JLC Central Tracker R&D

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ABSTRACT

The current status of the JLC central tracker R&D is reviewd, highlighting progress made since Beijing meeting. R&D's future direction is then discussed, taking into account possible changes in basic chamber parameters.

1 Introduction

I was asked to review the central tracker R&D status at the end of last week, since it turned out that none of the central tracker subgroup conveners could come to this meeting. On such short notice, it was definitely impossible for me to prepare a systematic review. I thus decided to concentrate on what we have done since Beijing meeting and, if time allows, try to show my personal view for future direction of our central tracker R&D.

1.1 Physics Requirements

Let me now begin my talk with reminding you of physics requirements on the central tracker performance[1]. The most stringent requirement comes from the recoil mass measurement for $e^+e^- \to Zh$ followed by $Z \to l^+l^-$. In order to confirm the narrowness of the Higgs boson, the recoil mass against the lepton pair from the Z decay should be measured to an accuracy only limited by the natural beam energy spread. This sets the following performance goal for the momentum measurement: $\sigma_{p_{l^\pm}}/p_{l^\pm} \lesssim 0.4$ % at $p_{l^\pm} = 50$ GeV. Separation of W and Z through jet invariant mass measurements demands a resolution comparable with the gauge boson natural widths. This necessitates good track-cluster matching: $\sigma_Z \simeq 1$ mm and 2-track separation better than 2 mm. Time stamping of tracks from different bunches will be very important to suppress otherwise overlapping mini-jet backgrounds, which requires $\sigma_{T_0} \lesssim$ bunch spacing (1.4/2.8 ns).

1.2 Current CDC Parameters

These physics requirements should be translated into chamber parameters and, consequently, R&D items. The momentum resolution is given by the following formula:

$$\frac{\sigma_{p_T}}{p_T^2} \simeq \sqrt{\left(\frac{\alpha' \sigma_{xy}}{Bl^2}\right)^2 \left(\frac{720}{n+4}\right) + \left(\frac{\alpha' C}{Blp_T}\right)^2 \left(\frac{10}{7}\left(\frac{X}{X_0}\right)\right)}. \tag{1}$$

With this formula we can readily verify that the current set of CDC parameters satisfies the requirement from the recoil mass measurement:

$$\left\{ \begin{array}{lcl} \sigma_{xy} & = & 85\mu\mathrm{m} \\ l & = & R_{out} - R_{in} \\ & = & 230(\text{outer cylinder}) - 45(\text{support tube}) = 185\mathrm{cm} \\ n & = & 80 \\ B & = & 2\mathrm{T} \\ L & = & 460\mathrm{cm} \quad (\text{full lever arm above } 45^\circ) \end{array} \right. . \tag{2}$$

The spatial resolution of 85μm indicates use of a cool gas mixture and a mini-jet cell structure. The required z resolution of 1mm also suggests use of the mini-jet cell structure with a stereo angle of $\tan\alpha_{stereo} \simeq 0.1$ through

$$\sigma_z = \sigma_{xy}/\tan\alpha_{stereo}. \tag{3}$$

The remaining physics demand on the time stamping capability can then be translated into the limit on the drift velocity through

$$\sigma_{T_0} \simeq \frac{\sigma_{xy}}{v_{drift}\sqrt{n}} \lesssim 1.4\mathrm{ns}. \tag{4}$$

A drift velocity of 10μm/ns satisfies the requirement. If we assume a jet cell with 5 sense wires and a maximum drift length of 5cm, there will be about 14k jet cells and, correspondingly, about 100k wires total.

1.3 R&D Items

The chamber parameters described above lead us to the following list of questions:

- Can we control gravitational and electrostatic sags for 4.6m-long wires?
- Can we achieve a spatial resolution of 85μm everywhere in this big chamber?
- Can we achieve 2-track separation better than 2mm?
- Can we stably operate 4.6m-long stereo cells?
- Is Lorentz angle small enough to allow straight cells?
- Is gas gain saturation observed for cool gas mixtures no problem?
- Is tension drop controllable for Al wires?
- Is neutron background ($\sim$2k hits/train for $B = 2$T[2]) no problem? How big is the signal charge for a single neutron hit? Is there any dead time expected?

These questions naturally comprise our R&D items.

2 What We Have Done Since Beijing

Corresponding to these R&D items, we set the following publication plan: (1) gravitational and electrostatic sags[3], (2) cosmic ray tests of a 4.6m chamber[4], (3) two-track separation (in preparation), (4) designing of stereo-wire geometry[5], (5) Lorentz angle measurement, (6) gas gain measurement[6], (7) wire tension measurement, (8) background studies, and (9) general gas properties. Since Beijing, (2) and (6) have been completed, while (5) being almost finished. In what follows, I will thus quickly go through these three topics.

2.1 Cosmic Ray Tests of a 4.6m-long Test Drift Chamber for JLC

The cosmic ray tests confirmed that an average spatial resolution of 100 μm is attainable over the full length of the 4.6m-long test chamber, even in the presence of significant gravitational and electrostatic wire-sags. Figure 1 plots the spatial resolution of the 4.6m chamber as a

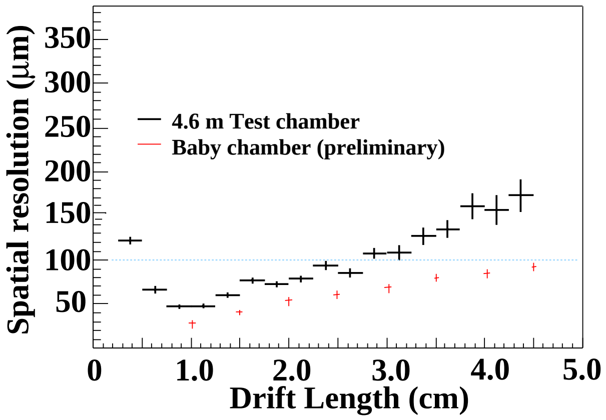

Figure 1: Spatial resolutions plotted as a function of drift length for the 4.6m chamber (cosmic ray test) and the baby chamber (beam test), respectively.

function of drift length, compared with a beam test result of a shorter test chamber, so called a "baby chamber", with the same cell structure. Their sizable discrepancy in the long drift region can be attributed to the Oxygen contamination due to some gas leak observed for the 4.6m chamber. With a proper treatment for the gas leak, we expect that its resolution will be comparable with that of the baby chamber, implying that an average spatial resolution of 85 μm is feasible.

2.2 Gas Gain Measurements

The gas gains for CO_2/iso-C_4H_{10} mixtures have been measured with a single wire proportional tube, primarily for supplementing the stereo-wire geometry study[5]. Figure 2 plots pulse height spectra for ^{55}Fe X-rays at different high voltages as measured by the proportional tube filled with $CO_2(90)$/iso-$C_4H_{10}(10)$. Already at 2.5 kV (our operation point), where the gas gain is

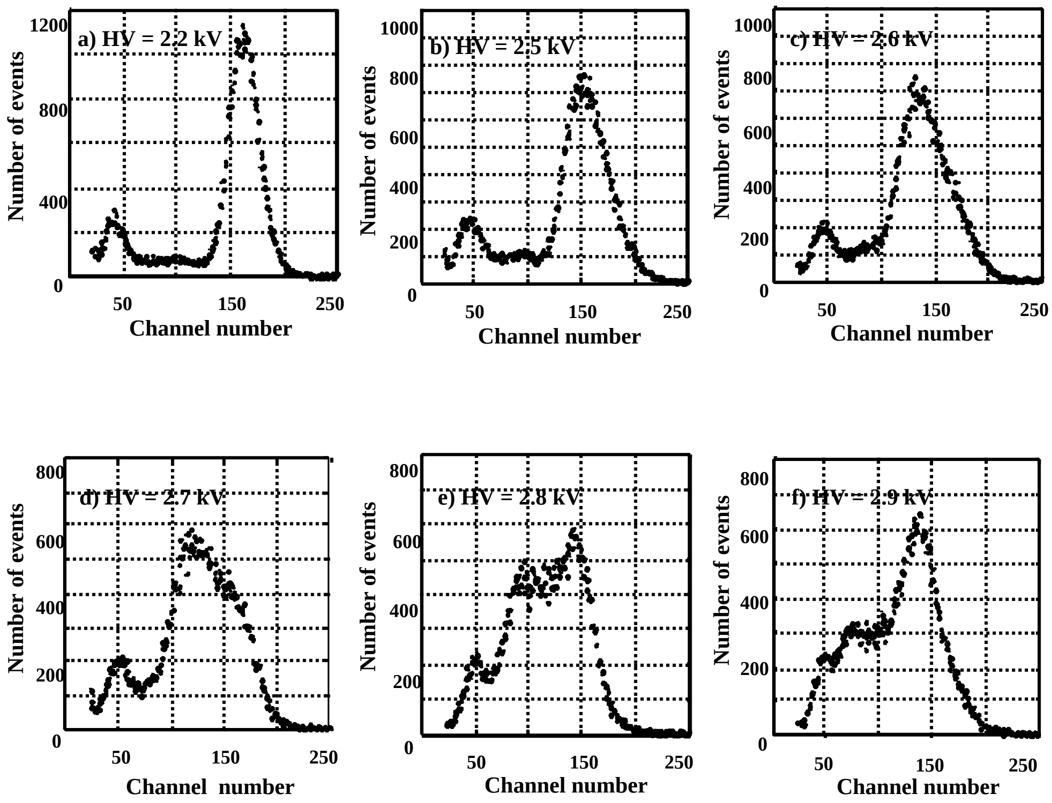

Figure 2: Pulse height spectrum for $CO_2(90)$/iso-$C_4H_{10}(10)$ when irradiated by ^{55}Fe X-rays.

measured to be $\lesssim 10^5$, we can see a significant broadening of the peak. Further high voltage increase leads us to the apparent onset of a new gas multiplication mode as observed as the third peak that eventually dominates the spectrum. This quick gas gain saturation can be attributed to the small diffusion nature of the gas mixture, resulting in concentration of avalanche charge on a small spot on the wire. Further studies are necessary to clarify the implications of this observation in terms of local dead regions, two-track separation, and dE/dx measurements.

2.3 Lorentz Angle Measurements

The Lorentz angle, being one of the key parameters to constrain the cell design, had been measured for our chamber gas at different magnetic fields up to 1.5T that is the maximum field available with magnets at hand. The measurement was based on the principle illustrated in Fig.3. Avalanche locations for track electrons created by laser beams at two different z

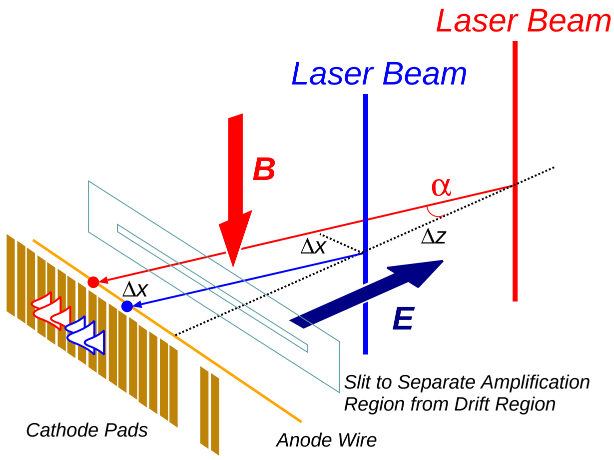

Figure 3: Principle of Lorentz angle measurement.

positions along the electric field are measured as two charge centroids with the cathode pads. Their distance, when divided by the z distance of the laser beams, gives the tangent of the Lorentz angle, if the magnetic field is applied perpendicular to the plane spanned by the anode wire and the electric field. Notice that by taking the difference we can cancel the effect of the drift field non-uniformity in the gas amplification region. In the first measurement carried out in 1998, we measured the avalanche locations for the two z locations one by one at different times (single beam method). There was some time dependent vibration of the chamber stand, introducing significant systematic errors in the Lorentz angle measurement. In order to cancel the effect of the vibration, we improved our system to measure the two avalanche locations at one time, using two simultaneous laser beams (double beam method). Preliminary results from the 1999 measurement with this improved system is plotted in Fig.4, showing reasonable agreements with GARFIELD[7] simulations.

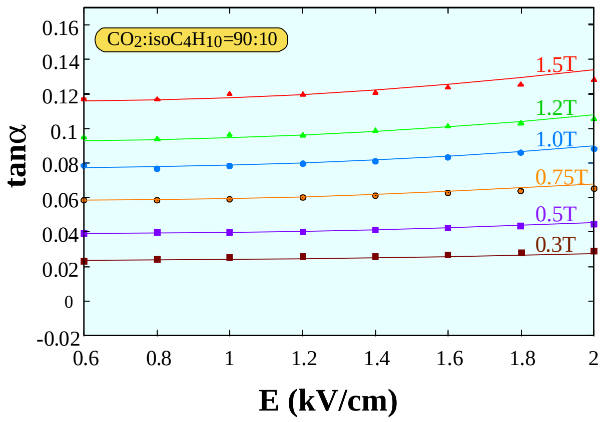

Figure 4: Lorentz angle as a function of electric field at different magnetic fields, for $CO_2(90)/\text{iso-}C_4H_{10}(10)$.

3 Short Term Plan

We were planning to redo the two-track separation experiment with a new beam defining system to investigate the dependence on the two-track distance along anode wires. For the measurement we had improved our DAQ system for the baby chamber. Because of an unfortunate accident, we lost the chance to do this experiment at KEK Tanashi: the 1.3 GeV electron synchrotron of KEK Tanashi broke just before our machine time, the last one before its disassembly. We are now looking for appropriate beams. On the other hand, dE/dx measurements with the baby chamber can be done at KEK Tsukuba. In parallel with preparations for beam tests, we are planning to further gas property studies including diffusion coefficient measurements and gas gain saturation studies at TUAT. Wire material studies are also in progress at Kinki Univ. Up to this point is the official status report from the JLC CDC group. In what follows, let me show you my personal view on a possible future direction of our R&D.

4 Future Direction (Personal View)

As discussed in this meeting extensively by T. Tauchi and Y. Sugimoto[8, 2], there is a demand for a higher magnetic field from beam-related background reduction point of view. We thus need to reconcile chamber parameters, taking into account such a new constraint. Let me now discuss what will happen if we increase our magnetic field from our present 2T to 3T. For simplicity, let us scale all the quantities with the dimension of length by a factor of 2/3, in order to preserve lepton ID momentum acceptance:

$$\left\{\begin{array}{lcll} B & = & 2\text{T} & \to & 3\text{T} \\ l & = & 185 \text{ cm} & \to & 123 \text{ cm} \\ \sigma_{xy} & = & 85\ \mu\text{m} & \to & 60\ \mu\text{m} \\ L & = & 460 \text{ cm} & \to & 307 \text{ cm} \\ n & = & 80 & \to & 80 \end{array}\right. . \tag{5}$$

If this is possible, we have

$$\left\{\begin{array}{lcl} \sigma_\kappa^{meas} & : & \times 1 \\ \sigma_\kappa^{MS} & : & \times 2/3 \\ \sigma_z & : & \times 1 \\ \sigma_{T_0} & : & \times 1 \end{array}\right. . \tag{6}$$

Notice that since the average track distance decreases by the factor of 2/3, the required two-track separation gets smaller by the same factor.

Of course, this kind of scaling is not practicable. It is difficult, if not impossible, to scale wire spacing, or σ_{xy}, or R_{in}: wire spacing is limited by feed-through thickness, wire instability due to electro-static force, etc., and σ_{xy} of 85 μm is already rather aggressive, and the inner radius is bounded by the outer radius of the support tube. If we keep the same wire spacing, the same σ_{xy}, and the same inner radius:

$$\left\{\begin{array}{lcll} B & = & 2\text{T} & \to & 3\text{T} \\ l & = & 185 \text{ cm} & \to & 110 \text{ cm} \\ \sigma_{xy} & = & 85\ \mu\text{m} & \to & 85\ \mu\text{m} \\ L & = & 460 \text{ cm} & \to & 307 \text{ cm} \\ n & = & 80 & \to & 50 \end{array}\right. \tag{7}$$

then what happens to chamber performance?

$$\left\{\begin{array}{llll}\sigma_\kappa^{meas} & \propto & \frac{\sigma_{xy}}{l^2 B\sqrt{n}} & \uparrow \\ \sigma_\kappa^{MS} & \propto & \frac{\sqrt{(X/X_0)}}{lBp} & \downarrow \\ \sigma_z & \propto & \frac{\sigma_{xy} L}{r\Delta\phi} & \downarrow \\ \sigma_{T_0} & \propto & \frac{\sigma_{xy}}{v_{drift}\sqrt{n}} & \uparrow \\ \text{required 2-track separation} & \propto & \text{track distance} & \downarrow \\ \text{Lorentz angle} & \propto & B & \uparrow \end{array}\right. . \tag{8}$$

Two-track separation and time stamping capability have to be studied carefully in physics simulation studies. Here, let us check the effects on momentum resolution and Lorentz angle.

4.1 Momentum Resolution

Fig.5 plots $\sigma_\kappa \equiv \sigma_{p_T}/p_T^2$ as a function of $\cos\theta$ for $p = 1, 5, 10, 20, 50, 100$, and 250 GeV, without and with IP constraint for the current 2T design of the JLC CDC. Fig.6, on the other hand, is

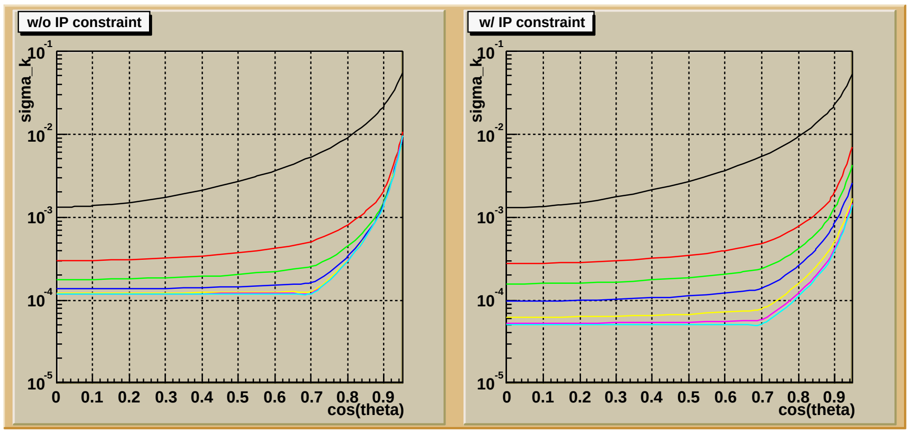

Figure 5: Momentum resolution as a function of polar angle without (a) and with (b) IP constraint, for the current 2T design.

a similar plot for the 3T design described above. We can see that the momentum resolution for

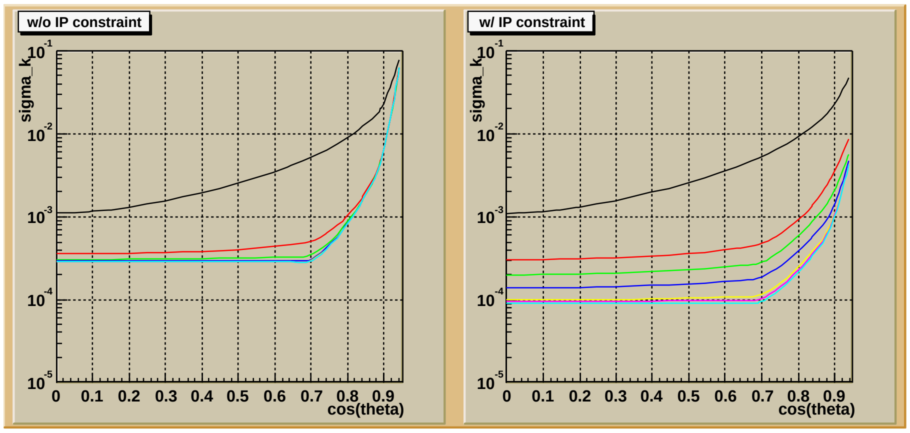

Figure 6: Same as Fig. 5 but for the 3T design described in the text.

$p \lesssim 5$ GeV, the region populated most in jetty final states, is dominated by multiple scattering and essentially stays the same. The asymptotic resolution became a factor of 2.5 worse than the 2T design with the CDC alone, while the the difference becomes smaller with the IP constraint. If we compare the momentum resolutions with IP constraint for $p = 50$ GeV, $\sigma_\kappa = 0.62$ GeV^{-1} and 1.0 for the 2T and 3T designs, respectively.

We expect more improvement from the inclusion of an intermediate tracker[9] for the 3T design than for the 2T design, because the effect of multiple scattering is expected to be less. Personally, I think this momentum resolution for the 3T design is acceptable.

4.2 Lorentz Angle

As for the Lorentz angle, we may have to worry about the loss of track electrons near some bad corners of a drift cell. Fig.7 compares the drift lines for $B = 2$T and 3T. At 2T, all the drift

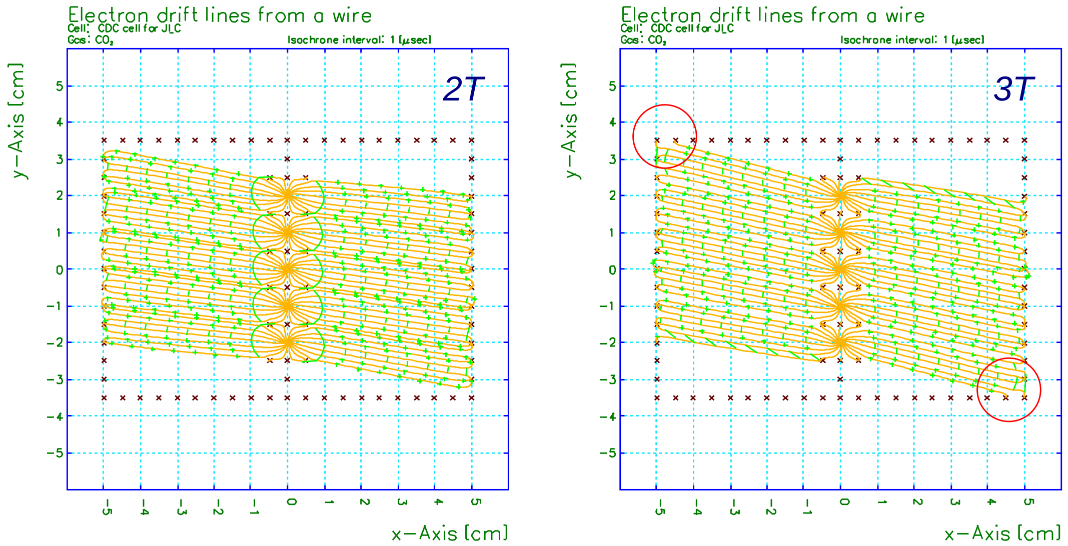

Figure 7: Drift lines at $B = 2$T and $B = 3$T.

lines are contained in the cell, while at 3T there appear some bad corners. We can avoid them by slightly shortening the drift region, if necessary, without tilting the cell.

4.3 From Engineering Point of View

From engineering point of view, the smaller the better. First of all the wire sags, both gravitational and electrostatic, are proportional to L^2/T, where L is the wire length and T is the wire tension. Shortening the chamber by the factor of 2/3 thus significantly reduces the wire sags. In addition, when supported only by the outer cylinder, the end-plate distortion due to the wire tension is proportional to R_{out}^4/t^2, where R_{out} is the radius of the outer cylinder and t is the end-plate thickness. The end-plate distortion can be significantly reduced, too.

4.4 Neutron Background and Chamber Gas

Another line of future R&D is on the neutron background. We may have to avoid gas mixtures with hydro-carbons susceptible to neutrons. If we use pure CO_2, for instance, the gas gain goes down, necessitating better electronics or higher anode voltage. The higher voltage causes bigger electrostatic wire sags and, possibly, more gas gain saturation. Another approach is to replace isobutane by a non-hydro-carbonic gas, for instance, $CO_2(90)/Ar(10)$. Requirement to the time stamping capability might require a faster gas anyway. In both cases, we need further

R&D. It is also very important to investigate possibilities to reduce the number of neutrons that enter the CDC sensitive region: some more absorber outside the CDC? We need more studies.

In any case, any design change should be made consistently to the whole detector system, and should be justified by physics simulation studies. We need inputs from ACFA physics simulation studies with new detector parameters.

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