Comments on Linear Collider Tracking 1
“The LC is expensive; the detector should be also”

/home/dpp/dr3/LC/tex/LCtracking_1.tex
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Tracking at the Linear Collider will be challenged by both high track densities and large backgrounds. There is a prevailing viewpoint that a TPC is required to overcome the resultant pattern recognition problems. The attraction of a TPC is that it provides three dimensional space points while drift chambers (including jet chambers) only provide two dimensional points. In a drift chamber, the entire event is projected onto the endplate. Using the three dimensional points in a TPC, full event pattern recognition can be decomposed into the pattern recognition within many semi-independent polar angle slices that each have greatly reduced noise and track density. But, TPCs are very complicated. Electric field distortions can limit the resolution. There is nothing like a drift chamber wire position to anchor the calibration. In addition, the useful z segmentation of a TPC, especially at small radius where the backgrounds are most severe, may not be as great as expected and azimuthal segmentation in a TPC (with induction read-out) is poorer than in a drift chamber. What should we do?

In this note, I try to compare the pattern recognition of different detectors based on the detector segmentation and the beam structure. I conclude that a CLEO-style drift chamber can provide similar pattern recognition capability when compared to a TPC (with induction read-out) at TESLA. In contrast, a drift chamber can not be operated at the NLC if the beam related backgrounds are as feared; the NLC beam structure is optimally bad.

A TPC with a read-out employing a new technology gas amplification device, ie a GEM or MicroMegas can provide significant improvement in pattern recognition because of an order of magnitude reduction in signal overlap. This is the driving motivation for the GEM or MicroMegas readout.

I conclude that the momentum resolution of a TPC can match that of a drift chamber only if the TPC has a GEM or MicroMegas readout. The technology to reach the momentum resolution goal in a drift chamber may be more straightforward, but not pleasant.

Other problems associated with building a very large drift chamber for a linear collider are discussed. The wire sag and endplate load increase with chamber size, but wire tension, wire size, and voltage are relatively fixed. There is a limit to the size of a CLEO-style drift chamber. I conclude that a drift chamber can be built up to 4 meters total length but the magnetic field, without DME, is limited to 3 Tesla. A drift chamber can be operated at 5 Tesla, but only with the problems associated with DME.

Issues that I do not understand are noted.

z and azimuthal segmentation and resolution in a TPC

ALEPH provides a good example of an induction readout TPC. Information can be found on a web page, http://alephwww.cern.ch/SUBDET/tpc.html. The latest and greatest TPC is at STAR and was described in a 2001 Vienna Instrumentation Conference talk.
By “segmentation”, I refer to the detector width that is exclusively used by an ionization signal. It is a measure of the ability to separate tracks from other tracks and noise. This is different than “resolution”, which is a measure of the quality of the position measurement.

In a TPC, primary ionization drifts to the endplates where it is detected by a 2-dimensional detector, typically a multi-wire-proportional-chamber with pad readout. The 2-dimensional detector provides \( r - \phi \) information while the drift time provides \( z \) information.

Z segmentation width in a TPC is limited by the pulse time width and by the longitudinal spread of the primary ionization. The ALEPH TPC has an electric field of 11kV/m over a drift distance of 2.2m in Ar-ethane (91:9) gas. Although an impressive potential, this is a much smaller electric field than in a drift chamber (300kV/m) but the velocity, 52 mm/\( \mu s \), is similar. The signal pulse FWHM is 300ns for a 1 meter drift. Given the drift velocity, this imposes a lower limit on the Z segmentation width, for radial tracks, of 16 mm. Because ALEPH reports a diffusion contribution of 4 mm/\( m^{1/2} \) (\( \sigma \)), or 10 mm FWHM at 1 meter drift, the remaining component of the signal pulse width must be due to electronic signal shaping. The read-out sampling rate, 11.4 Mhz, is consistent with the shaping width in that it corresponds to a distance of 4.5 mm, about half of the shaping width.

For large dip angle tracks, the Z segmentation width is limited by the longitudinal spread of the track that projects onto the pad height of the 2-dimensional detector, \( H_{\text{pad}} \cdot \cot(\theta) \) in Figure 1. The pad height in the ALEPH TPC is 30 mm while in the STAR TPC it is 20 mm. With 20 mm pad height, the Z segmentation width component is equal to 16 mm for \( \cos(\theta) = 0.62 \) and increases to 32 mm at \( \cos(\theta) = 0.85 \). The average combined Z segmentation width is 20 mm for 85% of the solid angle. Z resolution is much smaller, about 1 mm in the ALEPH TPC, because the signal pulse is sampled.

The azimuthal pad spacing is 6.2 mm in the ALEPH TPC while it is 6.2 mm (2.85 mm) in outer (inner) layers of STAR. ALEPH reports 180\( \mu \)m resolution in azimuth, 2.9% of the pad spacing. STAR reports 500\( \mu \)m resolution, 8% of the bigger pad spacing and 17% of the smaller pad spacing.

The azimuthal segmentation is dependent on the readout method. In TPCs that have been installed in major detectors, readout is of induction signals on pads. Gas amplification is produced by an avalanche on an anode wire as in a drift chamber. The pulse width is characteristic of an induction signal, not the pad size. STAR reports a “2-track resolution” of 25 mm; I consider this to be the same as azimuthal segmentation width. It is important to

![Figure 1: The longitudinal spread of the track determines the z segmentation at large dip angle.](image-url)
note that, when two tracks fall within the same $r$-$\phi$-$z$ volume cell in a TPC, hit information from both tracks is lost.

A GEM or MicroMegas readout can provide significant improvement in azimuthal segmentation. With these gas amplification devices, the signal is due to electron collection on the pad rather than through induction. Therefore, the segmentation width can be reduced to the pad size with a limit of about 500$\mu$m. For example, the pad width, and therefore the azimuthal segmentation width, could be set to 3 mm. Now we are talking about 400,000 pads, each with 560 buckets of pulse height information, 220 million capacitors.

As stated in the “Linear Collider Resource Book For Snowmass 2001”, page 398, proponents “assume” 150$\mu$m spatial resolution. The reference to the baseline detector is Mike Ronan’s LC-TPC talk at the 2001 Vienna Instrumentation Conference where it states that 150$\mu$m resolution is “required” to achieve the momentum resolution goal. It is assumed because it is required. While this goal does not appear aggressive when compared to the 180$\mu$m resolution achieved by ALEPH, the ALEPH resolution is surprisingly good considering CLEO typically hopes for resolution equal to 10% of the pad spacing in the drift chamber cathodes. They must have very good signal-to-noise. I do not know if there is something significantly different about the ALEPH anode-pad geometry or the gas amplification when compared to CLEO cathodes. In contrast, the STAR resolution is consistent with the CLEO cathodes.

Resolution should be improved with the smaller azimuthal segmentation width of a GEM or MicroMegas readout. Naively, when ions are collected on single 3 mm pads, the resolution would be 800 $\mu$m. However, speakers at Chicago showed much better resolution, presumably using smaller (and more) pads and/or compromising some segmentation by spreading the charge collection. Slides from Mike Ronan’s LC-TPC talk at the 2001 Vienna Instrumentation Conference appear to indicate that the best resolution, 60 $\mu$m, was achieved with 1 mm pads and/or only for that fraction of events in which the collected ionization falls on multiple pads.

**z and azimuthal segmentation and resolution in a drift chamber**

Drift chamber azimuthal resolution can be 88$\mu$m in a 1.5 Tesla magnetic field. (This is CLEO DR3, 80% core of distribution, full cell.) Z resolution is equal to (azimuthal resolution)/TANSCD. (The factor, “TANSCD” is CLEO-tracking-jargon, and is 0.03 in CLEO DR3 stereo wires and 0.1 in the ZD.)

There is no Z segmentation in a drift chamber. Charge division offers no help because it fails in a noisy environment. Even in a quieter environment, while charge division provides an independent z measurement of a hit, it does not provide segmentation because it does not allow multiple signals.

The azimuthal segmentation width in a square cell drift chamber is simply the wire spacing. For a CLEO-style chamber, this azimuthal segmentation width is 14 mm. In a jet chamber, parallel field lines reduce the spread of the charge collection time which allows the collection of multiple hits. The CDF jet chamber has 8.8 mm maximum drift but the 2-track separation is 4 mm. (CDF TDR, Nov. 96, p 4-17) If this is, indeed, the single sided “dead space” (pulse width times drift velocity) as appears to be indicated in the text, this value must be multiplied by 2 to obtain a segmentation width of 8 mm; the cell is dead for the
duration of the pulse width on both sides of the wire. There is a note that this result does not depend on “improvements in pulse shaping” and there is a recollection (by Jon Lewis, Jan 9, 2002) that the single sided “dead space” is only 2 mm. Therefore, the segmentation width may be as low as 4 mm.

In contrast to the case of the TPC, when two tracks create signals within the same r-ϕ-z volume cell in a drift chamber, the first time signal survives. Therefore, for equal segmentation width, a drift chamber will provide better pattern recognition in high track density because there will be more available hits on each track.

Segmentation and resolution values from the above two sections are summarized in Table 1 along with additional information which was not discussed for all chamber types.

<table>
<thead>
<tr>
<th>Tracking Detector Resolution and Segmentation</th>
<th>for a 2.5 meter half-length detector</th>
<th>not corrected to 5 Tesla field</th>
</tr>
</thead>
<tbody>
<tr>
<td>drift chamber CLEO-style</td>
<td>jet chamber CDF-style</td>
<td>TPC induction readout</td>
</tr>
<tr>
<td>azimutal resolution</td>
<td>88 μm</td>
<td>180-500 μm?</td>
</tr>
<tr>
<td>z resolution</td>
<td>26 mm</td>
<td>1 mm</td>
</tr>
<tr>
<td>azimuthal segmentation width</td>
<td>14 mm</td>
<td>25 mm</td>
</tr>
<tr>
<td>hits retained, 2-track crossing</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>z segmentation width</td>
<td>5 m</td>
<td>20 mm</td>
</tr>
<tr>
<td>z segments</td>
<td>1</td>
<td>250</td>
</tr>
<tr>
<td>maximum drift time</td>
<td>0.25 μs</td>
<td>48 μs</td>
</tr>
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</table>

Table 1: Tracking detector resolution and segmentation for representative 2.5 meter half-length detectors. The TPC has significantly improved z segmentation at the expense of a longer live time. Values are as observed in current installations, CLEO in a 1.5 Tesla field and CDF in a 1 Tesla field.

**Pattern recognition in the presence of beam related noise**

Proponents of the TPC are planning for random noise occupancy of 1% of the r-ϕ-z volume cells. Pattern recognition in the TPC is simple with this level of noise. One would define θ-roads which point to the interaction point and which have z-widths of 1 or 2 z segmentation widths. Pattern recognition is a 2-dimensional problem within the θ-road. Noise would be at the level of 1 or 2%, depending on the chosen width. After cluster-finding in azimuth, one could use pattern recognition similar to the initial stage of DOIT, the “integer track finding” stage. There is no ambiguity to resolve; there are also no precision measurements from drift times.

With the same noise in a drift chamber volume, projected onto the 2-dimensional readout, pattern recognition is impossible. The occupancy scales as a ratio involving the z and azimuthal segmentation widths,
\[
\frac{(CLEO \, z \, \text{segmentation width})}{(TPC \, z \, \text{segmentation width})} \times \frac{(CLEO \, \text{azimuthal segmentation width})}{(TPC \, \text{azimuthal segmentation width})} = 140. \quad (1)
\]

For equal live times, this corresponds to 140\% occupancy accumulated on each CLEO-style drift chamber wire, and 80\% occupancy for CDF-style jet chamber wires.

However, the detector live times (equal to the maximum drift time) of drift chambers are shorter. This may lead to a reduction in the background depending on the bunch structure of the collider. The beam structures of the NLC and TESLA designs are given in Table 2 along with the detector live times. Note that the detector live times for the drift chambers is not the maximum drift time given in Table 1 because there has been an attempt to predict these times for operation in a 5 Tesla magnetic field. This will be discussed further in a later section.

<table>
<thead>
<tr>
<th>Bunch Structure and Live Time</th>
<th>NLC</th>
<th>TESLA</th>
</tr>
</thead>
<tbody>
<tr>
<td>train frequency</td>
<td>120 hz</td>
<td>5 hz</td>
</tr>
<tr>
<td>bunches per train</td>
<td>190</td>
<td>2800</td>
</tr>
<tr>
<td>bunch spacing</td>
<td>1.4 ns</td>
<td>340 ns</td>
</tr>
<tr>
<td>train spacing</td>
<td>8333 (\mu s)</td>
<td>200 ms</td>
</tr>
<tr>
<td>train width</td>
<td>0.266 (\mu s)</td>
<td>952 (\mu s)</td>
</tr>
<tr>
<td>train (width/spacing)</td>
<td>3.2\times10^{-5}</td>
<td>4.8\times10^{-3}</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>detector live time (5 Tesla)</th>
<th>drift chamber</th>
<th>jet chamber</th>
<th>TPC induction readout</th>
</tr>
</thead>
<tbody>
<tr>
<td>CLEO-style</td>
<td>0.5 (\mu s)</td>
<td>0.5 (\mu s)</td>
<td>48(\mu s)</td>
</tr>
<tr>
<td>CDF-style</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 2: Beam structures for the different collider technologies are significantly different and affect the amount of background integrated within a detector live time.

In the NLC design, the live times of a CLEO-style drift chamber and the TPC are both equal or greater than the train width and both are much less than the train spacing. (The bunch spacing is irrelevant; it is much shorter than either live time.) Both detectors will be exposed to the background generated by one train, 0.8\% of the beam delivered in one second. The shorter live time in a CLEO-style drift chamber provides no background reduction; noise occupancy will be 140\%.

The fast gas in a CDF-style jet chamber can not be used at 5 Tesla; the live time can not be reduced below the NLC train width. Noise occupancy will be 80\%.

In the TESLA design, the live times of both a CLEO-style drift chamber and a CDF-style jet chamber, are about equal to 1.5 bunch spacings. Both will be exposed to 2 bunches, 0.014\% of the beam delivered in one second. The live time of the TPC is 140 bunch spacings but is much less than the train width. (It is just a coincidence that (TPC drift time)/(TESLA bunch spacing) is equal to the ratio of the z and azimuthal segmentation widths described
earlier.) Therefore, the TPC will be exposed to the the background of 140 bunches (but still only 1% of the beam delivered in one second). Relative to the TPC, noise occupancy in a CLEO-style drift chamber would be reduced by a factor of 70, bringing it down to 2% or twice the noise level observed in a TPC θ-road (with θ-road width equal to 1 z segmentation width.) Noise occupancy in a CDF-style jet chamber would be reduced to 1.1%.

In summary, if installed in the NLC, noise affecting pattern recognition would be 140 times worse in a CLEO-style drift chamber, when compared to a TPC. The two tracking devices would have similar (within a factor of 2) noise if installed at TESLA. The exposure of the TPC during one live time, in terms of the fraction of the beam delivered in one second, is similar at the NLC and TESLA. However, I don’t know if the noise situation in either detector is acceptable or if both are acceptable. In particular, I don’t know

if the background per current is the same in NLC and TESLA,
if the current is the same in NLC and TESLA, or
why the noise occupancy in the TPC is expected to be 1% (volume).

Pattern recognition in the presence of high track density

Events at the linear collider are “jetty”. I have a sample event from Mike Ronan’s LC-TPC talk at the 2001 Vienna Instrumentation Conference. I count 14 tracks in one nice jet with a φ spread of 0.4 radians. This width is observed at the tracking inner radius of about 50 cm where there is minimal spreading due to track curvature. (Dimensions are not shown in the event picture, but the figure in the “Linear Collider Resource Book For Snowmass 2001”, page 400, shows the tracking chamber inner radius at 50 cm.) Additional spreading due to track curvature at a radius of 100 cm is only about 20%. The track spread in z should also be 0.4 radians. This will have to serve, for now, as my description of the average jet.

In the TPC, the azimuthal segmentation width is 25 mm (Table 1). At a radius of 50 cm, within a jet φ spread of 0.4 radians, there are 8 φ segmentation widths. The z segmentation width is 20 mm so, at the same radius, the jet covers 10 z segmentation widths. The jet envelope is round, not square, so there are 64 r-φ-z TPC volume cells in each inner layer shared by the 14 tracks in the jet. Most of the tracks will occupy unique r-φ-z TPC volume cells at the minimum detector radius and will have hit information. Note that tracks that cross the gaps between panels will not have hit information. The readout on the endplate is necessarily divided into panels because the anode and gating wires are straight segments. A GEM and MicroMegas might be built without wires but these devices are sheets of limited size also requiring the endplate to be divided into panels. To ensure that no track is completely lost, the gaps between panels can be made to not follow straight lines; the panels can look like jigsaw puzzle pieces. However, there must be gaps at the smallest radius and, therefore, some tracks will have no hits in this critical region.

Pattern recognition would be more difficult in a TPC at a radius of 25 cm. Within a jet φ spread of 0.4 radians, there are 4 φ segmentation widths and 5 z segmentation widths; there would be 16 r-φ-z TPC volume cells shared by the 14 tracks in the jet. Typically, half of the tracks would be merged in some way. Recall that when two tracks overlap, hits on both tracks are lost. Furthermore, the two tracks would continue to overlap over some radial extent so both tracks would have no hits for a significant length.

The above describes the case of a TPC with induction readout. As described earlier,
a GEM or MicroMegas readout provides significant improvement in the azimuthal segmentation width and, therefore, the jet resolution. With an azimuthal segmentation width of 3 mm, the number of TPC volume cells available to the 14 tracks would increase to 530. Hit efficiency at the minimum radius would be close to 100%, except in the gaps between panels.

A smaller inner radius would be usable in a CLEO-style drift chamber. In a CLEO-style drift chamber the azimuthal segmentation width is 14 mm. At a radius of 25 cm, over a jet φ spread of 0.4 radians, there are 7 φ segmentation widths (cells). There is no z segmentation. The 7 azimuthal drift chamber cells are shared by the 14 tracks in the jet. Typically, all cells are occupied, twice. At first, this sounds worse than the case of a TPC. But, when tracks cross within a segment in a drift chamber, the earlier hit survives. Half of the tracks will have hit information at the minimum detector radius.

![Figure 2: In this CLEO Monte Carlo event, the highlighted track overlaps another track of very similar momentum and azimuth for most of radial range. It overlaps with two tracks in the first 8 layers. All 10 tracks were found. The very low momentum blob is out-of-time.](image)

At a radius of 50 cm (the minimum TPC radius), over a jet φ spread of 0.4 radians, there are 14 φ segmentation widths. The 14 azimuthal drift chamber cells are shared by the 14 tracks in the jet. Most of the tracks will have hit information at this intermediate radius.

Although hit efficiency is only 50% at low radius in a CLEO-style drift chamber, the hits are useful for pattern recognition. It is significant that the inefficiency is largely uncorrelated. The half-cell-stagger allows each track to have a few hits along the overlapping path. If the track is established at large radius, the pattern recognition algorithm provides extrapolation to the inner radius hits. At this point, the algorithm can use 0.5 mm discrimination provided by the accurate drift time measurement rather than the 14 mm segmentation width. This was demonstrated in a study of pattern recognition of overlapping tracks in Monte Carlo events. Efficiency was measured as a function of the number of isolated drift chamber layers. An isolated drift chamber layer was defined to be a layer in which no other generated track passes within ±14 mm, the azimuthal segmentation width. It was found that only 20
isolated layers are required for full efficiency. Alternatively, if the isolated region is defined as ±28 mm, only 10 isolated layers are required for full efficiency. An inspection of a sample of accurately found tracks verified that a small number of hits on each track, at low radius, was used to extrapolate the track into the interaction region. In the event shown in Figure 2, a track is highly overlapped with another of very similar momentum. In the first 8 layers, it overlaps with yet another track. Figure 3 shows the residual of hits in a road about the track. Hits in the overlapping region have been located and added to the fit. A hit efficiency of only 50%, in the inner layers, is sufficient.

In a CDF-style jet chamber, the azimuthal segmentation width is 8 mm (maybe 4 mm). At a radius of 25 cm, over a jet φ spread of 0.4 radians, there are 12 (24) φ segmentation widths. Again, there is no z segmentation. The 12 (24) azimuthal jet chamber cells are shared by the 14 tracks in the jet. Because about half (or less) of the tracks will pass through a shared azimuthal segmentation width, and because early hits are recorded, only about 1/4 (or less) of the tracks will be missing hits at the minimum detector radius. Unlike the case of a CLEO-style drift chamber, the track which will suffer the hit loss is correlated within the jet cell because the wire stagger is only about 200μm.

In summary, the drift chambers can achieve pattern recognition, in the presence of the linear collider track density, that is similar to that of a TPC with induction readout. A TPC with GEM or MicroMegas readout provides significant improvement.

**Momentum Resolution**

The momentum resolution goal stated in the “Linear Collider Resource Book For Snowmass 2001”, page 387, is δp_t/p_t=10^{-5}p_t. However, the expectation for the “L” detector,
on page 402, is \( \delta p_t / p_t = 3 \times 10^{-5} p_t \) above 100 GeV. For comparison, the CLEO drift chamber achieves \( \delta p_t / p_t = 1.1\% \) resolution at \( P=5.28 \) Gev (DR only), with 65 cm tracking length in a 1.5 Tesla field. Ignoring that the resolution at 5.28 GeV has any multiple scattering component, the measurement part of the CLEO resolution is \( \delta p_t / p_t = 3 \times 10^{-3} p_t \) assuming an average \( P / p_t = 1.5 \) in the Bhabha event sample. This extrapolates to \( 12 \times 10^{-5} p_t \) resolution for a CLEO-style drift chamber with 175 cm measurement length (2 meter outer radius chamber) in a 5 Tesla field.

The CLEO (DR only) momentum resolution is 4 times the expected “L” detector resolution because the latter also includes a 5 \( \mu \)m vertex device and/or does not take into account non-Gaussian components of the resolution. (In fact, the CLEO (DR only) momentum resolution is about 1.5 times the value predicted using only Gaussian effects.)

If the proposed vertex detector is used with a CLEO-style drift chamber, momentum resolution is improved. The measurement length is increased to 200 cm, the impact parameter is effectively fixed in the fit, and, correlated with the fixed impact parameter, the error in measured curvature is reduced. Scaling by \( L^2 \) and cutting the error in curvature to half, the momentum resolution is then \( \delta p_t / p_t = 4.5 \times 10^{-5} p_t \).

Contrary to the above result, a CLEO-style drift chamber must provide better momentum resolution when compared to a TPC with induction readout. A CLEO-style drift chamber has 88\( \mu \)m spatial resolution while the TPC is assigned to have 150\( \mu \)m spatial resolution. The number of measured points in a TPC may be 50% more but that enters into the resolution with a power of 1/2. The only way that a TPC can provide better momentum resolution is if the spatial resolution is less than 100\( \mu \)m. This can only be done with a GEM or MicroMegas readout.

I do not know if 100\( \mu \)m spatial resolution in a TPC is reasonable in a full system, with a manageable number of channels, and without compromising the segmentation improvement of a GEM or MicroMegas readout.

I also have not reproduced the momentum resolution calculations in the Snowmass book. Thus, I can not fully comment on how the resolution depends on non-Gaussian effects, the vertex detector, and the TPC spatial resolution.

**Other problems of building a drift chamber for the LC**

There are many other problems involved in building a CLEO-style drift chamber for the linear collider. The chamber is longer but the wire, wire tension, field cage, and voltage are constant. The sense wire diameter can not be increased, and the voltage can not be decreased, because the amplification would be reduced. The wire tension can not be increased because the wire would break. The field cage size can not be increased because the segmentation would be degraded, the number of points would be reduced, the poorer spatial resolution at large drift distance would be more significant, and the live time would be increased.

Electrostatic instability may then be a problem in the longer chamber. Before stringing DR3, using slightly less tension for a longer wire as compared to DR2, Ilya Kravchenko calculated the electric and mechanical forces which lead to the instability. Because wire is placed in the electrical center of the field cage and the gravitational sags are matched, the sense wire is in a local equilibrium for the typical applied high voltage. It is only when the wire is displaced away from the local equilibrium that the instability can occur. I choose
twice the gravitational sag to set the size of the local equilibrium. Under this condition, the ratio of the restoring mechanical force to the anti-restoring electric force, in DR3, is 14. For a 4 meter long chamber, the gravitational sag is 660 \( \mu \text{m} \) and the force ratio drops to 4. I consider this the limit. For a 7.8 meter long chamber, the gravitational sag is 2.5mm and the chamber is unstable.

Endplate deflection increases as \( R^3 \) but the deflection can be limited with a load bearing inner tube. Deflection, particularly how it relates to wire creep, is less of a problem with longer wires because it is a smaller fraction of the wire strain.

The magnetic field required to achieve the momentum resolution is the major problem. A high magnetic field is beneficial to the operation of a TPC; the magnetic field is parallel to the drift and, therefore, reduces transverse diffusion. In a drift chamber, the magnetic field is perpendicular to the drift and distorts the drift paths. CLEO has used Ar-Ethane(50:50) at 1.5 Tesla. The Lorenz angle was 68.9\( ^\circ \) and the efficiency was cut off at 6 mm drift. The cell efficiency was “ok” when the magnetic field was lowered to 1.2 Tesla; the maximum allowed Lorenz angle is 55\( ^\circ \). CLEO currently uses He-propane(60:40) at 1.5 Tesla with a Lorenz angle of 35\( ^\circ \). This gas is acceptable to only 2.3 Tesla. He-CO\(_2\)-isobutane(80:10:10) would be acceptable to 3.3 Tesla. The only way I know to have an acceptable Lorenz angle at 5 Tesla is to use DME in the gas mixture. The use of DME requires that the gas be ultra clean and that plastics are compatible. Note that when CLEO used DME in the PTL, the efficiency would change when the gas bottle was changed with no observable difference in the gas analysis. Furthermore, any gas that offers reduced Lorenz angle also has a reduced drift velocity. As discussed earlier, the maximum drift time would approach 2 bunch spacings at TESLA, increasing the exposure to beam related noise when compared to 1.5 Tesla operation. However, this is still acceptable at the anticipated noise level.

A CDF-style jet chamber must also be operated with a much slower gas at 5 Tesla. This is unfortunate because the remarkable feature of this chamber, the ability to clear the cell within the 132 ns bunch spacing, depends on the very fast gas. But CDF has a Lorenz angle of 35\( ^\circ \) at 1 Tesla. Jet cells are tilted at the Lorenz angle; running this gas at 5 Tesla is absurd. The Lorenz angle must be limited to 45\( ^\circ \) so the maximum drift time increases to 500ns as used above.

Careful studies would be required to show that any gas would provide a CLEO-style spatial resolution at 5 Tesla. In fact, studies are required to show that any detector, including a TPC, would operate at 5 Tesla.