Neutrons @ FOOT

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for INFN Bologna

ALMA MATER STUDIORUM
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Department of Physics and Astronomy

Program

- **Neutrons** produced in the **target** and in the **environment** (MC simulations)
- **Neutron** detection using the **standard** FOOT **setup** (principle)

RECAP

- Some limitations (qualitative)
- Event by event analysis ← NEW

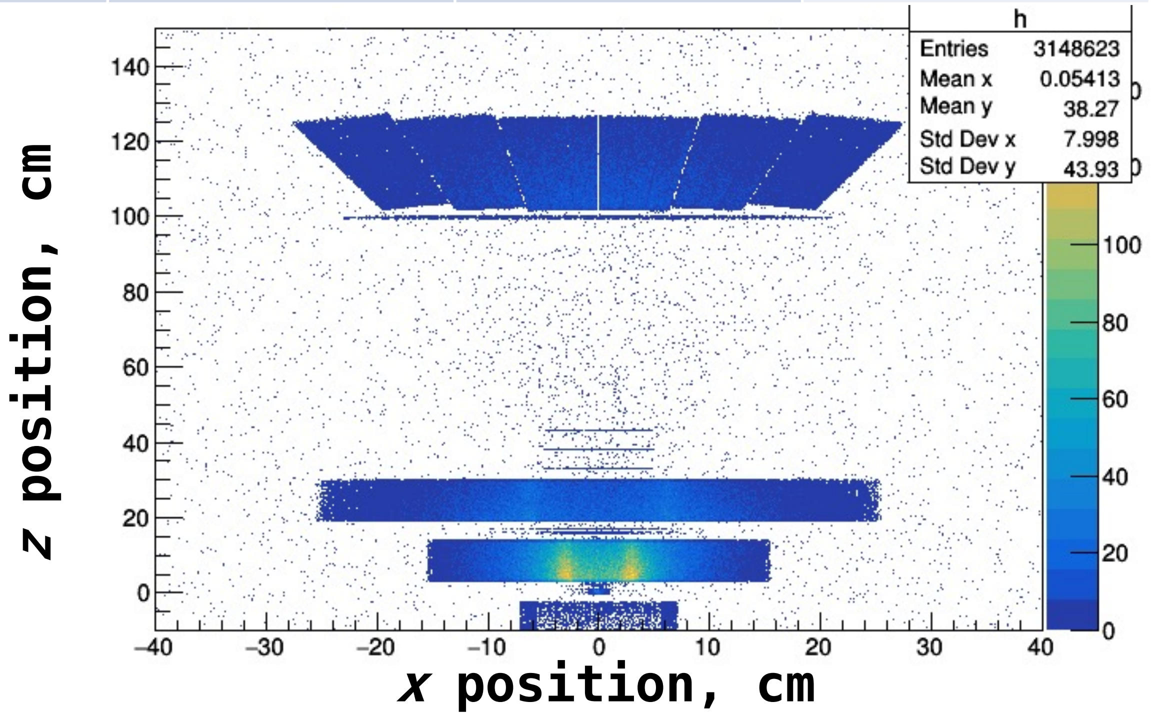
MC simulations – neutrons from target & environment

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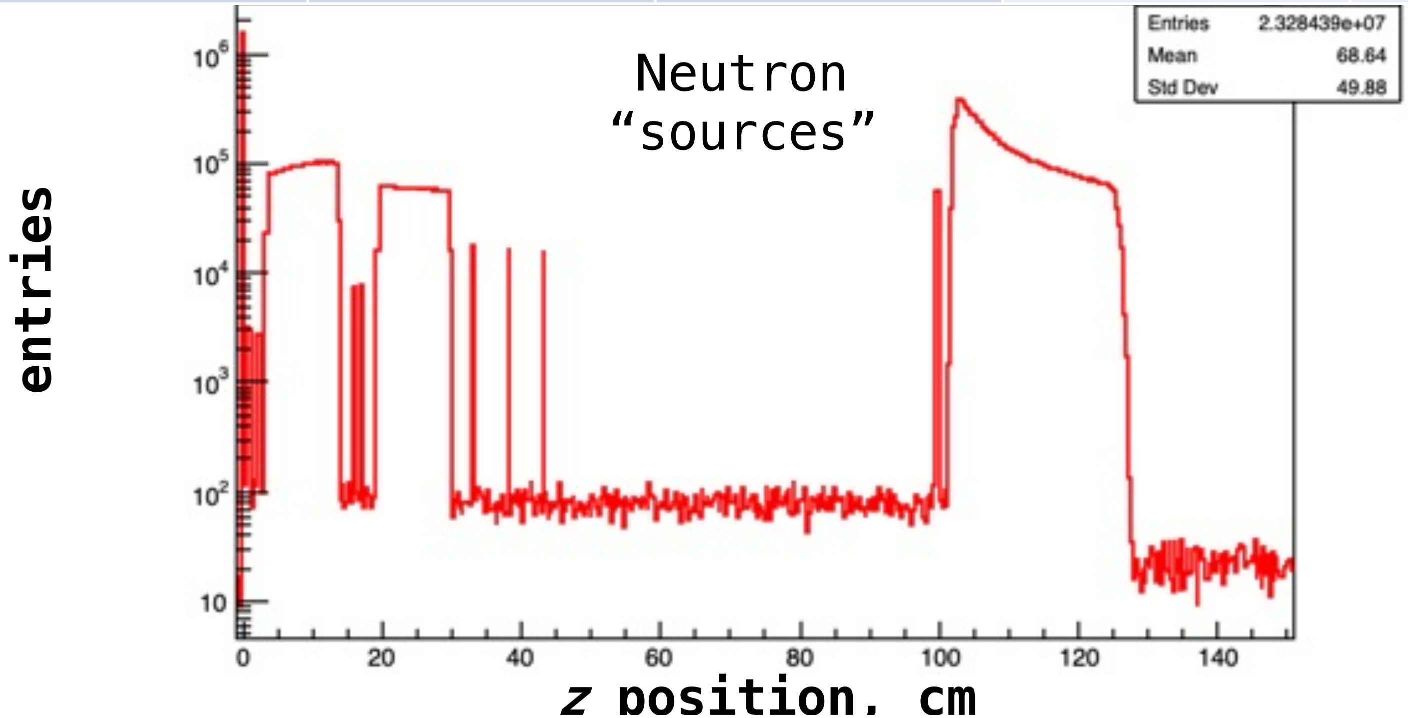
target	3.2	1.3 (40%)	0.6 (20%)	**0.4**	1.4
magnets	6.5				
Cal.	13.3				



MC simulations – neutrons from target & environment

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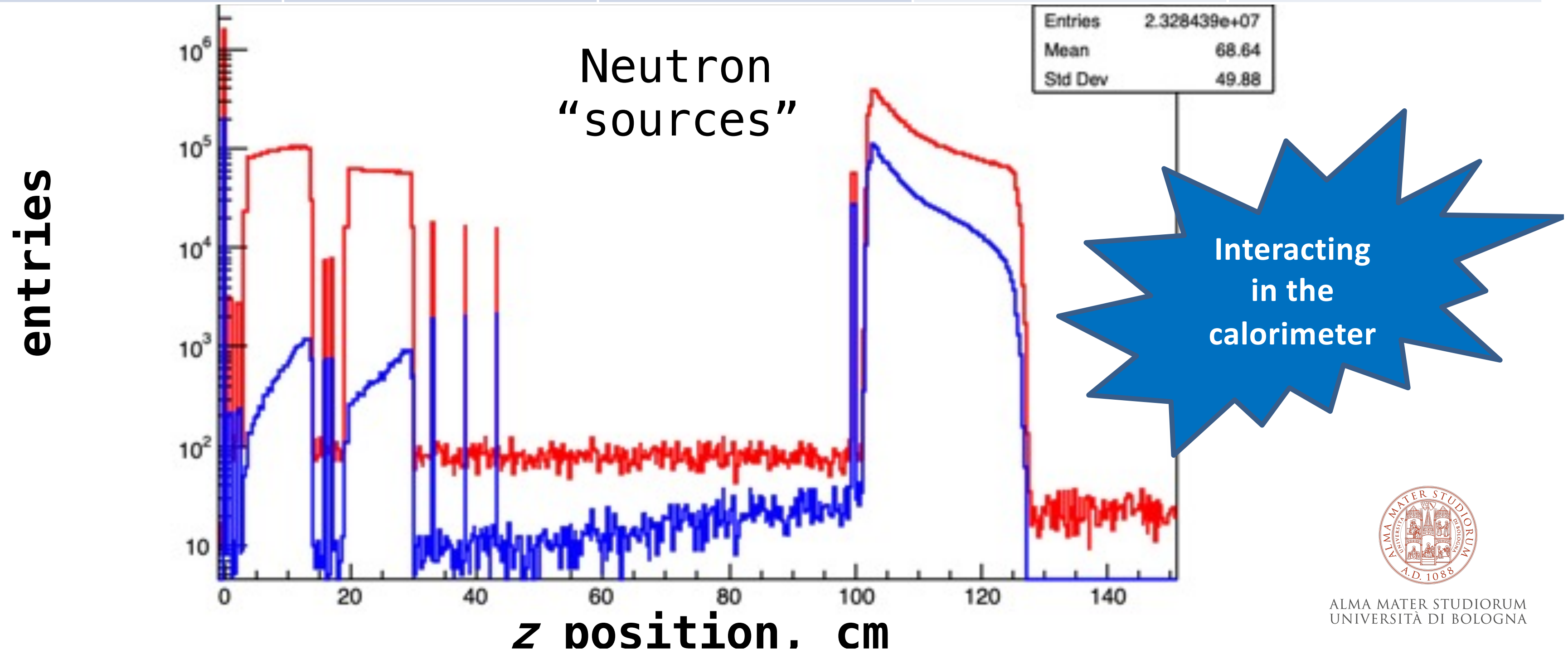
target	3.2	1.3 (40%)	0.6 (20%)	**0.4**	1.4
magnets	6.5			**0.06**	14.8
Cal.	13.3			**3.1**	



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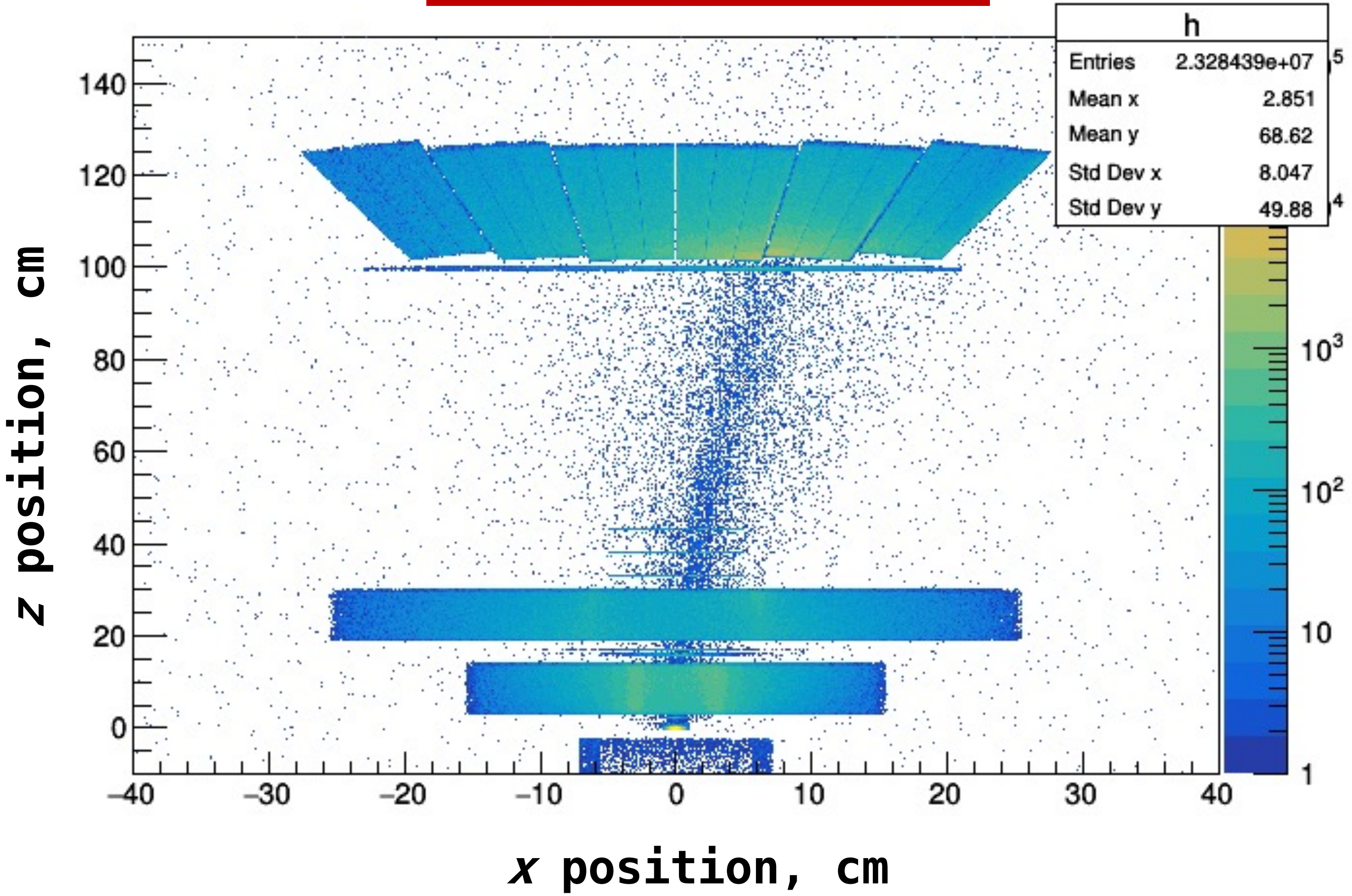
MC simulations – neutrons from target & environment

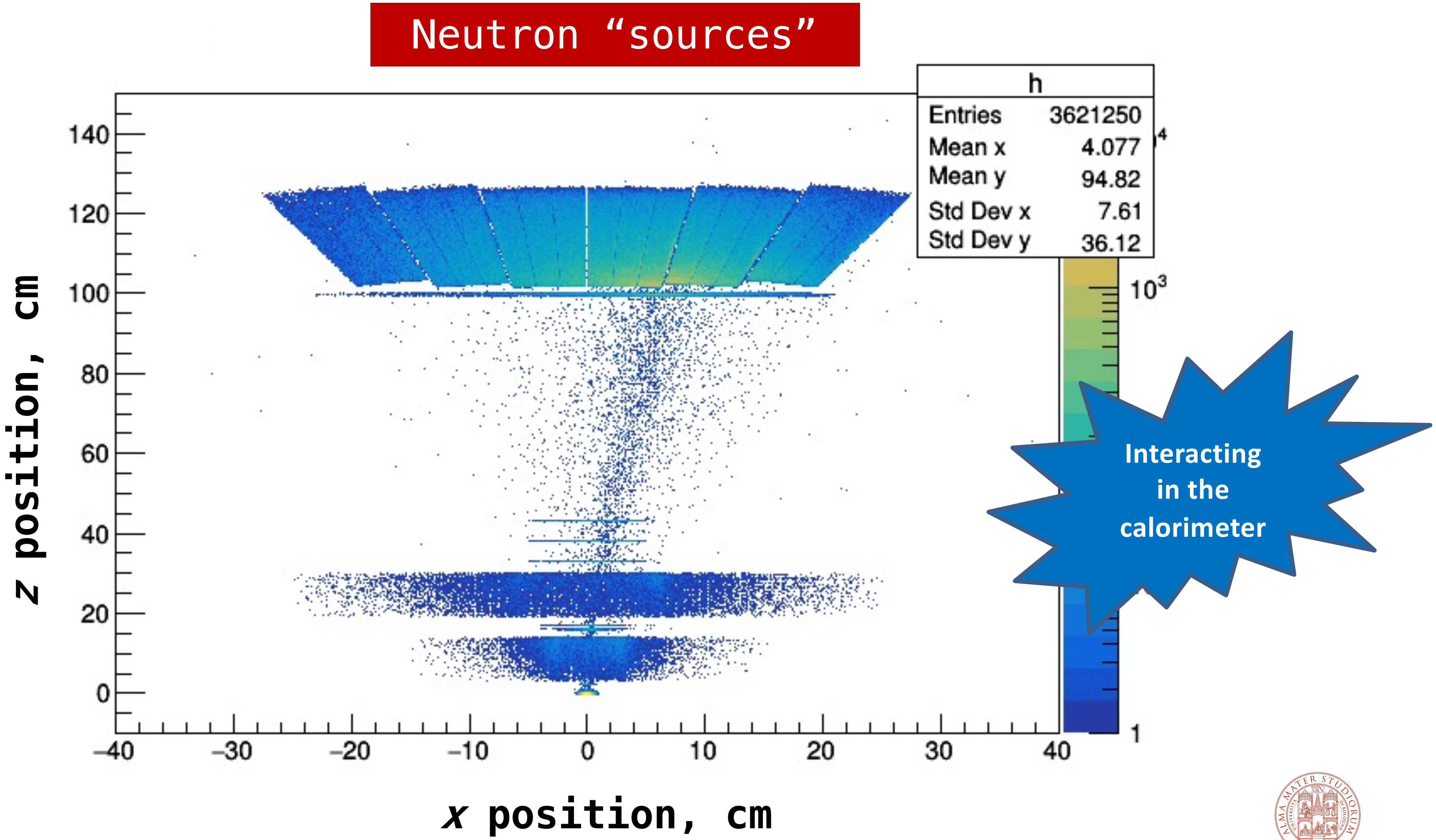
$^{16}O+C_2H_4$ @200MeV/u (newgeom) statistics: 1.4E6 fragmentations

Neutron “sources”



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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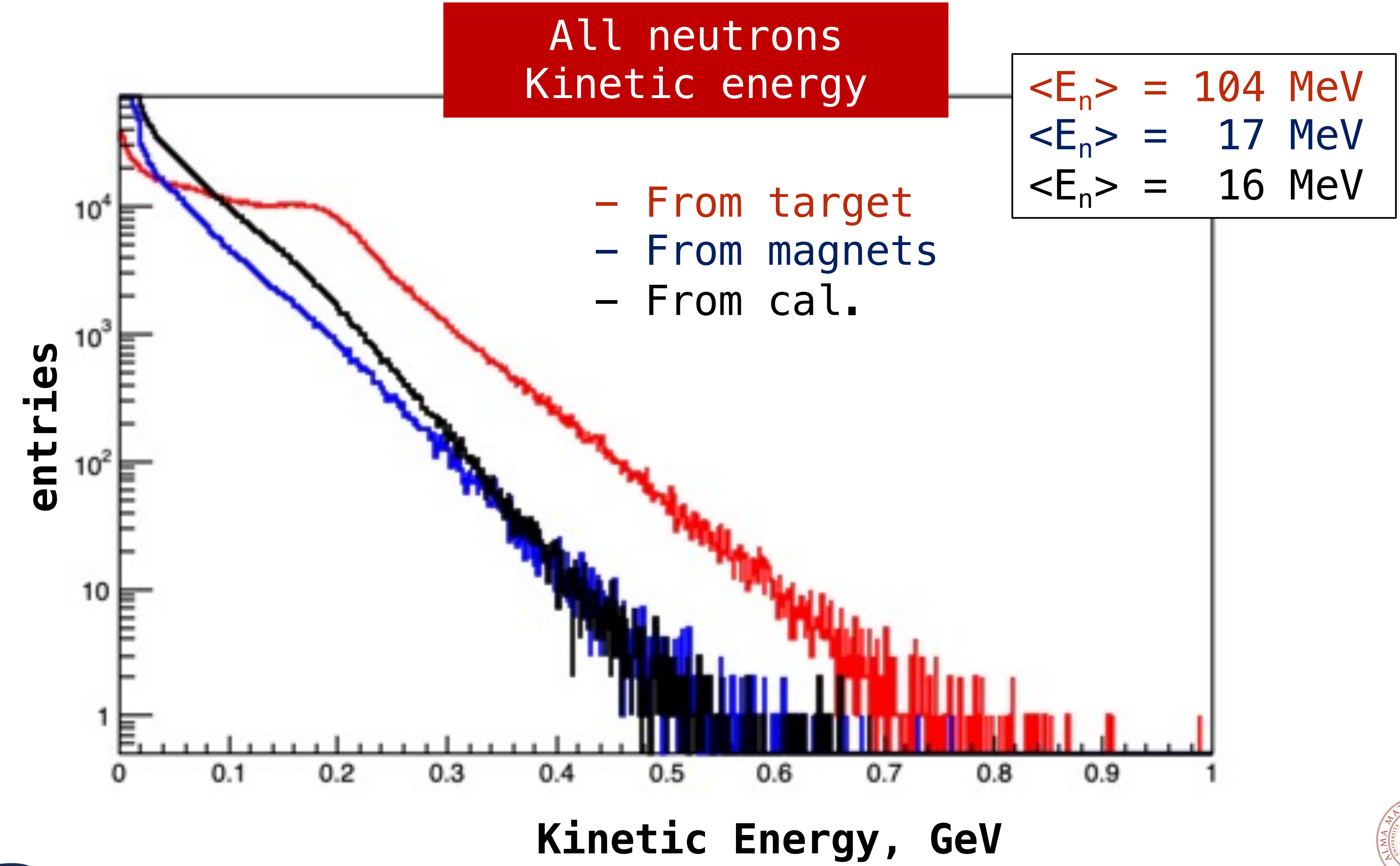

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MC simulations – neutrons from target & environment

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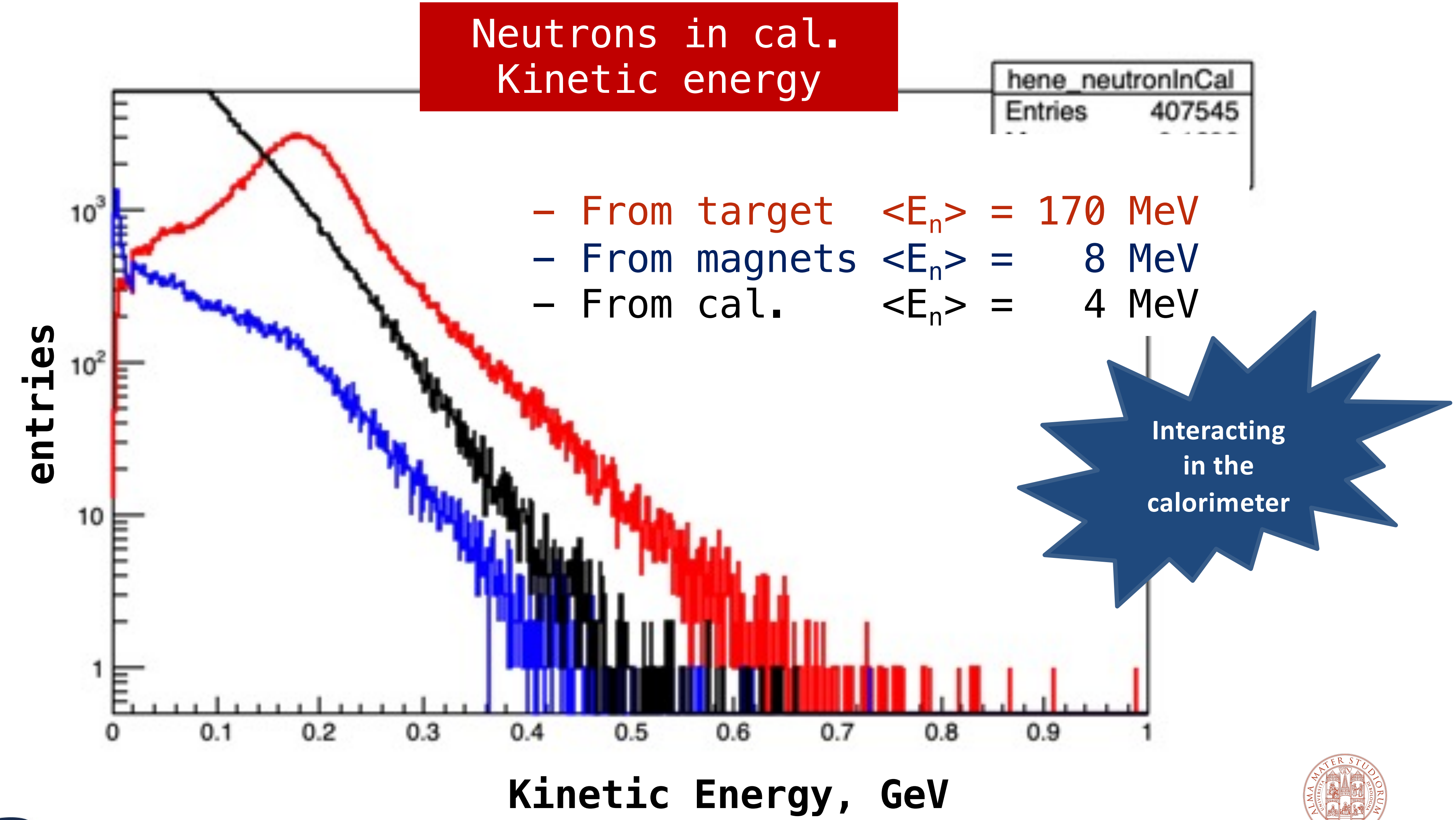

MC simulations – neutrons from target & environment

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?**

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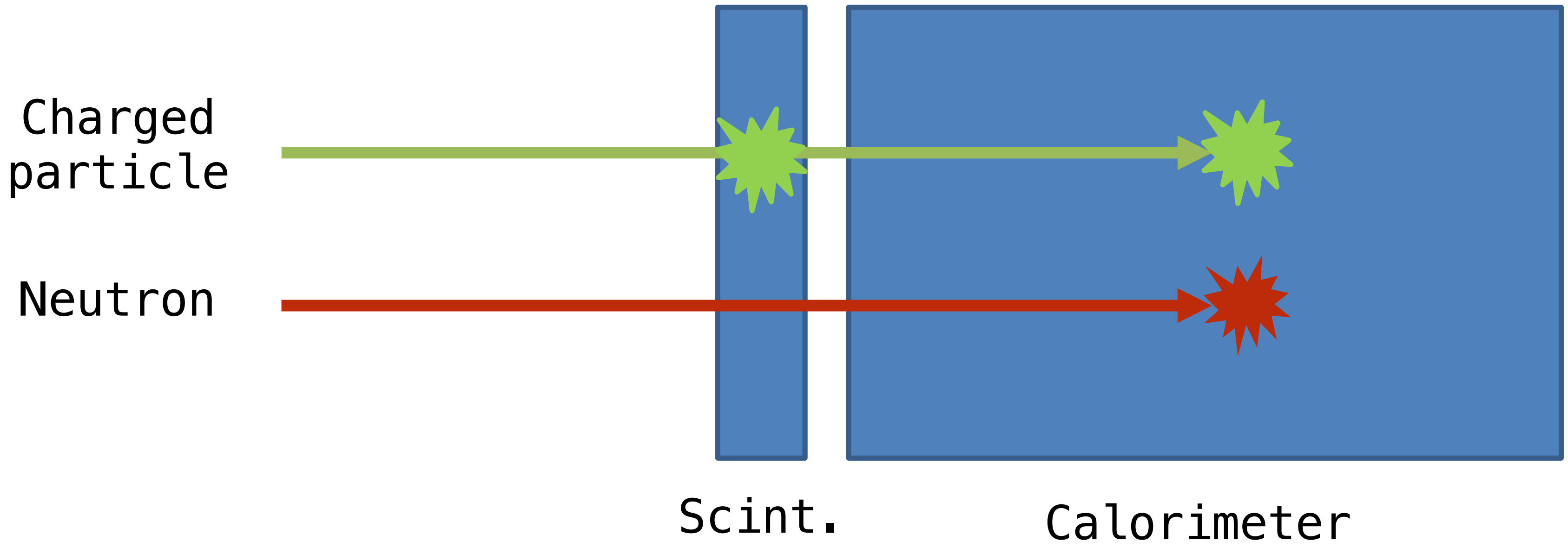
Detecting neutrons with existing setup

Basic idea: **anticoincidence scintillator – calorimenter**

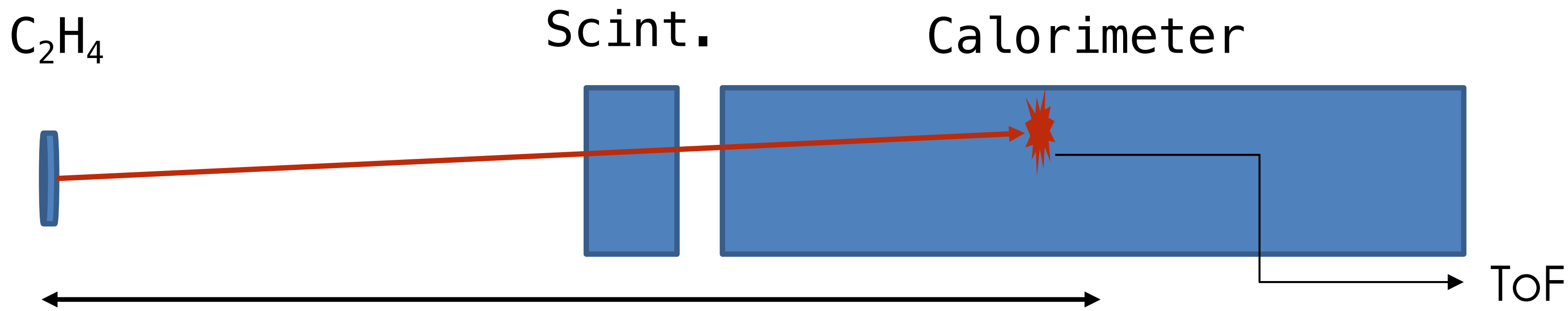


Average number of particles produced per fragmentation ?
Granularity of scintillator and calorimenter high enough ?

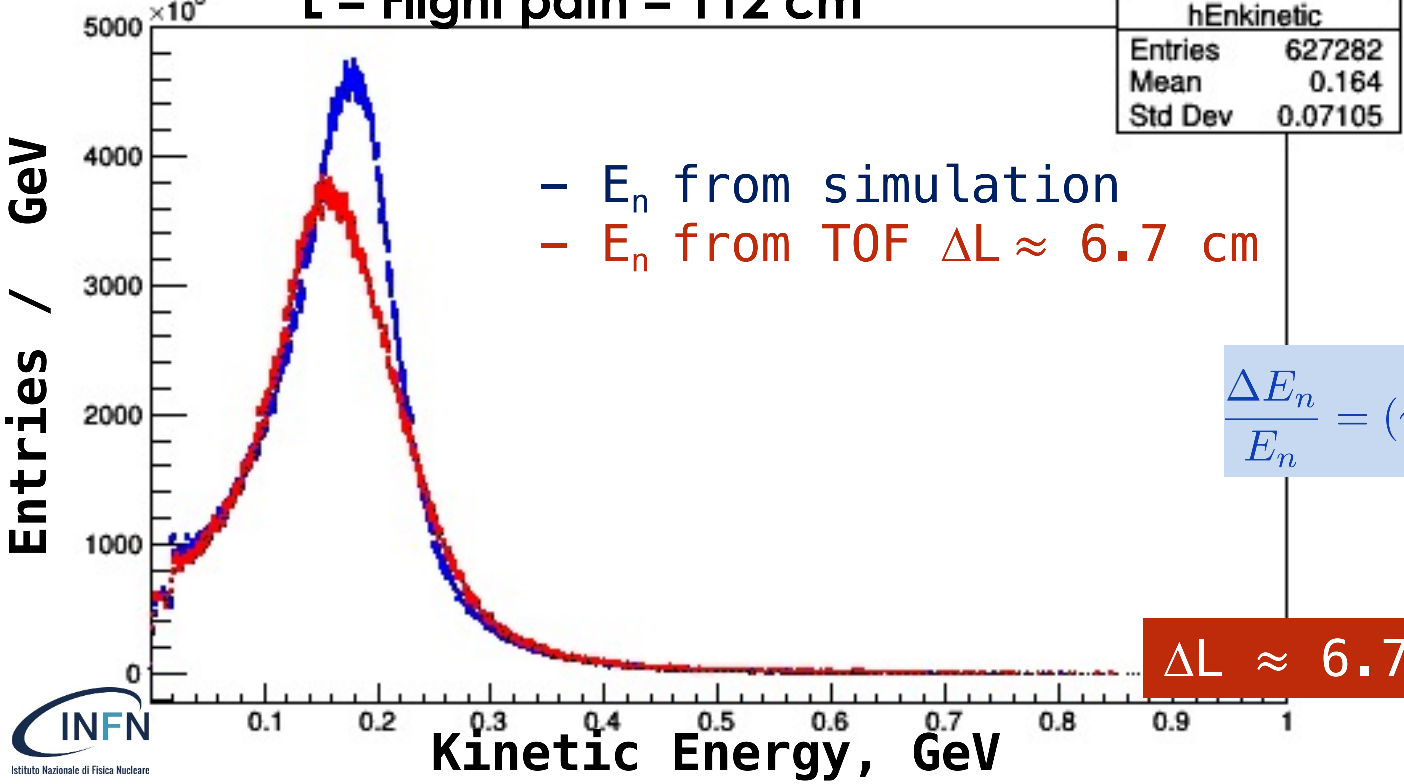
Detecting neutrons with existing setup

ΔE/E

Only events from the target



L = Flignt path = 112 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

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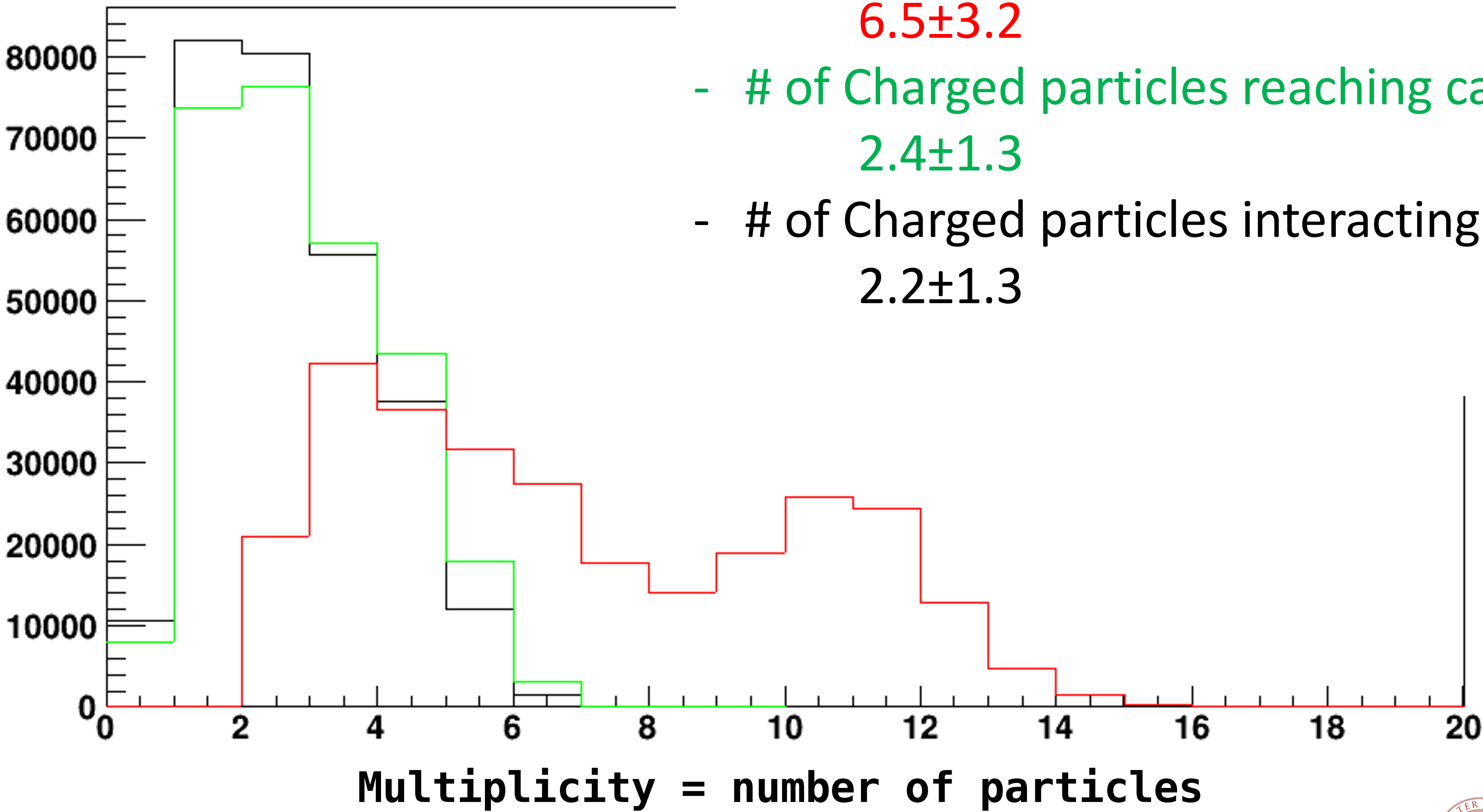
Detecting neutrons with existing setup

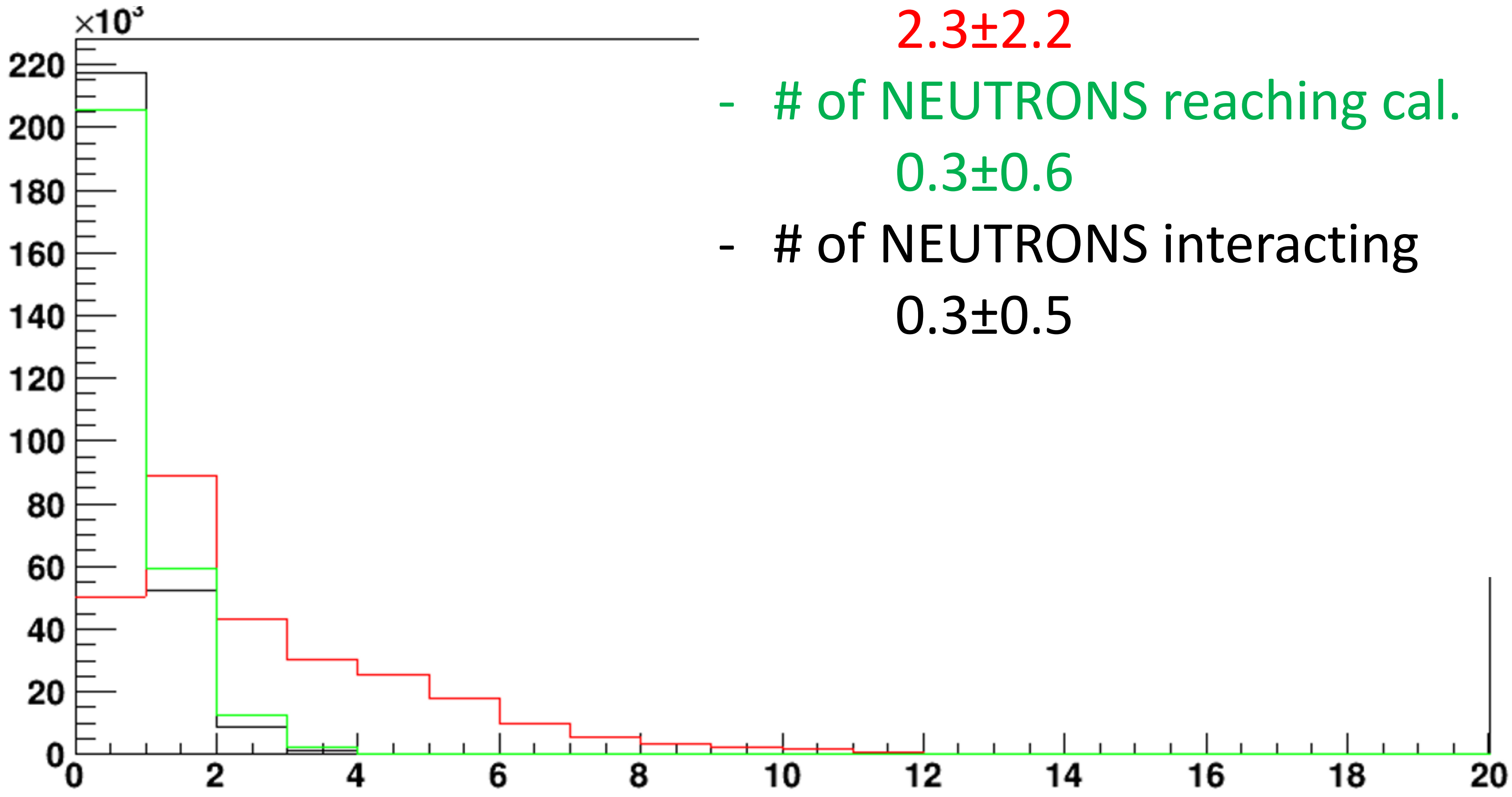
NEW



- # 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

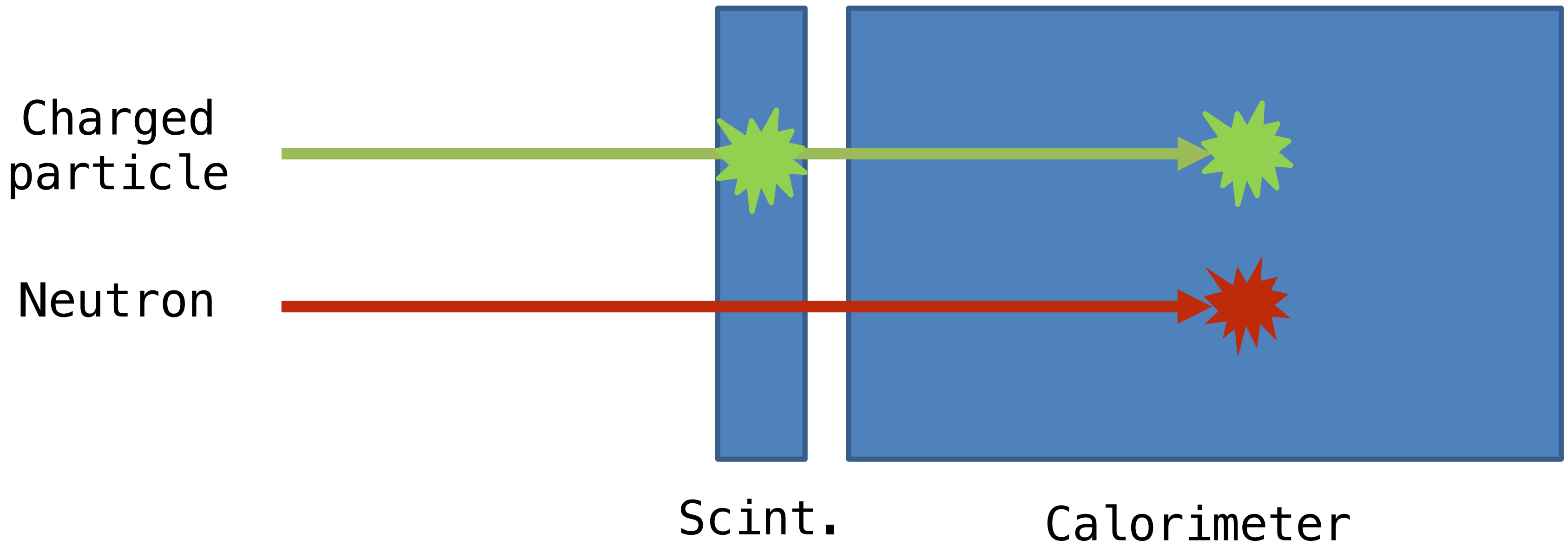


- \# of NEUTRONS from target
  2.3±2.2
- \# of NEUTRONS reaching cal.
  0.3±0.6
- \# of NEUTRONS interacting
  0.3±0.5

Multiplicity = number of particles

Detecting neutrons with existing setup SUMMARY

Basic idea: **anticoincidence scintillator – calorimenter**



Advantages

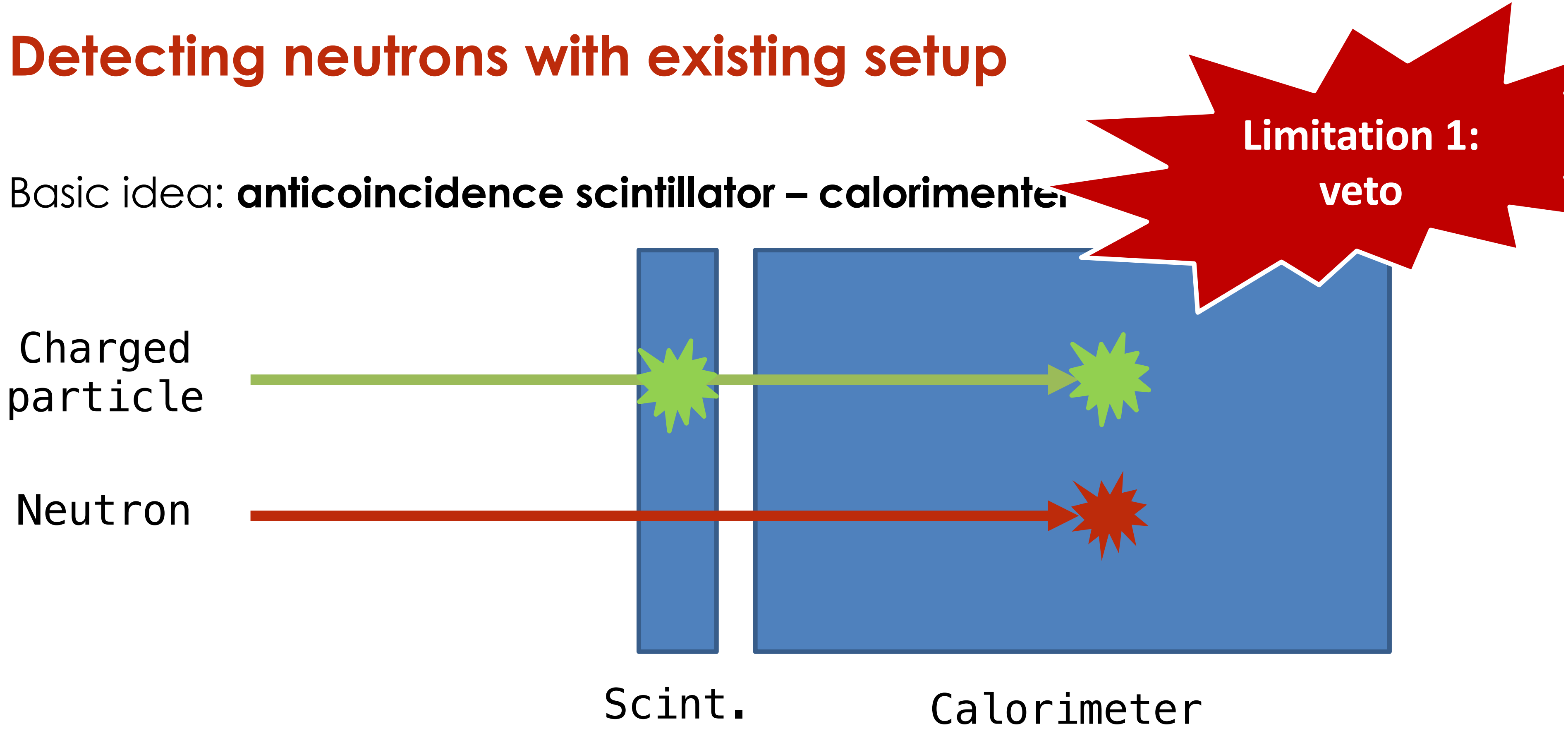
1. Simple technique
2. Exploits current setup

Limitations

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

Detecting neutrons with existing setup

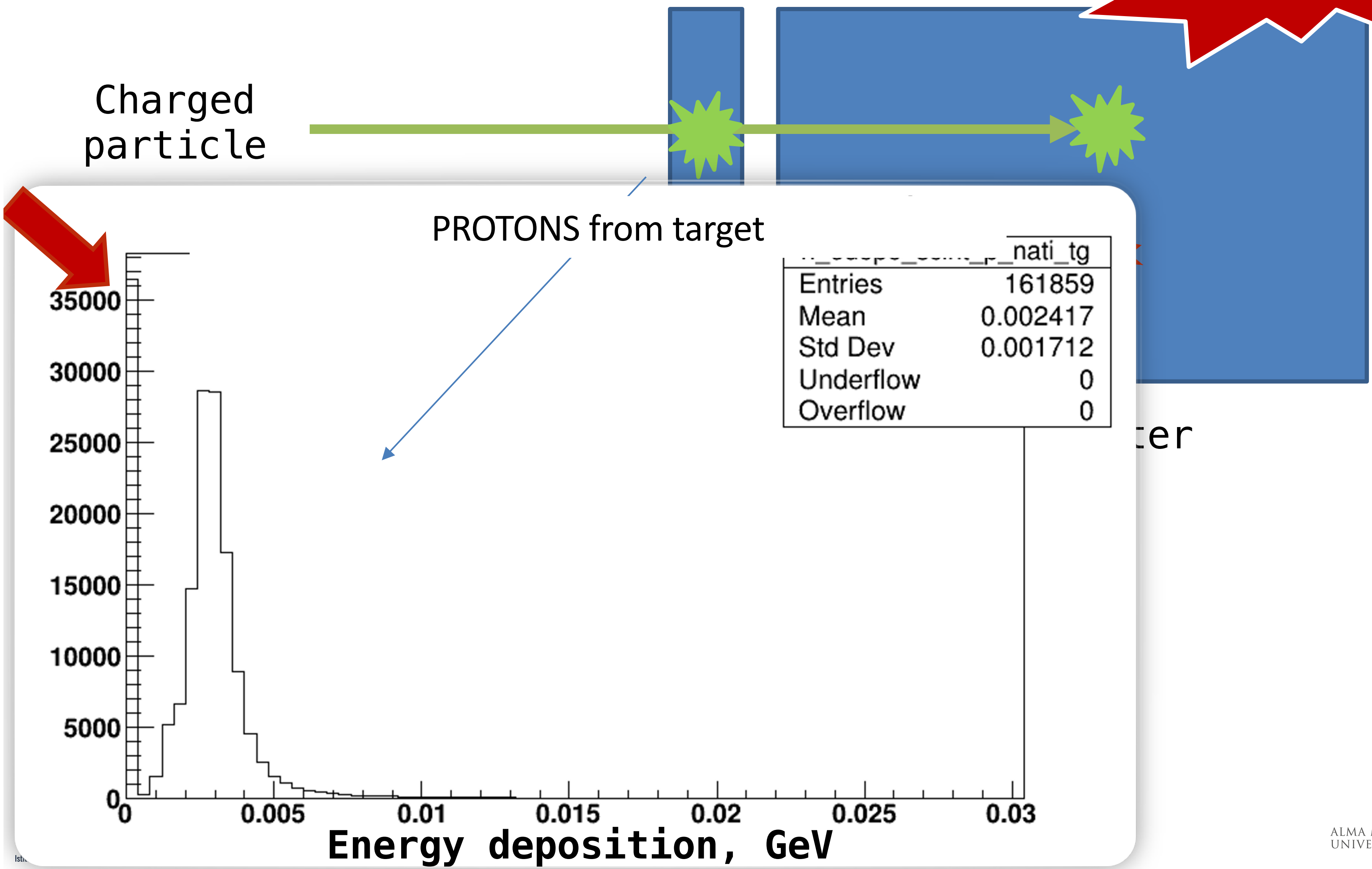
Basic idea: **anticoincidence scintillator – calorimenter**



Detecting neutrons with existing setup

Basic idea: **anticoincidence scintillator – calorimenter**

Limitation 1: veto



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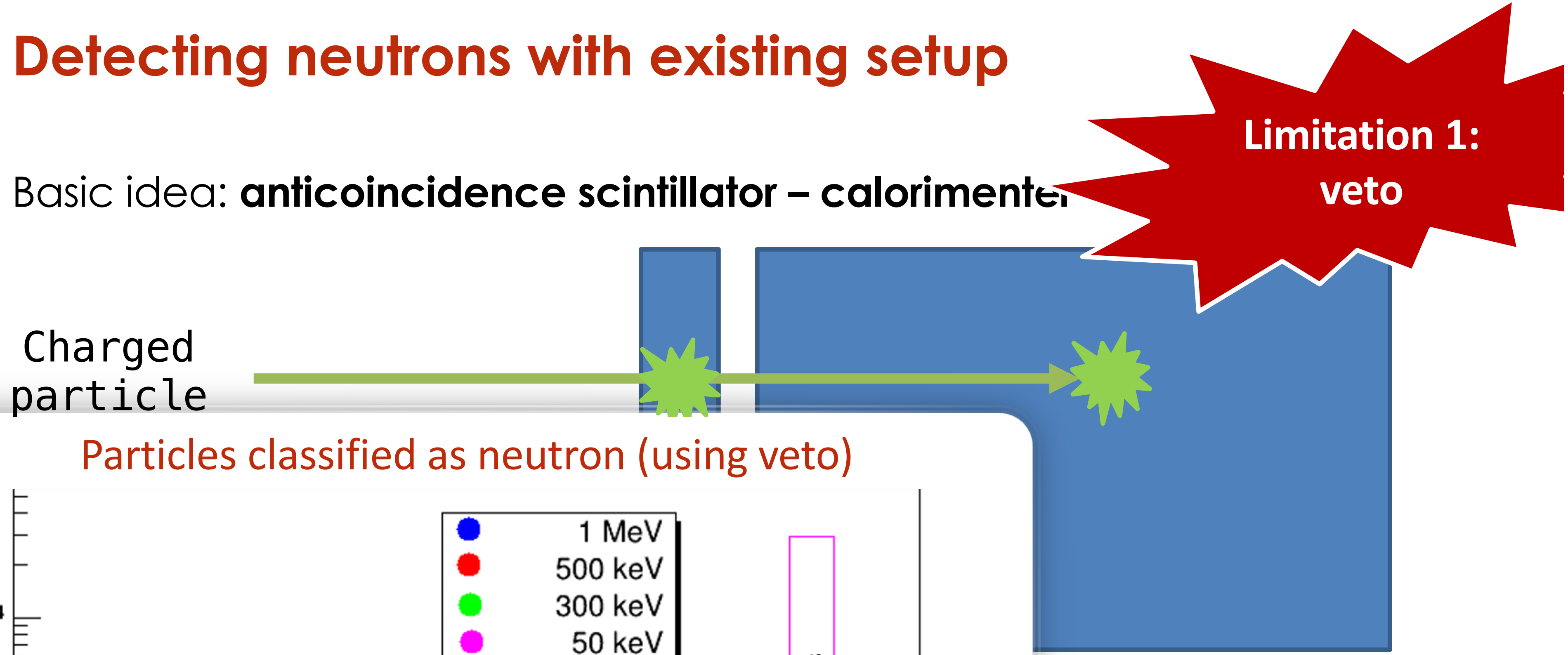
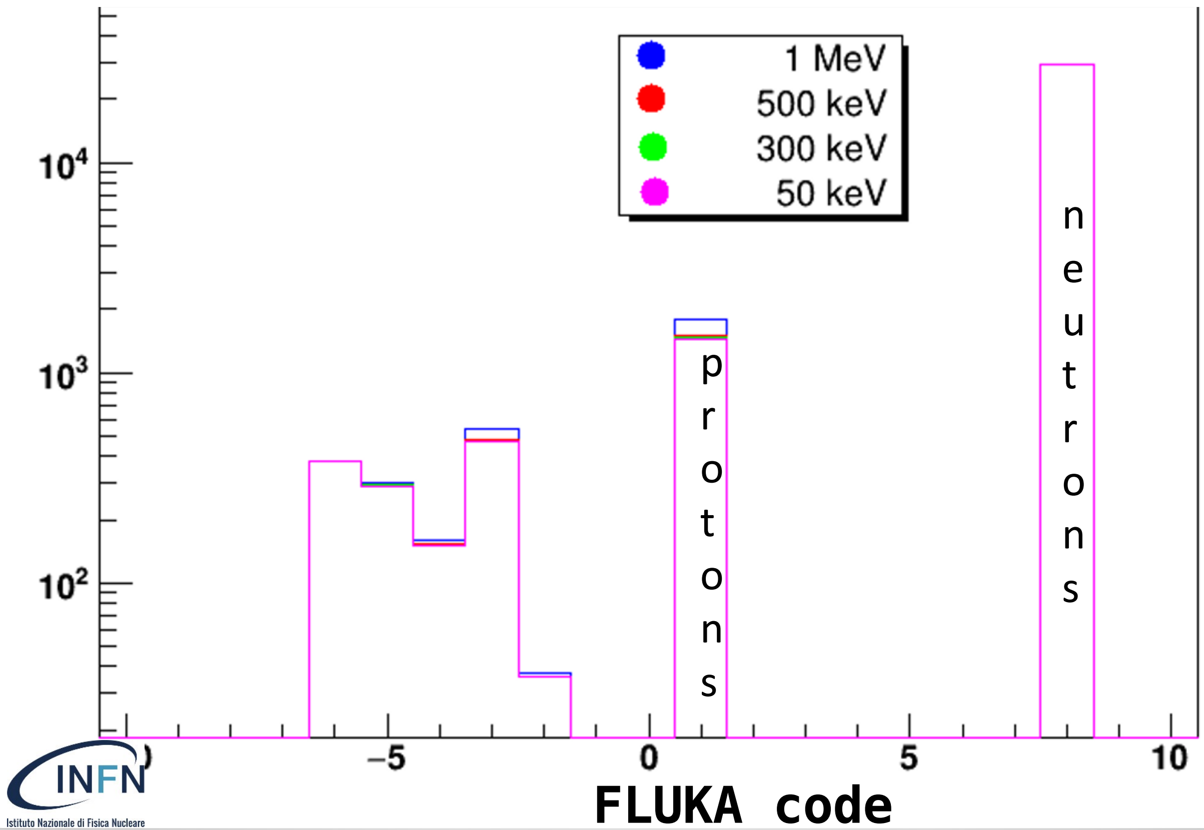
Detecting neutrons with existing setup

Basic idea: **anticoincidence scintillator – calorimenter**



Particles classified as neutron (using veto)



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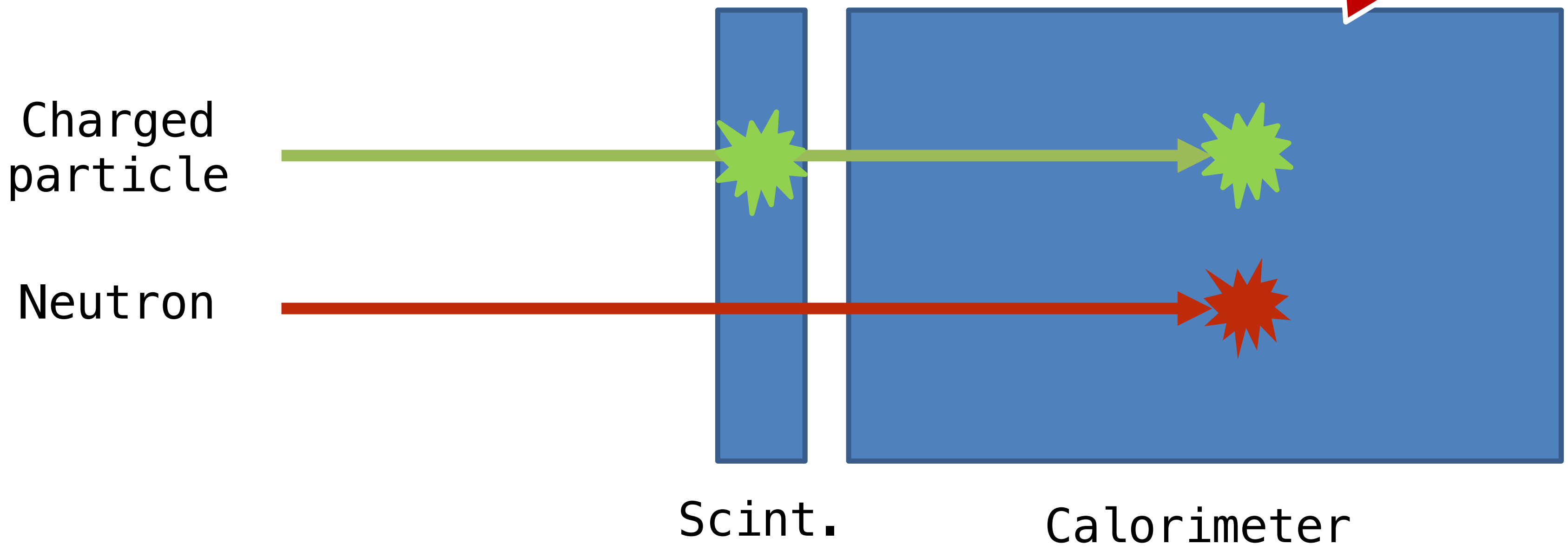
Detecting neutrons with existing setup

Limitation 2: n/γ

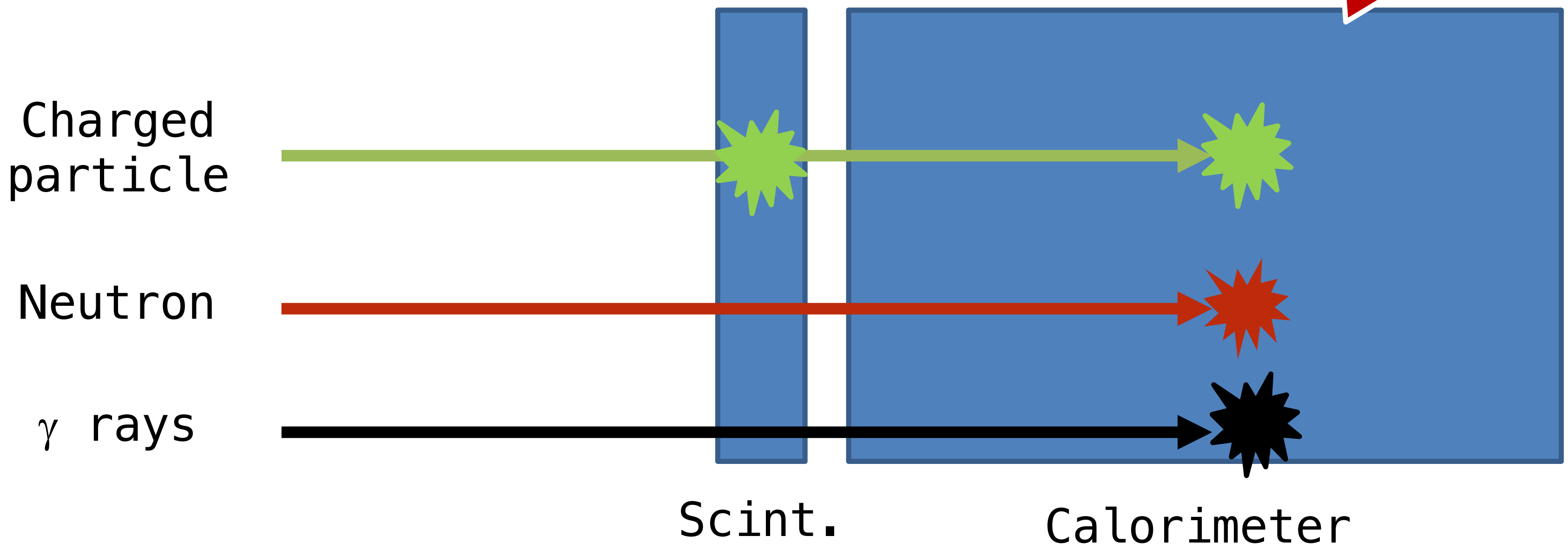
Basic idea: **anticoincidence scintillator – calorimenter**



Detecting neutrons with existing setup

Limitation 2: n/γ

Basic idea: **anticoincidence scintillator – calorimenter**

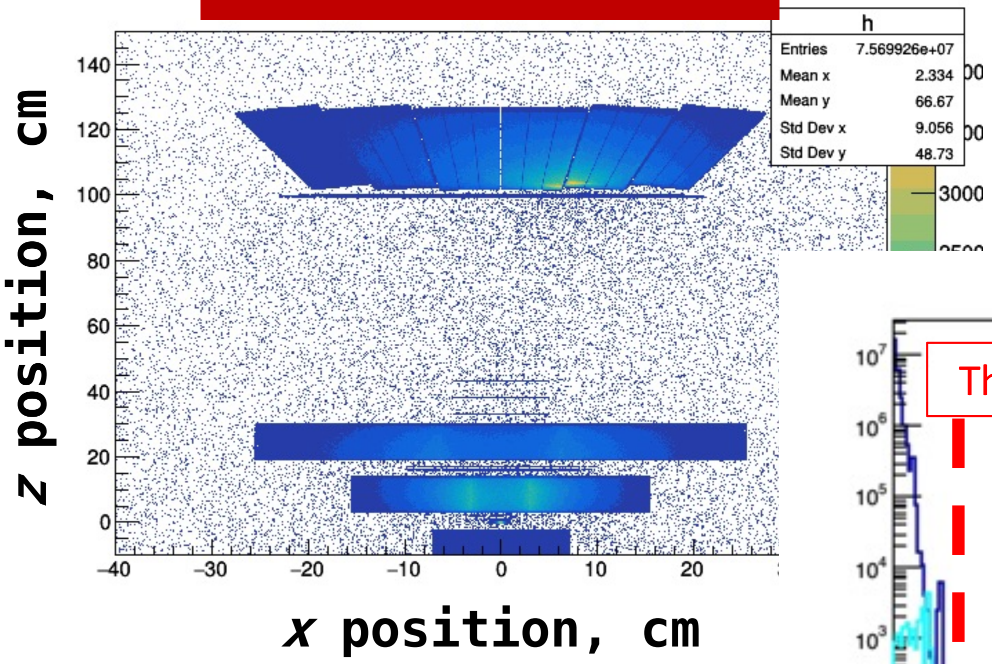


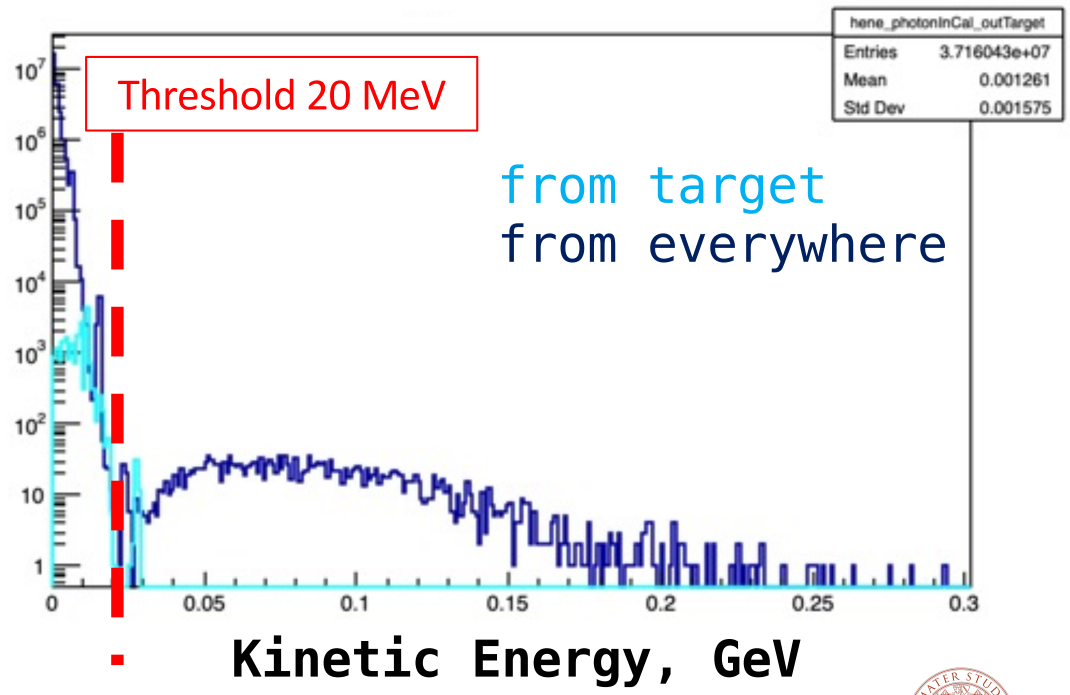
γ rays can feature the same signature

Detecting neutrons with existing setup

Limitation 2: n/γ

75.7x10^{6} γ rays
23.3x10^{6} neutrons





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

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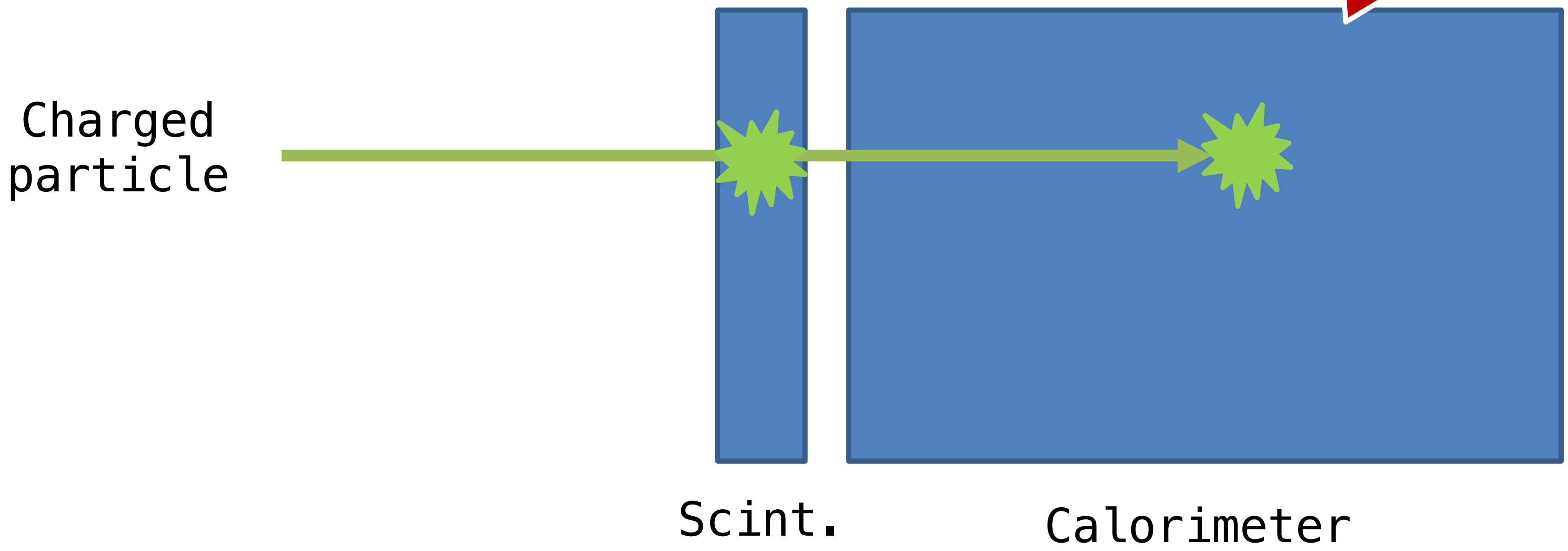
Detecting neutrons with existing setup

Limitation 3: cal. neutrons

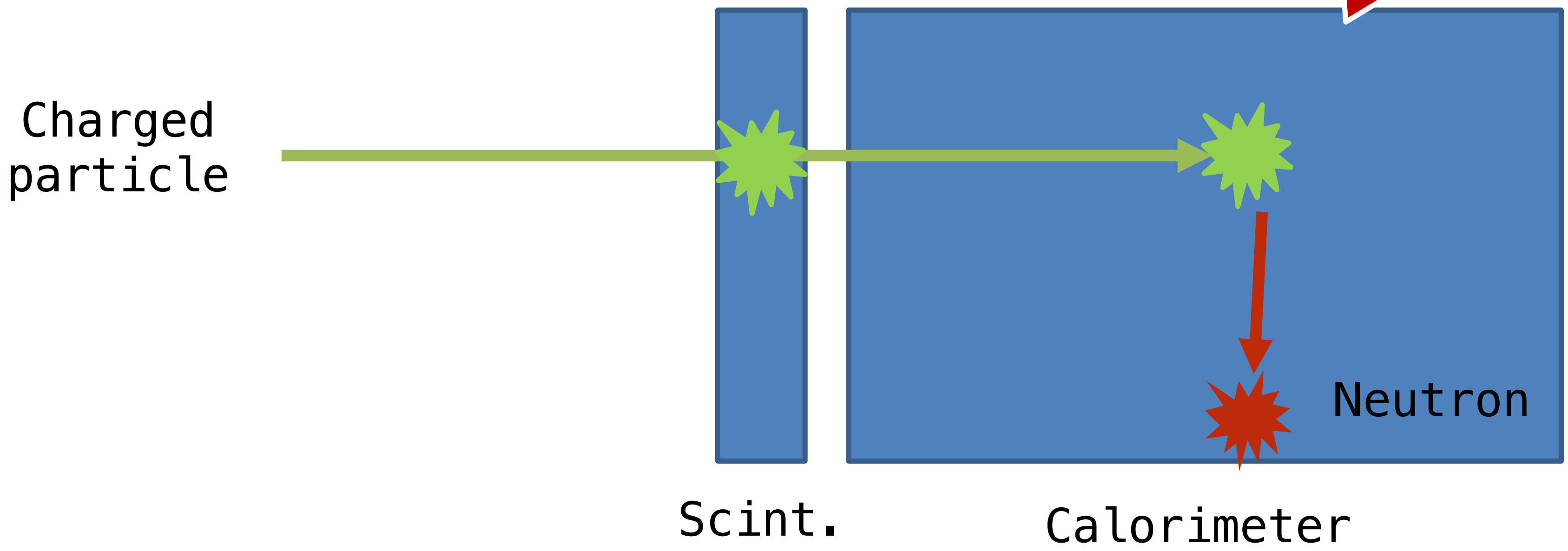
Basic idea: **anticoincidence scintillator – calorimenter**



Detecting neutrons with existing setup

Limitation 3:
cal. neutrons

Basic idea: **anticoincidence scintillator – calorimenter**



Neutrons produced in the calorimeter cannot be easily tagged

Detecting neutrons with existing setup

Limitation 3:
cal. neutrons

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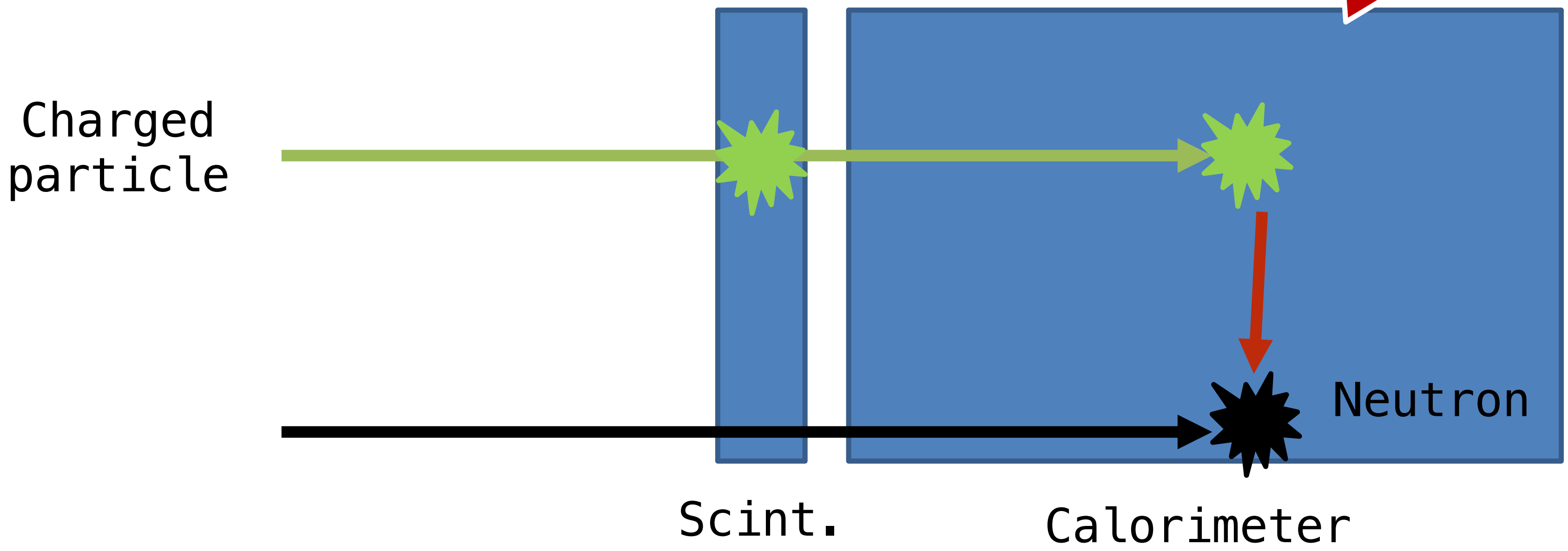

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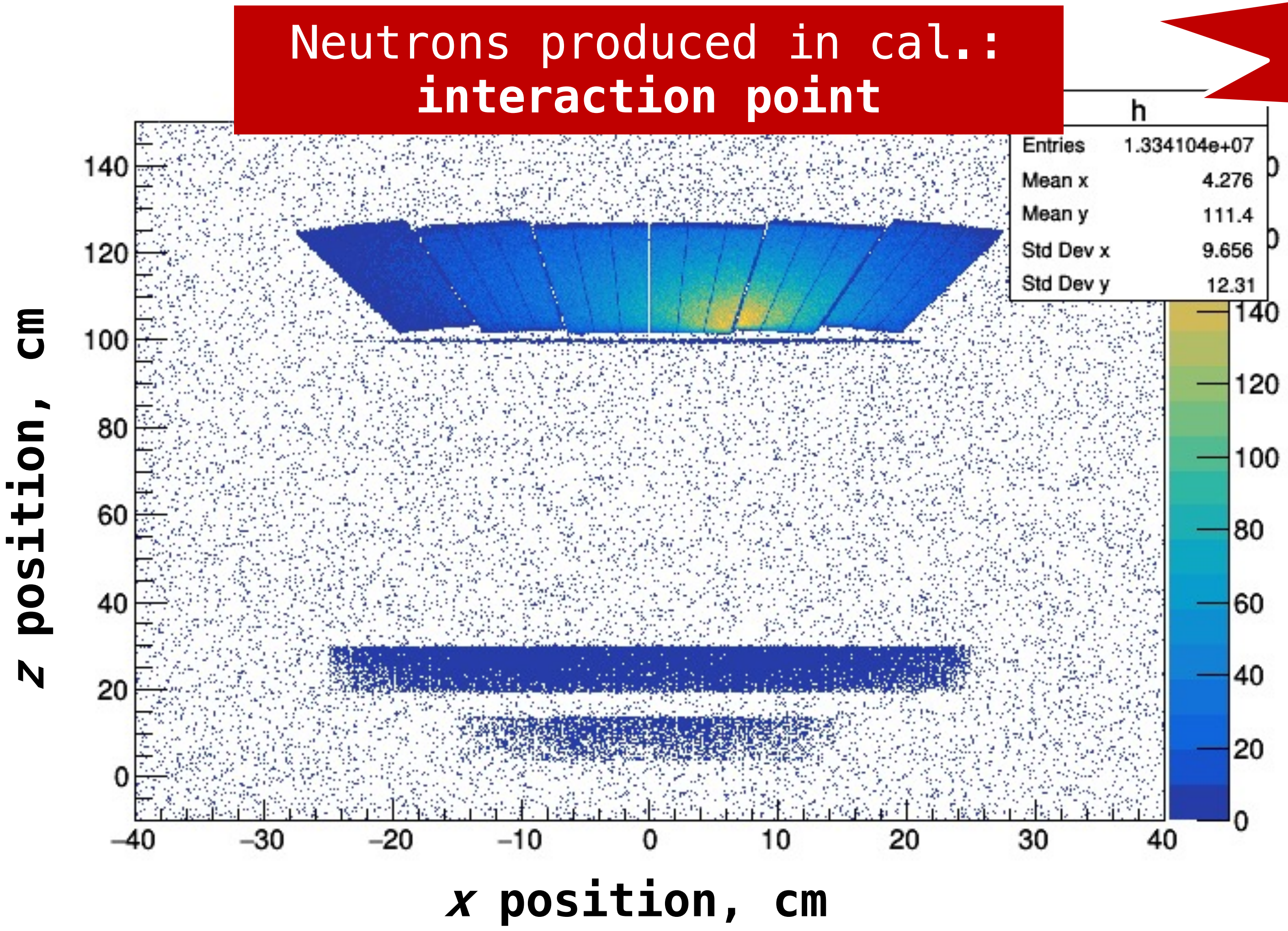
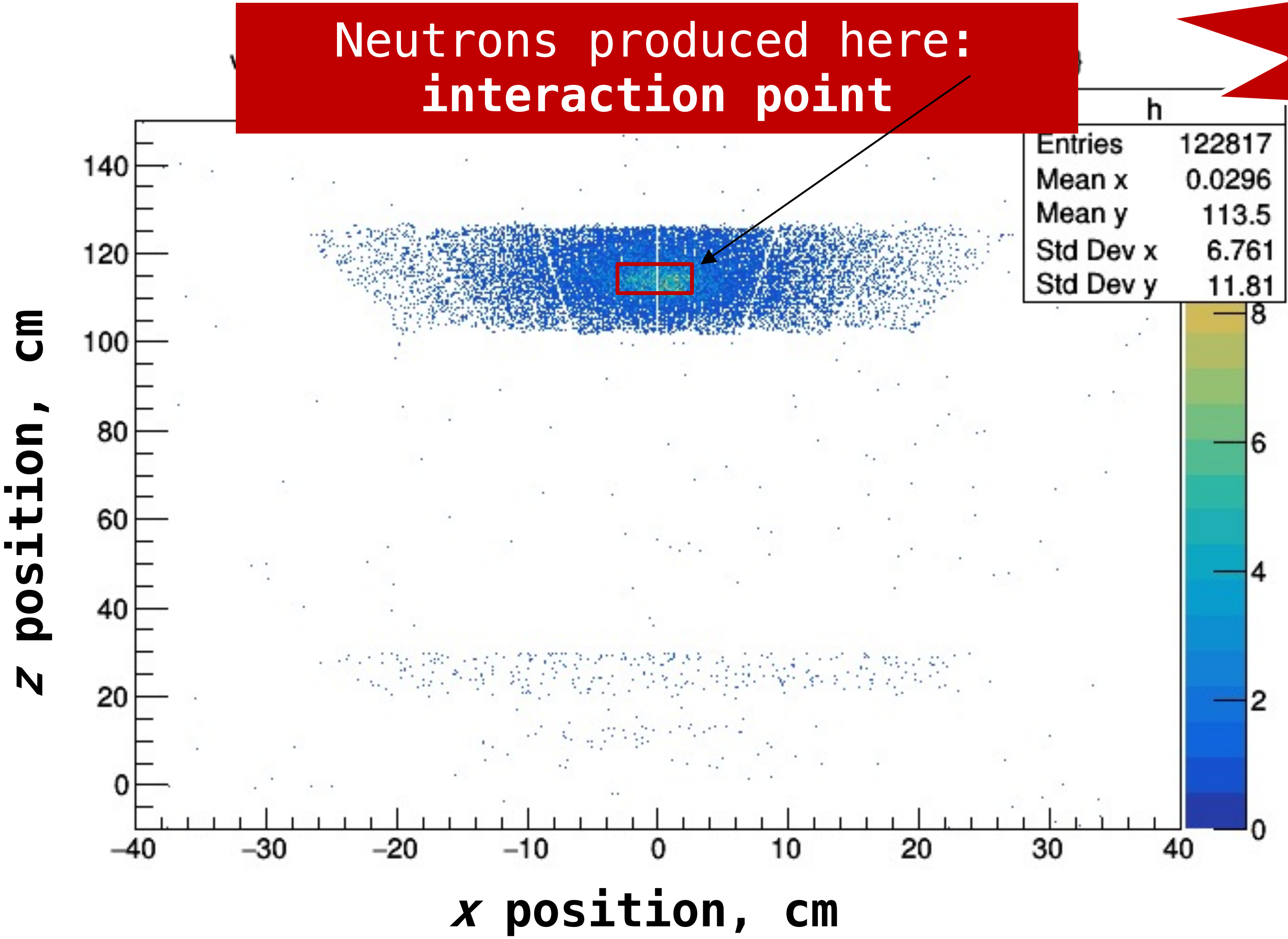


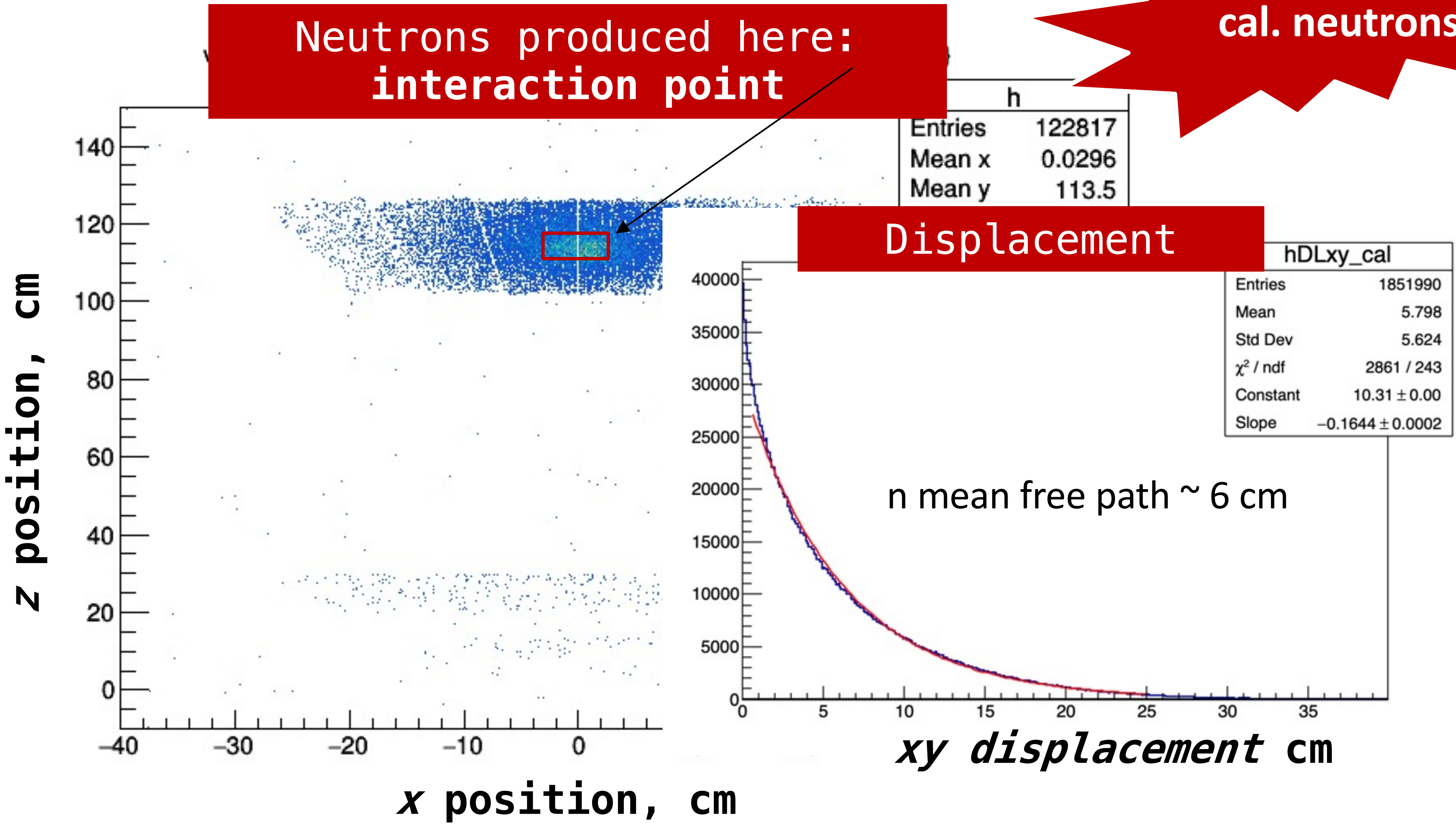
Detecting neutrons with existing setup

Limitation 3: cal. neutrons



Detecting neutrons with existing setup

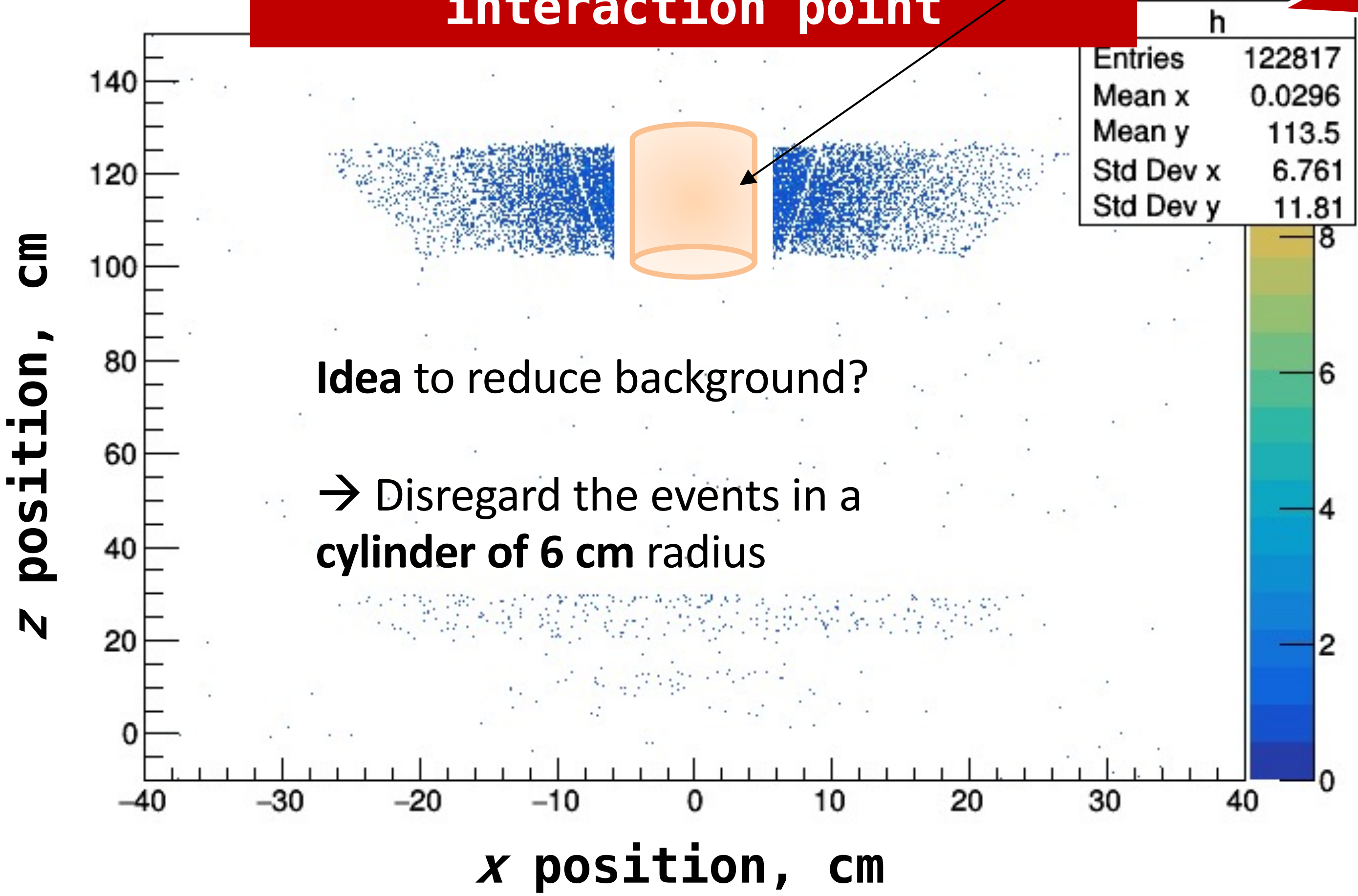
Limitation 3: cal. neutrons



Detecting neutrons with existing setup

Limitation 3: cal. neutrons

Neutrons produced here: **interaction point**



Idea to reduce background?

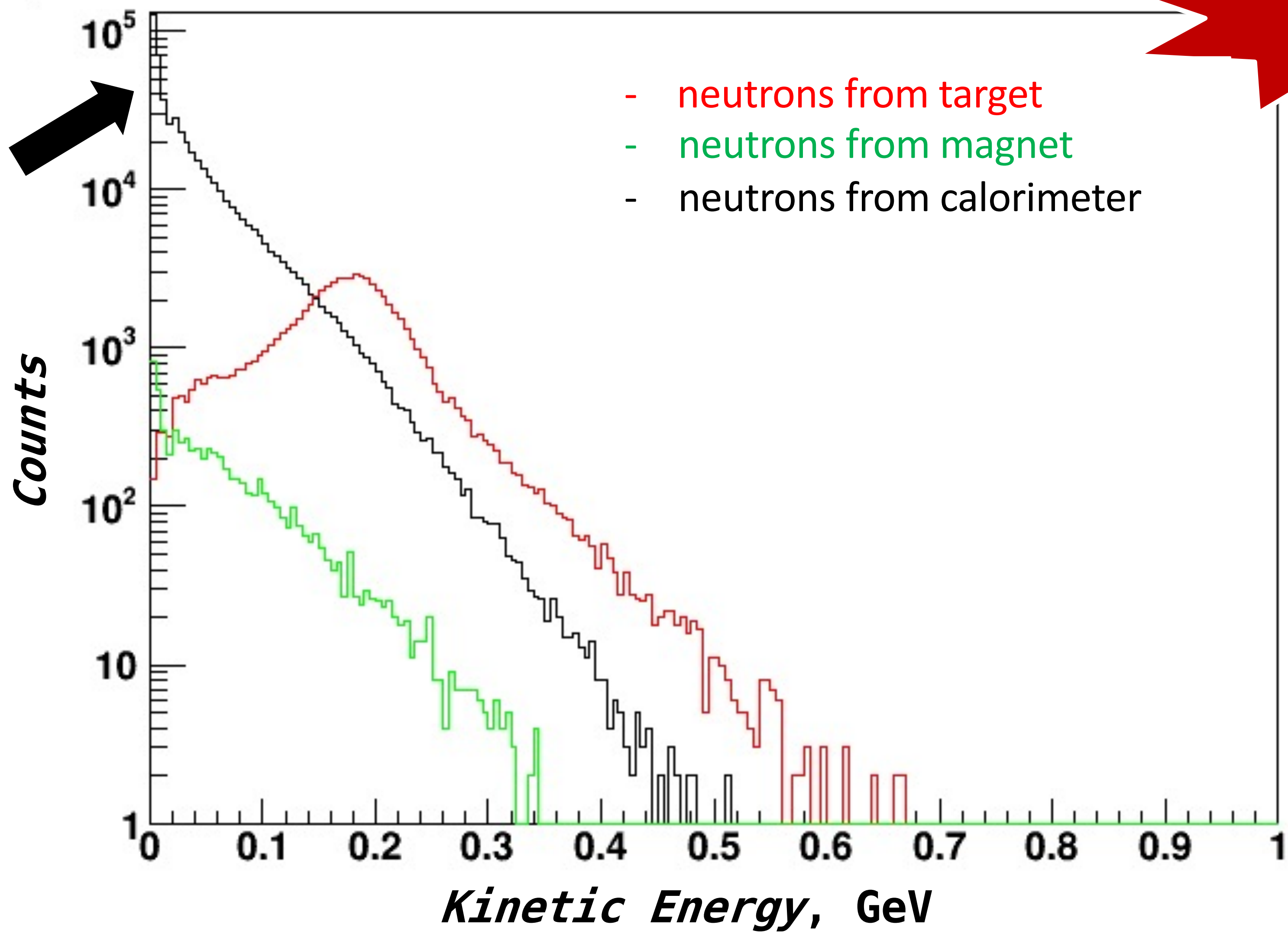
→ Disregard the events in a **cylinder of 6 cm** radius

Neutron kinetic energy is much larger in the cylinder

Detecting neutrons with existing setup

Limitation 3: cal. neutrons

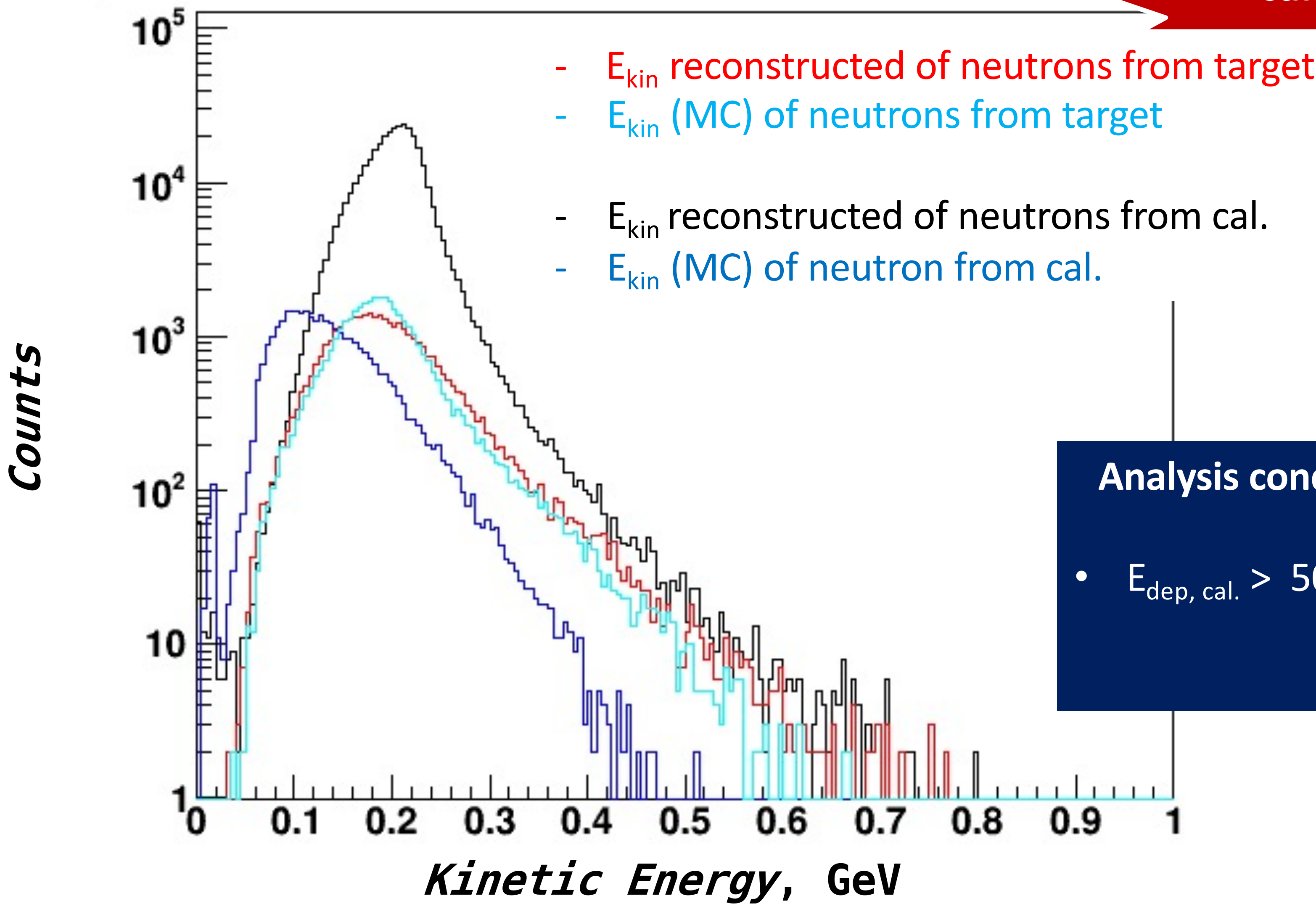
TRUE Monte Carlo



Detecting neutrons with existing setup

Limitation 3: cal. neutrons

TRUE Monte Carlo Vs reconstructed



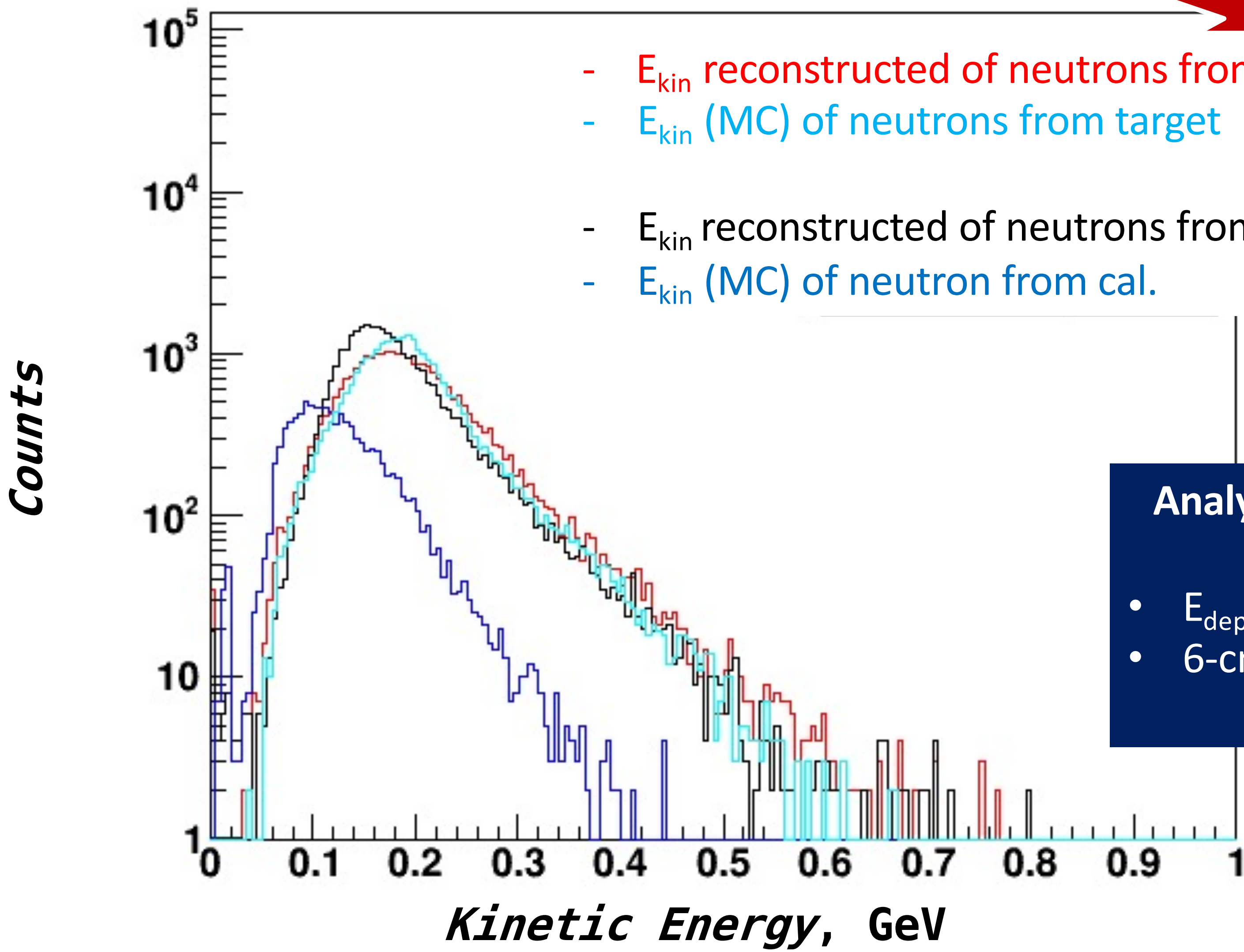
Analysis condition:

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

Detecting neutrons with existing setup

Limitation 3: cal. neutrons

TRUE Monte Carlo Vs reconstructed

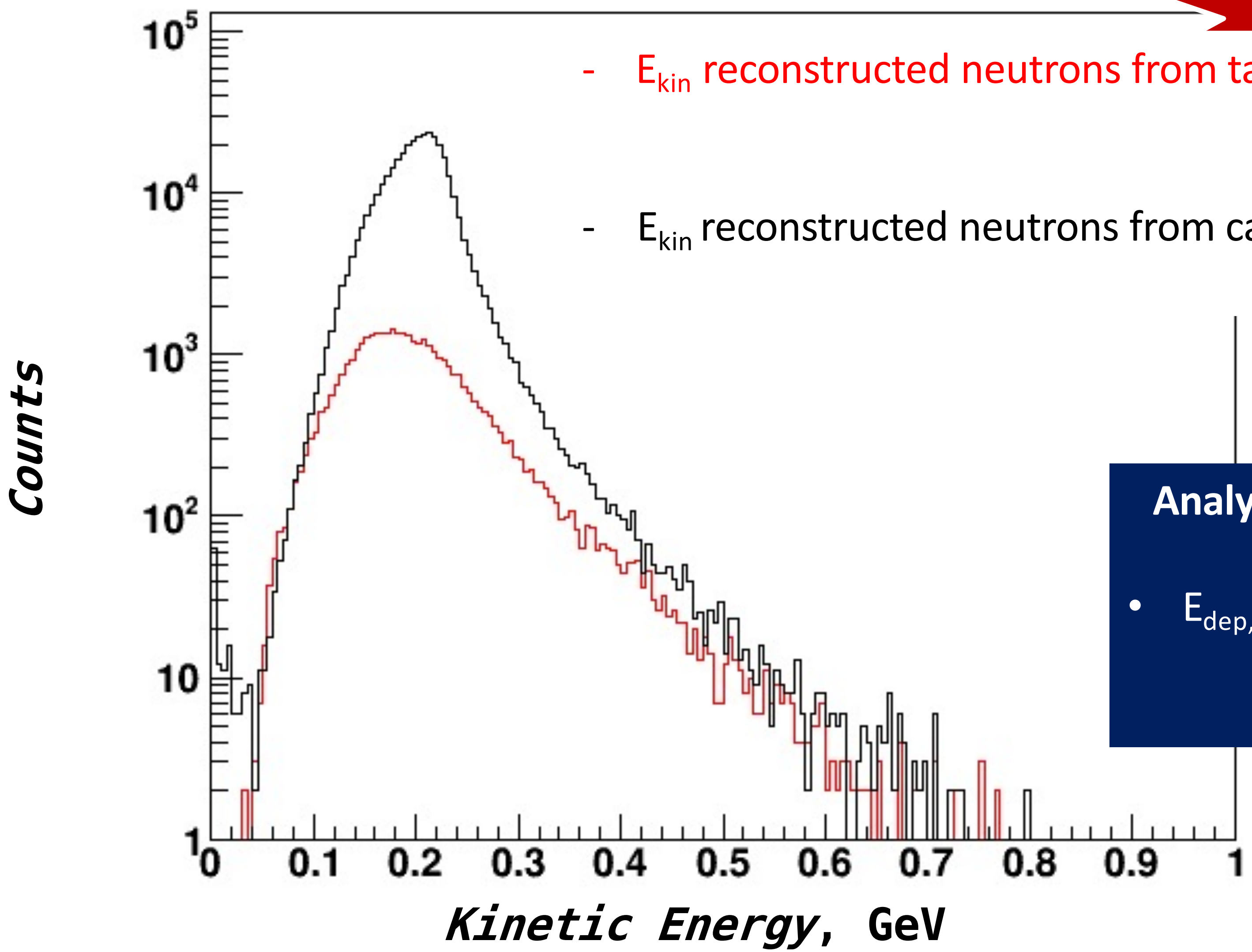


Analysis condition:

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

Detecting neutrons with existing setup

reconstructed



- E_{kin} reconstructed neutrons from target
- E_{kin} reconstructed neutrons from cal.

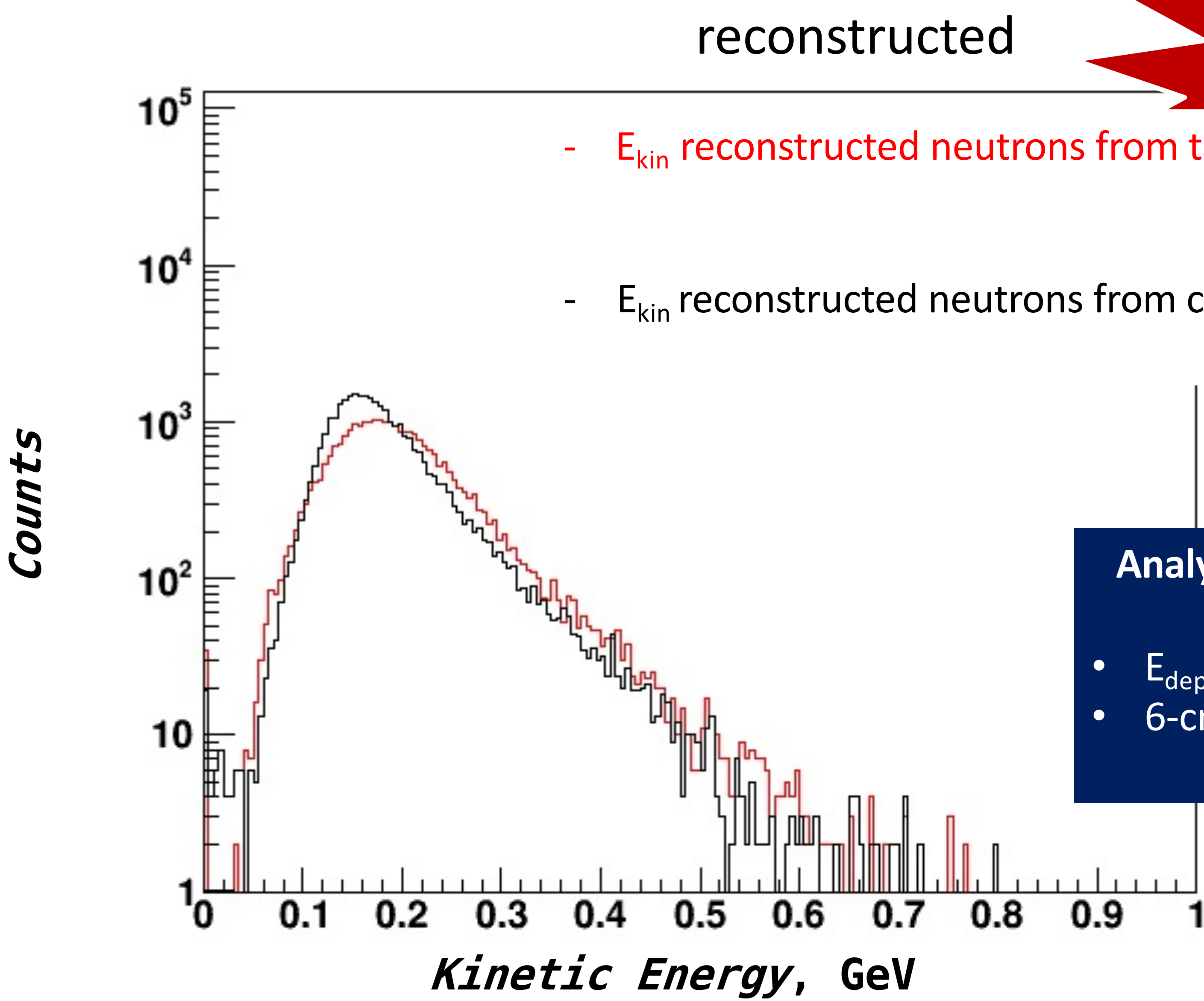
Limitation 3: cal. neutrons

Analysis condition:

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

Detecting neutrons with existing setup

Limitation 3: cal. neutrons



Analysis condition:

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

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 moderation are not suited.
- A few information for **high-energy neutrons only**, by **using the 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.
- **Veto** provided by TOF wall works ~ for **protons** (efficinecy 70-80%).
- **Neutrons** produced in **calorimeter** are an **issue** strongly limiting the energy region where we can provide data.

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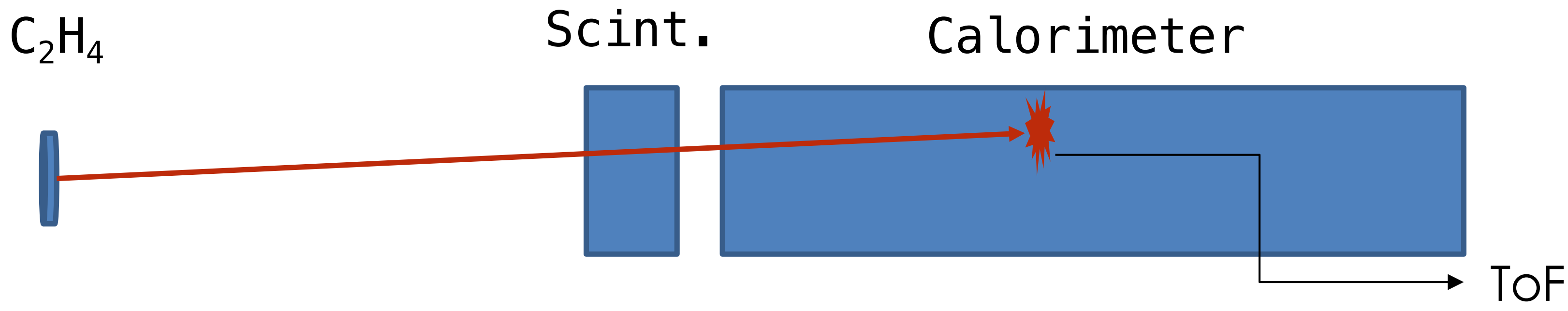
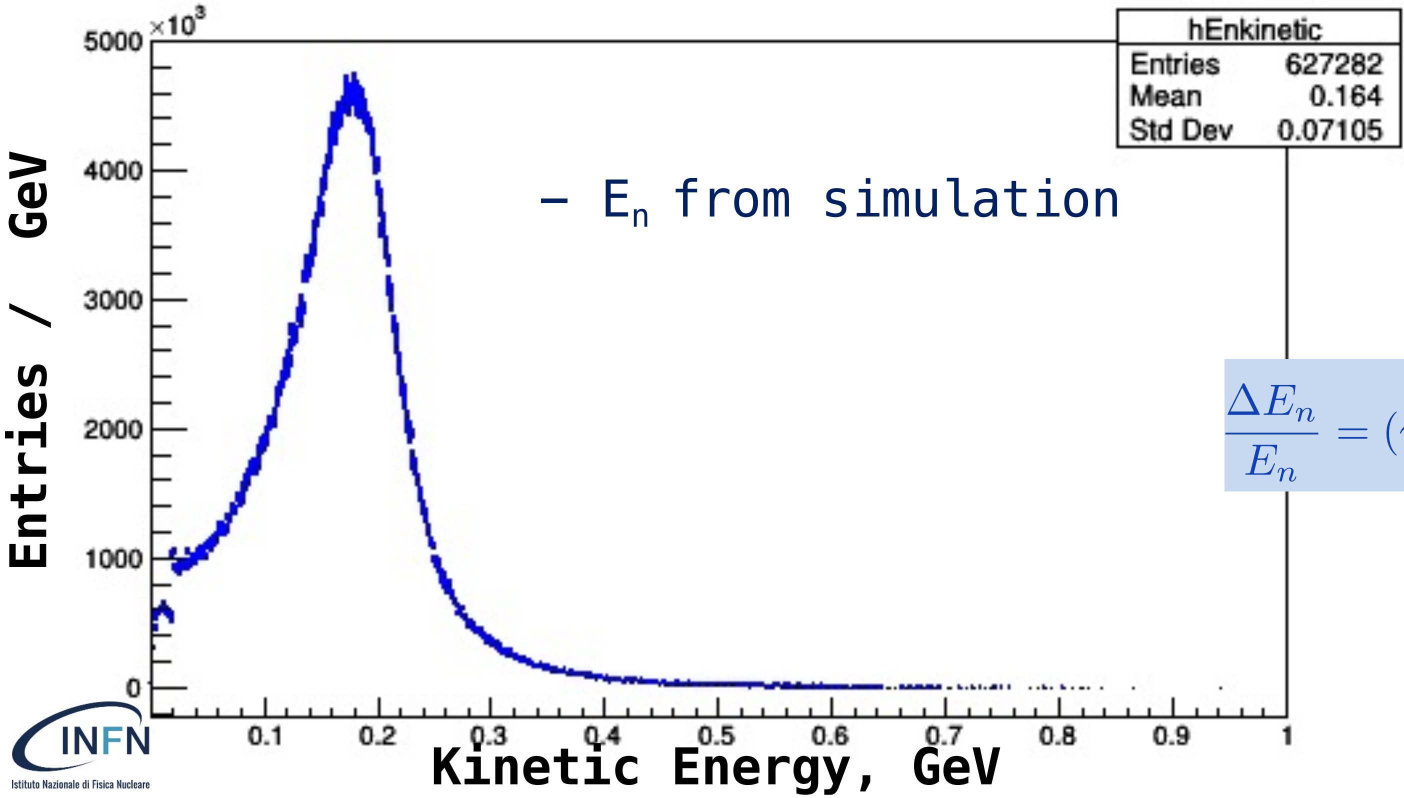
backup

Detecting neutrons with existing setup

ΔE/E

Only events from the target





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

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

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

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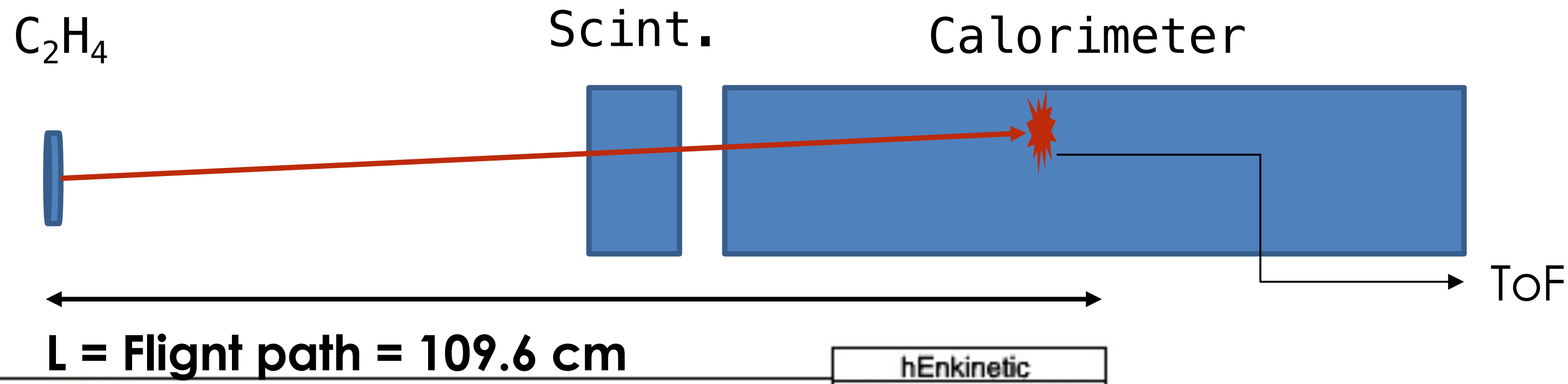
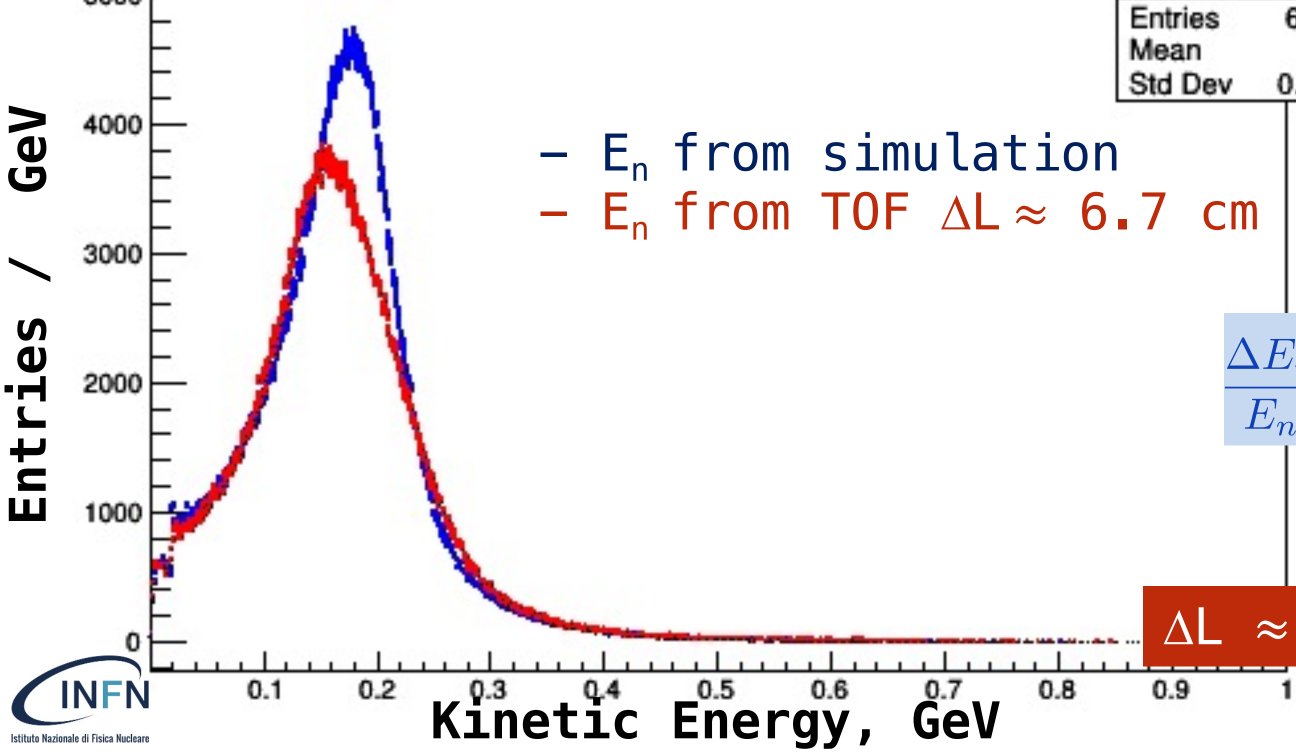
Detecting neutrons with existing setup ΔE/E

Only events from the target





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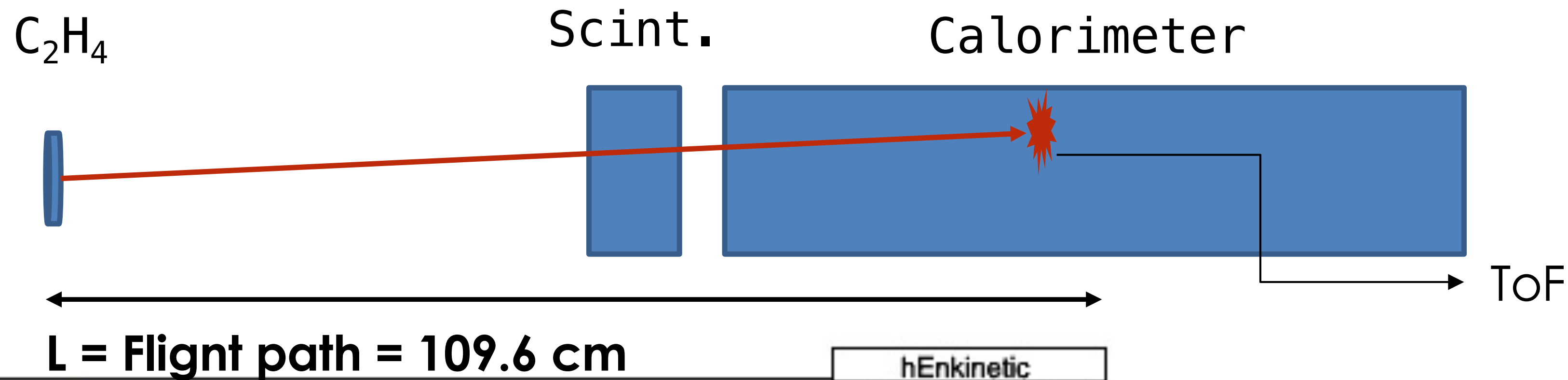
$$\frac{\Delta E_n}{E_n} = (\gamma+1)\gamma\sqrt{\left(\frac{\Delta t}{t}\right)^2 + \left(\frac{\Delta L}{L}\right)^2}$$

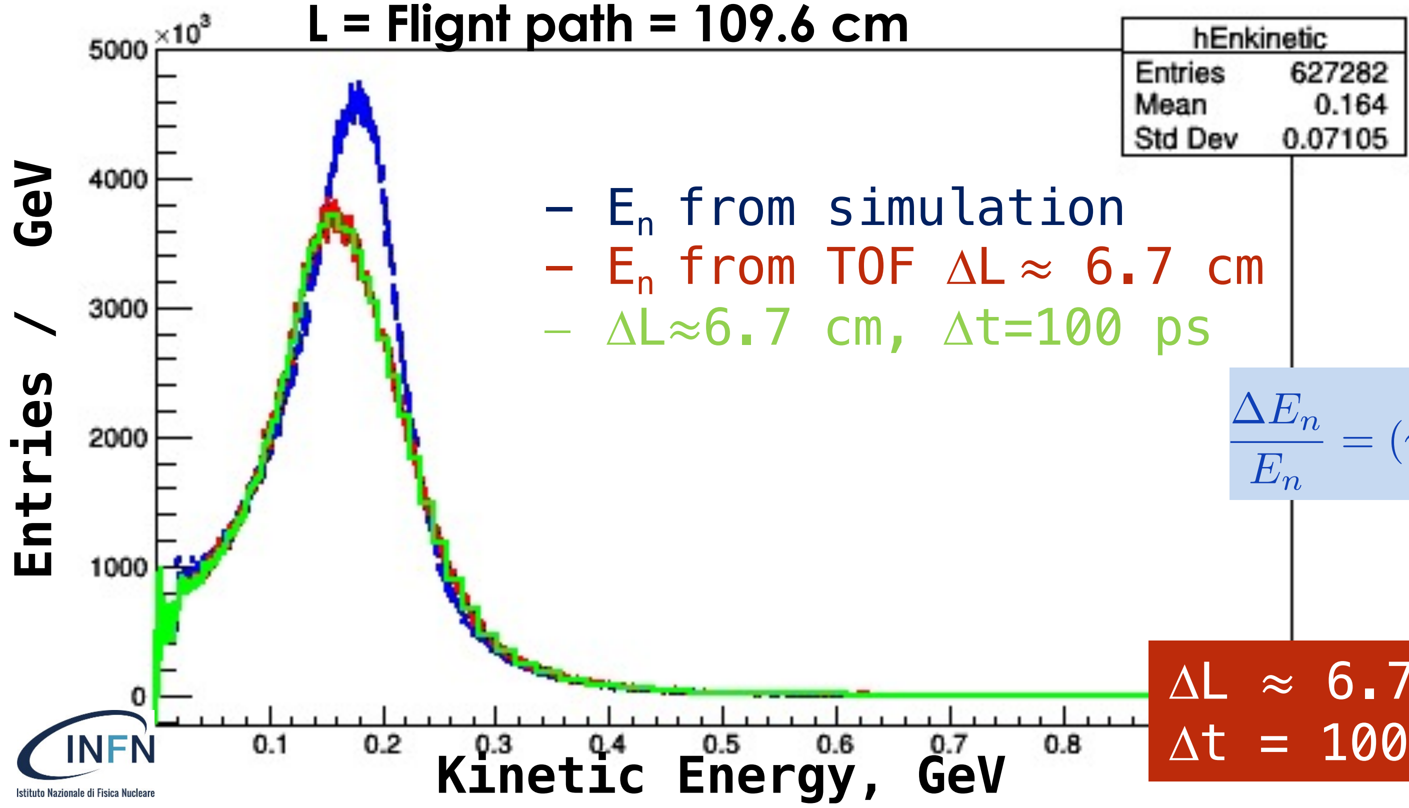
ΔL ≈ 6.7 cm

Detecting neutrons with existing setup

ΔE/E

Only events from the target





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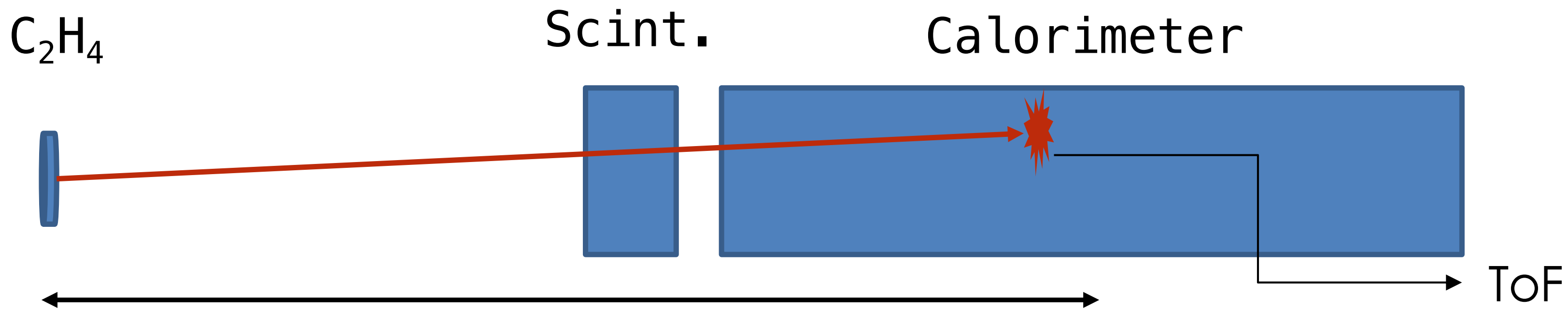
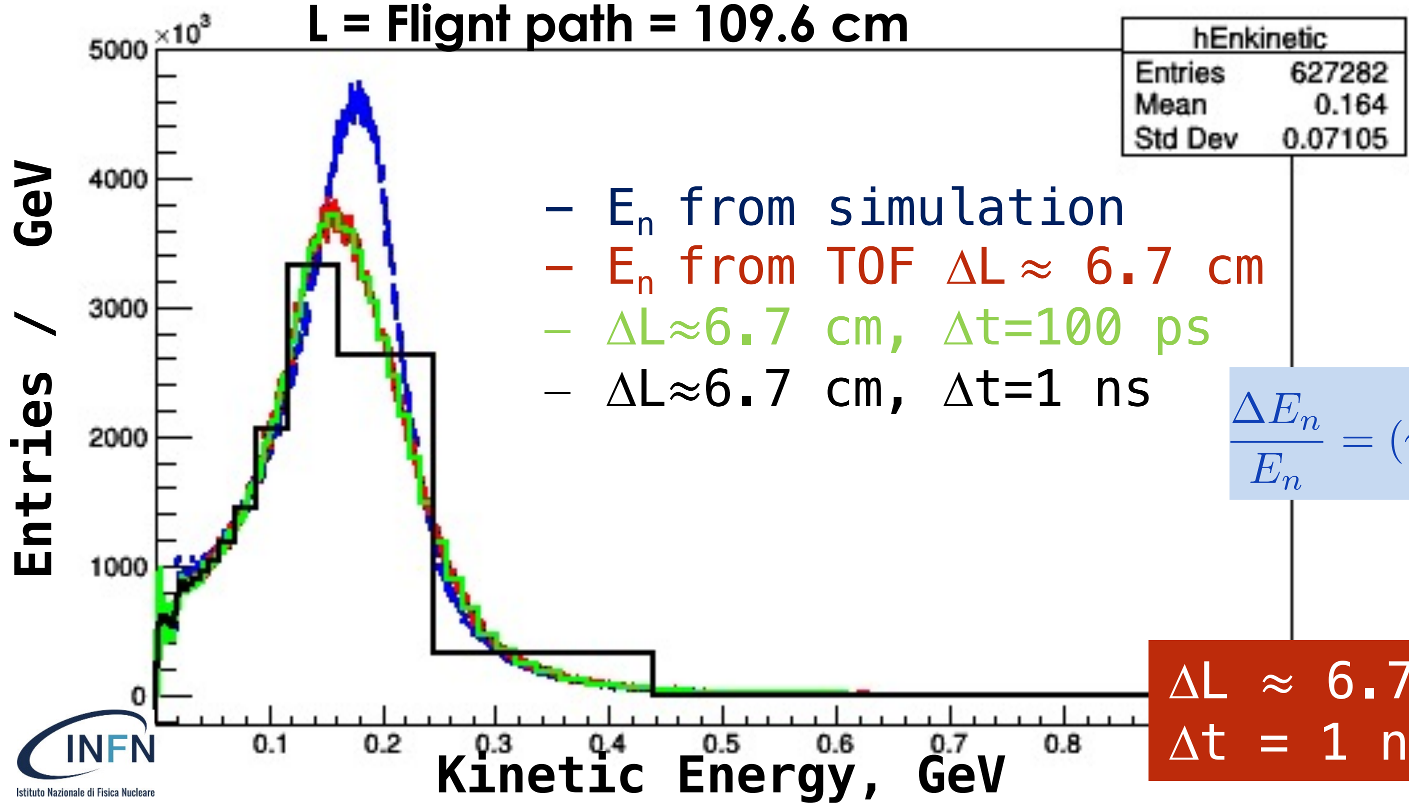
Detecting neutrons with existing setup $\Delta E/E$

Only events from the target



L = Flignt path = 109.6 cm



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

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

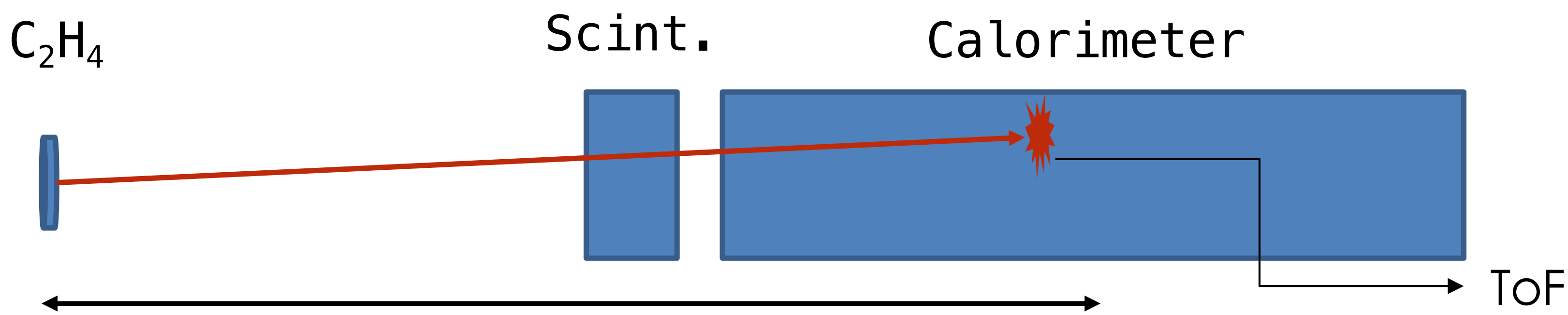
$$\frac{\Delta E_n}{E_n} = (\gamma+1)\gamma\sqrt{\left(\frac{\Delta t}{t}\right)^2 + \left(\frac{\Delta L}{L}\right)^2}$$

$\Delta L \approx 6.7$ cm
$\Delta t = 1$ ns

Detecting neutrons with existing setup

ΔE/E

Only events from the target



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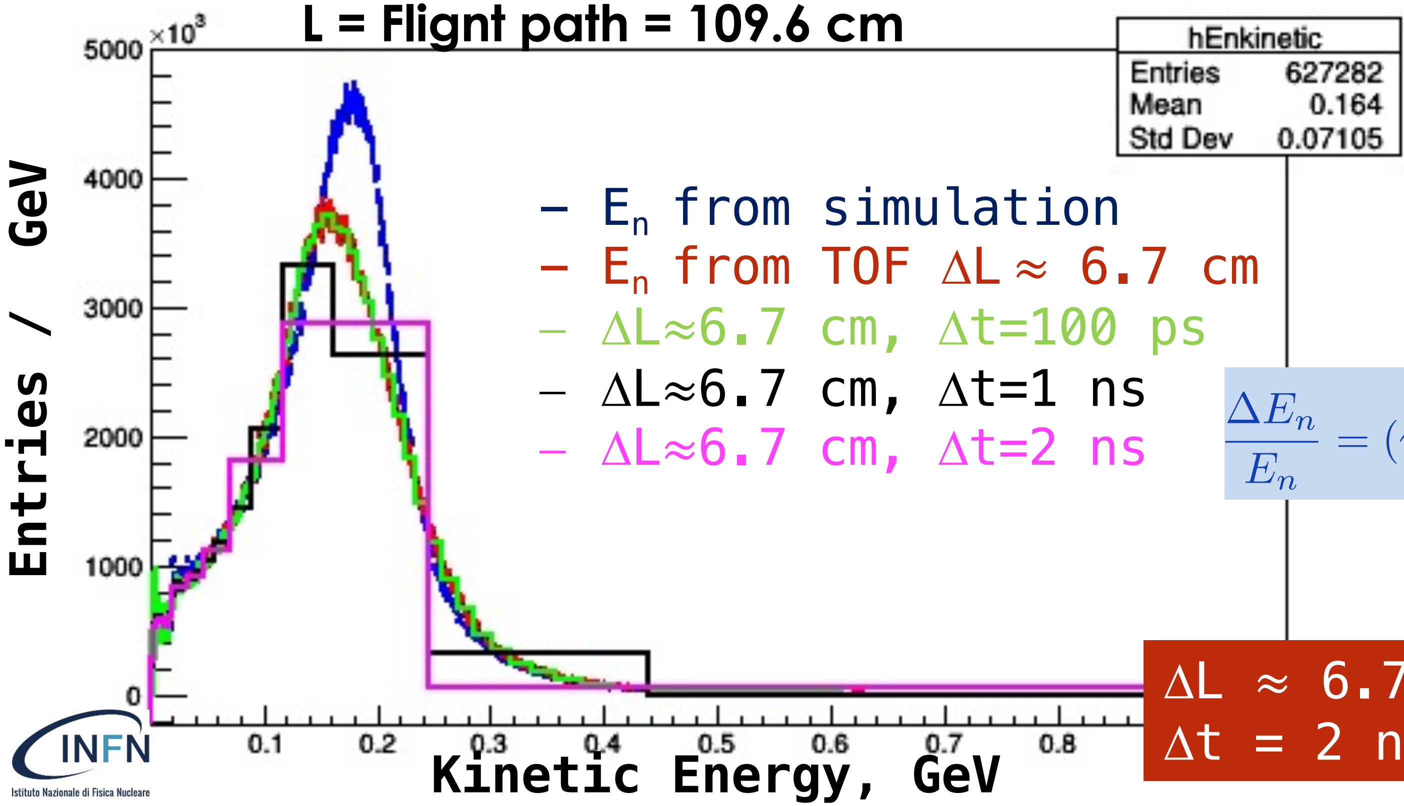

$$\gamma = \frac{1}{\sqrt{1-\beta^2}} = \frac{c\mathrm{ToF}}{\sqrt{c^2\mathrm{ToF}^2 - L^2}}$$

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

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

ΔL ≈ 6.7 cm
Δt = 2 ns

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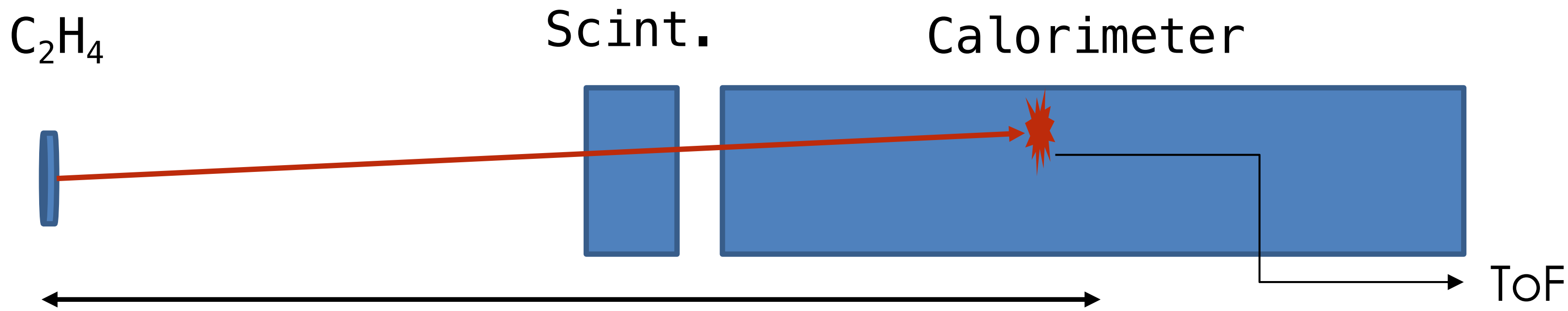
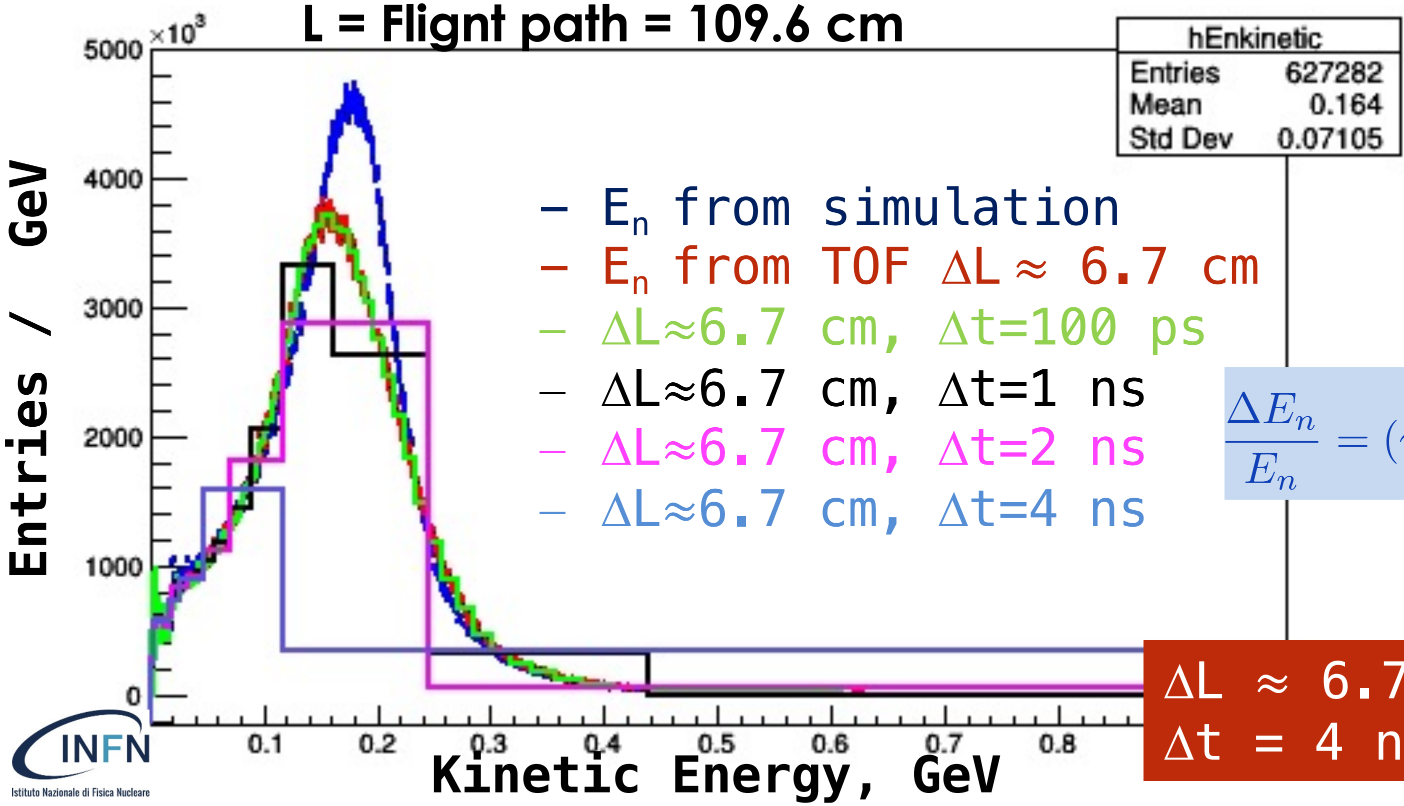
Detecting neutrons with existing setup

ΔE/E

Only events from the target





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

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

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

ΔL ≈ 6.7 cm
Δt = 4 ns

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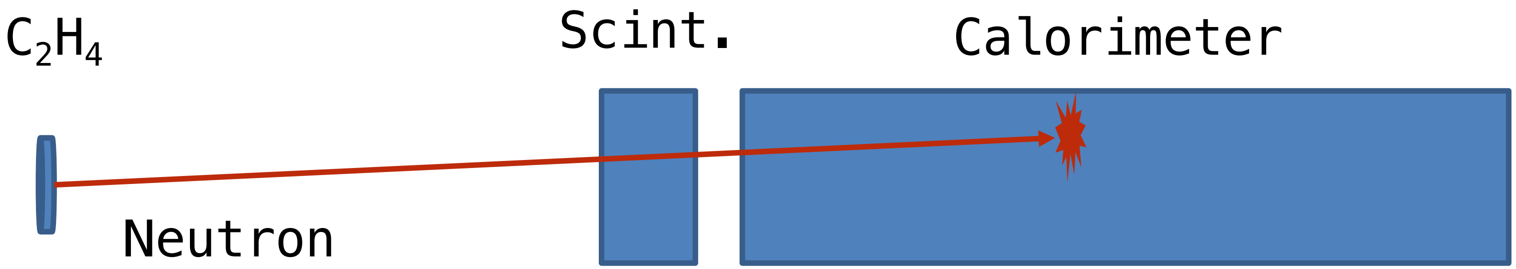
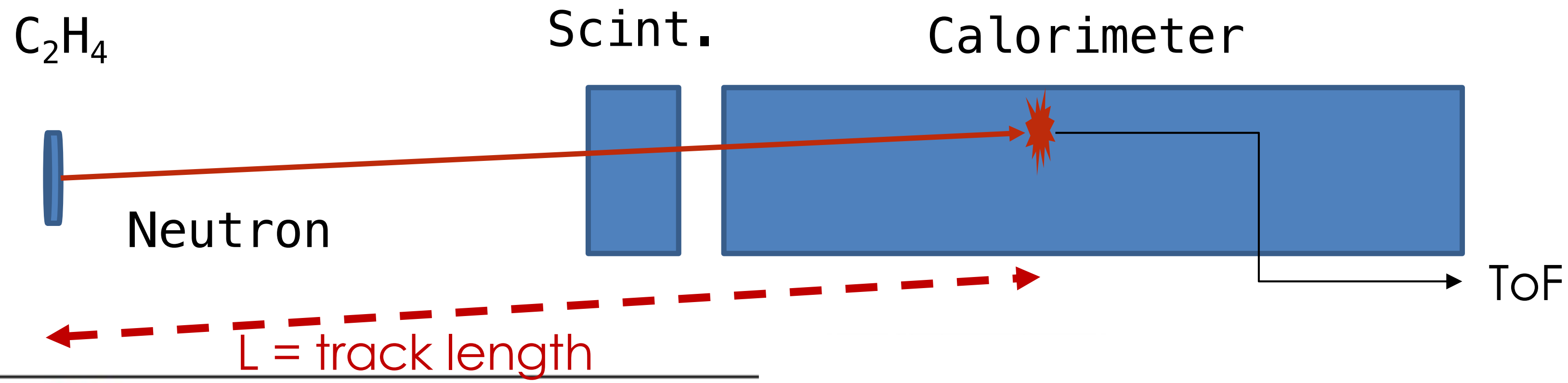
Detecting neutrons with existing setup

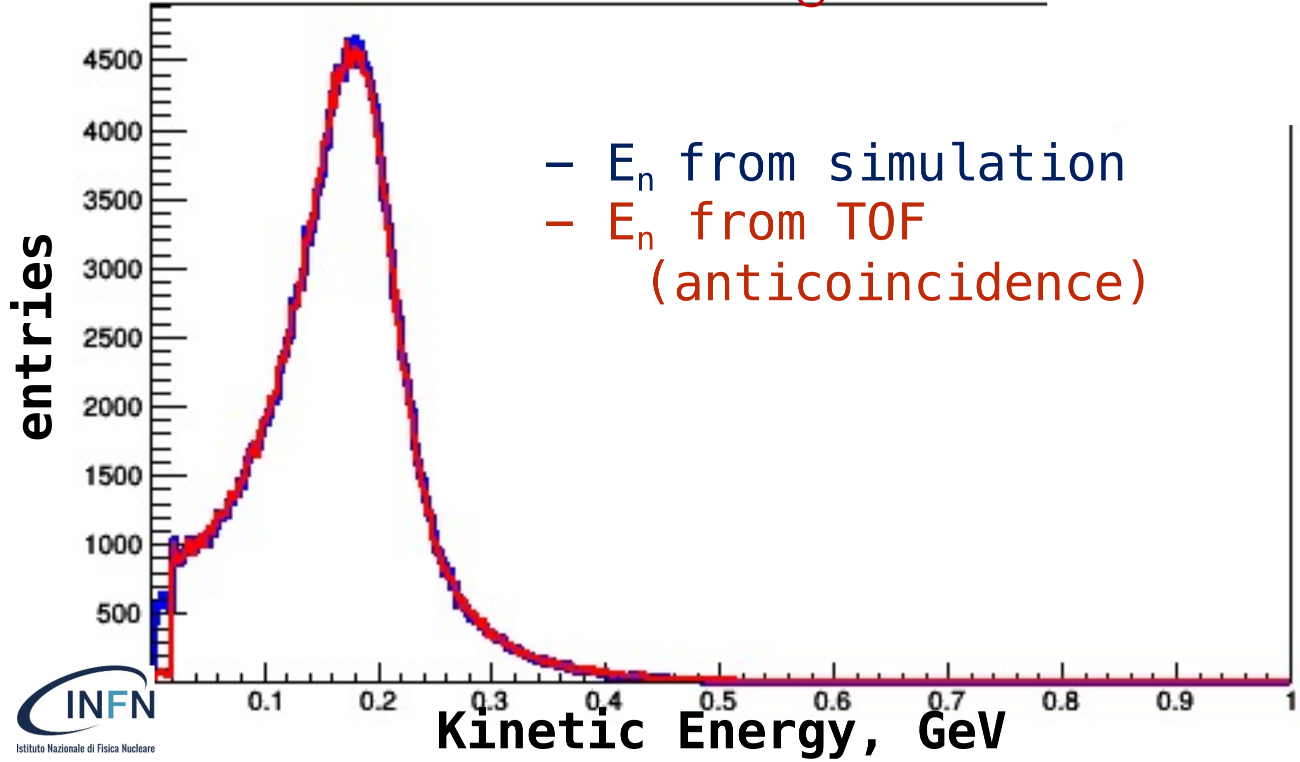
Only events from the target



Detecting neutrons with existing setup

Only events from the target





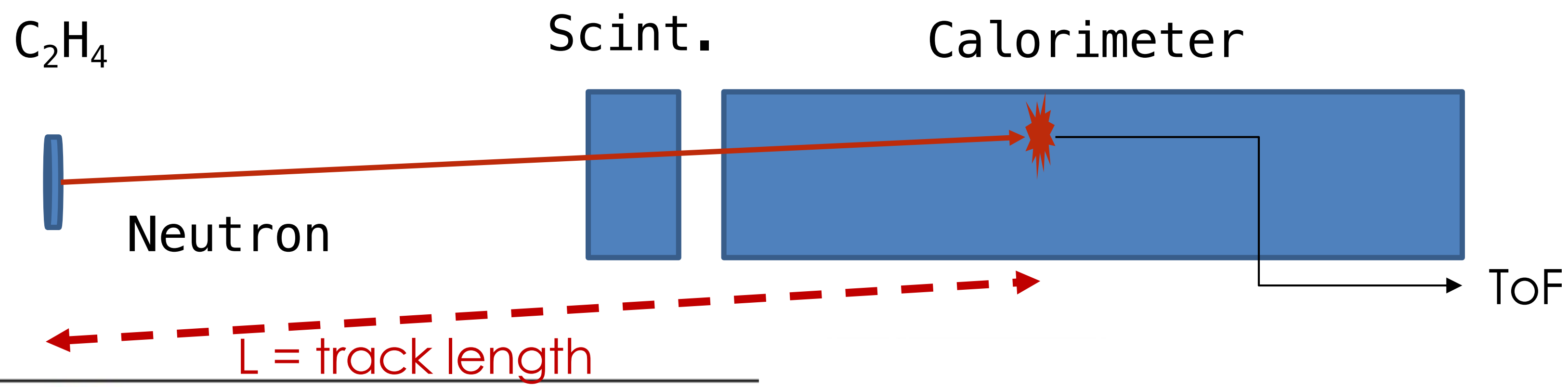
$$\gamma = \frac{1}{\sqrt{1-\beta^2}} = \frac{c\mathrm{ToF}}{\sqrt{c^2\mathrm{ToF}^2 - L^2}}$$

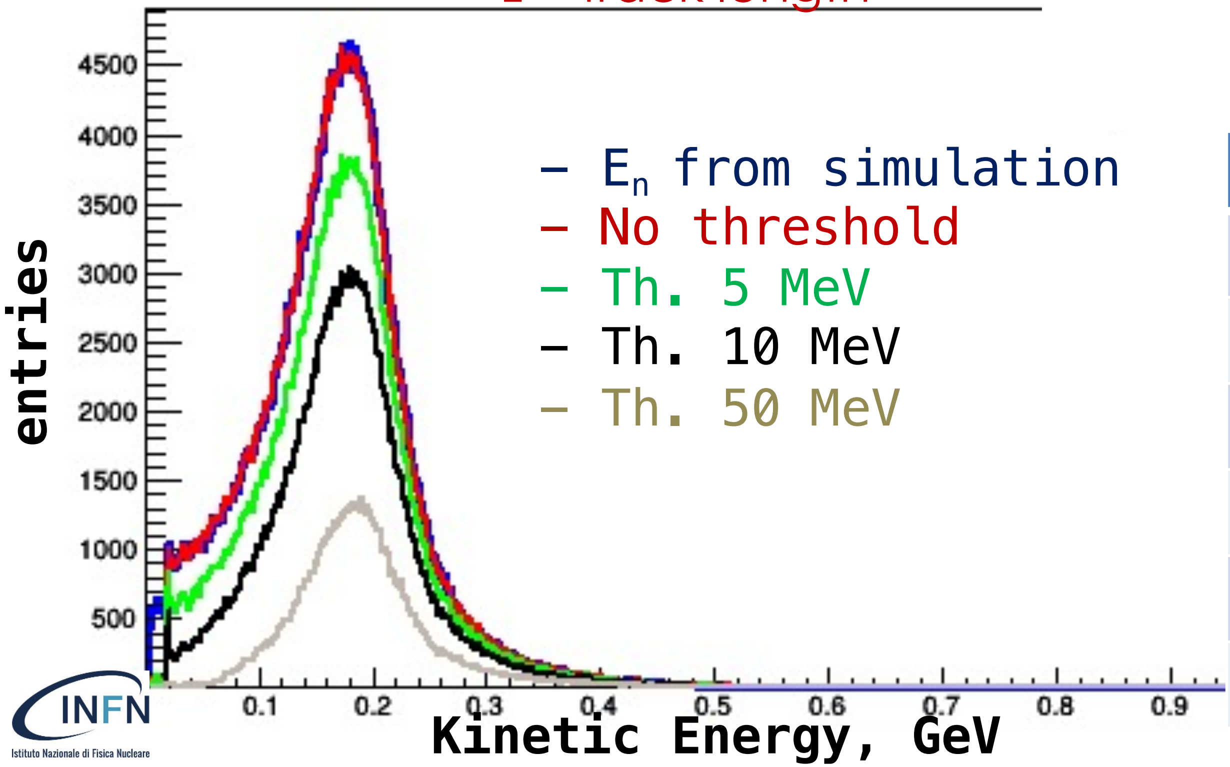
$$E_n = mc^2(\gamma - 1)$$

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

Detecting neutrons with existing setup EFFICIENCY

Only events from the target



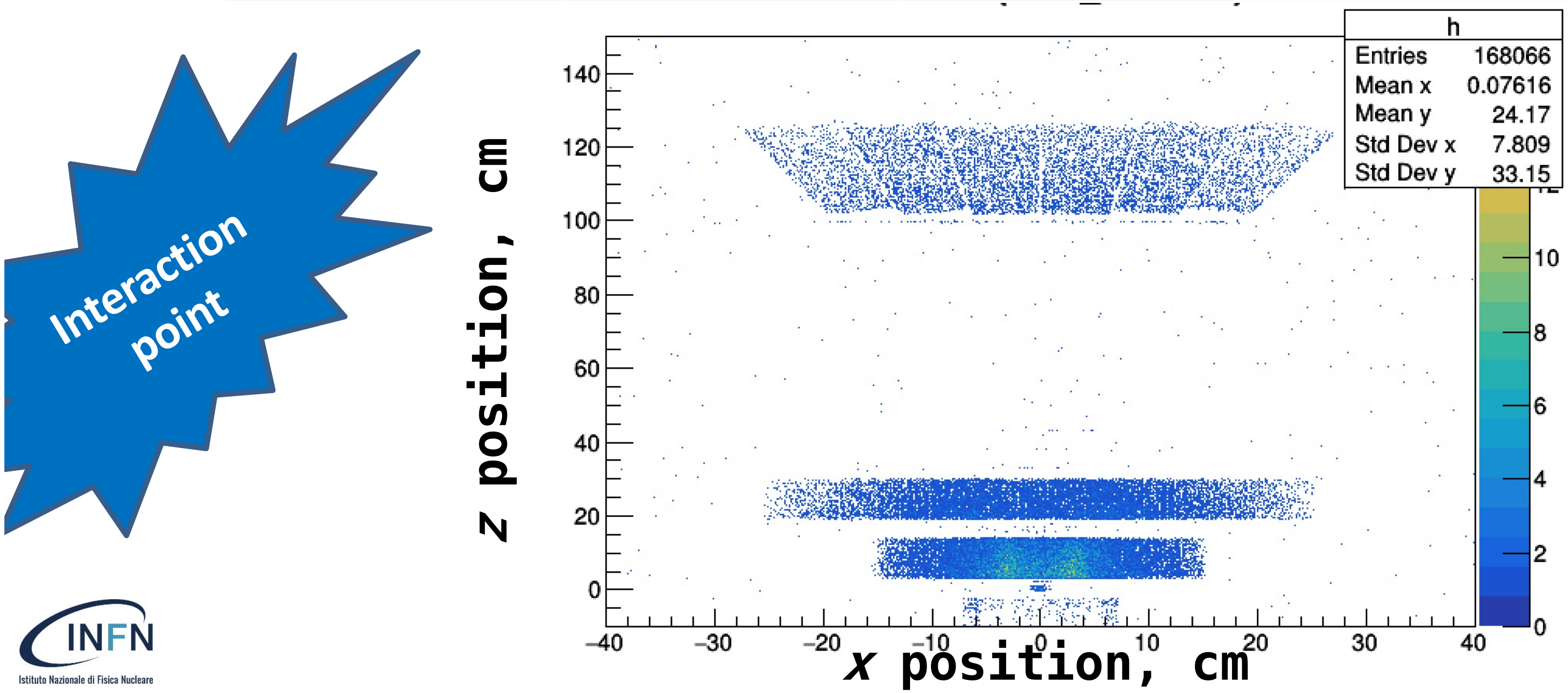


Threshold	Efficiency	
No	100%	**66%**
Fluka	75%	**46%**
5 MeV	55%	**34%**
10 MeV	45%	**28%**
20 MeV	40%	**23%**
50 MeV	20%	**12%**

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

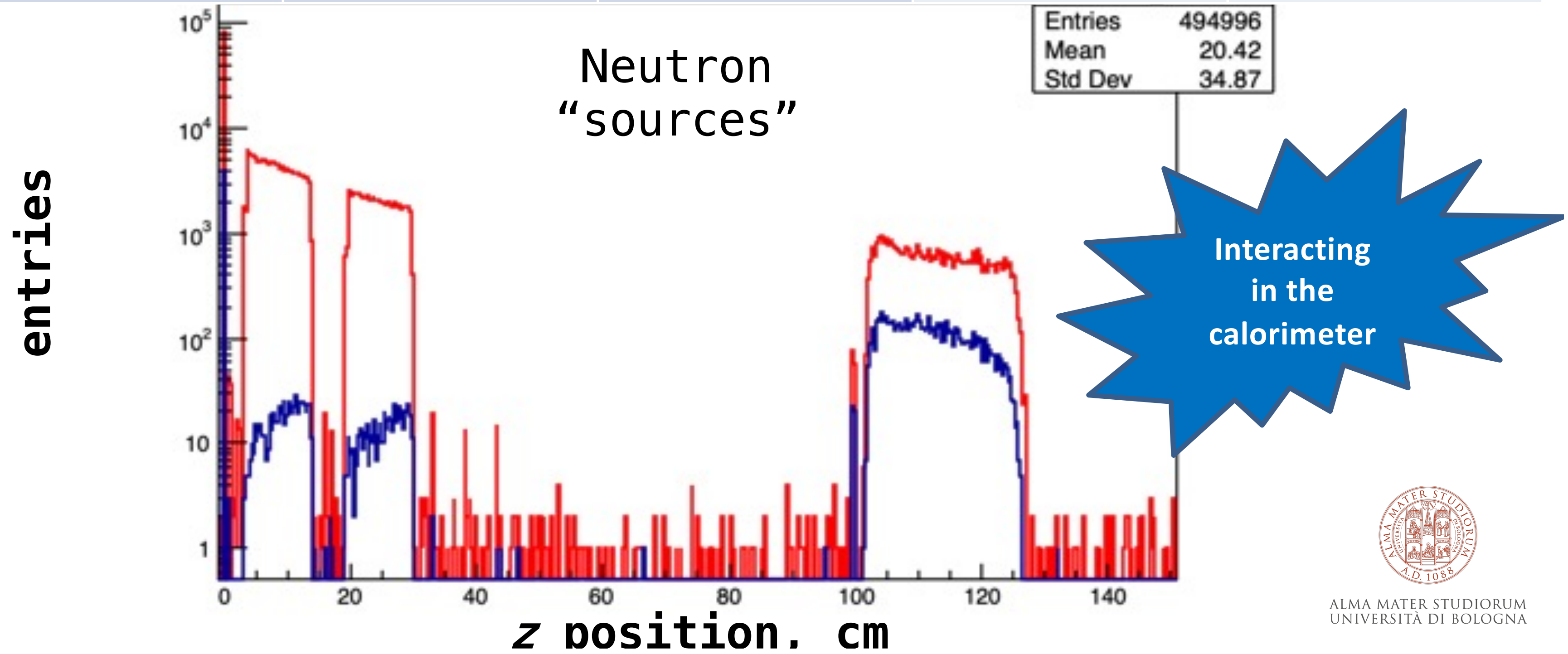


MC simulations – neutrons from target & environment

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**	

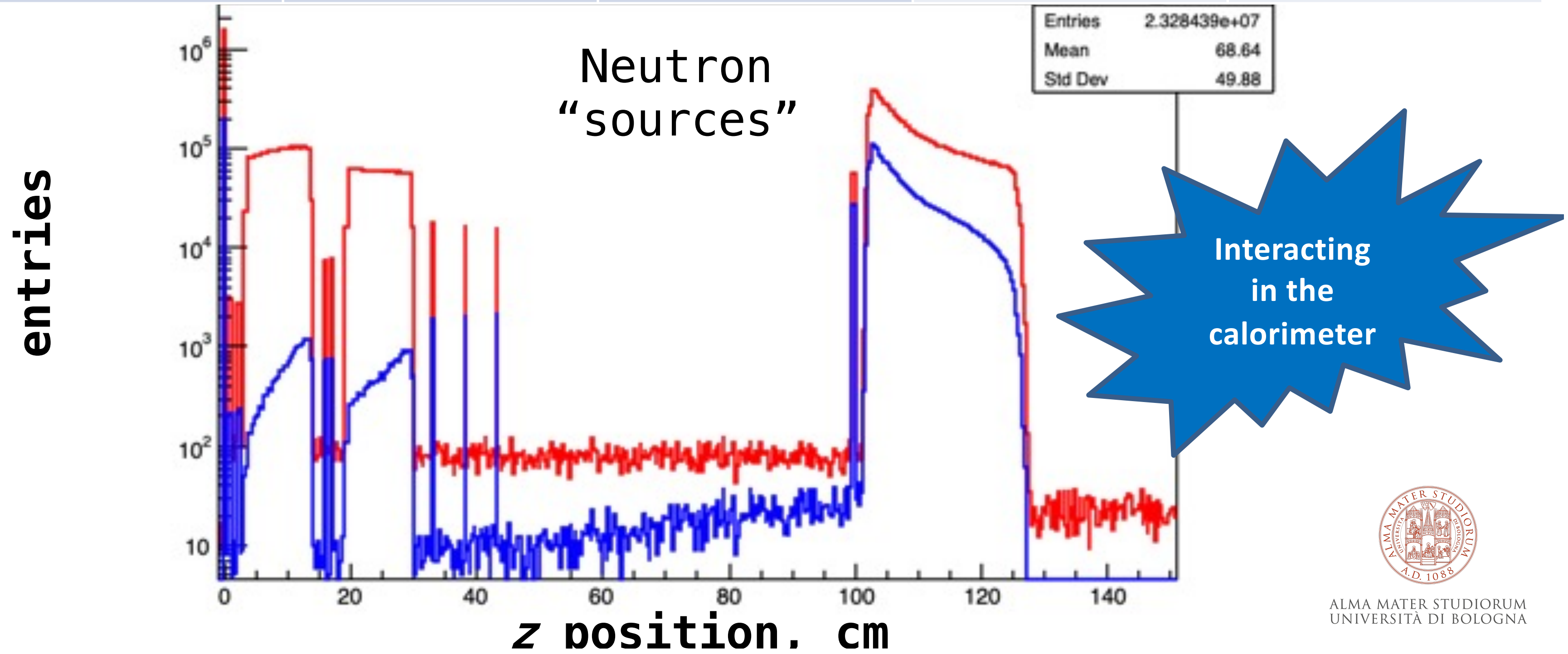


MC simulations – neutrons from target & environment

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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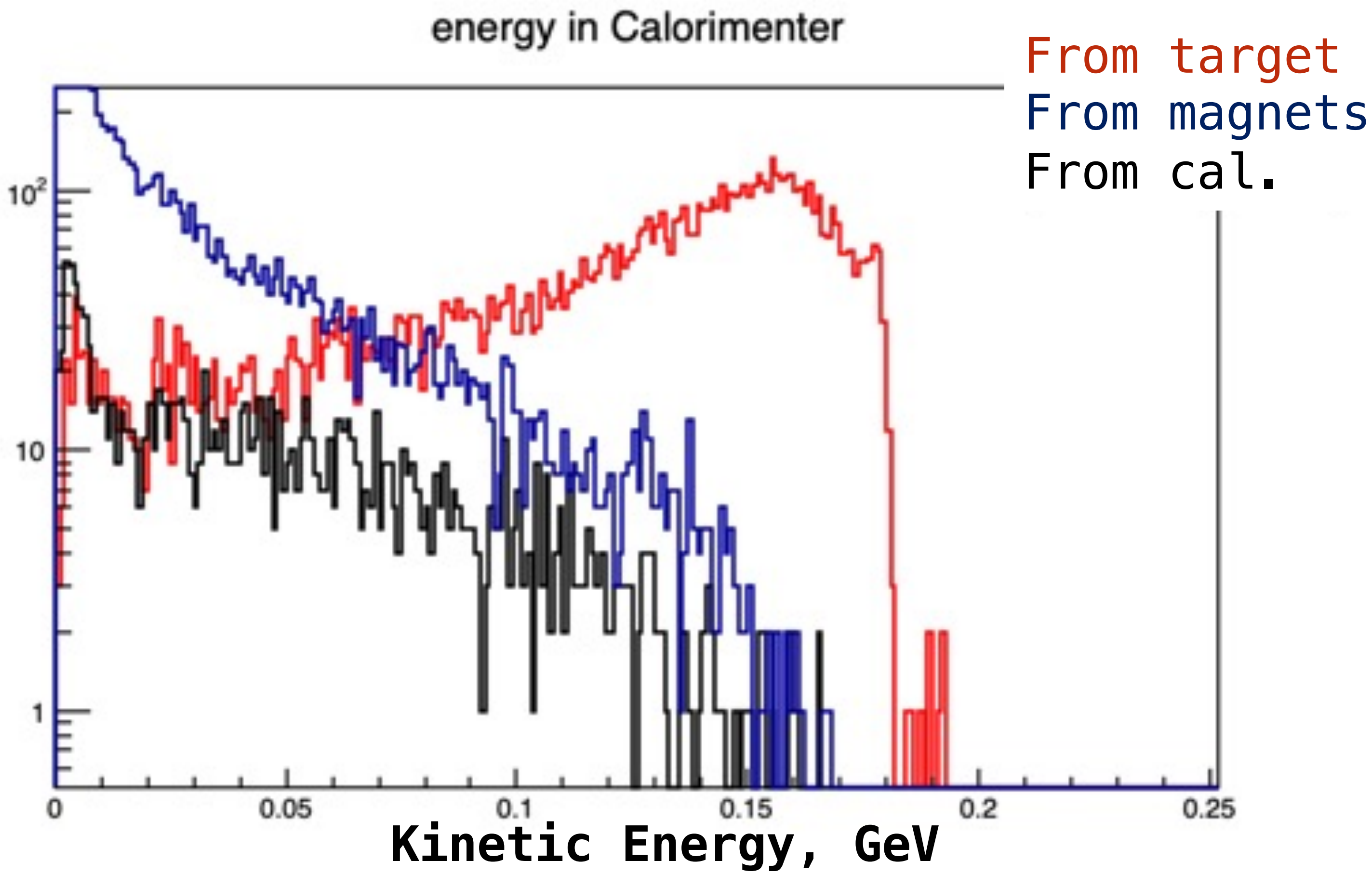
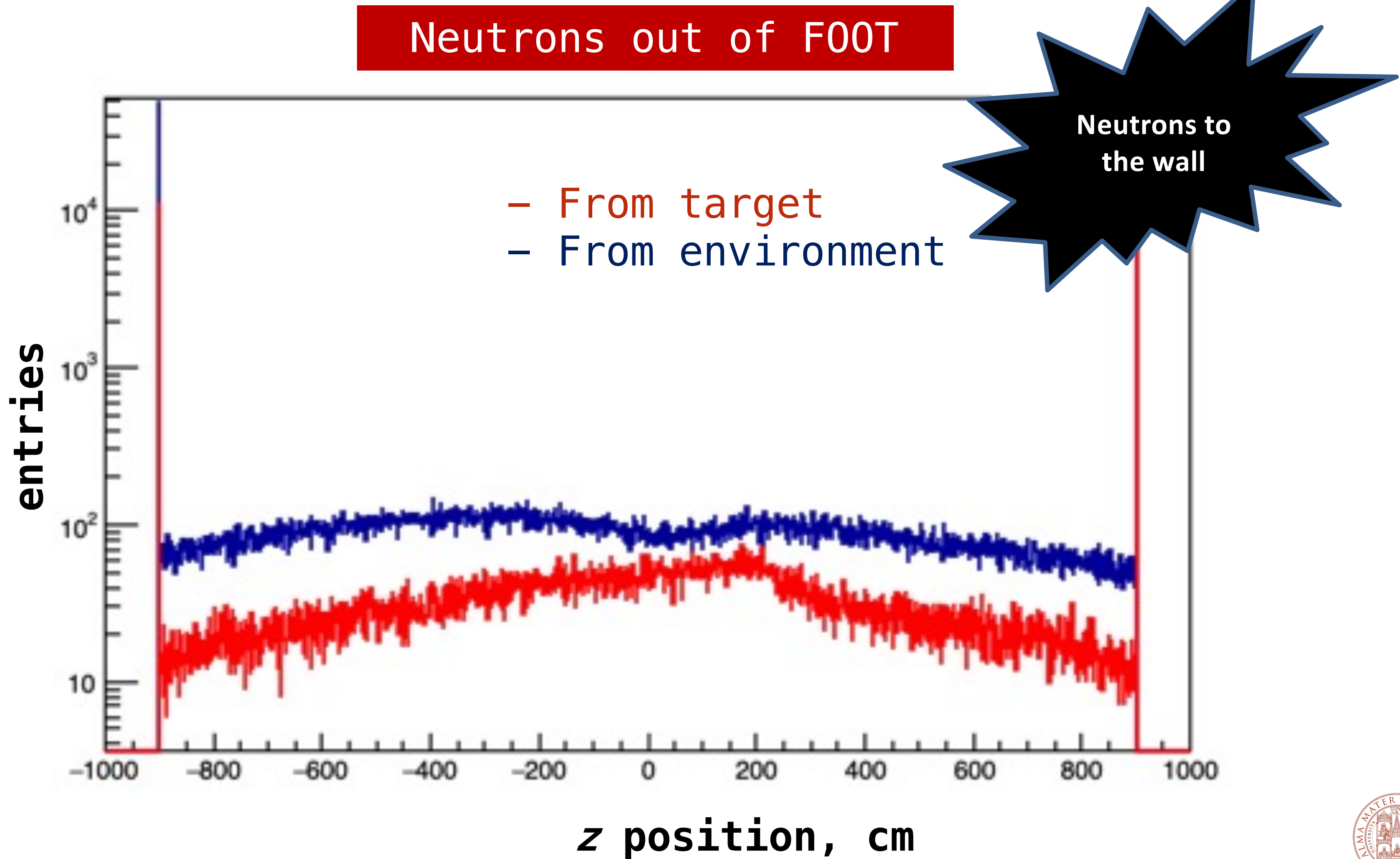
MC simulations – neutrons from target & environment

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



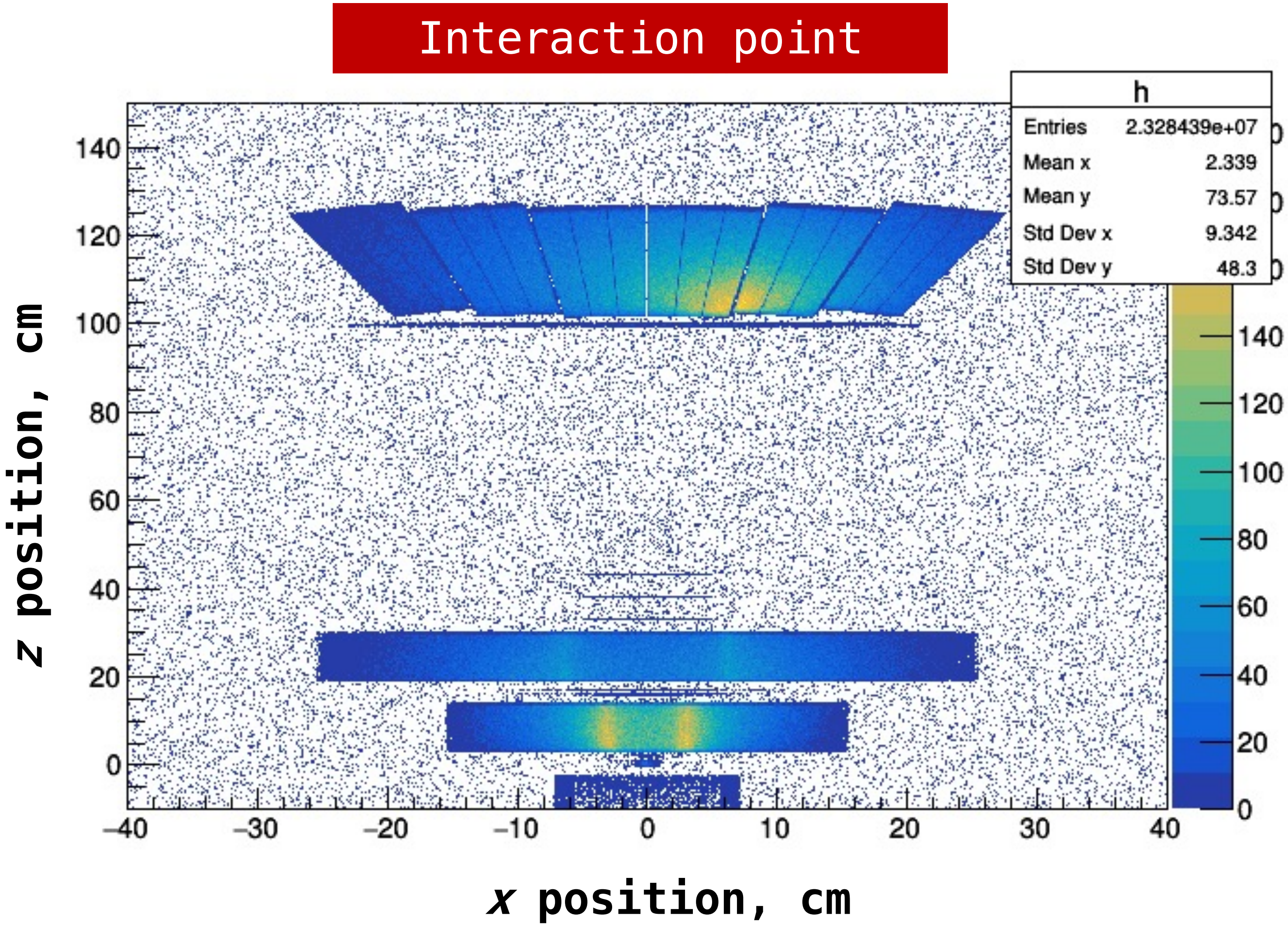
MC simulations – neutrons from target & environment

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



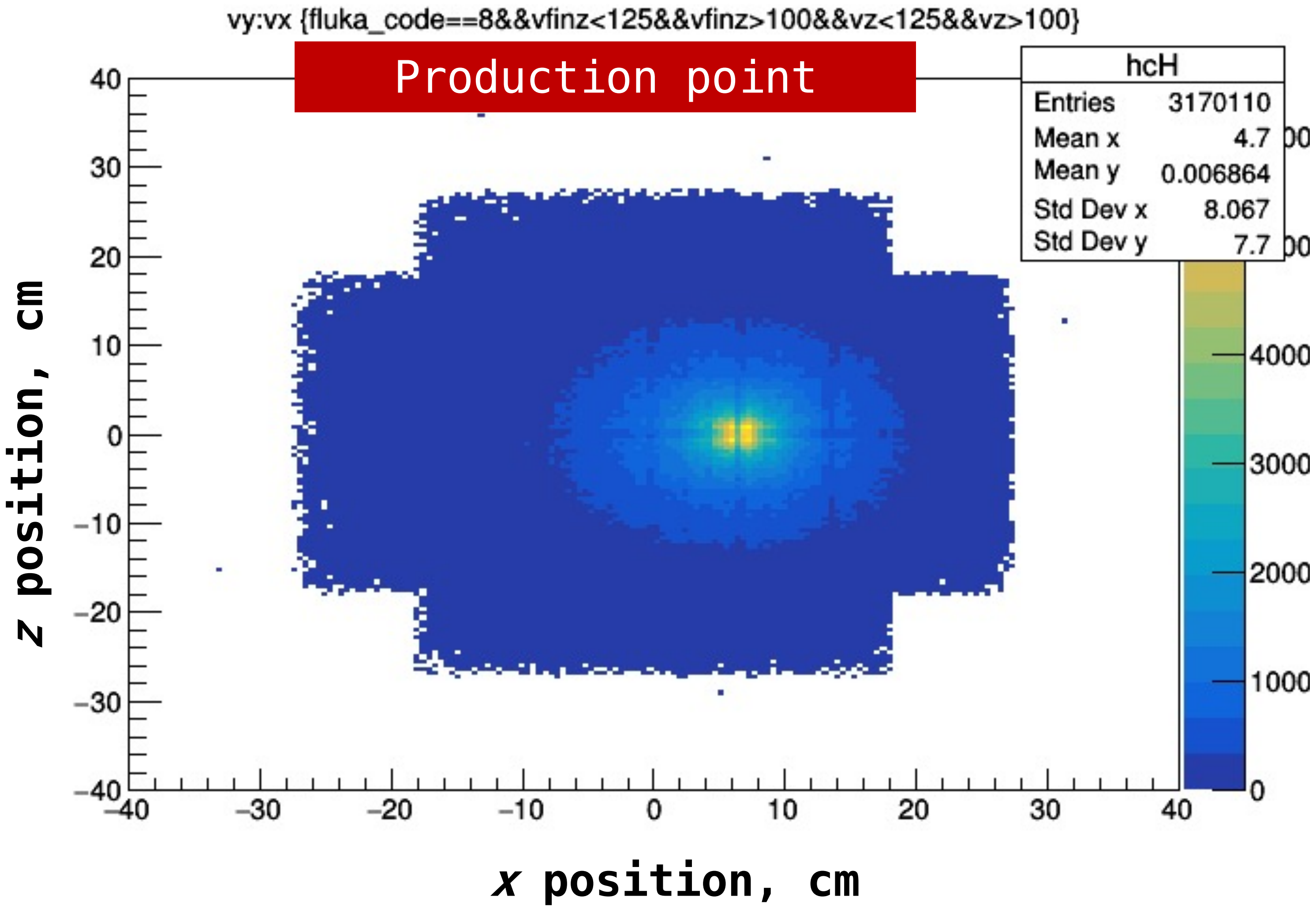
MC simulations – neutrons from target & environment

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



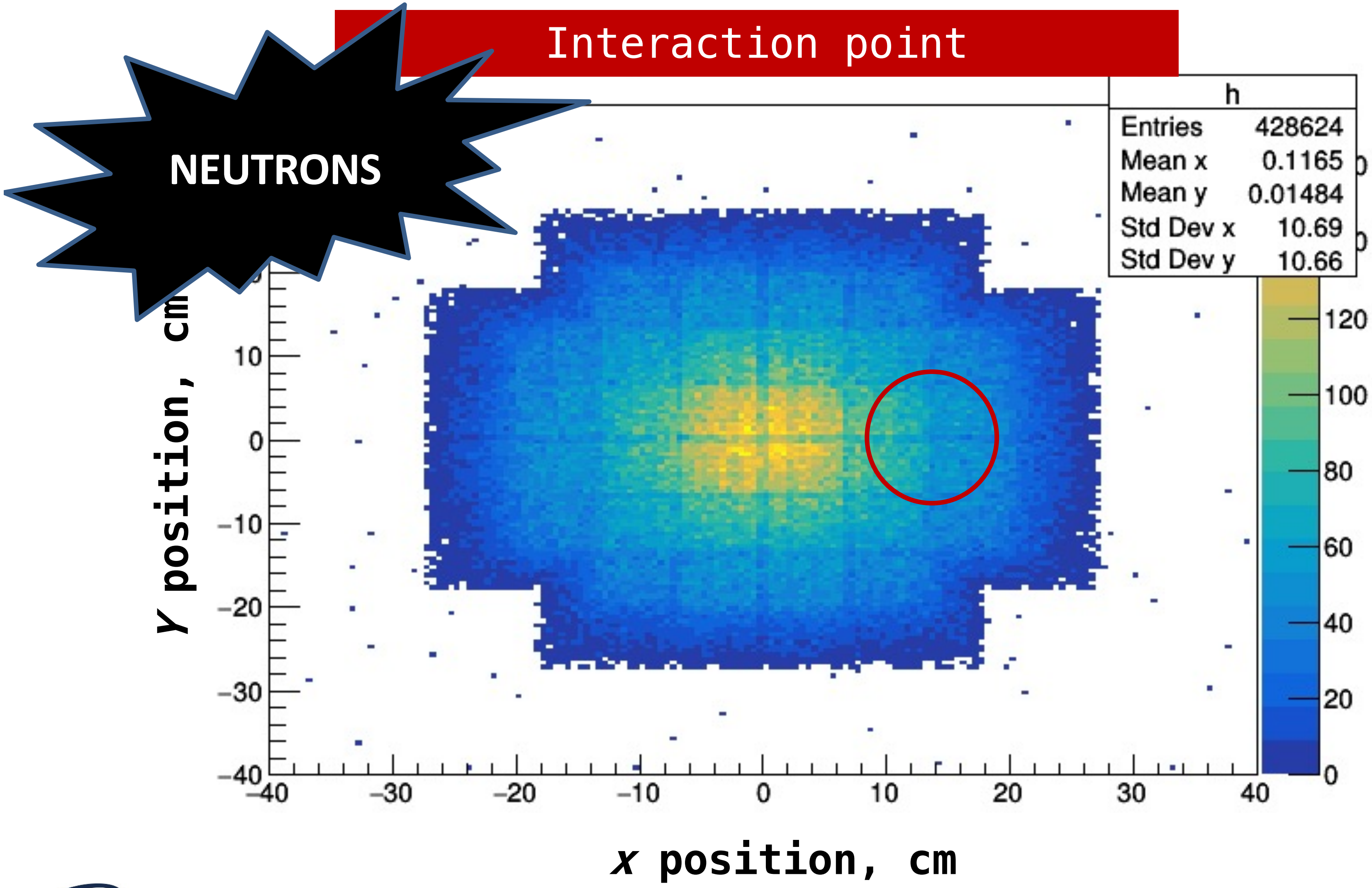
MC simulations – neutrons from target & environment

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



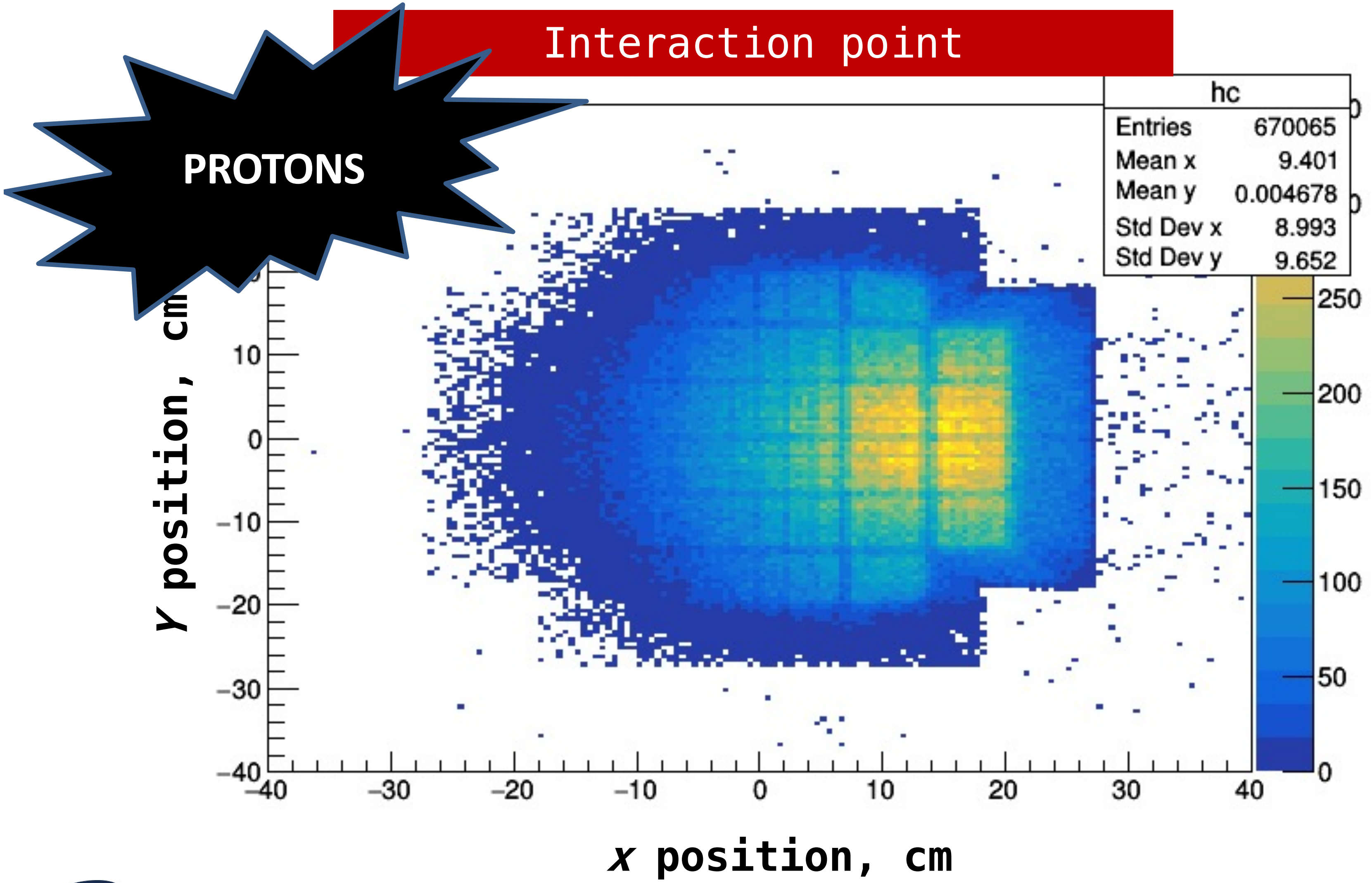
MC simulations – neutrons from target & environment

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



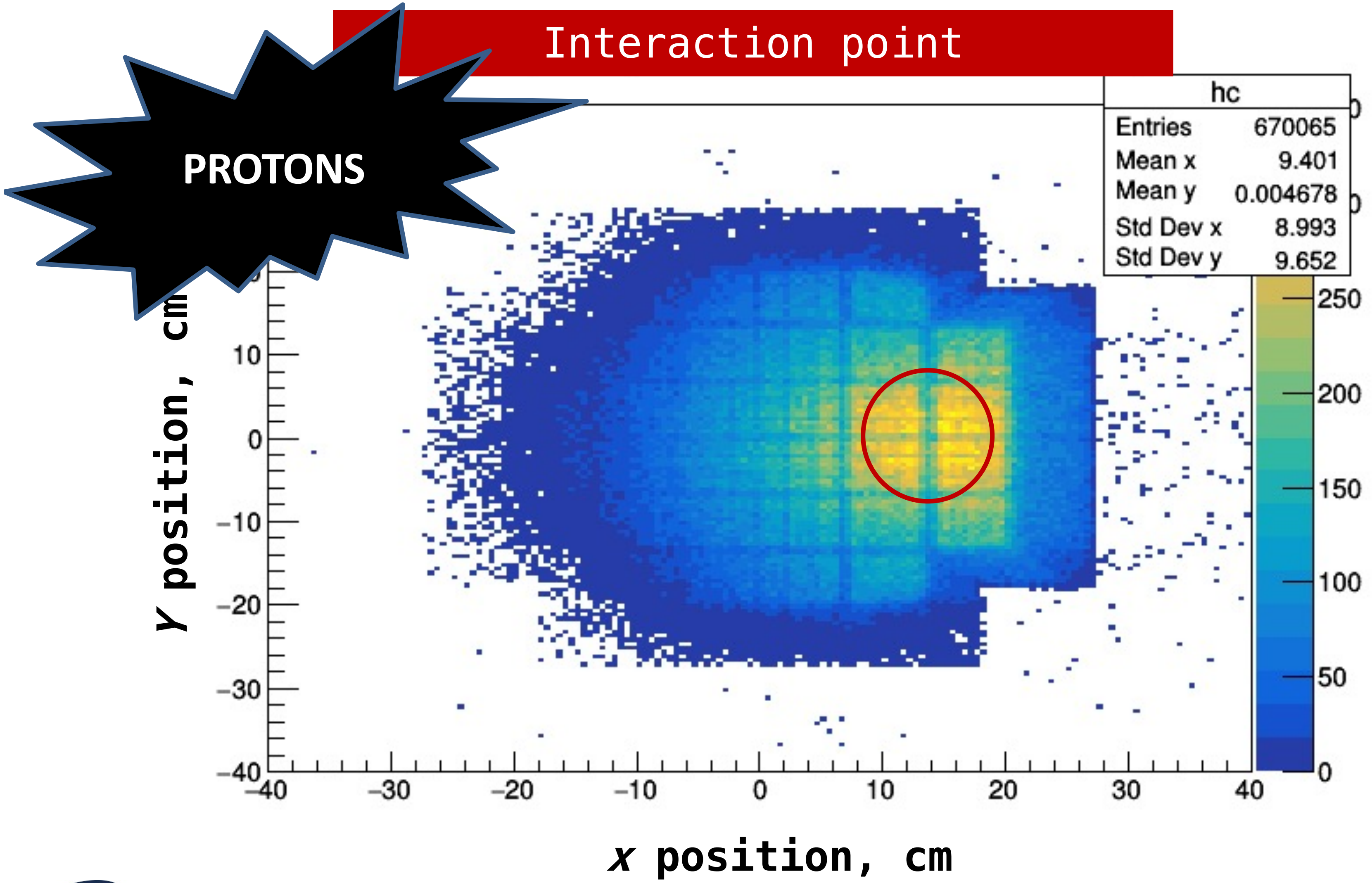
MC simulations – neutrons from target & environment

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



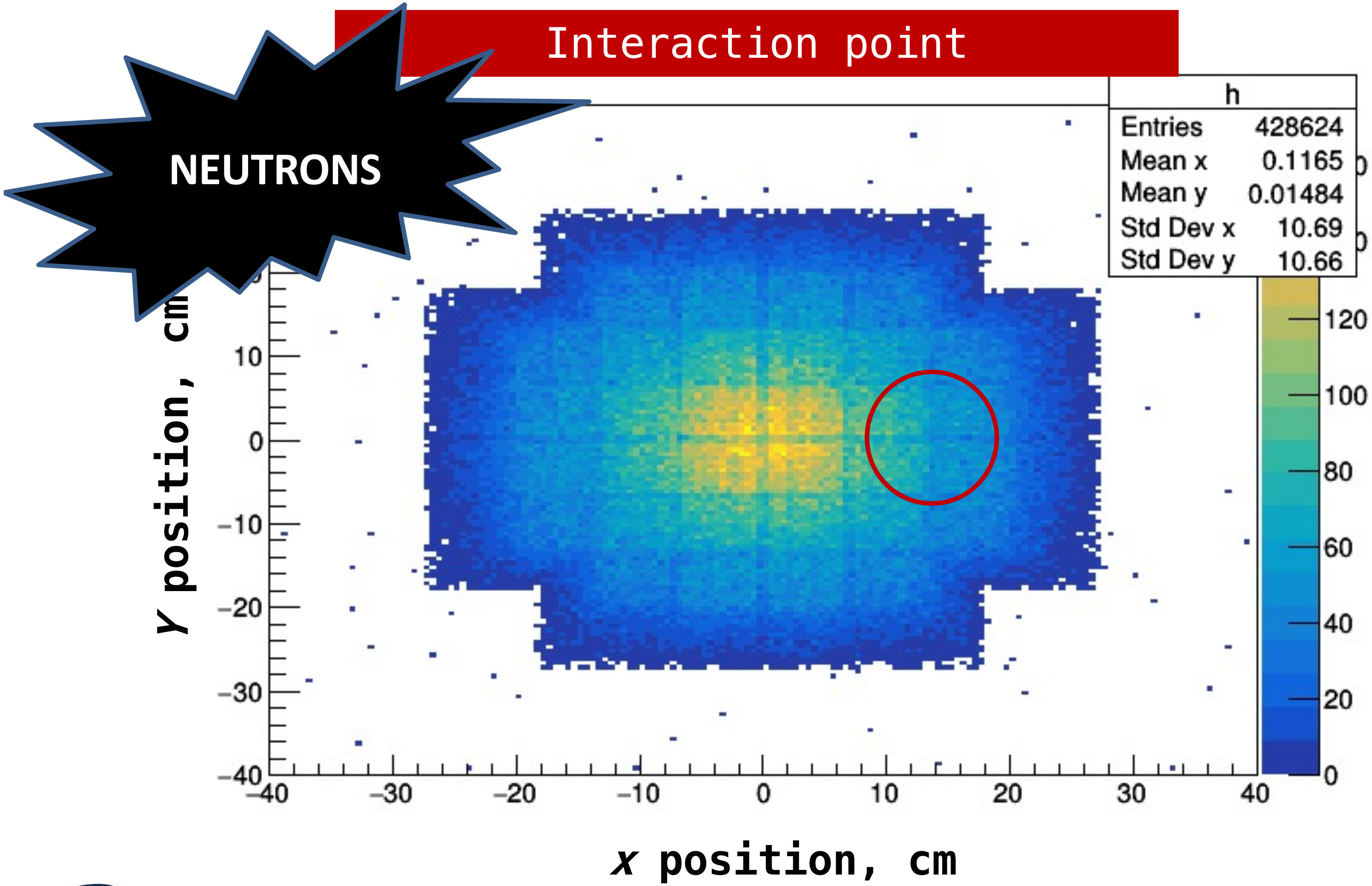
MC simulations – neutrons from target & environment

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



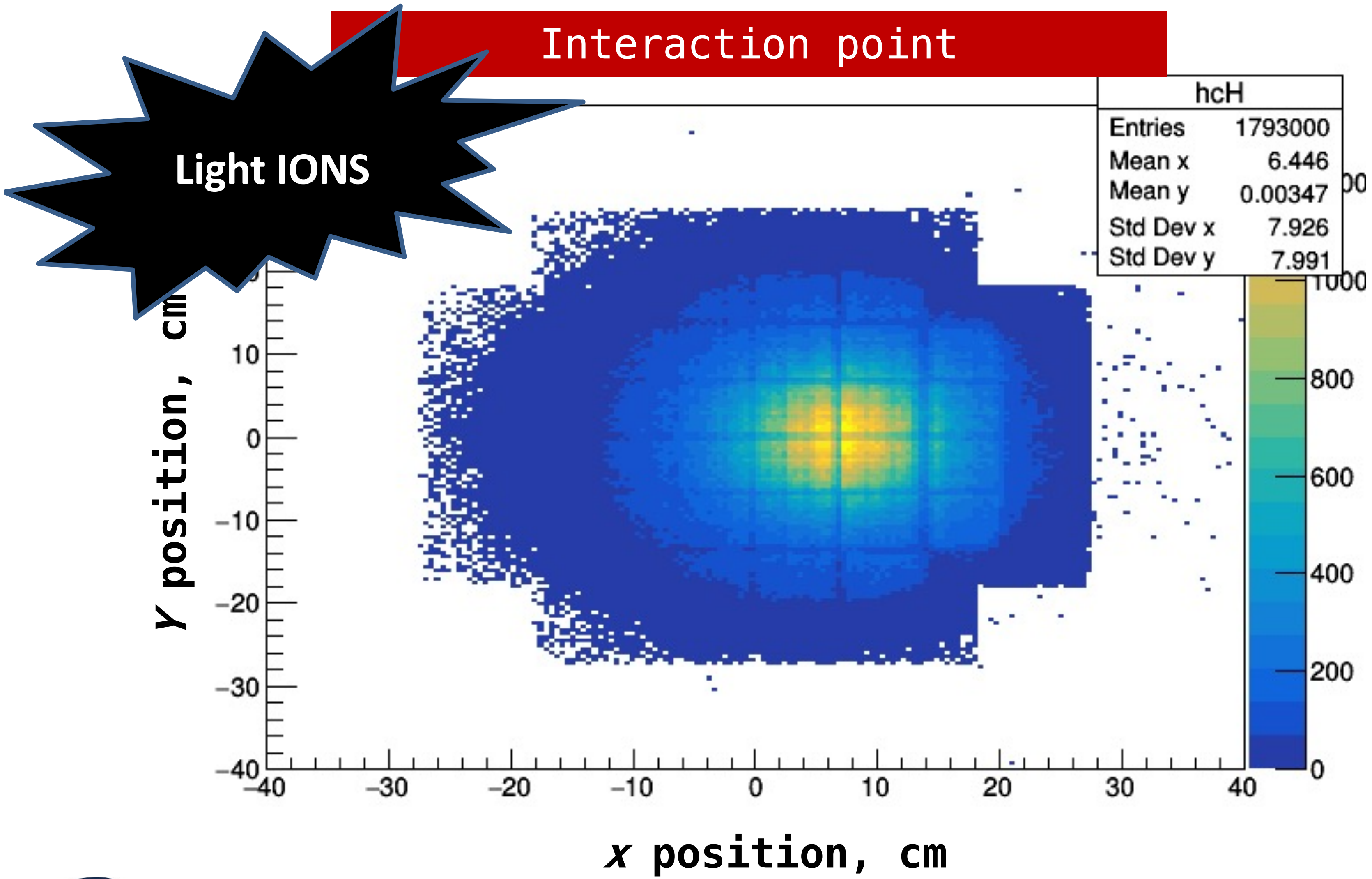
MC simulations – neutrons from target & environment

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

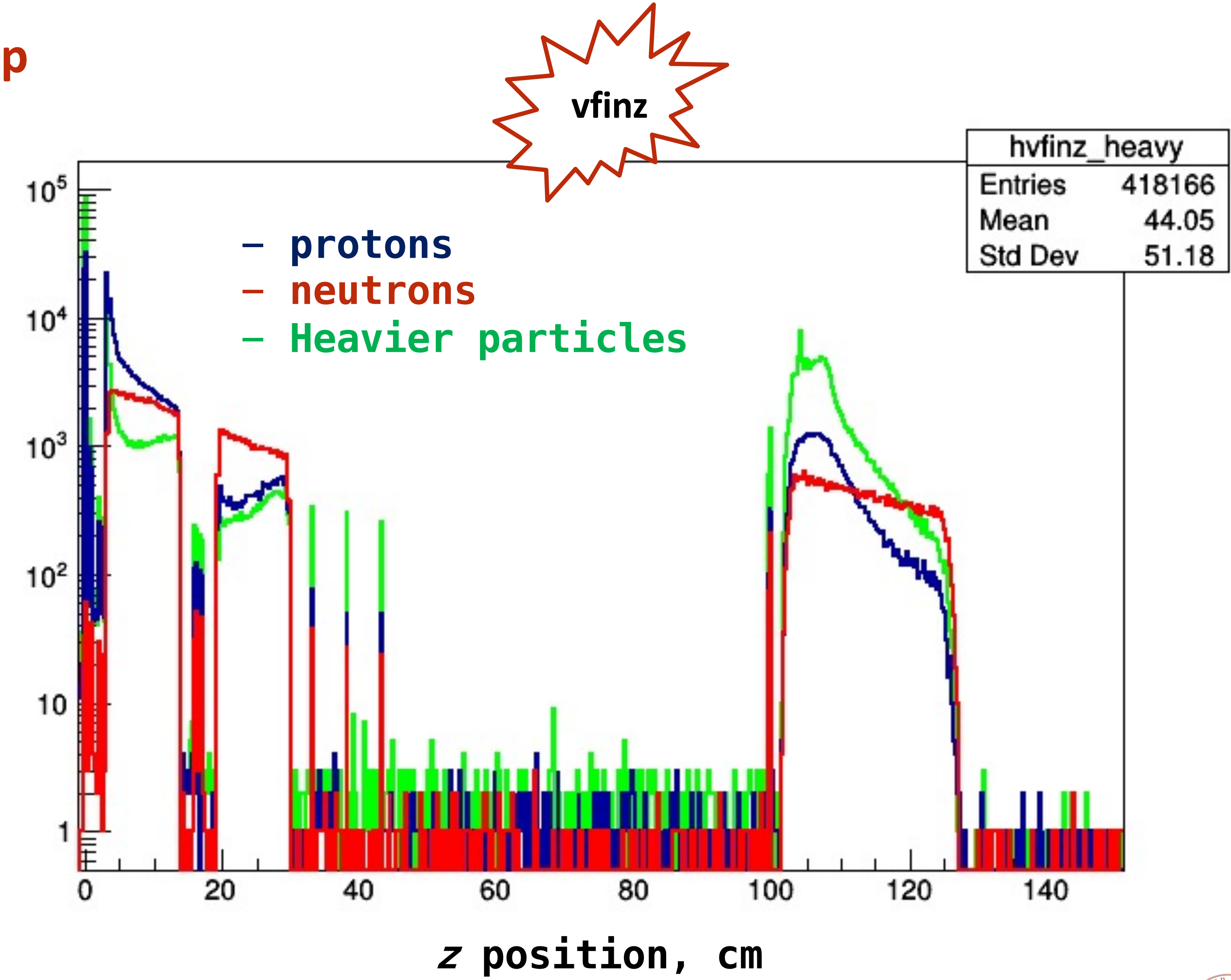


MC simulations – neutrons from target & environment

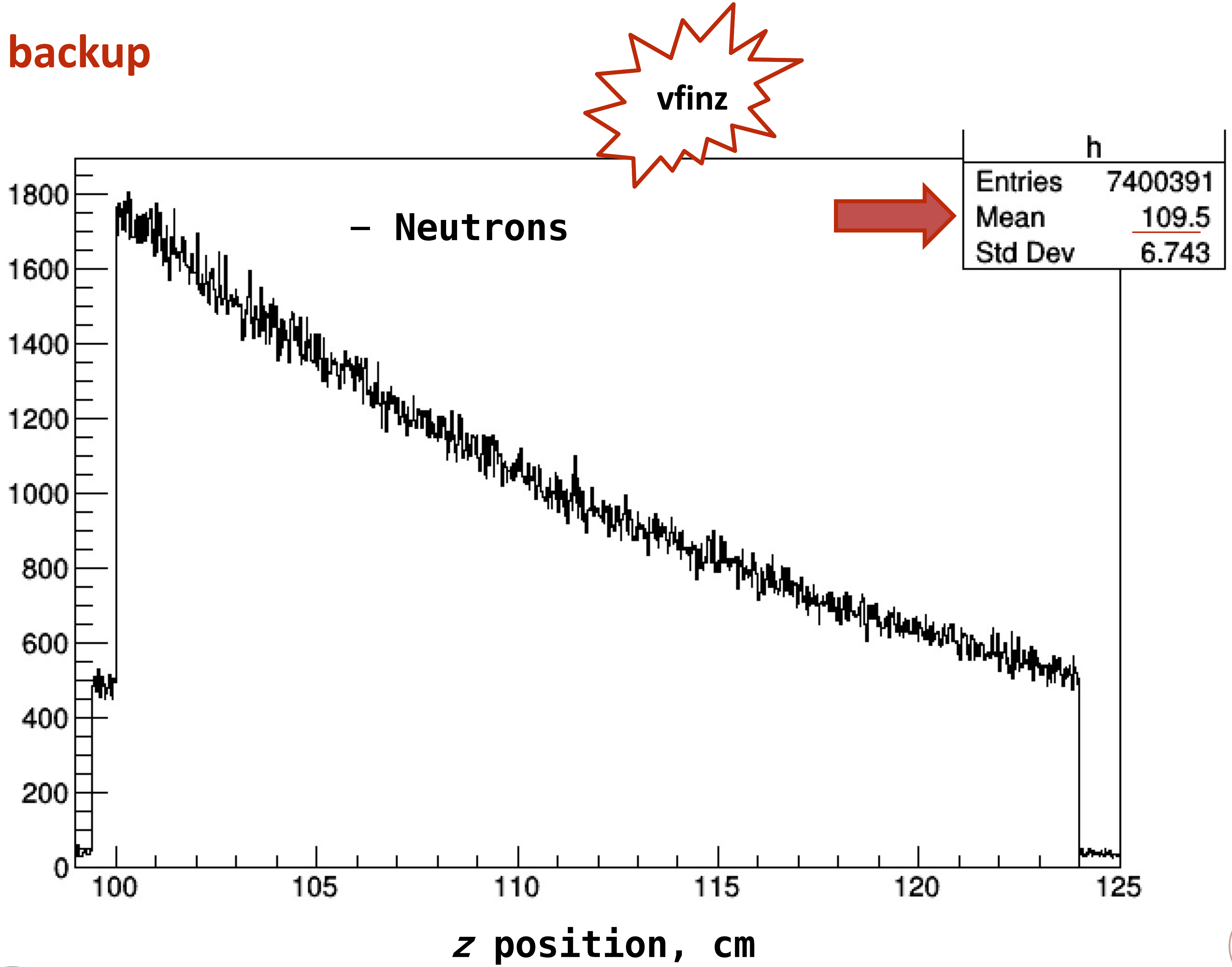
$^{16}O+C_2H_4$ **@200MeV/u** (newgeom) statistics: 1.4E6 fragmentations



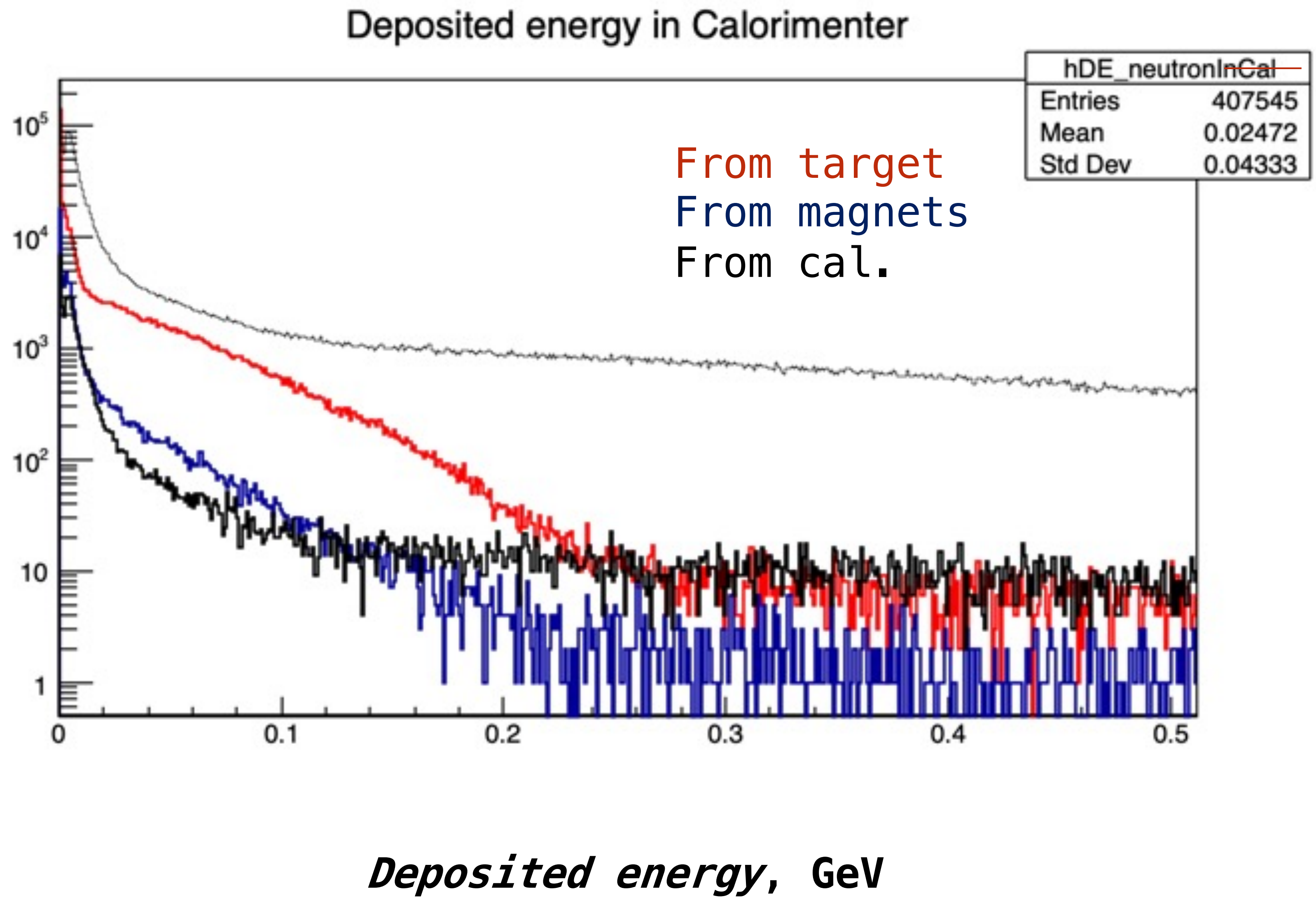
backup


vfinz
hvfinz_heavy
Entries 418166
Mean 44.05
Std Dev 51.18
– protons
– neutrons
– Heavier particles
10^5
10^4
10^3
10^2
10
1
0
20
40
60
80
100
120
140
z position, cm

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



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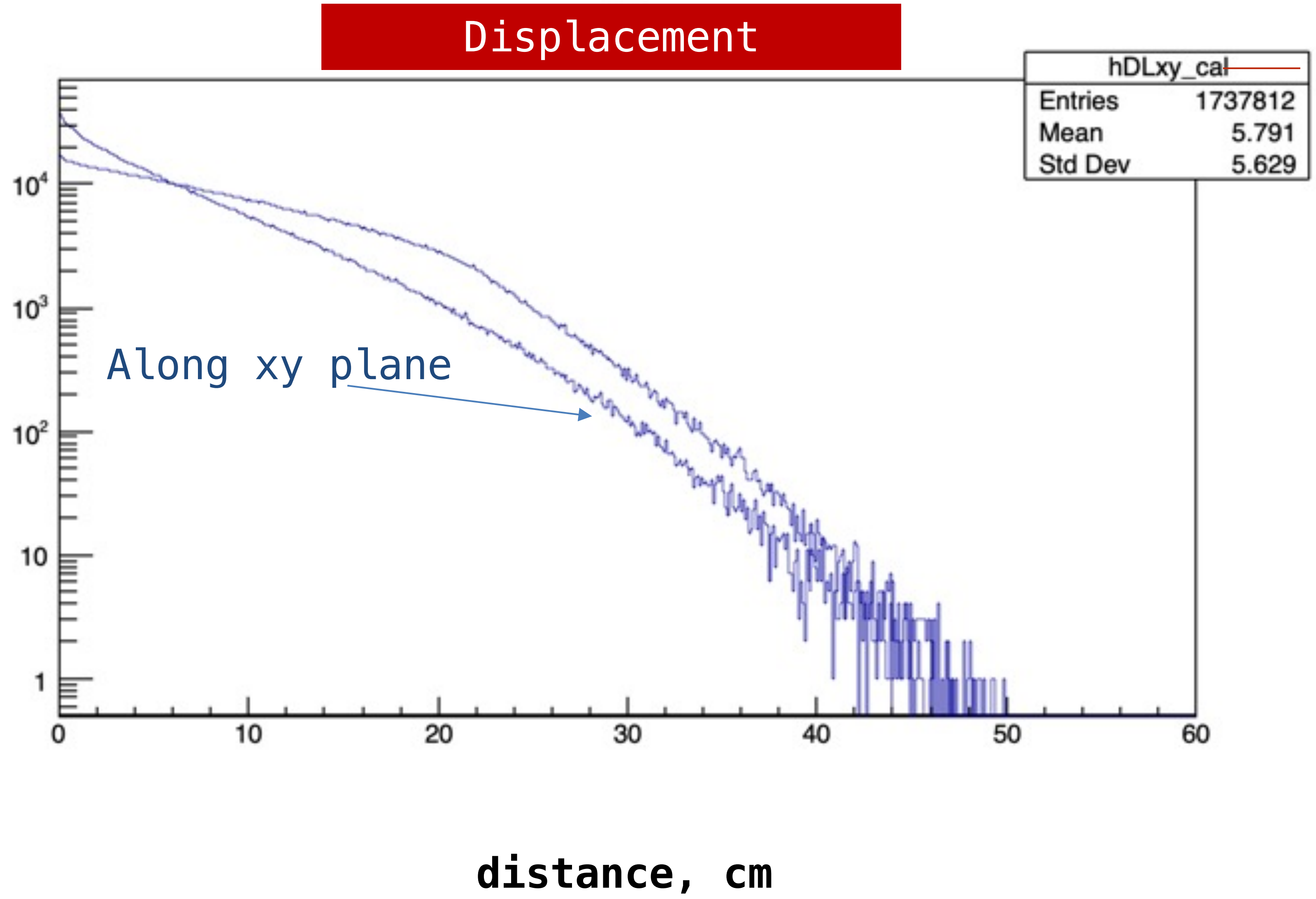
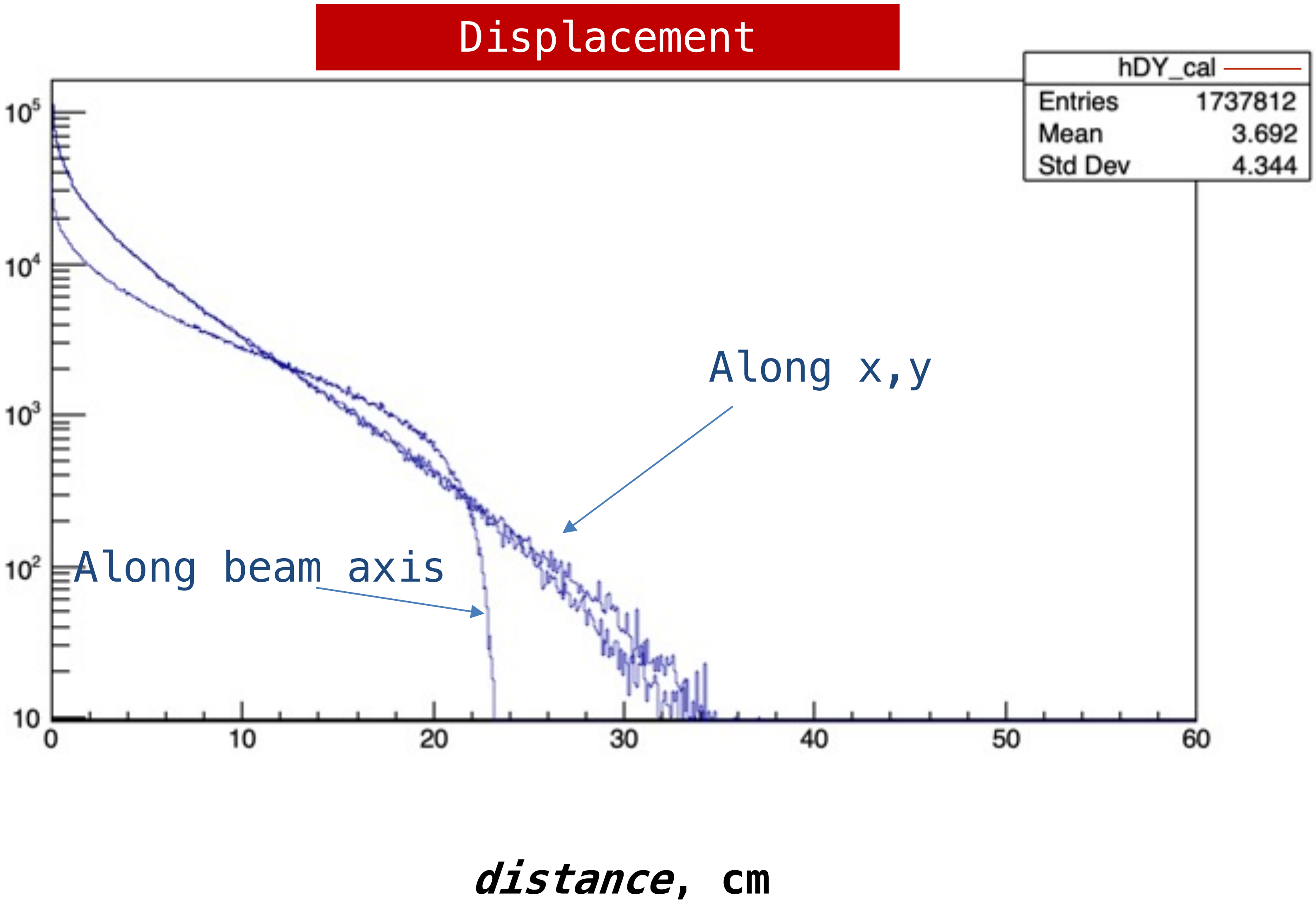
backup

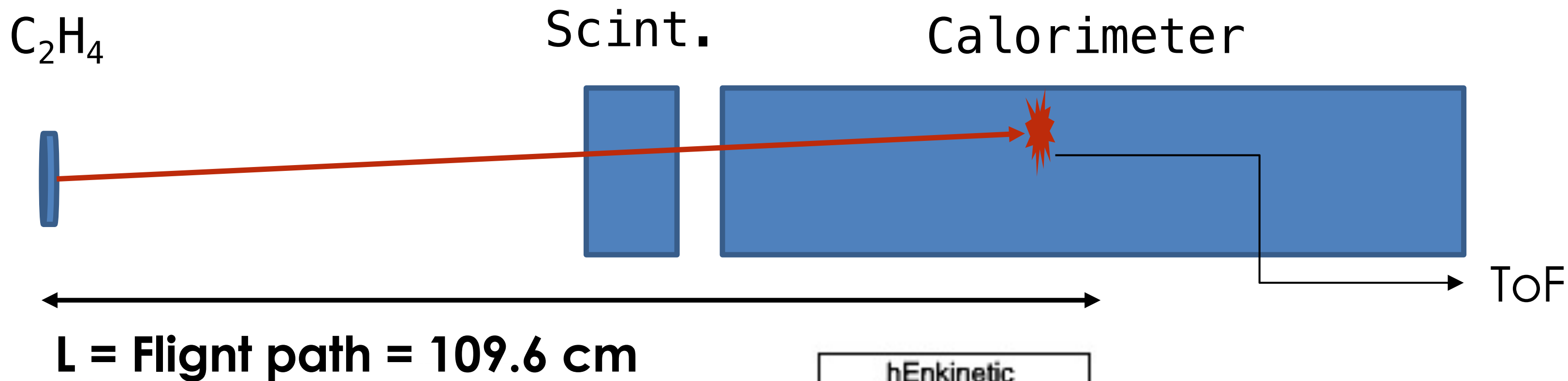

Displacement
hDLxy_cal
Entries 1737812
Mean 5.791
Std Dev 5.629
Along xy plane
10^4
10^3
10^2
10
1
0
10
20
30
40
50
60
distance, cm

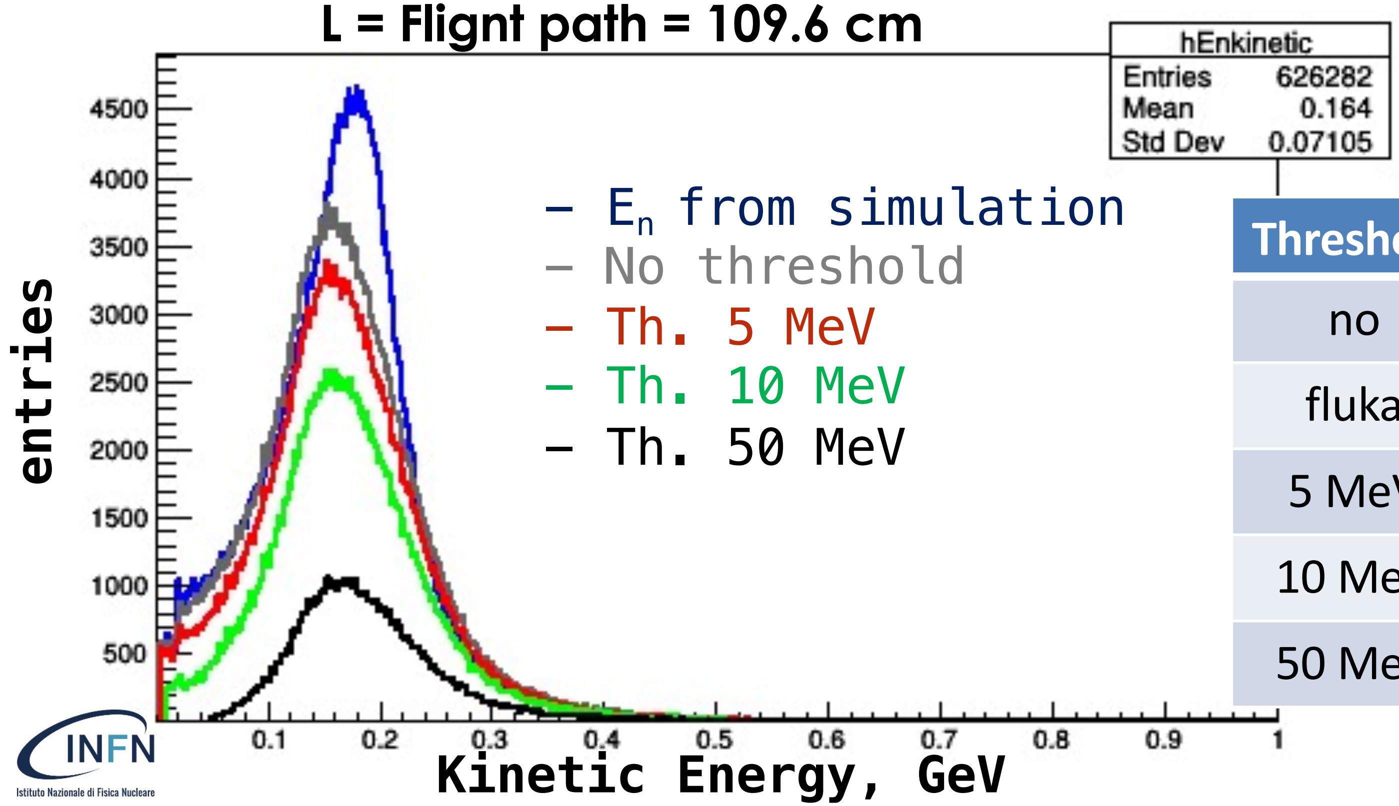
backup


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

Detecting neutrons with existing setup

Only events from the target

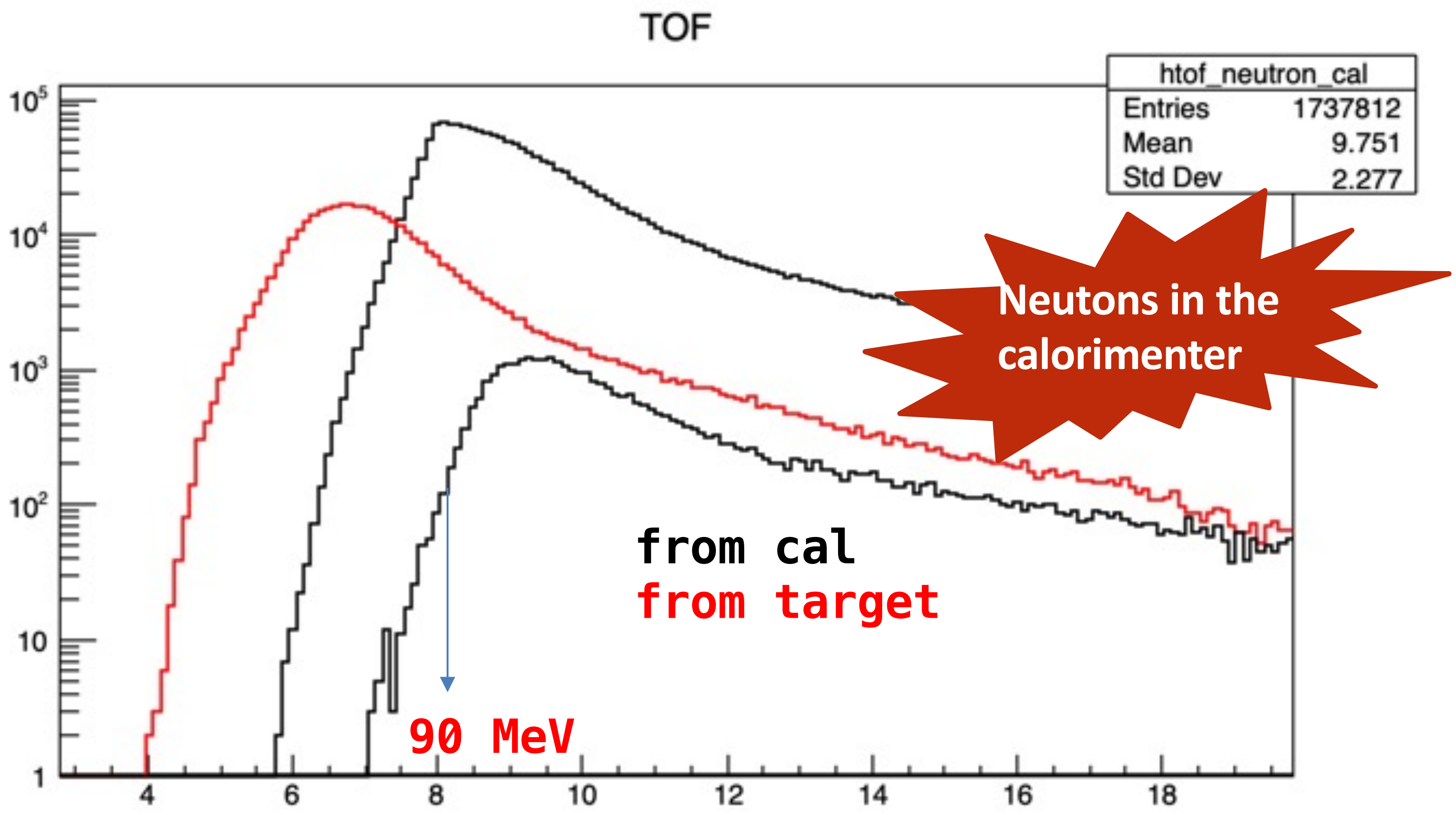




Threshold	Efficiency	
no	100%	**64%**
fluka	70%	**41%**
5 MeV	65%	**36%**
10 MeV	42%	**27%**
50 MeV	16%	**10%**

backup

timing

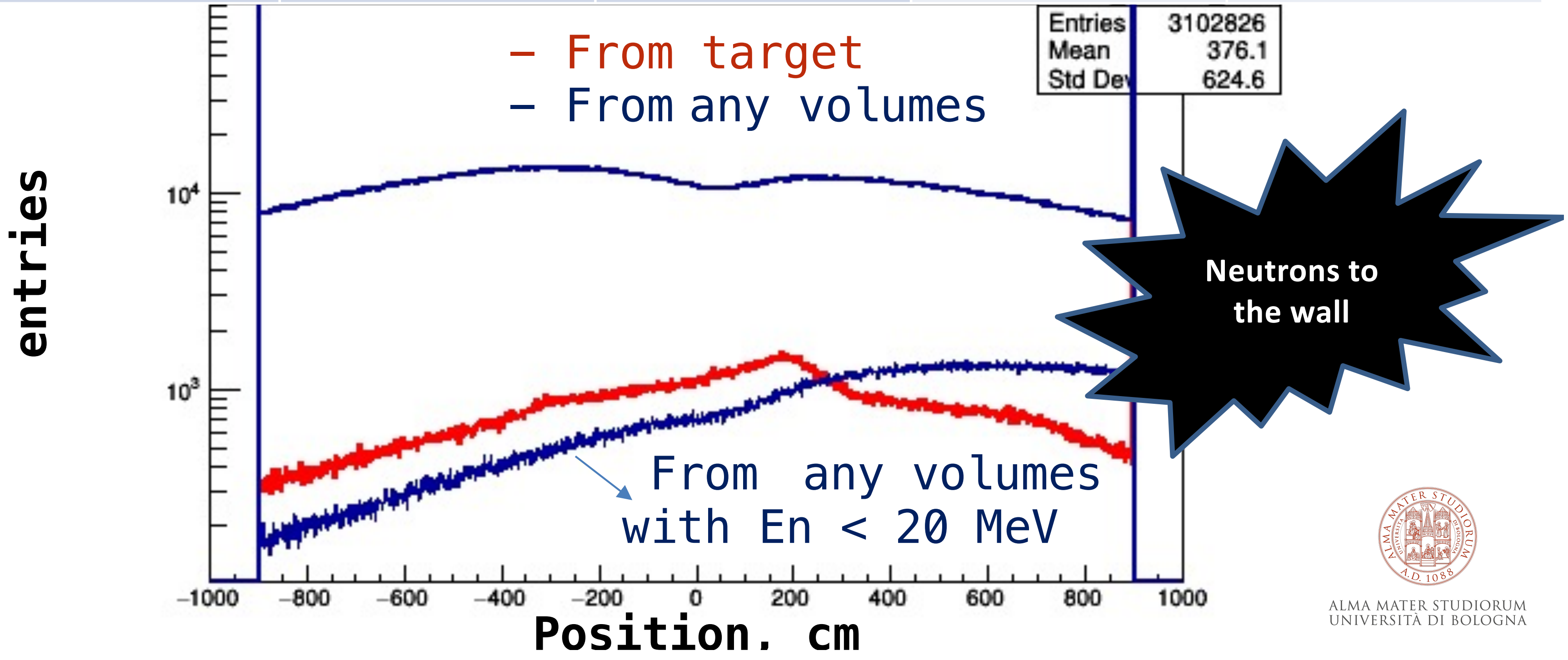


$T_{stop} - T_{start}$, ns

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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