The E.E.E. Project Masterclass

LNL, 27 Nov. 2023

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Outline

Chapter 1-The EEE Project

- The EEE Project
- The detector
- Working principles
- Working parameters

Chapter 2-The EEE Project telescope efficiency

- What is the efficiency
- What is the efficiency curve
- Exercise

Chapter 3- Hands-on

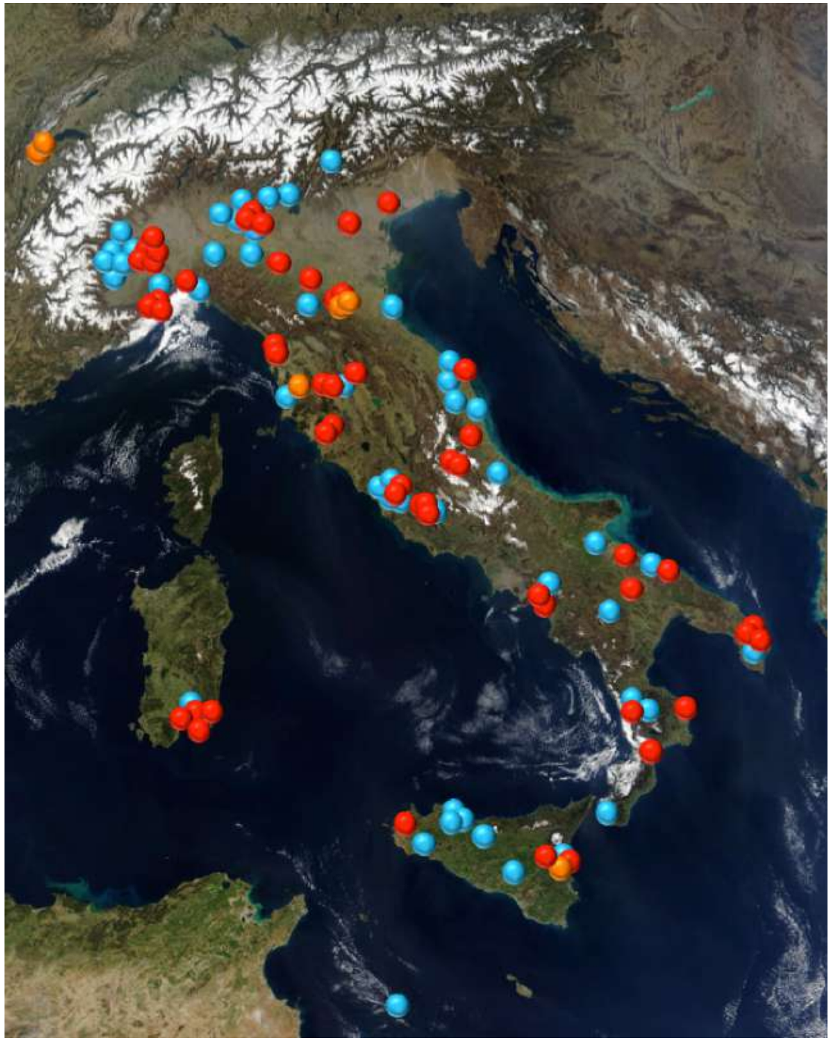
- Efficiency Measurement
- Data Analysis

Chapter 4- Hands-on

- Coincidences vs Distance (LNLE-01-POLA-02)

Chapter 1

The EEE Project



The goal of the EEE Project

✦ **Study of cosmic rays**

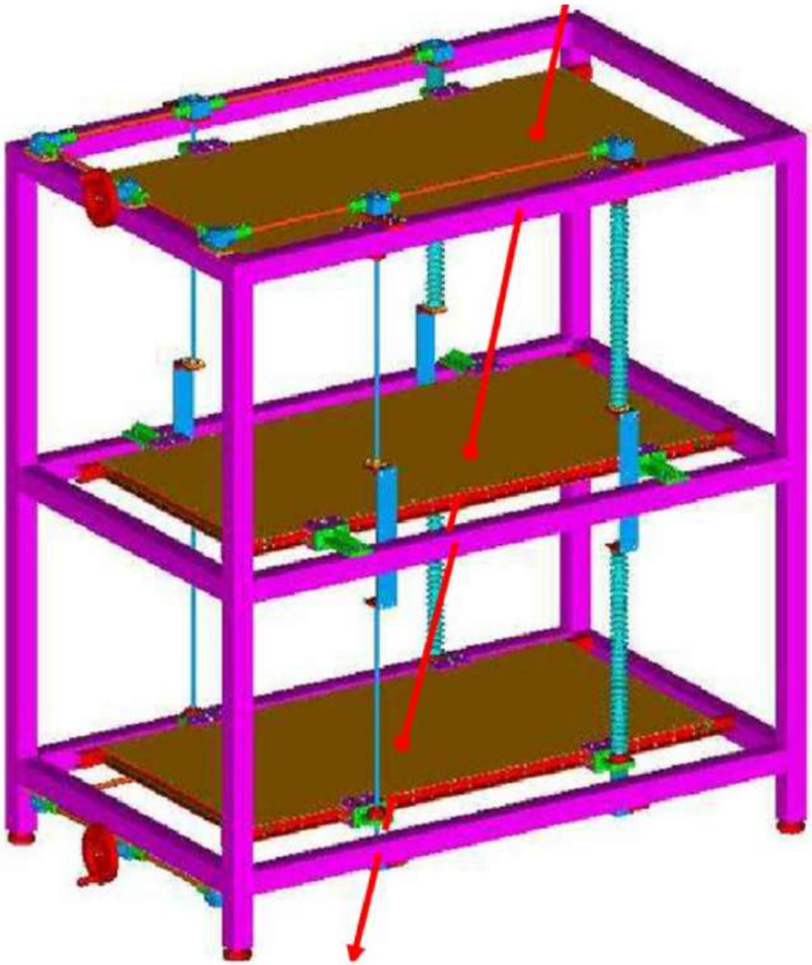
- Detection of EAS
- Cosmic rays variations
- Climate connections
- ….

✦ **Scientific education**

- Students and teachers directly involved
- Detectors mostly inside schools

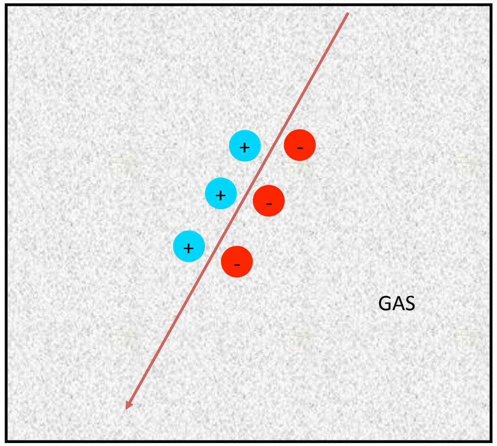
How do we study cosmic rays…

First: we detect them using a cosmic ray telescope!

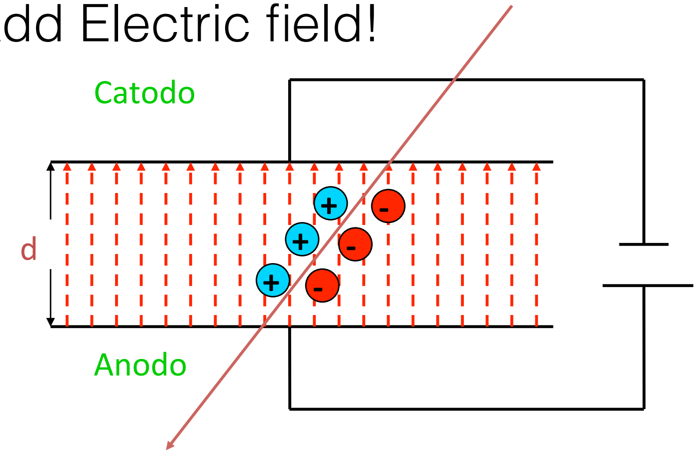


And how does the detector work?

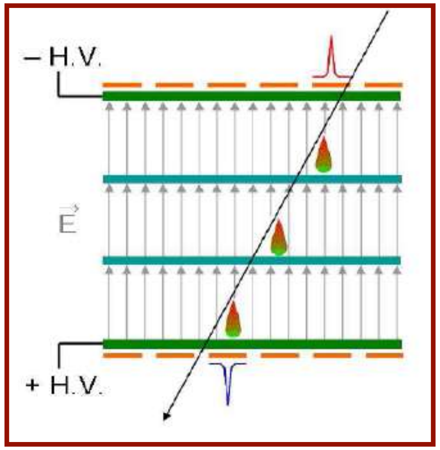
MRPC…a frontier gaseous detector!

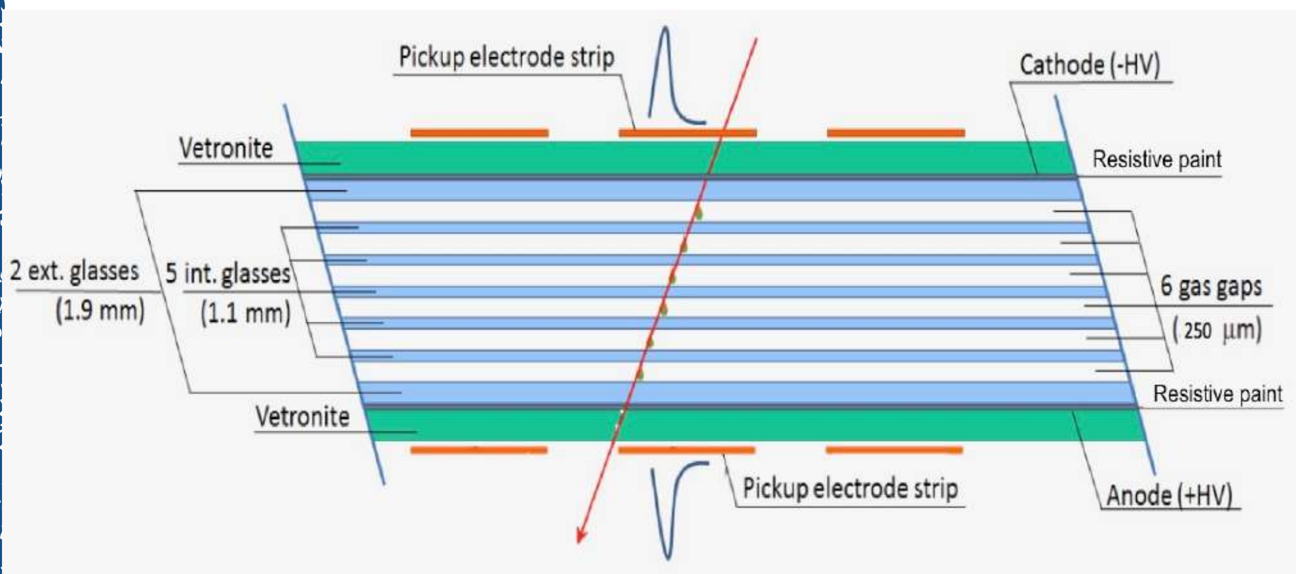


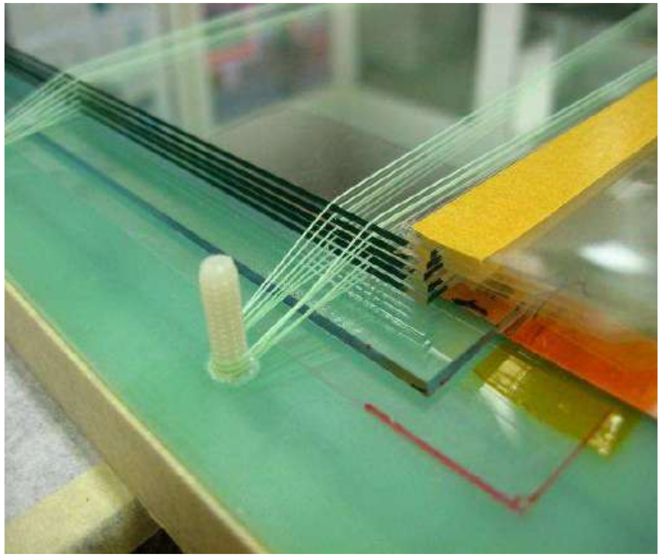
Add Electric field!



Add gaps!







Two basic ingredients

1.Gas

we use a mixture of Freon And SF_6

Two basic ingredients

1. ***Gas***

    we use a mixture of Freon And SF_6

Two basic ingredients

1.Gas

we use a mixture of eco-freon and helium

Two basic ingredients

1. Gas

we use a mixture of eco-freon and helium

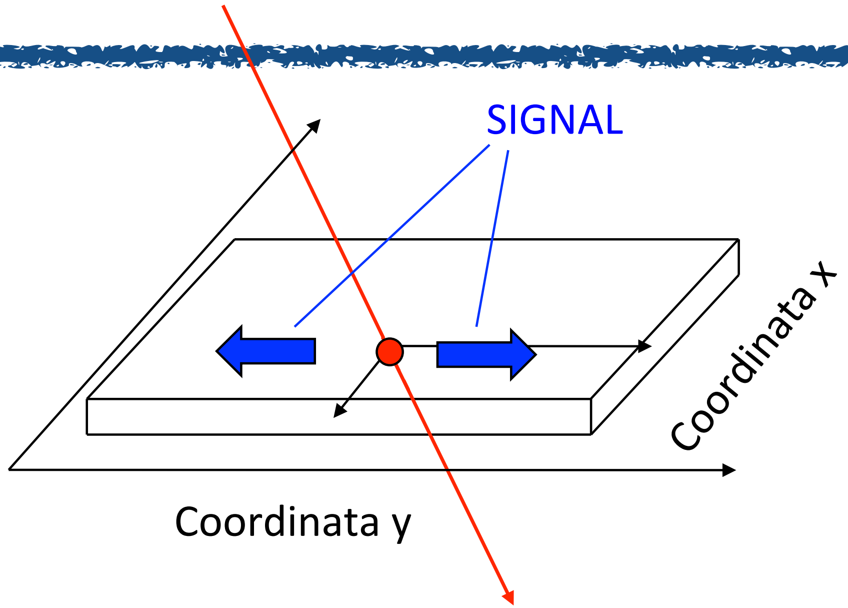
2. High Voltage

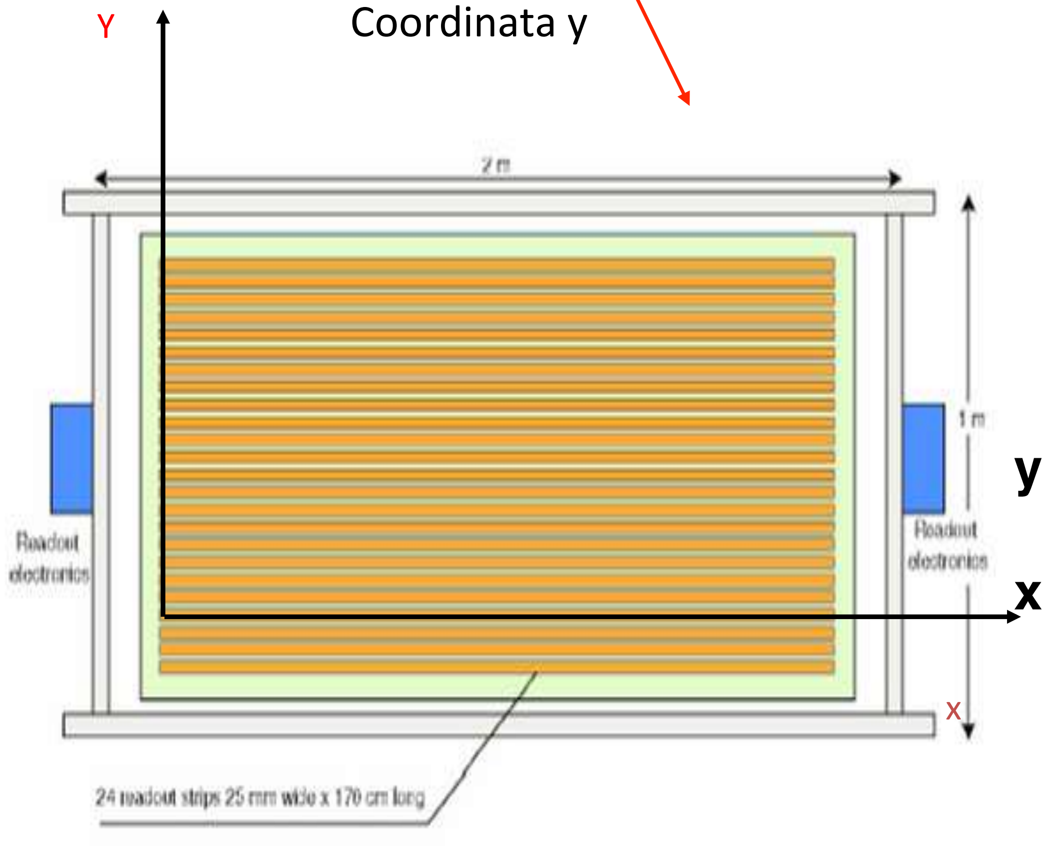
we keep the $\Delta V \sim 19$ kV

To make it work properly!

Let's see some details

Detector Details

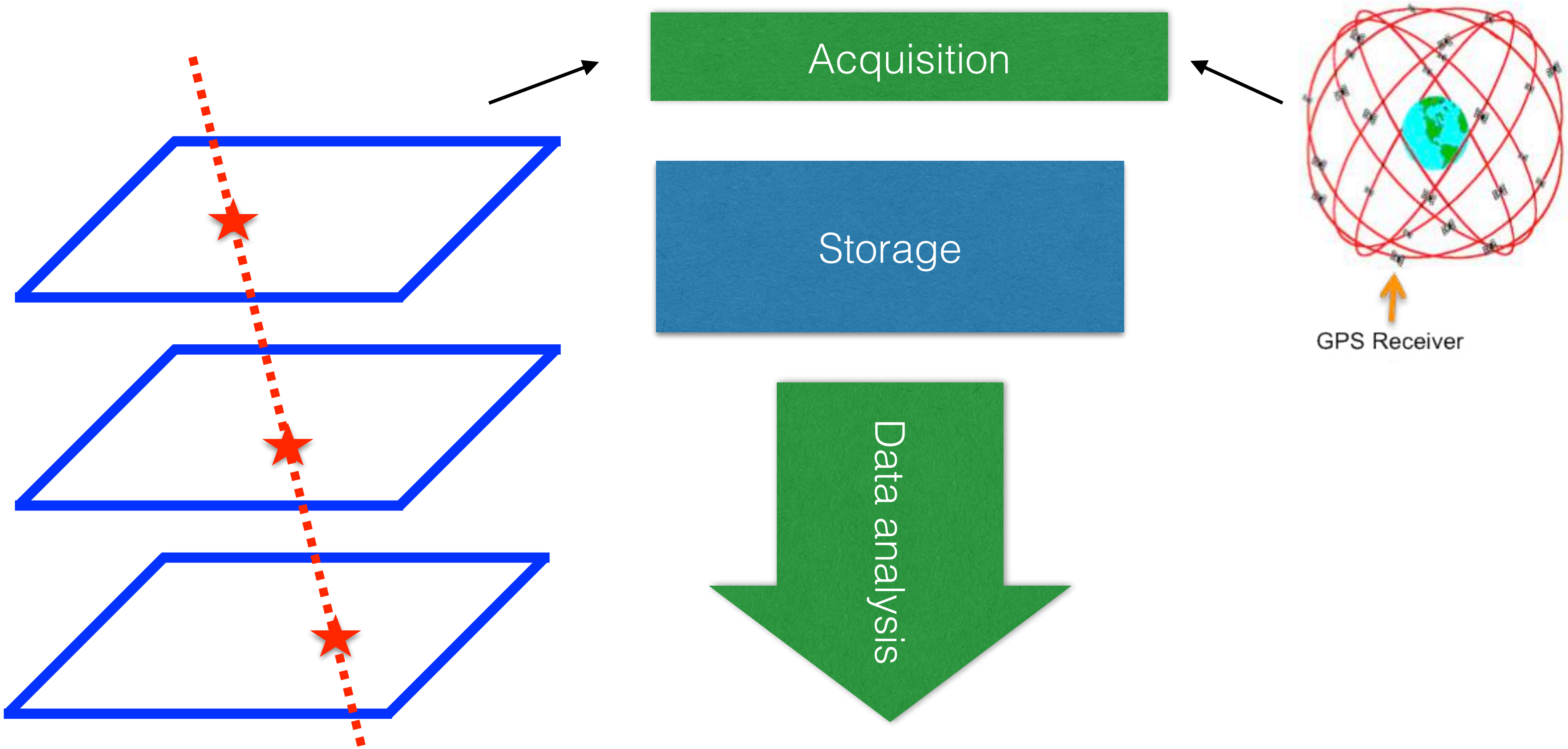




y coord. -> channel with signal

x coord. -> Signal arrival time difference

Available infos



at least…

- ***3 points….***
- ***1 line…..***
- ***1 time…***

NB: this is the minimal set of information

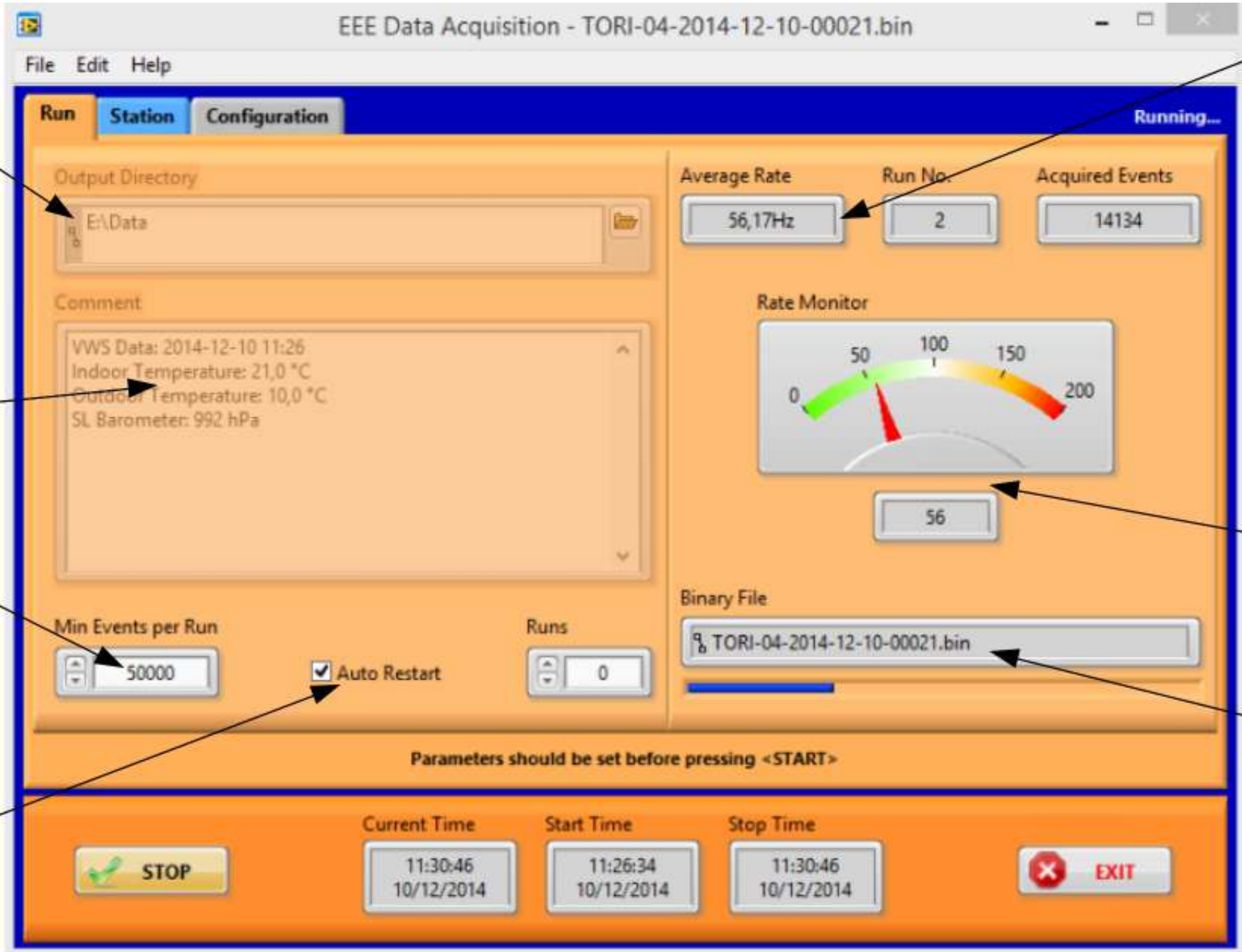
How do we run EEE Telescopes

Data folder

Weather station data

Max Nb.of events per run

Run auto restart



Average number of muons in the run

"online" number of muons

Current data file

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So can we measure

1. *The point of passage of the cosmic ray (i.e. muon)*

2. *The cosmic ray direction*

3. *The time of flight of the cosmic ray*

4. *We can discover if our cosmic ray is in coincidence with particles detected by other telescopes*

Now we know how the telescope works and what we can get from it, so

Chapter 2

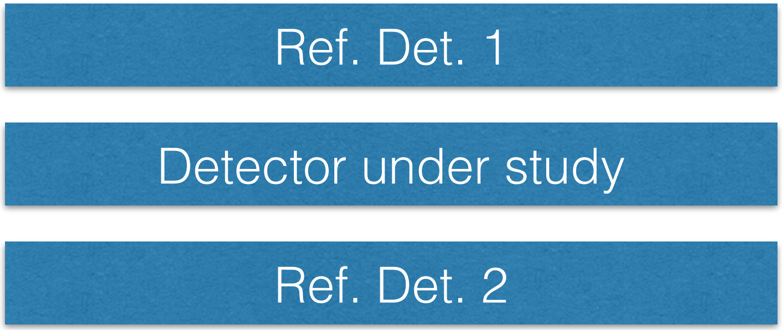
Based on the material prepared for the 2021 Erice Meeting https://agenda.centrofermi.it/event/197/

https://agenda.centrofermi.it/event/197/sessions/138/attachments/763/1130/AbbresciaErice2021.pdf
https://agenda.centrofermi.it/event/197/sessions/138/attachments/763/1134/Erice_Masterclass_20211117.pdf
https://sites.google.com/cref.it/eee-gasefficiciencymasterclass/material

Efficiency

The efficiency of the detector is defined as the fraction between the number of detected particles detected and the total number of detectable particles crossing it.

$$Eff = \frac{NUM}{DEN} = \frac{Particles\ detected}{Detectable\ particles\ passing\ through\ the\ detector}$$



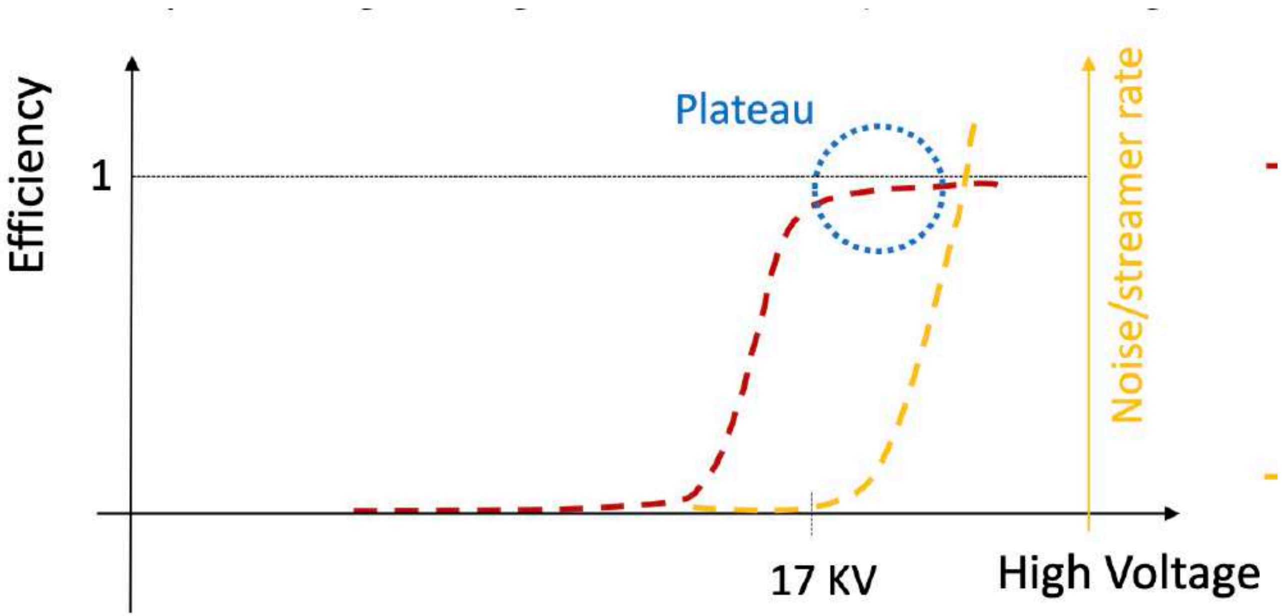
We can use two "Reference Detectors" to find out the number of particles crossing the "under study" detector

- ***Hardware and software way to determine e passage of a particle through the detector under study***

- ***Robust definition of "detected"***

Efficiency

The efficiency is function of several parameters, for our purpose: the HV and the gas mixture



The detector efficiency is a function of the applied High Voltage: it increases with the applied voltage till a plateau that represents the region where the detector is stable.

Of course another fundamental ingredient is the gas that is used.

Efficiency

Gaseous detectors are particularly sensible to temperature and pressure variations. To compare data collected in different conditions we can use the effective HV, computed as

$$HV_{eff} = HV * \frac{P_{ref}}{P} * \frac{T}{T_{ref}},$$

with $T_{ref} = 293.15$ K and $P_{ref} = 1010$ mbar.

We are ready for

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Hands-on 1

Build efficiency curves using "old" data

- ***Make a copy of the Google sheet containing the efficiency measurement performed with the Legnaro telescope : link***

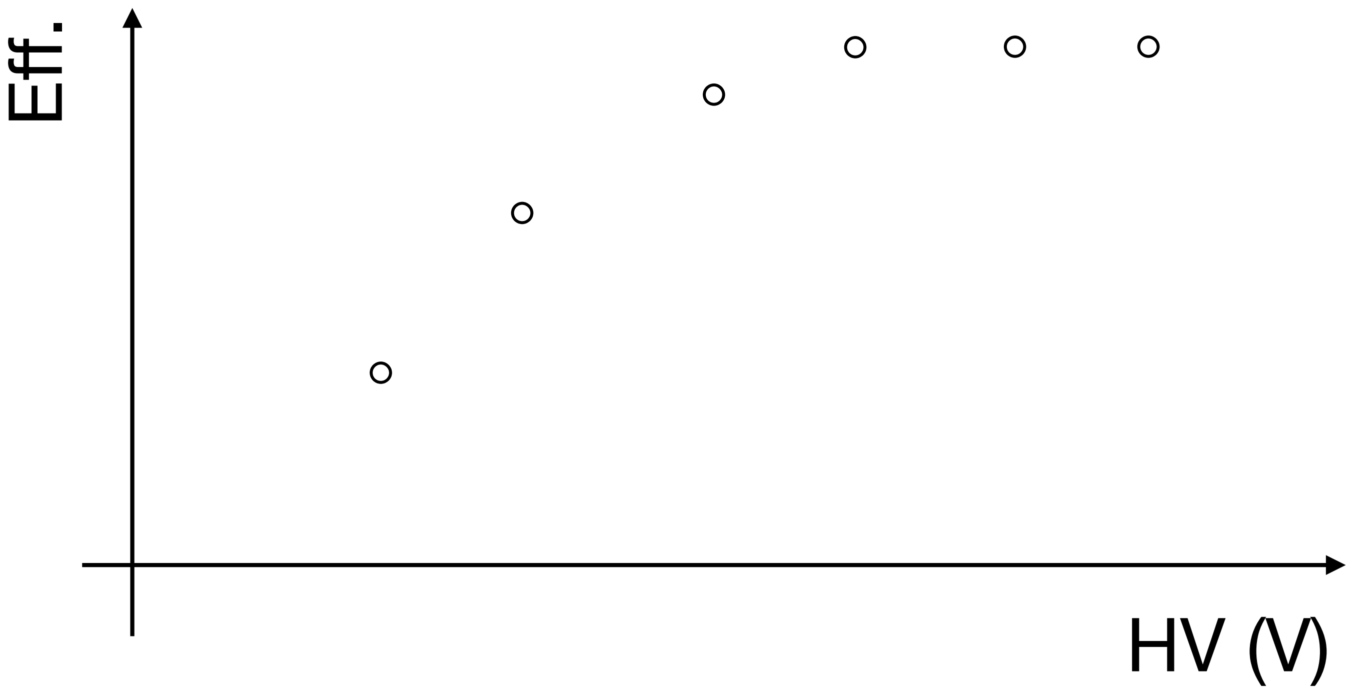
- ***Build the efficiency curve for all the chambers (bottom , middle and top) without and then correcting the High Voltage for Pressure and Temperature.***

- ***Describe the behaviour of the corrected curves; are the three curves in agreement?***

Hands-on 2

Perform the measurement for middle chamber

Each group (composed by students and teachers of 2 schools) will measure one efficiency point!

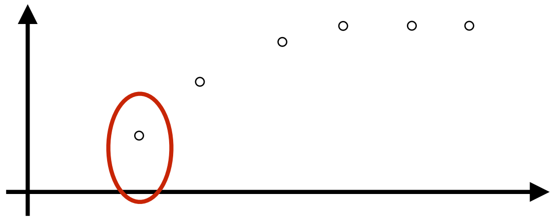


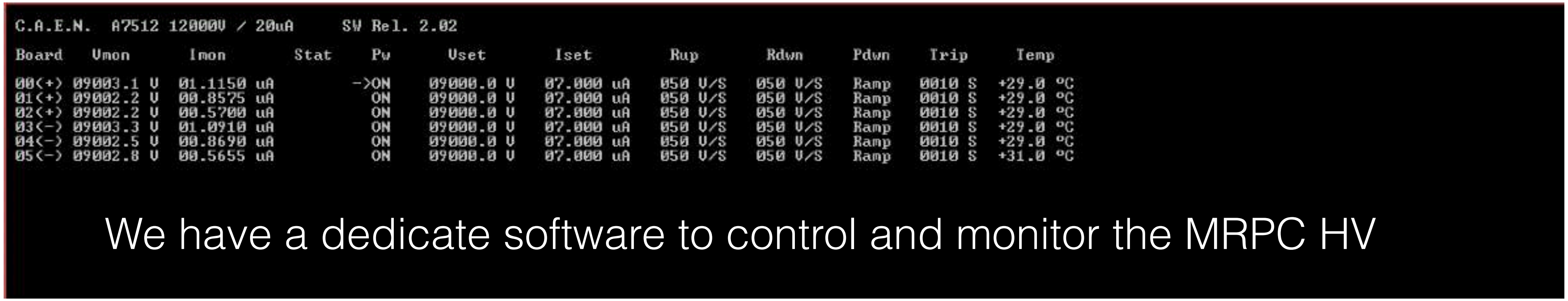
Then we will use all the measurements to get the efficiency curve

Hands-on 2-Part 1

Experimental part:

1- Set the Chamber HV



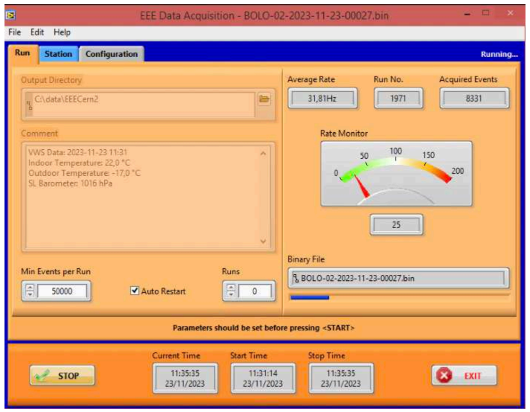

C.A.E.N. A7512 12000V / 20uA SW Rel. 2.02

Board	Vmon	Imon	Stat	Pw	Vset	Iset	Rup	Rdwn	Pdwn	Trip	Temp
00(+)	09003.1 V	01.1150 uA		->ON	09000.0 V	07.000 uA	050 V/S	050 V/S	Ramp	0010 S	+29.0 °C
01(+)	09002.2 V	00.8575 uA		ON	09000.0 V	07.000 uA	050 V/S	050 V/S	Ramp	0010 S	+29.0 °C
02(+)	09002.2 V	00.5700 uA		ON	09000.0 V	07.000 uA	050 V/S	050 V/S	Ramp	0010 S	+29.0 °C
03(-)	09003.3 V	01.0910 uA		ON	09000.0 V	07.000 uA	050 V/S	050 V/S	Ramp	0010 S	+29.0 °C
04(-)	09002.5 V	00.8690 uA		ON	09000.0 V	07.000 uA	050 V/S	050 V/S	Ramp	0010 S	+29.0 °C
05(-)	09002.8 V	00.5655 uA		ON	09000.0 V	07.000 uA	050 V/S	050 V/S	Ramp	0010 S	+31.0 °C

We have a dedicate software to control and monitor the MRPC HV

2- Check the Trigger Logic → **What?**

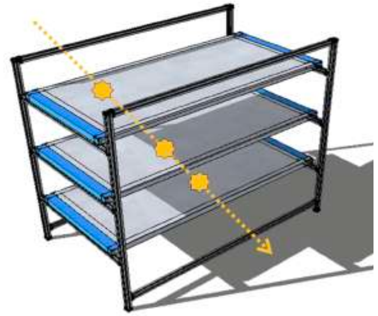
3- Acquire data



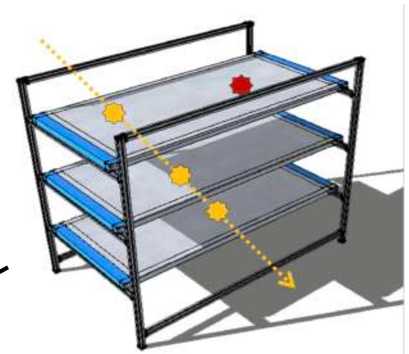
Start DAQ and acquire X runs of 50000

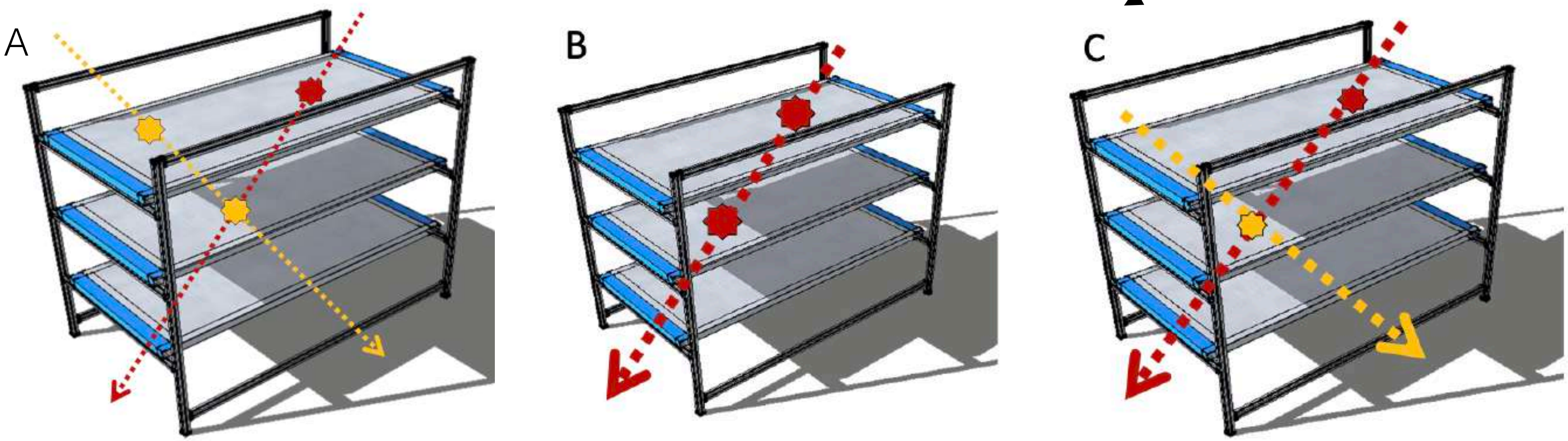
Trigger Logic

The trigger is the condition that we want to be satisfied to acquire (save information) the event.
Since we have 3 detectors our electronics is able to select (trigger) events with signals on all the chambers, we call this triple coincidence.



In principle a straight track can be reconstructed with only 2 position measurements, so why do we need 3 chambers? Of course the third chamber adds another time-position measurement, improving the precision of our experimental setup, but this is not the only reason: cut noise!

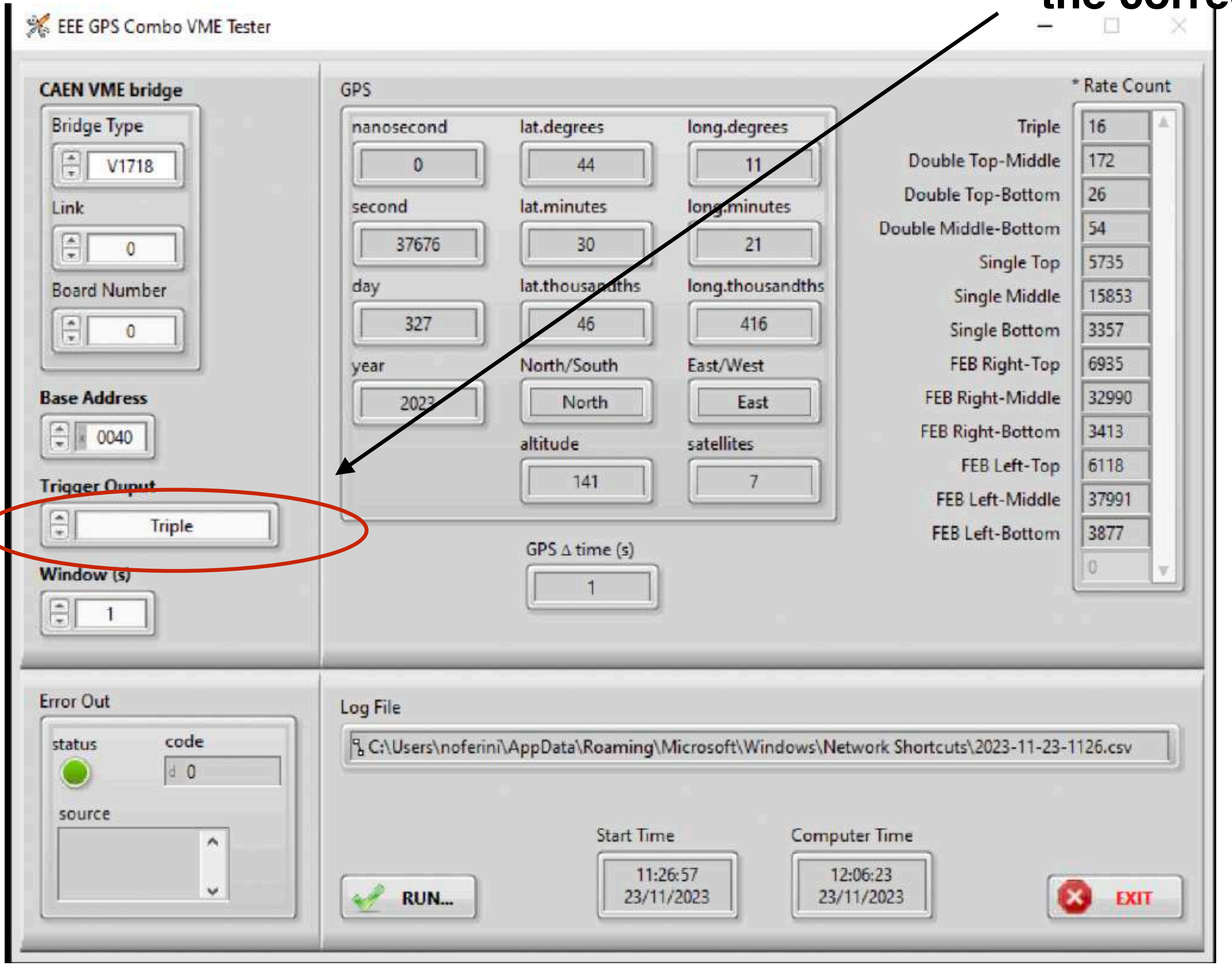




Check and set trigger Logic

We have a software that can manage the electronics devoted to form the trigger

Check the status and change it to the correct logic…..



Ref. Det. 1 (top)

Detector under study (middle)

Ref. Det. 2 (bottom)

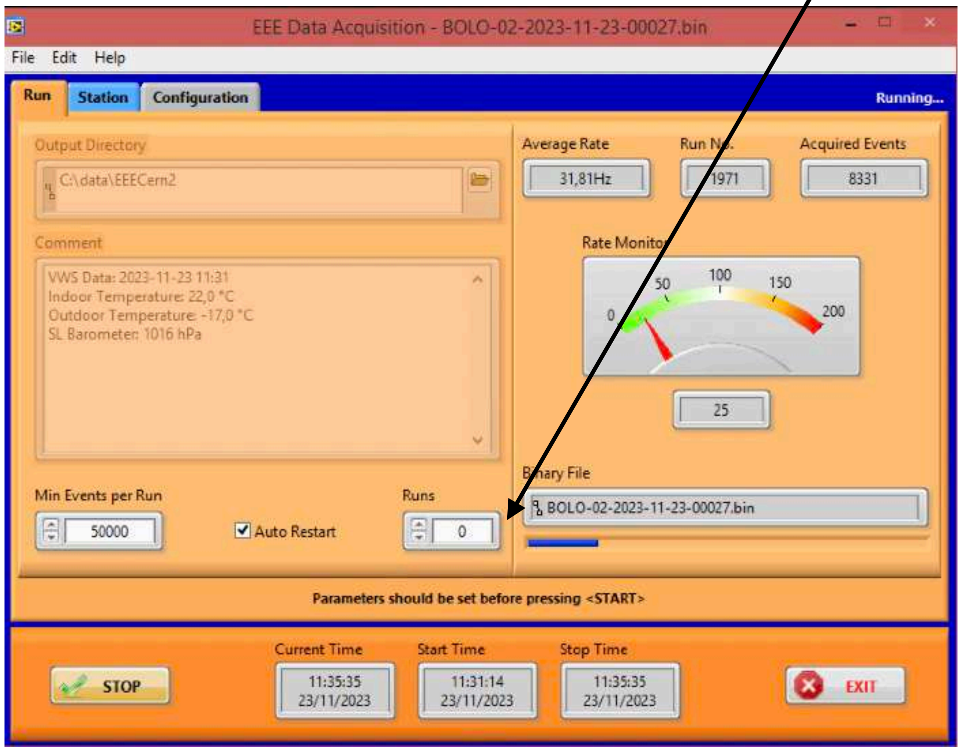
How many events do we need?

The number of events is connected to the precision we want in the measure.

Considering the LNLE telescope we need to acquire data for about 10 minutes.

So take the value of the top-bottom (double) coincidence rate and get the total number of events you will get in 10 minutes and then set the number of run of 50000 events in the DAQ code.

One Run is enough!



Measurement

Each group will work on the telescope for about 5/10 minutes and we will acquire data for 12/13 HV points from 14000 to 20000.

This part will be followed by

Hands-on 2-Part 2

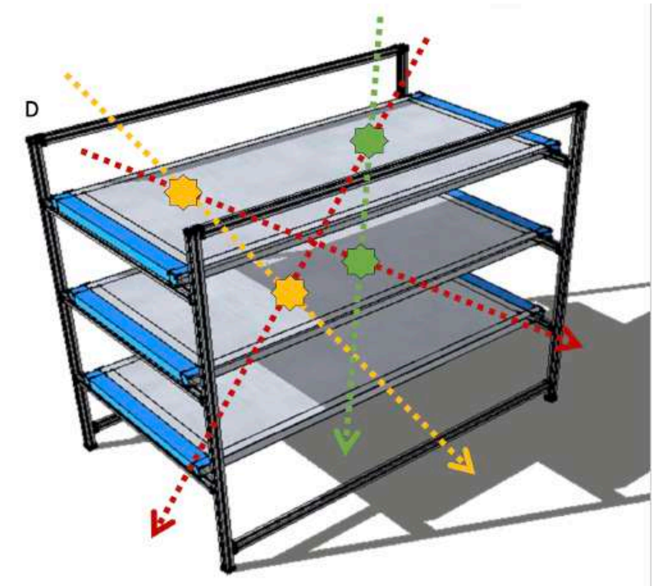
Data Analysis:

In some cases more particle can pass through the detector at the same time (indeed we are studying showers!).

In this case a double chamber layout will have an ambiguity in the reconstruction, with 4 candidate tracks, where 2 are real and 2 are "ghosts".

Exactly the same issue can affect the measurement of the efficiency, where the passage of a particle must be identified using only two chambers!

So…how to be sure (almost) that the two hits measured in the two reference chambers are related to a particle and are not noise or multitrack event?



Hands-on 2-Part 2

At the end of the measurement we will provide you the following file:

xB	yB	tB	xM	yM	tM	xT	yT	tT
131.38	68.8	412.77	134.2	63.52	409.79	136.51	59.2	408.24
108.07	51.2	401.24				82.79	54.4	438.64
75.68	48	440.79	84.15	62.96	438.14	91.09	75.2	434.61
64.62	32	430.49	38.33	22.32	428.54	16.83	14.4	437.02
40.13	32	421.44	37.09	56.64	420.29	34.6	76.8	416.39
19.59	6.4	363.54				51.98	22.4	414.19
109.65	12.8	417.64	114.87	31.28	411.84	119.13	46.4	409.59
60.67	51.2	408.94	35.04	52.96	406.32	14.06	54.4	407.29
67.39	59.2	420.32	55.87	61.84	418.02	46.45	64	416.34
78.45	56	429.16	77.8	46.32	427.02	77.26	38.4	423.99

Hit Position (in cm) and time (ns) of the hit for each chamber bottom (B) middle (M) and top (T)

Note: there are some rows (events) without hit on middle chamber…

Selection cut

On this data file we have performed a First event selection already performed for you:

- **Exactly one hit in the top and bottom chamber**
- **If more than one hit was present in the middle chamber, only the best candidate is reported in the file.**

In this way we cut some fake events.

But there is still some probability to acquire some fake events.

We add some information to the event computing the $1/\beta$ quantity for each candidate.

What is it?

β = velocity of the particle/speed of light (commonly used quantity in this field) so that $1/\beta$ is just the its inverse. By definition (except for measurement errors) $\beta \leq 1$.

Let's try to compute it.

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Selection cut: Formulas

First compute the particle velocity

$$V = L/T$$

where L is the track length and T is the time of flight. In 3D the distance between 2 points is:

$$L = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2 + (z_2 - z_1)^2}$$

In this telescope: zB=0, zM=66 cm, zT=120 cm

T is the Time of Flight of the particle defined as the difference between tB and tT. The time of the hit you find in the file is the time referred to a common time (trigger time).

Once we have the velocity we just need to:

$$\frac{1}{\beta} = \frac{c}{V} = \frac{c \times T}{L}$$

Where $c = 299792458\ m/s$

Selection cut: Excel

A	B	C	D	E	F	G	H	I	J	K	L
xB	yB	tB	xM	yM	tM	xT	yT	tT	L		
131.38	68.8	412.77	134.2	63.52	409.79	136.51	59.2	408.24	=SQRT((G2-A2)^2+(H2-B2)^2+(120-0)^2)		

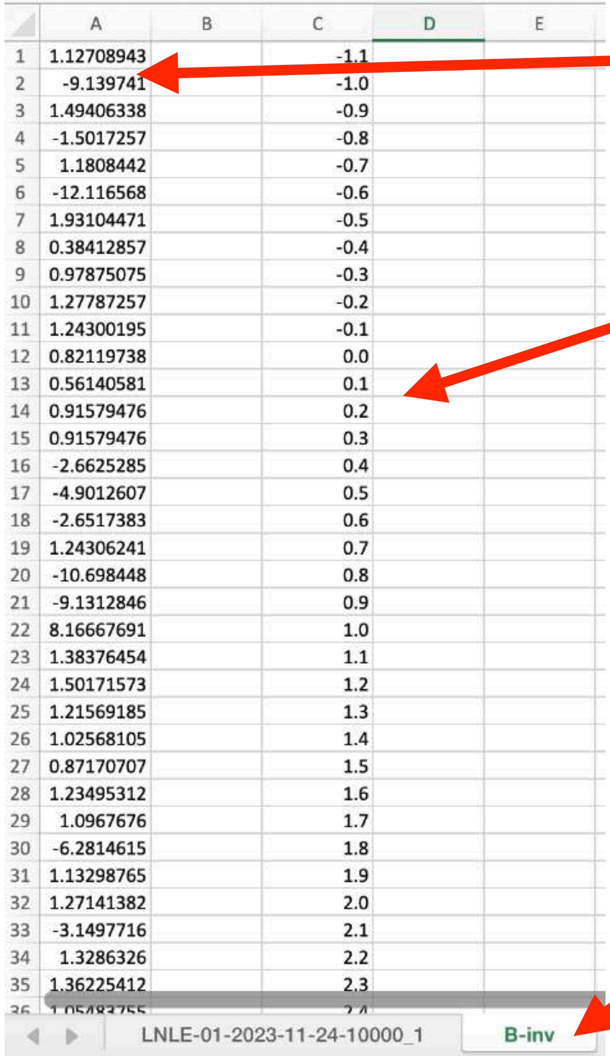
xB	yB	tB	xM	yM	tM	xT	yT	tT	L	T (tof)
131.38	68.8	412.77	134.2	63.52	409.79	136.51	59.2	408.24	120.492643	=C2-I2
108.07	51.2	401.24				82.79	54.4	438.64	122.675663	
75.68	48	440.79	84.15	62.96	438.14	91.09	75.2	434.61	124.005274	
64.62	32	430.49	38.33	22.32	428.54	16.83	14.4	437.02	130.359672	
40.13	32	421.44	37.09	56.64	420.29	34.6	76.8	416.39	128.209286	

xB	yB	tB	xM	yM	tM	xT	yT	tT	L	T (tof)	B_inv
131.38	68.8	412.77	134.2	63.52	409.79	136.51	59.2	408.24	120.492643	4.53	=29.9792458*K2/J2
108.07	51.2	401.24				82.79	54.4	438.64	122.675663	-37.4	

xB	yB	tB	xM	yM	tM	xT	yT	tT	L	T (tof)	B_inv
131.38	68.8	412.77	134.2	63.52	409.79	136.51	59.2	408.24	120.492643	[illegible]3	1.12708943
108.07	51.2	401.24				82.79	54.4	438.64	122.675663	-37.4	-9.139741
75.68	48	440.79	84.15	62.96	438.14	91.09	75.2	434.61	124.005274	6.18	1.49406338
64.62	32	430.49	38.33	22.32	428.54	16.83	14.4	437.02	130.359672	-6.53	-1.5017257
40.13	32	421.44	37.09	56.64	420.29	34.6	76.8	416.39	128.209286	5.05	1.1808442
19.59	6.4	363.54				51.98	22.4	414.19	125.320039	-50.65	-12.116568
109.65	12.8	417.64	114.87	31.28	411.84	119.13	46.4	409.59	124.975319	8.05	1.93104471
60.67	51.2	408.94	35.04	52.96	406.32	14.06	54.4	407.29	128.773957	1.65	0.38412857
67.39	59.2	420.32	55.87	61.84	418.02	46.45	64	416.34	121.907849	3.98	0.97875075
78.45	56	429.16	77.8	46.32	427.02	77.26	38.4	423.99	121.289637	5.17	1.27787257
73.31	56	415.59	108.29	47.2	412.19	136.91	40	409.92	136.751453	5.67	1.24300195
126.24	60.8	434.99	130.8	51.12	431.24	134.54	43.2	431.66	121.567471	3.33	0.82119738
105.31	59.2	427.16	88.58	56.56	426.89	74.89	54.4	424.84	123.888726	2.32	0.56140581
79.24	4.8	410.02				88.32	33.6	406.24	123.741207	3.78	0.91579476

Selection cut: How to fix the cut?

We expect 1/β to be greater than 1 by construction. Since it is a measured quantity it is affected by (mainly and hopefully) by random errors, so we expect a distribution of values with 1 as most favourable result. Let's try to have a look to the distribution



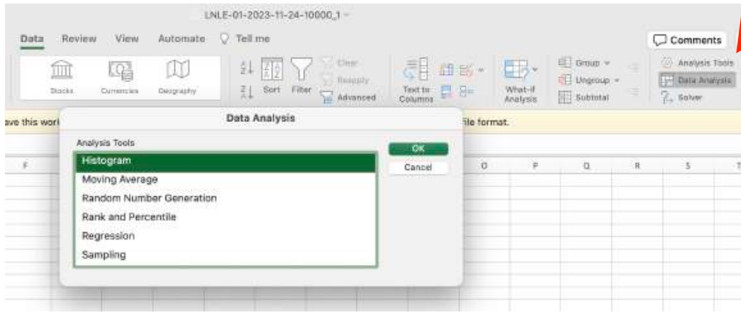
	A	B	C	D	E
1	1.12708943		-1.1		
2	-9.139741		-1.0		
3	1.49406338		-0.9		
4	-1.5017257		-0.8		
5	1.1808442		-0.7		
6	-12.116568		-0.6		
7	1.93104471		-0.5		
8	0.38412857		-0.4		
9	0.97875075		-0.3		
10	1.27787257		-0.2		
11	1.24300195		-0.1		
12	0.82119738		0.0		
13	0.56140581		0.1		
14	0.91579476		0.2		
15	0.91579476		0.3		
16	-2.6625285		0.4		
17	-4.9012607		0.5		
18	-2.6517383		0.6		
19	1.24306241		0.7		
20	-10.698448		0.8		
21	-9.1312846		0.9		
22	8.16667691		1.0		
23	1.38376454		1.1		
24	1.50171573		1.2		
25	1.21569185		1.3		
26	1.02568105		1.4		
27	0.87170707		1.5		
28	1.23495312		1.6		
29	1.0967676		1.7		
30	-6.2814615		1.8		
31	1.13298765		1.9		
32	1.27141382		2.0		
33	-3.1497716		2.1		
34	1.3286326		2.2		
35	1.36225412		2.3		
36	1.05483755		2.4		

LNLE-01-2023-11-24-10000_1 | B-inv

We copy the 1/β values in column A of a new Sheet

We create the bin limits for a histogram from -1.1 to 3.1

Use Histogram function of the Data analysis tab



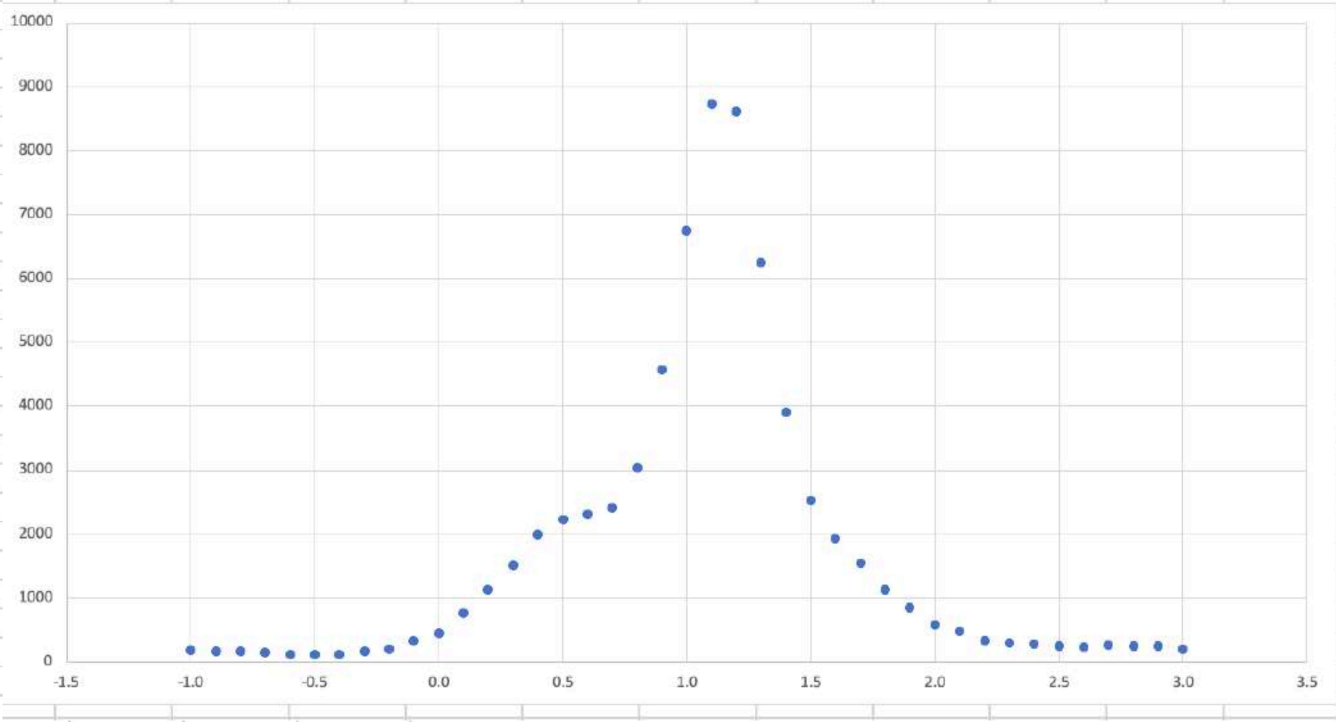
Selection cut: How to fix the cut?

	A	B
1	Bin	Frequency
2	-1.1	10381
3	-1.0	191
4	-0.9	173
5	-0.8	167
6	-0.7	146
7	-0.6	125
8	-0.5	123
9	-0.4	125
10	-0.3	174
11	-0.2	195
12	-0.1	326
13	0.0	448
14	0.1	764
15	0.2	1133
16	0.3	1512
17	0.4	2000
18	0.5	2234
19	0.6	2311
20	0.7	2418
21	0.8	3050
22	0.9	4577
23	1.0	6757
24	1.1	8726
25	1.2	8609
26	1.3	6259
27	1.4	3915
28	1.5	2523
29	1.6	1931
30	1.7	1554
31	1.8	1126
32	1.9	854
33	2.0	575
34	2.1	484
35	2.2	330
36	2.3	307
37	2.4	278
38	2.5	246
39	2.6	240
40	2.7	262
41	2.8	258

LNLE-01-2023-11-24-10000_1 | Sheet2 | B-inv

Excel automatically creates e new sheet with bins and Entries per bin (note first and last bin contain respectively the entries lower and greater than than)

We create a dispersion plot excluding these two bins and we can observe that most of the values are between 0.7 and 1.4: this is our 1/β cut.



M. Garbini, LNL 27 Nov. 2023

Selection cut 1: Excel

SUM =IF(AND(L2>0.7,L2<1.4),1,0)

	G	H	I	J	K	L	M	N
1	xT	yT	tT	L	T (tof)	B_inv	B_inv_cut	
2	136.51	59.2	408.24	120.492643	4.53	1.12708943	L2<1.4),1,0)	
3	82.79	54.4	438.64	122.675663	-37.4	-9.139741		
4	91.09	75.2	434.61	124.005274	6.18	1.49406338		

In M column we ask 1/β to be between 0.7 and 1.4 and we set the cell value to 1 if true and 0 if false

yB	tB	xM	yM	tM	xT	yT	tT	L	T (tof)	B_inv	B_inv_cut
68.8	412.77	134.2	63.52	409.79	136.51	59.2	408.24	120.492643	4.53	1.1270[illegible]3	1
51.2	401.24				82.79	54.4	438.64	122.675663	-37.4	-9.139741	0
48	440.79	84.15	62.96	438.14	91.09	75.2	434.61	124.005274	6.18	1.49406338	0
32	430.49	38.33	22.32	428.54	16.83	14.4	437.02	130.359672	-6.53	-1.5017257	0
32	421.44	37.09	56.64	420.29	34.6	76.8	416.39	128.209286	5.05	1.1808442	1
6.4	363.54				51.98	22.4	414.19	125.320039	-50.65	-12.116568	0
12.8	417.64	114.87	31.28	411.84	119.13	46.4	409.59	124.975319	8.05	1.93104471	0
51.2	408.94	35.04	52.96	406.32	14.06	54.4	407.29	128.773957	1.65	0.38412857	0
59.2	420.32	55.87	61.84	418.02	46.45	64	416.34	121.907849	3.98	0.97875075	1
56	429.16	77.8	46.32	427.02	77.26	38.4	423.99	121.289637	5.17	1.27787257	1
56	415.59	108.29	47.2	412.19	136.91	40	409.92	136.751453	5.67	1.24300195	1

Efficiency - v0

Next step is the evaluation of efficiency:

$$Eff = \frac{NUM}{DEN} = \frac{Particles\ detected}{Detectable\ particles\ passing\ through\ the\ detector}$$

Calculate the efficiency with a simple approach: the total number of lines represents the number of detectable particles passing through the detector and the detected particles are the ones with values on the middle chamber space and time hit.

Name Box	B	C	D	E	F	G	H	I
xB	yB	tB	xM	yM	tM	xT	yT	tT
131.38	68.8	412.77	134.2	63.52	409.79	136.51	59.2	408.24
108.07	51.2	401.24				82.79	54.4	438.64
75.68	48	440.79	84.15	62.96	438.14	91.09	75.2	434.61
64.62	32	430.49	38.33	22.32	428.54	16.83	14.4	437.02
40.13	32	421.44	37.09	56.64	420.29	34.6	76.8	416.39
19.59	6.4	363.54				51.98	22.4	414.19
109.65	12.8	417.64	114.87	31.28	411.84	119.13	46.4	409.59
60.67	51.2	408.94	35.04	52.96	406.32	14.06	54.4	407.29
67.39	59.2	420.32	55.87	61.84	418.02	46.45	64	416.34
78.45	56	429.16	77.8	46.32	427.02	77.26	38.4	423.99

Efficiency - v1

Then we can consider as real particles just the ones satisfying the $1/\beta$ condition and evaluate the efficiency using this sample.

Do you expect improvement in the efficiency evaluation?

Other questions :

What about the uncertainty of the measure?

Focus on Uncertainty

In efficiency measurements to calculate the uncertainties we use the properties of **binomial distribution:** it describes the probability to get **m** successes in **n** independent trials, given the probability **p** of success in one trial.
The formula is a bit complicated, we don't really need it but it's here:

$$P(m,n,p) = \frac{n!}{m!(n-k)!} p^m (1-p)^{n-m}$$

Given this we get that the expected number of success k in n trials is $k = n \times p$

and the error is $\sigma_k = \sqrt{np(1-p)}$

We can recognise our problem if we identify **p** as **Eff**, **n** is the number of particles crossing the detector (**den**) and **k** is the expected number of detected particles (**num**). So

$$k = n \times p \rightarrow k = n \times Eff \rightarrow Eff = \frac{k}{n}$$

And the error on Eff is (by simple propagation) is the error on k divide n.

$$\sigma_{Eff} = \frac{\sigma_k}{n} = \frac{\sqrt{nEff(1-Eff)}}{n} = \sqrt{\frac{Eff(1-Eff)}{n}}$$

Extreme Energy Events
Science inside Schools

Build the Curve

Each group will measure one efficiency point of the curve (from the experimental phase to the analysis phase) and provide it to the other groups to build the final efficiency curve.

All the data will be anyway available for the groups for further checks.

But it's not enough

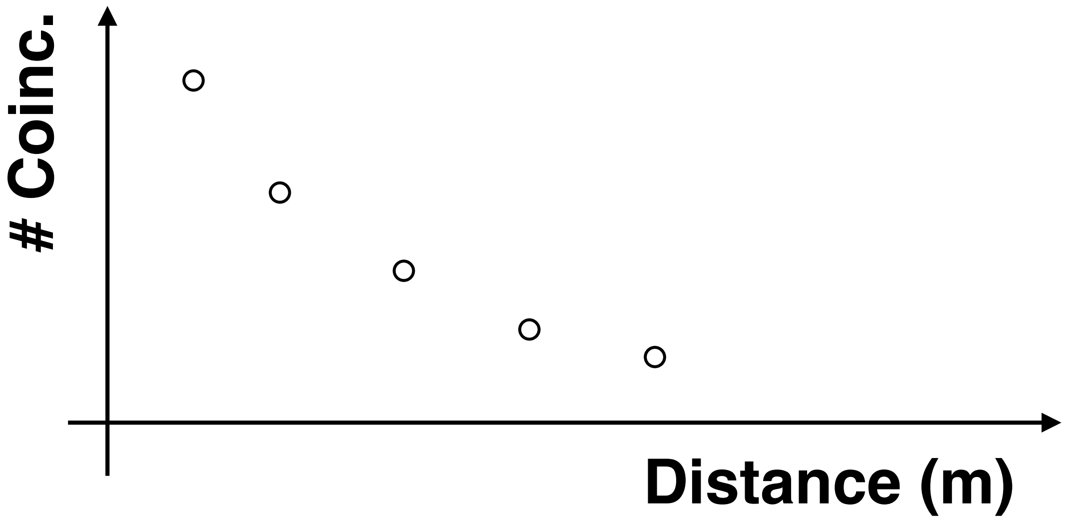
Coincidences vs distance

We have installed POLA-02 detector in Legnaro and we acquired data (and we will acquire more till tomorrow morning)

We have positioned POLA-02 at different distances from LNLE-01 EEE telescope.

You can find here the data files in the same format of the ICD analysis.

Study the behaviour of the number of coincidences vs. Distance of the two detectors.



Reporting the results

Tomorrow afternoon you can report your results during the afternoon session

10 minutes for each group!

Slides showing the results are welcome but you can add (without exceeding the 10 minutes time limit) video story of your experience!

Good Luck!