20th Anniversary

Lessons to learn from ARGUS:

- Have a better detector that can "see all"
- Learn how to use the hermeticity of the detector
- Have excellent physics ideas and follow them
- Have excellent physics analysis software
- Have a little bit of luck

- Don't underestimate the competition!

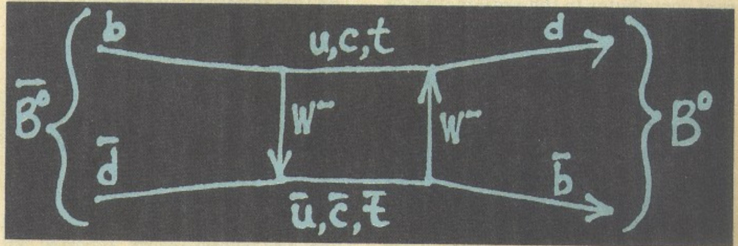
D. Cassel

Neutral B mesons show surprisingly large flavor mixing

In its heyday in the 1950s and 60s, the K meson was a spectacular source of profound surprises. Its "strange" longevity gave us the first hint of flavor conservation in the strong interactions, and eventually the concept of quarks as the carriers of these hadronic flavors. Its decay into states of opposite parity freed us from rigid adherence to mirror symmetry. Then the neutral kaon was seen to oscillate wondrously between states of opposite strangeness, and finally, in 1964, one of its decay modes yielded up the last great surprise. It provided us the only example we have to this day of *CP* violation. We had known since 1957 that *P* (parity inversion) was not an inviolate symmetry of nature. Now the last hope for mirror symmetry—invariance under the combined operation of *P* and *C* (charge conjugation)—was also dashed.

The neutral kaon could show us things to be seen nowhere else—flavor mixing and *CP* violation—because it was, it its day, unique among the known elementary particles. The K^0 differs from the $\bar{K}^0$, its antiparticle, only by virtue of its hadronic flavor, a quantum number not respected by the weak interactions; they are states of opposite strangeness. Thus the two neutral kaons are coupled by their ability to decay weakly to the same states, for example $\pi^+\pi^-$. Such couplings give rise to "flavor mixing." The two neutral-kaon states of definite mass are superpositions of the two states of opposite strangeness, with slightly different masses and very different lifetimes. This flavor mixing was the *sine qua non* for the observation of *CP* violation in the decay of the longer-lived neutral kaon.

The neutral kaon is no longer unique. In 1977 Leon Lederman and coworkers at Fermilab found the first indication of the bottom-flavored quark, the "third-generation" analog of the strange quark, and in 1983 the Cleo collaboration at CESR, the Cornell electron–positron storage ring, announced the first direct observation of the B^0 meson, the bottom-flavored analog of the K^0, with a mass of about 5 GeV—more than ten times that of the K (PHYSICS TODAY, April 1983, page 20.)



Second-order weak process couples B^0 to its antiparticle, thus permitting a mixing metamorphosis. A $\bar{B}^0$, consisting of a bottom quark (charge $-\frac{1}{3}$) and an antidown quark, becomes a B^0 by the exchange of two charged weak vector bosons W. In the intermediate state, all 3 generations of charge $+\frac{2}{3}$ quarks (up, charmed, top) can contribute, together with their antiquarks. The top quark, being the heaviest, dominates the amplitude.

Now we have the first clear evidence of flavor mixing between the B^0 and its antiparticle, the $\bar{B}^0$. In February, the ARGUS collaboration reported[1] that their data from the DORIS electron–positron storage ring at DESY in Hamburg indicate a mixing parameter of about 20%, much bigger than the fondest hopes of the theorists.

Briefly stated, if the B^0 meson did not engage in flavor mixing with the $\bar{B}^0$ during its brief picosecond lifetime, its semileptonic decay modes (those that yield leptons and hadrons) would always produce a characteristic *positive* lepton—a positron or a positive muon, never an electron or a μ^-. Correspondingly the $\bar{B}^0$ would signal its semileptonic decay with an e^- or a μ^-, never a positive lepton. What the ARGUS group found, in essence, was that roughly one semileptonic neutral B decay in six produced the wrong lepton charge, thus signaling that the B meson's bottom flavor had changed sign between its birth and death. By convention, in keeping with the analogy to K mesons, the bottom quark b, with bottom flavor (or "bottomness") -1 and electric charge $-\frac{1}{3}$, resides in the $\bar{B}^0$ meson, while its antiquark $\bar{b}$, with positive flavor and charge, inhabits the B^0.

Theorists had jumped on the first hint of B mesons in 1977 with great enthusiasm, pointing out that nature might well be offering here a second chance to see flavor mixing and *CP* violation. So long as *CP* violation data were limited to the decay of the neutral kaon, one couldn't really be sure what physics underlay this striking phenomenon. The data were consistent with the "standard model" of elementary particle interactions, with its 3 generations of quarks and leptons, but the data were painfully limited. Theorists longed for a new vantage point from which to observe *CP* violation. Even if the new observations remained consistent with the standard model, they might shed light on the observed value of the *CP*-violating phase angle in the three-generation formalism, which remains an unexplained free parameter in the model. The abundance of such arbitrary parameters in the standard model impels the search for a deeper theory. Furthermore, as Andrei Sakharov pointed out 20 years ago, by seeking to understand *CP* violation we come to grips with the matter–antimatter asymmetry of the cosmos.

But the surprising and welcome ARGUS result comes at a time when the

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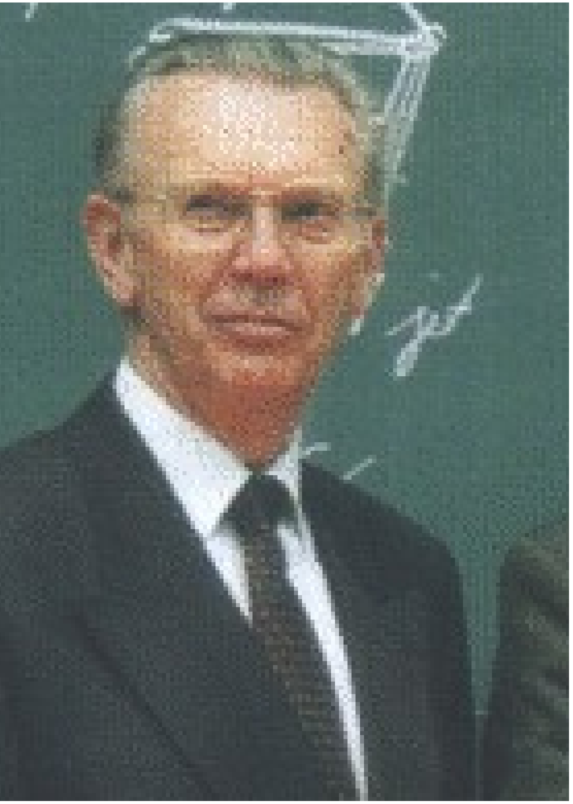
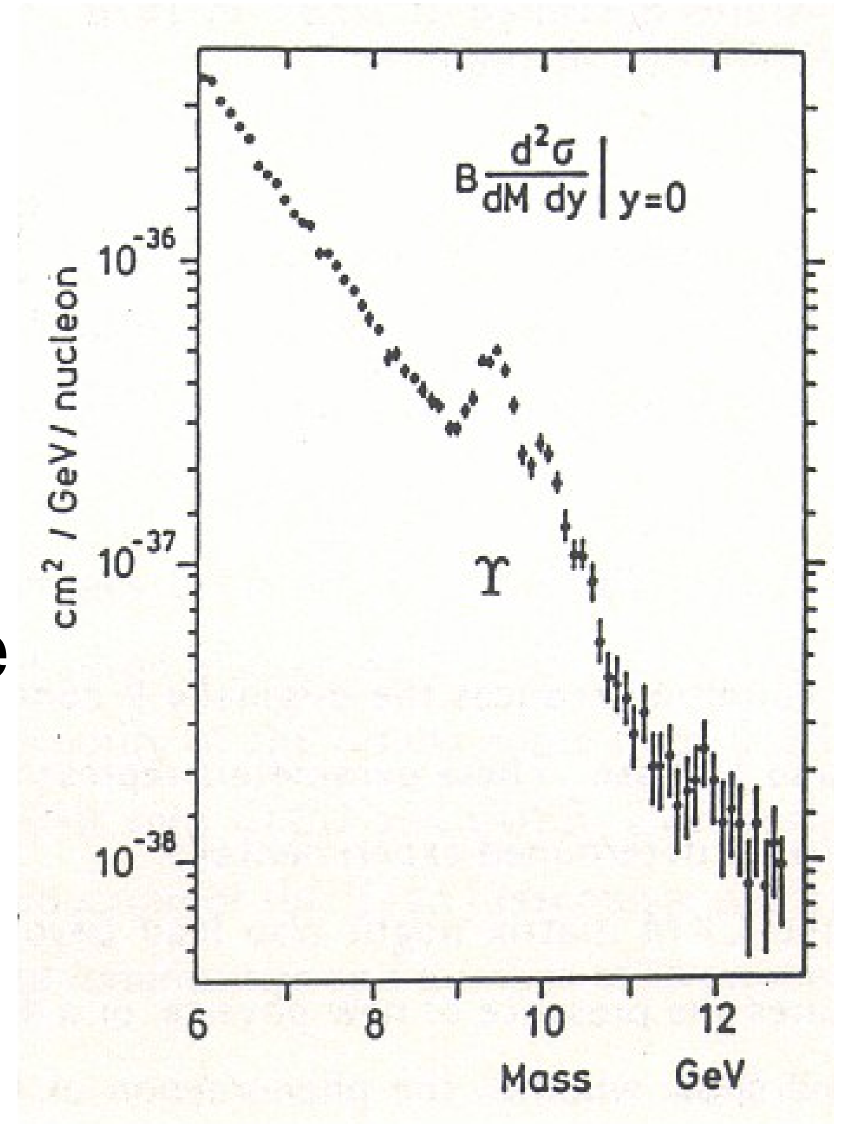
q'
q'
NC



1977

Had successfully built PETRA.
Planned that in parallel DORIS
continues with
a new Detector.



After the discovery of the **Y :**
Transform DORIS into a single
ring and increase its energy
to reach the **Y** states.

Designing a competitive Detector

SPEAR CESR (PETRA PEP)

Uniform, hermetic, large solid angle

Largest magnetic field, normal conducting

Shower before coil , pointing geometry

Particle Id.: dE/dx and ToF. Jet chamber

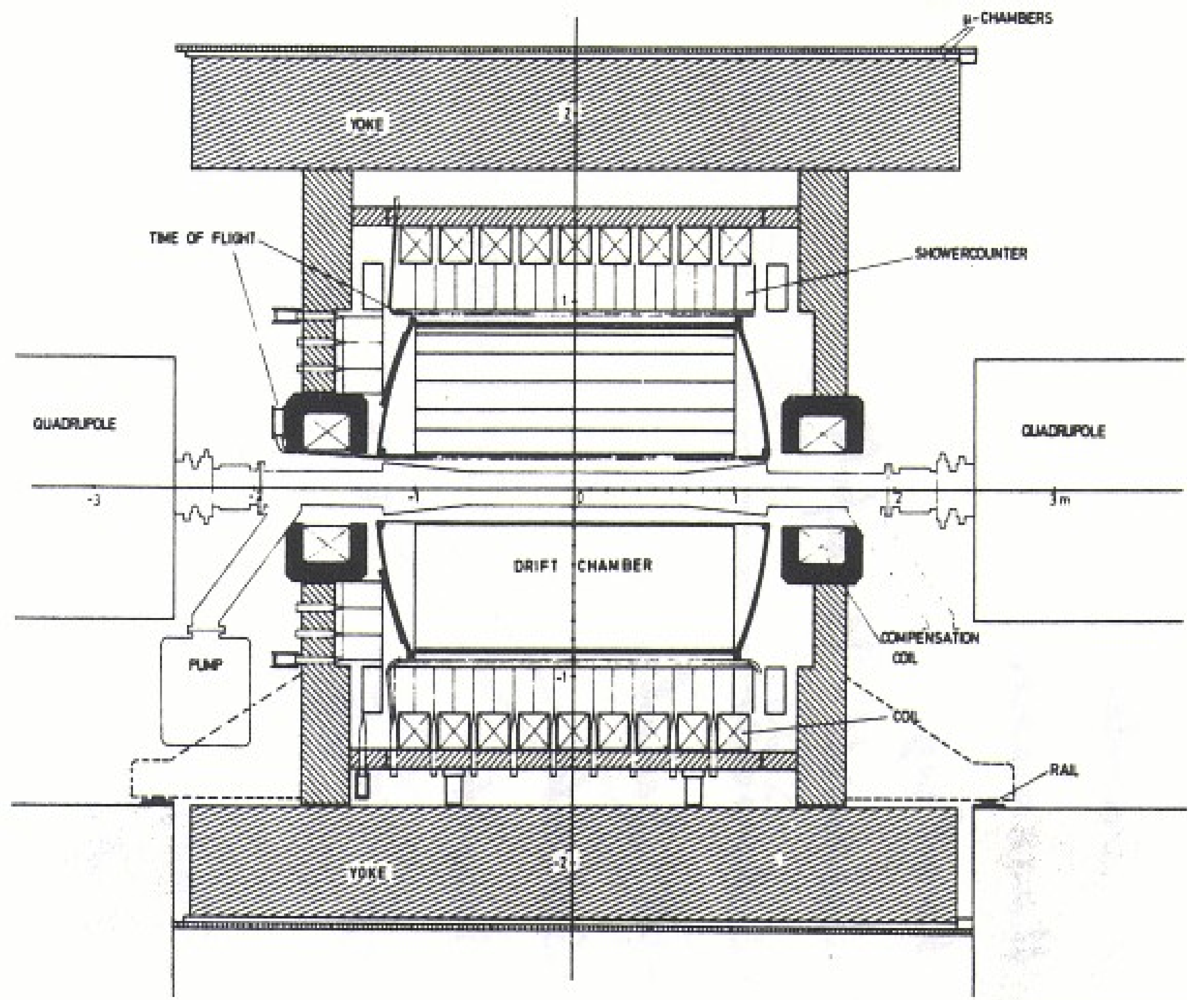
Meeting on DORIS Experiments

10th and 11th October 1977

D E S Y

Collection of transparencies used by the speakers

A	D. Degèle (DESY)	DORIS at High Energies
B	F.T. Walsh (DESY)	Physics Priorities at DORIS
C	H. Schröder (DESY)	Experiments at DASP in the Upsilon Region
D	J. Bürger (Univ. SIEGEN)	PLUTO Proposal to scan the Upsilon Energy Region
E	H.-J. Besch (Univ. BONN)	Experimental Possibilities of the BONANZA apparatus
F	J. Heintze (Univ. HEIDELBERG)	Some Remarks about the DESY-Heidelberg Apparatus
G	P. Waloschek (DESY)	Why γγ - Physics at DORIS ?
H	A. Courau (ORSAY)	γγ - Physics at DCI
I	B. Richter (SLAC)	Detectors at SPEAR
K	J. Heintze (Univ. HEIDELBERG)	Jet Chamber as Inner Detector for Storage Ring Experiments
L	T. Meyer (MPI MÜNCHEN)	Results from the Liquid Argon Tests of the CELLO Collaboration
M	W.B. Atwood (CERN)	A new Shower Detector
N	G. Poelz (Univ. HAMBURG)	Aerogel Cerenkov Counters
P	W. Schmidt-Parzefall (DESY)	A new Detector for DORIS



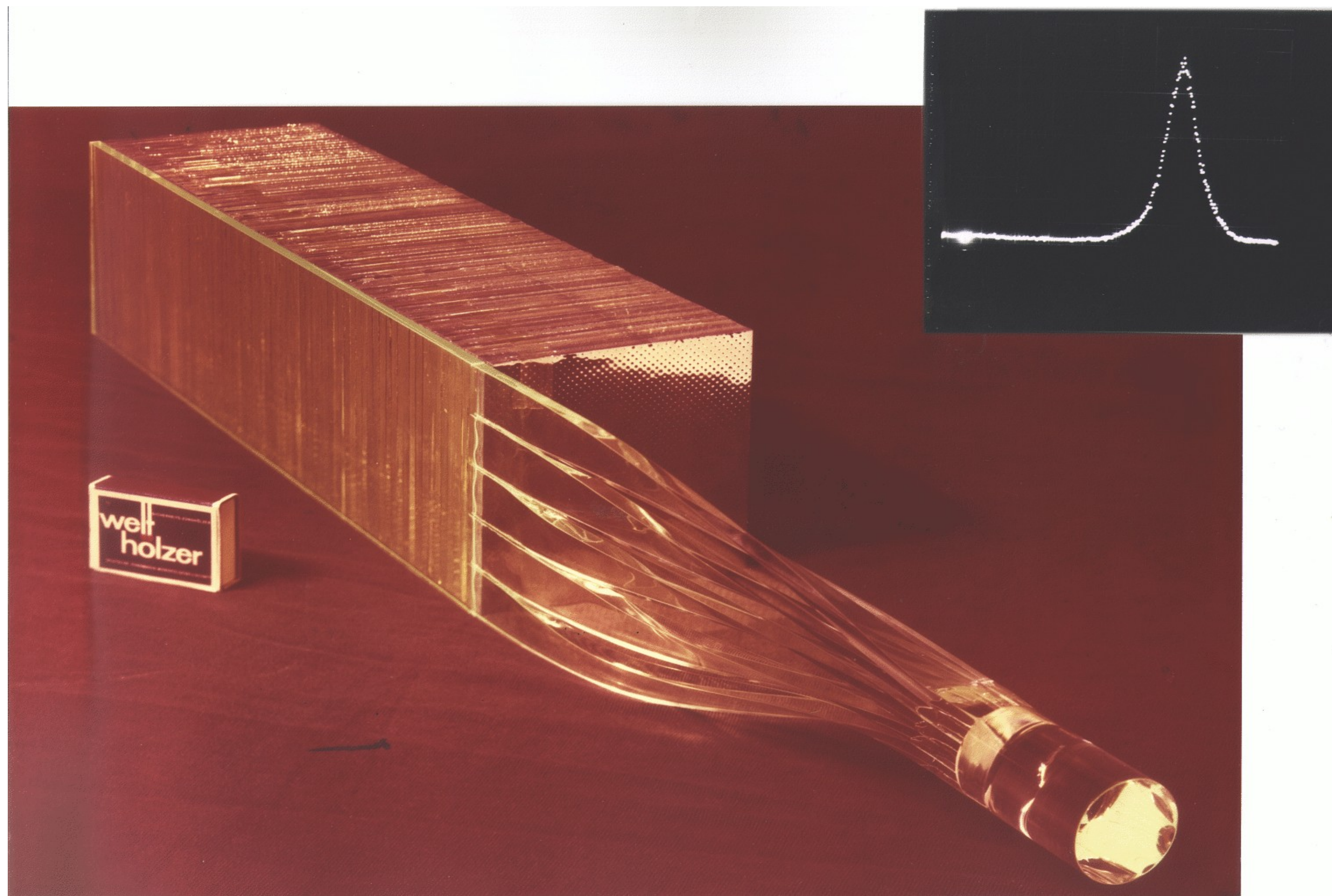
New shower counter with BBQ readout at DESY test beam

Atwood 9.2% at 1GeV

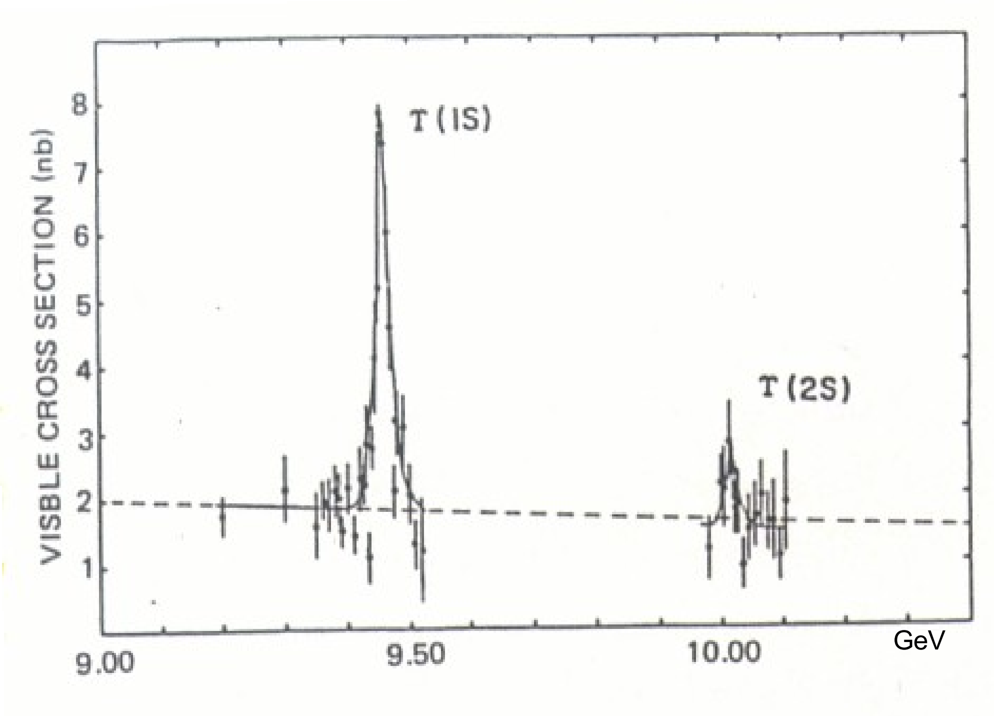
found 7.5% at 1GeV

marvelous

Can be used before coil



1978 DASP2



Energy upgraded DORIS single ring

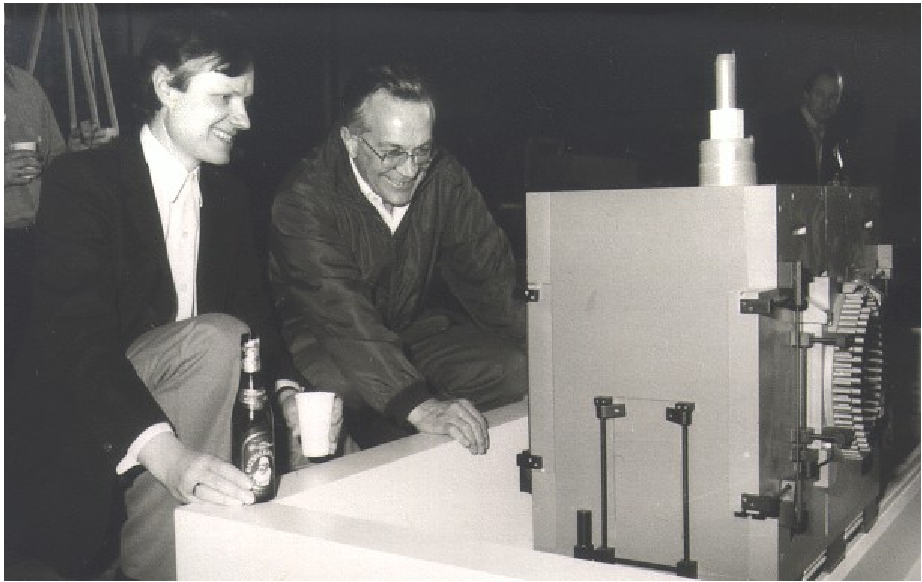
Collaboration

Results

Forming a Collaboration
by personal contacts

- D. Wegener, Dortmund — met at Göttingen and then at Karlsruhe. was my spokesman at DESY F23.
- K. Schubert, Heidelberg — met in CHOV at CERN
- L. Jönsson, Lund — G. Weber had worked with G. v. Dardel
- ITEP Moscow — H. Schopper had worked in Russia
- C. Darden, S. Carolina — had married a german wife

G. Weber



These 5 Institutes submitted

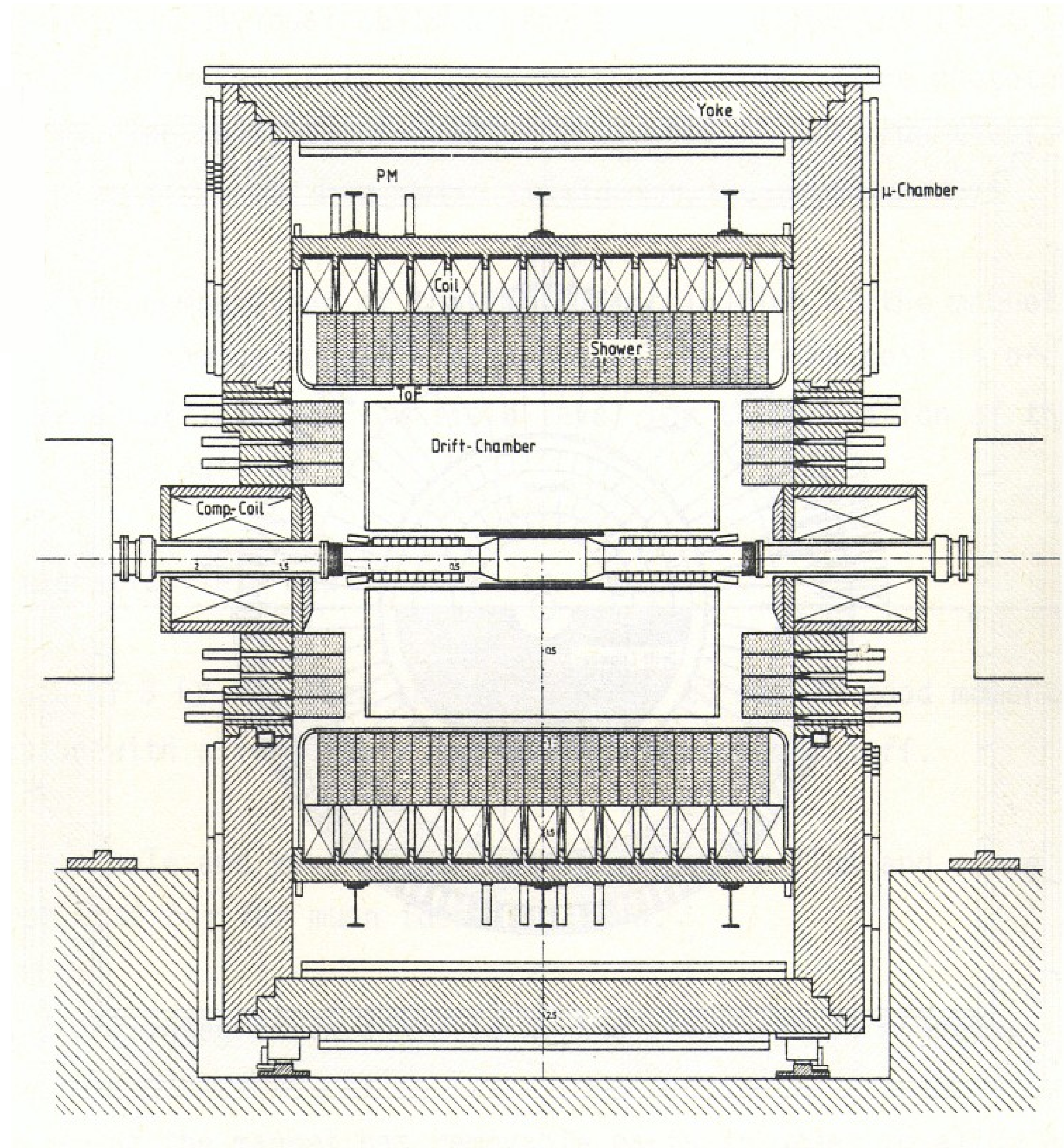
the ARGUS Proposal in Oct 1978

Oct 1978 ARGUS Proposal Version

Betr.: Beschlußfassung des Direktoriums vom 5.7.1979 Nr. 344

3. Genehmigung des Vorhabens "Bau des ARGUS-Detektors"

Nach ausführlicher Diskussion genehmigt das Direktorium das Vorhaben "Bau des ARGUS-Detektors" mit folgenden Maßgaben über die Kosten der einzelnen Teilaufgaben:



The larger the better but must fit into pit

- New Driftchamber

New Driftchamber Design

Use full gas volume at normal pressure

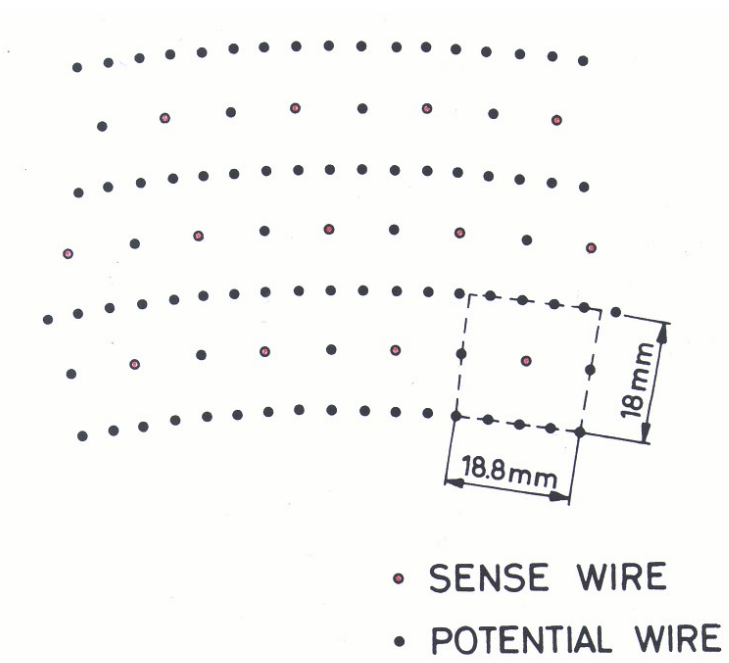
quadratic cells, size optimized for dE/dx

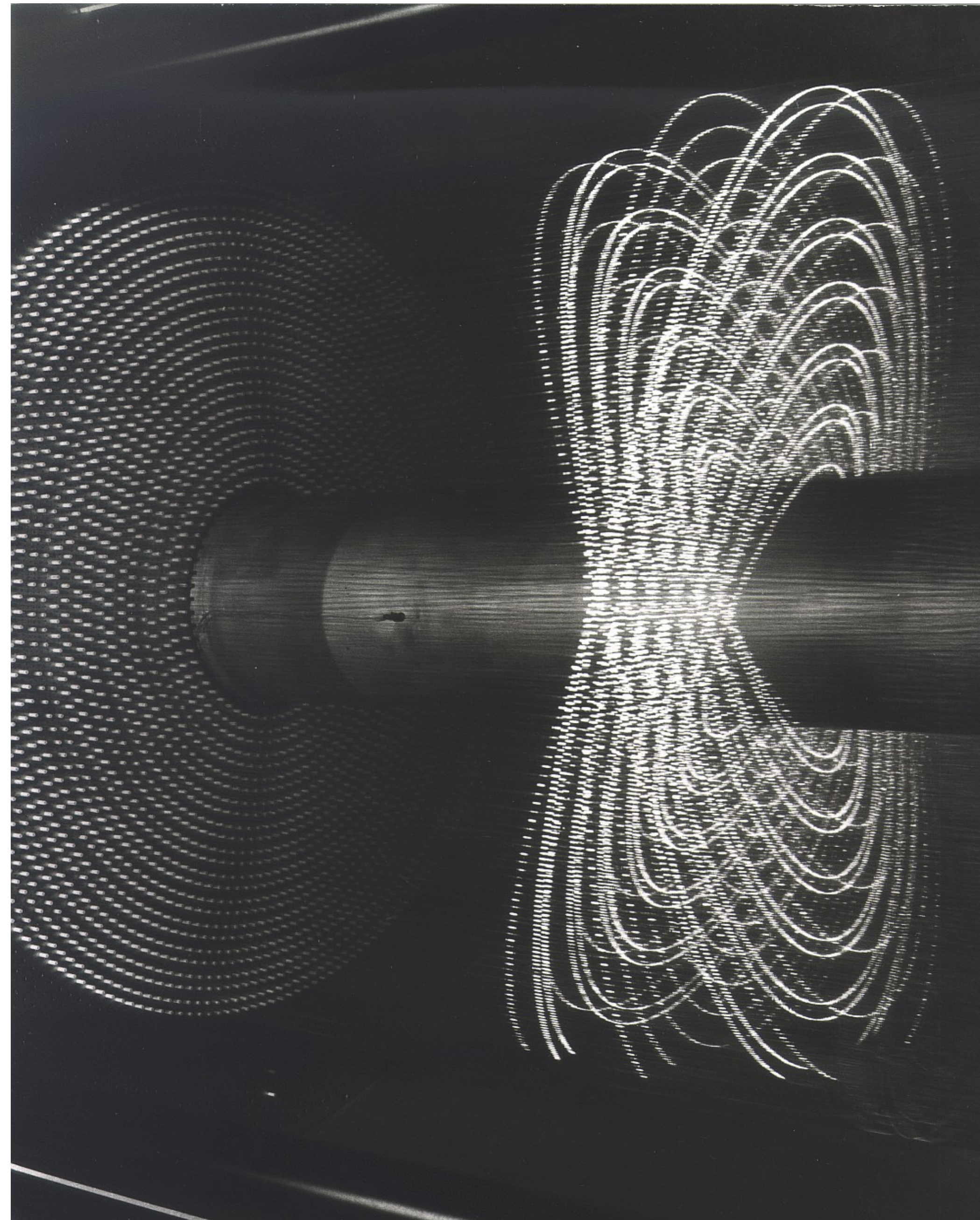
3 stereo views, 36 inclined layers

5940 sense wires

24588 potential wires

single hit electronics





Enlarging the Collaboration

- N. Kwak , Kansas had worked with CHOV at CERN

  R. Ammar, R. Davis

- P.Patel, T. S. Yoon Montreal

  J. Prentice, W. Frisken Toronto interested in HERA

  K. Edwards Ottawa

- G. Kernel, Ljubljana knew V. Sörgel
- H. Wegener, Erlangen

Finally about 80 Scientists

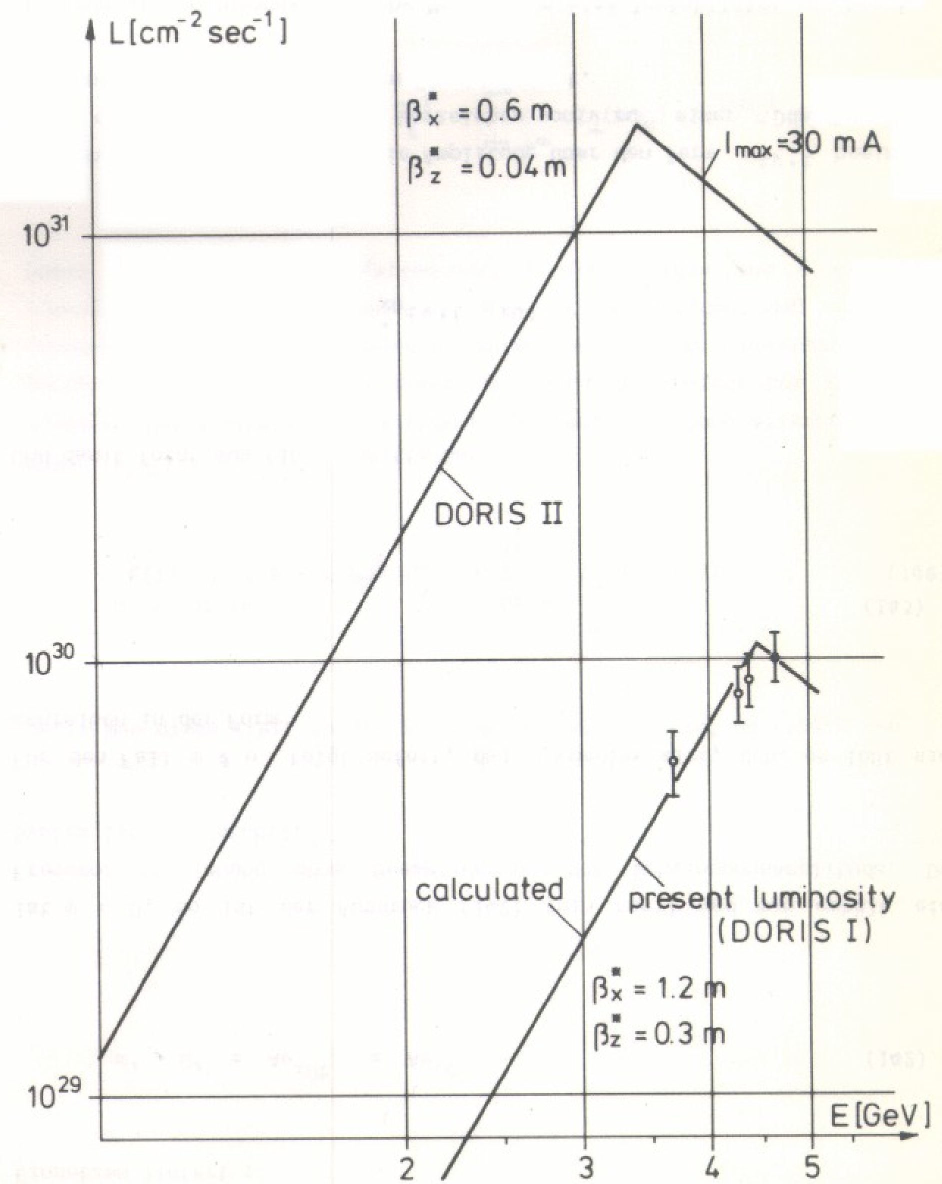
No Committees, no boards, no panels, but a lot fun

Unusual collection of brilliant people

1980

DORIS II , AN e^+-e^- STORAGE RING WITH MINI BETA SECTIO

H. Nesemann, J. Susta, F. Wedtstein, K. Wille
Deutsches Elektronen-Synchrotron DESY, Hamburg, Germany



Luminosity of DORIS II

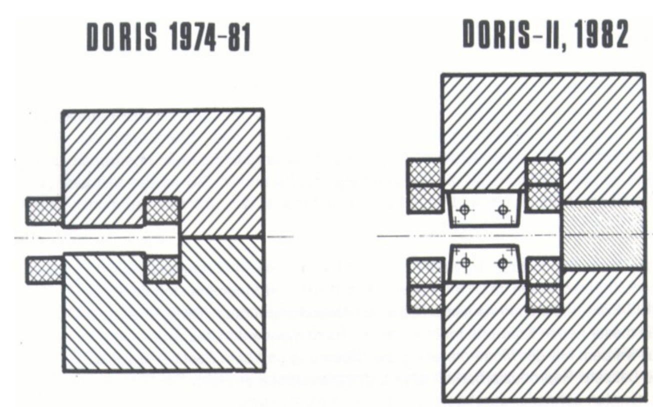
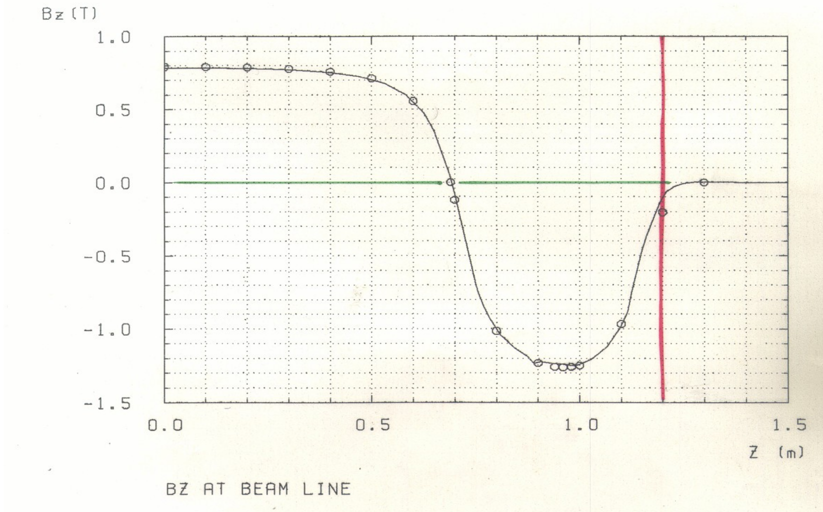
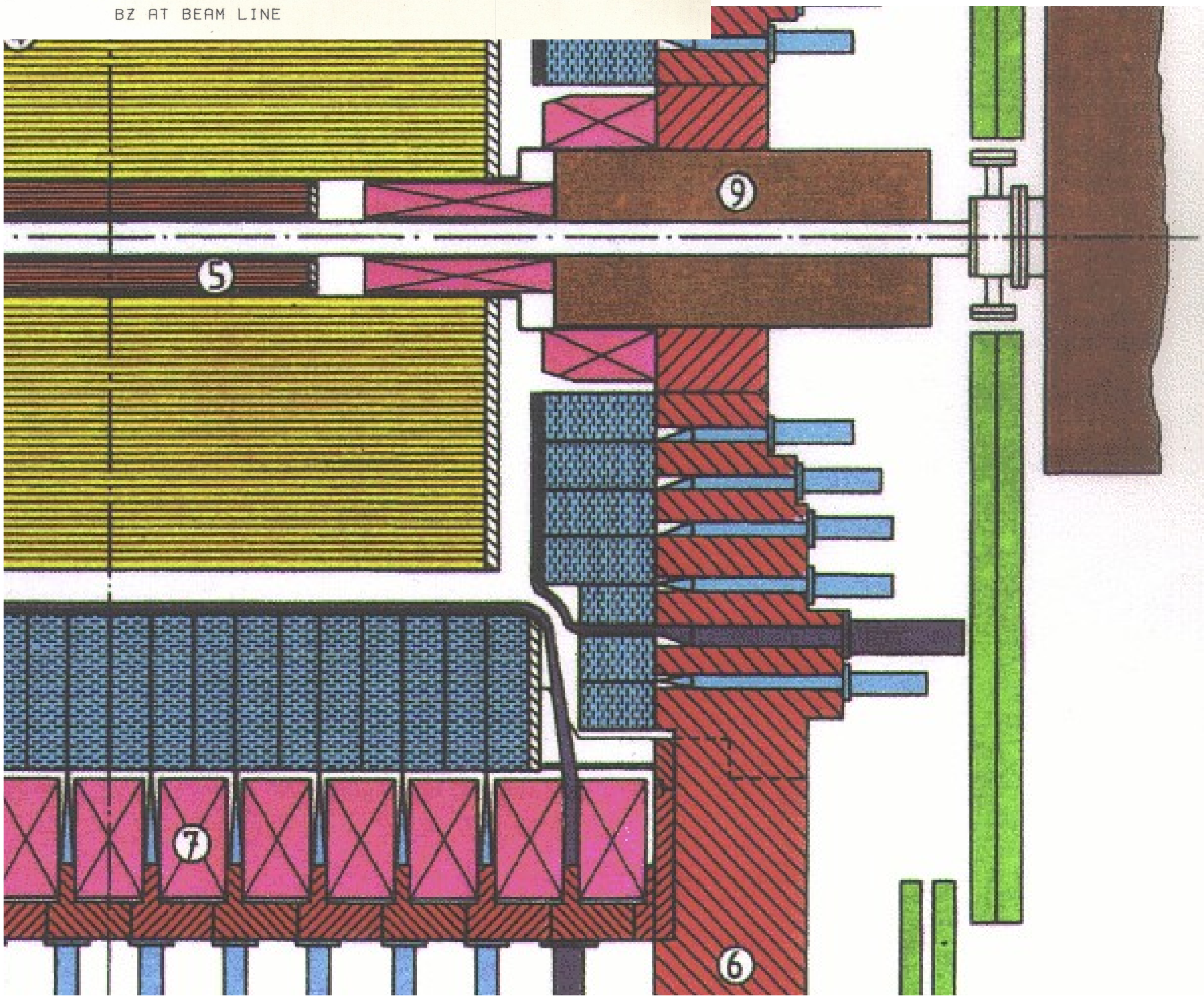


Abb. 78: Verkleinerung der Magnetapertur für DORIS II.

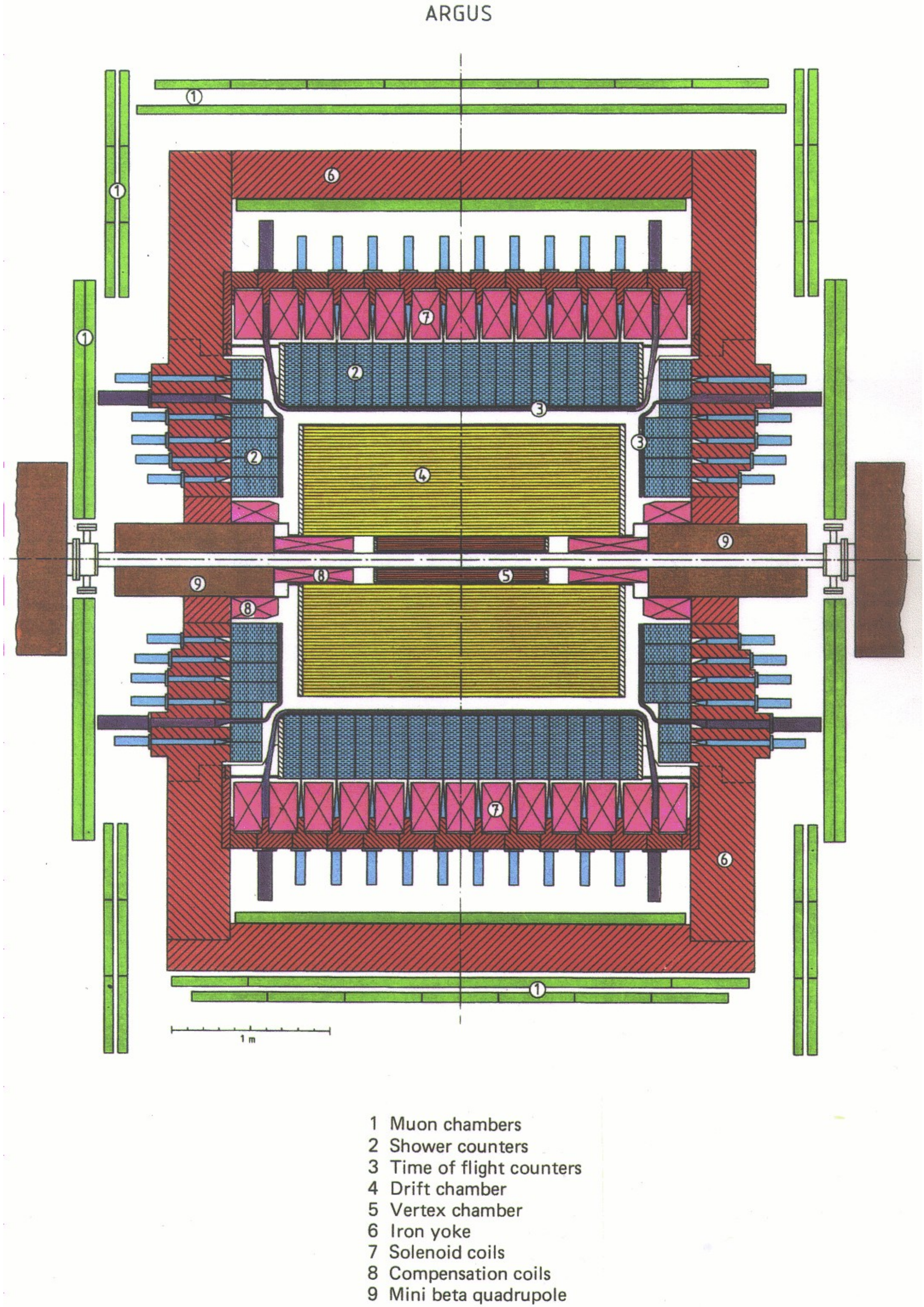
Integrated mini beta quads



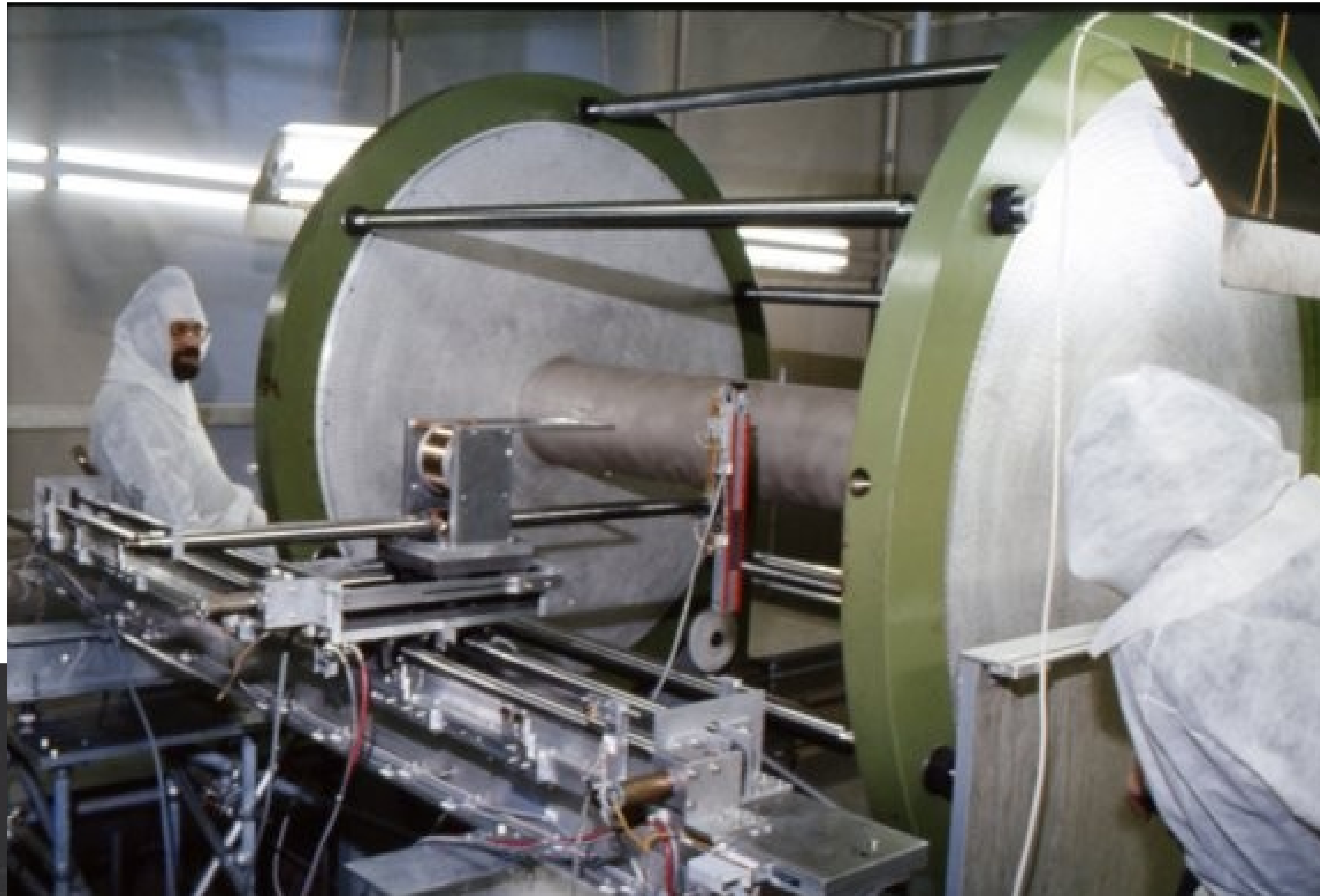


Final Layout

Worlds best Detector Concept at that time



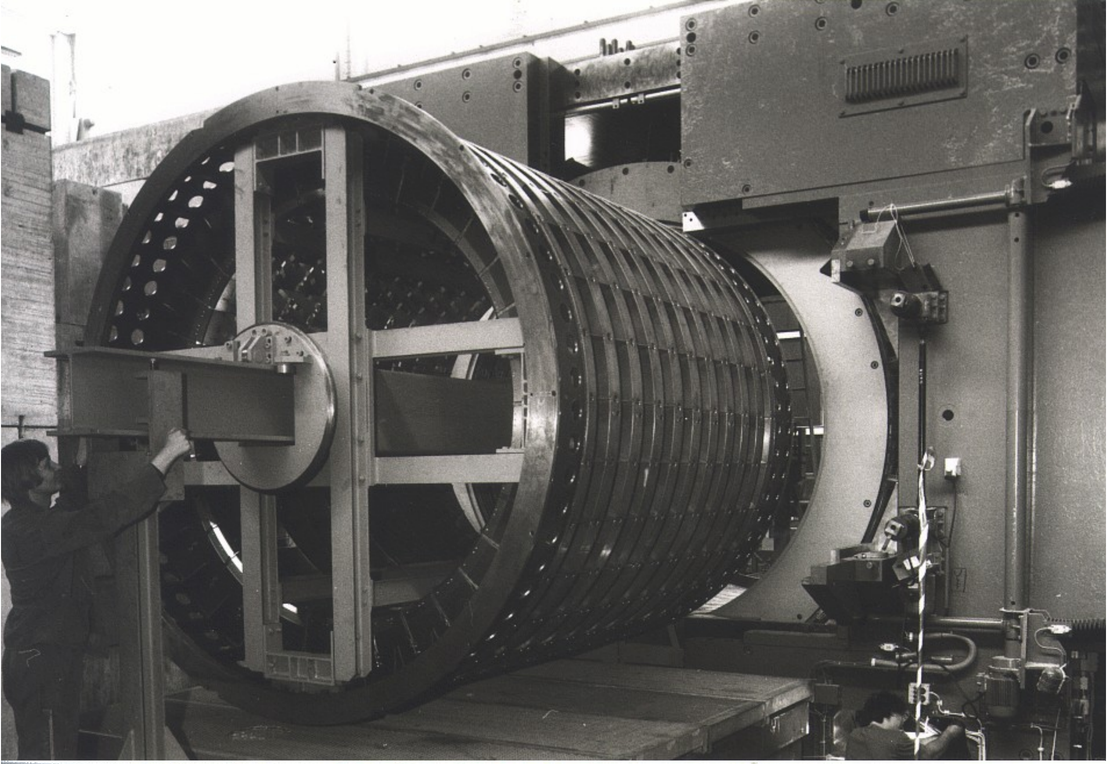
E. Michel   Driftchamber construction

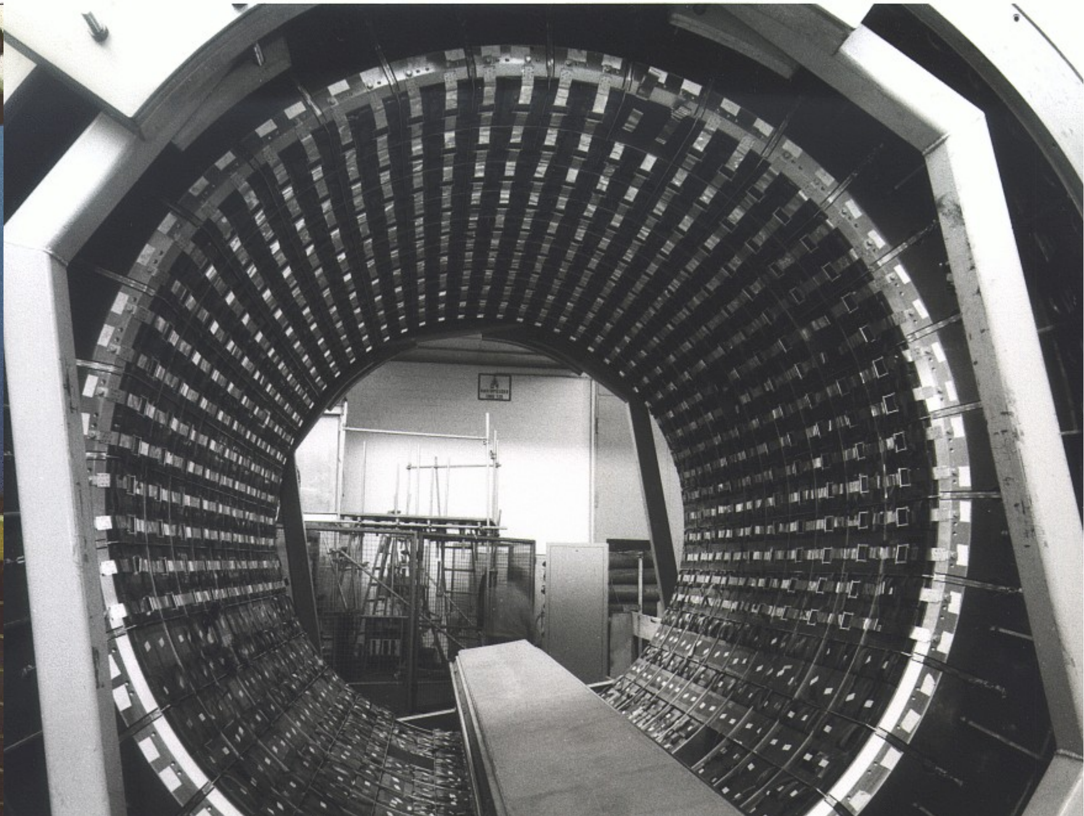


Endplates by Kockums, Malmö

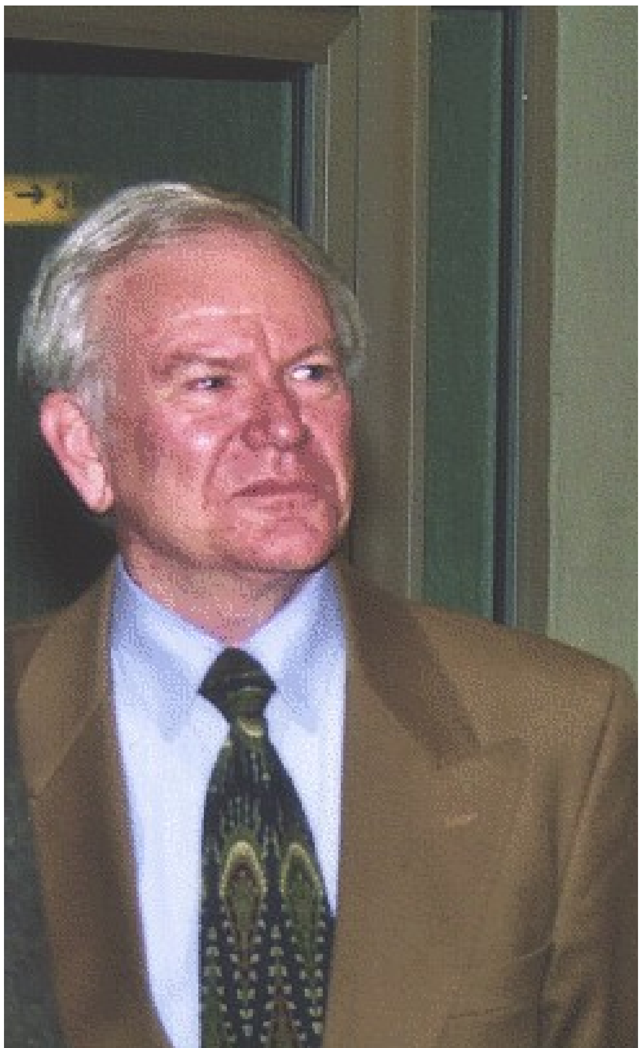
Showercounters
1280 barrel   480 endcaps

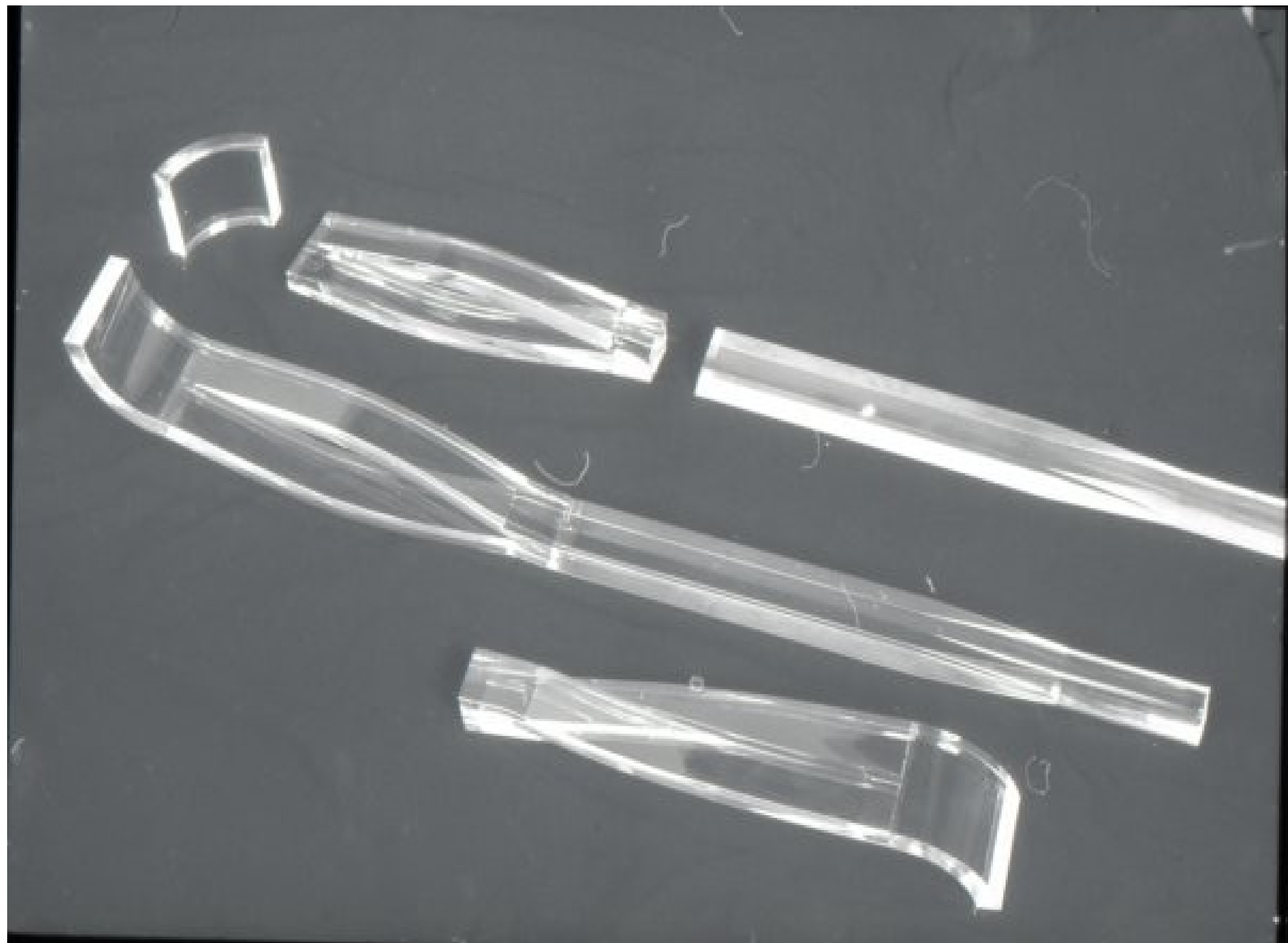
Installing the Shower-counters





Time of Flight Counters
64 barrel 48 endcaps





Muon Chambers

ITEP Moscow

1744 channels

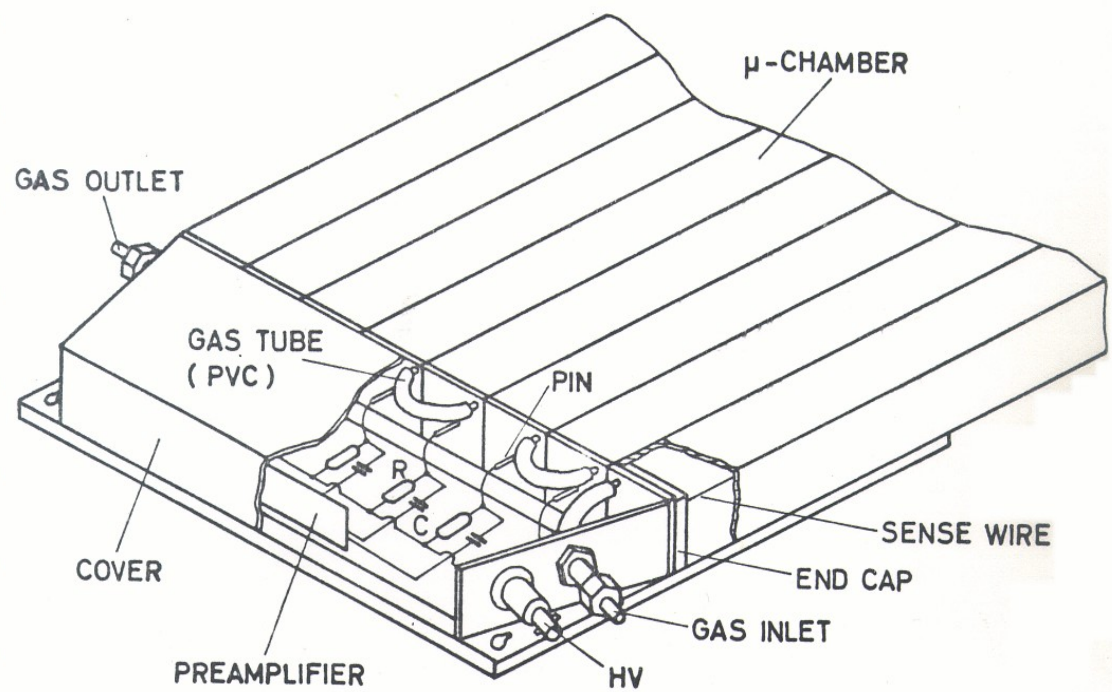
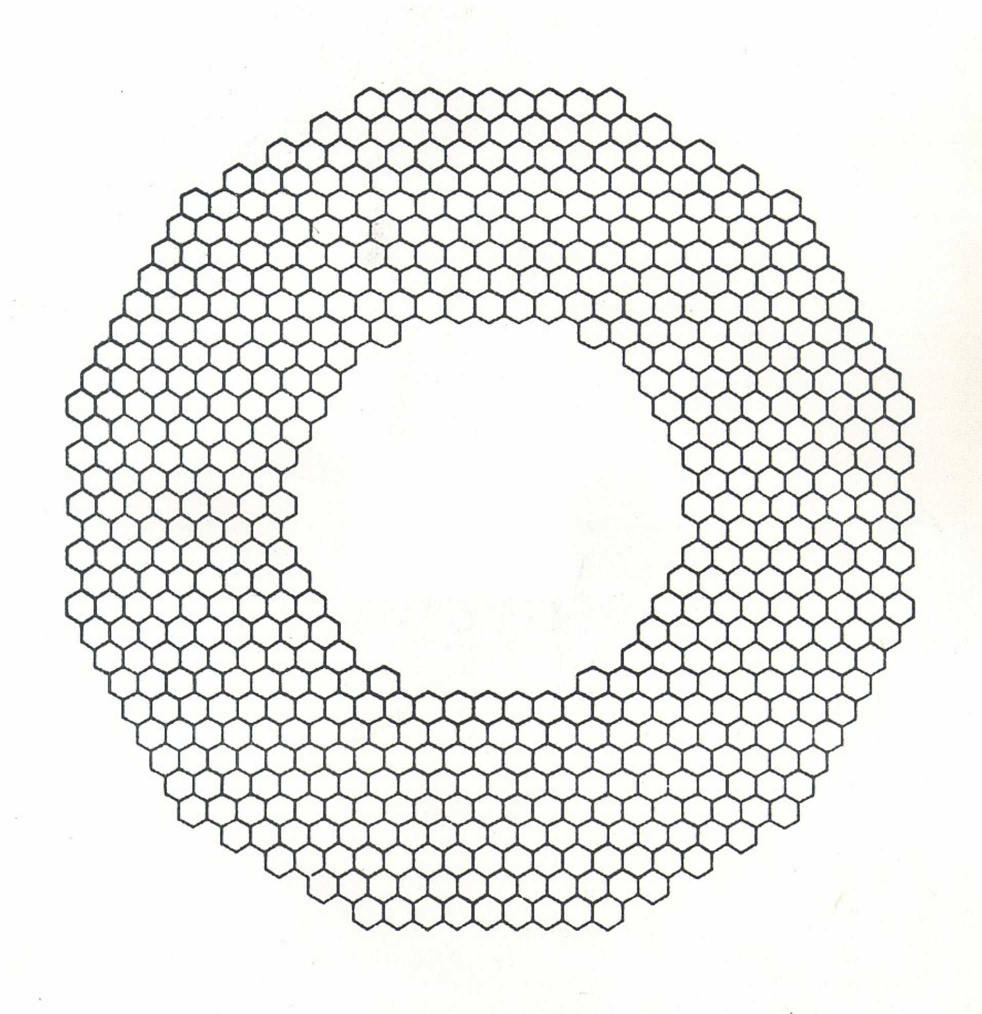


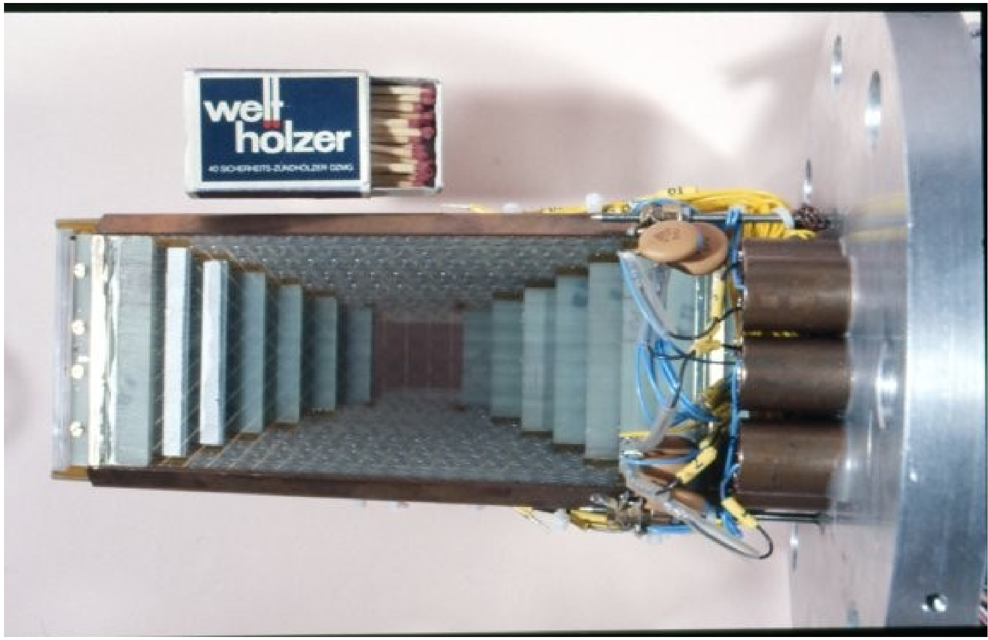
FIG. 2

Vertex Chamber

IPP Canada

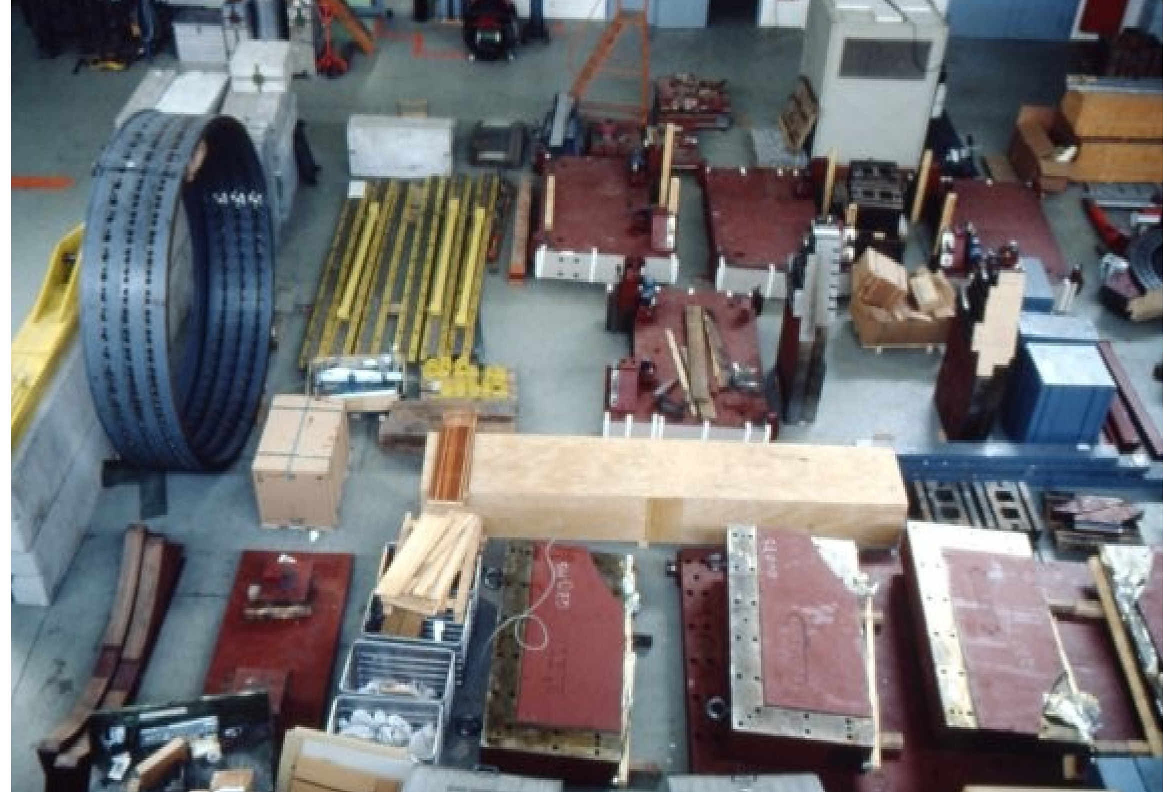
3 Versions



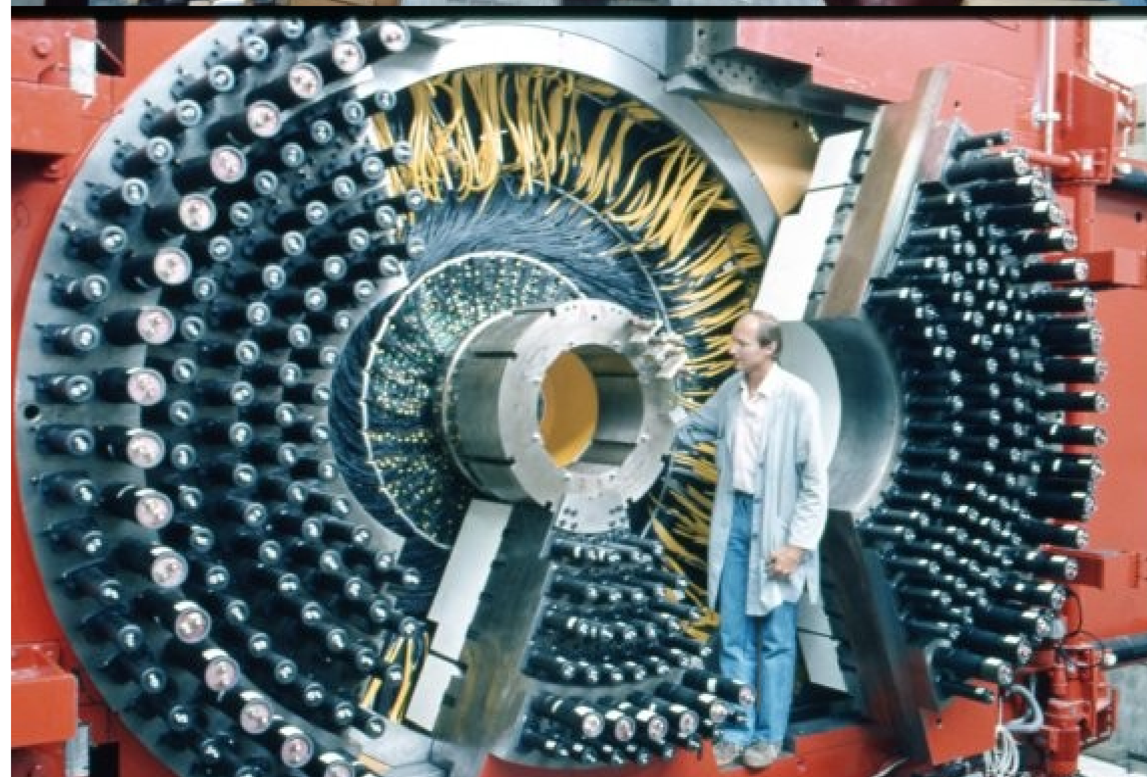


Magnet

before



after



Commissioning

Each institute delivered its detector component, fulfilling all specifications

dE/dx = ToF

Detector works reliably

component	property	value
drift chamber	# channels	5940 TDCs and ADCs
	acceptance for minimal tracks	$\lvert\cos\theta\rvert < 0.96$
	acceptance for full tracks	$\lvert\cos\theta\rvert < 0.76$
	minimal p_T	30 MeV/c
	momentum resolution	$\sigma(p_T)/p_T = \sqrt{0.01^2 + (0.009 \cdot p_T[\mathrm{GeV}/c])^2}$
	dE/dx resolution	$\sigma(dE/dx)/(dE/dx) = 4.5\text{–}5.5\,\%$
vertex drift chamber	# channels	594 TDCs
	acceptance for full tracks	$\lvert\cos\theta\rvert < 0.95$
	momentum resolution if used together with DC	$\sigma(p_T)/p_T = \sqrt{0.01^2 + (0.006 \cdot p_T[\mathrm{GeV}/c])^2}$
TOF counters	# channels, barrel	128 TDCs and ADCs
	# channels, endcap	96 TDCs and ADCs
	acceptance, barrel	$\lvert\cos\theta\rvert < 0.75$
	acceptance, endcap	$0.78 < \lvert\cos\theta\rvert < 0.95$
	time resolution	$\sigma(TOF) = 220$ ps
shower counters	# channels, barrel	1280 ADCs
	# channels, endcap	480 ADCs
	acceptance, barrel	$\lvert\cos\theta\rvert < 0.75$
	acceptance, endcap	$0.7 < \lvert\cos\theta\rvert < 0.96$
	cutoff energy	50 MeV
	energy resolution, barrel	$\sigma(E)/E = \sqrt{0.072^2 + 0.065^2/E[\mathrm{GeV}]}$
	energy resolution, endcap	$\sigma(E)/E = \sqrt{0.075^2 + 0.076^2/E[\mathrm{GeV}]}$
	spatial resolution, barrel	13 mrad at 5 GeV 24 mrad at 0.5 GeV
μ chambers	# channels	1744
	acceptance, inner layer	$0.43 \times 4\pi$
	acceptance, outer layer	$0.87 \times 4\pi$

Table 2.1: Summary of detector components

Crystal Ball

Workshop
on DORIS experiments

DEUTSCHES ELEKTRONEN-SYNCHROTRON DESY HAMBURG

held at DESY, Hamburg, Germany, 10–11 February 1981

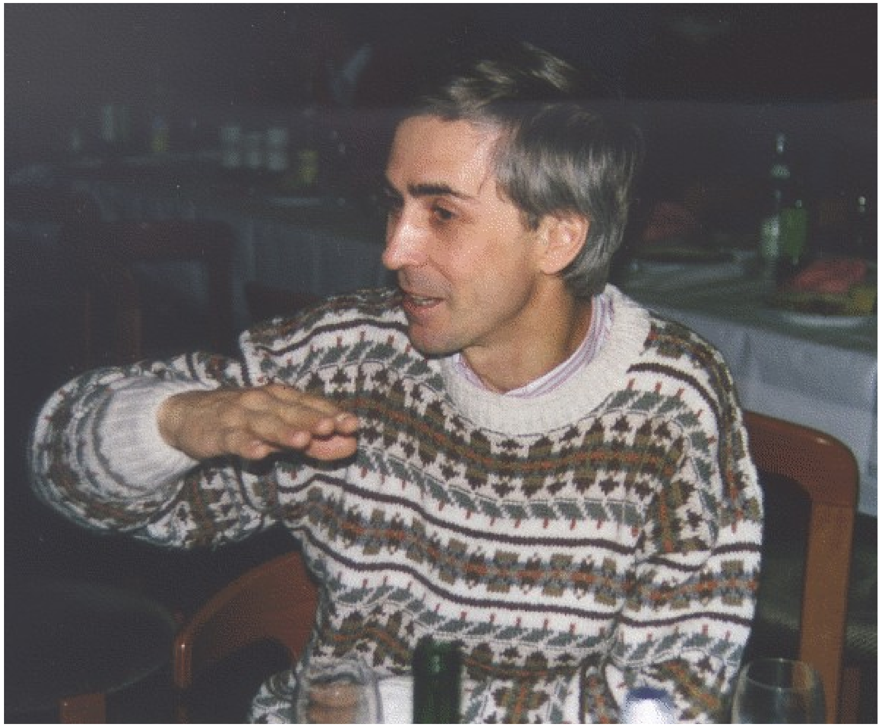
E. Bloom announced that the Crystal Ball would be moved from SLAC to DESY, if DORIS would be upgraded.

Then DORIS was essentially rebuilt using existing components and reached the expected high performance.

Abb. 7.1: Die Ankunft des Crystal Ball-Detektors am Frankfurt/Main Flugplatz.

1982 First Beam
Too high Background for ARGUS

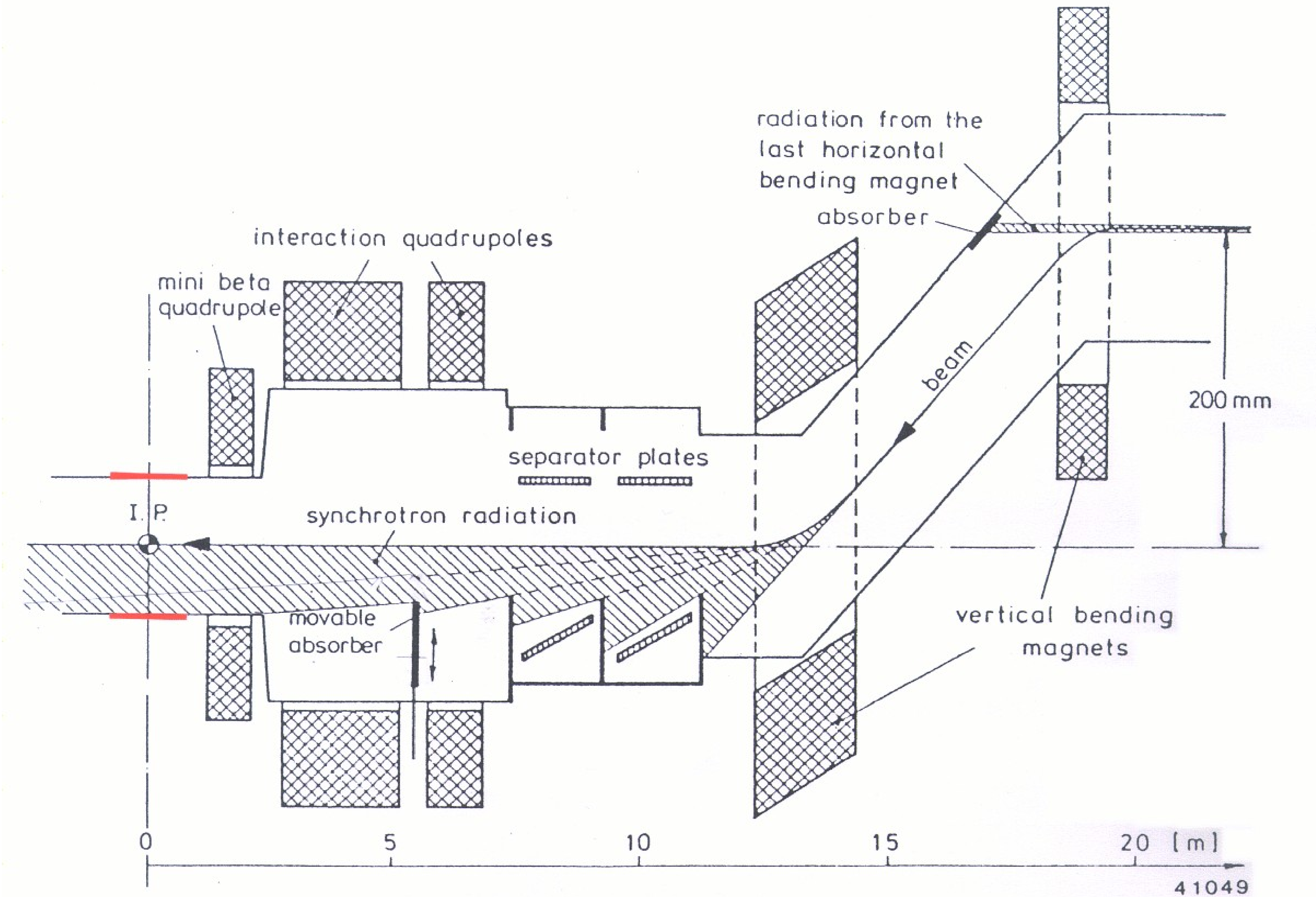
- Sörgel: "I want to give Crystal Ball the opportunity for a quick success. If you cannot run, that is your problem. You do not get any time for machine development in order not to disturb Crystal Ball."



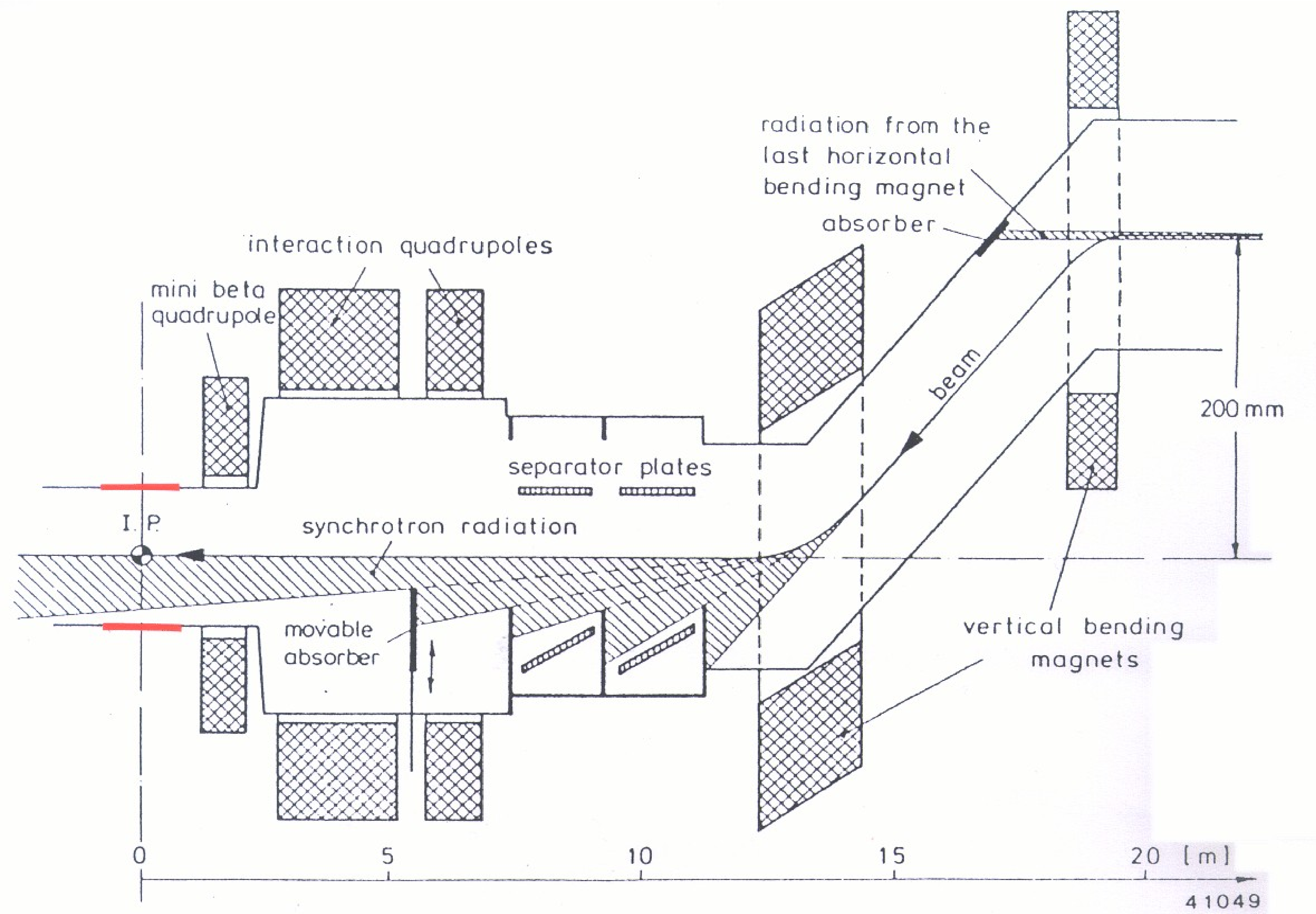
- Danilov: "This is completely un-acceptable. We have to do something."

Three conspiring nights

Synchrotron Radiation



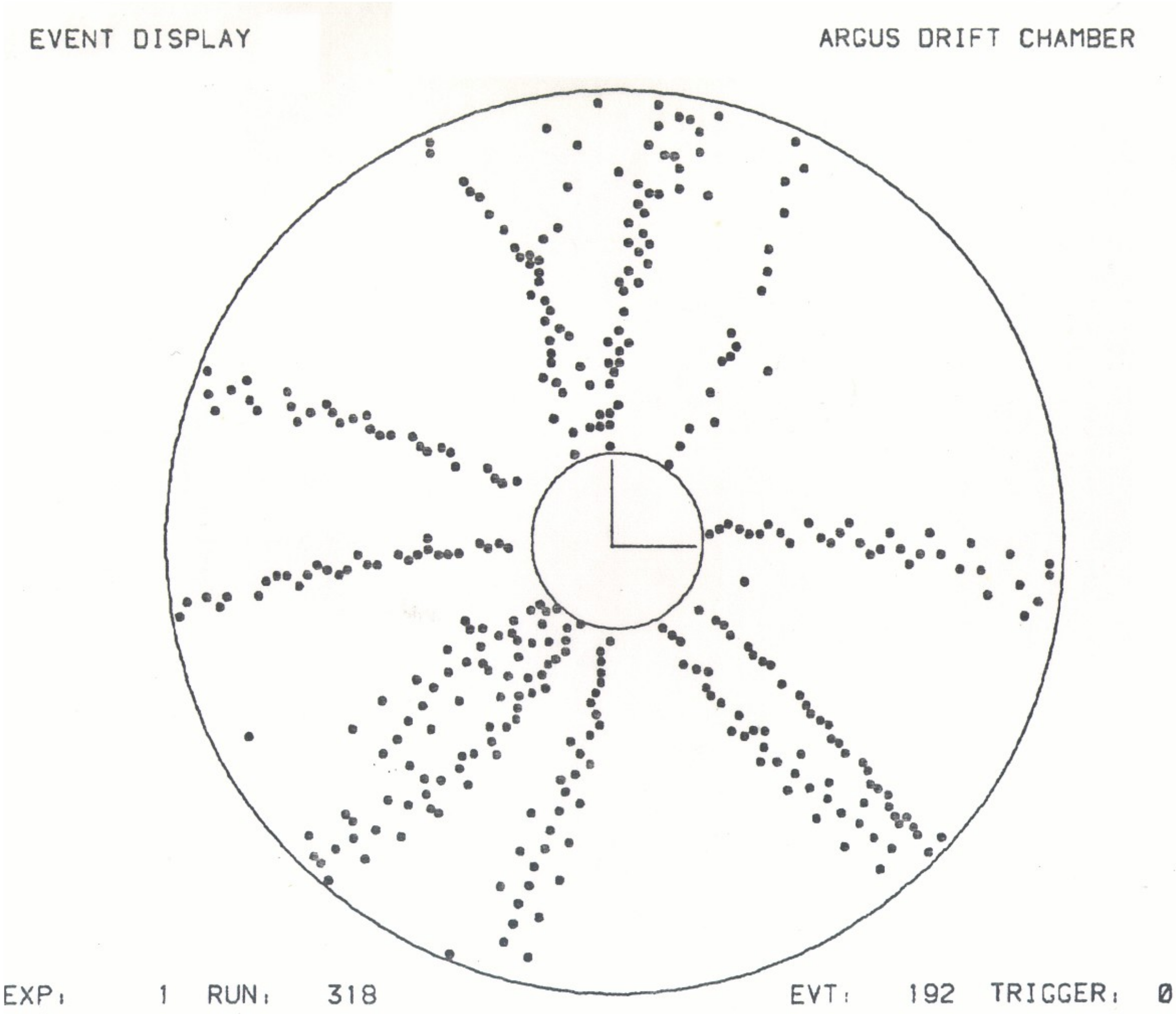
Synchrotron Radiation



One of the first events

Perfect and clean

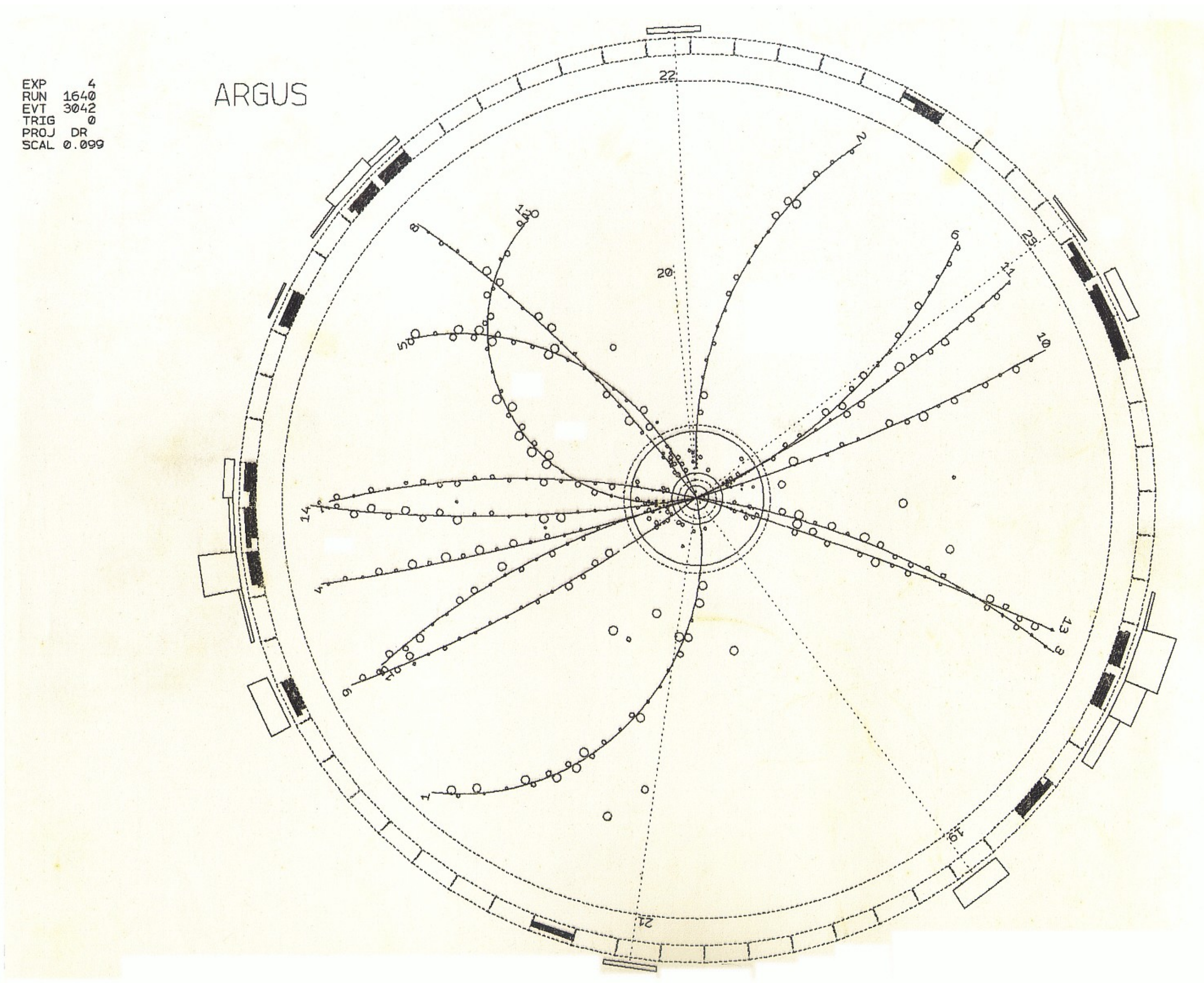
Ready to do good physics



Just happy

(Party)

Typical Event



Analysis Language

H. Albrecht had impressed me by rewriting the

DASP software.   Hired him.

He wrote the ARGUS off-line software.

He wrote a user surface KAL.

Could be used by everybody and was bug-free

Could be used for any physics analysis.

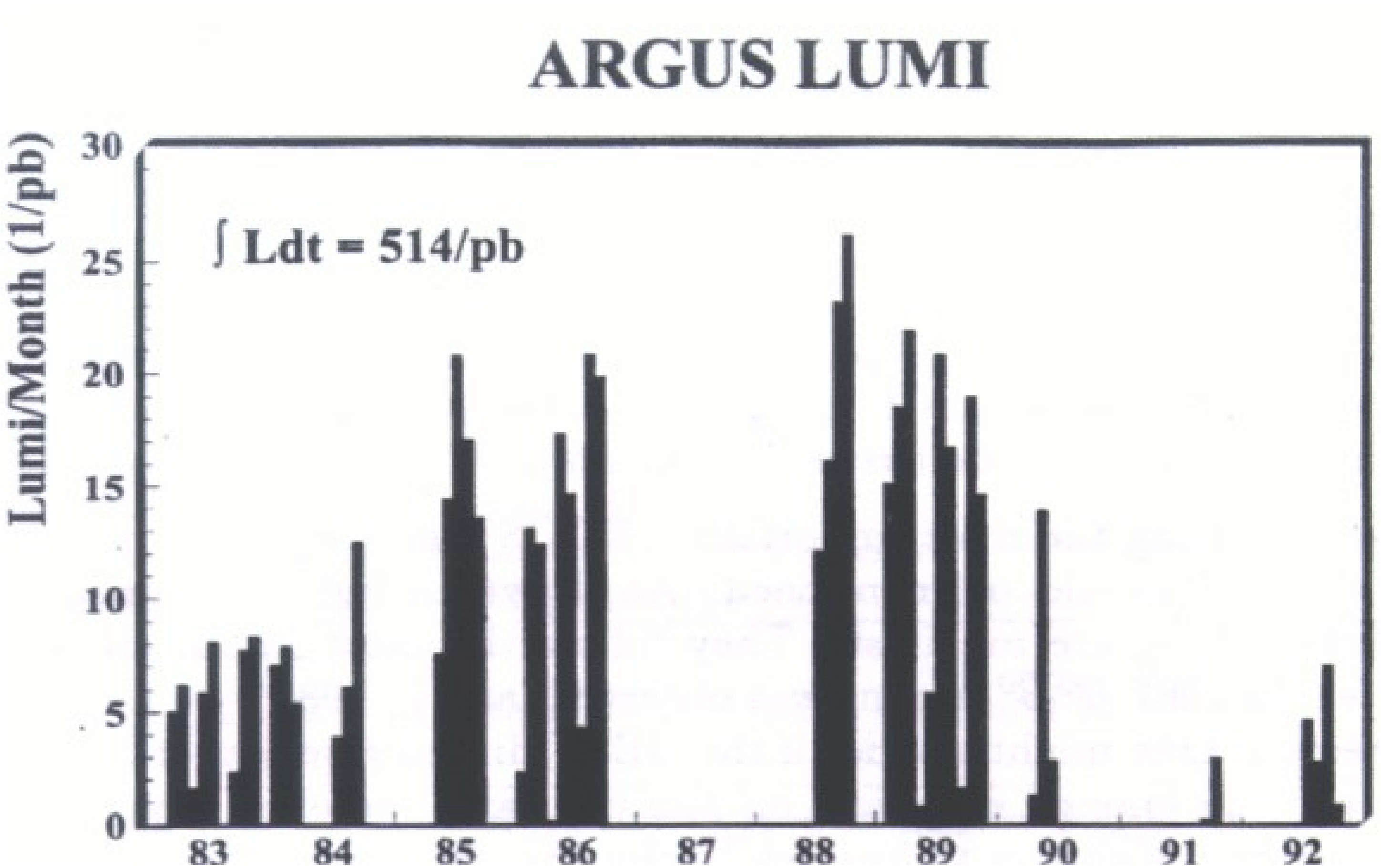
Was also imported by ALEPH

Software was still improved by a students initiative

Reliable results

DESY second class activity

Outside world class physics



Talks 8 6 53 76 105 75 71 102 96 104 49

Excellent spirit inside ARGUS

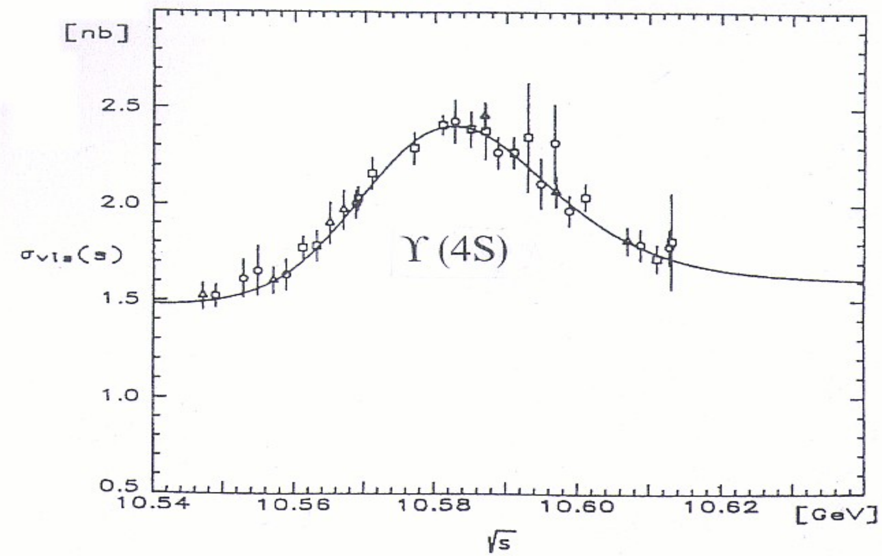
Fascination to see new physics for the first time

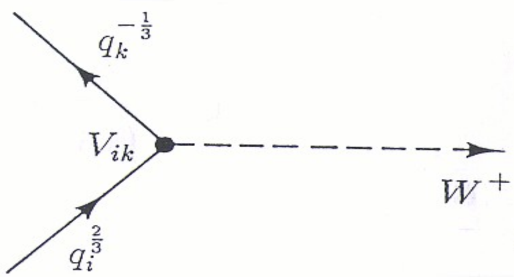
Like a Drug Fantastic pleasure

Weak interaction physics on the Y(4S)

$$e^+e^- \to \Upsilon(4S) \to B^0\overline{B}^0 \text{ or } B^+B^-$$

$$\overline{b}b \rightarrow \overline{b}d \quad \overline{d}b \text{ or } \overline{b}u \quad \overline{u}b$$





$k = d,\ s,\ b$

$i = u,\ c,\ t$

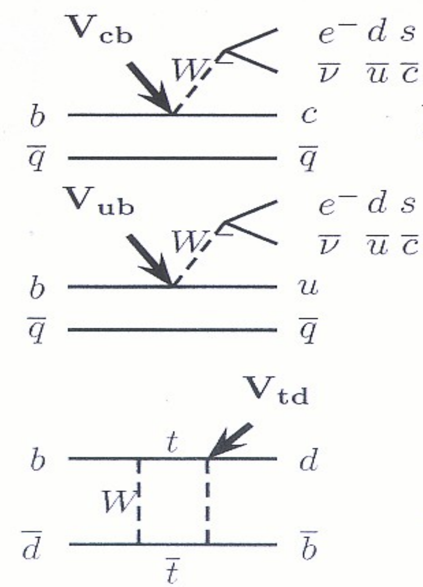
$$V_{ik} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

V_{ub} — b → u Transition

V_{cb} — B Lifetime

V_{td}, V_{ts}: $B^\circ \overline{B}^\circ$ $B_s \overline{B}_s$ – Mixing

CKM Matrix V_{CKM}

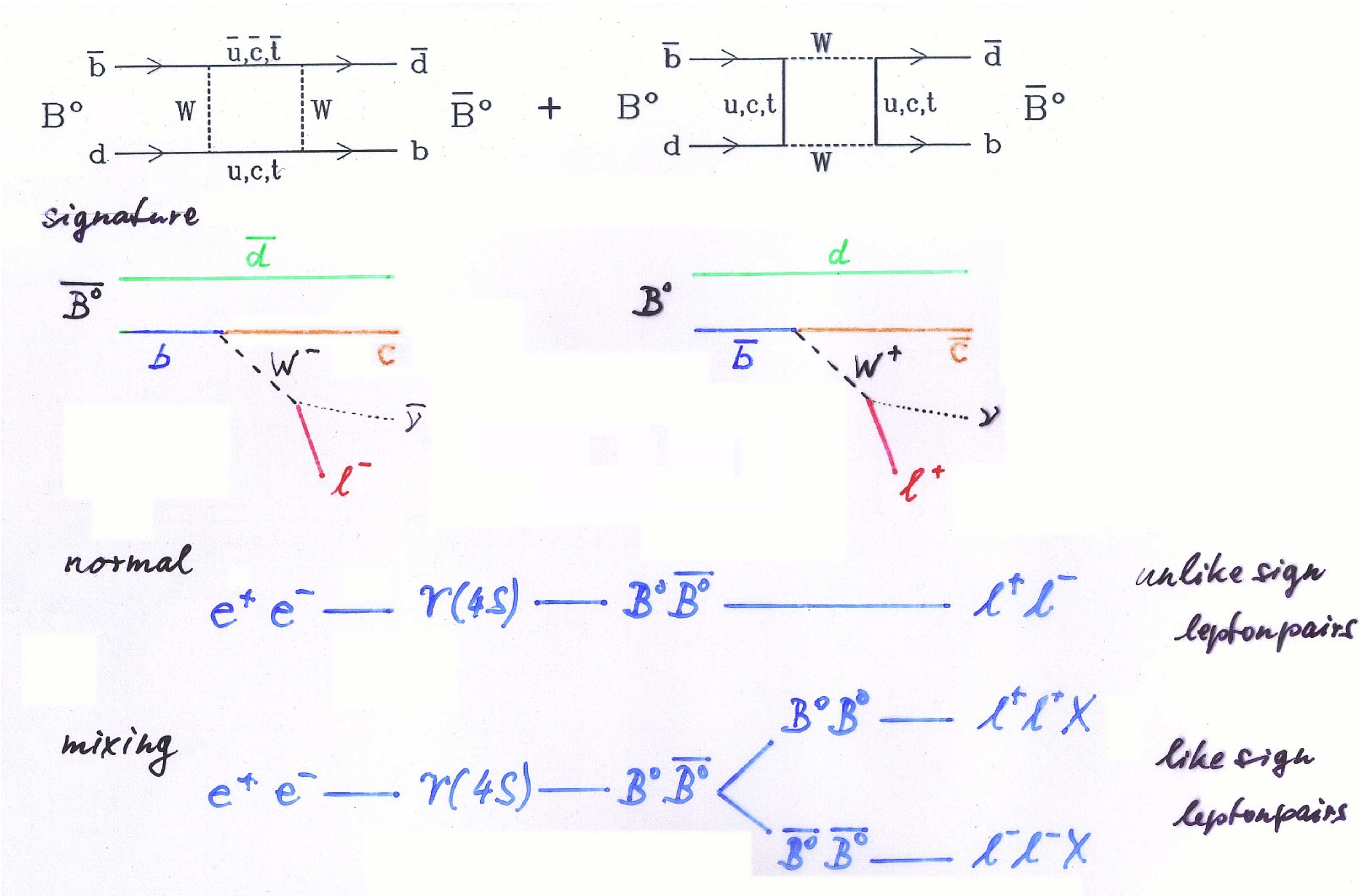


$\overline{B}^0 \to D^{*+}\ell^-\overline{\nu}$ 87

$\overline{B}^0 \to \pi^+\ell^-\overline{\nu}$ 89

$B^0\overline{B}^0 Mixing$ 87

B - Mixing


b̄
ū,c̄,t̄
d̄
B°
W
W
B̄°
d
u,c,t
b
+
b̄
W
d̄
B°
u,c,t
u,c,t
B̄°
d
W
b
signature
B̄°
d̄
b
W⁻
c
ν̄
ℓ⁻
B°
d
b̄
W⁺
c̄
ν
ℓ⁺
normal
e⁺ e⁻ — Υ(4S) — B°B̄° — ℓ⁺ℓ⁻
unlike sign leptonpairs
mixing
e⁺ e⁻ — Υ(4S) — B°B̄°
B°B° — ℓ⁺ℓ⁺X
B̄°B̄° — ℓ⁻ℓ⁻X
like sign leptonpairs

Dirty hadron collider

First evidence for $B\bar{B}$ mixing came from UA1:

- Studied dilepton events
- Measured $\chi_b = 0.121 \pm 0.047$
- Generally interpreted as $B_s^0\bar{B}_s^0$ mixing
- Was not a great surprise

Clean e+e- collider

	L $\Upsilon(4S)$ $[pb^{-1}]$	$\sigma_{vis}\,\Upsilon(4S)$ $[nb]$	n_B $[10^3]$
DORIS	103	0.85	176
CESR	118	1.11	263

Table 1: The 1987 B-Meson data Base

Early attempts

Lepton pairs

Since ITEP had the experts on leptons,

I had asked a student from ITEP to look into like-sign lepton pairs.

- Theorists say: “It is very interesting but you will see nothing.”

The student arrived at “nothing”. (Just to please me)

Because CLEO had recently published a limit on B-mixing,

also ARGUS published a “better” limit based on this “nothing”.

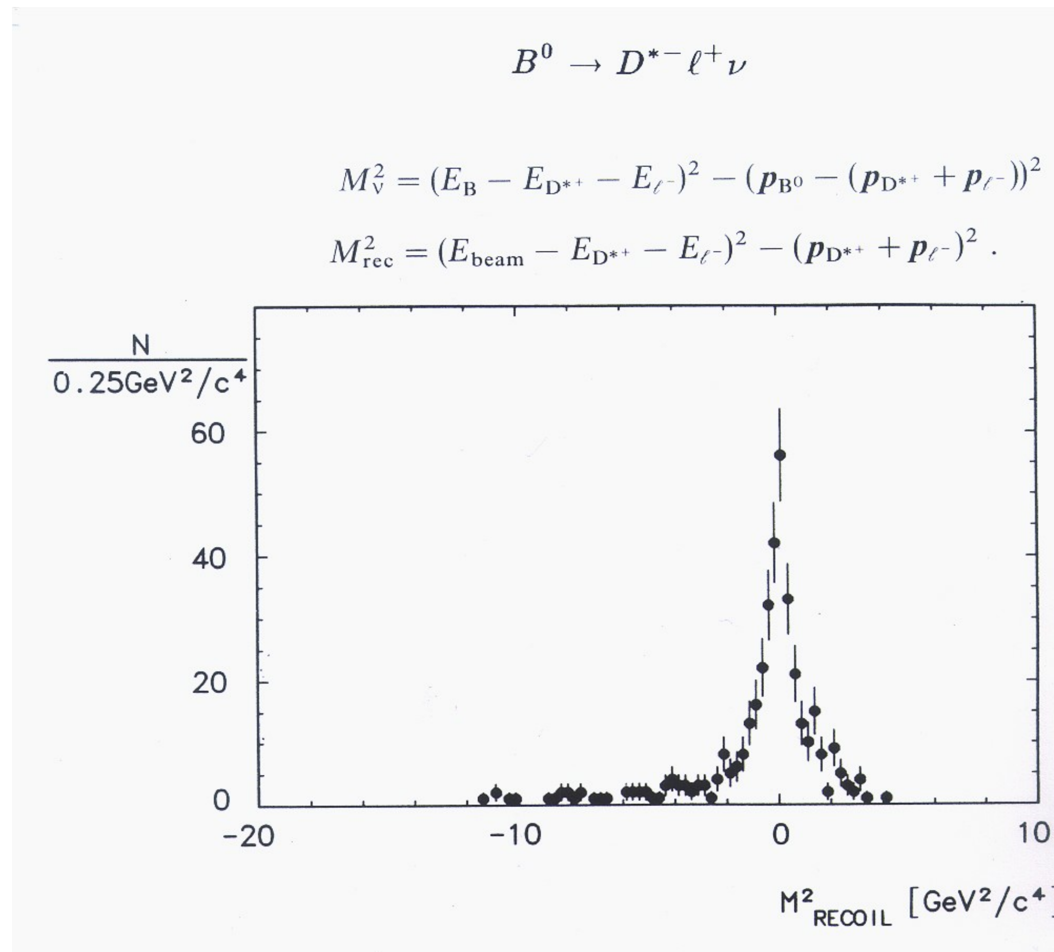
(Sent the paper to Physics Letters)

Early attempts

Reconstructed B-mesons

H.Schröder had found a method to reconstruct semileptonic B-decays with an invisible neutrino.

He had a thick folder with all these events printed out.



He showed me some events, having the signature of B-mixing.

Still too low statistics for a quantitative result.

First Evidence

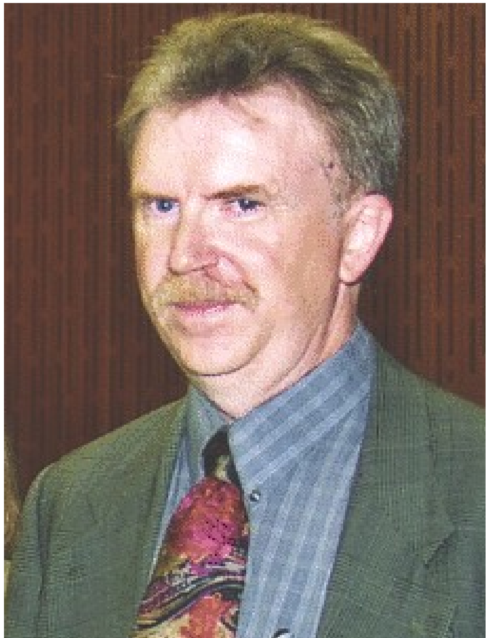
more data and reprocessing

Huge mixing signal

Lepton pairs

Reconstructed

B Mesons



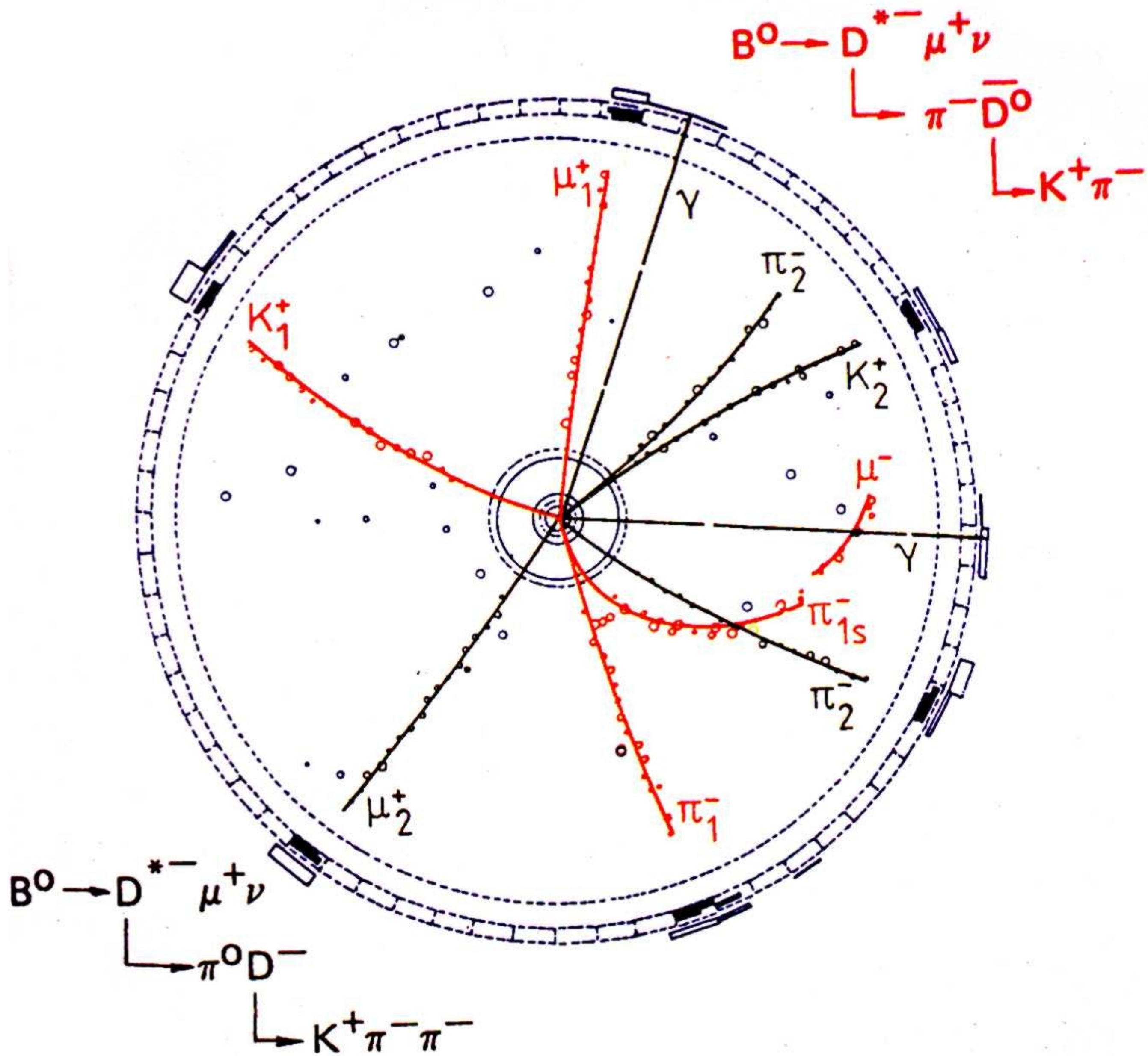
Background and fake

Withdraw wrong paper

The golden Event

Henning Schröder

	expected	found
unmixed	1.5	0
mixed	0.3	1



The final result

Zaitsev

Schröder

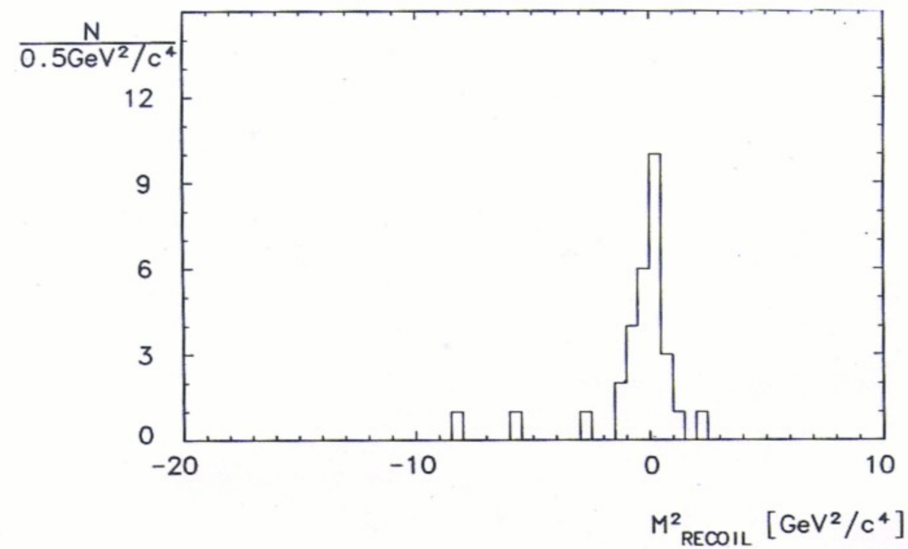
The mixing parameter r

$$r = \frac{N(B^0B^0) + N(\overline{B}^0\overline{B}^0)}{N(B^0\overline{B}^0)} = \frac{N(\ell^+\ell^+) + N(\ell^-\ell^-)}{N(\ell^+\ell^-) - 0.5\,N(\ell\ \ \ell\ \ )}$$

like-sign lepton pairs	$e^\pm e^\pm$	$\mu^\pm\mu^\pm$	$e^\pm\mu^\pm$
Dilepton candidates			
$\Upsilon(4S)$ + Continuum	8	16	26
Continuum	0	0	0
$\Upsilon(4S)$ direct	8.0 ± 3.9	16.0 ± 4.8	26.0 ± 5.8
Background			
Fakes	0.7	5.7	4.9
Conversion	0.5	-	0.5
Secondary decays	2.3	2.9	4.6
J/ψ decays	0.7	0.9	1.5
Signal	$3.8 \pm 3.9 \pm 0.9$	$6.5 \pm 4.8 \pm 1.3$	$14.5 \pm 5.8 \pm 1.8$
unlike-sign lepton pairs	e^+e^-	$\mu^+\mu^-$	$e^\pm\mu^\mp$
Dilepton candidates			
$\Upsilon(4S)$ + Continuum	60	92	149
Continuum	3	1	2
$\Upsilon(4S)$ direct	52.6	89.5	144.1
Corrected for J/ψ cut	$58.5 \pm 9.8 \pm 1.6$	$99.6 \pm 11.3 \pm 2.5$	144.1 ± 12.4
Background			
Fakes	1.4	12.1	10.2
Conversion	0.5	-	0.5
Secondary decays	0.7	1.5	1.6
J/ψ decays	1.0	0.9	1.5
Signal	$54.9 \pm 9.8 \pm 1.6$	$85.1 \pm 11.3 \pm 3.1$	$130.3 \pm 12.4 \pm 1.8$
Mixing parameter r	$0.17 \pm 0.19 \pm 0.04$	$0.19 \pm 0.16 \pm 0.04$	$0.28 \pm 0.14 \pm 0.04$

Combined mixing parameter $r = 0.22 \pm 0.09 \pm 0.04$

$$B^0 \to D^{*-}\ell^+\nu$$



$$r = \frac{N(B^0\ell^+) + N(\overline{B}^0\ell^-)}{N(B^0\ell^-) + N(\overline{B}^0\ell^+)} = 0.20 \pm 0.12\ .$$

$$r = 0.21 \pm 0.08$$

Understand

Quantum mechanics
of the two-state system

mixing parameter

$$r = \frac{N(B^0 B^0) + N(\overline{B^0}\,\overline{B^0})}{N(B^0 \overline{B^0})}$$

transitions

$B^0 \longleftrightarrow \overline{B^0}$

mass

$B^0, \overline{B^0}$ $\qquad$ $\frac{1}{\sqrt{2}}(B^0 \pm \overline{B^0})$

M $\qquad\qquad$ ΔM

time evolution

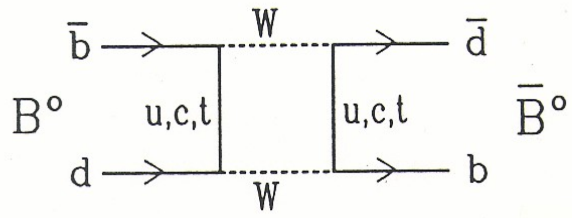
$$N_{B^0}(0) = 1, \qquad N_{\overline{B^0}}(t) = \frac{1}{2} e^{-\Gamma t}(1 - \cos \Delta M t)$$

time integrated

$$r = \frac{x^2}{2 + x^2}, \qquad x = \frac{\Delta M}{\Gamma}$$

Particle theory

G I M



naive

$$\sqrt{B_B \eta_{QCD}}\, f_B = f_K = 160 \text{ MeV}$$

M.K. Gaillard

$$V_{bu}^* V_{ud} + V_{bc}^* V_{cd} + V_{bt}^* V_{td} = 0.$$

B.W. Lee

$$V_{\rm CKM} = \begin{pmatrix} V_{\rm ud} & V_{\rm us} & V_{\rm ub} \\ V_{\rm cd} & V_{\rm cs} & V_{\rm cb} \\ V_{\rm td} & V_{\rm ts} & V_{\rm tb} \end{pmatrix}$$

$$= \begin{bmatrix} 0.9742 \text{ to } 0.9756 & 0.219 \text{ to } 0.225 & 0 \text{ to } 0.008 \\ 0.219 \text{ to } 0.225 & 0.973 \text{ to } 0.975 & 0.037 \text{ to } 0.053 \\ 0.002 \text{ to } 0.018 & 0.036 \text{ to } 0.052 & 0.9986 \text{ to } 0.9993 \end{bmatrix}$$

$$\Delta M = < B|j_\mu j^\mu|B > 2\int_0^\infty dk^2 \left[\frac{k^2}{4\pi}\left(\frac{V_{bu}^* V_{ud}}{k^2 - m_u^2} + \frac{V_{bc}^* V_{cd}}{k^2 - m_c^2} + \frac{V_{bt}^* V_{td}}{k^2 - m_t^2}\right)\left(\frac{g^2}{k^2 - m_W^2}\right)\right]^2$$

A. Ali

$$\frac{4}{3} m_b B_B f_B^2 \qquad \frac{1}{8\pi^2}|V_{bt}^* V_{td}|^2 m_t^2 \qquad G_F^2\, A\left(\frac{m_t^2}{m_W^2}\right)$$

$r > 0.21 - 0.08$

> 0.13

Z.Z. Aydin

$$\Delta M = \frac{G_F^2}{6\pi^2} m_b B_B f_B^2 |V_{bt}^* V_{td}|^2 m_t^2 A\left(\frac{m_t^2}{m_W^2}\right)\eta_{QCD}.$$

$|V_{td}| < 0.018$

T. Inami

$$A(z) = \frac{1}{4} + \frac{9}{4(1-z)} - \frac{3}{2}\frac{1}{(1-z)^2} - \frac{3}{2}\frac{z^2 \ln z}{(1-z)^3}$$

$m_t > 50$ GeV

C.S. Lim

Why not

Publish

OBSERVATION OF B^0–$\bar{B}^0$ MIXING

ARGUS Collaboration

H. ALBRECHT, A.A. ANDAM [1], U. BINDER, P. BÖCKMANN, R. GLÄSER, G. HARDER, A. NIPPE, M. SCHÄFER, W. SCHMIDT-PARZEFALL, H. SCHRÖDER, H.D. SCHULZ, R. WURTH, A. YAGIL [2,3]
DESY, D-2000 Hamburg, Fed. Rep. Germany

J.P. DONKER, A. DRESCHER, D. KAMP, H. KOLANOSKI, U. MATTHIESEN, H. SCHECK, B. SPAAN, J. SPENGLER, D. WEGENER
Institut für Physik [4], Universität Dortmund, D-4600 Dortmund, Fed. Rep. Germany

C. EHMANN, J.C. GABRIEL, T. RUF, K.R. SCHUBERT, J. STIEWE, K. STRAHL, R. WALDI, S. WESELER
Institut für Hochenergiephysik [5], Universität Heidelberg, D-6900 Heidelberg, Fed. Rep. Germany

K.W. EDWARDS [6], W.R. FRISKEN [7], D.J. GILKINSON [8], D.M. GINGRICH [8], H. KAPITZA [6], P.C.H. KIM [8], R. KUTSCHKE [8], D.B. MACFARLANE [9], J.A. McKENNA [8], K.W. McLEAN [9], A.W. NILSSON [9], R.S. ORR [8], P. PADLEY [8], J.A. PARSONS [8], P.M. PATEL [9], J.D. PRENTICE [8], H.C.J. SEYWERD [8], J.D. SWAIN [8], G. TSIPOLITIS [9], T.-S. YOON [8], J.C. YUN [6]
Institute of Particle Physics [10], Canada

R. AMMAR, D. COPPAGE, R. DAVIS, S. KANEKAL, N. KWAK
University of Kansas [11], Lawrence, KS 66045, USA

B. BOŠTJANČIČ, G. KERNEL, M. PLEŠKO
Institut J. Stefan and Department of Physics [12], Univerza v Ljubljani, 61111 Ljubljana, Yugoslavia

L. JÖNSSON
Institute of Physics [13], University of Lund, S-223 62 Lund, Sweden

A. BABAEV, M. DANILOV, B. FOMINYKH, A. GOLUTVIN, I. GORELOV, V. LUBIMOV, V. MATVEEV, V. NAGOVITSIN, V. RYLTSOV, A. SEMENOV, V. SHEVCHENKO, V. SOLOSHENKO, V. TCHISTILIN, I. TICHOMIROV, Yu. ZAITSEV
Institute of Theoretical and Experimental Physics, 117 259 Moscow, USSR

R. CHILDERS, C.W. DARDEN, Y. OKU
University of South Carolina [14], Columbia, SC 29208, USA

and

H. GENNOW
University of Stockholm, S-113 46 Stockholm, Sweden

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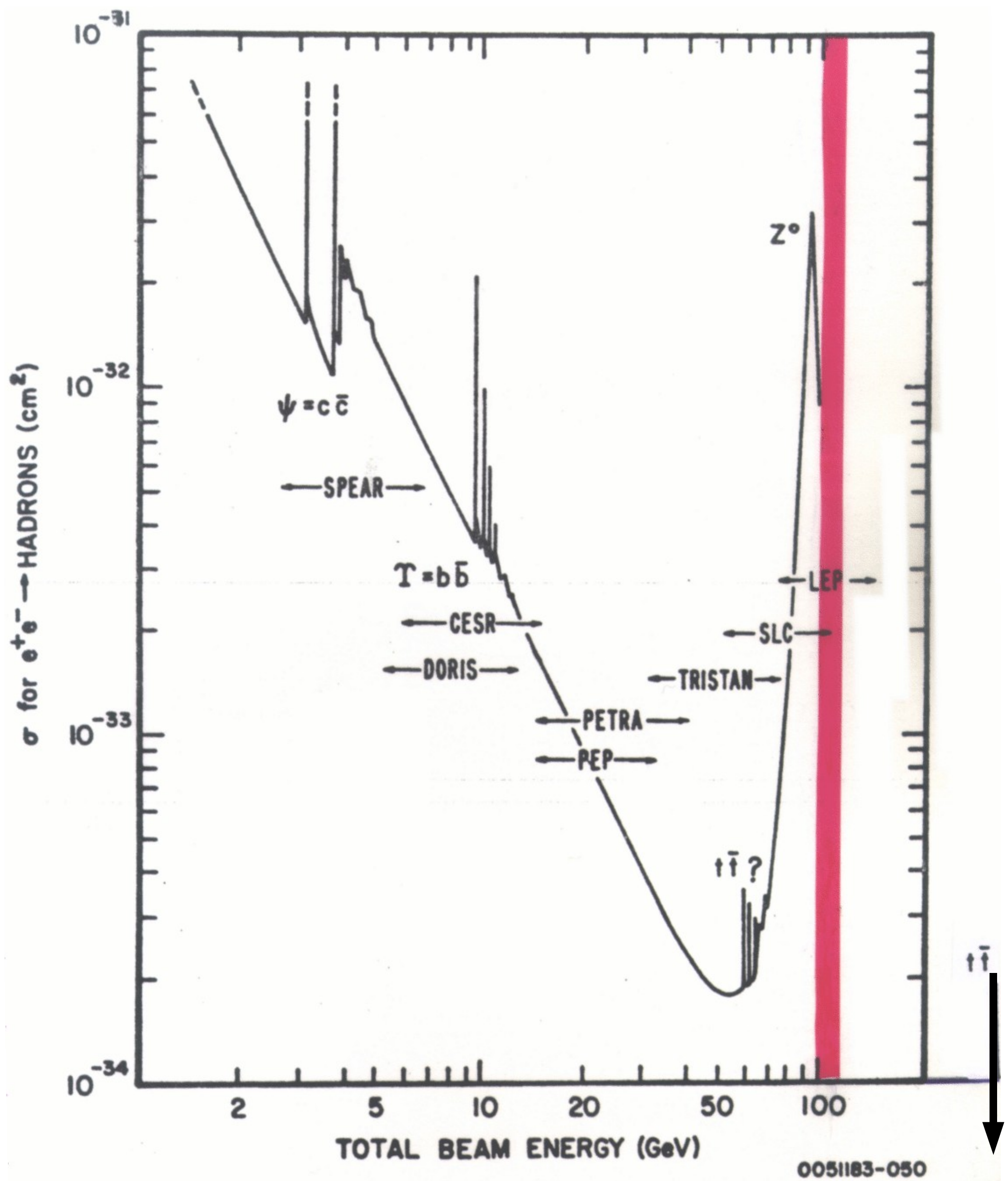
Impact



No top at LEP and SLC

No toponium

CP violation of B mesons

is observable

B factory required

No new physics

just around the corner

The result is correct

Collaboration Meeting in Bled (Ljubljana)

20th Anniversary

Alle

Richtigen

Genies

Unter

Sich