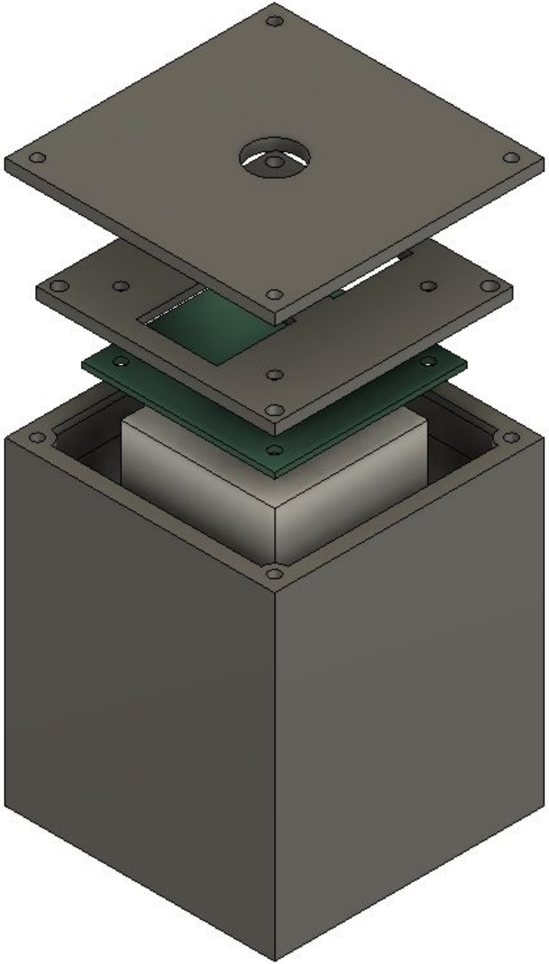


Measurement of the timing resolution of scintillation detectors samples of a future time-of-flight neutron detector for the BM@N experiment

Makhnev A.
on behalf of INR nDet team
07.2022

BM@N experiment

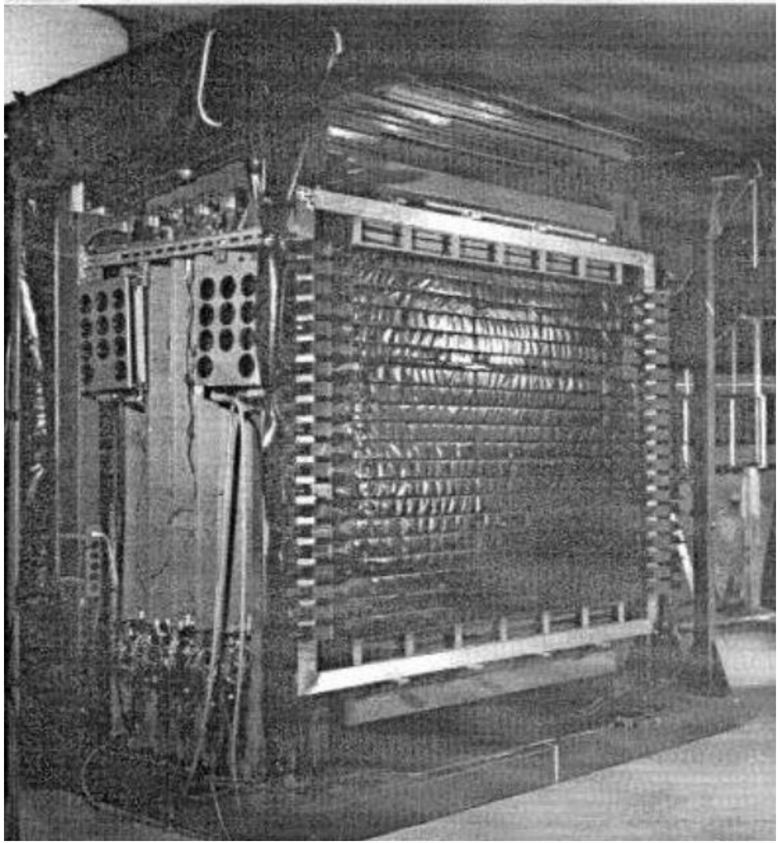
- Baryonic Matter at Nuclotron
- Fixed-target experiment and NICA's Nuclotron, JINR, Dubna, Russia
- First experiment in operation at NICA
- 2017-2018: world's first data on Λ-hyperons yield vs centrality at small and medium nuclei at 4.5 AGeV
- Heavy ion experiments (up to Au) after booster launch and BM@N upgrade

BM@N experiment

- Measurements of the symmetry energy of the equation of state at high nuclear matter density formed in the collision of heavy ions
- This study is important both for nuclear physics and for astrophysics
    - Structure of neutron stars
    - Processes during supernova explosions
    - Emission of gravitational waves during the merge of companion stars in binary neutron stars

Previous research and development

- LAND detector
  - total volume 2.0x2.0x1 m^3
  - 200 modules (plastic scint/Fe bars 200x10x10 cm^3)
  - 10 mutually perpendicular planes with 20 bars in each plane
  - two PMT for each bar readout (400 readout channels)
  - $\sigma t \approx 250$ ps,
  - $\sigma x,y,z \leq 3$ cm
  - one-neutron efficiency > 80% for energies > 400 MeV
  - multi-neutron detection capability without 1,2,3H isotopic discriminations



T. Blaich, et al., NIM. A 314 (1992) 136

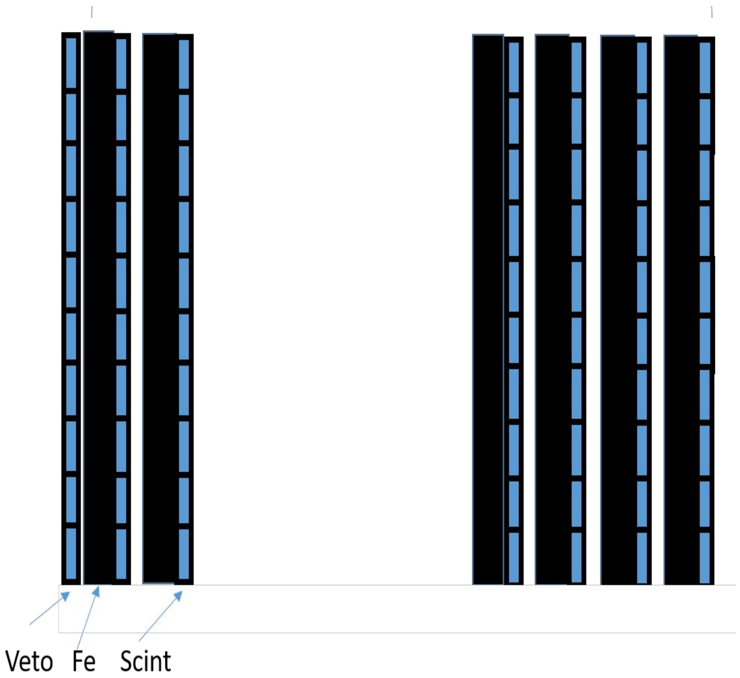
Previous research and development

- NeuLAND detector
  - total volume 2.5x2.5x3 m^3
  - 3000 modules (plastic scintillator bars (w/o Fe) 250x5x5 cm^3
  - 30 double planes mutually perpendicular with 100 bars each
  - two PMT for each bar readout (6000 readout channels)
  - $\sigma t \leq 150$ ps
  - $\sigma x,y,z \leq 1.5$ cm
  - one-neutron efficiency ~95% for energies 200-1000 MeV
  - multi-neutron detection capability

K.Boretzky et al., NIM, A 1014 (2021) 1

TOF neutron detector concept for the BM@N experiment

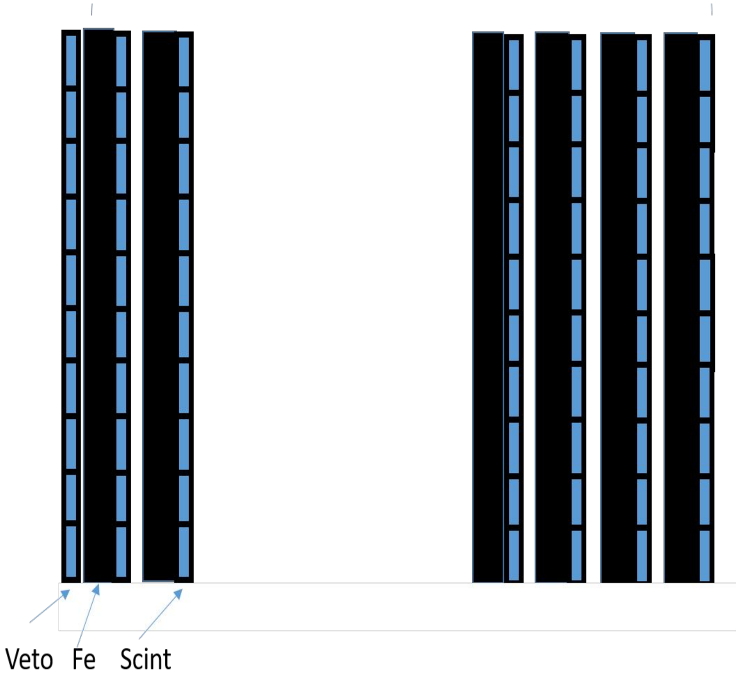
Requirements – to measure neutron energies up to 4 GeV with energy resolution comparable with LAND



TOF neutron detector concept for the BM@N experiment

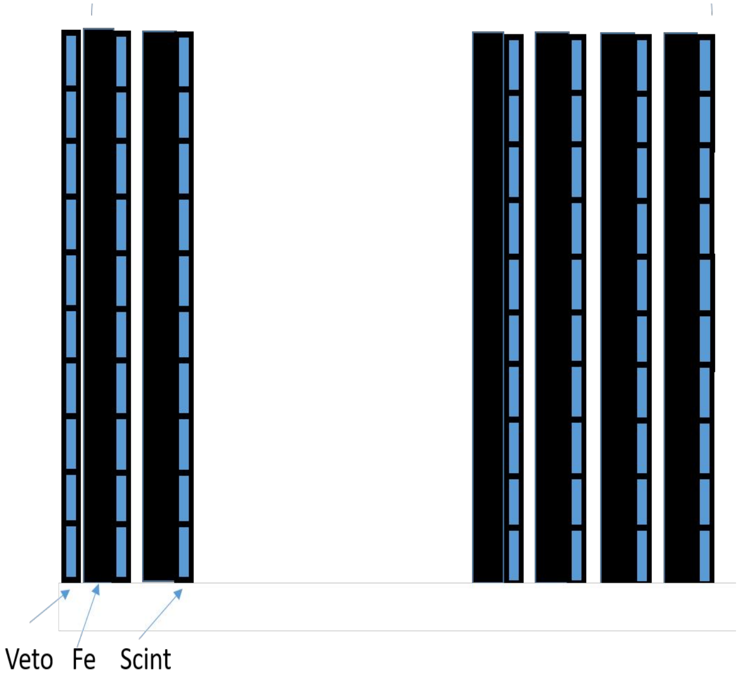
Proposed solution:

- Plastic scintillator + converter assemblies in layers
  - First scintillator layer - charged VETO det.
  - Converter layers from high density materials



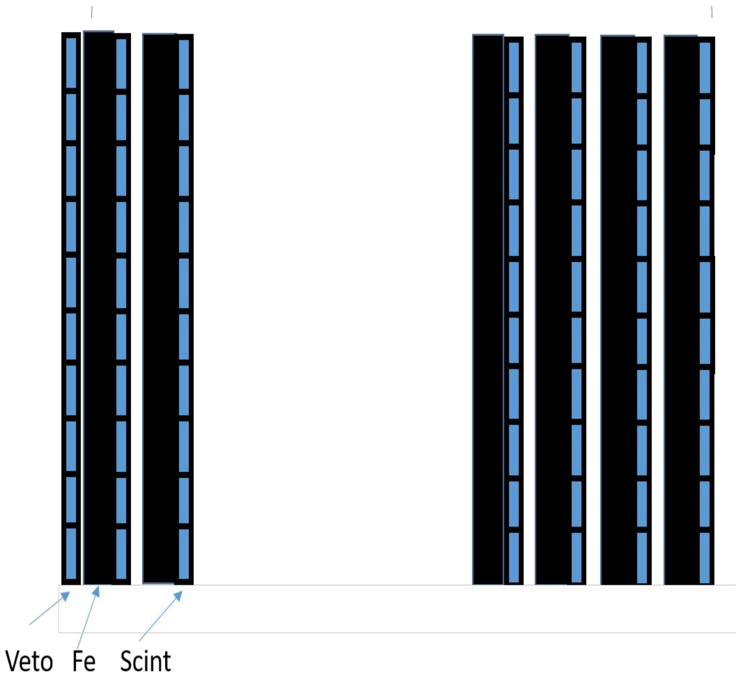
TOF neutron detector concept for the BM@N experiment

- Cells structure of scintillator layers:
  - Cell transverse size: 30x30 – 40x40mm²
  - Light readout from each scintillator cell by one SiPM directly coupled with a scintillator



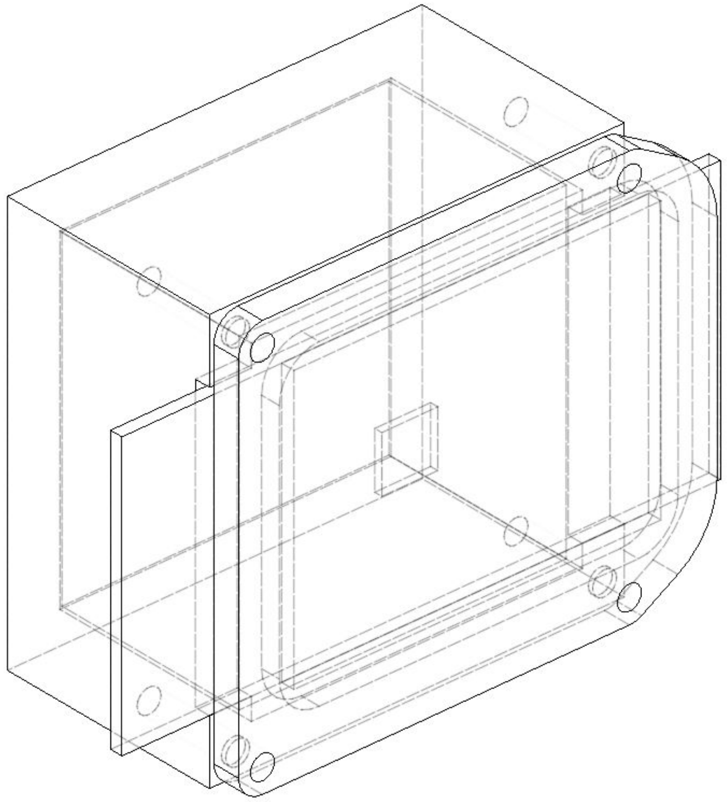
TOF neutron detector concept for the BM@N experiment

- Current simulations:
  - Scintillator cell transverse size
  - Thickness of the scintillators
  - Material of convertors
  - Number of layers



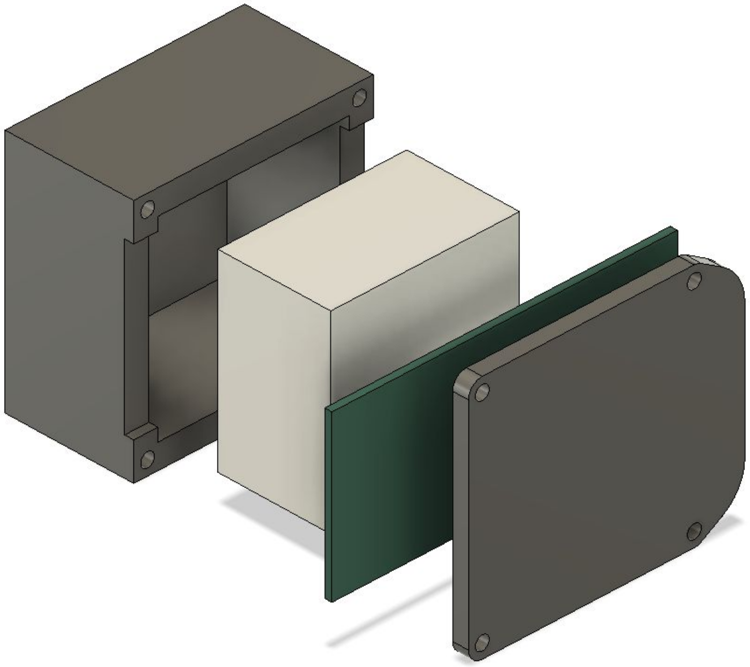
Sample detectors

- Scintillator + MPPC pair
- Variants with different scintillator sizes
    - 40*40*25 mm³
    - 35*35*25 mm³
    - 35*35*25 mm³
- Variants with different MPPCs
    - SensL MicroFC 60035
    - Hamamatsu S13360
- 3D-printed light-tight enclosures



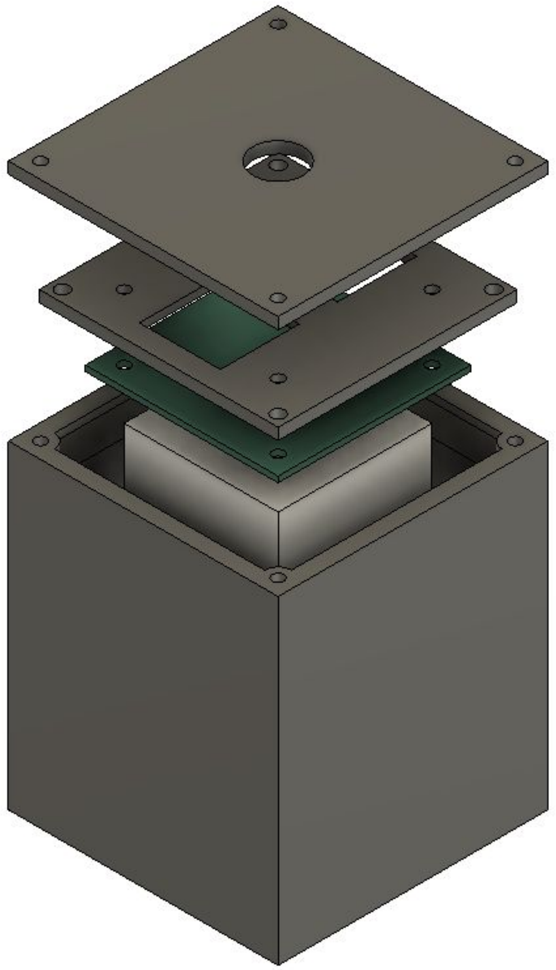
Sample detectors: SensL

- JINR-produced fast scintillator
    - Polystyrol + 1.5% p-terphenil and 0.01% POPOP
- SensL MicroFC 60035
    - 6x6mm sensitive area
    - 41% quantum efficiency
    - $3x10^6$ gain
    - Fast output
- Variants with different scintillator sizes
    - 40*40*25 mm³
    - 35*35*25 mm³
    - 30*30*20 mm³



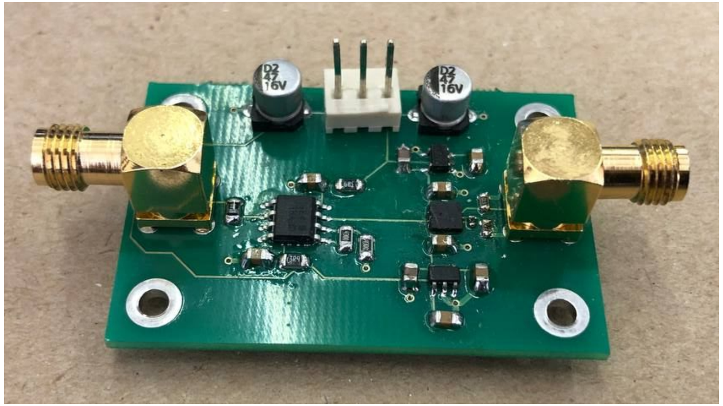
Sample detectors: Hamamatsu

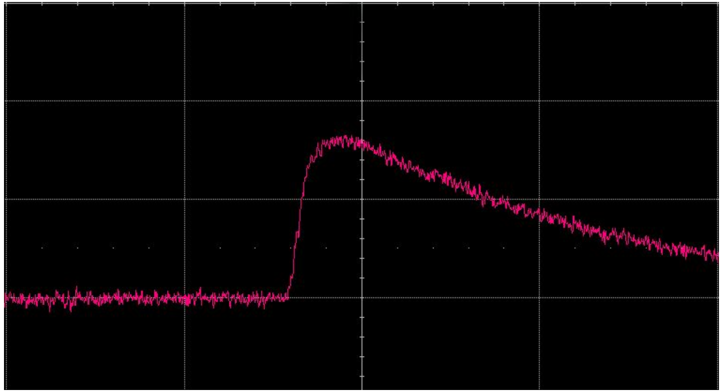
- JINR-produced fast scintillator
  - Polystyrol + 1.5% p-terphenil and 0.01% POPOP
- Hamamatsu S13360
  - 6x6mm sensitive area
  - 41% quantum efficiency
  - $1.7x10^6$ gain
- Variants with different scintillator sizes
  - 40*40*25 mm³
  - 35*35*25 mm³
  - 30*30*20 mm³



Electronics

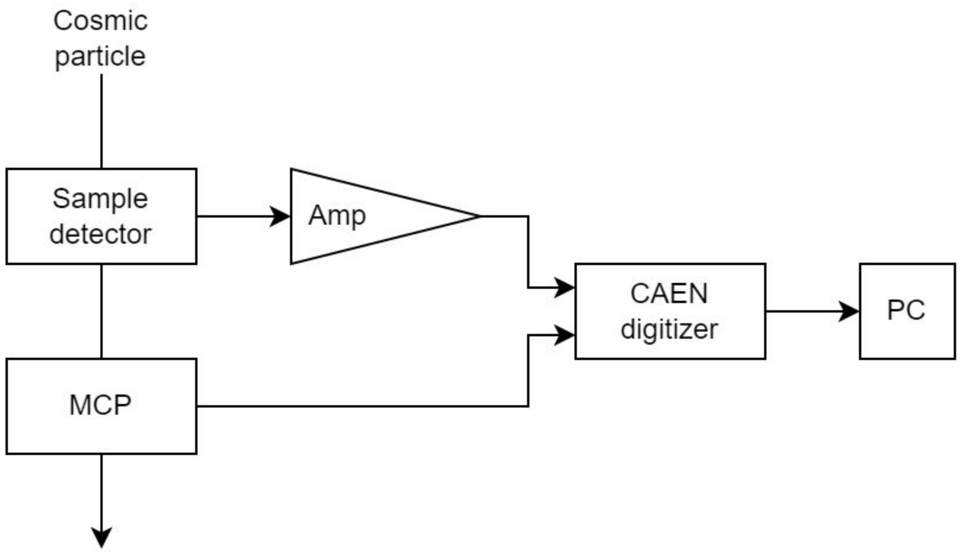
- Single channel amplifier developed
  - Preamp + line driver
- 20 dB amplification
- 600 MHz band
- <2.2 hV/√Hz noise
- ±2V dynamic range
- 50 Ohm single-ended output



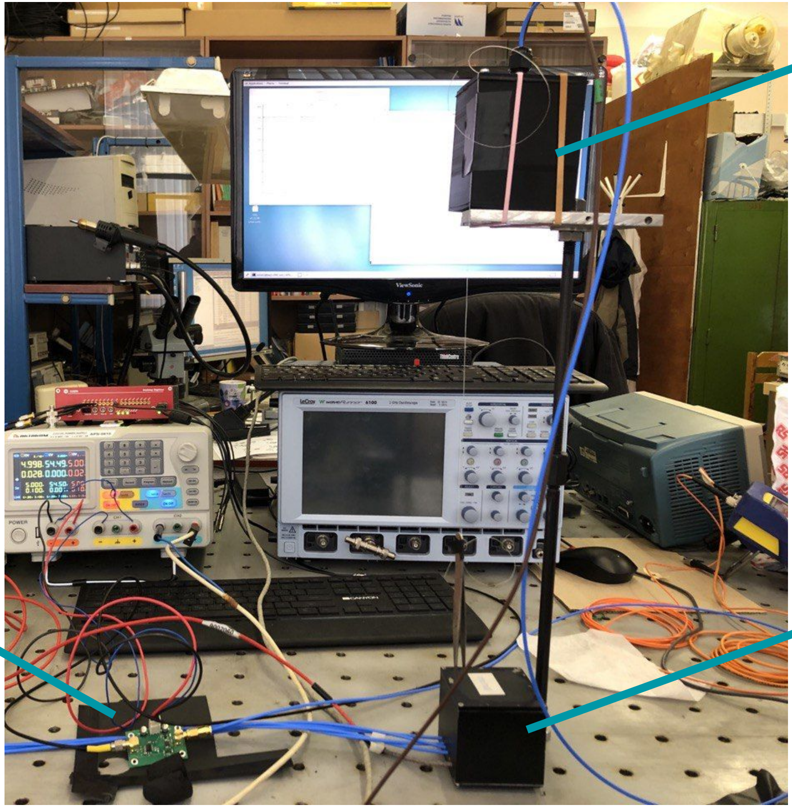


Measurement setup - cosmic rays

- Cosmic muon telescope
- MCP detector for trigger
  - Photonis FIT (ALICE T0 counter)
  - 18 ps best achieved resolution
  - Timestamp detector
- CAEN DT5742 digitizer
- 20-40 cm base
- ~1 day of exposure



Measurement setup - cosmic rays



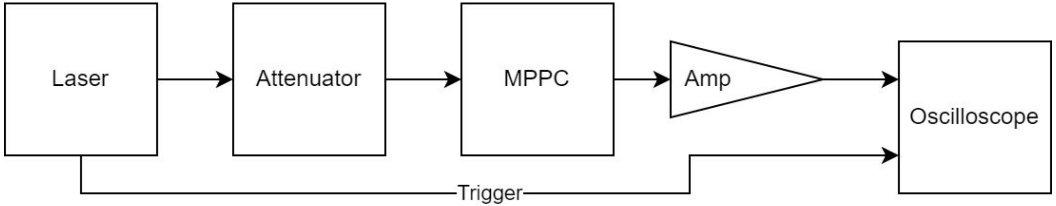
Sample detector

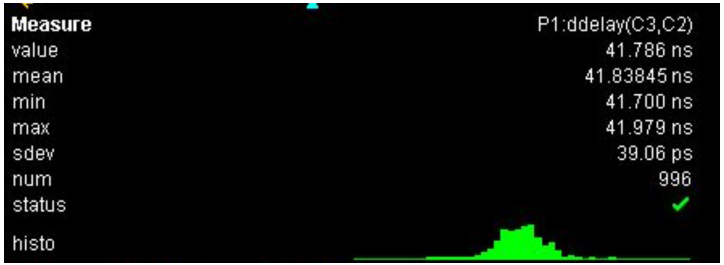
Sample detector amplifier

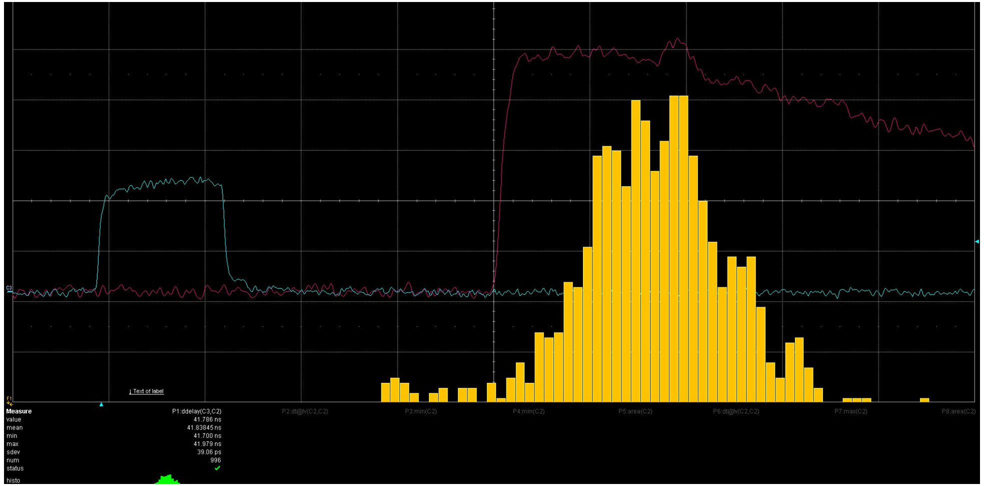
MCP FIT T0

Measurement setup verification - cosmic rays

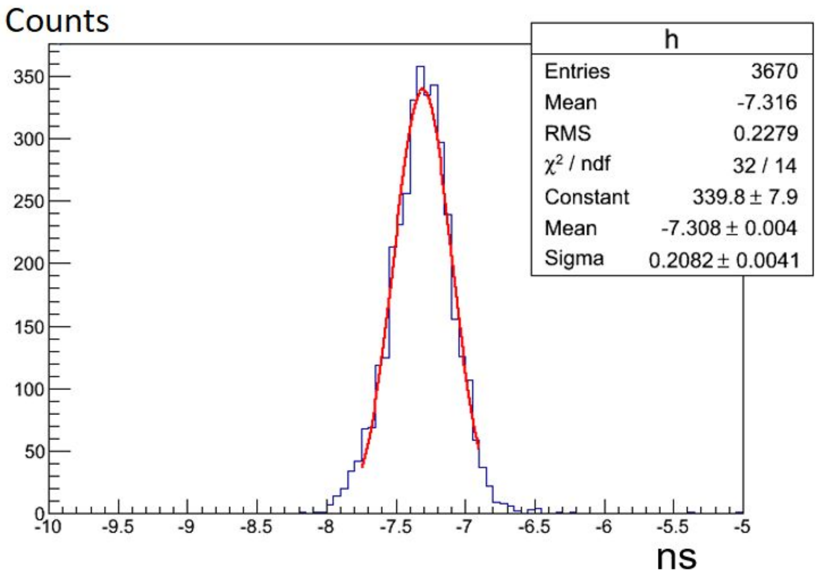
- MPPC irradiation with ps-scale laser
- 30-40ps setup resolution

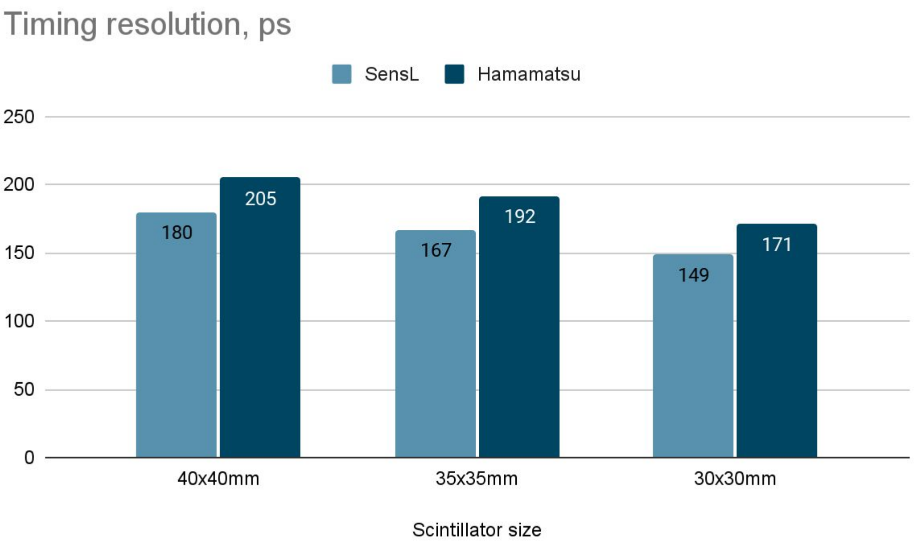






Measurement results - cosmic rays





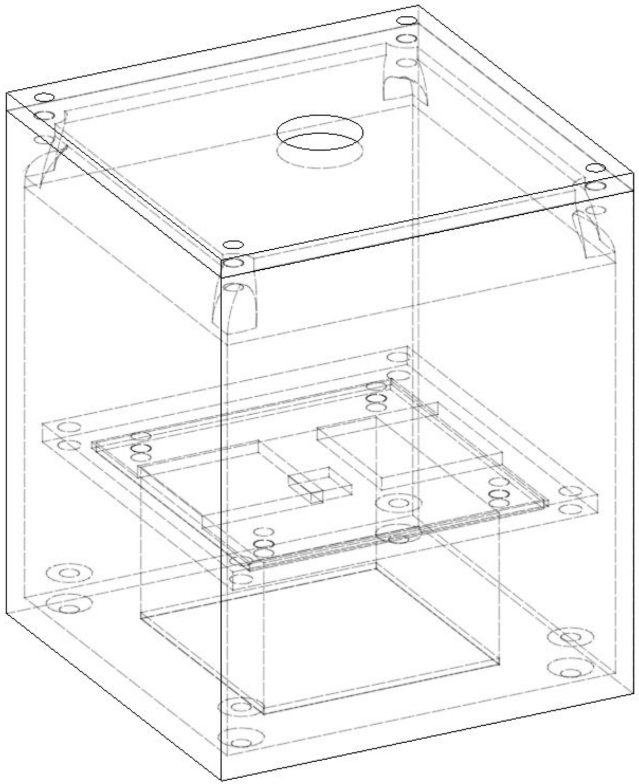
Conclusions

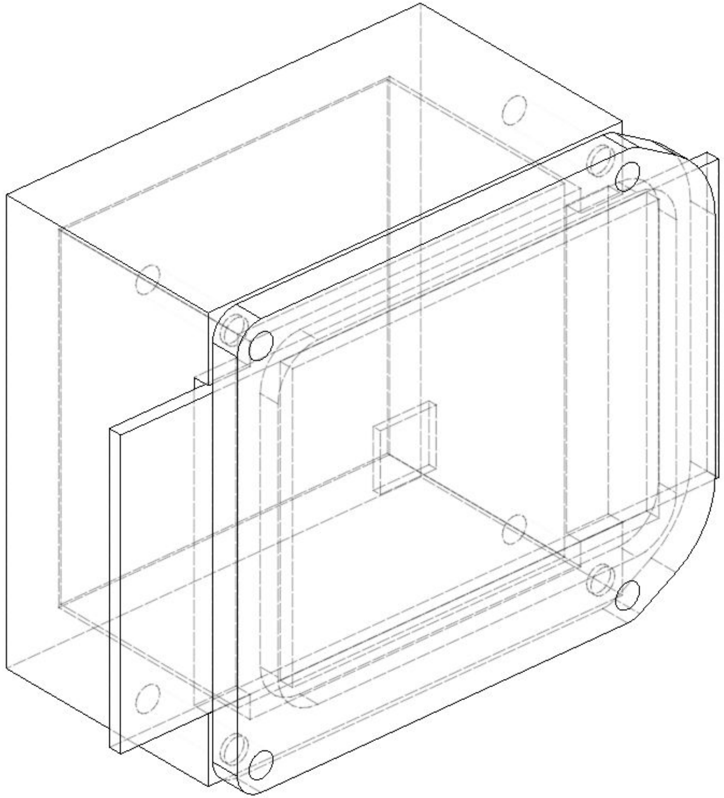
- Final detector design solution is mandated by the resolution vs cost compromise

- Current best result: 150ps with 30x30x25mm crystal and SensL MPPC
    - SensL MPPCs have a high price and low (if any) availability
- With the cost in mind, best solution is **40x40x25 with S13360 MPPC - 200 ps**
    - Small decrement in performance, but much better availability
- Possible compromise with 30x30x25mm crystal and S13360 MPPC - 170 ps

This work is supported by the RSF grant No 22-12-00132

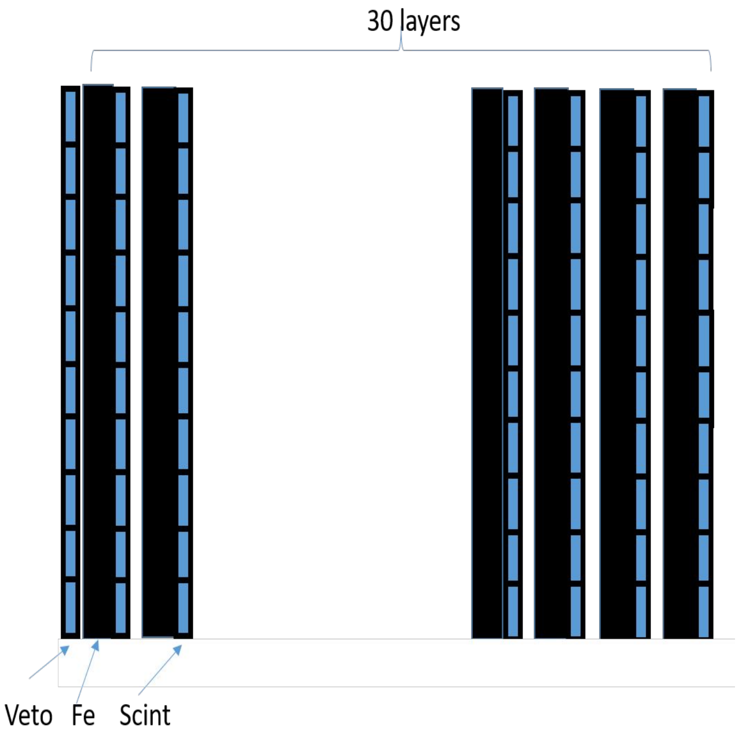
Sample detectors





Future ToF fast neutron detector: **nDet**

- Transverse size - 60 x 60 cm,
- 30 layers:
  - (Fe 1.6 cm + Sc 0.4 cm + Plastic 0.5 cm)
- 400 scintillator cells per layer
  - $4x4x0.4\ cm^3$
- Light readout from each cell by one SiPM directly coupled with scintillator
- Total number of cells in nDet: 12 400
- Total length of nDet ~ (3 λin)



Detection efficiency study

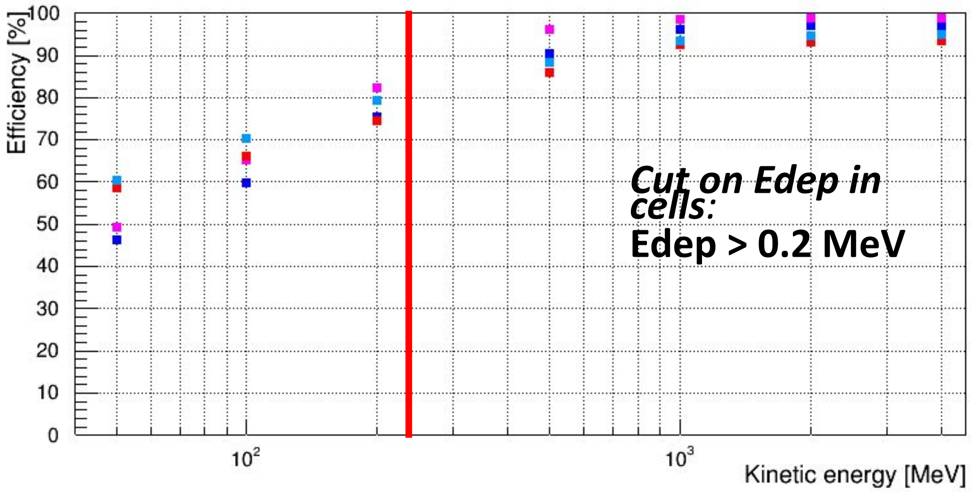
400 cells in one layer with transverse size 60 x 60 cm

30 layers
(Fe 1.6 cm + Sc 0.4 cm + Plastic 0.5 cm)
L= 75 cm (3.2 λ_{in})

30 layers
10 layers of (Fe 0.5 cm + Sc 0.4 cm + Plastic 0.5 cm)
+ 10 layers of (Fe 1 cm + Sc 0.4 cm + Plastic 0.5 cm)
+10 layers of)Fe 2 cm + Sc 0.4 cm + Plastic 0.5 cm)
L = 62 cm (2.4 λ_{int})

30 layers
10 layers of (W 0.5 cm + Sc 0.4 cm + Plastic 0.5 cm)
+ 10 layers of (Fe 1 cm + Sc 0.4 cm + Plastic 0.5 cm)
+ 10 layers of (Fe 2 cm + Sc 0.4 cm + Plastic 0.5 cm)
L = 62 cm (2.95 λ_{int})

25 layers
5 layers of (W 0.5 cm + Sc 0.4 cm + Plastic 0.5 cm)
+ 20 layers of (W 2 cm + Sc 0.4 cm + Plastic 0.5 cm)
L = 65 cm (4.55 λ_{int})



Taking into account the compromise between efficiency and cost, nDet with layers: Fe 1.6 cm + Sc 0.4 cm + Plastic 0.5 cm is considered as more optimal.