Resistivity measurements of insulators at very cold temperature

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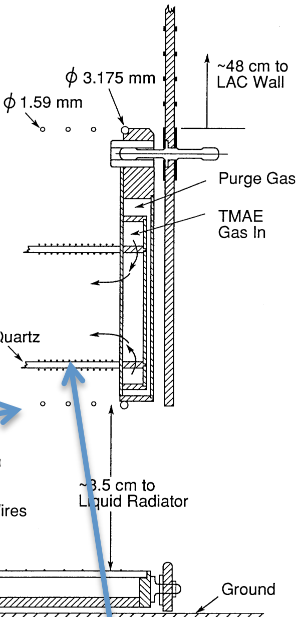
Fermilab, Nov.8, 2013

A few overall comments

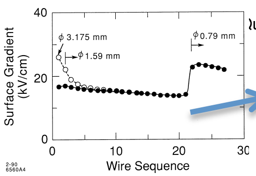
- How do TPC structures in LAr or LXe cryogenic experiments differ from TPC designs ~20 years ago, such as LBL TPC, CRID, DELPHI (which used to work well) ? **What is different ?**
- **First:** New TPCs use plastic materials, such as Teflon or polyethylene. As we will see, they have a volume resistance of $>10^{19}$ Ωcm at room temperature, 10^{24} - 10^{25} Ωcm at LXe temperatures, and 10^{27} - 10^{28} at LN_2 temperature. This is an astronomical increase compared to what was used before. Will high resistivity insulators charge up uniformly at cold temperatures, and if they will not, would surface gradients adjust abruptly while producing light ? What are time constants involved in these instabilities ? Does this concern matters ?
- **Second:** There are some significant conceptual design changes in new TPCs.

CRID TPC vs. typical LAr or LXe TPCs

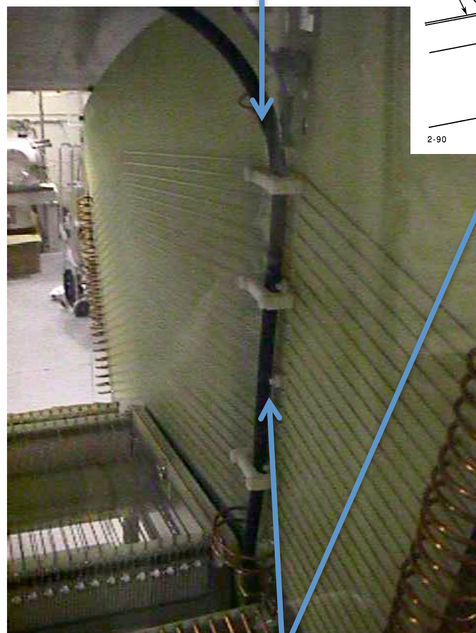
CRID TPC HV design:

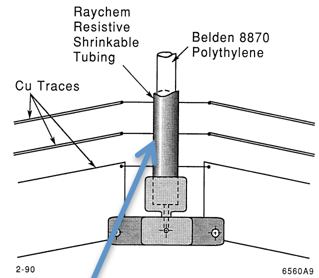


Wire gradients:

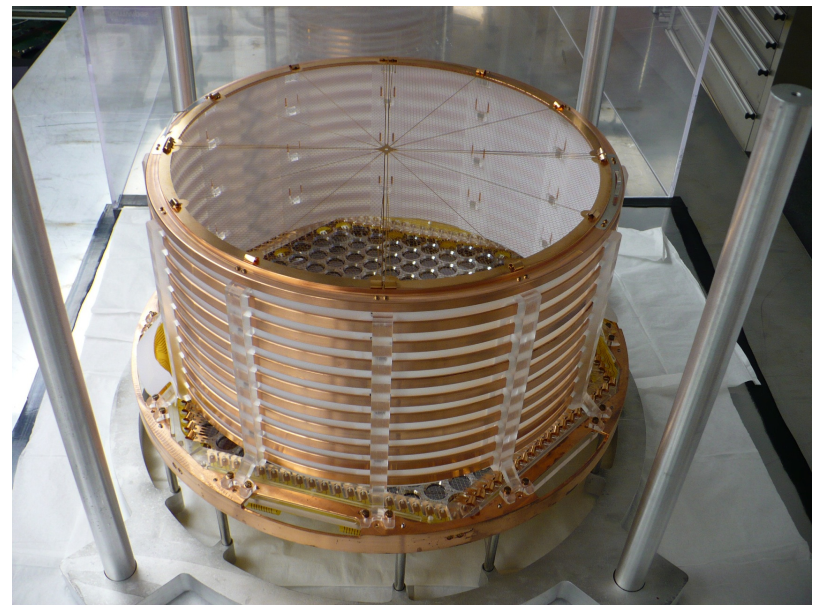


HV ground jacket ends





EXO LXe TPC HV design:



Drift field defining Cu-Be electrodes both sides of quartz window

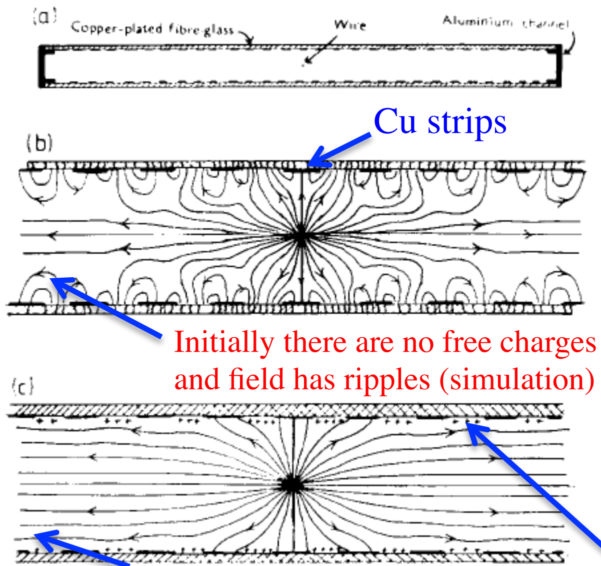
Raychem resistive tubing grades Polyethylene uniformly

- **CRID: Quartz and HV cable entry potentials were controlled very carefully. It was totally unacceptable to have electrodes only on outside of quartz windows.**
- **EXO, LUX, LZ, Darkside: Teflon is located on the inner side of the HV copper grid.**

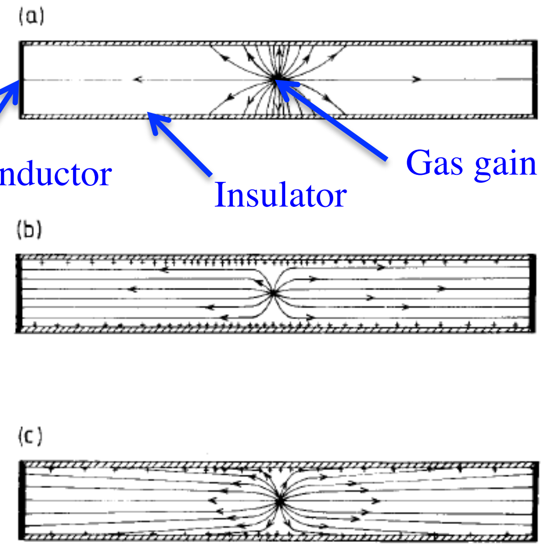
Electrodless chambers – is there some lesson ?

J. Allison et al., NIM 201(1982)341

1) Initial design with Cu electrodes:



2) Totally electrodless chamber (no Cu strips):



- Allison solved the problem analytically using the Laplace equation: **drift field quality is controlled by the deposition of positive ions on insulating surface.** Production of ions by wire amplification was essential to achieve the drift field uniformity. He used a fiber glass boards with volume resistivity of ~3×10^{14} Ωcm and surface resitivity of ~10^{12} Ω/square (Manufacturer's quote), but based on their measurement of time constants, the resistivity values were ~1000 larger, he says in the paper.
- **As we will see, resistivity of insulators in noble liquids are astronomical compared to Allison's values. Does it matter ?** Clearly, time constants will be much longer. His few seconds would become ~10^6 - 10^8 seconds, i.e., his detector would not work.

Setup to measure samples at cold temperature

http://www.slac.stanford.edu/~jjv/activity/dark/Vavra_Volume_resistivity_at_cold_temperatures.pdf

(a) (b)

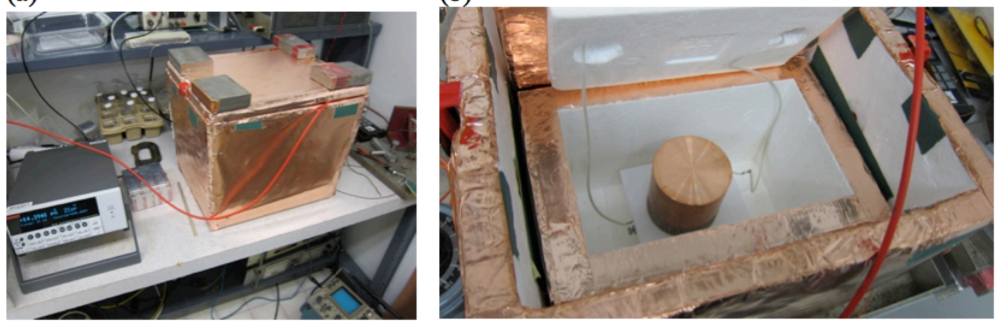


Figure 1: (a) Setup to measure the volume resistivity of samples using the Keithley 6517B instrument. (b) Double-shielded enclosure, LN_2 is put into the inner vessel.

(a) (b)

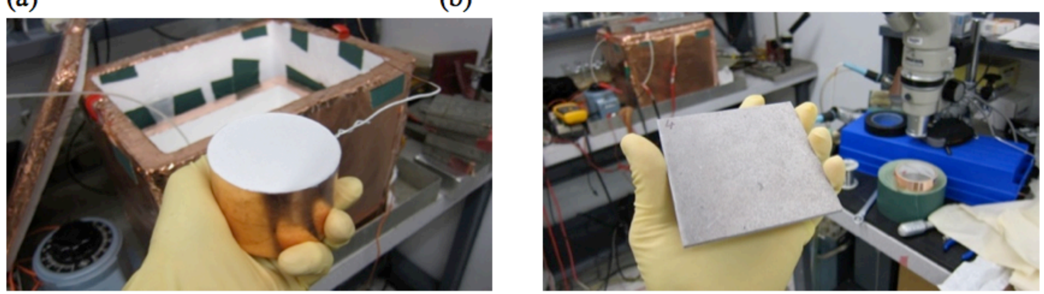
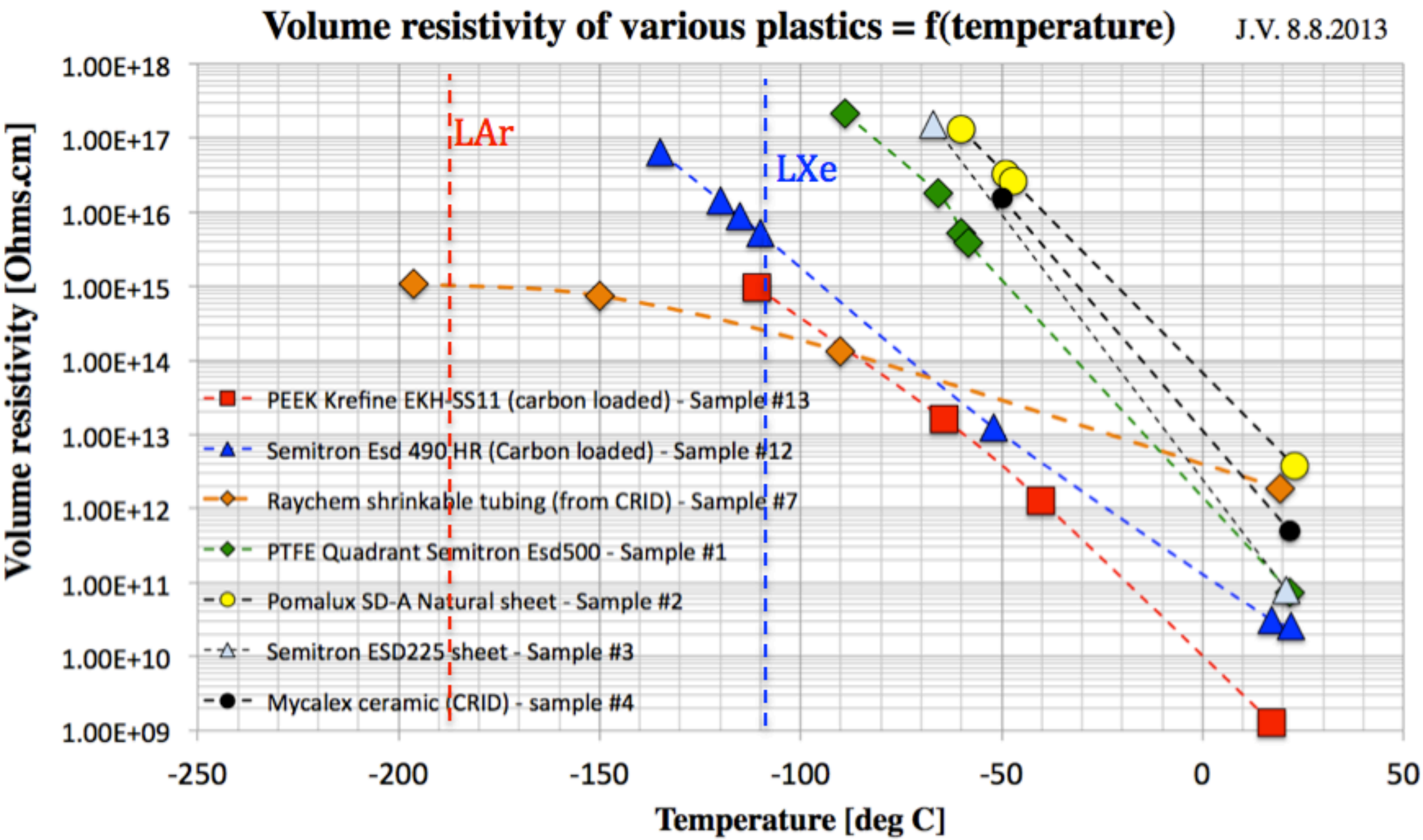
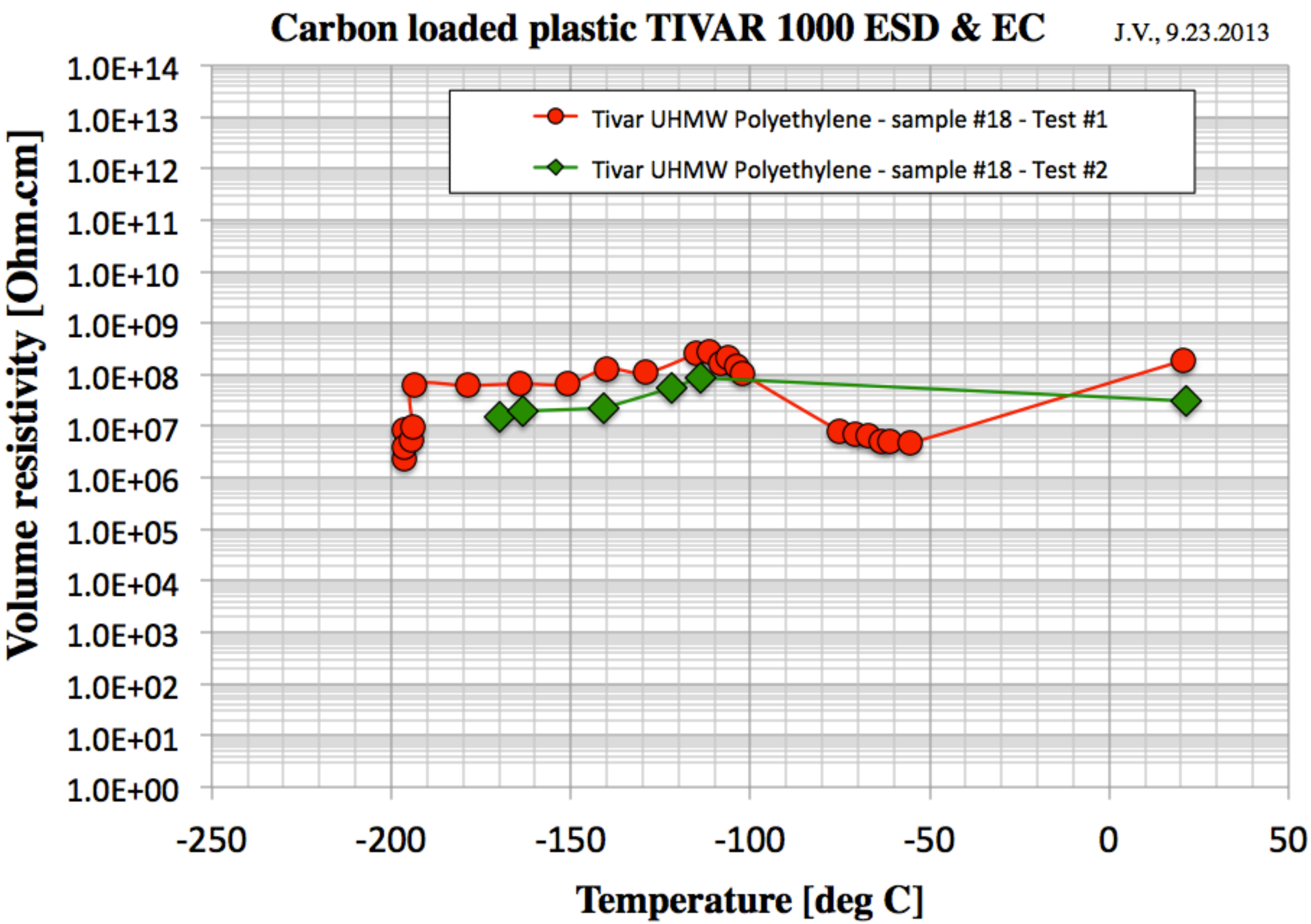


Figure 2: (a) Copper electrodes were plated by ~0.010"-thick Indium to keep a soft contact to the sample even at LN_2 temperature. (d) A typical sample – in this case a sheet of Mycalex.

- **A simple setup.**
- **Good up to volume resistivities of ~3x10^{18} Ωcm, limited by ~ ± 0.2pA sensitivity.**
- **Cannot measure very long time constants in this setup.**



- **Method: Cool the sample to a LN_2 temperature, and then measure as the resistivity of the sample as it slowly warms up.**



- **Very low resistance, which is nearly independent on temperature.**

Summary of results

http://www.slac.stanford.edu/~jjv/activity/dark/Vavra_Volume_resistivity_at_cold_temperatures.pdf

Table 1: Volume resistivity measurements:

Sample	**Material**	**Volume resistivity at room temperature** (all done at 20-21°C) ρ [Ω.cm]	**Volume resistivity at low temperature** (LN_2: -196.4°C, LXe: -109°C) ρ [Ω.cm]
1	Semitron ESd 500 (PTFE) (0.29"-thick) [3] [14]	7.5×10^{10}	>> 10^{18} at -196.4°C ≥ 10^{18} at -109°C
2	Pomalux SD-A natural (0.092"-thick) [4]	3.8×10^{12}	>> 10^{18} at -196.4°C >> 10^{18} at -109°C
3	Semitron ESd 225 (0.052"-thick) [5]	8.0×10^{10}	>> 10^{18} at -196.4°C >> 10^{18} at -109°C
4	Mycalex sheet (0.130"-thick) [6]	5×10^{11}	> 10^{18} at -196.4°C
5	Bakelite sheet (0.080"-thick)	1.0×10^{12}	> 1.5×10^{17} at -196.4°C
6	**Raychem shrinkable tubing (from CRID days) (0.050"-thick) [7]**	**1.9×10^{12}**	**~ 1×10^{15} at -196.4°C** **~ 3.5×10^{14} at -109°C**
7	Teflon PTFE (0.030"-thick) - from EXO exp.	> 4×10^{18}	>> 10^{18} at -196.4°C >> 10^{18} at -109°C
8	Fused silica sheet (0.125"-thick)	~2.2×10^{18}	>> 10^{18} at -196.4°C
9	Mylar (0.005"-thick)	~2.1×10^{18}	>> 10^{18} at -196.4°C
10	Acrylic sheet used in EXO test (0.057"-thick) [8]	~4.0×10^{18}	>> 10^{18} at -196.4°C
11	Raychem, RNF-100-4-BK-STK (0.023"-thick) [9]	~7×10^{18}	>> 10^{18} at -196.4°C
12	**Semitron ESd 490HR (0.046"-thick) [10]**	**2.6×10^{10}**	> 10^{18} at -196.4°C **~ 5.2×10^{15} at -109°C**
13	**PEEK Krefine EKH-SS11 (0.042"-thick) [11]**	**8.6×10^{9}**	> 10^{18} at -196.4°C **~ 1×10^{15} at -109°C**
14	Raychem, MWTM-115/34-1500/U (0.04"-thick) [12]	> 6×10^{17}	>> 10^{18} at -196.4°C

- **Raychem shrinkable tubing, Semitron Esd 490HR and PEEK Krefine EKH-SS11 have good resistivity behavior.**

Summary of results

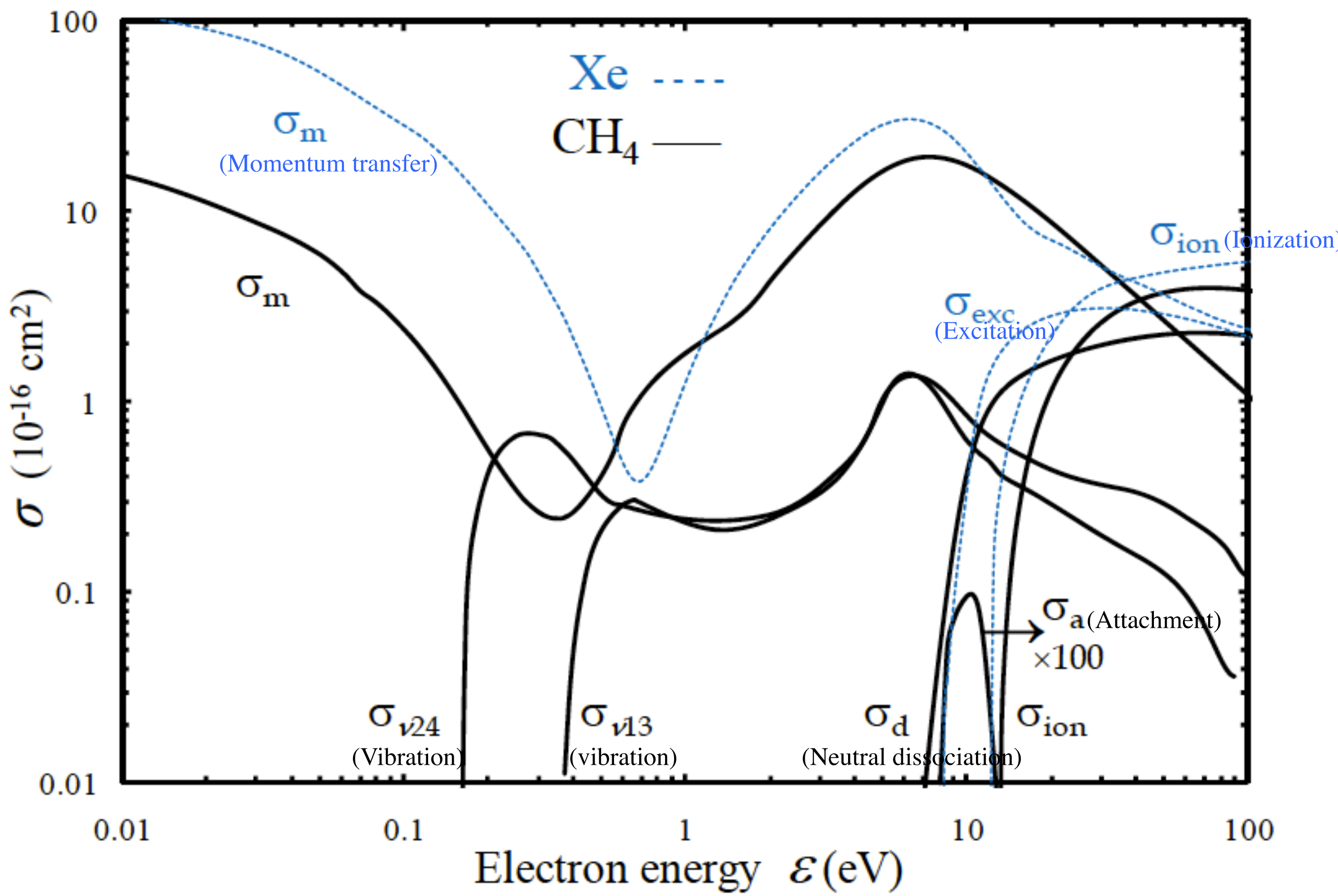
Continue Table 1:

15	Rexolite (0.035" thick) [13]	>3 x10^{18}	>> 10^{18} at -109°C
16	PVC (0.043" thick) [13]	>3 x10^{18}	>> 10^{18} at -109°C
17	LDPE (0.039" thick) [13]	>3 x10^{18}	>> 10^{18} at -109°C
18	**TIVAR 1000 ESD & EC (0.046" thick) [14]**	**10^{7} - 10^{8}**	**10^{7} - 10^{8} at -109°C**
19	Delrin (0.041" thick) [13]	~5.8 x10^{16}	>> 10^{18} at -109°C
20	Polycarb (0.041" thick) [13]	>3 x10^{18}	-
21	Polypro (0.044" thick) [13]	>3 x10^{18}	-
22	Ultem (0.040" thick) [13]	>3 x10^{18}	-
23	Peek (0.043" thick) [13]	>3 x10^{18}	-
24	Teflon (0.041" thick) [13]	>3 x10^{18}	-
25	Acrylic (0.040" thick) [13]	>3 x10^{18}	-
26	Cast-33 glue (cure 26, TFE) (0.064" thick) [13]	**7.8 x 10^{12}**	>> 10^{18} at -109°C
27	Insul Cast-502 (cure 26,TFE) (0.063" thick) [13]	**1.5 x 10^{16}**	-
28	Lord-340 glue cast (#70, 100-8) [13]	**1.3 x10^{15}**	>> 10^{18} at -109°C
29	CLR-1066/CLH 6330/TEE glue cast [13]	**7 x10^{15}**	-
30	CAST-502 clear, Insulcure-26, BYK-A-500 glue [13]	**6.4 x10^{16}**	-
31	Hysol Dexter glue cast (0.057" thick) [13]	**2.5 x10^{15}**	>> 10^{18} at -109°C
32	Sample 2 glue cast (0.060" thick) [13]		
33	Sample 3 glue cast (0.062" thick) [13]		
34	Sample 4 glue cast (0.059" thick) [13]		

- **All non-carbon loaded glue casts have a very high volume resistance at LAr or LXe temperatures. TIVAR 1000 ESD is carbon loaded.**

Electron-Xe scattering cross-sections

(J. Escada et al, JINST, Aug. 2007)



- **Electron has to reach only 8-9 eV to start producing an excititation in Xe, it needs ~20 eV to start ionizing. It does not take much and Xe TPC will be full of light.**

It seems to me that we have to answer a few questions:

- **Is it safe to have high resistivity material within TPC active volume ?**
- **What are time constants involved if the electrostatic balance is upset by some discharge ?**
- **Are there surface charge adjustements with accompanied light production ?**