ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA

Neutrons @ FOOT

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Department of Physics and Astronomy

Program

today

- Introduction (neutron detectors)
- **Neutrons** produced in the **target** (MC simulations)
- **Neutrons** produced in the **environment** (MC simulations)

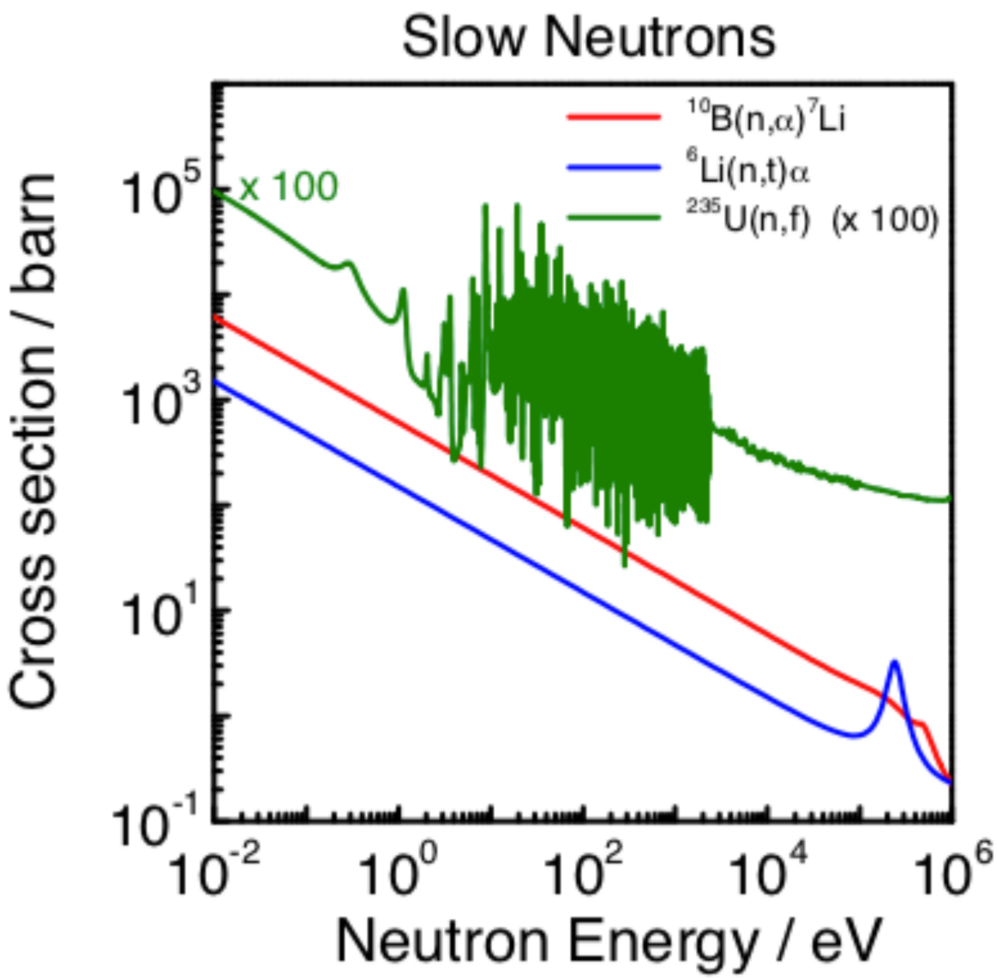
1) Detecting **neutrons** with the **existing setup** (efficiency?)

2) Detecting **neutrons** by adding a **new detector** (known efficiency)

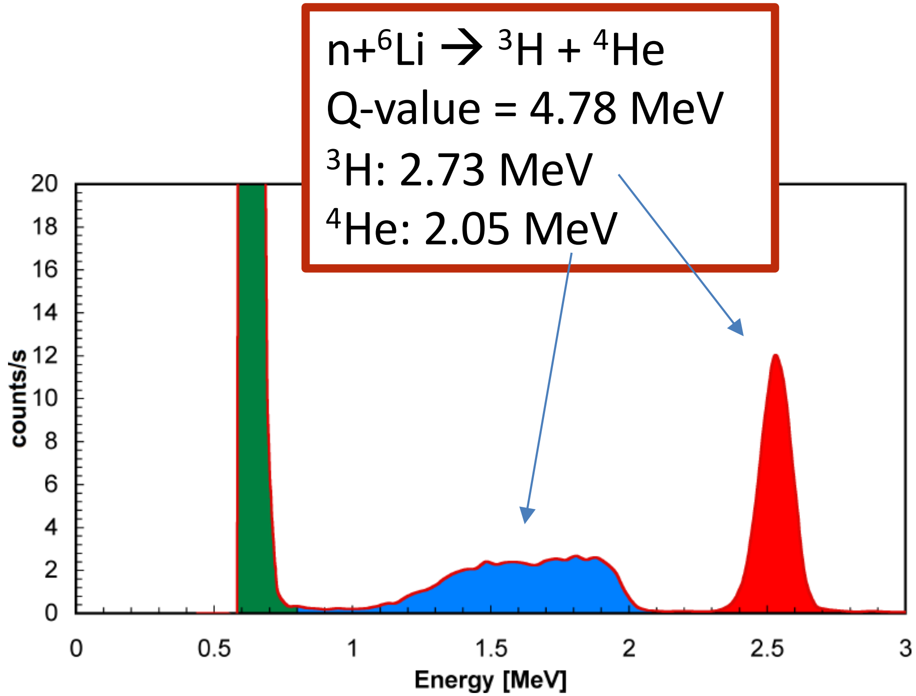
Introduction

Neutron detectors are based on the **conversion** of neutrons either to charged particles or γ rays (nuclear reactions, elastic and inelastic scattering).

Some **reference** reactions and their standard cross sections



Example: Silicon + Lithium



Introduction

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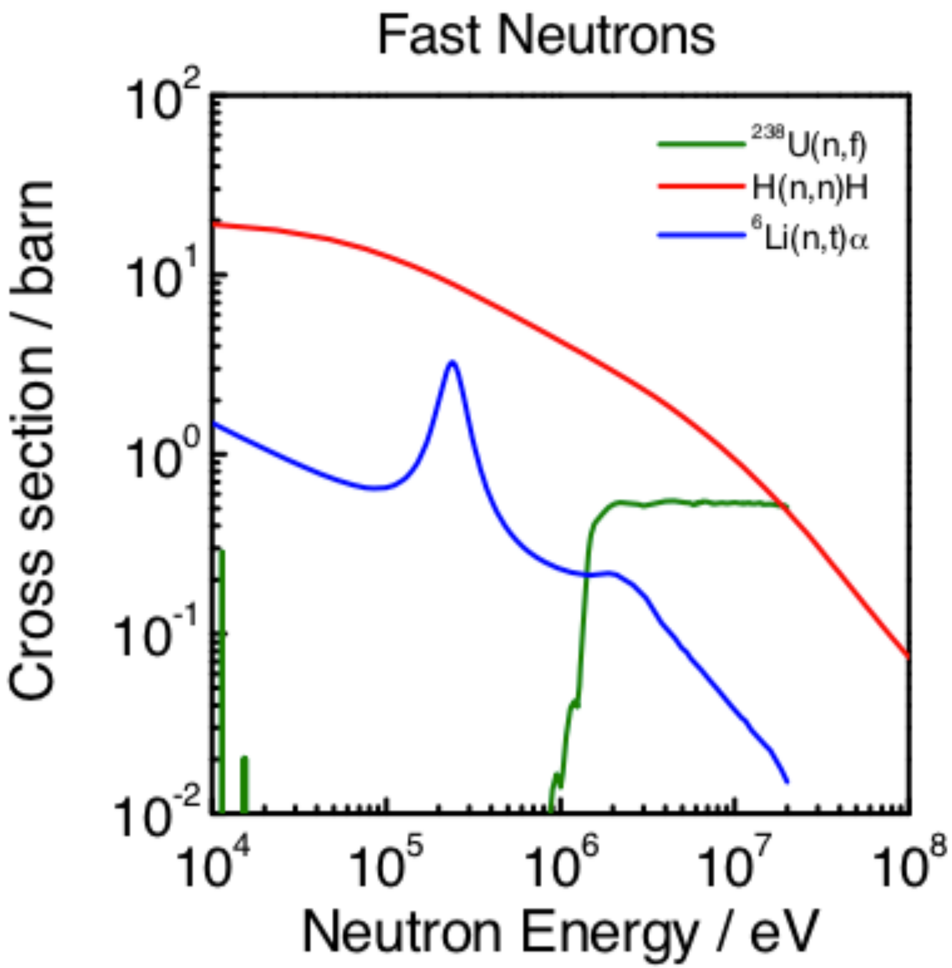
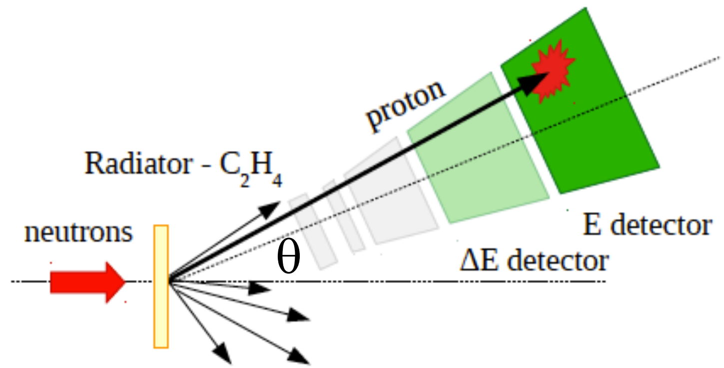
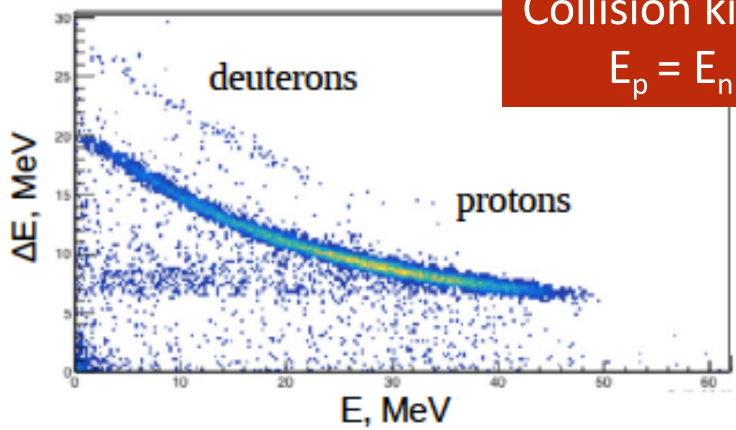


Example: Proton recoil telescope





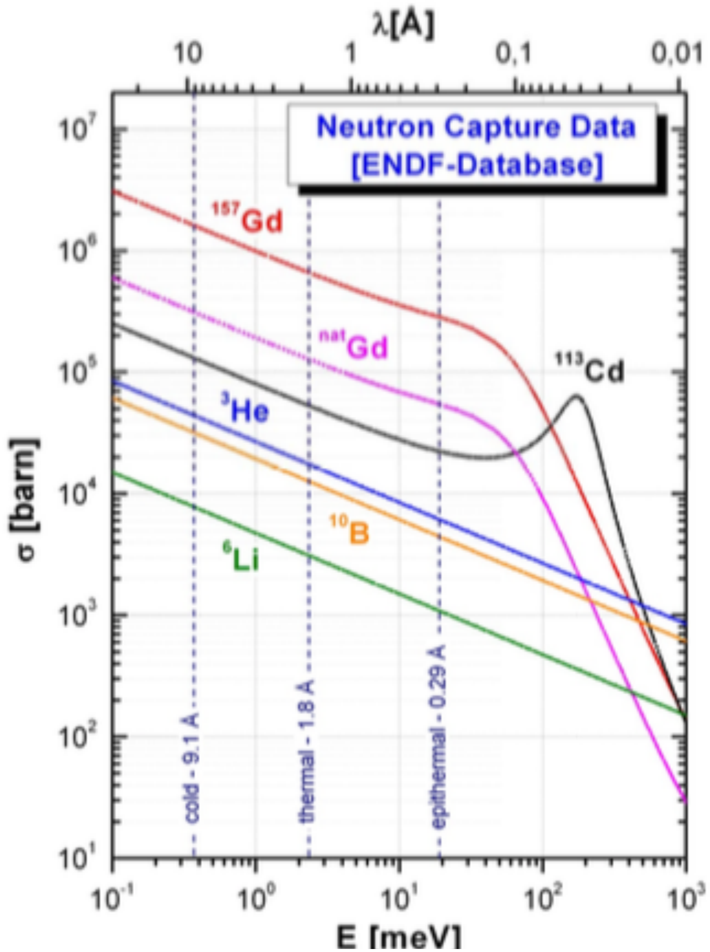
Collision kinematics:

$E_p = E_n \cos^2\theta$

Introduction

Neutron detectors are based on the **conversion** of neutrons either to charged particles or γ rays (nuclear reactions, elastic and inelastic scattering).

Other reaction cross sections? If not well known, the efficiency of the detector must be estimated.



Detectors are commonly based on neutron cross section standards, i.e.: any detector + converter of Li, B, H, U.

1. In combination with **time-of-flight technique** if we are interested in **neutron energy.**

2. In combination with a **moderator** to **enhance** the **detection efficiency**, information in energy less accurate or lost.

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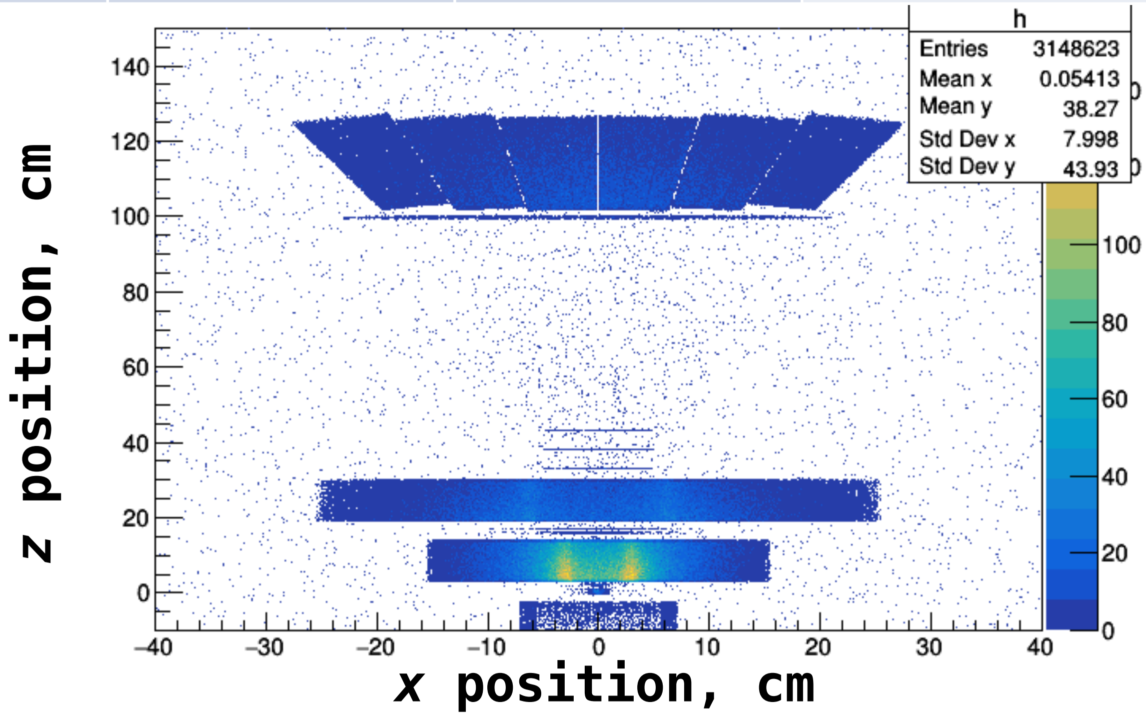
MC simulations – neutrons from target & environment

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



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MC simulations – neutrons from target & environment

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

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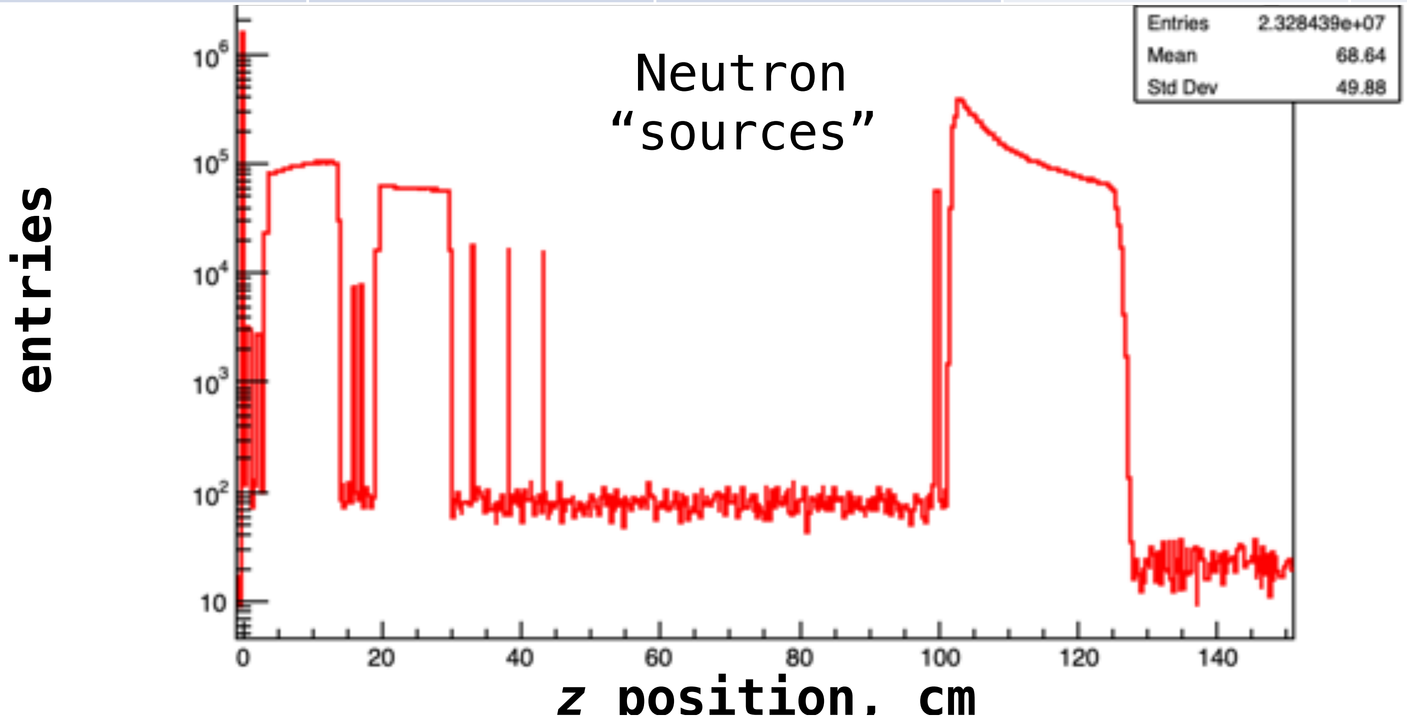
target	3.2	1.3 (40%)	0.6 (20%)	**0.4**	1.4
magnets	6.5				
Cal.	13.3				



MC simulations – neutrons from target & environment

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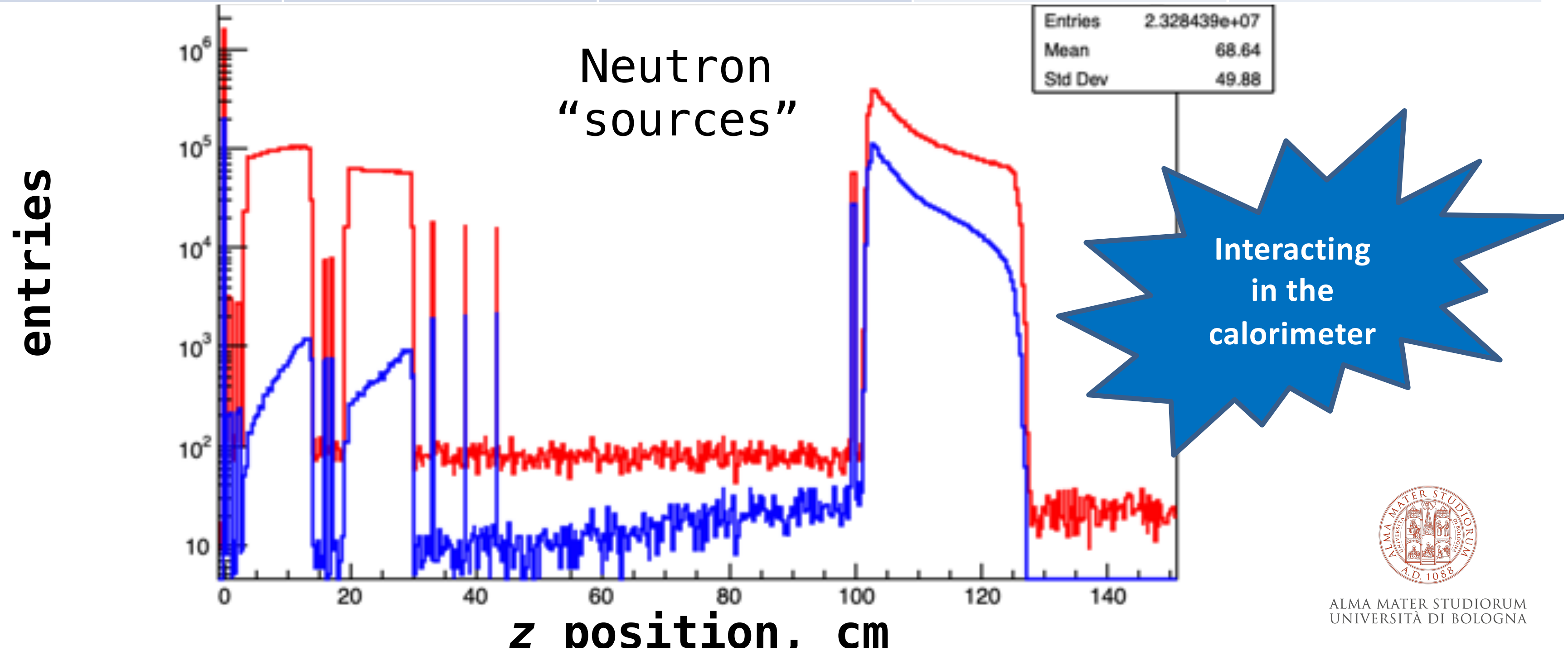
target	3.2	1.3 (40%)	0.6 (20%)	**0.4**	1.4
magnets	6.5			**0.06**	14.8
Cal.	13.3			**3.1**	



MC simulations – neutrons from target & environment

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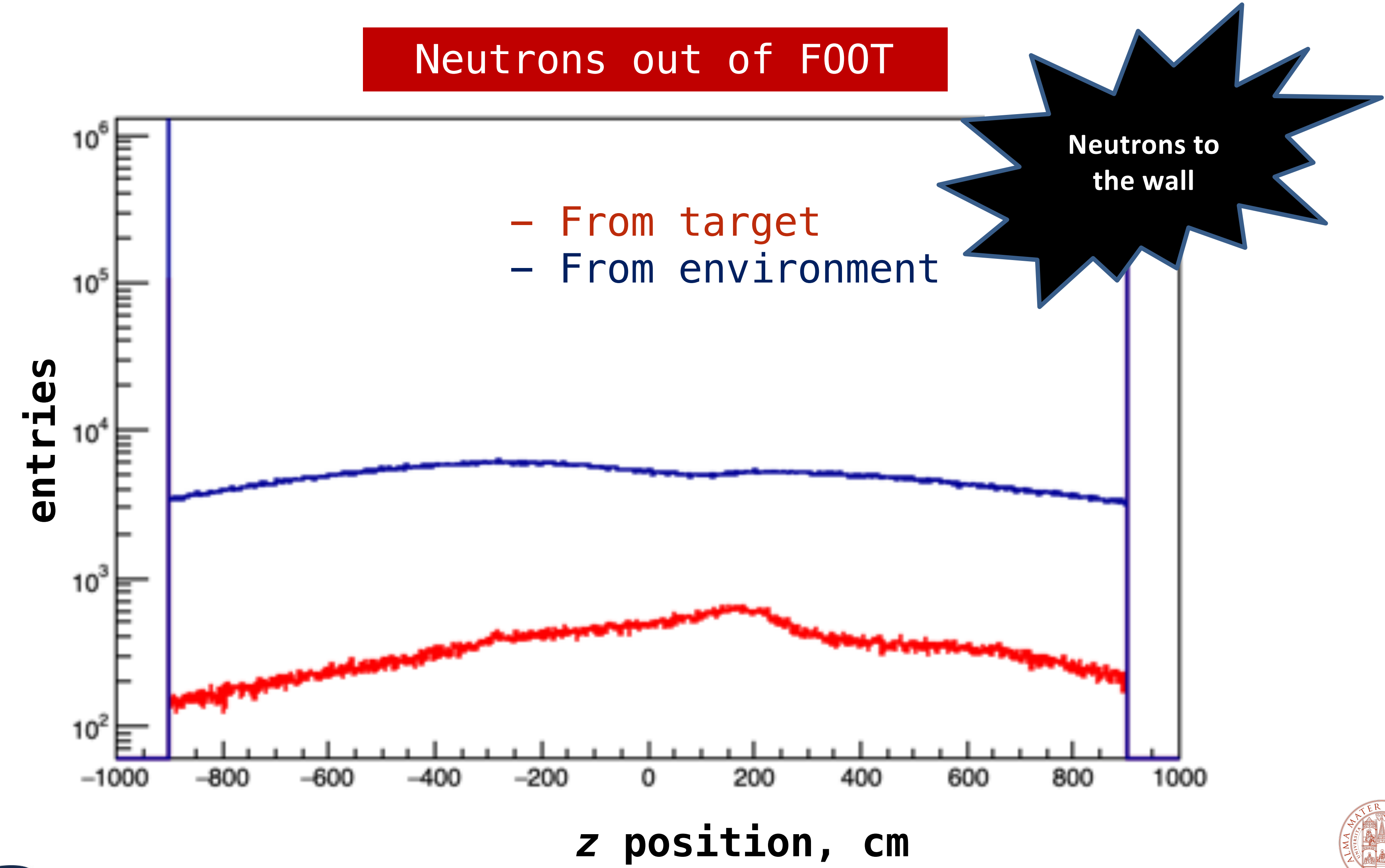
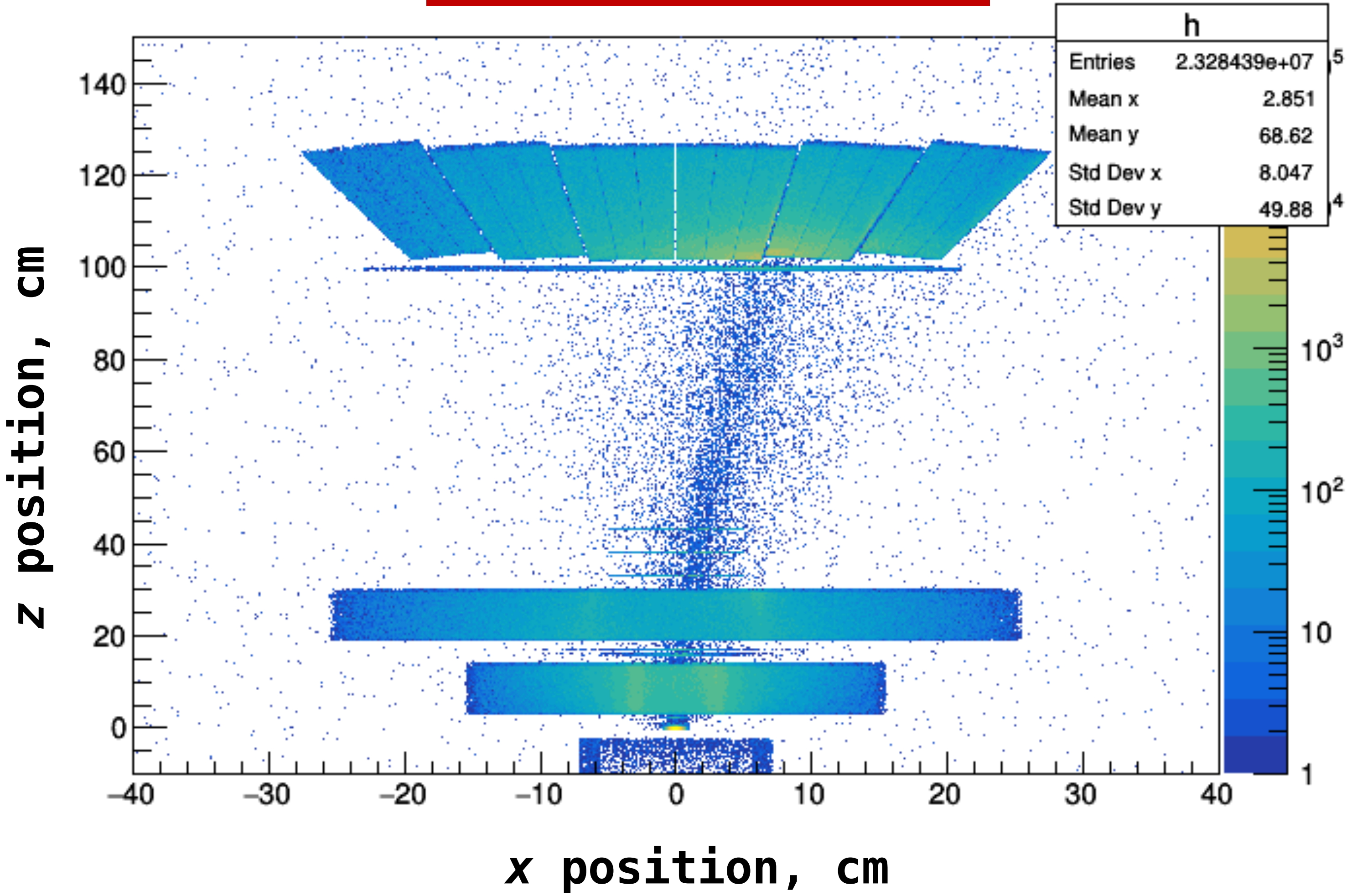


MC simulations – neutrons from target & environment

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

Neutron "sources"



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MC simulations – neutrons from target & environment

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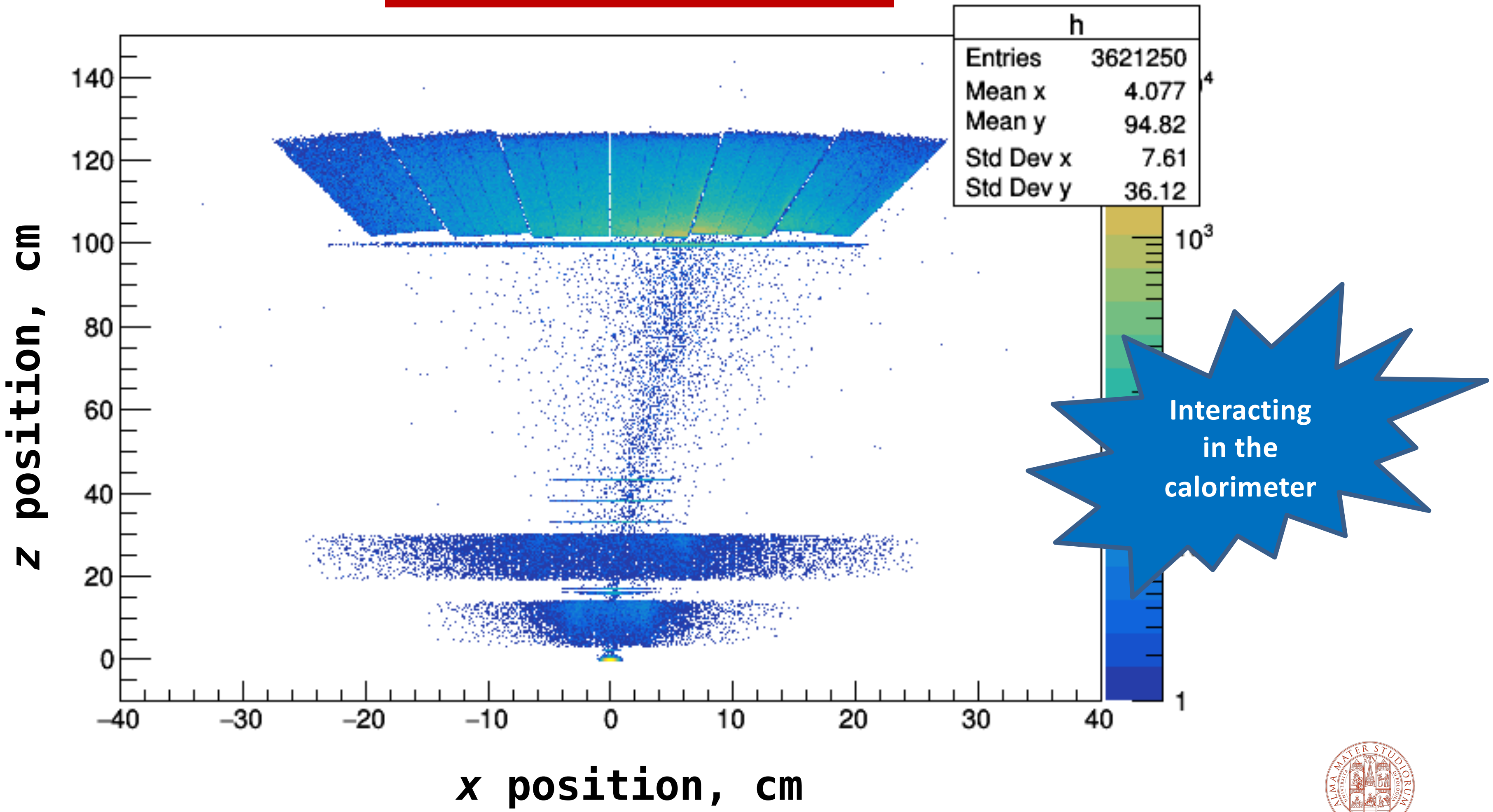
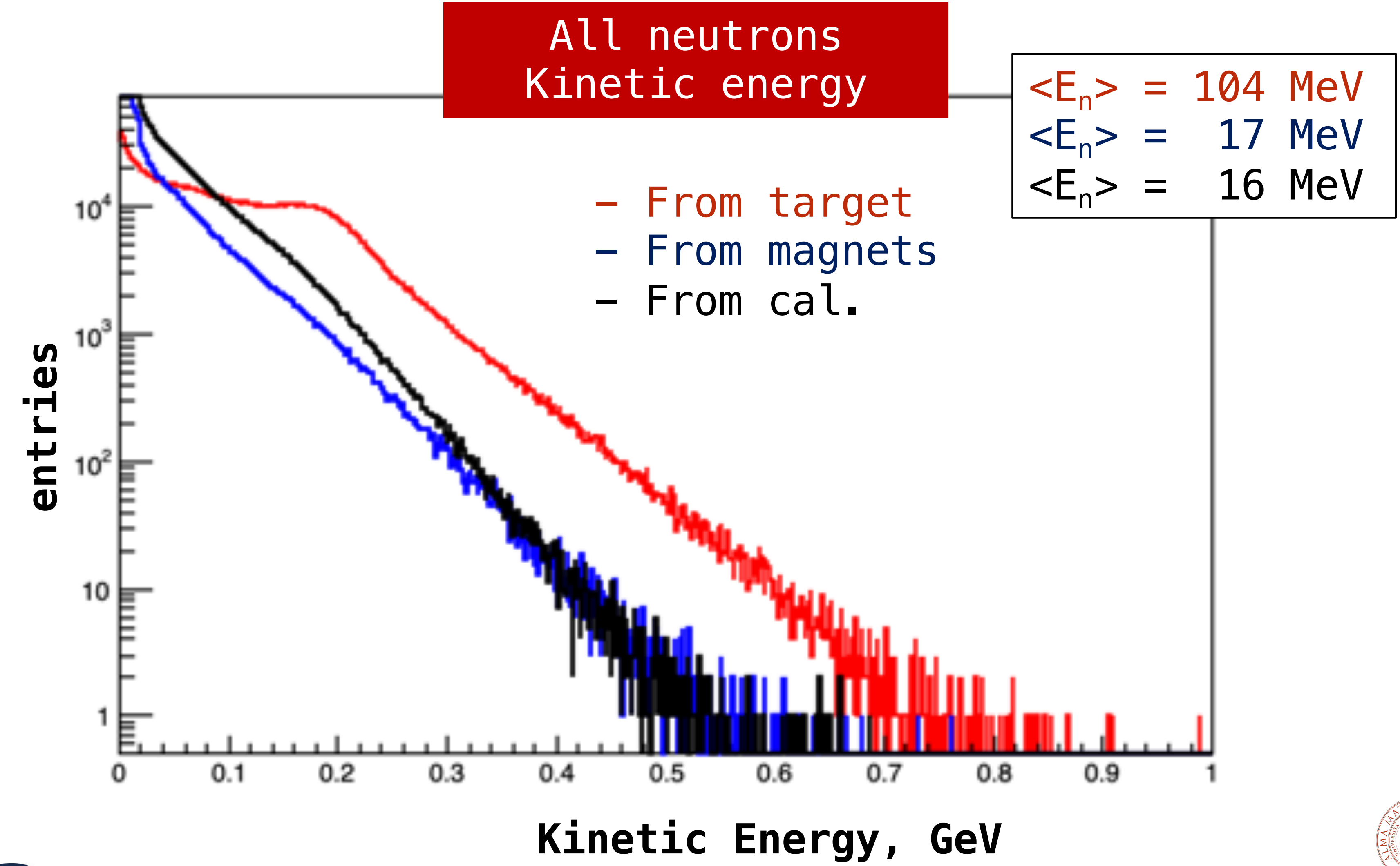


MC simulations – neutrons from target & environment

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



MC simulations – neutrons from target & environment

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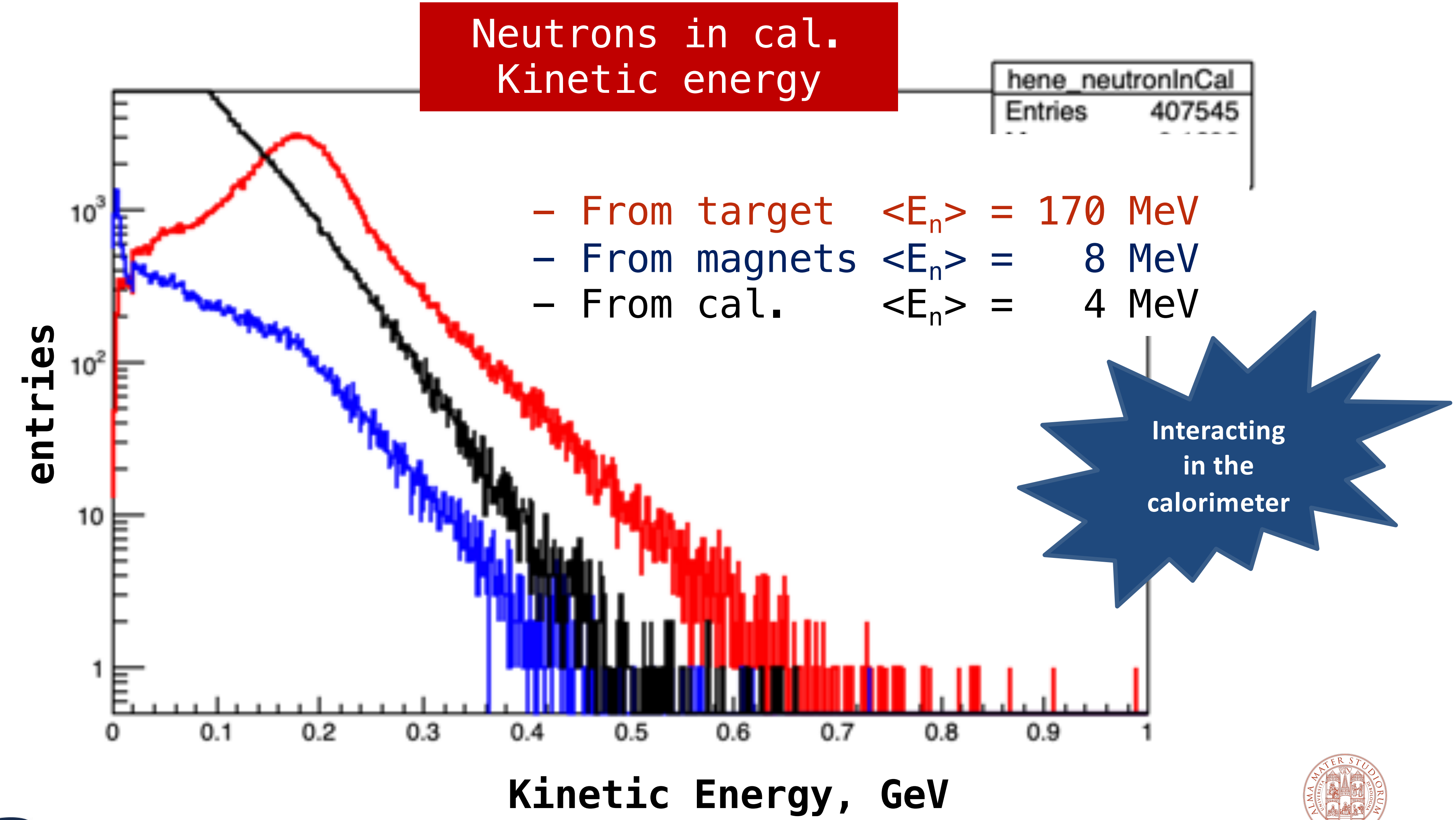

MC simulations – neutrons from target & environment

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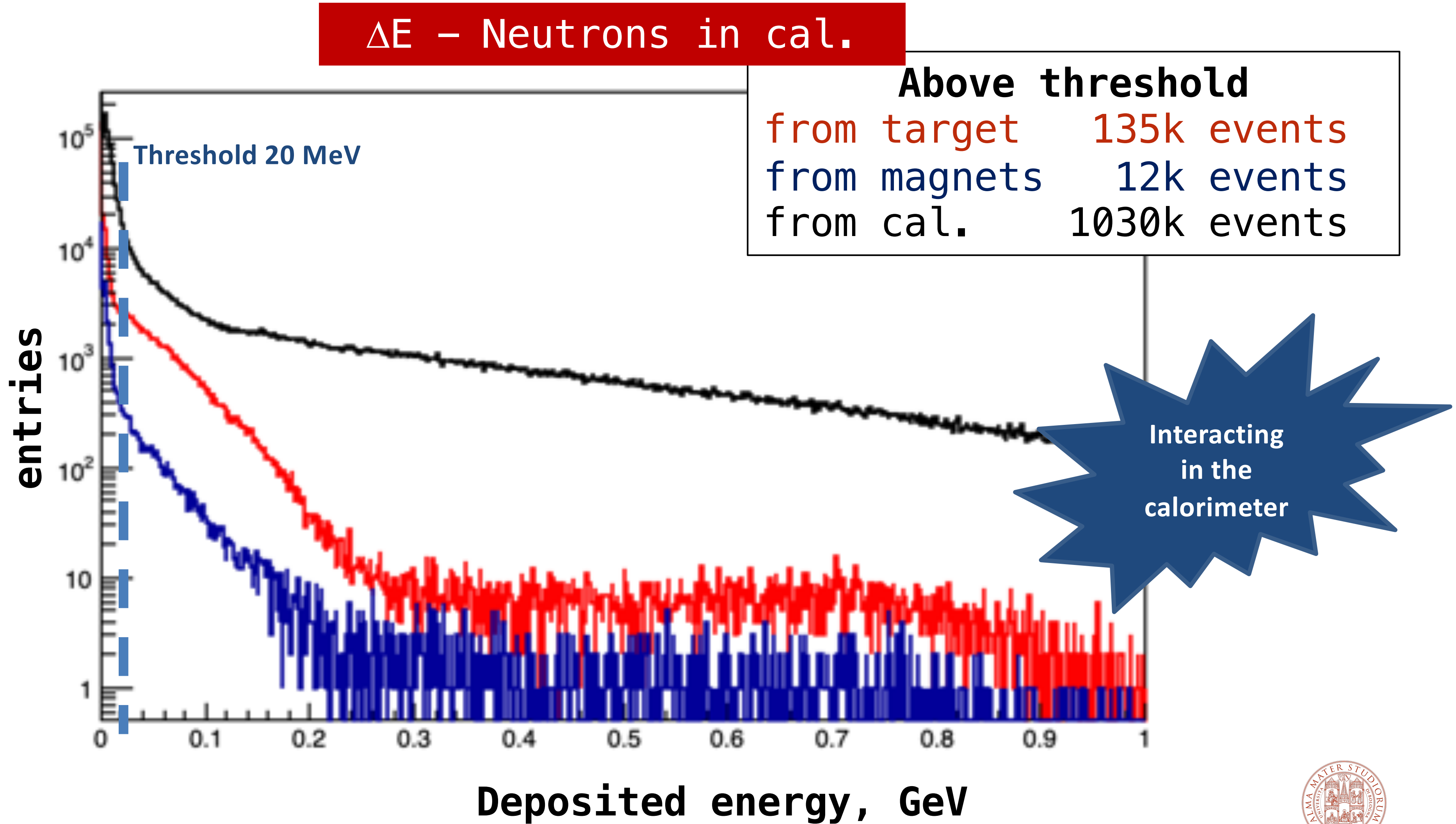


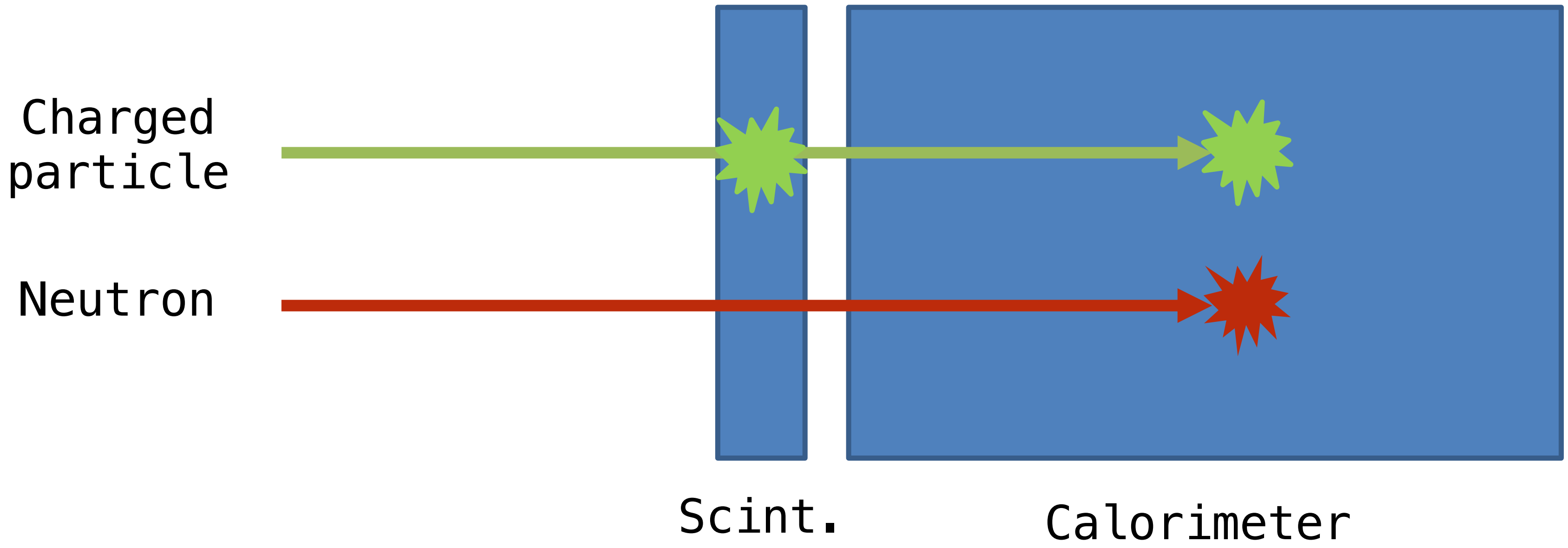
MC simulations – neutrons from target & environment

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** are not an issue **ONLY** if they **can be tagged.**
- **How to discriminate γ rays?**

Detecting neutrons with existing setup

Basic idea: **anticoincidence scintillator – calorimenter**

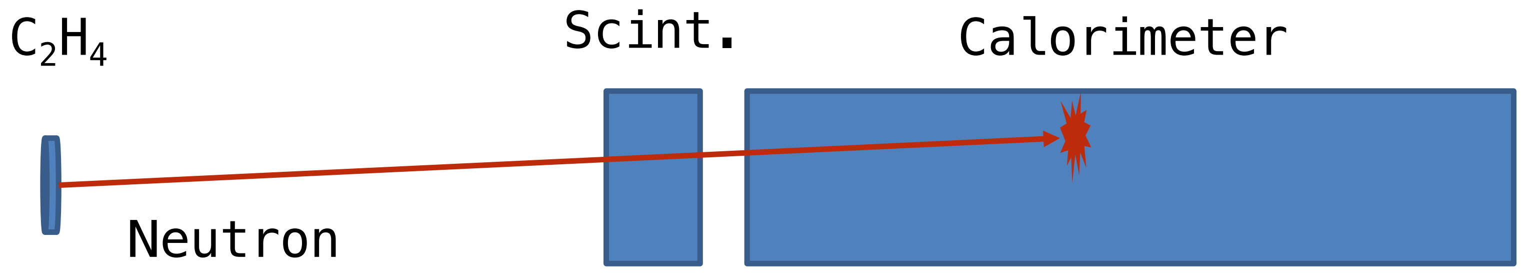


Average number of particles produced per fragmentation: 9

Granularity of scintillator and calorimenter high enough?

Detecting neutrons with existing setup

Only events from the target



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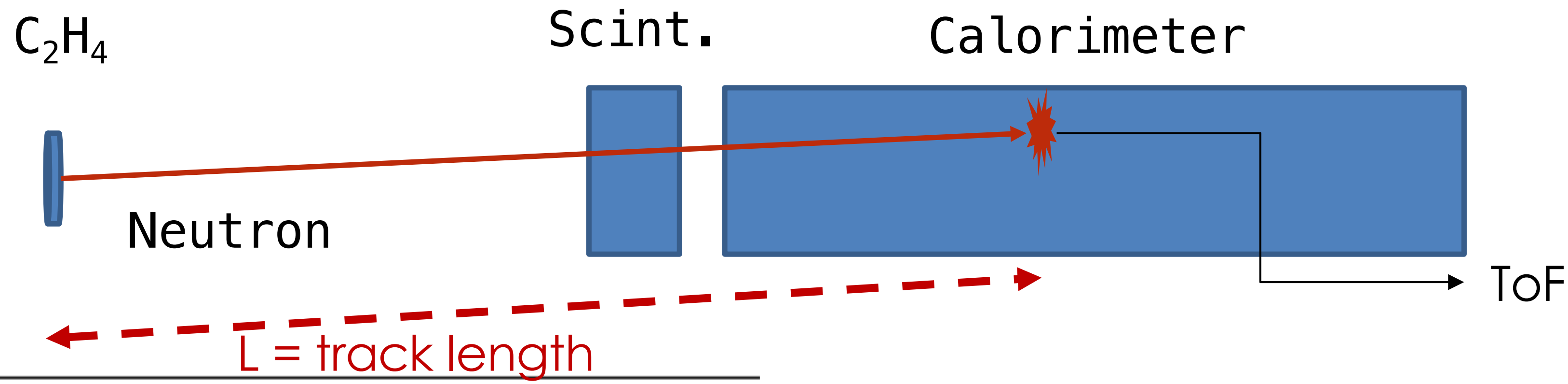

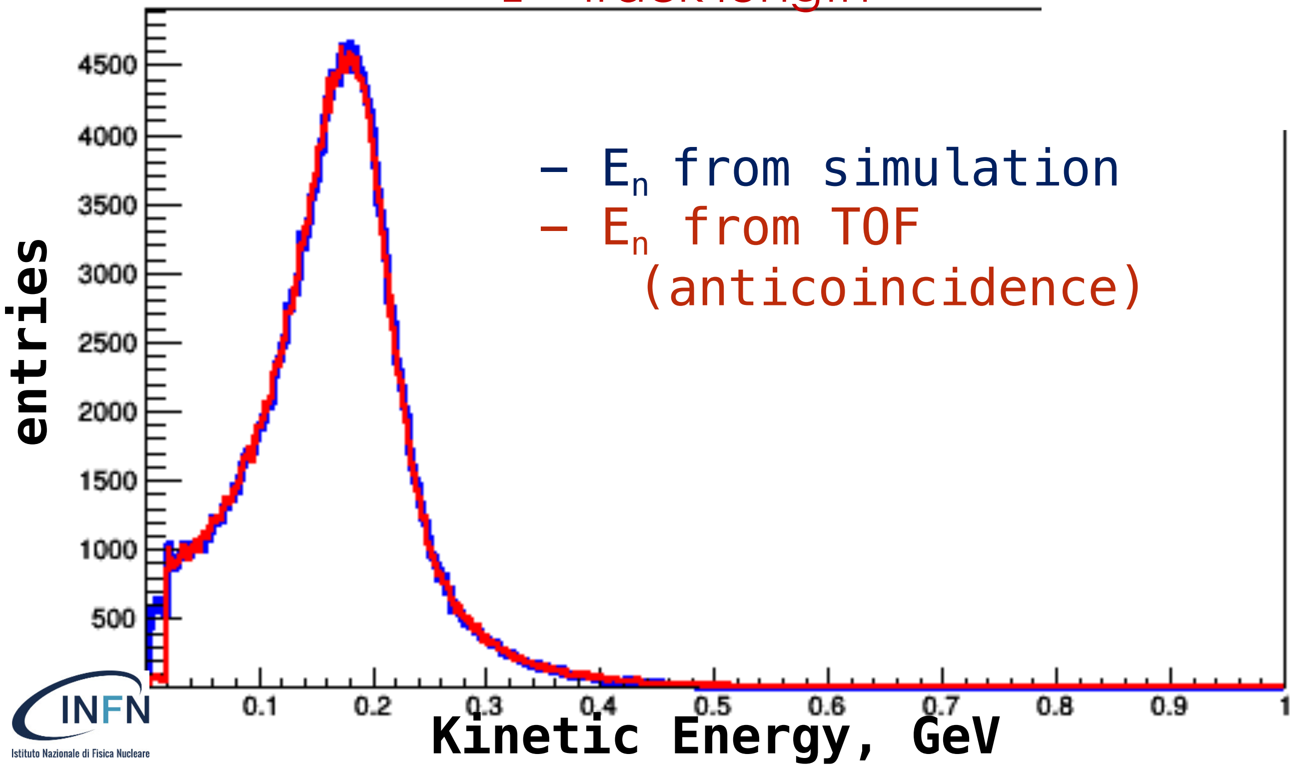

$$\gamma = \frac{1}{\sqrt{1-\beta^2}} = \frac{c\mathrm{ToF}}{\sqrt{c^2\mathrm{ToF}^2 - L^2}}$$

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

E_n	TOF
10 MeV	25 ns
20 MeV	18 ns
200 MeV	6.5 ns
500 MeV	4.8 ns

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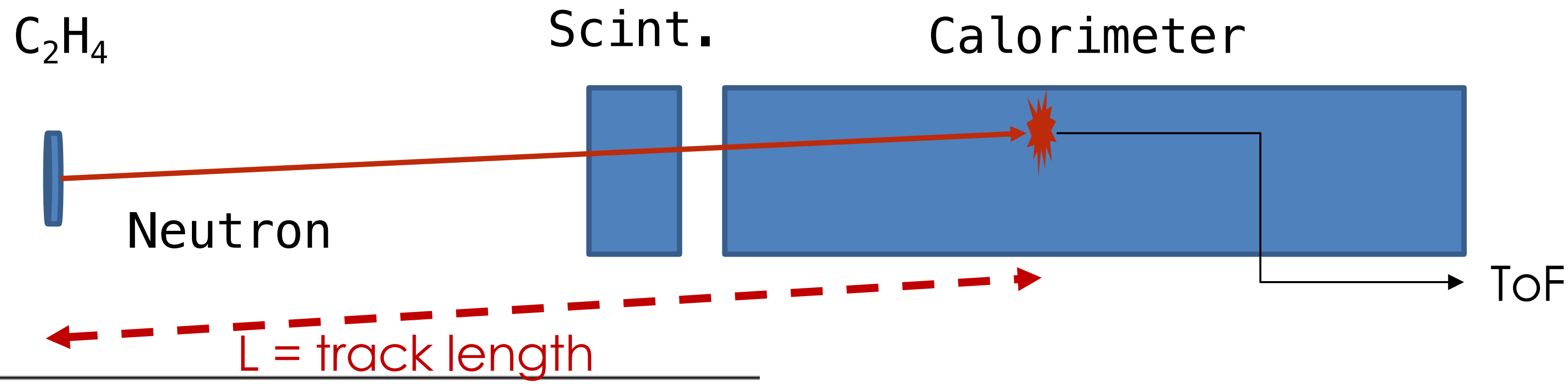
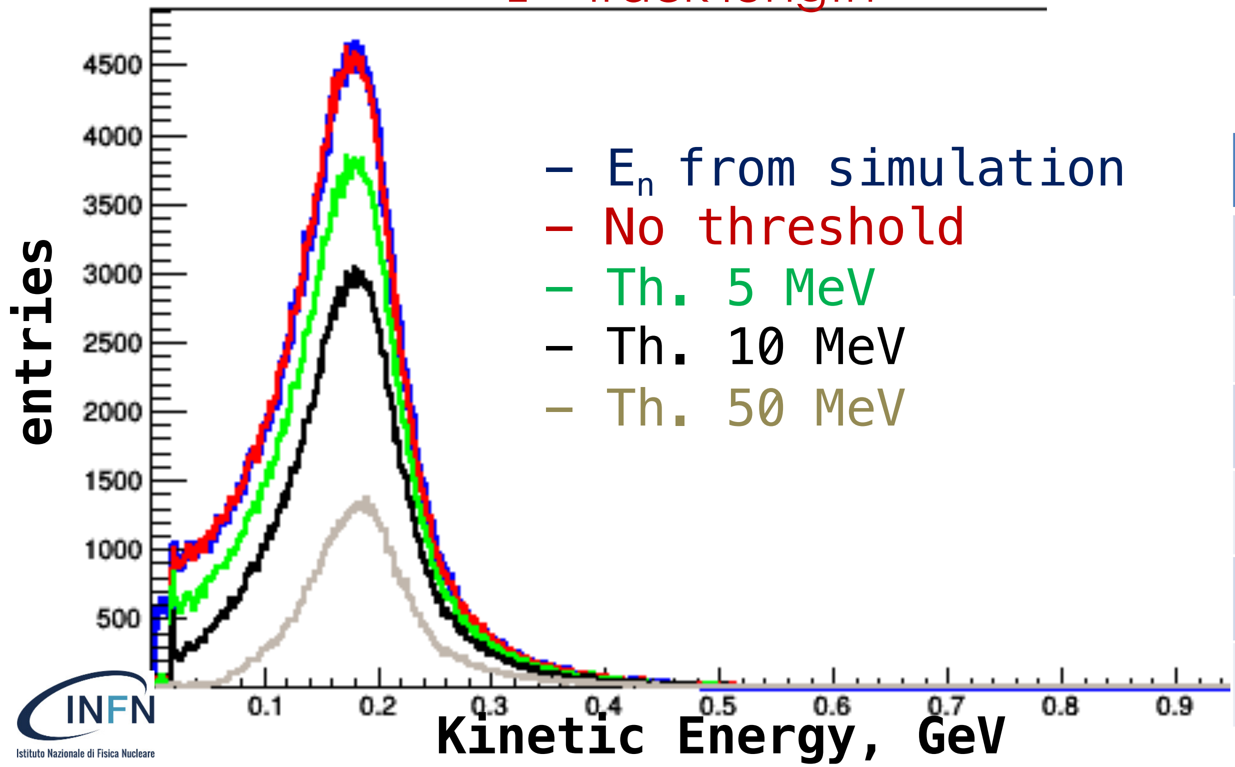
Detecting neutrons with existing setup EFFICIENCY

Only events from the target

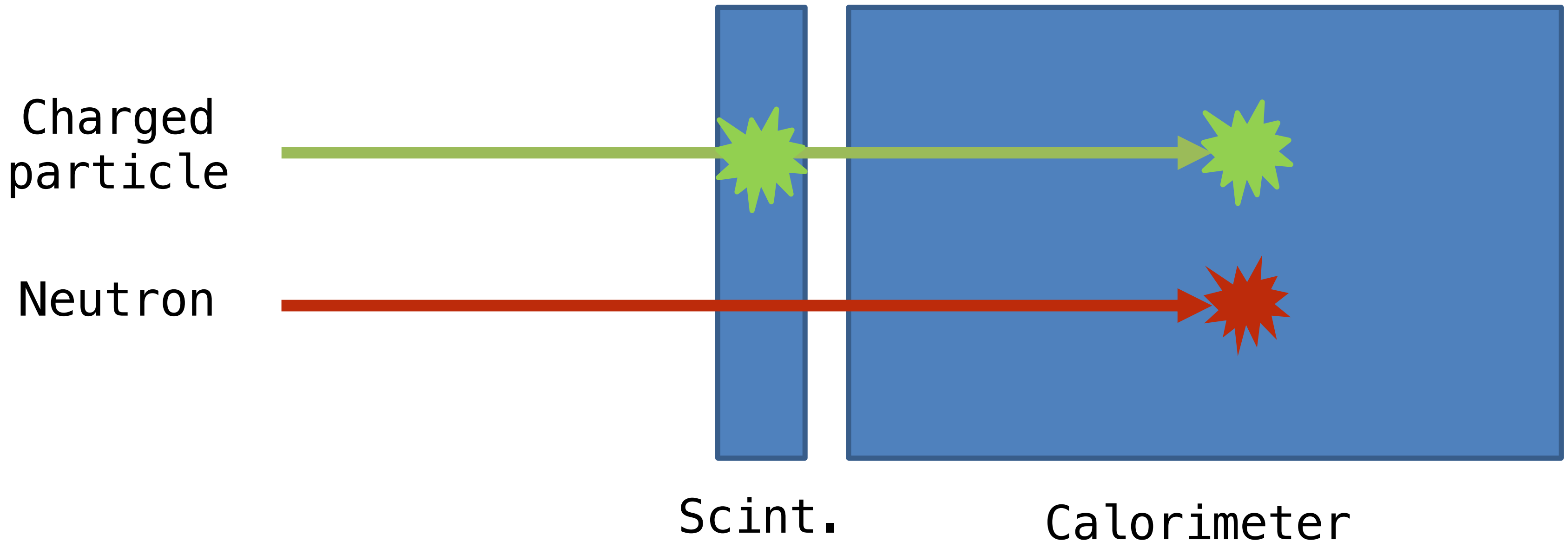




Threshold	Efficiency	
No	100%	**66%**
Fluka	75%	**46%**
5 MeV	55%	**34%**
10 MeV	45%	**28%**
20 MeV	40%	**23%**
50 MeV	20%	**12%**

Detecting neutrons with existing setup SUMMARY

Basic idea: **anticoincidence scintillator – calorimenter**



Advantages

1. Simple technique
2. Exploits current setup

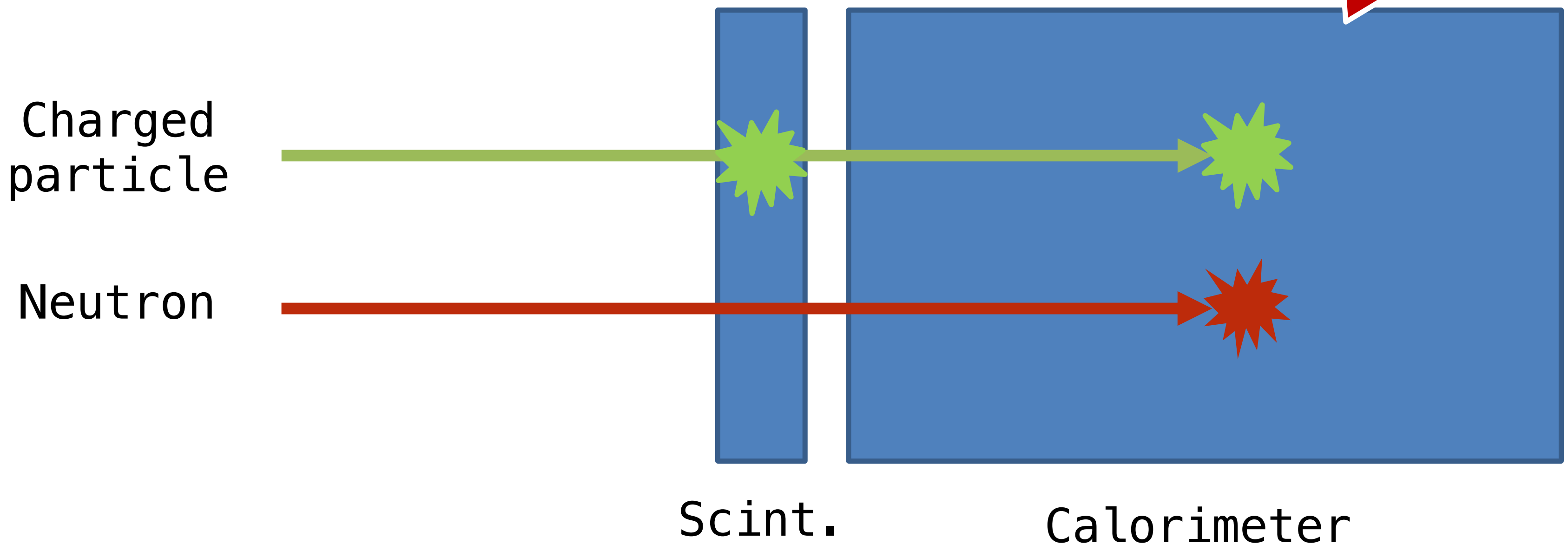
Drawbacks

1. n/γ discrimination
2. Tagging neutrons from calorimeter

Detecting neutrons with existing setup

Drawback 1: n/γ

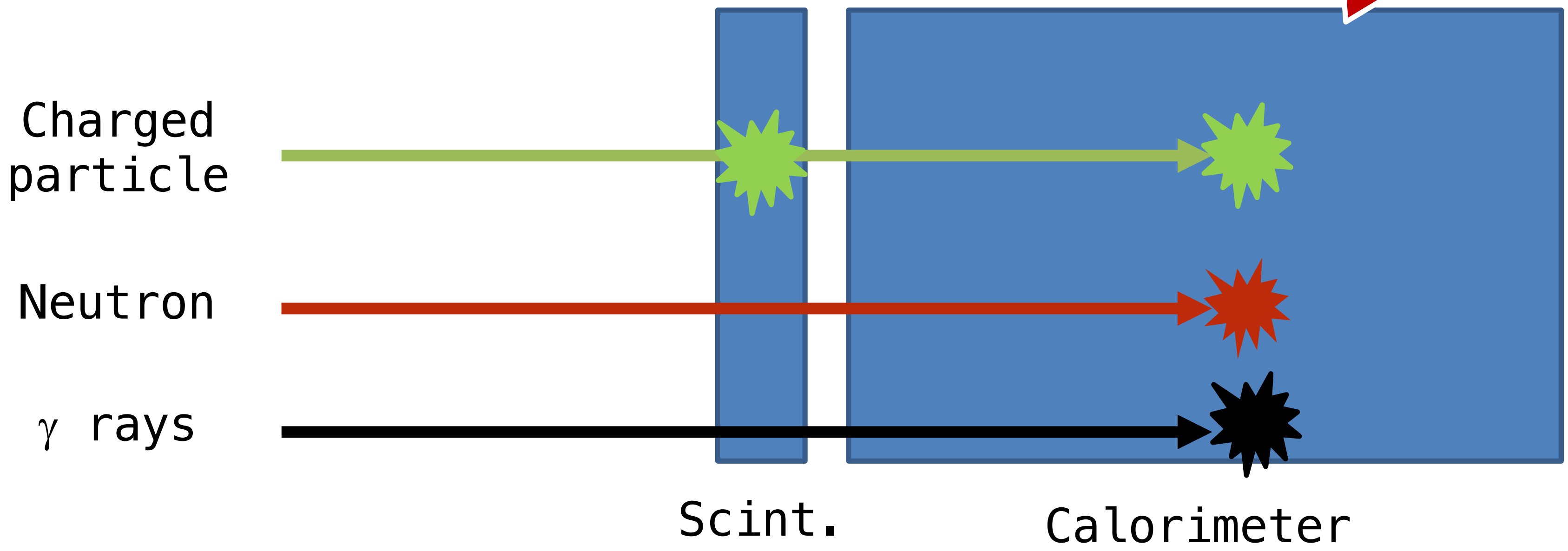
Basic idea: **anticoincidence scintillator – calorimenter**



Detecting neutrons with existing setup

Drawback 1: n/γ

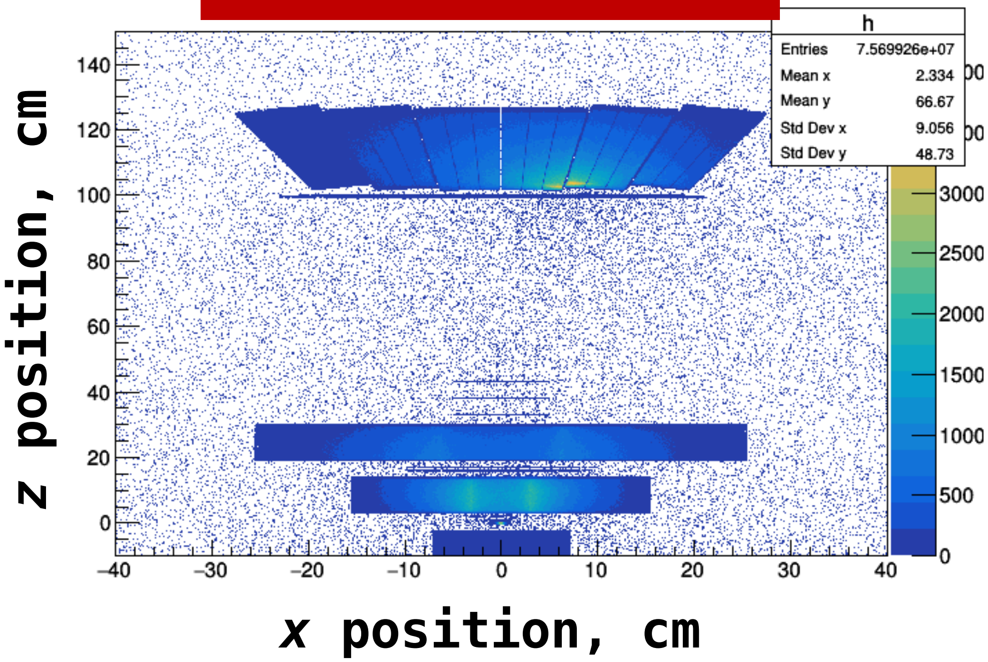
Basic idea: **anticoincidence scintillator – calorimenter**



γ rays can feature the same signature

Detecting neutrons with existing setup

75.7×10^6 γ rays
23.3×10^6 neutrons

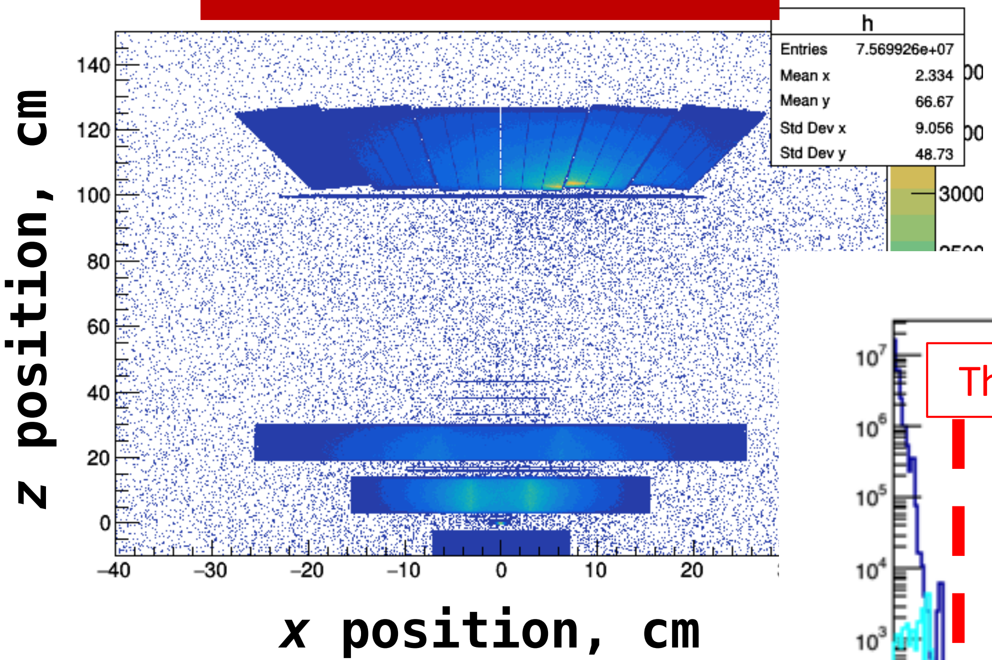


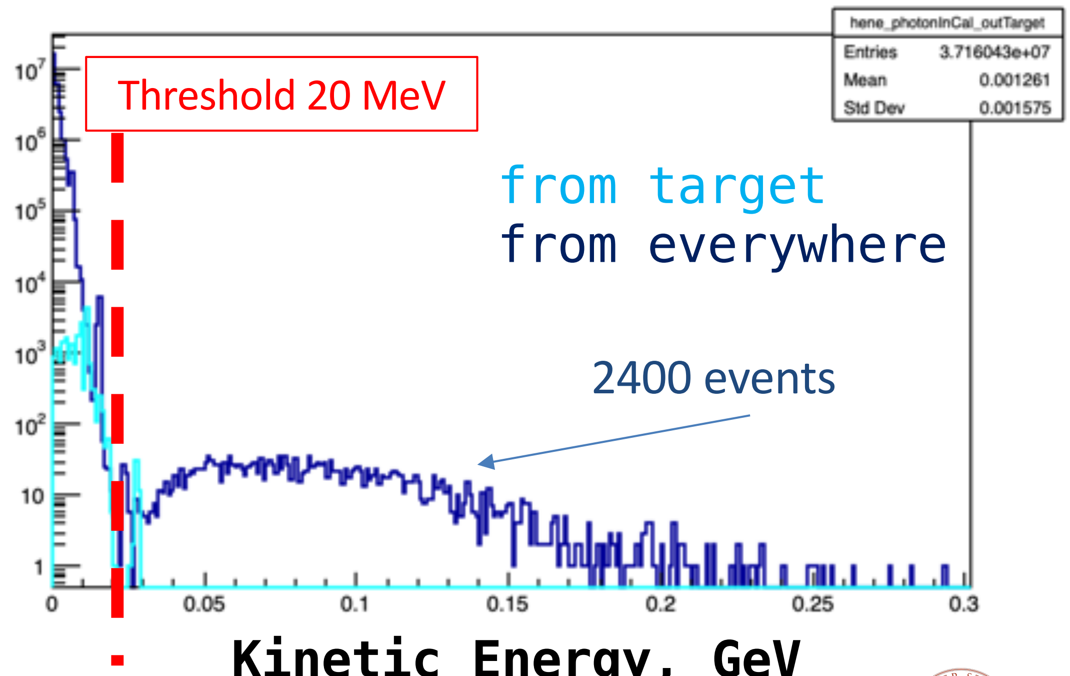
Drawback 1:
n/γ

Detecting neutrons with existing setup

Drawback 1: n/γ

75.7x10⁶ γ rays
23.3x10⁶ neutrons



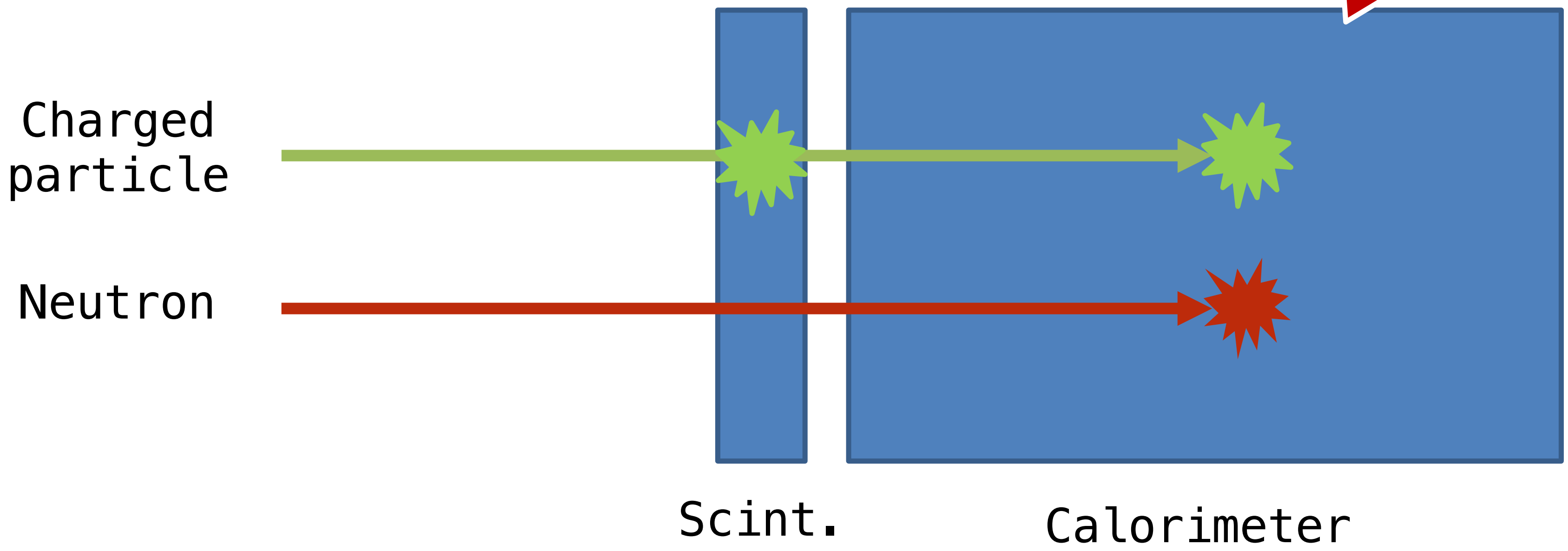


A discrimination level of **20 MeV** makes this **background negligible**

Detecting neutrons with existing setup

Drawback 2:
cal. neutrons

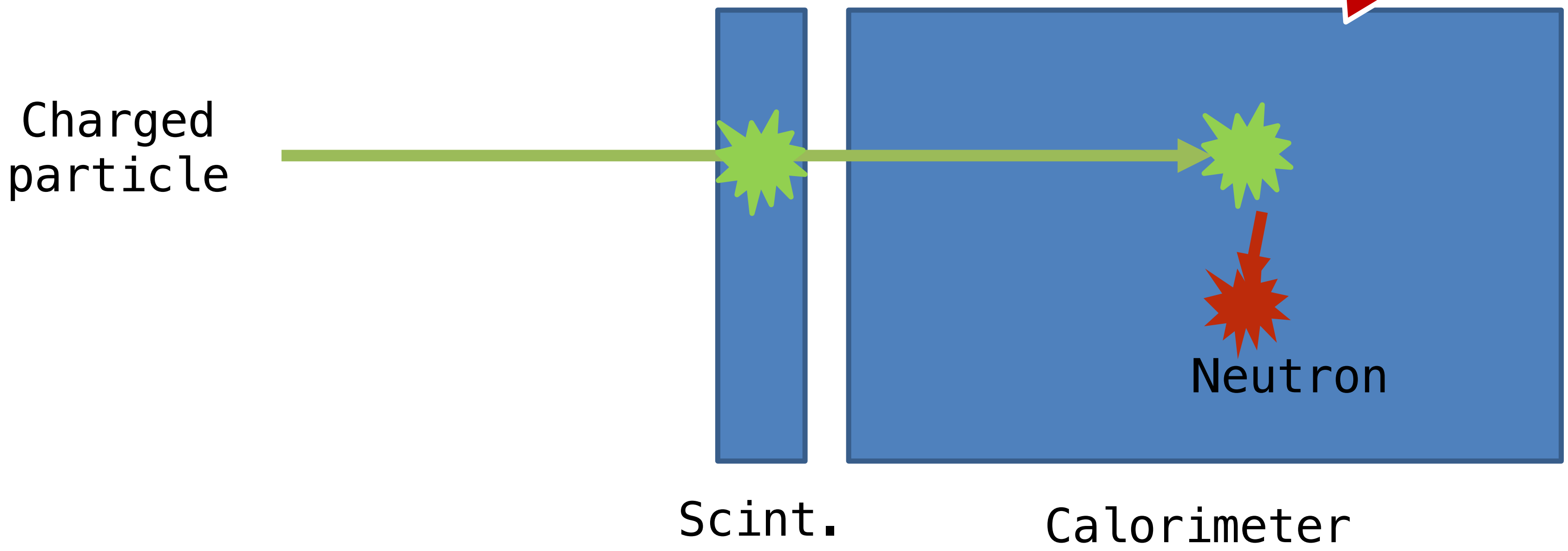
Basic idea: **anticoincidence scintillator – calorimenter**



Detecting neutrons with existing setup

Drawback 2: cal. neutrons

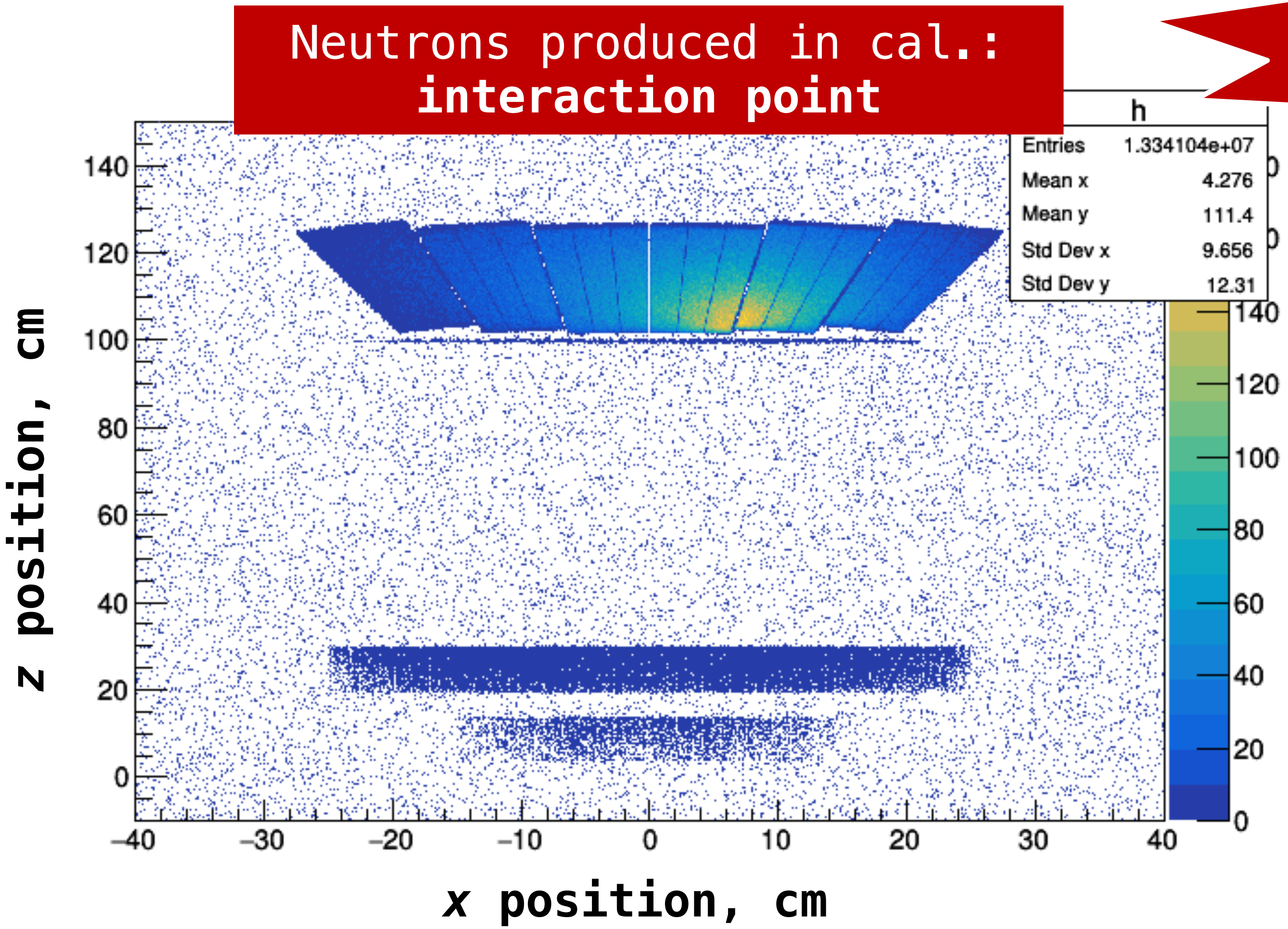
Basic idea: **anticoincidence scintillator – calorimenter**



Neutrons produced in the calorimeter cannot be easily tagged

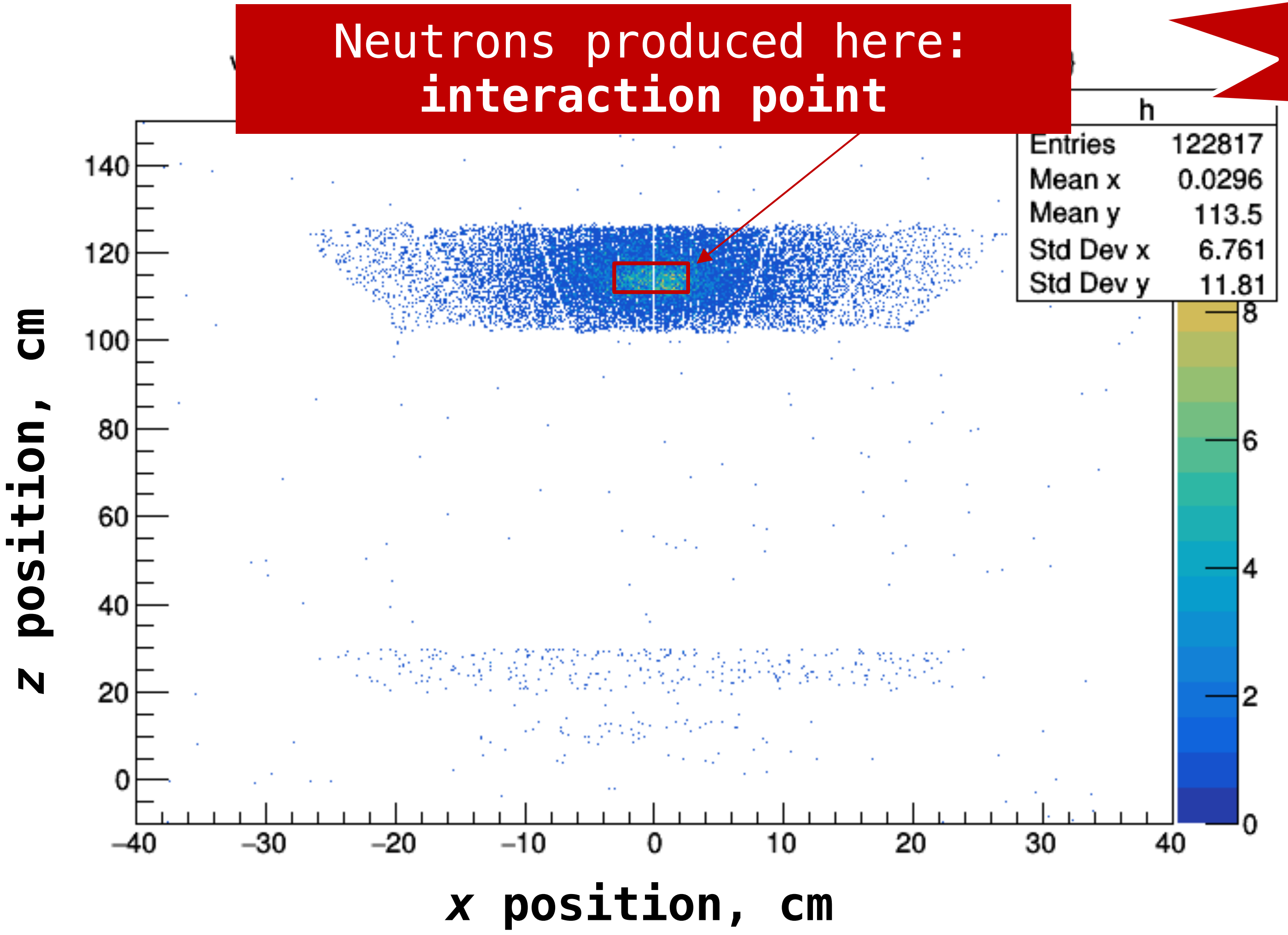
Detecting neutrons with existing setup

Drawback 2:
cal. neutrons

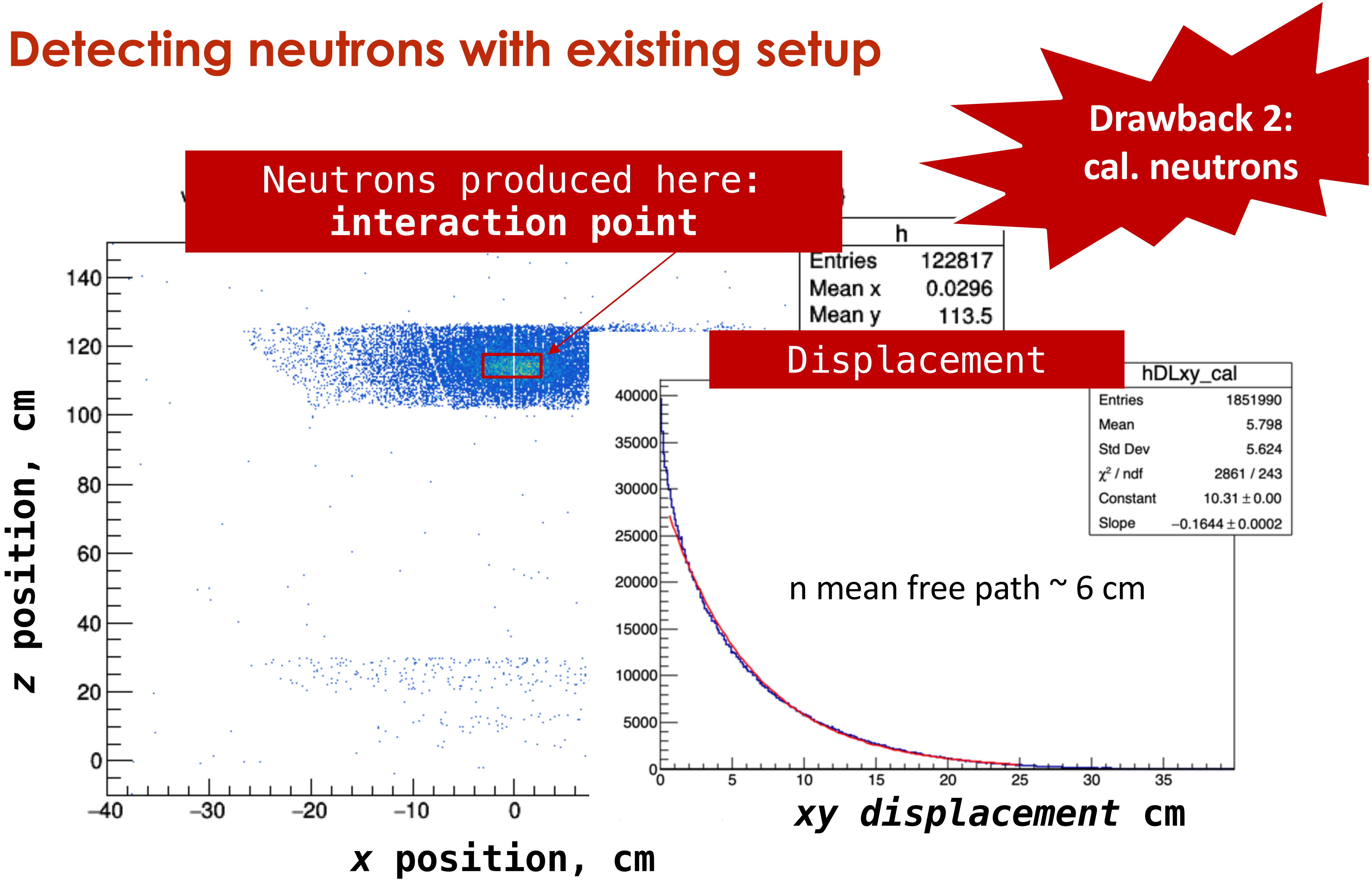


Detecting neutrons with existing setup

Drawback 2: cal. neutrons

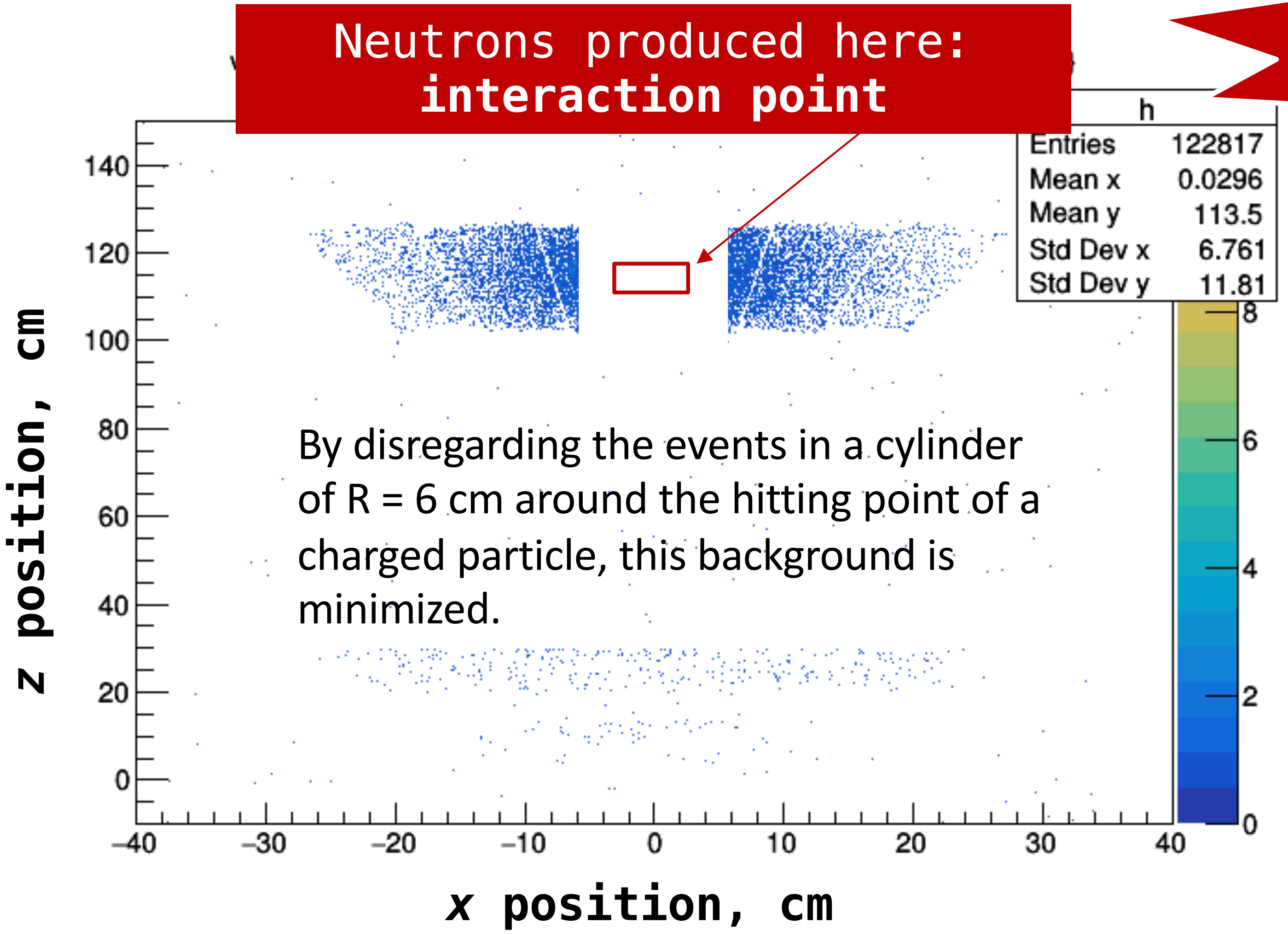


Detecting neutrons with existing setup



Detecting neutrons with existing setup

Drawback 2:
cal. neutrons



By disregarding the events in a cylinder of R = 6 cm around the hitting point of a charged particle, this background is minimized.

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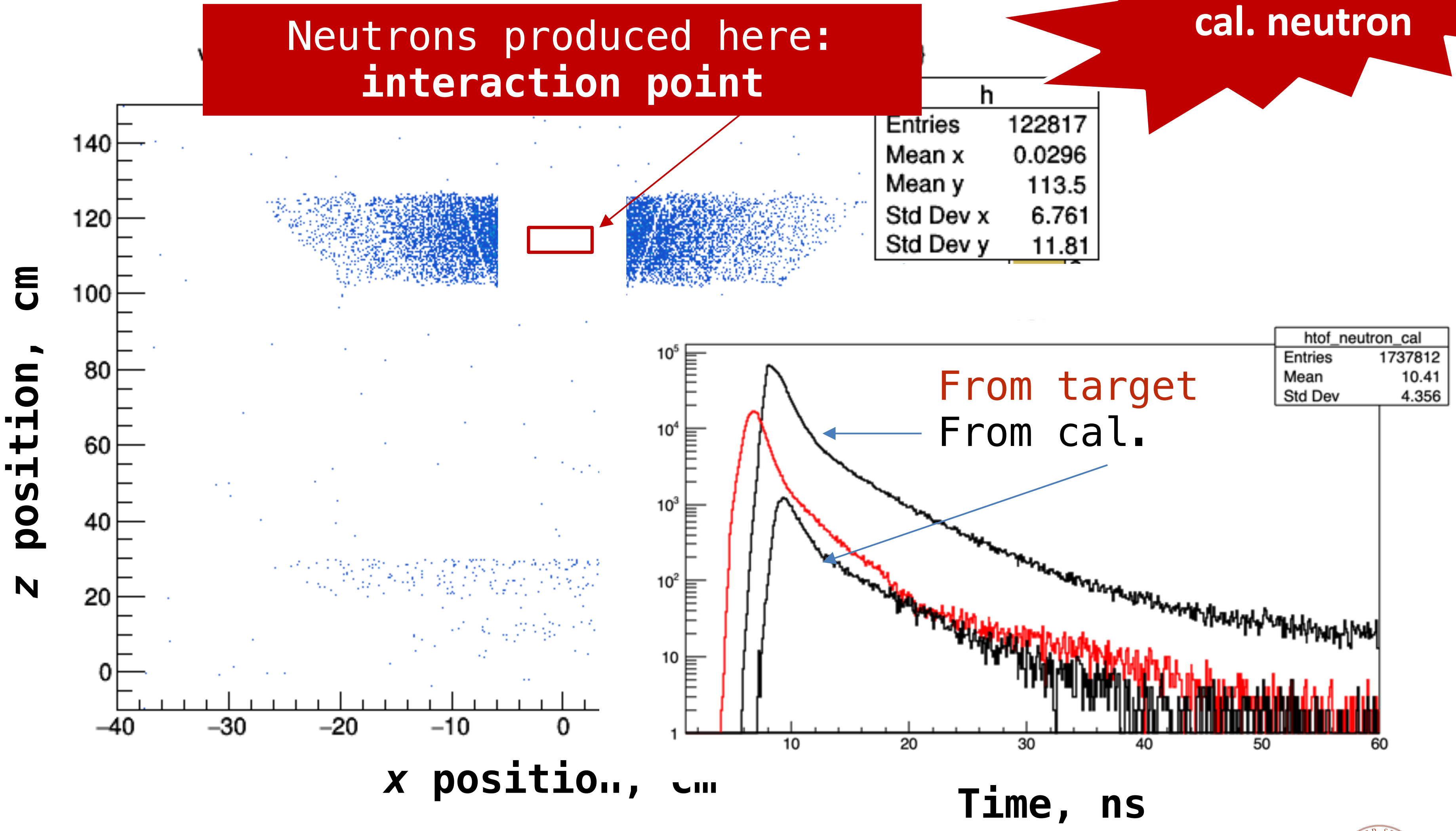
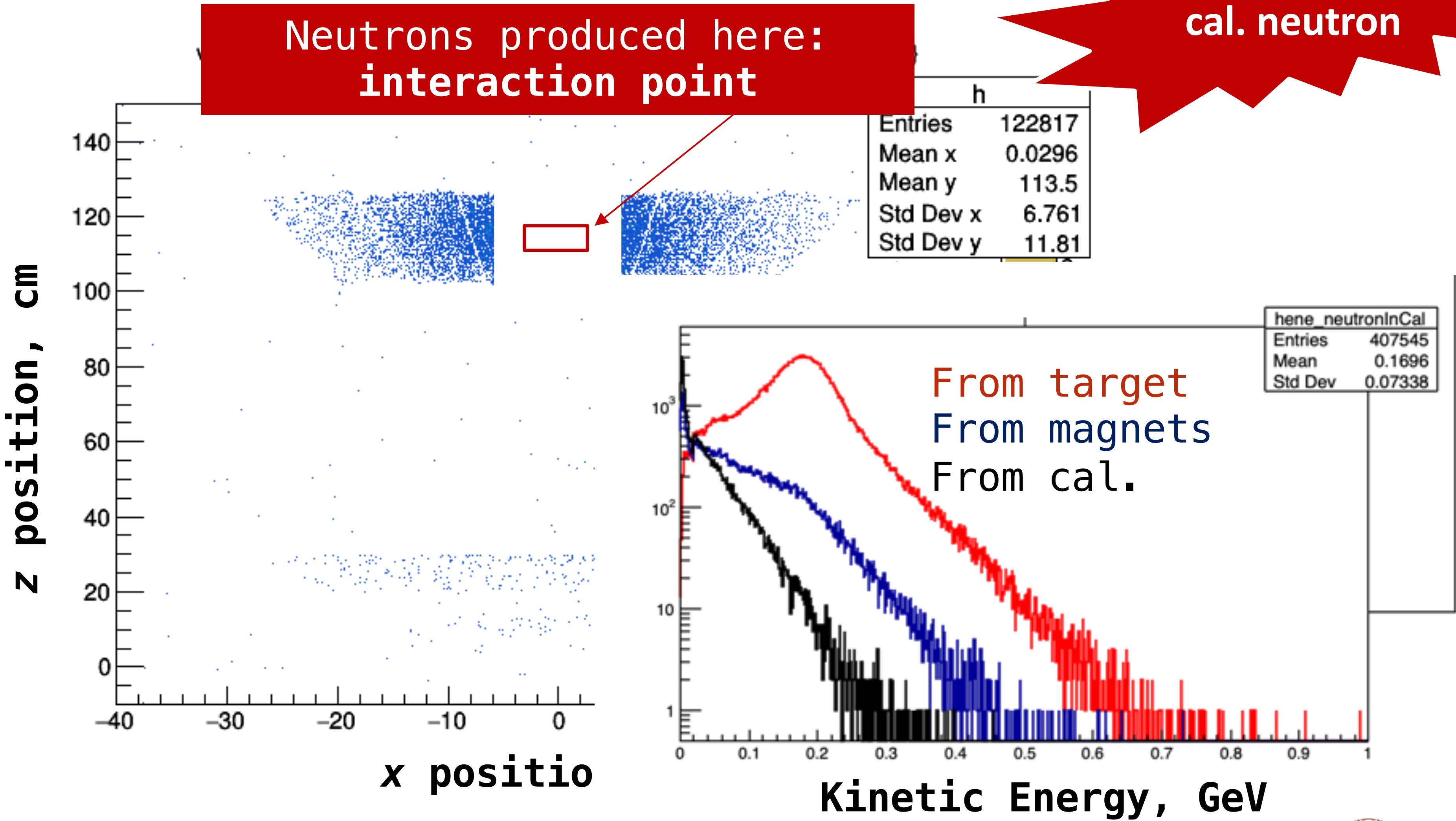
Detecting neutrons with existing setup

Drawback 2: cal. neutron



Detecting neutrons with existing setup

Drawback 2:
cal. neutron



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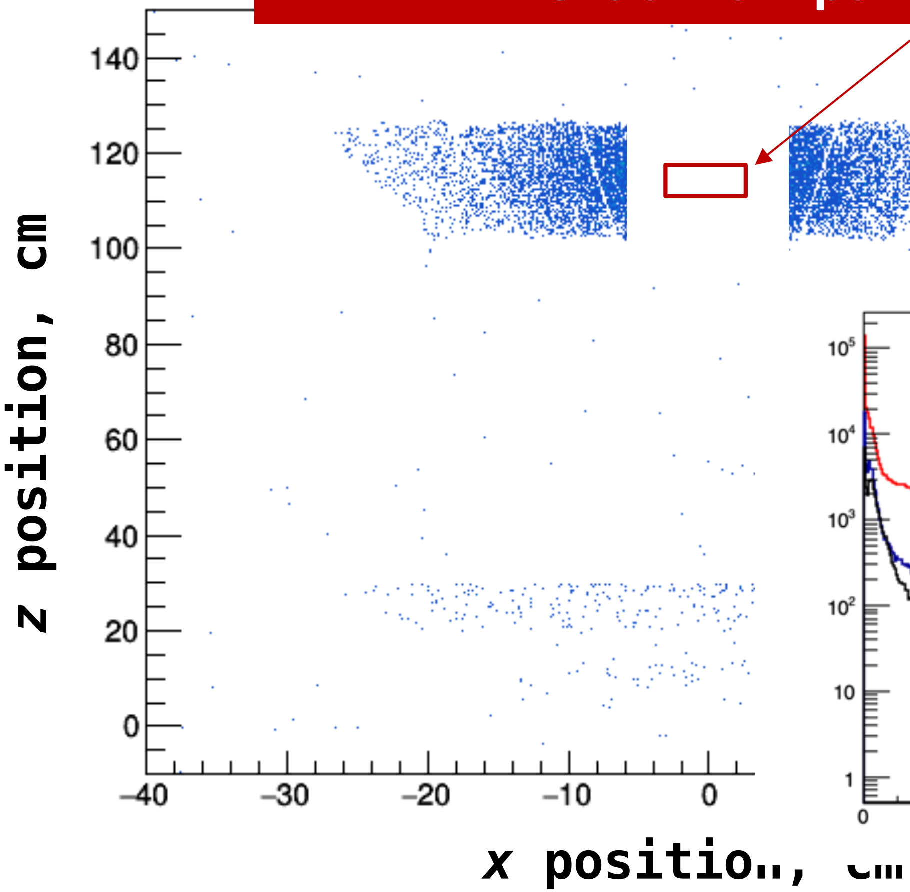
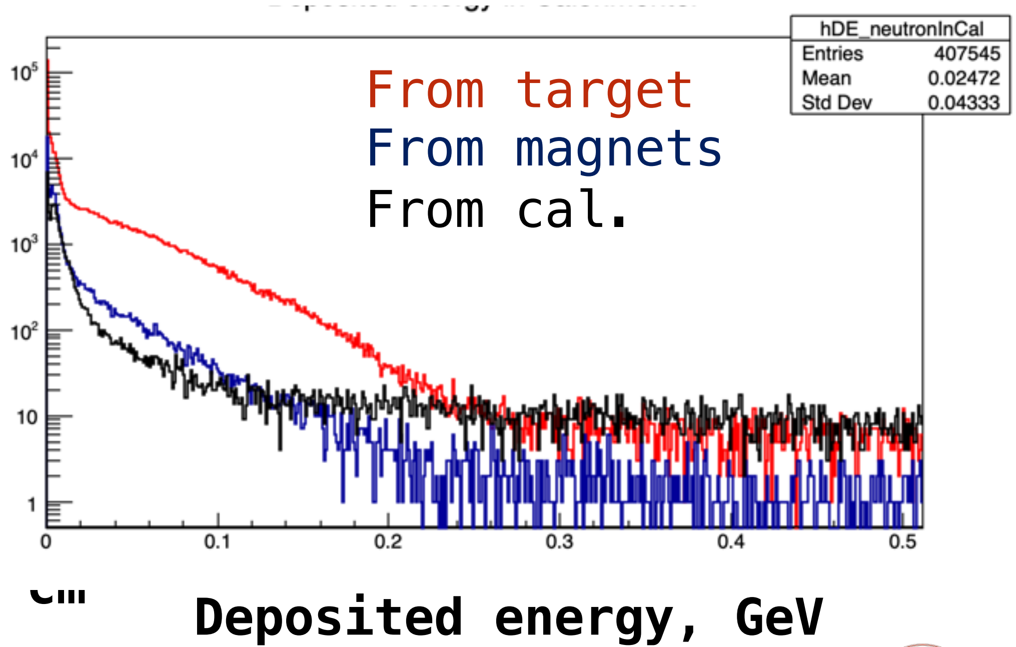
Detecting neutrons with existing setup

Drawback 2:
cal. neutron

Neutrons produced here:
interaction point

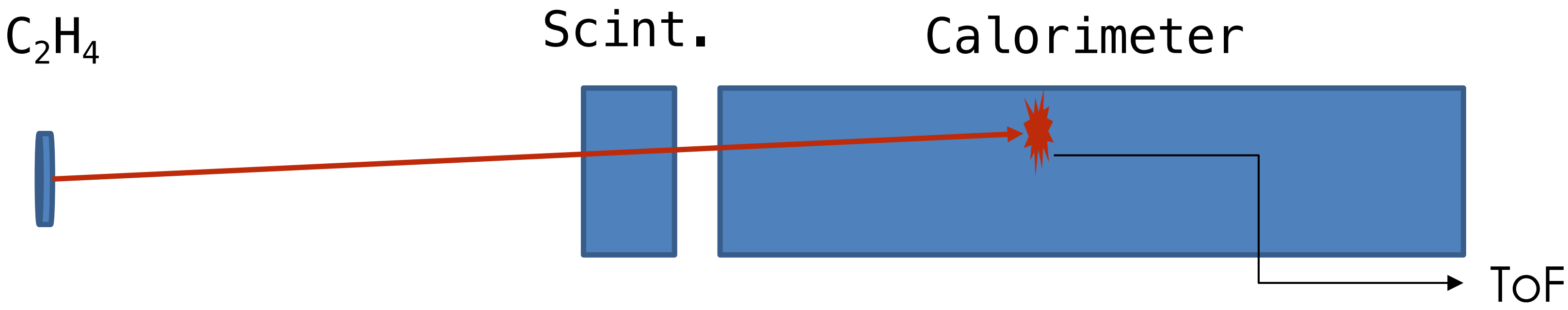


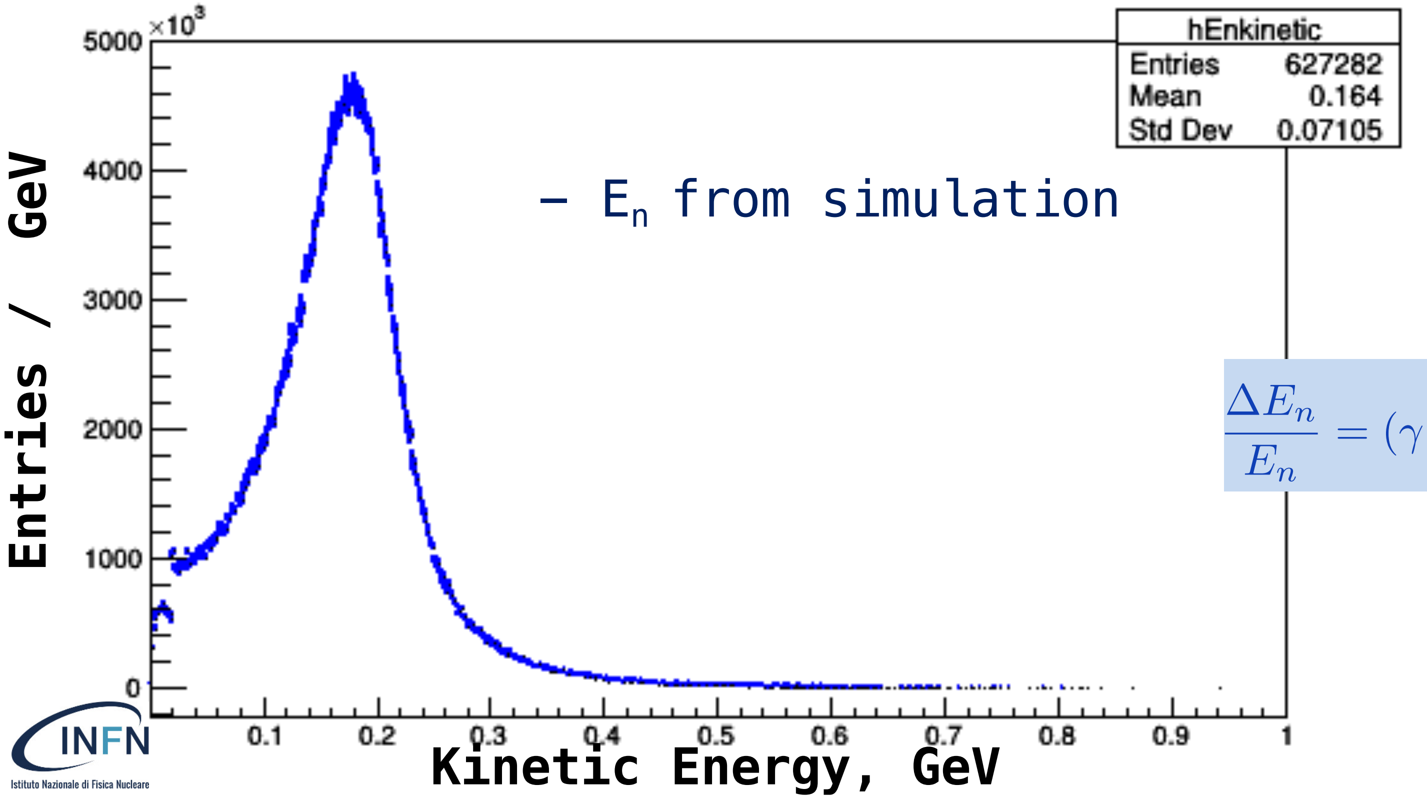


Detecting neutrons with existing setup

ΔE/E

Only events from the target





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

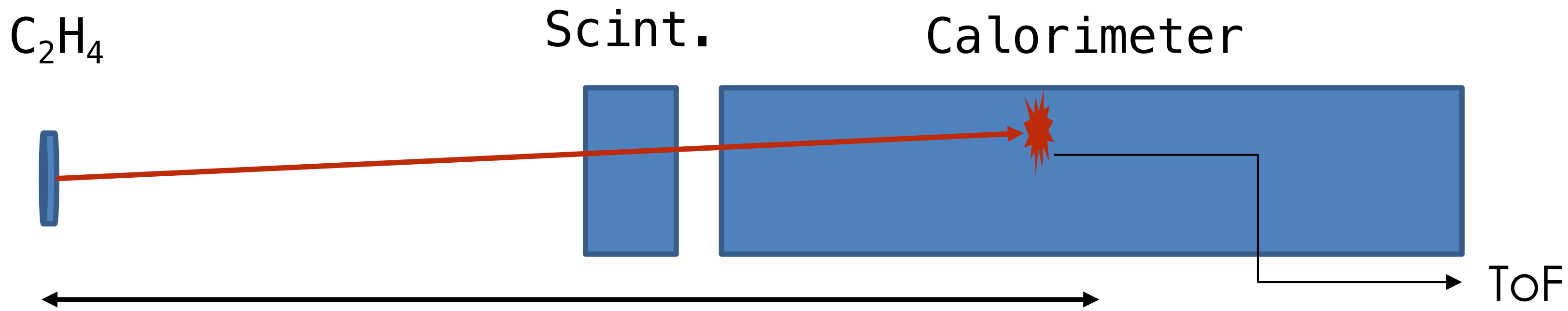
$$E_n = mc^2(\gamma - 1)$$

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

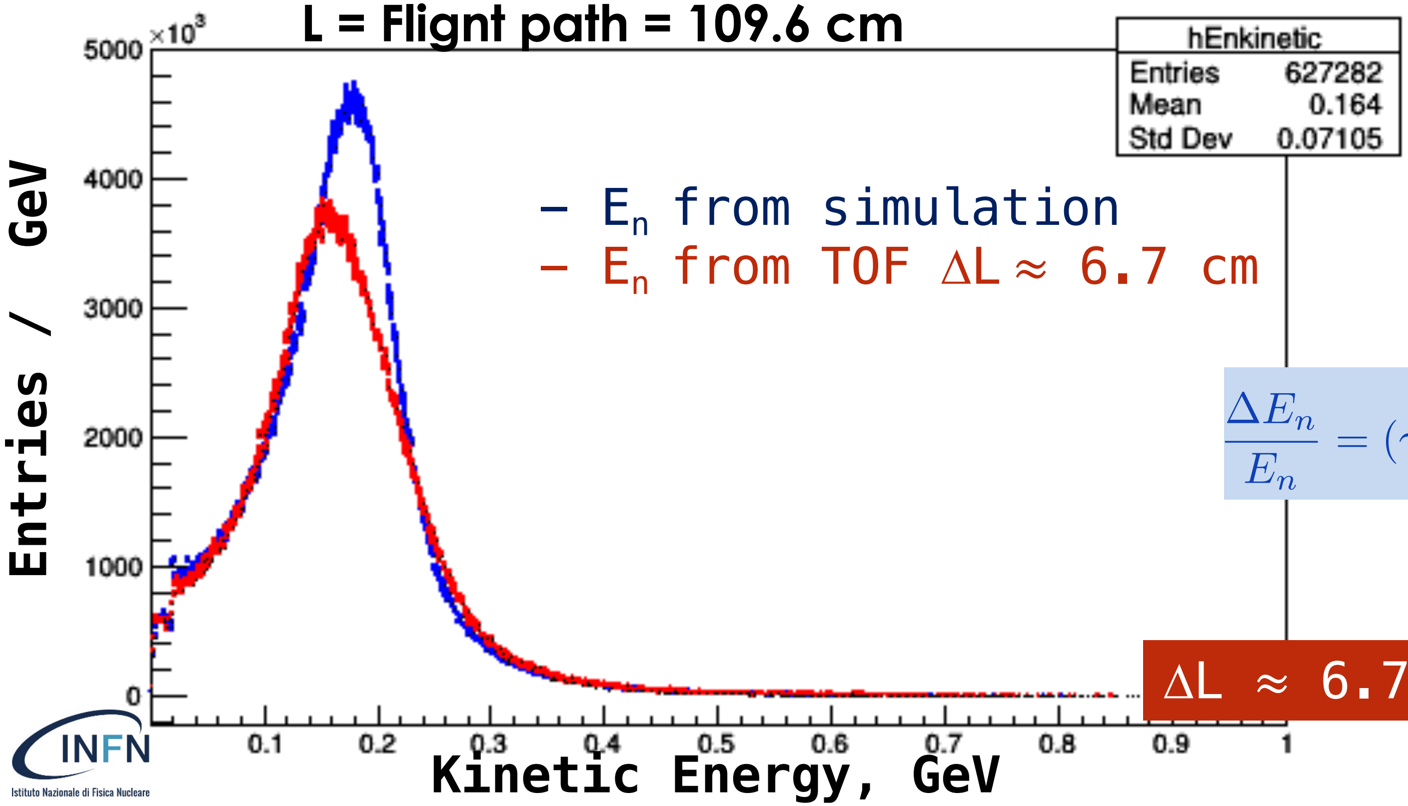
Detecting neutrons with existing setup

ΔE/E

Only events from the target



L = Flignt path = 109.6 cm



ΔL ≈ 6.7 cm

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

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

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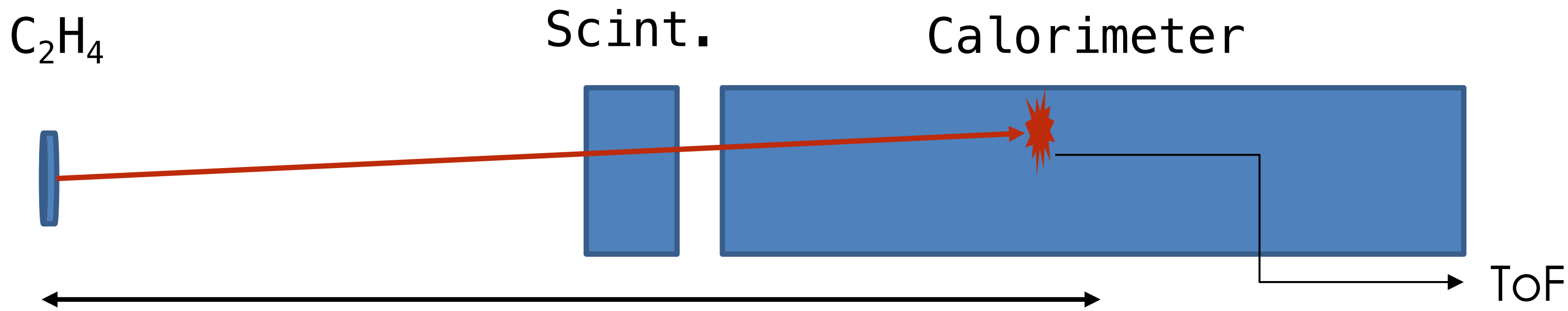
Detecting neutrons with existing setup

ΔE/E

Only events from the target



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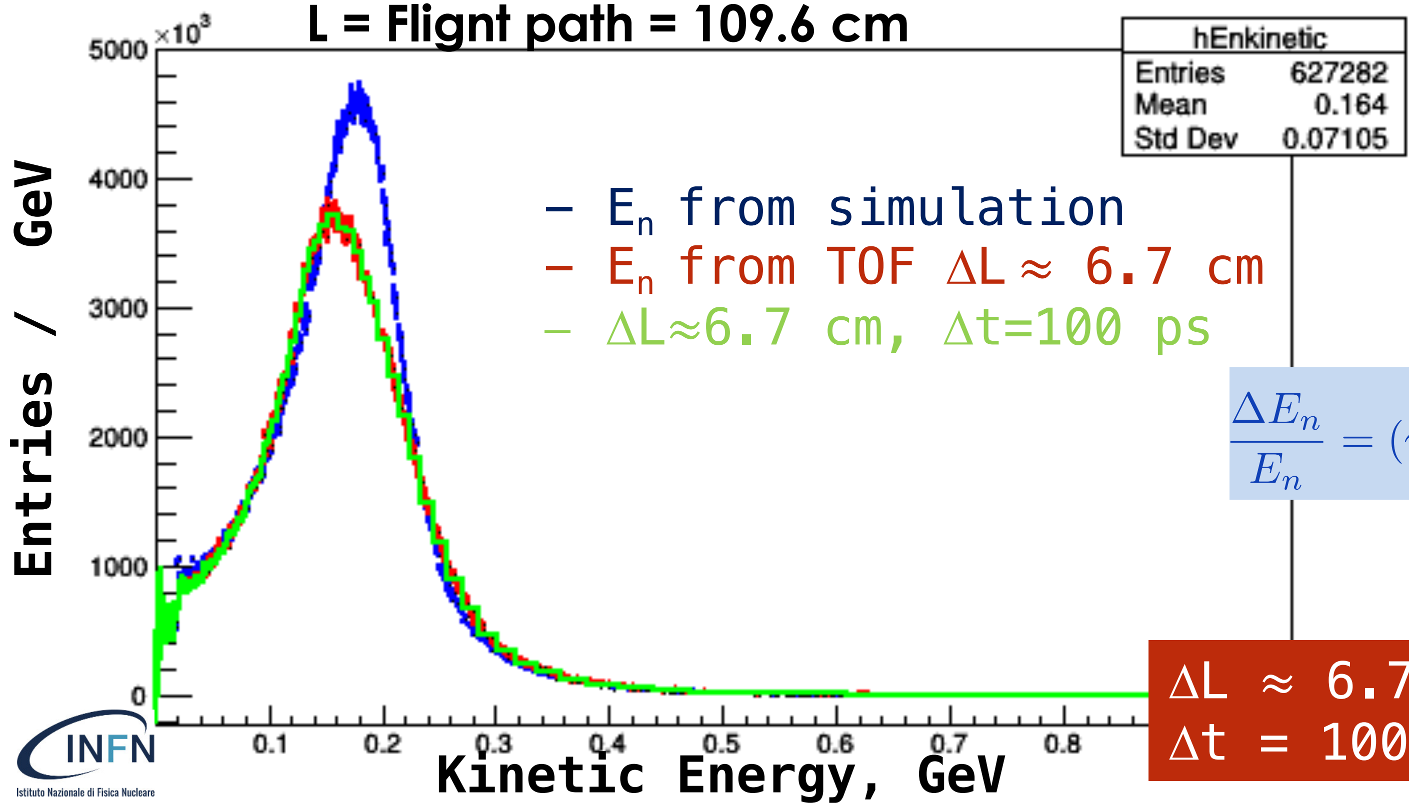

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$$E_n = mc^2(\gamma - 1)$$

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

ΔL ≈ 6.7 cm
Δt = 100 ps

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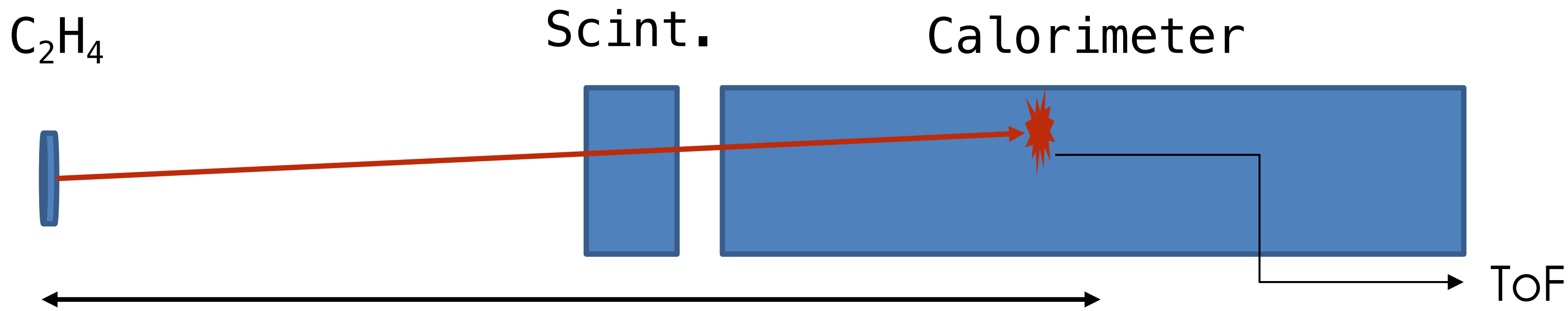
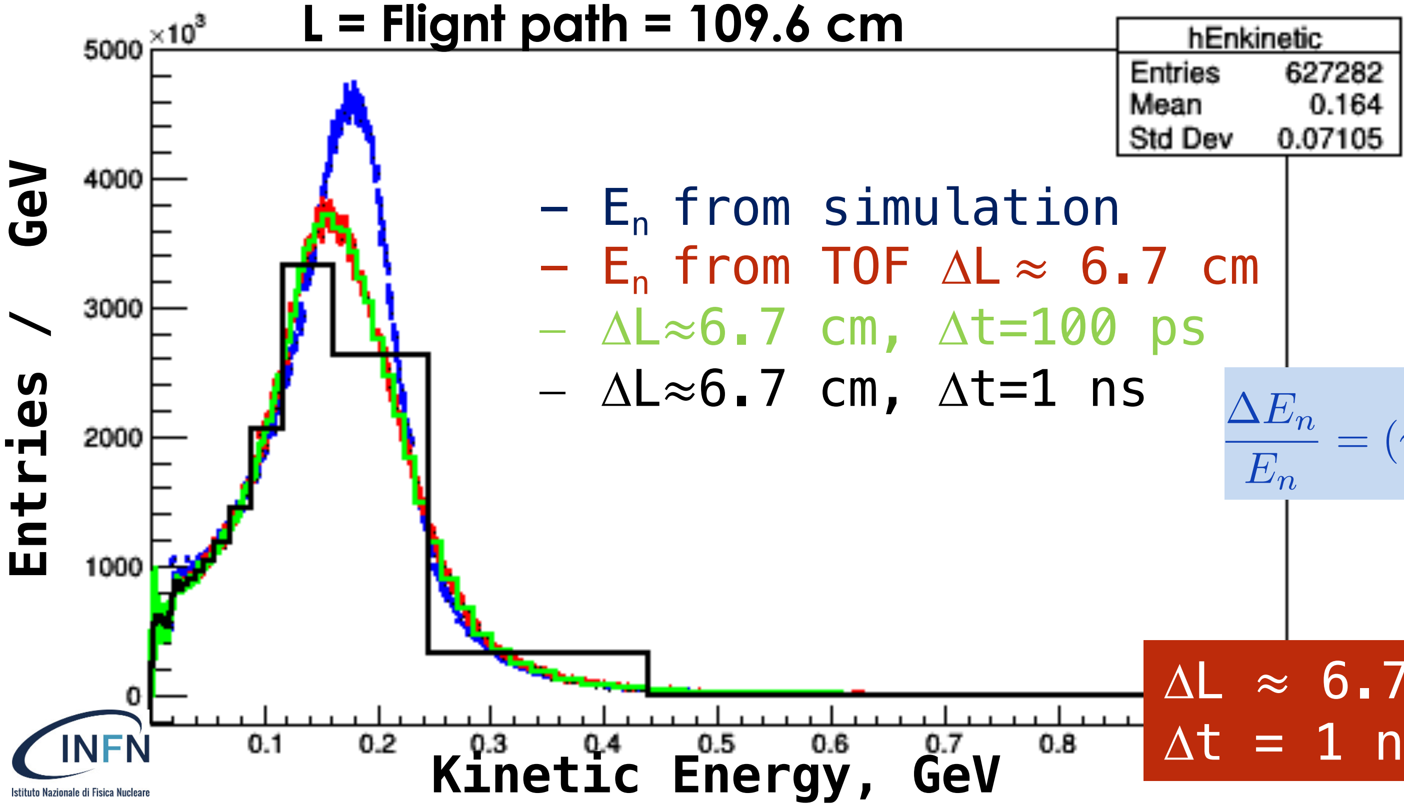
Detecting neutrons with existing setup

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

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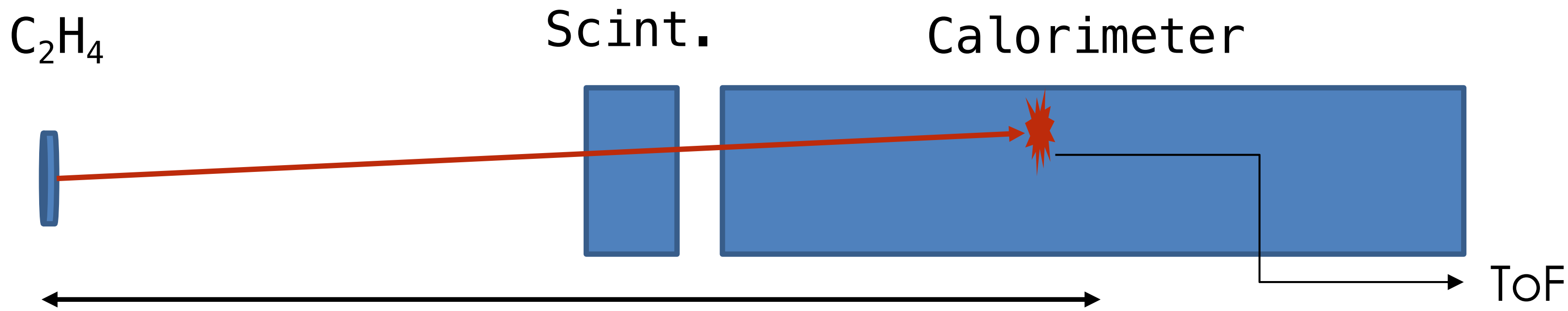
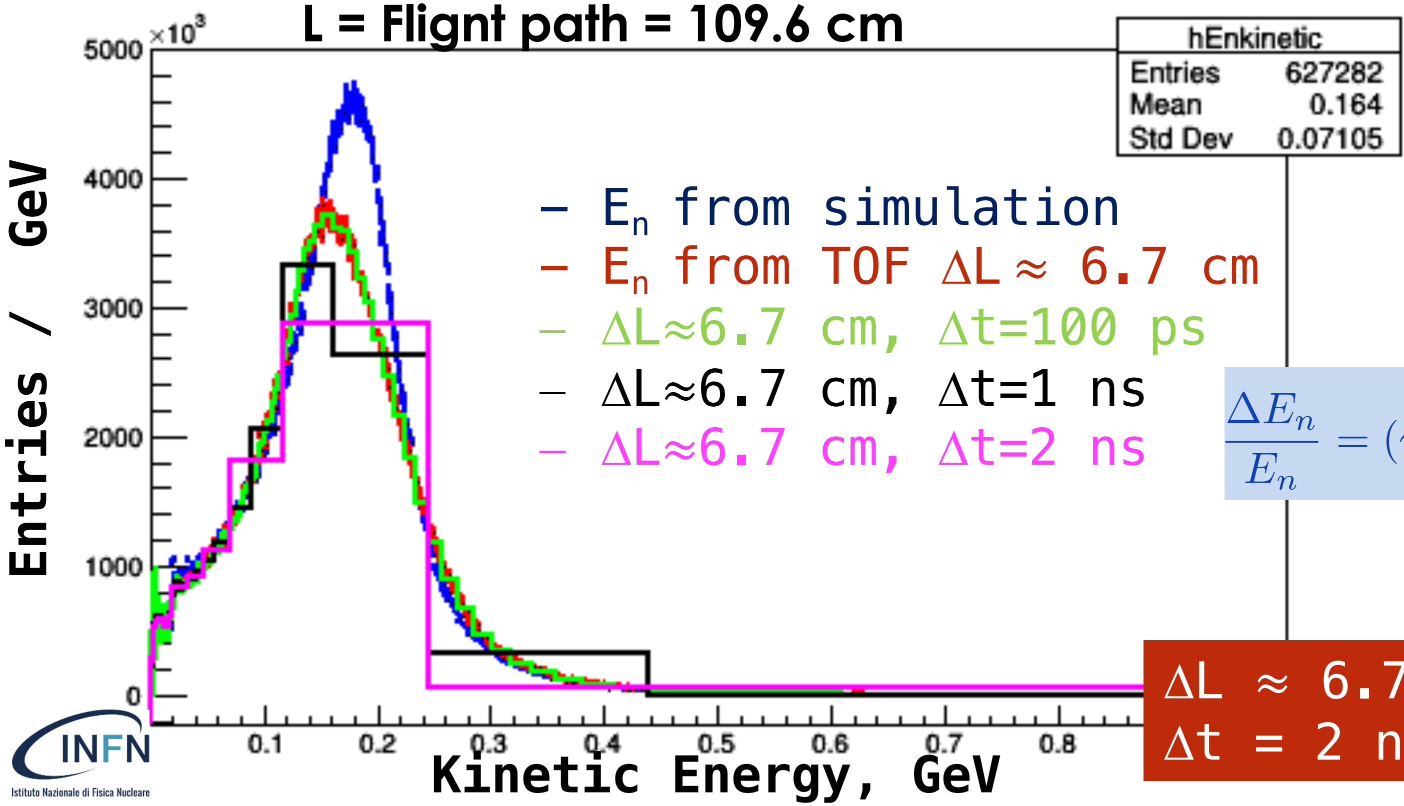
Detecting neutrons with existing setup $\Delta E/E$

Only events from the target



L = Flignt path = 109.6 cm



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

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

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

$\Delta L \approx 6.7$ cm
$\Delta t = 2$ ns

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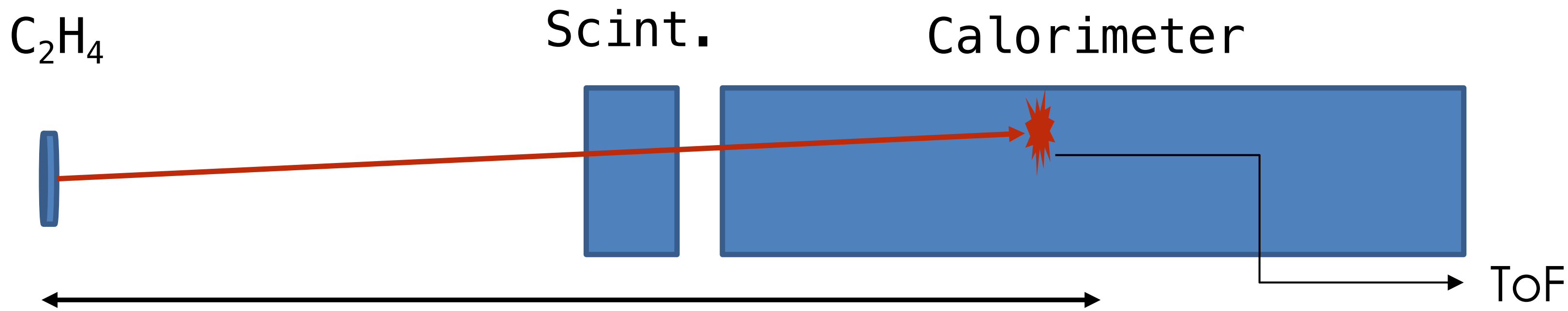
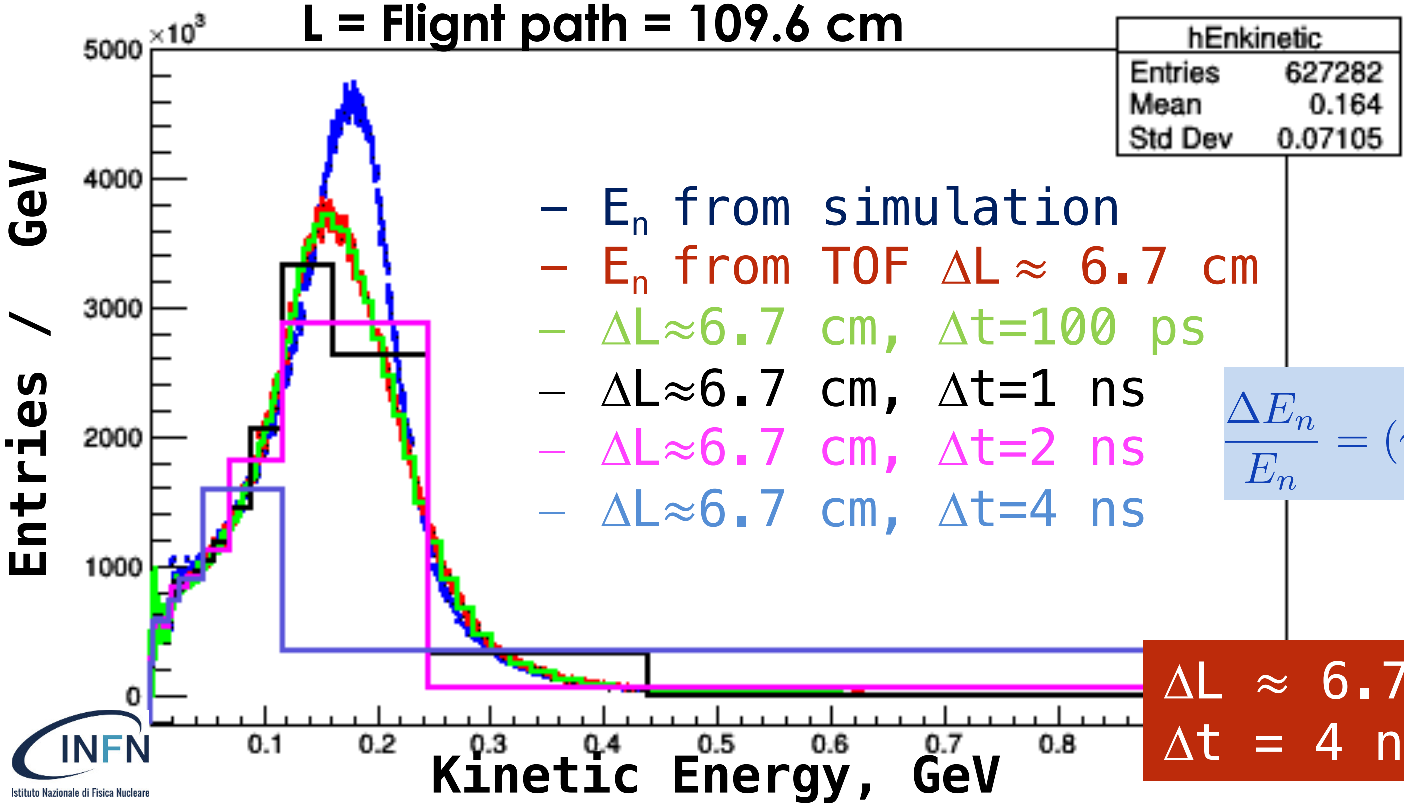
Detecting neutrons with existing setup

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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Conclusions

- We are studying the possibility of using the **present setup** to have some information about **neutrons**.

- Due to the large production of neutrons in the FOOT setup, neutron detectors based on their moderation are not suited.

- A few information for **high-energy neutrons only**, by **using the (traker +) scintillator and the calorimenter**, provided that the **calorimenter time resolution** is better than **1 ns**.

- the impact of γ **rays** is **negligible** if E_{dep} > 20 MeV.

- Typical efficiency of the current setup ~ 20%. **Concern**: the efficiency is derived from a simulation.

- **Better to work in direct kinematics (backup slides)**

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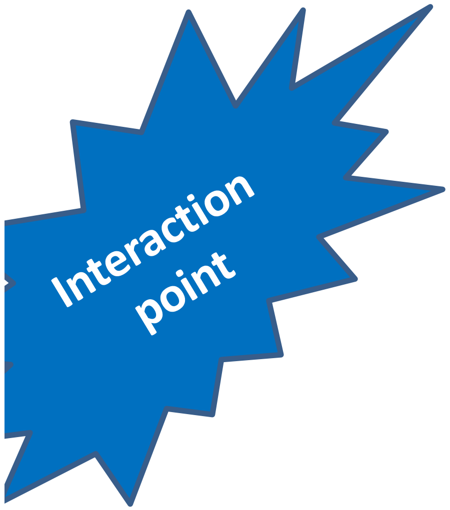
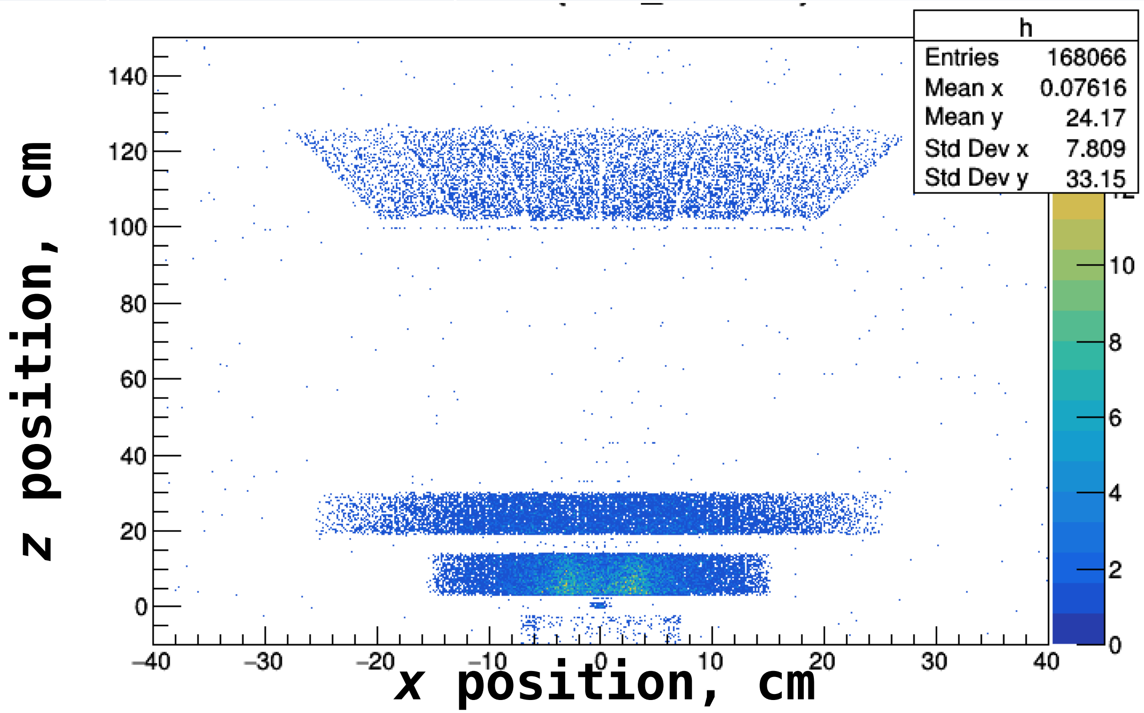
backup

MC simulations – neutrons from target & environment

$^1H+C_2H_4$ @200MeV (newgeom) statistics: 2.2E5 fragmentations

	Neutrons (10^3) Produced	Neutrons (10^3) interacting Magnets	Neutrons (10^3) towards Calorimeter	Neutrons (10^3) interacting Calorimeter	Neutrons (10^3) arriving to the world
target	168	65 (40%)	11 (7%)	**6.1**	92



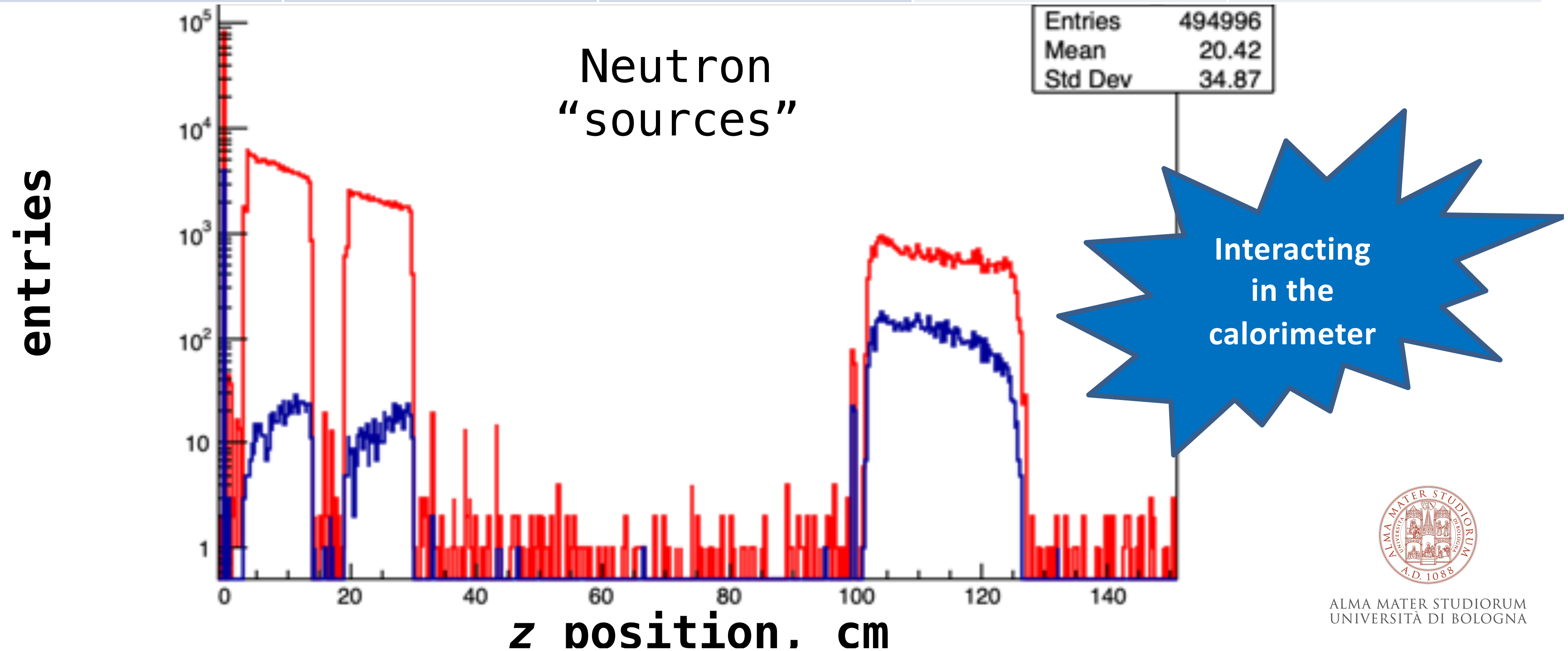


MC simulations – neutrons from target & environment

5E7 primaries

$^{1}H+C_2H_4$ @200MeV (newgeom) statistics: 2.2E5 fragmentations

	Neutrons (10^3) Produced	Neutrons (10^3) interacting Magnets	Neutrons (10^3) towards Calorimeter	Neutrons (10^3) interacting Calorimeter	Neutrons (10^3) arriving to the world
target	168	65 (40%)	11 (7%)	**6.1**	x92
magnets	267			**1.3**	254
Cal.	56			**9.9**	

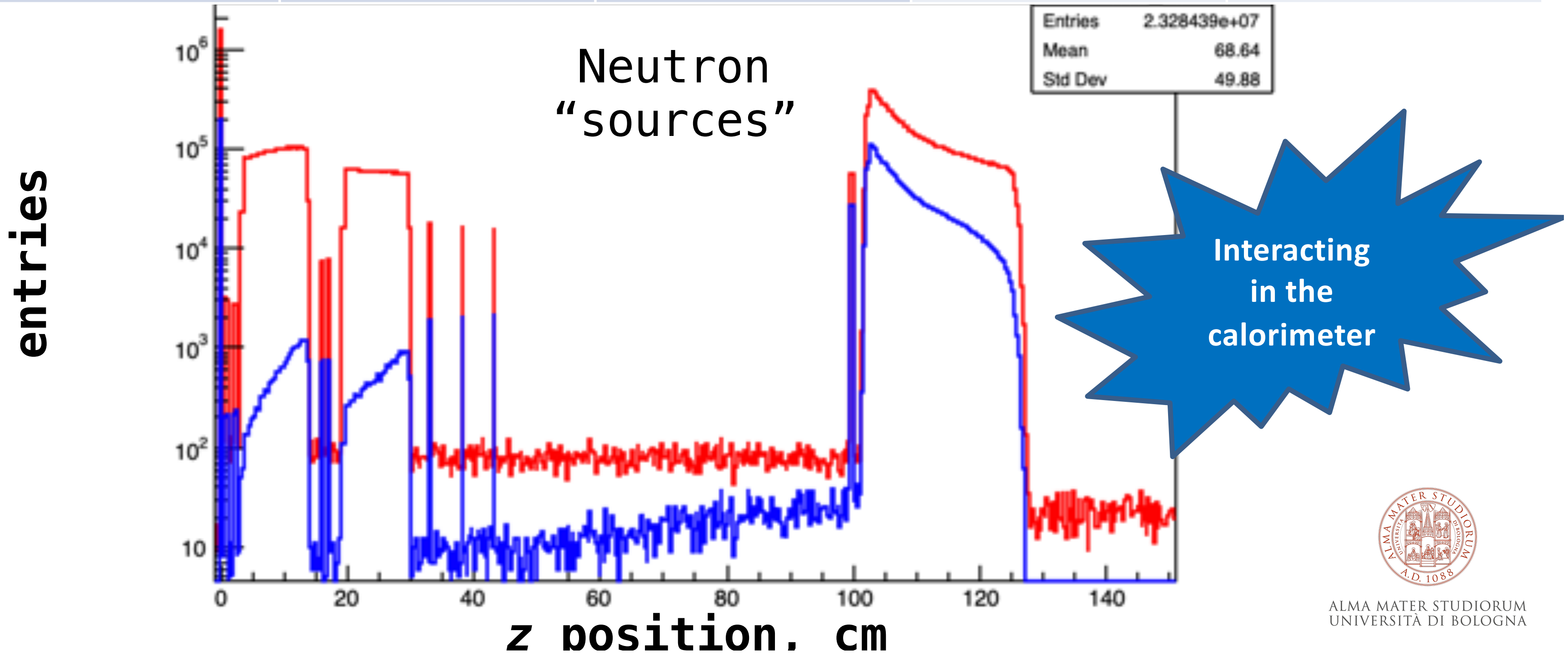


MC simulations – neutrons from target & environment

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
magnets	6.5			**0.06**	14.8
Cal.	13.3			**3.1**	



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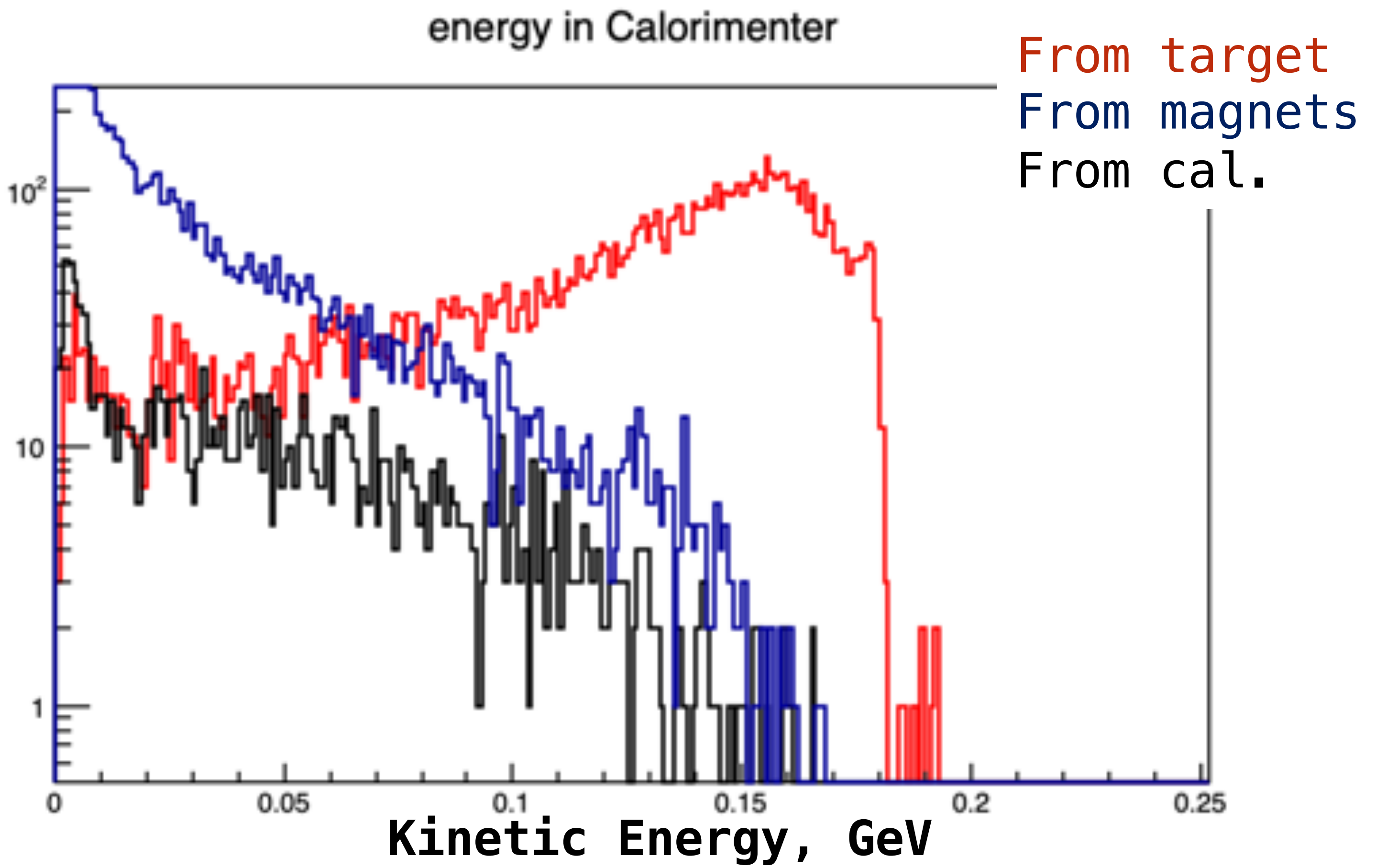
MC simulations – neutrons from target & environment

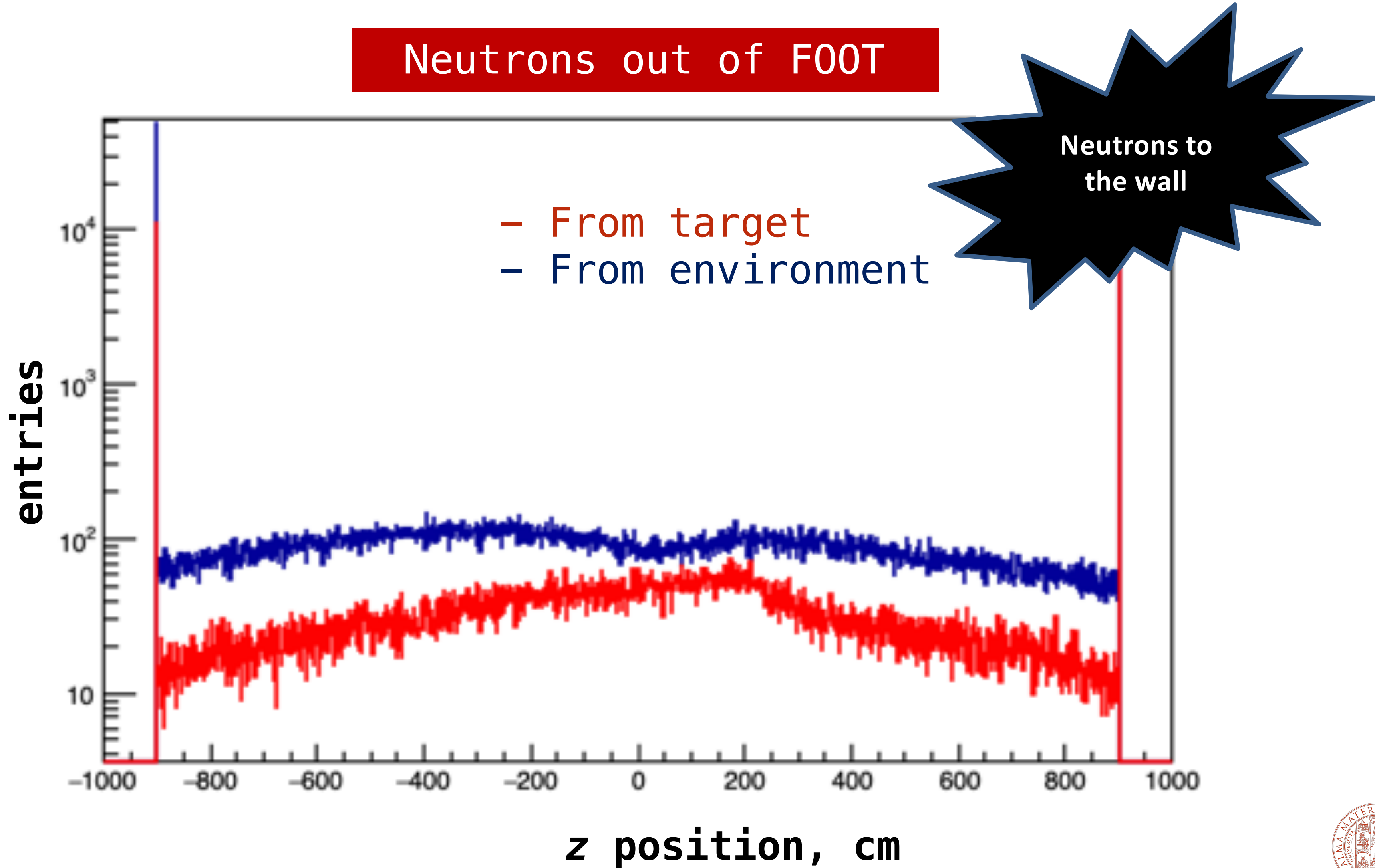
$^{1}H+C_2H_4$ @200MeV (newgeom) statistics: 2.2E5 fragmentations



MC simulations – neutrons from target & environment

$^{1}H+C_2H_4$ @200MeV (newgeom) statistics: 2.2E5 fragmentations

Neutrons out of FOOT



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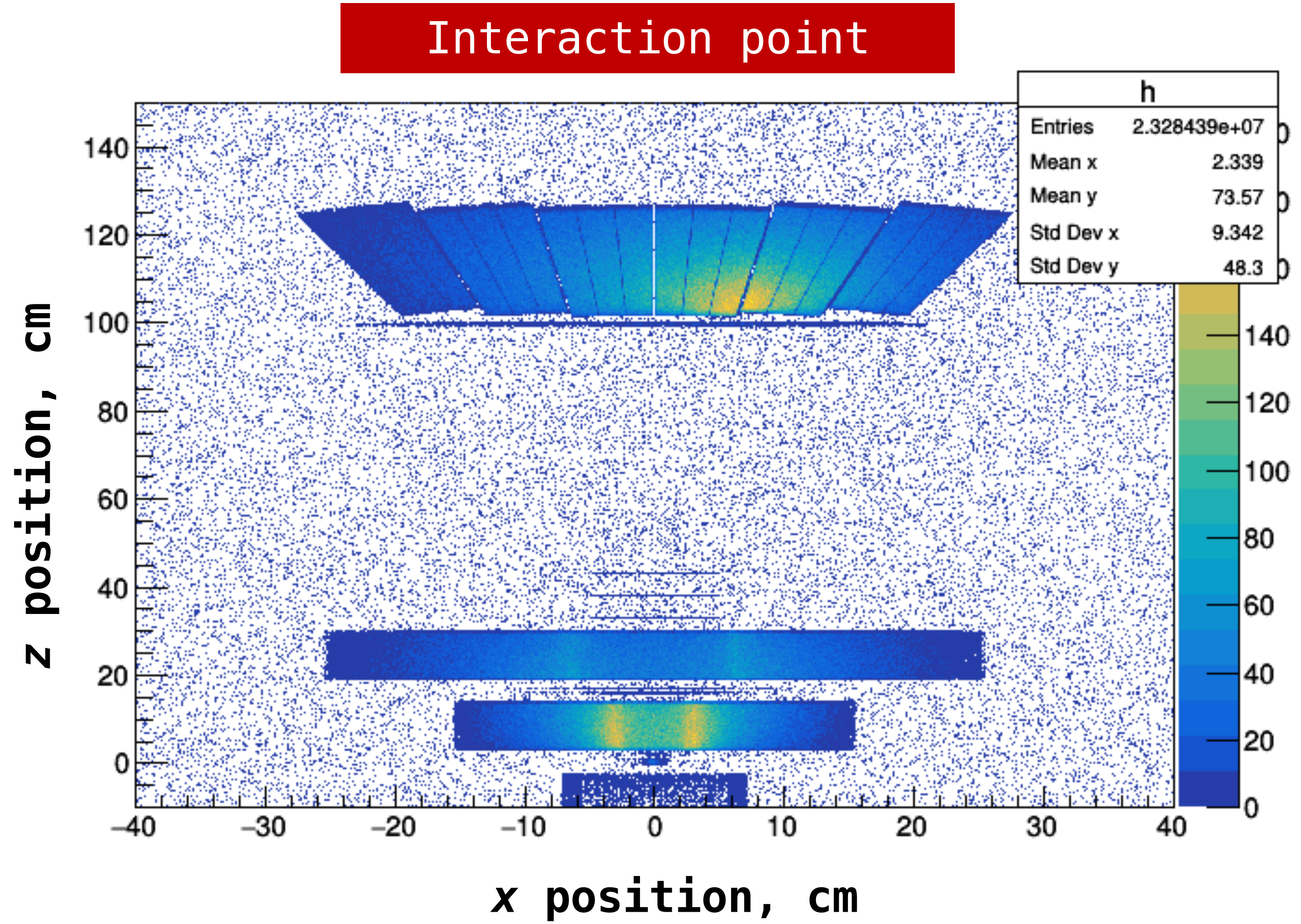
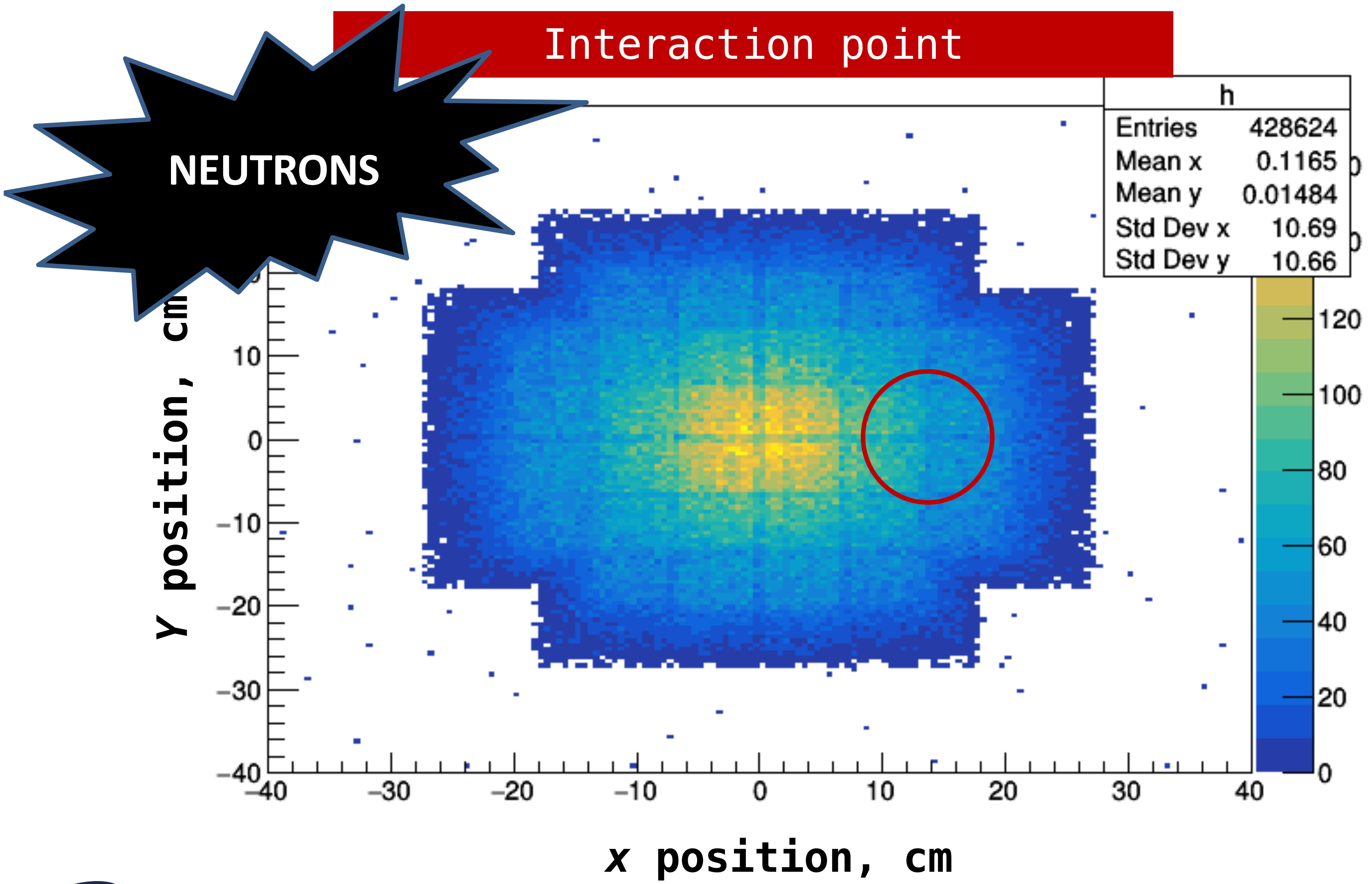
MC simulations – neutrons from target & environment

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



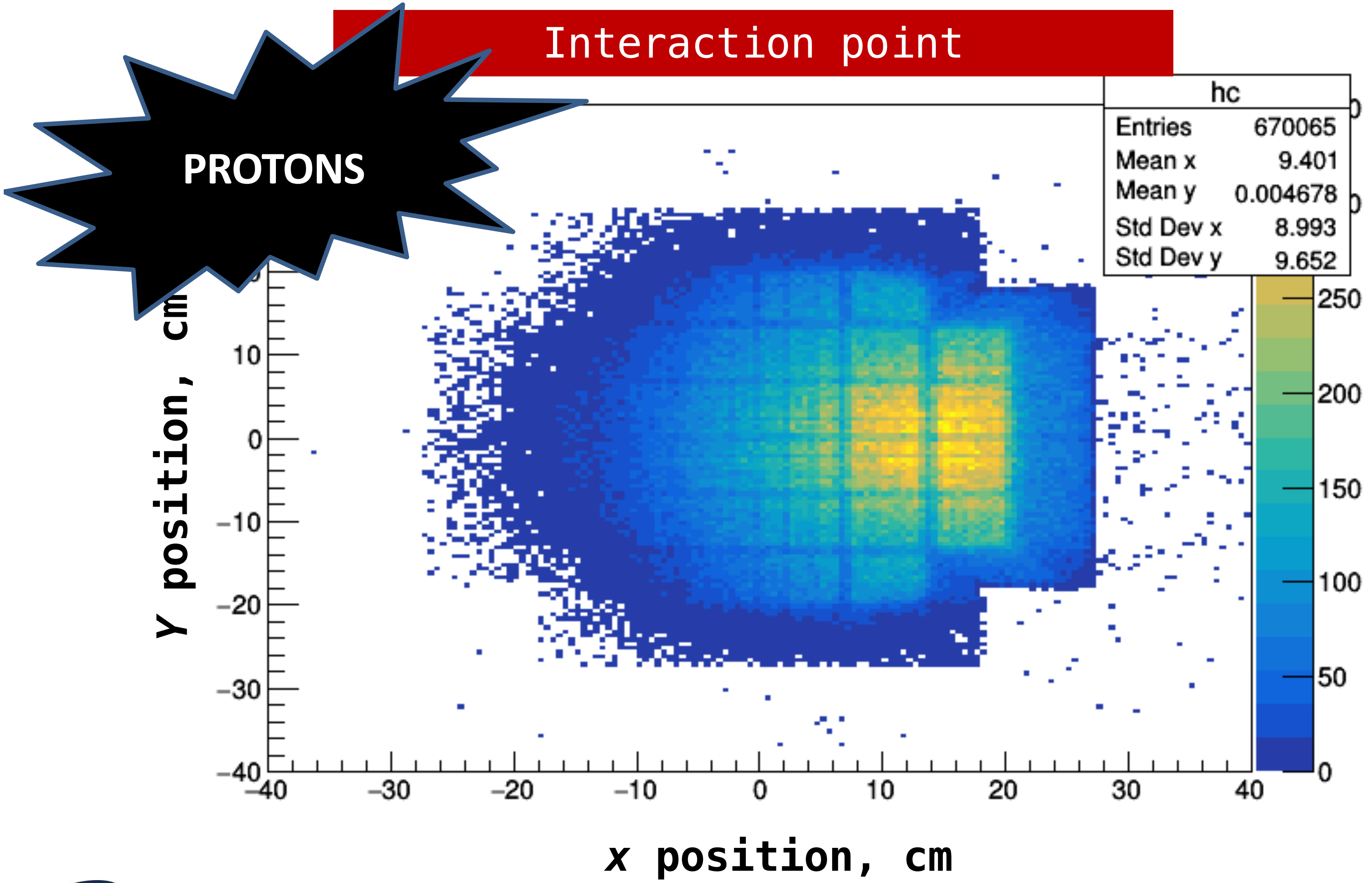
MC simulations – neutrons from target & environment

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



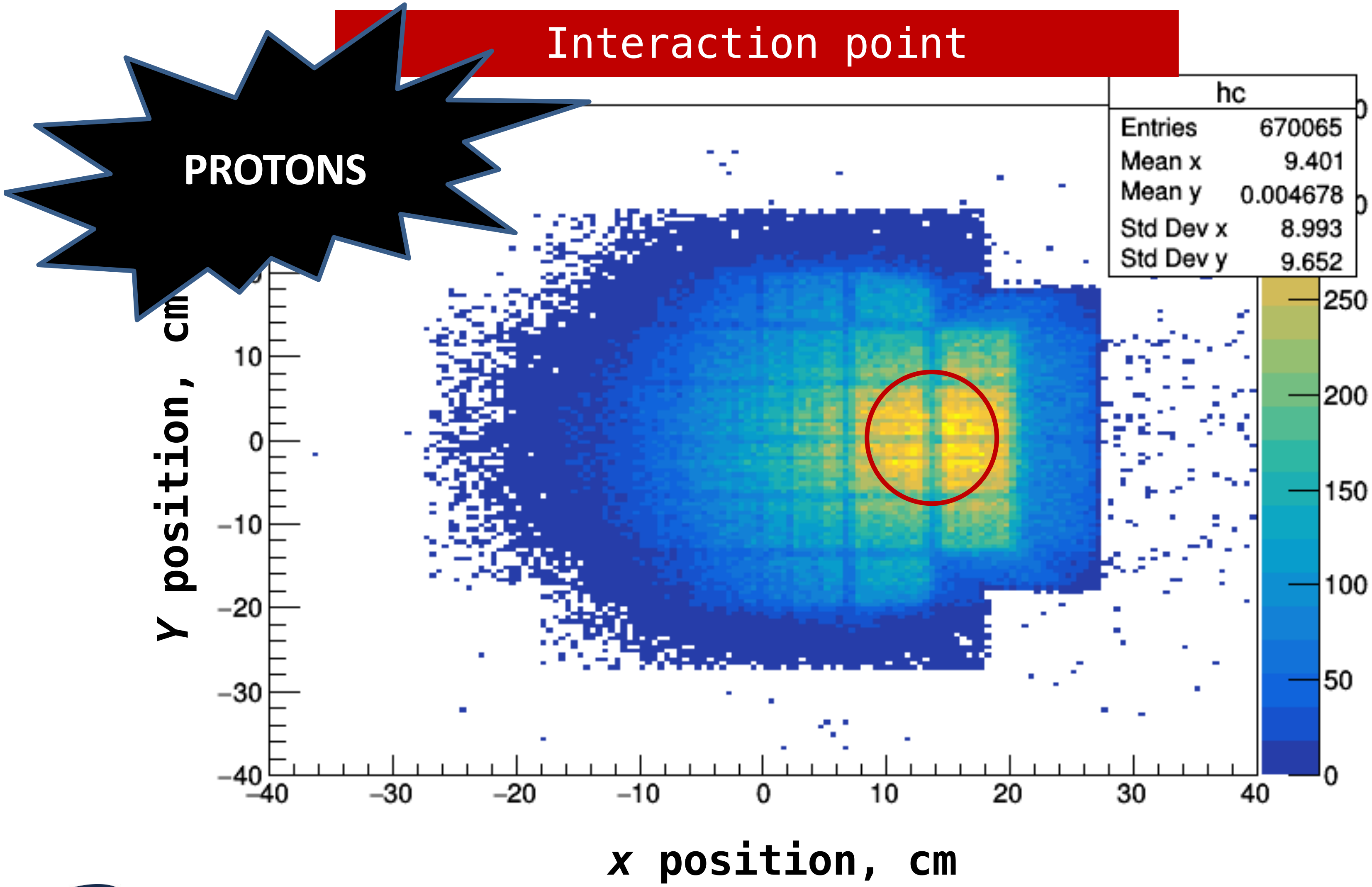
MC simulations – neutrons from target & environment

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



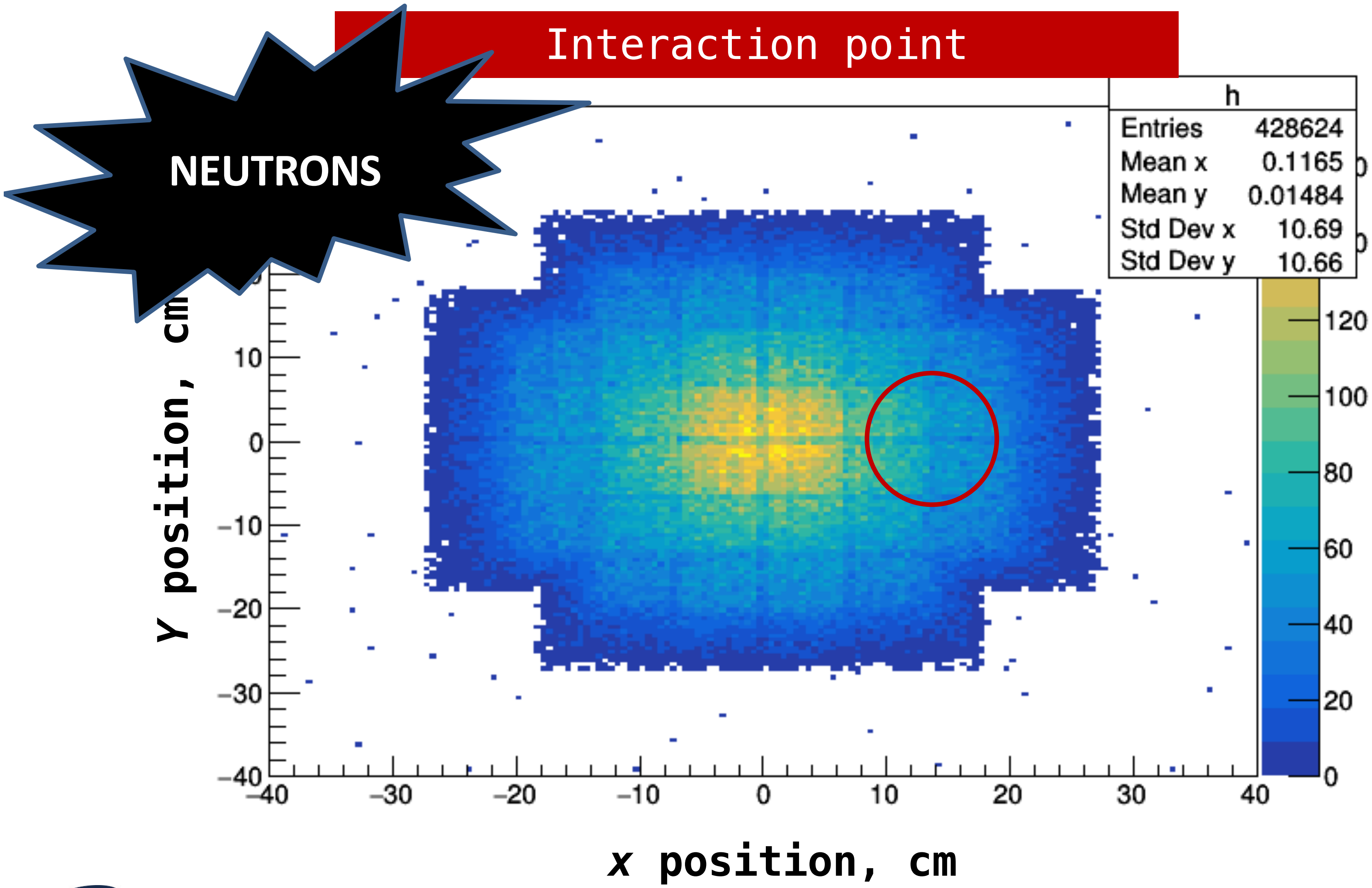
MC simulations – neutrons from target & environment

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



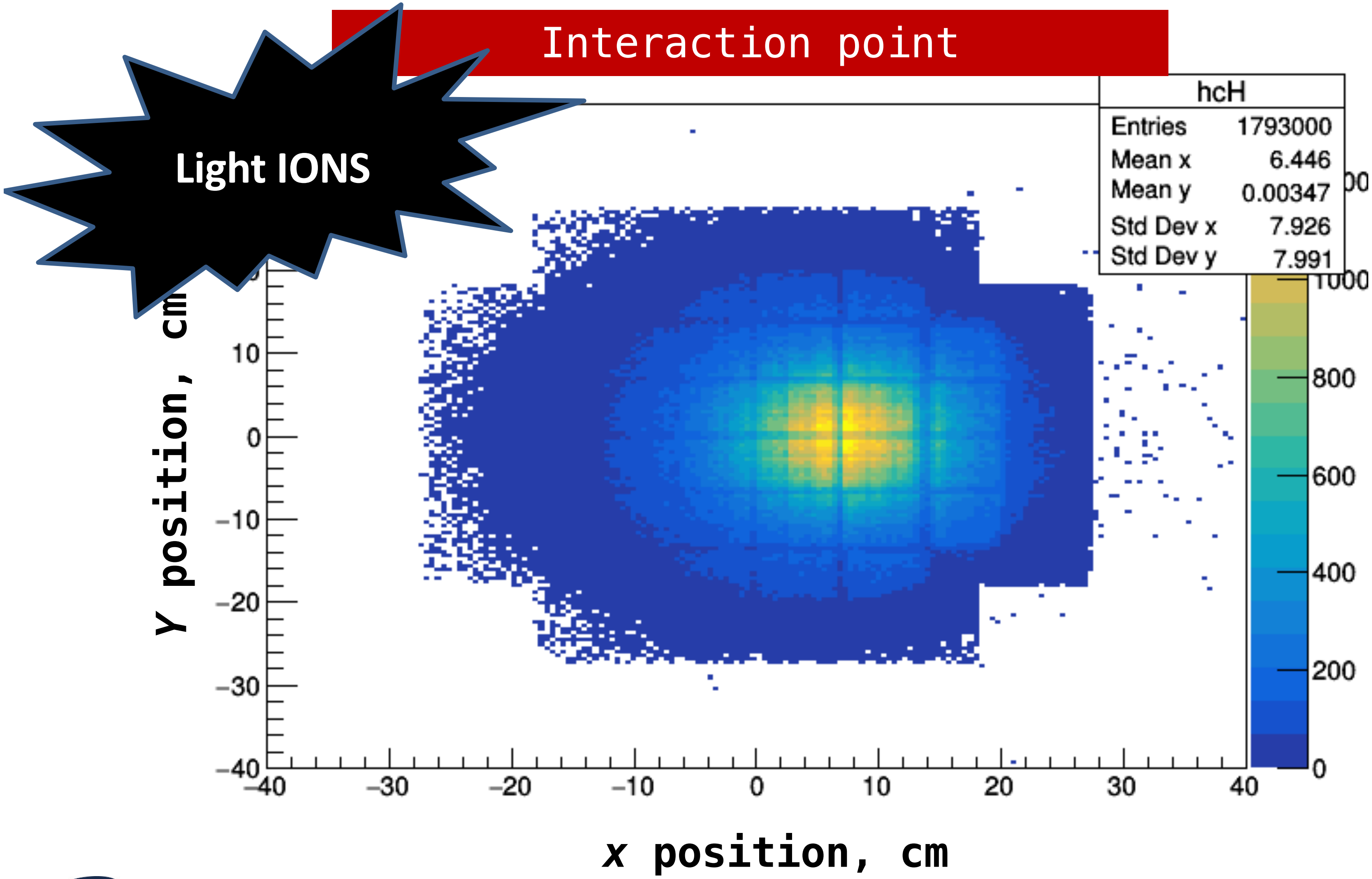
MC simulations – neutrons from target & environment

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

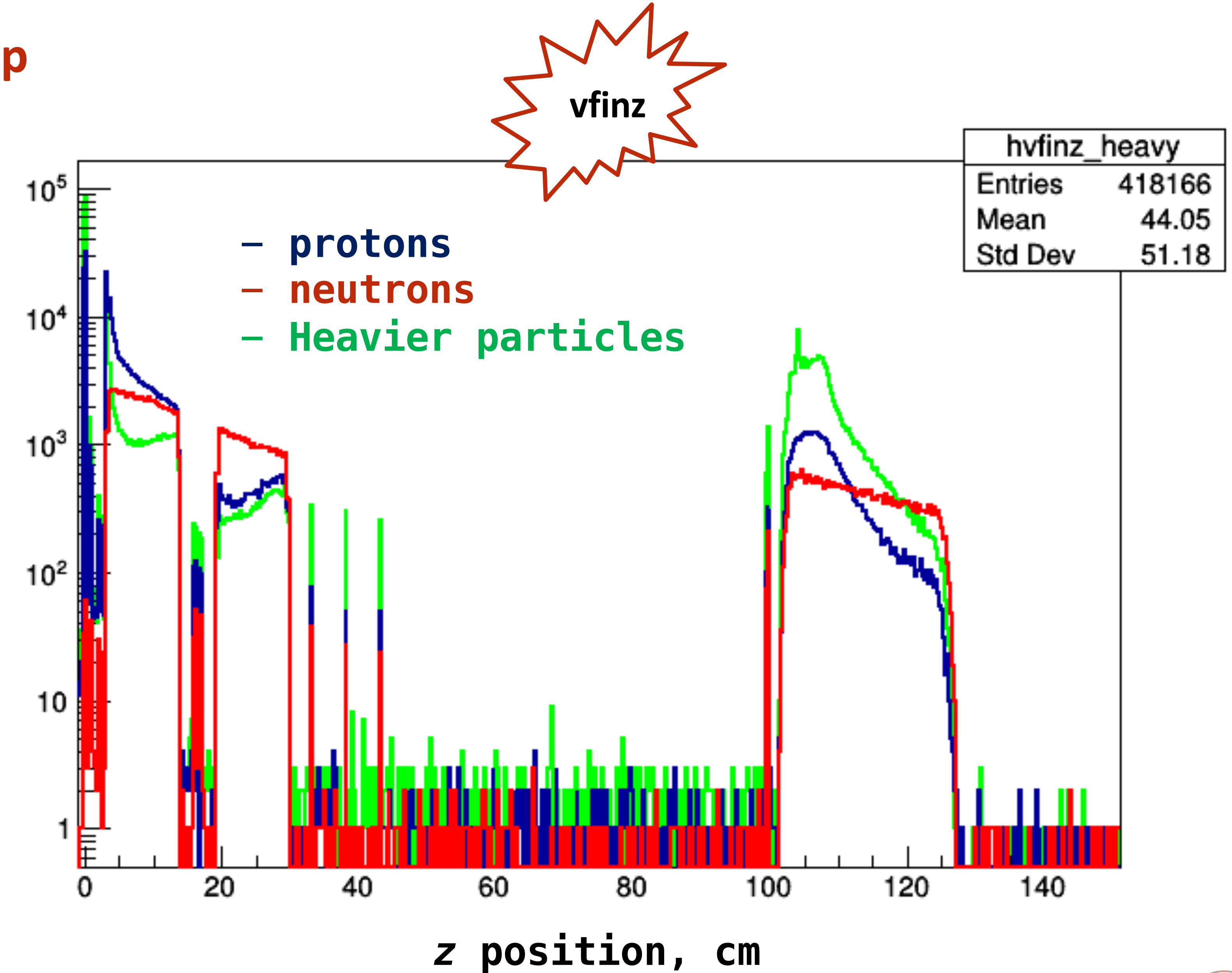


MC simulations – neutrons from target & environment

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



backup



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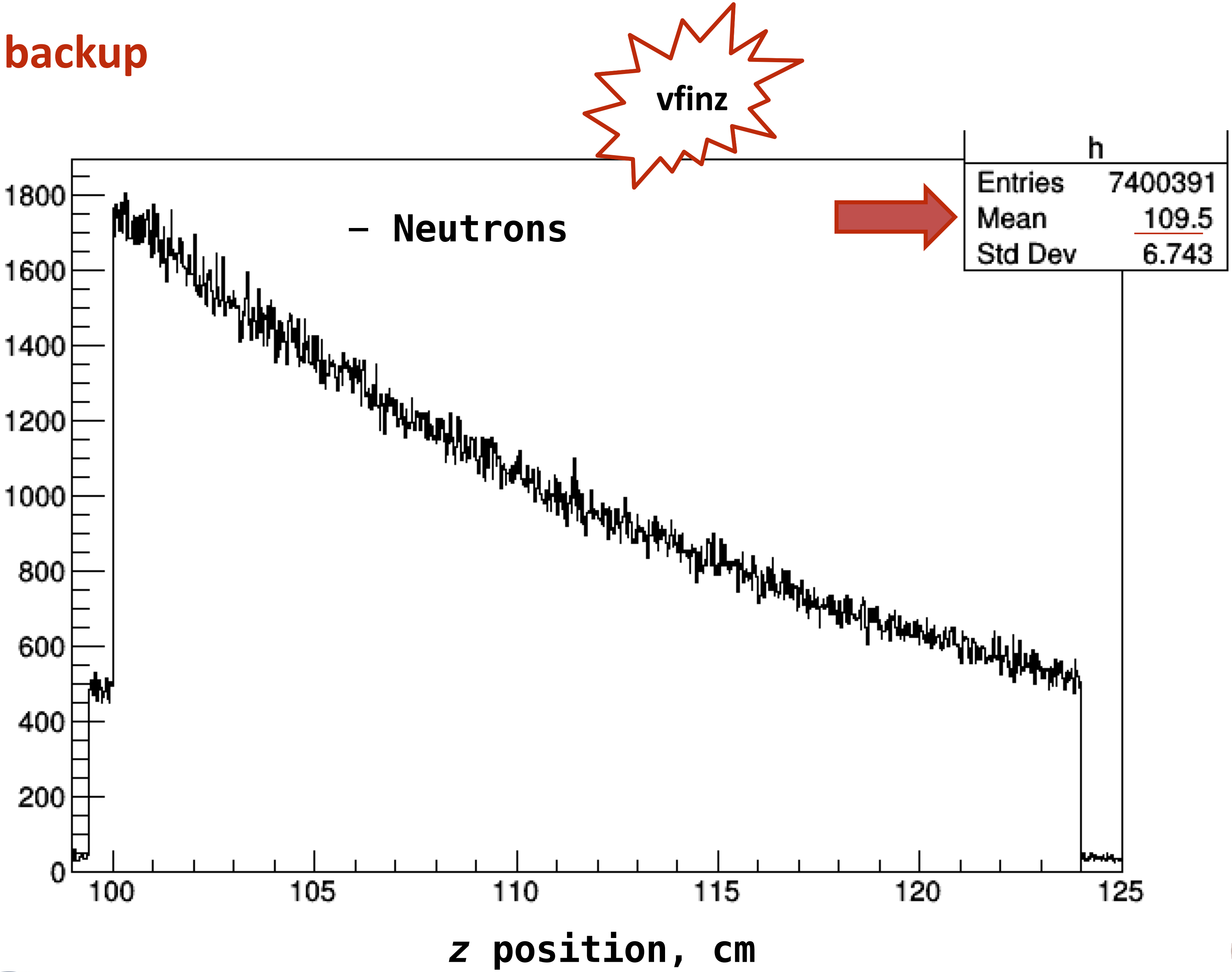
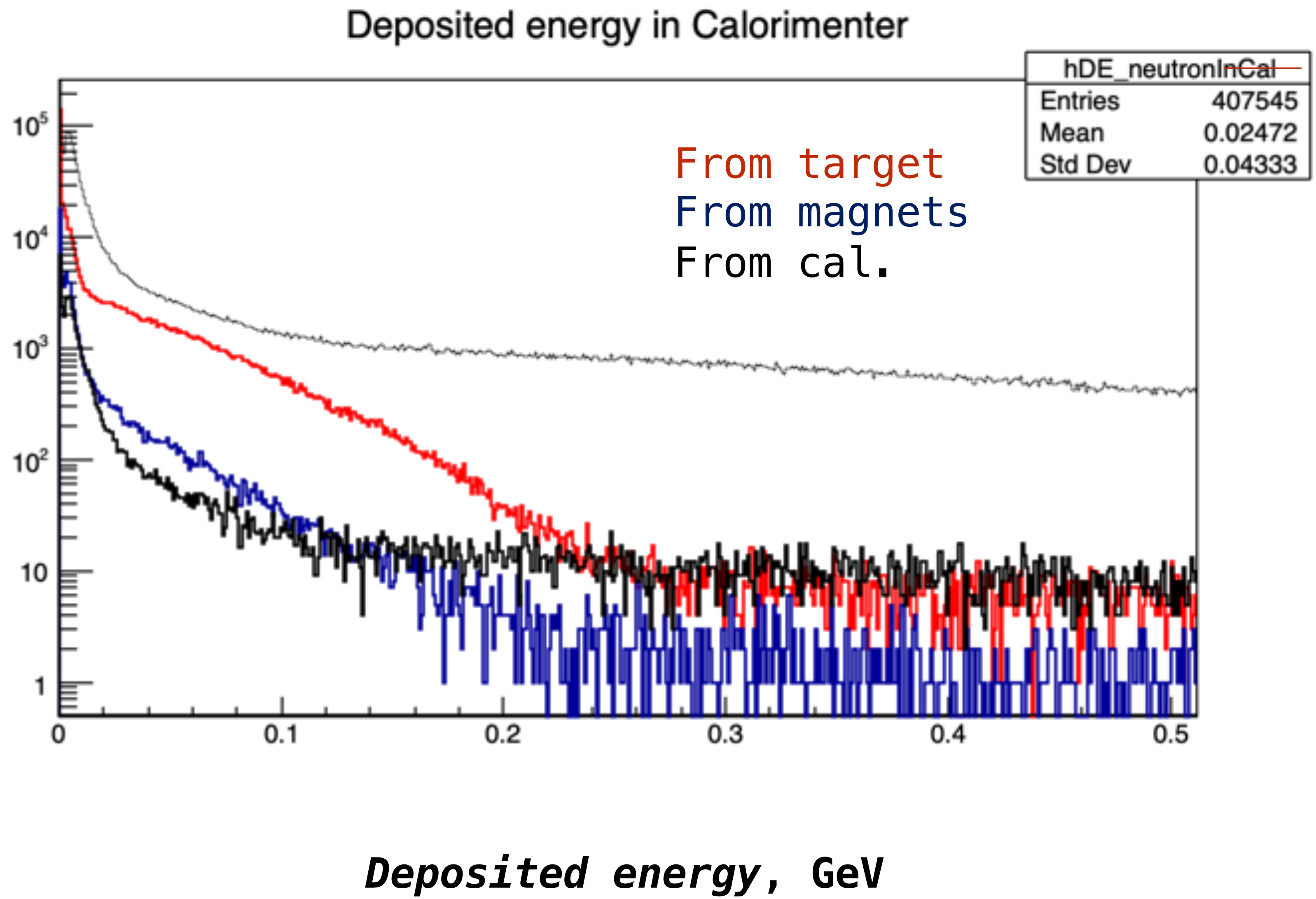
backup



vfinz
h
Entries 7400391
Mean 109.5
Std Dev 6.743
– Neutrons
1800
1600
1400
1200
1000
800
600
400
200
0
100
105
110
115
120
125
z position, cm

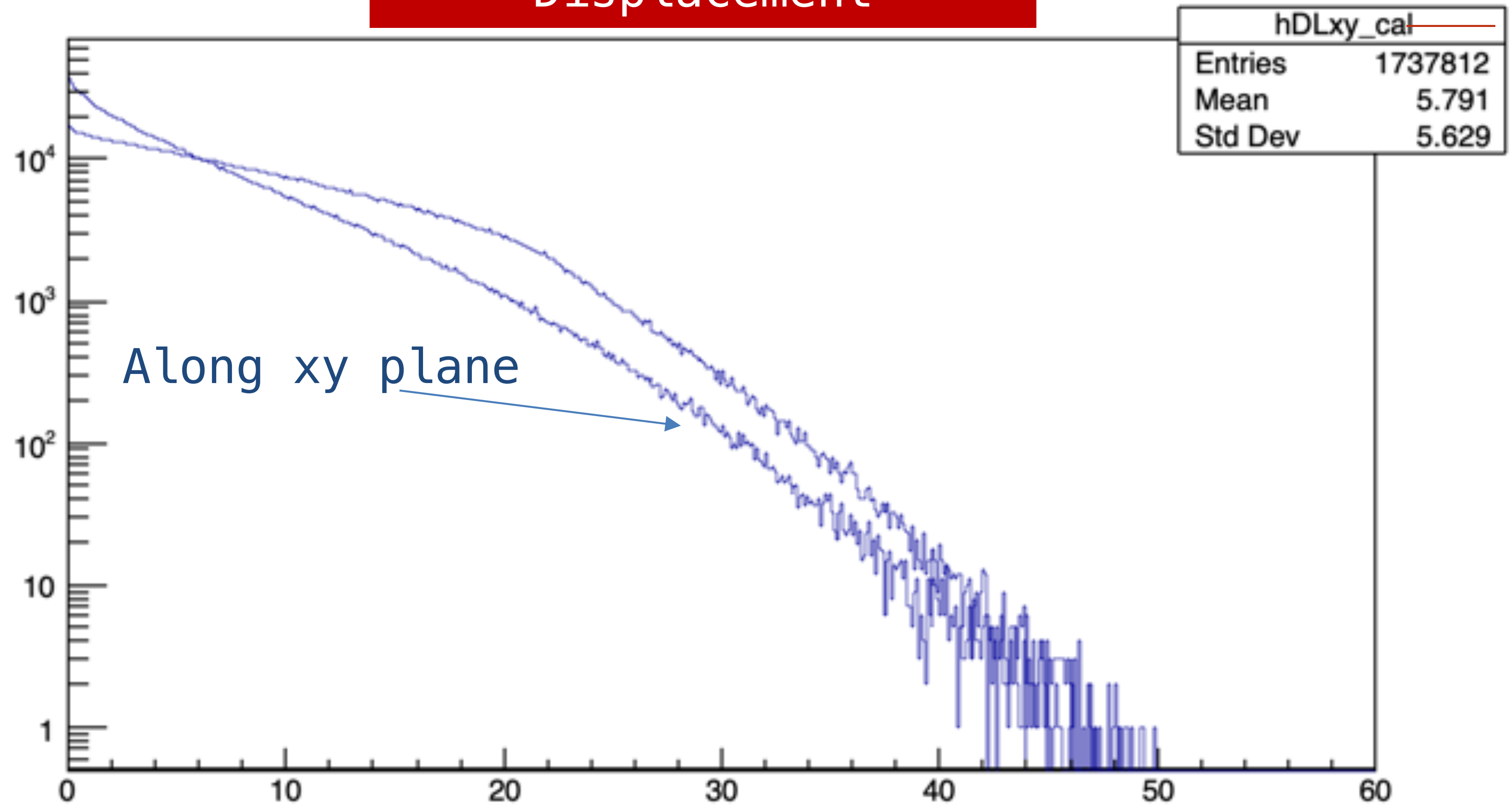
backup



Deposited energy in Calorimenter
hDE_neutronInCal
Entries 407545
Mean 0.02472
Std Dev 0.04333
From target
From magnets
From cal.
10^5
10^4
10^3
10^2
10
1
0
0.1
0.2
0.3
0.4
0.5
Deposited energy, GeV

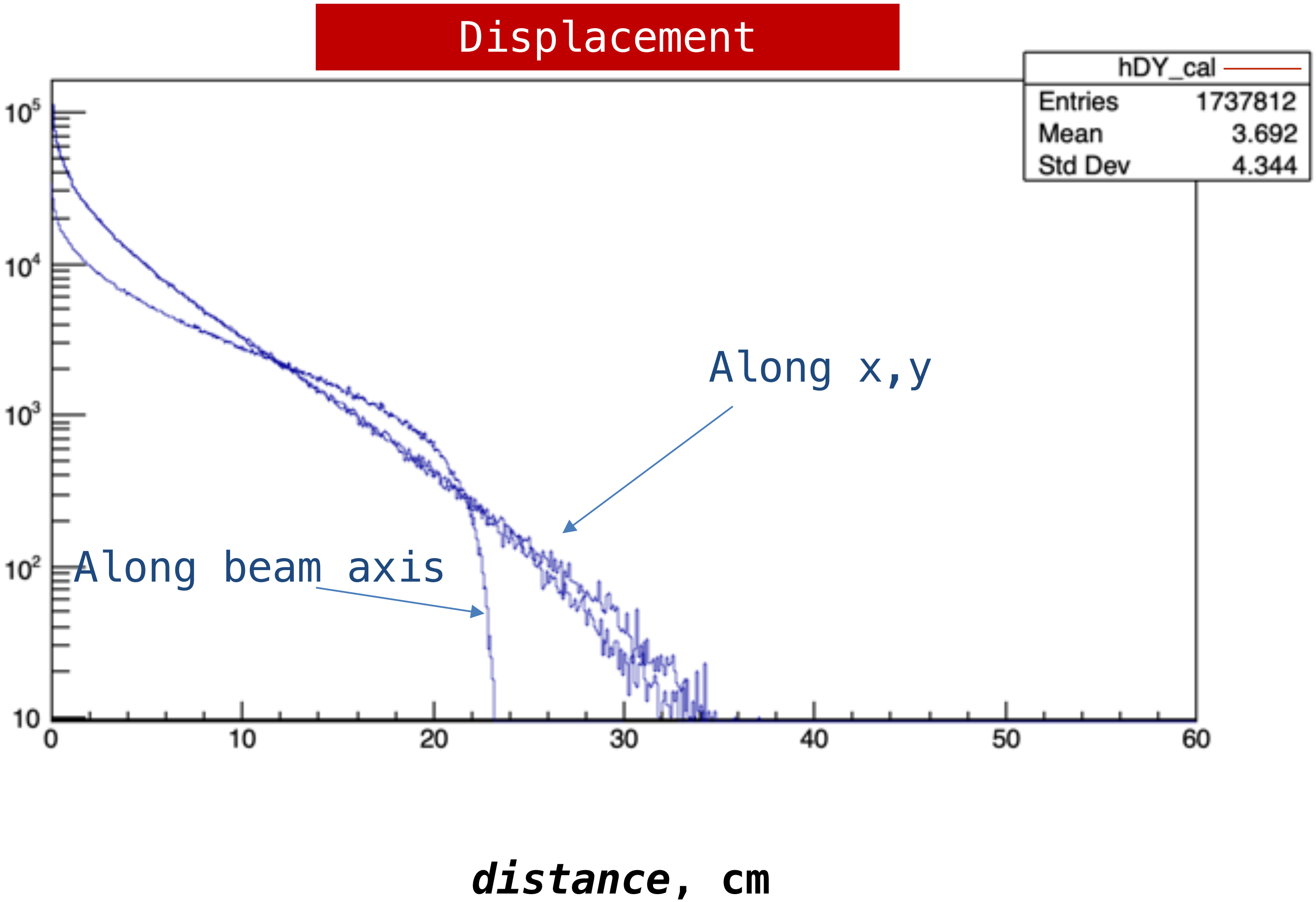
backup

Displacement



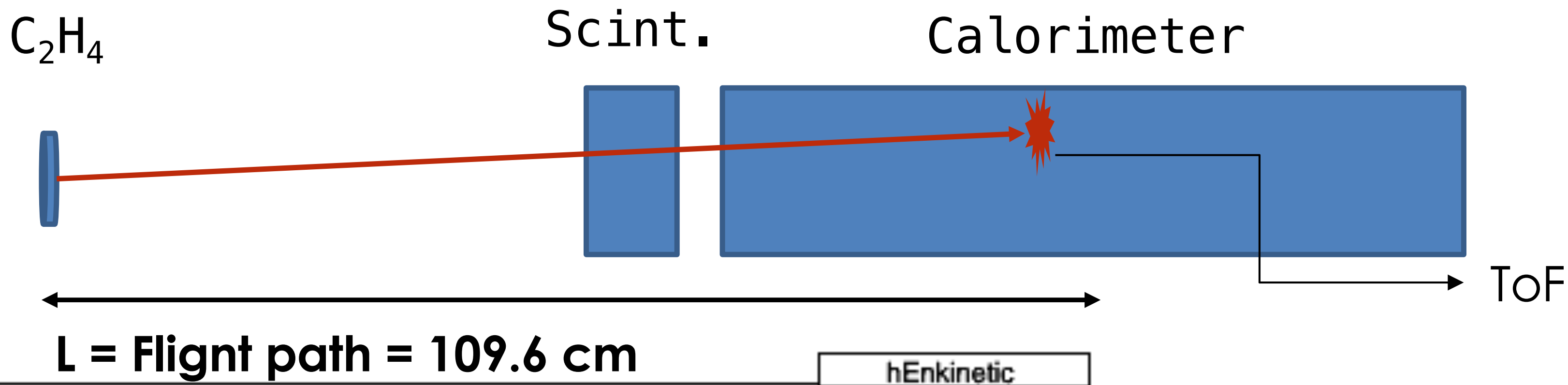
distance, cm

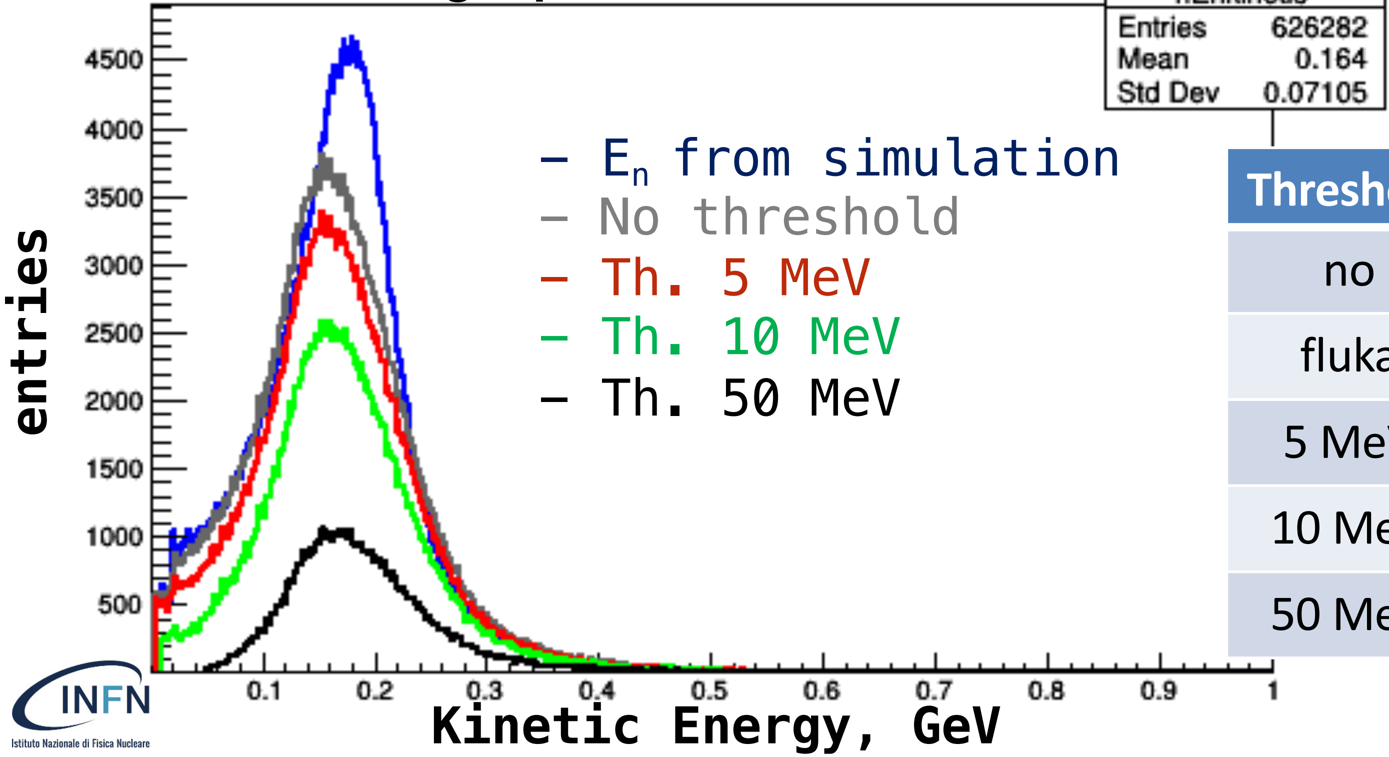
backup


Displacement
hDY_cal
Entries 1737812
Mean 3.692
Std Dev 4.344
10^5
10^4
10^3
10^2
10
0
10
20
30
40
50
60
Along x,y
Along beam axis
distance, cm

Detecting neutrons with existing setup

Only events from the target

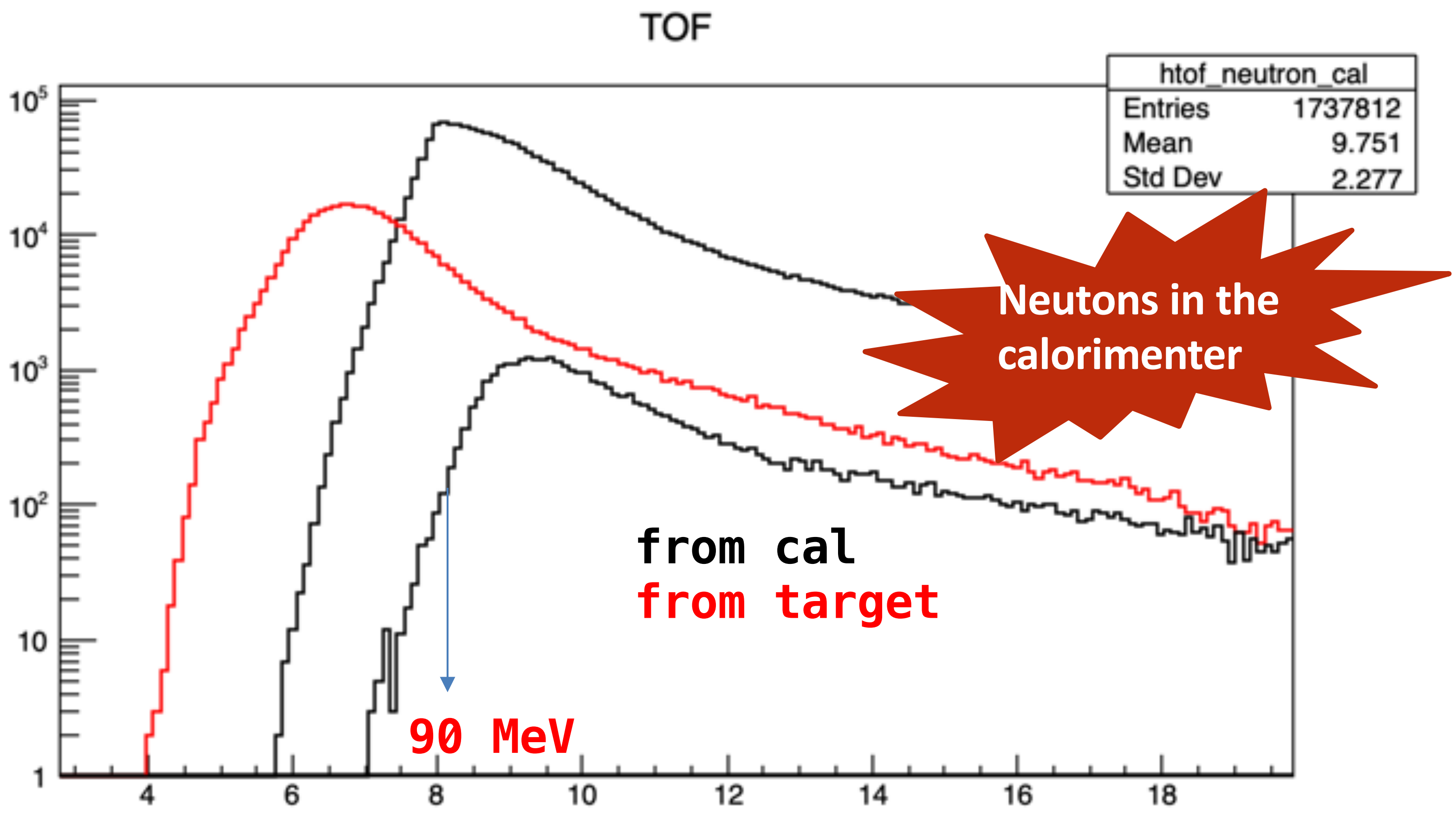




Threshold	Efficiency	
no	100%	**64%**
fluka	70%	**41%**
5 MeV	65%	**36%**
10 MeV	42%	**27%**
50 MeV	16%	**10%**

backup

timing

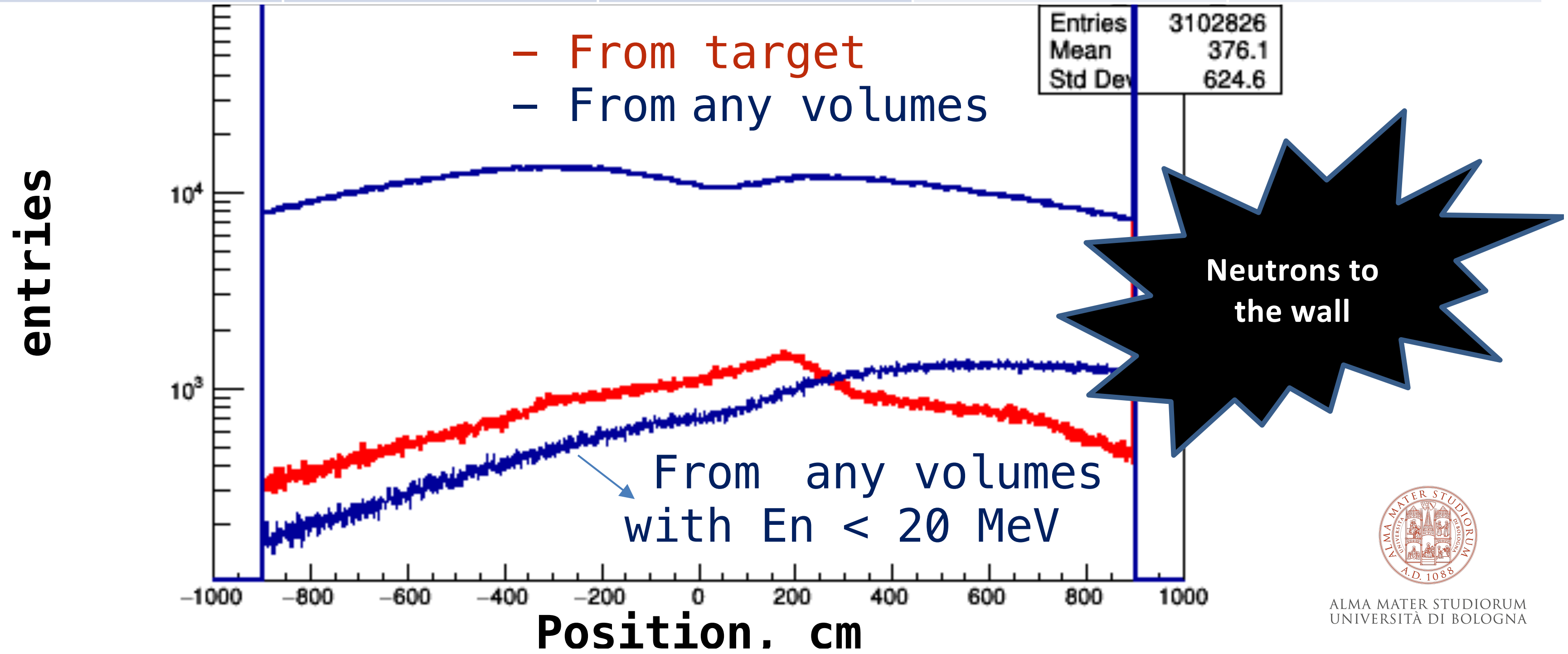


$T_{stop} - T_{start}$, ns

MC simulations – neutrons from target & environment

$^{16}O+C_2H_4$ @200MeV/u (V15) statistics: 2.9E6 fragmentations

	Neutrons (10^6) Produced	Neutrons (10^6) intecting Magnets	Neutrons (10^6) towards Caolorimeter	Neutrons (10^6) interacting Calorimeter	Neutrons (10^6) arriving to the world
target	7.4	3.2	1.4	0.9 (~60%)	3.1 (=2.6+0.5)
magnets	17.1			0.15	31.8
Cal.	28.8			8.3	



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