**EVENT SIMULATION IN NA35:
STUDY OF RELATIVISTIC NUCLEUS-NUCLEUS COLLISIONS**

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NA35 Collaboration

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1. INTRODUCTION

The NA35 experiment is a survey study of nucleus – nucleus collisions at the SPS energies of 60 to 200 GeV/A [1], [2]. It will investigate the stopping power of the nuclear medium by recording the energy/momentum flux distributions of the electromagnetic and hadronic fractions of the final state, as well as the π^- and π^+ rapidity distributions. It will look for signatures of the quark – gluon plasma formation in the high energy density region created near mid – rapidity in violent head – on collisions. In this report we will describe how event simulations have been used in the pre – run stage of the experiment. For this we will describe first the experimental setup, then we will discuss what we have used for event generators and detector simulation procedures and finally we will present some of the cases in which event simulations have been used.

2. THE NA35 SETUP

The NA35 setup consists of a combination of a visual vertex detector, a 2 m Streamer Chamber, followed downstream by a set of 4 different calorimeters (Fig.1). The major parts of the experiment have been used in two other SPS experiments, NA5 and NA24 [2].

Figure 1: Top view of the NA35 experimental layout.

2.1 BEAM AND TRIGGER COUNTERS

The light ion beam (^{16}O in 1986 and hopefully ^{40}Ca in 1987) extracted from the SPS towards the North Area is split twice to serve the three experiments NA34, NA35 and NA38. For NA35, the beam is prepared by a set of thin quartz Cerenkov counters, Si surface barrier detectors and scintillator halo veto counters. Behind the target another set of Si counters detect the fragmentation of the projectile and make an interaction trigger by the requirement light – ion in, no light – ion out. The target is placed at the entrance of the Streamer Chamber which itself is inside of the Vertex Magnet.

2.2 STREAMER CHAMBER

The Streamer Chamber (Fig.2) with a sensitive volume of $200 \times 120 \times 72 \text{ cm}^3$ is a visual detector in which the primary ionization of the charged particles transversing the sensitive volume can be amplified by a very fast high voltage pulse (20 KV/cm, 15 ns) to produce streamers, whose emitted light is then recorded [3]. The fiducial volume of the chamber lies in the homogeneous magnetic field region produced by the superconducting Vertex Magnet (1.5 T), allowing for momentum measurement by reconstruction of the trajectories in space.

Figure 2: The Streamer Chamber in the superconducting Vertex Magnet.

The size of the streamers, which are elongated along the direction of the electric field, with typical sizes of about 1 mm diameter by 1 cm length, will determine the spatial accuracy in the reconstruction and the two track resolution. It is therefore essential to keep the streamer size to the minimum possible. Unfortunately the streamer brightness is correlated with it's size and therefore to achieve the resolution needed in this experiment it is necessary to use image intensified cameras. We have selected a 90

mm two stage magnetically focused image intensifier (ITT F4093). A 70 mm film is then proximity focused on the output stage of the intensifier. The same image intensifiers and film cameras have been used by the UA5 collaboration in order to image a double 6 m long Streamer Chamber at the SPS $p\bar{p}$ Collider [2]. For monitoring purposes, two directly digitized CCD cameras also image the Streamer Chamber. The 1000×1000 pixel CCD images are analyzed by an image processing system to give on line track brightness on the different parts of the fiducial volume and charged particle multiplicity of the events. Given the analyzing power of the magnet and the expected position resolution, charged particle momenta up to 20 GeV/c can still be measured with better than 5% resolution.

Streamer Chamber Observables

By scanning the Streamer Chamber pictures, one obtains charged particle multiplicities, which can then be subdivided into positive and negative multiplicities. By measuring and reconstructing the tracks one then obtains for $Z=1$ particles laboratory momentum distributions and $p_{\perp}$ distributions. For laboratory momenta < 700 MeV/c one can separate pions from protons by their ionization. Since 98% of all the negative particles are π^- , one also gets π^- cross-sections, rapidity distributions, $p_{\perp}$ and $E_{\perp}$ distributions and two, three and more π^- correlations. The charged decays of strange particles, Λ , $\bar{\Lambda}$, K^0 , $K^{\pm}$ can be identified in the chamber leading to total and differential cross-sections for strange particle production.

2.3 PHOTON POSITION DETECTOR (PPD)

Mid-rapidity particles are detected by a combination of two calorimeters, the Photon Position Detector (PPD), and an electromagnetic and hadronic calorimeter (Ring Calorimeter). The PPD [4] is a highly segmented gas sampling shower detector with coordinate readout (Fig.3).

The sensitive area 3×3 m² except for a central hole of 0.5×0.5 m² is made out of layers of lead and proportional tubes, 9.6 radiation lengths deep. It is subdivided into 4 quadrants, each with 8 planes of analogue Y and Z readout and 4 45° inclined readout planes with wire chamber electronics. The energy sampling is made with proportional tubes made out of extruded Al profile with a triangular cross section and an inter-wire distance of 7 mm.

PPD Observables

The high granularity of the PPD gives for low multiplicities essentially 100% efficiency for π^0 reconstruction if the $\gamma-\gamma$ separation is more than 3 cm. How much the π^0 reconstruction efficiency suffers for high multiplicity events is presently being studied. What the PPD surely can do is give mid-rapidity γ multiplicities, γ E and $E_{\perp}$ distributions and probably high $p_{\perp}$ π^0 spectra.

2.4 RING CALORIMETER

The electromagnetic (EM) and hadron (H) Ring Calorimeter (Fig.4) form a barrel 3.0 m diameter sensitive area with a 56 cm diameter hole. [5] It covers approximately 25° to 110° in the c.m. polar angle and 2π in azimuth.

The combination of the EM and H sections correspond to 8.04 interaction lengths, containing fully 200 GeV hadrons. The calorimeter is subdivided into 240 cells (24 in azimuth, 10 in polar) in such a way as to cover equal intervals of rapidity around c.m. rapidity $\pm$ one rapidity unit.

Ring Calorimeter Observables

The transverse spread of the hadronic showers makes it impossible to measure the energy of single hadrons with the 240 cells of the Ring Calorimeter for the high multiplicities expected in the ^{16}O interactions. Instead we will get hadronic energy flux distributions in mid rapidity and mid-rapidity $E_{\perp}$ distributions.

Figure 3: The Photon Position Detector consisting of about 10000 proportional tubes in 12 planes sandwiched between Pb plates.

2.5 INTERMEDIATE AND VETO CALORIMETERS

In order to be able to trigger on missing projectile energy, the acceptance of the Veto Calorimeter has to be reduced from the 56 cm diameter hole of the Ring Calorimeter to something of the order of 8 cm diameter. This is achieved by the Intermediate Calorimeter which is a Pb-scintillator, Fe-scintillator EM and hadronic cylindrical calorimeter that is inserted into the Ring Calorimeter. Since the magnetic field brakes the axial symmetry, the Intermediate Calorimeter has a rectangular inner hole 20 cm x 10 cm. The structure is the same as that of the Ring Calorimeter and is read out by 7 wavelength-shifter rods.

RING - CALORIMETER

Figure 4: The 240-fold segmented Ring Calorimeter.

The Veto Calorimeter has also an EM (Pb/scintillator) and hadronic (Fe/scintillator) section with a total of 9.86 interaction lengths and a $1 \times 1 \text{ m}^2$ cross-section with a central hole of 2.5 cm radius to let the beam go through (Fig.5). It is subdivided into 4 cells with separated EM and H readout. This calorimeter will then measure the total energy in the projectile fragmentation region.

The overall acceptances of the NA35 setup is shown in Fig.6 on the $p_{\perp} - y$ plane, superimposed on the 200 GeV p + Xe data taken with an interaction trigger. The Streamer Chamber sees all the charged particles forward of $y=0$ and can determine their momenta up to 20 GeV/c. The PPD and Ring Calorimeters measure EM and hadronic energy at mid-rapidity $\pm$ one unit. The Intermediate Calorimeter takes then over from $y=4.4$ up to $y=6.2$ for pions. The Veto Calorimeter accepts baryons from $y=4$ at low $p_{\perp}$ and $y=6$ at 1 GeV/c $p_{\perp}$ up to the highest energies.

Figure 5: The Veto Calorimeter.

Figure 6: The phase space accepted by the different elements of NA35. The data points correspond to 200 GeV p + Xe.

3. EVENT GENERATORS AND DETECTOR RESPONSE SIMULATION

Before, during and after the data taking of such a complicated experiment, there is the need to simulate events to optimize the detector design, estimate the detector acceptances and efficiencies; to understand the trigger performance and biases; to extract the physical observables and to be able to compare the experimental results to model predictions. This process is done in two stages, first one has to generate events leading to the four momenta of the produced particles in the final state which are then used as input to the detector response simulation.

The event generation can be done by either using a model that, given the initial conditions, follows the collision process up to the final stage; or by superposition of experimental results for $p + p$ and $p + A$ collisions.

In NA35 we have used as event generators:

1. Hijet [6], written by T. Ludlam, which uses Isajet to generate the elementary baryon – baryon collisions.
2. Superposition of NA5 events of 200 GeV $p + H$, $p + He$, $p + Ne$ and $p + Xe$ collisions recorded in the same Streamer Chamber using an interaction trigger.
3. Superposition of NA24 events which measured high $p_{\perp} \pi^0$ and single γ s with the same PPD, Ring and Veto Calorimeters.

The detector response simulation is usually done using the Geant3 code [7]. In NA35 we have so far not used it since we have actually measured data for the different detector systems. Instead we have used:

- for the trajectories of charged particles in the magnetic field of the Vertex Magnet, simple helices corresponding to a uniform field of 1.5 T.
- for the Streamer Chamber response NA5 and NA9 film, where NA5 used single and NA9 double image intensifiers in their cameras.
- for the behaviour of the optics we have used information from NA9 about streamer size and brightness and the manufacturers Modulation Transfer Functions (MTF) for the lenses, image intensifier and different film types.
- for the calorimeter response we have used NA24 calibration shower profiles.

4. SOME APPLICATIONS OF EVENT SIMULATION IN NA35

4.1 Problem Nr.1

How is the optical system for the Streamer Chamber photography to be optimized in order to get the best picture quality, highest sensitivity and best two streamer resolution? Specifically, given the streamer's size and brightness, the image intensifier type (ITT F4093, a 90mm ϕ two stage magnetically focused with a nominal gain of 4000), what should be the type of lens, it's focal length and aperture; what should be the demagnification on film and the film format; what should be the position of the three recording cameras; what should be the film type, it's sensitivity, resolution and antiblooming characteristics?

- First approach

Input:

- NA9 streamer size and brightness information.
- The MTF for different lenses (Zeiss T Planar 1:2 $f=110\text{mm}$, Zeiss S Planar 1:5,6 $f=120\text{mm}$, Zeiss Makro Planar T $f/4-120\text{mm}$, Cerco Orthogon 1:5,6 $f=65\text{mm}$, Cerco Orthogon 1:2,8 $f=100$), for the ITT F4093 image intensifier, for different films (Kodak 2484, Kodak 2495, Ilford HP5, 3M 6905, 3M 6906), some of these are shown in Fig.7.
- The formulas of geometrical optics and transfer function theory.

Figure 7: The MTF vs the resolution for some of the components of the optical system.

Taking for example a 0.7 mm ϕ streamer size in the chamber, a 110 mm Zeiss Planar, the ITT image intensifier and a demagnification of 30 onto 70 mm Kodak 2498, one sees in the upper part of Fig.8 what the apparent streamer size in space would be as function of the depth of the chamber from which the streamer is imaged and for different f stops. On the lower part one sees the light intensity that a nominal AgBr crystal would collect as function of the chamber depth for two chamber-lens distances at $f=5.6$.

Results:

- A demagnification of 30 and a 70 mm film format was chosen.
- The 110 mm Zeiss Planar $f=5.6$ lenses were selected, custom optimized for the demagnification of 30.
- The stereo angle between the cameras was set to 16° .
- The optical axis of the lenses point down to the center of the chamber.
- The optical axis of the image intensifier is tilted with respect to that of the lens so that the front face of the image intensifier lays on the mid-chamber image plane, reducing depth of field problems.

All these should give a two streamer resolution of 2.3 mm at 50% MTF.

- Second iteration

Figure 8: Resolution and collected light intensity for one example of the optical system. See text.

Since the actual performance of all the optical system is essential to be able to reconstruct the very high multiplicity events that are expected, an actual live simulation of the system is being done.

Input:

- The Streamer Chamber with the right gas mixture and high voltage pulse.
- The optical system corresponding to one camera: 110 mm Zeiss Planar lens, ITT F4093 image intensifier, 70 mm film.
- Tracks generated by cosmic rays and by an UV N_2 laser.
- Standard resolution patterns placed at the entrance window of the Streamer Chamber illuminated by electroluminicent plates.

Results:

The analysis of the images and the optimization of the film type and developing procedure is still in progress, but as one sees in Fig.9 a two streamer limiting resolution of 1.4 mm is already achieved.

Figure 9: Picture of the inner part of a resolution chart (the distance between dots is 1.4 mm) and a cosmic ray induced track in the Streamer Chamber.

4.2 Problem Nr.2

How large are the charged particle multiplicities expected in central collisions of 200 GeV/A ^{16}O + ^{139}La ? How will the Streamer Chamber react to these extremely high multiplicities? What is the efficiency with which tracks can be reconstructed from the Streamer Chamber pictures? How does this depend on the emission angles, and with what speed can such an event be analyzed?

- First approach

Input:

- Pictures of 200 GeV p + Xe interactions taken in the NA5 Streamer Chamber.

The film was digitized at the University of Marburg with a linear CCD camera. Then 15 high multiplicity events were superimposed with an image processor by having all their production vertices aligned. The result was then plotted. The same exercise was also done photographically by superimposing the negatives to synthesize a new event.

Results:

The charged particle multiplicities turned out to be of the order of 200 charged particles (Fig.10). Single tracks could be resolved over most of the Streamer Chamber volume except for a small 0° cone where the particle density was too high over most of the length of the chamber.

There are several deficiencies of this approach though, mainly since NA35 will have smaller streamers and better resolution than NA5, and because an $^{16}\text{O} + \text{Xe}$ interaction is not simply a superposition of $p + \text{Xe}$ collisions.

Figure 10: A simulated $^{16}\text{O} + \text{Xe}$ Streamer Chamber event done by superposition of NA5 $p + \text{Xe}$ events.

- Second iteration

Input:

- Hijet as event generator
- Na9 information about streamer distributions for minimum ionizing tracks.
- Na9 information about flare size distribution and formation probabilities.

Flares are produced by high energy δ -rays emitted by the transversing particles along the direction of the coincident axis of the electric and magnetic fields, shunting the high voltage and ground electrodes, and thereby producing a spark that is about 1000 times brighter than the streamers. This spark then overexposes the image over a much larger area than it's actual size, obscuring the tracks around it.

Results:

Using all this information 1000 events are being synthesized by the VME based measuring machine at IHEP, Heidelberg, which is the prototype for the data analyzing facilities at Frankfurt and Munich. The generated streamer distribution in space is projected into a plane that corresponds to the view of each one of the three cameras. The resulting 2K x 3K byte matrix is then put on 70 mm film. The charged particle multiplicities get up to 250 , but at the downstream part of the chamber even the most forward particles, where the track density peaks, can be resolved (Fig.11). These synthesized Streamer Chamber pictures are being used to develop our measuring strategies and to train the scanners.

Figure 11: Portion of a synthesized Hjet event with realistic streamer and flare distributions, the height of the picture corresponds to 25 cm.

4.3 Problem Nr.3

Given the reaction kinematics and the high particle multiplicities, what will be the Λ detection efficiency from their charged decay inside the Streamer Chamber?

- First approach

Input:

- Highjet's triple differential cross-section for Λ production from 200 GeV/A $^{16}\text{O} + \text{Xe}$ interactions.
- Superposition of 200 GeV p + Xe NA5 events to get the projected track density and from it the excluded fiducial volume in which no secondary vertex can be found. (Fig.12).

Figure 12: Particle density profiles in the Streamer Chamber as function of the distance from the target. From NA5 simulated events.

Results:

- From a predicted Λ multiplicity of 8.2 per central collision, only those with $p_{\text{lab}} < 10 \text{ GeV}/c$ can be analyzed ($f_a = 0.5$)
- of these 64% have a charged decay into $\pi^- + p$ ($f_b = 0.64$)
- of these 13% decay inside the Streamer Chamber ($f_c = 0.13$)
- of these 67% decay outside the dead area ($f_d = 0.67$)
- the scanning efficiency for finding the secondary vertex is estimated at 80% ($f_e = 0.8$)

All these ($8.2 \times \prod f_i$) gives an expected mean Λ multiplicity of 0.18 detected per event. The differential efficiency is shown in Fig.13 in the $p_{\perp}$ vs y plane.

- Second iteration

Input:

Figure 13: Contour lines of relative Λ production cross section (closed lines) and overall detection efficiency for $^{16}\text{O} + \text{Xe}$ central collisions at 200 GeV/A.

- The synthesized Hjet Streamer Chamber pictures of Problem Nr.2.

Since the Λ multiplicity, their four momenta and decay point in the chamber are all known for each event, a more accurate value of our detection efficiency will be known when these pictures are analyzed. This work is in progress.

4.4 Problem Nr.4

In order to investigate the stopping power of nuclei at the CERN energies, it is necessary to do for different targets a systematic study of the impact parameter dependence of the energy contents in the projectile fragmentation region, of the charged particle and π^0 multiplicities and their mean $p_{\perp}$ or $E_{\perp}$, of their rapidity distributions and of the energy flow in mid-rapidity. The energy contained in the projectile fragmentation region, the $E_{\perp}$ distributions for hadrons and γ and the γ multiplicity in mid-rapidity have to be done with the Vertex Magnet field off in order not to destroy the axial symmetry. On the other hand, in order to measure the $p_{\perp}$ and y distributions for charged particles, the magnetic field has to be on. Therefore we need an impact parameter sensitive trigger that is independent of the magnetic field in order to be able to correlate the information obtained with and without field for the same type of events. It is probable that the EM energy in mid-rapidity as recorded by the PPD could be such a trigger; but the response of the PPD to events with different topologies with field on and off had to be simulated.

- First approach

Input:

- Hijet generated events for 200 GeV/A $^{16}\text{O} + ^{139}\text{La}$ at all impact parameters.
- NA24 calibration data for the PPD and the EM and hadronic part of the Ring Calorimeters.

These consist of about 2000 shower profiles per calibration energy in all three calorimeters. The calibration set consists of five γ energies between 1 and 5 GeV, nine with electrons at energies between 10 GeV and 170 GeV as well as five energies with hadrons at energies between 10 GeV and 60 GeV. An interpolation and extrapolation procedure was devised to simulate showers at energies different than the calibration points. This procedure of using the calibration data has the advantage that it gives the real response of the 4 sets of PPD planes with analog readout for both EM and hadronic showers including the fluctuations in shower development.

Results:

It turns out that the PPD is thick enough ($9.7 \chi_0$) to stop almost all the γ energy from mid-rapidity π^0 s. On the other hand it is thin enough (0.5 absorption lengths) to absorb only 10% of the impinging hadronic energy. Hijet produces events that, impact parameter averaged, have an energy flow of 373 GeV towards the PPD, from which 70% is in form of charged particles and 30% in neutrals. The simulation of the PPD response gave that of this energy only 36.5 % is detected, namely all the neutral and 10% of the charged energy. As the magnetic field is switched on, high energy particles are swept in while many low energy ones are swept out, with the overall result that the energy detected by the PPD grows by 10% from 36.5% to 40.1%. The relationship between the incident and the detected energy of the PPD is shown in Fig.14.

Figure 14: Relationship between the energy detected by the PPD and the actual energy incident on it.

The impact parameter sensitivity of the PPD energy is shown in Fig.15 and Fig.16. The first shows in the measured energy vs the impact parameter plane the contour lines of the yield of events. One sees that for grazing impact parameters up to $b = 3$ fm the measured energy is proportional to the impact parameter, while for more central collisions the response saturates. This behaviour is actually due to the physics given by Hijet, since once the projectile completely dives into the target there is no more change in the deposited energy in the c.m.

Figure 15: Results of the simulation of the response of the PPD as function of the impact parameter of the collision of 200 GeV/A $^{16}\text{O} + ^{139}\text{La}$.

So it turned out that the energy response of the PPD can give us the trigger that we were looking for. By taking events with more than a given minimum energy in the PPD we can select different impact parameter domains, Fig.16. Of the events collected at a given trigger level there is a subsample of about 70% that is trigger bias free.

- Second iteration

For the off-line data analysis program it is not enough to have the overall PPD response, but individual showers have to be reconstructed, one has to discriminate between EM and hadronic showers and finally one has to see what is the π^0 reconstruction efficiency. For this purpose a data bank is being created with Hijet events and simulated showers to feed it to the shower reconstruction program in order to optimize the cluster finding procedures.

Figure 16: Impact parameter distributions of the events selected by a PPD trigger for different lower energy thresholds for the interaction of $^{16}\text{O} + ^{139}\text{La}$ at 200 GeV/A.

5. CONCLUSIONS

The NA35 experiment has and is heavily using event simulations to design and optimize the detection systems, to do detector acceptance and efficiency studies, to investigate trigger strategies, to develop and optimize the data analysis software and to train the scanning personal. Once data has been taken and the results are being analyzed we will use the event simulation to extract the physics and to compare it to different models by folding into them our detector performances.

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