MASTERCLASS

Correlation of cosmic-rays flux and pressure

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POLAR QUEST 1928 2018
Extreme Energy Events
Science Inside Schools

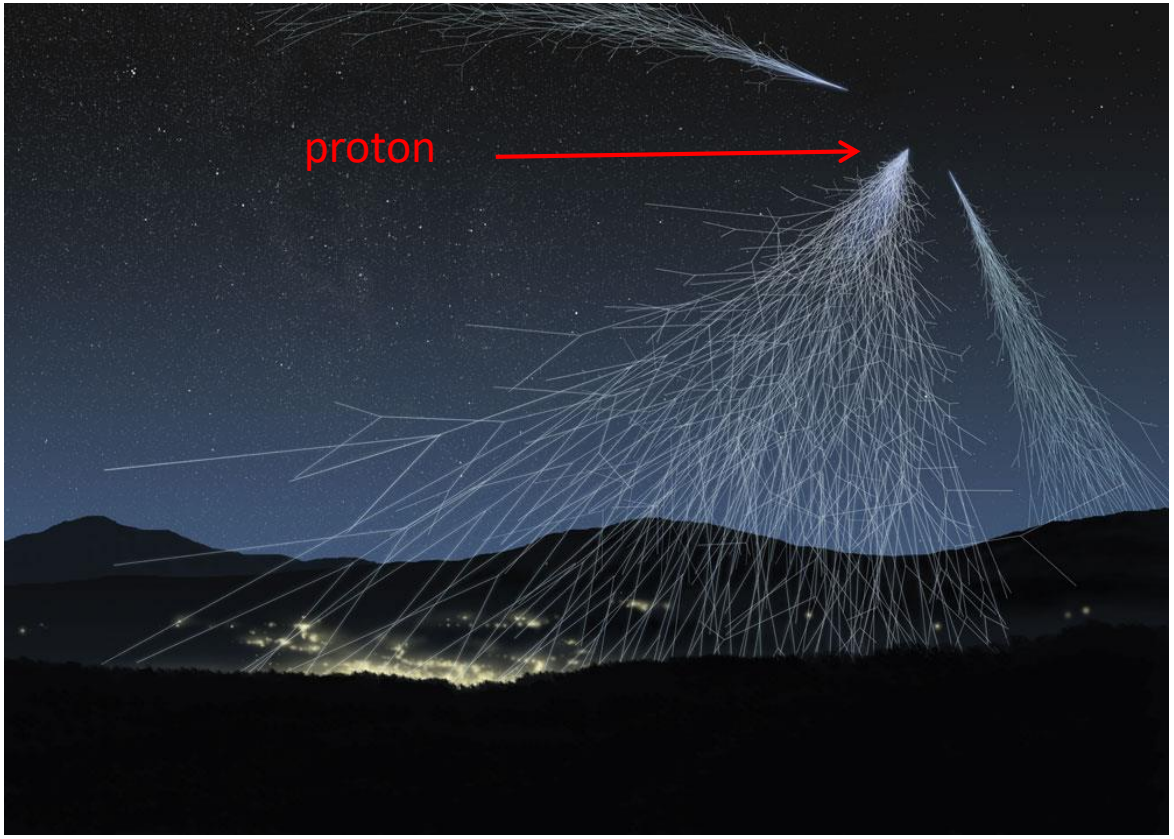
A Cosmic Ray shower

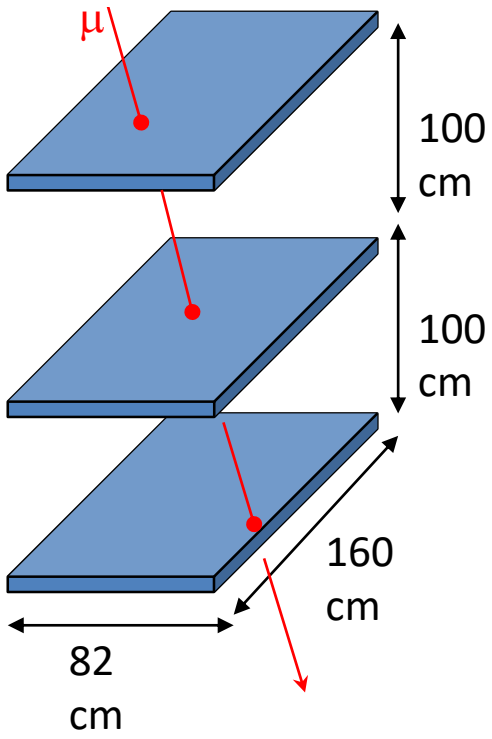
Cosmic rays are high-energy particles originating outside the Solar system.

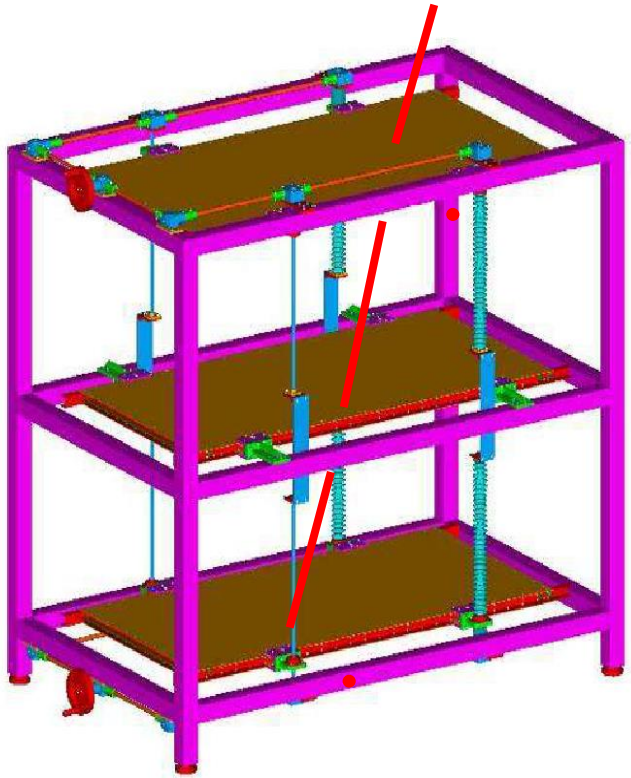
They are mainly composed of protons but also light nuclei are present.

When a primary cosmic ray interacts with the atmosphere starts to produce many other particles (secondaries) which propagate close to the initial direction of the primary
→ Shower development.

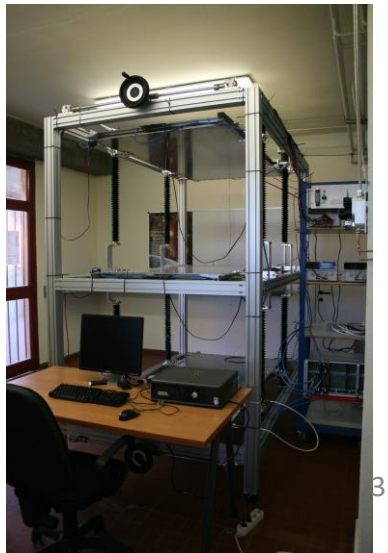
At ground we observe a flux of charge particles of about
1 per cm^2 per minute (mainly muons).







The EEE telescope geometry
An EEE telescope is realized by the combination of three chambers (MRPC).
If a muon goes through all the three chambers a signal is released in each one allowing the reconstruction of its trajectory.



The EEE station

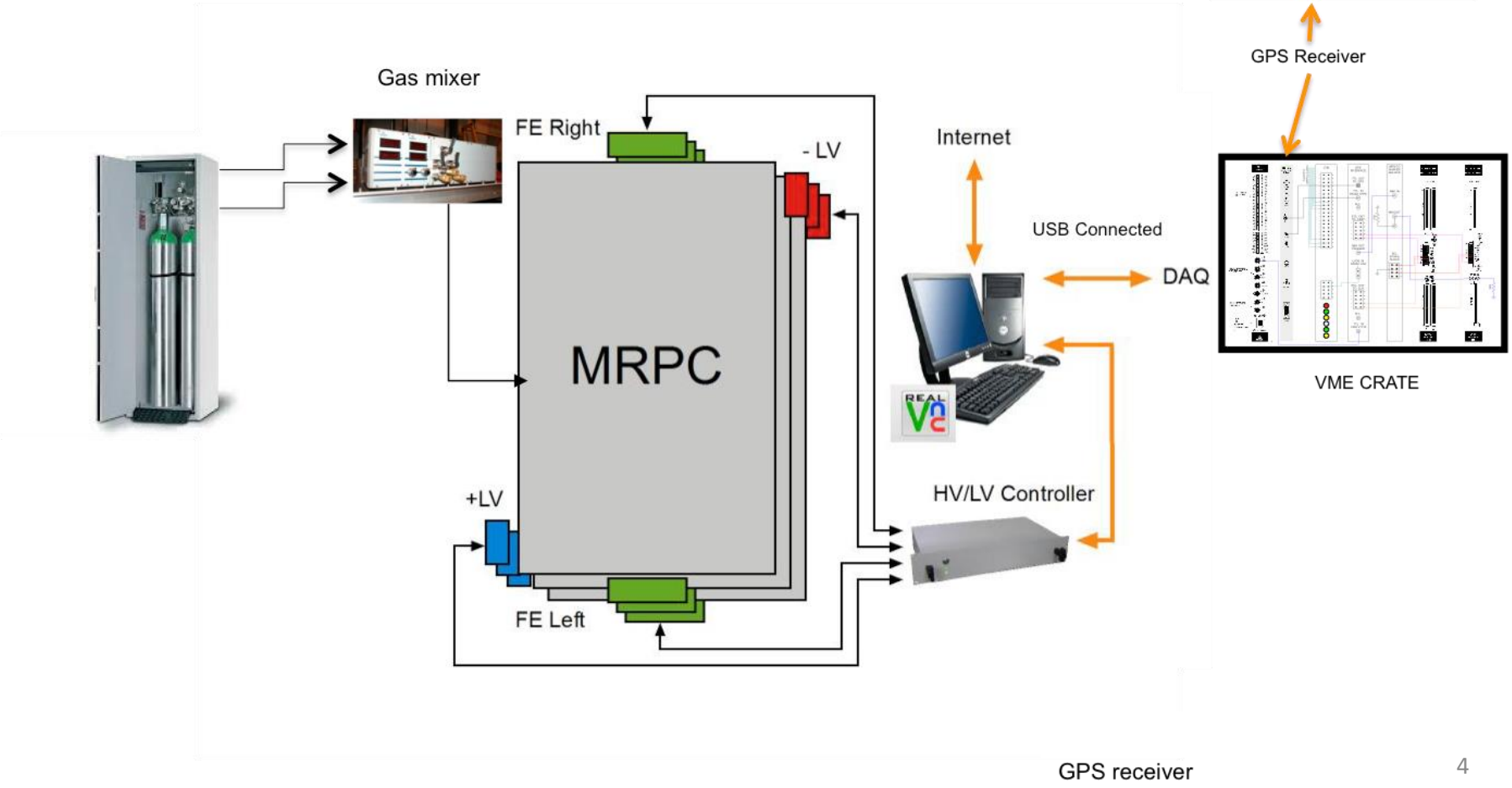
The EEE station

An EEE station is composed by:

A telescope (+ gas system + electronics) → to trigger and reconstruct the muon trajectory

A GPS Receiver → to associate a time to the event with high precision

A Desktop PC where the Data Acquisition software is running



What we can 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.

Data Quality Monitor (DQM)

Before to analyze data we need to be sure that the quality is good.

1.we can check if the data we are acquiring are of "good" quality…

2.Take action if they are not!

…to do this, we should analyze the data locally or…use a centralized procedure → DQM

The EEE Project DQM

Extreme Energy Events Monitor

Ultimo aggiornamento: ore 15:21 - ven 12 dicembre 2014

ELOGBOOK delle SCUOLE | ELOGBOOK dello SHIFTER | Stato trasmissione CNAF

EEE Main Monitoring Table

Questa tabella mostra la situazione dei telescopi in acquisizione
In **verde** sono indicati i telescopi in presa dati e trasferimento nelle ultime 4 ore.
In **giallo** sono indicati i telescopi in cui trasferimento e/o acquisizione sono sospesi da più di 4 ore.
In **rosso** sono indicati i telescopi in cui trasferimento e/o acquisizione sono sospesi da più di un giorno.

Scuola	Giorno	Ora	Nome dell'ultimo File trasferito	Numero Files trasferiti oggi	Ultima Entr nell'e-logbo delle Scuole	Report giornaliero DQM	RATE of iggers r the st Run in DQM	RATE of Tracks for the last Run in DQM	Link DQM
ALTA-01	mer 10 dicembre	08:06	ALTA-01-2014-12-10-00020.bin	20 [History]	10:56 21/11/2014	11/12 [History]	27.4	21.0	ALTA-01
BARI-01	ven 12 dicembre	15:06	BARI-01-2014-12-12-00024.bin	24 [History]	09:59 06/12/2014	12/12 [History]	21.7	18.8	BARI-01
BOLO-01	ven 12 dicembre	15:02	BOLO-01-2014-12-12-00024.bin	26 [History]		12/12 [History]	47.4	26.9	BOLO-01
BOLO-03	gio 11 dicembre	18:08	BOLO-03-2014-12-11-00054.bin	54 [History]	13:22 12/12/2014	12/12 [History]	40.2	29.6	BOLO-03
CAGL-01	ven 12 dicembre	15:07	CAGL-01-2014-12-12-00020.bin	20 [History]	08:25 11/12/2014	12/12 [History]	18.8	15.5	CAGL-01
CAGL-02	ven 12 dicembre	14:48	CAGL-02-2014-12-12-00044.bin	44 [History]	12:01 03/12/2014	12/12 [History]	37.9	33.3	CAGL-02

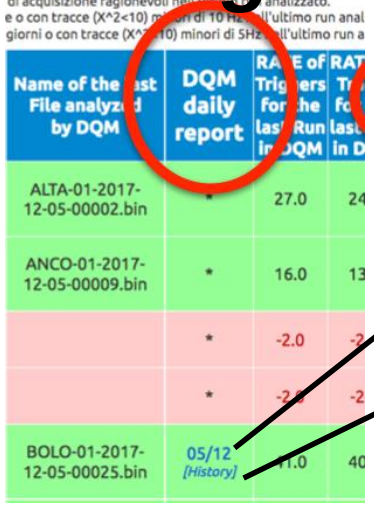
We will have soon also the polar statistics in the same page!!!!!!!

Link: eee.centrofermi.it/monitor

DQM daily report

Information are reported day by day!

The EEE Project DQM-Report giornaliero



Name of the File analyzed by DQM	DQM daily report	RATE of Triggers for the last Run in DQM	RAT... for the last ... in D...
ALTA-01-2017-12-05-00002.bin	*	27.0	24
ANCO-01-2017-12-05-00009.bin	*	16.0	13
	*	-2.0	-2
	*	-2.0	-2
BOLO-01-2017-12-05-00025.bin	05/12 [History]	11.0	40

Once per day relevant summary plot are automatically produced

And you have some history too

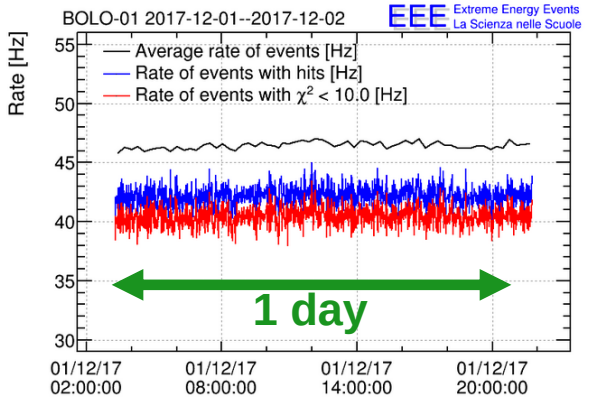
BOLO-01 Daily Report History

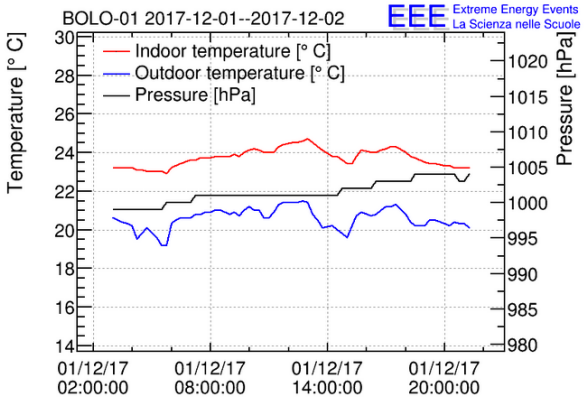
2018-05-21	2018-05-19	2018-05-18	2018-05-17	2018-05-16
2018-05-15	2018-05-14	2018-05-13	2018-05-12	2018-05-11
2018-05-10	2018-05-09	2018-05-08	2018-05-07	2018-05-06
2018-05-05	2018-05-04	2018-05-03	2018-05-02	2018-05-01
2018-04-30	2018-04-29	2018-04-28	2018-04-27	2018-04-26
2018-04-25	2018-04-24	2018-04-21	2018-04-20	2018-04-19
2018-04-18	2018-04-17	2018-04-16	2018-04-15	2018-04-14
2018-04-13	2018-04-12	2018-04-11	2018-04-10	2018-04-09
2018-04-08	2018-04-07	2018-04-06	2018-04-05	2018-04-04
2018-04-03	2018-04-02	2018-04-01	2018-03-31	2018-03-30
2018-03-29	2018-03-28	2018-03-27	2018-03-26	2018-03-25
2018-03-24	2018-03-23	2018-03-22	2018-03-21	2018-03-20
2018-03-19	2018-03-07	2018-03-06	2018-03-05	2018-03-04
2018-03-03	2018-03-02	2018-03-01	2018-02-28	2018-02-27
2018-02-26	2018-02-25	2018-02-24	2018-02-23	2018-02-22
2018-02-21	2018-02-20	2018-02-19	2018-02-18	2018-02-17

What if you choose one of them?

The EEE Project
DQM-Daily Report

EEE DQM summary report





SUMMARY

- Station: BOLO-01
- Time period: 2017-12-01--2017-12-02
- Number of runs processed: 65
- Total number of events: 3079214
- Number of events with hits: 2797984
- Number of events with a track: 2681009
- Data files: root, csv header, csv trending, csv weather

Set of trending files

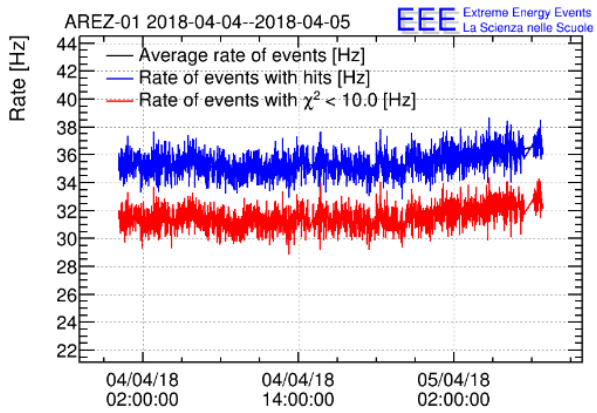
The files we will analyze

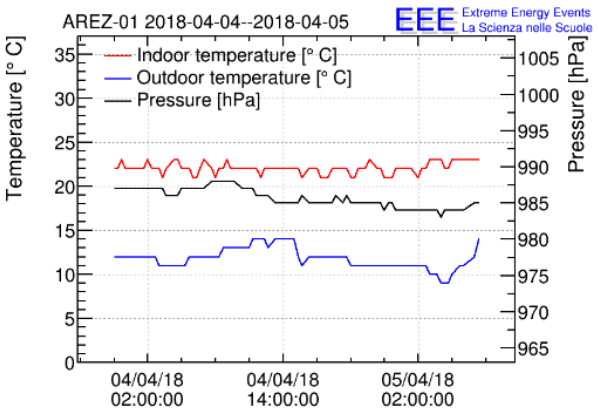
PLOT
RunDuration
NumEvents
AverageRate
NumTrackEvents
NumMalformedEvents
NumBackwardEvents
NumNoHitsEvents
NumNoHitEvents
RateHitEvents
RateTrackEvents
FractionTrackEvents
IndoorTemperature
OutdoorTemperature
Pressure

Set of trending plots…click and see

Daily data

EEE DQM summary report





SUMMARY

- Station: AREZ-01
- Time period: 2018-04-04--2018-04-05
- Number of runs processed: 86
- Total number of events: 4037606
- Number of events with hits: 4036590
- Number of events with a track: 3594300
- Data files: root, csv header, csv trending, csv weather

Available infos:

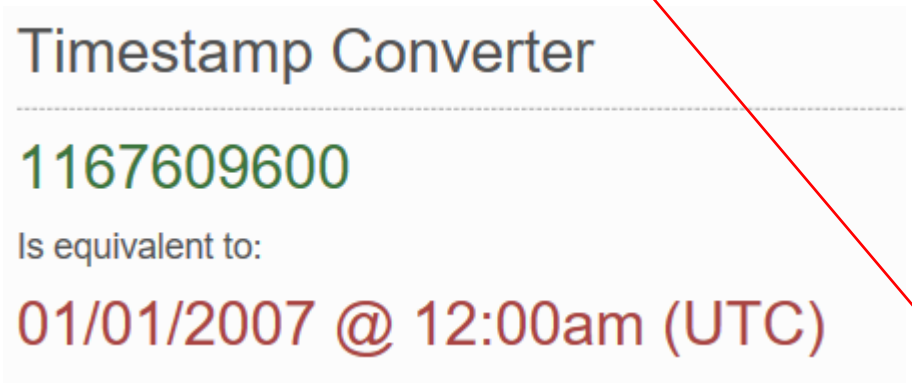
- Time (timestamp)
- Rates
- Pressure
- Temperature IN
- Temperature OUT

Data are available in two formats (ROOT and CSV).
Trending info → how observables (flux rate, temperature, pressure, …) evolve with time.

Our time reference system

Event time is reported in terms of seconds elapsed since a given time reference (timestamp). Usually the reference for the Unix timestamp is taken on the 1st January 1970 (https://www.unixtimestamp.com/index.php).

In our case we take the reference at the 1st January 2007 (when EEE started to take data).



The correspondence between EEE and Unix time stamp is very simple. The 0 time in EEE corresponds to a unix timestamp of 1167609600 s!

In general to convert the EEE timestamp in a date you need to follow two steps.

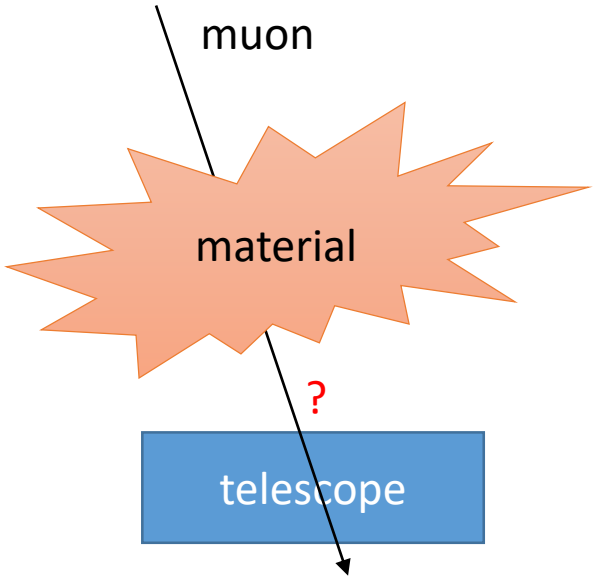
1) Converting it in a Unix timestamp simply adding the offset.
2) Converting the Unix timestamp by using a service on the web

Let’s move to the our topic
→ CR flux-pressure correlation

Why we expect the pressure influences the measured flux?

We want to understand the effect of the matter in front of our telescope.

What do we expect?



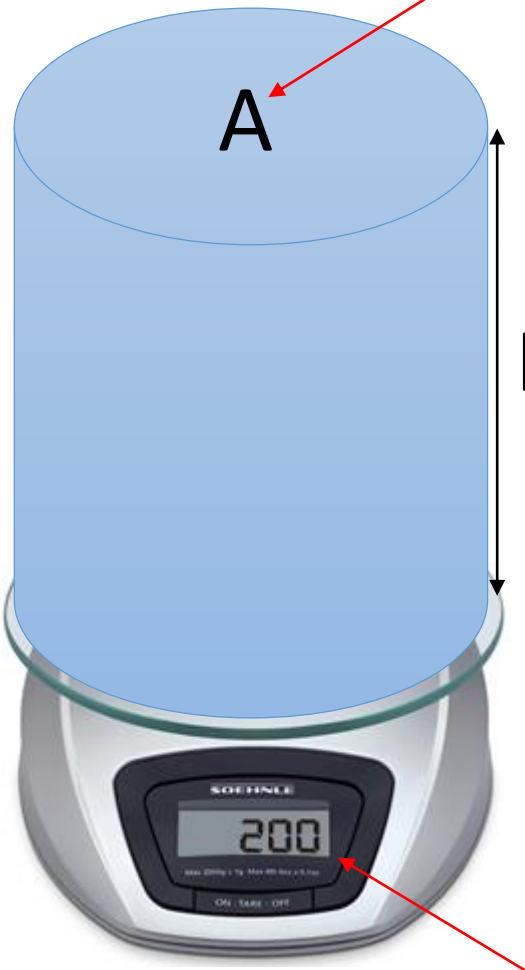
If we put some matter in front of our telescope the muon may be absorbed during its propagation in the material → we expect to reduce the arrival probability to the telescope.

→ Pressure is an indirect measurement of the matter above our telescope.

Why we want to measure it?
The variation in the cosmic ray flux can be a signature of particular phenomena we are interested to: solar activity, change in the geomagnetic field (i.e. polar!).
To quantify such effects we need to be sure that external conditions (i.e. pressure) don't influence our measurement, otherwise we need to correct for know effects.

Pressure

ρ = density = M_{block} / V



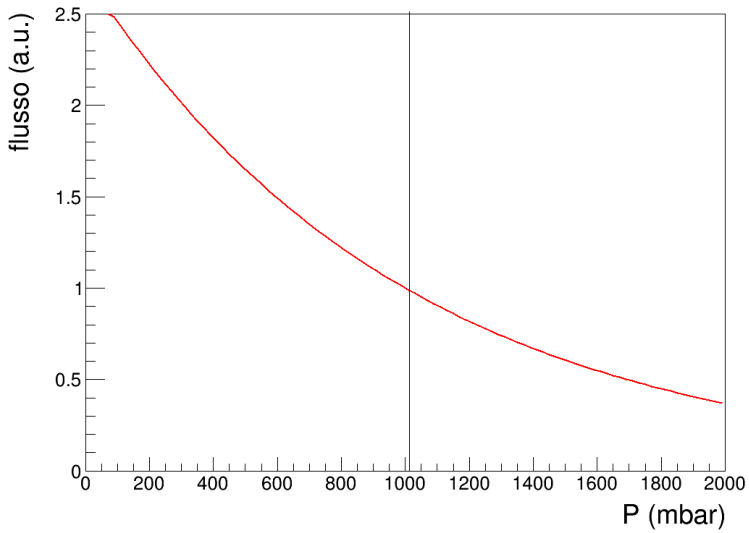
The pressure is proportional to the amount of matter weights on an unit surface.
Then it depends on the matter density and on the height of the block.

→ We can use the pressure measurement to measure the amount of matter above our head → the amount of matter seen by the muon in its propagation!

Weight= mg = ρ**gh**A = **P** x A

The absorption law (I)

$$\text{flusso}(P) = \text{flusso}(P = 0)\, e^{-\alpha P}$$



Absorption follow an exponential law -> the number of particles which survives after a block of matter decreases exponentially with the amount of matter.
The pressure is proportional to this amount so we expect a flux at ground which depends exponentially on the pressure.

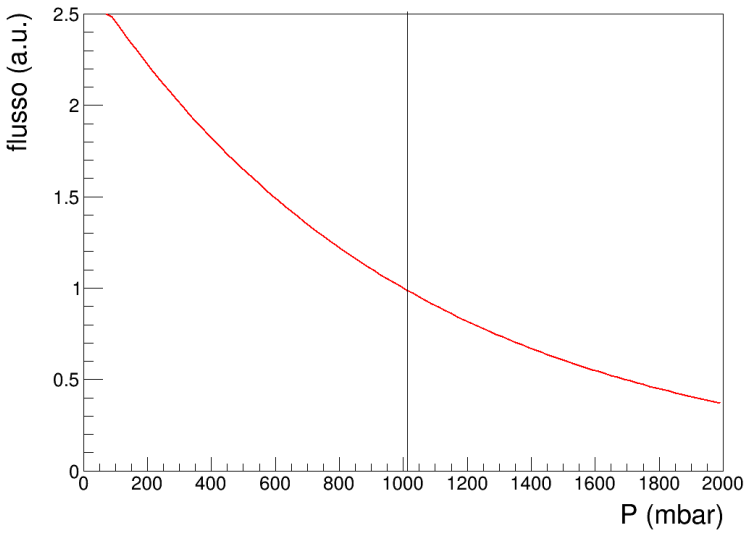
The coefficient in the exponent (α) is called barometric coefficient.

We want to measure it using our telescope network.

Since our measurement is affected also by other effects (for instance by the interaction with the building hosting the telescopes) we would like to test if this coefficient is it the same for all the telescopes or not.

The absorption law (II)

$$flusso(P) = flusso(0)e^{-\alpha P}$$



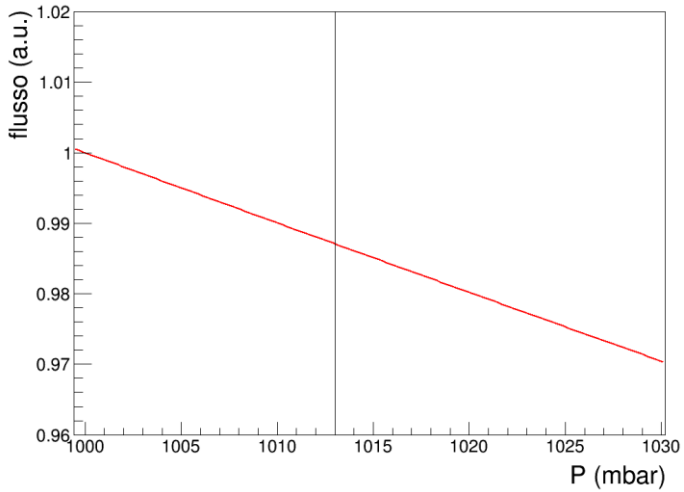
Since P=0 is not a realistic case it is convenient to represent the same law referred to a P_0 physical value (i.e. 1 atm).

$$flusso(P) = flusso(P_0)e^{-\alpha(P-P_0)}$$

We just used the relation:

$$flusso(P_0) = flusso(0)e^{-\alpha P_0}$$

Usually we are collecting data with small variation of pressure around 1 atm.
If we zoom the exponential curve around 1 atm (1013 mbar) the trend looks linear.



For small variation the exponential law can be approximated by:

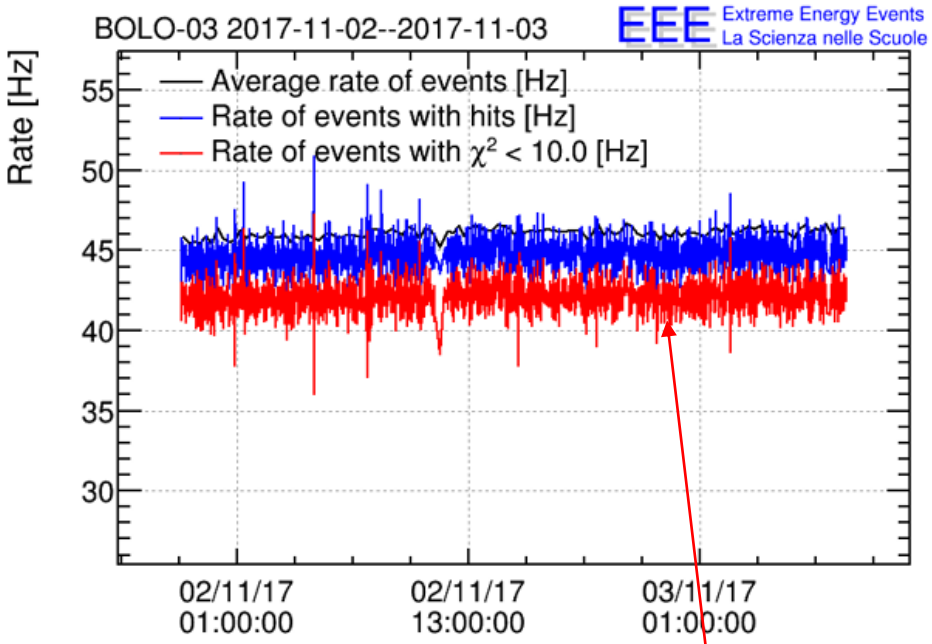
$$\text{flusso}(\text{P}) = \text{flusso}(\text{P} = \text{P}_0 = 1013\,\text{mbar})e^{-\alpha(P-P_0)} =$$
$$= \text{flusso}(\text{P} = \text{P}_0)\cdot(1-\alpha\Delta P)$$

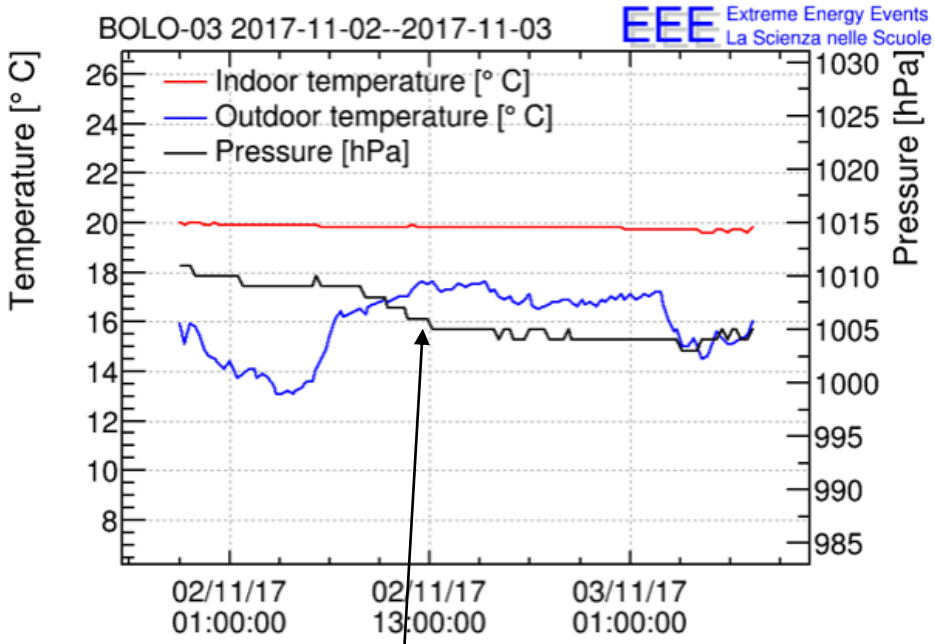
Daily report data

First of all:

- choose a telescope and a day
- check that the data are good
- The pressure variation is high enough (>10 mbar)

1 hPa = 1 mbar





The muon flux (number of muon per second) can be found for EEE each telescope in the daily report.

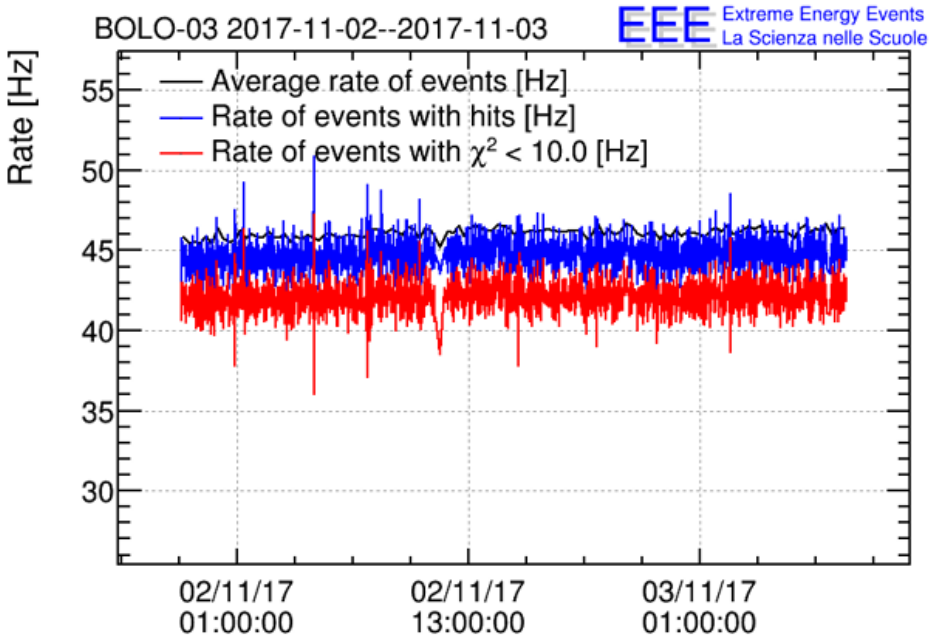
Weather information also available!

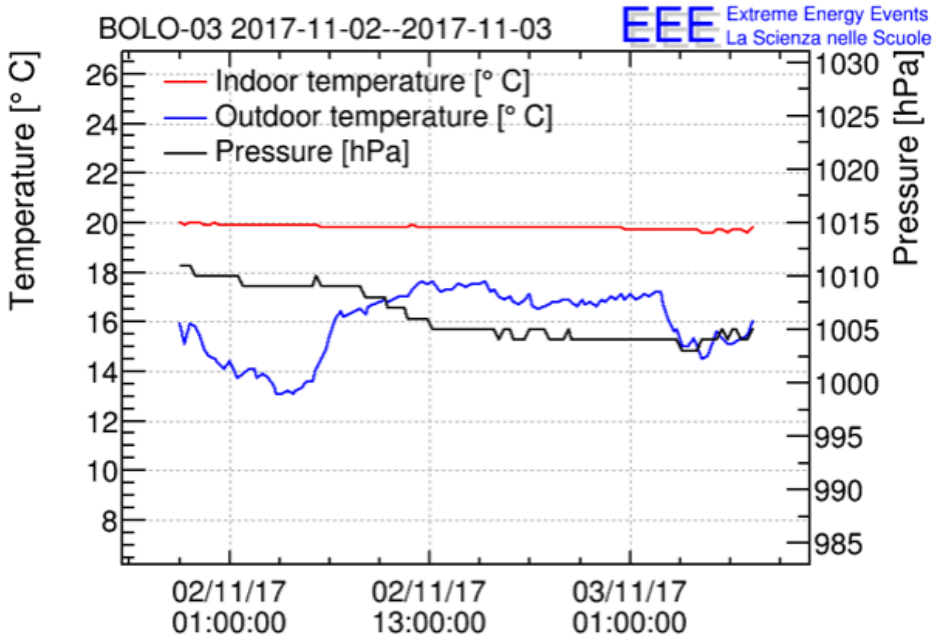
Daily report data

First of all:

- choose a telescope and a day
- check that the data are good
- The pressure variation is high enough (>10 mbar)

1 hPa = 1 mbar

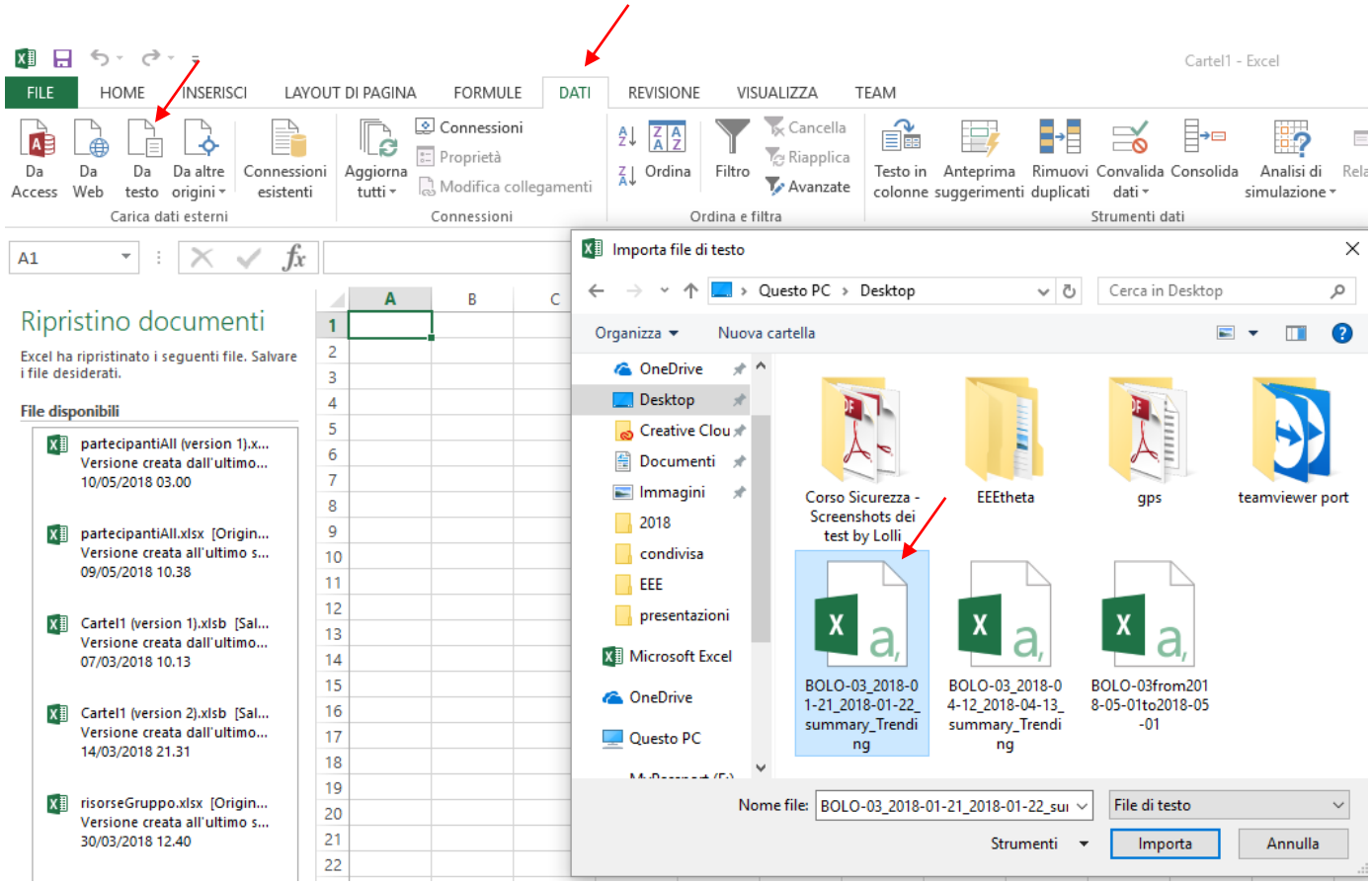




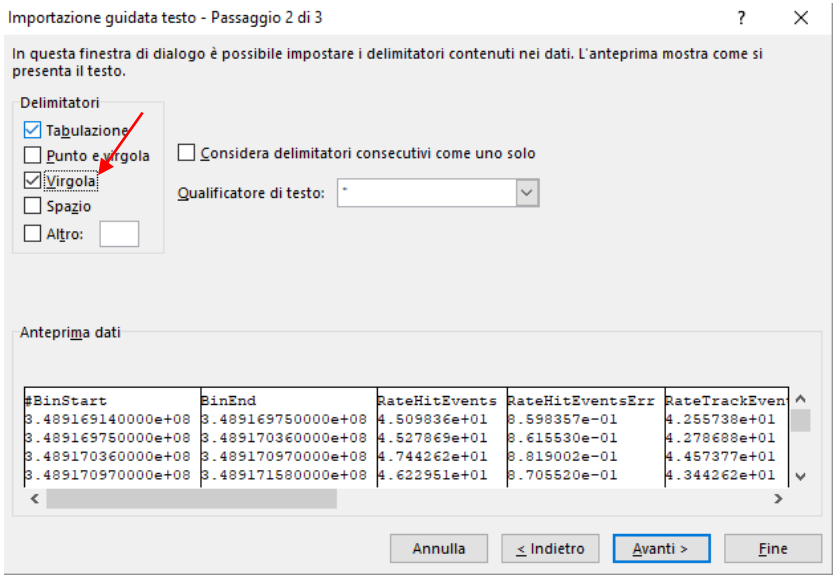
- Number of events with hits: 4036590
- Number of events with a track: 3594300
- Data files: root, csv header, csv trending, csv weather

Then, click to download trending data

Import data in Excel (I)

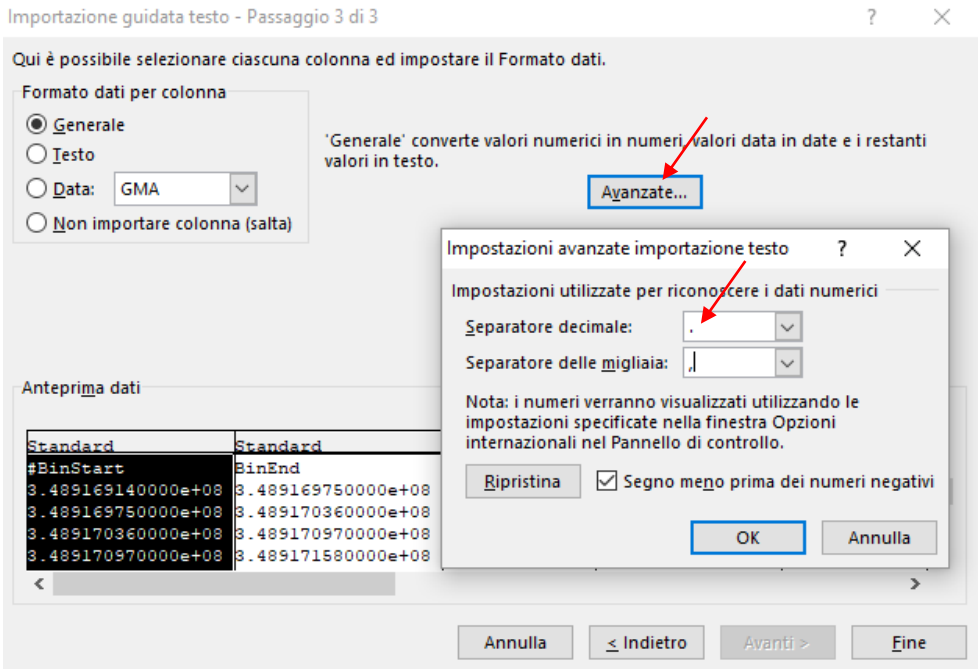


Import data in Excel (II)



Comma separation!

Be sure that decimal separation is set to "."



Import data in Excel (III)

A lot of columns are available. We are interested to few of them

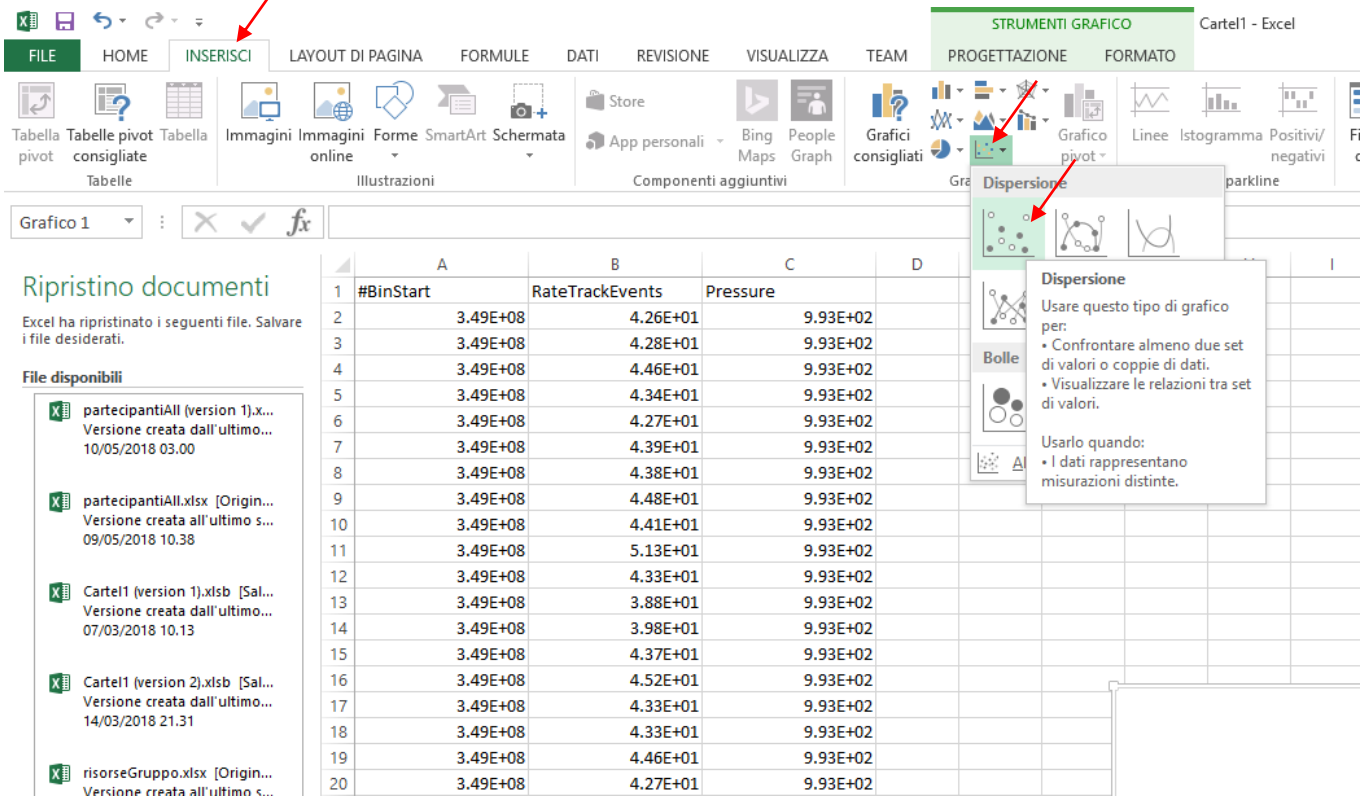
	A	B	C	D	E	F	G	H	I	J	K	L
1	#BinStart	BinEnd	RateHitEvents	RateHitEventsErr	RateTrackEvents	RateTrackEventsErr	FractionTrackEvents	FractionTrackEventsErr	IndoorTemperature	OutdoorTemperature	Pressure	UniqueRunId
2	3.49E+08	3.49E+08	4.51E+01	8.60E-01	4.26E+01	8.35E-01	9.44E-01	4.40E-03	1.62E+01	1.20E+01	9.93E+02	7403800001
3	3.49E+08	3.49E+08	4.53E+01	8.62E-01	4.28E+01	8.38E-01	9.45E-01	4.34E-03	1.62E+01	1.20E+01	9.93E+02	7403800001
4	3.49E+08	3.49E+08	4.74E+01	8.82E-01	4.46E+01	8.55E-01	9.40E-01	4.43E-03	1.62E+01	1.20E+01	9.93E+02	7403800001
5	3.49E+08	3.49E+08	4.62E+01	8.71E-01	4.34E+01	8.44E-01	9.40E-01	4.48E-03	1.62E+01	1.20E+01	9.93E+02	7403800001
6	3.49E+08	3.49E+08	4.55E+01	8.63E-01	4.27E+01	8.37E-01	9.39E-01	4.54E-03	1.62E+01	1.20E+01	9.93E+02	7403800001
7	3.49E+08	3.49E+08	4.70E+01	8.78E-01	4.39E+01	8.49E-01	9.34E-01	4.62E-03	1.62E+01	1.20E+01	9.93E+02	7403800001
8	3.49E+08	3.49E+08	4.66E+01	8.74E-01	4.38E+01	8.47E-01	9.39E-01	4.48E-03	1.62E+01	1.20E+01	9.93E+02	7403800001
9	3.49E+08	3.49E+08	4.82E+01	8.89E-01	4.48E+01	8.57E-01	9.28E-01	4.76E-03	1.62E+01	1.20E+01	9.93E+02	7403800001
10	3.49E+08	3.49E+08	4.71E+01	8.79E-01	4.41E+01	8.51E-01	9.37E-01	4.53E-03	1.62E+01	1.20E+01	9.93E+02	7403800001
11	3.49E+08	3.49E+08	5.43E+01	9.44E-01	5.13E+01	9.17E-01	9.45E-01	3.96E-03	1.62E+01	1.20E+01	9.93E+02	7403800001
12	3.49E+08	3.49E+08	4.58E+01	8.59E-01	4.33E+01	8.35E-01	9.45E-01	4.29E-03	1.62E+01	1.20E+01	9.93E+02	7403800001
13	3.49E+08	3.49E+08	4.13E+01	8.23E-01	3.88E+01	7.98E-01	9.40E-01	4.72E-03	1.62E+01	1.20E+01	9.93E+02	7403800001
14	3.49E+08	3.49E+08	4.23E+01	8.33E-01	3.98E+01	8.07E-01	9.40E-01	4.66E-03	1.62E+01	1.20E+01	9.93E+02	7403800001
15	3.49E+08	3.49E+08	4.63E+01	8.71E-01	4.37E+01	8.47E-01	9.45E-01	4.29E-03	1.62E+01	1.20E+01	9.93E+02	7403800001
16	3.49E+08	3.49E+08	4.77E+01	8.84E-01	4.52E+01	8.61E-01	9.49E-01	4.09E-03	1.62E+01	1.20E+01	9.93E+02	7403800001
17	3.49E+08	3.49E+08	4.58E+01	8.67E-01	4.33E+01	8.42E-01	9.45E-01	4.33E-03	1.62E+01	1.20E+01	9.93E+02	7403800001
18	3.49E+08	3.49E+08	4.61E+01	8.69E-01	4.33E+01	8.43E-01	9.40E-01	4.47E-03	1.62E+01	1.18E+01	9.93E+02	7403800002
19	3.49E+08	3.49E+08	4.77E+01	8.84E-01	4.46E+01	8.55E-01	9.36E-01	4.54E-03	1.62E+01	1.18E+01	9.93E+02	7403800002
20	3.49E+08	3.49E+08	4.58E+01	8.66E-01	4.27E+01	8.37E-01	9.33E-01	4.73E-03	1.62E+01	1.18E+01	9.93E+02	7403800002

Timestamp

Rate of good-quality tracks

Pressure

Have a look to the data

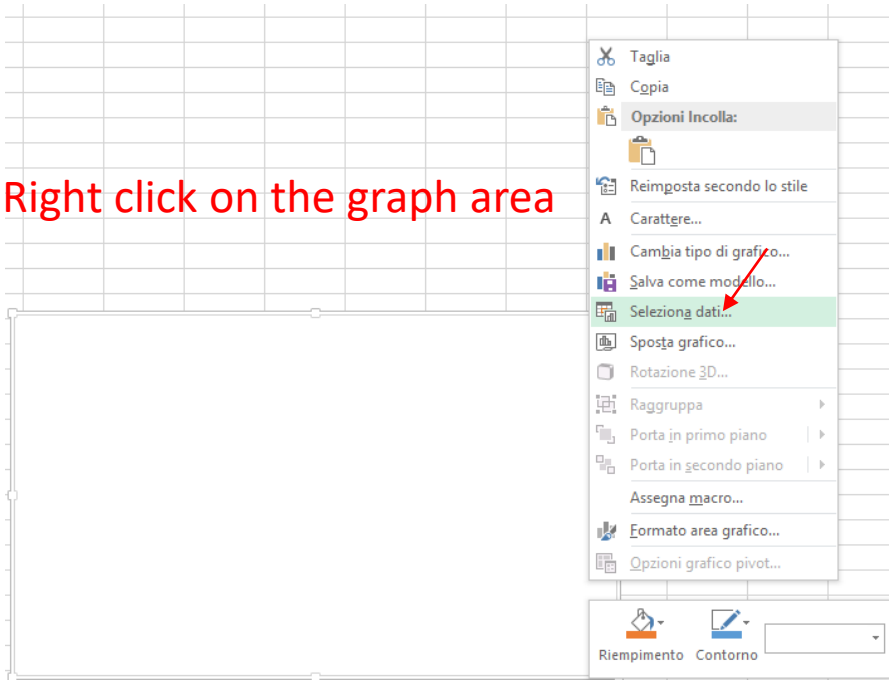


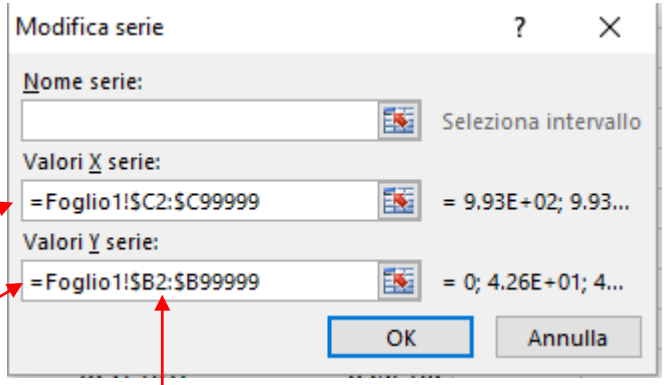
	A	B	C	D
1	#BinStart	RateTrackEvents	Pressure	
2	3.49E+08	4.26E+01	9.93E+02	
3	3.49E+08	4.28E+01	9.93E+02	
4	3.49E+08	4.46E+01	9.93E+02	
5	3.49E+08	4.34E+01	9.93E+02	
6	3.49E+08	4.27E+01	9.93E+02	
7	3.49E+08	4.39E+01	9.93E+02	
8	3.49E+08	4.38E+01	9.93E+02	
9	3.49E+08	4.48E+01	9.93E+02	
10	3.49E+08	4.41E+01	9.93E+02	
11	3.49E+08	5.13E+01	9.93E+02	
12	3.49E+08	4.33E+01	9.93E+02	
13	3.49E+08	3.88E+01	9.93E+02	
14	3.49E+08	3.98E+01	9.93E+02	
15	3.49E+08	4.37E+01	9.93E+02	
16	3.49E+08	4.52E+01	9.93E+02	
17	3.49E+08	4.33E+01	9.93E+02	
18	3.49E+08	4.33E+01	9.93E+02	
19	3.49E+08	4.46E+01	9.93E+02	
20	3.49E+08	4.27E+01	9.93E+02	

We can start by inserting a graph showing the trend of the track rate vs pressure

Select data

Right click on the graph area



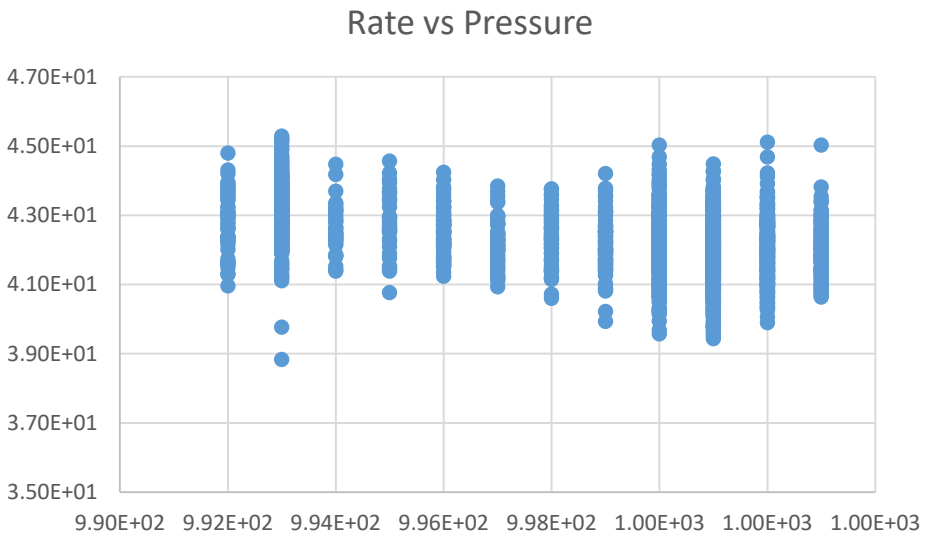


Pressure column

Rate column

We skip the first row

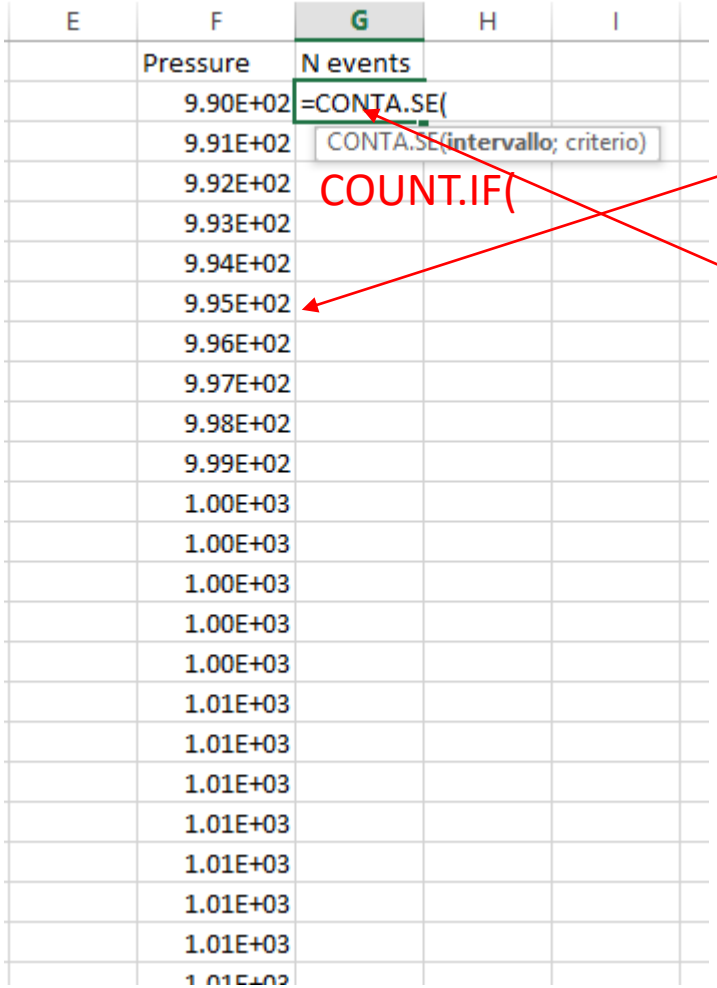
Scatter plot



It is quite difficult to appreciate variation in the flux in a scatter plot because of the large fluctuations (the statistics of each point corresponds to 1 minute of data acquisition)

We are interested to the mean value for a given value of the pressure.

Make a plot with the mean values of the rates



Define a column with the possible value of the pressure

Counts the events with the correspondent value of the pressure:
Interval → Pressure column
Criterion → Correspondent pressure value

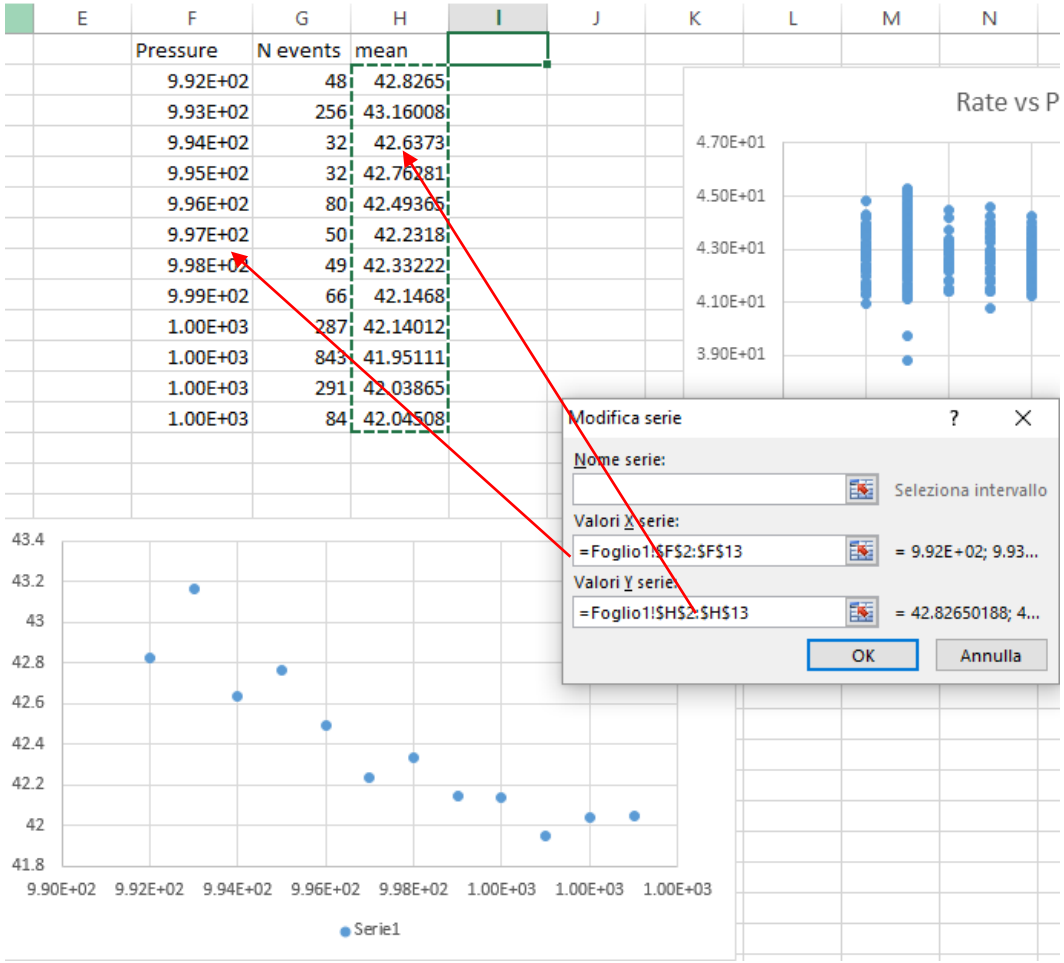
Compute the mean for each value of the pressure

F	G	H	I	J
Pressure	N events	mean		
9.92E+02	48	=SOMMA.SE(C:C;F2;B:B)/G2		
9.93E+02	256	SUM.IF(		
9.94E+02	32			
9.95E+02	32			
9.96E+02	80			
9.97E+02	50			
9.98E+02	49			
9.99E+02	66			
1.00E+03	287			
1.00E+03	843			
1.00E+03	291			
1.00E+03	84			

Sum the value of the rates with the correspondent value of the pressure:
Interval → Pressure column
Criterion → Correspondent pressure value
Sum values → RateTrackEvents column

Then divide for the number of events with that value of pressure

Rate vs Pressure



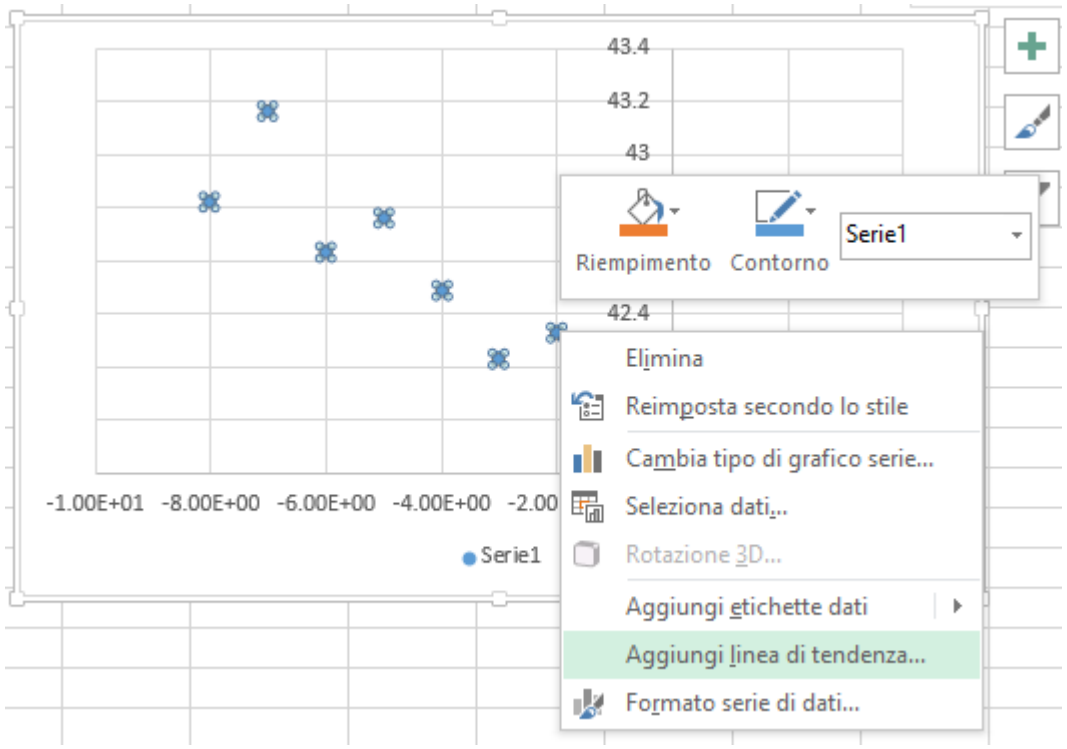
We can make a new graph using the mean value.

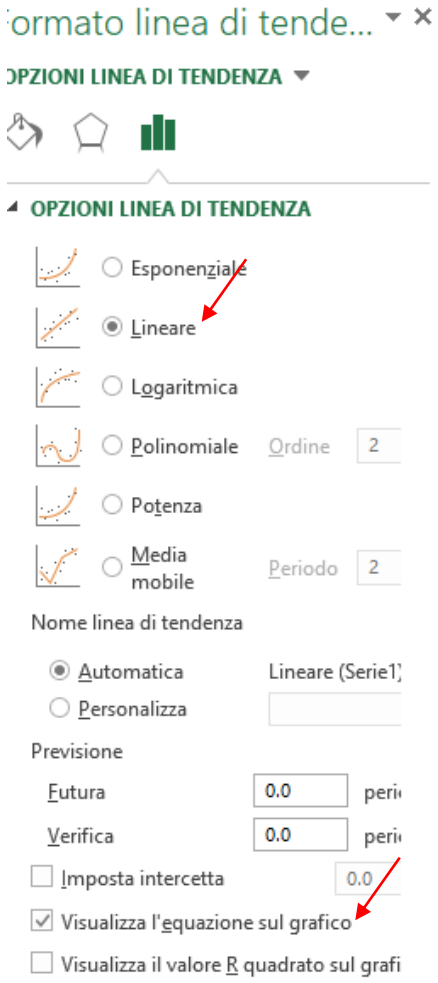
Now we want to extract the barometric coefficient by fitting with a line.

Before to do that we need to have ΔP on the x-axis respect to a realistic reference (1000 mbar is fine)

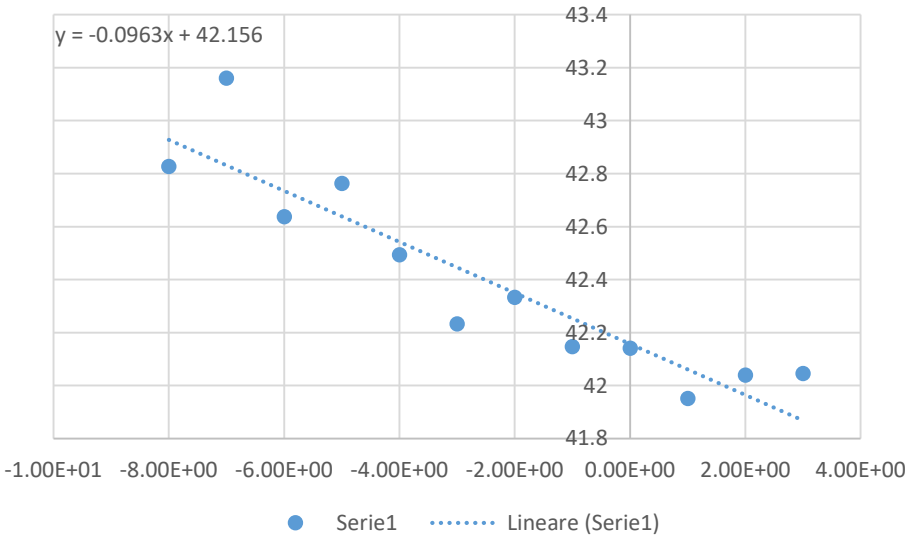
F	G	H	I
Pressure	N events	mean	DeltaP
9.92E+02	48	42.8265	=F2-1000
9.93E+02	256	43.16008	
9.94E+02	32	42.6373	
9.95E+02	32	42.76281	
9.96E+02	80	42.49365	
9.97E+02	50	42.2318	
9.98E+02	49	42.33222	

Perform the fit with a line





Interpretation of the results



Note that with Excel we cannot fit with our original function:

$$flusso(\Delta P) = flusso(P_0)(1 - \alpha \Delta P)$$

But we fitted with:

$$flusso(\Delta P) = a\Delta P + b$$

However we can rearrange the formula used to fit to extract the parameters we are interested to, since the same formula can be rewritten as:

$$flusso(\Delta P) = b\left(1 + \frac{a}{b}\Delta P\right)$$

Now, let's repeat the measurement for different telescopes and period to see how this coefficient change.

So in our case:

$$\alpha = -\frac{a}{b} = -\frac{-0.0963}{42.126} = 0.0023\ mbar^{-1}$$