Leading Neutron Production in the H1 Experiment at HERA

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Representing the H1 Collaboration

- Physics Motivation:

  → Introduction to pion exchange model.

- The New Forward Neutron Calorimeter.

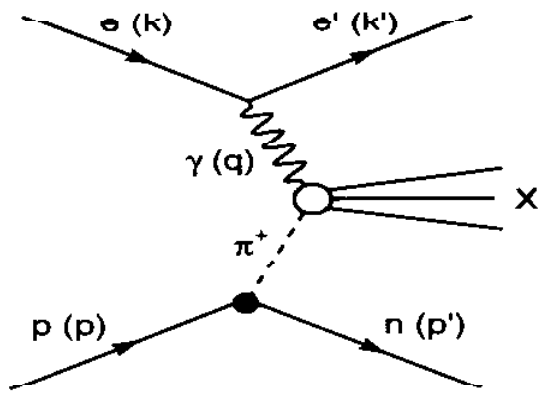
  → Installed into H1 at the beginning of 1996.

- Preliminary Results from 1995 and 1996 data.

- Summary.

Inclusive Neutron Production

$$e + p \rightarrow e + n + X$$



- In analogy with standard DIS, the cross section is given by:

$$\frac{d^4\sigma(ep \rightarrow enX)}{dx\, dQ^2\, dt\, dz} = \frac{4\pi\alpha^2}{Q^4}\frac{1}{x}[1-y+\frac{1}{2}y^2]F_2^{p\rightarrow n}(x, Q^2, t, z$$

where: $F_2^{p\rightarrow n}(x, Q^2, t, z) = f_{n/p}(t, z)F_2^{\pi}(\beta, Q^2)$

- The Lorentz invariants are:

$$Q^2 = -(k-k')^2 \qquad t = (p-p')^2$$

$$y = \frac{2p\cdot(k-k')}{s} \qquad z = 1-\frac{2k'\cdot(p-p')}{s} \approx E_n/E_p$$

$$x = Q^2/(ys) \qquad \beta = x/(1-z-x)$$

Neutron Flux Factor

$$f_{n/p}(z, p_t^2) = \frac{2g_\pi^2}{16\pi^2} \frac{|t|}{(m_\pi^2 - t)^2} (1-z)^{(1+2\alpha'_\pi|t|)} G_1^2(t)$$

- The $\pi^0 NN$ coupling is $g_\pi^2/4\pi = 13.75$.
- Form factor $G_1(t) = e^{R_1^2(t-m_\pi^2)}$.
- $\alpha'_\pi \approx 1$ GeV^{-2} is the slope of the pion Regge trajectory.

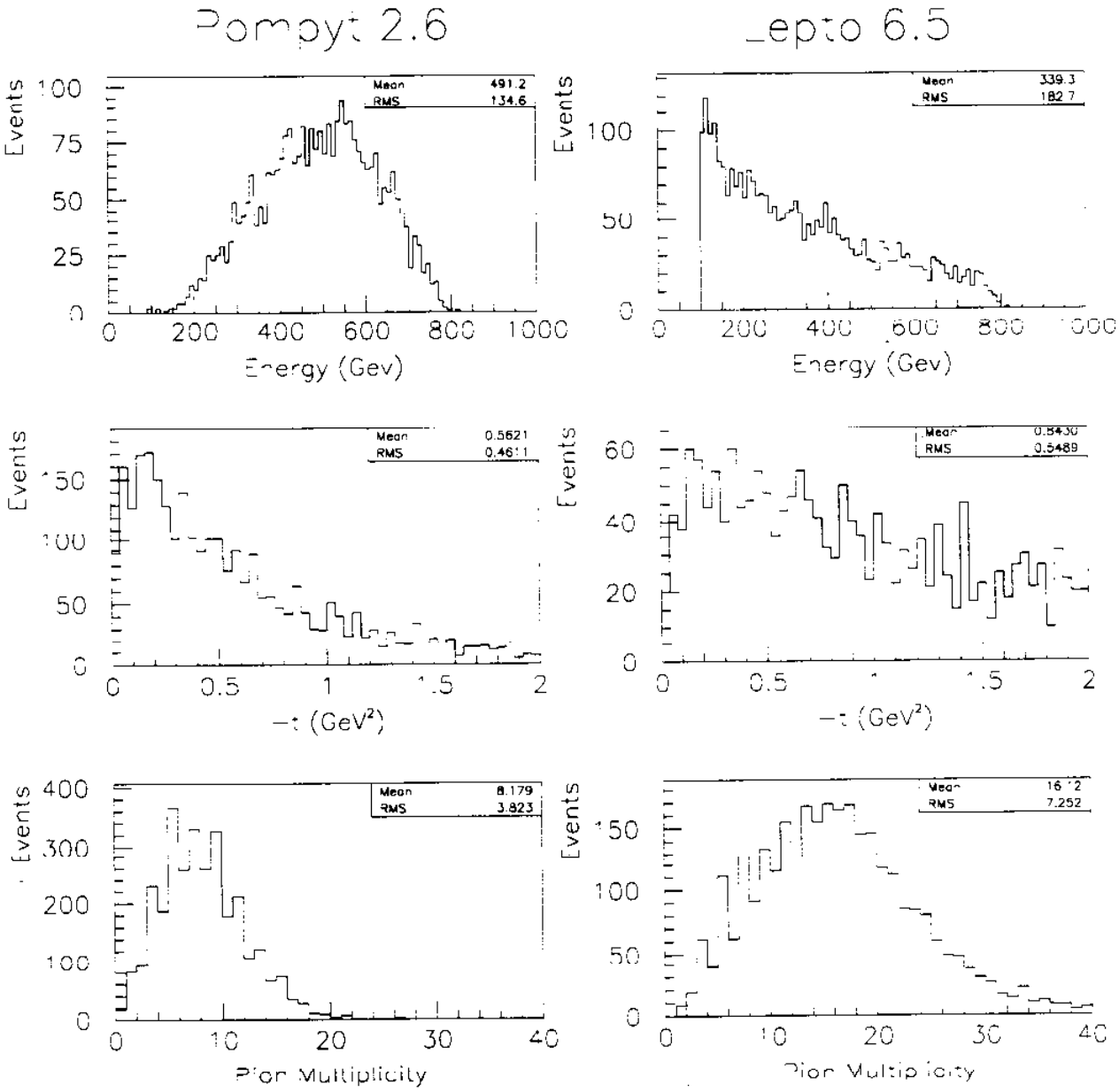
Pion exchange leads to definite predictions which differ from standard DIS expectations:

→ A peak in the neutron energy spectrum at approximately 500 GeV.

→ A peak in the t distribution at $t \approx 0.1$ GeV^2.

→ Less multiplicity in $e\pi$ DIS events compared to ep DIS events because of the smaller energy of the pion.

Pion exchange leads to definite predictions which differ from standard DIS expectations:

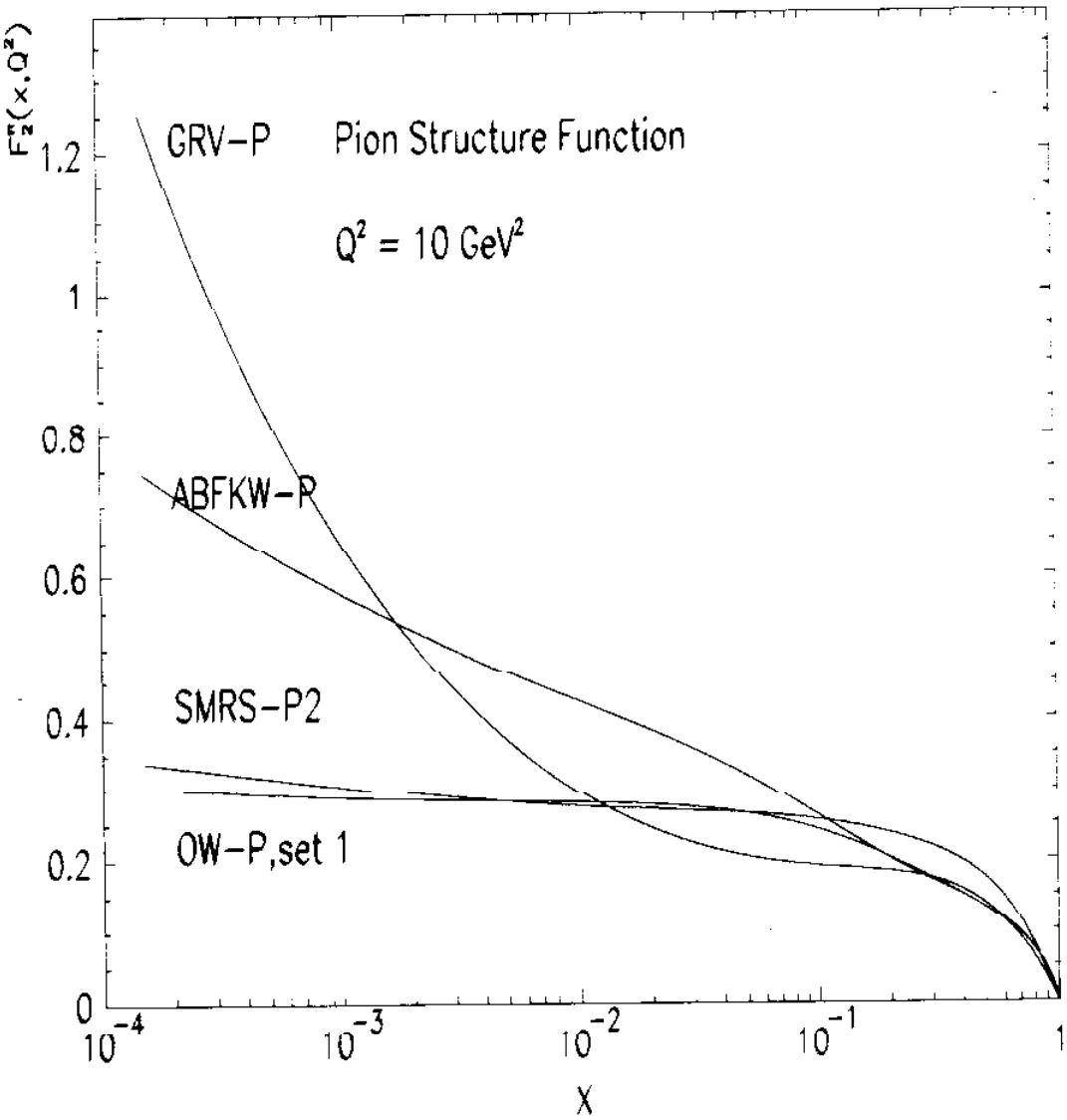


Properties of HERA Events from DIS on Pions in the Proton

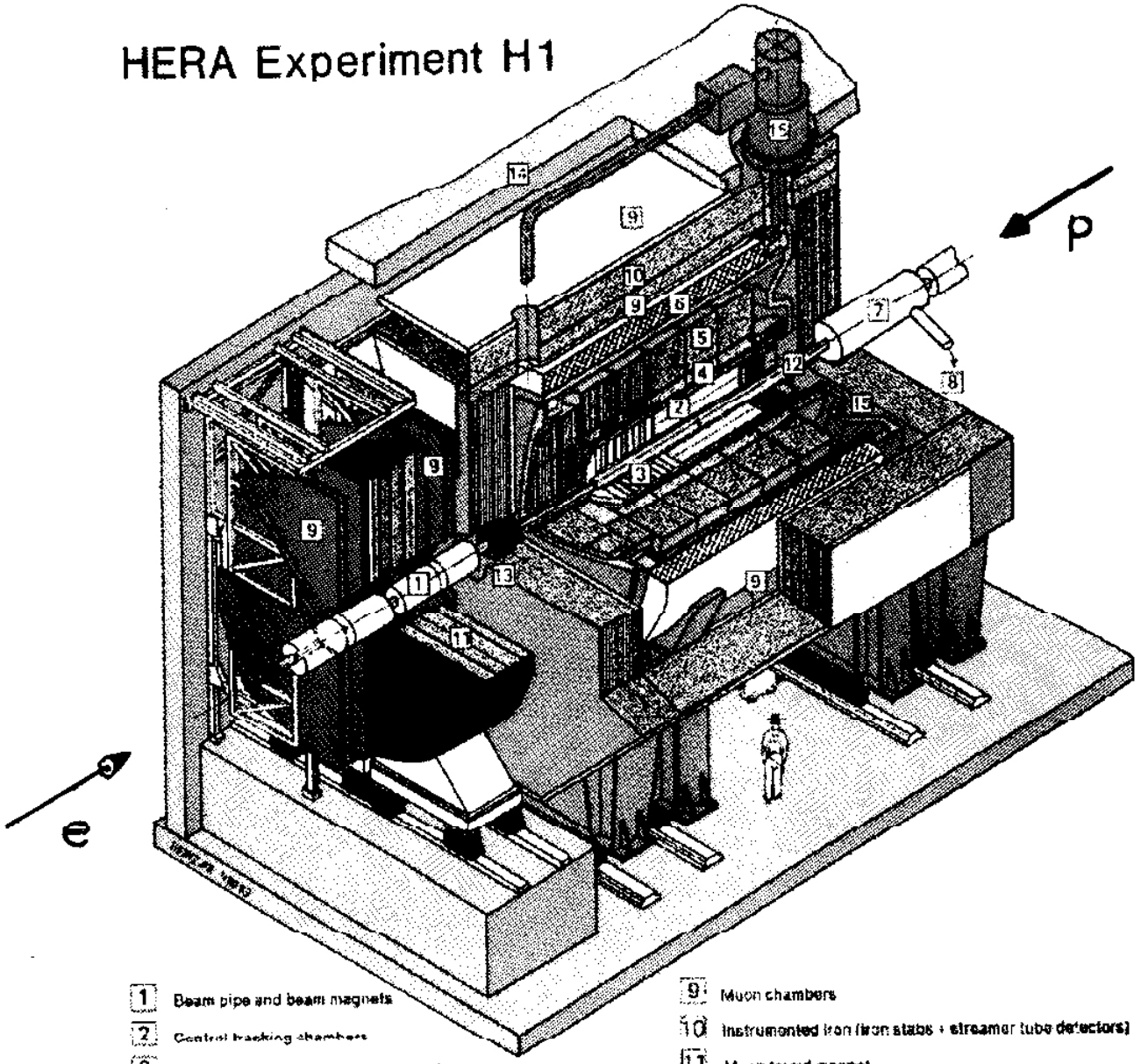
M. Przybycień, T. Sjöstrand, G. Ingelman

DESY 96-073

- Absolute normalization of the pion exchange cross section depends upon the pion structure function.
- Pion structure function has only been determined indirectly by Drell-Yan processes for ($x > 0.1$).



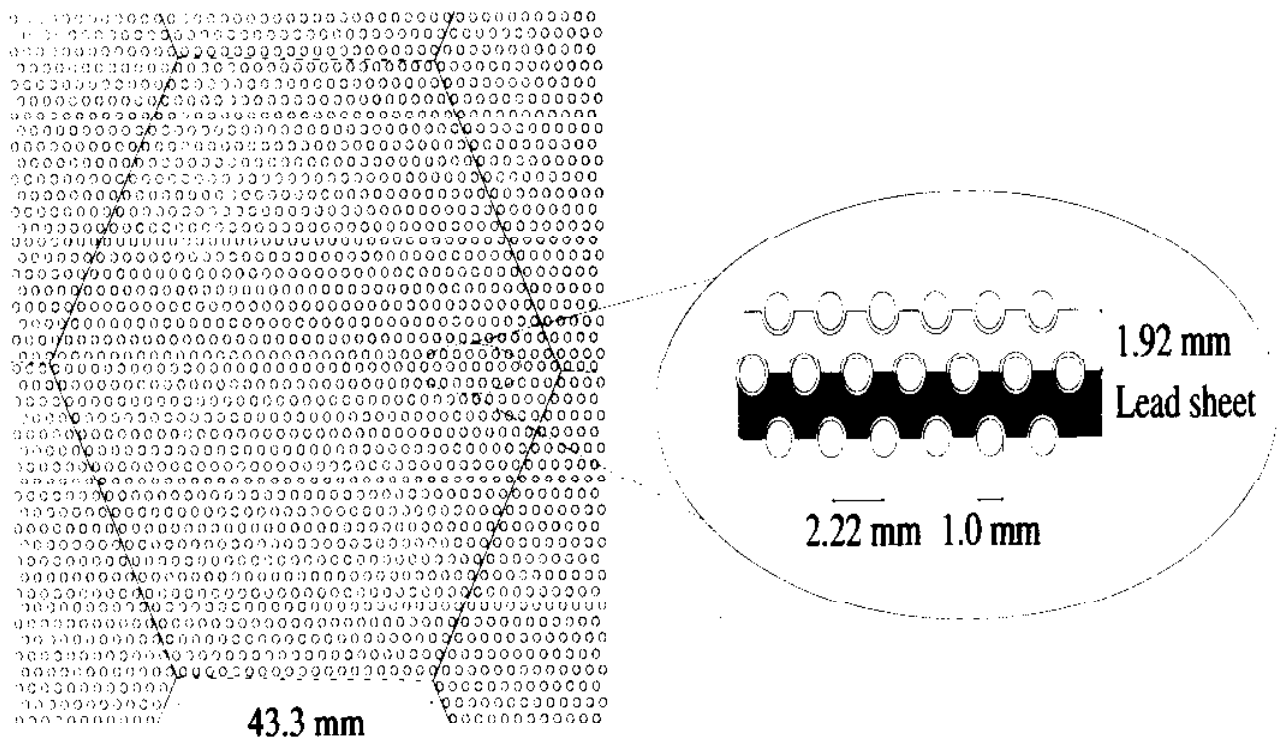
HERA Experiment H1



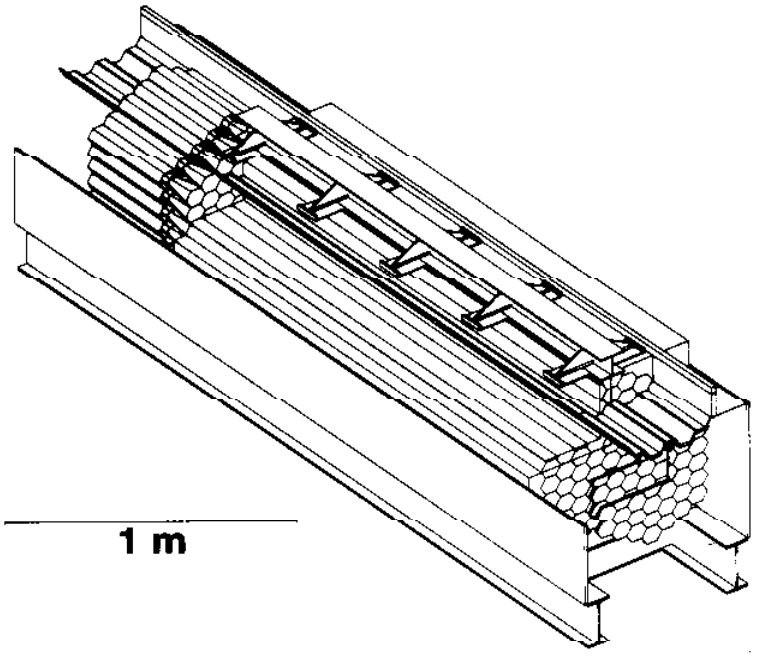
1 Beam pipe and beam magnets
2 Central tracking chambers
3 Forward tracking and Transition radiators
4 Electromagnetic Calorimeter (lead) } Liquid Argon
5 Hadronic Calorimeter (stainless steel) } Liquid Argon
6 Superconducting coil (1.2T)
7 Compensating magnet
8 Helium cryogenics
9 Muon chambers
10 Instrumented iron (iron slabs + streamer tube detectors)
11 Muon toroid magnet
12 Warm electromagnetic calorimeter
13 Plug calorimeter (Cu, Si)
14 Concrete shielding
15 Liquid Argon cryostat

Description of the FNC

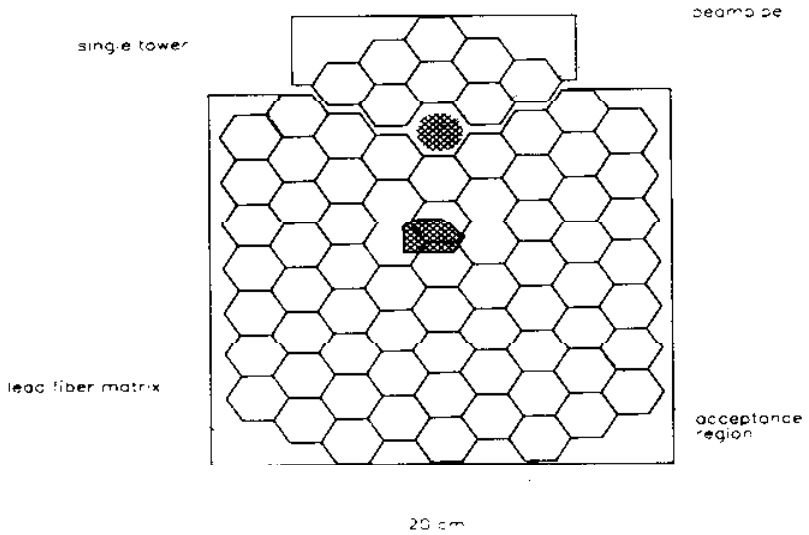
- Pb/scintillating fiber matrix.
- The volume ratio of lead to fiber is about 4:1. This was done to make the calorimeter compensating (e/h = 1.15 ± 0.02).
- 75 modules. Each module contains 1141 scintillating fibers coupled to a common PM.
- Nuclear interaction length $\lambda_I \approx 21$ cm.

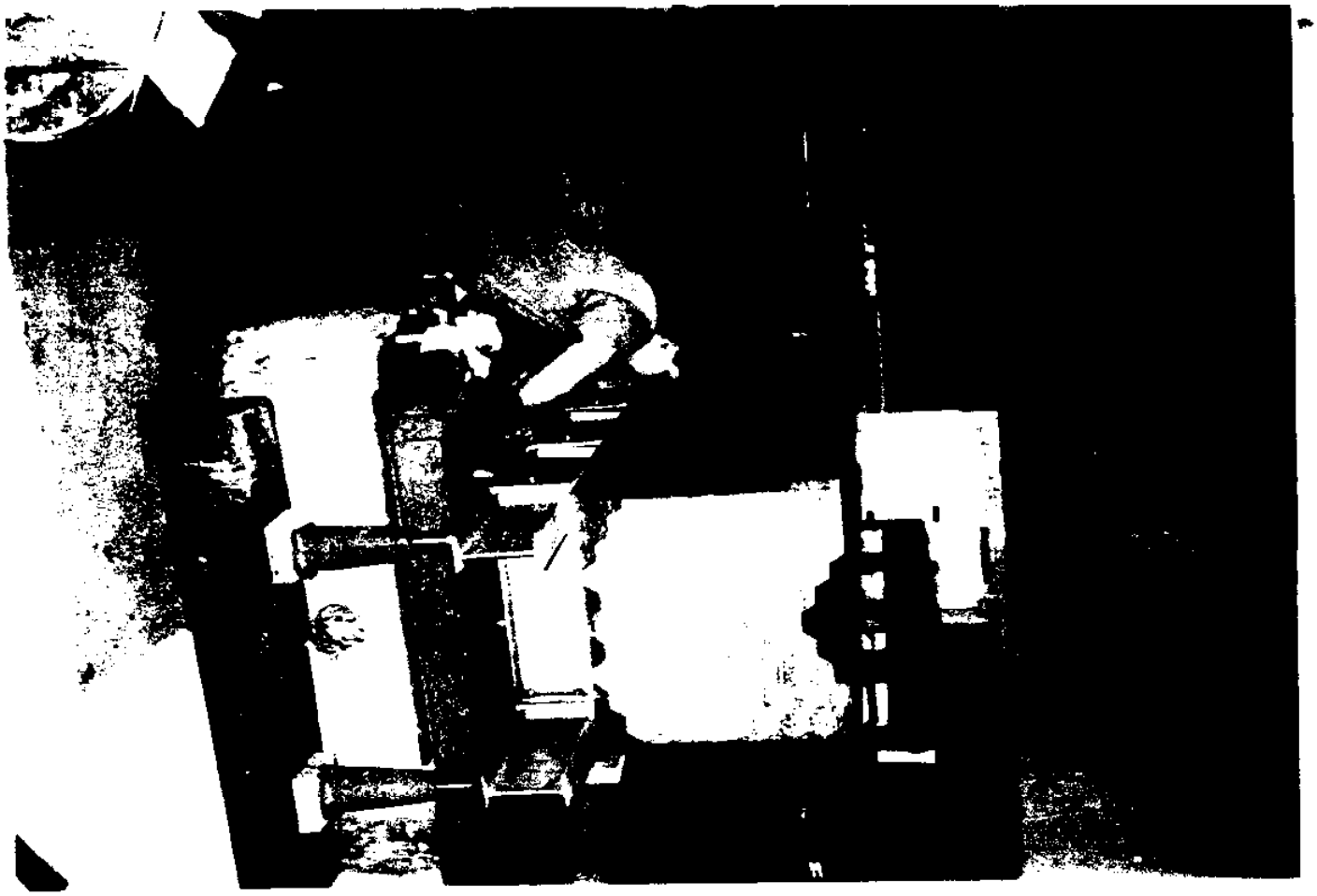


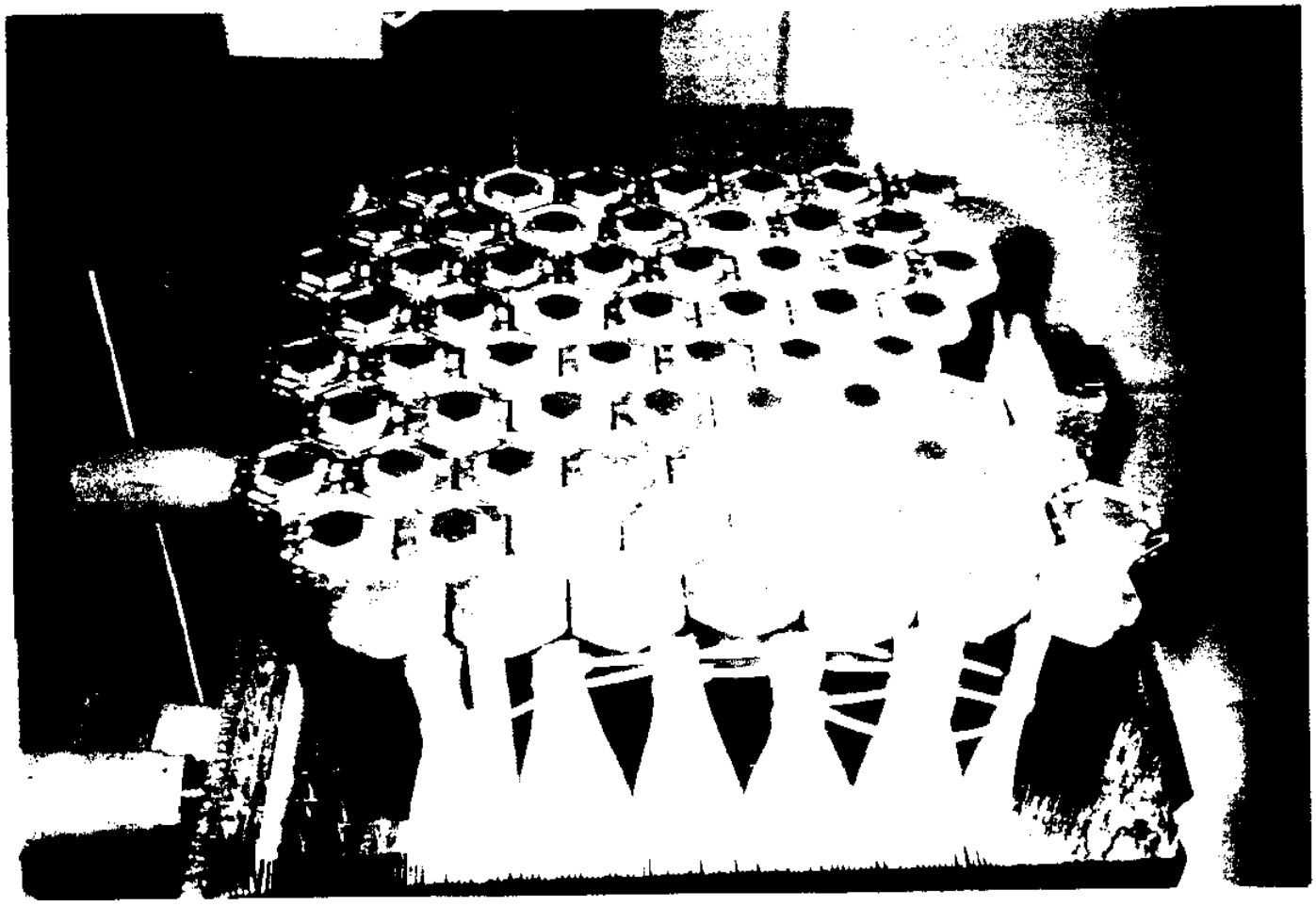
Schematic Diagram of the FNC



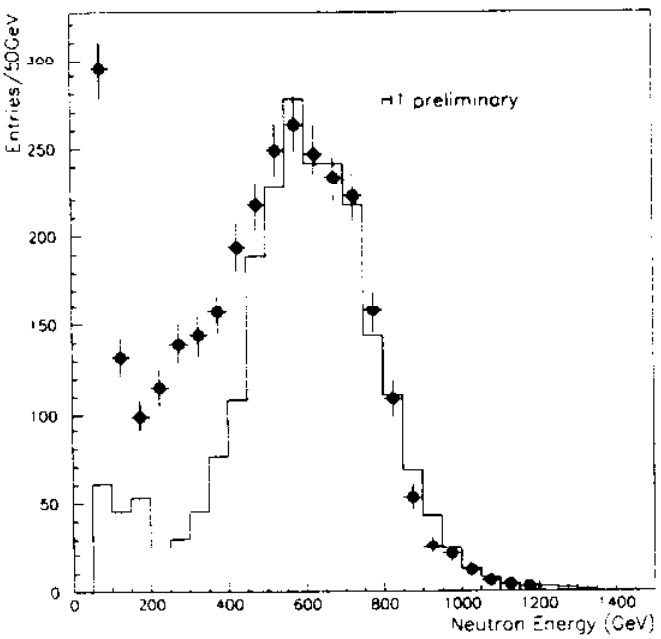
Front Face of the FNC

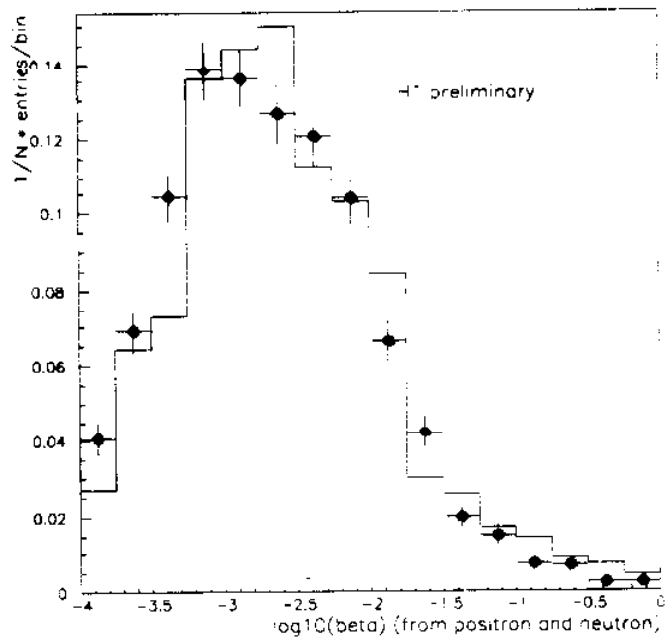






Results from the 1995 FNC



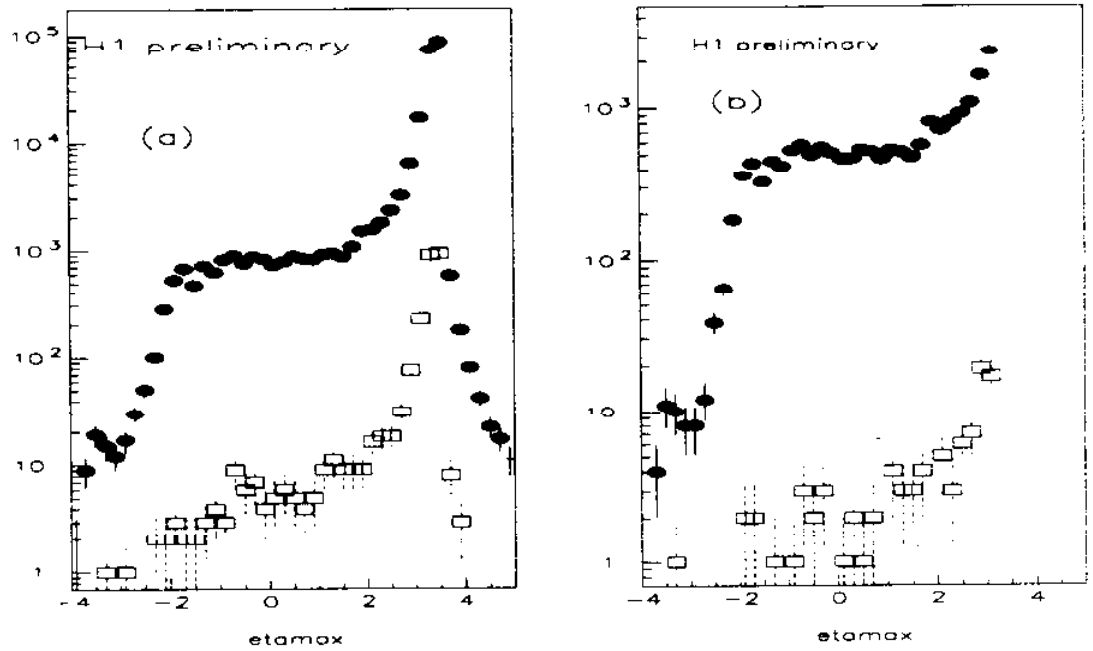


- The normalization of the Monte Carlo histograms are to the peak heights. For neutron energies above 400 GeV, the Monter Carlo calculations provide a reasonable description of the data.

- If the pion exchange model is used to correct for acceptance, [illegible]% of all DIS events with $2 < Q^2 < 100$ GeV^2 and $5 \cdot 10^{-[illegible]} < x < 10^{-2}$ include a neutron with $E >$ [illegible] GeV

→ **Expectation from the Monte Carlo is 7%.**

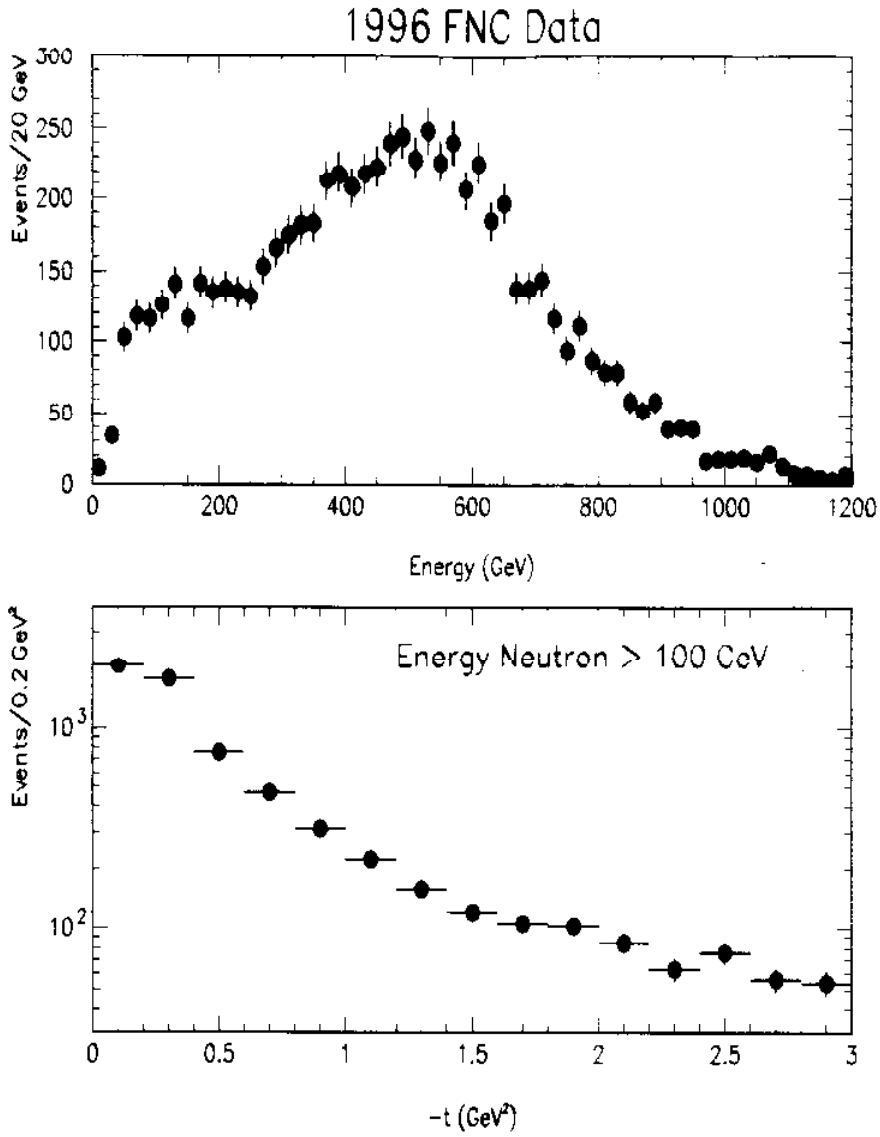
1995 Neutrons with a Large Rapidity Gap



- Assuming all neutrons in the large rapidity gap sample arise from proton dissociation, results in the estimate that the proton dissociates in $(25^{+32}_{-9})\%$ of diffractive events.

- Assuming that all neutrons with $\eta_{\rm max} < 2$ arise from pion exchange, one obtains an upper limit of $(3.3^{+3}_{-1})\%$ pion exchange in the diffractive sample with $x_P < 0.05$.

Distributions from the New FNC



- Approximately 1/4 of the 1996 Data.
- $Q^2 > 5$ GeV^2, $0.05 < y < 0.7$

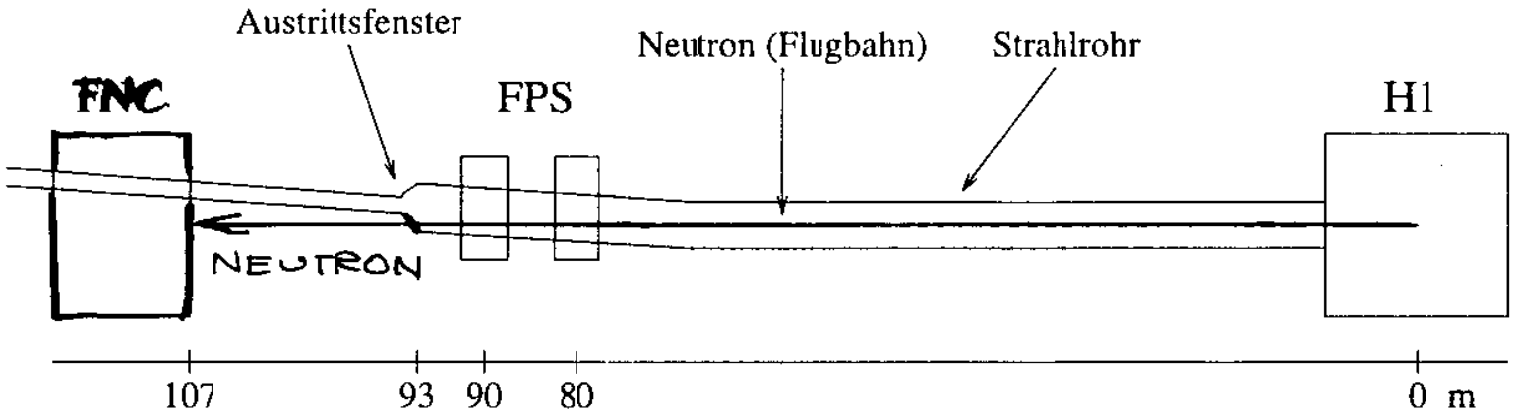
Monte Carlo Predictions

- Lepto 6.5 and Pythia [illegible] were used as generators. Only events with a generated neutron with energy greater than [illegible] GeV were accepted.
- Only the neutron was accepted [illegible] simulated. The other particles in the event [illegible] the [illegible] calculation.

Event listing (summary)

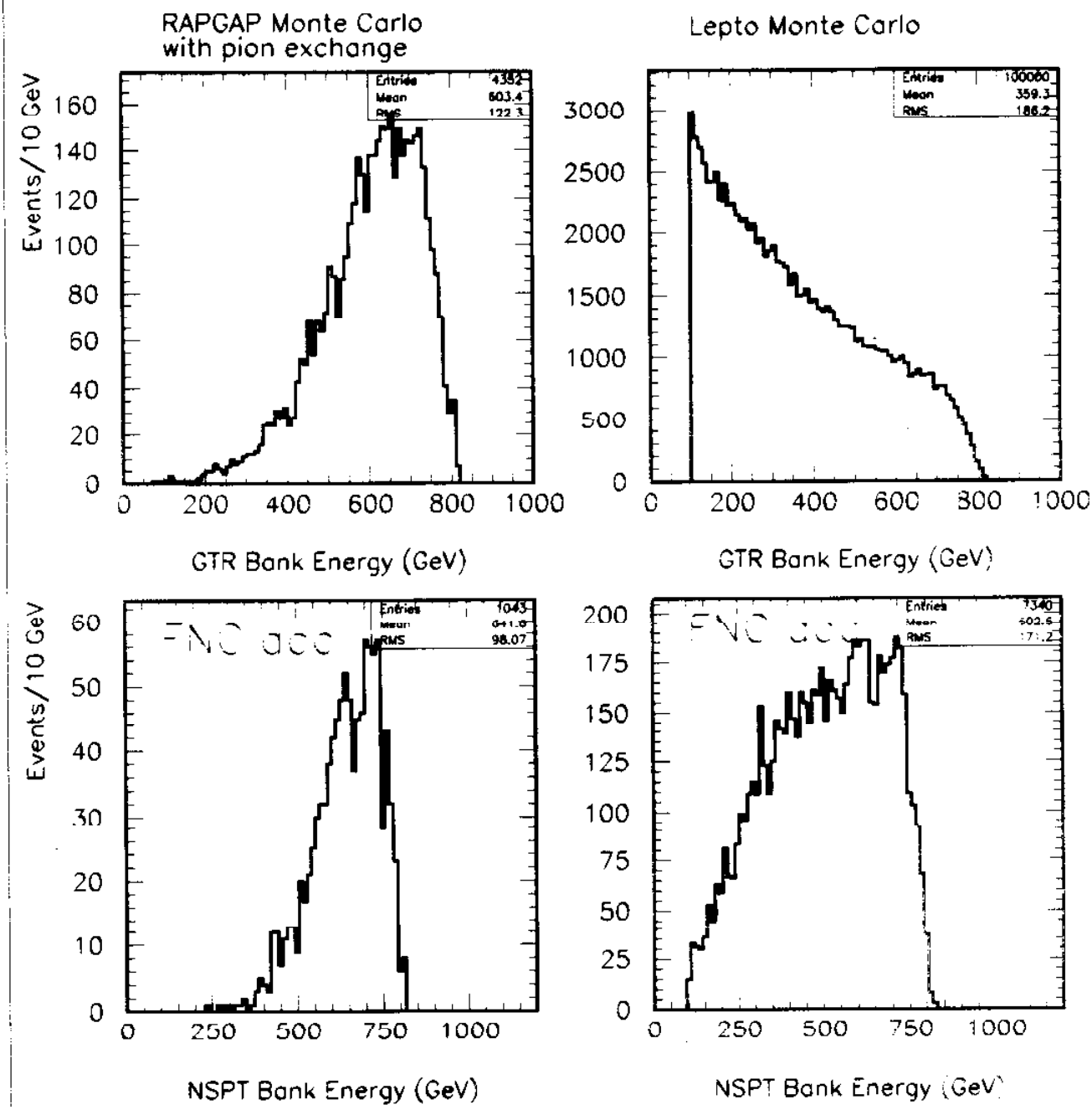
I	particle/jet		KS	KF	orig	p_x	p_y	p_z	E	m
1	!e+!		21	-11	0	0.000	0.000	-27.500	27.500	0.001
2	!p+!		21	2212	0	0.000	0.000	820.000	820.001	0.938
3	!Z0!		21	23	1	1.787	0.954	-12.725	12.586	-2.757
4	e+		1	-11	1	-1.787	-0.954	-14.775	14.914	0.001
5	!g!		21	21	2	-0.131	-0.121	0.774	0.794	0.000
6	!u!		21	2	5	-0.450	-0.836	0.340	-0.129	-1.000
7	!u!		21	2	6	1.335	0.118	-12.374	12.446	0.006
8	(u)		13	2	0	1.335	0.118	-12.374	12.446	0.006
9	(ud_1)		13	2103	2	0.524	0.115	665.673	665.673	0.450
10	(u~)		13	-2	5	0.319	0.715	0.486	0.977	0.325
11	(u)		13	2	2	-0.392	0.007	153.484	153.485	0.225
12	(u)	A	12	2	8	1.335	0.118	-12.374	12.446	0.006
13	(u~)	V	11	-2	10	0.319	0.715	0.486	0.977	0.325
14	(u)	A	12	2	11	-0.392	0.007	153.484	153.485	0.225
15	(ud_1)	V	11	2103	9	0.524	0.115	665.673	665.673	0.450
16	(cluster)		11	91	14	0.132	0.122	819.157	819.158	1.290
17	pi+		1	211	16	0.058	-0.225	251.333	251.333	0.140
→ 18	n0		1	2112	16	0.075	0.348	567.824	567.825	0.940
19	(string)		11	92	12	1.655	0.832	-11.888	13.423	5.952
20	(omega)		11	223	19	0.562	-0.082	-5.053	5.145	0.785
21	pi+		1	211	19	0.754	0.537	-6.470	6.538	0.140
22	(K0)		11	311	19	0.495	0.133	-0.394	0.816	0.498

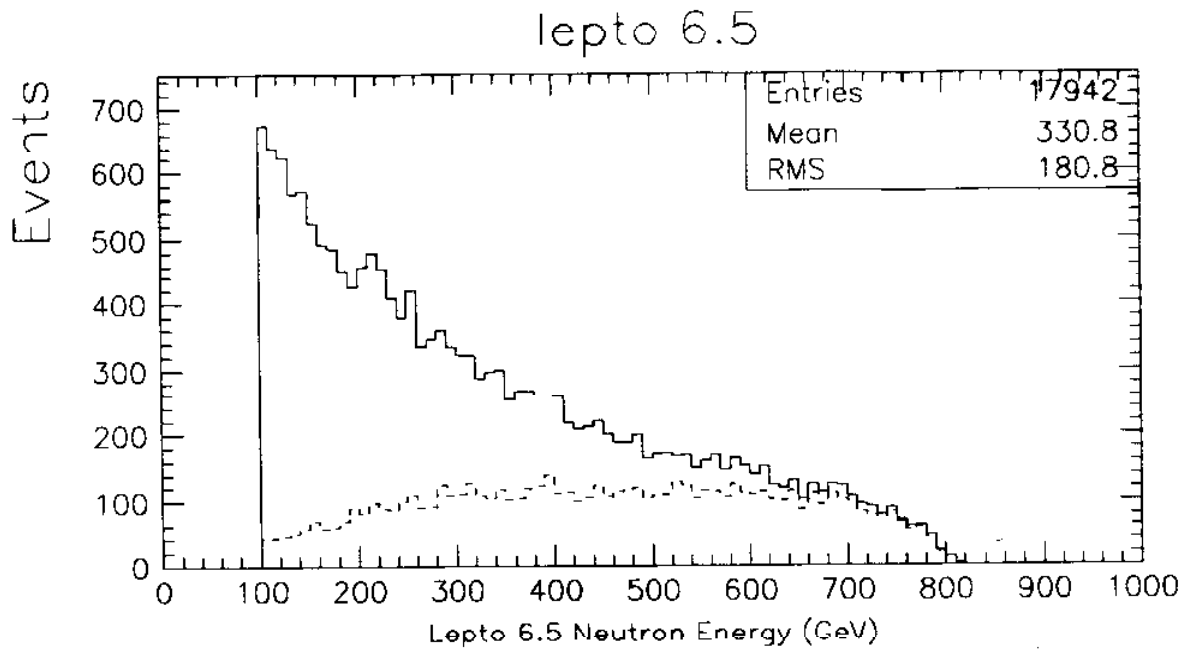
Position of FNC in HERA RING

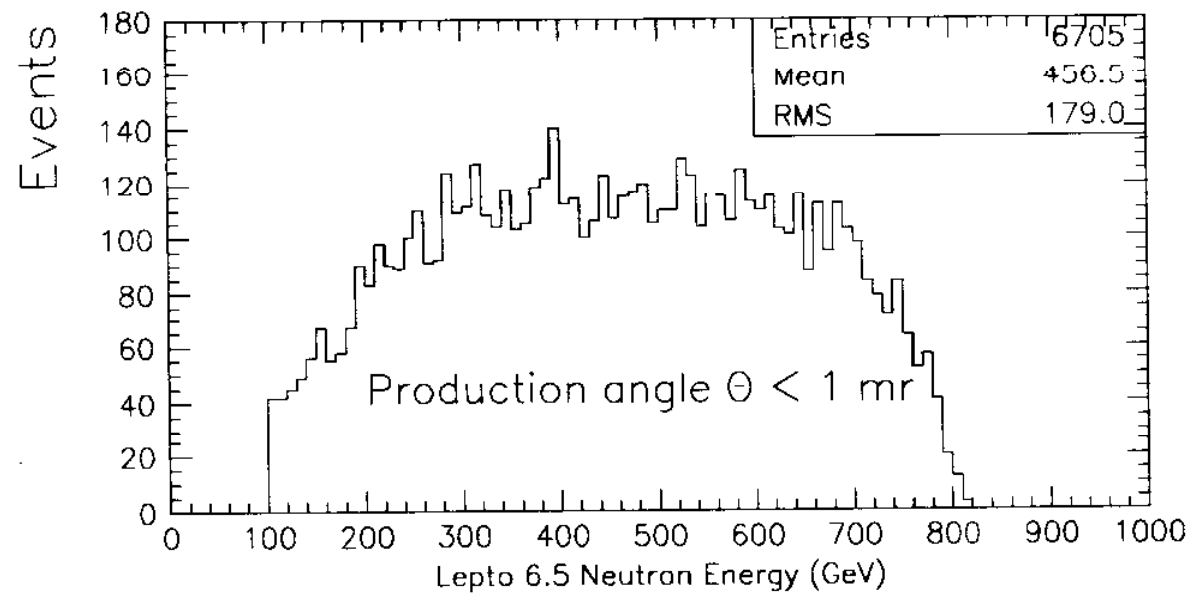


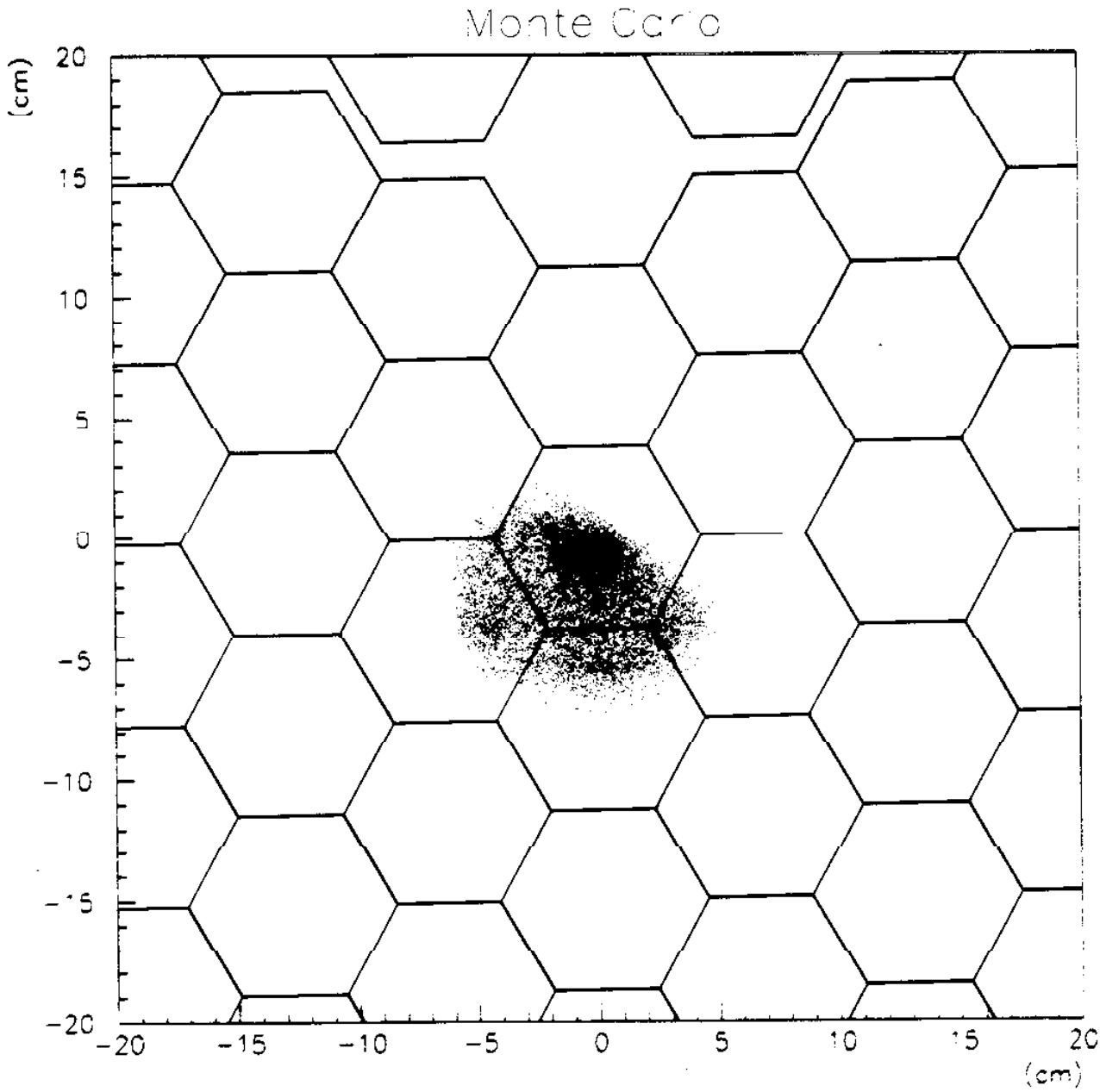
- Window in Proton Beampipe minimizes Material in the Neutrons flight path

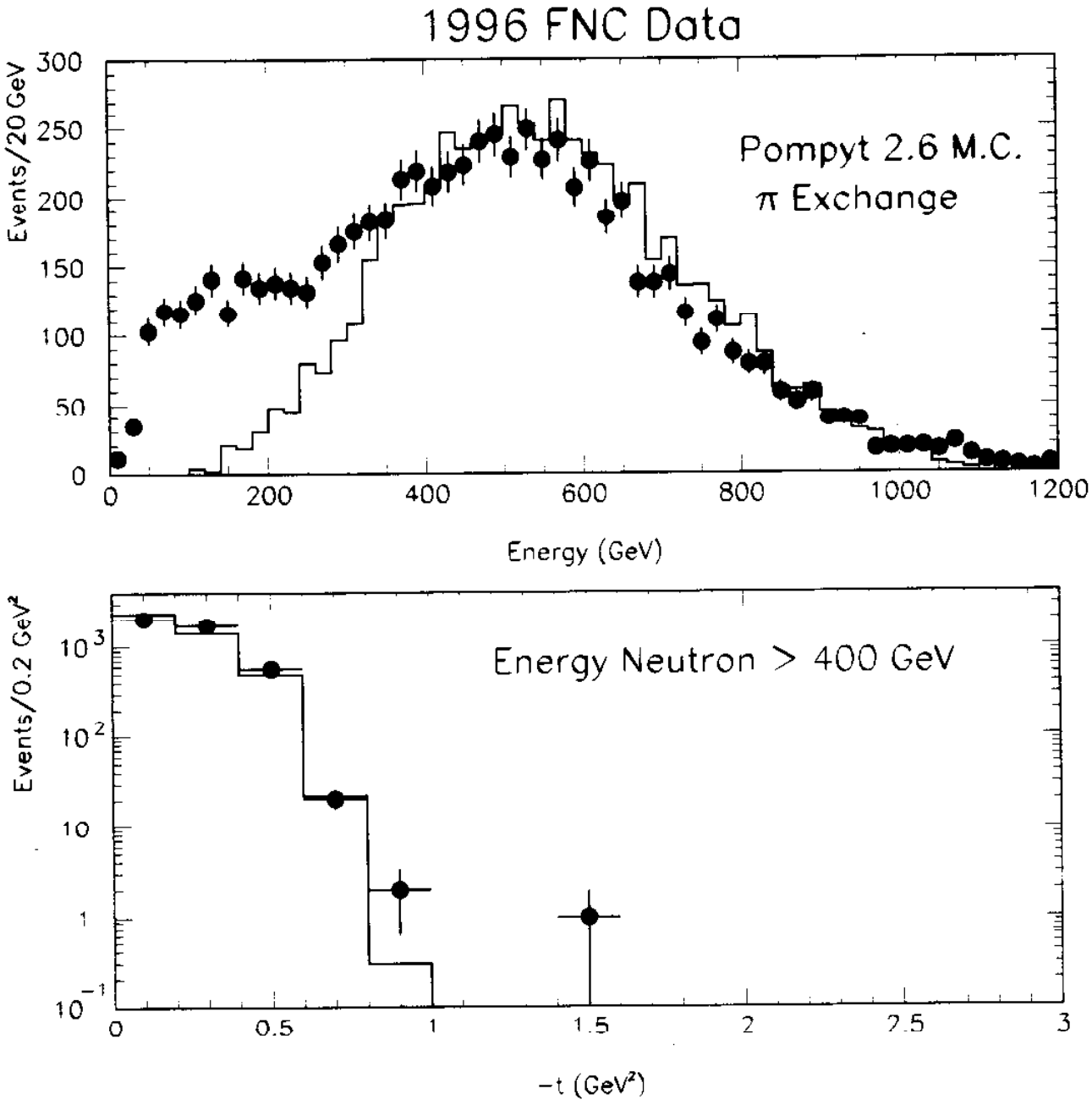
- GEOMETRY of Proton Beampipe determines the FNC-ACCEPTANCE

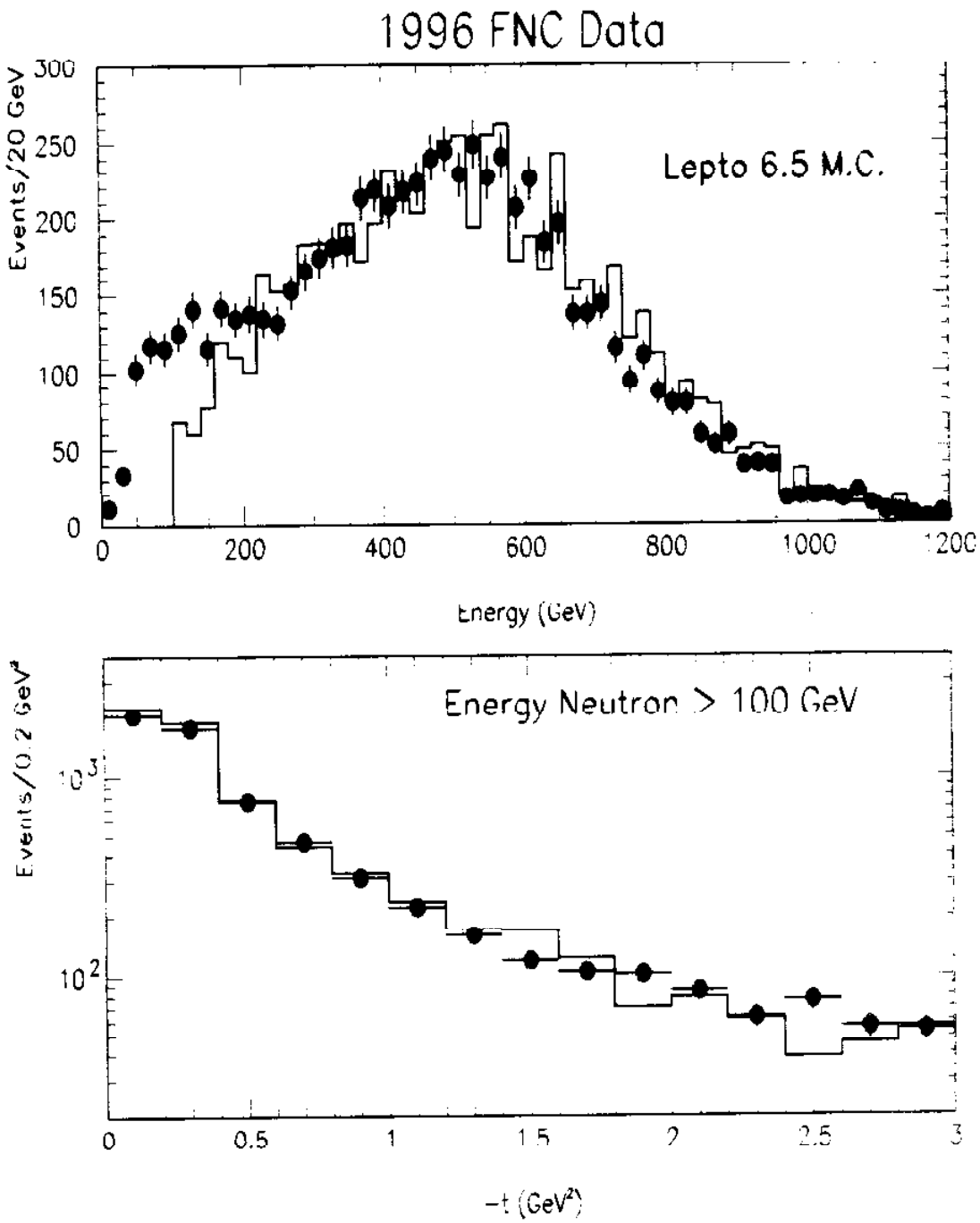

RAPGAP Monte Carlo
with pion exchange
Lepto Monte Carlo
Events/10 GeV
GTR Bank Energy (GeV)
GTR Bank Energy (GeV)
Events/10 GeV
NSPT Bank Energy (GeV)
NSPT Bank Energy (GeV)


lepto 6.5
Entries 17942
Mean 330.8
RMS 180.8
Events
Lepto 6.5 Neutron Energy (GeV)


Entries 6705
Mean 456.5
RMS 179.0
Production angle Θ < 1 mr
Events
Lepto 6.5 Neutron Energy (GeV)


Monte Carlo
(cm)
20
15
10
5
0
-5
-10
-15
-20
-20
-15
-10
-5
0
5
10
15
20
(cm)

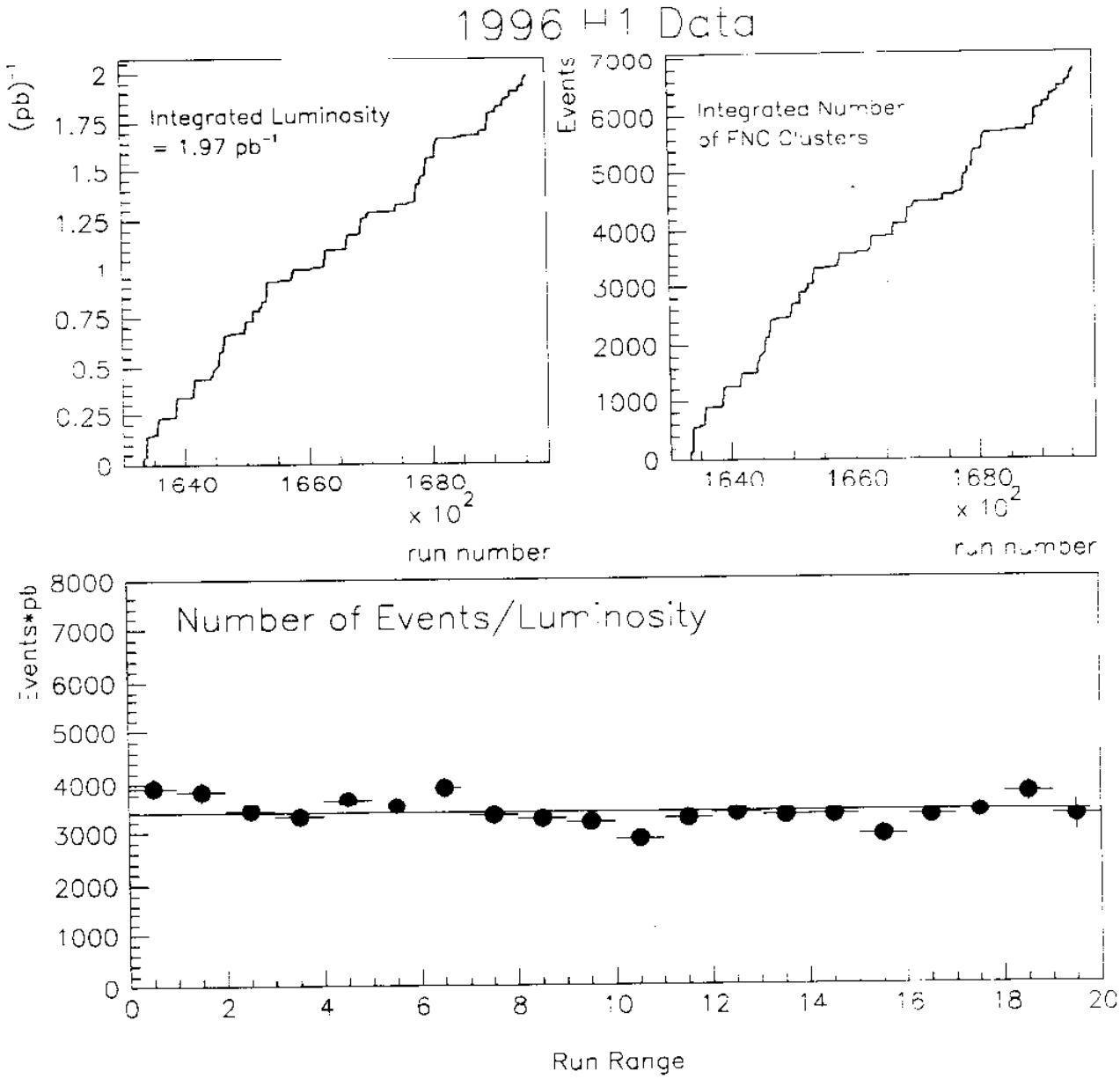

1996 FNC Data
Events/20 GeV
Pompyt 2.6 M.C.
π Exchange
Energy (GeV)
Events/0.2 GeV²
Energy Neutron > 400 GeV
−t (GeV²)

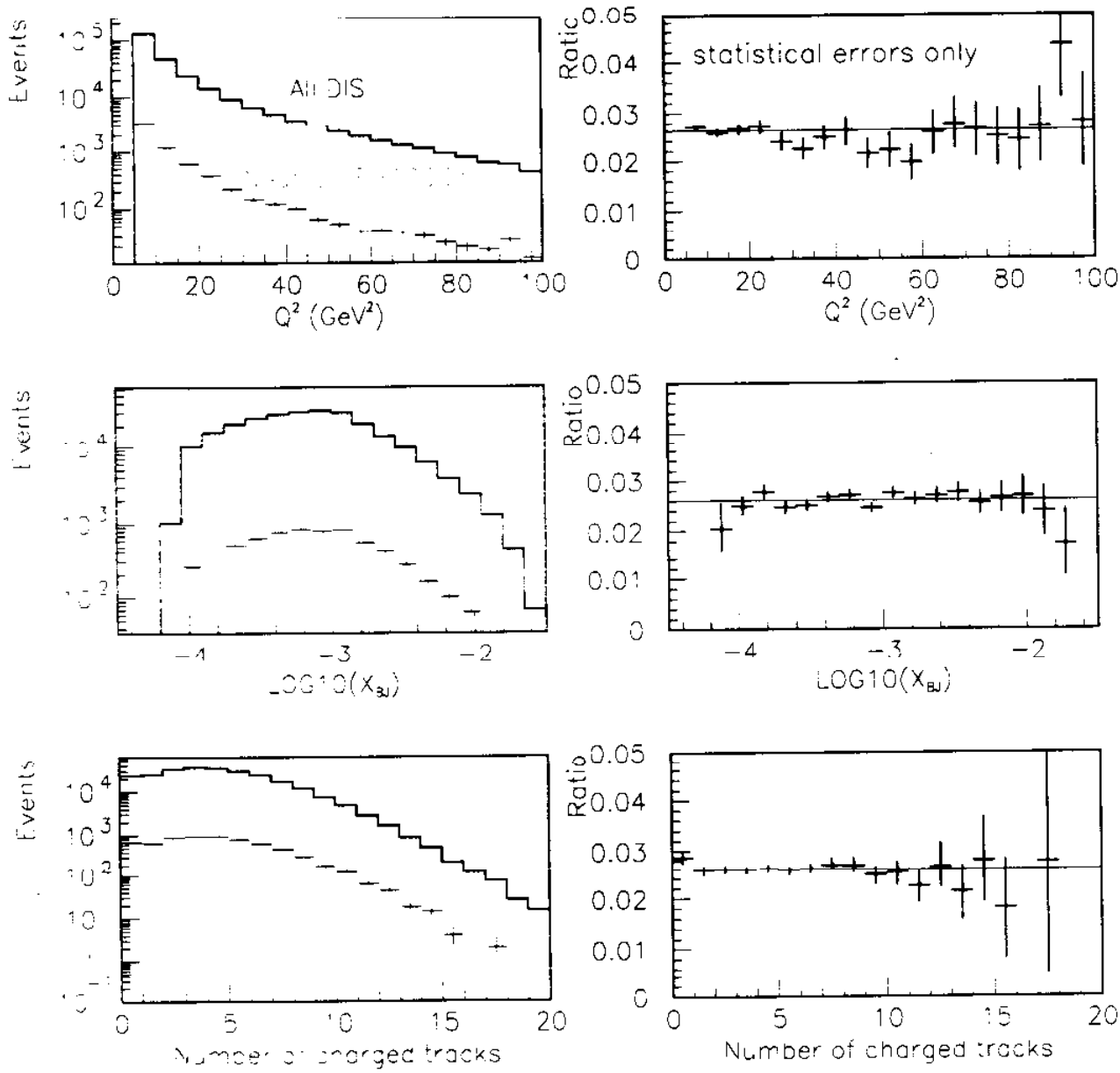


- Contamination from other neutral particles? Unknown at the present time but probably small.

Monte Carlo predictions should be normalized according to cross section and luminosity.

FNC luminosity well understood ...




Events
All DIS
Q^2 (GeV^2)
Ratio
statistical errors only
Q^2 (GeV^2)
Events
LOG10(X_{BJ})
Ratio
LOG10(X_{BJ})
Events
Number of charged tracks
Ratio
Number of charged tracks

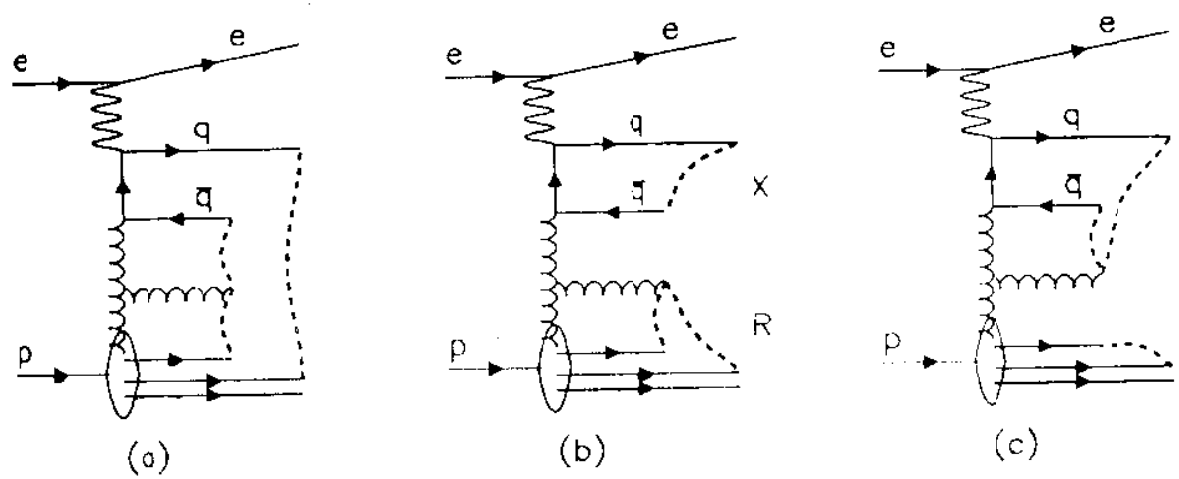
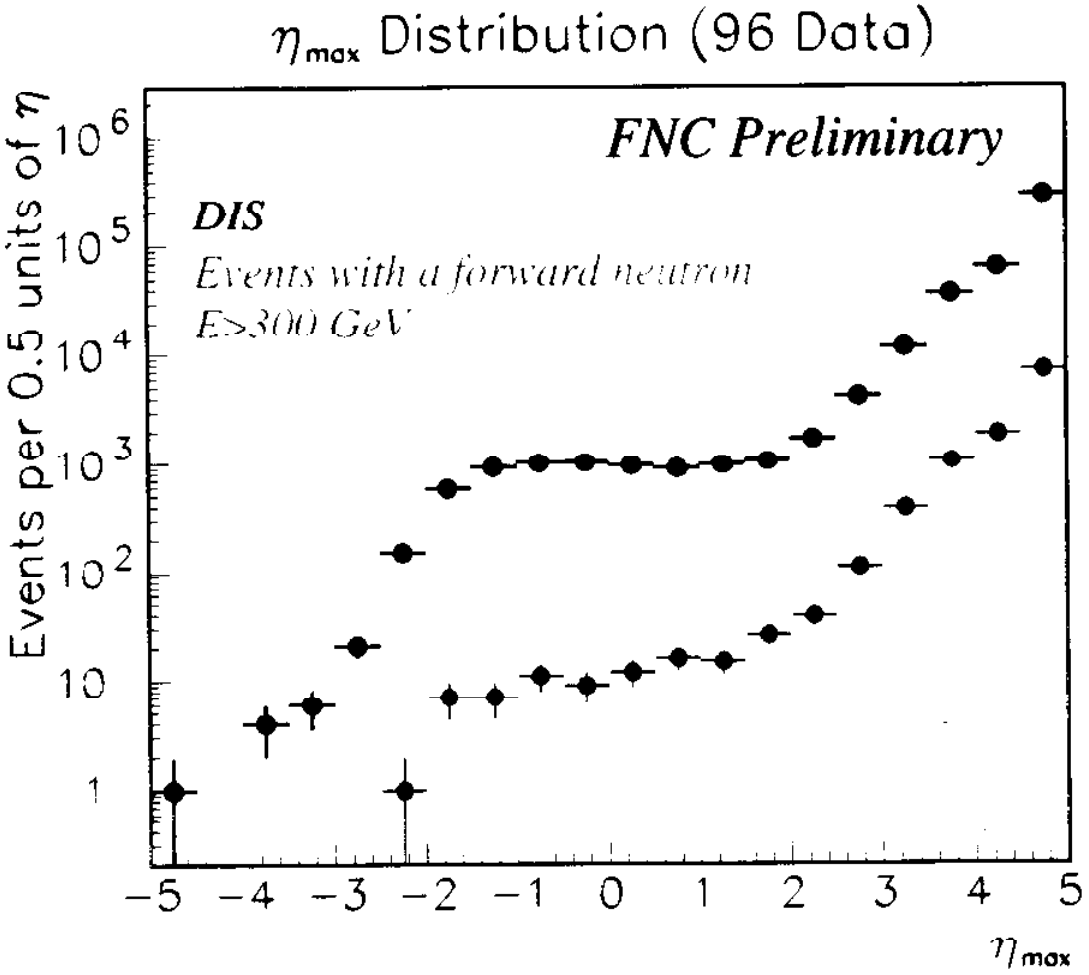
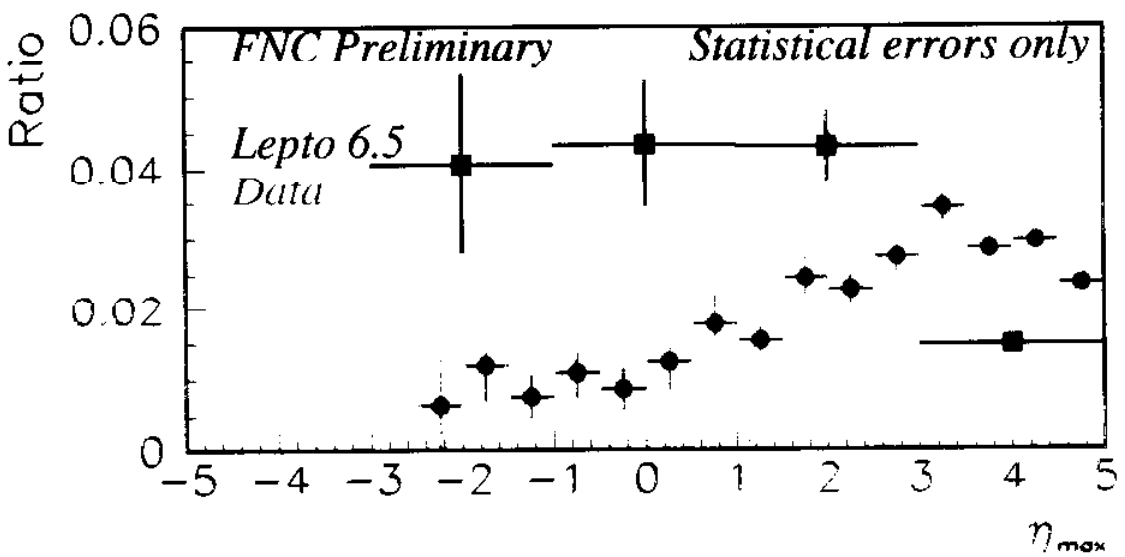


Figure 8: The string configuration in a gluon-initiated DIS event in (a) conventional Lund string model connection of partons, and (b,c) after reconnection due to soft colour interactions.



Ratio: Events with forward neutron (E>300 GeV) / DIS



Conclusions

- Approximately 1/4 of the 1996 FNC data has been analyzed.
- A preliminary study suggests that Lepto 6.5 gives a good description of neutrinos with $E_\nu >$ 100 GeV. High energy neutrinos with $E_\nu >$ 400 GeV can also be well described by Pythia 2.6 with τ-renormalization.
- Events with $E_\nu >$ 200 GeV look very much like normal DIS events.
  - ratio flat in Q^2, x_{Bj}, and multiplicity -

Plans for the Future

- Normalize the Monte Carlo predictions according to cross section and luminosity.
- Measure the $\nu + p \to \nu + \mu + X$ cross section in a specific kinematic region.