Physics at Accelerators
From the KWI/MPI Cyclotron to the CERN SPS

Hans J. Specht
Universität Heidelberg

GSI, 13 June 2017

On the occasion of Rudolf Bock's 90th Birthday

W. Bothe and the KWImF in Heidelberg in the 1930/40s

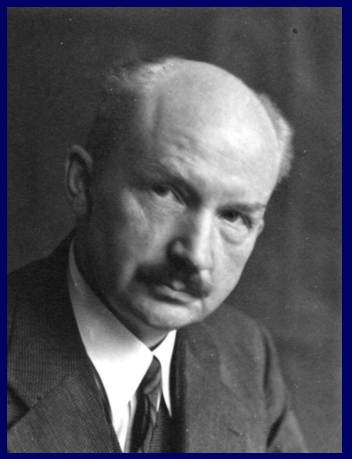
1930 Kaiser-Wilhelm Institut für medizinische Forschung (Pathology, Physiology, Physics, Chemistry)

1932 W. Bothe Director of the University's Physics Institute (successor to Lenard)

1934 W. Bothe Director of the KWImF Physics Institute
Only few staff assistants
Best known:

1935-1946 W. Gentner

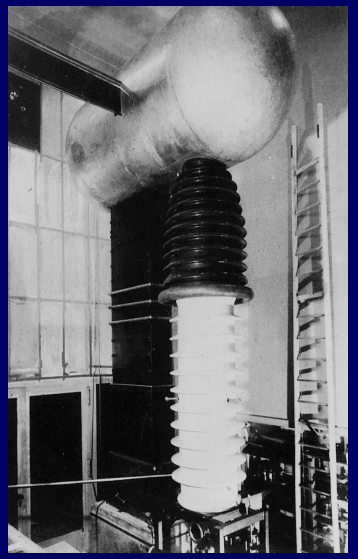
1935-1952 H. Maier-Leibnitz



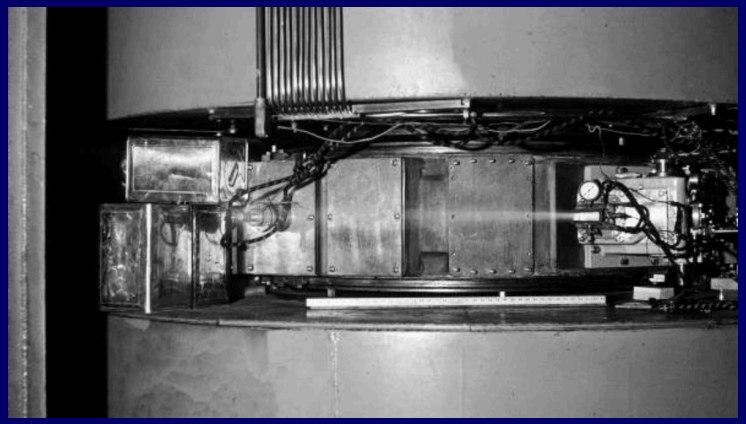
1936 Van-de-Graaff acceler.
1st in Europe; Gentner
(0.5 MeV p+^{7}Li → 2α+17 MeV γ)

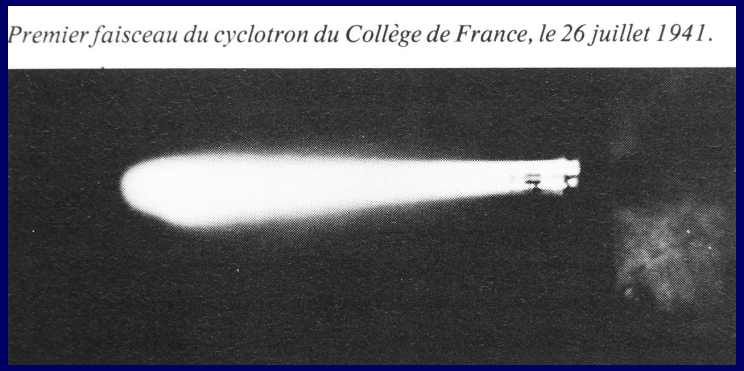
1936ff Main research domain:
nuclear photo effect
('nucl.giant dipole res.')

1937 Physics Conf. in Paris
Lecture by Gentner



Cyclotrons in the 1930/40s





Premier faisceau du cyclotron du Collège de France, le 26 juillet 1941.

USA:

1930-1939 Ernest Lawrence, Berkeley
(inspiration by Wideroe publ.1928)
5 cyclotron generations: 4"… 60"(40 MeV α)
1934 Patent; 1939 Nobel Prize

Europe:

1937 Kurchatov et. al, Leningrad, 1937
1939 Chadwick, Liverpool; Cockroft, Cambridge

1937 1st French cyclotron under preparation by
Frederic Joliot-Curie, College de France
Visit by W. Bothe, W. Gentner et. al

1938-1939 Extended visit of Gentner in Berkeley
1940-1942 Gentner in Paris (in 1940 also Bothe)
1941 First beam extracted; later 7 MeV d

1939 80t magnet ordered by the KWImF
1943 magnet delivered
1944 1st German cyclotron running

The steep recovery of Nuclear Physics in the 1950s

CKAR-ZEITUNG

Nachrichten

MENS AGITAT MOLEM

Bezugspreis: Monatlich 3,15 DM zuzüglich -,45 DM Trägerlohn, Abhol.-Abonnements 3,15 DM, Postbezieher monatlich 3,60 DM (einschließl. Zeitungsgebühr) zuzügl. Zustellungsgebühr. Streifbandversand monatl. 3,60 DM zuzügl. Porto. Anzeigen: Einspaltig, 46 mm breit, Gesamtausgabe 1,- DM pro mm, Teilausgabe nach Preisliste 12. Kein Ersatzanspruch bei Störung durch höhere Gewalt

nerstag, 4. November 1954 — Einzelpreis 0,20 DM

raten

ag für Eisenhower

Glauben bestärkt, daß die große Mehrs amerikanischen Volkes eine ge- Regierung wünscht.

ger der Demokraten herrschte am habend große Freude über die Wahlsse, die nach Ansicht vieler demokra- Politiker auf einen demokratischen den Präsidentenwahlen in zwei Jahdeuten. Im Hauptquartier der Repu- hingegen herrschte düstere Stim- nd man wollte keine Gründe für das Abschneiden der Partei in einigen enen Staaten nennen. Adlai Ste- n, der vor zwei Jahren für die Demo- n die Präsidentschaftswahlen gegani dann von Eisenhower geschlagen war, sagte, der demokratische Wahlein „Omen für künftige Ereignisse". Wahl zeige „eine deutliche Veränderegenüber der vor zwei Jahren." Der ge demokratische Präsident T r u m a n am Mittwoch, daß er über den Ver- Kongreßwahlen „sehr erfreut" sei.

sche Beobachter in Washington ver- am Mittwoch die Ansicht, daß der Sieg der Demokraten bei den Wahn Repräsentantenhaus größer gewe- e, wenn Präsident Eisenhower nicht letzten Tagen selbst in den Wahleingegriffen hätte. Allerdings sind mmen zu hören, die den Erfolg der aten als persönliche Niederlage des ten werten, der in den letzten Wo- ensiv auch für solche Kandidaten in hlkampf eingegriffen hatte, die nun Wahlen unterlagen.

hm überrascht

lperioden der übrigen 58 Senatoren st in zwei bzw. vier Jahren. Der umrepublikanische Senator Joseph t h y stand diesmal nicht zur Wahl. ner glühendsten Anhänger aber, der Abgeordnete Charles K e r s t e n

ar die Mehrheit des demokratischen ten Averell H a r r i m a n so knapp, bisherige republikanische Gouverewey alle Wahlzettel sicherstellen

Nobelpreis für Walther Bothe

Höchste internationale Auszeichnung des Heidelberger Forschers

Foto: Voss jr.

Die schwedische königliche Akademie der Wissenschaften hat gestern am späten Abend den Nobelpreis für Physik 1954 den Professoren Dr. Walther B o t h e (Heidelberg) und Max B o r n (Göttingen) verliehen. Den Nobelpreis für C h e m i e erhielt Dr. Linus Karl P a u-

1949…1953 J.H.D.Jensen (Nobel Prize 1963), O. Haxel and H. Kopfermann at the Physics Inst. of Heidelberg University

1954 W. Bothe Nobel Prize (back at MPImF)

1954 Foundation of CERN

1955-1958 Gentner Director CERN SC

1955 Pariser Vertraege
F.J. Strauss Atom Minister

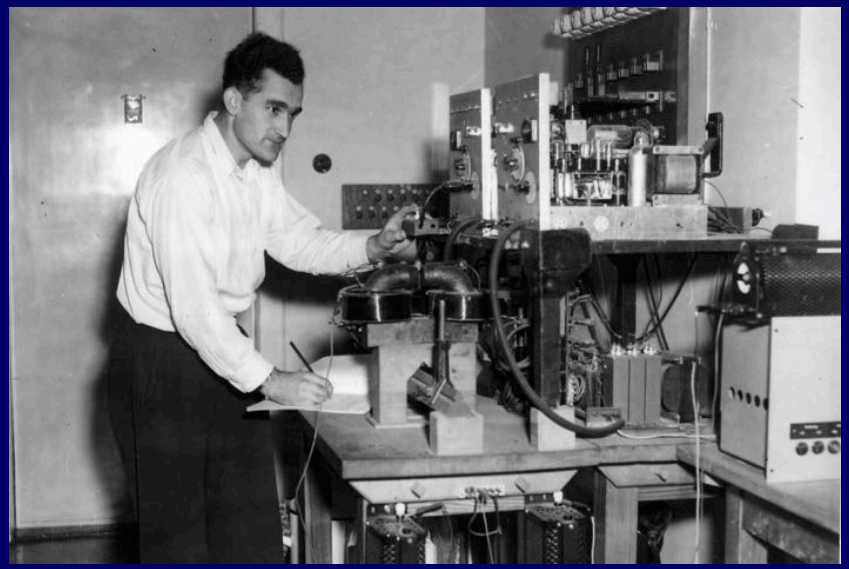
1956-1957 Maier-Leibnitz FRM Muenchen (approval, construction and criticality of 1st German reactor within 1 year)

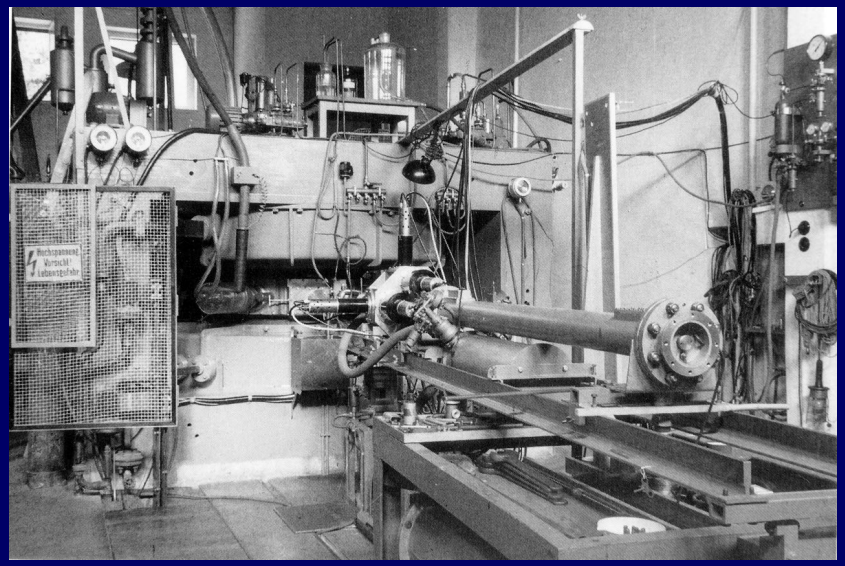
1957 Moessbauer effect (Nobel Prize 1961) (experiments done in the MPImF)

1957 Death of W. Bothe
1958 Gentner successor to Bothe (MPIK)

1954-1959 Schmelzer at the CERN PS (since 1948 in Bothes Institute)

R. Bock and the MPImF Cyclotron in the 1950s





1953-54 Diploma Thesis
'Kernspektroskopie von V^{48} '

Isotope produced with the cyclotron beam
Coincidence set-up

Contribution to major changes of the cyclotron

Ein Festfrequenz-Zyklotron mit einem Dee
R.Bock, A.Doehring, J.Jänecke, O.Knecht, L.Koester, H.Maier-Leibnitz, Ch.Schmelzer und U.Schmidt-Rohr
Zeitschr. Angew. Phys. **10** (1958) 49-55

R. Bocks first publication

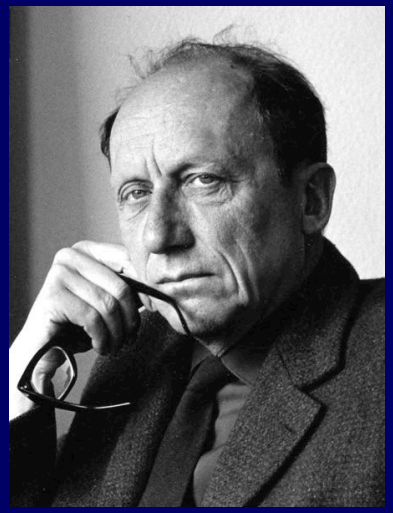
1955-58 Doctoral Thesis; mentor W. Bothe

Thesis title 'Anregungsfunktionen fuer deuteronen-induzierte Kernreaktionen'

Cyclotron data:

Magnet 80 t, field 1.7 T, 1-Dee-System 13 MHz, max Energy 11.8 MeV (deuterons); stop 1973

The MPIK and its Tandem Accelerators in the 1960s

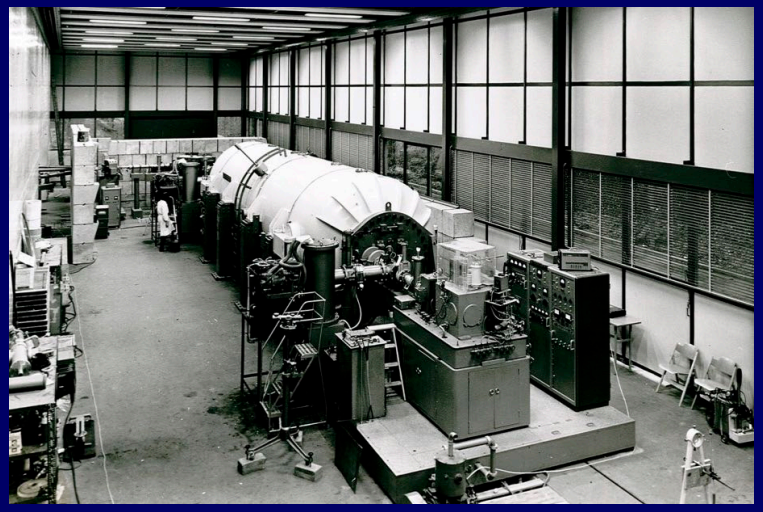


1958 W. Gentner Director of the newly formed MPIK, successor Institute to the Physics Institute in the MPImF

1962 New 6MV EN Tandem Accelerator running; 1967 10MV MP (1st EN Tandem in Chalk River in 1959, followed by an inflation of 8 Tandems until 1961 and 26 until 1968; HD #7)

1959-1967 R. Bock Assistant/Wiss. Mitarbeiter in the MPIK; 1965 Habilitation; 1967 o. Professor at the University of Marburg; until 1974 work at the MPIK

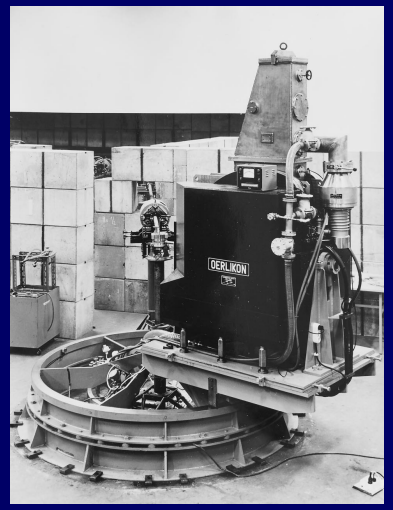
Group of R. Bock first one to start Heavy Ion Physics at the MPIK



Hardware responsibilities

together with G. Hortig et al.: set up of the Tandem Lab with installation of the accelerator and experimental facilities

Brown-Buechner magnetic spectrograph (mostly used with photo emulsions)



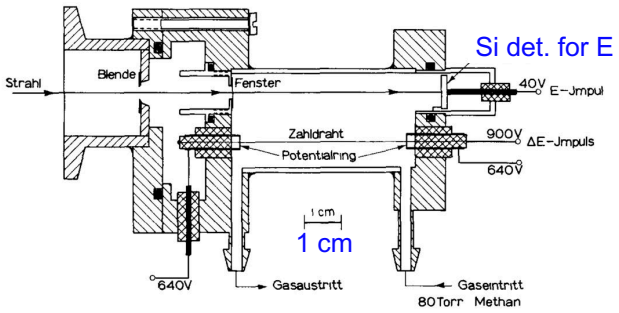
R. Bock and Heavy Ion Physics at the MPIK I

Volume 22, number 4 PHYSICS LETTERS 1 September 1966

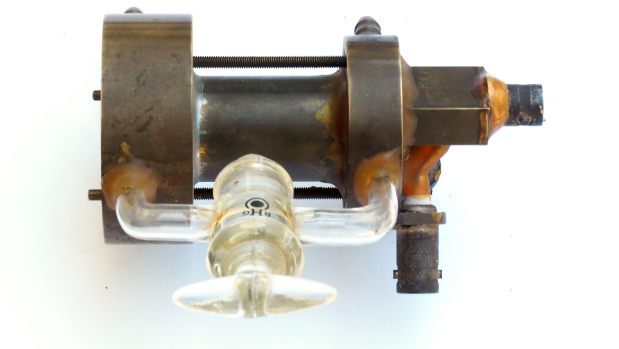
DIFFRACTION MODEL INTERPRETATION OF HEAVY ION INDUCED TRANSFER REACTIONS

R. BOCK, M. GROSSE-SCHULTE and W. VON OERTZEN
Max Planck Institut für Kernphysik, Heidelberg, Germany

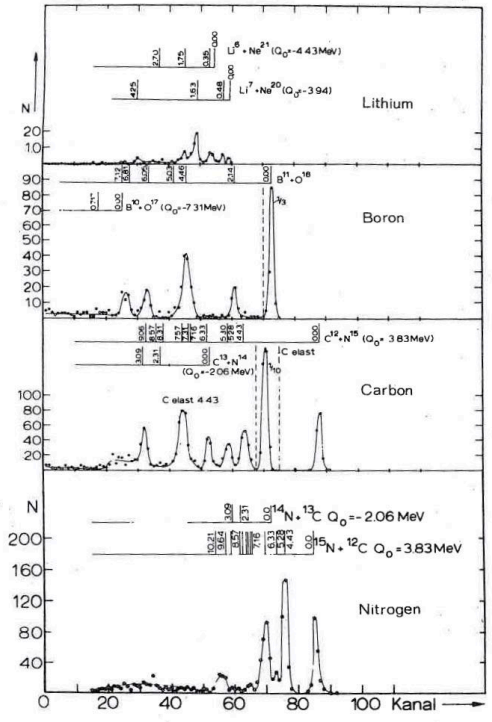
prop. counter for dE/dx, resol. 5%



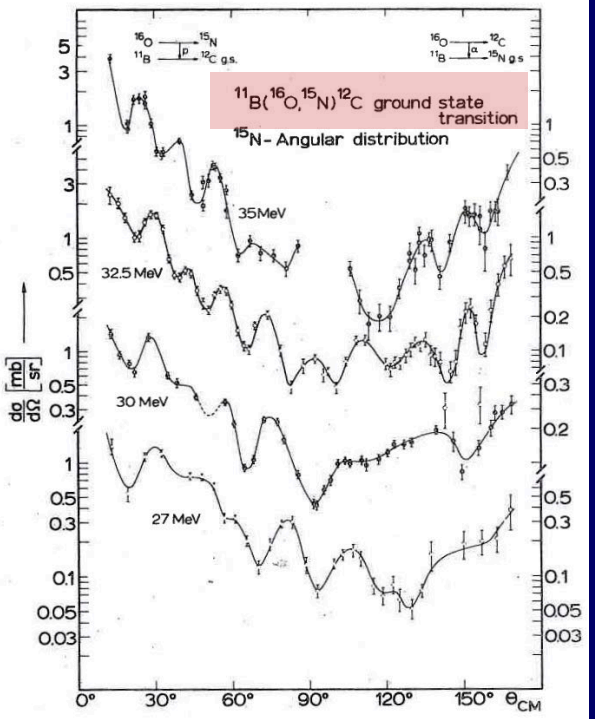
Si 0.7×8 mm², $\delta\theta$=0.3° → several h/data-point



precision nuclear structure studies



nucl. collision dynamics; diffraction structure



Talk by R. Bock at Int. Conference on Heavy-Ion Physics, Dubna, Oct. 1966; 1st Russ. visit!

Starting an impressive set of collaboration arrangements with Russian Institutes

R. Bock and Heavy Ion Physics at the MPIK II

Tandem Physics: Heavy Ions
(MPI Kernphysik, Heidelberg)
1963-1970

R.Bock, H.H.Duhm, G.Hortig und R.Rüdel
Study of the Mechanism of N^{14}-induced Reactions on Be^{9} at 25 MeV
Proc. of the Internat. Conf. on Nuclear Physics, Paris 1964, pp.1123-1125

R.Bock, R.Rüdel, H.H.Duhm and M.Große-Schulte
N^{14}-induzierte Transfer-Reaktionen in Be^{9} von 20 bis 30 MeV
Nucl. Physics **70** (1965) 481

R.Bock, M.Große-Schulte and W.von Oertzen
Diffraction Model Interpretation of Heavy Ion Induced Transfer Reactions
Phys. Letters **22** (1966) 456

W.von Oertzen, H.H.Gutbrod, M.Müller, U.Voos and R.Bock
Heavy Ion Transfer Reactions with Identical Initial and Final States
Phys. Letters **26B** (1968) 291

H.H.Gutbrod, R.Bock K.Hildenbrand, W.von Oertzen and U.C.Voos
Transfer Reactions above the Coulomb Barrier
Proc. of the 1969 La Plagne Conference, p. II.5.1

Tandem Physics: Light Projectiles
1964-1969

R.Bock, H.H.Duhm, R.Rüdel und R.Stock
The Excitation of the 7/2⁻ Level at 1.28 MeV in Cr^{53} by the $Cr^{52}(d,p)Cr^{53}$-Reaction
Phys. Letters **13** (1964) 151

R.Bock, H.H.Duhm, S.Martin, R.Rüdel und R.Stock
Die Niveaustruktur von Cr^{53} und Cr^{55}
Nucl. Physics **72** (1965) 273

R.Bock, H.H.Duhm, R.Jahr, R.Santo and R.Stock
A Study of the Low-lying Levels of ^{53}Cr by Inelastic Scattering
Phys. Letters **19** (1965) 417-419

R.Bock, H.H.Duhm, W.Melzer, F.Pühlhofer and B.Stadler
An Array of Position Sensitive Surface Barrier Counters for Use in a Magnetic Spectrograph
Nucl. Inst. Meth. **41** (1966) 190-194

M.Betigeri, R.Bock, H.H.Duhm, S.Martin und R.Stock
Die Reaktionen $^{30}Si(d,p)^{31}Si$ und $^{30}Si(^{3}He,d)^{31}P$

small selection of about 50 publications from 1964 to 1974; many PhD students

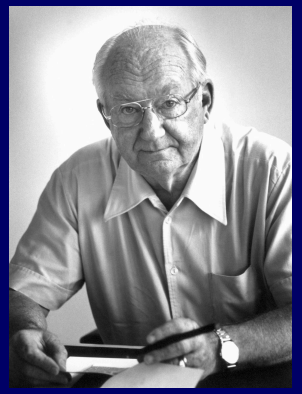
Research both on reaction mechanism and nuclear structure using heavy ions and light projectiles
(1960 Bromley et al., Chalk River, elastic scattering)

THE pioneering work on heavy ions in Germany

1969 Co-responsible for Int. Conference on 'Nuclear Reactions Induced by Heavy Ions', Heidelberg →

The KAH and the Foundation of GSI 1966-1969

1959 Start of development of the UNILAC by C. Schmelzer et al., Heidelberg (original team: D. Boehne and the PhDs N. Angert, K. Blasche, B. Franzke)



1966 Kernphysikalische Arbeitsgemeinschaft Hessen (KAH)

Members: F. Beck, P. Brix, E. Kankeleit (Darmstadt), W. Greiner, E. Schopper (Frankfurt), R. Bock and W. Walcher (Marburg)

Goal: define a common research facility for the Hessian Universities

Final conclusions after 3 years:

1) novel concept of a joint facility, independent of the universities, but run by members of the universities
2) research field: heavy ion physics (not medium-energy hadron physics)
3) facility: UNILAC Schmelzer (not TALIX, not 800 MeV proton machine)

17. December 1969 Foundation of GSI
1975 first beam, 1976 first U-beam

GSI Directorate in 1971

The Users Community behind GSI in 1972

R. Bock

P. Armbruster

G. Herrmann W. Greiner C. SCHMELZER J. Rafelski

Heavy-Ion deep-inelastic Scattering at the UNILAC

VOLUME 39, NUMBER 17 PHYSICAL REVIEW LETTERS 24 OCTOBER 1977

Reaction between ^{238}U and ^{238}U at 7.42 MeV/Nucleon

K. D. Hildenbrand, H. Freiesleben, F. Pühlhofer, W. F. W. Schneider, and R. Bock
Gesellschaft für Schwerionenforschung, D-6100 Darmstadt, Germany

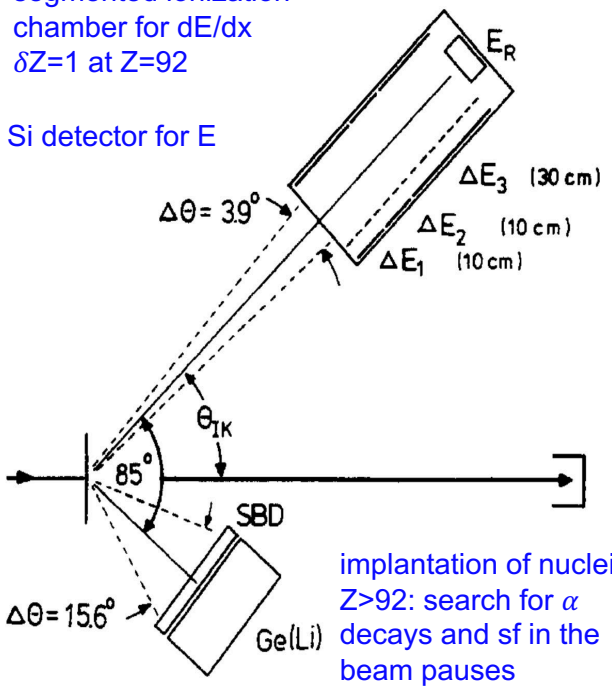
and

D. v. Harrach and H. J. Specht
Physikalisches Institut der Universität Heidelberg, Heidelberg, Germany

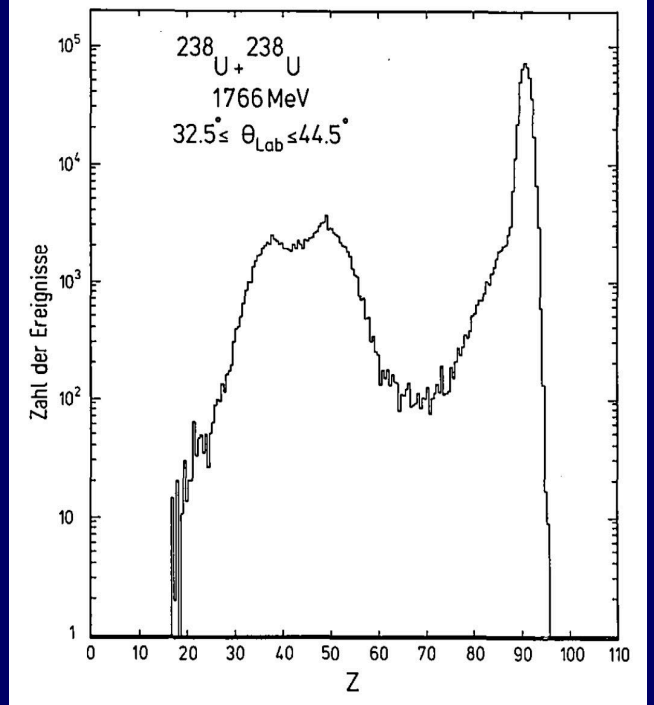
(Received 5 August 1977)

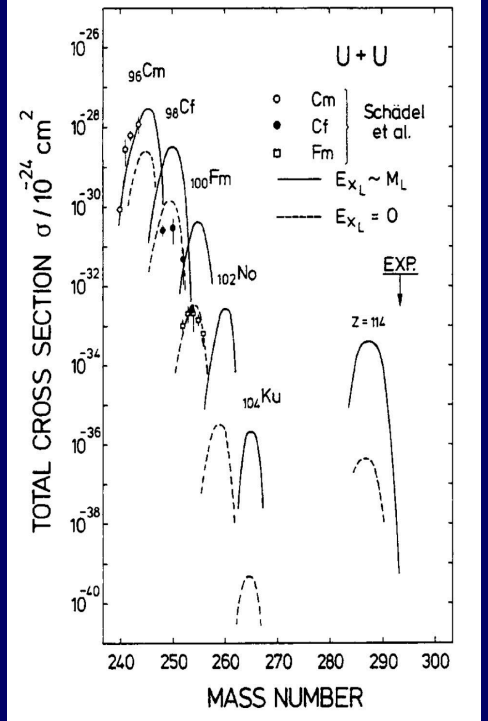
segmented ionization chamber for dE/dx
$\delta Z=1$ at $Z=92$

Si detector for E



implantation of nuclei
Z>92: search for α decays and sf in the beam pauses





deep-inelastic scattering: R. Bocks main activity at the UNILAC, mostly with A. Gobbi et al.

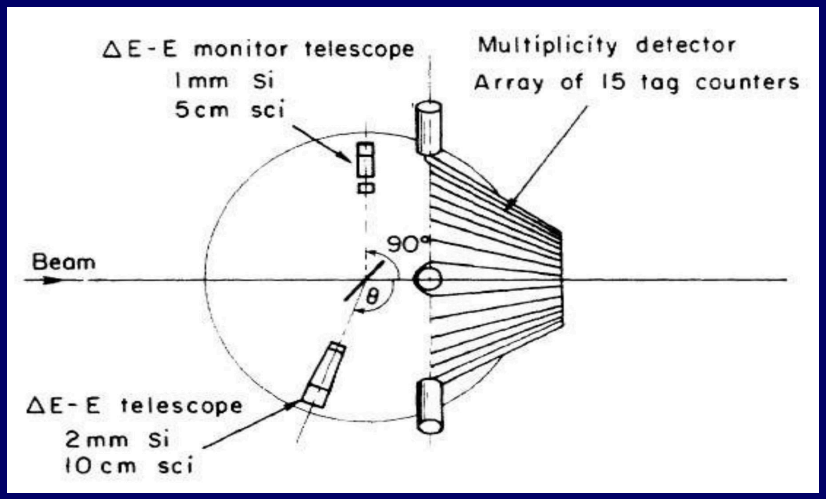
1st U+U results: strong nucleon transfer, but hardly survival for Z>100 because of fission

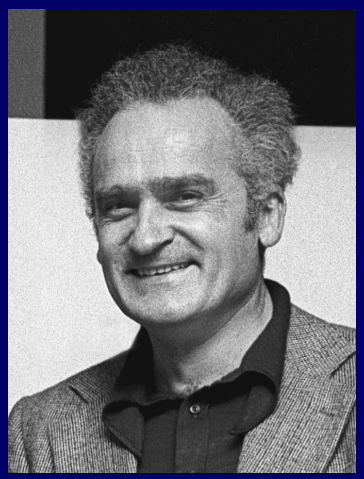
Relativistic and ultra-relativistic Heavy-Ion Collisions
a revolution for the low-energy community

Foundation of the GSI-Marburg-Berkeley Collaboration

1974; first experiments at the Bevalac at $E_{kin}/A \approx 1$ GeV in 1975

H.A.Grunder





R.Bock

R.Stock, Marburg

H.Gutbrod, GSI

Particle telescopes in a scattering chamber; techniques developed by R. Bock's group at the MPIK and GSI

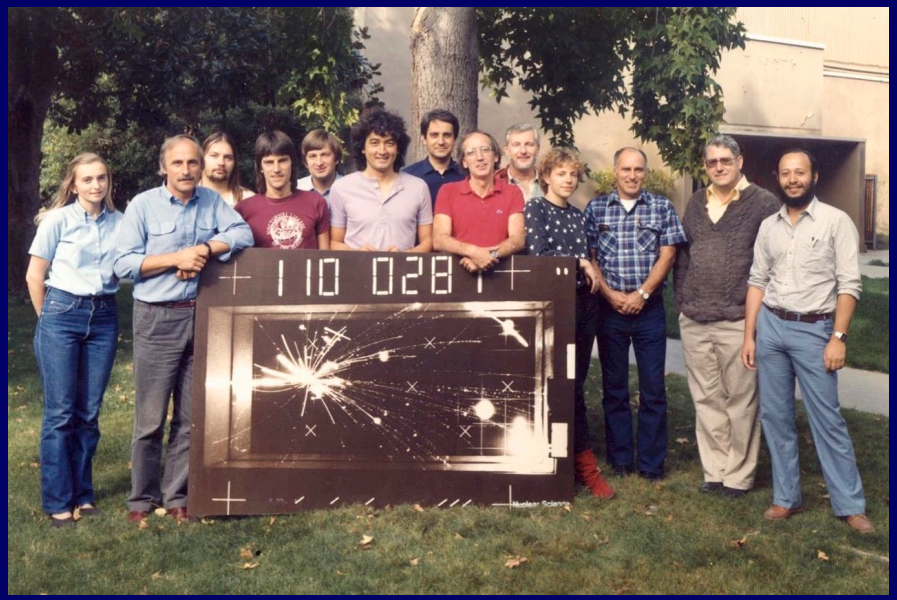
An incredibly far-sighted step in 1974, before first beams from the UNILAC were available

PHYSICAL REVIEW C VOLUME 16, NUMBER 2 AUGUST 1977

Central collisions of relativistic heavy ions*

J. Gosset,† H. H. Gutbrod, W. G. Meyer, A. M. Poskanzer, A. Sandoval, R. Stock, and G. D. Westfall

Streamer Chamber and Plastic Ball at the BEVALAC



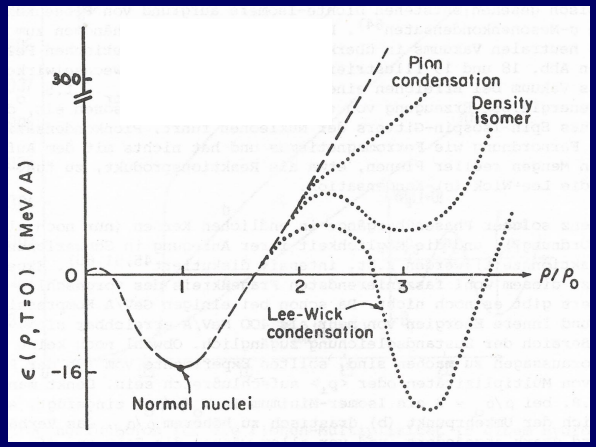
a huge jump to two 4π Detectors (dominated by GSI until termination of the program)

The dual theoretical Background in 1974/75

PHYSICAL REVIEW D VOLUME 9, NUMBER 8 15 APRIL 1974

Vacuum stability and vacuum excitation in a spin-0 field theory*

T. D. Lee and G. C. Wick
Columbia University, New York, New York 10027
(Received 17 January 1974)



Stability and variability of the vacuum
Lee/Wick: dense abnormal states of nuclear matter at high ρ

'foreshadowing chiral symmetry restoration, but with nucleonic degrees of freedom' (G. Baym 2015)

Volume 59B, number 1 PHYSICS LETTERS 13 October 1975

EXPONENTIAL HADRONIC SPECTRUM AND QUARK LIBERATION

N. CABIBBO
Istituto di Fisica, Universitá di Roma,
Istituto Nazionale di Fisica Nucleare, Sezione di Rome, Italy
G. PARISI
Istituto Nazionale di Fisica Nucleare, Frascati, Italy

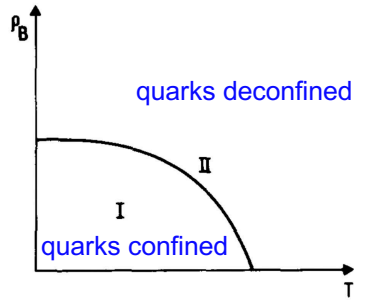
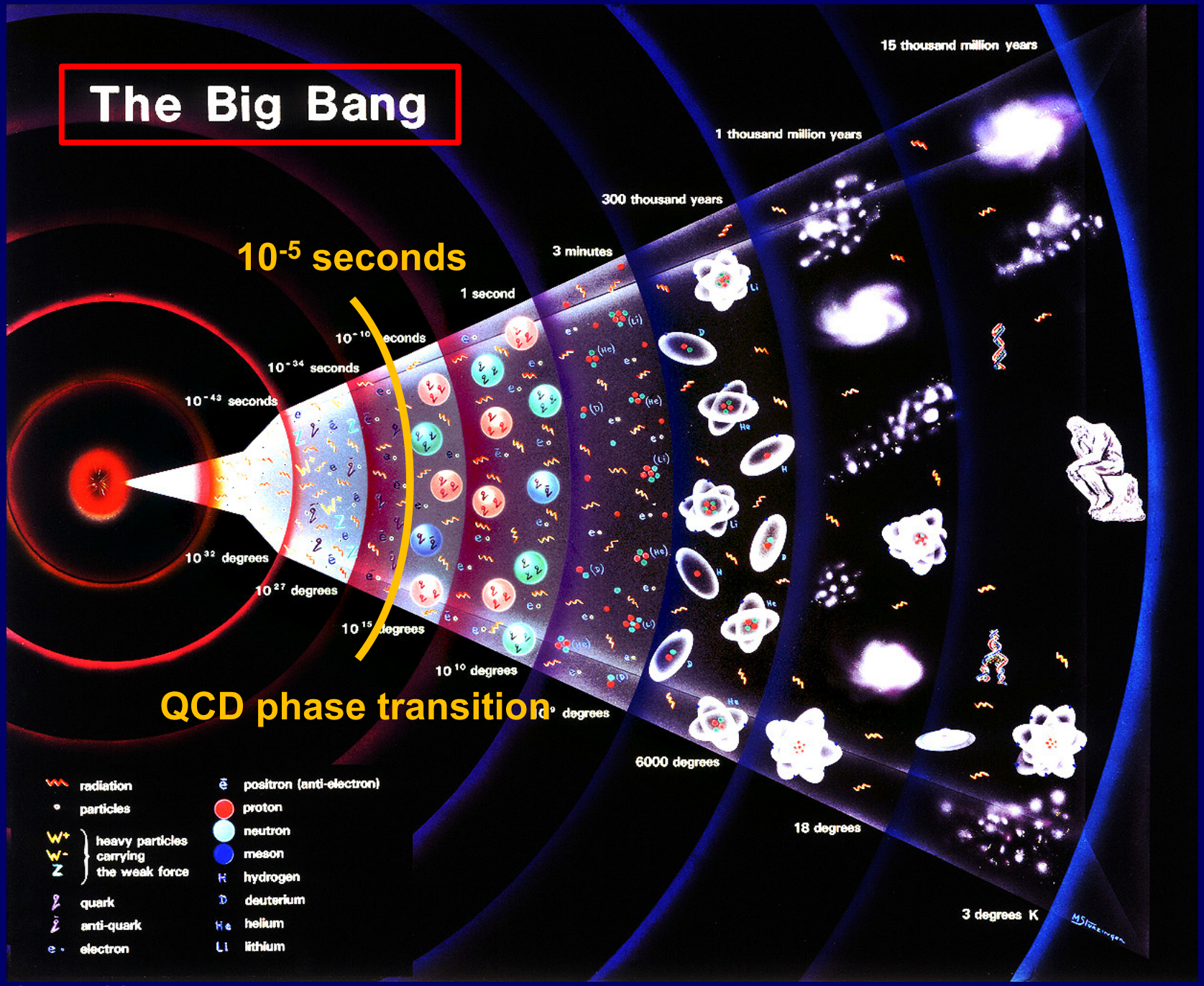


Fig. 1. Schematic phase diagram of hadronic matter. ρ_B is the density of baryonic number. Quarks are confined in phase I and unconfined in phase II.

(see also Collins and Perry on high ρ, PRL 34, 1975, 1353)

first re-interpretation of Hagedorns exponential spectrum and limiting temperature in terms of a 'critical' temperature separating hadrons and deconfined quarks


The Big Bang
15 thousand million years
1 thousand million years
300 thousand years
3 minutes
1 second
10-5 seconds
10-10 seconds
10-34 seconds
10-43 seconds
10 32 degrees
10 27 degrees
10 15 degrees
10 10 degrees
degrees
6000 degrees
18 degrees
3 degrees K
QCD phase transition
radiation
particles
W+
W-
Z
heavy particles carrying the weak force
quark
anti-quark
electron
positron (anti-electron)
proton
neutron
meson
H hydrogen
D deuterium
He helium
Li lithium

The Roots 1974-1984: Nuclear and Particle Physics

	Workshops/Conf.	Accelerators	Physics	Persons/Actions
1974	Columbia (GeV/u Coll. of HI)	BEVALAC 1974	Compressed Nucl. Matter Lee/Wick 1974	Contract GSI/LBL Bock - Grunder (Stock/Gutbrod)
1975 -1978	LBL and GSI (alternating)	ISR Discuss. on HI (Pugh/Santa Fé)	First ideas on QGP Cabibbo/Parisi 1975	CERN DG L. van Hove (1977)
1979	pre QM LBL	SIS100 Prop. GSI VENUS Prop. LBL	Dileptons in pp Fermilab 1977	BMFT Committee, DE (1979-1980)
1980	pre QM Bielefeld TH QM1 GSI		αα collisions ISR	PS LoI GSI/LBL SPS Disc. LvH/BW/HS
1981	LBL, BNL	SIS12/100 Prop. GSI		CERN DG H. Schopper
1982	QM2 Bielefeld (M.Jacob/H.Satz)	ISR to be stopped (CERN Council)		PS Prop. GSI/LBL ^{16}O ECR ion source
1983	QM3 BNL	ISR last run	Dileptons in pp R807/808, ISR	Contract CERN/GSI/LBL SPS NA34 Prop. Willis et al.
1984	QM4 Helsinki	SPS, AGS, SIS18 settled		Approval of 1st Gen. Experiments at SPS

The 1970's: high-energy pp experiments

Most striking example

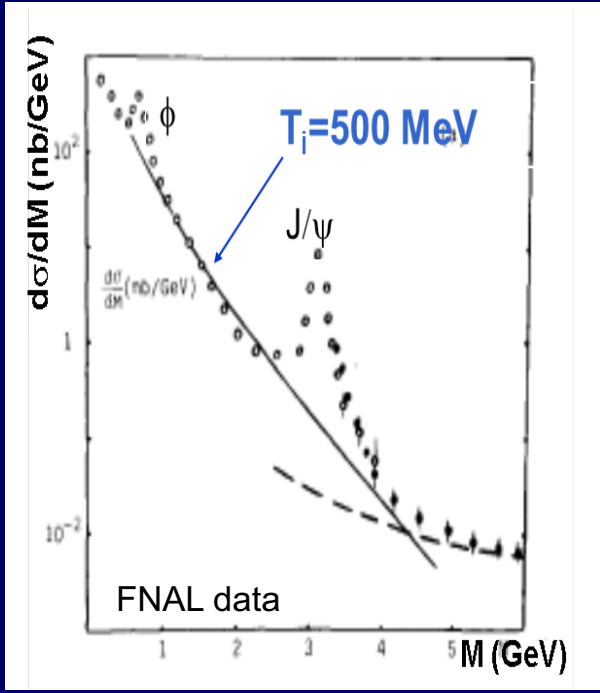
Volume 78B, number 1 PHYSICS LETTERS

QUARK–GLUON PLASMA AND HADRONIC PRODUCTION OF LEPTONS, PHOTONS AND PSIONS

E.V. SHURYAK
Institute of Nuclear Physics, Novosibirsk, USSR

Received 16 March 1978

1st use of the name 'Quark-Gluon Plasma'



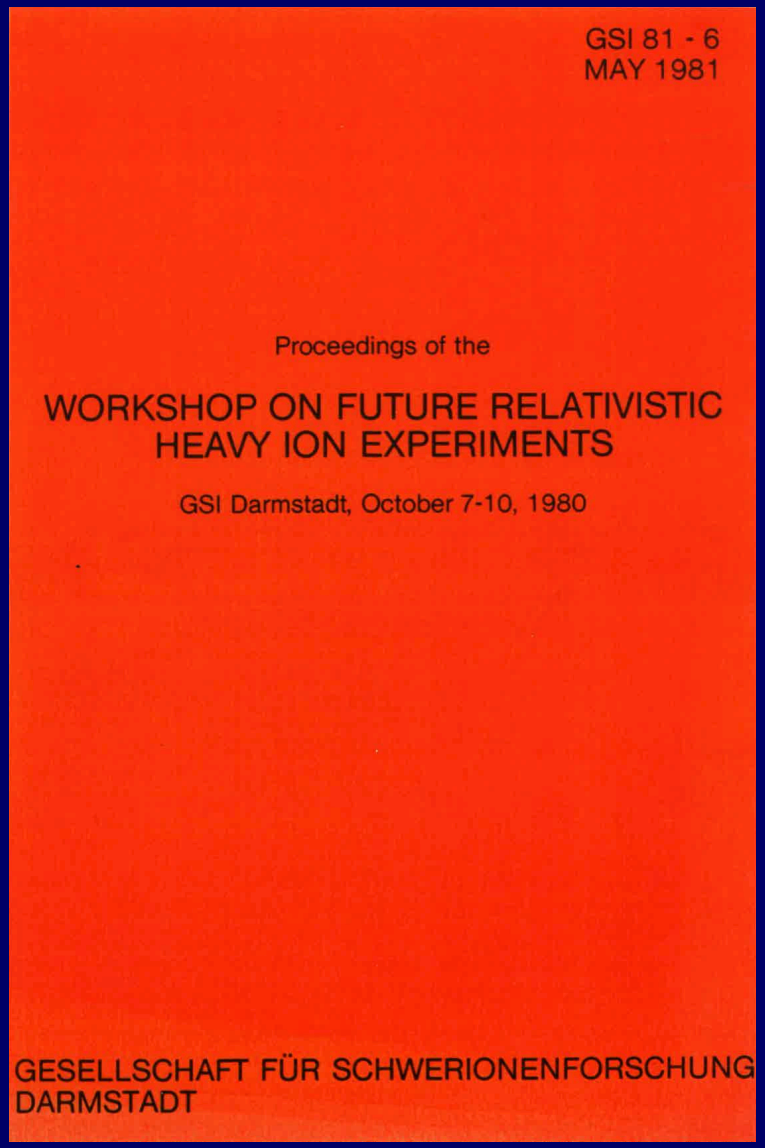
Lepton pair data in the IMR
Branson et al., PRL 1977

Problematic data, but milestone in theoretical interpretation

SIS100 (1979) and SIS12/100 (1981) at GSI

Far-reaching prophetic Proposals, but ….

‘First Quark Matter Conference’ (1980)



Organizers: R. Bock and R. Stock

Ad-hoc Committee Nuclear Physics of the German BMFT (June 1979 - May 1980)

Recommendation 16 (on SIS100): ’it is proposed to reinvestigate, whether or not the field of ultra-relativistic heavy ions could not be opened at an accelerator at CERN in a collaboration CERN/GSI’

Milestone

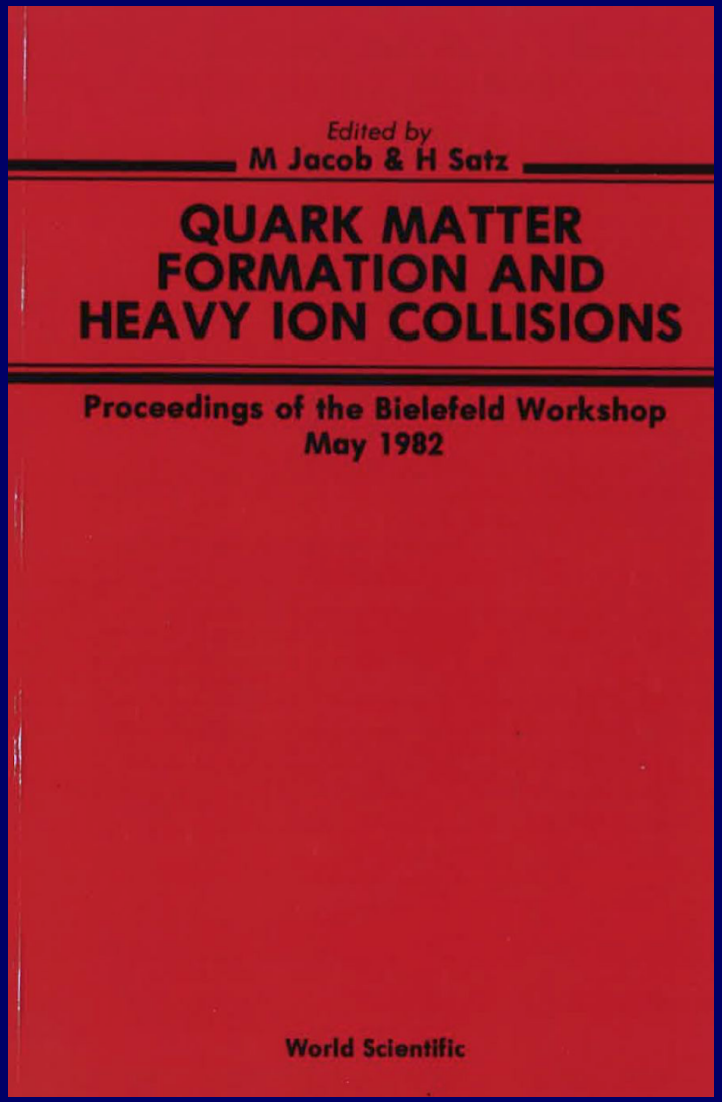
First organized discussions between particle and nuclear physicists on studying QGP formation in ultra-relativistic nucleus-nucleus collisions. Particle physicists ~30%, including W.J.Willis. Discussions dominated by the ‘dream of keeping the ISR’ (summary speaker HJS)

Immediate consequences

- Letter-of-Intent for 2 experiments at the CERN-PS by GSI/LBL (27 Oct. 1980)
- A long discussion between CERN DG L. van Hove, W.Willis and HJS on the use of the SPS instead of the ISR for heavy ions (Nov. 1980) $\sqrt{s}$ for Z/A=1/2 20 vs. 32 AGeV; luminosity gain!

II Quark Matter Conference (1982)

Organizing Committee: T. Ericson, M. Jacob, H. Satz, W. Willis



Milestones

First systematic discussion between particle and nuclear physicists, on the theoretical and experimental aspects of QGP formation in ultra-relativistic nucleus-nucleus collisions. Particle physicists >50%

Discussion of basic physics ideas on all hadronic and electromagnetic observables (only J/ψ missing, Satz/Matsui 1986)

Basic instrumental discussions on the first-generation experiments at the CERN SPS, organized in 6 working groups; summary by M. Albrow. Further summaries: Bevalac physics (S. Nagamia), Accelerator prospects (H. Pugh) and Theory (L. van Hove)

Also presented at QM82 Bielefeld: PS Proposal R. Stock et al.

CERN/PSCC/82-1
PSCC/P53
26 January, 1982

STUDY OF RELATIVISTIC NUCLEUS-NUCLEUS REACTIONS INDUCED

BY ^{16}O BEAMS OF 9-13 GEV PER NUCLEON AT THE CERN PS

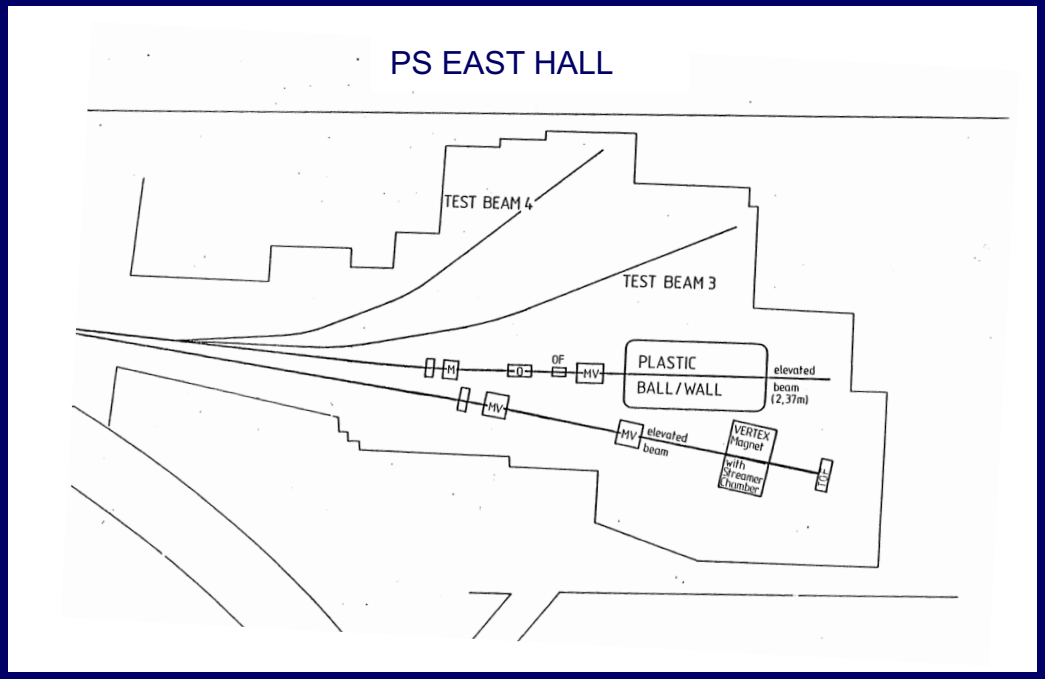
Proposal submitted to the CERN PSCC by the
GSI[1] -LBL[2] -Heidelberg[3] -Marburg[4] -Warsaw[5] -Collaboration

February 1982

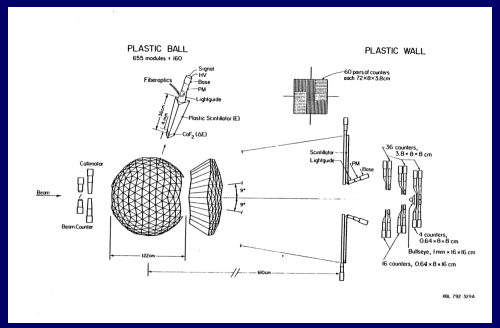
N. Angert[1], H. Bialkowska[5], R. Bock[1], H.H. Gutbrod[1], H. Harris[1], M.R. Maier[4], A.M. Poskanzer[2], F. Pühlhofer[4], H.G. Pugh[2], R.E. Renfordt[3], H.G. Ritter[1], A. Sandoval[1], L.S. Schroeder[2], E. Skrzypczak[5], R. Stock[1], H. Ströbele[1], R.Szwed[5], A. Warwick[1], F. Weik[1], H. Wiemann[1], K.L. Wolf[2]

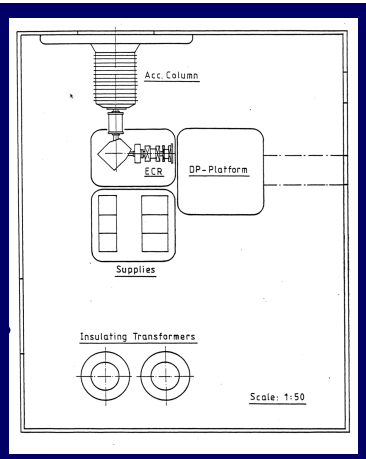
ABSTRACT

We propose to study the target fragmentation modes and $\pi^{\pm}$, K^{o}, Λ, $\bar{p}$ and $\bar{\Lambda}$ production in collisions of ^{16}O with target nuclei ranging from ^{40}Ca to ^{206}Pb. The acceleration of ^{16}O in the PS will be facilitated by a high charge state ion source installed by us at the Linac I. Experimental equipment will be the Plastic Ball spectrometer, currently employed by us at the Bevalac, LBL Berkeley, and the streamer chamber of the MPI-München group, presently used at the SPS inside a CERN Vertex magnet. The experiments require the acceleration of 10^{7} oxygen ions per PS cycle and two splits in the East Hall external beam system delivering about 10^{5} ions/s to the streamer chamber and the main part of the intensity to the Plastic Ball. A beam of hadrons (preferably protons) of similarly low intensity, in the 10 to 26 GeV energy range, is needed for setup purposes and in order to study the scaling with projectile mass. The anticipated date of data taking is spring 1984, with an initial request of 250 hours of devoted PS running time.



Milestone: offer of an Oxygen injector for LINAC1





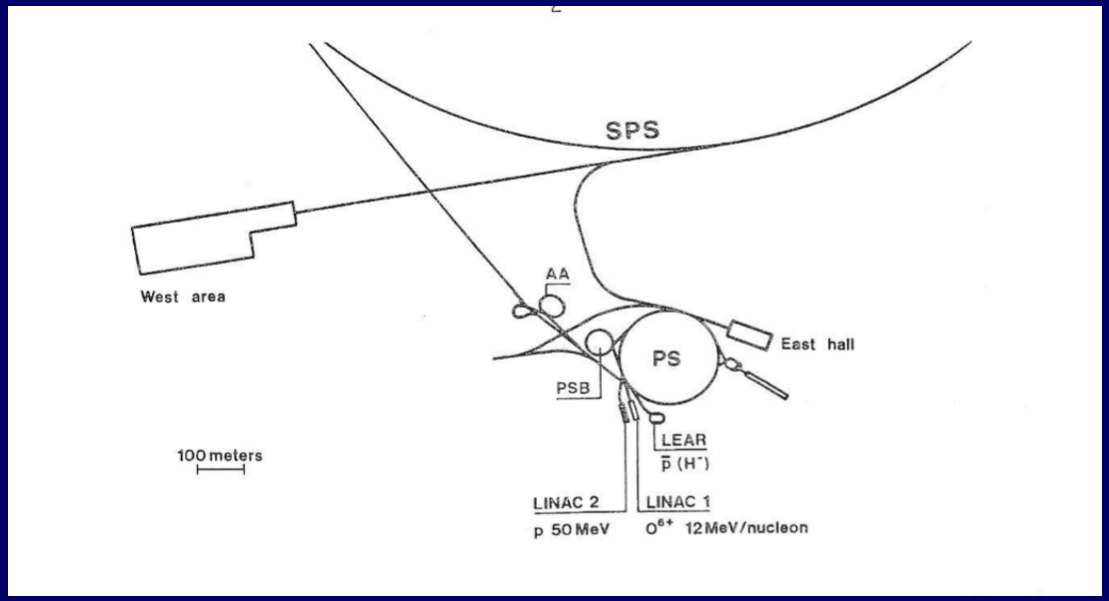
Approved in 1983 as PS190 for the PS; later re-approved as NA35 and WA80 for the SPS

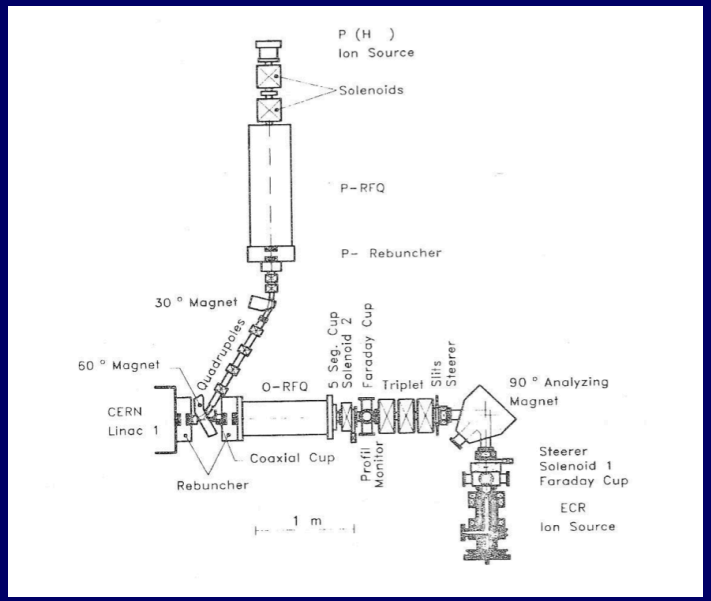
Convergence at CERN 1983: Contract CERN-GSI-LBL

Construction of an $^{16}O/^{32}S$ injector for LINAC1

New elements: ECR Ion Source (R. Geller, Grenoble), pre-tested at GSI

RFQ: LBL Berkeley; beam transport: GSI





Steps for full acceleration incl. SPS

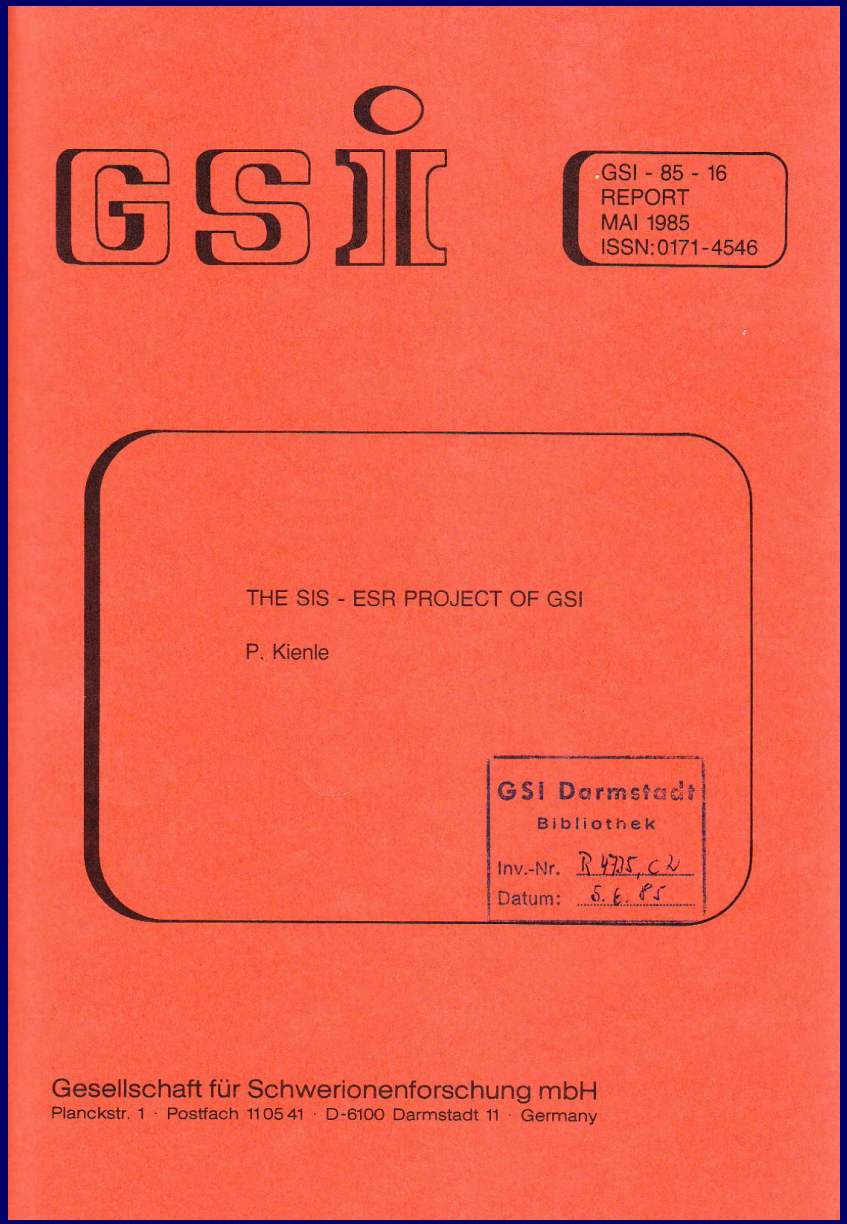
ECR source $^{16}O^{6+}$	5.6 keV/u
RFQ	140 keV/u
LINAC1, Stripper	12.5 MeV/u
Booster+PS	7.0 GeV/u
SPS	60-225 GeV/u

Intensity ~10^8 ions/SPS pulse

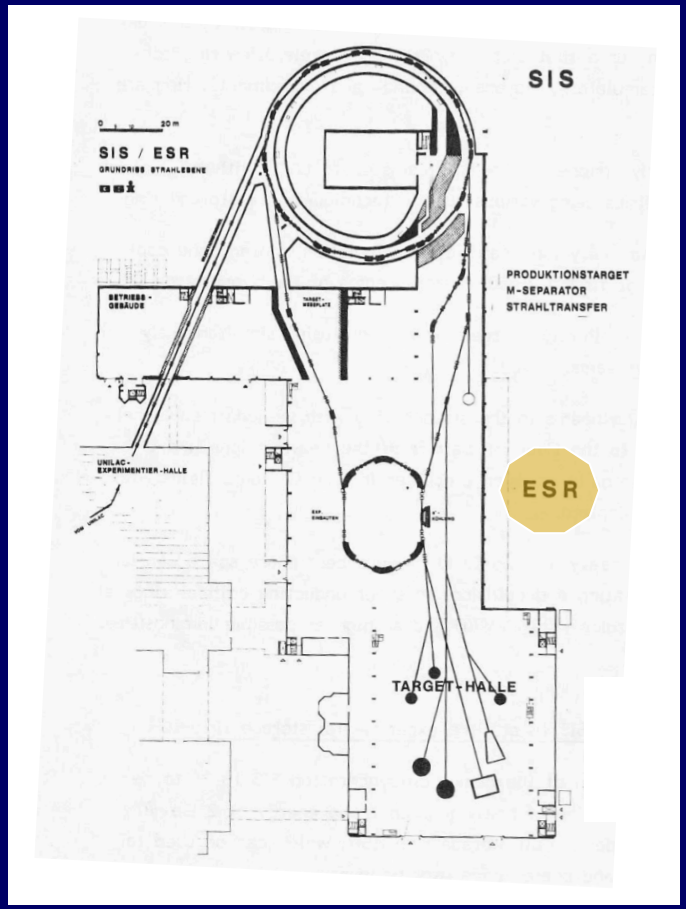
first ^{16}O beams 11/1986

first ^{32}S beams 09/1987

Convergence at GSI: SIS18 + ESR



Leon van Hove's verdict:
'Sunshine at GSI if cooling works, if not total darkness' (1984)



de facto: fragment separator
4π detector (R.Bock), KAOS,
ALADIN (U.Lynen), HADES…

First-generation Experiments ('Recuperation Era')

two experiments with GSI leadership (R.Bock)

experiment/ spokesperson		approved
NA34-2 H.J.Specht	4π calorim.,Si, hadron spectrom., dimuons, γ's (U-scint.cal. + NaI R807/808, NA3 spectrom.,…)	11/1984
NA35 R.Stock	streamer chamber, mid-rapidity calorim.,… (NA5 str.ch.+cal., magn. WA78, NA24 γ PPD,…)	11/1984
NA36 C.R.Gruhn	TPC, calorim., →strange mesons, hyperons (EHS+new TPC,…)	11/1984
NA38 L.Kluberg	dimuon spectrom.,→thermal radiation, charmonia (NA10+active target + EM cal.,…)	09/1985
WA80 H.Gutbrod	plastic ball, EM calorimeters, multiplicity detect. (plastic ball GSI/LBL, Pb-glass,…)	09/1985
WA85/94 E.Quercigh	Ω' spectrometer, → strange mesons, hyperons (Ω' spectrometer + RICH)	04/1987

PRESSE

Laboratoire Européen pour la Physique des Particules
European Laboratory for Particle Physics
Europäisches Laboratorium für Teilchenphysik

PR 23.87
30.10.87

CERN SUBATOMIC ACCELERATORS

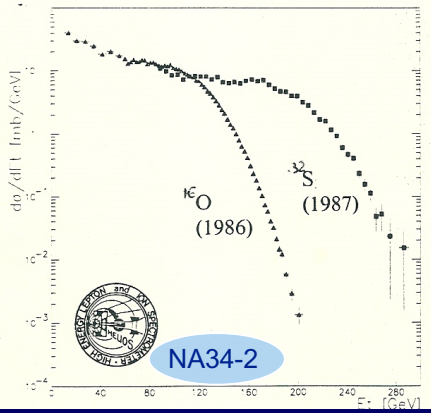
SET UP WORLD RECORD IN ACCELERATOR ENERGY

IN SEARCH FOR "QUARK-MATTER"

Already acknowledged as the world's most versatile system of subatomic particle accelerators, the CERN complex of big machines put on a spectacular performance in late September and early October, accelerating ions (=atomic nuclei) and taking them to the highest energy ever reached in a laboratory.

CERN machines usually work with protons (nuclei of hydrogen carrying one unit of electric charge), but to extend their studies of matter physicists worked with oxygen ions in 1986 and with sulphur ions this year. Ions are atoms stripped of electrons and are 16 times (oxygen) or 32 times (sulphur) heavier than protons carrying multiple (respectively 8 and 16) charges. To provide these ions, one of the CERN injector accelerators was adapted in collaboration with the German Gesellschaft für Schwerionenforschung (GSI - Darmstadt), and the Lawrence Berkeley Laboratory (California) using an ion source developed by the Centre d'Etudes Nucléaires (Grenoble). These research centres have strong traditions of research using ion beams, but only the unique CERN system of interlinked machines could provide the high energies needed to open up new horizons.

From 25 September to 14 October the CERN Super-Proton-Synchrotron (SPS) accelerated a beam of sulphur (^{32}S) atomic nuclei with a total energy of 6.4 TeV (i.e. 200 GeV per nucleon) surpassing its own world record mark of 3.2 TeV set last year in the oxygen nuclei (^{16}O) running period.



CERN Press Release
30.10.1987

First results from a ^{32}S beam (one year after the start with the ^{16}O beam)

Central collisions

S-Au ε = 2.6 (1987)
Pb-Pb ε = 3.2 (1995)

$> \varepsilon_{crit}$ = 1 GeV/fm^3

CERN Heavy-Ion Facility 'LINAC 3' for Pb Beams


CERN 93-01
28 April 1993

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

CERN HEAVY-ION FACILITY DESIGN REPORT

N. Angert (GSI), M.P. Bourgarel (GANIL), E. Brouzet, R. Cappi, D. Dekkers, J. Evans, G. Gelato, H. Haseroth, C.E. Hill, G. Hutter (GSI), J. Knott, H. Kugler, A. Lombardi (INFN, Legnaro), H. Lustig, E. Malwitz (GSI), F. Nitsch, G. Parisi (INFN, Legnaro), A. Pisent (INFN, Legnaro), U. Raich, U. Ratzinger (GSI), L. Riccati (INFN, Torino), A. Schempp (IAP, Frankfurt), K. Schindl, H. Schönauer, P. Têtu, H.H. Umstätter, M. van Rooij, D. Warner, M. Weiss.

Editor: D. Warner

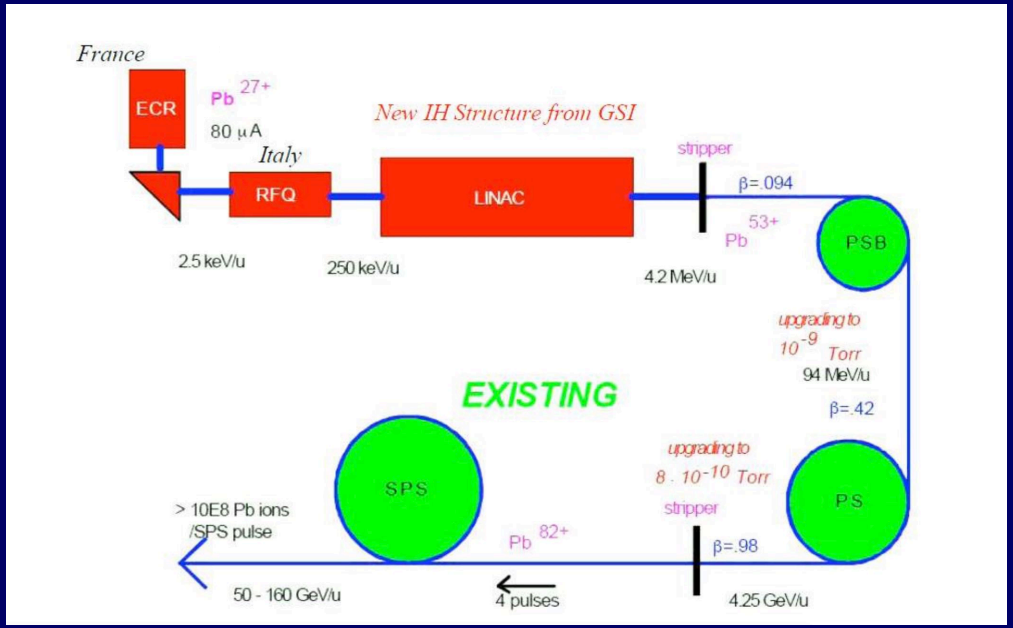
GENEVA
1993

H.Haseroth et al., Concept, CERN 90-01

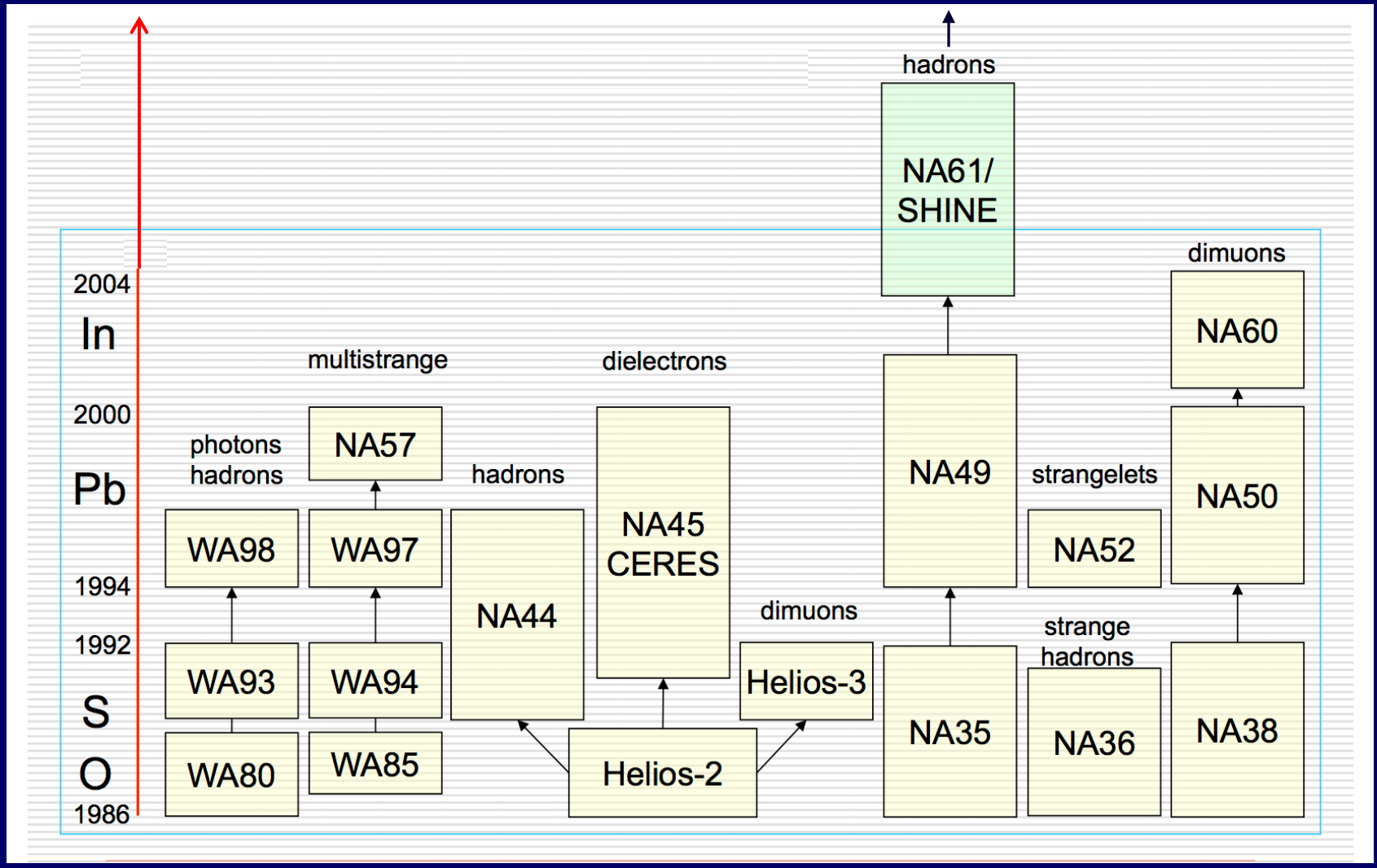
Realization by international collaboration

CERN, GANIL, GSI, INFN LEGNARO, INFN TORINO, IAP Frankfurt
(assistance by Czech Republic, India, Sweden and Switzerland)

First Pb beams in 1994



CERN SPS Heavy-Ion Program incl. the Pb-Beam Era

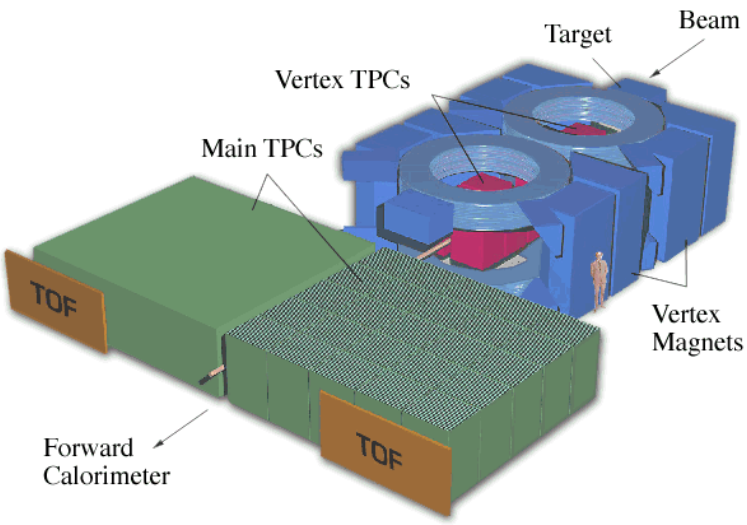


H. Gutbrod

R. Stock/M.Gazdzicki

The seed of NA49 is beating all records in the SPS heavy-ion program…

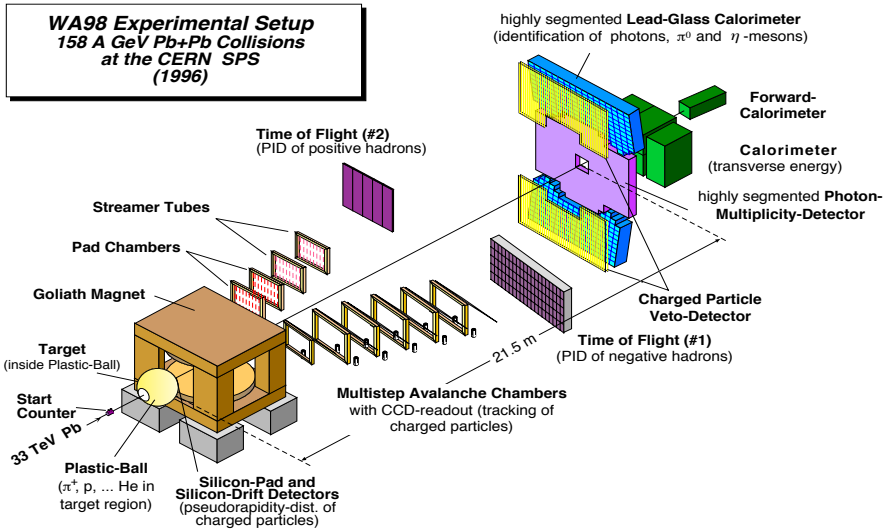
Experimental Setups



NA49, 1st spokesperson R.Stock

'universal' hadron coverage with large acceptance

vertex TPC built by GSI,
main TPC MPI Muenchen,
TOF F.Puehlhofer et al., Marburg



WA98, 1st spokesperson H.Gutbrod

hadrons with large acceptance

photons (hadron decays and direct)
R.Santo et al., Muenster

Hadron Yields – Statistical Hadronization

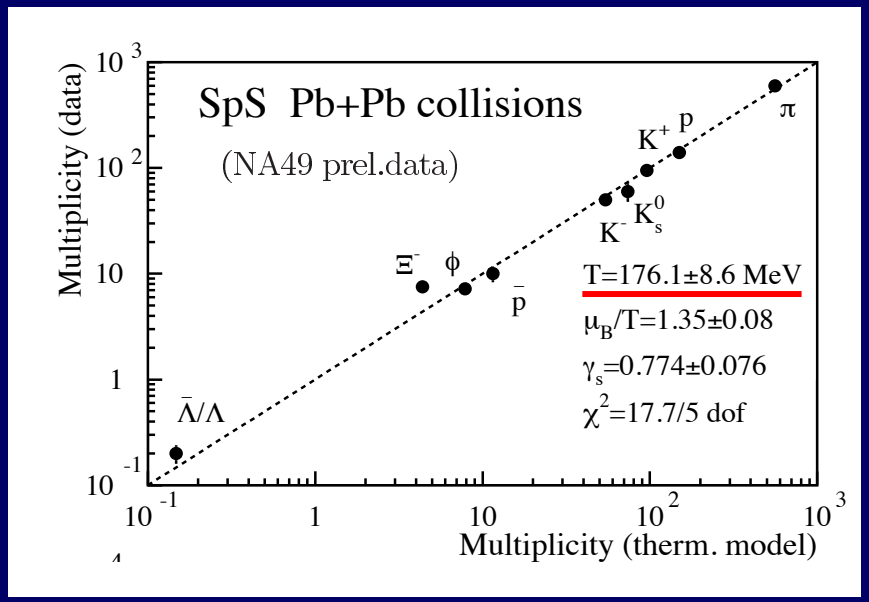
Since pp: Statistical Bootstrap Model (SBM), R.Hagedorn, Nuovo Cim.S. 1965
- populate hadron species according to phase space probabilities -

for AA:
grand canonical ensemble

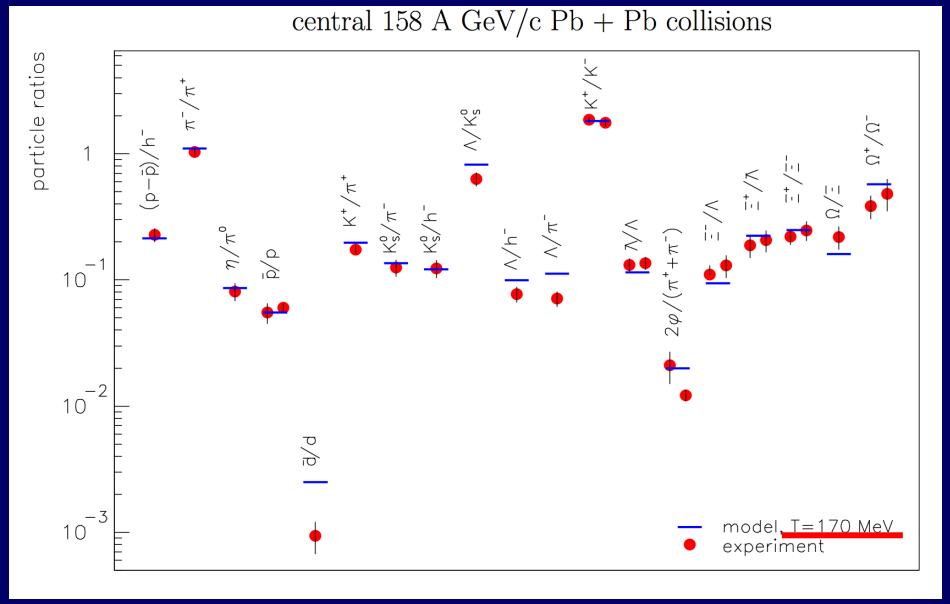
$$n_i = N/V = \frac{g_i}{2\pi^2}\int_0^\infty \frac{p^2\,dp}{\exp((E_i-\mu_i)/T)\pm 1} \qquad \mu_i = \mu_B B_i + \mu_S S_i + \mu_{I_3} I_i^3$$

free parameters from fits to the data: T, μ_B (V, μ_S, μ_{I3} from conservation laws)

F.Becattini, J.Cleymans, K.Redlich et al.

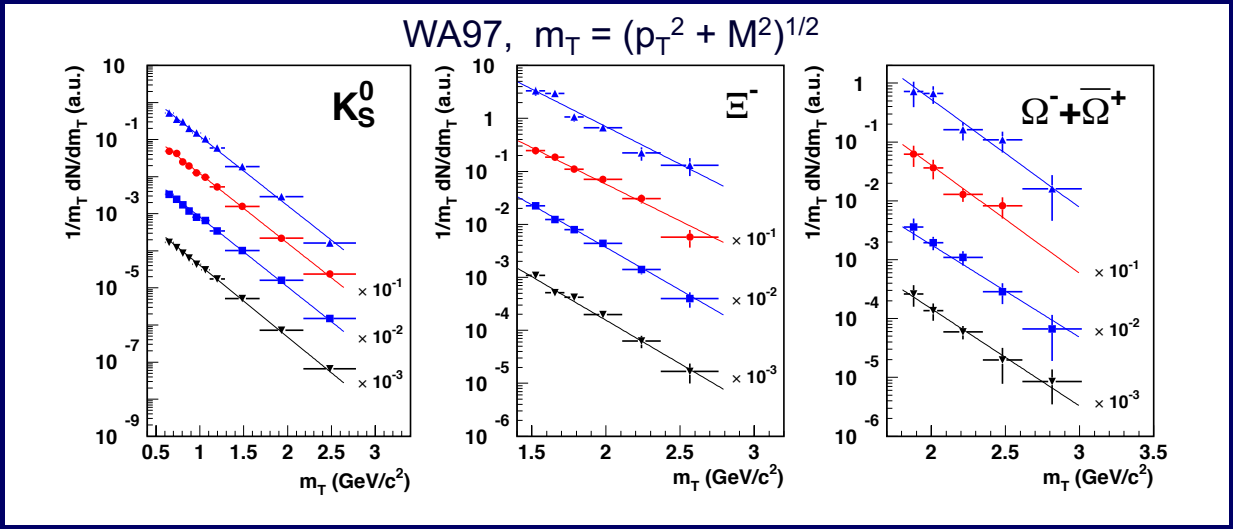


P.Braun-Munzinger, J.Stachel et al.



perfect agreement between yield data and model description

Radial flow – 'Hubble-like' expansion of the fireball

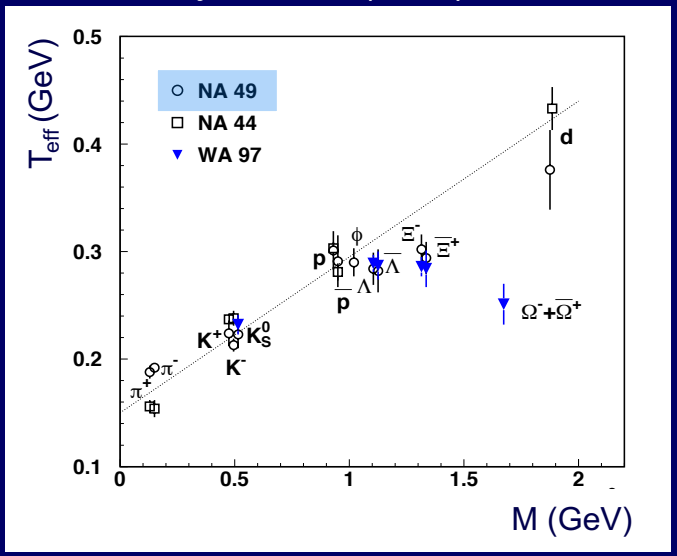


all m_T spectra exponential

fit with
$1/m_T\, dN/m_T \sim \exp(-m_T/T_{eff})$

T_{eff} – 'effective temperature'

Eur.Phys.J C 14 (2000) 633



linear rise of T_{eff} with M

→ two components in p_T/m_T spectra:
thermal and radial collective expansion

roughly $T_{eff} \sim T_f + M \langle\beta_T\rangle^2$

precise procedure: 'Blast wave' analysis

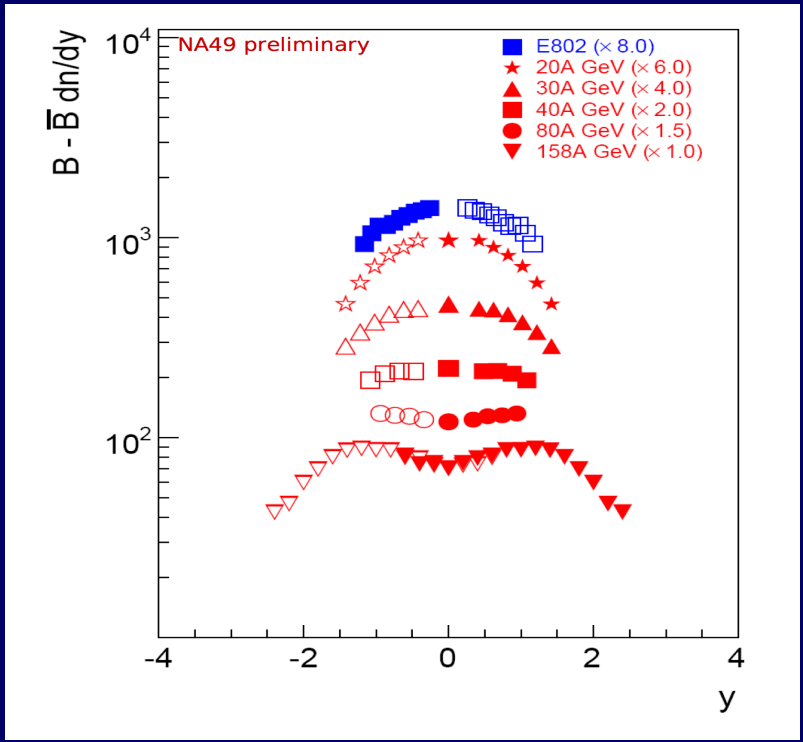
T_f temperature at thermal freeze-out: 100-120 MeV
v_T flow velocity at thermal freeze-out: ~ 0.5c

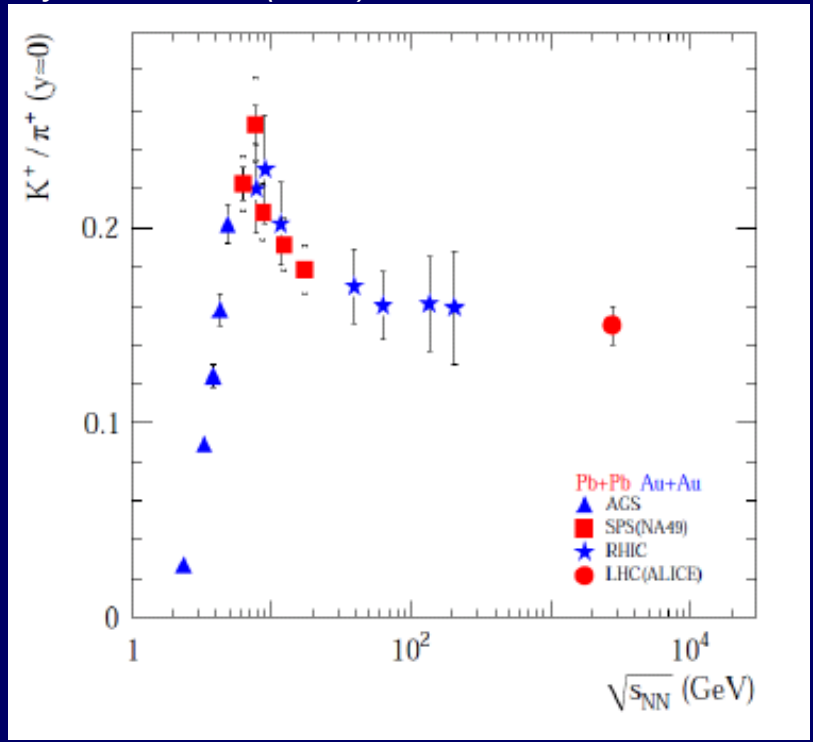
Almost explosive expansion → strong pressure at the earlier collision stages

NA49 Results at lower SPS Beam Energies

systematic energy scan for 158, 80, 40, 30, 20 AGeV

Phys. Rev. C77 (2008) 024903 for AGS and NA49





increased stopping at lower energies

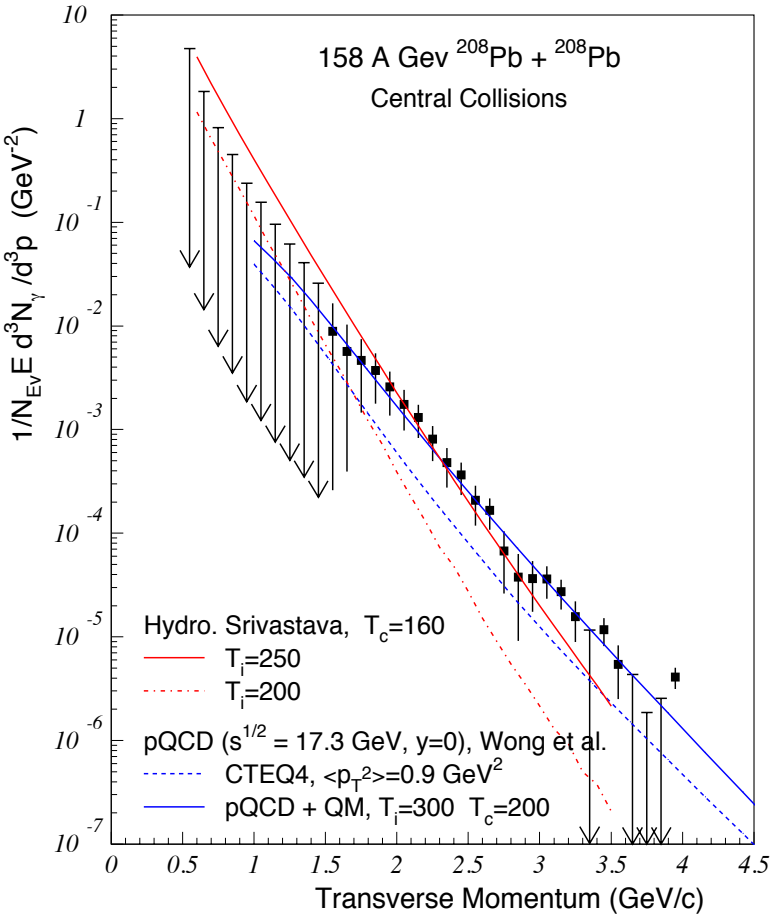
the only structure in the beam energy dependence of any heavy ion results

Onset of deconfinement? M. Gazdzicki

(ongoing program of NA61)

WA98: Excess of real photons

PRL 85 (2000) 3595; nucl-ex/0006007 (PRC)



First and only excess of real photons seen at SPS (only upper limits by NA34-2 and CERES/NA45)

interpretation of excess as direct (thermal) photons on top of hard processes

quantitative description by theory ambiguous

Press Conference – ‘New State of Matter created at CERN’

PRESS RELEASE

Organisation Européenne pour la Recherche Nucléaire
European Organization for Nuclear Research

PR01.00
10.02.00

New State of Matter created at CERN

At a special seminar on 10 February, spokespersons from the experiments on CERN's Heavy Ion programme presented compelling evidence for the existence of a new state of matter in which quarks, instead of being bound up into more complex particles such as protons and neutrons, are liberated to roam freely.

Theory predicts that this state must have existed at about 10 microseconds after the Big Bang, before the formation of matter as we know it today, but until now it had not been confirmed experimentally. Our understanding of how the universe was created, which was previously unverified theory for any point in time before the formation of ordinary atomic nuclei, about three minutes after the Big Bang, has with these results now been experimentally tested back to a point only a few microseconds after the Big Bang.

Professor Luciano Maiani, CERN[1] Director General, said *"The combined data coming from the seven experiments on CERN's Heavy Ion programme have given a clear picture of a new state of matter. This result verifies an important prediction of the present theory of fundamental forces between quarks. It is also an important step forward in the understanding of the early evolution of the universe. We now have evidence of a new state of matter where quarks and gluons are not confined. There is still an entirely new territory to be explored concerning the physical properties of quark-gluon matter. The challenge now passes to the Relativistic Heavy Ion Collider at the Brookhaven National Laboratory and later to CERN's Large Hadron Collider."*

The aim of CERN's Heavy Ion programme was to collide lead ions so as to create immensely high energy densities which would break down the forces which confined quarks inside more complex particles. A very high energy beam of lead ions (33 TeV) was accelerated in CERN's Super Proton Synchrotron (SPS) and crashed into targets inside the seven different experimental detectors. The collisions created temperatures over 100 000 times as hot as the centre of the sun, and energy densities twenty times that of ordinary nuclear matter, densities which have never before been reached in laboratory experiments. The collected data from the experiments gives compelling evidence that a new state of matter has been created. This state of matter found in heavy ion collisions at the SPS features many of the characteristics of the theoretically predicted quark-gluon plasma, the primordial soup in which quarks and gluons existed before they clumped together as the universe cooled down.

The lead beam programme started in 1994, after the CERN accelerators has been upgraded by a collaboration between CERN and institutes in the Czech Republic, France, India, Italy, Germany, Sweden and Switzerland. A new lead ion source was linked to pre-existing, interconnected accelerators, at CERN, the Proton Synchrotron (PS) and the SPS. The seven large experiments involved measured different aspects of lead-lead and lead-gold collisions. They were named NA44, NA45, NA49, NA50, NA52, WA97/NA57 and WA98. Some of these experiments use multipurpose detectors to measure and

[1] CERN, the European Laboratory for Particle Physics, has its headquarters in Geneva. At present, its Member States are Austria, Belgium, Bulgaria, the Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Italy, Netherlands, Norway, Poland, Portugal, the Slovak Republic, Spain, Sweden, Switzerland and the United Kingdom. Israel, Japan, the Russian Federation, the United States of America, Turkey, the European Commission and UNESCO have observer status.

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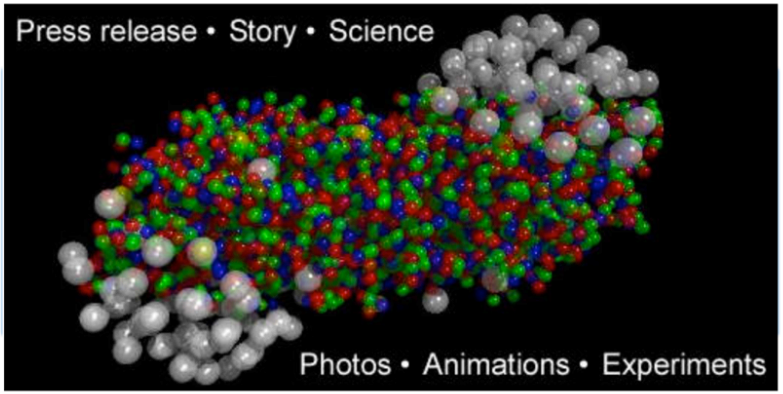


Preparatory Workshop Chamonix 1998

Press Conference CERN 10 Feb 2000

- Talks by all experiments
- Paper PR01 U. Heinz and M. Jacob

‘White Paper’- U. Heinz and M. Jacob (arXiv:nucl-th/0002042v1 16 Feb 2000)

R. Bock and RHIC at BNL

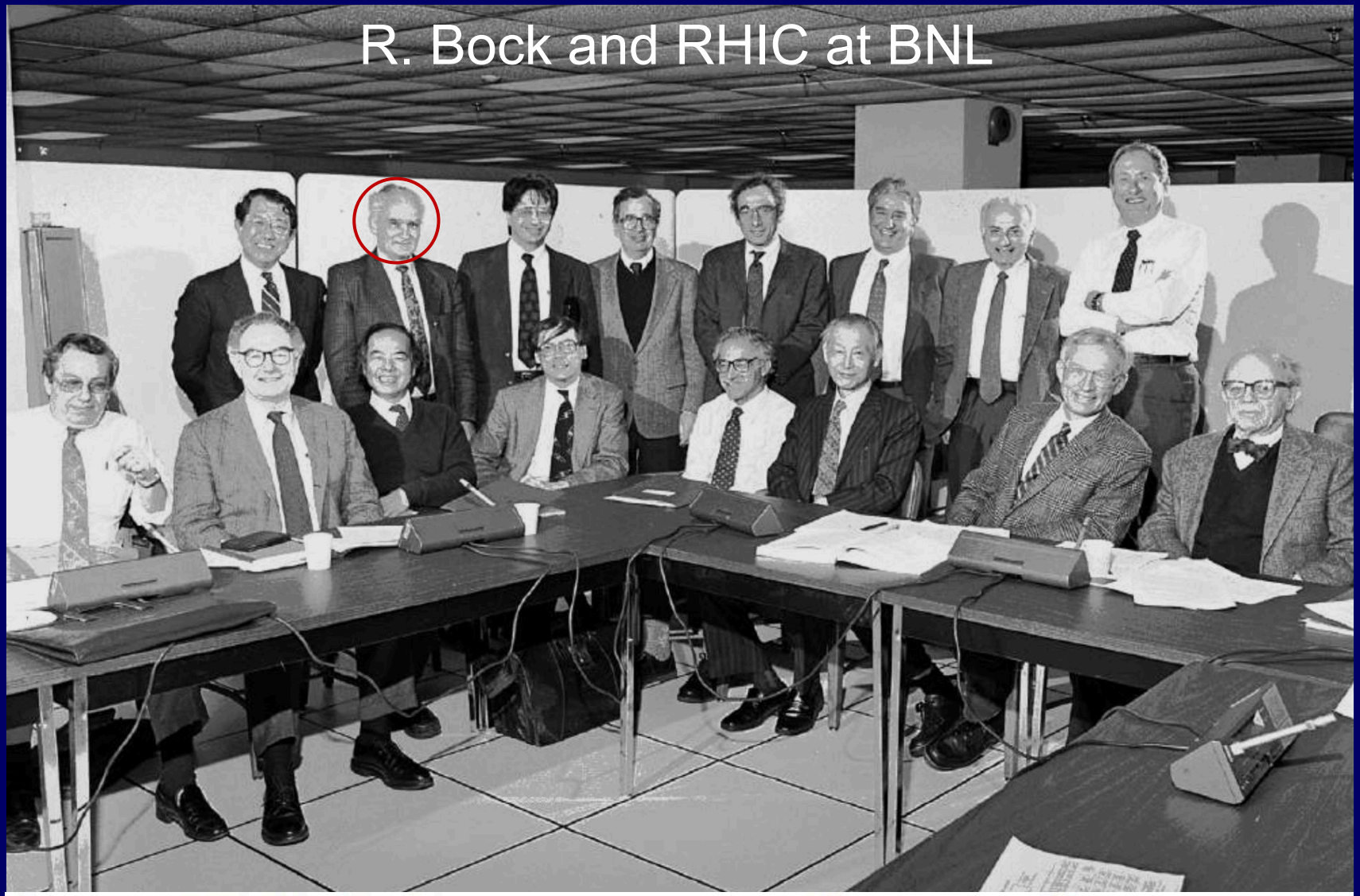


Figure 3. 1991 RHIC Policy Committee. Front row: J Ball, J Sandweiss, T D Lee, J Symons, E Henley, S Hayakawa, W Willis, H Feshbach; back row: S Ozaki, R Bock, N P Samios, J Schiffer, G Baym, P Darriulat, M Schwartz, A Kerman.

Member of the RHIC Policy Committee 1991-1995

GSI Management Structure during 1992-1999

Directorate structure:
(now incl. outsiders, ignoring the rigid GF/GmbH structure)

Scientific secretary: D. Gross

Chairman	H.J.Specht
Research	V. Metag (Giessen)
Accelerators	N. Angert
Infrastructure	W. von Rüden (CERN)
Administration	H. Zeitträger

Participation of the 'Leitende Wissenschaftler' in the routine meetings
(P.Armbruster, R.Bock, J.Kluge)

The 4 Scientific Directors since 1969:
Schmelzer, zu Putlitz, Kienle, Specht (1993)

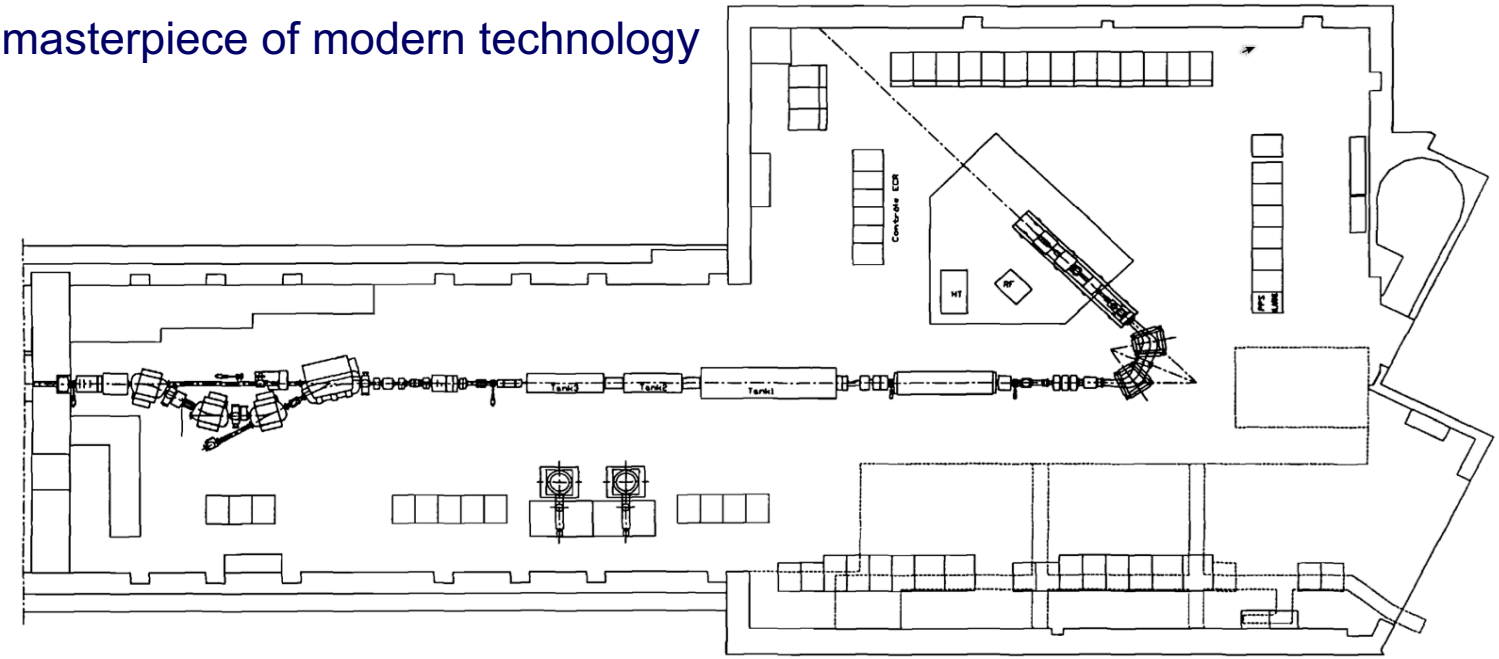
Original Directorate in 1970/71:
Armbruster, Brix (till 1971), Schuff, Herrmann, Bock, Böhne, Schmelzer (90th birthday, 1998)

Congratulations and all the best towards 100…

BKP

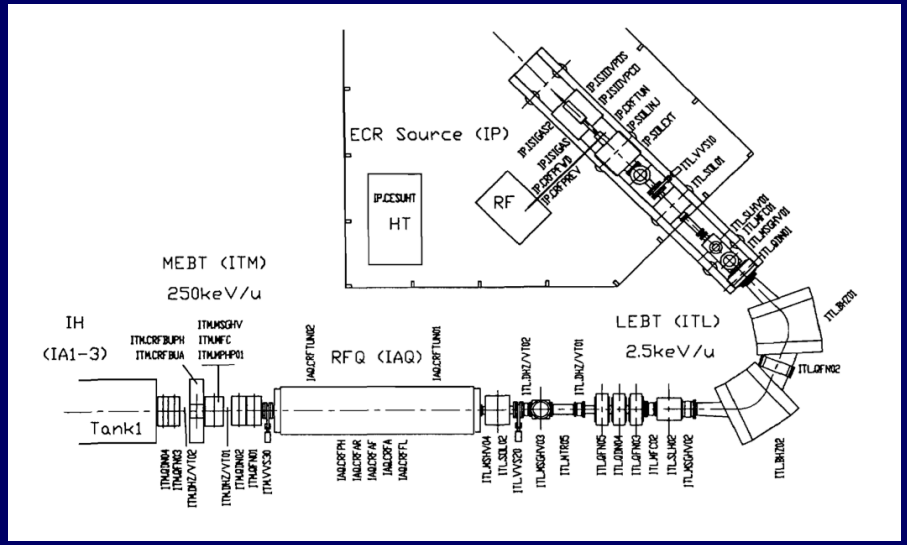
CERN Heavy-Ion Facility ‘LINAC 3’ for Pb Beams

masterpiece of modern technology



Steps for full acceleration incl. SPS

ECR source	Pb^{27+}	2.5 keV/u
RFQ		250 keV/u
LINAC 3		4.2 MeV/u
Stripper	$Pb^{27+} \rightarrow Pb^{53+}$	
Booster+PS		4.25 GeV/u
Stripper	$Pb^{54+} \rightarrow Pb^{82+}$	
SPS		20-158 GeV/u
Intensity		~10^8 Pb-ions/SPS pulse



What next at the SPS?

Beam Energy Scan from 20 - 160 AGeV

$\sqrt{s}$ = 6 - 17 AGeV

Precision studies of deconfinement and chiral phase transitions

onset of transitions	structure in scan
order of transitions	extended τ_{FB}
critical point	direct proof for chiral mixing (ρ-a_1)

Already running: NA61 (energy + atomic number scans)

Under discussion: successor to NA60 (highest luminosities)

Others?