Toward studying photonuclear reactions with active-target TPC

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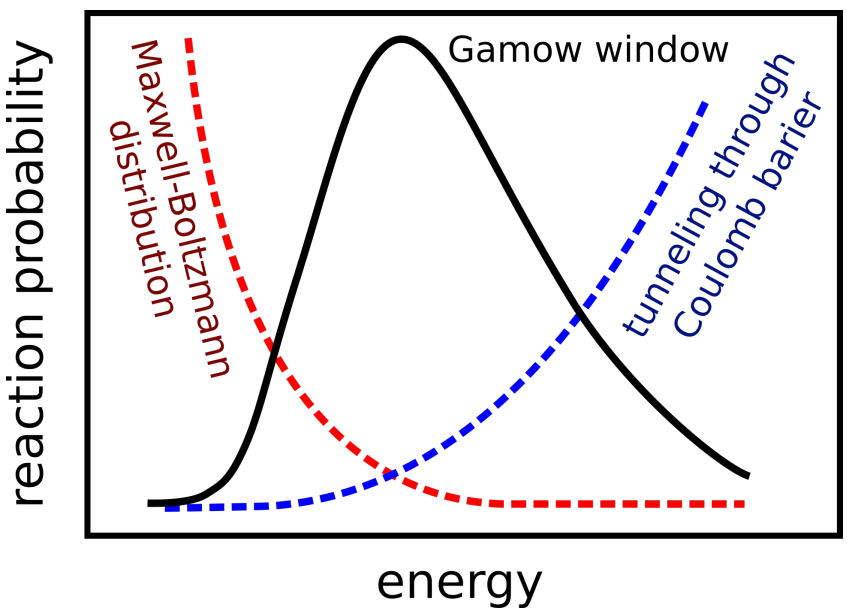
CPAD Instrumentation Frontier Workshop 2021

Nuclear astrophysics

Stellar nuclear reactions occur within narrow energy windows

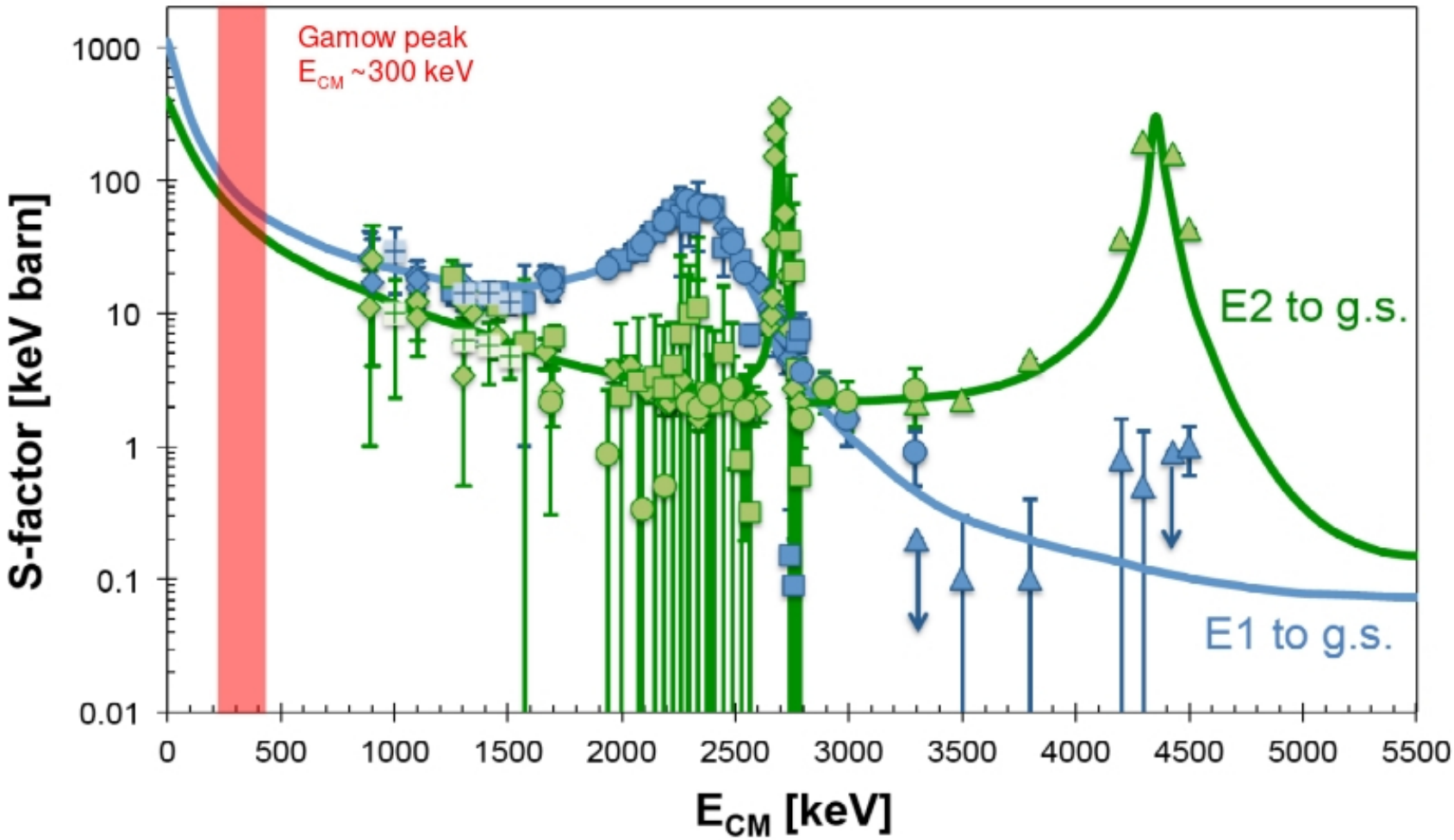


The $^{12}C/^{16}O$ ratio depends on the relative rates of the reactions:

$$3\alpha \rightarrow {}^{12}\mathrm{C}$$

$$^{12}\mathrm{C}(\alpha,\gamma)^{16}\mathrm{O}$$

$^{12}C(\alpha,\gamma)^{16}O$ reaction S-factors



Nacre II, Y. Xu *et al.*, Nuclear Physics A **918** (2013)

$$S(E) = \frac{E}{\exp\left(-2\pi\eta\right)}\sigma(E), \quad \eta = \frac{Z_1 Z_2 \alpha}{\beta}$$

The detailed balance principle:

$$^{12}\mathrm{C}(\alpha,\gamma)^{16}\mathrm{O} \rightleftharpoons {}^{16}\mathrm{O}(\gamma,\alpha)^{12}\mathrm{C}$$

$$\sigma_{\alpha\gamma} = \sigma_{\gamma\alpha}\frac{2J_\mathrm{O}+1}{(2J_\alpha+1)(2J_\mathrm{C}+1)}\frac{E_\gamma^2}{E_{CM}}\frac{1}{\mu_{\alpha\mathrm{C}}c^2}$$

$$\sigma_{\alpha,\gamma}(1\text{ MeV}) \approx 50\text{ pb}$$

$$\sigma_{\gamma,\alpha}(1\text{ MeV}) \approx 2\text{ nb}$$

$$\sigma_{pp\to H^0}(13\text{ TeV}) \approx 60\text{ pb}$$

Gamma-beam facilities:

- HIγS (**H**igh **I**ntensity **G**amma-Ray **S**ource, USA)
  Intensity $10^7\gamma$/s, resolution 10% FWHM

- NewSUBARU (Japan)
  Intensity $10^5\gamma$/s, resolution 1.2% FWHM

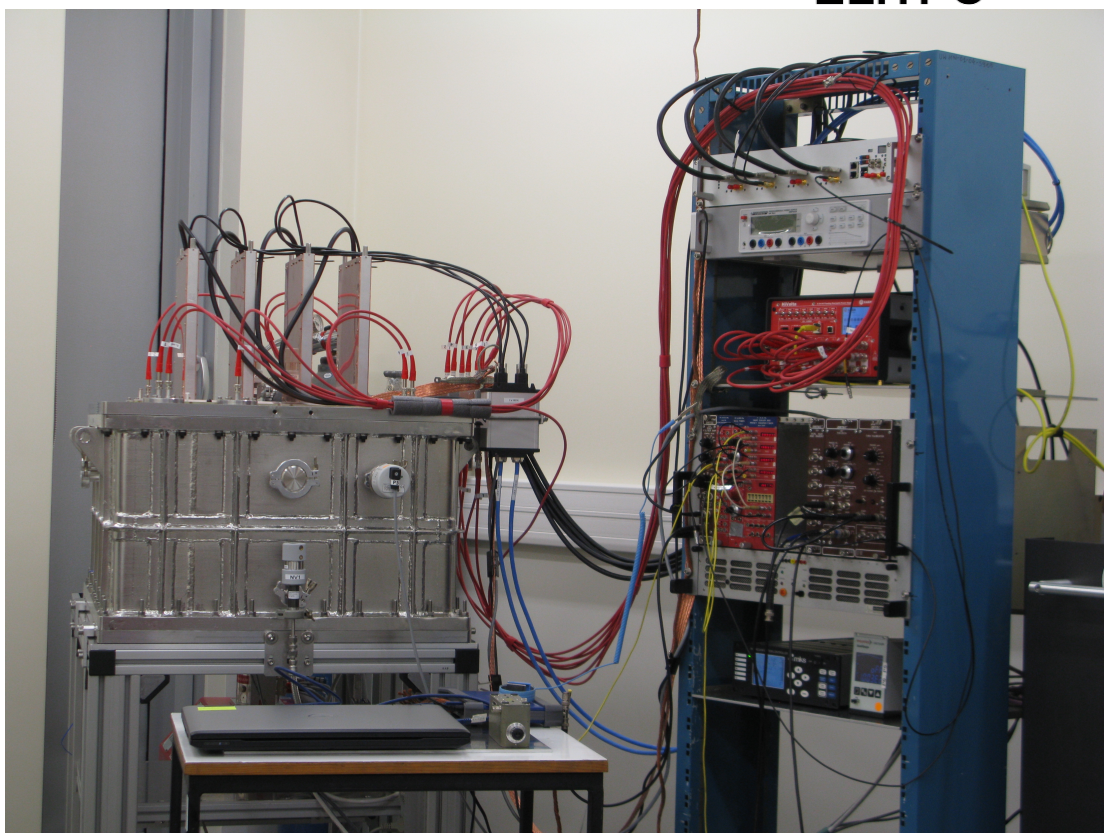
- ELI-NP (**E**xtreme **L**ight **I**nfrastructure **N**uclear **P**hysics, Romania, under construction)
  Intensity $10^9\gamma$/s, resolution 0.5% RMS

ELITPC detector: active-target TPC with electronic readout

ELITPC

Goals:

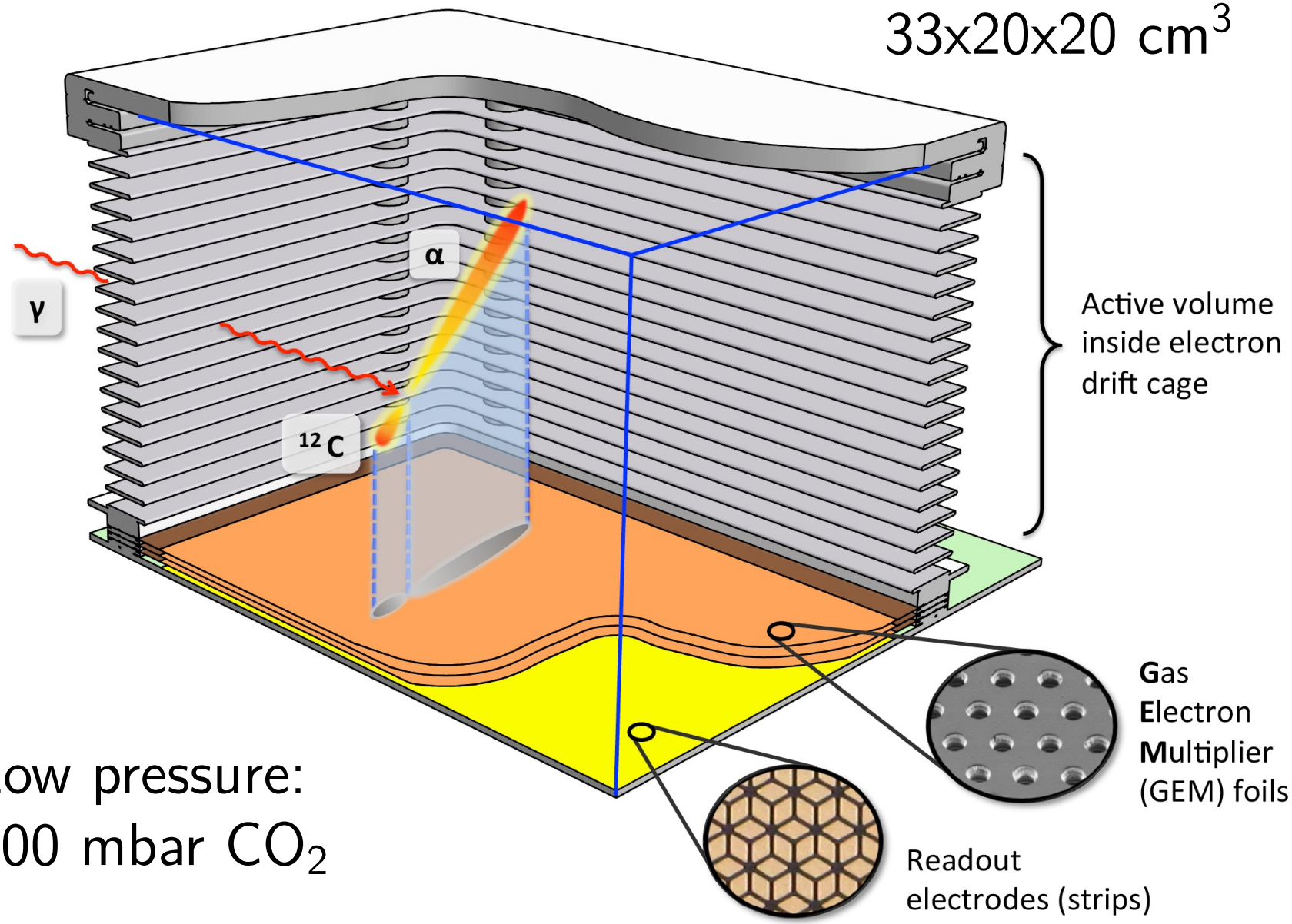
- study nuclear astrophysics relevant (γ, α) (γ, p) reactions,
- measure energy & angular distributions of low-energy charged products,
- reduce uncertainty of $^{12}\mathrm{C}(\alpha,\gamma)^{16}\mathrm{O}$ from 40-80% to 10%.



Model detector

ELITPC detector:

Active volume:
33x20x20 cm^3

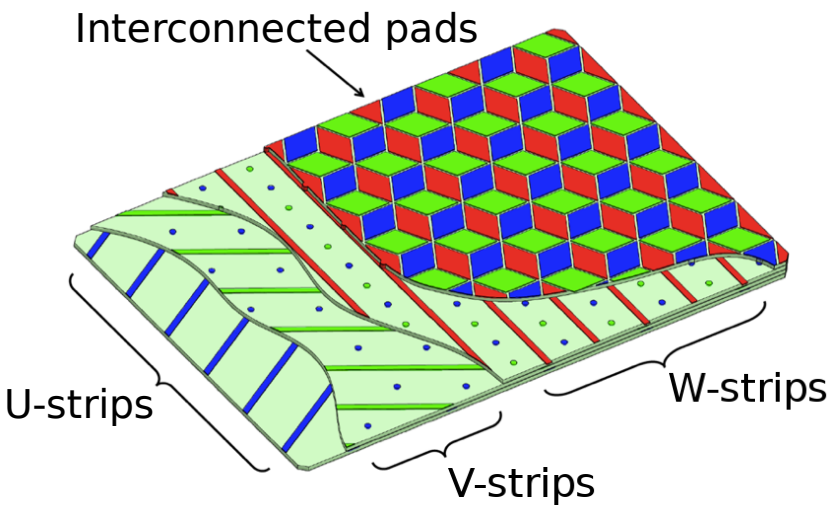


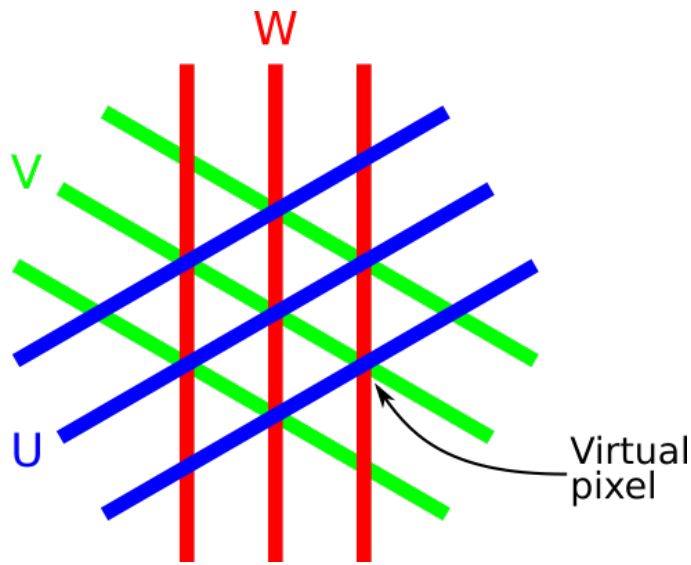
Low pressure:
100 mbar CO_2

O. Tesileanu *et al.*, Romanian Rep. in Phys. **68**, Supplement (2016)

Strip readout

XY plane: $\sim$ 1000 channels (U,V,W)
Z axis: drift time



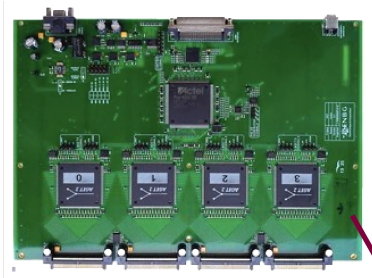


M. Ćwiok, Acta Phys.Pol. B **47** (2016)

DAQ system

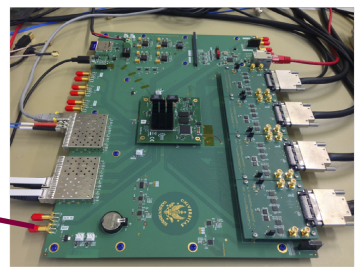
Generic **E**lectronics for **T**PCs

(GET collab. CEA/IRFU, CENBG, GANIL, MSU/NSCL)



ASIC & **AD**C[1]
12-bit ADC
4 AGET chips
256 channels

ASIC for **GET**[1]
512 time-cells per channel
sampling frequency 1 - 100 MHz



z-CoBo
Concentrator **Bo**ard
1024 channels

Gas | Air

UVW readout PCB

Signal routing PCB

ZAP

ZAP

ZAP

ZAP

AsAd

AsAd

AsAd

AsAd

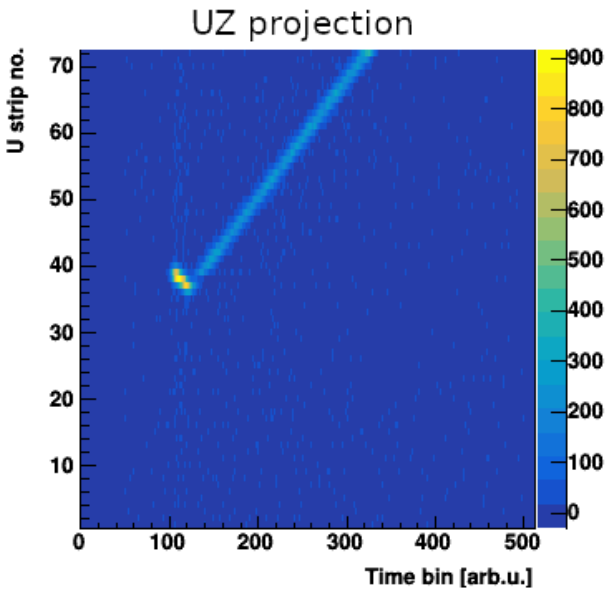
DAQ module

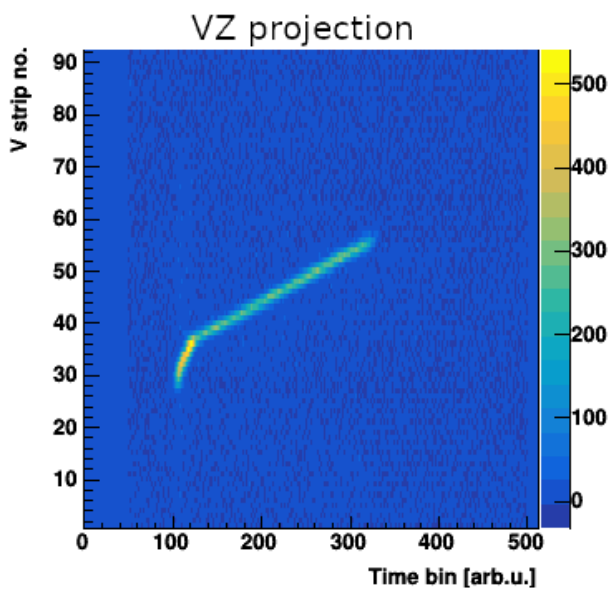
DAQ
Server PC

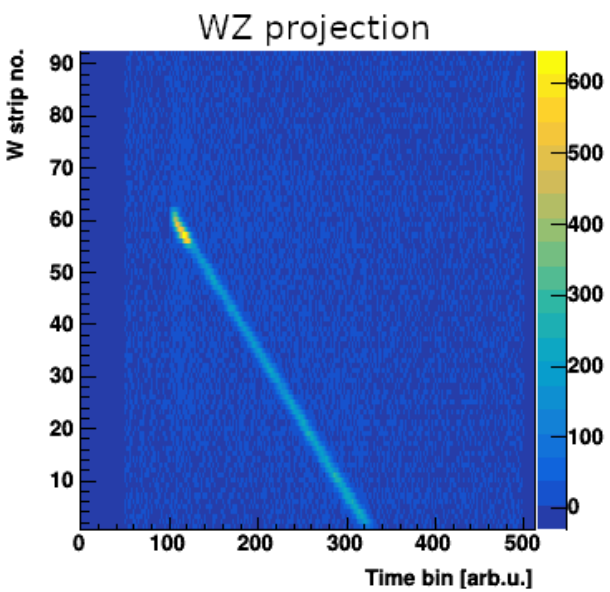
custom design UW

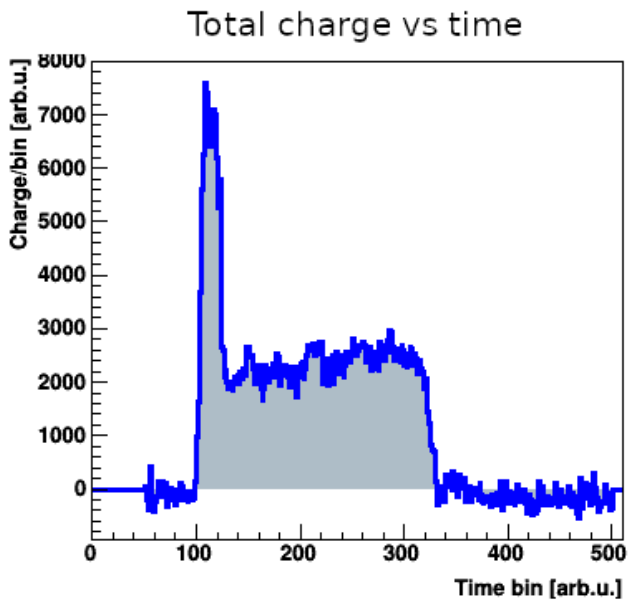
[1]E.Pollacco *et al.*, NIMA **887** (2018) 81

Example event from test detector









256 channels

active volume 10x10x20 cm^3

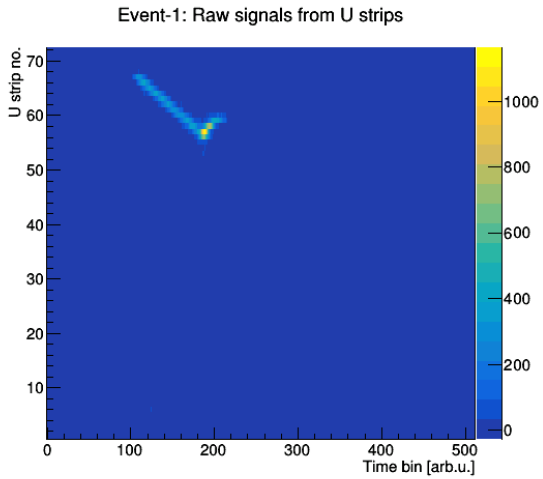
100 mbar CO_2

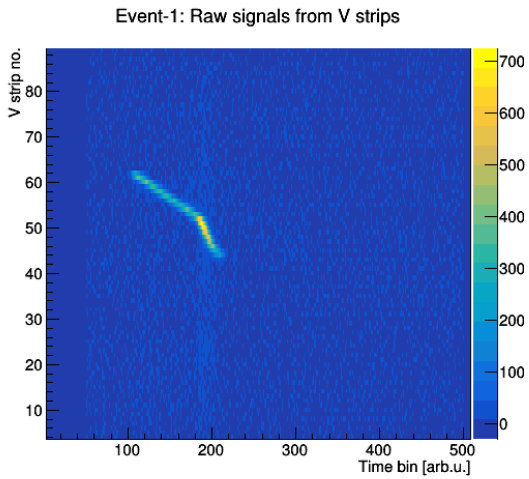
n beam

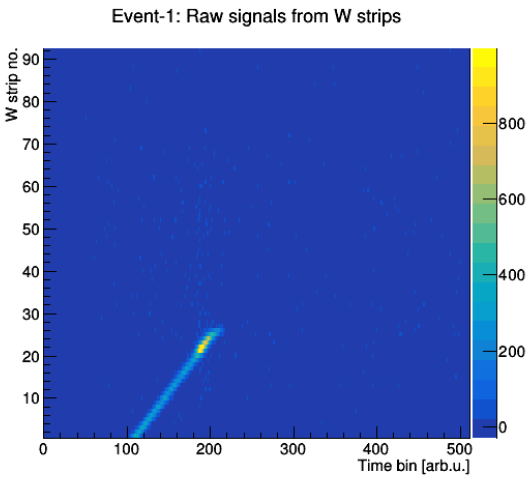
3MV Tandem accelerator IFIN-HH, Romania

Event reconstruction — ongoing development

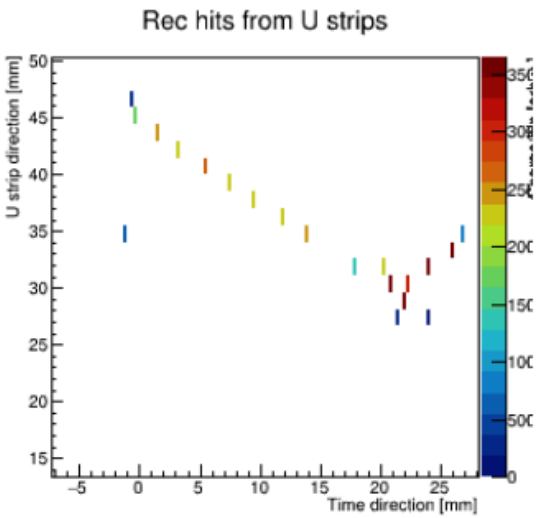
Raw signal

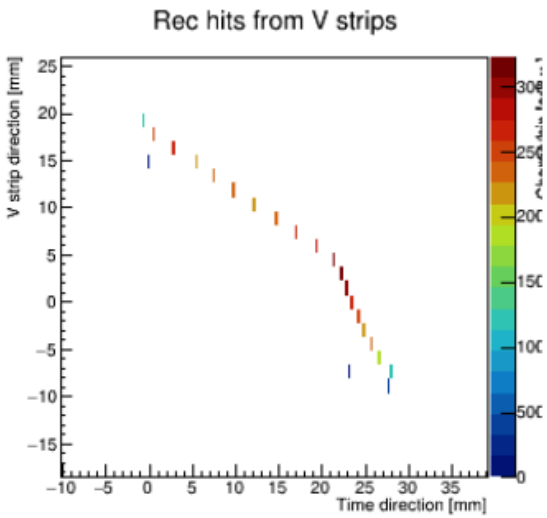


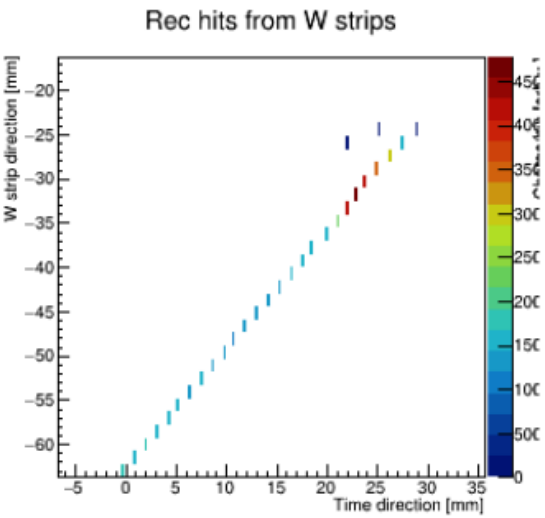




Hit reconstruction

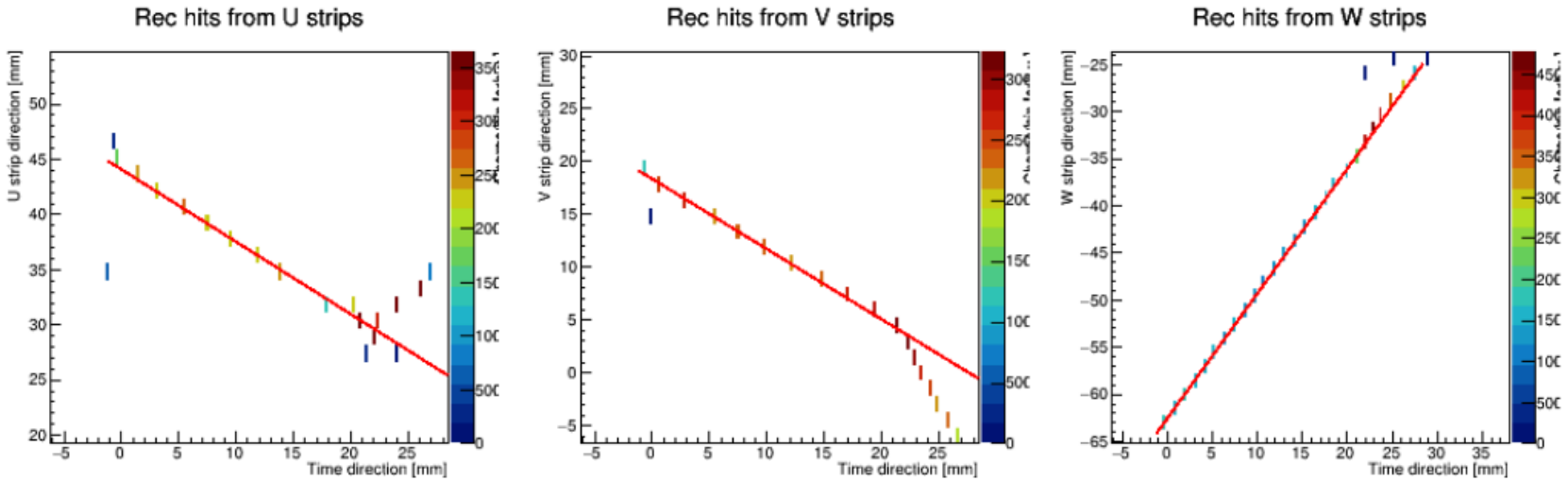




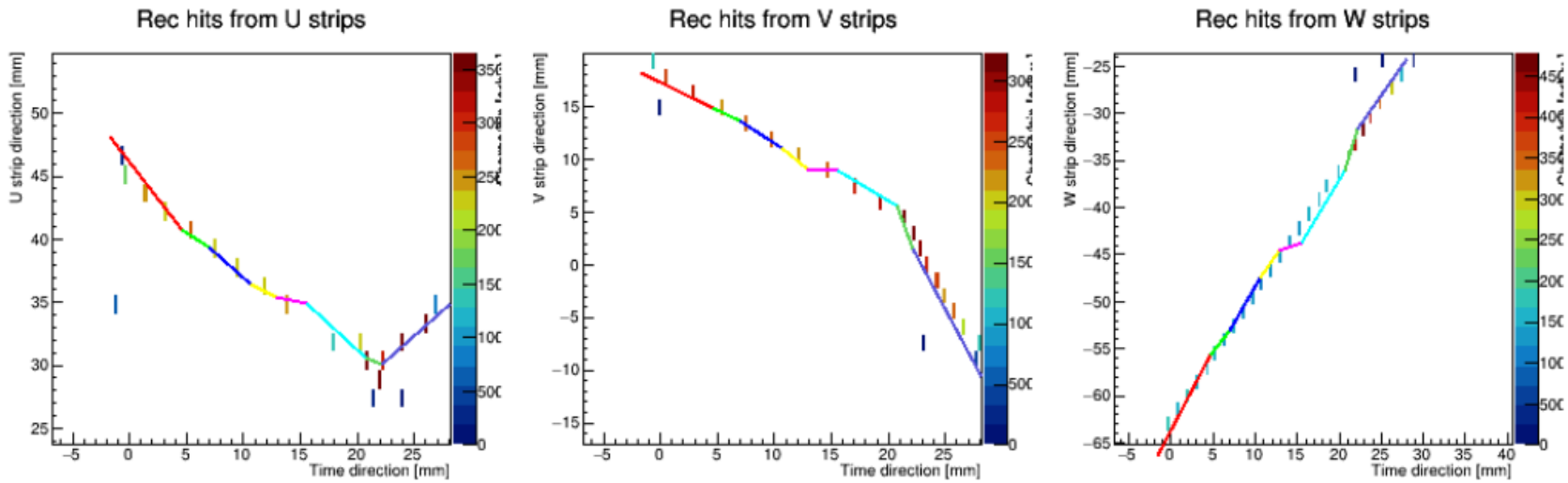


Event reconstruction — ongoing development

classic line detection algorithm→ Hough transform



3D segment fitting



Summary

- The availability of high intensity γ-ray beams present new opportunity for studying astrophysics relevant nuclear reactions.
- An active-target TPC with electronic readout suited for studying photonuclear reactions is developed at the University of Warsaw. The model detector is fully operational.
- $^{16}\mathrm{O}(\gamma,\alpha)^{12}\mathrm{C}$ disintegration reactions will be studied in upcoming experiments with γ-ray beams of HIγS and ELI-NP.

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Scientific work supported by the Polish Ministry of Science and Higher Education from the funds for years 2019-2021 dedicated to implement the international co-funded project no. 4087/ELI-NP/2018/0, by University of Connecticut under the Collaborative Research Contract no. UConn-LNS_UW/7/2018 and by the National Science Centre, Poland, under Contract no. UMO-2019/33/B/ST2/02176.