60 Jahre Physik
Faszination der Vielfalt

Hans J. Specht
Universität Heidelberg

Heidelberg, 28. Januar, 2016

Die frühen Jahre 1956-1965

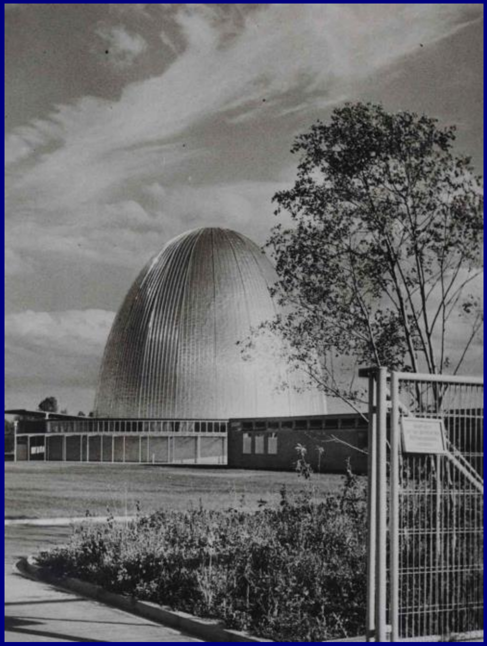
Studium an LMU München, TH München und ETH Zürich 1956-1959
TH München 1960-1965; Diplom 1962; Promotion 1964

Das H. Maier-Leibnitz Umfeld in München 1961 bis 1965
Zentrum: Forschungsreaktor München (FRM)

1952 Berufung H. Maier-Leibnitz von Heidelberg an die TH München

1955 1.Conference ‘Peaceful Uses of Atomic Energy’, Genf

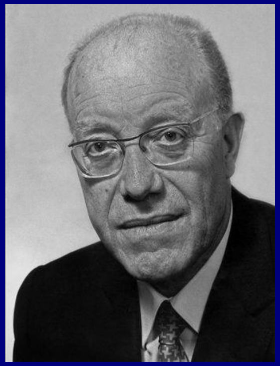
1956 Unterzeichnung des FRM-Kaufvertrags; Baubegin FRM Nov.; Inbetriebnahme Okt.1957 (<1a)



1960’s Eine wissenschaftliche Goldgrube:

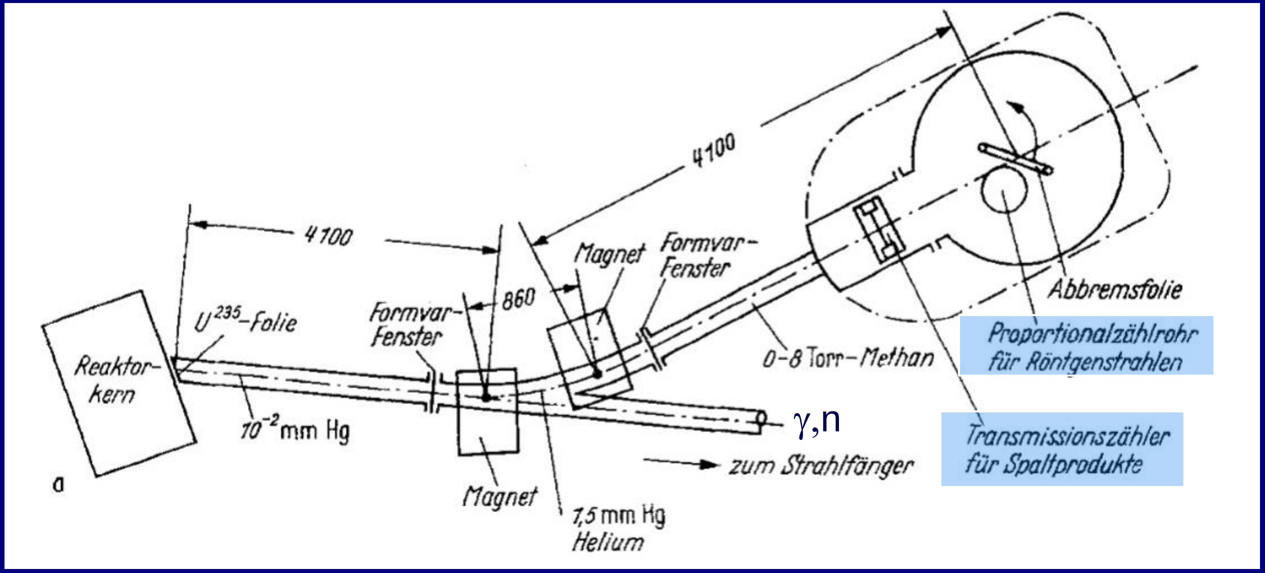
“gleichzeitig 100 Diplomanden und 100 Doktoranden”;
“jeder ist für seine Arbeit verantwortlich”,“jeder hilft jedem”
(Zitate ML im Emeriti Kolloquium Heidelberg 1991)

1963 Genehmigung einer Department-Struktur
9→16 Lehrstühle; ~ 240 Planstellen
(Hilfe durch R.Mössbauer, Nobelpreis 61)



1965 Beginn des Physik-Departments
(unmittelbar mehrere Neuberufungen)

Strahlrohr “Massenseparator” (P.Armbruster) am FRM
Ergänzung “Atomphysik” für meine Dissertation



Gasgefüllter Massenseparator:

U-235 Target nahe am Reaktorkern

2 stark-fokussierende Magnete (CERN PS);
He-Gasfüllung von 1.5 Torr im Feldbereich

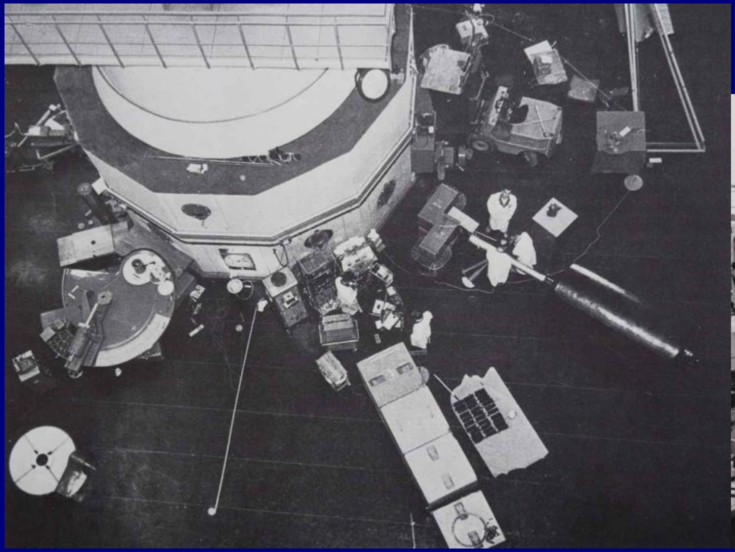
→ Massentrennung der Spaltfragmente mit $\langle A_L \rangle \sim 100$ und $\langle A_S \rangle \sim 140$ bei 1/0.5 MeV/u
Intensität 300/s; $\sigma_m \sim 4\%$; Energie Variation

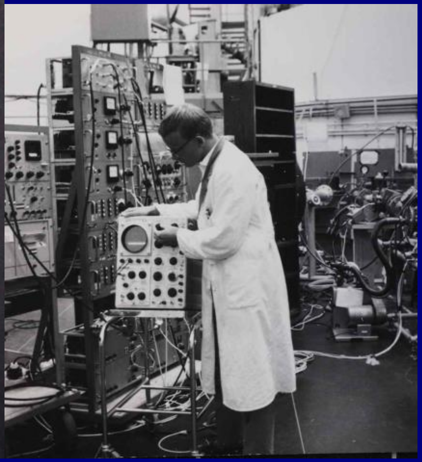
Experimentbereich:

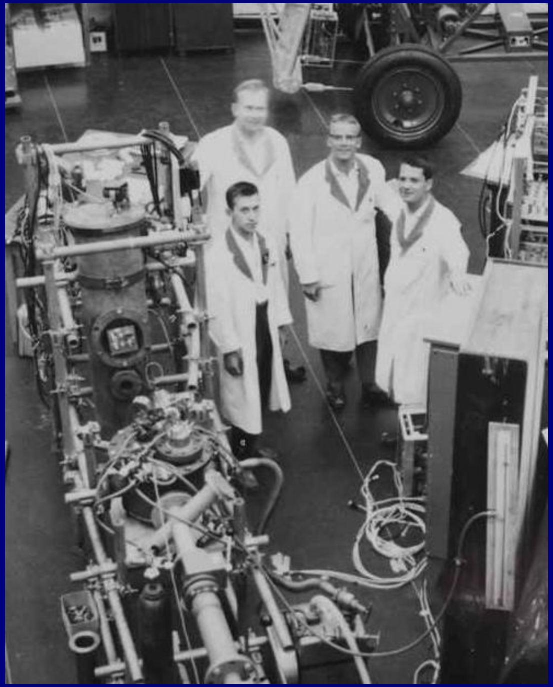
Kernphysik:
β- und γ-Spektroskopie
an gestoppten Spaltfragmenten

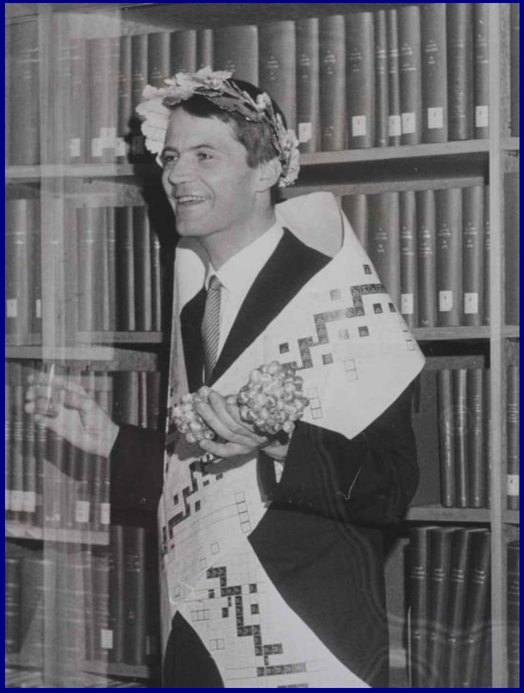
Atomphysik:
Spektroskopie von Röntgenspektren aus A-A Kollisionen im gesamten Targetbereich von Be bis Pb

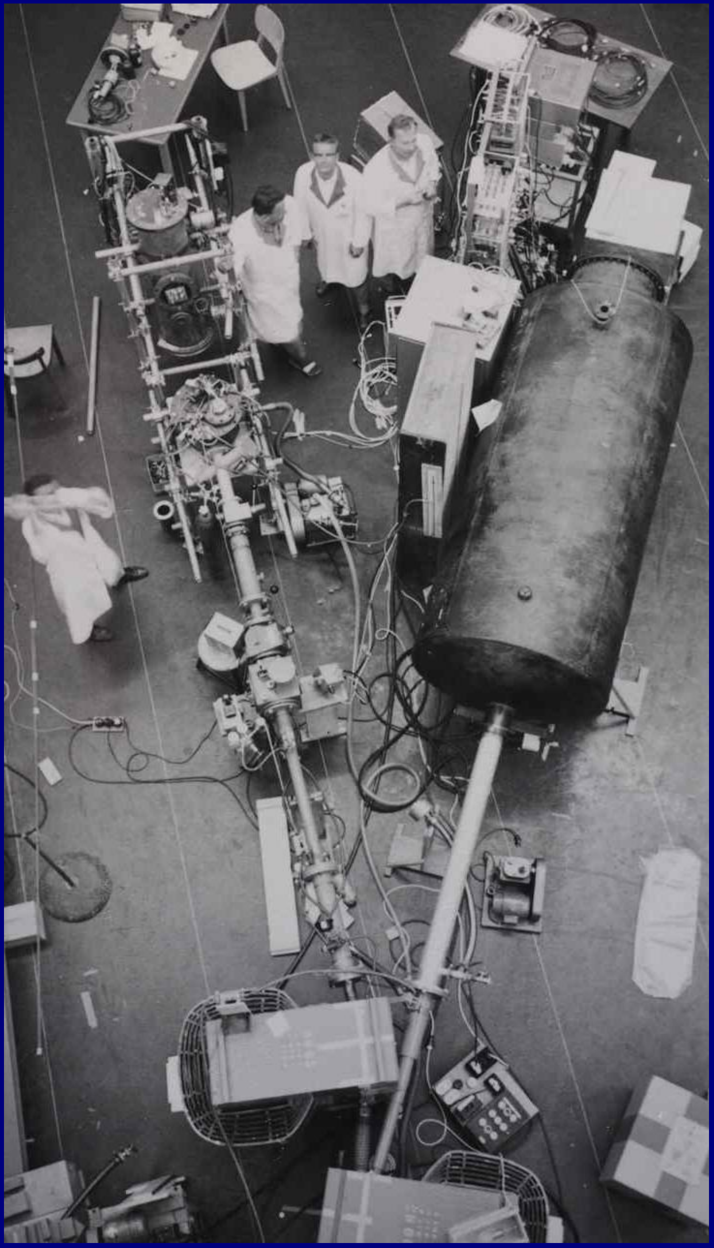
Photos 1959/1963-64





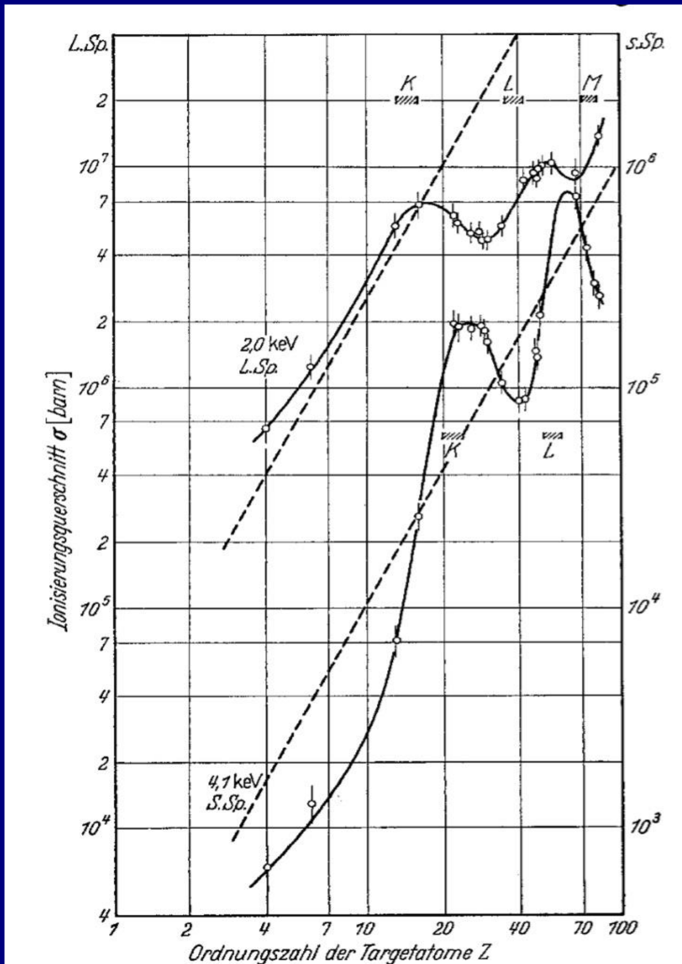




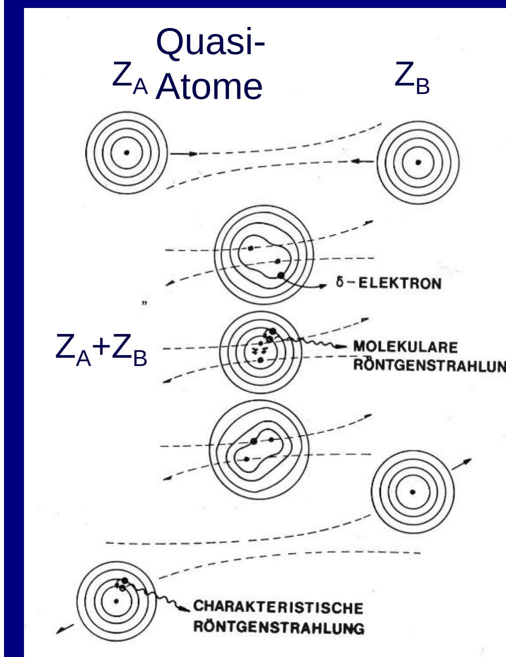


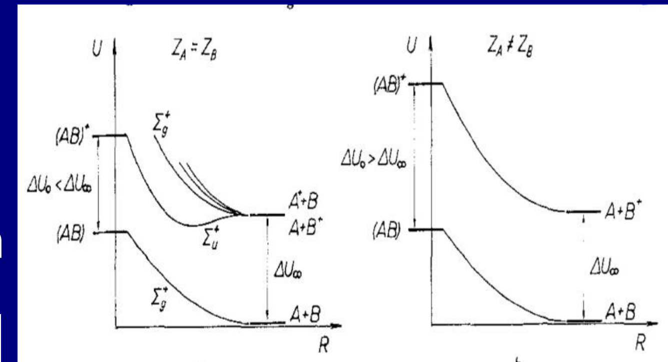
P. Armbruster (Habilitation 1964) mit einigen seiner Doktoranden

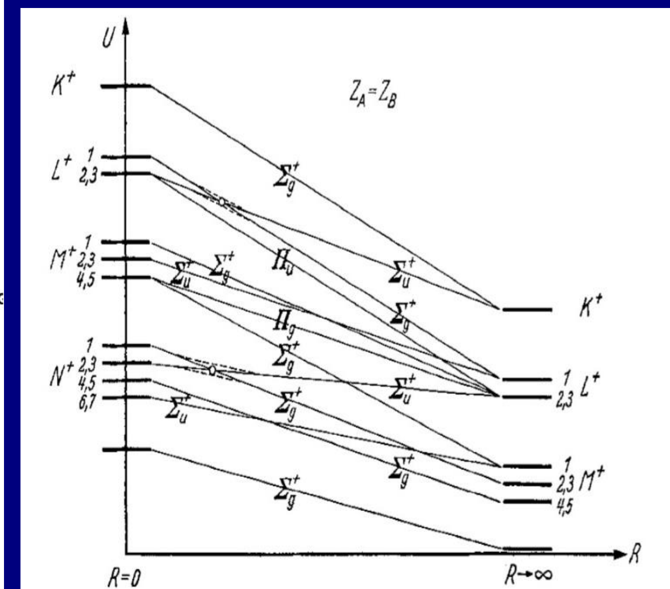
Zentrale Resultate der Dissertation



Fast-adiabatische
Atom-Kollisionen
$v_{Kern} << v_{Elektron}$
für die inneren Schalen







Ionisations-Querschnitt der L-Schalen
von $<Z_L> = 38$ und $<Z_S> = 54$ vs. Z_{target}
Resonanzartige Überhöhung
bei ”Energie-Entartung” (L-K, L-L, …)

“Korrelations Diagramm”: MO Niveauschema
für innere Elektronen-Schalen
Grenzfall: vereinigtes “Quasi-Atom” (Z_A+Z_B)
Korrekte Interpret. vor Fano/Lichten, PRL1965

→ Eröffnung des Gebiets der “Quasi-Atome” (wieder aktuell als MIMS)

Publikation der Dissertation 1965: in deutscher Sprache

Hintergrund für Deutsch:

Favorisiert von H. Maier-Leibnitz

Editor Z. für Physik

Zeitschrift für Physik 185, 301—330 (1965)

Aus dem Laboratorium für Technische Physik der Technischen Hochschule München

Ionisation innerer Elektronenschalen bei fast-adiabatischen Stößen schwerer Ionen *

Von

Hans J. Specht

Mit 19 Figuren im Text

(Eingegangen am 28. Januar 1965)

Characteristic X-rays produced in nearly adiabatic collisions when fission products of 5—80 MeV energy are stopped in various materials have been studied using proportional counter detection. The cross sections for the ionization of inner electronic shells of both the colliding particles were measured as a function of the velocity and the mass of the fragments and the atomic number of the target atoms. The measured cross sections range from 10^{-22} to 10^{-16} cm^2. There is no agreement with the values predicted on the basis of a simple Born approximation description. Characteristic maxima were found in the dependence of the cross section on the atomic number of the projectile whenever the binding energy of the excited electron equals the electron binding energies of the various inner shells of the projectile. The cross sections depend less strongly on the velocity of the projectiles than predicted by the simple theory. The measured X-ray quanta have energies from 1.2 to 11.4 keV. The observed energy values exceed the theoretical ones by about 0.10 keV for projectile atomic numbers >10. A qualitative explanation of the various effects is presented.

1. Einführung

Beim Beschuß der Atome eines Targets mit geladenen Teilchen wie Protonen oder schweren Ionen tritt — neben anderen Prozessen — Anregung und Ionisation in den Elektronenhüllen der Stoßpartner auf. Dabei ist auch eine Ionisation *innerer* Elektronenschalen möglich; sie kann nachgewiesen werden durch Messung der charakteristischen Röntgen-Strahlung, die bei der Auffüllung der betreffenden Schale emittiert wird. Die Berücksichtigung der Fluoreszenzausbeute erlaubt dann Aussagen über den Ionisierungsquerschnitt.

Die Untersuchung solcher Prozesse hat Bedeutung für das Problem des Energieverlustes geladener Teilchen in Materie, ferner für Messungen von niederenergetischer γ-Strahlung bei Kernreaktionen mit schweren Ionen, bei denen solche Ionisationsprozesse mit nachfolgender Röntgen-Strahlung einen erheblichen Untergrund bilden können, schließlich für das Problem der bei der Kernspaltung emittierten prompten Röntgen-Strahlung, deren Herkunft bisher umstritten ist.

* Auszug aus der von der Fakultät für Allgemeine Wissenschaften der Technischen Hochschule München genehmigten Dissertation.

Konsequenz:

Resultate unter den Atomphysikern speziell in USA bis 1969 unbekannt

“Entdecker”: R.Brandt, N.Y. ….

Postdoc in Chalk River/Canada 1965-1968

Chalk River Nuclear Laboratories (CRNL)

1944 Foundation as a spin-off of the Montreal Research Laboratory of the NRC

1945 First Nuclear Reactor outside the US

1952 Atomic Energy of Canada Limited (AECL) Parallel development of Nuclear Power Reactors → (CANDU, highly successful)

1957 National Research Reactor (NRU) Still operating today (1/3 of world production of medical isotopes)

1950's Start of Basic Research in nuclear physics, neutron physics (Nobel Prize 1994), Material Sciences,…

1959 Nuclear Physics: first Tandem Accelerator EN-1 world-wide (6 MV); same at MPI-HD1962 (1st in EU)

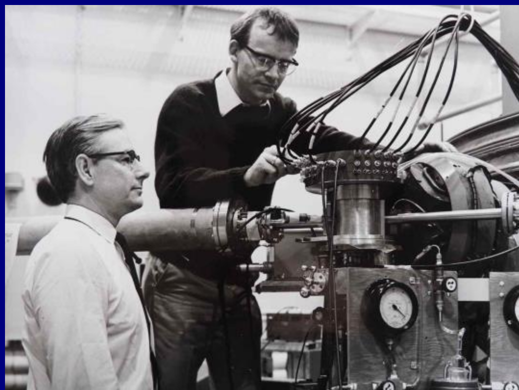
Opening of light-ion physics by A. Bromley et al. ('C-C Molecules')

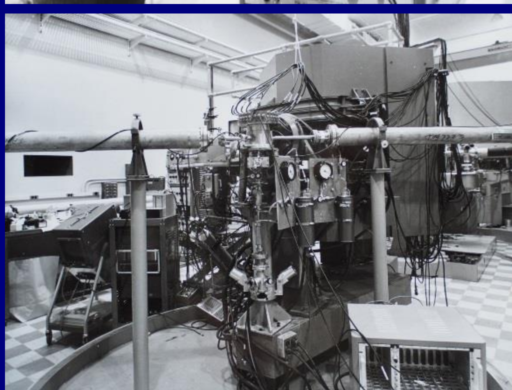
1967 Start of the MP Tandem (12 MV) (just in time for me)

Very competitive program both in nuclear reactions and spectroscopy

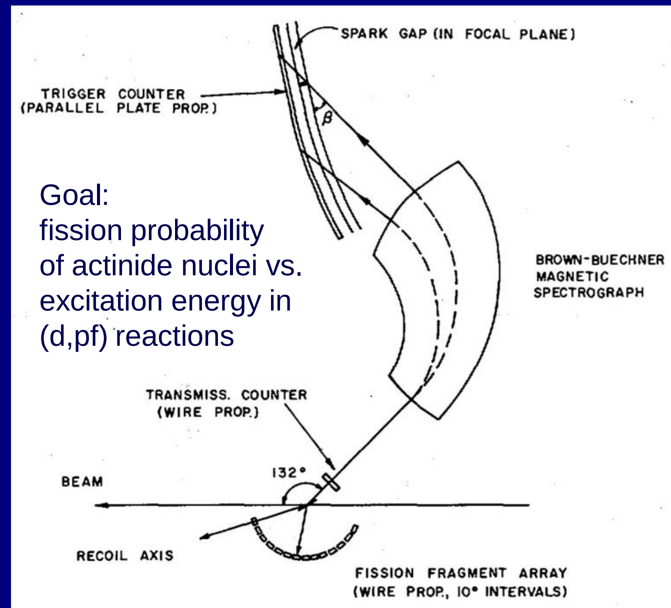
1980's Decline due to the competition by the new Canadian National Laboratory TRIUMF (1974)

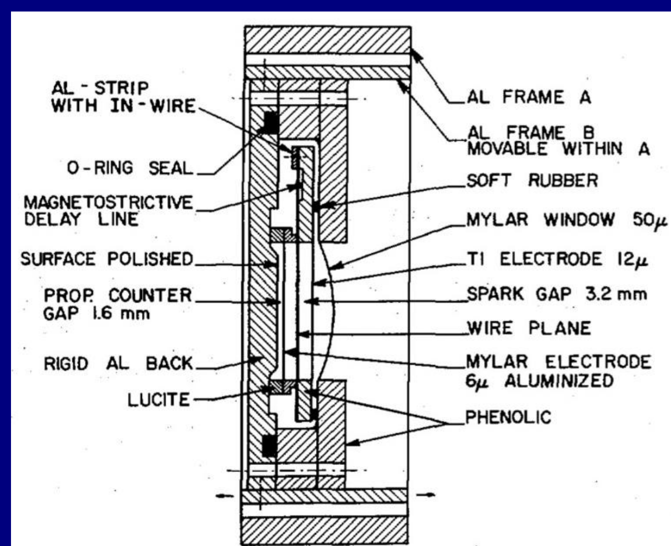
Spark Chamber Set-up for a Magnetic Spectrograph

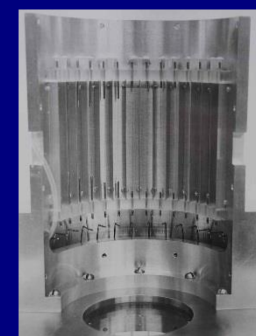


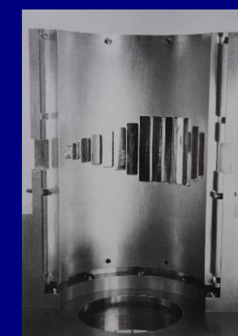


Goal:
fission probability
of actinide nuclei vs.
excitation energy in
(d,pf) reactions



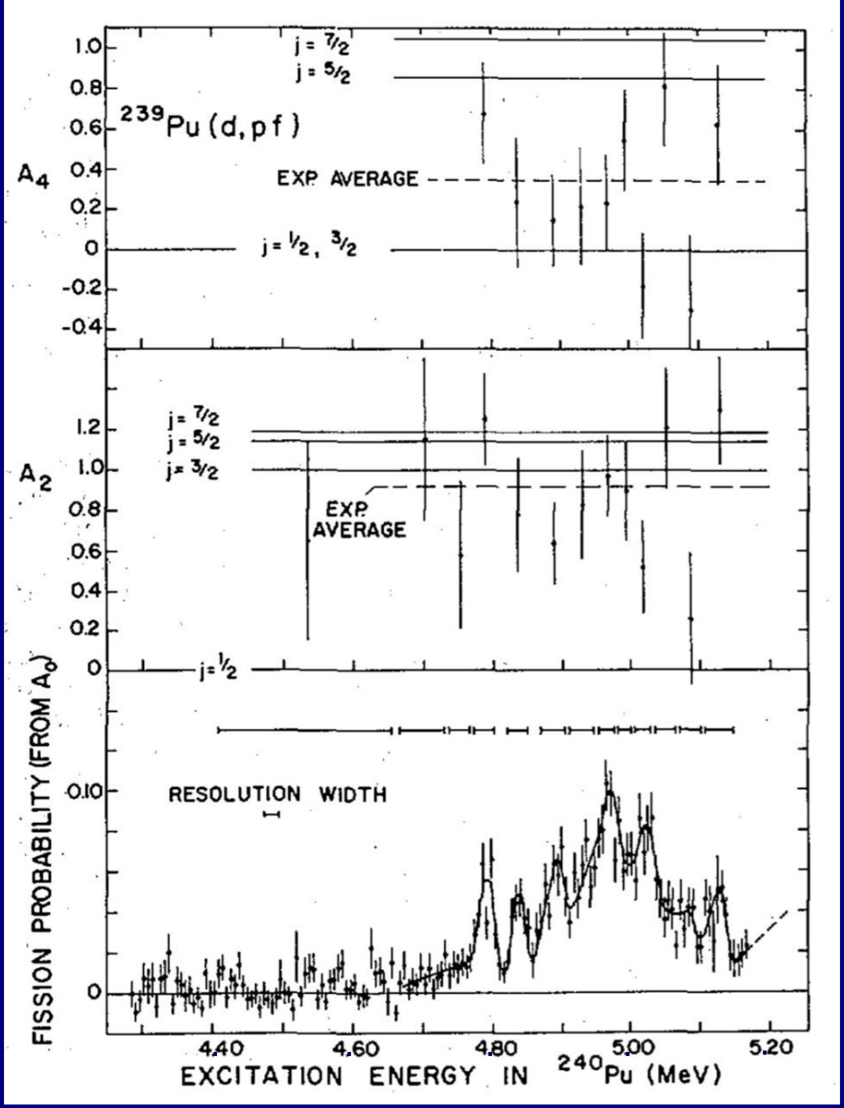






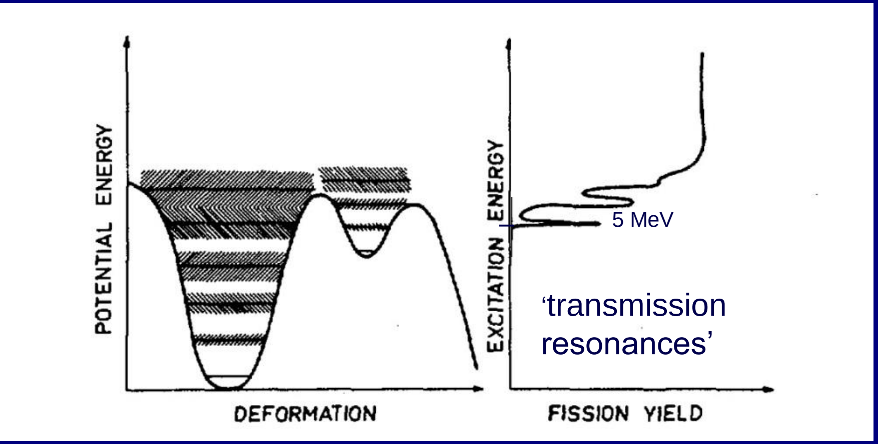
J.C.D. Milton, J.S.Fraser and HJS (Milton: Boss of Nucl.Phys., later of Physics Division)

A High-Resolution Study of the ^{239}Pu (d, pf) - Reaction



Change of emphasis in fission research:

From the properties of the fission fragments (done at nuclear reactors) to the properties of the highly deformed fissioning nucleus (done at accelerators)



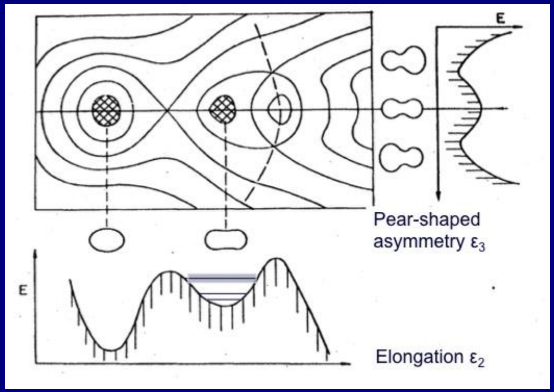
The sensation in these years:
The fission barrier may be double-humped

→ Measure the excitation function of a fissionable nucleus to search for structure

First evidence for sub-structure of vibrational entrance-channel states

LMU München 1969-1973

New ‘Campus’ Garching close to the FRM in the 1970’s



1969 Joint ‘Beschleuniger-Laboratorium’ TH und LMU
(4 Professors H4 each)
LMU: Meyer-Berkhout, de Boer, Skorka, Zupancic
Start of the Emperor Tandem MP-8 1970/71

1970 Dedicated buildings for the Physics Department of the TH and the ‘Sektion Physik’ of the LMU Munich

1970 Habilitation; 1971 Professor H3

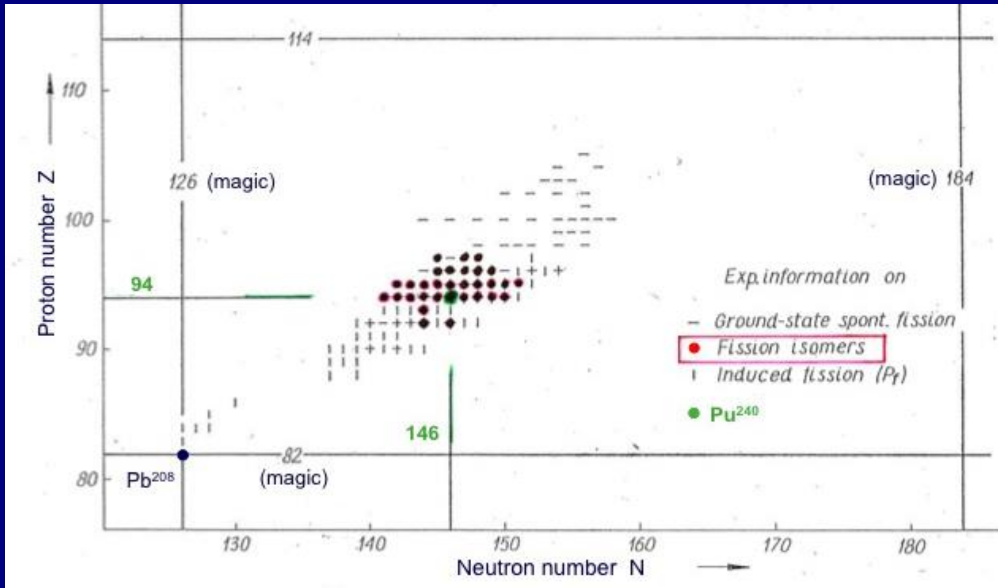
Independent research group on nuclear fission
Collaboration with E. Konecny, Physics Department THM

Guiding topic: the shape of the fission barrier

- Spectroscopy of rotational states in the 2nd minimum (Diss. D. Heunemann, J. Weber)
- Spectroscopy with the (d,pf) reaction at the Q3D (Diss. P. Glässel, Dipl. R. Männer)
- Fission fragment mass distributions (relation to ε_3)

Summary of all results: ‘Nuclear Fission’, HJS, Rev. Mod. Phys. 46 (1974) 773

Shape of the Barrier: THE issue in Nuclear Fission in the 1970's

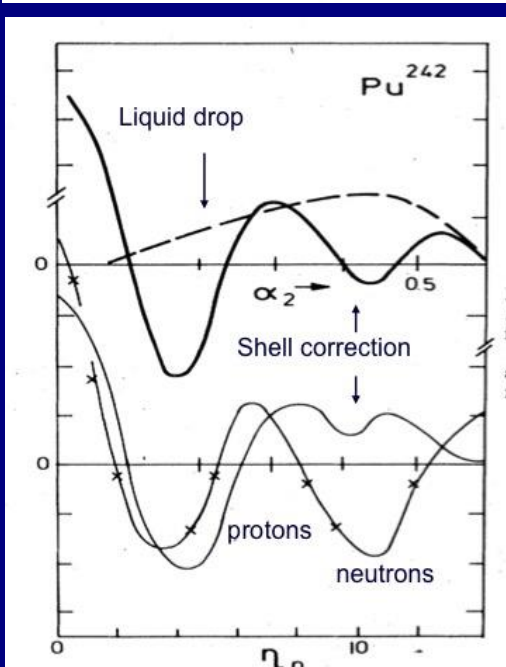


Spontaneously Fissioning Isomers:

detection by Polikanov, Dubna 1962
half-life range 10^{-9}-10^{-3} s

usual spontaneous fission
half-life range 10^4-10^9 y

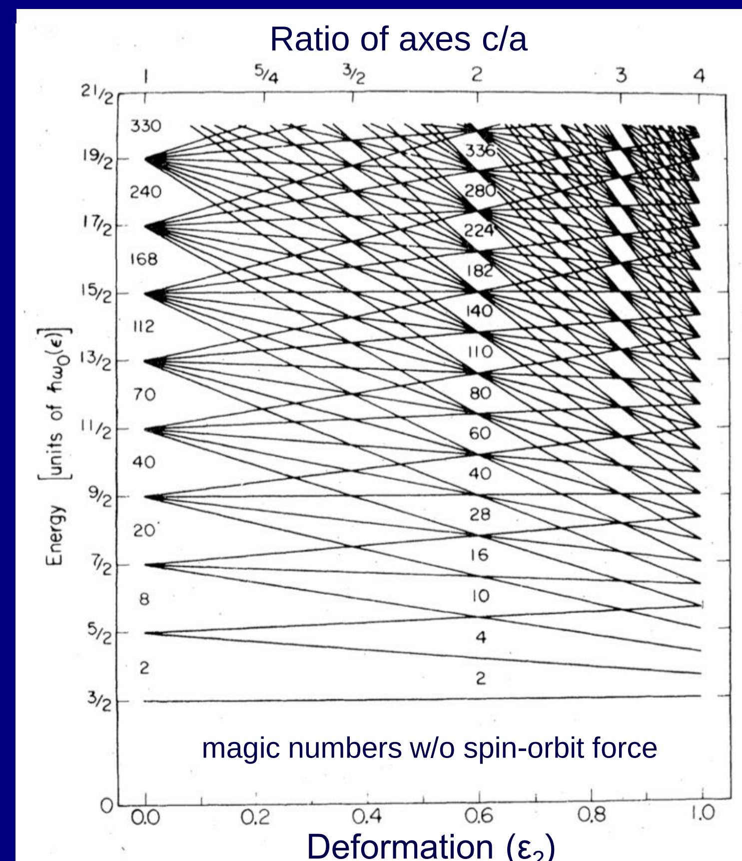
Spin Isomers or Shape Isomers?



Generalized shell structure in harmonic oscillator potential

→ Magic nucleon numbers shape-dependent

Superposition of Liquid drop and Shell correction
V.Strutinsky 1966-68



The Key Experiment of the field in 1972

Volume 41B, number 1 PHYSICS LETTERS 4 September 1972

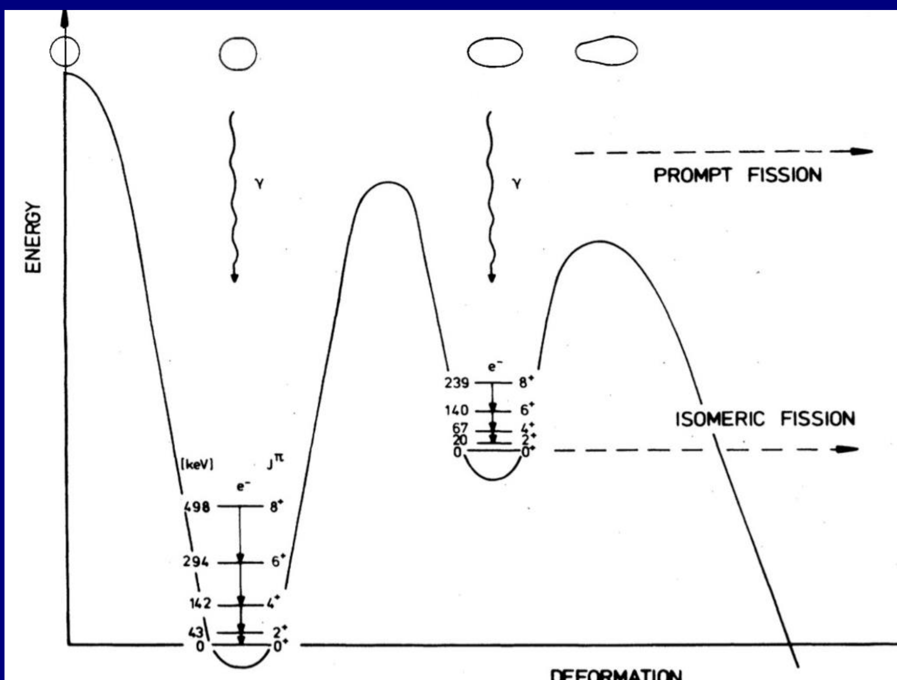
IDENTIFICATION OF A ROTATIONAL BAND IN THE ^{240}Pu FISSION ISOMER

H.J. SPECHT, J. WEBER
Sektion Physik der Universität München, Germany

E. KONECNY and D. HEUNEMANN
Physik-Department der Technischen Universität München, Germany

Basic idea:

Determine the moment of inertia associated with the lowest rotational band in the second well by the measurement of the conversion electrons of the fully converted transitions (<0.1 ns) preceding isomeric fission (4 ns)

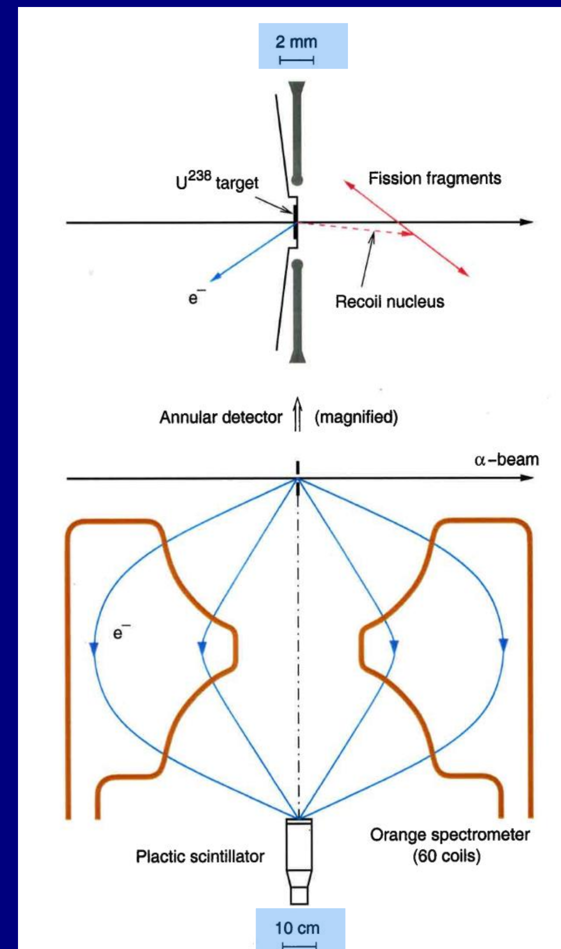


Reaction:

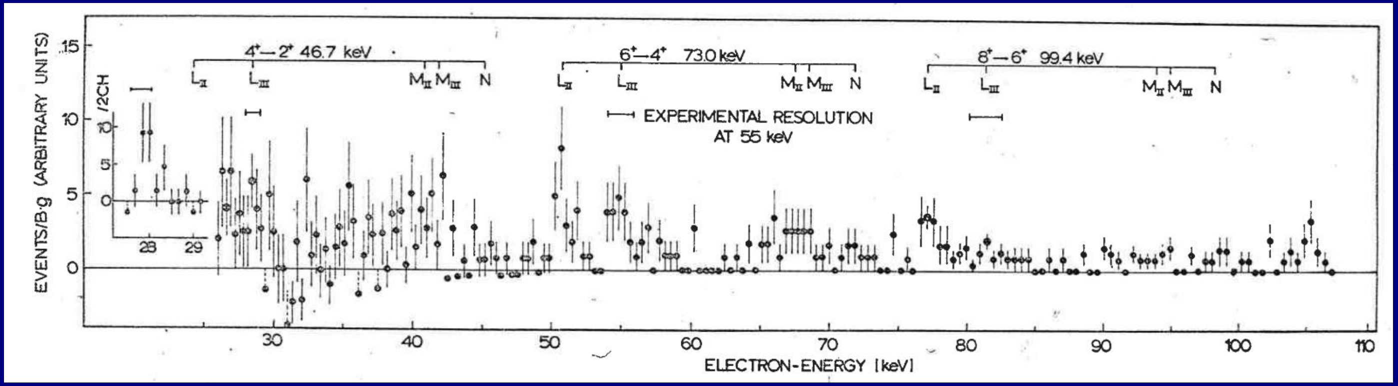
^{238}U (α,2n) ^{240}Pu

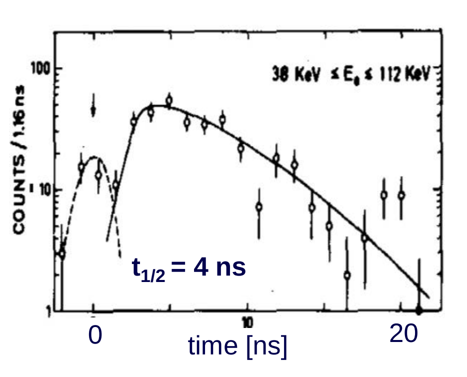
Recoil nucleus ^{240}Pu fissions in front of a small Si-detector, itself shielded against the 10^5 more intense prompt fission fragments

Conversion e^- measured in a high resolution magnetic spectrometer

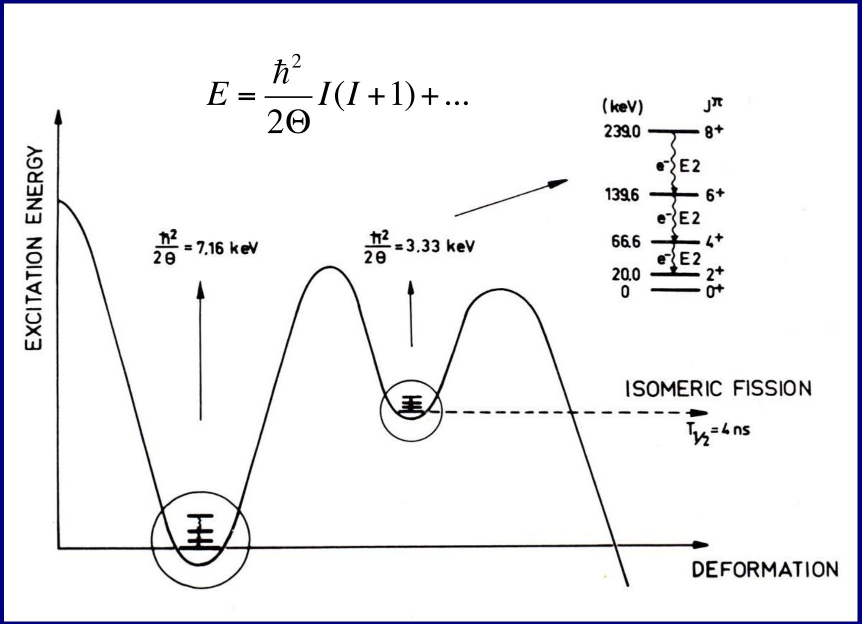


The Key Experiment of the field in 1972

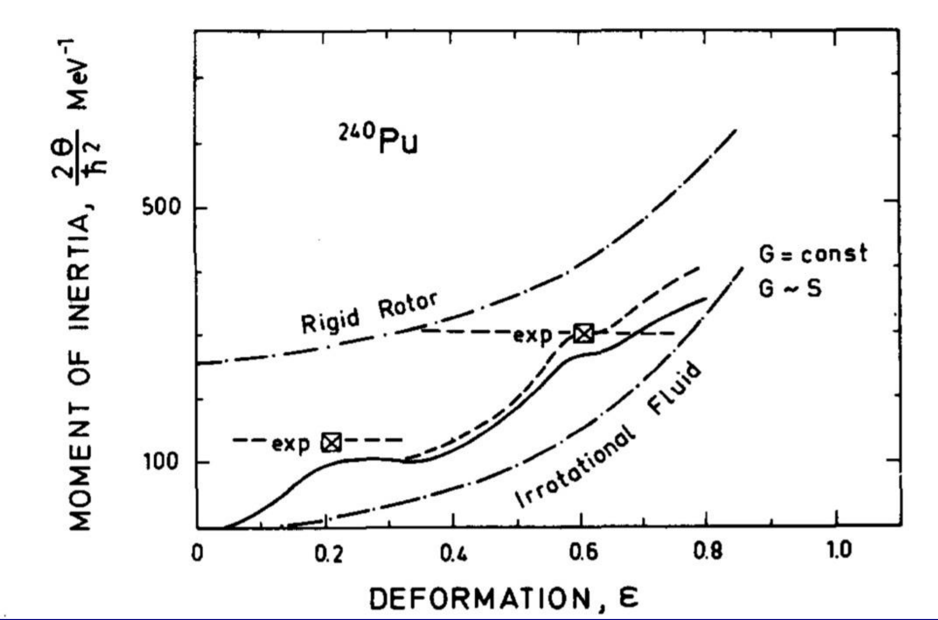




Point-by-point scan of the magnetic spectrometer → 3 weeks of beam time



Fit of the E2 energies to the QM rotator

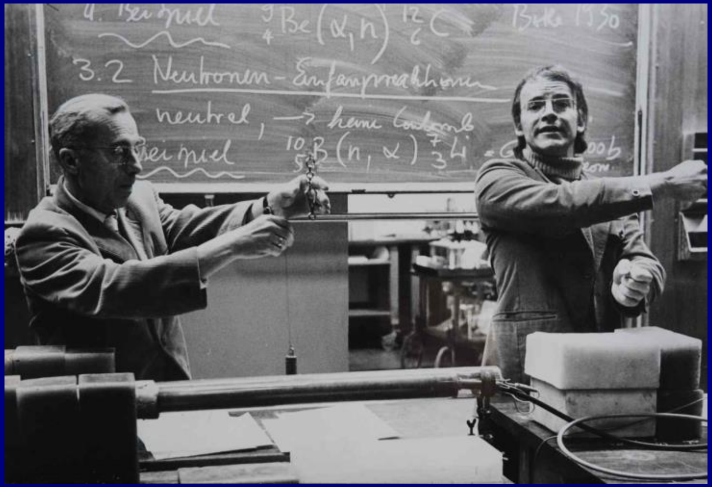


Measured moments of inertia compared to theory

First experimental proof for shape isomerism, consistent with a 2:1 axes ratio

Ruf an die Universität Heidelberg 1973

II. Physikalisches Institut



Experiments at the MPI HD and GSI DA 1973-83

Tandem Accelerator MP-5 at the MPI, first beam 1967
UNILAC Accelerator at GSI, first beam 1974

Research Group 1: D. Habs and V. Metag (MPI)
- Fission-isomer spectroscopy
- Sub-barrier transmission resonances
- Coulomb fission (at GSI)

Research Group 2: P. Glässel and D. von Harrach (+ MPI)
- Three- and four-body decays in nuclear collisions

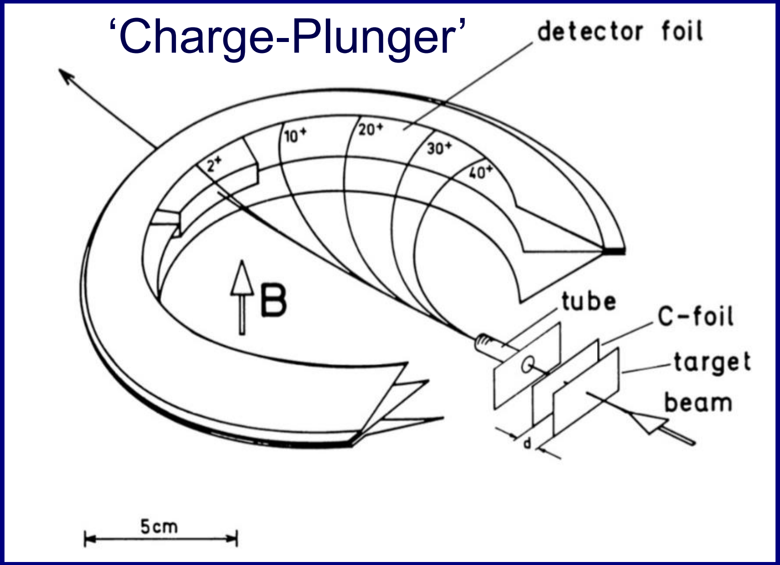
Research Group 3: R. Männer
- Multiprocessorsystem ‘Polyp’; Systolic Array 28k

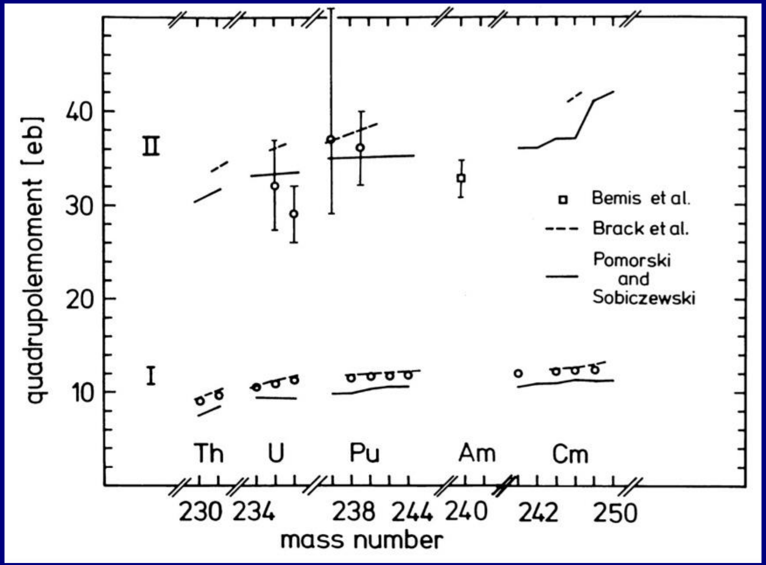
Research Group 4: R. Schuch
- Inner-shell ionization in atomic collisions

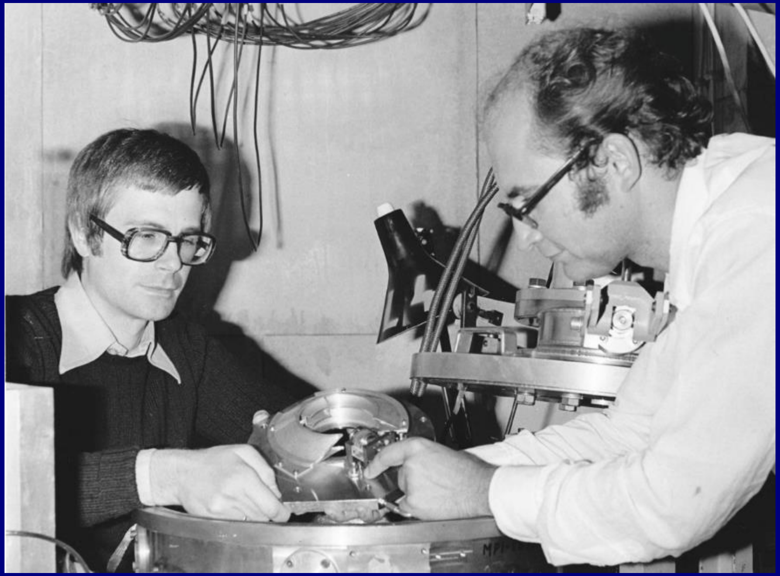
About 30 Diploma and PhD students in this decade

Visitors (each for 1 year):
- C.O.Wene, Lund Univerity
- J.Wilhelmi, Los Alamos
- P.Paul, Stony Brook University
- J.Pedersen, NBI Copenhagen
- S.Kapoor, BARC Bombay
- L.Grodzins, MIT

Quadrupole Moments of Fission Isomers (Habs/Metag et al.)







consecutive conversion transitions
→ Auger cascade → high charge states

measure charge state distribution in B-field

reset charge states to 1^+ - 2^+ in a C-foil

vary distance between the C-foil and target
→ measure decay time distribution (0.1-1ns)
→ quadrupole moments from decay time

Systematics from 5 fission isomers:
→ axes ratio 2.0 ± 0.1

Spectroscopic Properties of Fission Isomers, Metag/Habs/HJS, Phys.Rep.65 (1980)1-41

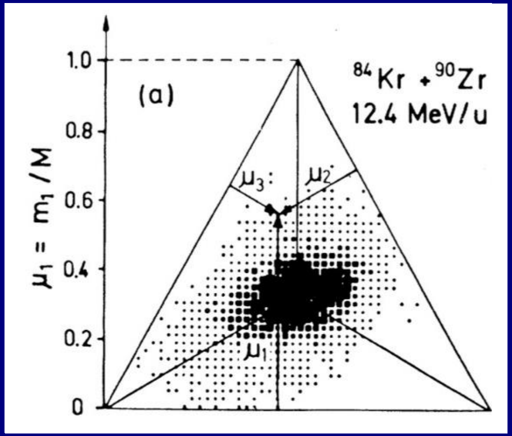
3- and 4-body decays in nuclear collisions (Glässel, v. Harrach)

Technique:

- Kinematically complete measurements in large-area detectors (exclusive)

Research topics:

- Coulomb fission of heavy elements (e.g. U + W)
- Search for transuranium elements in U + U/Cm
- Angular momentum transfer in deep-inelastic reactions
- ‘Break-up’ processes in lighter collision systems → → access to scission times (‘proximity effects’)



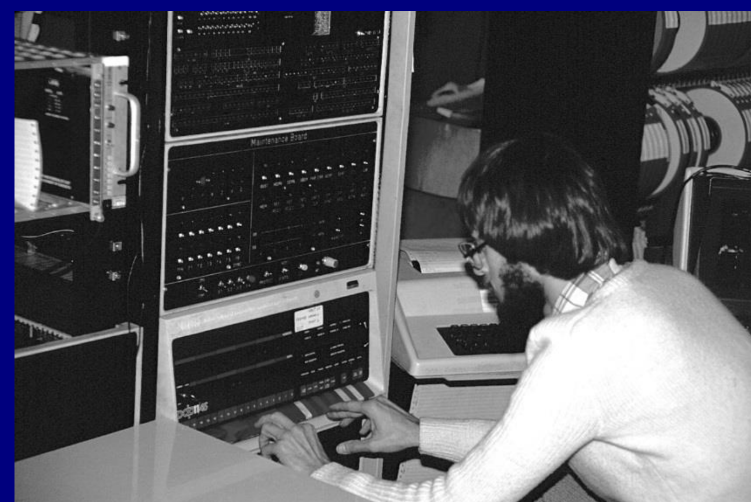
Set-up at GSI

two freely movable avalanche detectors and one ionization ch.

evacuated container 3 m Ø, 4 m high (“Heidelberger Fass”)

$1{\times}1\ m^2$ parallel-plate avalanche detectors for x/y, t and dE/dx

Three- and four-body decays in nuclear collisions at GSI



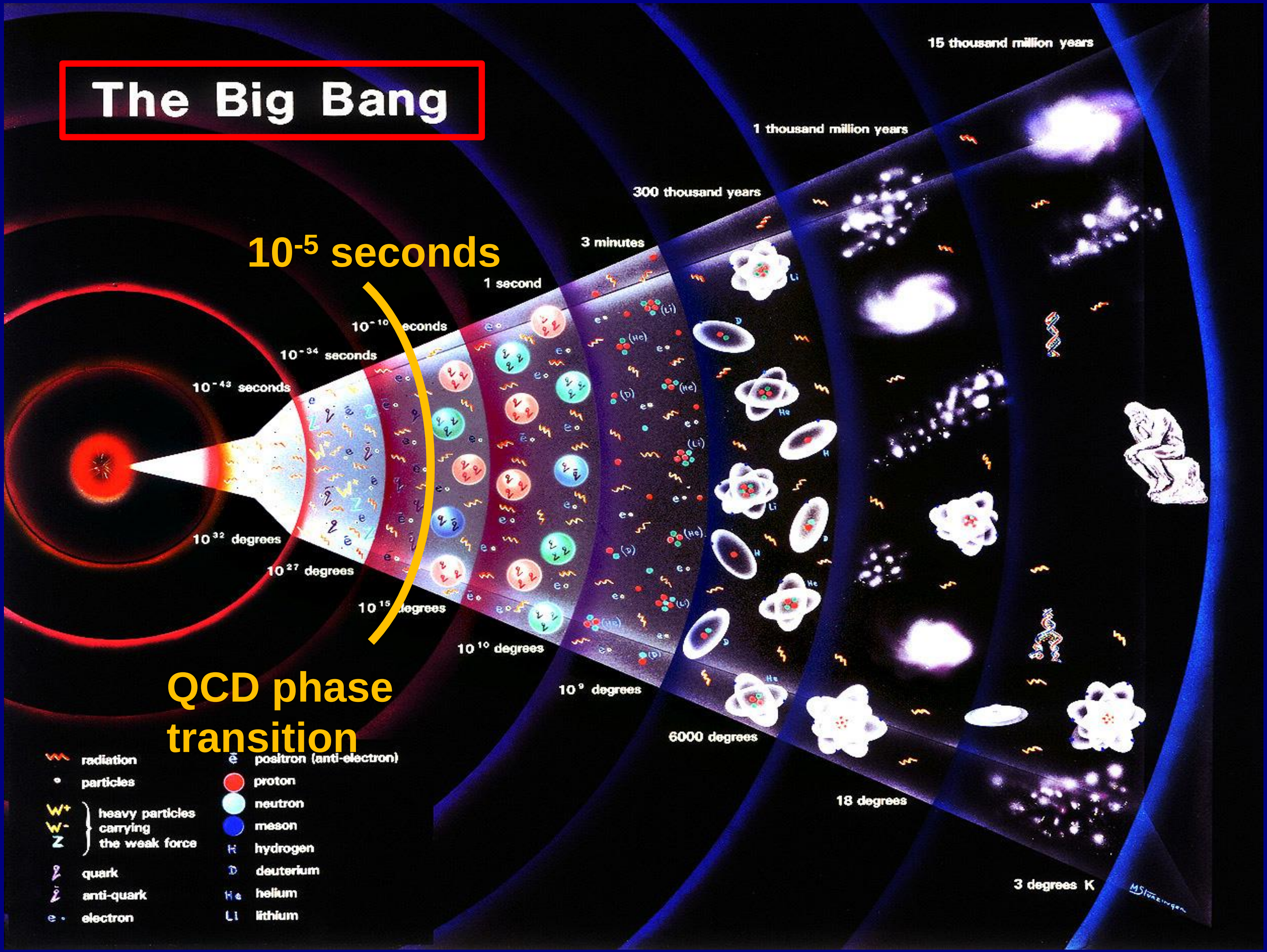
Postdocs: P. Glässel, D. von Harrach, R. Männer   Visitor: L. Grodzins (MIT)

PhD theses: Y. Chivelekoglu, J. Schukraft (intermezzo with HD X-tal Ball)

A new era since 1983:

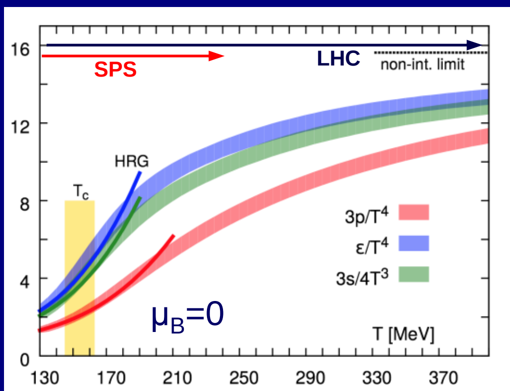
High-Energy Heavy Ion Physics at CERN

Motivation: the early Universe in the Laboratory

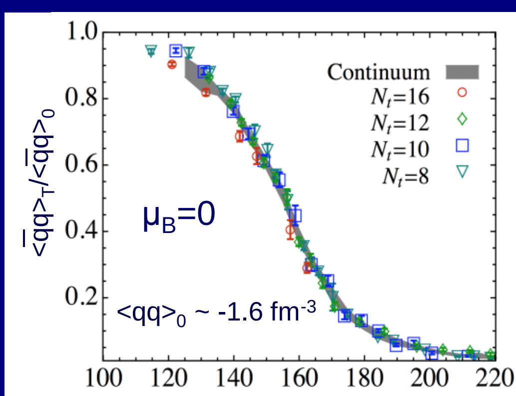


Theoretical guidance for the QCD phase diagram (Lattice QCD)

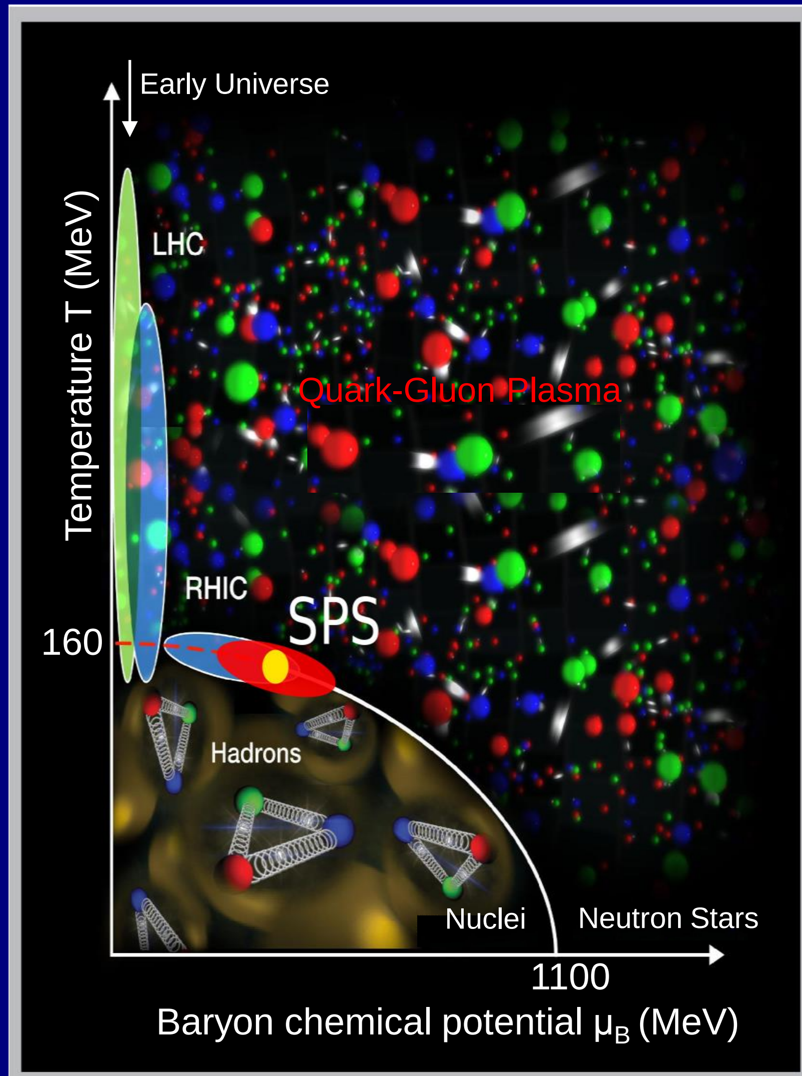
small μ_B
crossover transition
ε_c~1 GeV/fm^3
T_c~160 MeV



deconfinement transition



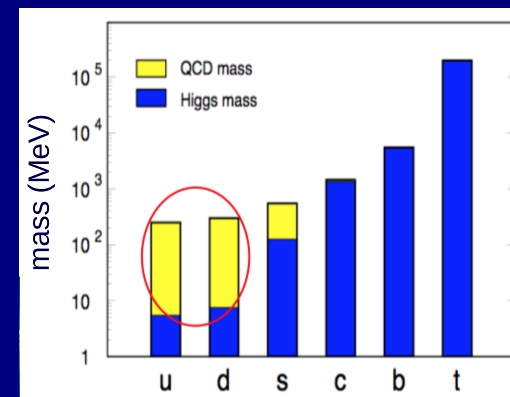
chiral symmetry restoration



μ_B related to density (baryons - anti-baryons)

large μ_B
1st order transition

Critical point



chiral symmetry breaking

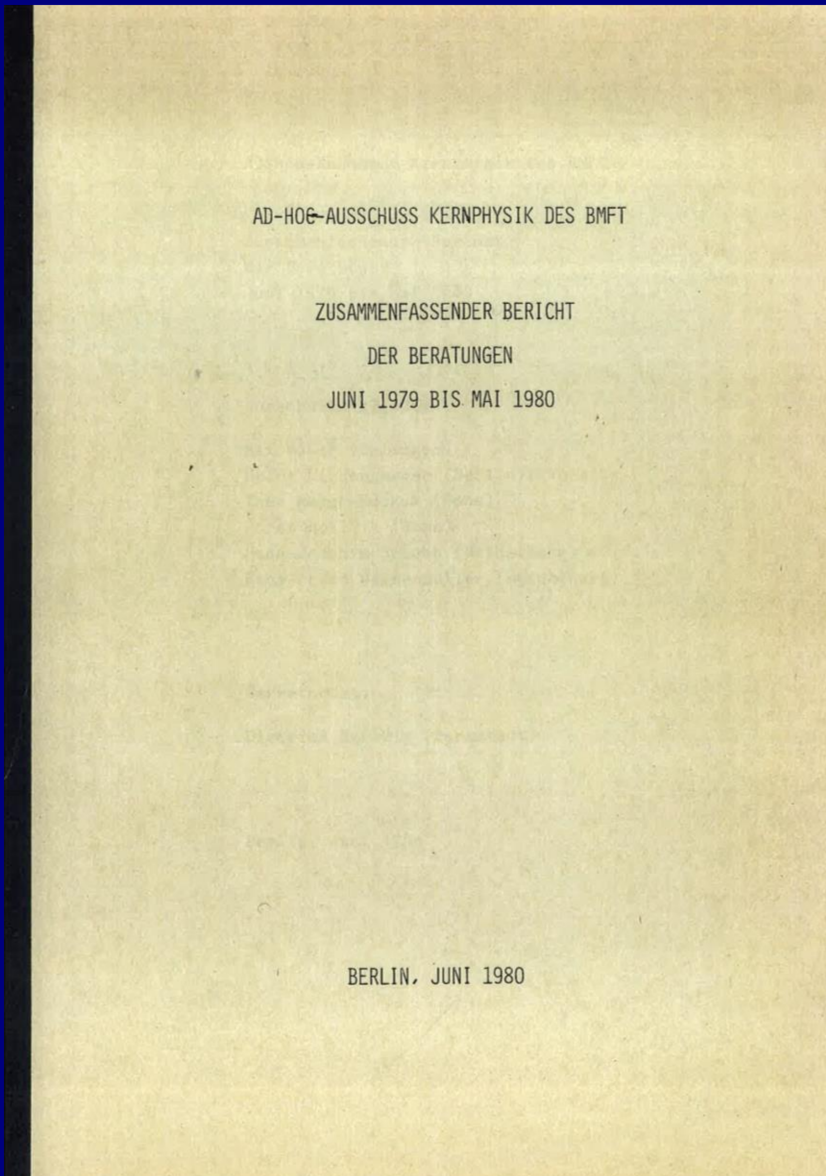
QCD mass (u,d) dominant in the visible part of the Universe (98%)

Roots of Heavy Ion Physics at the CERN SPS

Colloquium CERN 60th, H.J.Specht, 2014

	Worksh./Conf./Com.	Accelerators	Physics	Persons/Actions
1974	Columbia (BeV/u Coll. of HI)	BEVALAC LBL (1st beam)	EoS Compress. Nucl. Matt.; π Condensates	Contract LBL-GSI (Grunder-Bock,Stock)
1975 -1978	LBL and GSI (alternating)	Start ISR Discuss. (Pugh/Santa Fe')	First ideas on QGP Cabibbo/Parisi 1975 Dileptons in pp	CERN DG L. van Hove (1977)
1979	Pre QM LBL	VENUS Prop. LBL SIS100 Prop. GSI	↓	M.Jacob,B.Willis et al.
1980	Lindenberger-Committee; '1st QM' GSI		αα collisions ISR	PS LoI GSI/LBL Disc. v.Hove/Specht/Willis
1981	BNL (ISABELLE)	SIS12/100 Prop. GSI Start SPS Discussion		CERN DG H. Schopper
1982	2nd QM Bielefeld (M.Jacob/H.Satz)	ISR to be stopped (CERN Council)		PS Prop. Stock et al. (^{16}O ECR ion source)
1983	3rd QM BNL	ISR last run	Dileptons in pp (ISR-R807/808)	SPS LoI Willis et al. Contract CERN/GSI/LBL
1984	4th QM Helsinki	SPS-CERN firm AGS-BNL firm SIS18-GSI firm		Approval of 1st Gen. Experiments at SPS

The “Lindenberger-Ausschuss” in 1980 on SIS100 at GSI


AD-HOC-AUSSCHUSS KERNPHYSIK DES BMFT

ZUSAMMENFASSENDER BERICHT

DER BERATUNGEN

JUNI 1979 BIS MAI 1980

BERLIN, JUNI 1980

Ad-hoc-Ausschuss Kernphysik des BMFT
Juni 1979 bis Mai 1980

Members:

- M. Huber
- H. Lindenberger (Vorsitz)
- T. Mayer-Kuckuk
- H.Rollnik
- H.J. Specht
- H.A. Weidenmüller

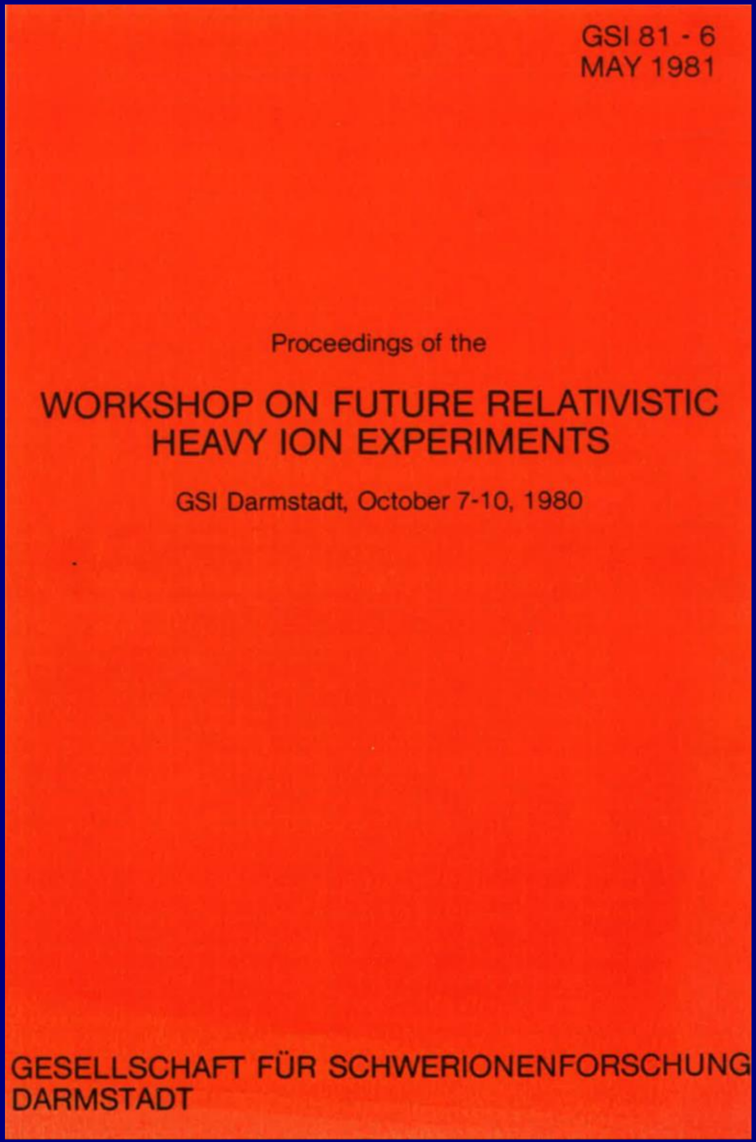
Mandate (among others):

Judgment on planned new machines (GSI, Jülich, München,…)

Recommendation 16 (on SIS100):

“Es wird angeregt, nochmals zu versuchen, ob das Arbeitsgebiet hochrelativistischer schwerer Ionen nicht an einem Beschleuniger des CERN in einer Kooperation CERN/GSI erschlossen werden kann...”

My ‘Phase Transition’ to the Phase Transitions



Editors: R. Bock and R. Stock

‘First’ Quark Matter Conference
7-10 October 1980

Milestone

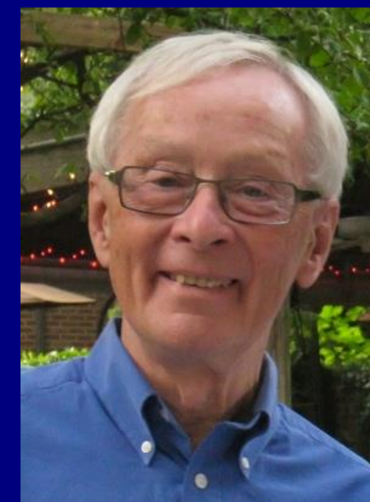
First organized discussions between particle and nuclear physicists on studying QGP formation in ultra-relativistic nucleus-nucleus collisions. Particle physicists ~30%, including W.J.Willis. Discussions dominated by the dream of ‘keeping the ISR.
(Summary speaker HJS)

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.J.Willis, and HJS on the use of the SPS instead of the ISR for heavy ions (Nov. 1980)

Sabbatical at CERN 1983-1984: R807/808 at the ISR

Axial Field Spectrometer (AFS) in October 1983

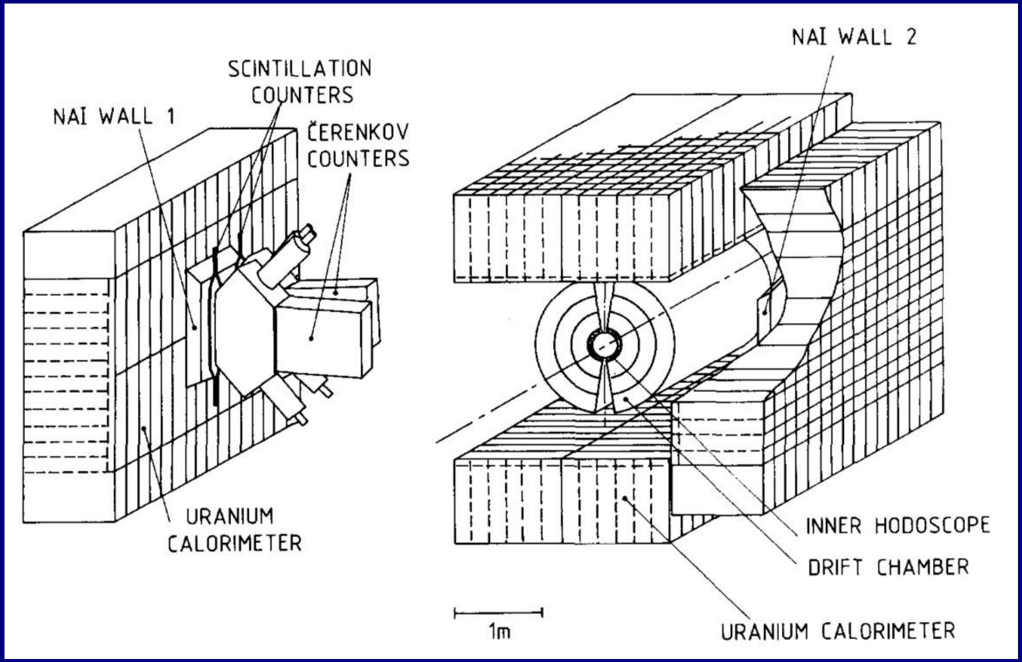


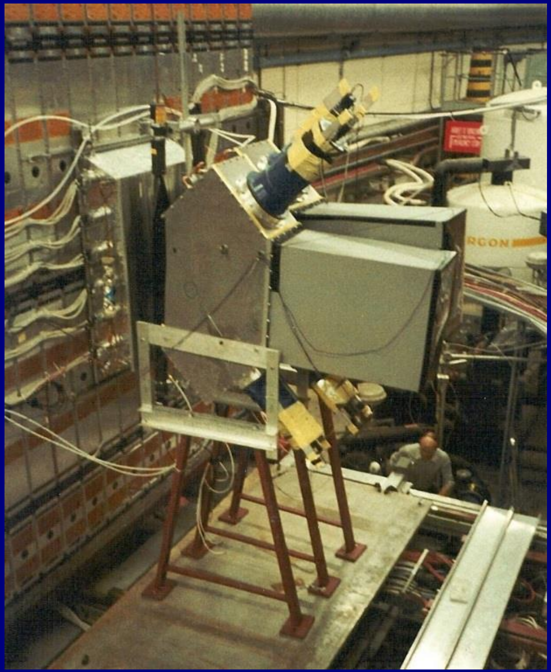
William J. Willis

About 70 members of the collaboration. Particularly close to me besides Willis:
M. Albrow, T. Akesson, H. Bøggild, D.Lissauer, I. Mannelli, R. Palmer,…

CERN Director General at this time: H. Schopper

First Measurement of e^+e^- Pairs with M_{ee}<1GeV in proton-proton collisions at the ISR ($\sqrt{s}$=63 GeV)





Add-on to R808:

Cherenkov detector between the NaI- and U Calorimeters and the drift chamber for electron identification

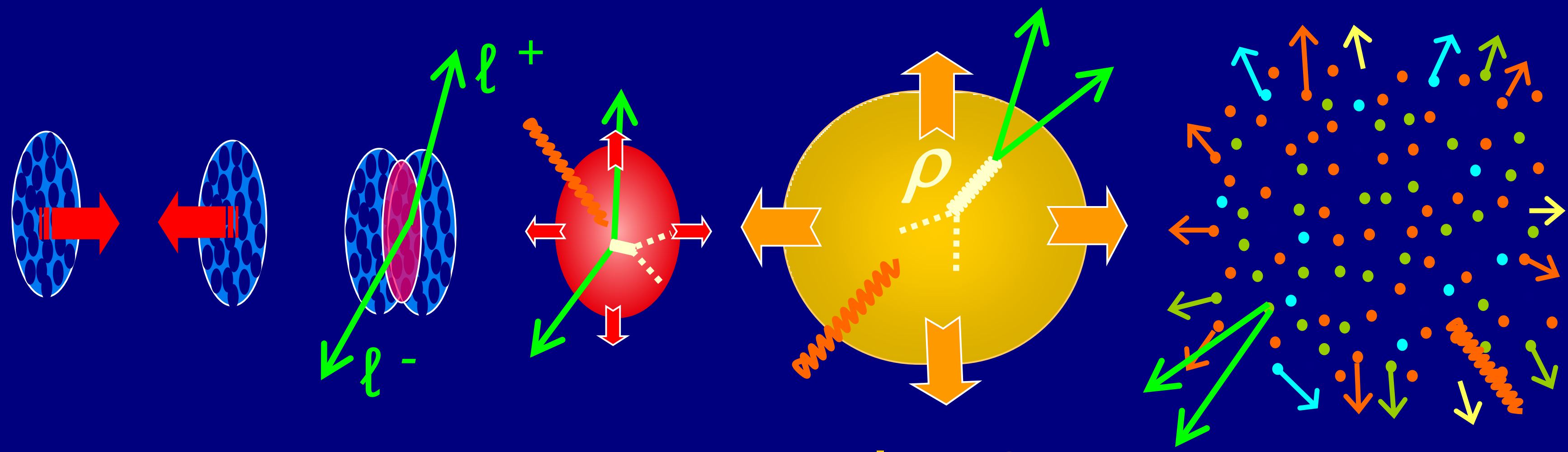
My main responsibilities:

Build-up and integration of the Cherenkov detectors
Participation in the data analysis, taken over in 1984 by J.Schukraft and V.Hedberg

Start of my still ongoing emphasis on the measurement of lepton pairs

Nuclear collisions: the case for lepton pairs

Time evolution of a nuclear collision



A+A **_NN_-coll.** **QGP** **Hadron Gas** **Freeze-Out**

"Hubble" expansion: T= 240→170 170→110 ~110 (MeV)

Lepton pairs emitted at all stages; no final state interactions

Analogy: neutrinos escaping the interior of the Sun

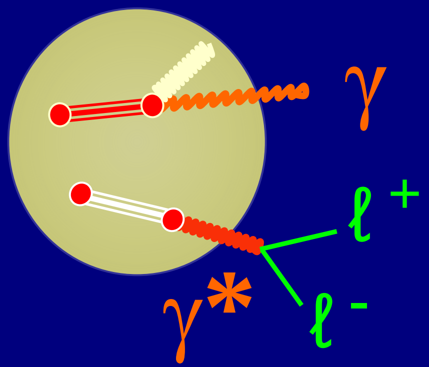
Goal: precision measurement of thermal radiation

Difficulties: - 10^{-4} (α_{em}^2) of hadrons

- requires isolation from other sources

> 'If you want to make a major discovery build a dilepton detector'
> (Sam Ting)

Electromagnetic probes: dileptons vs. real photons



photons: 1 variable: p_T

lepton pairs: 2 variables: M, p_T

relevant for thermal radiation:

p_T sensitive to temperature and expansion velocity

M only sensitive to temperature (Lorentz invariant)

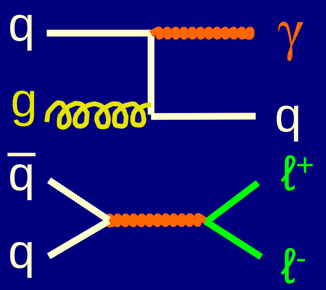
for flat spectral functions, i.e. for hadron-parton duality (M>1.5 GeV)

(1) $dN/dM \sim M^{3/2} \times exp(-M/T)$ → 'Planck-like'

the only Lorentz-invariant thermometer of the field

(2) lowest order rate ~ $\alpha_{em}\alpha_s$

lowest order rate ~ α_{em}^2



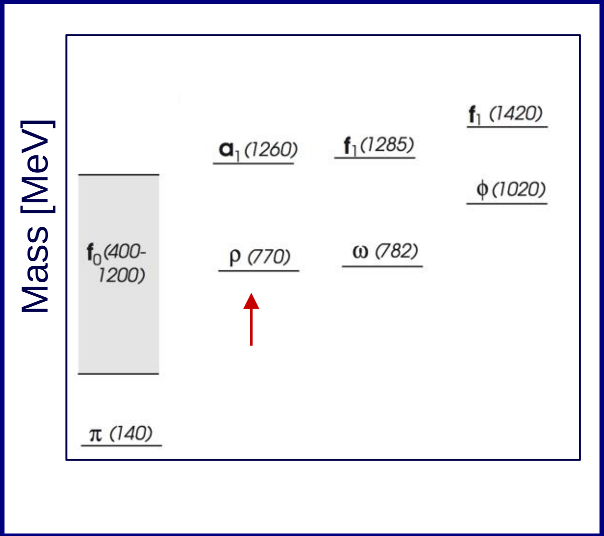
QCD Compton

qq̄ annihilation

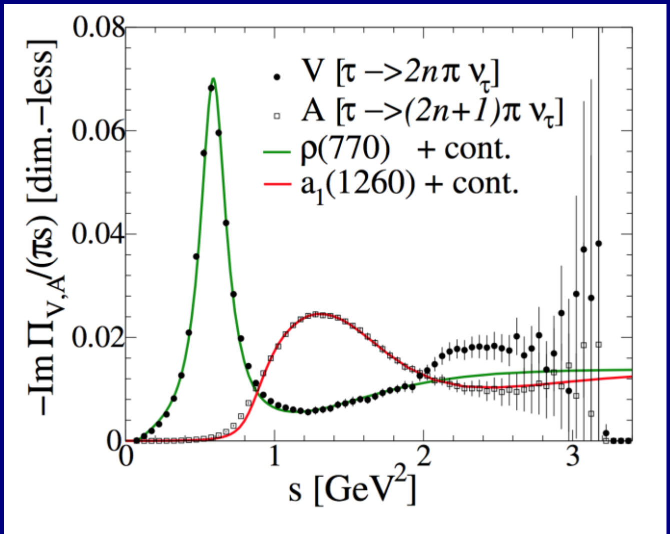
dileptons more rich and more rigorous than photons

Dileptons and the spectral functions of the chiral doublet ρ/a_1

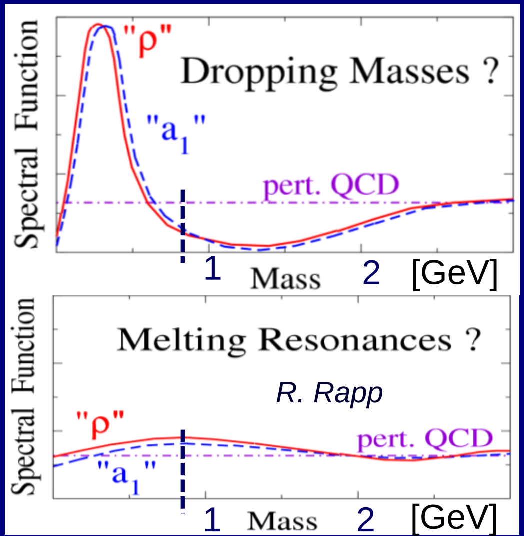
P-S, V-A splitting in the physical vacuum due to spontaneous breaking of chiral symmetry



Splitting of chiral partners

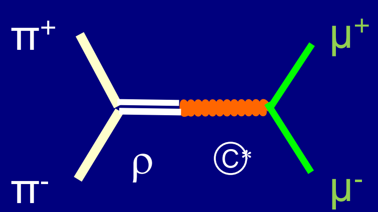


ALEPH data: Vacuum



at T_c: Chiral Restoration

thermal dileptons with M<1 GeV mostly mediated by the vector meson ρ (1^{--})



strong coupling of γ* to ρ (VMD)

- life time τ_ρ =1.3 fm << $\tau_{collision}$ > 10 fm (unique in the PDG)
- continuous “regeneration” by $\pi^+\pi^-$ → sample in-medium evolution

axial vector a_1 (1^{++}) accessible through chiral mixing ($\pi\, a_1 \rightarrow \mu^+\mu^-$, ‘4π’)

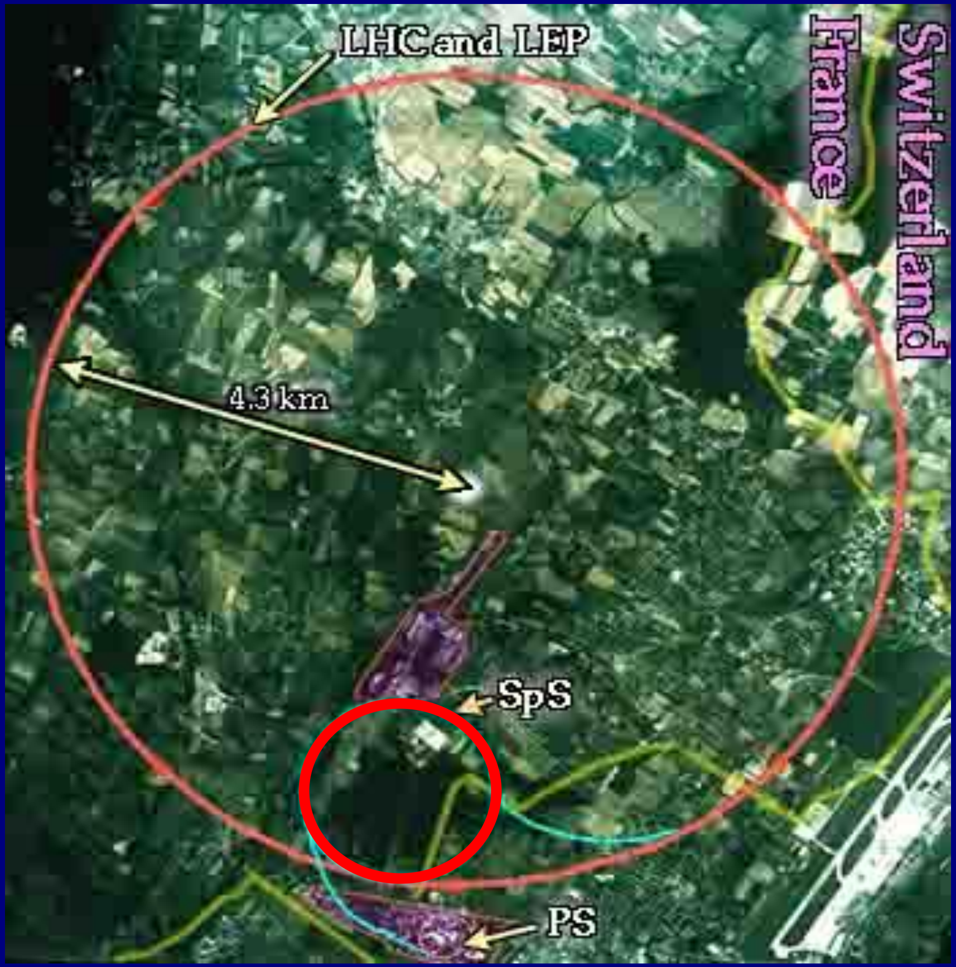
In-medium changes of the ρ properties (relative to vacuum)

Selected theoretical references (status 2005)

	mass of ρ	width of ρ
Pisarski 1982	↘	↗
Leutwyler et al 1990 (π,N)	→	↗
Brown/Rho 1991 ff	↘	→
Hatsuda/Lee 1992	↘	→
Dominguez et. al1993	→	↗
Pisarski 1995	↗	↗
Chanfray, Rapp, Wambach 1996 ff	→	↗
Weise et al. 1996 ff	→	↗

very confusing, experimental data crucial

Dilepton Experiments at the CERN SPS (1984-2004)



1. Generation
1984 – 1987
HELIOS/NA34-2
NA38

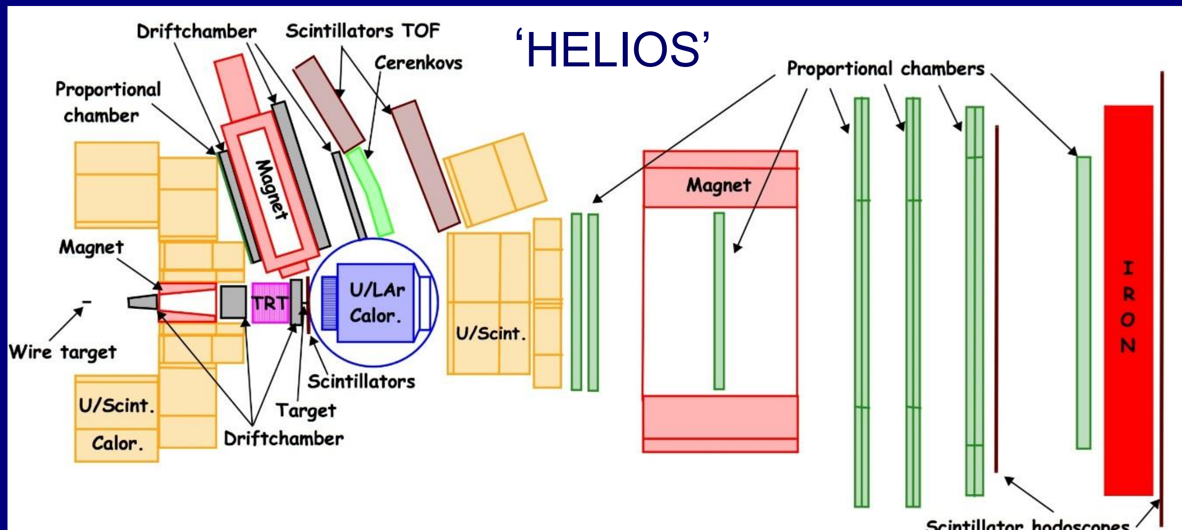
2. Generation
1988 – 2000
CERES/NA45
HELIOS/NA34-3
NA38/NA50

3. Generation
2002 – 2004
NA60

1st Generation Experiments 1984-1989 ('Recuperation Era')

NA34-1
(1984)
N.McCubbin

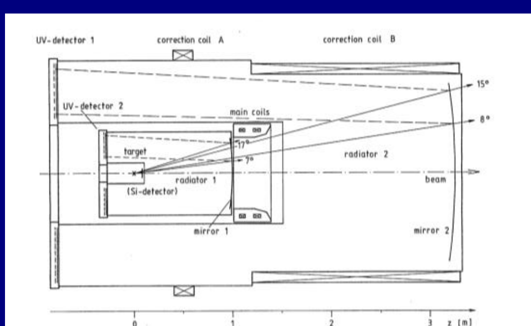
pBe collisions
e^+e^-, $\mu^+\mu^-$,
eμ, γ



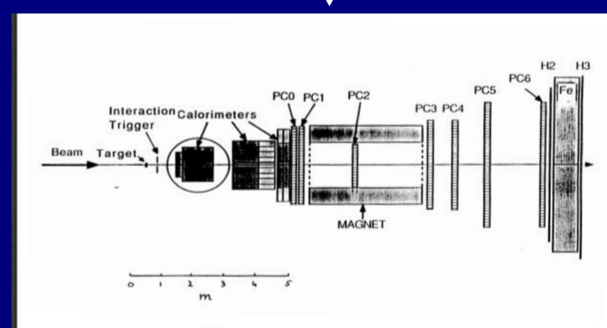
NA34-2
(1984)
H.J.Specht

AA collisons
no $\mu^+\mu^-$, γ
Hadronen

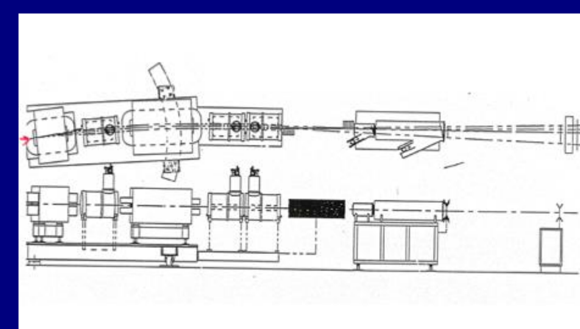
2 years after the first O beam 1986



NA45 (1989), e^+e^-
H.J.Specht

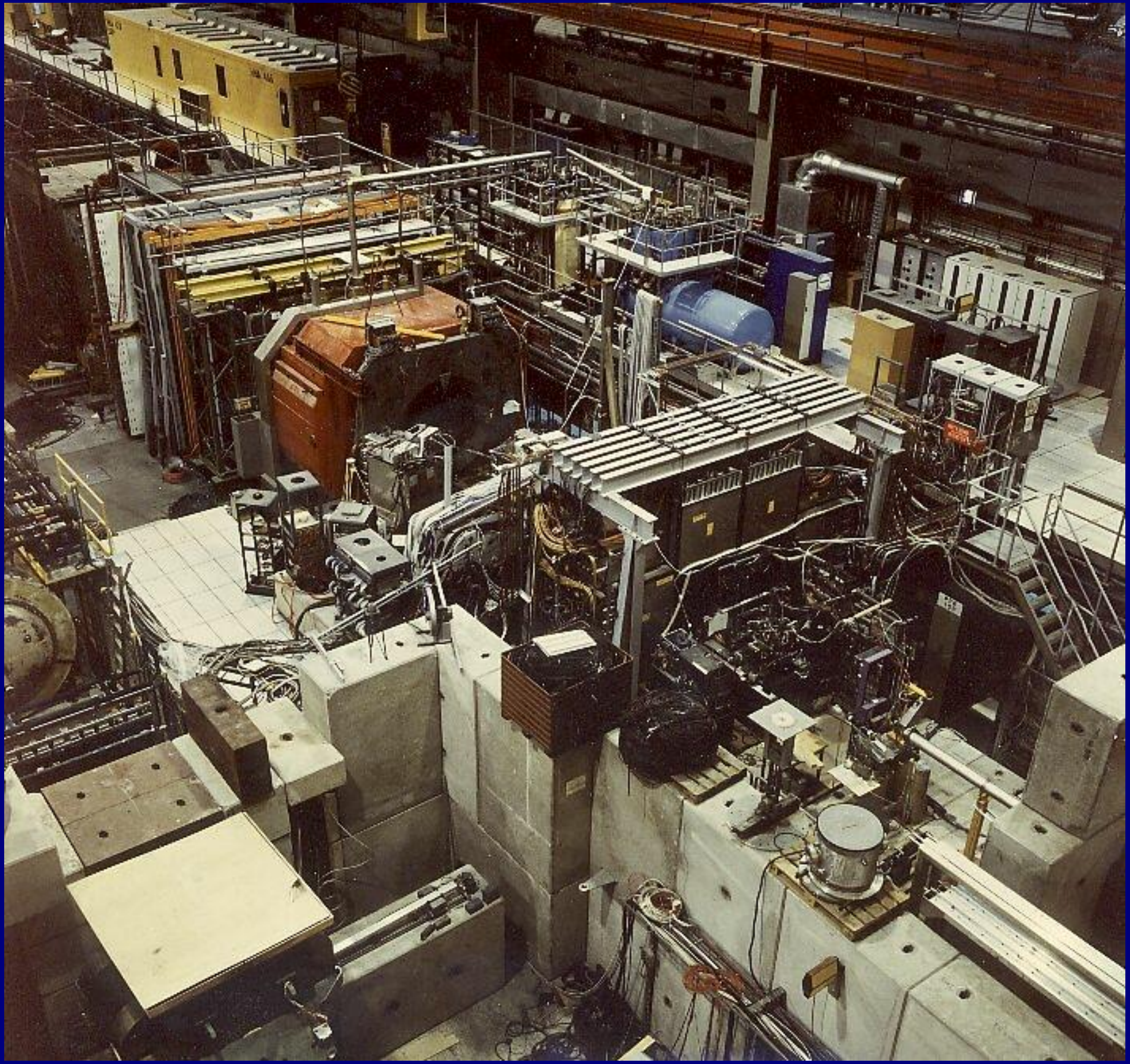


NA34-3 (1989), $\mu^+\mu^-$
G.London

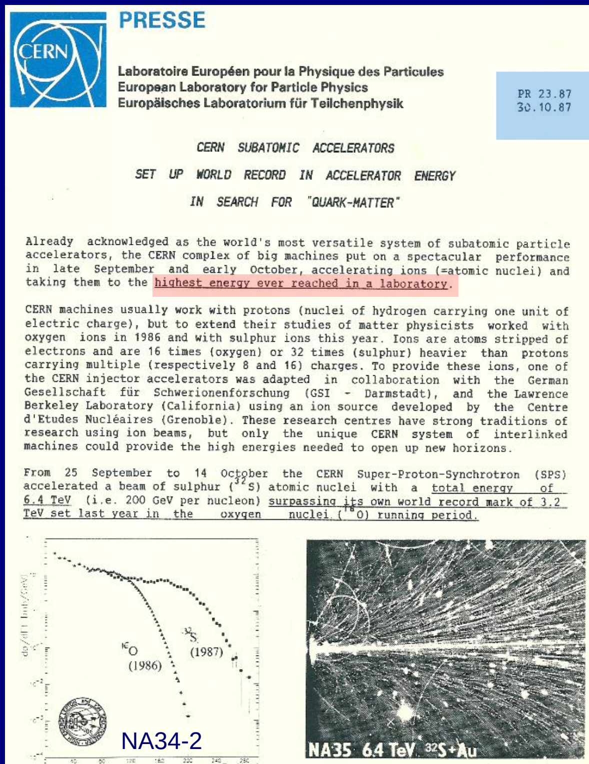


NA44 (1989), hadrons
H.Bøggild

The NA34/HELIOS Experiment



Example of results from HELIOS/NA34-2



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"

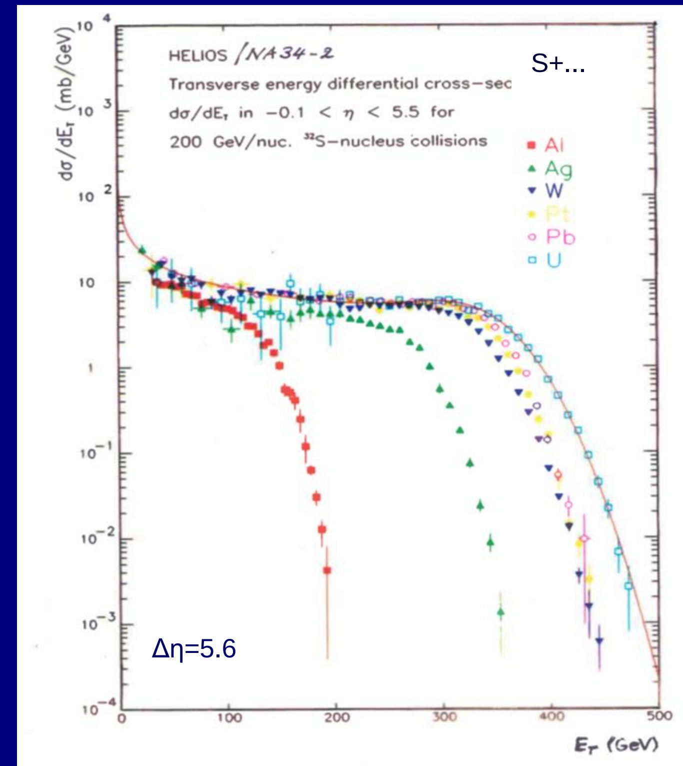
Already acknowledged as the world's most versatile system of subatomic particle accelerators, the CERN complex of big machines put on a spectacular performance in late September and early October, accelerating ions (=atomic nuclei) and taking them to the highest energy ever reached in a laboratory.

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.

The only results
on
Transverse
Energy Dissipation
in '4π'

Shuryak-Bjorken
↓



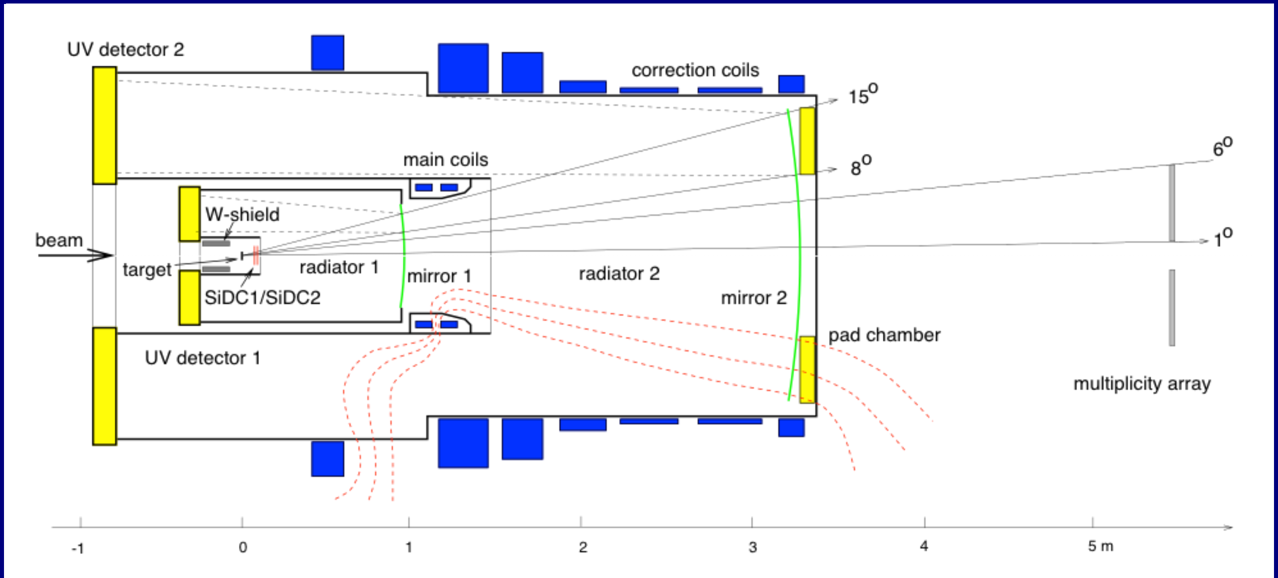
Central collisions: S-Au $\varepsilon = 2.6$; later,1995, Pb-Pb $\varepsilon = 3.2$ $> \varepsilon_{crit} = 1$ GeV/fm^3

Other results: hadron p_T spectra; photon p_T spectra (via e^+e^- conversions), soft photons

Postdocs: P. Glässel, U. Goerlach, J. Soltani, J. Schukraft (CERN)
PhD theses: H.W. Bartels, A. Drees, A. Pfeiffer; Dipl. A. Hölscher, M. Neubert,…

Major parallel effort: R&D for CERES/NA45 (5 publ.), including many students

2^{nd} Generation: Di-electron spectrometer CERES/NA45

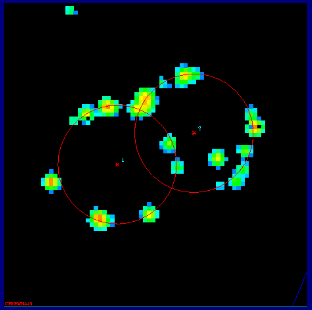


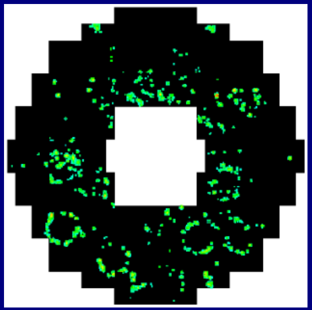
Pioneering experiment built 1989-1991

focused on Low Mass Region (LMR)

Running periods:

- 1992-1993
  ^{32}S and proton beams
- 1995-1996
  ^{208}Pb beams





RICH Cherenkov rings

Original set-up (p and ^{32}S):
puristic hadron-blind tracking with 2 RICH detectors
Later addition (^{208}Pb):
2 SiDC detectors + pad (multi-wire) chamber

Low field (air coils), limited tracking → limited resolution
slow detectors, no trigger → very limited statistics

UV detectors: 2-stage parallel plate + 1-stage wire amplif.; 50k pads

CERN/SPSC 88-25
SPSC/P237
15 June 1988

PROPOSAL

STUDY OF ELECTRON PAIR PRODUCTION IN HADRON AND NUCLEAR COLLISIONS AT THE CERN SPS

U. Faschingbauer, M.G. Trauth, J.P. Wurm

Max-Planck-Institut für Kernphysik, Heidelberg, Germany

A. Drees, P. Fischer, P. Glässel, M. Guckes, D. Irmscher, L.H. Olsen, A. Pfeiffer, H. Ries, A. Schön, H. Sickmüller, H.J. Specht (Spokesman), T.S. Ullrich

Physikalisches Institut, Universität Heidelberg, Germany

E. F. Barasch, A. Breskin, R. Chechik, Z. Fraenkel, D. Sauvage, V. Steiner, I. Tserruya

Weizmann Institute of Science, Rehovot, Israel

(Other groups are expected to join later)

Abstract

We propose to measure e^+e^- pairs produced in hadron and nuclear collisions at SPS energies. The goal is to systematically study the pair continuum in the mass region from 100 MeV/c^2 to beyond 3 GeV/c^2 and the vector mesons ρ/ω and Φ. The experimental set-up is centered around a novel magnetic spectrometer, based solely on ring-image Cherenkov techniques. The apparatus also allows a high-statistics study of real photons and high-$p_\perp$ pions.

SPS Proposal CERES/NA45 June 1988

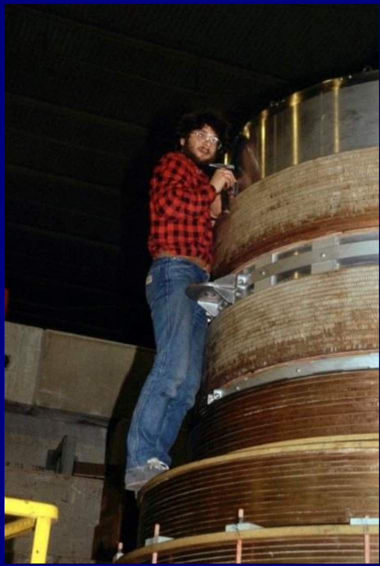
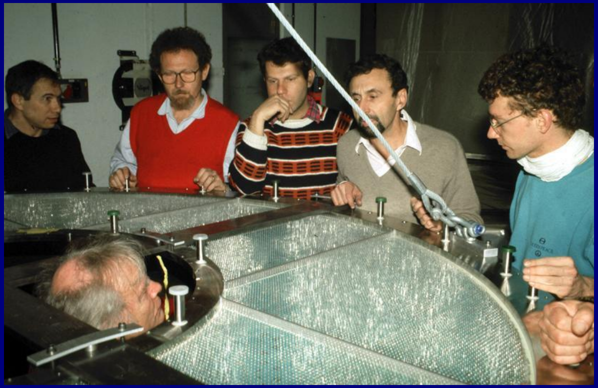
Original collaboration:

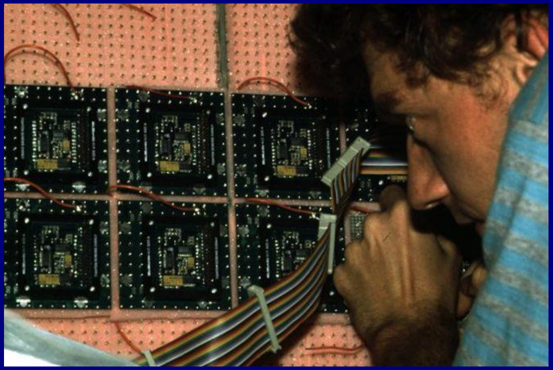
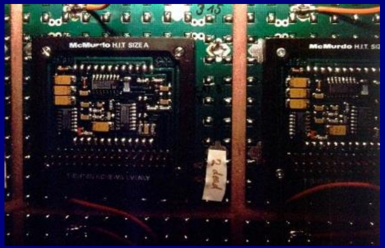
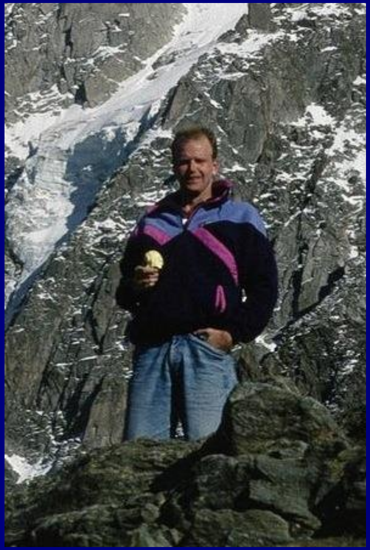
MPI Heidelberg
(Si-drift detectors)

Universität Heidelberg,
(RICH detectors, pad readout electronics for 2×50K channels, magnets, system control)

Weizmann Inst. Rehovot
(UV detector planes)

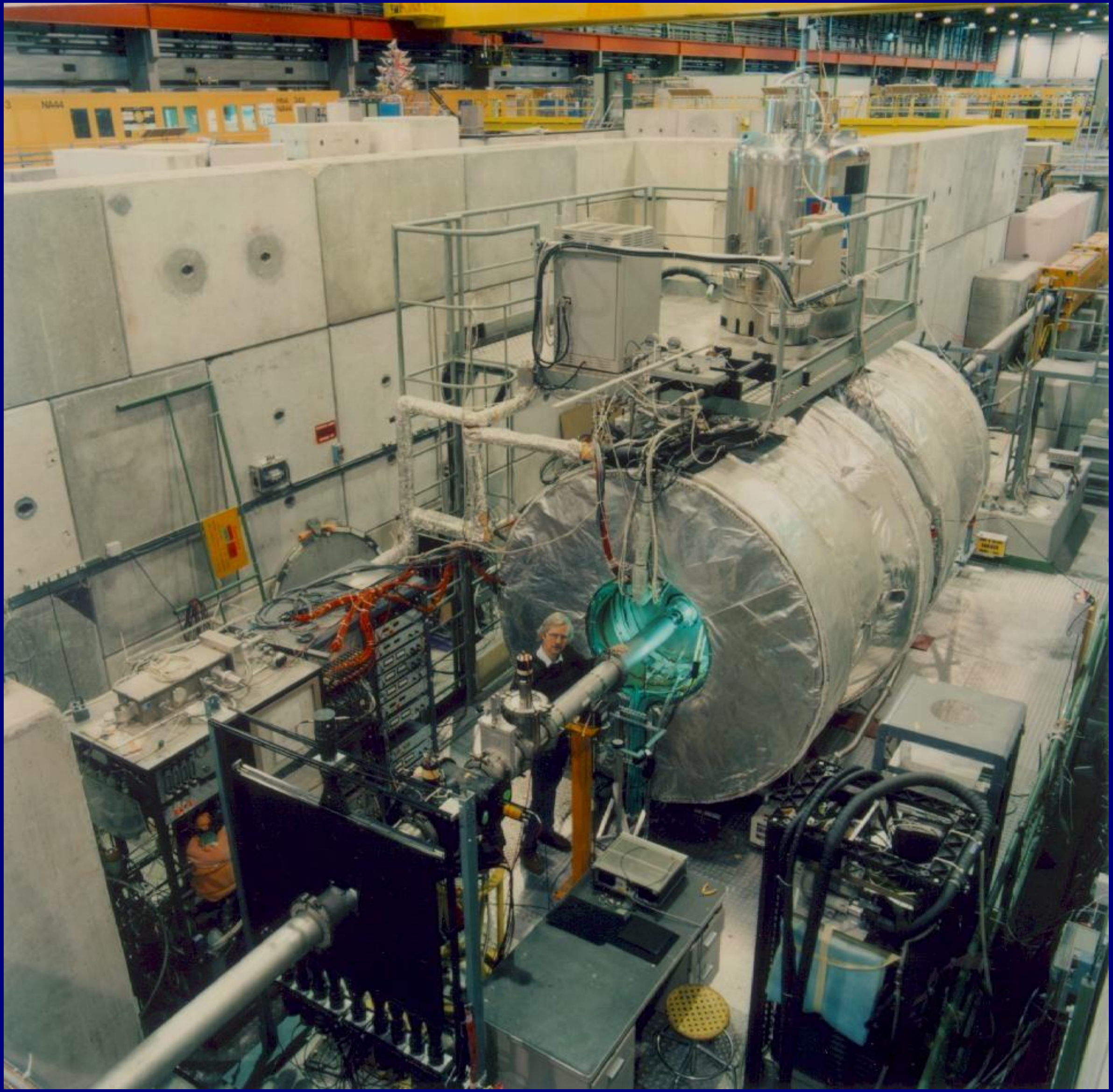
Proposal 1988, approval 1989, random collection of photos 1990


Heidelberg: A. Drees, P. Fischer, A. Pfeiffer, A. Schön, C. Schwick, T. Ullrich, HJS
Weizmann: A. Breskin, V. Steiner, I. Tserruya CERN: J. Schukraft

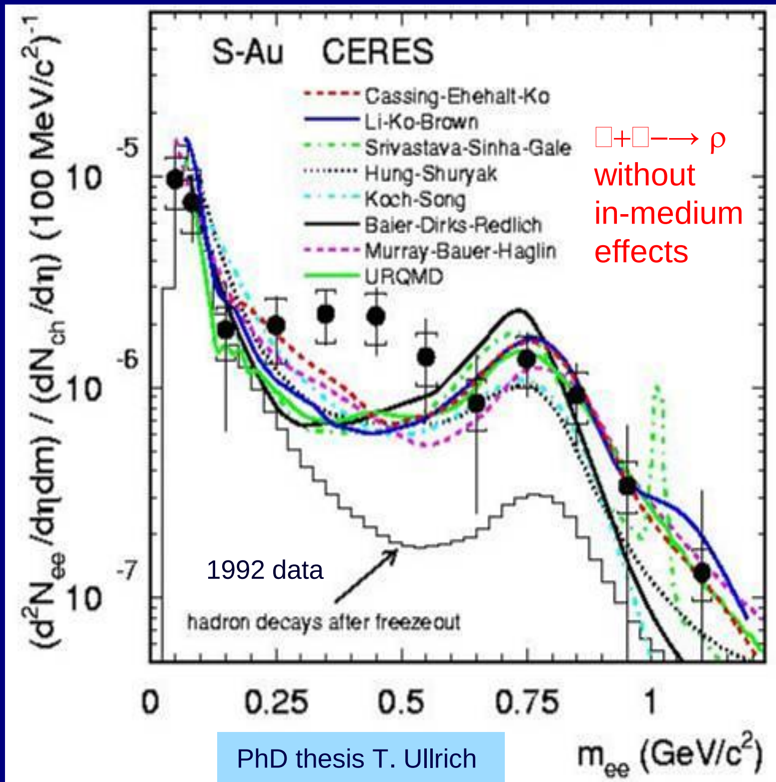
CERES/NA45 set-up 1994



UV-photon detectors based on photo effect in TMAE vapor at 40°C
→ whole spectrometer heated to 50°C

CERES/NA45 results for S-Au

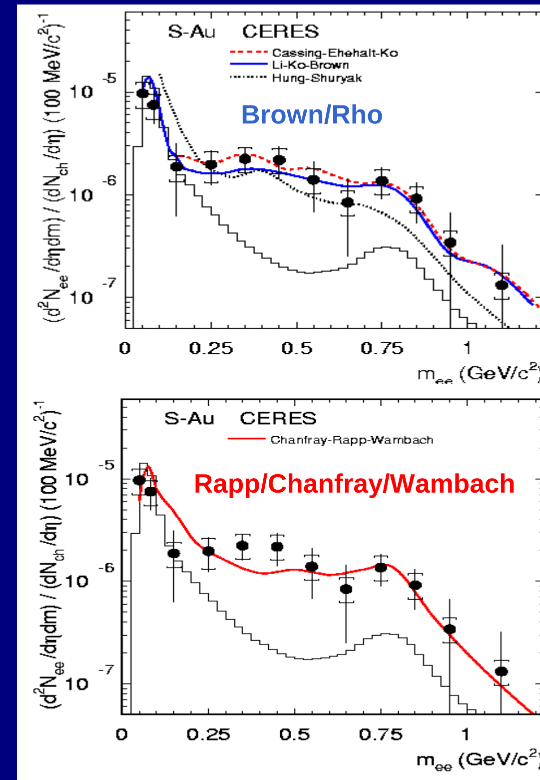
Data: QM'95; Phys.Rev.Lett.75 (1995)1272



A. Drees, QM'96, NPA 610 (1996) 436c

'First' clear sign of new physics in LMR

Li,Ko,Brown, NPA 606 (1996) 568



R/C/W, NPA 617 (1997) 472

strong excess of dileptons above meson decays

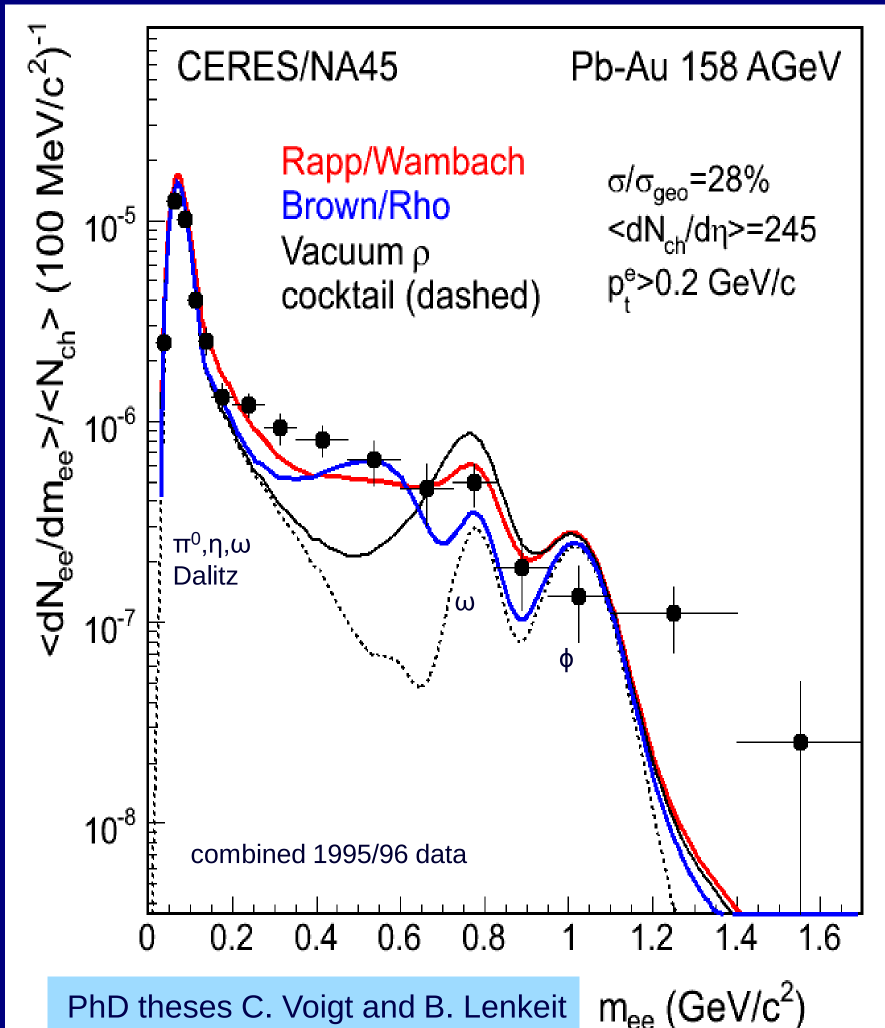
enormous boost to theory: 535 citations, most cited SPS data paper

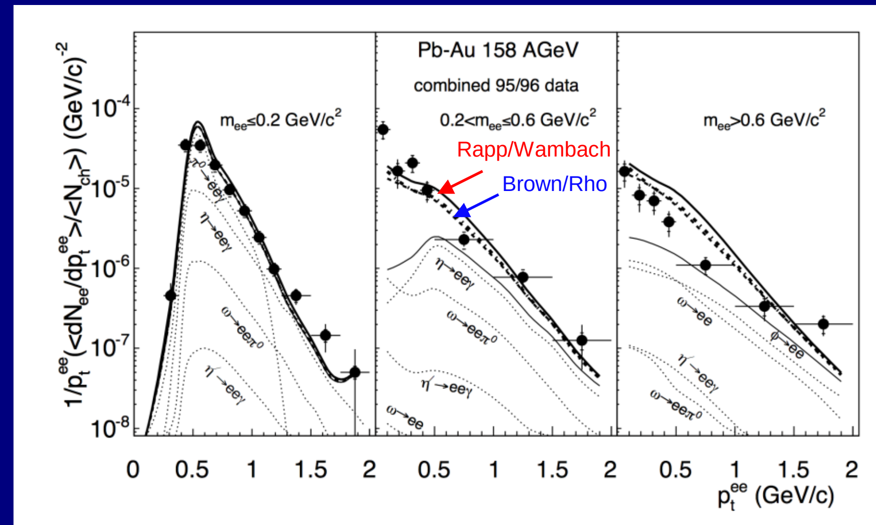
surviving interpretation: $\pi^+\pi^- \rightarrow \rho^* \rightarrow e^+e^-$, but in-medium effects required

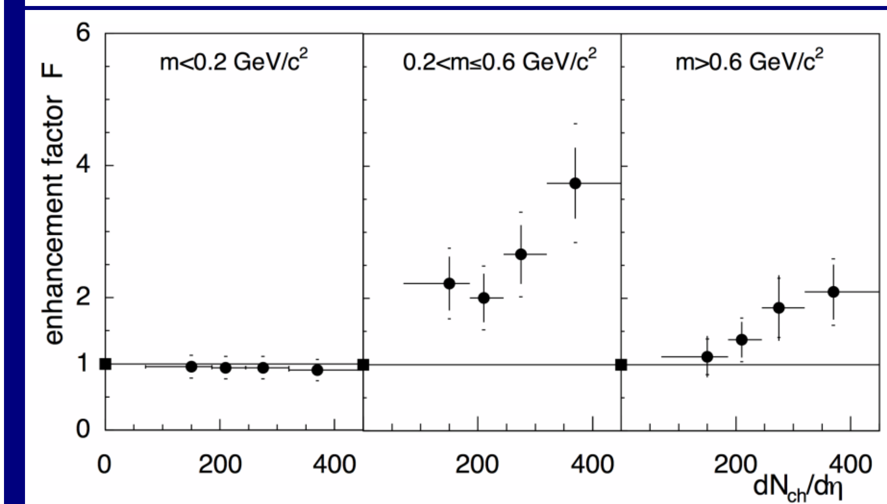
lasting ambiguity (10 a): mass shift and broadening indistinguishable

CERES/NA45: Summary of the Pb-beam results

[PLB 422 (1998) 405; NPA 661 (1999) 23c]; Eur. Phys. J C 41 (2005) 475-513



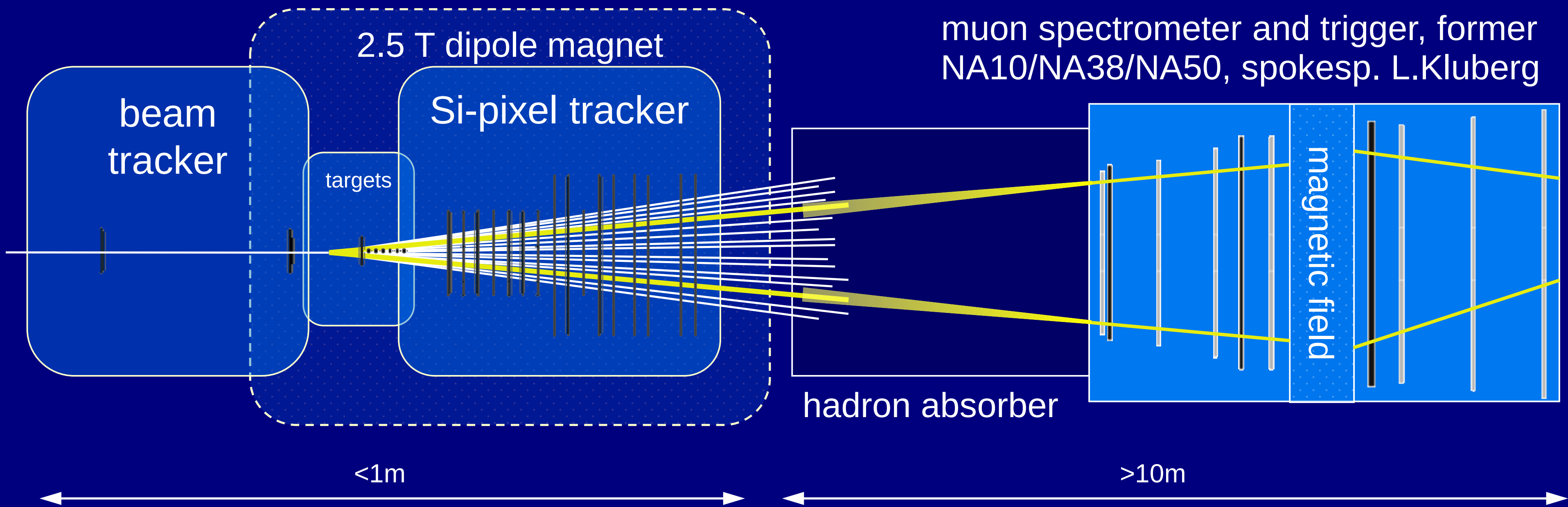




Resolution and statistical accuracy improved, but
mass shift and broadening still indistinguishable

3rd generation Experiment: Dimuons in NA60

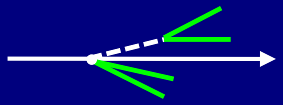
(basic idea P. Sonderegger, exp. approved 2000, spokespersons C. Lourenço, later G. Usai)



Track matching in coordinate <u>and</u> momentum space

Improved dimuon mass resolution

Distinguish prompt from decay dimuons



Additional bend by the dipole field

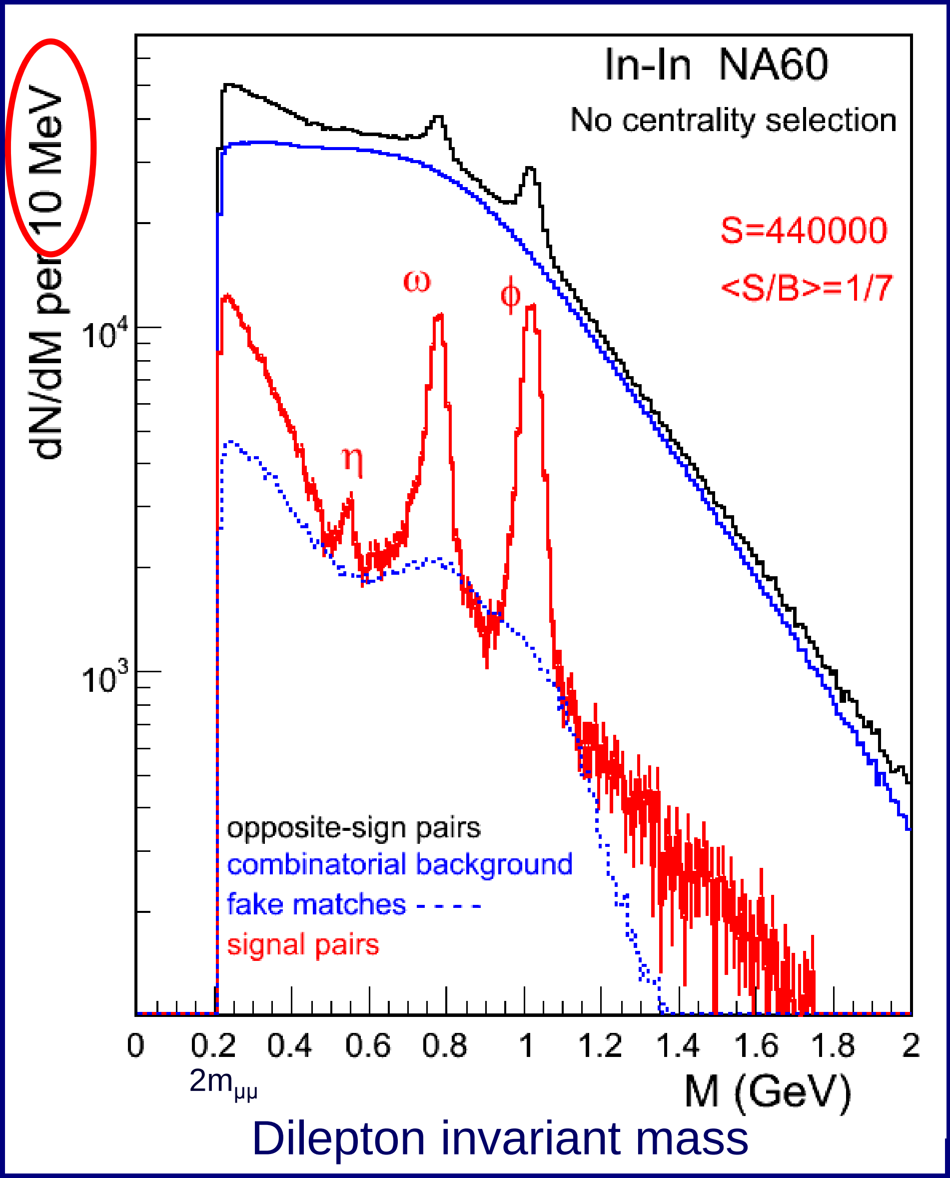
Dimuon coverage extended to low p_T

Radiation-hard silicon pixel detectors (LHC development)

High luminosity of dimuon experiments maintained

In-In 158 GeV/u: NA60 2003 data and major analysis steps

Phys. Rev. Lett. 96 (2006) 162302



Statistics equivalent to 10^{12} interactions

Starting from the raw data:

Subtraction of combinatorial background and fake matches

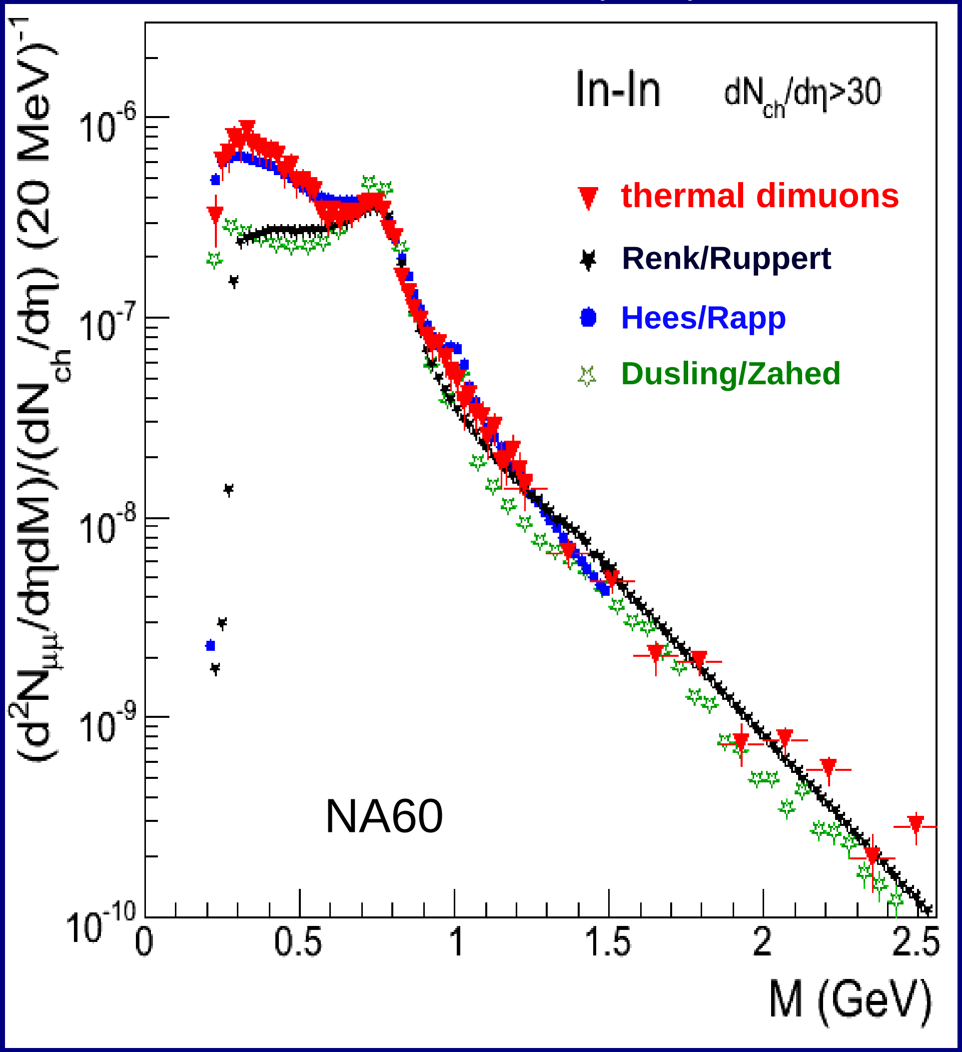
Subtraction of the hadron decay cocktail for M<1 GeV

Subtraction of Drell-Yan and open charm (measured by displaced decay vertices) for M>1 GeV

Acceptance correction in the variables M-p_T-y-cosΘ_{CS}

Thermal dimuon mass spectrum: the only solid proof of deconfinement at SPS energies

[EPJ C 59 (2009) 607]; CERN Courier 11/ 2009, 31-34; Chiral 2010 , AIP Conf.Proc. 1322 (2010) 1



all physics-background sources subtracted, integrated over p_T , fully corrected for acceptance, absolutely normalized to $dN_{ch}/d\eta$

effective statistics highest of all experiments, past and present (by a factor of nearly 1000)

M<1 GeV

ρ dominates, 'melts' close to T_c

M>1 GeV

~ exponential fall-off → 'Planck-like'

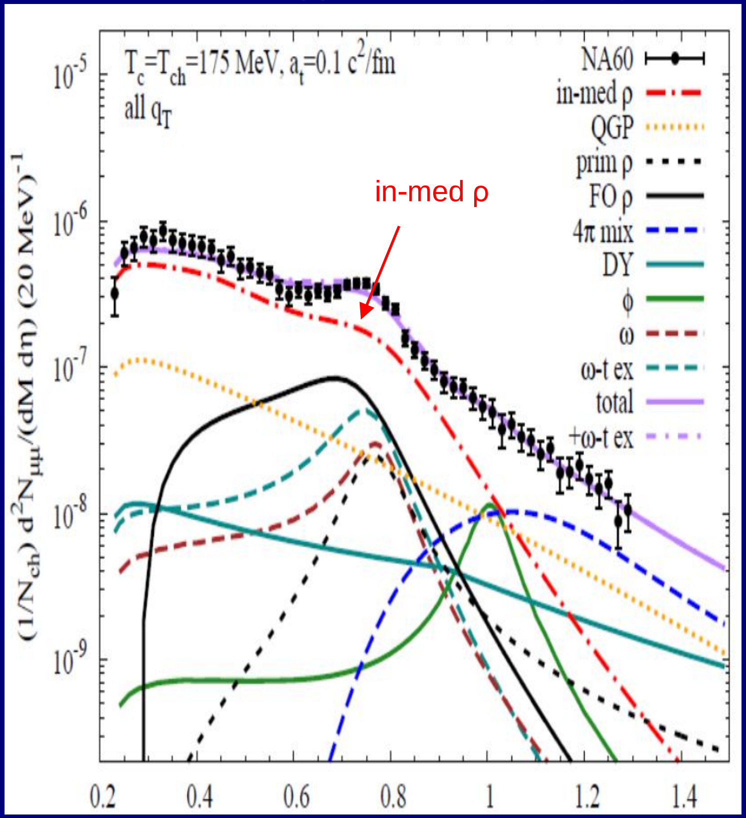
fit to $dN/dM \propto M^{3/2} \times \exp(-M/T)$

range 1.1-2.2 GeV: T=220±11 MeV

$T>T_c$=160-170 MeV: partons dominate

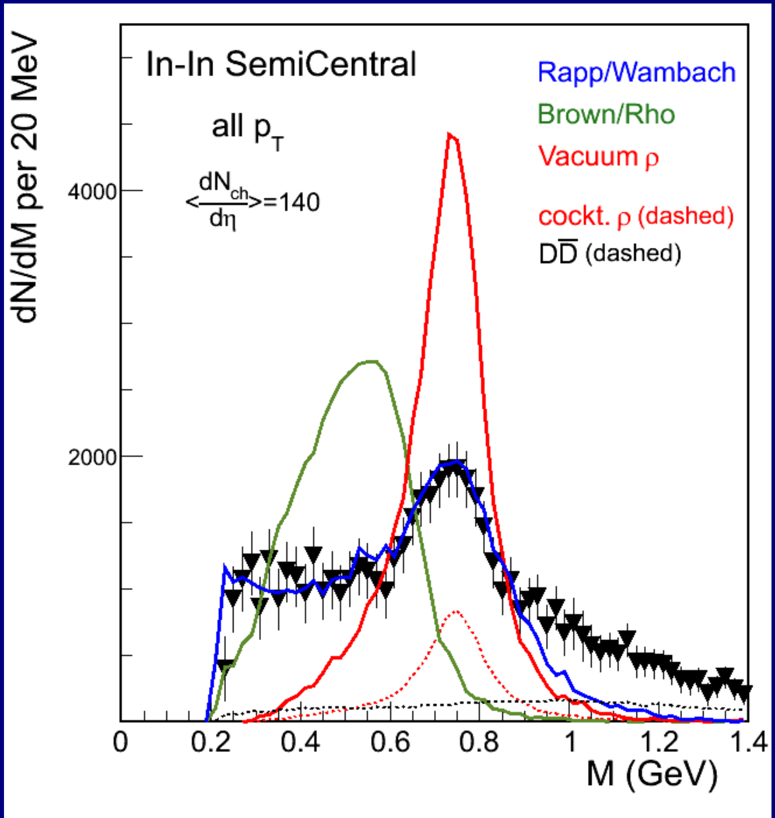
Towards chiral restoration: mass shift vs. broadening

H. v. Hees, R. Rapp, NPA A 806 (2008) 339



Perfect agreement in absolute terms
Rapp: 'spectrum directly reflects thermal emission rate'

Phys.Rev.Lett. 96 (2006) 162302



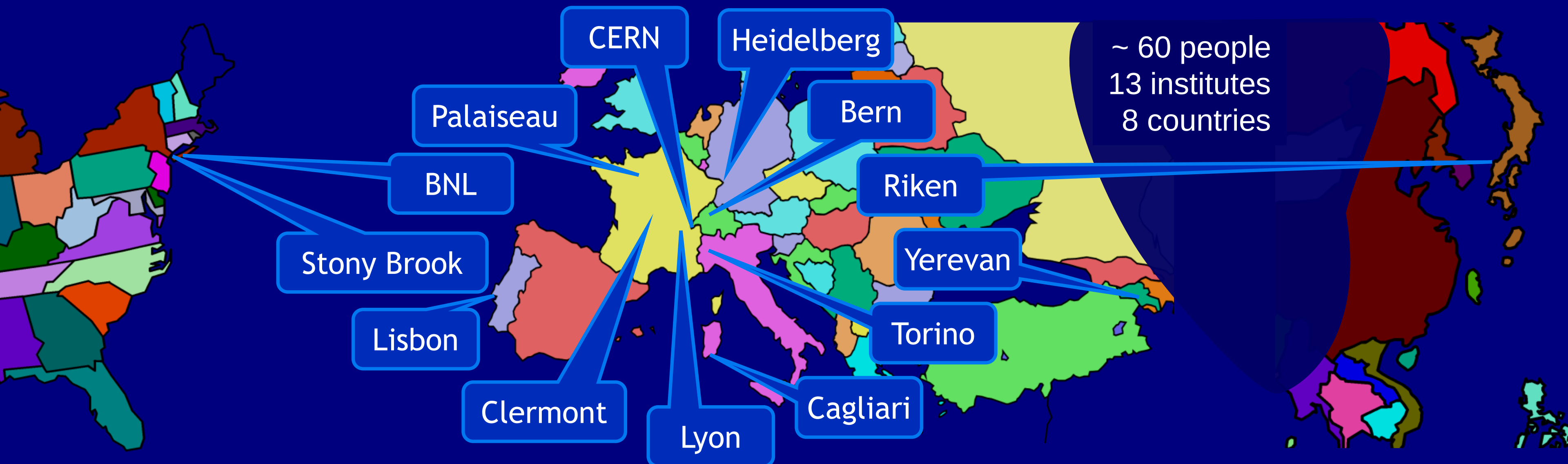
before acceptance correction:
ρ spectral function, averaged over space-time and momenta

only broadening of ρ observed, no mass shift → 'hadrons melt'

On chiral restoration and ρ melting: *P.M.Hohler and R. Rapp, PLB 731 (2014) 103*

The NA60 experiment

http://cern.ch/na60



R. Arnaldi, K. Banicz, K. Borer, J. Buytaert, J. Castor, B. Chaurand, W. Chen,B. Cheynis, C. Cicalò, A. Colla, P. Cortese, S. Damjanovic, A. David, A. de Falco, N. de Marco, A. Devaux, A. Drees, L. Ducroux, H. En'yo, A. Ferretti, M. Floris, A. Förster, P. Force, A. Grigorian, J.Y. Grossiord, N. Guettet, A. Guichard, H. Gulkanian, J. Heuser, M. Keil, L. Kluberg, Z. Li, C. Lourenço, J. Lozano, F. Manso, P. Martins, A. Masoni, A. Neves, H. Ohnishi, C. Oppedisano, P. Parracho, P. Pillot, G. Puddu, E. Radermacher, P. Ramalhete, P. Rosinsky, E. Scomparin, J. Seixas, S. Serci, R. Shahoyan, P. Sonderegger, H.J. Specht, R. Tieulent, E. Tveiten, G. Usai, H. Vardanyan, R. Veenhof and H. Wöhri

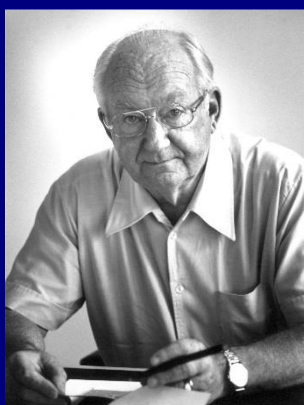
Scientific Director of GSI 1992-1999

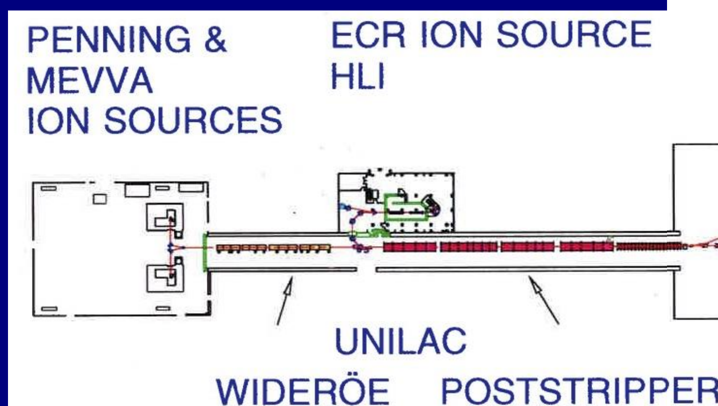
GSI Accelerators and Experimental Facilities in the 1990's

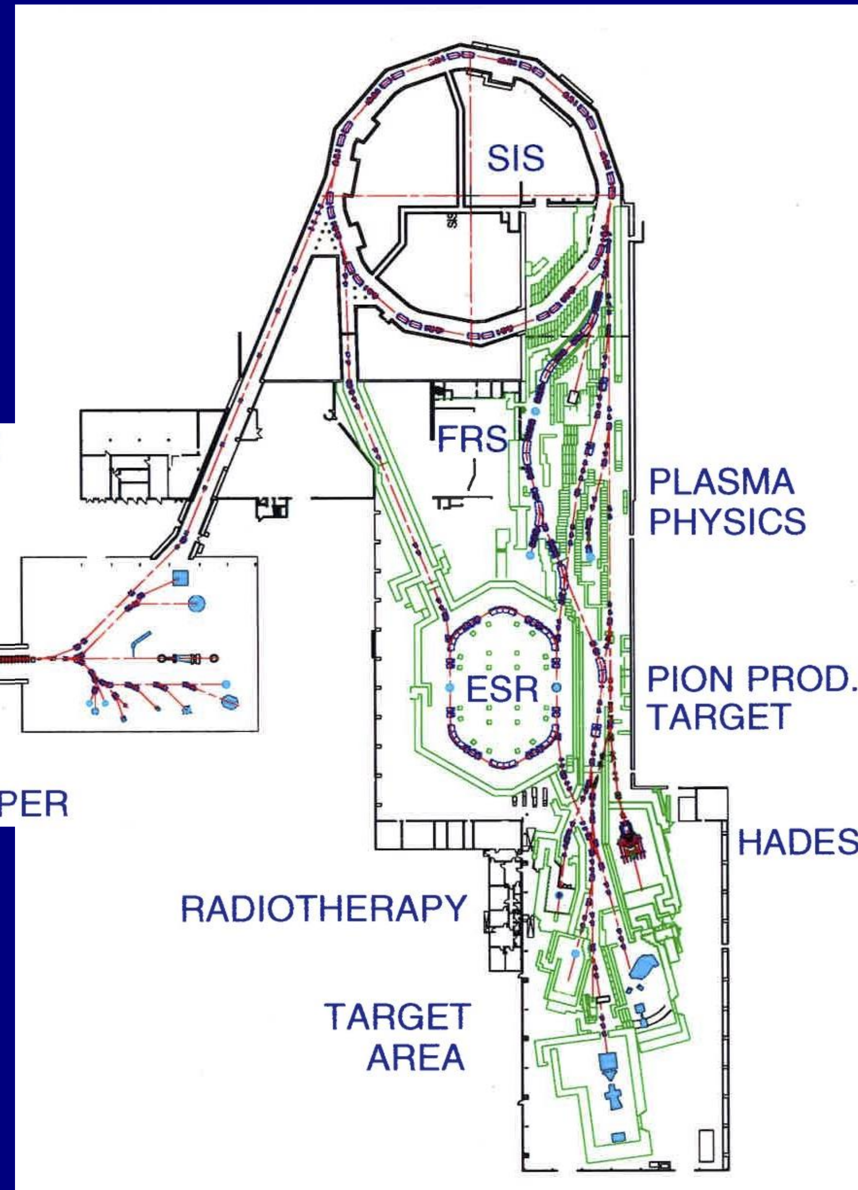
1959 Start of development of the UNILAC by C. Schmelzer et al., Heidelberg

1969 Foundation of GSI, Darmstadt

1976 First Uranium beams, initially up to 9 MeV/u, later increased to 20 MeV/u







1985 Approval of the SIS18/ESR Project

1990 Start of operation of SIS18/ESR, protons max. 4.5 GeV, U 1.0 GeV/u

1998 Start of studies towards further expansion of the GSI facilities

Management Structure during 1992-1999

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

Scientific secretary: D. Gross

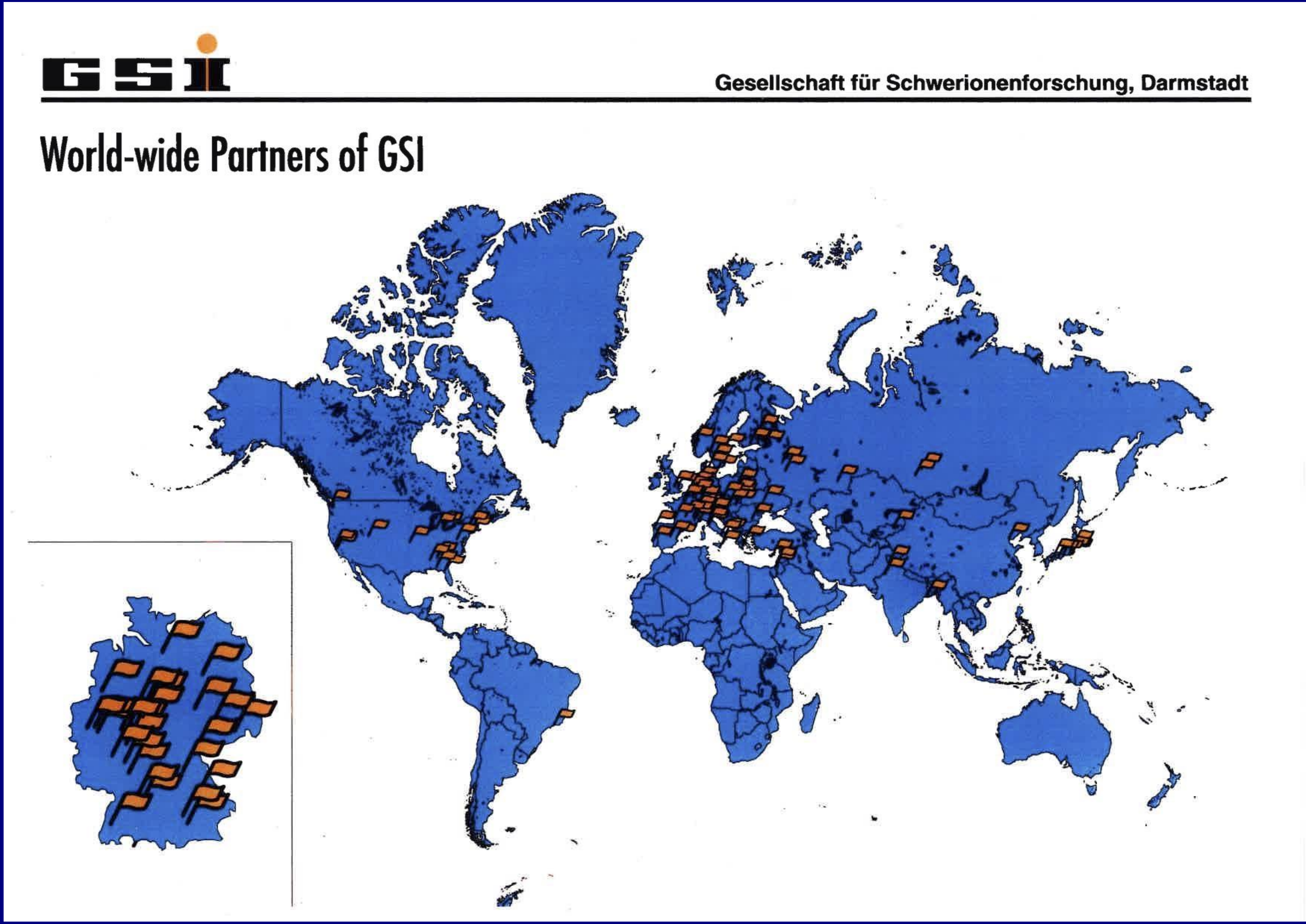
Chairman	H.J.Specht
Research	V. Metag (Giessen)
Accelerators	N. Angert
Infrastructure	W. von Rüden (CERN)
Administration	H. Zeitträger

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)

Increasing international use of GSI during the 1990's



Research at GSI during the 1990's

HEAVY ION SCIENCE

Key Issues

1. Nuclear (and Particle) Physics

- **Bulk Properties of Nuclear („Hadronic") Matter**
    - Liquid-Gas Phase Transition
    - Nuclear Compression („Equation-of-State")
    - Hadron-Quark/Gluon Phase Transition
- **Quantum Properties of Nuclei at Extreme Conditions**
    - Very high Z (>109 Mt)
    - Very high Spins
    - Very high Excitation Energies („multi phonon states")
    - Extreme Values of Isospin („far-off stability")

2. Atomic Physics

- **Precision Spectroscopy of H-like Heavy Ions**

3. Other Fields of Science and Applications

- **Inertial Confinement Fusion**
- **Radiobiology and Radiation Therapy**
- **Material Sciences**

Original slide shown in 1992 and 1999

Operational basis:

700 Employees (250 Scientists and Engineers)
1000 Users (100 internal, 400 from abroad)
Budget: 125 MDM (Operation 100, Investm. 25)

Main priority:

Full use of the rich opportunities connected with the UNILAC and the new facilities

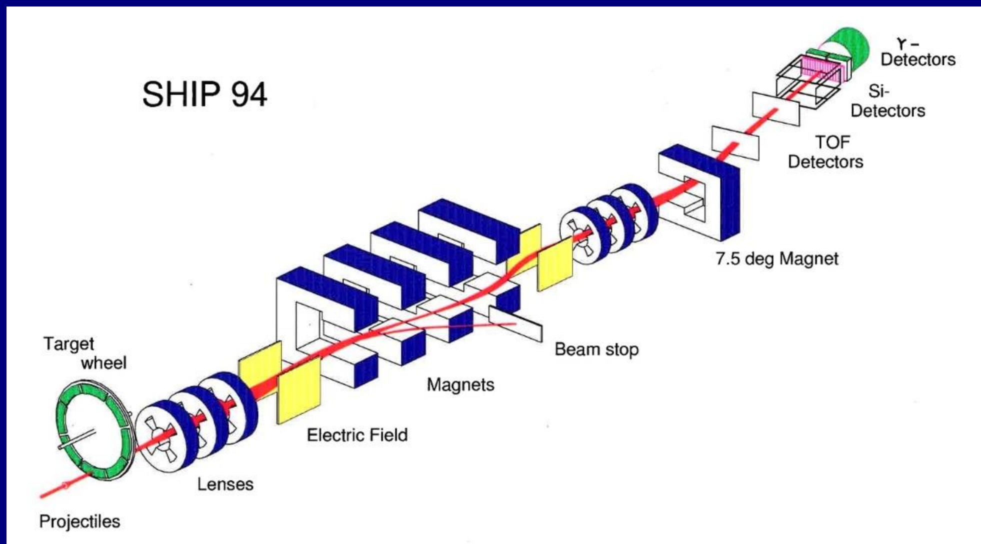
Enormous progress in all fields, e.g.
>500 new isotopes far off stability (up to today)
Most visible: new elements Z=110-112

Major new projects:

- Tumor Therapy with C-Ions (patient treatment in situ, using SIS18)
- PHELIX (Pulsed High Power Laser System, also in conjunction with Heavy Ions)

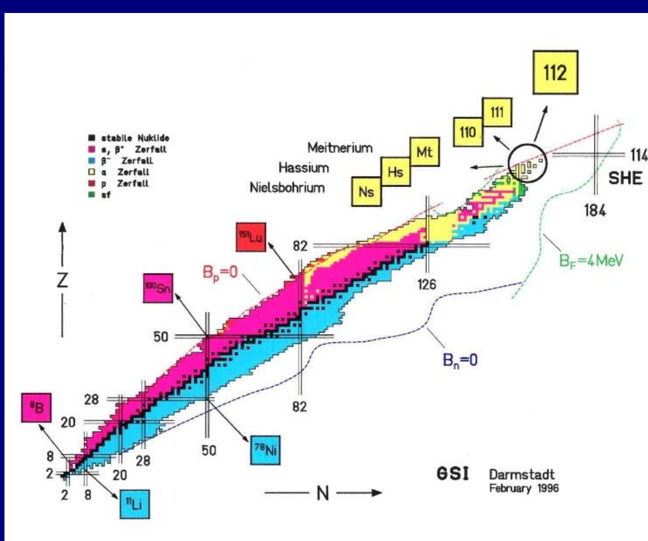
Superheavy Elements at GSI

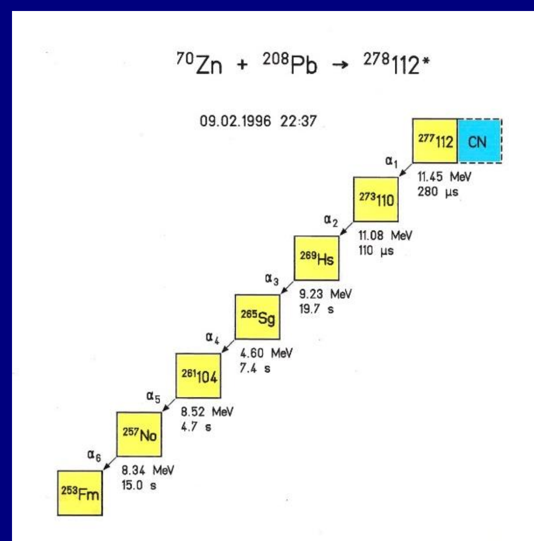
6 new elements detected since 1981, Z=110-112 in 1994-96

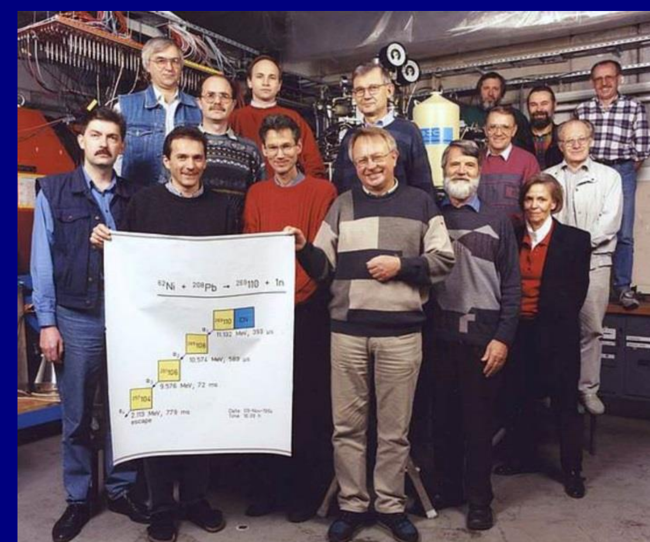


the SHIP spectrometer for fusion products

mass-separated products implanted in a Silicon detector





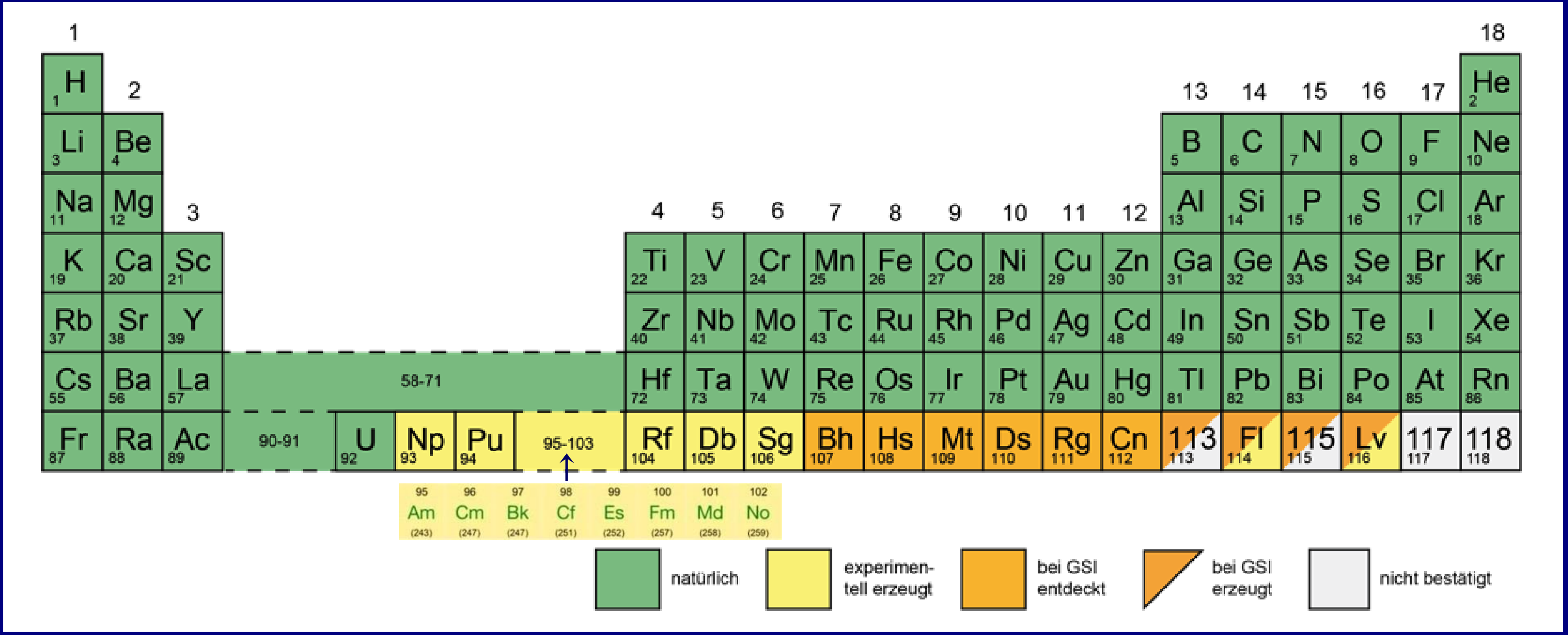


The 3 ‘Fathers’ of all Elements above U^{92}

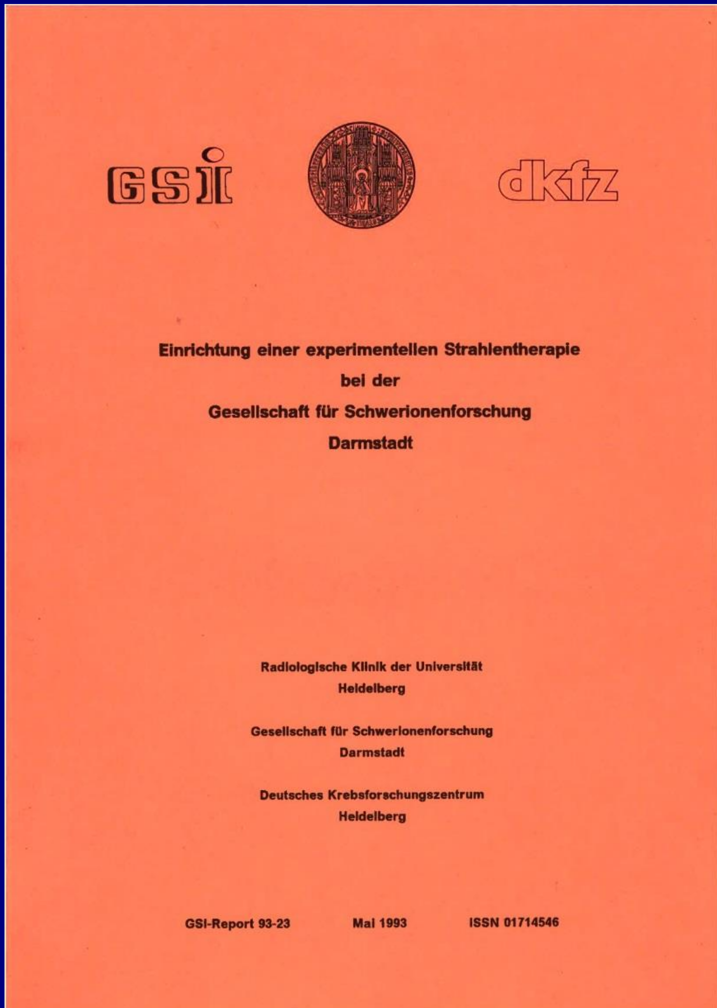
A unique occasion at GSI
12 November 1996

Peter Armbruster (65)
Glenn T. Seaborg (88)
Yuri Oganesian (63)

Transuranium elements 20a later



Cancer Therapy: Pilot Project with ^{12}C-Ions at GSI



Einrichtung einer experimentellen Strahlentherapie
bei der
Gesellschaft für Schwerionenforschung
Darmstadt

Radiologische Klinik der Universität
Heidelberg

Gesellschaft für Schwerionenforschung
Darmstadt

Deutsches Krebsforschungszentrum
Heidelberg

GSI-Report 93-23 Mai 1993 ISSN 01714546

Project Proposal May 1993
(100-page document)

Radiologische Klinik Universität Heidelberg
- Responsible: M. Wannenmacher
- Execution: G. Gademann → J. Debus

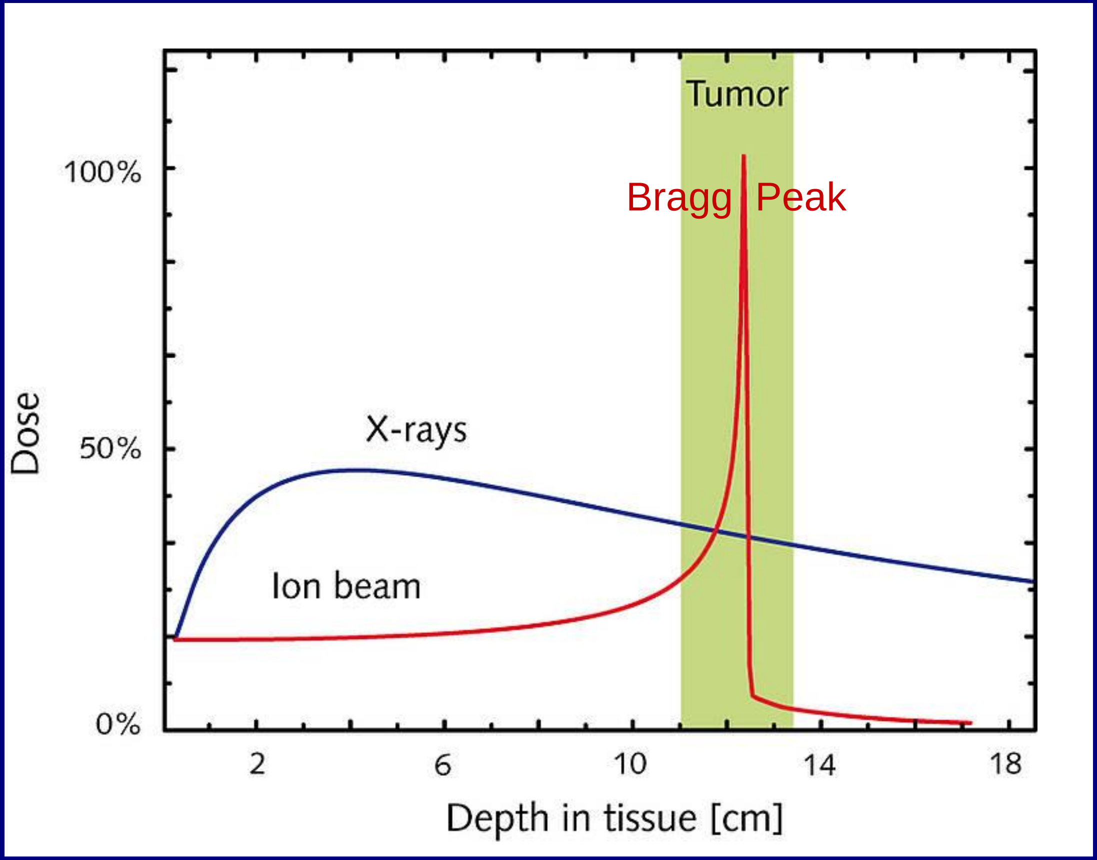
GSI Darmstadt
- Resonsible: H.J. Specht
- Execution: G. Kraft, D. Böhne, T. Haberer

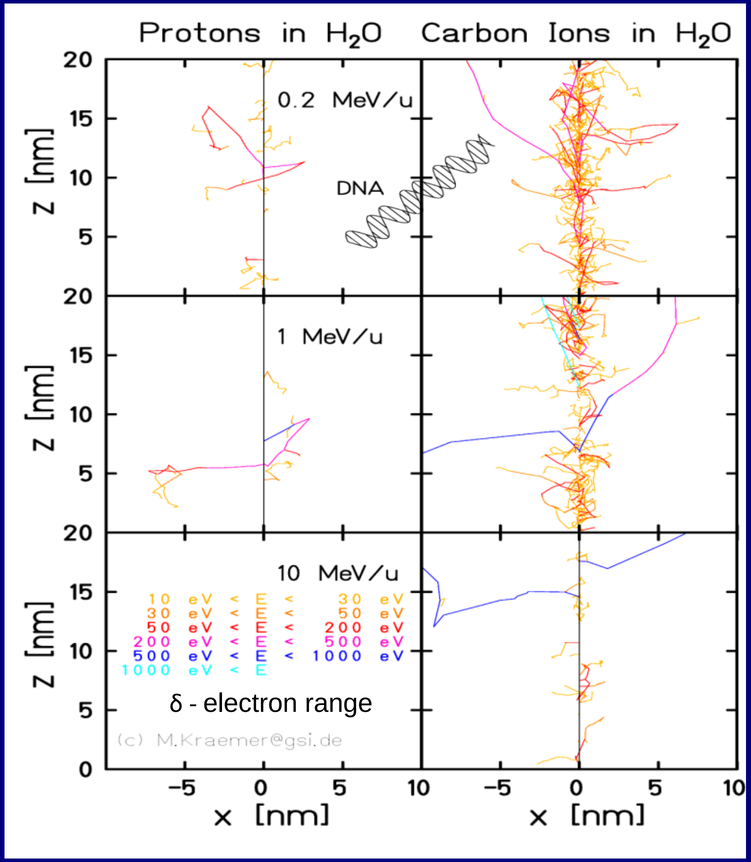
DKFZ Heidelberg
- Responsible: H. zur Hausen
- Execution: W. J. Lorenz, G. Hartmann

FZR Rosendorf (joint later)
- Responsible: F. Pobell
- Execution: W. Enghardt

Only other facility world-wide: HIMAC/Japan (under construction at that time)

Hadrons (protons, C-ions) vs. X-rays (e-bremsstrahlung)





Depth dose distribution

Longitudinal:
inverted dose profile for p and ^{12}C relative to X

Lateral:
smallest scattering for ^{12}C

Dose distribution on a nm scale

single DNA strand breaks (p,X)
→ reparable

multiple DNA strand breaks (^{12}C)
→ irreparable

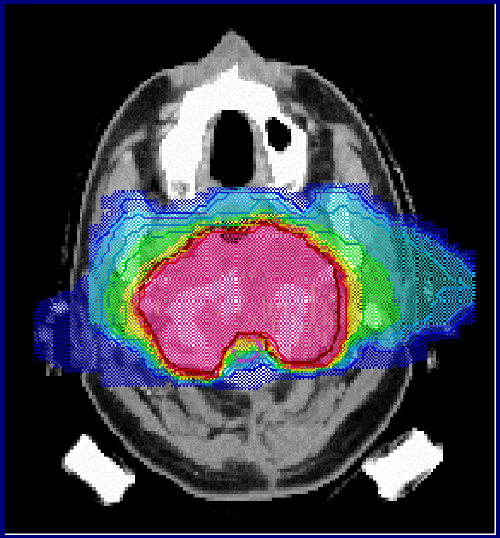
Results of the Pilot project with ^{12}C-Ions at GSI

1993-1997 develop. of hard- and software

- Rasterscan with intensity modulation
- Treatment plan (Voxelplan + LEM)
- In situ PET control
- Hospital-like cave and control room
- Parallel beam operation for physics

1997-2008 Treatment of ~450 Patients

- Chordoma, Chondrosarcoma, Prostata…



Superposition of only two (!) irradiation fields

Spectacular success, opening the way to the Clinic machine in Heidelberg

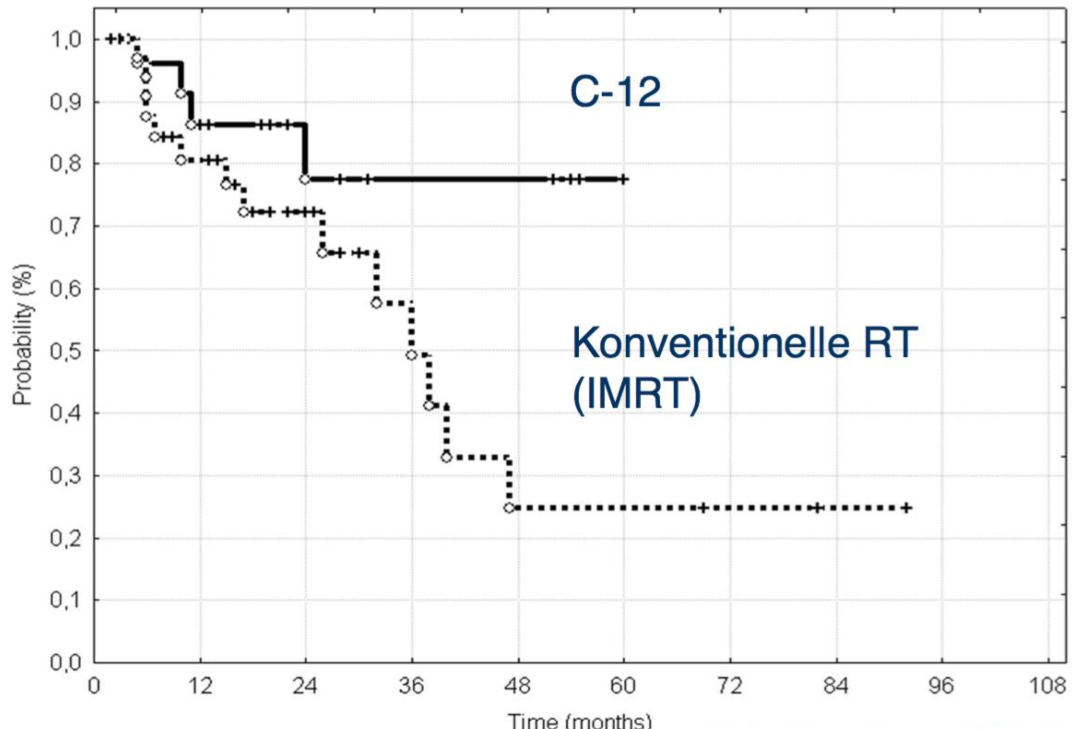
Control of Salivary Gland Tumors

HIT Heidelberger Ionenstrahl-Therapiezentrum

UniversitätsKlinikum Heidelberg

Speicheldrüsentumore

Vergleich Tumorkontrolle C-12 vs. Photonen
(adenoidcystische Karzinom)

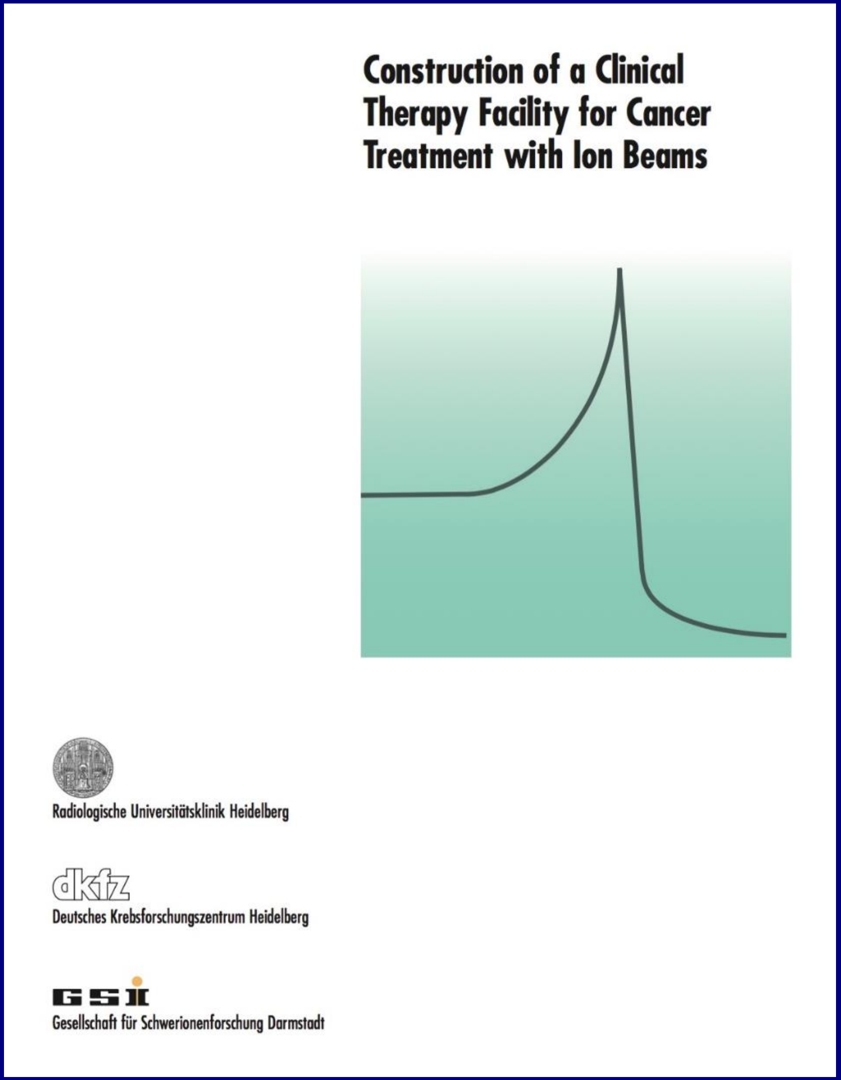


Schulz-Ertner, Cancer. 2005 Jul 15;104(2):338-44

Inauguration of the Therapy Project at GSI on 15.09.1998

Wannenmacher, Debus, Siebke, zur Hausen,
Amaldi, Kraft, Specht

Haberer, Rütgers, Specht, Hoffmann-Dehnert



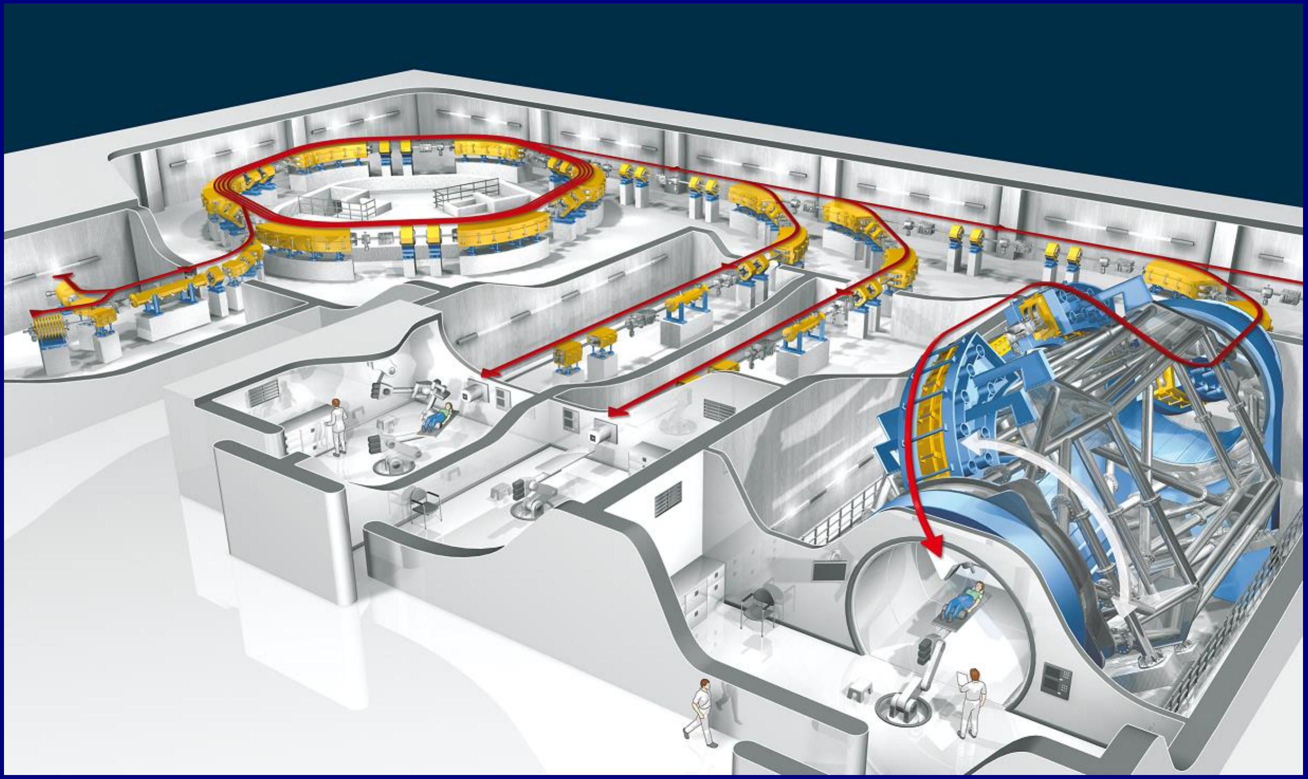
Official Project Proposal for Heidelberg, here handed over to Minister J. Rütgers

Project leader: Radiologische Uni-Klinik HD

Heidelberger Ionenstrahl-Therapiezentrum (HIT)

Ärztlicher Direktor Radiologische Universitätsklinik Heidelberg:
J. Debus (since 2003), successor to M. Wannenmacher
Technischer Direktor: T. Haberer

Fast change of different beams: p,^{4}He,^{12}C,^{16}O

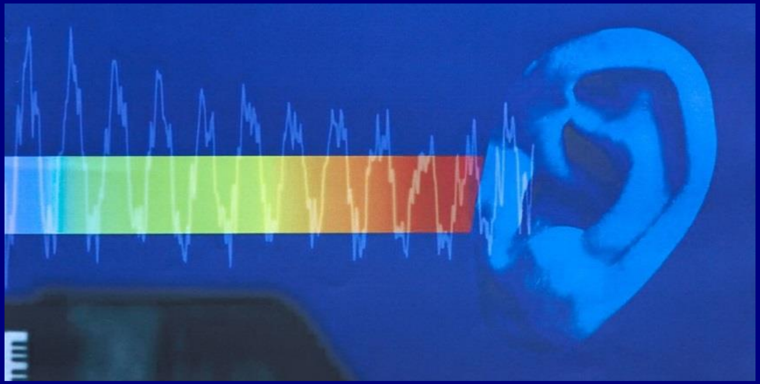


First and only heavy-ion Gantry world-wide

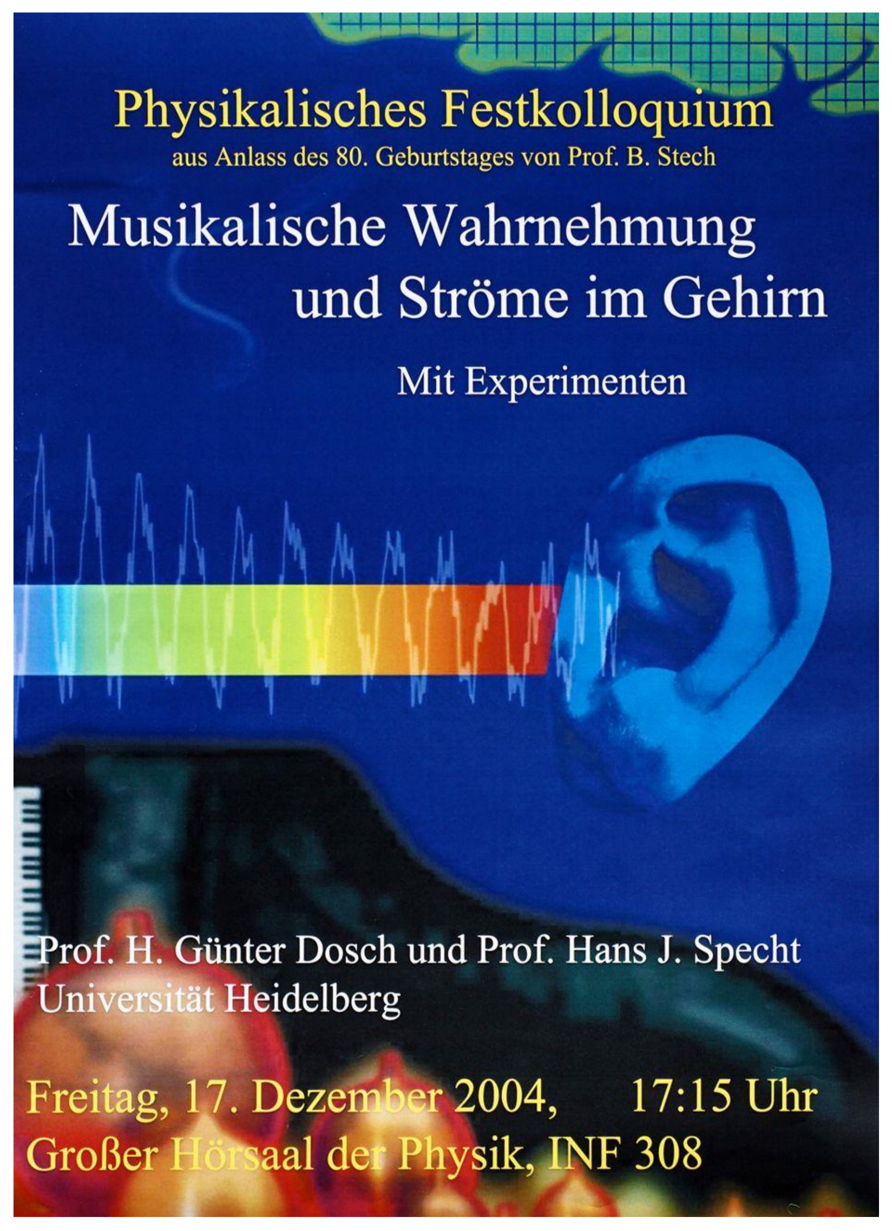
Responsibility for development and construction at GSI (H. Eickhoff et al.)
Collaboration with Siemens

First patients in 2009, >3000 patients so far. All indications → website HIT

Music, Physics, Neuroscience



Lecturing on Physics and Music



The start: 1986, 600th Anniversary Uni HD
"Helmholtz und danach: Physik und Musik"

>20 Lectures: CERN, Harvard, München, Wien, Berlin, Music Festivals Verbier + Bonn…

1994 at GSI

Research Topics and Strategy

- Psychoacoustical hearing tests

- Musical hearing tests (AMMA)

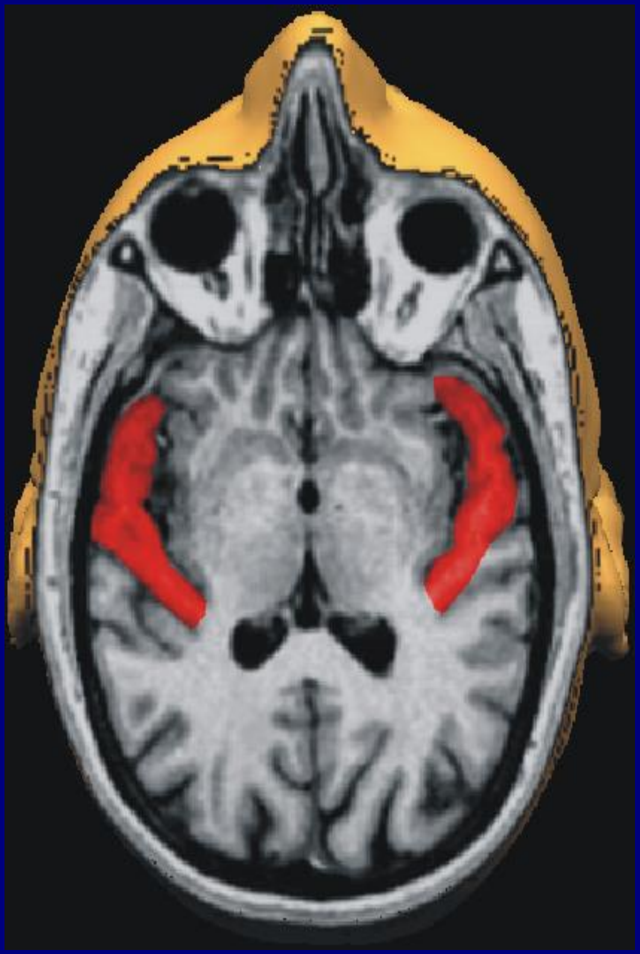
- Anatomical structure of the primary hearing cortex (MRT)

- Acoustically evoked magnetic fields in the hearing cortex (MEG)

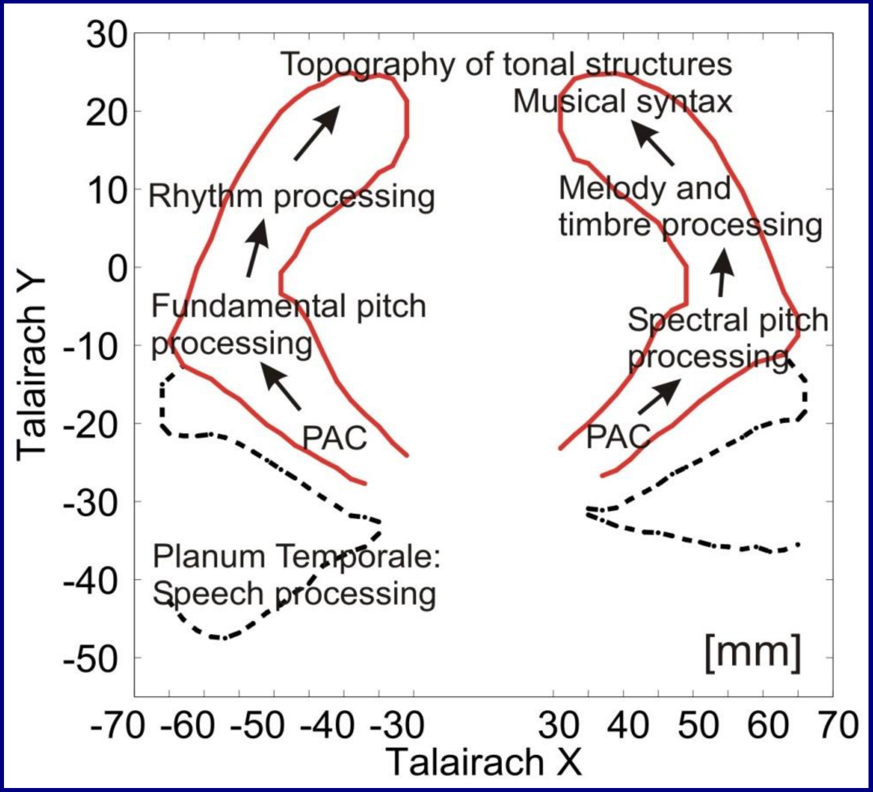
Insight from correlating perceptive and objective quantities

> 400 test subjects, mostly professional musicians

Primary hearing cortex: Heschl‘s Gyrus



Example: MEG signals



Hierarchical structure, accessible through the time-ordering of the MEG signals

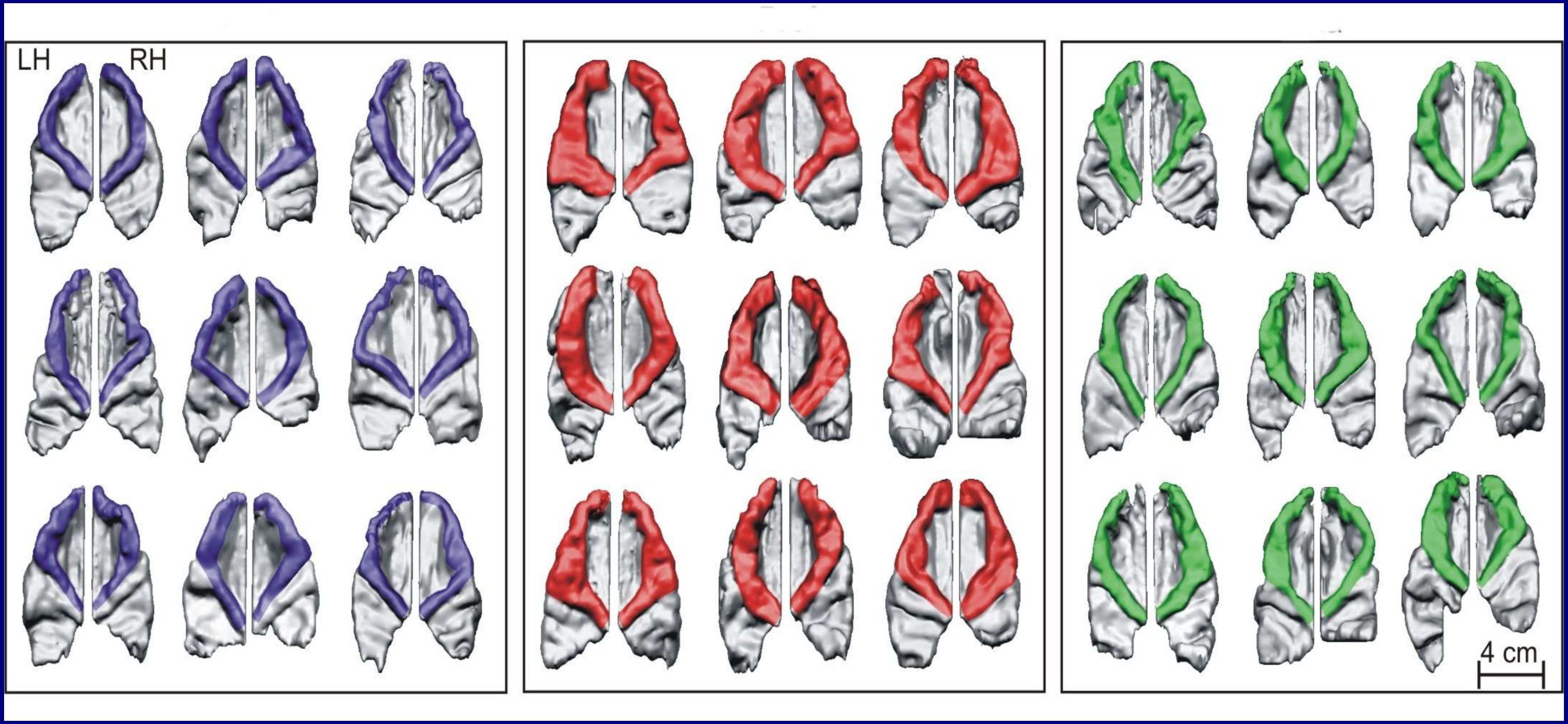
Heschl‘s Gyrus (HG) and supratemporal Gyrus (STG):
Early music processing

Example of results I: Size of the hearing cortex from MRT

Nature Neuroscience 5, 688-694, 2002 (467 citations)

P.Schneider[1,2], M. Scherg[1], H.G. Dosch[2], H.J. Specht[2], A. Gutschalk[1], A. Rupp[1],
[1]Neurologische Universitätsklinik, [2]Fakultät für Physik, Heidelberg

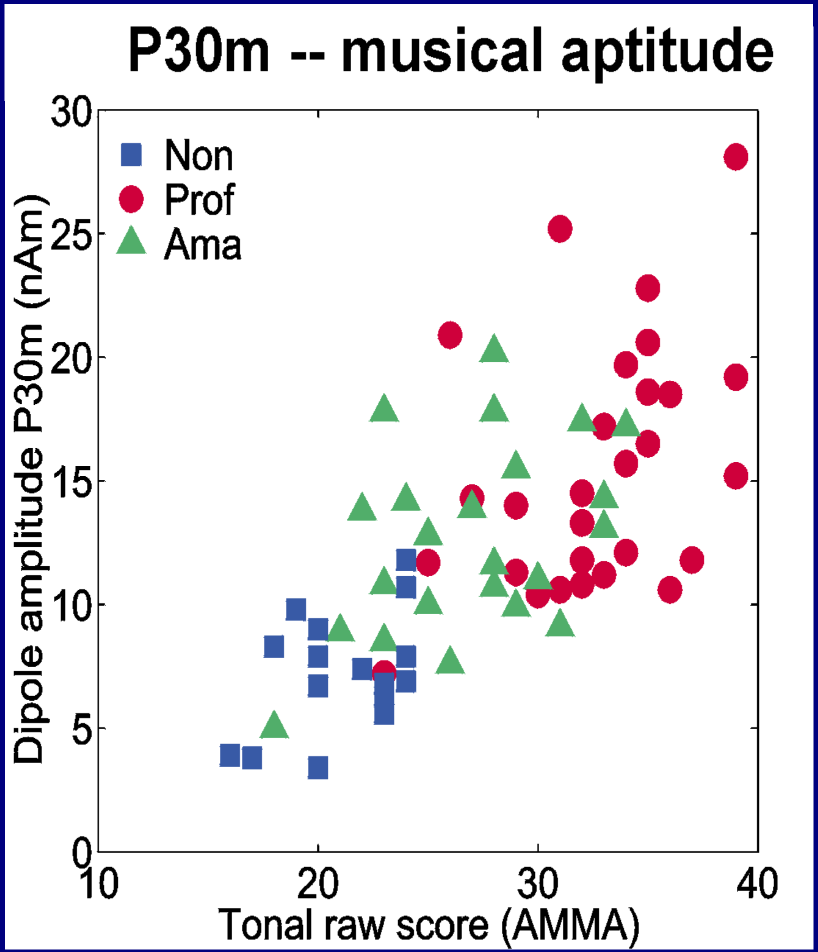
Non-musicians (37) | Professional musicians (62) | Amateurs (25)



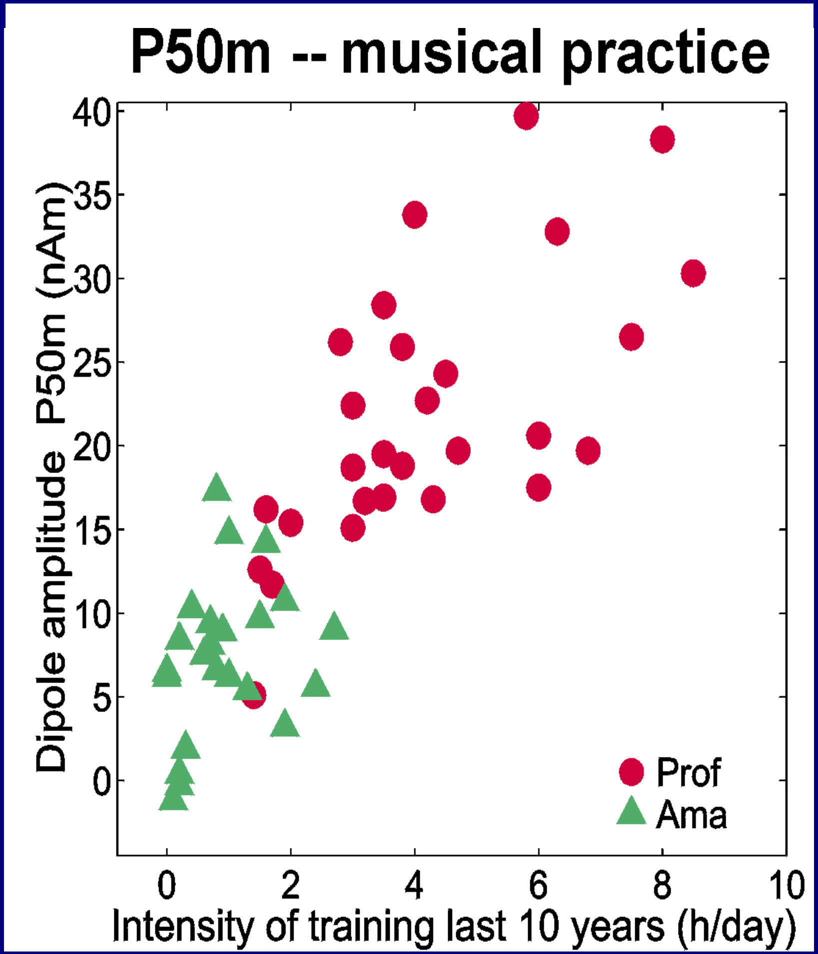
Different sizes, largest for professionals

Example of results II: Dipole strength from MEG

Dipole-Amplitudes proportional to the respective volume



AMMA: objective musicality test (Gordon)



Daily training frequency (hours per day)

Strong correlations both for musical aptitude and musical practice

Similar results from MRT (associated volumes)

Finale