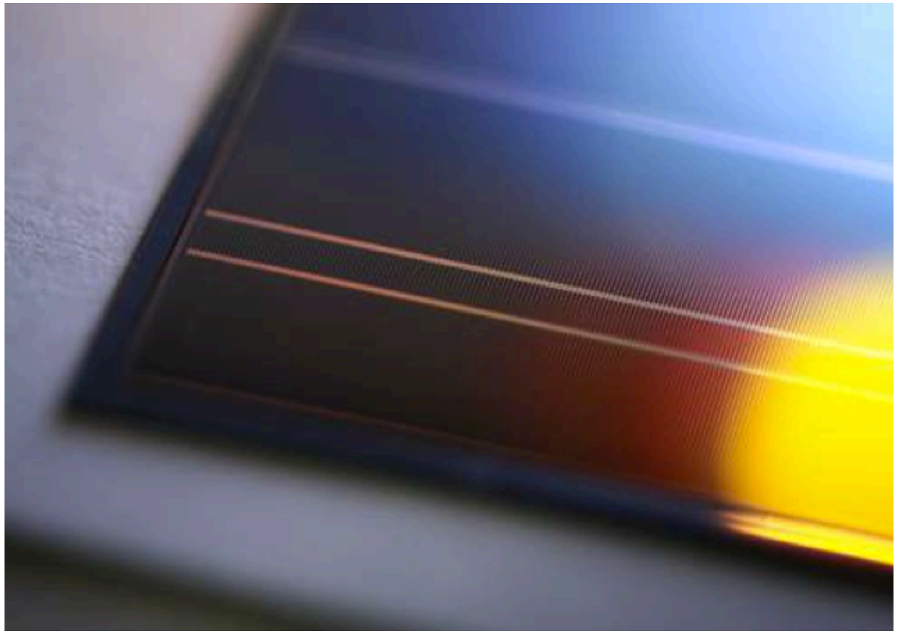
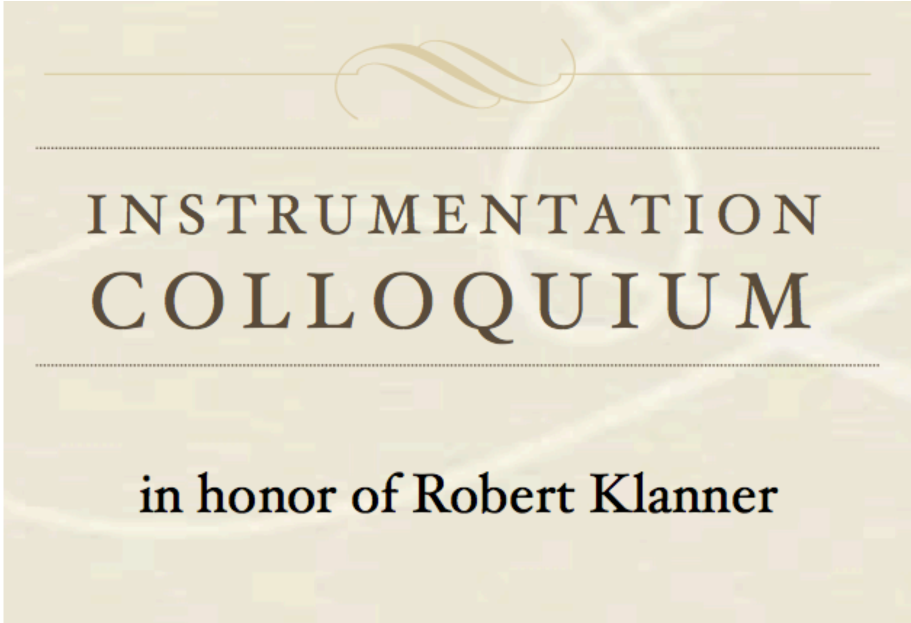
The early stage of silicon strip detectors

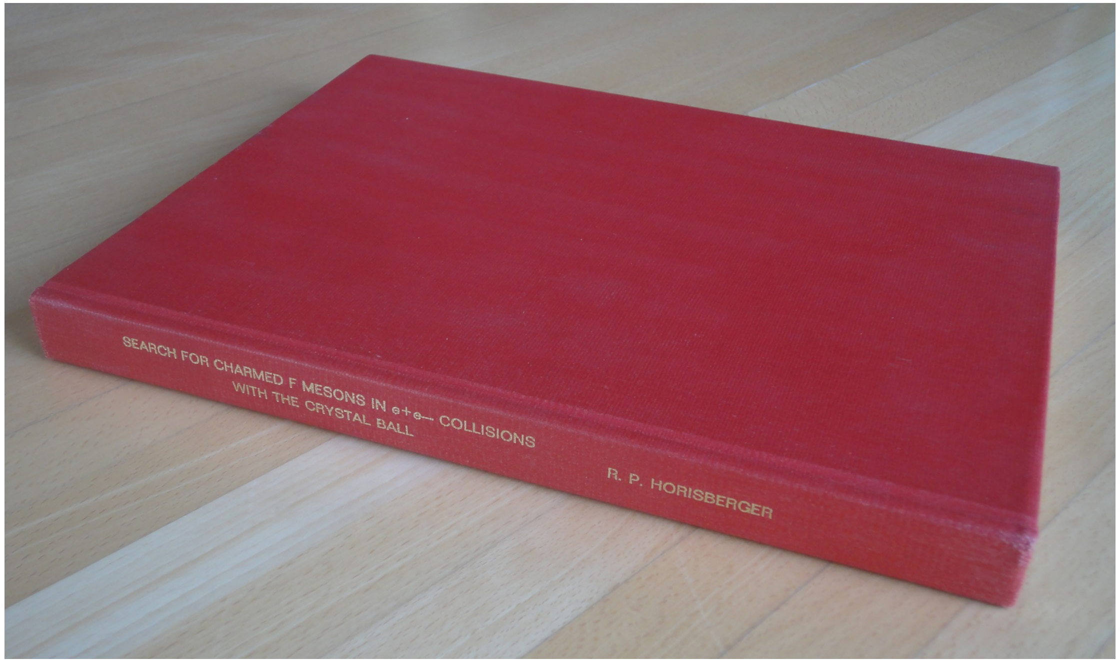




a personal view on a
remarkable period in time
by

Roland Horisberger
PSI / ETH Zürich

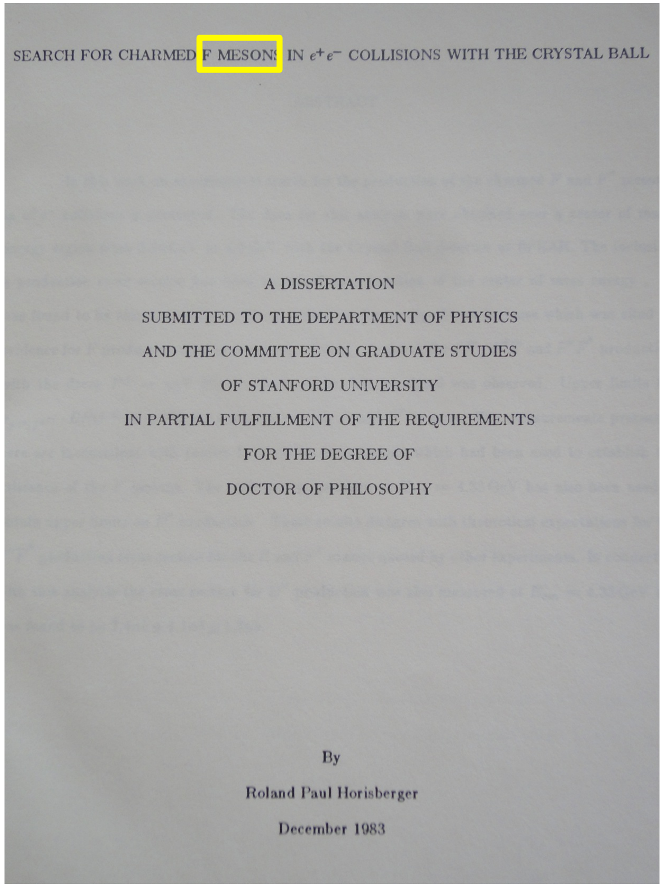
A strange start goes with a charming end



SLAC 1983

Crystal Ball Experiment at SPEAR

Stanford University



SEARCH FOR CHARMED F MESONS IN e^+e^- COLLISIONS WITH THE CRYSTAL BALL

A DISSERTATION
SUBMITTED TO THE DEPARTMENT OF PHYSICS
AND THE COMMITTEE ON GRADUATE STUDIES
OF STANFORD UNIVERSITY
IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE DEGREE OF
DOCTOR OF PHILOSOPHY

By
Roland Paul Horisberger
December 1983

Uff, I am finally done, my thesis

with golden letters and preciously bound

only a few examples exist in this world.

SLAC report not yet out → one piece goes to Europe.

Who the . . . would . . . ?

As a CERN–fellow search for my future

PAUL SCHERRER INSTITUT

Experience:

- physics analysis, software: ok
- hardware, electronics: zero, nada !

Career plan:

- do something exiting
- go where the action is
- do something new

Old British physicist asks me to develop for DELPHI at LEP a silicon micro-strip vertex detector
→ what's that? Microplex ?

I stay, do my thing for years and witness an extraordinary group of people developing silicon detectors

A SILICON STRIP VERTEX DETECTOR FOR LEP

Bernard HYAMS
CERN, Geneva, Switzerland

The design of a silicon strip diode detector for use at LEP is described. It will use a custom-designed NMOS read-out chip, to reduce the size and cost of the associated electronics.

Members of the DELPHI collaboration are proposing to equip their detector with a high resolution vertex detector, using silicon strip diode detectors. The objective is to have better than 10 μm precision and close tracks resolved if separated by more than 100 μm. This can be achieved with strip detectors with 25 μm pitch, provided that all strips are read-out.

Multiple scattering in the beam pipe at LEP will limit the precision for particles with momenta less than ~ 5 GeV/c. It is essential to use a light mechanical construction to limit further multiple scattering and nuclear interactions. This dictates an assembly and electrical read-out with less mass than the 0.3 mm thick silicon wafers. This excludes bringing out separate wires from each strip, since the wire mass would far exceed the detector mass.

It appears that these requirements can be achieved.

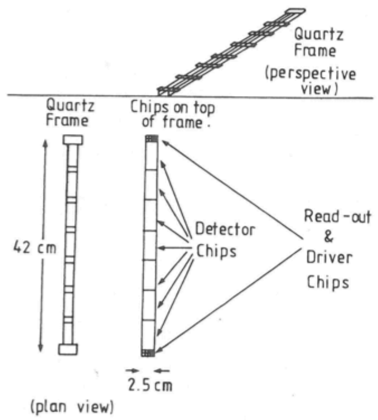


Fig. 1. Arrangement of detector and read-out chips on support structure.

Fig. 1 shows a unit cell holding a series of silicon strip detectors. The cylindrical vertex detector can be assembled from about 100 such cells. The cell "framework" is made of 0.5 mm quartz plates, sufficiently rigid to span some 40 cm with negligible sagging. The silicon is glued to the frame, forming an integral part of the structure.

To reduce cabling (and cost!), the signals will be read out with a chip designed for this purpose; designated "Microplex".

It will have 128 independent channels, each with a width of 35 μm. The total chip width, including supply lines will be 6.4 mm, giving an average density of just over 50 μm per channel. The individual detector wafers will be about 6 cm long and 2.5 cm wide. Their strips will be wire bonded in series, to form a 36 cm long total detector cell. Alternate strips will be read out at opposite ends of the cells.

Each channel of Microplex has a gated charge-sensitive preamplifier, a storage capacitor (to hold the analog signal) and one cell of a shift register to enable the channels to be read out (fig. 2).

The design figures for Microplex channels are to have less than 1000 electrons rms input noise, about 150 ns gate width to hold the analog signal for a few milliseconds and to read out $N \times 128$ channels sequentially at about 2 MHz ($1 \leq N \leq 5$).

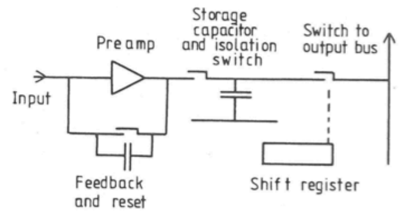


Fig. 2. Schematic circuit of one channel of read-out chip.

Hosted by NA32 but working on LEP

PAUL SCHERRER INSTITUT

NA32 experiment at CERN looks for hadronic charm production

The ACCMOR collaboration is quite large, very busy and dynamic

CERN group hosts me. May 1984 I start to work “illegally” for DELPHI by testing a new VLSI readout chip for silicon micro strip detectors. Its called Microplex chip for an undefined and quite impossible to build silicon micro-vertex detector.

→ have many questions and the field is new

→ learning on the job & learning by doing

→ asking questions to people and I do get some answers

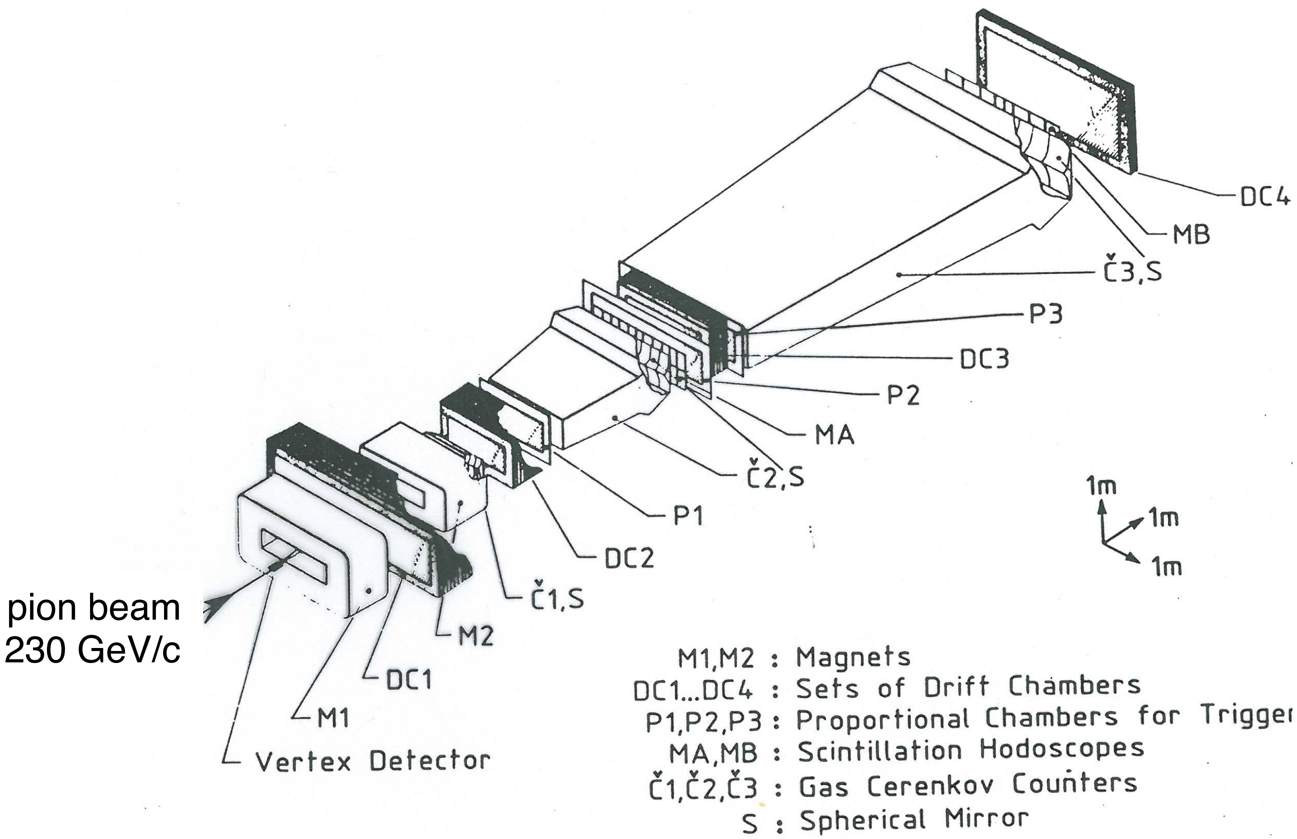
→ NA32 has lots of people that work in exciting new silicon detectors

→ realize that a some NA32 physicists always give me good answers

→ one guy (pullover over shoulders & special haircut) gives real good answers

NA11 experiment searches hadronic charm

experimental observation of hadronic produced charm particle is rather difficult

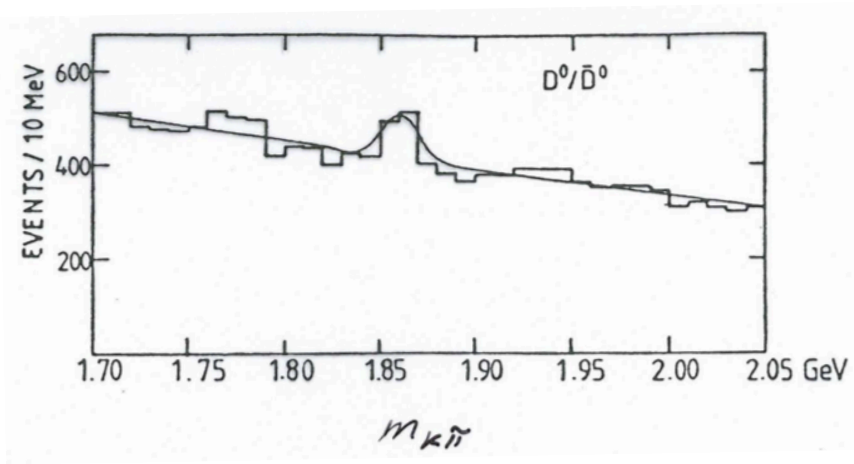


NA11 experiment is rather complex and quite a big effort in hardware and people

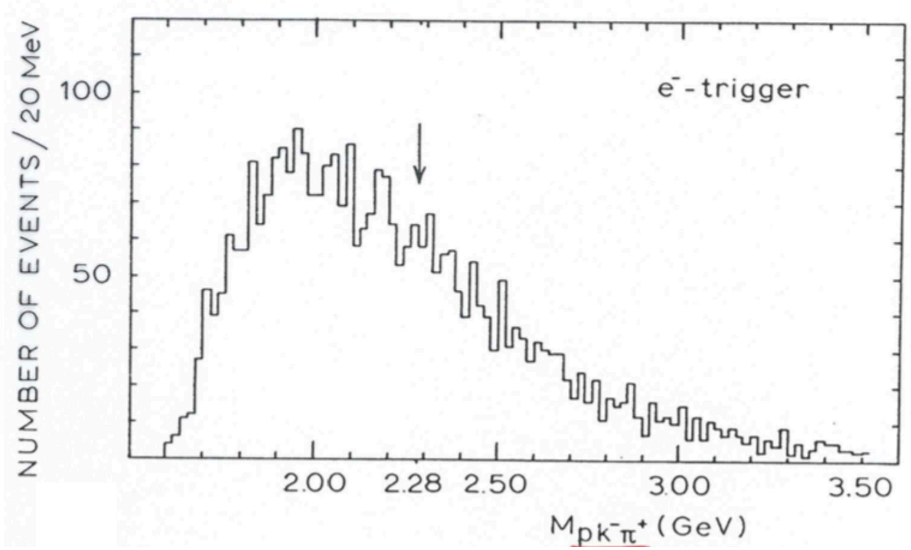
NA11 experiment searches hadronic charm

experimental reconstruction of hadronic produced charm particle is not easy

$D^0 \rightarrow K\pi$



$\Lambda_c \rightarrow p\, K^- \pi^+$



experimental observation of easier channels worked, but seldom produced charm particles and lower branching ratio decays were not possible.

→ overwhelming, high rate hadronic backgound processes

→ selection of charm events by very precise livetime tagging should help !

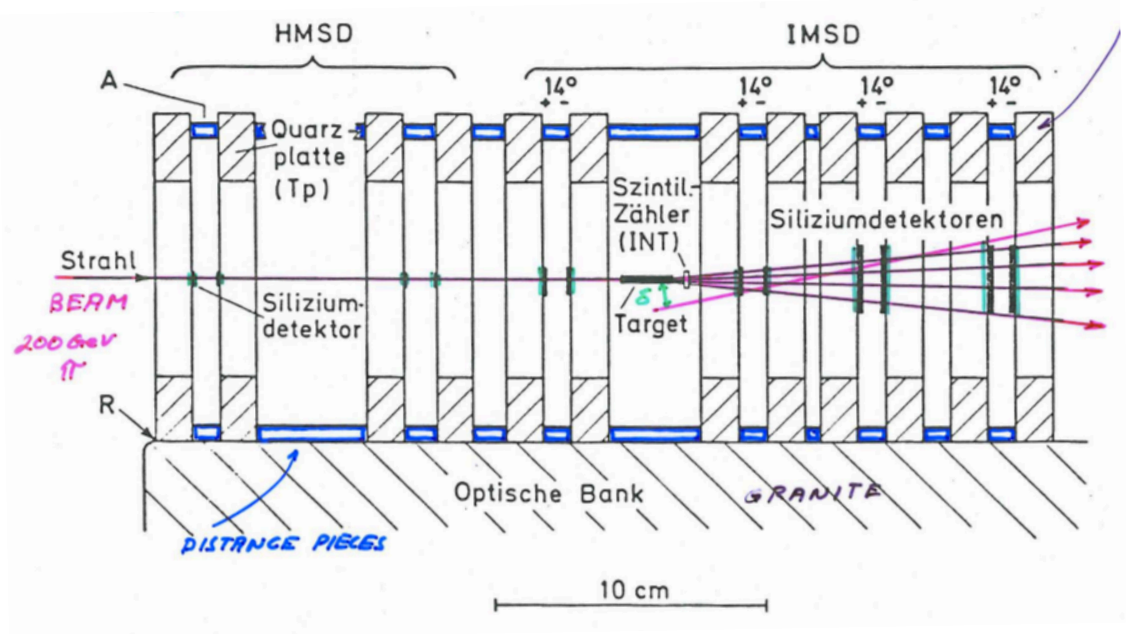
→ improve experiment by adding novel, very precise silicon vertex detectors

Silicon detectors boost NA32 experiment

Several groups of ACCMOR collaboration develop novel silicon detector technologies

NA11/32 becomes breeding ground of today's silicon precision vertex detectors

Silicon micro strip detectors in NA32



$\Lambda_c \rightarrow p\ K^-\ \pi^+$

with Si-strip detectors

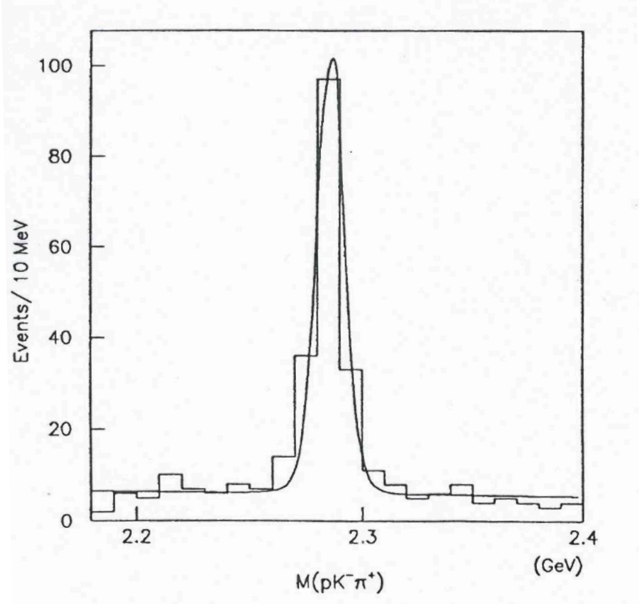


Fig. 1. pKπ invariant mass spectrum.

The addition of silicon micro strip detectors made a huge difference !

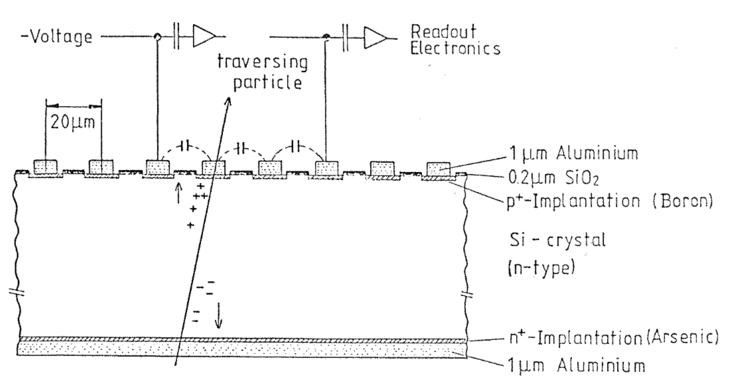
Silicon strip detectors developed for NA32

PAUL SCHERRER INSTITUT

Small group pioneered and developed silicon micro strip detectors for NA32

A wealth of innovation:

- analog pulse height readout
- precision by interpolation
- capacitive charge division
- AC-coupled low noise electronics
- system & integration



Strip detector:	resolution
20µ strip pitch	
60µ readout pitch →	4.5µ
120µ readout pitch →	7.9µ

Nuclear Instruments and Methods 205 (1983) 99–105
North-Holland Publishing Company

A SILICON COUNTER TELESCOPE TO STUDY SHORT-LIVED PARTICLES IN HIGH-ENERGY HADRONIC INTERACTIONS

B. HYAMS and U. KOETZ *
CERN, Geneva, Switzerland

E. BELAU, R. KLANNER, G. LUTZ, E. NEUGEBAUER and A. WYLIE
Max-Planck-Institut für Physik und Astrophysik, Werner-Heisenberg-Institut, Munich, Fed. Rep. Germany

J. KEMMER
Technische Universität, Munich, Fed. Rep. Germany

Received 5 July 1982

A telescope consisting of six silicon microstrip detectors achieving 5 μm spatial resolution for minimum ionizing particles has been built. The design and fabrication of the counters, electronics, and mechanical set-up is described, and first results of its performance in a 175 GeV/c beam are reported.

1. Introduction

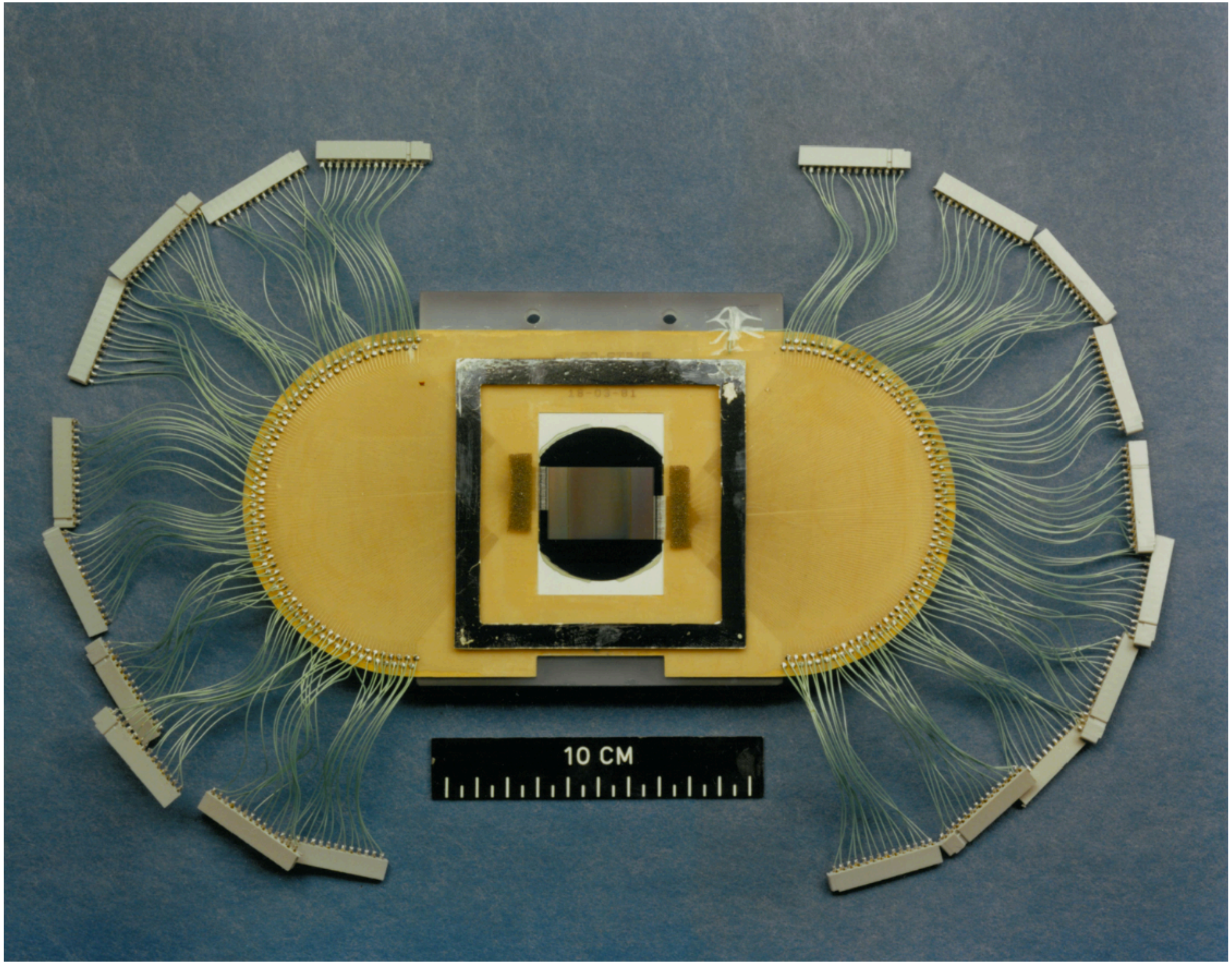
The telescope described in this article has been built for an experiment to study the production and properties of charmed particles in 100–200 GeV hadronic interactions in a beryllium target at the CERN Super Proton Synchrotron (SPS) **. The lifetime of charmed particles of a few times 10^{-13} s, their production cross-sections of a few microbarns, and the general features of hadronic interactions in this energy range, such as the charged multiplicity of ~ 10 and the concentration of most of the particles in a narrow forward cone, have defined the required performance of the counters:
– spatial resolution of $\leqslant 10$ μm;

2. The silicon microstrip detectors

2.1. Principles of operation

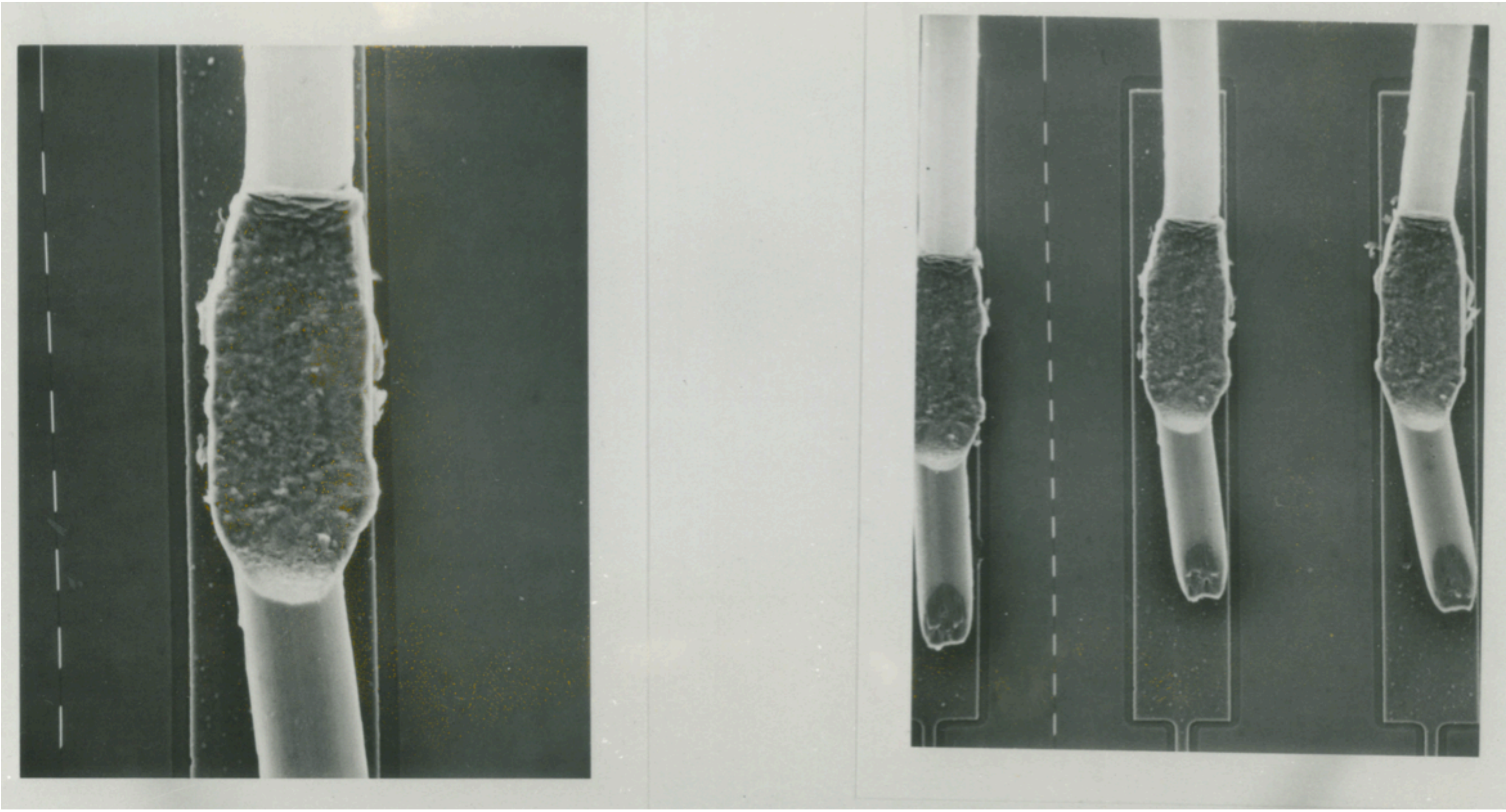
Fig. 1 shows schematically a cross-section of the detector. The basic material is a high-ohmic (~ 2 kΩ · cm) n-doped silicon crystal, 2 inches in diameter and 280 μm thick. One face of the crystal in aluminized. On the other face, the sensitive area of the counter (a rectangle of 24 mm × 36 mm in our case) is covered with p^+ implanted diode strips (1200 strips of 12 μm × 36 mm and 20 μm pitch) and Al contacts. Connecting the strips to a negative voltage of 160 V depletes the n-doped silicon crystal of free charge carriers, leaving

Silicon strip detectors developed for NA32



Silicon strip detectors developed for NA32

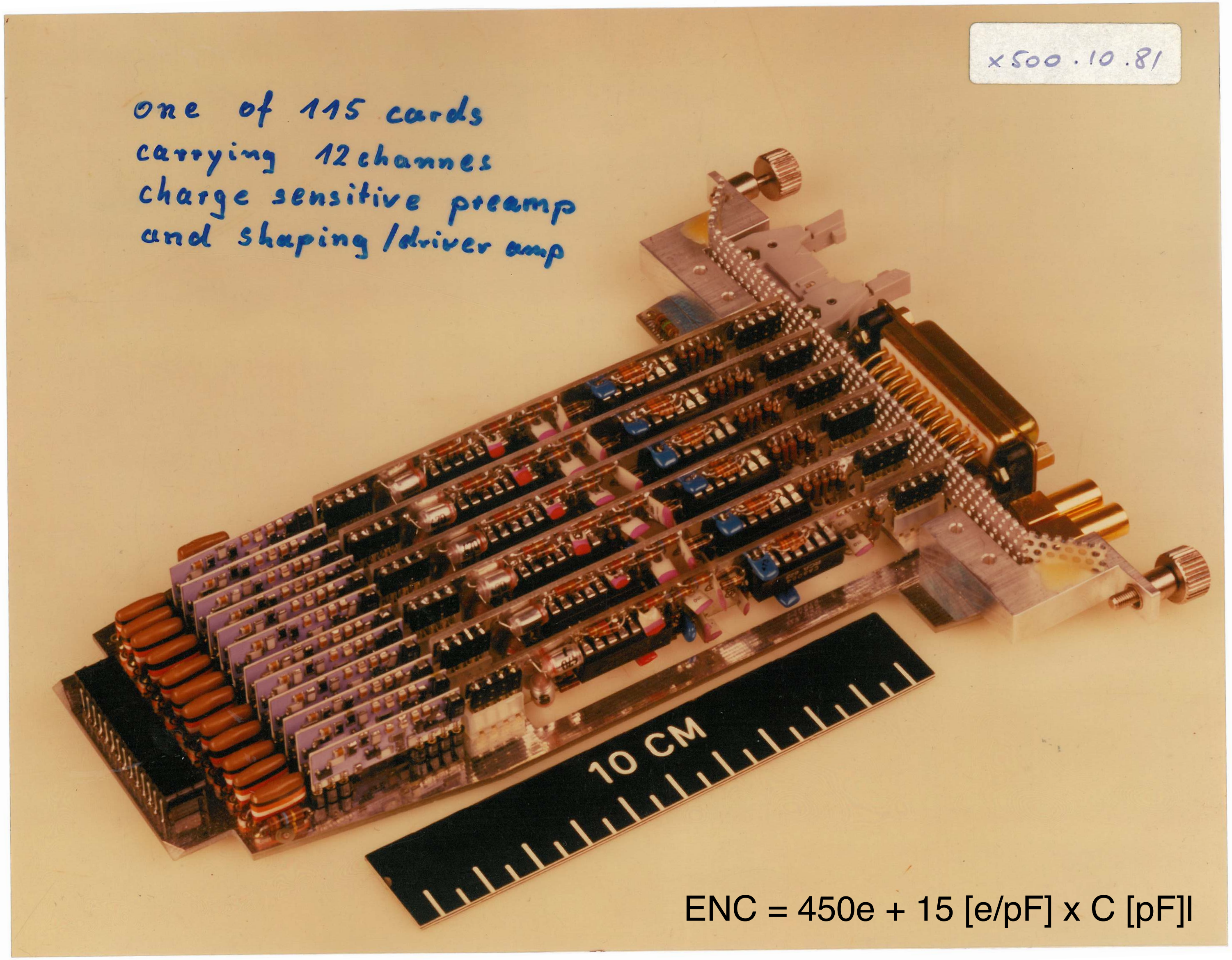
In HEP ultrasonic wire bonding was at the time pretty exotic !



Silicon strip detectors developed for NA32

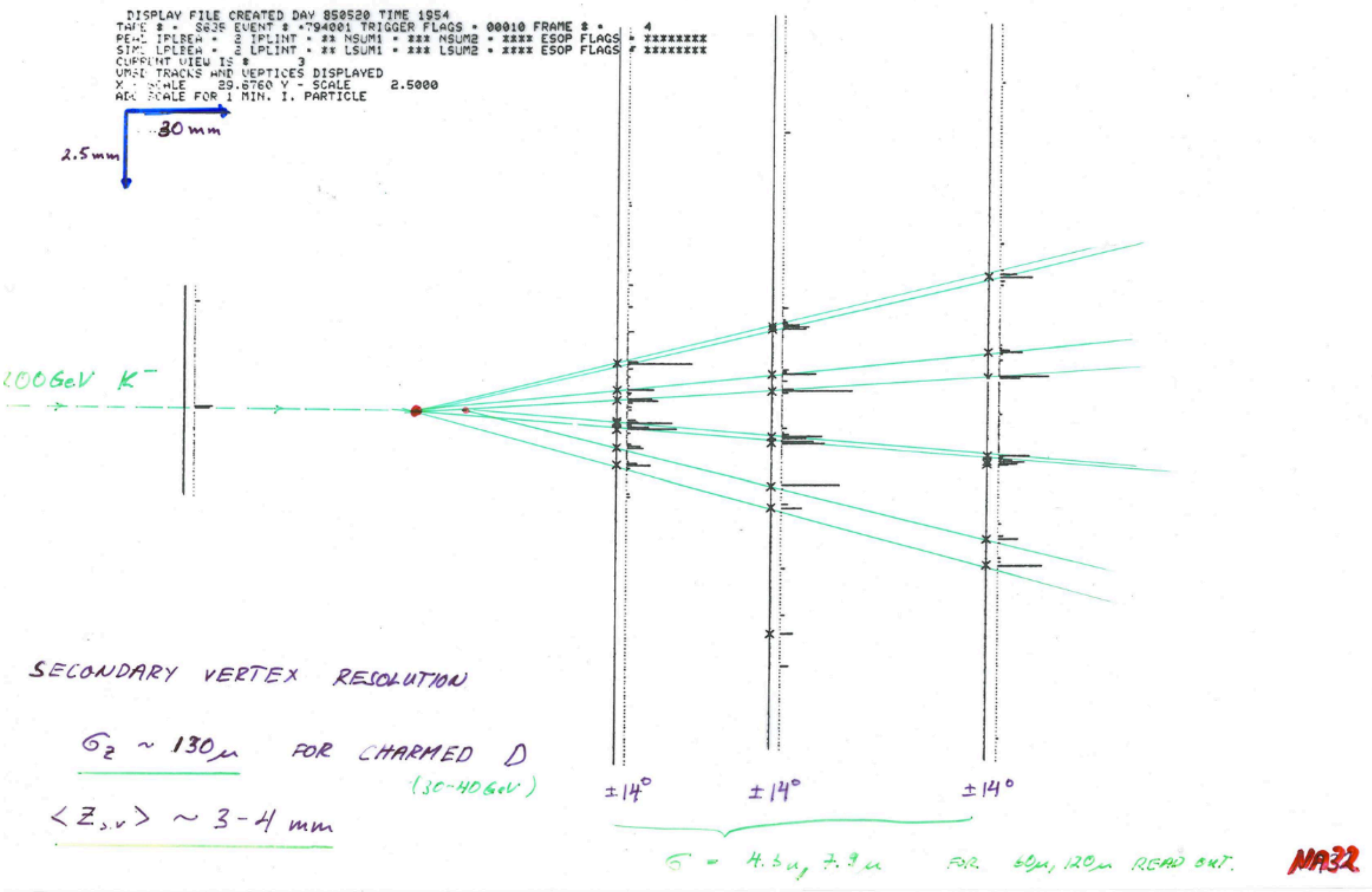
PAUL SCHERRER INSTITUT

cost per electronic channel was the limit for larger applications (~100-200 CHF/channel)



ENC = 450e + 15 [e/pF] x C [pF]l

Secondary charm vertices with NA32



Signal interpolation in Si-strip detectors

the “classical” paper on how to obtain the best resolution with charge interpolation

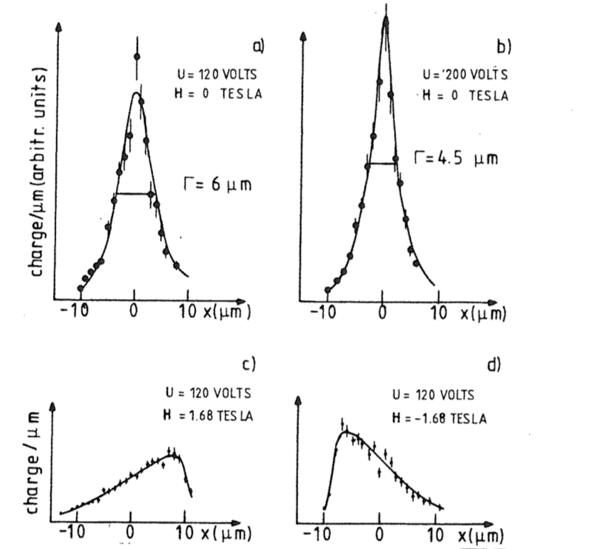


Fig. 6. The charge distribution collected by the diode strips: a) $U = 120$ V, $H = 0$ T; b) $U = 200$ V, $H = 0$ T; c) $U = 120$ V, $H = 1.68$ T; d) $U = 120$ V, $H = -1.68$ T.

CHARGE COLLECTION IN SILICON STRIP DETECTORS

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J. KEMMER
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U. KÖTZ *
DESY, Hamburg, Fed. Rep. Germany

M. RIEBESELL **
University of Hamburg, Fed. Rep. Germany

NIM 214 (1983) 253-260

The charge collection in silicon detectors has been studied, by measuring the response to high-energy particles of a 20 μm pitch strip detector as a function of applied voltage and magnetic field. The results are well described by a simple model. The model is used to predict the spatial resolution of silicon strip detectors and to propose a detector with optimized spatial resolution.

1. Introduction

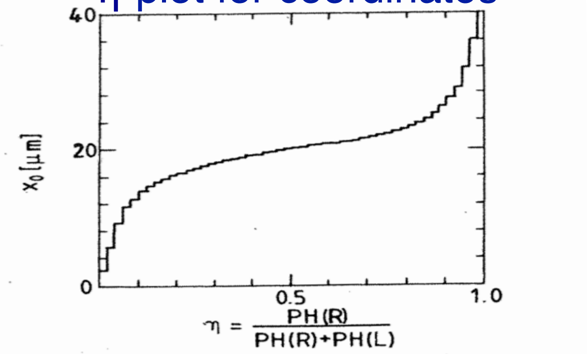
Recently the planar process, developed for producing microelectronics, has been adapted to the fabrication of detectors for ionizing radiation [1]. One of the first applications of this new technology was the development of microstrip detectors with high spatial resolution as a vertex telescope for elementary-particle inter-

2. The experimental apparatus

2.1. The microstrip detector

A high-ohmic (~ 3 kΩ cm) n-doped silicon crystal, oriented in the 1,1,1-direction, 2 inches in diameter and 280 μm thick, is used as base material. One face of the crystal is aluminized. On the other face the sensitive area of the counter (2 mm × 32 mm) is covered with p^+

η-plot for coordinates



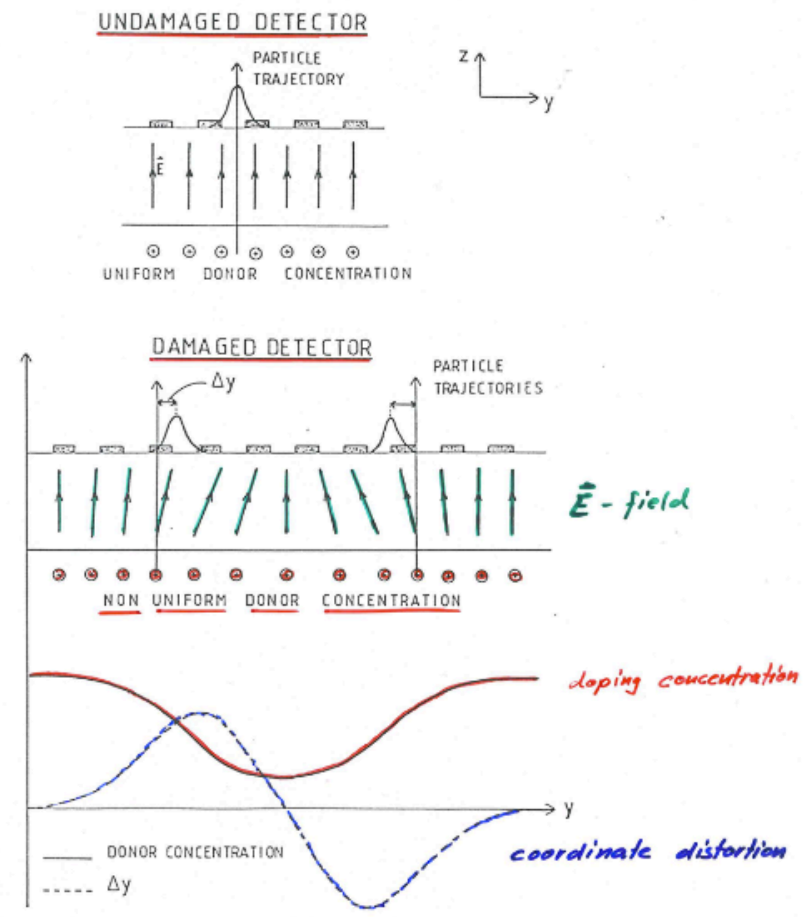
η-algorithm is now used everywhere in silicon detectors

test beam 1994: 25μ strip readout → 1.3μ resolution

→ H-LHC, FCC

Silicon detectors damaged by π beam

after running several years in the pion beam small coordinate shifts showed up.



first observation of doping change → type inversion

RADIATION DAMAGE IN SILICON STRIP DETECTORS

H. Dietl[3], T. Gooch[1], R. Klanner[2], M. Pepé[4] and F. Wickens[4]

The high resolution silicon strip detectors of the ACCMOR collaboration [1] have been used during 1982-1984 to measure production and decay of charm particles in hadronic interactions. During this time, they have been exposed to $2.3 \cdot 10^{12}$ hadrons, focussed onto a spot of $\Gamma_x \times \Gamma_y = 12$ mm x 0.5 mm. The following effects have been observed [2]:

(i) an increase in leakage current approximately proportional to the number of particles traversing a detector element $I_{leak} = I_0 + \alpha \cdot N \cdot d$ ($\alpha = 1.3 \cdot 10^{-8}$ nAmp/cm, N . . . number of particles traversing the detector element of thickness d, I_0 . . . leakage current without radiation damage)

(ii) a voltage current characteristic, deviating from the $V^{1/2}$-dependence of an undamaged detector (Fig. 1). This is interpreted as a result of an increased bulk resistivity due to radiation damage

(iii) a systematic shift of the measured coordinate (Fig. 2) of up to 10 µm. It can be explained by the transverse electric field inside the silicon crystal due to the change in resistivity from radiation damage. It is found that 0.05 doping centres are removed per one cm path of a minimum ionizing particle in the crystal.

References

[1] B. Hyams et al., NIM 205 (1983) 99;
E. Belau et al., NIM 214 (1983) 253.

[2] H. Dietl et al., Radiation Damage in Silicon Strip Detectors, paper submitted to this conference.

Figure Captions

Fig. 1 Current voltage characteristics for detector elements with strong (#25) and little (#8) radiation damage.

Fig. 2 Systematic shift in measured coordinate as function of position. The beam, which caused the radiation damage, was centred at 0 with a full width of 400 µm.

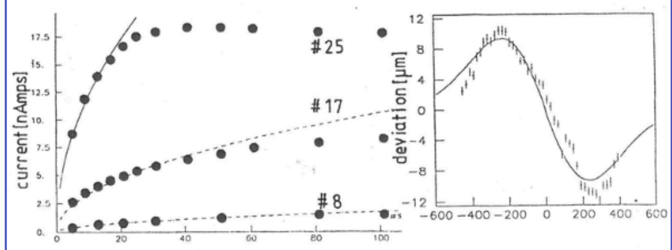


Fig. 1 voltage [Volts]

Fig. 2 position [µm]

1) Bristol University, Bristol, U.K.
2) DESY, Hamburg, Fed. Rep. Germany
3) Max Planck Institut für Physik, Munich, Fed. Rep. Germany
4) Rutherford Appleton Laboratory, Chilton, Didcot, U.K.

Bari 1985

Radiation Damage (by Robert Klanner, 1984/5)

PAUL SCHERRER INSTITUT PSI

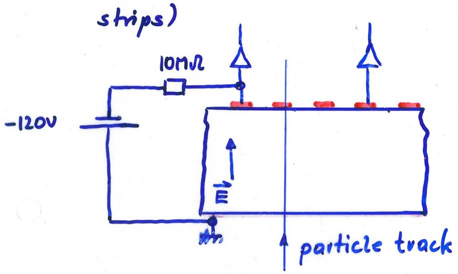
①

Radiation Damage Experience with High Resolution Silicon Strip Detectors

(R.Klanner NA11/NA32 expt CERN)

(1) Detectors used in Experiment: (Kemmer TU München)

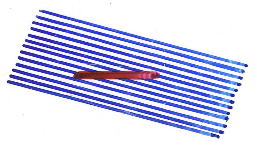
- strip detectors 20μm pitch, capacitative charge division readout with 60μm pitch
  - ⇒ area / volume of one element: $0.02\ cm^2$ / $6 \times 10^{-4}\ cm^3$
- 3kΩ n-doped (P) - ion implantation, oxide passivation
- spatial resolution: ~ 5μm (relies on uniformity of charge collection to readout strips)



systematic distortions in detectors ≤ 1μm

⇒ transverse field component ≤ 1%

- layout in experiment
  - beam focussed to 10mm x 0.3mm
  - intensity ~ 2×10^6 200 GeV/c π^- per second



← detector strips

beam

②

(2) Results after ~100 effective days of running: (82/83/84)

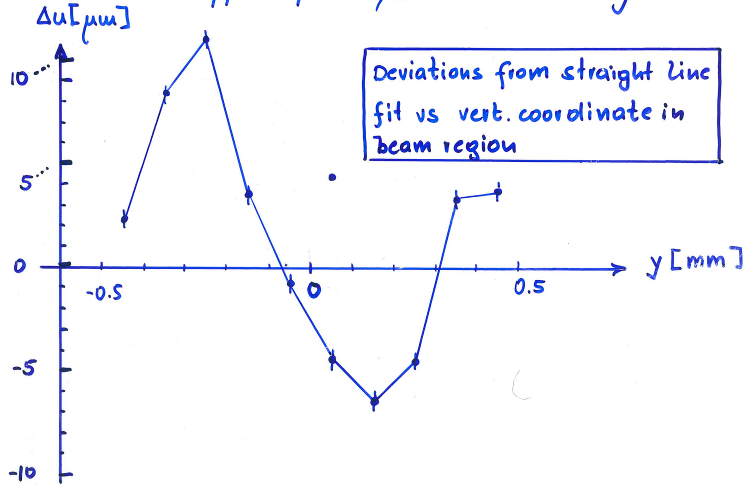
max flux: ~ 8×10^{13} particles / cm^2

integrated over detector ~ 2.4×10^{12}

⇒ (i) device stability and dark current:
- no effect observed

(ii) charge trapping:
- no effect observed (< 2% decrease)

(iii) systematic distortions:
- effect of ~ 10μm in beam region



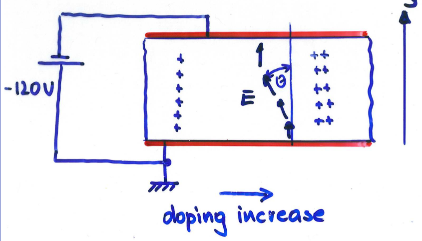
assumption:

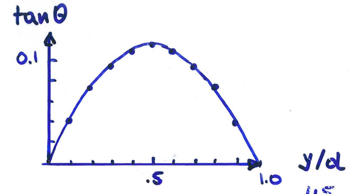
distortion due to change in doping → yields transverse field component:

(e.g. for a linear change of doping concentration)

Donor removal (by Robert Klanner)

③





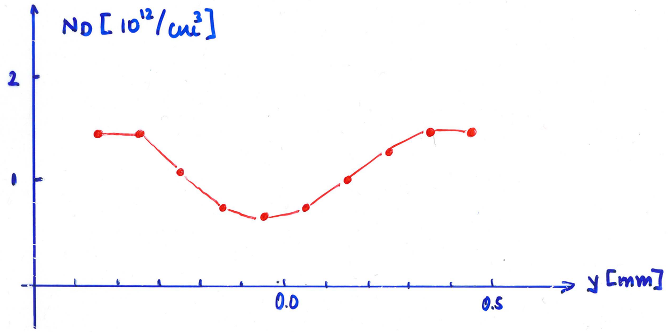
for $N_D = 10^{12} cm^{-3}$

$\frac{dN_D}{dy} = 4 \cdot 10^{13} cm^{-4}$

$d = 280 \mu m$

$\phi = 120$ Volts

⇒ reconstructed doping profile of irradiated detector:

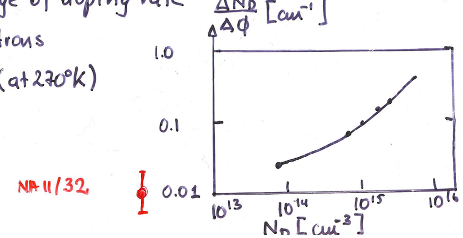


⇒ estimated rate of doping change: $\frac{\Delta N_D}{\Delta \phi} [cm^{-1}]$

⇒ 10^{-2} per traversing particle per cm.

[H.J. Stein and R. Gereth – J. Appl. Physics 39 (1968) 2890

measured change of doping rate $\frac{\Delta N_D}{\Delta \phi} [cm^{-1}]$
for 1.7 MeV electrons
for n-Silicon (at 270°K)



④

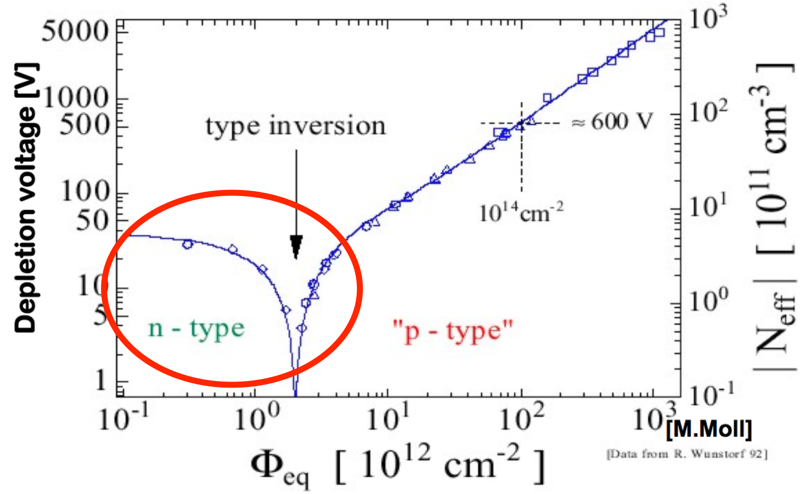
(3) Conclusions:

- For precision silicon detectors, change of doping due to ionizing radiation is a limitation

Typically: $\frac{\# \text{traversing particles}}{cm^2} \lesssim 10 \cdot N_D [cm^{-3}]$

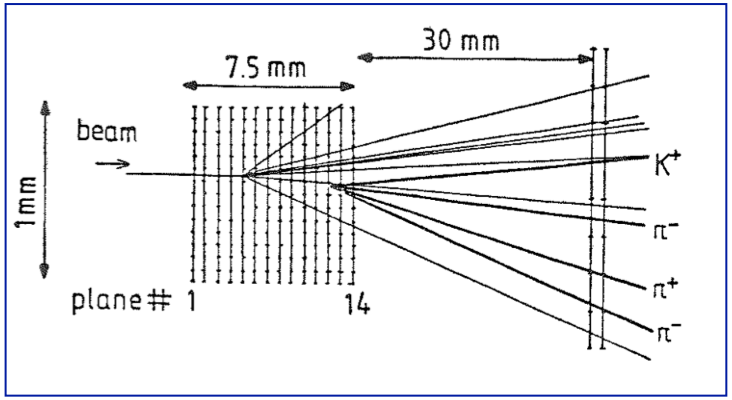
NB: Results preliminary – effect only recently noticed in NA-11/NA-32 analysis, no direct measurement of change in doping yet alone

modern N_{eff} plot by RD-50
on donor removal/ type inversion



NA32 gets a visionary target track trigger

- active target with track trigger capability
- select secondary vertex charm decays
- 14 silicon detectors, each 48 channels of 20μ pitch
- level 2 trigger by ESOP processor → 8μsec decision
- 1984 data run of NA32



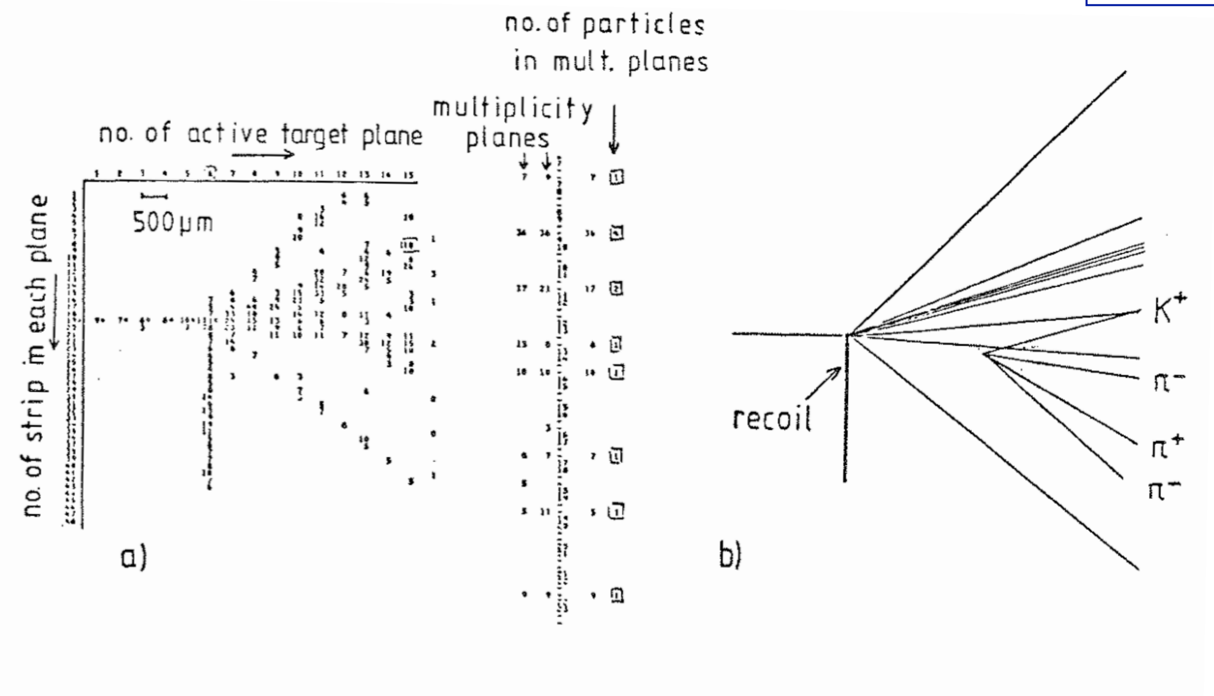


Fig. 22 (a) Display of an event as seen in the active target. The numbers are measured pulseheights in units of 1/10 M.I.P. (b) Tracks reconstructed (in the same event) in forward telescope projected into active target. A $D^0 \rightarrow K\pi\pi\pi$ decay can be seen in the active target.

30 years later:

CMS plans for H-LHC a track trigger for installation in 2024

Whoao !

What a courage !

Robert you'r something !

Robert gets into novel silicon detectors

Silicon Drift Chamber (SDC) proposed by Gatti & Rehak gets built & tested

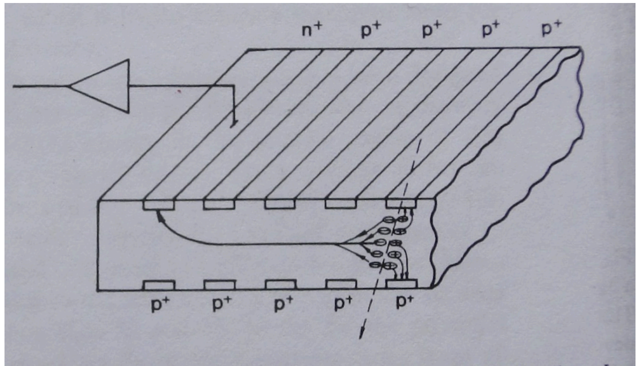


Fig. 1. Perspective view (not to scale) of a SDC showing the working principle.

calculated drift fields

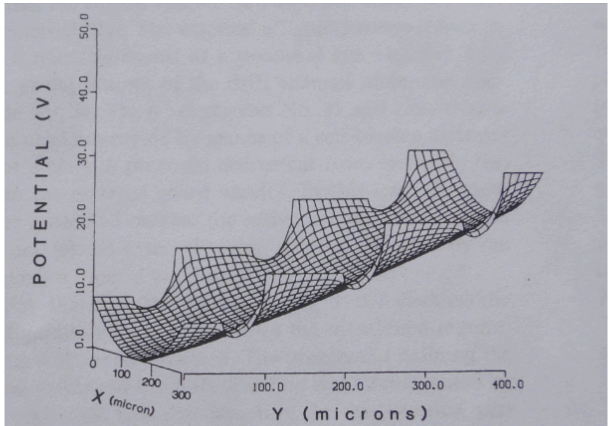


Fig. 5(a). Potential energy for electrons in the drift region. Potential difference between neighbouring p$^+$ strips: 7.5 V.

SEMICONDUCTOR DRIFT CHAMBERS FOR POSITION AND ENERGY MEASUREMENTS *

NIM 235 (1984) 224-234

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J. KEMMER
Fakultät für Physik der Technischen Universität München, FRG

Peter HOLL, Robert KLANNER, Gerhard LUTZ and Andrew WYLIE
Max Planck Institut für Physik und Astrophysik, München, FRG

Semiconductor drift chambers have been recently suggested and feasibility tests performed. This paper presents the first operative silicon drift detectors for position and energy measurements. Design criteria and experimental results in the laboratory and on an accelerator beam are reported.

1. Introduction

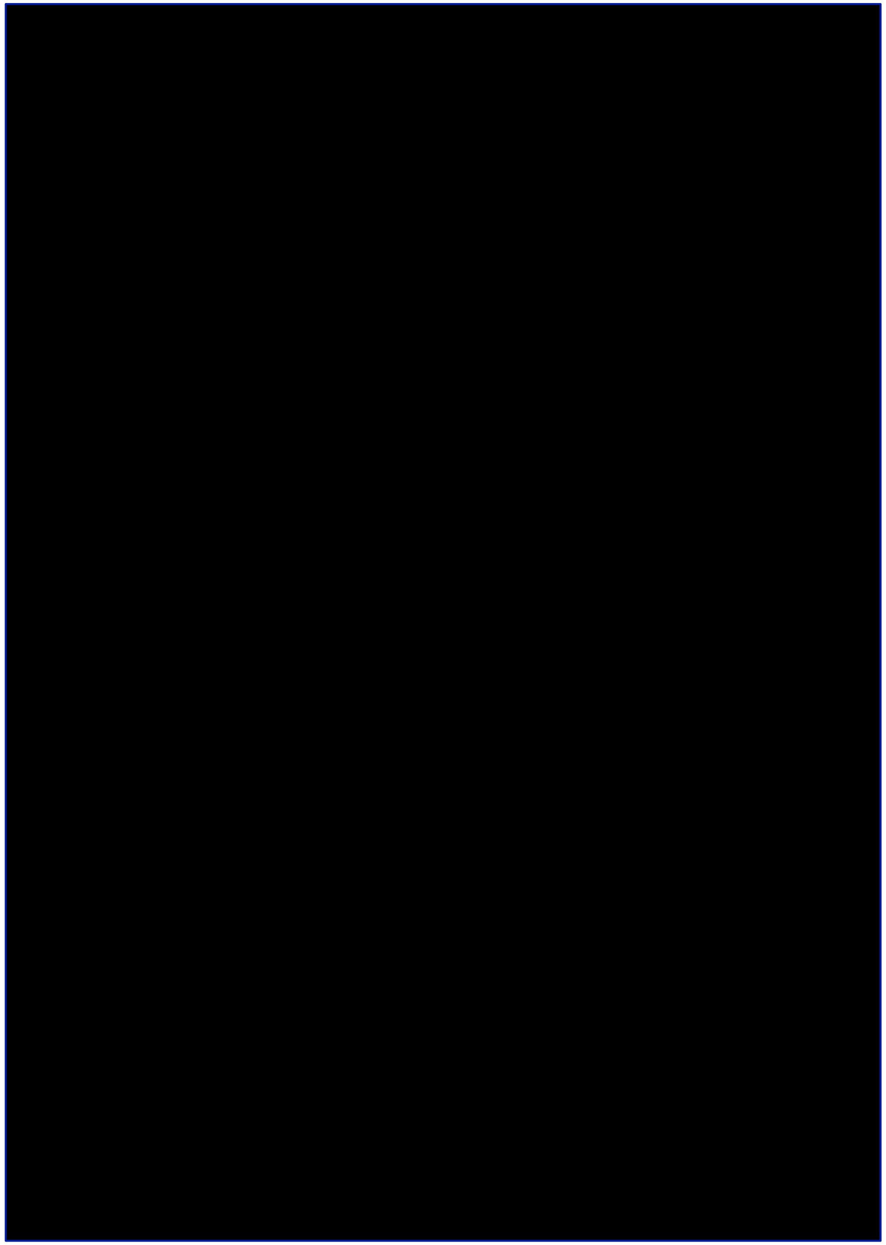
The semiconductor drift chamber (SDC) was recently proposed [1,2]. It is based on the principle that a thin, large area semiconductor wafer, with rectifying junctions implanted on both surfaces, can be fully depleted through a small anode contact [2,3]. The depletion field confines the electrons generated by the ionizing particle in a buried potential channel parallel to the

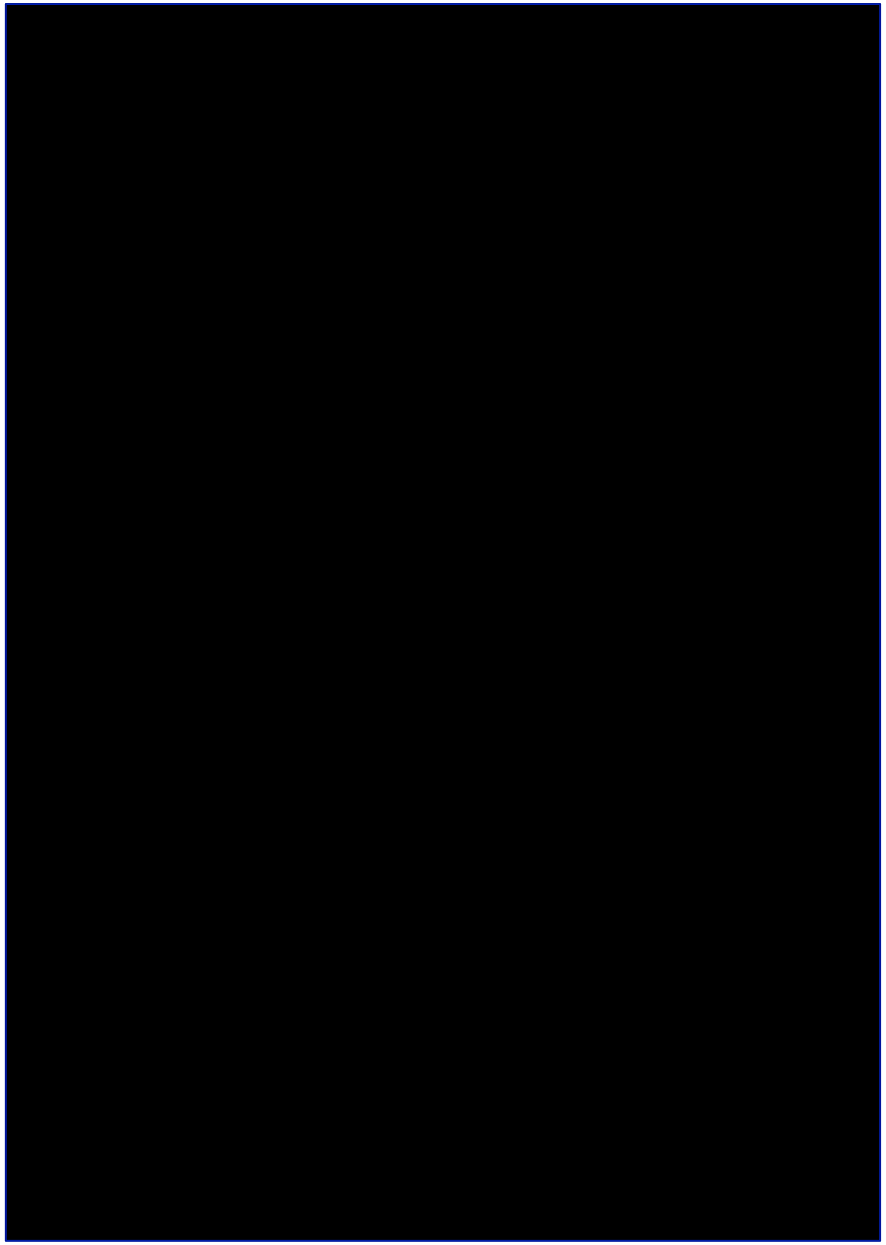
The work presents the first operative detectors conceived on the basis of the principles of the SDC. Two kinds of detectors have been designed mainly for position measurements, while a third one is for energy measurements. Experimental tests performed in the laboratory and at the CERN SPS are presented here.

Section 2 of this paper describes the design of the detectors and section 3 the manufacturing process. In section 4 the behaviour of silicon drift detectors under

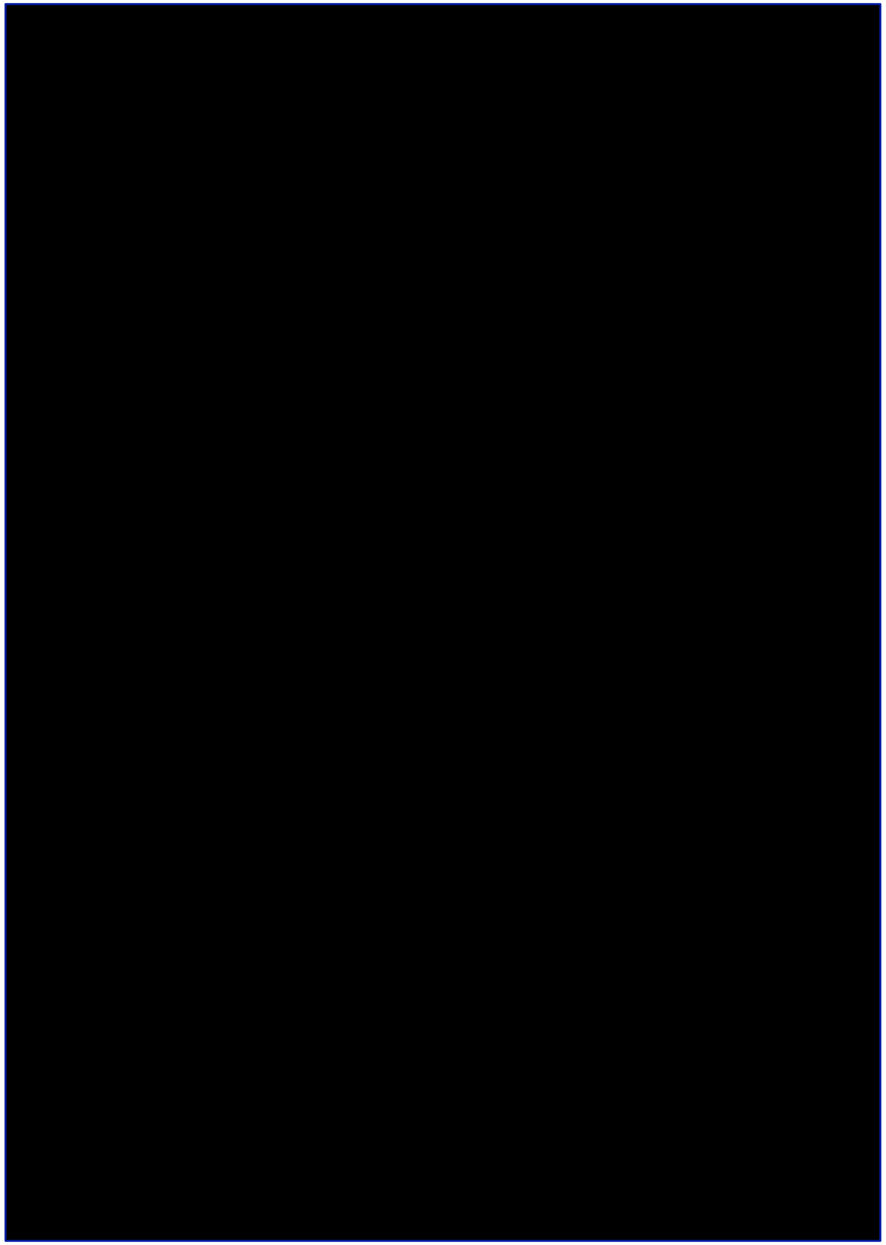
measurements for me an admirable degree of experimental professionalism

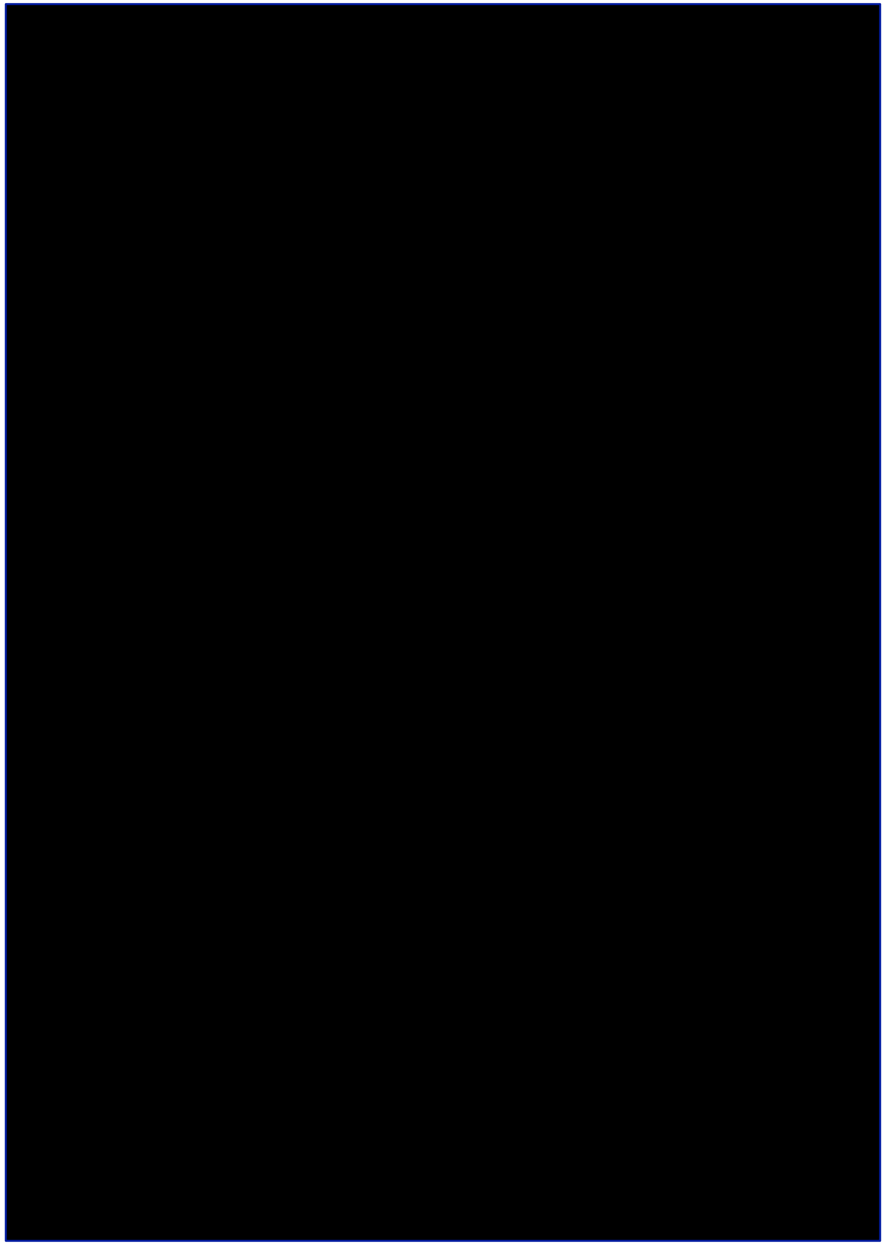
Roberts talk in San Miniato, July 1984



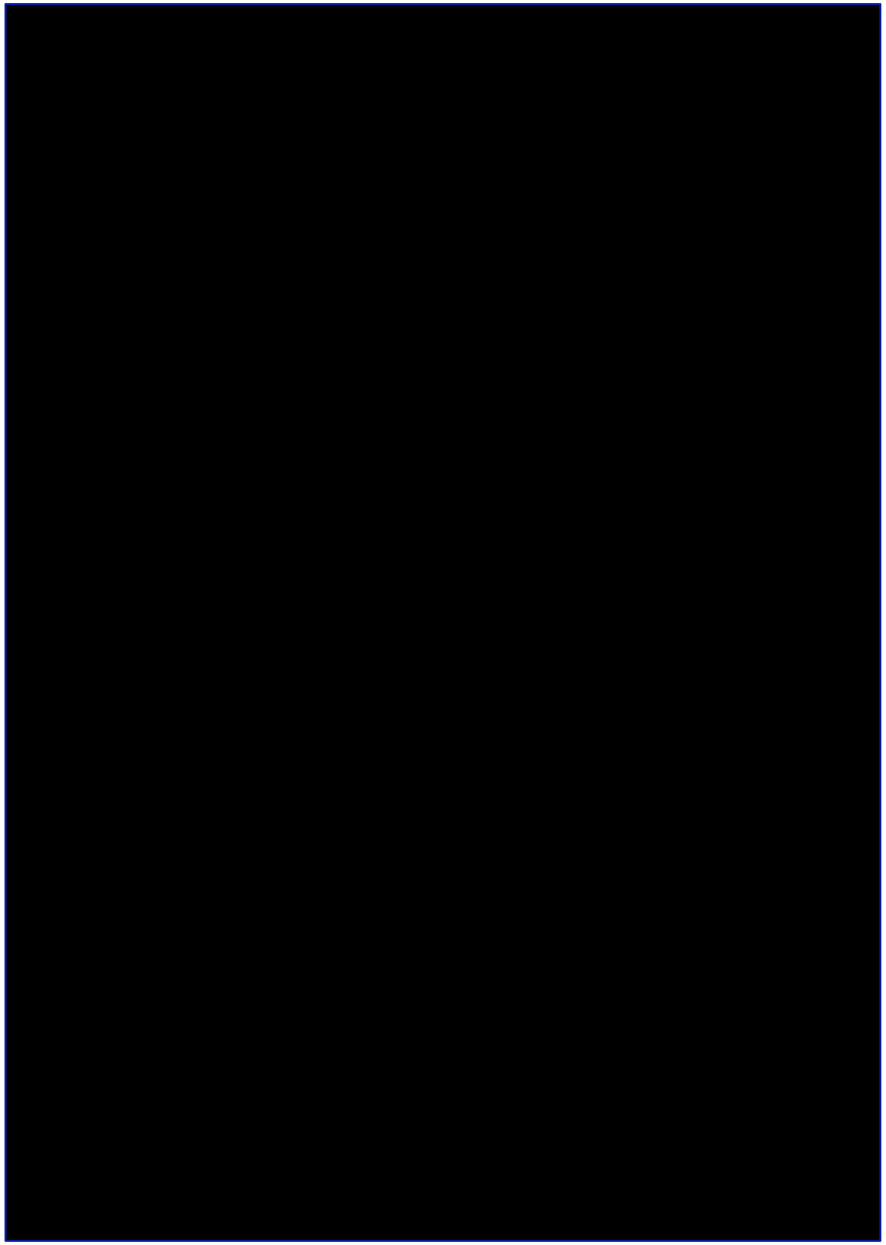


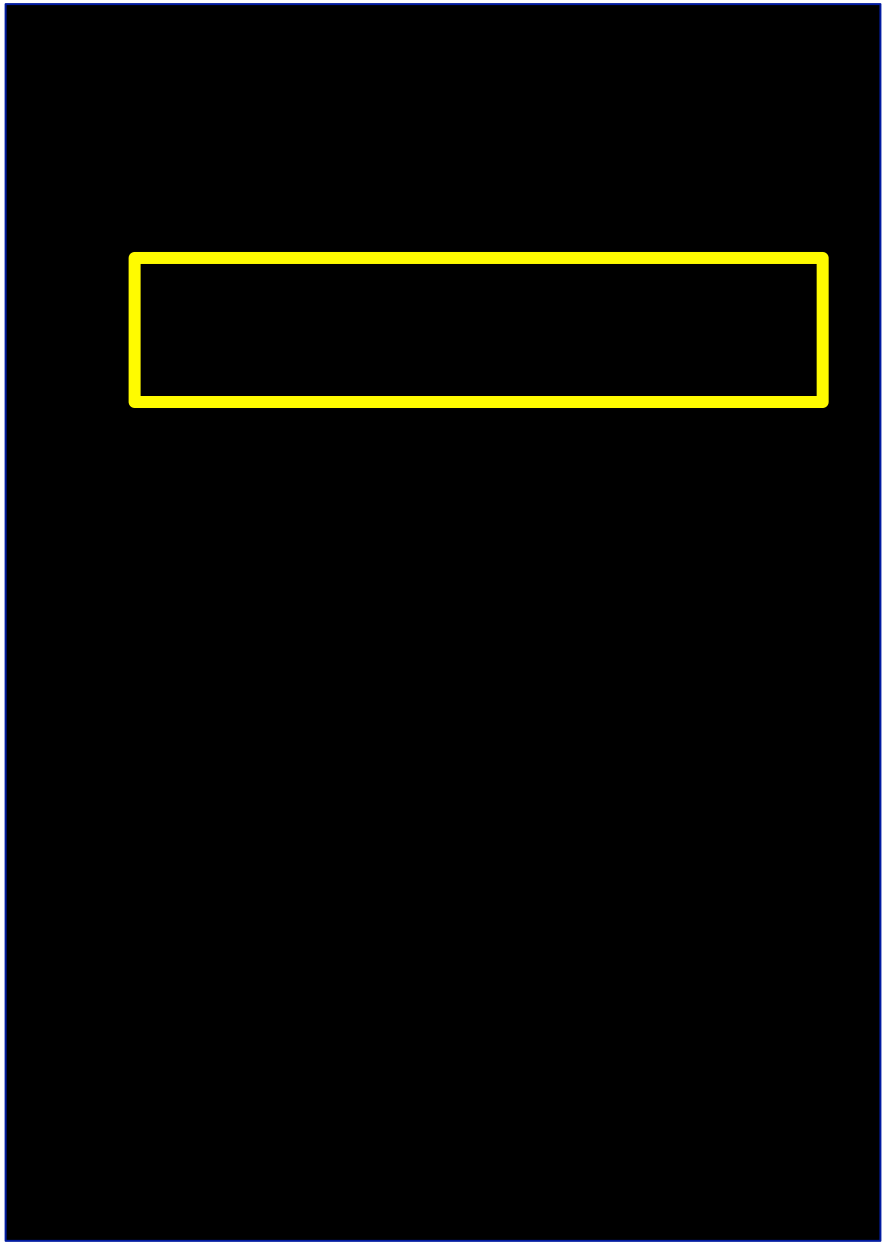
clear and concise, that's his trademark



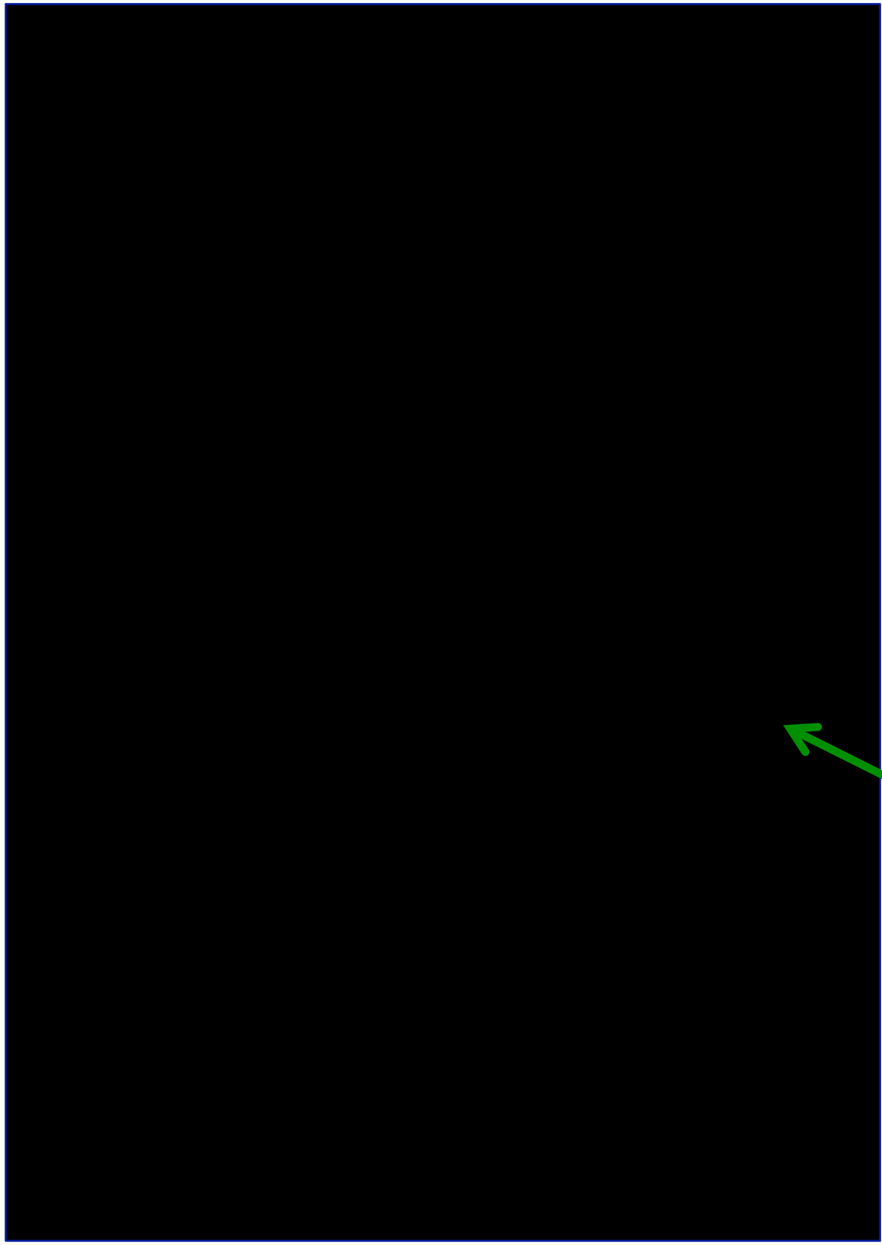


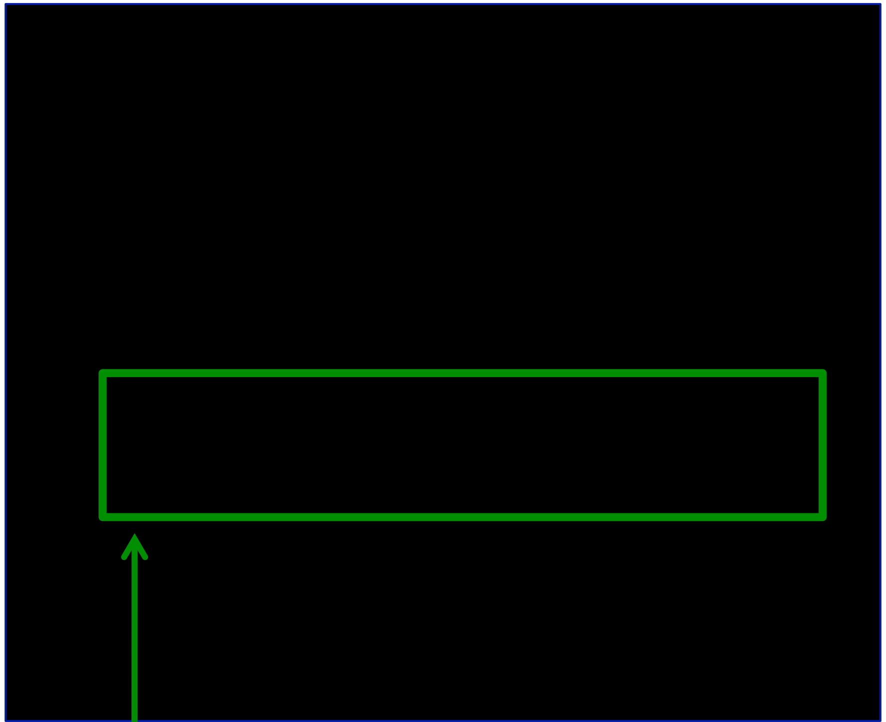
this clear and lucid way to grasp the quintessence





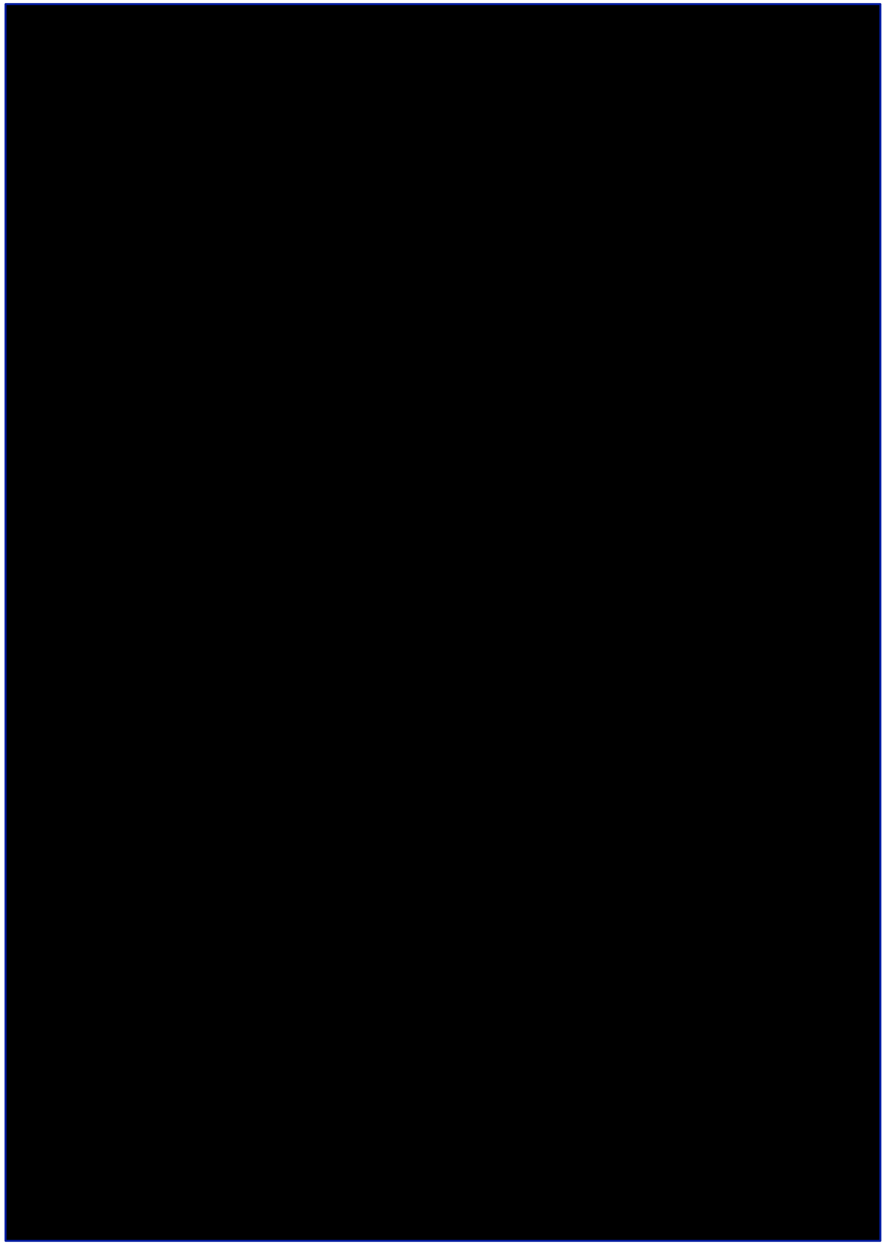
his feet on the ground and a clear vision for the future

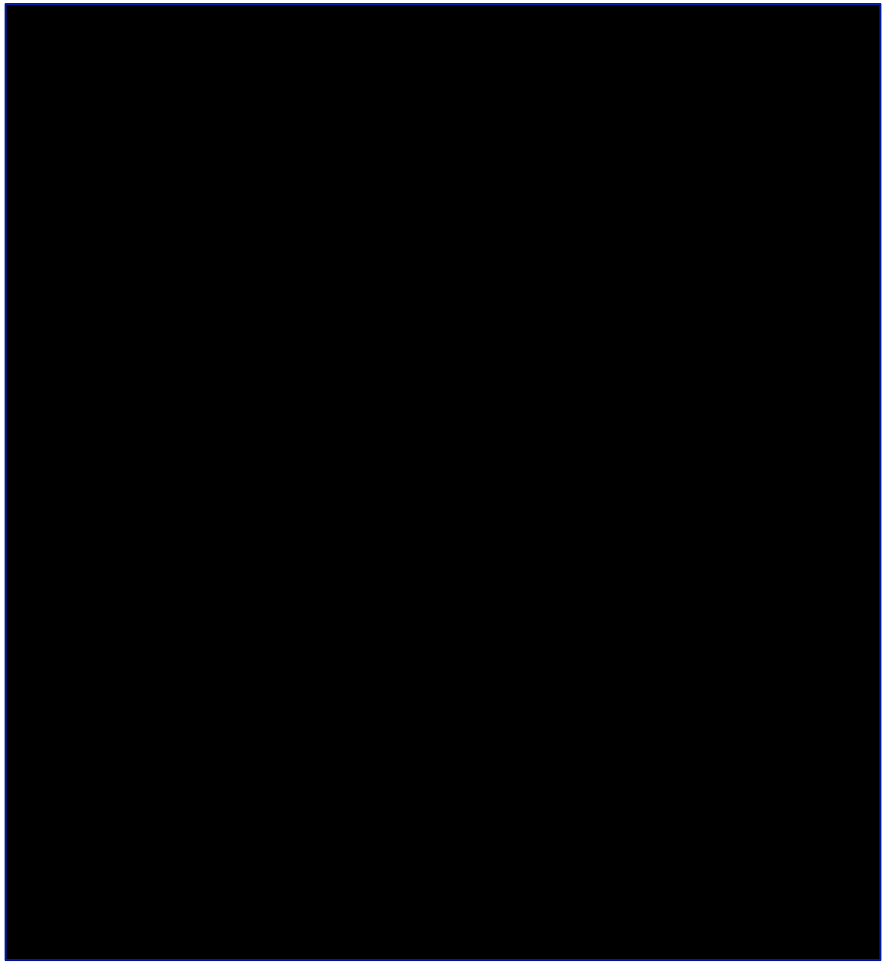




that’s what I tried to work on

Silicon sampling calorimeter !!! → CMS will get one now !

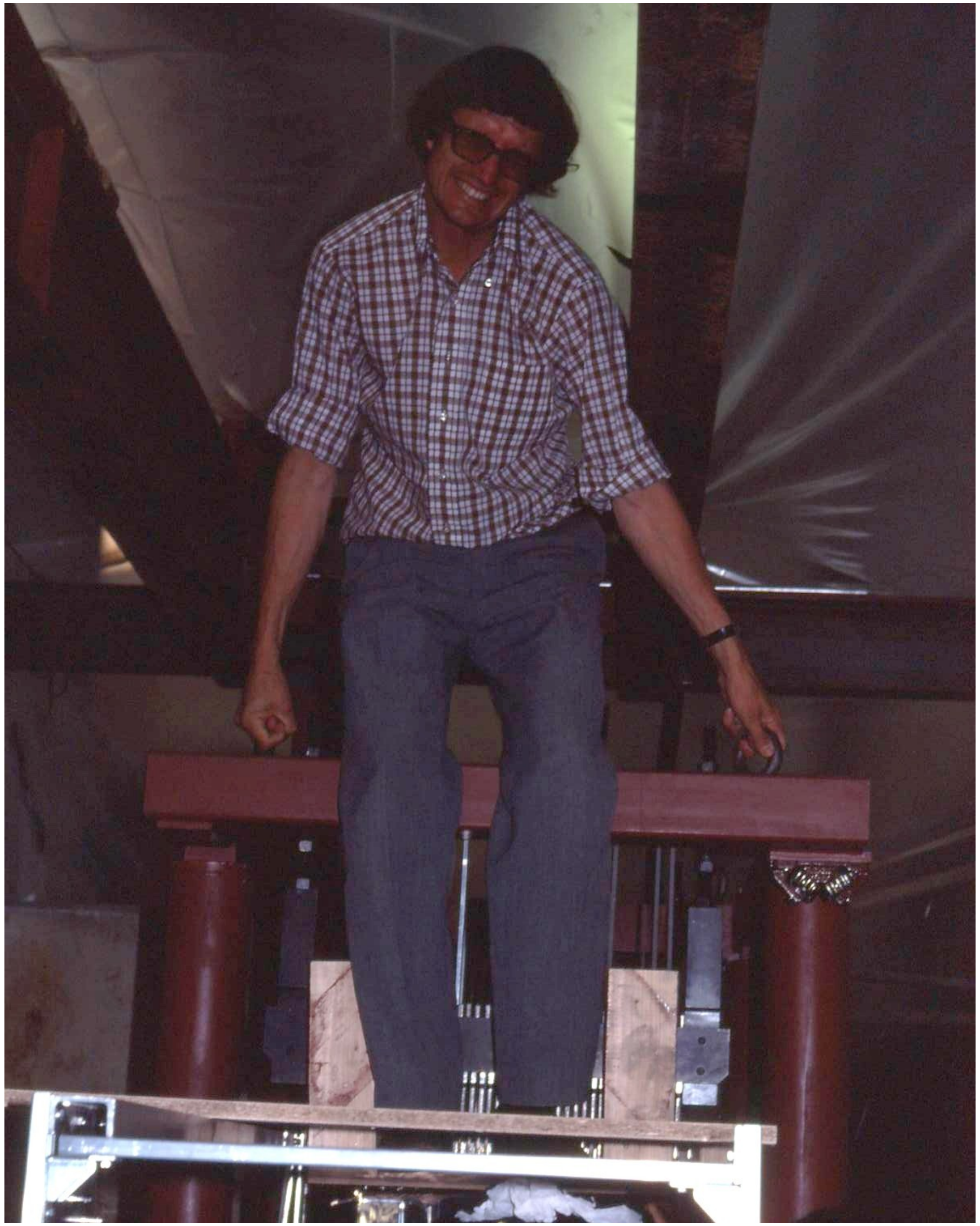




Ups ! he is getting into calorimetry now → Zeus, DESY

→ things get heavier

Robert prepares himself for calorimetry



as usual:

people trying to
follow him have
a tough time . .

this was already
the case when he
was still in the
Steiermark

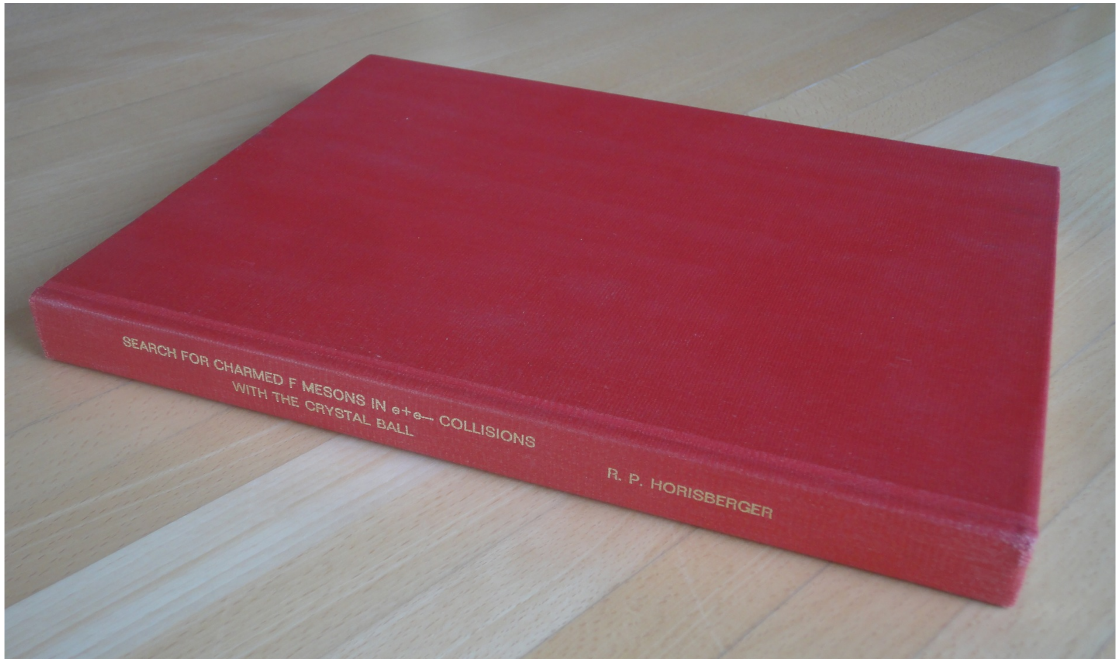
his Steiermark friends keep trying and trying

and just can’t catch up with him !

70. Birthday of Robert Klanner

Paul Scherrer Institute would like to congratulate for your birthday and thank you for all your efforts that you gave as a long member of the PSI Advisory Board (PAB)

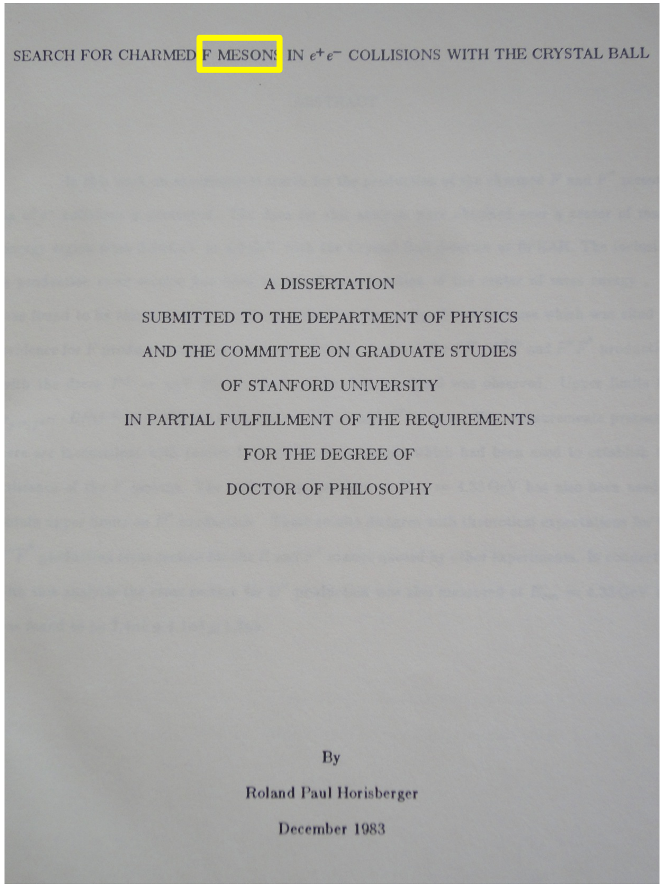
Who the . . . would . . . ?



SLAC 1983

Crystal Ball Experiment at SPEAR

Stanford University



SEARCH FOR CHARMED F MESONS IN e^+e^- COLLISIONS WITH THE CRYSTAL BALL

A DISSERTATION
SUBMITTED TO THE DEPARTMENT OF PHYSICS
AND THE COMMITTEE ON GRADUATE STUDIES
OF STANFORD UNIVERSITY
IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE DEGREE OF
DOCTOR OF PHILOSOPHY

By
Roland Paul Horisberger
December 1983

Robert Klanner would !

He just loves to read thesis !

Is he a thesis messy ?

let make a deal !!