The XXVII International Scientific Conference
of Young Scientists and Specialists (AYSS-2023)

Scintillation Detectors Array GADAST and the Investigation of Proton Radioactivity Reactions

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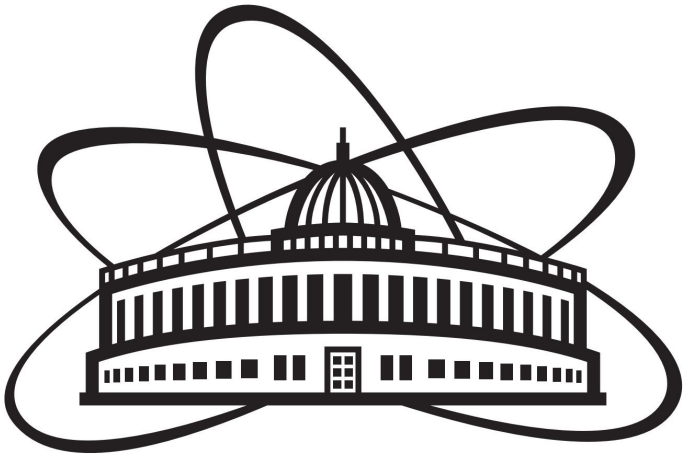
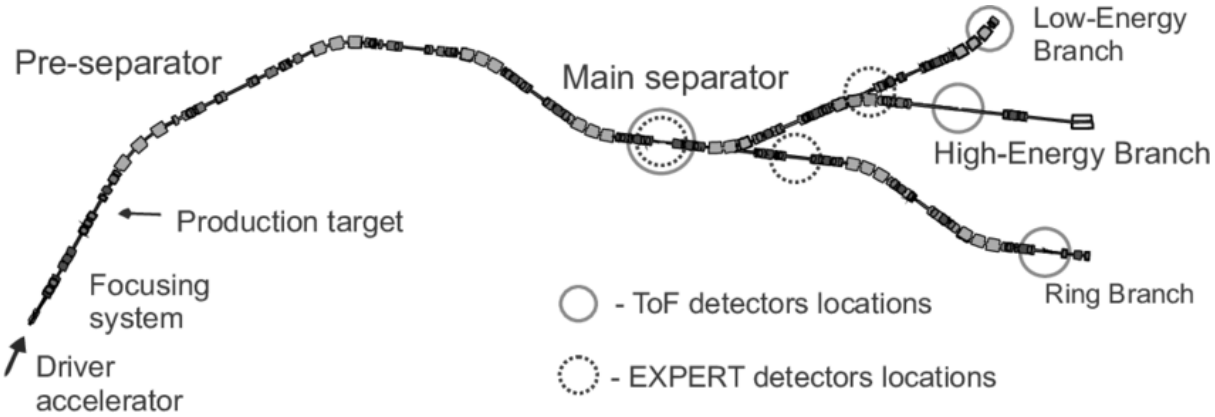
Intern researcher, JINR, Flerov's Laboratory of Nuclear Reactions, Department №6 "Structure of light exotic nuclei"



- **SuperFRS** (Superconducting FRagment Separator) Experiment Collaboration
- **EXPERT** (EXotic Particle Emission and Radioactivity by Tracking) project

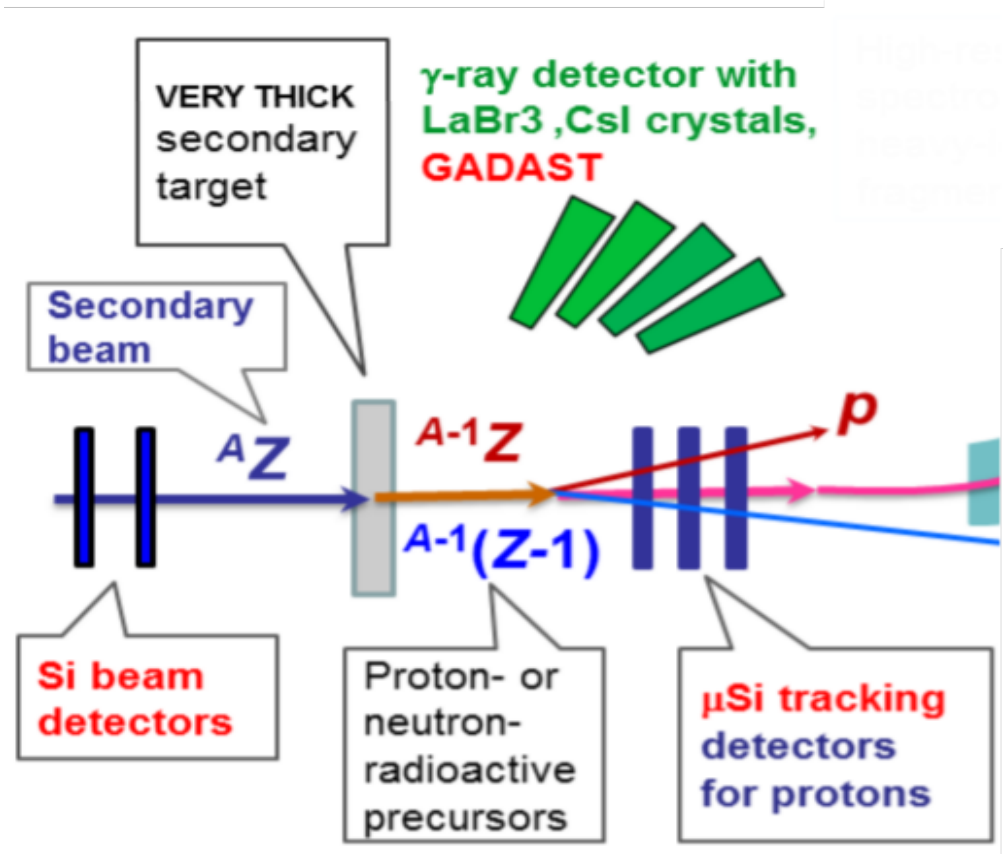


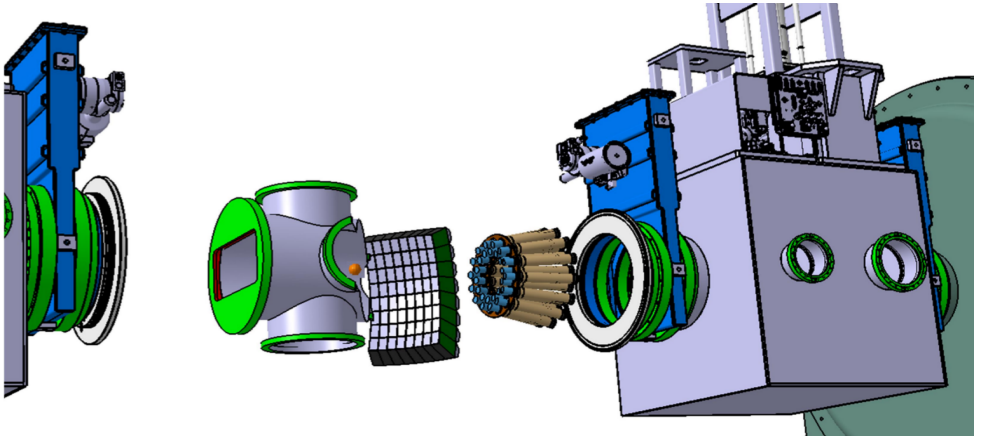
SuperFRS

Physical interest of EXPERT

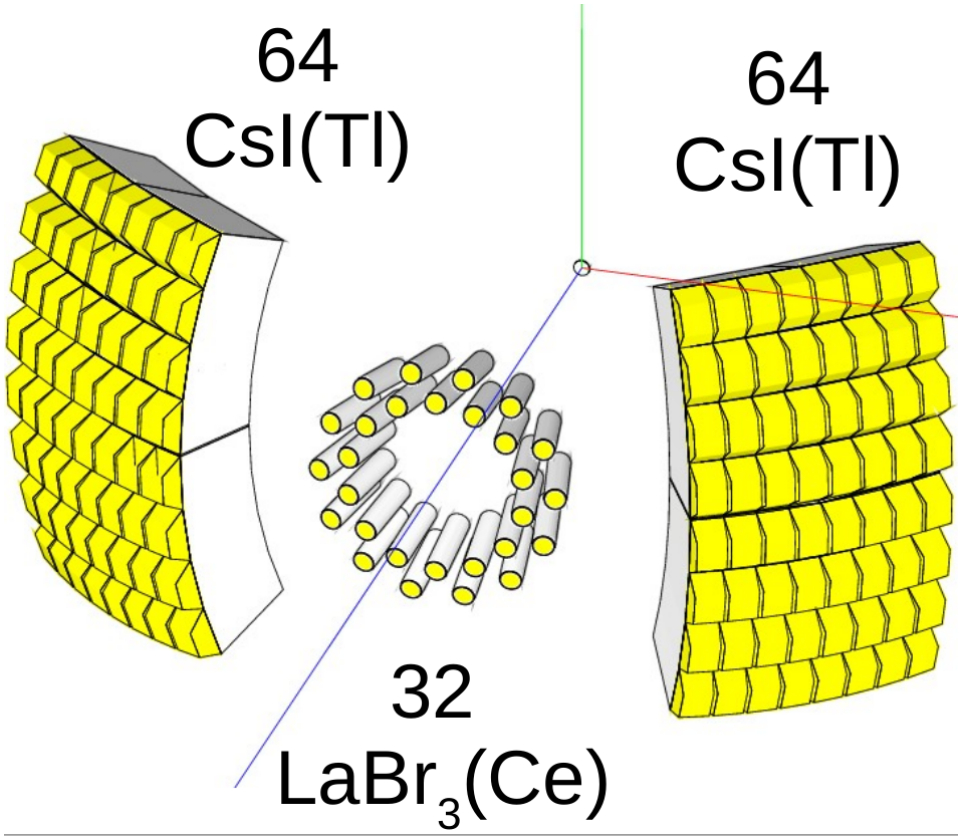
- Studies of the unknown exotic nuclear systems near proton and neutron driplines;
- Studies of p, $2p$, $4p$, $6p$, n, $2n$, $4n$, $6n$ (exotic radioactivity) resonance decays and spectroscopy of continuum states;
- Studies of beta-delayed particle (multi-particle) emission from exotic isotopes.

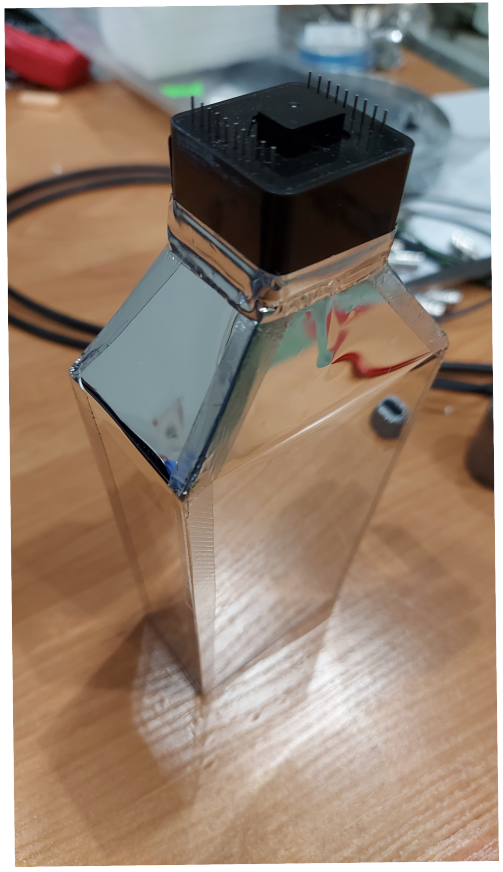
EXPERT experiment setup





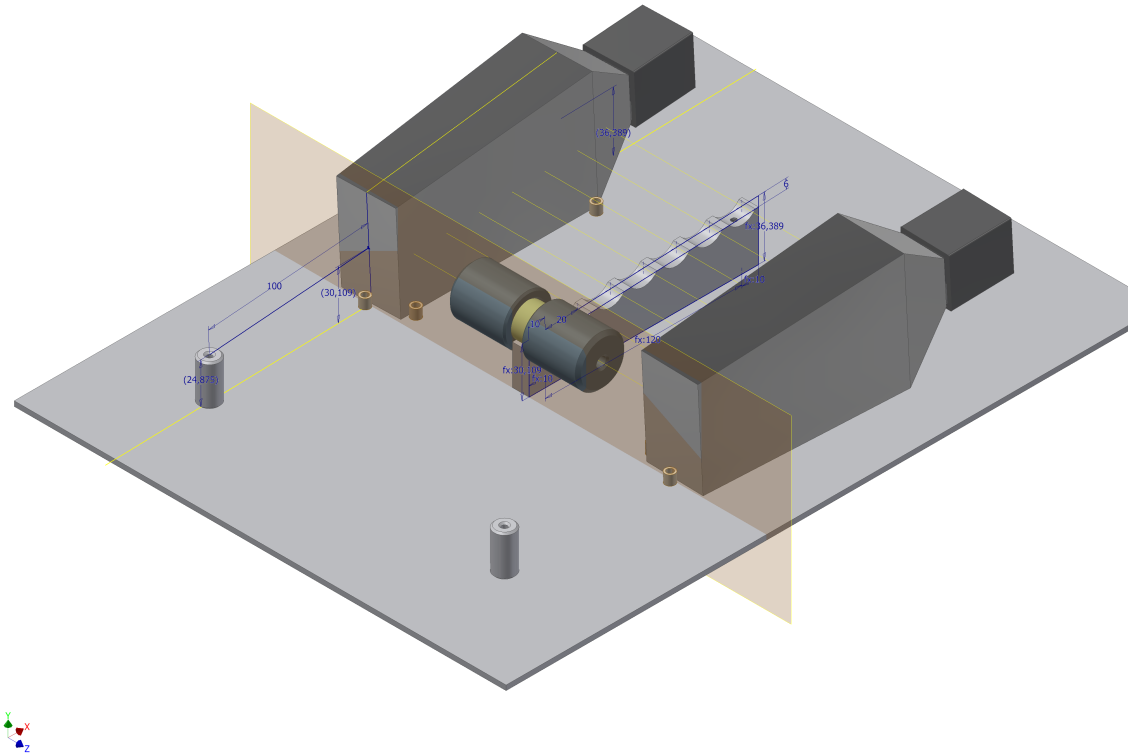
GADAST (GAmma-ray Detector Around the Secondary Target)





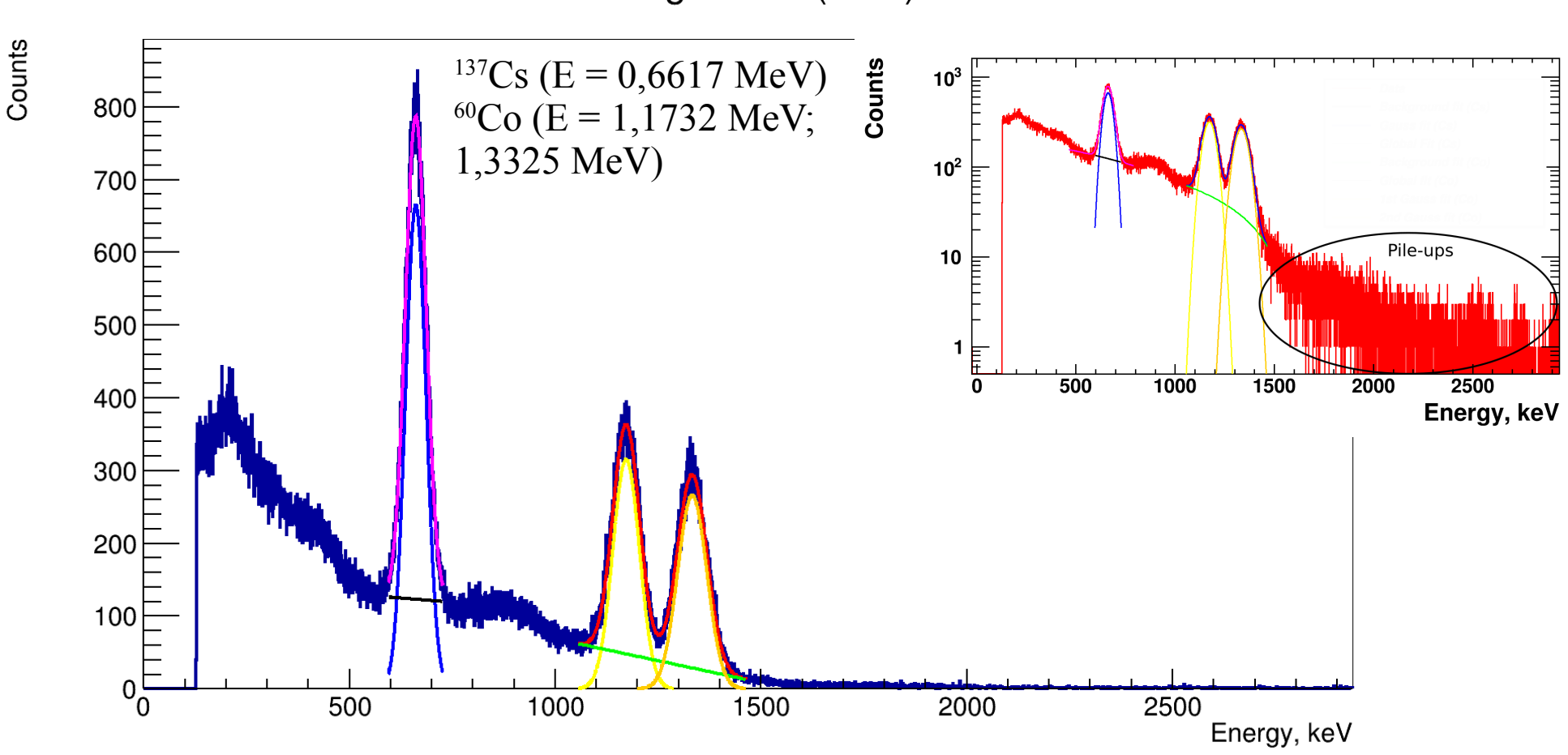
32 CsI(Tl) modules as in-kind contribution from Czech Republic to FAIR

GADAST measurement tests



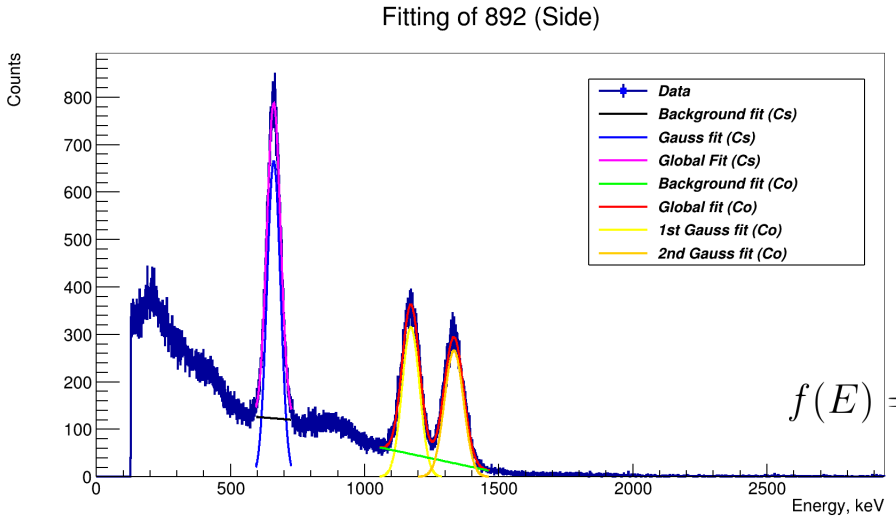
Conducted at Heavy Ion Laboratory of Warsaw University

Experimental data analysis



Experimental data analysis

typical energy resolution of such scintillation detectors is ~8% FWHM at 1 MeV for crystals uniformly irradiated by gamma-rays



The light output non-uniformity shall not exceed 5%

^{137}Cs:

$$f(E) = A \cdot \exp\left(-\frac{1}{2}\frac{(E-\mu)^2}{\sigma^2}\right) + (aE+b)$$

^{60}Co:

$$f(E) = A_1 \cdot \exp\left(-\frac{1}{2}\frac{(E-\mu_1)^2}{\sigma_1^2}\right) + A_2 \cdot \exp\left(-\frac{1}{2}\frac{(E-\mu_2)^2}{\sigma_2^2}\right) + (aE+b)$$

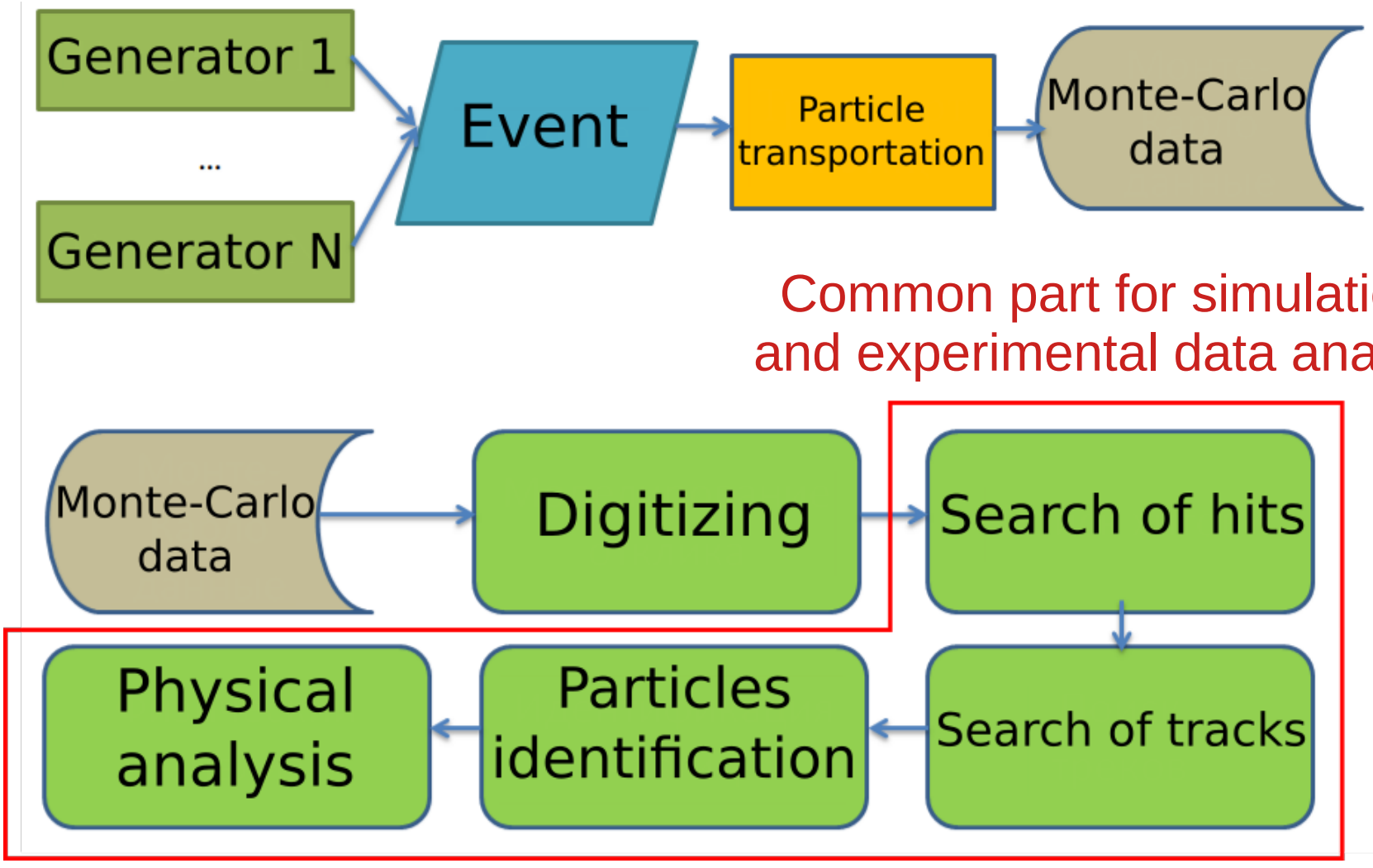
Energy resolution (1 MeV):
Average – 7.47%
Best – 6.435%

Light output non-uniformity (661 keV):
Average – 1.2%
Best – 0.57%

ExpertROOT

- Framework based on FairRoot;
- Includes GEANT4, ROOT, …;
- Developed for the needs of EXPERT and ACCULINNA-2 (JINR);
- Intented for common tasks of experimental nuclear physics: simulation, reconstruction, data acquisition, analysis.

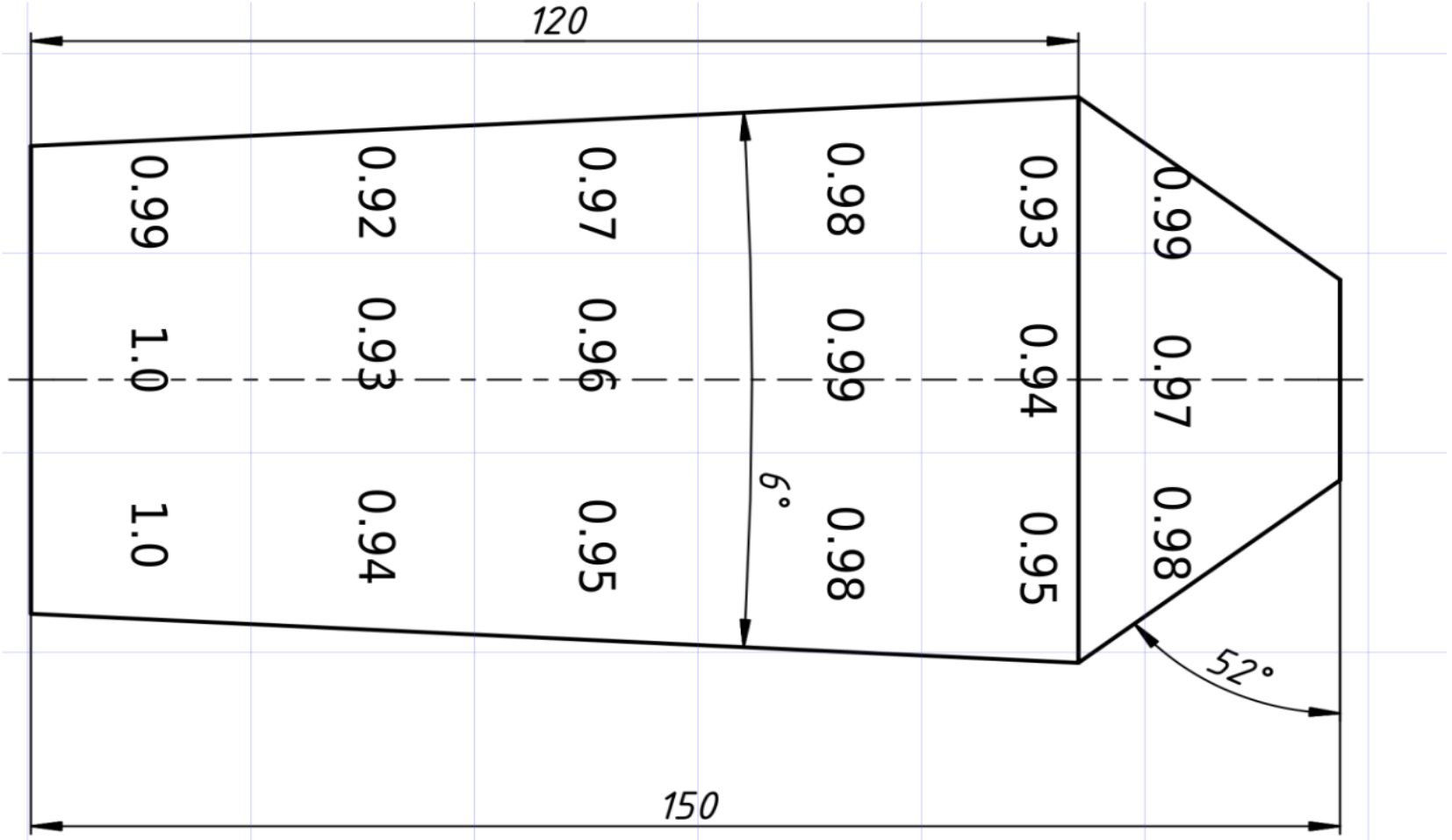
ExpertROOT workflow



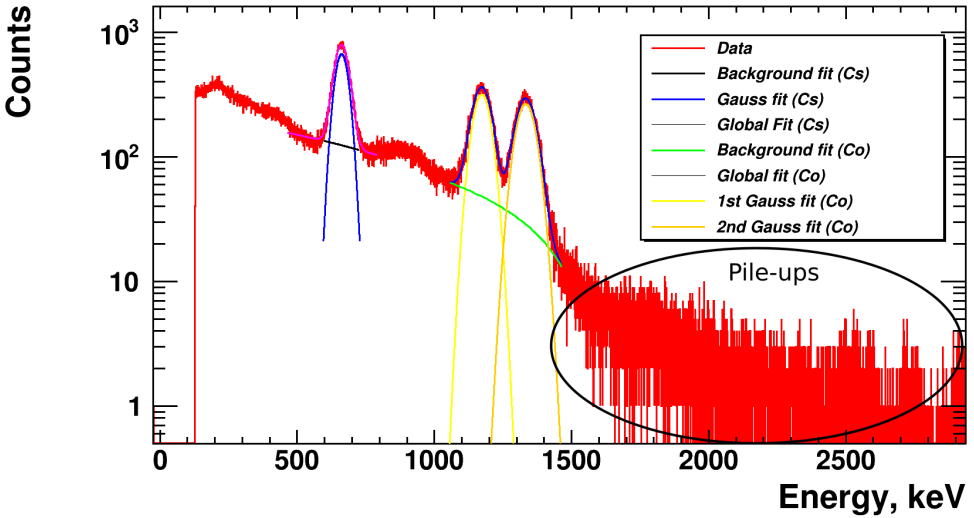
GADAST simulation model

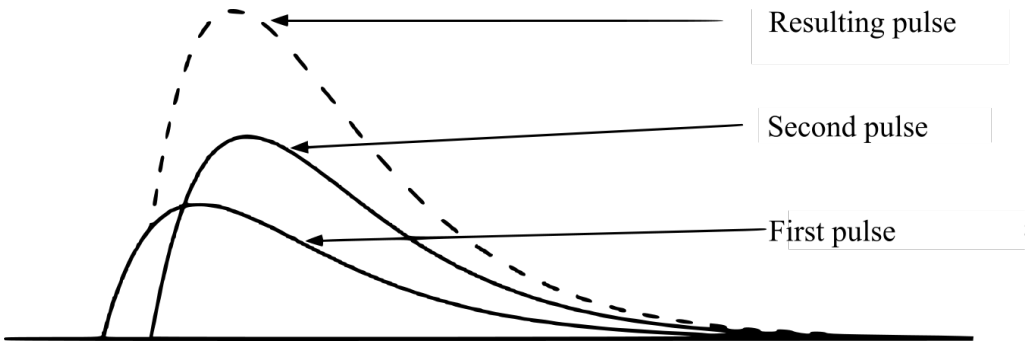
- Geometry of the experiment (including integrated surrouding environment);
- Non-uniformity of resolution within the detector’s volume;
- Light output non-uniformity in the crystal;
- Arbitrary source activities;
- Modeling the pile-up effect.

Light output non-uniformity (LONU)



Pile-ups





$$A_k = A_i + \sum_{j=1}^{i-1} A_j \exp\left(-\frac{t_{ij}}{\tau}\right) (i = 1 \ldots N)$$

A_i – i-th pulse amplitude;

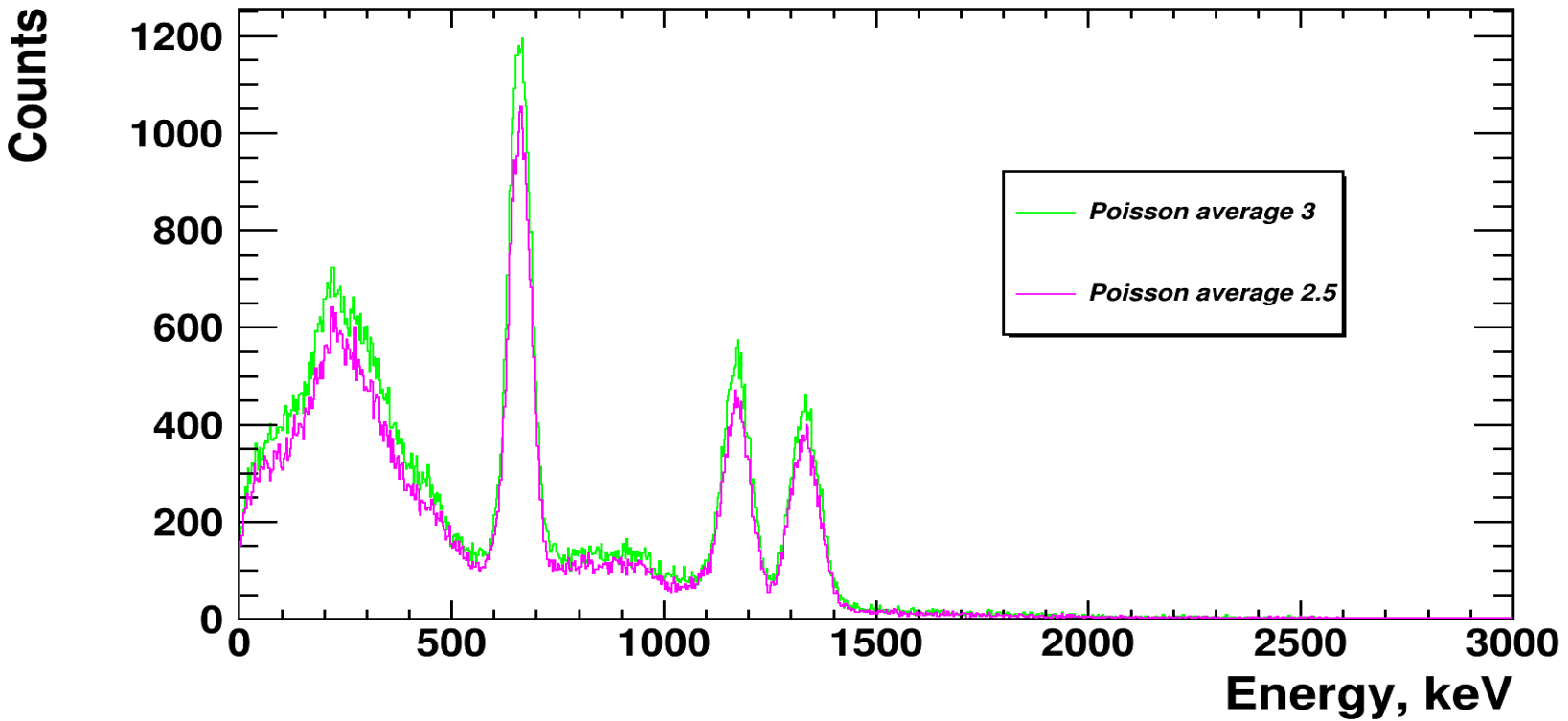
A_j – amplitudes of signals that came before *i*-th pulse;

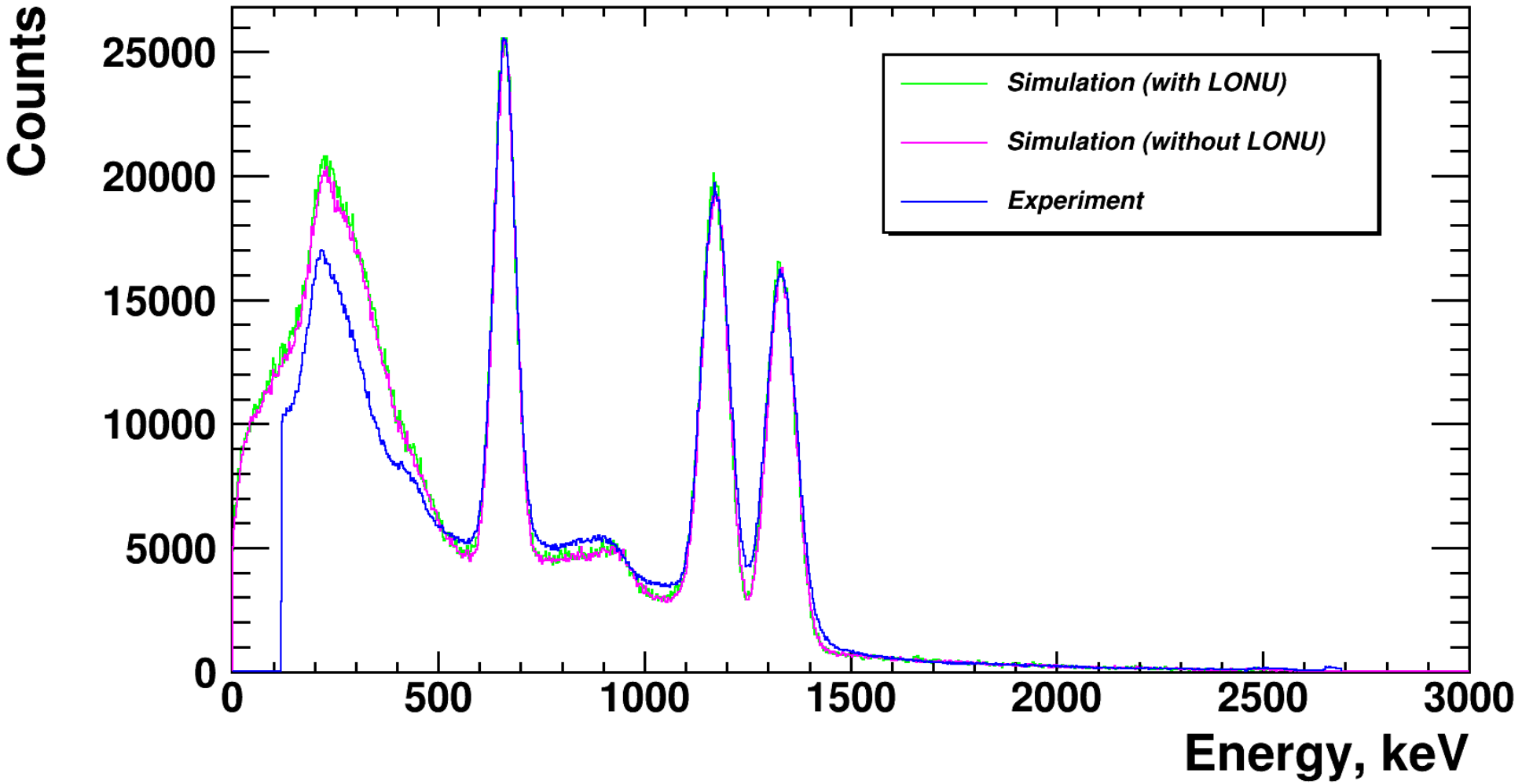
t_{ij} – time difference between *i*-th and *j*-th pulses;

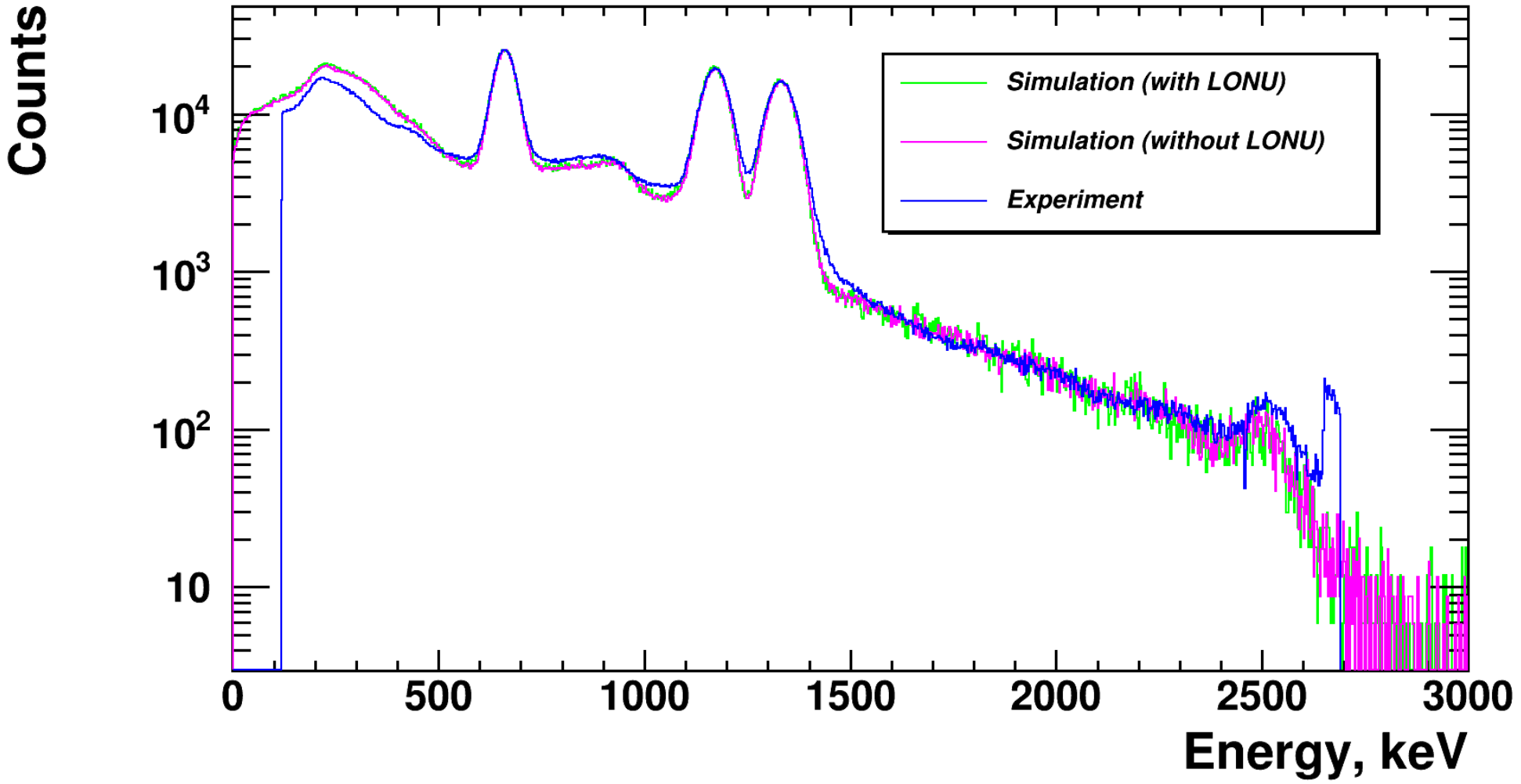
τ – decay constant.

Arbitrary source activities

$$f(k;\lambda) = \Pr(X{=}k) = \frac{\lambda^k e^{-\lambda}}{k!}$$




Counts
25000
20000
15000
10000
5000
0
0
500
1000
1500
2000
2500
3000
Energy, keV
Simulation (with LONU)
Simulation (without LONU)
Experiment

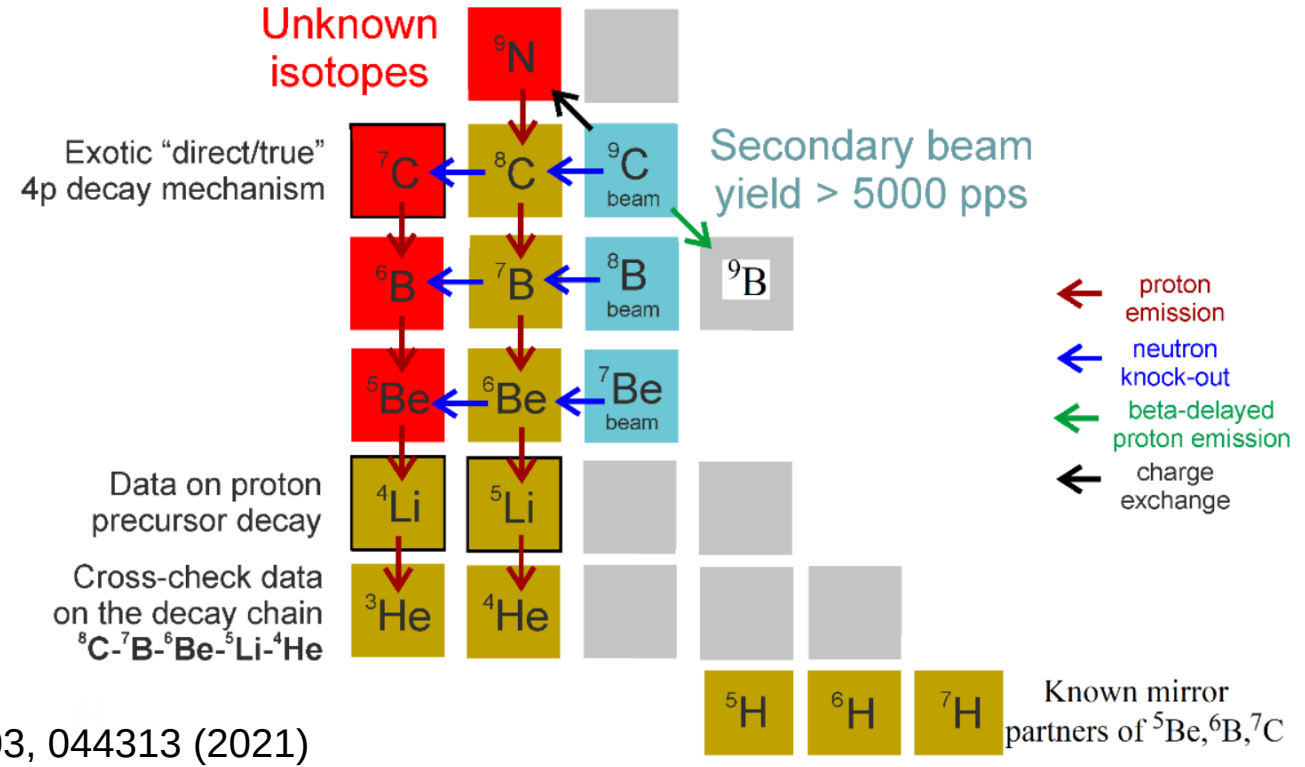

Counts
10^4
10^3
10^2
10
0
500
1000
1500
2000
2500
3000
Energy, keV
Simulation (with LONU)
Simulation (without LONU)
Experiment

Results on GADAST

- 32 CsI(Tl) detectors energy resolution and light output non-uniformity were determined;
- Simulation of the experiment with consideration of source activities, pile-ups, light output non-uniformity was performed;
- High energy tail simulation is consistent with the experimental results, thanks to pile-up accounting.

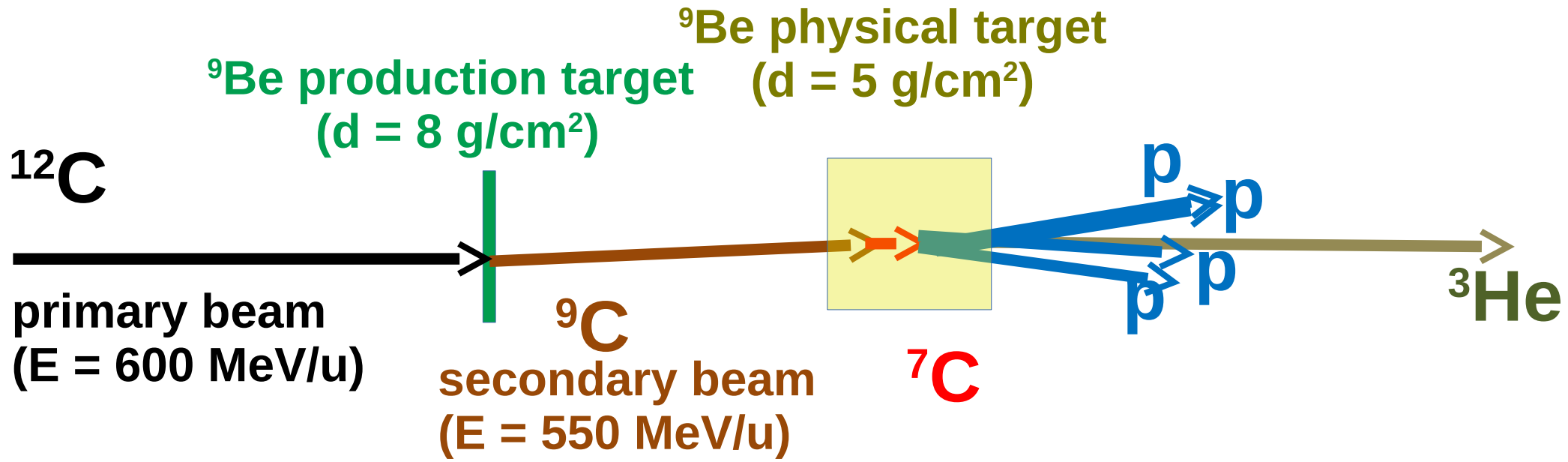
Physical interest of ^{7}C

- ^{7}C – mirror isotope of ^{7}H [1];
- Potential true four-proton decay (unobserved so far).



[1] Muzalevskii, I. A. et al, PRC 103, 044313 (2021)

Preparation of the experiment on ^{7}C at FRS@FAIR.



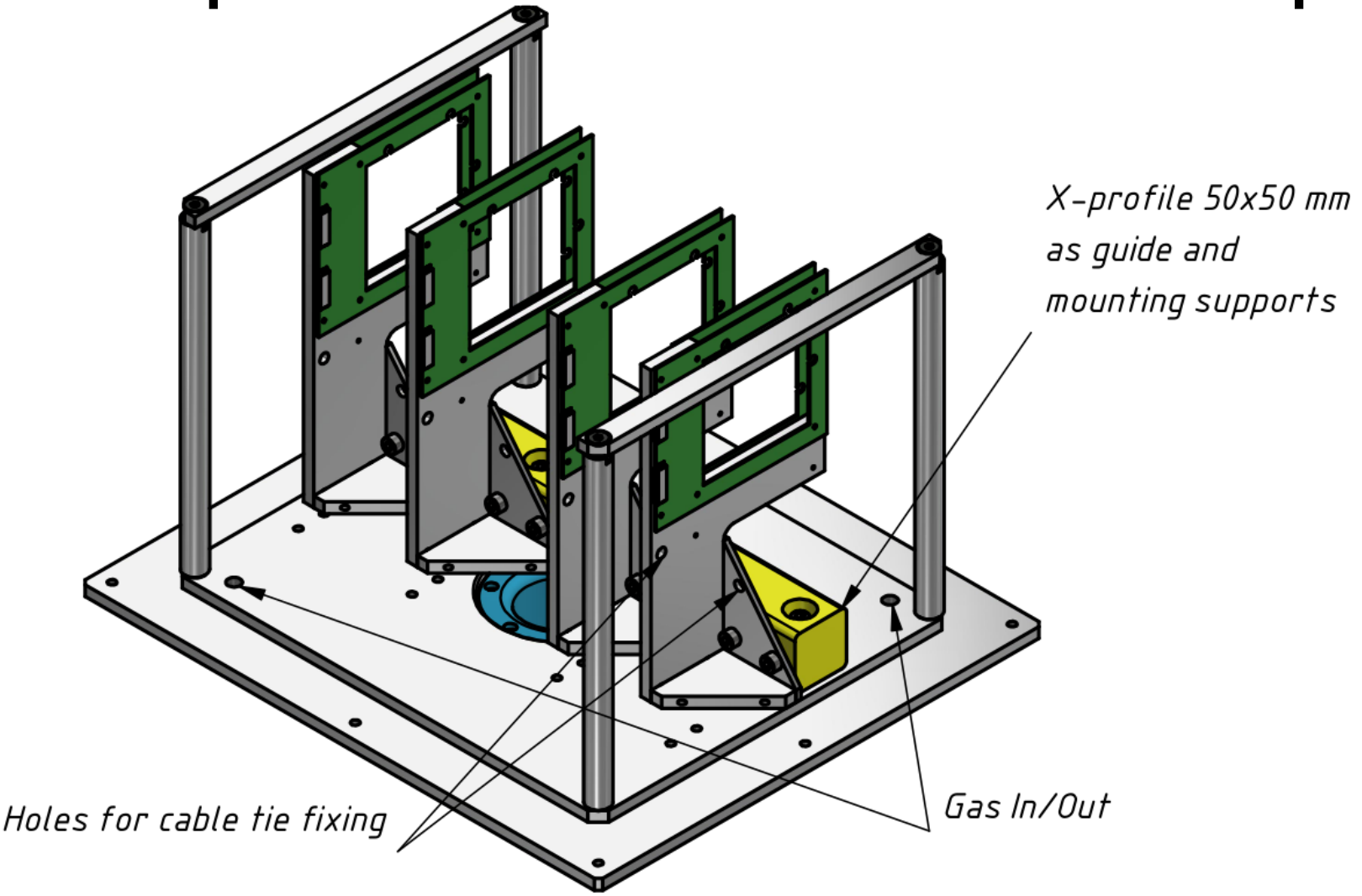
^{12}C → ^{9}C

fragmentation

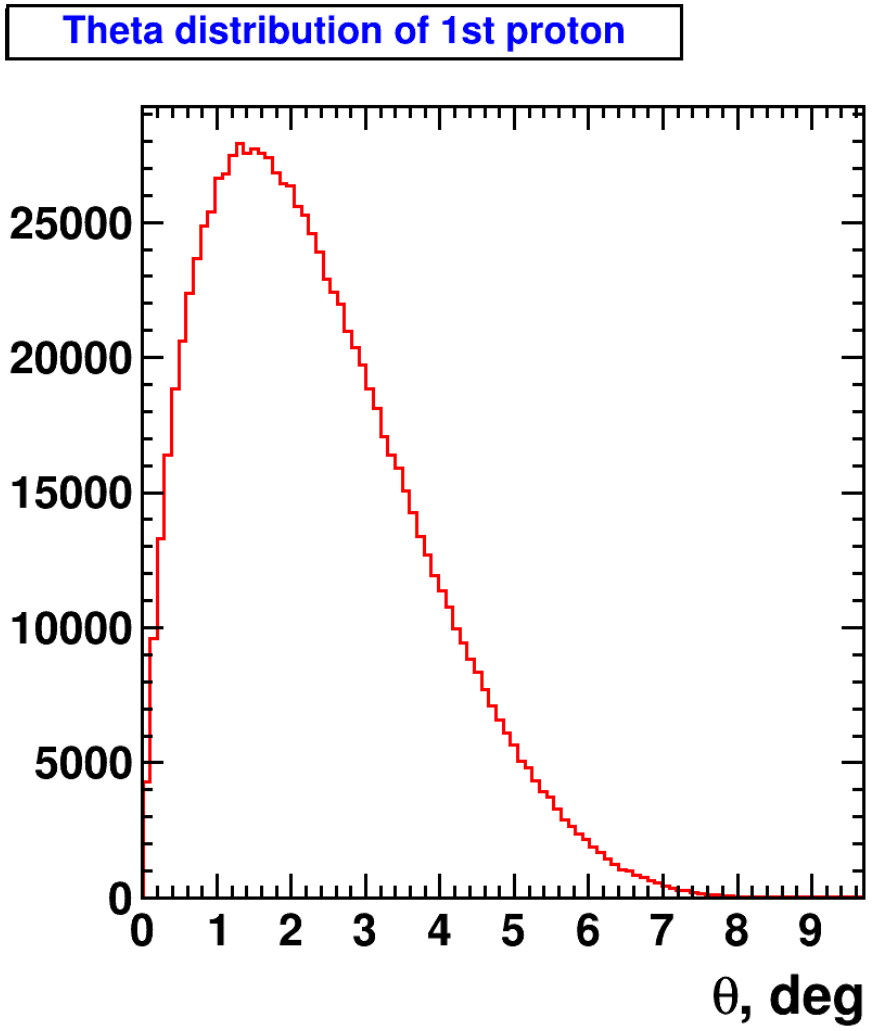
^{9}C → ^{7}C

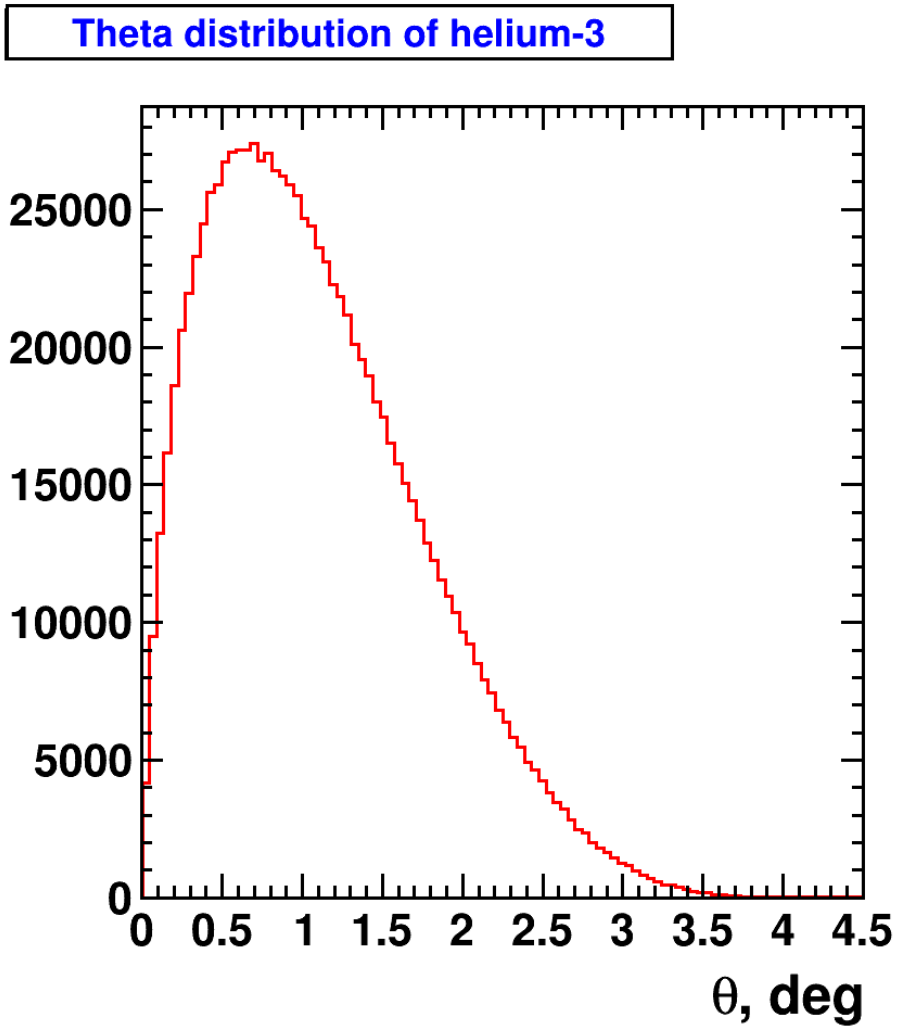
fragmentation

Experimental chamber setup

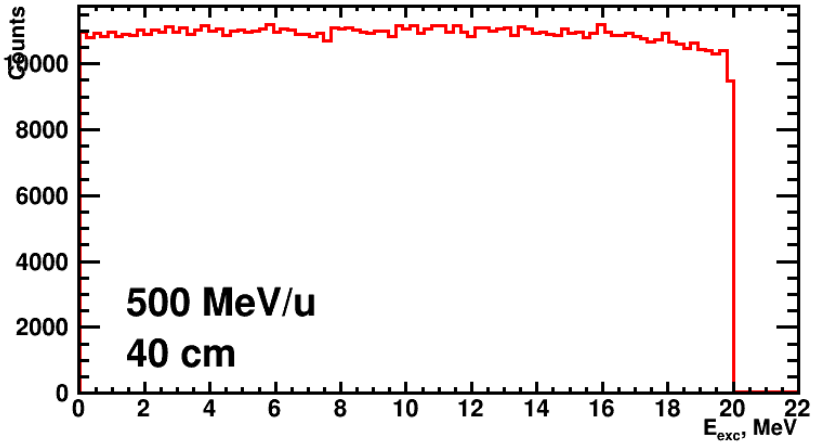


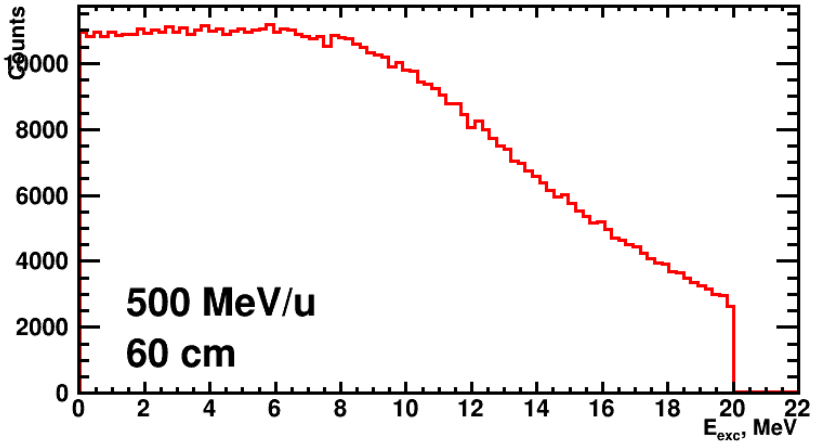
Kinematics of the experiment

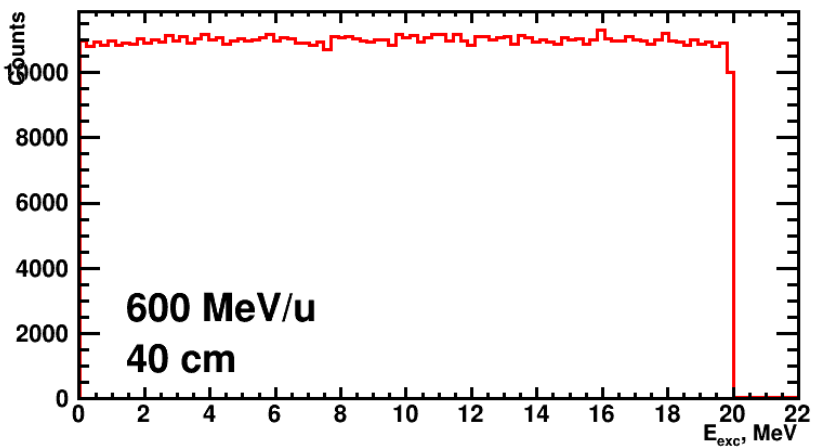


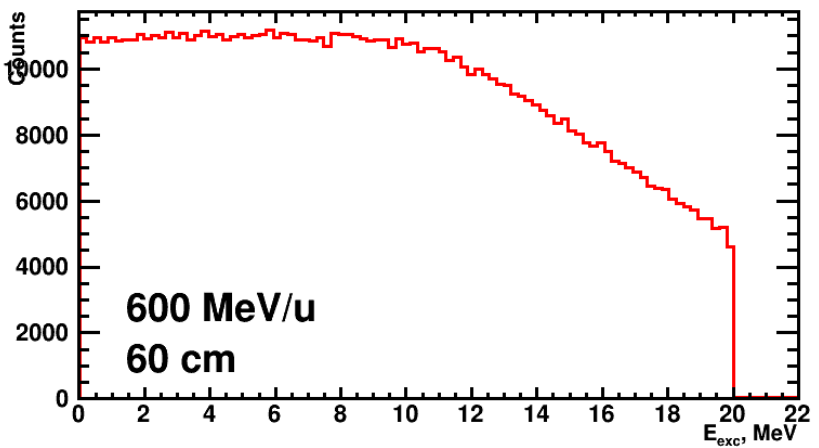


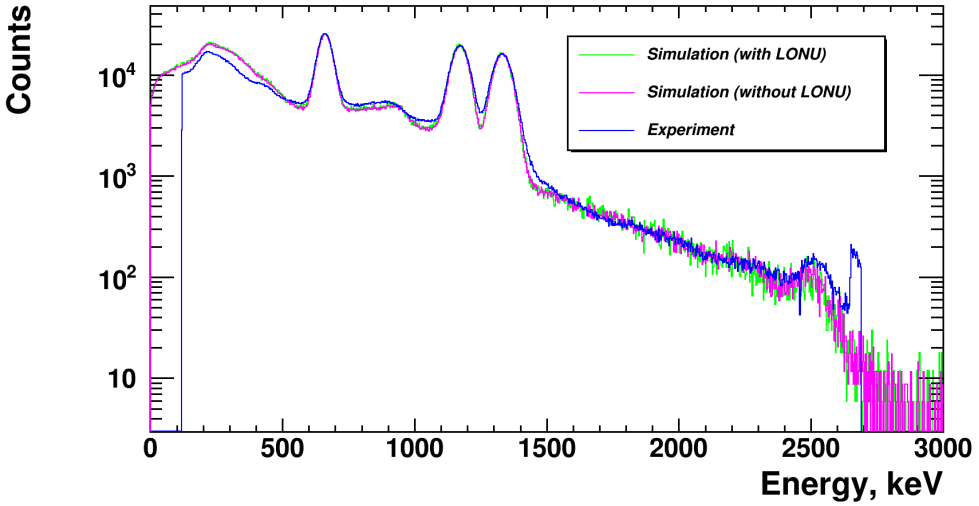
Efficiency considerations

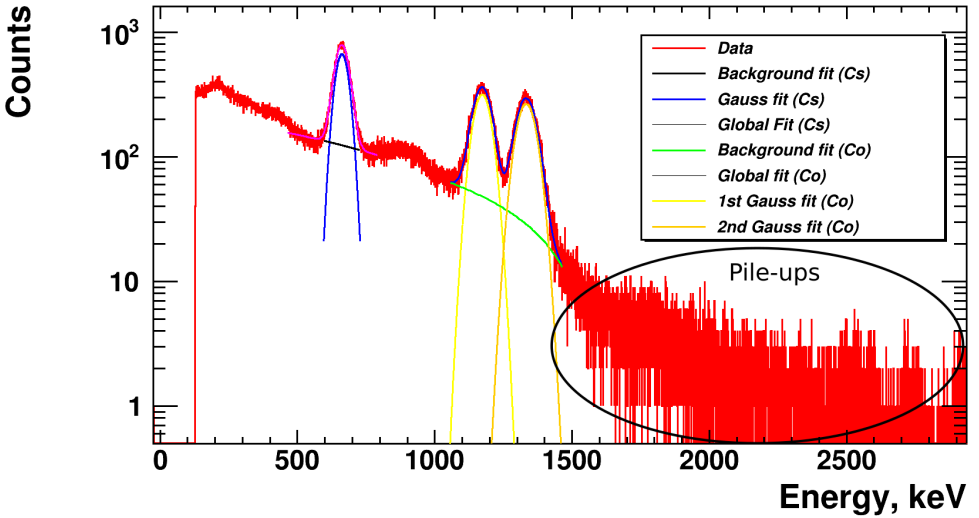


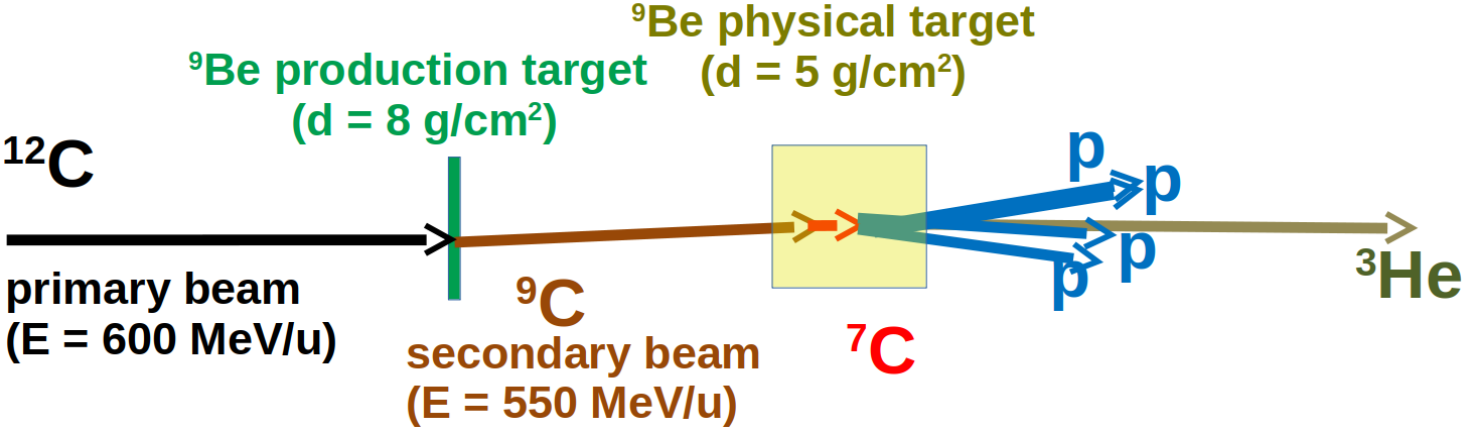


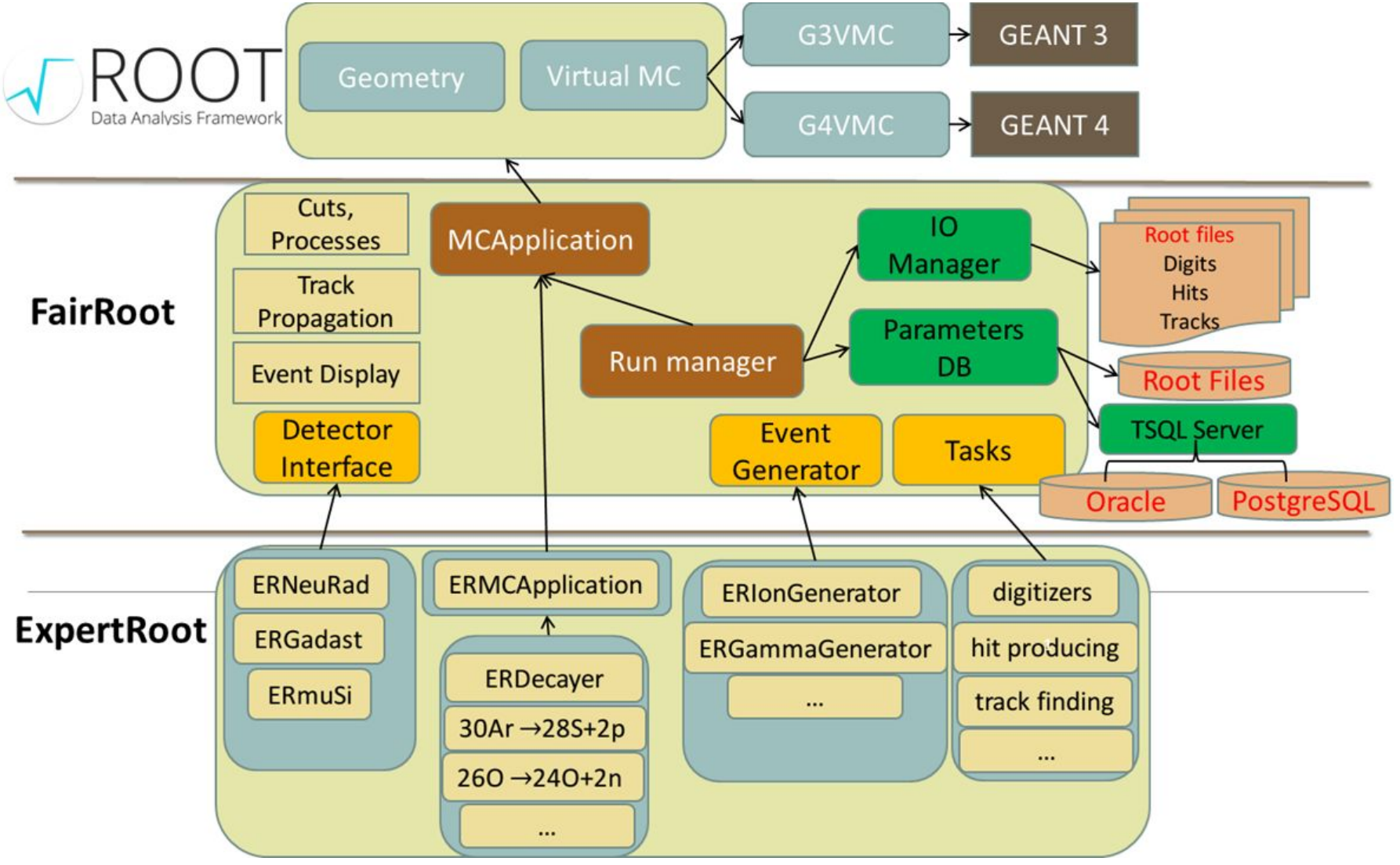





Counts
Simulation (with LONU)
Simulation (without LONU)
Experiment
Energy, keV


Counts
Data
Background fit (Cs)
Gauss fit (Cs)
Global Fit (Cs)
Background fit (Co)
Global fit (Co)
1st Gauss fit (Co)
2nd Gauss fit (Co)
Pile-ups
Energy, keV


^{9}Be physical target
(d = 5 g/cm^2)
^{9}Be production target
(d = 8 g/cm^2)
^{12}C
primary beam
(E = 600 MeV/u)
^{9}C
secondary beam
(E = 550 MeV/u)
^{7}C
p
p
p
p
^{3}He


ROOT
Data Analysis Framework
Geometry
Virtual MC
G3VMC
GEANT 3
G4VMC
GEANT 4
FairRoot
Cuts, Processes
Track Propagation
Event Display
Detector Interface
MCApplication
Run manager
IO Manager
Parameters DB
Event Generator
Tasks
Root files
Digits
Hits
Tracks
Root Files
TSQL Server
Oracle
PostgreSQL
ExpertRoot
ERNeuRad
ERGadast
ERmuSi
ERMCApplication
ERDecayer
30Ar →28S+2p
26O →24O+2n
...
ERIonGenerator
ERGammaGenerator
...
digitizers
hit producing
track finding
...