DOSE CALCULATIONS FOR CBM EXPERIMENT

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Calculations of doses and fluences in the area of experimental hall and research equipment for CBM project of future accelerator Facility for Antiproton and Ion Research (FAIR) in Darmstadt were performed. Code FLUKA was used with adaptation to CBMROOT framework according to technology applied in the framework ALIROOT.

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1. INTRODUCTION

New experimental systems and facilities for research in the area of high energy physics are being developed with using of high intensity beams of relativistic particles. Interaction of such beams with nuclei of target, construction and shielding materials results in high levels of radiation exposure of detector materials and environment, activation of detector and constructional materials etc. That is why calculations of particles fluences and radiation doses must be performed with sufficient accuracy for optimization of detector design, shielding materials and operation conditions of accelerator. The code FLUKA [1] is most suitable and tested freeware software for such tasks in high energy physics and written in FORTRAN language. The most part of modern program frameworks for simulation of ionizing particles transport use ROOT [2] and GEANT4 [3] codes. These codes are written in C++ and some adaptation procedures are therefore needed. Calculations of doses and fluences in the area of experimental hall and research equipment for CBM project [4] of future accelerator Facility for Antiproton and Ion Research (FAIR) in Darmstadt were performed.

2. CBM PROJECT

The goal of the Compressed Baryonic Matter Experiment (CBM) on nucleus-nucleus collisions at the new accelerator facility at GSI is the investigation of highly compressed nuclear matter. Matter in this form exists in neutron stars and in the core of supernova explosions. In the laboratory, superdense nuclear matter can be created in the reaction volume of relativistic heavy-ion collisions. The highest net baryon densities are expected for nuclear collisions in the beam energy range between 10 and 40 GeV/u. In highly compressed cold nuclear matter the baryons lose their identity and dissolve into quarks and gluons. The main goal of CBM project is detailed study of region near phase transition from baryons to quark-gluon plasma. It is necessary to detect very rare events, therefore high beam intensity is needed. High intensity beams cause high levels of radiation. The CBM setup consists of the following subsystems (see Fig.1):

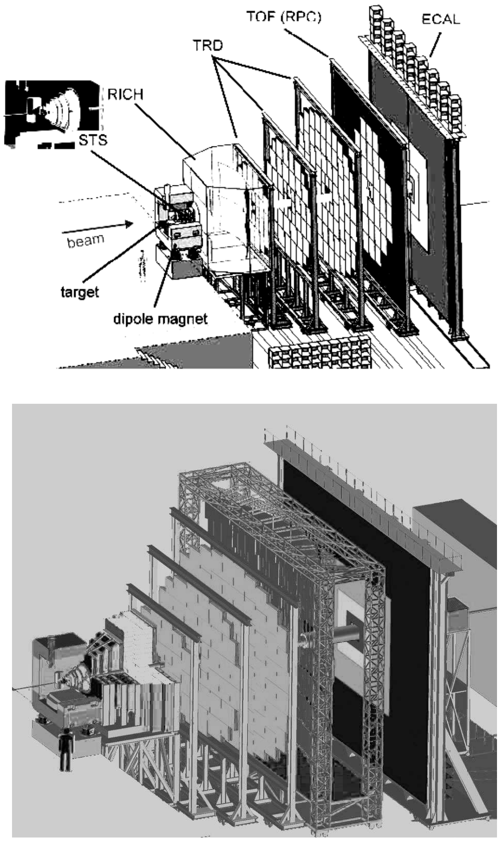

Fig.1. *Structure of CBM setup (top), alternative approach with muon detector MUCH (bottom)*

- a large acceptance superconducting dipole magnet;
- a radiation-hard Silicon Tracking Station (STS) comprizing pixel/strip detectors;
- a Silicon pixel microvertex detector with high position resolution and low material budget;

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- a Ring Imaging Cherenkov detector (RICH) for soft electron identification;
- Transition Radiation Detectors (TRD) for identification of electrons with momenta above $2\,GeV/c$;
- a muon detection system consisting of several layers of absorbers and tracking chambers. This system is an alternative to RICH and TRDs, which then would be used as tracking stations for hadron identification;
- Resistive Plate Chambers (RPC) for time-of-flight measurement (hadron identification);
- an Electromagnetic calorimeter (ECAL) for identification of photons.

3. DOSE AND FLUENCE CALCULATION FOR HIGH ENERGY PHYSICS FACILITIES

High Energy Physics experiments are being increasingly required to operate at higher energies and higher luminosities. However, the high collision rates (up $10^9\,Hz$), necessary to study rare physics events, will also result in high levels of radiation backgrounds. Therefore, in addition to physics requirements, the various detector subsystems must also be designed to operate in high radiation environments.

There is not very large number of detail information about methods and physics of radiation protection for area of high energy physics. One of the useful guides for radiation safety specialists is new recommendations of the National Council on Radiation Protection and Measurements "Radiation Protection for Particle Accelerator Facilities" (2003) [5].

One can emphasize two main targets for radiation influence: effects of radiation on electronics and optical devices; irradiation of personnel.

Predicting particle fluences and doses at future high energy physics experiments is important for estimating the following:
- Detector counting rates or occupancies. Determined by convolving the predicted particle energy spectra with detectorsensitivity functions;
- Radiation damage to detectors and electronics;
- Activation and consequences for detector access and maintenance scenarios;
- Radiation-exposure to personnel working in nearby caverns during beam operation.

Radiation safety of personnel. It is necessary to perform radiation safety rules. There are two risks for personnel. It is irradiation by products of beam interaction (in beam-on mode) with target and constructional materials and irradiation by products of activation of constructional materials during beam-off period. Restrictions and scenarios of access to measurement area (time and place) are main means to protect personnel from irradiation danger. Building of radiation shield is effective method of protection both electronics and personnel.

Information about radiation levels (spatial and time dependence), parameters of shield is very important for correct estimation of risks for personal and equipment hazard. This information is needed before construction of shielding, detector structures, scheduling of equipment access and measurements for optimal choice (finances, manpower, reliability of electronics and optic devices operation). Therefore, use of simulation code for calculation of dose levels and fluxes is obliged. Geometry of detector systems for high energy physics is very complex, with various materials. Only Monte Carlo method codes for transport of ionizing particles can solve such tasks.

Radiation effects on electronics are normally divided into 3 different categories according to their effect on the electronic components:

Total Ionizing Dose (TID): TID effects are a typical case of cumulative effects. Cumulative effects are gradual effects taking place during the whole lifetime of the electronics exposed in a radiation environment. TID is the measurement of the dose, that is the energy, deposited in the material of interest by radiation in the form of ionisation energy. The unit to measure it in the International System (SI) is the Gray, but for radiation effects community still uses most often the old unit, the rad ($1\,Gray = 100\,rad$). There are many good experimental data and precise theoretical models for electrons and photons for energies up to nearly $30\,MeV$ and poor data, not very accurate theoretical description for other particles and region of High Energy Physics.

Displacement damage: It is also case of cumulative effects. Hadrons may displace atoms (therefore called displacement effect) in the silicon lattice of active devices and thereby affect their function. Bipolar devices and especially optical may be very sensitive to this effect. The total effect of different types of hadrons at different energies are normalized to $1\,MeV$ neutrons using the NIEL (Non Ionizing Energy Loss) equivalent. According to NIEL scaling, any particle fluence can be reduced to an equivalent $1\,MeV$ neutron fluence producing the same bulk damage in a specific semiconductor. NIEL scaling hypothesis should not be regarded as a universally and ideally valid rule. But its using is however always useful, in order to cancel out most of the particle and energy dependencies of the observed damage in silicon detectors.

Single event effects (SEE): Very localized event induced by a single particle. It is not a cumulative effect. Highly ionizing particles can directly deposit enough charge locally in the silicon to disturb the function of electronic circuits. Energetic Hadrons ($> 20\,MeV$) can by nuclear interactions within the component itself generate recoils that also deposits sufficient charge locally to disturb the correct function. There are subdivision of this effect. Single Event Upset (SEU) - the deposited charge is sufficient to flip the value of a digital signal. Single Event Upsets normally refer to bit flips in memory circuits. Single event latchup (SEL) - Semiconductor manufacturers are aware of possible electrical latchup initiated by transients on input/output lines, or improper power supply sequencing. Circuits are often protected against these failure modes. Nevertheless, circuits operating in a radiation environment might be subject to an ionizing particle-induced latchup. Single event burnout (SEB) - Single event burnout refers to destructive failures of power MOSFET transistors in high power applications.

4. DOSE AND FLUENCE CALCULATIONS FOR CBM EXPERIMENT

At the first stage of development for CBM simulation project we created program converters for transformation of geometry information from CBM simulation project to geometry records in the input file for FLUKA code. We used Geometry Description Markup Language (GDML) Schema [6] for intermediate building and checking the CBM geometry. The GDML is an application-indepedent geometry description format based on XML. It can be used as the primary geometry implementation language as well as it provides a geometry data exchange format for existing applications. One can see examples of geometry of CBM experimental setup - general view of setup in the experimental hall (see Fig.2) and part of equipment with magnet, beam pipe and Silicon Tracking Station (see Fig.3). These images were obtained from FLUKA input file after conversion procedure. Length units in the figures are shown in the centimetres.

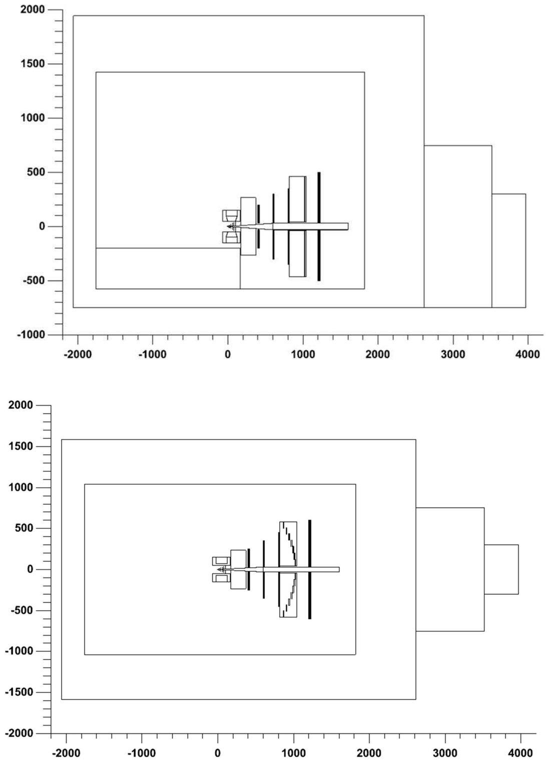

Fig.2. *The general view of measurement setup in the experimental hall*

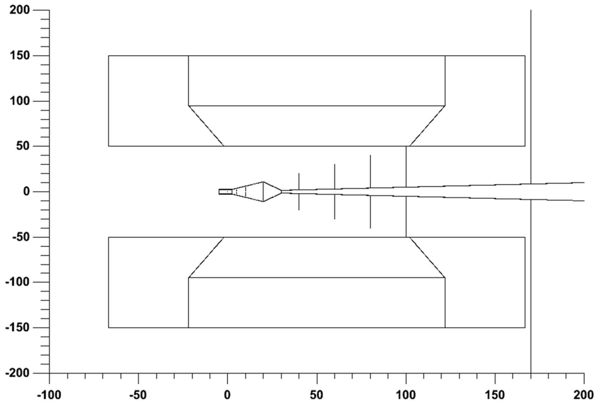

Fig.3. *Geometry view - part of equipment with magnet, beam pipe and Silicon Tracking Station*

Dose and fluence calculations were performed with using standard means of FLUKA code. One can see examples of such calculations (graphical presentation) in Fig.4. Density of deposited energy instead of dose in the region of magnet is used for illustration. In Fig.4 all values are normalized on the one primary collision of relativistic gold nucleus of ^{198}Au (total energy $25\,GeV/u$) with nucleus of target (also Au).

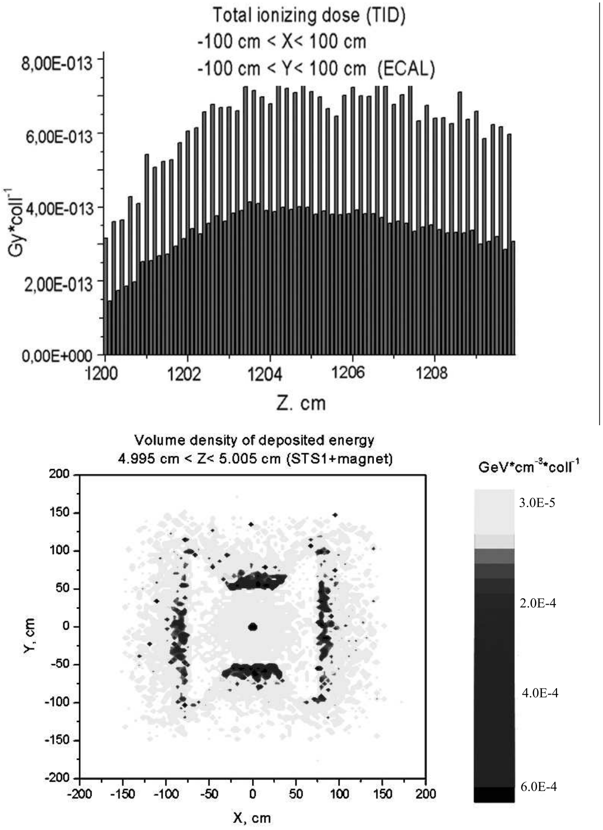

Fig.4. *Dose and deposited energy distributions for various parts of CBM experimental setup*

On the second development stage of CBM simulation project the CBMROOT framework was built [7]. The CBMROOT framework is fully based on the ROOT system. The Virtual Monte Carlo concept [8] allows performing simulations using various Monte

Carlo engines without changing the user code. The user can create simulated data and/or perform analysis with the same framework. Geant3 and Geant4 transport engines were supported, however the user code that creates simulated data does not depend on a particular Monte Carlo engine.

FLUKA Monte Carlo engine was implemented to CBMROOT framework according to technology applied in the framework ALIROOT [9]. The logic diagram of CBMROOT framework is shown in Fig.5.

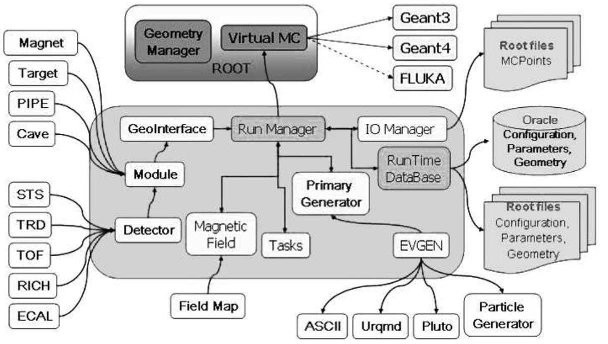

Fig.5. *The logic diagram of CBMROOT framework*

This approach allowed to calculate doses and fluenses for various particles using FLUKA engine and CBM setup geometry in the CBMROOT framework. Results of such calculation are presented in Fig.6, Fig.7 and demonstrate anticipated dose distribution and fluence of high energy neutrons in the area of MUCH detector and magnet. In these figures results are normalized by number of primary particles - products of Au nuclei collision with total energy $25\,GeV/u$.

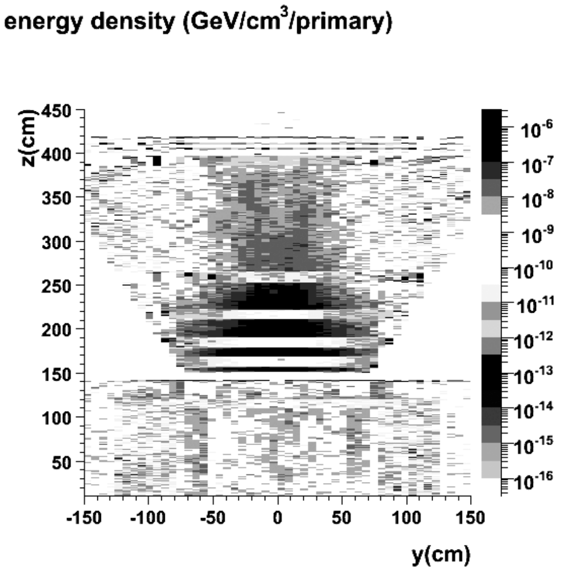

Fig.6. *Example of dose calculation in the region of magnet and muon detector (MUCH). Density of deposited energy instead of dose is used for illustration*

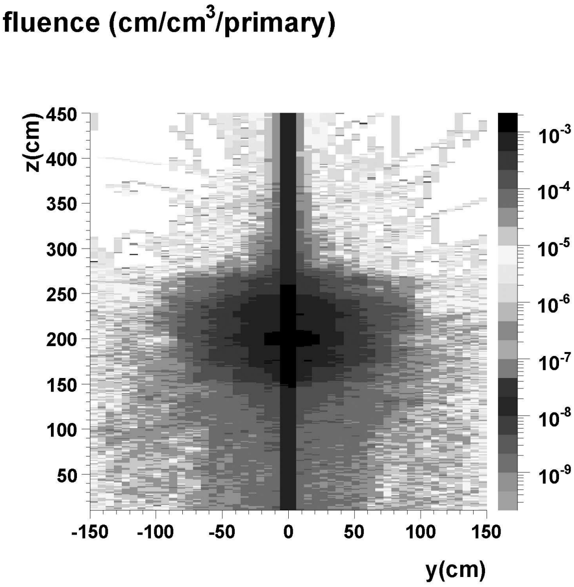

Fig.7. *Fluence of high energy neutrons in the area of MUCH detector and magnet*

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РАСЧЕТ ДОЗОВЫХ РАСПРЕДЕЛЕНИЙ ДЛЯ ЭКСПЕРИМЕНТАЛЬНОЙ УСТАНОВКИ ПРОЕКТА CBM

О.А. Бесшейко, Л.А. Голинка-Бесшейко, И.Н. Каденко, Е.О. Севастюк

Были проведены расчеты поглощенных доз и потоков частиц для экспериментального оборудования проекта CBM будущего ускорительного комплекса в Дармштадте для исследований взаимодействия релятивистских антипротонов и тяжелых ионов. Для расчетов использовался программный код FLUKA. Была проведена адаптация расчетного кода FLUKA для работы в программной оболочке симуляции эксперимента CBMROOT с использованием подходов, которые применяются в фреймворке ALIROOT.

РОЗРАХУНКИ ДОЗОВИХ РОЗПОДІЛІВ ДЛЯ ЕКСПЕРИМЕНТАЛЬНОЇ УСТАНОВКИ ПРОЕКТУ CBM

О.А. Безшийко, Л.О. Голінка-Безшийко, І.М. Каденко, О.О. Севастюк

Було проведено розрахунки поглинутих доз і потоків частинок для експериментального обладнання проекту CBM майбутнього прискорювального комплексу в Дармштадті для дослідження взаємодії релятивістських антипротонів і важких іонів. Для розрахунків використовувався програмний код FLUKA. Було проведено адаптацію коду FLUKA для роботи в програмній оболонці симуляції експерименту CBMROOT з використанням підходів, які застосовуються в програмній оболонці ALIROOT.