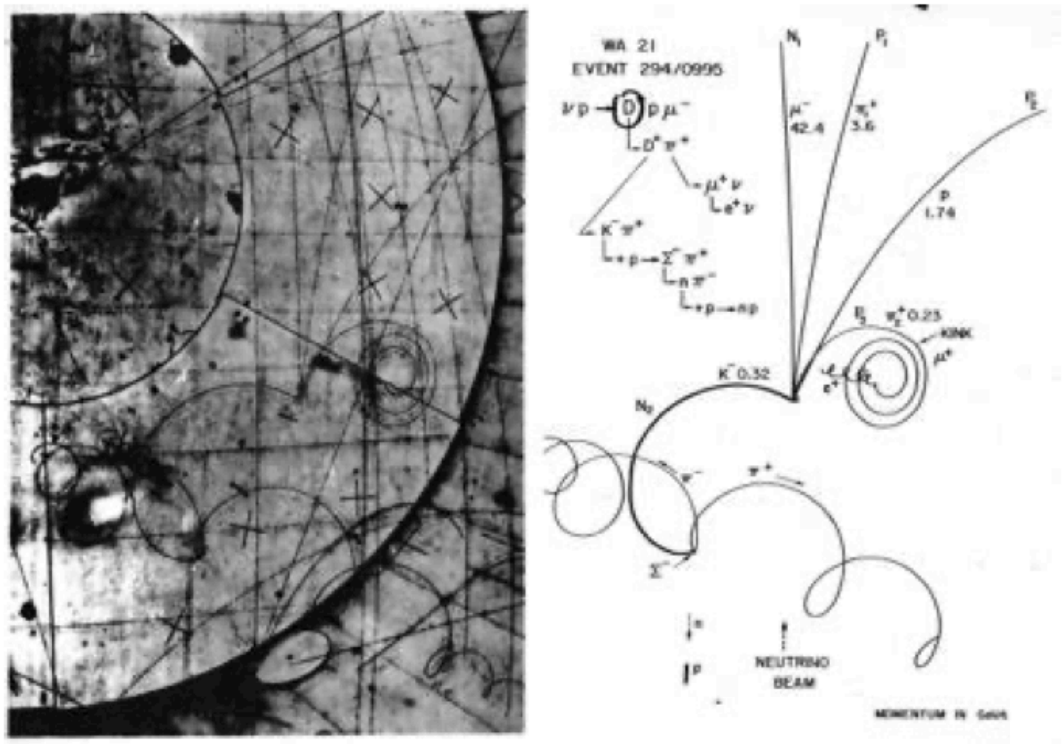
DELPHI and Radiation Hardness R&D

Touring students from Liverpool, 2014

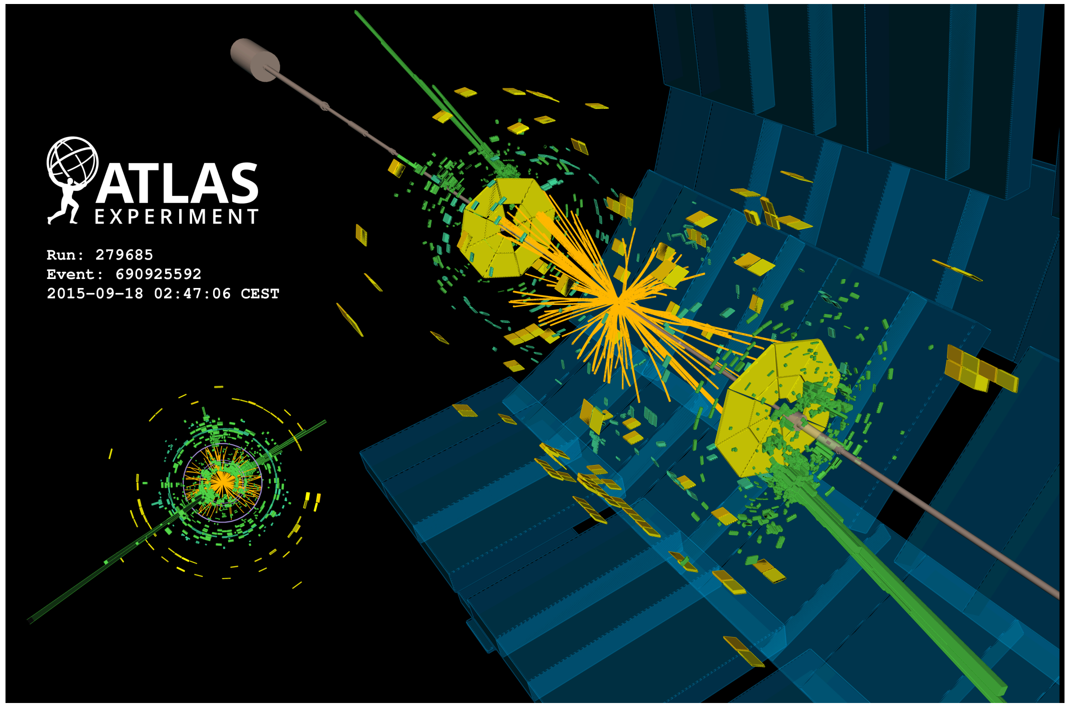
EDIT Instrumentation School, 2011

Silicon in Instrumentation

BEBC - Phil’s first experiment
1 image every second



ATLAS - As designed by Phil
40 million images every second



How did Phil go from bubble chambers to fully electronic imagers? The use of silicon has been a central thread, driven by need for charm/beauty tagging

It was recognised early on that the technology in Si chip foundries was drawing investments of billions of dollars, massive daily production and turnover, sophisticated design packages - how to access this?

I wish to present to you today three specific and ground breaking innovations of Phil which made this possible

1) Electronics that worked! 2) Sensors that worked! 3) Detectors that survived the most intense radiation environments imaginable!

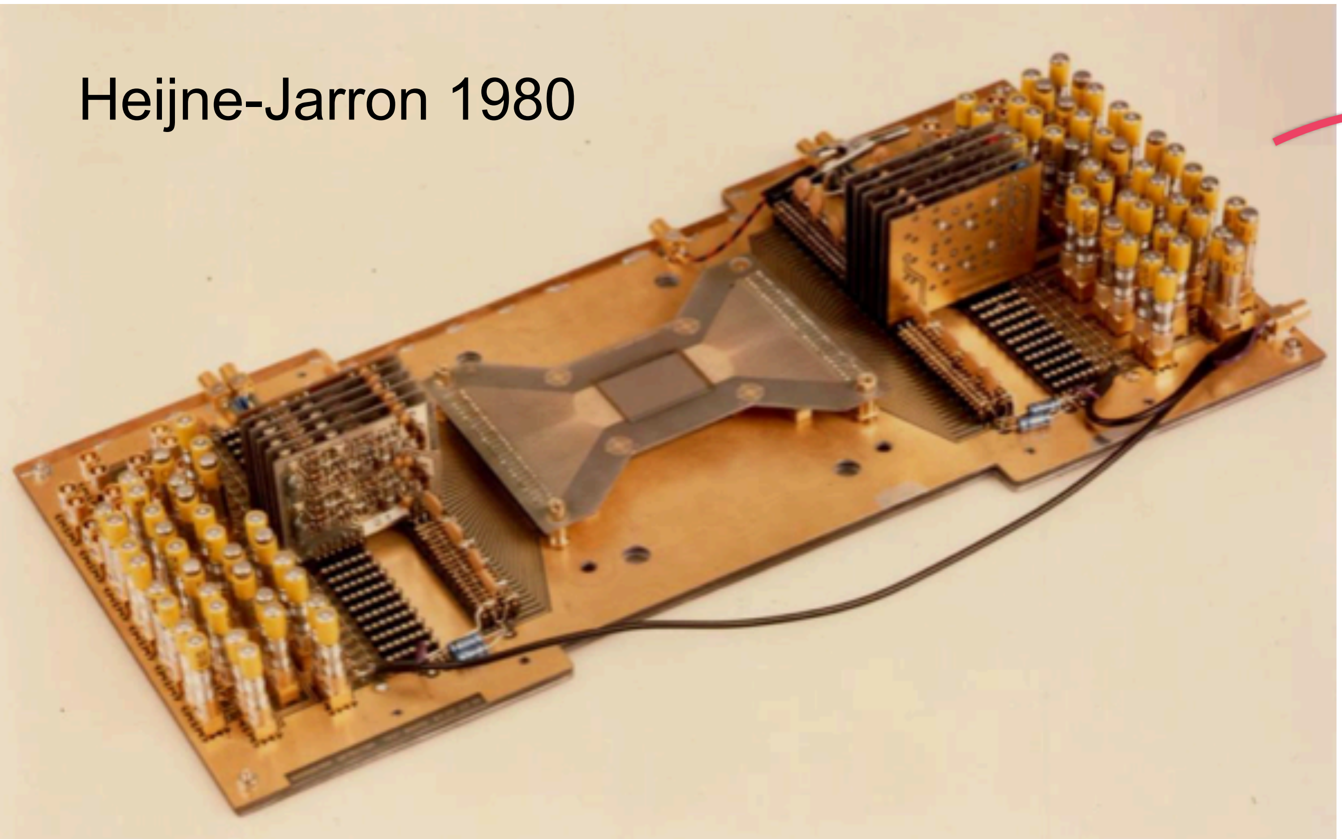
Plus a bonus excursion into medical physics

The Readout Challenge

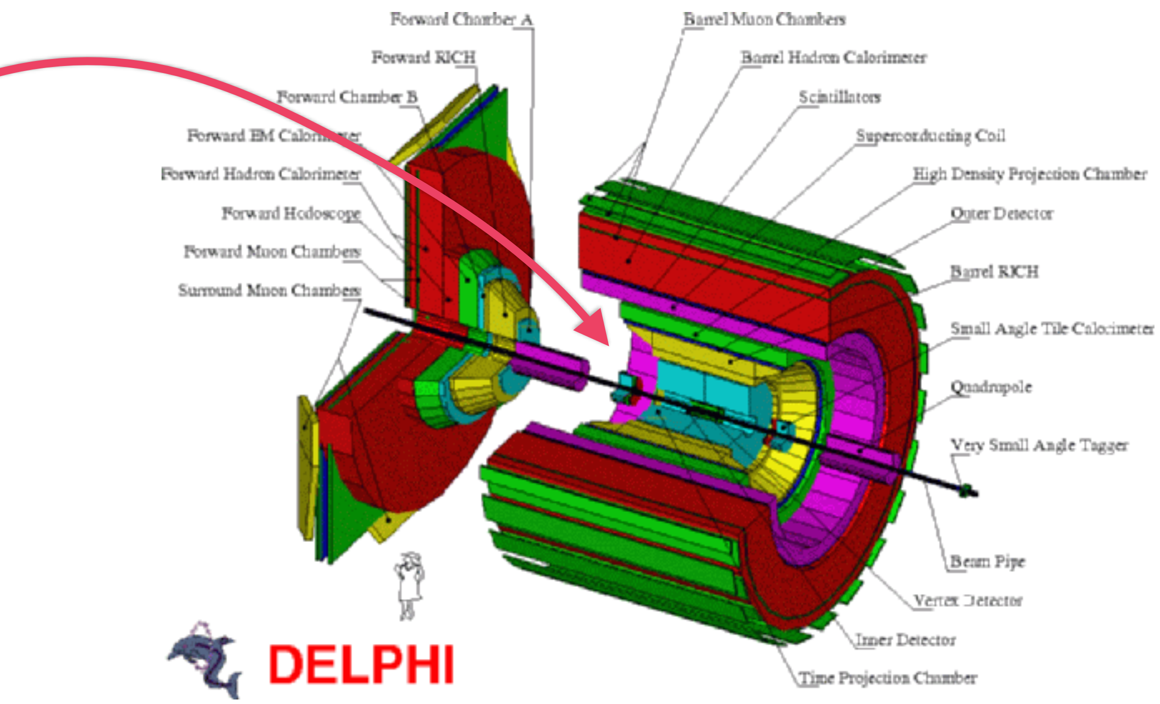
I contacted Mike Tyndel who kindly provided me with Phil's "to do" list from this transformative period:

1) Simulation software to estimate the physics requirements in terms of granularity, resolution and material
2) Developing and evaluating the first 'low power' CMOS readout chip (The MICROPLEX series)
3) Figuring out how to bias and AC couple silicon detectors. Phil worked closely with Micron on this, leading the work on FoxFET biasing
4) Developing pad layouts and wire-bonding techniques for connecting detectors and ASICs. This was extremely challenging with parameters such as wire type (Gold, Aluminium), wire size, wire bonder power not to mention human expertise all up in the air

This to-do list still left us with time for pub-lunches, visits to CERN, a spot of philosophy.. Phil made important contributions, starting with DELPHI, then OPAL, then eventually ATLAS

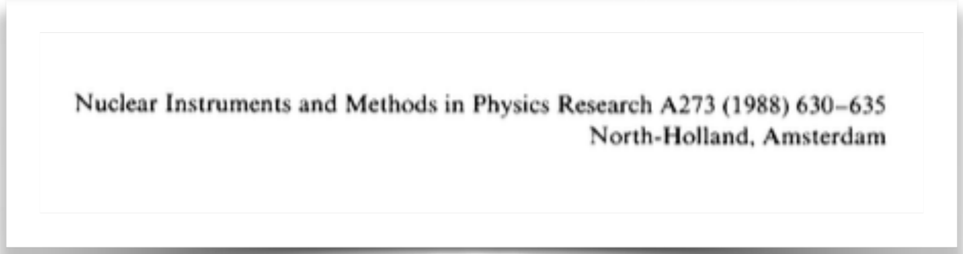


Heijne-Jarron 1980

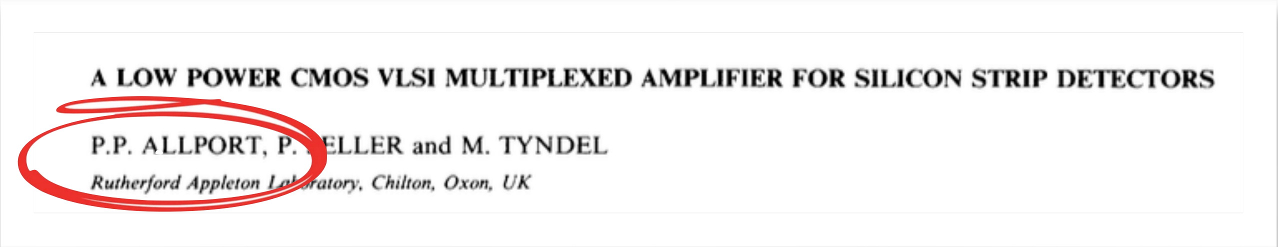


How can we have imagined that a readout with discrete components on dual cards might be compatible with the compact lightweight detectors of the future comprising millions of channels?

1989: The RAL Microplex chip is born



Nuclear Instruments and Methods in Physics Research A273 (1988) 630–635
North-Holland, Amsterdam

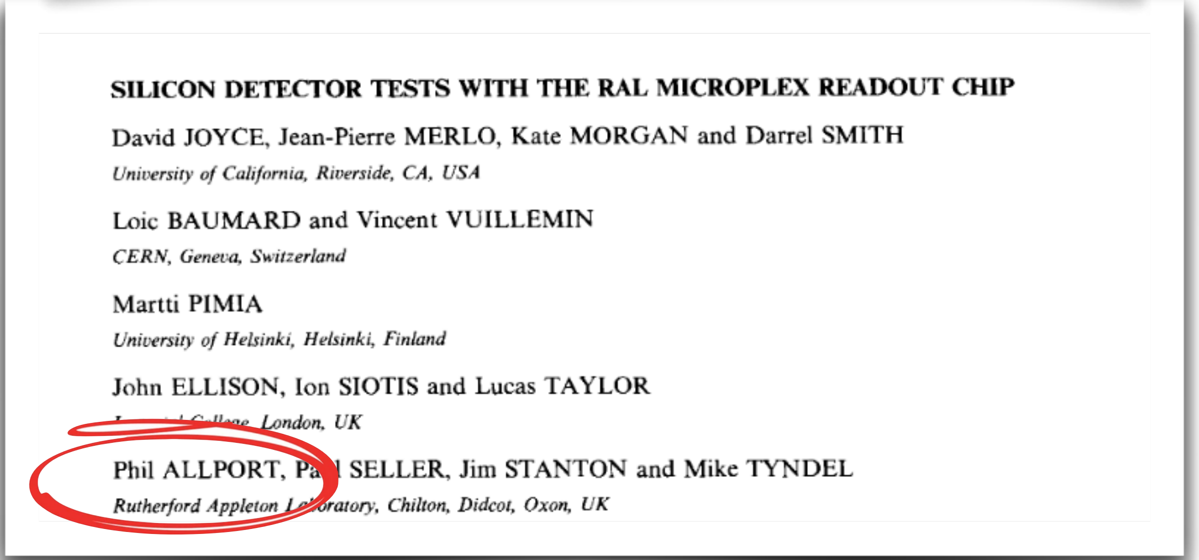


A LOW POWER CMOS VLSI MULTIPLEXED AMPLIFIER FOR SILICON STRIP DETECTORS

P.P. ALLPORT, P. ELLER and M. TYNDEL

Rutherford Appleton Laboratory, Chilton, Oxon, UK

Nuclear Instruments and Methods in Physics Research A279 (1989) 189–194
North-Holland, Amsterdam



SILICON DETECTOR TESTS WITH THE RAL MICROPLEX READOUT CHIP

David JOYCE, Jean-Pierre MERLO, Kate MORGAN and Darrel SMITH

University of California, Riverside, CA, USA

Loic BAUMARD and Vincent VUILLEMIN

CERN, Geneva, Switzerland

Martti PIMIA

University of Helsinki, Helsinki, Finland

John ELLISON, Ion SIOTIS and Lucas TAYLOR

I l College, London, UK

Phil ALLPORT, Pa l SELLER, Jim STANTON and Mike TYNDEL

Rutherford Appleton Laboratory, Chilton, Didcot, Oxon, UK

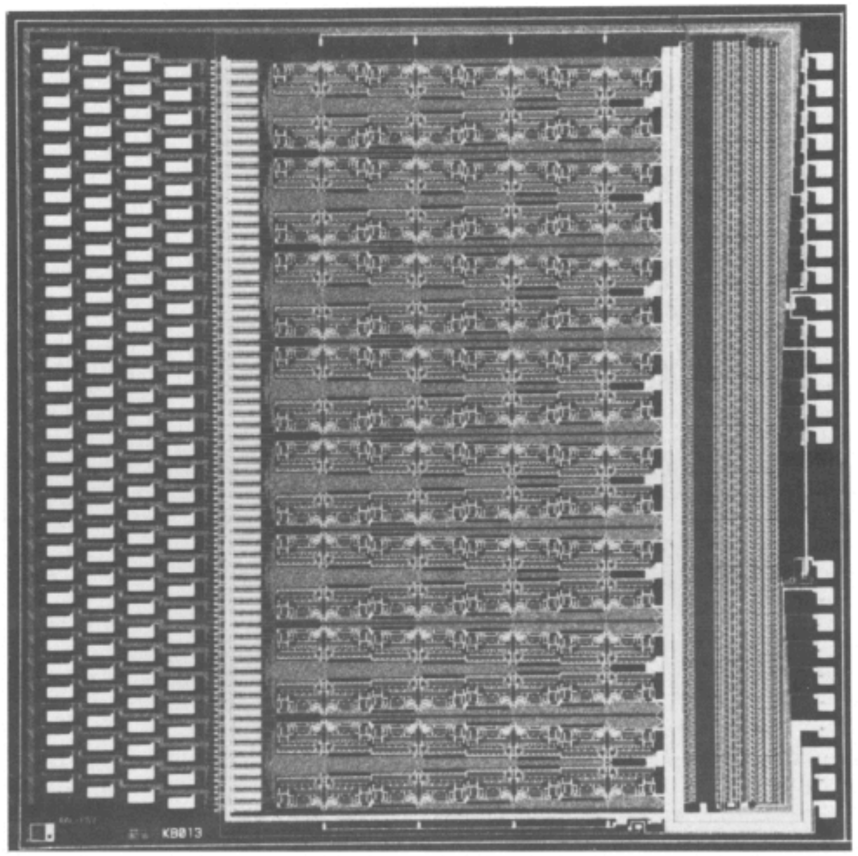


Fig. 3. The CMOS VLSI 128 channel amplifier with multiplexed readout.

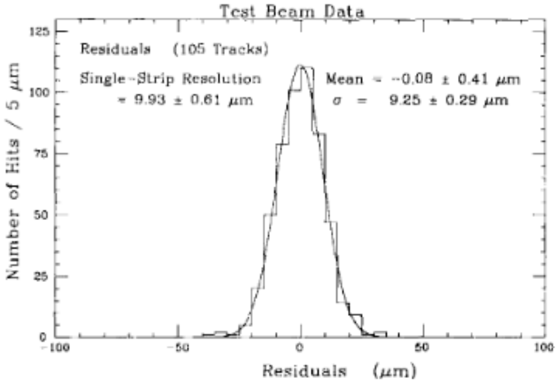
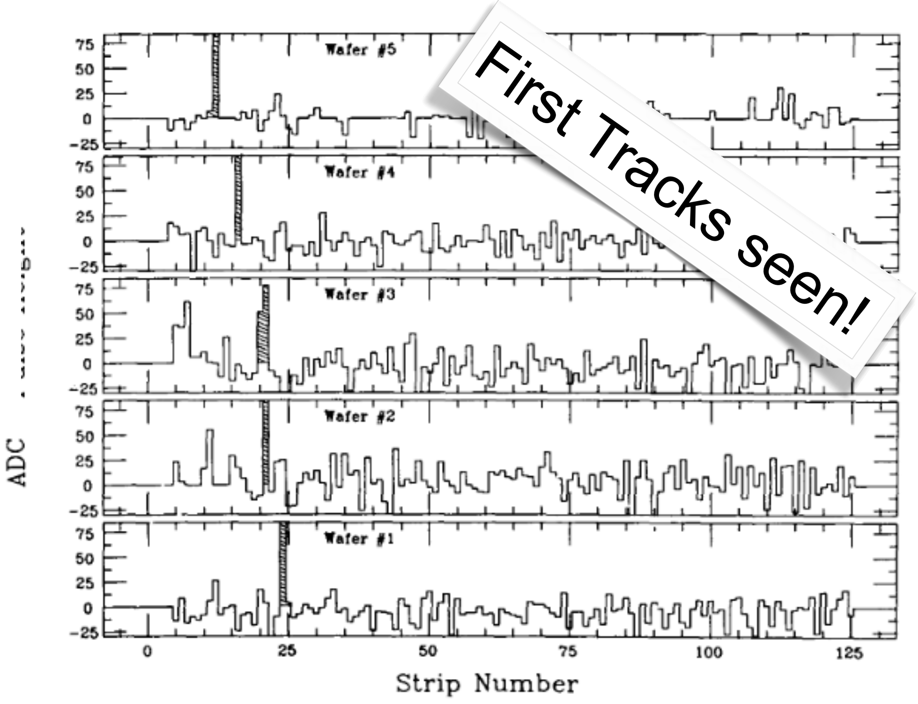


Fig. 7. Residuals.

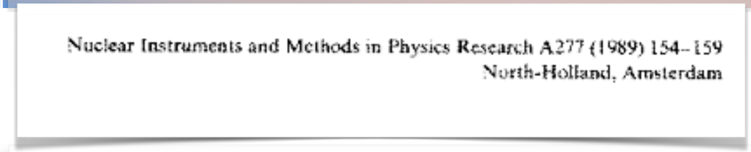
Single hit resolution: 11.8 μm



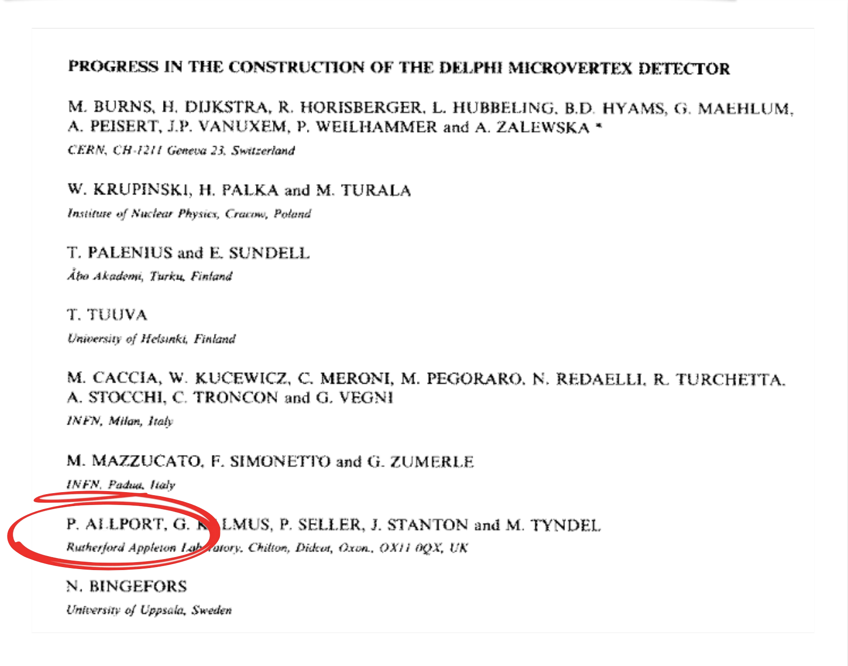
First Tracks seen!

Fig. 6. ADC values for one event.

1989: CMOS VSLI adopted into DELPHI



Nuclear Instruments and Methods in Physics Research A277 (1989) 154–159
North-Holland, Amsterdam



PROGRESS IN THE CONSTRUCTION OF THE DELPHI MICROVERTEX DETECTOR

M. BURNS, H. DIJKSTRA, R. HORISBERGER, L. HUBBELING, B.D. HYAMS, G. MAEHLUM, A. PEISERT, J.P. VANUXEM, P. WEILHAMMER and A. ZALEWSKA *
CERN, CH-1211 Geneva 23, Switzerland

W. KRUPINSKI, H. PALKA and M. TURALA
Institute of Nuclear Physics, Cracow, Poland

T. PALENIUS and E. SUNDELL
Åbo Akademi, Turku, Finland

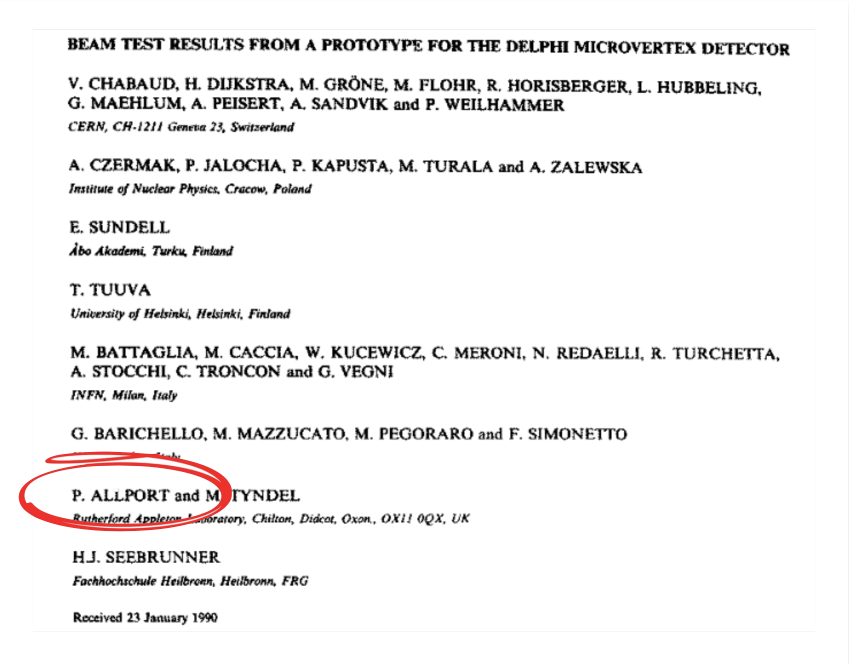
T. TUUVA
University of Helsinki, Finland

M. CACCIA, W. KUCEWICZ, C. MERONI, M. PEGORARO, N. REDAELLI, R. TURCHETTA, A. STOCCHI, C. TRONCON and G. VEGNI
INFN, Milan, Italy

M. MAZZUCATO, F. SIMONETTO and G. ZUMERLE
INFN, Padua, Italy

P. ALLPORT, G. K LMUS, P. SELLER, J. STANTON and M. TYNDEL
Rutherford Appleton Lab atory, Chilton, Didcot, Oxon., OX11 0QX, UK

N. BINGEFORS
University of Uppsala, Sweden



BEAM TEST RESULTS FROM A PROTOTYPE FOR THE DELPHI MICROVERTEX DETECTOR

V. CHABAUD, H. DIJKSTRA, M. GRÖNE, M. FLOHR, R. HORISBERGER, L. HUBBELING, G. MAEHLUM, A. PEISERT, A. SANDVIK and P. WEILHAMMER
CERN, CH-1211 Geneva 23, Switzerland

A. CZERMAK, P. JALOCHA, P. KAPUSTA, M. TURALA and A. ZALEWSKA
Institute of Nuclear Physics, Cracow, Poland

E. SUNDELL
Åbo Akademi, Turku, Finland

T. TUUVA
University of Helsinki, Helsinki, Finland

M. BATTAGLIA, M. CACCIA, W. KUCEWICZ, C. MERONI, N. REDAELLI, R. TURCHETTA, A. STOCCHI, C. TRONCON and G. VEGNI
INFN, Milan, Italy

G. BARICHELLO, M. MAZZUCATO, M. PEGORARO and F. SIMONETTO

P. ALLPORT and M TYNDEL
Rutherford Applet oratory, Chilton, Didcot, Oxon., OX11 0QX, UK

H.J. SEEBRUNNER
Fachhochschule Heilbronn, Heilbronn, FRG

Received 23 January 1990

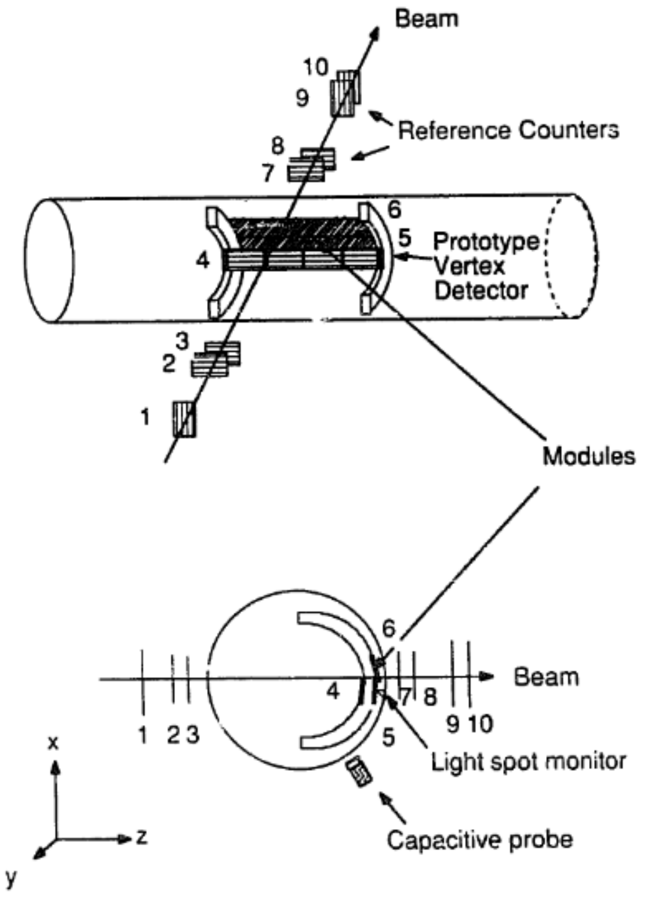


Fig. 2. The detector arrangement for the beam test (not to scale).

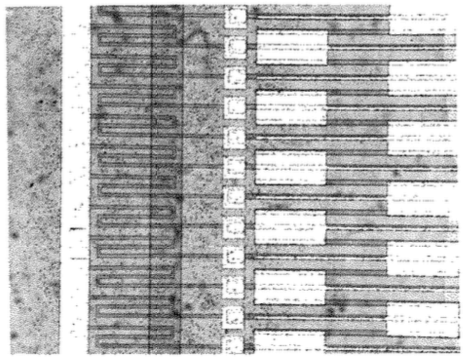
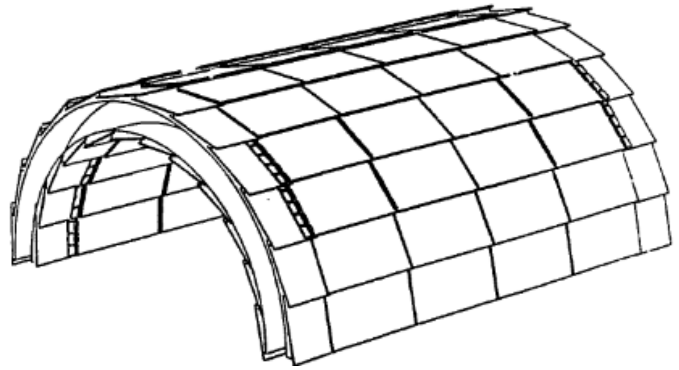


Fig. 5. Photograph of the bond pad area of an ac-coupled detector showing the bond pads, 60×100 μm², the diode strips and the polysilicon resistors with 5 μm line width.



- First photograph of sensor
- First schematic of realistic detector design
- 10880 channels instrumented for beam test

- Noise measurements from the new MX3 chip give **S/N of 16** and **5 μm resolution**
- Stability monitoring with laser spots and capacitive probes

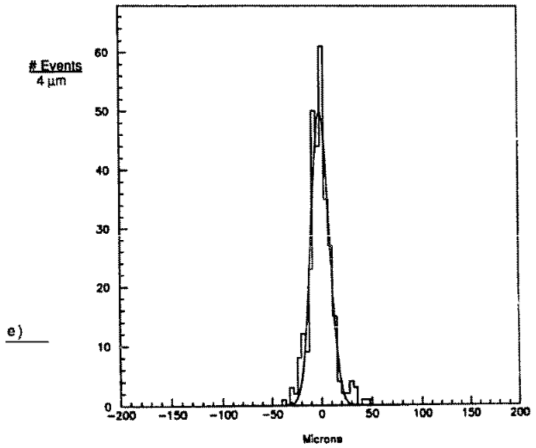
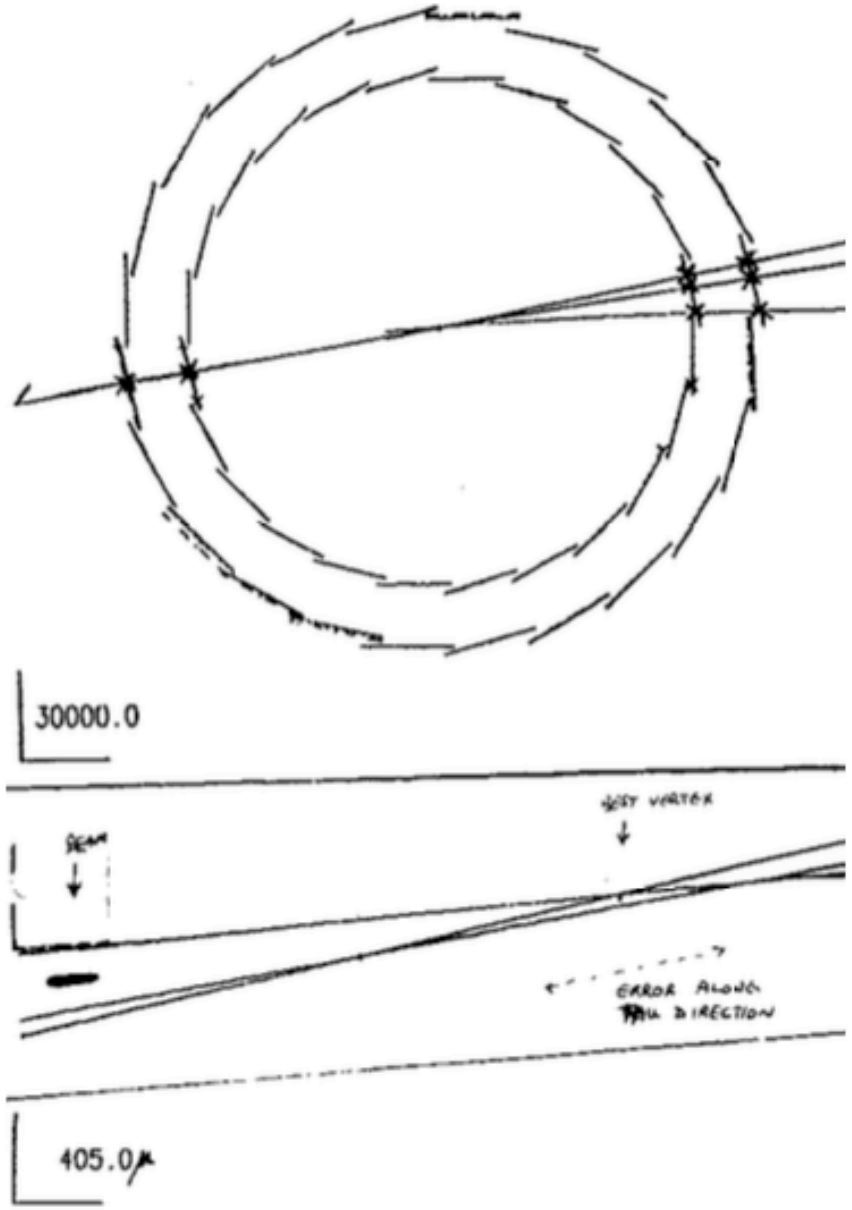


Fig. 8. Residues for the DELPHI half module.

1991 a working vertex detector

- Detector installed in March 1990
- Used 1990 data
- Performed according to expectations!

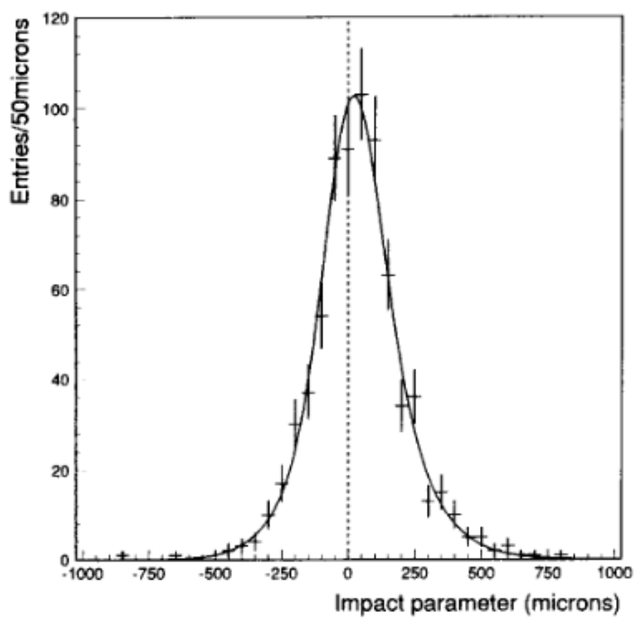


Physics Letters B 267 (1991) 422–430
North-Holland

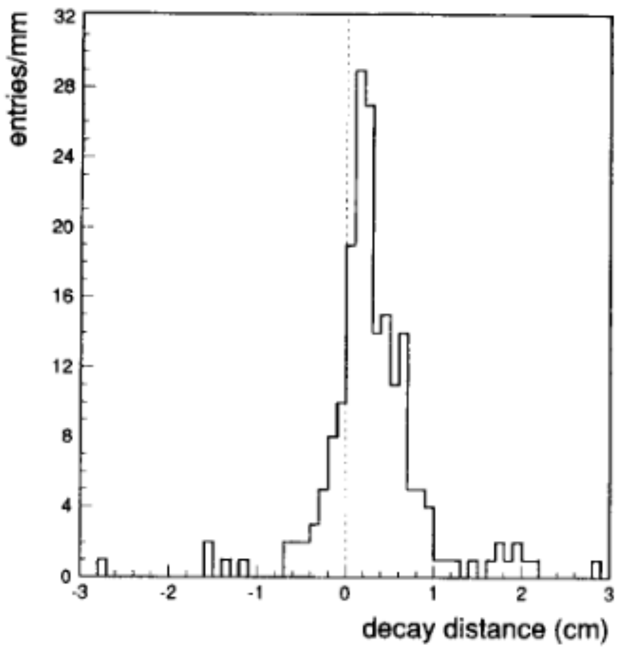
PHYSICS LETTERS B

A measurement of the lifetime of the tau lepton

DELPHI Collaboration

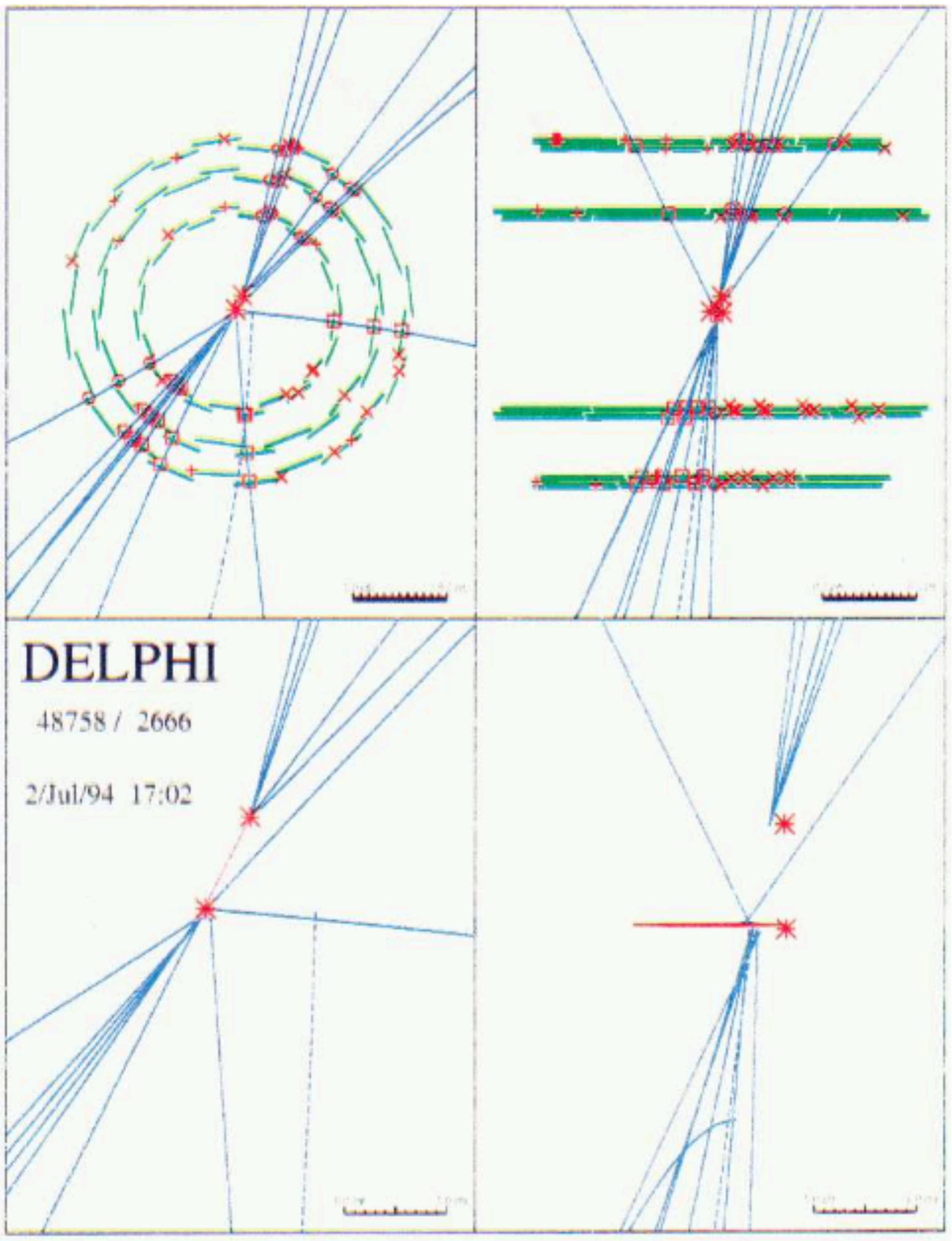


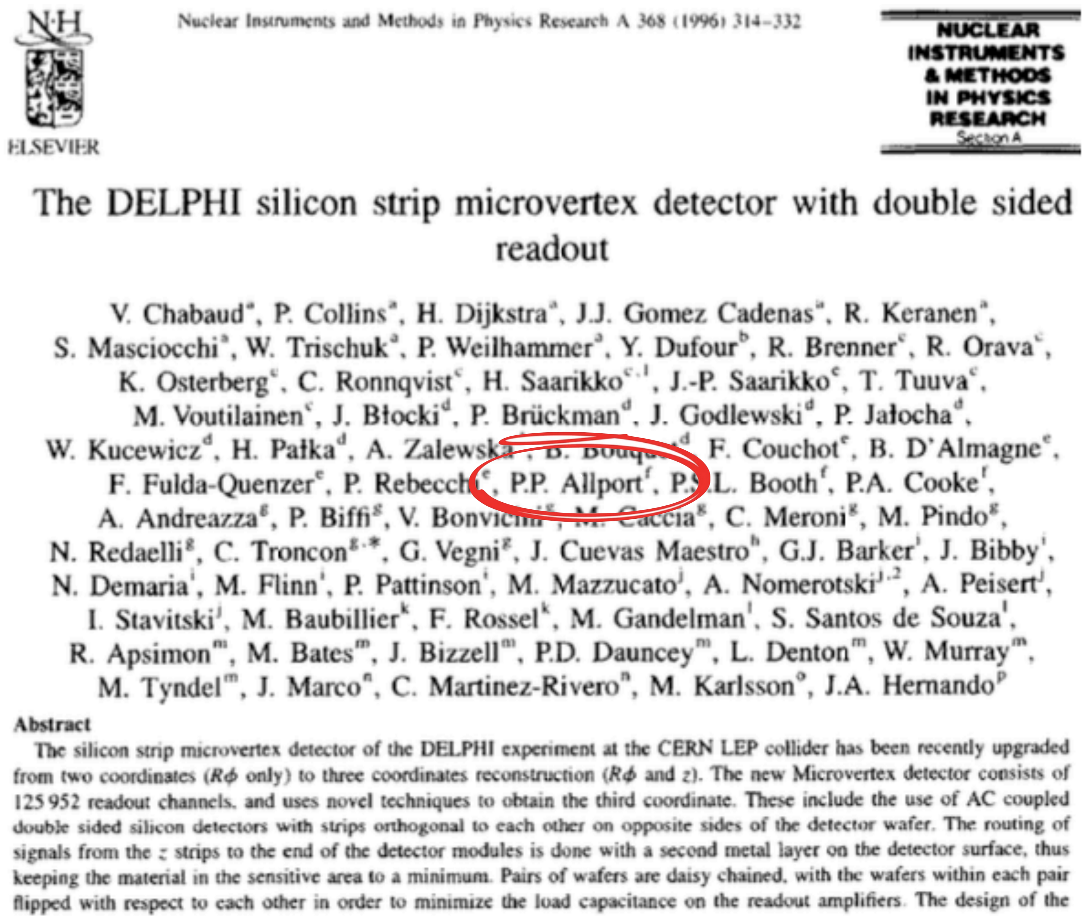
$\tau_\tau = 310 \pm 31$ (stat.) ± 9 (syst.) fs.



$\tau_\tau = 321 \pm 36$ (stat.) ± 16 (syst.) fs.

Jump one vertex detector to 1994





ELSEVIER

Nuclear Instruments and Methods in Physics Research A 368 (1996) 314–332

NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH
Section A

The DELPHI silicon strip microvertex detector with double sided readout

V. Chabaud[a], P. Collins[a], H. Dijkstra[a], J.J. Gomez Cadenas[a], R. Keranen[a],
S. Masciocchi[a], W. Trischuk[a], P. Weilhammer[a], Y. Dufour[b], R. Brenner[c], R. Orava[c],
K. Osterberg[c], C. Ronnqvist[c], H. Saarikko[c,1], J.-P. Saarikko[c], T. Tuuva[c],
M. Voutilainen[c], J. Błocki[d], P. Brückman[d], J. Godlewski[d], P. Jałocha[d],
W. Kucewicz[d], H. Pałka[d], A. Zalewska[d], B. Bouquet[d], F. Couchot[e], B. D'Almagne[e],
F. Fulda-Quenzer[e], P. Rebecchi[e], P.P. Allport[f], P.S.L. Booth[f], P.A. Cooke[f],
A. Andreazza[g], P. Biffi[g], V. Bonvicini[g], M. Caccia[g], C. Meroni[g], M. Pindo[g],
N. Redaelli[g], C. Troncon[g,*], G. Vegni[g], J. Cuevas Maestro[h], G.J. Barker[i], J. Bibby[i],
N. Demaria[i], M. Flinn[i], P. Pattinson[i], M. Mazzucato[j], A. Nomerotski[j,2], A. Peisert[j],
I. Stavitski[j], M. Baubillier[k], F. Rossel[k], M. Gandelman[l], S. Santos de Souza[l],
R. Apsimon[m], M. Bates[m], J. Bizzell[m], P.D. Dauncey[m], L. Denton[m], W. Murray[m],
M. Tyndel[m], J. Marco[n], C. Martinez-Rivero[n], M. Karlsson[o], J.A. Hernando[p]

Abstract

The silicon strip microvertex detector of the DELPHI experiment at the CERN LEP collider has been recently upgraded from two coordinates ($R\phi$ only) to three coordinates reconstruction ($R\phi$ and z). The new Microvertex detector consists of 125 952 readout channels, and uses novel techniques to obtain the third coordinate. These include the use of AC coupled double sided silicon detectors with strips orthogonal to each other on opposite sides of the detector wafer. The routing of signals from the z strips to the end of the detector modules is done with a second metal layer on the detector surface, thus keeping the material in the sensitive area to a minimum. Pairs of wafers are daisy chained, with the wafers within each pair flipped with respect to each other in order to minimize the load capacitance on the readout amplifiers. The design of the

LEP Synchrotron radiation "mapped"

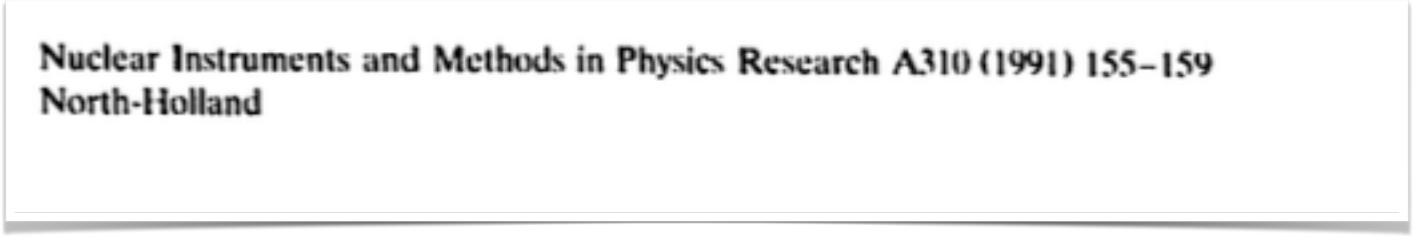
Add extra shields and reduced beam-pipe:

- 1990: 1.2 mm Al diameter 160 mm
- > 1990: 1.4 mm Be diameter 106 mm

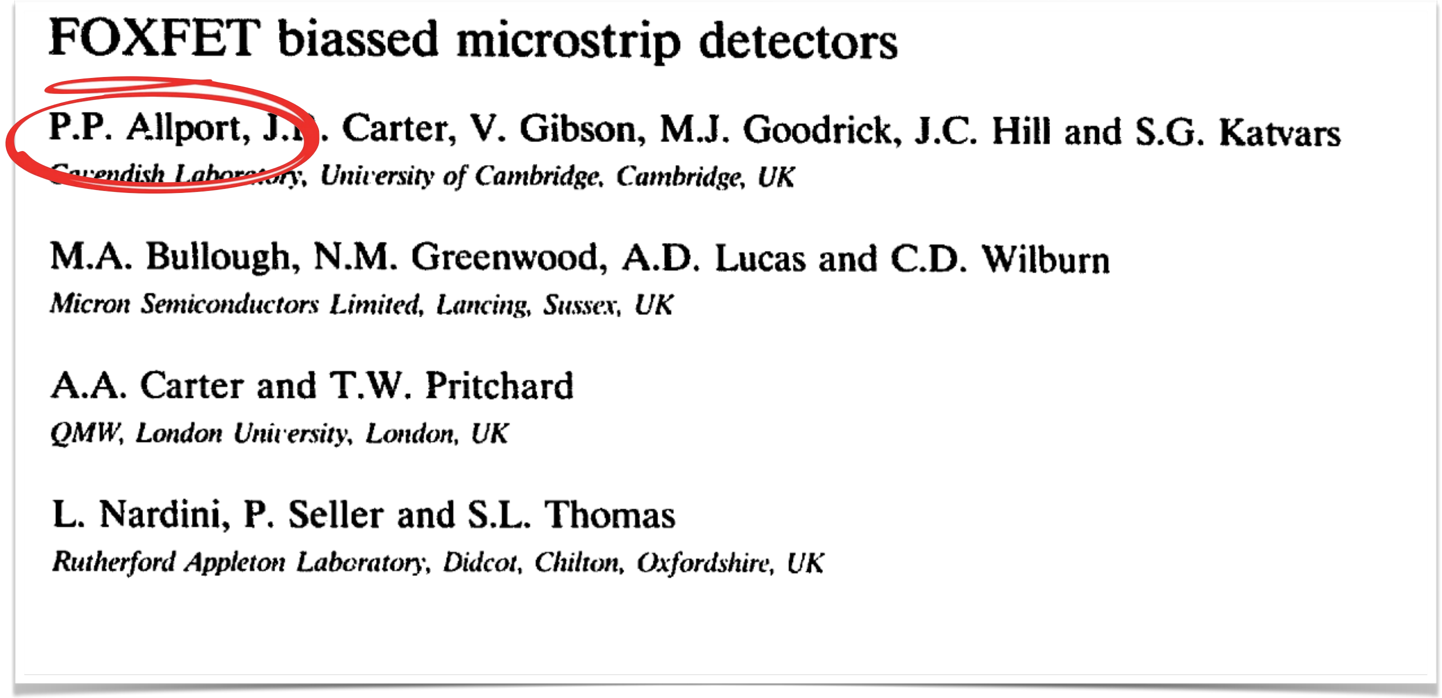
- Add an extra layer.
- $\sigma^2 = (\frac{130 \to 69}{p_T})^2 + (7 \to 3 \times \sigma_{\mathrm{VD}})^2$

Add z readout to two layers, but keep low X/X0 →
Double Sided Sensors
Innermost layer extended coverage (planning for future!)

FOXFET biasing



Nuclear Instruments and Methods in Physics Research A310 (1991) 155–159
North-Holland



FOXFET biassed microstrip detectors

P.P. Allport, J.R. Carter, V. Gibson, M.J. Goodrick, J.C. Hill and S.G. Katvars
Cavendish Laboratory, University of Cambridge, Cambridge, UK

M.A. Bullough, N.M. Greenwood, A.D. Lucas and C.D. Wilburn
Micron Semiconductors Limited, Lancing, Sussex, UK

A.A. Carter and T.W. Pritchard
QMW, London University, London, UK

L. Nardini, P. Seller and S.L. Thomas
Rutherford Appleton Laboratory, Didcot, Chilton, Oxfordshire, UK

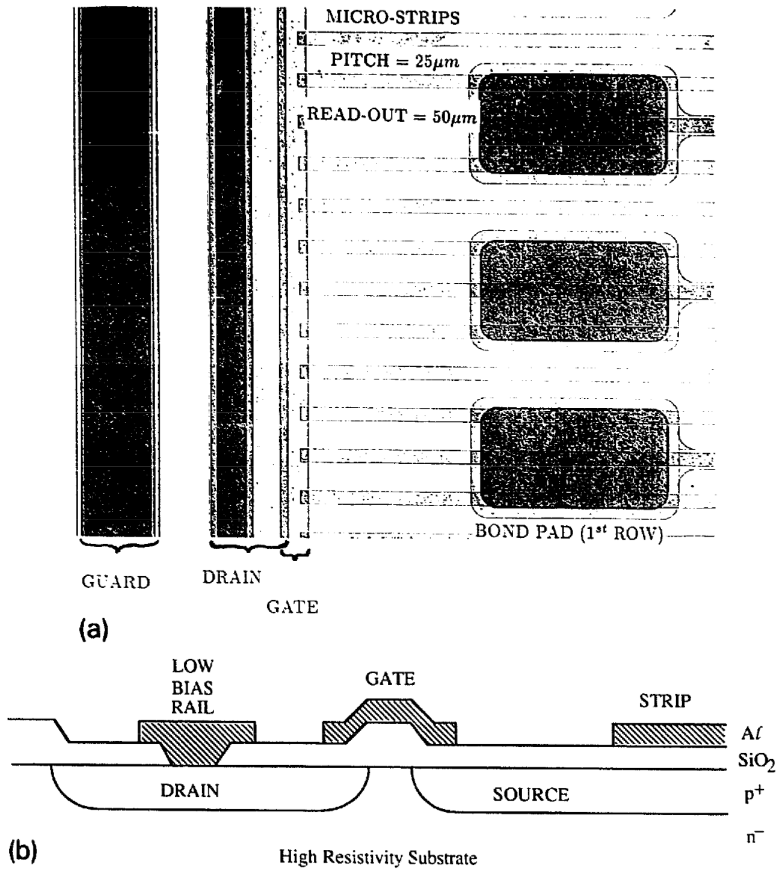
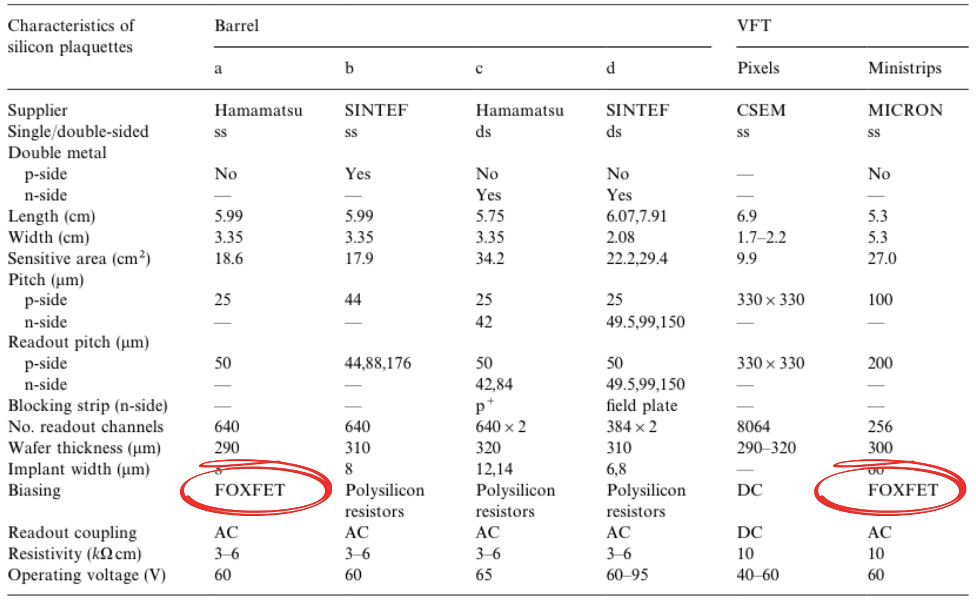


Fig. 1. FOXFET detector bias structure.

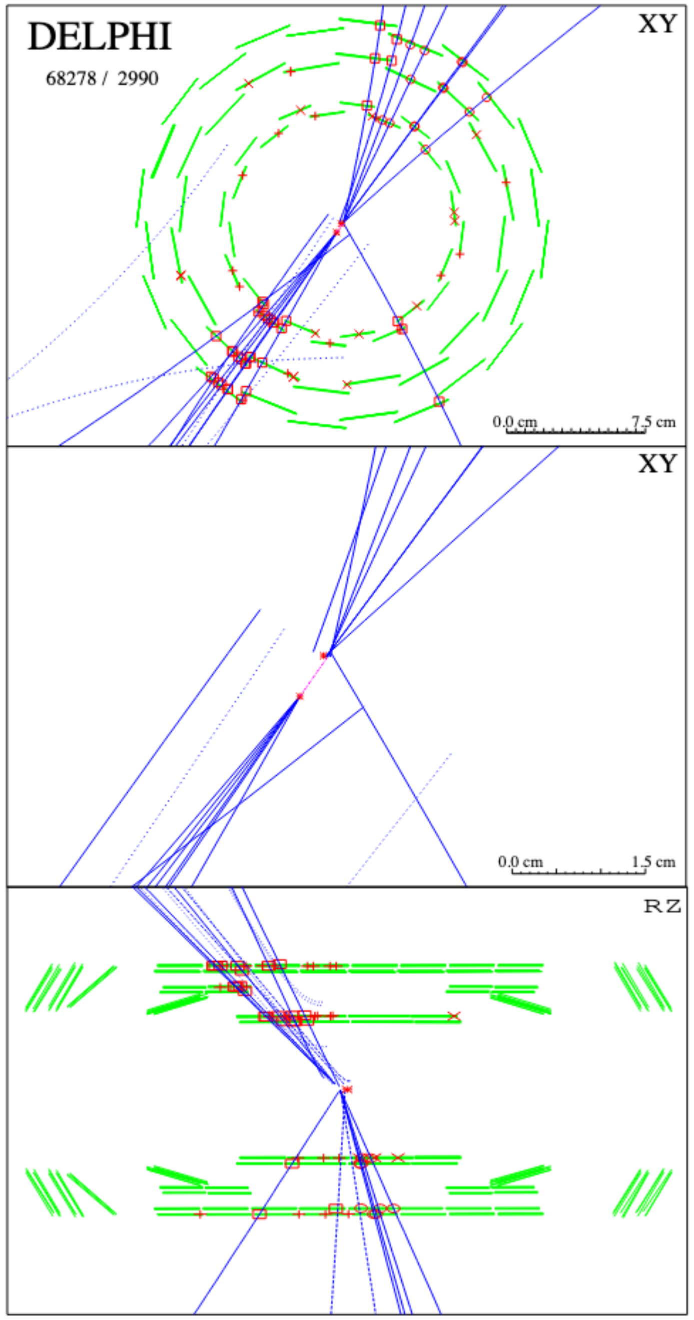
- First sensors fabricated and equipped with MX3
- Uniform pedestal and noise values obtained
- Used for both micro and mini strips in the extended silicon tracker installed for LEP 2

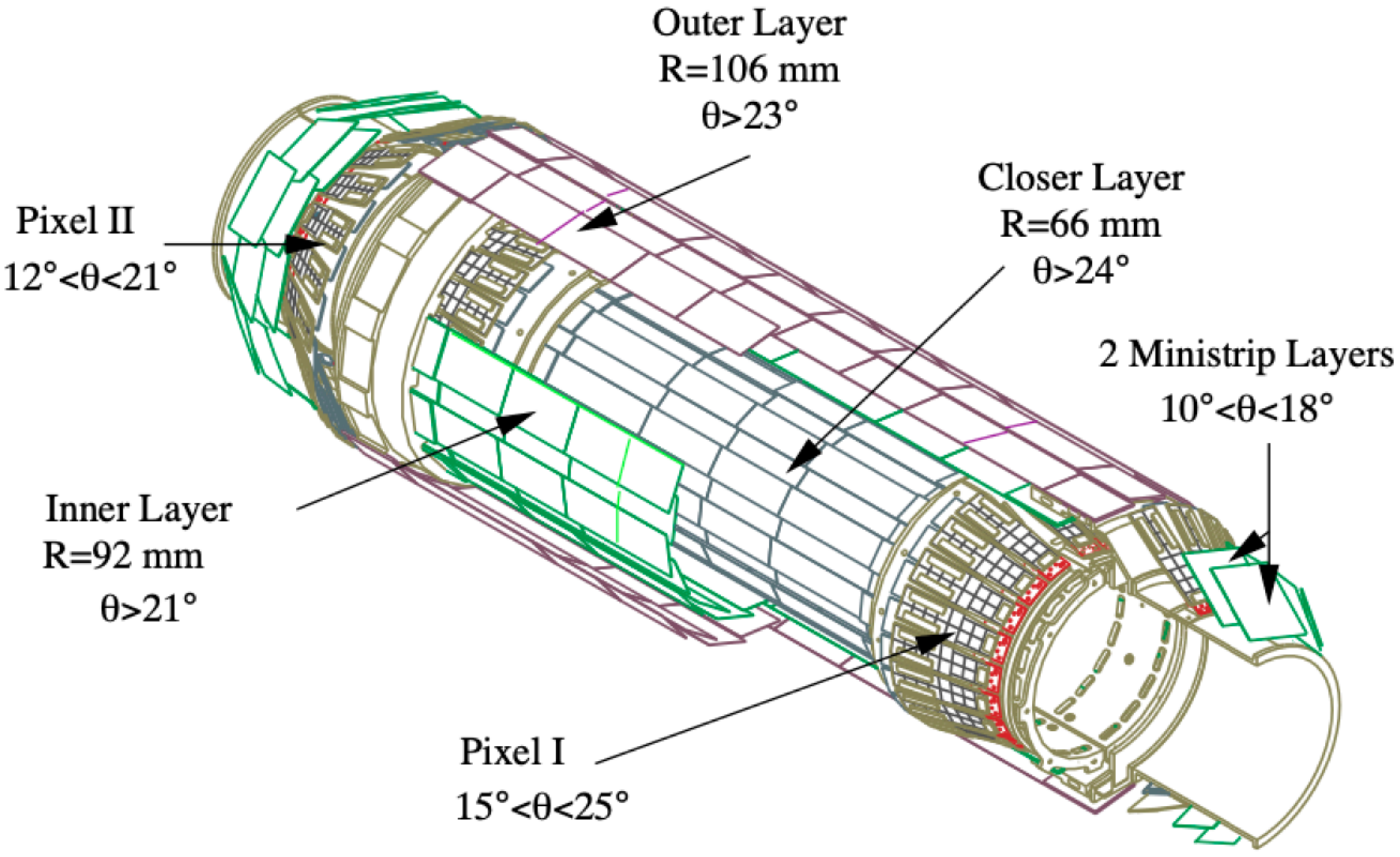


Characteristics of silicon plaquettes	Barrel				VFT	
	a	b	c	d	Pixels	Ministrips
Supplier	Hamamatsu	SINTEF	Hamamatsu	SINTEF	CSEM	MICRON
Single/double-sided	ss	ss	ds	ds	ss	ss
Double metal						
p-side	No	Yes	No	No	—	No
n-side	—	—	Yes	Yes	—	—
Length (cm)	5.99	5.99	5.75	6.07,7.91	6.9	5.3
Width (cm)	3.35	3.35	3.35	2.08	1.7–2.2	5.3
Sensitive area (cm²)	18.6	17.9	34.2	22.2,29.4	9.9	27.0
Pitch (μm)						
p-side	25	44	25	25	330 × 330	100
n-side	—	—	42	49.5,99,150	—	—
Readout pitch (μm)						
p-side	50	44,88,176	50	50	330 × 330	200
n-side	—	—	42,84	49.5,99,150	—	—
Blocking strip (n-side)	—	—	p^+	field plate	—	—
No. readout channels	640	640	640 × 2	384 × 2	8064	256
Wafer thickness (μm)	290	310	320	310	290–320	300
Implant width (μm)	8	8	12,14	6,8	—	60
Biasing	FOXFET	Polysilicon resistors	Polysilicon resistors	Polysilicon resistors	DC	FOXFET
Readout coupling	AC	AC	AC	AC	DC	AC
Resistivity (kΩcm)	3–6	3–6	3–6	3–6	10	10
Operating voltage (V)	60	60	65	60–95	40–60	60

1996: DELPHI Silicon Tracker

“Typical” DELPHI event, $\sqrt{s}$=161 GeV





Outer Layer
R=106 mm
θ>23°

Pixel II
12°<θ<21°

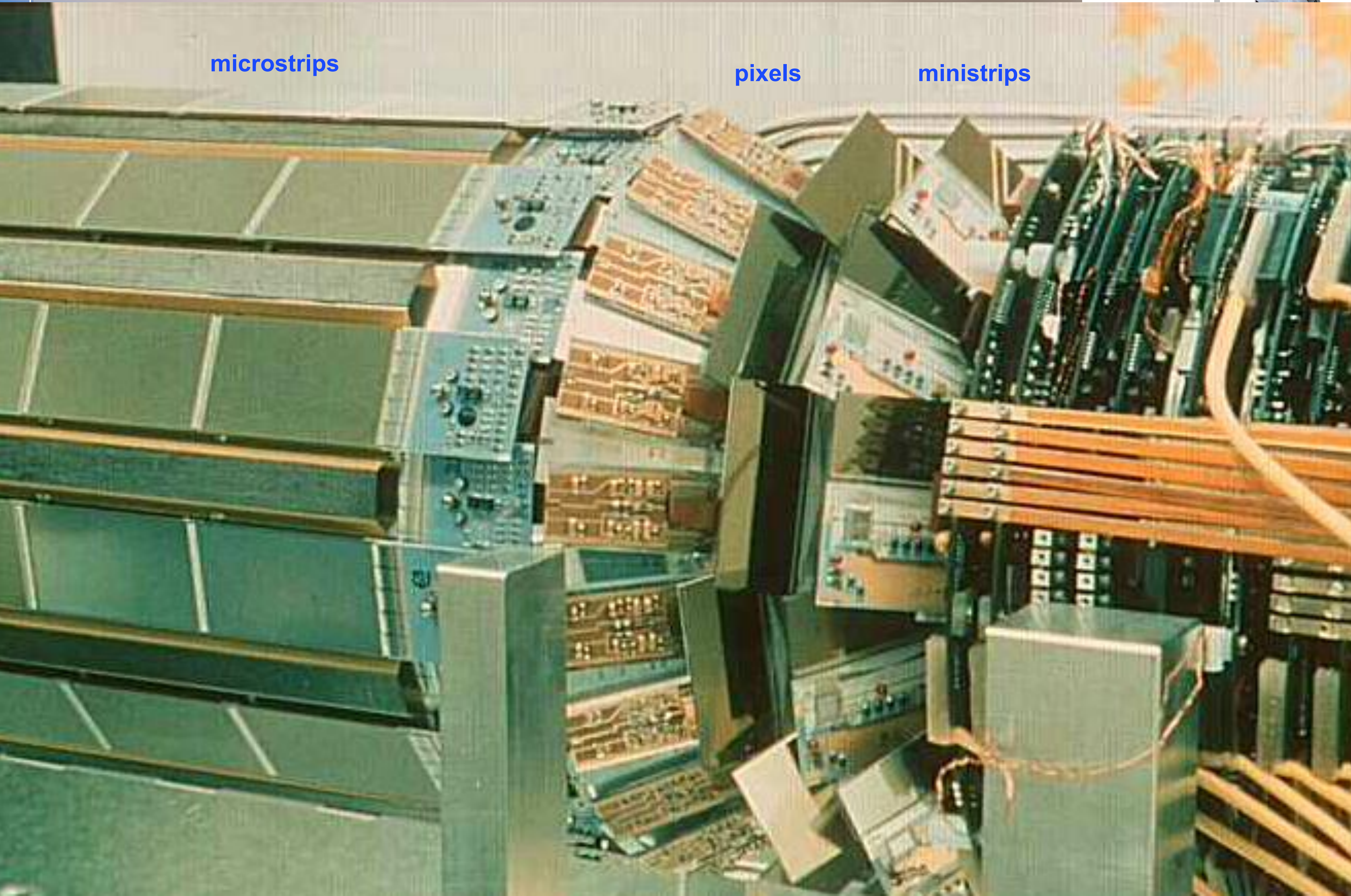
Closer Layer
R=66 mm
θ>24°

2 Ministrip Layers
10°<θ<18°

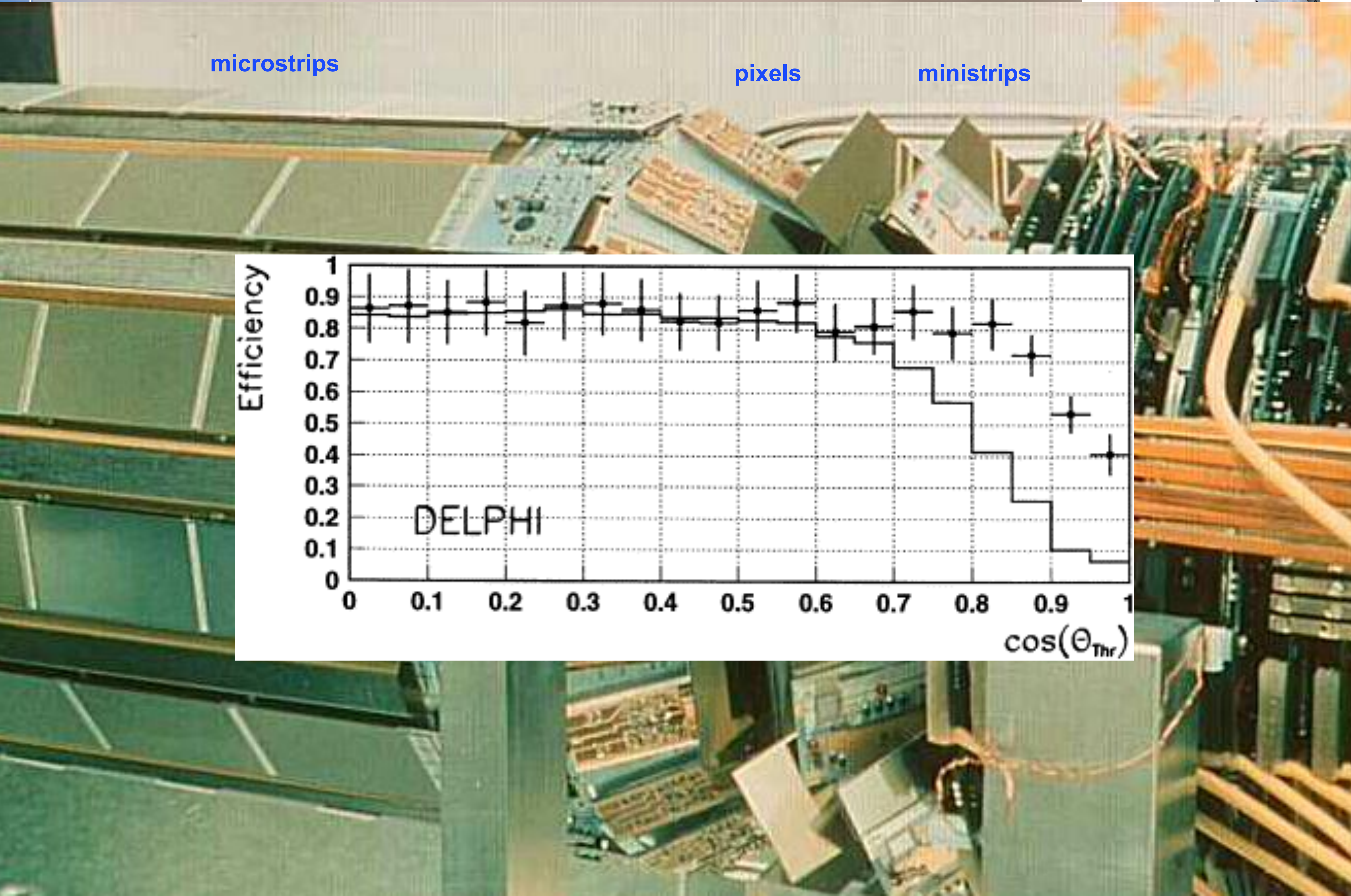
Inner Layer
R=92 mm
θ>21°

Pixel I
15°<θ<25°

DELPHI Silicon Tracker



DELPHI Silicon Tracker



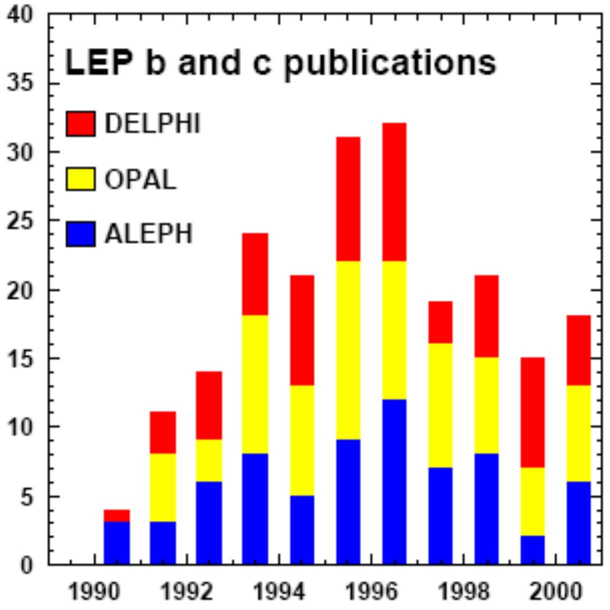
Impact of Silicon

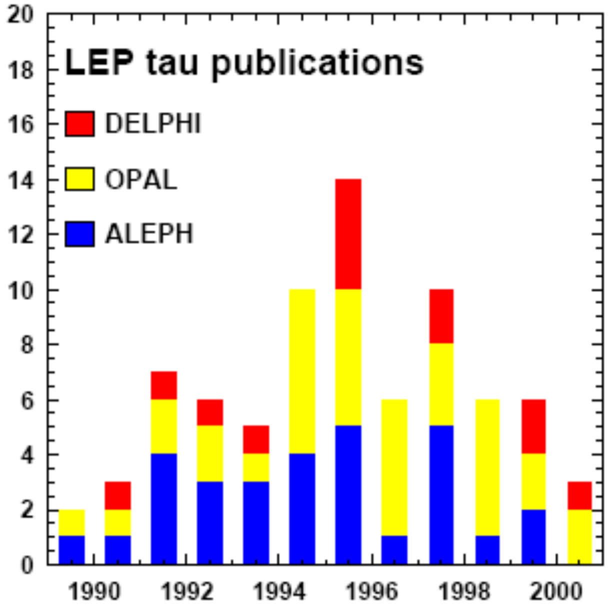
Singapore Conference, 1990

'The LEP experiments are beginning to reconstruct B mesons… It will be interesting to see whether they will be able to use these events'

Gittleman, Heavy Flavour Review

10 fun packed years later, heavy flavour physics represented 40% of LEP publications





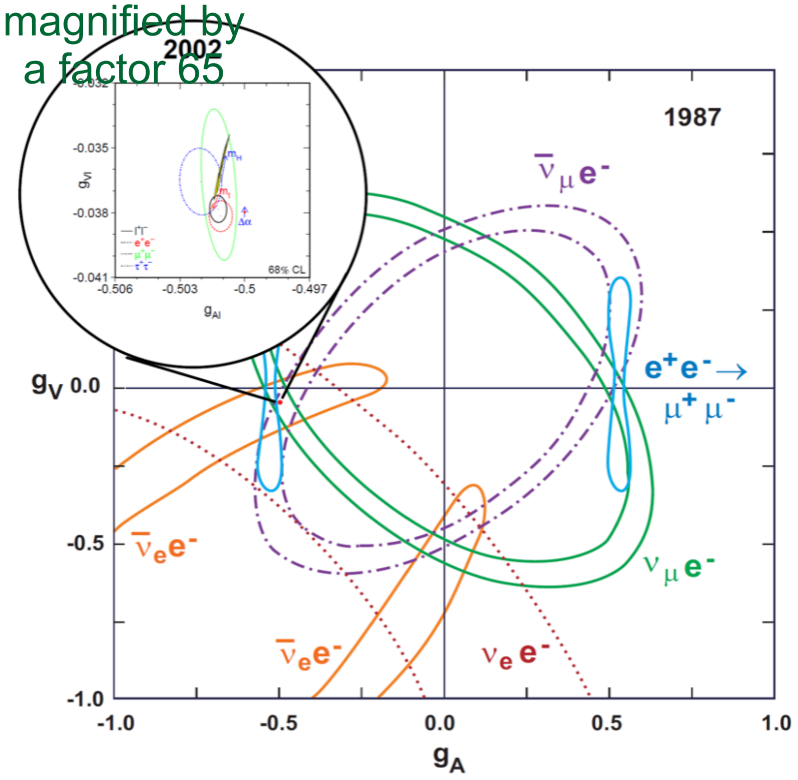
Impact of Silicon

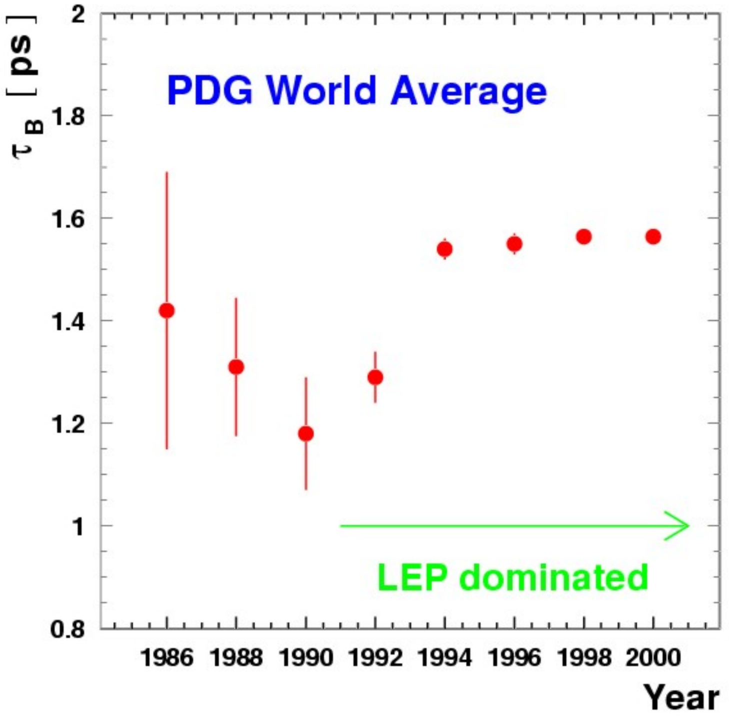
Dramatic demonstration of the validity of the SM, *e.g.* in the vector & axial couplings.

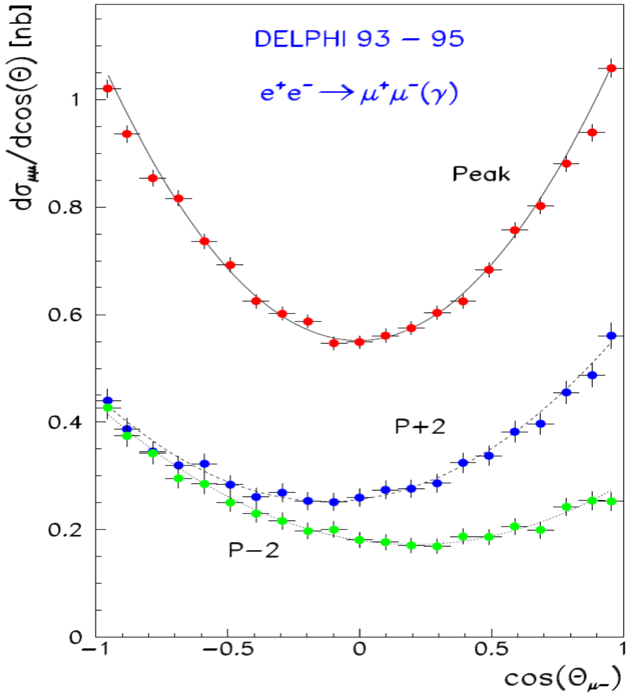
Impact on b hadron lifetimes

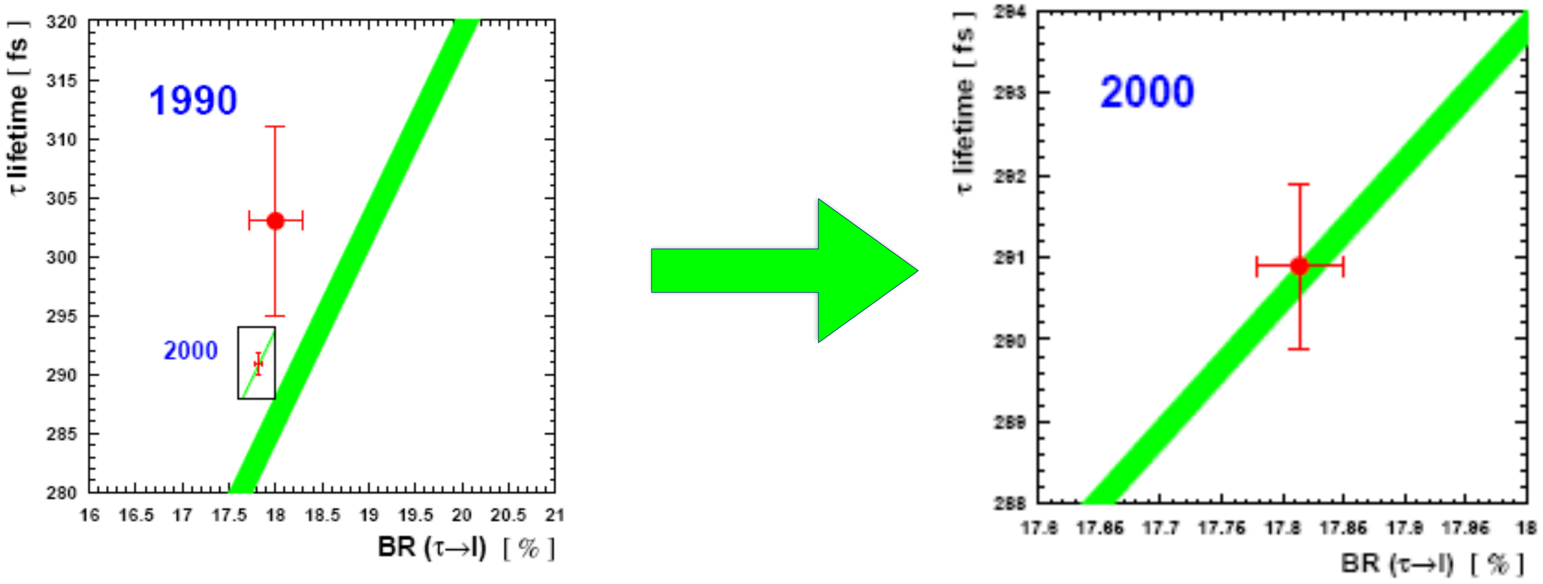
Forward-backward asymmetries (& at SLD L-R asymmetries)

magnified by a factor 65

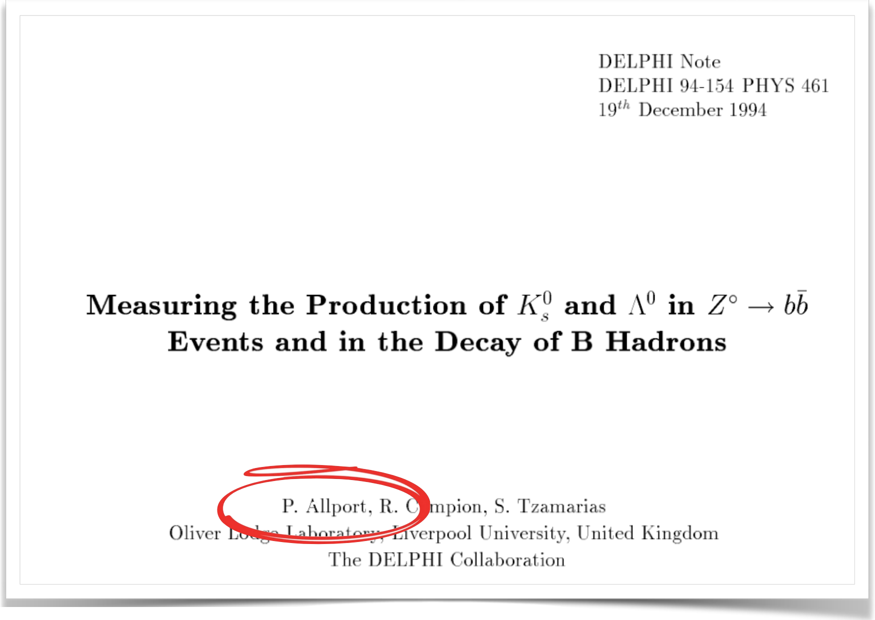








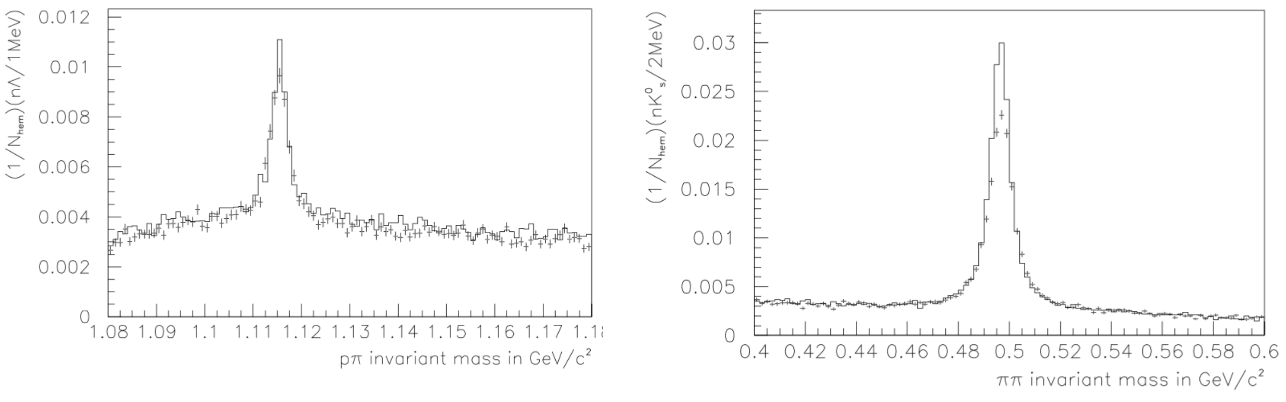
Phil’s diverse interests



DELPHI Note
DELPHI 94-154 PHYS 461
19^{th} December 1994

Measuring the Production of K^0_s and Λ^0 in $Z^\circ \to b\bar{b}$ Events and in the Decay of B Hadrons

P. Allport, R. Campion, S. Tzamarias
Oliver Lodge Laboratory, Liverpool University, United Kingdom
The DELPHI Collaboration



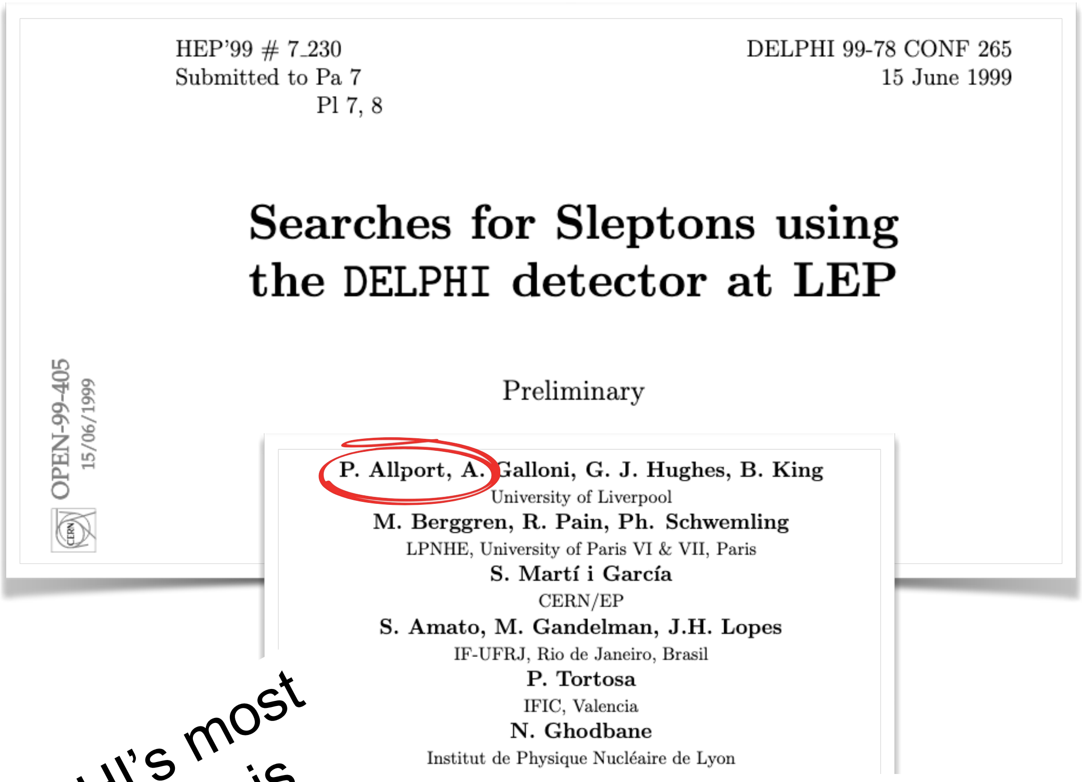
$$< K^0_s >_{b\bar{b}} = 1.08 \pm 0.03(stat) \pm 0.05(syst)$$

$$< \Lambda^0 >_{b\bar{b}} = 0.338 \pm 0.021(stat) \pm 0.042(syst)$$

$$Br(B \to K^0_s X) = 0.290 \pm 0.011 \pm 0.027$$

$$Br(B \to \Lambda^0 X) = 0.059 \pm 0.007 \pm 0.009$$

$$Br(B_{baryon} \to \Lambda^0 X) = 0.28^{+0.17}_{-0.12}$$



HEP’99 # 7_230
Submitted to Pa 7
Pl 7, 8

DELPHI 99-78 CONF 265
15 June 1999

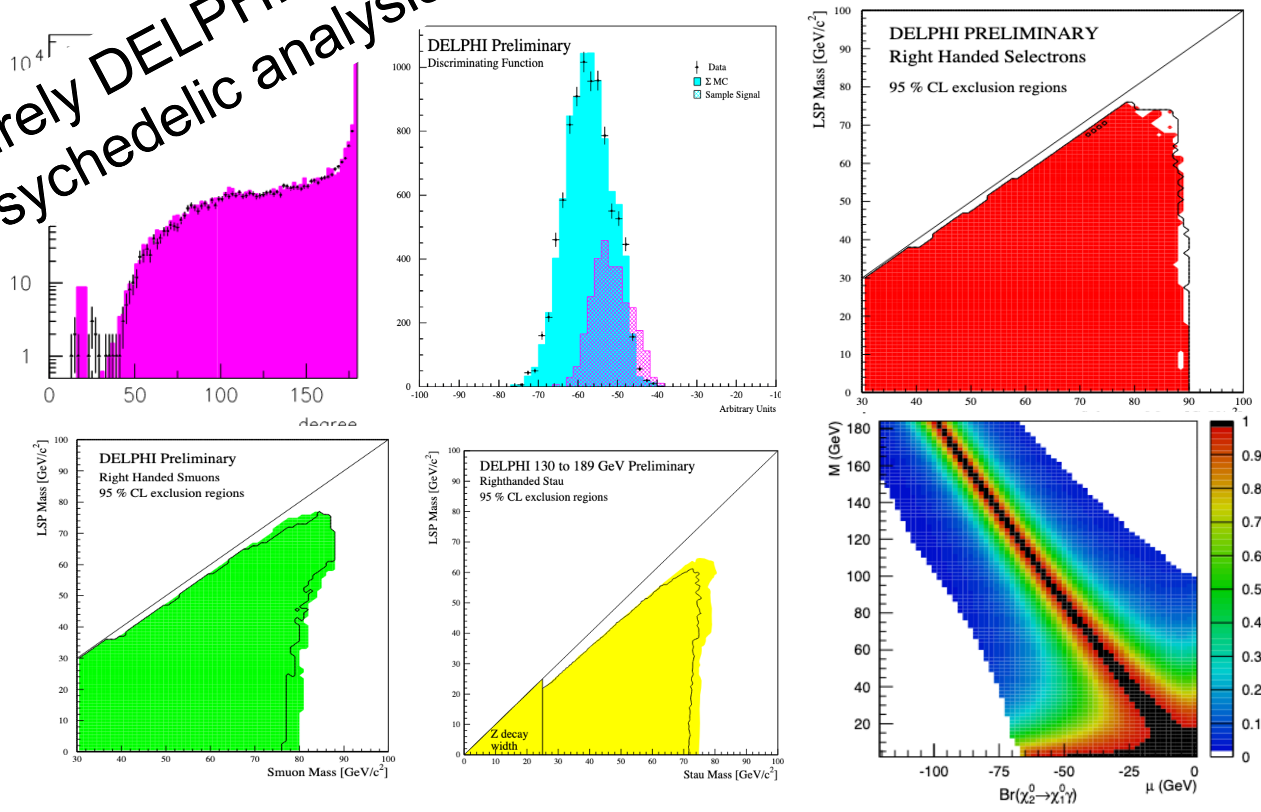
CERN-OPEN-99-405
15/06/1999

Searches for Sleptons using the DELPHI detector at LEP

Preliminary

P. Allport, A. Galloni, G. J. Hughes, B. King
University of Liverpool
M. Berggren, R. Pain, Ph. Schwemling
LPNHE, University of Paris VI & VII, Paris
S. Martí i García
CERN/EP
S. Amato, M. Gandelman, J.H. Lopes
IF-UFRJ, Rio de Janeiro, Brasil
P. Tortosa
IFIC, Valencia
N. Ghodbane
Institut de Physique Nucléaire de Lyon

Surely DELPHI’s most psychedelic analysis



Vertex 1995 Ein Gedi - Moving on

Phil & Karole in Ein Gedi…

….with our much missed colleague Peter Weilhammer

The alignment and performance of the DELPHI double sided vertex detector

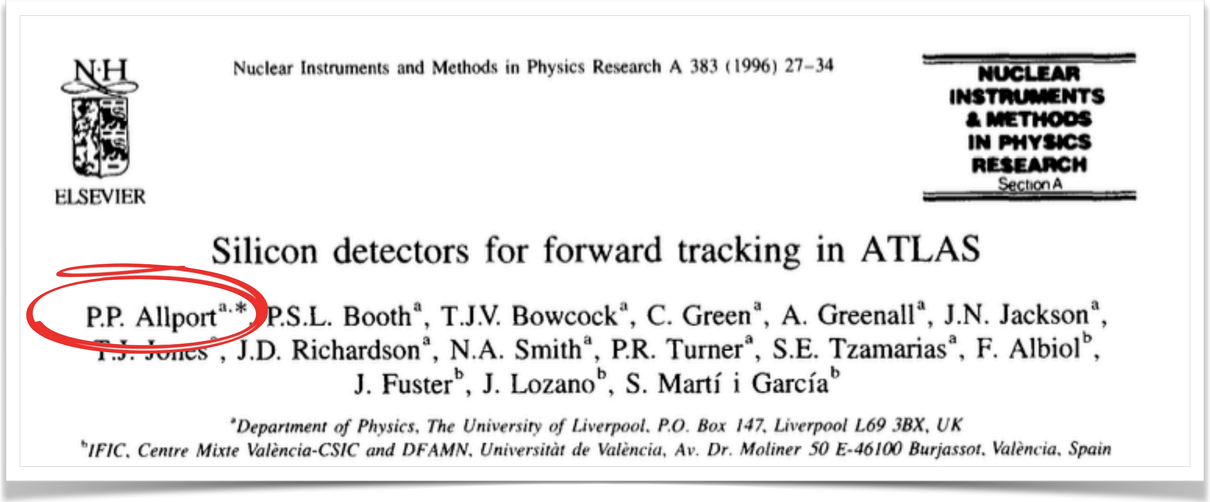
P. Collins (CERN) (Jun, 1995)

Contribution to: Vertex 1995, 13-27

The ATLAS detector at the LHC

P.P. Allport (Liverpool U.) (Jun, 1995)

Contribution to: Vertex 1995, 143-147



Nuclear Instruments and Methods in Physics Research A 383 (1996) 27–34

NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH
Section A

ELSEVIER

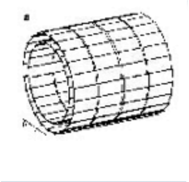
Silicon detectors for forward tracking in ATLAS

P.P. Allport[a,*], P.S.L. Booth[a], T.J.V. Bowcock[a], C. Green[a], A. Greenall[a], J.N. Jackson[a], T.J. Jones[a], J.D. Richardson[a], N.A. Smith[a], P.R. Turner[a], S.E. Tzamarias[a], F. Albiol[b], J. Fuster[b], J. Lozano[b], S. Martí i García[b]

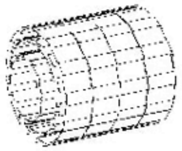
[a] *Department of Physics, The University of Liverpool, P.O. Box 147, Liverpool L69 3BX, UK*

[b] *IFIC, Centre Mixte València-CSIC and DFAMN, Universitàt de València, Av. Dr. Moliner 50 E-46100 Burjassot, València, Spain*

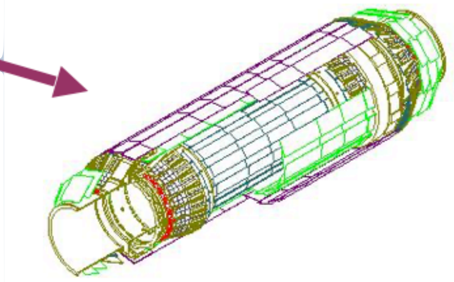
Large Systems



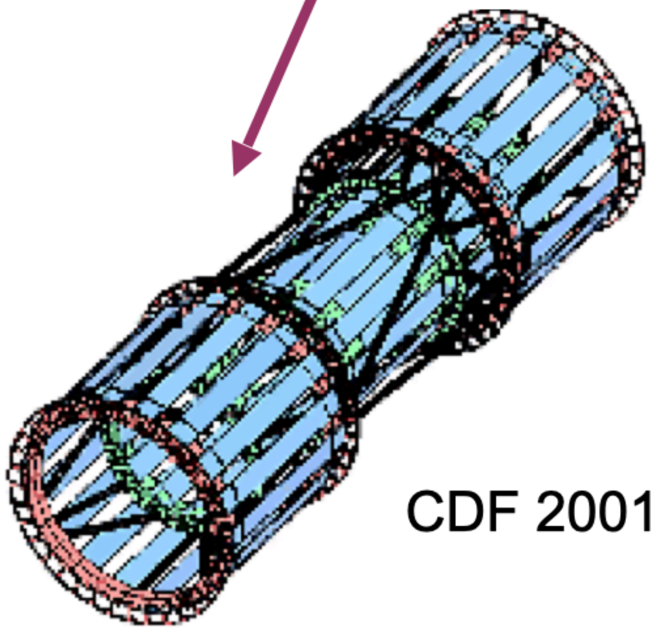
DELPHI
1990



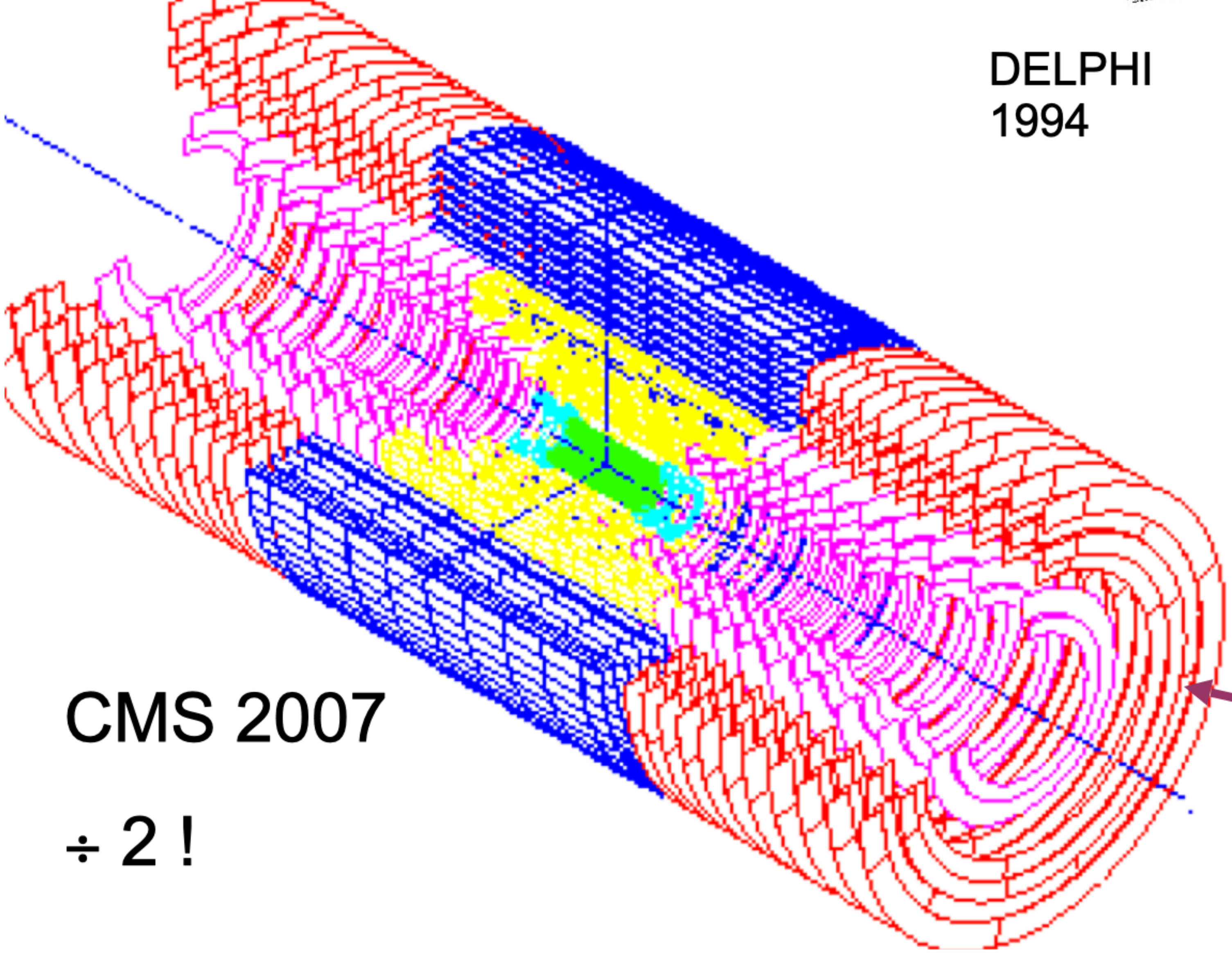
DELPHI
1994



DELPHI
1996



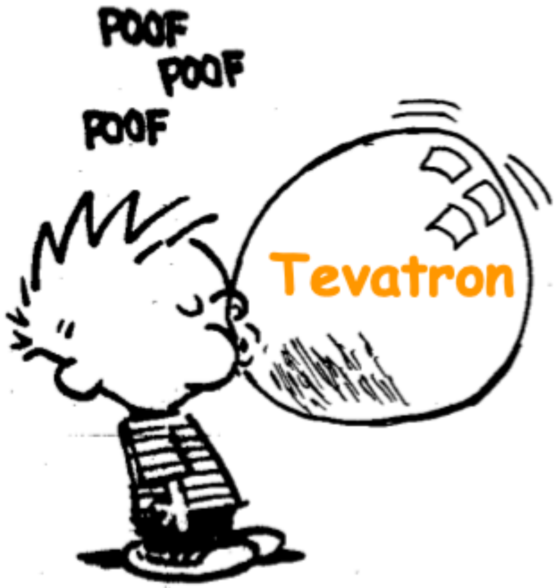
CDF 2001



CMS 2007

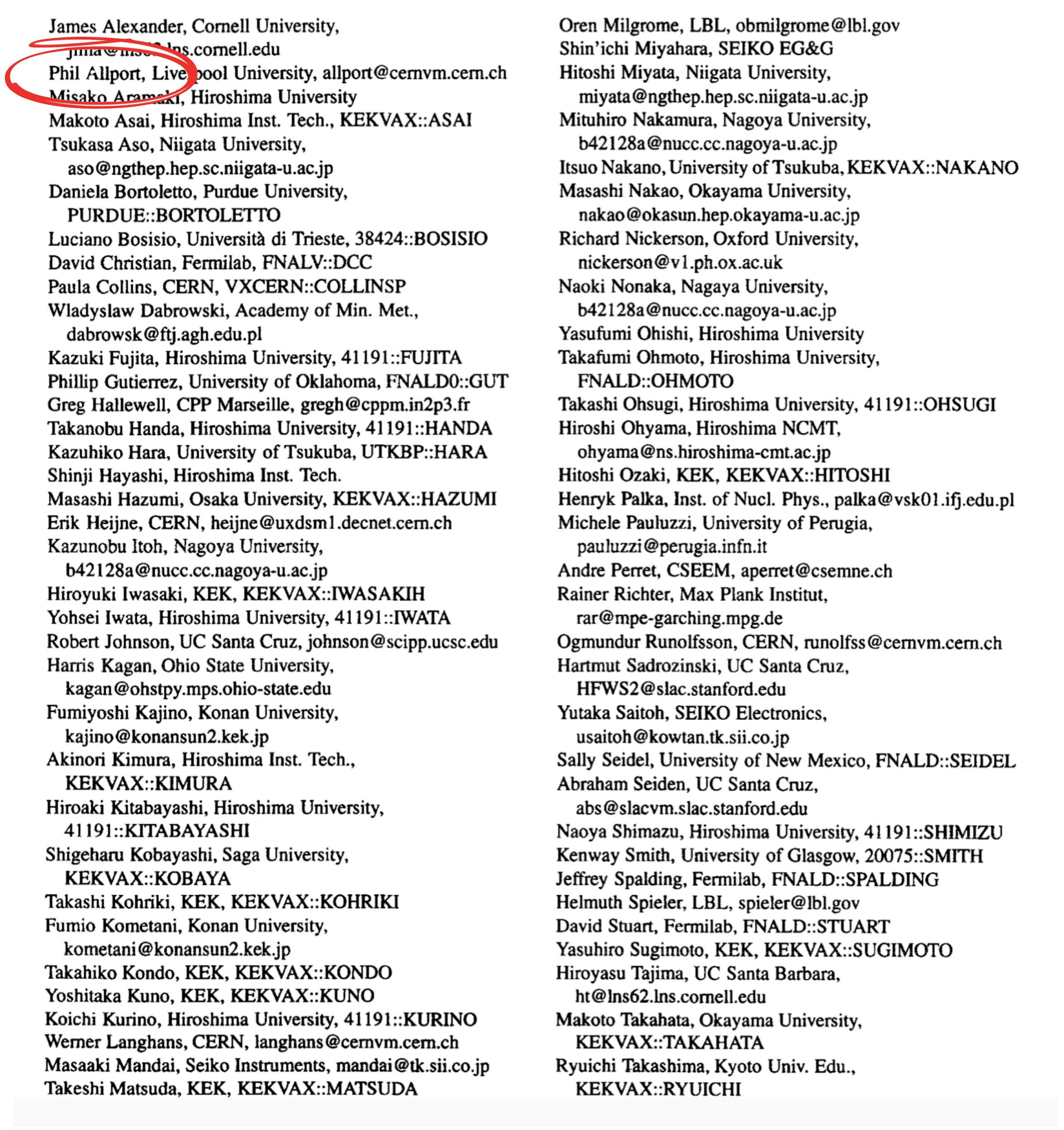
÷ 2 !

Large Systems



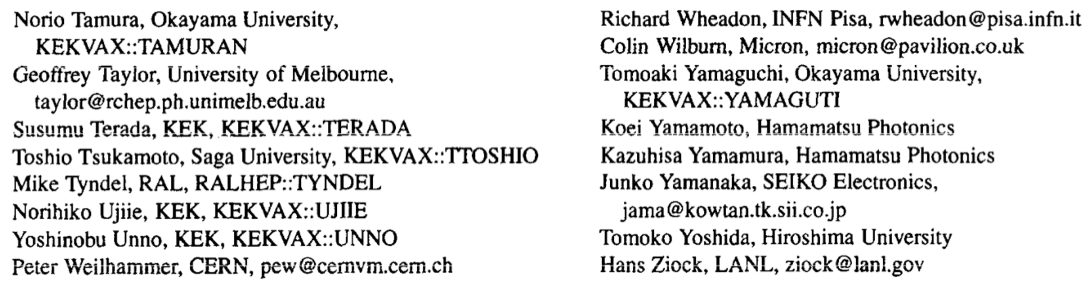
Hiroshima Conference 1995

Phil in the heart of it



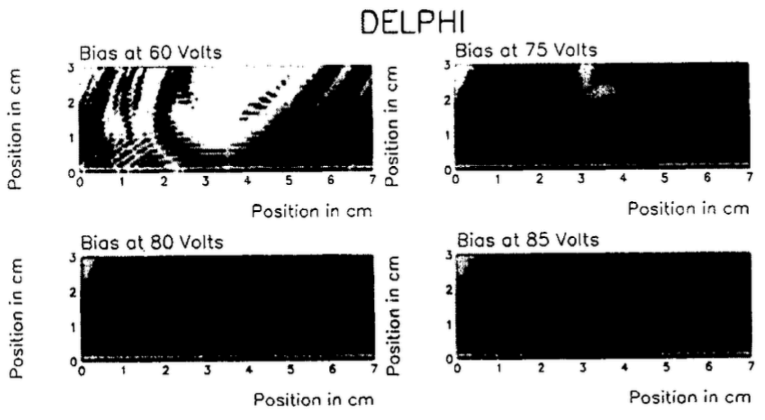
James Alexander, Cornell University,
jima@[illegible]lns.cornell.edu
Phil Allport, Liverpool University, allport@cernvm.cern.ch
Misako Aramaki, Hiroshima University
Makoto Asai, Hiroshima Inst. Tech., KEKVAX::ASAI
Tsukasa Aso, Niigata University,
aso@ngthep.hep.sc.niigata-u.ac.jp
Daniela Bortoletto, Purdue University,
PURDUE::BORTOLETTO
Luciano Bosisio, Università di Trieste, 38424::BOSISIO
David Christian, Fermilab, FNALV::DCC
Paula Collins, CERN, VXCERN::COLLINSP
Wladyslaw Dabrowski, Academy of Min. Met.,
dabrowsk@ftj.agh.edu.pl
Kazuki Fujita, Hiroshima University, 41191::FUJITA
Phillip Gutierrez, University of Oklahoma, FNALD0::GUT
Greg Hallewell, CPP Marseille, gregh@cppm.in2p3.fr
Takanobu Handa, Hiroshima University, 41191::HANDA
Kazuhiko Hara, University of Tsukuba, UTKBP::HARA
Shinji Hayashi, Hiroshima Inst. Tech.
Masashi Hazumi, Osaka University, KEKVAX::HAZUMI
Erik Heijne, CERN, heijne@uxdsm1.decnet.cern.ch
Kazunobu Itoh, Nagoya University,
b42128a@nucc.cc.nagoya-u.ac.jp
Hiroyuki Iwasaki, KEK, KEKVAX::IWASAKIH
Yohsei Iwata, Hiroshima University, 41191::IWATA
Robert Johnson, UC Santa Cruz, johnson@scipp.ucsc.edu
Harris Kagan, Ohio State University,
kagan@ohstpy.mps.ohio-state.edu
Fumiyoshi Kajino, Konan University,
kajino@konansun2.kek.jp
Akinori Kimura, Hiroshima Inst. Tech.,
KEKVAX::KIMURA
Hiroaki Kitabayashi, Hiroshima University,
41191::KITABAYASHI
Shigeharu Kobayashi, Saga University,
KEKVAX::KOBAYA
Takashi Kohriki, KEK, KEKVAX::KOHRIKI
Fumio Kometani, Konan University,
kometani@konansun2.kek.jp
Takahiko Kondo, KEK, KEKVAX::KONDO
Yoshitaka Kuno, KEK, KEKVAX::KUNO
Koichi Kurino, Hiroshima University, 41191::KURINO
Werner Langhans, CERN, langhans@cernvm.cern.ch
Masaaki Mandai, Seiko Instruments, mandai@tk.sii.co.jp
Takeshi Matsuda, KEK, KEKVAX::MATSUDA

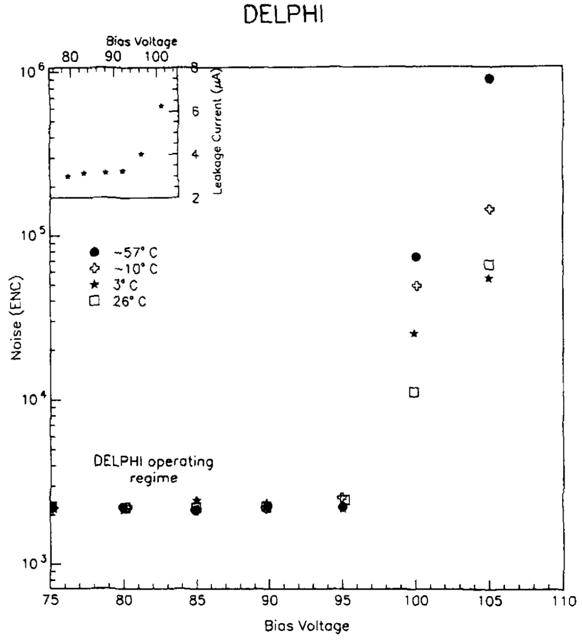
Oren Milgrome, LBL, obmilgrome@lbl.gov
Shin'ichi Miyahara, SEIKO EG&G
Hitoshi Miyata, Niigata University,
miyata@ngthep.hep.sc.niigata-u.ac.jp
Mituhiro Nakamura, Nagoya University,
b42128a@nucc.cc.nagoya-u.ac.jp
Itsuo Nakano, University of Tsukuba, KEKVAX::NAKANO
Masashi Nakao, Okayama University,
nakao@okasun.hep.okayama-u.ac.jp
Richard Nickerson, Oxford University,
nickerson@v1.ph.ox.ac.uk
Naoki Nonaka, Nagaya University,
b42128a@nucc.cc.nagoya-u.ac.jp
Yasufumi Ohishi, Hiroshima University
Takafumi Ohmoto, Hiroshima University,
FNALD::OHMOTO
Takashi Ohsugi, Hiroshima University, 41191::OHSUGI
Hiroshi Ohyama, Hiroshima NCMT,
ohyama@ns.hiroshima-cmt.ac.jp
Hitoshi Ozaki, KEK, KEKVAX::HITOSHI
Henryk Palka, Inst. of Nucl. Phys., palka@vsk01.ifj.edu.pl
Michele Pauluzzi, University of Perugia,
pauluzzi@perugia.infn.it
Andre Perret, CSEEM, aperret@csemne.ch
Rainer Richter, Max Plank Institut,
rar@mpe-garching.mpg.de
Ogmundur Runolfsson, CERN, runolfss@cernvm.cern.ch
Hartmut Sadrozinski, UC Santa Cruz,
HFWS2@slac.stanford.edu
Yutaka Saitoh, SEIKO Electronics,
usaitoh@kowtan.tk.sii.co.jp
Sally Seidel, University of New Mexico, FNALD::SEIDEL
Abraham Seiden, UC Santa Cruz,
abs@slacvm.slac.stanford.edu
Naoya Shimazu, Hiroshima University, 41191::SHIMIZU
Kenway Smith, University of Glasgow, 20075::SMITH
Jeffrey Spalding, Fermilab, FNALD::SPALDING
Helmuth Spieler, LBL, spieler@lbl.gov
David Stuart, Fermilab, FNALD::STUART
Yasuhiro Sugimoto, KEK, KEKVAX::SUGIMOTO
Hiroyasu Tajima, UC Santa Barbara,
ht@lns62.lns.cornell.edu
Makoto Takahata, Okayama University,
KEKVAX::TAKAHATA
Ryuichi Takashima, Kyoto Univ. Edu.,
KEKVAX::RYUICHI

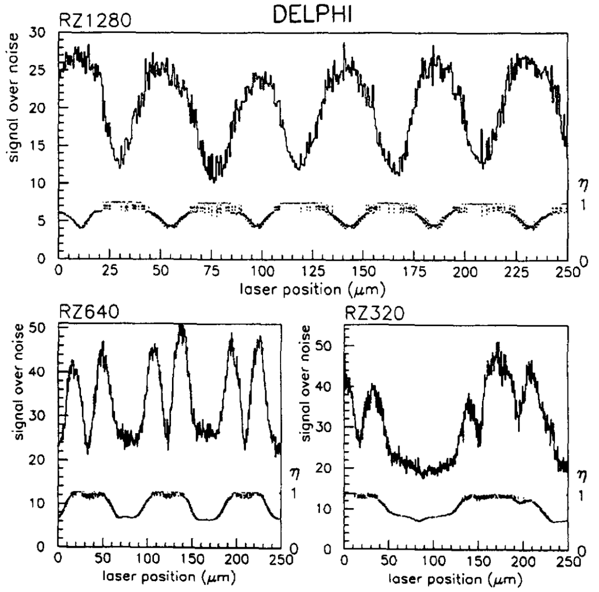


Norio Tamura, Okayama University,
KEKVAX::TAMURAN
Geoffrey Taylor, University of Melbourne,
taylor@rchep.ph.unimelb.edu.au
Susumu Terada, KEK, KEKVAX::TERADA
Toshio Tsukamoto, Saga University, KEKVAX::TTOSHIO
Mike Tyndel, RAL, RALHEP::TYNDEL
Norihiko Ujiie, KEK, KEKVAX::UJIIE
Yoshinobu Unno, KEK, KEKVAX::UNNO
Peter Weilhammer, CERN, pew@cernvm.cern.ch

Richard Wheadon, INFN Pisa, rwheadon@pisa.infn.it
Colin Wilburn, Micron, micron@pavilion.co.uk
Tomoaki Yamaguchi, Okayama University,
KEKVAX::YAMAGUTI
Koei Yamamoto, Hamamatsu Photonics
Kazuhisa Yamamura, Hamamatsu Photonics
Junko Yamanaka, SEIKO Electronics,
jama@kowtan.tk.sii.co.jp
Tomoko Yoshida, Hiroshima University
Hans Ziock, LANL, ziock@lanl.gov







Hiroshima Conference 1995

and the story of the lost luggage..

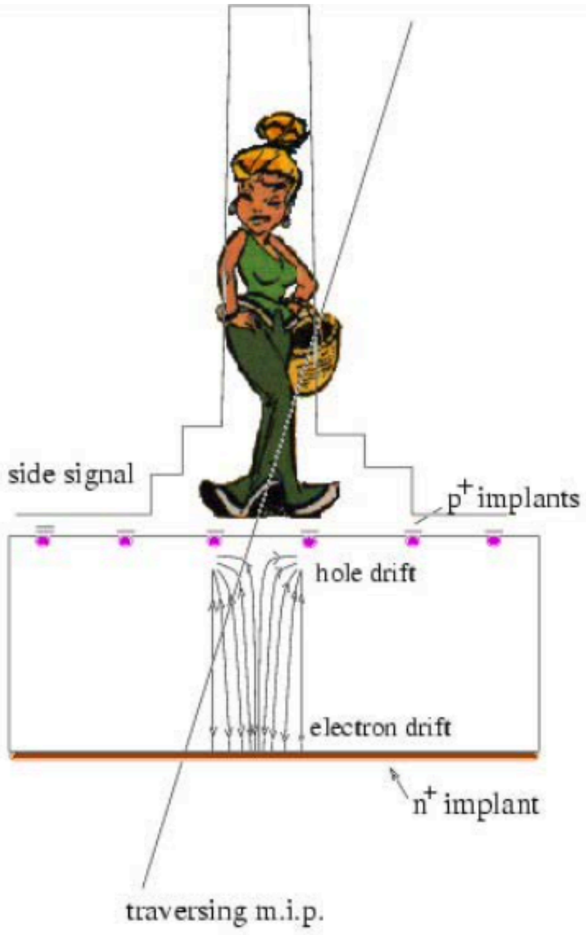
Radiation Damage and Charge Spreading

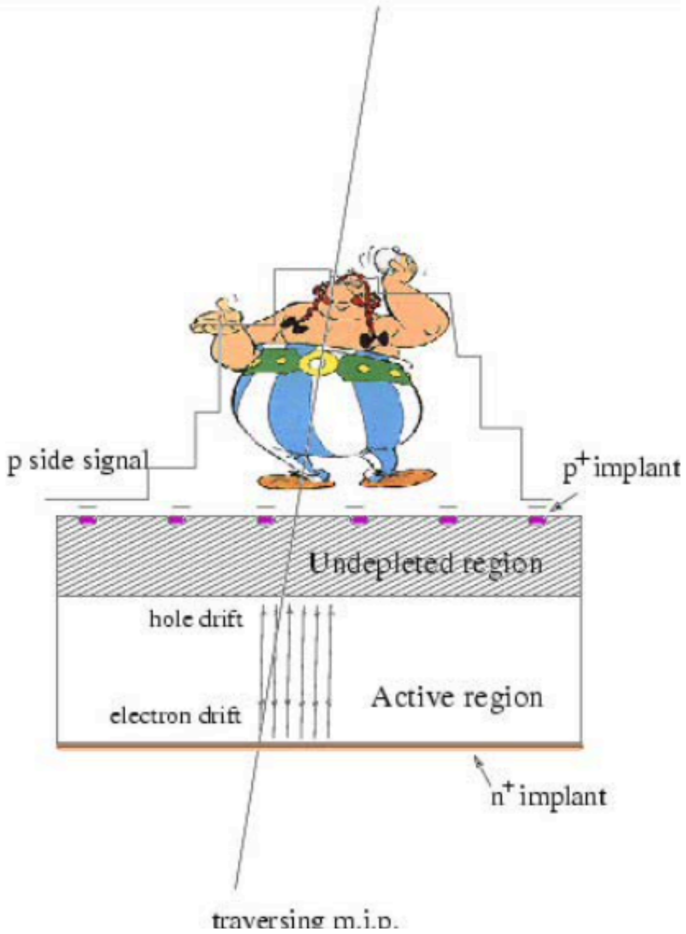
In non-irradiated detectors charge shareing comes from diffusion

In irradiated detectors there is extra charge sharing if the charge stops drifting due to underdepletion or to trapping. sometimes this is not desirable!

The charge spreading can have two bad effects

- loss of resolution
- loss of efficiency because the S/N of individual strips is smaller

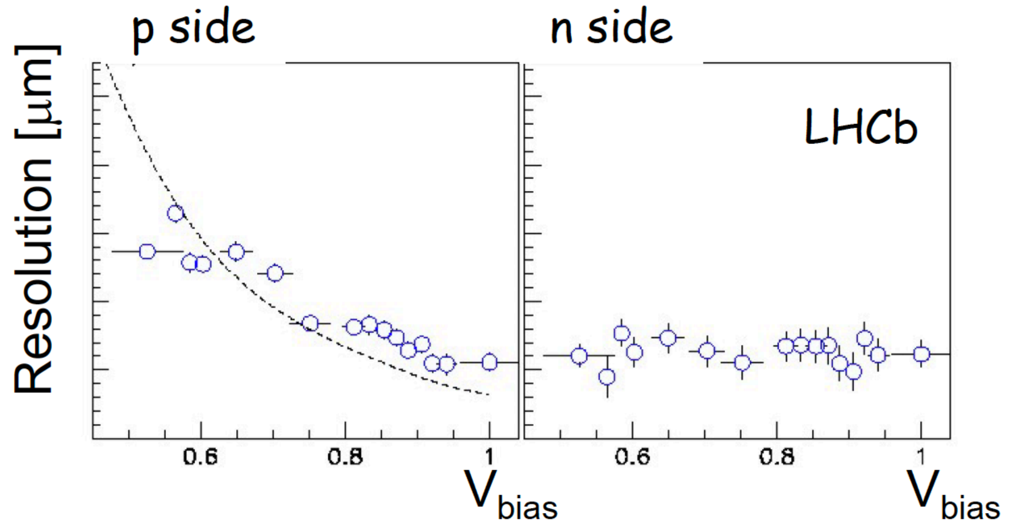




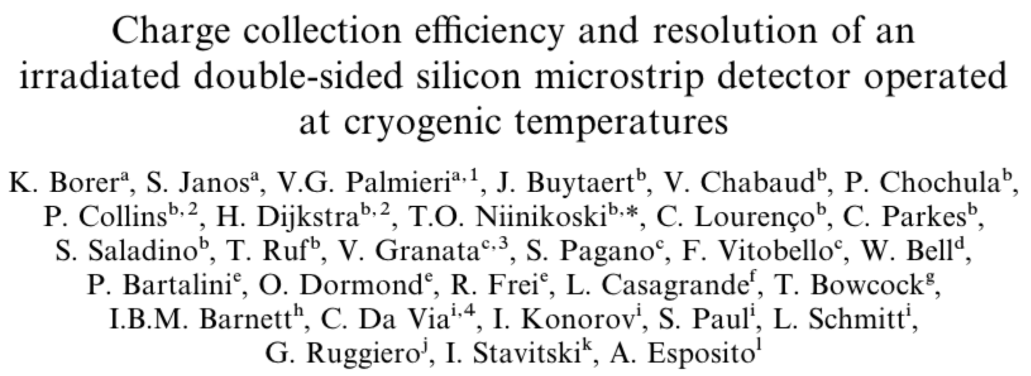
The n-in-p revolution

in the 90s Phil pioneered the switch from traditional hole collecting semiconductor sensors to electron collecting, and from n-type bulk to p-type bulk for radiation resistant applications

- potentially cheaper, single sided technology, good control of strip isolation available
- faster drift times from electrons, less sensitive to noise

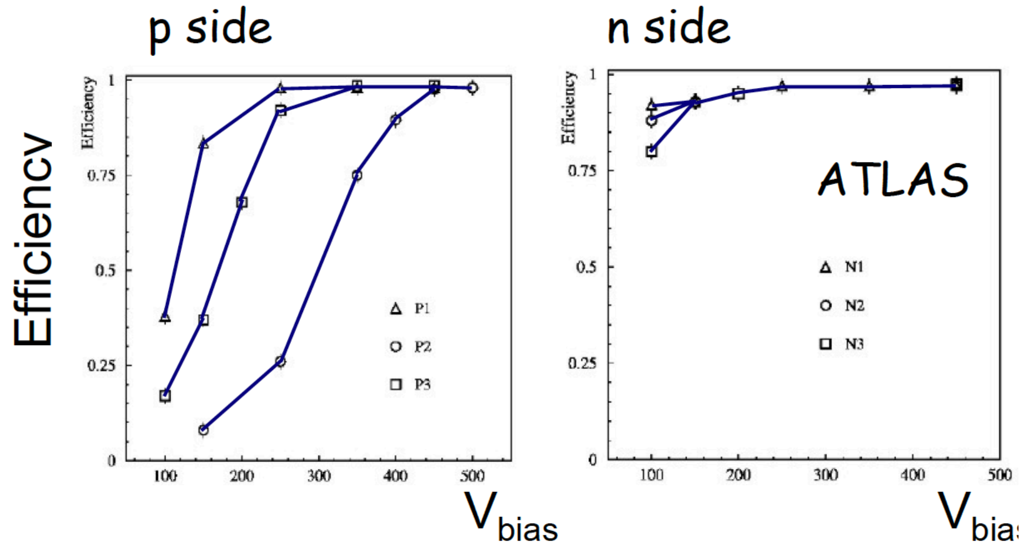


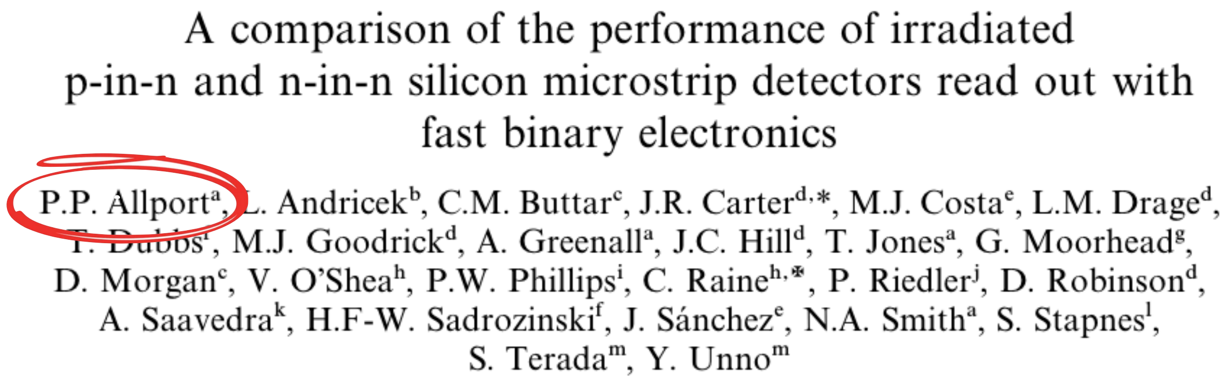
NIM A 440 (2000) 17



Charge collection efficiency and resolution of an irradiated double-sided silicon microstrip detector operated at cryogenic temperatures

K. Borer[a], S. Janos[a], V.G. Palmieri[a,1], J. Buytaert[b], V. Chabaud[b], P. Chochula[b], P. Collins[b,2], H. Dijkstra[b,2], T.O. Niinikoski[b,*], C. Lourenço[b], C. Parkes[b], S. Saladino[b], T. Ruf[b], V. Granata[c,3], S. Pagano[c], F. Vitobello[c], W. Bell[d], P. Bartalini[e], O. Dormond[e], R. Frei[e], L. Casagrande[f], T. Bowcock[g], I.B.M. Barnett[h], C. Da Via[i,4], I. Konorov[i], S. Paul[i], L. Schmitt[i], G. Ruggiero[j], I. Stavitski[k], A. Esposito[l]





A comparison of the performance of irradiated p-in-n and n-in-n silicon microstrip detectors read out with fast binary electronics

P.P. Allport[a], L. Andricek[b], C.M. Buttar[c], J.R. Carter[d,*], M.J. Costa[e], L.M. Drage[d], T. Dubbs[f], M.J. Goodrick[d], A. Greenall[a], J.C. Hill[d], T. Jones[a], G. Moorhead[g], D. Morgan[c], V. O'Shea[h], P.W. Phillips[i], C. Raine[h,*], P. Riedler[j], D. Robinson[d], A. Saavedra[k], H.F-W. Sadrozinski[f], J. Sánchez[e], N.A. Smith[a], S. Stapnes[l], S. Terada[m], Y. Unno[m]

LHCb and ATLAS studied double sided sensors and showed in two independent, almost simultaneous publications the greater robustness of the electron collecting side after irradiation.

This has affected the design of all modern Si-trackers and is one of Phil's most tremendous contributions

HEV/HPLV - The Ventilator Challenge

HEV/HPLV is a novel ventilator designed in response to the COVID-19 crisis

It is a high quality, low cost and suitable for use in ICUs, for invasive and non-invasive ventilatory support

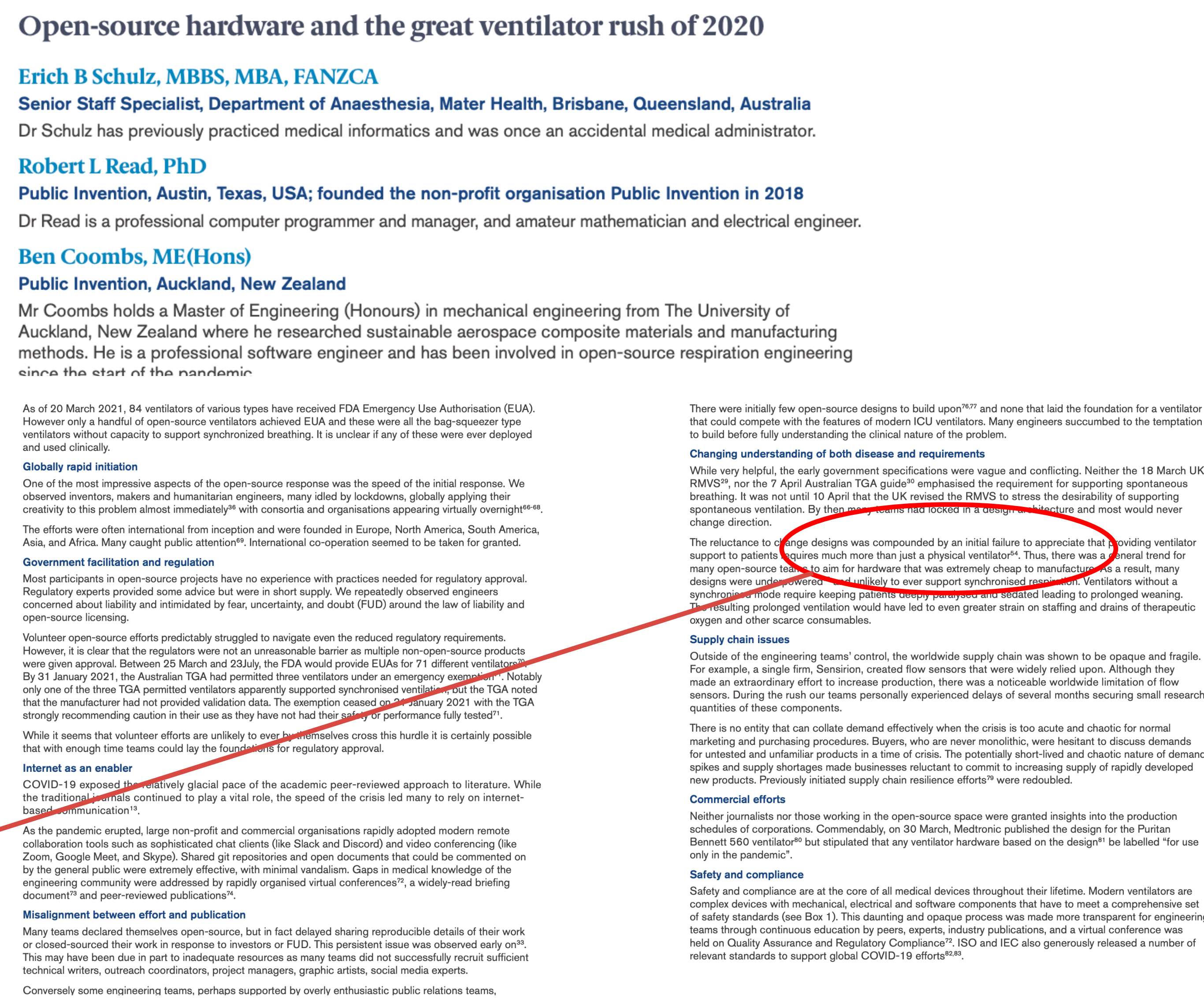
Modes include Pressure control, Volume control, Pressure Support, Delivery of oxygen enriched air, CPAP

Globally, pneumonia is the most common infectious cause of death. The COVID pandemic has drawn attention to the lack of ventilation equipment in LMICs (Low to Middle Income countries), and HEV/HPLV will remain relevant.

Some recent perspective


ANZCA
FPM

Australasian
Anaesthesia
2021


Open-source hardware and the great ventilator rush of 2020

Erich B Schulz, MBBS, MBA, FANZCA
Senior Staff Specialist, Department of Anaesthesia, Mater Health, Brisbane, Queensland, Australia
Dr Schulz has previously practiced medical informatics and was once an accidental medical administrator.

Robert L Read, PhD
Public Invention, Austin, Texas, USA; founded the non-profit organisation Public Invention in 2018
Dr Read is a professional computer programmer and manager, and amateur mathematician and electrical engineer.

Ben Coombs, ME(Hons)
Public Invention, Auckland, New Zealand
Mr Coombs holds a Master of Engineering (Honours) in mechanical engineering from The University of Auckland, New Zealand where he researched sustainable aerospace composite materials and manufacturing methods. He is a professional software engineer and has been involved in open-source respiration engineering since the start of the pandemic.

As of 20 March 2021, 84 ventilators of various types have received FDA Emergency Use Authorisation (EUA). However only a handful of open-source ventilators achieved EUA and these were all the bag-squeezer type ventilators without capacity to support synchronized breathing. It is unclear if any of these were ever deployed and used clinically.

Globally rapid initiation

One of the most impressive aspects of the open-source response was the speed of the initial response. We observed inventors, makers and humanitarian engineers, many idled by lockdowns, globally applying their creativity to this problem almost immediately[36] with consortia and organisations appearing virtually overnight[66-68].

The efforts were often international from inception and were founded in Europe, North America, South America, Asia, and Africa. Many caught public attention[69]. International co-operation seemed to be taken for granted.

Government facilitation and regulation

Most participants in open-source projects have no experience with practices needed for regulatory approval. Regulatory experts provided some advice but were in short supply. We repeatedly observed engineers concerned about liability and intimidated by fear, uncertainty, and doubt (FUD) around the law of liability and open-source licensing.

Volunteer open-source efforts predictably struggled to navigate even the reduced regulatory requirements. However, it is clear that the regulators were not an unreasonable barrier as multiple non-open-source products were given approval. Between 25 March and 23July, the FDA would provide EUAs for 71 different ventilators[70]. By 31 January 2021, the Australian TGA had permitted three ventilators under an emergency exemption[71]. Notably only one of the three TGA permitted ventilators apparently supported synchronised ventilation, but the TGA noted that the manufacturer had not provided validation data. The exemption ceased on 31 January 2021 with the TGA strongly recommending caution in their use as they have not had their safety or performance fully tested[71].

While it seems that volunteer efforts are unlikely to ever by themselves cross this hurdle it is certainly possible that with enough time teams could lay the foundations for regulatory approval.

Internet as an enabler

COVID-19 exposed the relatively glacial pace of the academic peer-reviewed approach to literature. While the traditional journals continued to play a vital role, the speed of the crisis led many to rely on internet-based communication[13].

As the pandemic erupted, large non-profit and commercial organisations rapidly adopted modern remote collaboration tools such as sophisticated chat clients (like Slack and Discord) and video conferencing (like Zoom, Google Meet, and Skype). Shared git repositories and open documents that could be commented on by the general public were extremely effective, with minimal vandalism. Gaps in medical knowledge of the engineering community were addressed by rapidly organised virtual conferences[72], a widely-read briefing document[73] and peer-reviewed publications[74].

Misalignment between effort and publication

Many teams declared themselves open-source, but in fact delayed sharing reproducible details of their work or closed-sourced their work in response to investors or FUD. This persistent issue was observed early on[33]. This may have been due in part to inadequate resources as many teams did not successfully recruit sufficient technical writers, outreach coordinators, project managers, graphic artists, social media experts.

Conversely some engineering teams, perhaps supported by overly enthusiastic public relations teams,

There were initially few open-source designs to build upon[76,77] and none that laid the foundation for a ventilator that could compete with the features of modern ICU ventilators. Many engineers succumbed to the temptation to build before fully understanding the clinical nature of the problem.

Changing understanding of both disease and requirements

While very helpful, the early government specifications were vague and conflicting. Neither the 18 March UK RMVS[29], nor the 7 April Australian TGA guide[30] emphasised the requirement for supporting spontaneous breathing. It was not until 10 April that the UK revised the RMVS to stress the desirability of supporting spontaneous ventilation. By then many teams had locked in a design architecture and most would never change direction.

The reluctance to change designs was compounded by an initial failure to appreciate that providing ventilator support to patients requires much more than just a physical ventilator[54]. Thus, there was a general trend for many open-source teams to aim for hardware that was extremely cheap to manufacture. As a result, many designs were underpowered and unlikely to ever support synchronised respiration. Ventilators without a synchronised mode require keeping patients deeply paralysed and sedated leading to prolonged weaning. The resulting prolonged ventilation would have led to even greater strain on staffing and drains of therapeutic oxygen and other scarce consumables.

Supply chain issues

Outside of the engineering teams' control, the worldwide supply chain was shown to be opaque and fragile. For example, a single firm, Sensirion, created flow sensors that were widely relied upon. Although they made an extraordinary effort to increase production, there was a noticeable worldwide limitation of flow sensors. During the rush our teams personally experienced delays of several months securing small research quantities of these components.

There is no entity that can collate demand effectively when the crisis is too acute and chaotic for normal marketing and purchasing procedures. Buyers, who are never monolithic, were hesitant to discuss demands for untested and unfamiliar products in a time of crisis. The potentially short-lived and chaotic nature of demand spikes and supply shortages made businesses reluctant to commit to increasing supply of rapidly developed new products. Previously initiated supply chain resilience efforts[79] were redoubled.

Commercial efforts

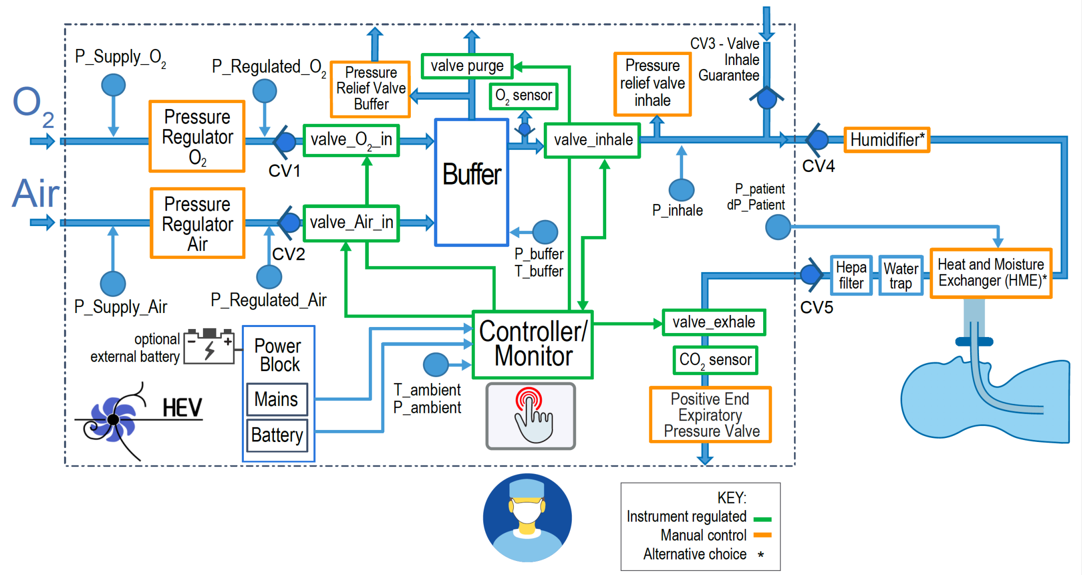
Neither journalists nor those working in the open-source space were granted insights into the production schedules of corporations. Commendably, on 30 March, Medtronic published the design for the Puritan Bennett 560 ventilator[80] but stipulated that any ventilator hardware based on the design[81] be labelled "for use only in the pandemic".

Safety and compliance

Safety and compliance are at the core of all medical devices throughout their lifetime. Modern ventilators are complex devices with mechanical, electrical and software components that have to meet a comprehensive set of safety standards (see Box 1). This daunting and opaque process was made more transparent for engineering teams through continuous education by peers, experts, industry publications, and a virtual conference was held on Quality Assurance and Regulatory Compliance[72]. ISO and IEC also generously released a number of relevant standards to support global COVID-19 efforts[82,83].

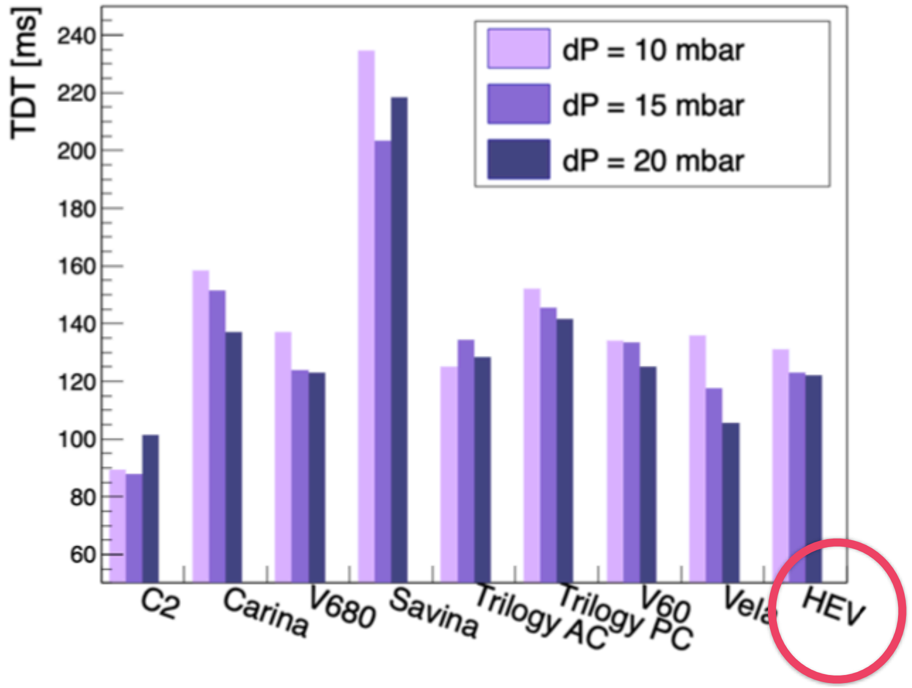
While very helpful, the early government specifications were vague and conflicting. Neither the 18 March UK RMVS, nor the 7 April Australian TGA guide emphasised the requirement for **supporting spontaneous breathing**. It was not until 10 April that the UK revised the RMVS to stress the desirability of supporting spontaneous ventilation. **By then many teams had locked in a design architecture** and most would never change direction.

HEV/HPLV took a particle physics approach

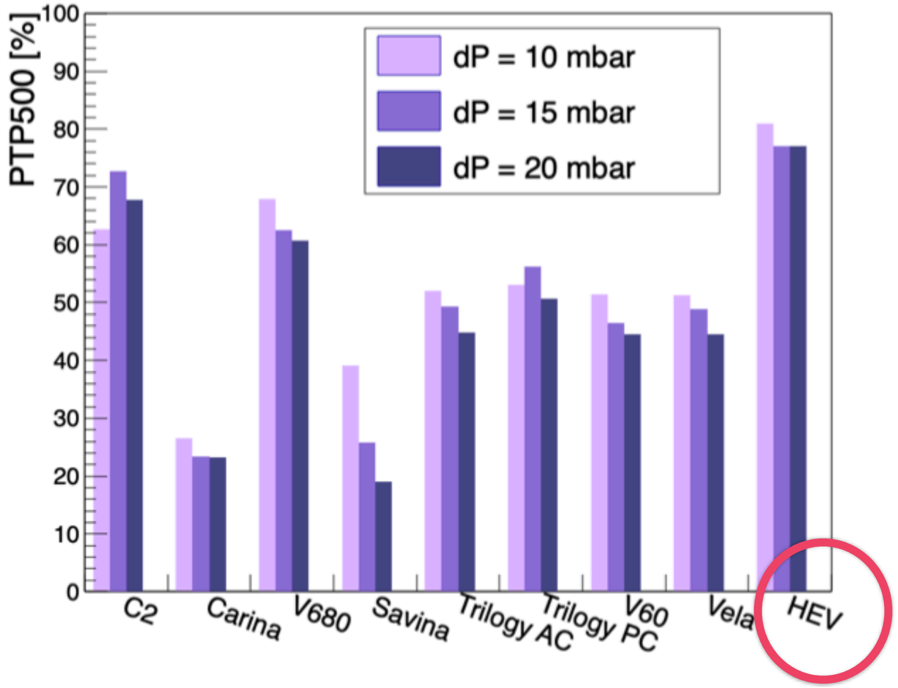


Design takes an old concept, but uses particle physics techniques of control and monitoring to deliver a modern performance, for an affordable, reliable device

Performance, compared to commercial devices



Trigger reaction time (ideally should be below 150 ms)



Pressure integral at 500 ms compared to ideal (should be as high as possible)

ORIGINAL RESEARCH article

Front. Med. Technol., 16 August 2022
Sec. Diagnostic and Therapeutic Devices
Volume 4 - 2022 | https://doi.org/10.3389/fmedt.2022.899328

This article is part of the Research Topic
Medical Technologies in Diagnostic & Therapeutics
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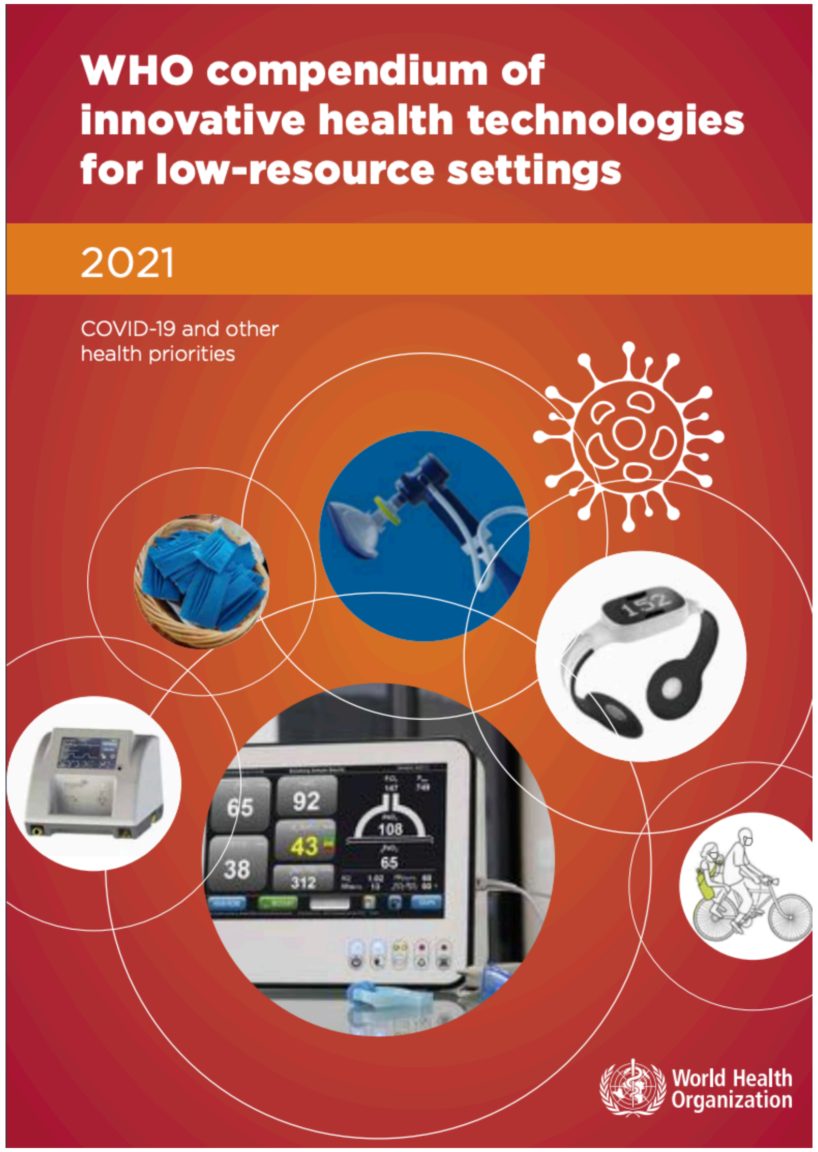
Testing of pandemic ventilators under early and agile development

Nikolaos Tachatos[1], Nicola Steffen[1], Mark Zander[1], Nikola Stankovic[2], Mirko Meboldt[1], Thomas O. Erb[2], Jürg Hammer[3] and Marianne Schmid Daners[1*]

Current status



WHO compendium of innovative health technologies for low-resource settings

2021

COVID-19 and other health priorities

World Health Organization

ROYAL SOCIETY
OPEN SCIENCE

rsos.royalsocietypublishing.org

Research

Article submitted to journal

Subject Areas:
Mechanical Ventilator, Biomechanical Engineering

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Covid-19, ventilation modes, Triggering, Oxygen enrichment

Author for correspondence:
Insert corresponding author name
e-mail: paula.collins@cern.ch

The HEV Ventilator - at the Interface between Particle Physics and Biomedical Engineering

Jan Buytaert[a], Paula Collins[a,1], Adam Abed Abud[a,b], Phil Allport[c], Antonio Pazos Álvarez[d], Kazuyoshi Akiba[e], Oscar Augusto de Aguiar Francisco[a,q], Aurelio Bay[f], Florian Bernard[f], Sophie Baron[a], Claudia Bertella[a], Josef X. Brunner[g], Themis Bowcock[b], Martine Buytaert-De Jode[a], Wiktor Byczynski[a,h], Ricardo De Carvalho[i], Victor Coco[a], Ruth Collins[j], Nikola Dikic[m], Nicolas Dousse[i], Bruce Dowd[k], Kārlis Dreimanis[aa], Raphael Dumps[a], Paolo Durante[a], Walid Fadel[a], Stephen Farry[b], Antonio Fernández Prieto[d], Arturo Fernández Téllez[pp], Gordon Flynn[k,l], Vinicius Franco Lima[b], Raymond Frei[f], Abraham Gallas Torreira[d], Tonatiuh García Chávez[pp], Evangelos Gazis[bb], Roberto Guida[a], Karol Hennessy[b], Andre Henriques[a], David Hutchcroft[b], Stefan Ilic[m], Artūrs Ivanovs[aa], Aleksandar Jevtic[m], Emigdio Jimenez Dominguez[pp], Christian Joram[a], Kacper Kapusniak[a], Edgar Lemos Cid[d], Jana Lindner[n], Rolf Lindner[a], M. Iván Martínez Hernández[pp], Mirko Meboldt[z], Marko Milovanovic[o,a], Sylvain Mico[a], Johan Morant[a], Michel Morel[a], Georg Männel[bb], Dónal Murray[q], Irina Nasteva[r], Niko Neufeld[a], Igor Neuhold[a], Francisco Pardo-Sobrino López[s], Eliseo Pérez Trigo[d], Gonzalo Pichel Jallas[d], Edyta Pilorz[a], Lise Piquilloud[t], Xavier Pons[a], David Reiner[u], Hector David Régules Medel[pp], Saul Rodríguez Ramírez[pp], Mario Rodíguez Cahuantzi[pp], Carl Roosens[v], Philipp Rostalski[p,bb], Freek Sanders[a], Eric Saucet[i], Marianne Schmid Daners[z], Burkhard Schmidt[a], Patrick Schoettker[t], Rainer Schwemmer[a], Heinrich Schindler[a], Archana Sharma[a], Derick Sivakumaran[z], Christophe Sigaud[a], Vasilios Spitas[bb], Nicola Steffen[z], Peter Svihra[q], Guillermo Tejeda Muñoz[pp], Nikolaos Tachatos[z], Efstratios Tsolakis[2], Jan van Leemput[v], Laurence Vignaux[w], Francois Vasey[a], Hamish Woonton[x,y], Ken Wyllie[a]

A high quality, low-cost ventilator, dubbed HEV, has been developed by the particle physics community working together with biomedical engineers and physicians around the world. The HEV design is suitable for use both in and out of hospital intensive care units, provides a variety of modes and is capable of supporting spontaneous breathing and supplying oxygen enriched air. An external air supply can be combined with the unit for use in situations where compressed air is not readily available. HEV supports remote training and post market surveillance via a web interface and data logging to complement standard touch screen operation, making it suitable for a wide range of geographical deployment. The HEV design places emphasis on the ventilation performance, especially the quality and accuracy of the pressure curves, reactivity of the trigger, measurement of delivered volume and control of oxygen mixing, delivering a global performance which will be applicable to ventilator needs beyond the COVID-19 pandemic. This article describes the conceptual design and presents the prototype units together with a performance evaluation.

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After review by the respiratory expert panel, HEV and HPLV were selected to feature in the WHO compendium, as an “innovative technology that can have an immediate or future impact on the COVID-19 preparedness and response, have the potential to improve health outcomes and quality of life, and/or offer a solution to an unmet medical/health technology need”, and the academic description was published by Royal Society Open Science https://royalsocietypublishing.org/doi/10.1098/rsos.211519o

Licences have been signed in many countries internationally and prototypes are under development and are serving to support R&D in pressure sensors and algorithms for ventilator development in academic institutions

Phil’s support at the early stages, as an international reviewer of the project, and then his membership of the team, was CRUCIAL. We are forever indebted to him for his encouragement and words of wisdom.

Thank you Phil

I hope I’ve been able to demonstrate to you that Phil’s choices of research path, his endless curiosity and enthusiasm, and his innovations have had a lasting and profound impact on the field

Certainly this is the case for the experiments and detectors I have worked on

This quote from Themis Bowcock sums up many of the talks today “*Phil is one of the only people who could talk equally fluently about silicon and Nietzsche in the same sentence*”

Finally, a message from Jan Timmermans, DELPHI Spokesperson:

“I hope you can transmit on behalf of DELPHI our thanks for his contributions to DELPHI.
And personally I hope he can still be very active in future detector technologies for a long time”

Thank you! And special thanks to Jan Timmermans, Spyros Tzamarias, Hans Dijkstra and Mike Tyndel for sharing memories and providing material