SSC-SDE-19

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SOLENOIDAL DETECTOR NOTES

LATERAL SEGMENTATION
25 June 1989

John Hauptman

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Lateral Segmentation

The question of lateral segmentation in SSC calorimeters has been addressed for several years (1984 to 1989) and by many people. I am surely not aware of all the work, but I will revisit this question by collecting and plotting calculations from the following sources:

Fernandez, et al., Snowmass 1984, p. 107.
Protopopescu, Snowmass 1986, p. 180.

Freeman and Newman-Holmes, Berkeley 1987, p. 673.

Bay, et al., SSC-202, Jan. 1989.

Bengtsson, et al., FSU-SCRI-89-01, Jan. 1989.

There are three figures-of-merit which have been commonly used to assess the quality of an SSC calorimeter, (i) the W $\rightarrow q\bar{q}$ mass resolution, (ii) electron identification, and (iii) the relative reconstruction and identification efficiencies of W $\rightarrow q\bar{q}$ and QCD jets which fake a W decay. The first two are "trivial" to do, while the third requires full-event simulations of large "data" samples.

The results of these calculations for (i) are shown in Figure 1. It must be noted that for most of these numbers I have read the FWHM from a plot, then divided the FWHM by 2.36 to get a rms width, σ. Also, as far as I can tell, all groups used a tower geometry with uniform $\eta-\phi$ segmentation which was equal for both electromagnetic and hadronic sections, *except* for Fernandez/1984, in which the hadronic section was a factor of two more coarse than the electromagnetic. Therefore, the "effective" combined segmentation for this calculation is that value plotted on the abscissa, i.e. for .01 electromagnetic and .02 hadronic, the effective segmentation is taken to be .015. Finally, I have also included a point from UA1 data (Carboni, Vanderbilt 1987) at $\Delta\eta$ = .17 showing their calculated resolution of 7.9±0.5 GeV. Counting bins in their data, in which the W and Z are not mass-resolved, I agree with this number.

The numbers from Bay, et al., were estimated differently from the other estimates, and therefore can not be directly compared. When the calculations are done similarly, the results are in general agreement, although I do not have all the numbers to plot.

I was surprised by the good agreement among these calculations. Anyway, apparently the W mass resolution does not improve below a segmentation of $\Delta\eta = \Delta\phi$=.05 in the central region. Presumably, the mass resolution at very small segmentation is limited by the energy resolutions assumed for the calorimeters in these calculations, although that is not proven. Freeman and Newman-Holmes did calculate the mass resolution versus assumed calorimeter energy resolution, but only for some nominal segmentation, not a very fine segmentation. Between "perfect" energy resolution and some nominal energy resolution, the W mass resolution degraded by about 20%. (Freeman and Newman-Holmes, Figure 3.)

A reasonable conclusion based on W mass resolution is that going below $\Delta\eta = \Delta\phi$=.05 would not be worth the expense.

The second figure-of-merit is electron identification or tagging. This largely refers to an isolated electron, but electrons buried in jets, or near the edges of jets, may also be of interest. People have used several criteria, but a simple criterion is just to require that a candidate electron tower be surrounded by quiet (say, less that 5%) towers. Many people have found answers to this problem, and I will just plot their answers to the question "what segmentation is required to identify electrons" in Figure 2. The numbers, with references, are below.

reference	comments	$\Delta\eta$=$\Delta\phi$
Non-Magnetic Det, Berk'87, p.472	2 cm × 2 cm at 1 m	.02
Compact Det, Berk'87, p.388	from Baltay, et al., Snow'84	.03
LSD, Berk'87, p.340	"e/π could be better if $\Delta\eta$ finer"	.02-.03
Partridge, Berk'87, p.657	t→e tagging near θ=0	.02
Williams, Snow'86, p.327		.02
Baltay, et al., Snow'86, p.355	"the finer the better"	.03
"Identification of e-", Snow'86, p.420		.01-.02

The "mean" here is about $\Delta\eta$=$\Delta\phi$ = .023. These numbers are for an unassisted calorimeter. There is a further point that one might get away with a coarser segmentation if one uses a precision pre-radiator or a shower-max chamber as in CDF. These require some study in the SSC environment. I fear that some wishful thinking is taking place here, and that event pile-up and stray tracks from jets bent into a candidate electron tower will degrade the identification. So a careful calculation is required.

Permit me to ramble a minute here. Whenever it is possible to make direct and robust measurements in a detector, such that *the raw measurements themselves give you the answer*, then that is best. Ancillary information (e.g. from a pre-radiator or shower-max chamber) cannot often be used in a first level trigger because the geometrical association cannot be made that quickly. The Berkeley TPC is a good example of a detector whose raw data contain exceptionally good information. The big Berkeley bubble chambers are another example, and both of these devices were workhorses for two generations of good physics.

Although people with different tastes and different experiences with detectors will arrive at different conclusions, mine is that there is no substitute for direct identification, especially for electrons at both the trigger and refined analysis levels. Since electrons are so important, there should be a confirming measurement which can be employed at the third level trigger and in the analysis.

A conclusion based on electron identification is that a segmentation of $\Delta\eta$=$\Delta\phi$ = .02 in the electromagnetic calorimeter is driven by the need to identify isolated electrons.

The third, most difficult figure-of-merit is the calorimeter capability to identify hadronic W decays, W $\rightarrow q\bar{q}$, and to distinguish these W's from ordinary, copious QCD fragmentations. As far as I know, I am the only one to do this problem as a function of segmentation, although Protopopescu has done it at $\Delta\eta = \Delta\phi$=.05. It requires generating tens of thousands of events with Pythia/ISAJET and passing the stable, interacting particles through a good calorimeter simulation program. I store separately electromagnetic and hadronic towers with energies above 0.1 GeV for a segmentation of $\Delta\eta = \Delta\phi$=.01, and then I combine towers to generate event records with .03, .05, etc. I have generated two large event samples: (1) gg $\rightarrow$ Higgs $\rightarrow W^+W^- \rightarrow \ell\nu + q\bar{q}$ and (2) qq $\rightarrow$ qW $\rightarrow \ell\nu$ + q. The quarks give jets, and the game is to distinguish the quark-jet in process (2) from the two W quark-jets in process (1). The W decay to light quarks is kinematically like $\pi^0 \rightarrow \gamma\gamma$ decay, and gives two distinct jets most of the time, so there are two clumps in the calorimeter. As the W energy approaches 1 TeV, these clumps begin to coalesce. For a highly asymmetric decay in the W center-of-mass, one jet can go backwards and be very slow in the lab, and the other carries most of the energy into one clump in the calorimeter. The single quark from process (2) gives one clump, but some fraction of the time, like α_s, there are two or more secondary jets, and the energy pattern in the calorimeter can resemble a W decay. We have to trust that our simulation codes get this right. By doing some complicated pattern recognition and event reconstruction (including the missing ν), I find that the efficiency to keep W's relative to the probability for a jet to fake a W is about 100, that is, you can reduce the QCD quark background by 100 relative to the W signal. The dependence of these efficiencies on the lateral segmentation is shown in Figure 3 (from Snowmass 1984 and from Berkeley 1987). There is a long story about whether or not the simulation codes generate the proper amount of multi-jets or not. So as a test, I forced Pythia to make more multi-jets and, as expected, the rejection against these multi-jets deteriorates (by a big factor, too, so life may be very difficult with W $\rightarrow q\bar{q}$).

In addition, there are two handles on this process which can serve to improve its effectiveness. One is the capability to tag the initial WW state (Gutay, et al., Berkeley 1987, p. 788), and the second is that quarks from the W will have a multiplicity corresponding to 41 GeV partons, whereas the QCD background jet will on the average have a much larger multiplicity. (Lee Pondrom, ANL meeting, June 13-15, 1989). Neither of these handles have yet been employed.

In any case, my conclusion is that beyond a hadronic segmentation of $\Delta\eta$=$\Delta\phi$ = .04, combined with an electromagnetic segmention of .02, the W $\rightarrow q\bar{q}$ identification degrades rapidly.

One final comment: we do all of these detector designs with the standard model in mind, but if we ever want to see past the end of our nose, then we should over-design just in case something more interesting and demanding than the standard model develops. So why not design for the Higgs, then make the calorimeter 50% better *for no good reason.* This is not fiscally irresponsible: an increase in channel count by a factor of 2 may only increase the overall cost of the calorimeter system by a few percent.

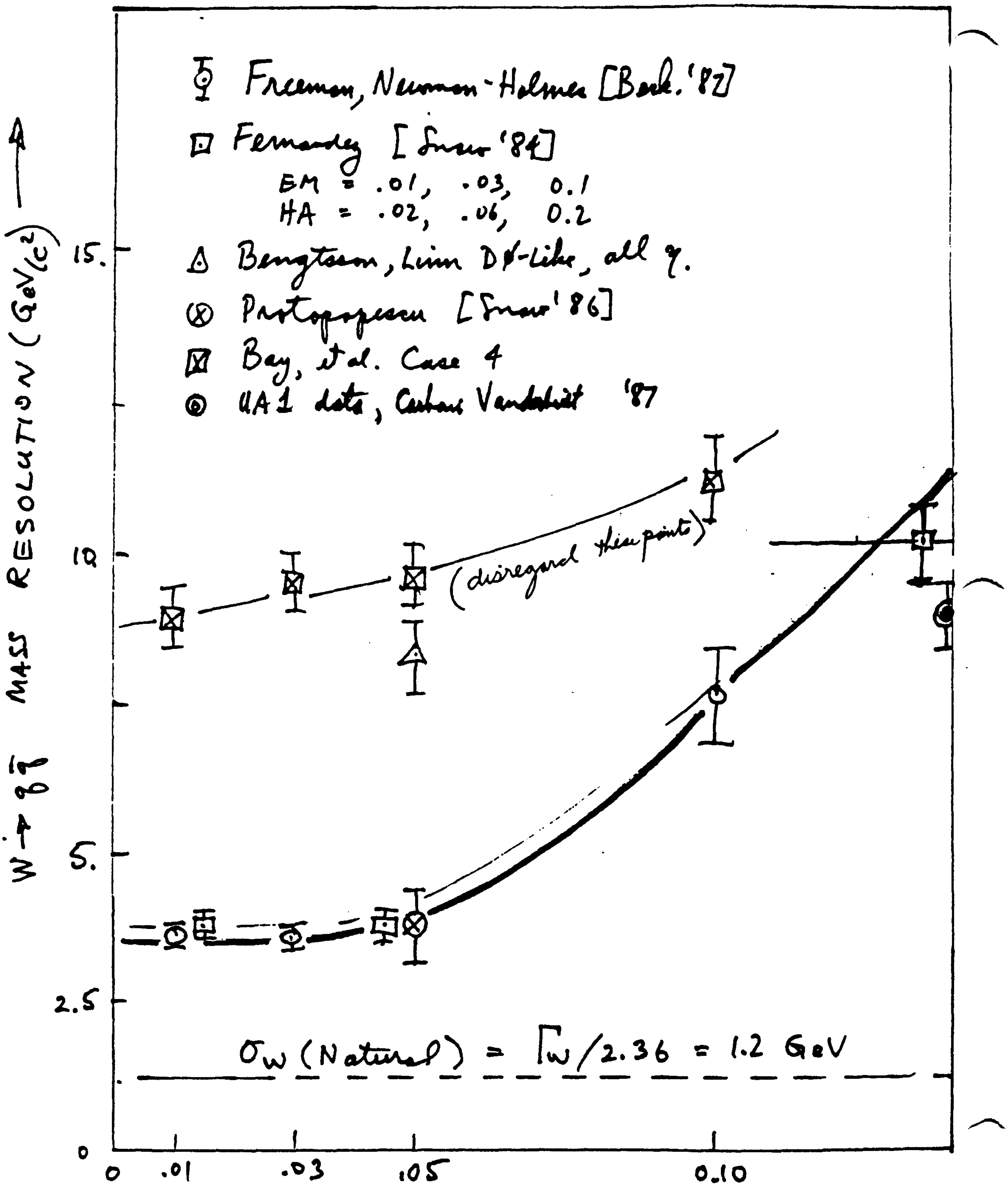


Figure 1: η, φ LATERAL SEGMENTATION →

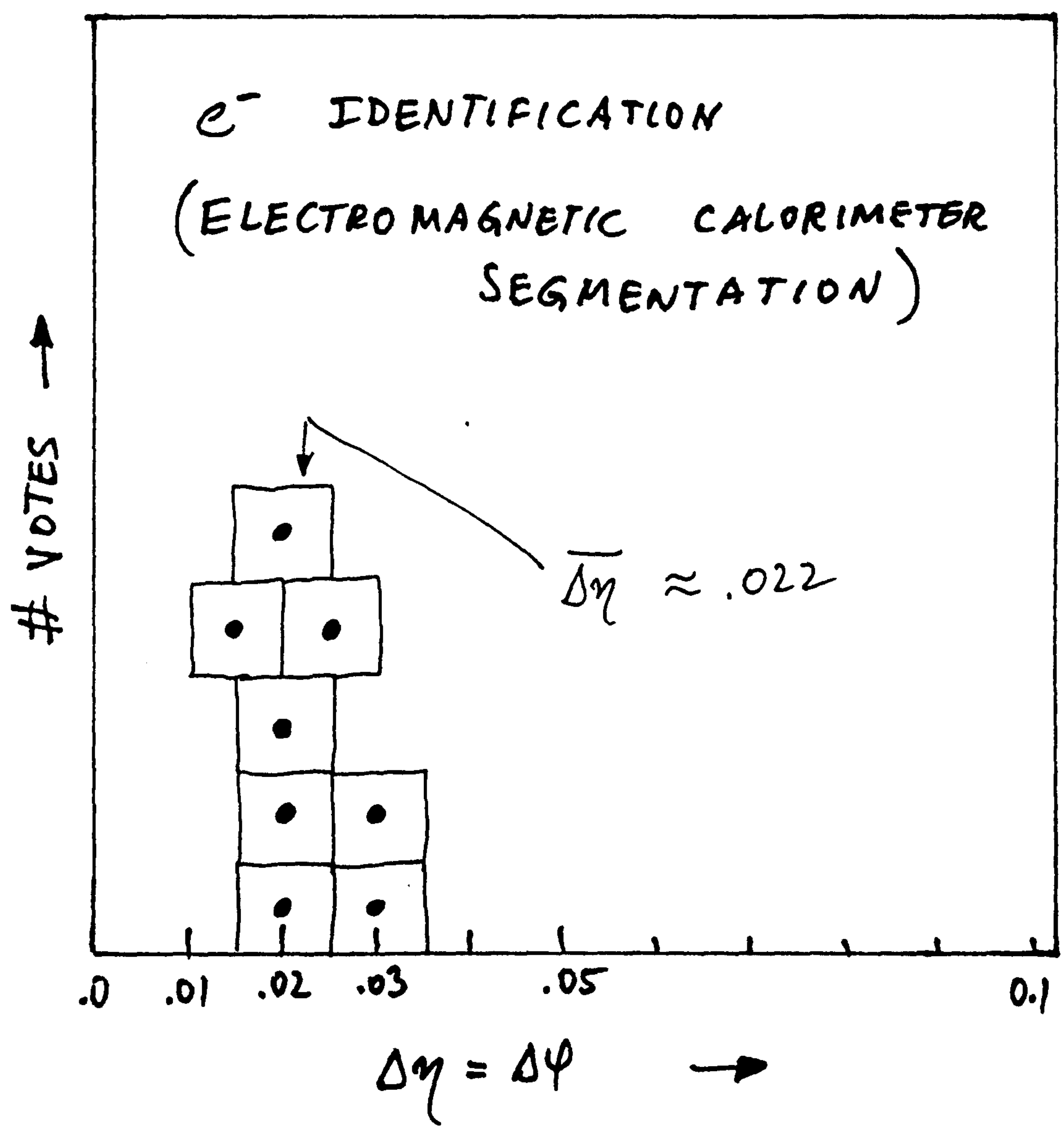
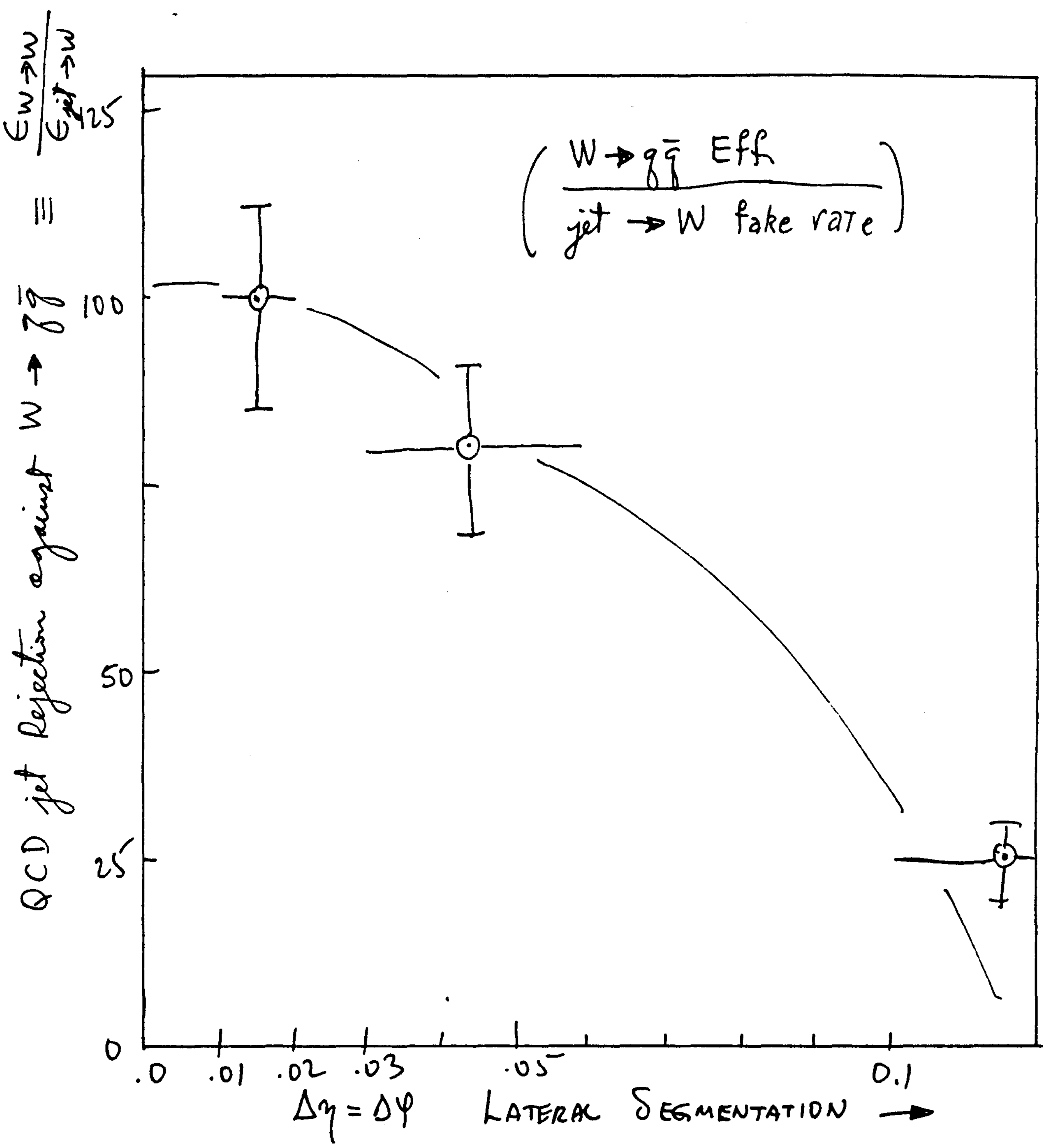


Figure 2. ELECTRON IDENTIFICATION.



QCD jet Rejection against W → q q̄ ≡ ε W→W / ε jet→W
125
100
50
25
0
W → q q̄ Eff / jet → W fake rate
.0
.01
.02
.03
.05
0.1
Δη = Δφ LATERAL SEGMENTATION →

Figure 3.