RolandFest

In honour of Roland Windmolders, one of the longest serving members of the collaborations studying muon physics at CERN.

T.Sloan Lancaster University 6 Feb 2013

Muon Physics at CERN- Its 40 Year History

Muon experiments at CERN SPS proposed 1972
EMC 1974 to 1986
NMC 1986 to 1990
SMC 1990 to mid-1990s
COMPASS mid 90s - present

Roland has been working here since ~1980 i.e more than 30 years.

He has been an important member of each of these collaborations which studied both spin-dependent and spin-independent muon physics.

I think he worked on the Mirabelle bubble chamber before that (I remember his cat Mirabelle – she used to like lettuce)

European Muon Collaboration (EMC)

- Motivated by discovery of large DIS cross section at SLAC (1969) (Nobel Prize 1990)
- 1972 Gabathuler, Clifft – Brasse,Gayler propose a muon beam at the then new CERN SPS.
- European Muon Collaboration (EMC) born from these two groups – proposal written 1974 - signed by 48 people.
- 1974-1978 Beam and apparatus built.
- 1978 – 1982 NA2 experiment. (Collaboration of ~100 physicists).

NA2 - The EMC Forward Spectrometer

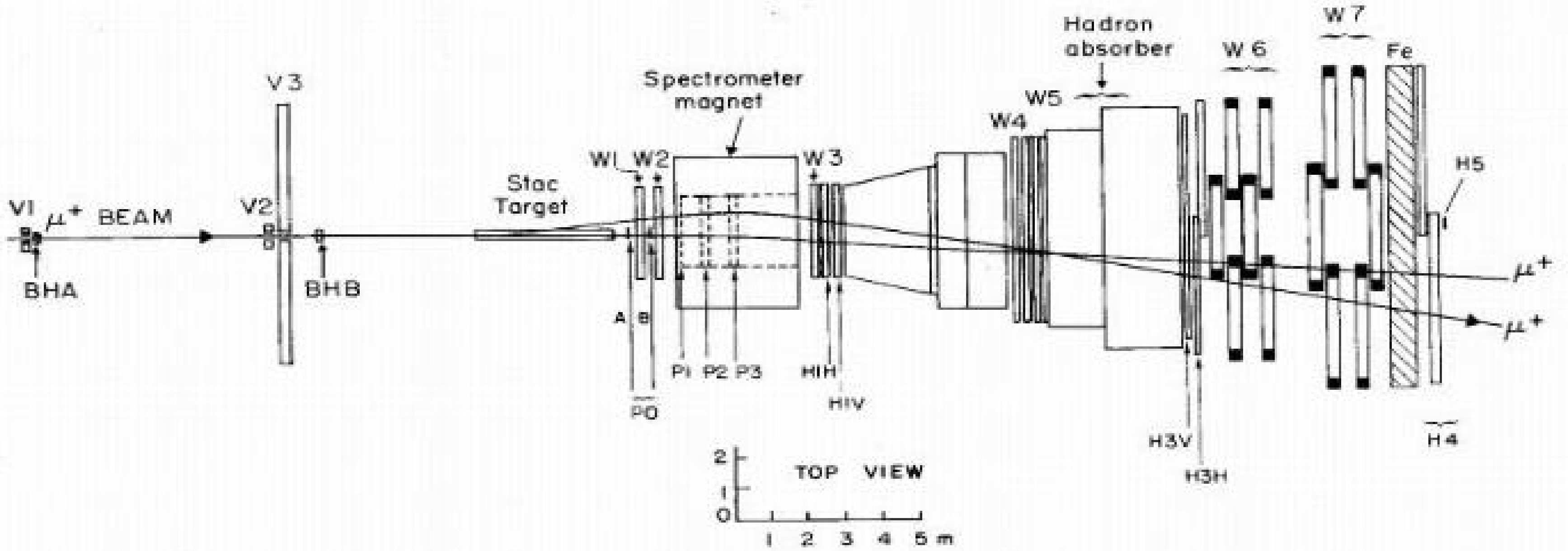
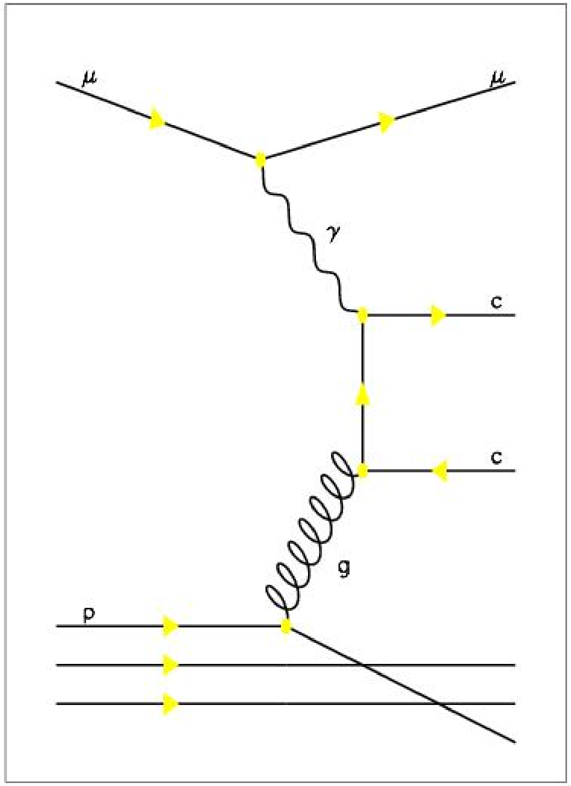


FIG. 1

Areas of Work

- Inclusive deep inelastic scattering – measurement of structure functions (led to discovery of EMC effect).
- Final state hadrons (– Lund Model).
- Multimuons – (charm production was mediated by photon gluon fusion).
- Should have measured spin structure functions but polarised target was not ready.

The Multimuon Group



- Discover that charm production mediated by photo-gluon fusion.
- Semileptonic decay of charmed quark gives 2 or 3 muon events.
- Ratio of number of 3 mu to 2 mu events should be branching ratio.

Dimuons

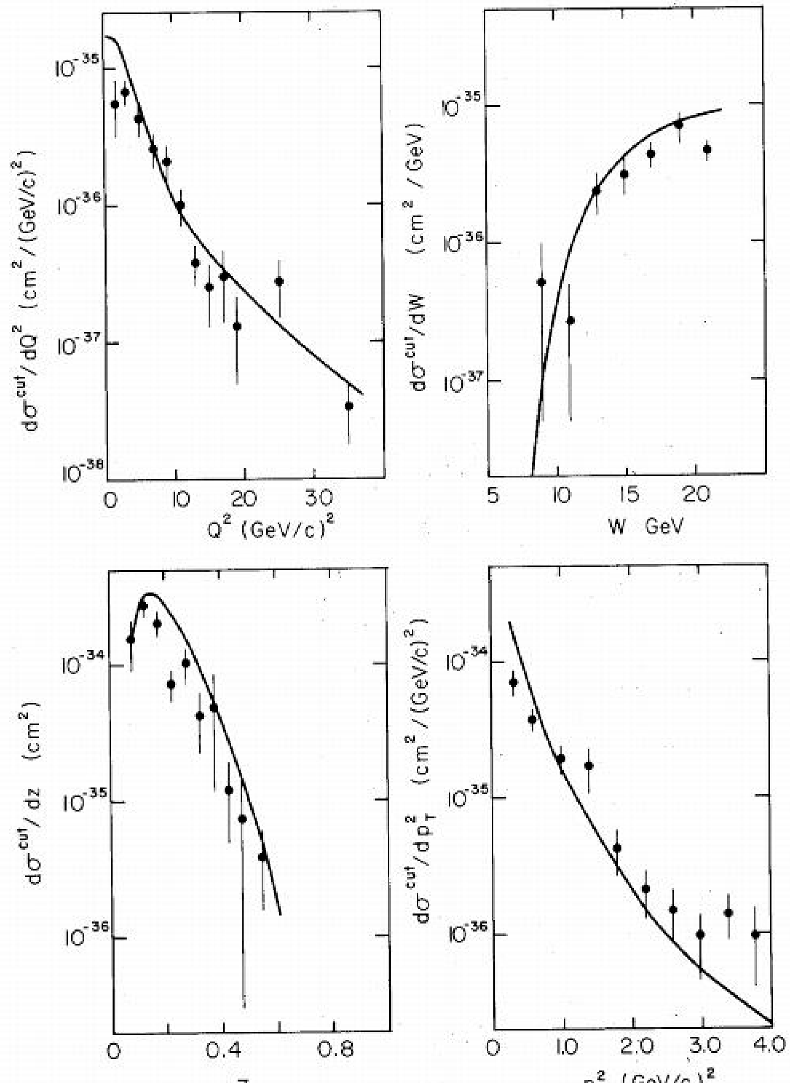
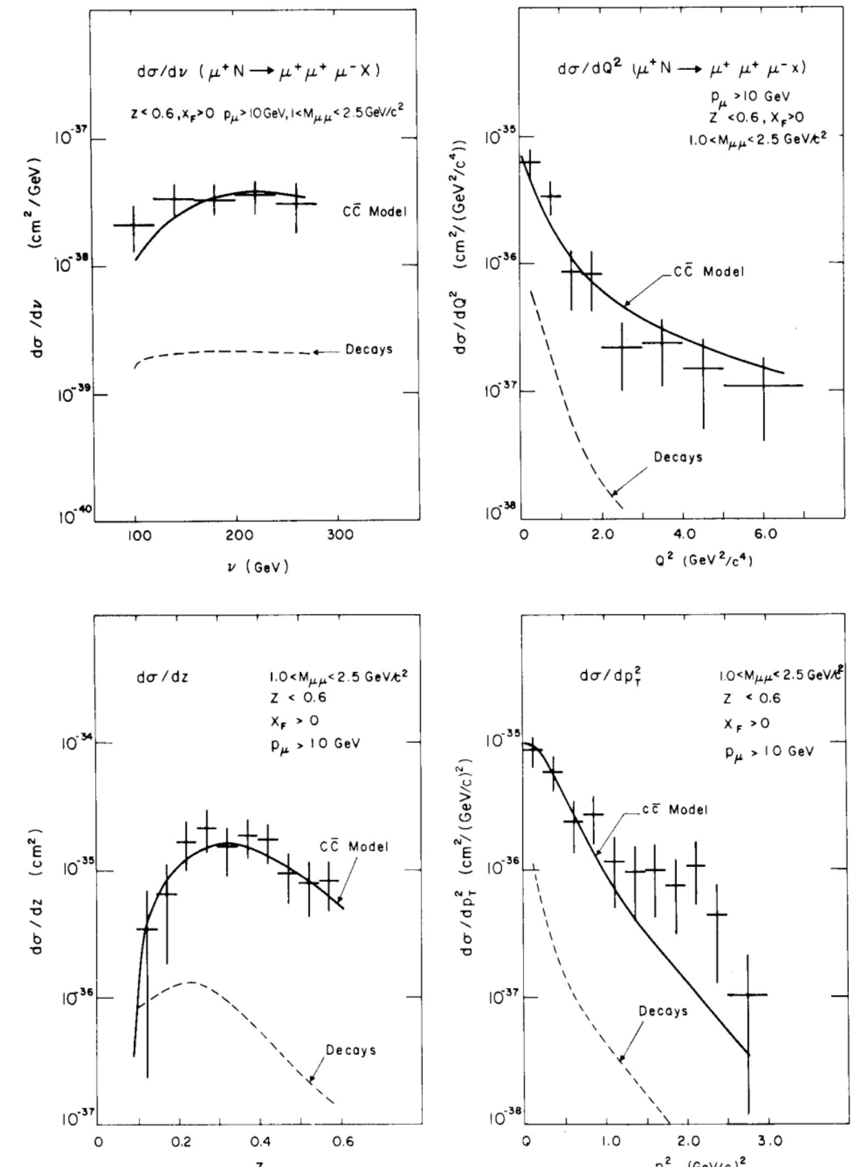


FIG. 4

Trimuons



The EMC Effect

Quark structure of bound nucleons different from free nucleons.

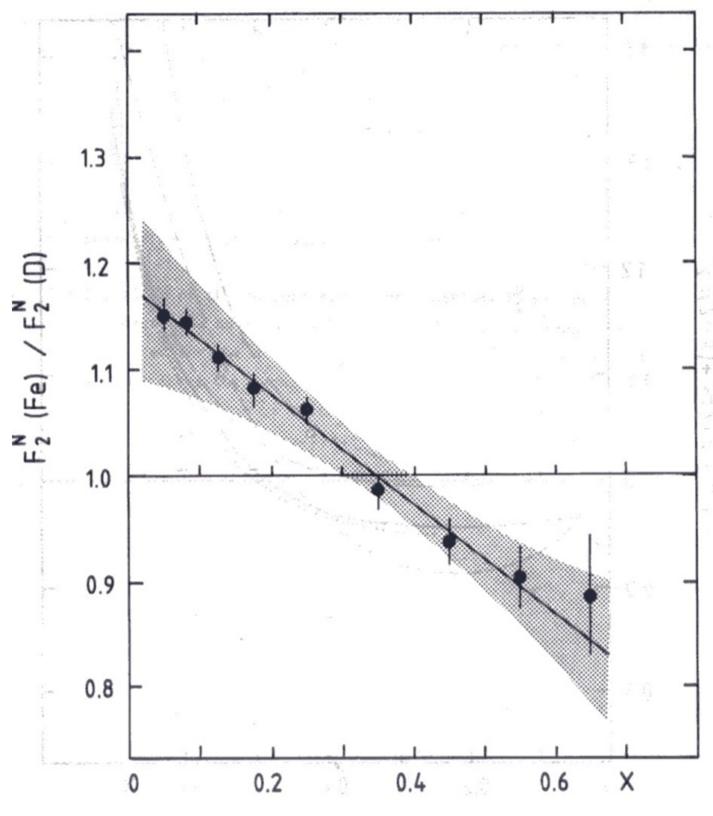


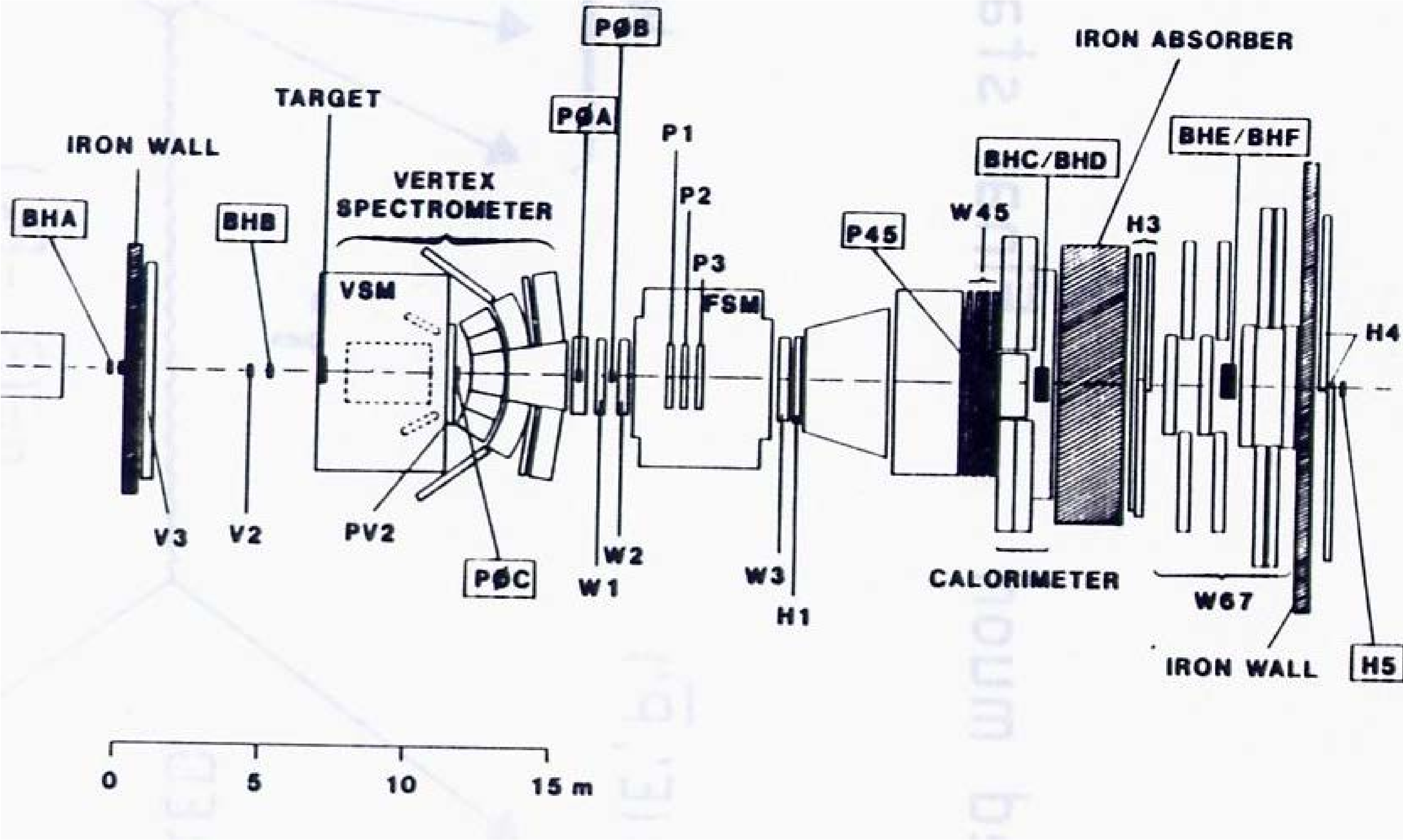
Fig. 2

Further study of final state hadrons – NA9 experiment

Several new institutions joined EMC for this phase including Univ. of Mons (and Roland) ~ data taking 1982-1985

Collaboration grew to ~150 physicists

Picture of NA9/NA28 Apparatus



NA9 Identified particle spectra.

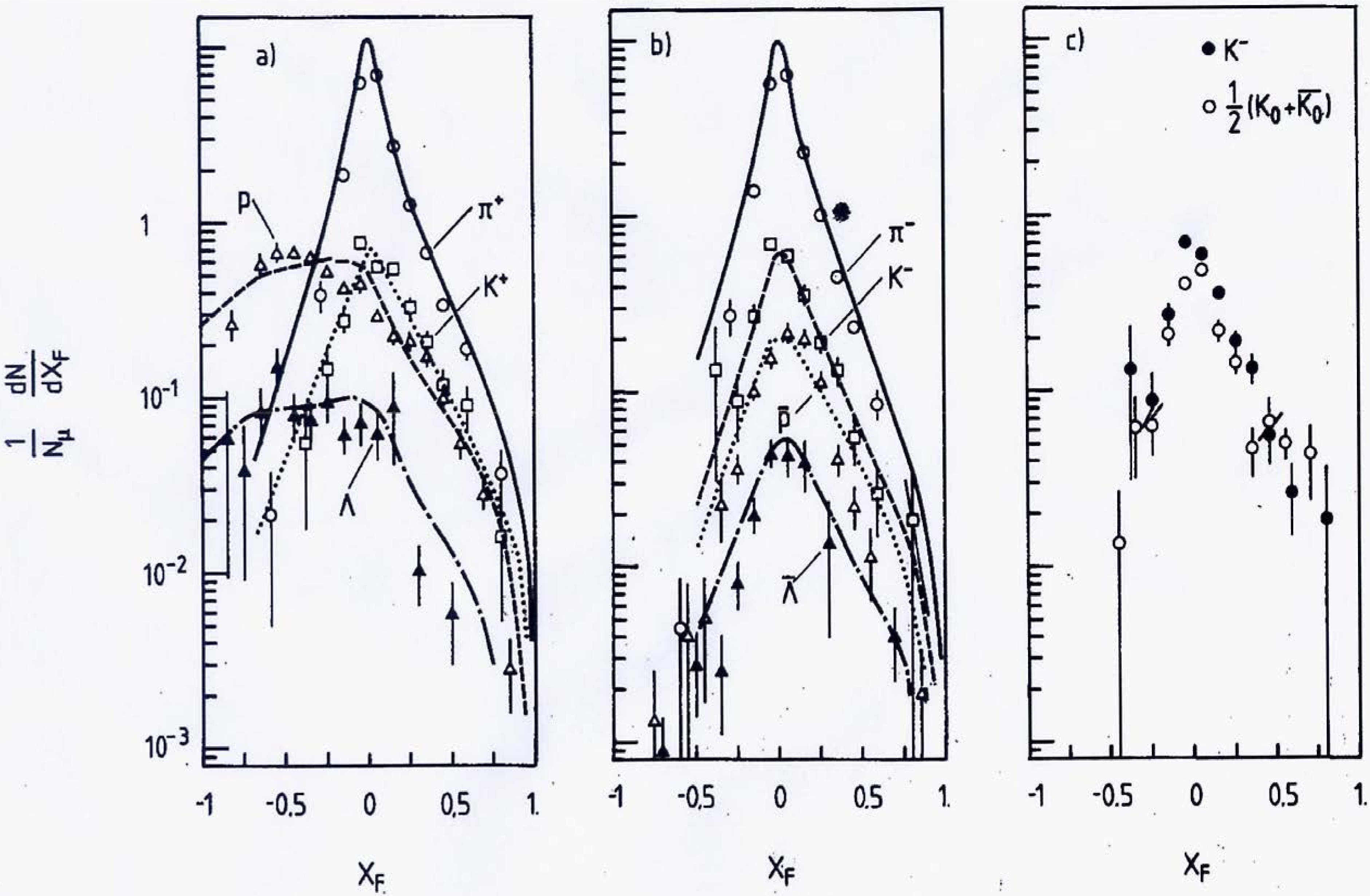
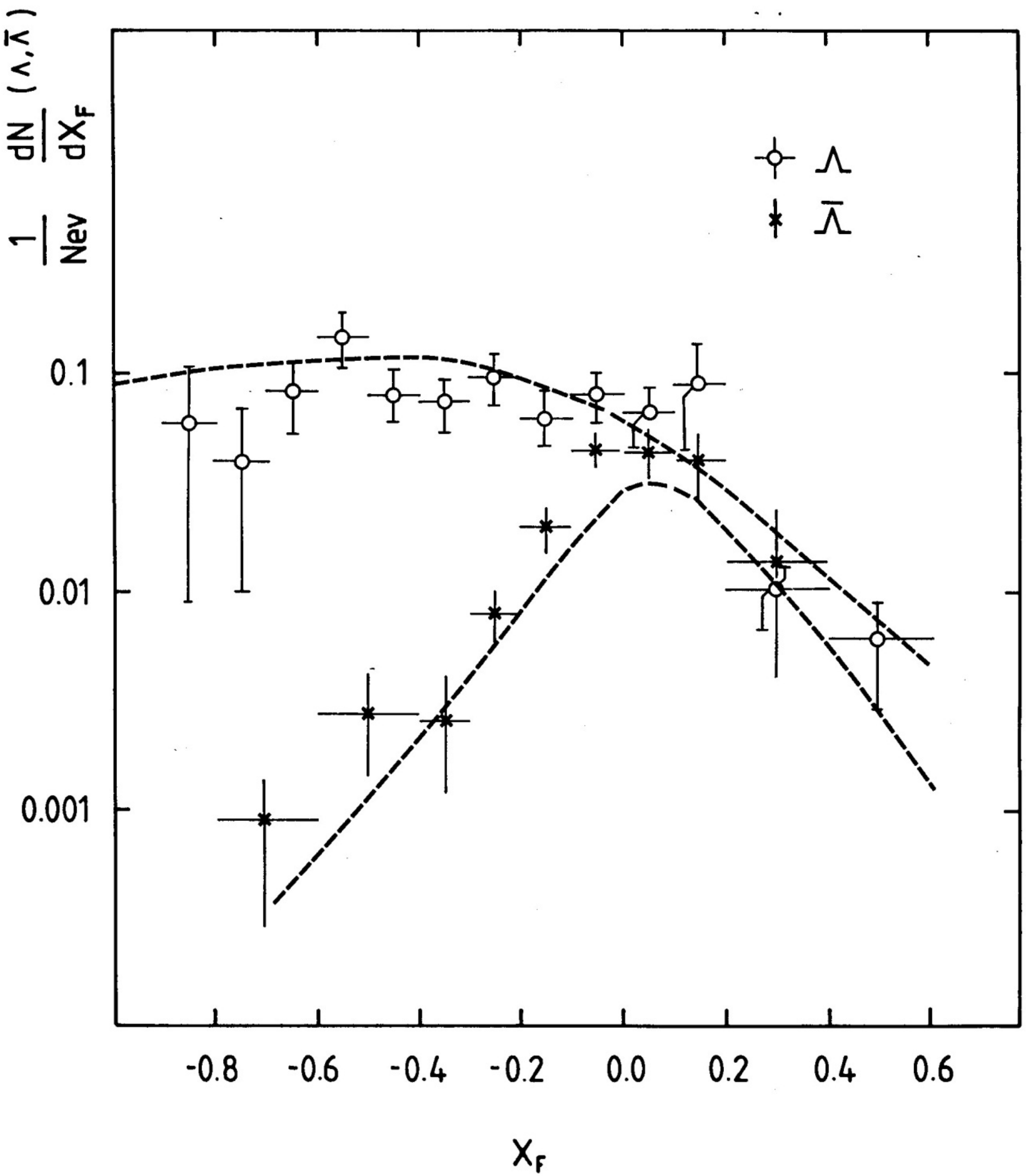
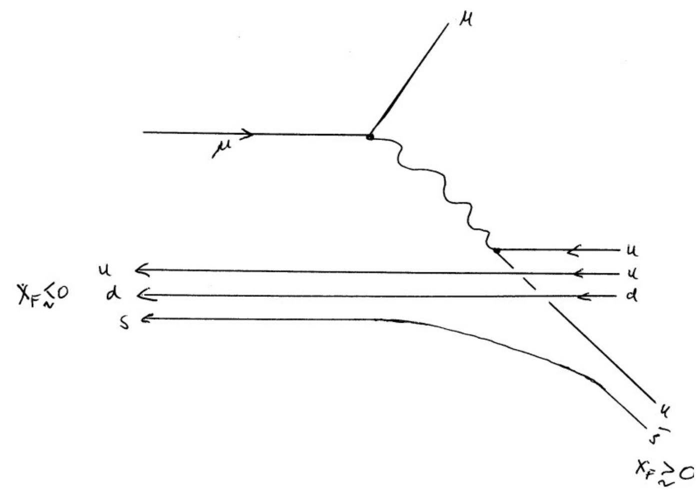


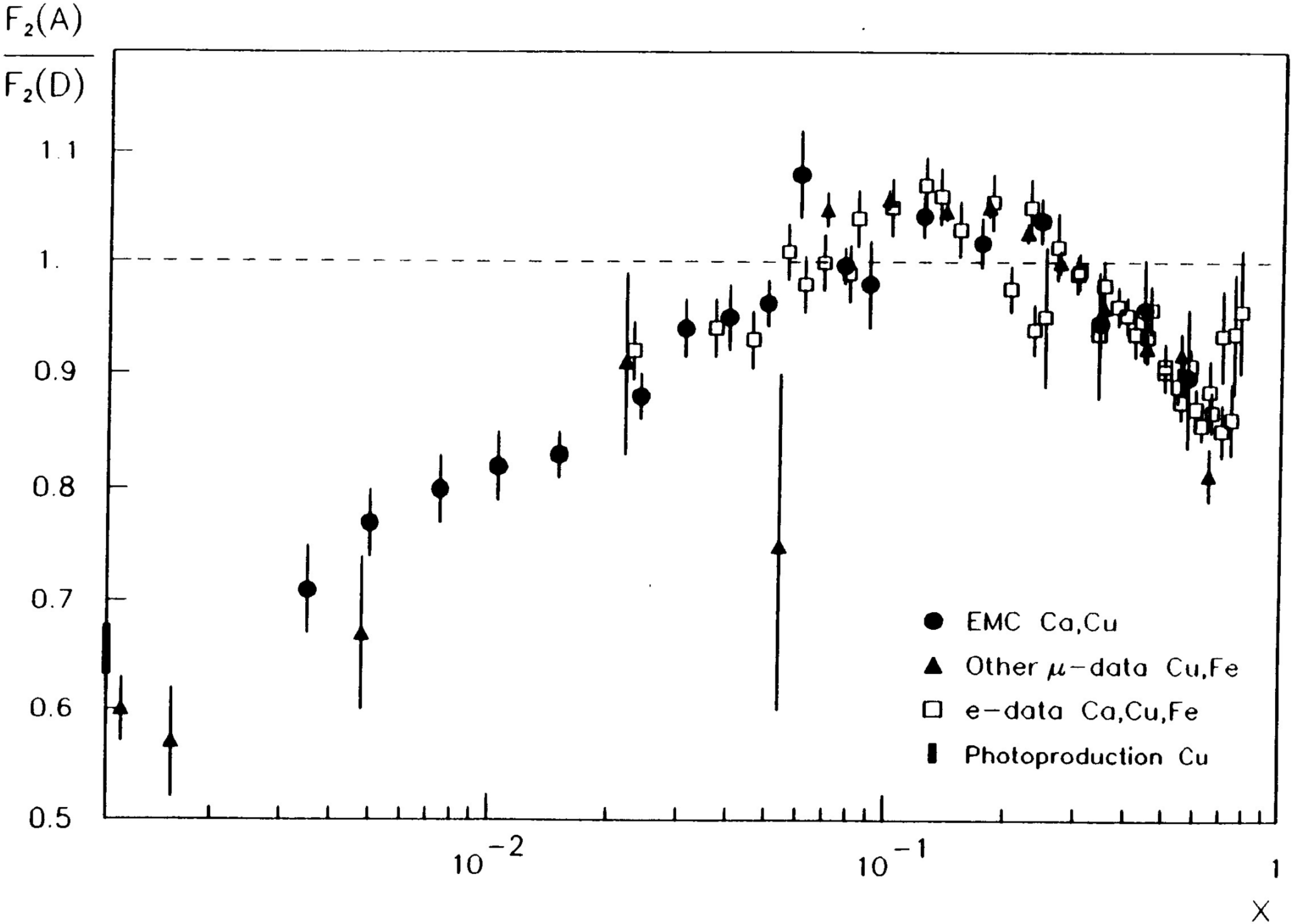
Fig. 4a)



Discover target and projectile fragmentation – predicted by Lund model (became PYTHIA)



EMC effect and shadowing (NA28)



1983 - return to forward spectrometer + polarised target.

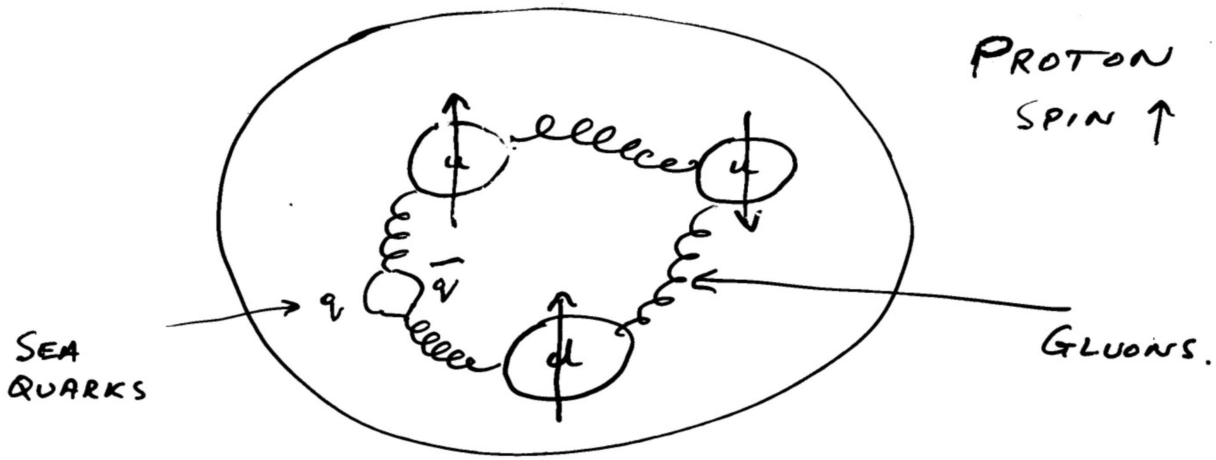
Many members of the collaboration wanted to continue running NA9 and NA28 and abandon (postpone) polarised target measurements.

Argument was made that we understand the proton spin structure via the quark parton model and measuring the spin structure functions would not be fruitful.

One had to have sympathy with that argument at the time since baryon magnetic moments were well predicted by the model.

BARYON MAGNETIC MOMENTS

BARYON	WAVE FUNCTION	QUARK MODEL MAG. MOMENT	EXPERIMENT (μ_N)
Ω^-	$\uparrow s \uparrow s \uparrow s$	$\mu_{\Omega^-} = 3\mu_s = -2.1\mu_N$	$-2.02 \pm .05$
Λ^0	$\uparrow s \uparrow u \downarrow d$	$\mu_\Lambda = \mu_s = -0.7\mu_N$	$-0.613 \pm .005$
Ξ^0	$\uparrow s \uparrow s \downarrow u$, $\uparrow s \downarrow s u \uparrow$, $s\downarrow s\uparrow u\uparrow$ ..... KNOWN WEIGHTS	$\mu_{\Xi^0} = \frac{4\mu_s - \mu_u}{3} = -1.6\mu_N$	$-1.25 \pm .014$
Ξ^-	$\uparrow s \uparrow s \downarrow d$	$\mu_{\Xi^-} = \frac{4\mu_s - \mu_d}{3} = -0.6\mu_N$	$-0.651 \pm .003$
Σ^+	$\uparrow s \uparrow u \downarrow u$	$\mu_{\Sigma^+} = \frac{4\mu_u - \mu_s}{3} = +2.9\mu_N$	$+2.458 \pm .010$
Σ^-	$\uparrow s \uparrow d \downarrow d$	$\mu_{\Sigma^-} = \frac{4\mu_d - \mu_s}{3} = -1.1\mu_N$	$-1.16 \pm .025$
p	$\uparrow u \downarrow u \uparrow d$	$\mu_p = \frac{4\mu_u - \mu_d}{3} = 3.0\mu_N$	2.793
n	$\uparrow d \downarrow d \uparrow u$ ...	$\mu_n = \frac{4\mu_d - \mu_u}{3} = -2.0\mu_N$	-1.913



Quark parton model applied to spin asymmetry.

SUMMING OVER ALL DISPOSITIONS:-

$$|p^{\uparrow}\rangle = \frac{1}{\sqrt{18}}\Big\{2\,|u^{\uparrow}d^{\downarrow}u^{\uparrow}\rangle + 2\,|u^{\uparrow}u^{\uparrow}d^{\downarrow}\rangle + 2\,|d^{\downarrow}u^{\uparrow}u^{\uparrow}\rangle$$
$$- |u^{\uparrow}u^{\downarrow}d^{\uparrow}\rangle - |u^{\uparrow}d^{\uparrow}u^{\downarrow}\rangle - |u^{\downarrow}d^{\uparrow}u^{\uparrow}\rangle$$
$$- |d^{\uparrow}u^{\downarrow}u^{\uparrow}\rangle - |d^{\uparrow}u^{\uparrow}u^{\downarrow}\rangle - |u^{\downarrow}u^{\uparrow}d^{\uparrow}\rangle\Big\}$$

$$A = \frac{\sigma^{\uparrow} - \sigma^{\downarrow}}{\sigma^{\uparrow} + \sigma^{\downarrow}} = \frac{\sum e_i^2\,(q_i^{\uparrow} - q_i^{\downarrow})}{\sum e_i^2\,(q_i^{\uparrow} + q_i^{\downarrow})}$$

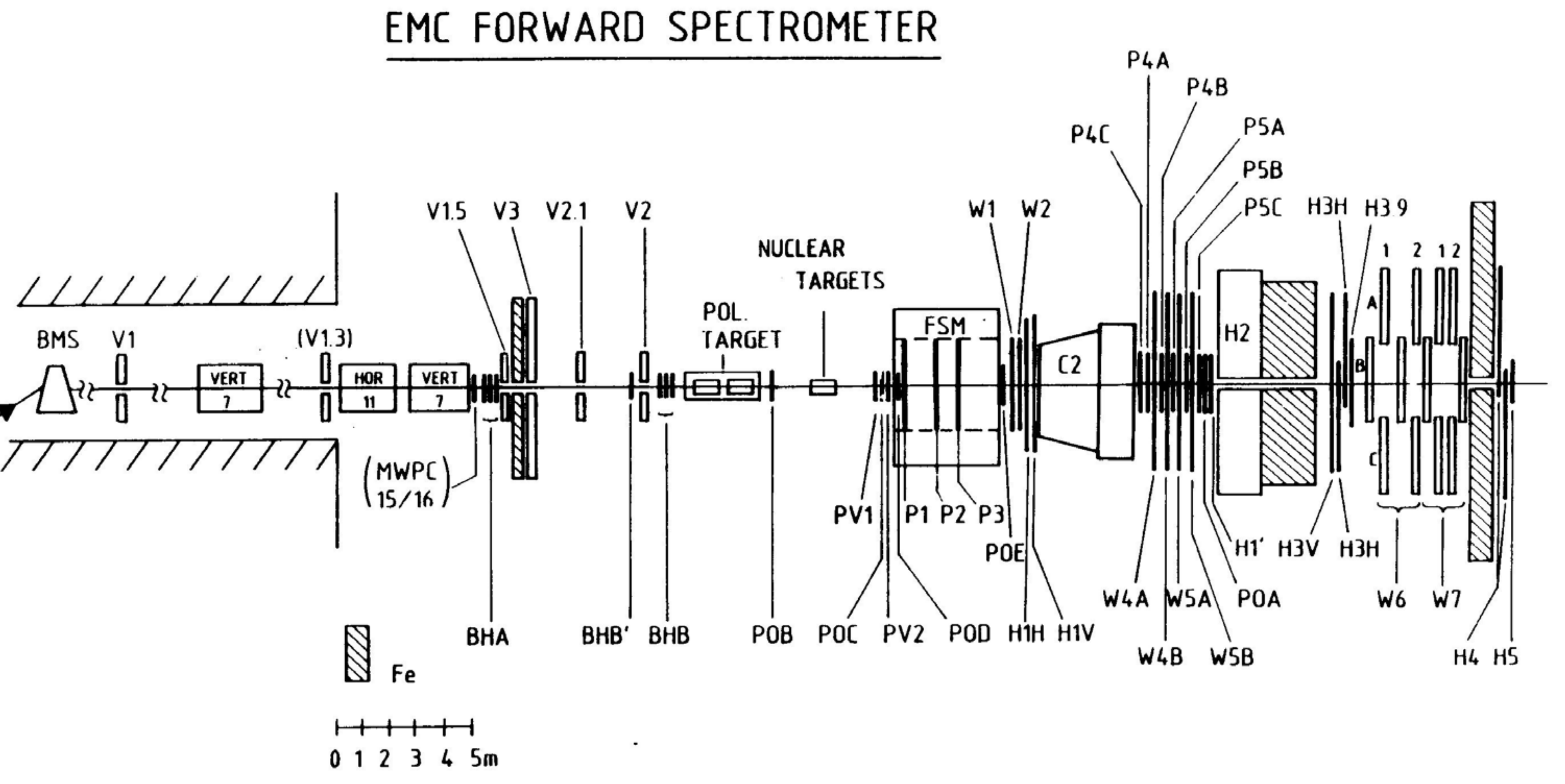
$$= \frac{5}{9}.$$

MODELS MODIFIED:-

1) DILUTION BY SEA AT SMALL x

2) $u(x) \to 1$ AT LARGE x

EMC Final Phase – polarised structure functions 1984

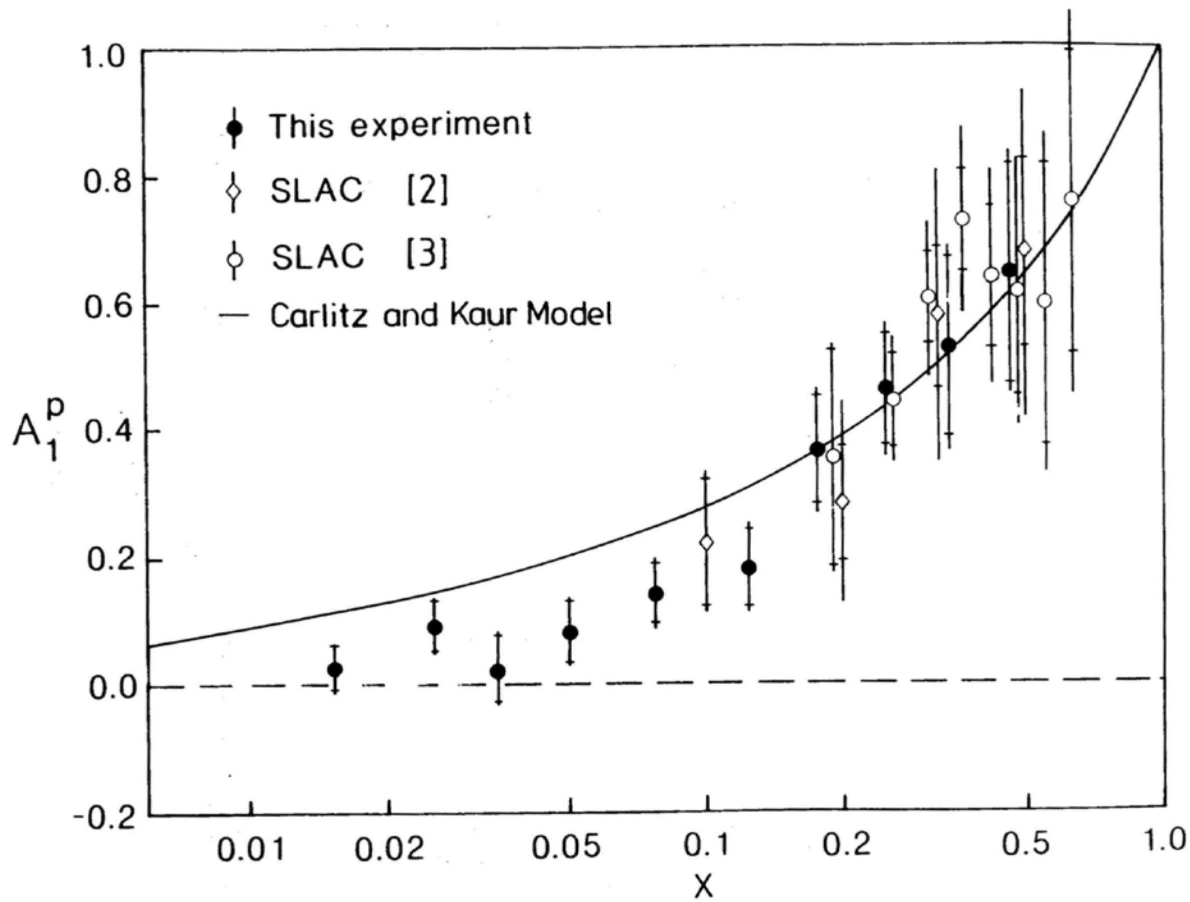


Polarised Structure Functions

Data disagreed with Quark Parton model

Result implied that quarks only carried a fraction of the proton spin.

Spin crisis.



FRACTION OF NUCLEON'S SPIN CARRIED BY QUARKS:-

$$\int_0^1 g_1^p dx = \Gamma_1^p = +\frac{g_A}{12} f(\alpha_s) + a_8 \frac{f(\alpha_s)}{36} + \Delta\Sigma \frac{h(\alpha_s)}{9}$$

$$\int_0^1 g_1^n dx = \Gamma_1^n = -\frac{g_A}{12} f(\alpha_s) + a_8 \frac{f(\alpha_s)}{36} + \Delta\Sigma \frac{h(\alpha_s)}{9}$$

$f(\alpha_s)$; $h(\alpha_s)$ – QCD Radiative correction factors ~ 1

SU3:-

$a_8 = \frac{1}{\sqrt{3}}(3F - D)$; $g_A = F + D = 1.26$ (= G_V/G_A FROM n β DECAY)

(F, D Symmetric, antisymmetric SU(3) couplings from hyperon decay, $F = 0.48 \pm 01$, $D = 0.76 \pm 01$)

In QPM

$\Delta\Sigma = \Delta u + \Delta\bar{u} + \Delta d + \Delta\bar{d} + \Delta s + \Delta\bar{s}$

= Total fraction of proton spin carried by quarks

$$a_8 = \frac{1}{\sqrt{3}}\{\Delta u + \Delta\bar{u} + \Delta d + \Delta\bar{d} - 2(\Delta s + \Delta\bar{s})\}$$

$$g_A = \Delta u + \Delta\bar{u} - \Delta d - \Delta\bar{d}$$

- use Γ_1^p, Γ_1^n to obtain $\Delta\Sigma$; then g_A and a_8 to solve for Δu, Δd, Δs.
- previously Ellis - Jaffe sum rule obtained by assuming $\Delta s = 0$ to get predictions for Γ_1^p, Γ_1^n
- the modern data shows that the Ellis - Jaffe sum rule is violated, so the strange sea is polarised.

EMC MEASURED $\int_0^1 g_1^p dx = 0.126 \pm .010 \pm .015$

ie $\Delta\Sigma = 0.12 \pm .09 \pm .14$.

i.e. ~12% OF SPIN OF PROTON CARRIED BY QUARKS

The spin crisis

First explanations of spin deficit.

2) Jaffe, Efremov & Teryaev

Altarelli & Ross.

- Adler, Bell, Jackiw triangle anomaly induces a QCD Radiative correction to

$$\Delta\Sigma \to \Delta\Sigma - \alpha_s(Q^2)\Delta g(Q^2)$$

- ie There is some polarization of the gluons.

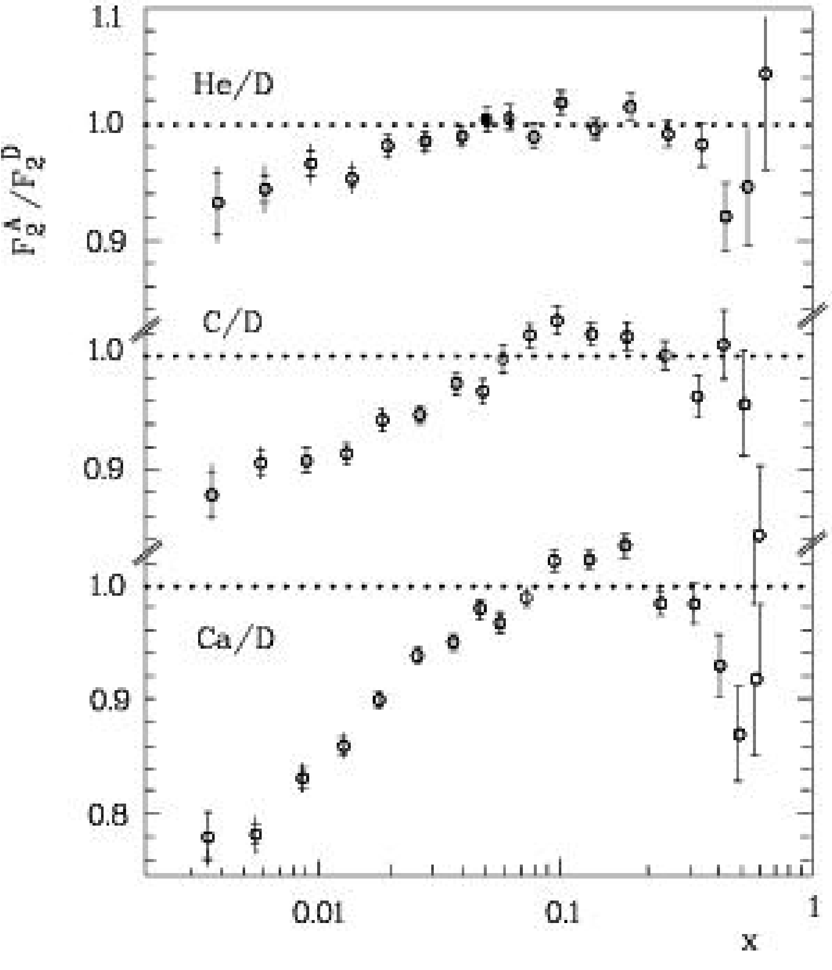
- "Nice" correction which is finite at all Q^2. As Q^2 approaches 0 Δg approaches 0, so no effect on the calculation of *p*,*n* magnetic moments.

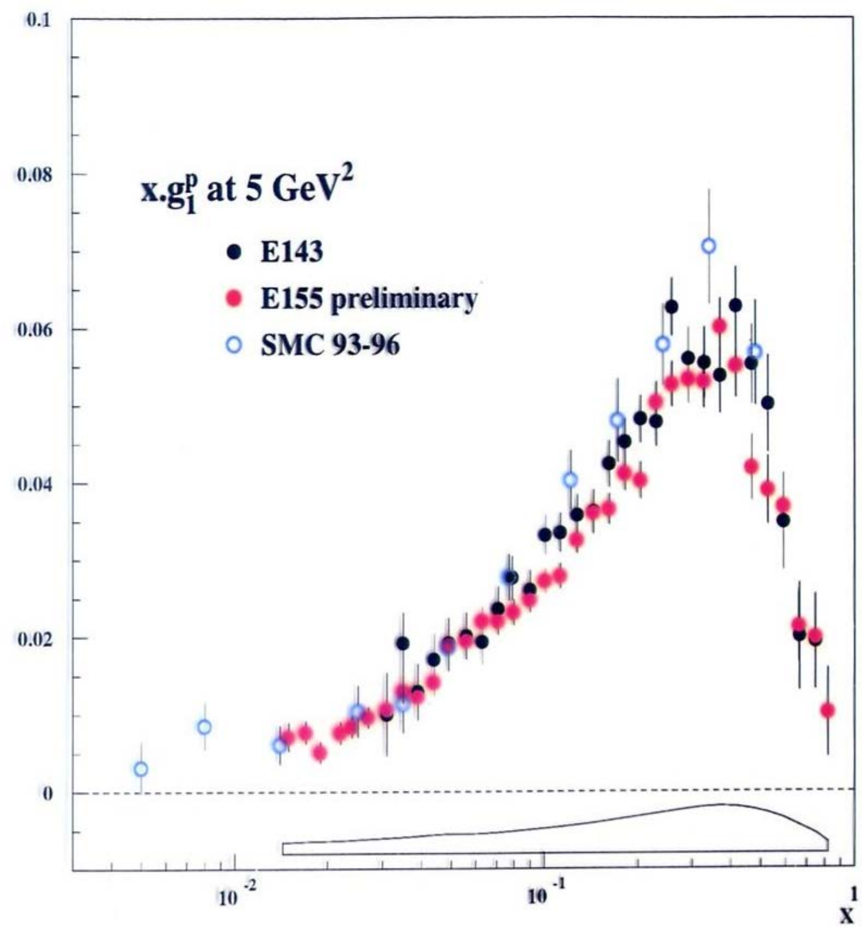
3) Brodsky, Ellis, Karliner

- Proton is a skyrmion.

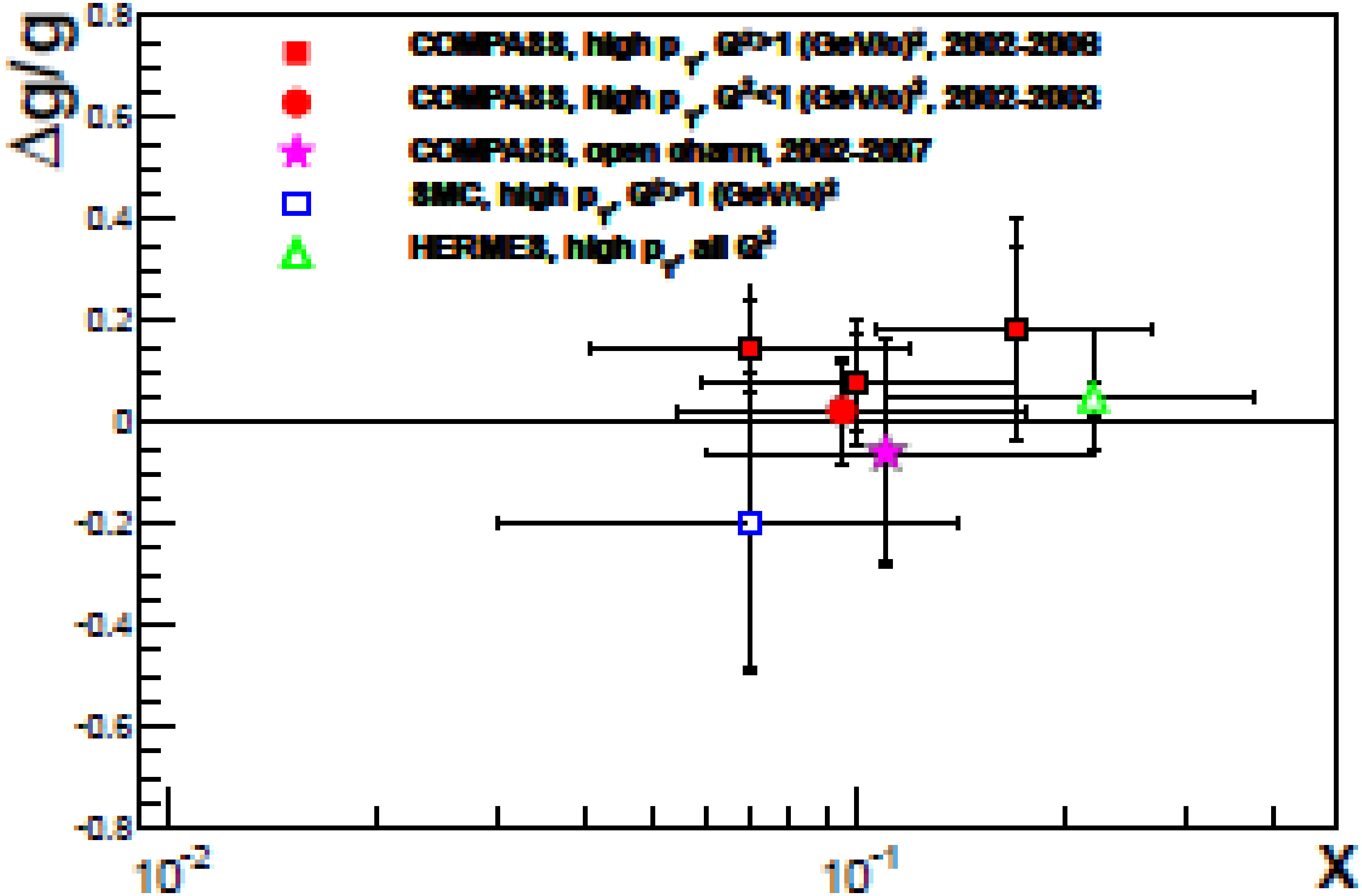
- ie A lump of matter which rotates.

Subsequent collaborations – NMC SMC





COMPASS δg ~ 0



Δg/g
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
COMPASS, high p_T, Q²>1 (GeV/c)², 2002-2006
COMPASS, high p_T, Q²<1 (GeV/c)², 2002-2003
COMPASS, open charm, 2002-2007
SMC, high p_T, Q²>1 (GeV/c)²
HERMES, high p_T, all Q²
10⁻²
10⁻¹
x

EMC – a happy and sociable collaboration

Desperate for shift people

Sometimes too many on shift – e.g. last EMC shift


CERN


mambo
SODA

Concluding remarks

I could only find 1 picture with Roland

His style is to work quietly in the background without fuss.

But always at the forefront when furthering the collaboration’s interest and understanding the physics (QCD fits, D state of deuteron, new methods of determining fragmentation functions).

As well as this he is a learned man with an extensive knowledge of history and art. His retirement will allow to further these interests.

So, Roland, it has been a privilege to work you – wish you all the very best to you and to Madeleine for a well earned, long and happy retirement.

Spare stuff.

Dimuons

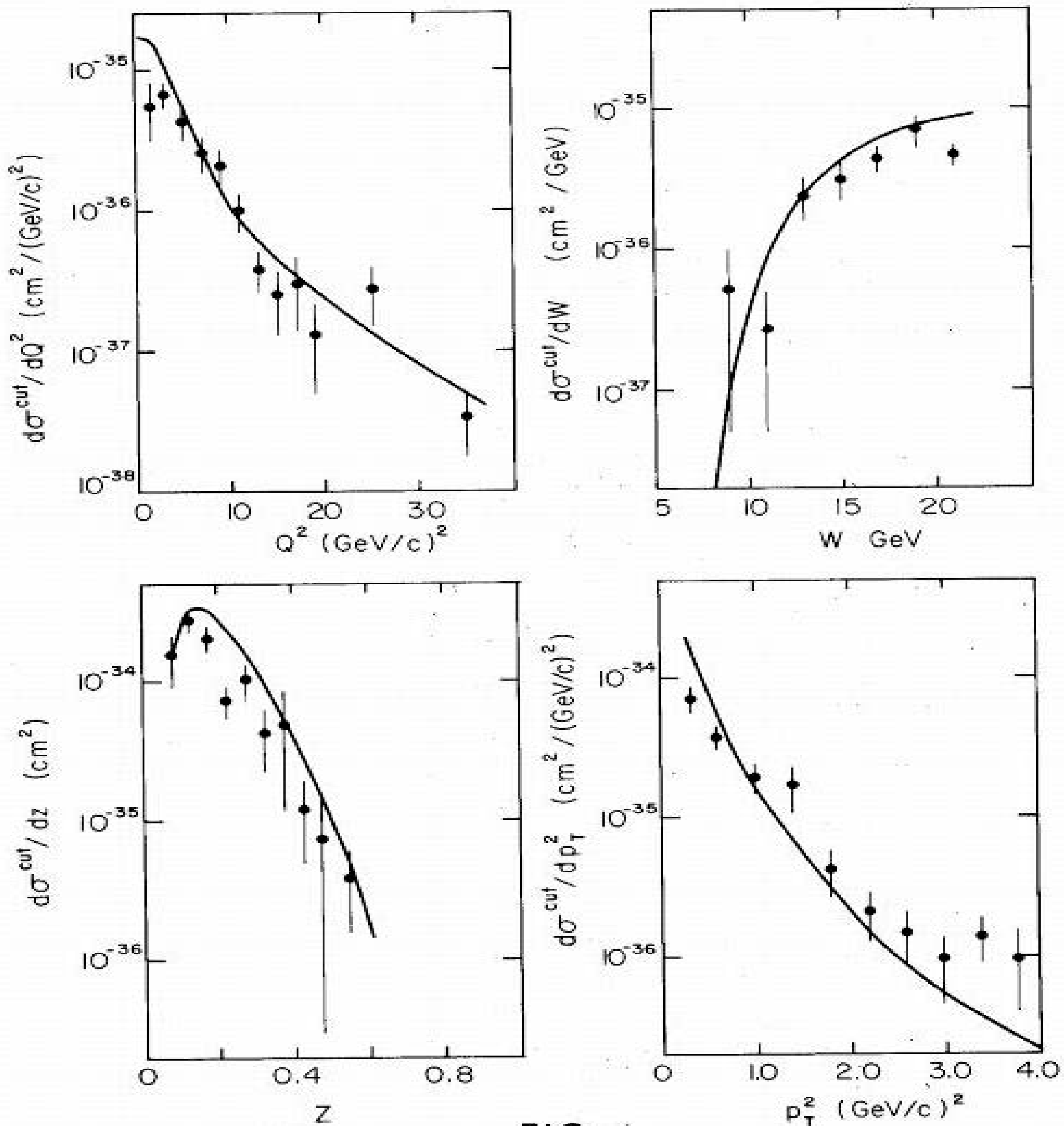
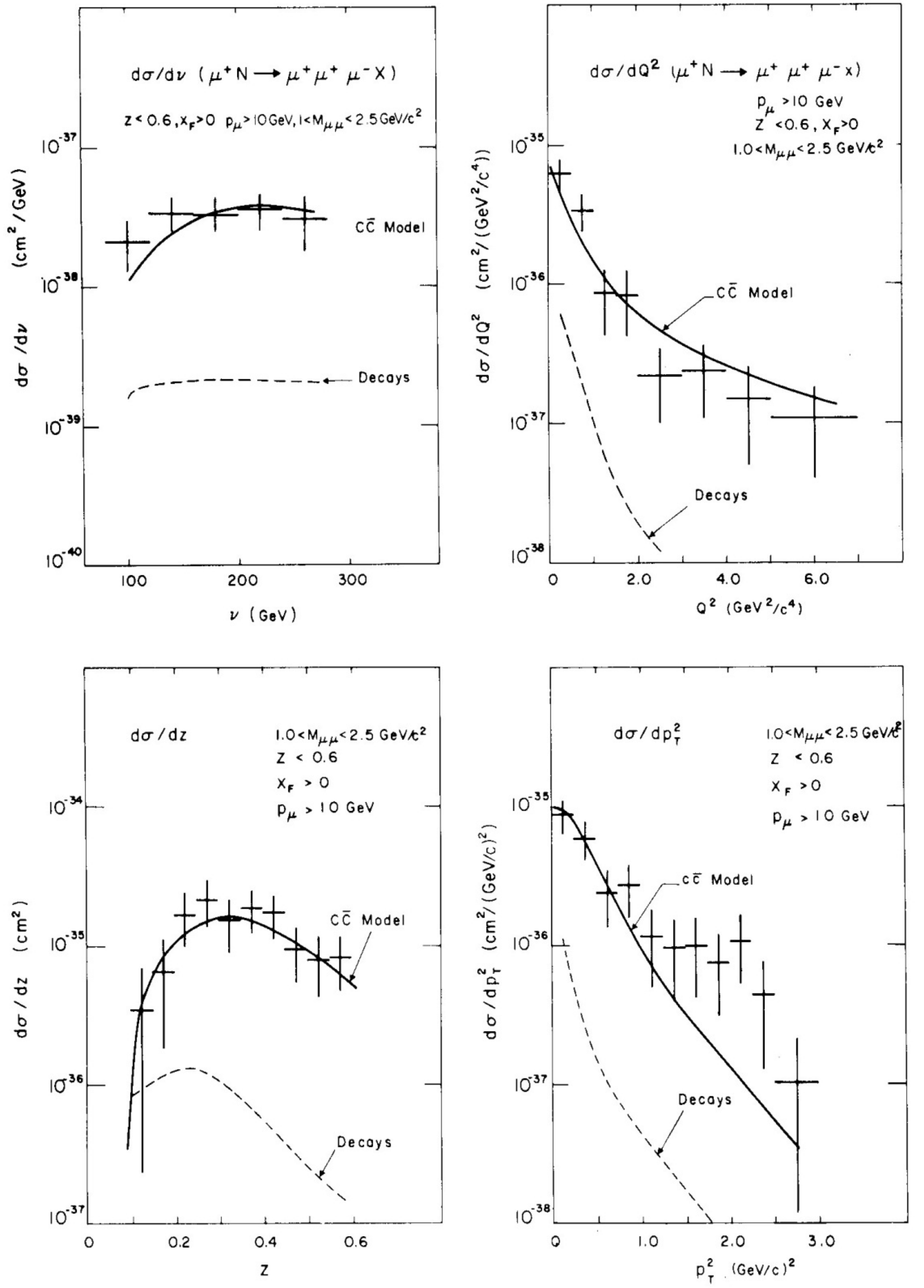


FIG. 4

14

Trimuons



dσ/dν (μ⁺N → μ⁺μ⁺ μ⁻X)
Z < 0.6, x_F > 0 p_μ > 10 GeV, 1 < M_μμ < 2.5 GeV/c²
dσ/dν (cm²/GeV)
CC̄ Model
Decays
ν (GeV)
dσ/dQ² (μ⁺N → μ⁺ μ⁺ μ⁻ x)
p_μ > 10 GeV
Z < 0.6, X_F > 0
1.0 < M_μμ < 2.5 GeV/c²
dσ/dQ² (cm²/(GeV²/c⁴))
CC̄ Model
Decays
Q² (GeV²/c⁴)
dσ/dz
1.0 < M_μμ < 2.5 GeV/c²
Z < 0.6
X_F > 0
p_μ > 10 GeV
dσ/dz (cm²)
CC̄ Model
Decays
Z
dσ/dp²_T
1.0 < M_μμ < 2.5 GeV/c²
Z < 0.6
X_F > 0
p_μ > 10 GeV
dσ/dp²_T (cm²/(GeV/c)²)
cc̄ Model
Decays
p²_T (GeV/c)²

200 GeV data
Proves R~0
i.e. Jp=0- or 1-
gluon

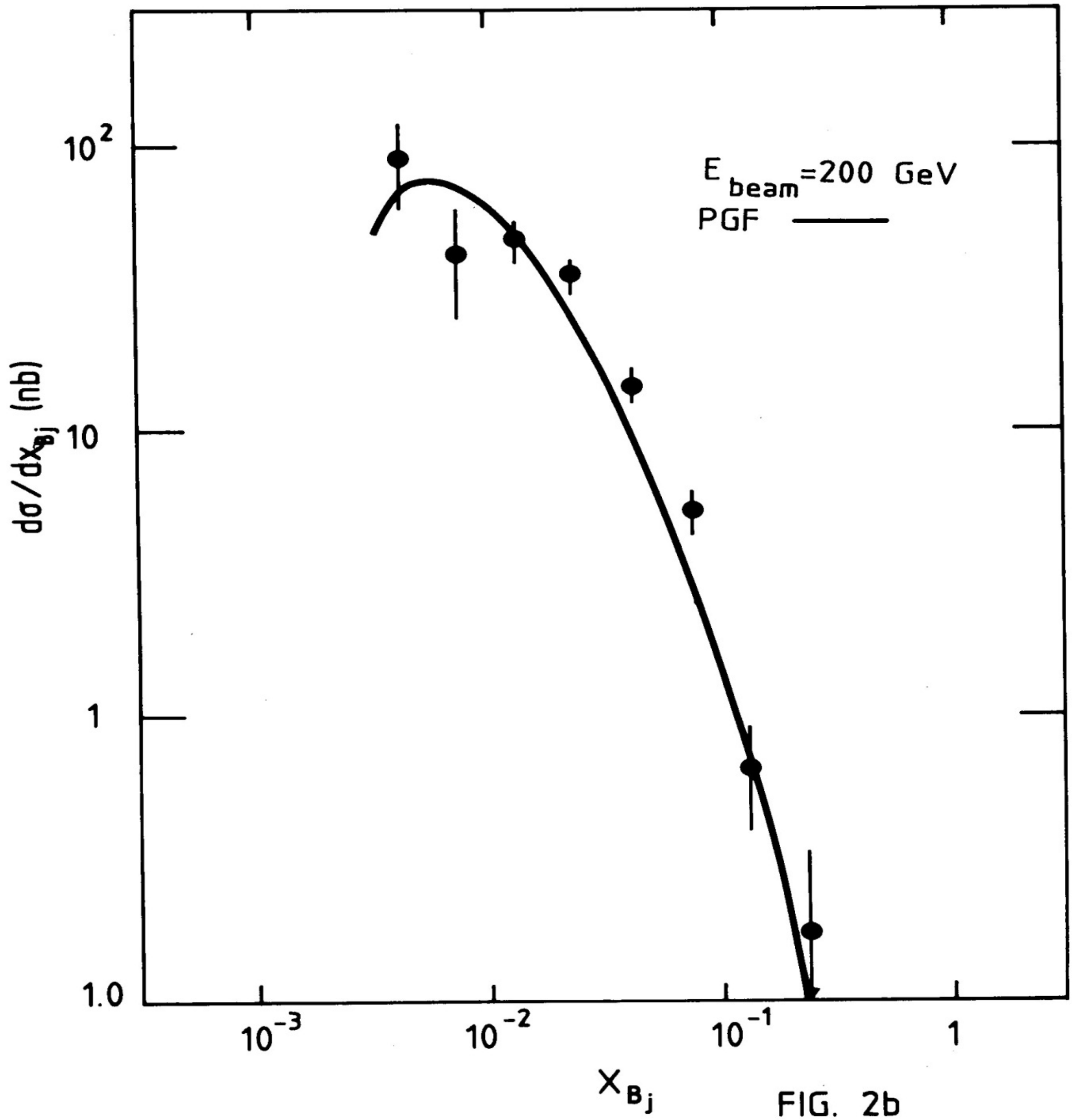


FIG. 2b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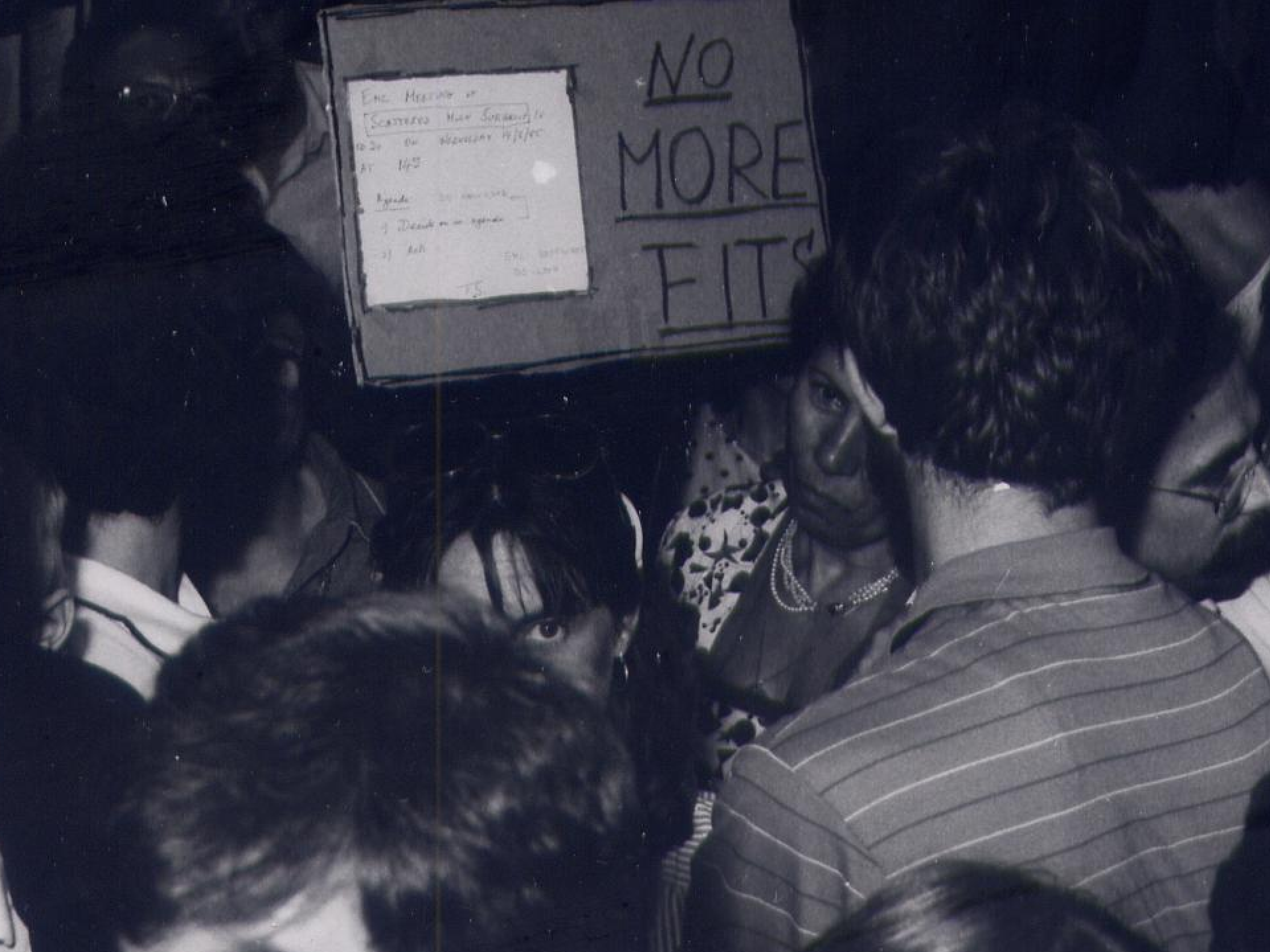
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):10:09   GOODBYE EMC - AU REVOIR,ADJOE,CIAO,AUF WIEDERSEHEN,SEEYA BRUCE
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DAT      45 20:09:22  FATAL HARDWARE ERROR ON MM1 JOB= 28 IO FN=  3000 IO
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HPCHK    22 20:09:47  HV : 3 MODS ON   0 OFF  0 BAD CHAN
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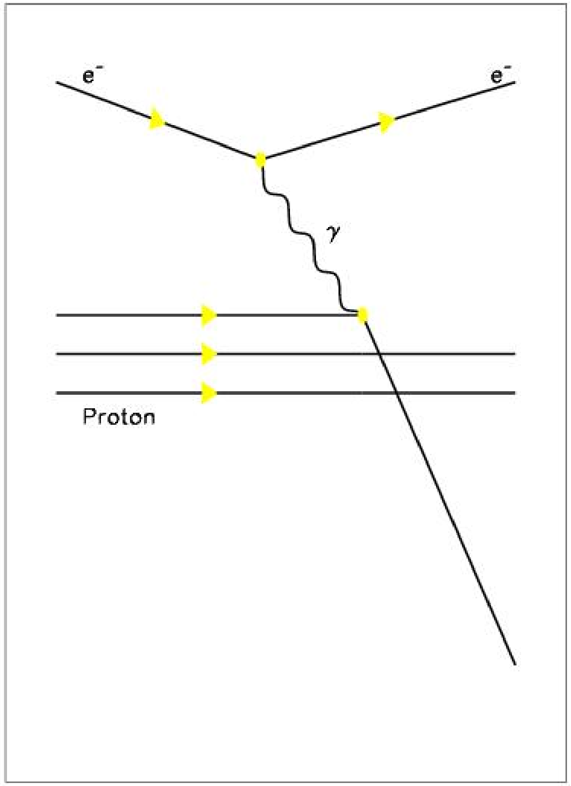
Structure Functions

- Study inclusive muon scattering,
- Led to discovery of EMC effect, shadowing in DIS,
- Spin problem.



New EMC experiment

Parasitic Experiment during polarised target run.

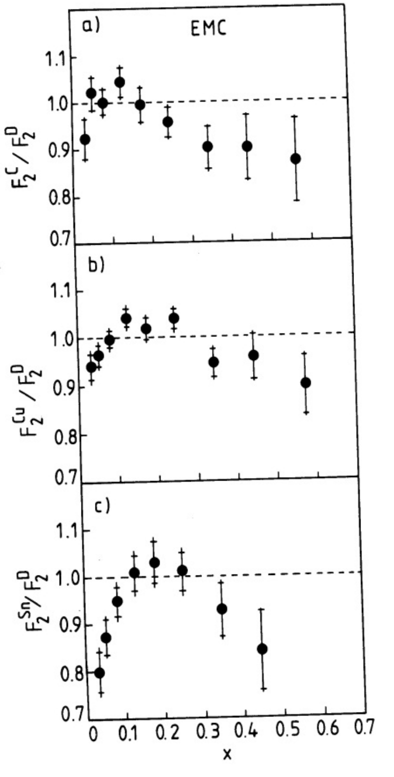
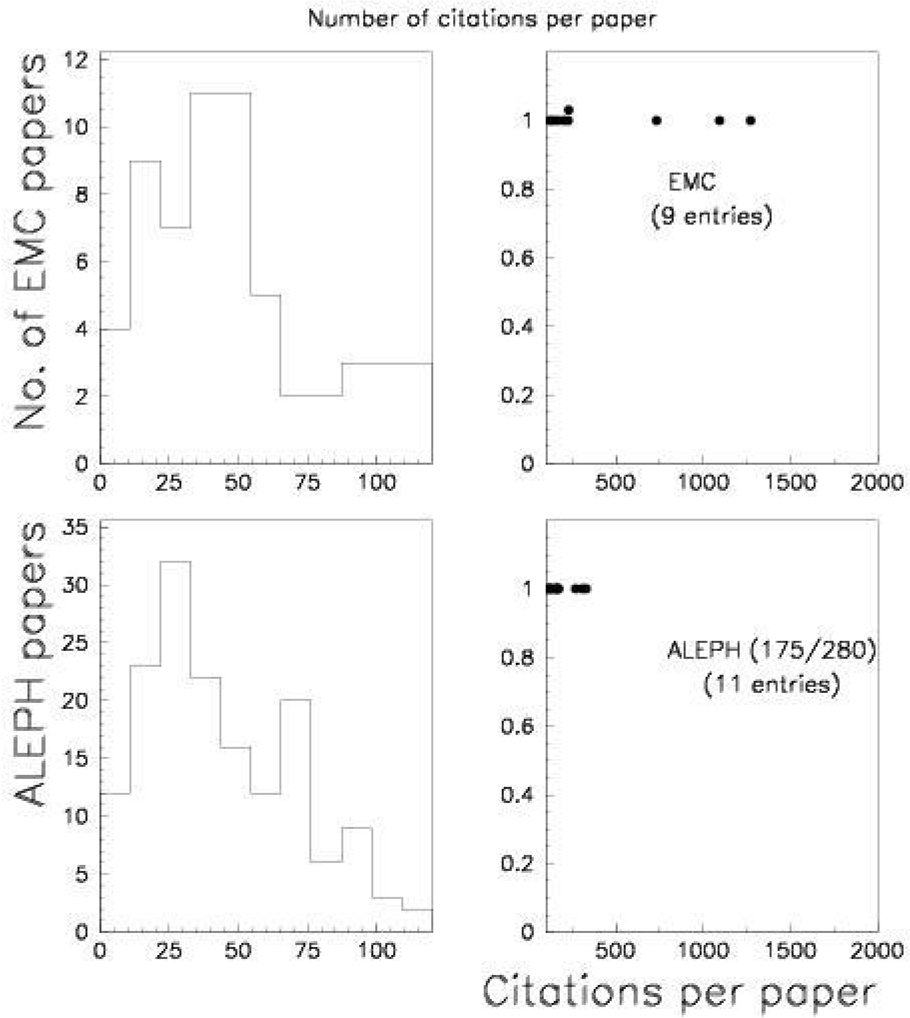


Fig.2

EMC Papers Heavily cited



An EMC paper with 8 Citations

Search for D0 to mu mu

(flavour changing neutral current)

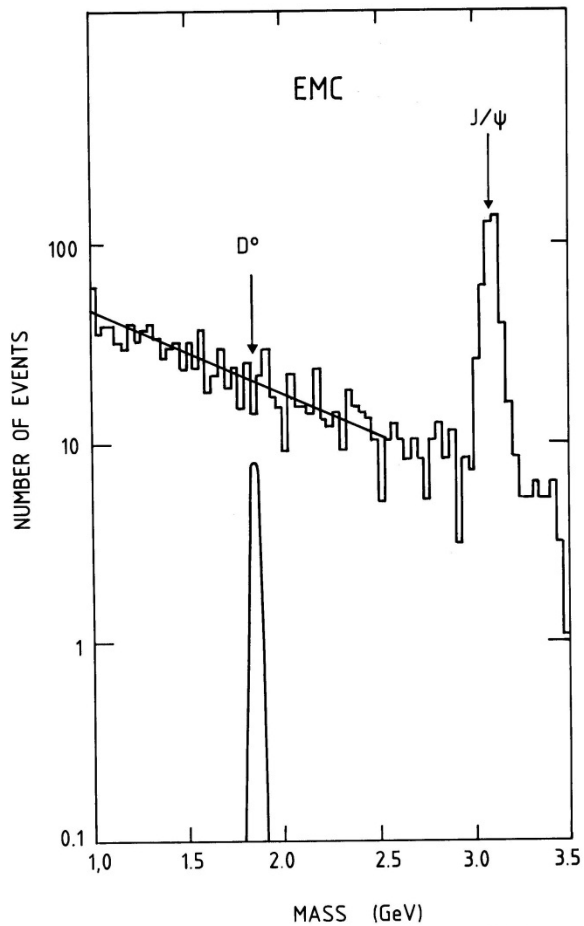
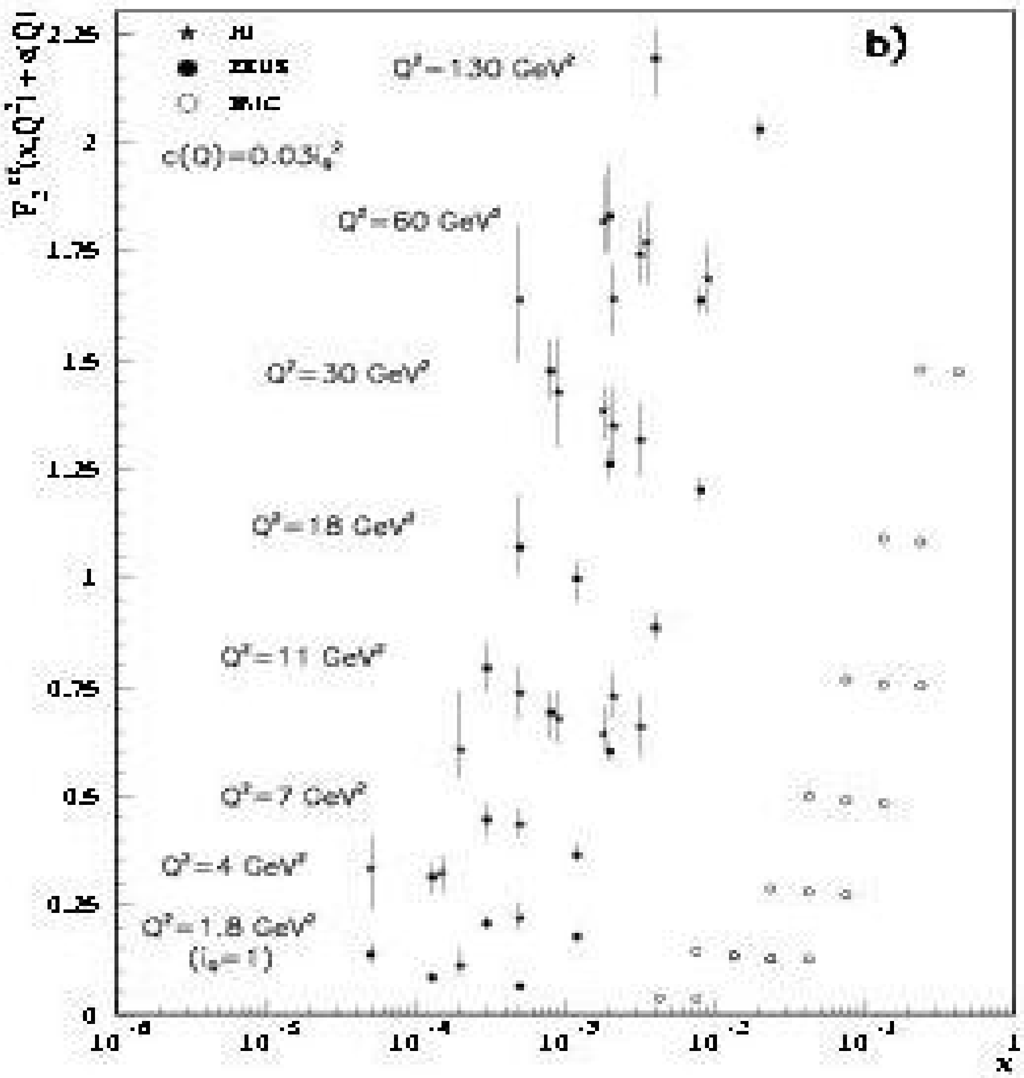


FIG. 1

EMC

- The European Muon Collaboration by T.Sloan, University of Lancaster Oct 2005.

- Brief History
- 1974 Proposal written by MIF and 47 others
- 1974-78 Apparatus Built
- 1978-1980 NA2 i.e. Forward spectrometer detector
- 1981-1983 NA9 Forward and wide angle detectors
- 1984-1985 Polarised target

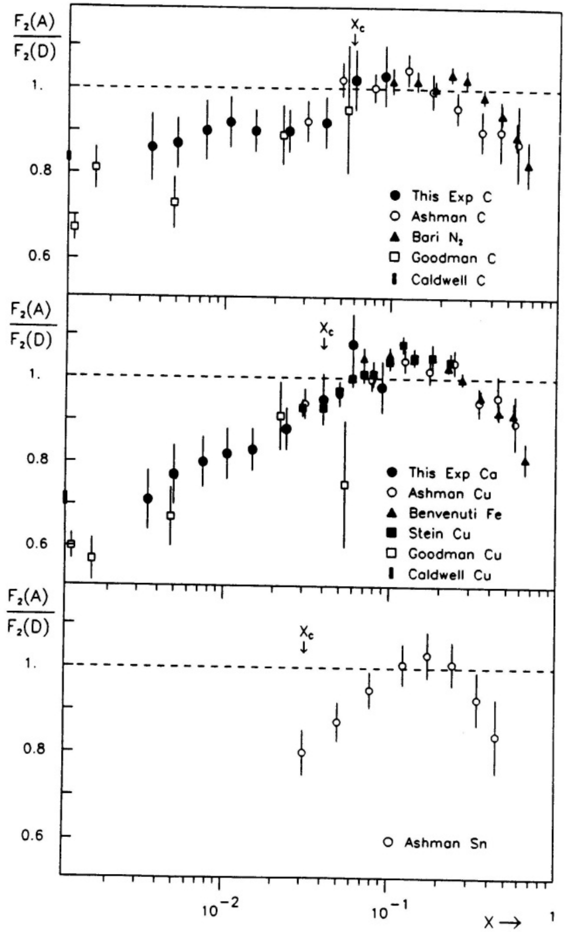


b)
H1
ZEUS
NMC
c(Q)=0.03i_g^2
Q²=130 GeV²
Q²=60 GeV²
Q²=30 GeV²
Q²=18 GeV²
Q²=11 GeV²
Q²=7 GeV²
Q²=4 GeV²
Q²=1.8 GeV²
(i_g=1)
x

Shadowing (NA28 phase of EMC)

Dedicated Experiment during NA9

Pioneered the use of FastBus



Muon experiments at CERN SPS proposed 1972
EMC 1974 to 1986
NMC 1986 to 1990
SMC 1990 to ?
COMPASS ?- present

COMPASS members who were members of original EMC

G. Baum, B. Badelek, D. von Harrach, E. Kabuss, E. Rondio, A. Sandacz and Roland Windmolders.

Roland has been working here since about 1980. He has been an important member of each of the collaborations.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