Neutrons @ FOOT

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for the working group

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Program

- **Neutrons** produced in the **target** and in the **environment** (MC simulations)
- **Neutron** detection using the **standard** FOOT **setup** (principle)
- Some limitations (qualitative)
- Event by event analysis (TOF wall + BGO)
- Towards a test beam @ CNAO (characterization of BGO)

RECAP

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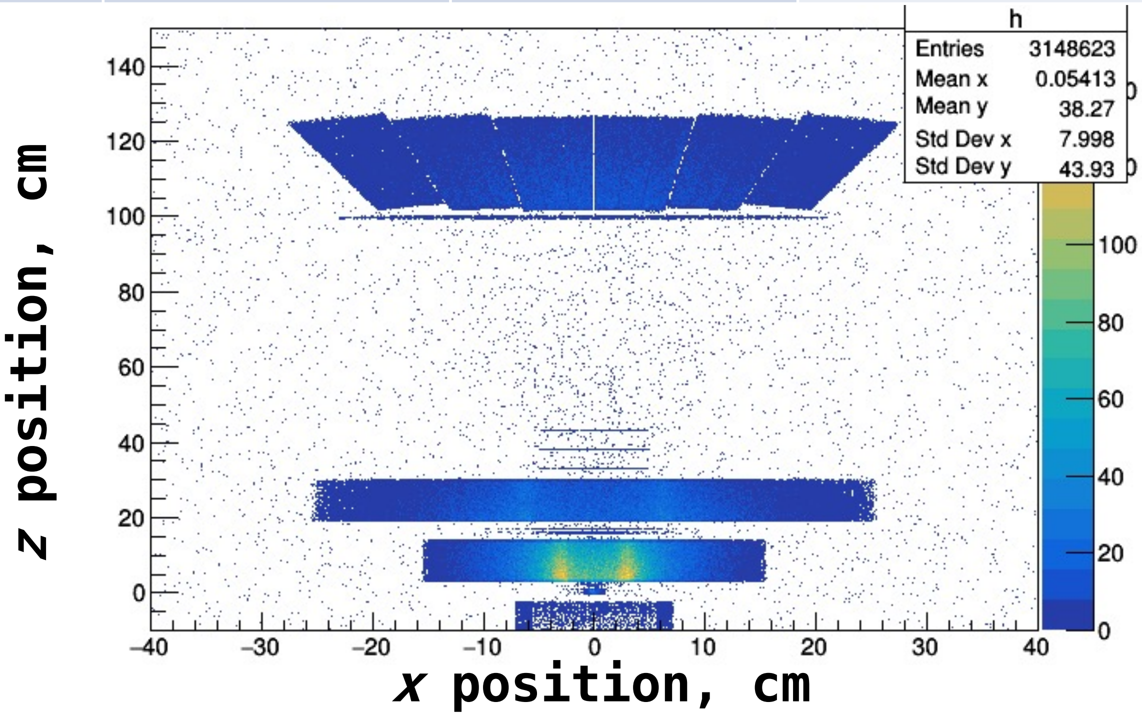
MC simulations – neutrons from target & environment

5E7 primaries

$^{16}O+C_2H_4$ @200MeV/u (newgeom) statistics: 1.4E6 fragmentations

	Neutrons (10^6) Produced	Neutrons (10^6) interacting Magnets	Neutrons (10^6) towards Calorimeter	Neutrons (10^6) interacting Calorimeter	Neutrons (10^6) arriving to the world
target	3.2	1.3 (40%)	0.6 (20%)	**0.4**	1.4

Interaction point



MC simulations – neutrons from target & environment

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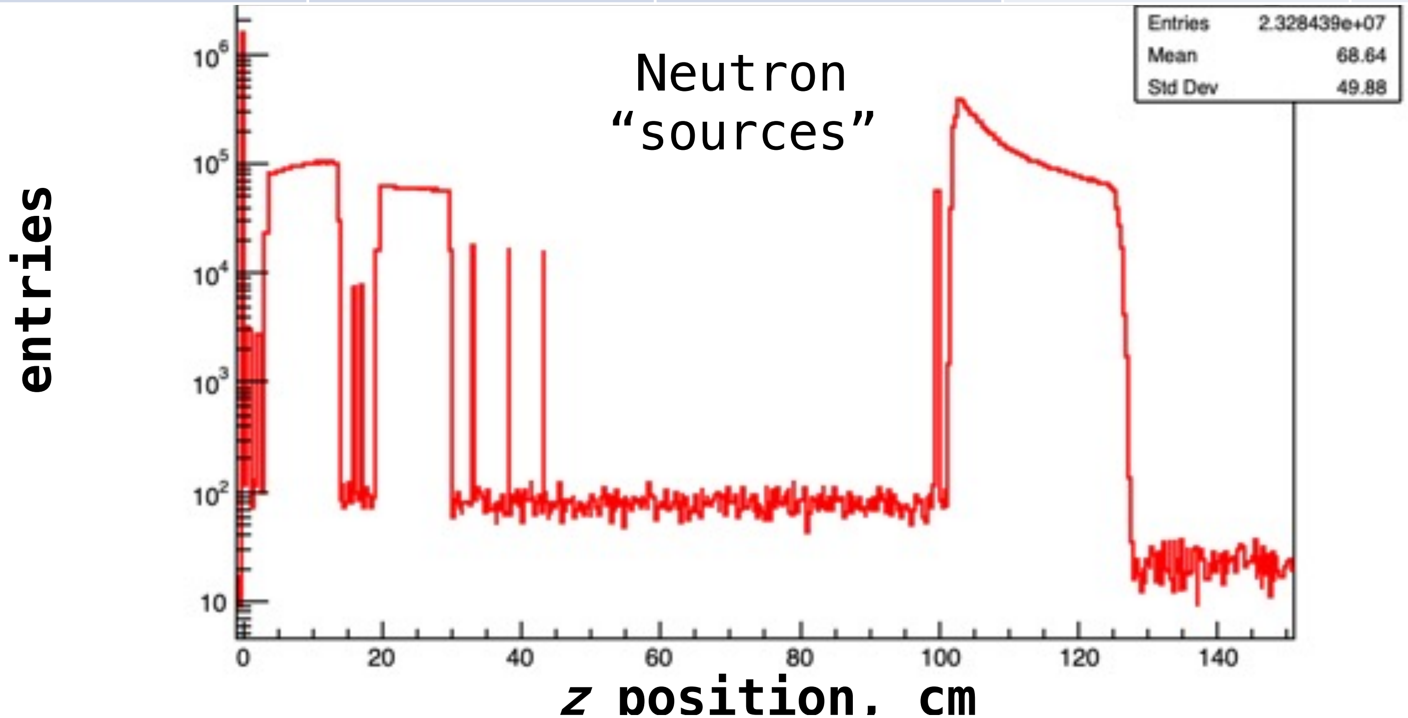
target	3.2	1.3 (40%)	0.6 (20%)	**0.4**	1.4
magnets	6.5				
Cal.	13.3				



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MC simulations – neutrons from target & environment

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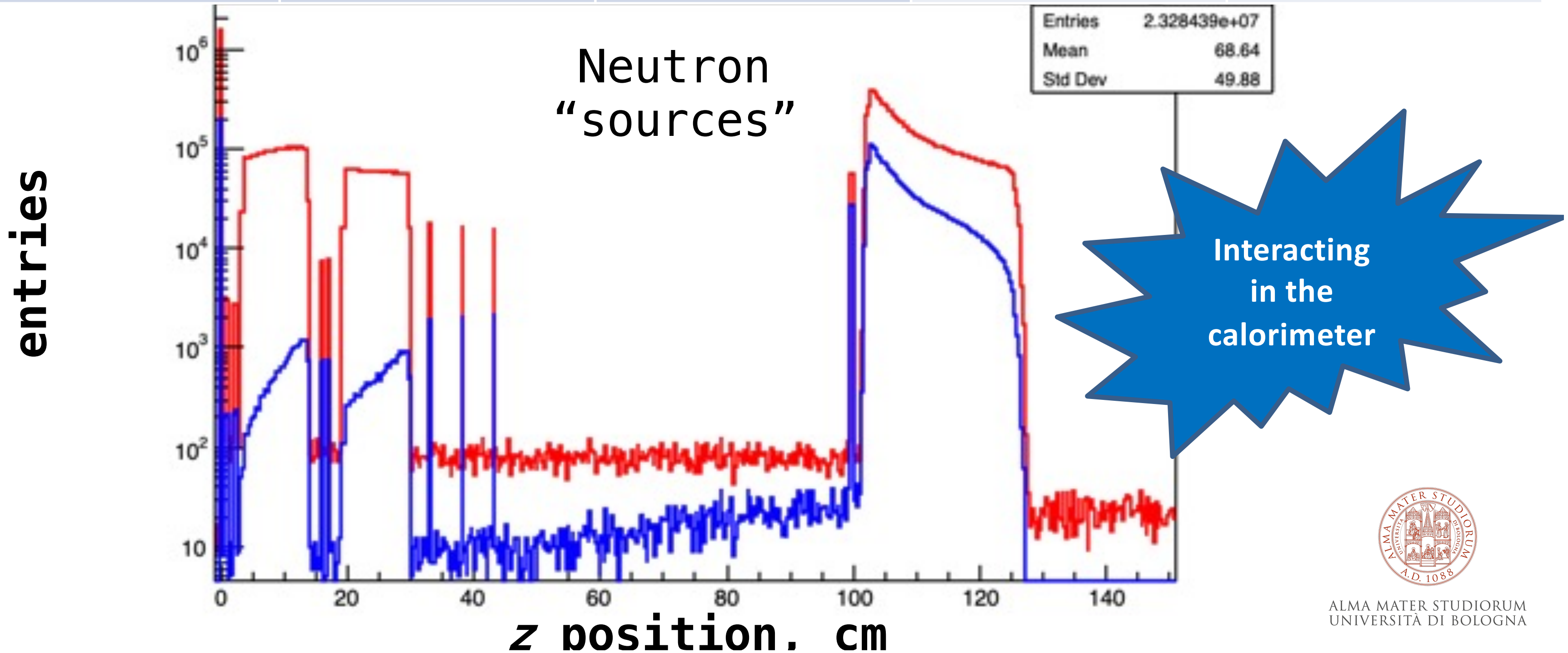
target	3.2	1.3 (40%)	0.6 (20%)	**0.4**	1.4
magnets	6.5			**0.06**	14.8
Cal.	13.3			**3.1**	



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MC simulations – neutrons from target & environment

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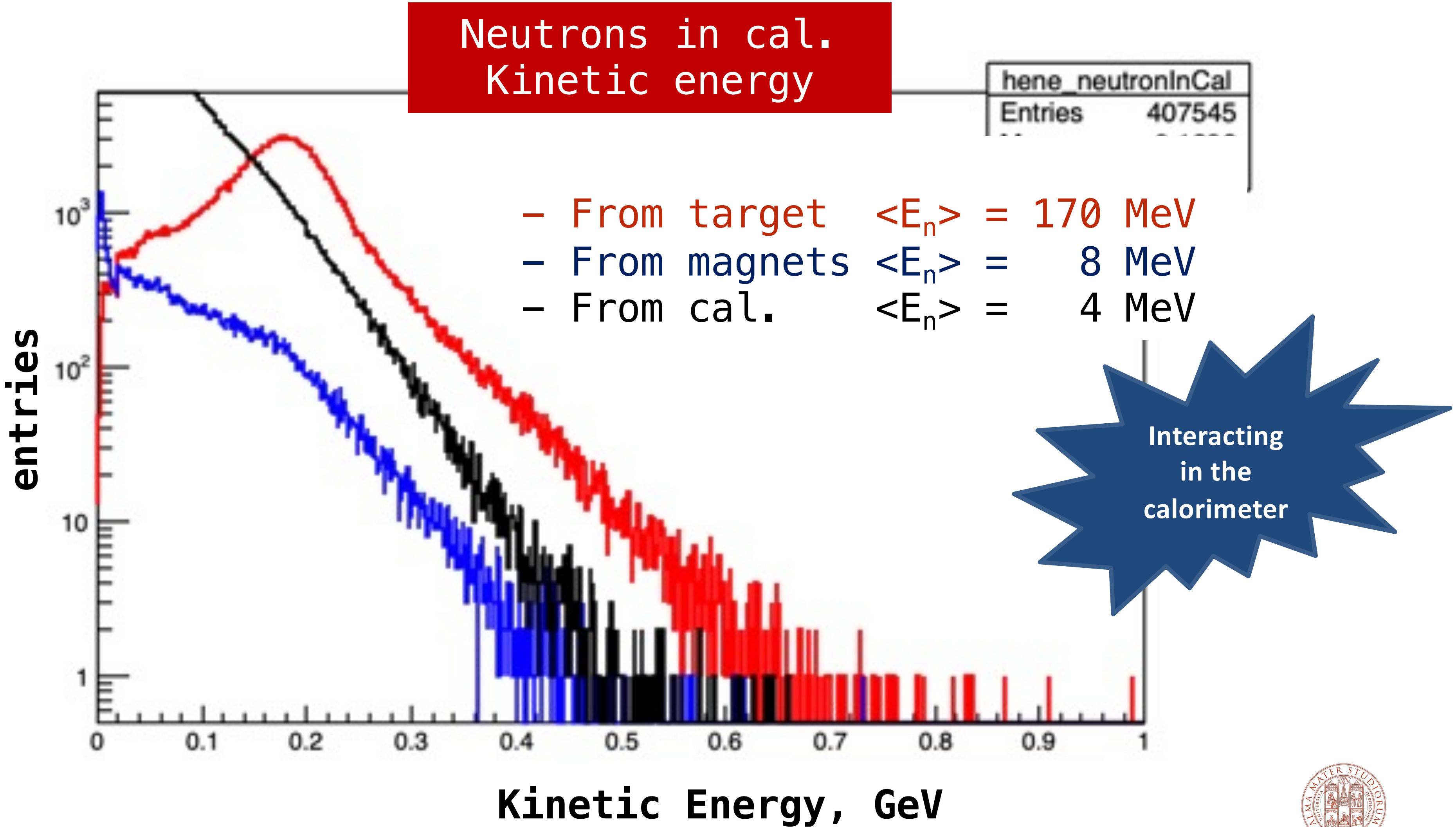


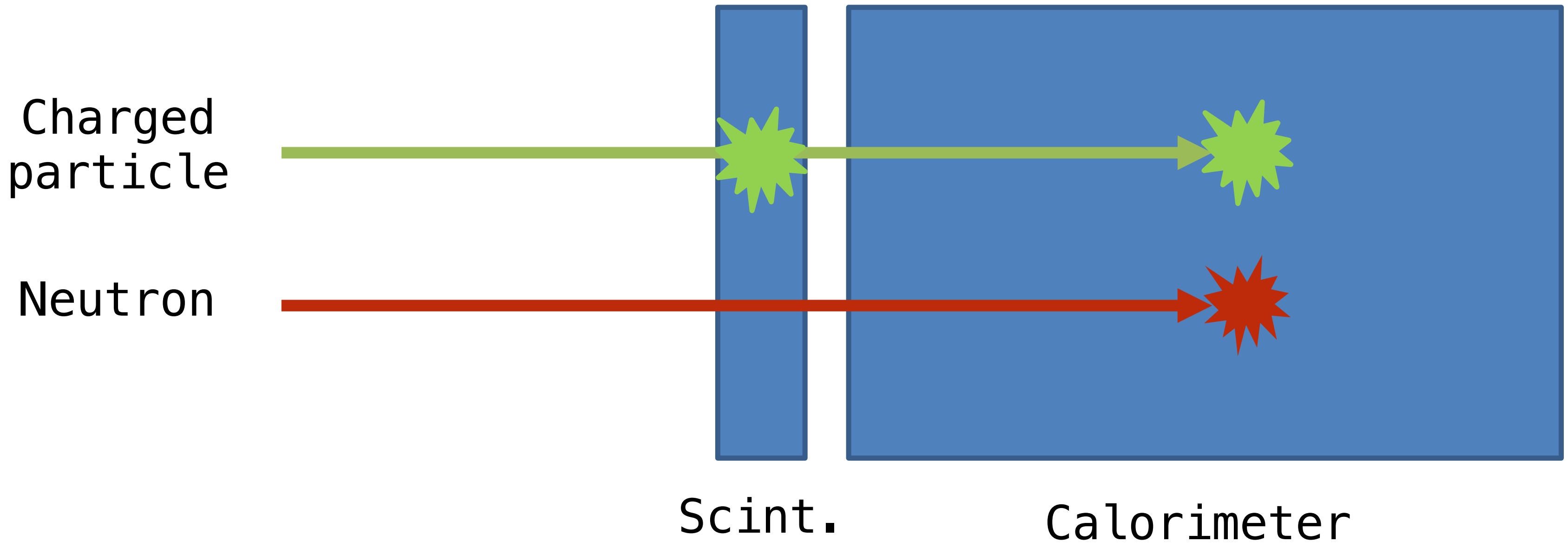
MC simulations – neutrons from target & environment

Some comments:

- **Large production** of **neutrons** outside the C_2H_4 target.
  - → **Avoid** detectors based on moderation (sensitive to thermal neutrons)
  - → Only **high-energy neutrons** originating from target can have experimental **signature higher than background** .
- **Neutrons from** the **target** interacting in the calorimenter are a **factor 6 > neutrons from** the **magnets. With condition on ΔE → factor 10.**
- **Neutrons from the calorimenter** need to be **tagged.**
- **How to discriminate γ rays?**

Detecting neutrons with existing setup

Basic idea: **anticoincidence scintillator – calorimenter**



Detecting neutrons with existing setup

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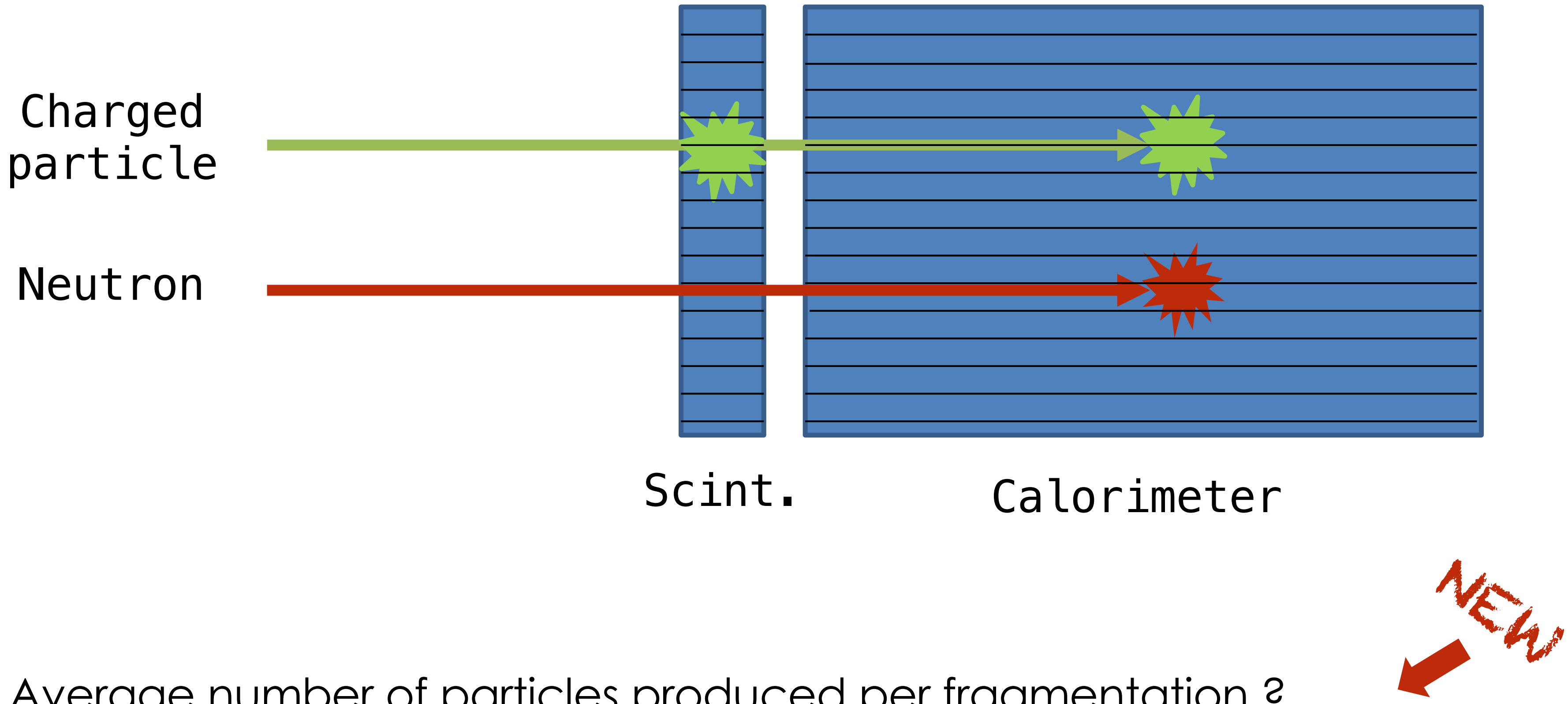
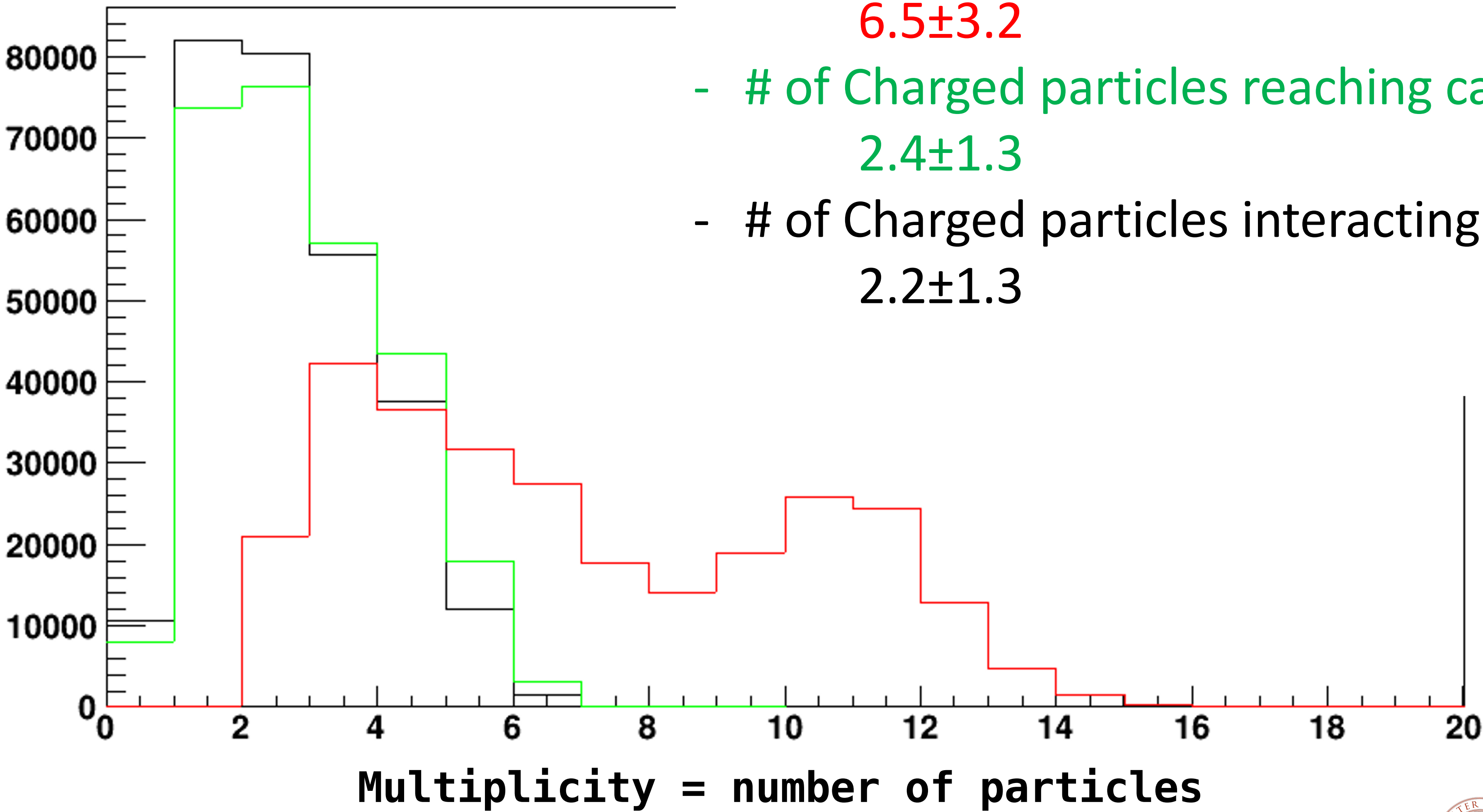


Average number of particles produced per fragmentation ?

Granularity of scintillator and calorimenter high enough ?

Detecting neutrons with existing setup

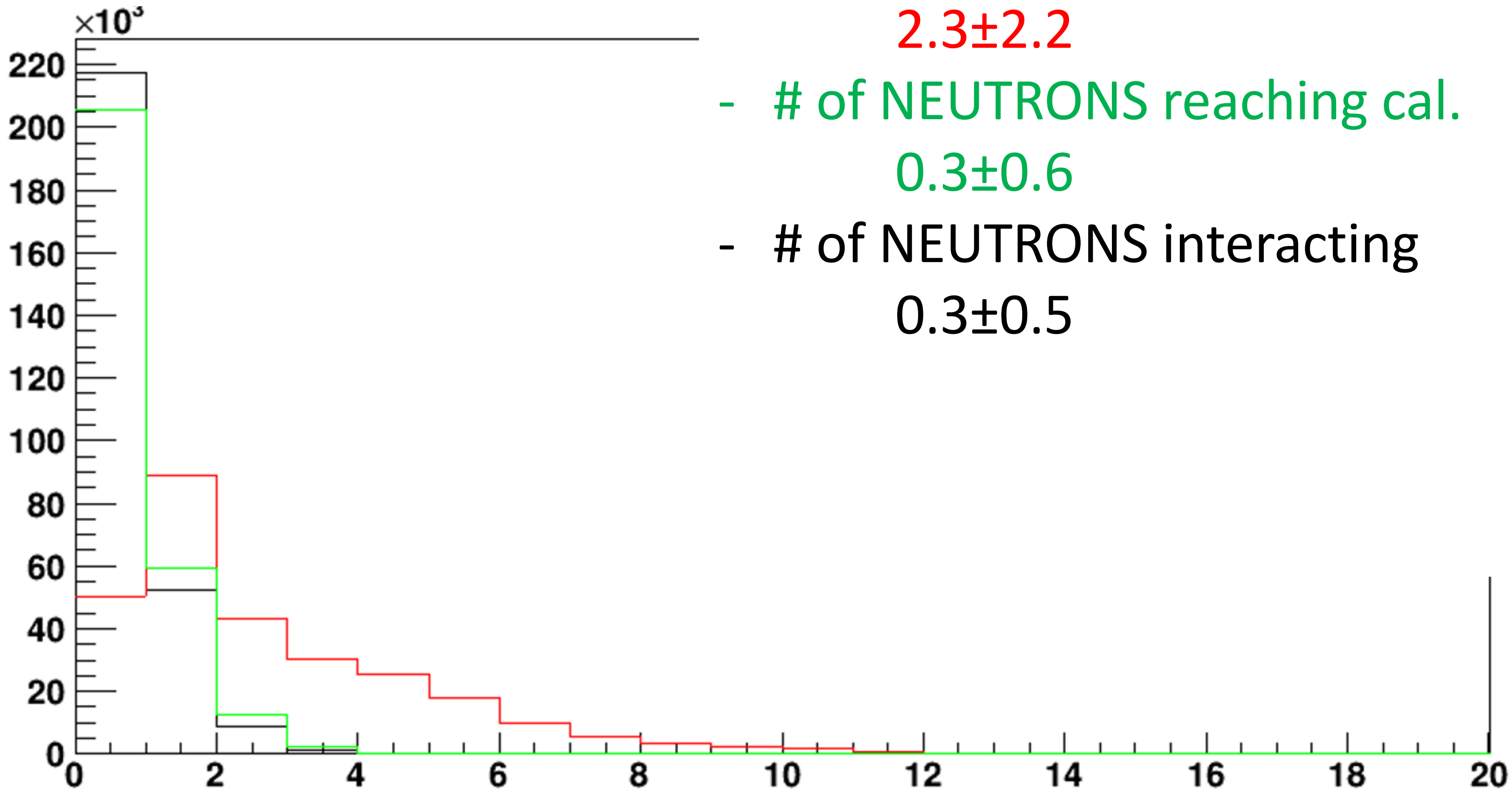
NEW



- \# of Charged particles from target
  6.5±3.2
- \# of Charged particles reaching cal.
  2.4±1.3
- \# of Charged particles interacting
  2.2±1.3

Detecting neutrons with existing setup

NEW

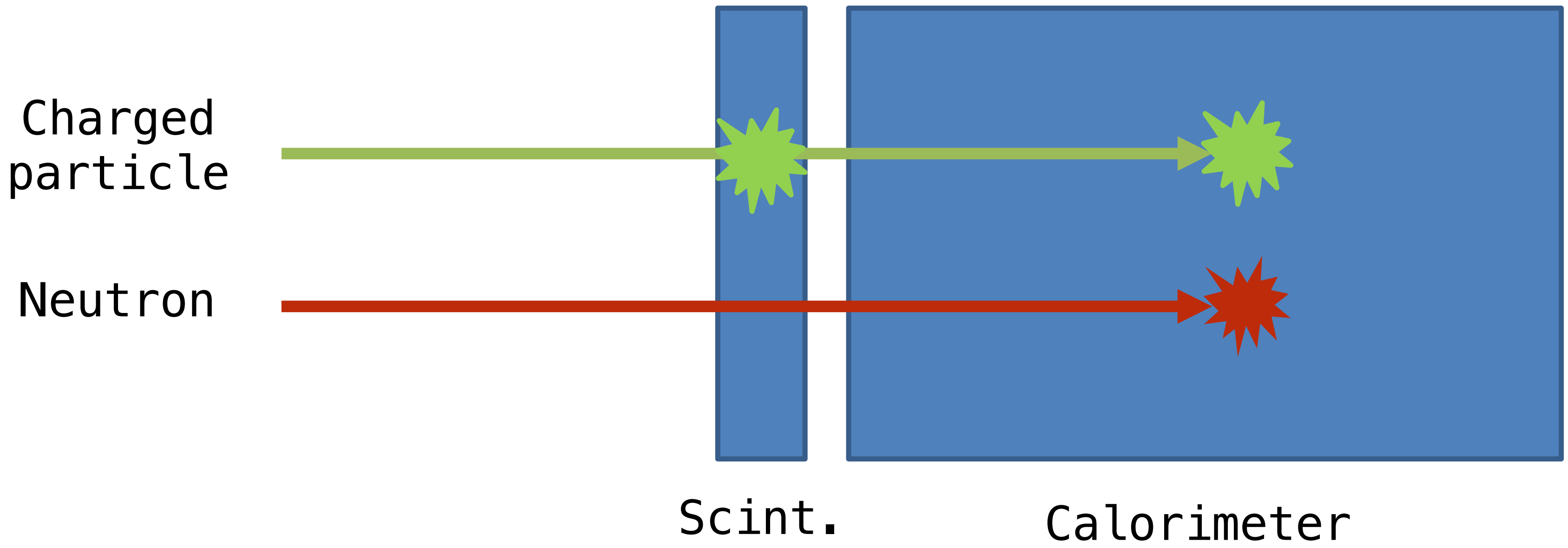


Multiplicity = number of particles

- # of NEUTRONS from target
  2.3±2.2
- # of NEUTRONS reaching cal.
  0.3±0.6
- # of NEUTRONS interacting
  0.3±0.5

Detecting neutrons with existing setup SUMMARY

Basic idea: **anticoincidence scintillator – calorimenter**



Advantages

1. Simple technique
2. Exploits current setup

Limitations

1. Efficiency of the veto
2. n/γ discrimination
3. Tagging neutrons from calorimeter

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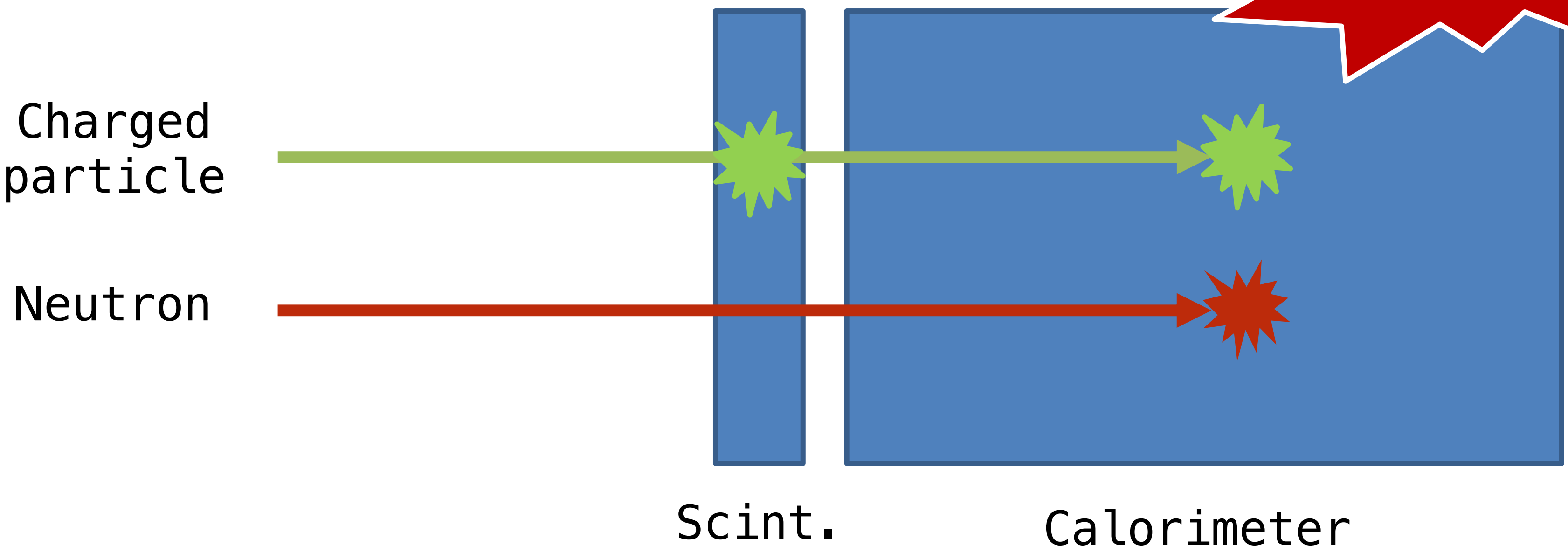
Detecting neutrons with existing setup

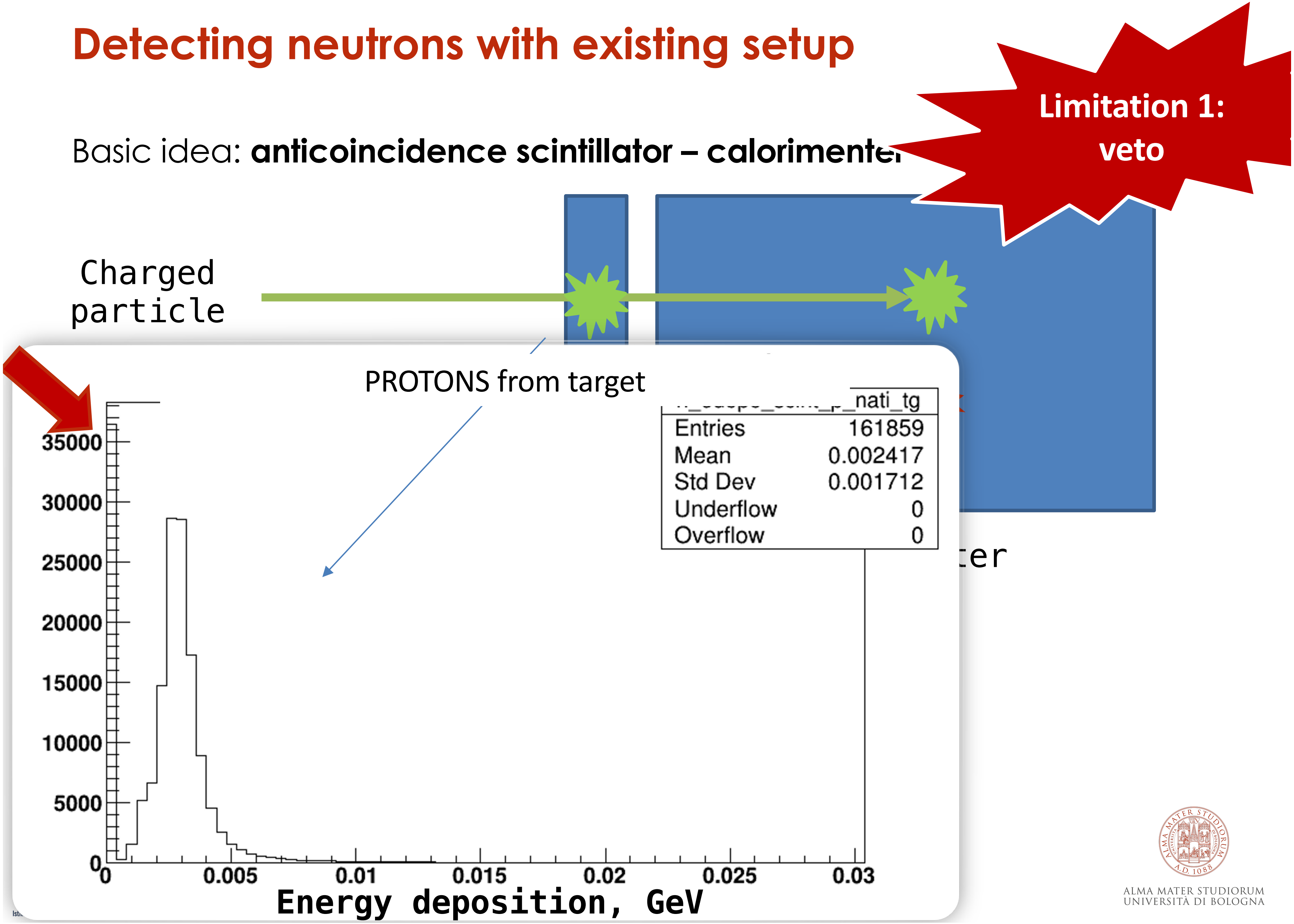
Limitation 1: veto

Basic idea: **anticoincidence scintillator – calorimenter**



Detecting neutrons with existing setup

Basic idea: **anticoincidence scintillator – calorimenter**



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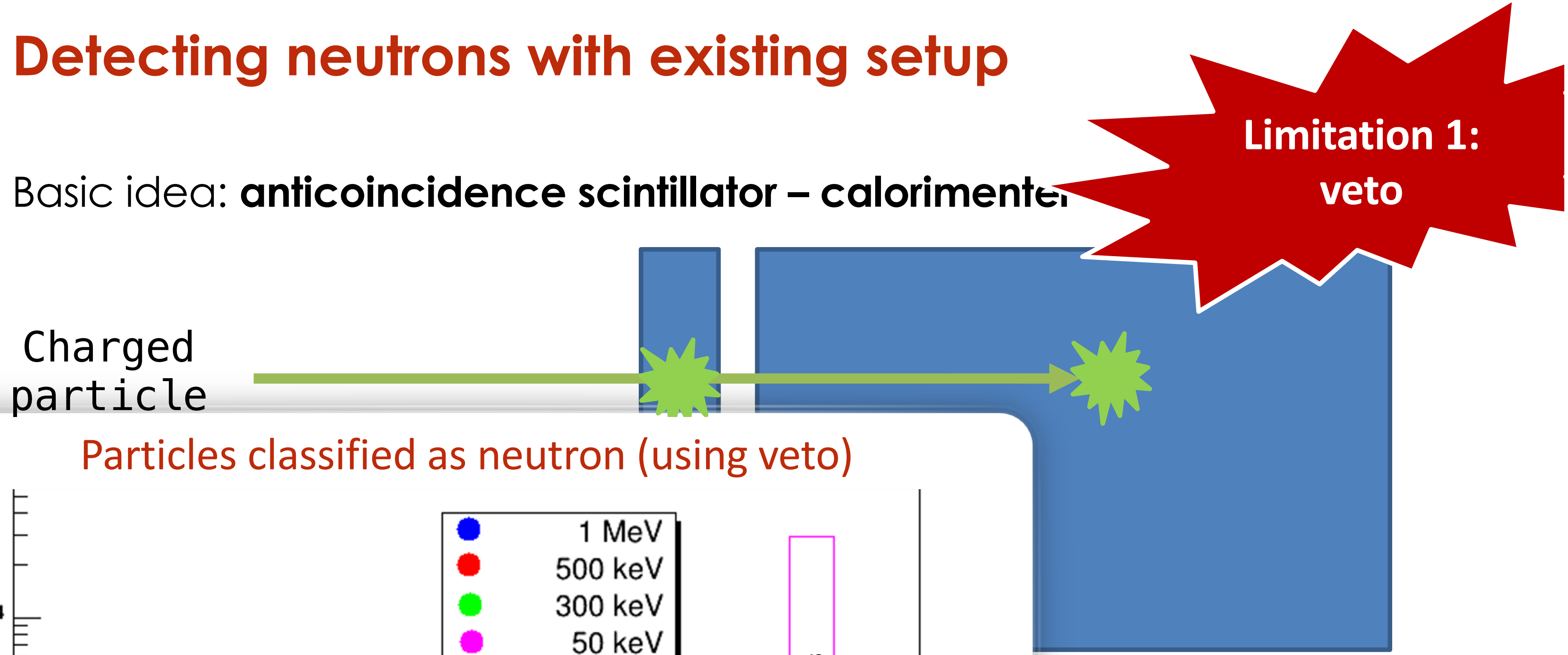
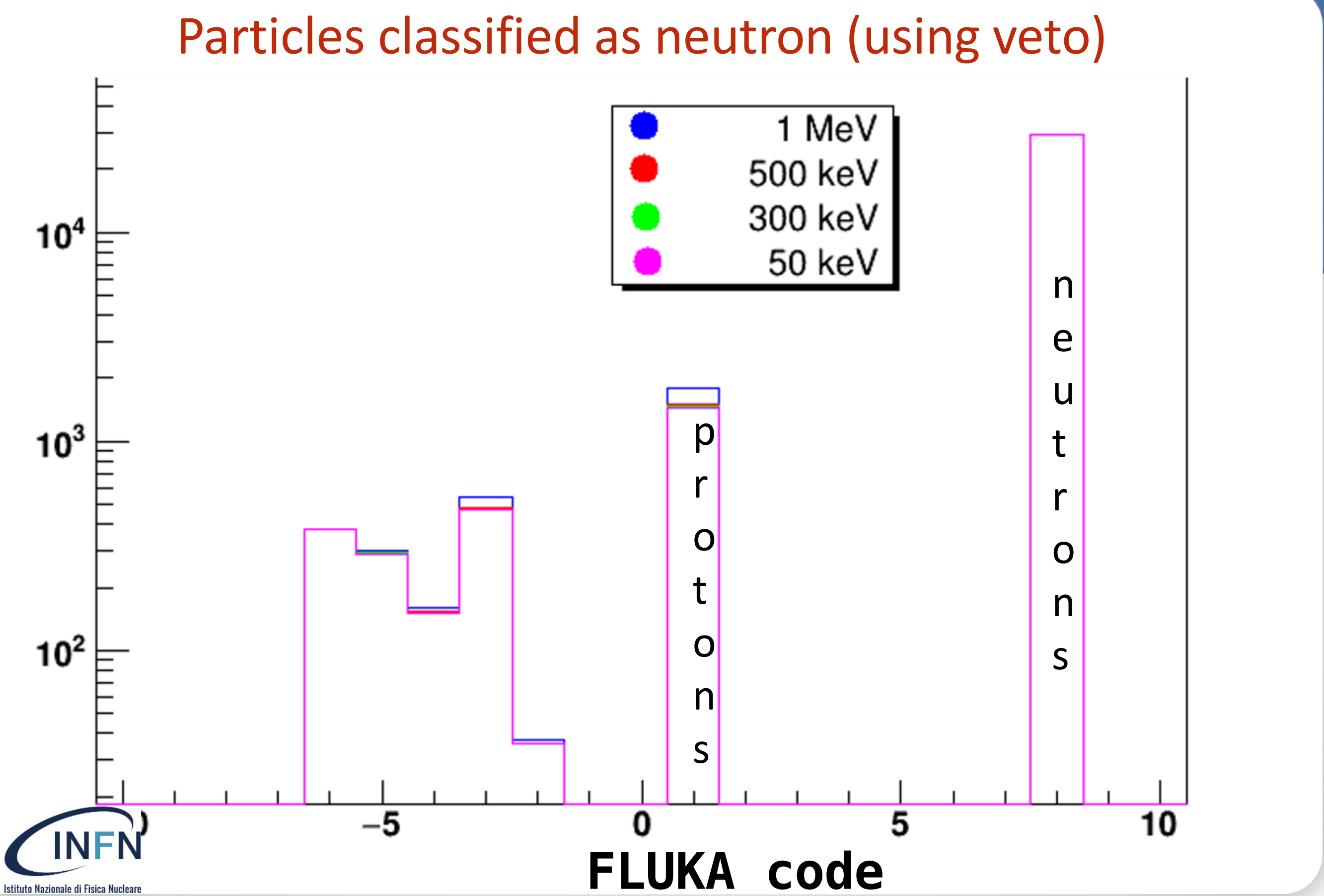
Detecting neutrons with existing setup

Basic idea: **anticoincidence scintillator – calorimenter**





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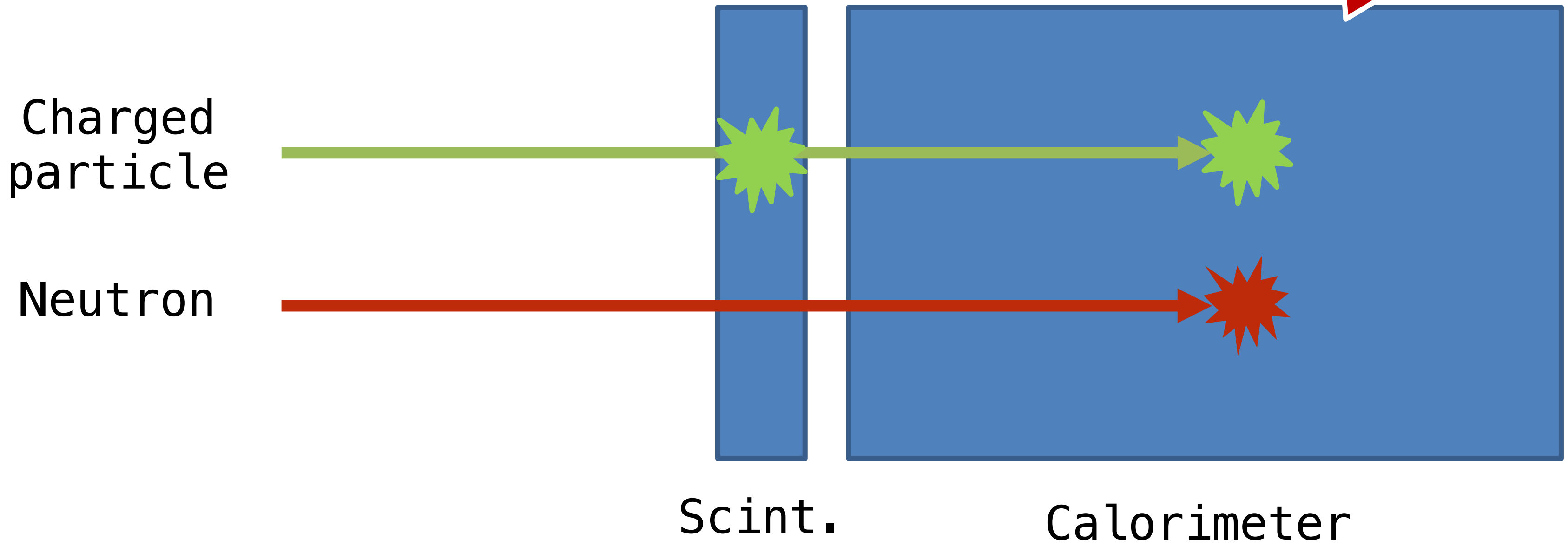
Detecting neutrons with existing setup

Limitation 2: n/γ

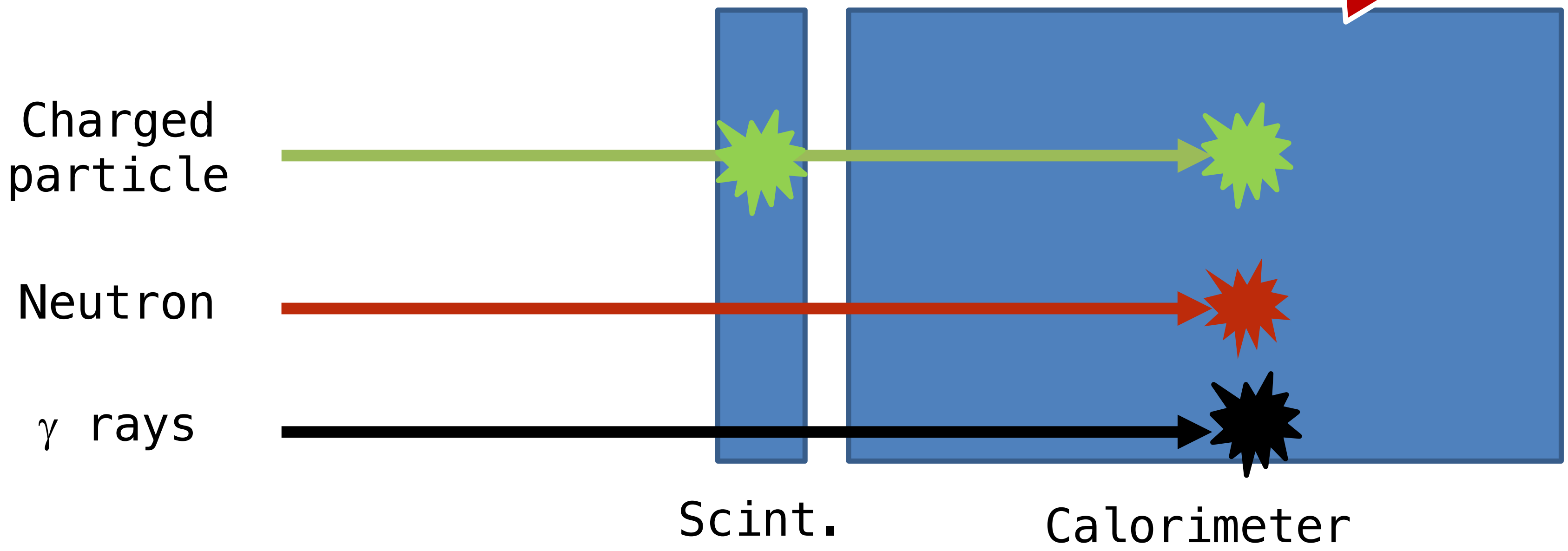
Basic idea: **anticoincidence scintillator – calorimenter**



Detecting neutrons with existing setup

Limitation 2: n/γ

Basic idea: **anticoincidence scintillator – calorimenter**

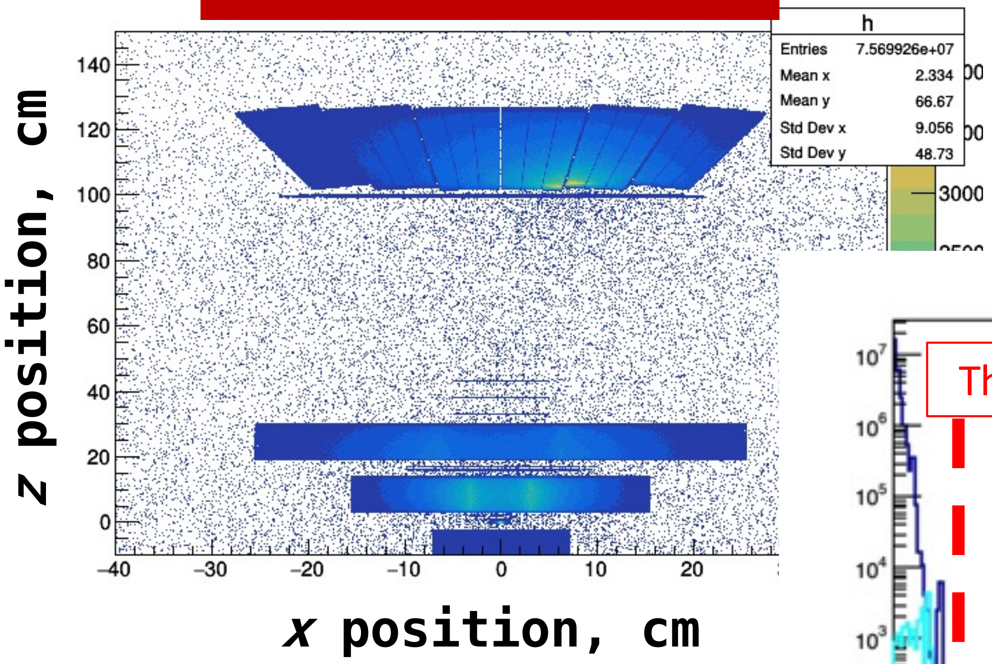


γ rays can feature the same signature

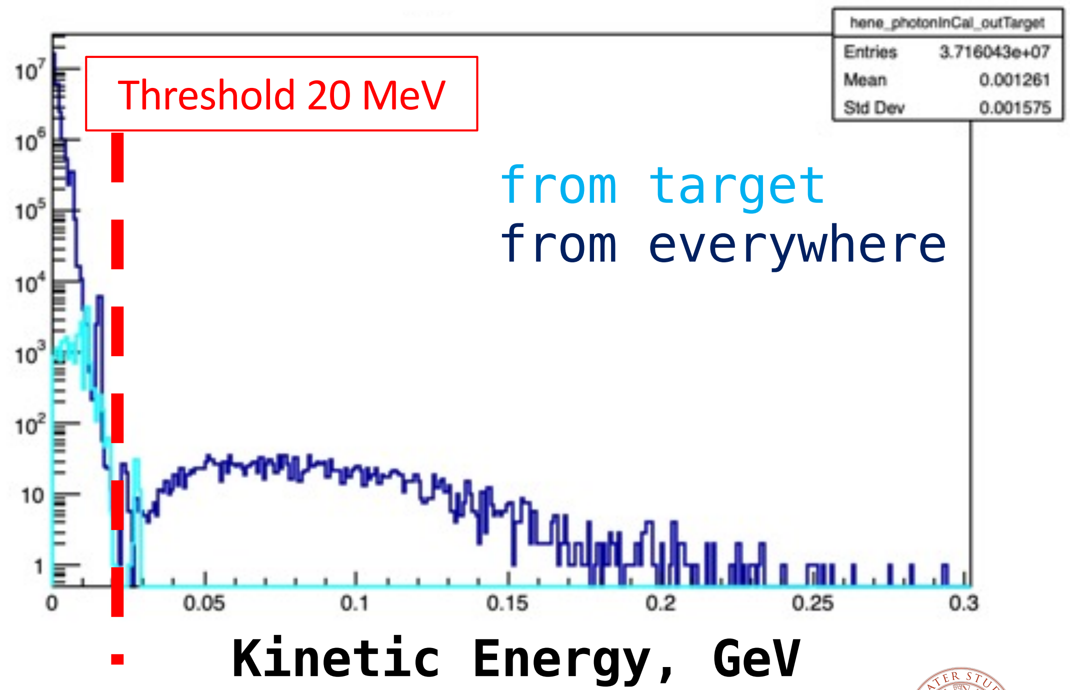
Detecting neutrons with existing setup

Limitation 2: n/γ

75.7×10^{6} γ rays
23.3×10^{6} neutrons



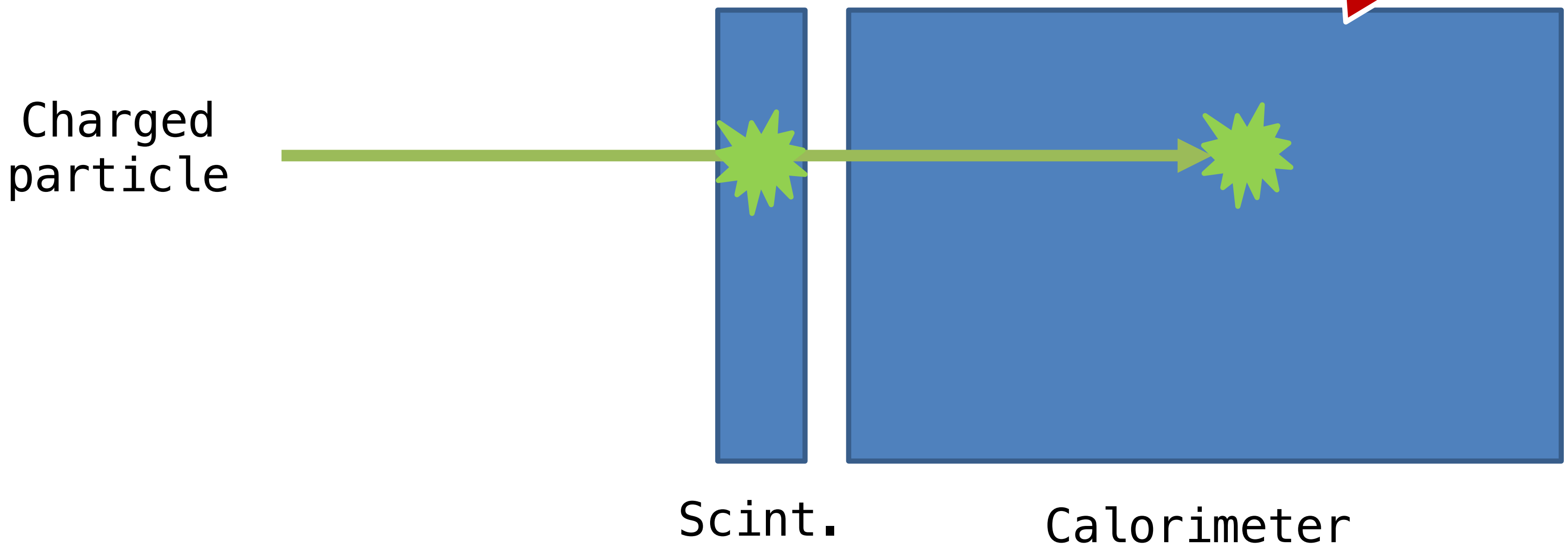
A discrimination level of **20 MeV** makes this **background negligible**



Detecting neutrons with existing setup

Limitation 3: cal. neutrons

Basic idea: **anticoincidence scintillator – calorimenter**



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Detecting neutrons with existing setup

Limitation 3: cal. neutrons

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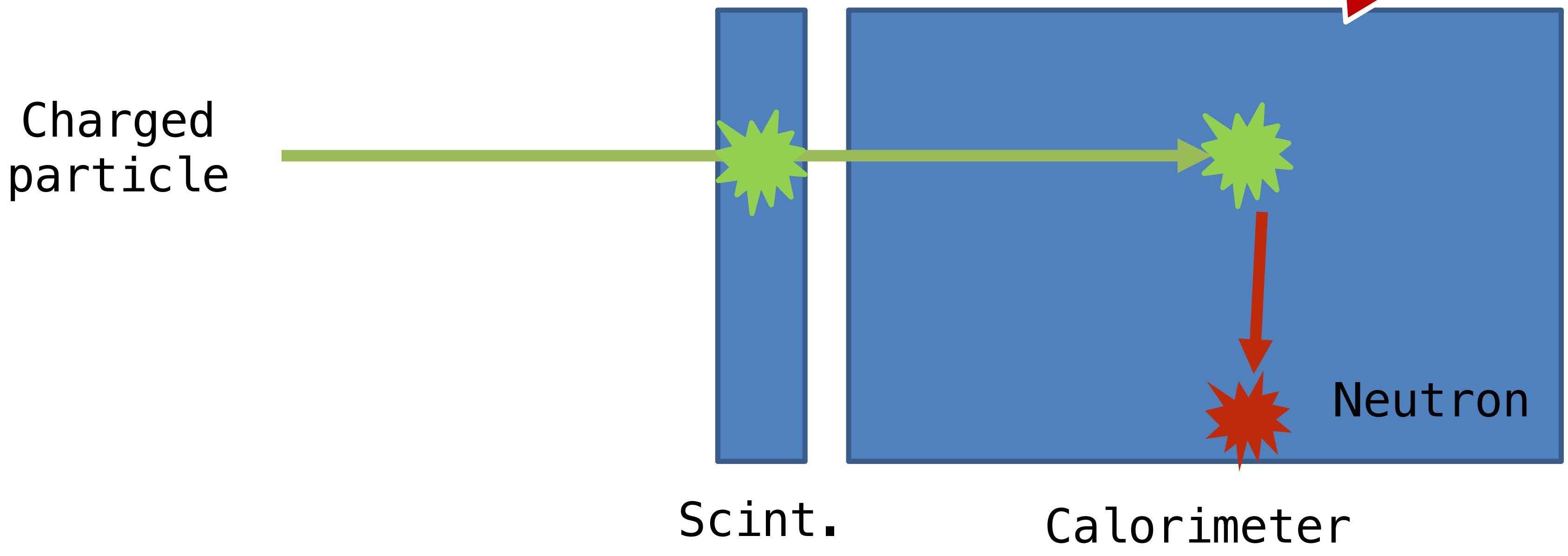
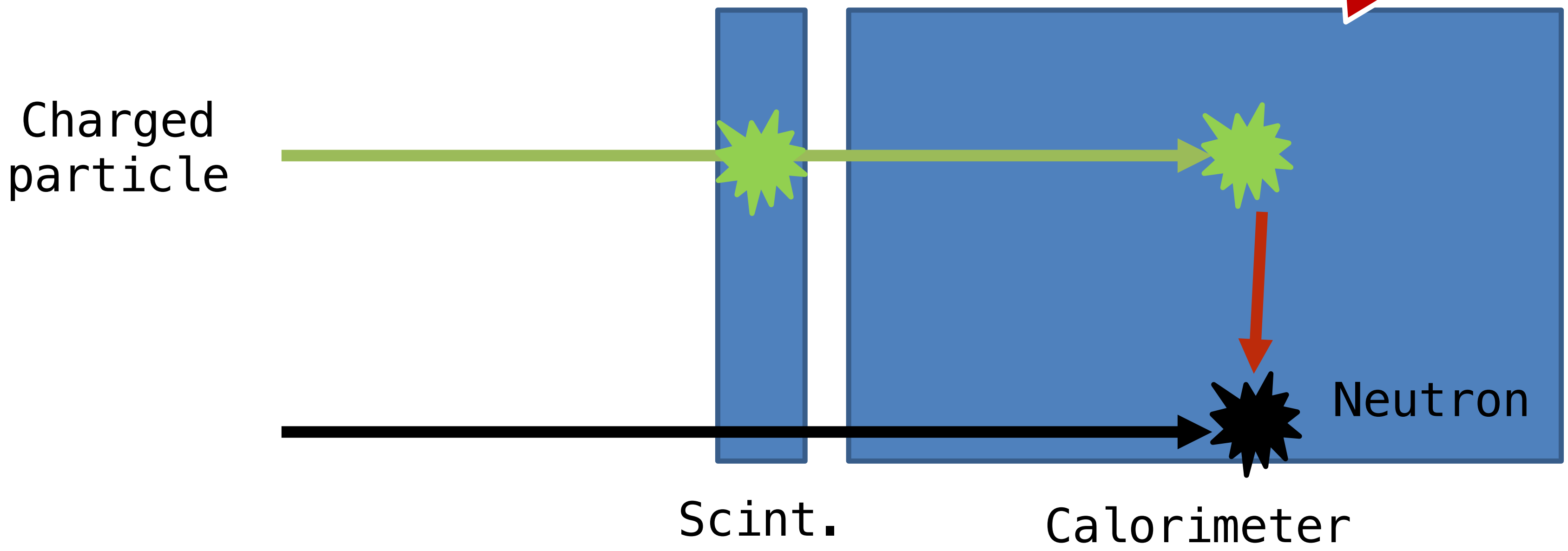


Neutrons produced in the calorimeter cannot be easily tagged

Detecting neutrons with existing setup

Limitation 3: cal. neutrons

Basic idea: **anticoincidence scintillator – calorimenter**



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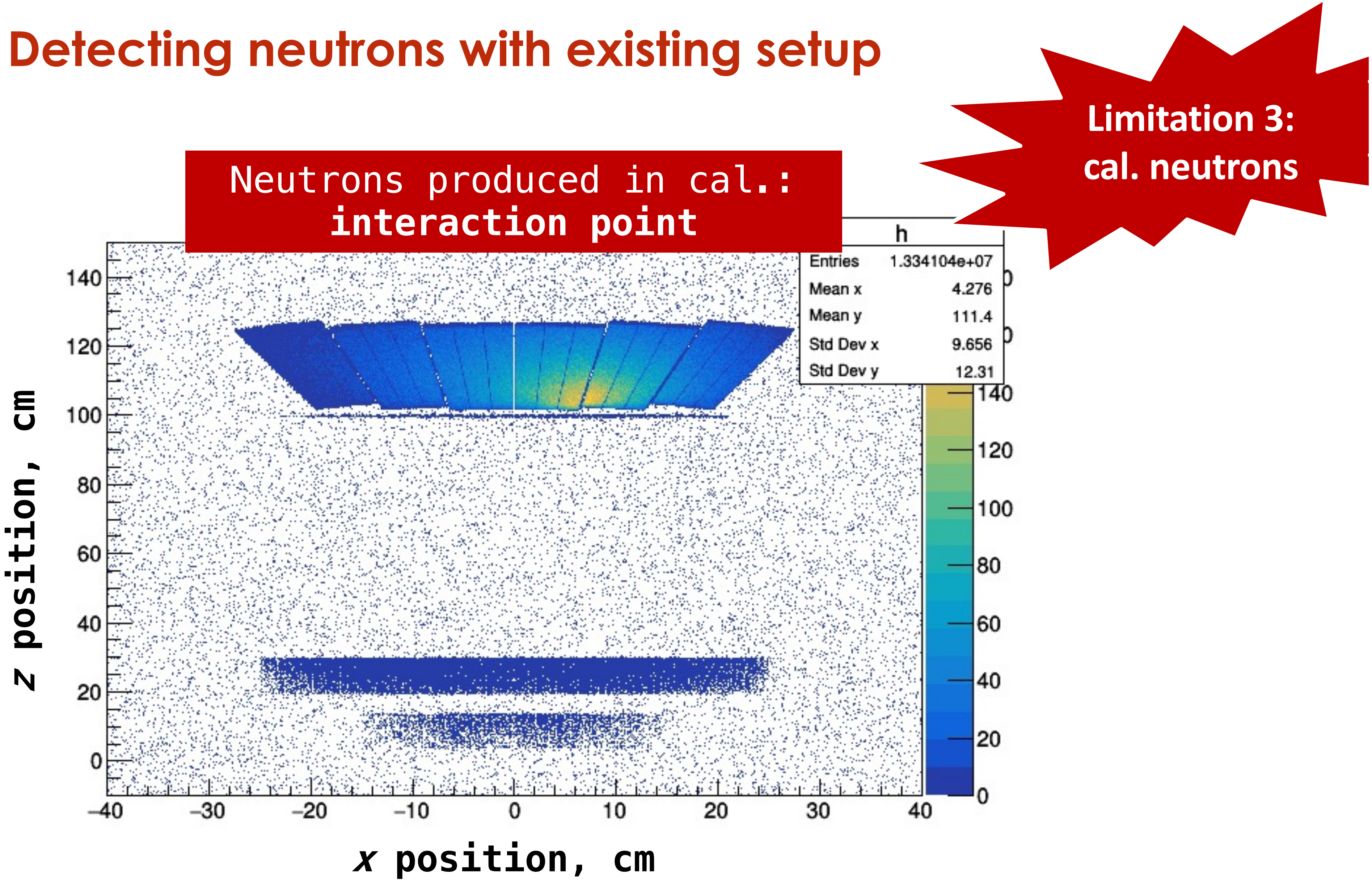
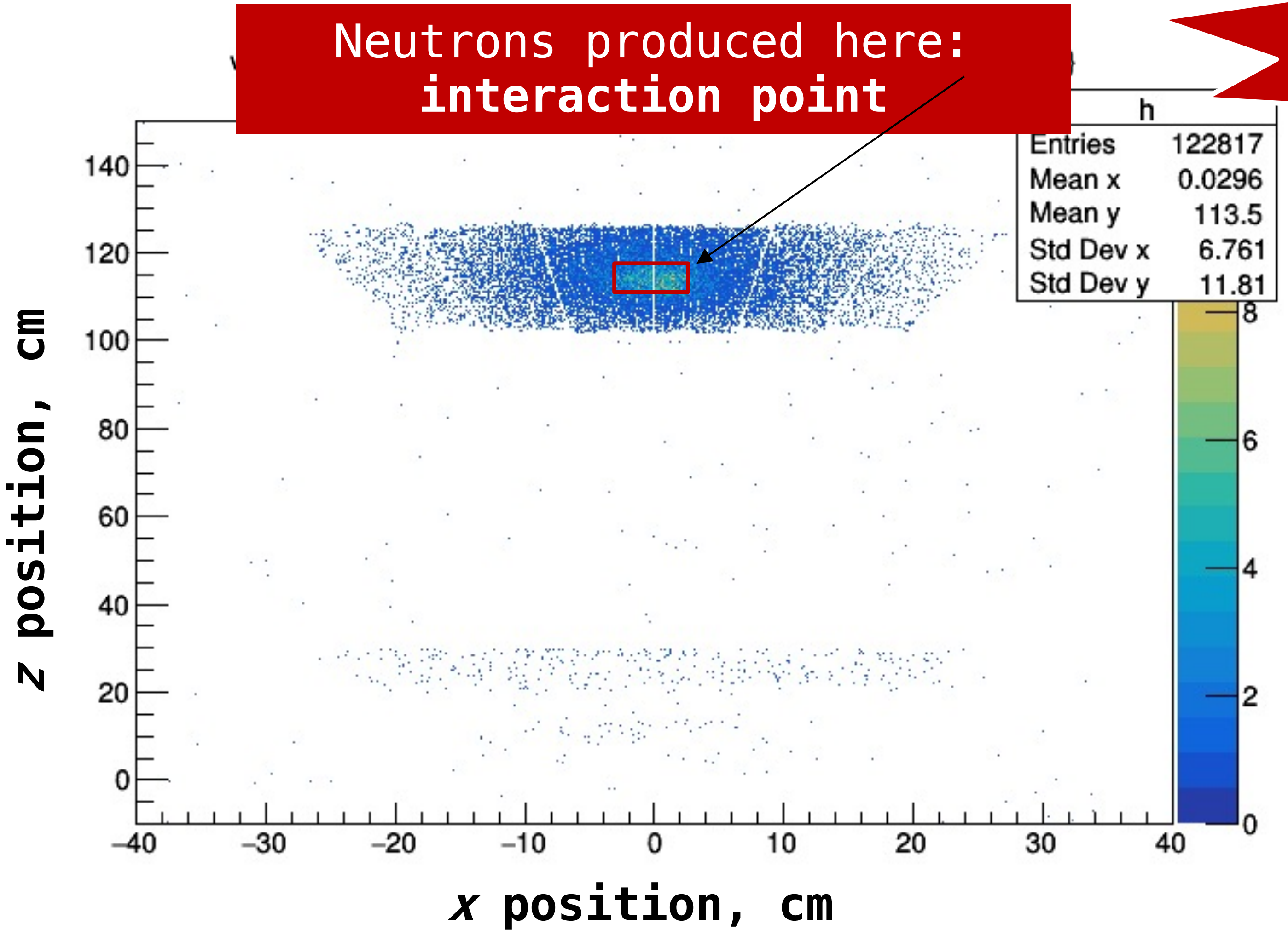
Detecting neutrons with existing setup



Detecting neutrons with existing setup



Limitation 3:
cal. neutrons

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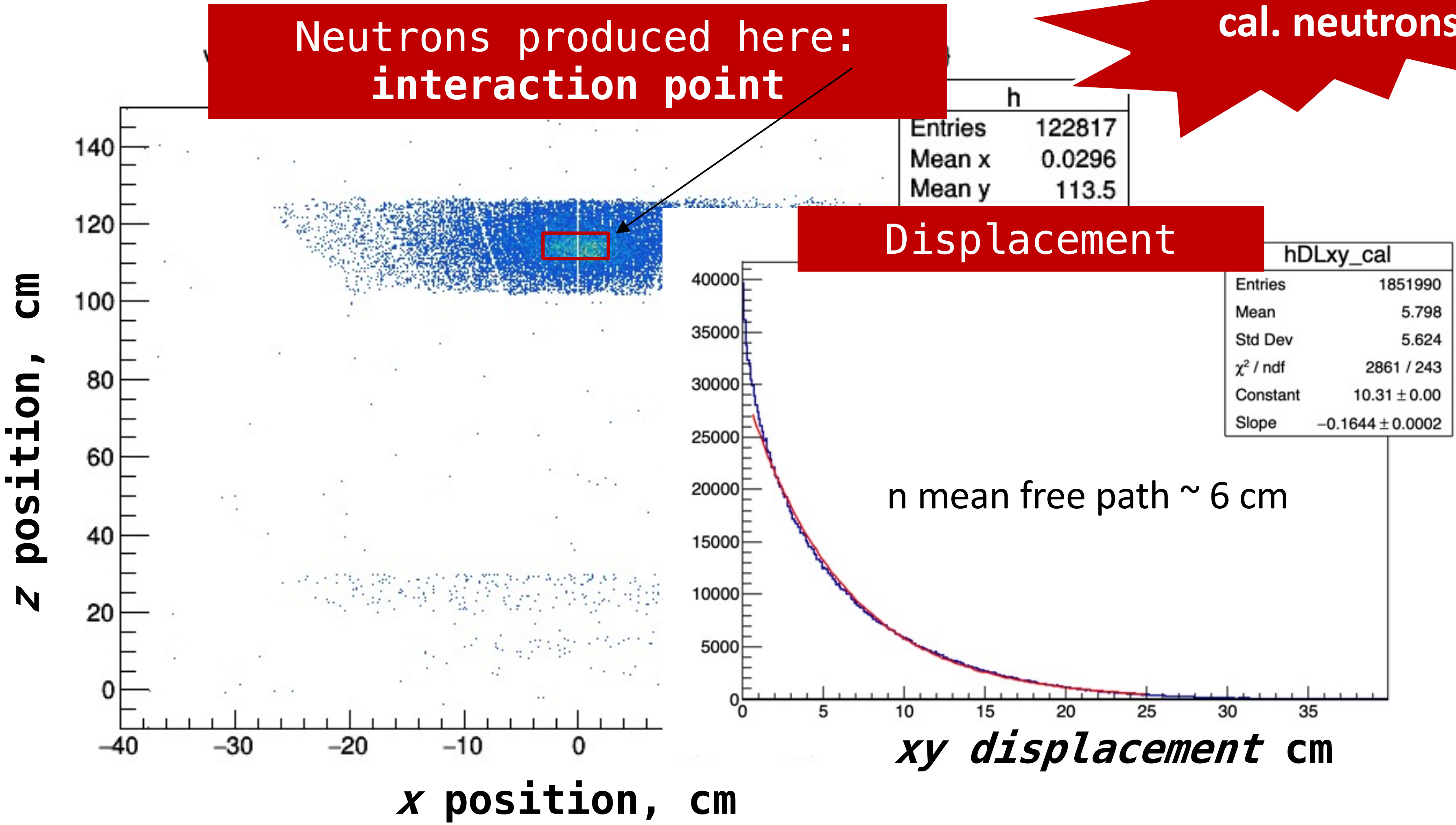
Detecting neutrons with existing setup

Limitation 3: cal. neutrons



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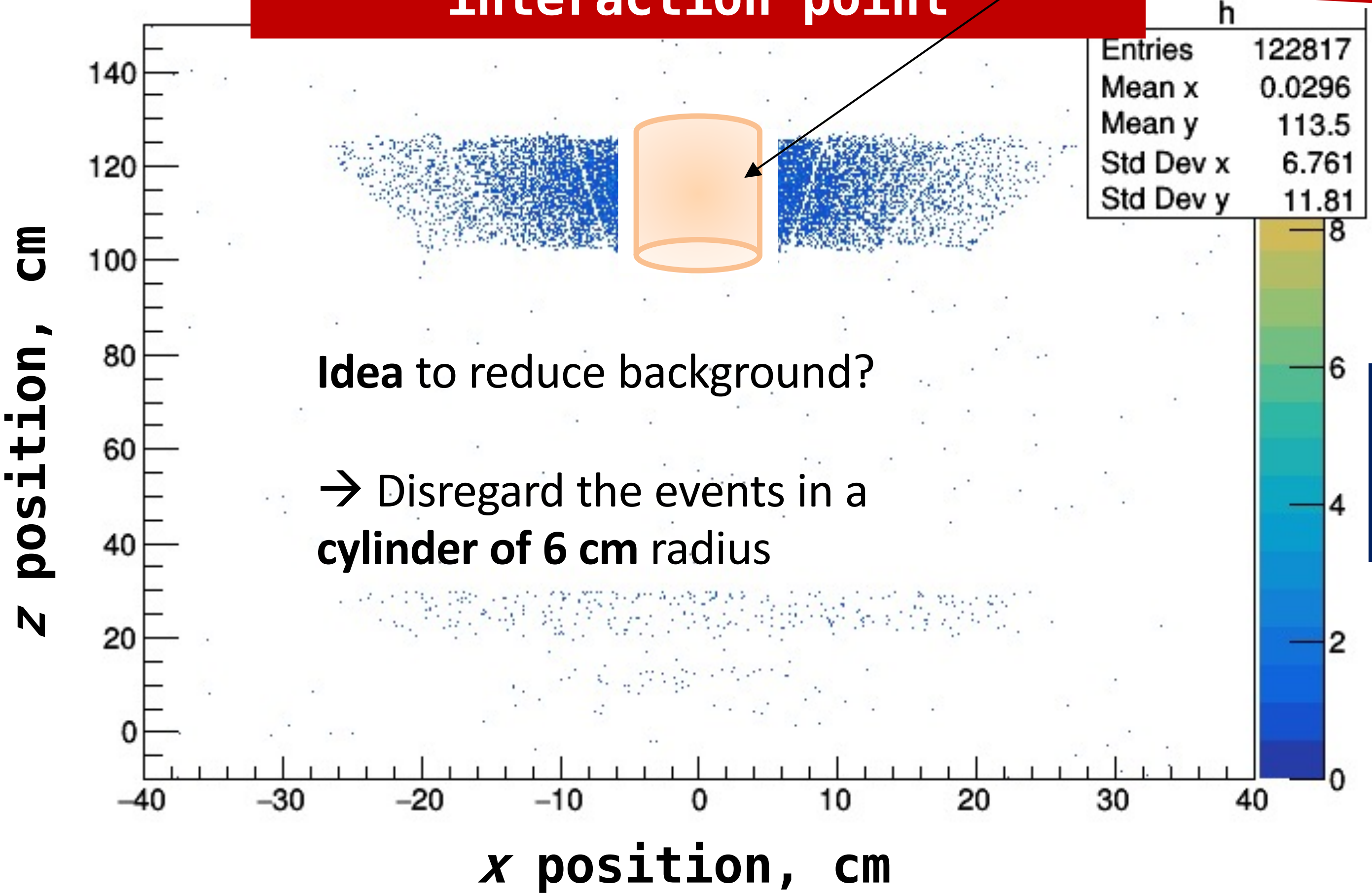
Detecting neutrons with existing setup

Limitation 3:
cal. neutrons



Idea to reduce background?

→ Disregard the events in a **cylinder of 6 cm** radius

Neutron kinetic energy is much larger in the cylinder

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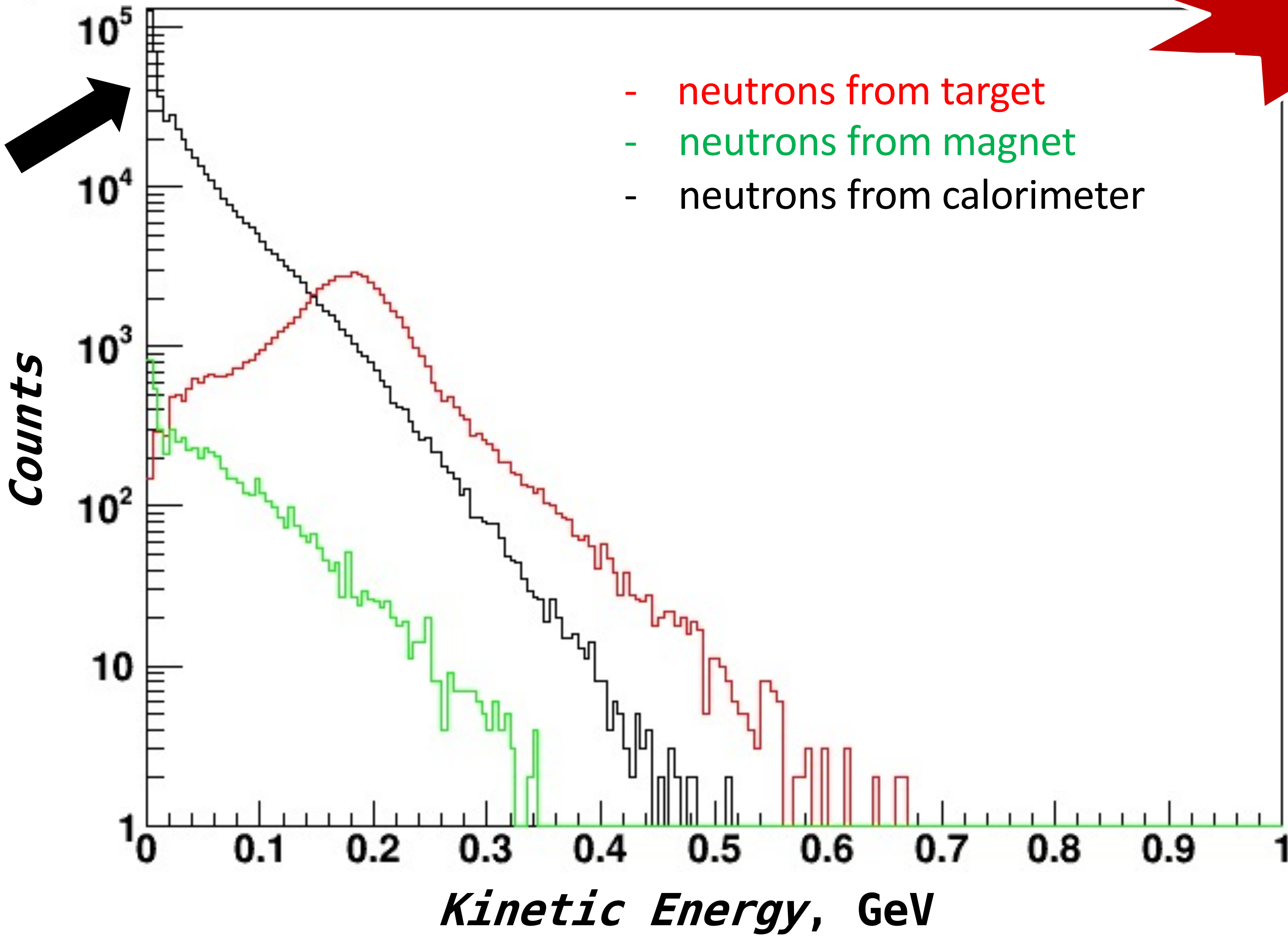
Detecting neutrons with existing setup

Limitation 3: cal. neutrons

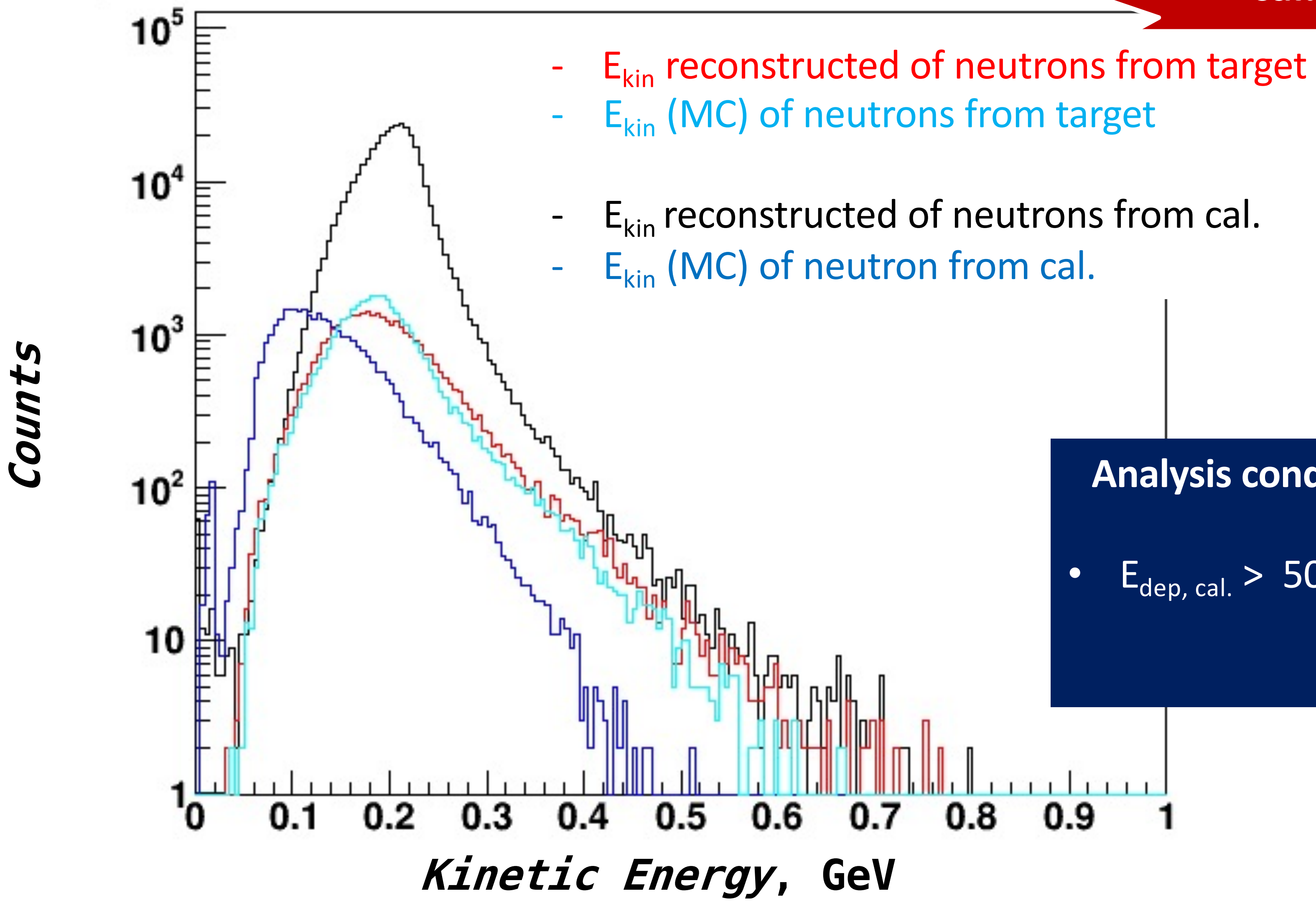
TRUE Monte Carlo



Detecting neutrons with existing setup

Limitation 3: cal. neutrons

TRUE Monte Carlo Vs reconstructed



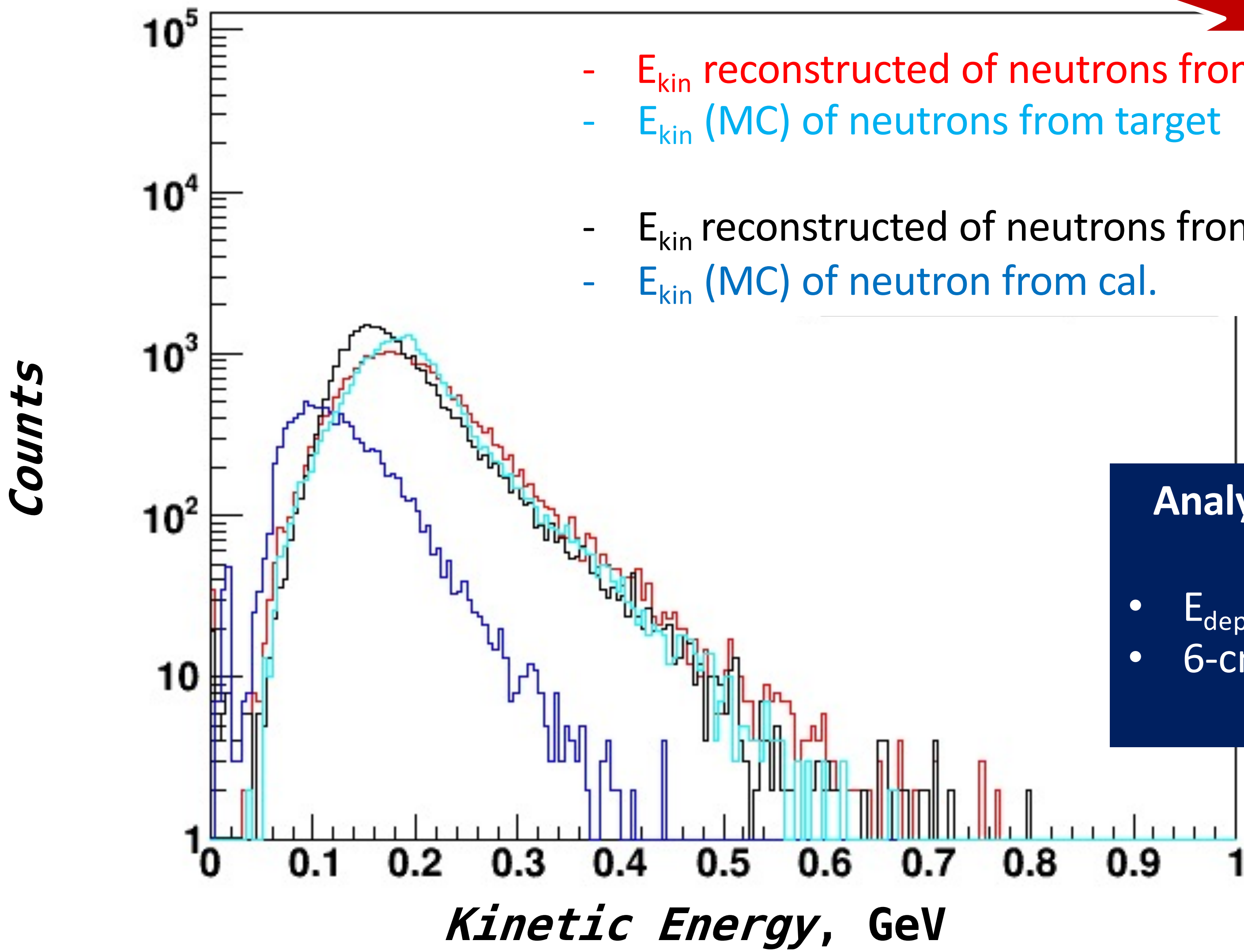
Analysis condition:

- $E_{dep,\ cal.} > 50$ MeV

Detecting neutrons with existing setup

Limitation 3: cal. neutrons

TRUE Monte Carlo Vs reconstructed



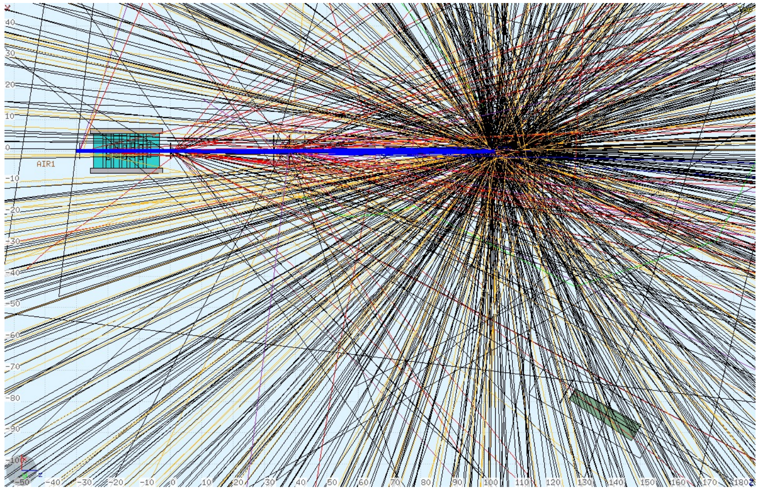
Analysis condition:

- $E_{dep,\ cal.} > 50$ MeV
- 6-cm cylinder

Conclusions 1/2

- The system consisting of **BGO + TOF wall** is being studied for its use as neutron detector. A few remarks:

  - ➢ The calorimeter acts as a **neutron source** when charged particles hit it;



  - ➢ **Simultaneous measurement** of charged particle and **neutron** seems **very challenging** (signal : backgrounds ~ 1 : 1) → need for more studies;

  - ✓ Most suited for **dedicated neutron measurements,** out of the beam.

  - ✓ **Veto** provided by TOF wall works ~ for **protons** (efficinecy 70-80%). Should be larger.

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Towards a test beam @ CNAO

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Towards a test beam @ CNAO

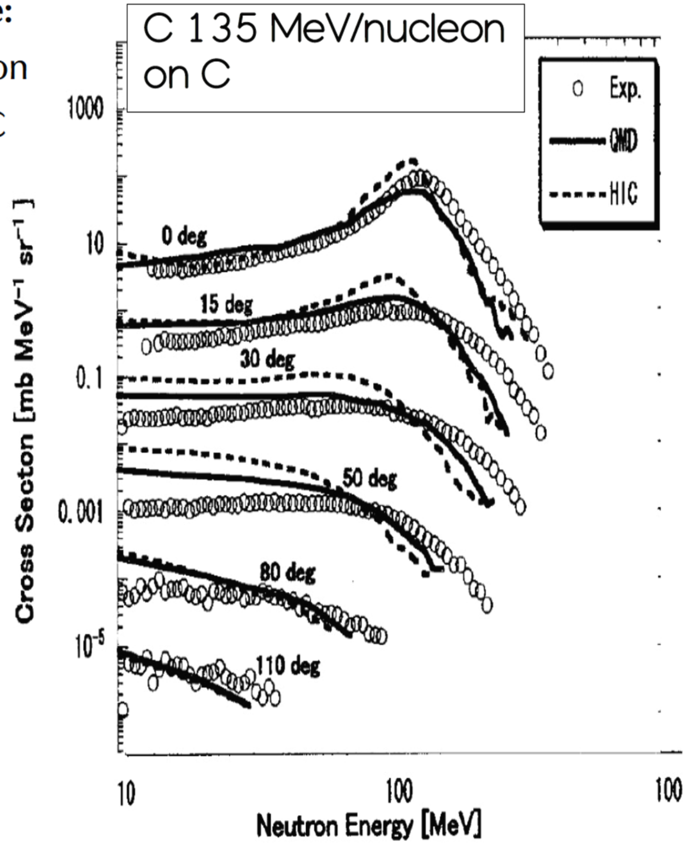
Compare to literature

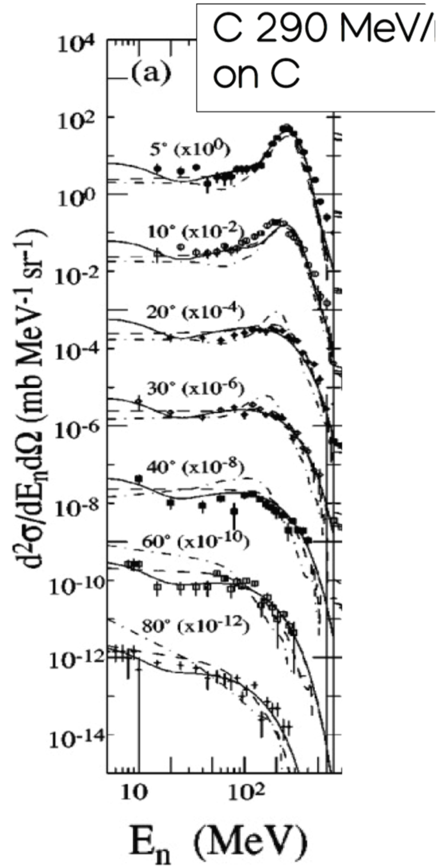
$^{12}C + {}^{12}C$ differential cross section

epeating experiments in the literature:
uble differential inclusive cross section
or the production of neutron in $^{12}C+{}^{12}C$
reactions

^{12}C @ 135 MeV/u
→ 0°, 15°, 30°, 50°, 80° 110°

^{12}C @ 290 MeV/u
→ 5°, 10°, 20°, 30°, 40°, 60°, 80°

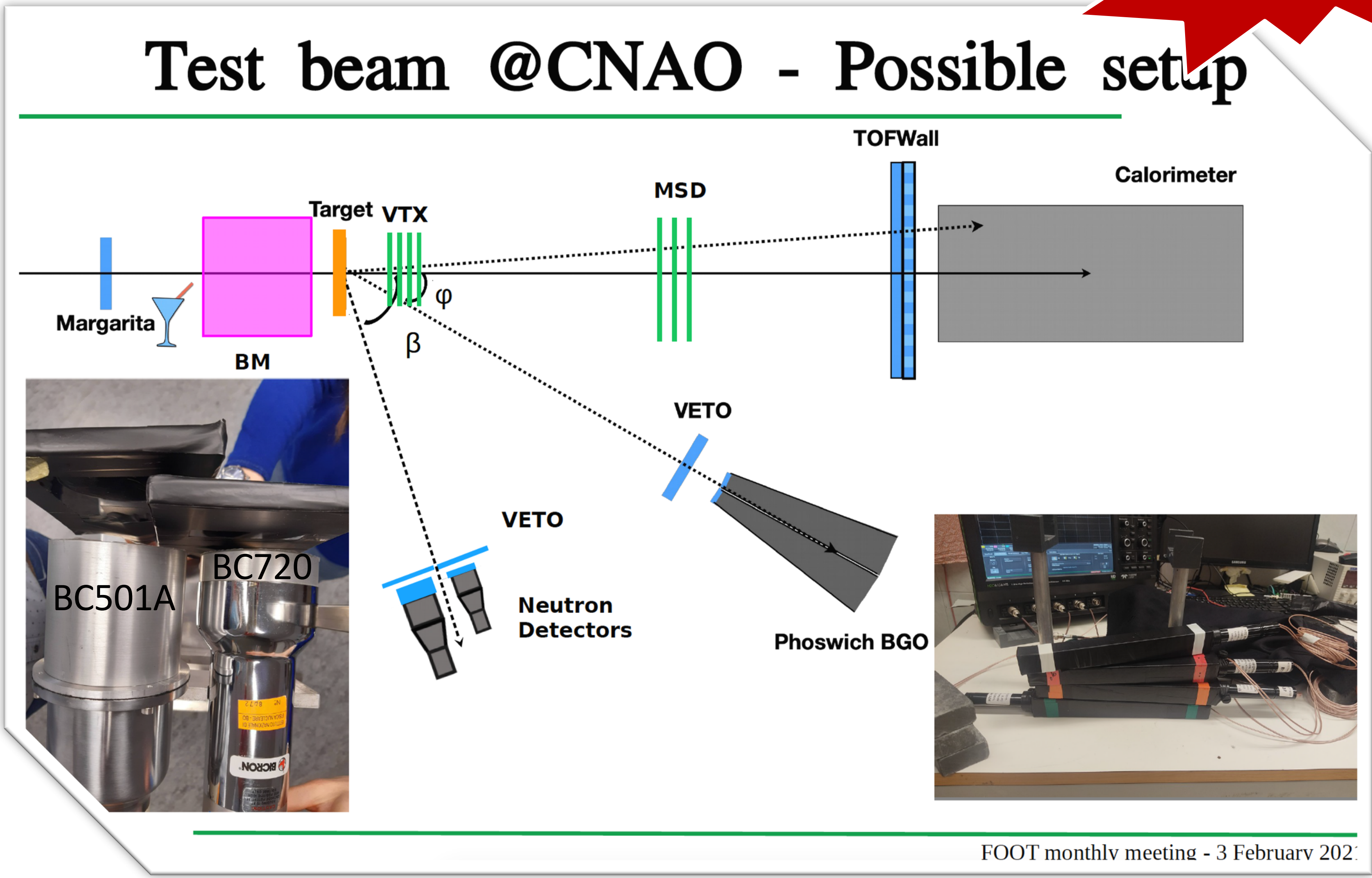




PHYSICAL REVIEW C 64 (2001) 034607 and 05460

Towards a test beam @ CNAO

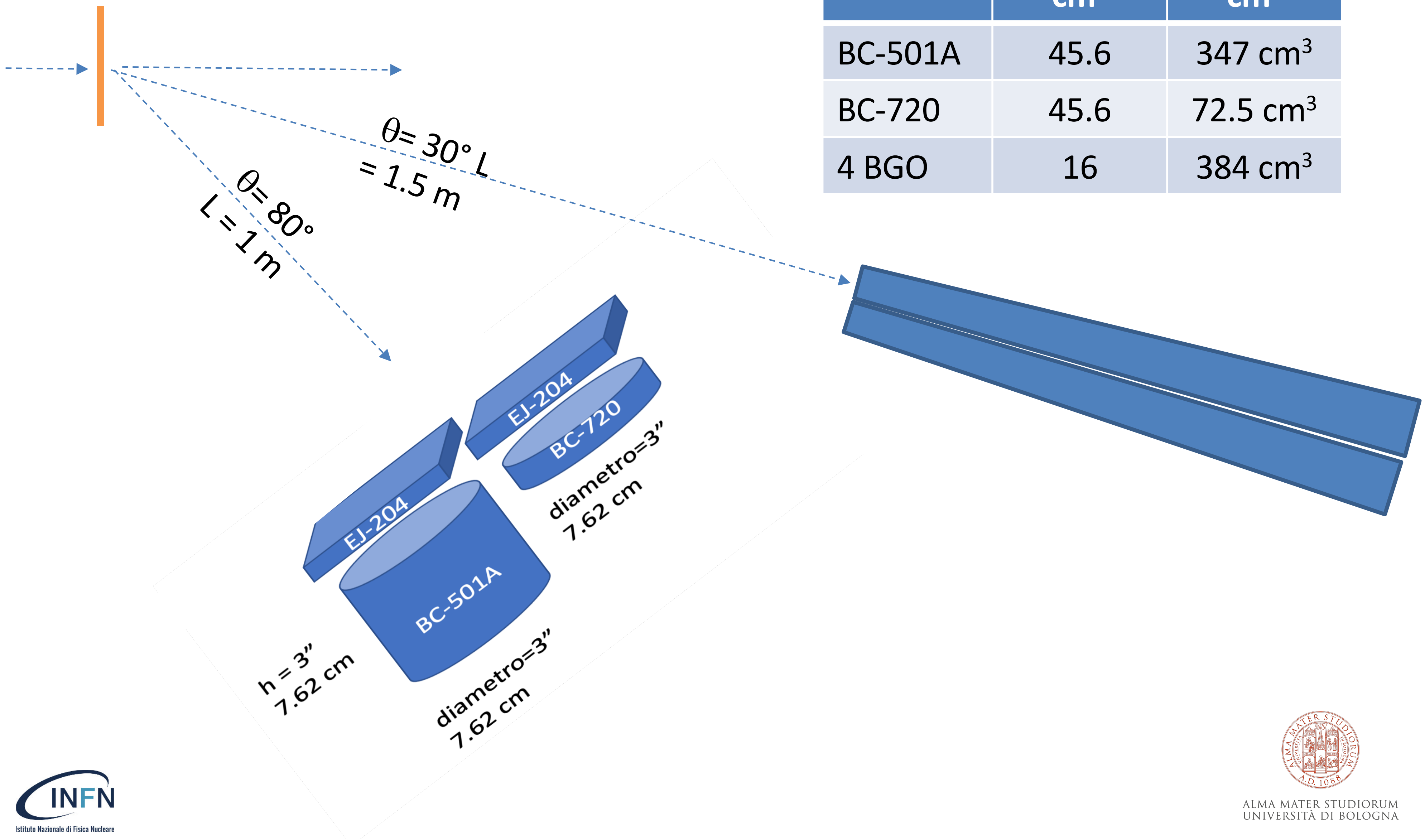
BC 501A
BC 720
4 BGO



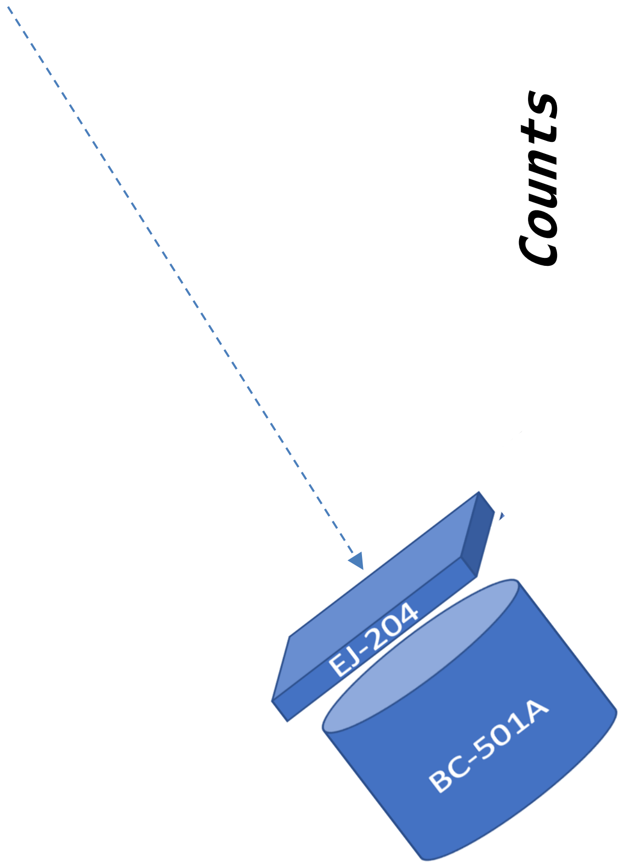
Towards a test beam @ CNAO

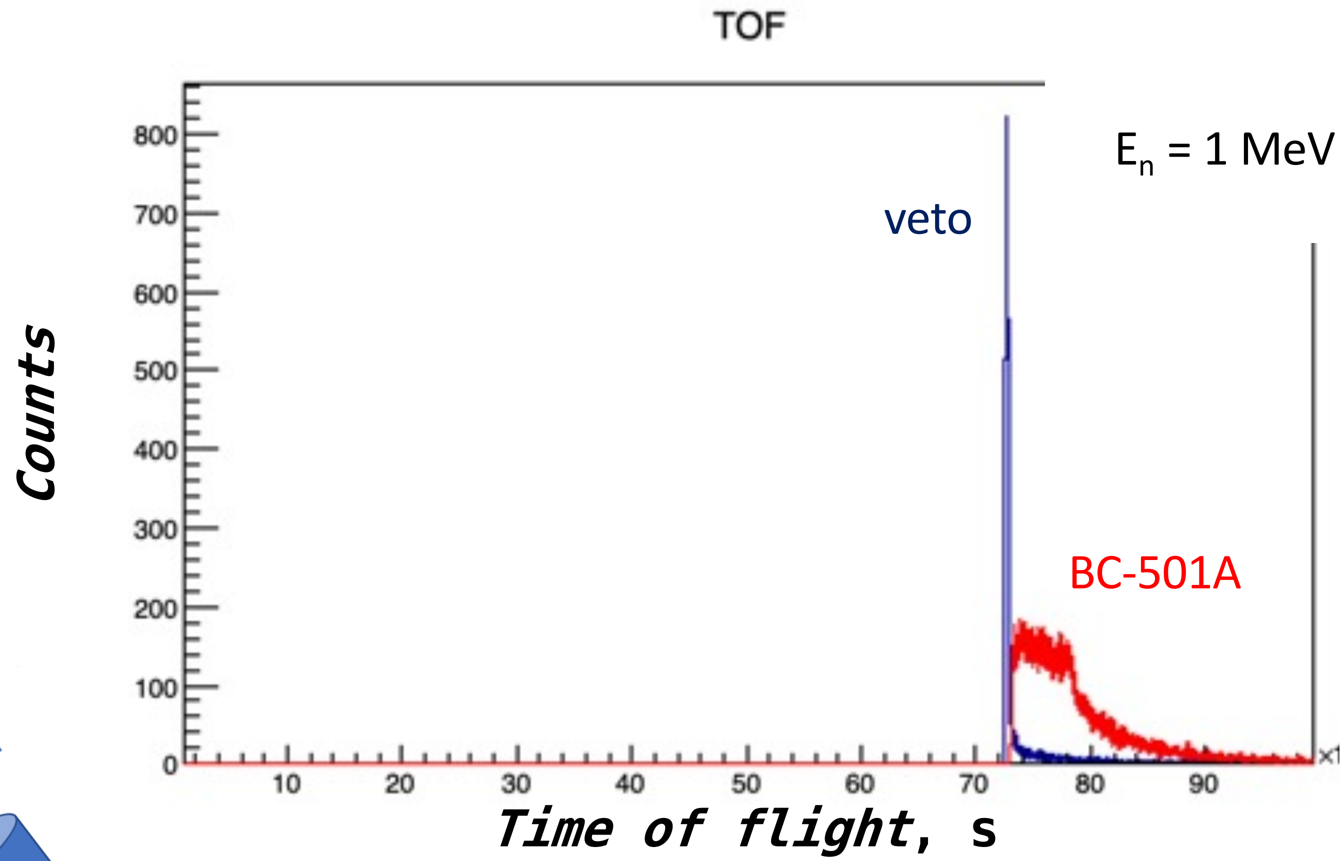
BC 501A
BC 720
4 BGO

Detector	Area cm^2	Volume cm^3
BC-501A	45.6	347 cm^3
BC-720	45.6	72.5 cm^3
4 BGO	16	384 cm^3



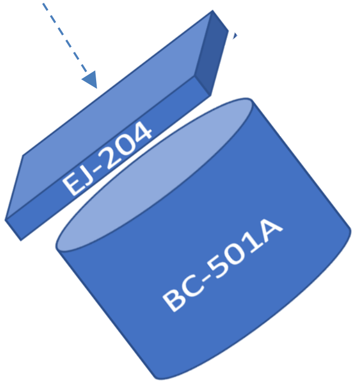
Towards a test beam @ CNAO

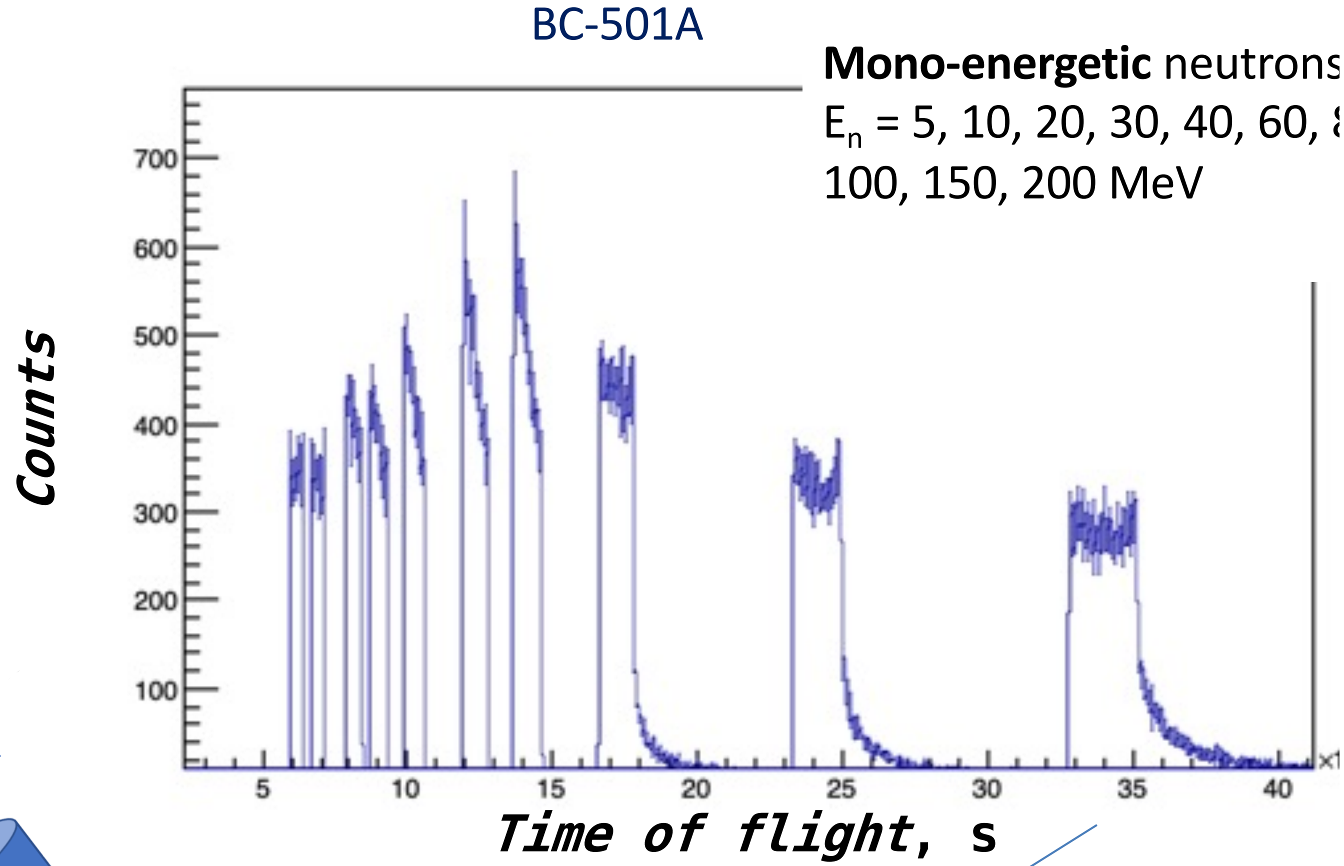




Towards a test beam @ CNAO

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

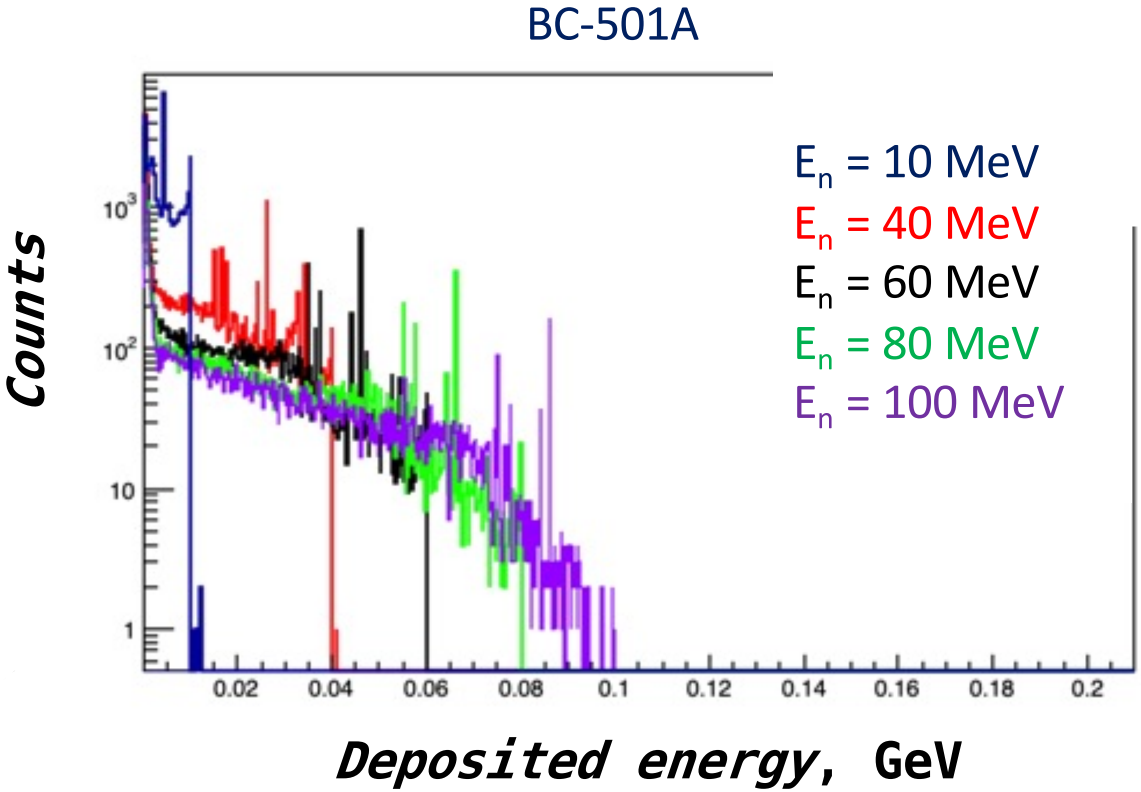


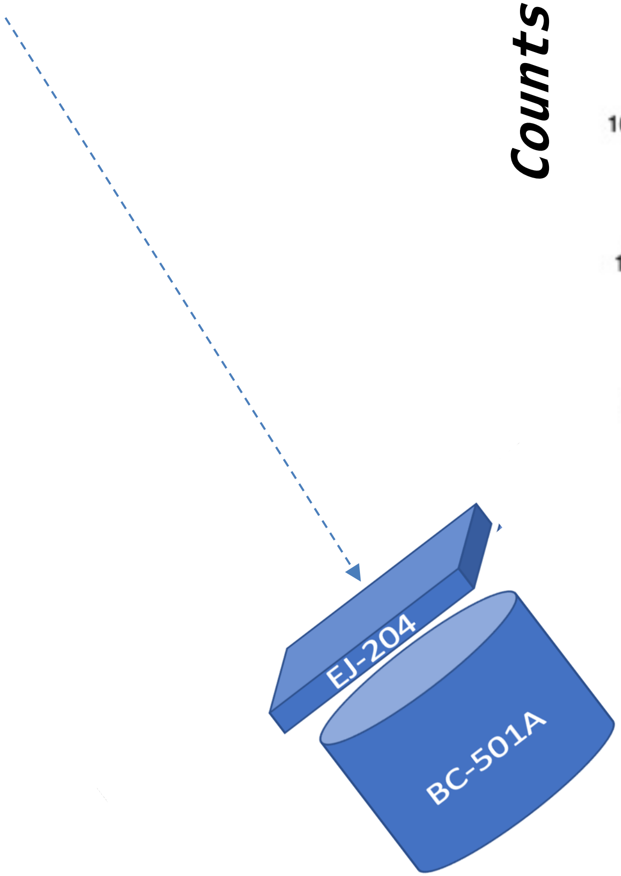


Mono-energetic neutrons
E_n = 5, 10, 20, 30, 40, 60, 8
100, 150, 200 MeV

$$\frac{\Delta E_n}{E_n} = (\gamma+1)\gamma\sqrt{\left(\frac{\Delta t}{t}\right)^2 + \left(\frac{\Delta L}{L}\right)^2}$$

Towards a test beam @ CNAO





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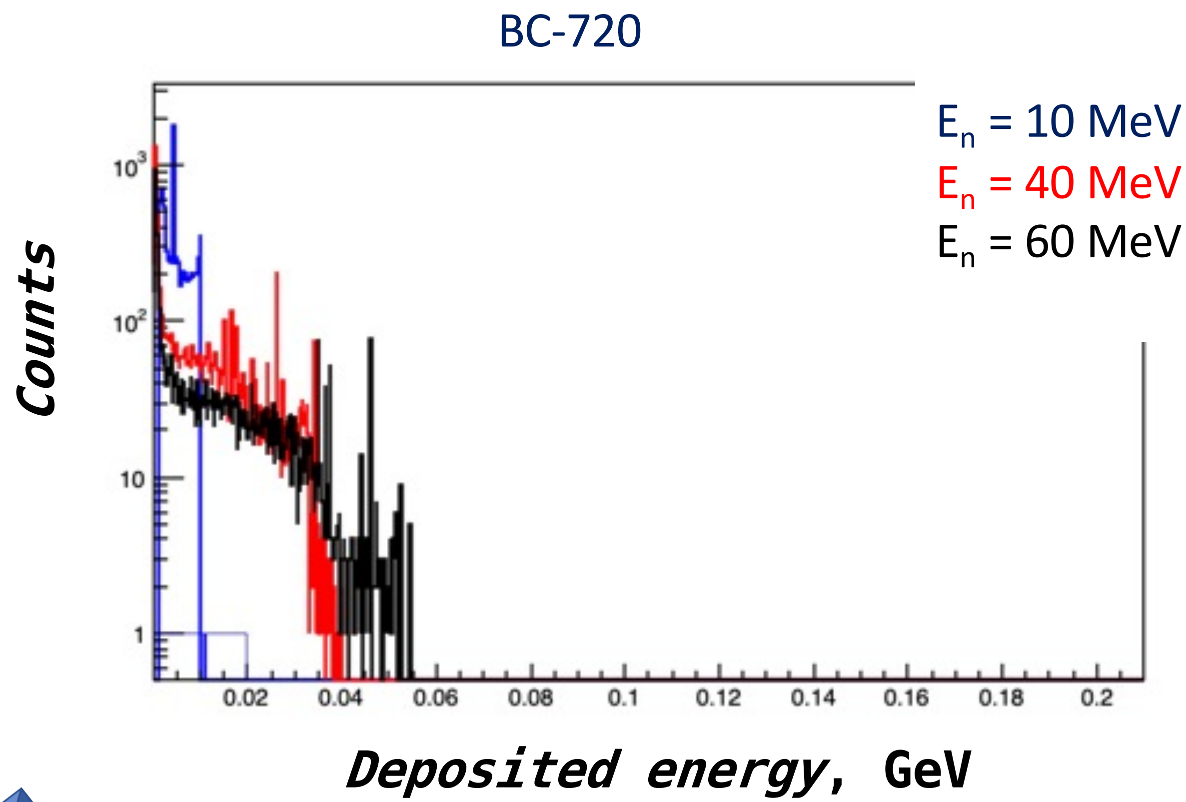

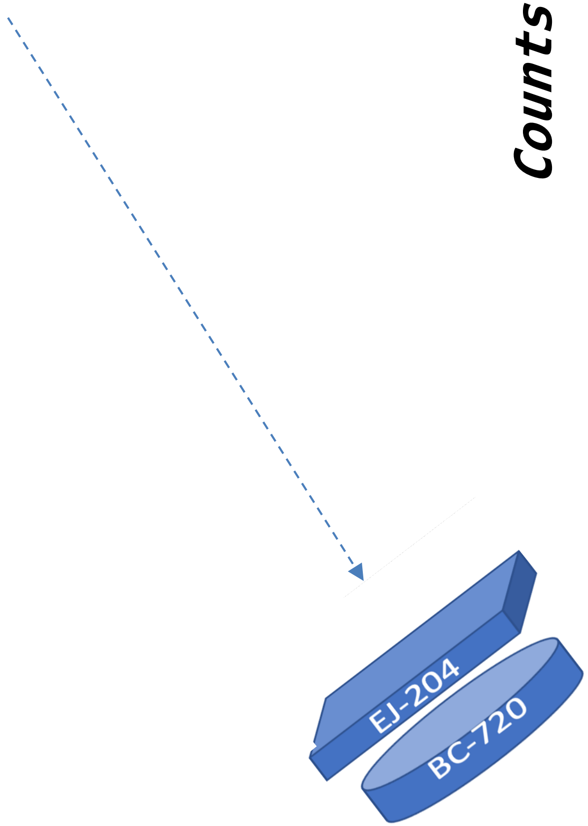

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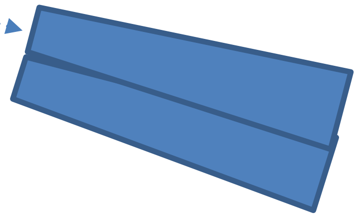
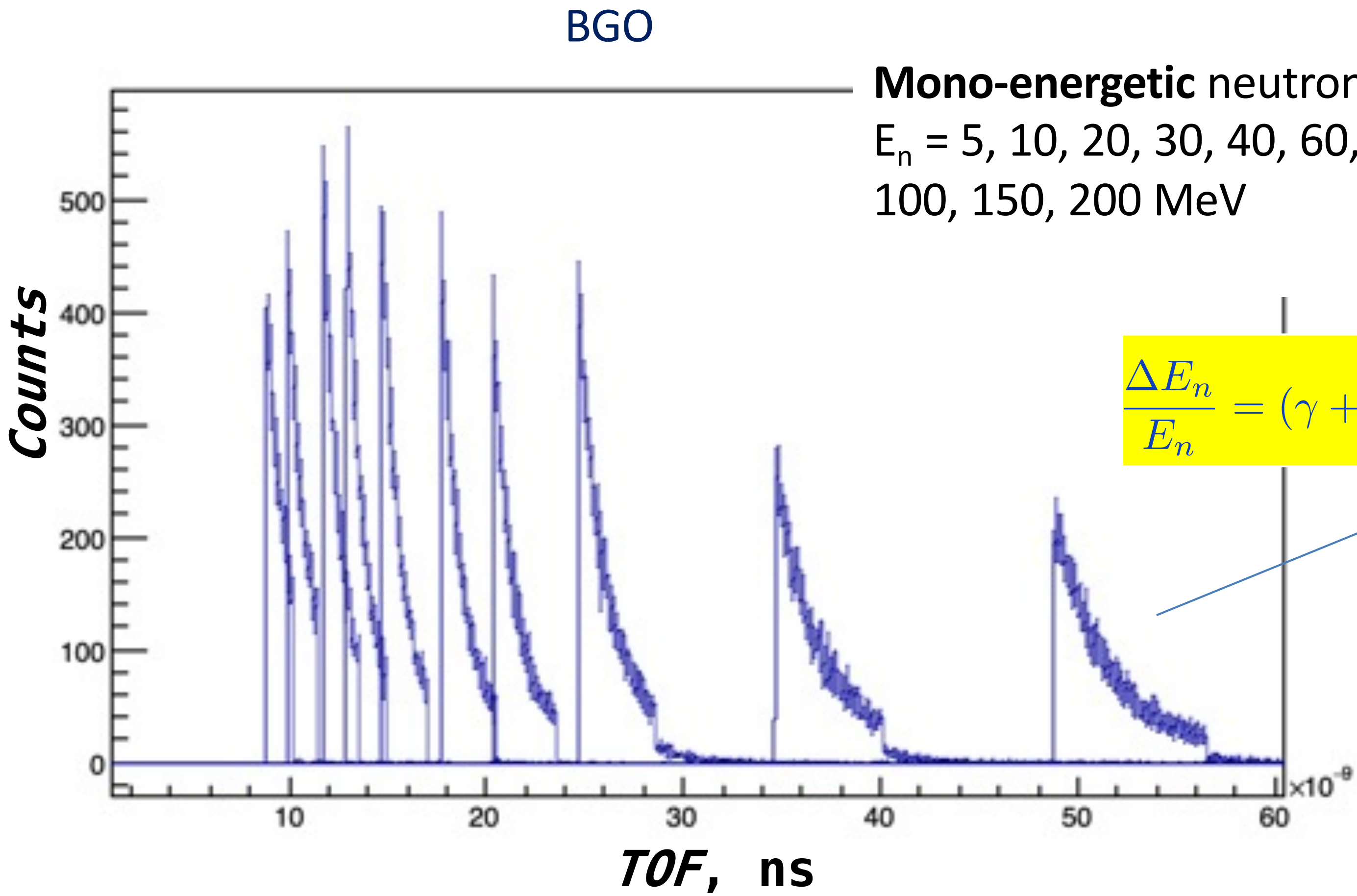


Mono-energetic neutrons
E_n = 5, 10, 20, 30, 40, 60, 80, 100, 150, 200 MeV



$$\frac{\Delta E_n}{E_n} = (\gamma + 1)\gamma \sqrt{\left(\frac{\Delta t}{t}\right)^2 + \left(\frac{\Delta L}{L}\right)^2}$$

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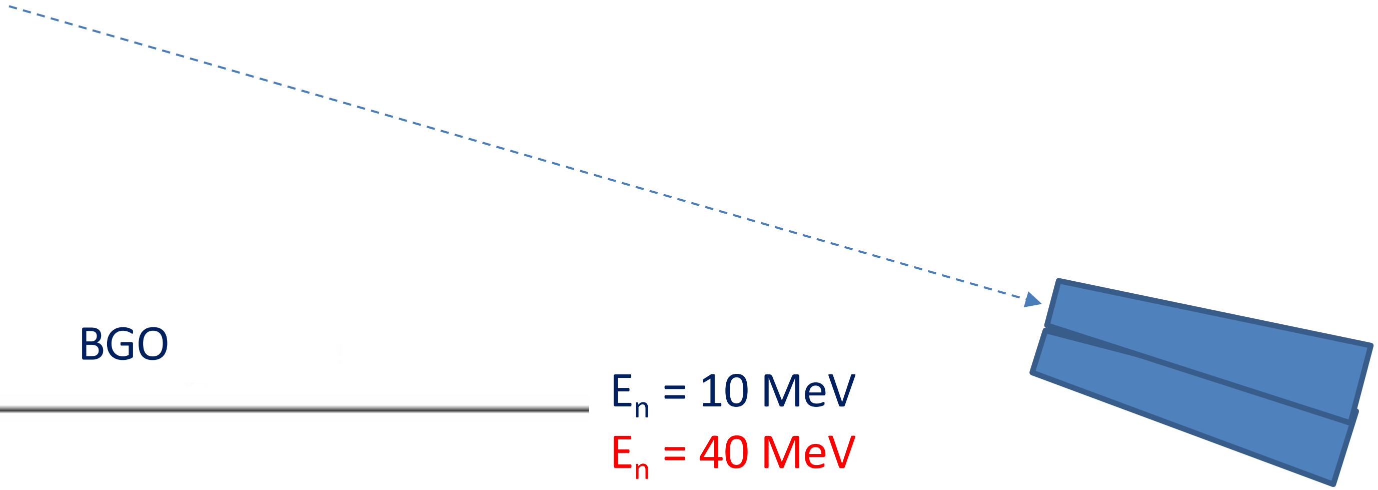
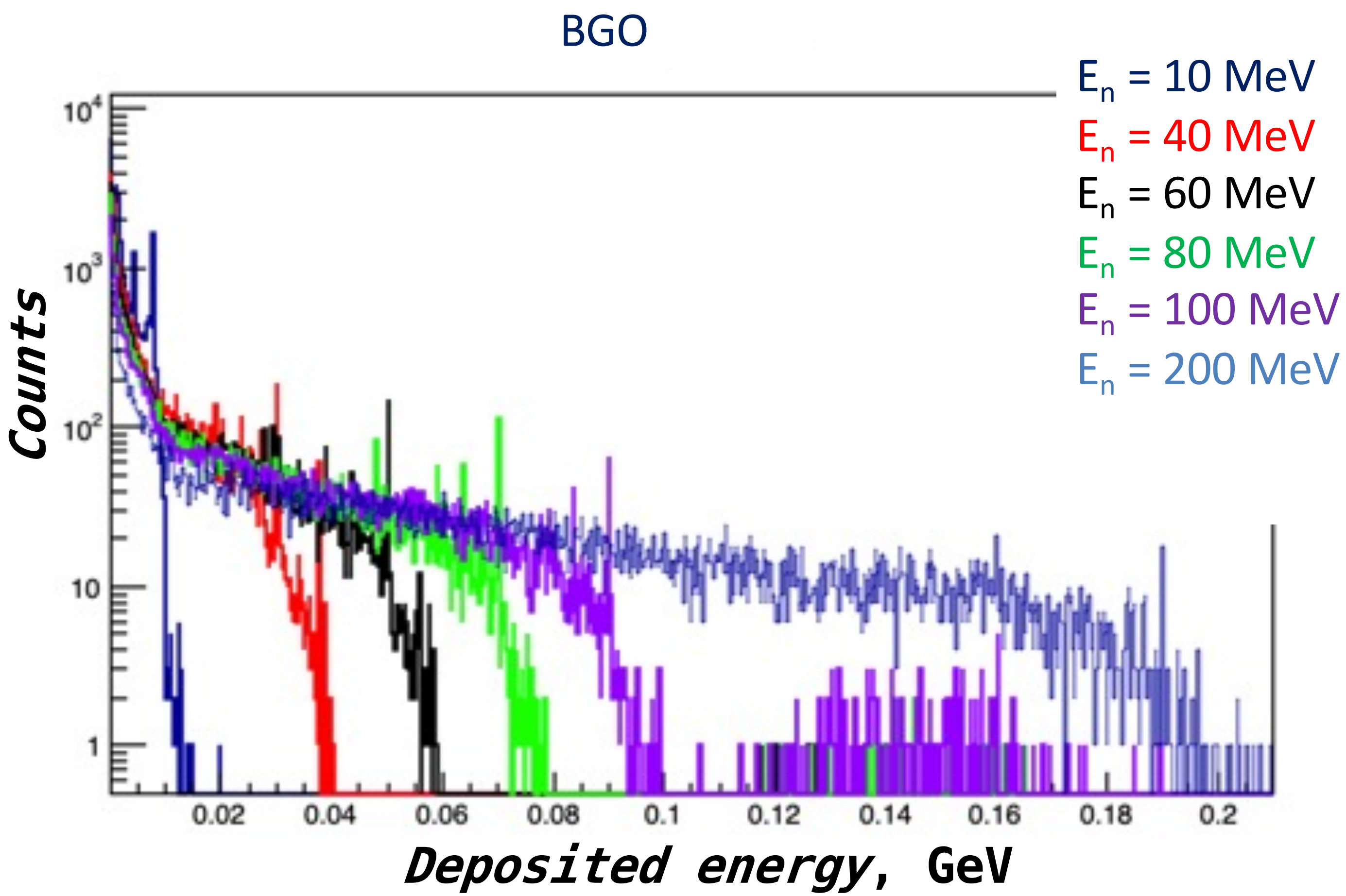
Towards a test beam @ CNAO





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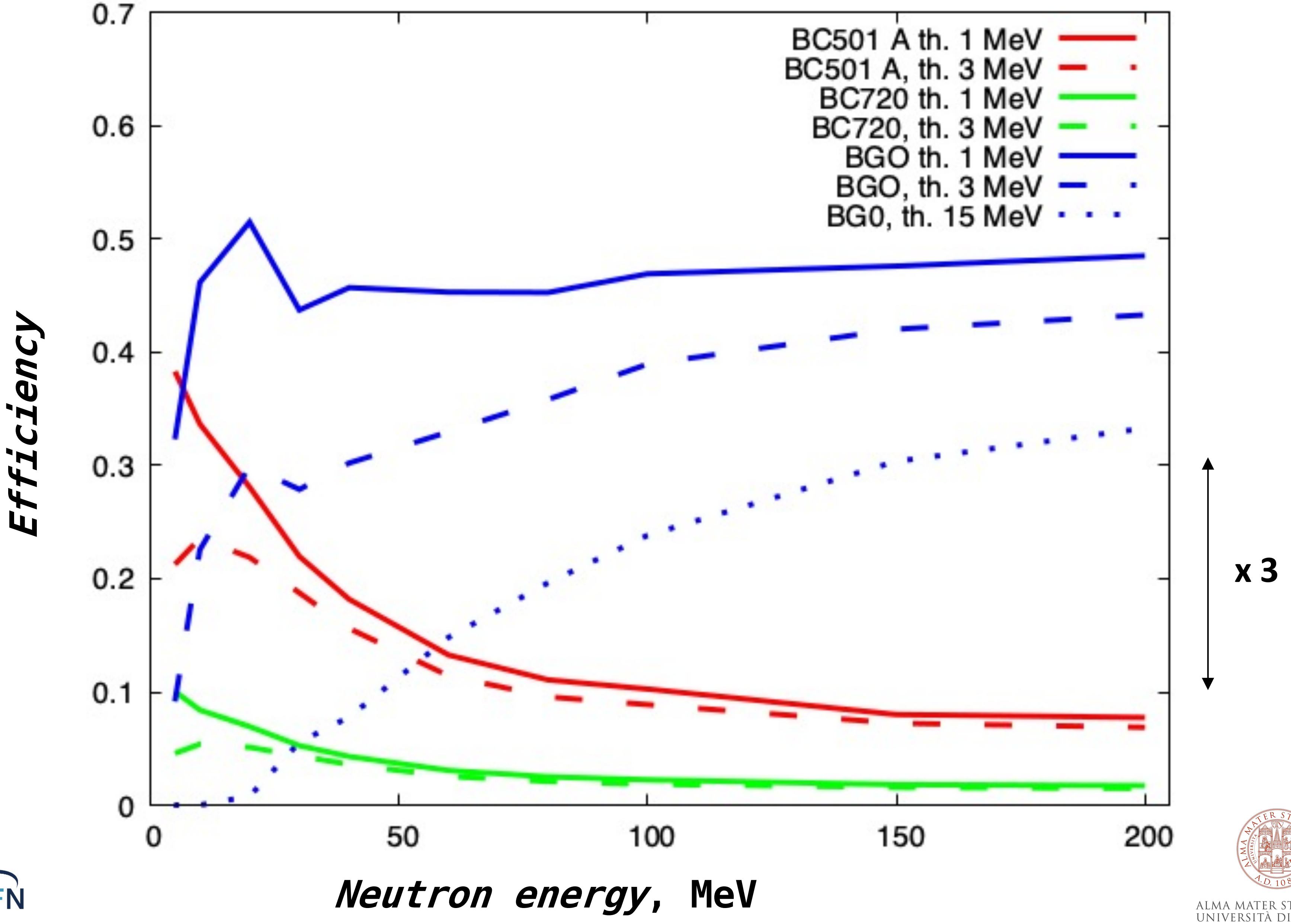
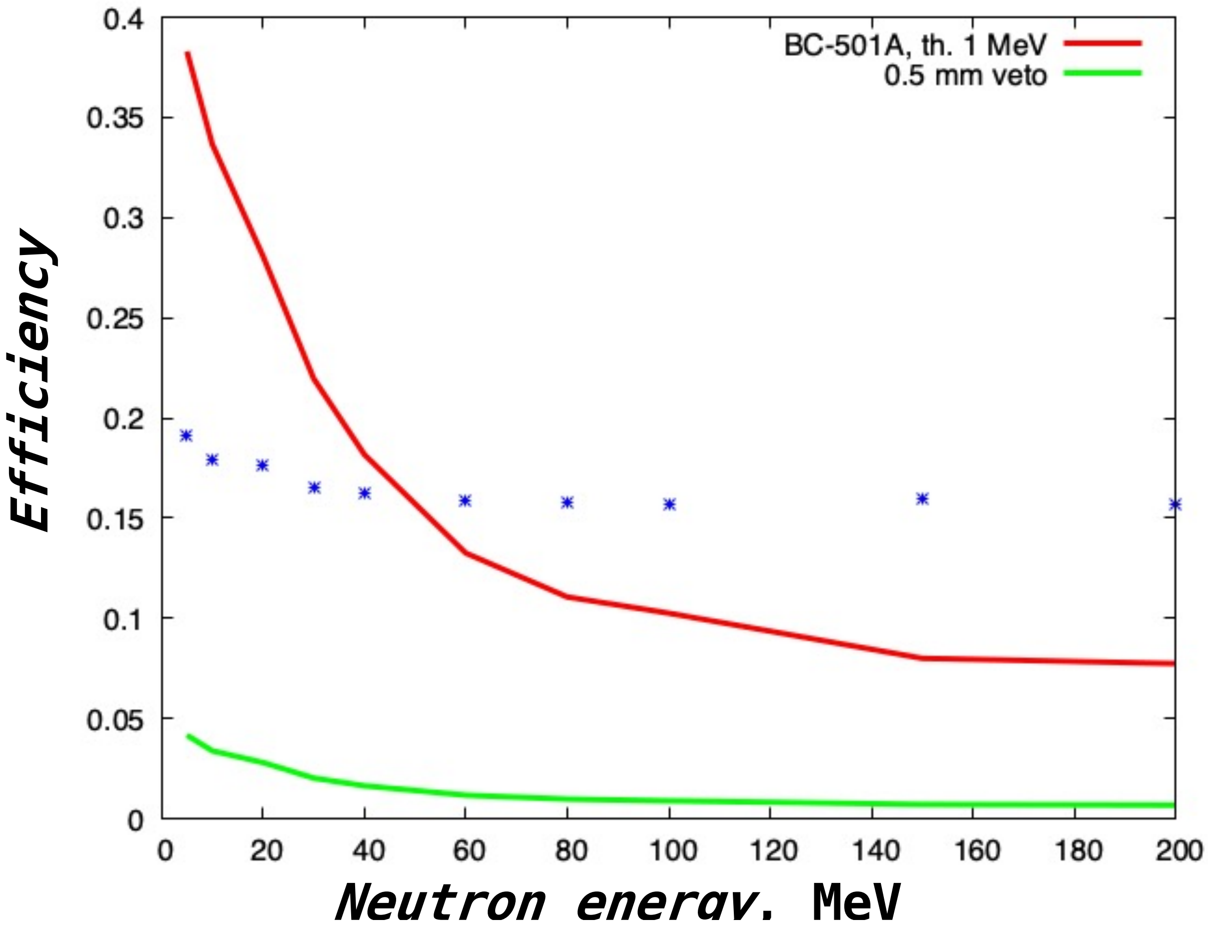


Conclusions 2/2

- A TEST @ CNAO can provide useful information about present and future detectors for neutron studies.

- Idea to improve the energy resolution?



- FLUKA simulations enable us to estimate the efficiency of the detectors and to optimize the thicknesses of the veto (ongoing)

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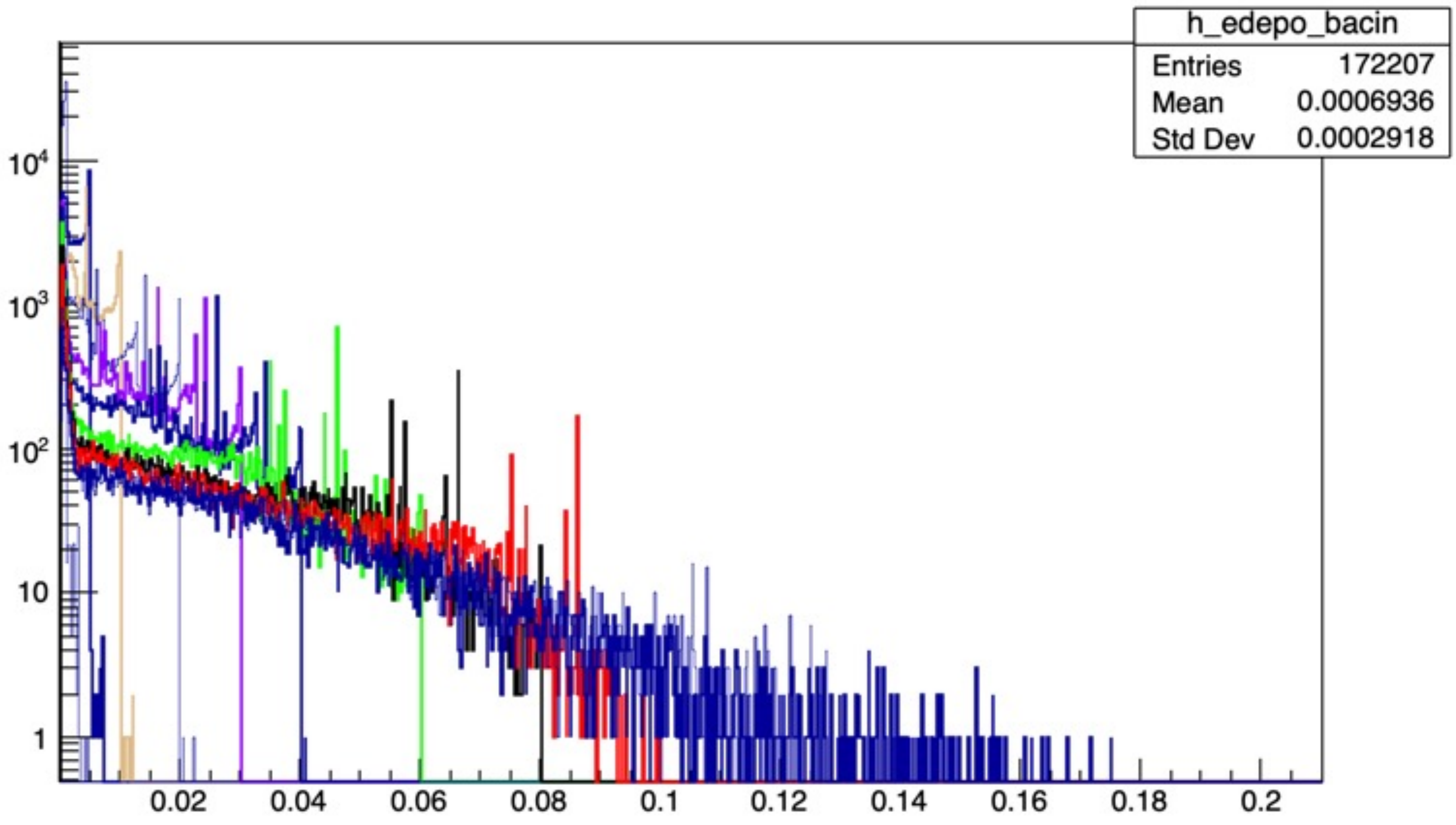
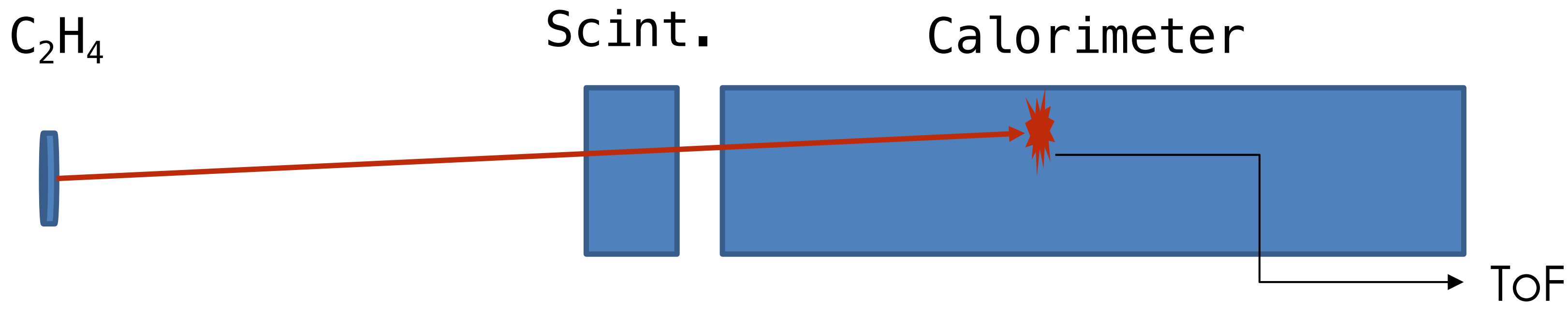
BC-501A

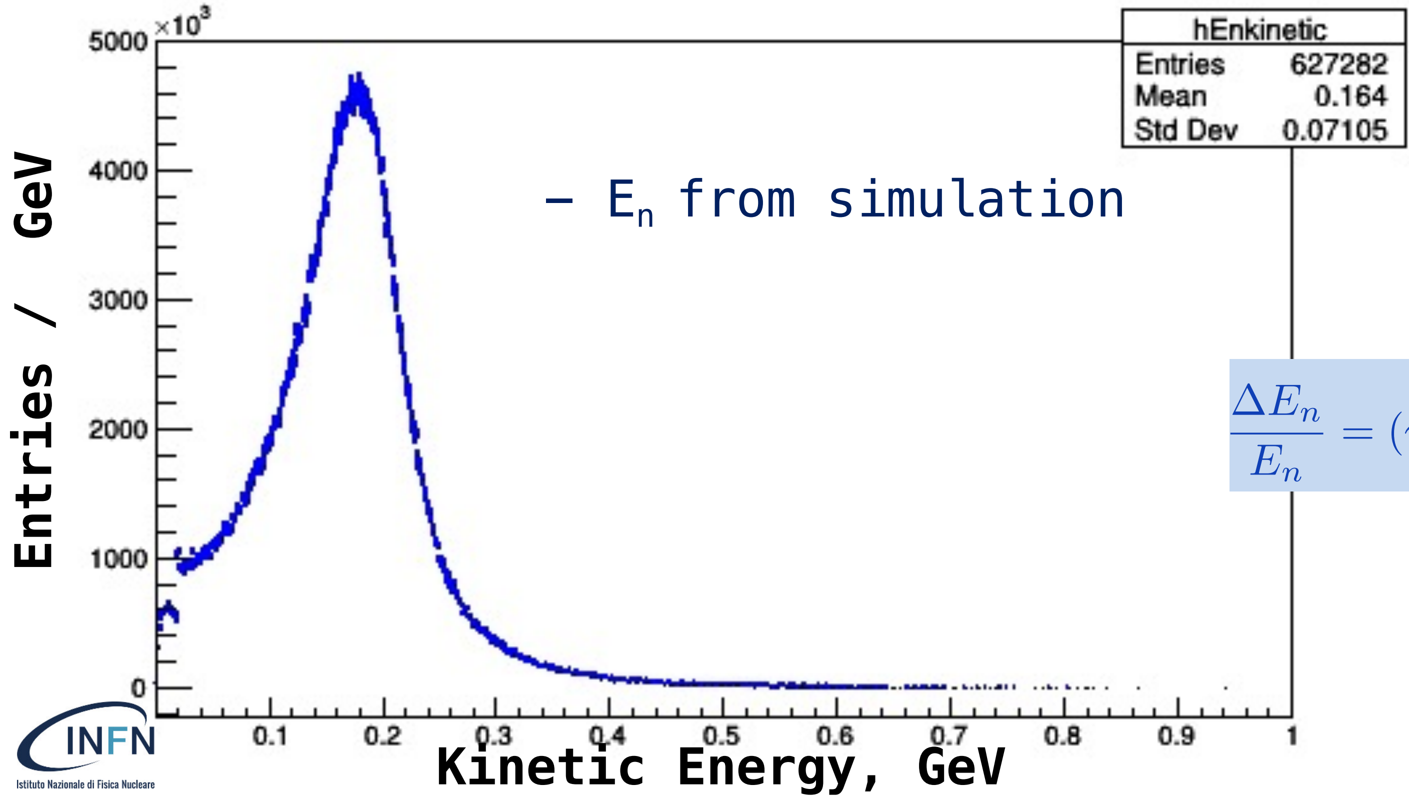


Detecting neutrons with existing setup

$\Delta E/E$

Only events from the target





$$\gamma = \frac{1}{\sqrt{1-\beta^2}} = \frac{c\mathrm{ToF}}{\sqrt{c^2\mathrm{ToF}^2 - L^2}}$$

$$E_n = mc^2(\gamma - 1)$$

$$\frac{\Delta E_n}{E_n} = (\gamma + 1)\gamma\sqrt{\left(\frac{\Delta t}{t}\right)^2 + \left(\frac{\Delta L}{L}\right)^2}$$

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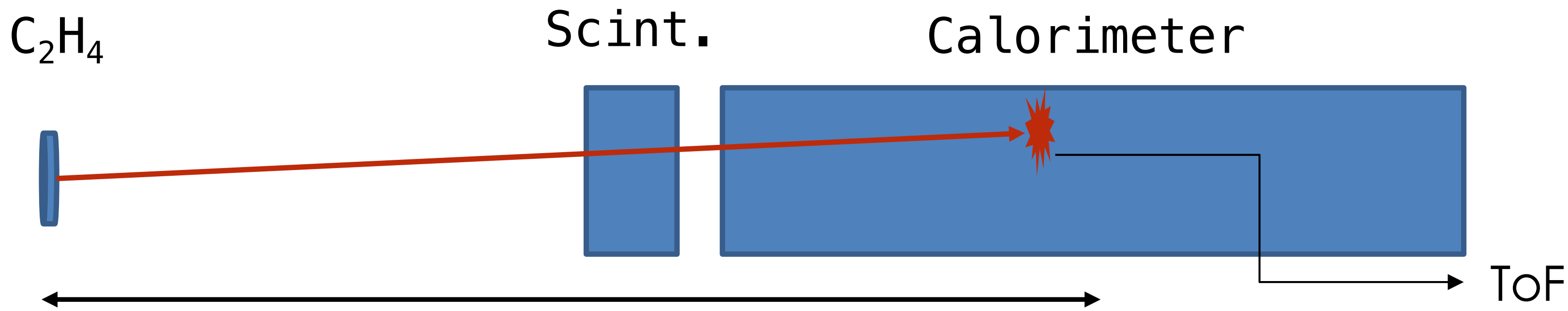
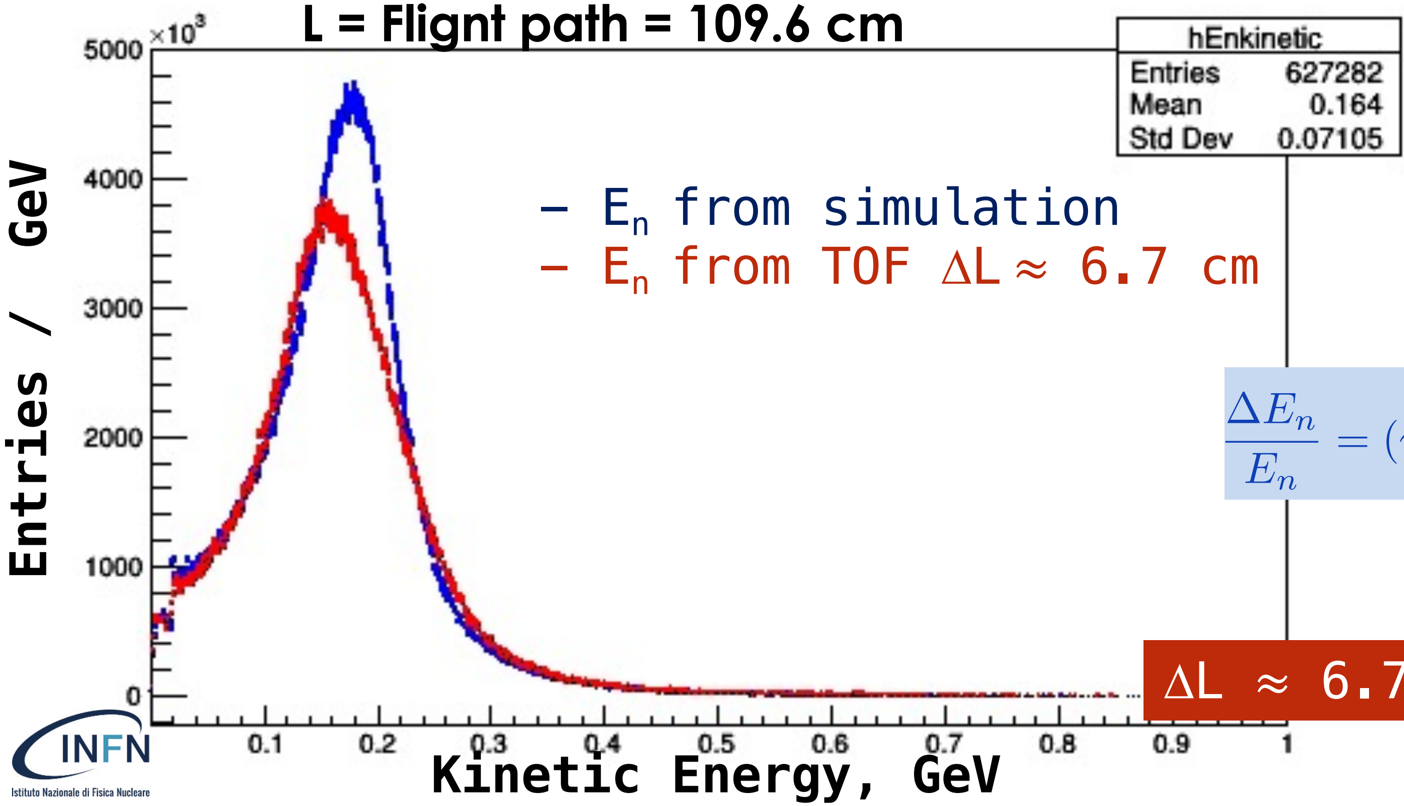
Detecting neutrons with existing setup ΔE/E

Only events from the target



L = Flignt path = 109.6 cm



$$\gamma = \frac{1}{\sqrt{1-\beta^2}} = \frac{c\text{ToF}}{\sqrt{c^2\text{ToF}^2 - L^2}}$$

$$E_n = mc^2(\gamma - 1)$$

$$\frac{\Delta E_n}{E_n} = (\gamma+1)\gamma\sqrt{\left(\frac{\Delta t}{t}\right)^2 + \left(\frac{\Delta L}{L}\right)^2}$$

ΔL ≈ 6.7 cm

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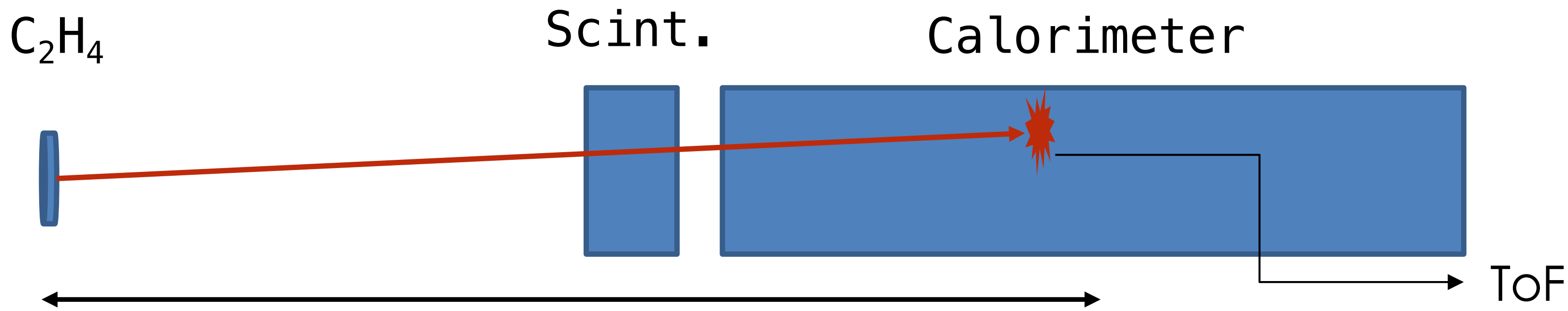
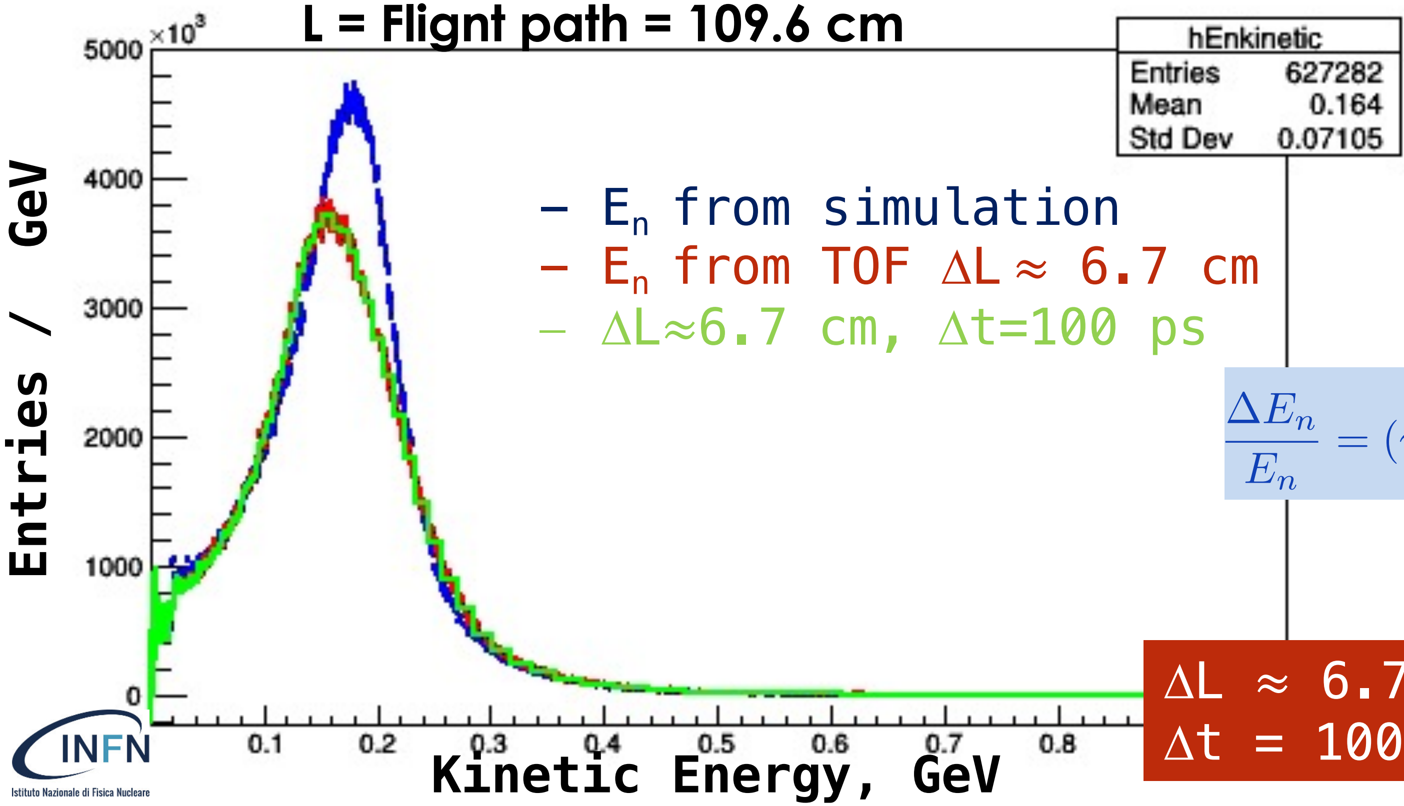
Detecting neutrons with existing setup

ΔE/E

Only events from the target





$$\gamma = \frac{1}{\sqrt{1-\beta^2}} = \frac{c\mathrm{ToF}}{\sqrt{c^2\mathrm{ToF}^2 - L^2}}$$

$$E_n = mc^2(\gamma - 1)$$

$$\frac{\Delta E_n}{E_n} = (\gamma+1)\gamma\sqrt{\left(\frac{\Delta t}{t}\right)^2 + \left(\frac{\Delta L}{L}\right)^2}$$

ΔL ≈ 6.7 cm
Δt = 100 ps

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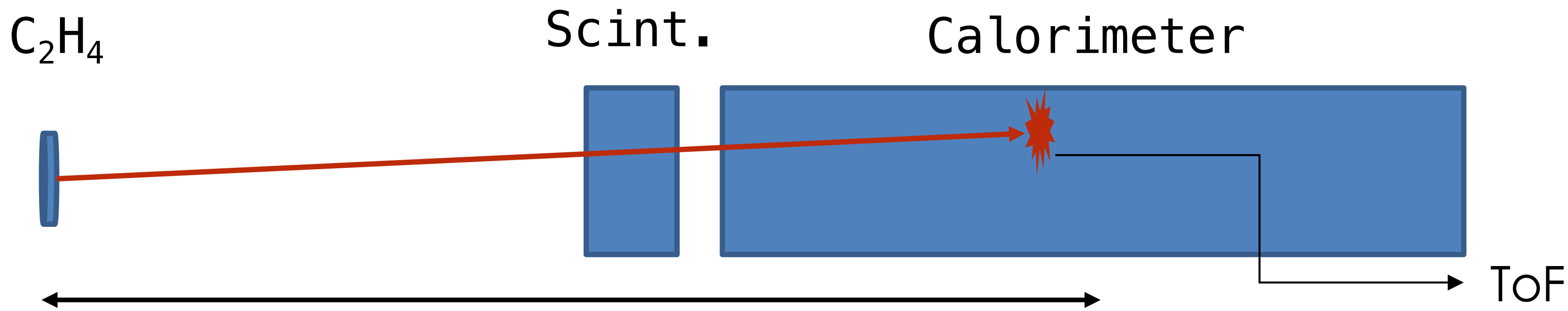
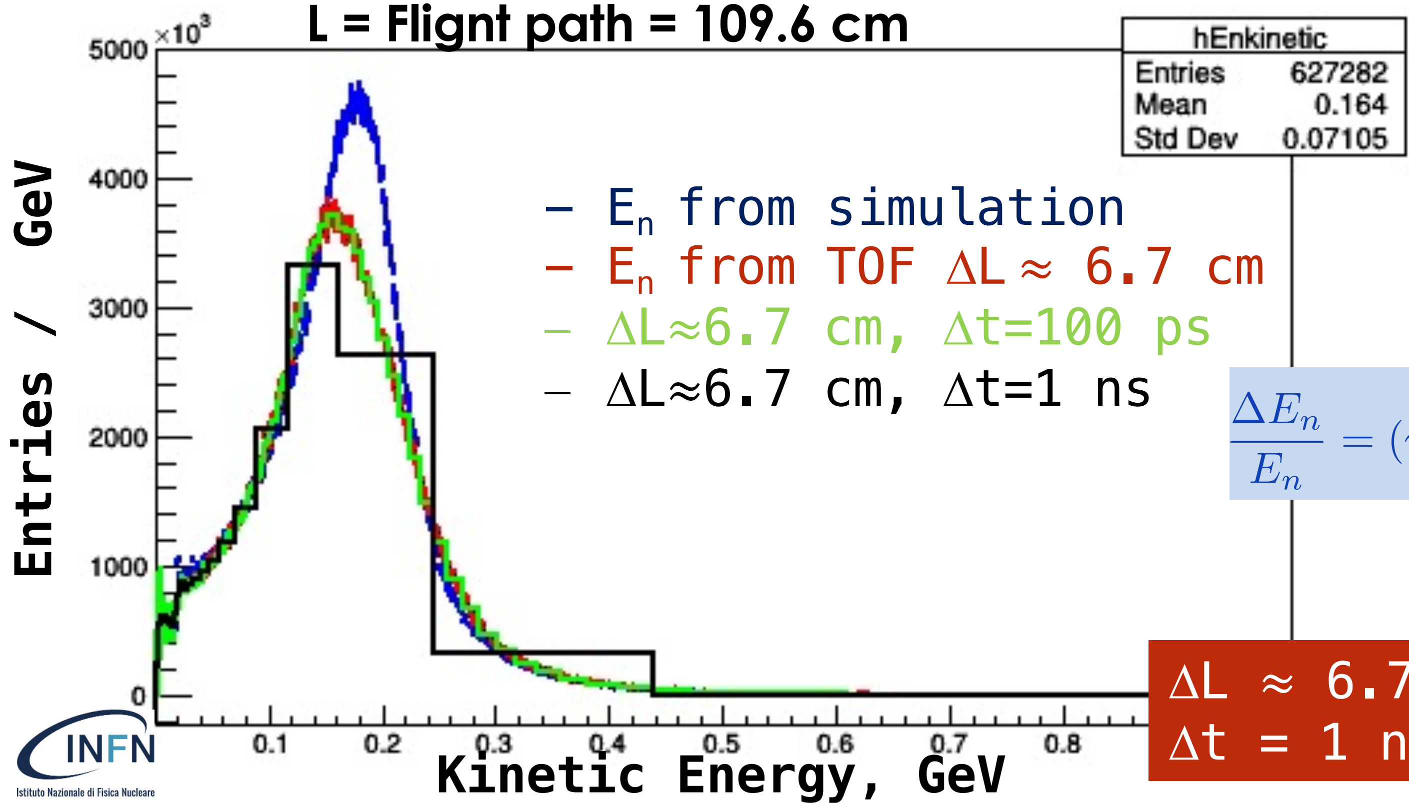
Detecting neutrons with existing setup

ΔE/E

Only events from the target



L = Flignt path = 109.6 cm



$$\gamma = \frac{1}{\sqrt{1-\beta^2}} = \frac{c\mathrm{ToF}}{\sqrt{c^2\mathrm{ToF}^2 - L^2}}$$

$$E_n = mc^2(\gamma - 1)$$

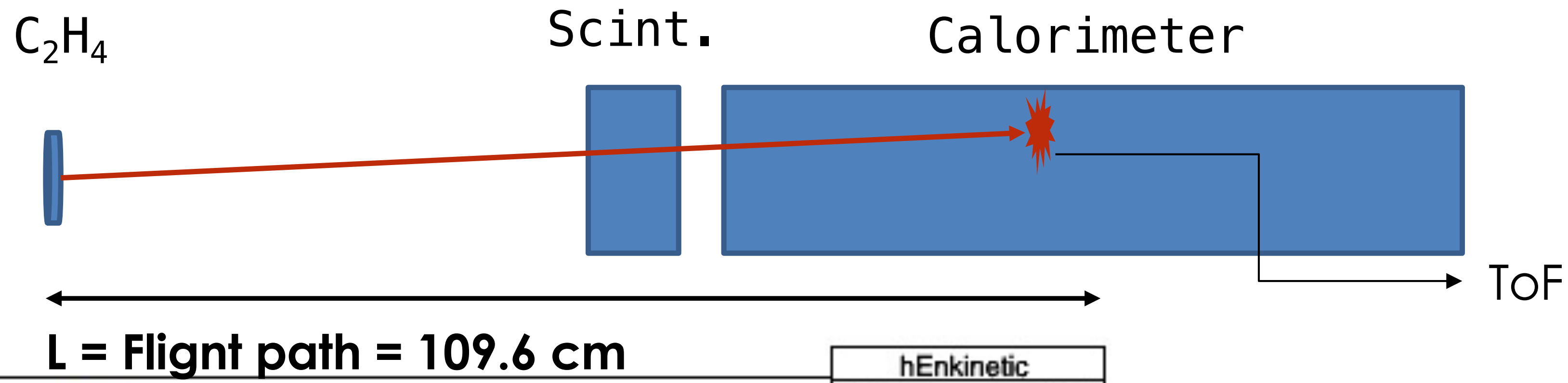
$$\frac{\Delta E_n}{E_n} = (\gamma+1)\gamma\sqrt{\left(\frac{\Delta t}{t}\right)^2 + \left(\frac{\Delta L}{L}\right)^2}$$

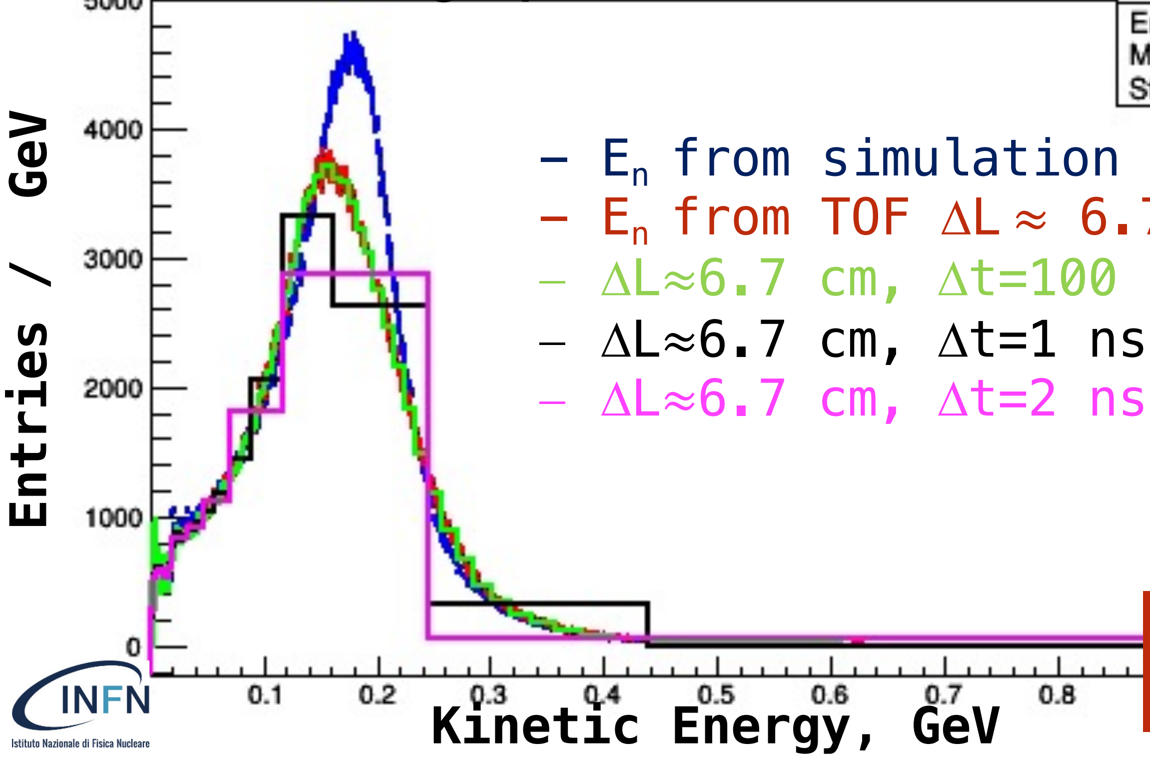
ΔL ≈ 6.7 cm
Δt = 1 ns

Detecting neutrons with existing setup

ΔE/E

Only events from the target





$$\gamma = \frac{1}{\sqrt{1-\beta^2}} = \frac{c\mathrm{ToF}}{\sqrt{c^2\mathrm{ToF}^2 - L^2}}$$

$$E_n = mc^2(\gamma - 1)$$

$$\frac{\Delta E_n}{E_n} = (\gamma+1)\gamma\sqrt{\left(\frac{\Delta t}{t}\right)^2 + \left(\frac{\Delta L}{L}\right)^2}$$

ΔL ≈ 6.7 cm
Δt = 2 ns

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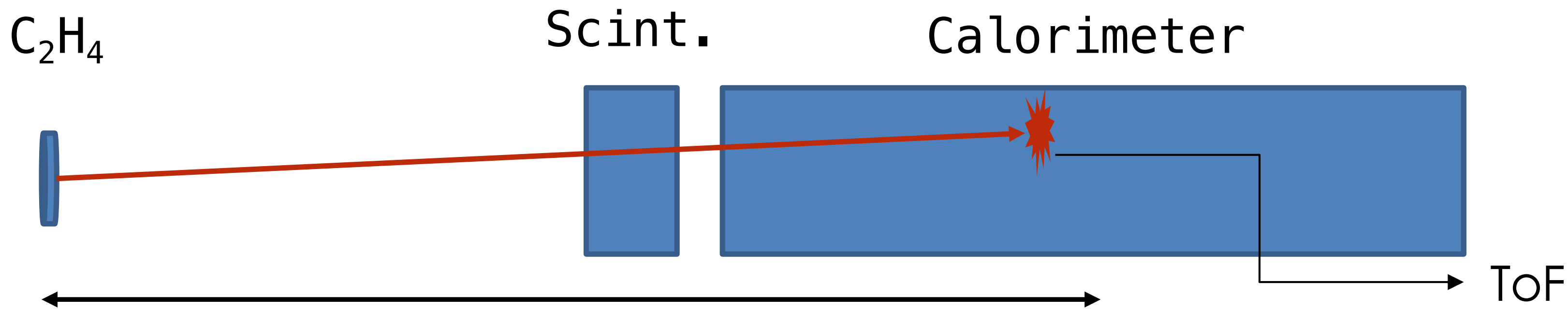
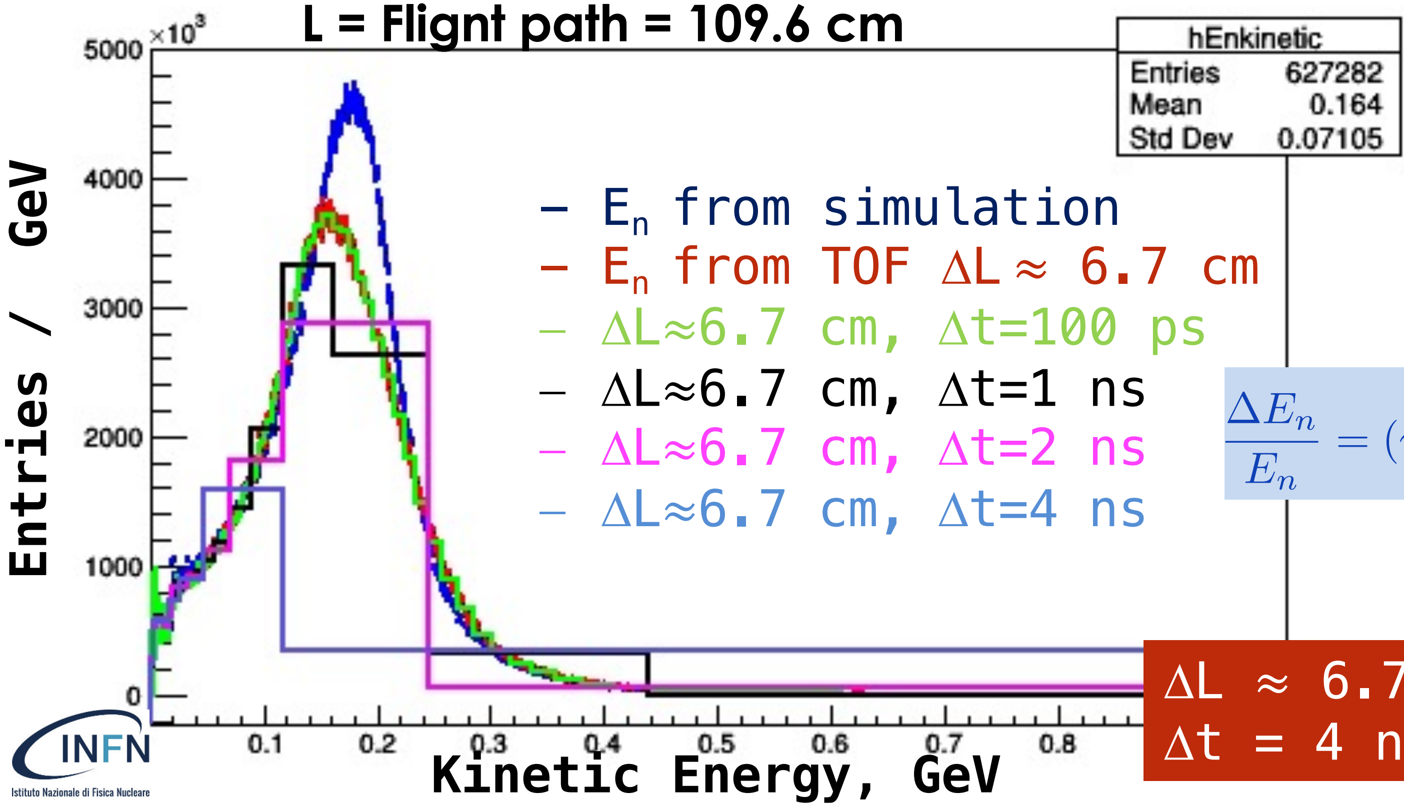
Detecting neutrons with existing setup ΔE/E

Only events from the target



L = Flignt path = 109.6 cm



$$\gamma = \frac{1}{\sqrt{1-\beta^2}} = \frac{c\mathrm{ToF}}{\sqrt{c^2\mathrm{ToF}^2 - L^2}}$$

$$E_n = mc^2(\gamma - 1)$$

$$\frac{\Delta E_n}{E_n} = (\gamma+1)\gamma\sqrt{\left(\frac{\Delta t}{t}\right)^2 + \left(\frac{\Delta L}{L}\right)^2}$$

ΔL ≈ 6.7 cm
Δt = 4 ns

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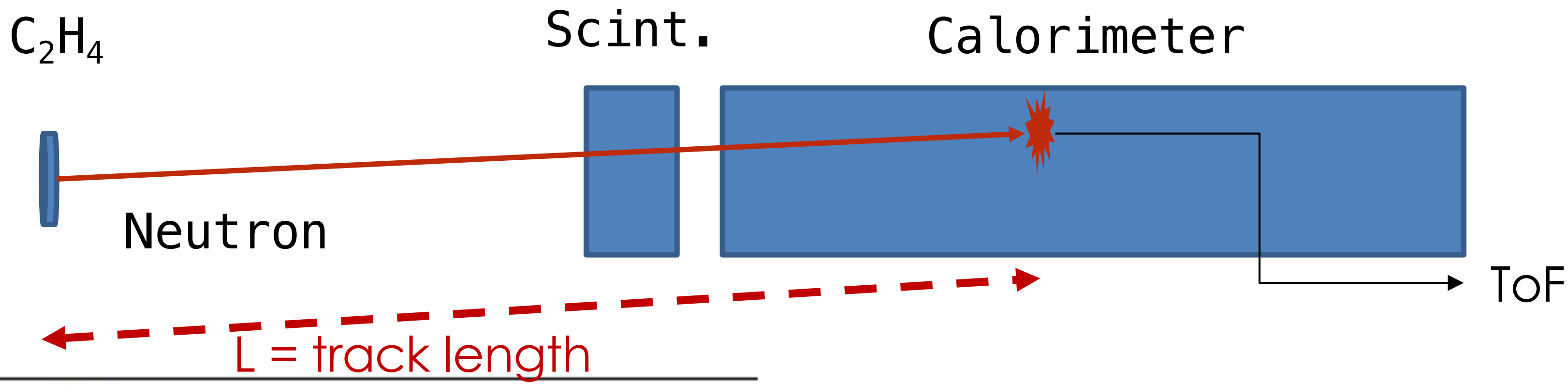
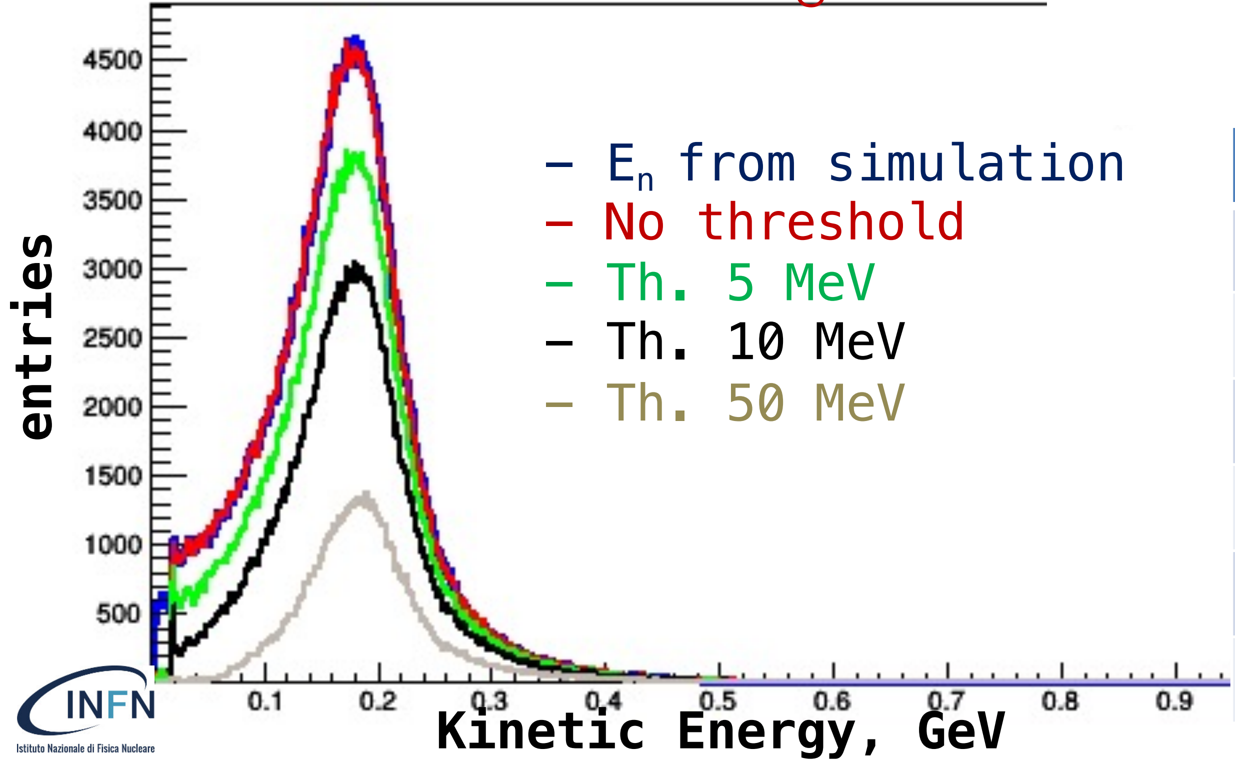
Detecting neutrons with existing setup

EFFICIENCY

Only events from the target





Threshold	Efficiency	
No	100%	**66%**
Fluka	75%	**46%**
5 MeV	55%	**34%**
10 MeV	45%	**28%**
20 MeV	40%	**23%**
50 MeV	20%	**12%**

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