
Status/schedule GVD construction, results from 2015/16 cluster

MANTS Meeting, Mainz, 1-2 October 2016

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for the Baikal Collaboration

Outline:

1. The first demonstration GVD Cluster “Dubna”:
operation and selected results
2. Upgrade of DUBNA array in 2016
3. Infrastructure
4. Schedule GVD construction

The site

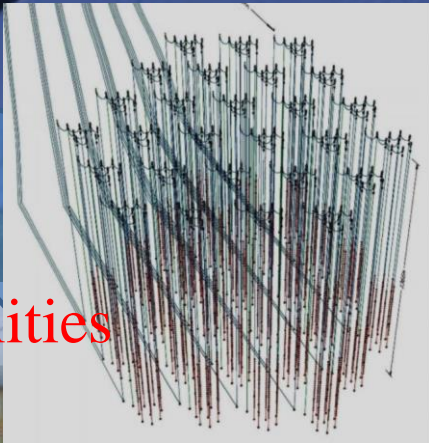
Shore station



Location: 104°25' E; 51°46' N

36 km

Baika'lsk

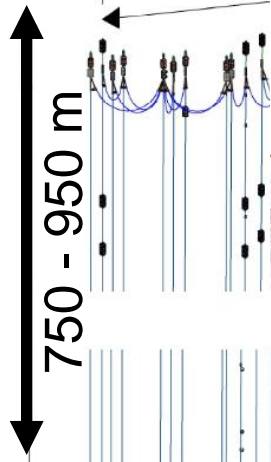


Workshop, Storage facilities



Stage 2 mounting new string **Timeline: 5-40 days**

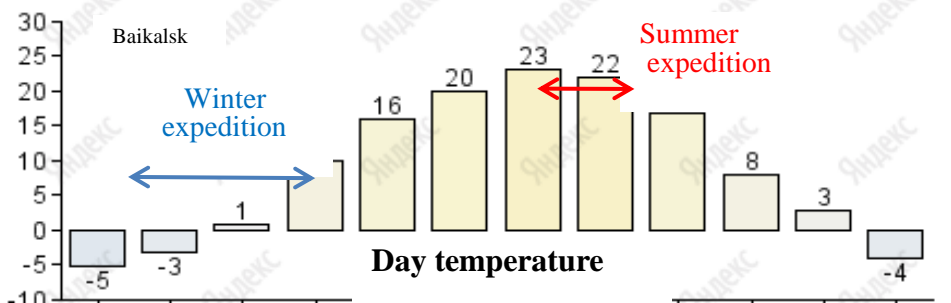
5 days for a group (4-5 men) to fully assemble and install new string from a finished parts



Cluster GVD

NT-200

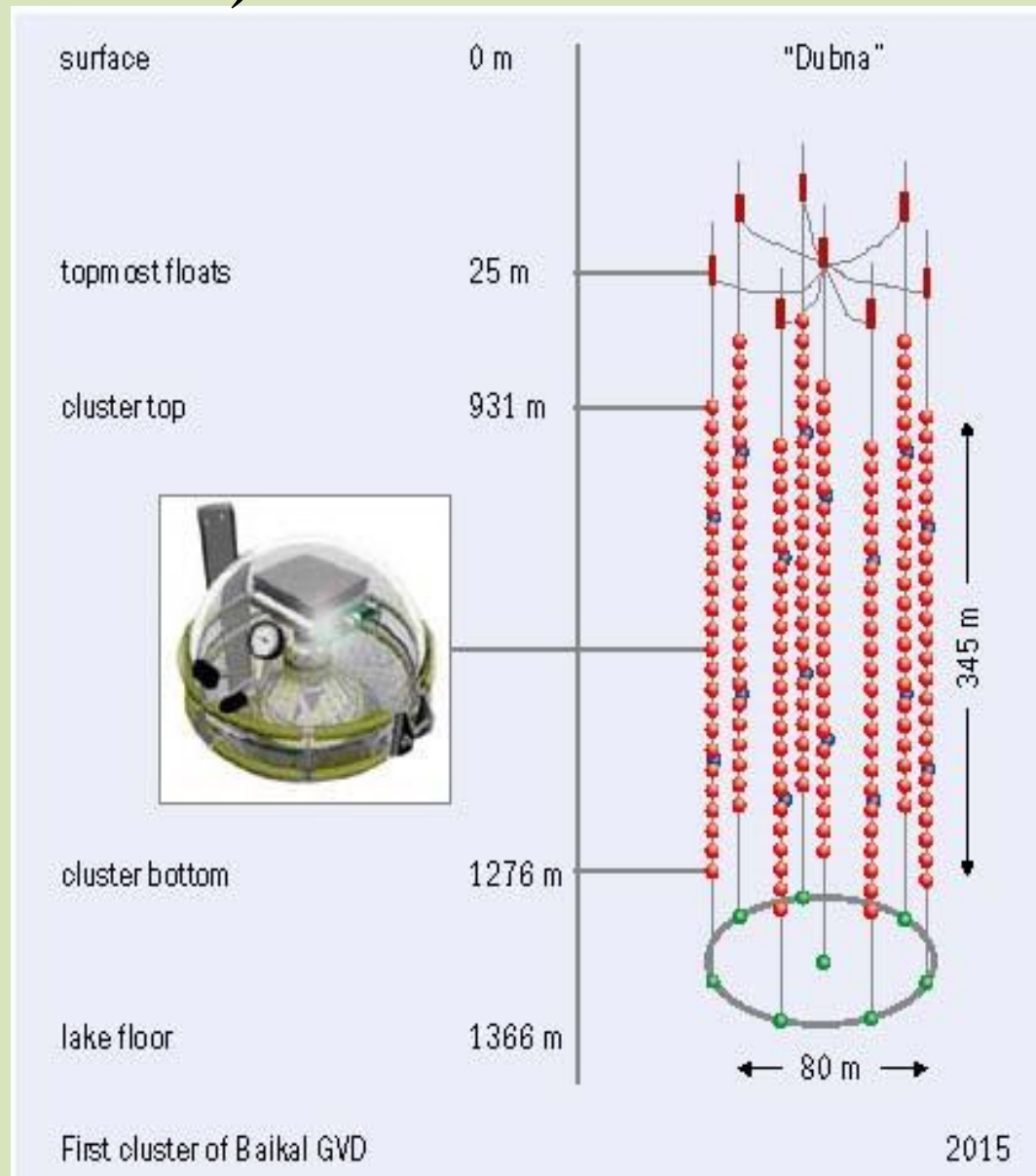
Ice thickness ~ 60-90 cm (up to 120 cm)



First Demonstration Cluster “DUBNA” (April 2015)

- 192 OMs at 8 Strings 2×12 OMs per String.
- Acoustic Positioning System
- Instrumentation String for environment monitoring
- LED beacon for inter-string time calibration

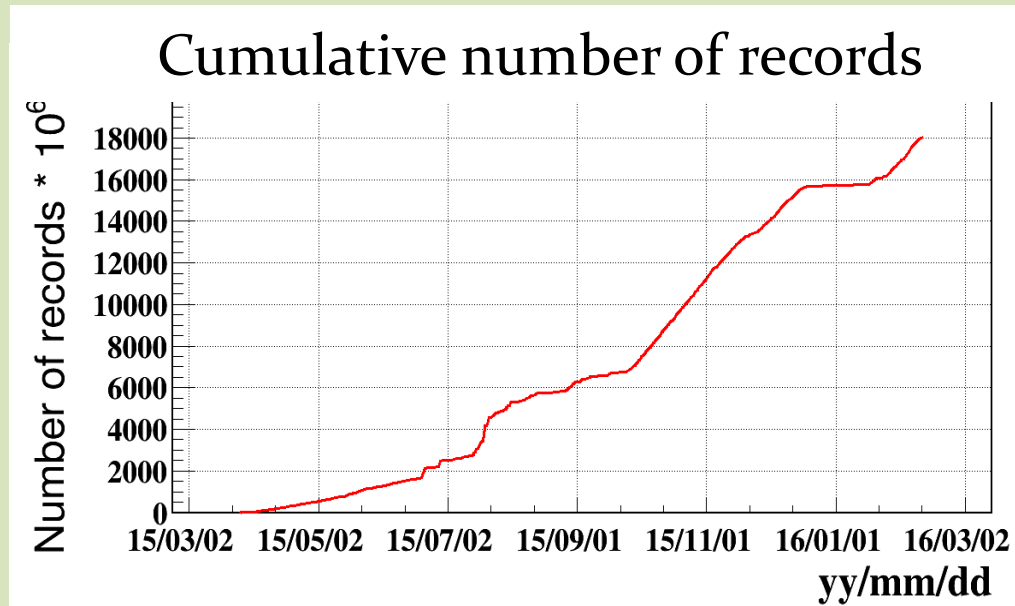
Active depth 950 – 1300 m
Instrumented volume 1.7 Mt



Selected results with Cluster “DUBNA”

Operation from April 2015
up to February 2016

- Operation: 213 days
- Efficiency: 72 %
- Runs: 622
- Event rate $\sim 10^2$ Hz
- Life time ~ 184 days
- Data: 1.6×10^9 events



Trigger: coincidence of two neighboring OMs
with thresholds 1.5pe & 4pe

1. Cascade detection
2. Muon detection
3. Analysis of malfunctions and equipment reliability

Cascade detection

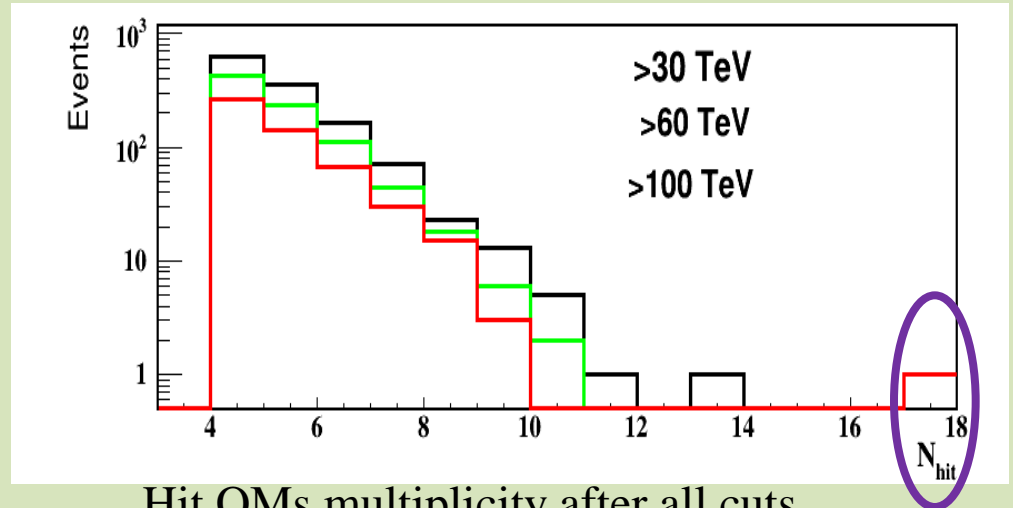
(“Cascades in GVD” Zhan DJILIKIBAEV on 2 Oct 2016 from 14:30 to 15:00)

2015 data analysis

- Total number – 437 970 024 events (thresholds: low/high = 1.5/4 p.e.)
- Life time: = 41.6 days

After all cuts

Cuts	Events
$E > 30 \text{ TeV}$	1291
$E > 60 \text{ TeV}$	859
$E > 100 \text{ TeV}$	539



Hit OM multiplicity after all cuts

Demonstration Cluster

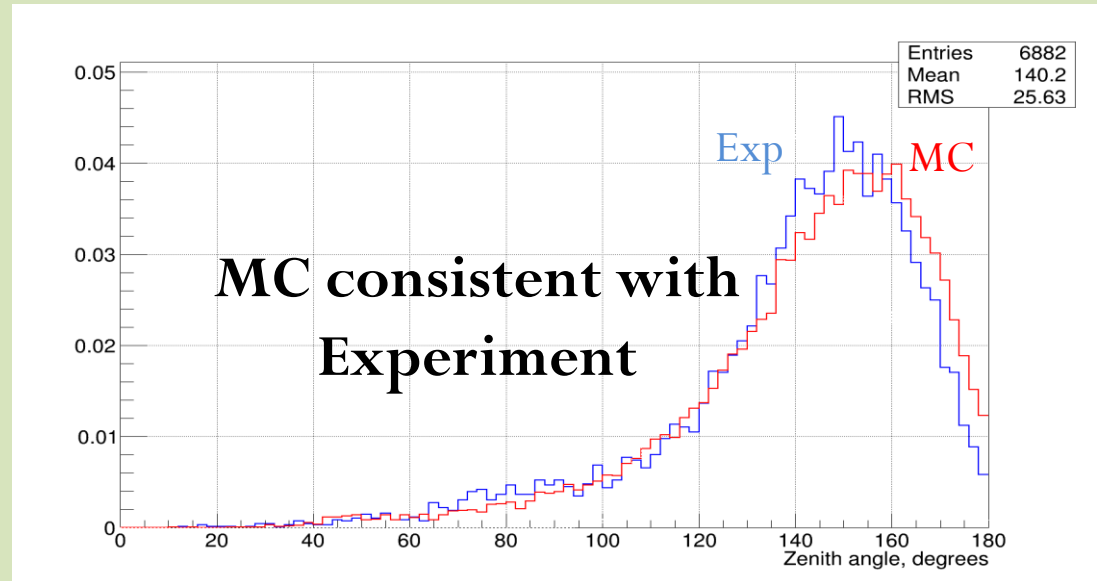
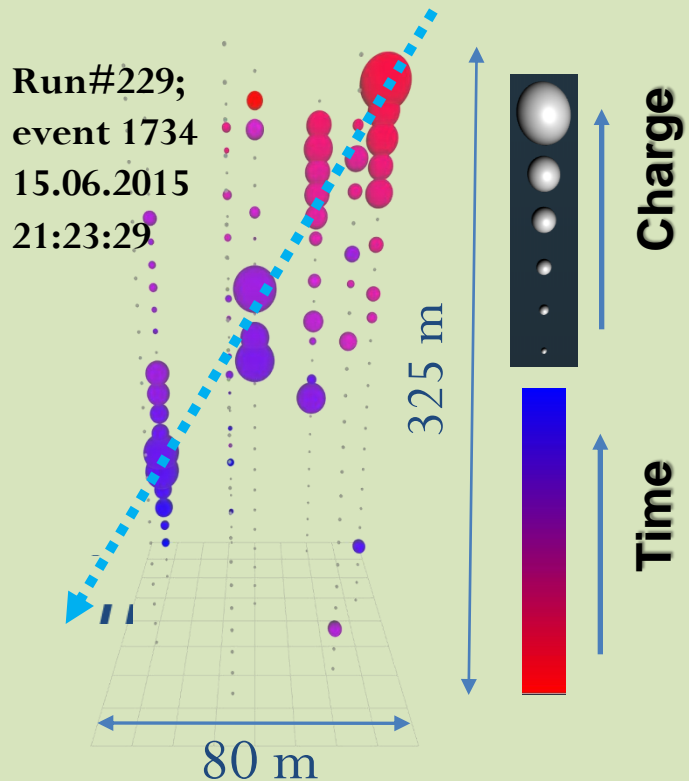
For 1 year observation 0.4-0.6 events are expected from IC flux with $E^{-2.46}$ spectrum
($E > 100 \text{ TeV}$, $N_{hit} > 20 \text{ OM}$)

One event with $N_{hit} = 17 \text{ OMs}$ and $E > 100 \text{ TeV}$

Muon detection

Status of analysis

1. Trigger optimization for maximum muon effective area.
 2. Data preparation (event building, calibration, OM coordinate evaluation)
 3. Noise rejection
 4. Muon track reconstruction
 5. MC for actual cluster configurations and background conditions.
 6. Rejection events from muon groups
 7. Reconstruction of zenith angle distribution of atm. muons
 8. Up-going muons selection
- } In progress now



Reconstructed zenith angle distribution
(groups of muons not fully suppressed)

Nearly vertically upward going muons

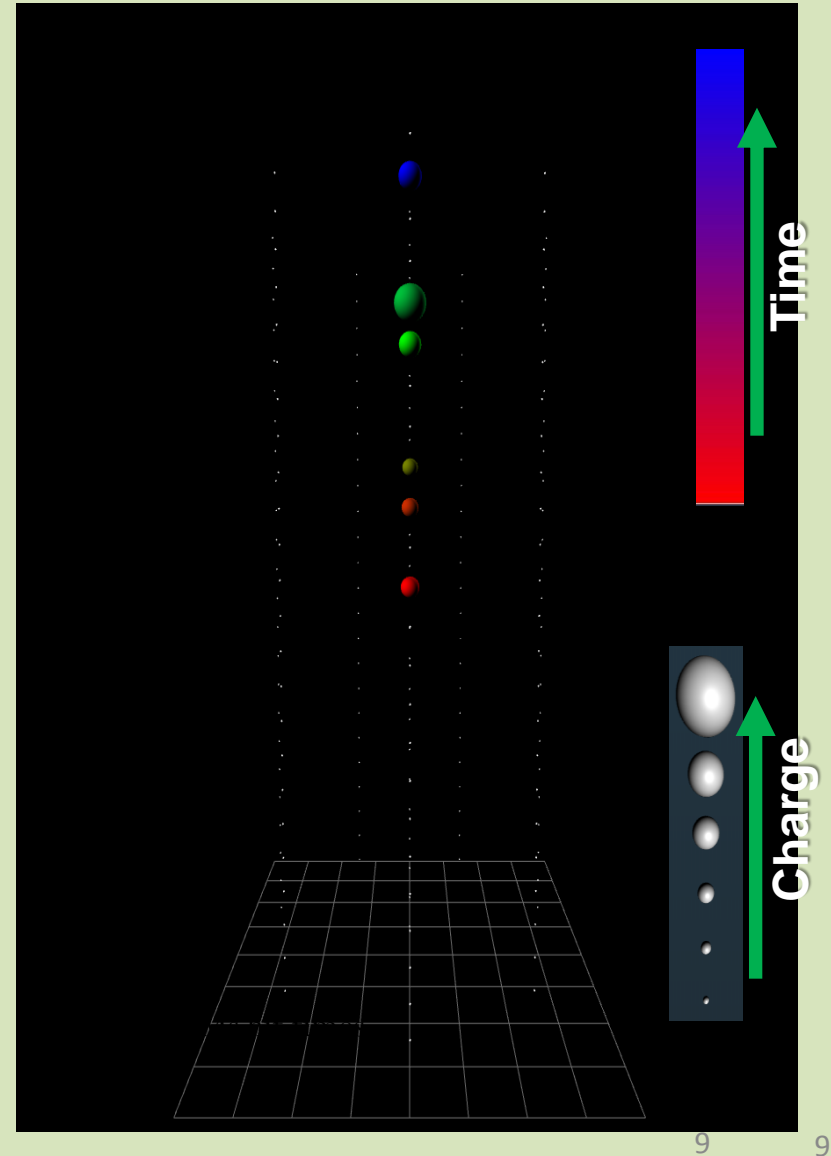
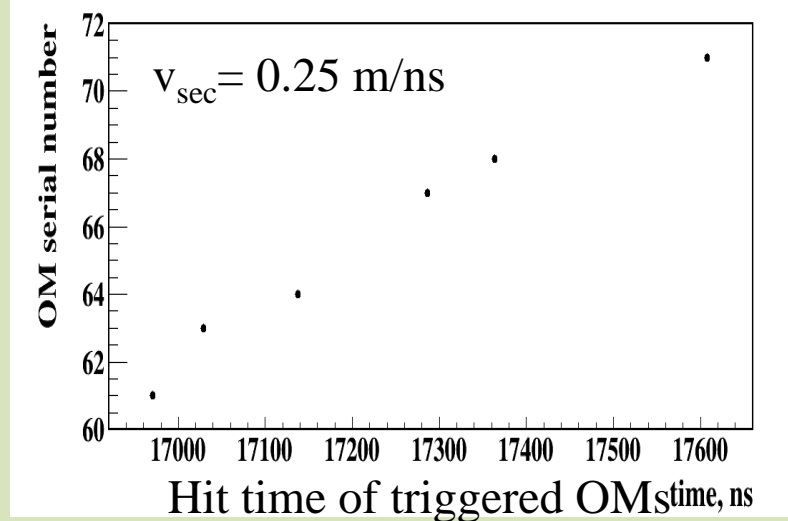
Selection of nearly vertically upward going muons

- Section with >4 hit OMs
- Mean signal pass velocity between fixed OM and other hit OMs

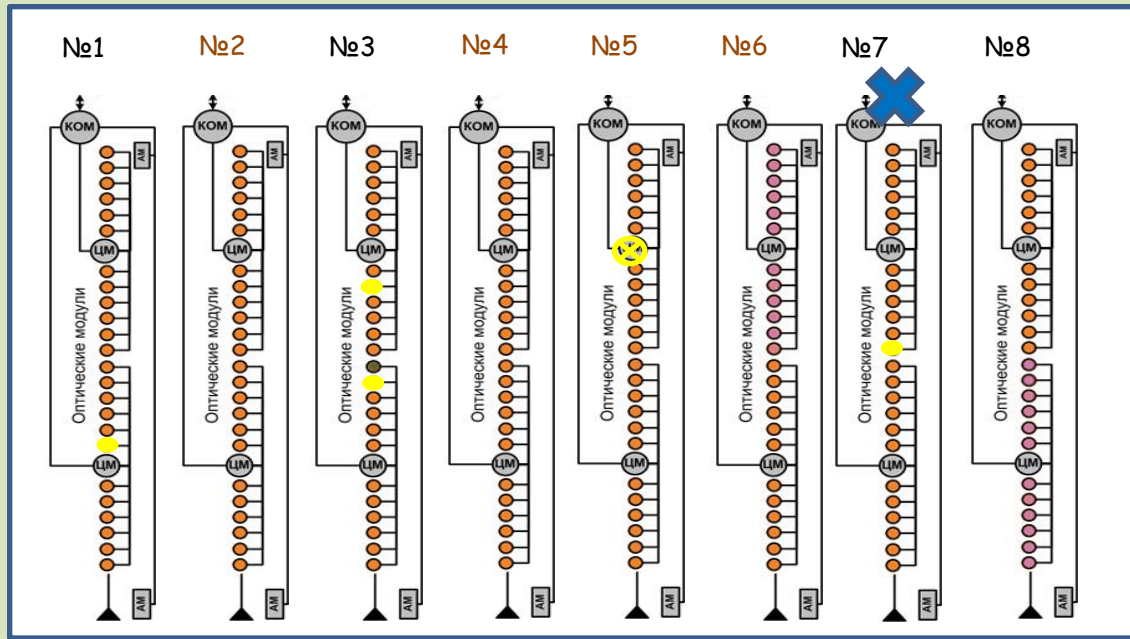
$$v_i = \frac{1}{n-1} \sum \frac{z_{ij}}{t_{ij}}; \quad 0.2 < v_i < 0.4 \text{ m/ns}$$

- Mean signal pass velocity along section

$$v_{sec} = \frac{1}{n} \sum v_i; \quad 0.22 < v_{sec} < 0.34 \text{ m/ns}$$



Cluster DUBNA: malfunctions and weak points

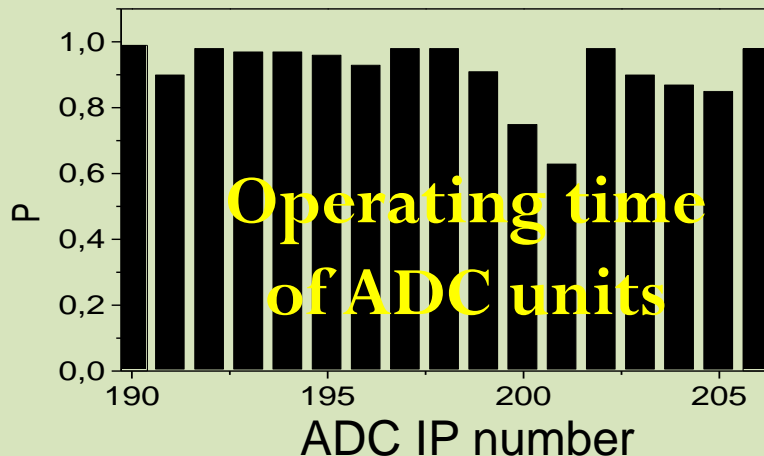


Malfunctions

- 4 channels
- 1 acoustic modem at Str.1
- 1 ADC unit

Connection losses with ADC units

2015: April-October



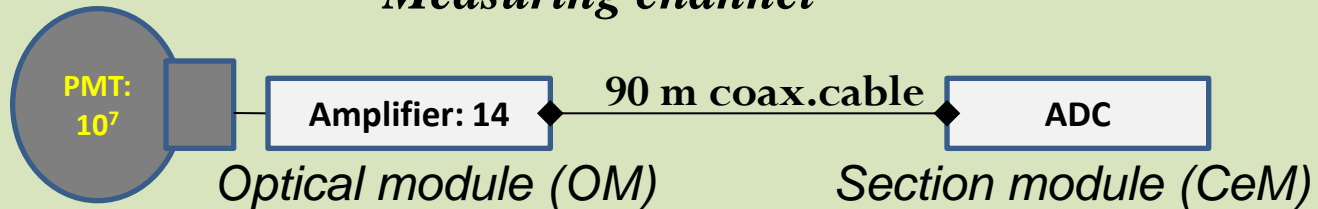
The use of ADC of different types

4 versions of ADC units (17 units in total)

- ✘ 4ch ADC (Spartan 3) 3 **Trigger rate <10 HZ**
- 4ch ADC (Spartan 6) 8
- 12ch ADC (Spartan 6) V₁ 5 **Mechanical ventilation**
- 12ch ADC (Spartan 6) V₂ 1

Analysis of channel malfunctions

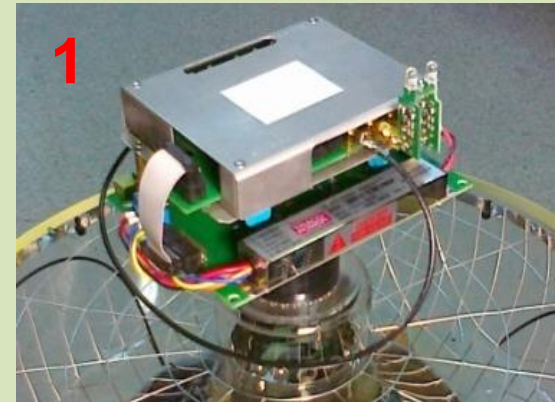
Measuring channel



4 channels out of operation (2012 – 2015)

Test of faulty modules at the lab

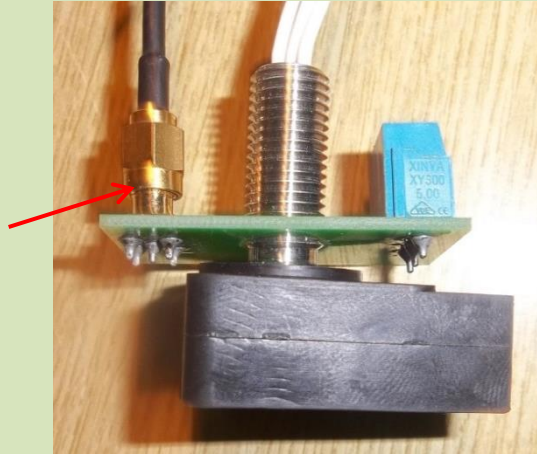
1. Breakdown of OM controller : **1**
2. Leaking of OM connector: **1**
3. Lack of communication with ADC unit: **2**
(malfunctions of the CeM)



Malfunctions of the CeM

1. Two channels out of operation.

Bad contact of SMA connector in the CeM



2. The loss of connection with ADC board

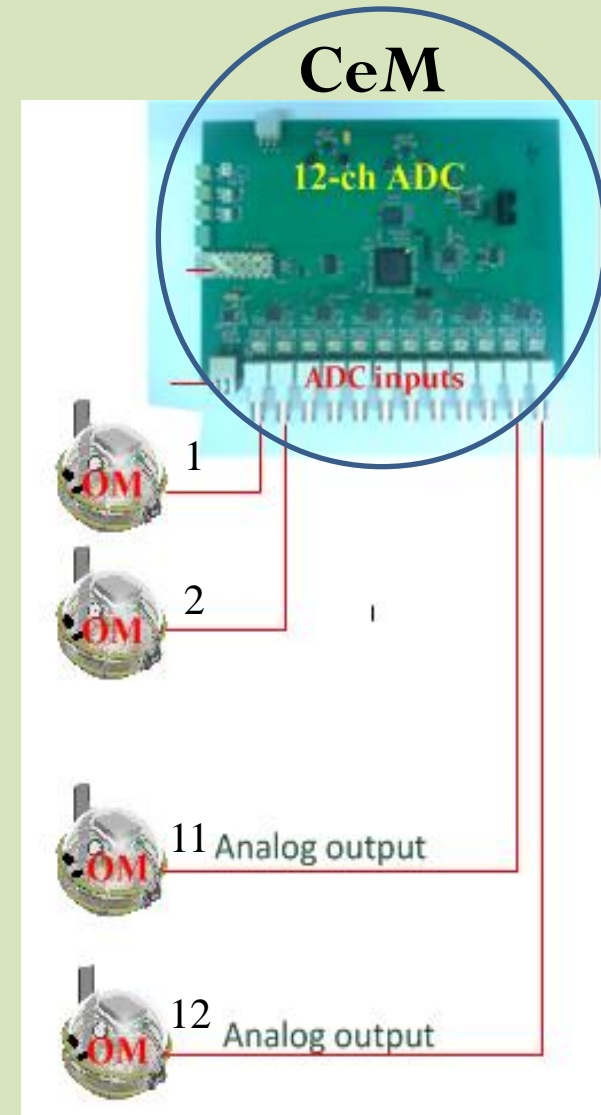
Mistake of ADC firmware.

3. Failure of ADC boards

ADC #205, 12-ch (October 2015)

Power breakdown while loading basic ADC firmware

ADC unit was recovered by reprogramming.



GVD Section: 12 channels

OM reliability estimation

Year	2012	2013	2014	2015	Summ
Number of installed OMs	24	48	40	80	192
Time of operation, year	4	3	2	1	-
Total operating time of OMs (OM number × year)	96	144	80	80	400
Number of failure channels	1	1	2	0	4
Number of failure OMs	1	0	1	0	2

Failures of channels: ~1 failures / 100 year

Failures of OMs: ~1 failures / 200 year

Calculation OM reliability using FIDES gives: 1 failures / 142 year

Upgrade of DUBNA array in 2016

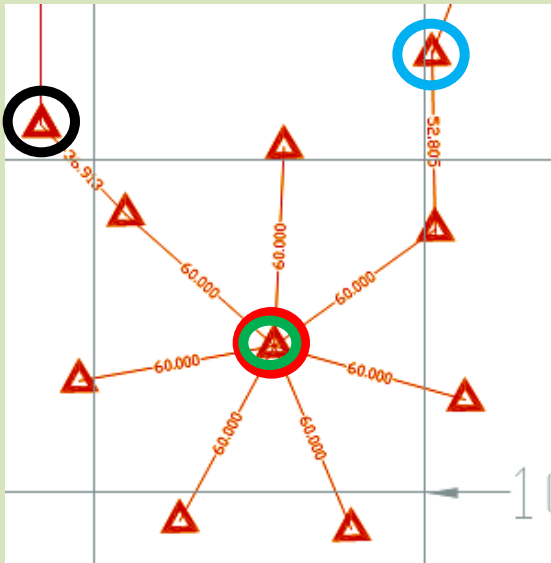
Main objectives:

- Repair faulty nodes;
- Unification ADC units;
- Installing 8 additional *Sections* on the cluster

Expedition 2016

1. 4 strings were partially disassembled, ADC units were upgraded. 7 strings - 12ch ADCs; 1 string - 4ch ADCs.
2. Peripheral strings were moved apart from 40 to 60 m.
3. 8 *sections* were installed at the top of the cluster (96 OMs). Number of OMs on a string is increased from 24 to 36.
4. 3 new calibration LED sources were added.
5. Electro-optical cable has been deployed for the connection of the second cluster to shore
6. A system for time synchronization between clusters has been installed for testing.

Upgraded cluster “DUBNA”

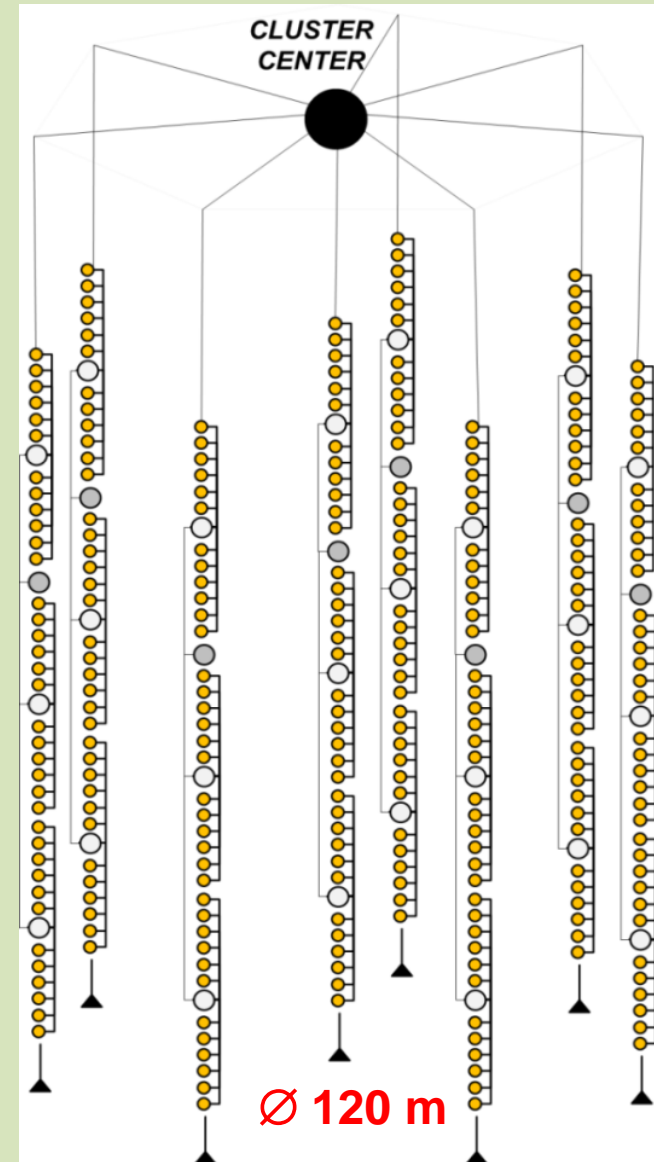


- - DAQ center
- - Instrumentation string
- - Cable Buoy Station

- 288 OMs at 8 Strings 3×12 OMs per String.
- Acoustic Positioning System on each string.
- 4 LED beacons for inter-string calibration.
- Instrumentation String for environment monitoring.

Active depth 750 – 1275 m

Instrumented volume 6.0 Mt



The working configuration of the Cluster

22 working sections.

264 working channels.

2 sections out of operation
(Failures ADC #200 and #206)

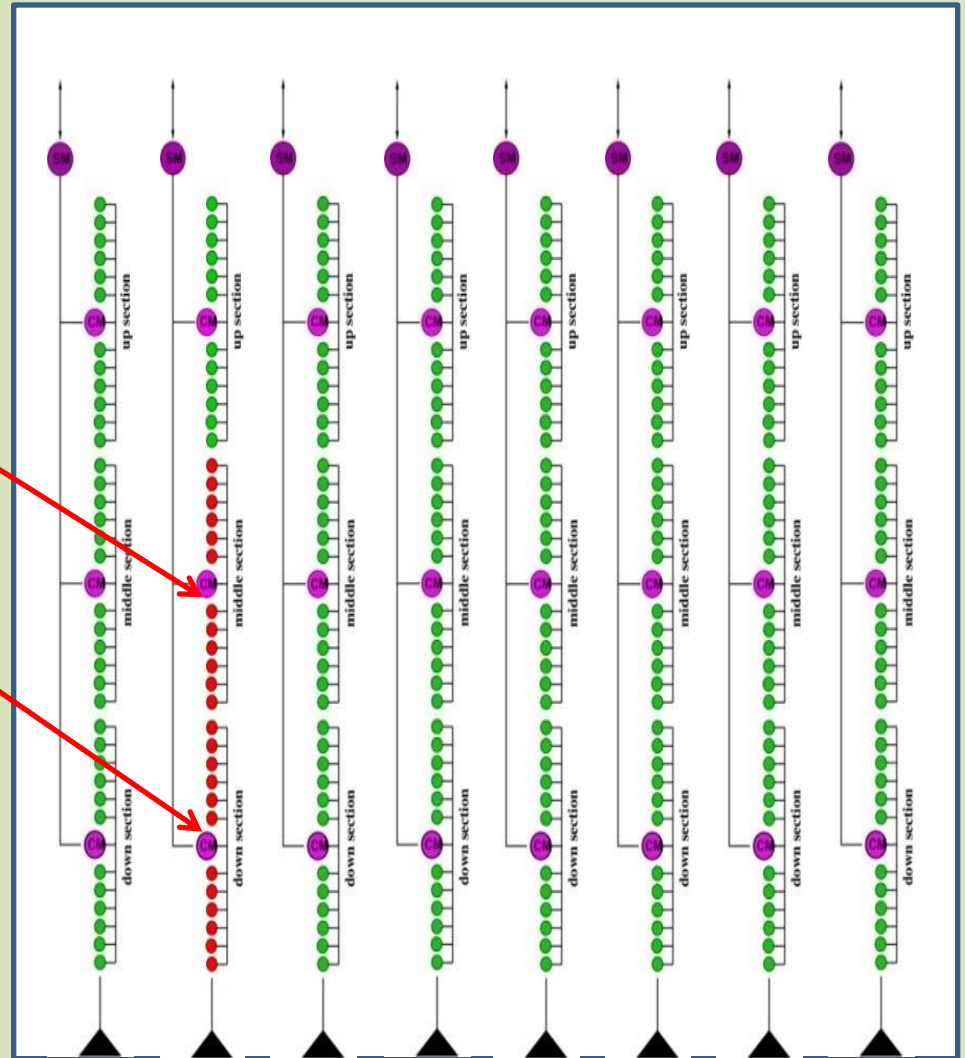
Problem was diagnosed at March 30

Exact cause is unknown

Possible cause: power breakdown
during detector operation

*27 March: Mechanical damage to the
electro-optical cable close to the shore.*

29 March: The cable was restored.

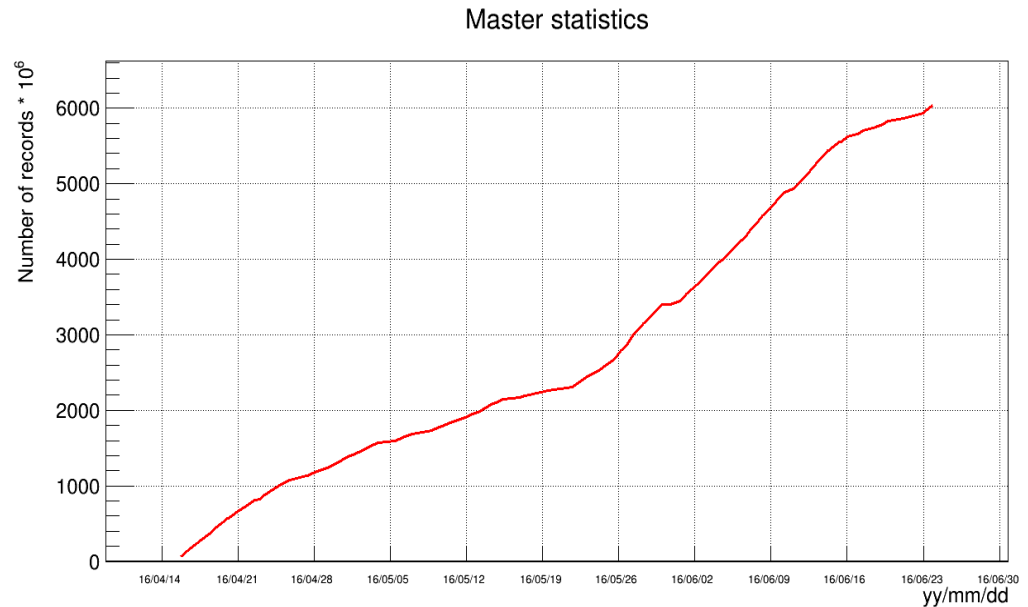


Cluster operation - 2016

Cumulative number of ADC records

Statistic for ~2 month operation:
(10 April – 23 Jun)

- Operation: 55 days
- Efficiency: 75 %
- Total: 177 Runs
- Trigger rate 60 - 110 Hz
- Data : $3.02 \cdot 10^8$ events



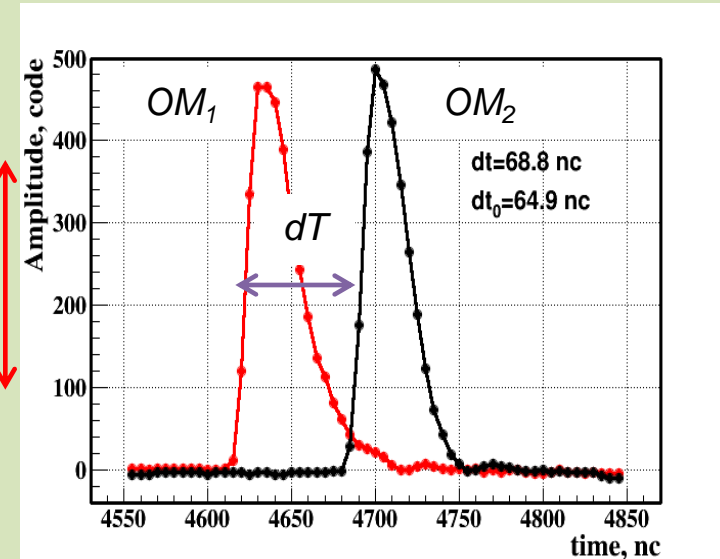
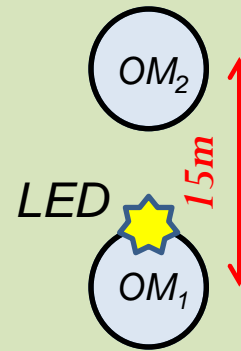
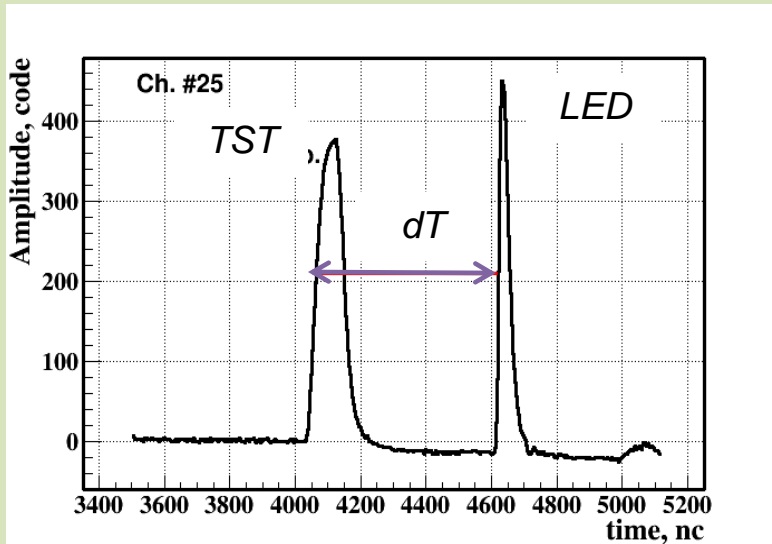
Trigger: coincidence of two neighboring OMs
with thresholds 1.5pe & 4pe

Time calibration of the channels and strings was performed.
Data analysis in progress now.

Check the time calibration: two methods

Signal delay of each channel

Time difference of two channels



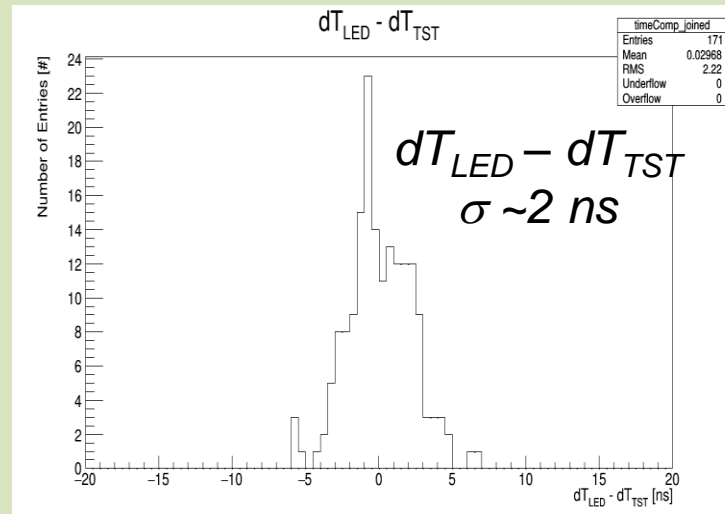
$$dT_{TST} = T_{OM1} - T_{OM2}$$

T_{OM} - OM delay

$$T_{OM} = dT - T_0 + T_{CABLE}$$

$T_0 \approx 500 \text{ ns}$ - time shift
of the test pulse

T_{CABLE} - lab. measured
cable delay



$$dT_{LED} = dT - dT_{exp}$$

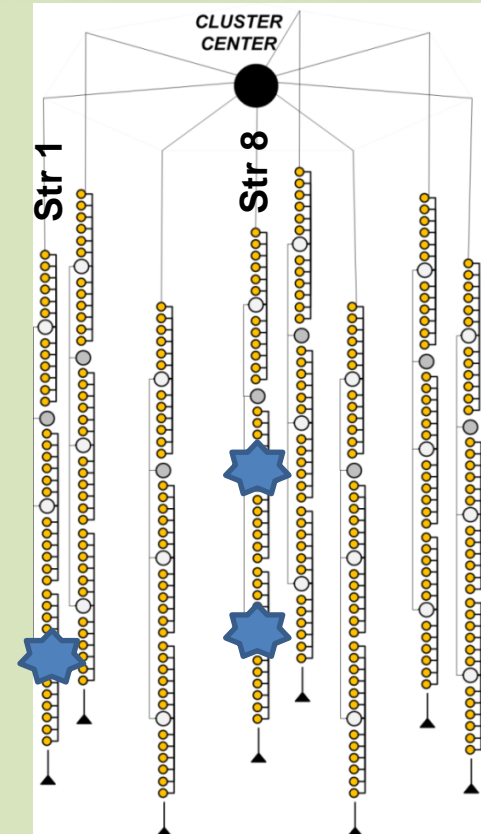
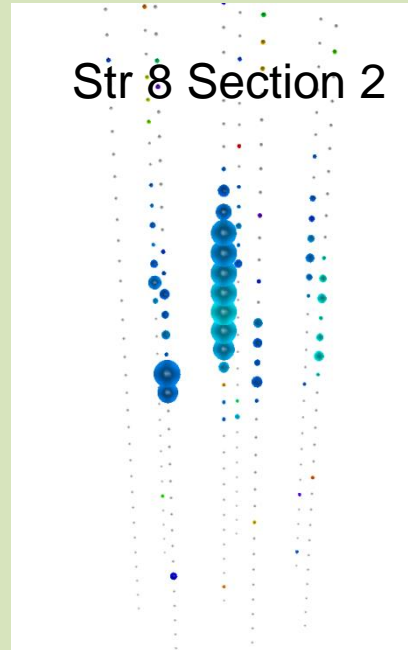
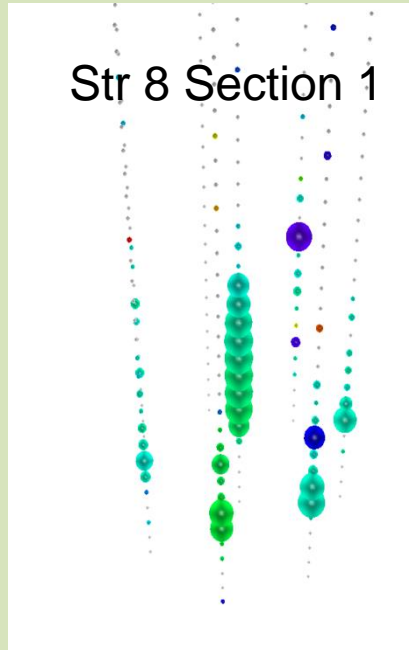
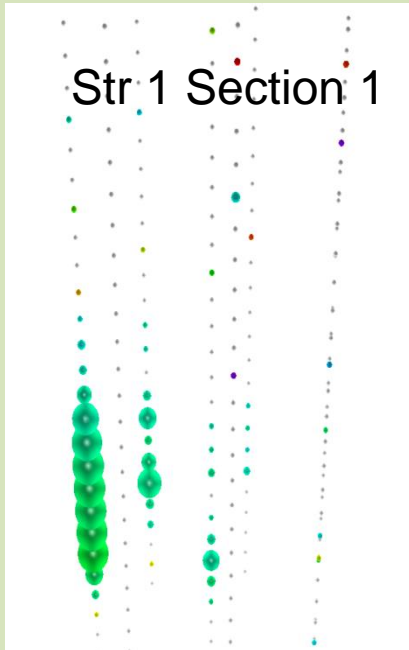
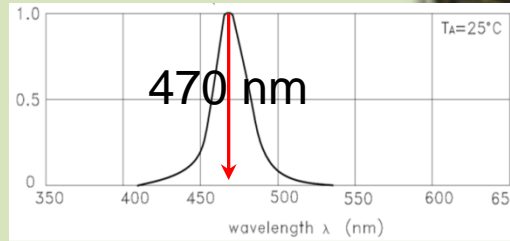
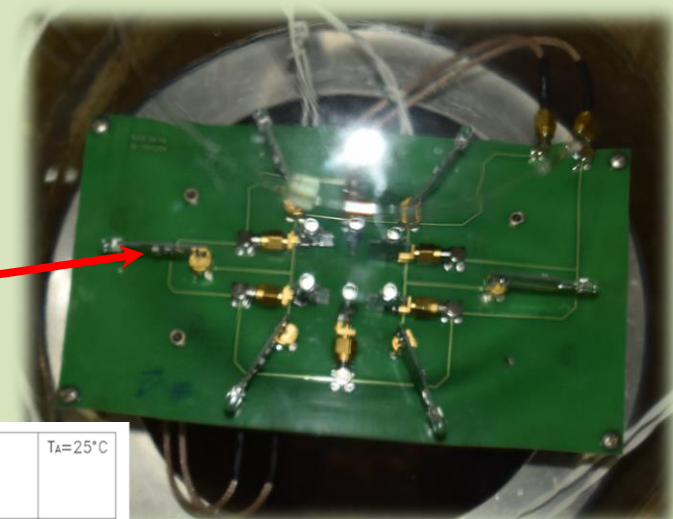
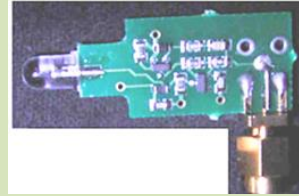
$dT_{exp} = 64.9 \text{ ns}$, expected
time difference

Consistency of two calibration procedures

New LED light sources for inter-string calibration

3 new LED light sources (LED beacon) for the time calibration of the Strings were installed. Each LED beacon comprises 12 synchronized LEDs: 6 vertical and 6 horizontal.

LED: Kingbright L7113 PBC-A



Infrastructure

Reserve Shore Station



Reserve Shore Station



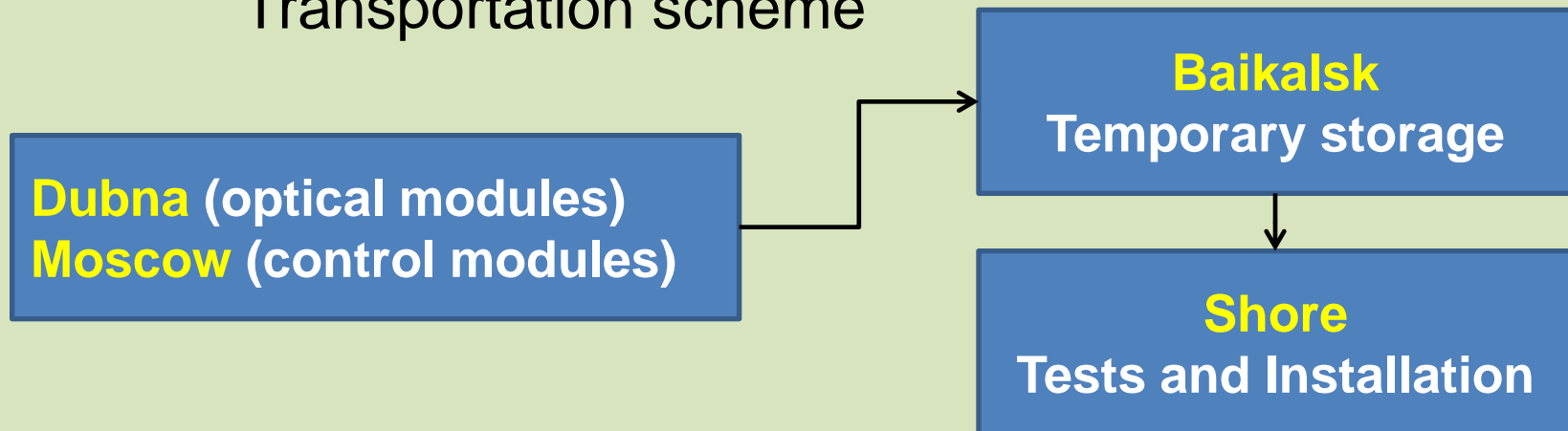
Operating Shore Station

Baikal'sk

Workshop, Storage facilities

The building in Baika'lsk is prepared for a local lab and a temporary store for optical modules of the next stages of the detector.

Transportation scheme



The optical modules production facility (Dubna)



New production line of optical modules for the next detector extensions is started in Dubna.

The line capacity is currently 8 modules per day.



Long-term testing room

Storage room



New facility for long-term tests of optical modules is operating in Dubna.

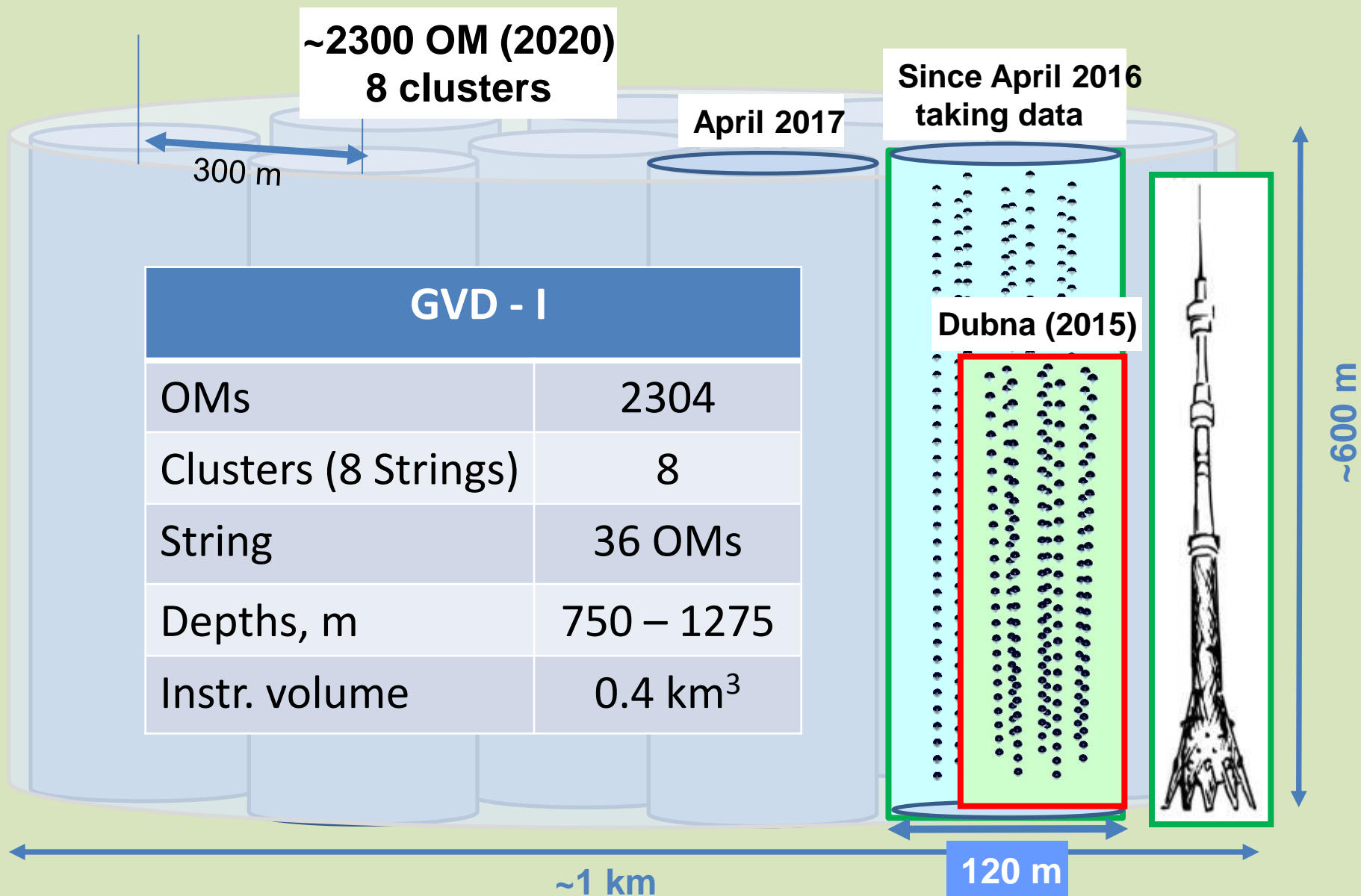
GVD-1 timeline

Cumulative number of clusters vs. year

Year	2015	2016	2017	2018	2019	2020
Clusters	<i>2/3</i>	<i>1</i>	<i>2</i>	<i>4</i>	<i>6</i>	<i>8</i>
OMs	<i>192</i>	<i>288</i>	<i>576</i>	<i>1152</i>	<i>1728</i>	<i>2304</i>

Completion of the GVD Stage 1 is expected in 2020

Present and future of the BAIKAL-GVD



Conclusion:

- Prototyping & Early Construction Phase of Project is concluded with construction and commission of the first GVD Cluster “Dubna” in 2015
- In 2016 Cluster “Dubna” has been upgraded to baseline configuration of GVD Cluster with 288 OMs
- Completion of the GVD Stage 1 is expected in 2020

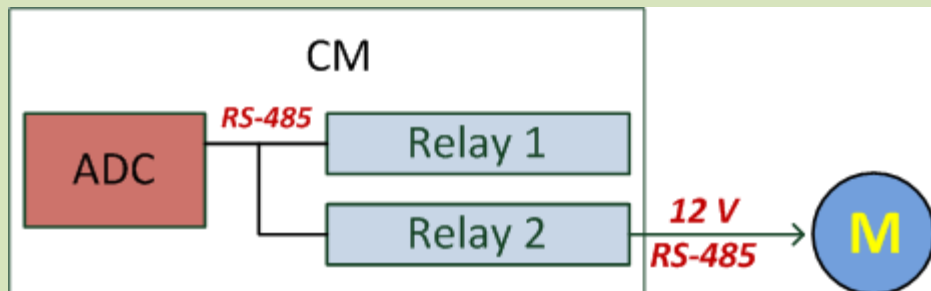
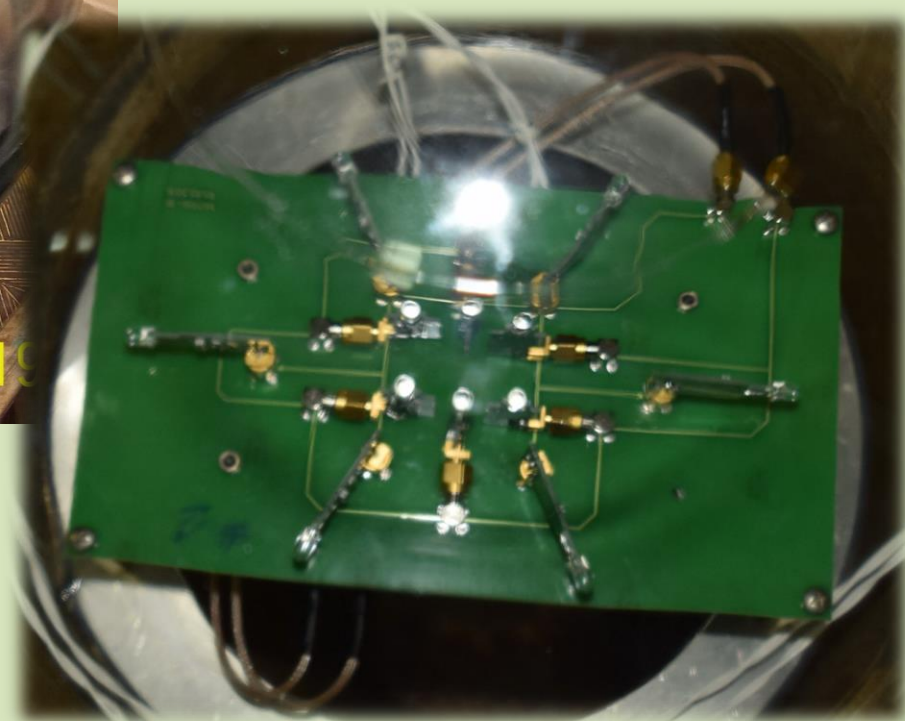
Thank you

New LED light sources for calibration system



“Matrix” 2016:

- 1 OM Controller & 2x6 LEDs (six horizontal directions)
- All LED flashes are synchronized
- Connection through CeM

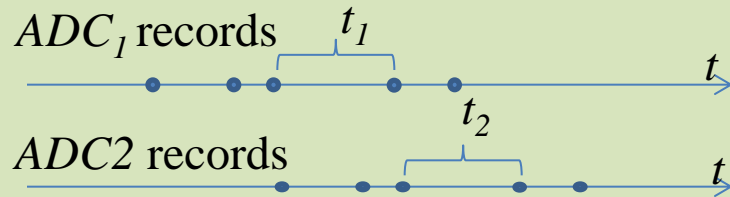


Event building - 2016

Correct trigger number (N_{TR}) on all ADC boards provides a simple way of the merging of ADC records;

Test of the event building: Δt distributions of the time intervals between records.

Test parameter: $\sigma(\Delta t)$

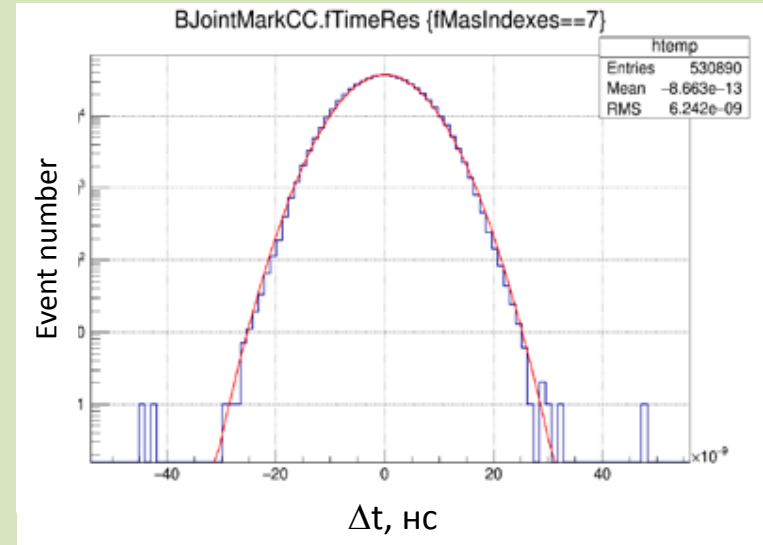


$$\Delta t = t_1 - t_2 \approx 0 \pm 10 \text{ ns (ADC clock 100 MHz)}$$

$\sigma(\Delta t)$ for all ADCs in relation to Cluster Center ADC

#ADC	220	208	195	211	219	197	212	207	217	204
σ , ns	5.4	5.8	6.0	5.7	5.7	5.7	5.6	6.0	5.8	5.6

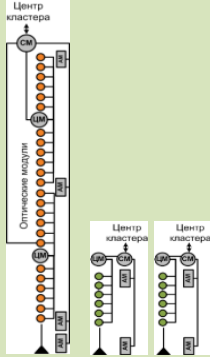
#ADC	209	202	216	192	210	214	222	215	213	221
σ , ns	6.02	5.6	5.8	5.6	5.7	5.7	5.7	5.8	5.6	5.8



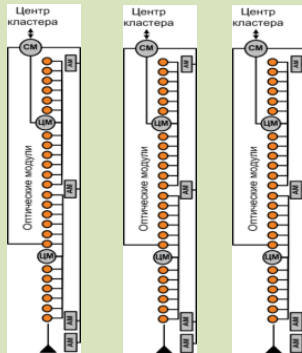
Δt distribution for ADC #209 and ADC 190 (Cluster Center)

History

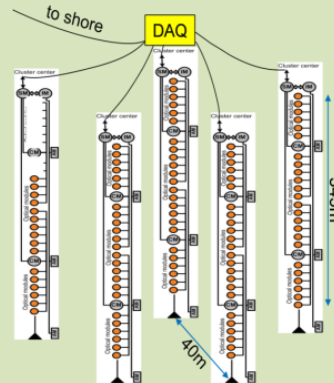
2012



2013



2014



2012. The first full-scale GVD string (24 OMs)

ADC – FPGA Spartan 3, 4-ch

2013. 2 additional strings

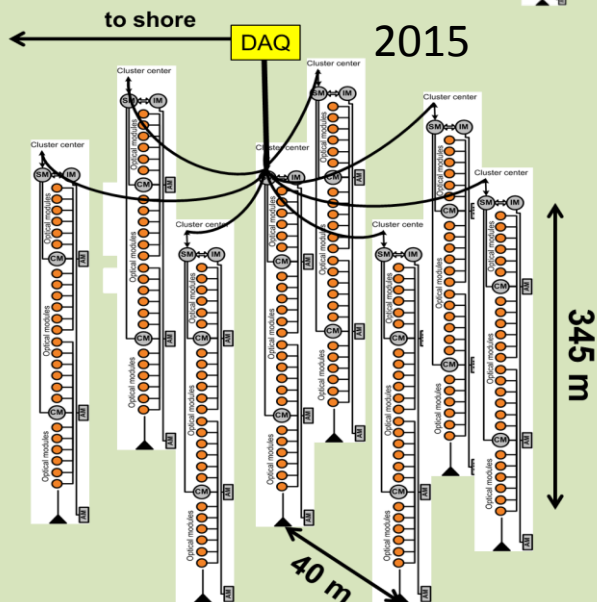
ADC – FPGA Spartan 6, 4-ch

2014. 2 additional strings

ADC – FPGA Spartan 6, 12-ch (V1)

2015. 3 additional strings

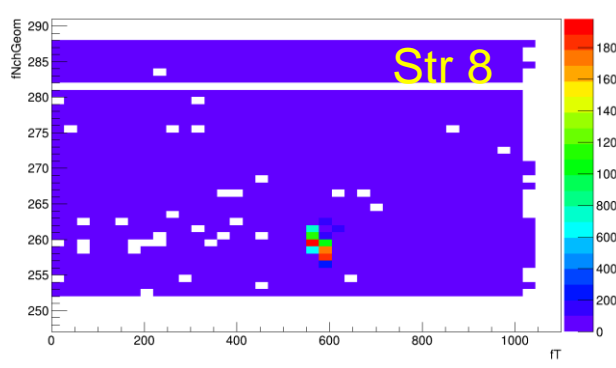
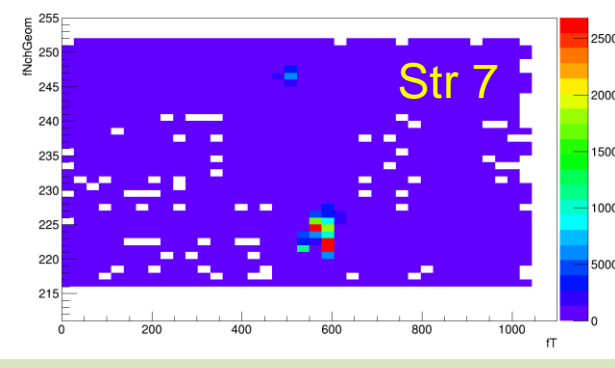
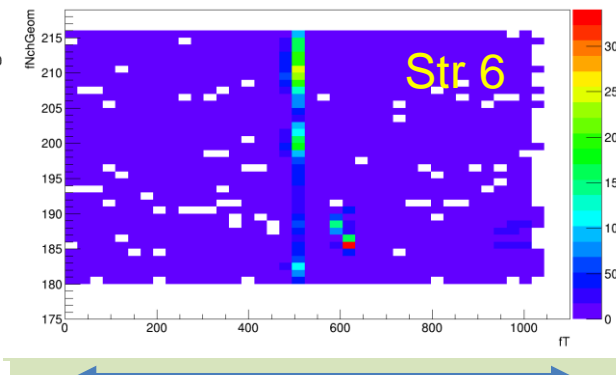
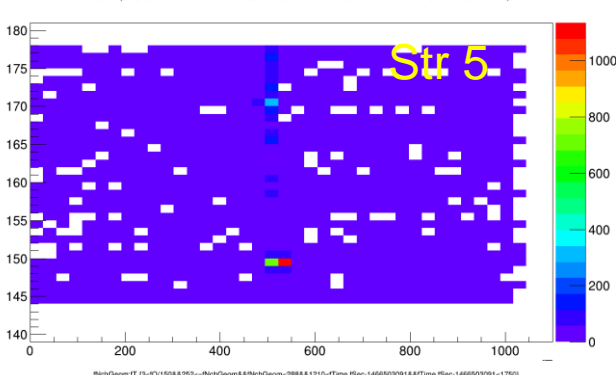
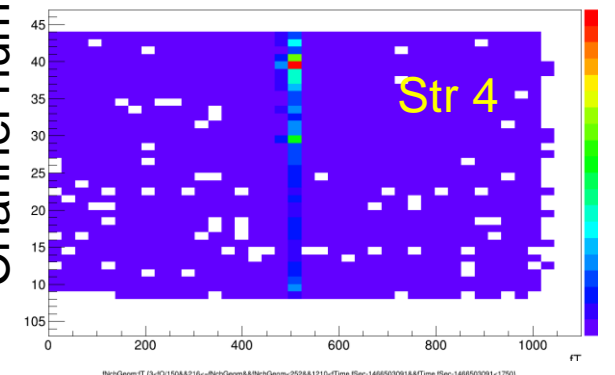
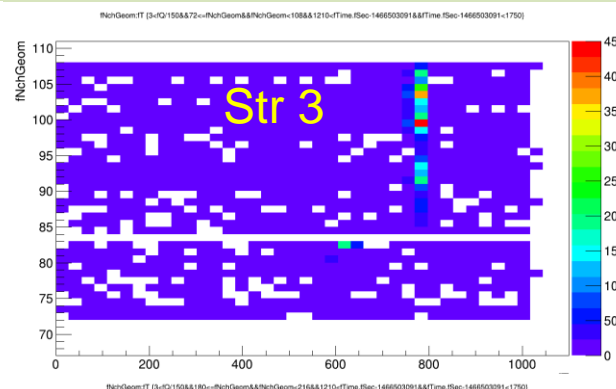
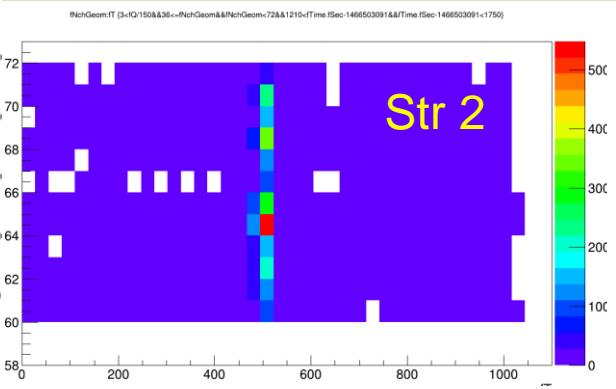
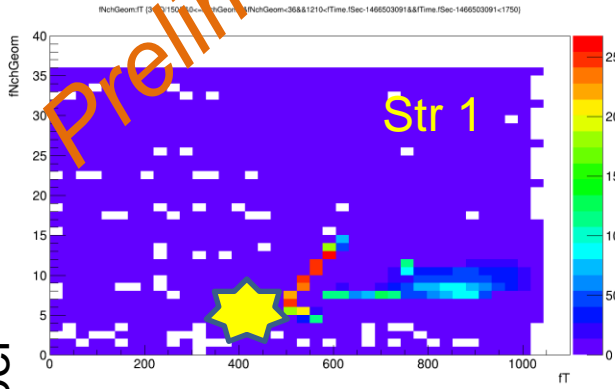
ADC – FPGA Spartan 6, 12-ch (V1,2)



Test of location of the pulses in the time window of ADC (peripheral string, bottom)

Preliminary

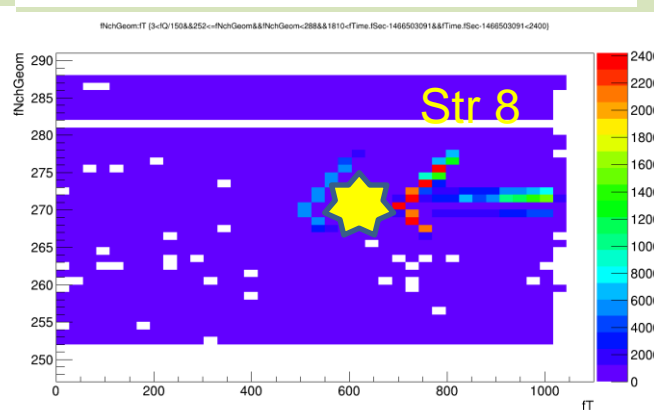
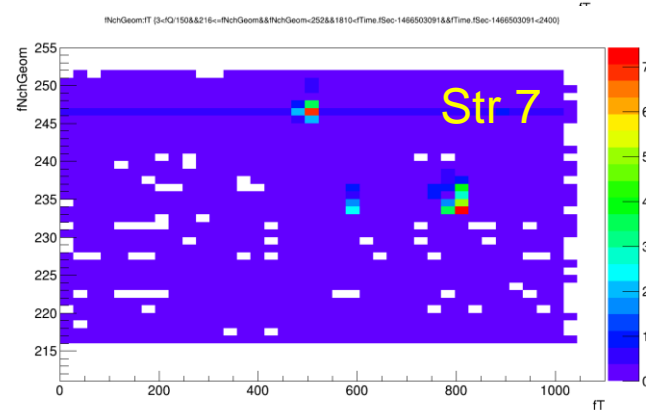
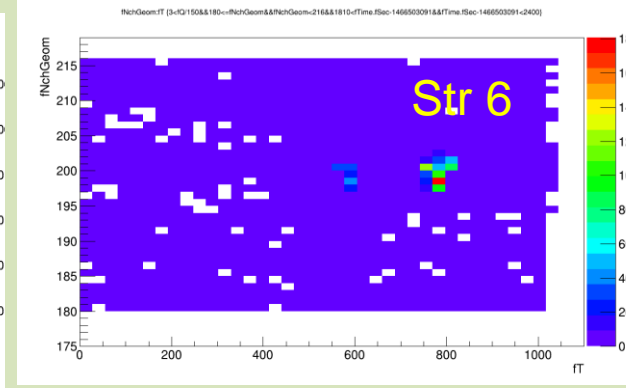
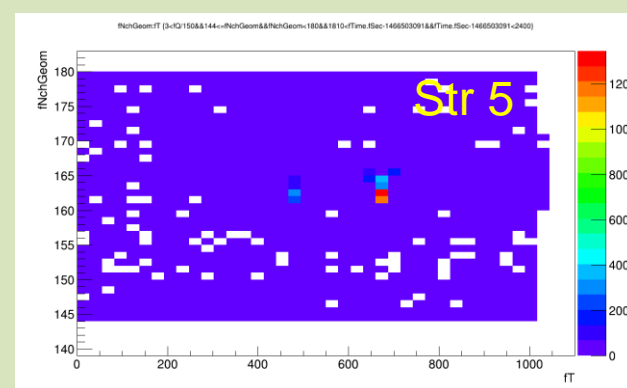
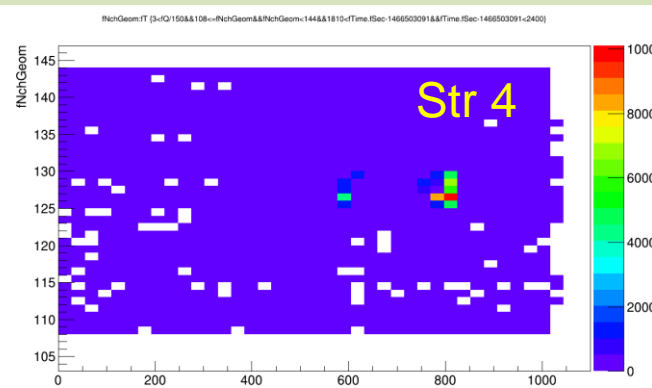
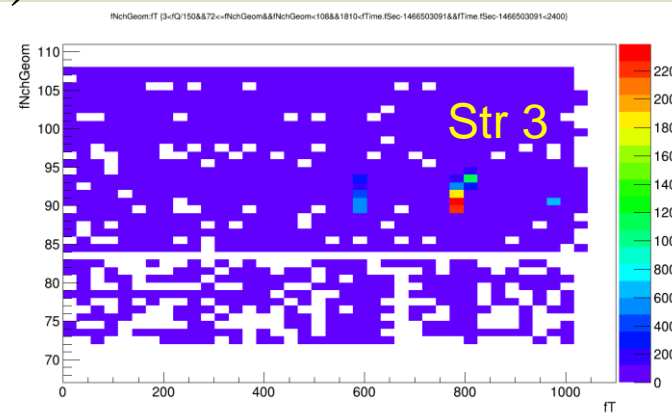
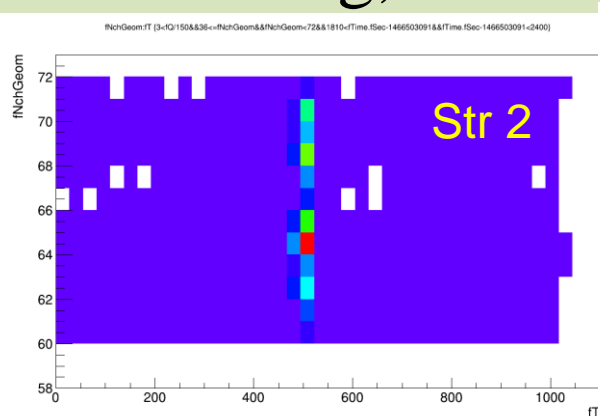
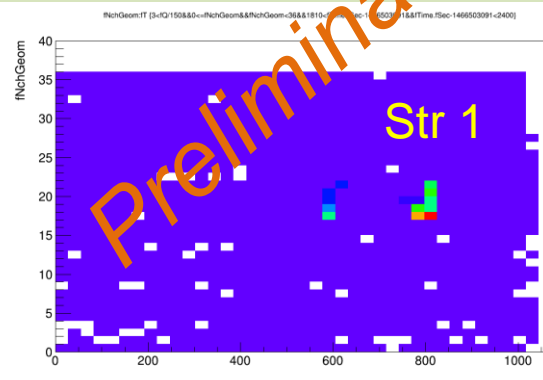
Channel number



← ADC time window: 5 μ s
Pulse location: 2.5 - 4 μ s →

Test of location of the pulses in the time window of ADC (central string, center)

Preliminary

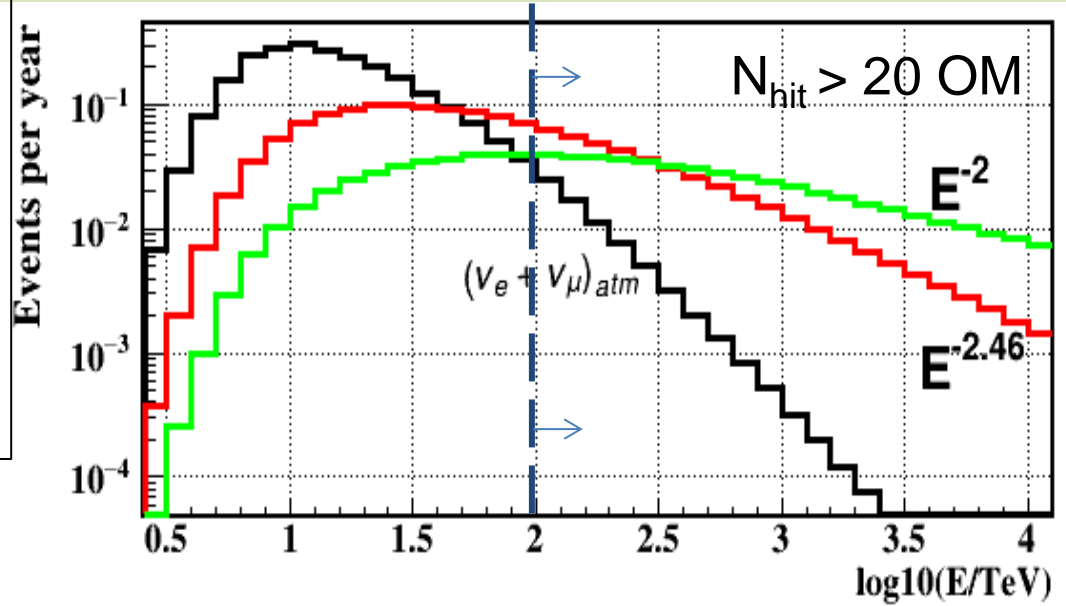


Pulse positions: 2.5 - 4 mks

Demonstration Cluster

For 1 year observation 0.4-0.6 events are expected from IC flux with $E^{-2.46}$ spectrum
($E > 100$ TeV, $N_{hit} > 20$ OM)

Expected number of events for 1 yr. observation



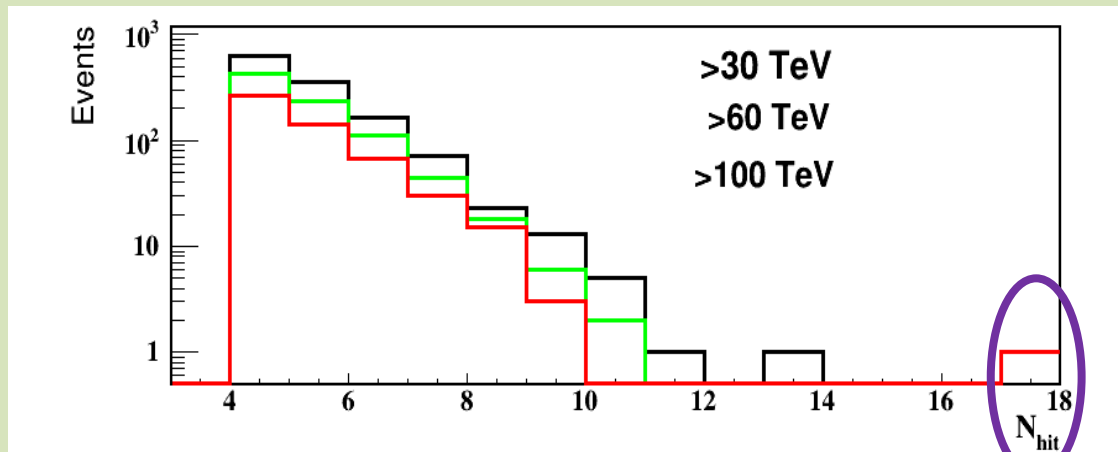
2015 data analysis

- Total number – **437 970 024** events (thresholds: low/high = 1.5/4 ph.el.)
- Life time – 3 597 921 s = **41.6** days

Hit OMs multiplicity after all cuts

After all cuts

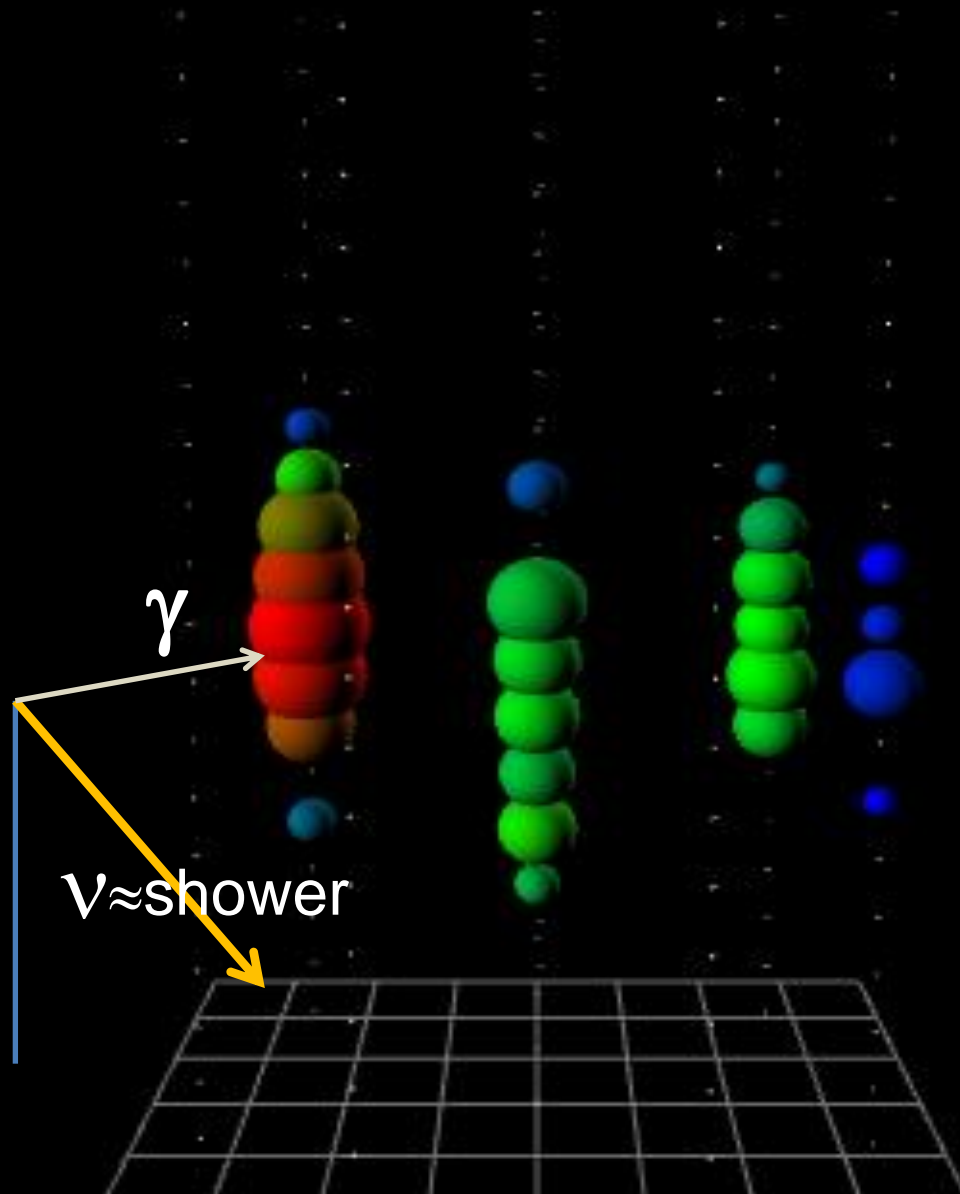
Cuts	Events
$E > 30$ TeV	1291
$E > 60$ TeV	859
$E > 100$ TeV	539



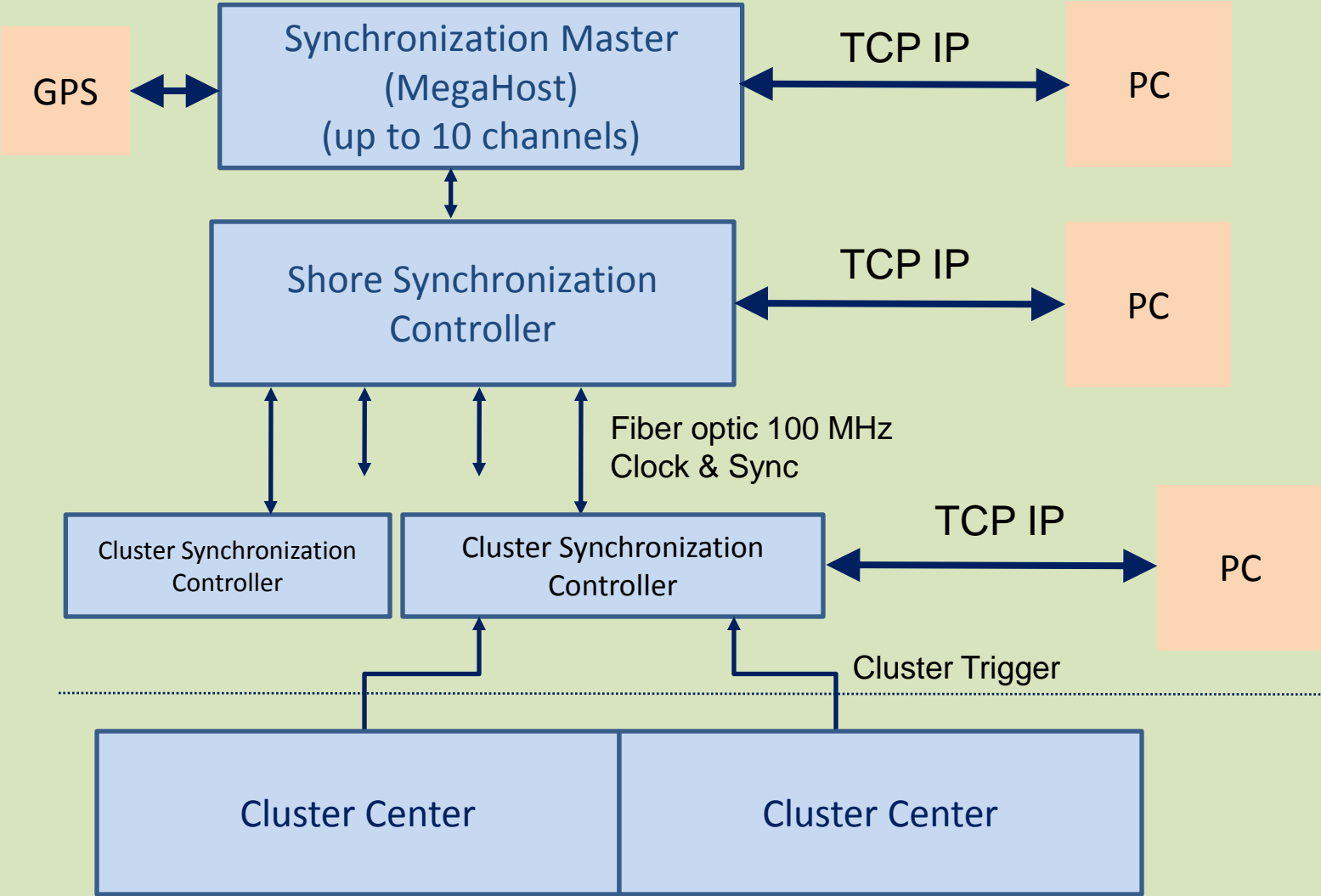
One event with $N_{hit} = 17$ OMs and $E > 100$ TeV !

Promising event (e584:8566299)

$E = 158 \text{ TeV}$, $\theta = 59^\circ$, $\rho = 73 \text{ m}$, $z = -62 \text{ m}$



Synchronization System



Cluster Synchronization Controller

