CENTRO FERMI

MUSEO STORICO DELLA FISICA E CENTRO STUDI E RICERCHE ENRICO FERMI

Progetto Extreme Energy Events (EEE)
La Scienza nelle Scuole

Extreme Energy Events
Science inside Schools

# Masterclass: data analysis on eco-mixtures


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# Master Class Overview & Goals

The goals of this Master Class are:

1. Achieve a better understanding of gaseous detector working principles (talk of Prof. M. Abbrescia)
2. Generate and understand the main characteristics of an efficiency curve
3. Understand the impact of temperature-pressure correction
4. Understand and compare efficiency results with different gas mixtures
5. Learn the basic principle on how the efficiency of an EEE chamber can be measured

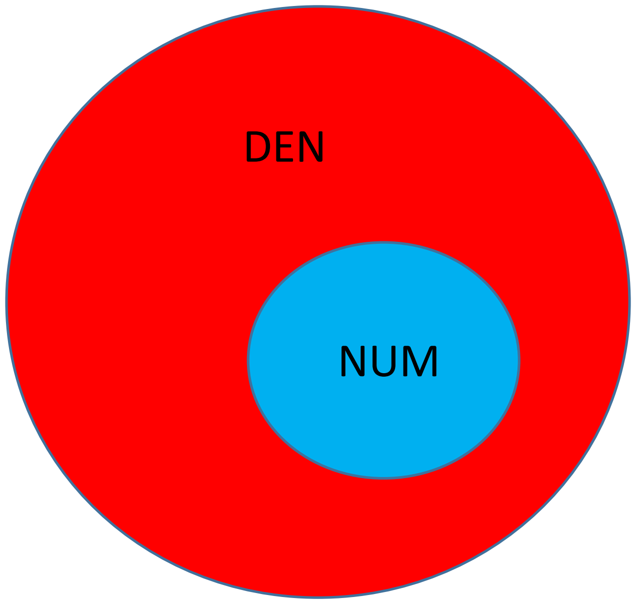
The Master Class is composed of 4 exercises with their relative dataset (links available here)

1. Comparison of efficiency curves within 2 telescopes with “standard” (98% R134a + 2% SF6) gas mixture
2. Comparison of efficiency curves within 2 telescopes with pure Ecofreon (R1234ze, GWP=7)
3. Comparison of efficiency curves within 2 telescopes with a new gas mixture (40% R1234ze + 60% CO2)
4. Compute the efficiency of one of the EEE chambers. Understand the event selection procedure and its effect on the final measurement.

# Efficiency

The efficiency of a detector can be defined, in general terms, as the ratio between the number of detectable particles passing through it and the number of such particles that it was able to detect.

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




Two key elements are needed to measure an efficiency:

- A way (hardware + software) to determine the passage of a particle through the detector under study
- A good definition of $"detected"$

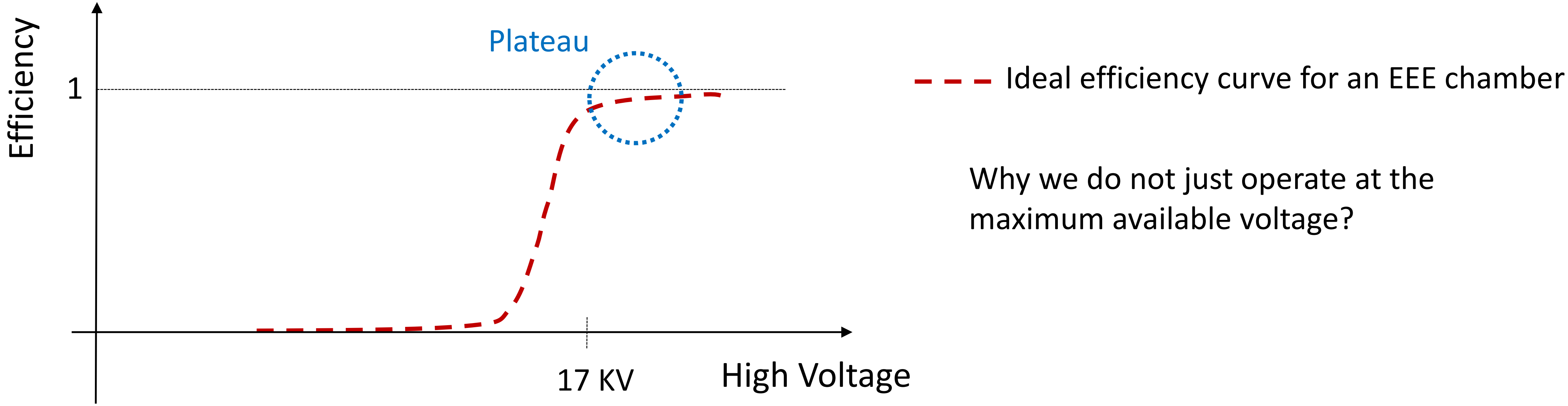
$$NUM \subset DEN \quad \Rightarrow \quad Eff \leq 1$$

# Efficiency

The detector efficiency is a function of several parameter. The main ones, treated today, are the applied High Voltage (HV) and gas used.

The efficiency increases with the applied voltage till a plateau, that represents the region where the detector is stable and should be operated, is reached.

Ideally we want to work with detectors that are 100% efficient; our MRPCs are close to this value for an HV above 17000 V (with standard gas mixture).




Why we do not just operate at the maximum available voltage?

# Efficiency

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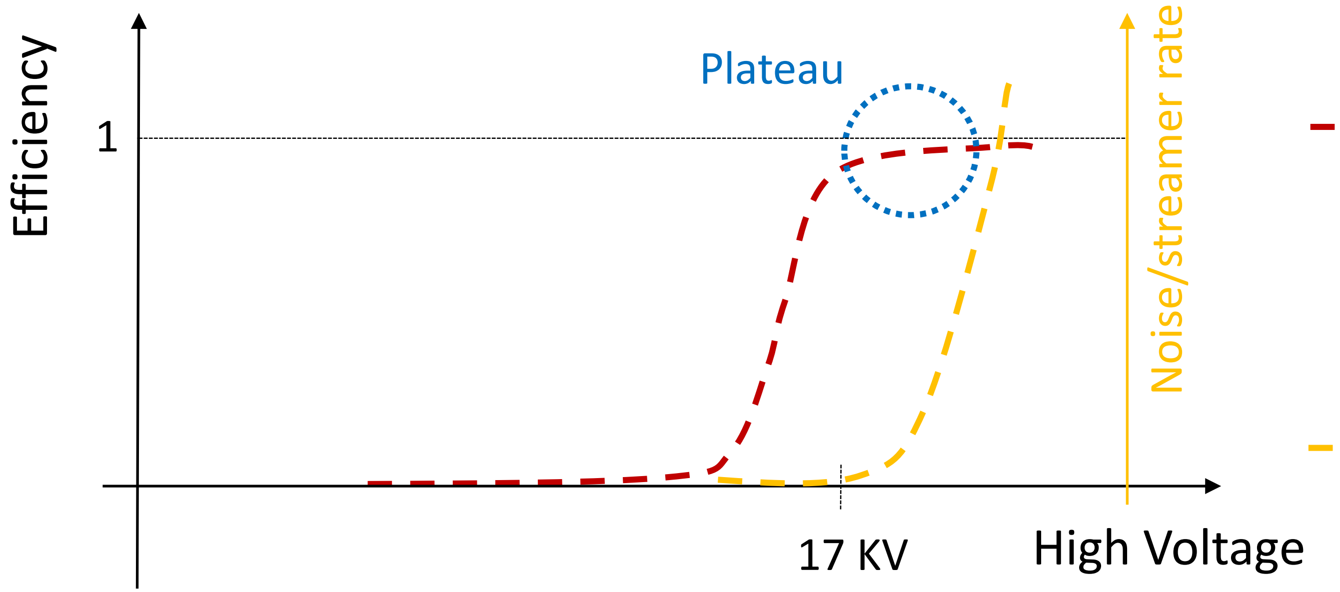



Ideal efficiency curve for an EEE chamber

Why we do not just operate at the maximum available Voltage?

Example of noise and streamer rate w.r.t. HV ( more on this later)

# Exercise 1

A1 TELESCOPE-ID

| TELESCOPE-ID | HV (V) | P (mbar) | T (K) | Efficiency (%) | Error (%) | NOTE |
|---|---|---|---|---|---|---|
| BOLO-01 | 15276 | 1013 | 295.35 | 0.34 | 0.01 | STANDARD GAS |
| BOLO-01 | 15887 | 1013 | 296.35 | 0.54 | 0.01 | STANDARD GAS |
| BOLO-01 | 16489 | 1013 | 298.55 | 0.72 | 0.01 | STANDARD GAS |
| BOLO-01 | 17085 | 1014 | 296.95 | 0.84 | 0.01 | STANDARD GAS |
| BOLO-01 | 17592 | 1005 | 302.75 | 0.90 | 0.01 | STANDARD GAS |
| BOLO-01 | 18292 | 1013 | 297.85 | 0.94 | 0.01 | STANDARD GAS |
| BOLO-01 | 18842 | 1013 | 300.25 | 0.97 | 0.01 | STANDARD GAS |
| BOLO-01 | 19404 | 1015 | 295.35 | 0.97 | 0.01 | STANDARD GAS |
| BOLO-01 | 19871 | 1015 | 297.75 | 0.98 | 0.01 | STANDARD GAS |
| CERN-01 | 10000 | 960 | 298.15 | 0 | 0.01 | STANDARD GAS |
| CERN-01 | 10500 | 960 | 298.15 | 0 | 0.01 | STANDARD GAS |
| CERN-01 | 11000 | 960 | 298.15 | 0.01 | 0.01 | STANDARD GAS |
| CERN-01 | 11500 | 960 | 298.15 | 0.02 | 0.01 | STANDARD GAS |
| CERN-01 | 12000 | 960 | 298.15 | 0.04 | 0.01 | STANDARD GAS |
| CERN-01 | 12500 | 960 | 298.15 | 0.06 | 0.01 | STANDARD GAS |
| CERN-01 | 13000 | 960 | 298.15 | 0.13 | 0.01 | STANDARD GAS |
| CERN-01 | 13500 | 960 | 298.15 | 0.23 | 0.01 | STANDARD GAS |
| CERN-01 | 14000 | 960 | 298.15 | 0.35 | 0.01 | STANDARD GAS |
| CERN-01 | 14500 | 960 | 298.15 | 0.49 | 0.01 | STANDARD GAS |
| CERN-01 | 15000 | 960 | 298.15 | 0.62 | 0.01 | STANDARD GAS |
| CERN-01 | 15500 | 960 | 298.15 | 0.72 | 0.01 | STANDARD GAS |
| CERN-01 | 16000 | 960 | 298.15 | 0.81 | 0.01 | STANDARD GAS |
| CERN-01 | 16500 | 960 | 298.15 | 0.87 | 0.01 | STANDARD GAS |
| CERN-01 | 17000 | 960 | 298.15 | 0.91 | 0.01 | STANDARD GAS |
| CERN-01 | 17500 | 960 | 298.15 | 0.94 | 0.01 | STANDARD GAS |
| CERN-01 | 18000 | 960 | 298.15 | 0.95 | 0.01 | STANDARD GAS |
| CERN-01 | 18500 | 960 | 298.15 | 0.96 | 0.01 | STANDARD GAS |
| CERN-01 | 19000 | 960 | 298.15 | 0.97 | 0.01 | STANDARD GAS |
| CERN-01 | 19500 | 960 | 298.15 | 0.98 | 0.01 | STANDARD GAS |
| CERN-01 | 20000 | 960 | 298.15 | 0.98 | 0.01 | STANDARD GAS |

1. build the efficiency curve for BOLO-01 alone (HINT)
2. build the efficiency curve for CERN-01 alone
3. build a unique plot with the data of both the telescopes

Gas detectors are particularly sensible to temperature and pressure variations. To confront 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.

4. repeat (3) correcting the High Voltage for Pressure and Temperature
5. looking at this last plot what can you conclude? Are the results in agreement?

# Exercises 2 & 3

Data format is the same as exercise 1, with different gas mixtures:

1. build the efficiency curve for BOLO-01 alone
2. build the efficiency curve for CERN-01 alone
3. build a unique plot with the data of both the telescopes (correcting the High Voltage for Pressure and Temperature)

- Compare the curves obtained in the three exercises. Which conclusions can you draw out of the experimental data?
- Which gas mixtures would you suggest, taking into account what have been discussed in the talk of Prof. Abbrescia?

# Exercises 4

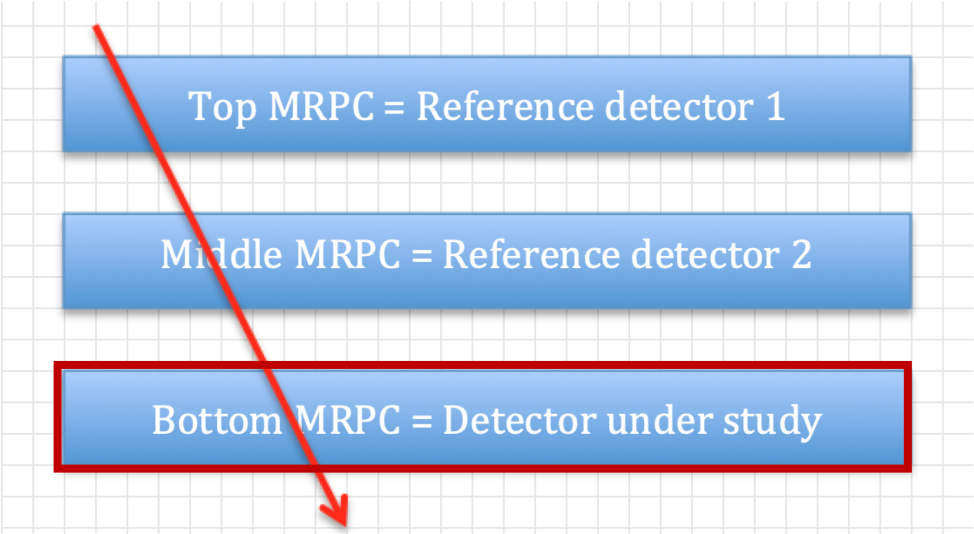
It is now time to try to compute yourself one of the efficiency point for one of the EEE chambers!
To add a bit of fun we decided to study a BOTTOM chambers.

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

Remember what we need?

- A way (hardware + software) to determine the passage of a particle through the detector under study.
- A good definition of *"detected"*

The simple way: a passing particle is determined by a signal in the TOP and MIDDLE chambers. The particle is detected by the BOTTOM chamber if it has generated a signal in coincidence.




Chamber interdistance = 50 cm

# Exercises 4

| TOP chamber | | | MID chamber | | | BOT chamber | | |
|---|---|---|---|---|---|---|---|---|
| x(cm) | y(cm) | T(ns) | x(cm) | y(cm) | T(ns) | x(cm) | y(cm) | T(ns) |
| 17.9251 | -27.2 | 306.524 | 11.2496 | -8 | 308.209 | 7.6462 | 11.2 | 309.193 |
| 70.5312 | -4.8 | 323.459 | 61.2329 | 4.8 | 324.372 | 53.4228 | 12.8 | 332.931 |
| 26.1964 | 11.2 | 309.349 | 36.4901 | -24 | 310.837 | | | |
| -68.6036 | 1.6 | 294.337 | -62.7971 | 17.6 | 294.618 | -58.0305 | 32 | 296.991 |
| -51.3658 | -17.6 | 303.613 | -19.1575 | 11.2 | 306.401 | | | |
| -46.8154 | -1.6 | 311.743 | -29.9805 | 8 | 312.49 | -13.5337 | 17.6 | 314.005 |
| -57.2276 | 1.6 | 321.361 | -33.0141 | -1.6 | 322.978 | -7.1821 | -3.2 | 329.585 |

The events (one event = one row) in the file are already selected by requiring a signal in the TOP and MIDDLE chambers.
For each chamber you can find the x,y coordinate (in cm) and the time (in ns) of the passing particle. When no signal was detected from the BOTTOM chamber, the corresponding cells are left empty.

In total there 4000 events.
In the simple approach you can count (hint) the number of full cells in any of the column belonging to the BOTTOM chamber, and divide for the total number of event.
Try do it. What is the result?

But, is it a correct measurement of the efficiency?

# Exercises 4: selection cut

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

Detectable particles passing through the detector

Particle detectors are not universal, and can have different sensitivity (or no sensitivity) to different types of particles. In our case, since the reference detector are the same as the one under study, we don’t need to warry about this!

Is a coincidence of TOP and MIDDLE chambers enough to say that a particle is passed through?

If a particle has passed from the reference chambers, are we sure that it has passed also the BOTTOM chamber?

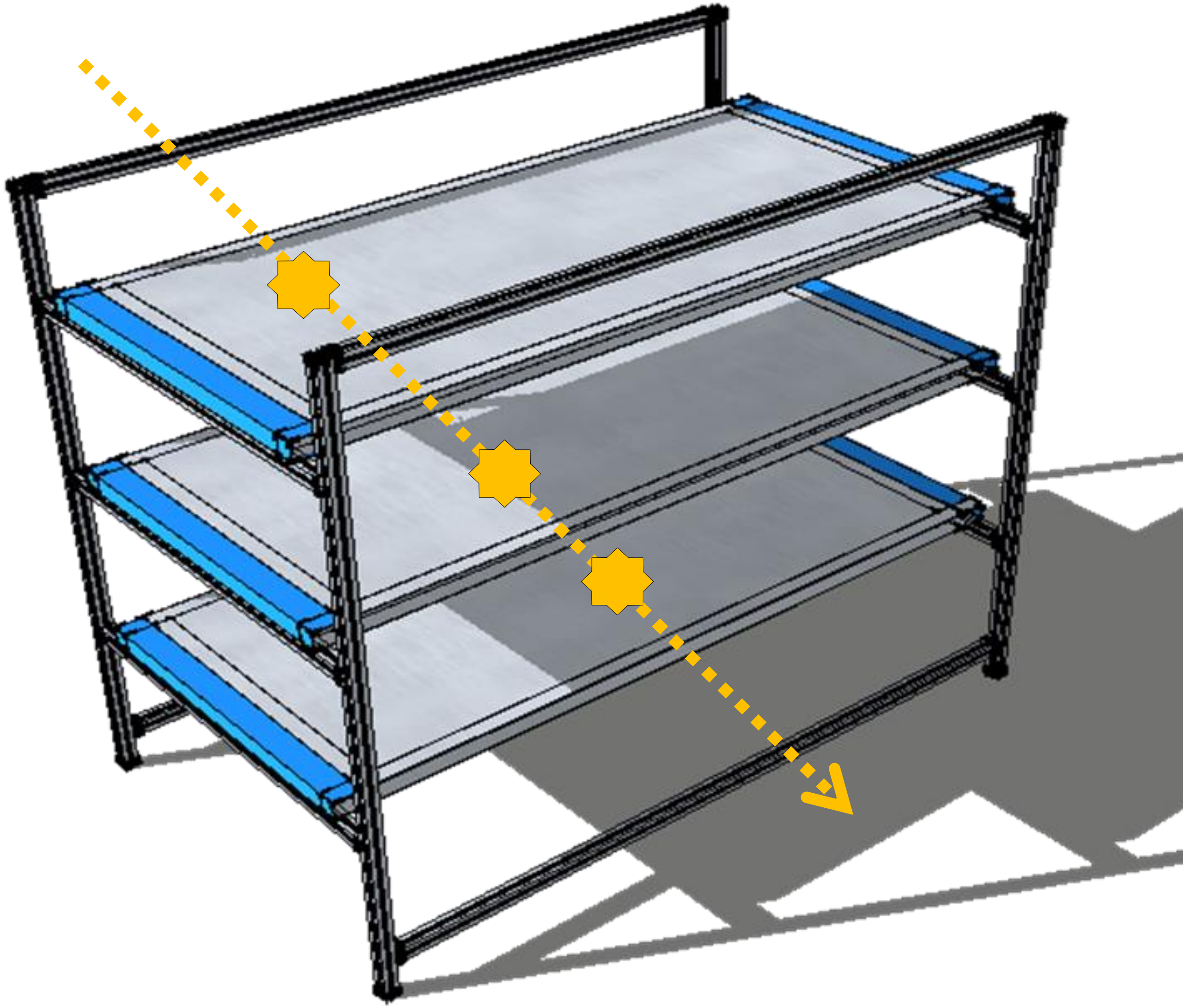
SOLUTION: we must apply selection cuts!

- Time Of Flight
- Geometrical acceptance

# Why 3 chambers?

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…

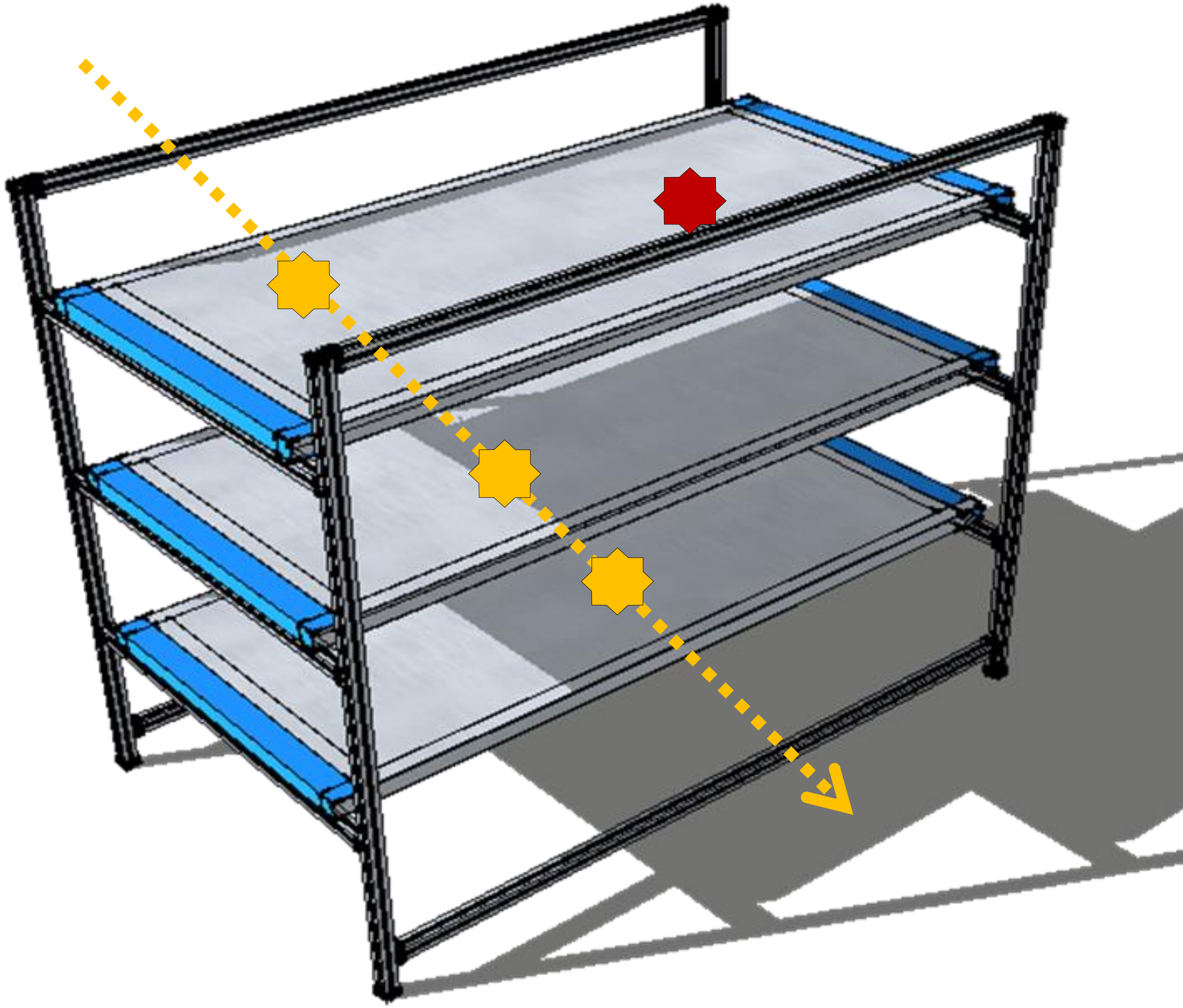


# Noise effect

Inside the chambers take place continuous processes that can mimic the signal generated by the particle. We refer to them as “Noise”.

Many of this signals are blocked by the front-end electronics (the boards at each end of the chamber), which can “discriminate” them on the base of the signal amplitude.

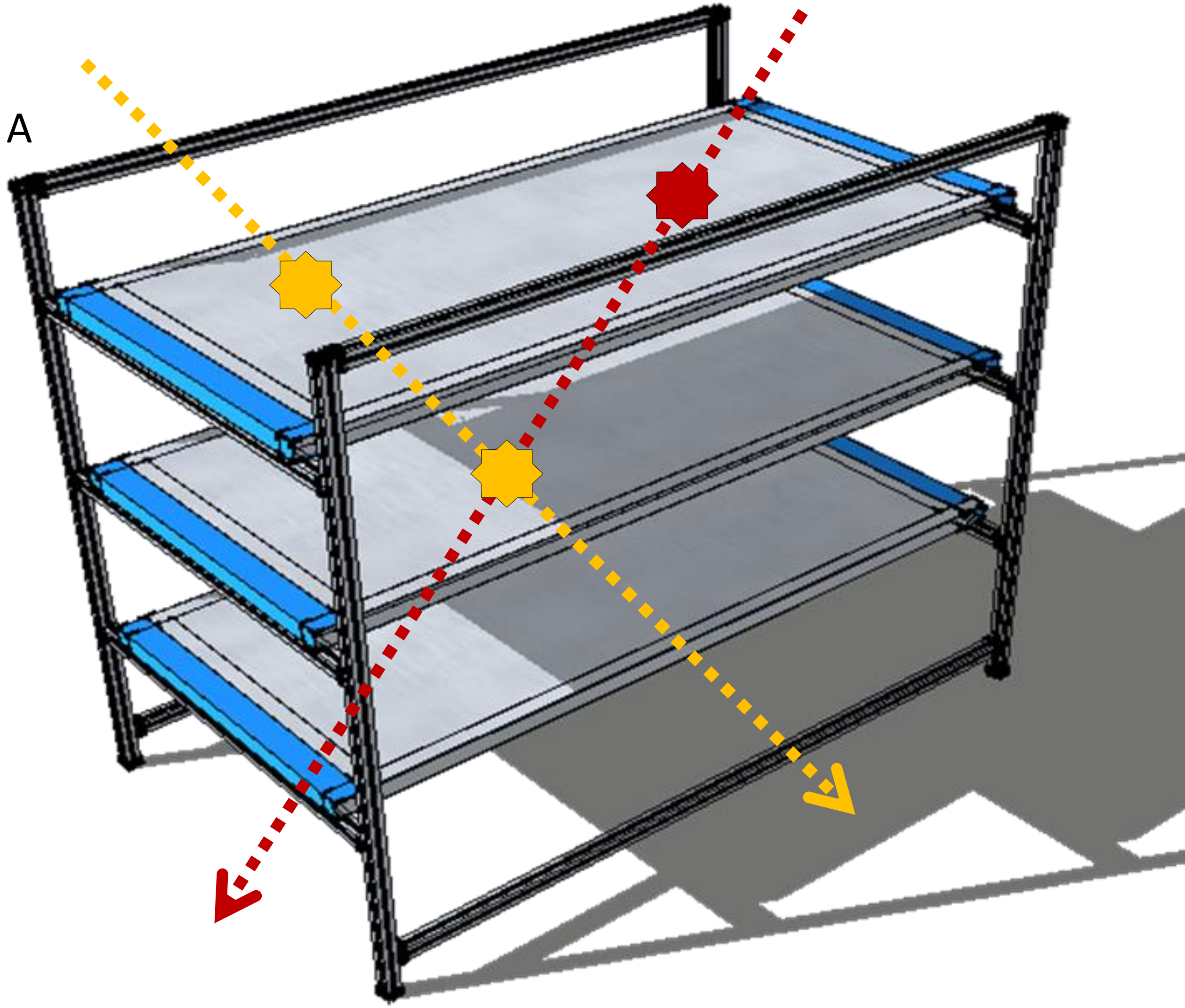
Nevertheless some noise signals can still be accepted and propagated to the acquisition system and to the trigger.

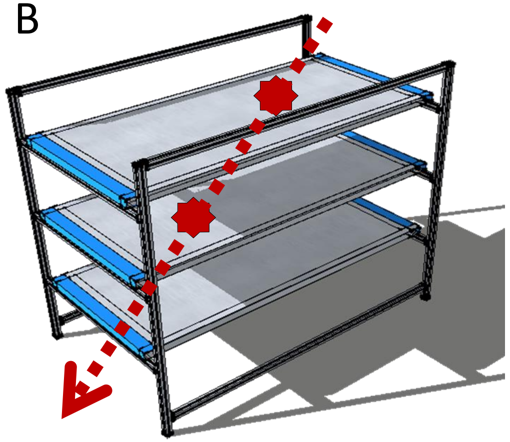


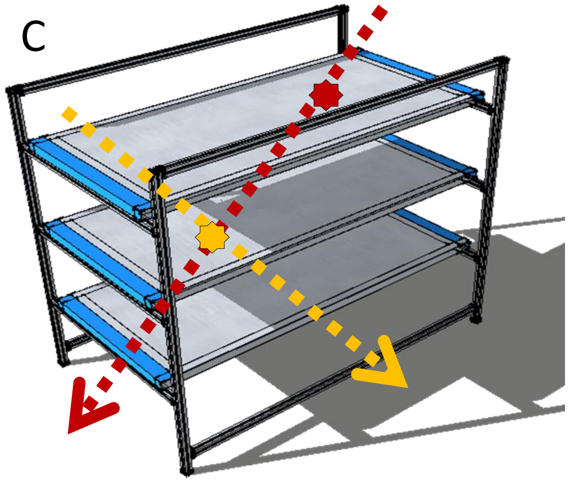
# Noise effect

A double chamber layout will no more be able to correctly reconstruct the particle!

Also other combination can occur..




~10-200 Hz

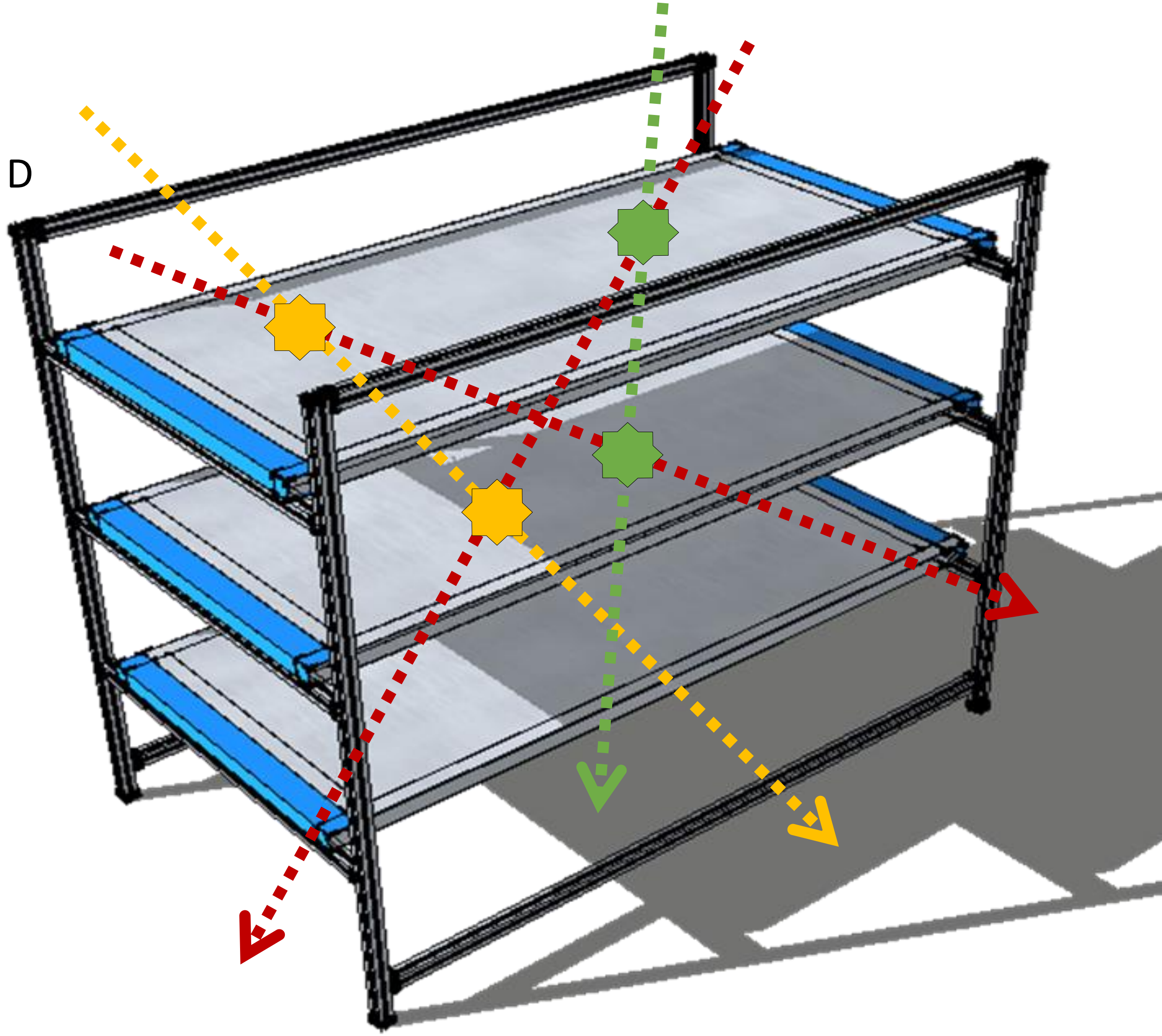
# Multitrack & ghosts

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 ”ghost”

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



# Selection cuts: TOF

| TOP chamber | | | MID chamber | | | BOT chamber | | |
|---|---|---|---|---|---|---|---|---|
| x(cm) | y(cm) | T(ns) | x(cm) | y(cm) | T(ns) | x(cm) | y(cm) | T(ns) |
| 17.9251 | -27.2 | 306.524 | 11.2496 | -8 | 308.209 | 7.6462 | 11.2 | 309.193 |
| 70.5312 | -4.8 | 323.459 | 61.2329 | 4.8 | 324.372 | 53.4228 | 12.8 | 332.931 |
| 26.1964 | 11.2 | 309.349 | 36.4901 | -24 | 310.837 | | | |
| -68.6036 | 1.6 | 294.337 | -62.7971 | 17.6 | 294.618 | -58.0305 | 32 | 296.991 |
| -51.3658 | -17.6 | 303.613 | -19.1575 | 11.2 | 306.401 | | | |
| -46.8154 | -1.6 | 311.743 | -29.9805 | 8 | 312.49 | -13.5337 | 17.6 | 314.005 |
| -57.2276 | 1.6 | 321.361 | -33.0141 | -1.6 | 322.978 | -7.1821 | -3.2 | 329.585 |

| TOF |
|---|
| TOF |
| 3.37 |
| 1.826 |
| 2.976 |
| 0.562 |
| 5.576 |
| 1.494 |
| 3.234 |

First event selection already performed for you:

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

This selection get rid of several events seen in the previous slides, but not all of them (i.e. B and C)!

The position of the hit will not help us (there is always one track for two point), but what about the time?

SOLUTION: you can compute the TOF (Time Of Flight) of the particle between the two upper chambers and check if it is compatible with a particle going downward with a speed close to the speed of light.

# Selection cuts: geometrical acceptance

Some particles detected from the reference chambers can actually miss the third chambers, or be out of “acceptance”. This does not happen when the chamber under study is the middle.

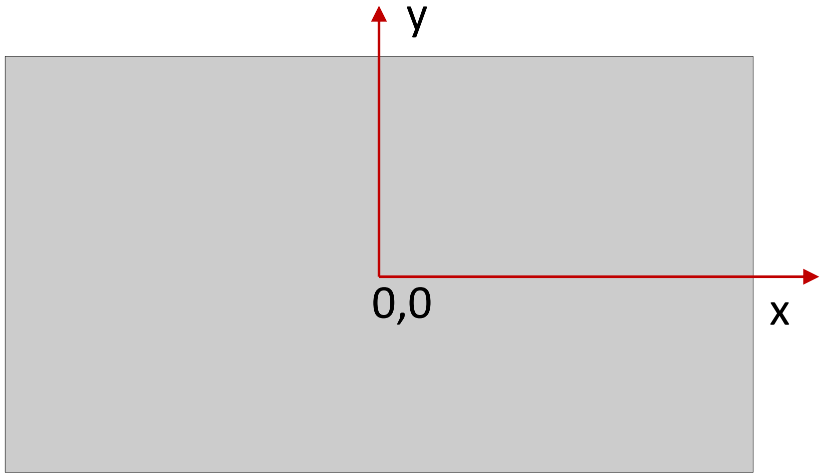
This lead to a second cut that must be applied to the events -> geometrical acceptance cut.

It is easy to compute the projected particle coordinates in the bottom chamber. Such theoretical intercept tell us if the particle crossed the bottom chamber.

Hint: gap between two chambers is constant (50 cm)

Sensitive area of the chamber:
$-70 < x < 70$ cm
$-38 < y < 38$ cm

Take this number as a guideline, you can see what happen if you change them!




| BOT extrapolation | | |
|---|---|---|
| x(cm) | y(cm) | T(ns) |
| 4.5741 | 11.2 | 309.894 |
| 51.9346 | 14.4 | 325.285 |
| 46.7838 | -59.2 | 312.325 |
| -56.9906 | 33.6 | 294.899 |
| 13.0508 | 40 | 309.189 |
| -13.1456 | 17.6 | 313.237 |
| -8.8006 | -4.8 | 324.595 |

# Definition of “detected”

A “noise” hit can be present also in the bottom chamber, artificially biasing (this time toward an higher value) the measured efficiency. So how should we define the “detected” particle?

Solution: check if the hit measured with in the bottom chamber is where excepted.
You can use the “residuals”. A residual id the difference between the theoretical intercept point and the measured one. It can be applied to every quantity (space, time, …)

Hint: you have already computed the track projection in the bottom chamber. The residuals in x and y can be computed either independently or as a radial distance.

Cut suggestion: the spatial resolution of our telescope is ~2 cm. A radial cut of ~10 cm can do the job. Can you explain this last number on the base of spatial resolution? As before, you can play with this value and see the effect on the efficiency measurement.

| OP chamber | | MID chamber | | | BOT chamber | | | BOT extrapolation | | | Residuals | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| y(cm) | T(ns) | x(cm) | y(cm) | T(ns) | x(cm) | y(cm) | T(ns) | x(cm) | y(cm) | T(ns) | Dx | Dy | Dt | Radial res |
| -27.2 | 306.52 | 11.25 | -8 | 308.21 | 7.6462 | 11.2 | 309.19 | 4.5741 | 11.2 | 309.89 | -3.072 | 0 | 0.701 | 3.0721 |
| -4.8 | 323.46 | 61.233 | 4.8 | 324.37 | 53.423 | 12.8 | 332.93 | 51.935 | 14.4 | 325.29 | -1.488 | 1.6 | -7.646 | 2.1851 |
| 11.2 | 309.35 | 36.49 | -24 | 310.84 | | | | 46.784 | -59.2 | 312.33 | | | | |
| 1.6 | 294.34 | -62.8 | 17.6 | 294.62 | -58.03 | 32 | 296.99 | -56.99 | 33.6 | 294.9 | 1.0399 | 1.6 | -2.092 | 1.9082 |
| -17.6 | 303.61 | -19.16 | 11.2 | 306.4 | | | | 13.051 | 40 | 309.19 | | | | |
| -1.6 | 311.74 | -29.98 | 8 | 312.49 | -13.53 | 17.6 | 314.01 | -13.15 | 17.6 | 313.24 | 0.3881 | 0 | -0.768 | 0.3881 |

# Exercise 4: summary

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1. Calculate the efficiency of the BOTTOM chamber with the simple approach
2. Compute the TOF of the particle using the TOP and MIDDLE chambers information. Apply a quality cut.
3. Compute the projection of the particle on the BOTTOM chamber. Check if projection is within the geometrical acceptance of the BOTTOM chamber
4. Compute the residuals and check compatibility of the measured hit in the bottom w.r.t. to the projection
5. Calculate again the efficiency applying one or more of the previous cuts

| TOP chamber | | | MID chamber | | | BOT chamber | | | BOT extrapolation | | | Residuals | | | | TOF |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| x(cm) | y(cm) | T(ns) | x(cm) | y(cm) | T(ns) | x(cm) | y(cm) | T(ns) | x(cm) | y(cm) | T(ns) | Dx | Dy | Dt | Radial res | TOF |
| 17.925 | -27.2 | 306.52 | 11.25 | -8 | 308.21 | 7.6462 | 11.2 | 309.19 | 4.5741 | 11.2 | 309.89 | -3.072 | 0 | 0.701 | 3.0721 | 3.37 |
| 70.531 | -4.8 | 323.46 | 61.233 | 4.8 | 324.37 | 53.423 | 12.8 | 332.93 | 51.935 | 14.4 | 325.29 | -1.488 | 1.6 | -7.646 | 2.1851 | 1.826 |
| 26.196 | 11.2 | 309.35 | 36.49 | -24 | 310.84 | | | | 46.784 | -59.2 | 312.33 | | | 1 | 1000 | 2.976 |
| -68.6 | 1.6 | 294.34 | -62.8 | 17.6 | 294.62 | -58.03 | 32 | 296.99 | -56.99 | 33.6 | 294.9 | 1.0399 | 1.6 | | 1.9082 | 0.562 |
| -51.37 | -17.6 | 303.61 | -19.16 | 11.2 | 306.4 | | | | 13.051 | 40 | 309.19 | | | | 1000 | 5.576 |
| -46.82 | -1.6 | 311.74 | -29.98 | 8 | 312.49 | -13.53 | 17.6 | 314.01 | -13.15 | 17.6 | 313.24 | 0.3881 | 0 | -0.768 | 0.3881 | 1.494 |
| -57.23 | 1.6 | 321.36 | -33.01 | -1.6 | 322.98 | -7.182 | -3.2 | 329.59 | -8.801 | -4.8 | 324.6 | -1.619 | -1.6 | -4.99 | 2.2759 | 3.234 |

| Selection cuts | | | Quality cuts | |
|---|---|---|---|---|
| TOF | Acceptance | TOF+ACC | Radial res | BOT not empty |
| 1 | 1 | 1 | 1 | 1 |
| 1 | 1 | 1 | 1 | 1 |
| 1 | 0 | 0 | 0 | 0 |
| 1 | 1 | 1 | 1 | 1 |
| 1 | 0 | 0 | 0 | 0 |
| 1 | 1 | 1 | 1 | 1 |
| 1 | 1 | 1 | 1 | 1 |

Suggested procedure:

- ➢ Calculate relevant quantities (extrapolation, residuals, TOF)
- ➢ Generate columns to store the result of the cut (0=rejected, 1 passed)
- ➢ The DEN and NUM values can then be computed by summing the values in the corresponding column.

# Additional suggestions



=IF(OR(J6="",G6=""),"",J6-G6)

| E | F | G | H | I | J | K | L | M | N | O | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| D chamber | | BOT chamber | | | BOT extrapolation | | | Residuals | | | |
| y(cm) | T(ns) | x(cm) | y(cm) | T(ns) | x(cm) | y(cm) | T(ns) | Dx | Dy | Dt | R |
| -8 | 308.21 | 7.6462 | 11.2 | 309.19 | 4.5741 | 11.2 | 309.89 | -3.072 | 0 | 0.701 | |
| 4.8 | 324.37 | 53.423 | 12.8 | 332.93 | 51.935 | 14.4 | 325.29 | -1.488 | 1.6 | -7.646 | |
| -24 | 310.84 | | | | 46.784 | -59.2 | 312.33 | =IF(OR(J | | | |
| 17.6 | 294.62 | -58.03 | 32 | 296.99 | -56.99 | 33.6 | 294.9 | 1.0399 | 1.6 | -2.092 | |
| 11.2 | 306.4 | | | | 13.051 | 40 | 309.19 | | | | |
| 8 | 312.49 | -13.53 | 17.6 | 314.01 | -13.15 | 17.6 | 313.24 | 0.3881 | 0 | -0.768 | |
| -1.6 | 322.98 | -7.182 | -3.2 | 329.59 | -8.801 | -4.8 | 324.6 | -1.619 | -1.6 | -4.99 | |

# Additional suggestions

| Q | R | S | T | U | V |
|---|---|---|---|---|---|
| TOF | Selection cuts | | | Quality cuts | |
| TOF | TOF | Acceptance | TOF+ACC | Radial res | BOT not empty |
| 3.37 | =IF(AND(Q4<$Z$22, Q4>$Z$23),1,0) | | | 1 | 1 |
| 1.826 | IF(logical_test, [value_if_true], [value_if_false]) | | | | 1 |
| 2.976 | 1 | 0 | 0 | 0 | 0 |
| 0.562 | 1 | 1 | 1 | 1 | 1 |
| 5.576 | 1 | 0 | 0 | 0 | 0 |
| 1.494 | 1 | 1 | 1 | 1 | 1 |
| 3.234 | 1 | 1 | 1 | 1 | 1 |

=IF(AND(Q4<$Z$22, Q4>$Z$23),1,0)

Z22 and Z23 are de cells which contain the upper and lower limit of the TOF

# Additional suggestions

| | Selection cuts | | | Quality cuts | | DEN | NUM |
|---|---|---|---|---|---|---|---|
| | TOF | Acceptance | TOF+ACC | Radial res | BOT not empty | | |
| 37 | 1 | 1 | 1 | 1 | 1 | =R4*S4*U4*V4 | |
| 26 | 1 | 1 | 1 | 1 | 1 | | |
| 76 | 1 | 0 | 0 | 0 | 0 | | |
| 62 | 1 | 1 | 1 | 1 | 1 | | |
| 76 | 1 | 0 | 0 | 0 | 0 | | |
| 34 | 1 | 1 | 1 | 1 | 1 | | |
| 34 | 1 | 1 | 1 | 1 | 1 | | |

At the end, just sum the values in the column “NUM” and divide by the sum of the column “DEN”

# Final remarks

Be careful when applying cuts. All the cuts applied to the NUM, must be applied also to the DEN! IF an event is discarded by a selection cut it must be also discarded in the computation of the “detected events”.

Few final (optional) questions:

Which cut rise the efficiency and which instead lower it?
What is the impact of each cut, how much the final measure is affected?
Which one is the most relevant?
Can you suggest other cuts that must/should applied?

What can you tell us about the uncertainty of the measure?
How the procedure followed and the choice of the cut parameter affect the measure?
They can be reduced by increasing the number of collected events?

Enjoy!