‘Don Perkins and Neutral Currents’

Professor Dieter Heidt
Emeritus Professor
DESY

dieter.haidt@desy.de

Don Perkins
and the
Neutral Currents

Dieter Haidt

DESY, Hamburg

Memorial Meeting at Oxford, March 14, 2024

How Don became a ν-physicist

- Meeting at CERN 1959 for preparing physics at the ISR
  Don was invited as **expert in cosmic ray physics**

    ISR : 1964 approved and 1971 start running

- ν beams at CERN and BNL open a new era in weak interactions

    step by an order of magnitude in energy

- Colin Ramm invited Don to participate in the CERN neutrino program

    ready for runs in **improved** ν-beam at CERN PS with 1m HLBC

- Don presented the first neutrino data at SIENA 1963
  including the first search for weak neutral currents

Don's 1st search for Neutral Currents

Perkins presented at SIENA

11 events with identified hadrons

all of low energy

Problem

the intrinsic neutron background

$\nu N \rightarrow \mu + \mathbf{n} + X$

n interacts in chamber and simulates NC

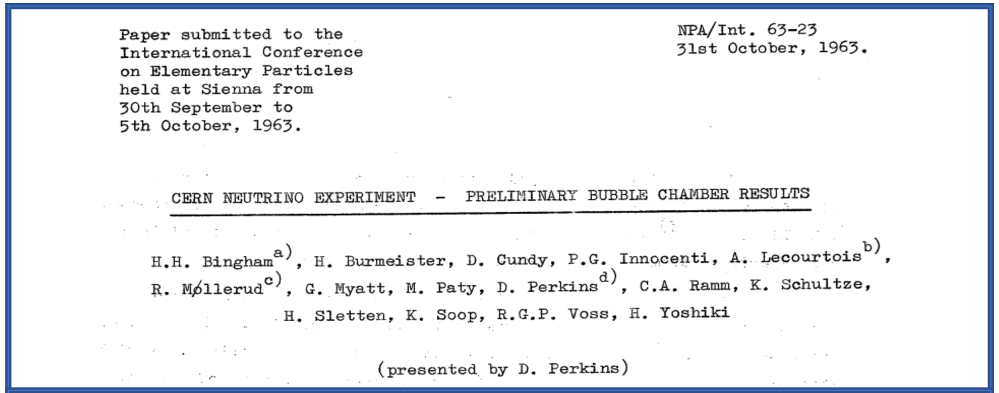
$L_{chamber} \approx \lambda_n$ (neutron interaction length)

Result

upper limit : $\frac{\nu p \rightarrow \nu p}{\nu n \rightarrow \mu p} < 5\ \%$

Impact

are there really weak neutral currents ?



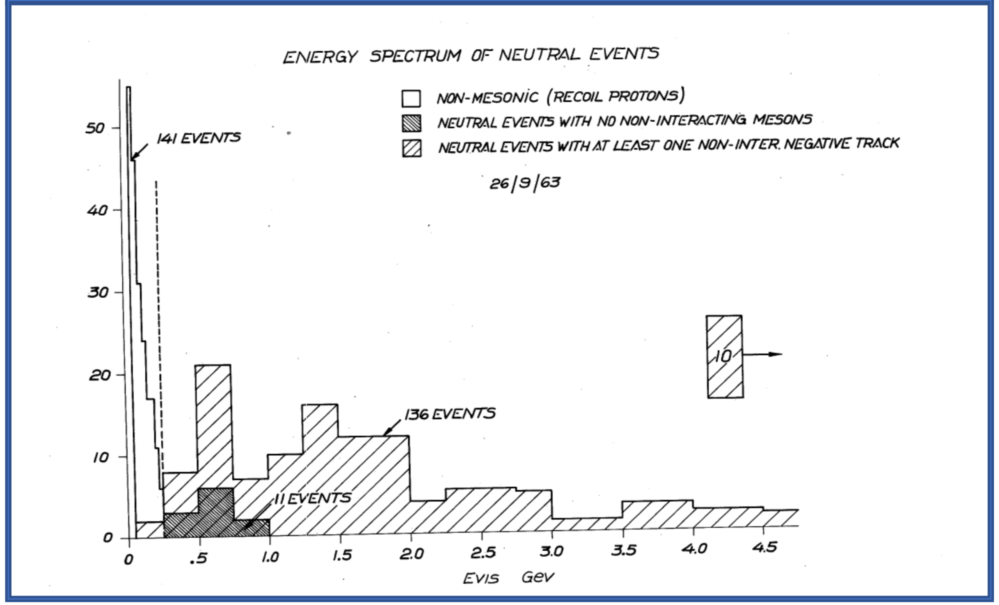
Paper submitted to the International Conference on Elementary Particles held at Sienna from 30th September to 5th October, 1963.

NPA/Int. 63-23
31st October, 1963.

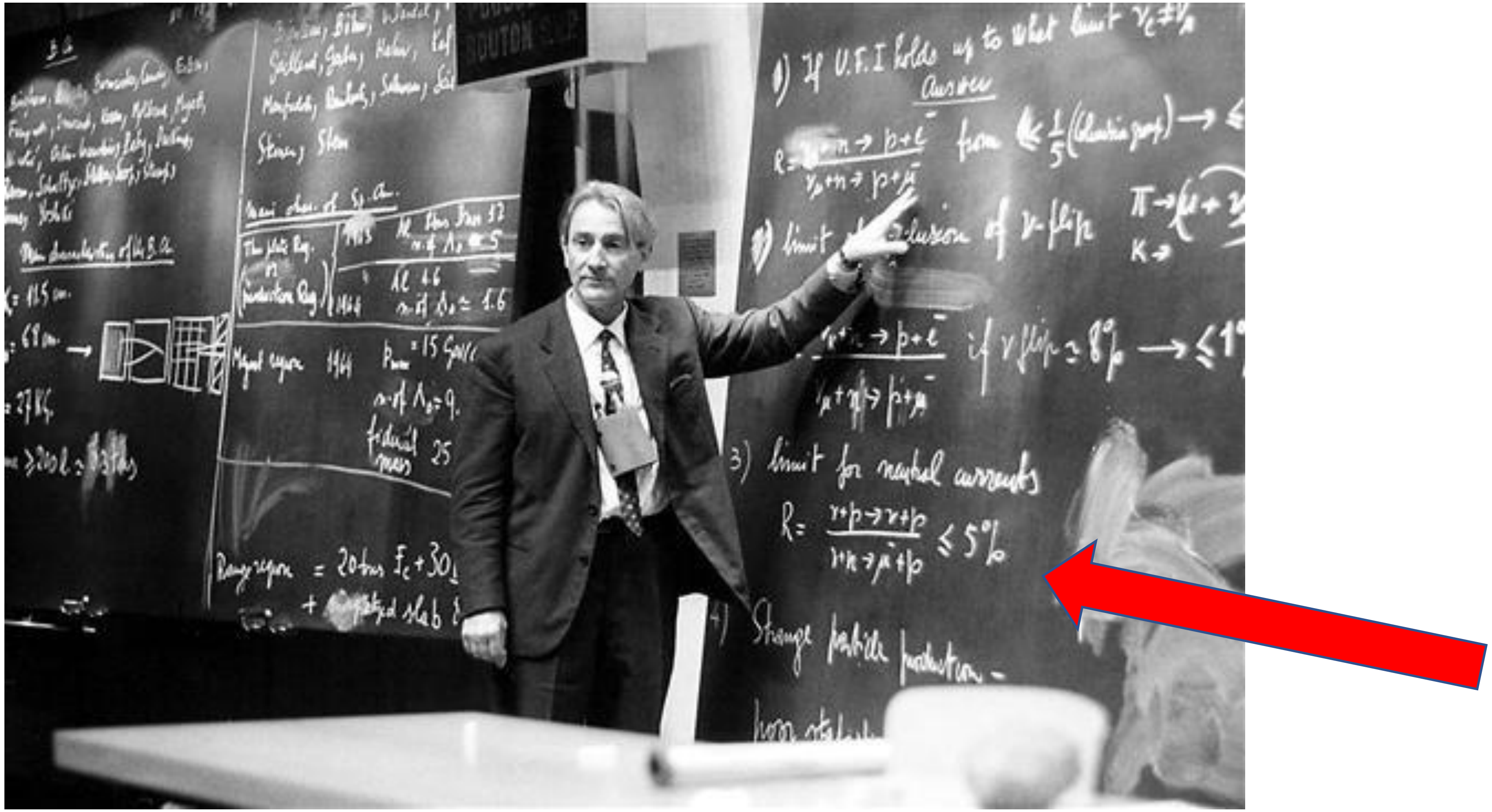
CERN NEUTRINO EXPERIMENT - PRELIMINARY BUBBLE CHAMBER RESULTS

H.H. Bingham[a], H. Burmeister, D. Cundy, P.G. Innocenti, A. Lecourtois[b], R. Møllerud[c], G. Myatt, M. Paty, D. Perkins[d], C.A. Ramm, K. Schultze, H. Sletten, K. Soop, R.G.P. Voss, H. Yoshiki

(presented by D. Perkins)



Bernardini reporting ν-results



Lagarrigue's dream

Conclusion of Siena Conference : ν-physics has a big potential

new field with many new topics

present limitation : low statistics

Solution : build a large bubble chamber

heavy liquid : big target mass -> many events

cylindrical shape with **long** axis : good distinction $\mu^{\pm} \leftrightarrow \pi^{\pm}$

μ not identified (no need since NC unknown)

subtraction method : $\mu^{\pm}$ -candidate - # identified $\pi^{\pm}$

Preparing physics with Gargamelle at Milan

The Gargamelle Collaboration : 7 european laboratories

Aachen, Brussels, CERN, École Polytechnique, Milan, Orsay and UC London

Experience in running a bubble chamber and evaluating of a ν-experiment

The Milan Meeting : Discuss physics program in October 1968

Dominant topic : the discovery of the proton's substructure at SLAC

What would a ν-experiment contribute ?

Probe : SLAC : electromagnetic current ⟷ GGM : charged weak current

new tools : ν and $\bar{\nu}$

Explore proton structure (see talk by Chris Llewellyn – Smith)

Set up priority list (W…NC) for future ν-experiment

Proposal for a ν-experiment in Gargamelle

CERN-TCC/70-12 March 16, 1970

i) Total cross-sections in the high energy region, for ν and $\bar{\nu}$;

ii) Inelastic continuum excitation of the hadronic amplitude-structure factors and "partons";

iii) Existence of the intermediate W-boson;

iv) Coupling constants for diagonal and non-diagonal weak interactions;

v) Neutral currents.

$\sigma_{tot}(E_\nu)$

DIS

W

GGKL

NC

The Gargamelle Experiment

Dec 1970 : first expansion of the chamber

Mar 1971 : start data taking in ν_μ- and $\bar{\nu}_\mu$- wide band beam

Initial aim : measure total cross section and investigate nucleon structure

Data recorded on film and distributed to 7 laboratories

Strict rules for scanning and measuring established before start in 1971

Event categories :

A. Events with muon candidate : the regular $\nu + N \rightarrow \mu$+anything

B. Events with only identified hadrons : needed for neutron background

C. Events consisting of 1 or more protons

D. Events with isolated electron or photon

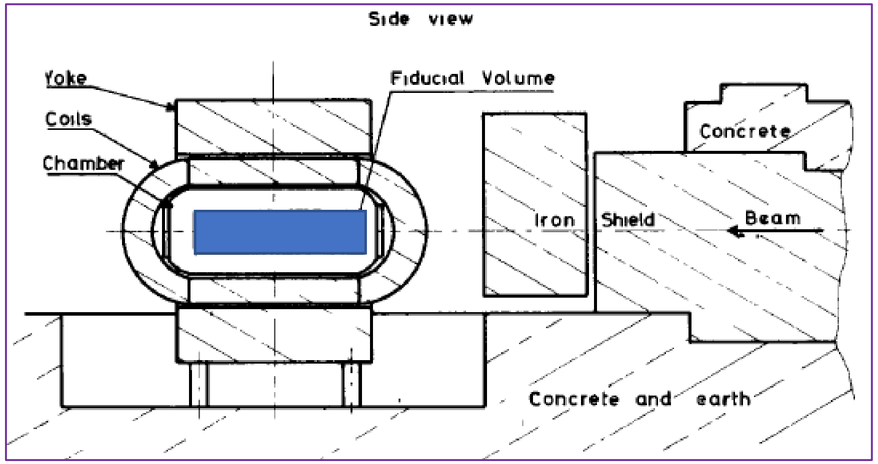
The Bubble chamber

The beginning

The end

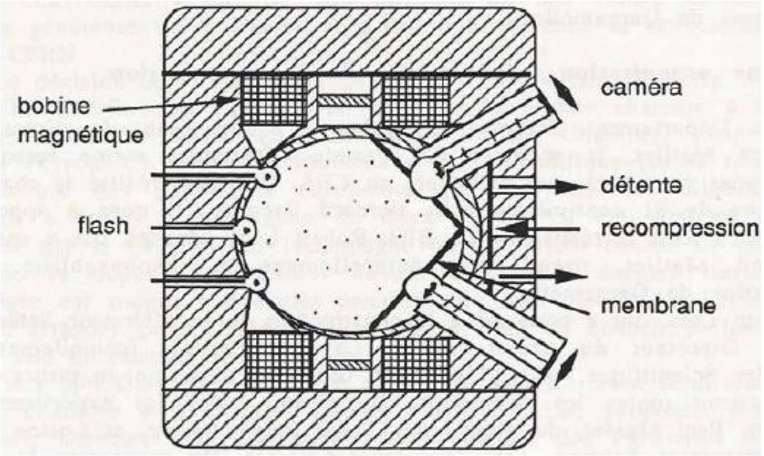
Some technical Details

The setup : longitudinal section



The body is inside magnet coil and iron yoke
Muon shield : 22m iron
Length 4.8 m and diameter 1.8 m ($\ll \lambda_{int}$)
Filling : heavy liquid freon density 1.5 g/cm^3
Fiducial volume 3 m^3 → big target mass
High detection efficiency for the final state particles

The optical system



Tracks illuminated by flashlight
Recorded by 2 rows of 4 cameras (fisheye optics)
Images are transported through 2m iron yoke

Development of special scan tables

Priorities revisited

Breakthrough in theory : 1971 t'Hooft & Veltman : proof of renormalization

Weinberg's model of leptons attracts attention

Weak and electromagnetic interactions on the same footing → expect NC

Collaboration meeting at Paris in March 1972 :

1. The key-role of category B : **if** NC exist, then they are already in category B
2. The Milan group looks at the events with hadrons only and observes that they show no exponential falloff as expected if neutrons dominate
3. Decision to start dedicated NC search for leptonic and hadronic channels

Analysis of the films simultaneously for Charged and Neutral Currents

Perkins' Memo

- Memo written immediately after the Paris meeting
- Recapitulation of the knowledge and experience gained in the previous experiments with freon and propane
- Neutrino meeting CERN 69-28

  with Gerald Myatt's background study
- Interpretation within the simple linear model

MEMO

To: Gargamelle ν-Collaboration

From: D.H. Perkins 14th April, 1972

NEUTRAL CURRENTS

This note is written in connection with the study, in Gargamelle, of the question of neutral hadronic weak currents. We re-capitulate the old data in the 1.2m HLBC, to emphasize once more that (i) there is probably an appreciable neutral-current effect, (ii) conditions for proving the existence of neutral currents in Gargamelle are much more favourable than in the 1.2m chamber, and (iii) that there is (yet another) reason for running GGM with C_3H_8 at the first opportunity.

Appearance of neutron interactions

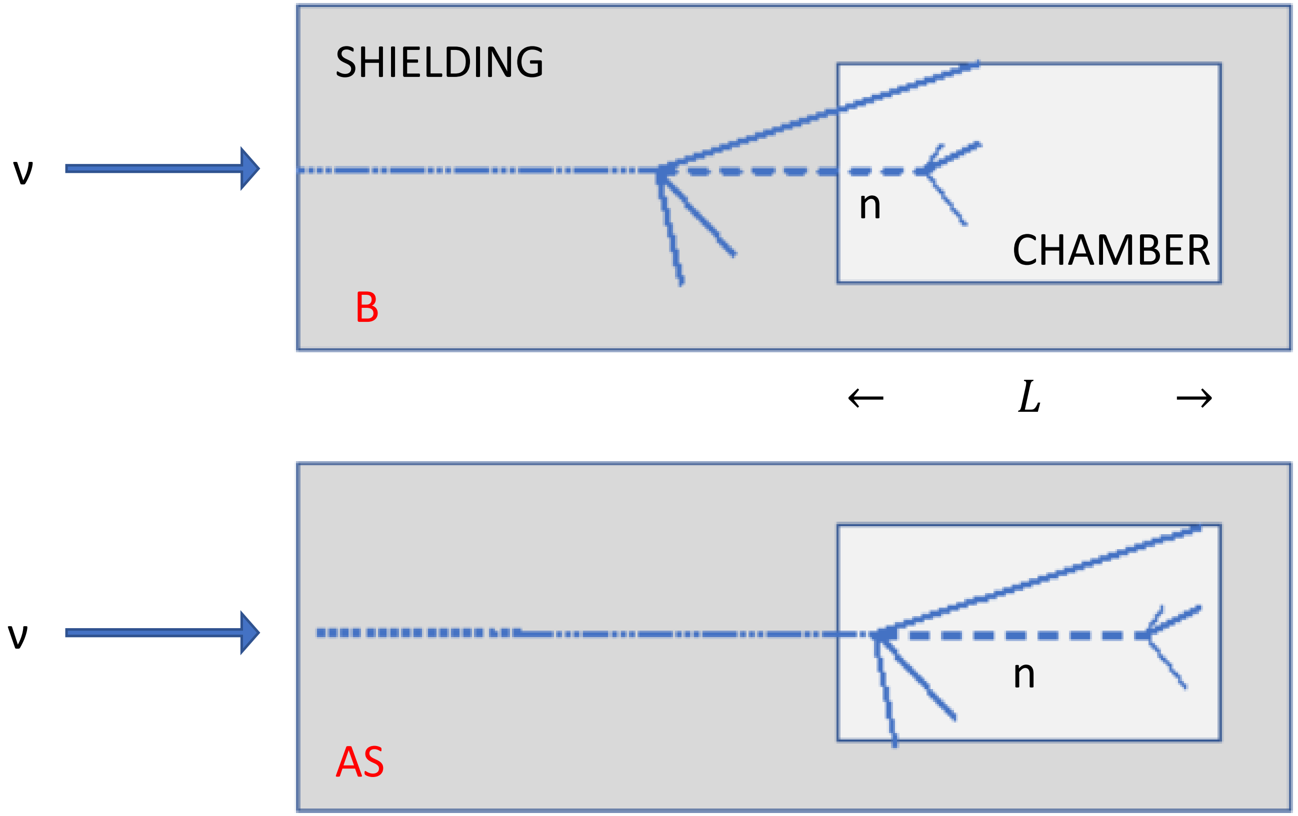
Linear Model

Neutron emitted in a ν-interaction travels along the ν-direction

Predict the ratio of nonassociated (B) and associated n-interactions (AS)

z= L/λ(ch)

$$\frac{B}{AS} = \frac{\rho\lambda(sh)}{\rho\lambda(ch)} \frac{1-e^{-z}}{z-1+e^{-z}}$$



Lessons from previous ν-experiments

Runs in CERN PS wide band neutrino beam with 1m HLBC

Freon 1963/4 data fully analysed by Enoch Young (Don's PhD student) : CERN 67-12

Propane 1967 : C_3H_8 (with free and bound protons)

An important insight **:** 1963 NC/CC underestimated : single unidentified positive tracks taken as π^+

1970 : σ(νp→ νp)/ σ(νn→ μ^-p) < 0.12 ± 0.06 and σ (νp→ ν π^+ n)/ σ(νn→ μ^- π^+ p) < 0.08 ± 0.04

D.Cundy et al: PL 31B(19790)478

Don Perkins' estimate of neutron background

Use calculated B/AS 1.2 resp 5.1 and the observed associated events → predict #B = B/AS #AS
#B observed vs #B predicted: freon 38 ± 6 ↔ 12 ± 4 and propane 79 ± 9 ↔ 31 ± 13
Excess is not conclusive, since the model is too simple (geometry, E- and θ-dependences not included)

Perkins' Conclusions

- The existing data are indicative, but not conclusive
- The prospects for a discovery with Gargamelle look promising
- Don's warning : Watch the neutron background !

> Although I know that many people in CERN are working on this problem, there appear to be innumerable pitfalls in the analysis and a thorough discussion at an early stage would be well worthwhile.

- Clear strategy for the analysis of the Gargamelle data

  strengthen cutoff in hadronic energy to 1 GeV

The Challenge

Signal : ν induced interaction without a charged lepton in the final state

Background : all processes faking the signal
known : neutron interactions are crucial
must prove : #background events $\ll$ #candidates

Competition:
Gargamelle $\longleftrightarrow$ HPW = Harward-Pennsylvania-Wisconsin

Feel the tension between being first and being right

A welcome Event : great excitement

360.000 pictures scanned
Isolated forward *electron* found
at Aachen Dec 1972.
Originally misclassified as $\mu+\gamma$
Anecdote : Faissner-Perkins

Interpretation: $\bar{\nu}_\mu \, e \to \bar{\nu}_\mu \, e$

Properties of electron :

- **Identification** : unique by bremsstrahlung and curling
- **Energy** 385$\pm$100 MeV
- **Angle** 1.4 $\pm$ 1.4 degree

Background : 0.03 $\pm$0.02

$\nu_e \, n \; \to e + p$
$(proton\ invisible)$

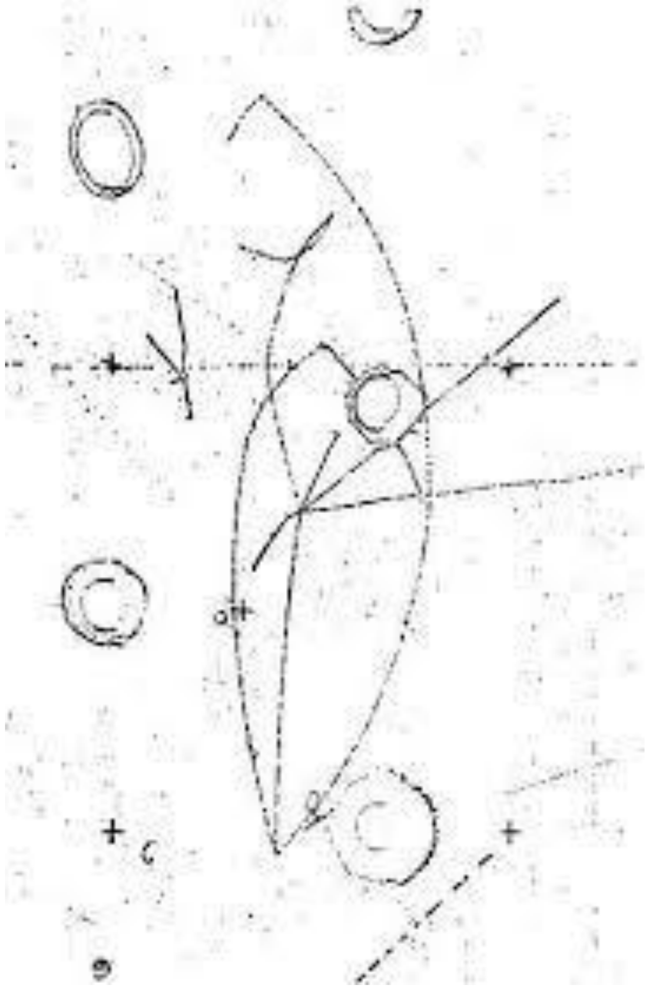
Submitted to Phys Lett : 2/7/1973

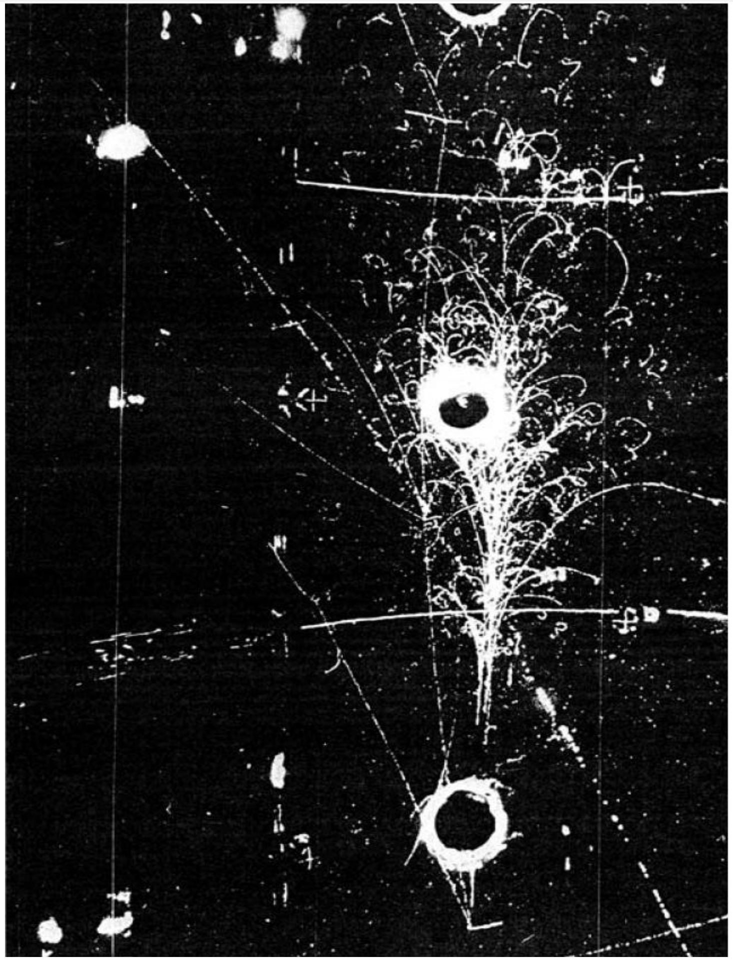
$\bar{\nu}_\mu$**-beam**

Celebrating the Aachen Event

- Helmut Faissner and Klaus Schultze at the scan table with collaborators
- Missing : the student who reclassified a *μ + overlaid γ* as *isolated e + bremsstrahlung*
- Faissner was head of the CERN ν sparkchamber experiment 1963/4
- Vivid discussions Faissner-Perkins at the Gargamelle Collaboration meetings

Two NC candidates





The Result of the NC Search

Collaboration meeting in March 1973

Lagarrigue presented the analysis based on

83(ν)+207(ν̄) kpix

NC sample

leptonic channel : one

hadronic channel : 102 in ν and 64 in ν̄ film

CC sample for comparison

ignore μ, criteria for hadron final state as for NC

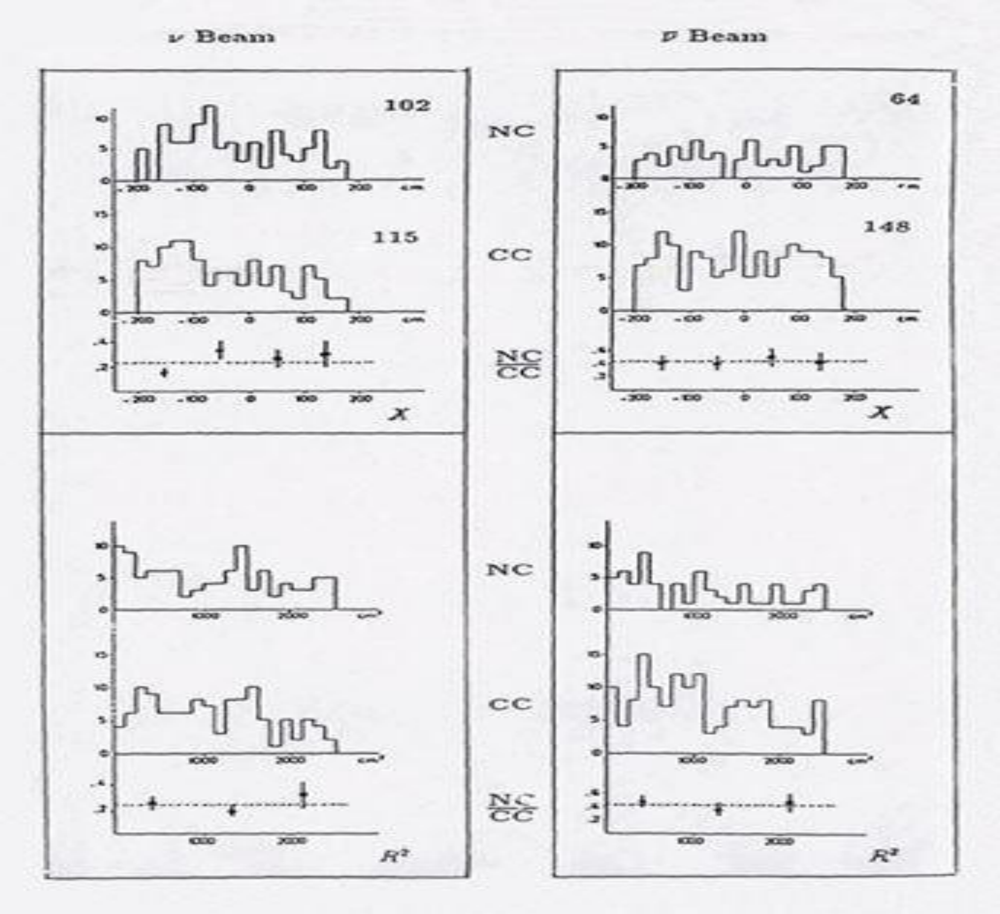
Expectation for **NC/CC**

ν → NC/CC flat along chamber axis

n → exponential fall off (λ≪ L_{GGM})

ORSAY Monte Carlo

Intriguing result : discovery ?



Two Pitfalls

The Don's warning comes true !

1. Neutrons make cascades

   #n* ~ cascade length

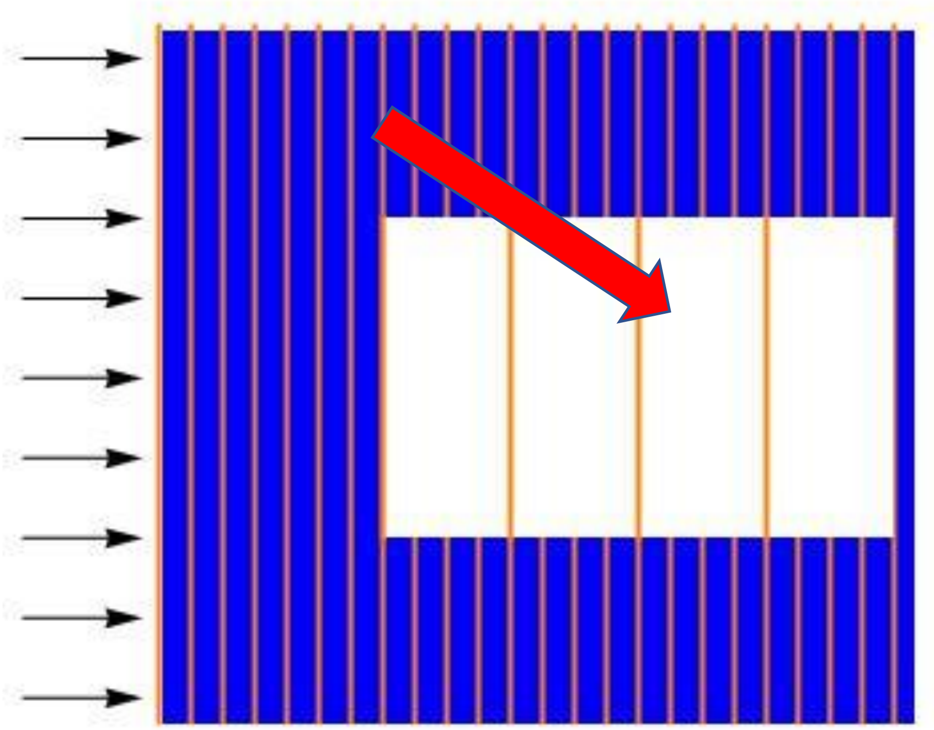
2. ν-flux is broad

   huge amount of ν-interactions outside chamber (i.e. sources of neutrons)

Damped euphoria :

No distinctive feature left

back to prove #n* ≪ #NC



Predicting the Neutron Background became my preoccupation

- The Monte Carlo method : only way to cope with the complexity of the experiment
- Predicting the neutron flux requires
  1. Geometry of the setup known
  2. Matter distribution known
  3. Neutrino flux measured
  4. Dynamics of ν-interaction measured
  5. Propagation of final state hadrons unknown – need a model
- A solution within a few weeks seemed hopeless until breakthrough

  meson component inactive → need only model for **linear nucleon cascade**

  elasticity at each interaction : $E_{out} = \lambda E_{in}$ get λ from NN-data (Fry, DH)

  cascade stops, when the entering neutron cannot produce a star with **E > 1 GeV**
- Result : Absolute prediction of neutron background

  No free parameters

The Proof

- Beginning of July 1973

  Pullia : The final AS events sample is ready : 15 (ν) and 11 ($\bar{\nu}$)

  The neutron background program is ready and predicts : B/AS = 1.0 ± 0.3

- Worst case hypothesis : **All NC candidates are background**

$$\left(\frac{B}{AS}\right)_{meas} = \frac{\#NC}{\#AS} = \frac{102}{15} = \mathbf{6.8 \pm 0.3} \quad \Longleftrightarrow \quad \left(\frac{B}{AS}\right)_{calc} = \mathbf{1.0 \pm 0.3}$$

- Reject hypothesis (both ν and $\bar{\nu}$): **new effect exists**
- Flaws ? No doubts anymore after 2 weeks of very hot discussions :

  July 19 presentation in CERN Auditorium by Musset

  July 25 submit paper to Phys.Lett

The Authors of the Discovery

Volume 46B, number 1 PHYSICS LETTERS 3 September 1973

OBSERVATION OF NEUTRINO-LIKE INTERACTIONS WITHOUT MUON OR ELECTRON IN THE GARGAMELLE NEUTRINO EXPERIMENT

F.J. HASERT, S. KABE, W. KRENZ, J. Von KROGH, D. LANSKE, J. MORFIN, K. SCHULTZE and H. WEERTS
III. Physikalisches Institut der Technischen Hochschule, Aachen, Germany

G.H. BERTRAND-COREMANS, J. SACTON, W. Van DONINCK and P. VILAIN[*1]
Interuniversity Institute for High Energies, U.L.B., V.U.B. Brussels, Belgium

U. CAMERINI[*2], D.C. CUNDY, R. BALDI, I. DANILCHENKO[*3], W.F. FRY[*2], D. HAIDT, S. NATALI[*4], P. MUSSET, B. OSCULATI, R. PALMER[*4], J.B.M. PATTISON, D.H. PERKINS[*6], A. PULLIA, A. ROUSSET, W. VENUS[*7] and H. WACHSMUTH
CERN, Geneva, Switzerland

V. BRISSON, B. DEGRANGE, M. HAGUENAUER, L. KLUBERG, U. NGUYEN-KHAC and P. PETIAU
Laboratoire de Physique Nucléaire des Hautes Energies, Ecole Polytechnique, Paris, France

E. BELOTTI, S. BONETTI, D. CAVALLI, C. CONTA[*8]. E. FIORINI and M. ROLLIER
Istituto di Fisica dell'Università, Milano and I.N.F.N. Milano, Italy

B. AUBERT, D. BLUM, L.M. CHOUNET, P. HEUSSE, A. LAGARRIGUE, A.M. LUTZ, A. ORKIN-LECOURTOIS and J.P. VIALLE
Laboratoire de l'Accélérateur Linéaire, Orsay, France

F.W. BULLOCK, M.J. ESTEN, T.W. JONES, J. McKENZIE, A.G. MICHETTE[*9] G. MYATT[*] and W.G. SCOTT[*6,*9]
University College, London, England

Received 25 July 1973

Volume 46B, number 1 PHYSICS LETTERS 3 September 1973

SEARCH FOR ELASTIC MUON-NEUTRINO ELECTRON SCATTERING

F.J. HASERT, H. FAISSNER, W. KRENZ, J. Von KROGH, D. LANSKE, J. MORFIN, K. SCHULTZE and H. WEERTS
III Physikalisches Institut der technischen Hochschule, Aachen, Germany

G.H. BERTRAND-COREMANS, J. LEMONNE, J. SACTON, W. Van DONINCK and P. VILAIN[*1]
Interuniversity Institute for High Energies, U.L.B., V.U.B. Brussels, Belgium

C. BALTAY[*2], D.C. CUNDY, D. HAIDT, M. JAFFRE, P. MUSSET, A. PULLIA[*3] S. NATALI[*4], J.B.M. PATTISON, D.H. PERKINS[*5], A. ROUSSET, W. VENUS[*6] and H.W. WACHSMUTH
CERN, Geneva, Switzerland

V. BRISSON, B. DEGRANGE, M. HAGUENAUER, L. KLUBERG, U. NGUYEN-KHAC and P. PETIAU
Laboratoire de Physique des Hautes Energies, Ecole Polytechnique, Paris, France

E. BELLOTTI, S. BONETTI, D. CAVALLI, C. CONTA[*7], E. FIORINI and M. ROLLIER
Istituto di Fisica dell 'Università, Milano and I.N.F.N. Milano, Italy

B. AUBERT, L.M. CHOUNET, P. HEUSSE, A. LAGARRIGUE, A.M. LUTZ and J.P. VIALLE
Laboratoire de l'Accélérateur Linéaire, Orsay, France

and

F.W. BULLOCK, M.J. ESTEN, T. JONES, J. McKENZIE, A.G. MICHETTE[*8] G. MYATT[*5], J. PINFOLD and W.G. SCOTT[*5, *8]
University College, University of London, England

Received 2 July 1973

The Electron-Photon Symposium at BONN August 27-31, 1973

- First time that results from Weak Interaction are included.

  Since then the title was changed to **Lepton**-Photon Symposium
- Plenary session : G.Myatt presented the Gargamelle Discovery

  He included a last minute contribution by HPWF

  Data of both experiments agree
- Parallel session : talk by F. Bullock.

  Detailed discussion of the experiment and neutron background

  Intervention by Rubbia (HPW) with critical questions – we were quick to reply anecdote

  The epithany of C.N.Yang : he stood up at the end and said :

  weak neutral current have been discovered

The Disaster

Autumn 1973 :

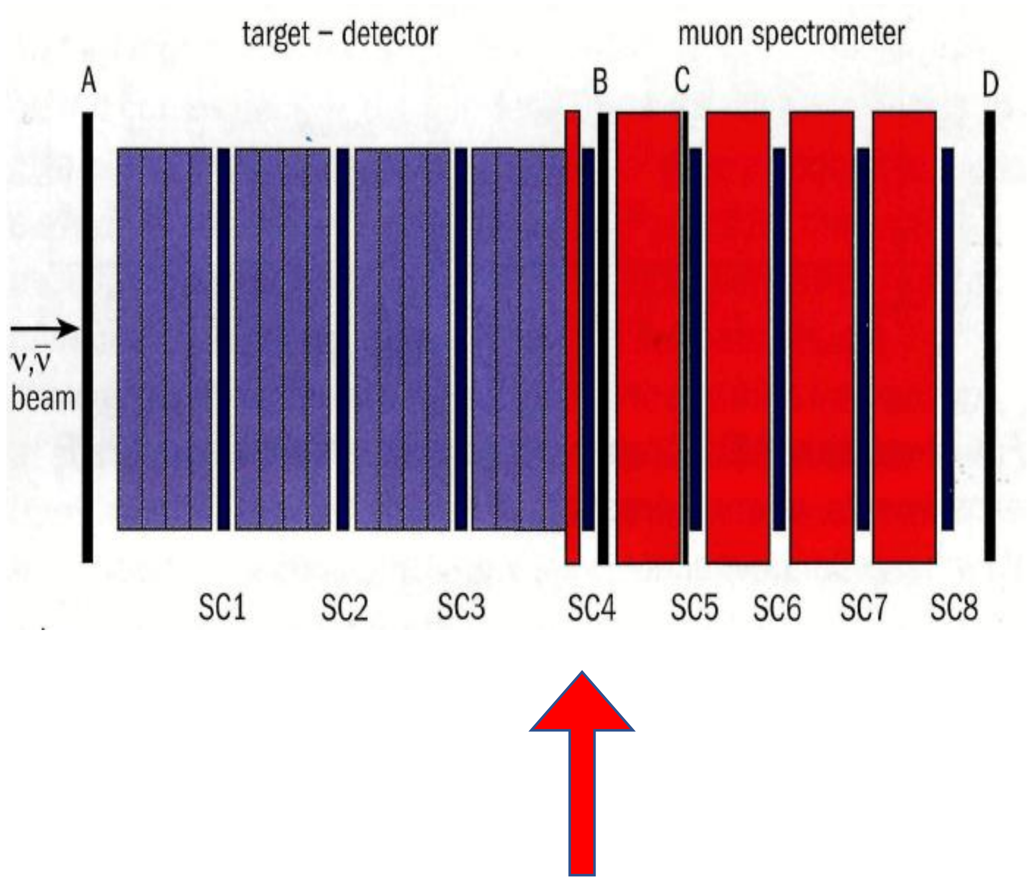
HPWF postpone publication for more statistics : introduce 13’ iron plate

Increase muon acceptance

fatal consequence : punchthrough

NC misidentified as CC : loose NC effect

Gargamelle treated with derision and critics



Perkins meets the DG Jentschke

CERN Courier : May 31, 2003

When the claim to have found neutral currents in Gargamelle was followed by the report from Fermilab that the NC/CC ratio they found was consistent with zero, many physicists … believed that the Gargamelle result must be wrong. Indeed, one senior CERN physicist bet so heavily against Gargamelle that he lost half his wine cellar. But Jentschke himself was always very supportive of the experiment … I did meet him on one occasion in the CERN lift. He told me he was worried about the Gargamelle result, because some people had told him that it could be wrong … and [that] would be very bad for CERN. My response was that, coming after the "split A2" affair, it would be an absolute disaster. However, I knew the group had gone through the event analysis many times and for almost a year we had searched intensively for some other explanation for the effects observed, without success. So I thought the result was absolutely solid, and he should just ignore rumours from across the Atlantic. I don't know if my words reassured him, but he got out of the lift with a smile on his face.

Checking the Neutron Cascade

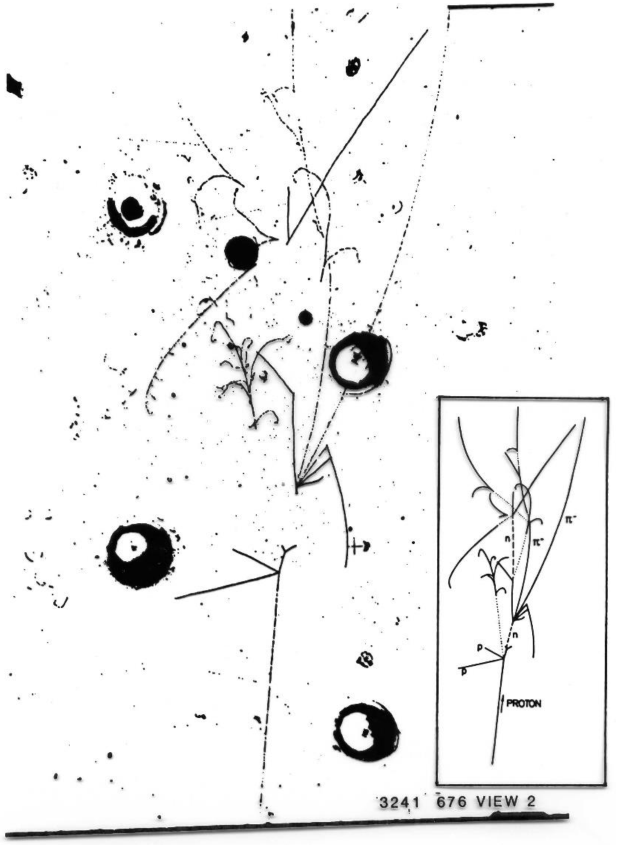
Urgent question :

Is the cascade program right or wrong ?

Expose Gargamelle to fast extracted proton pulses of 4,7,12,19 GeV from the PS and observe directly the induced cascade. 2 runs in Nov/Dec 1973

Example : A proton of 7 GeV is entering and generating a neutron cascade (event 3241 676 view2)

Predict beforehand the properties of the proton-induced cascades with the neutron background program



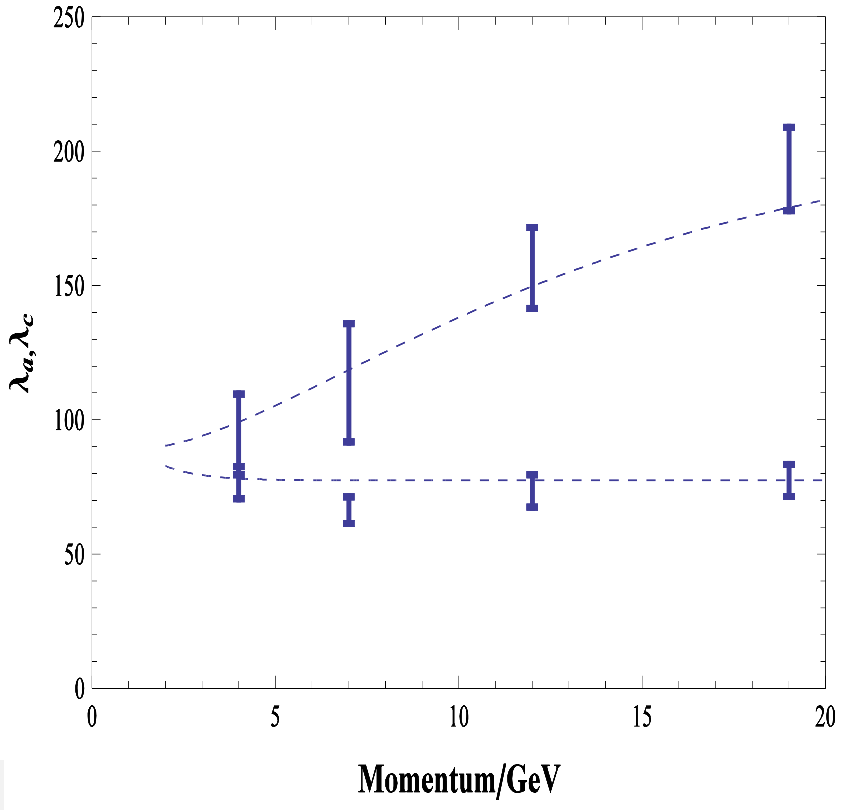
Results

Measurements

1. apparent interaction length in chamber
2. cascade length

Comparison with prediction of the cascade program (dotted lines)

Reported to APS Meeting Washington (April 1974)



All aspects of the cascade are confirmed

Final Acceptance

- Gargamelle was right
- Overwhelming evidence in Spring 1974

    Gargamelle doubled statistics in agreement with previous results

    New experiment in narrow band ν-beam by Berry Barish et al

    Single pion production in ANL 12 foot bubble chamber

    HPWF confirms the NC signal Joke : discovery of alternating currents

- The discovery of weak neutral currents by the Gargamelle collaboration stands out as a significant contribution to High Energy Physics
- CERN gained a leading role with the discovery of weak neutral currents

The Impact of the Discovery

- All major laboratories set up a long range research program to explore the new force
- Two immediate applications

  1. Gravitational collapse

     W→ $e\nu$ now also Z → νν (e,μ,τ)

  2. Predict W- and Z-masses : GSW + sin_W^2

     1973-1976 $sin_W^2 \approx 0.30 \pm 0.05$

$$M_W = \frac{\sqrt{\frac{\pi\alpha}{\sqrt{2}G}}}{\sin\theta} = \frac{37.3\ \mathrm{GeV}}{\sin\theta} \approx 70\ \mathrm{GeV}$$

- Discovery of W impossible in ν-experiments

  Cline, Rubbia and Mc Intyre propose $\bar{p}p$ collider

  Realization at CERN 1976-1981 :

  discovery of W and Z 1983

  HERA observes the W-propagator 1993

The electroweak way:

- 1973 discovery of weak neutral currents

  1973-1978 : establish GSW at Born level

  1983 discovery of gauge bosons

  1978-2012 : explore the flavor, gauge boson and Higgs sectors

  2012 discovery of the Higgs boson
- Push frontiers in

  energy → new colliders : PETRA, SPEAR, TRISTAN, LEP, HERA, LHC

  precision → large calorimeters
- Large collaborations evaluate omnipurpose detectors
- Large data sets and the world wide web

Result The Standard Model a gauge theory in full glory

The admired Don Perkins

Physics is simple

it is just that many physicists

try and make it complicated