UNIVERSITY OF PERUGIA
PHYSICS DEGREE COURSE

Pulse Shape Studies of Neutral Particles with a Liquid Scintillator

Presented by:
Lucia Salvi

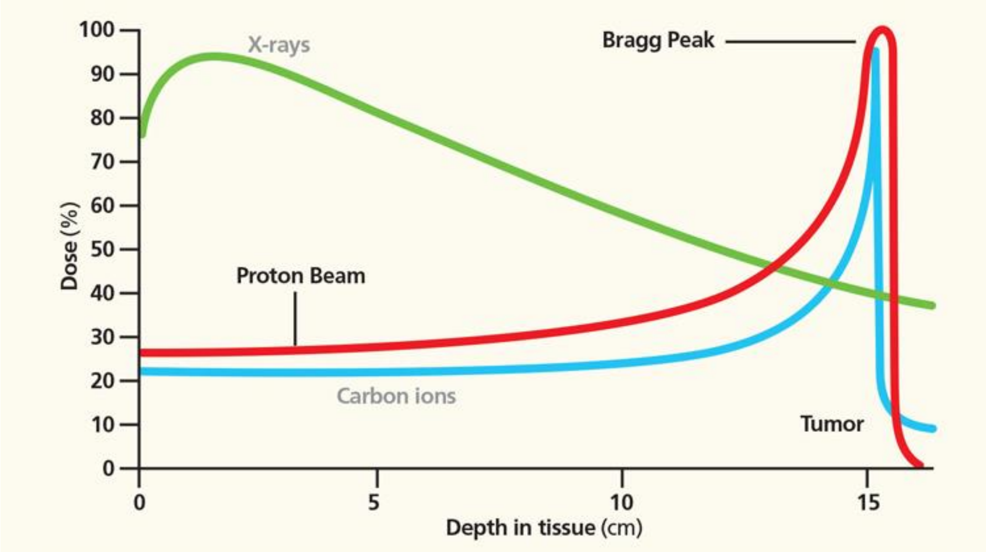
October 27, 2022

HADRONTHERAPY

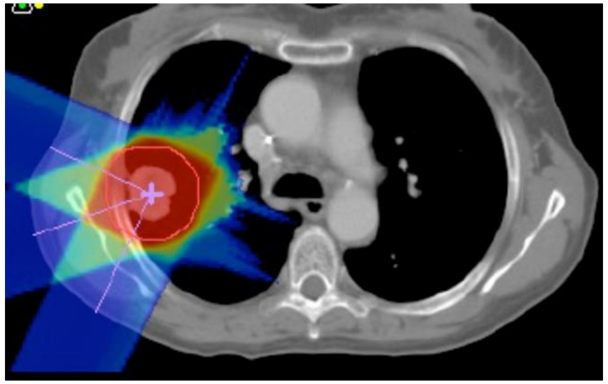
Hadrontherapy: peak of the dose at the end of the path

Radiotherapy: large dose both in the entrance channel and beyond the treatment volume

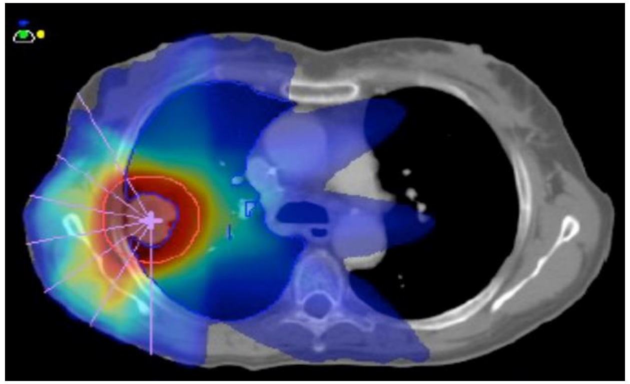
but…



Hadrontherapy 150-400 MeV/u



Radiotherapy 1-15 MeV/u



HADRONTHERAPY

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Radiotherapy: large dose both in the entrance channel and beyond the treatment volume

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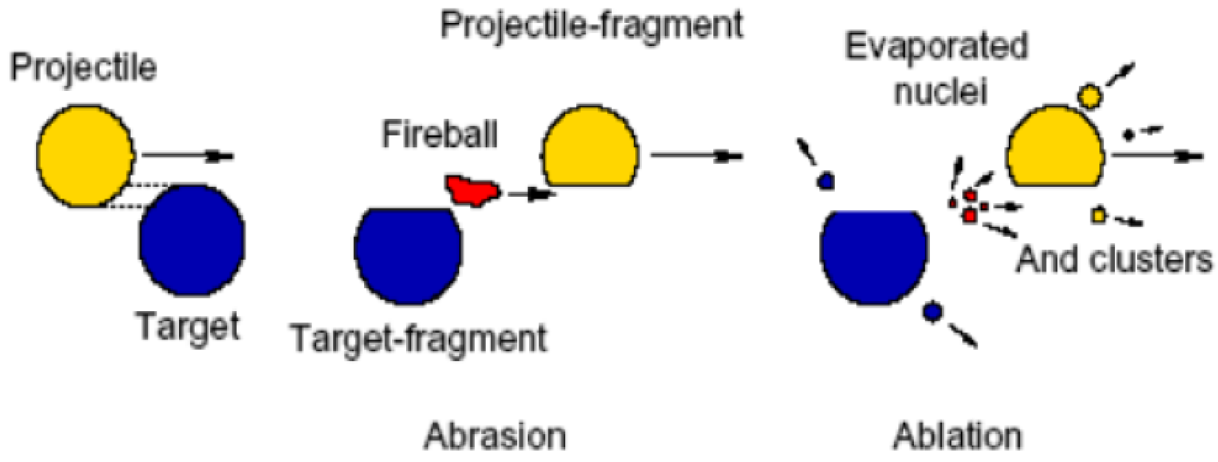
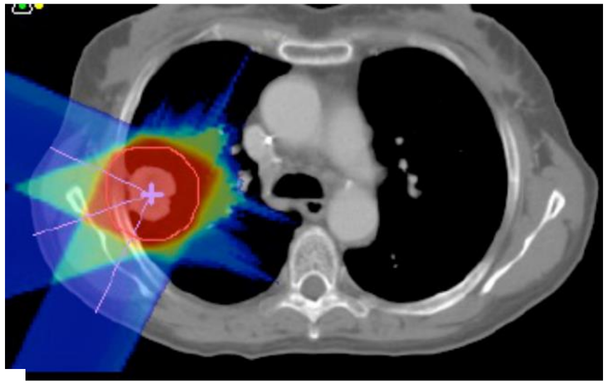


Hadrontherapy 150-400 MeV/u



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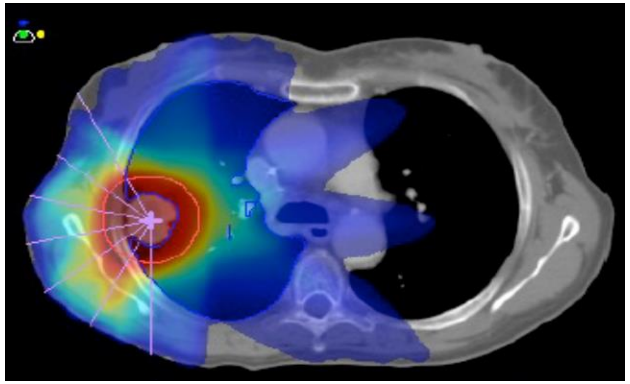


Projectile fragmentation:

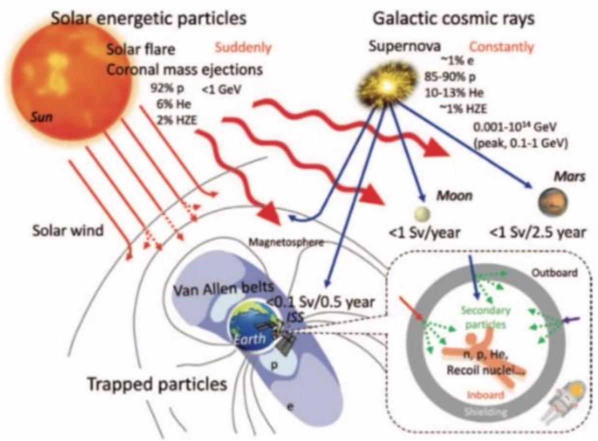
- secondary particles with lower Z w.r.t. projectile
- longer range
- energy loss tail beyond Bragg Peak

Target fragmentation:

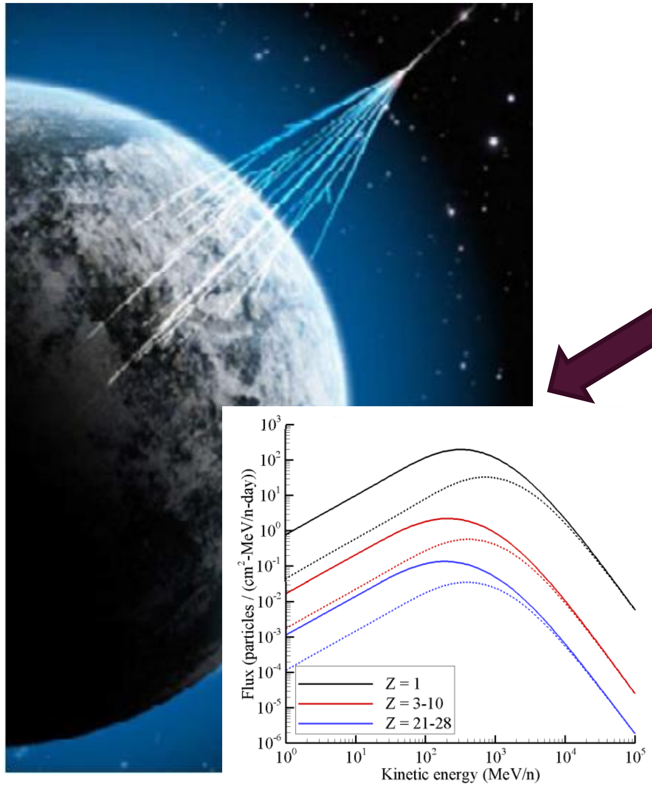
- low energy charged fragments
- short range
- impact in the entrance channel

NEUTRON PRODUCTION

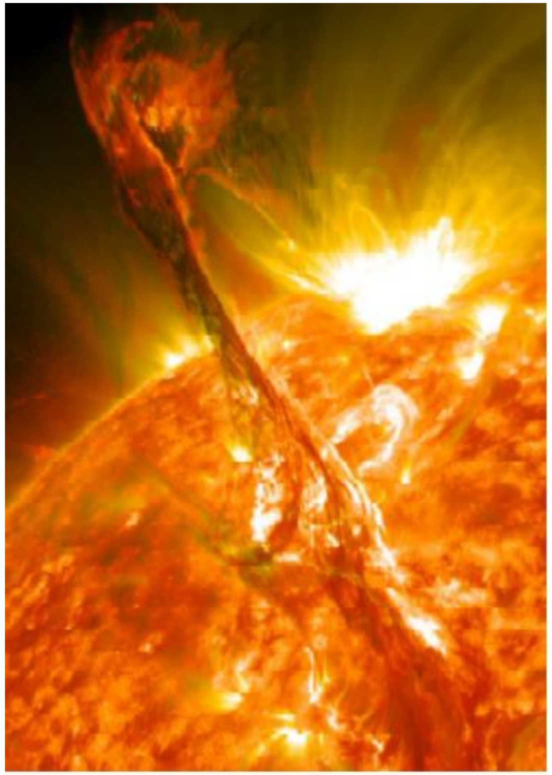
RADIATION PROTECTION IN SPACE



Galactic cosmic rays



Solar particle events



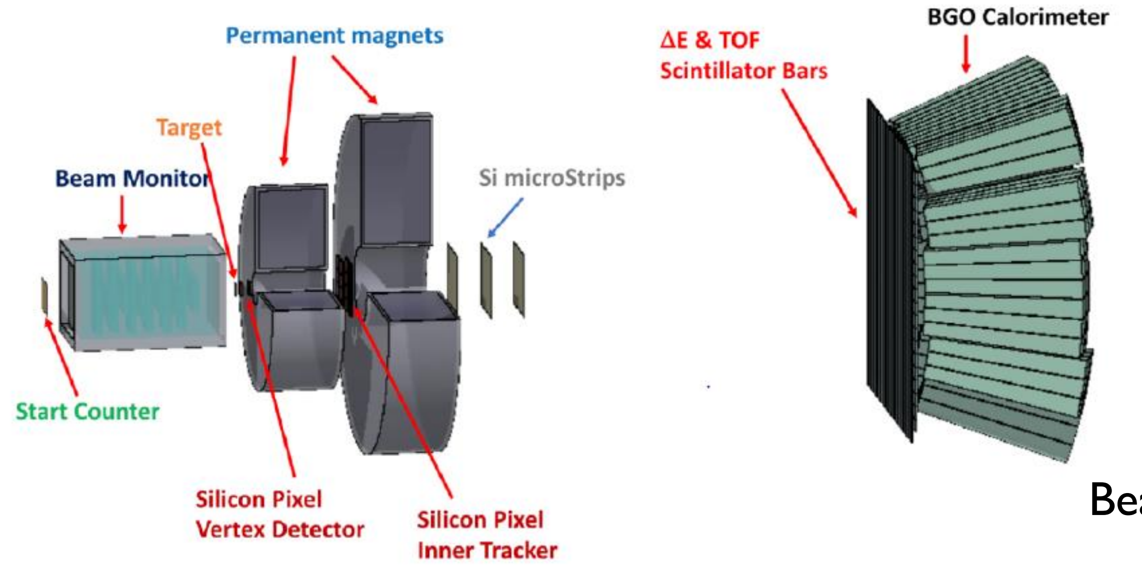
Long term exploration

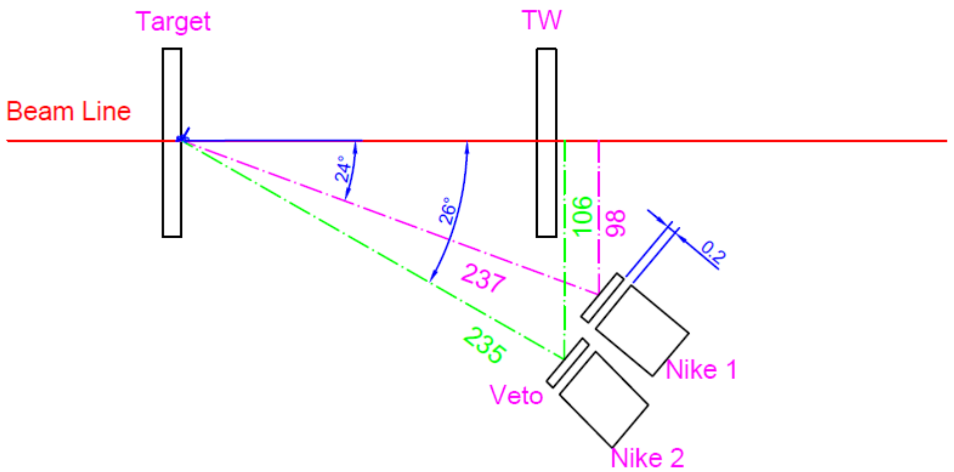
BUT…

Fragmentation on the shielding material
700 - 1000 MeV/u

NEUTRON PRODUCTION

FOOT EXPERIMENT





Aims:

- Target fragments $^{d\sigma}/_{dE_{kin}}$ precision 10%
- Projectile fragments $^{d^2\sigma}/_{dE_{kin}\,d\theta}$ precision 5%

Beam: ^{16}O 200 and 400 MeV/u

Target: C and $(C_2H_4)_n$, 1 and 0.5 cm thick

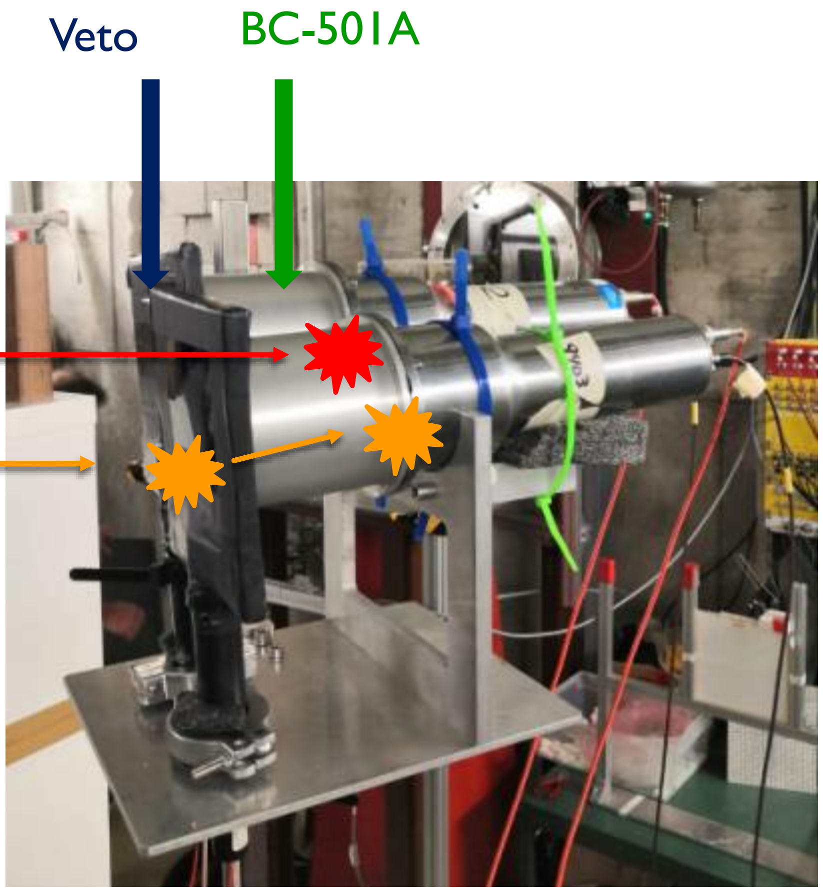
Detector: liquid scintillator BC-501A, diameter and length 7.62 cm

Veto: plastic scintillators, 9x9x0.5 cm^3

NEUTRON DETECTORS

Data collected: GSI laboratory, Darmstadt, Germany, July 2021

Analyzed data: 3465891 ^{16}***O, 400 MeV/u,*** $(C_2H_4)_n$ ***, 1 cm***



Neutral particles: anticoincidence event

Number of events: 2662

Charged particles: coincidence event

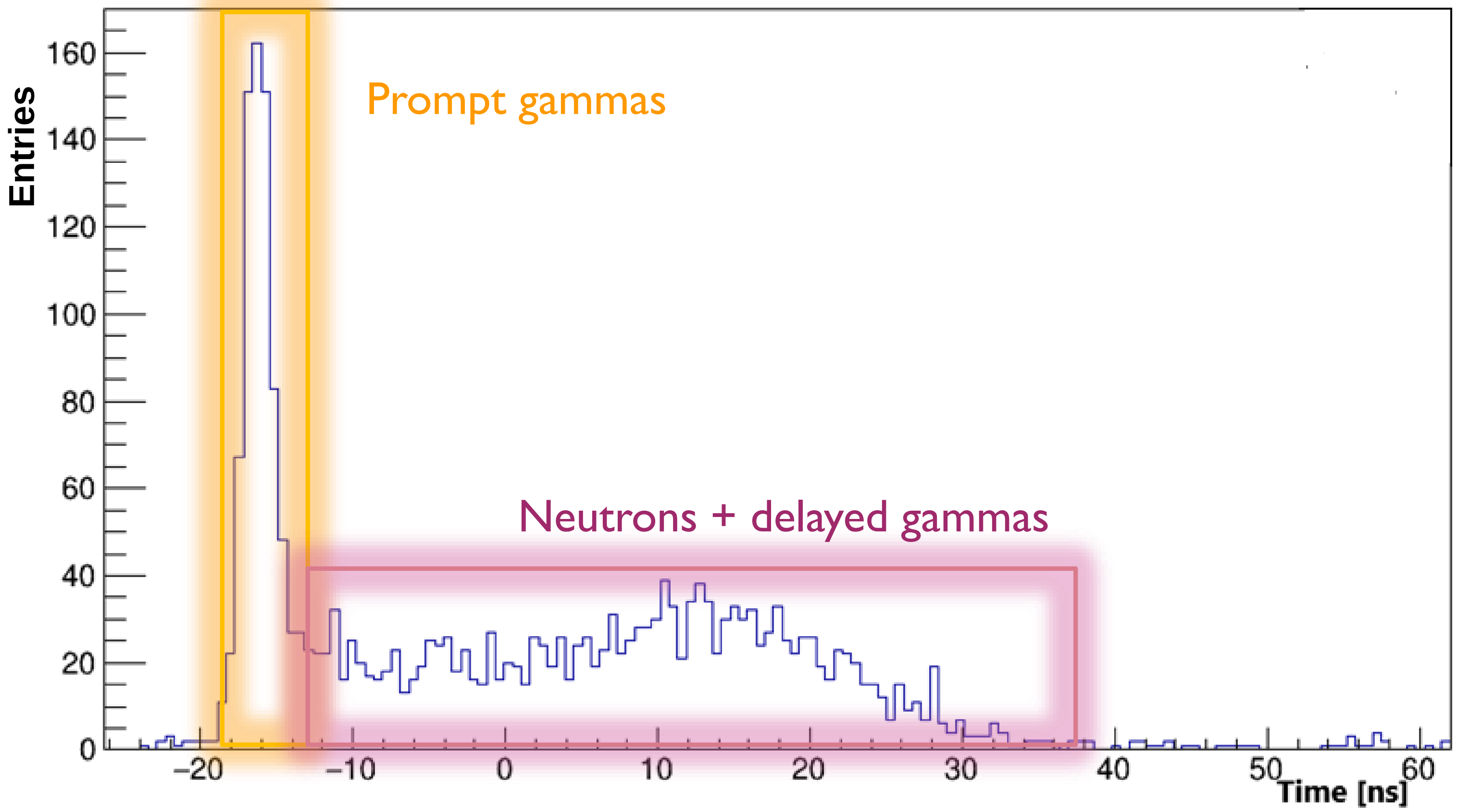
Number of events: 466

BC-501A: neutron detection based on neutron – proton elastic scattering

$$E_p = E_n \cos^2\theta$$

TIME OF FLIGHT CALIBRATION

BC-501A scintillator



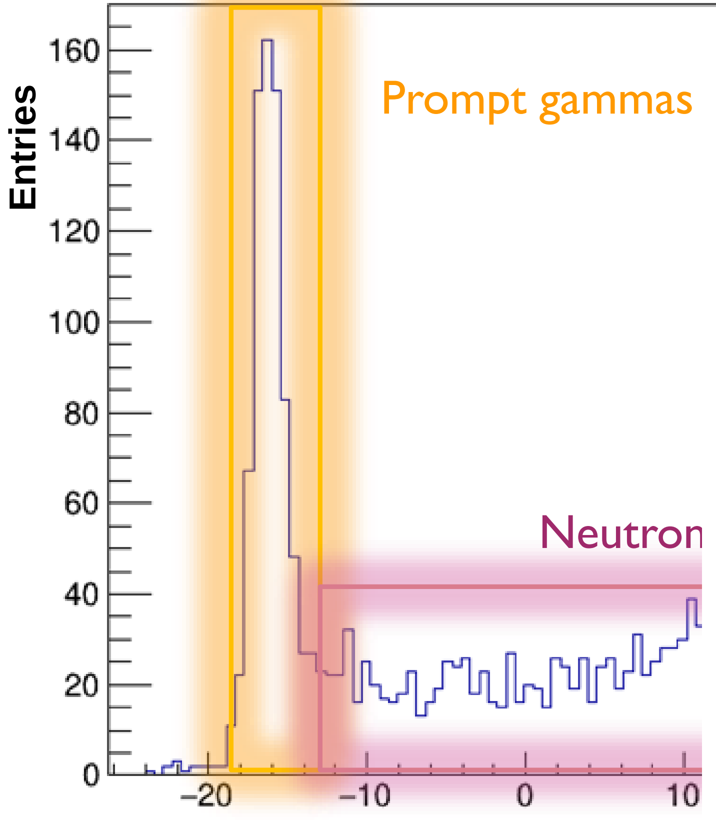
$$TOF_\gamma = \frac{L}{c} \sim 7.9 \text{ ns}$$

$$TOF = T_{sc} - T_{det}$$

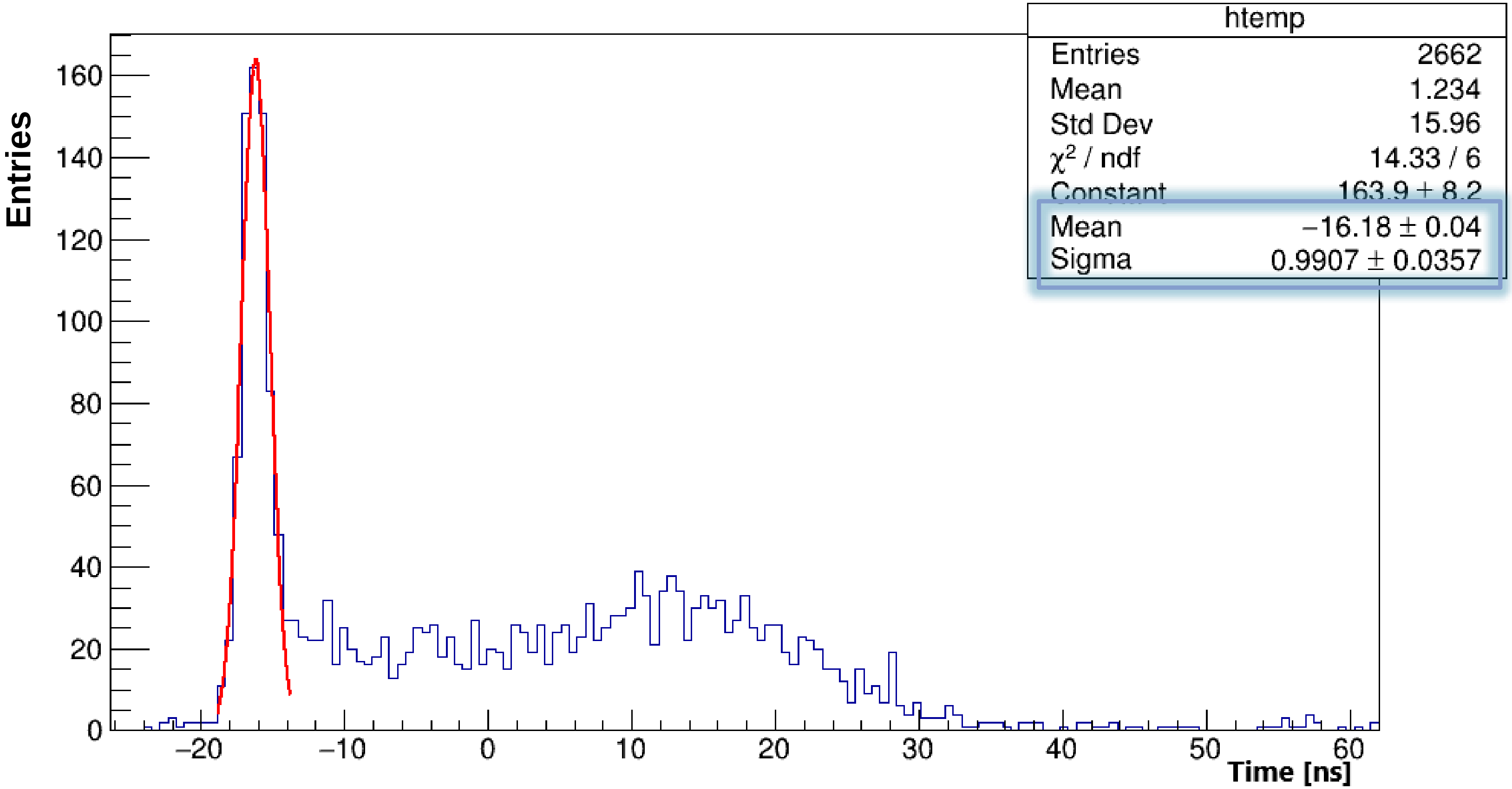
^{16}O, 400 MeV/u, $(C_2H_4)_n$, 1 cm

TIME OF FLIGHT CALIBRATION

BC-501A scintillator



Gaussian fit to the prompt gamma peak

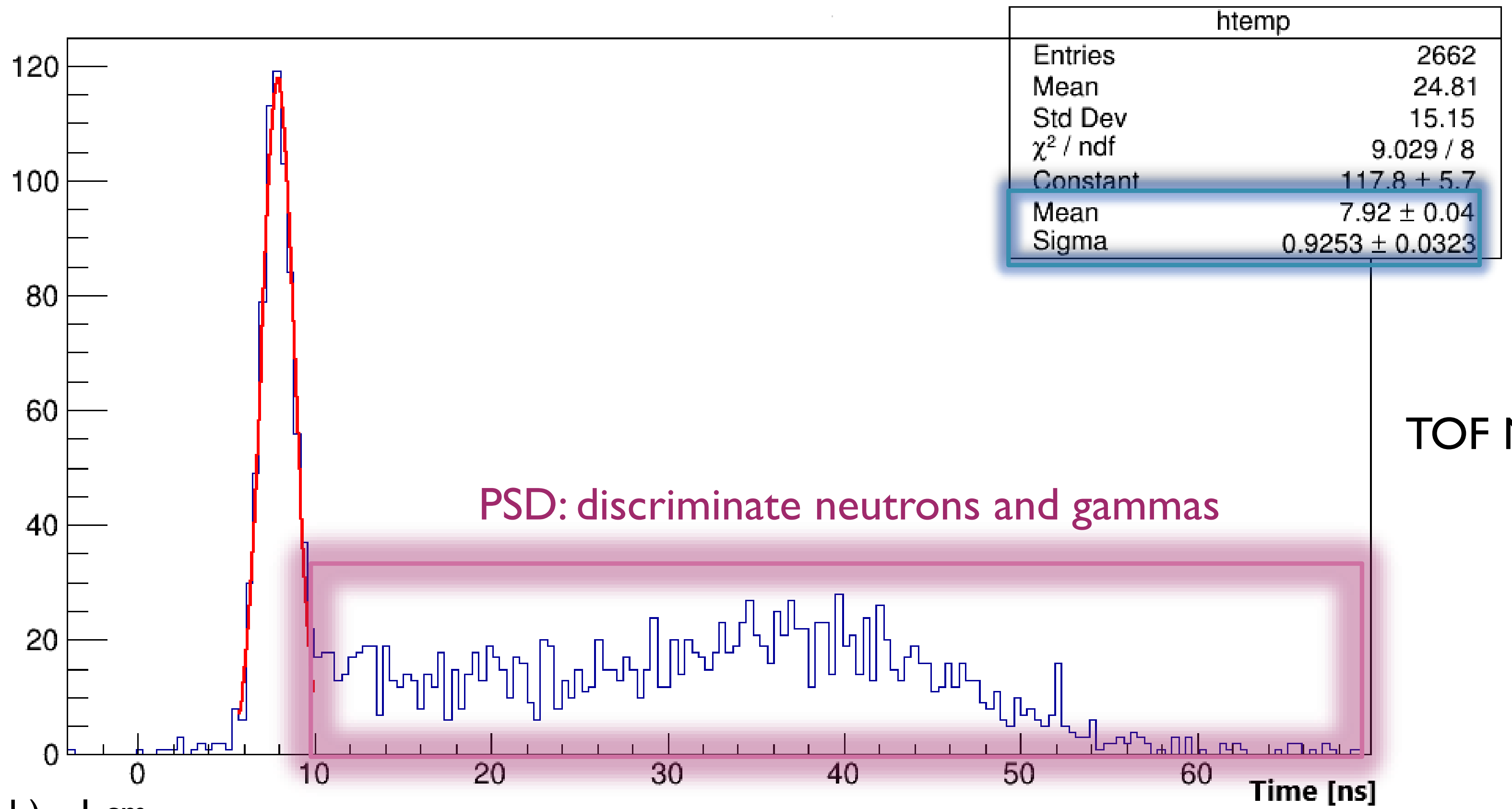


^{16}O, 400 MeV/u, $(C_2H_4)_n$, 1 cm

PROMPT GAMMA DISCRIMINATION

BC-501A detector

Time of flight distribution

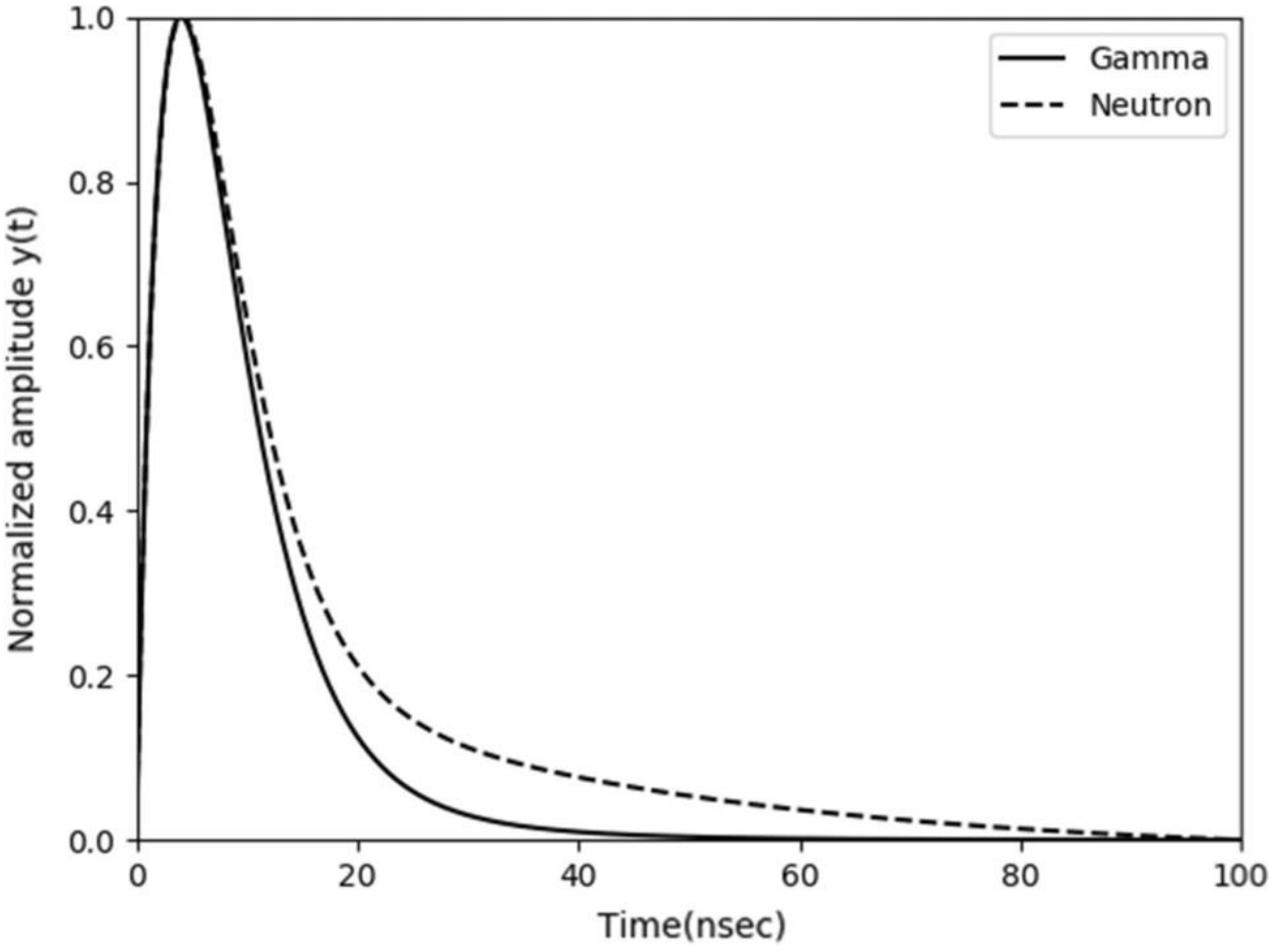


^{16}O, 400 MeV/u, $(C_2H_4)_n$, 1 cm

TOF gamma prompt:
7.9 ± 0.9 ns

TOF NEUTRONS > $\mu + 2\sigma \sim 9.8$ ns

PULSE SHAPE DISCRIMINATION

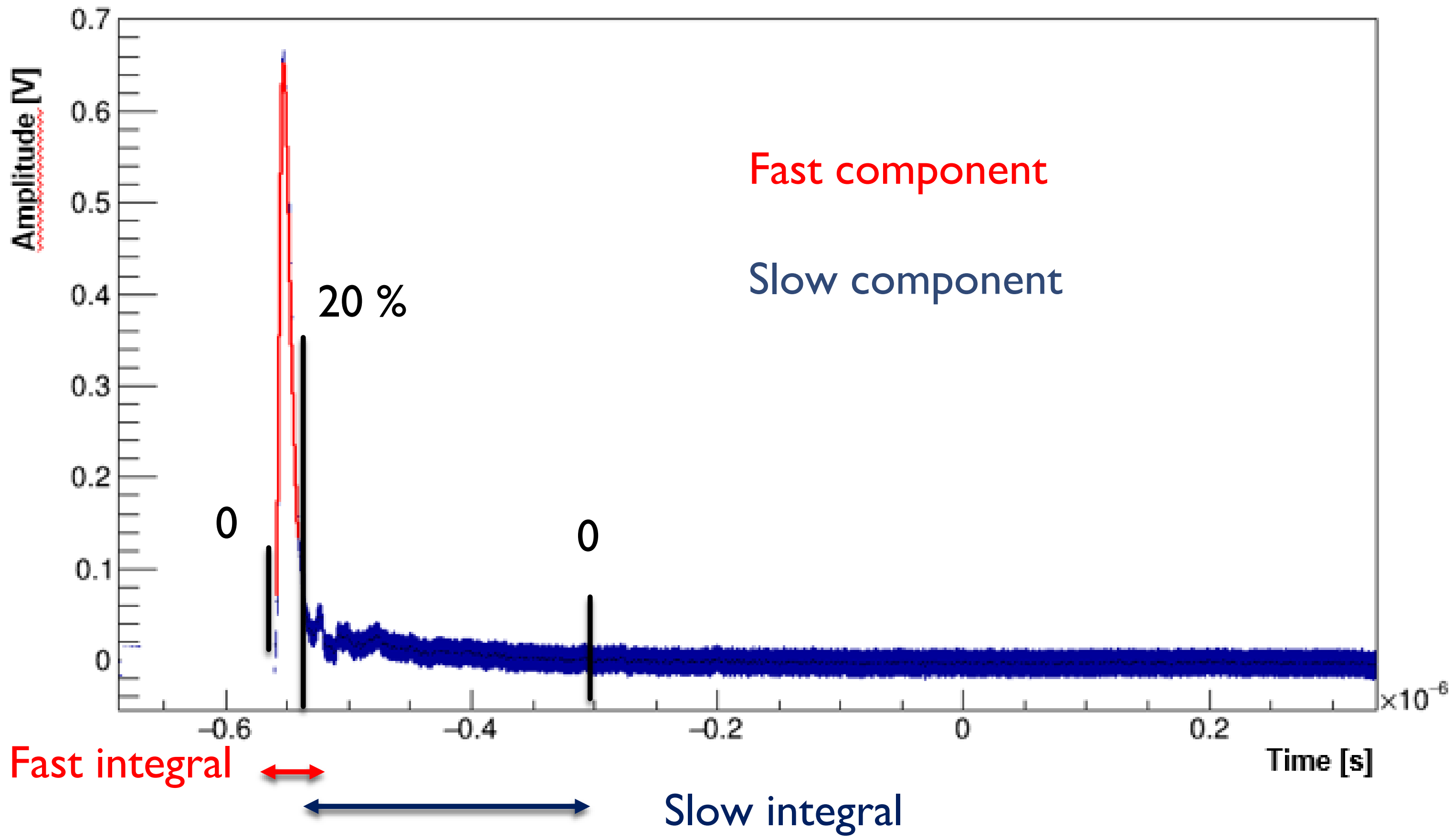


Analysis of the pulse shape

- Gammas: fast signal, exponential decay with τ_{fast} **~ 3.16** ns
- Neutrons: signal with longer tail; slow component, decay described by two exponential dustributions with τ_{fast} **~ 3.16** ns and τ_{slow} **~ 32.3** ns

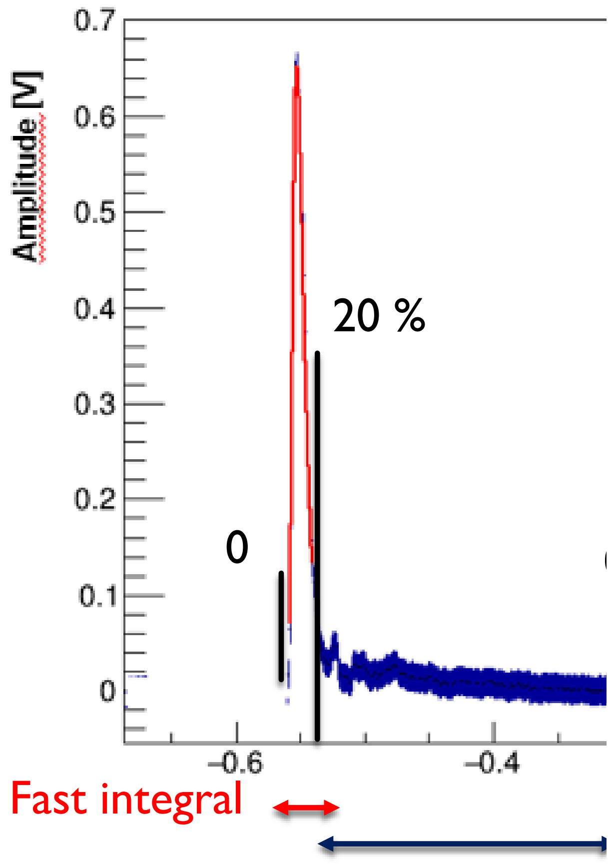
Separation of the fast and slow component

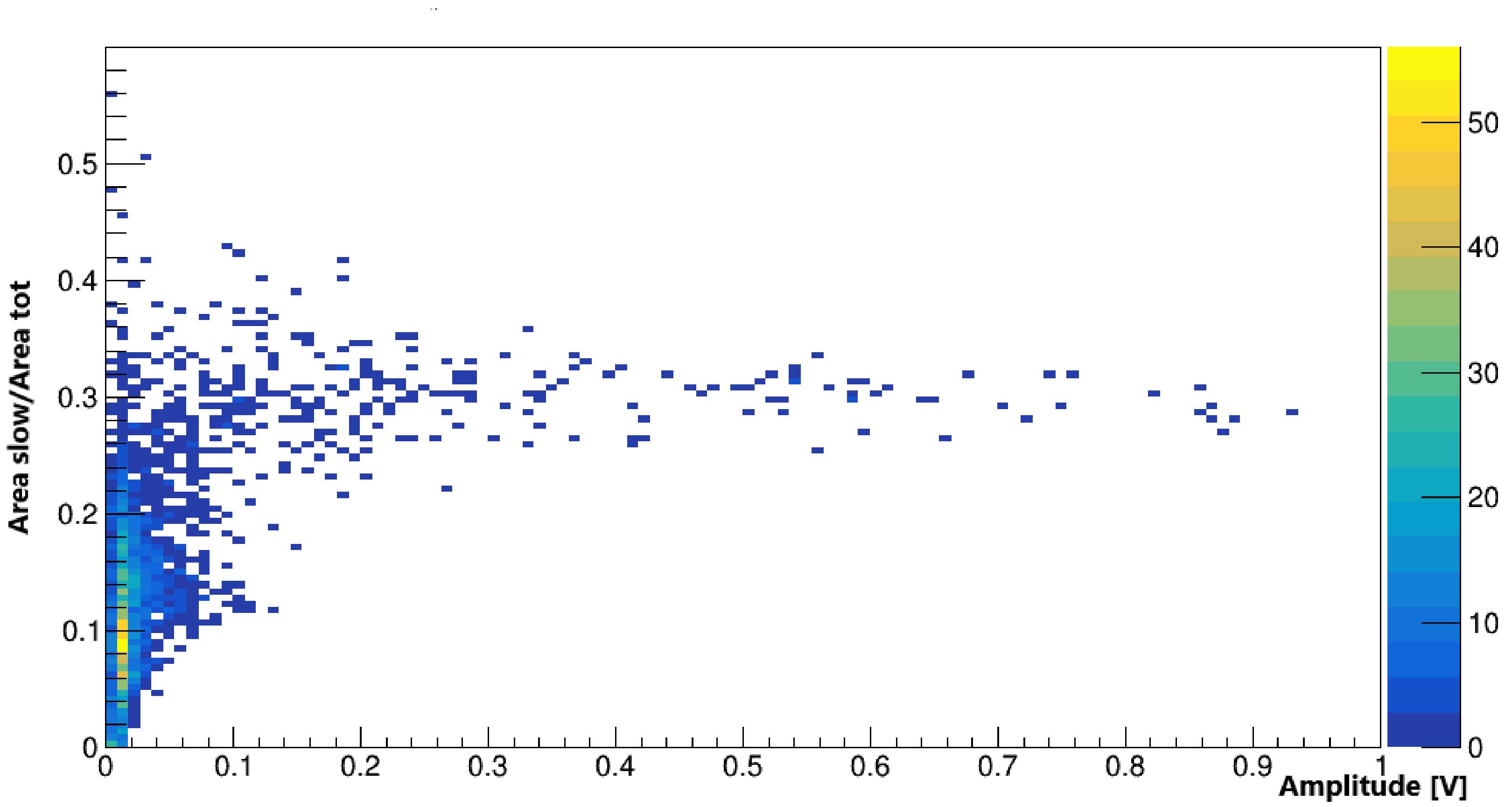
PULSE SHAPE DISCRIMINATION



^{16}O, 400 MeV/u, $(C_2H_4)_n$, 1 cm

PULSE SHAPE DISCRIMINATION

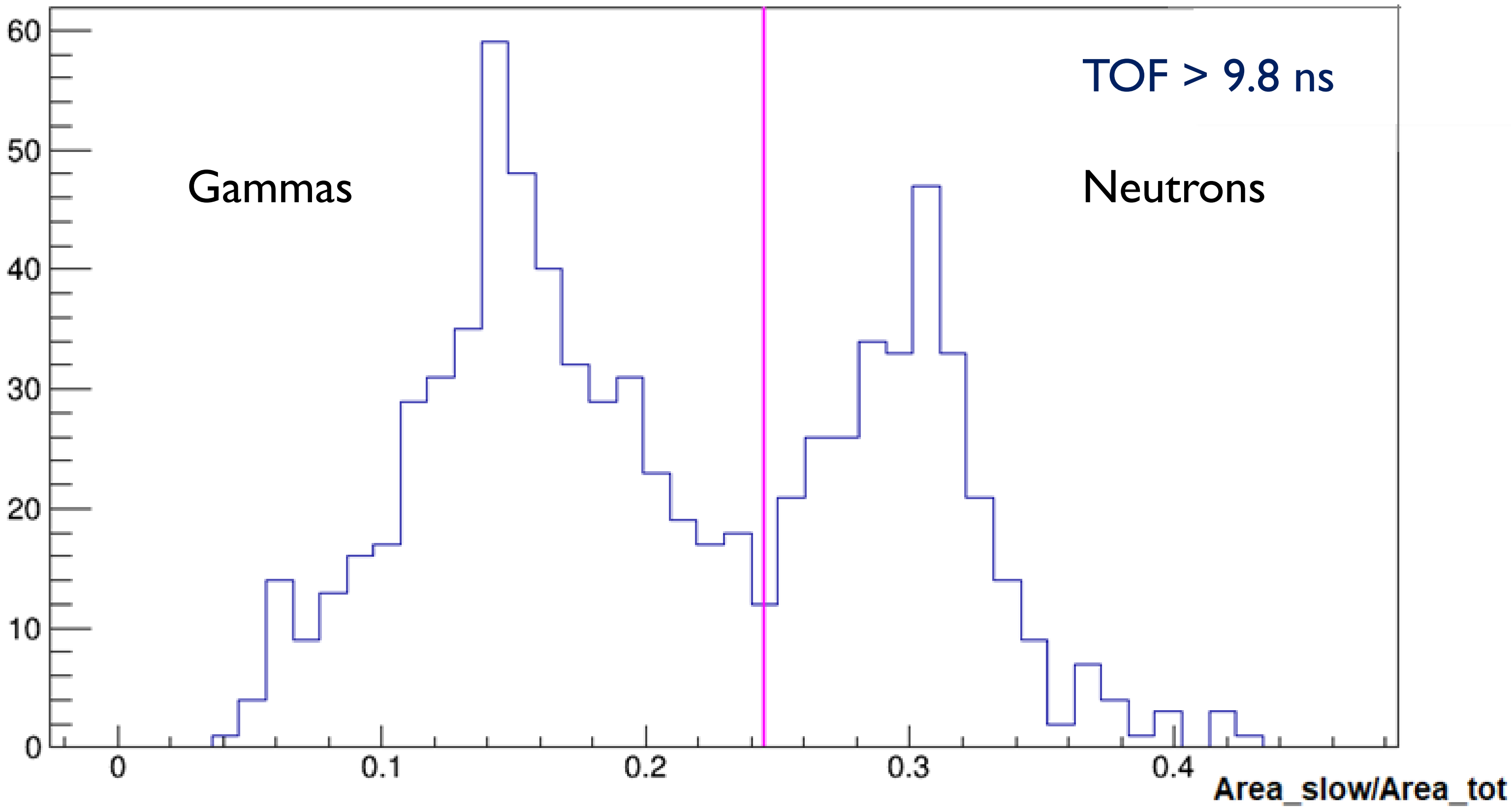




^{16}O, 400 MeV/u, $(C_2H_4)_n$, 1 cm

NEUTRONS AND GAMMAS DISCRIMINATION

BC-501A detector



^{16}O, 400 MeV/u, $(C_2H_4)_n$, 1 cm

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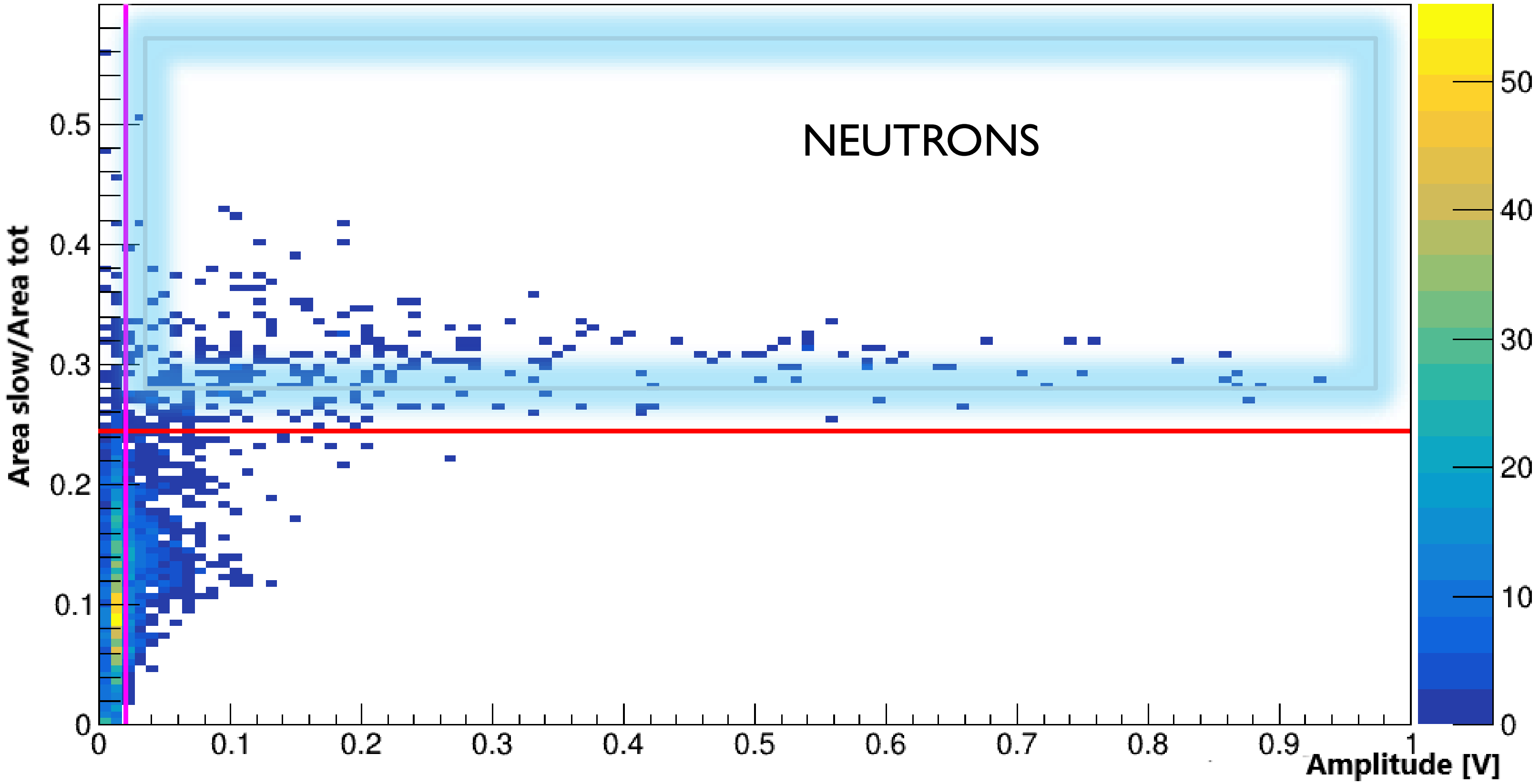


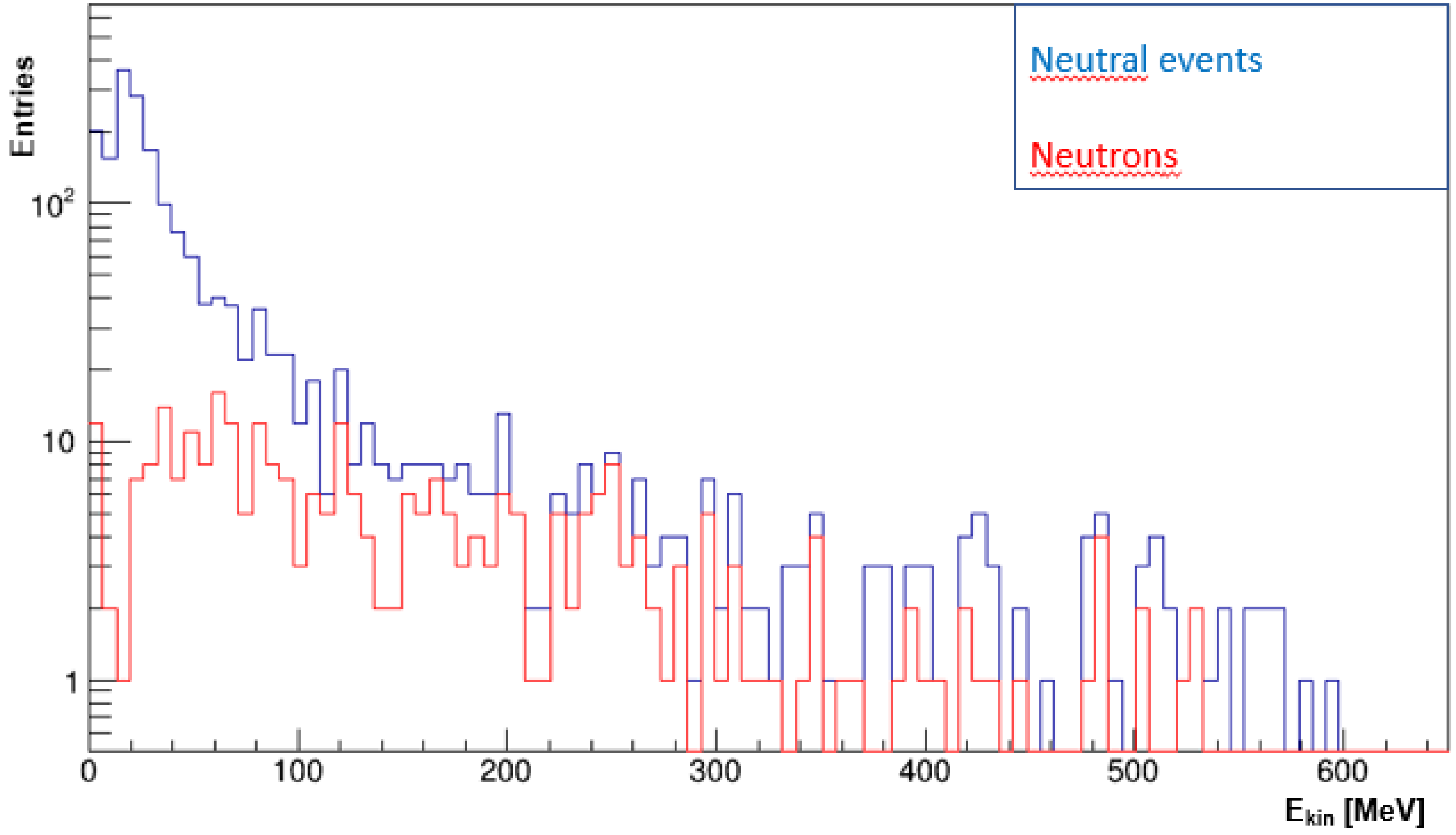
Neutrons identified with the conditions:

- Amplitude > 0.02 V
- TOF > $\mu_{gamma\ peak} + 2\sigma_{gamma\ peak}$
- Area slow/Area tot > 0.245

^{16}O, 400 MeV/u, $(C_2H_4)_n$, 1 cm

KINETIC ENERGY DISTRIBUTION

BC-501A detector



$E_{kin} = mc^2 (\gamma - 1)$

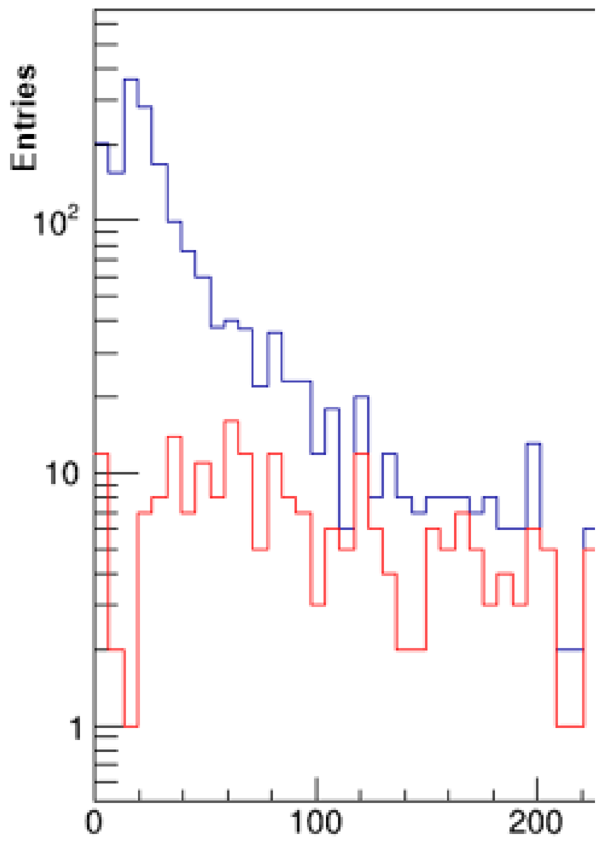
$m = 939$ MeV/c^2

$$\gamma = \frac{1}{\sqrt{1-\beta^2}}$$

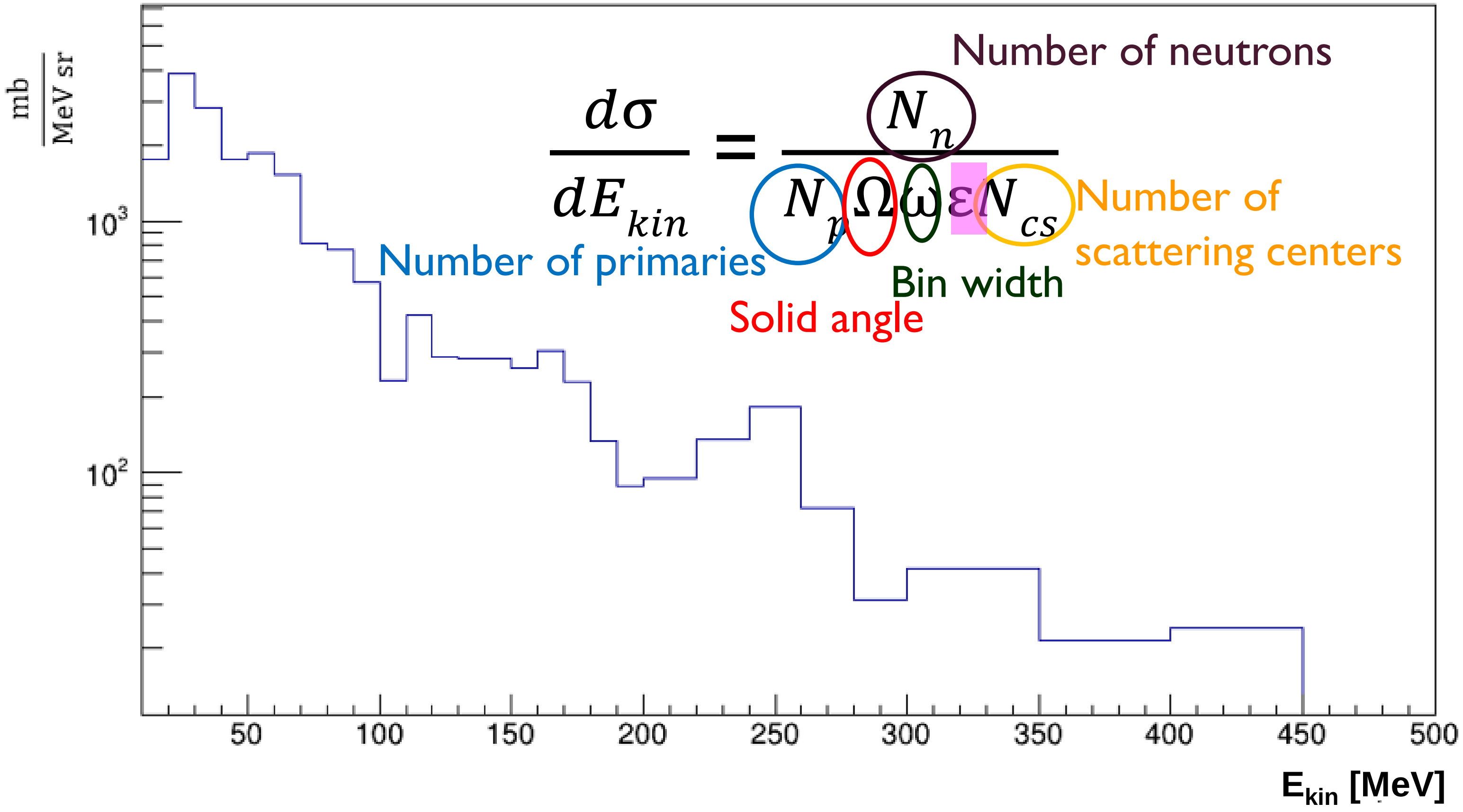
^{16}O, 400 MeV/u, $(C_2H_4)_n$, 1 cm

KINETIC ENERGY DISTRIBUTION

BC-501A detector



Preliminary cross section @ 24°

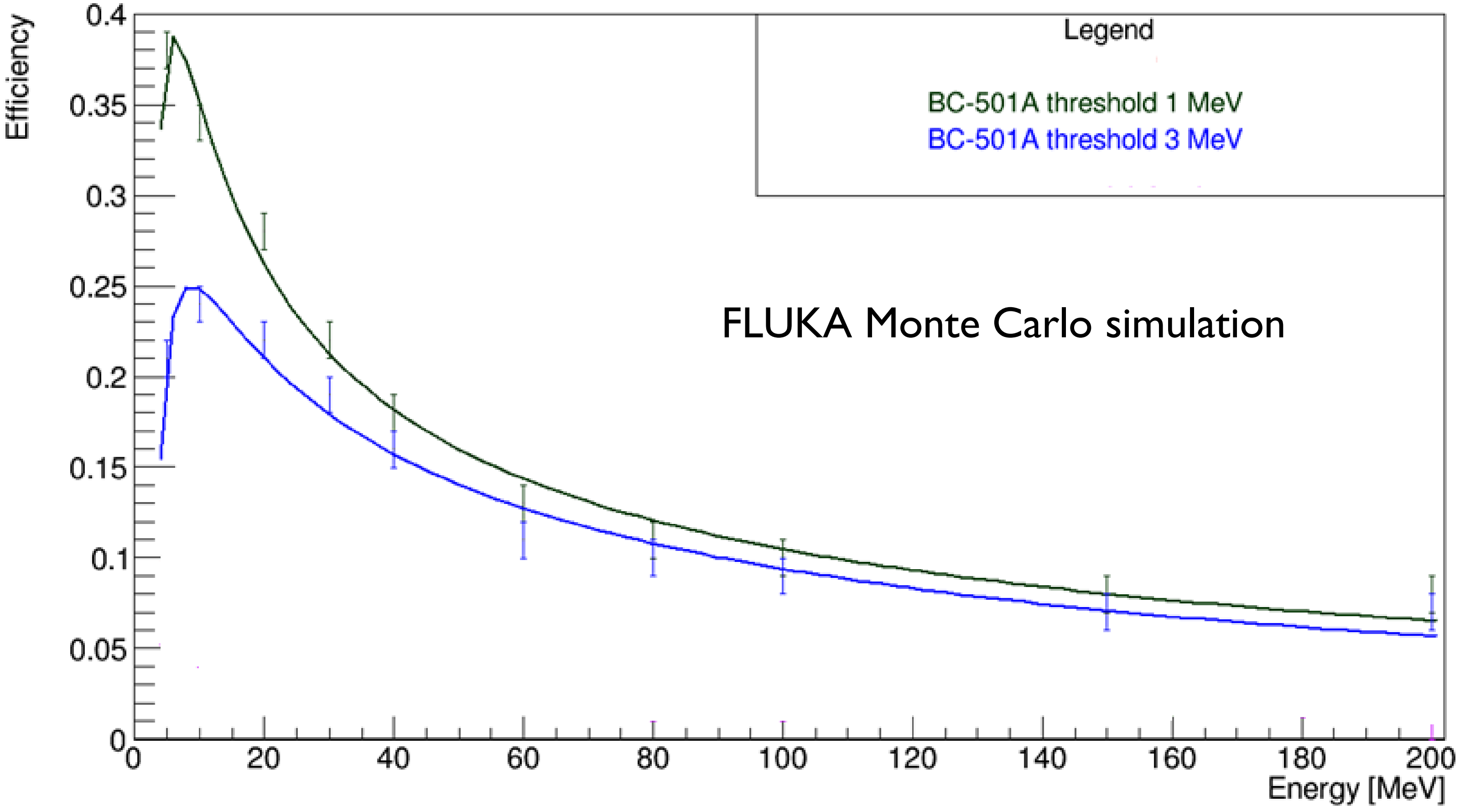


$$\frac{d\sigma}{dE_{kin}} = \frac{N_n}{N_p\,\Omega\,\omega\,\varepsilon\,N_{cs}}$$

^{16}O, 400 MeV/u, $(C_2H_4)_n$, 1 cm

EFFICIENCY PARAMETRIZATION

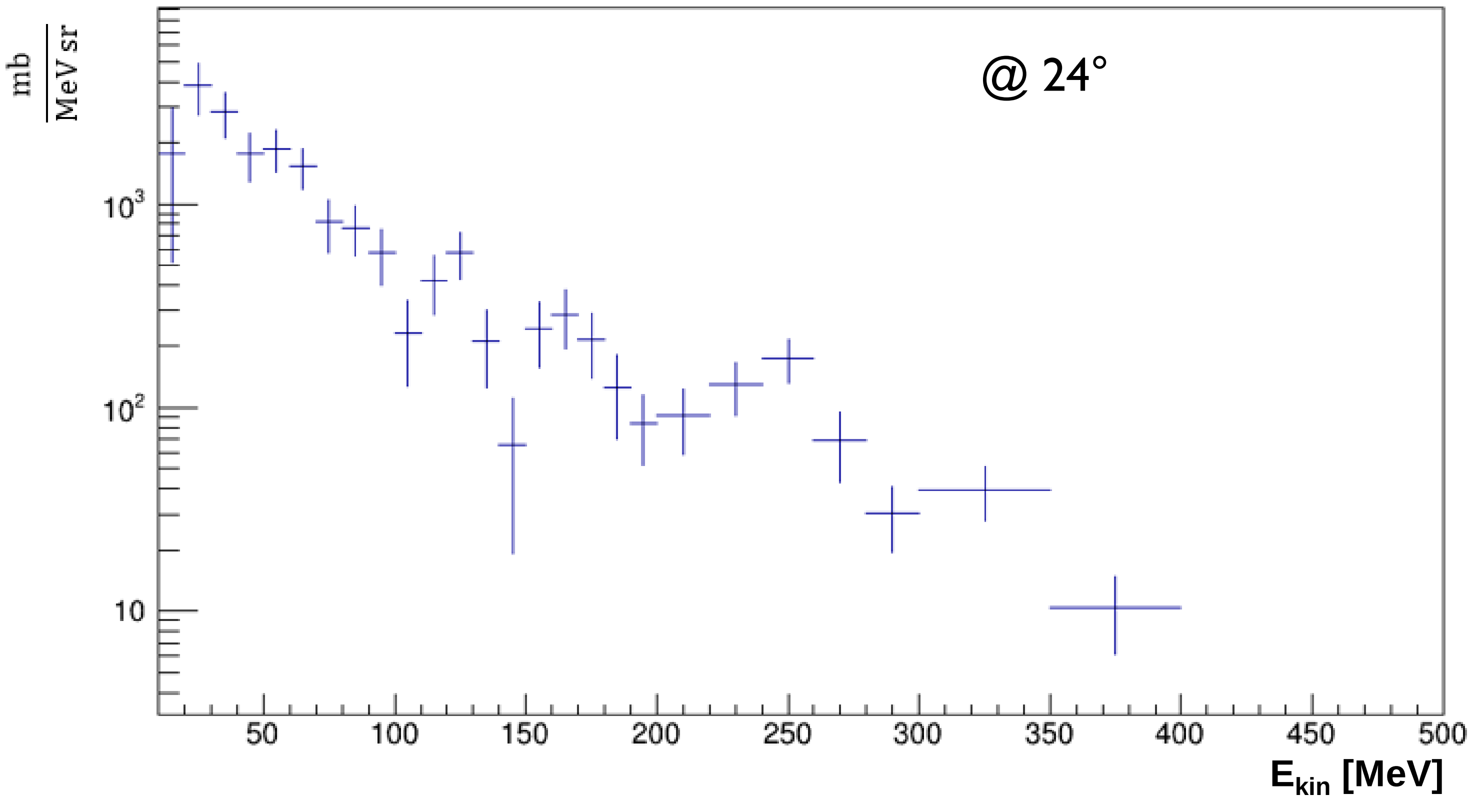
BC-501A detector



$$\varepsilon\,(E) = \frac{a}{\sqrt{E}} + \frac{b}{E} + \frac{c}{\sqrt{E^3}} + \frac{d}{E^2} + e$$

^{16}O, 400 MeV/u, $(C_2H_4)_n$, 1 cm

PRELIMINARY CROSS SECTION MEASUREMENT



^{16}O, 400 MeV/u, $(C_2H_4)_n$, 1 cm

Uncertainties due to only statistic fluctuations

CONCLUSIONS

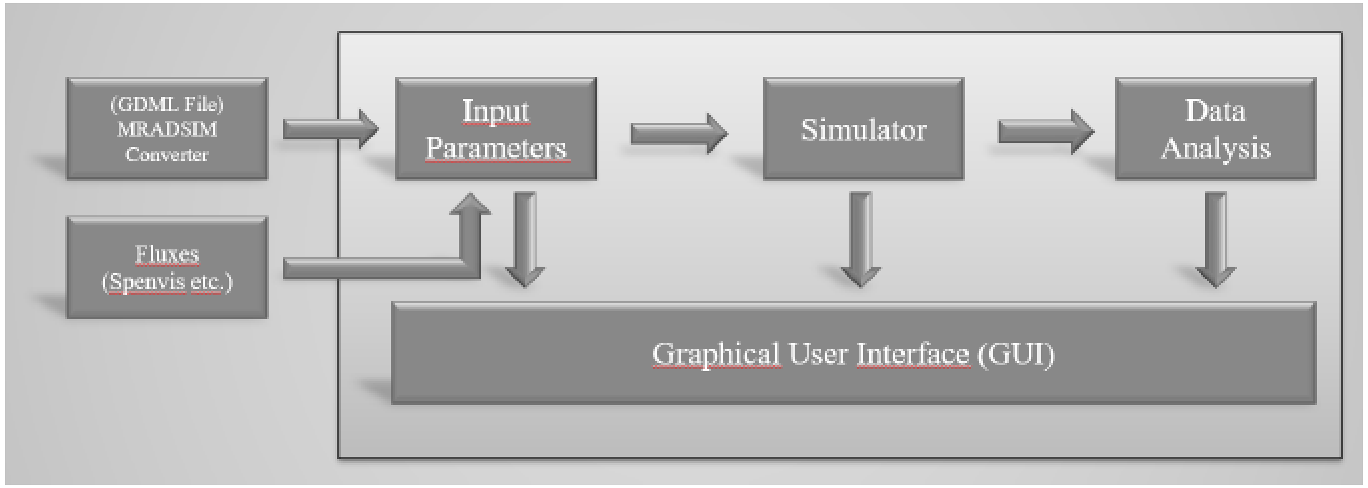
- From this feasibility study, the most important points have been shown:

  neutrons-gammas discrimination

  preliminary cross section measurement

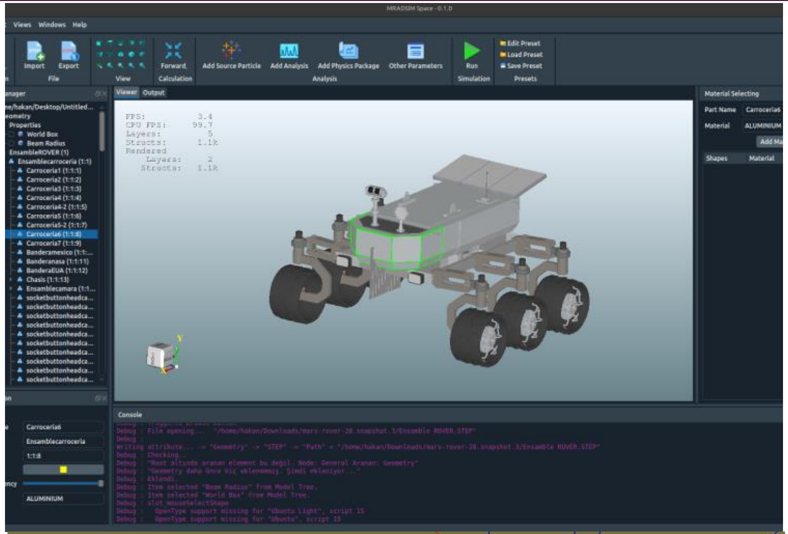
MRADSIM: MATTER RADIATION SIMULATION

A software with a graphic interface, user friendly, in order to simulate the radiation effects on electronic and electromechanical devices.

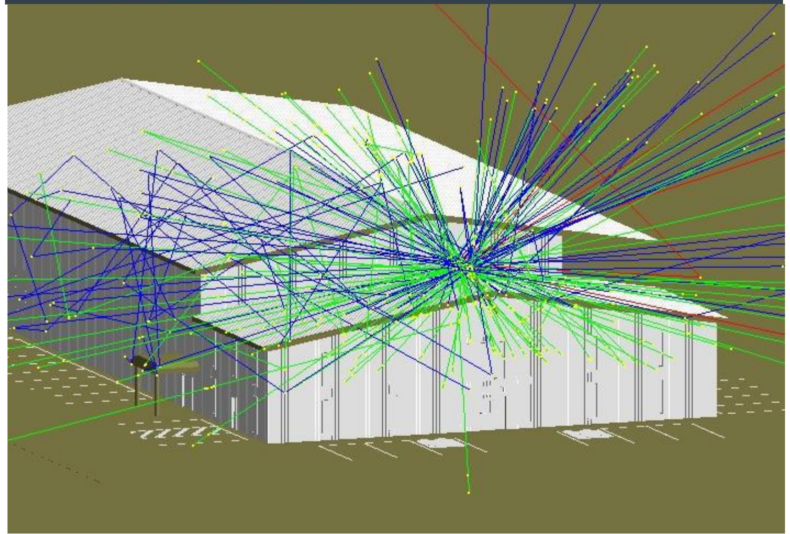


- Conversion tool: from a step file (CAD output) to a GDML (simulation input);
- Simulation tool: based on Geant4;
- Graphic interface: modern and intuitive, allows the user to visualize the geometry of the project, set the parameters of the simulation and display the results obtained

MRADSIM: MATTER RADIATION SIMULATION



Applications:
- Aerospace industry;
- Medical centers for radiotherapy;
- Research centers and particle accelerators;
- Sustainable energy plants;
- Study of biological samples (DNA) exposed to radiation;
- Other areas characterized by a massive use of electronics to predict and correct possible errors caused by external radiation



HARDEST: HANE HARDENING FOR SATELLITE SYSTEMS

Global alliances are preparing for the defence of Space, i.e. the protection of satellite assets and their components to harden them against the effects caused by High Altitude Nuclear Explosion (HANE).

Several tests carried out in the 50s and 60s:
STARFISH Prime, 1962

914-kiloton thermonuclear air burst, May 22, 1970 nuclear test

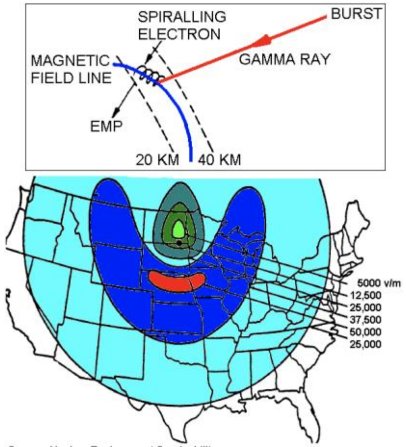
Relevant disturbances in the communications of several satellites and complete loss of 7 satellites within a few month of the explosion

ThalesAlenia Space
a Thales / Leonardo company

HARDEST: HANE HARDENING FOR SATELLITE SYSTEMS

Under study:

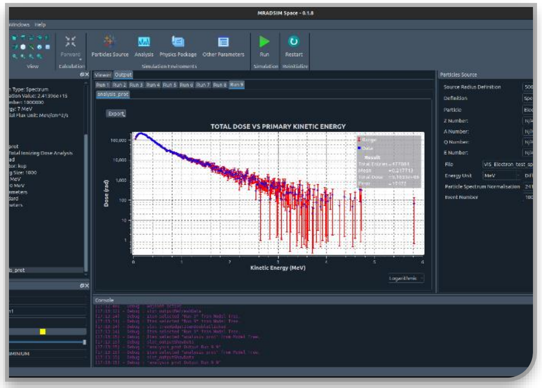
- Thermonuclear detonations in altitude (to date explosions between 50 km and 540 km high);
- Effects on electronic/electromechanical parts and ground effects;
- Natural sources in space (trapped electrons and protons, solar protons, GCR and X - rays) and sources from HANE (X – rays, gamma and ions);
- Generation of electromagnetic pulse, repopulation of Van Allen belts, ionization interacting with N_2/O_2 in high atmosphere, surrounding materials.



Source: Nuclear Environment Survivability, U. S. Army, report AD-A278230 (1994)

In planning phase:

- Development of nuclear explosion models with Geant4;
- Back-tracing of electrons and protons to follow them in Van Allen belts to calculate the repopulation;
- Propagation to satellites and transport with MRADSIM through the satellite with electronic/electromechanical components on board and analyze the output;
- Evaluate component criticality, active and passive mitigation techniques, model test and mitigation development with particle beams.

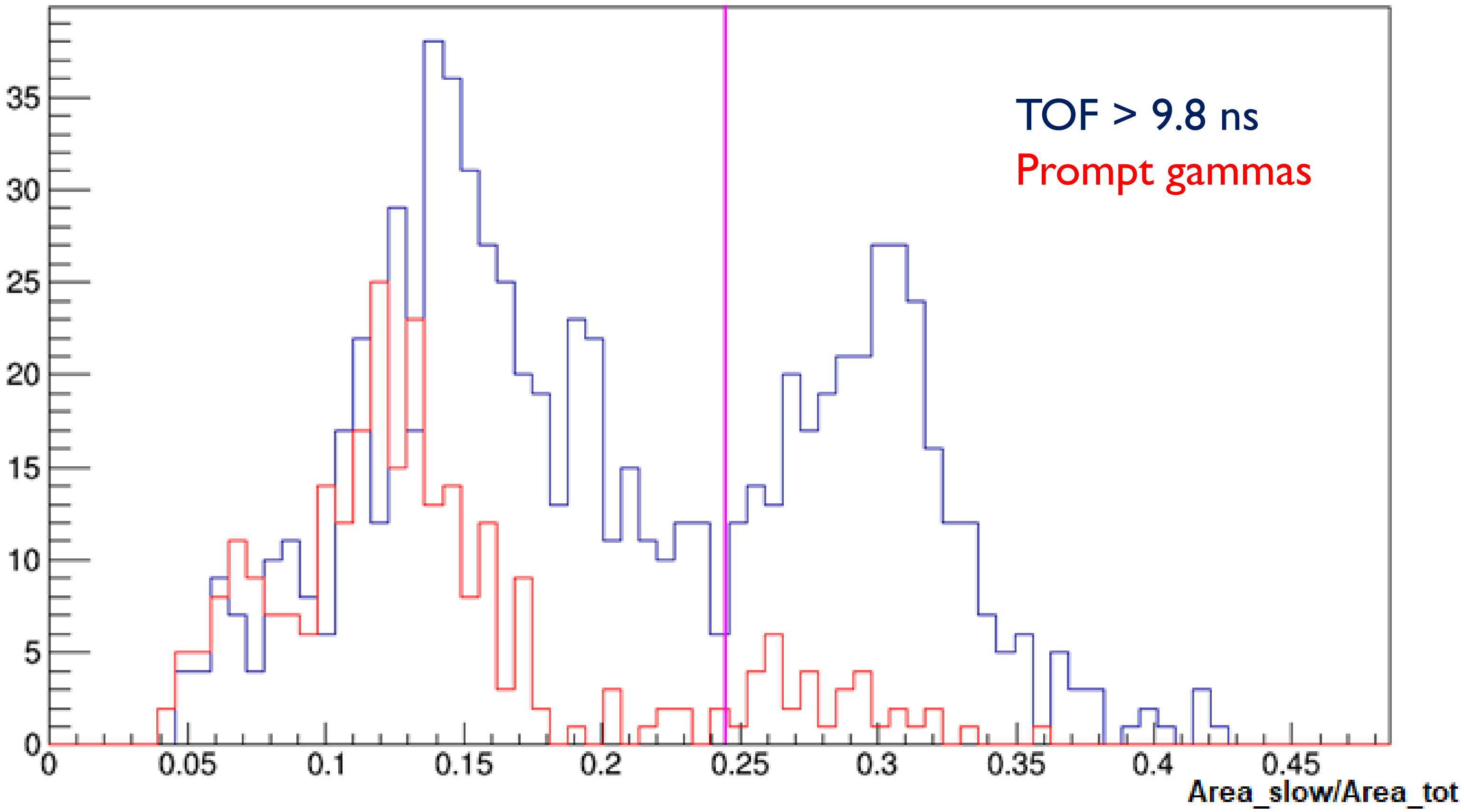


THANKS FOR YOUR ATTENTION

BACKUP

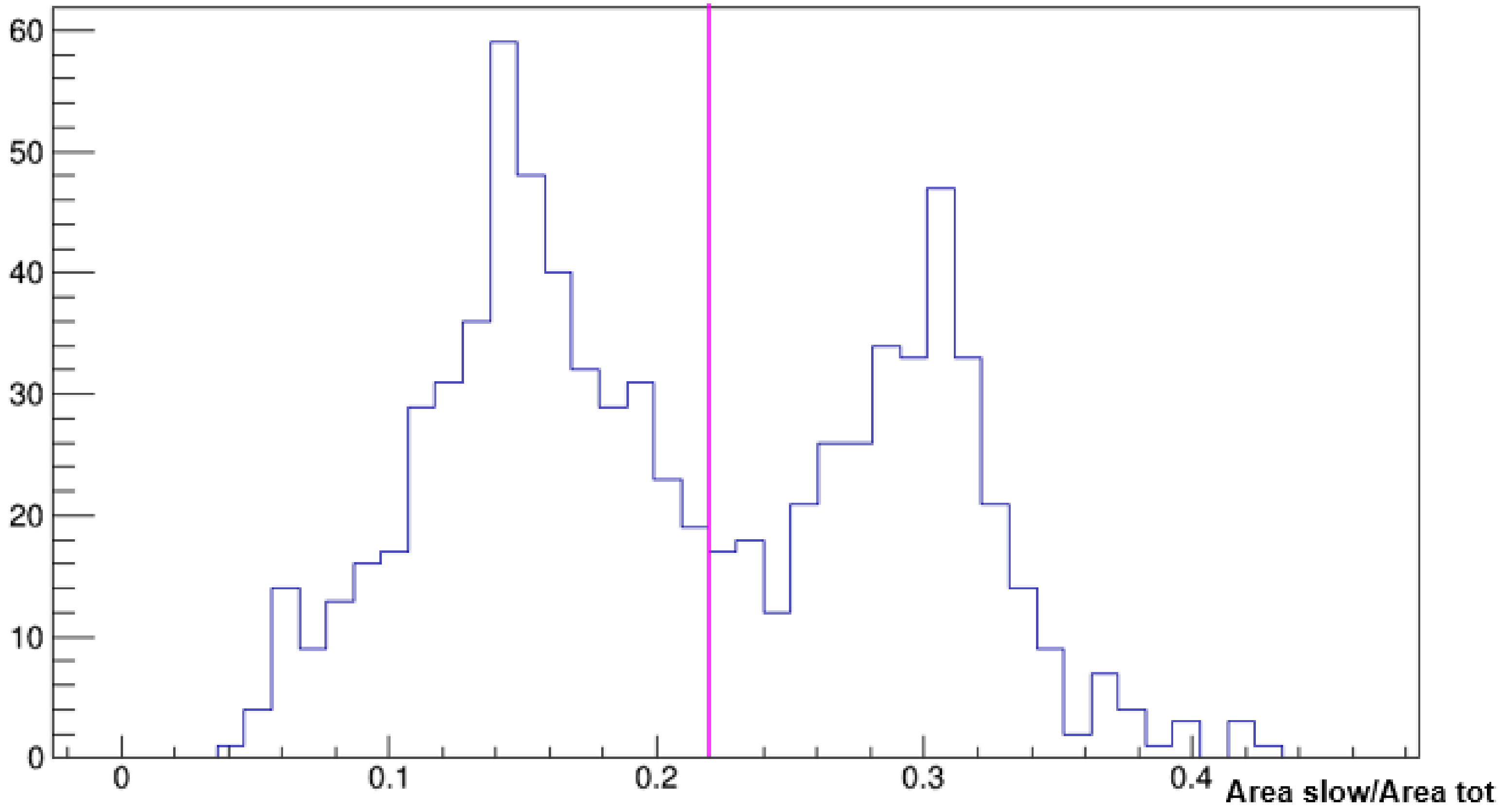
NEUTRONS AND GAMMAS DISCRIMINATION

BC-501A detector



^{16}O, 400 MeV/u, $(C_2H_4)_n$, 1 cm

NEUTRONS AND GAMMAS DISCRIMINATION

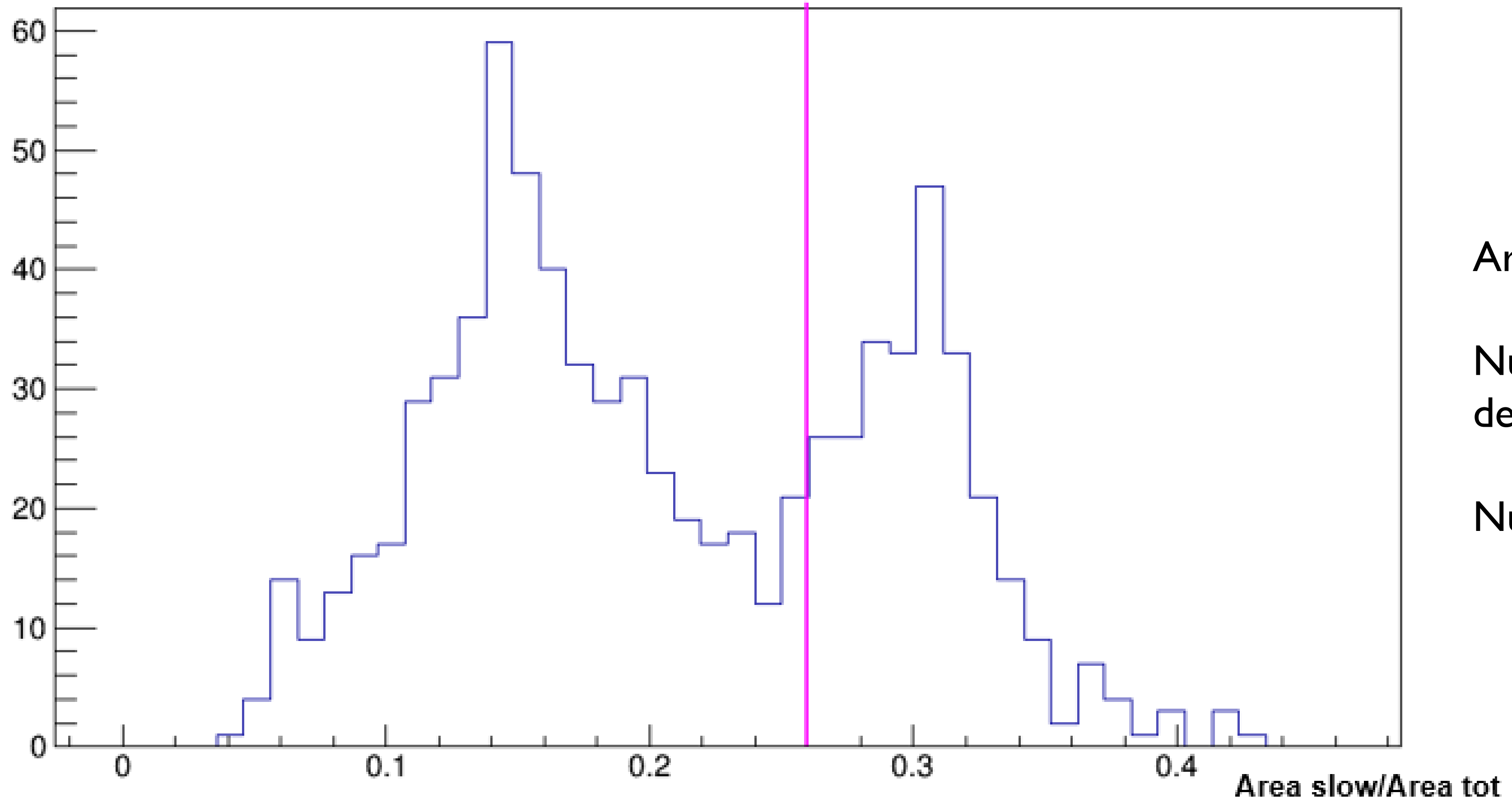


Area slow/Area tot > 0.220

Number of neutrons and delayed gammas 784

Number of neutrons 333

NEUTRONS AND GAMMAS DISCRIMINATION

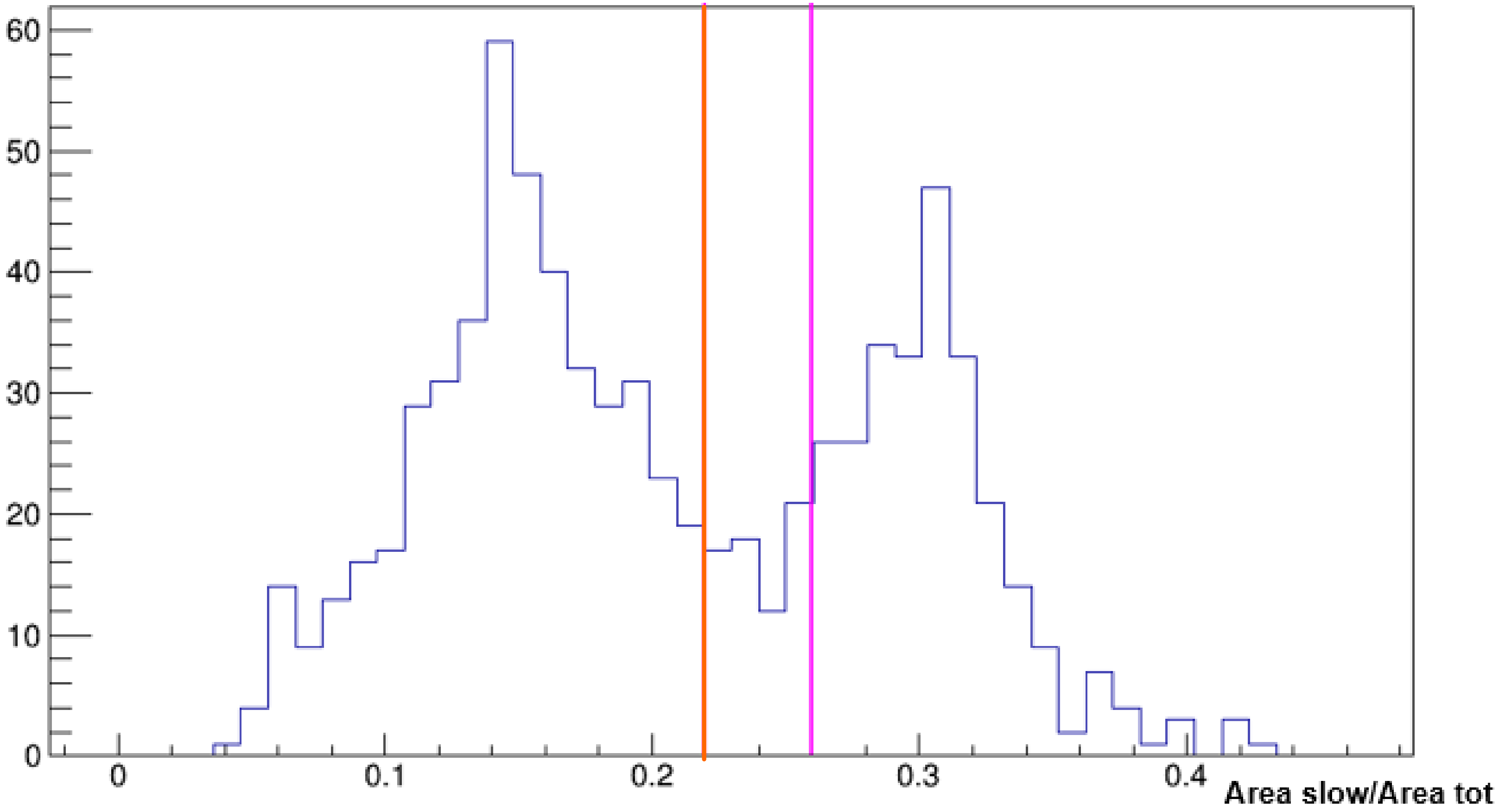


Area slow/Area tot > 0.260

Number of neutrons and delayed gammas 784

Number of neutrons 265

NEUTRONS AND GAMMAS DISCRIMINATION



Area slow/Area tot > 0.220

Area slow/Area tot > 0.260

Semidispersion ~ 5%