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Physics sources of noise in ring imaging Cherenkov detectors

For the ALICE HMPID Group

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Abstract

The combination of a simulation program for the detector response with a transport code like FLUKA allows the detailed study of physics sources of noise in the RICH. As an example we present the results of a full simulation of the RICH response in the ALICE radiation environment for the highest anticipated charged particle multiplicities of 8000 particles per unit of rapidity in central PbPb collisions at $\sqrt{s} = 5.5$ TeV/nucleon. The contributions of primary and secondary charged and neutral particles to the overall occupancy are discussed. © 1999 Elsevier Science B.V. All rights reserved.

1. Introduction

The ALICE collaboration has proposed to use a proximity focusing ring Cherenkov counter (RICH) for high momentum particle identification [1]. The detector will be installed at mid rapidity at a radius of ≈ 490 cm. For the highest anticipated charged particle multiplicities the predicted number of charged pions and kaons with momenta above 1 GeV/c (signal particles) amounts to $\approx 5\ \mathrm{m}^{-2}$ at the position of the RICH. The flux of lower momentum primary particles and secondary particles produced in detector elements below the RICH and in structural elements like the front absorber, beam pipe and flanges is of the order of $100\ \mathrm{m}^{-2}$. Those particles have in general a much larger angle of incidence (θ_{inc}) than the signal particles ($< 10°$).

The sizable radiation and absorption lengths of the RICH radiator and quartz windows (13% and 3.7%, respectively) and the hydrogen content of the gas gap, make the RICH also sensitive to the neutral particle flux.[1] The fluxes of photons and neutrons are by, respectively, one and two orders of magnitude higher than that of charged particles. To evaluate the performance of the RICH it is mandatory to estimate the contribution of the charged and neutral particle background to the overall occupancy.

2. Simulation of the RICH response

To simulate its performance in the ALICE radiation environment a description of the RICH has been implemented into the ALICE GEANT 3.21 [3]-based detector simulation code GALICE [4]. A detailed description of the simulation procedure

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[1] For a detailed description of the detector, see the contribution of F. Piuz to these proceedings [2].

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can be found in Ref. [5,6].[2] Here we summarize the most important aspects.

Cherenkov photons undergo absorption and medium boundary interactions. The optical properties of the RICH media, i.e. refraction indices, absorption constants and the quantum efficiency of the photo-cathode as a function of the photon energy have been defined to GEANT according to our best knowledge.

The production of feedback photons is included by the call to a user routine each time a signal is generated on the pad plane. The number of generated feedback photons is proportional to the total avalanche charge. The photons are generated with an origin at the location of the avalanche on the sense wire, with an isotropic angular distribution and with energies shared among the three carbon lines. In order to track the feedback photons they are put as Cherenkov photons on the GEANT particle stack.

The production of background hits through gamma conversions or hadronic interactions in one of the detector planes or the support frames is taken into account automatically by GEANT during tracking. By setting the kinetic energy threshold for the tracking to its lowest reasonable value (50 keV for gammas, electrons and positrons), we aim at the best possible description of the background in a high-radiation environment.

Background particles can have any angle of incidence and their path in the gas gap projected on the pad plane can pass many pads (gap-size$*\tan\theta_{\mathrm{inc}} >$ padsize). In this case the signal generation is performed at each crossing of a pad boundary or the crossing of the mid-plane of two adjacent wires.

3. Simulation of the secondary particle flux

Charged and neutral background particles are produced in structural elements (absorber, beam-pipe flanges) and other detectors. GEANT and FLUKA [7] simulations have been performed to calculate the expected flux of background particles.

The present version of FLUKA does not provide generation and tracking of Cherenkov photons. Hence, the simulation of the detector response is not possible within the same program. Instead, we store the momentum vector of particles entering the RICH region in a file which is subsequently used as an input to GALICE ('boundary source').

FLUKA was run with the EMF option for explicit electro-magnetic shower evolution. Close to the material surfaces, the gamma and electron kinetic energy cuts were set to 50 and 100 keV, respectively. Higher cuts where used in shielded regions in order to decrease the calculation time. Neutrons were produced and tracked down to thermal energies. All other particles were tracked down to a kinetic energy of 1 MeV.

The same kinetic energy cuts were used in the GALICE simulations. Except for neutrons which are only tracked down to minimum kinetic energy of 10 keV. The GEANT/MICAP interface has been used to simulate the RICH response to low-energetic neutrons resulting from the FLUKA simulation.

The primary particle flux has been simulated by sampling from pion and kaon pseudo-rapidity distributions obtained from the HIJING event generator as described in Ref. [8]. The normalisation was adjusted to obtain 8000 charged particles per unit of rapidity in the central region.

Table 1
Neutral and charged particle fluxes at $R = 4.8$ m

Particle	Flux (m^{-2})
All $\pi^{\pm}$	41.00
Primary $\pi^{\pm}$	32.00
All $K^{\pm}$	1.4
Primary $K^{\pm}$	1.3
μ^{+},μ^{-}	14
Electrons/Positrons	44
Protons (secondary)	3.69
All charged	103.5
All γ	1490
Primary γ	120
$\gamma(E_{\gamma} > 1$ MeV)	559
All neutrons	9100
Neutrons ($E_{\mathrm{kin}} > 100$ keV)	3100
Thermal neutrons	205

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[2] For a study of the expected RICH response to signal particles see also the contribution of A. di Mauro to these proceedings [6].

4. Results

4.1. Charged and neutral particle fluxes

A break-down of the charged and neutral particle fluxes at the radial position of the RICH as obtained with FLUKA is shown in Table 1. The flux of primary pions and kaons amounts to 32 and 1.4 m^{-2}, respectively. A similar contribution to the charged particle flux comes from electrons and positrons (44 m^{-2}). The proton flux is low (3.7 m^{-2}), but a potential hazard results from their stronger ionisation loss.

The γ flux amounts to 1500 m^{-2}. Most of the γ are products from secondary interactions. About 30% of the total flux is shining from the L3 magnet onto the RICH.

The total neutron flux amounts to 9100 m^{-2}, out of which 34% are neutrons with kinetic energies above 100 keV and 2% are thermal neutrons. The fast neutrons can create a signal by knocking out a proton from the methane gap.

4.2. Event displays

The pattern of hit pads in one module for a central PbPb collision is shown in Fig. 1(a). The charge amplification expressed as the single-electron pulse-height (SEPH) for this event is 20 ADCchan. 9.3% of the pads have a signal above threshold.

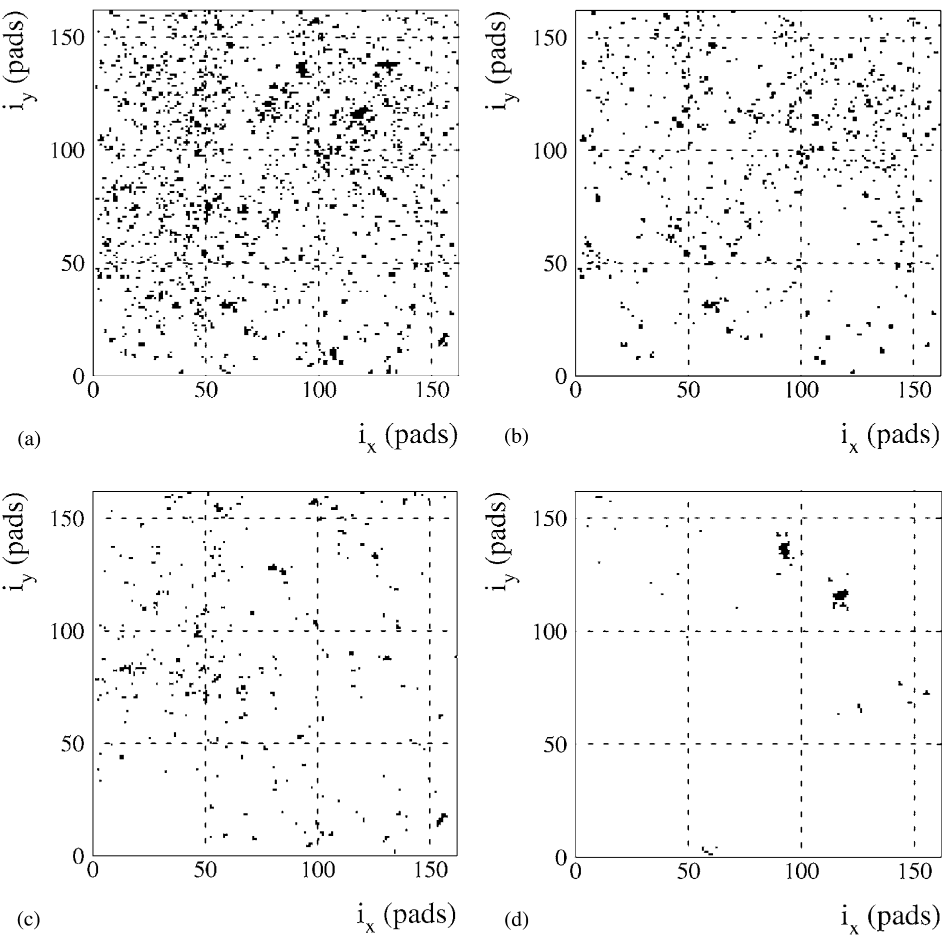

Fig. 1. Simulated full event (PbPb central collision) as seen by a RICH module. Contributions are from (a) all particles, (b) primary pions, (c) gammas, (d) neutrons.

Table 2
Simulated occupancies (in %) of the seven RICH modules for one central PbPb collision (SEPH: 20 ADCchan)

8.3	8.6		
9.3	9.1	11	$\longrightarrow z$
9.6	8.6		

Table 3
Simulated mean occupancy as a function of the amplification expressed as the average SEPH

SEPH ADCchan	Mean occupancy (%)
10	5.6
20	9.2
30	11.2
43	12.7

To get an impression of the influence of the background hits we show in Fig. 1(b) the hit pattern produced by primary charged pions alone. In this case the occupancy amounts to only 4%.

The pattern produced by gamma conversions in the RICH alone is shown in Fig. 1(c). As for hadronic interactions, backscattering from the cathode-plane can produce track segments as can be seen in the lower right part of the picture.

The contribution of neutrons to the overall occupancy is small ($\approx 4\%$). Locally, however, the knock-out of a proton by a fast neutron can lead to a substantial release of charge creating a large pad cluster as can be seen from Fig. 1(d).

4.3. Occupancy

The occupancies for each of the seven RICH modules as obtained from one simulated central PbPb (SEPH 20 ADCchan) are shown in Table 2. The average occupancy amounts to 9.23%.

The effect on the occupancy of varying the SEPH from 10 ADCchan to 40 ADCchan is demonstrated in Table 3. If the production of feedback photons is not included in the simulation the occupancy amounts to 8.3% for a SEPH of 10 ADCchan and 10.7% for 43 ADCchan, demonstrating the importance of the effect. Decreasing the amplification will also decrease the number of signal hits. Hence, the choice of the amplification has to come from an optimisation of pattern recognition efficiency and resolution.

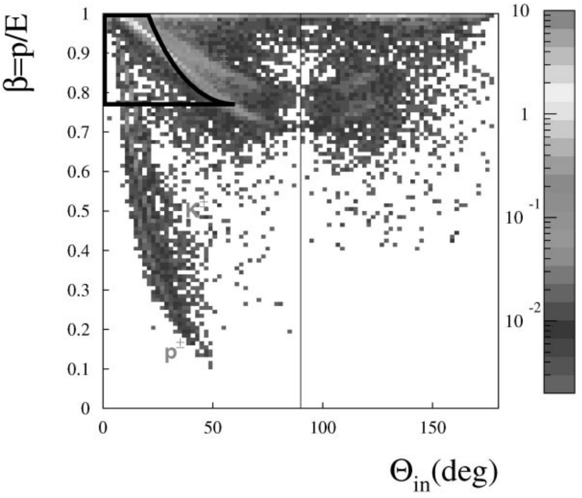

Fig. 2. β versus angle of incidence (θ_{inc}) of charged particles traversing the RICH radiator.

Table 4
Simulated contributions of individual particle fluxes to the mean occupancy

Particle	Contribution in %
Pions	37
μ^+, μ^-	13
Photons	22
e^+, e^-	23
Neutrons	4.0

In Fig. 2, the relativistic β of charged particles traversing the RICH radiator is plotted versus the angle of incidence. Most particles lie outside the area surrounded by the black line. These are either below the Cherencov threshold or their angle of incidence is so high that all photons are reflected at the freon-quartz boundary. If we consider that for signal particles $\approx 85\%$ of the occupancy results from photons it is plausible that despite a charged particle flux of $\approx 100\ \mathrm{m}^{-2}$ to which one has to add the response to neutral particles, the resulting occupancy corresponds to a flux of signal particles of only $\approx 50\ \mathrm{m}^{-2}$.

Finally, we show in Table 4 the relative contributions of the different particle species to the occupancy. The values were obtained by observing the decrease in occupancy when the respective particle was taken out of the total flux. Half of the occupancy results from pions and the muons from their decay. Primary pions and kaons alone lead to an occupancy of 3.2%.

References

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