HEED++: history, structure and physics

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Introduction

- HEED - "High Energy Electro-Dynamics", calculation (simulation) of interaction of fast charged particles with matter and its ionization.
- Created for calculation of gaseous (gas-filled) detectors of fast charged particles.
- The user describes the geometry and materials of the detector, and run the primary particle (particles) one time or in the loop.
- Final stage of calculation: coordinates of each conduction electron in each "sensitive" volume.
- Drift and gaseous amplification in electric field is not calculated (assumed that other programs are responsible).
- Allows to model complex installations with gases and solids, magnetic field.
- Uses the Monte Carlo method for particle transport via (almost) arbitrary geometry.
- Can be used for includion of any other processes.
- Ingredients can be used for treatment of experimental data (track reconstruction, passage through magmetic field).

90's, Fortran-77

- The case of solid scintillation detectors:
  I. B. Smirnov. *Calculation of fluctuations of ionization loss of fast charged particles.* Preprint LNPI-1758, 1991, 17 pages (in Russian).
  Fast calculation of the Vavilov distribution and calculations by strongly simplified "PAI".
- Gaseous (gas-filled) detectors needed more precision. It was desirable to emit delta-electrons and to model their the ranges and space fluctuations.
  Applications: cathode strip chambers (CSC).
- Technics of that time: "main frames", textual terminals with one window, appearing "graphical" X-window displays and "personal computers", Fortran-77, GEANT 3, HBOOK, PATCHY(CMZ).
- First discussions about C++ and first difficult attempts of application.
- Fiasco of SSC and interest to LHC.
- Approximately 1994-97. HEED-F77 with allocation of common blocks in "included" files, but with simplified parallel-plane geometry, newertheless useful for most of the "proportional chambers".
  Application for CSC's for CMS, LHCb, may be for ALICE.
- PAI: W.W.M. Allison, J.H. Cobb, *Relativistic Charged Particle Identification be Energy Loss* Ann. Rev. Nucl. Part. Sci. 30 (1980) 253.
- PAI is modified by separation of shells and subsequent simulation of atomic relaxations and delta-electrons.
  Later called PAIR: PAI with relaxation.
- The first interface with Garfield (in F77, R. Veenhof, *GARFIELD, A Drift Chamber Simulation Program.* CERN, 1994, CERN program library, entry W5050, http://cern.ch/garfield.)

CERN Program Library Long Writeup W5013

GEANT

Detector Description and

Simulation Tool

Application Software Group

Computing and Networks Division

Ann. Rev. Nucl. Part. Sci. 1980. 30: 253–98

RELATIVISTIC CHARGED PARTICLE IDENTIFICATION BY ENERGY LOSS

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Other programs of that time

- GEANT3 (last version - 3.21) F77, de facto standard in HEP up to 90's. Physics of ionization was not detailed enough.
- GEANT4 C++, developed from middle of 90's, used in "big" experiments, reports about many other applications.
  Some features seemed to be arguable (for example, raw pointers in classes).
  Physics of ionization was not detailed enough.
- Many other less known programs (for example EGS4, MCNP), but no one corresponded to our needs for various reasons.

2000's, C++

- Straw tubes (for example, for ATLAS) — geometry is not consisting of parallel planes!
- More careful approach to C**++**.
  Smart pointers:
  I. B. Smirnov. *Raw Pointers in Application Classes of C++ Considered Harmfull*, ACM SIGPLAN Notices, Vol. 42 (2007), No. 4, 23.
  Alternative title: Methodology of object management.
  (Remark: "double r;" — the value, "double* ar = &r;" — a pointer to the value, "TypeOfSmartPointer< double > sr" — a "smart" pointer.)
  Main feature: ownership (a part of) or independence of one object from another.
  Copying (strong) pointer and
  reference to independent object (not a "weak" pointer).
  No raw pointers in application classes!
  The result: no "segmentation faults", no other errors with "free" memory, and very convenient modeling of physical objects. Geometrical description of a particluar "volume", its material and other physical and non-physical information is kept in a single object.
- More "universal" geometric library. Conversions between coordinate systems, enveloped objects of arbitrary shapes, curved trajectories.
- HEED**++** (2005), New interface of with GARFIELD.
  I. B. Smirnov, *Modeling of ionization produced by fast charged particles in gases*, Nucl. Instr. and Meth. A 554 (2005) 474.
- Details are here: http://ismirnov.web.cern.ch/ismirnov/

Practical range of δ-electrons

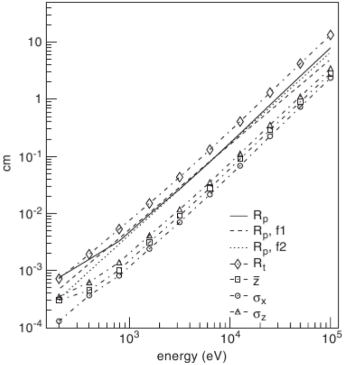
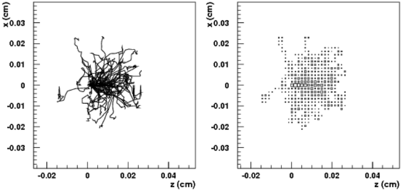


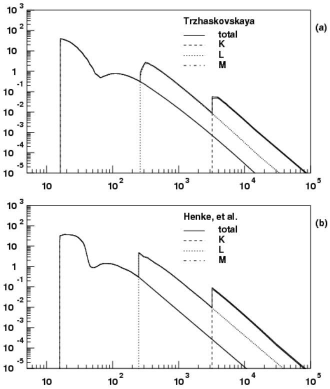
Fig. 1. The practical range R_p of the electrons in argon calculated by HEED (solid line) and two empirical formulas (dashed and dotted lines). Also shown are the total length of way of electrons R_t by HEED (rhombuses), the mean z-position $\bar{z}$ (if z is the initial direction of movement) of the "centers of gravity" of the ionization clouds (boxes) and its fluctuations (RMS) along the z-axis σ_z (triangles) and x-axis σ_x (circles).

Trajectories of δ-electrons



Trajectories (in sm) of 50 δ-electrons in Argon, emitted with initial energy of 50 keV from the point (0,0) along z-ais. The trajectories themselves are on the left plot. The ionization created by them is on the right plot.

Separation of shells in photo-absorption cross section



Example of separation of shells for the photoabsorption cross section for Ar.

Primary clusters

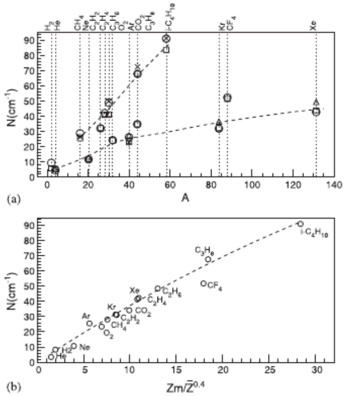


Fig. 2. The number of primary clusters for minimum-ionizing particles for various gases at NTP according to calculations by HEED (circles) and a number of measurements: Ref. [57] (squares), the average of numbers from Ref. [18] and seven other works quoted in Table 5 of Ref. [18] (stars), and Ref. [58] (triangles). (a) shows the dependency on the atomic or molecular weight. (b) shows the data of HEED only as function of $Z_m/\bar{Z}^{0.4}$. In (a) the dashed lines are drawn by hand to guide the eye. In (b) the dashed line represents fit to the given points except CF_4: $3.996x - 0.025x^2$ ($x = Z_m/\bar{Z}^{0.4}$).

Ionization energy loss distributions

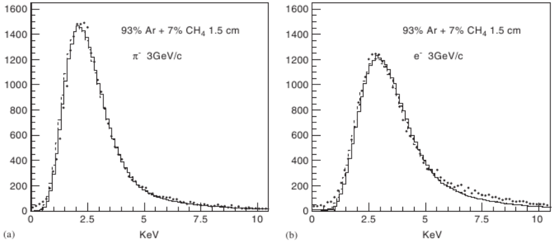


Fig. 3. The experimental (points) and theoretical "ionization loss" distributions expressed in energy units. Histograms drawn by solid lines are obtained by the PAIR model, dashed lines (they are practically coincide with solid ones) are by the PAI model.

Experimental data from:
F. Harris, T. Katsura, S. Parker, et al., *The experimental identification of individual particles by the observation of transition radiation in the X-ray region.* Nucl. Instr. and Meth. 107 (1973) 413–422.
Calculations by HEED++.

Conclusion

- The HEED++ program agrees with experimental data.
- It can be used for simulations of gas filled detectors of high energy charged particles.

Thank you!