ENDA-INR extensive air shower experiment

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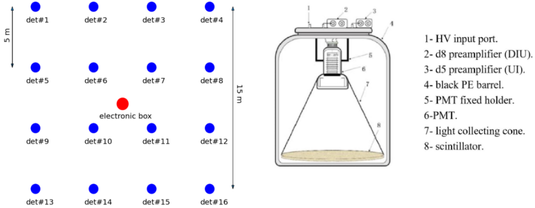
Outline

1. ENDA-INR
2. Registration methodology
3. Simulation and reconstruction of EAS
4. Preliminary results

ENDA-INR

ENDA-INR is a prototype of the ENDA cluster (consists of 16 en-detectors), located on the territory of INR RAS in Moscow. Used to study EAS (for energy above 1 PeV), testing registration methods and methods for signal processing.
Some parameters: array size - 15x15 m^2, neutrons recorded time interval: from 100 μs to 5 ms after EAS passage[1].

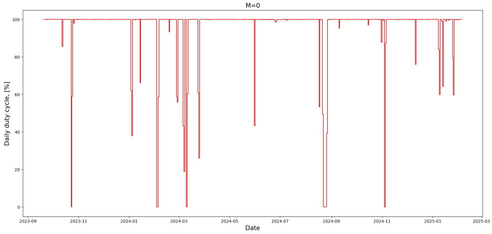
View of the array



ENDA-INR configuration and en-detector scheme

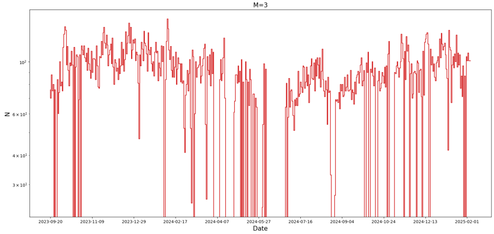
[1] Shchegolev O.B. et al. J. Phys. Conf. Ser. 1690 (2020). DOI: 10.1088/1742-6596/1690/1/012011

Prototype start working in data acquisition mode since September of 2021, since 20 September of 2023 all detectors works on Beijing Hamamatsu CR-165.

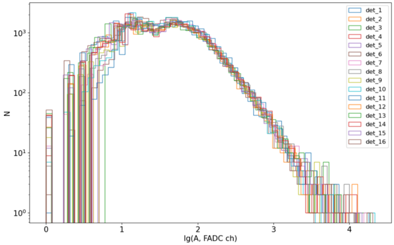


Daily duty cycle, %

Data from 20.09.2023 to 05.02.2025.
Duty cycle $\sim 96.1\%$.
Mean number of background neutrons per event - 0.47.
Delete unstable periods of array work, and events with noise.
Select events with number of triggered detectors ≥ 10 with $A \geq 6$mV.

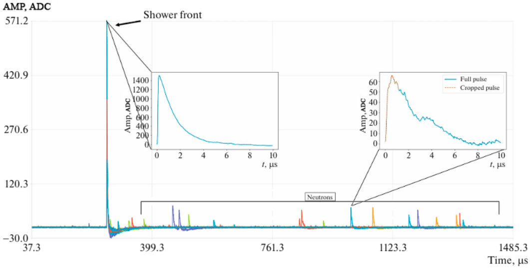


Counting rate of M3 trigger

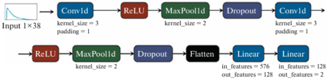


Pulse height spectra

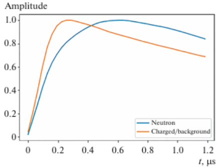
Selection signals from thermal neutrons



Waveform of an EAS event.



CNN architecture[a].

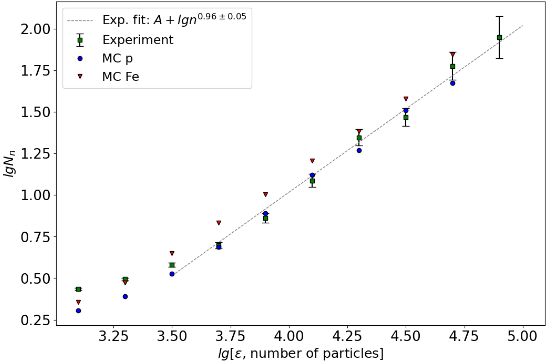


The profile of the pulse front

[a] Kurinov K. O. et al. JETP 136 (2023). DOI: 10.1134/S1063776123040039

Simulation

EAS simulation: CORSIKA-7.56, EGS4 option, (QGSJET-II-04 and GHEISHA). Tresholds: $\gamma, e^{\pm}, \pi^0$: 60 keV, μ : 100 MeV, h : 50 MeV.Altitude 170 m above sea level. Primary energy range 1 ÷ 100 PeV. The zenith angle range: 0 ÷ 45. Primary particles: p, He, N, Fe.
Detector simulation: Fast simulation program that based on Geant4 simulation program.



Dependence of N_n from total energy deposit

Reconstruction (EAS parameters)

Maximum Likelihood Estimation with Lagutin (Uchaikin) modification function:

$\rho_e(r, s_\perp) = m^{-2}\rho_{NKG}(\frac{r}{m}, s_\perp)$ where m $=$ 0.78 - 0.21 $s_\perp$ and 0.6 $\leq s_\perp \leq$ 1.8.

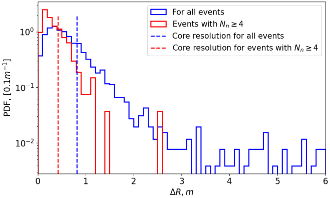
Selection:

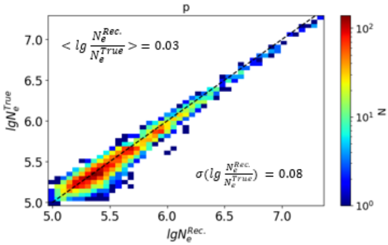
$N_{trig} \geq 10\,\text{det}, A > 18$ MIP;

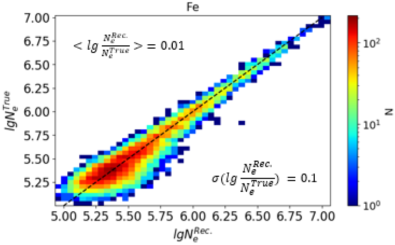
Shower core reconstructed inside the array borders.

$\Delta R = \sqrt{(x^{Rec} - x^{True})^2 + (y^{Rec} - y^{True})^2}$;

Core resolution - 1.05 m (quantile 68% of ΔR).

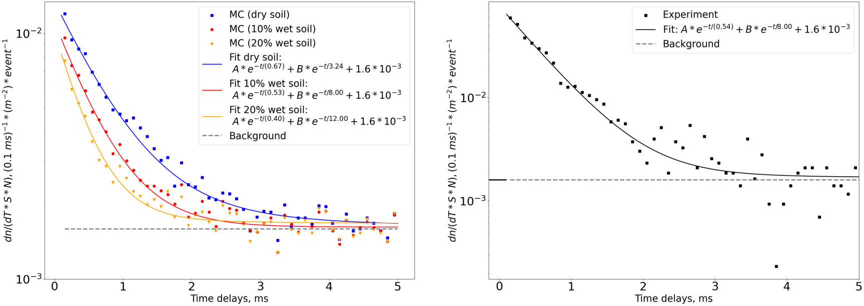






Experimental results (neutrons time distributions)

Time distribution of thermal neutrons can be described as: $y_t = A * e^{-t/\tau_1} + B * e^{-t/\tau_2} + C$, where $\tau_1 = 0.54$ ms, $\tau_2 = 8.00$ ms, $C = 1.6 * 10^{-3}\ ms^{-1}m^{-2}$.
Dashed line - background estimated by zero master $= 0.47\frac{n}{event}/S_{det}/N_{det}/Time^{reg} = 1.6 * 10^{-3}\ ms^{-1}m^{-2}$, bin width - 0.1 ms.
Flux of thermal neutrons on the sea level $\sim 10^{-3}\ cm^{-2}s^{-1}$.[2]



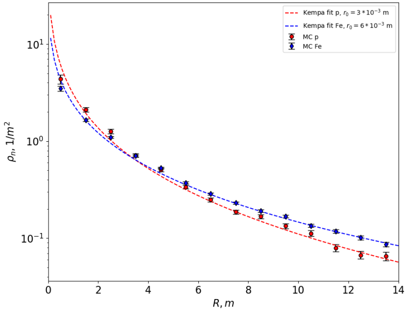
Time distributions

[2] Gromushkin D. M. et al. Bulletin of the Russian Academy of Sciences: Physics. T 73, (2009).

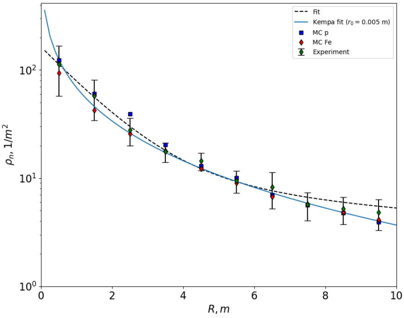
Neutrons Lateral Density Function (LDF)

LDF can be described by double exponential function: $\rho_n = A * e^{-R/r_1} + B * e^{-R/r_2} + C$,
where $r_1 = 1.24$ m, $r_2 = 6.01$ m.
PRISMA-32: $r_1 = 1.4$m, $r_2 = 8.2$ m.
Kempa fit - theoretical LDF for hadrons in EAS[3].

Background - (Poisson [$\mu = 0.47$]).



Simulation



Experiment and simulation with background

[3] Kempa J., Nuovo Cimento 31A (1976) 568 and 581.

Conclusions

- ENDA-INR works in stable data acquisition mode.
- Neutrons time distribution, dependence of total energy deposit from the number of registered neutrons and lateral density function of neutrons have been obtained.
- Results showed good agreement with the simulation results and also with the data previously obtained at the PRISMA-32[4].

[4] Gromushkin D. M., Volchenko V. I., Petrukhin A. A., et al., Phys. At. Nucl. 78, 349, (2015).

Thanks for your attention!