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SOLENOIDAL DETECTOR NOTES

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FORWARD TRACKING WITH ENHANCED ELECTRON IDENTIFICATION†

EHIT Collaboration

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Abstract

Design concepts and developments are described for the construction and use of charged particle tracking detectors in the intermediate pseudorapidity range ($1.4 < \eta < 2.4$). Electron identification is enhanced by simultaneous detection of transition radiation X-rays and ionisation energy loss.

Physics Agenda and Detector Concept

The physics agenda set the detector requirements. A representative range of processes to consider includes Higgs searches, t-quark physics (Wb, Ws, $H^{+}b$, $\bar{t}\gamma$, $W\bar{b}$, $Z^{o}c$ decays), Z′ search and triple gauge boson vertex studies [1].

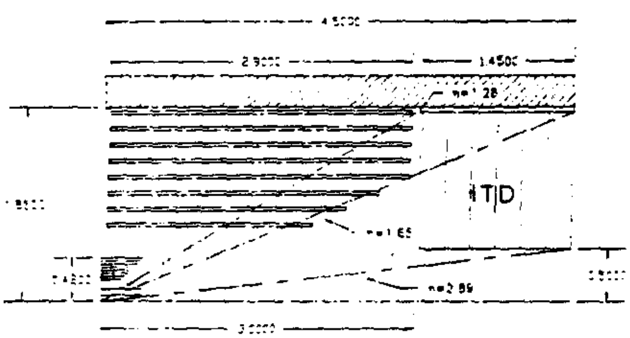

Figure 1 a) Charged track detector layout for use in 2T solenoidal magnetic field; 6 ITD modules are shown [2,3]

The (s)fermion channels have "large" cross-sections and detailed signatures, and the boson channels have low rates (at high masses) and simple signatures. Both types of process identify tracking, $e^{\pm}$ identification and charge sign determination over an angular range exceeding ±2 units of rapidity as prime requirements. In congested events it is a great benefit to have $e^{\pm}$ identification ($^{dE}/_{dx}$ + TRD) located on the electron track, as well as calorimeter signatures.

Figure 1 shows a detector concept for an Intermediate angle Track Detector (ITD) [2,3] using detectors that measure $\phi.r$ (150 μm accuracy) and r (2 cm accuracy) at fixed z (beam direction) in a 2T solenoid. The momentum resolution is compared to that of a dipole detector in figure 2. The accuracies are comparable but a solenoid is preferred because of azimuthal uniformity, advantages in systematic errors and track matching to an inner track/vertex detector (e g silicon in SDC, see figure 1), and in suppression of background caused by (very) low momentum secondaries produced in the beam pipe [4]. The measurement is obtained using radial-wire drift chambers that measure ϕ-differences directly. To obtain given a momentum error the number of sense planes needed is only half that of a Cartesian grid of the same cell-size. Because the radial-wire cell size is better matched to the varying hit density ($d^2N/drd\phi \sim 1/r$ in endcaps) the advantage grows to a factor of three.

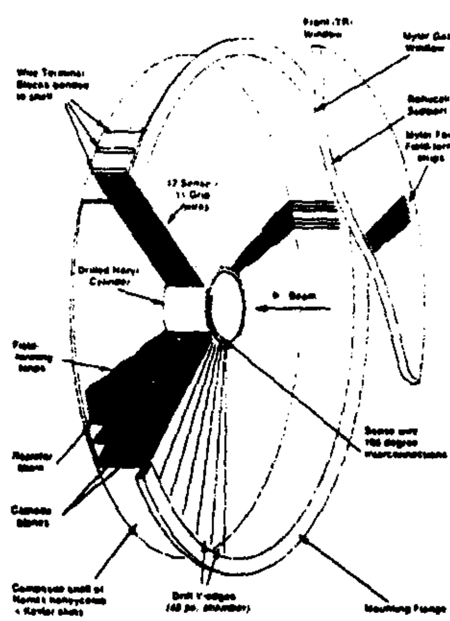

Figure 1 b) 48-sector radial chamber module used in the H1 experiment [5].

The equations of a track originating on the beam line at $r = z = 0$ in a uniform magnetic field are

$$\phi = \phi_o + {}^{eBz}/_{2p_z}$$
$$r = 2p_T .\sin({}^{eBz}/_{2p_z})/eB$$

Event associated tracks are thus exactly straight lines in the ϕ-z plane. This makes for easy track-finding within and between modules.

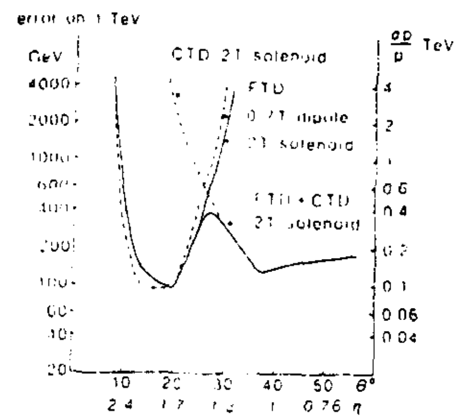

Figure 2: Comparative momentum resolutions for solenoidal and dipole intermediate angle tracking detectors (FTD) [4].

Detector Layout and Performance

The ITD in figure 1 has 6 (or 5) modules per end-cap with 300 sectors ($50 \leq r \leq 150$ cm). The maximum drift distance varies with radius from 5.2 to 15.7 mm. Each module has eight radial wire sense-layers giving a modest total of 14400 (or 12000) channels per end-cap. For readout, each sense wire is joined to another well separated in azimuth (105° in H1). Using resistive sense wire, charge division readout gives 2 cm position resolution in r. The whole detector is constructed of light composite materials. The z-space between modules is filled with suitable transition radiator (TR) material (polypropylene foils in H1). Traversing electrons emit ~1.4 collinear X-ray photons ($<E_X>$~6 keV) which convert in the chamber gas (30% Xe) in each module. Deposited charge ($^{dE}/_{dx}$ + TR) is used to distinguish e from hadrons.

With a gas gain of 2.10^4 the sense wire irradiation dose is 0.08 C cm^{-1} y^{-1} at $\mathcal{L} = 1.10^{33}$ cm^{-2} s^{-1} and the occupancy, (hit rate/cell) x (busy time), is 0.12. The busy time is equal to 2 x (two hit resolution)/(drift velocity). The H1 forward tracker has already achieved 1.5 mm two-hit resolution [5]. Given radial wire sense wire geometry and azimuthal electric drift fields in a solenoidal magnetic field, the component of drift velocity perpendicular to the wire cannot exceed

$$v_{perp} = {}^{E}/_{2kB} . \sin(2\theta_L)$$

where θ_L is the Lorentz angle of rotation of the electron drift relative to E, and $k = {}^{E}/(vB \sin\theta_L)$. k ~ 1.1 for most gas mixtures. We therefore design our chamber for a fast gas with E = 3 - 4 kV cm^{-1}, B = 2T, $\theta_L = 45°$, v_{perp}~ 100 μm ns^{-1}. (See [6] by J.M.Bailey for our work on gas mixtures).

The occupancy and lifetime figures indicate that the detector is viable up to $\mathcal{L} = 3.10^{33}$ cm^{-2} s^{-1}. Detector congestion and pattern recognition is discussed below. The major technical concern is the maintenance of the cathode-plane voltage gradient in the presence of the high anode current draw.

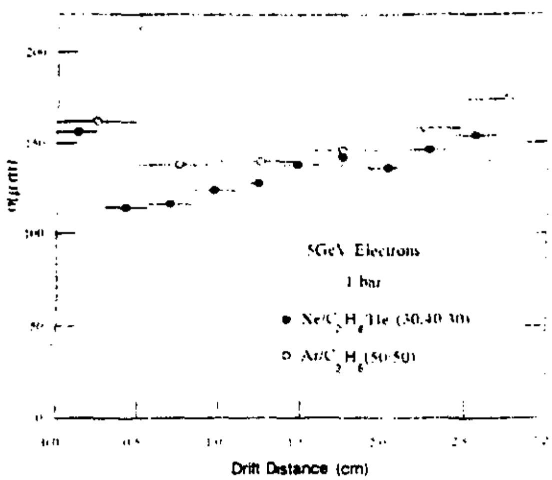

Figure 3 a) Position resolutions in ϕ.r as a function of drift distance in an H1 48 sector radial wire chamber [5]

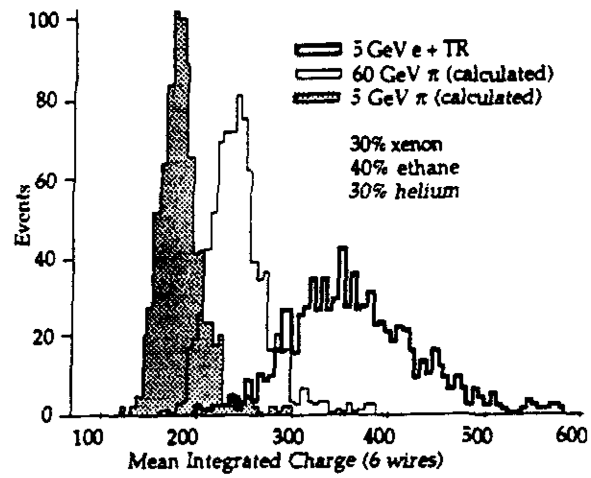

Figure 3 b) Integrated charge measurement for three 12 wire modules in the H1 configuration for 5 GeV e with preceding radiator; also shown are π spectra calculated from measurement of 5 GeV e without radiator [5].

The 48-sector H1 forward tracker [5] acts as a prototype for this device. Mechanical construction provides wire position accuracy of 38 μm rms. Pulse height measurement is independent of position along the sense wire to within 2% and is very uniform between sense wires. Figure 3(a) shows position resolution as a function of drift distance (everywhere better than 150 μm) and figure 3(b) the integrated charge measurement for electrons and pions. At 90% electron efficiency these provide a pion rejection of 200 at 5 GeV/c and 25 at 40 GeV/c. Similar precision is anticipated in each case for the SSC ITD as described. The ϕ.r and r measurements are naturally correlated by the readout (8-bit nonlinear FADC in this case). The device therefore provides three-dimensional space points with deposited charge information.

Crossing Tagging and Pattern Recognition

In a multi-hit device such as a drift chamber, one should distinguish between the busy time (related to the two-hit resolution) and the memory time (maximum drift time) from which the total number of hits read out with an event can be estimated. The number of read-out channels in the detector is kept below 30,000 (both end caps) by taking advantage of this distinction. We exchange time of drift for money (number of channels). The result is an accumulation of background hits due to out of time events. (The average memory time of a cell is 105 ns at $v_{perp} = 100\ \mu m\ ns^{-1}$). To suppress them we propose the addition of an ancillary *crossing-tagger*. A conventional way to realise such a device is a 1.5 mm spacing MWPC with cathode readout strips arranged parallel to the drift chamber isochrones. These are read out (cheaply) via updating discriminators (3,000 channels per module at 1.5 mm spacing) and have a three-bunch-crossing latch time. An in-time ITD drift chamber hit thus has a crossing tagger latch exactly over it. Since the tagger strip matches the drift chamber isochrone geometry this can be done before any pattern recognition. The crossing tagger also trivially resolves the left-right ambiguity (the natural way to lay out the strips joins the isochrones of neighbouring cells), and provides prompt pattern signals that could be used in triggering. An exciting approach would be to use microstrip gas avalanche chambers with 30 μm position resolution and 125 μm two-track resolution [7]. These naturally have outstanding rate compatibility [1].

TABLE 1
ITD Hit rates for $H \rightarrow Z^oZ^o$ events

	without crossing trigger	with crossing trigger
Mean number of hits	73 (190) [108]	21 (31) [25]
Fraction of hits from Higgs	21% (8%) [14%]	73% (49%) [66%]
Fraction of hits from wrong bunch-crossing		1.5% (1.7%) [2.5%]
Fraction of Higgs hits lost (within 2 mm of earlier hit)	7% (14%) [9%]	
Luminosity	$\mathcal{L} = 1.10^{33}\ cm^{-2}\ s^{-1}$ ($\mathcal{L} = 3.10^{33}\ cm^{-2}\ s^{-1}$) [maximal pair conversions]	

We have made pattern recognition studies using 20 + 20 TeV PYTHIA events [8] for $H \rightarrow Z^oZ^o$ superimposed on a background of minimum bias events. Table 1 gives the results for one detector plane. We conclude that the use of crossing triggers with the radial chambers provides a means of substantially eliminating hits from wrong bunch crossings. The remaining contamination comes almost exclusively from events in the same bunch crossing as the triggered event, and would of course be present in any detector with a time resolution equal to the bunch crossing interval. Such contamination must be removed by other means such as the use of the z-vertex, for which of course an accurate charged track detector is essential! The fraction of Higgs hits lost is small and is characteristic of the two-track resolution, better than in, for example, 4 mm diameter straw tubes.

Summary

The 300-wedge ITD is a powerful detection device. It gives 3D space points. Accurate $\phi.r$ measurement provides excellent momentum resolution and relatively straightforward track finding in a region of uniform axial (z) magnetic field. Electrons are identified in jets with pion rejection factors of 200 (5 GeV/c) to 25 (40 GeV/c). The geometry matches the physics - dense packed where needed, φ-z straight lines. The excellent resolution (150 μm in $\phi.r$, < 2cm in r) has been proven in a large detector. Less than 30,000 full readout channels are needed. A crossing-tagger (30K hit channels) picks the wanted hits with only 1 - 2% background because it is precise in both time and space.

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