INVESTIGATION OF T(^{1}H, γ)^{4}He REACTION IN THE ASTROPHYSICAL ENERGY RANGE

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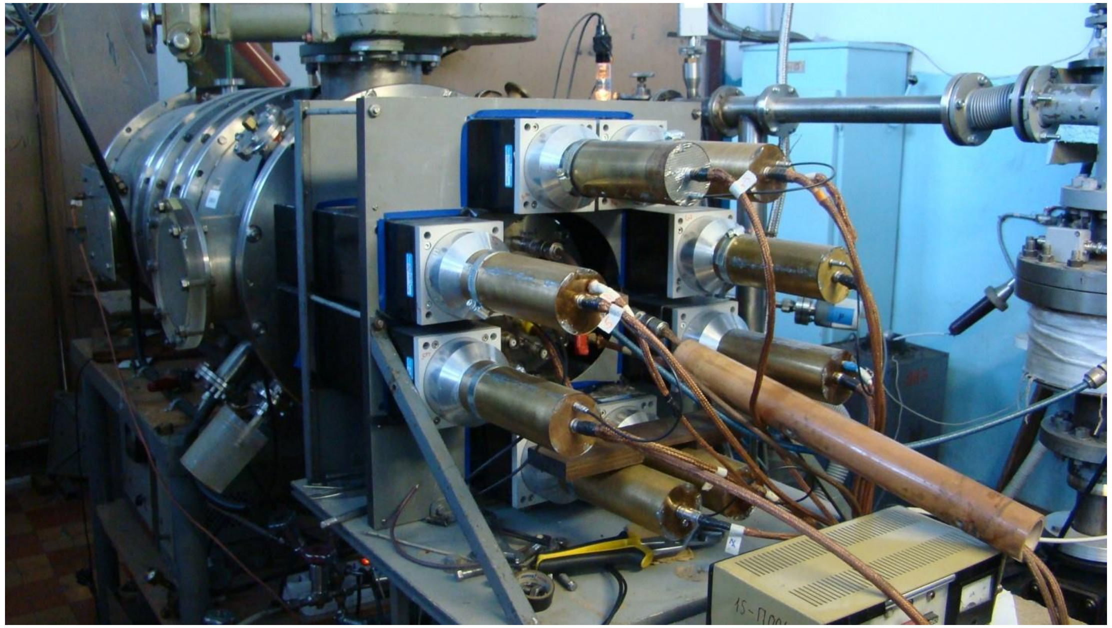
Investigation goal

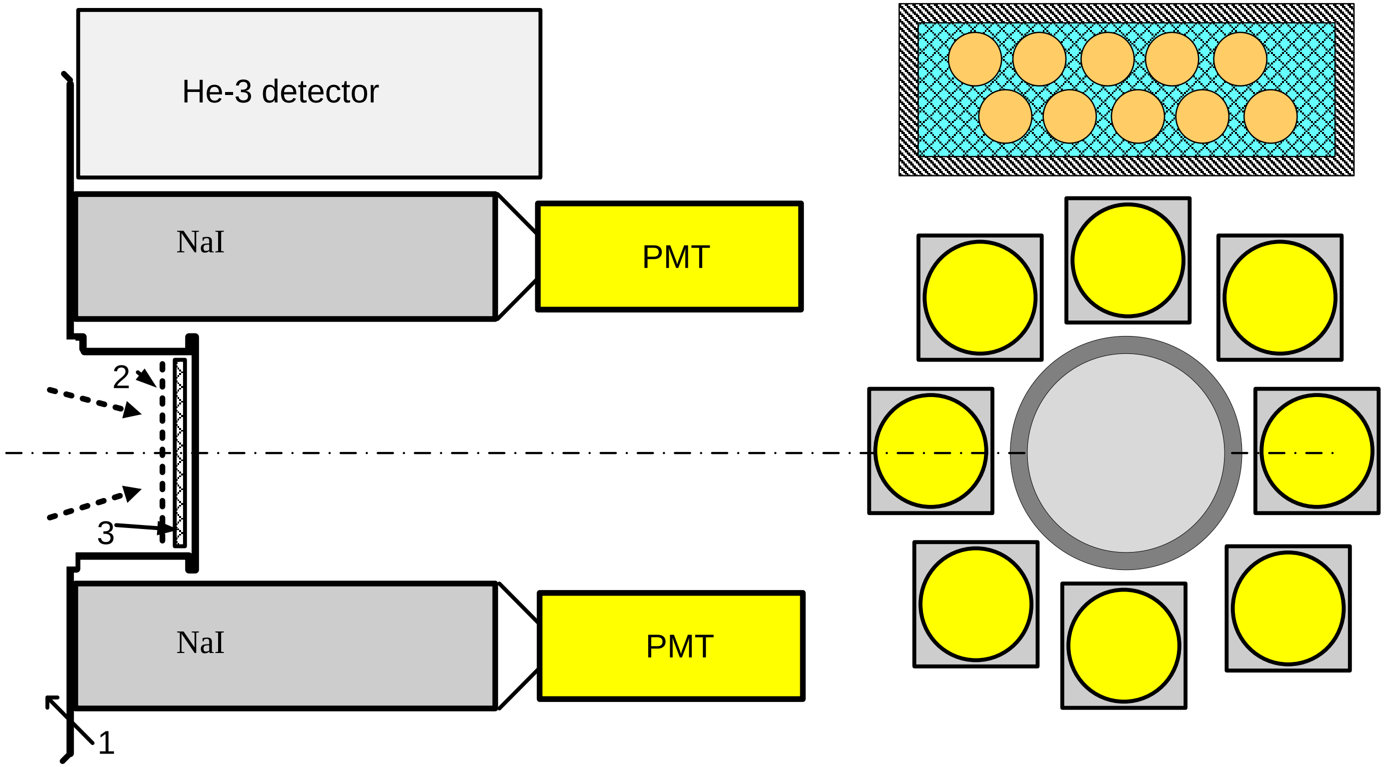
- It is necessary to get more accurate data describing ^4He-producing reactions rates in primordial synthesis;
- A discrepancy for $T(H,\gamma)^4He$ reaction S-factor parametrizations is present in astrophysical energy range(tens of keV);
- Parametrizations are described in following works:
  - *R.S. Canon. Phys Rev. C 65 (2002) [1]*
  - *B. Dubovichenko. Nucl. Phys. A 963 (2017) [2]*
- The behavior of $T(H,\gamma)^4He$ reaction S-factor in astrophysical energy range should be determined experimentally



IDM-40 pulse Hall accelerator with the assembly of 8 NaI(Tl) detectors

Experimental equipment

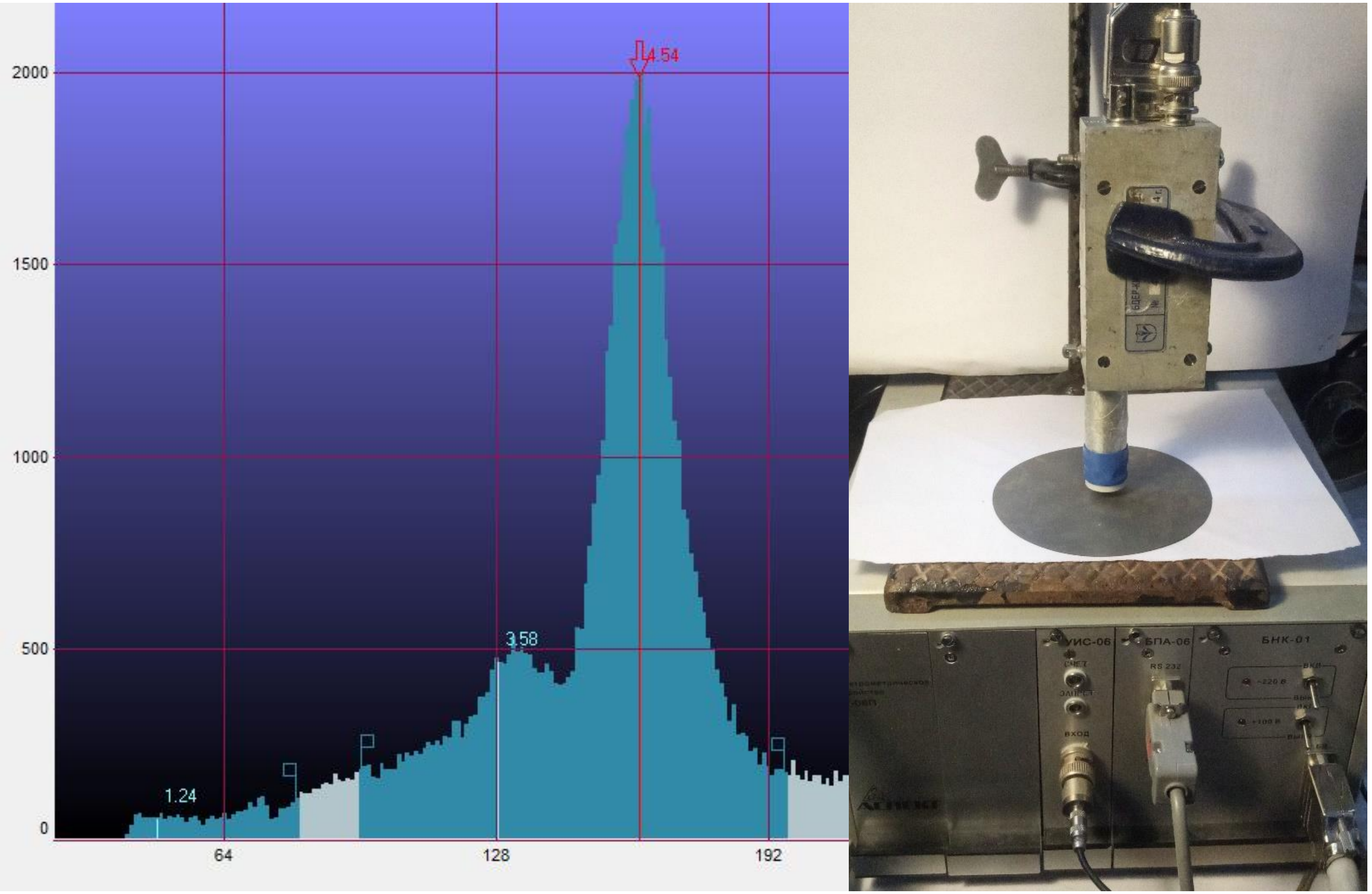
- Pulse Hall accelerator IDM-40 [3];
- Energy range in the experiment is 12 – 34 keV (lab. RF) = 7.8 – 20.1 keV in center-of-mass RF;
- 8 NaI(Tl) detectors placed around the target chamber;
- Neutrons ^{3}He detector used to detect neutrons generated in side reactions with tritium;
- Quadrupole mass analyzer controls the composition of residual gases;
- Accelerating impulse duration is 10 μs;
- Background signal is suppressed due to accelerator pulse operation mode;



1 – IDM-40 accelerator; 2 – grid; 3 – TiT target; NaI – NaI(Tl) detectors; PMT – photomultiplier tubes connected to the NaI(Tl) detectors

Tritium targets

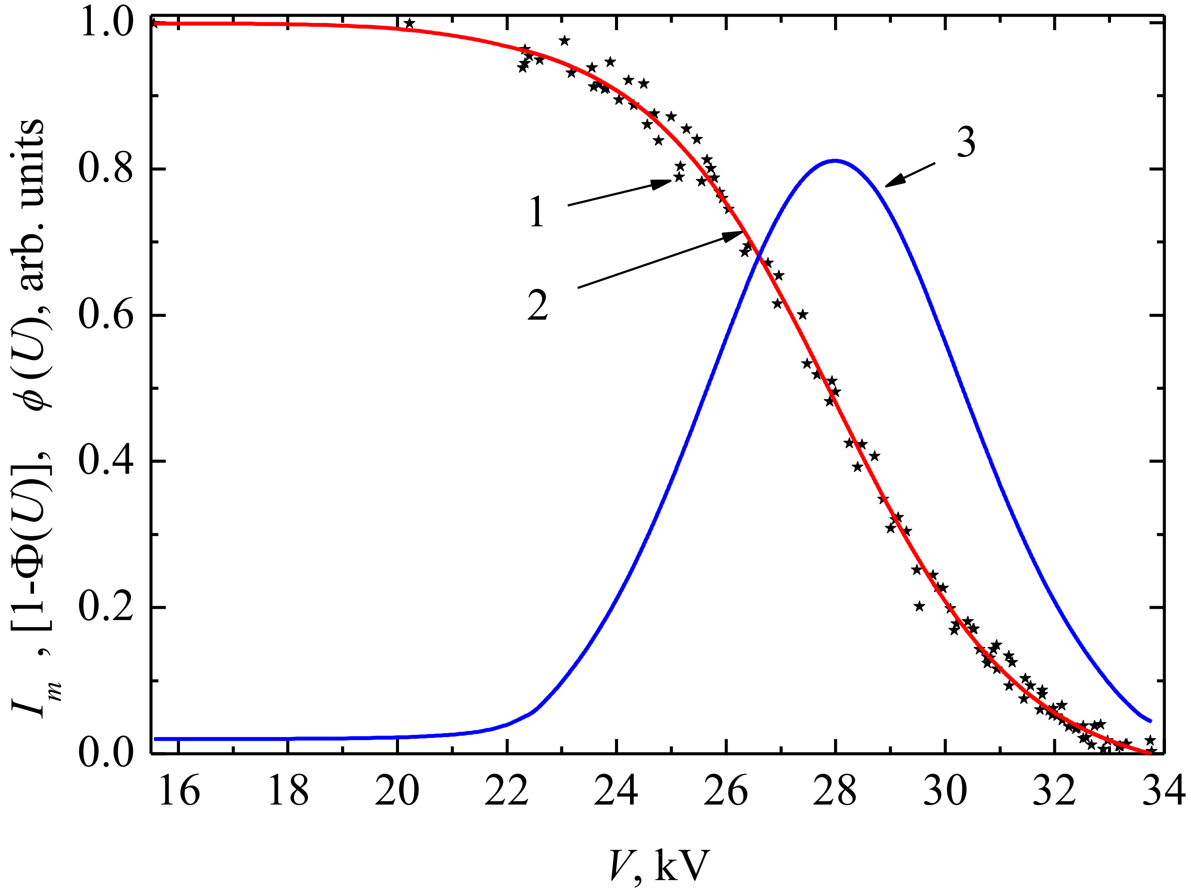
- TiT coating width is 1.5 µm
- Tritium distribution over coating depth – RBS + ERD (elastic recoil detection) techniques;
- Tritium distribution over target area – by analyze of Ti K-lines X-ray intensity;
- Ti characteristic X-ray emission is caused by tritium decay electrons
- The coating is saturated by T over targets area with maximal inhomogeneity 7%



Left side – a typical Ti X-ray spectrum; left 3.58 keV peak is the maximum in tritium decay electrons spectrum; right 4.54 keV peak corresponds to Ti unresolved K_α и K_β; right side – X-ray semiconductor detector mounted over the target

Beam ions energy spread

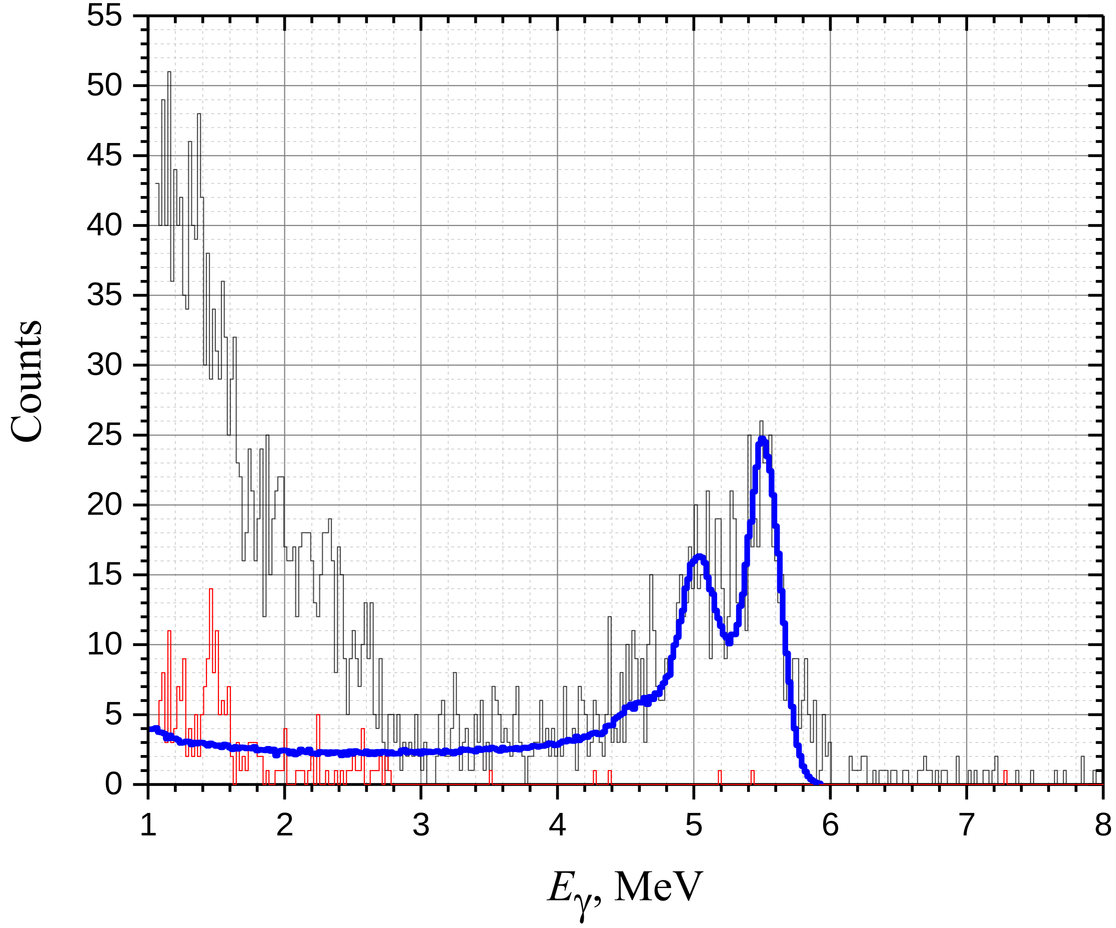
- $\sim 5 \cdot 10^{14}$ incident ions to the target in every pulse;
- Energy spread of incident ions was measured using multigrid electrostatic spectrometer;
- Target current (a number of incident ions) was measured with different cutoff voltage values on spectrometer grids;
- Incident ions spectrum was obtained by differentiating target current dependence on cutoff voltage
- Beam energy spread function is a Gaussian with FWHM(E) = 16%
- Still tens of keV energies!



Experimental dependence of target current on grid cutoff voltage: 1 – experimental values; 2 – target current values approximation; 3 – obtained energy spectrum of hydrogen ions. Accelerating voltage is 28 keV.

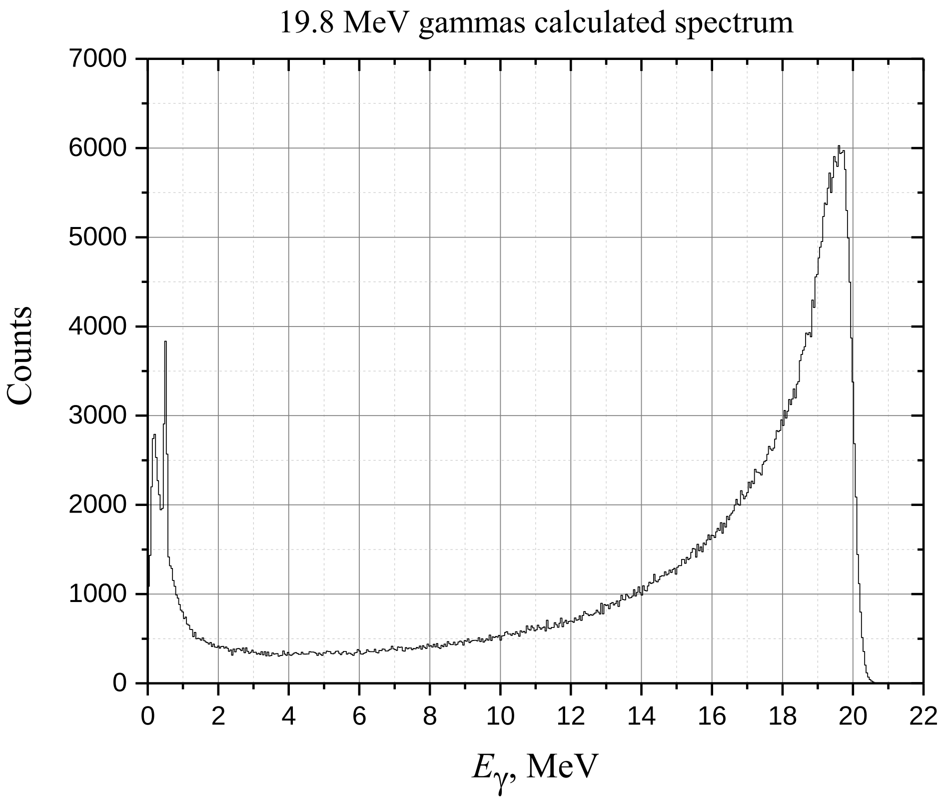
Detectors assembly simulation in Geant4

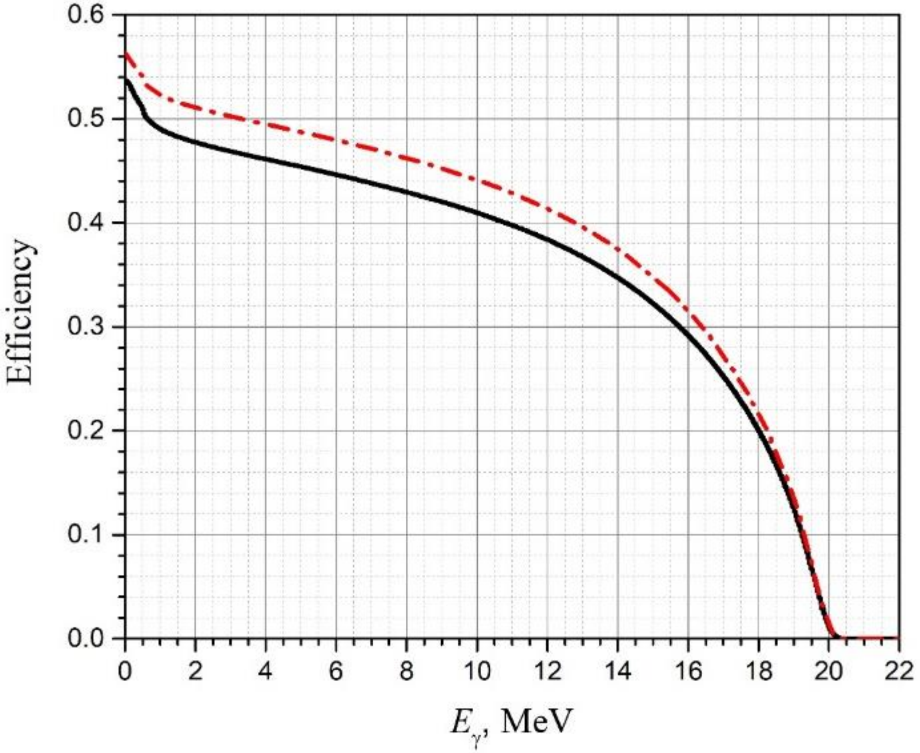
- A detector assembly simulation was created in Geant4 toolkit;
- In this simulation experimental spectra for 19.8 MeV γ quanta were simulated with registration efficiency determined;
- The proper work of the simulation code was proven by comparison of simulated spectra with experimental one for $E_\gamma = 5.5$ MeV (from pd reaction)



Experimental (grey line) and calculated (blue line) spectra for 5.5 MeV gammas from $\mathrm{d}(H,\gamma)^3He$ reactions. Background counts are red.

Simulated spectra, 19.8 MeV





- For 19.8 MeV gammas an analogue of instrumental spectrum was simulated (left side);
- Gamma quanta registration efficiency curves were calculated;
- An anisotropy of gammas from $T(H,\gamma)^4He$ reaction was taken into account - *R.S. Canon. Phys Rev. C 65 (2002*)
- 19.8 MeV registration efficiency curves (right side): solid line – for isotropic emission of gammas; dash-dotted line – for anisotropic one

Neutron background problem

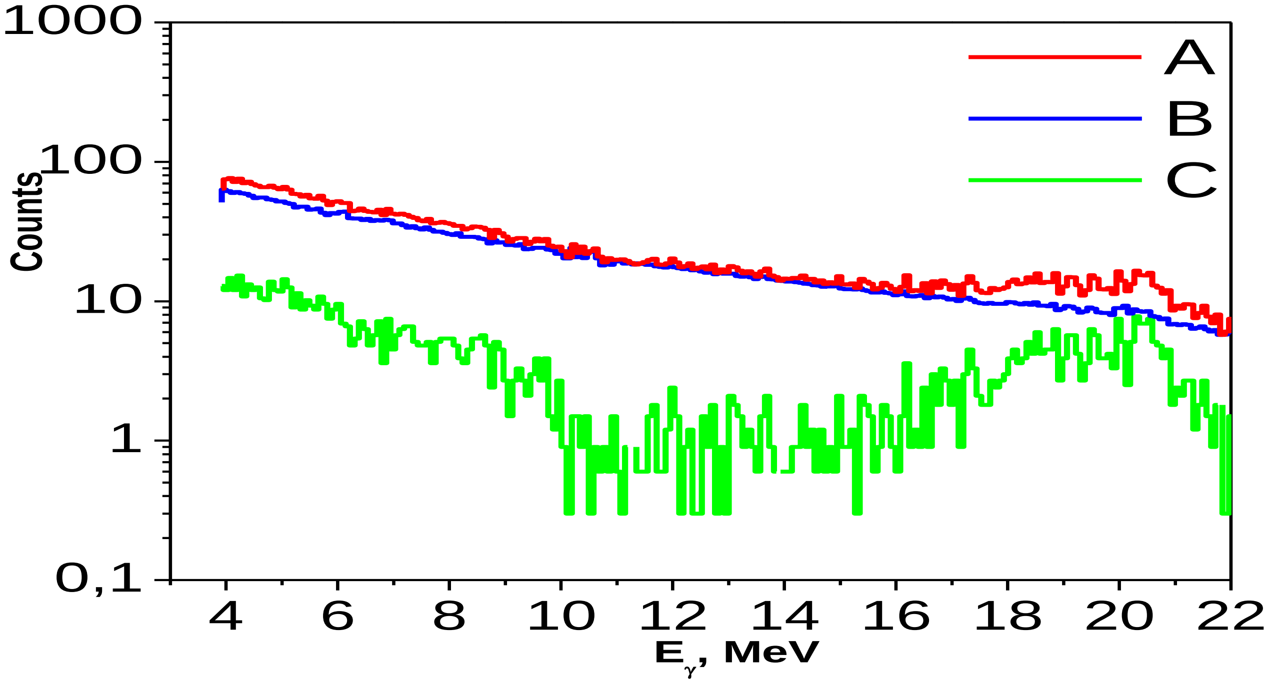
- The following side reactions may be caused by incident ions beam:

$T(T, nn)^4He$, $T(T, n_1)^5He^*$,

$T(T, n_0)^5He$, $T(^2H,n)^4He$

- Neutrons are detected by ^3He detector;

- Neutron-induced reactions gamma spectrum is obtained by changing of accelerating H ions to ^4He but for the same number of registered neutrons



Gamma quanta spectra: top spectrum (red line A) is $T(^1H,\gamma)^4He$ reaction yield; mid spectrum (blue line B) is $T(^4He,\gamma)X$ side reactions yield; bottom spectrum (green line C) is the difference of spectra

Results discussion

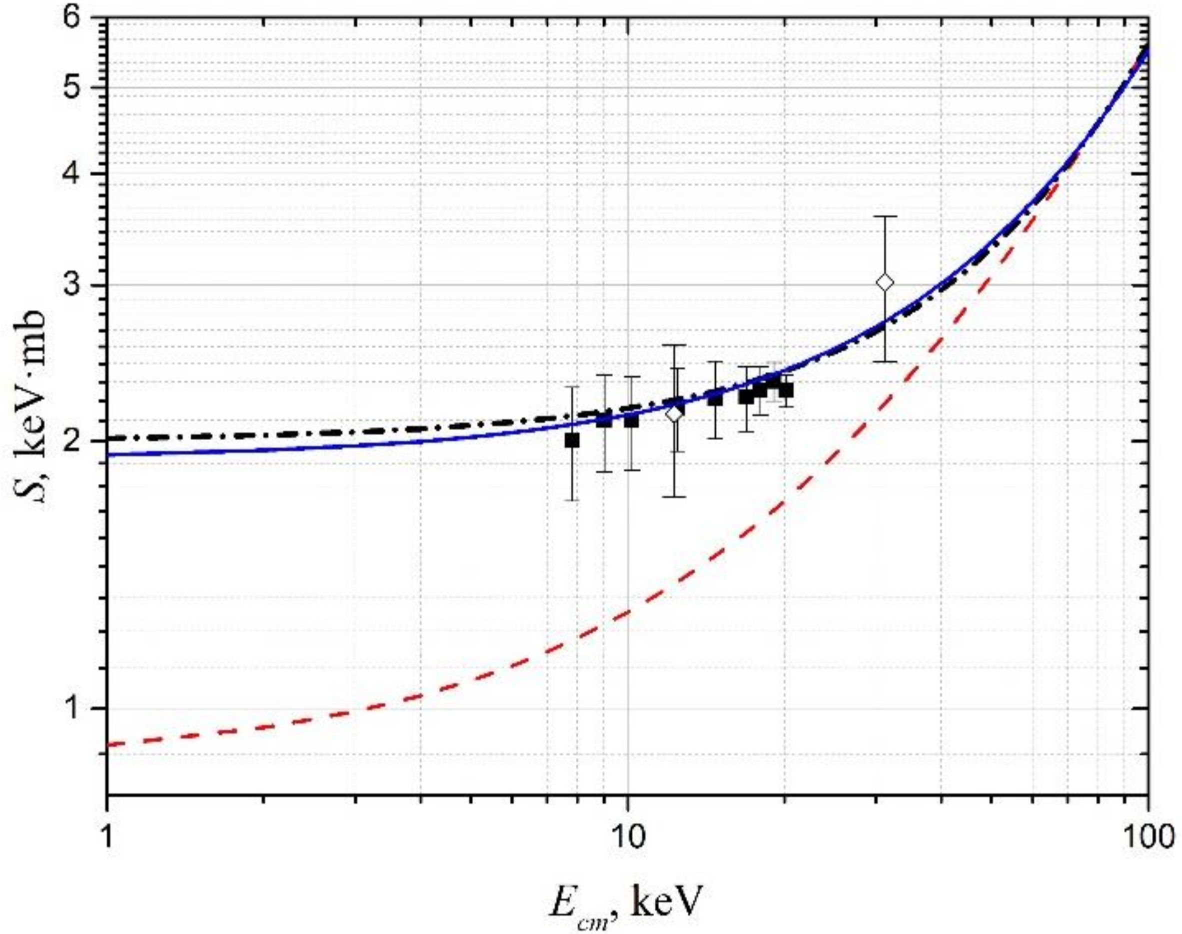
Experimental data was processed in correspondence with equations described in *V.M .Bystritsky and F.M. Pen'kov. Physics of Atomic Nuclei 66 (1) 75 (2003) [4].*

Experimental data parametrization by 2nd order polynomial with the coefficients:

$$S_0 = (1.91 \pm 0.27)\ keV\ mb;\ \ S_1 = (2.19 \pm 1.67) \cdot 10^{-2}\ mb;$$

$$S_2 = (1.41 \pm 0.83) \cdot 10^{-4}\ \frac{mb}{keV}$$

- corresponds well with experimental parametrization [*R.S. Canon. Phys Rev. C 65 (2002)] ([1])* - (dash-dotted line and 2 blank diamonds);
- Significantly differs from theoretical model from *B. Dubovichenko. Nucl. Phys. A 963 (2017) ([2])* (dashed line), that was obtained by calculations



T(^{1}H,γ)^{4}He reaction S-factor dependence on effective energy of collision $E_{col.}$ Filled squares are our experiment, blank diamonds – *[R.S. Canon]*., solid line – our parametrization of S-factor, dash-dotted line – *S*-factor *[R.S. Canon]*, dashed line – *S*-factor *[B. Dubovichenko]*

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