PROJECTION CHAMBERS AND dE/dx AT ISABELLE[†]

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Many of the exciting prospects at ISABELLE involve the observation of charged particles from the decay of high mass objects. The decay of some of these particles into charged lepton pairs offers a clear signature of their existence. However, if one of the leptons is a neutrino, then the method of establishing the momentum of that neutrino by reconstructing the momenta of all other particles suggests itself. Clearly, this will only work when the solid angle of the detector is high and the charged and neutral energy resolution is good. In addition, the leptonic decay rates of these particles Z^0 , $W^\pm$, ...

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are thought to be small fractions of the hadronic rates and so the prize of observation of these particles through their hadronic decays seems rewarding.

This is not to say that this challenge is to be taken lightly, and our self imposed task described below, has been to attempt to see if an escalation of the present technology (and imaginable variants thereof) can be expected to offer a reasonable chance of measuring the momentum and identifying the charged particles over a wide momentum range. A powerful photon detector outside the magnetic field is taken as an obvious supplement to the design. We have also assumed that the exotica are produced largely near $x = 0$ and that it is sensible to optimise the acceptance there. This is in slight contrast to the attitude taken to a large hadron spectrometer in the 1976 workshop. It is not so much that we are choosing sides as that the technique we describe below lends itself to wide acceptance centered about $x = 0$. In facing up to the design of the central spectrometer, we assumed that a charged W of $60 \text{ GeV}/c^2$ would decay into two hadronic jets of 10 particles each and the overall motion of the W is not such as to superimpose much additional momentum.¹ The particles that we must measure are not of very high momentum, say, less than $30 \text{ GeV}/c$ momentum; our solenoid is thought to be matched to that range.

1. C. Quigg, "Production and Detection of Intermediate Vector Bosons and Heavy Leptons in pp and $p\bar{p}$ Collisions," Fermilab Preprint, January 1977.

Although superficial calculations of rate at modest luminosity are encouraging, we have adopted a geometry suggested by Sadoulet as a focus for our study since it is likely to behave well at a higher luminosity than alternative arrangements. Our remarks apply to the "bicycle wheel" design described in the Sadoulet paper.²

(D.H.W.)

Rate Limits Due to Bicycle Wheel Geometry

The first limit we have to confront is a gain shift on the proportional wires that occurs at high rates due to local buildup of charge. Walenta³ has measured this and finds a 2% gain decrease when the rate is 3×10^3 tracks/sec/mm wire length where the total avalanche size is 2×10^6 ion pairs/track.

Let us consider the inner wire on our bicycle wheel. From our rate calculations at $L = 2.5 \times 10^{32}$

we have 1.6×10^3 tracks/sec/mm at 90° which is acceptable.

Even at a small forward angle like 0.1 radian, if one were to design a detector that long, we have only 125 tracks/sec/mm.

Here the track length is 10 times as long per drift cell so that

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2. B. Sadoulet, "Comments on Charged Particle Detectors for the pp Large Solid Angle Detector", CERN Preprint.
 3. A.H. Walenta, Report on gain shifts and wire life, these Proceedings.

we have the equivalent of 1.25×10^3 tracks/sec/mm - also acceptable. We assume an avalanche size of 2×10^6 which may be 40 ion pairs with a gain of 0.5×10^5 . This can be tuned to be acceptable depending on pressure, cell size, etc.

Another limit is due to the accumulation of deposits on a wire which Walenta³ claims necessitates cleaning after 10^{11} particles/cm. In our case we have at worst 1.6×10^4 tracks/cm/sec which is approximately 10^9 tracks/cm/day. This gives a lifetime of the order of 100 days. It seems, however, that using ammonia as a quencher may lengthen this life considerably. One can also experiment with lower gain, pulsing the high voltage only for an event trigger, or curling up low P_T particles in a magnetic field.

A more stringent limit comes from the distortion of the drift trajectory due to the buildup of positive ions in the drift gap at high fields. Sadoulet² has calculated this effect for the bicycle wheel geometry. The result is that the error in the position of a track due to alteration of the drift angle by space charge is:

$$ds = \frac{f q e a}{2 E_o u^+ E_o^2} \tan \alpha g^3 n \quad (1)$$

where f = fraction of ions escaping into gap ~ 0.1 (Ref. 4)

q_e = primary ion pairs/track length $\sim 1.6 \times 10^{-19} \times 10^4$
pairs/m

A = amplification $\sim 10^5$

$W^+ = u^+ E_0$ = positive ion drift velocity $\sim 1.6 \times 10^{-4} \text{ m}^2/\text{s}/v$
in Argon, $E_0 \sim 1.5 \times 10^5 \text{ v/m}$

α = drift angle due to $E \times B$ drift

n = particles/sec -m^2

g = drift gap

for the above numbers $ds \sim 10^{-7} g^3 n$ (MKS).

The effect goes as the gap size cubed (!) and is worst near the outer edge of the detector. There, for $L = 2.5 \times 10^{32}$, we have a flux $n \sim 10^6$ particles/ m^2/sec . To keep the error down to 10^{-4} m (drift chamber accuracy) we would require a gap size of 10 cm at the outer edge. Our 32 sector design calls for a gap of 30 cm giving an error 27 times larger. We can reduce this effect (see Eq. 1) by increasing the electric field, or decreasing the amplification or, most directly, by increasing the number of segments and reducing the gap size. There are enough parameters for a satisfactory solution to be found. (J.A.)

Momentum Resolution with the Bicycle Wheel

We have estimated the momentum resolution of the bicycle wheel device with dimensions shown in Fig. 3.

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4. J. Marx, TPC Proposal on fraction of positive ions, these Proceedings.

Figure 3

We assume there are 20 position wires (and 200 dE/dx wires) per sector. The resolution in Z is taken to be 2% of the wire length and the resolution in the azimuthal direction is taken to be 200 μ . We assume the wires are located accurately and ignore all systematics.

Error in P_T :

We consider first the error in momentum in the plane perpendicular to the Z direction. For 3 equal spaced points the sagitta is given by $s = x_2 - (x_1 + x_3)/2$.

The error in this is then $\sigma_s^2 = \sigma_{x2}^2 + \sigma_{x1}^2/4 + \sigma_{x3}^2/4 = \frac{3}{2} \sigma_x^2$ for equal errors. The sagitta error decreases slowly with increased number of points. (Sadoulet has an error decreasing as $1/\sqrt{n}$. We believe this to be too strong a dependence on n.) We have arbitrarily divided σ_s^2 by an additional factor of 2 to go from 3 to 20 wires.

$$\sigma_s^2 = \frac{3}{4} \sigma_x^2$$

or

$$\sigma_s = 173 \mu.$$

P_T (GeV/c)	Turning Angle	s (cm)	$\frac{\Delta s}{s}$
0.5	61°	19	9×10^{-4}
1	33°	9.6	1.8×10^{-3}
1.5	22°	6.3	2.7×10^{-3}
5	6.7°	1.9	9.1×10^{-3}
10	3.35°	.96	.018
20	1.68°	.48	.036
40	$.84^\circ$	.24	.072

We have neglected multiple scattering in the calculation. With typical gas mixtures this will give errors comparable with the geometrical ones calculated above.

Error in Momentum Due to Errors in Measuring Angle with Respect to Z Axis

Since
$$p = \frac{P_T}{\sin\theta}$$

$$\left(\frac{dp}{p}\right)^2 = \left(\frac{dp_T}{p_T}\right)^2 + \left(\frac{d(\csc\theta)}{\csc\theta}\right)^2$$

We have a track measurement as shown below (Fig. 4):

To simplify the calculation we assume the origin of the track fixed. The error calculated will thus be too small but for 10 or 20 points the effect of this assumption should not be large.

$$\tan \theta = \frac{r_i}{z_i}$$

$$\frac{1}{\sigma_{\tan \theta}^2} = \cot^4 \theta \sum_{\text{all wires}} \left(\frac{r_i}{\Delta z_i} \right)^2$$

The sum has been evaluated yielding 8500 for 20 wires and 3450 for the first 10 wires. For 20 wires we then obtain

$$\left(\frac{dp}{p} \right)^2 = \left(\frac{dp_T}{p_T} \right)^2 + \frac{(\cos \theta \sin \theta)^2}{8600} = \left(\frac{dp_T}{p_T} \right)^2 + \Delta^2$$

θ	Δ 20 wires	Δ 10 wires
15°	-	0.004
25°	-	0.007
35°	-	0.008
45°	0.005	0.009
60°	0.005	0.007
75°	0.003	0.004
90°	0	0

(B.R.,O.B.)

Track Finding in dE/dx Central Detector

Here is a preliminary look at the problem of finding the track hit times and pulse heights which are associated with a given trigger event. The main problem is the high event rate which leaves track signals in the chamber during the time data is being collected for the triggered event.

Let us assume a solenoid magnetic field 6 m long and 1.5 m radius with a 20 cm inner radius; assume a "bicycle wheel" transversal projection chamber with 32 sectors. For a luminosity of $L = 2 \times 10^{32}$ we obtain the following particle rates (Paige):

Rates are:

every interaction

1 every 100 nsec

outside wire 32 sectors / 2.7×10^7

1 every 1185 nsec ~ 1000 nsec

inside wire 32 sectors / 7×10^7

1 every 460 nsec ~ 500 nsec

When a trigger occurs, signals will be obtained from wires for the longest drift time on that wire. The drift times are:

$$\text{max drift distances} = \frac{2\pi r}{32} = \frac{2\pi \times 1.5 \times 10^6}{32} \mu\text{m}$$

$$\text{max time} = \frac{\text{drift distance}}{50 \mu/\text{nsec}} = \frac{2\pi \times 1.5 \times 10^6}{32 \times 50} = 6 \mu\text{sec}$$

$$\text{inner drift} = \frac{2\pi \times (0.2) \times 10^6}{32 \times 50} = \frac{4}{5} \mu\text{sec}$$

We will record 6 tracks on the outer wire and 2 on the inner

$$\frac{6 \text{ } \mu\text{sec}}{1000 \text{ nsec}}$$

$$\frac{4/5 \text{ } \mu\text{sec}}{500 \text{ nsec}}$$

mostly coming from other events which occur every 100 nsec. On the average, however, these tracks will not point back to the interaction region by

$$500 \text{ nsec} \times 50 \text{ } \mu/\text{nsec} = 2.5 \text{ cms}$$

or by

$$1000 \text{ nsec} \times 50 \text{ } \mu/\text{nsec} = 5 \text{ cms}$$

so that they can easily be excluded after reconstruction. However every track on the inner wire must be reconstructed before all the unwanted data on the dE/dx lines can be filtered.

In addition, a given sector may or may not have a track from the trigger event, so that every sector must be reconstructed, i.e. $32 \text{ sectors} \times 2 \text{ tracks} = \underline{64 \text{ tracks most of which are unwanted}}$. A scintillation counter covering all of a sector might select only those sectors with tracks from the trigger event and thus reduce this burden.

In addition the burden might be reduced by splitting the drift chambers into 2 parts with opposite directions of drift. Thus, at the boundary, the sum of drift times = constant and a quick check might eliminate sectors with no tracks of interest. Note that the $v \times B$ drift angle complicates this test.

This opposite drift test is probably better than the scintillator test. The overall level of spurious data is somewhere between 2 and 6 tracks per sector, say 4; in toto 4×32 sectors = 120 spurious tracks.

Finally, the rate of track signals on the inner wires - every 500 nsec - is sufficiently fast that overlap of track signals might be a problem. If track signals are of the order of 150 nsec FWHM then the chance of overlap is $(1 - e^{-\frac{150}{500}}) \sim 1/4$ so that a significant reduction in quality of dE/dx information might occur.

In summary: The equivalent of 120 spurious tracks accompany the trigger event and must be removed by reconstruction (perhaps partial and fast) techniques. The dE/dx information on the inner wires will be degraded at high rates. (T.W.)

Rate Limitations on Drift Wire Operating in the Proportional Mode

Experiments on gain shift due to space charge effects indicate that several % gain shifts occur on signals from drift wire operating in proportional mode when the local flux of ionizing tracks is $\sim 3 \times 10^3$ tracks/sec/mm of wire for sections of track ~ 1 cm long.³

The number of tracks/sec/mm for which a sense wire at radial distance R from the interaction region in an n sectored detector with sense wire separation $\Delta/2$ will collect the ionization from particles crossing it at an angle θ is

$$\frac{dN}{dz} = \frac{2\pi L f(\theta) \sin^3 \theta}{Rn}$$

L = luminosity in cm^{-2}

$f(\theta) = \langle \bar{n} \rangle \frac{d\sigma}{d\Omega}$ in cm^2 (Ref. 5)

R = distance of wires from beam line in mm

n = number of azimuthal sectors in detectors.

This situation is illustrated in Fig. 8.

From the above considerations we may expect that the relevant quantity to examine is $Q(\theta) = \frac{dN}{dz} \times \frac{\Delta}{\sin\theta}$ and that $Q(\theta)$ would have to be kept less than 3×10^3 track cm/sec mm for acceptable pulse heights response of that fraction of that wire.

$f(\theta)$ may be approximated by $8/\theta^{1.8} \times 10^{-27}$ /ster for $1 \text{ mrad} < \theta$

< 1 radian and $f(\theta) \sim 7 \times 10^{-27}$ /ster for $1 \text{ radian} < \theta < \pi/2$.

This gives $Q(\theta) \sim 1400 \sin^2\theta/\theta^{1.8}$ up to 1 radian, and $Q(\theta) \sim$

$1200 \sin^2\theta$ for $1 < \theta < \pi/2$. ($R = 200 \text{ mm}$, $n = 32$, $L \sim 2 \times 10^{32} \text{ cm}^{-2}$, $\Delta = 1 \text{ cm}$.)

5. Figs. 4a and 4b of F. Paige rates est. papers - this workshop.

The overall behavior is very flat and it would seem to be feasible to keep it inside the acceptable operation region with reasonable segmentation of the detector, (L.R.)

Data Handling Requirements

1. Basic Parameters

If our detector consists of 32 "spokes" of 200 wires each, we have 6400 channels of dE/dx information. At \$60 per ADC, it would cost \$375,000 disregarding TDC's and all other electronics, which seems excessive. We cannot group together wires from different spokes - the 32 planes are just barely enough to cope with expected event multiplicities.

The use of CCD's should solve this problem - holding the wire signals for serial transmission to ADC's. 500 bucket CCD's now cost \$25,00/channel, but costs are expected to come down substantially in a few years. It is now possible to read in analog signals at 30 MHz clock frequency and read out at 20 KHz; this raises the possibility of separating dE/dx information from two or more tracks through the same cell.

The system used by Platner⁶ for TDC readout could be adapted to transmit wire signals to an ADC as follows:

6. E.D. Platner, BNL 21898 and these proceedings,

At 5 μ sec per ADC read, each wire plane needs 10 ADC's to obtain one pulse-height measurement from each wire in 1 msec - more for multiple-track readout. In the same time interval, a 100 MHz readout of dual 16-bit TDC registers can read 300 wires. If every tenth wire in each spoke has drift-time measurement, two serial lines can read in all TDC data in that time interval.

To put data on tape in uncompressed form would require $\sim 64,000$ bits per event. A 6250 bpi, 75 ips 9-track tape could record at most 60 events per second, and would be filled in 6 minutes at that rate. Some form of preprocessing seems to be necessary.

2. Possibilities for Preprocessing

Elimination of zeros might gain a factor of 2 to 4, partially offset by the need to provide address information. This is certainly the easiest form of data compression.

Encoding TDC information yields only a small gain, since it is a small fraction of the total.

Summing signals from adjacent wires within a spoke is the most promising way to compress data. This, however, implies a preset cutoff level for the Landau tail.

If the CCD clock runs fast enough during data taking to separate pulses from multiple tracks, tracking done before readout to the ADC's could pass only the time slices corresponding to each track to the ADC. But a fast, efficient, not easily confused tracking routine is necessary for such a program to succeed.

A microprocessor can perform about 1000 operations in 1 msec, so data compression and signal summing from groups of wires is easily possible, using one processor for each spoke. If a factor of 3 is gained by each technique, we could log approximately 500 events per second at top speed - or 100 events/second at 30 min. per tape.

The processors could also calculate z-coordinates on wires equipped with readout at both ends.

The "bicycle-wheel" detector will be severely limited by tape writing time if no form of preprocessing is used. Preliminary analysis by microprocessors could increase the rate to around 300 events/sec. This rate is still less than 10^{-4} the predicted rate of wide angle single particle production: a selective fast trigger is necessary to make best use of this detector (jets, multiplicity, non- π , lepton, etc.).

A minimum cost estimate for the data acquisition electronics for each spoke is:

200 preamplifiers	\$2000		
200 CCD shift registers	2000		
20 TDC registers	200		
20 ADC's	3000		
1 Microprocessor	<u>1000</u>		
	<u>\$8200</u>	x	<u>32</u>
	\$262,400		

(W.D.)

Conclusions

We have taken the "standard" luminosity of 2×10^{32} as a goal for a device that measures charged particle momenta over a wide solid angle. It appears that a projection chamber is capable of operation in this mode providing care is taken to optimize the geometry with this high flux in mind. Some of our calculations have indicated that optimism is required but in no direction have the demands on the apparatus appeared to be well beyond those attainable. In addition dE/dx measurements yielding particle identification over the median momentum range, about 2-30 GeV/c, are also feasible.