Status of simulations on discrimination and directionality of nuclear recoils in gas

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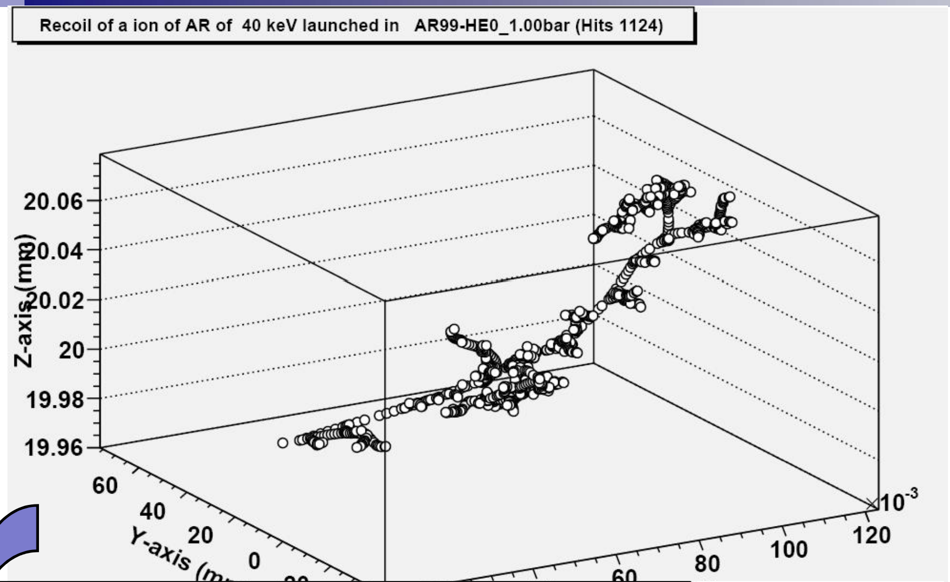
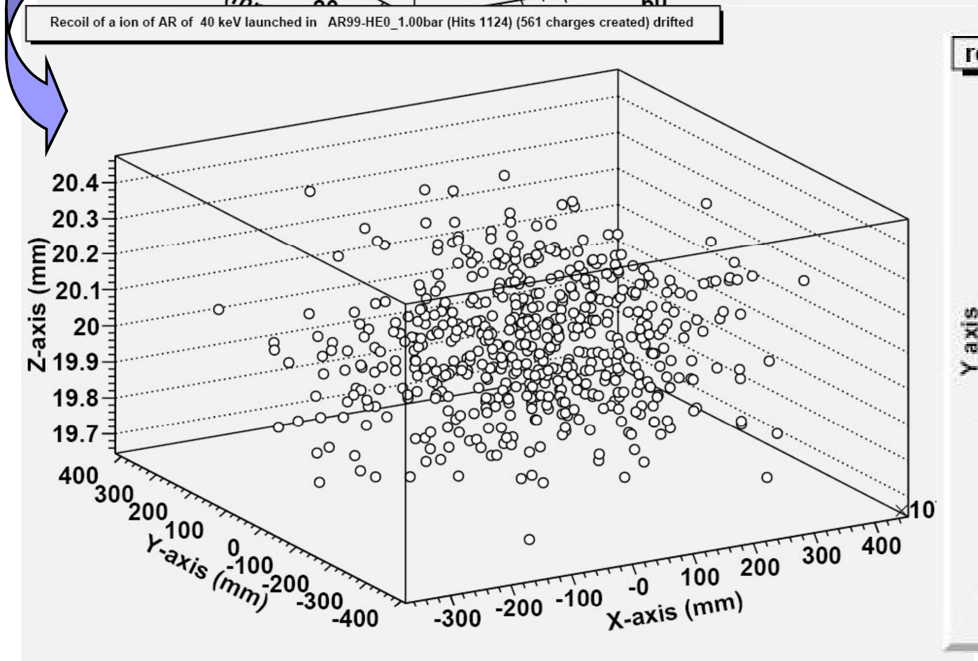
Summary:

- Discrimination between nuclear recoils and electrons (results of gamma background in the gas).
  - Recoils simulated by SRIM2006 (www.srim.org).
  - Electrons simulated by GEANT4 (http://geant4.web.ch) using PENELOPE models included in the package.
  - Drift is put by hand. MAGBOLTZ calculations for gas' drift parameters.
  - Resolution features are like in MicroMegas detector (300 μm pixel is assumed).

- Looking for a head-tail signature of nuclear recoils, before drifting (for the moment) as a start point of our study.
  - Some starting base results for directionality.
  - An algorithm is proposed to determine the sense, and later de direction of the recoil. The effect of drifting over its results to be studied.



2 cm drift



Diffusion is simulated by moving each charge according to a gaussian distribution which has got a width that depends on the height the event has to drift across the chamber:

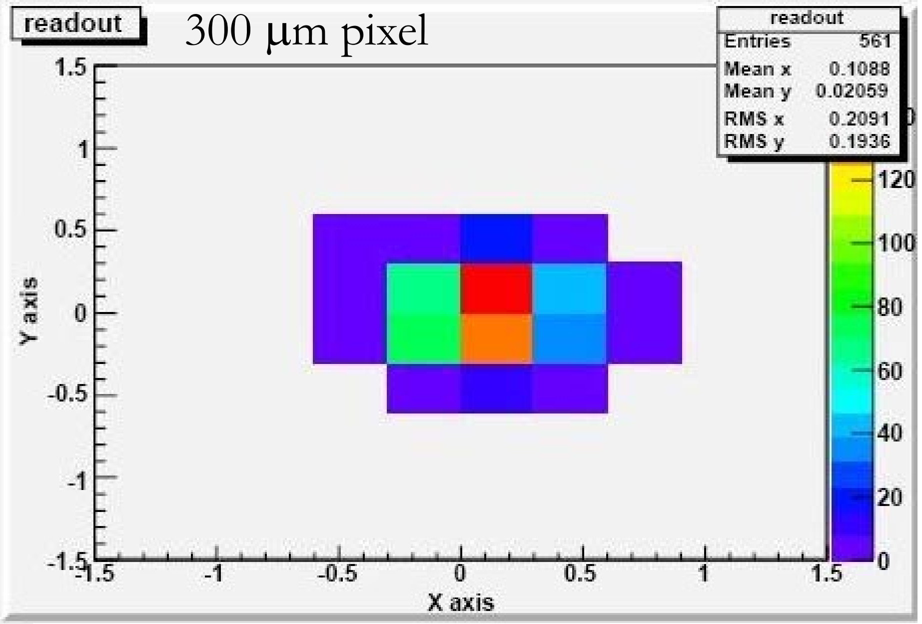
$\sigma = \sigma_0\, d^{1/2}$, d = drifted longitude.

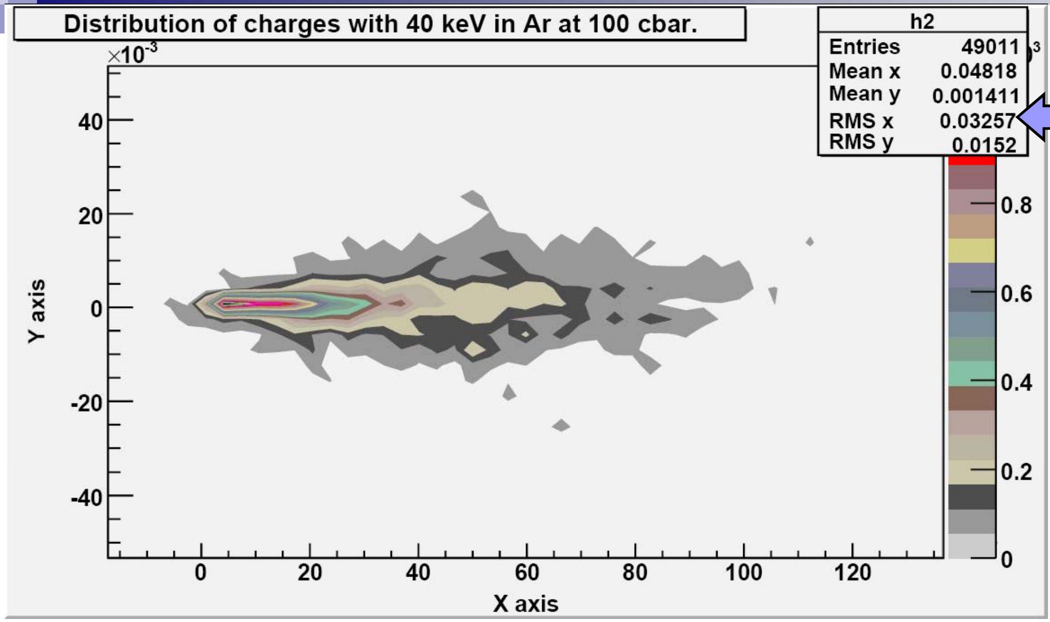
Displacements (in the tree directions) calculated in this way are added to the original position of the charges.

We launch SRIM's single trace simulation, several times in order to construct the whole set of branches of a complete recoil. We stop when a secondary recoil would start with less than 100 eV.

Resolution: a realistic pixel

300 µm pixel

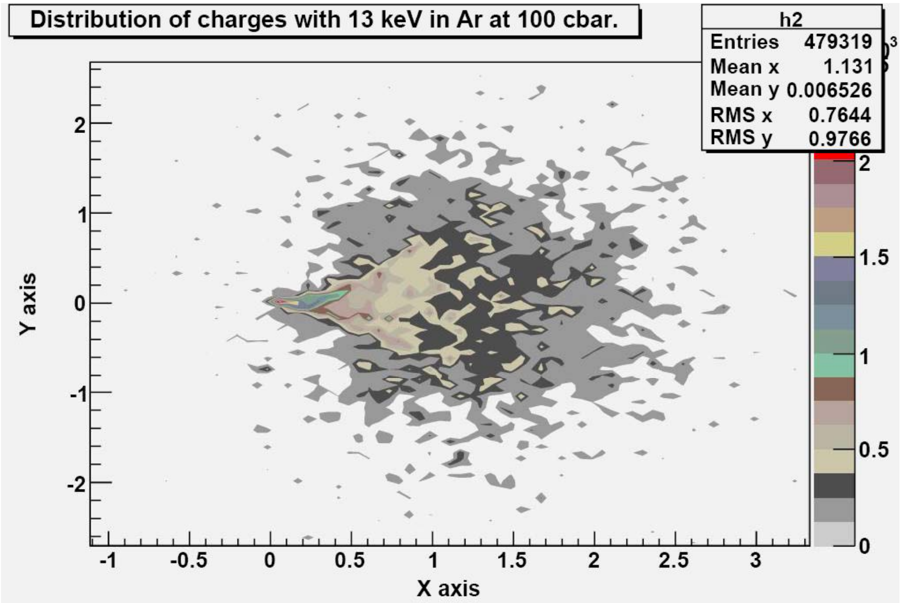




Superposed distributions of generated charge for recoils. A way to visualize its behaviour as a group.

Although different in each particular story, recoils' behaviour as a whole can easily be characterized.

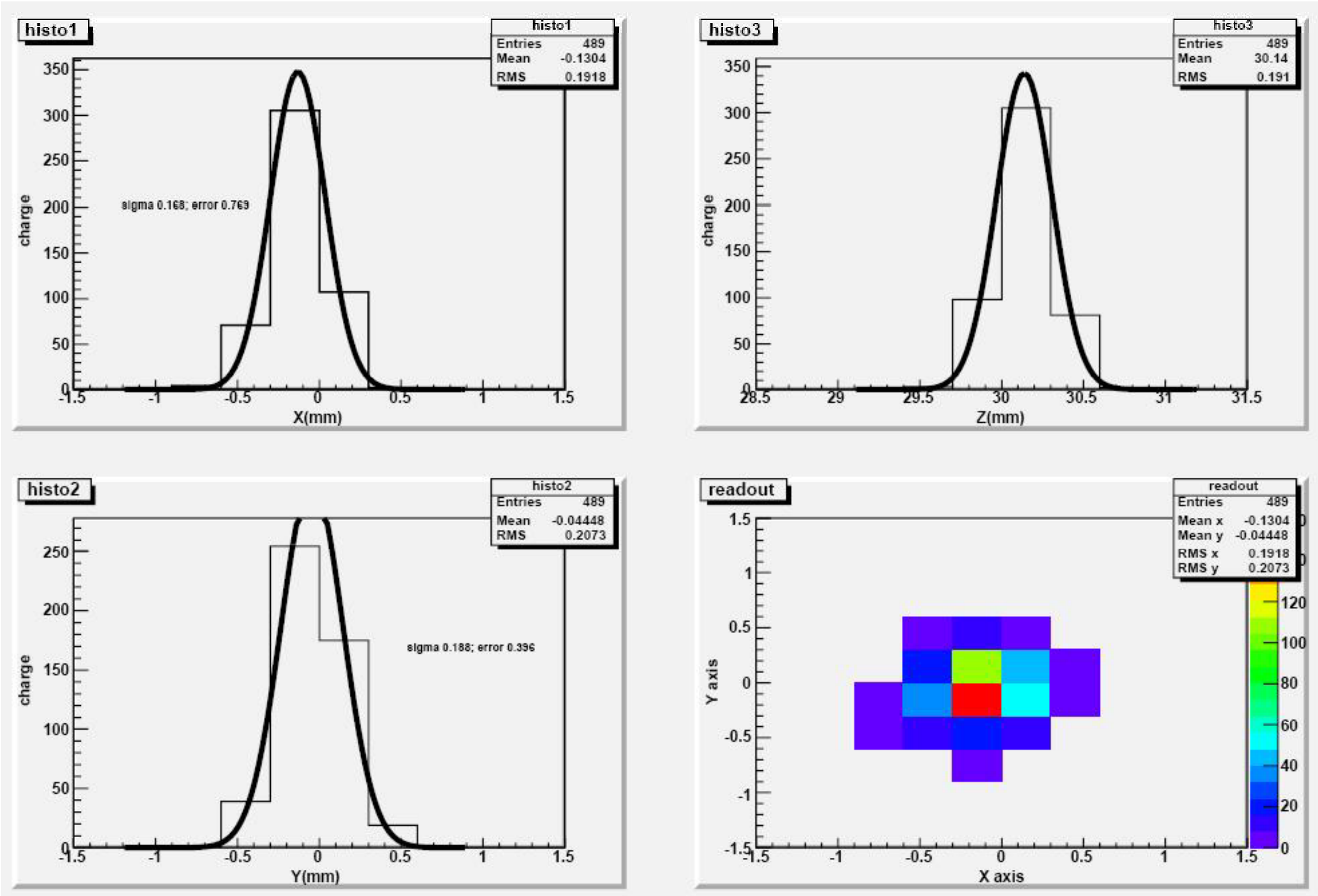
In opposite, electrons in general show a chaotic behaviour; but it includes particular events which can mimic a recoil (or whatever you could imagine).



Discrimination is not easy, even without considering the diffusion due to the drift.

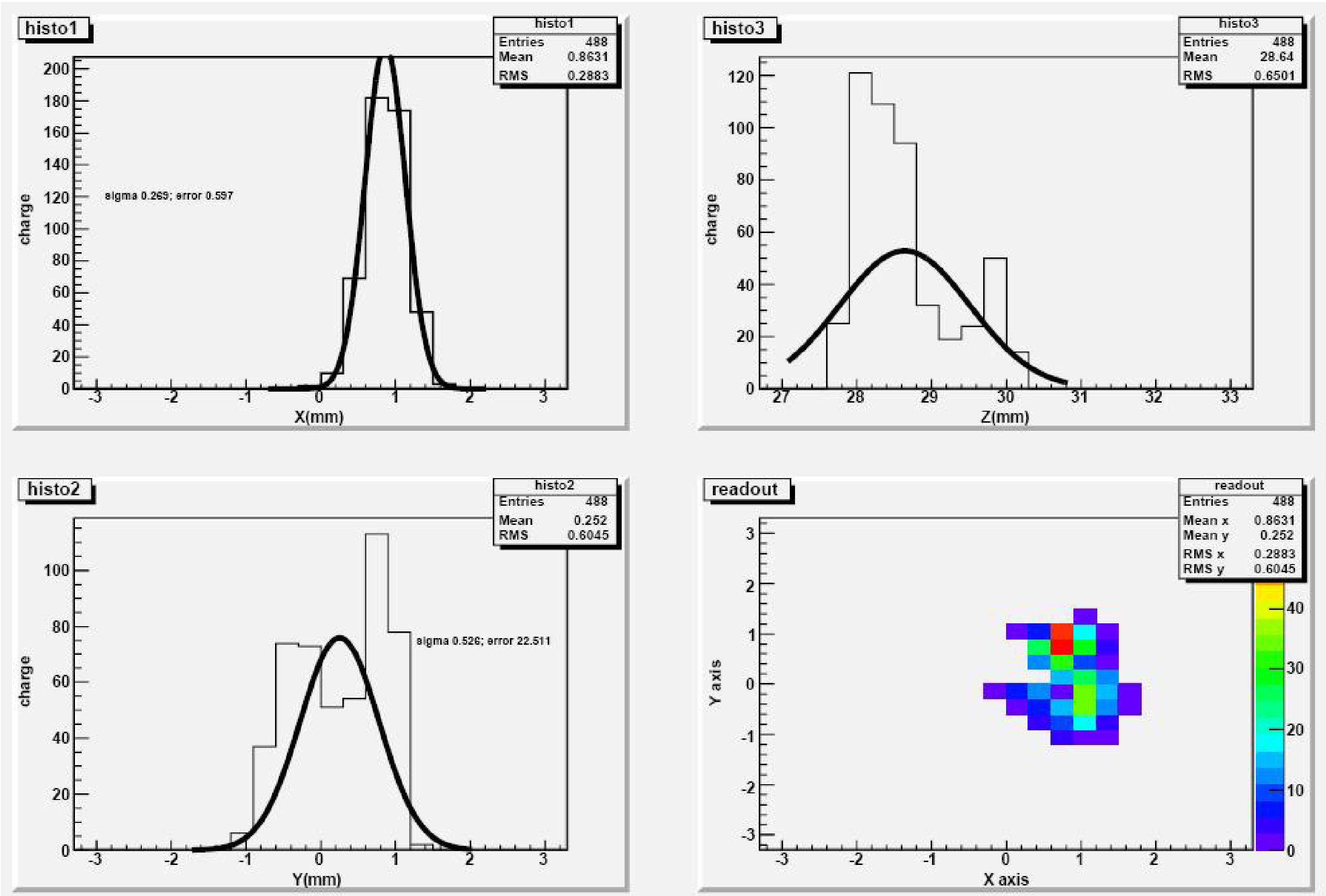
How we see a recoil event (40 keV recoil after drifting 3cm)

as a *pointlike event*, that's to say, three symmetric gaussian distributions which size corresponds to the diffusion equation.



How we see an electron event (13 keV electron after drifting 3 cm)

- The size of the gaussian fit is bigger than expected.
- The two fits are not equals, the event is not symmetric.
- The signal is not well fitted with a gaussian.



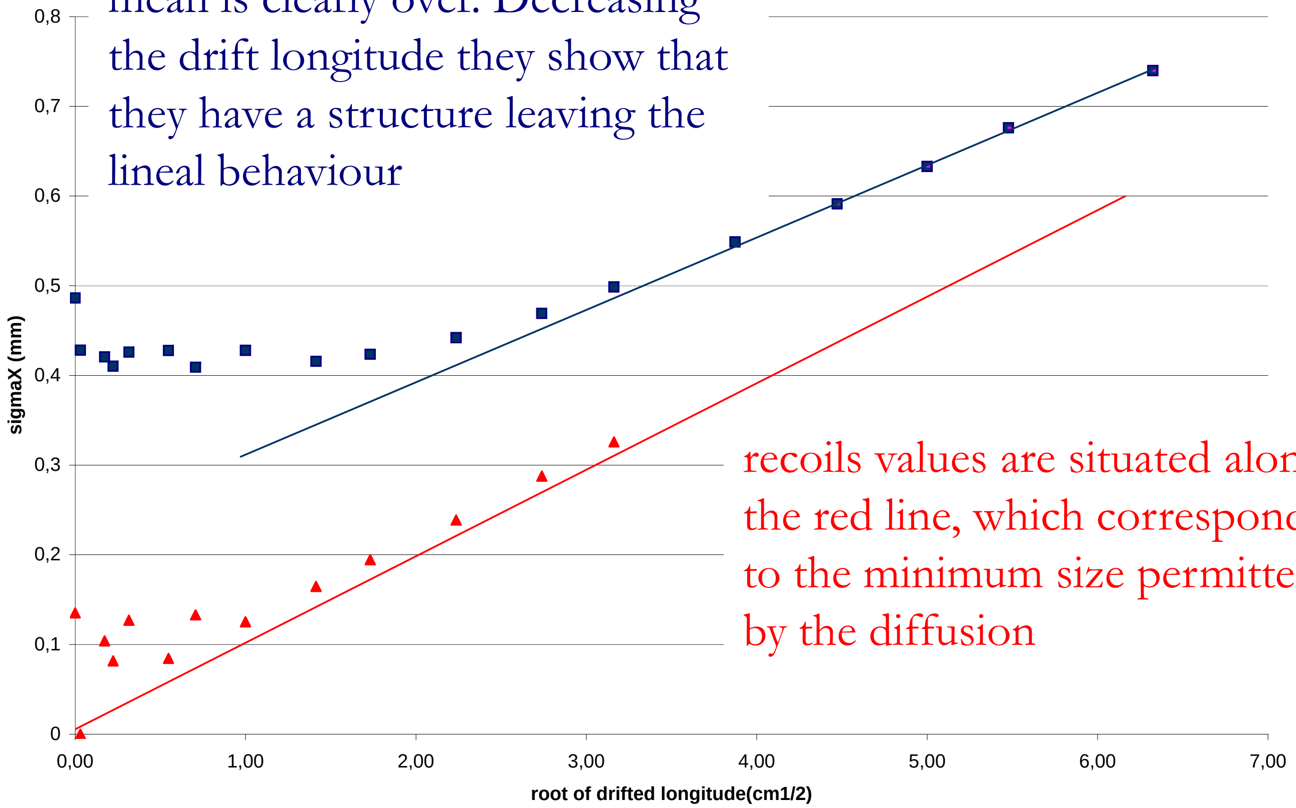
The sigma of the biggest gaussian will be a natural definition of the size of the event and our primary discriminator.

Size of events, as sigmaX, as function of drifted longitude:

Atmospheric Pressure
$\sigma x = 100\ \mu m/cm^{1/2}$

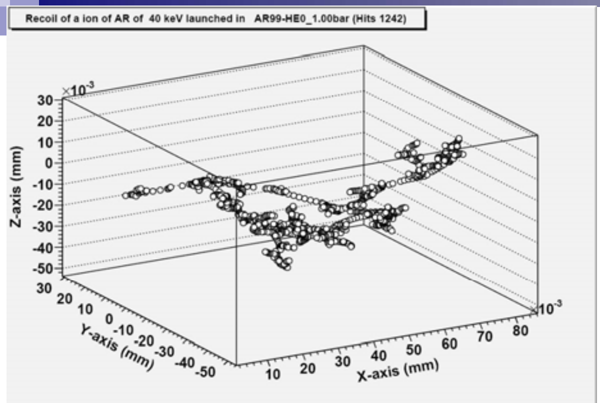
Results for the pair:
40 keV recoils
12 keV electrons

sigma's distribution of electrons starts in the red line too, but the mean is clearly over. Decreasing the drift longitude they show that they have a structure leaving the lineal behaviour



recoils values are situated along the red line, which corresponds to the minimum size permitted by the diffusion

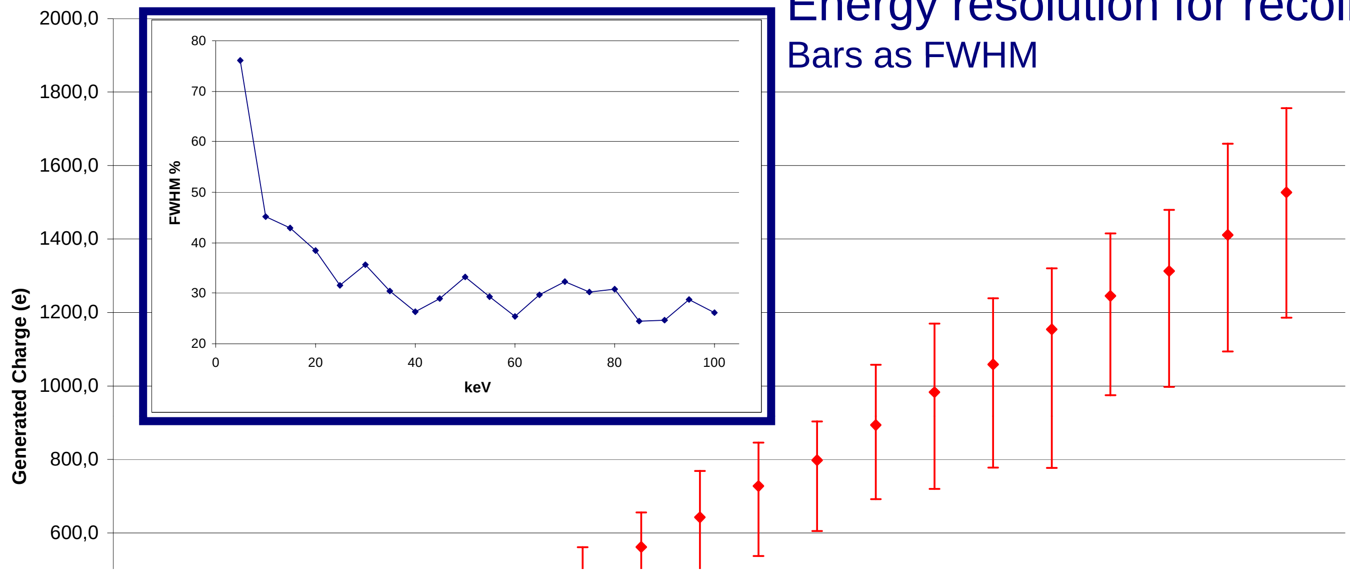
The size imposed by diffusion rise the flat of electrons' original size around 15 cm.
That's an initial limitation in chamber height (FOR THESE ENEGIE, PRESSURE, GAS).



We put a 100 eV cut in energy to decide if a new branch must be simulated after a collision. This energy is not visible. So the particular story of a recoil determines the total amount of energy that is used to generate charge by ionization. This is the main factor which affects to the resolution. Quenching values obtaining in this way are quite similar to Lindhart's (example, @ 40 keV: Lindhart's Q=0,30 and SRIM2006's Q = 0,32).

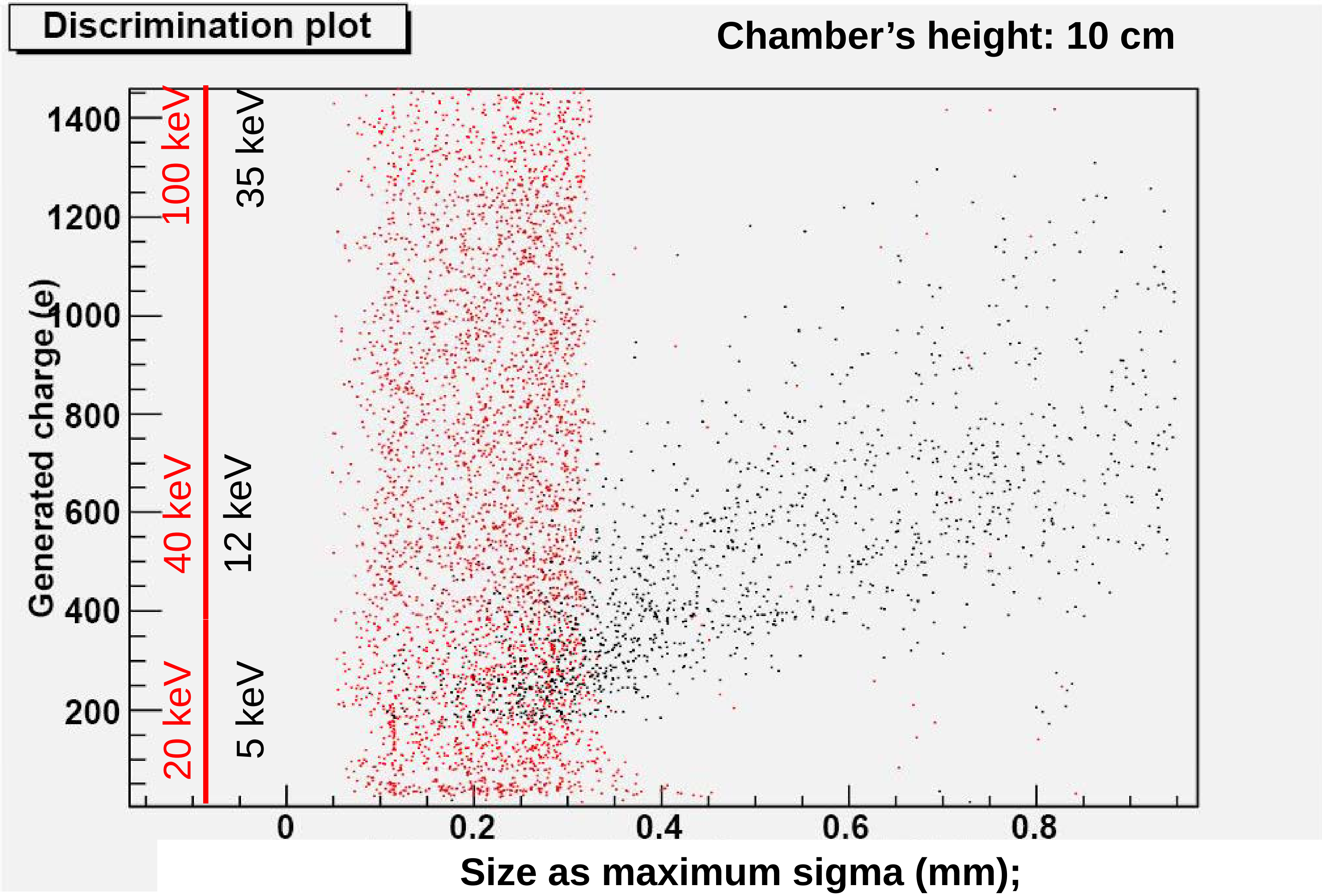
Energy resolution for recoils:

Bars as FWHM



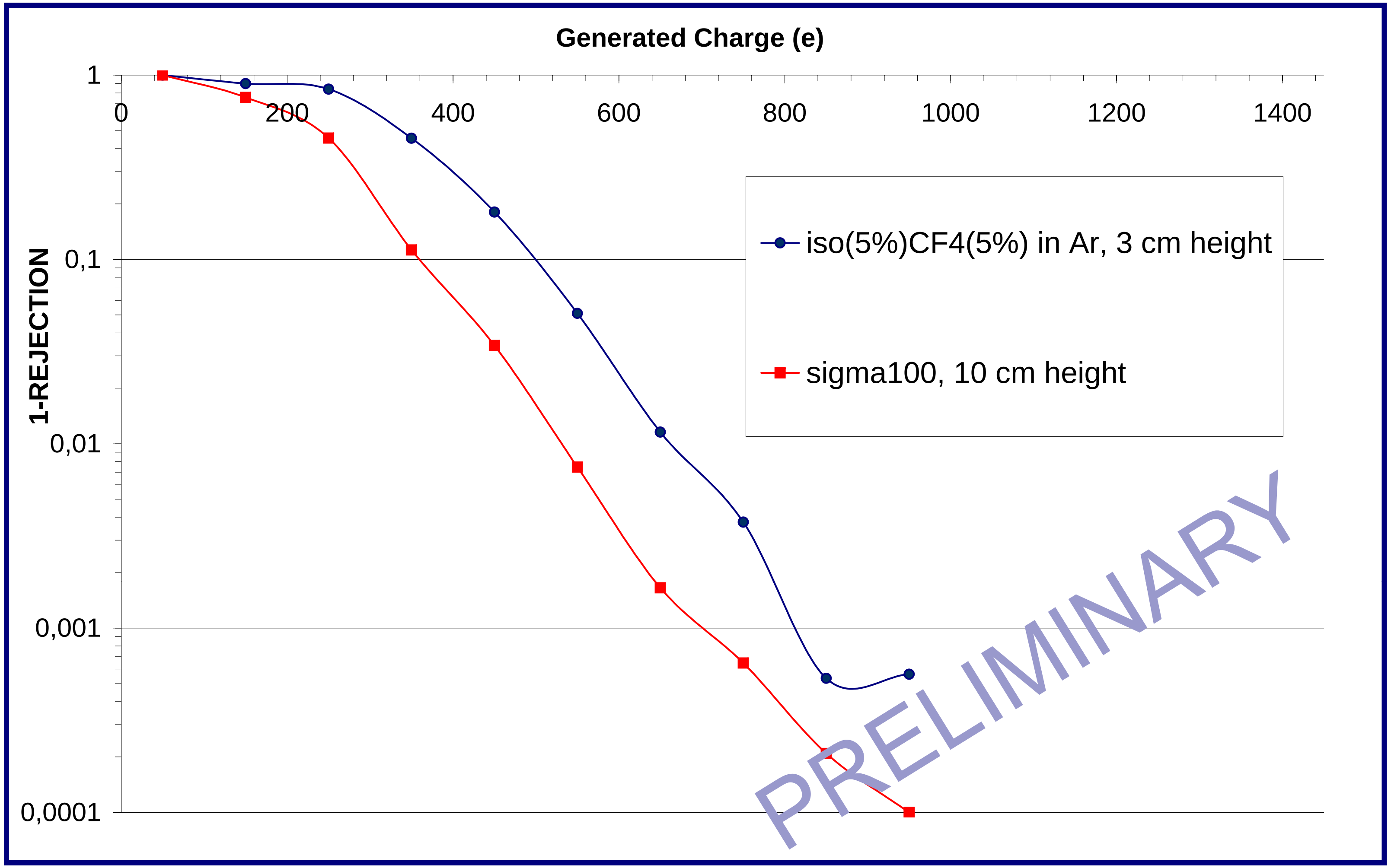
According to this SRIM2006's simulations. Variability in generated charge for a given energy is very bigger than that imposed by Fano's limit.

IMPORTANT TO BE VALIDATED EXPERIMENTALLY



After drifting at atmospheric pressure in a gas with $\sigma x = 100\ \mu m/cm^{1/2}$

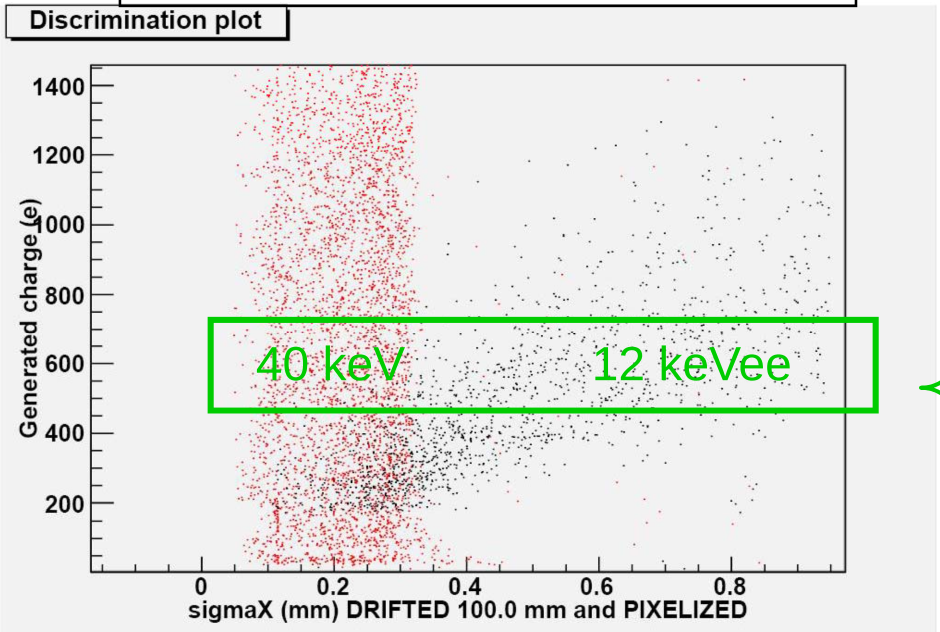
REJECTION CAPABILITY in the 0 – 100 keV recoil energy



Use more observables to apply a SEQUENCED CUT

Which requires a more detailed study of a particular energy region because of cuts to apply to the several observables depends on energy or even on the value of the other observables (MULTIVARIBLE ANALYSIS).

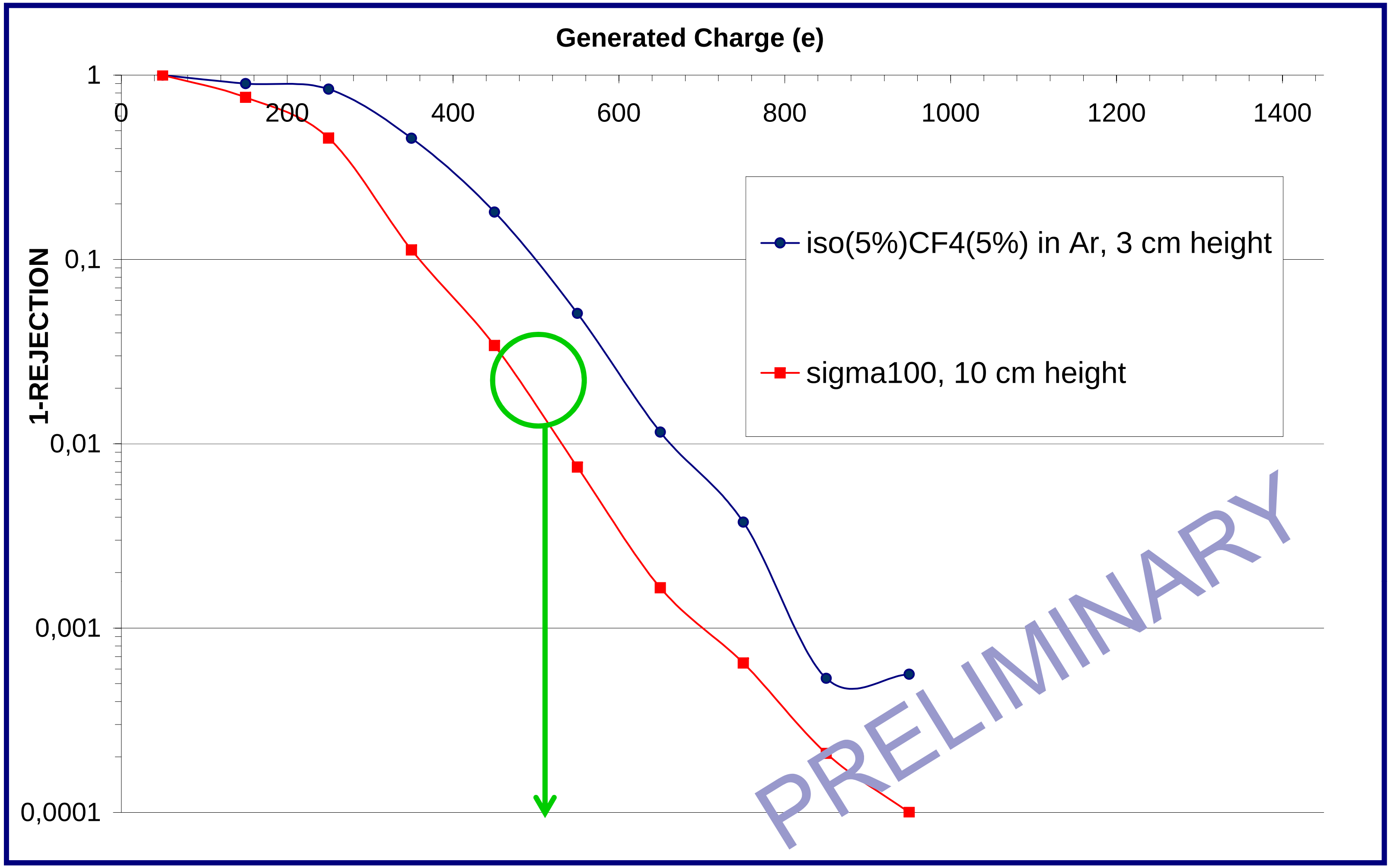
10 cm atmospheric pressure chamber

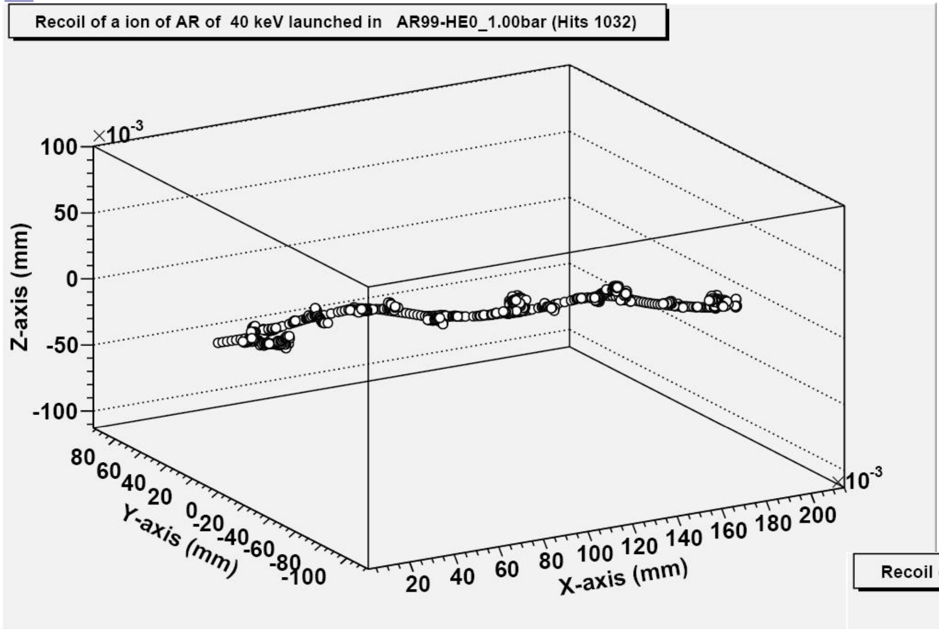


EXTRA CUTS:

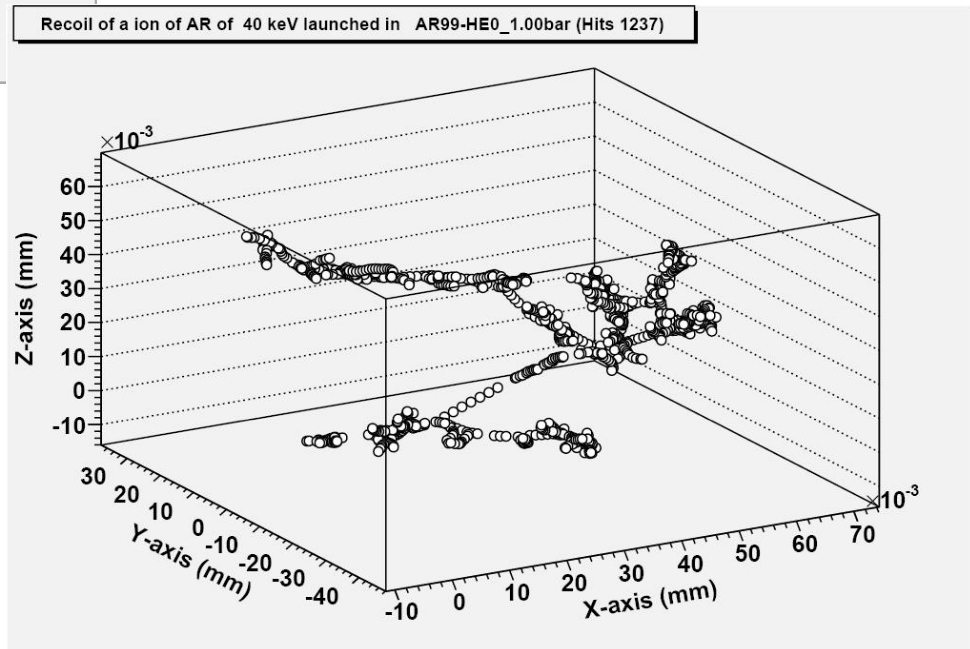
- GOODNESS OF FIT:
  Chi2/NDF < cut2
- ASYMMETRY :
  |SigmaX/SigmaY – 1| < cut3
- MULTIPLICITY:
  Number of total activated pixels < cut4
  -z direction (time) included-
- MAXIMUM LONGITUDE you can measure inside the distribution < cut 5

SEQUENCED CUT APPLIED FOR 40KeV<->12keV pair



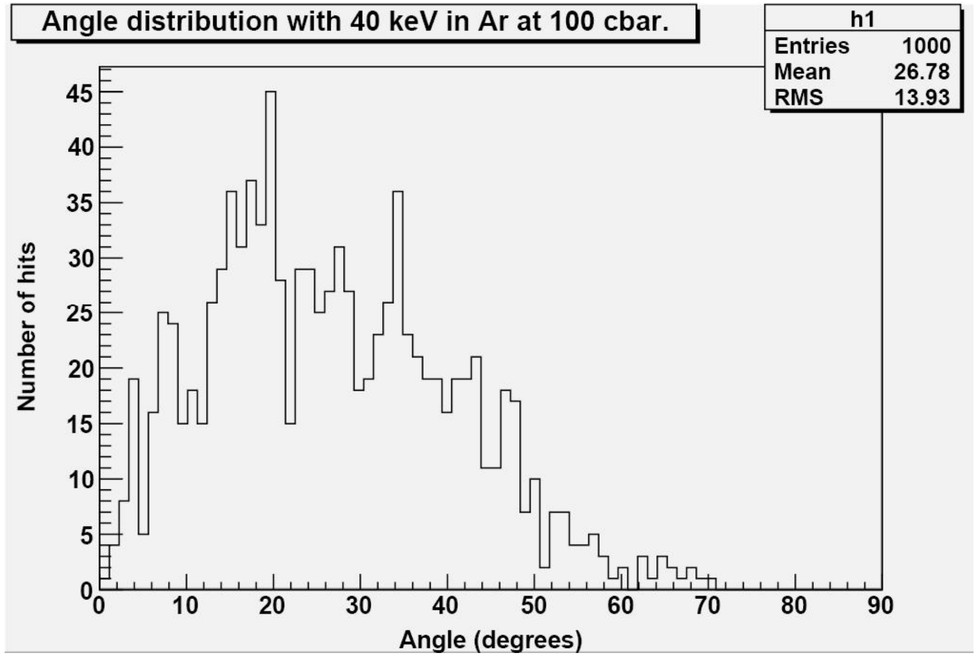


Due to the possibility of having a collision with another nucleus, recoils' stories show a lot of variety of unexpected behaviours in all the range of energies (5-100 keV).



NOTE: as we don't consider the drift (for the moment), pressure is understood only as a scale factor.

Simple adjust by minimum square method, weighted by charge



Angle deviation to the initial direction

Wide distributions of errors, never less than 25º mean, that are not notably improved by increasing the initial energy of the recoil.

Energy keV	Angle error mean deg
5	25,26
10	28,03
20	27,69
40	26,78
60	25,58
100	24,76

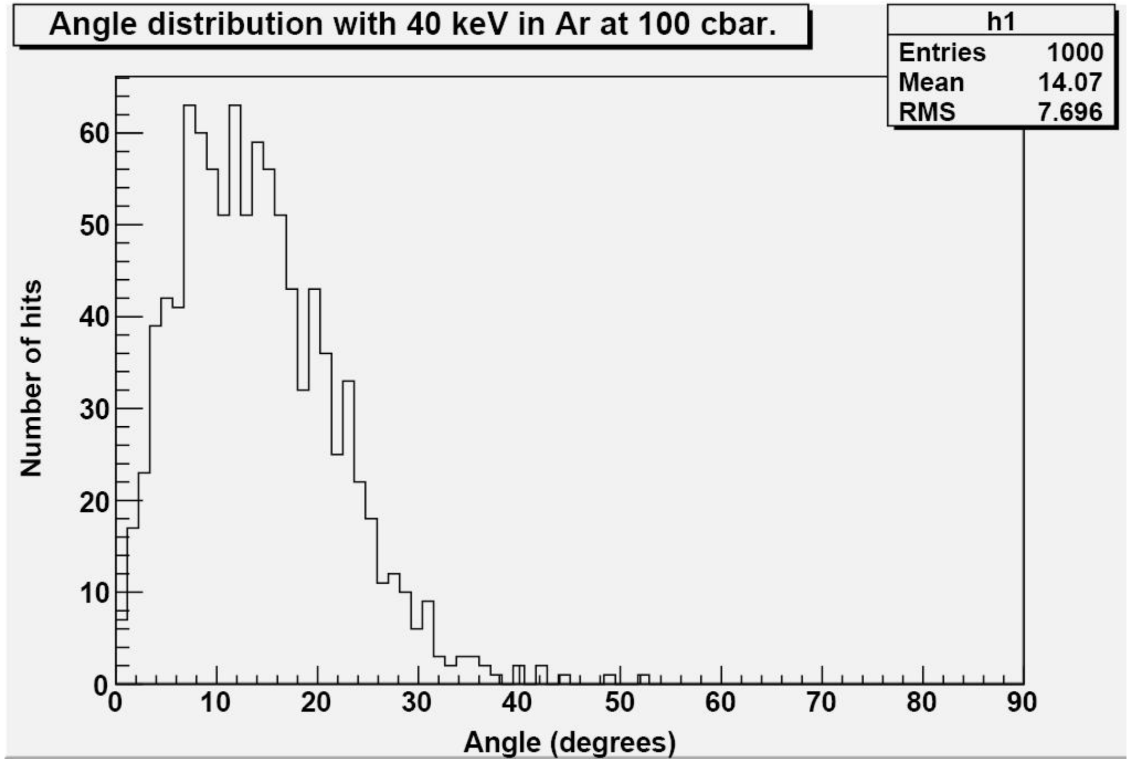
Note: for 5 keV containing an important secondary branch is less likely .

Adjust known the recoil's origin

Knowing the origin of the recoil's track would permit us:

- ➢ to reduce drastically the events we need to claim a WIMP signal

- ➢ to use the position of each generated charge in our adjust so as to improve our initial direction estimation

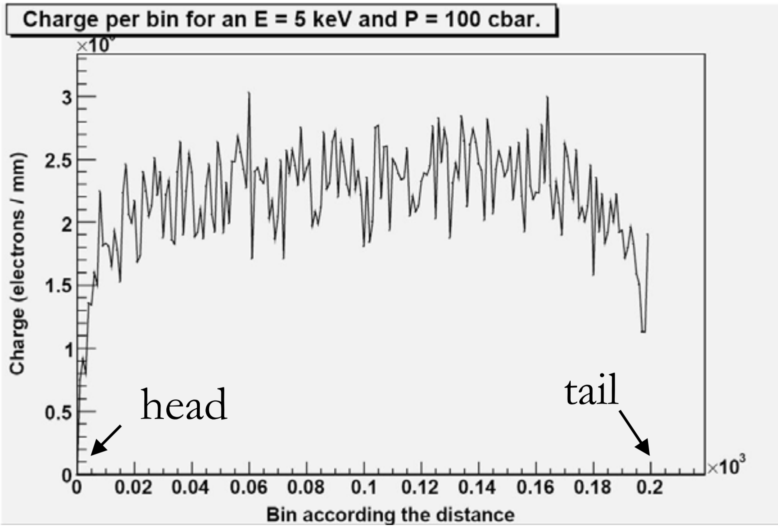


Also weighting by $1/d^2$

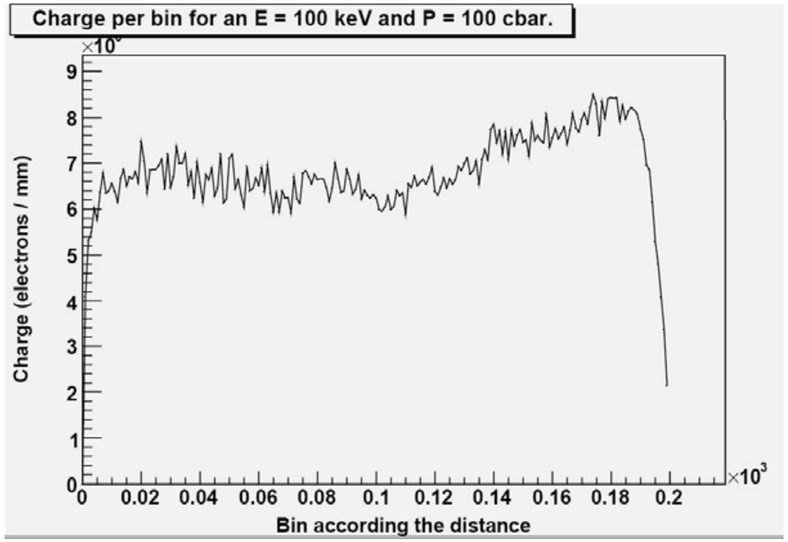
d = distance to origin

Energy keV	Angle error mean deg
5	15,49
10	15,19
20	14,69
40	14,07
60	13,50
100	13,09

Looking for the sense: LINEAL density of charge along the track direction



These are average results for recoils



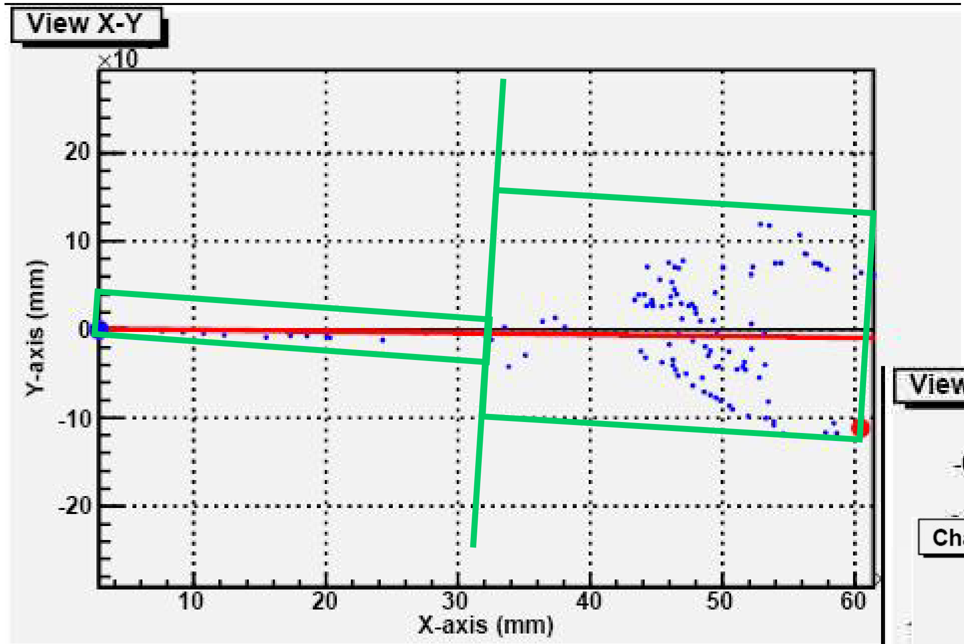
It seems that the integrated value of charge is not enough to distinguish between the two extremes because we don't see more that more total charge is generated at head or tail.

However, in most of cases we observe that, at fist, recoils have great hits and finally they use to show a more complicated tree structure of weaker hits.

- So being sensitive to the volume of the generated charge's spatial distribution is needed in order to identify the initial and final parts of a recoil. The algorithm will have to be topological.

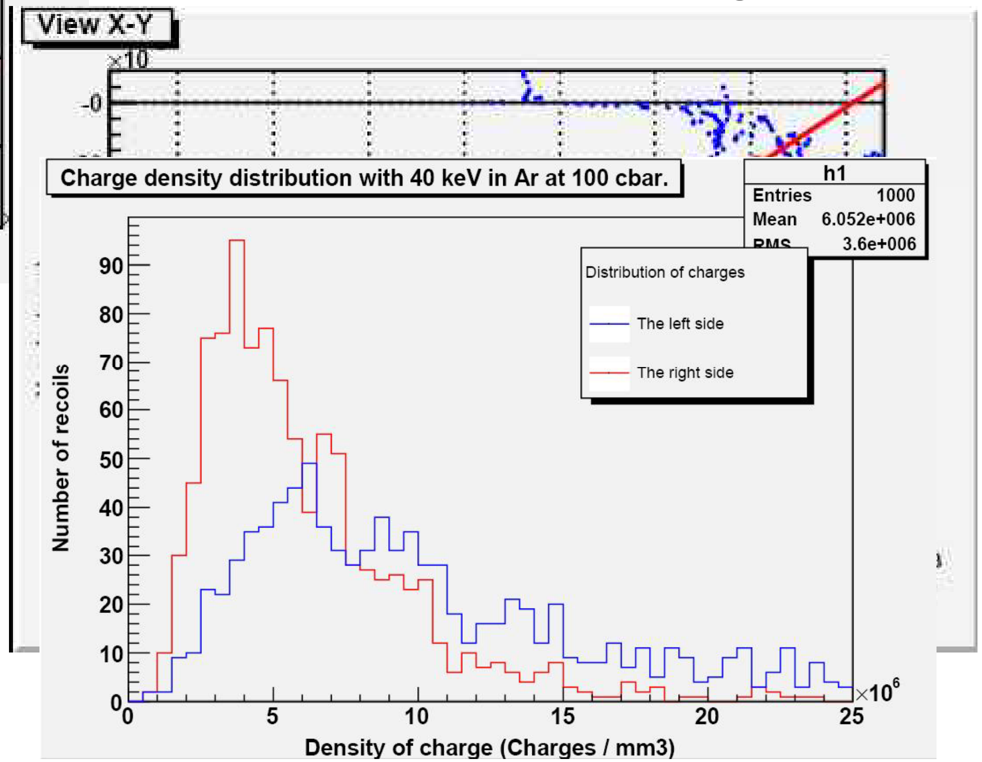
Better drift conditions, less pressure or a better space resolution would be required.

Comparing densities of charge



1. Firstly we choose the two extremes by making a simple adjust weighted by charge.

2. Later we find the transversal plane and define the two volumetric regions.



3. Finally sum the charge, calculate the densities and compare:

4. We could demand a minimum density to assure that we have found a well defined starting point.

❑We can adjust the threshold so as to get around 95% of success in selecting a point next to the real origin. That means to sacrifice certain effective rate in our detector which depends on the initial energy of the recoil. The error in angle's distribution obtained in this way is close to the ideal one:

E = 100keV

density threshold e/cm3	recoils selected %	success %	angle error's mean deg	ideally deg
0	100	77,5	19,04	13,09
6E+06	37,4	95,5	13,51	13,09

E = 40keV

density threshold e/cm3	recoils selected %	success %	angle error's mean deg	ideally deg
0	100	72,4	21,96	14,07
1,9E+07	22,2	94,2	15,62	14,07

❑If we were able we also could increase our selection ratio by attending only to a quarter of the charge distribution instead of a half:

E = 100keV

density threshold e/cm3	recoils selected %	success %	angle error's mean deg	ideally deg
0	100	81,8	18,39	13,09
1E+07	61,5	95,8	13,30	13,09

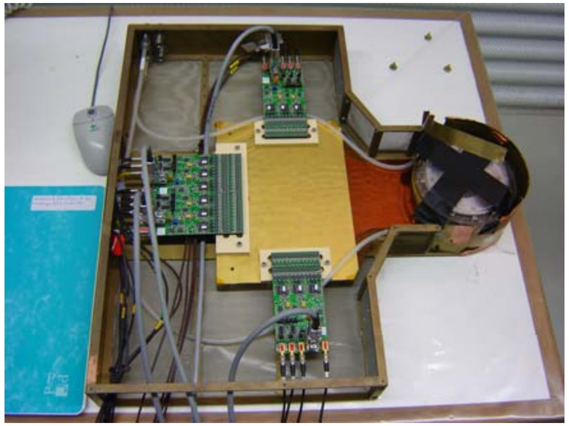
E = 40keV

density threshold e/cm3	recoils selected %	success %	angle error's mean deg	ideally deg
0	100	74,4	21,99	14,07
3,7E+07	41,6	94,5	15,06	14,07

CONCLUSIONS AND PROSPECTS

- DISCRIMINATION: Rejection factors around 10^{-3} over 25keVee have been simulated for realistic chamber at atm pressure, and it's clear that we have the capability to applied a more elaborated analysis and improve a lot.

  PROSPECTS: to VALIDATE this in a real MicroMegas setup in Canfranc Underground Lab!



- DIRECTIONALITY AND SENSE: a promising start point (but a great challenge).

  PROSPECTS: study drift, finite resolution, pressures and different gases.
- COLLATERAL: during the way a software tool is being developed.

  PROSPECTS: to develop a compact ROOT based tool able to simulate the complete process in the chamber and analyze its results (besides of real experimental future data).