CERN achievements in Relativistic Heavy Ion Collisions

Giuseppe E Bruno
Università di Bari and INFN – Italy

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Outline:
- The *epic* past
- The *exciting* present
- The *bright* future

*but actually I will speak most of the past*
THE PAST
forewords

- What is my role in this section?
- I was CERN summer student in 1998, and I should speak about, e.g., a Letter of Intent that dates back 1980
- my role is that of historian
  - definition, from a first dictionary: “an expert in or student of history, esp. that of a particular period, geographical region, or social phenomenon”
  - like that I should not worry that much: I’ve been studying some old papers in the last month!
  - from a second one: “a person who is an authority on history and who studies it and writes about it”
  - oh, oh! I’m not an authority!
moreover, I have to do this service in Greece  
... where history was conceived by Herodotus

I will limit to stick to the following maxim from the medieval theology:

“Factum infectum fieri non potest, neque Deus”

a fact cannot become a “non-fact”, even God cannot do that.

By the way, is that the reason why God has invented historians?

But actually, a similar argument was formulated implicitly much earlier by Διοδώρος Χρόνος (Diódôros Chrónos):

ho kurieuôn logos (the Master argument, l’argument dominateur):

1. every true statement about the past is necessary
2. the impossible cannot derive from the possible
3. it is possible what it is not true now and will not be true

ho kurieuôn logos: if 1 and 2 are true, then 3 is false
forewords

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ho kurieuôn logos: if 1 and 2 are true, then 3 is false

coming back to my first sentence (I was CERN summer student in 1998)... We are physicists: facts and proofs!
- I can proof it: have a closer look at my t-shirt!
the statistical bootstrap hypothesis leads to an exponentially increasing spectrum of hadronic states \(\rightarrow\) there is a limiting temperature

hadronic matter cannot exist for \(T > T_c\)
Asymptotically free quarks in neutron stars?

Superdense Matter: Neutrons or Asymptotically Free Quarks?

J. C. Collins and M. J. Perry
Department of Applied Mathematics and Theoretical Physics, University of Cambridge, Cambridge CB3 9EW, England
(Received 6 January 1975)

We note the following: The quark model implies that superdense matter (found in neutron-star cores, exploding black holes, and the early big-bang universe) consists of quarks rather than of hadrons. Bjorken scaling implies that the quarks interact weakly. An asymptotically free gauge theory allows realistic calculations taking full account of strong interactions.

There are several astrophysical and cosmological situations where one needs the equation of state for matter of densities greater than $10^{15}$ g cm$^{-3}$: in particular, the center of a neutron star, the early phases of the big-bang universe, and black-hole explosions. However, such densities might at first sight appear to be outside the range of normal physics, so that nothing can

☐ J.C. Collins and J. Perry → quark deconfinement in superdense matter
The quark liberation

N. Cabibbo and G. Parisi

- the Hagedorn limiting temperature is present in any system that undergoes a 2\textsuperscript{nd} order phase transition
- first phase diagram
The 1980 LoI by the GSI and LBL groups

Study of particle production and target fragmentation in central \( ^{20}\text{Ne} \) on Pb reactions, at 12 GeV per nucleon energy of the CERN PS external beam

Letter of Intent

GSI Darmstadt - LBL Berkeley - Collaboration

CERN LIBRARIES, GENEVA

CM-P00044648

Abstract

We propose to study in two simultaneous experiments the target fragmentation modes, and \( \pi^- \), \( K^0 \) and \( \Lambda,\bar{\Lambda} \) production in central collisions of \( ^{20}\text{Ne} \) with a heavy target nucleus. The acceleration of \( ^{20}\text{Ne} \) at the PS will be facilitated by a high charge state \( ^{20}\text{Ne} \) source, provided by us. Experimental equipment will be the Plastic Ball and Wall spectrometer, currently employed by us at the Bevalac, LBL Berkeley, and a streamer chamber now used at CERN by the Munich group. The experiments require acceleration of about \( 10^7 \) Ne ions per PS cycle, and a split in the external beam delivering about \( 10^4 \) ions/s to the streamer chamber and the main part of the intensity to the Plastic Ball/Wall. The anticipated time of experiment is about the spring of 1983, with the long lead-time caused mostly by source construction and injector linac acceleration tests.

A seminal document:
- 16 pages
- 3 figures
- the two later NA35 and WA80 experiments, and their successors, derives from it!

To be compared with the present LoI for an upgrade of a sub-detector:
- e.g., the LoI for the ALICE ITS upgrade: 187 pages, 153 figures
The 1980 LoI by the GSI and LBL groups
1980 GSI Workshop

in October 1980, at the initiative of Rudolf Bock and Reinhard Stock, a Workshop on Future Relativistic Heavy-Ion Experiments took place at GSI Darmstadt.
The early times

- In 1980 the atmosphere should have been of enthusiasm. The possibility to produce in laboratory, albeit for a very short period, a deconfined states of quark and gluons, the QGP, looked to be at hand.

- Few years passed before ion beams from SPS became available
  - at that time the CERN priority was the LEP
  - The Director of non-LEP activities, Robert Klapisch, had the mission to maintain a broad physics program, with reduced CERN investments
    - the CERN Heavy-ion facility was designed and constructed by several CERN member state laboratories with also contributions of non-member states: same approach later (1993) for the “from-light-to-heavy” upgrade
    - severe budgetary constraints, which did not permit any big investment in the building of new detectors
    - key moment was the “Workshop on the Future of Fixed Target Physics” (December 1982)
      - the group "Nuclear Beams and Targets” was convened by W.J. Willis and the summary given by M. Albrow
      - the SPS community took interests in heavy-ion physics
      - in Autumn 1984, seven new experiments were recommended by SPSC, two of them (NA35 and WA80) being the direct descendants of the 1980 Letter of Intent
The early times

<table>
<thead>
<tr>
<th>Exp.</th>
<th>P_{lab}/A [GeV/c]</th>
<th>y_{nn}</th>
<th>y_{160+Au}</th>
<th>Detector</th>
<th>Acceptance</th>
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<tbody>
<tr>
<td>Na34</td>
<td>200</td>
<td>3.03</td>
<td>2.37</td>
<td>U-Cal</td>
<td>-0.1 &lt; η &lt; 5.5</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>LA-Cal</td>
<td>0.9 &lt; η &lt; 4.9</td>
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<td>Si-Mult</td>
<td>0.9 &lt; η &lt; 2.0</td>
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<td>Ext. Spec.</td>
<td>Δφ &lt; 5°</td>
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<td>Na35</td>
<td>60</td>
<td>2.42</td>
<td>1.80</td>
<td>Ring Cal</td>
<td>2.08 &lt; η &lt; 3.72</td>
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<td></td>
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<td></td>
<td>PPD</td>
<td>1.95 &lt; η &lt; 3.37</td>
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<td></td>
<td></td>
<td></td>
<td>ZDC</td>
<td>0 &lt; θ &lt; 0.3°</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>5.9 &lt; η</td>
</tr>
<tr>
<td></td>
<td>200</td>
<td>3.03</td>
<td>2.37</td>
<td>Ring Cal</td>
<td>2.28 &lt; η &lt; 3.94</td>
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<td></td>
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<td>PPD</td>
<td>2.18 &lt; η &lt; 3.61</td>
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<td>ZDC</td>
<td>0 &lt; θ &lt; 0.3°</td>
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<td></td>
<td>5.9 &lt; η</td>
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<td></td>
<td>Streamer Ch.</td>
<td>0.6 &lt; y &lt; 4.6</td>
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<td>Na36</td>
<td>200</td>
<td>3.03</td>
<td>2.37</td>
<td>TPC</td>
<td></td>
</tr>
<tr>
<td>Na38</td>
<td>200</td>
<td>3.03</td>
<td>2.37</td>
<td>EM Cal</td>
<td>2 &lt; η &lt; 4.2</td>
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<td>Di-Muon</td>
<td>2 &lt; M &lt; 4 GeV/c^2</td>
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<td></td>
<td></td>
<td></td>
<td>2.8 &lt; η &lt; 4.0</td>
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<tr>
<td>WA80</td>
<td>200</td>
<td>3.03</td>
<td>2.37</td>
<td>ZDC</td>
<td>0 &lt; θ &lt; 0.3°</td>
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<td></td>
<td>5.9 &lt; η</td>
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<td>MIRAC</td>
<td>2.4 &lt; η &lt; 5.5</td>
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<td>MIRAM</td>
<td>2.17 &lt; η &lt; 4.74</td>
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<td>LAM</td>
<td>1.3 &lt; η &lt; 2.4</td>
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<td>Plastic Ball</td>
<td>30 &lt; θ &lt; 160°</td>
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<td></td>
<td></td>
<td>SAPHIR</td>
<td>1.5 &lt; η &lt; 2.1</td>
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<td></td>
<td>Δφ &lt; 20°</td>
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<td>WA85</td>
<td>200</td>
<td>3.03</td>
<td>2.37</td>
<td>Q Spectr.</td>
<td>2.2 &lt; y &lt; 3.2</td>
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<td></td>
<td>p_T &gt; 0.6 GeV/c</td>
</tr>
</tbody>
</table>

For experiments where the configuration did not change with beam energy, it is listed under 200 GeV/c

LA-Cal: Liquid Argon Calorimeter
PPD: Photon Position Detector
MIRAC: Mid Rapidity Calorimeter
LAM: Large Angle Multiplicity
Saphir: Pb Glass Photon Detector
NA35: Study of Relativistic Nucleus-Nucleus Collisions at 60 and 200 GeV/nucleon

- collaboration: Athens, Bari, BNL, LBL, Cracow, GSI, Frankfurt, Friburg, Heidelberg, Marburg, München, Texas A&M, Warsaw, Zagreb
- spokesman: R. Stock
- successors: NA49, NA61

The streamer chamber

A simulated $^{16}$Xe collision

Streamers-chamber picture of a central S-S collisions
WA80: Study of Relativistic Nucleus-Nucleus Collisions at the CERN SPS

- Collaboration: BNL, GSI, Groningen, LBL, Lund, Moscow, Münster, Oak Ridge, Knoxville
- Spokesman: H.H. Gutbrod
- Successors: WA93

Direct photons + π⁰ and η
NA34/Helios2: Study of high energy densities over extended nuclear volumes via nucleus-nucleus collisions at the SPS

- spokesman: H.J. Specht
- successors: HELIOS3

Helios/II in 1989

<table>
<thead>
<tr>
<th>Sub-Detector</th>
<th>Main Characteristics</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electron Spectrometer:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Si-Pad</td>
<td>400 Si “pads”, situated 15cm down-stream of target. Pad size varies from 0.2 x 2 mm² close to the beam direction to 2 x 7 mm² at the outer perimeter of the detector. There is a central hole (diameter ~ 0.5mm) to allow the beam to pass through.</td>
<td>[4, 6]</td>
</tr>
<tr>
<td>Si-strips</td>
<td>3 planes of Si strip detectors, at 6, 12, and 18cm from the target. All strips are vertical and on a 25 µm pitch. The read-out uses capacitive charge-division.</td>
<td>[5]</td>
</tr>
<tr>
<td>DC-Chambers</td>
<td>DC1 : x,y,u,v,x,y planes. Total of 384 wires. DC2 : x,y,u,v,x,y planes. Total of 480 wires. DC3 : x,y,u,v,x,y planes. Total of 540 wires. The DC system has an angular resolution of 1.3 mrad.</td>
<td>[6, 15]</td>
</tr>
<tr>
<td>Magnetic</td>
<td>For reconstructed tracks in the multiplicity typical of high-energy pile collisions, the two-track efficiency is ~ 70% for a track separation of 4mm, rising to full efficiency at around 1cm. Dipole magnet with calorimetry yields: pT kick ~ 60 MeV/c in horizontal (x-z) plane.</td>
<td>[7]</td>
</tr>
<tr>
<td>TRD</td>
<td>8 module Transition Radiation Detector. Each module is a 6mm thick radiator of 250 propylenglycol foils, followed by a drift chamber filled with Xe/CF4/Isobutane and equipped with x and y read-out, using “cluster-counting”. The TRD is fully efficient at ~ 4900. For isolated 5 GeV particles, the hadron rejection is ~ 10^5 for an electron efficiency of 90%. In the multiplicities typical of high energy pile collisions, the hadron rejection is degraded by a factor of 10 to 20.</td>
<td>[8, 9, 16]</td>
</tr>
<tr>
<td>Scint-pad</td>
<td>Plane of 80 scintillator “pads” positioned between drift chamber (DC3) and calorimeter (ULAC). Pad size varies from 2 x 4 cm² close to the beam direction to 10 x 10 cm² at the outer perimeter of the detector. There is a central hole to allow the non-interacting beam to pass through.</td>
<td></td>
</tr>
<tr>
<td>ULAC</td>
<td>Uranium Liquid Argon Calorimeter. Electro magnetic section is 36 cells; total of 114Xe. Each cell has (thickness in mm): U(13.8), Li(8.8), Ar(3). Read-out plane(14). Li(9.4), Ar(2). The granularity of the electro-magnetic section read out is 2 x 2 cm² pads. Resolution: 11.8%/E(GeV). Hadronic section: 5.8%.</td>
<td>[10]</td>
</tr>
<tr>
<td>Proportional</td>
<td>Uranium-Scintillator calorimeter: 5.8%.</td>
<td>[7]</td>
</tr>
<tr>
<td>Chambers</td>
<td>Beam-VETO</td>
<td>Uranium-Scintillator calorimeter covering wide angle region.</td>
</tr>
<tr>
<td>Propotional</td>
<td>FC0 : x,y,u,v planes. Total of 1556 wires. Chambers</td>
<td></td>
</tr>
<tr>
<td>FC1 : x,y,u,v planes. Total of 1556 wires. (PC)</td>
<td></td>
<td>[11, 12, 14]</td>
</tr>
<tr>
<td>PC2 : x,y,u,v,x,y planes. Total of 1686 wires. PC3 : x,y,u,v,x,y planes. Total of 3696 wires. PC4 : x,y,u,v,x,y planes. Total of 5894 wires. PC5 : x,y,u,v,x,y planes. Total of 5096 wires.</td>
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<tr>
<td>Beam Magnet</td>
<td>Large aperture (1 cm diameter) super-conducting dipole magnet with pT kick ~ 1.2 GeV/c in horizontal (x-z) plane.</td>
<td></td>
</tr>
<tr>
<td>Hodoscopes H2, H3</td>
<td>Each hodoscope consists of two layers of scintillators: each layer has 10(H2) or 11(H3) rows. Each row contains two horizontal scintillator slabs, 3 x 0.24 m².</td>
<td>see section 2.3.2</td>
</tr>
</tbody>
</table>

Table 1: Summary of main sub-detectors
NA38: Study of high energy nucleus-nucleus interactions with the enlarged NA10 di-muon spectrometer

- Collaboration: Annecy, CERN, Clermont-Ferrand, Lisbon, Lyon, Orsay, Palaiseau, Strasbourg
- Spokesman: L. Kluberg
- Successors: NA50, NA60
NA36: The production of strange baryons and anti-baryons with relativistic light ion collisions at the CERN SPS

- collaboration: Bergen, LBL, Birmingham, CERN, Krakow, Madrid, Omaha, Santiago, Strasbourg, Wien
- spokesman: C.R. Gruhn

Figure 1: NA 36 experimental layout.
WA85: Study of high energy nucleus-nucleus interactions using the Ω’ spectrometer equipped with a multiparticle high $p_t$ detector

- Athens, Bari, Bergen, Birmingham, CERN, Paris, Madrid, Oslo
- spokesman: R.Zitoun → E. Quercigh
- successors: WA94, WA97, NA57

MWPC of the OMEGA spectrometer used in “butterfly” mode, to cope with the high multiplicity:

$\rightarrow p_t > 0.6$ GeV/c; $|y_{\text{cms}}| < 1$
The early times

Table 1
Large ion experiments

<table>
<thead>
<tr>
<th>Quark Matter Conference</th>
<th>87</th>
<th>88</th>
<th>90</th>
<th>91</th>
<th>93</th>
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<tr>
<td>BNL</td>
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<tr>
<td>E802</td>
<td>magn. spectr. part. ident.</td>
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<tr>
<td>E814</td>
<td>← 4π calorimeter forward spectr.</td>
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<tr>
<td>E810</td>
<td>TPC magn. field</td>
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<td>E859 → E866</td>
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<td>E877 upgr. spectr.</td>
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<td>E858 spectr.</td>
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<td>CERN</td>
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<td>NA34</td>
<td>Helios spectr.</td>
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<td>HELIOS 3</td>
<td>dimuon spectr.</td>
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<tr>
<td>NA35</td>
<td>Streamer chamber</td>
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<td>+ TPC</td>
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<tr>
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<td>dimuon spectr.</td>
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<td>NA36</td>
<td>TPC magn. field</td>
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<td>NA44 focusing spectr.</td>
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<td>NA45 e^+e^- spectr.</td>
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<td>WA80</td>
<td>Plastic Ball calorimetry</td>
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<td>WA93 magn. spectr.</td>
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<td>WA85</td>
<td>Omega</td>
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<td>WA94 RICH</td>
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</table>
From light to heavy ions

Ref: N. Angert et al. “Cern heavy-ion facility design Report” CERN-93-01
The CERN SPS heavy ion physics program

- NA61/SHINE
- NA49
- NA45 CERES
- NA44
- Helios-3
- Helios-2
- NA35
- NA36
- NA38
- NA50
- NA52
- NA60
- NA57
- NA98
- WA98
- WA97
- NA93
- WA93
- WA94
- NA94
- WA85
- WA80
- In
- Pb
- S
- O
- 2004
- 2000
- 1994
- 1992
- 1986

Photons, hadrons, multistrange, dielectrons, dimuons, strangelets, strange hadrons.
A new state of matter?

in 2000 the baton was passed to RHIC (AGS→SPS→RHIC→LHC)
at CERN a seminar was organized with the major experimental results
Main results from the SPS

- collective dynamics: HBT, radial flow, directed and and elliptic flow
- J/psi suppression
- strangeness enhancement
- low mass di-leptons productions
  - photons, vector bosons
- several others...
- search for the onset of deconfinement
  - back to the present: NA61/SHINE
Collective motions

- HBT interferometry

- radial flow

\[ \frac{d^2 N_j}{m_T \, dy \, dm_T} = \int_0^{R_G} A_j m_T \cdot K_1 \left( \frac{m_T \cosh \rho}{T} \right) \cdot I_0 \left( \frac{p_T \sinh \rho}{T} \right) rdr \]

\[ \rho(r) = \tanh^{-1} \beta_\perp (r) \]

\[ \beta_\perp (r) = \beta_S \left[ \frac{r}{R_G} \right]^{n(=1)} \quad r \leq R_G \]

Schnedermann, Sollfrank, Heinz, PRC48 (1993) 2462


NA44

NA49

\[ T = 98 \pm 1 \text{ MeV} \]
\[ \beta_T = 0.67 \pm 0.01 \]
\[ \chi^2/NDF=488/105 \]
Collective motions

- HBT interferometry
- radial flow

\[ \frac{d^2N_j}{m_Tdydm_T} = \int_{0}^{R_G} A_j m_T \cdot K_1 \left( \frac{m_T}{r} \right) \]

\[ \rho(r) = \tanh^{-1} \beta_\perp (r) \]

Schnedermann, Sollfrank, Heinz, PRC48 (1993) 2462
Directed and elliptic flow

\[ \frac{dN}{d(RP)} \mu 1 + 2 v_n \cos(n[RP]) \]

\[ v_1 = \langle \cos(RP) \rangle \]
\[ v_2 = \langle \cos[2(RP)] \rangle \]

- opposite directed flow at large rapidity for p and π
- \( v_2(\pi) \) flat with y; \( v_2(p) \) peaks at mid-y
- both π and p have the flow axis of the elliptic flow in the plane of the directed flow
- shadowing by spectator matter cannot be at the origin of the elliptic flow
- the elliptic flow is caused by the pressure in the high density region created during the initial collision

PRL 80 (1998) 4136

Protons

Pb-Pb 158 A GeV/c, semi-peripheral

NA49

Pions
The $J/\psi$ suppression

The idea behind (T. Matsui and H. Satz):

- Debey screening of the color force between $c$ and $\bar{c}$: the $J/\psi$ melts in the QGP

The main actors: NA38, NA51, NA50 and NA60

The strangeness enhancement

The idea behind (J. Rafelski and B. Muller):
- multi-strange (anti-)baryons much more abundantly produced in a QGP, then in hadronic system

The main actors:
- West area: WA85, WA94, WA97,
- Nord area: NA35, NA36, NA44, NA49, NA52, NA57

In a QGP:

In a hadron gas:
\[ \pi + N \rightarrow K + \Lambda \]
\[ \pi + \Lambda \rightarrow K + \Xi \]
\[ \pi + \Xi \rightarrow K + \Omega \]

Low mass di-leptons

- The idea behind:
  - Photons and di-leptons are direct probes of the early collision stages; largest emission rates in hot and dense matter
  - Vector meson ($\rho$, $\omega$, $\phi$) modifications as a signature of the in-medium chiral symmetry restoration close to the QCD phase boundary
- The main actors: HELIOS3, NA38, NA45, NA60

**Graphs:**

NA60: inclusive excess $\mu\mu\mu$ mass spectrum

All known sources subtracted integrated over $p_T$
Fully corrected for acceptance absolutely normalized to $dN_{ch}/d\eta$

$M<1$ GeV
- $\rho$ dominates, ‘melts’ close to $T_c$
- best described by H/R model

$M>1$ GeV
- $\sim$ exponential fall-off $\rightarrow$ ‘Planck-like’
- fit to $dN/dM \mu M^{3/2} \exp(-M/T)$
- range 1.1-2.0 GeV: $T=205\pm12$ MeV
- 1.1-2.4 GeV: $T=230\pm10$ MeV
- $T>T_c$: partons dominate
ρ meson: the approach to chiral restoration

van Hees+Rapp (2008)  


Data acceptance-corrected

‘spectral directly reflects thermal emission rate’ (Rapp)

Before acceptance correction:

underlying space-time averaged ρ spectral function (purely accidental)

Only broadening of ρ observed, no mass shift
“... we now have compelling evidence that a new state of matter has indeed been created .... The new state of matter features many of the characteristics of the theoretically predicted quark gluon plasma ...” (L. Maiani)

If it is not a Quark Gluon Plasma, then what is this system?
intermezzo

- while at the peak of this reach SPS program, the same community had to face the challenge of the LHC preparation
  - R&D for new detectors,
  - constructions
  - physics simulations, etc...

- but the real challenge was to coagulate into a single large collaboration several smaller groups
THE PRESENT

The present is LHC ...
The LHC experiments

- complementary capabilities:
  - high $pt$, high rate, jets: the realm of CMS and ATLAS
  - low $pt$ coverage, low material budget, excellent PID: ALICE
  - LHCb has not a heavy ion program, but is providing excellent results in pp and p-Pb interactions
LHC is the realm of rare probes

- Energy loss and elliptic flow in the HF sector

\[ R_{AA} = \frac{d^2 N_{AA}}{dy dp_T} / <N_{coll}> d^2 N_{pp} / dy dp_T \]

- The Upsilon sequential suppression

- From J/ψ suppression to the (re-)combination of c̅c pairs into J/ψ
Is the p-Pb just a control experiment at the LHC?

Unfortunately I have no time to discuss the p-Pb results.
THE PRESENT

The present is LHC ...

... and the SPS (NA61/SHINE experiment)
**NA61/SHINE comprehensive scan in energy and size of colliding nuclei to study the properties of the transition between hadron gas and quark gluon plasma**

<table>
<thead>
<tr>
<th></th>
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<tbody>
<tr>
<td>Pb+Pb</td>
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* Marek Gazdzicki, “Recent results and plans of NA61/SHINE”
THE FUTURE
THE FUTURE

The future is the LHC ...
- high luminosity HI with the ALICE upgrade (and ATLAS, CMS)
The ALICE ITS upgrade

- First layer closer to IP: \( r_0 = 39\,\text{mm} \rightarrow 22\,\text{mm} \)
- Reduced material budget: \( X/X_0 = 1.14\% \rightarrow 0.3\% \text{ for the IB layers} \)
- Improved tracking efficiency and \( p_T \) resolution at low \( p_T \)
- Faster readout: 50 kHz in Pb-Pb, 200 kHz in pp (currently limited at 1 kHz with full ITS)

It will allow, e.g., to measure the charm production down to \( p_T = 0 \) and the \( \Lambda_c \) in Pb-Pb.
THE FUTURE

The future is the LHC ... 
- high luminosity HI with the ALICE upgrade (and ATLAS, CMS)?
- A Fixed Target ExpeRiment at the LHC (AFTER)!

... and the SPS ?
- NA60+
- CHIC experiment ?
Compress the spectrometer reducing the absorber and enlarge transverse dimensions.
THE FUTURE

The future is the LHC ...
- high luminosity HI with the ALICE upgrade (and ATLAS, CMS)
- A Fixed Target ExpeRiment at the LHC (AFTER)?

... and the SPS ?
- NA60+
- CHIC experiment  

The far future ?
- Heavy Ions with the FCC ??

“CERN: the next 60 years (the FCC study)” M. Koratzinos
Ions at FCC

- Centre-of-mass energy per nucleon-nucleon collision:
  \[ \sqrt{s_{NN}} = \sqrt{\frac{Z_1 Z_2}{A_1 A_2}} \sqrt{s_{pp}} \]
  \[ \sqrt{s_{PbPb}} = 39 \text{ TeV} \]
  \[ \sqrt{s_{pPb}} = 63 \text{ TeV} \]
  for \( \sqrt{s_{pp}} = 100 \text{ TeV} \)

- First (conservative) estimates of luminosity: \( \times 5 \) larger \( L_{\text{int}} \) per month of running wrt LHC (after LS2)

- Physics opportunities with heavy ion beams at the FCC (AA, pA) are investigated by a dedicated WG within the FCC-hh group: next WS in September at CERN (https://indico.cern.ch/event/331669)

- Main directions:
  - Quark-Gluon Plasma studies: larger size, higher temperature, new hard probes available (e.g. top quarks)
  - Saturation of small-\( x \) gluon densities (with pA): reach down to \( x \sim 10^{-6} \) (one order of magnitude smaller than at LHC)
  - Photon-induced collisions (\( \gamma+\gamma, \gamma+A \)): saturation and EW studies

- More details: https://indico.cern.ch/event/282344/session/16/contribution/109

\[ s_{NN} = Z_1 Z_2 A_1 A_2 \]
\[ s_{PbPb} = 39 \text{ TeV} \]
\[ s_{pPb} = 63 \text{ TeV} \]
\[ s_{pp} = 100 \text{ TeV} \]
Final words

I would like to close, instead of with conclusions, with a citation which was quoted by Howell Pugh, at the beginning of the CERN heavy-ion adventure:

“One does not discover new lands without consenting to lose sight of the shore for a very long time”

from « Les Faux-monneyeurs (The Counterfeiters) », by André Gide

However, I have been advised that, given the title of the novel, a historian should better not use such a citation.
Acknowledgement

I would like to thank my friends and colleagues, R. Arnaldi, C. Blume, A. Dainese, M. Gazdzicki, E. Quercigh, E. Scomparin, P. Seyboth, G. Usai, for their help in the preparation of this talk.
Spares
Search for the onset of deconfinement

NA49 started to pursue this search at the SPS (strangeness production, event by event fluctuations, etc...) \(\rightarrow\) taken over by NA61/SHINE

RHIC:
- good coverage, but much lower statistics than fixed target experiments

FAIR (CBM):
- SIS-100 (>2020) limited coverage
- SIS-300 better coverage but unclear timeline (>2025)

SPS:
- Wide coverage of phase diagram
- Existing facility
- Competitive high-intensity beams
- Other experimental program (NA61) already ongoing

plot and text from G. Usai presentation on last Tuesday
The Phase Diagram of QCD Matter

Temperature $T$

Thermodynamic quantities

Quark-gluon plasma (deconfinement, chiral symmetry)

Critical endpoint

First order transition

Ground-state nuclear matter

Hadron gas

Color superconductivity

Baryo-chemical potential $\mu_B$

Cross over

ICFP 2014 Giuseppe E. Bruno
forewords

☐ I claimed that I was summer student in 1998. Some proofs

not enough?
<table>
<thead>
<tr>
<th>Ioni</th>
<th>$p_{fascio}/A$ (GeV/c)</th>
<th>$\sqrt{s_{NN}}$ (GeV)</th>
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<tr>
<td>AGS</td>
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<tr>
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<tr>
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<td>17.3, 12.3, 8.8</td>
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</tbody>
</table>
ITS Timeline

- **Completion of R & D**: 2014-2015
- **Production, construction, tests**: 2016
- **Integration, commissioning at surface**: 2017
- **Installation in ALICE**: 2018
- **High lumi Pb-Pb with upgraded ALICE**: 2019-2020