„Nuclear Interactions and Hadronic Matter" Centre of Excellence

National Institute for Physics and Nuclear Engineering

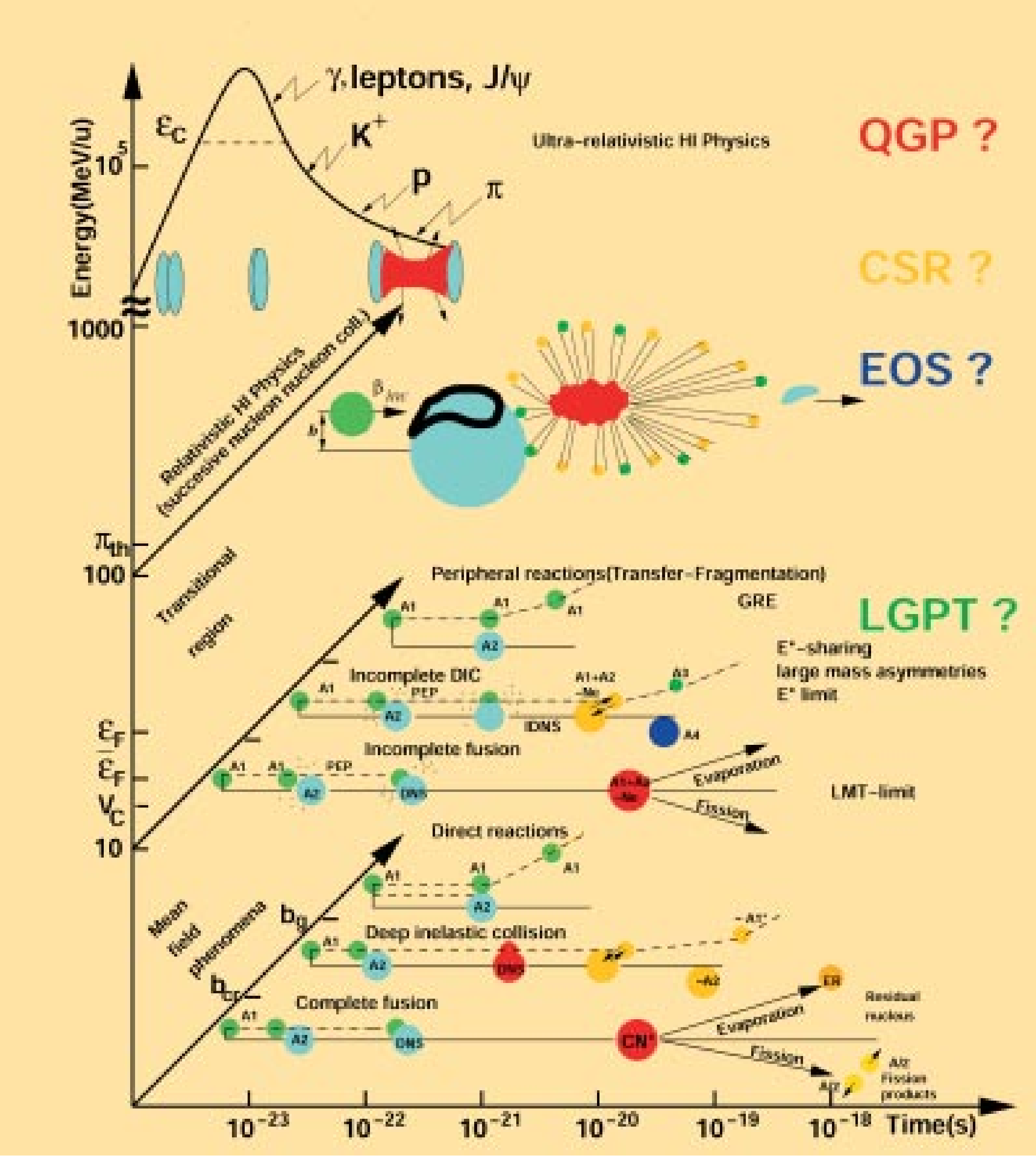


Fig.1

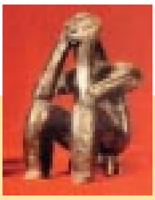
Nuclei comprise more than 90% of the mass of the directly observed matter in universe. However, due to their high density, beyond everything we may meet in our everyday world, 14 orders of magnitude greater than that of water, the nuclei are occupying one quadrillionth of the volume of the normal matter.
The basic research in the field of nuclear interactions and hadronic matter aims at a broad range of open problems, not only the discovery of the fundamental forces in nuclei.

A suggestive tridimensional representation, as a function of the projectile energy per nucleon, impact parameter and the interaction time, which gives an overview of the main phenomena evidenced or aimed to be evidenced in heavy ion collisions is represented in Fig.1.

The strong interaction, responsible for keeping neutrons and protons together in a nucleus, many-body aspects and collective phenomena were extensively studied using the interaction of heavy ions at energies up to a couple of tens MeV/nucleon. To gain deeper information on the properties of nuclear interaction, the nuclei have to be excited up to the energy where they dissociate into loosely interacting nucleons. This is the subject of the heavy ion physics in the Fermi energy domain. In this energy range, one could address the question of a phase transition of nuclear matter, from the self-bound state inside the nucleus to a gas of free nucleons Liquid Gas Phase Transition (LGPT). Barionic matter under extreme conditions of pressure and temperature can be studied above 100MeV/nucleon. Information on the equation of state

(EOS) of nuclear matter can be obtained by studying different phenomena evidenced in this energy range. Experimental evidence on collective expansion of a hot and compressed fireball, populated in heavy ion collisions opened a new direction of research. Questions related to the thermal and chemical equilibrium, dynamical expansion, its geometrical configuration and evolution with the incident energy and collision geometry, clusterization process etc., still are under investigation, being of general interest from these energies up to the ultra-relativistic regime.

The understanding of the hadron properties in a hot and dense nuclear matter environment is one of the most important topics in nuclear physics Chiral Symmetry Restauration (CSR). The atomic nucleus being a conglomerate of constituents with strong interactions between them, the internal degrees of freedom used in its description are dependent on the level from which the nucleus is looked at. As the projectile energy goes higher, phenomena connected with the nucleon structure become predominant. At some hundreds of MeV/nucleon the mesonic excitations and resonant states of the individual nucleons begin to show up. Using incident beams at energies in the GeV range, phenomena occuring on a scale smaller than the nucleon size can be accessed. Consequently, the internal structure of the nucleon begins to play an important role. The explanation of these phenomena has to be based on the image of nucleons as collective systems of quarks and gluons. Thus, at ultra-relativistic energies, appropriate conditions for a transition of nuclear matter from hadronic state to microscopic conglomerates of quarks and gluons are created. Being specific, for high energy processes the process is known as deconfinement Quark Gluon Plasma (QGP). Besides the interest for nuclear physics, the study of phenomena which take place during the interaction of relativistic and ultra-relativistic heavy ions has a strong impact on astrophysics, as this is the only way to create, at laboratory level, phenomena supposed to occure in the very first moments of the Universe expansion (Big Bang) or in the neutron and giant stars. The high complexity and cost of the accelerators, experimental devices and computing infrastructures specific to this field of research, significantly enhanced the world-wide scientific collaborations. Although the large scientific centres are created around large-scale experimental facilities, bringing together international research groups of experimentalists and theoreticians, the construction and operation of such facilities is strongly based on the contributions coming from participating national laboratories or universities of different countries, where part of the complex detection and identification devices, associated electronics, software packages, theoretical models, are designed, developed and constructed. Thus, this trend by no means breaks up the small centres, on the contrary, the small centres remain a permanent source of human resources, specialists and leaders in the field, if the local infrastructure is maintained at a internationally competitive level. How this strategy is followed in our Centre of Excellence „Nuclear Interactions and Hadronic Matter“, the main results obtained in our activities and the future perspectives will be summarized in this booklet.



„Being born upon an obscure planet located at the rim of a middling galaxy among a hundred billion galaxies of an aging universe, it is our sacred duty to know its deepest secrets, as well as we are able"

S.Glashow and M.Lederman

DRACULA Project

DEVICE AND PERFORMANCES

The DRACULA device (Fig.2), based on two large area position sensitive ionization chambers, start and stop PPADs (Parallel Plate Avalanche Counters), NaI and Ge γ-arrays, delivers information on the total energy, velocity vector, atomic charge and mass of the detected fragments and on γ-multiplicity. It was extensively used for detailed studies of dissipative collisions of light heavy ions.

Fig.2

System	Energy (MeV)	Type of measurment
$^{19}F+^{27}Al$	11.4, 125, 136.9	inclusive, TOF, γ-fragment
$^{19}F+^{12}C$	11.4, 136.9	inclusive, TOF, γ-fragment
$^{27}Al+^{27}Al$	140.14	inclusive, TOF, γ-fragment
$^{27}Al+^{12}C$	140.14	inclusive, TOF, γ-fragment
$^{19}F+^{27}Al$	113.5-130	excitation function
$^{27}Al+^{27}Al$	120-132	excitation function

PHYSICS

- detailed correlations and systematic behaviour of experimental observables at variance with medium and heavy systems: interaction times (Fig.3), charge distribution width (Fig.4)
- properties of the dinuclear system by the analysis of fluctuations in the excitation functions of the cross section, interaction time and charge distribution variance (Fig.5)
- charge equilibration process in deep inelastic collisions
- angular momentum transfer in deep inelastic collisions
- comparison with phenomenological and microscopic models

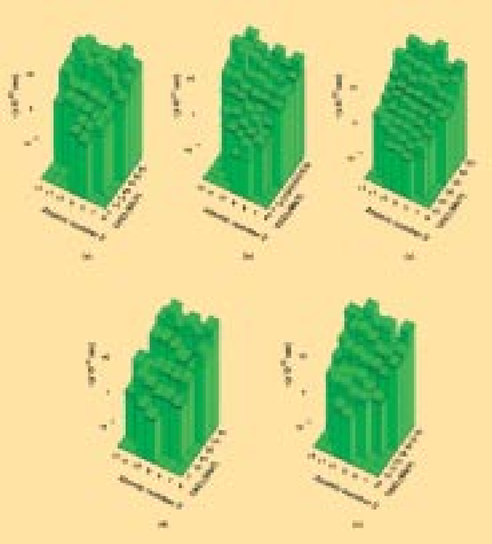


Fig.3

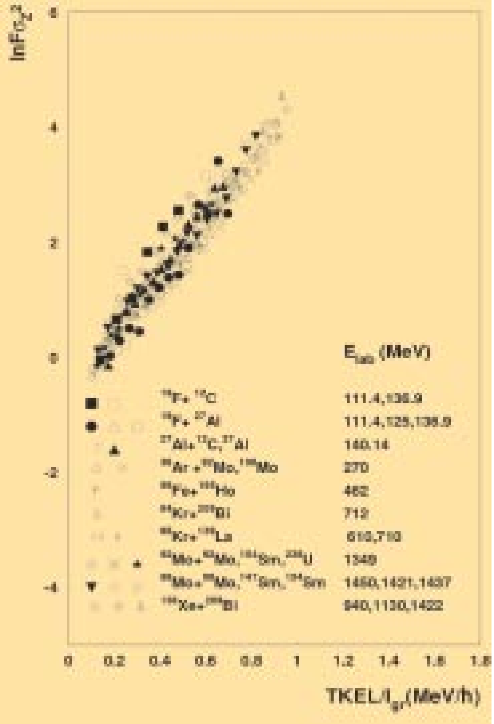


Fig.4

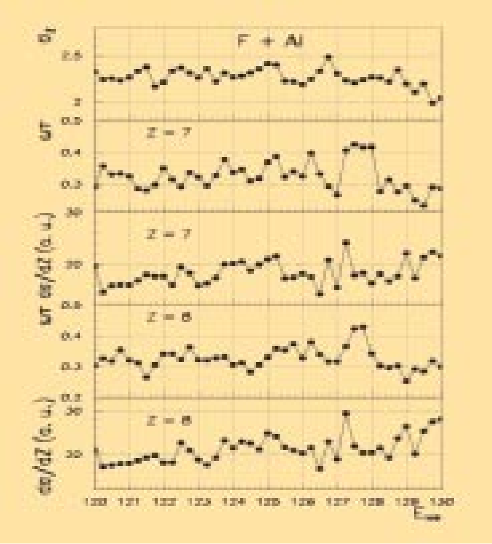


Fig.5

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CHIMERA Project

DETECTOR

The CHIMERA Device is based on 1192 detection cells (300μm Si detector + CsI(Tl) crystal) arranged in cylindrical geometry around the beam axis, in 35 rings (18 forward rings (1-30 degrees) and 17 rings assembled in such a way to shape a sphere of 40cm radius (30-176 degrees)) (Fig.6).

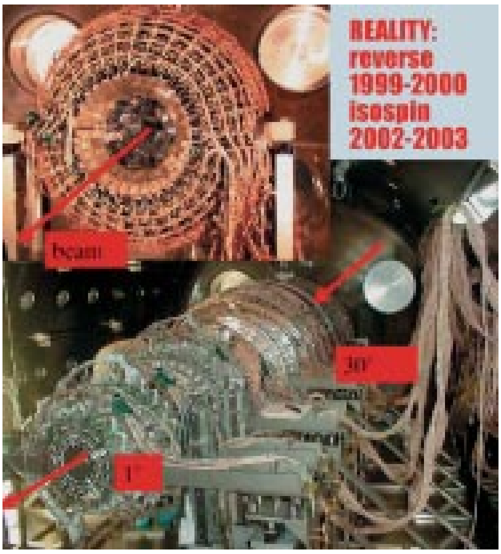

Fig.6

PERFORMANCES

- 94% of 4π angular coverage
- good angular resolution
- identification in mass and/or charge of the detected particles (Fig.7)
- low threshold and high dynamical range in energy
- direct velocity measurement for all particles above the detection threshold (Fig.8)
- total reconstruction of the event even for rather high particle multiplicity ($\leq$40)

EXPERIMENTS

REVERSE
^{124}Sn + ^{64}Ni
^{112}Sn + 58Ni
^{124}Sn + ^{27}Al
at 35 MeV/A
ISOSPIN
^{124}Sn + ^{64}Ni
^{112}Sn + ^{58}Ni
^{124}Sn + ^{27}Al
at 25 MeV/A
^{124}Sn + ^{124}Sn
^{112}Sn + ^{112}Sn
at 35 MeV/A

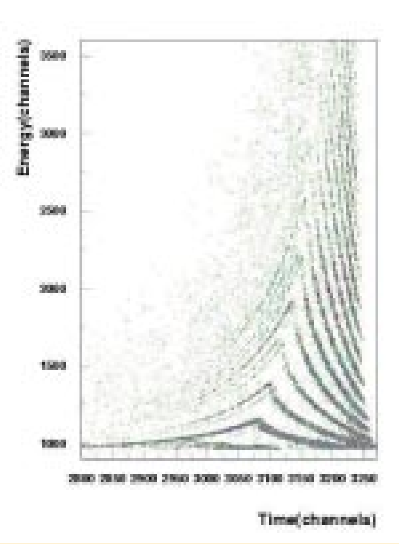

Fig.7

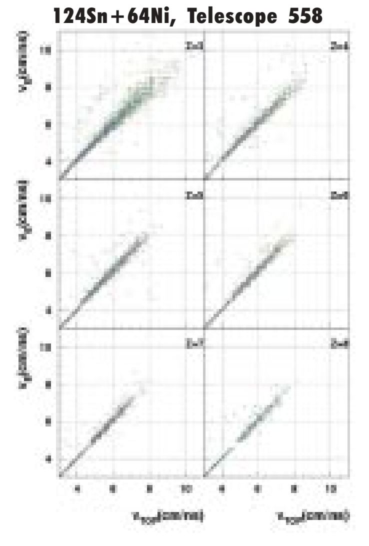

Fig.8

PHYSICS

- Isospin Dependence on the dynamical formation and evolution of the „neck" in peripheral collisions
- Cluster Production in central collisions at „subthreshold" – origin of multifragmentation
- Dynamical Fission and the influence of nuclear matter viscosity on the process time scale
- Thermal and chemical equilibrium in nuclear matter populated at intermediate energies
- Impact parameter dependence of the preequilibrium processes in heavy ion collisions
- Threshold energies of collective phenomena and azimuthal distributions

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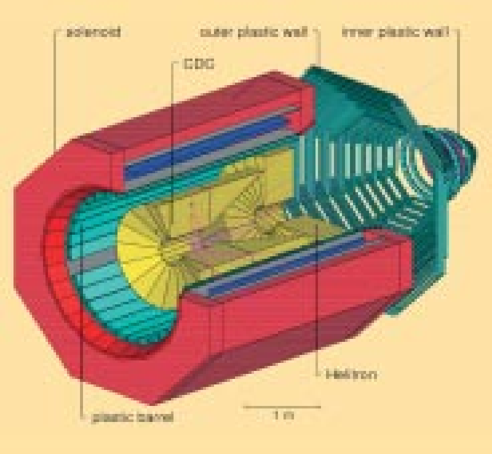
FOPI Project

The 4π detector system FOPI has been built at the Heavy Ion Synchrotron SIS at GSI Darmstadt to get the most complete event characterization possible of relativistic heavy ion collisions (0.1-2AGeV), in order to study the properties of hot and dense nuclear matter.



The beam energy regime available here spans the range from where nuclear mean-field effects dominate up to the excitation of internal nucleonic degrees of freedom within a sizable fraction of the collisional system. Over this energy span, the measurable signals from heavy ion collisions include heavy nuclear fragments (up to Z~20), individual nucleons, and mesons which are produced in the hot and compressed nuclear matter. Because of the large variation in detector requirements for the various particle types, the FOPI system has been built with a modular design whose different components have been optimized for the detection of a particular type of particle.

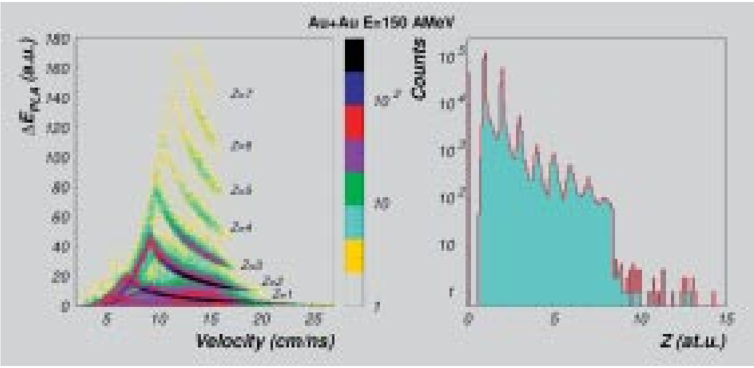


Fig.9

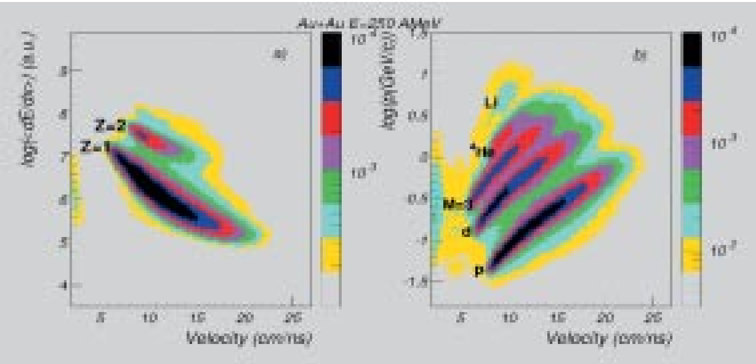


Fig.10

The Forward Plastic Wall consists of an outer shell of 512 scintillator strips and an inner shell of 252 scintillator paddles. The wall measures the charge and velocity of all charged particles emitted with laboratory polar angles between $1^o < \Theta_{lab} < 30^o$ over the full azimuth. Its charge identification performance can be followed in Fig.9. For a better charge identification a cluster shell has been placed in front of the plastic wall. This shell is formed by two arrays, one of large solid angle ionization chambers (Parabola, not shown in the picture) and the other one of 60 scintillator paddles (Rosace).

The main central part of the detector consists of a Superconducting Solenoid and the Central Drift Chamber (CDC) surrounded by a Scintillator Barrel. The CDC is a drift chamber of the jet type that allows tracking of the paths taken by all charged reaction products emitted in the polar angle range $30^o < \Theta_{lab} < 150^o$. The flight paths are curved by the magnetic field from the solenoid, therefore (transverse) momentum determination and mass identification of these reaction products is possible (see Fig.10).

The plastic strips of the Barrel cover the laboratory polar angular range $45^o < \Theta_{lab} < 140^o$ and almost the full azimuth.Because of their length, these strips must be read-out on both sides. By combining the velocity measured in the Barrel with the momentum and energy loss from the CDC, a better particle identification is acchieved. For momentum determination and mass identification of the reaction products in the forward direction, a second drift chamber, the HELITRON, was added. The chamber acts as a vector chamber and measures the helix of the product trajectory between target and detector. The HELITRON adds isotope separation to the elements identified by the Forward Wall within the angular range $7^o < \Theta_{lab} < 30^o$. The existing components of the FOPI have been used in several experiments with symmetric and asymmetric projectile-target systems.

FOPI Project

PHYSICS

Transition Energy

The incident energy at which the azimuthal distributions in semi-central heavy ion collisions change from in-plane to out-of-plane enhancement – E_{tran} – was studied as a function of mass of emitted particles, their transverse momentum and centrality for Au+Au collisions.

A systematic decrease of E_{tran} as a function of mass of the reaction products, their transverse momentum and collision centrality is evidenced.

Fig.11 shows an example of such a behaviour for Au+Au, CM2 centrality ($6fm \leq b \leq 8fm$). For a rotating emitting source one would expect a larger in-plane alignment for heavier fragments. This effect alone can not explain the mass dependence of E_{tran}.

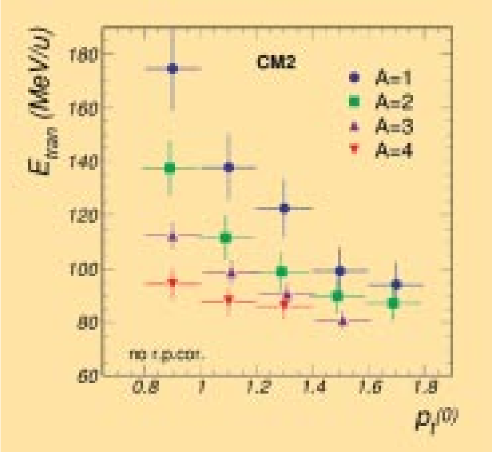


Fig.11

Therefore a dynamical effect has to be considered besides the pure geometrical one of shadowing. Different particles, originating from different regions of the fireball would feel the shadowing in a different way. At large $p_t^{(0)}$ the contribution comes from larger expansion velocities, earlier expansion phase of the fireball, and consequently higher shadowing.

At lower values of $p_t^{(0)}$, the light particles are emitted earlier, being in a larger extent affected by the rotation of the fireball. Heavier fragments being emitted later, when most of the fireball's angular momentum was removed by light particle emission, evidence a stronger squeeze-out pattern.

Azimuthal Dependence of Collective Expansion for Symmetric Heavy Ion Collisions

Detailed studies of azimuthal dependence of the meanfragment and flow energies in the Au+Au and Xe+CsI systems were studied as a function of incident energy and centrality.

Fig. 12 presents, as an example, the azimuthal dependence of $<E_{kin}^{cm}>$ for Z=2 products as a function of the incident energy in Au + Au at ER4 centrality, as a function of centrality in Au+Au at 250AMeV, and for the two measured systems at 250AMeV and ER4 centrality. ER4 centrality represents a range in the impact parameter between 2 and 4fm. Comparisons between data and model calculations show that the flow energy values along different azimuthal directions could be viewed as snapshots of the fireball expansion with different exposure times. For the same number of participating nucleons more transversally elongated participant shapes from the heavier system produce less collective transverse energy.

For the 400AMeV Au+Au collisions Fig.13 shows the results of the Boltzmann-Uehling-Uhlenbeck (BUU) transport code, using momentum dependent mean fields ($m^*/m=0.79$), in-medium elastic cross section $\sigma=\sigma_0 \tanh(\sigma_{free}\ \sigma_0)=\rho^{-2/3}$ and soft (K=210MeV, gray zone) or stiff (K=380MeV, dashed zone) EoS. Good agreement with BUU calculations is obtained for a soft nuclear equation of state.

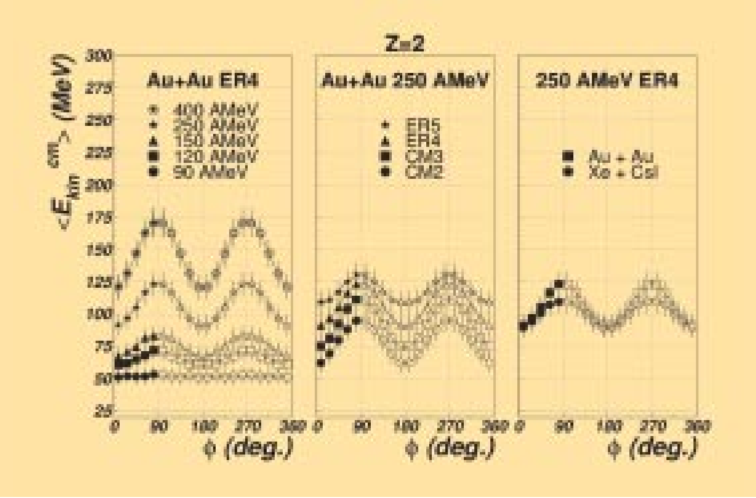


Fig.12

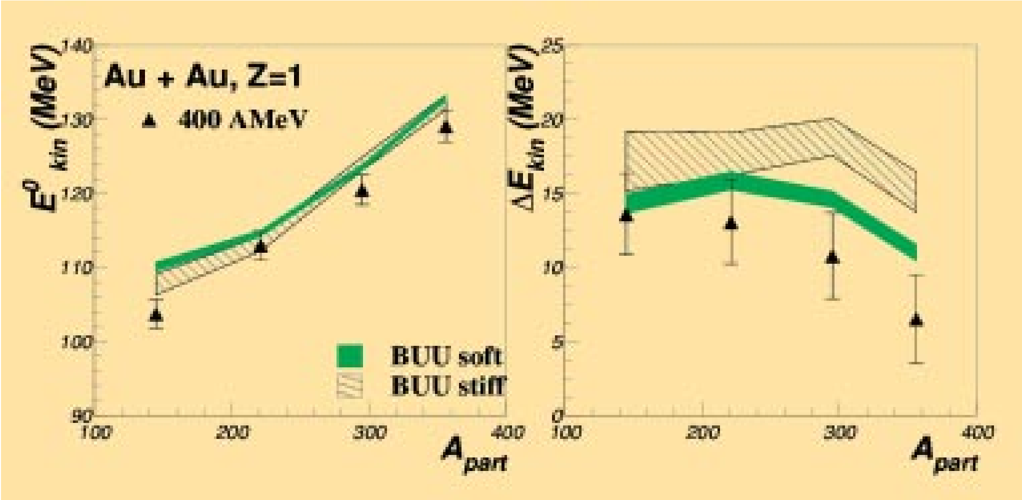


Fig.13

Collective Expansion in Highly Central Collisions

Predicted many years ago, the collective expansion of hot and dense nuclear matter produced in heavy ion collisions was experimentally evidenced only recently. The measured mass dependence of the fragments' kinetic energy and their abundance give strong support for the existence of an important collective expansion which cools down the disassembling matter, so that heavy clusters can exist. A model treatment of the disassembling mechanism shows that $v^2_{flow+Coul}$ has a complex dependence on the fragment mass.

Experimental results on $<E_{kin}>/A$ as a function of A for Au+Au highly central collision at 250AMeV and comparison with the model predictions can be followed in Fig.14.

A dependence of the extracted „flow" energy as function of polar angle and mass of the collinding systems was also evidenced. The experimental results can be followed in Fig.15.

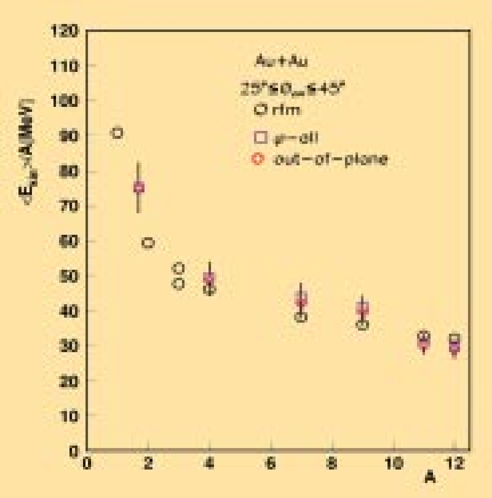


Fig.14

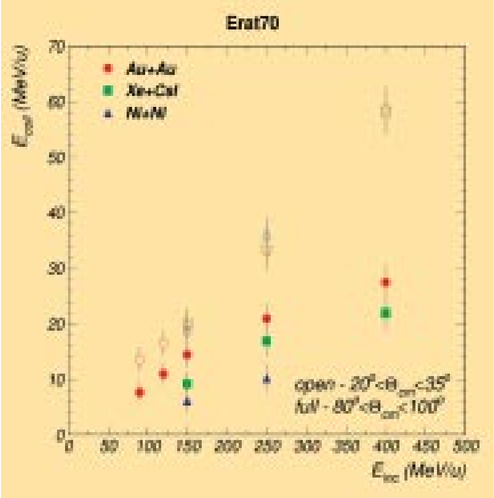


Fig.15

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ALICE Project

ALICE (A Large Ion Collider Experiment) is an experiment at the Large Hadron Collider (LHC) at CERN-Geneva, optimized for the study of heavy ion collisions, at a centre-of-mass energy per nucleon pair of 5.5 TeV.

ALICE aims to study the properties of the hot Quark-Gluon Plasma (QGP) formed in such collisions, its dynamical evolution, phenomena associated with the phase transition of rehadronization and finally the evolution of the hadronic final state until freeze-out.

To achieve this goal ALICE, as the only dedicated heavy ion experiment at LHC, is designed to measure a large set of observables over as much phase space as achievable and thereby covering hadronic and leptonic observables as well as photons.

The experiment will have a central barrel, housed in the L3 magnet, covering the range $-0.9 \leq \eta \leq 0.9$ in pseudorapidity, with complete azimuthal coverage. The central barrel comprises an Inner Tracking System (ITS) of silicon detectors, a large Time Projection Chamber (TPC), a Transition Radiation Detector (TRD – green shell in the picture), and a Time-Of-Flight array (TOF).

In addition there will be close to mid-rapidity two single arm detectors, an array of ring-imaging Cherenkov counters (HMPID) to identify hadrons up to high momenta and an array of crystals (PHOS) for the detection of photons.

This central barrel will be complemented at pseudorapidities of $2.5 \leq \eta \leq 4.0$ by a muon spectrometer with its own dipole magnet.

At more forward and backward rapidities detectors will be located to measure the multiplicity of charged particles, the time of interaction and for trigger purposes, as well as several more specialized detectors.

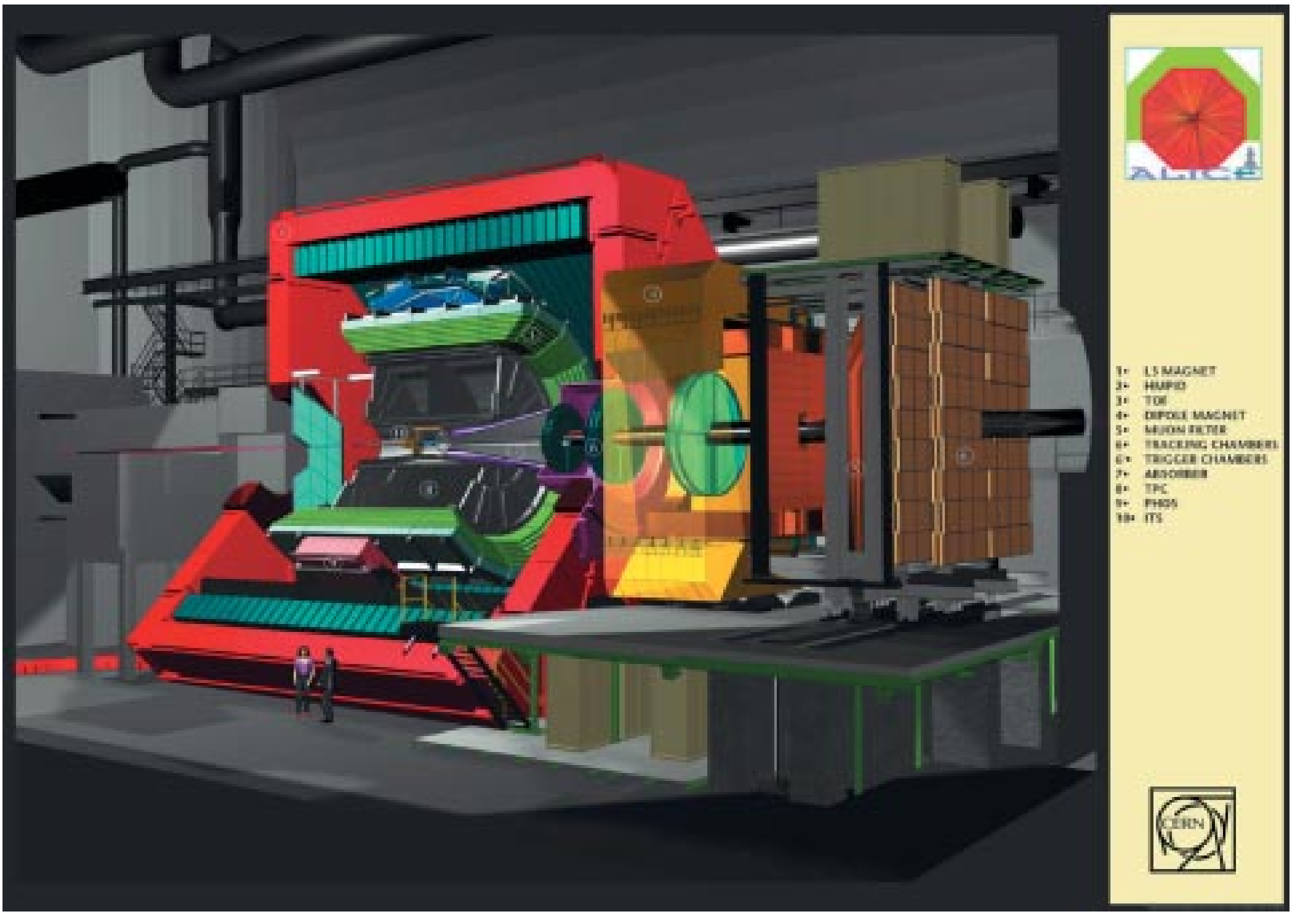

Fig.16

Since 1999 our group is a member of the ALICE Collaboration, joining the Transition Radiation Detector (TRD) team.

The main activities in which the members of the group have had significant contributions could be grouped as follows: TRD DETECTORS; FRONT LINE ELECTRONICS and GRID ACTIVITES.

ALICE Project

1. TRD Detectors

The experimental setup used for in-beam tests of the first TRD prototypes is shown in Fig.17.

An example of the average pulse height as a function of the drift time for pions and electrons and the pion rejection efficiency as a function of momentum, for a radiator of 17 microns diameter fibres, can be seen in Fig.18 and Fig.19, respectively.

Fig.17

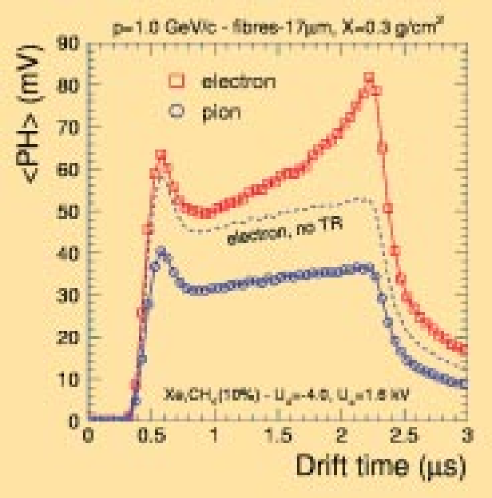

Fig.18

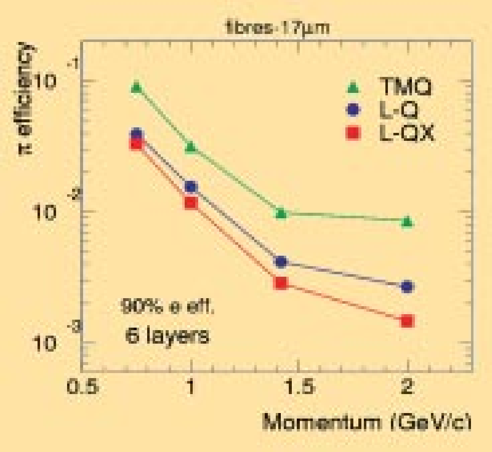

Fig.19

2. Front End Electronics

The preamplifier-shaper (PASA) is the first block of the front-end electronics, receiving signals from the detector pads. The first front-end electronics prototype realized with discrete components is shown in Fig.20. In Fig.21 the experimental results obtained with this prototype are presented. The very first version of preamplifier/shaper chip, designed in the 0.35 microns technology, is presented in Fig.22. The final version has a number of 16 channels per chip and its real size is 2x3mm^2

Fig.20

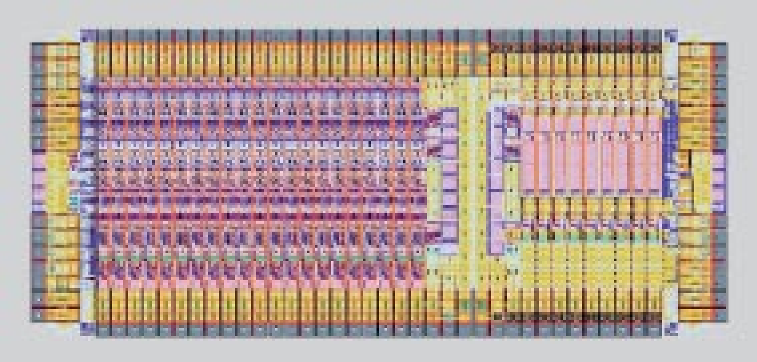

Fig.22

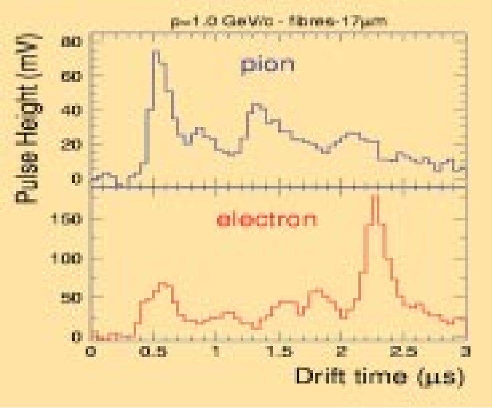

Fig.21

3. GRID Activities

Our group is involved in Grid Computing activities. Starting from November 2002 the Computing Cluster of our Centre of Excellence is included in the ALICE Grid Structure, using AliEn Grid Environment, like a Computing Element (CE), becoming the first international Grid application in Romania (see Figs.23, 24). Our CE consists from about 10 CPUs (AMD Athlon MP and Intel Pentium processors) with a total computing power of 5588 SI2k, and a total disk storage capacity of about 200GB. The communication between computing nodes is at 100Mb/s and our link to the Internet is made at 100Mb/s. Until now we have used our Cluster to run ALICE test jobs and Nuclear Structure model calculations. In the near future we plan to increase our computing power with about 40 CPUs, using dual machines based on the last Intel Xeon and AMD Opteron CPUs. We plan to configure a Storage Element (SE) for the ALICE Grid with a disk space of about 2TB and to upgrade our link to the Internet provider at 1Gb/s. The final aim is to have a Tier2 Centre by the time when the first experimental information will be delivered by the ALICE experiment at CERN.

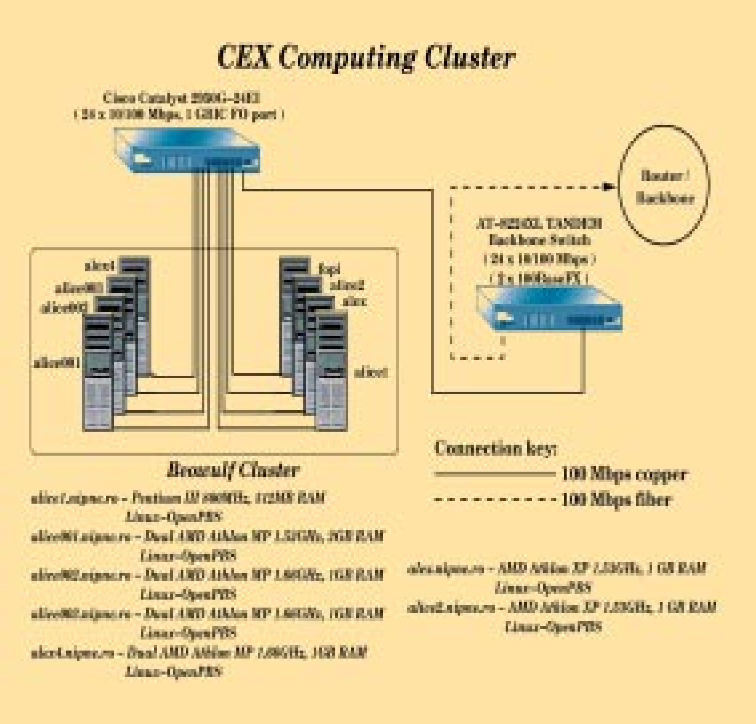

Fig.23

Fig.24

References

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The Detector Laboratory

Based on the contributions of our group to the R&D activities mentioned above, we received the challenging task of building of the ALICE-TRD subdetector together with GSI-Darmstadt, JINR-Dubna, IK-Frankfurt, PI-Heidelberg. An exploded view of the ALICE-TRD shell can be followed in Fig.25.

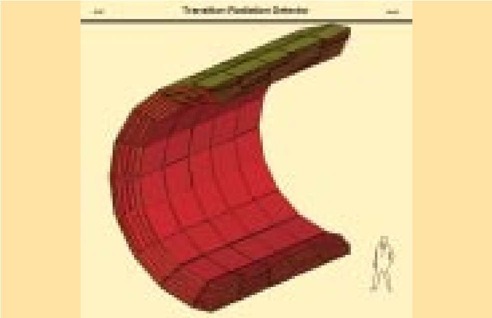

Fig.25

This activity will take place in the Detector Laboratory of our Centre of Excellence „Nuclear Interactions and Hadronic Matter". It has been organized starting from November 2003.

The laboratory building is shown on this booklet's cover. The total laboratory area of 250m^2 is divided on three levels of cleanliness: 1000part/ft^3 (9m^2 area), 10,000 part/ft^3 (27m^2 area) and 100,000part/ft^3 (the rest of the area).

Here 20% of the ALICE-TRD modules will be built. As described in the TDR-TRD, a total number of 108 individual modules, covering a total area of 147m^2 and having 232,000 read-out channels, will be constructed and tested in our Centre of Excellence.

The equipment used in the laboratory, standardized for all the five participating institutions, includes:

1. the computer controlled winding machine, used for multi wire electrodes (Fig.26)
2. special tools (equipment) for mechanical mounting of the TRD components
    - special tables for assembling the detector frames and radiators (Fig.27)
    - vacuum tables for assembling the read-out electrodes (pad-planes) (Fig.28)
    - glass tables for assembling the multiwire electrodes (Fig.29)
3. specially designed tools for transport and alignment of the mechanical components
4. gas circulation system
5. electronics and data acquisition system for detector tests
6. Detector Construction Data Base (DCDB)

Fig.26

Fig.27

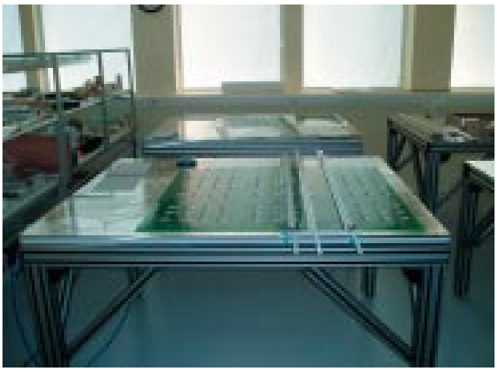

Fig.28

Fig.29

The tests and measurements of the TRD individual modules will produce a huge amount of data. All these data need to be recorded in a common data base (DCDB). This database will permit retrieval of all data relevant for set-up and calibration during running of the experiment and later during offline analysis.

CBM Project

The CBM (Compressed Baryonic Matter) Collaboration proposes to build a dedicated heavy-ion experiment to investigate the properties of highly compressed baryonic matter as it is produced in nucleus-nucleus collisions at the future accelerator facility at GSI Darmstadt.
The main goal is to explore the QCD phase diagram in the region of moderate temperatures but very high baryon densities (Fig. 30). The envisaged research program includes the study of key questions of QCD like confinement, chiral symmetry restoration and the nuclear equation of state at high densities.
The most promising diagnostic probes are vector mesons decaying into dilepton pairs, strangeness and charm. We intend to perform comprehensive measurements of hadrons, electrons and photons created in collisions of heavy nuclei.

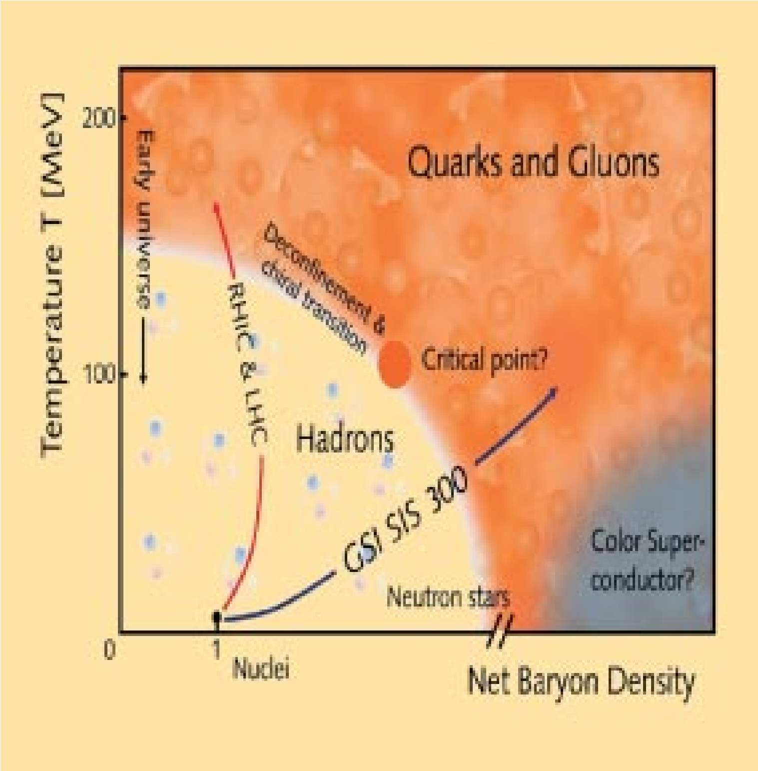

Fig.30

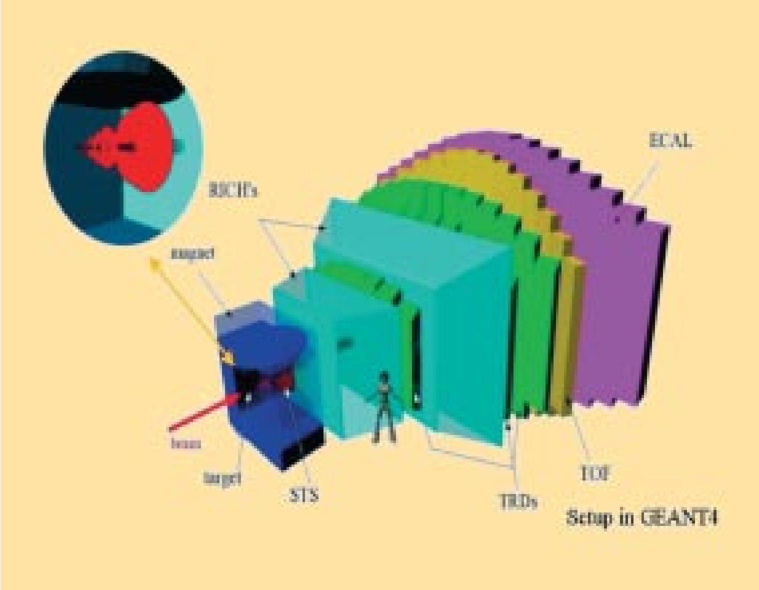

Fig.31

The CBM will be a fixed target experiment which will cover a large fraction of the populated phase space for the beam energy range from about 8 to 45 AGeV.
The major experimental challenge is posed by the extremely high reaction rates of up to 10^7events/second.
These conditions require unprecedented detector performances concerning speed and radiation hardness. The detector layout comprises a high resolution Silicon Tracking System (STS) in a magnetic dipole field for particle momentum and vertex determination, Ring Imaging Cherenkov Detectors (RICHs) and Transition Radiation Detectors (TRDs) for the identification of electrons, an array of Resistive Plate Chambers (TOF) for hadron identification via TOF measurements, and an electromagnetic calorimeter (ECAL) for the identification of electrons, photons and muons.
A schematic view of the CBM configuration can be followed in Fig.31. The detector signals are processed by a high-speed data acquisition and trigger system.

Our group is involved in R&D activities concerning high counting rate TRDs, RPCs (Resisitive Plate Counters), FEE (Front End Electronics), TOF wall design, Monte Carlo simulations of the detector response etc.

R&D Activities

Besides the activities concerning the construction of the TRD detector for ALICE experiment, R&D activities for new type of detectors and the associated front end electronics take place in our Detector Laboratory. We are involved in three Joint Research Activities (JRA4, JRA11 and JRA12) within I3HP (Integrated Infrasctructure Initiative) Project of FP6 (Sixth Framework Programme).

The goal of the JRA4 (Development of High Speed Gas Detectors with Integrated Associated Electronics) is to develop transition radiation detectors capable of handling high counting rates (up to 200 kHz for an individual read-out cell) with a pion rejection performance of several hundred at an electron efficiency of 90%.

In Fig.32 our first prototype of a High Counting Rate Transition Radiation Detector (HCRTRD) is presented. The energy spectrum for ^{55}Fe source using Ar/CO$_2$(15%) gas mixture is presented in Fig.33. The experimental set-up used in the beam tests at GSI-Darmstadt is presented in Fig.34.

The aim of JRA12 (New techniques for time-of-flight particle identification in nuclear collisition experiments) is the extension of the counting rate capabilities of multistrip symmetric timing Resitive Plate Counter (RPC) developed by our group in collaboration with GSI-Darmstadt keeping a time resolution below 100 ps for minimum ionizing particles.

The experimental setup used for testing our first RPC prototype with the ^{60}Co source is shown in Fig.35.

The time resolution obtained in the beam tests at the SIS accelerator of GSI- Darmstadt with minimum ionizing particles is better than 80 ps, see Fig.36.

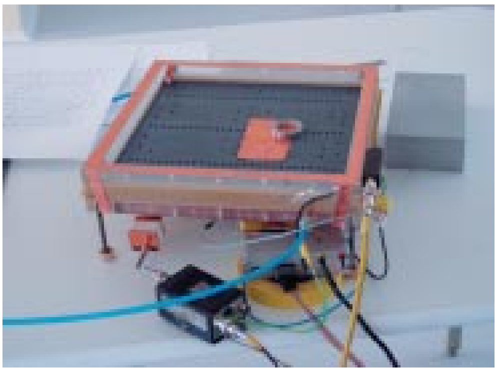

Fig.32

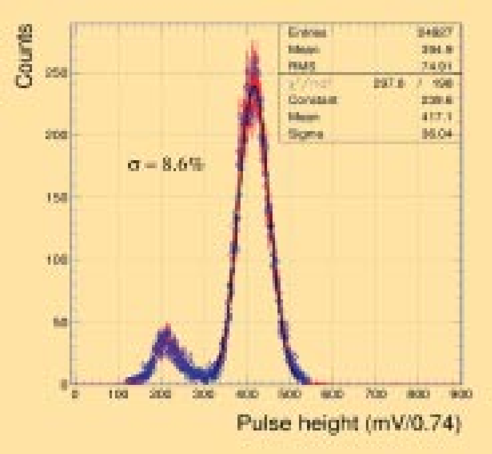

Fig.33

Fig.34

Fig.35

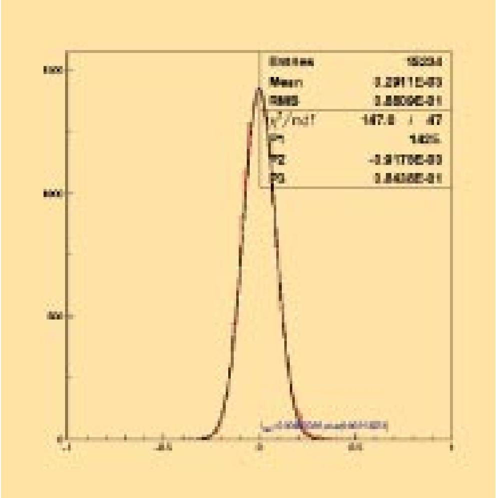

Fig.36

R&D Activities

For the JRA11(Novel Radiation Hard Chemical Vapour Deposition Diamond Detectors for Hadron Physics) the goal is to develop a start detector from a single crystal Chemical Vapour Deposition Diamond Detector (CVD-DD) with a time resolution better than 100 ps and a large detection efficiency for minimum ionizing particles.

The electronic setup used for CVD-DD characterisation (change collection distance measurements) is presented in Fig.37. Using two identical polycristalin CVD-DD for time of flight measurements with minimum ionizing particles (^{90}Sr) (Fig.38) we obtained a time resolution smaller than 100 ps (Fig.39).

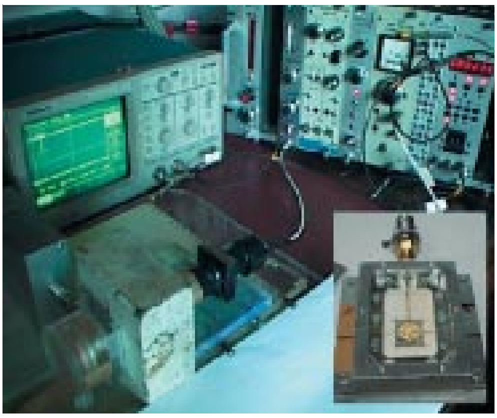

Fig.37

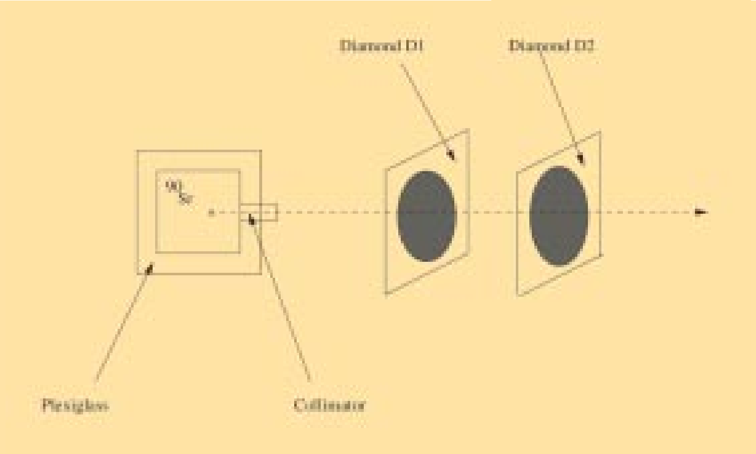

Fig.38

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M.Petrovici et al. Nucl.Instr.andMeth. A508(2003)75
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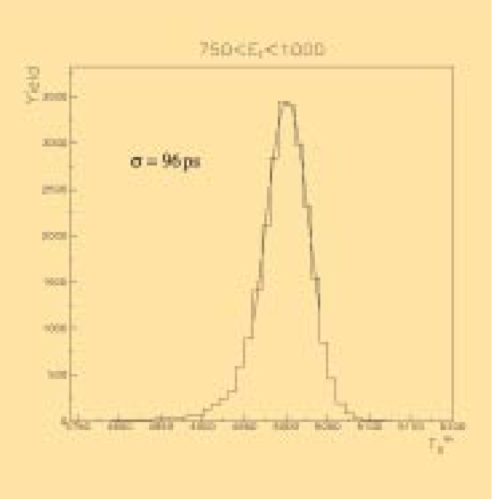

Fig.39

Over the years a special attention was given to the transfer of some results towards other fields of activity and applications. Presently R&D activities concerning the posibility of application of high time and position resolution RPC for Positron Electron Tomography are going on. Fig.40 shows the first prototype built for this purpose.

Fig.40

Members of the Centre of Excellence

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The members of our Centre of Excellence are authors or coauthors of: more than 243 papers published in international journals, more than 136 contributions to the international workshops and conferences, more than 25 invited talks, 20 patents, co-organisators of 3 international Conferences taking place in Romania. In the last 5 years 9 diploma and PhD theses were finished in our group.

DRACULA-Collaboration: 2 Countries, 6 Institutions, 22 Participants
CHIMERA-Collaboration: 6 Countries, 22 Institutions, 79 Participants
FOPI-Collaboration: 8 Countries, 12 Institutions, 50 Participants
ALICE-Collaboration: 27 Countries, 79 Institutions, ~950 Participants
CBM-Collaboration: 12 Countries, 39 Institutions, ~250 Participants

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