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PEGASYS -- A PROPOSED INTERNAL TARGET-SPECTROMETER FACILITY FOR THE PEP STORAGE RING

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PEGASYS -- A PROPOSED INTERNAL TARGET-SPECTROMETER FACILITY FOR THE PEP STORAGE RING

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ABSTRACT

A proposal for an internal gas-jet target and forward spectrometer for the PEP storage ring is described. The beam structure, allowable luminosity ($\mathscr{L} = 10^{33}$ cm^{-2}s^{-1} for H_2, D_2 decreasing as $Z^{-1.75}$ for nuclear targets) and energy ($E_e \leq 15$ GeV) make the ring ideal for multiparticle coincidence studies in the scaling regime, and where perturbative QCD may be an apt description of some exclusive and semi-inclusive reactions.

1. INTRODUCTION

The utility of storage rings for coincidence measurements, and for applications where ultra-thin targets are required or are the only targets available is well known and will not be elaborated on further[1]. An internal target facility at the PEP storage ring, PEGASYS (PEP Gasjet-Spectrometer System) would provide unique opportunities in the Bjorken scaling regime, and complement the programs at SLAC End Station A, the Tevatron muon facility and CEBAF in the future.

2. THE PEP STORAGE RING

The PEP storage ring is 2.2 km in circumference, and has 6 interaction regions[2]. The ring can run at 5-15 GeV per beam, with an energy spread of $\Delta E/E = 6 \times 10^{-5} E(\mathrm{GeV})$. Circulating currents of 20 mA (in three bunches) per beam are typical for high energy operation. Internal target luminosities will be constrained by the desired storage lifetime. Figure 1 shows that the luminosity of H_2 and D_2 may be 10^{33} cm^{-2} s^{-1} for target thicknesses of 10-20 ng/cm^2; the luminosity (in terms of nuclear scattering centers) decreases roughly as $Z^{-1.75}$. This luminosity results from e.g. a 20 mA current, and a 2-hour beam lifetime. In practice, the time in between fills will probably be 4-12 hours, but the current can be higher if running at less than full energy.

The PEP ring will continue to operate for high energy physics (the TPC collaboration) in the intermediate term. A synchrotron radiation physics program has begun at PEP and promises long term stability for the machine.

3. THE INTERACTION REGION

3.1 The Gas Jet Target

After considerable study, the cold cluster target appears to be the most promising for the PEP storage ring; such a target has been used by UA-6 at the SPS for hydrogen[3)], and a similar target is operational with hydrogen, nitrogen and argon for future use at the CELSIUS ring[4)]. This target relies on condensation of the gas into microclusters of 10^5 - 10^6 atoms to minimize the transverse momentum of the atoms and thus the opening angle of the jet. Skimmers further suppress the tails of the density profile relative to the core. The maximum density used (for hydrogen) at the SPS was 4×10^{14} cm^{-2}, and a factor of 2 improvement in density will be straightforward. Nevertheless, some development will be needed to achieve our nominal goal of 2×10^{15} cm^{-2}.

3.2 The Spectrometer

There are two important elements of the concept for the detector. The first is a forward spectrometer with as large a solid angle as is feasible, and excellent particle identification.

Furthermore, it should have sufficient resolution of all kinematic quantities such that the missing mass resolution for simple event topologies will be better than the pion mass. The second is to design an environment in and around the scattering chamber that will allow us to exploit the thin, point-like nature of the gas jet target for observing the low-energy decay of the target spectator nucleus. This means equilibrium and pre-equilibrium nucleon emission, heavy fragment emission, gamma decay, and perhaps the recoil of the entire target nucleus itself.

3.2.1 The Forward Spectrometer

Figure 2 shows the top and side views of the proposed spectrometer and gas jet target. The magnet is being designed to cover $\theta_x = \pm 42°$, $\theta_y = \pm 19°$, representing a solid angle of approximately 830 msr. The $\int B d\ell \approx 2.2$ T-m, and cutting the pole faces to diverge radially in the vertical direction minimizes the vertical focussing. As the beam path must be essentially field-free throughout the PEP straight section, a thin tapered iron plate with a bore hole lies in the spectrometer mid-plane. A soft iron tube containing the beam pipe occupies the bore hole leaving a small cylindrical air gap between them. The two-layer magnetic shielding will reduce the integrated transverse magnetic field to a few Gauss-meters, and with a minimum sacrifice of solid angle.

Since virtually all experiments will require an inelastically scattered electron as a part of the trigger, excellent π-e discrimination is necessary, particularly at low scattered electron energies where the π/e ratio becomes very unfavorable. The atmospheric CO_2 Cerenkov detector (pion threshold $\approx$ 4.9 GeV/c), and electromagnetic calorimeter (segmented liquid-scintillator design) provide the requisite discrimination. The heavy gas Cerenkov detectors (Freon 114 at 2 atm.), and time-of-flight scintillators are responsible for π-K-p separation. Both the CO_2 and heavy gas Cerenkov detectors are diffuse-scattering in design, and will use large 20" hemispherical photomultiplier tubes (PMT's). The scintillators will be 20 cm x 5 cm in cross section, and read out by 5" PMT's. Conservatively the time resolution will be 350 ps FWHM.

A summary of the particle identification capability of the forward spectrometer is shown in Figure 3. The trapezoidal bars for the TOF system indicates where the particle identification is at least 100:1 (lower lines), and 10:1 (upper lines). As the asymptotic number of photoelectrons $N(\beta=1)$ for the Cerenkov detectors is designed to be moderately large (6 for CO_2, 40 for Freon), amplitude information may be used. Here the trapezoidal bars indicate the threshold momentum (lower lines), and momentum corresponding to 50% light output (upper lines).

The tracking will be performed by three planes of drift chambers, each a stereo triplet of planes. Monte Carlo studies indicate that the momentum resolution should be $(\Delta p/p) \approx 1.1 \times 10^{-3}$ p (GeV/c).

3.2.2 Ancillary Detectors

A number of detector systems are being considered for the more backward angles, both within and outside the vacuum chamber. Figure 2 (top) shows an array of movable neutron time-of-flight counters with long flight paths ($\approx$ 6 m). These would permit detection of high momentum neutrons ($p \gg p_F$) in coincidence with scattered electrons in deep-inelastic kinematics, necessary for studying the quark structure of the NN short-range correlation.[5-7] A 'mini-ball' array of CsI detectors could occupy $\approx 1/2 \times 4\pi$ solid angle within 10-15 cm of the gas jet target to detect p,d,t, ^{3,4}He (up to 100 MeV for protons).[8,9] This would be important for the study of 'tagged' structure functions, i.e. structure functions modified in nuclei by selecting specific initial state correlations.[10] Solid-state telescopes providing E-ΔE and time-of-flight information may be mounted within the scattering chamber to observe heavy nuclear fragments indicative of massive energy deposition in the target nucleus. Such measurements, heretofore only performed in p-A collisions and inclusively,[11] would be of much greater importance with x,Q^2 dependencies and in coincidence with the forward 'jet'. The electronics and data acquisition system are being designed to take data at 200 Hz, with a typical event size of 300 words.

4. THE PHYSICS PROGRAM

4.1 Overview

The energy range of PEP is well-suited for studies in the scaling region ($Q^2 > 1$ $(GeV/c)^2$) in deep-inelastic scattering, which manifests the point-like coupling of virtual photons to quarks in the nucleon or nuclear target. The attainable momentum transfers that may be achieved with good statistics in semi-inclusive or exclusive channels is obviously process-dependent, but as a general rule $2 \leq Q^2 \leq 5$ $(GeV/c)^2$. This is thought to be the regime also where perturbative QCD descriptions of many processes should become relevant.

A rough schema of the physics program at present is

- o Quark Propagation and Hadronization in Nuclei
  - Quark-Nucleon cross section
  - "Formation Length"
  - Target Spectator Decay

- o pQCD
  - $p(e,e'\gamma p)$, $p(e,e'\pi^0 p)$, $p(e,e'\rho^0 p)$
  - "Color Transparency" in $A(e,e'x)$, $x = \pi$, K, ρ, p

- o Higher-Twist Contributions to Semi-Inclusive $(e,e'\pi^{\pm})$

- o "Tagged" Structure Functions
  - Initial State Correlations and the EMC Effect
  - Quark Structure of the NN interaction

To demonstrate the strength of this facility we give a brief example concerning the "formation length" of hadronization.

4.2 Quark-Nucleon Cross-Section and Formation Length

Although the notion of a formation length τ in the materialization of struck quarks into hadrons is not new, experimental data on the issue is nearly non-existent. Greatly differing theoretical approaches have run unchecked. While in all cases $\tau \propto \nu$ (representing the Lorentz factor in boosting from the rest frame of the hadron to the lab frame), the formation length may[12] or may not[13] depend on the hadron mass M_h, and may[12,14] or may not be[13] z-dependent ($z \equiv E_h/\nu$). The only experimental method that can address these questions is to imbed the fundamental process $\ell + N \rightarrow \ell' + h + X$ (ℓ = lepton, h = hadron) into nuclei of varying radii and look for the attenuation of hadrons in the ratio of production cross sections per nucleon between nuclear and nucleon targets. Such a depletion would occur at a given z if the materialization occurred predominantly <u>within</u> the nucleus and is thus subject to scattering or absorption with a characteristic cross-section of 20 mb. (The current quark is believed not to interact inelastically in a nuclear medium, i.e. $\sigma_{qn} \approx 0$, and there is some experimental evidence for this). The only evidence for nuclear attenuation in leptoproduction ever observed is from a MIT-SLAC collaboration of more than a decade ago[15]; this experiment suffered from virtually no particle identification, poor statistics and limited coverage in $p_\perp^2$ ($<1(\mathrm{GeV}/c)^2$). Recent data from EMC[16] at much higher energies are consistent with no nuclear attenuation, and further give evidence that $\sigma_{qN} \approx 0$. The data are shown in summary form in Fig. 4, and are consistent with the estimates that the formation length is roughly (0.1-1)ν fm, with ν in GeV. Thus at EMC or Tevatron muon energies (100-600 GeV) the leading hadrons appear far downstream of the nucleus, while at PEP (E=15 GeV) this distance is well-matched to the range of nuclear radii. Figure 5 shows the kind of detail that we will achieve with PEGASYS which is due to enormous statistics, good particle identification and large acceptance. Recall that the MIT-SLAC data were confined to $p_{\perp}^2 < 1$, and with large errors associated with them.

5. PROSPECTUS

The facility will be officially proposed by the fall of 1988. Funding would begin FY 91, and experiments by fall of 1991 at the earliest, or more realistically by 1992. The nuclear physics operation will be compatible with high energy physics operation (E = 13.5-14.5 GeV) and operation for synchrotron radiation research (E = 8-10 GeV). We anticipate dedicated nuclear physics running for part of the program as well.

I would like to acknowledge all the members of the PEGASYS collaboration who are working so hard to make the project a reality (American/CERN/Florida State/ Georgetown/ LBL/ LLNL/ Maryland/ Massachusetts/ Ohio/ Purdue/ RPI/ Stanford/ Virginia/ Washington). Work performed under the auspices of the U.S. Department of Energy by the Lawrence Livermore National Laboratory under contract #W-7405-ENG-48.

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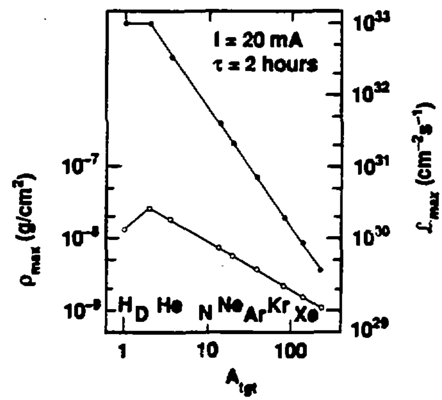
Fig. 1. Luminosity (in cm^{-2} sec^{-1}) as a function of atomic weight A for internal target physics at PEP. A 20 mA current is assumed, and a 2-hour beam lifetime.

Fig. 2. Schematic top (top) and side (bottom) views of the proposed spectrometer and gas jet target. A shaped iron plate with a concentric soft iron pipe in its bore will occupy the spectrometer mid-plane to exclude flux from the beam path.

Fig. 3. Summary of the particle identification ability of the forward spectrometer of PEGASYS. For the TOF system, the trapezoidal bars indicate where the separation between two species will be at least 100:1 (lower lines), and 10:1 (upper lines). For the Cerenkov detectors, the trapezoidal bars indicate the momentum threshold (lower lines), and where the light output is 50% of asymptotic (upper lines).

Fig. 4. Attenuation of hadrons ($z > 0.4$) vs. $\nu = E - E'$. Dots, data of Ref. 16, Square, data of Ref. 15.

Fig. 5. a) Attenuation of π^+ s that would be measured with PEGASYS ($\nu = 7$, $\Delta\nu = 1$; $Q^2 = 2$, $\Delta Q^2 = 1$) with and without linear z-dependence. b) Attenuation of π^+, K^+ expected, assuming $\tau \propto M_h^{-1}$ ($z = 0.7$, $\Delta z = 0.2$; $Q^2 = 2$, $\Delta Q^2 = 1$). c) Dependence of the attenuation of π^+ on the inelastic quark-nucleon cross section, vs. ν ($z = 0.7$, $\Delta z = 01$; $Q^2 = 2$, $\Delta Q^2 = 1$) d) Expected effect of elastic quark rescattering[17] vs. $p_\perp^2$. a)-c) assuming $A = 64$, d) $A = 40$; all, 30 days of running.



I = 20 mA
τ = 2 hours
10^{-7}
10^{-8}
10^{-9}
ρ_{max} (g/cm^3)
10^{33}
10^{32}
10^{31}
10^{30}
10^{29}
$\mathcal{L}_{max}$ (cm^{-2}s^{-1})
H D He N Ne Ar Kr Xe
1
10
100
A_{tgt}

FIG. 1

PEGASYS

Top view

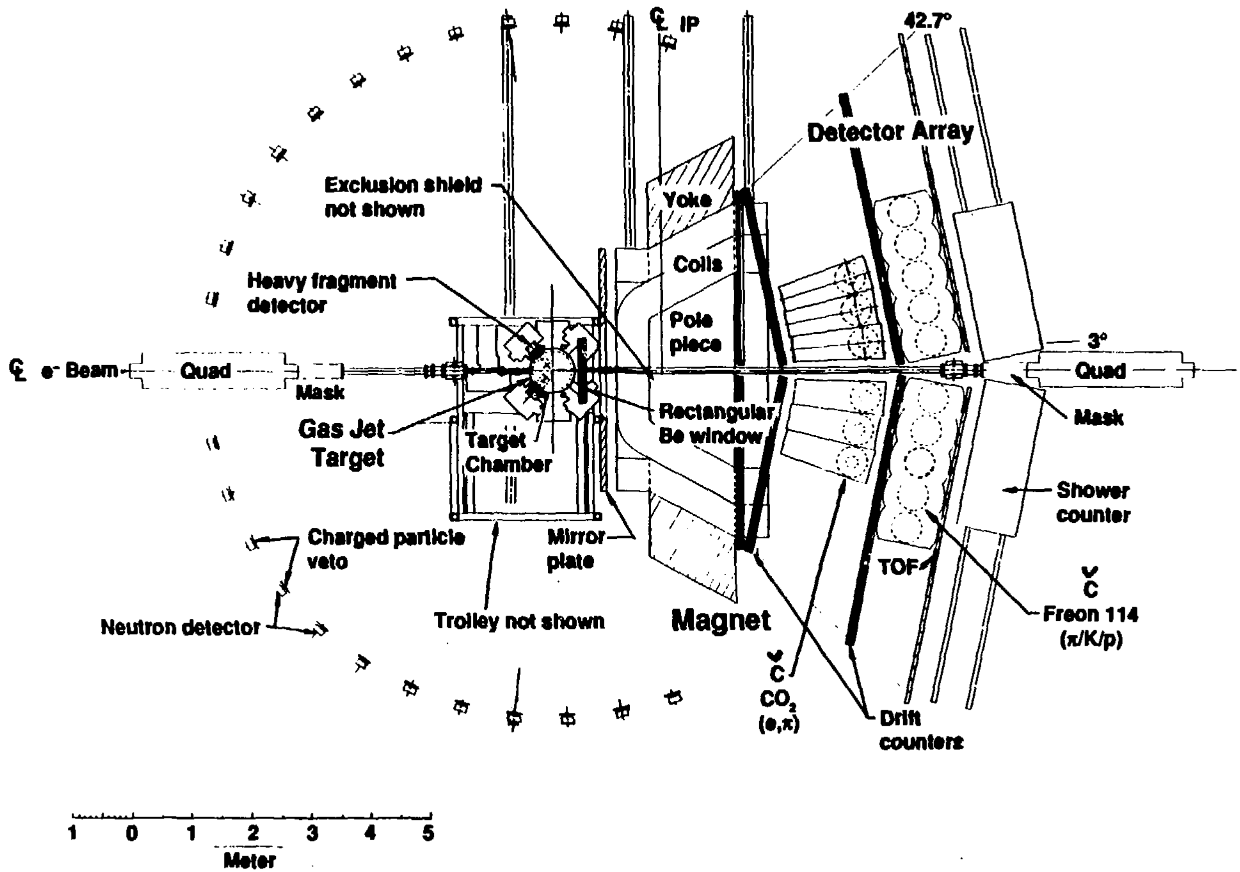


FIG. 2 (top)

PEGASYS

Side view

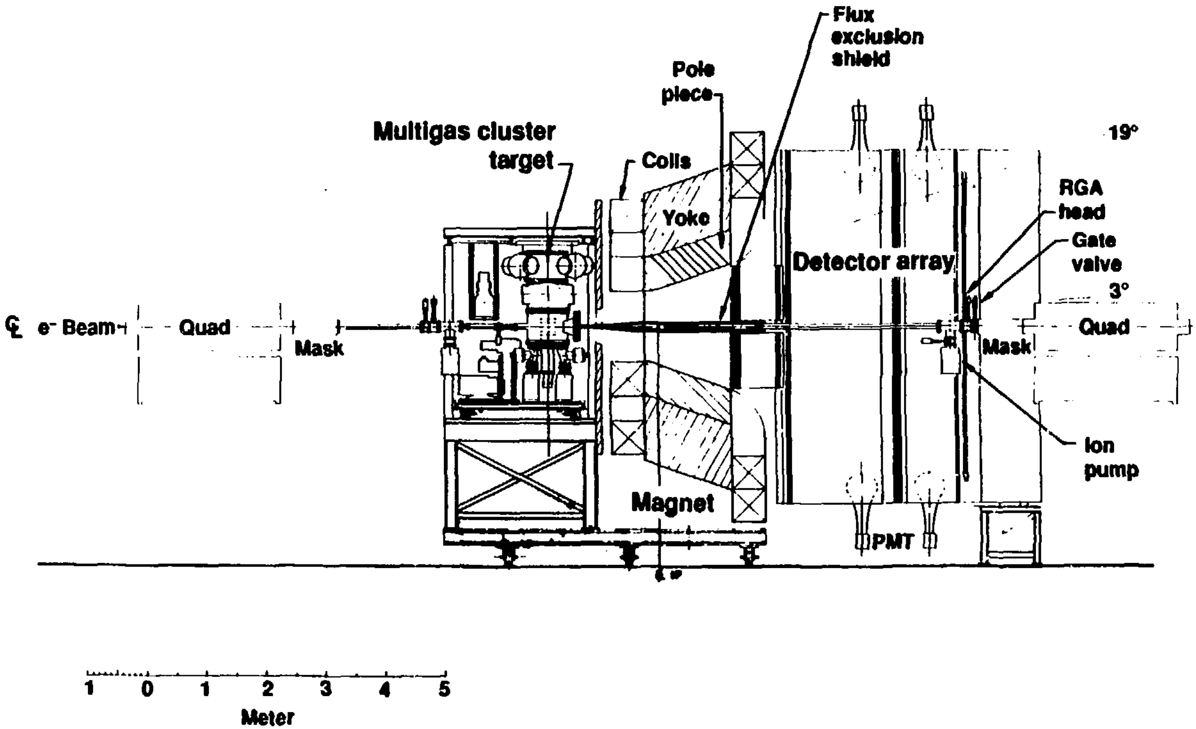


FIG. 2 (bottom)

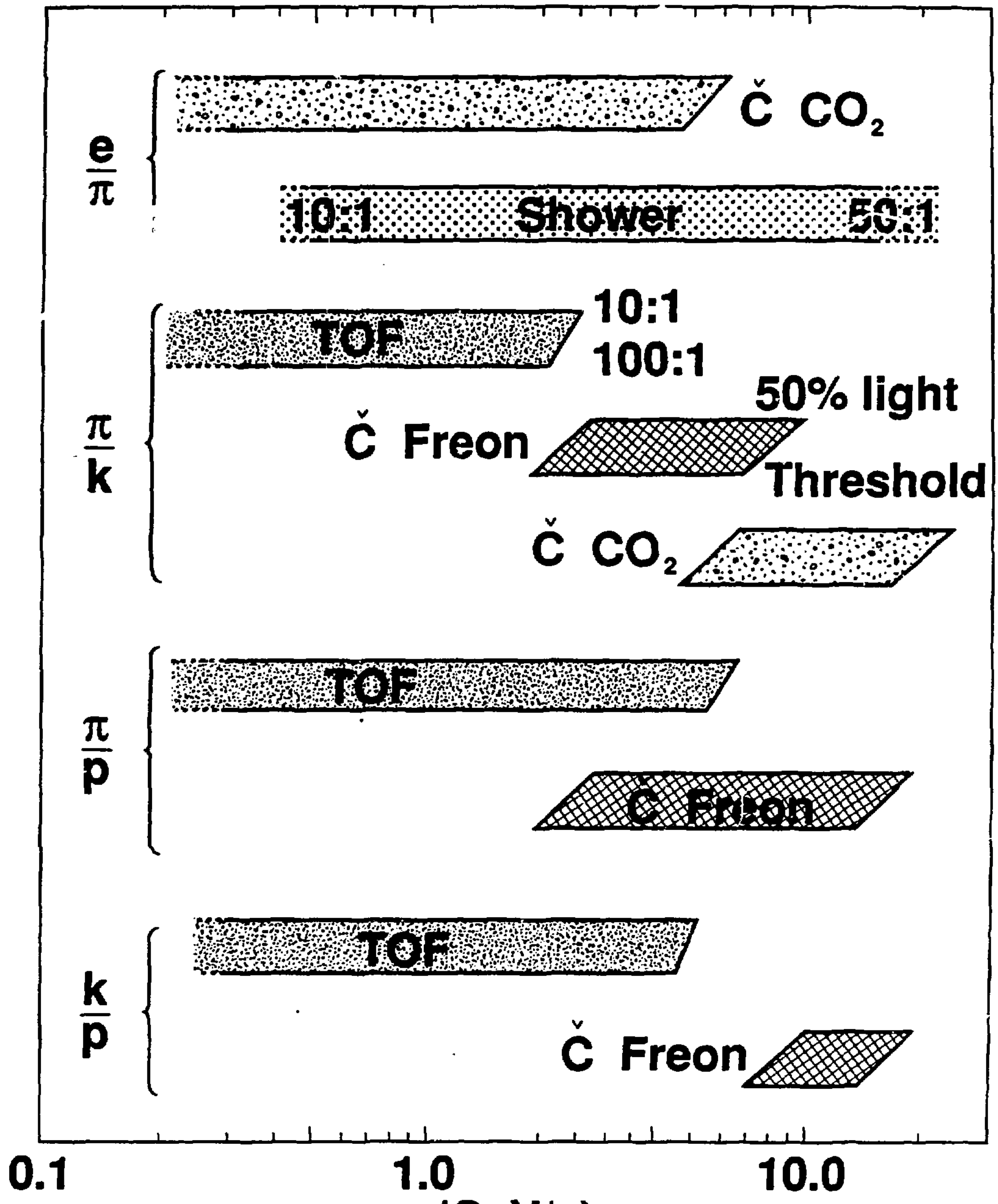

Č CO2
e/π
10:1 Shower 50:1
TOF
10:1
100:1
50% light
Č Freon
π/k
Threshold
Č CO2
TOF
π/p
Č Freon
TOF
k/p
Č Freon
0.1
1.0
10.0
p (GeV/c)

FIG. 3

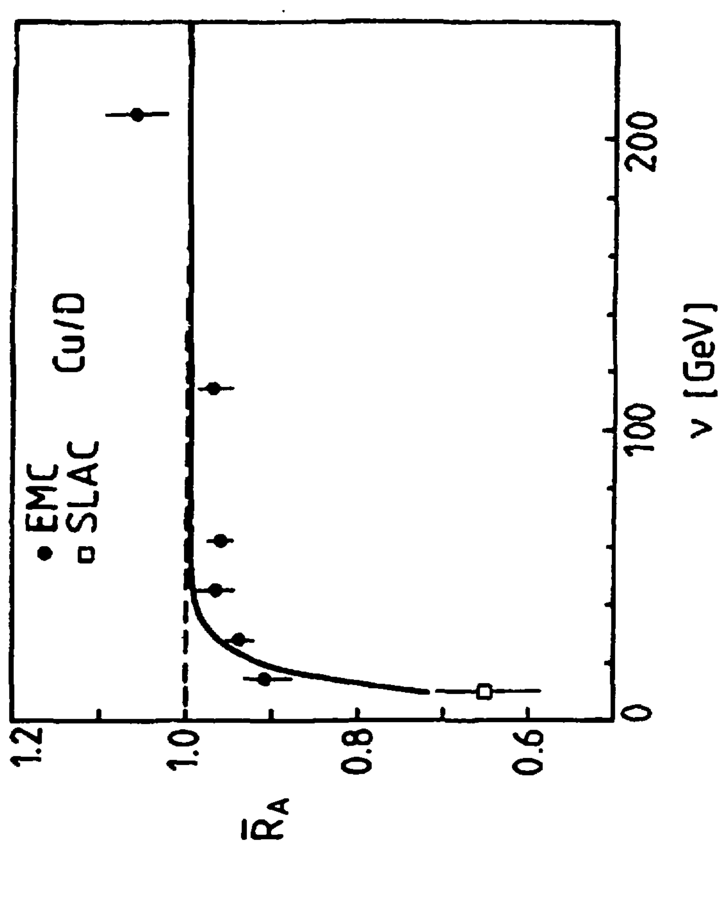


FIG. 4

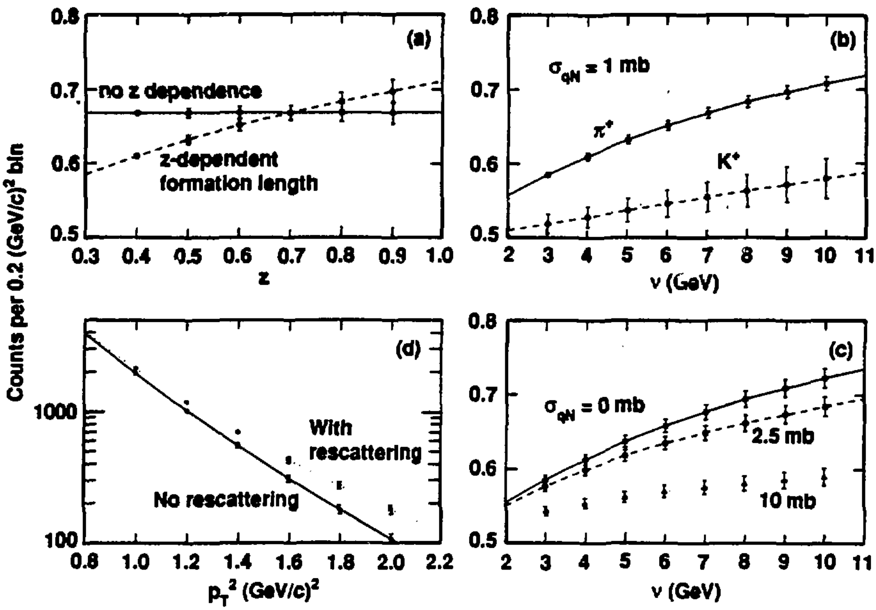


FIG. 5

CW-1014-U-7