A JET SPECTROMETER FOR SSC ENERGIES AND LUMINOSITIES

James Bensinger
Brandeis University, Waltham,MA 02154

Nikos Giokaris
The Rockefeller University, New York, NY 10021

Abstract

A limited solid angle ($\Delta\theta=\Delta\phi=\pm 0.8$ radians) spectrometer designed to study high transverse momentum (p_T) jets at SSC energies and luminosities are described. The reasoning for its overall size and the particular type of each detector component is explained. Trigger rates for two jet production, expected from QCD, as well as number of electronic channels are listed.

Physics-Motivation

The SSC energy will be at least twenty times higher than any of its predecessors. This will give the possibility to look at much smaller distances and therefore to search for new phenomena. By measuring high p_T jet production at 90° one can test the validity of QCD at the new energy scale, search for quark compositeness, study the quark fragmentation, look for extra gluons and new heavy particles and find the heavy flavor content of jets. Some, but not all, of these measurements will be done by the general purpose 4π detectors. For example to tag the jet flavor hadron identification is needed. However adding a Cherenkov counter in a 4π detector means pushing the calorimeter back by several meters and therefore making its cost prohibitively high. However a limited solid angle jet spectrometer equipped with a Cherenkov ring imaging (RICH) and transition radiation (TRD) and a finely segmented calorimeter could perform all of the above mentioned measurements better, faster and at a lower cost. We describe such a spectrometer in this note.

Spectrometer Design

Several authors[1,2] have considered already the possibility of using limited solid angle spectrometers at 90° to do high p_T physics. In Ref. 1 a spectrometer with a very small solid angle ($\Delta\theta = \Delta\phi = \pm 2°$) is described. It is designed to measure inclusive single charged hadron production with high p_T. The spectrometer of Ref. 2 has an aperture of 0.25 steradian. This is still not big enough to measure the whole jet but, according to Ref. 2, "it could be integrated into a 4π non-magnetic calorimeter to characterize the pedestal under the jet being studied and to observe nearby energy flow associated with the jet, and other jets in the event".

The approach we have chosen here is the following: a) Make the tracking system and the calorimeter large enough so that most of the energy of jets, with their core inside the calorimeter central region, will be measured. Also make sure that the central region is large enough so that a significant number of jets with p_T up to several Tev will be detected. These requirements dictate[3] that the calorimeter and the tracking system cover a solid angle of $\Delta\theta = \Delta\phi = \pm 0.8$ radians (2.5 steradian, $\Delta\eta = \pm 0.9$). According to Ref. 3, if we require that the jet axis is contained within the central $\Delta\theta = \Delta\phi = \pm 0.3$ radians of the detector, at least 85% (98%) of the total energy of jets with $E_T = 100$ Gev (2 Tev) will be detected. Also, for an integrated luminosity of $10^{40} cm^{-2}$, jets with E_T up to about 3 Tev could be studied (see Table VIII). b) Since the most interesting information about a jet is carried by its core, we have chosen to do particle ID only in the central $\Delta\theta = \Delta\phi = \pm 0.5$ radians part of the detector. For that reason and to keep the detector cost and number of channels reasonable, only the central, $\Delta\theta = \Delta\phi = \pm 0.3$ radians part of the calorimeter is finely segmented. The resulting spectrometer is shown in Fig. 1. It is 12 m long and its axis is at 90° with respect to the incoming beams.

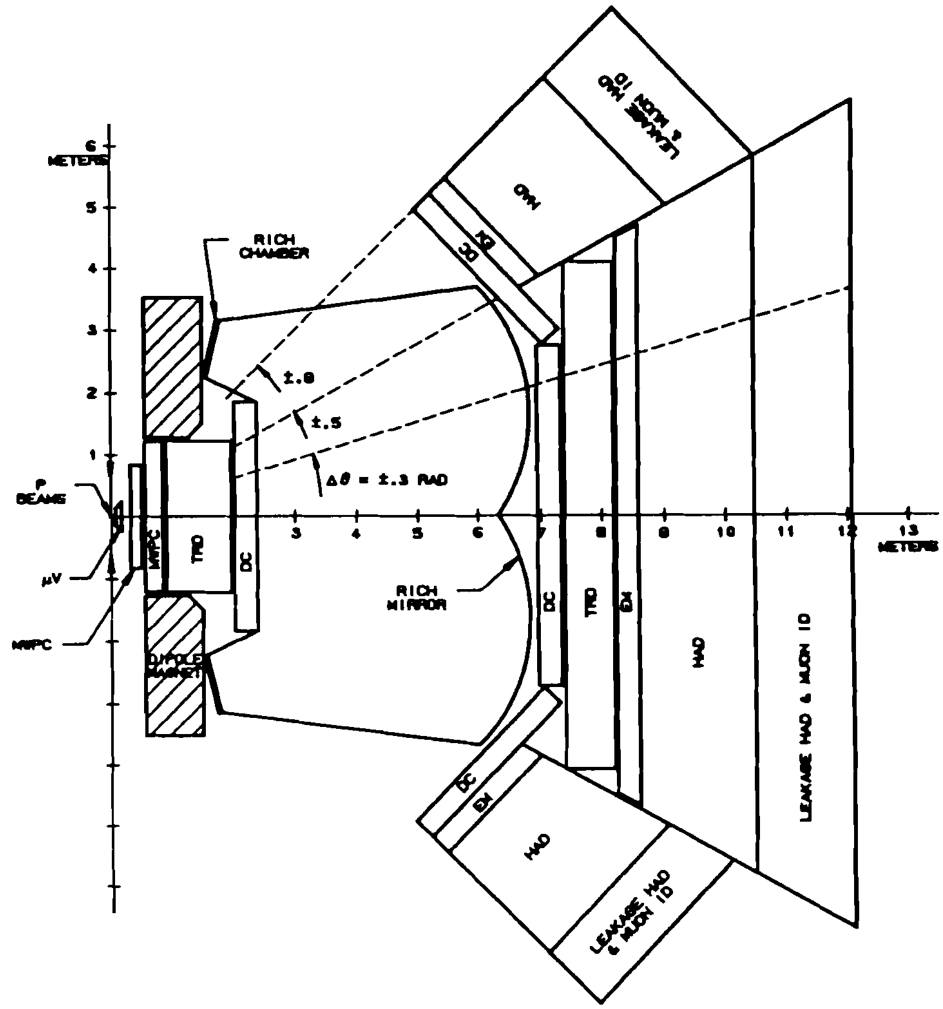

Fig. 1: Schematic diagram of the spectrometer (horizontal view) μV - microvertex detector, MWPC - multiwire proportional chamber, DC - drift chamber, RICH - ring imaging Cherenkov counter, TRD - transition radiation detector, EM - electromagnetic calorimeter, HAD - hadronic calorimeter.

The spectrometer consists of a silicon microvertex detector, a magnetic spectrometer, a transition radiation detector (TRD), a Cherenkov ring imaging counter (RICH), a calorimeter and a muon identifier.

In the following we describe each detector component in more detail.

Detector components

Calorimetry

The calorimetry we chose is Pb-LAr (0.5% CH_4 is added in the LAr to speed up the electron drift velocity[4]). Recent SLD test results[5] indicate that the e/π ratio for such a calorimeter is about 1.1. The near equalization of the electromagnetic and hadronic signals is attributed to the transition effect. Therefore an improved hadronic resolution of about $55\%/\sqrt{E}$ is expected. The other advantages of such a calorimeter are its uniform response, its radiation resistance and absence of cracks. There are three cryostats with an EM and a HAD calorimeter in each. The calorimeter in the central cryostat covers the central $\Delta\theta=\pm0.5$ radians. $\Delta\phi=\pm0.8$ radians solid angle. The calorimeters in each of the two side cryostats cover the $\Delta\theta=\pm0.5 \rightarrow \pm0.8$ radians, $\Delta\phi=\pm0.8$ radians solid angle. The segmentation, number of readout depths, number of electronic channels and the thickness of the EM (HAD) calorimeters are listed in Table I(II). The 3X3 cm^2 segmentation in the central region allows for a π^0 vs single gamma separation up to (π^0) momenta of about 80 Gev.

The total number of the calorimeter electronic channels is 130K.

Table I
EM Calorimeter

	Region	
	$\Delta\theta=\Delta\phi\pm0.3$ radians	$\pm$ 0.3 → $\pm$ 0.8 radians
Segmentation (cm^2)	3X3	10X10
# Readout Layers	3	2
# Channels	85K	30K
Thickness (Rad. Lengths)	20	20

Table II
Hadronic Calorimeter

	Region	
	$\Delta\theta=\Delta\phi=\pm0.3$ radians	$\pm$ 0.3 → + 0.8 radians
Segmentation (cm^2)	10X10	20X20
# Readout Layers	2	2
# Channels	5K	10K
Thickness (Inter. Lengths)	10	10

Tracking

The tracking system consists of a silicon vertex detector and four stations of drift chambers. A one meter long dipole magnet is used for momentum analysis. In the following we describe each one of these components in more detail.

Vertex Detector. The main purpose of the vertex detector is to search for secondary vertices. It also assists the drift chambers for the track reconstruction in front of the magnet. It consists of five silicon strip planes. The parameters of the detector are listed in Table III. The total number of strips is 7K. The silicon will survive several years of running at $L=10^{33}cm^{-2}sec^{-1}$. Present day electronics however will have to be improved by at least one order of magnitude to be able to withstand the above luminosity.

Table III
Silicon Vertex Detector

Layer #	1	2	3	4	5
Distance from IR(cm)	2	3	4	5	6
Orientation	X	X	X	Y	Y
Size(cm^2)	4X4	6X6	8X8	10X10	12X12
Pitch(μm)	30	30	50	100	100
# of Strips	1.3K	2K	1.6K	1K	1.2K
Single Rates* (Mhz per strip)	0.23	0.15	0.18	0.3	0.25K

* For minimum bias events at $L=10^{33}cm^{-2}sec^{-1}$.

Drift Chambers. To do the track reconstruction and to measure the momentum, two stations of MWPC's, with mini-drift, and two stations of drift chambers are employed. Their locations are shown in Fig. 1 and their parameters are listed in Table IV. They could also be used for particle ID in the low momentum region. The total number of wires is 57K.

Table IV
Drift Chambers

Station #	1	2	3	4
Distance from IR(m)	0.5	0.8	2	7
# of Modules	1	1	1	3
# Planes/Module	4X2U2V2Y	4X2U2V2Y	4X2U2V4Y	5X3U3V5Y
Size (m^2)	1X1	1.6X1.6	4X4	4X4
Sense Wire Distance (mm)	1	1	4	10
Resolution (μm)	100	100	200	200
# of Wires	10K	16K	12K	19K
Single Rates* (Mhz per Wire)	0.3	0.2	0.3	0.13

* For minimum bias events at $L=10^{33}cm^{-2}sec^{-1}$. The effect of the magnetic field has not been taken into account.

Magnet. The dipole magnet is 1m long (0.7m to 1.7m from the IR). It has a field of 15 KG and bends the particles vertically. Assuming a drift chamber resolution (for the first two stations) of about 100 μm we can achieve a momentum resolution of $\Delta p/p=2\%p$ (p in 100 GeV/c).

Particle ID

TRD. There are two stations of TRD's at distances from the IR of 1m (inside the magnet) and 7.3 m respectively. They cover only the central $\Delta\theta=\Delta\phi=\pm0.5$ radians of the spectrometer. The parameters of the detectors are given in Table V. FNAL experiment E715 (Ref. 6) succeeded an E_π/E_e (efficiency ratio) of $10^{-3}/0.99$ using the cluster counting technique with a similar detector in the momentum range of 10-100 Gev. The total number of TRD sense wires is 24K.

As has been pointed out[2], a trigger based on matching TRD groups of wires and calorimeter towers could be used as an electron trigger with high p_T. The TRD could also give π/K,p separation for leading particles in high p_T jets.

Table V
Transition Radiation Detector

Station #	1	2
Distance from IR(m)	1	7.3
# of Modules/station	6	6
Radiator		
-material	Polypropylene	Polypropylene
-size(m^2)	1x1	7X7
-# of layers/module	200	200
-foil thickness(μm)	17	17
-foil separation(mm)	0.7	0.7
PWC		
-gas mixture	Xe + 33%CH_4	Xe + 33% CH_4
-cathode-anode distance(mm)	8	8
-drift time(nsec)	360	360
-threshold(Kev)	6.5	6.5
-# of sense wires/PWC	1,000	3,000
-single rates* (KHz per wire)	100	30
Total Length		
-m	1	1
-radiation lengths	0.02	0.02

*For minimum bias events at $L=10^{33}cm^{-2}sec^{-1}$. The effect of the magnetic field has not been taken into account.

RICH. The ring imaging Cherenkov counter covers the central ±0.5 rads of the spectrometer. The parameters of the radiator and the photon detector are listed in Tables VI,VII respectively.

The mirror is split into two pieces (see Fig. 1). Each piece is tilted around the vertical axis so that it reflects and focuses the photons outside the spectrometer aperture into the photon detectors which are placed behind the magnet yoke with their centers on the horizontal plane. Because the pion threshold is ~12 Gev the photon detector rate will be much lower than the charged particle rate inside the radiator (see Table VI). The ISAJET[7] MONTE-CARLO predicts that, for minimum bias events, the rate of pions with momenta above 12 Gev is less than three orders of magnitude of the total pion rate. This means that the photon detector rate will be much less than 10^5Hz for $L=10^{33}cm^{-2}sec^{-1}$. Because of the orientation and the position of the two photon detectors (their plane is almost parallel to particle trajectories and they are located behind the magnet steel) the minimum bias charged particle rate through them should be negligible. Of course there are more types of photodetectors that could be used and should be considered carefully. Matrix of photomultipliers or multianode PM's[8] are two examples.

Table VI
Ring Imaging Cherenkov Radiator

Length(m)	4
Solid Angle	$\Delta\theta=\Delta\phi=\pm0.5$ radians
Gas and Pressure	94%Ne and 6%CF_4 at 1Atm
Spherical Mirror Size(m^2) (each piece)	4X4
Spherical Mirror Radius(m)	10
Threshold for Pions(Gev)	11.5
Angular Resolution(mrad)	0.3
Figure of Merit*	N_o=75
Charged Particle Rate** Inside the Radiator(Hz)	10^8

*Number of detected photons is equal to: $N=N_o x L x \sin^2\theta$ where: L=length of radiator, θ is the Cherenkov-light angle.

**Assume: $L=10^{33}cm^{-2}sec^{-1}$, Cross section at 40Tev 100mb, Charge particle multiplicity dN/dn=6.4. The effect of the magnet on this rate has not been taken into account.

Table VII
Multistep RICH Photon Detector

# of Modules	2	
Optical Window	CaF_2	
Photoagent Gas	(He+20%CH_4+0.3 Torr TMAE+1% H_2 at 1 Atm)	
Gain (e/γ)	$3X10^5$	
Readout	Cathode wedge and strip pads with FADC's	
Active Surface(m^2) (each module)	1X1	
Spatial Resolution RMS(mm)	0.8	
Separation Range* (GeV)	π-K	12 → 145
	K-p	40 → 250
Active Gas Layer Thickness(cm)	2.5	
Rate Limit(Mhz)	1	
# of Wedge & Strip Pads (each module)	500	
# of FADC's (each module)	1,500	

*Assumes that momentum has been measured with an accuracy of 10% or better and a minimum number of 1 photoelectron has been detected (lower limit) and the mean Cherenkov light rings' radii for the two hypotheses differ by more than 3 rms of the spatial resolution. Also we have assumed that there are less than 5 photoelectrons per event per pad (this has not been checked yet).

Muon ID. The muon identification is done with 8 drift chambers positioned in the gaps between 7 plates of steel. Each plate is one interaction length thick (~ 19 cm). For 5 cm drift space the muon chambers have a total of 2K wires. The muon identifier acts also as a leakage section for the hadronic showers.

Trigger Rates-Backgrounds

1-Jet. The pp→jet+anything production rates and the number of events for one year (10^7 sec) effective running as a function of the p_T threshold are listed in Table VIII. These estimates are based on the predictions of Ref. 9 for a 40 Tev CM energy and a luminosity $L=10^{33}cm^{-2}sec^{-1}$. We have assumed that the jet axis is contained in the central ($\Delta\theta=\Delta\phi=\pm0.3$ radians) of the detector. As mentioned earlier this assures that at least 85% (98%) of the total energy of jets with $\langle E_T\rangle=100$ Gev (2Tev) respectively will be detected. The number of particles that enter the spectrometer is about 20 (200) for jets with $\langle E_T\rangle=100$ Gev (2Tev) respectively. From Table VIII we see that an effective trigger rate of a few Hz would require a hardware p_T threshold of about 200 Gev.

The most serious background to the 1-jet trigger is from the accompanying particles from minimum bias events during the integration time of the calorimeter. This background is described in Table IX (Ref. 7). We have assumed an integration time of 500 nsec (50 minimum bias events for $L = 10^{33}$ $cm^{-2}sec^{-1}$ and $\sigma_{inel}=100$ mb). This is with the magnet off. Turning the magnet on will reduce this background by ~2/3. Also it should be noted that if before-after sampling is used this background will be subtracted automatically and it will only contribute to the pedestal width. The resulting deterioration in the energy resolution will be negligible because the fluctuations of this background are proportional to its square root. However the exact size of these fluctuations will probably be the limiting factor of the lowest p_T value that jets could be studied.

Table VIII
1-Jet Event Rates

p_T Threshold (Gev)	Rate (Hz) (for $L=10^{33}cm^{-2}sec^{-1}$)	# of Events for $\int Ldt=10^{40}cm^{-2}sec^{-1}$
100	158	158×10^7
250	8	8×10^7
500	0.6	6×10^6
1,000	0.05	5×10^5
1,500	0.005	5×10^4
2,000	0.0007	7×10^3

Table IX
Minimum Bias Background

Solid angle($\Delta\theta=\Delta\phi$)	±0.3 radians	±0.5	±0.8
# of pions (charged + neutral)	20	57	150
<Contribution to p_T> (Gev)	7.4	21	55

Number of Channels and Costs

Table X

Electronic Channels

Vertex detector	7K
Drift chambers	57K
TRD	24K
RICH	3K
Calorimeter	130K
Muon-ID	2K
Total	223K

Conclusions-Suggestions for Further Study

A limited solid angle spectrometer that can measure the whole jet and can do a good job with hadron, electron and muon identification could be built with a reasonable number of channels and at a modest cost.

This work is far from finished. A lot of questions have to be answered before the design is final. We list here some of them: 1) What is the effect of the magnetic field on the single rates? Also how many secondaries from interactions inside the magnet yoke reach the RICH chambers? 2) Will the two MWPC's and the first TRD station survive so close to the IR? Do they (and the magnet) have to be moved further back? 3) Is the number of photoelectrons per event per pad in the RICH chamber less than 5? 4) Is U better than Pb (in terms of physics and cost) for the calorimeter? 5) Is there a space charge problem, because of the slow moving positive ions, in the LAr calorimeter? If yes, what are the alternatives (scintillating glass?, BaF_2? etc.)? 6) What are the electron and muon trigger rates and their backgrounds? 7) What are possible schemes for levels 2 and 3 secondary-vertex, 1-jet, electron and muon triggers? 8) What is the optimum overall calorimeter size and segmentation? 9) What is an honest lower limit on p_T for the 1-jet trigger? 10) Is there a time of flight (TOF) system needed for additional information on particle identification at the low momentum region?

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