Notes on ionization statistics in BoNuS RTPC test gases.

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This note summarizes important properties of the gases used in the BoNus RTPC tests.

Radiation and Gas Mixtures

We have been primarily using ^{55}Fe radioactive sources, cosmic rays, and, at TUNL, low energy protons to illuminate and test the RTPC. Nominal gas mixtures have been 80/20 $ArCO_2$ and 80/20 He/DME, although the precise mixing ratios have varied widely due to difficulties with measuring and/or regulating the flow rates.

^{55}Fe Statistics

The x-ray energy from this source is ~5.9 keV. It is assumed that all of the x-ray energy is deposited at a point, although energetic delta rays and escape-peak photons can spread or reduce the energy deposited. Table 1 shows w_i, the mean energy required to liberate a single electron-ion pair, and n_t, the total number of pairs expected in our gases when stopping a ^{55}Fe x-ray [1]. Also shown are the mass attenuation coefficients [2], which reflect the absorption cross sections for photons of this energy.

Gas	w_i ***(eV)***	n_t	μ/ρ **cm²/g**
He	41	144	0.42
DME	23.9	247	
80/20 He/DME		**165**	
Ar	26	227	259
CO2	33	179	
80/20 ArCO2		**217**	

Table 1. Ion pairs produced in RTPC gases by 5.9 keV x-rays, and the x-ray mass attenuation coefficients for those x-rays.

Two points: the probability of stopping one of these x-rays is two orders of magnitude higher in Ar than in He (important for rate studies); the charge released in the argon mixture is 30% larger than in the He mixture (not too significant).

Cosmic Ray Statistics

Charged cosmic rays that penetrate the atmosphere and enter our lab space are primarily muons, and are essentially all minimum-ionizing. The integral intensity of vertical muons above 1 GeV/c at sea level is ~ 70 $m-^{2}\ s^{-1}\ sr^{-1}$ (or about 1 $cm^{-2}min^{-1}$ for horizontal detectors)†. The angular distribution is like $\cos^2\theta$. When these minimum-ionizing particles (mips) deposit energy in the RTPC gas they leave behind a trail of n_p individual electron-ion pairs. Some of the liberated electrons have enough energy to ionize other gas molecules, so the total number of pairs, n_t, is larger than n_p. Table 2 gives, for mips,

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† Particle Data Booklet

dE/dx, n_p, and n_t for our RTPC test gases. Note that n_p indicates how many localized clusters of charge one should expect over each cm of track length (i.e. how many bumps in the signal waveform, while n_t represents the total amount of charge (integrated signal current).

Gas	***[dE/dx]$_{mip}$ (keV/cm)***	***w_i (eV)***	***n_p (cm^{-1})***	***n_t (cm^{-1})***
He	0.32	41	4.2	8
DME	3.9	23.9	55	160
80/20 He/DME			**14.4**	**38.4**
Ar	2.44	26	23	94
CO_2	3.01	33	35.5	91
80/20 $ArCO_2$			**25.5**	**93.4**

Table 2. Ionization properties of RTPC gases at N.T.P. when exposed to minimum-ionizing particles.

The difference in the numbers of primary clusters (25 vs. 14) is probably not significant to us: both are certainly dense enough to appear to be continuous tracks. The total amount of released charge is some 2.5 times larger in $ArCO_2$ than in HeDME. We easily should be able to compensate for this difference by increasing the GEM gain. To date, however, we have not achieved good tracking of mips in any gas or test chamber.

Comparing the charge for mip tracks with the charge released by iron x-rays, we see that, in HeDME one x-ray releases the same amount of signal charge as 4.3 cm of track length. In $ArCO_2$ the x-ray equivalent track length is 2.3 cm. Our pRTPC has a tracking depth of 2 cm for radial tracks, so a radial track in HeDME generates about 46% of an x-ray equivalent charge. In $ArCO_2$ the fraction is 87%.

Electrons from x-rays are created within a small volume and arrive at the first GEM in a blob with radius of order 1 mm. Ionization from through-going radial tracks, on the other hand, have an extent as large as the radial depth of the tracking volume. Thus the signal current for tracks would be about 5% (1 mm / 20 mm) of the signal current for x-rays if the same amount of charge were involved. Given the differing amounts of ionization, however, the signal current for tracks in $ArCO_2$ is roughly 4% of the signal current for x-rays, while in HeDME the ratio must be about 2%. If we want the average signal from tracks in HeDME to appear in the middle of our ADC range (500 counts), we need to adjust the overall system gain so that x-ray signals appear huge in the ADC (25000 counts!).

To compare signal currents from mip tracks in HeDME with those in $ArCO_2$ we have to consider both that the total charge in HeDME is ~2.5 times smaller than in $ArCO_2$, and that the drift velocity in HeDME is some 2 times slower than in the other gas. The electrons arrive at the first GEM over different time intervals. Thus the HeDME signal current should be about 2x2.5=5 times smaller than the $ArCO_2$ signal current.

TUNL Protons

The energy loss per unit length for 5 (10) MeV (kinetic energy --100 to 140 MeV/c momentum) protons is 30 (20) times larger than for mips. Thus the number of electron-ion pairs is greater by the same factor. This is the reason that our TUNL data has (and our BoNuS data will have) such large signals and dense tracks.

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[1] A. Sharma, Properties of Some Gases Used in Tracking Detectors (http://www.slac.stanford.edu/pubs/icfa/summer98/paper3/paper3.pdf)

[2] NIST data from http://physics.nist.gov/PhysRefData/XrayMassCoef/tab3.html