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SEARCH FOR HIGH P_T JETS IN DEEP INELASTIC MUON SCATTERING

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ABSTRACT

A muon experiment is proposed to search for the existence of high-P_T jets in deep inelastic muon scattering ($\mu p \rightarrow \mu$ (high P_T) + X).

We request 500 hours of data taking time in the muon area at 5×10^6 muons per pulse. The experimental apparatus is a modified version of the facility previously used by the Chicago-Harvard-Oxford-Illinois group and by the Chicago-Princeton group.

The key ideas of this experiment which separate this effort from previous experiments are: 1) full detection of jet containing all charged and neutral particle secondaries, 2) measurement of charge structure of the jet final state, 3) detailed particle identification using a new Čerenkov device, 4) preselection of high-P_T events ($P_T^\mu > 1$ GeV) in the trigger. The experiment is also sensitive to μe events (from decay of heavy leptons) produced in high energy muon interactions ($\mu p \rightarrow \mu eX$).

Introduction

Deep inelastic lepton scattering experiments performed thus far measured single particle inclusive scattering or two-particle inclusive scattering. We suggest here a novel approach to further study the structure of nucleon by searching for the "jet-like" recoil in deep inelastic collisions. Early results from ISR and Fermilab high-P_T hadron experiments have given increasing credence to the picture that high-P_T events have a "jet-like" structure and have nearly co-planar opposite side characteristics.

The observation of jet-like structure in a deep inelastic muon interactions would provide a fundamental understanding of elementary lepton-quark forces and quark fragmenting properties. The possible existence of free quarks claimed by a Stanford group makes this study more compelling than ever. We propose a measurement of high-P_T muon in coincidence with a high-P_T jet using the modified muon facility and highly segmented calorimeter. The interpretation of the data is made easy since the muon is regarded as an elementary jet. The key idea is to stiffen the scattered muon momentum requirement in the trigger considerbly ($E_\mu > 33$ GeV) with a minimum angle of 0.030 rad. Reasonably good statistics can be obtained up to $P_T \approx 9$-10 GeV/c.

Four sets of drift chambers located close to the target replace the somewhat bulky and obsolete wire-chambers. The freeing of these chambers permits the installation of a segmented calorimeter, E-319 toroidal magnets (used as analyzer and shielding) and other μ-stiffeners. Original E-398 μ shields remain intact. The Chicago Cyclotron magnet used in the muon momentum measurement is maintained at a weak field $\approx$ 2 Kg (at a considerable saving of energy as well) so as not to disturb significantly the hadronic shower characteristics. Also charge signatures of the shower will be recognized. Kinematics of the reaction will be selected to coincide as closely as possible with the pp jet experiments. Particle identification is provided by a new type of Čerenkov detector under study. This apparatus is also capable of detecting the presence of high energy electron accompanying the scattered muon ($\mu p \rightarrow \mu e X$). The electron momentum will be measured prior to entering the calorimeter. The front section of the calorimeter will be lead -scintillators of sufficient fine grain to permit a segregation of electrons from pions at the 10^{-3} level. The energy of the hadron shower will be measured in subsequent calorimeter modules.

Physics Motivation. Section (a)-(f) deal with pp scattering; (g)-(j) with μp.

(a) Two particle inclusive data have suggested that in the presence of a high P_T trigger most of the P_T is balanced by a few large P_T particles back to back with trigger in the collision C.M. system.

(b) The presence of a high P_T particle correlated positively with the occurence of a second high-P_T particle at nearby rapidity in the same hemisphere. This suggests that the high P_T trigger is the result of the decay of some "primary" high-P_T object. The high-P_T of this parent system is balanced by a high-P_T object, which decays into several particles, in the opposite hemisphere.

(c) These objects will be called jets. One model for their production is the hard scattering of constituents one from each of the colliding hadrons. If these constituents are assumed to be quark-partons, to fit the observed single particle inclusive cross section

$$\frac{d^2\sigma}{dP_T^2} \propto \frac{1}{P_T^8} f\left(\frac{P_T}{\sqrt{S}}\right) \qquad (1)$$

we have to assume

$$\frac{d\sigma}{dt} = \frac{1}{st^3} \qquad (2)$$

In a vector-gluon model $\frac{d\sigma}{dt} \sim \frac{1}{t^2}$ is more natural. This difficulty can be averted if we assume that the hard scattering is an elastic qM collision. Now the jets should not be symmetric between the two hemispheres.

(d) The observation of a jet in the same hemisphere as a high-P_T trigger is obscured by an effect called trigger bias (Landshoff effect). The basic idea is that for a given trigger P_T, if the trigger is a member of a multiparticle jet decay, then the jet will have had a $P_T^{jet} \gg P_T^{trigger}$. Since $d^2\sigma/dP_T{}^{jet}$ is falling rapidly such an event will be rare compared to one where $P_T^{jet} \sim P_T^{trigger}$. Thus events observed with a high P_T trigger may see only those, possibly rare, events where the jet momentum is concentratied in a single decay particle.

(e) Because of trigger bias, it is possible that $d^2\sigma/dP_T{}^{jet}$ follows a P_T^{-4} law, as expected for hard q-q scattering by gluon exchange while we still see a P_T^{-8} dependence in single particle inclusive measurements.

(f) It is therefore useful to attempt to use two calorimeters to see both jets. One can then determine

(i) $d^2\sigma/dP_T{}^{jet}$, as we will not have trigger bias

(ii) M^2 for jet 1 and for jet 2 if the basic hard process is elastic quark scattering then there is equal distribution in both hemispheres.

(iii) One can look at the average charge on both jets. For valence quarks alone it should be 2/3. This is complicated by the presence of non valence quarks since we can not force each of the quarks to have a large fraction of its parent hadron's momentum.

Cronin and collaborators have established that the single particle inclusive cross-section $Ed^3\sigma/dP^3 = A^{\alpha(P_T)}\ E\ \frac{d^3\sigma}{dP^3}$ where $\alpha(P_1) \sim 1.1$ for pion production 1.3 for kaon production and 1.4 for proton production at large P_T (>3 GeV/c). The trigger bias effect discussed above implies that these experiments see jets whose P_T is almost entirely carried by the detected particle. It is possible that this anomalous α dependence ($\alpha > 1$) is due to multiple scattering of the produced particle in the target nucleus. If we collect an entire jet, which we identify as a decayed quark, the estimated quark-proton cross-section of 10 mb implies a quark mean free path of about 7 fm in nuclear matter, thus we do not expect much rescattering. In this case $\alpha^{jet}(P_T)$ should be unity if the A dependence of Cronin is actually due to scattering. Therefore it might be interesting to take some data with a heavy target in a pp jet experiment. Now we turn to the lepton-hadron picture.

(g) If we accept the qq scattering picture for large P_T hadronic events; then it becomes compelling to consider $\mu^+ p \to \mu^+$ (high P_T) + X. The reason for this is that from the known incident and final momenta of the muon we can determine the momenta of the scattered <u>parton</u>; additionally we know that

$$d\sigma/dt^{\mu^+ \text{parton}} = e^2\ \text{parton}/t^2 \qquad (3)$$

And we can determine through x that we are in the valence quark region of the target.

Therefore it is useful to collect the high P_T debris of the target in events where a high-$P_T\mu^+$ is observed. First one can see if a jet exists. Note that if a jet exists, from the μ^+ momenta we know its axis. One does not have to reconstruct the jet direction from the sphericity of the hadronic final state.

(h) Again we can look at the average multiplicity, the distributing P_T with respect to the jet axis (already it is known from $\gamma_V p \rightarrow \pi X$ that $P_T(\pi)$ w.r.t. jet (γ_V) axis is small.), average invariant mass and average charge of the jet. For example for a proton target at large x, $\langle q\rangle^{\text{jet}}$ average = 5/9 in the quark-parton model.

(i) A mystery in deep inelastic lepton scattering is why the total multiplicity of charged secondaries depends only on $\ln \nu$ and not on Q^2. It would be interesting to see if this behavior is true also for large $P_T^{\mu^+}$ (after we extract the jet multiplicity). Note that $P_T^2 = yQ^2$, $y = E'/E$ (e.g., for $y = .2$, $Q^2 = 30$ and $P_T = 2.5$). For a jet one may want to force large y to get large P_T for ν small (x large).

In the quark parton model the interactions which prevent free quarks from being seen in the final state are not well understood. The observation of the nature of the hadronic final state in large P_T lepton scattering may give an idea of these final state interactions. In particular, we can see if the final state is characteristic of inelastic hadron scattering at the energy of the scattered parton.

(j) Already jets are seen in $e^+e^- \rightarrow$ hadrons at SPEAR. It is again interesting to determine whether these jets can be identified with the jets in $pp \rightarrow$ high-P_T and those that might be seen in $\mu^+ p \rightarrow \mu^+ (P_T \text{big}) + X$.

Dilepton Events

Dimuon and trimuon events have been observed in high muon energy interactions.* The sources of these multimuon events are not yet fully understood. A measurement of $\mu p \rightarrow \mu e X$ will help resolve a great deal of ambiguity since the ratio production rate $\frac{\sigma(\mu p \rightarrow \mu e X)}{\sigma(\mu p \rightarrow \mu\mu X)}$ is different for charm production and heavy lepton production. For example if h^{++} (heptons) are produced in our previous experiment $\frac{\sigma(\mu^+ p \rightarrow \mu^+ e^+ X)}{\sigma(\mu^+ p \rightarrow \mu^+ \mu^+ X)} = \frac{1}{2}$, rather than 1 for charm production.

No current muon experiment can identify both muon and electron in the final state.

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* C. Chang et. al., Physical Review Letters (to be published)

The Apparatus

Considerable experience now exists in muon scattering experiments. Two major muon experiments performed thus far concentrated on single particle detection. E398 measured inclusive hadron production in muon scattering with little provision to measure the neutral secondaries and sharply concentrated charged particle shower in the jet axis. Also the transverse momentum of the scattered muon (P_T^μ) is ~ 0.1 GeV. In E26/E319 it is possible to measure muon scattering at large P_T and the energy of the shower. However the direction and the charge structure of a jet is unknown.

We envision some improvement and modifications of the Muon Facility to permit a specific study of the jet structure. The apparatus is shown in Fig. 1. The envisioned improvements are

1) Replace large wire-spark chambers by smaller drift chambers. This would save an enormous amount of space for the muon stiffener. Also resolution of muon momentum determination is improved.

   Momentum of the muon (to determine x) and of individual charged secondaries will be measured with a weak (12 Kg-m) field about 6 m after the target. Tracks will be measured in two pairs of drift chambers set at about 2 m intervals from the target. A weak field is necessary (about 2 Kg maximum) because of the possible effect the magnetic field produces in the jet structure. The bending power of the reduced magnetic field imparts only ± 0.3 GeV/c P_T to the secondaries, corresponding to an optimum $\pm$ 0.35 GeV/c smearing in P_T (of the order of natural $\langle P_T \rangle$ per hadron). Excessive smearing tends to separate the charged hadron tracks passing through the magnet which in turn complicates considerably the event reconstruction. In addition, one really does not need a high field since x is measured independently by the measurement of E_h(jet) by a segmented calorimeter.

In order to retain reasonably good momentum resolution with a low magnetic field, good spacial resolution and wide plane separation is used. Assuming about 300 μm resolution in the drift chambers with 2 m separation, this gives a resolution of $\frac{\Delta p_\mu}{p_\mu} \leq 0.002p$. In addition the E26/E319 toroids analyzes muon momentum to ± 8.5%. (for larger E_μ)

2) Calorimeter

We incorporate the considerable experience of our group in calorimeter construction and measurement. The segmented calorimeter (each module 15 cm x 15 cm) is of critical importance to the study of jet structure.

The calorimeter will be capable of separating electrons from hadrons. Thin segmented lead plate scintillator sandwiches will be the front end followed by the regular iron-scintillator type. Previous experience indicates that a pion rejection of 10^3 is possible. The front end also aids in neutral particle detection (e.g. π^o).

3) Particle identification will be studied by the Čerenkov Detector

A Čerenkov detector of a new type, currently under development at Michigan State, University of Pennsylvania and University of Wisconsin, is proposed to go between the first two drift chambers. Spherical mirrors image the Čerenkov light produced in one atmospheric SF_6. The mirror image will be refocussed and corrected for curvature onto a fast phosphor image intensifier. The output of the image intensifier, refocussed and reduced further, fall on a CCD array. A special control and readout system would be developed at the University of Wisconsin. Čerenkov light will appear as a ring of light on the plane of the CCD with a radius related to the Čerenkov angle of the particle producing the light. The overlapping rings are not ambiguous due to good resolution of the image, knowledge of the center before-hand from drift chamber tracks, and a relatively large number of photo-electrons. Particle identification from threshold to very high γ is as follows: π-K separation between 5 and 65 GeV and K-p separation between 10 and 100 GeV is expected at 2σ level.

The μ Beam, Trigger Rates and Event Rates

1) The muon beam intensity has been upgraded steadily during the past few years. During the muon running period from June 1976 to December 1976, the average intensity at E_μ = 225 GeV was 2.5×10^6 muons/pulse at 10^{13} protons per pulse. By the time we are ready to take data (estimated date: Winter, 1978) 2×10^{13} protons/pulse could be delivered to the neutrino laboratory. Thus a flux of 5×10^6 μ/pulse can be obtained. We plan to use a 2 m liquid deuterium target.

2) The trigger rate of the experiment is dictated by the P_T cut-off of the apparatus. We plan to place sufficient shielding to stiffen the scattered muon energy requirement thereby increasing P_T of the muon by a factor of 10. This is accomplished by placing 8 (32" each) 72"-diameter iron-toroids used in E-319 directly downstream of the highly segmented calorimeter. Additional shielding (~3m) will be placed further downstream to fill up all spaces up to the existing

muon shielding. The total μ shielding will be 15.0 meters or $\Delta E_\mu = 33$ GeV. Scintillator counter banks select events having muon trajectories with $\Theta_\mu > 0.030$ mrad. E319 trigger banks will be placed before and after the toroids. The existing trigger counters behind the last shielding will be used.

At $P_T^\mu > 1$ GeV, the event rate is estimated to be about one event/pulse assuming a one-meter liquid deuterium target. Background triggers vary from unity to a factor of two higher from halo-induced splashes near the target. The trigger rate is not high for the existing data handling system. (Figure 2)

Resources and Scheduling

Most equipment needed in this experiment is on hand. We do not envision difficulty in procuring most of it. The E319 toroids are now available. The segmented calorimeter can be built in part from existing units of the E319 calorimeter; in part it would consist of elements either built by or already available to additional collaborators, who might join this effort at a later time. We also note that a set of four drift chambers may exist by the time of our experimental set-up. As was noted before, the new Čerenkov counter may be the only new equipment to be assembled. Given the resources available to this group, such a system can be assembled and tested within one year. We are proceeding on this basis.

A major question one may face centers around the decision to conduct further Fermilab muon experiments in light of the highly publicized CERN SPS μ-beam to be commissioned in 1978.

The CERN μ-experiment is designed to study either single particle inclusive channels (Rubbia) or exclusive channel (Gabathuler-Brasse). No current plan is known for a search of jets using calorimeters and μ-stiffener proposed here. The event rate of this experiment is such that higher beam intensity is not an elementary necessity.

Finally this experiment is complementary to investigations that will be done by the muon experiment conducted down stream. In that experiment, the main purpose is to investigate multi muon production mechanisms.

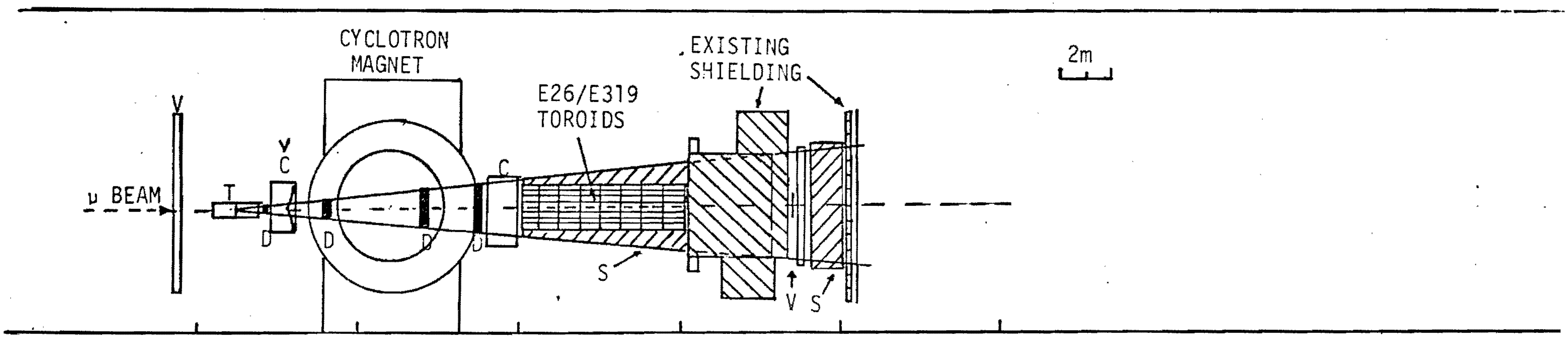
Therefore we are confident that our proposal is a unique and a highly topical search of new phenomena in deep inelastic collisions, irregardless of the status of the CERN μ-program and other approved muon experiments.

We can start mounting during the next fiscal year immediately after other scheduled experiments using the muon facility are fully completed. Installation of new detectors will take 3-4 months. Data taking takes about two months (500 hours).

FIGURE 1

APPARATUS

MUON LABORATORY LAYOUT



CAPTIONS

T: LD_2 TARGET

Č: CID CERENKOV DETECTOR

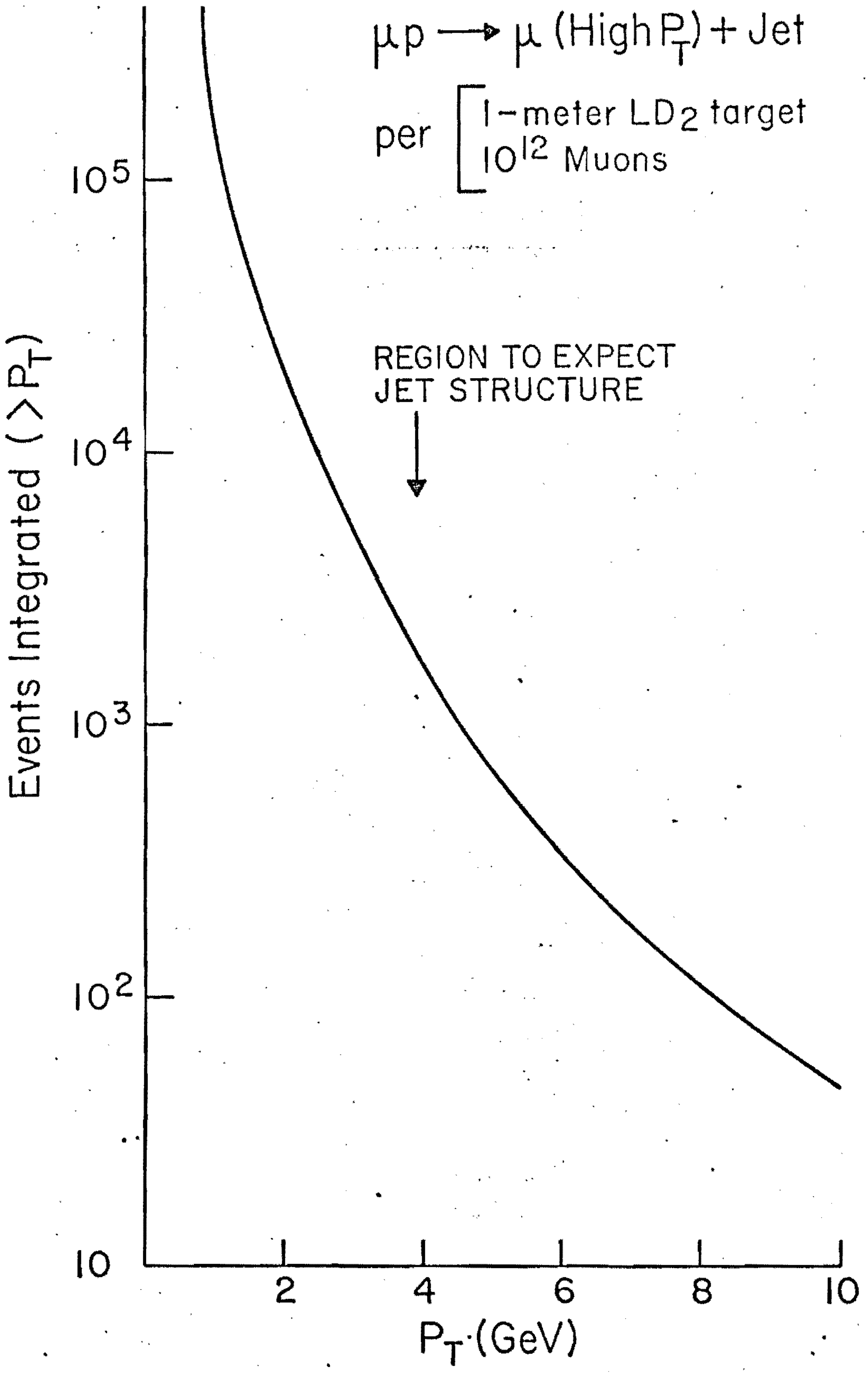
C: SEGMENTED CALORIMETER

D: DRIFT CHAMBERS

V: BEAM AND HALO VETO COUNTERS

S: SHIELDING

FIGURE 2



$\mu p \rightarrow \mu$ (High P_T) + Jet
per [1-meter LD_2 target, 10^{12} Muons]
REGION TO EXPECT JET STRUCTURE
Events Integrated (>P_T)
10^5
10^4
10^3
10^2
10
2
4
6
8
10
P_T (GeV)