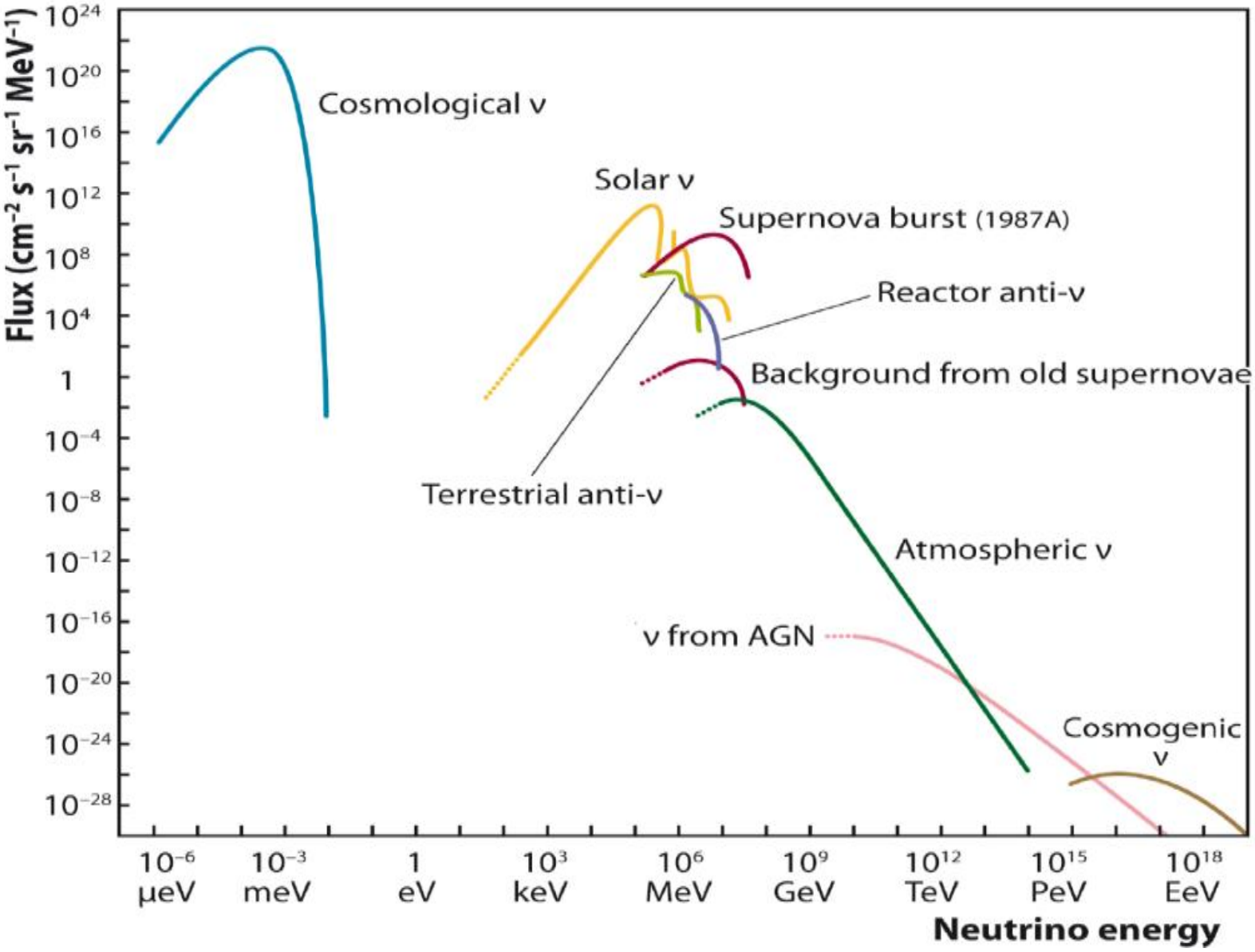


SOURCES OF NEUTRINOS

- **TERRESTRIAL**: Reactor antineutrinos, geoneutrinos, atmospheric neutrinos
- **EXTRATERRESTRIAL**: Big Bang, fusion, supernovae, cosmic → energies up to PeVs



About neutrinos...

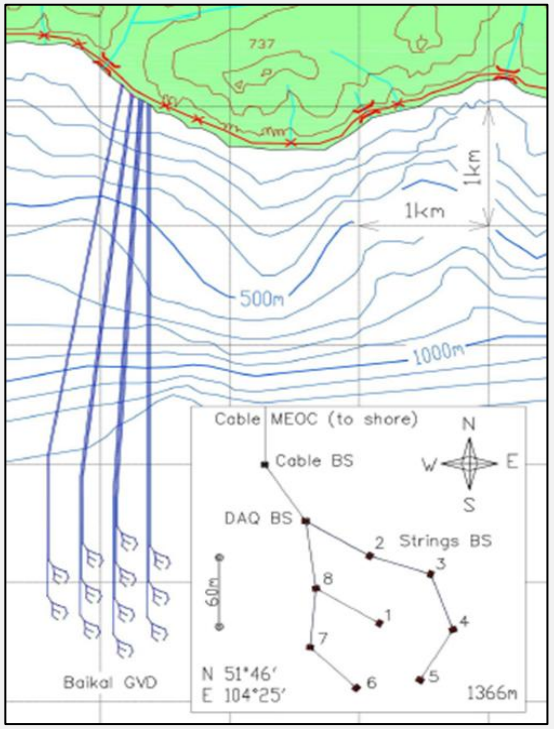


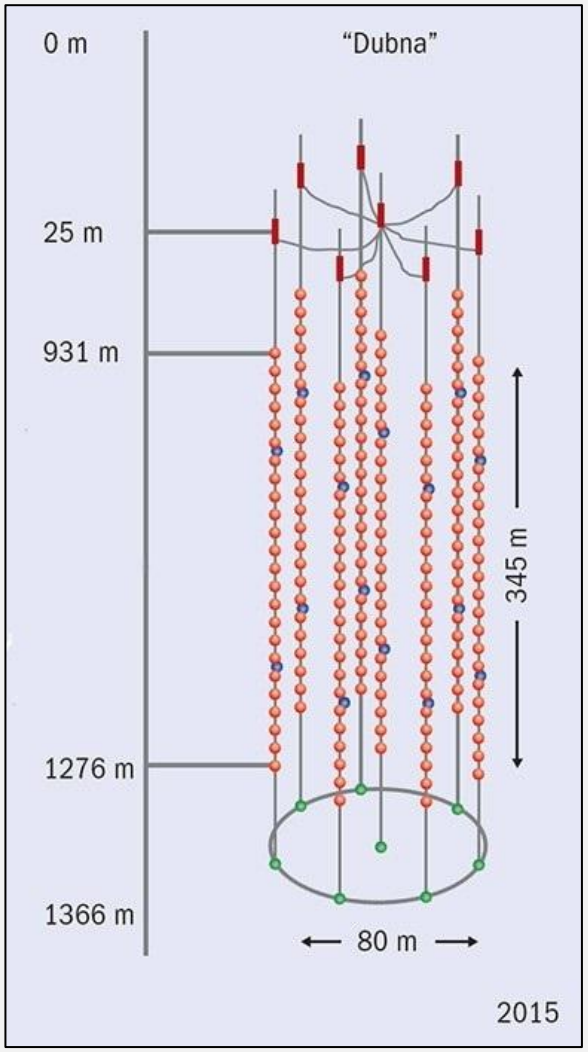
About Baikal GVD...

„**Gigaton Volume Detector**“ neutrino telescope in lake **Baikal**

Phase I.

- 1 Cluster → 8 Strings → 288 OMs → 1 DAQ
- Current state: **3 Clusters**
- Goal until 2020: 8 Clusters → 2304 OM → 0.3 – 0.4 km^3



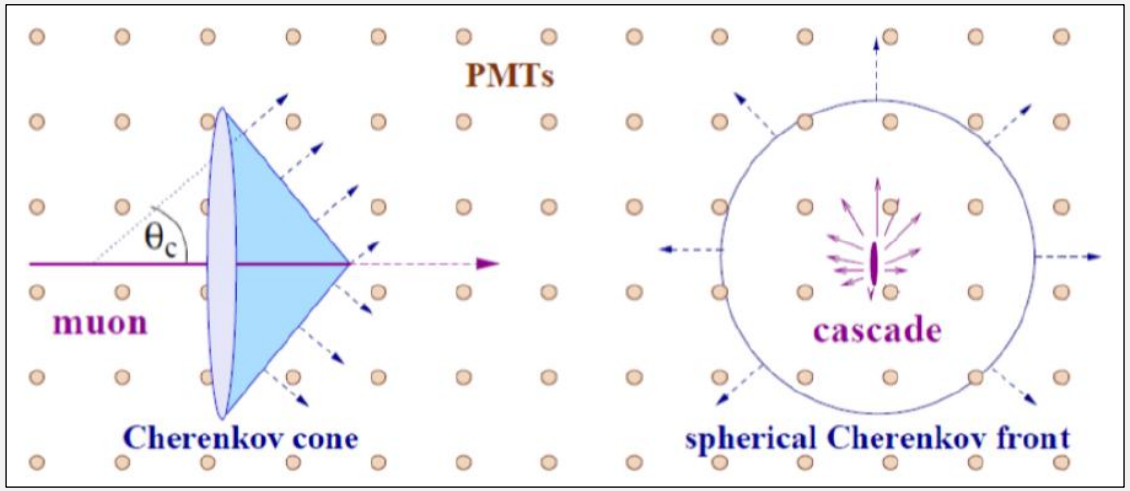


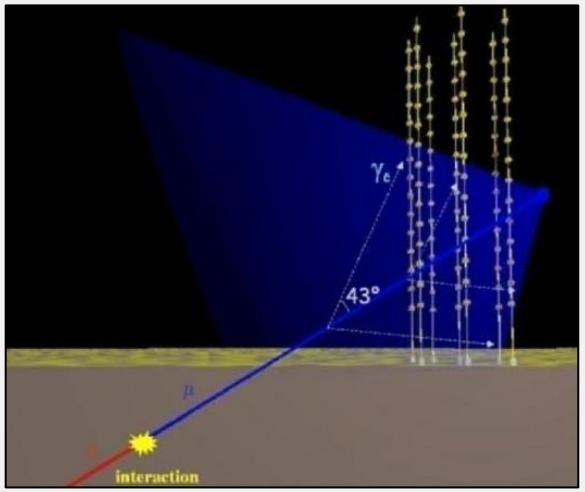
Detection of neutrinos in Baikal GVD

- Points of interest: High-energy **galactic** & ultra high-energy **extragalactic neutrinos**
- Interaction with matter near the detector:

$$\nu_l(\bar{\nu}_l) + N \rightarrow l^-(l^+) + \text{hadrons} \rightarrow \textbf{CC}$$
$$\nu_l(\bar{\nu}_l) + N \rightarrow \nu_l(\bar{\nu}_l) + \text{hadrons} \rightarrow \textbf{NC}$$

- Tracking of muons via **Cherenkov radiation** → information about neutrino energy and direction
- **BACKGROUND**: mainly atmospheric muons → 2π geometry
- **ENVIROMENTAL EFFECTS**: absorption and scattering of light

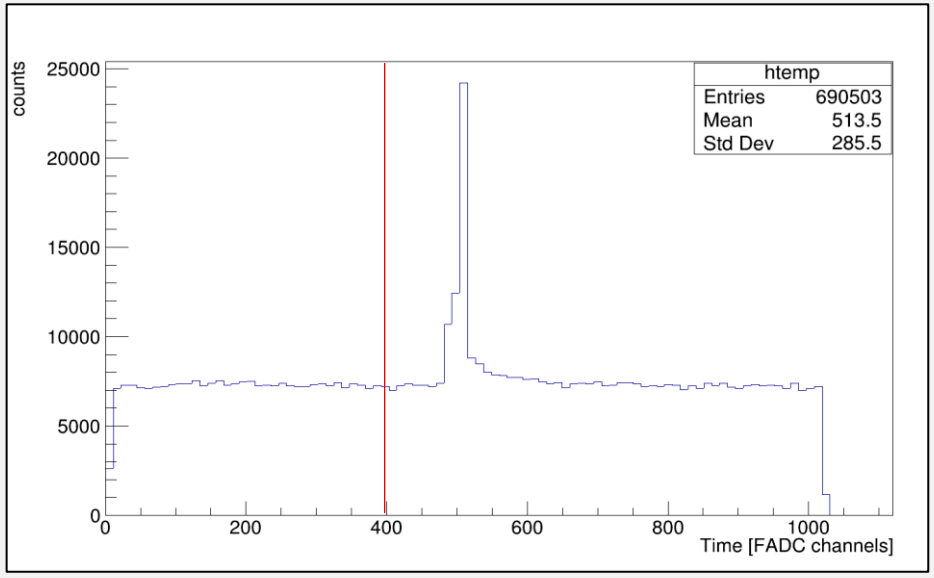




Peter – charge calibration

Charge calibration of OMs

- **GOAL**: Determine which FADC channel corresponds to 1 photoelectron for each OM
- **METHOD**: Fitting of charge distributions
- **CHALLENGE**: Number of OMs and runs ($\sim 288 \times 600$ per year per cluster)
- **SOLUTION**: Automatization of fitting via C++ & ROOT macros (+ a little bit of Bash)

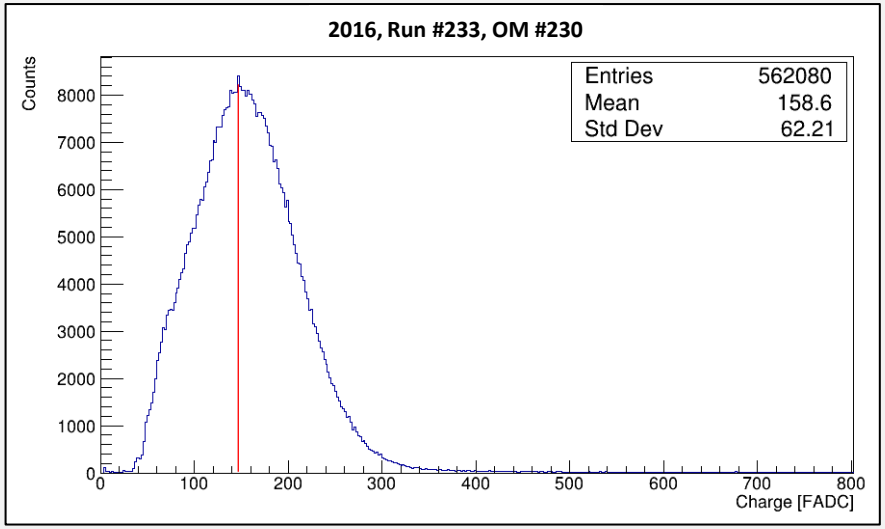


- **TRIGGER** for **EVENT** → $5\mu s$ time window with the event in the middle
- First $2\mu s$ → **NOISE** → low light → subject of our analysis

Fitting of charge distributions

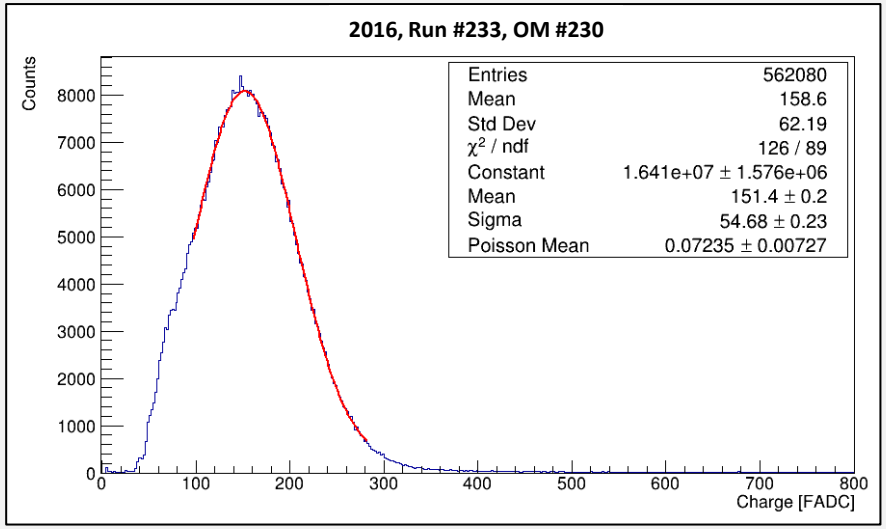
- QM process → fluctuation → Gauss
- Fitting function: $const.e^{-p}\left(p\frac{e^{\frac{(x-\mu)^2}{2\sigma^2}}}{\sqrt{2\sigma^2\pi}}+\frac{p^2}{2}\frac{e^{\frac{(x-2\mu)^2}{2(\sqrt{2}\sigma)^2}}}{\sqrt{2(\sqrt{2}\sigma)^2\pi}}\right)$

Raw charge distribution histogram



Mean is our point of interest

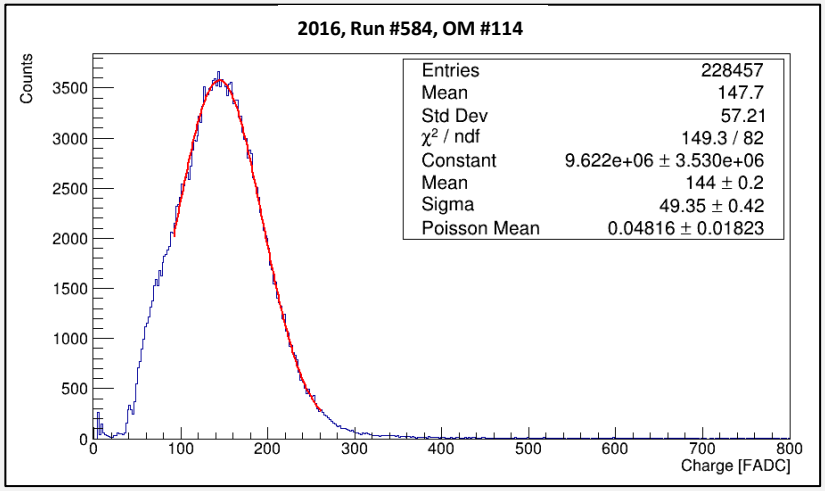
Fitted charge distribution histogram



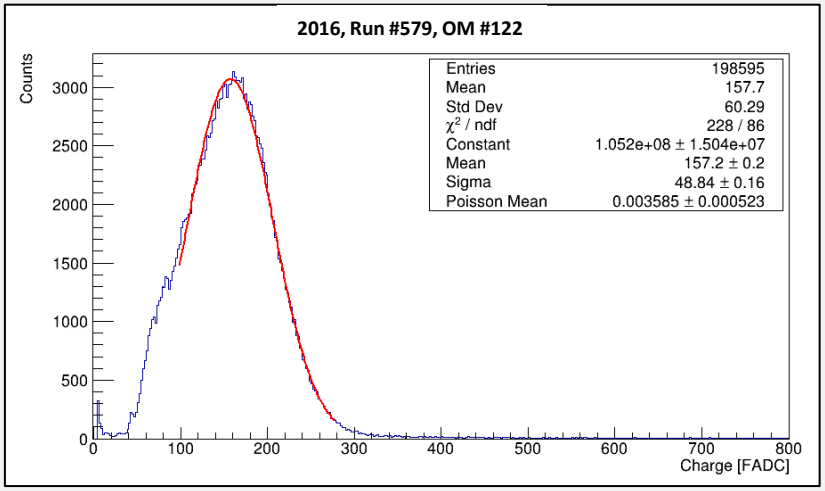
Obtained by fitting,
exported into ASCII files

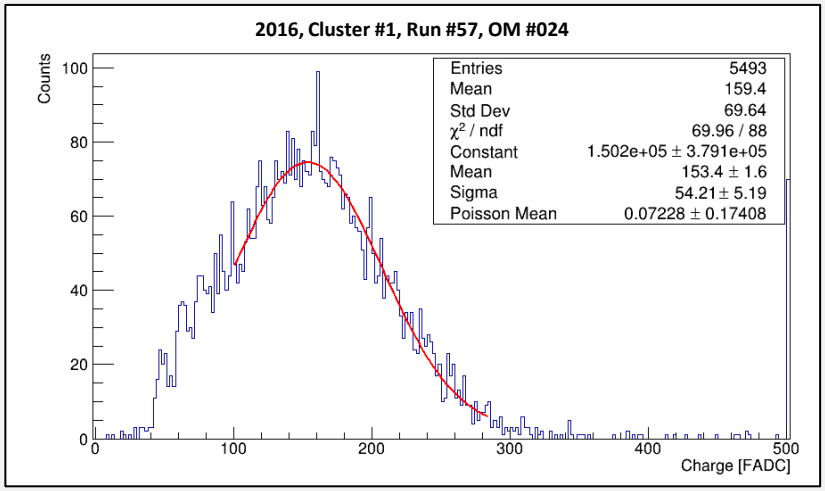
Challenges of automatic fitting

Great fit

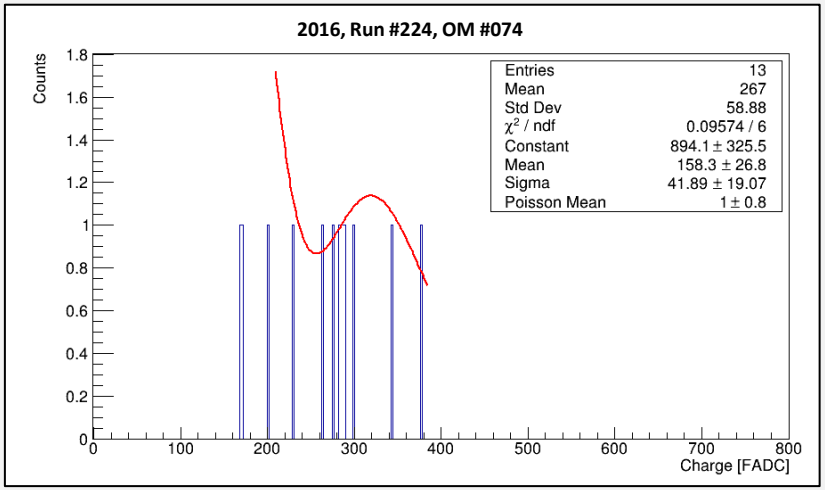


Too wide interval





Low counts

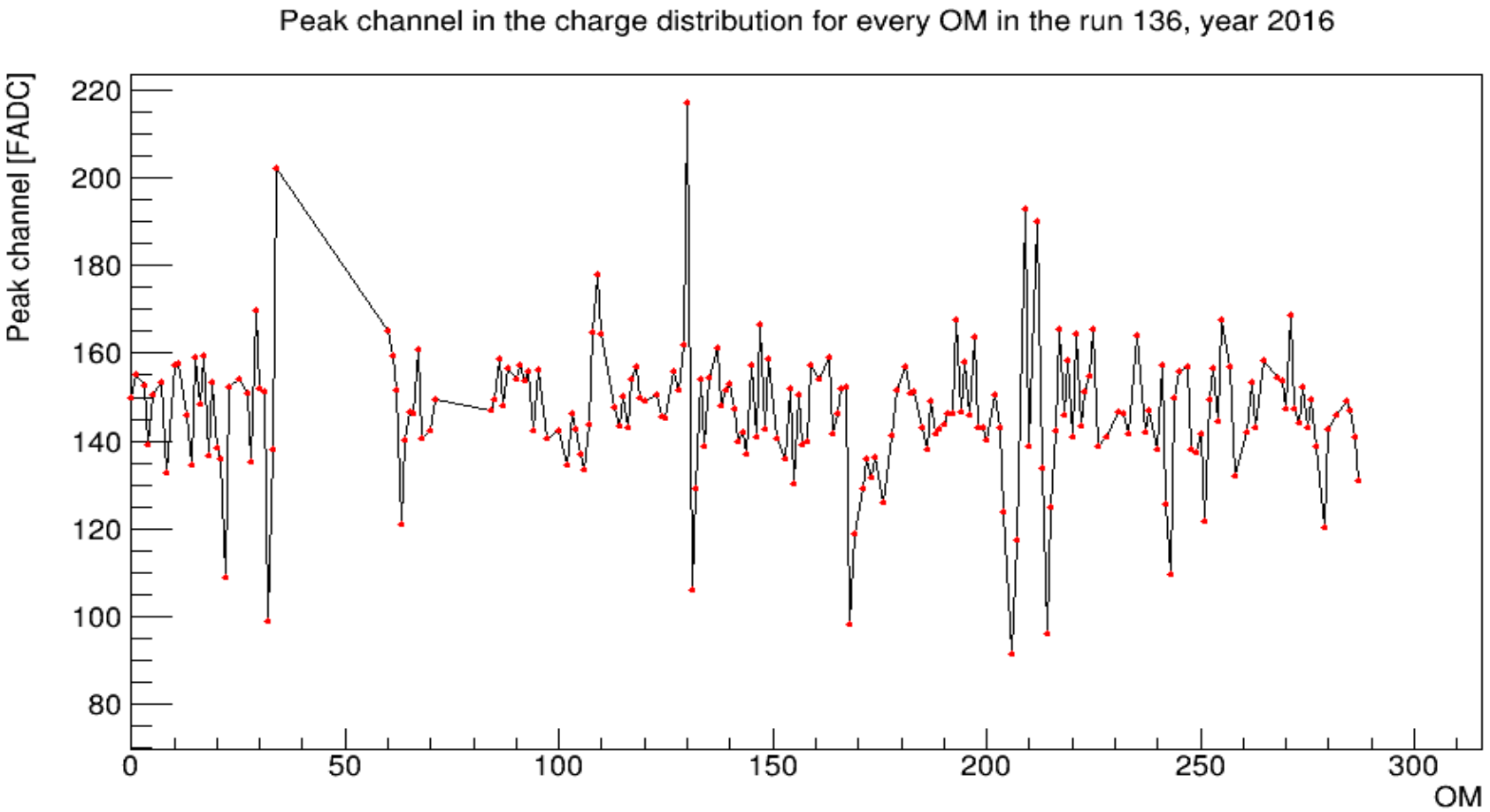


Just bad…

SOLUTION: Introducing **conditions** and **tests** into the code to discard “bad” fits. Optimizing boundaries.

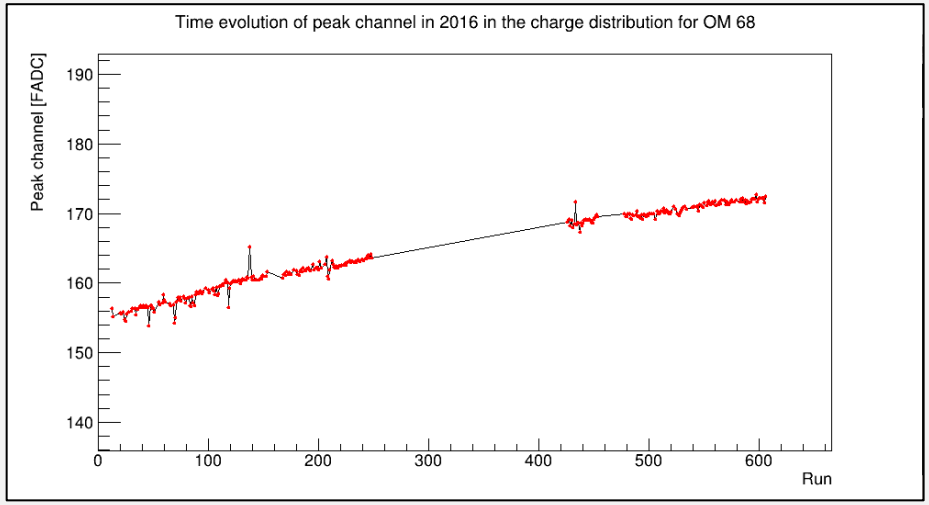
Overview of OMs in a run

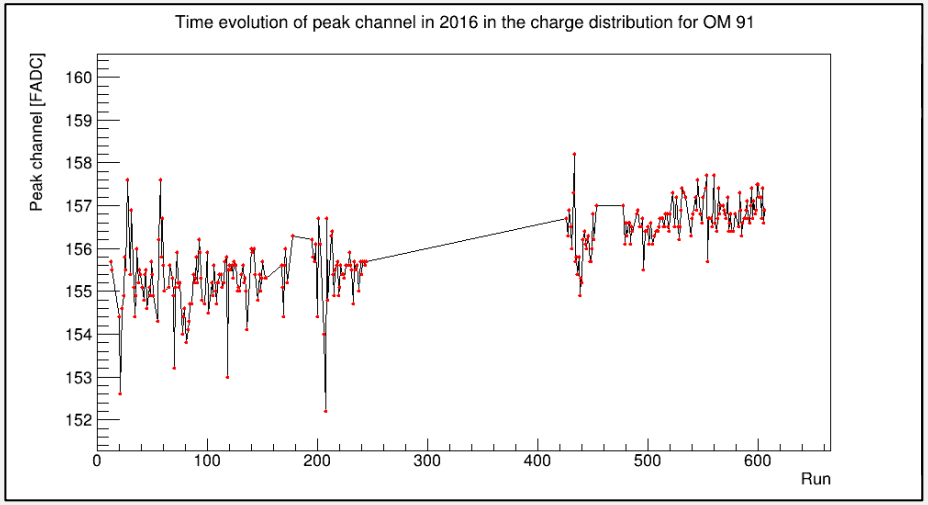
- Peak channel mostly in the vicinity of ~150 [FADC]
- Large deviations could be from bad fits → further tweaking of pass conditions needed

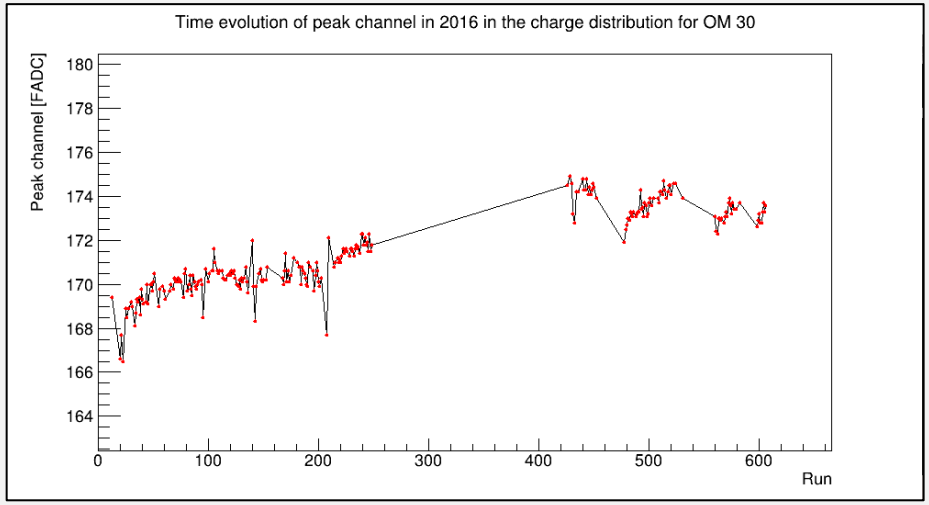


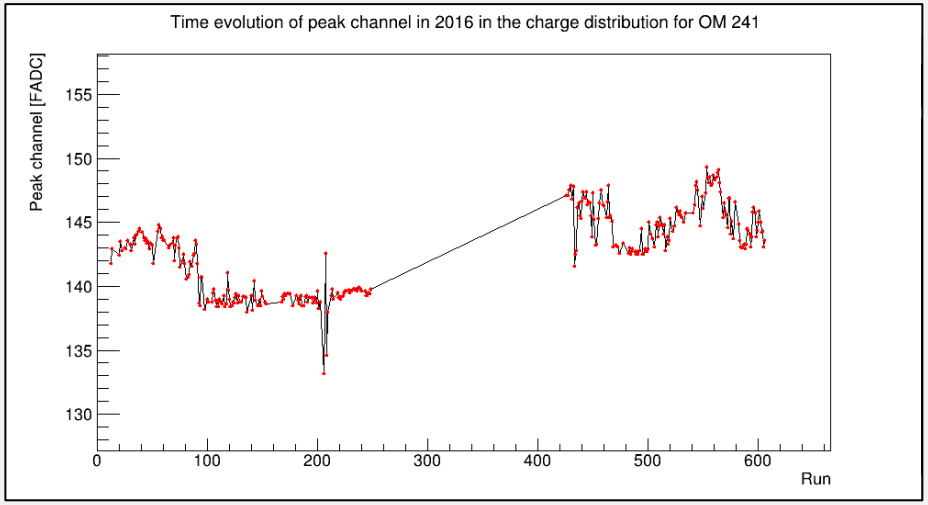
Evolution of the mean value within a year

Slowly **rising** trend, will be interesting to look at in the long term…









Eliška – double pulses

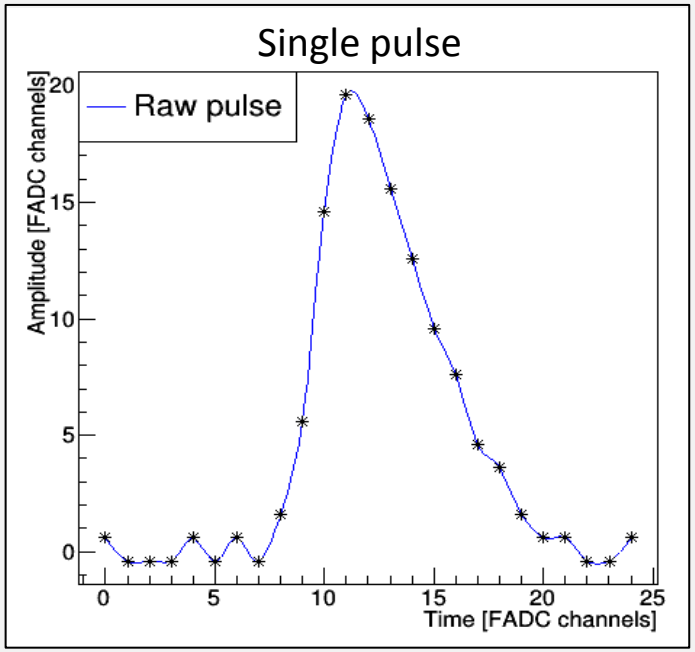
Single pulses (SP) and double pulses (DP)

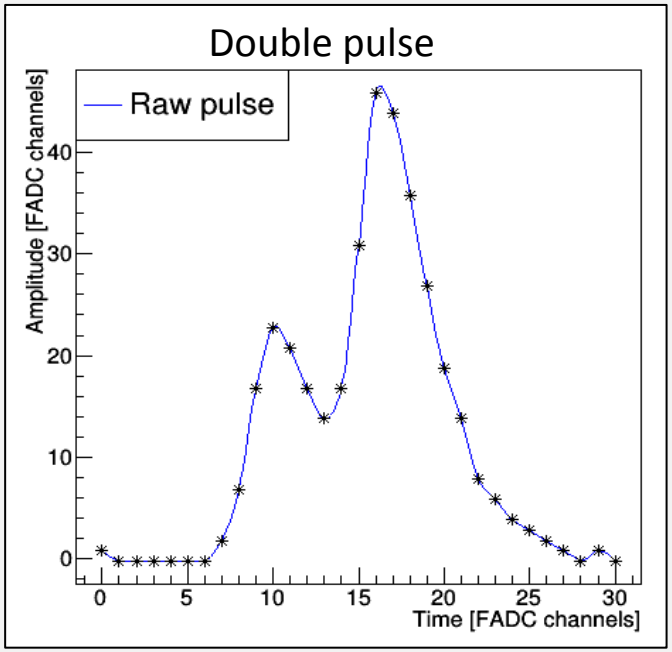
What is a double pulse?

- The waveform that consists of two or more peaks.

Motivation

- Each signal is considered as SP in Baikal GVD.
- DPs from **muon bunches** and astrophysical **tau neutrinos**.
- DPs from attributes of photomultipliers → pre-pulses and after-pulses.

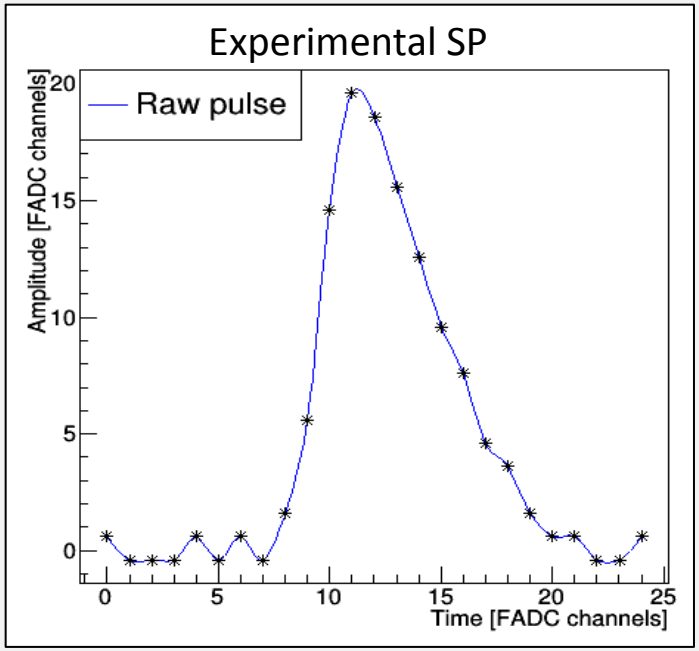


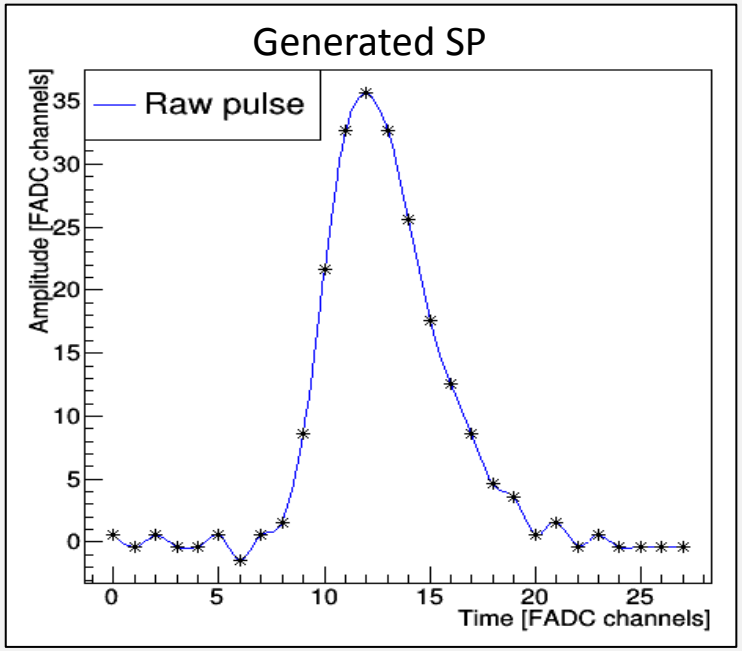


Data simulations

Data simulation program

- Self developed C++ algorithm.
- Precise analysis of statistical uncertainty of **noise distribution**.
- Simulation based on knowledge of **analytic function of SPs** (gumbel function) and **amplitude dependence** on number of detected photoelectrons.
- RESULT: Library of generated SPs and DPs for testing of effectivity of ID algorithm.

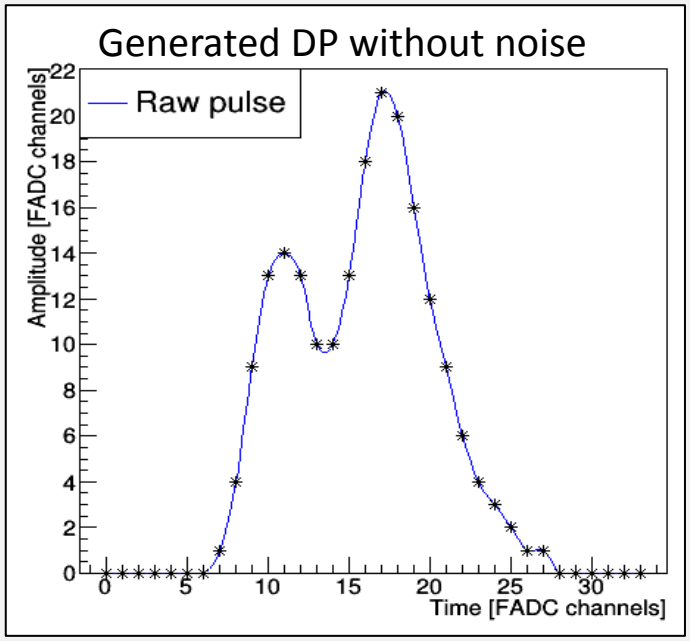


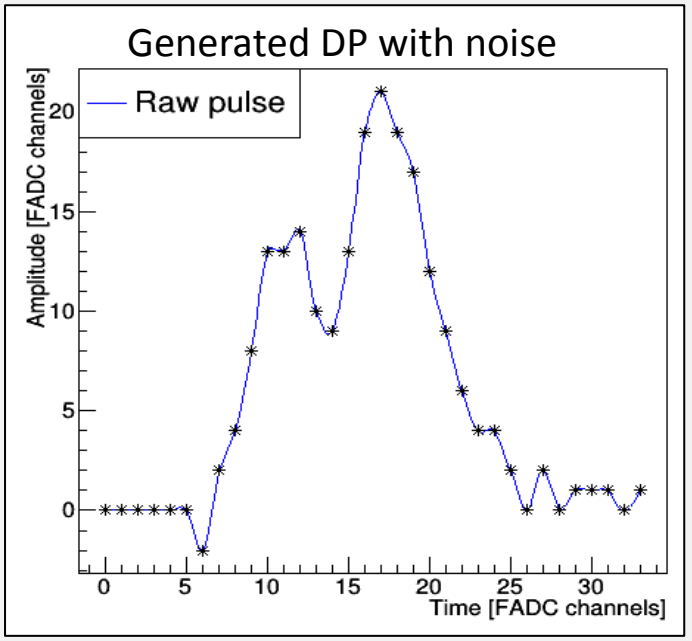


Data simulations

Data simulation program

- Self developed C++ algorithm.
- Precise analysis of statistical uncertainty of **noise distribution**.
- Simulation based on knowledge of **analytic function of SPs** (gumbel function) and **amplitude dependence** on number of detected photoelectrons.
- RESULT: Library of generated SPs and DPs for testing of effectivity of ID algorithm.



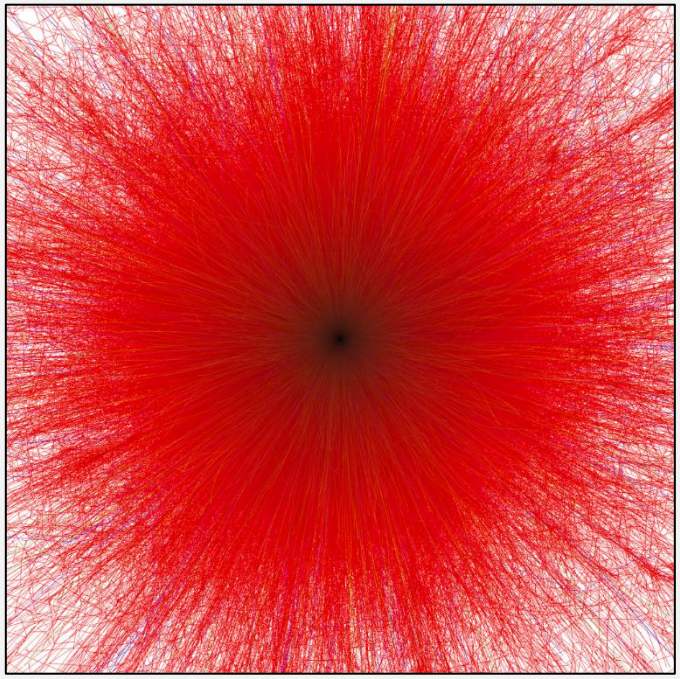


Zuzana - CORSIKA

CORSIKA simulations

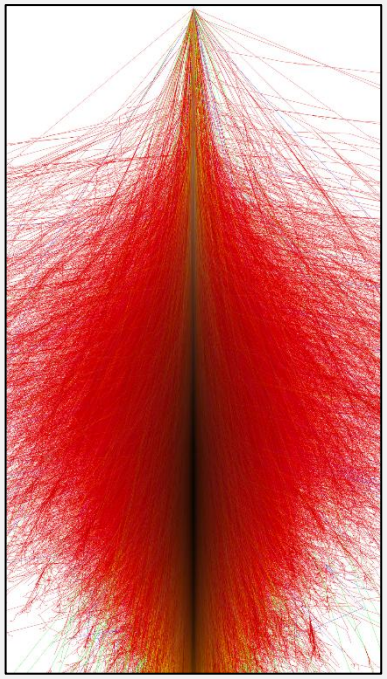
CORSIKA (COsmic Ray SImulations for KAscade)

- Program for simulations of the secondary air showers induced by primary cosmic rays.
- Access to the basic characteristics of primary as well as secondary particle: type, energy, linear momentum and arrival direction, etc.



Source: https://www.ikp.kit.edu/corsika/

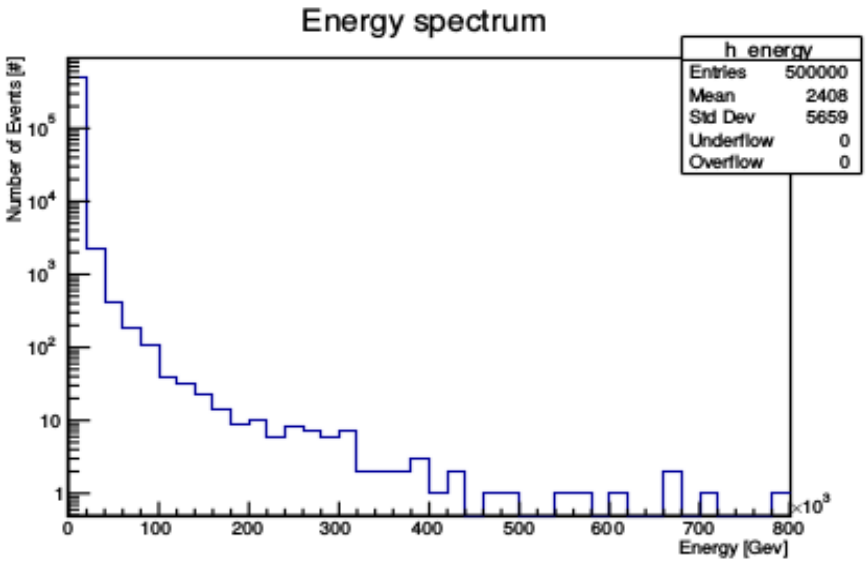
xy projection of the air shower
(Iron, 10^{14} eV, 0°)

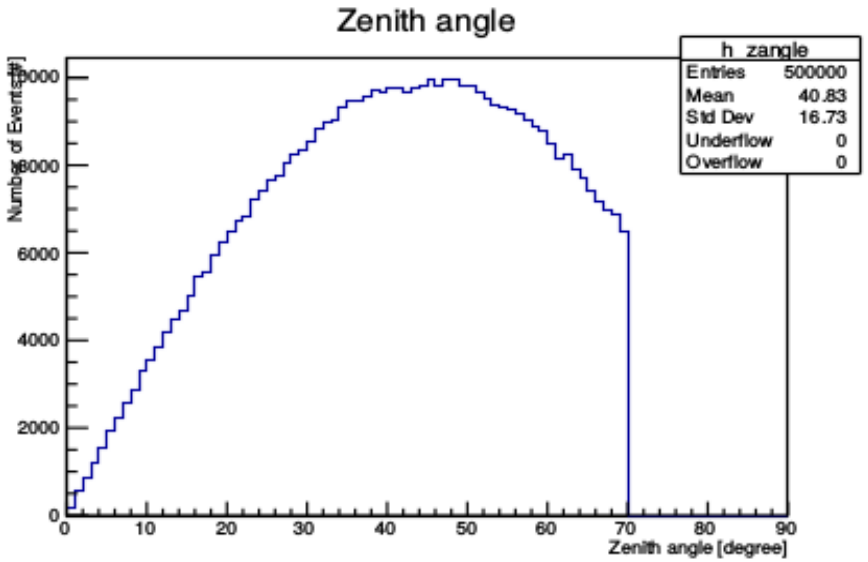


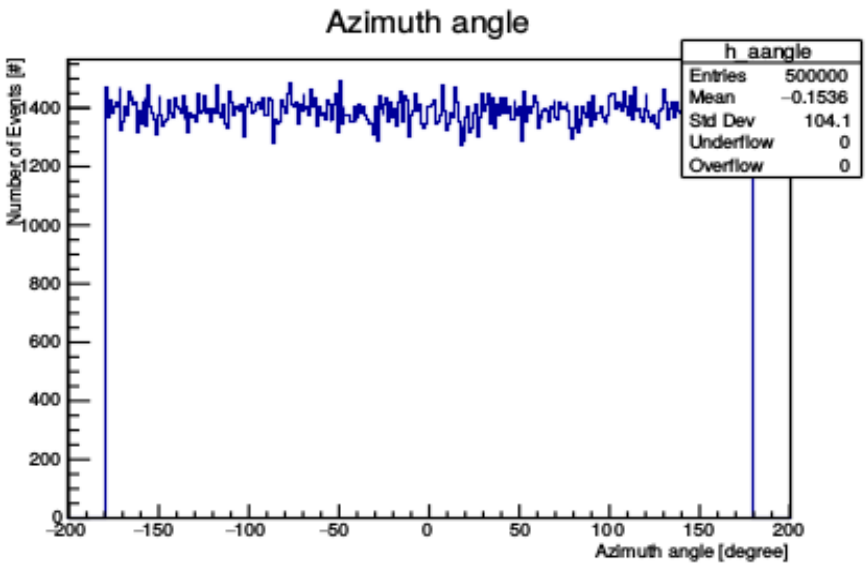
Source: https://www.ikp.kit.edu/corsika/

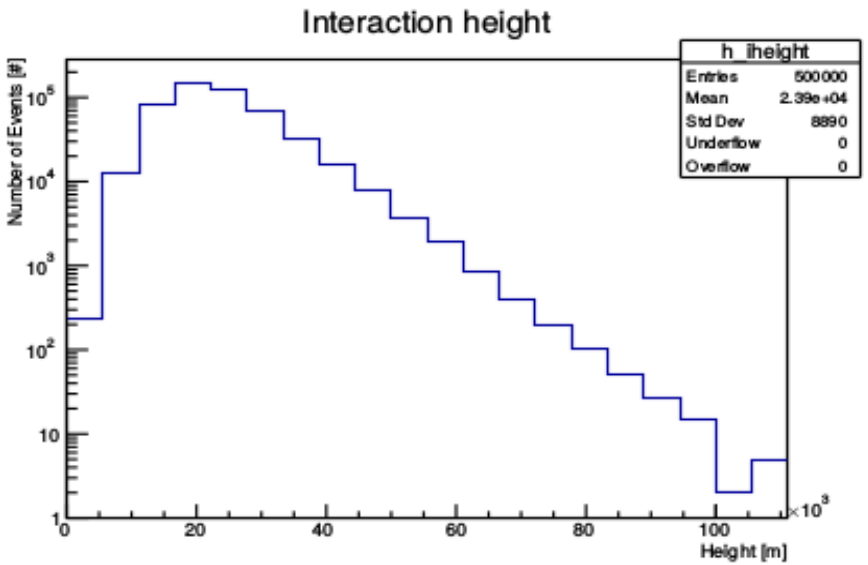
xz projection of the air shower
(Iron, 10^{14} eV, 0°)

Results for primary protons



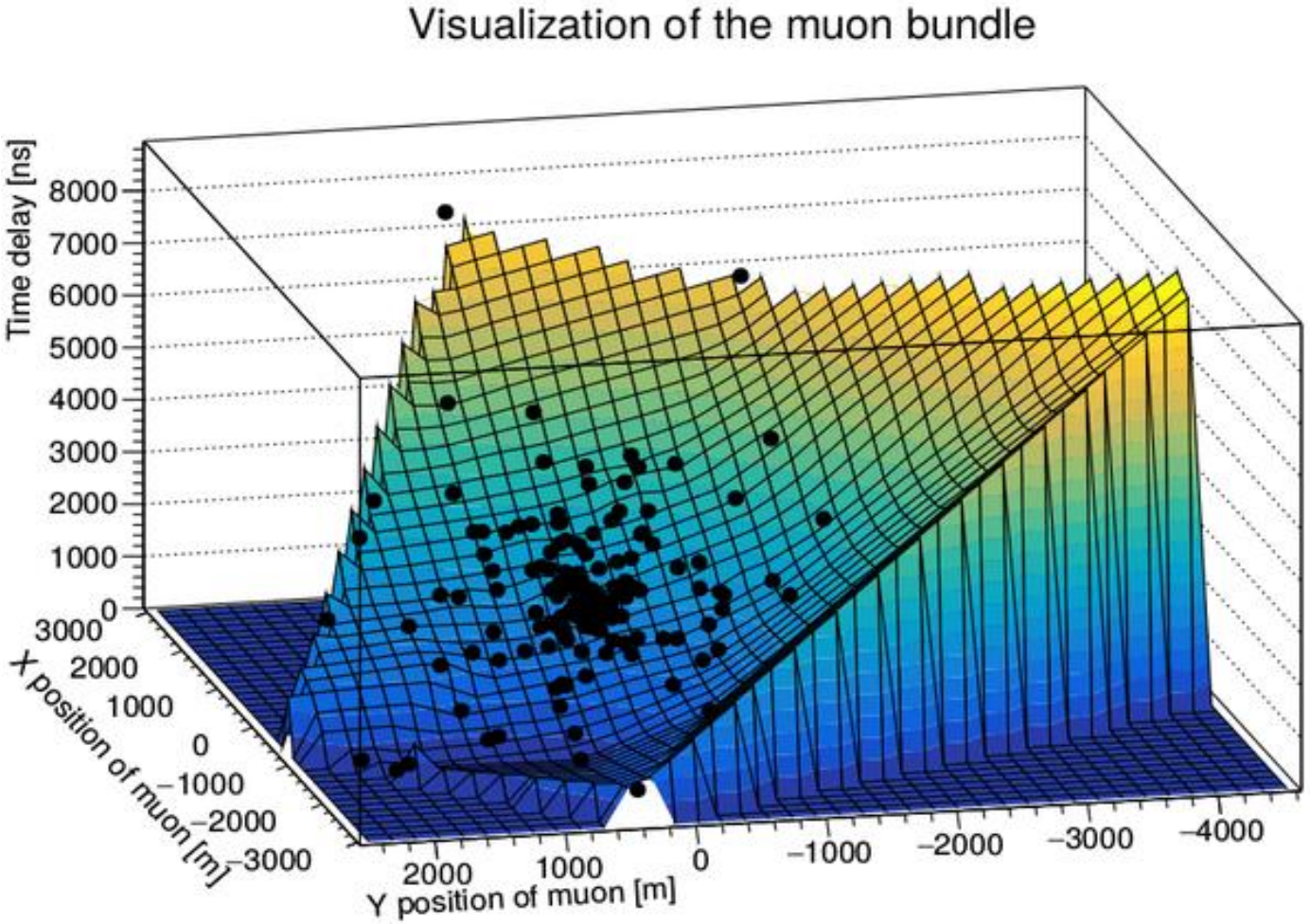






Results for secondary muons

- Front of secondary muon shower → slightly curved
- However flat front is still a good approximation



Thank you for your attention!