Adding a new dimension to CERN

Heavy ions at CERN

Herwig Schopper
CERN and University Hamburg

Talk at 30 years of Heavy Ions at CERN, 9 November 2016

Thank you organisers for inviting me
and also for chosing the title!

But be warned:
I am not an expert in heavy ions,
Cannot tell you much about physcis which you know better
Only a very interested observer and sometimes a helper

To remind you of some historical events, partly forgotten
my personal recollections, forgive any mistakes

One of the earliest pioneers: Rolf Hagedorn

He came to CERN in 1954 as successor of Gerhart Lüders.

Known from the Lüders-Pauli CPT theorem

But both doing accelerator beam calculations!!

I got to know him in 1960s when I did my first experiment at CERN and found him quite accessible for an experimental physicist.

He explained to me his main ideas concerning the heating up of strongly interacting matter in high energy collisions in a way easily understandable for somebody like me who had worked in low energy nuclear physics and knew the shell model and liquid drop model of the nucleus

The concept that the energy content of strongly interacting matter could not surpasse a certain temperature,
the famous Hagendorn-temperature, was fascinating

It plays still a vital role today

But has its value of about 176 MeV been explained yet.

Of course, the energy content can only be increased without increasing the temperature if new degrees of freedom become available. As to their nature, Hagedorn could only speculate since quarks and gluons were not yet known.

These developments of the years 1964-1984, are nicely described in a recent book,
by Johann Rafelski, student of Greiner and close collaborator of Hagedorn

Johann Rafelski with Hagedorn

But Hagedorn was not only a remarkable theorist he developed one of the earliest userfriendly interactive computing programs for algebraic manipulations, the SIGMA.

Rolf Hagedorn was a remarkable personality always ready to help those in need.

Hagedorn and his wife liked to ride horses in the hills of the French Central Plateau, at Le Chambon, a place where his daughter went to a Boarding School Le Collége-Lycé International. A school at the time filled with children associated with the holocaust survivors and the Hagedorns helped in many ways.

On the experimental side, in the 1970s and 80s,

the study of heavy ion reactions grew out of nuclear physics and eventually became an interdisciplinary field of its own (Darmstadt, Berkley)

- **First discussions about injecting heavy ions into the CERN machines started in the early 1970ies**
- **Giuseppe Cocconi suggested to transfer ions up to $^{16}0$ (and even U) from PS to ISR and eventually to SPS.**

In 1982 a triangle was formed:
- **GSI, Darmstadt,**
- **CERN**
- **LBL Berkeley**

Proposal to get heavy ions to CERN.

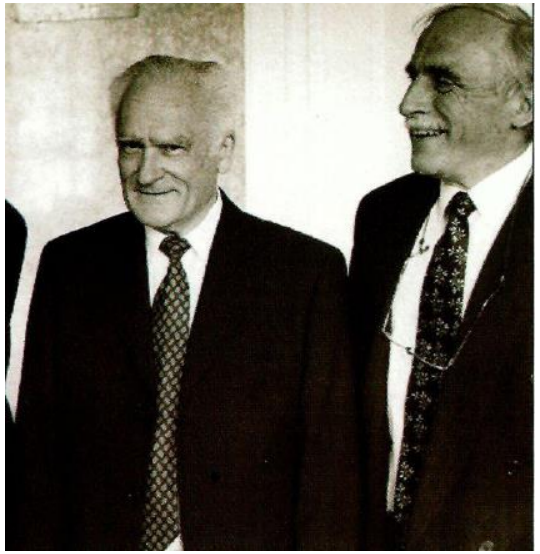
MoU was signed and GSI promised to bring an ECR-ion source and LBL a RFQ Linac to CERN.

GSI and LBL were prepared to abandon this physics in their home labs.

Main players:

H.H.Gutbrod (SI)

Herrmann Grunder (LBL)



Rudolf Bock(GSI), Reinhard Stock (Marburg)

The 1982 Proposal

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]

Overall Situation at CERN in 1982

- **Director General from 1.January 1981 Herwig Schopper**

First task: not new dimensions, but compactification

Unite CERN I (Leon van Hove) and CERN II (John Adams)

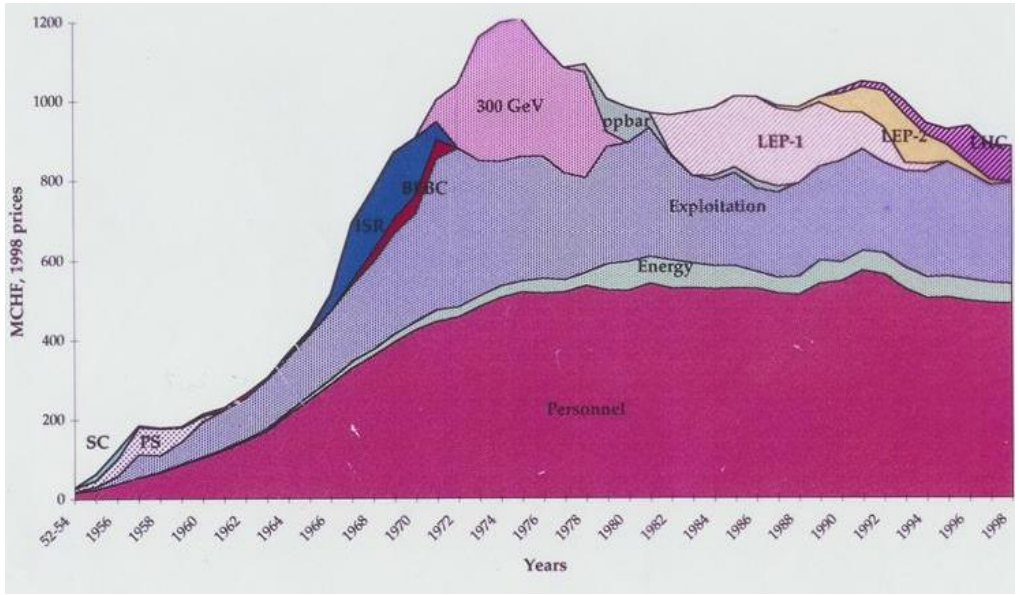
- **2 Directors for Research:**
  E.Gabathuler for Colliders

  R.Klapisch for other programmes
  including Heavy Ions

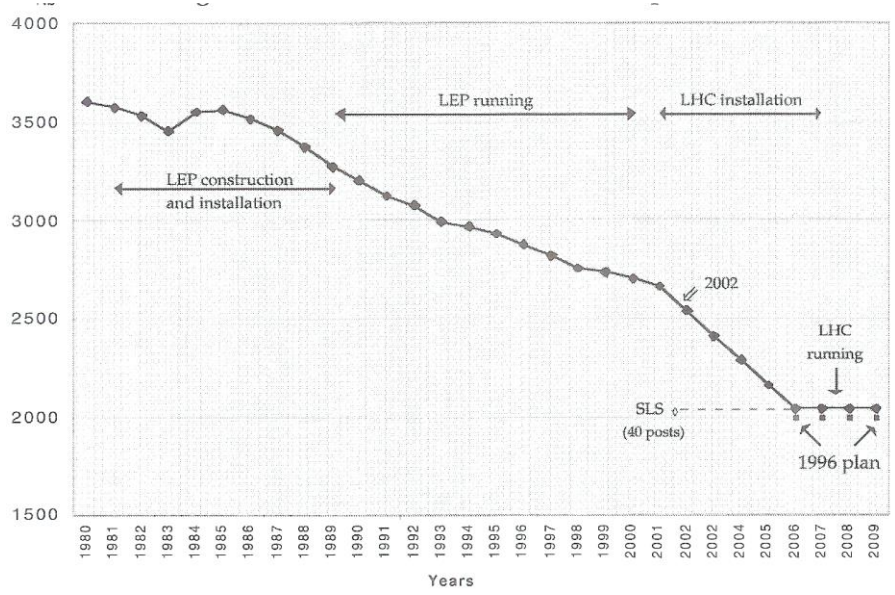
- **LEP Projekt leader E. Picasso**

My main task:
Propose LEP, get it approved and build it

Conditions for approval:
constant budget, lower than before



Abragam committee:
reduce staff, in spite increasing users
early retirement



Staff Association: resign!

Programms which had to be stopped or reduced in favour of LEP:

– **ISR, the only proton-proton collider in the world, stopped in 1983,**
a particularly painful decision, I lost many friends
– **BEBC (financed France and Germany) closed**
– **fixed target programme at the PS slowly phased out**
– **SPS fixed target programme in the West hall considerably reduced**
– **SC operation with ISOLDE reduced by 1/3**
– **The long-term accelerator research limited to development of sc cavities and magnets.**

exception: SPS proton-antiproton collider with UA1 and UA2
Continued full steam: Z and W discovery

Only one new programme was started:
Heavy ions in SPS

Decision to start 'heavy ion' programme was one of the most difficult decision taken against the recommendations of all advisory committees,
a rare case where a Director General had to use its full power!

Condition: The experiments had to be financed by outside groups or exploiting existing equipment at CERN

new policy corresponding to that for LEP experiments

but a heavy load remained for the CERN accelerator people:
It implied conversion of accelerators to heavy nuclei (e.g. lead nuclei)
(Linacs, PS and SPS beams to be fired on heavy metal targets)

The reaction of the interested physicists was marvellous and

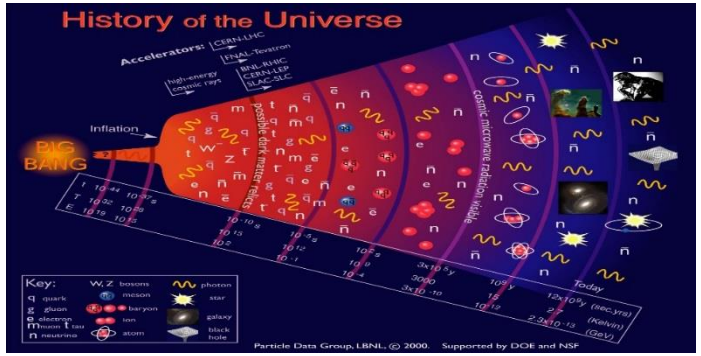
a new age of heavy ion physics started at CERN.

Meeting at Bielefeld 1980

Main arguments to convince me came from T.D.Lee durning lunch in the glass box

- I knew him from Parity violation experiment
- He had no direct personal interest
- His physics motivation sounded convincing

Main arguments:
find the theoretically predicted quark-gluon plasma which played an important role in the development of the universe



One other decision
taken against all advice
concerned the size of the LEP Tunnel

Story practically forgotten

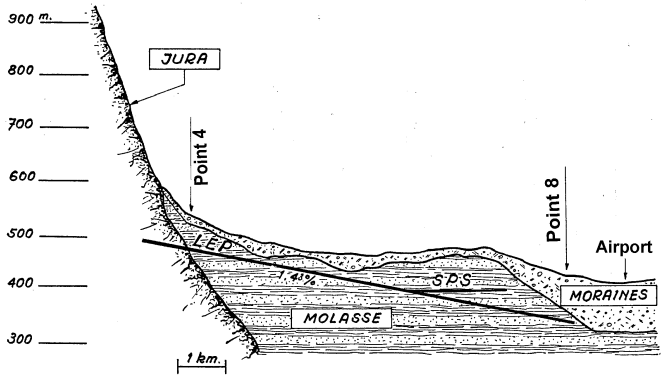
Heavy ion physics only indirectly concerned
ALICE

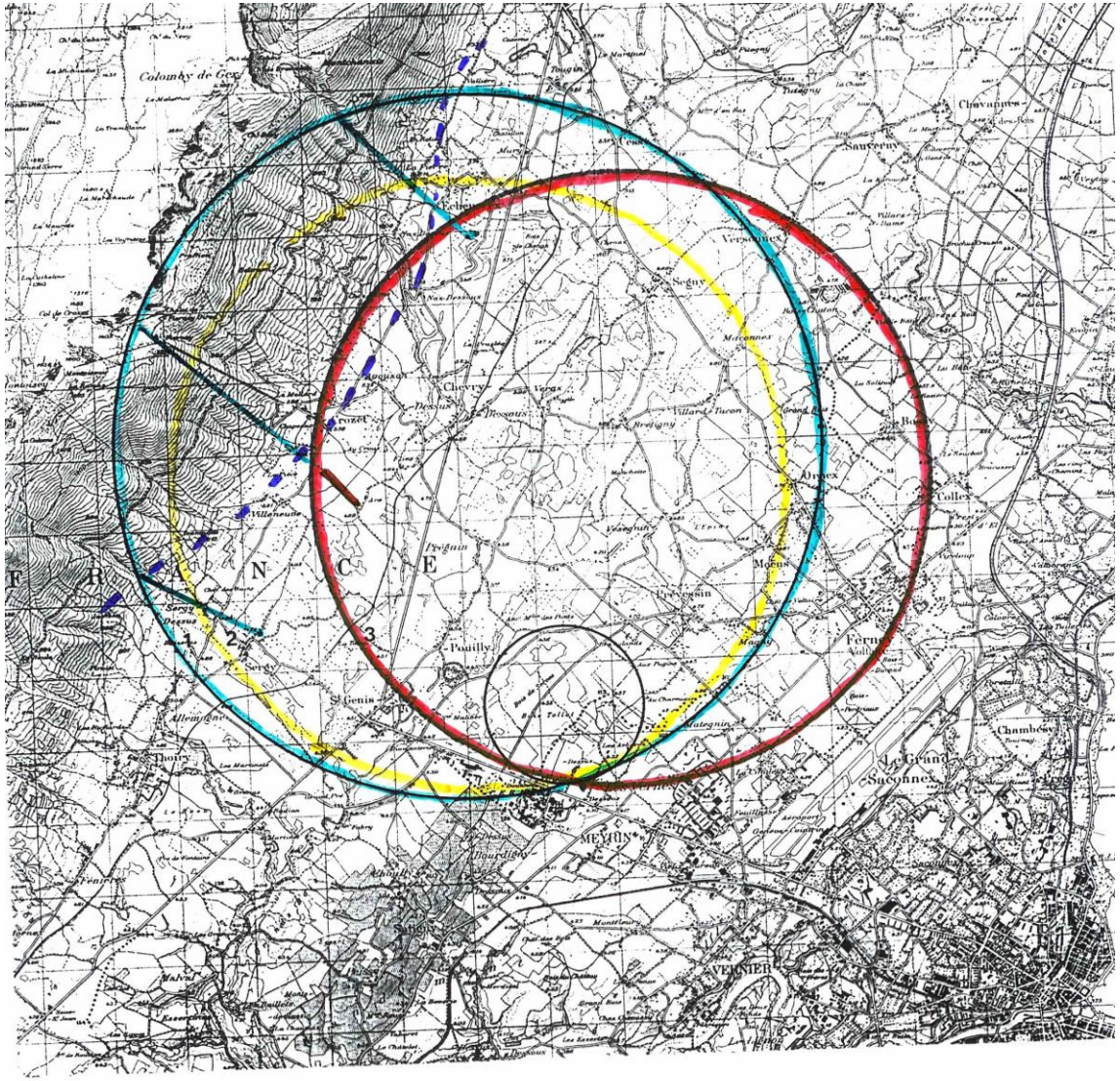
To make the risk tolerable:

Rotate the ring somewhat out of Jura

(3 km remained difficult)

Put tunnel on inclined plane





Green : impossible

Yellow approved by Council

Red: retained

Strong Objections against 27 km Tunnel

Letter from John Adams to Herwig Schopper
(12 March 1981):
„It seems to me that your choice now is either to battle on with the 27 km circumference LEP with possible delays in starting construction, continous trouble with the French authorities at all levels and a serious risk of delays and overspending on the project, or to go flat out for a smaller LEP …..which would avoid all these problems“

Adams proposed 22 km circumference

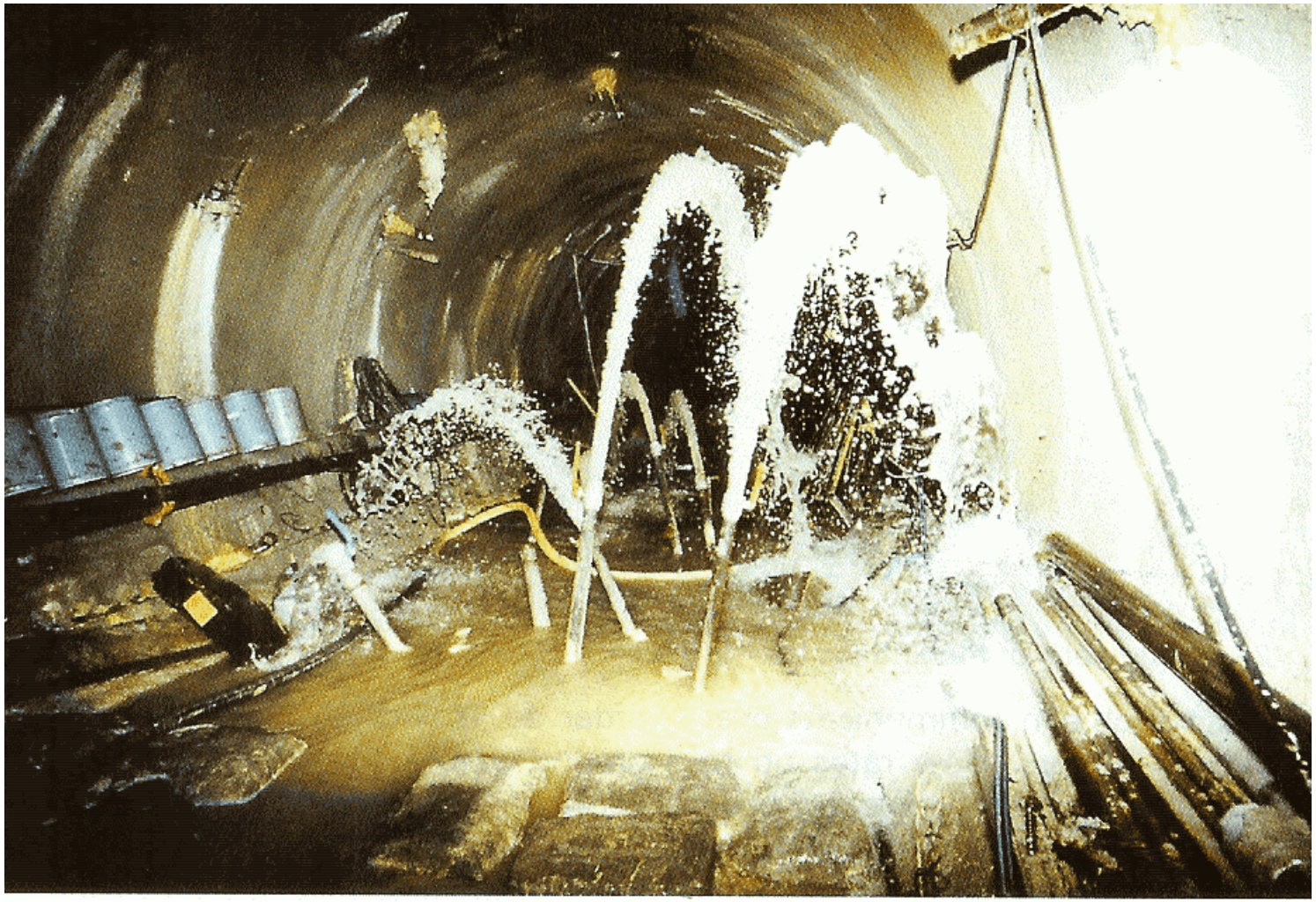
Similar letters by others, e.g C.Rubbia

In spite of warnings with Emilio Picasso
we took decision (without committees!)
to keep 27 km tunnel
to allow highest possible energy for LHC

22 km circumference would have been
sufficient for Z and W physics

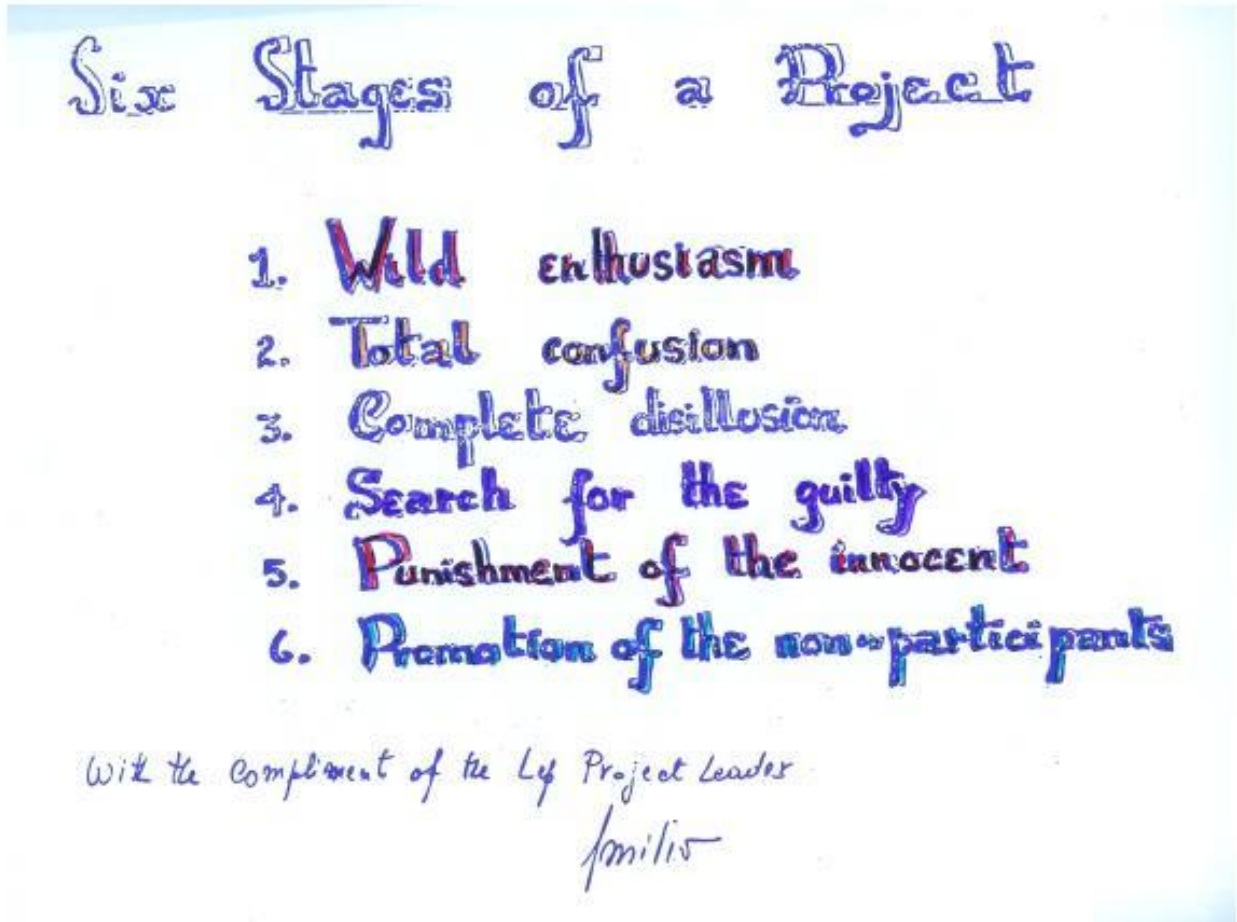
LEP tunnel size was only chosen in view of LHC !!

Competition with SCC!



No disastrous event, but we had to pay for our decision:
water delayed LEP by about 1 year

Letter from Project leader Emilio Picasso



Six Stages of a Project

1. Wild enthusiasm
2. Total confusion
3. Complete disillusion
4. Search for the guilty
5. Punishment of the innocent
6. Promotion of the non-participants

With the Compliment of the Ly Project Leader

Emilio

The heavy ion programme at the SPS could start

- 5 heavy ion experiments were approved in 1984 and started to work in 1986
- The first detectors were put together from equipment used in previous generations of experiments
- first results with ^{16}O 200 GeV/nucleon at SPS reported at Nordkirchen 1987
- New ion souces from Grenoble and Berkley gave Sulpher ion beam with 200 GeV/nucleon
- New step: 1993 Linac 1 was replaced by Linac 3 and ion source for heavier nuclei was developed (institutes from Czech Republic, France, India, Italy, Germany, Sweden and Switzerland), lead beams became possible
- Of course, at rather modest centre-of-mass energy (5 - 20 GeV)

These experiments were leading the field until 2000 when RHIC came into operation

First indication of Quark-Gluon Plasma

The energy density for a QGP at T_c expected $\varepsilon_c \approx 1$ GeV/fm^3.

The energy density reached in central Pb–Pb collisions at the SPS was estimated

(from measured transverse energy of the produced particles)

to be $\varepsilon_c \approx 3$ GeV/fm$_3$,

hence above the critical value ε_c.

The two clearest indications for the production of a deconfined medium in Pb–Pb were:

• the enhancement of the production of strange and multi-strange baryons (hyperons) with respect to the rates extrapolated from pp data

(predicted by J. Rafelski and B. Müller in 1982);

• the suppression of the production of the J/psi meson (the lowest cc bound state), with respect to the rates extrapolated from pp

(predicted by T. Matsui andH. Satz in 1986).

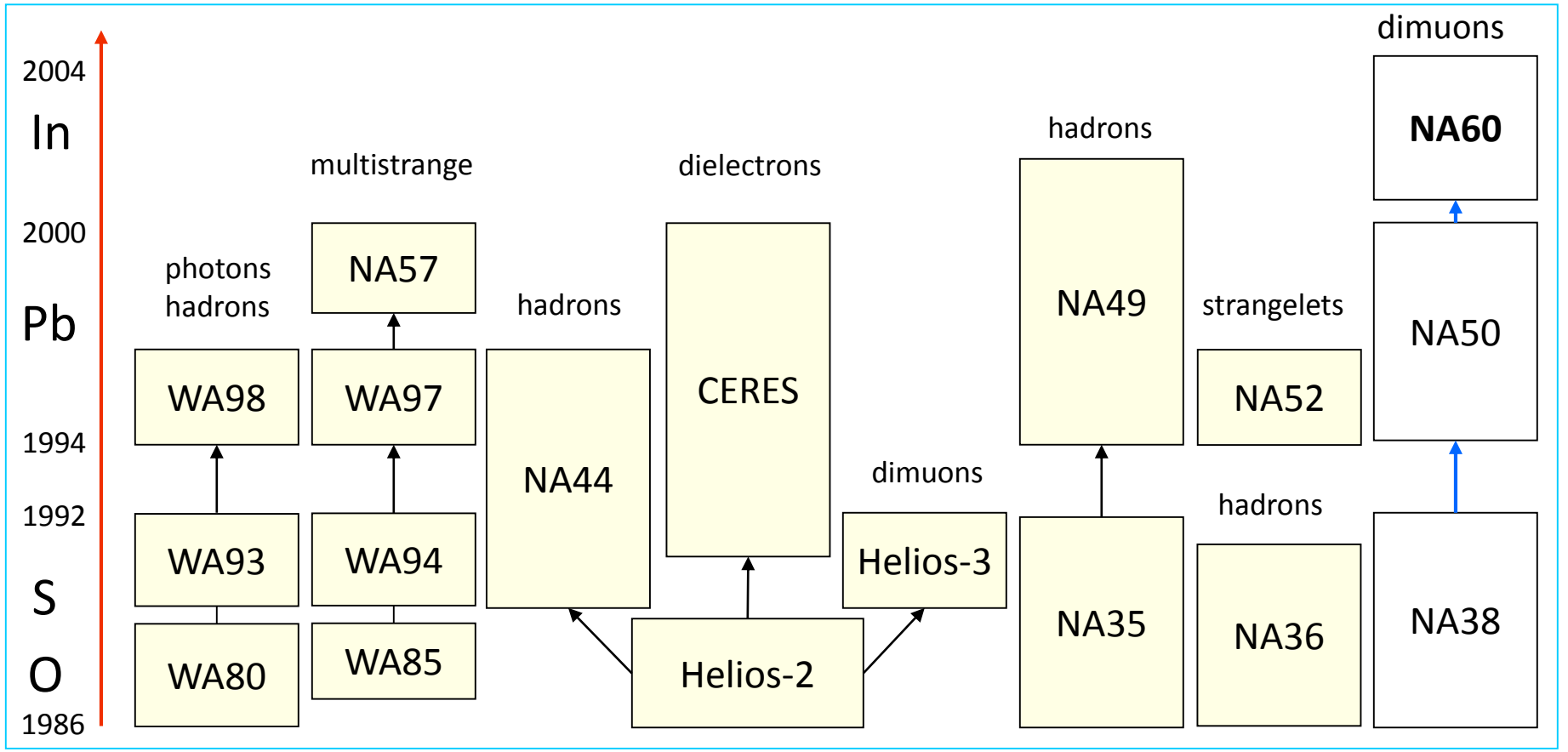
Q-G Plasma was observed just before RHIC started

Press conference on first indication of G-Q plasma formation.

Some doubts, but confirmed later

The CERN SPS heavy ion physics program

- 1986 : Oxygen at 60 and 200 GeV/nucleon
- 1987 – 1992 : Sulphur at 200 GeV/nucleon
- 1994 – 2002 : Lead from 20 to 158 GeV/nucleon
- 2003 : Indium at 158 GeV/nucleon
- and p-A collisions as a reference baseline



New Epoc: Heavy Ions at the LHC

- In 1987, during a workshop to choose CERN's next accelerator project, the LHC, the possibility of using heavy ions was mentioned for.
- In 1990, in the US the Relativistic Heavy Ion Collider (RHIC) - was approved .

  The European community faced the decision which project to join.

  The schedules for RHIC and LHC were, at that time, quite comparable, and a sequential exploitation of both machines seemed impossible
- **It was decided to participate from Europe at a modest scale at RHIC and to start in parallel a dedicated effort for a large general purpose heavy ion detector at LHC.**

- **A small group (Ch.Fabian, H.Gutbrod, H.Specht, W.Willis et al.) sketched a detector concept comprised of a large solenoid, coupled with one dipole at each end and full tracking.**
  This was similar to the smaller 4π detector the group had proposed several years earlier for RHIC.

- **From 1991 on, a group of about 20 persons met at CERN regularly to work on a proposal for a dedicated heavy ion experiment at the LHC**

  The idea of building a dedicated heavy-ion detector for the LHC was first aired in March 1992 at the Evian meeting "Towards the LHC experimental Programme".
  First an Expression of Interest (1992) was submitted

Bill Willis † 2012

Gutbrod

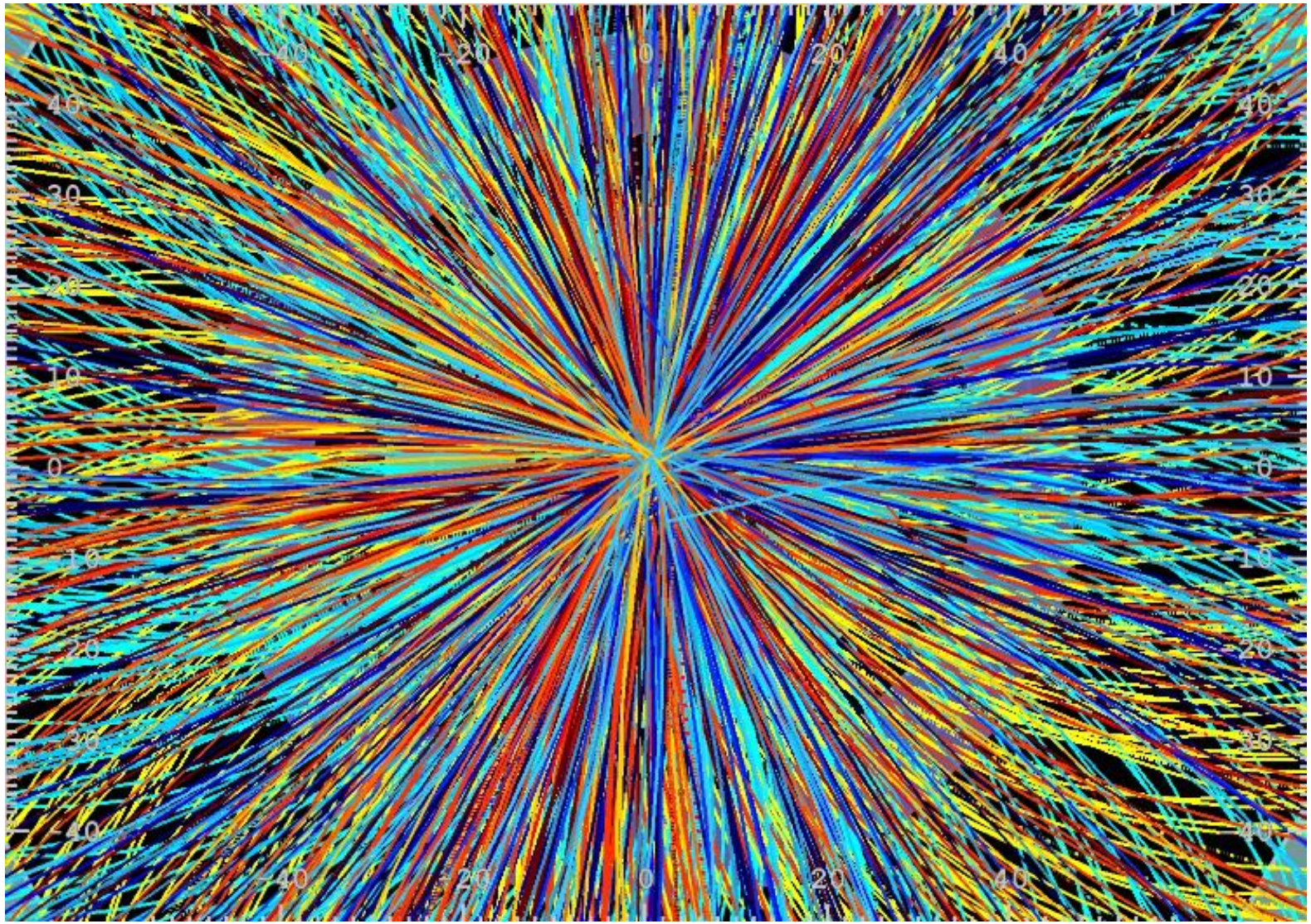
Fabjan

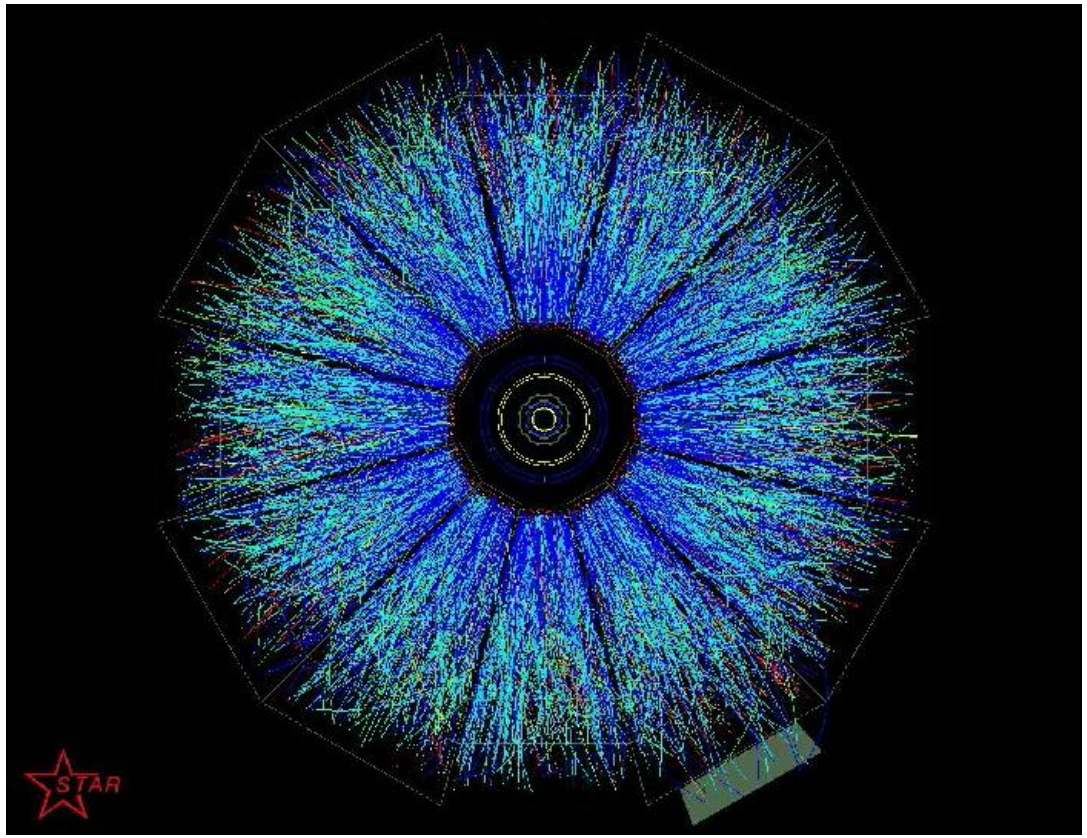
Specht

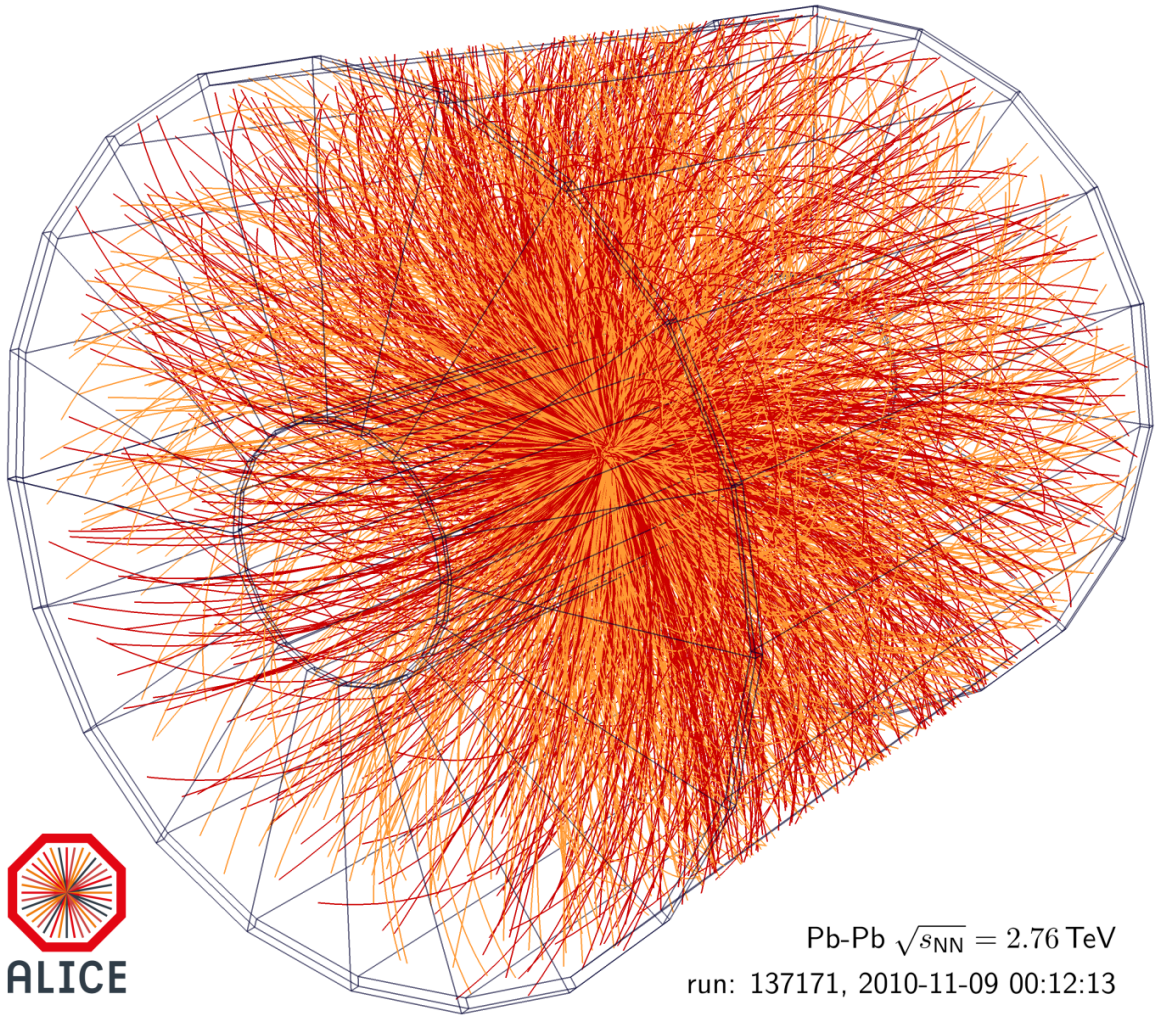
Designing a heavy ion experiment in the early 90's for use at the LHC some 15 years later, posed daunting challenges:

- **an extrapolation with respect to c.m.energy by a factor of 300 and colliding ion masses by a factor of 7.**
- **Main challenge to detect the extreme number of particles in every single event,**
  Up to 50,000 charged particles are expected to be emitted in a lead–lead collision,
  about ten thousand going through the ALICE central detector.
- **Several events per bunch crossing**
- **New Techniques for detector were necessary**
  (survey by C. Fabjan[a] and J. Schukraft)
- **Fantastic technical achievements were accomplished**

Physics and art




STAR


ALICE
Pb-Pb $\sqrt{s_{\mathrm{NN}}} = 2.76$ TeV
run: 137171, 2010-11-09 00:12:13

The complicated birth of ALICE

- Sam Ting was proposing an upgraded L3 for the LHC program
- Ting's proposal was turned down in fall 1992 and he invited the heavy ion group to use the L3 magnet and part of the L3 infrastructure
- This invitation was accepted in February 1993 and the original proposal was changed into ALICE
- The transfer of ownership of the L3 magnet and the infrastructure of the L3 to the ALICE collaboration was performed at a seafood dinner hosted by Jürgen Schukraft in a restaurant at Ferney-Voltaire.
- In March 1993, the Letter of Intent for 'A Large Ion Collider Experiment' was submitted
- ALICE took off with full steam supported by the L3 infrastructure team

I had a special interest to watch since I had been working on L3

CERN/LHCC/93-16
LHCC/I 4
1 March 1993

1 March 1993

Letter of Intent
for
A Large Ion Collider Experiment
at the
CERN Large Hadron Collider

Spokesperson: **J. Schukraft,**
Deputy: **H. Gutbrod,**

Collaboration of 40 institutes

Athens, Bari-Politecnico, Bari-Uni., Beijing, Bergen, Bhubaneswar, Birmingham, Calcutta, Catania, CERN, Chandigarh, Cracow, Dubna, Frankfurt, Geneva, GSI, Heidelberg-MPI, Heidelberg Uni. Jaipur, Jammu, Kharkov, Kiev, Kosice, Legnaro, Lund, Marburg, Minsk, Messina, Moscow INR, Moscow Kurchatov, Moscow ITEP, Nantes-SUBATECH, Novosibirsk, Oak Ridge, Orsay, Oslo, Padua, Prague, Protvino, Rehovot, Rez, Rome, St. Petersburg, Utrecht/NIKHEF, Turin/INFN-HEP, Turin/INFN-NP, Warsaw, Wuhan, Zagreb

CERN / LHCC / 95–71
LHCC / P3
15 December 1995

15 December 1995

ALICE

Technical Proposal

for

A Large Ion Collider Experiment

at the

CERN LHC

63 collaborating institutes

Collaboration Board

Chairperson: E. Quercigh
Deputy: I. Otterlund
Secretary: F. Navach

Membership :

– One representative from each participating Institute
– Management Board members

Technical Board

W. Klempt
Technical Co-ordination

Management Board

Spokesperson: J. Schukraft
Deputy: H. Gutbrod

Technical Co-ordination W. Klempt	Engineering & Integration L. Leistam	Test Beam F. Piuz	Administrative Co-ordination J. de Groot
V. Manko	G. Paić	L. Riccati	R. Stock

MINUTES OF THE 130th MEETING OF THE RESEARCH BOARD HELD ON THURSDAY 6 FEBRUARY, 1997

Present : B. D'Almagne, J. Ellis replacing Veneziano), L. Evans,M. Ferro-Luzzi Secretary), L. Foà, D. Forkel-Wirth, G. Goggi, J.-P. Gourber, U. Goerlach part-time), K. Hübner, E. Iarocci,C. Jarlskog, K.-H. Kissler, R. Klanner, C. Llewellyn Smith Chairman), J. May, A. Richter, D. Simon,E. Tsesmelis, M. Turala, S. Weisz , P. Wells, H. Wenninger and P. Zerwas.

Apologies: G.Veneziano

4. REPORTS AND MATTERS ARISING FROM THE LHCC MEETING OF 23-24 JANUARY,1997

E. Iarocci reported on the meeting. The main topic had been the discussion of the ALICE proposal.... Production schedules, milestones and current status of R&D had been reviewed and found acceptable. The committee had completed the full assessment of the scientific, technical and financial aspects of the proposal.... The principal referee (U. Goerlach) described in considerable detail the management structure of the collaboration and its organisation, concluding that the project appeared to be under control and working well. The Research Board discussed the above reports at some length. L. Foà presented the cost analysis and gave a favourable opinion on the financial side of the project. .....In conclusion the Research Board **approved** the ALICE project

Management of CERN large experiments

Learning period of 30 years of large international collaboration

First steps by UA1 and UA2

Followed by LEP experiments

(several hundered physicists, many institutes, own budget)

interesting social experiment, 'independent' projects

2 experiments guided by strong personalities (J.Steinberger, Sam Ting)

2 experiments organised democratically

All worked

LHC experiments followed the democratic line

also ALICE

CERN model for large projects of globel collaboration

Bottom- up management

ALICE today

Success thanks to many people

42 countries, 174 institutes, 1800 members

Phantastic results obtained by ALICE

- **new state of matter**
- **new phenomena:**

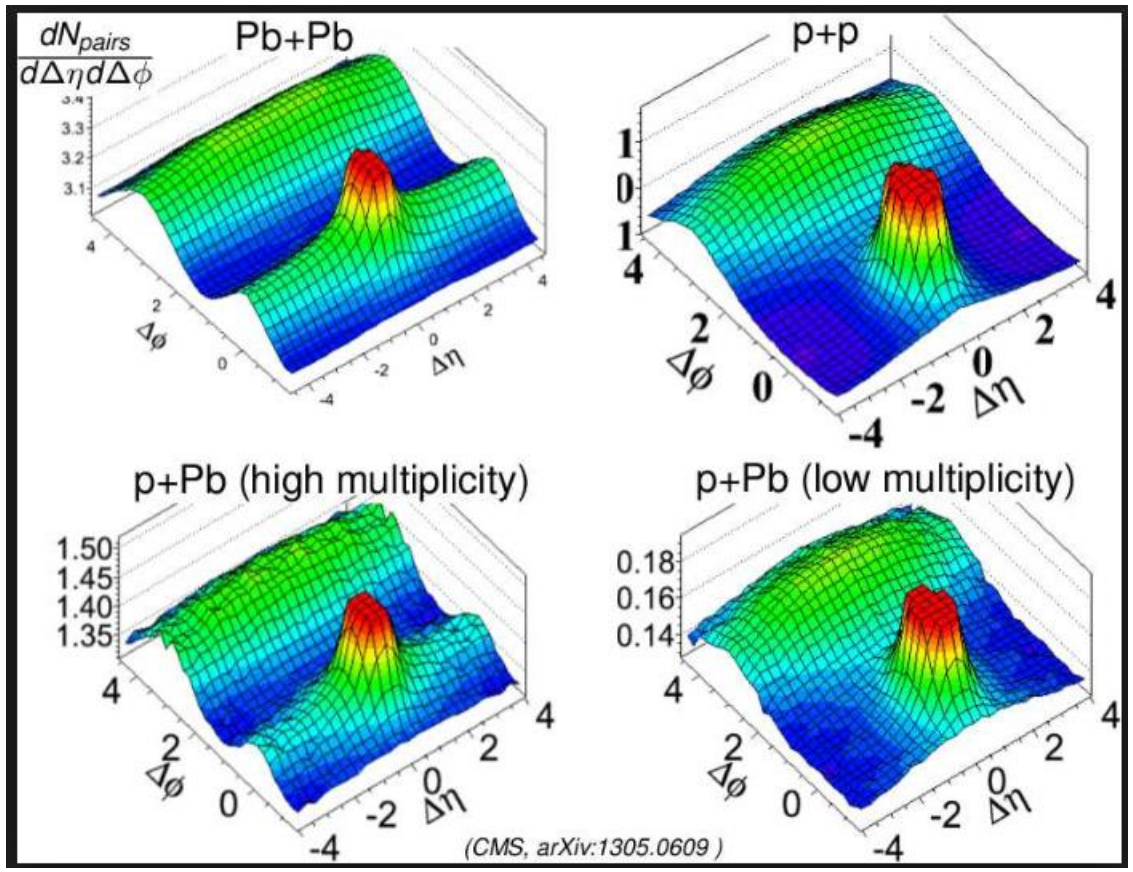
  QGP confirmed, many expected properties confirmed

  jet quenching,

  elliptical flow,

  ideal liquid with low shear viscosity

  Quite recent surprise: new collective phenomena, ridge - also for p- Pb!


$\frac{dN_{pairs}}{d\Delta\eta d\Delta\phi}$
Pb+Pb
p+p
p+Pb (high multiplicity)
p+Pb (low multiplicity)
(CMS, arXiv:1305.0609)

Future of heavy ion physics

p-p collisions:

Standard Model confirmed to high degree (Higgs)
Many new theories falsified or parameter space reduced
So far no indication of new physics

Heavy ion collisions:

For Heavy Ion Physics no Standard Model
New state of nuclear matter with many degrees of freedom,
New unexpected phenomena have been detected
Good chances of more to come
Long life of interesting physcis

The enormous success was made possible by the common effort of many people
physicists, enginers, technicians, computer experts, etc

Recognition and visibility in scientific community and outside,
Johanna Stachel, President of German Physical Society (largest in the world)

Congratulations and
Best wishes for a long life of ALICE at LHC

Thank you