Princeton/BaBar/TNDC-96-53
C. Lu, K.T. McDonald and A.J.S. Smith
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Choice of Drift Chamber Sense Wire

Summary

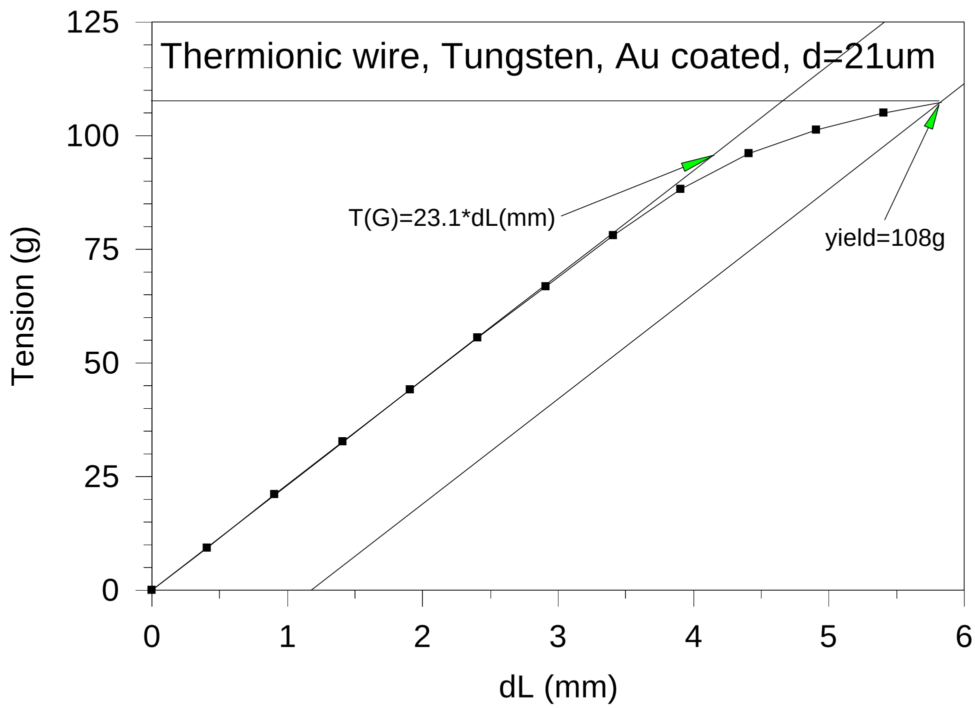
We surveyed three candidates for the sense wire, all nominally 20-μ-diameter, gold-plated tungsten wire:

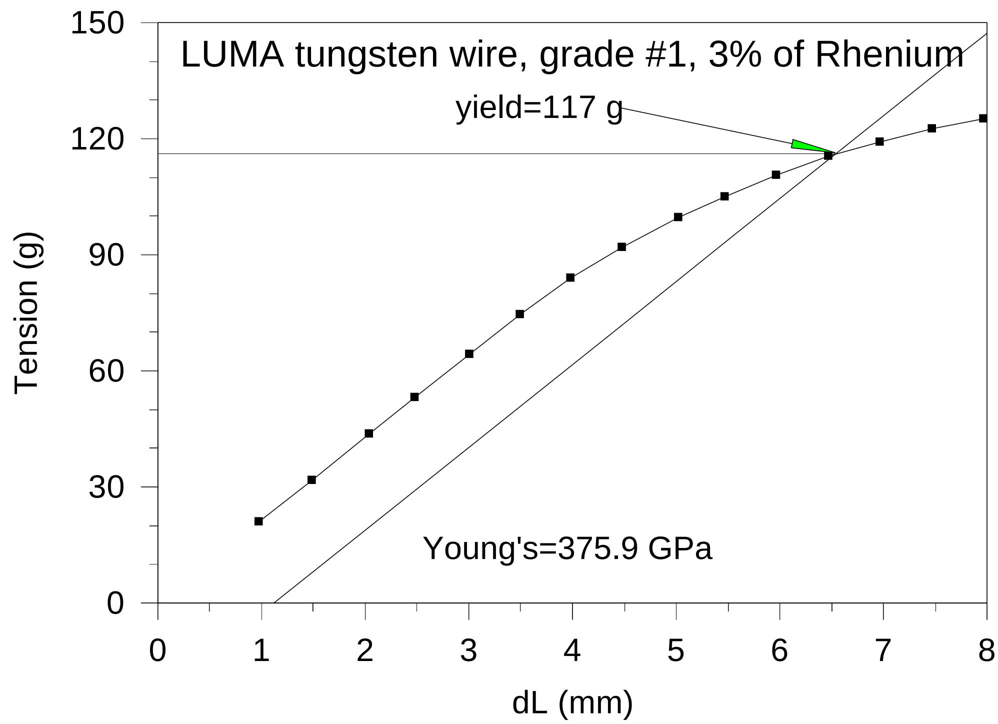
- Thermionic Products.
- Luma 861, 3% rhenium, straightness grade 1.
- Luma 861, 3% rhenium, straightness grade 2.

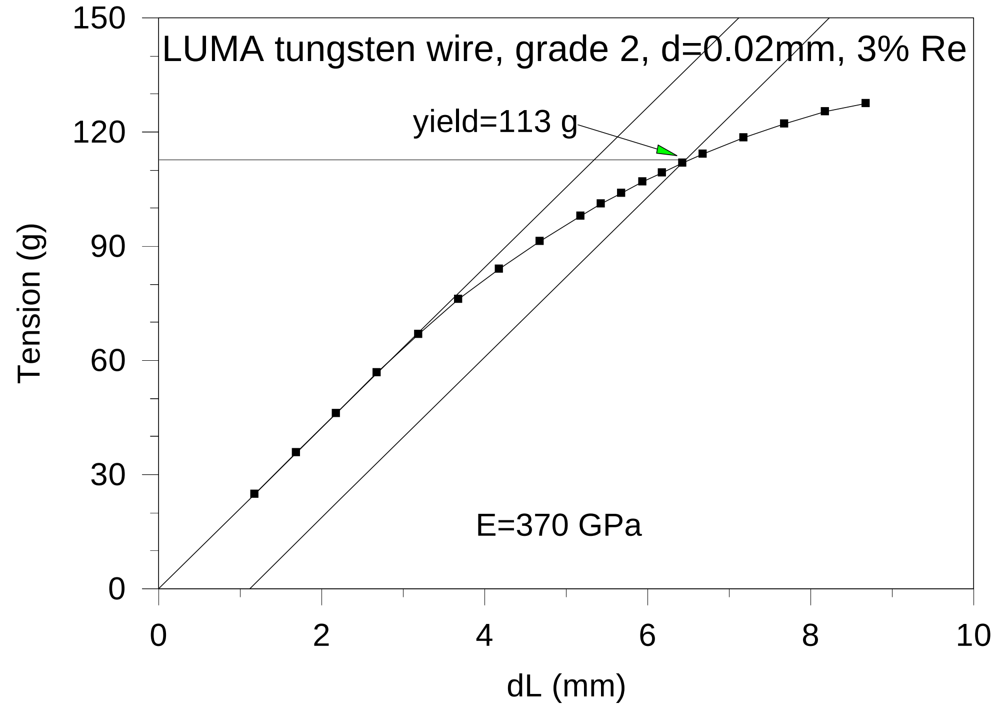
Luma 821 wire (without rhenium) has too low a yield strength to be considered.

We recommend ... (recommendation still pending).

1 Yield Curves

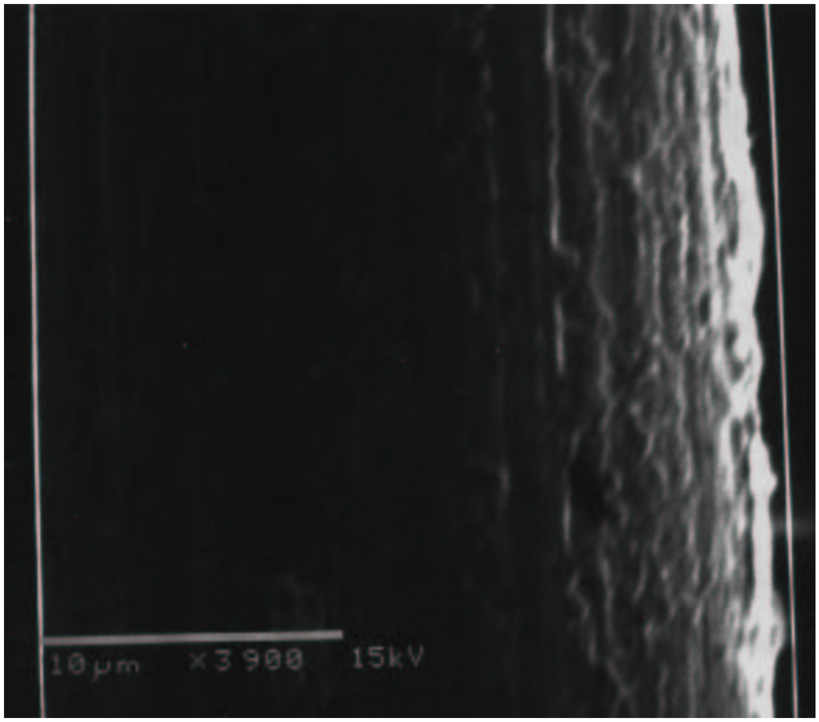




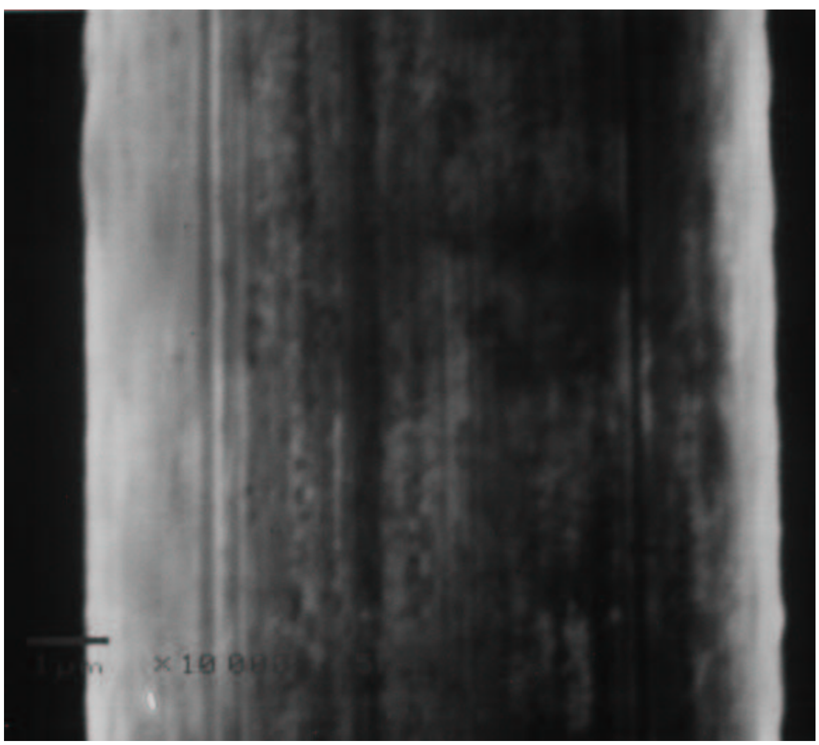


All three candidate wires appear to have adequately high yield strengths.

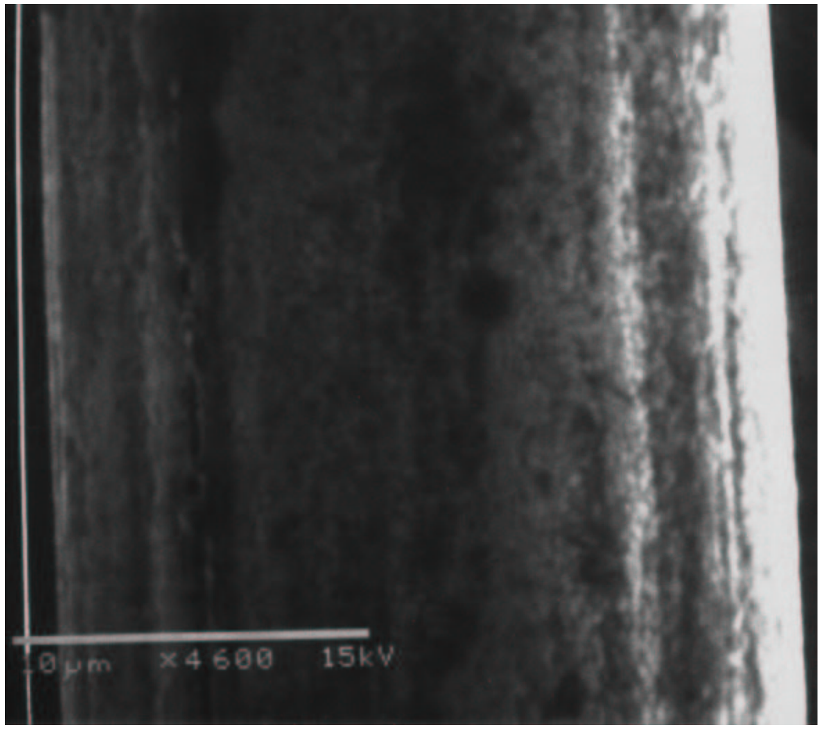
2 Electron Micrographs



Above, Thermionic Products wire.



Above, Luma grade-1 wire.



Above, Luma grade-2 wire.

As has been noted before, the surface quality of the Luma wire appears superior to that of the Thermionic Products wire.

3 Curliness

All three candidates satisfy the formal straightness requirement we used for the field wires: a 1-m length of wire suspended vertically with a 1-g weight must not deflect more than 1 cm horizontally. It turns out that this is a very loose requirement. That is, even wire that curls badly under no load will straighten well under a 1-g load.

Therefore we devised a more stringent curliness test: Suspend a 1-m length of wire vertically with no additional load, and measure the height the free end rises above the ideal. A smaller rise corresponds to a less curly wire. Results:

Wire	Rise
Thermionic Products	2 mm
Luma, grade 1	3 mm
Luma, grade 2	50 mm

By this measure Luma grade 2 wire is less desirable than either the Thermionic Products or the Luma grade 1.

4 Buckling

We must be able to thread the wire through the stringing needle, which is easier if the wire is stiffer. As a measure of stiffness we devised the following test: a wire sample is clamped with 25 mm projecting vertically downward below the clamping point. The wire is lowered until it makes contact with the pan of a Mettler AT1005 balance. More precisely, the wire is lowered into a small conical indentation in an aluminum plate that rests on the pan of the balance. The indentation serves to keep the lower end of the wire from slipping sideways during the measurement. Finally, the upper end of the wire is lowered an additional 2.5 mm (10% of the length of the free wire) and the force (reported in grams) required for this is recorded. We believe the measurements are accurate to better than 0.1 mg. A larger force corresponds to a stiffer wire. Results:

Wire	Buckling Force
Thermionic Products	5.7 mg
Luma, grade 1	5.8 mg
Luma, grade 2	2.6 mg

This test provides a measure of the longitudinal force needed to buckle the wire into a bow shape. Thus it is a variant of the Euler buckling criterion.

The results indicate that the Thermionic Product wire and the Luma grade-1 wire are equally stiff, and both significantly stiffer than Luma grade-2 wire.

5 Choice of Wire Diameter

The nominal sense wire diameter is 20 μm. The sample of Thermionic Products wire that we obtained has a diameter about 20 μm (as measured with a Mitutoyo model 293-701 digital micrometer), while the Luma grade-1 3%-rhenium wire has a diameter of about 19 μm.

5.1 Measurements of Wire Resistance

The measured resistance of the Thermionic Products wire is 187 Ω/m, while that of the Luma grade-1 3%-rhenium wire is 281 Ω/m. [Luma grade-1 wire without rhenium has a resistance of 187 Ω/m.]

Calculation indicates that a pure tungsten wire of 19-μm diameter should have a resistance of about 200 Ω/m. We infer that the gold coating reduces the resistance slightly, but the 3% rhenium increases the resistance significantly. The resistivity of rhenium is about four times that of tungsten according to one handbook. (We may be able to use these facts to make measurements of the thickness of the gold coating on the tungsten wire.)

5.2 Effect of Wire Resistance on the Readout Electronics

BaBar Note #262 by W. Innes (Nov. 3, 1995) argues that sense wire resistance is a key parameter in chamber performance. He suggests that the dominant source of front-end noise is not in the pre-amp but is due to the wire resistance, and noise $\propto \sqrt{R_{\rm wire}}$. In the same approximation, the drift-chamber timing resolution varies as $\sqrt{R_{\rm wire}}$ when the signal-to-noise ratio is small.

Accepting the above statements (which are not self-evident) for purposes of further discussion, the use of the Luma grade-1 3%-rhenium 20-μm wire rather than the Thermionic Products wire would result in 23% worse timing resolution for a fixed chamber gain. More accurate estimates can be made with program DCSIM, in which the frequency dependence of the noise is included.

5.3 Options for Luma Wire

We could recover the lost resolution in either of two ways:

1. Raise the chamber voltage until the gain is $(1.23)^2 = 1.5$ times larger.

   We calculate below that increasing the gas gain from 5×10^4 to 7.5×10^4 would require increasing the chamber voltage from 1685 V to 1727 V, which would be a relatively minor change.

   However, the increased gain would imply an increased chamber aging rate, which may be undesirable.

   Also, the higher wire resistance would be less than optimally matched to the characteristics of the pre-amp (D. Dorfan).

2. Increase the wire diameter until the resistance is 187 Ω/m.

   If we used 25-μm diameter Luma grade-1 3%-rhenium wire its resistance would be $281(20/25)^2 = 180$ Ω/m. To keep the gas gain at 5×10^4 we would have to raise the chamber voltage from 1685 to 1753 V.

   The aging rate would likely be 20% less because while the current remains the same the wire surface area has increased by 25%. Hence the chamber life would be 20% longer.

   A thicker wire would be stiffer, and therefore easier to handle during stringing.

   The thicker wire would be more robust mechanically. Its yield strength would now be about 166 gm. This would provide a greater margin of safety against breakage during stringing and crimping.

   Of course, the wire tension would have to be raised from 34 to 49 gm to maintain the same sag and electrostatic stability, adding a total of 107 kg to the present wire load of 3500 kg.

   Use of a 25-μm-diameter sense wire rather than 20 μm would increase the number of radiation lengths in the chamber volume by 5% as summarized in Table 1. [Changing the gas mixture to 83/17 helium/isobutane would reduce the number of radiation lengths by 5%, and would lower the operating voltage of the chamber by about 100 volts.]

   [In view of the various reasons listed above SLD chose to use a 25-μm sense wire rather than 20-μm (C. Prescott).]

Table 1: Summary of radiation lengths in the drift chamber volume.

Material	Rad. Len. ($\times 10^3$)	Rad. Len. ($\times 10^3$)
Sense wire	0.20	0.30
	(20 μm)	(25 μm)
Field wire (Al)	0.57	0.57
Field wire (Au)	0.25	0.25
Clearing wire (Al)	0.12	0.12
Clearing wire (Au)	0.08	0.08
Helium (90%)	0.08	0.08
Isobutane (10%)	0.64	0.64
Total	1.94	2.04

5.4 Calculation of Gas Gain

In support of comments above we calculate the gas gain.

A model of gain for a 80/20 mixture of helium-isobutane was reported by M.A. McDougald in TNDC-96-51 (Nov. 20, 1996), based on measurements taken with the BaBar Prototype I drift chamber.

The results are summarized as parameters of a 'Diethorn fit', namely $\Delta V = 33.9$ volts = energy a drift electron must have to ionize a gas atom, and $E_0 = 31.8$ kV/cm = minimum field strength for gas gain. In Diethorn's model the first Townsend coefficient is directly proportional to the field strength.

We approximate the drift chamber cell as a cylinder of radius $b = 0.75$ cm. The sense-wire radius is called a and is taken as either 0.001 or 0.00125 cm. For a given voltage V on a cell the electric field varies with radius r as

$$E = \frac{V}{r \ln(b/a)}.$$

The radius at which gas gain commences is called r_0 and is given by

$$r_0 = \frac{V}{E_0 \ln(b/a)}.$$

The gas gain G is then given by Diethorn as

$$G = \exp\left[\frac{r_0 E_0 \ln 2}{\Delta V} \ln \frac{r_0}{a}\right].$$

This expression was used to calculate the numbers in the preceding section.

The Prototype I results are also fairly well fit by an extrapolation of measurements made by us on related gas mixtures. For example, we measured the first Townsend coefficient of a 95/5 mixture of helium and isobutane at atmospheric pressure to be

$$\alpha = A + BE = -80.56 + 0.0242E,$$

for electric field E measured in volts/cm [C. Lu, K.T. McDonald and Y. Zhu, Nucl. Instr. and Meth. **A334**, 328 (1993)]. For pure isobutane our fit was

$$\alpha = -1960 + 0.0242E,$$

No gas gain occurs until the electric field exceeds

$$E_0 = -A/B,$$

which is 3329 V/cm for the 95/5 mixture and 81 kV/cm for pure isobutane. That is, gas gain sets in at much lower field strength in mixtures with significant amounts of helium.

A simple interpolation of parameter A in the two fits gives

$$\alpha = -418 + 0.0242E,$$

for an 80/20 He-isobutane mixture, with corresponding $E_0 = 17.3$ kV/cm.

As electrons drift in to smaller radii their number n increases according to

$$\frac{dn}{dr} = -\alpha n = -n(A + BE) = -n\left(A + \frac{Br_0E_0}{r}\right).$$

The solution of this differential equation evaluated at $r = a$ is the gas gain G:

$$G = \exp[A(r_0 - a)] + Br_0E_0 \ln(r_0/a)]$$

This expression gives very similar results to the Diethorn formula. Indeed, we see that our parameter B corresponds to $\ln 2/\Delta V$ in Diethorn's model. In this interpretation, our estimate of ΔV would be 28.6 V. As noted above, Diethorn takes parameter A to be zero.

The dependence of the gain on chamber voltage is readily shown by noting that r_0 is directly proportional to V, so

$$\frac{dG}{G} = Br_0E_0 \ln(r_0/a)\frac{dr_0}{r_0} = Br_0E_0 \ln(r_0/a)\frac{dV}{V}.$$

Equivalently,

$$G \propto V^{Br_0E_0 \ln(r_0/a)}.$$

For a gas gain near 5×10^4 the gain varies as the 17th power of the voltage.