Baikal-GVD

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on behalf of the Baikal collaboration

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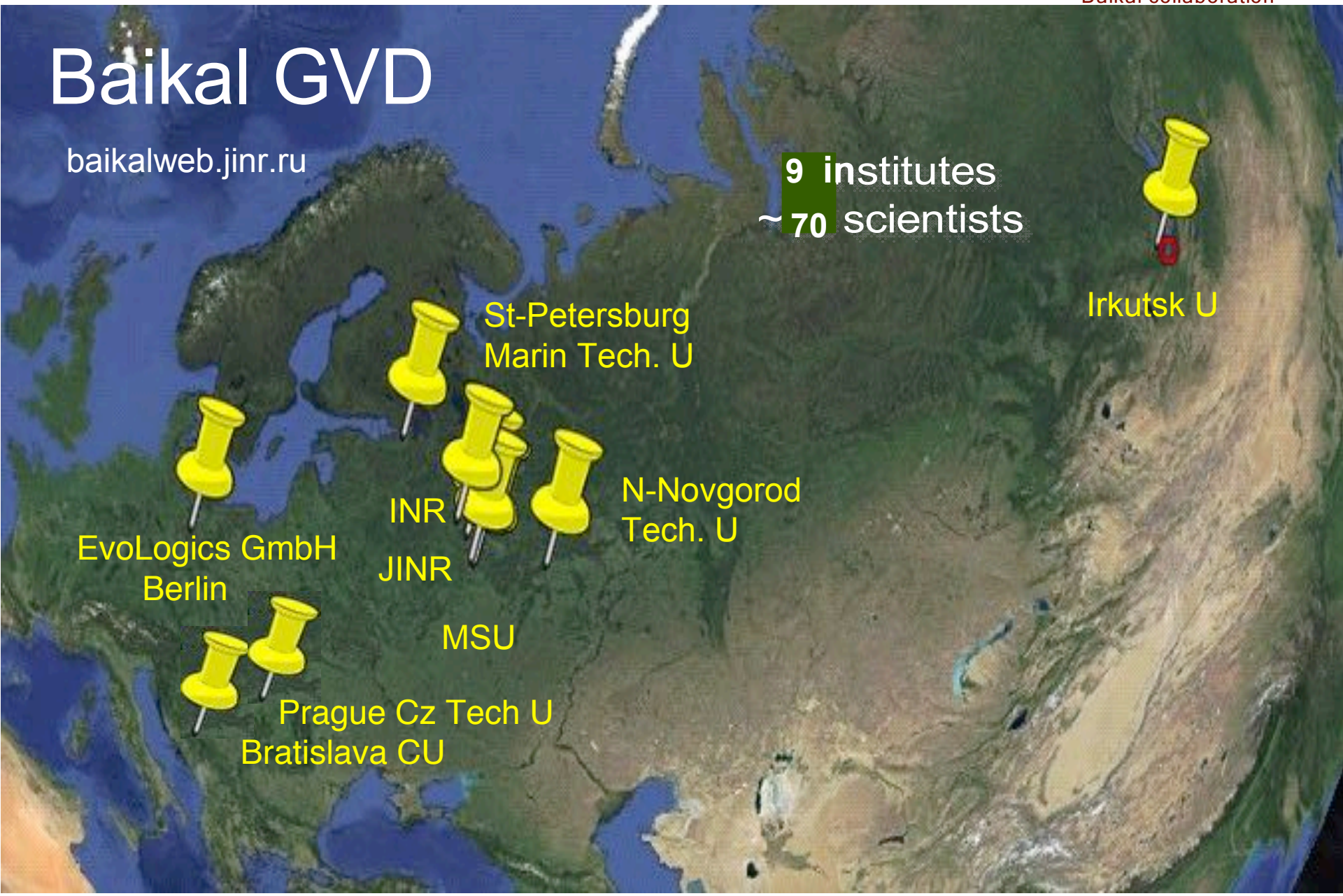
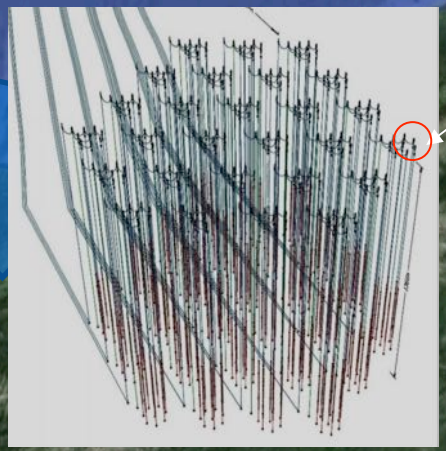
Outline

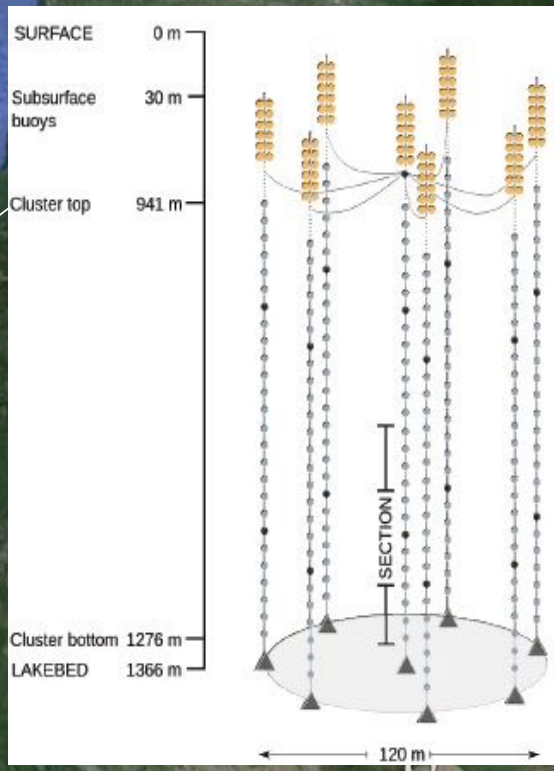
- Introduction
  - About the Baikal collaboration and the GVD project
- The first GVD cluster «Dubna 2015»
  - Basic elements and stages
  - Calibrations
  - Data processing and performance
- Expedition 2016
  - Extension of the «Dubna»
  - Next plans
- About the Baikal NTs sensitivity to νFluxes
  - GVD efficiencies: cascades and muons
  - DM annihilations: GC * LMC * dSphs
- Summary


Baikal GVD
baikalweb.jinr.ru
9 institutes
~ 70 scientists
Irkutsk U
St-Petersburg
Marin Tech. U
N-Novgorod
Tech. U
INR
JINR
EvoLogics GmbH
Berlin
MSU
Prague Cz Tech U
Bratislava CU

Baikal Gigaton Volume Detector (GVD):

	GVD (2020)	4*GVD
OMs	2302	10368
Clusters	12	27
Sections	2/Str.	4/Str.
Depths, m	950 – 1300	600 – 1300
Instr. volume	0.4 km^3	1.5 km^3



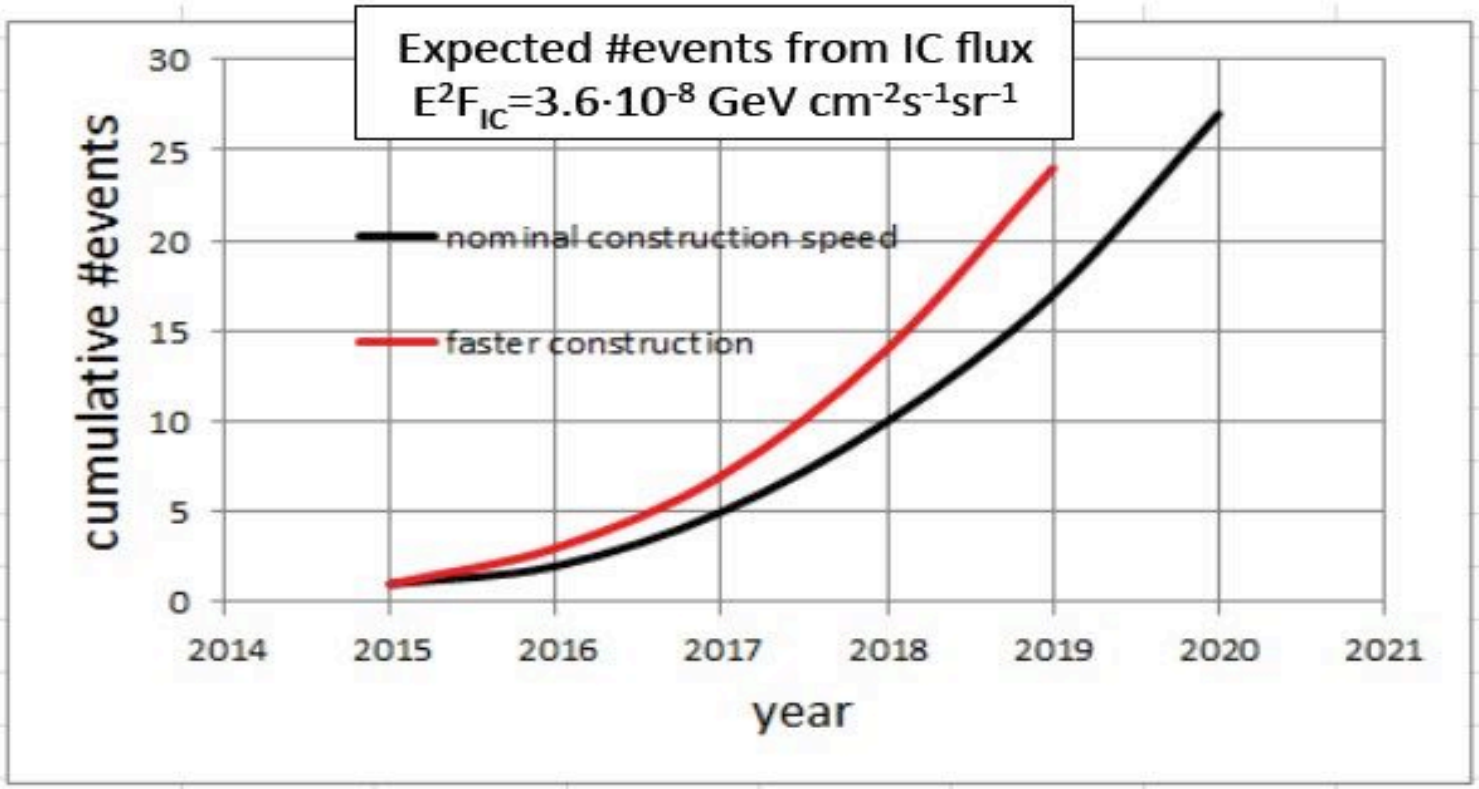


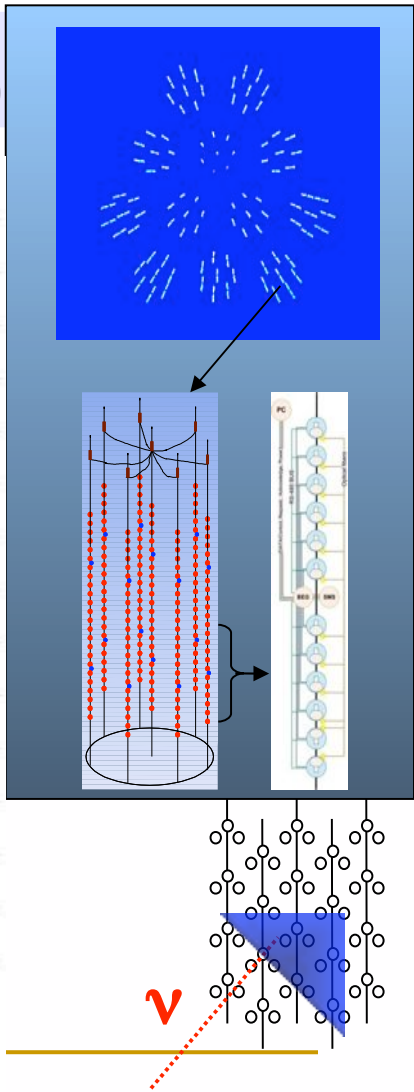
Data INTAS Project 99-1669

Image Landsat

Baikal Gigaton Volume Detector (GVD) is targeting on VHE neutrinos from astrophysical sources visible in gamma-rays either invisible DM clumps

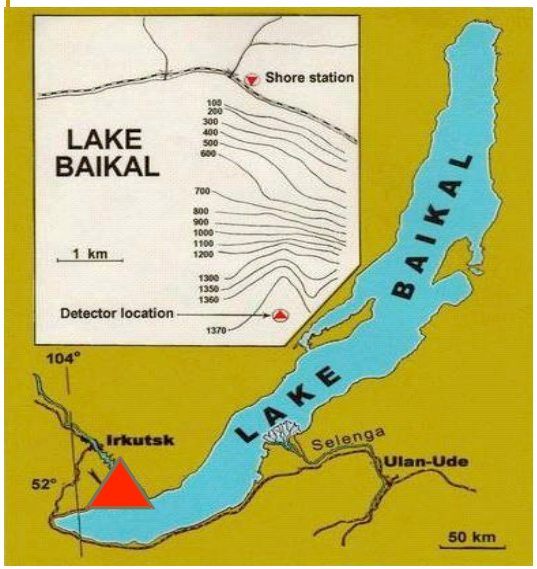
Research&Development 2008 2009 2010 | Prototyping&C 2011 2012 | Data taken 2013 2014 | 1st cluster 2015 | 12 2020



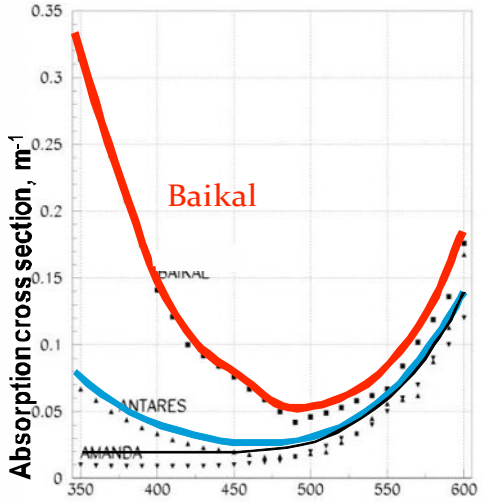


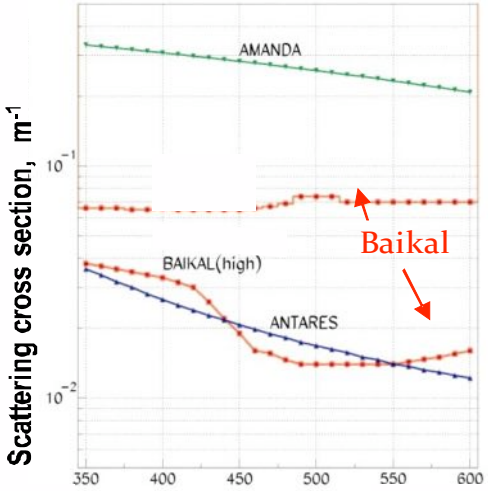
E > 100 TeV: ~1 event/cluster/year

The Baikal site and water properties

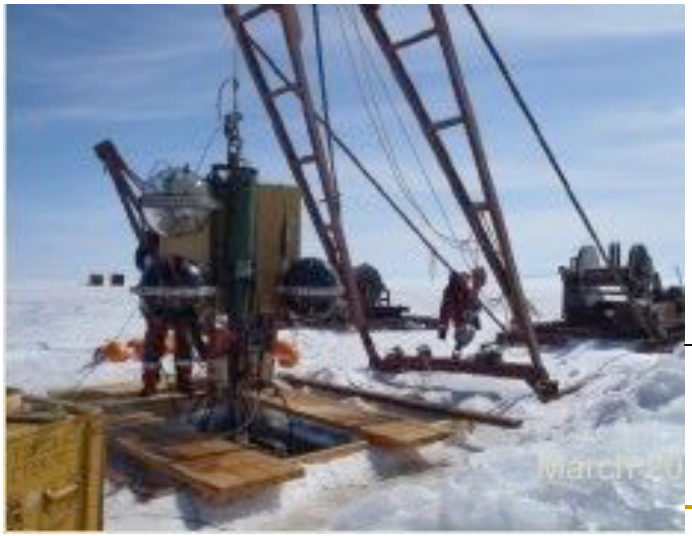


3.6 km to shore, 1370 m max depth





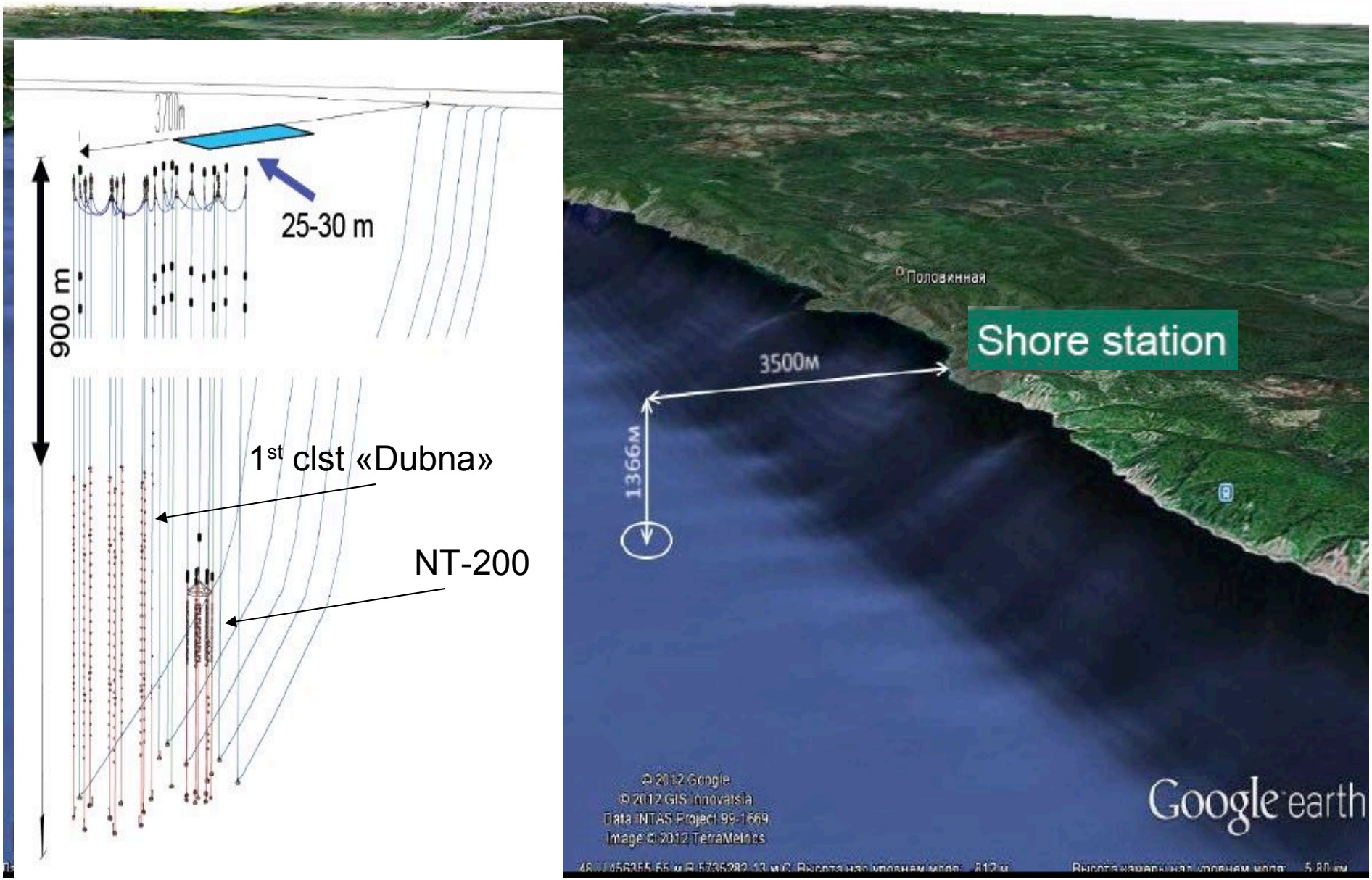
Absorption length – 22-24 m ; Scattering length: 30-50 m
(L_{eff} ~ 300-500 m)



- No high luminosity bursts from biology.
- No K^{40} background.
- Deployment simplicity: ice is a natural deployment platform

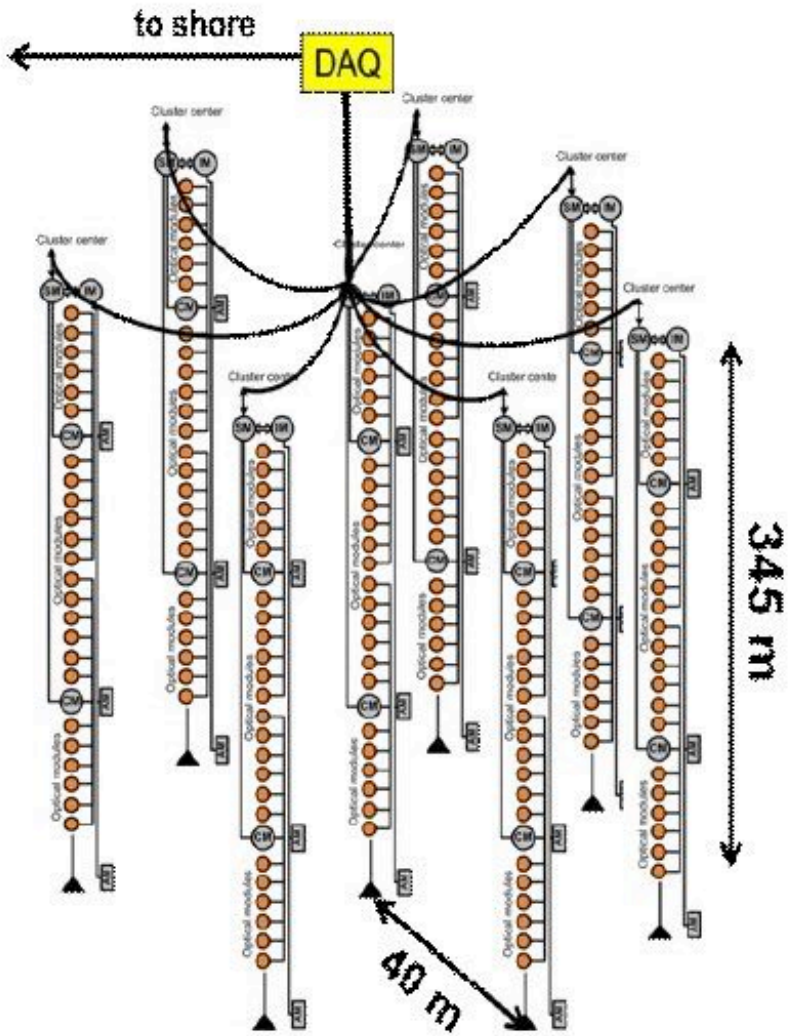
- **Telescope installation, maintenance, upgrade and rearrangement**
- **Installation & test of a new equipment**
- **All connections are done on dry**
- **Fast shore cable installation (3-4 days)**

Since April 2015 the 1st cluster «Dubna» is operating



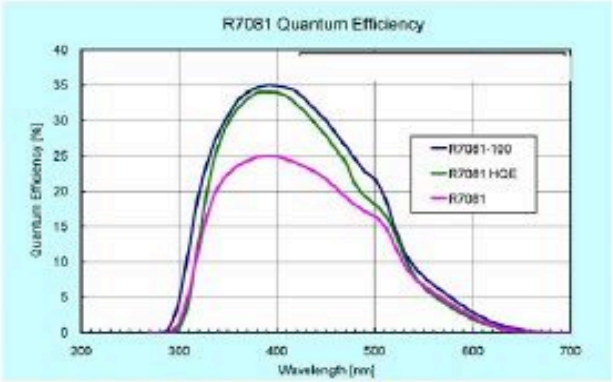
April 2015: first cluster of the GVD

- 192 OMs located at 8 strings;
  - 2 sections per string
  - 12 OMs per section
  - each OM spaced by15 m
- DAQ-center
- Optical cable to shore
- Acoustic positioning system;
- Active depth 950 — 1300 m



the peripherical strings have been located at a reduced radius of 40 m around a central one (compared to 60 m for the baseline configuration)

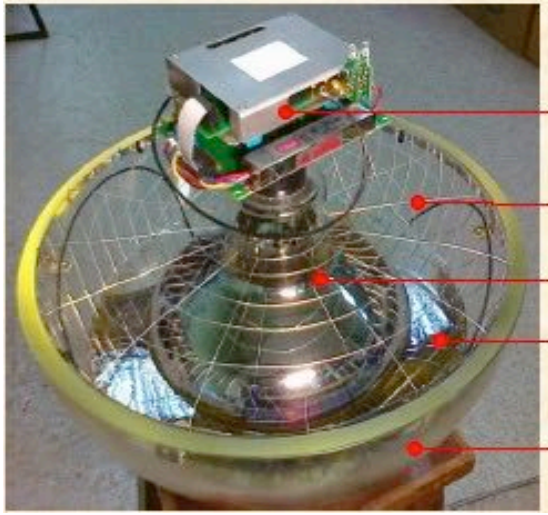
Optical module design



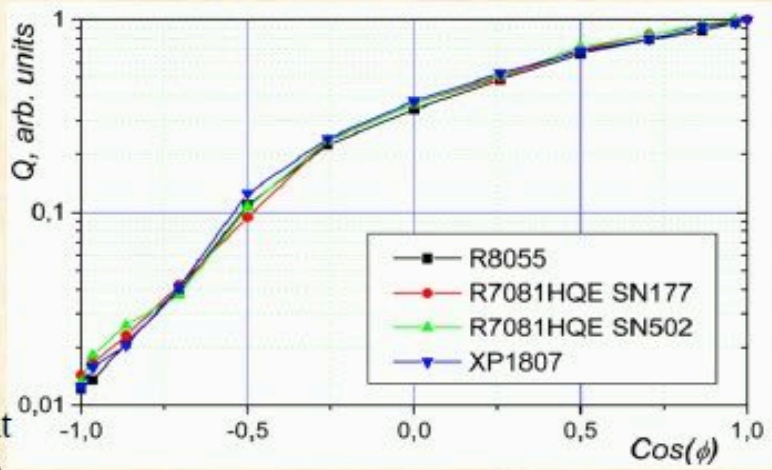
Quantum efficiency

R7081-100 Hamamatsu

D=10 inch. SBA photocathode QE ≈ 35% @ 400nm; Gain ~10^7, dark count ~8 kHz



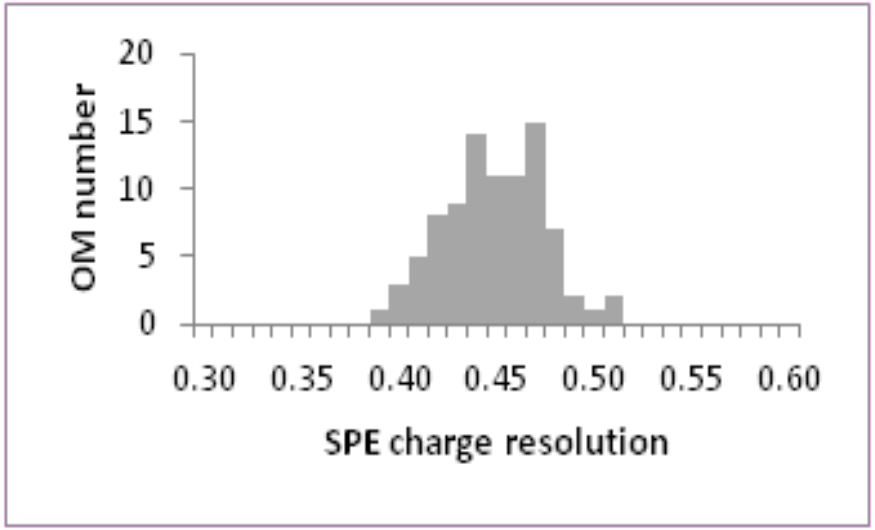
Angular sensitivity



Optical module: functions and calibrations

Basic functions for section operation

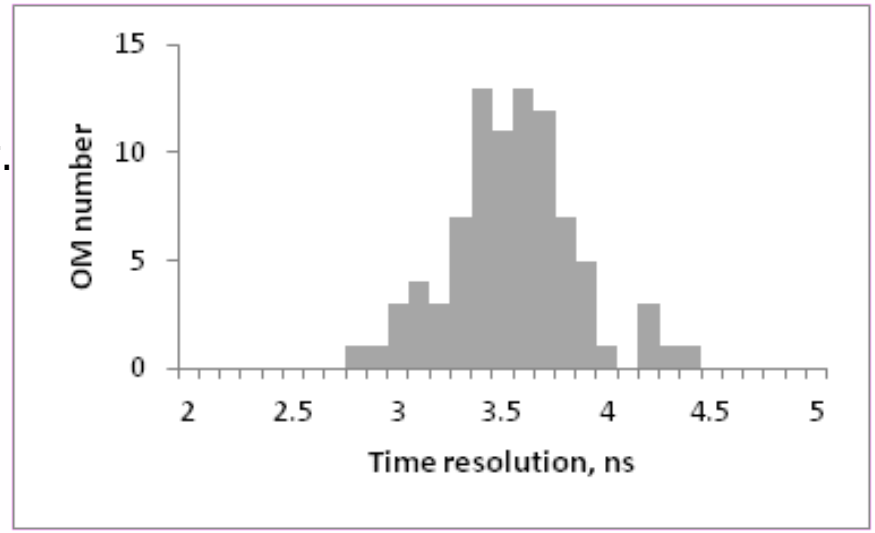
- Detection of the particle radiation
- Shaping of the output analog pulse for signal transmission to the ADC board
- Control of the PMT operation modes
- Calibration and monitoring of the parameters of OM electronic components.



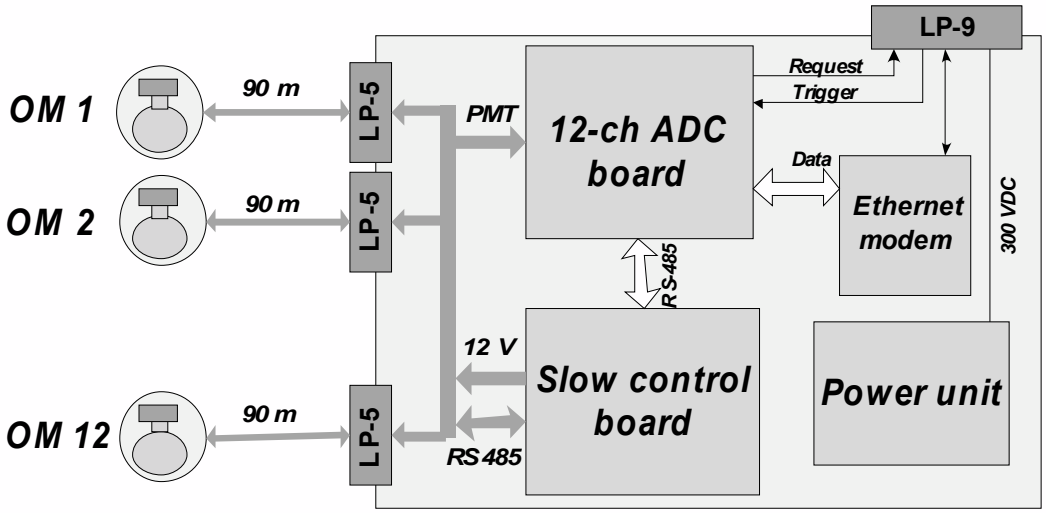
Fully automatized test procedures

- Electronic components, stress tst, modes var.
- Adjustment of the PMT power supply volt.
- Performance with oscilloscope LeCroy
- SPE spectrum, threshold 0.2SPE
- Nonlinearity of measuring channels

(LED pulses, linearity range ~100p.e.)

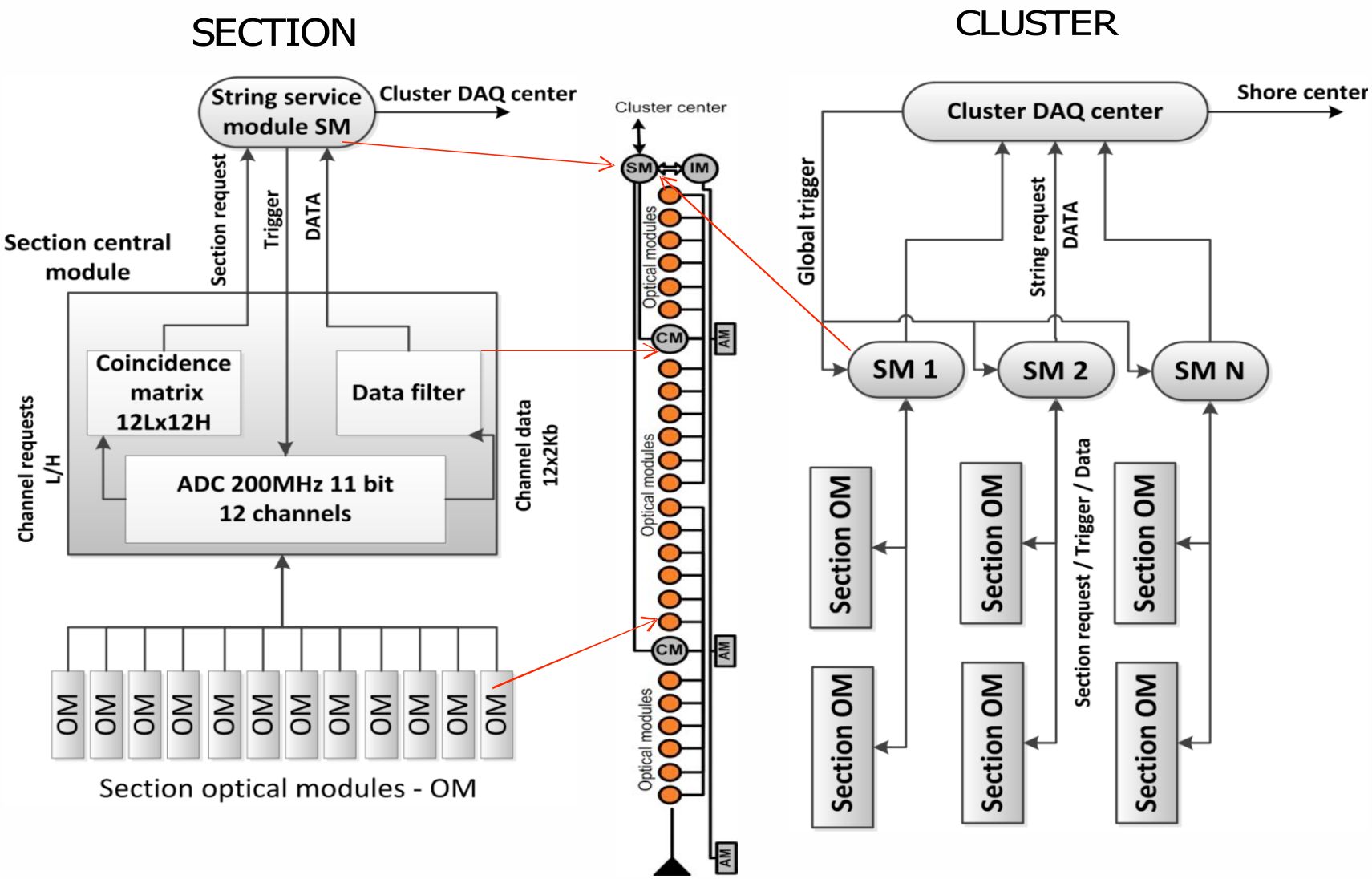


Section: 12 OMs and CEM



12-channel ADC unit:	PMTs analog pulse conversion, time synchronization, data processing, local trigger.
Data transmission:	Two outputs of ADC board: optical output (for future detector extension) and 100 BASE-TX (present stage).
shDSL modem:	Extending the Ethernet line up to 1 km.
Slow control board:	OM power on/off and control of OM operation (RS485).

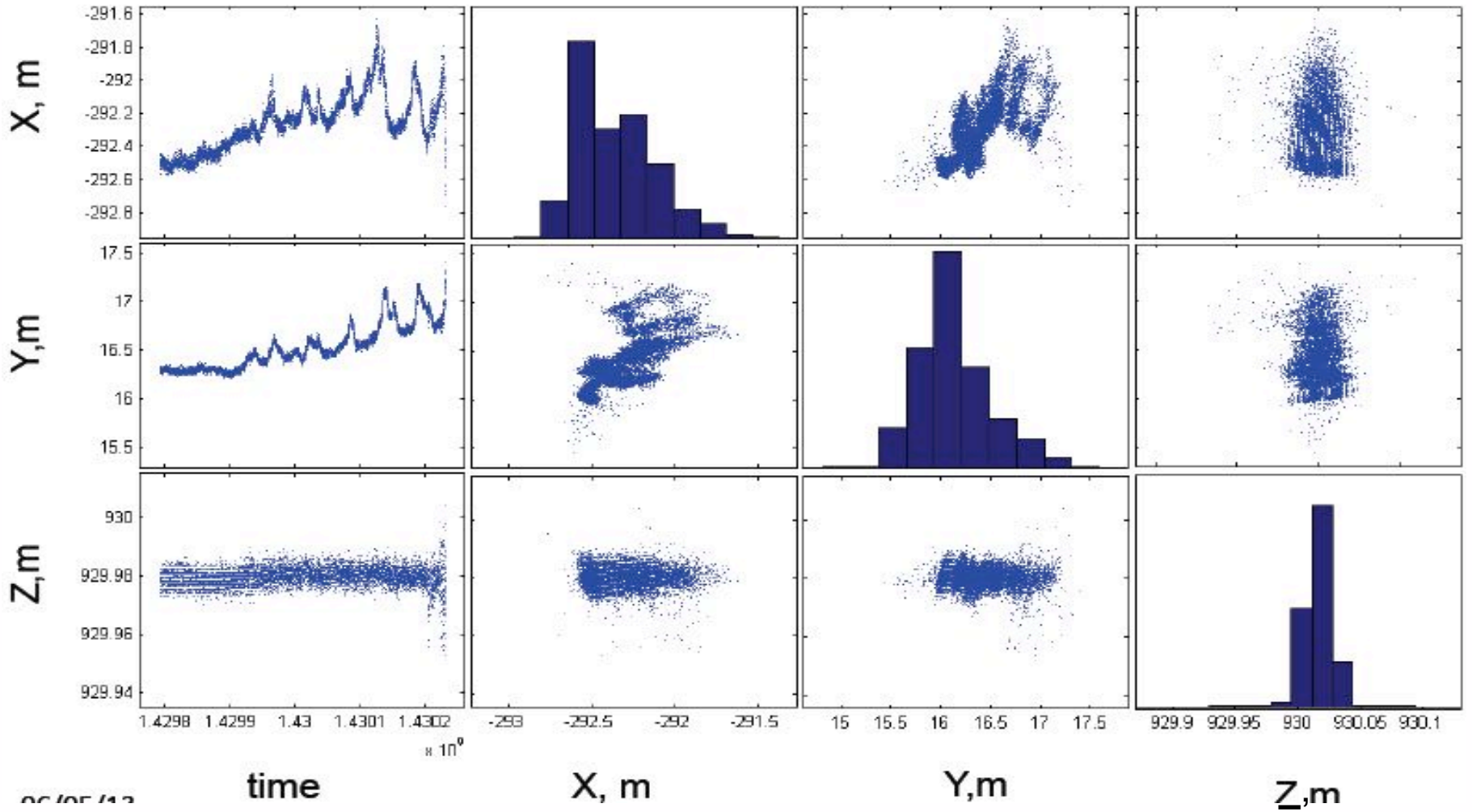
Triggering and Data Transmission



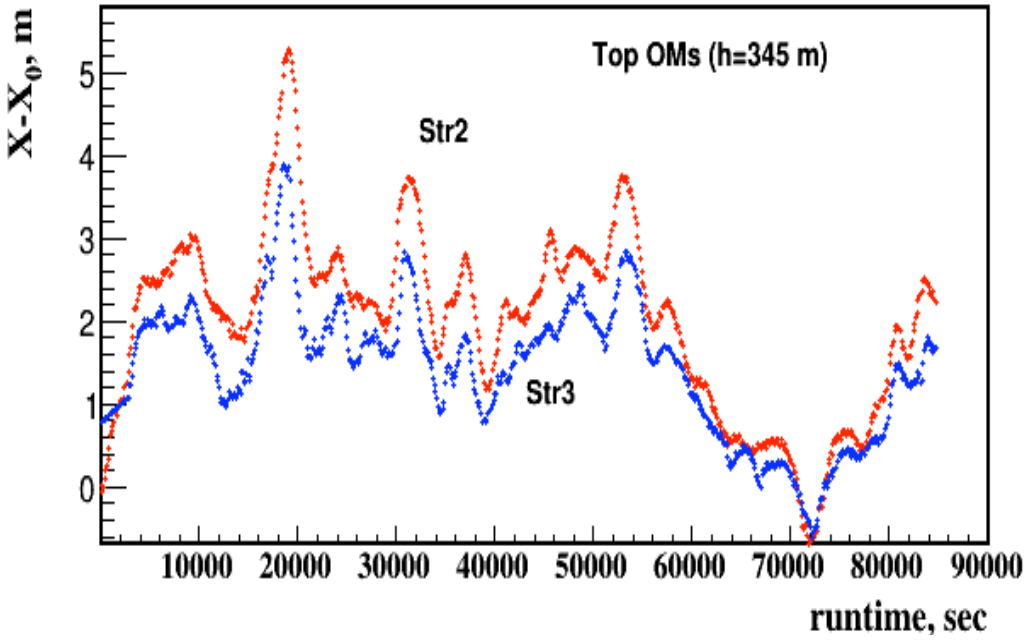
Performance of acoustic positioning system in 2015

Performance of acoustic positioning system:

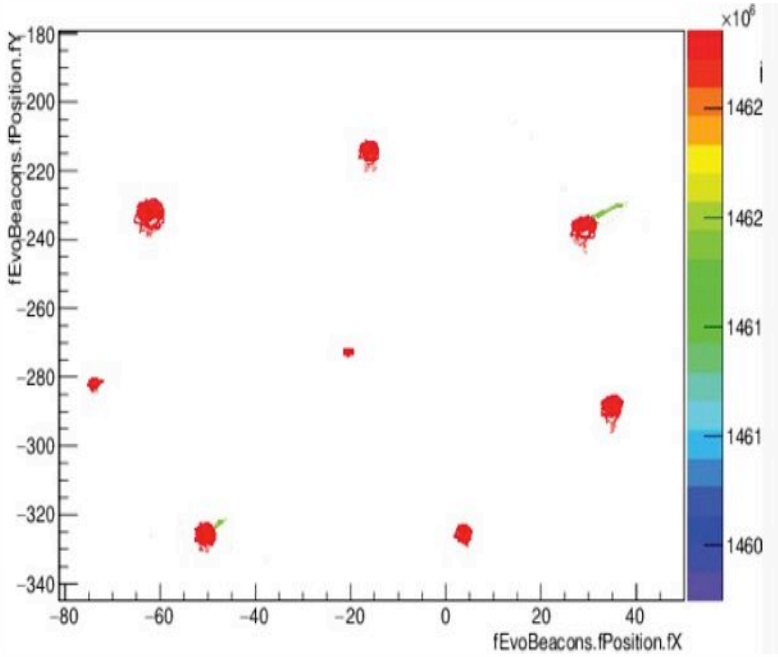
- data every 30 seconds

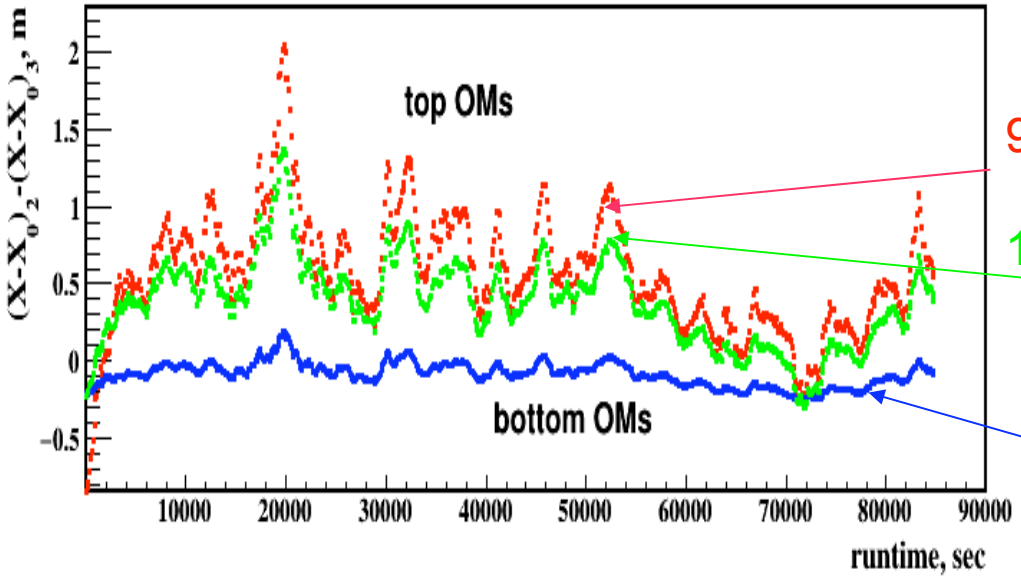


Performance of acoustic positioning system in 2015



Y-X node positions in Nov 2015





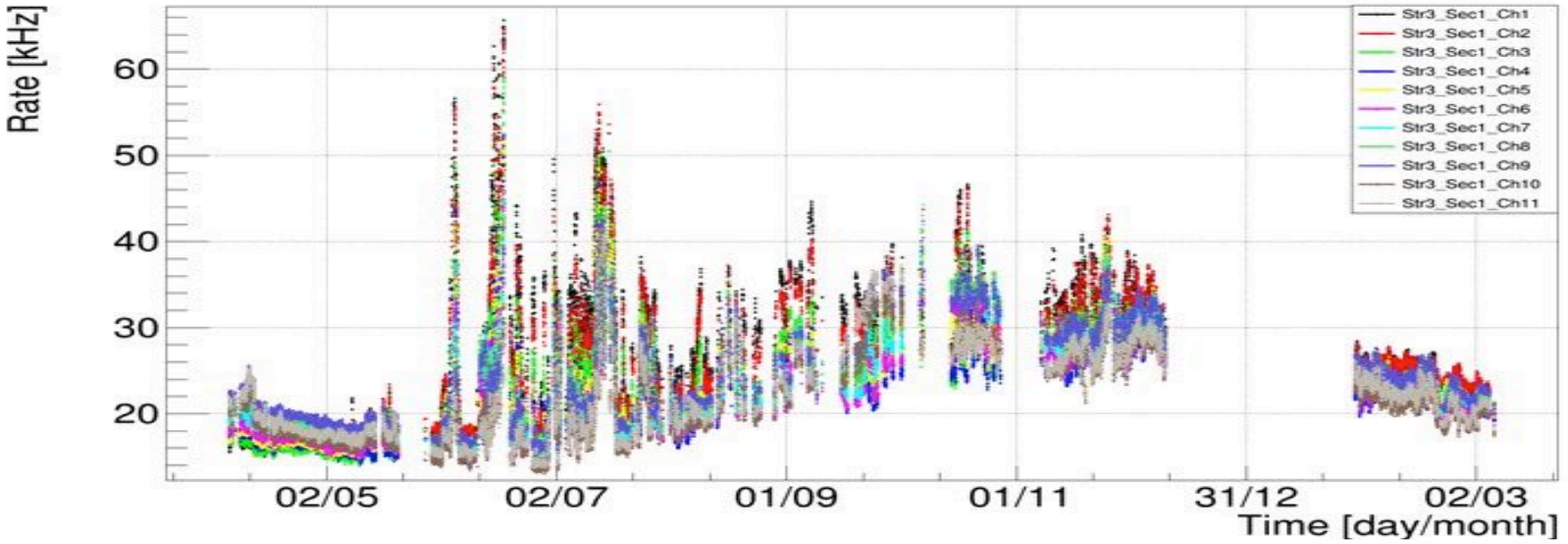
925 m

1105 m

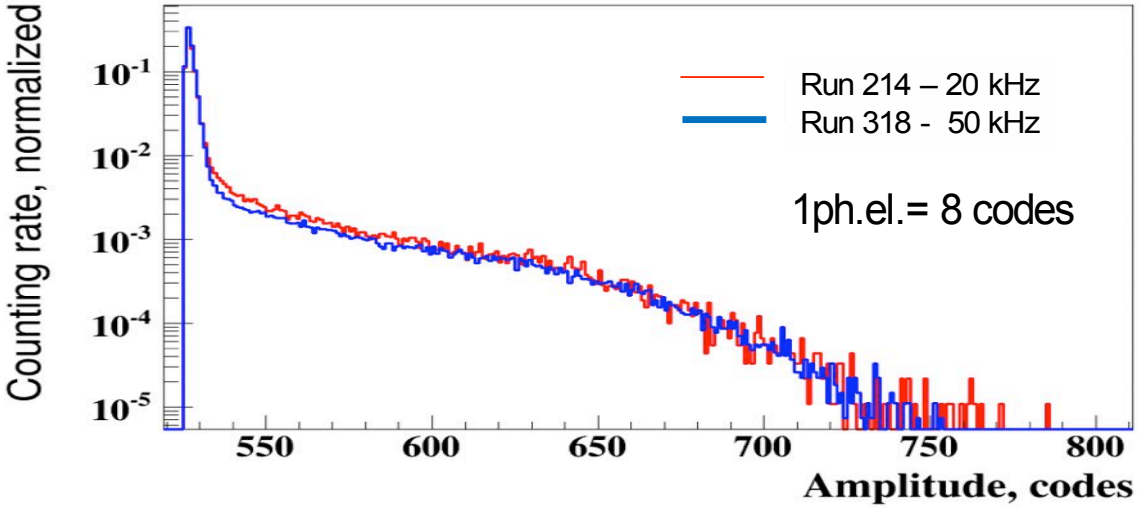
1270 m

Operation-2014, 2015

Counting rates of OMs



Amplitude distribution of selected OM recorded pulses

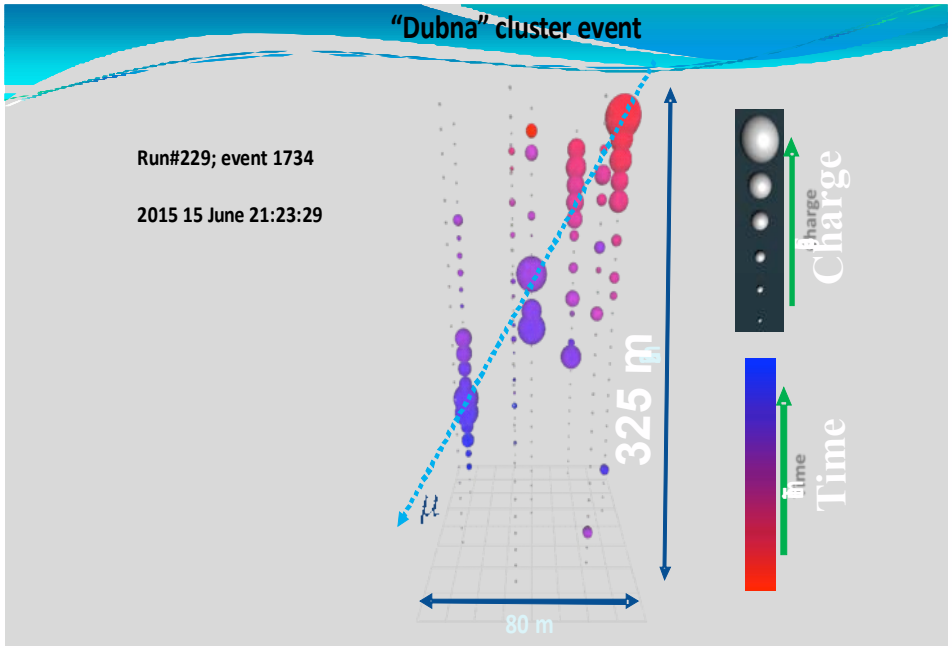


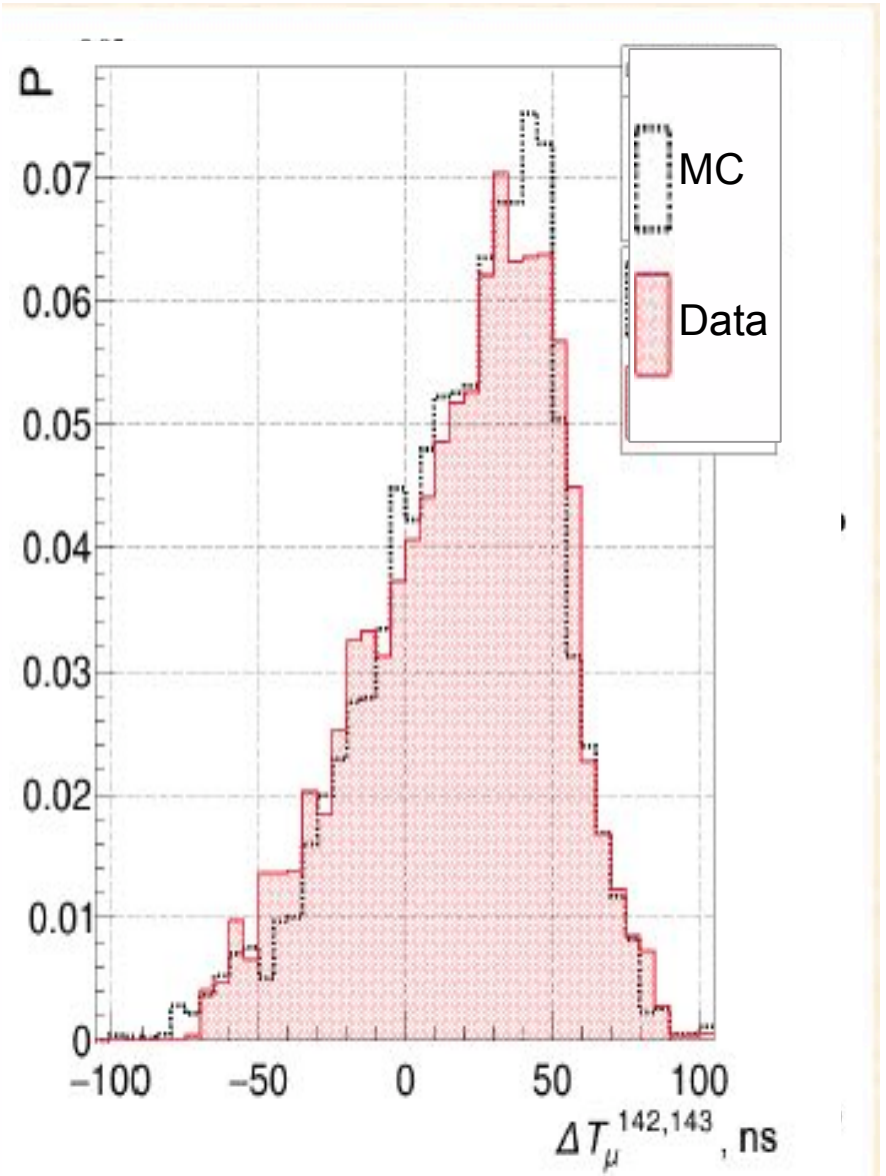
Atmospheric muons

Runs - 265, 266 (July 2015)

Statistics ~$50 \cdot 10^6$ events

LED – calibration
Data consistent with expectation



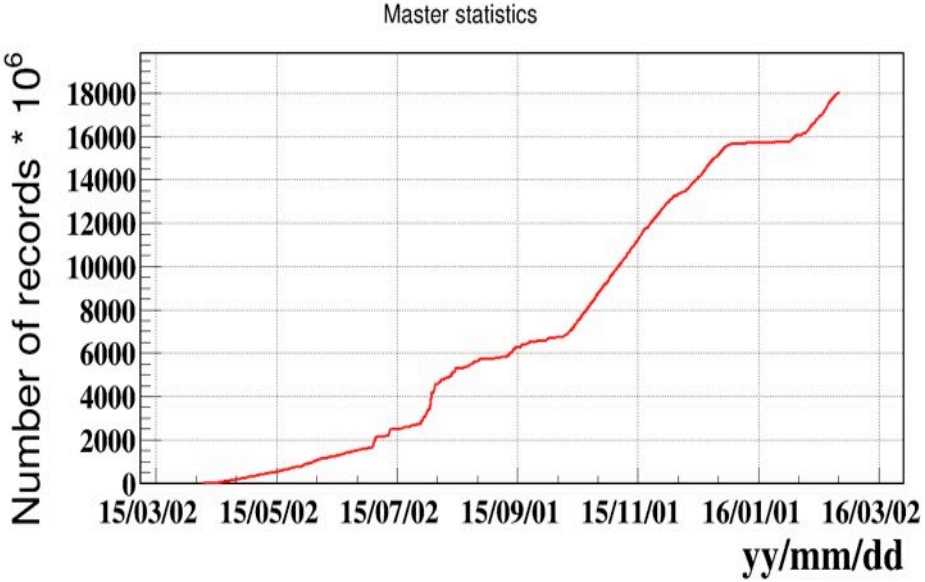


Operation in 2015yr

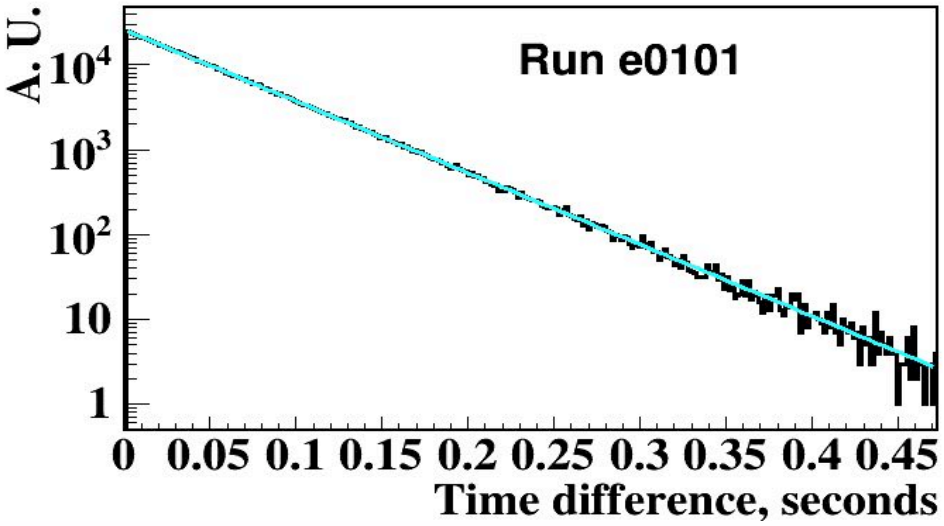
(24 March – 10 February) - 294 days

- Operation: 213 days
- Efficiency: 72%
- Number of runs: 662
- Data: 1.6 ·10^9 events
- Event rate ~ 100 Hz
- Life time ~ 184 days

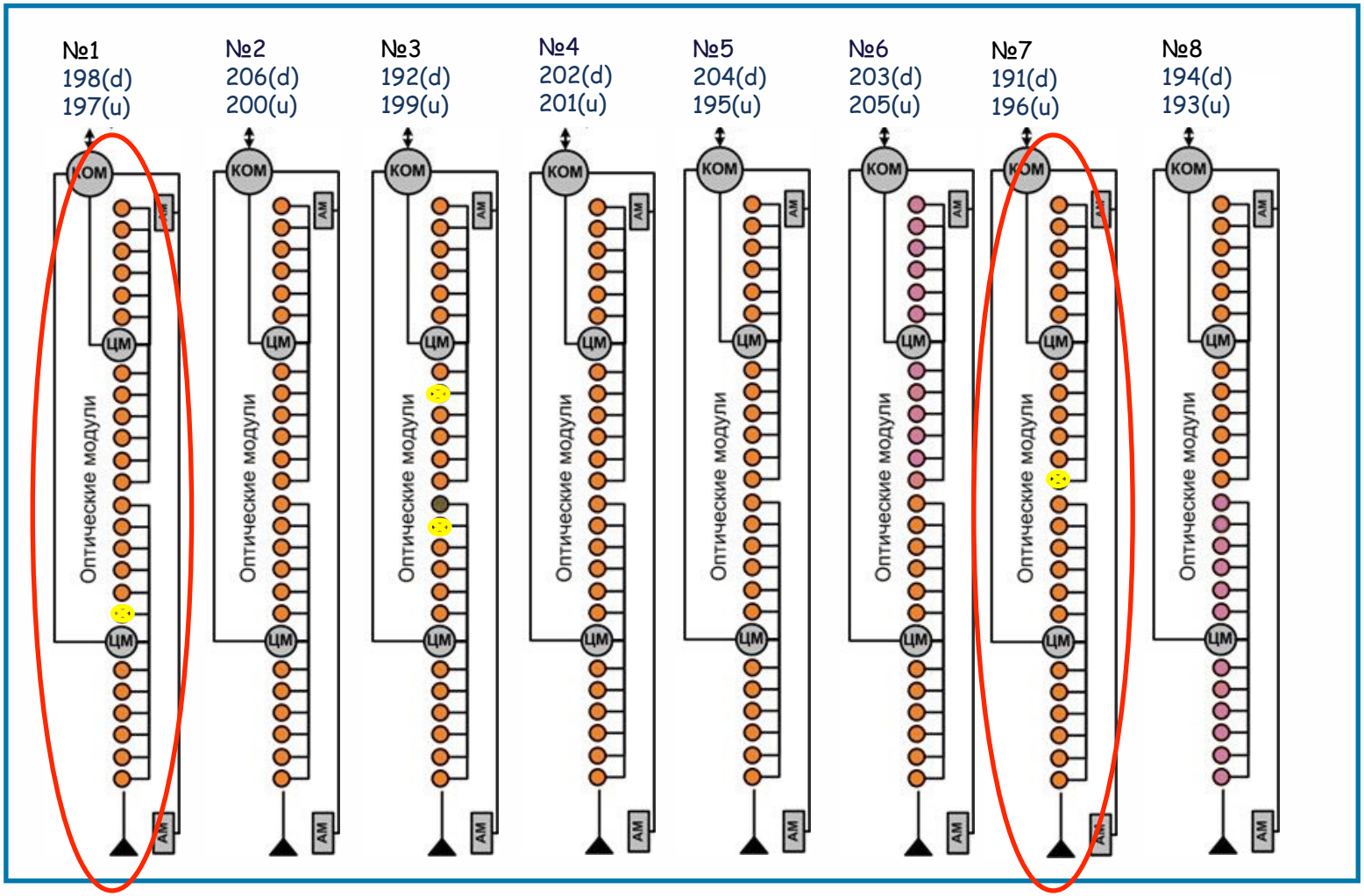
Cumilative number of events



ΔT between subsequent events

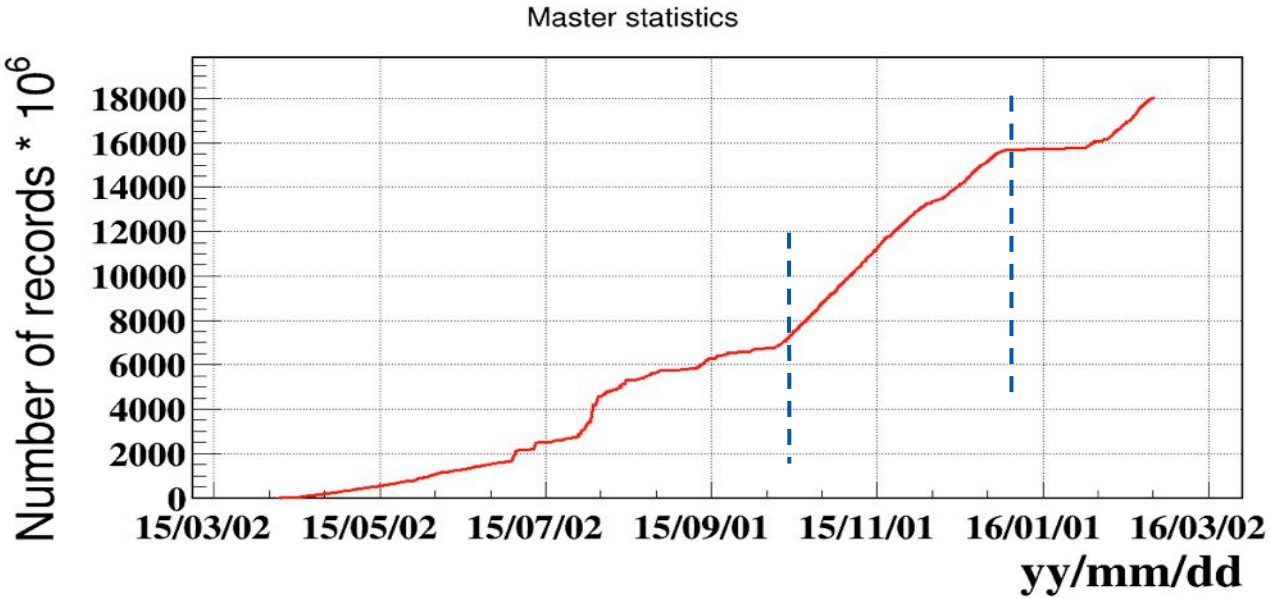


Performance of cluster 2015 (malfuncions)



String 1, 3 and 7 were deployed in first stage with electronics of 2013-14

Operation in 2015yr: data sample for Reco&A



Dates 24.10.2015 ÷ 17.12.2016, LT= 41.64 days.
Config: 7 strings; different cnfgs/runs.
Trigger: L&H th = 1.5p.e.&4p.e. coincidence of two neighboring Oms.

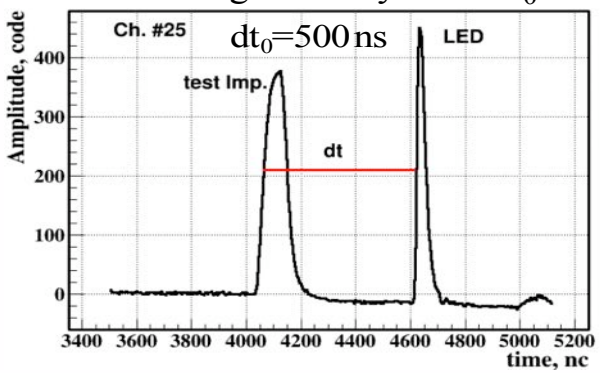
- Statistics: 437 970 024 events
- After causality cuts: 18 840 822 events

  $N_{hit} > 3$; $|t_i - t_j| < \Delta r_{ij}/v + \delta t)$

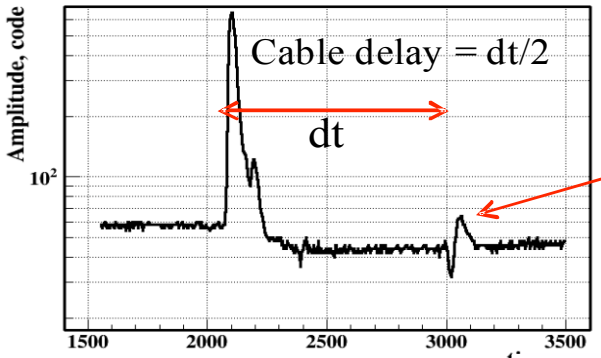
Time calibration – two methods

Measurement of signal delay of each channel

PMT signal delay = $dt-dt_0$



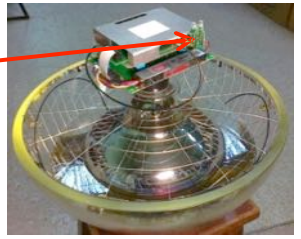
Signal delay in cable (~90 m) is measured in lab.

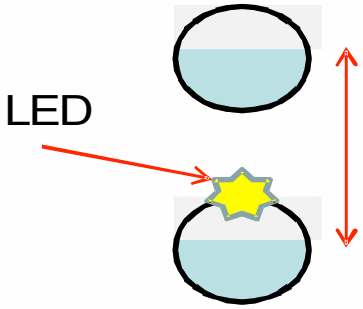


reflected pulse

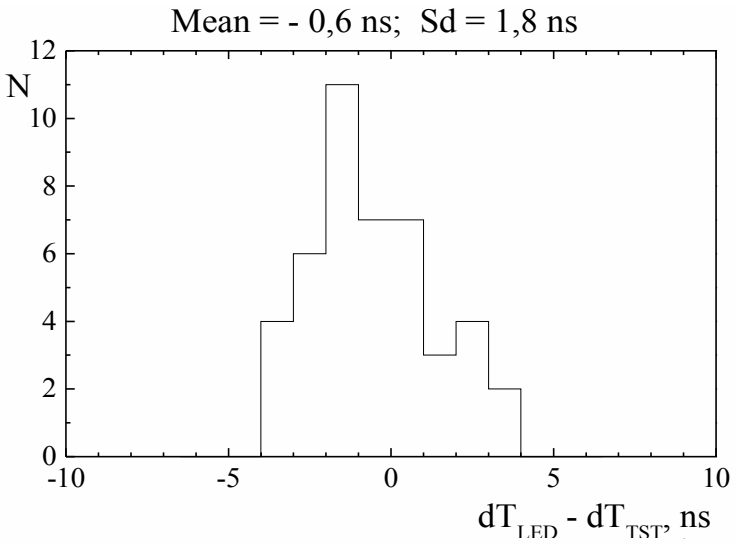
Time difference of two channels

two LEDs





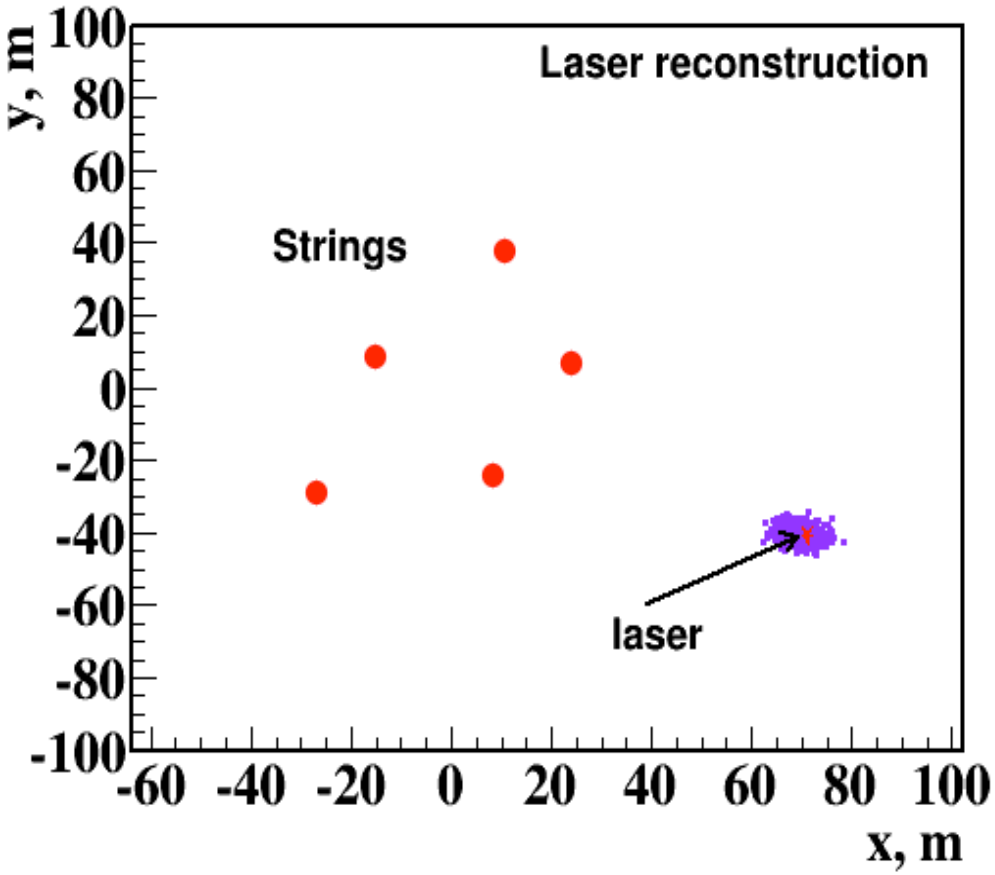
15 m- distance between OMs
dT_0 = 64.9 ns – expected time difference



Reconstruction of laser-light source position

- Laser and OMs coordinates from data of acoustic positioning system
- Time offsets of OMs from LED calibration
- Iterative reconstruction procedure – OMs with residual δt > 15 ns are excluded from analysis

$$\chi^2_t = \frac{1}{(N_{hit}-4)} \sum_{i=1}^{N_{hit}} \frac{(T_i(x,y,z,t_0) - t_i)^2}{\sigma^2_{ti}},$$



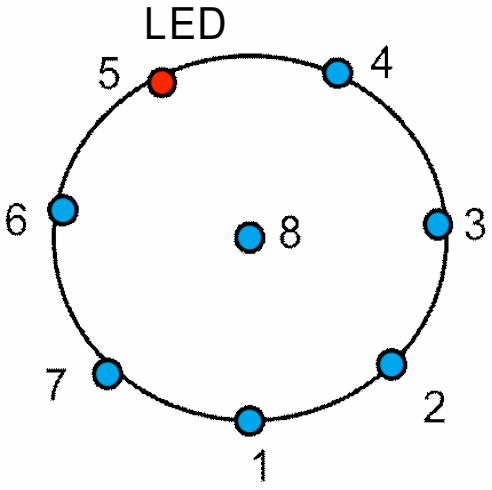
External calibration laser:

- 480 nm light pulses

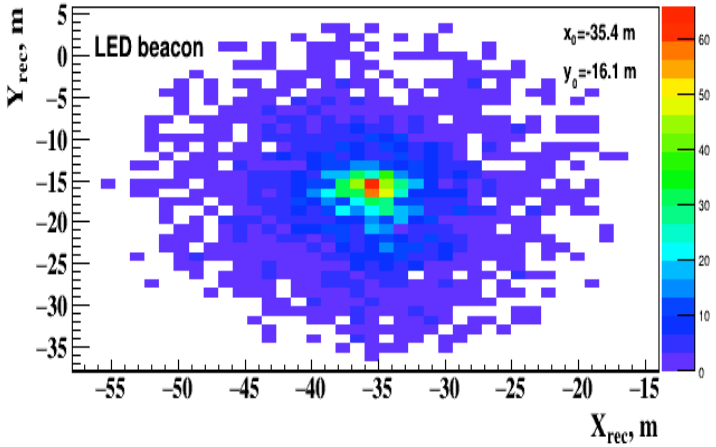
- Five fixed intensities: ~10^{12} – 610^{13} □ */ pulse*
(~10 PeV – 600 PeV shower energy)

- Distances: 50 – 250 m.

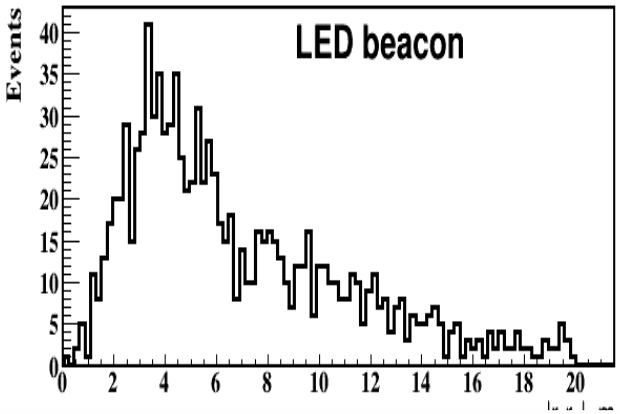
LED-beacon – calibration light source for shower detection (run e621)

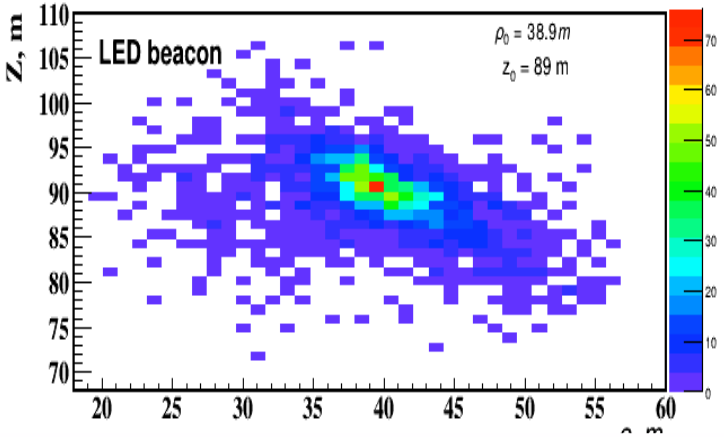


LED-source coordinates:
x = -35.4 м; y = -16.1 м; z = 89 м



Coordinates reconstruction

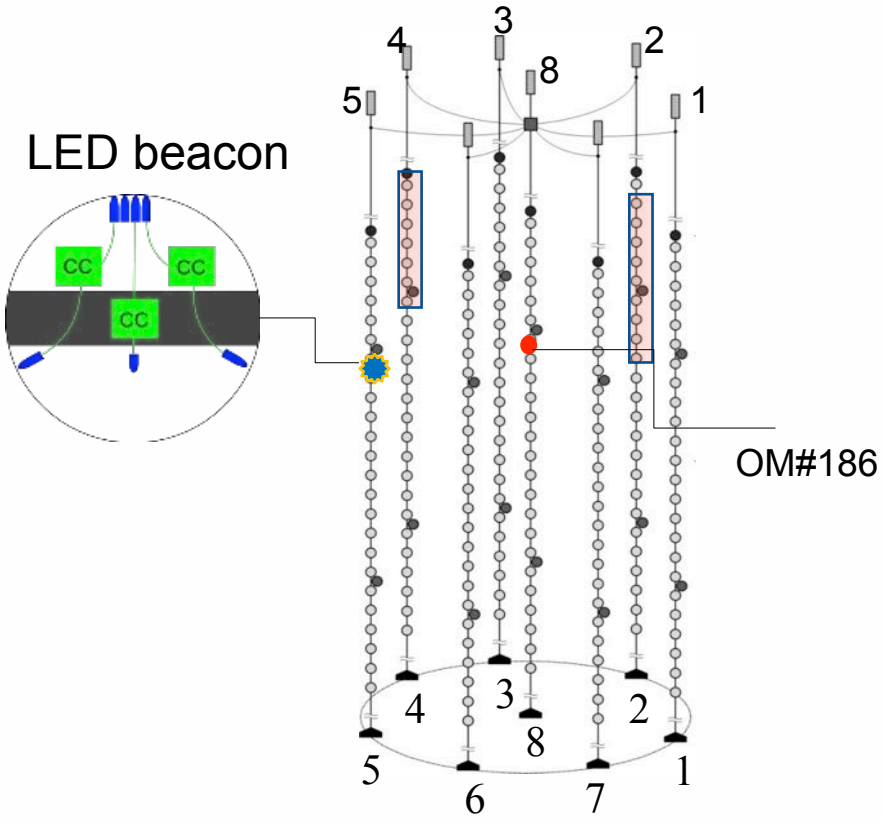




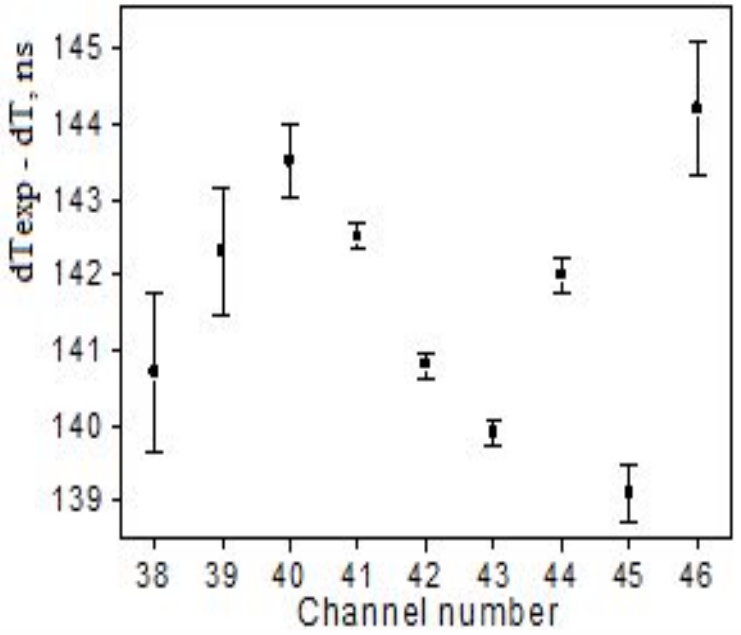
Reconstruction accuracy 4m

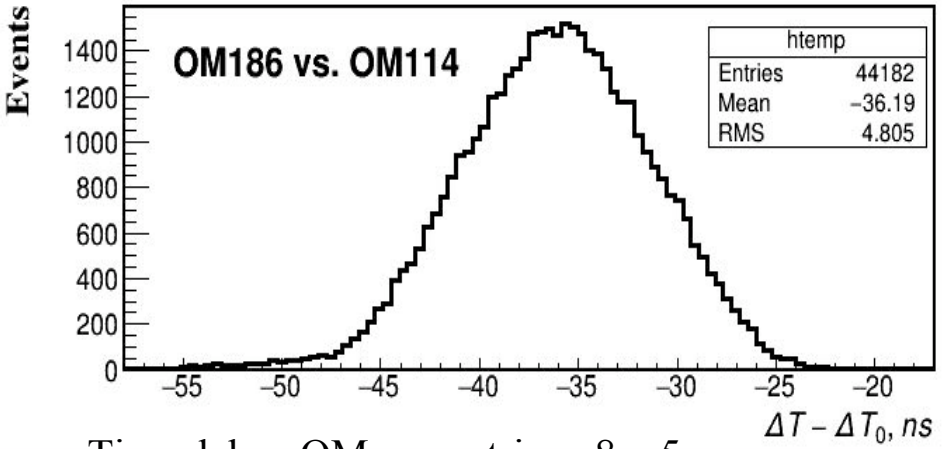
Calibration with matrix of LEDs

Source of light is a matrix of 6 pairs of LEDs, while light directed on top and horizon. Coordinates from EvoL APS.



Time delay of OMs on strings 2 and 8: mean dT=142 ns, RMS = 7 нс





Time delay OMs on strings 8 и 5

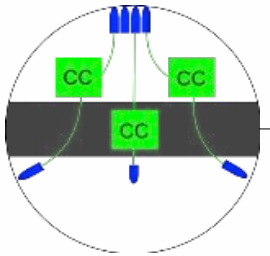
Calibration with matrix of LEDs

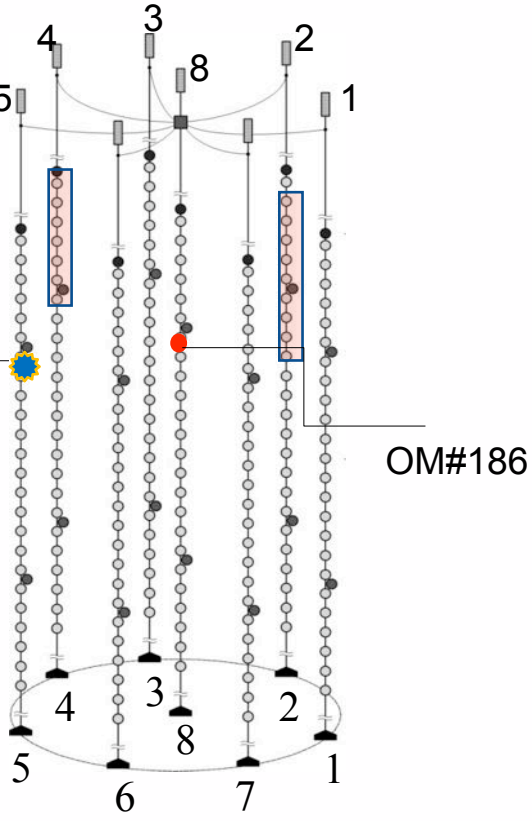
Reconstruction of cascade direction and energy

$$L_A = -\sum_{i=1}^{N_{hit}} \ln P_i(A_i, E_{sh}, \vec{\Omega}_{sh}(\theta, \varphi)),$$

where P_i calculates in respect of tabulated $\bar{n}_{pe}(\rho, z, \theta, \varphi, \tau)$

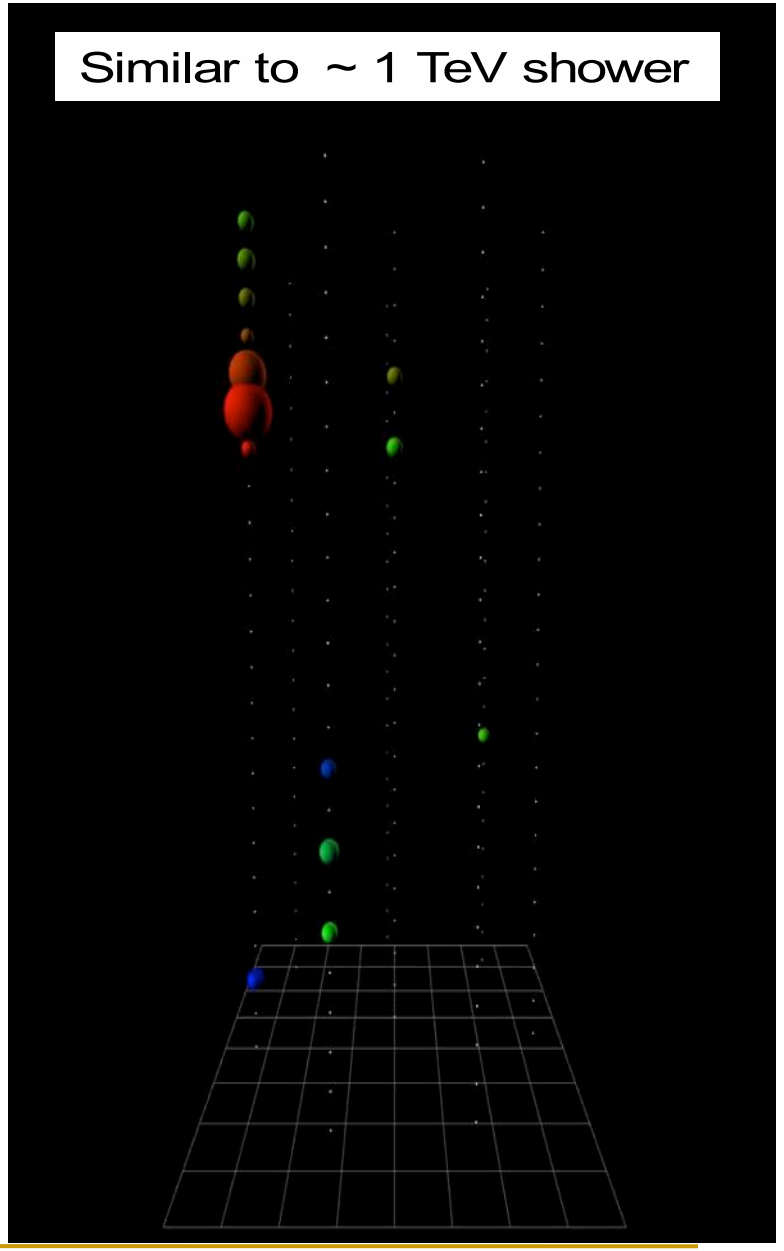
LED beacon





OM#186

Similar to ~ 1 TeV shower



Expedition 2016

April 2016: extension of the 1st cluster GVD by 3rd sections

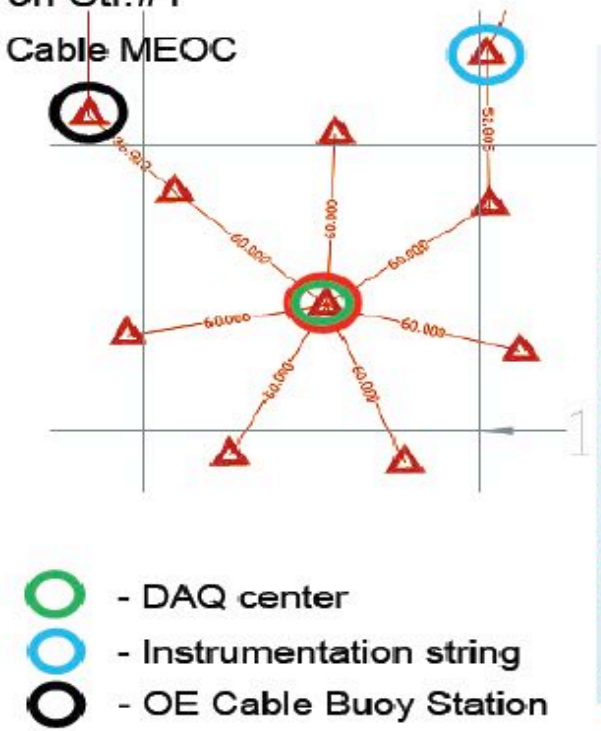
Upgrade of DUBNA array in 2016

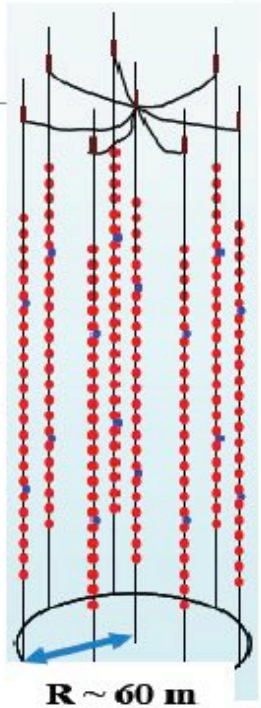
- 96 OMs at 8 sections
- Replace system modules on Str.#7
- Replace acoustic modem on Str.#1

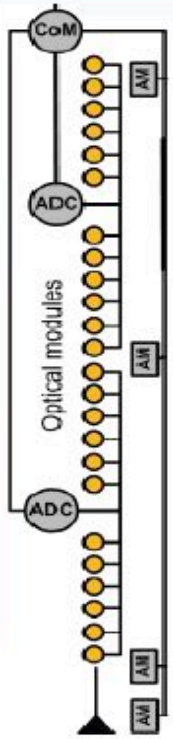
- 288 OMs at 8 Strings
  3 Sections per String
  12 OMs per Section
- DAQ-Center
- Cable to Shore
- Acoustic Positioning System
- Instrumentation String with detector calibration and environment monitoring equipment
- Two LED beacons for interstring calibration

Active depth 750 – 1275 m

Instrumented volume 6.0 Mt

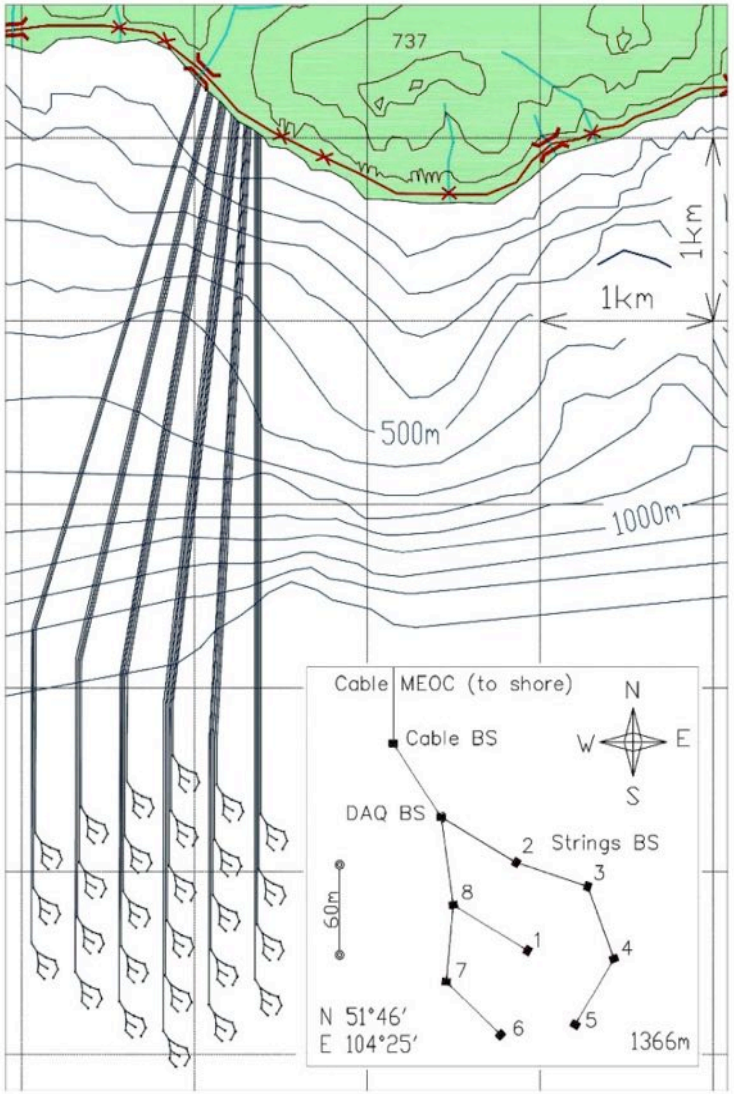


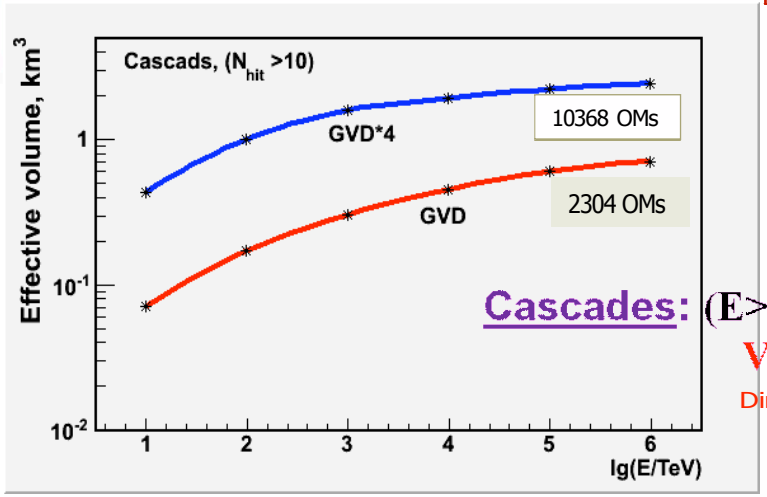


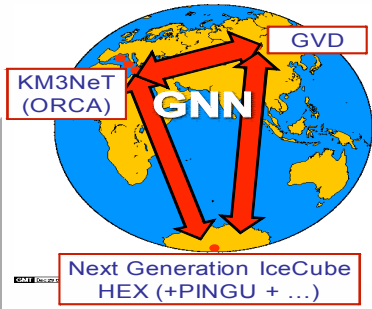


525 m

GVD with 12 clusters and more; Performance



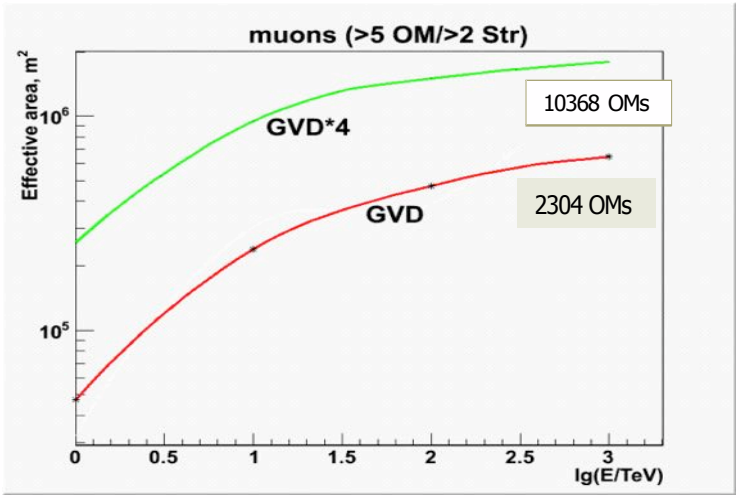




Cascades: (E>10 TeV):

V_{eff} ~0.4–2.4 km³

Direction resolution: 3.5° - 5.5°



Muons: (E>1 TeV):

S_{eff} ~ 0.3–1.8 km²

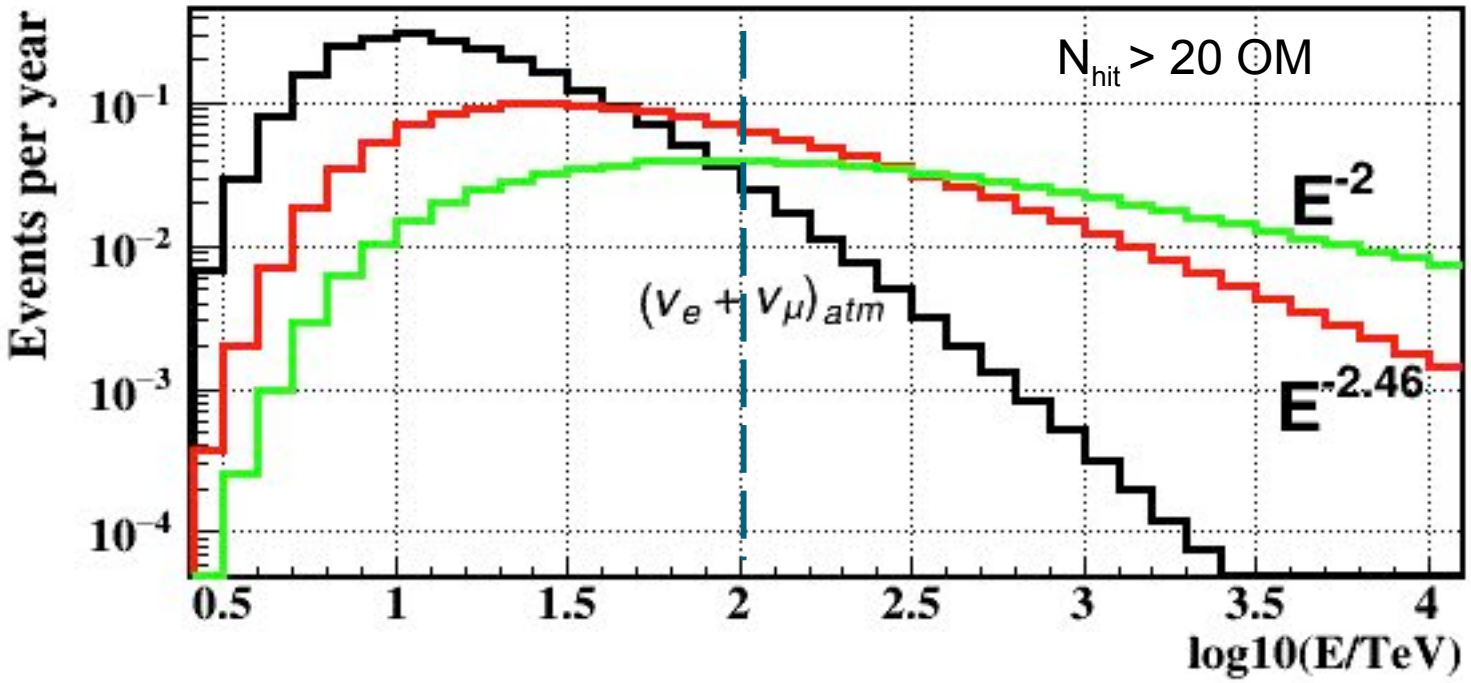
Direction resolution - 0.25°

Sensitivity of the cluster to neutrino induced showers

IC flux for one flavor

$1.2 \cdot 10^{-8}\ E^{-2}\ GeV^{-1}\ cm^{-2}\ s^{-1}\ sr^{-1}$

$4.1 \cdot 10^{-6}\ E^{-2.46}\ GeV^{-1}\ cm^{-2}\ s^{-1}\ sr^{-1}$



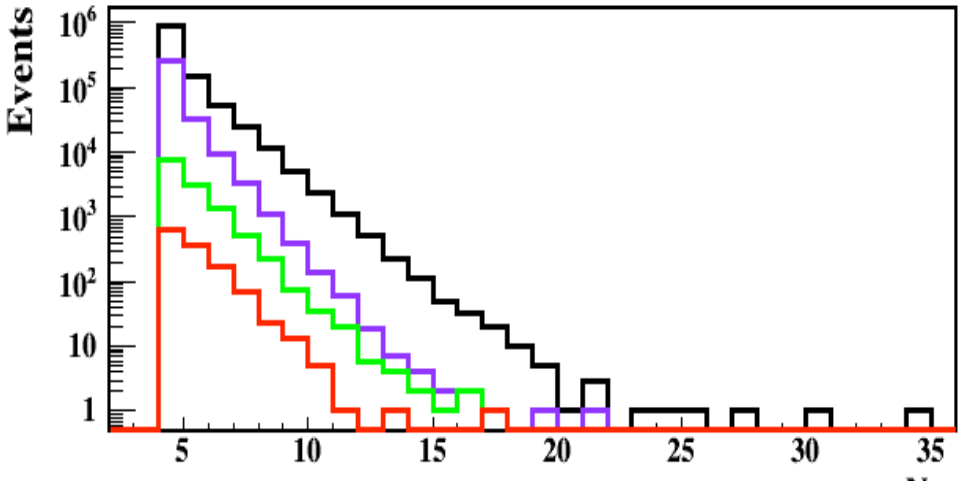
Expected number of events with selection (E_{sh} >100 TeV, N_{hit} >20):

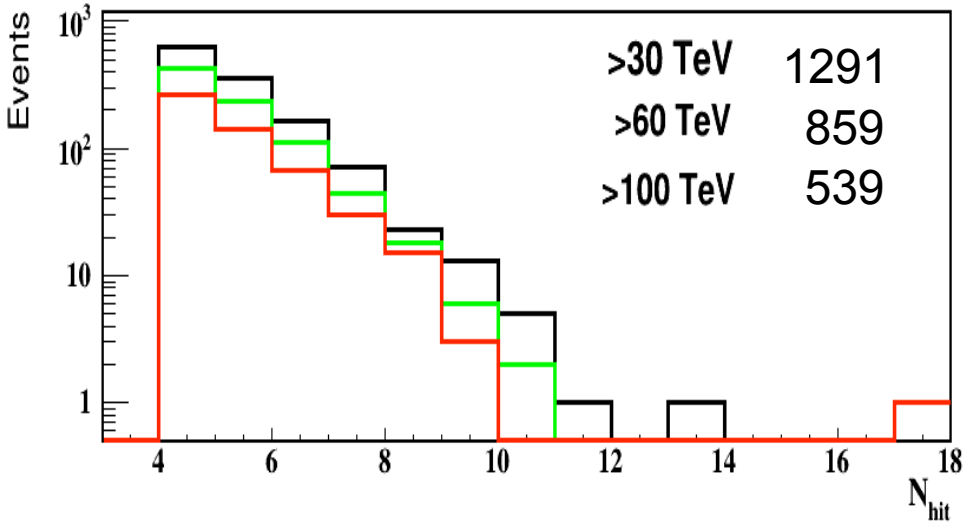
0.4 – 0.8 for 1 yr exposition; (1:1:1, without systematics)

0.05 evt - atm. ν;

0.05 evt — atm. μ

Hit OM multiplicity vs cuts reconstruction of showers





Reconstruction of shower coordinates (χ^2) 1 171 077

After quality cuts 316229

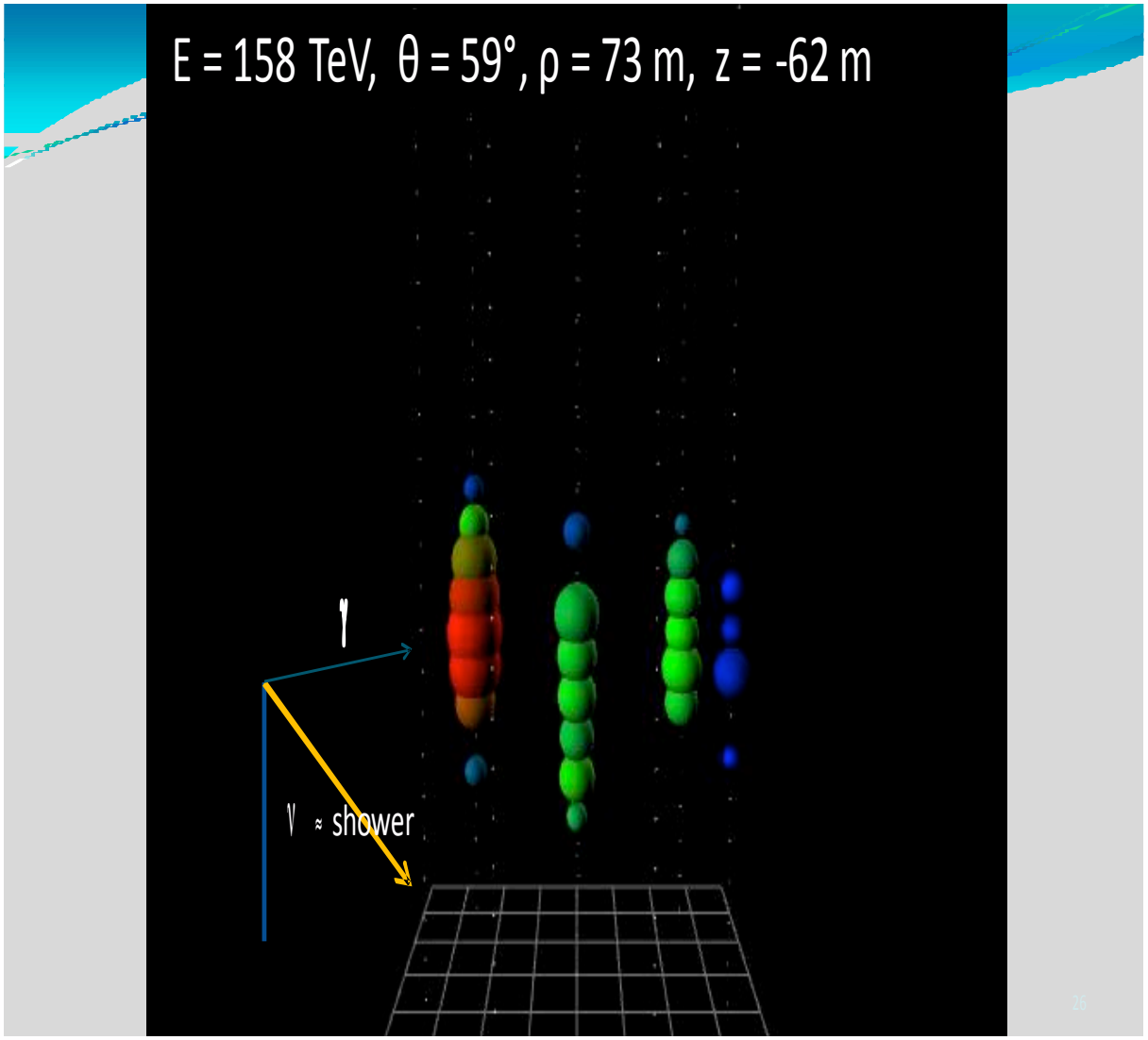
Reconstruction of shower energy and direction (LLH) 12931

Esh > 30 TeV 1291

No events were found with Esh>100 TeV and Nhit>20 Oms

So far there is no candidates on astrophysical neutrinos yet

«Dubna» big shower (Nhit=18)



Selection of nearly vertically upward going muons and Nearly vertical event

- Section with >3 hit OMs
- Mean signal pass velocity between fixed OM and other hit OMs

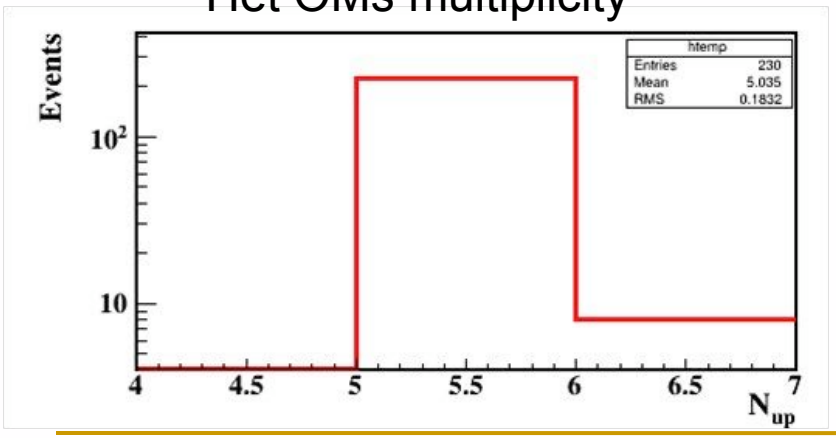
  $0.2 < v_i < 0.4$ m/ns

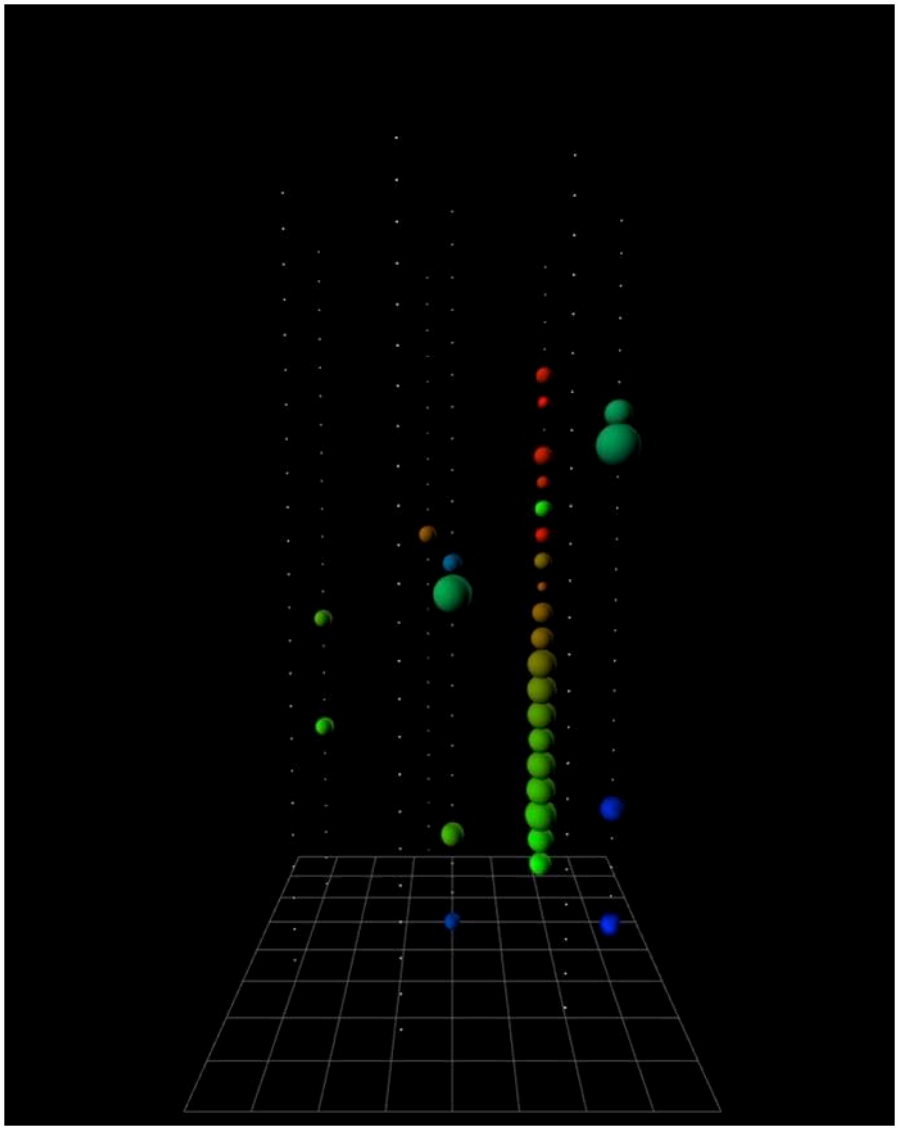
  $$v_i = \frac{1}{n-1}\sum\frac{z_{ij}}{t_{ij}}$$
- Mean signal pass velocity along section

  $0.26 < v_{sec} < 0.34$ m/ns

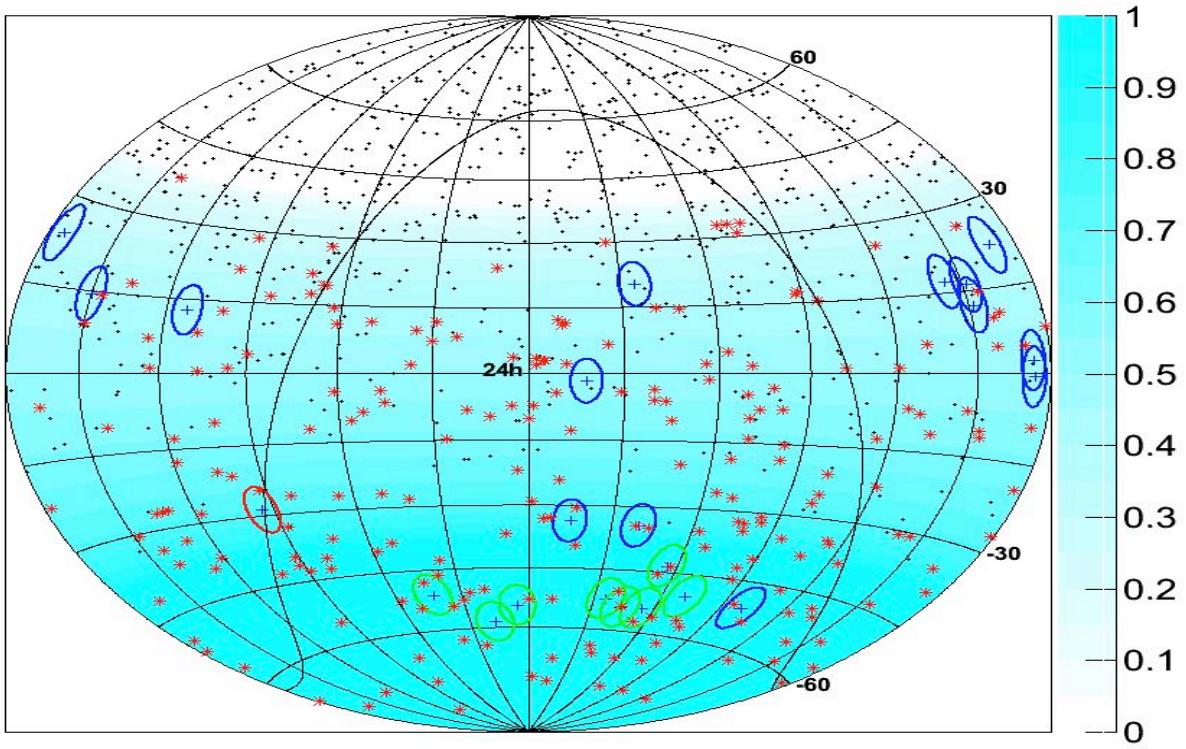
  $$v_{sec} = \frac{1}{n}\sum v_i$$

Het OMs multiplicity



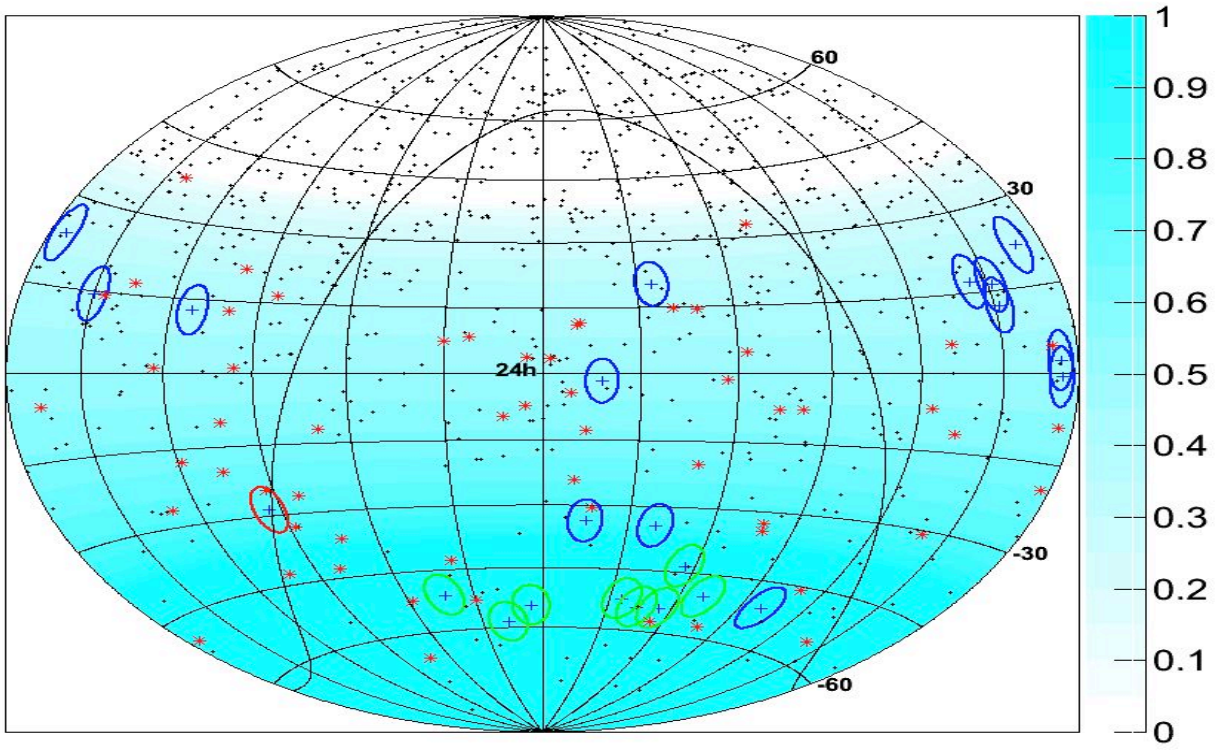


Reconstructed events with Esh>1 TeV: red marked events are with Zenith > 90º



The GC, 14 classical dSphs, 8 DES dwarfs

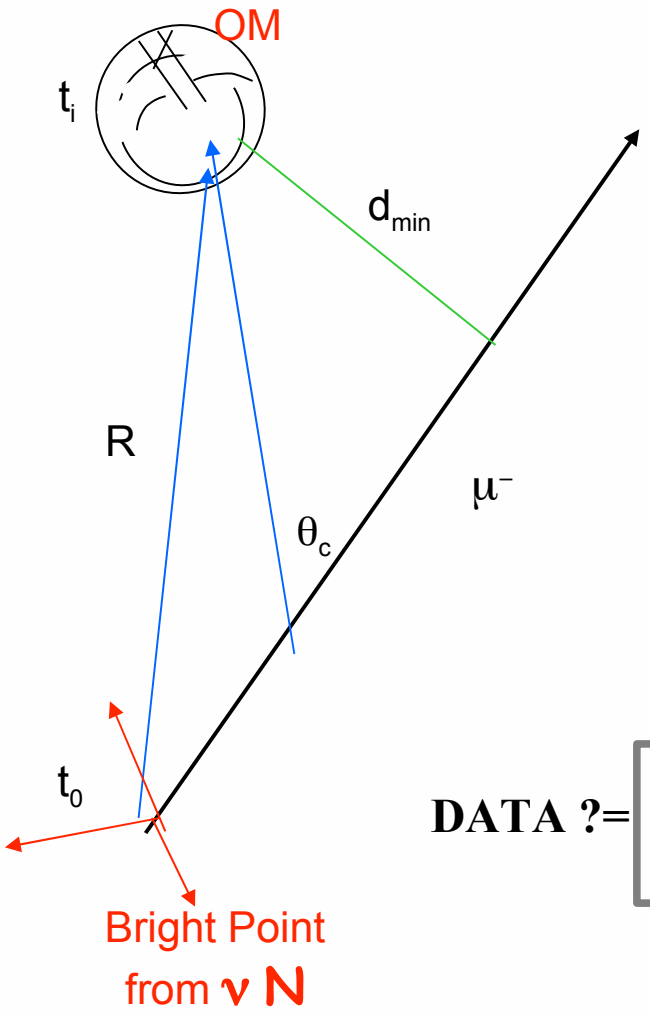
Reconstructed events with Esh>1 TeV: red marked events are with Zenith > 90º and Esh>100TeV



The GC, 14 classical dSphs, 8 DES dwarfs

Sensitivity to neutrino induced muons

Expected rate of muons



Model dependent function

E_{max}

$$N_\mu = \int A^\nu_{eff}(E_\nu, \theta_\nu, \phi_\nu) \frac{d\Phi_\nu}{dE_\nu d\Omega_\nu} dE_\nu \, d\Omega_\nu$$

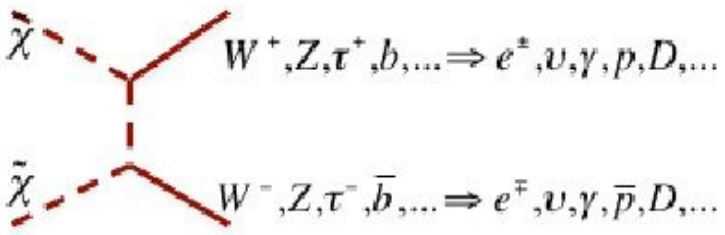
E_{th}

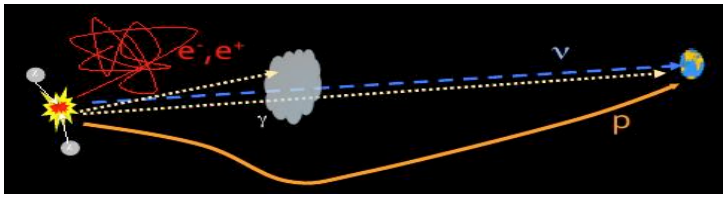
Detector function

DATA ?= SIGNAL ν + ATM ν + ATM μ + KHz_noise

MC estimate

GVD sensitivity to DM annihilations in the GC





$$\frac{d\phi_\nu}{dE} = \frac{\langle \sigma_A v \rangle}{2} J_2(\Psi) \frac{R_0 \rho^2_{local}}{4\pi m^2_{DM}} \frac{dN_\nu}{dE}$$

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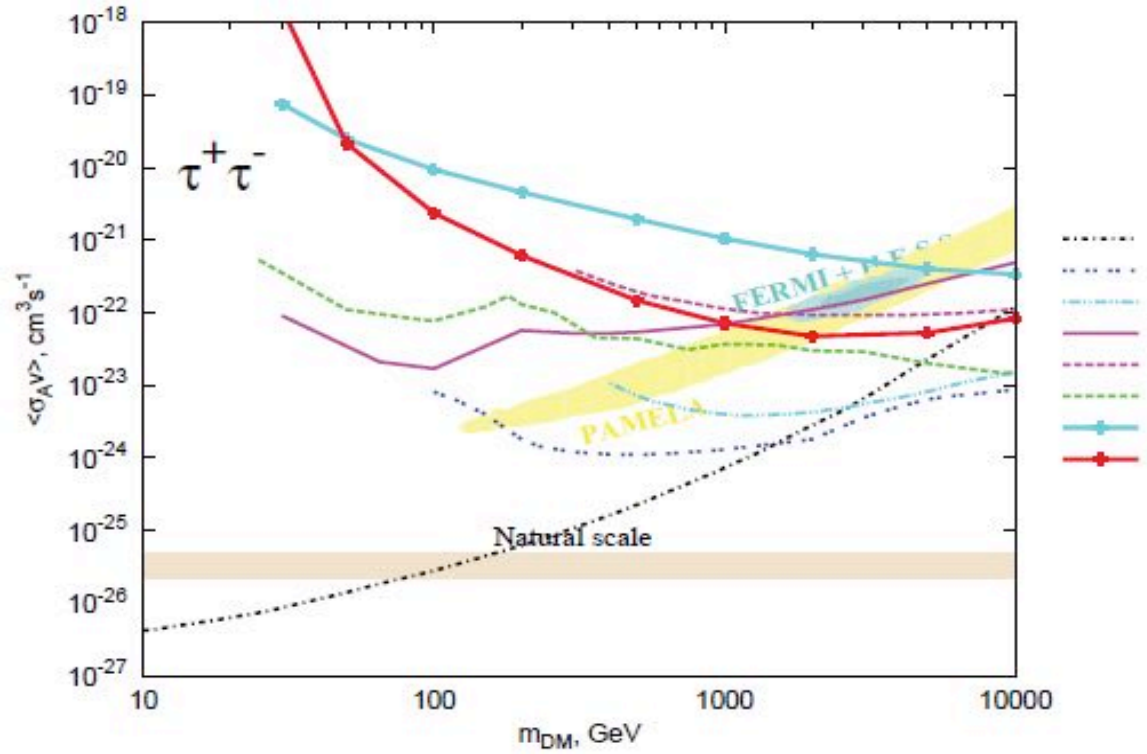
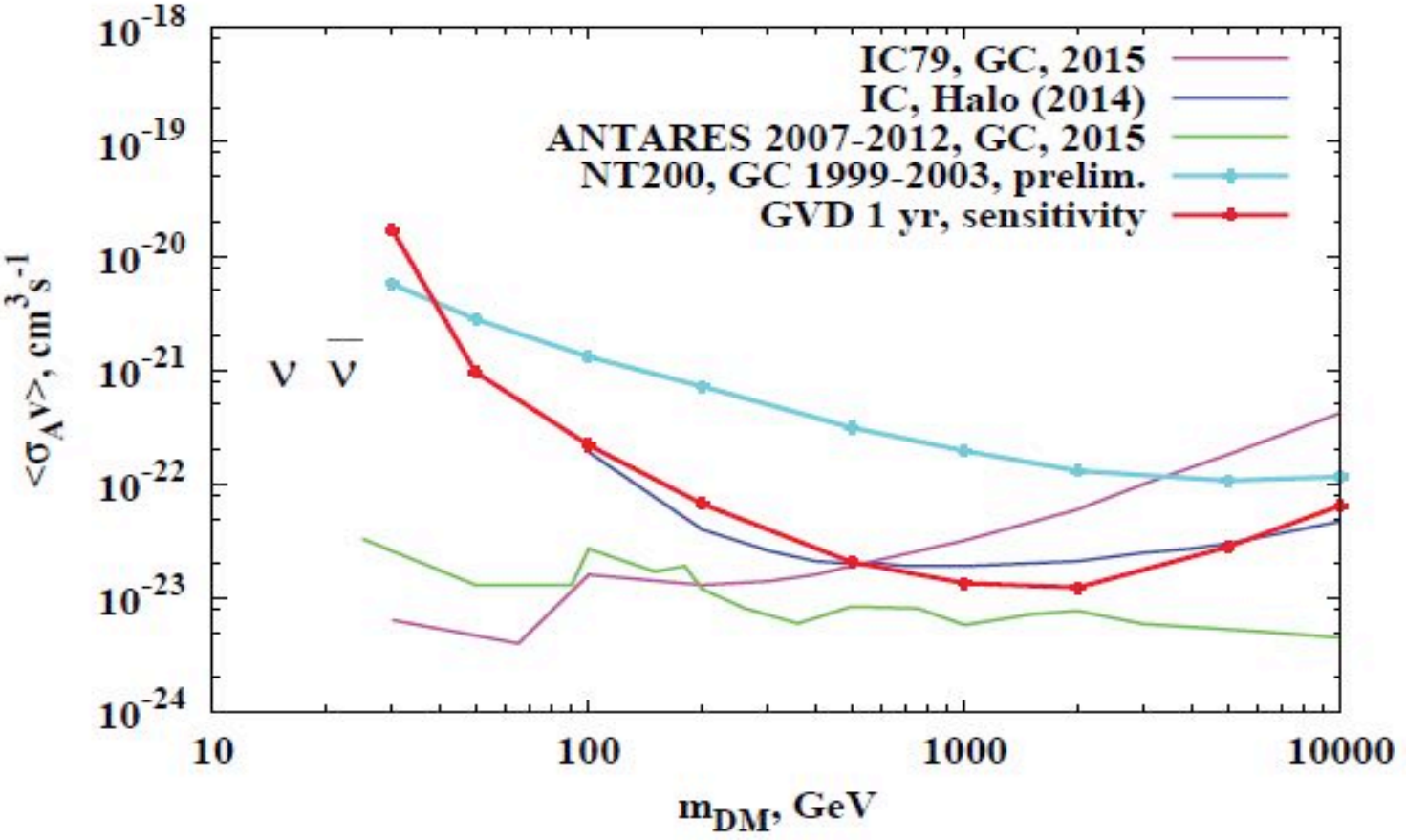


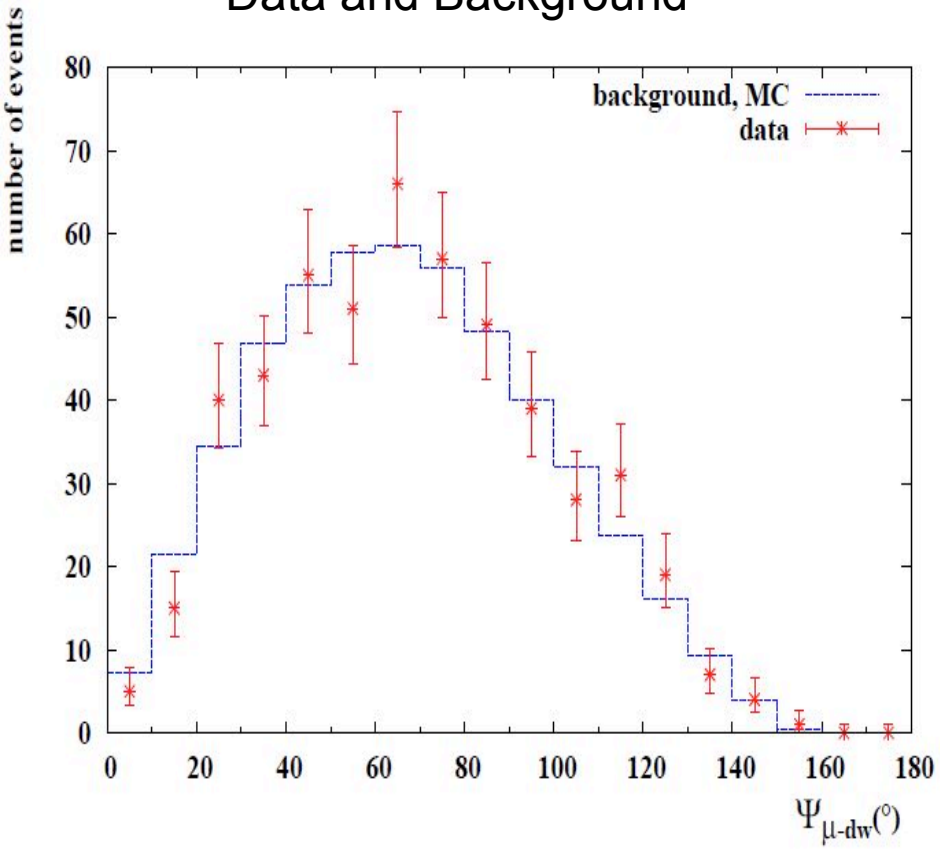
Stringent bounds with Nts on the galactic DM

Comparison for annihilation $\chi\bar{\chi} \to \nu\bar{\nu}$

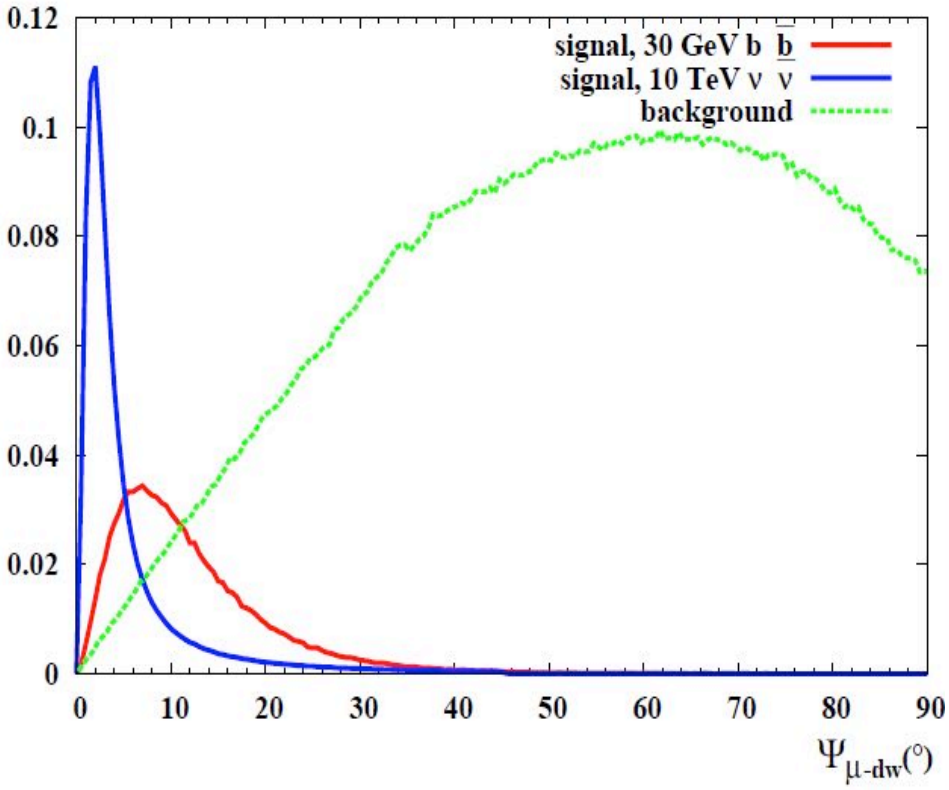


Reticulum2: angular functions

Data and Background

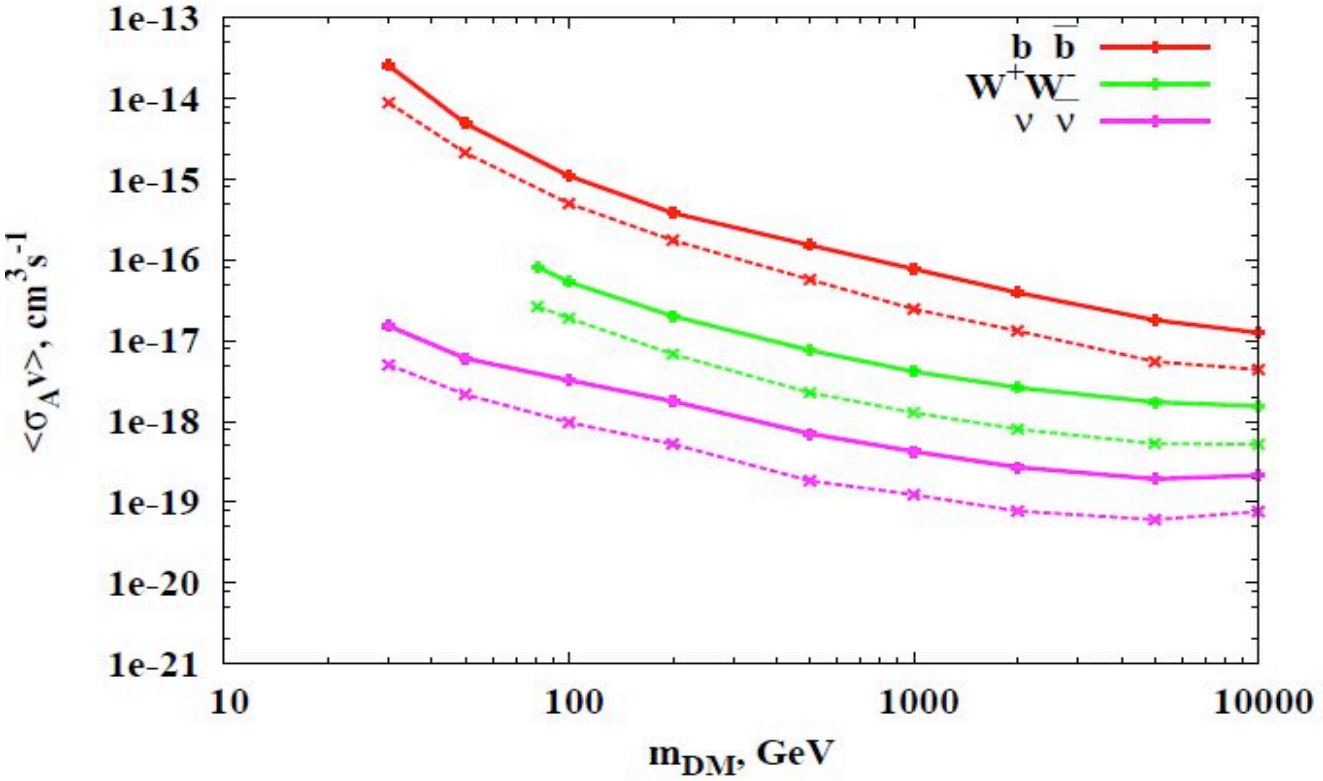


Signal and Background



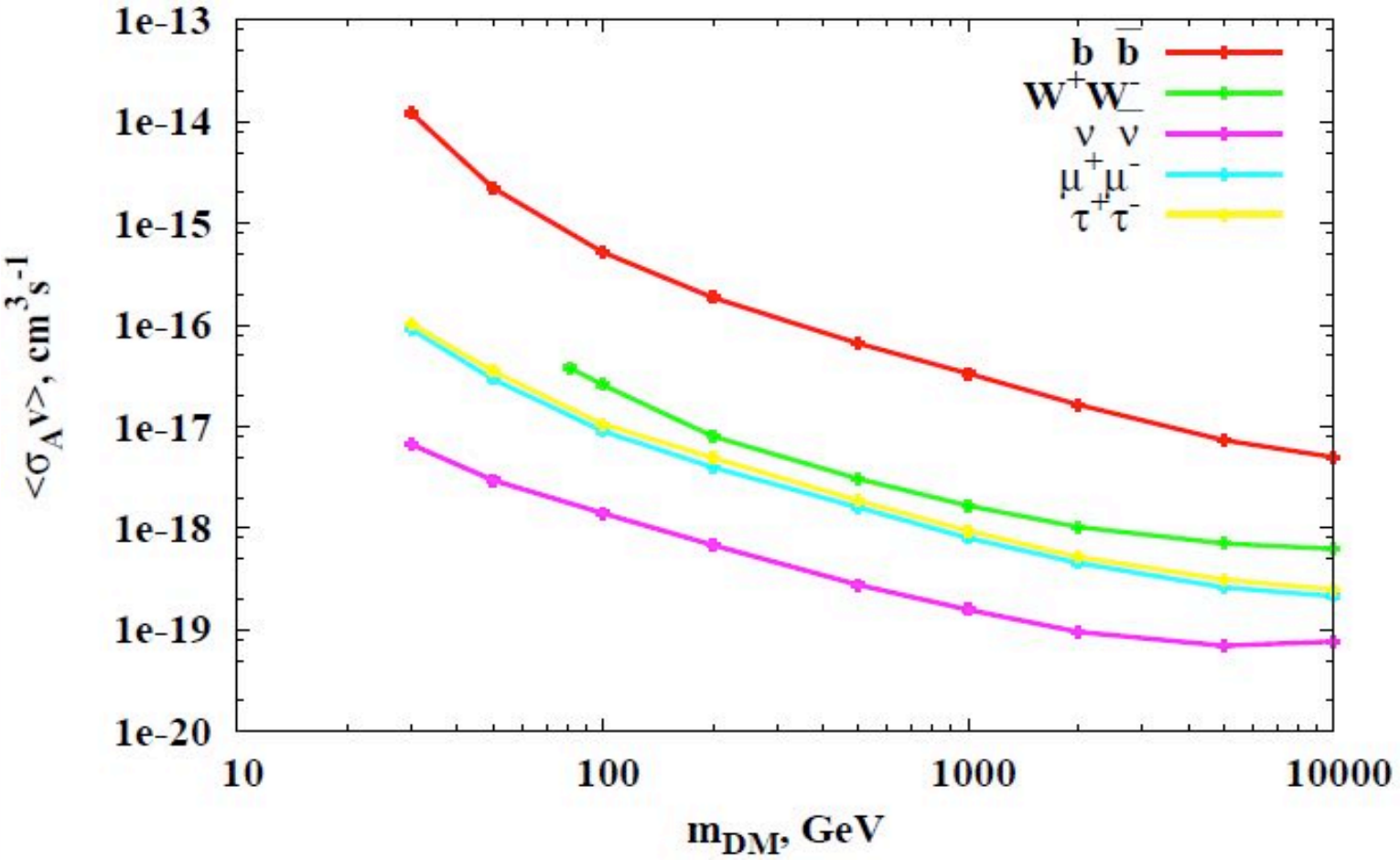
Ret2 and Seg1 dSphs

Upper limits for $\langle \sigma_A v \rangle$: for Segue 1 (solid) and Reticulum 2 (dashed)



systematic uncertainties: experiment (about 30%) and theory (up to 15%) with astrophysical uncertainties

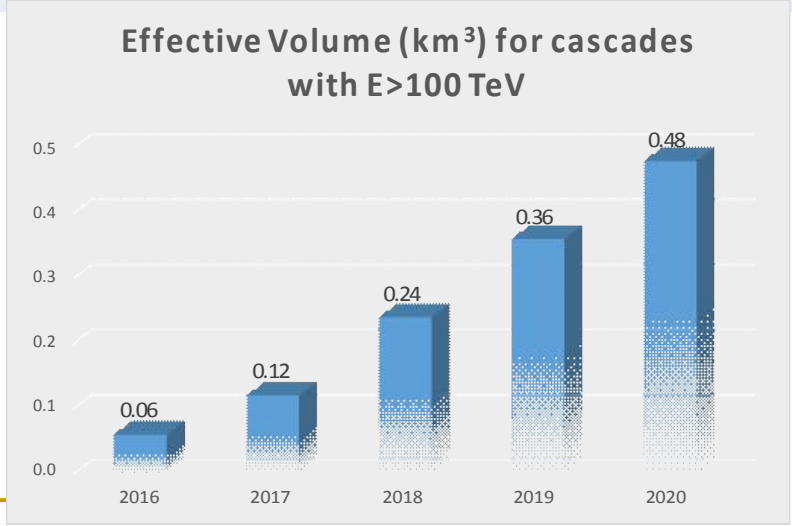
Combined analysis with 5 dSphs: Sculptor, Coma Berenices, Segue-1, Reticulum2 and Tucana2



The GVD-1 timeline

Cumulative number of clusters vs year

Year	2015	2016	2017	2018	2019	2020
Cluster 192 OM	*1* *192*	*1* *192*	*3* *576*	*5* *960*	*7* *1344*	*10* *1920*
Cluster- 288 OM	*2/3* *192*	*1* *288*	*2* *576*	*4* *1152*	*6* *1728*	*8* *2304*



SUMMARY

The first cluster «Dubna» of the GVD in Lake Baikal demonstrates its stability during working regime since April 2015. Appeared malfunctions or failures have been mostly resolved in 2016 expedition.

In April 2016 the «Dubna» has been upgraded to baseline configuration comprising 288 OMs and extending its instrumentation volume up to 6Mt.

Preliminary results are obtained in HE cascades reconstructions for 41.64 life days of the cluster "Dubna".

Improvements in UpL are expected in targeting of DM in the GC with the GVD-1 compare to the NT200 and searches of the dSphs.

By 2020, the GVD phase-1 (10-12 clusters) is planned to be completed.

Baikal GVD works in 2016 to be cont next

Thank you!

Backup slides