Silicon microstrip detectors for investigation of proton radioactivity

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

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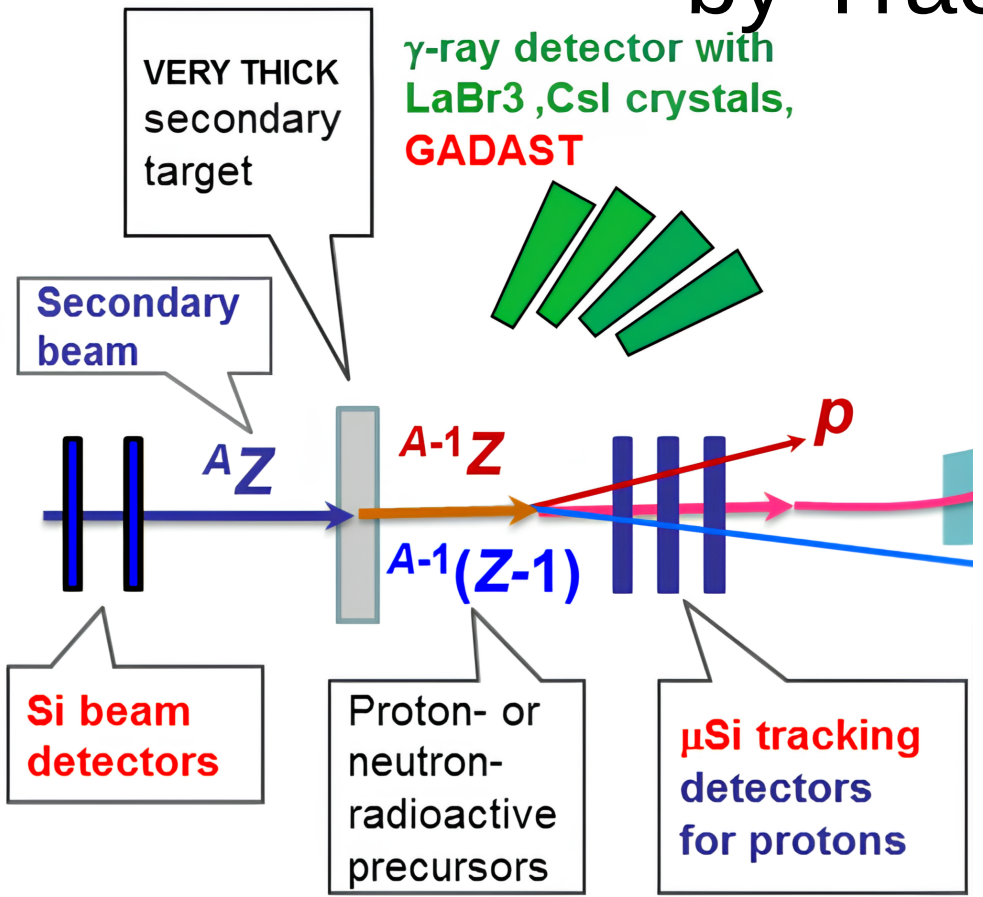
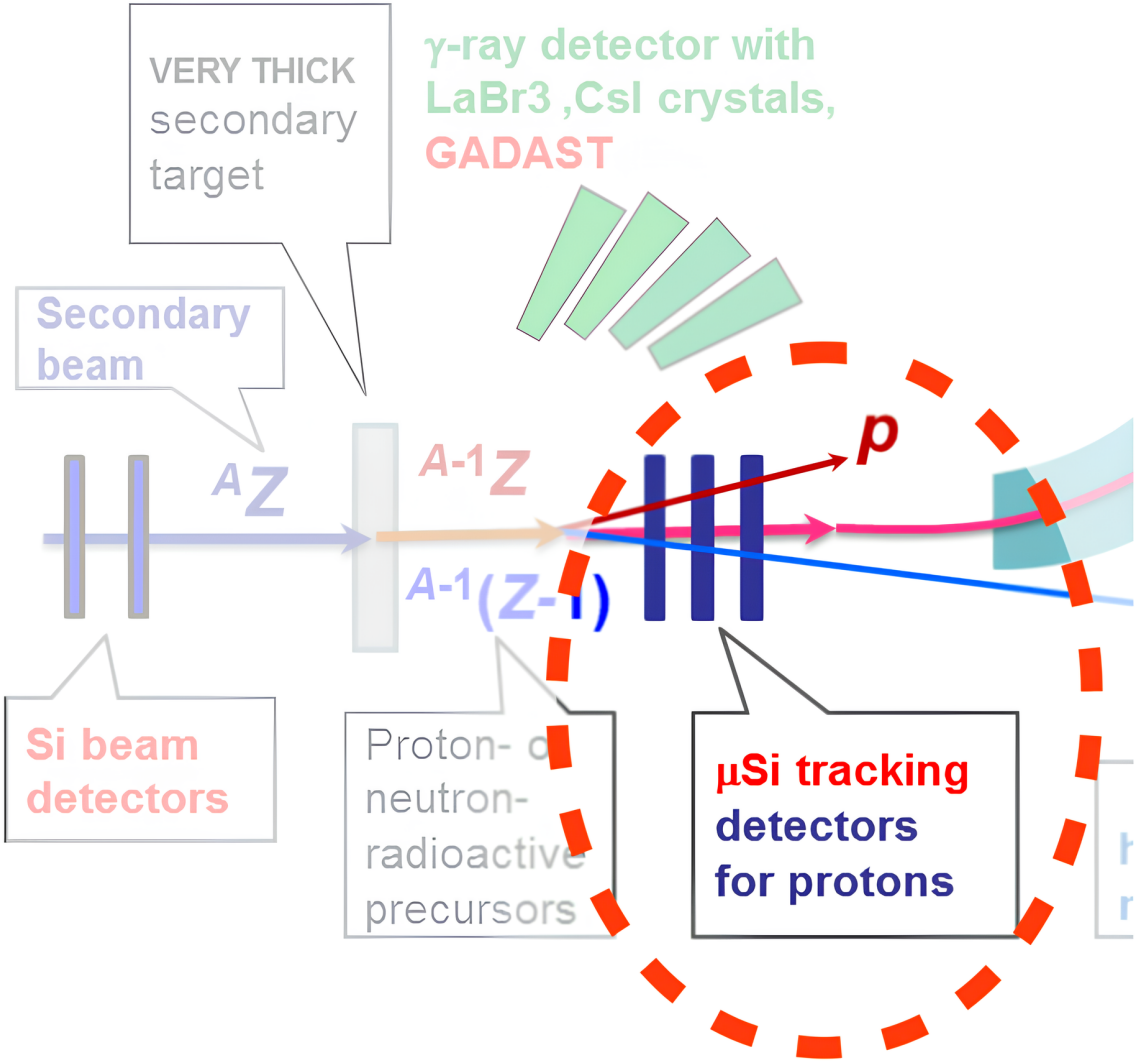
EXPERT (EXotic Particle Emission and Radioactivity by Tracking)



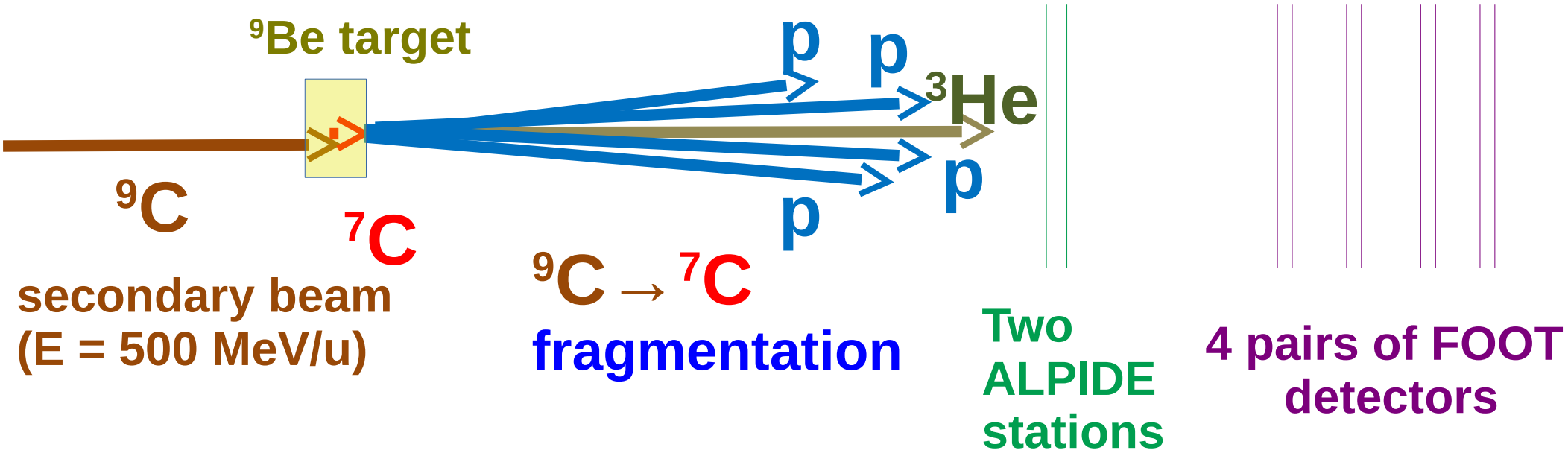
- Studies of the unknown exotic nuclear systems near proton and neutron driplines;
- Studies of p, 2p, 4p, n, 2n, 4n (exotic radioactivity) resonance decays.

Silicon microstrip tracking detectors **FOOT**



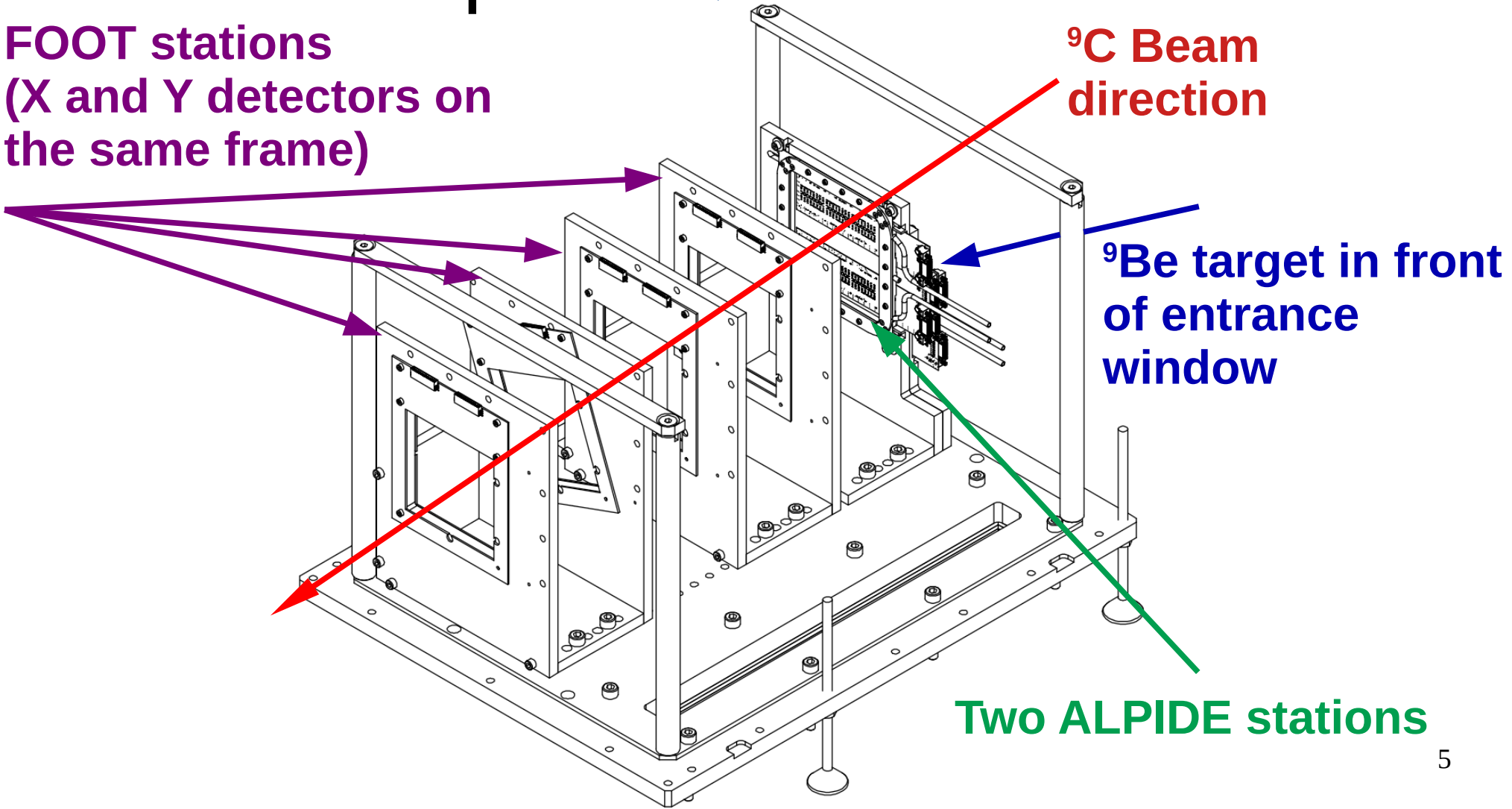
- Investigation of in-flight decays;
- Registration of charged particles (decay products);
- Tracks and verticies reconstruction.

Population of ^{7}C state

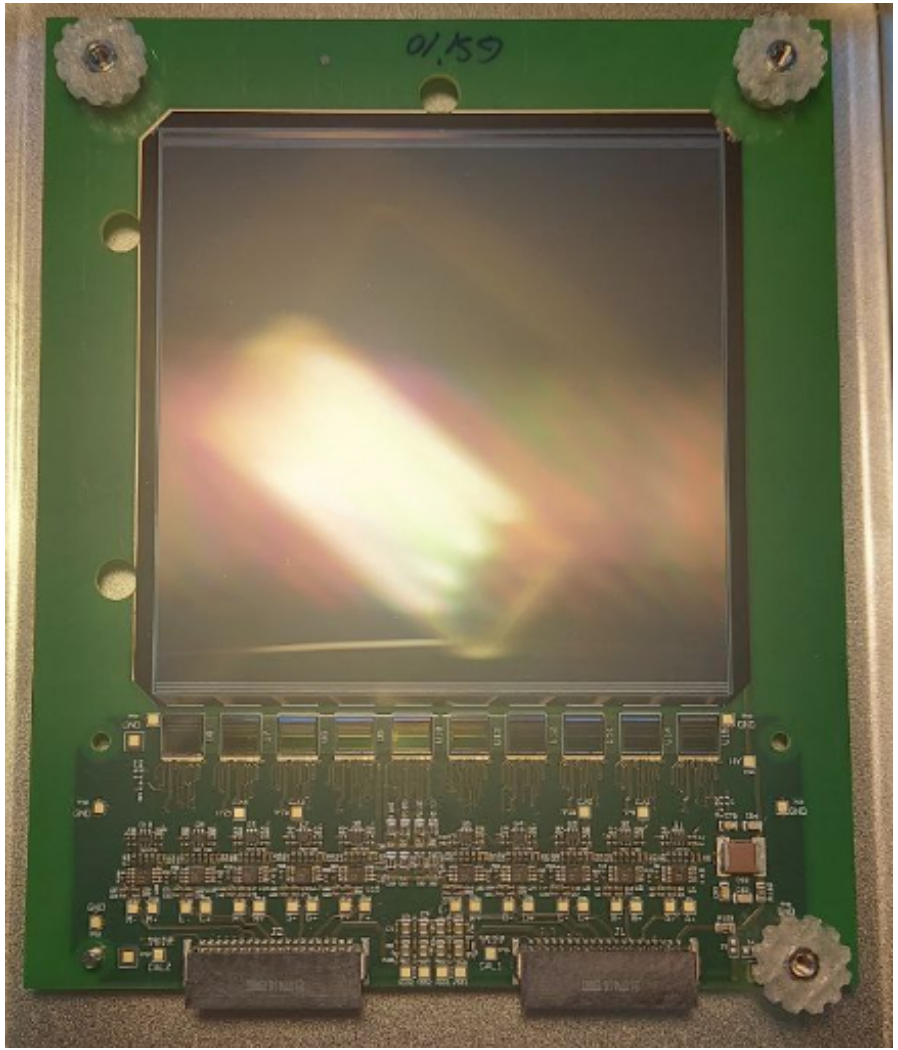


- Test run – Feb. 2024;
- The main experiment – 2025;

Experiment chamber

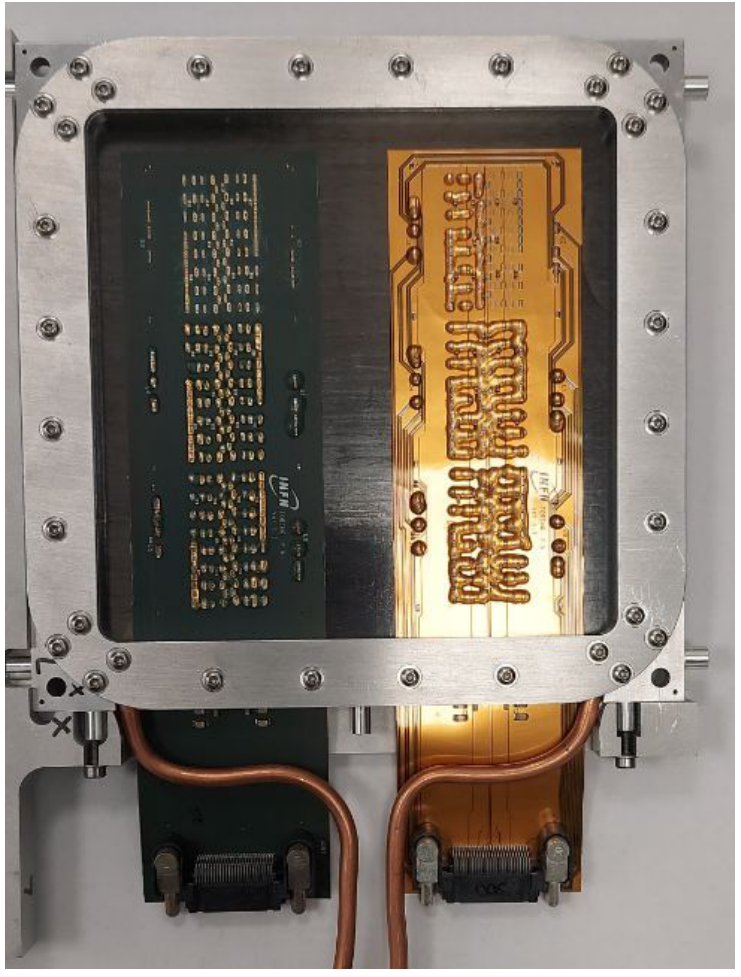


Tracking detector **FOOT**



- 640 strips;
- Single-sided detector;
- 10x10 cm^2 area;
- 150 μm thickness;
- 150 μm strip size;
- Front-end electronics.

Silicon pixel detector **ALPIDE**



- **Intended for a more precise tracks reconstruction;**
- 2 flexible circuit boards (FCB);
- 6 silicon chips on each FCB;
- 1.5x3 cm^2 chip area, 100 μm thick;
- Each chip 512x1024 pixels;
- Carbon plate (10x10 cm^2, 1 mm thick).

Goal

- Full simulation of the experiment (geometry, detectors functionality, reaction, tracks and vertex reconstruction)

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ExpertRoot

- Derivative of FairRoot (includes Geant4, ROOT, etc...);
- Developed for the needs of EXPERT and ACCULINNA-2 (JINR)

https://github.com/FLNR-JINR/er

^{9}C beam characteristics

- E_{9C} = 500 MeV/u;
- XY spot with r = 1 cm;
- φ = [0;360]°;
- θ = Gaussian

  (θ_0 = 0°, σ_θ = 0.5°).

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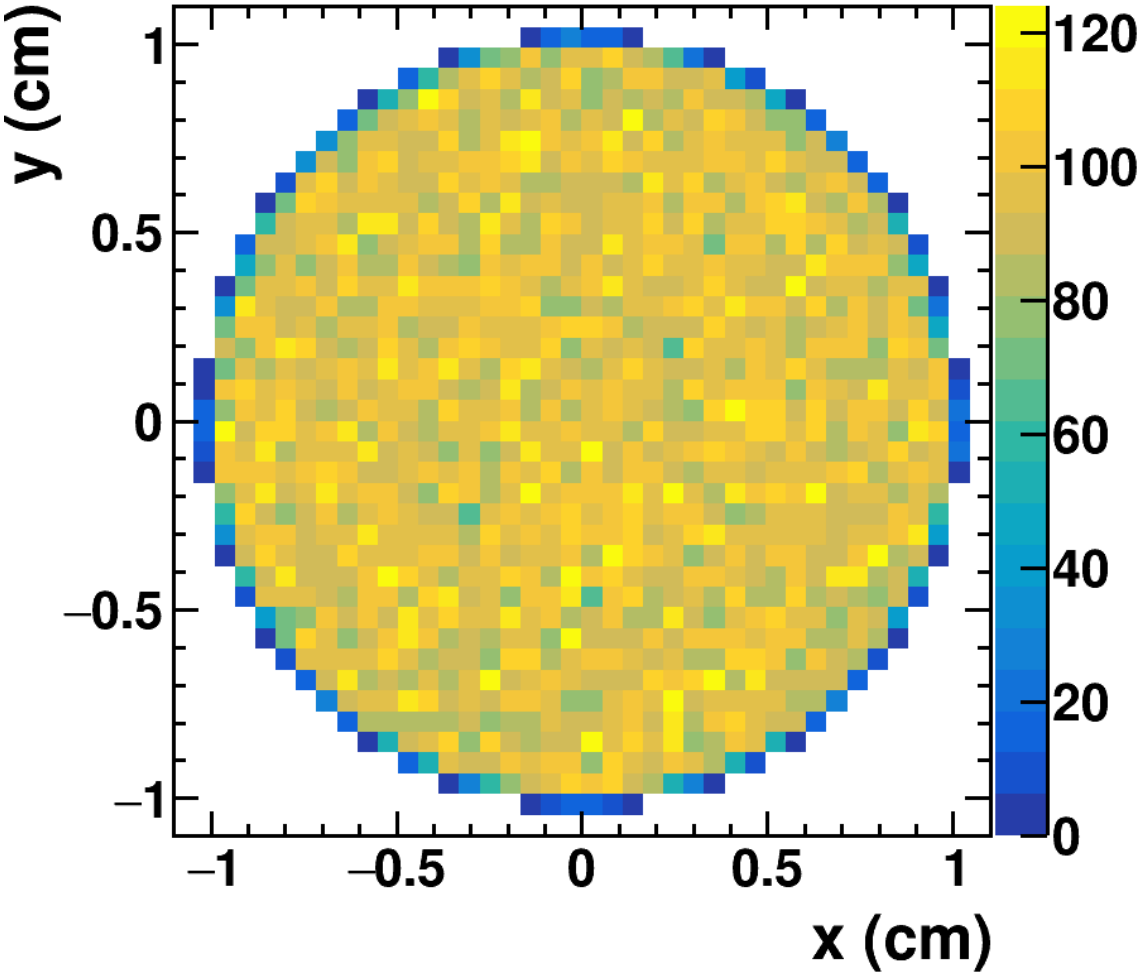

Reaction model

- ^{9}Be target, 5.5 cm thick;
- $^{9}C \rightarrow {}^{7}C$:

  fragmentation on ^{9}Be;
- $\tau_{decay}(^{7}C) \sim 10^{-21}$ s;
- Uniform ^{7}C excitation energy:

  ($0 < E_{exc} < 20$ MeV);
- Phase space generator of ^{7}C decay.

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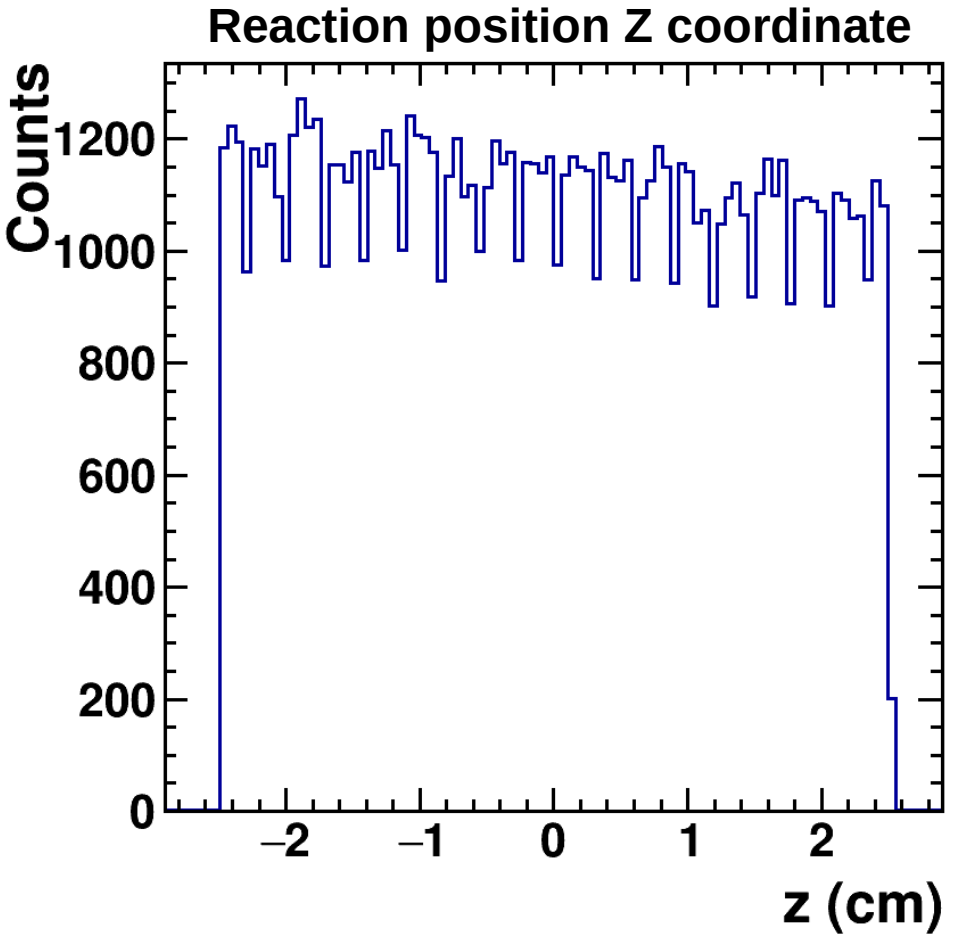
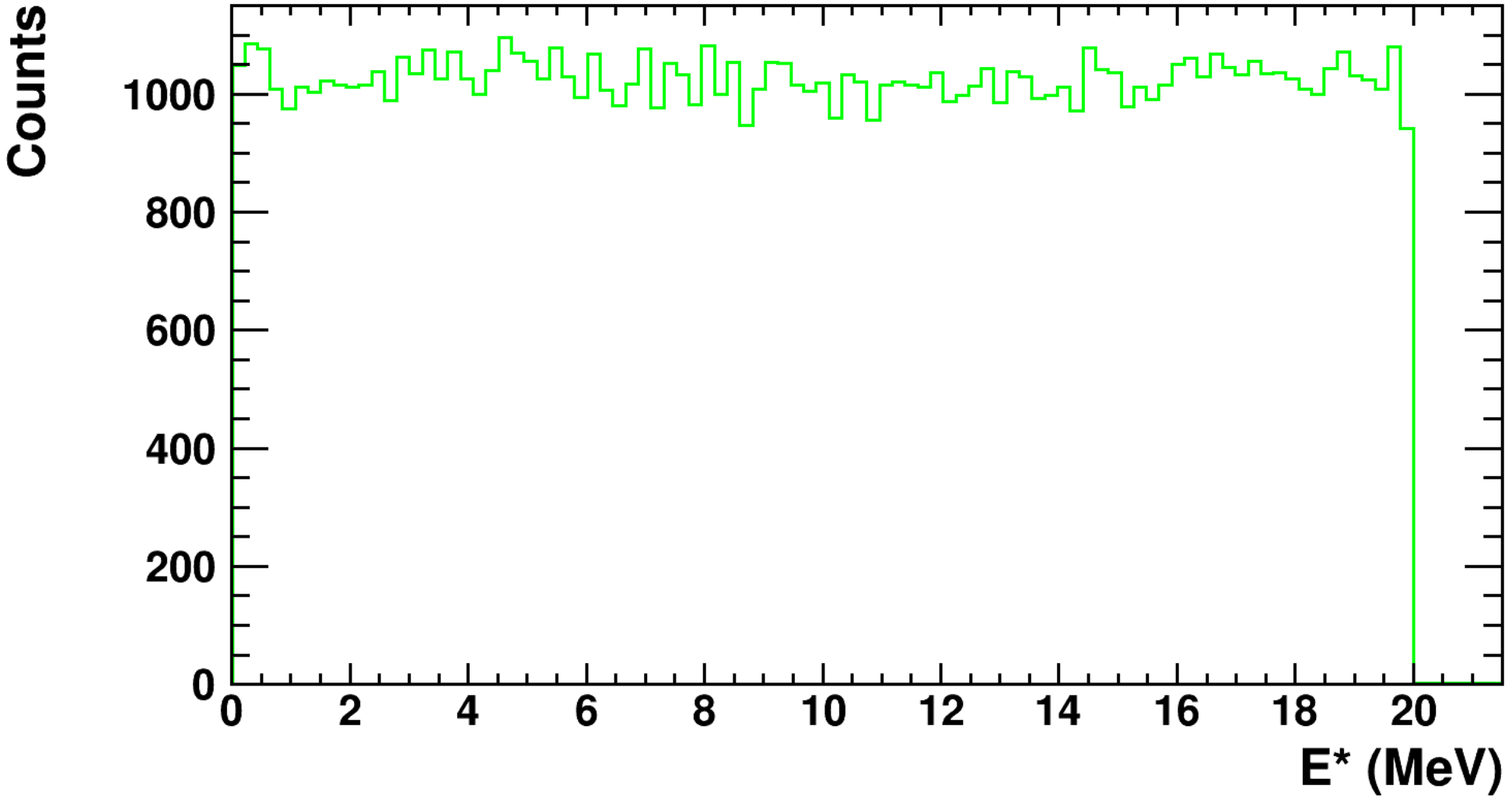
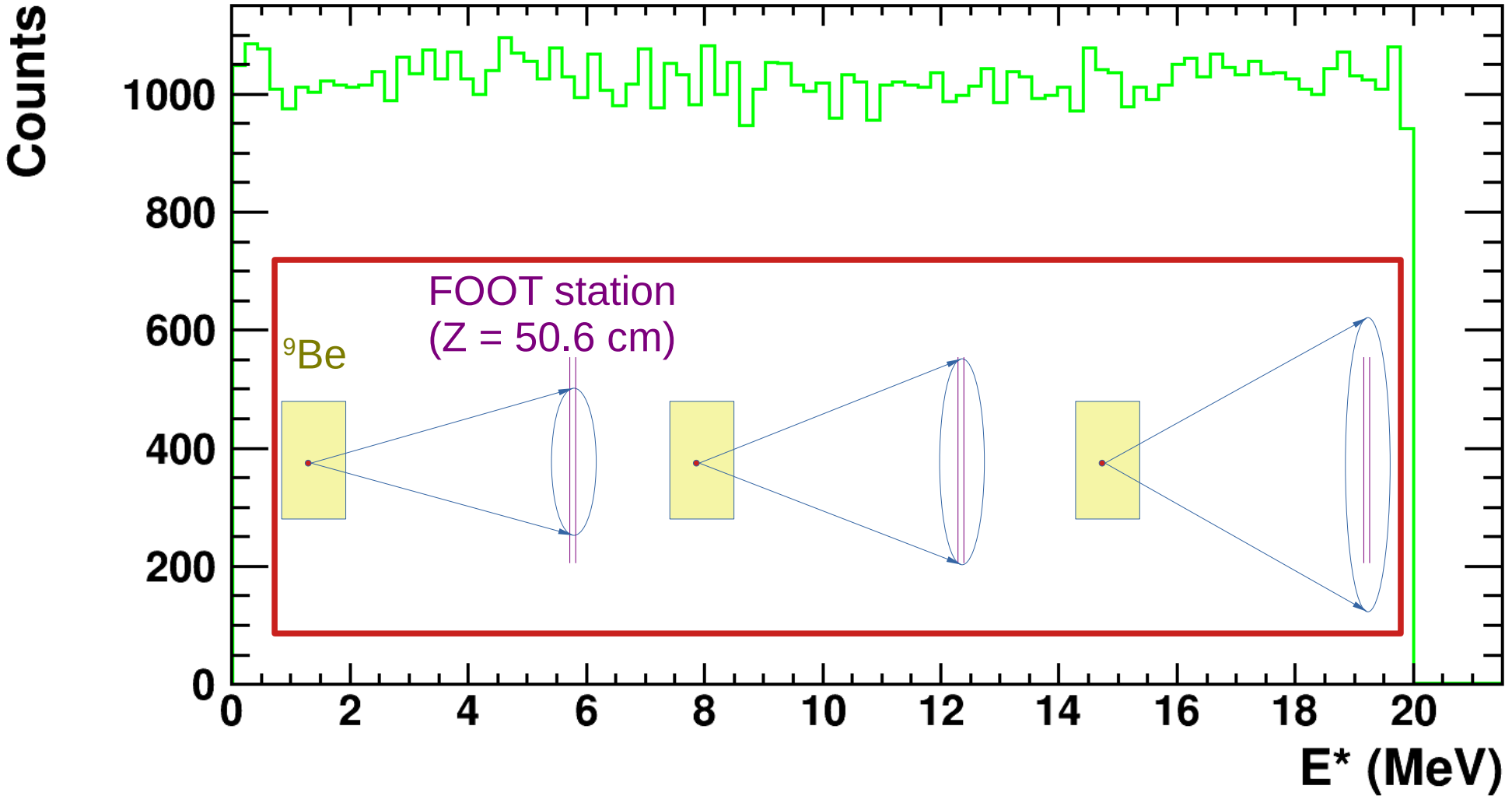


Excitation energy

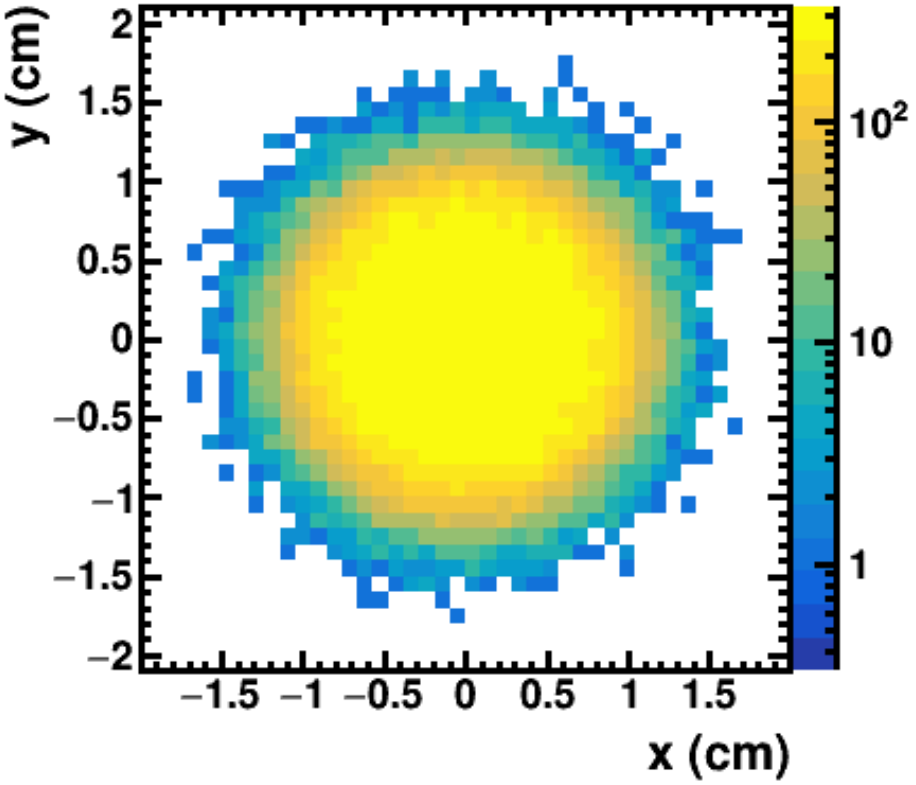


Excitation energy

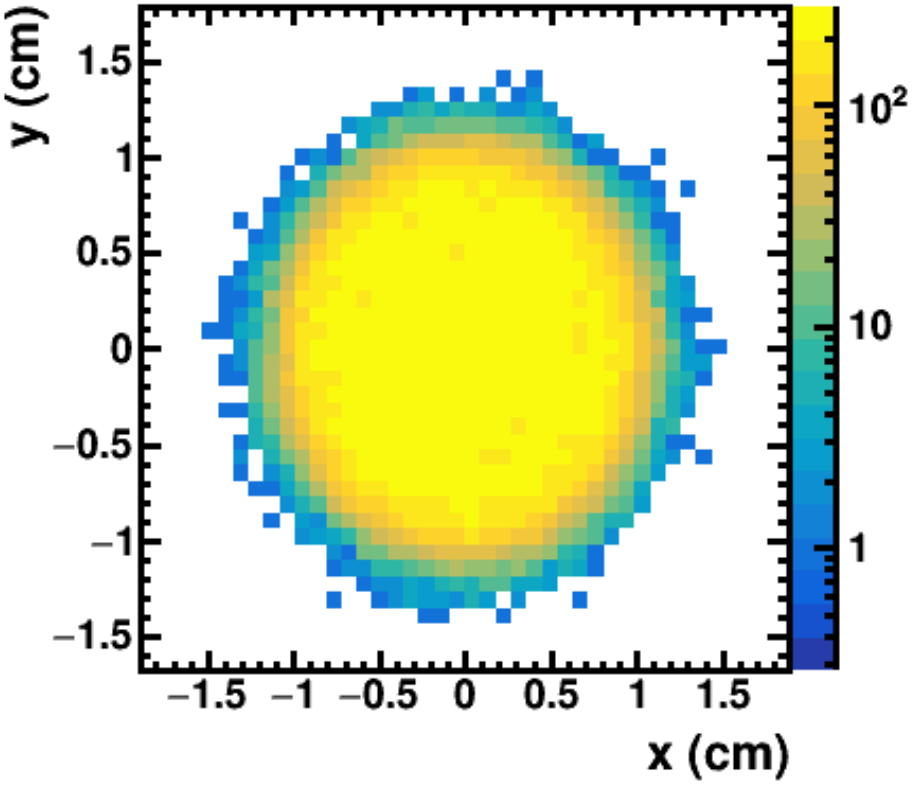


Geometrical efficiency (ALPIDE)

Proton spatial distribution

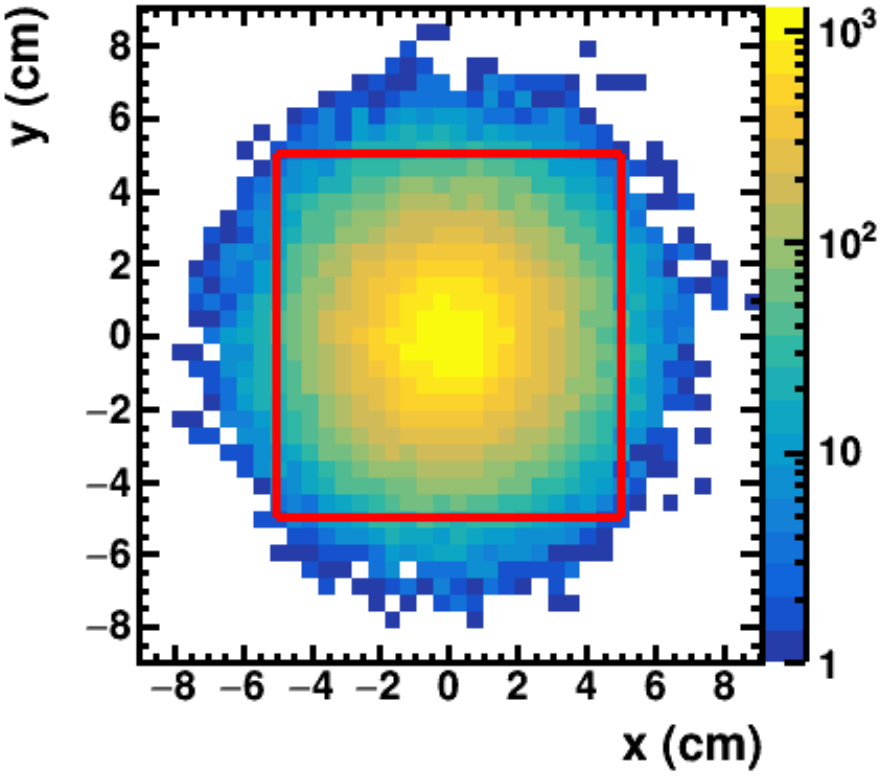


^{3}He spatial distribution

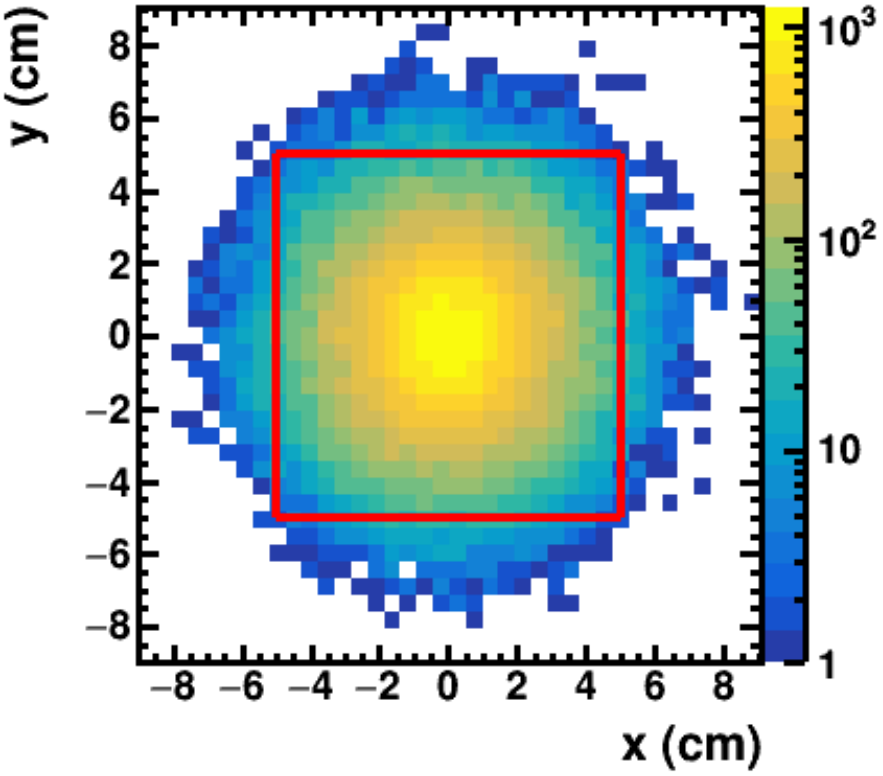


Geometrical efficiency (Farthest FOOT)

Proton spatial distribution



Proton spatial distribution – 3p coincidence condition



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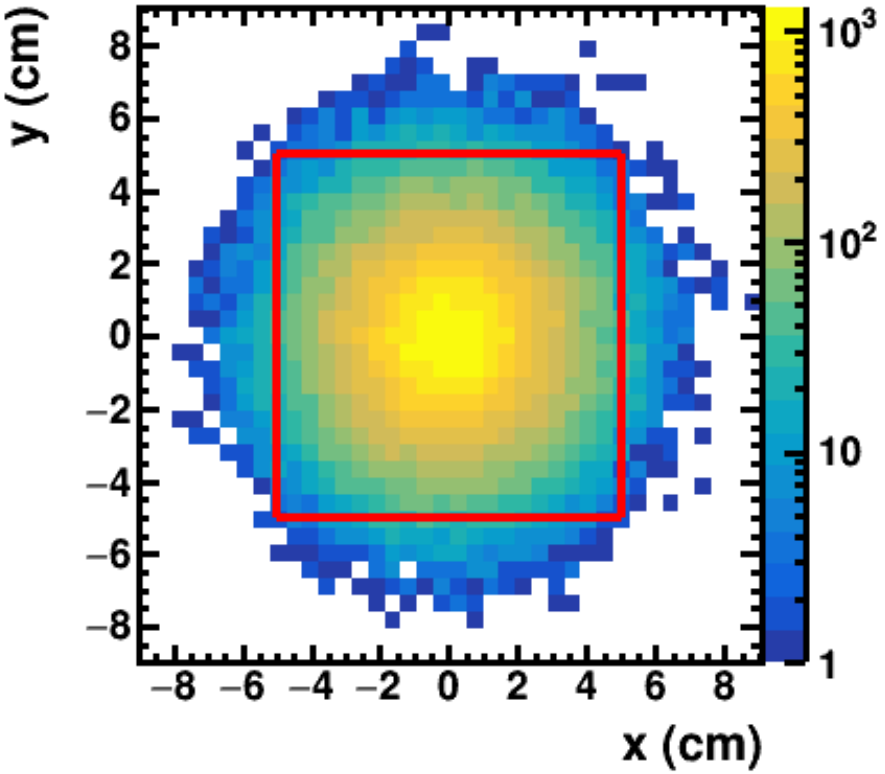

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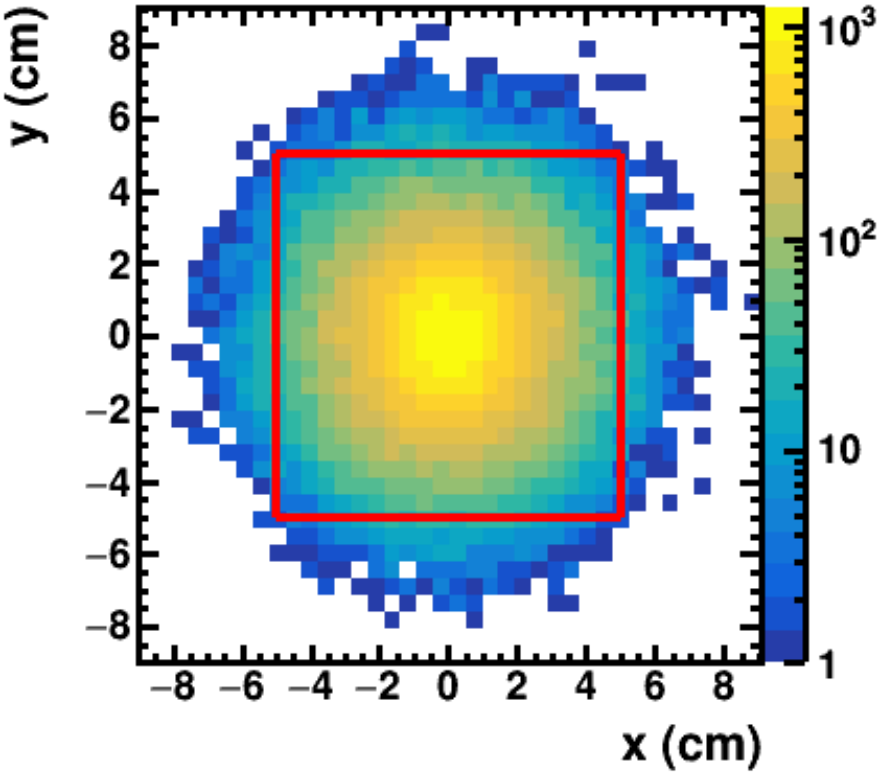
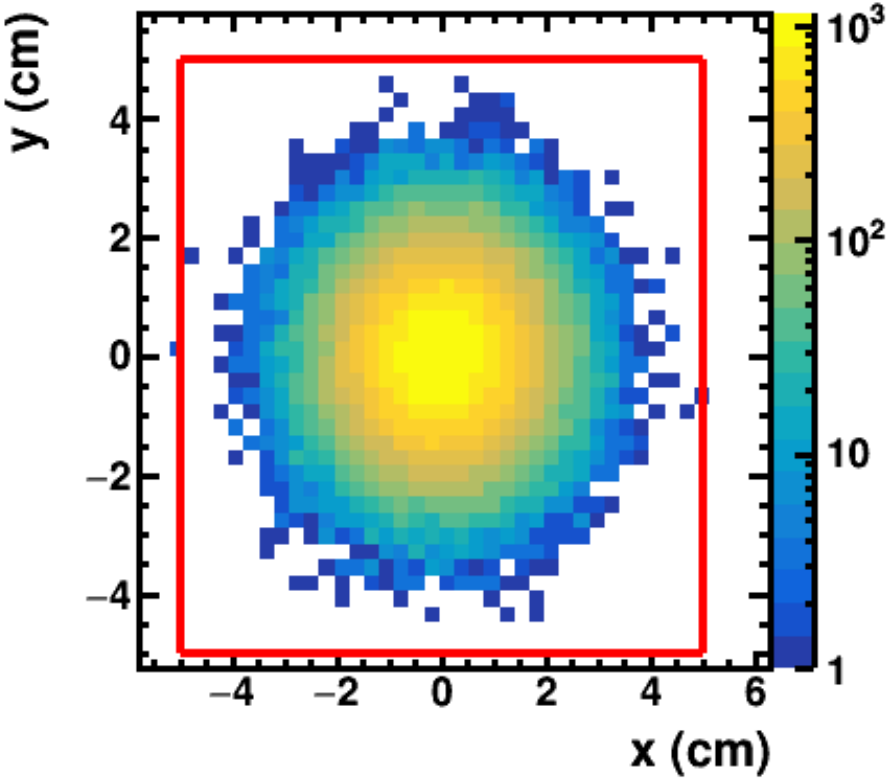


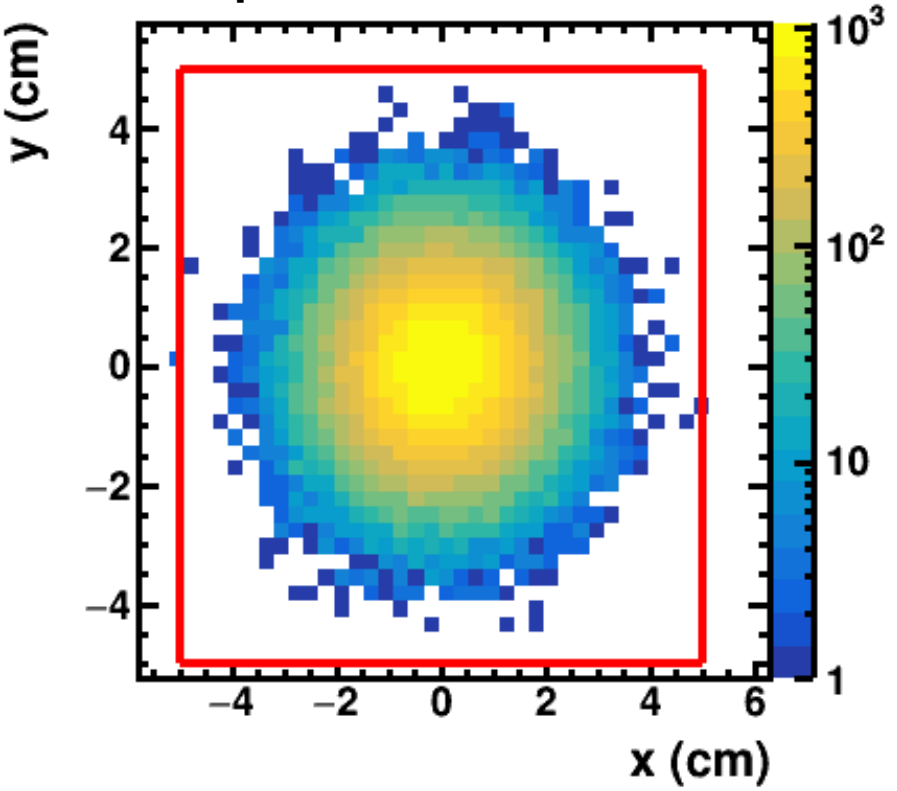
4p coincidence = **90.3%** (0 < E_{exc} < 20

Geometrical efficiency (Farthest FOOT)

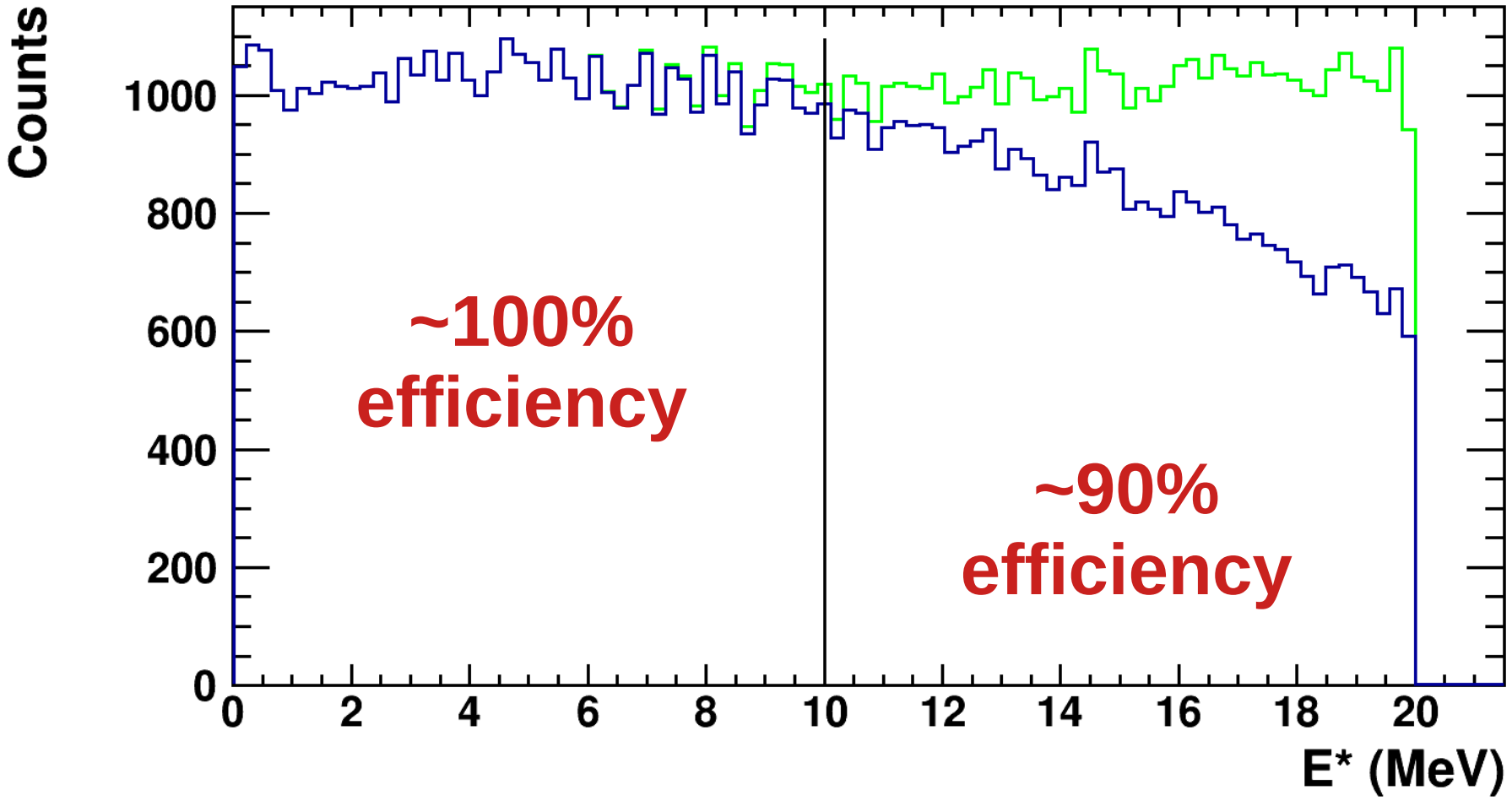
^{3}He spatial distribution



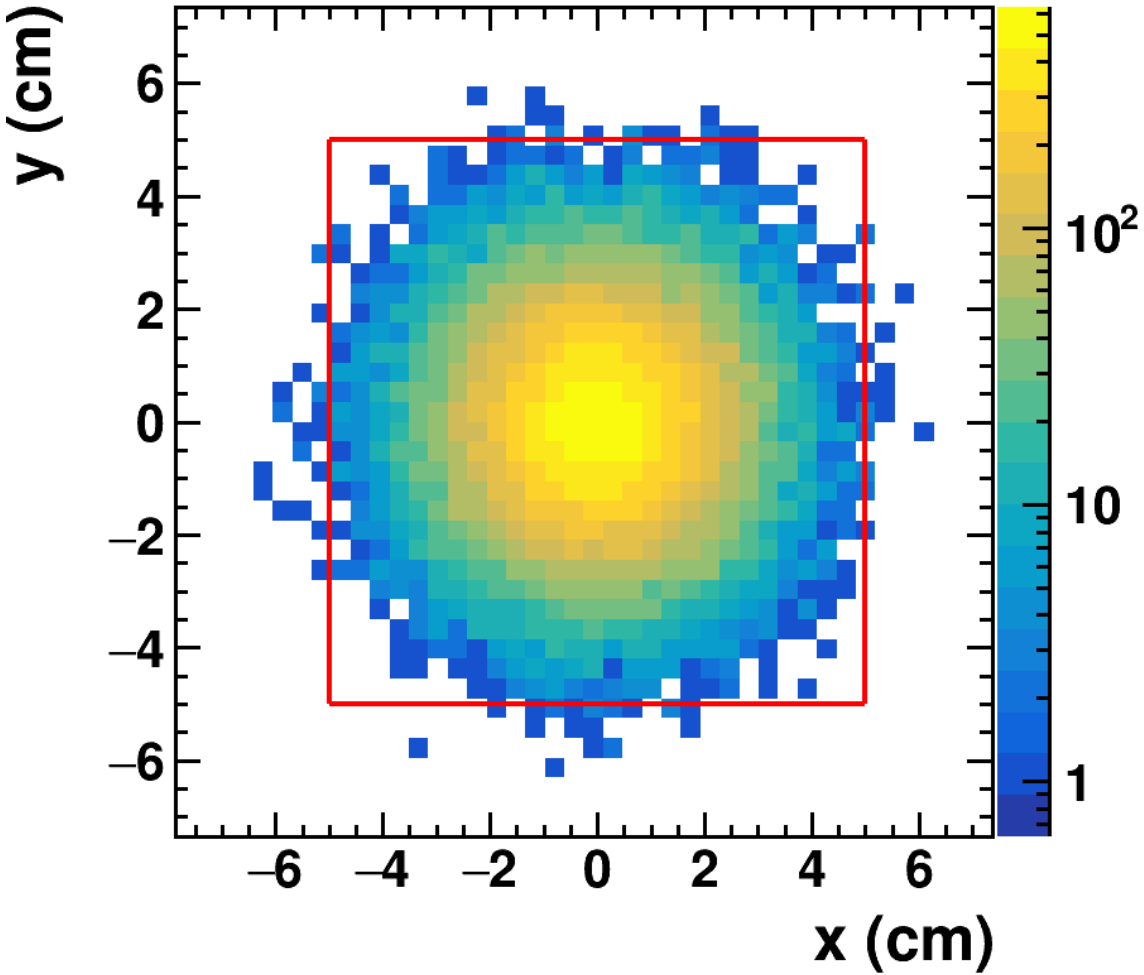
^{3}He spatial distribution –
4p coincidence condition



Geometrical efficiency vs excitation energy with 4p coincidence

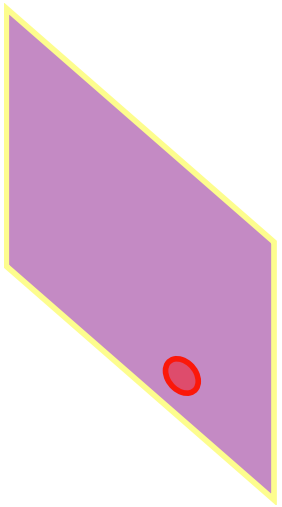


Geometrical efficiency (Farthest FOOT)

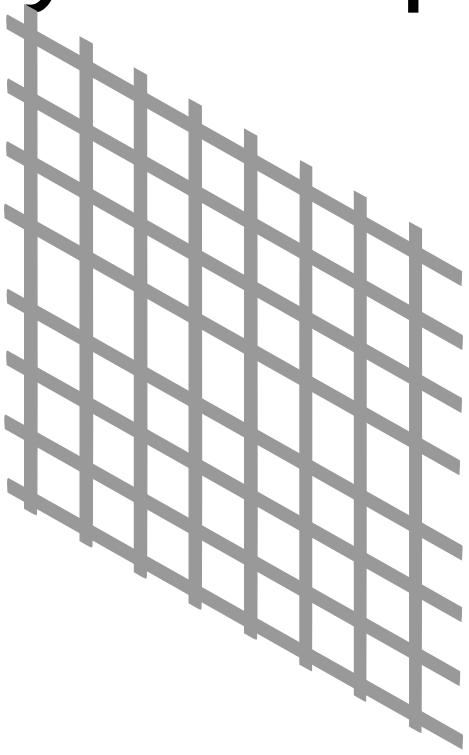


4p coincidence geometrical efficiency = **99.5%** ($0 < E_{exc} < 10$ MeV).

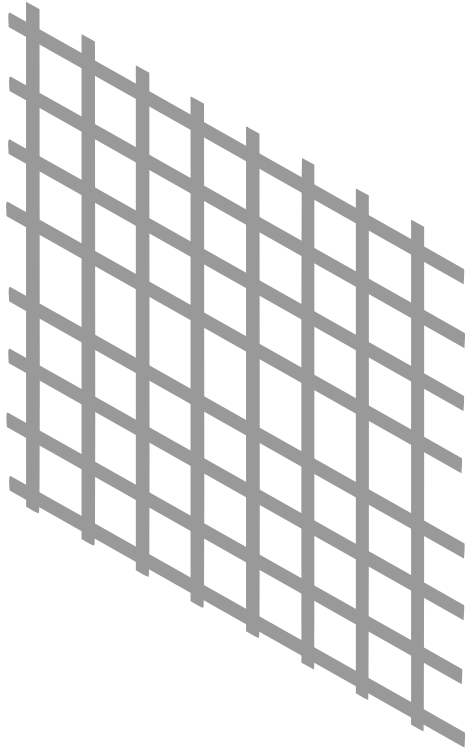
Tracks & vertex reconstruction (3p decay example)



decay vertex



X and Y
FOOT detectors



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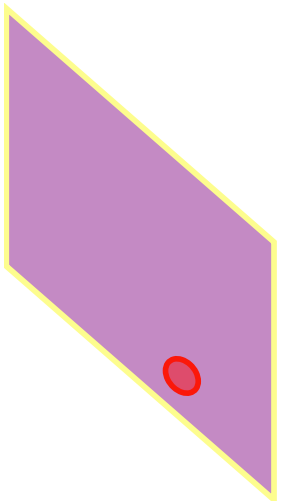
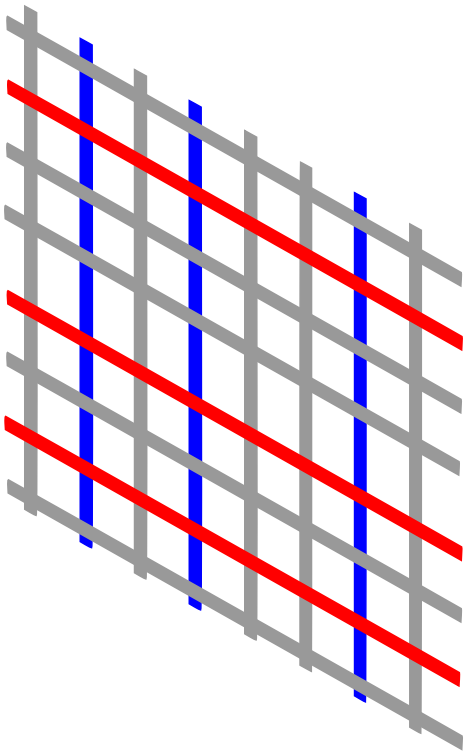
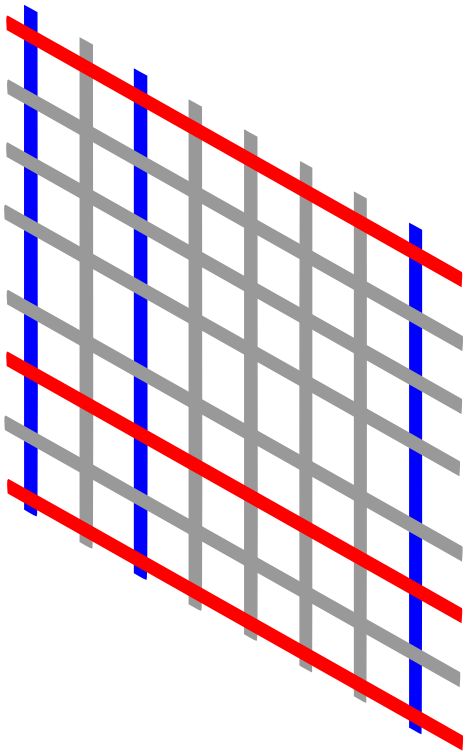
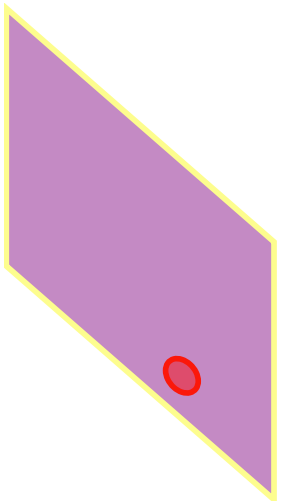


decay vertex



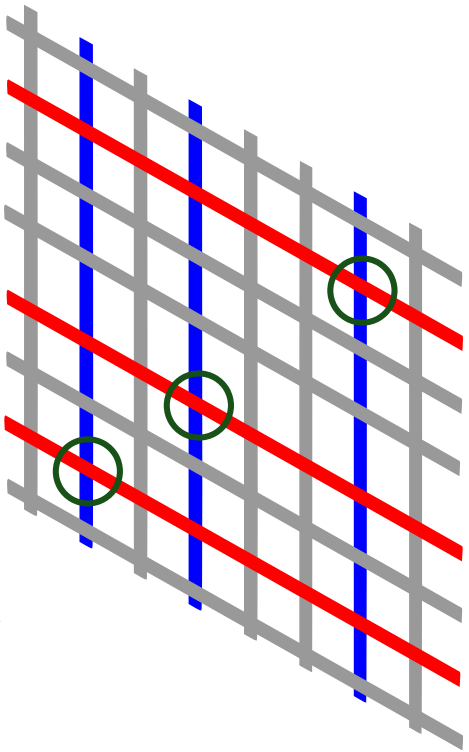


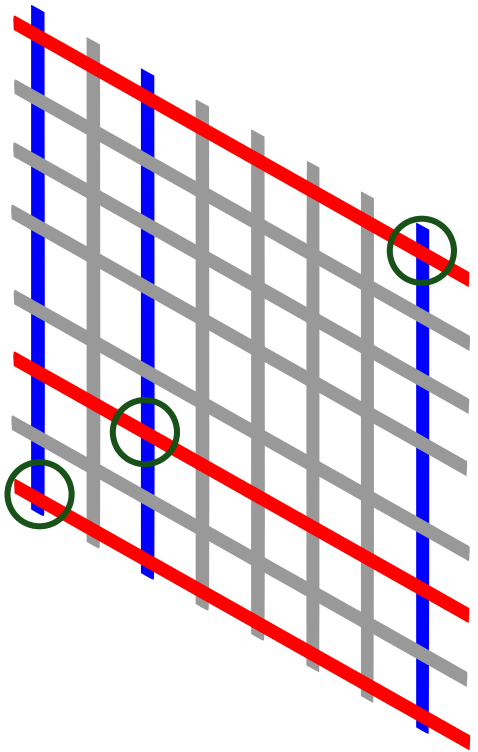
Signal in strips

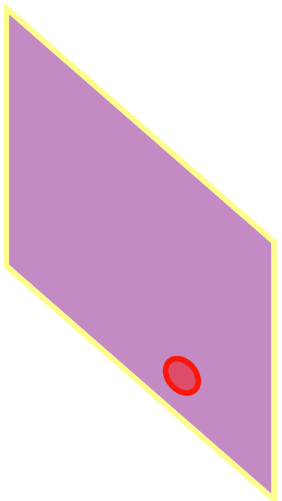


true hits

decay vertex



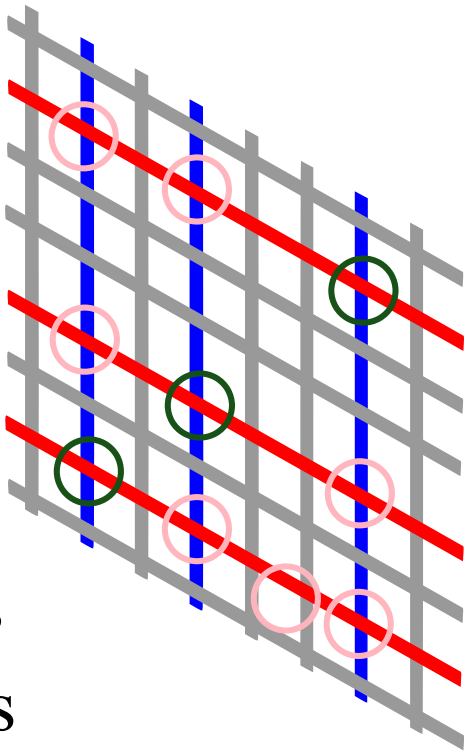


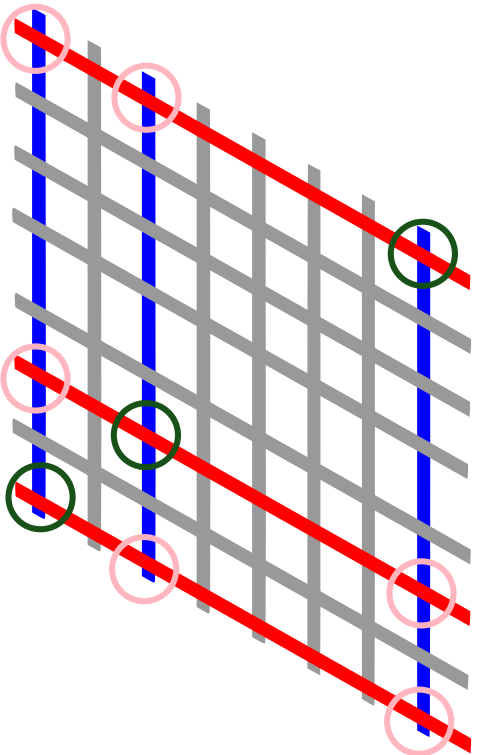


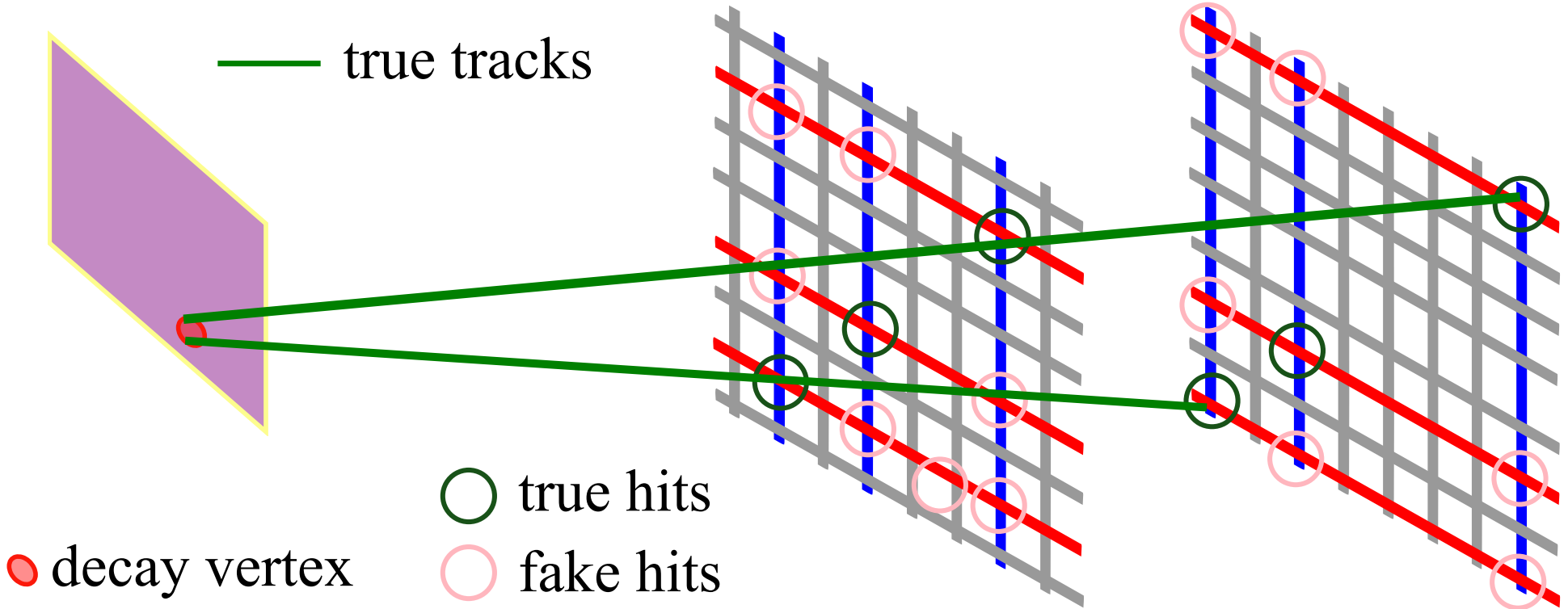
decay vertex

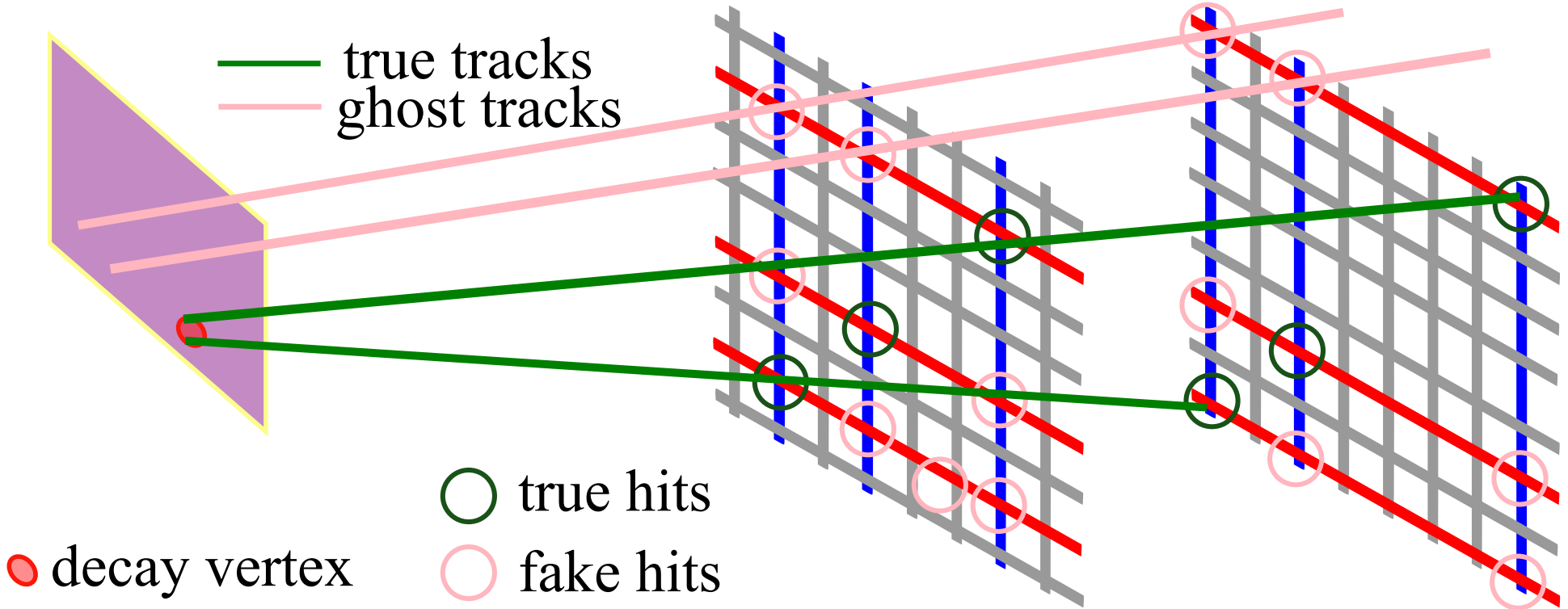
true hits

fake hits

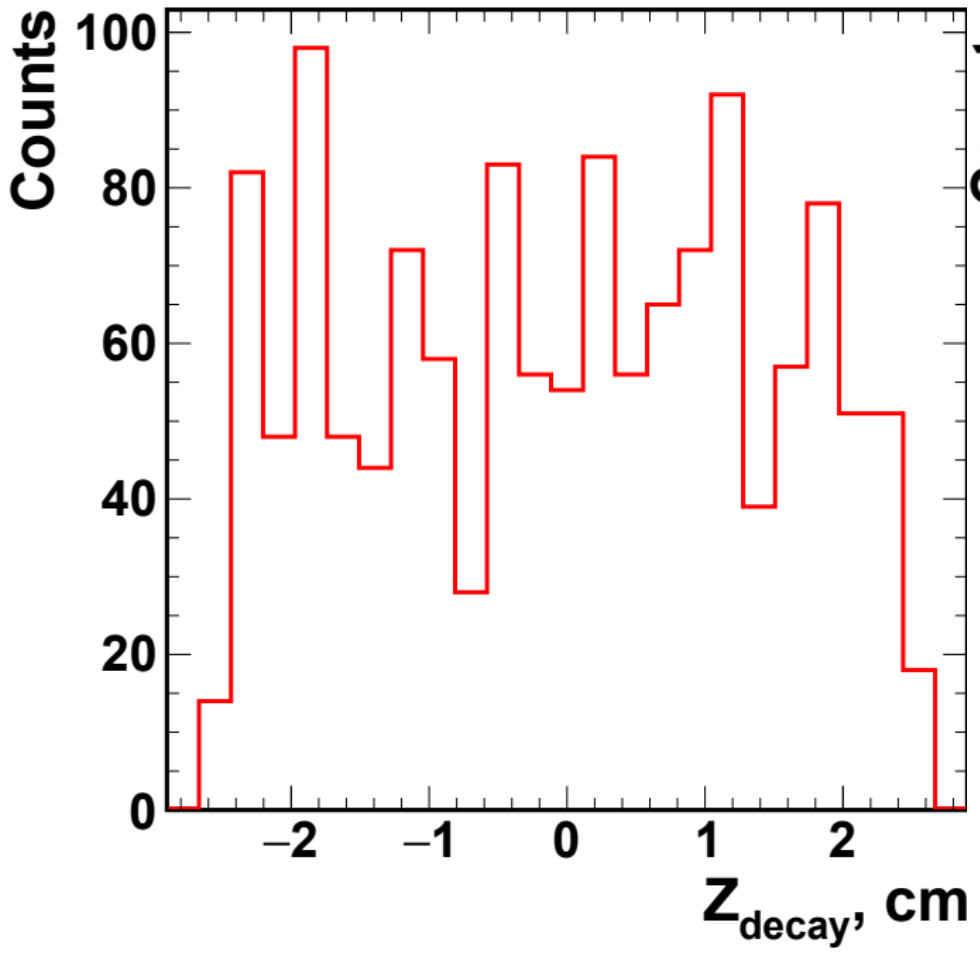


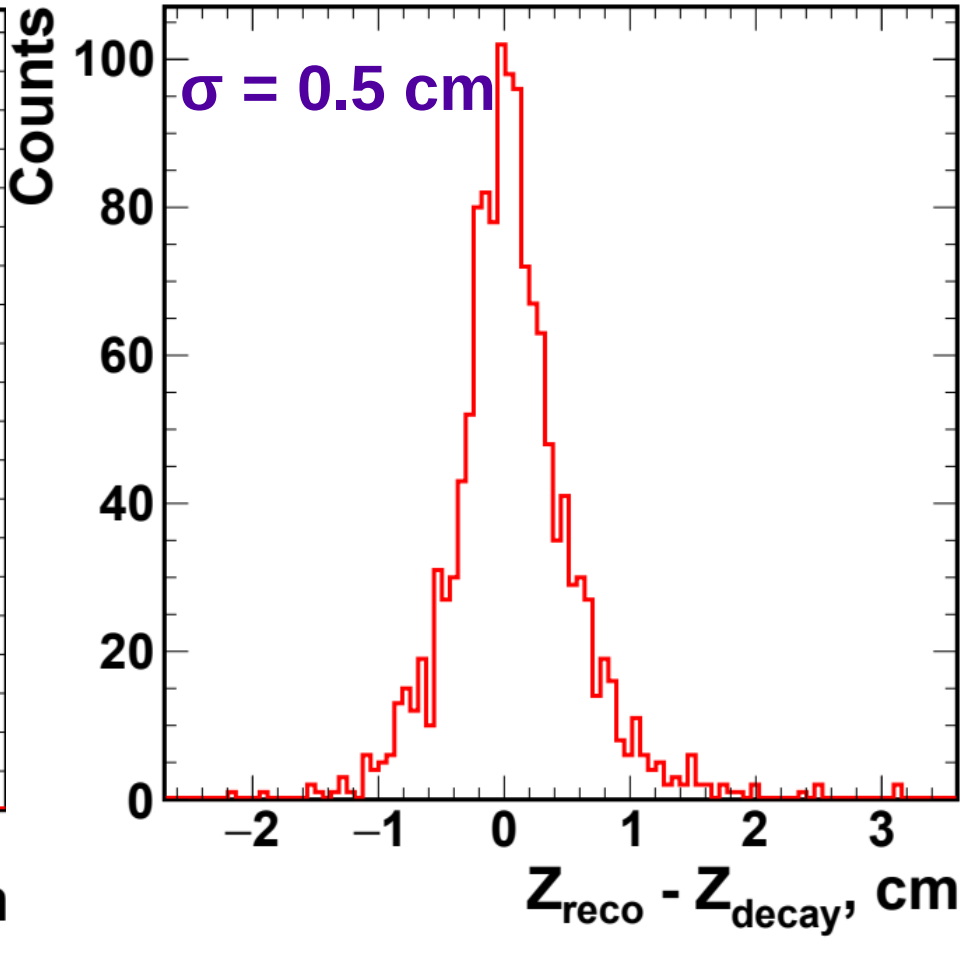



true tracks
true hits
fake hits
decay vertex


true tracks
ghost tracks
true hits
fake hits
decay vertex

3p decay vertex reconstruction





Conclusion

- Kinematics of ^{7}C state population is studied;
- Preliminary implementation of ALPIDE pixel detector in ExpertRoot

  (in addition to existing FOOT detectors);
- Geometrical efficiency of decay products registration is greatly affected by excitation energy:

  90.5% ($0 < E_{exc} < 20$ MeV),

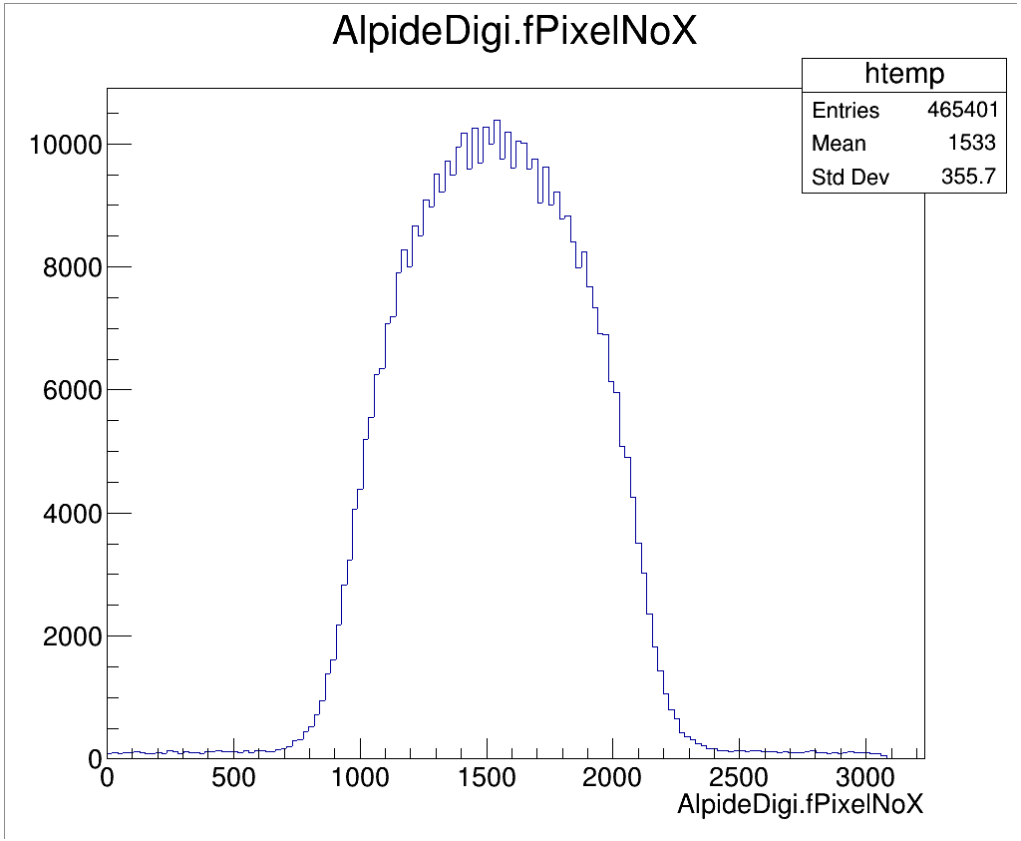
  99.5% ($0 < E_{exc} < 10$ MeV).
- Vertex reconstruction for a case of *3p* decay is investigated, the dispersion of reconstruction $\sigma_{3p} = 0.5$ cm.

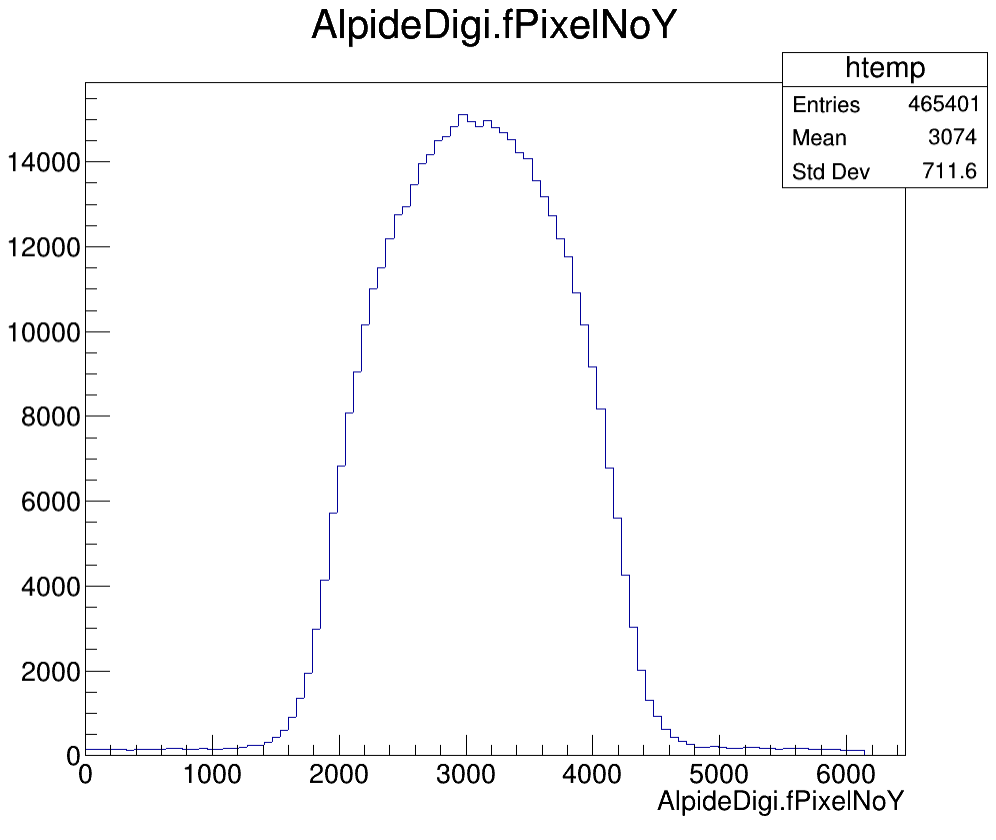
Outlook

- Hit reconstruction and track finding in case of a rotated pair of FOOT detectors, accountance of clusters;
- Further improvement of the ALPIDE detector (cluster consideration, detector inherit efficiency...);
- Vertex reconstruction in case of four- and five product decay.

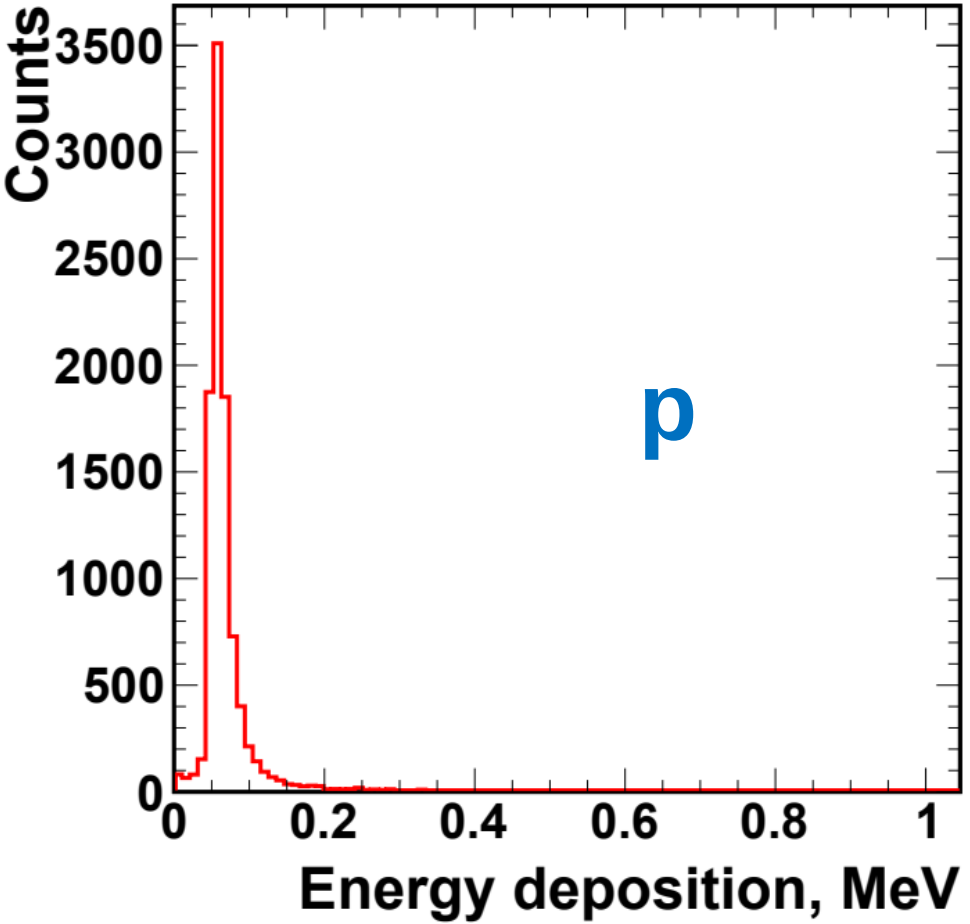
Backup slides

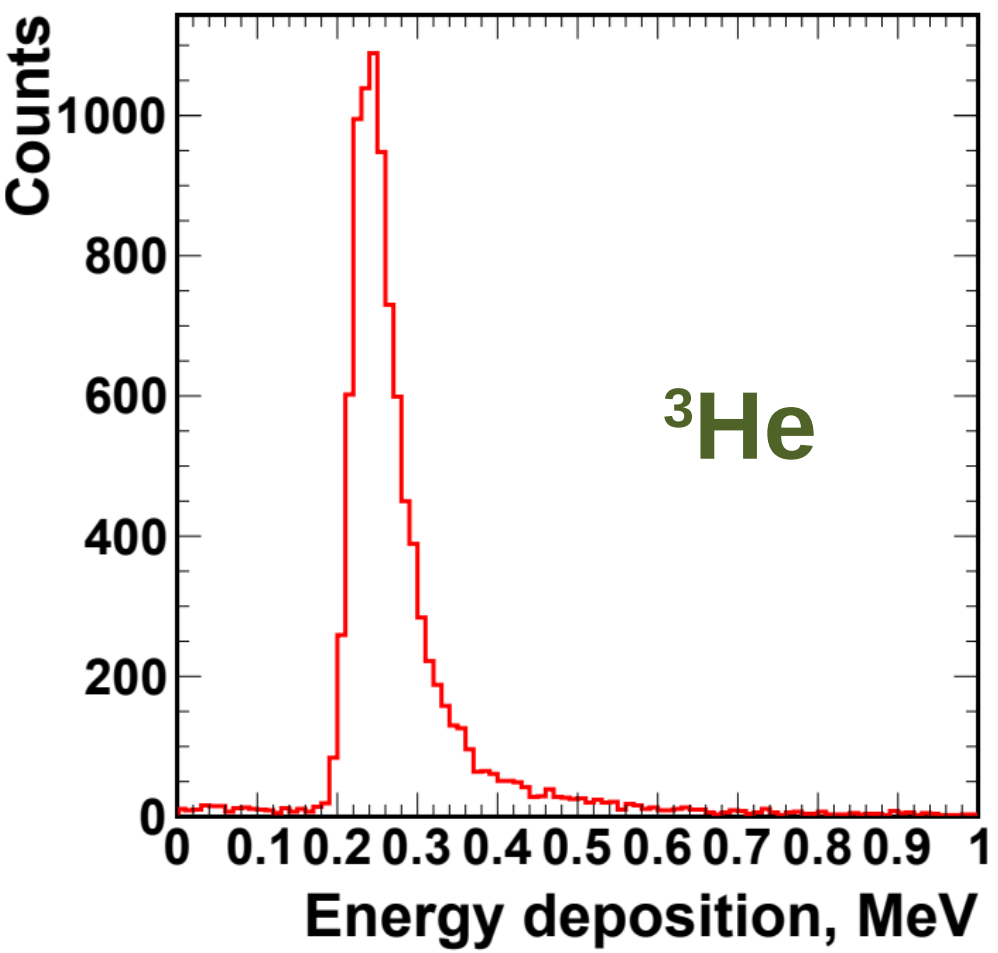
ALPIDE pixels implementation



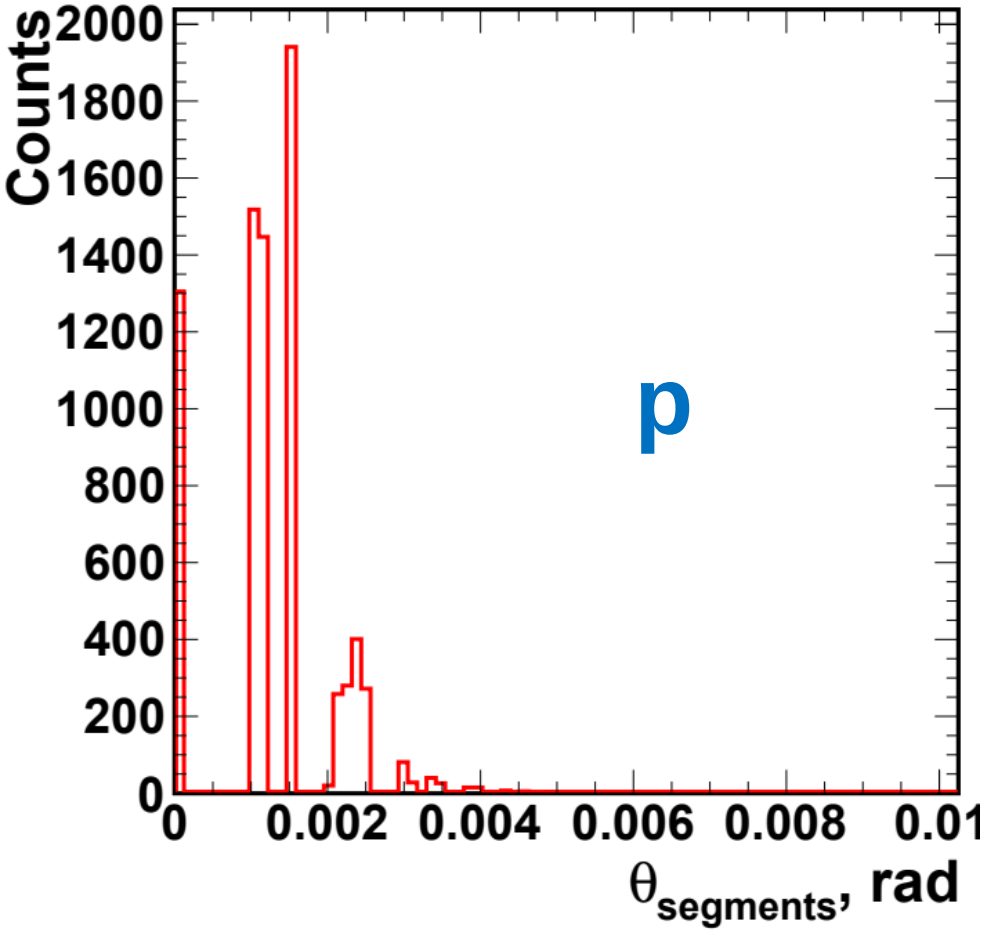


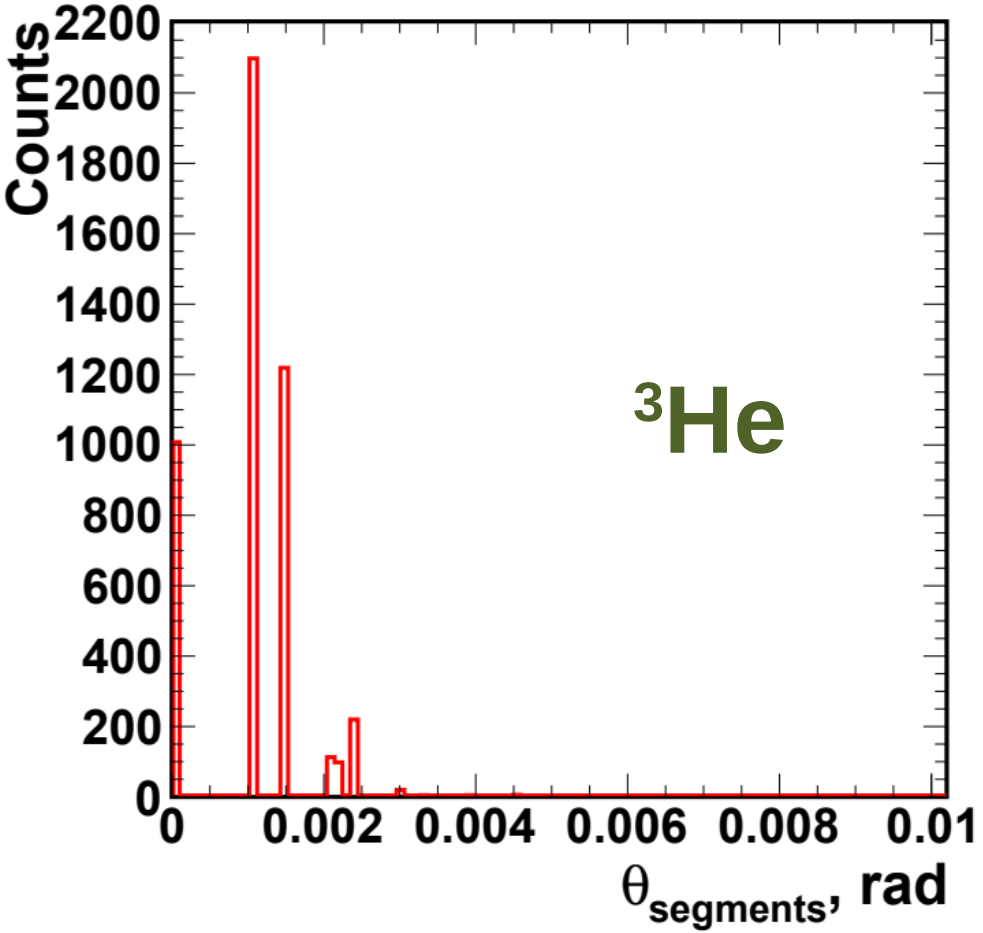
Energy deposit cuts on decay products



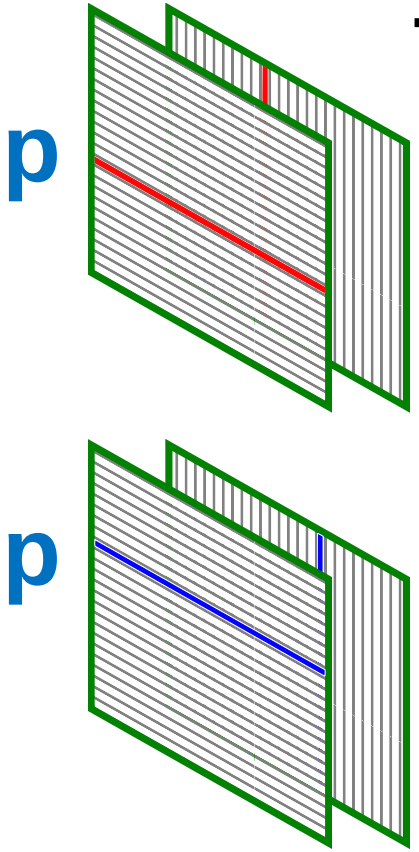


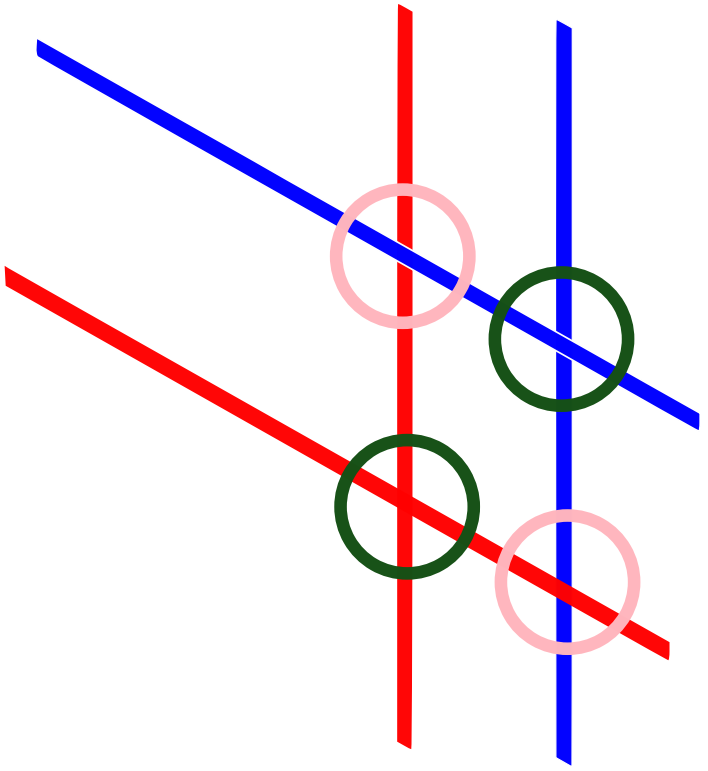
Θ between track segments for decay products





Tracks for two protons





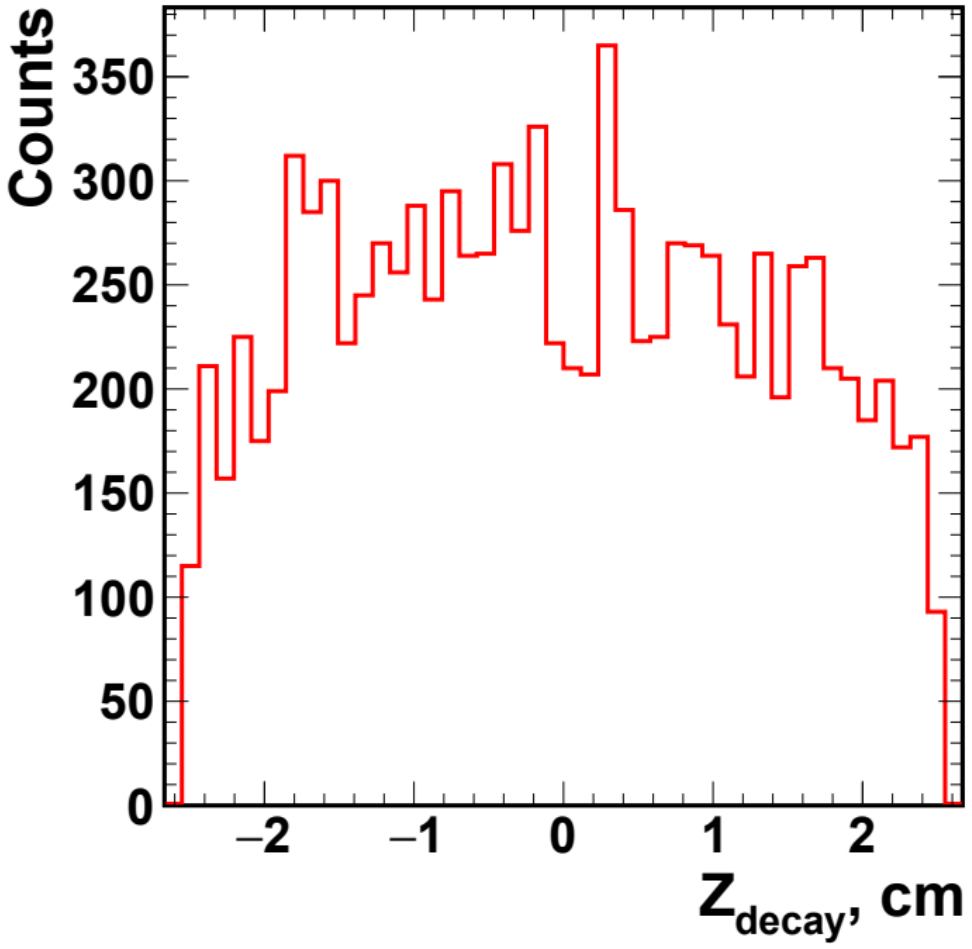
General case:

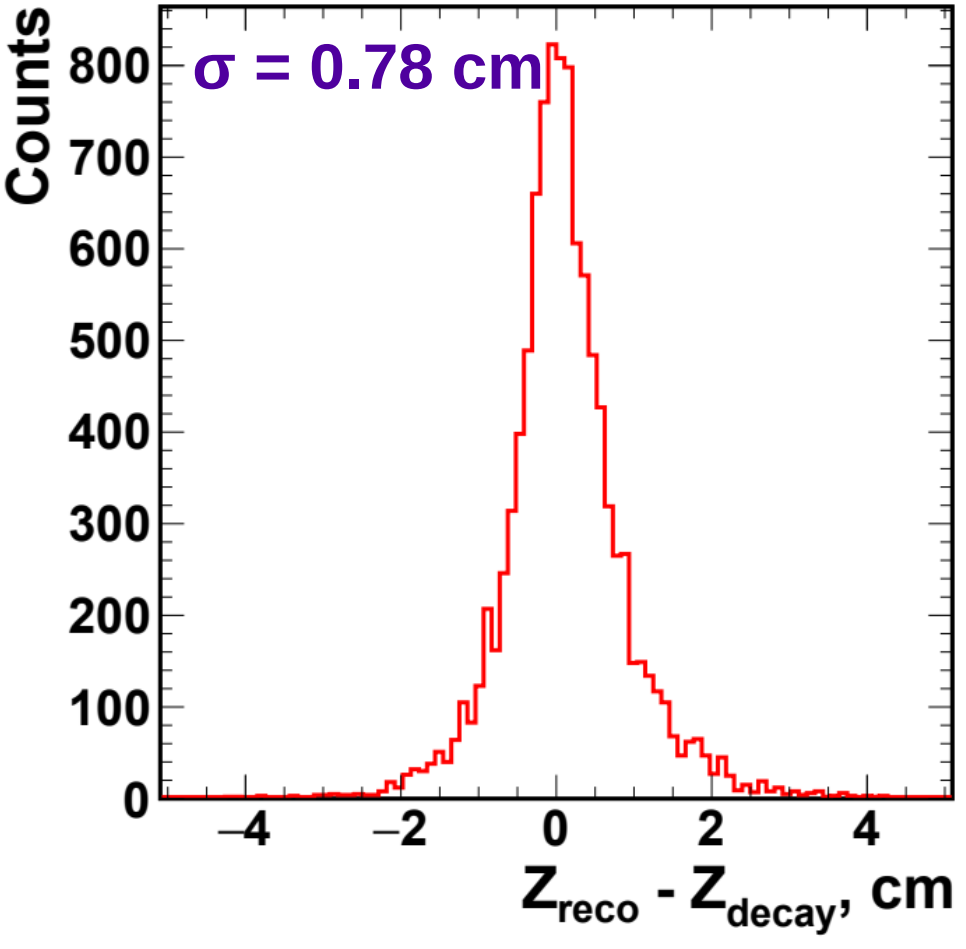
- $N^2 - N$ fake hits;
- N – true hits.

True hits

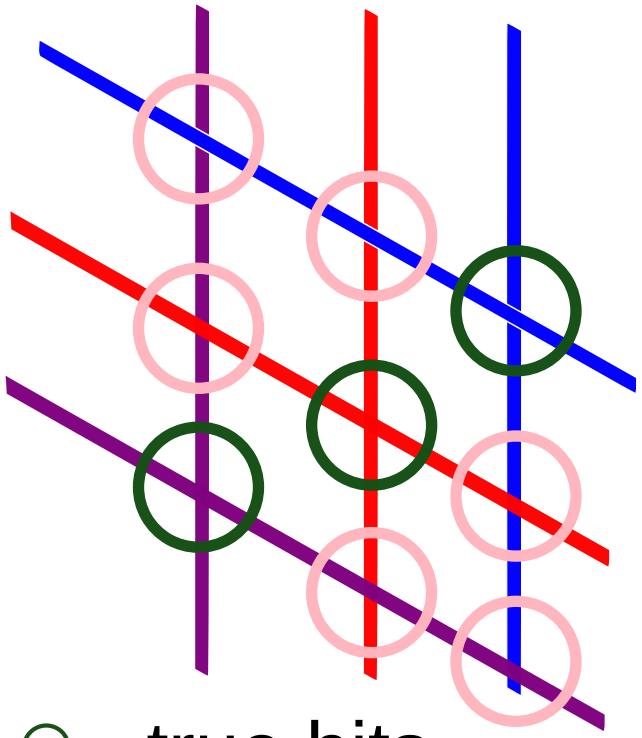
Fake hits

2p decay vertex reconstruction





Tracks for *3p* decay

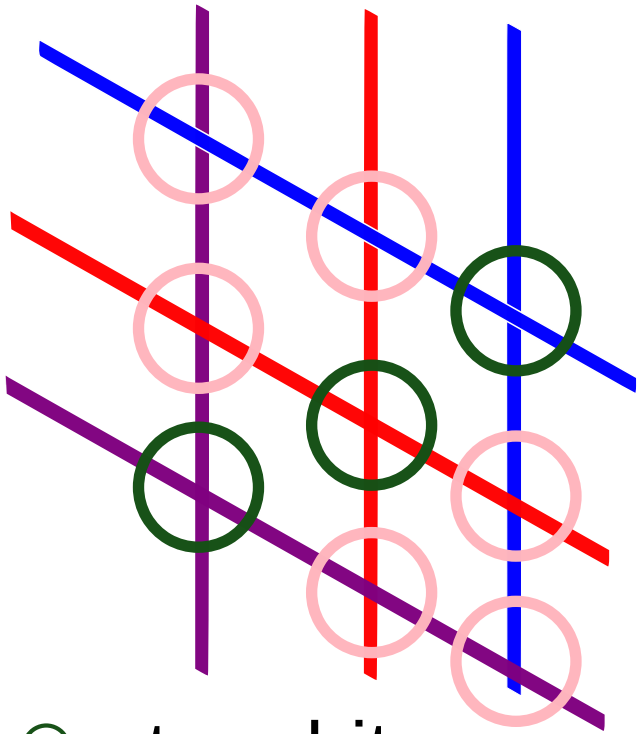


true hits

fake hits

Addition of 3rd proton – 4 more fake hits, 1 true.

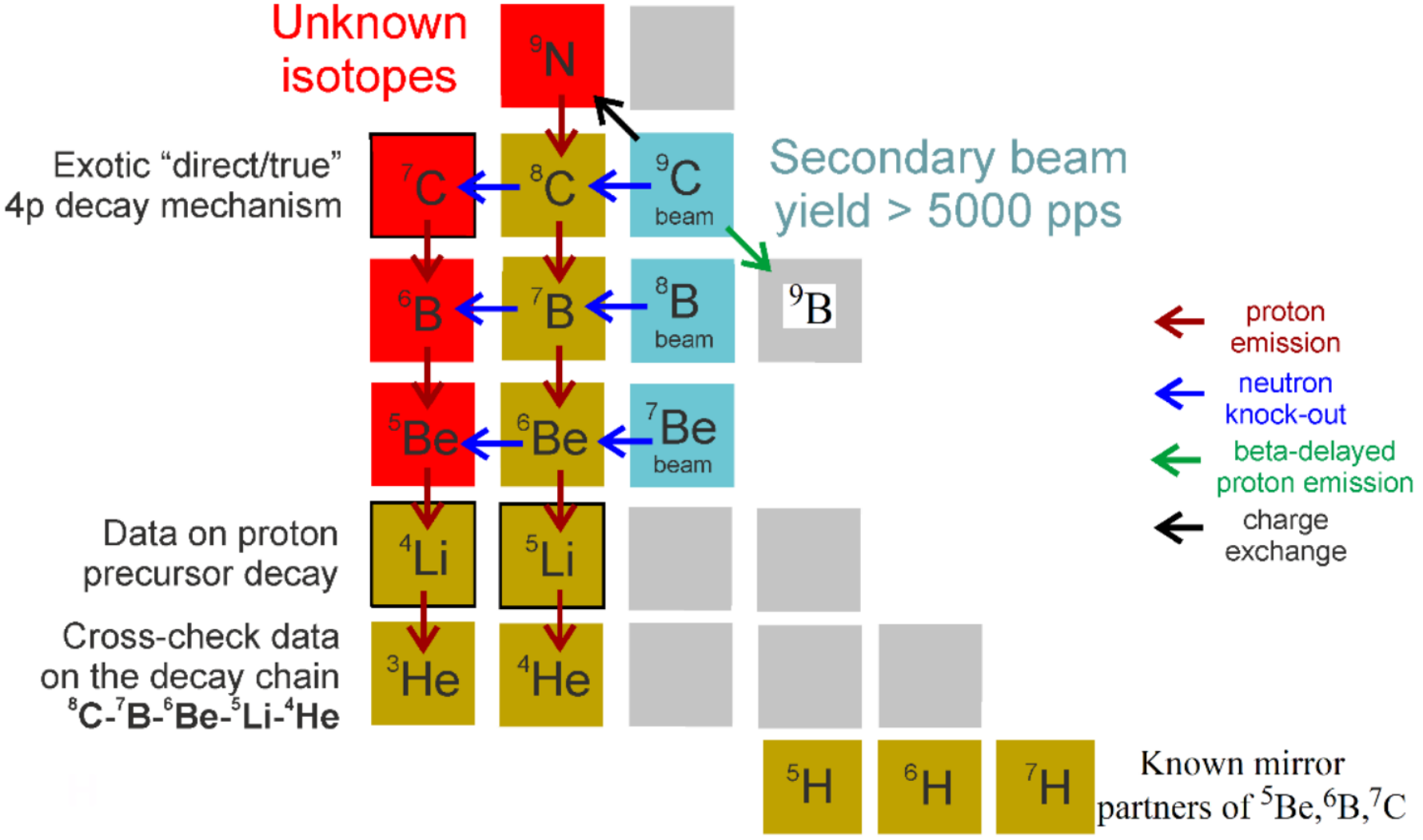
Tracks for *3p* decay



true hits

fake hits

- 9 reconstructed track candidates;
- Probability of hitting the same strip by different protons is negligible;
- Hits from different protons can’t have the same X or Y coordinates;
- Only certain combinations of tracks can be valid, better precision of vertex finding for more protons.


Unknown isotopes
^{9}N
Exotic "direct/true" 4p decay mechanism
^{7}C
^{8}C
^{9}C beam
Secondary beam yield > 5000 pps
^{9}B
^{6}B
^{7}B
^{8}B beam
^{5}Be
^{6}Be
^{7}Be beam
proton emission
neutron knock-out
beta-delayed proton emission
charge exchange
Data on proton precursor decay
^{4}Li
^{5}Li
Cross-check data on the decay chain ^{8}C-^{7}B-^{6}Be-^{5}Li-^{4}He
^{3}He
^{4}He
^{5}H
^{6}H
^{7}H
Known mirror partners of ^{5}Be,^{6}B,^{7}C