From nuclear recoil track to MWPC signals
END-TO-END
DRIFT detector simulation

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Presentation outline

- Description of DRIFT END-TO-END simulation
- Recoil track simulation using SRIM
- Electric field and induced pulses simulation using GARFIELD
  - MWPC with repetitive readout response to a single positive ion moving from anode to grid wire/drift region
- Read-out electronics: CREMAT amplifier and shaper
- Signal shape sensitivity to:
  - diffusion
  - recoil direction
    - anode and grid signal simulation for X,Y,Z directed Sulfur recoils

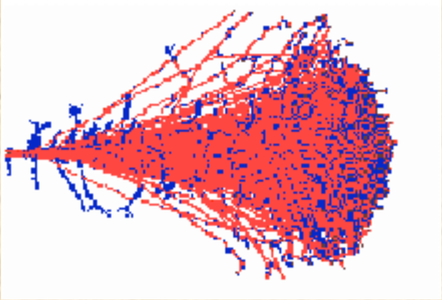
END-TO-END Simulation

Steps of END-TO-END DRIFT detector simulation:

- Recoil track simulation with SRIM
    - reading file with 3D position of ionisation charge

2. Electrons trap by CS_2 ions – NIP formation
   (assumed 100% efficiency)
3. Ionisation charge thermal diffusion in X,Y,Z
   f=(Electric field, Z position)
4. Electron detachment from NIP
   (assumed 100% efficiency)
4. Gas gain estimation for each NIP
5. Charge induction calculation f=(time of positive ion motion in MWPC) for each NIP
6. Transforming calculated charge into electric pulse
7. Writing pulses into .ndd format file readable by DRIFT data analysis programs.

The Stopping and Range of Ions in Matter : SRIM

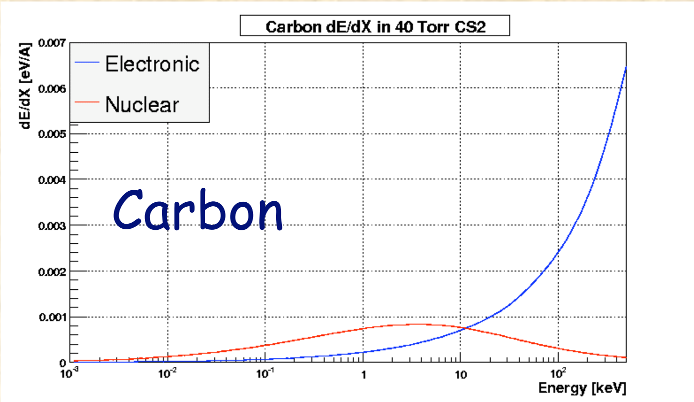


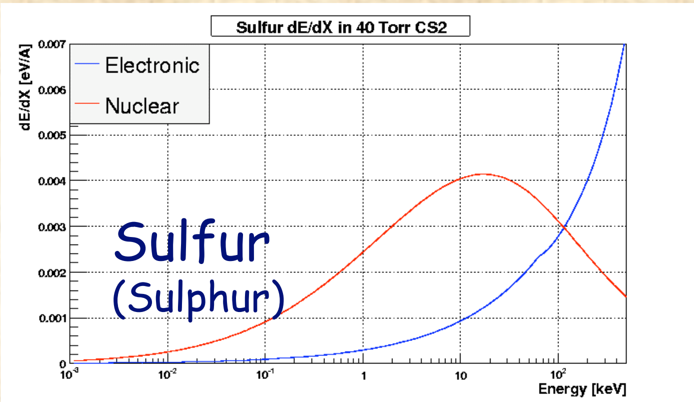
Simulation program developed by James F.Ziegler : calculates the stopping power and range of ions in matter.

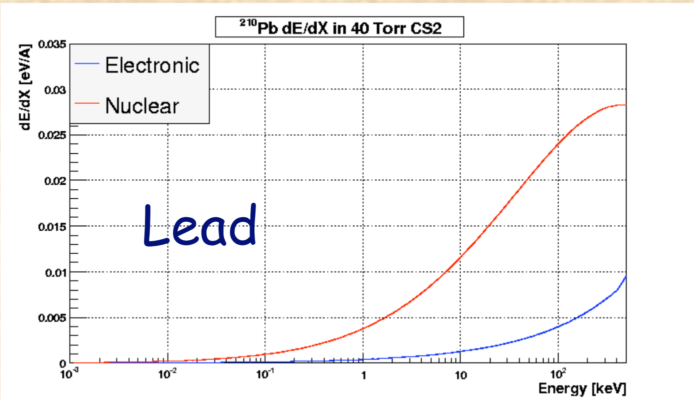
SRIM includes TRIM (The Transport of Ions in Matter) which calculates using MC a final 3D distribution of ions and cascading recoils created in the target.

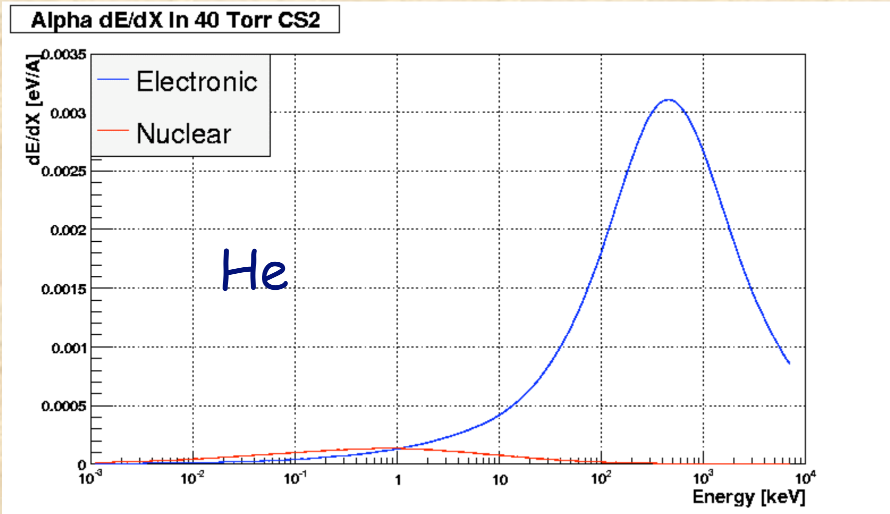
Calculations of the stopping powers are based on the Brandt-Kitagawa theory (Phys. Rev. B25 (1982) 5631) which creates a formalism for scaling from proton stopping powers to that of any other ion at the same velocity .

dE/dx for He,S,C and Pb in 40 Torr CS2





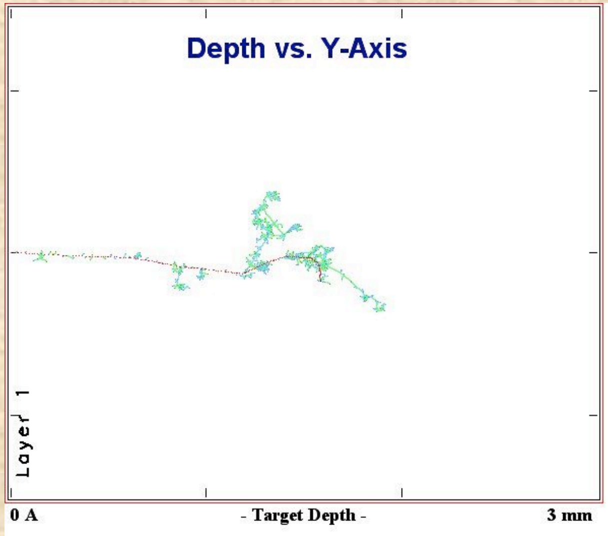




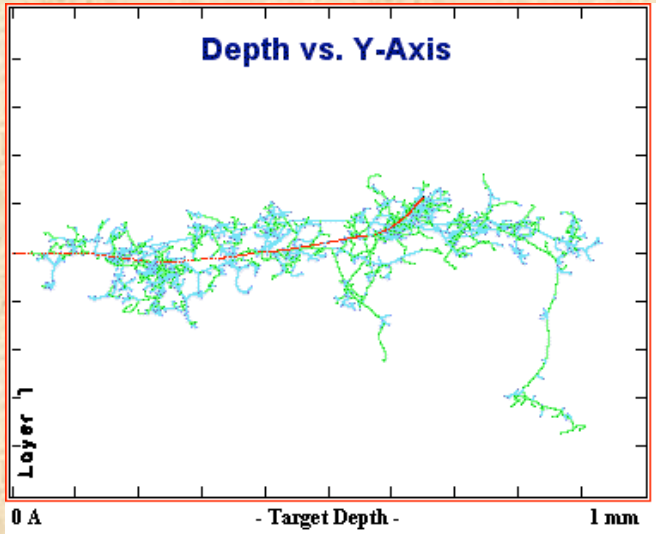
He loses energy mainly in electronic channel.

The heavier nuclear recoils the higher kinetic energy when energy loss in nuclear channel starts to dominate and the larger recoil cascade at the same ion energy.

Nuclear Recoil Cascades (SRIM)



Example of the nuclear recoil cascade from 100 keV S ion in 40 Torr CS2



Example of the nuclear recoil cascade from 103 keV Pb ion in 40 Torr CS2.

-red line : Pb ion
-blue line : S recoils
-green line : C recoils

Nuclear recoil track: 3D ionisation charge distribution in space

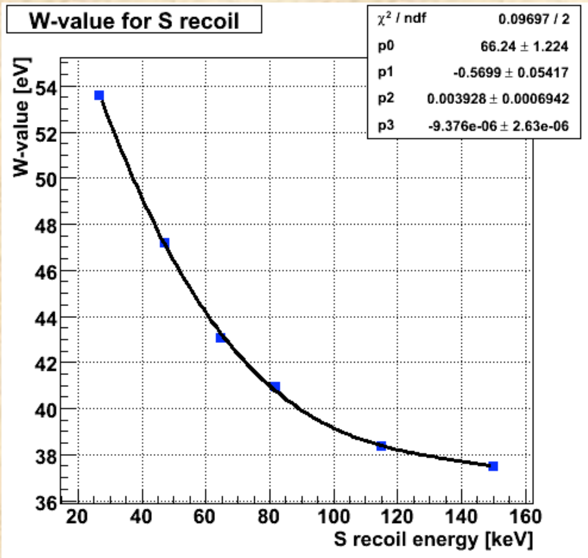
```
============================== SRIM-2006.02 ==============================
 ======================================================================
 =                 Ion Energy vs Position File                  =
 ======================================================================
 =  AXIS DEFINITIONS: X=Depth, Y,Z= Lateral plane of target surface.=
 =  (If beam enters target at an angle, this tilt is in Y direction)=
 =  Shown are: Ion Number, Energy (keV), X, Y, Z Position           =
 ==================  CALCULATION   DATA  ==============================
  Ion Data: Name, Mass,   Energy , Energy Interval
          S     031.97  300keV     1eV
 ======================================================================
Ion      Energy     Depth (X)     Y          Z       Energy Lost in
Number    (keV)    (Angstrom)  (Angstrom)  (Angstrom)  Last Collision (eV)
------- ----------- ---------- ----------- ----------- ------------------
0000001 1.0000E+02  1.0000E+07  0.0000E+00  0.0000E+00  0.0000E+00
0000001 9.8871E+01  1.0220E+07  0.0000E+00  0.0000E+00  1.1291E+03
0000001 9.7841E+01  1.0440E+07 -5.8692E+03  4.1084E+03  1.0297E+03
0000001 9.7814E+01  1.0658E+07 -1.4129E+04  9.5749E+03  2.7161E+01
0000001 9.7809E+01  1.0876E+07 -2.3315E+04  1.8565E+04  4.8624E+00
0000001 9.7793E+01  1.1095E+07 -3.1891E+04  2.6139E+04  1.5695E+01
0000001 9.6649E+01  1.1313E+07 -3.8889E+04  3.1436E+04  1.1447E+03
0000001 9.6645E+01  1.1530E+07 -4.7882E+04  4.5119E+04  4.1359E+00
0000001 9.5787E+01  1.1747E+07 -5.6961E+04  5.9669E+04  8.5814E+02
0000001 9.4792E+01  1.1963E+07 -7.1806E+04  7.4139E+04  9.9462E+02
0000001 9.3883E+01  1.2178E+07 -8.6170E+04  8.9668E+04  9.0903E+02
0000001 9.3873E+01  1.2392E+07 -1.0420E+05  1.0765E+05  9.5665E+00
0000001 9.2830E+01  1.2605E+07 -1.2091E+05  1.2584E+05  1.0436E+03
0000001 9.1433E+01  1.2817E+07 -1.4161E+05  1.4836E+05  1.3964E+03
0000001 9.1423E+01  1.3024E+07 -1.8808E+05  1.7046E+05  1.0773E+01
0000001 9.0264E+01  1.3231E+07 -2.3675E+05  1.9302E+05  1.1586E+03
0000001 8.9239E+01  1.3440E+07 -2.6593E+05  2.0201E+05  1.0247E+03
0000001 8.8108E+01  1.3649E+07 -2.9530E+05  2.1495E+05  1.1312E+03
0000001 8.7175E+01  1.3857E+07 -3.1836E+05  2.3577E+05  9.3278E+02
0000001 8.6255E+01  1.4064E+07 -3.4046E+05  2.5527E+05  9.2063E+02
0000001 8.5328E+01  1.4271E+07 -3.6186E+05  2.7279E+05  9.2692E+02
0000001 8.4422E+01  1.4475E+07 -3.7349E+05  3.0946E+05  9.0536E+02
0000001 8.3522E+01  1.4678E+07 -3.8712E+05  3.4600E+05  9.0022E+02
0000001 8.2634E+01  1.4880E+07 -4.0114E+05  3.8374E+05  8.8816E+02
0000001 8.2387E+01  1.5082E+07 -4.1568E+05  4.2041E+05  2.4721E+02
0000001 8.1493E+01  1.5283E+07 -4.1898E+05  4.5744E+05  8.9389E+02
0000001 8.0760E+01  1.5485E+07 -4.2012E+05  4.9184E+05  7.3328E+02
```

<u>Example of SRIM output</u>:

-"EXYZ" file with: x,y,z position of ion collisions and energy lost

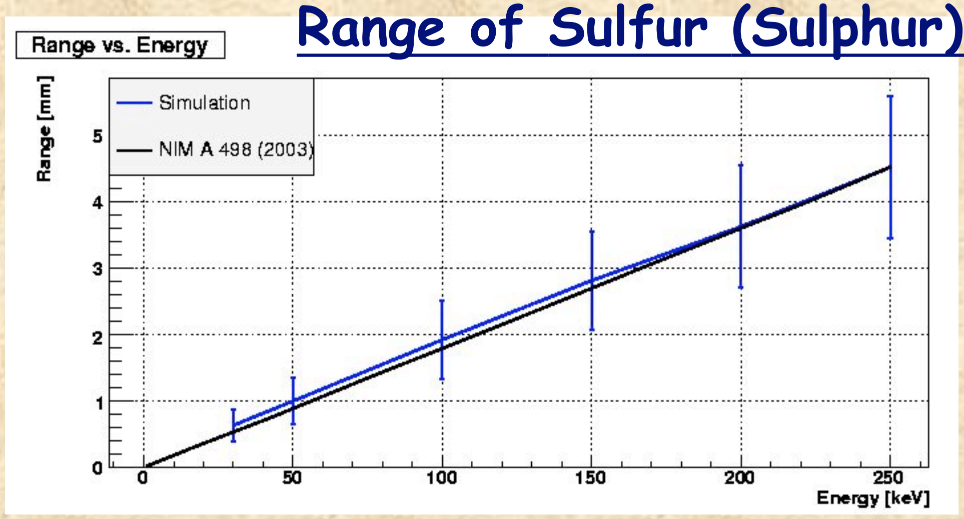
<u>Number of ionisation charge derivation from W-values</u> :

(Taken from NIMA 498 (2003) 155-164)

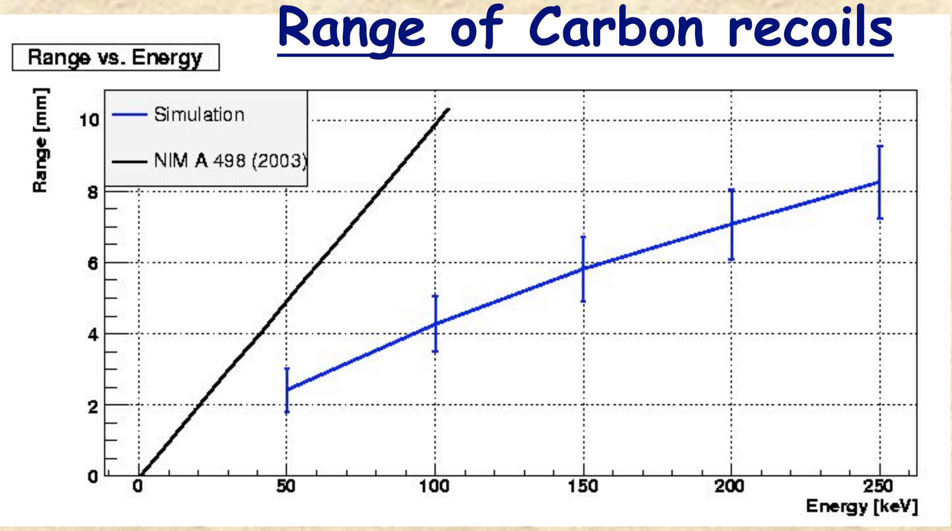


Nuclear recoil projected ranges

Range of Sulfur (Sulphur) recoils



Range of Carbon recoils



SRIM simulation results comparison with measurements:

-Very good agreement for Sulfur (Sulphur) recoils

-Large difference for Carbon recoils

Simulation error bar – 1σ

Thermal Ion Diffusion

Diffusion suppressed to thermal level:

$$\sigma = \sqrt{\frac{4\epsilon_k L}{3eE}}$$

and

$$\epsilon_k = \frac{3}{2} k_B T$$

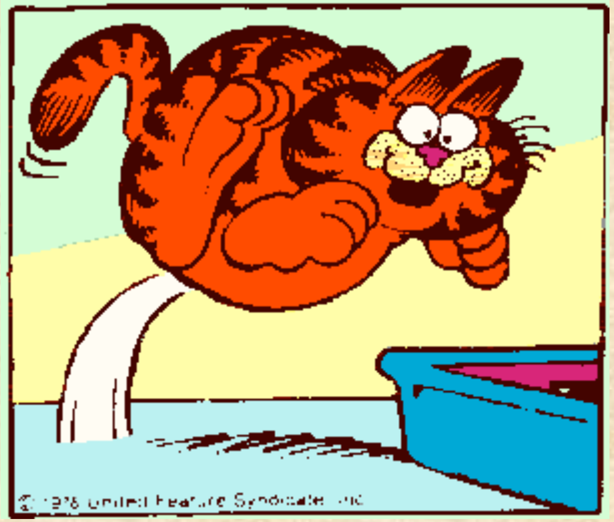
Hence:

$$\sigma\,[m] = \sqrt{\frac{L}{E}} \sqrt{\frac{2k_B T}{e}} \;\rightarrow\; \sigma\,[mm] = 0.72 \sqrt{\frac{L\,[m]}{E\,[\frac{kV}{cm}]}}$$

NIP drift distance

Electric field in detector drift volume

Electric field and induced currents calculation using Garfield



Garfield (written by R.Veenhof from CERN) :

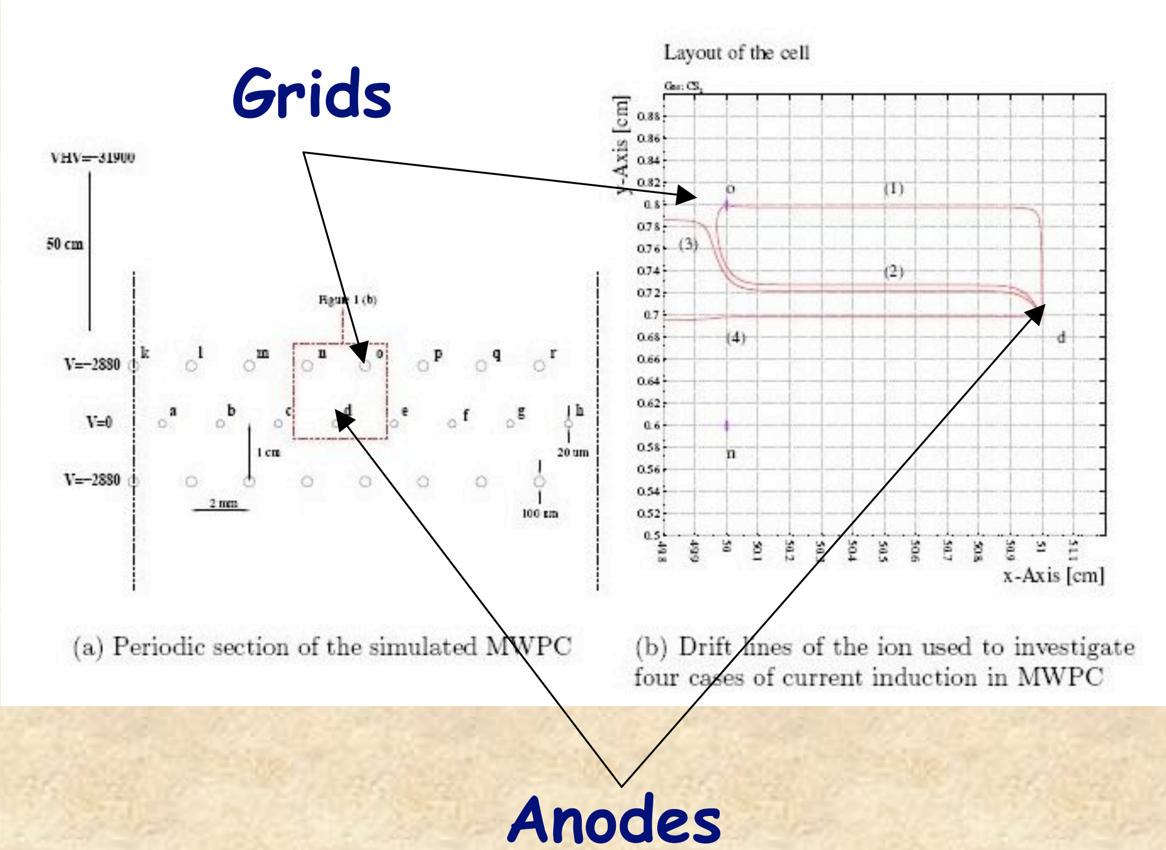
• calculates 2D electric fields with wires and planes

• accepts 2D and 3D external field Maps computed i.e by Maxwell, Tosca, FEMLAB ..

• is interfaced to Magboltz and HEED programs for computation of charge transport in gases

• calculates (with great precision) induced currents/charges on arbitrary electrode defined in the volume.

Signal induction in MWPC with crossed wires (2D approximation)



Calculation of currents induced on anode and grid in a periodic cell having 8 anode and 8 grid readout channels by avalanche ions moving along four representative drift lines (1-4)

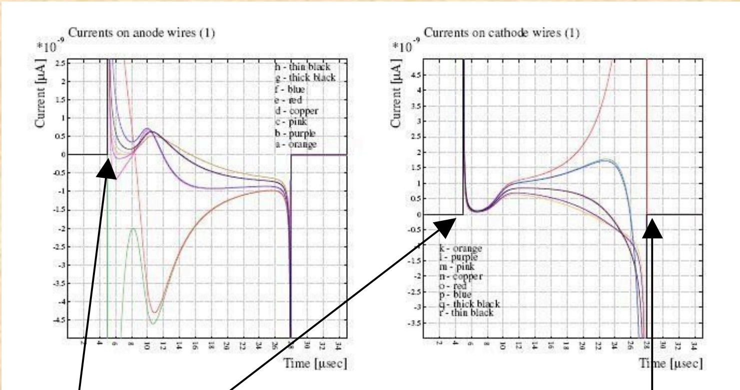
Lines (1-2) start from the anode and end on the grid

Lines (3-4) start from the anode and go into drift volume

Induced currents

Anode/Grid currents (left/right plot)

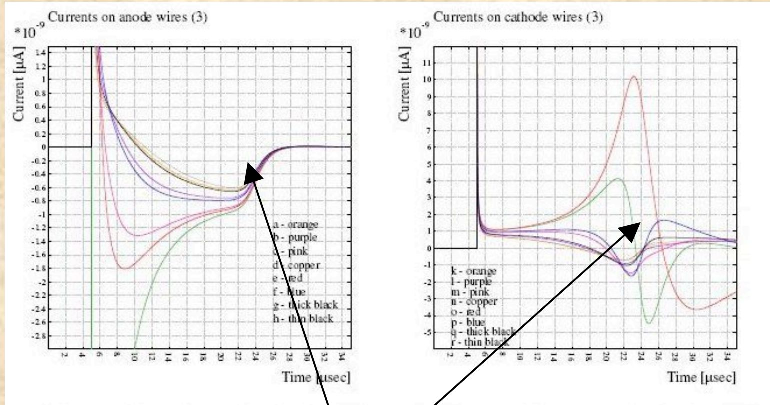
Line 1



(a) Currents induced on anode wires for drift line (1)

(b) Currents induced on grid wires for drift line (1)

Line 3



(a) Currents induced on anode wires for drift line (3)

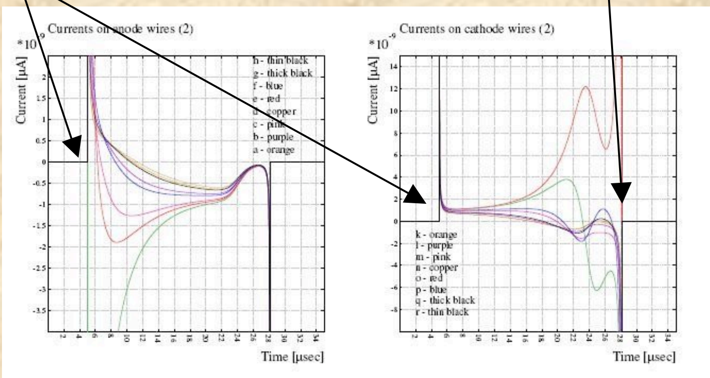
(b) Currents induced on grid wires for drift line (3)

Ion starts drifting

Ion arrives to grid

Ion passes grid wires, current without sharp end.

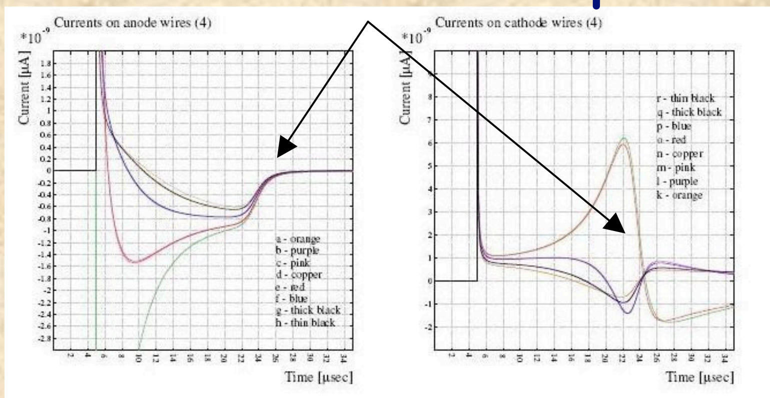
Line 2



(a) Currents induced on anode wires for drift line (2)

(b) Currents induced on grid wires for drift line (2)

Line 4



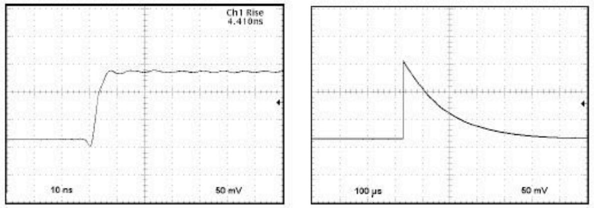
(a) Currents induced on anode wires for drift line (4)

(b) Currents induced on grid wires for drift line (4)

Positive ion drift velocity in MWPC V=4*NIPs drift velocity (E_MWPC~4*E_drift

From induced charge to readout electric pulse

CREMAT CR-111 charge premaplifier output: 0.15 V/pC



cremat

Cremat, Inc.
45 Union St.
Watertown, MA 02472
(617) 527-6590
FAX: (617) 527-2849
http://cremat.com

Specifications Assume temp =20 °C, V_s = ±6.1V, unloaded output

	CR-111	units
Preamplification channels	1	
Equivalent noise charge (ENC)*		
ENC RMS	630	electrons
	0.1	femtoCoul.
Equivalent noise in silicon	6	keV (FWHM)
ENC slope	3.7	elect. RMS /pF
Gain	0.15	volts /pC

CREMAT CR-200 pulse shaper output: Gaussian pulse with shaping time σ = 4 μs and fixed gain x10.

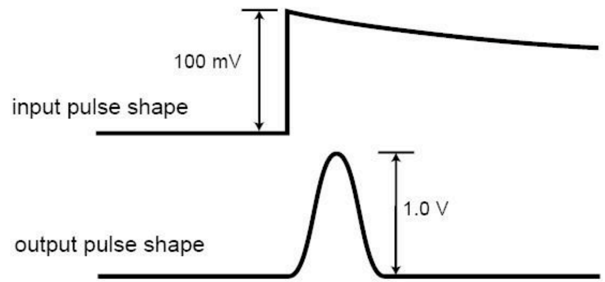
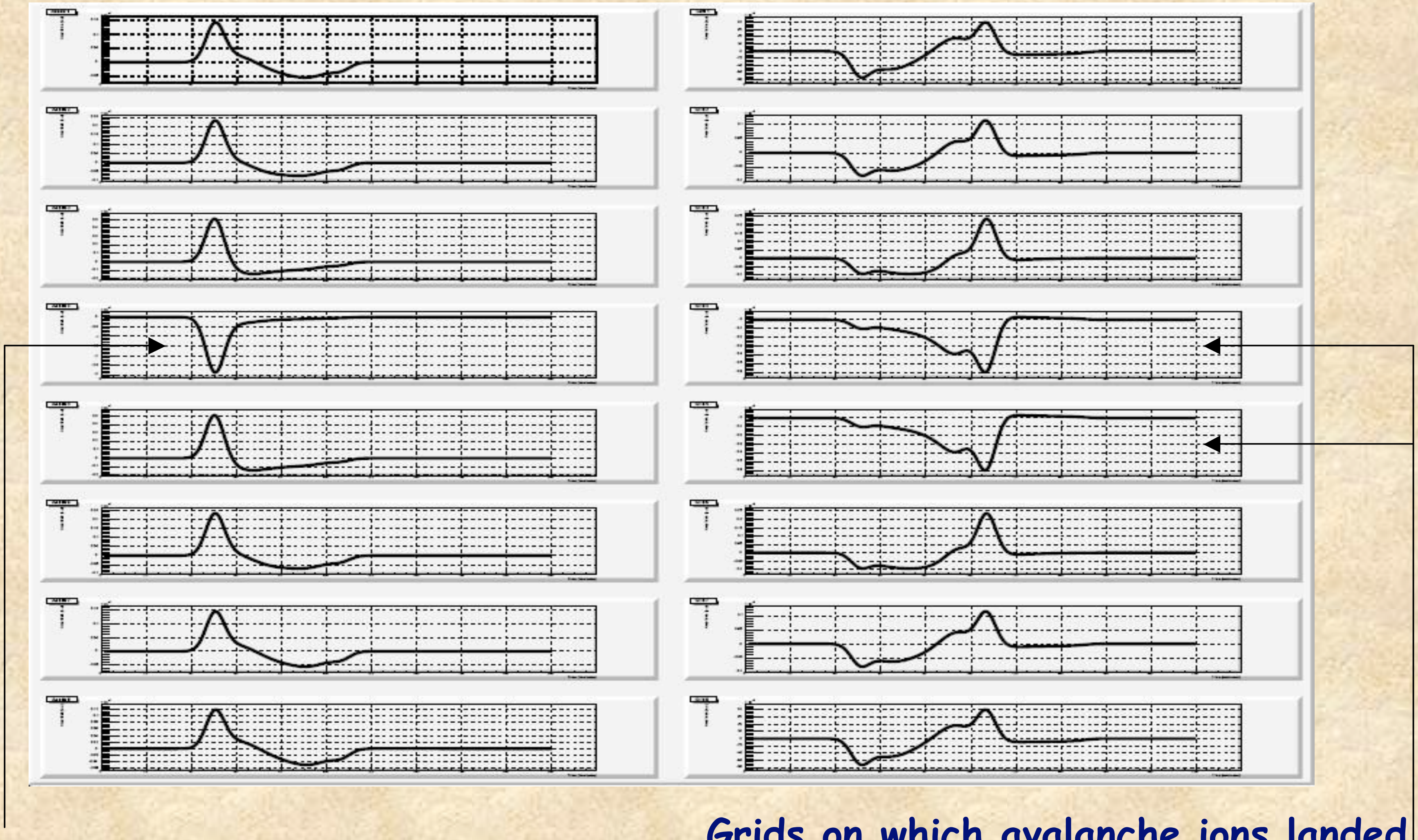


Figure 1. Comparison of sample input and output pulse shapes

Integration of induced currents– within each 1 μs window response from CR-111-CR-200 chain is calculated and summed over entire ion drift time giving total signal output from each anode and grid readout channel

Final signal look-up map

Anode pulses / Grid pulses

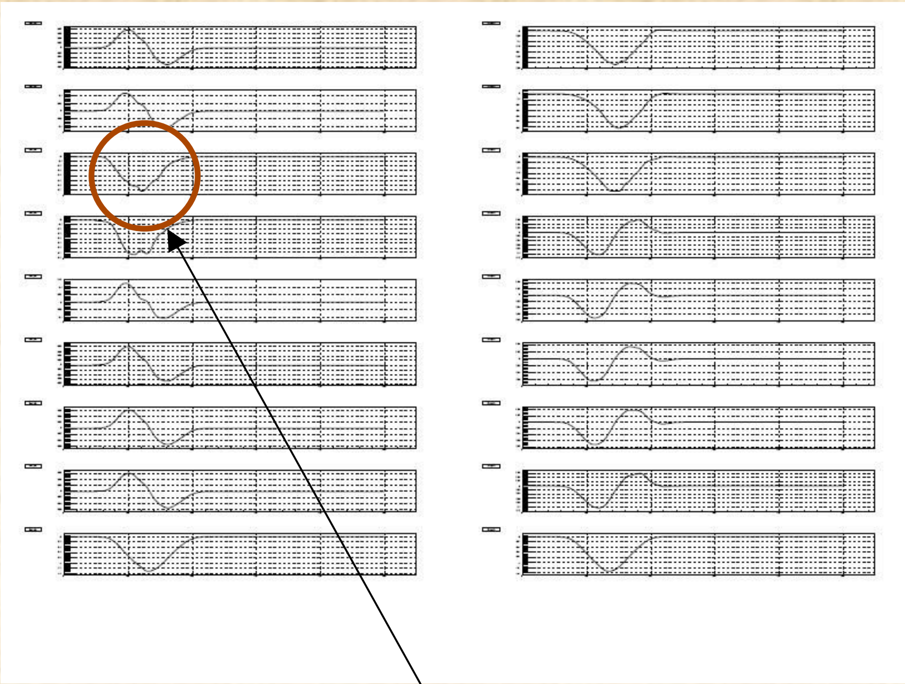


Anode (with avalanche) 1/6 scale

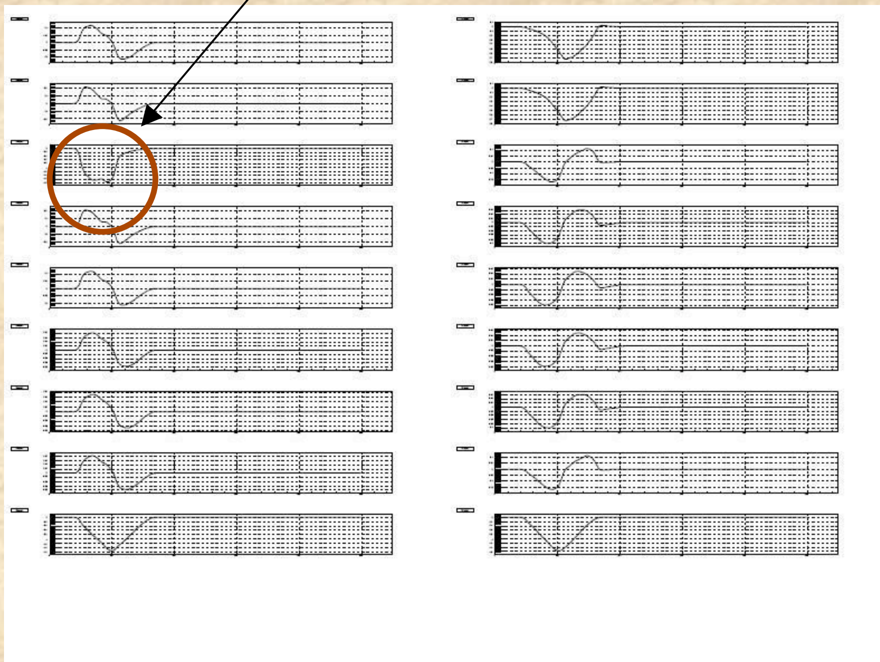
Grids on which avalanche ions landed 1/2 scale

Final pulse from the track = SUM of pulses from all NIPs

Pulse shape from a track with and without diffusion

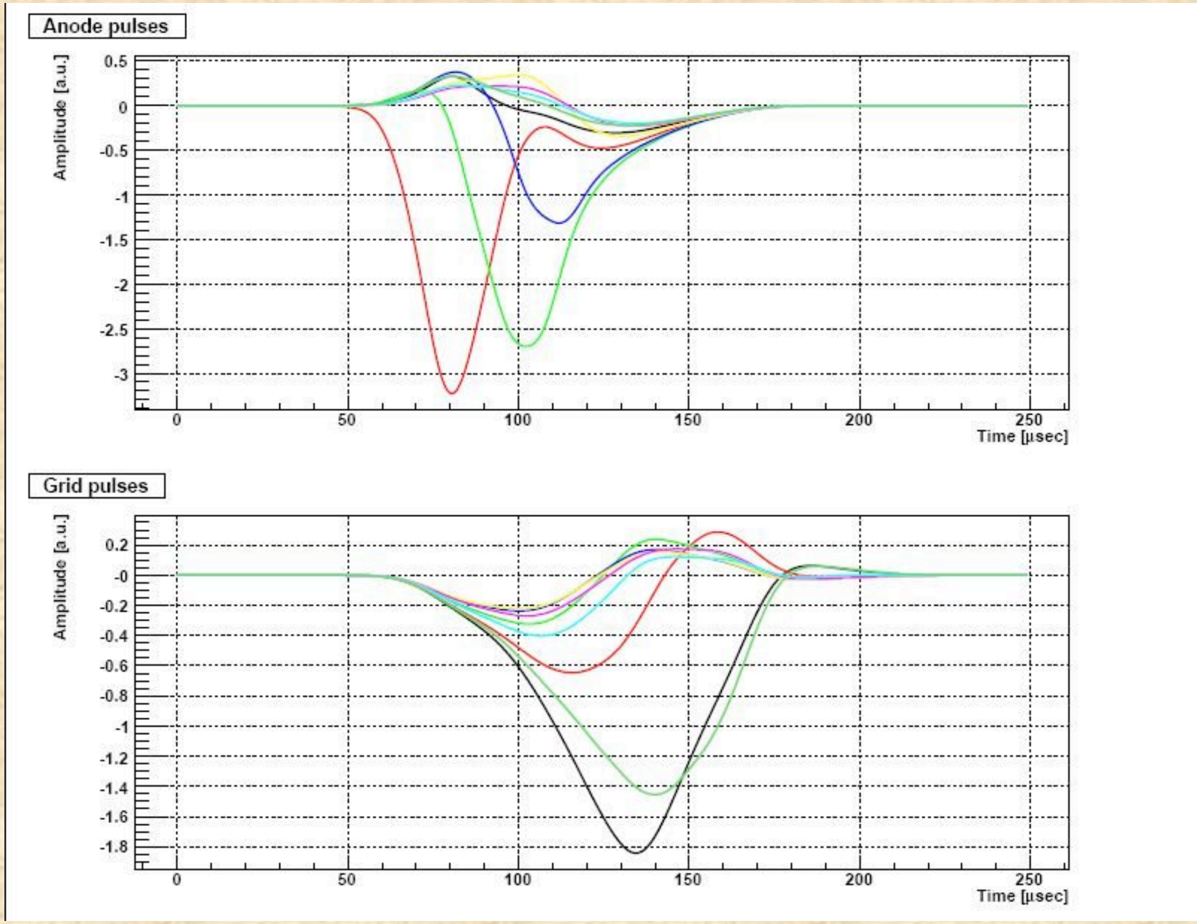


Zero diffusion



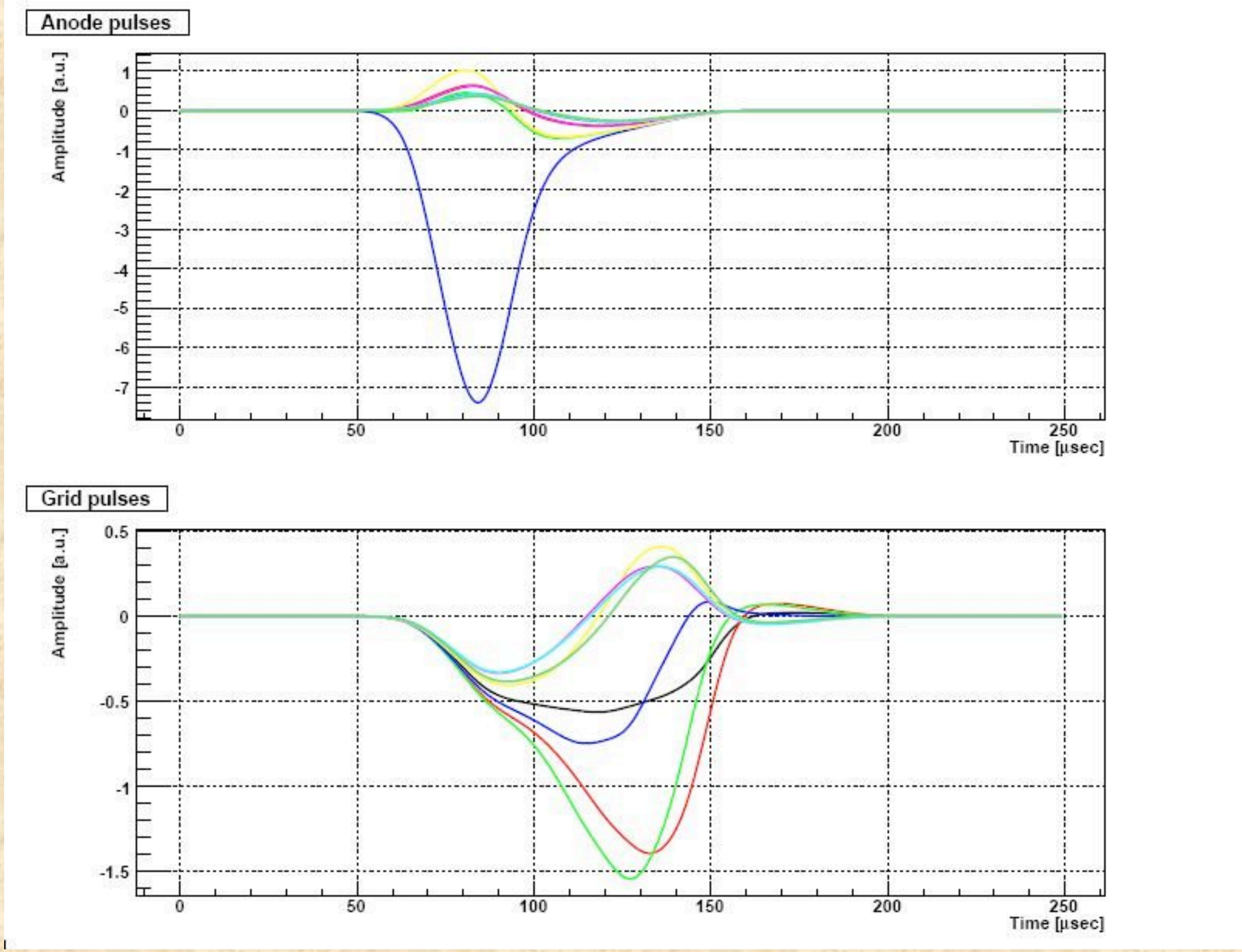
Diffusion over 50 cm of drift

Directional 250 keV S recoils



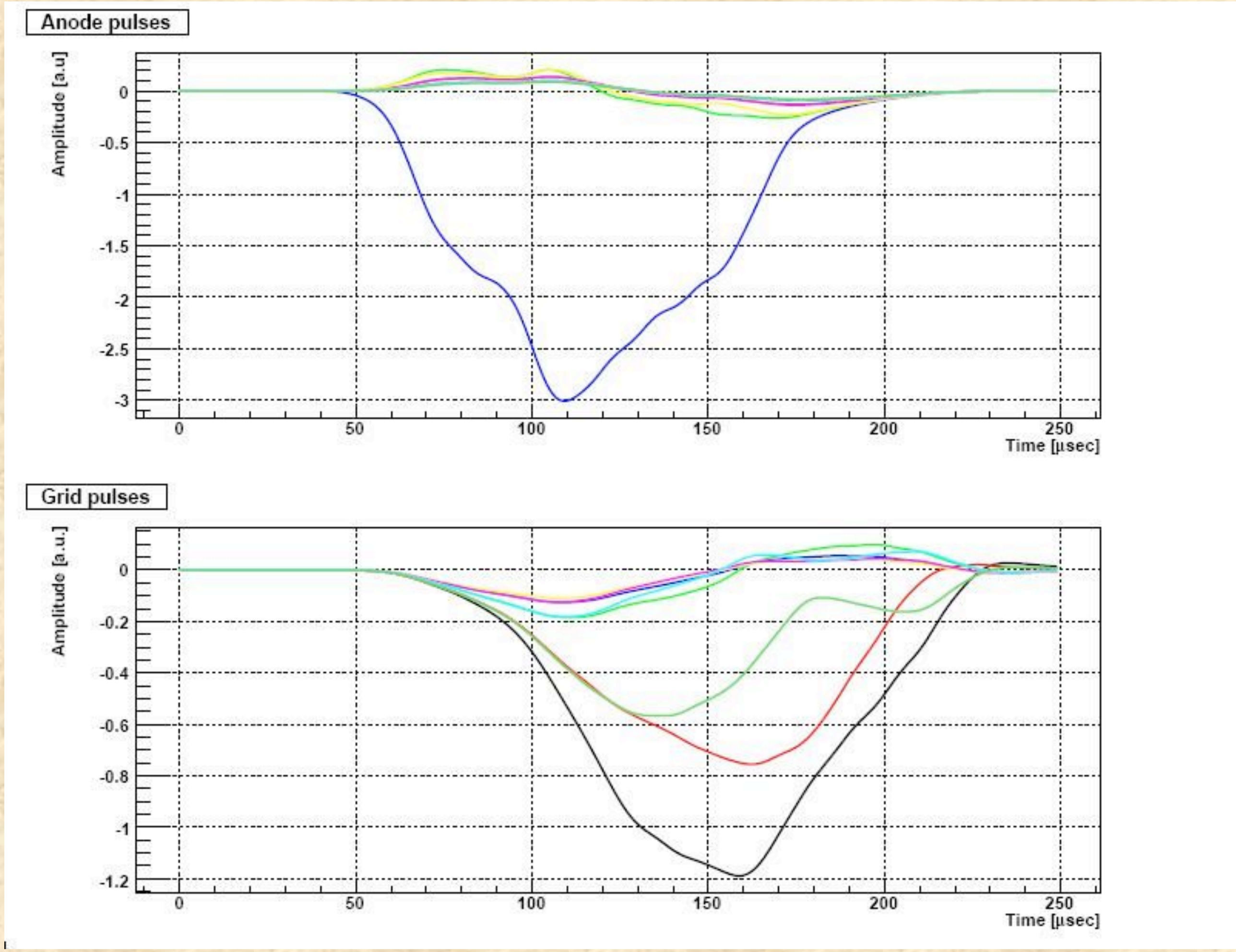
X-run:
Many anode wires hit

Directional 250 keV S recoils



Y-run: Many grid wires hit

Directional 250 keV S recoils



Z-run:
Long pulses

Conclusions

DRIFT END-TO-END simulation program has been described. It is in its early stage and is under the process of validation.

Its validation with DRIFT data analysis program will be presented by Demitri Muna.

Thank you.