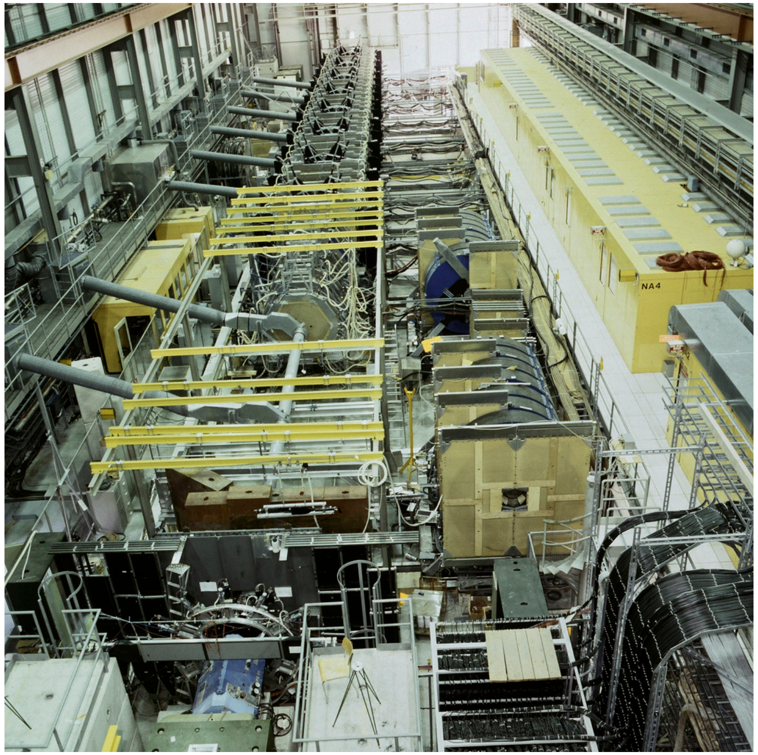
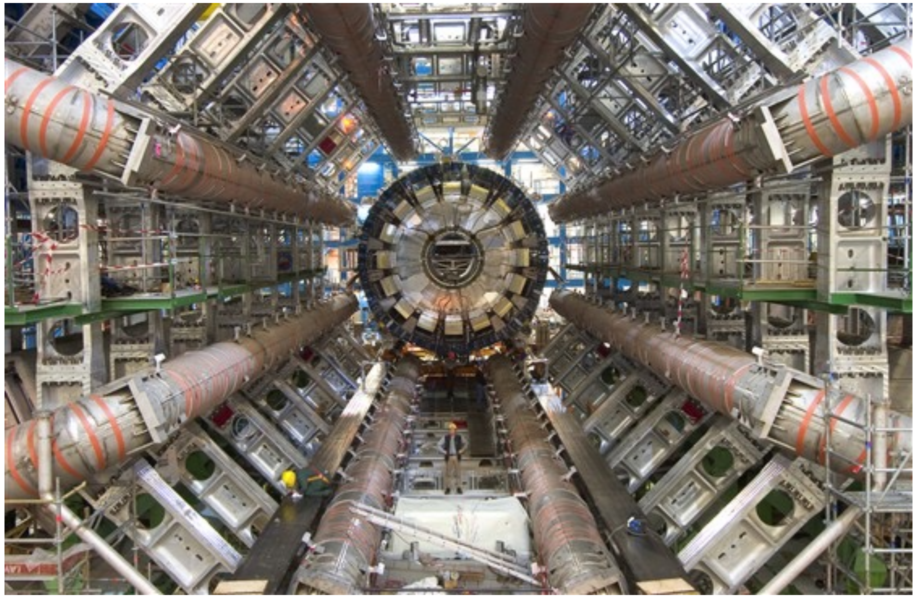


Max and I

with

BCDMS and ATLAS

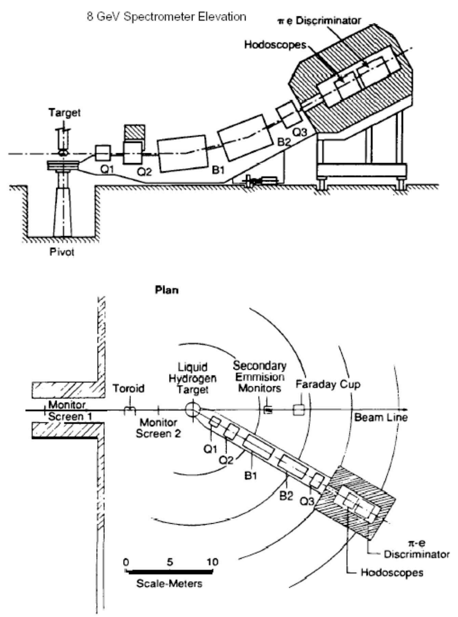
December 9, 2022

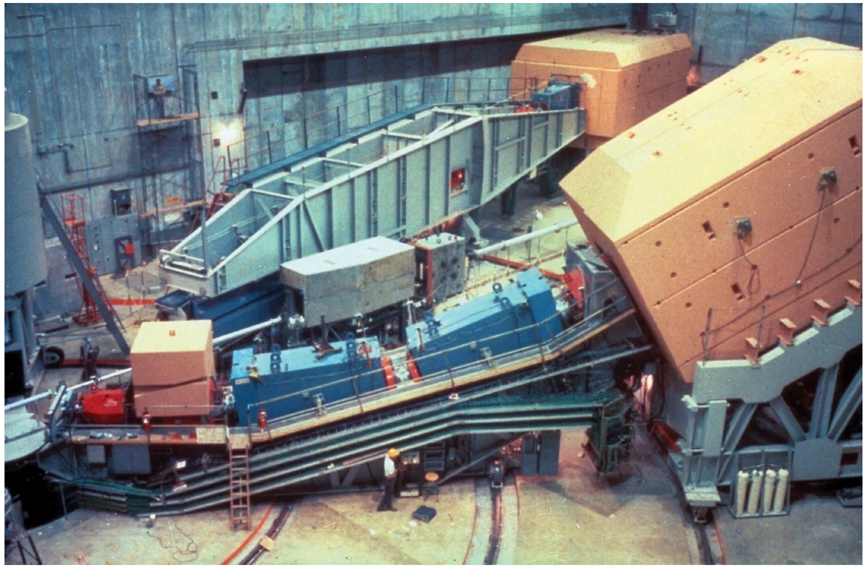


BCDMS –Bologna, CERN, Dubna, Munich, Saclay

- First contact with Max during my sabbatical year at CERN 1979-80
- NA4 experiment on deep inelastic muon scattering
  - CERN North Area
  - World's most intense high energy muon beam
  - 1979 – 1982
- Context for the experiment
  - 1970's an extraordinarily fertile period for HEP
  - More than history for those of us who lived it
- These discoveries were the foundation for Max's scientific career
  - Discovery of point-like constituents of the proton
    - SLAC deep inelastic scattering experiment
    - Neutrino experiments
  - Discovery of weak neutral currents
    - In neutrino scattering by Gargamelle collaboration
  - Discovery of scale breaking and QCD
  - Discovery of parity violation in electron scattering

Discovery of proton constituents at SLAC 1968 – 1972





Measure scattering probability vs energy and angle of scattered electron.

$$\frac{d^2\sigma}{d\Omega dE'} = \Sigma(E,E',\theta')$$

Model interpretation (esp.Bjorken)

Theoretical description assuming interaction via a virtual photon.

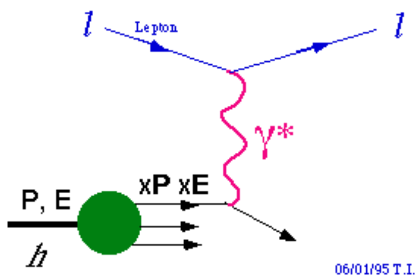
$$\frac{d^2\sigma}{dxdQ^2} = \frac{4\pi\alpha^2}{Q^4}\frac{1}{x}F_2(x,Q^2)\{\dots\}$$

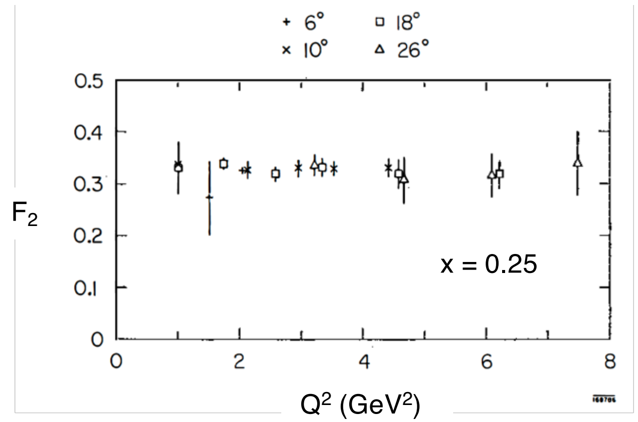
$$Q^2 = 2EE'(1-\cos\theta'), \quad x = Q^2/[2M_p(E-E')]$$

Wavelength of photon $\propto 1/Q$

Deep Inelastic Scattering

in Parton Model

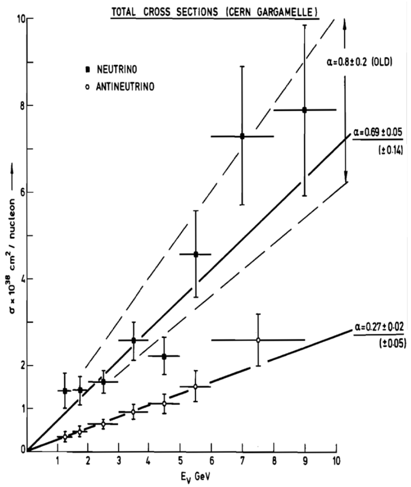




F_2 independent of Q^2 for scattering off point-like constituents with a fraction x of the proton's energy

Complemented by neutrino experiments at CERN

- Gargamelle bubble chamber in ν beam
  - Neutrino and antineutrino cross sections for scattering off nucleons



$\sigma \propto E_\nu$
As expected for point-like target

$\sigma_\nu \sim 3\sigma_{\bar{\nu}}$
As expected for Spin-1/2 target

ICHEP XVI - 1972

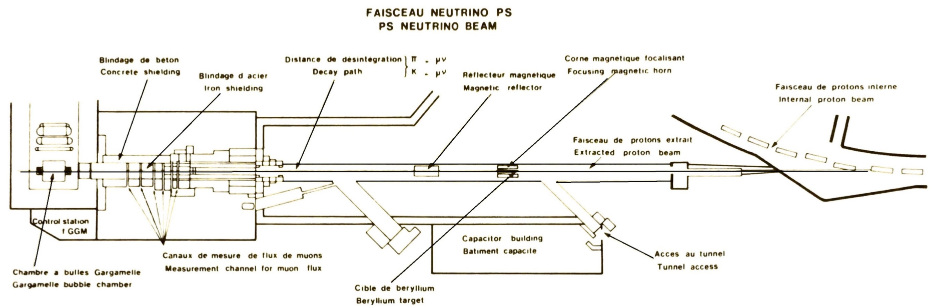
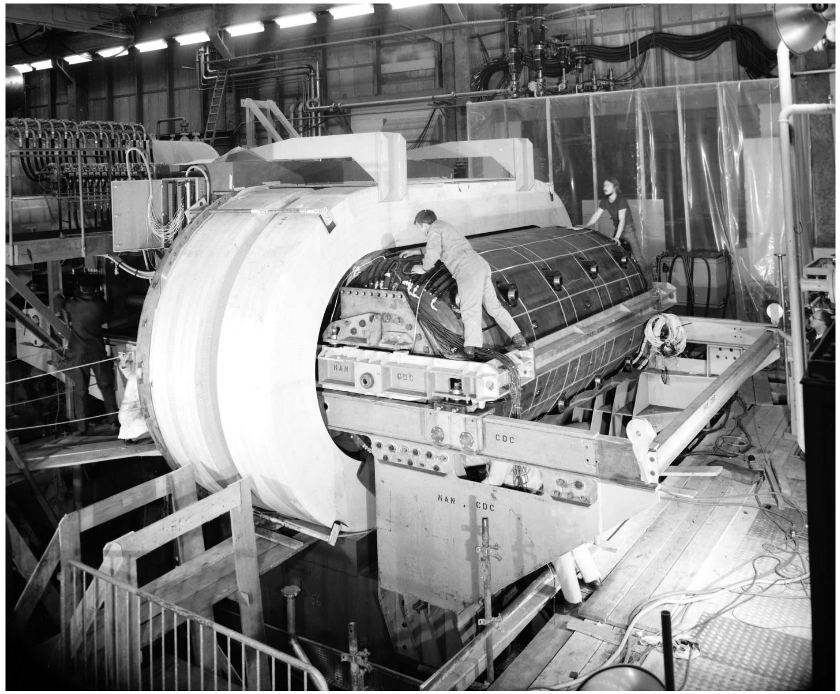
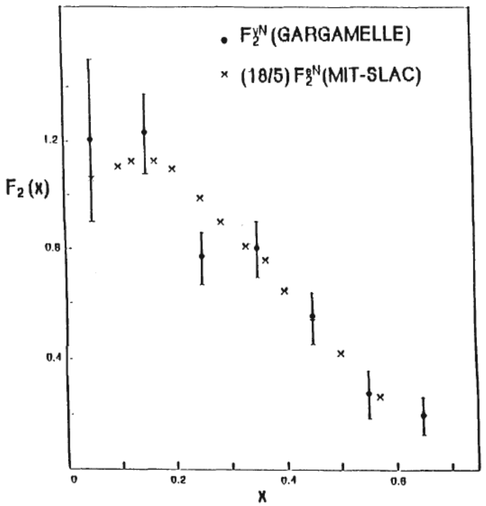


Fig. 1-2. The CERN neutrino beam lay-out.



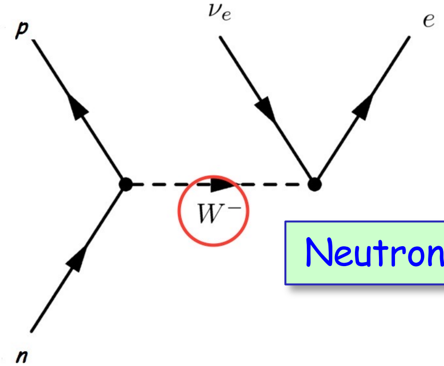
  - Similar nucleon structure functions



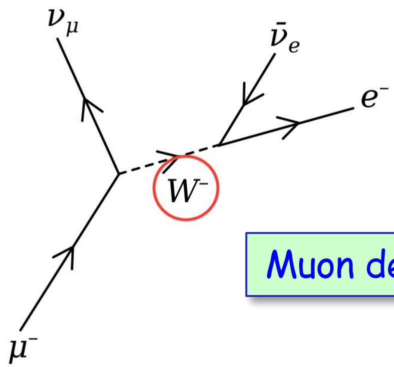
ICHEP XVII - 1974

Discovery of weak neutral currents

- Prior to 1973 all well known weak processes involved a charged weak current



Neutron decay

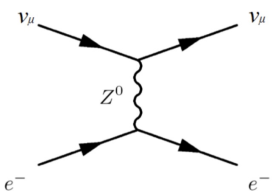


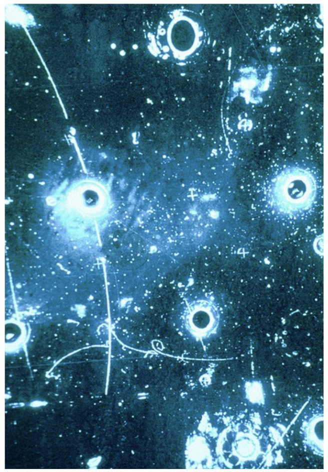
Muon decay

  - Theories of Glashow, Salam and Weinberg included a neutral weak current but all experimental searches had been negative

- Summer of 1973, Gargamelle collaboration reported evidence for a neutral weak current

Purely leptonic process



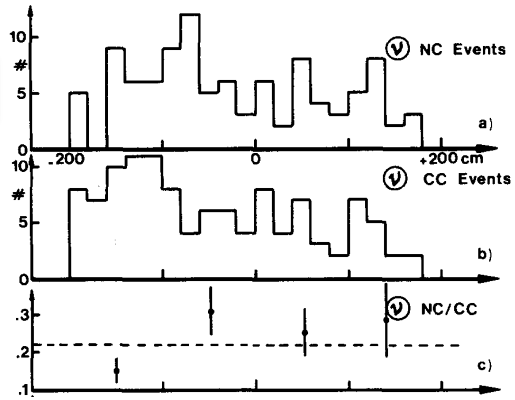


$\leftarrow \bar{\nu}_\mu$

$\bar{\nu}_\mu + e^- \rightarrow \bar{\nu}_\mu + e^-$

Neutrino nucleon scattering

$\nu_\mu + N \rightarrow \nu_\mu + X$

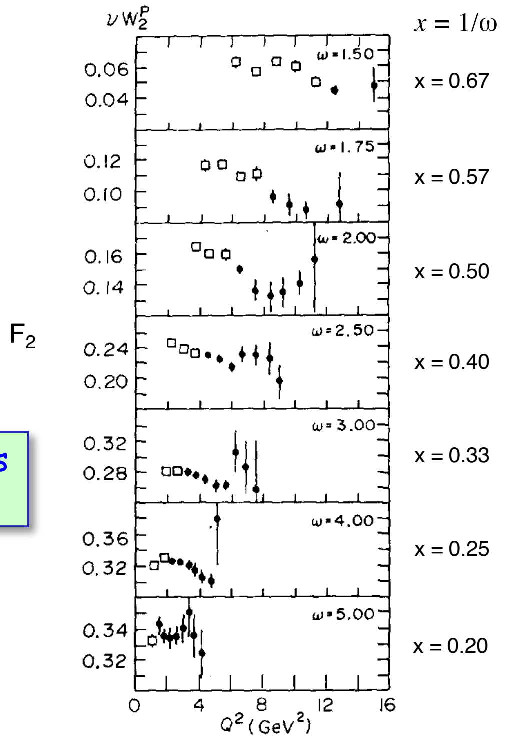


Longitudinal position (cm)

Scaling is violated

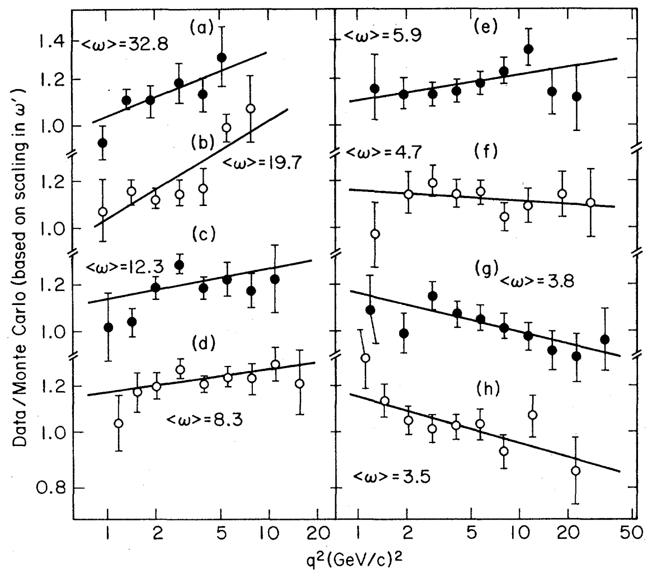
- Theorists noted that if quarks are constrained to the nucleon then scaling should not be exact
  - They are “free” only at infinite q^2
    - Asymptotic freedom
  - => Logarithmic violations of scaling
  - The form of the scaling violations was predicted
    - Amenable to experimental test
- Experimenters looked more carefully

SLAC, electrons 4.5 - 28 GeV



Phys. Lett. 52B (1974) 249-252

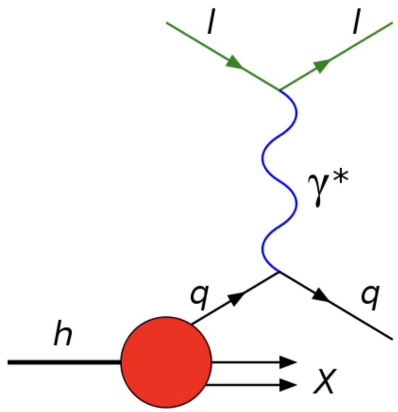
Fermilab, muons 56, 150 GeV

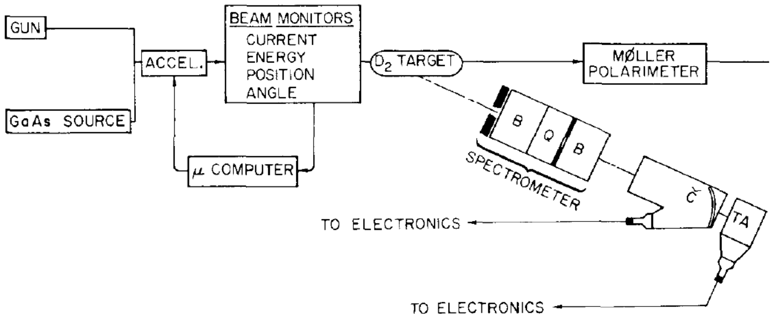


Phys. Rev. Lett. 35 (1975) 901-904

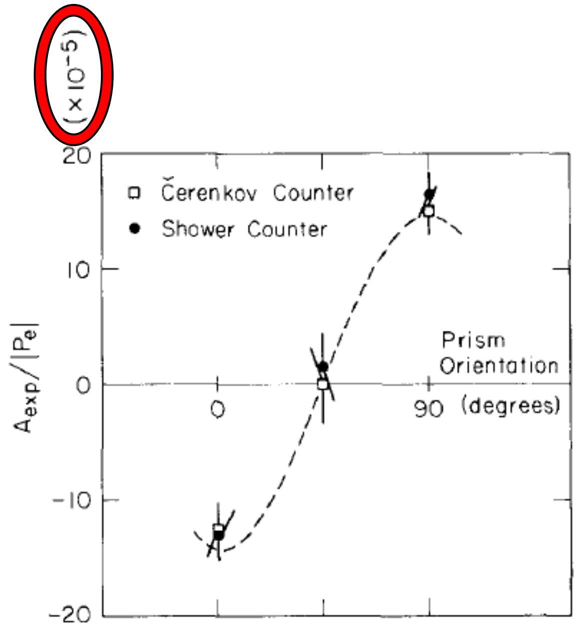
Parity violation in electron scattering

- Z^0 exchange must contribute to electron scattering
  - Same quantum numbers as the photon
  - Charged current weak interaction violates parity conservation
  - According to Glashow-Weinberg-Salam, neutral current should too
  - Effect likely tiny because of small effective coupling constant
- Reported 1978 from Prescott et al. at SLAC





$$A_{\text{exp}} = \frac{Y(+) - Y(-)}{Y(+) + Y(-)}$$



- Constrains neutral current couplings for the electron

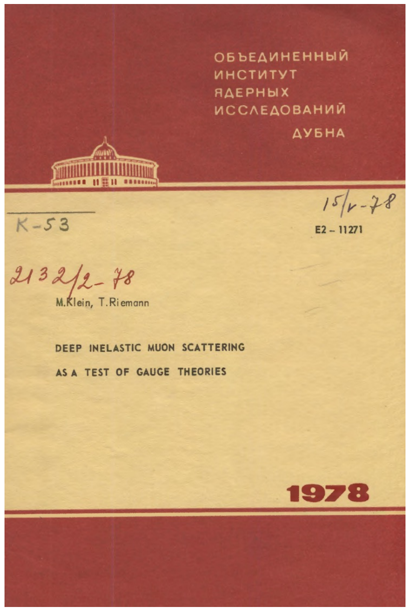
Phys. Lett. 77B (1978) 347-352

BCDMS (NA4)

- SPS became operational in 1976 at 400 GeV
  - Major investments in high quality neutrino beams (West Area) and muon beams (North Area)
- In mid-1970's CERN approved second-generation lepton scattering experiments
  - Neutrino experiments WA1 (CDHS), WA18 (CHARM)
  - Muon scattering experiments NA2 (EMC), NA4 (BCDMS)
- Construction of NA4 1976-79
  - Collaboration of Bologna, CERN, Dubna, Munich and Saclay
  - Initiated by Carlo Rubbia
    - Diverted in late 70's to build a proton-antiproton collider and detector
      - Direct observation of $W^{\pm}$ and Z^0 led to Nobel Prize
  - Goal was to study deep inelastic muon scattering with high precision
    - Superb muon beam
      - ~10^7 muons/sec in diameter of ~ 5 cm
      - Energies up to 280 GeV
      - Control of polarization, i.e. $\begin{matrix} p \rightarrow \\ s \Rightarrow \end{matrix}$ vs $\begin{matrix} p \rightarrow \\ s \Leftarrow \end{matrix}$ (important for weak-interaction effects)

Early professional years

- 1976
  - A promising young student at Humboldt University, Berlin finished his PhD thesis on “Resonances as a source of correlation in high energy multi-particle reactions”
  - A stepping-stone with an international bubble chamber collaboration
  - His talents became appreciated by the wider community
- 1977
  - Won fellowship at Joint Institute for Nuclear Research (JINR), in Dubna, USSR
  - Max was able to indulge his formal interests and talents with Tord Riemann


ОБЪЕДИНЕННЫЙ ИНСТИТУТ ЯДЕРНЫХ ИССЛЕДОВАНИЙ ДУБНА

K-53

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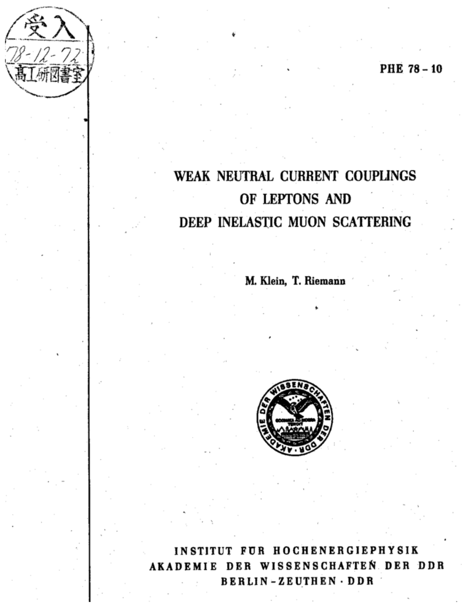
2132/2-78

M.Klein, T.Riemann

DEEP INELASTIC MUON SCATTERING AS A TEST OF GAUGE THEORIES

1978

Phys. Lett. B 76 (1978) 79-82

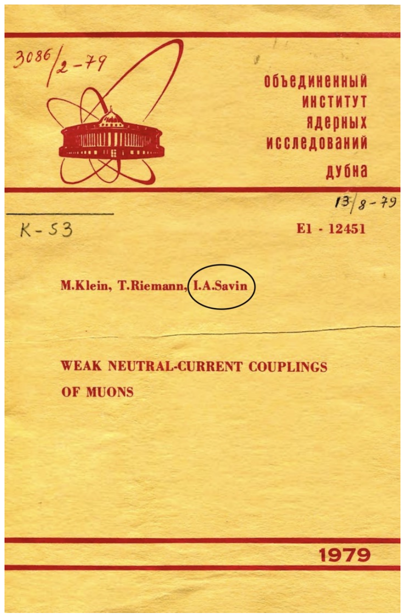

受入 78-12-22 高エ研図書室

PHE 78 - 10

WEAK NEUTRAL CURRENT COUPLINGS OF LEPTONS AND DEEP INELASTIC MUON SCATTERING

M. Klein, T. Riemann

INSTITUT FÜR HOCHENERGIEPHYSIK
AKADEMIE DER WISSENSCHAFTEN DER DDR
BERLIN-ZEUTHEN · DDR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объединенный институт ядерных исследований дубна

13/8-79

K-53

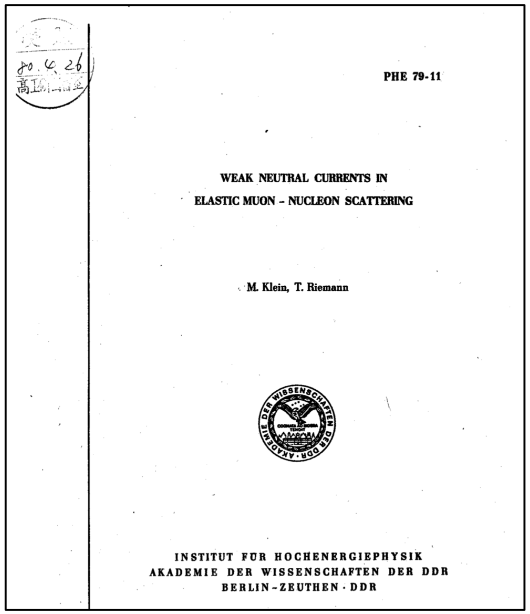
E1 - 12451

M.Klein, T.Riemann, I.A.Savin

WEAK NEUTRAL-CURRENT COUPLINGS OF MUONS

1979

Phys. Lett. B 85 (1979) 385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PHE 79-11

WEAK NEUTRAL CURRENTS IN ELASTIC MUON - NUCLEON SCATTERING

M. Klein, T. Riemann

INSTITUT FÜR HOCHENERGIEPHYSIK
AKADEMIE DER WISSENSCHAFTEN DER DDR
BERLIN-ZEUTHEN · DDR

Z. Phys. C 8 (1981) 239

Early professional years

- Papers and reports on the physics potential of deep inelastic scattering of muons
  - Cross section estimates
  - How to test QCD
  - Asymmetries

For a given magnitude of beam helicity λ there exist three independent cross section asymmetries: two parity violation asymmetries of the type measured at SLAC [3] and Serpukhov [10]:

$$A^{\pm} = \frac{d\sigma^{\pm}(+\lambda) - d\sigma^{\pm}(-\lambda)}{d\sigma^{\pm}(+\lambda) + d\sigma^{\pm}(-\lambda)} = -k\lambda(\pm a_{\mu} V + v_{\mu} A), \quad (4)$$

and a third asymmetry to be measured by conjugation of the muon beam:

$$B = \frac{d\sigma^{+}(-\lambda) - d\sigma^{-}(+\lambda)}{d\sigma^{+}(-\lambda) + d\sigma^{-}(+\lambda)} = k(\lambda v_{\mu} - a_{\mu})A. \quad (5)$$

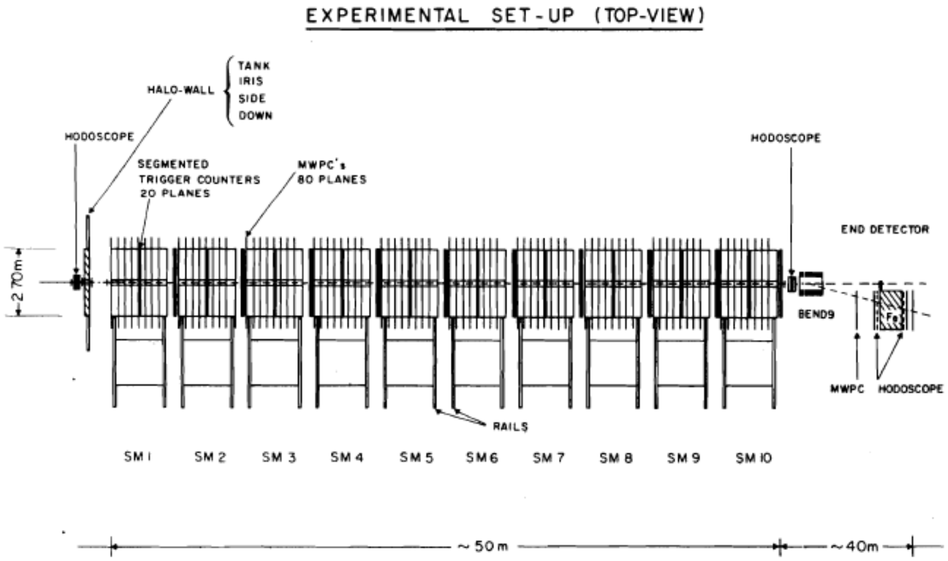
The measurement of these asymmetries is an obvious challenge for CERN SPS muon experiments reaching large Q^2 with high statistical accuracy ‡1.

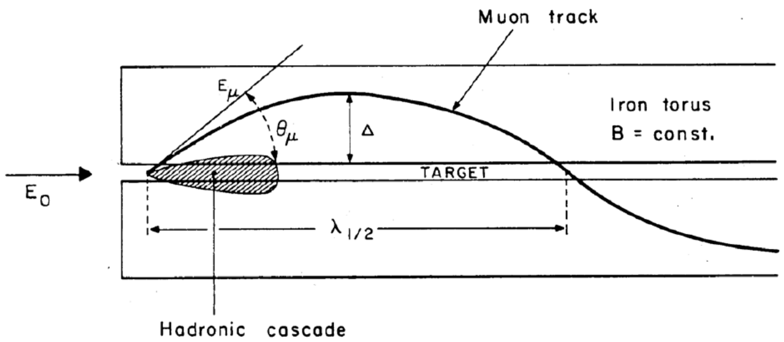
π^+ decay to negative helicity μ^+
π^- decay to positive helicity μ^-

v_μ and a_μ are the vector and axial vector coupling constants of the muon to the Z^0

The BCDMS detector design

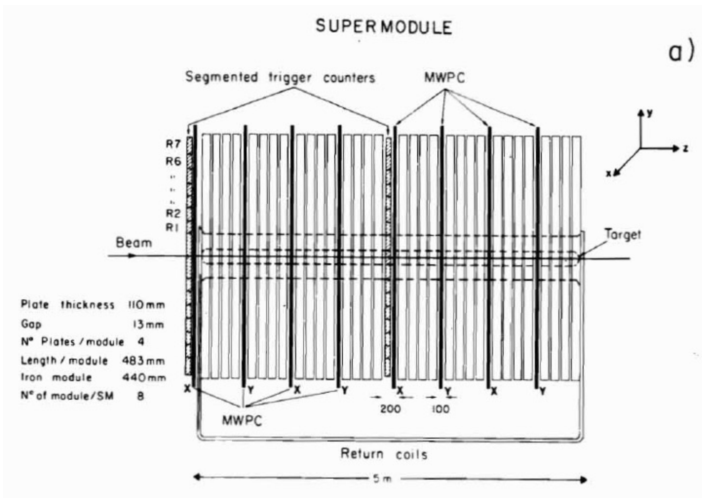
- An innovative design
  - Allowed very long target and high beam intensity

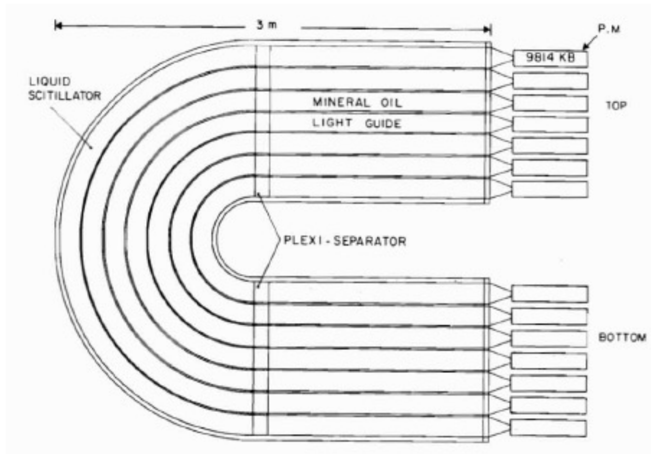




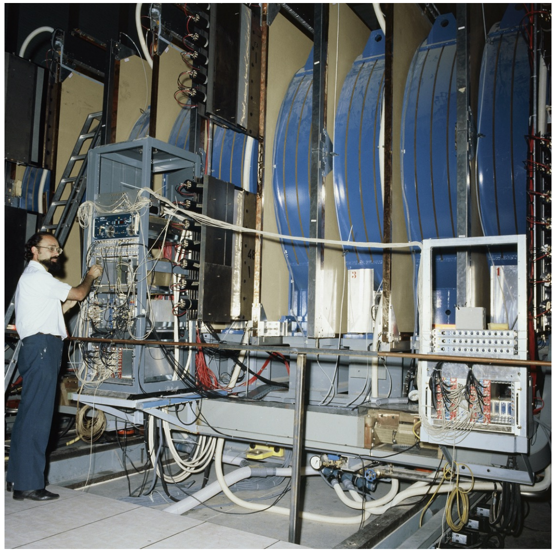
$$\lambda_{1/2} = 6.66\ p_T\ /\ B$$

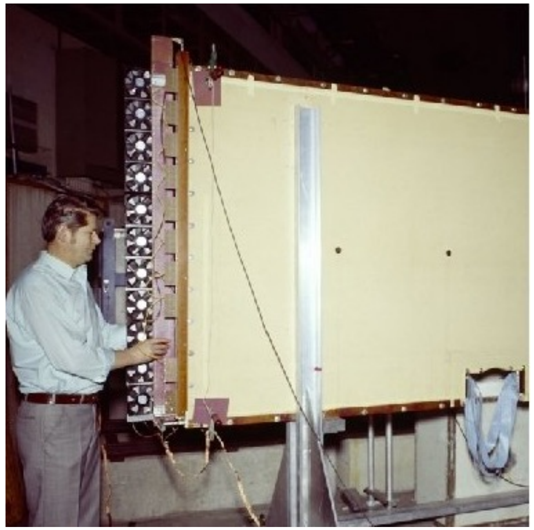
$$\Delta = \frac{M}{0.3B}\ \frac{Q^2}{Q^2_{max}}$$ → M/0.3 B ~ 1.5 m





Detector preparation





Completed detector

Exploitation of detector

- Structure functions from a carbon target (1979–82)
  - High accuracy essential
    - Scale breaking effects are expected to be logarithmic in Q^2
    - High statistics not a problem but systematic effects more subtle
  - Complications from detector
    - Must know magnetic field in iron to high precision
    - Must fully understand muon behavior traversing iron
    - Must understand MWPC performance close to hadronic shower
- Max presented very early results at ICHEP-80 in Madison, Wisc.

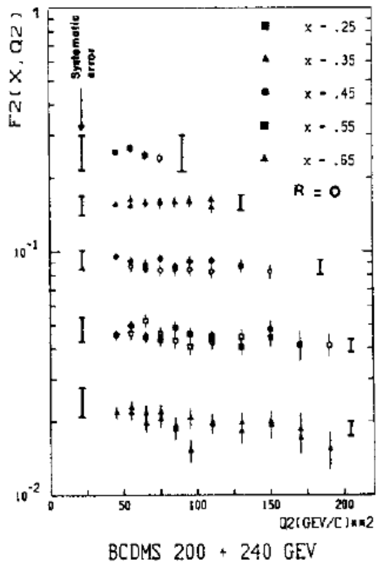
E1-81-44

DEEP INELASTIC MUON-NUCLEON SCATTERING AT HIGH Q^2

BCDMS Collaboration

Presented by M.Klein at the 20th International Conference on High Energy Physics, Madison, Wisconsin, 16-23 July 1980, USA, CERN/EP-80-133

Fig.7b. $F_2(x,Q^2)$ measured at 200 GeV (closed symbols, Q^2>40 $(GeV/c)^2$) and at 240 GeV (open symbols, Q^2> >50 $(GeV/c)^2$) given with statistical errors at the bin centers, for R=0 and not corrected for Fermi motion. The error bars at the edges indicate the estimated systematic uncertainty (see text). Whenever above Q^2 = = 50 $(GeV/c)^2$ only a closed symbol appears, both measurements coincide.



Exploitation of detector

- First journal publication in PLB in spring 1981

A MEASUREMENT OF THE NUCLEON STRUCTURE FUNCTION FROM MUON–CARBON DEEP INELASTIC SCATTERING AT HIGH Q^2

D. BOLLINI, P.L. FRABETTI, G. HEIMAN, L. MONARI and F.L. NAVARRIA
Istituto di Fisica dell'Università and INFN, Bologna, Italy

A.C. BENVENUTI [1], M. BOZZO [2], R. BRUN, H. GENNOW [3], M. GOOSSENS, R. KOPP, F. NAVACH [4], L. PIEMONTESE, J. PILCHER [5] and D. SCHINZEL
CERN, European Organization for Nuclear Research, Geneva, Switzerland

D.Yu. BARDIN, J. CVACH, N.G. FADEEV, I.A. GOLUTVIN, Y.T. KIRYUSHIN, V.S. KISSELEV, M. KLEIN, V.G. KRIVOKHIZHIN, V.V. KUKHTIN, W.-D. NOWAK, I.A. SAVIN, G.I. SMIRNOV, G. VESZTERGOMBI, A.G. VOLODKO and J. ŽÁČEK
Joint Institute for Nuclear Research, Dubna, USSR

D. JAMNIK [6], U. MEYER-BERKHOUT, A. STAUDE, K.M. TEICHERT, R. TIRLER, R. VOSS and Č. ZUPANČIČ
Sektion Physik der Universität [7], Munich, Germany

and

T. DOBROWOLSKI, J. FELTESSE, J. MAILLARD, J.M. MALASOMA, A. MILSZTAJN, J.F. RENARDY, Y. SACQUIN, G. SMADJA, P. VERRECCHIA and M. VIRCHAUX
CEN, Saclay, France

Received 29 April 1981

Deep inelastic scattering cross sections have been measured with the CERN SPS muon beam at incident energies of 120 and 200 GeV. Approximately 100 000 events at each energy are used to obtain the structure function $F_2(x, Q^2)$ in the kinematic region $0.3 < x < 0.7$ and 25 GeV^2 $< Q^2 <$ 200 GeV^2.

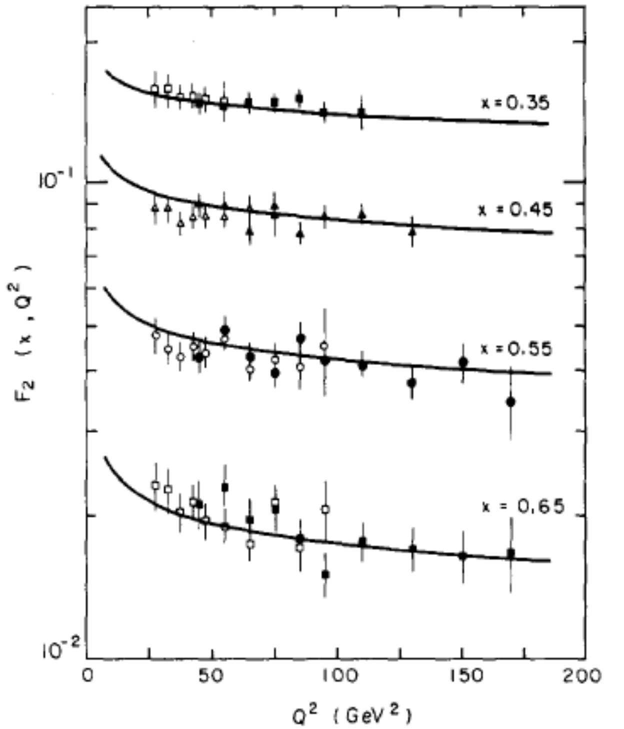


Fig. 2. $F_2(x, Q^2)$ measured with 120 GeV μ^+ (open symbols) and with 200 GeV μ^+/μ^- (closed symbols) using $R = 0$. The curves represent the best fit to the data with the Gonzalez–Arroyo et al. [10] parametrization with Λ = 85 MeV, α = 0.68 and β = 3.65.

Dubna group played a major role in the experiment
- Hardware preparation
- Radiative corrections to cross sections
- Young physicists from eastern Europe

Scale breaking is expected to be strongest
For Q^2 < 50 GeV^2
- Extend acceptance to lower x and Q^2
- Use H_2 and D_2 targets

Exploitation of detector

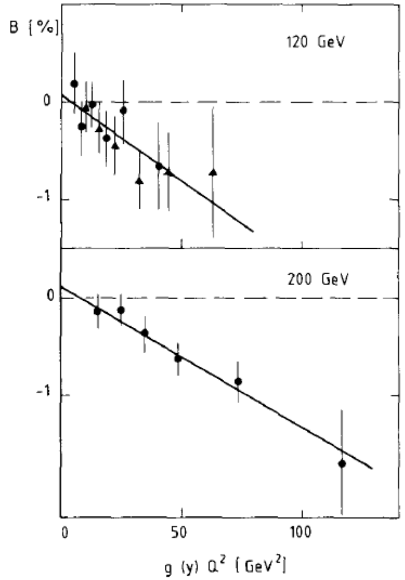
- Second publication submitted to PLB in October 1982
  - Measurement of electroweak asymmetry for muons
  - Identified by Max in his short-author-list paper of 1978
  - Arises from interference between amplitudes for photon and Z^0 exchange
  - Exploits natural polarization of μ^+ and μ^- beams
    - μ^- has spin in direction of motion while μ^+ has the opposite
    - $|\lambda| = 0.81 \pm 0.04$ at 200 GeV and 0.66 ± 0.05 at 120 GeV
  - Allows a measurement of coupling strengths of muon to Z^0
    - Vector coupling a_μ and axial-vector coupling v_μ
    - In standard model these are –0.5 and –0.04
    - This is many years before LEP and HERA which would measure them with great precision

$$B = \frac{\sigma^+(-|\lambda|) - \sigma^-(+|\lambda|)}{\sigma^+(-|\lambda|) + \sigma^-(+|\lambda|)} = 1.79\times10^{-4}(a_\mu - |\lambda| v_\mu)\cdot g(y) Q^2$$

$$y = (E - E')/E$$

$$g(y) = [1-(1-y)^2]/[1+(1-y)^2]$$

g(y) increases monotonically from 0 to 1 as y increases from 0 to 1.

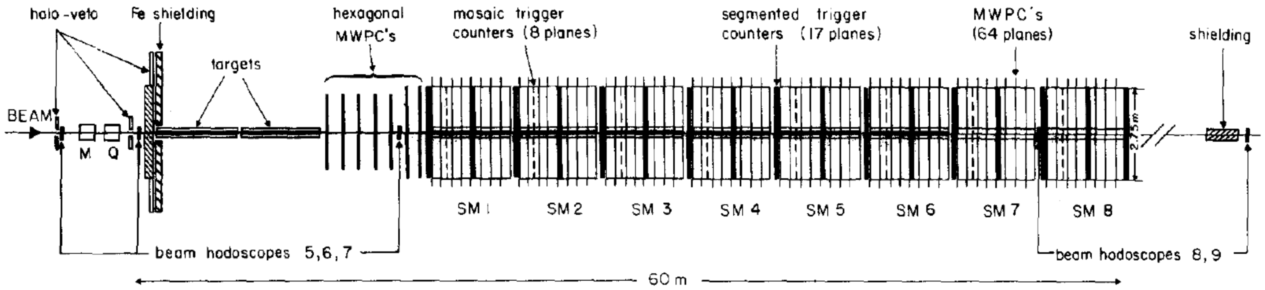


Measurement gives couplings consistent with GWS model.

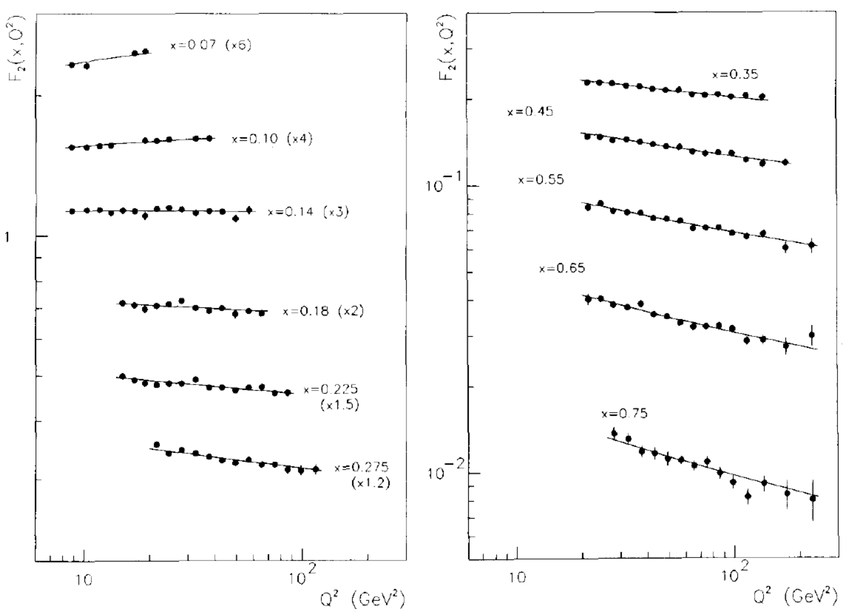
- Max received the 1984 Max von Laue Medal from the Scientific Academy of the DDR for this work

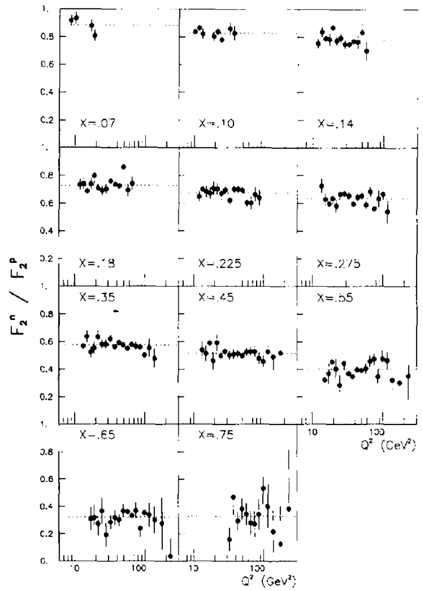
BCDMS in later years

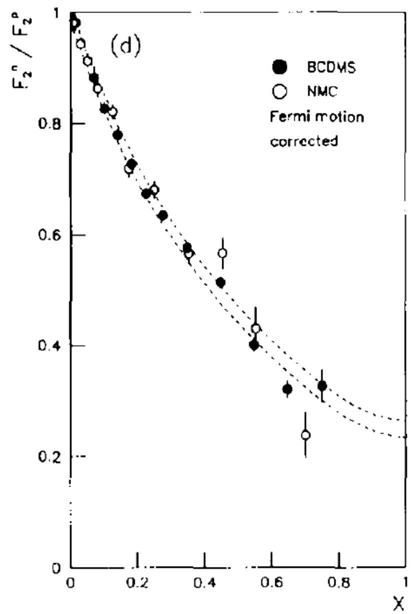
- Added low-x extension in front of supermodules for data taking from 1982



- Ran with hydrogen and deuterium targets to extract structure functions for protons and neutrons

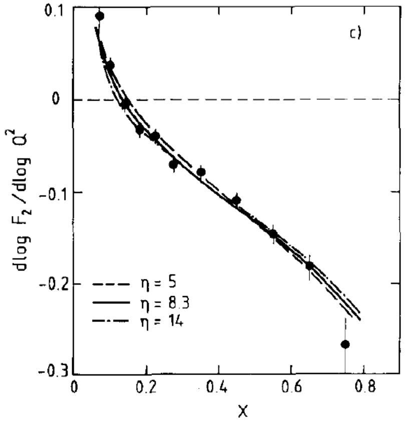




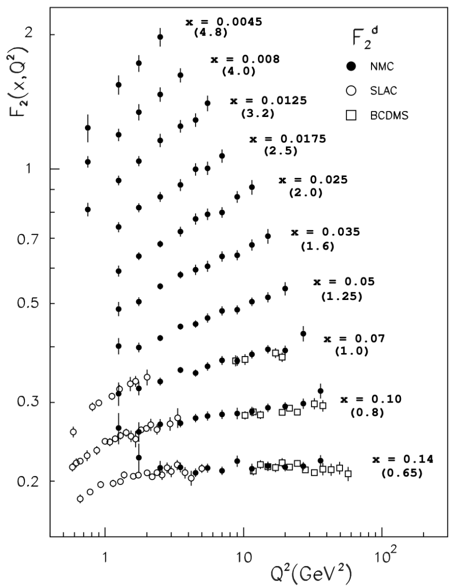


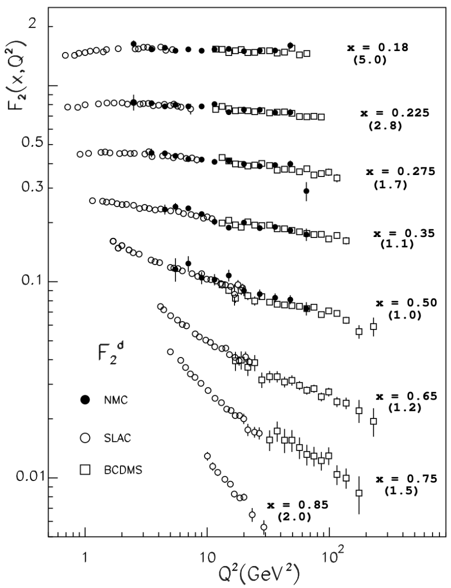
BCDMS in later years

- Principal results
  - clarified the EMC effect
  - Scale breaking observed in form predicted by QCD



  - Structure functions well measured and in agreement with NMC and SLAC experiments

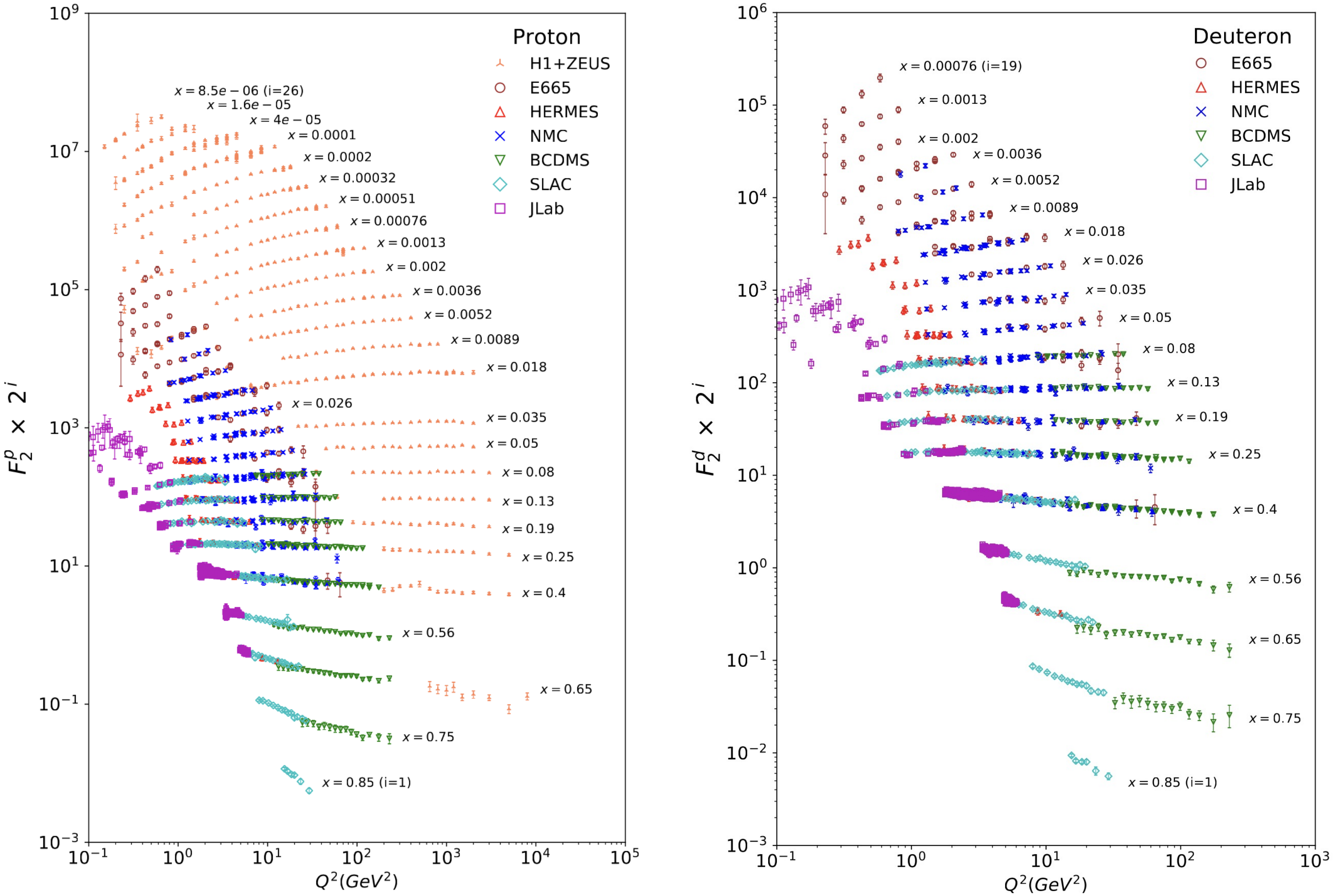




NMC results from the 1990's

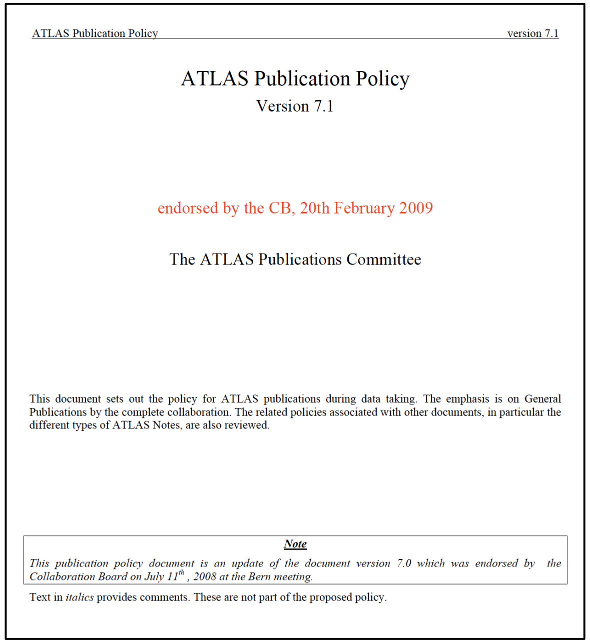
Current state of the art (PDG 2022)

- The colliders have revolutionized structure function determination
  - Especially at very low x and high Q^2
- Fixed target experiments still contribute at high x and moderate Q^2
  - And for the deuteron



Max comes to ATLAS

- Max joined ATLAS in early 2007
  - Had just become a senior professor at Liverpool
  - A well-known expert on deep inelastic scattering and structure functions from his work on the H1 experiment at HERA
    - Author of many reviews on the subject
    - Frequent conference raporteur
  - Know for his leadership abilities as spokesman of H1 experiment
- Identified immediately by ATLAS management for senior roles
  - Deputy Chair of Publication Committee 2007 – 2008
  - Chair of Publication Committee 2008 – 2009
    - Critical in 2007-08 shortly before data taking was to begin
    - To reach common agreement on publication procedures for 3000 people
      - Types of publications
      - Who signs them?
      - How are they developed and reviewed internally?
      - Where are they published?
  - I had the pleasure of working with Max on PubCom and followed him as Chair


ATLAS Publication Policy version 7.1

ATLAS Publication Policy
Version 7.1

endorsed by the CB, 20th February 2009

The ATLAS Publications Committee

This document sets out the policy for ATLAS publications during data taking. The emphasis is on General Publications by the complete collaboration. The related policies associated with other documents, in particular the different types of ATLAS Notes, are also reviewed.

Note

This publication policy document is an update of the document version 7.0 which was endorsed by the Collaboration Board on July 11th , 2008 at the Bern meeting.

Text in *italics* provides comments. These are not part of the proposed policy.

Max in ATLAS

- A comprehensive report was needed on the technical performance and physics capability of the "as built" detector
  - The "CSC book" (Computing Service Challenge)
  - Publication Committee made responsible for the report
  - Grew to 2 volume report
    - First volume of ~ 700 pages on the technical performance
      - Charged particle tracking
      - Electron and photon measurements
      - Muon measurements
      - Jet measurements
      - B-quark identification
      - Trigger
    - Second volume of ~ 1,100 pages on the performance for physics measurements
      - Standard model processes
      - Top quark measurements
      - B-quark physics
      - Higgs boson searches and measurement
      - Search for supersymmetry
      - Search for other exotic processes
  - Editors and reviewers identified in April 2008
  - Initial target for all the pieces was July 2008

Max at ATLAS week in Berne

The CSC book 'exercise' has illustrated that in real life rules need to stand but also to be adapted to what is required. The goal is to release the CSC book for print in September. This is possible if all involved continue to work hard and coherently.

Chapter Editors and PubComm Referees

Chapter	Chapter Editors	Pub Comm Referees
Introduction	K Jakobs D Charlton T Kluge	
Flavour tagging CP	L Vacavant G Watts	
Jet/Etmiss/Tau CP	W Mader J Proudfoot	J Pilcher NN
Muon CP **and** Tracking (2 chapters)	O Kortner C Schiavi S Haywood	
E/gamma CP	D Froidevaux D Zerwas	D Fournier A Weidberg
Trigger	A Brandt S Xella	J Haller NN
Standard Model	L di Ciaccio T LeCompte	A Goshaw U Klein
Top	M Bosman P Ferrari	A Onofre M Schumacher
Higgs	R Mazini W Murray	B Mansoulie NN
Exotics	F Ledroit G Brooijmans	
SUSY	D Costanzo A Barr	D Pallin C Troncon
B Physics	S Hassani M Smizanska	M Wilson B Wosiek

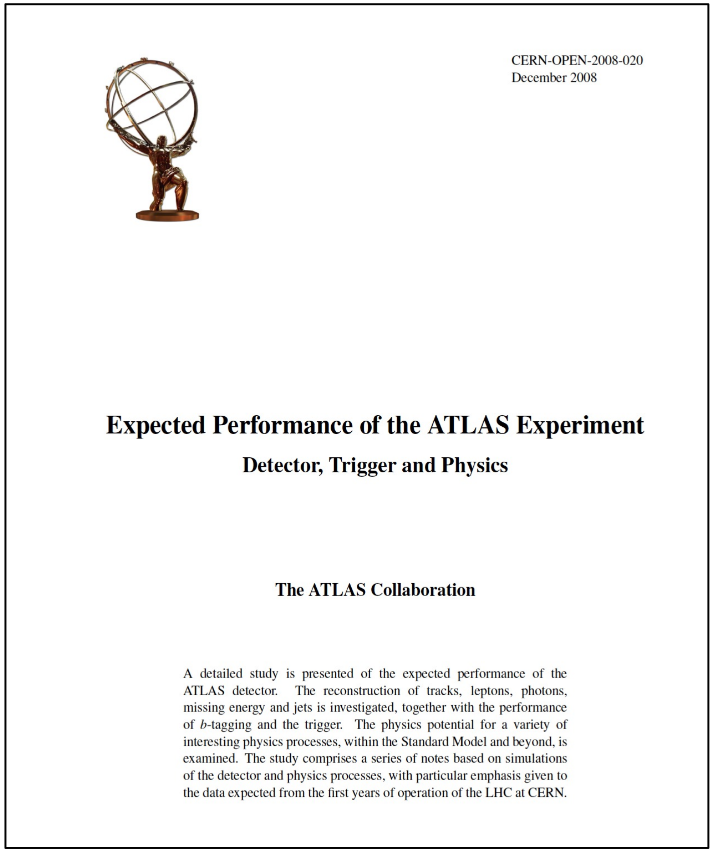
Max in ATLAS

- First data taking had been expected in 2008-9
  - Plans upset by “the magnet incident” in Sept. 2008

- Failure of bus bar splice between two dipole magnets at 9.3 kA
  - Electrical arc burned through cryostat and vaporizing LHe produced a pressure wave knocking magnets off their stands
  - 53 magnets had to be replaced and 2.8 km of vacuum pipe cleaned
- Repairs and improvements handled in very professional way
- First collisions delayed until 2010

Max in ATLAS

- The heroic task was successfully completed in Dec. 2008
  - Pressure somewhat relieved by the “magnet incident”
  - Max and Uta carried a big load
- Other PubCom accomplishments under Max
  - Web-based reviewing capability for publications
  - Guide to preparing publications
  - Creation of ATLAS style guide for text
  - Establishment of ATLAS style for plots
  - Creation of ATLAS LaTeX environment for publications
- Max helped lay the foundation of a remarkably productive scientific enterprise



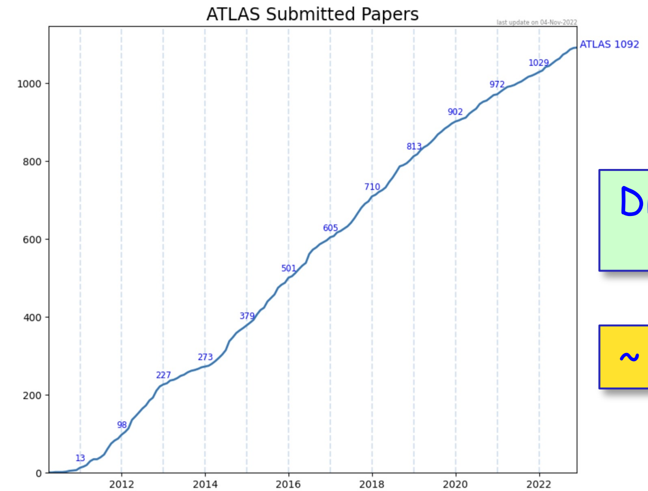
CERN-OPEN-2008-020
December 2008

Expected Performance of the ATLAS Experiment

Detector, Trigger and Physics

The ATLAS Collaboration

A detailed study is presented of the expected performance of the ATLAS detector. The reconstruction of tracks, leptons, photons, missing energy and jets is investigated, together with the performance of *b*-tagging and the trigger. The physics potential for a variety of interesting physics processes, within the Standard Model and beyond, is examined. The study comprises a series of notes based on simulations of the detector and physics processes, with particular emphasis given to the data expected from the first years of operation of the LHC at CERN.



Discovery of the Higgs boson in 2012
- Crowning achievement for the LHC

~ 7.1 papers per month over 13 years

At awarding of Breakthrough Prize in Fundamental Physics 2013

Max in ATLAS

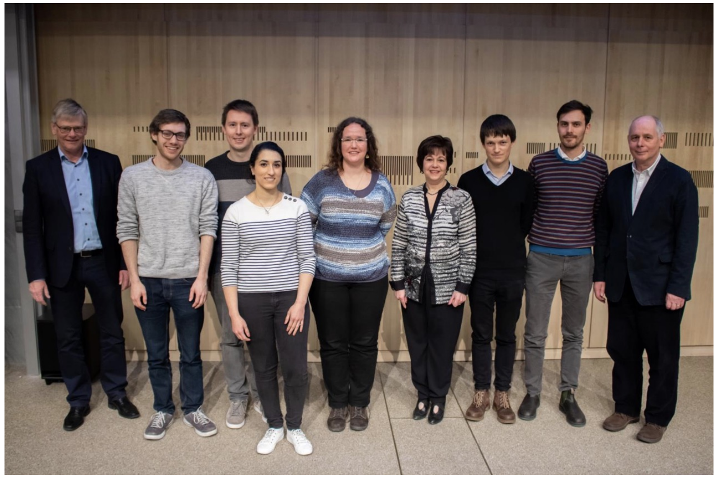
- Many physics activities
  - Leadership of the Liverpool group
    - Ongoing ATLAS work, R&D and upgrades planning, “the future”
  - Guidance of postdoctoral physicists and students
  - Participation in physics analyses
  - Service on editorial boards for papers

- Elected to serve as chair of the ATLAS Collaboration Board
  - Deputy 2017
  - Chair 2018, 2019
    - I had the pleasure of working with Max as a member of his advisory committee
  - Deputy 2020
- Represented the collaborating institutions in the management of the experiment
  - Responsible for ATLAS policies and procedures
  - Chair participates in biweekly meetings of the Executive Board
  - Responsible for election of spokesperson and other members of ATLAS executive group
  - Awards
    - ATLAS Outstanding Achievement Awards
    - ATLAS PhD thesis awards

Max in ATLAS

ATLAS Thesis Award 2017

ATLAS Thesis Award 2018



ATLAS Outstanding Achievement Awards 2018

Max, encouraging and rewarding outstanding work.

Conclusions

- A pleasure to work and interact with Max over more than 40 years
  - Many professional accomplishments
  - Many personal interactions
- I look forward to many more
  - Lots of physics questions still to be answered