Outline Towards the test beam @ CNAO

- **Repeating experiments** in the literature: double differential inclusive cross section for the production of neutron in **p+^{12}C and ^{12}C+^{12}C reactions**
  - ➢ angle
  - ➢ Incoming particle energy

- Raw **estimation** of the **expected count rate**, **neutron energy spectrum** and **background** from available simulation (5x10^7 primaries)

Cristian Massimi MC simulation: expected neutron flux in the 'detector'

Mauro Villa and co are proposing a low energy neutron setup.. <10 MeV "LE"

michela.marafini and co are proposing a high energy neutron setup.. >10 MeV "HE"

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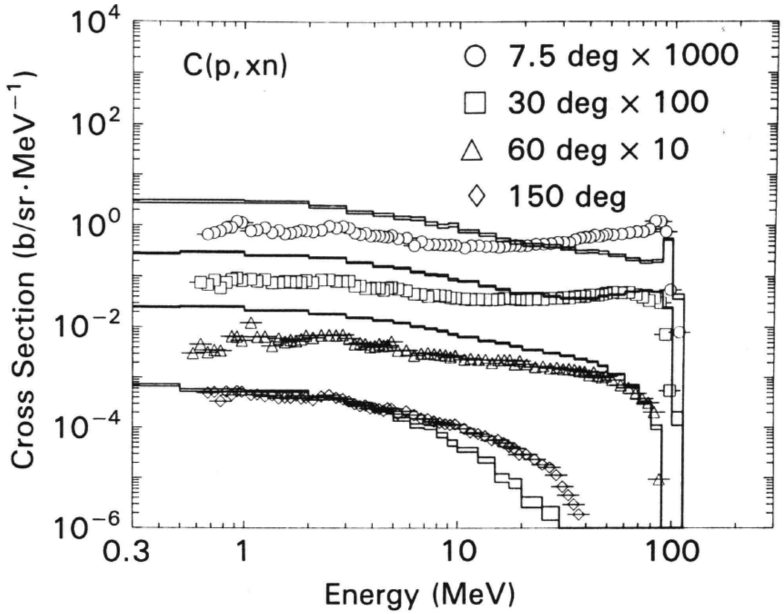
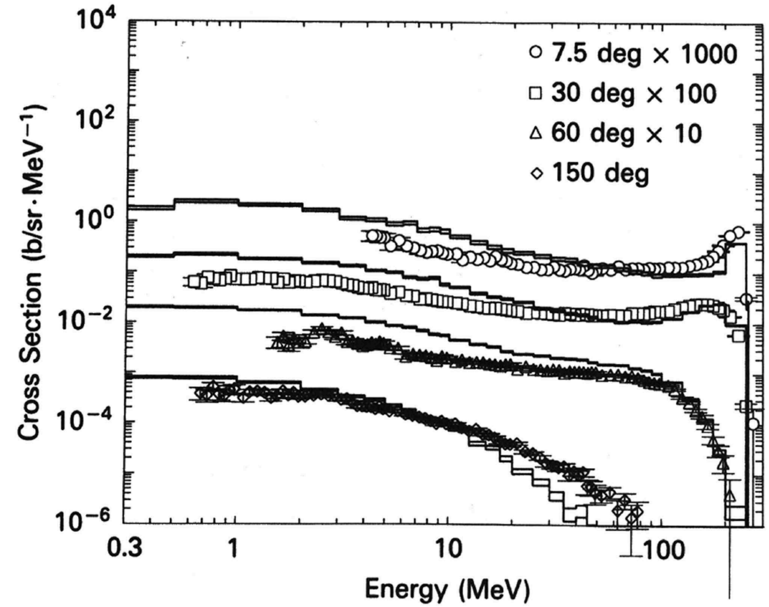
C(p,xn) differential cross section (inclusive)





p @ 113 MeV

p @ 256 MeV

Angles: 7.5, 30, 60, 150 deg

~ 1 mb · sr^{-1} · MeV^{-1}

NUCLEAR SCIENCE AND ENGINEERING:
110, 289-298 (1992)
102, 310-321 (1989)

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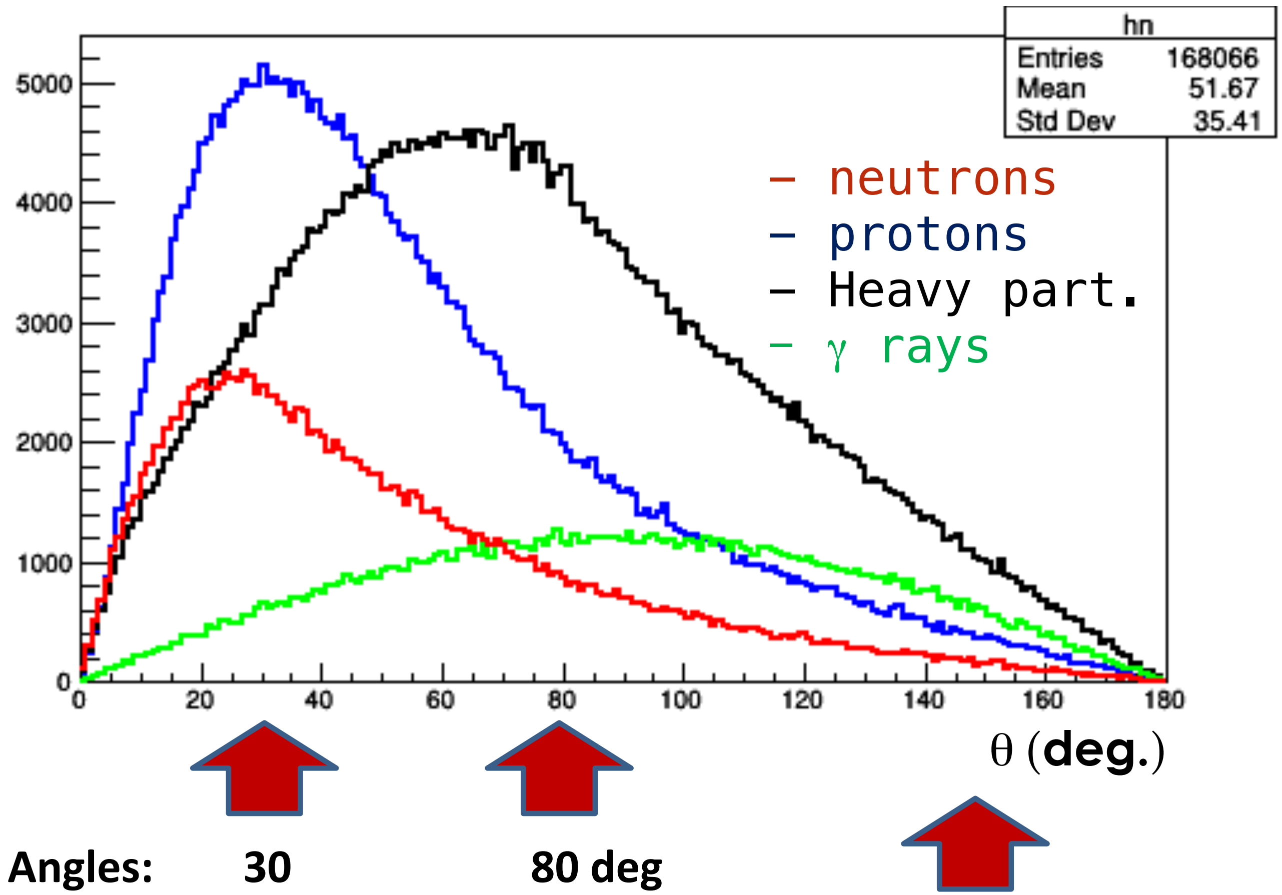
MC simulations – particles from target (5-mm thick)

$^{1}H+C_2H_4$ @200MeV/u (newgeom) statistics: 5×10^7 primaries

Area = 45 (25) cm^2
$\Delta\theta$ ~ 2 deg.



Angles: 30 80 deg

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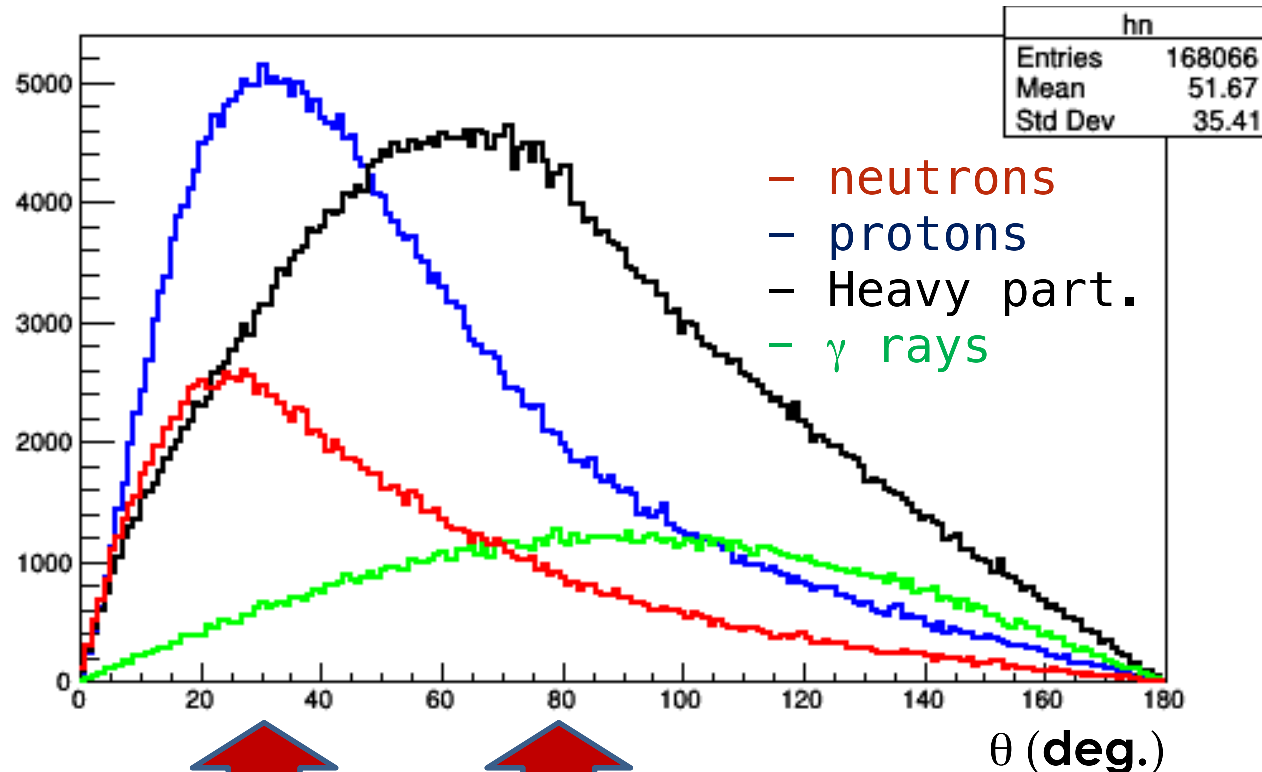
MC simulations – particles from target (5-mm thick)

$^{1}H+C_2H_4$ @200MeV/u (newgeom) statistics: 5×10^7 primaries

Area = 45 (25) cm²
$\Delta\theta \sim 2$ deg.

@Distance = 100 cm

E_n	TOF
1 MeV	72 ns
10 MeV	23 ns
50 MeV	10.6 ns
100 MeV	7.8 ns
200 MeV	5.9 ns



Angles: 30 80 deg

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MC simulations – particles from target (5-mm thick)

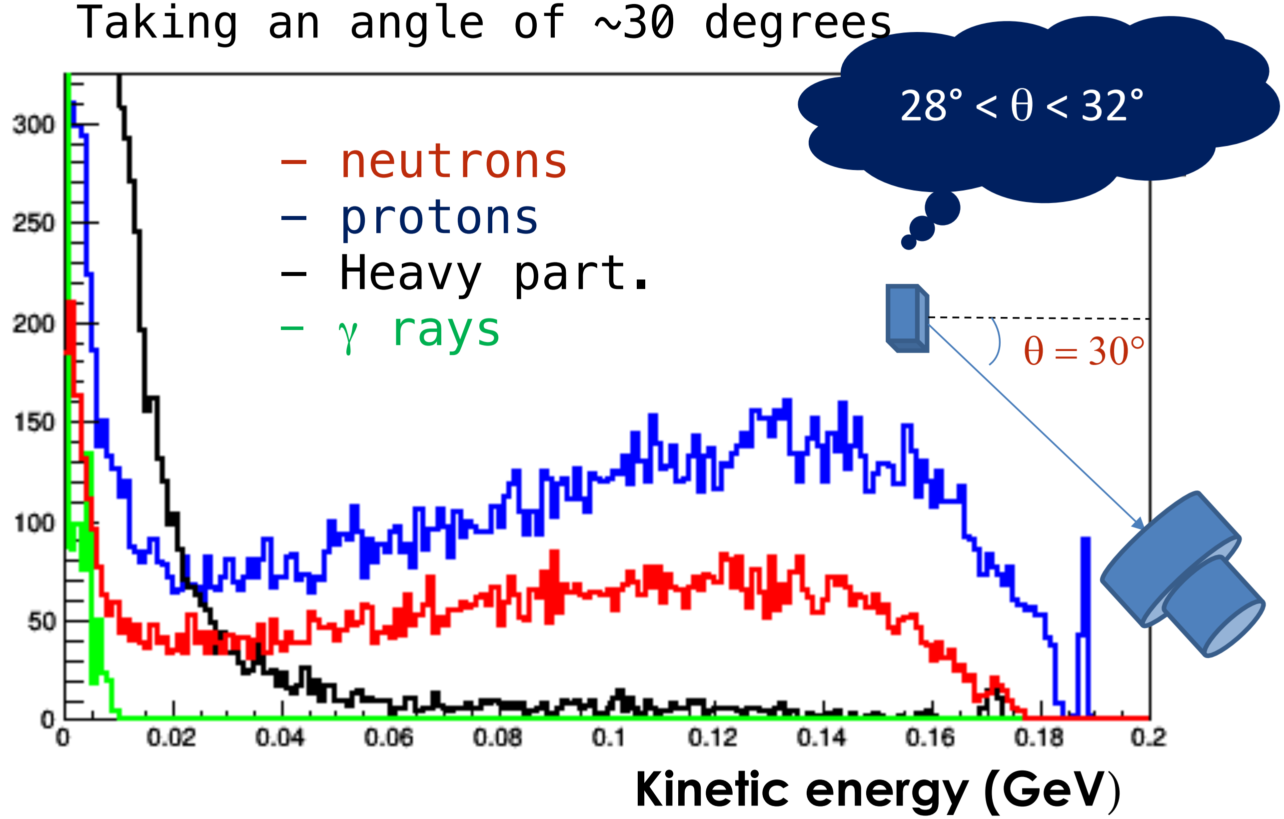
$^{1}H+C_2H_4$ **@200MeV/u** (newgeom) statistics: $5x10^7$ primaries

Area = 45 (25) cm^2
$\Delta\theta$ ~ 2 deg.

@Distance = 100 cm

E_n	TOF
1 MeV	72 ns
10 MeV	23 ns
50 MeV	10.6 ns
100 MeV	7.8 ns
200 MeV	5.9 ns

Taking an angle of ~30 degrees



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MC simulations – particles from target (5-mm thick)

$^{1}H+C_2H_4$ **@200MeV/u** (newgeom) statistics: 5×10^7 primaries

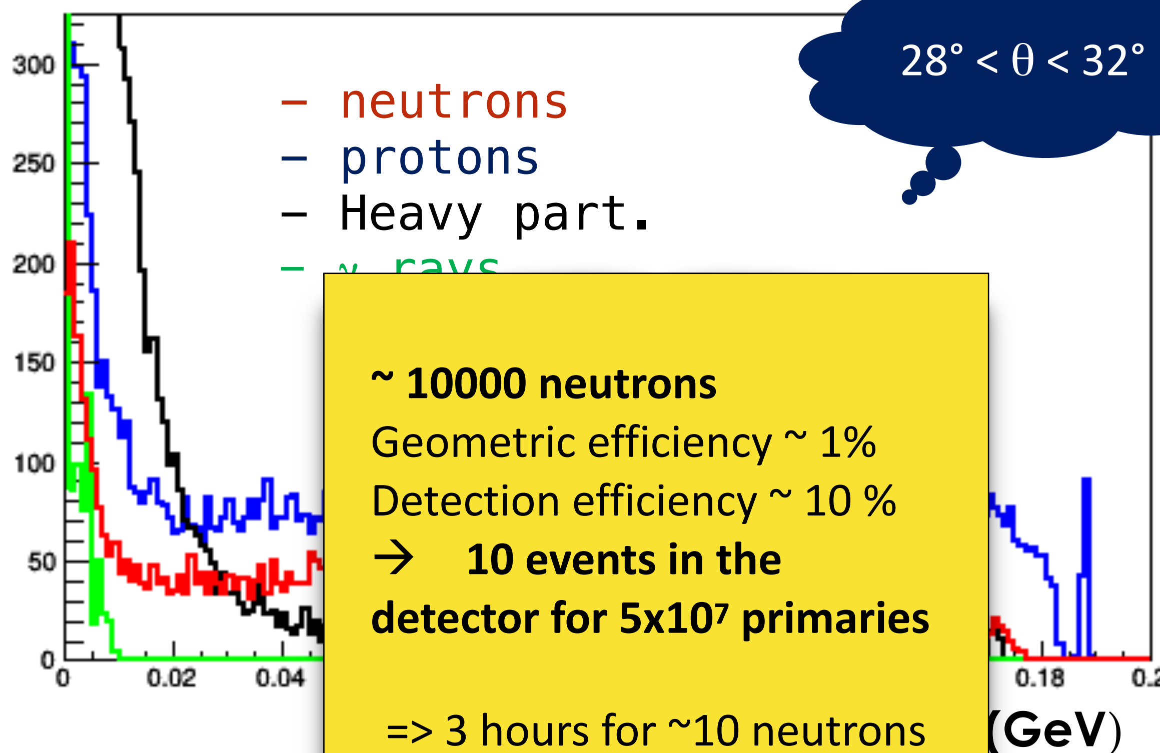
Taking an angle of ~30 degrees

28° < θ < 32°

Area = 45 (25) cm²
Δθ ~ 2 deg.

@Distance = 100 cm

E_n	TOF
1 MeV	72 ns
10 MeV	23 ns
50 MeV	10.6 ns
100 MeV	7.8 ns
200 MeV	5.9 ns



~ 10000 neutrons
Geometric efficiency ~ 1%
Detection efficiency ~ 10 %
→ **10 events in the detector for 5×10^7 primaries**

=> 3 hours for ~10 neutrons (beam 1kHz)

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MC simulations – particles from target (5-mm thick)

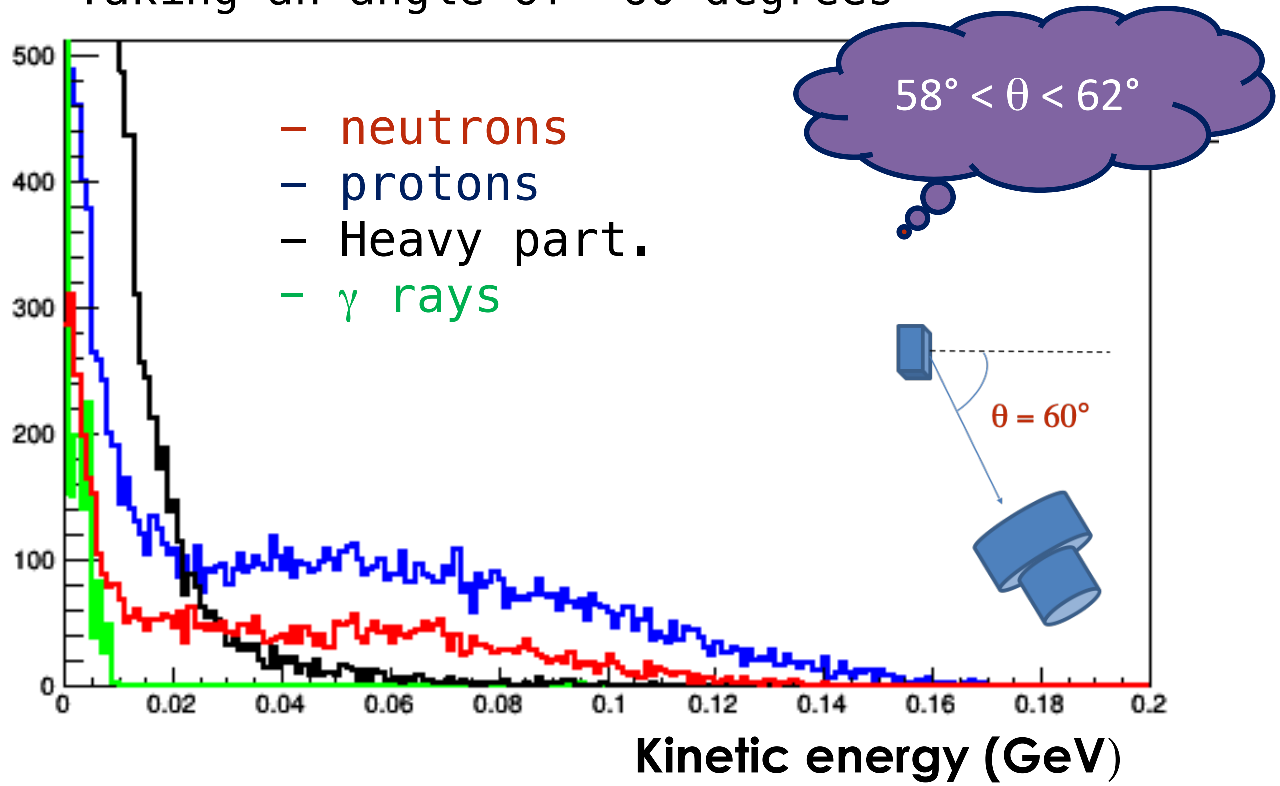
$^{1}H+C_2H_4$ @200MeV/u (newgeom) statistics: 5×10^{7} primaries

Area = 45 (25) cm^2
$\Delta\theta$ ~ 2 deg.

@Distance = 100 cm

E_n	TOF
1 MeV	72 ns
10 MeV	23 ns
50 MeV	10.6 ns
100 MeV	7.8 ns
200 MeV	5.9 ns

Taking an angle of ~60 degrees



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MC simulations – particles from target (5-mm thick)

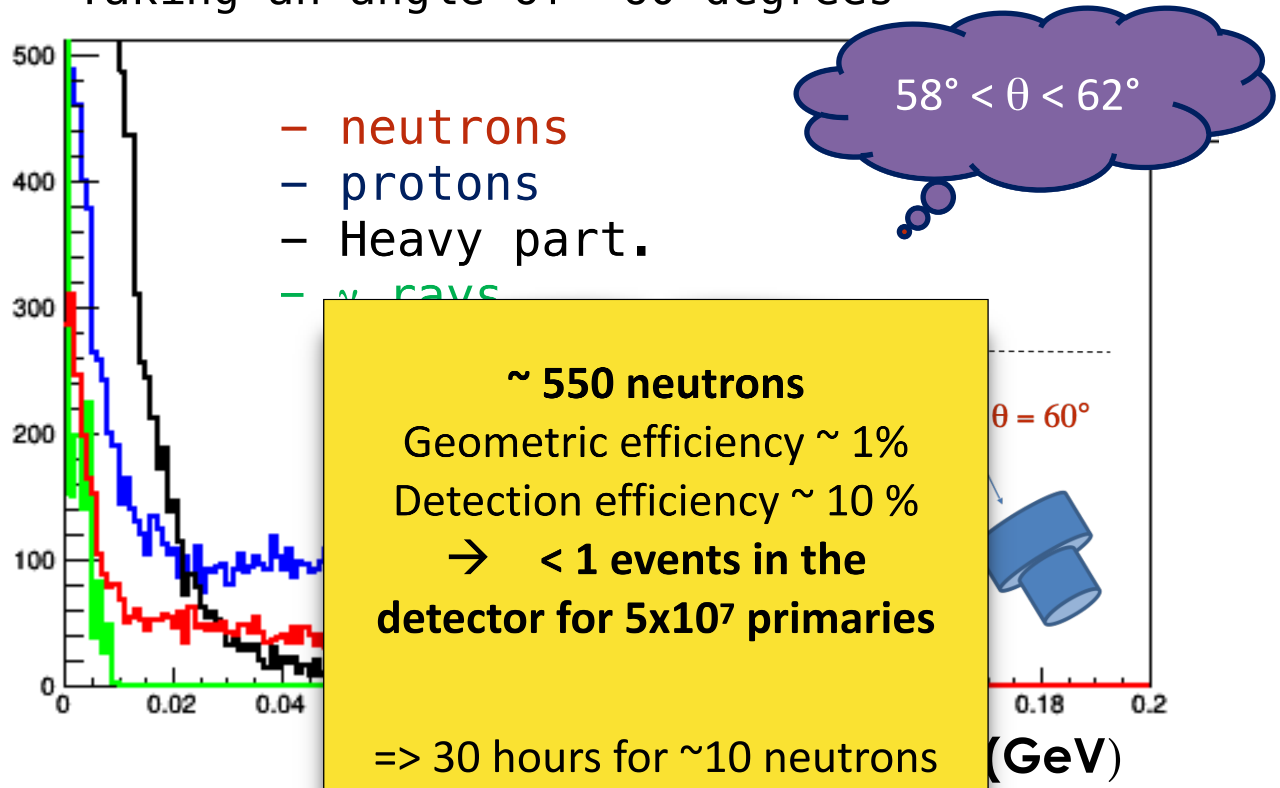
$^{1}H+C_2H_4$ @200MeV/u (newgeom) statistics: 5×10^{7} primaries

Taking an angle of ~60 degrees

Area = 45 (25) cm²
Δθ ~ 2 deg.

@Distance = 100 cm

E_n	TOF
1 MeV	72 ns
10 MeV	23 ns
50 MeV	10.6 ns
100 MeV	7.8 ns
200 MeV	5.9 ns



~ 550 neutrons
Geometric efficiency ~ 1%
Detection efficiency ~ 10 %
→ < 1 events in the detector for 5×10^{7} primaries

=> 30 hours for ~10 neutrons (beam 1kHz)

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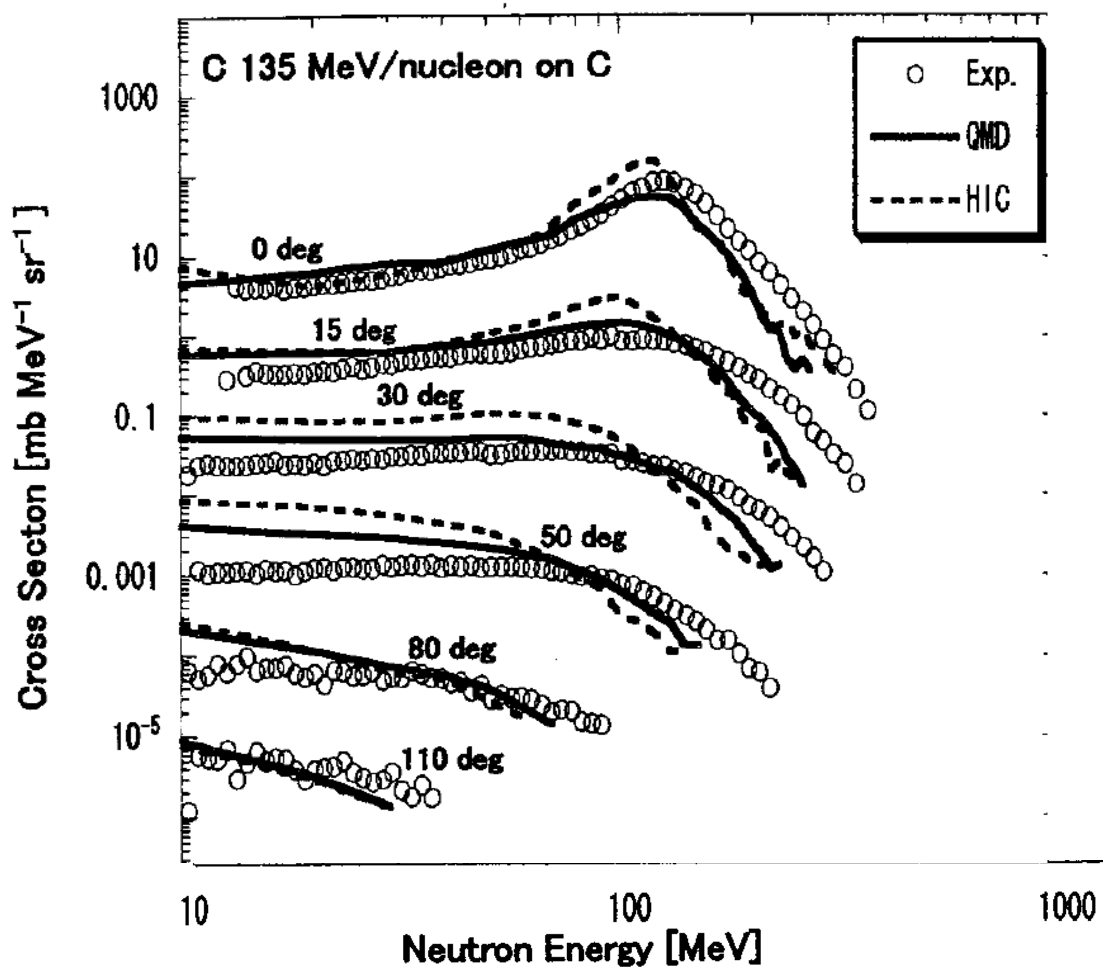
12C + 12C → n + x differential cross section (inclusive)

Target and thickness (mm)	Projectile type and energy (MeV/nucleon)
C (1.0)	He (135)
	C (135)
	Ne (135)

~ 3 mb · sr^{-1} · MeV^{-1}

^{12}C @ 135 MeV/u
^{12}C @ 290 MeV/u



PHYSICAL REVIEW C **64** (2001) 034607 and 054609

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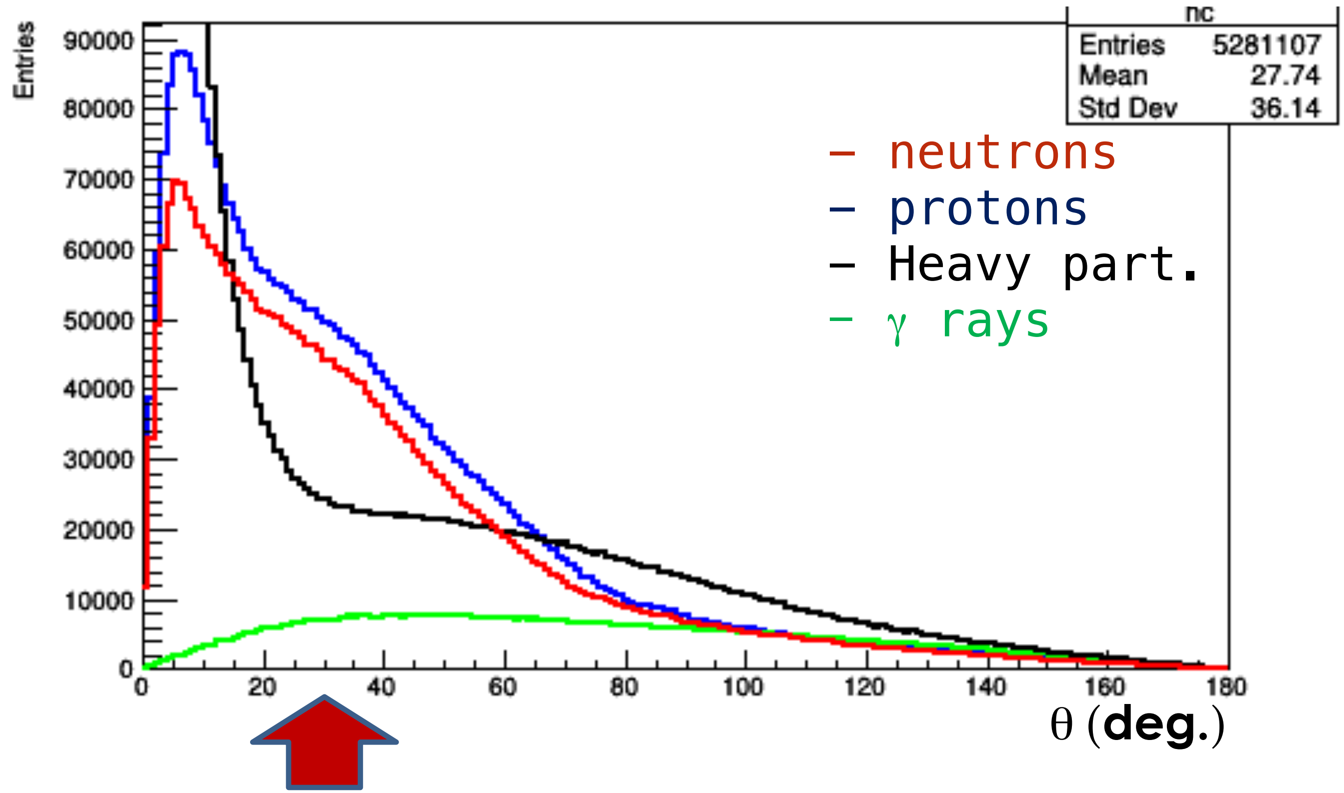
MC simulations – particles from target (5-mm thick)

$^{1}H + C_2H_4$ @200MeV/u (newgeom) statistics: 5×10^7 primaries

Area = 45 (25) cm^2
$\Delta\theta \sim 2$ deg.



Angles: 30

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MC simulations – particles from target (5-mm thick)

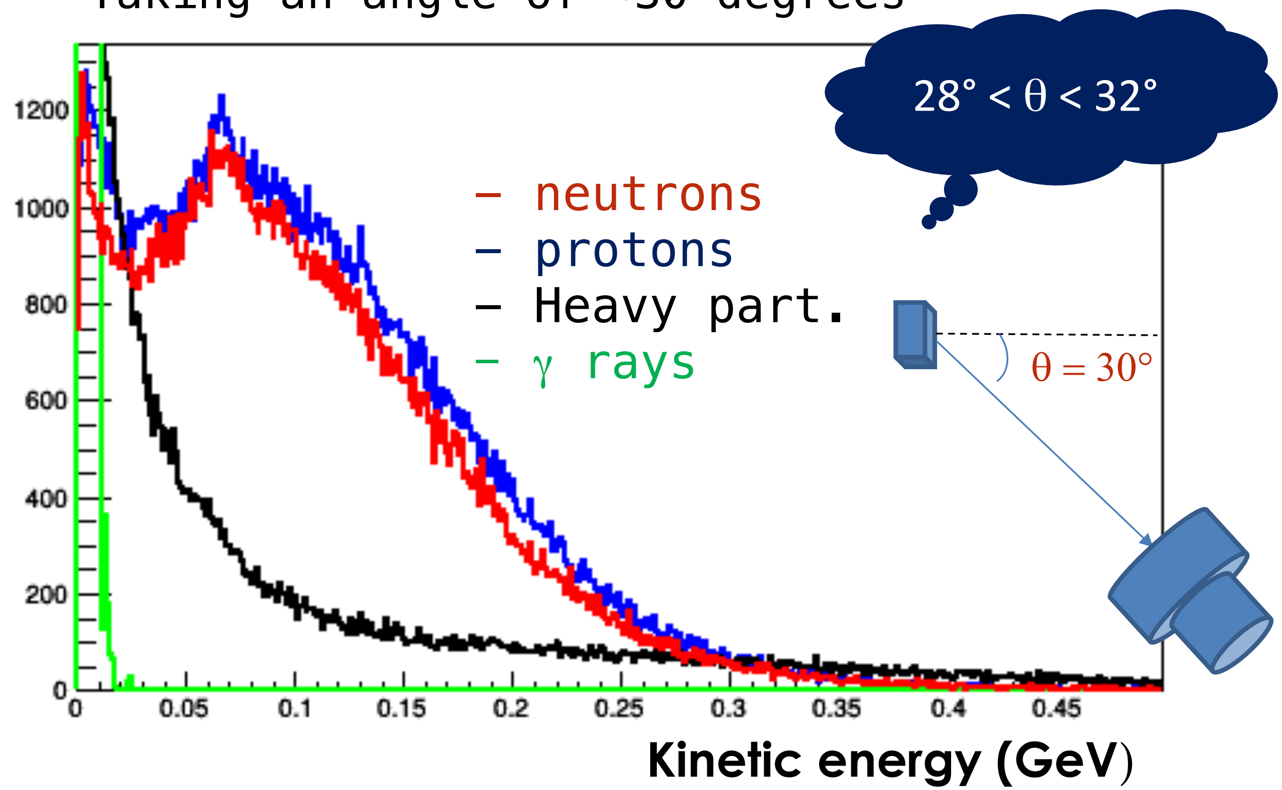
$^{1}H+C_2H_4$ **@200MeV/u** (newgeom) statistics: 5×10^7 primaries

Area = 45 (25) cm^2
$\Delta\theta$ ~ 2 deg.

@Distance = 100 cm

E_n	TOF
1 MeV	72 ns
10 MeV	23 ns
50 MeV	10.6 ns
100 MeV	7.8 ns
200 MeV	5.9 ns

Taking an angle of ~30 degrees



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MC simulations – particles from target (5-mm thick)

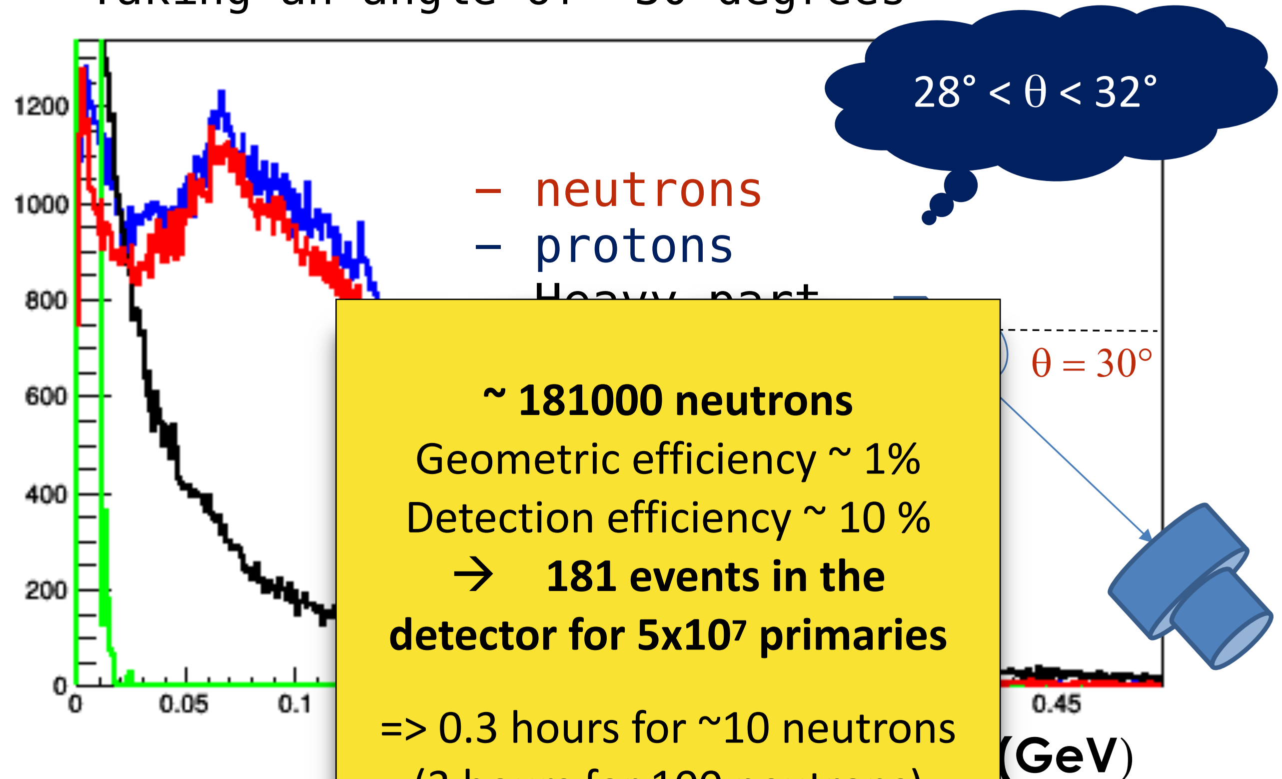
$^{1}H+C_2H_4$ @200MeV/u (newgeom) statistics: 5x10^{7} primaries

Area = 45 (25) cm^{2}
$\Delta\theta$ ~ 2 deg.

@Distance = 100 cm

E_n	TOF
1 MeV	72 ns
10 MeV	23 ns
50 MeV	10.6 ns
100 MeV	7.8 ns
200 MeV	5.9 ns

Taking an angle of ~30 degrees



~ 181000 neutrons
Geometric efficiency ~ 1%
Detection efficiency ~ 10 %
→ **181 events in the detector for 5x10^{7} primaries**

=> 0.3 hours for ~10 neutrons
(3 hours for 100 neutrons)
(beam 1kHz)

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MC simulations – particles from target (5-mm thick)

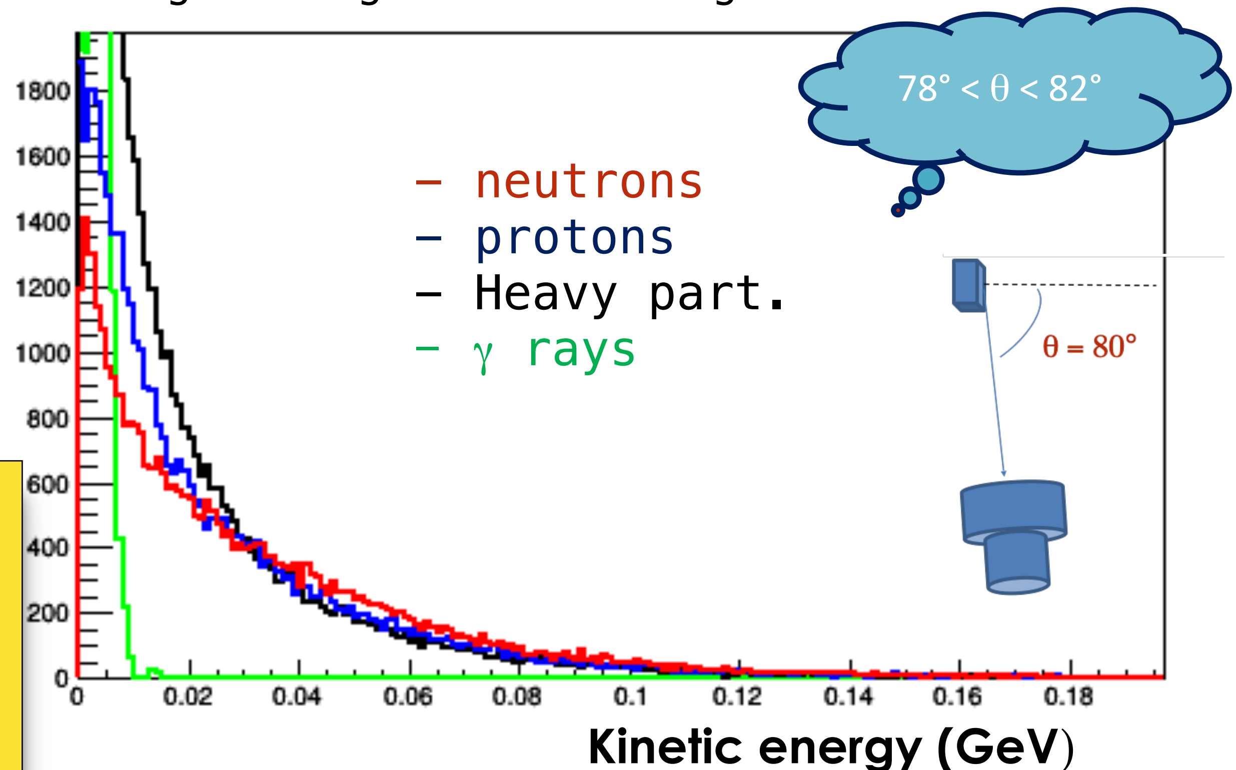
$^{1}H+C_2H_4$ @200MeV/u (newgeom) statistics: 5×10^7 primaries

Area = 45 (25) cm²
Δθ ~ 2 deg.

@Distance = 100 cm

E_n	TOF

Taking an angle of ~80 degrees



~ 36000 neutrons
Geometric efficiency ~ 1%
Detection efficiency ~ 10 %
→ **36 events in the detector for 5×10^7 primaries**

=> 3 hours for ~30 neutrons (beam 1kHz)

michela.marafini Cristian Massimi Mauro Villa

Summarising

During the next test beam at CNAO It could be possible to **repeat** some **measurements** present **in the literature** about neutron production in p+^{12}C and ^{12}C+^{12}C reactions:

- p + ^{12}C @ 30 and 60 (150?) deg. with **energy** of **113** and **256 MeV**
- ^{12}C + ^{12}C @ 30 and 80 deg. with **energy** of **135** and **290 MeV/u**

These tests will provide the information about the feasibility of detecting neutrons with the present setup and with other detectors.

Dedicated simulations are required to be able to better prepare the test and estimate the required beam time.

Dedicated beam time (approximately … h) is necessary to perform the test => 5 hours at 1 MHz ? :)

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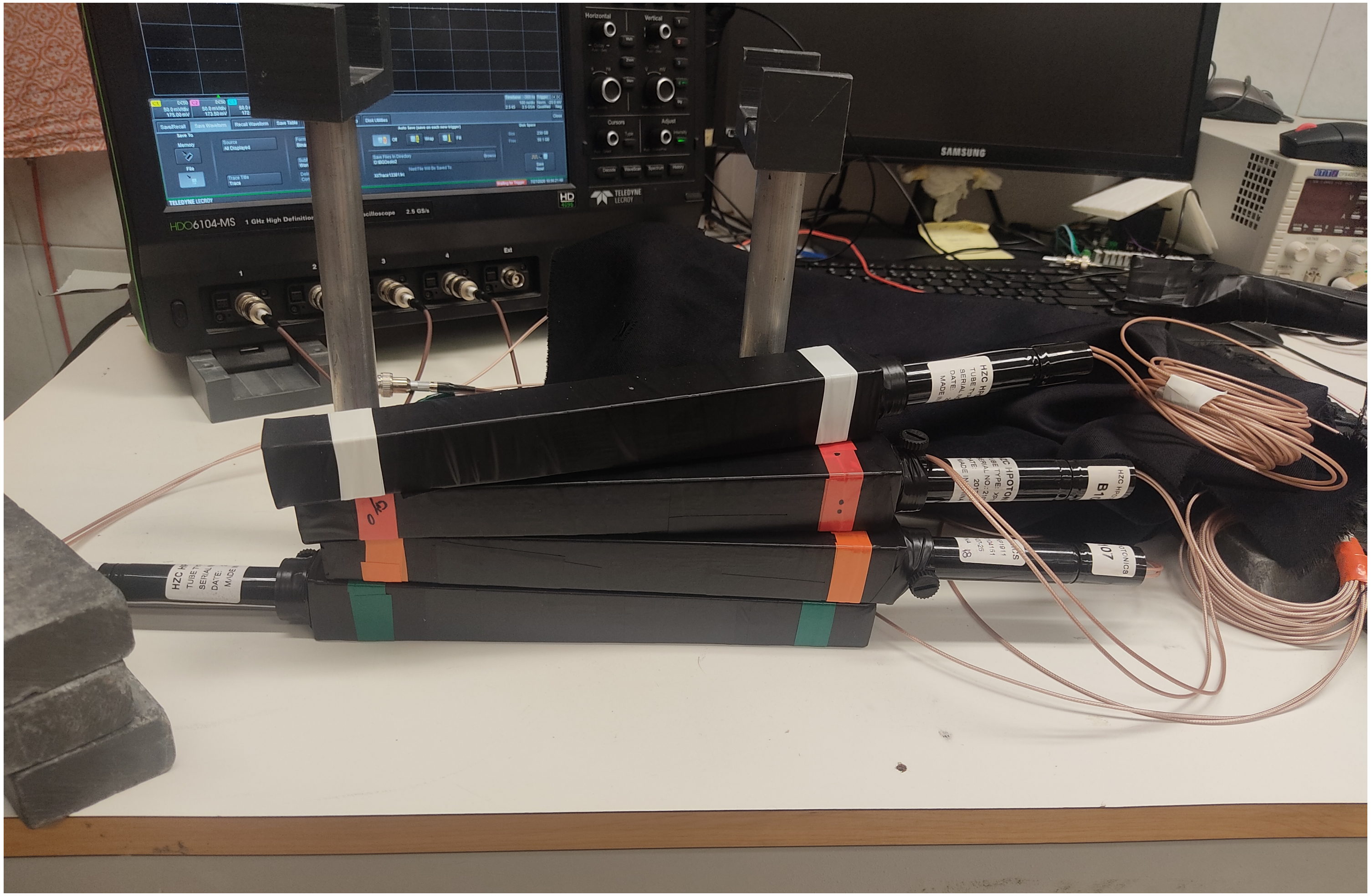
Possible Setup (HE)



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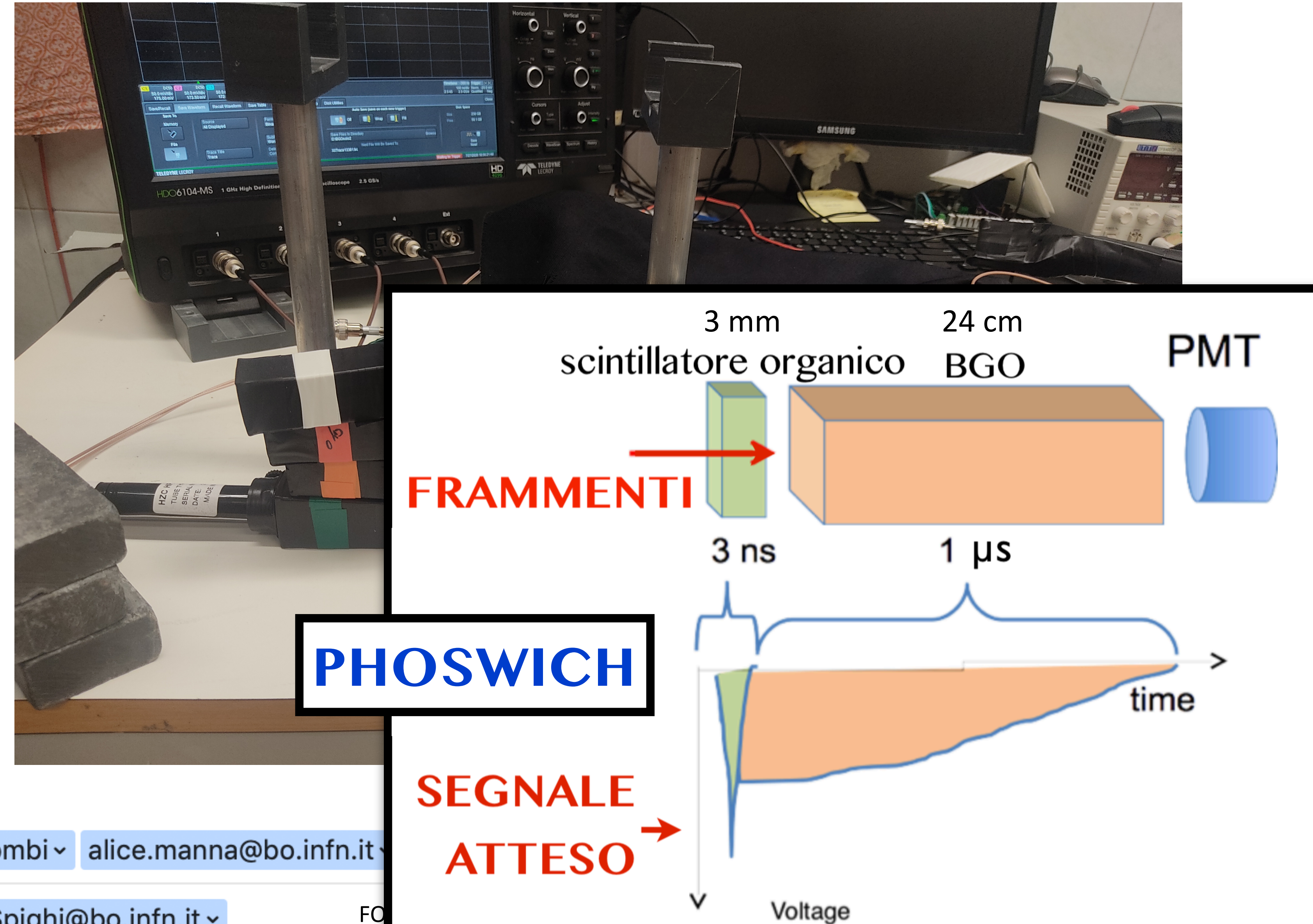
Possible Setup (HE)



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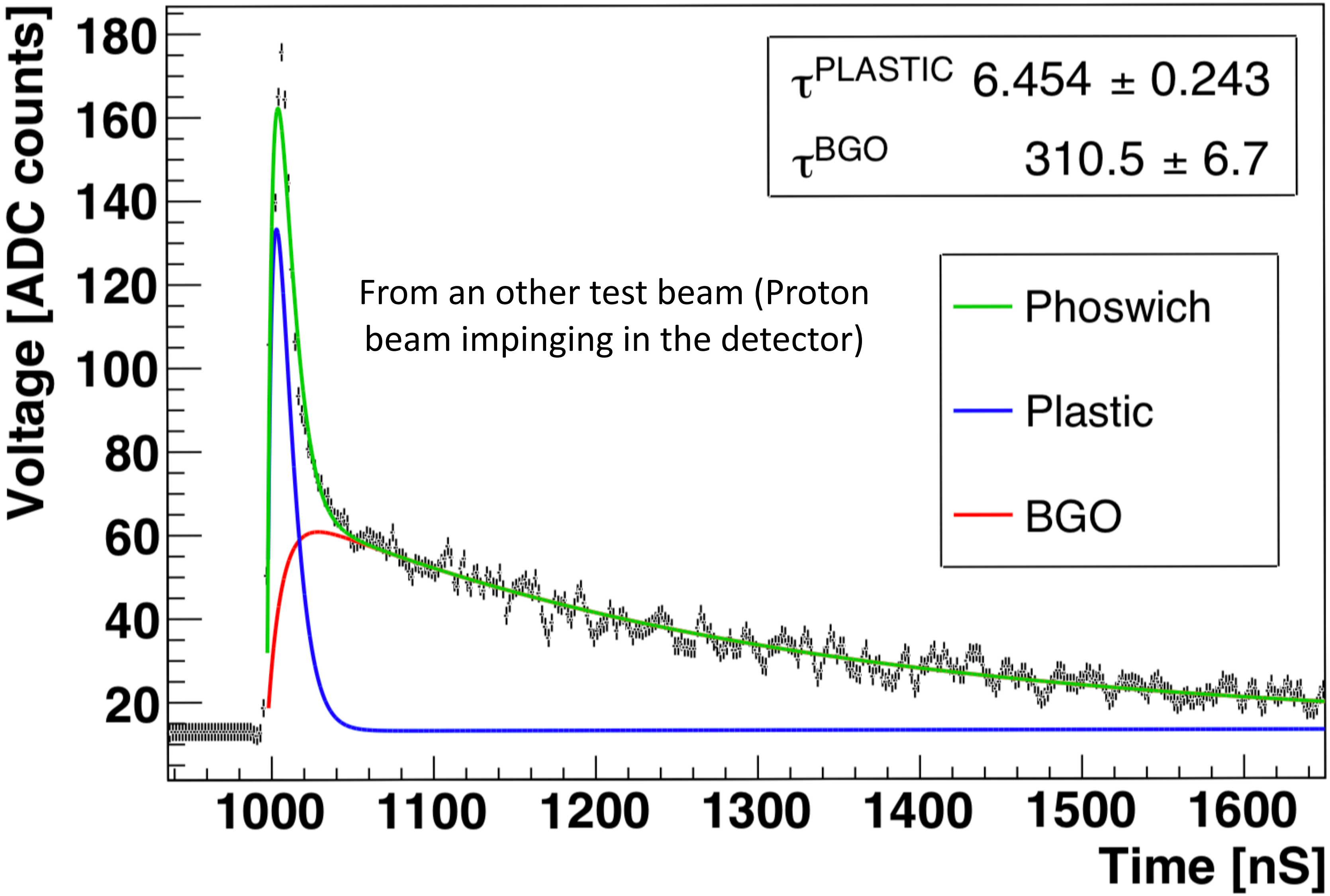
Possible Setup (HE)



From an other test beam (Proton beam impinging in the detector)

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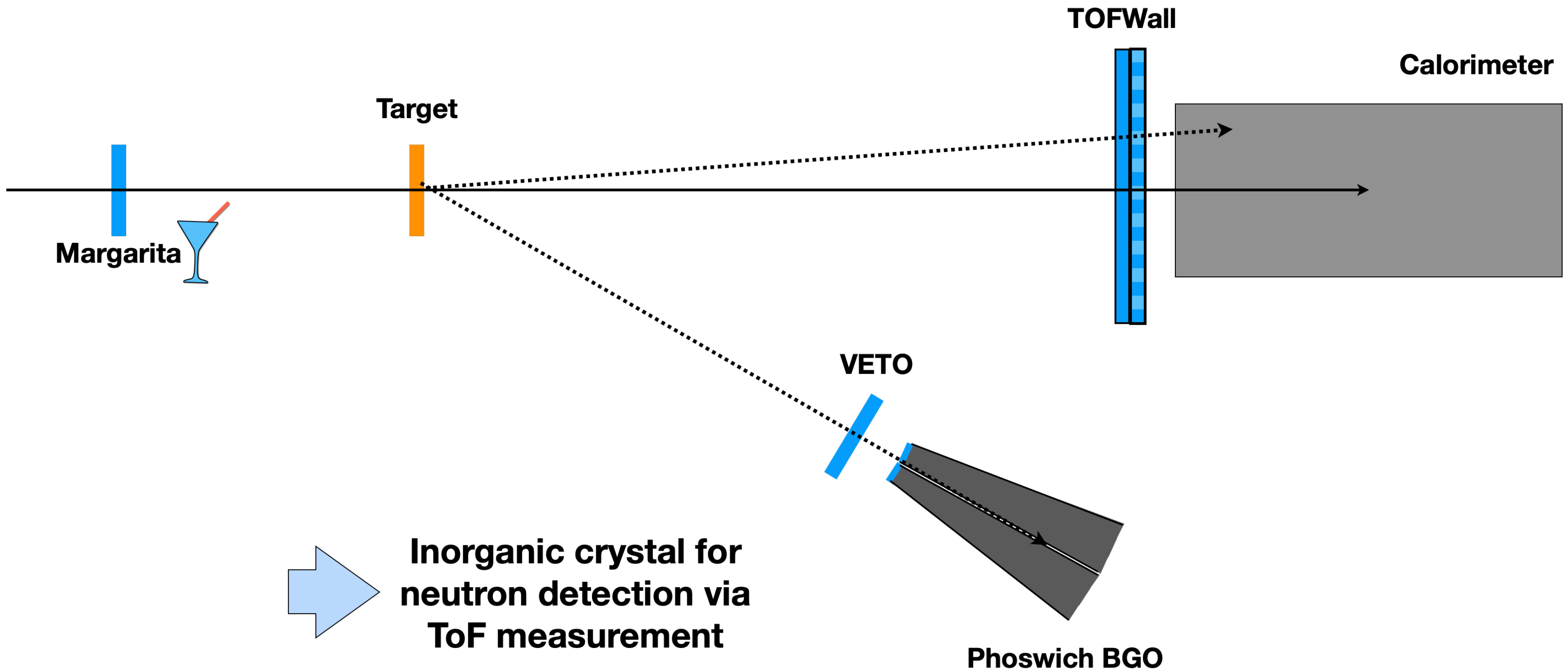
Roberto.Spighi@bo.infn.it

FO

Voltage

Possible Setup (HE)



Inorganic crystal for neutron detection via ToF measurement

- **Distance: ~1 m**
- **4 crystals:**
  - **Front face: 2.5 cm**
  - **Back face: 3.5 cm**
  - **3 mm EJ232 (plastic scintillator)**

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Xylene/Toluene: NE213 / BC501

- Liquid scintillating detector optimized for n/γ discrimination; det size 3in x 3 in

Scintillation Properties	BC-501A	BC-501
Light Output, %Anthracene	78	80
Wavelength of Maximum Emission, nm	425	425
Decay Time, short component, ns	3.2	3.3
Atomic Composition		
No. of H Atoms per cc ($\times 10^{22}$)	4.82	5.25
No. of C Atoms per cc ($\times 10^{22}$)	3.98	4.08
Ratio H:C Atoms	1.212	1.287
No. of Electrons per cc ($\times 10^{23}$)	2.87	2.97

Additional Properties of BC-501A	
Mean Decay Times of first three components (Ref. 2)	3.16, 32.3 & 270 ns

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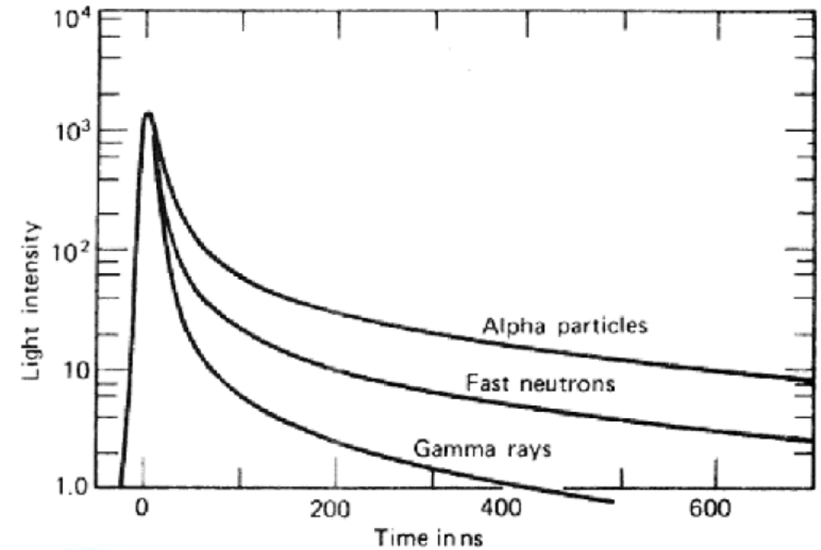
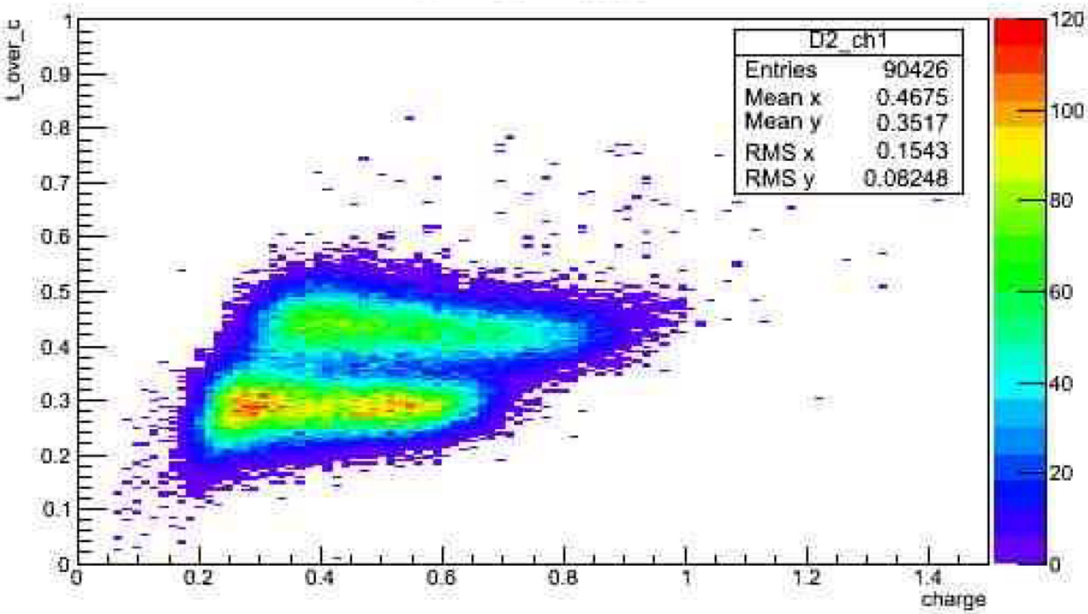
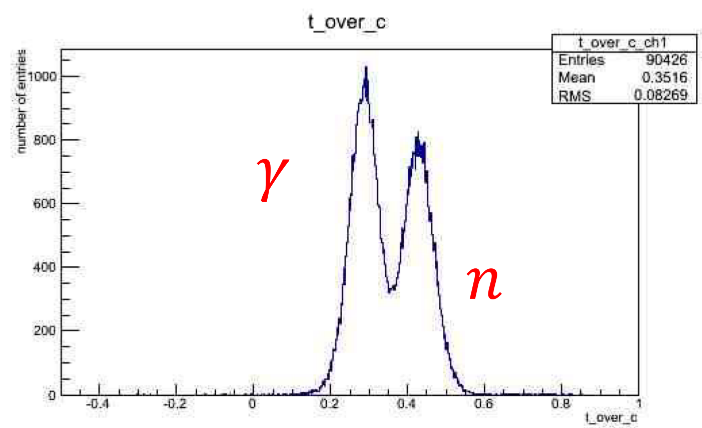
Possible Setup (LE)

In a past experiment with those detectors with Am-Be source

0.1-14 MeV Neutrons







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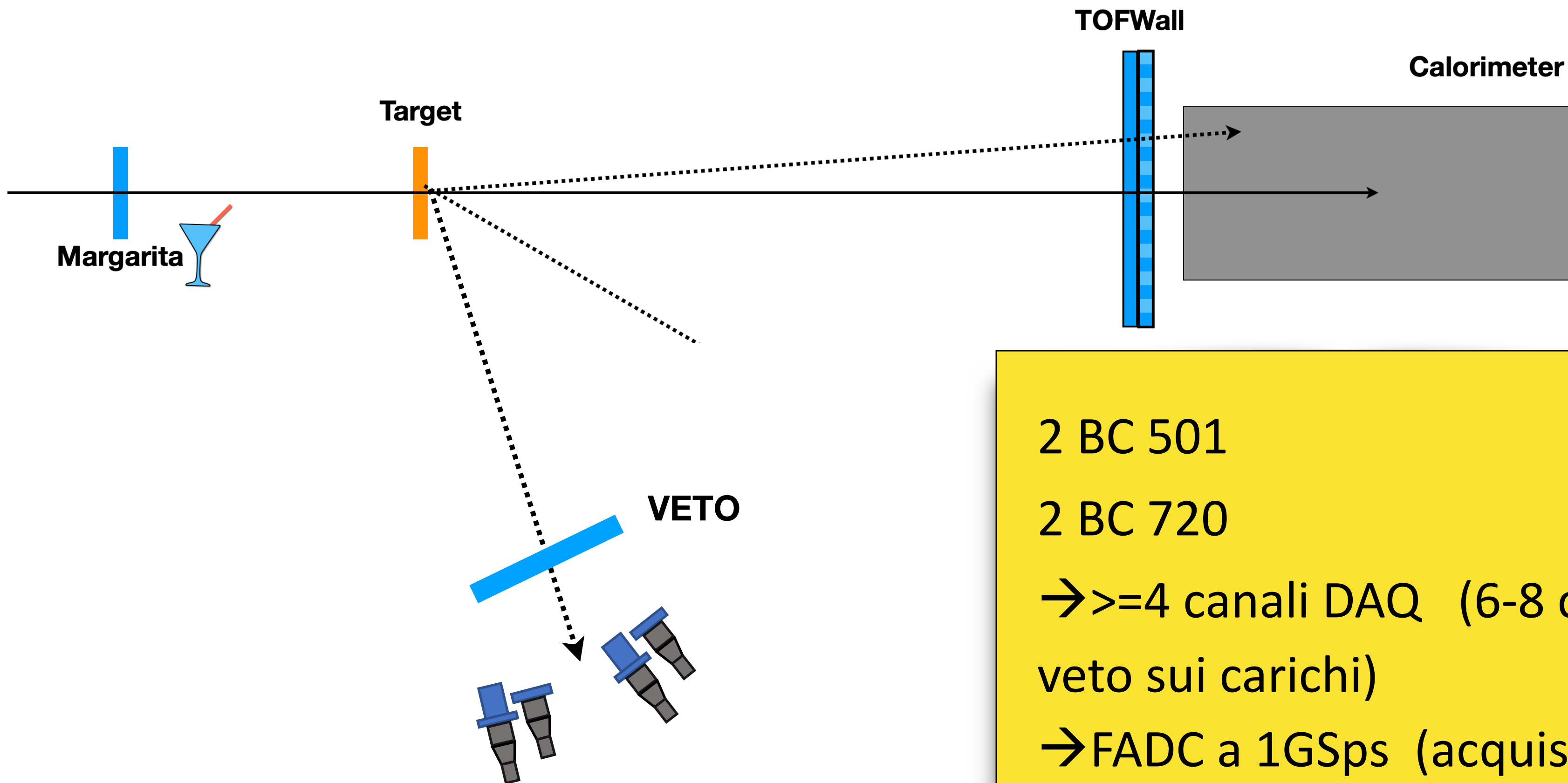
BC-720

ZnS(Ag) phosphor embedded in a clear hydrogenous plastic and functions by means of the proton recoil interaction in the plastic, the proton being detected by the ZnS.

Detector size:
3” diameter

Scintillation Properties	
Decay Time, µs	0.2
Wavelength of Max. Emission, nm	450

Possible Setup (LE)



2 BC 501

2 BC 720

→>=4 canali DAQ (6-8 con veto sui carichi)

→FADC a 1GSps (acquisire almeno 1 us) (WaveDream o Caen V17xx)

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Open Issues:

DAQ Channels

- 4 BGO => WDAQ Calorimeter (6 free channels => 2 free channels)
- 1 Veto. => WDAQ Margarita (8 free channels => 7 free channels)

and/or

- 2 BC-720 + 2 NE213 => WDAQ Calorimeter (6 free channels => 2 free channels)
- 1 Veto. => WDAQ Margarita (8 free channels => 7 free channels)

Trigger strategy

- Margarita in AND with OR of the neutron detectors => Luca.. is it possible?

The low energy measurement can be in parallel or in a different run => the number of different allowed triggers will define the strategy

- Define a run for efficiency measurements (and Delta calbes)
- Schedule a special run at high rate

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TO DO LIST

- Define the distance from the detectors
- Build the Veto
- Keep testing the BGO at SBAI and low energy detectors at Bologna with cosmic rays and sources

Make a tour on MC simulation (Fluka):

- Can we put a box of the correct size in the FOOT simulation in order to study the expected background?

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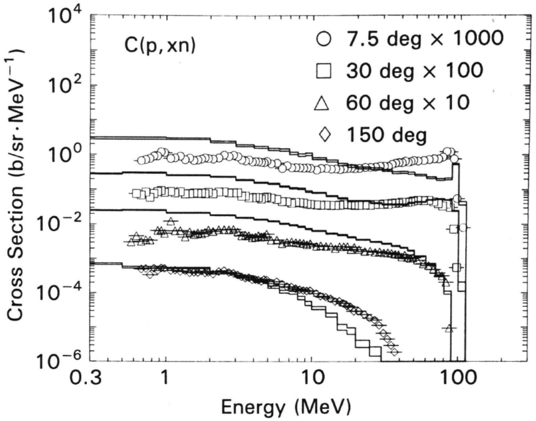
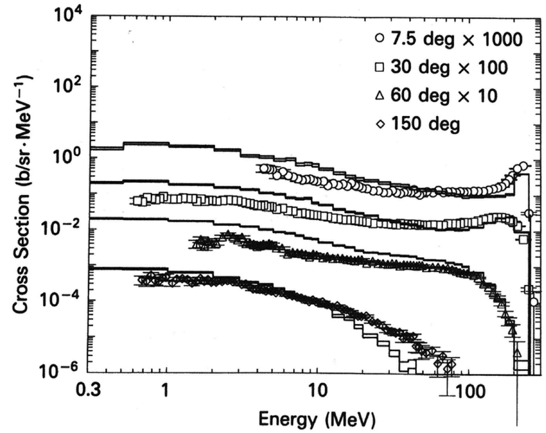
Backupslides

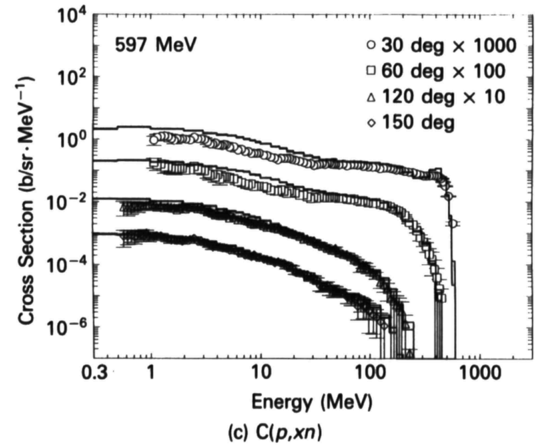
C(p,xn) differential cross section (inclusive)



113 MeV



256 MeV



597 MeV

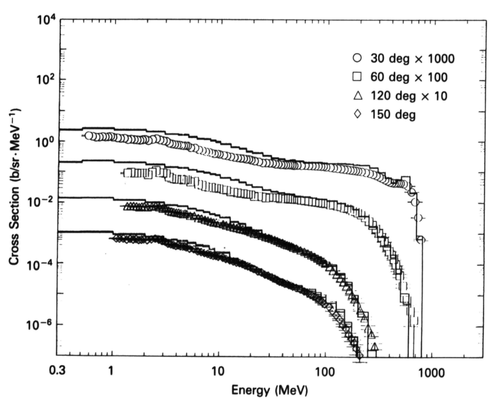


Fig. 3. Experimental differential cross sections for carbon compared with HETC calculations.

800 MeV

Thin target, heavy-Ion induced reactions

Handbook on Secondary Particle Production And Transport by High-energy Heavy Ions

by Nakamura and Heilbronn

Beam ion and energy (MeV/nucleon)	Targets	Measured spectra	θ (deg)	Emin (MeV)	Facility
He (135)	C, Al, Cu, Pb	ddx, n/dΩ total	0, 15, 30, 50, 80, 110	10 (all angles)	RIKEN
He (230)	Al, Cu	ddx, n/dΩ total	5, 10, 20, 30, 40, 60, 80	5.5, 5, 4, 3.5, 3.5, 3	HIMAC (PH2)
C (135)	C, Al, Cu, Pb	ddx, n/dΩ total	0, 15, 30, 50, 80, 110	10 (all angles)	RIKEN
C (290)	C, Cu, Pb, marsbar	ddx, n/dΩ total	5, 10, 20, 30, 40, 60, 80	10, 3, 3, 7, 4, 3, 3	HIMAC (SB3)
C (400)	Li, C, CH_2, Al, Cu, Pb	ddx, n/dΩ total	5, 10, 20, 30, 40, 60, 80	8.5, 5, 3.5, 3, 3, 3	HIMAC (PH2 and SB3)
N (400)	C, Cu	ddx, n/dΩ total	5, 10, 20, 30, 40, 60, 80	6, 6, 5, 5.5, 5.5, 5	HIMAC (PH2)
Ne (135)	C, Al, Cu, Pb	ddx, n/dΩ total	0, 15, 30, 50, 80, 110	10 (all angles)	RIKEN
Ne (337)	C, Al, Cu, U	ddx total	30, 45, 60, 90	12 (all angles)	LBL Bevalac
Ne (400)	C, Cu, Pb, ISS wall	ddx, n/dΩ total	5, 10, 20, 30, 40, 60, 80	9,6, 3.5, 3.5, 3, 3	HIMAC (SB3)
Ne (600)	Li, C, CH_2, Al, Cu, Pb, marsbar	ddx, n/dΩ total	5, 10, 20, 30, 40, 60, 80	6, 5.5, 4, 3, 3, 3	HIMAC (PH2 and SB3)
Ar (95)	C, Al, Cu, Pb	ddx, n/dΩ total	0, 30, 50, 80, 110	10 (all angles)	RIKEN
Ar (400)	C, Cu, Pb	ddx, n/dΩ total	5, 10, 20, 30, 40, 60, 80	10, 7, 3.5, 3.5, 3, 3	HIMAC (PH2 and SB3)
Ar (560)	C, Cu, Pb, marsbar	ddx, n/dΩ total	5, 10, 20, 30, 40, 60, 80	10, 7, 3.5, 3.5, 3, 3	HIMAC (PH2)
Fe (500)	Li, CH_2, Al	ddx, n/dΩ total	5, 10, 20, 30, 40, 60, 80	12, 11, 7, 4, 3, 3	HIMAC (PH2)
Kr (400)	Li, C, CH_2, Al, Cu, Pb	ddx, n/dΩ total	5, 10, 20, 30, 40, 60, 80	20 (all angles)	HIMAC (PH2)

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Thin target, heavy-Ion induced reactions

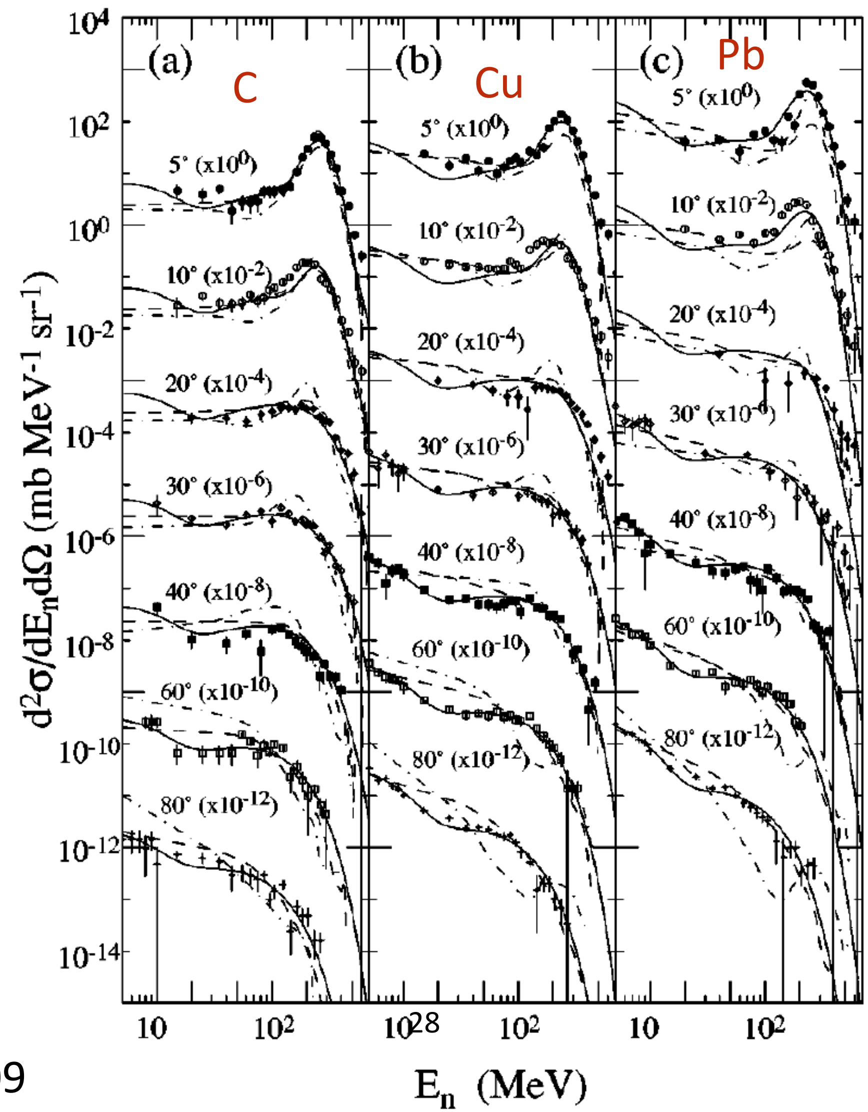
@ 290 MeV/u

Example: **inclusive cross section**

TABLE II. Summary of the beams and targets used in the experiment.

Beam (MeV)	Thickness (g/cm^2) C target	Cu target	Pb target
C at $E/A=290$	1.80	4.47	2.27
C at $E/A=400$	9.00	13.4	9.08
Ne at $E/A=400$	1.80	4.47	2.27
Ne at $E/A=600$	3.60	4.47	4.54
Ar at $E/A=400$	0.720	1.34	1.70
Ar at $E/A=560$	1.08	1.79	2.27

Differential cross section



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Thin target, heavy-Ion induced reactions

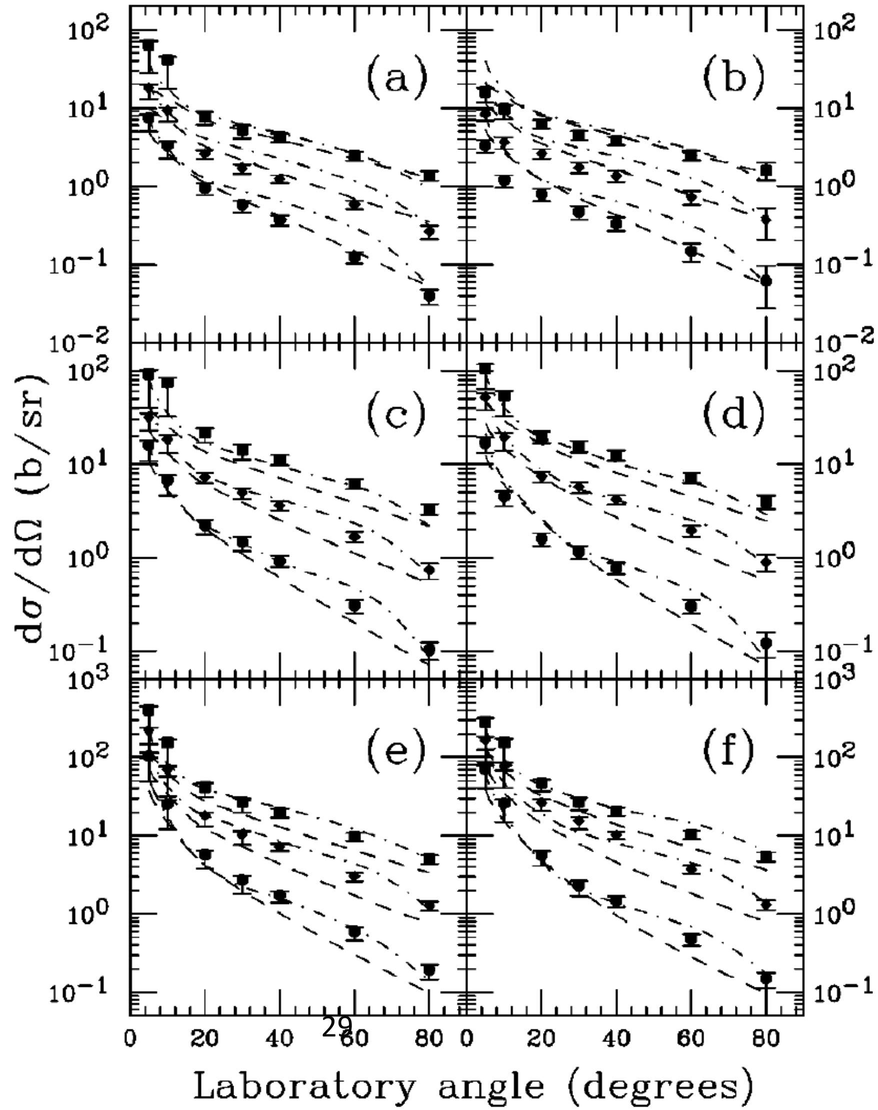
@ 290 MeV/u
@ 400 MeV/u
@ 600 MeV/u

Example: **inclusive cross section**

TABLE II. Summary of the beams and targets used in the experiment.

Beam (MeV)	Thickness (g/cm^2) C target	Cu target	Pb target
C at $E/A = 290$	1.80	4.47	2.27
C at $E/A = 400$	9.00	13.4	9.08
Ne at $E/A = 400$	1.80	4.47	2.27
Ne at $E/A = 600$	3.60	4.47	4.54
Ar at $E/A = 400$	0.720	1.34	1.70
Ar at $E/A = 560$	1.08	1.79	2.27

Angular distribution



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Thin target, heavy-Ion induced reactions

@ 135 MeV/u

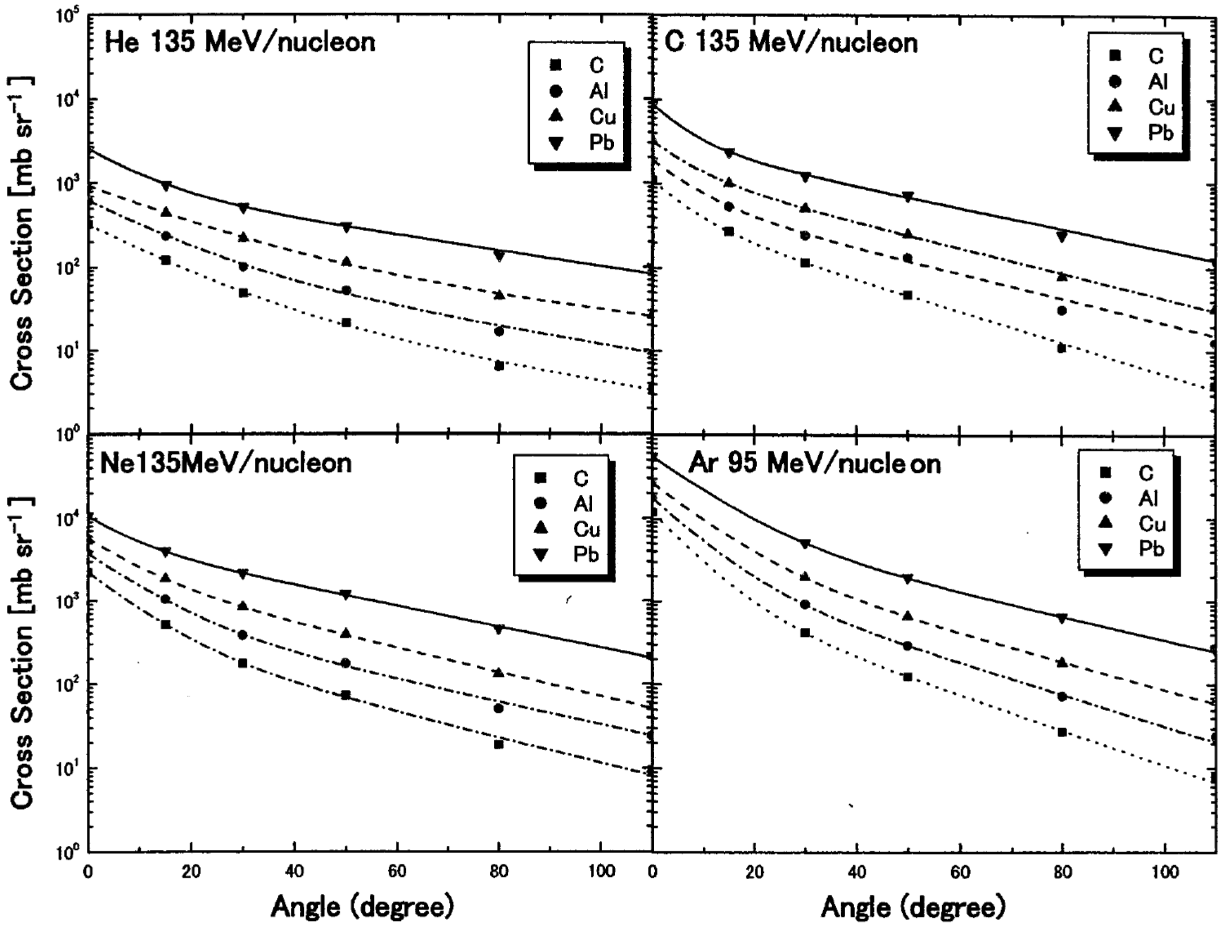

FIG. 8. Angular distributions of neutron production cross sections integrated above 20 MeV.

Angular distribution

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