Cherenkov and scintillation counters with light collection using re-emitting light guides.

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Outline

- Light collection in rectangular plastic bars (WLS or scintillation light)
- Development of ASHIPH counters at BINP
- Scintillation counters of large area for TAIGA experiment
- Future developments with SiPM readout.

Light collection in rectangular plastic bars (WLS or scintillation light)

The light propagation inside the rectangular transparent bar is rather simple. For any point inside the bar, in the case of isotropic emission there are only two cases:

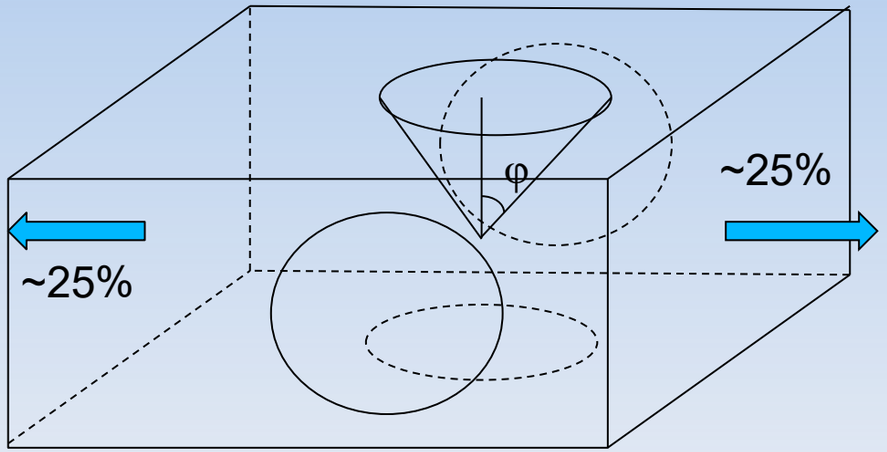
- A photon could go outside the bar.
- A photon can be trapped under conditions of total internal reflection.

Simple estimations could be done:

- The angle of total internal reflection is $\varphi = \arcsin(1/n)$, where n is refractive index.
- There are 4 cones within which the light could escape the bar. They cover solid angle -- $\Omega = 4 \cdot 2\pi(1 - \cos(\varphi))$.
- The probability for a photon to be inside total internal reflection is

$W = (4\pi - \Omega)/ 4\pi = 1 - 2(1 - \cos(\arcsin(1/n))) = 2 \cdot \cos(\arcsin(1/n)) - 1$

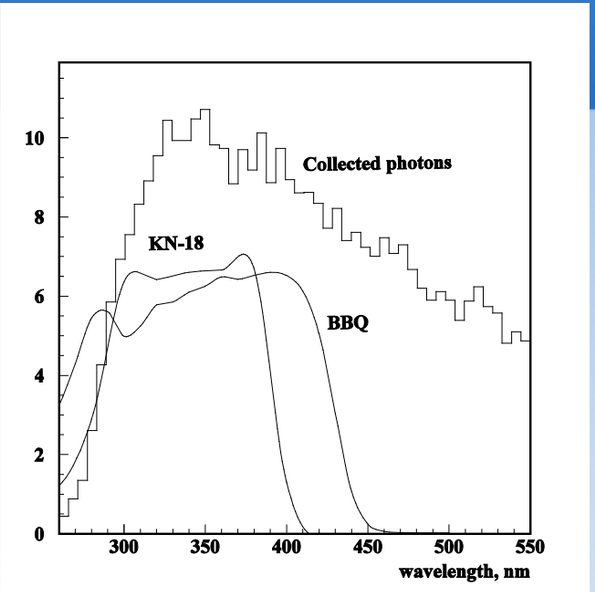
This result is for two directions and could be taken as the estimation of the maximum of the light collection coefficient .

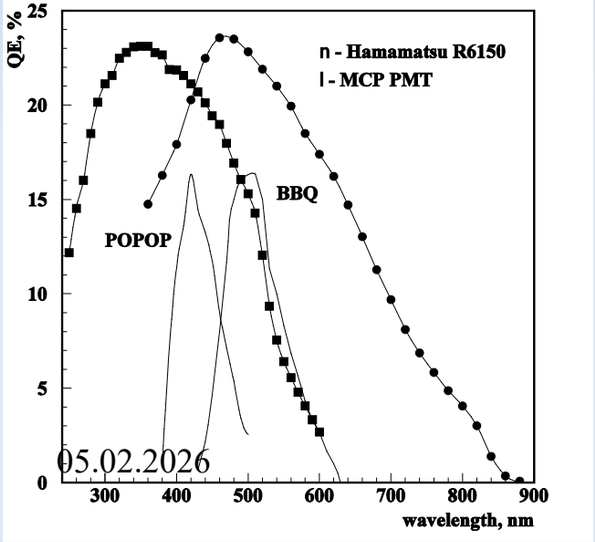


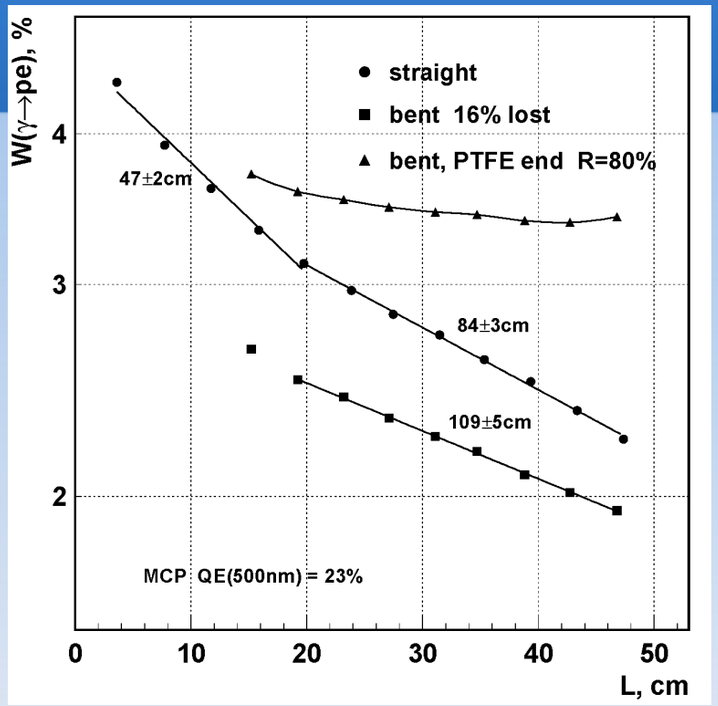
- PMMA bars (n=1.496) LC_{max} = 24% (one direction)
- PVT based scintillators (n=1.58) have LC_{max} = 27% (one direction)

ASHIPH detectors

Aerogel SHIfter and PHotomultiplier

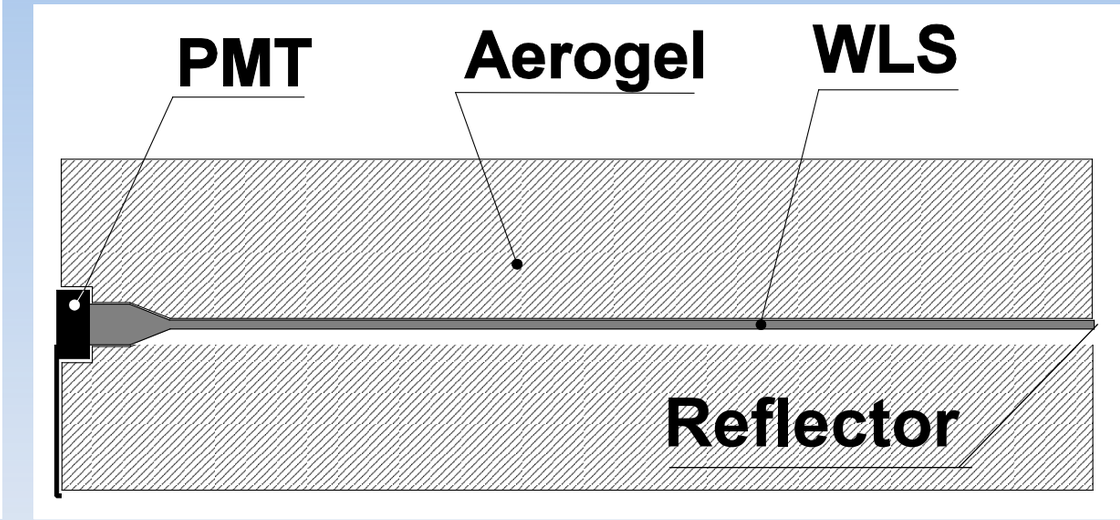






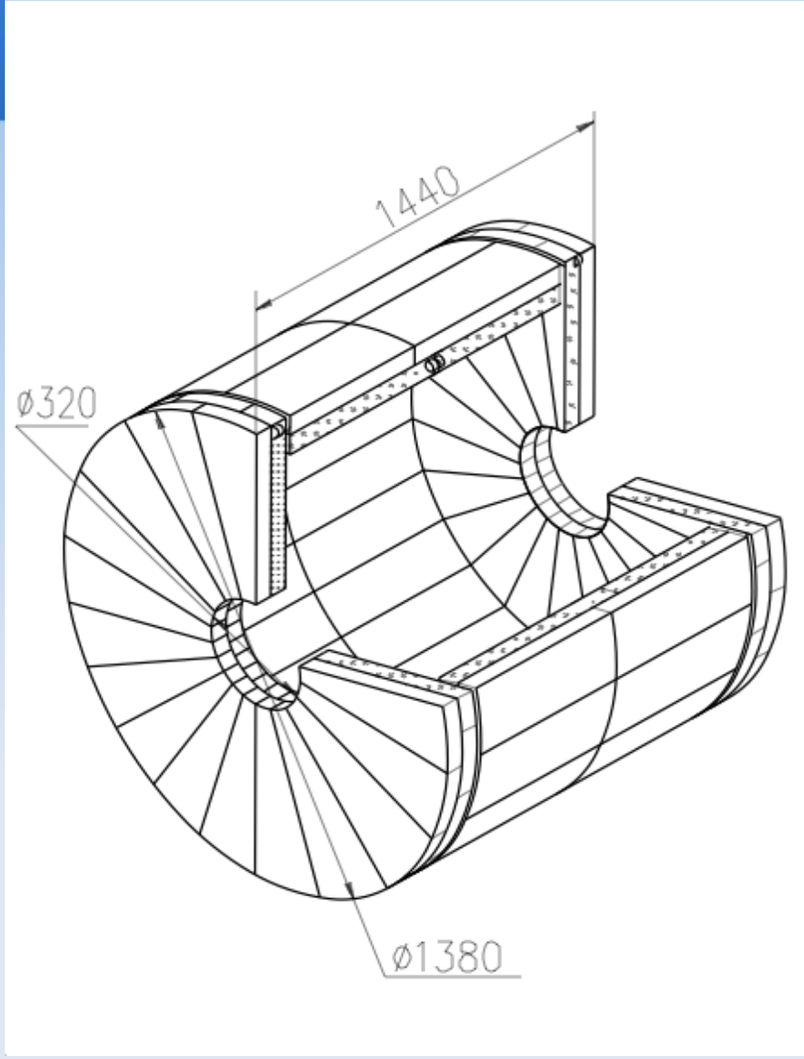
- PMMA light guide doped with BBQ dye is used as wavelength shifter
- Light guides length -- 600 mm
- Cross section - 3x12 and 3x17 mm

Suggested at BINP. A.Onuchin et.al. NIM A315(1992)517



- Intensive research work was carried out at BINP to optimize the composition of the re-emitting plastic.
- The production of PMMA plates doped with BBQ dye was organized at the Kargin Institute in Dzerzhinsk, Russia.
- The production of the plates, including their polishing and bending, was organized in the laboratory.

KEDR ASHIPH system



- 160 counters in 2 layers
- Solid angle 96% of 4π
- n=1.05, V_{Σ}=1000 l, high transparency SAN-96 aerogel
- π/K- separation in the momentum range 0.6÷1.5 GeV/*c*
- 160 MCP PMTs, photocathode diameter ø18mm, able to work in the magnetic field up to 2 T
- Fully installed in the detector in 2013. Now in operation.

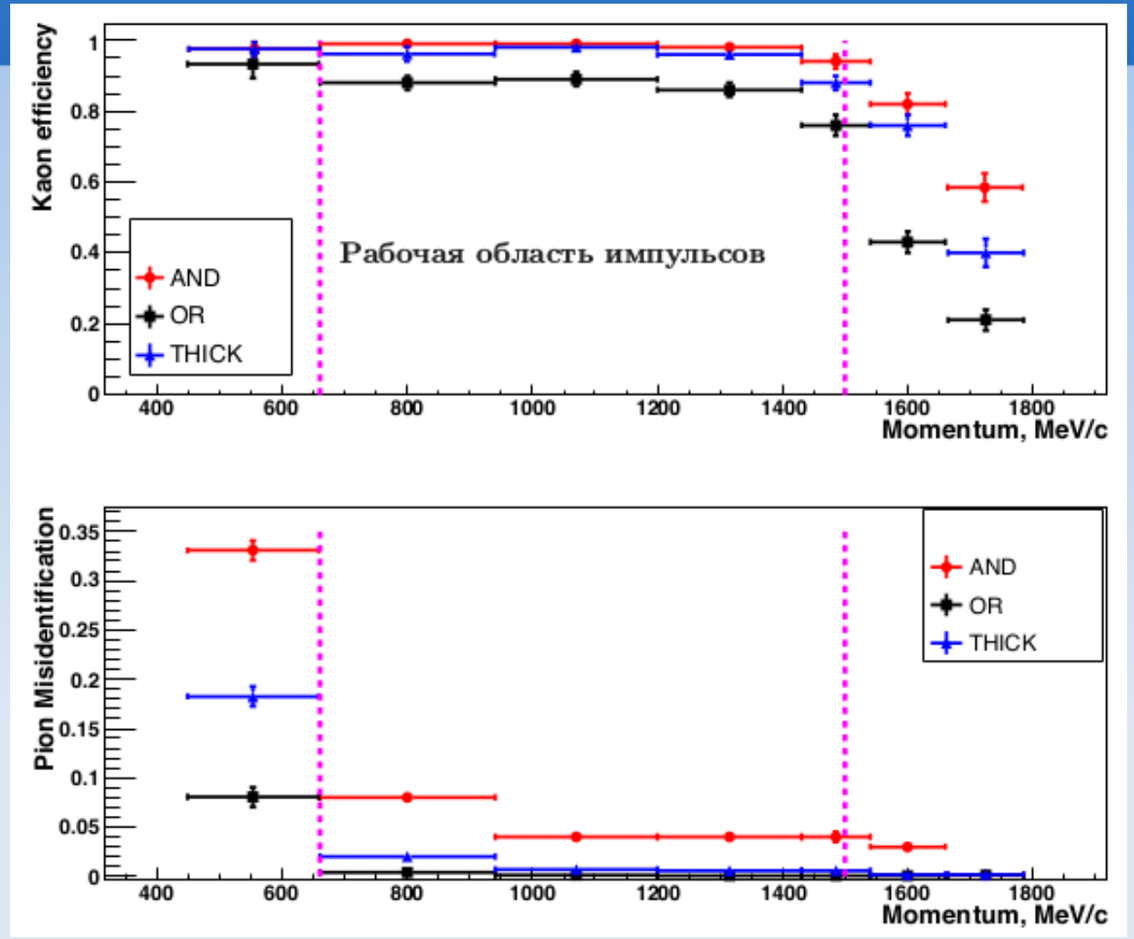
KEDR ASHIPH system(2)

- Npe = 6.4±0.2 – layer 1
- Npe = 5.0±0.2 – layer 2
- Npe = 10.9±0.2 – sum of the signals in 2 layers (80%)
- π/K separation at 1.2GeV/*c* is 4.3σ
- The ASHIPH system was used for measurement of J/psi decays into 2(pi+pi-)pi0, K+K-pi+pi-pi0, 2(pi+pi-), and K+K-pi+pi- final states:

  Eur. Phys. J. C (2022) 82: 938

- The ASHIPH system was used in measuring of D0 and D+ meson masses:

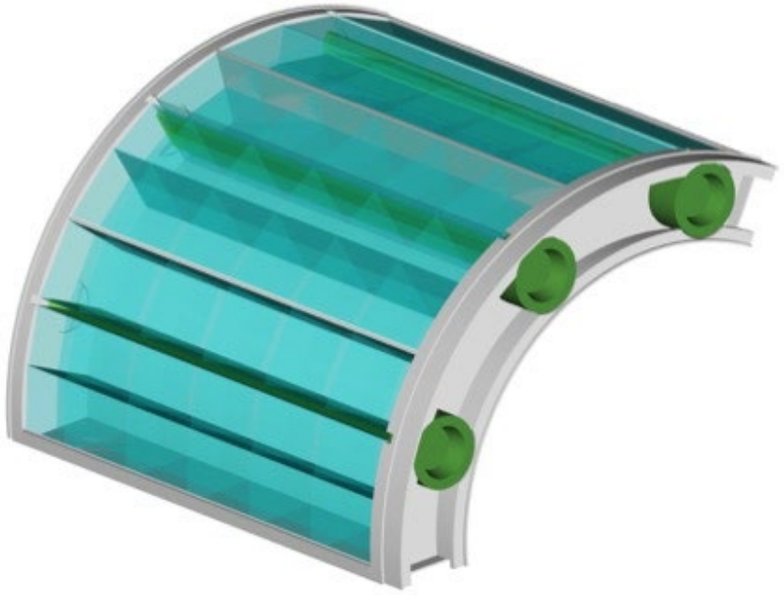
  JHEP 11 (2025) 001

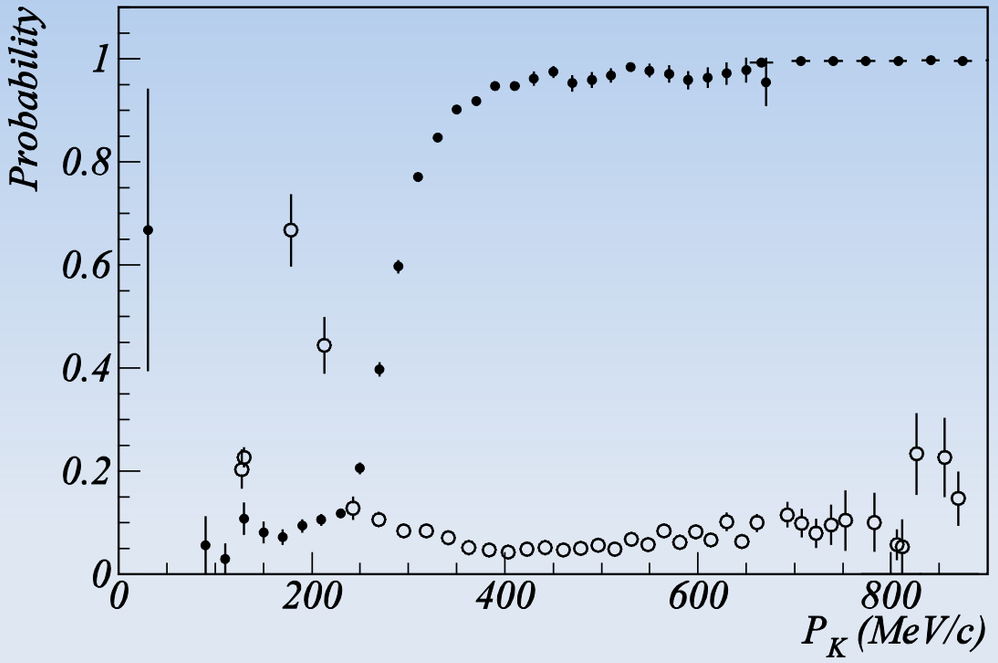


SND ASHIPH system

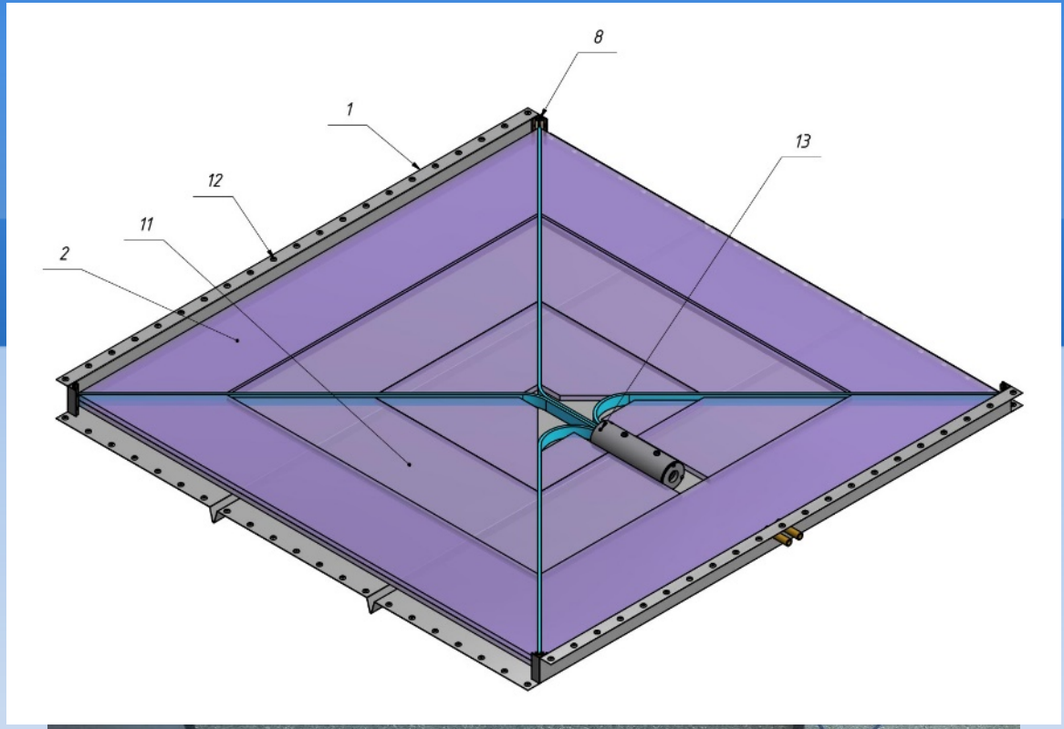
SND:

- 9 counters (1 layer)
- n=1.13 (9l)
- WLS (BBQ)
- Thickness ~ 30 mm
- MCP PMT øPC=18 mm
- 0.6x4π



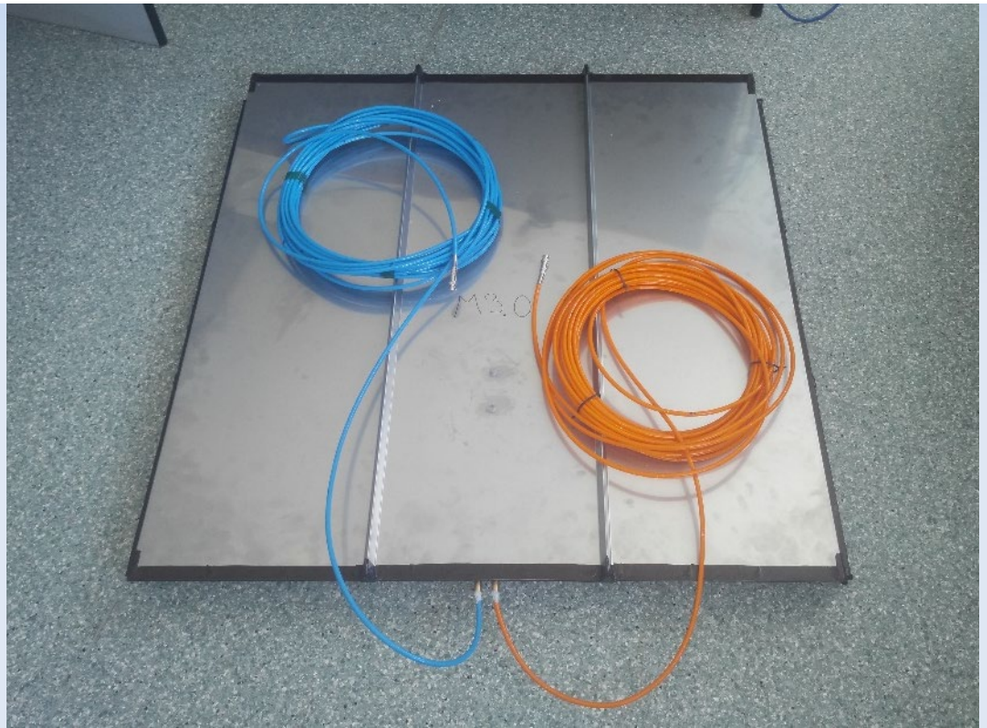


Scintillation counters of large area for TAIGA experiment

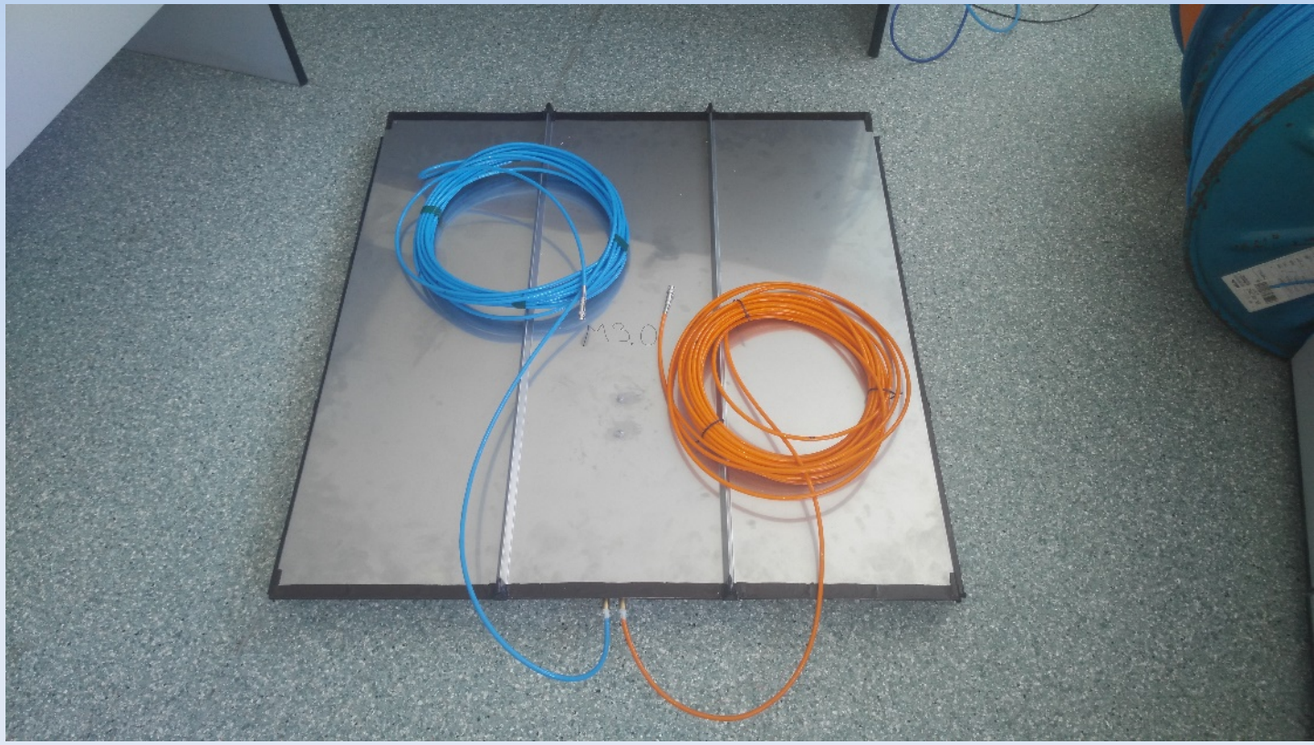


Design features:

- Light collection using re-emitting plates (5x20 mm cross section), length -- ~800 mm
- The side surfaces of the scintillation plates are not processed; only the end face looking at re-emitting plate is milled.
- Small photomultiplier tube (FEU-85-4) with photocathode diameter of 25 mm
- Thin counter → scintillator thickness 1-2 cm. -> low cost
- Stainless steel hermetic housing
- Could operate at temperatures from -50 to +40 C°
- S = 1 m^2
- N_{pe}/MIP ~ 30 pe, RMS/A_{mean} = 20%




ФЭУ-85-4



Status of TAIGA-muon scintillation system

100 scintillation counters were produced, 78 installed and are taking data.
The production of counters continus.

Future developments with SiPM readout.

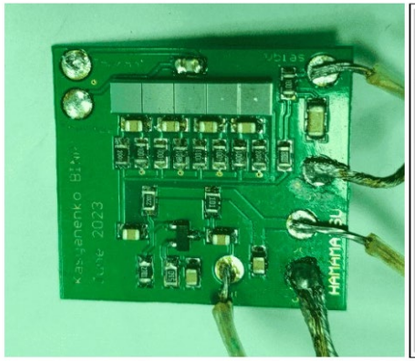
Cherenkov and scintillation light collection with re-emitting plates are well suited for use with SiPM readout:

- The required light detection area is rather small. This limits the noise conditions.
- There is no need to bent bars due to compactness of detectors and their immunity to the magnetic field.
- The replacement of traditional PMT with SiPM significantly increase number of detected photons.
- The maximum of the re-emitter's emission spectrum match the maximum efficiency of the silicon photomultiplier.

There are several projects with ASHIPH and scintillation counters with SiPM readout:

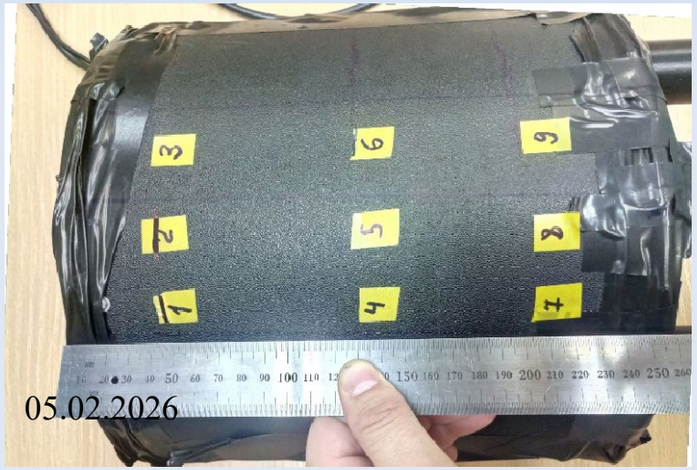
- Upgrade of SND ASHIPH with SiPM readout
- PID systems for STCF project
- TAIGA-Muon new scintillation counter

SND prototype and beam test results

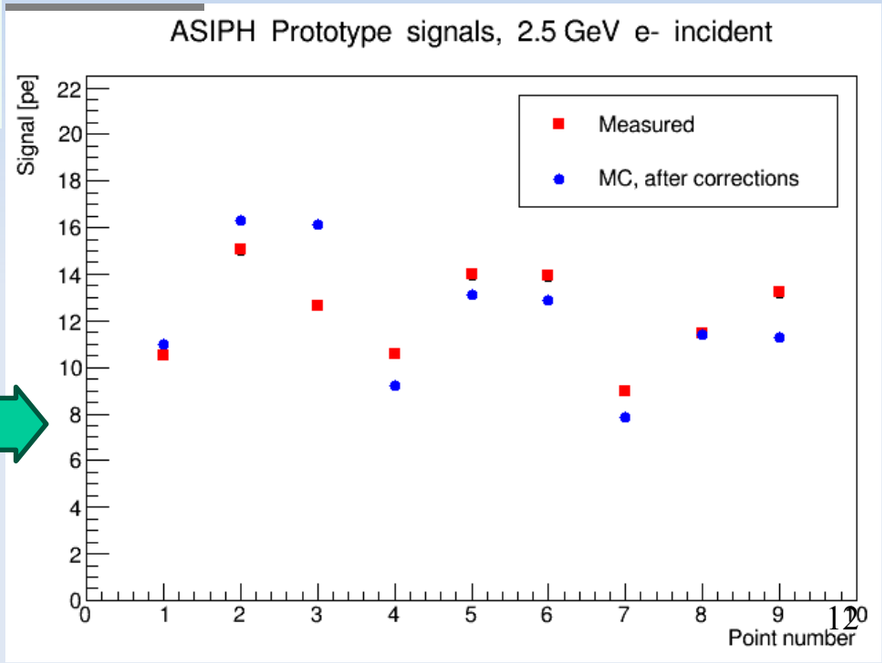


MCP PMT → SiPM
Gives increase of
amp. by 2÷2.5 times

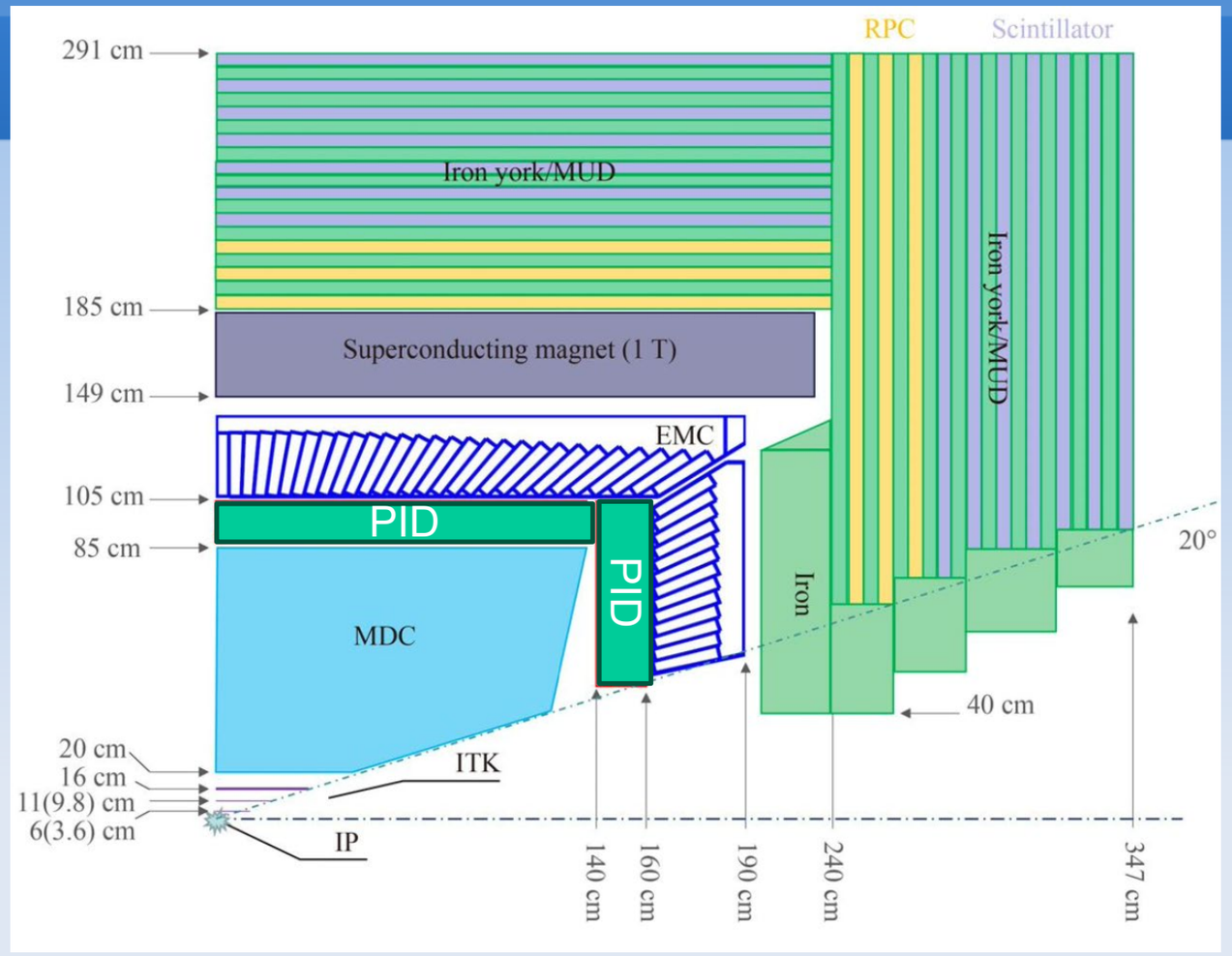
SND ASHIPH counter was upgraded
and tested with relativistic electrons (2.5 GeV)
at the BINP beam test facilities.

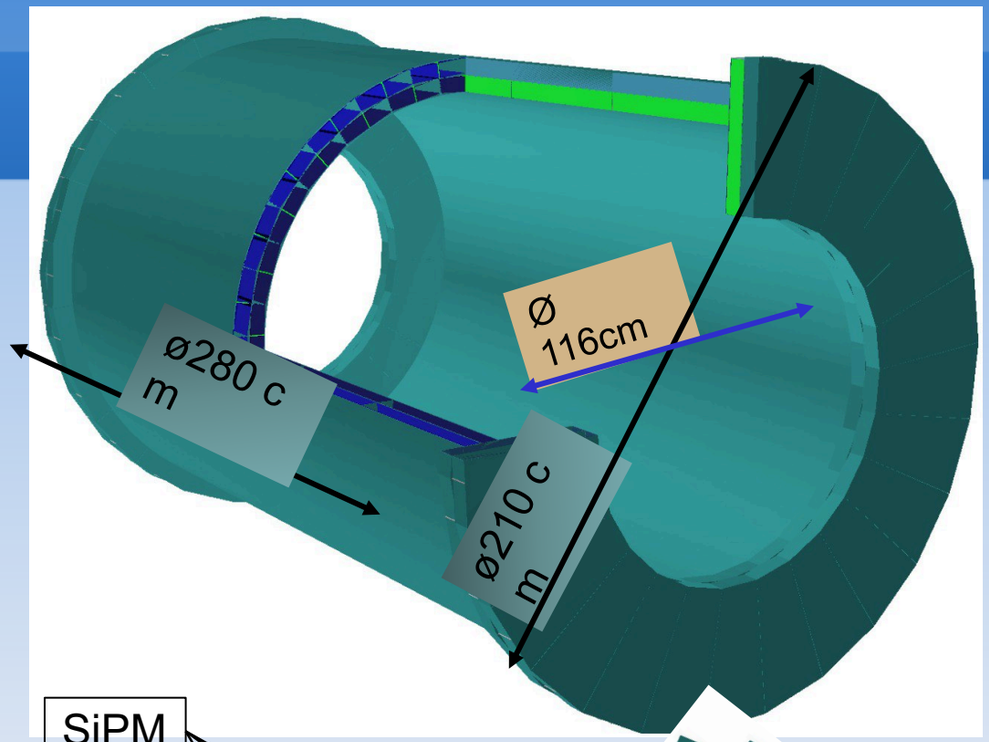


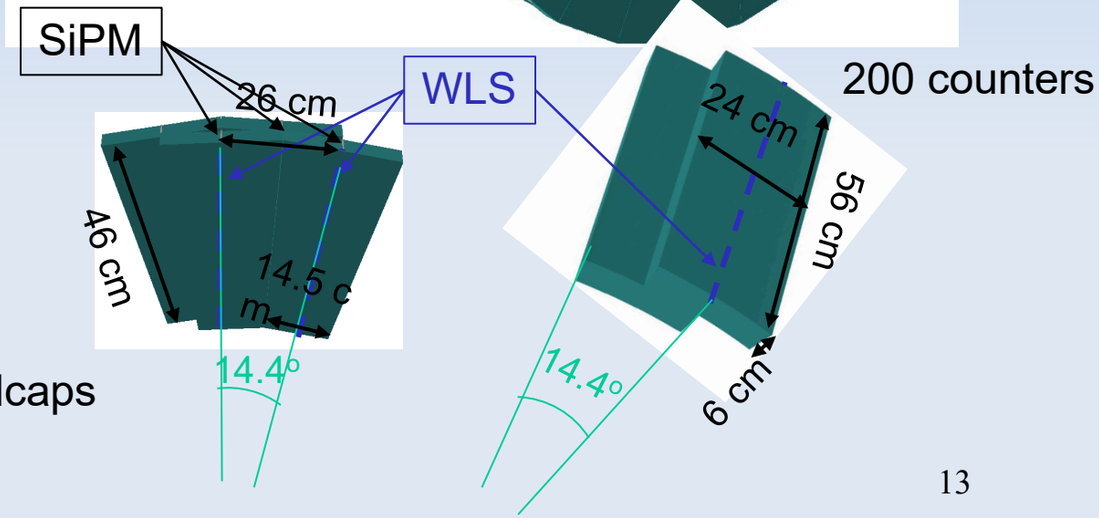
- Beam test results and GEANT4 simulation are in good agreement
- Expected effect of Amp. increas is demonstrated!!!



ASHIPH system proposal for STCF (basic)



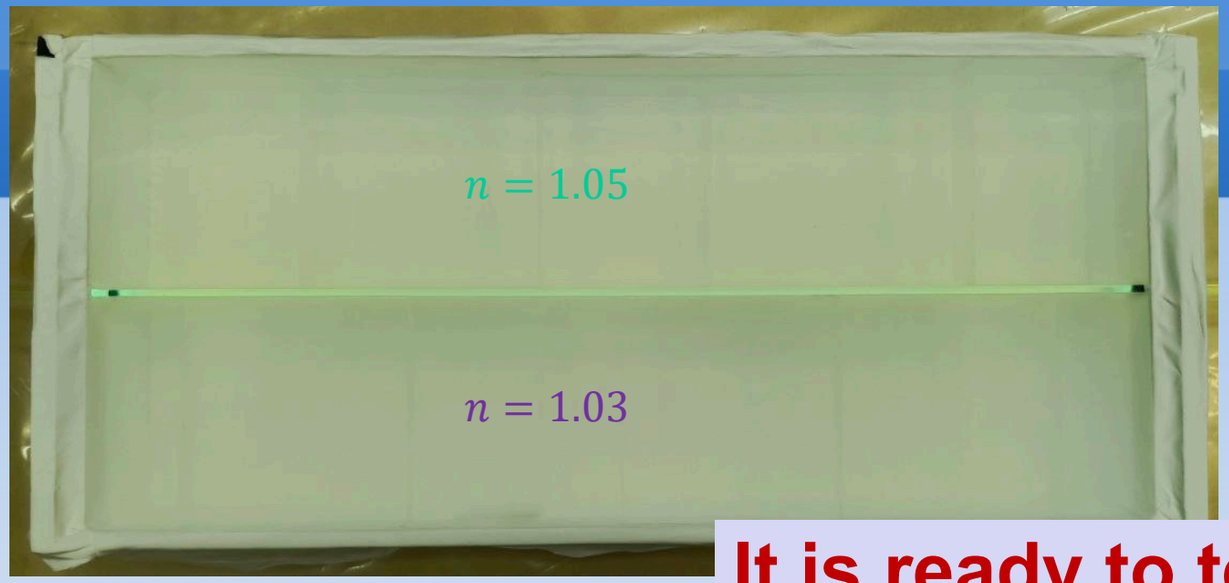




200 counters

100 counters in 2 endcaps

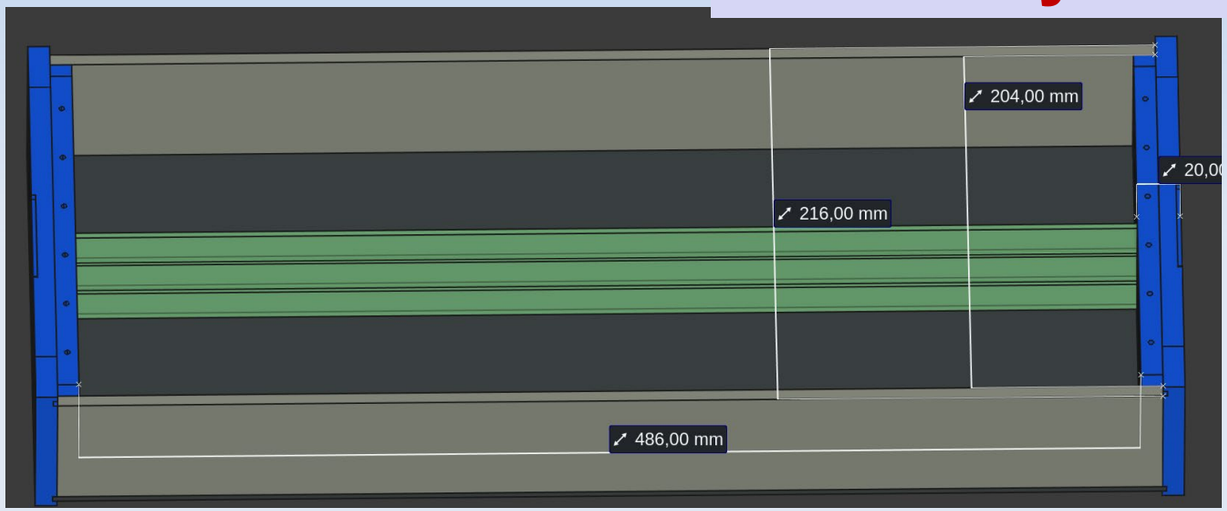
Design of ASHIPH prototype for STCF

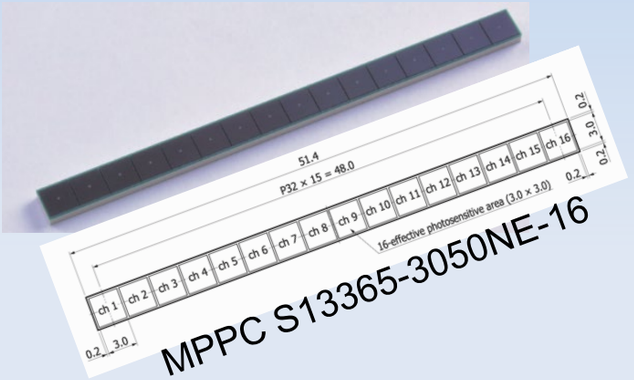


Main goals:

- To test light collection uniformity
- To test and chose WLS dye:
  - BBQ (τ=15 ns)
  - NOL-14 (τ=0.74 ns)
- To test and chose SiPMs
  - Hamamatsu
  - NDL
  - JoinBon and …
- To test and develop FEE
- To test π/K-separation and chose aerogel

It is ready to test!!!



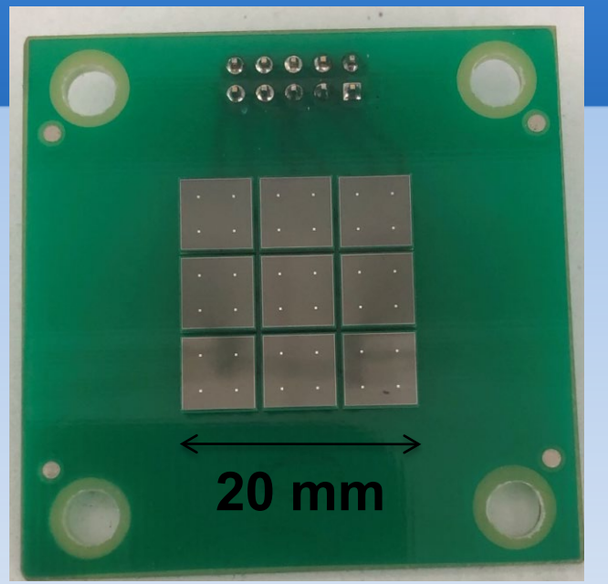


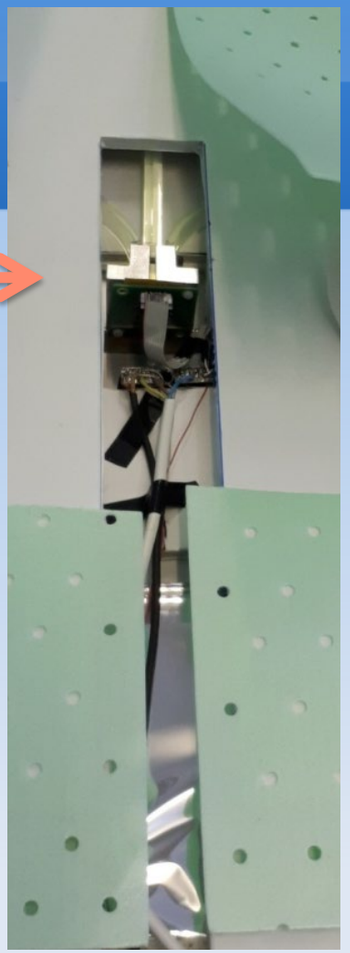
- 3 arrays 5 SiPMs each were made from MPPC S13365-3050NE-16 (Hamamtsu)
- 3 channels of V1742 (CAEN) degitizer will be used to readout

TAIGA-muon new scintillation counters

Testing of the counter with a SiPM matrix:

- 9 Hamamatsu S13360-6050VE units (6x6 mm)
- Sdet = 324 mm2
- 1 readout channel
- A_{mean} = 90 pe (factor of 3 increase)





Conclusions

- The method of light collection using re-emitting plates has proven its effectiveness and has been used for many years in the KEDR, SND, and TAIGA experiments.
- The replacement of traditional PMTs with matrixes of SiPMs significantly improves parameters of ASHIPH Cherenkov and scintillation counters using light collection on re-emitting plates. This technology will be used in future experiments like SND, STCF and TAIGA-100