Charged Particle and Nuclear Fragment Emission in Neutrino Interactions in the CHORUS Emulsion Target

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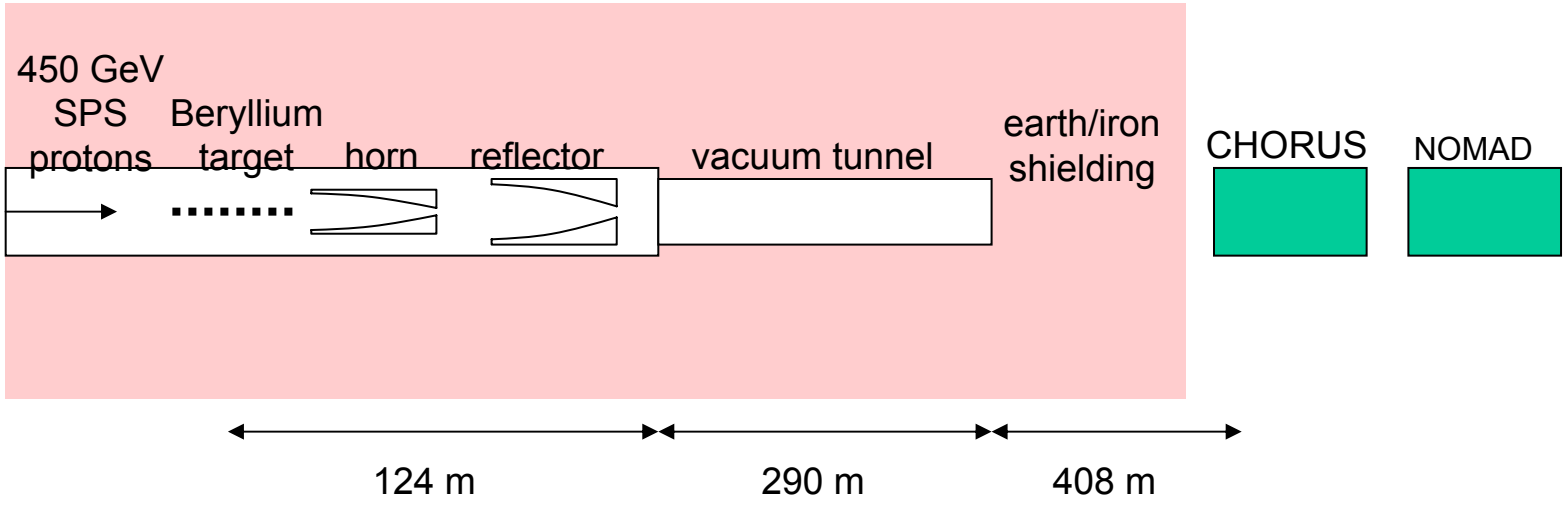
Preliminary results

The  **Collaboration**

Belgium (Brussels, Louvain-la-Neuve), **CERN**, **Germany** (Berlin, Münster), **Israel** (Haifa), **Italy** (Bari, Cagliari, Ferrara, Naples, Rome, Salerno), **Japan** (Aichi, Kinki,Kobe, Nagoya,Osaka, Toho,Utsunomiya) ,**Korea** (Gyeongsang), **The Netherlands** (Amsterdam), **Russia** (Moscow), **Turkey** (Adana, Ankara, Istanbul)

NUINT'02, University of California, Irvine 12-15 December.

Neutrino Beam



ν_μ : $\bar{\nu}_\mu$: ν_e : $\bar{\nu}_e$

1.00 : 0.05 : 0.017 : 0.007

$\langle E_\nu \rangle \sim 27$ GeV

$\nu_\tau CC \sim 3.3 \cdot 10^{-6}\, \nu_\mu CC$ (0.1 background event)

CHORUS detector

94-97
four years of data taking

- **Neutrino target**
- Active nuclear emulsion target (770 kg)
- Scintillating fiber tracker

- **Hadron Sign and momentum**
- air-core magnet-spectrometer

$\Delta p/p = \sqrt{(0.035 \cdot p(GeV/c))^2 + 0.22^2}$

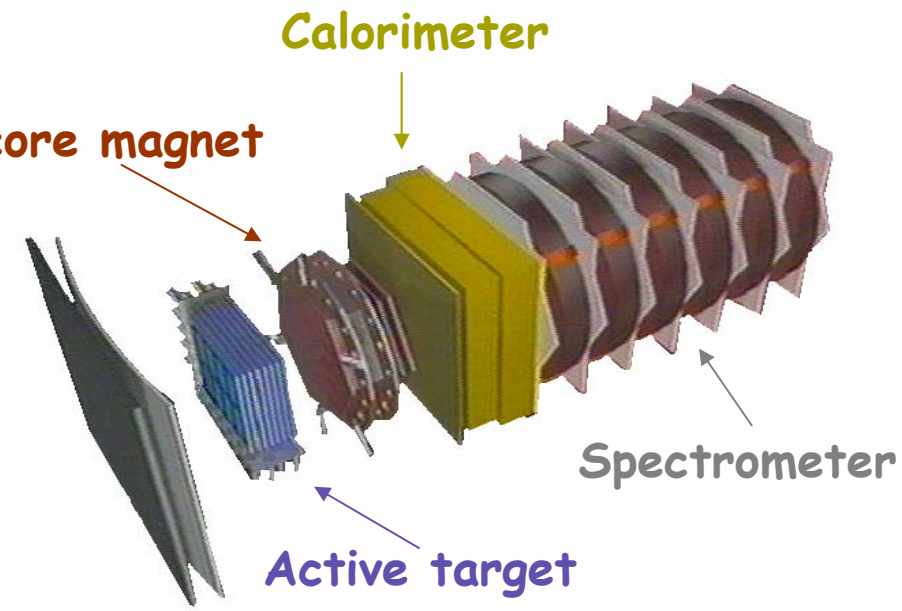
Showers energy, missing P_t

lead&fibers "spaghetti" calorimeter

$\Delta E/E = 32\%/\sqrt{E}$ (hadrons)

$\Delta E/E = 14\%/\sqrt{E}$ (electrons)

$\Delta \theta_{hadrons}$ = 60 mrad @ 10 GeV

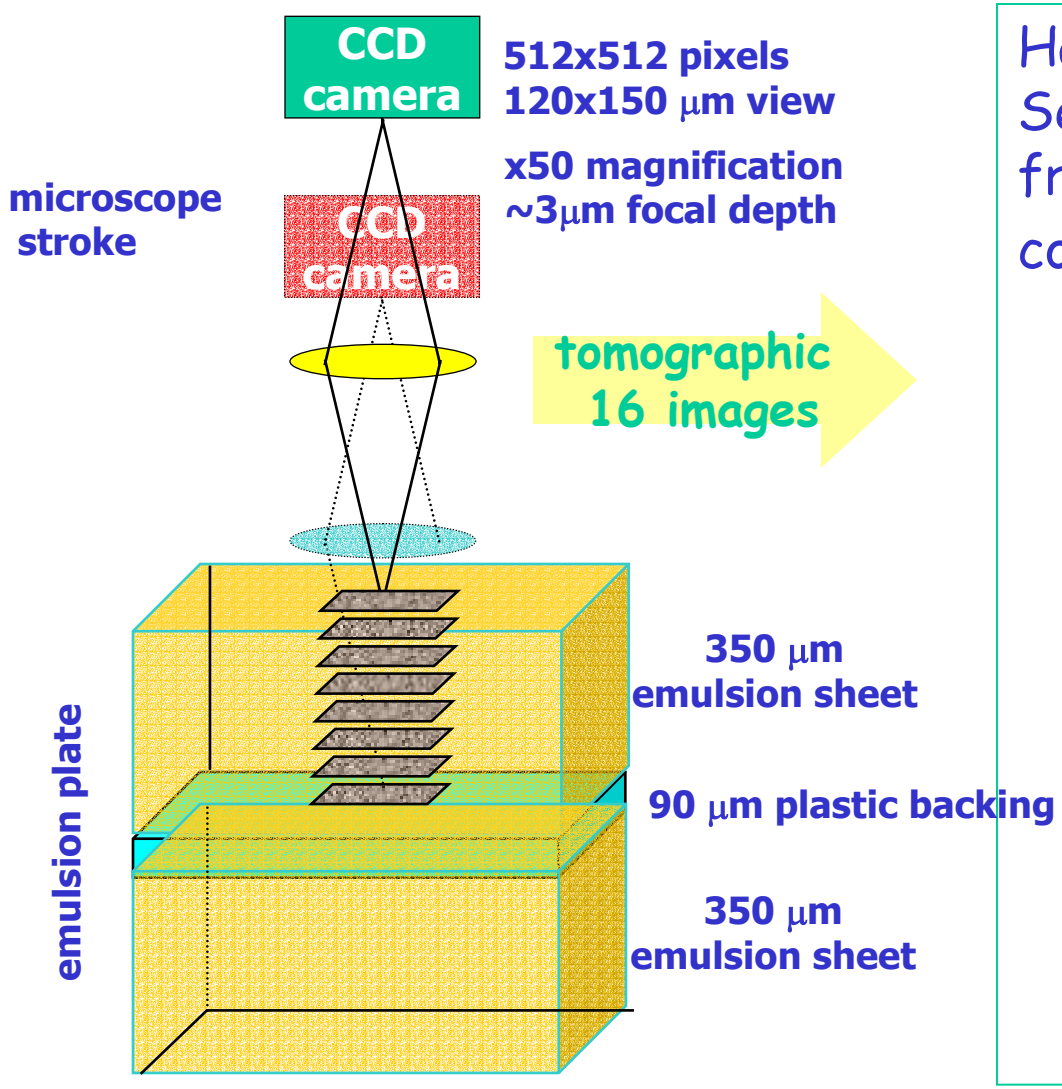


- **Muon ID, sign and momentum**
- iron-core muon spectrometer

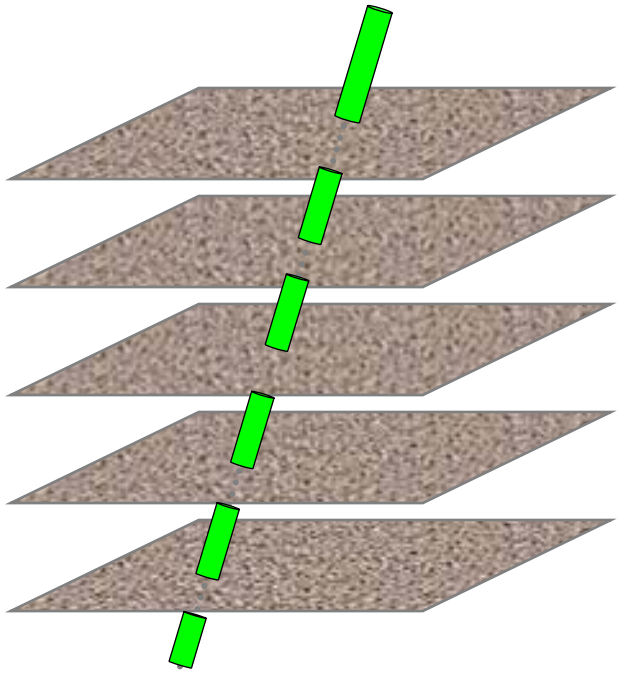
$\Delta p/p \sim 10\%\text{-}15\%$ ($p < 70$ GeV)

Automatic Emulsion Data Taking

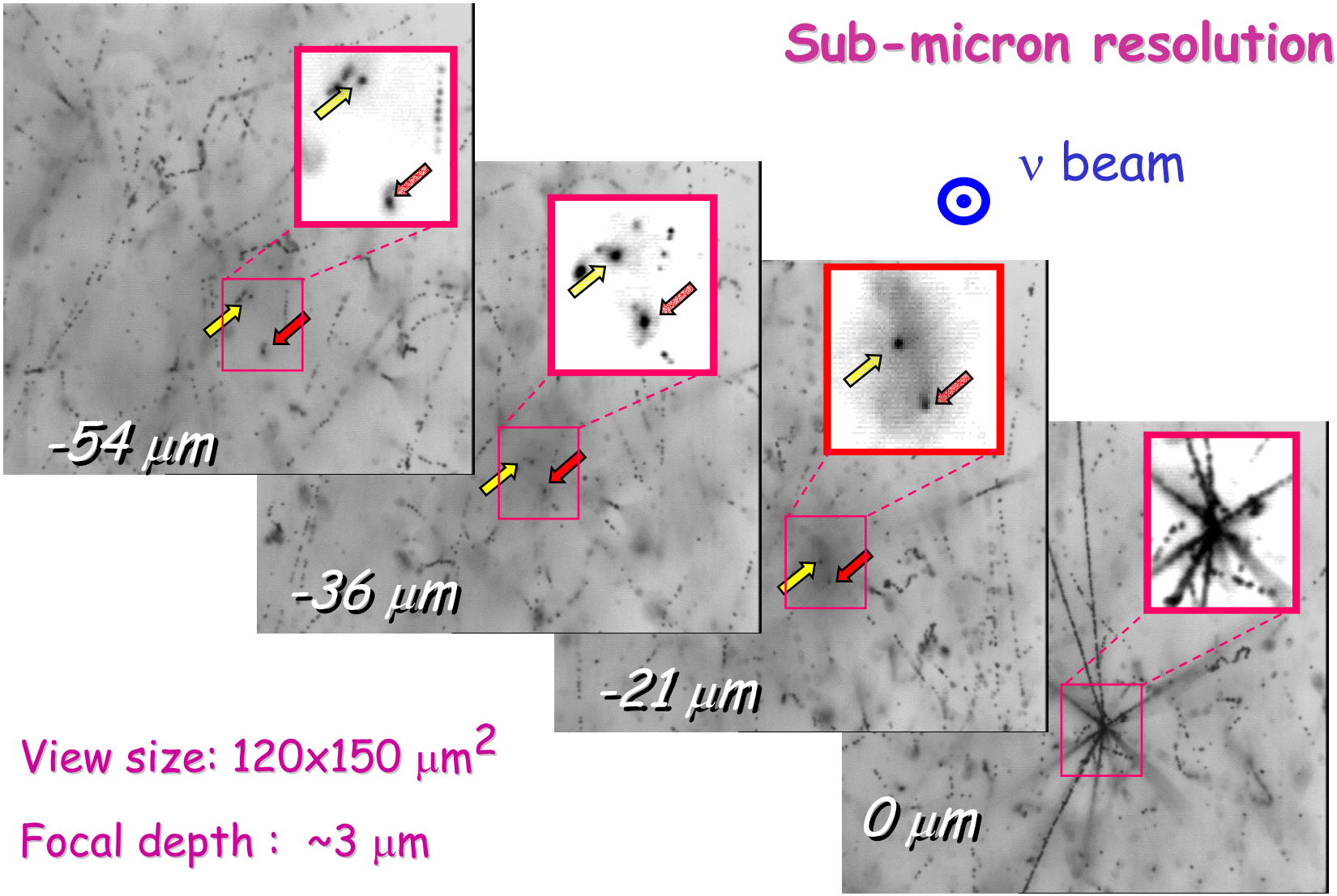
(pioneered by the Nagoya group)



Hardware video processors (Track Selector) reconstruct tracks as frame-to-frame emulsion grain coincidence.



ν interaction in the emulsion



Sub-micron resolution !

ν beam

View size: 120x150 μm^2

Focal depth : ~3 μm

Red frame: ~30x40 μm^2

DATA

Neutrino-Emulsion Interactions 1< E_ν <200GeV

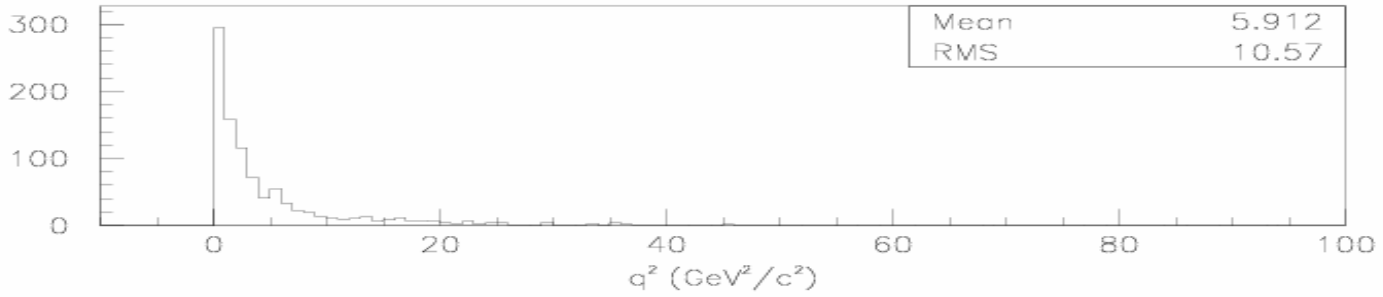
# of event scanned 987

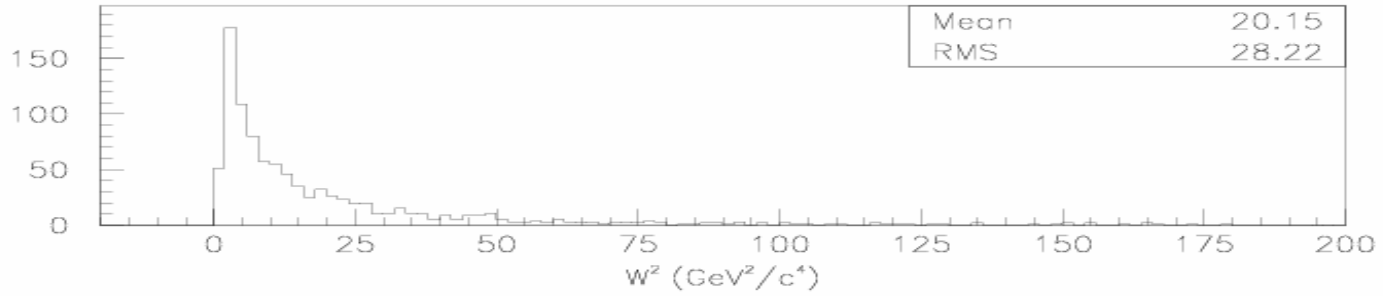
No cut on muon momentum

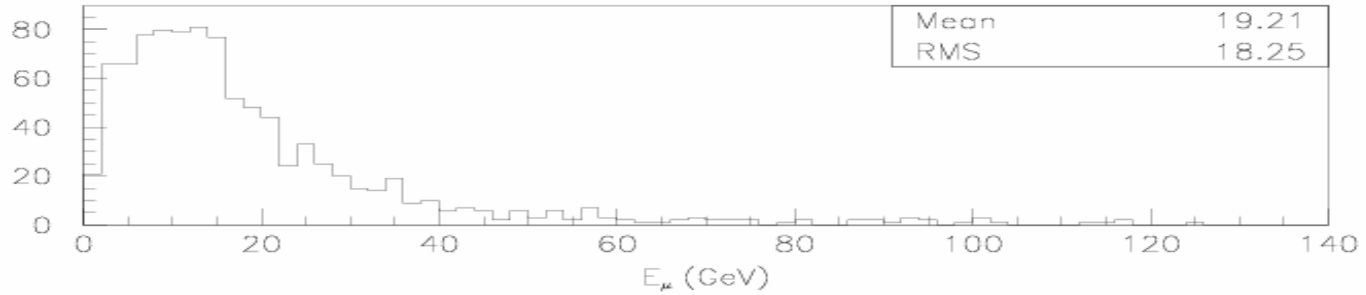
Kinematic variables reconstructed event-by-event at <E_ν> about 27 GeV

- <E_μ> =(19.2±0.5) GeV
- <Q^2> = (5.9±0.5) GeV^2/c^2
- <W^2> = (20.2±0.9) GeV^2/c^4

Sample Distribution of Kinematic Variables







Charged Tracks in Emulsion

Grain density is a function of β

- Shower particles: (Minimum Ionizing Particles)
  g_0, $\beta \geq 0.7$
- Grey Tracks: (medium Ionizing Particles)
  $1.4g_0 < g < 5g_0$
  $0.25 \leq \beta < 0.7$
- Black tracks: (Heavy Ionizing Particles)
  $g > 5g_0$, $\beta < 0.25$

Since the emulsion sheets were exposed perpendicular to the beam direction, for most of the tracks it is very difficult to count the grains, even for experienced operators.

An alternative procedure was applied

Operator Check and Manual Measurements

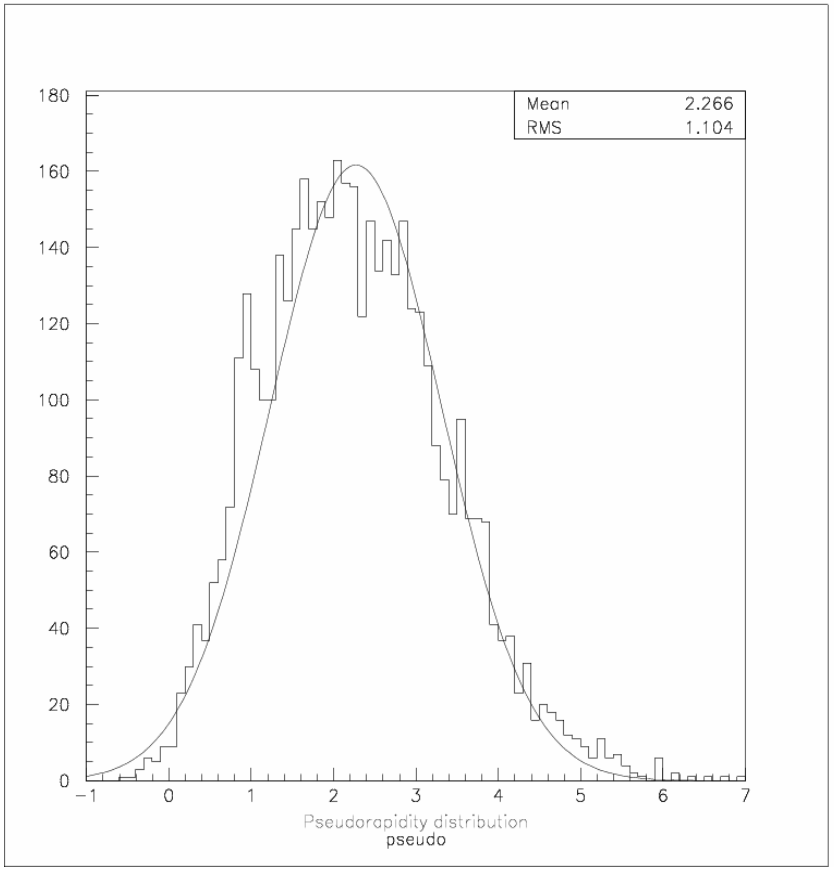
Procedure for Ionization assignment

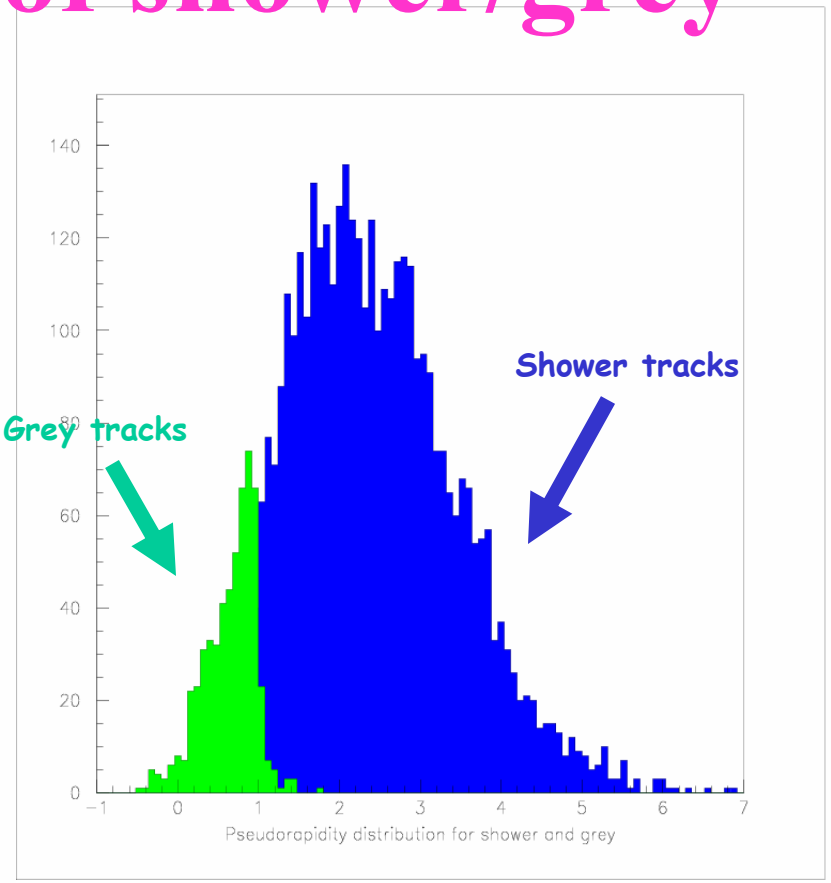
- Black tracks: continuous lines, short lengths, often stop in the plate
- Grey tracks: usually emitted at wide angles, look like "thicker" than MIP
- The others, MIP, shower tracks: mostly emitted in the forward direction
- Experimental procedure during the present manual check: Label the tracks as black, grey, showers; black ones are just counted event-by-event; for the others, the emission angle is measured.

Pseudo-rapidity

- Pseudo-rapidity $\eta = -\ln \tan(\theta/2)$
- The emission angle,θ, of the "non-black" tracks is measured
- Cut on the pseudo-rapidity variable to classify as shower/grey tracks
- **Advantage;** more effective, largely independent of the scanner's judgement, but usually in agreement with it

Classification of shower/grey

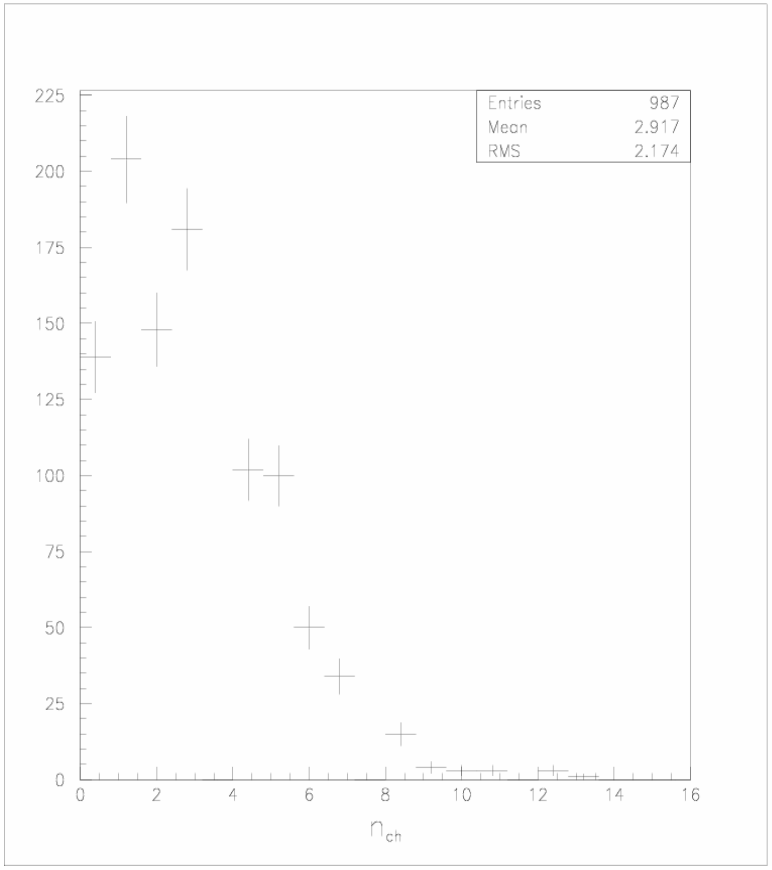


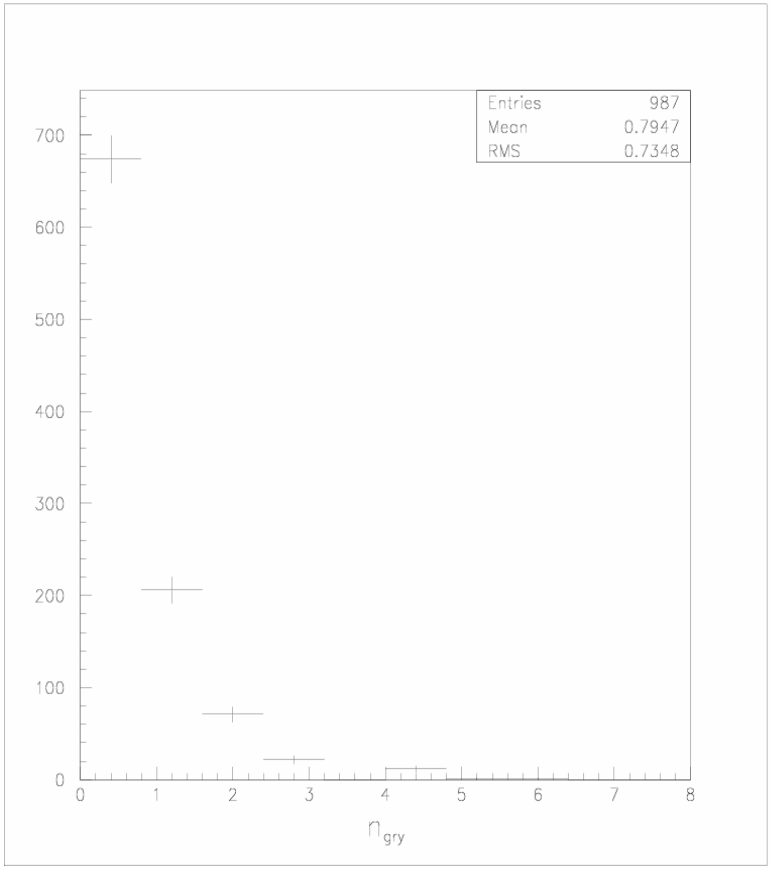


Putting cut on Pseudo-rapidity

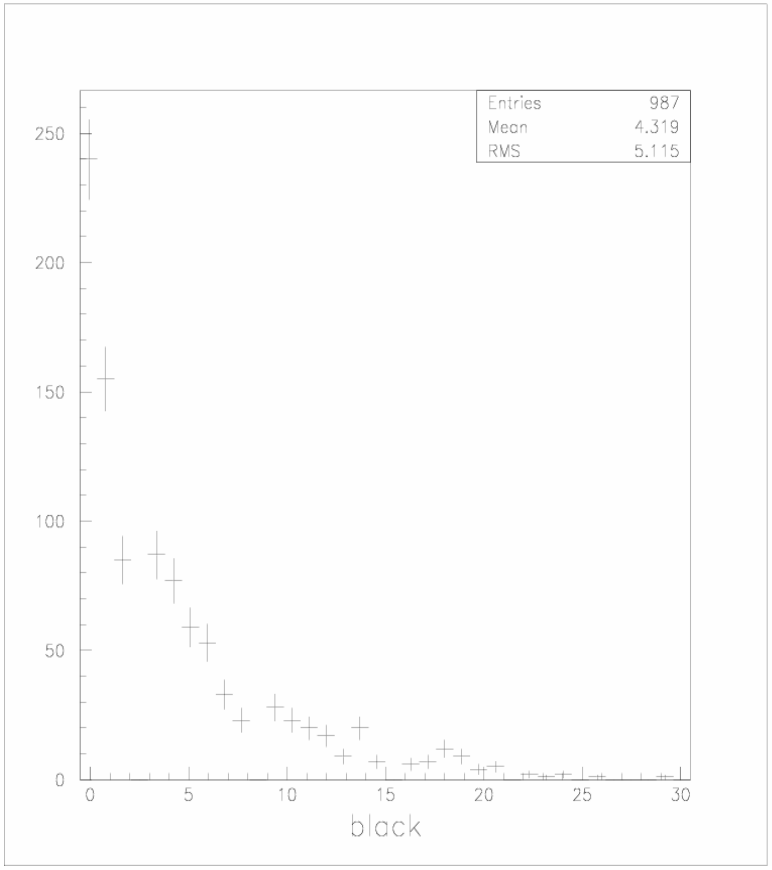
$\eta < 1$ Grey tracks ; $\eta > 1$ shower tracks

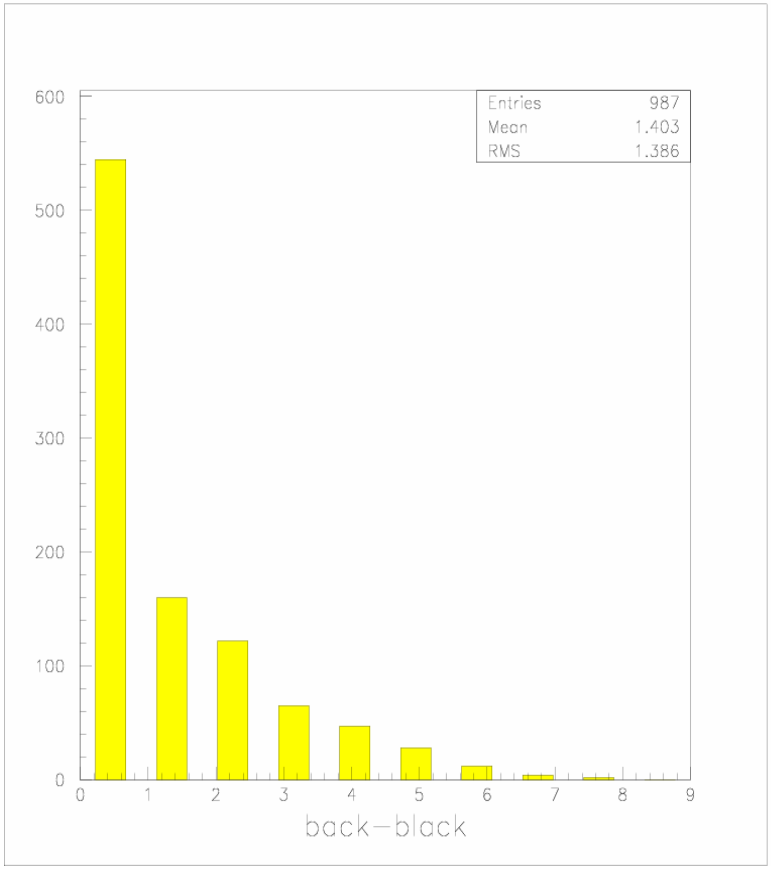
Shower & grey track multiplicity distributions



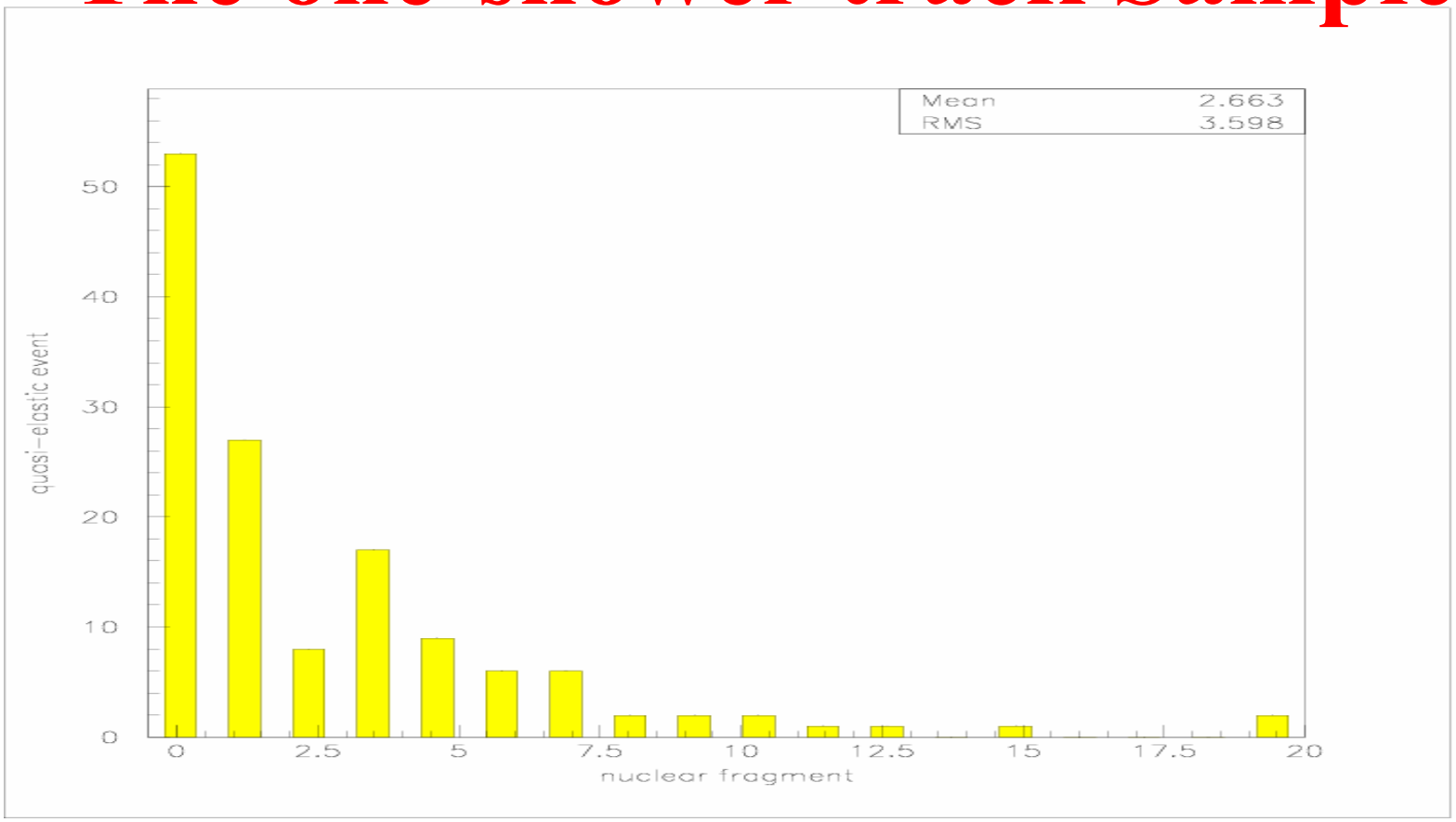


Black track distributions





The one-shower track Sample



$\nu_\mu \quad n \rightarrow \mu^- p$

According to the # of black tracks, 3 categories of ν-Nucleus interactions:"

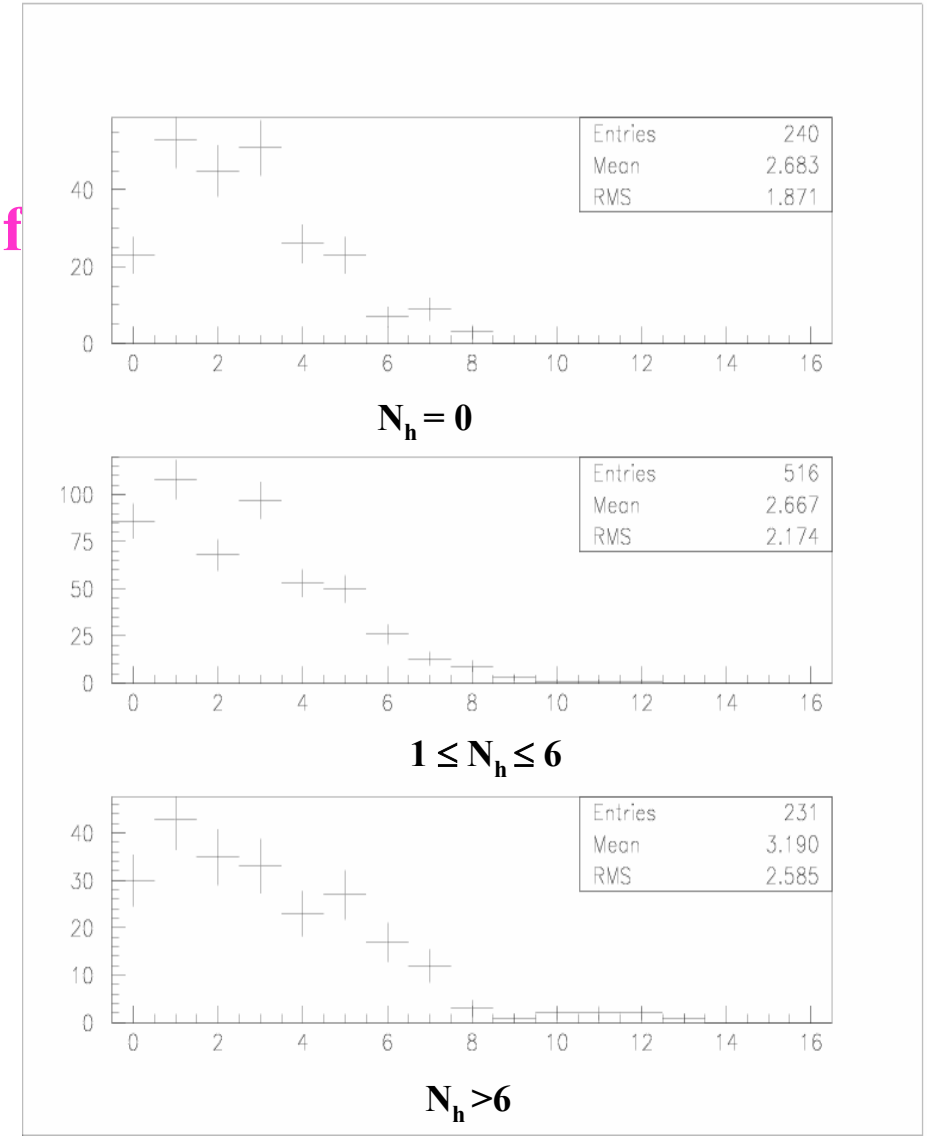
- $N_h = 0$ $1 \le N_h \le 6$ $N_h > 6$

Target nuclei in the composite of emulsion target:

- the light H
- the medium C,N,O
- the heavy Br, Ag

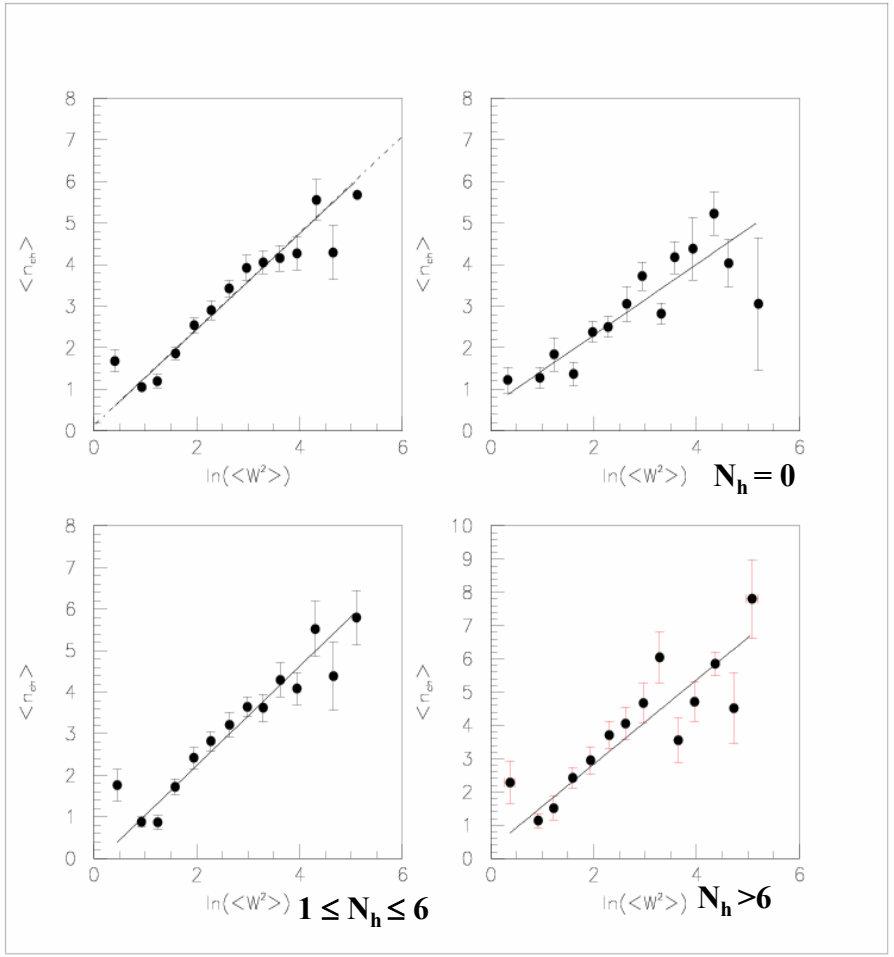
*** only if Nh = 0 the hit nucleus could be H;**

*** if Nh > 8, the hit nucleus is 'heavy'**

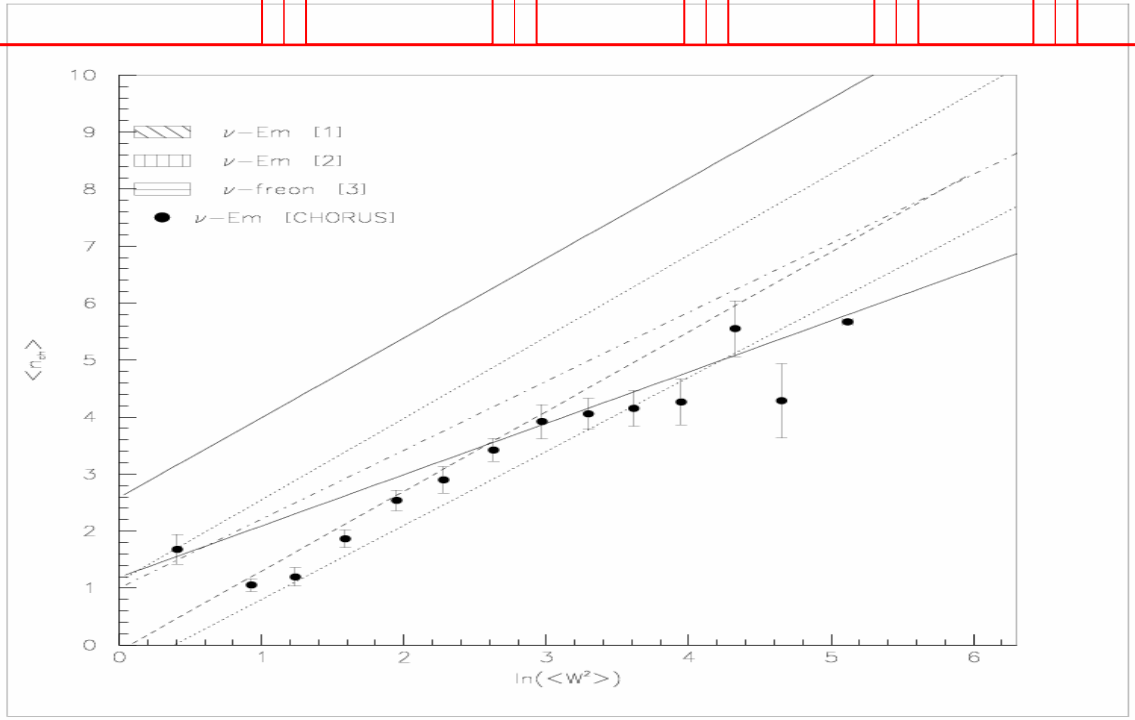


Multiplicity as a Function of W^2

- $\langle n_{ch} \rangle = 2.9 \pm 0.07$ where $n_{ch} = n_s - 1$ (minus muon)
- To compare with other experiment using $\langle n_{ch} \rangle = A + B \ln(\langle W^2 \rangle)$
- Fitted for W^2 between 1GeV^2 and 160GeV^2



Experiment	E_ν(GeV)	W^2	A	ΔA	B	ΔB
ν-Em (CHORUS)	34	1÷200	0.1	0.1	1.15	0.05
ν-Em[1]	50	-	1.9	0.7	1.2	0.2
ν-Em[2]	8.7	1÷20	1.07	0.05	1.3	0.1
ν-freon	6	1÷40	-0.34	0.11	1.47	0.06
ν-H (CHORUS)	34	1÷200	0.5	0.2	0.85	0.08
ν-CNO (CHORUS)	34	1÷200	-0.1	0.1	1.19	0.06
ν-AgBr (CHORUS)	34	1÷200	0.3	0.2	1.27	0.09



Dispersion Distributions

- Dispersion Distribution

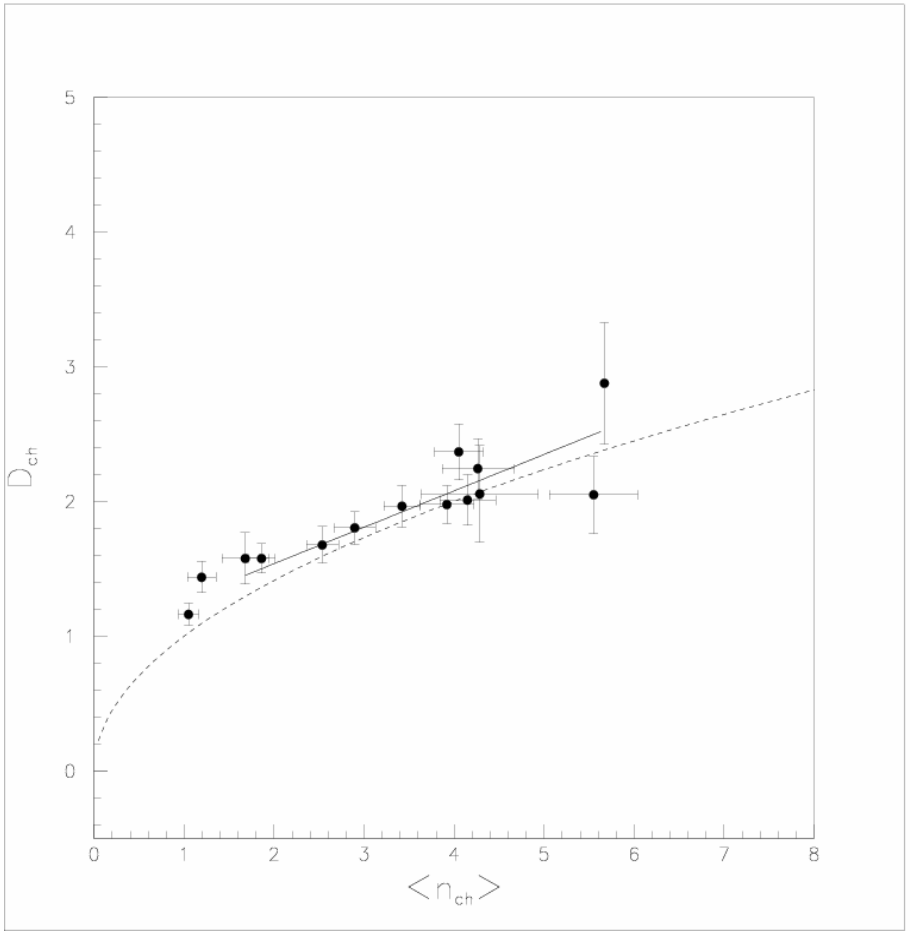
$$D_{ch} \equiv \sqrt{\langle n^2{}_{ch} \rangle - \langle n_{ch} \rangle^2}$$

- For independent particle production

$$D_{ch} \equiv \sqrt{\langle n_{ch} \rangle}$$

- For charged particle production in hadronic interactions

$$D_{ch} = A + B\langle n_{ch} \rangle$$



Dipersion for different ν-Nucleus Interactions

- The fit parameter:

For ν-Em int.

- A=0.99±0.08; B=0.27±0.03

For N_h=0

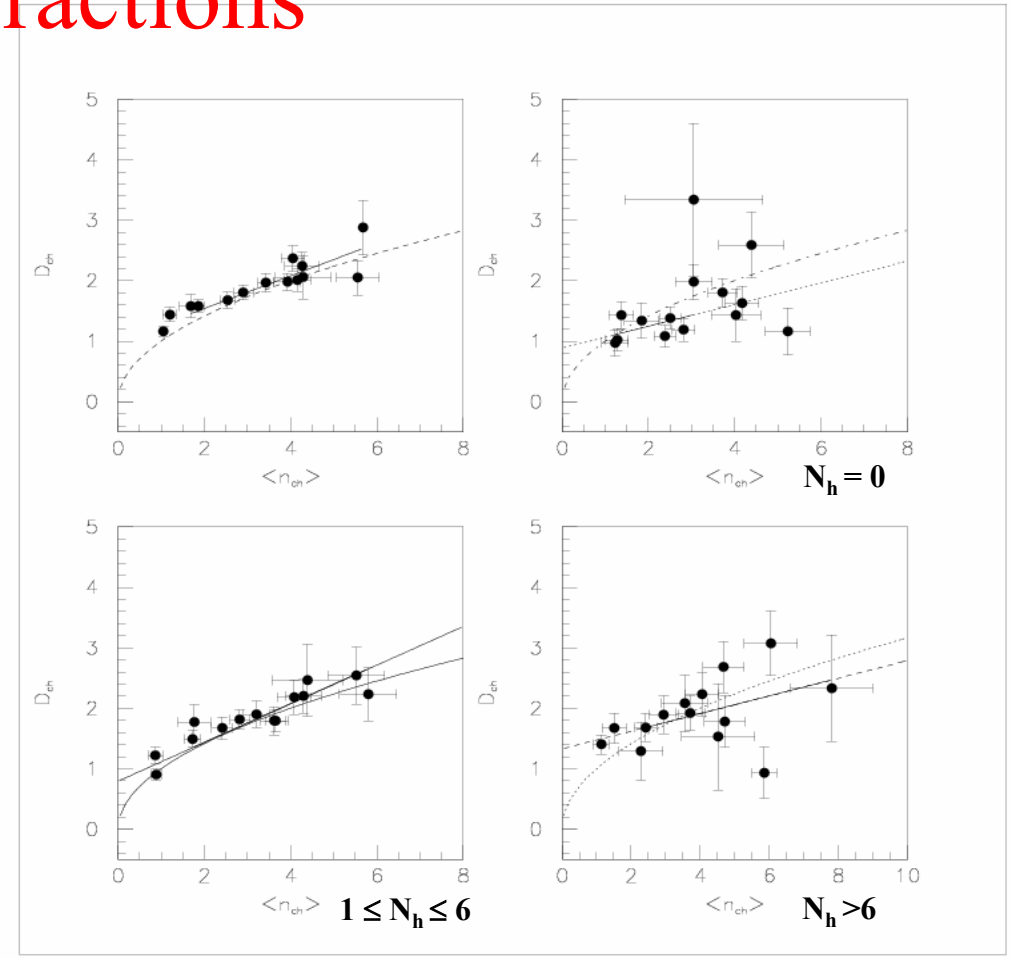
- A=0.8±0.1; B=0.18±0.06

For 1≤N_h≤6

- A=0.79±0.09; B=0.32±0.03

For N_h>6

- A=1.3±0.2; B=0.14±0.05



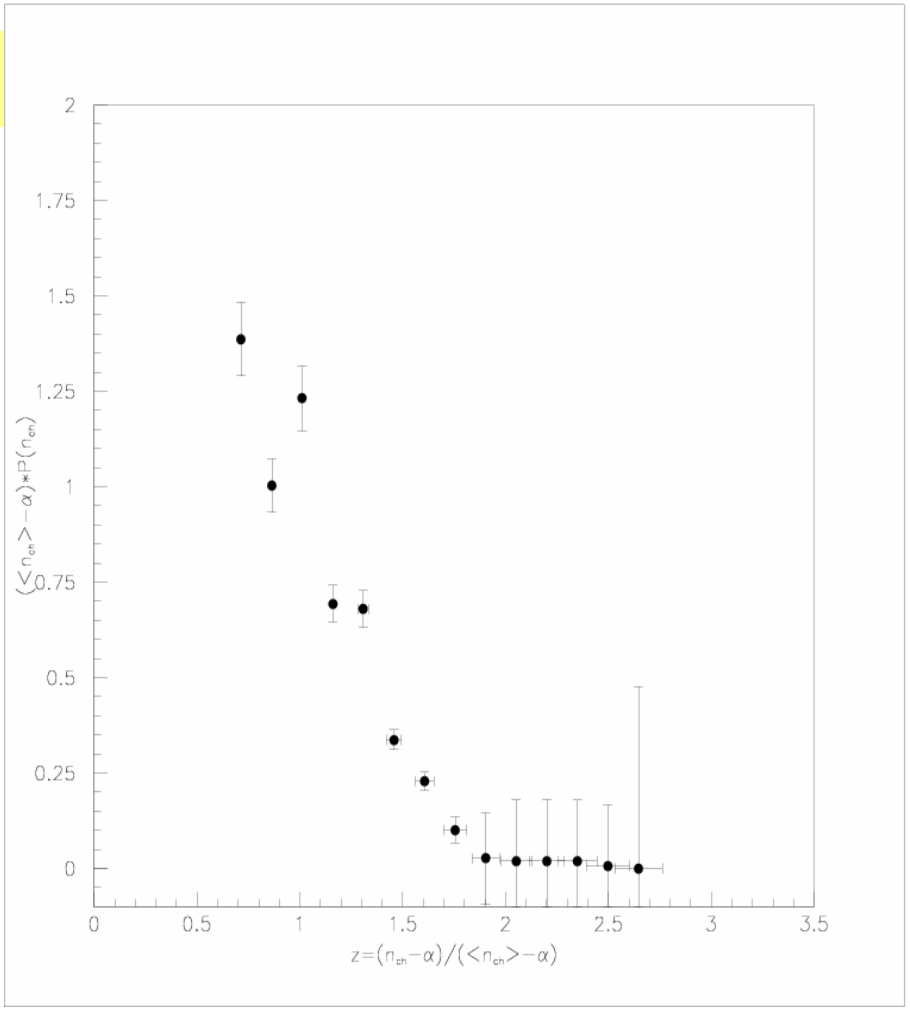
KNO-Scaling

- KNO function

$$K = (\langle n_{ch} \rangle - \alpha).P(n_{ch}) = \Psi(z')$$

- where $z = \dfrac{n_{ch}}{\langle n_{ch} \rangle}$
- Since $A \neq 0$ define $\alpha = -\langle n_0 \rangle$
- Define new z' as $z' = \dfrac{n_{ch} - \alpha}{\langle n_{ch} - \alpha \rangle}$
- KNO Scaling law becomes

$$K = (\langle n_{ch} \rangle - \alpha).P(n_{ch}) = \Psi(z')$$



Ref: Nucl. Phys. **B40**,317 (1972)

CONCLUSIONS

- Pseudo-rapidity can be used to classify shower&grey tracks
- The multiplicity of shower tracks can be expressed as a linear function of $\ln W^2$
- The dispersion D_{ch} can be expressed as a linear function of the multiplicity
- The emulsion data look like consistent with KNO scaling