

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.

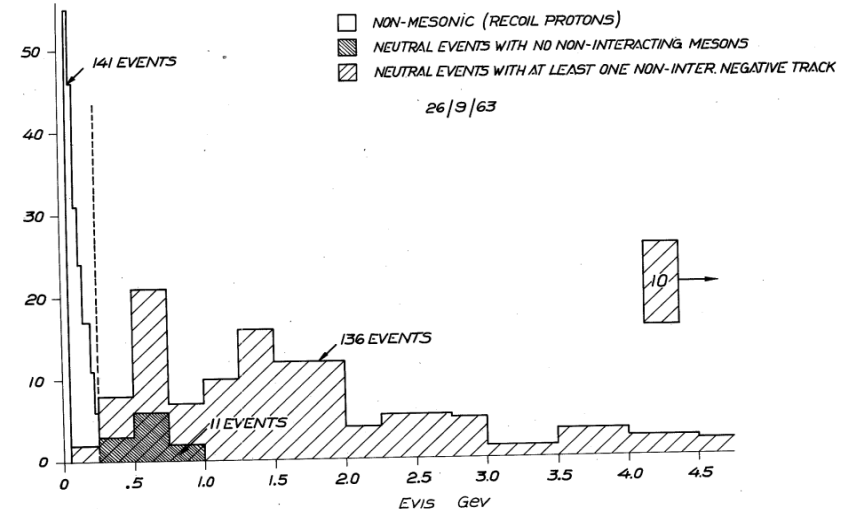
NPA/Int. 63-23
31st October, 1963.

CERN NEUTRINO EXPERIMENT - PRELIMINARY BUBBLE CHAMBER RESULTS

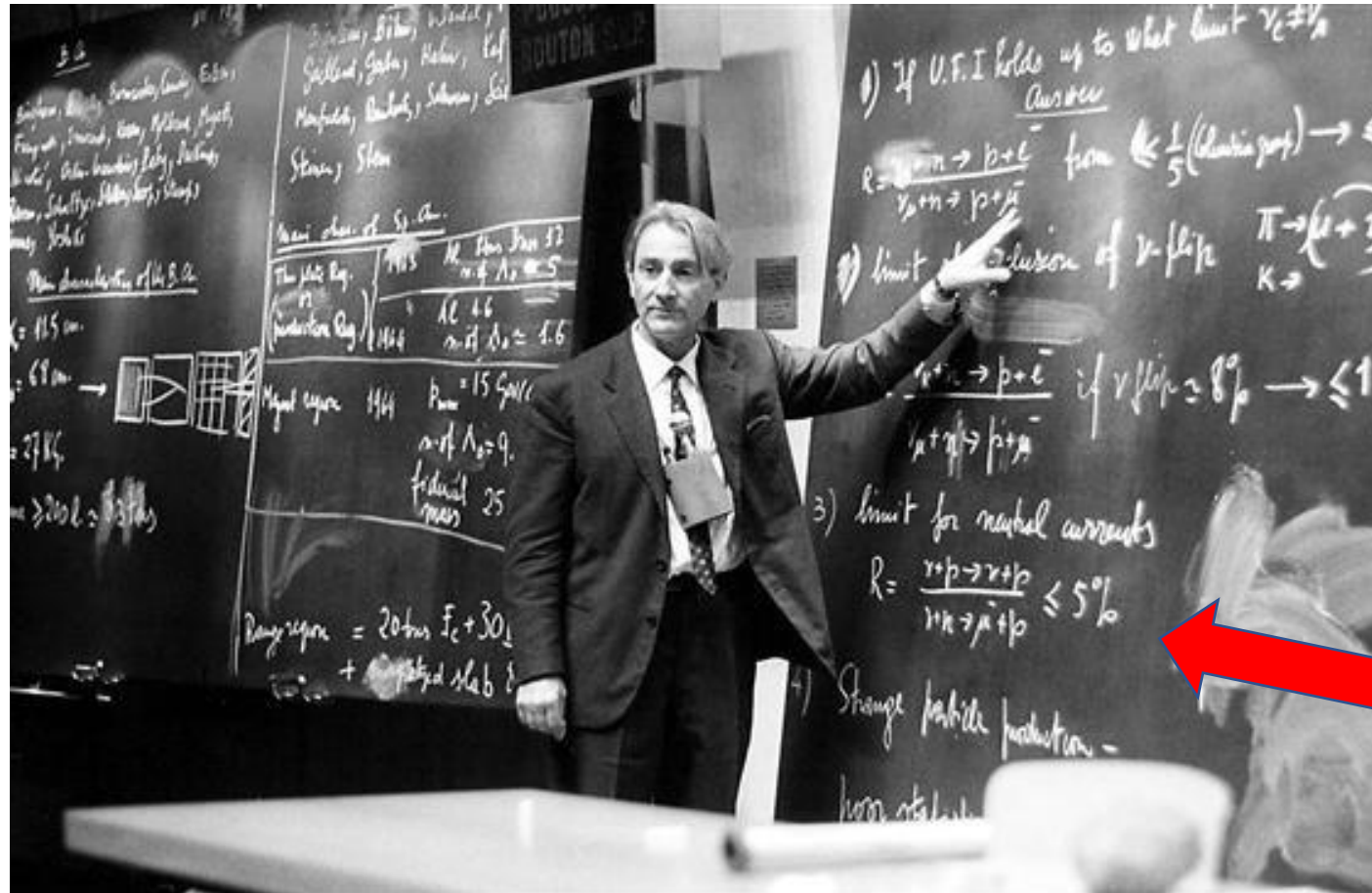
H.H. Bingham^{a)}, H. Burmeister, D. Cundy, P.G. Innocenti, A. Lecourtois^{b)},
R. Møllerud^{c)}, G. Myatt, M. Paty, D. Perkins^{d)}, C.A. Ramm, K. Schultze,
H. Sletten, K. Soop, R.G.P. Voss, H. Yoshiki

(presented by D. Perkins)

ENERGY SPECTRUM OF NEUTRAL EVENTS



Bernardini reporting v-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 \rightarrow many events

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

μ not identified (no need since NC unknown)

subtraction method : μ^\pm -candidate - # identified π^\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 $\nu+N \rightarrow \mu+\text{anything}$ |
| 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

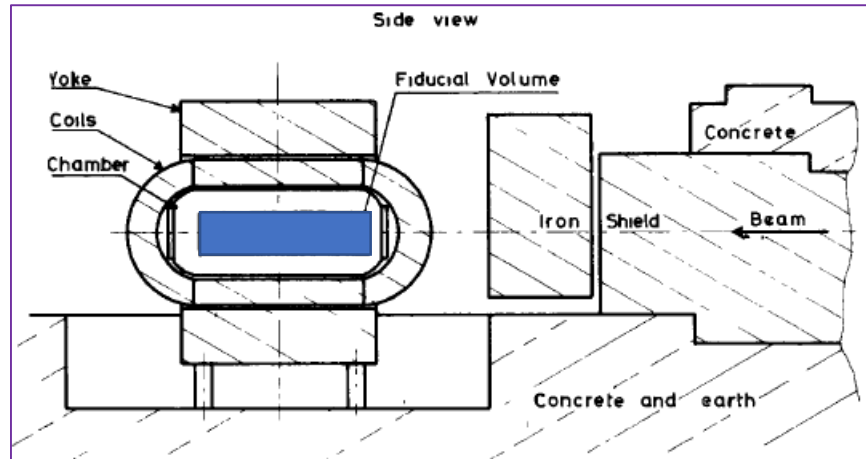


The end



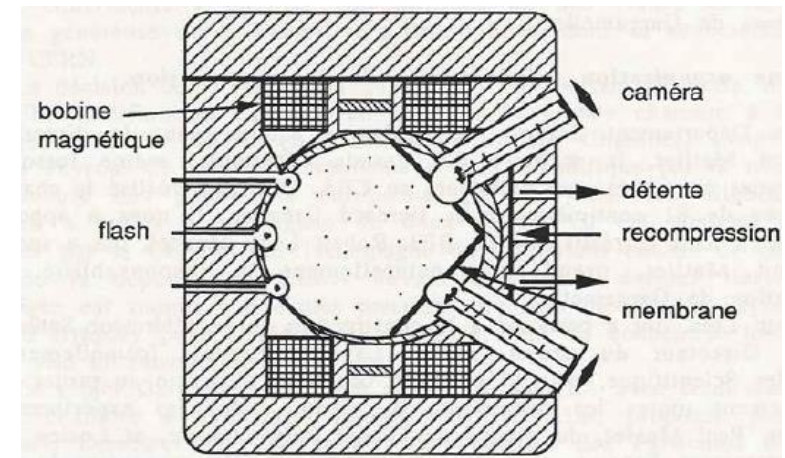
Some technical Details

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 $3 \text{ m}^3 \rightarrow$ 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

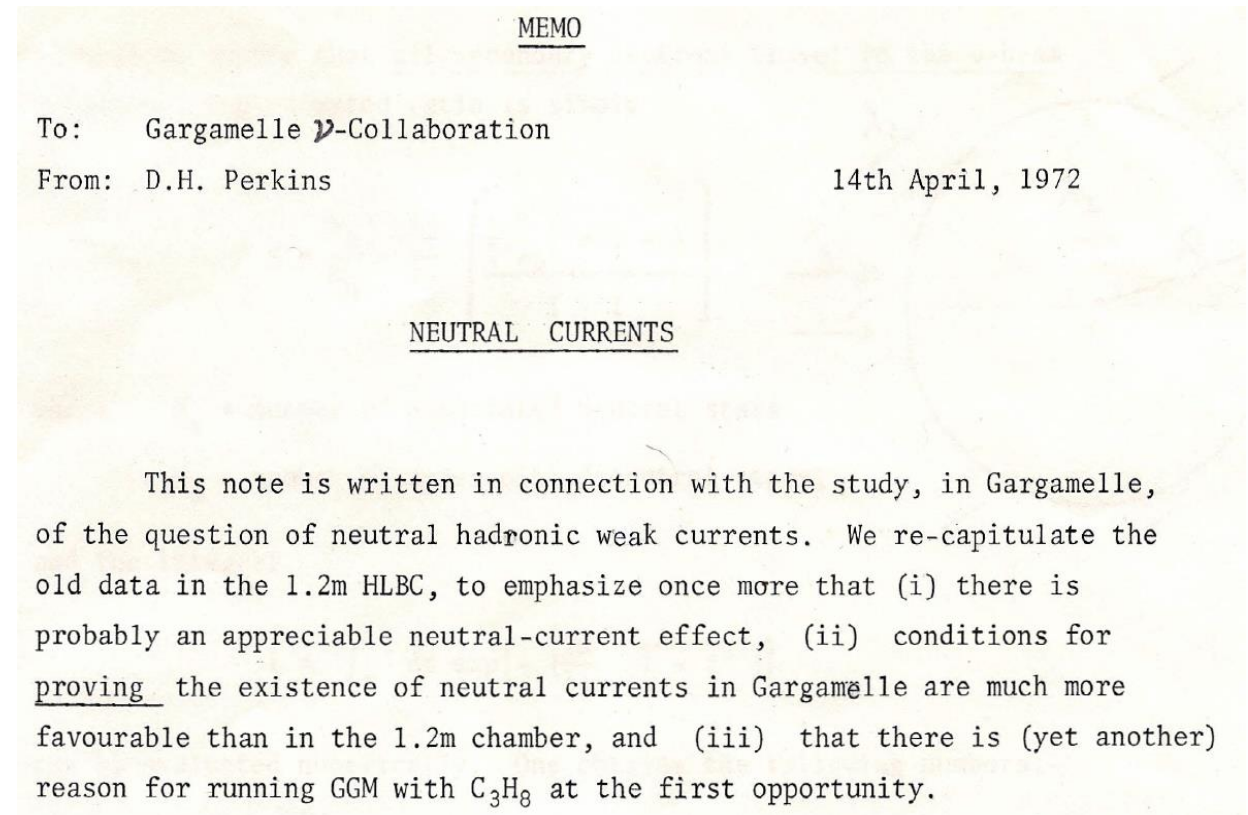
Collaboration meeting at Paris in March 1972 :

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



Appearance of neutron interactions

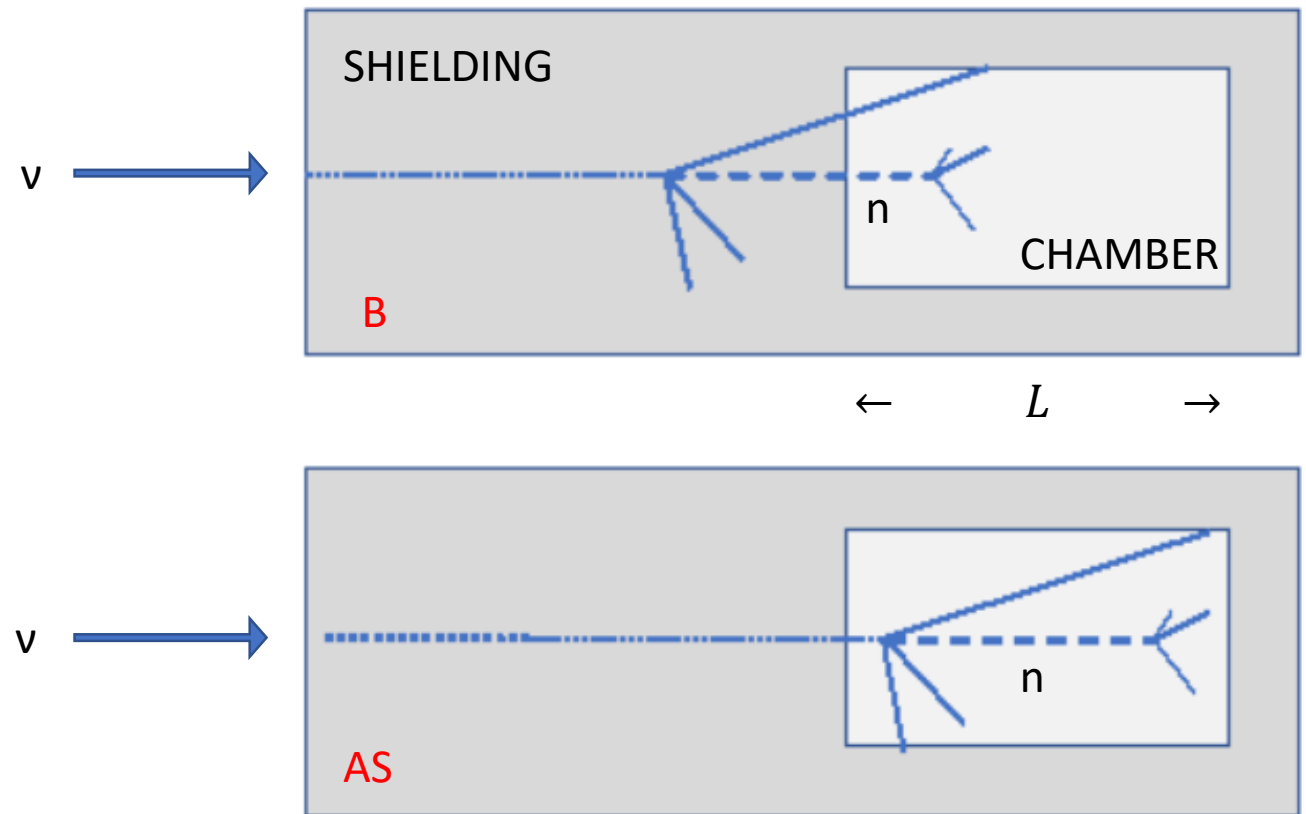
Linear Model

Neutron emitted in a v-interaction travels **along** the v-direction

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

$$z = L/\lambda(ch)$$

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



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 : $\sigma(\nu p \rightarrow \nu p) / \sigma(\nu n \rightarrow \mu^- p) < 0.12 \pm 0.06$ and $\sigma(\nu p \rightarrow \nu \pi^+ n) / \sigma(\nu n \rightarrow \mu^- \pi^+ p) < 0.08 \pm 0.04$

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 \rightarrow predict $\#B = B/AS \#AS$

#B observed vs **#B predicted**: freon $38 \pm 6 \leftrightarrow 12 \pm 4$ and propane $79 \pm 9 \leftrightarrow 31 \pm 13$

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  HPW = Harvard-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: $\bar{\nu}_{\mu} e \rightarrow \bar{\nu}_{\mu} e$

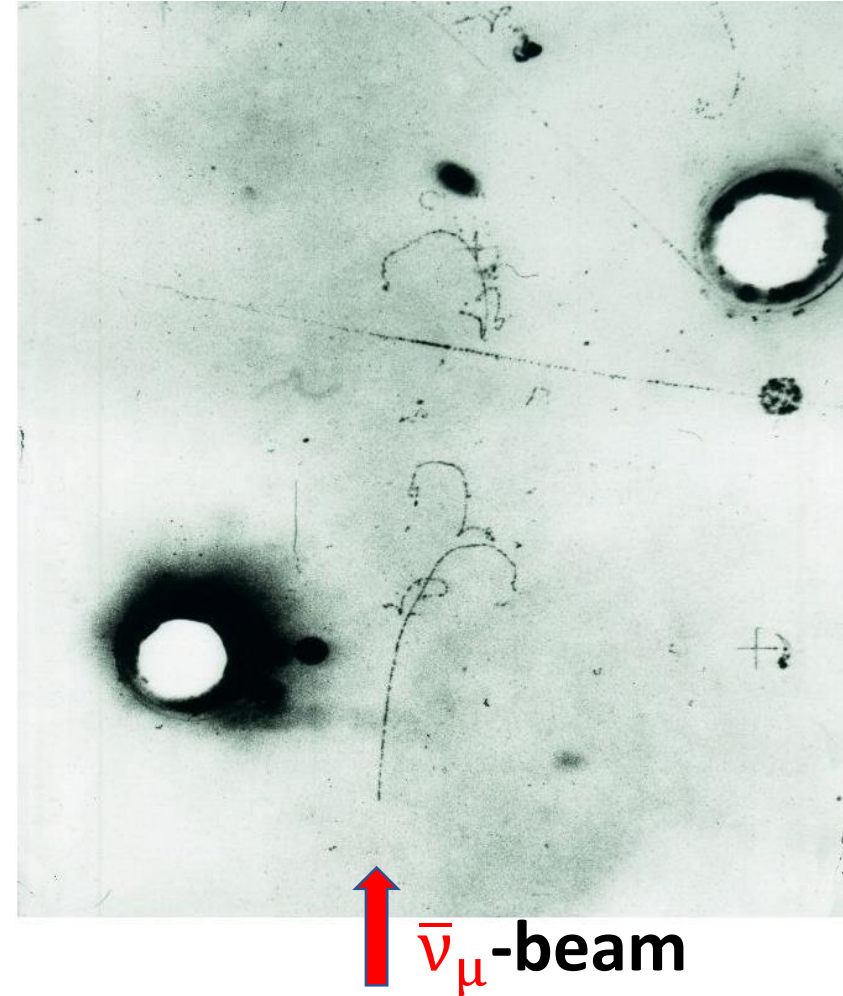
Properties of electron :

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

Background : 0.03 ± 0.02

$\nu_e n \rightarrow e + p$
(*proton invisible*)

Submitted to Phys Lett : 2/7/1973

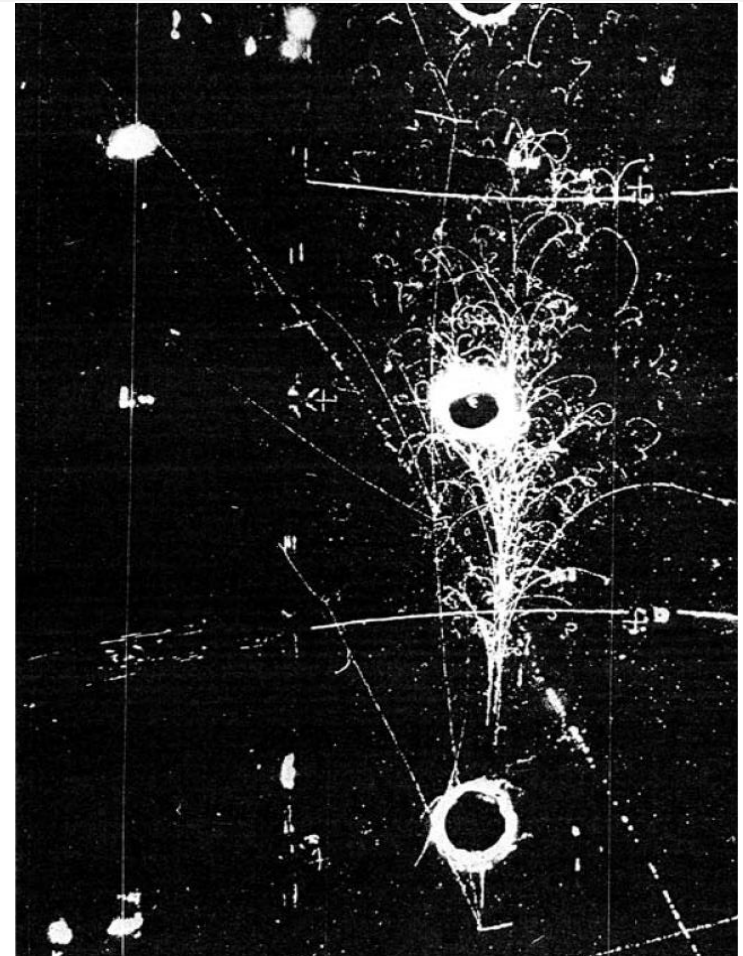
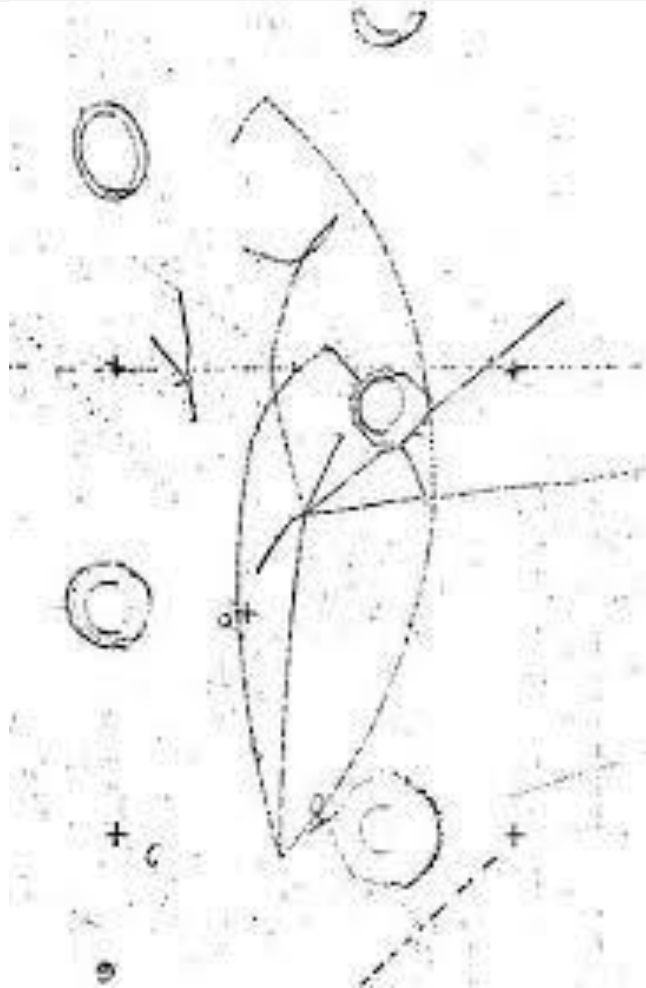


Celebrating the Aachen Event

- Helmut Faissner and Klaus Schultze at the scan table with collaborators
- Missing : the student who reclassified a $\mu + overlaid \gamma$ as *isolated e + bremsstrahlung*
- Faissner was head of the CERN v 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($\bar{\nu}$) kpix

NC sample

leptonic channel : **one**

hadronic channel : **102** in ν and **64** in $\bar{\nu}$ film

CC sample for comparison

ignore μ , criteria for hadron final state as for NC

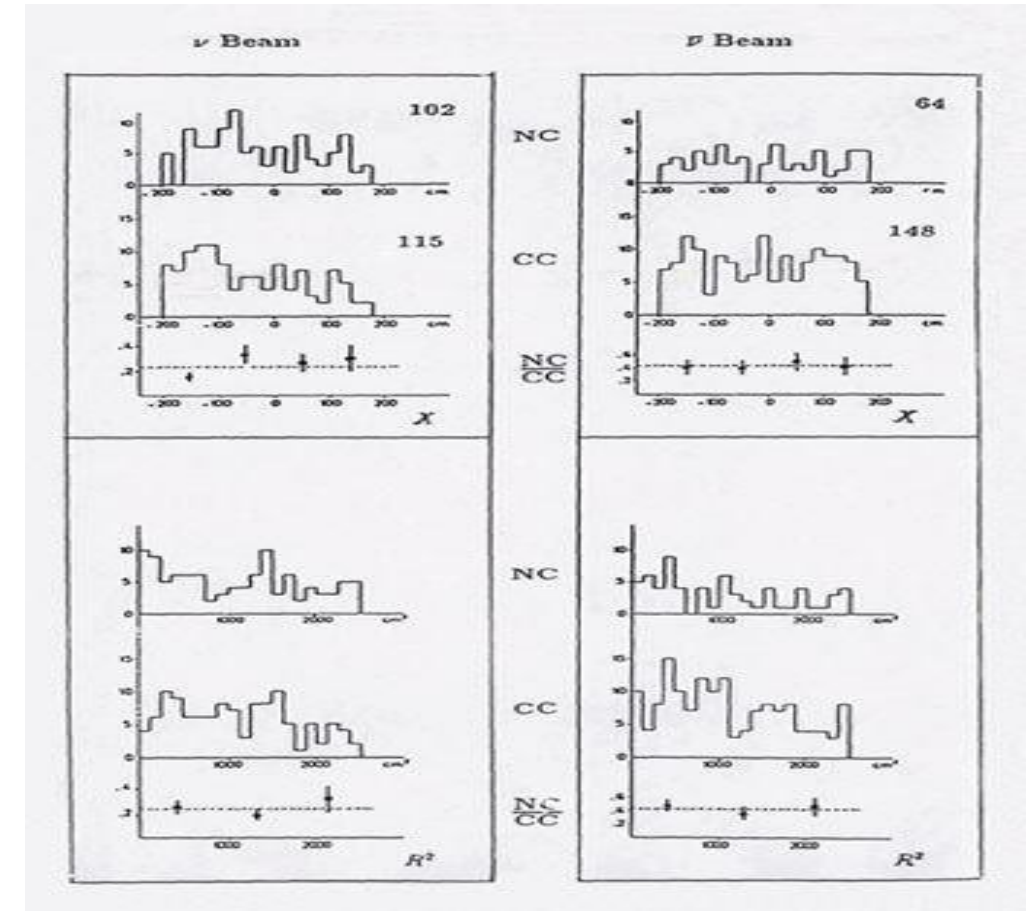
Expectation for **NC/CC**

$\nu \rightarrow$ NC/CC flat along chamber axis

$n \rightarrow$ exponential fall off ($\lambda \ll L_{GGM}$)

ORSAY Monte Carlo

Intriguing result : **discovery ?**



Two Pitfalls

The Don's warning comes true !

1. Neutrons make cascades

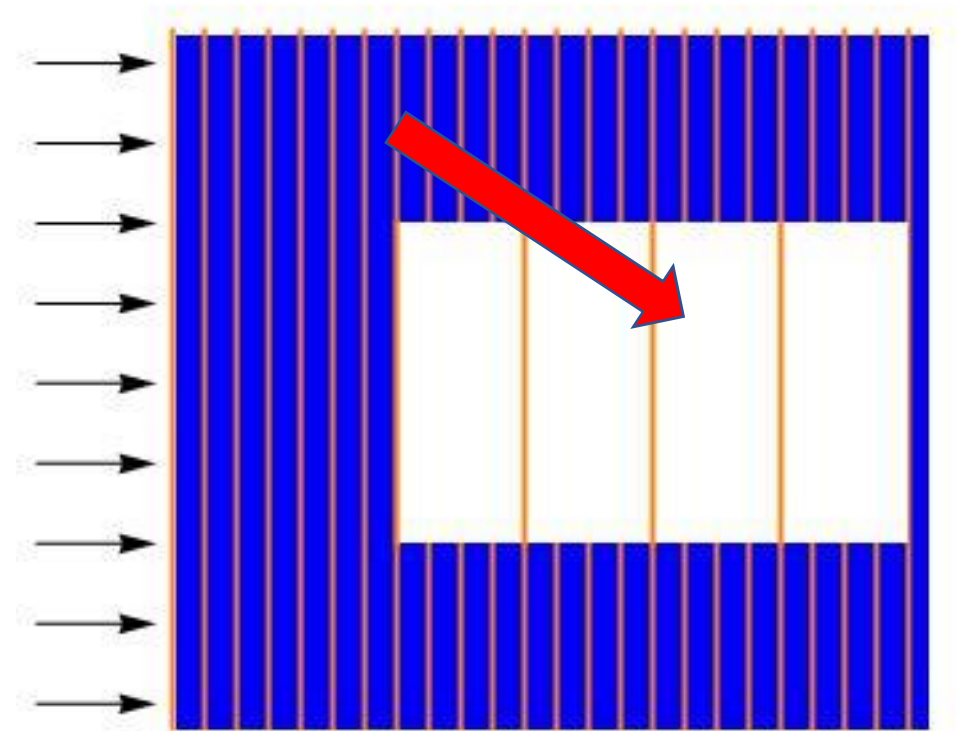
$\#n^* \sim \text{cascade length}$

2. v-flux is broad

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

Damped euphoria :

No distinctive feature left
back to prove $\#n^* \ll \#NC$



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 : $E_{\text{out}} = \lambda E_{\text{in}}$ get λ from NN-data (Fry, DH)
 - cascade stops, when the entering neutron cannot produce a star with **$E > 1 \text{ GeV}$**
- 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 : $B/AS = 1.0 \pm 0.3$

- 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

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

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 :

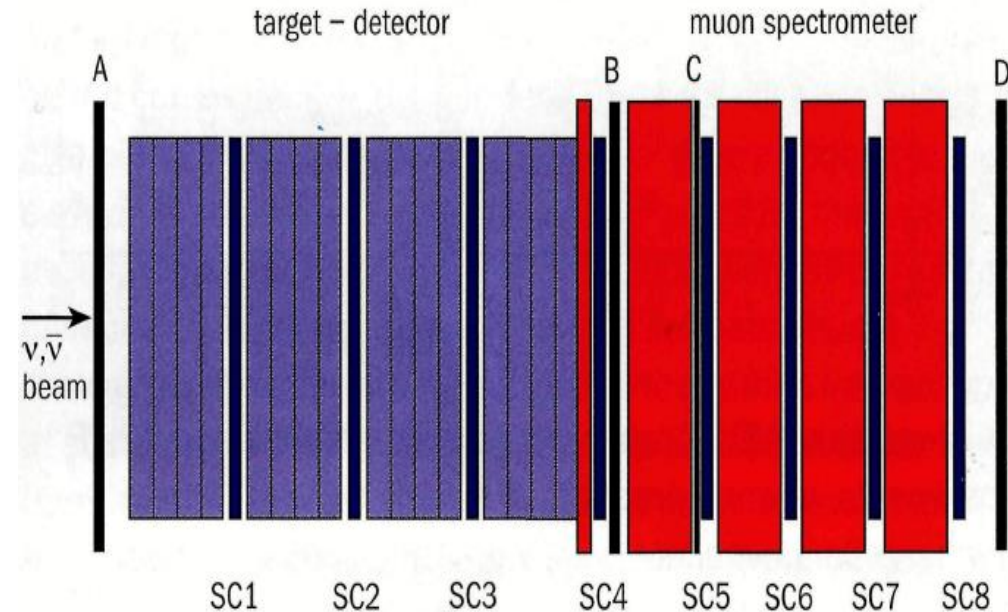
HPWF postpone publication for more statistics : introduce **13' iron plate**

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

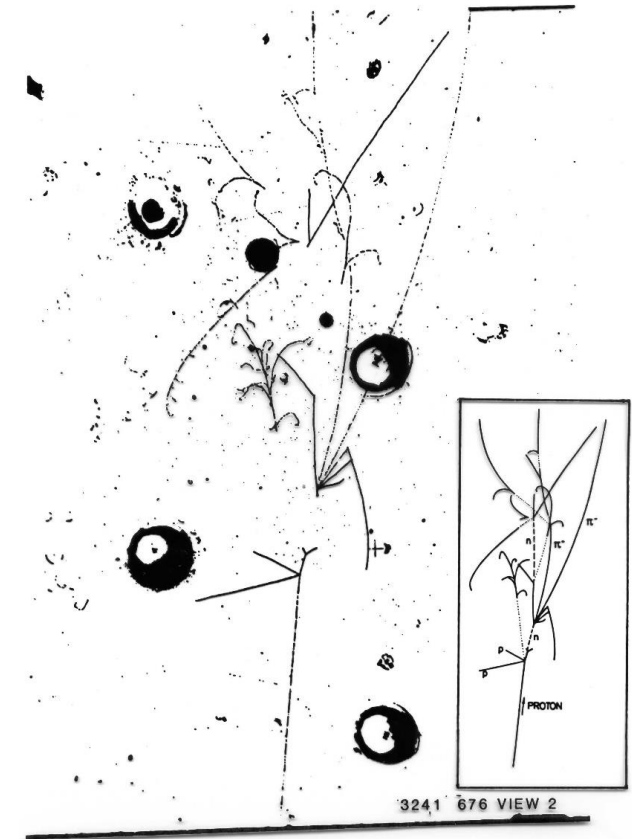
Urgent question :

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

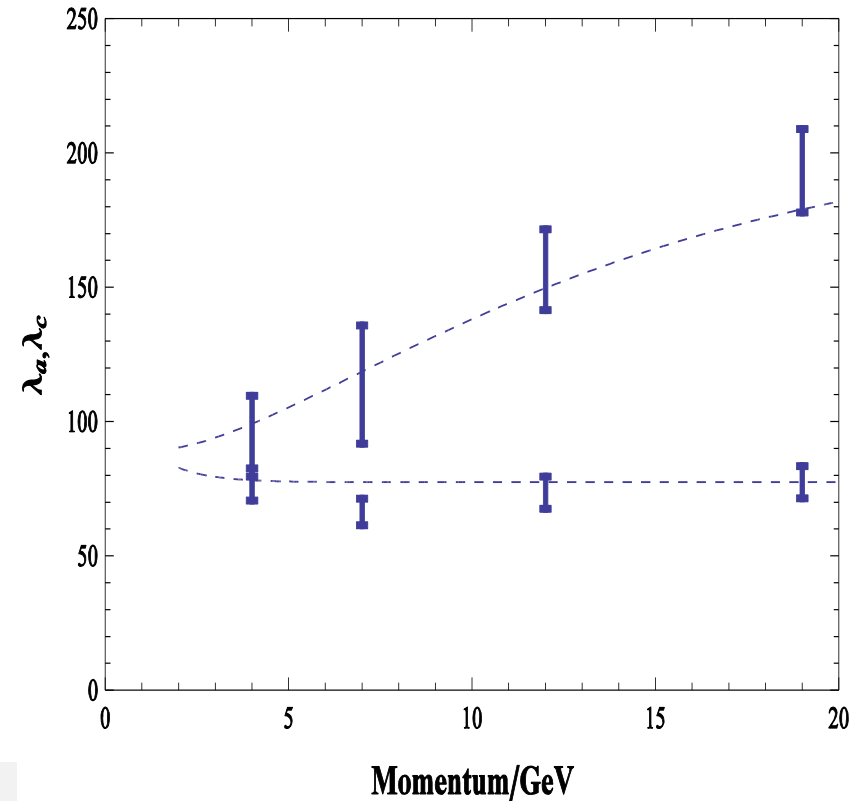
1. apparent interaction length in chamber

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

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

2. Predict W- and Z-masses : GSW + \sin^2_W

$$1973-1976 \quad \sin^2_W \approx 0.30 \pm 0.05$$

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

- Discovery of W impossible in v-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 \rightarrow new colliders : PETRA, SPEAR, TRISTAN, LEP, HERA, LHC
precision \rightarrow 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

