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FUTURE DETECTOR NEEDS FOR HIGH ENERGY PHYSICS*

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Abstract

High energy physics, as exemplified by the SSC, requires the analysis of increasingly complex events which occur at ever higher event rates. The SSC detectors embody an order of magnitude increase in cost and complexity. Research and development for a 500 M$ detector with 500K data channels must procede in step with accelerator design. Up to a decade of R&D at 1% per year (5M$) invested should be expected. This implies the close involvement of industry.

SSC Event Rates

The SSC[1),2)] will provide a luminosity $L=10^{33}$ $cm^{-2}sec^{-1}$ at a cm energy $\sqrt{s}=40$ TeV. The bunch crossings occur every 33 nsec. An inelastic cross section of 100 mb means an event rate of 100 MHz. A charged particle density of 6 per unit of rapidity spread over $|y|<y_{max}=11.35$ means a total particle rate of 600 MHz per unit of rapidity or 13.6 Gz particle rate in 3.3 events/crossing.

These enormous rates are required by our science[3)] to uncover the new phenomena expected at the SSC. However, the implications for existing detector technology are cautionary. A cylindrical detector or radius R, length 2L covering $|y|<2$ (or $\theta>15^{\circ}$) would for R=10 cm absorb a dose of 100 krad in 1000 hours of operation. If divided into 600 1 mm cells, each cell would see 2 MHz of rate, leading to 3% accidentals within a 16 nsec gate.

Data logging can be achieved only after multilevel triggering[4)]. The fundamental physics variable indicative of a scattering between basic constitutents is the transverse momentum $P_{\perp}$. The jet rate for $|y|<2$ and $P_{\perp}$ >0.03 TeV is still 100 KHz, and falls to 1 Hz only for $P_{\perp}>0.5$ TeV.

Detector Granularity and Depth

The events of interest due to the hard scattering of constituents contain "jets" of particles. These jets are clustered about the constituent direction. Shown in Fig. 1 is the cone angle of the jet. For example, a detector which will just resolve 2.0 TeV jets over ±6 units of rapidity requires 37K "towers" divided in $\Delta y\sim.045$ and $\Delta\phi/2\pi\sim1/140$. A further factor of 5 subdivision longitudinally leads to 185K data channels.

A traditional wide angle detector is divided into distinct cylindrical subassemblies stacked radially.

Vertex Detectors

The vertex detector tags weak decays by finding decay vertices. The scale is set by $(c\tau)_{D+}$~280μm, $(c\tau)_{\tau}$~100μm, $(c\tau)_B$~420μm[5]. At the beam pipe (R=1 cm) this object will absorb 10 Mrad in 1000 hours.

Tracking Detector

The tracking chambers measure the charge, and vector momentum of all tracks by utilizing magnetic deflection. The error dP/P scales as P/R^2. For detector surfaces with 20μm resolution spread over 20cm, one has dP/P<10% for P<0.1 TeV.

Calorimetry

The function of calorimetry is to measure energy flow in the event. One must have hermetic coverage over $|y|<6$ or $\theta>5$ mrad, so that the existence of ν are inferred accurately for $(P\ ) \gtrsim 0.03$ TeV. Electromagnetic showers are contained in ~20 radiation lengths $(X_o)$of absorber while 98% of hadronic cascade energies are contained in 7 absorption lengths (λ_o) for P<2.0 TeV[6]. The transverse shower sizes are ~X_o and λ_o respectively, which for R~0.4, 0.5m imply $\Delta\phi/2\pi$ ~ 1/2120, 1/30. This segmentation is fairly well matched to a 2 TeV jet.

Given that tracking resolution goes as P/R^2 while calorimetric resolution goes as $1/\sqrt{P}$ and shower containment goes as ln P, SSC detectors will center on calorimetry. A comparison of the resolution of the tracker mentioned above and Uranium calorimetry ($dP/P \sim 0.4/\sqrt{P}$) is shown in Figure 2. This is not to say that magnetic analysis is precluded. In fact it is crucial for weak decay vertex detection and for good jet mass resolution. However, it need only resolve low momenta.

A Uranium-liquid Argon calorimeter is limited to ~100 nsec drift time. This means 10 events/gate with a mean particle occupation/cell of ~2%. If a hadron shower is spread over 3x3 cells, then 18% of all towers are occupied. Clearly faster drift times should be investigated.

Muon Detection

Muons are detected by penetration of material. Hadrons will punchthrough[6] a length λ with a probability=p. Figure 3 shows λ vs P for p=0.01. For P<1 TeV one needs ~28 λ_o total, 21 λ_o in addition to calorimetry, or 3.5m of steel.

If the steel is magnetized to 20 KG, then dP/P for muons is 9.6% up to the maximum measurable momentum. This value is P=7 TeV if one has the steel instrumented with detectors of 200μm resolution and an exit lever arm of 1m.

For $|y|<2$ and a 0.4m decay length, the decay rate for muons is ~2.4 MHz/$(P_\perp^{min})^{3.5}$. The 28 λ_o depth, means $P_\perp^{min}$=5.7 GeV or 5.6 KHz at that depth. A trigger cut of $P_\perp$=66 GeV means a rate of 1 Hz.

Tracking R&D Issues

Several summaries of outstanding detector problems[7] and the R&D necessary to attack them[8] exist. Here we explore only tracking. Given that material costs for calorimetry and muon detection scale as R^3, this seems a logical starting point.

As discussed above calorimetry will be the premier detector at the SSC. This implies a compact, fine grained, radiation hardened, high speed, highly accurate tracking detector. The parameters of a generic wide angle tracking detector are given in Table I5

Table I

Tracking Detector

$\langle n \rangle$=24/event, 79/crossing

50 samples

thickness/sample=T=4mm

10<R<30 cm

cell spacing s=1mm

axial length $L \leq 1.2$m($|y|<2$)

occupation=3%

128K cells

resolution within a cell=σ=20μm

$\Delta\phi/2\pi$ ~ 1/44,000

2 TeV jet angles resolved by 320

Gaseous Detectors

Conventional gaseous detectors are hard pressed[9] to achieve the design specifications. With a fast gas[10] like CH_4 or CF_4 the drift time gate is an acceptable 16 nsec. The resolution σ can be achieved only at 4 Atm. This means 0.2 nsec drift time resolution. However at 200$/channel this means 25.6M$ for electronics. At $\geq$0.2W/channel this implies $\geq$25.6 KW front end electronics power dissipation at the chamber ends. The 100 Krad dose is 20x the CMOS power on dosage. With 4% methalyl added to the gas one can achieve $\leq$10μA standing currents[11] and >98% efficiencies by accomodating large gain shifts. However, this issue of long term gas aging is not settled.

Silicon Detectors

Silicon microstrip technology is rapidly advancing[5]. Radiation damage[12] leads to a reverse current[13] of 3.6μA/Mrad. Damage to the readout electronics is similiar to that for chambers. For 40μm pitch one would need 3.2M channels, consisting of 1.2 m long strips to read out only 1 coordinate. At present detector costs of 200$/cm^2 and electronics costs of $100/channel, this system costs 600M$.

Scintillating Fibers

The SSC is in the energy regime where calorimetry deposes tracking. It may be that the SSC is also a turning point for tracking detector technology. Scintillating glass suffers from a low efficiency/fiber and a slow response time[5]. Scintillating plastic suffers radiation damage[14] of a 10% light output loss for a 50 krad dose. By doping the scintillator, one can tolerate <3 Mrad[15].

These polystyrene plastic fibers are fast, radiation hard, rugged, simple, and very granular. There is a Saclay UA2 proposal for 60K fibers arranged into 7 xuv triplets read out by image intensifier and CCD. This detector will yield valuable operational experience. As with silicon strips, a 40μm diameter means 3.2M channels per coordinate.

The fibers could be used for both vertex and tracking detectors. By wavelength shifting twice, one might also use them for calorimeter readout[16]. Assuming that problems of inhomogenity and dead spaces could be solved, one then has a tremendous detector integration and simplification. Clearly, this is a fertile area for more R&D.

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Figure Captions

1) Angle within which 1/2 of all jet particles are contained as a function of jet energy.
2) Tracking vs calorimetry
   a) momentum resolution as a function of P
   b) Required length for 10% resolution (tracking) or 98% shower containment (calorimetry) in Uranium.
3) Depth of absorber required for 1% punchthrough probability vs energy.

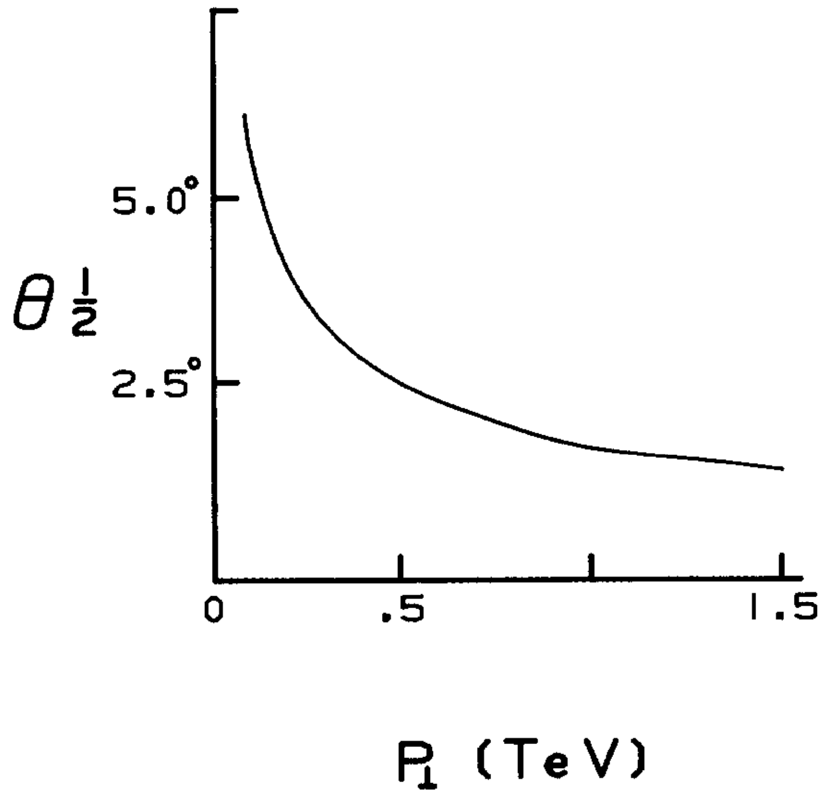

Figure 1

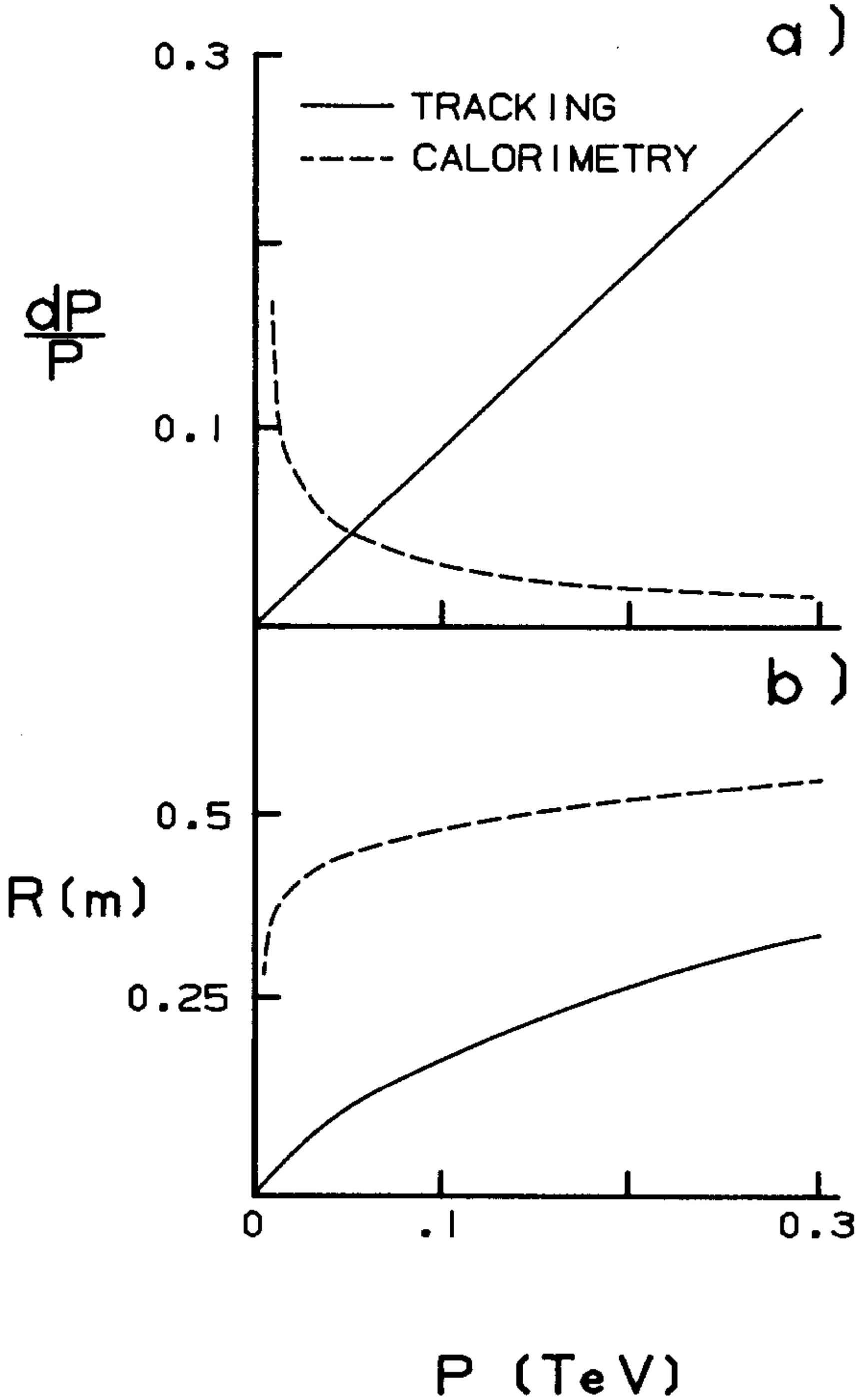

Figure 2

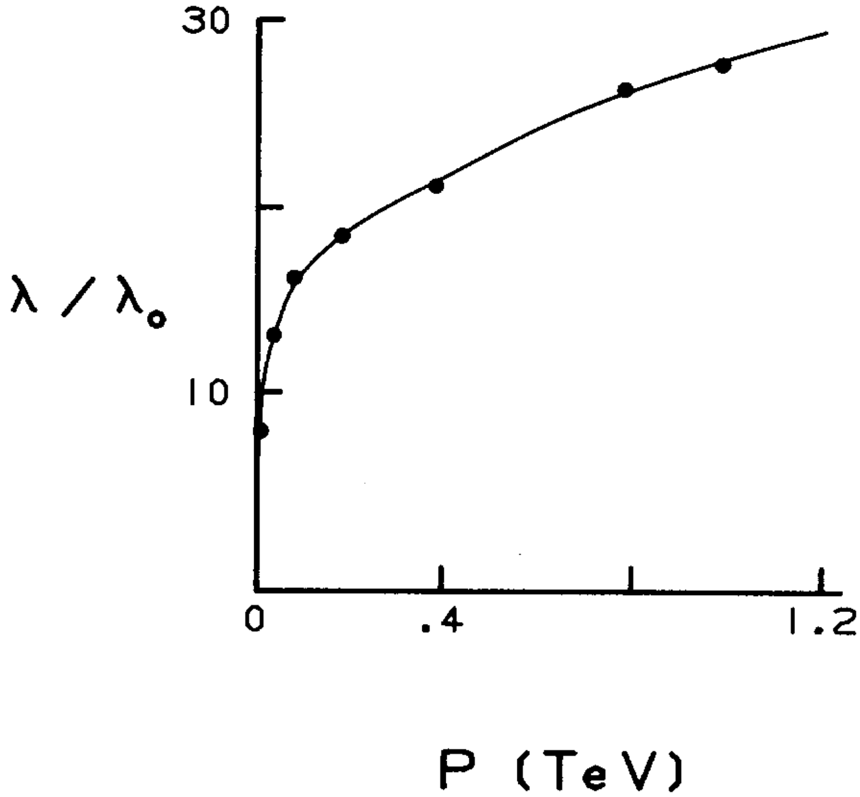

Figure 3