Herwig Schopper: a century in physics

Three „early-career“,
ground-breaking contributions
to
Accelerators and Experimentation

C. W. Fabjan

1.3.2024

Three contributions in very different fields

Showing the Herwig Schopper hallmarks:
Innovation, Implementation, Impact

1. The world‘s first polarised proton source:
   A novel tool for novel physics

2. Europe‘s first R&D programme for Superconducting Accelerator components
   Aiming „Big“ and „Innovative“

3. Invention of a new detector: the STAC (aka hadron calorimeter)
   The start of precision energy spectroscopy

Polarised proton beam: Germination of an idea

Early 1950‘s: As part of his Ph.D. at Hamburg University

- Investigated formation mechanism of thin metal films
- Developed novel method using polarised light

This work led to a question, together with his supervisor and mentor (department head) Rudolf Fleischmann:

- Just as polarised light is a powerful tool for condensed matter research
- Would polarised nucleons be a powerful tool for nuclear physics?

Idea: Use Stern-Gerlach approach to separate polarised protons, but…

H. Schopper proved mathematically and convinced Fleischmann

- Concept does not work with protons on their own
- First polarise hydrogen, then ionise while maintaining proton polarisation

Polarised proton beam:
Separate and select hyperfine states

Exploit polarisation of hyperfine spin states of hydrogen

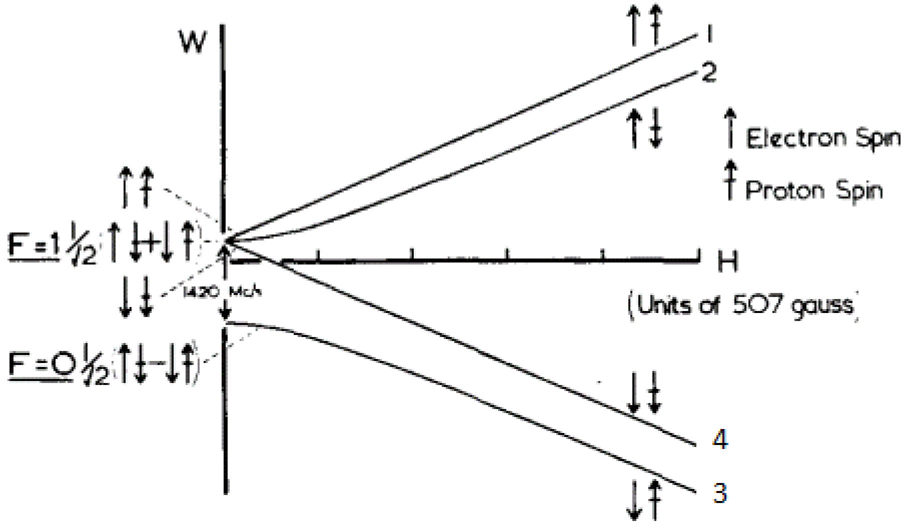


Fig. 1. Breit—Rabi diagram.

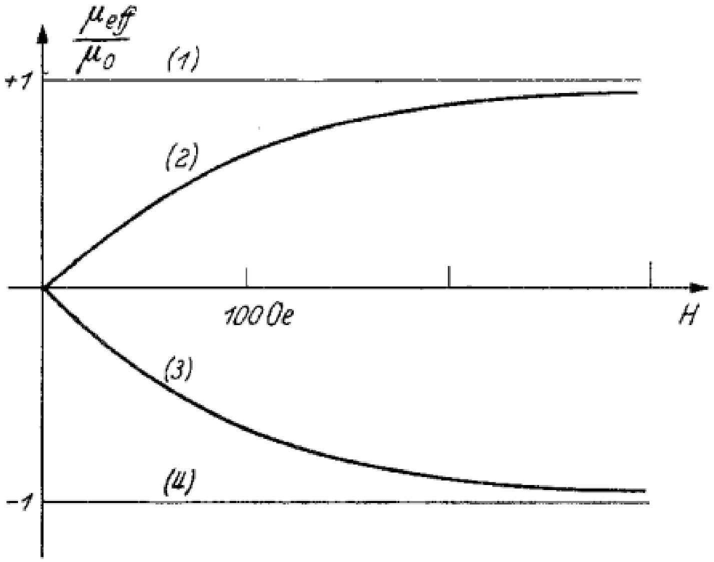


Fig. 1. Magnetisches Moment des H-Atoms als Funktion der Magnetfeldstärke (μ_{eff} = Komponente von μ in Feldrichtung; μ_0 = BOHRsches Magneton)

States 1 and 4 proton and electron spin parallel
States 2 and 3: spins antiparallel

effective magnetic moments vs field strength at low field states 1 and 4 can be separated from 2 and 3

Polarised proton beam: innovative implementation

Rabi (Nobel Prize 1944) and collaborators: molecular beam resonance method for precision measurements of nuclear moments: aim for high precision

Schopper and collaborators:

- Aim for high intensity of atomic beams
- Analysis of optimal field configuration → Quadrupole is best compromise

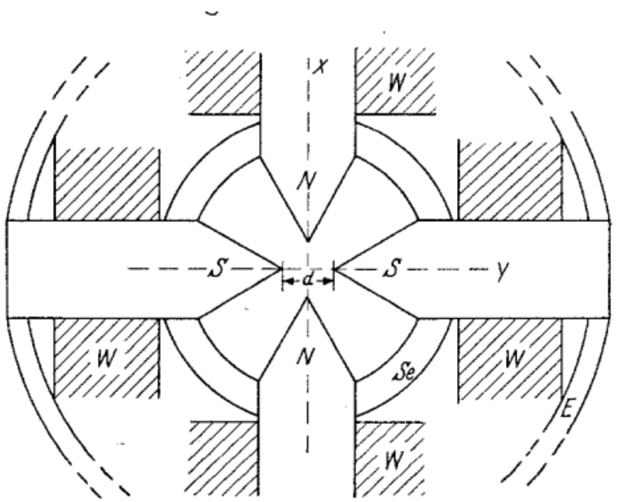
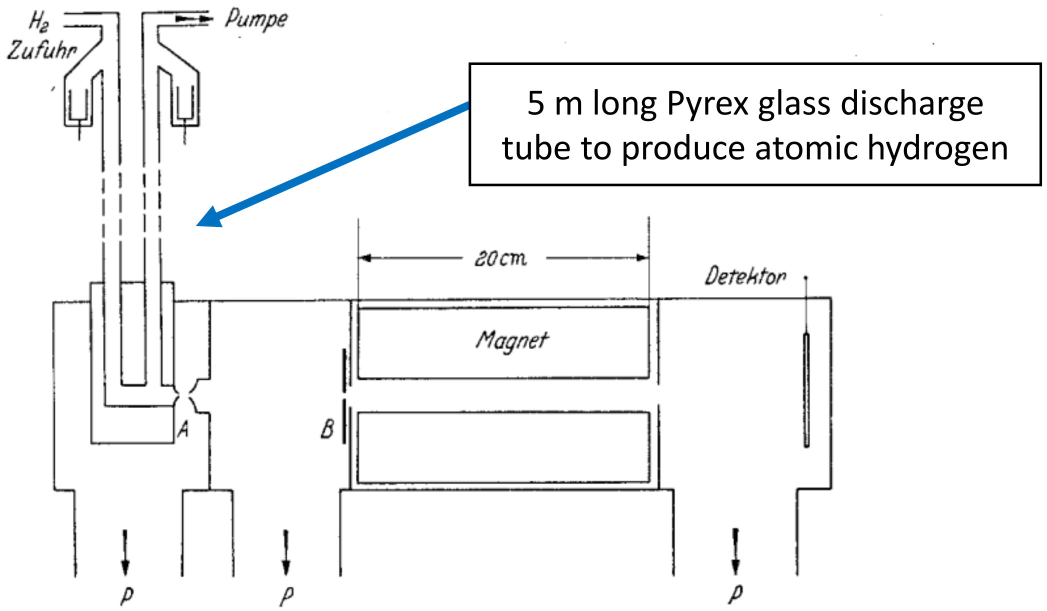


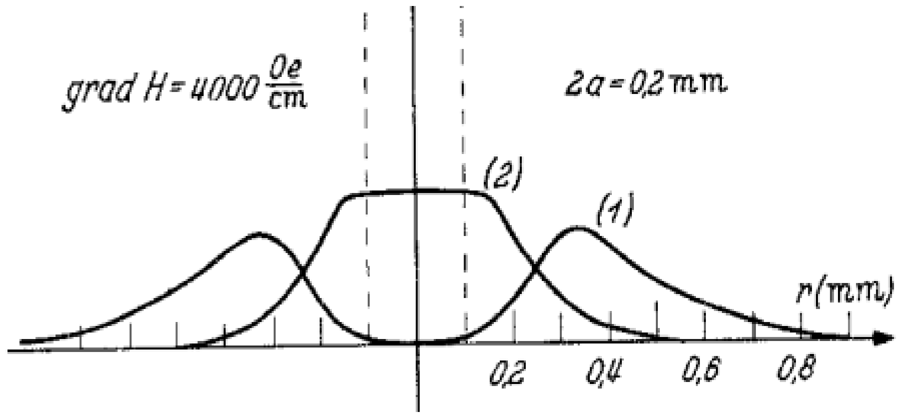
Fig. 2. Technische Ausführung des magnetischen Vierpolfeldes. N, S Polschuhe; W Wicklungen; Se Segmente zur vakuumdichten Begrenzung des Strahlraumes; $d = 4$ mm; E Eisenjoche



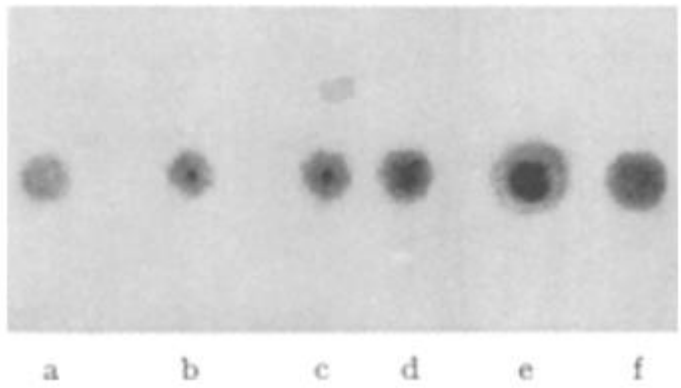
Schematischer Aufbau der Apparatur. A Austrittöffnung, dann Vorblende, B strahlbegrenzende Blende, P Anschlüsse der Pumpen

Polarised proton beam:
„deflection consistent with expectations“

Calculated deflection for
components 1 and 2



Five hour beam exposure
on screen coated with MoO_3 (and alchemie)
H reduces oxide, color change yellow to blue



measured deflection vs. field strength (a to f)
exposure e): component (2) focused on axis;
component 1 forms ring dissociated
from other components

Polarised proton beam: First publication of this topic (1956): “Formation of a hydrogen beam with aligned nuclear spins”

1956-1958: H. Schopper at Erlangen

- Continued research in weak interactions
- Achieved faculty position of „Dozent“
- Finished work on polarised hydrogen beam with graduate student G. Clausnitzer

Zeitschrift für Physik, Bd. 144, S. 336—342 (1956)

Aus dem Physikalischen Institut der Universität Erlangen

Erzeugung eines Wasserstoffatomstrahles mit gleichgerichteten Kernspins*

Von

G. Clausnitzer, R. Fleischmann und H. Schopper

Mit 5 Figuren im Text

(Eingegangen am 14. Oktober 1955)

G. Clausnitzer: Doctoral student of H.Sch.

R. Fleischmann: as head of institute traditionally signed all papers

Polarised proton beam: impact at CERN, 1957

Just one year later (1957):

R. Keller developed in a 52-page CERN Yellow Report the concept of a polarised ion source

Optimised for injection into the CERN Synchro-Cyclotron

Considered three different methods: method of Schopper et al is „by far“ the best-suited

CERN 57-30

Division du Synchro-cyclotron
1er août 1957

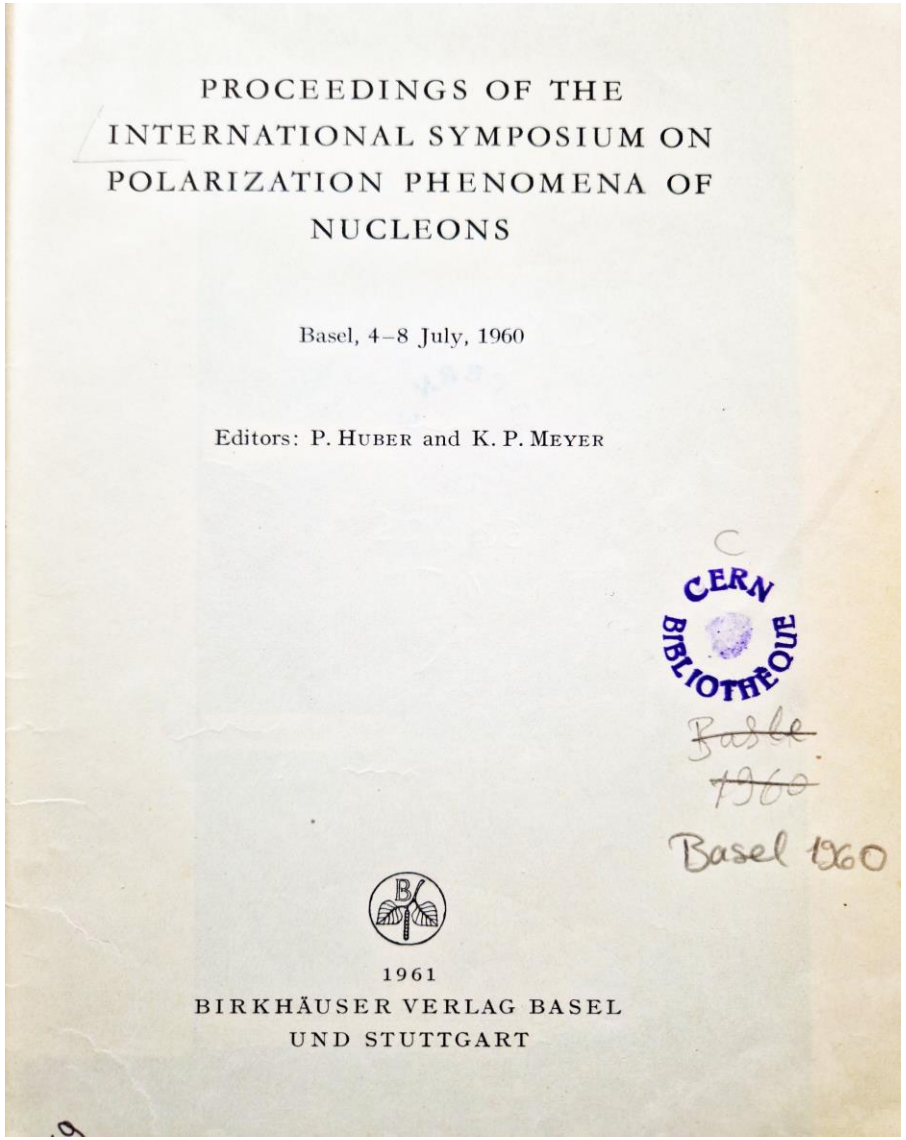
ORGANISATION EUROPÉENNE POUR LA RECHERCHE NUCLÉAIRE
CERN EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

Projet d'une source d'ions polarisés

par

R. Keller

Polarised proton beam: International Symposium 1960


PROCEEDINGS OF THE
INTERNATIONAL SYMPOSIUM ON
POLARIZATION PHENOMENA OF
NUCLEONS

Basel, 4–8 July, 1960

Editors: P. Huber and K. P. Meyer

1961
BIRKHÄUSER VERLAG BASEL
UND STUTTGART

Nobel Laureate W. Paul gave opening Talk:
„Survey of Methods of Producing Sources of Polarized Protons“
Reviewed the Schopper et al source
comparing quadrupoles and sextupoles
Conclusion: quadrupole is optimal

In the same Proceedings:
„Production of Polarized Protons by Quadrupole …Separation…“
Injector for CERN SC
by R. Keller, L. Dick and M. Fidecaro, CERN

Polarised proton beams: Rapid progress in Europe and USA

A SOURCE FOR THE PRODUCTION OF POLARIZED PROTONS

G. H. STAFFORD, J. M. DICKSON and D. C. SALTER

The Rutherford High Energy Laboratory, National Institute for Research in Nuclear Science, Harwell, Berkshire, England

and

M. K. CRADDOCK*

The Clarendon Laboratory, Oxford, England

Received 5 January 1962

Atomic beam techniques have been used to develop a polarized proton source which has now been installed on the Rutherford Laboratory 50 MeV proton linear accelerator and successfully operated for over 6 months. An accelerated beam with an intensity of 7.5×10^7 protons per second and a polarization of 0.32 is obtained. The construction of the source, its installation on the accelerator, and operating experience are discussed. Systematic errors which arise in the conventional method of making asymmetry measurements are reduced because of the ability to change the direction of the beam polarization by reversing the magnetic field across the ionizer in the source. Backgrounds are low, typically 1 part in 1000. The energy resolution is $\pm$ 0.15 MeV and the energy of the beam can be readily adjusted. All these factors contributed towards making the source a very powerful additional facility for nuclear physics experiments.

1. Introduction

Nuclear forces are known to be spin dependent. In order to study this dependance it is very desirable to have available beams of protons which are polarized. At proton energies above about 100 MeV polarized beams have been successfully produced[1]) by scattering an unpolarized beam off a target such as beryllium or carbon. If the scattering angle is chosen correctly, high polarization can be obtained. The polarization decreases with energy so that at 50 MeV and at convenient scattering angles the P.L.A. and has been in successful operation for over 6 months.

2. Principle

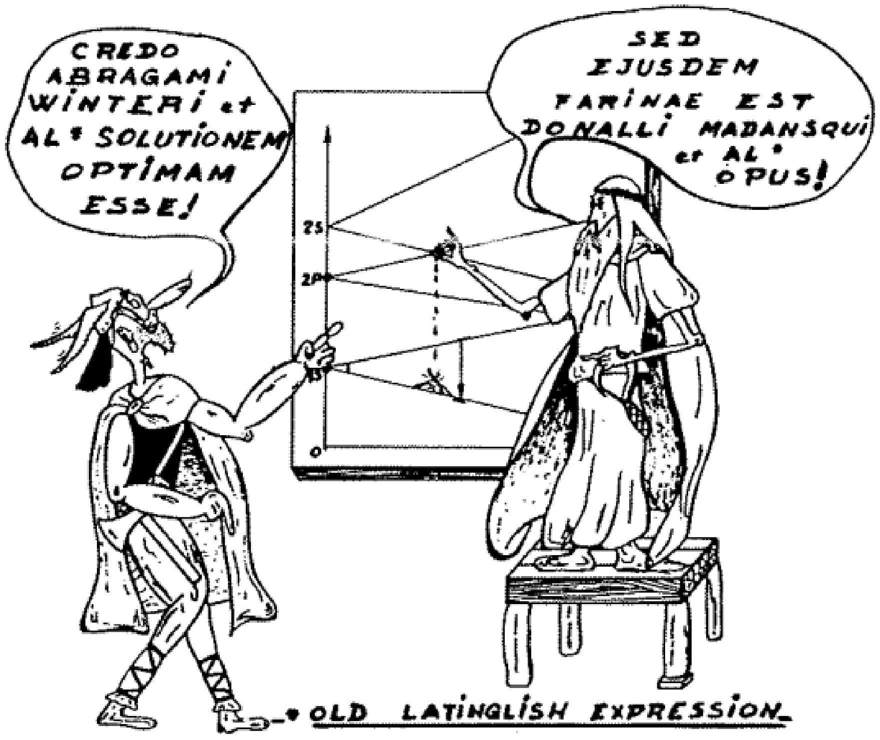
Several sources for producing polarized particles are known to be under development, for example, at Minnesota[3]), CERN[4]), Basel[5]) and Saclay[6]). All are based on an atomic hydrogen beam experiment carried out by Clausnitzer, Fleischmann and Schopper[7]), but they differ in the method of application of the general principle.

Work by
G. Clausnitzer

International Conference on Polarized Targets and Ion Sources
Saclay, France December 5-9, 1966

Conference chair A. Abragam: aim is bringing together two „cultures“:

- Nuclear and particle physicists and the developers of polarised beams and targets
- Physics motivation: talks by R.H. Dalitz, J.D. Jackson, M. Jacob...
- Rapid development of techniques and ... passions animating the participants



from R. Beurtey; this conference

An Historical Perspective of Spin

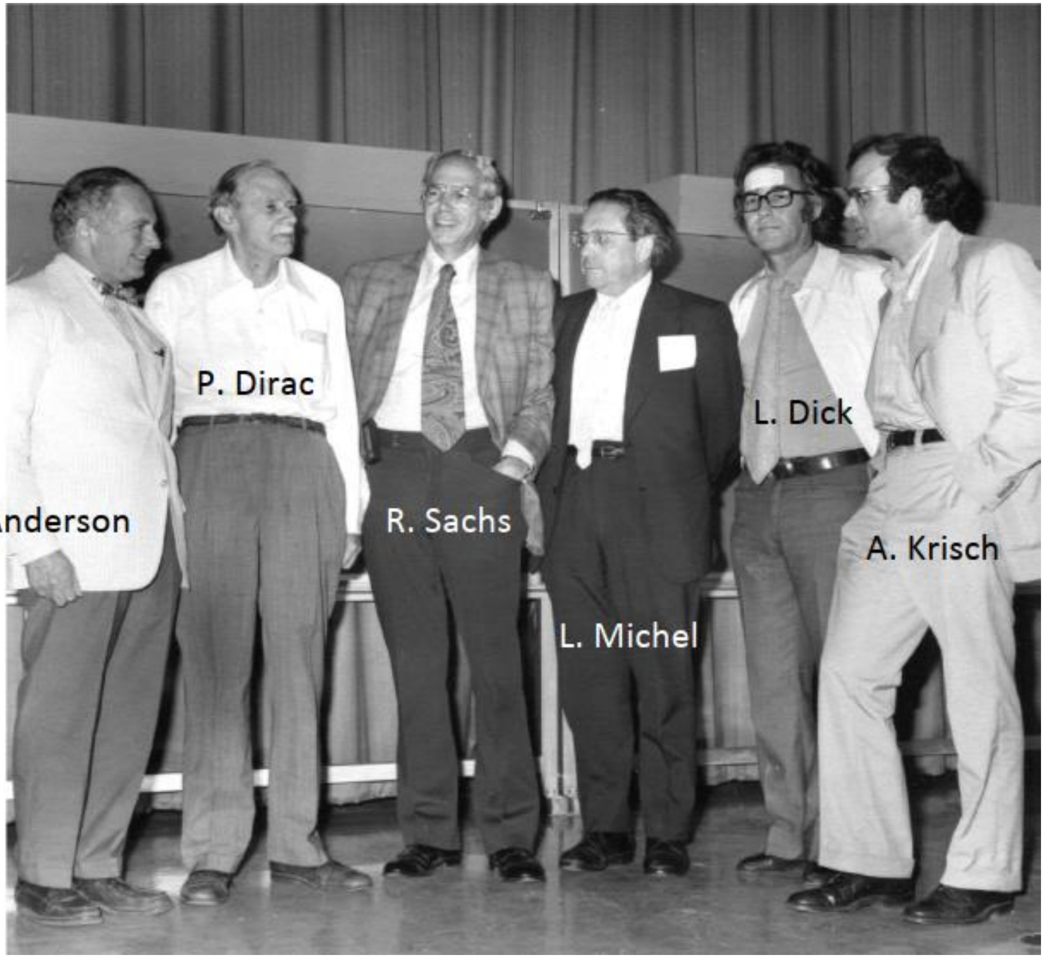
P.A.M. Dirac

at

Summer studies on high-energy physics with polarized beams

Argonne National Laboratory, July 1974

July 1974



Richard Milner

Developing Spin as an Experimental Tool: 1950-75

- 1951: Heusinkveld and Freier: first nuclear polarization scattering experiment
  Paul: proposes magnetic multipoles to focus atomic beams
- 1952: Kastler develops technique of optical pumping
- 1953: Overhauser proposes technique of dynamic nuclear polarization
- 1956: Clausnitzer, Fleischmann, Schopper make polarized ions via atomic beam method
- 1957: Wu observes parity violation in polarized ^{60}Co
- 1958: Development of atomic beam source begins in Erlangen
- 1960: Laser developed
- 1962: London proposes idea of dilution refrigerator
- 1963: Hughes at Yale begins consideration of polarized electron sources
- 1964: Gruebler, Schwandt, Haeberli develop first source of polarized H^-
- 1969: First DNP polarized proton samples with high polarization

Experimentation with polarised nucleons has become an indispensable and powerful tool in particle physics
Polarised proton beams at 250 GeV/c in RHIC
Development of polarised targets at CERN
M. Borghini, T. Niinikoski

Superconductivity for accelerators

H. Schopper took up joint appointment in Karlsruhe, after one year at Cornell (1961)

Head of university institute for nuclear physics, providing the freedom of research and

Director of „Karlsruhe Nuclear Research Centre“ (KfK), providing a strong technology base with industry connections

Realised and promoted synergy between these institutions

Ultimately, this strategy led to the „Karlsruhe Institute of Technology“, KIT

H. Schopper views „Big“

Considered plans for a 100 GeV s**uperconducting** synchrotron

Ultimately, priority given to the CERN SPS

views „Innovative“

initiated **first European** R&D effort on novel superconducting accelerator components: Radiofrequency (RF) separators and cavities

Superconductivity (SC) for accelerators:
SC separator R&D at Karlsruhe

Motivation: enter a new research field; establish state-of-the-art technical infrastructure

- Two refrigerators capable of 300 W at 1.8 K, among the most powerful cryogenic facilities worldwide

SC accelerator components: the road to higher-energy accelerators

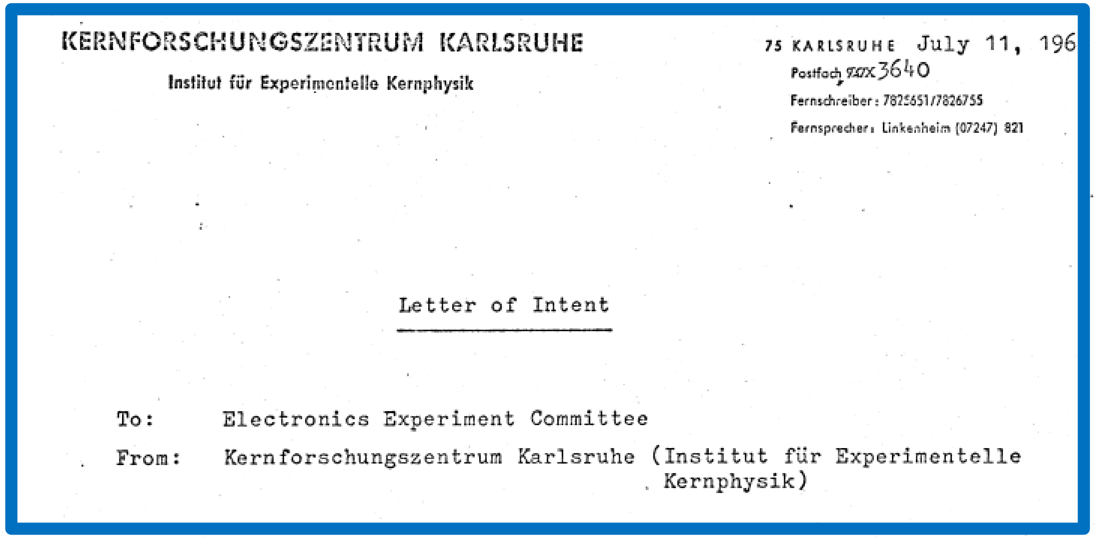
- Higher fields; much reduced RF power losses; cheaper to operate

Learning the trade with R&D on SC particle separator: 1968-1978

- Technique turned out to be very subtle and fiendishly difficult:
  - RF operation in superconductors: „skin effect“ in a few hundred atomic layers
  - RF performance requires extreme control of surface quality

1968: Letter of Intent to construct SC Separator,

- Signed by A. Citron and H. Schopper
- Detailed design and performance specifications
- Aggressive timescale



KERNFORSCHUNGSZENTRUM KARLSRUHE

Institut für Experimentelle Kernphysik

75 KARLSRUHE July 11, 196

Postfach 3640

Fernschreiber: 7825651/7826755

Fernsprecher: Linkenheim (07247) 821

Letter of Intent

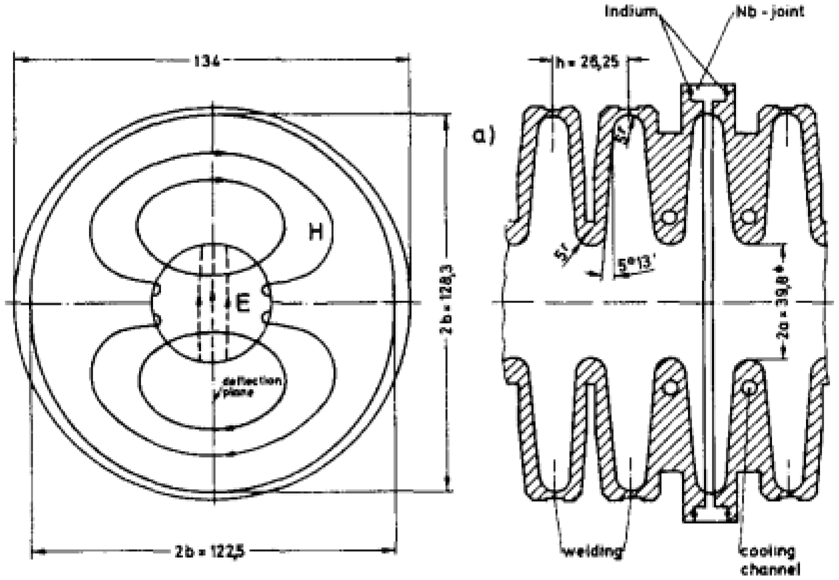
To: Electronics Experiment Committee

From: Kernforschungszentrum Karlsruhe (Institut für Experimentelle Kernphysik)

Superconductivity for accelerators: SC Separator progress, 1971

MEASUREMENTS ON THE FIRST 20-CELL DEFLECTOR SECTIONS FOR A SUPERCONDUCTING RF SEPARATOR

W. Bauer, A. Citron, G. Dammertz, M. Grundner, L. Husson, H. Lengeler , E. Rathgeber
Universität and Kernforschungszentrum Karlsruhe
Karlsruhe, Germany



W. Bauer, A. Citron, G. Dammertz, H.C. Eschelbacher, H. Hahn, W. Jüngst, H. Miller, E. Rathgeber, and H. Diepers - Proc.Conf.High Energy Accelerators, CERN, 1971, p. 253

Superconductivity for accelerators: CERN-Karlsruhe SC separator for Omega

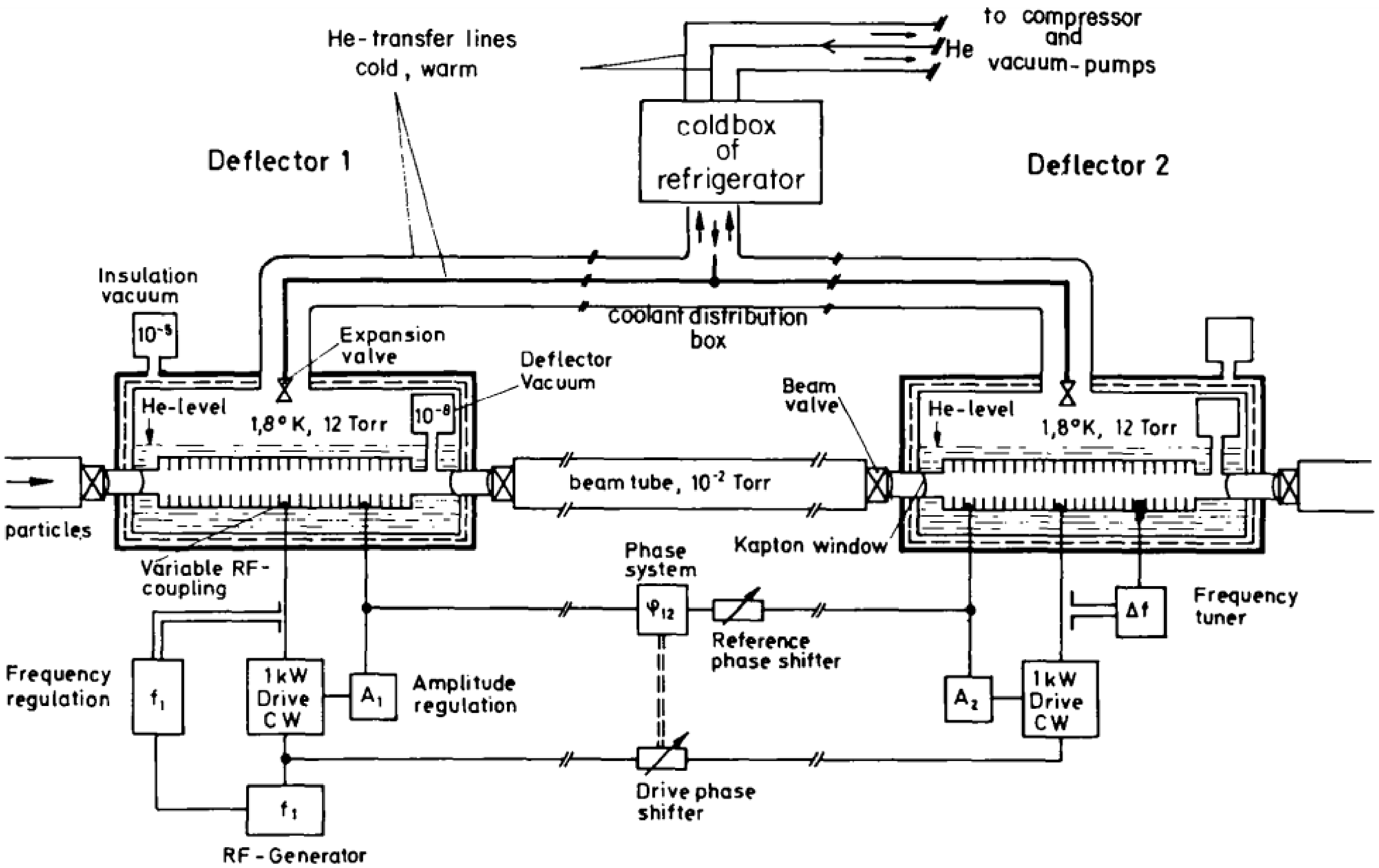


Fig. 1. Schematic layout of the superconducting rf-separator with its rf-, cooling- and vacuum systems.

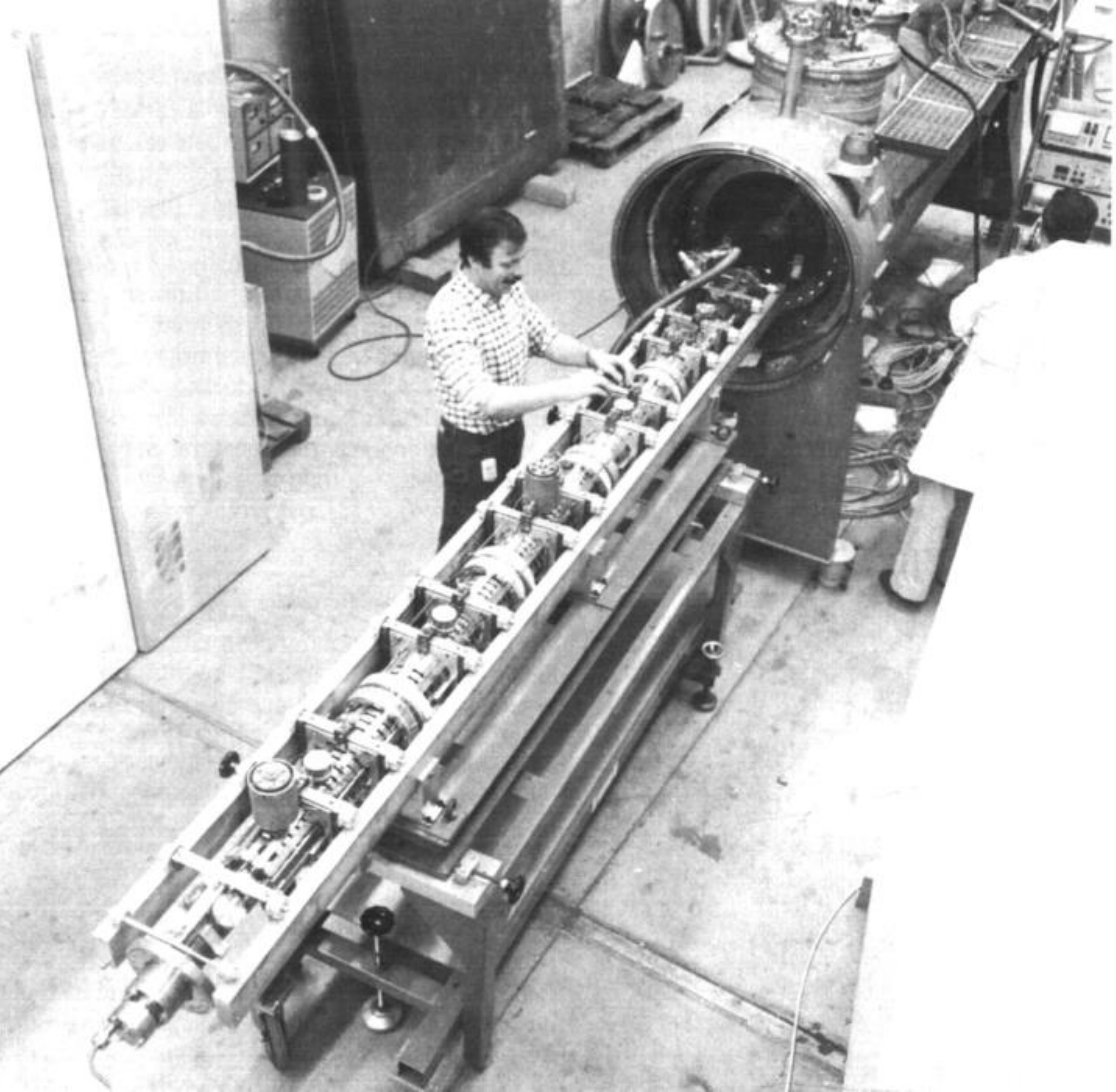
2 Niobium deflectors , each 2.7 m long with 104 cells

from:

A. Citron, G. Damertz, M. Grunder,
L. Husson, R. Leim and H. Lengeler
KfK
D. Plane and G. Winkler
CERN
NIM 155 (1978) 93

c

SC particle separator during installation



1977: SUCCESS
Separator worked extremly reliably during many thousand of hours

Strengthened confidence that superconducting radiofrequency components can be used in accelerators

The bigger challenge
Superconducting RF Cavity R&D at Karlsruhe

The Schopper style: Analysis of the problem

New method to measure the quality factor, Q, of the cavity, avoiding errors due to imprecisely known coupling losses

Measurement of Q- value performed under systematic variations of coupling geometry

One of the first studies of SC cavities for accelerators

April 1968 KFK 758

Institut für Experimentelle Kernphysik

Coupling losses and the measurement of Q-values
of superconducting cavities

J. Halbritter, R. Hietschold, P. Kneisel, H. Schopper

Extensive work on SC film and cavity production and measurements

Superconductivity for accelerators: reports on RF separator and cavity R&D at Karlsruhe

H. Schopper stimulated and promoted R&D on SC accelerator structures worldwide

Proceedings of the 1968 Proton Linear Accelerator Conference, Upton, New York, USA

PROGRESS REPORT ON THE INVESTIGATIONS OF SUPERCONDUCTING STRUCTURES AT KARLSRUHE

H. Schopper

Institut für Experimentelle Kernphysik des Kernforschungszentrums und der Universität Karlsruhe, Germany

Many questions from conference participants indicating novelty of and interest in Karlsruhe work

H. Schopper, Optimization of superconducting RF particle separators, in *Proc. 7th Int. Conf. on High-Energy Accelerators (HEACC 69), Yerevan, USSR, 27 Aug.–2 Sep. 1969*, pp. 662–668,

Impact: Realising the full potential of SC cavities

1978: Les Houches Summer study:

Detailed discussion of potential SC cavities for LEP100 presented by W. Bauer, Karlsruhe

PROCEEDINGS OF THE LEP SUMMER STUDY

Les Houches and CERN

10-22 September 1978

SUPERCONDUCTING ACCELERATING CAVITIES

FOR HIGH-ENERGY e^+e^- STORAGE RINGS

Walter Bauer

Institut für Kernphysik, Kernforschungszentrum Karlsruhe, Germany

1979: Start of feasibility study at CERN in collaboration with European institutions;

E. Picasso named team leader; action plan developed by Ph. Bernard and H. Lengeler

In parallel: preparation at KfK for cavity to be installed at DORIS storage ring at DESY

11th International Conference on High-Energy Accelerators; Geneva, Switzerland, July 1980

FIRST RESULTS ON A SUPERCONDUCTING RF-TEST CAVITY FOR LEP

Ph. Bernard, G. Cavallari, E. Chiaveri, E. Haebel, H. Heinrichs, H. Lengeler, E. Picasso and V. Picciarelli

CERN, Geneva, Switzerland

H. Piel

University of Wuppertal, Wuppertal, Germany

Superconductivity for accelerators: On the road to success

1983: a CERN-built and Karlsruhe-built 500 MHz SC niobium cavities were tested successfully at PETRA

Cornell tested a 1500 MHz 2x5 cell cavity

1987 Proceedings of The Third Workshop on RF Superconductivity, Argonne National Laboratory, Illinois, USA

Impressive progress reported by: CEBAF, CERN, Cornell, DESY, HERA, KEK,…Wuppertal

RADIO FREQUENCY SUPERCONDUCTIVITY AT CERN: A STATUS REPORT

G. Arnolds-Mayer[1], C. Benvenuti, Ph. Bernard, D. Bloess, G. Cavallari, E. Chiaveri, W. Erdt, E. Haebel, N. Hilleret, P. Legendre[2], H. Lengeler, G. Passardi, J. Schmid, R. Stierlin, J. Tückmantel and W. Weingarten

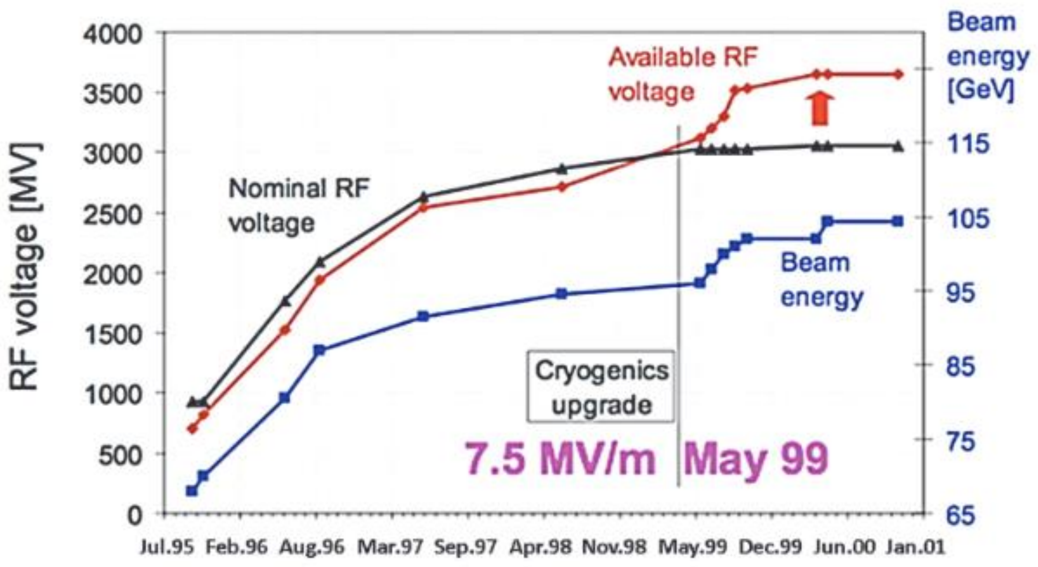
CERN, Geneva, Switzerland

Test of final prototype of a 352 MHz 4-cell SC niobium cavity for LEP

Report on R&D of Nb coating of copper cavities: The perfect symbiosis

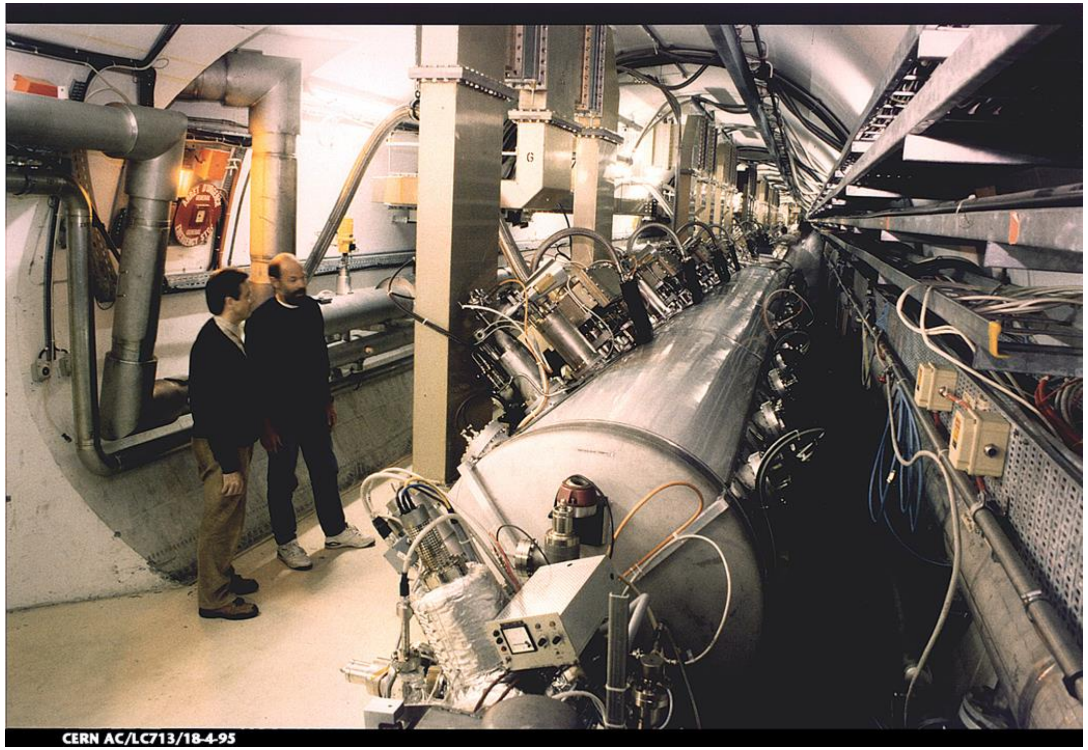
The steep ascent to the world-record 209 GeV peak

30 years after the start for the R&D programme at Karlsruhe…



Cavity performance exceeded specification of 6MV/ m

C. Benvenuti was the mastermind for the SC Nb coating development
E. Chiaveri was in charge of the industrial fabrication



Superconducitve cavities installed in the LEP tunnel

STAC (aka "hadron calorimeter")
A new tool for new physics

1966: H. Schopper at CERN on leave of absence from Karlsruhe
In search for new physics and independent research opportunities:
nucleon scattering with neutrons
Initiated 24 GeV/c neutron beam and
Invented new detector for high-energy neutron energy measurement
for PS and future ISR experimentation

Early, crude attempts were motivated by Cosmic Ray studies
H. Schopper's insight: these devices can be turned into precision instruments

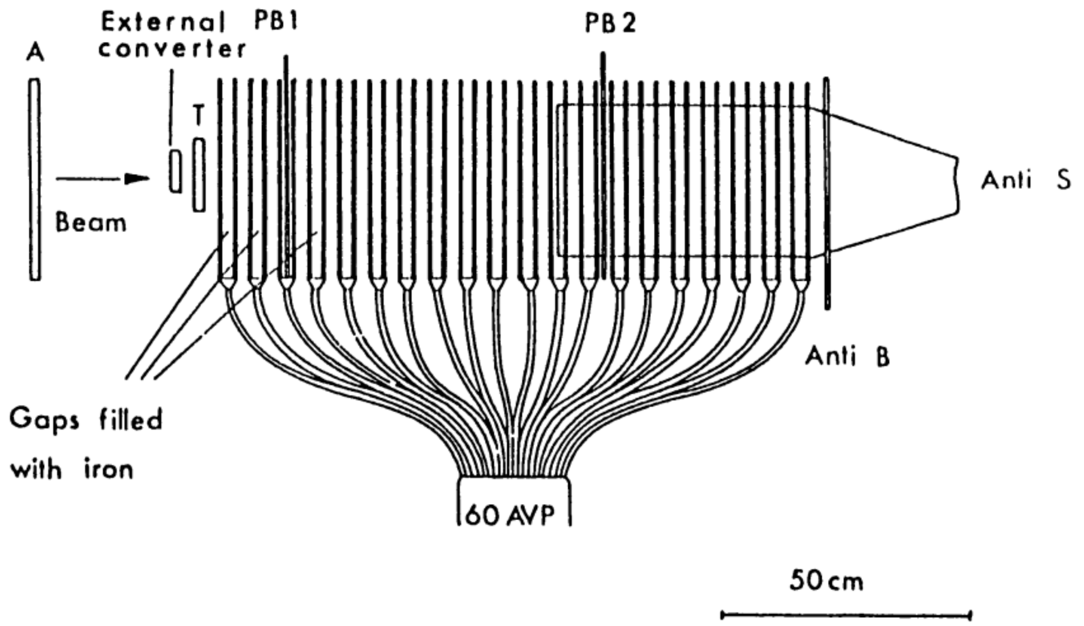
STAC: first prototype
The begin of precision energy spectroscopy

STAC[1)]: Sampling Total Absorption Counter[2)]

[1)] To the regret of H. Schopper, the majority prefer the confusing and whimsical term „calorimeter“

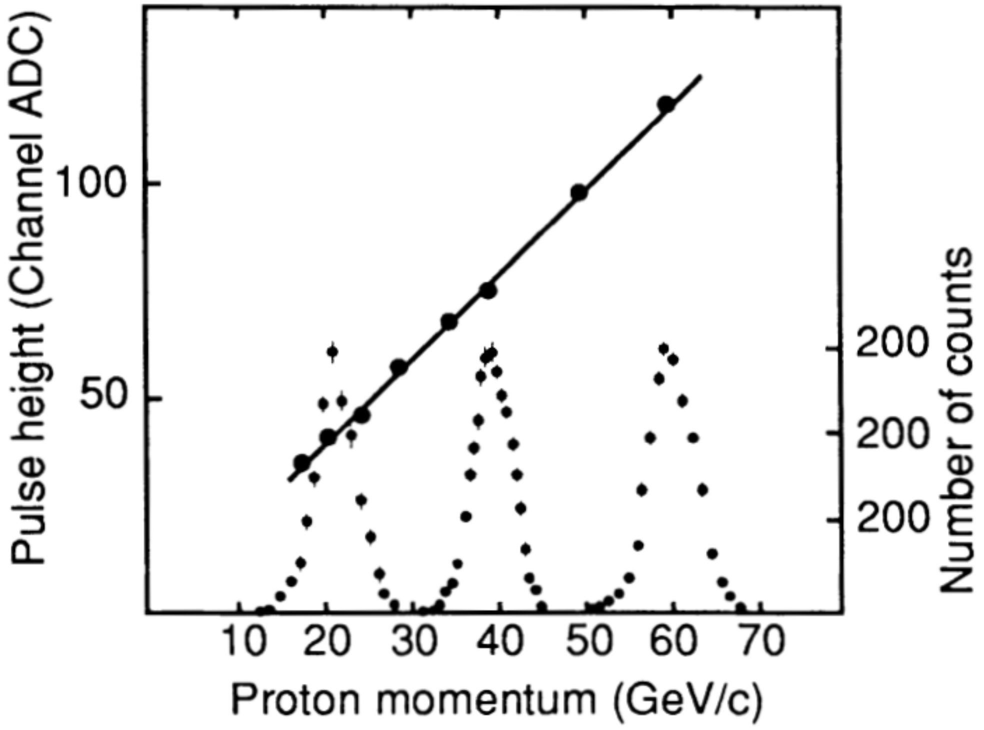
[2)] Compromise proposal: „STAC: **S**chopper **T**otal **A**bsorption **C**alorimeter“

The „Original“: Iron-plates interleaved with Scintillator-plates

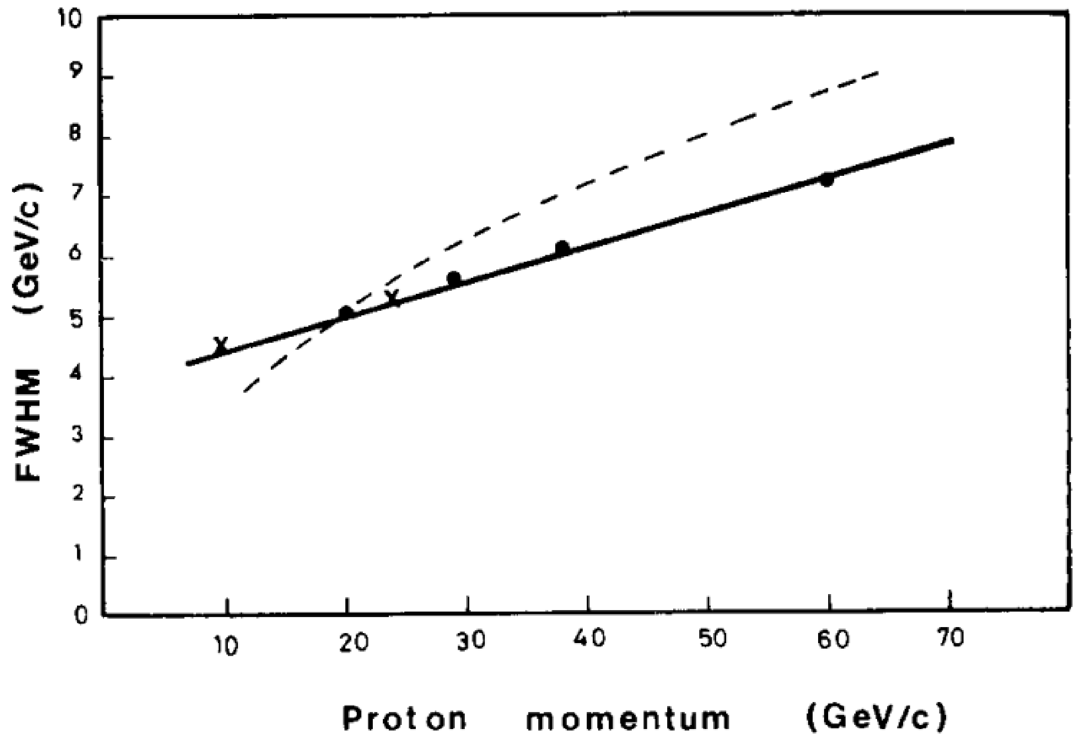


STAC designed to allow systematic study of performance

Exploring the new world of STACs

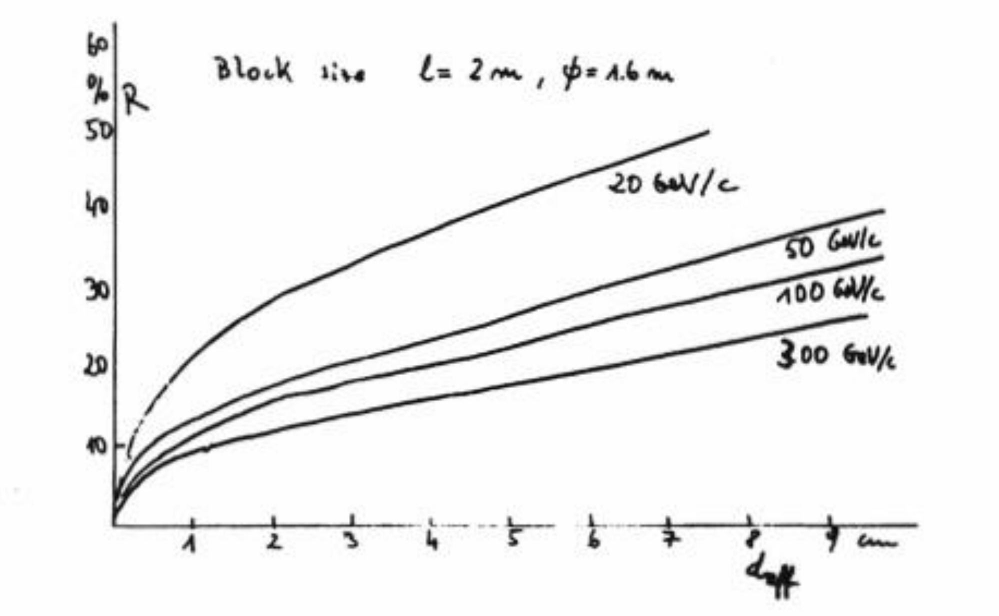


STAC shows linear response versus energy

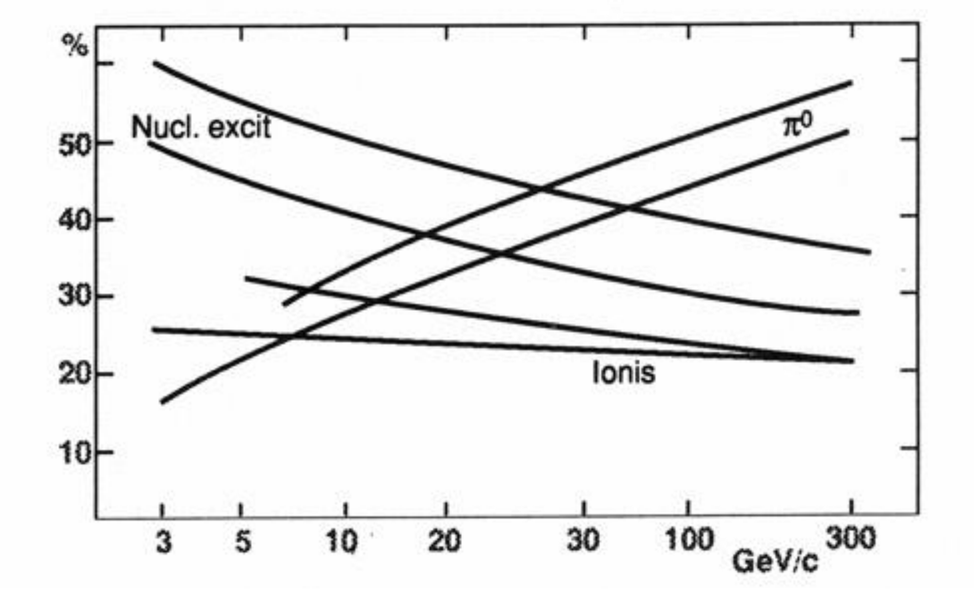


Relative energy resolution improves with energy

STAC: Disentangling contributions to energy resolution



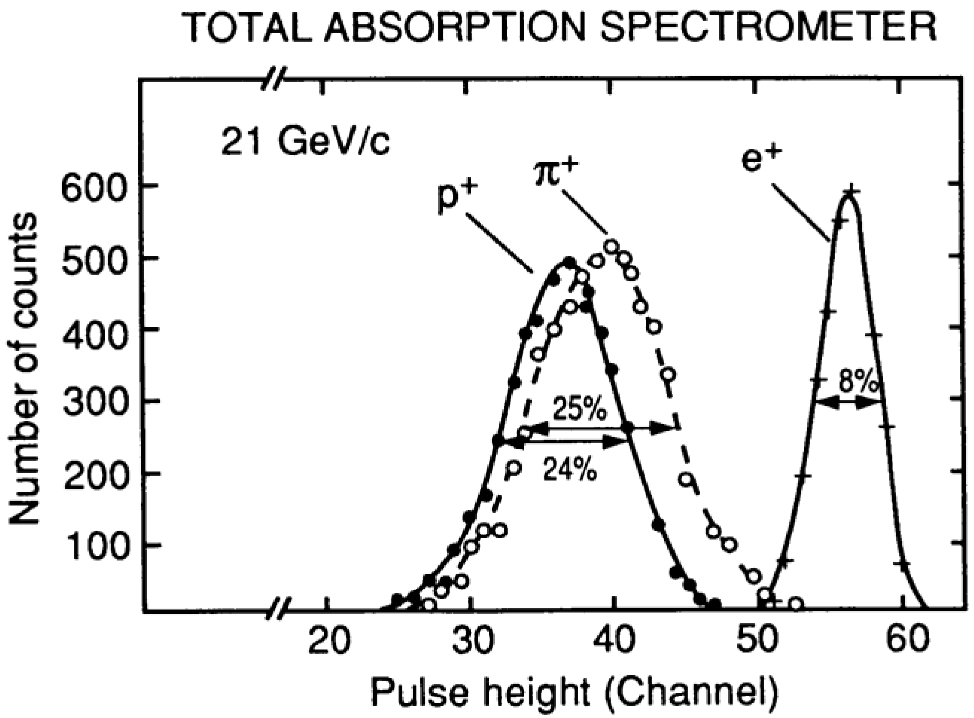
From H. Schopper's private notes
Influence of sampling size d_{eff} on energy resolution

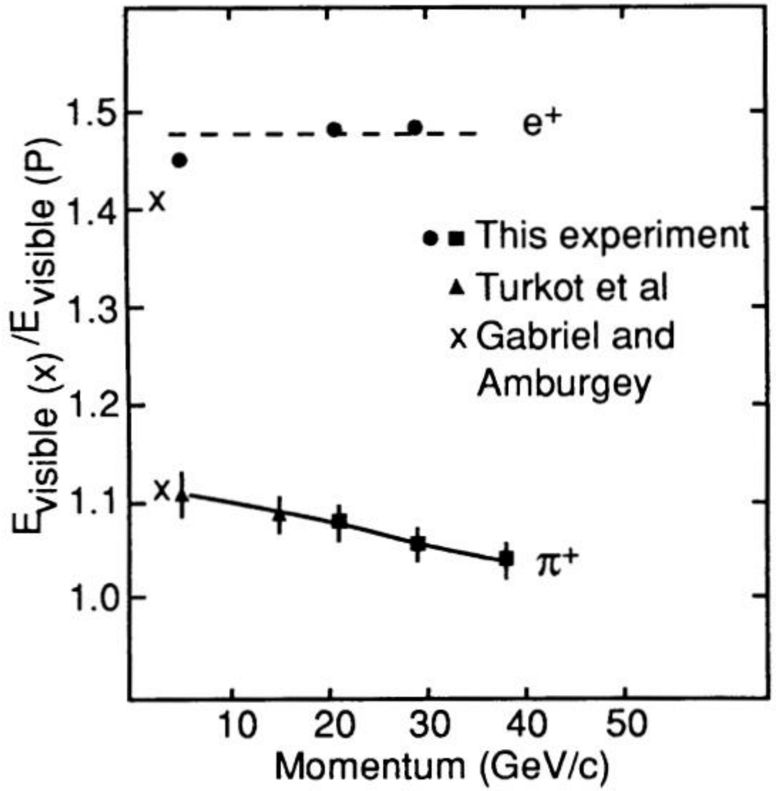


Dissecting the components of the hadronic shower

Another first and game-changer: using a Monte Carlo program to understand and optimize the instrument by adapting code developed by J. Ranft for shielding calculations

STAC: towards an understanding of the inner workings





Key insight: photons and electrons give different response compared to hadrons
Key concept: „Invisible“ energy due to nuclear interactions is key driver of resolution
Led to „Compensation“ of response by intrinsic or instrumental construction of STACs with improved energy resolution

Herwig’s STAC prototype

The STAC revolution started
almost 60 years ago.
STACs are now an essential
and major component of almost
every particle physics experiment.

Thank you and Happy Birthday

Thank you, Herwig Schopper,

for these (and other) seminal and wide-ranging contributions to our field, which illustrate also your ‚Credo' that „It's the unity of physics that makes it beautiful".

Happy 100th Birthday

I am grateful for advice and comments from C. Benvenuti, J. Gillies, N. McCubbin, T. Niinikoski, T. Taylor, D. Treille, W. Weingarten