Central Tracking Design for a τ – Charm Factory

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ABSTRACT

We discuss the considerations involved in the design of a central tracking system for a τ – Charm Factory, including the required momentum resolution, angular coverage, material contributing to multiple scattering, and a variety of other issues. These ideas were discussed during meetings of the Tracking Working Group at the τ – Charm Factory Workshop at the Stanford Linear Accelerator Center in May, 1989.

1. GOALS OF A CENTRAL TRACKER

One of the most important lessons learned at SPEAR that must be applied to detector design for a τ – Charm Factory, is the need for large coverage of the available phase space for efficient charged particle tracking. This means full 4π solid angle coverage, efficient tracking down to very low momentum, and the highest possible resolution for the track parameters. The organizers of the τ – Charm Factory workshop have provided a list of minimal and ultimate detector parameters for charged particle tracking:

Minimal tracking parameters

1. Momentum measurement accuracy: $[\sigma_p/p]^2 = [0.4\% p(\mathrm{GeV/c})]^2 + [0.3\%/\beta]^2$
2. Angular momentum accuracy: $\sigma_\phi = 0.5$mr, $\sigma_\theta = 3$ mr
3. p_t^{min} for efficient tracking: 0.05GeV/c
4. θ_{min} for efficient tracking: 300 mr
5. Vertex precision: $[\sigma_{xy}]^2 = [80\mu\mathrm{m}/p(\mathrm{GeV/c})]^2 + [150\mu\mathrm{m}]^2$, $\sigma_z = 0.4$ mm
6. Hermeticity: no cracks.

Ultimate tracking parameters Same as above, except:

4. θ_{min} for efficient tracking: 100 mr
5. Vertex precision: $[\sigma_{xy}]^2 = [15\mu\mathrm{m}/p(\mathrm{GeV/c})]^2 + [20\mu\mathrm{m}]^2$, $\sigma_z = 0.4$ mm

These goals must be met within the constraints imposed by the machine:

1. free space between $\mu\beta$ quads: 1.60 m; outer radius of $\mu\beta$ quads: 0.2 m;
2. vacuum chamber radius: $|z| \leq 0.4$ m: 15 mm, tapering out to 35 mm from 0.4 to 0.8 m in Z;
3. 52 nsec between bunch collisions; at the peak of the J/ψ, 1200 – 5,000 events/sec.

We are talking about a fourth-generation magnetic spectrometer for the SPEAR energy region; these goals are particularly demanding, and will push the limit of tracking technology. The first question to ask, therefore, is whether the tried-and-true cylindrical jet-cell drift chamber is the technology which best suits our needs. The discussion that follows will assume a detector of this type, and comparisons with competing technologies will be made where appropriate.

2. Angular Coverage

The small free space between $\mu\beta$ quads severely limits the achievable solid angle coverage. At least 15 cm on each end of the detector must be available for endplates ($\simeq$5 cm of aluminum to take up the force of the tensioned wires) and for electronics/heat dissipation. This leaves an active drift chamber half-length of 65 cm. Efficient tracking down to 100 mr will require at least 10 track position measurements before 6.5 cm radius. Cramming that many wires in such a small radius will be difficult for many reasons: a large amount of material will contribute to multiple scattering, particularly serious for impact parameter resolution; electrostatic instabilities in the closely-spaced wires may be a serious problem; and the chamber will be very difficult to build and instrument. Even then, the momentum resolution will be effectively non-existent.

Thus we must fall back on providing adequate coverage down to 300 mr (95.5% of the solid angle). This requires at least 10 track position measurements (including stereo) at radii from 4 to 19.5 cm, which is conceivable (although the momentum, angle, and dE/dx resolutions can be expected to degrade at small angles; see below). The calorimetry and particle ID can surround the $\mu\beta$ quads, limiting their coverage to $\theta_{min} > 300$mr.

Although it is difficult to measure tracks below 300 mr, one would like to be able to detect the presence of such tracks (both charged and neutral), if only to veto on events containing them when detector hermeticity is required (*e.g.*, in an analysis involving neutrinos in the final state). Thus room must be left in front of the quads for a simple charged and neutral particle tagger (which would also serve as a luminosity monitor). This could be a series of thin planar chambers followed by a shower counter. Care must be taken to shield this forward detector against synchrotron radiation.

3. Inner and Outer Radii

We will see that the required resolution can be met with a range of geometries. To some extent, the decision as to which geometry is most appropriate must take into account the constraints from the accelerator and other parts of the detector. Specifically:

1. The outer radius (r_{max}) must not be made too large, or the precision barrel EM calorimeter (presumably crystal) will become too expensive.
2. The time–of–flight (TOF) particle identification system is most effective at large radii. This speaks for a large r_{max}.
3. The inner radius (r_{min}) must be as close as possible to the beampipe to get the best precision on the vertex position.
4. The momentum resolution depends inversely on $\Delta r = r_{max} - r_{min}$ (see below), speaking for a large r_{max}.
5. A very small r_{min} (and therefore a small beampipe) places great constraints on the synchrotron radiation masking, beampipe impedance, and may necessitate beampipe cooling.
6. If the first layer of material is at a large radius, then a precision measurement just beyond it can permit a good measurement of the track angle, provided the vertex is known. Several higher–momentum tracks in the event are needed to establish the event vertex. The precision measurement on a lower–momentum track combined with the vertex constraint can "remove" the error on track angle due to multiple scattering in the large–radius material. This speaks for a large r_{min} *if* the precision measurement is just outside

the material of the beampipe, and *if* that measurement is of comparable precision to the knowledge of the event vertex, in both dimensions. This scheme assumes that there are no secondary vertices in the event.

7. If one can satisfy the resolution requirements with a small radius (high field) tracker, this may free some space between r_{max} and the TOF/EM calorimeter for other detectors such as CRIDs or precision dE/dx chambers. This will introduce material in front of the EM calorimeter, reducing (or eliminating) its sensitivity to very low energy photons. For certain experiments, however, it may be desirable to sacrifice low energy photon detection for enhanced particle identification capability.

4. Momentum Resolution

In an axial magnetic field, the momentum resolution for high momentum tracks due to measurement error is approximately given by:

$$\sigma_p/p = \frac{26\sigma p_t}{0.3B\Delta r^2\sqrt{n}},$$

where σ is the single–hit position resolution (in the $r\phi$ direction) in meters, $\Delta r = r_{max} - r_{min}$ in meters, p_t is the component of the momentum perpendicular to the magnetic field in GeV/c, B is the magnitude of the magnetic field in Tesla, and n is the number of (equally–spaced) position measurements.

The momentum resolution is degraded by multiple scattering in the material of the tracking volume (gas and wires):

$$\sigma_p/p = \frac{0.014}{0.3B\beta\Delta r}\left(\frac{p}{p_t}\right)\sqrt{1.43\cdot\#\mathrm{rl}} = \frac{0.014}{0.3B\beta\sqrt{\Delta r}}\left(\frac{p}{p_t}\right)^{3/2}\sqrt{1.43/X_0}$$

where β is the track velocity, $\#\mathrm{rl} = \Delta r/X_0$ is the radial thickness of the gas and wires in radiation lengths, and X_0 is the effective radiation length of the gas and wires. Note that both contributions to the momentum resolution degrade rapidly for tracks with small polar angle.

We clearly want the best achievable position resolution σ. This is limited by the wire positioning accuracy, the stability and knowledge of the drift time–to–distance (TDR) relation, low ionization statistics near the wire, and the diffusion in the gas over the drift distance (in practice, diffusion has been the most serious effect in jet–cell drift chambers). There are trade–offs here: a low–density gas such as helium will reduce the multiple scattering, but will worsen the ionization statistics near the wire and may also worsen the drift diffusion. Small drift distances reduce the diffusion problem, but require more wires (more instrumentation and more material for multiple scattering). Low density gases also have a very low synchrotron photon conversion cross–section, greatly reducing the contribution of such photons to background hits.

The measured path length Δr is limited by the detector half–length $L = 65$ cm for small–angle tracks ($r = L \tan\theta$) and by the outer radius of the chamber r_{max} for large angle tracks. The outer radius must be small enough to leave room for the EM calorimeter between the DC and the coil/cryostat. The cost of the calorimeter and coil will thus scale with r_{max}^2. For large–angle tracks, measurement errors give $\sigma_p/p \simeq 1/r_{max}^2$, and multiple scattering gives $\sigma_p/p \simeq 1/\sqrt{r_{max}}$.

The strength of the magnetic field must be limited, so that low–momentum tracks do not curl up. There are two issues here: in order to detect the low–momentum tracks, they must go out to a large enough radius to leave at least 10 hits; and if the maximum radius of the curling track is less than the inner radius of the barrel EM calorimeter, they will keep looping, leaving many hits in the chamber (and never reaching the particle ID detectors). Thus we want to keep the outer radius of the chamber as small as possible, consistent with our momentum resolution goals. The maximum radius of a curling track is given by $p_t/0.15B$. If we require this to be >20 cm (same as required for tracks with $\theta = 300$ mr) then we obtain $B \leq 1.67$ Tesla. Achieving our goal of $\sigma_p/p = 0.4\% p_t$ with such a field (using $\sigma = 100\mu$m measurements spaced 1 cm apart) will require $4 \leq r \leq 48$ cm. Tracks with $p_t < 0.12$GeV/c will loop, and only tracks within $|\cos\theta| < 0.80$ will have measurements in all layers.

In the interests of particle ID (TOF, EM calorimetry), we would like to keep $p_t^{loop} \equiv 0.15Br_{max} \leq 0.100\text{GeV/c}$. There is no point in going much lower in momentum, even if the physics requirements demanded it, because 50 MeV pions and 85 MeV kaons will range out in the 1 mm Be beampipe. We take 1 cm radial wire spacing ($n = 100r_{max}$), $\sigma = 200\mu\text{m}$, and $\sigma_p/p = 0.004$:

$$r_{max} = \left(\frac{1.3\sigma}{(\sigma_p/p)p_t^{loop}}\right)^{2/3} = 0.75m,$$

and the magnetic field $B = 0.9$ T. To keep the angular coverage at 300 mr, the chamber must extend to $L = \pm 2.4$ m in z (beyond the 0.2 m outer radius of the $\mu\beta$ quads). At this point, electrostatic instabilities (see below) become important. The chamber can be made shorter by sacrificing momentum and angular resolution for small-angle tracks. For high-momentum tracks at large angles, one always gains in momentum and angular resolution by increasing r_{max} (and reducing B to keep p_t^{loop} constant). However, for fixed momentum resolution, or fixed p_t^{loop}, the multiple scattering contributions increase (see exercise below).

The large magnetic field causes other problems. The drift Lorentz angle will increase, making the drift trajectory more complicated; the understanding of the time-to-distance relationship and the dE/dx collection region will suffer. Also, the coil thickness increases with field strength.

5. An Exercise

We have mentioned three important quantities which depend on the product $B\Delta r^m$ where m is some positive exponent. Taking $\Delta r \approx r_{max}$, and $n = 100r_{max}$ as above, and inserting our requirements on momentum resolution accuracy, we have:

$$\sigma_p/p^2 = \frac{2.6\sigma}{0.3Br_{max}^{2.5}} = 0.004,$$

$$(\sigma_p/p)_{ms} = \frac{0.014\sqrt{1.43/X_0}}{0.3B\beta\sqrt{r_{max}}} = 0.003,$$

$$p_t^{loop} = 0.15 B r_{max}.$$

In the previous section, we fixed p_t^{loop} and σ_p/p to some values, and derived the required values of B and r_{max}. Here we don't worry about p_t^{loop}. If we use the first of the above equations to fix the product $B r_{max}^{2.5}$, and we take $\sigma = 200\mu$m, then different values of r_{max} will yield the following values for B, p_t^{loop}, and $1/X_0$:

r_{max} (m)	B (T)	p_t^{loop} (GeV/c)	$1/X_0$ (m^{-1})
1.0	0.43	0.065	5.4×10^{-4}
0.8	0.76	0.091	13.2×10^{-4}
0.6	1.55	0.140	41.9×10^{-4}

To see what the required values of $1/X_0$ mean, we can compare with the Mark II jet–cell drift chamber, with argon drift gas filling $\Delta r = 1.2$ m. The chamber has 1.1% radiation length of gas and 0.9% radiation length of wires. Argon has $1/X_0 = 90.9 \times 10^{-4}$ m, which is larger than any of the values in the above table. To make it usable and still achieve the specified resolution, we would have to go to smaller r_{max} along with larger B. Instead we can try a lower density gas such as helium, which has $1/X_0 = 1.9 \times 10^{-4}$ m. (See below for discussion of issues related to the choice of gas.) In that case, the material is dominated by the wires; for the Mark II wire density, $1/X_0 = 74.4 \times 10^{-4}$ m. This could be reduced by some combination of the following:

1. Using aluminum rather than copper wires. This can be dangerous for long chambers since the wires must be tensioned against gravitational sag and electrostatic repulsion, and aluminum tends to stretch.
2. Using larger cells, increasing the drift distance and therefore also the diffusion and the complexity of the TDR and dE/dx collection region.
3. The charge on the anode wires must be compensated by an equal charge on the cathode wires. The latter are made thick, to reduce the electric field on the surface of the wire, preventing cathode wire aging ("whisker growth").

If one doubles the number of cathode wires, their thickness can be reduced by half. This reduces the wire density by half.

4. The wires are, of course, well localized, and they contribute an "opacity" of maybe 1% per layer in the chamber. It may be possible, in the track fit, to identify potential collisions of tracks with wires, since the resolution in interpolating a track near a wire is better than 200 μm, while the wire radius might be 100 μm. In cases where there are very few scatterings, one can fit for the scattering angles, thereby recovering some of the momentum resolution. At the least, one can identify tracks with a momentum resolution that is not degraded by collision with any wires.

We see from the above exercise that it becomes easier to satisfy the multiple scattering requirement if r_{max} is *reduced.* This may be counter to intuition (and to one of the equations above), but it comes from the fact that we are simultaneously *fixing* the product $Br_{max}^{2.5}$; when we reduce r_{max} we rapidly increase B. Of course, one need not do that; we can increase B while leaving r_{max} large if we like. In that case, the momentum resolution due to position resolution will exceed specifications, and multiple scattering will dominate out to a larger momentum.

6. Angular Resolution

For high-momentum tracks, the angular resolutions from equally spaced measurements are approximately:

$$\sigma_\phi \approx \frac{15\sigma}{\Delta r\sqrt{n}} \quad , \quad \sigma_\theta \approx \sin^2\theta\sigma_s = \sin^2\theta\frac{3.4\sigma_z}{\Delta r\sqrt{n}},$$

where $s = p_z/p_t = \cot\theta$, and σ_z is the position resolution in z.

Taking $\Delta r = 75$ cm, $n = 75$, and $\sigma = 200\mu$m, we get $\sigma_\phi = 0.46$ mr, just about within specifications. For small-angle stereo wires making an angle α with respect to the z axis, $\sigma_z = \sigma/\alpha$. If half the wires are stereo, we fall within $\sigma_\theta = 3$ mr for $\alpha = 0.035$ and $\sigma_z = 5.7$ mm. Note that charge division typically gives $\sigma_z \simeq 10$ mm.

Because it gives 3D space points directly, charge division can be helpful in pattern recognition; but the difficulty in achieving adequate resolution makes it less useful. In addition, charge division works best for large wire gains, while dE/dx resolution depends on low wire gains to avoid saturation effects.

There are limits to how large one can make the stereo angle. The stereo wires only contribute to the momentum measurement if $\sin\alpha \ll 1$. The radius of the stereo wires is a function of z:

$$r(z) = r_L\sqrt{1 + (z^2 - L^2)\alpha^2/r_L^2},$$

where $r_L = r(z = \pm L)$. A wire strung at $r_L = 6$ cm with stereo angle $\alpha = 0.035$ has $r(z = 0) = 5.5$ cm. This does not bode well for an axial wire at 5 cm. Care must be taken to allow adequate radial separation between wires. Otherwise, electrostatic instabilities and/or severe distortions of the TDR and dE/dx collection region will result. The Mark II drift chamber groups the sense wires in superlayers, alternating axial and stereo, with a larger gap in between. This makes pattern recognition easier as well as solving the stereo angle problem.

At small radius, the wires need be made no longer than what is required to cover 300 mr. In addition to allowing for close radial spacing of the stereo wires, this will help in the trigger, and in reducing the total charge deposited on the inner anode wires (see below). It may also be possible to put z-strips on the inner wall of the chamber. It is important to have several good z measurements of small-angle tracks, to be sure they were correctly tagged.

7. Vertex Resolution

The resolution in impact parameter due to measurement errors is approximately:

$$\sigma_{xy} = 3.6\sigma/\sqrt{n} \quad , \qquad \sigma_z = 2.2\sigma_z/\sqrt{n}.$$

For 70 measurements of 200 μm precision, and with a stereo angle of $\alpha = 0.035$, we get $\sigma_{xy} = 86\mu$m and $\sigma_z = 1.50$ mm. The z resolution is not optimal, and the xy resolution falls between the minimal and ultimate specifications.

To improve on this performance, we would have to significantly increase the position resolution, at least near the IP. Solutions involving separate high–precision vertex drift chambers or solid–state detectors will necessarily introduce a prohibitive amount of material (see next section). Other solutions include combining high precision wires in the main DC volume, thus avoiding extra walls. Perhaps a separate gas volume, separated by a thin wall, and with separate temperature and pressure control may be feasible.

8. Multiple Scattering

Multiple scattering in the material of the detector contributes to the resolution of the track parameters in two ways. The material in the tracking volume (gas and wires) degrades the momentum resolution and the angular resolutions, and material between the IP and the tracking volume (beampipe, chamber walls) degrades the xy and z impact parameter resolutions and the angular resolutions. The material in the tracking volume contributes as follows:

$$\sigma_\phi = \frac{0.014}{p\beta}\left(\frac{p}{p_t}\right)^2 \sqrt{0.23 \cdot \#\mathrm{rl}}$$

$$\sigma_\theta = \frac{0.014}{p\beta}\sqrt{0.20 \cdot \#\mathrm{rl}}$$

$$\sigma_s = \frac{0.014}{p\beta}\left(\frac{p}{p_t}\right)^2 \sqrt{0.20 \cdot \#\mathrm{rl}}$$

where, as above, #rl is the radial thickness of the gas and wires in radiation lengths.

The material between the interaction point and the tracking volume does not degrade the momentum resolution, but all other track parameters will suffer. If we treat the material as one scattering layer of radial thickness in radiation lengths of #rl at radius R, we have:

$$\sigma_\phi = \frac{0.014}{p\beta}\left(\frac{p}{p_t}\right)\sqrt{p/p_t \cdot \#\mathrm{rl}}$$

$$\sigma_\theta = \frac{0.014}{p\beta}\sqrt{p/p_t \cdot \#\mathrm{rl}}$$

$$\sigma_s = \frac{0.014}{p\beta}\left(\frac{p}{p_t}\right)^2\sqrt{p/p_t \cdot \#\mathrm{rl}}$$

$$\sigma_{xy} = \frac{0.014}{p\beta}R\left(\frac{p}{p_t}\right)\sqrt{p/p_t \cdot \#\mathrm{rl}}$$

$$\sigma_z = \frac{0.014}{p\beta}R\left(\frac{p}{p_t}\right)^2\sqrt{p/p_t \cdot \#\mathrm{rl}}$$

Note that the factors of p/p_t mean that the resolution degrades rapidly for small polar angle tracks. We want to keep the amount of material, and R, as small as possible. The beampipe and inner wall of the chamber can be made of beryllium, strong enough to withstand the vacuum in the beampipe. They must be coated with thin layers of heavy metals (*e.g.*, Ni, Pt, Ag) to absorb low energy synchrotron photons. In addition, there will be heating due to the image charge from the high-current beam (I^2R). The beampipe must be coated with a high-conductivity metal (skin depth $\simeq 1\mu$m; *e.g.*, Au, Pt), and may have to be cooled. A beampipe/inner wall of 3.5 mm Be at 15 mm radius gives $\sigma_{xy} = \sigma_z = 21\mu\mathrm{m}/p\beta$ and $\sigma_\phi = \sigma_\theta = 1.4/p\beta$ mr at $\cos\theta = 0$.

9. Position Resolution

We have been assuming that we can achieve position resolution of $\sigma = 100\mu$m over a large volume. The SLD drift chamber expects to achieve this through careful control over wire positioning and temperature and pressure of the drift gas. It is not clear that a low mass drift gas such as helium can give equal or better performance. We list some of the issues below.

1. The TDR must be well understood. The drift velocity depends on E/P; unless the chamber is operated at the flat part of the v_{drift}–vs–E/P curve, the voltages and gas pressure must be tightly controlled. Even then, the cell electrostatics must be carefully designed to give a simple dependance of the TDR on the track position and direction near the wire. This becomes difficult when trying to minimize the density of wires.

2. The wire positioning must be done to high precision at the endplate, and the amount of gravitational sag and electrostatic bowing must be well understood. In order to avoid correlated positioning errors, each sense wire should be on a separate feedthrough.

3. The trajectories of the drifting charges must be as uniform as possible, to avoid large fluctuations in the arrival time of ionization clusters from a non–radial track trajectory. Uniform drift trajectories also ensure that the ionization is not spread out due to geometrical effects; thus the double–track separation can be kept small (this is only important at small radii).

4. The accuracy of the TDCs must be sufficient to not contribute to the position resolution. If the TDCs are slow, then the gas must have a slow drift velocity. For the Mark II, using HRS gas with $v_{drift} = 50\mu$m/nsec, the TDCs have a 2 nsec least count.

5. There are designs for chambers with very high position resolution, making use of large numbers of wires, or cells with solid potential planes to provide a well defined TDR. Unfortunately, such designs invariably increase the multiple

scattering by an unacceptable amount.

6. The gas must have a low diffusion coefficient. This may not be commensurate with a low–density gas such as helium. (P. Coyle has calculated the diffusion coefficient for a He/CO_2/Isobutane mixture to be $\simeq 150\mu m/\sqrt{cm}$, a surprisingly low number). The drift distance must be kept small to minimize the contribution due to diffusion; this is unfortunately in conflict with the requirement that the cell size be large (less wire density).

A TPC? A TPC, despite the advantage that it has no wires and provides a large number of samples, has a very large drift distance and therefore has unacceptable position resolution due to diffusion. It also has thick endplates and inner and outer walls (to support detectors and field cages), which will increase the multiple scattering and degrade the efficiency for low energy photon detection in the outer EM calorimeter. Finally, a TPC is very slow for such a high rate environment, and does not provide information for a trigger.

Gases This is a good place to list other issues which depend on the drift gas.

1. The gas must be well quenched to avoid feedback from photons in the ion recombination.
2. The gas must be low in hydrocarbon content to avoid polymerization at the cathode wires ("whisker growth"). This ageing effect can be kept low by also keeping the gain low (needed for dE/dx) and the fields at the surface of the cathode wires low (this unfortunately requires thick cathode wires).
3. The electron mobility in the gas must be kept low to keep the Lorentz angle small and the TDR well understood.

10. Particle Identification with DE/DX

Particle identification via measurement of specific ionization is a powerful tool for tracks in the momentum range at a tcF. Unfortunately, the requirements for high resolution dE/dx measurement are in conflict with considerations of multiple scattering in momentum measurement. The best dE/dx resolution is obtained with many measurements along a long trajectory in a dense, pressurized gas. We list some of the considerations below:

1. The dE/dx resolution scales roughly like $1/(n \cdot t \cdot P)^{1/3}$ where n is the number of samples, t is the sample thickness, and P is the pressure. For fixed p_t^{loop}, the contribution of multiple scattering to the momentum resolution scales like $(n \cdot t \cdot P)^{1/2}$.

2. The wire gain must be kept low, to avoid space–charge pileup saturation effects.

3. The dE/dx collection region, defined by the electrostatic configuration of the wires in the cell, must be kept uniform, or at least well understood.

4. The pressure and temperature must be kept stable.

5. The gas must yield a large number of ion pairs per unit path length to reduce statistical fluctuations in charge measurement. Argon at STP yields 94 ion pairs/cm, while helium yields 9.

11. Pattern recognition

The low multiplicity of charged tracks at tcF momenta makes pattern recognition relatively easy. It may be advantageous to arrange the wires in multi–wire jet cells to aid in triggering. If the sense wires are arranged with a small stagger with respect to the radial direction, one can resolve left–right ambiguities locally for a short segment of a track. However, such closely–spaced wires can exert strong forces on each other, leading to electrostatic instabilities for long wires.

There must be a high density of measurements at small radii to find small-angle tracks exiting in z. As discussed above, at least 10 measurements (some of which should be stereo) should be available in the first 20 cm. Wires spaced at 1 cm intervals in radius would be adequate, but may contribute unacceptably to multiple scattering. Wires must be spaced far enough apart in radius to allow axial and stereo wires to coexist (see above). At larger radii, where the chamber is longer in z, care must be taken to avoid electrostatic instabilities (see below).

To recover closely spaced tracks such as e^+e^- pairs from photon conversions it is important to have multihit capability, with good double-track resolution, at very small radii.

12. OTHER DESIGN CONSIDERATIONS

Electronics The electronics must provide a fast rise-time and fast TDCs for best drift time measurement. It should have multihit capability, especially at smaller radii. The charge measurement for dE/dx should have a large dynamic range, it should be low noise, and it should also have multihit capability (FADCs?). A pole-zero filter should be employed to cancel the 1/t ion drift tail.

Bowing and Electrostatic Stability The wires must be tensioned between endplates to minimize gravitational sag and electrostatic deflection. If the wires are close together, and arranged in a staggered jet cell, the electrostatic forces can be large enough to produce instabilities.

For reference, the wire displacement at its midpoint between endplates is given by $D = L^2F/2T$, where L is the *half*-length of the wire, T is the tension of the wire in newtons, and F is the total force on the wire. For gravity, $F = g\mu$, where $g = 9.8 \times 10^{-3}$ Nt/g, and μ is the mass/length of the wire in g/m. For closely spaced wires with a stagger s, the electrostatic force $F \simeq s$. This is best estimated using an electrostatic simulation of the cell.

Endplates and outer barrel The tensioning of many wires produces a large stress at the chamber endplates. These endplates should be pre-stressed during stringing to avoid changing the tension on the wires after they have been strung. The endplates and outer barrel need to be strong enough to withstand the force. However, the material in the cylindrical walls and endplates should be minimized so as to avoid producing photon showers in the material before the photons reach the barrel or endplate EM calorimeter.

Radiation, Anode death The large current in the storage ring will produce backgrounds in the detector at small radii, such as tracks from beam–gas collisions, and synchrotron photons. These can produce large singles rates on the inner wires, and therefore large currents. Anode wires have been known to corrode in various ways if the integrated charge/length exceeds certain values. The wires can degrade to the point of breakage, which can be disastrous if no provision is made for access for removal, or electrical isolation (*e.g.*, straws). The problem can be made less severe by using a low–density gas which reduces photon conversion, careful design of synchrotron photon masks, and reducing the length of the innermost wires (making the endplates in a cone shape to cover no more than 300 mr at inner radii).

Beam–gas Triggers If the innermost wires are very short, they can be useful for reducing the trigger rate from beam–gas collisions, with secondaries produced at large z which will thus not hit those wires.

Beampipe Heating The large beam currents (≥ 0.5 A) at a τ – Charm Factory can heat the beampipe, requiring cooling even at the IP, where we want to minimize material (a thin beampipe of beryllium has limited capacity for conducting heat away). Scaling from work for a very high current $B\bar{B}$ factory indicates that I^2R heating from the image charge in the beampipe is not a problem for a 4 cm radius beampipe with a 0.5 A beam. However, higher order modes can be a problem if the beampipe is not made sufficiently smooth. The problem is minimized if the beampipe remains at a constant radius as it passes through the $\mu\beta$ quads and the IP.

Pileup Since the beam crossing rate is so large, and the large cell size (and perhaps slow drift velocity) produces large drift times, the presence of hits from events other than the one that triggered the detector may be a problem.

13. QUESTIONS:

1. What technologies other than jet drift chamber might suit our needs?
2. What is the best achievable σ for different gases, drift distances? How best to limit diffusion?
3. How to design large cells, with density of wires much less than that of the Mark II? A uniform drift electric field, useful in understanding the TDR and charge collection region, usually requires a large number of field shaping wires.
4. Closely spaced axial and stereo wires over long distances: are there electrostatic instability problems?
5. How best to arrange the wires, consistent with the above considerations, to optimize pattern recognition?
6. What is the best achievable dE/dx resolution for different gases?
7. Will the radiation and beam–gas backgrounds damage the innermost anode wires, and if so, how can they be electrically isolated, or removed, if they break?
8. Is beampipe heating a problem? how to design a sufficiently smooth, thermally conducting beampipe? Is special cooling necessary? How much material will this require?
9. Is pileup a problem?
10. Precision vertexing - is it needed? How best to implement?

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