Modelling the radioluminescence of alpha particles in air by Monte Carlo method

***Ioana Lalău*[1,2] & Mihail-Răzvan Ioan[1]**

[1]*Horia Hulubei National Institute of Physics and Nuclear Engineering, POBox MG-6, Magurele, Romania*
ioana.lalau@nipne.ro
[2]*University of Bucharest, Faculty of Physics, POBox MG-11, Magurele-Bucharest, Romania*

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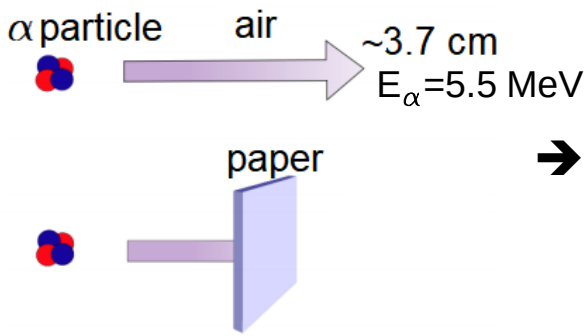
1. Motivation



➔ close proximity detection

Traditional detection methods (proportional counter, scintillator counter, PIPS detectors):

- Time consuming and tedious
- Involve scanning very close to the contaminated surface
- Require protective equipment
- Expose the personnel to other hazards and risks (other radiation types, fire, etc.)

- **Remote detection of alpha radiation ➔ radioluminescence.**
- Alpha - radioluminescent light can be transmitted through air for considerable distance, several order of magnitude greater than the mean free path of alpha particles.

Alpha particles induced radioluminescence

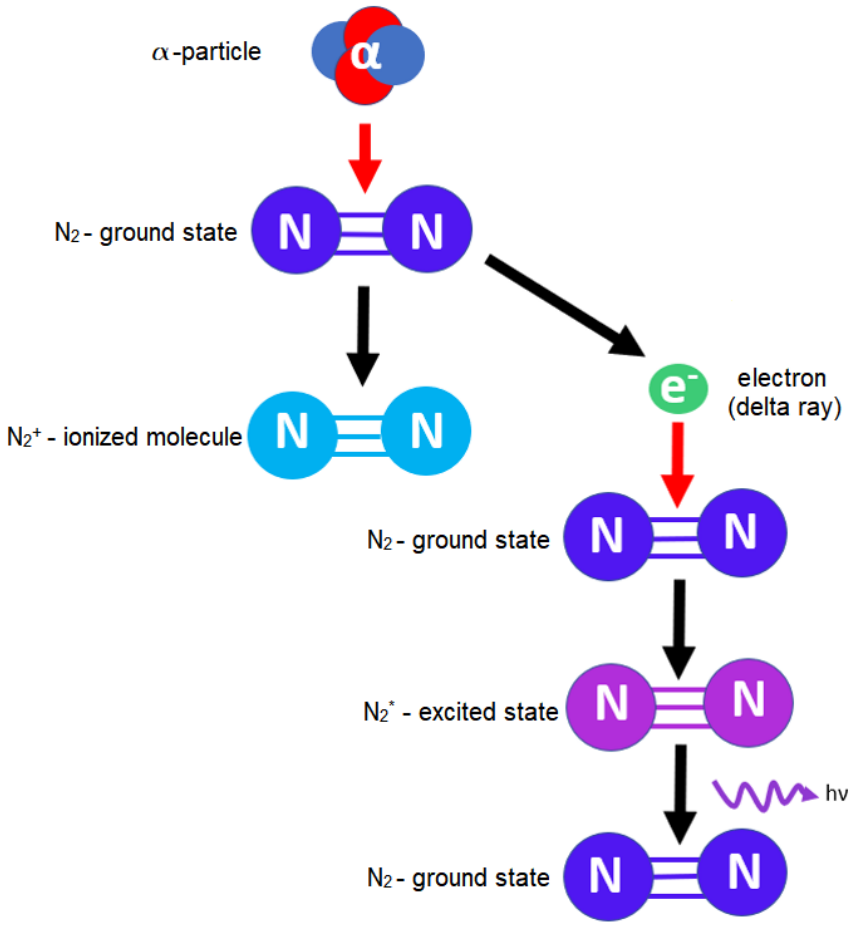


Fig. 1. *Radioluminescence process.*

- High energy alpha particles ionize air (predominantly, molecular nitrogen)

➔various processes (e.g. ionization with delta rays and electron capture) promote nitrogen molecules to excited states

➔nitrogen molecules are de-excited emitting fluorescence light in the near UV region between 300-400 nm

Radioluminescence Spectra

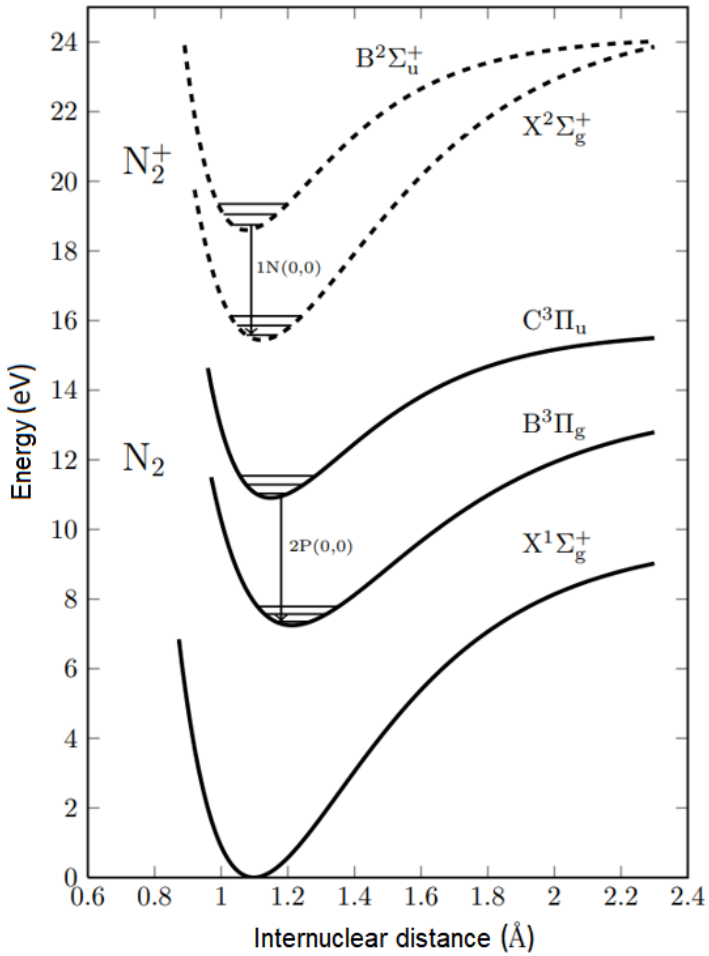


Fig. 2. *Selected energy levels of N_2 molecule illustrated with Morse potential plots, using molecular constants from Lofthus and Krupenie*

A. Lofthus and P. H. Krupenie, "*The spectrum of molecular nitrogen*," Journal of Physical and Chemical Reference Data, vol. 6, no. 1, pp. 113 – 307, 1977.

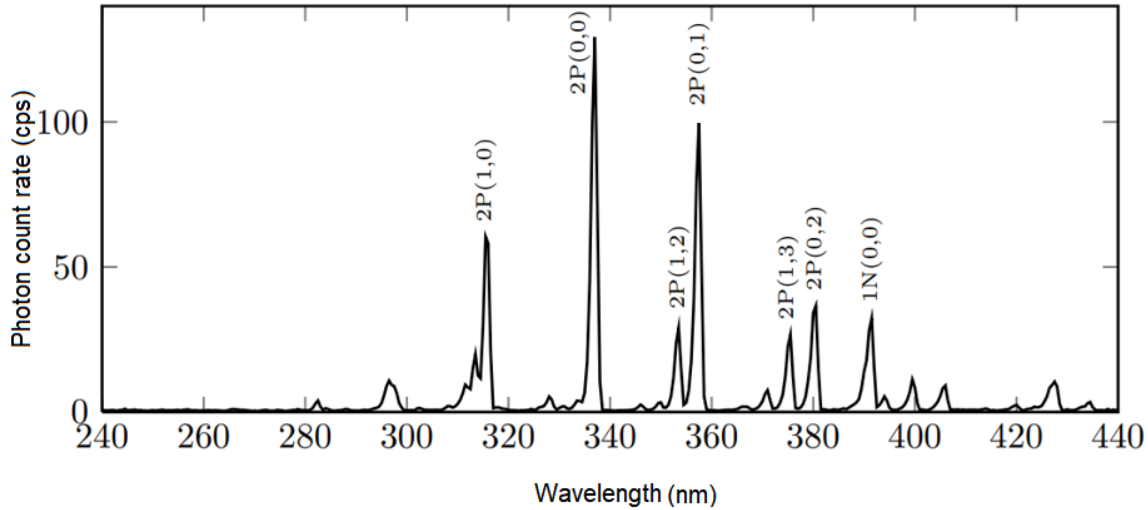


Fig. 3. *Radioluminescence emission spectrum of air excited by Am-241 alpha particles*

$$e_s^-(\uparrow) + N_2(X^1\Sigma_g^+) \longrightarrow N_2^*(C^3\Pi_u) + e_t^-(\downarrow)$$

$$e_s^- + N_2^+(X^2\Sigma_g^+) \longrightarrow N_2^*(C^3\Pi_u)$$

$$e_s^- + N_2(X^1\Sigma_g^+) \longrightarrow N_2^{+*}(B^2\Sigma_u^+) + e_t^- + e_s^-$$

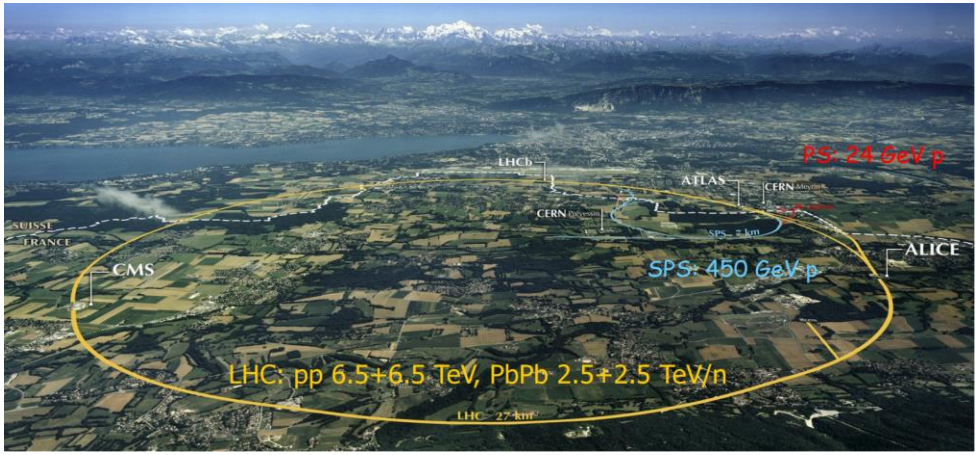
Sand, J. (2016). *Alpha Radiation Detection via Radioluminescence of Air*. (Tampere University of Technology. Publication; Vol. 1449)

FLUKA

- Fully integrated particle physics Monte Carlo simulation package
- Is a general purpose tool for calculations of particle transport and interactions with matter
- Can simulate with high accuracy the interaction and propagation in matter of about 60 different particles, including photons and electrons from 1 keV to thousands of TeV, neutrinos, muons of any energy, hadrons of energies up to 20 TeV (up to 10 PeV by linking FLUKA with the DPMJET code) and all the corresponding antiparticles, neutrons down to thermal energies and heavy ions.
- Can handle even very complex geometries, using an improved version of the well-known Combinatorial Geometry (CG) package. The FLUKA CG has been designed to track correctly also charged particles (even in the presence of magnetic or electric fields). Various visualization and debugging tools are also available.

APPLICATIONS

- Cosmic ray physics
- Neutrino physics
- Accelerator design (n_ToF, CNGS, LHC systems)
- Particle physics: calorimetry, tracking and detector simulation etc. (ALICE, ICARUS, …)
- ADS systems, waste transmutation ("Energy amplifier", FEAT, TARC, …)
- Shielding design
- Dosimetry and radioprotection
- Radiation damage
- Space radiation
- Hadron therapy
- Neutronics



"FLUKA: a multi-particle transport code" A. Ferrari, P.R. Salla, A. Fasso and J. Ranft, **CERN-2005-10 (2005), INFN/TC_05/11, SLAC-R-773**

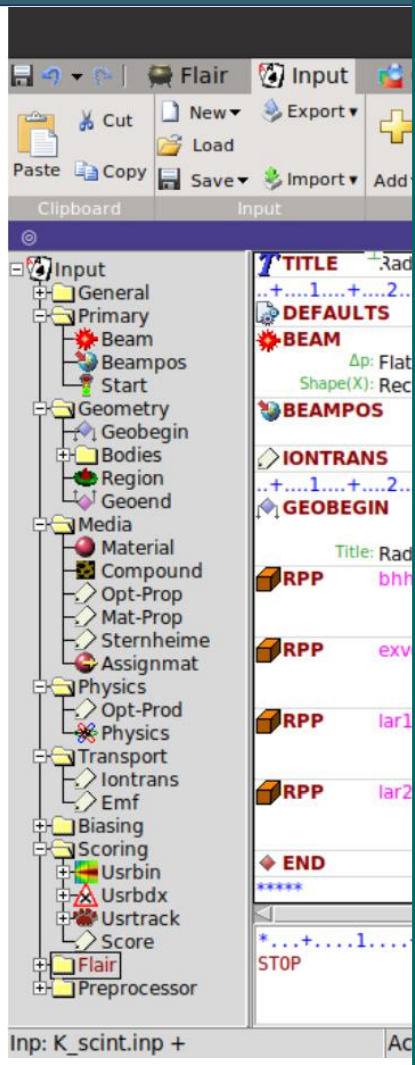
"*The FLUKA Code: Developments and Challenges for High Energy and Medical Applications*" T. T. Böhlen, F. Cerutti, M. P. W. Chin, A. Fassò, A. Ferrari, P.G. Ortega, A. Mairani, P.R. Sala, G. Smirnov and V. Vlachoudis, **Nuclear Data Sheets 120, 211-214 (2014)**

http://www.fluka.org/fluka.php

FLUKA – input parameters

Any input consists of different cards, each card belonging to particular categories: **BEAM, GEOMETRY, MEDIA, PHYSICS, TRANSPORT, SCORING.**

- **BEAM** and **BEAMPOS** or **SOURCE** card **-** primary particle properties
- **GEOMETRY –** combinatorial geometry
- **MEDIA**
  - ➔ **OPT-PROP** card - defines optical properties of the material
    - * wavelength range for optical transport, refraction index, absorption coefficient
- **PHYSICS**
  - ➔ **OPT-PROD** card - requests and controls production of Cerenkov, Transition and Scintillation Radiation in specified materials
    - * i-th scintillation photon emission energy, fraction of energy loss going into i-th scintillation photon emission
    - * in case of scintillation light, only monochromatic photons are considered for the moment (with a maximum of 3 different lines)
- **TRANSPORT**
  - ➔ **IONRANS –** determines the transport of ions (A>1)
  - ➔ **EMF**
- **SCORING** of photon flux
  - ➔ **USRBDX** defines a boundary crossing fluence (photons per cm^2 per primary)
  - ➔ **USRBIN** (photons per unit volume per primary)



Simulations and results. Alpha radioluminescence

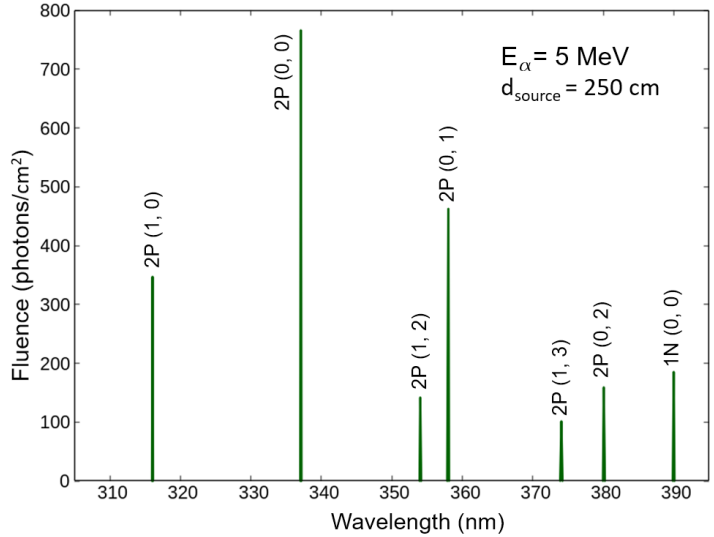


Fig. 4. *Simulated radioluminescence emission spectrum of air excited by alpha particles*

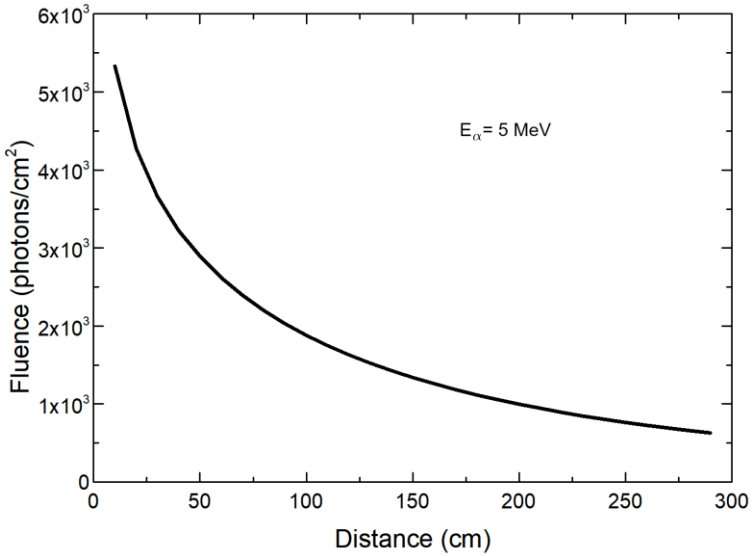


Fig 5. *Simulated radioluminescence photons distance dependence*

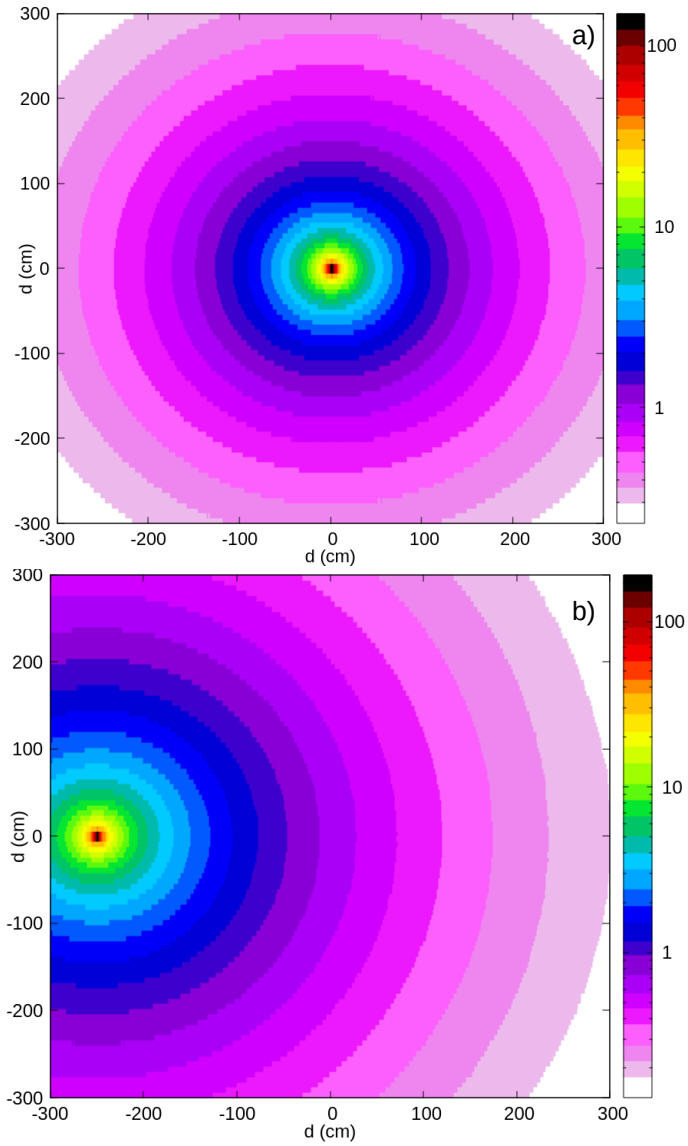


Fig. 6. *Photon density (photons/cm^3). a) Projection on x – axis; b) Projection on z -axis*

Simulations and results. Beta radioluminescence

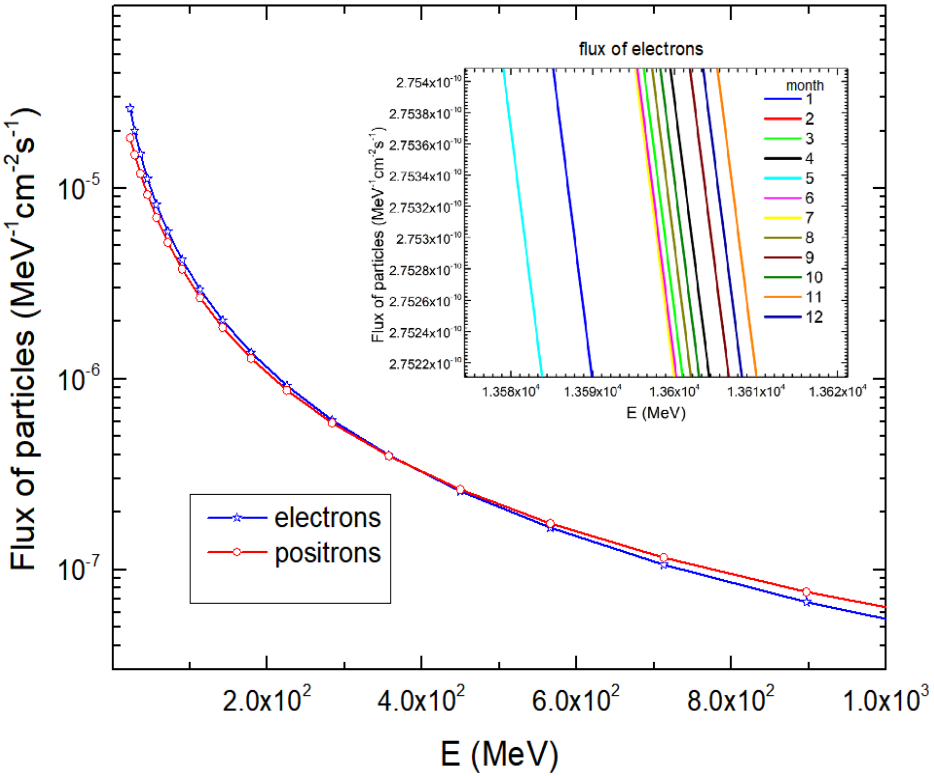


Fig. 7. *Electron and positron cosmic ray flux estimated by EXPACS*

https://phits.jaea.go.jp/expacs/

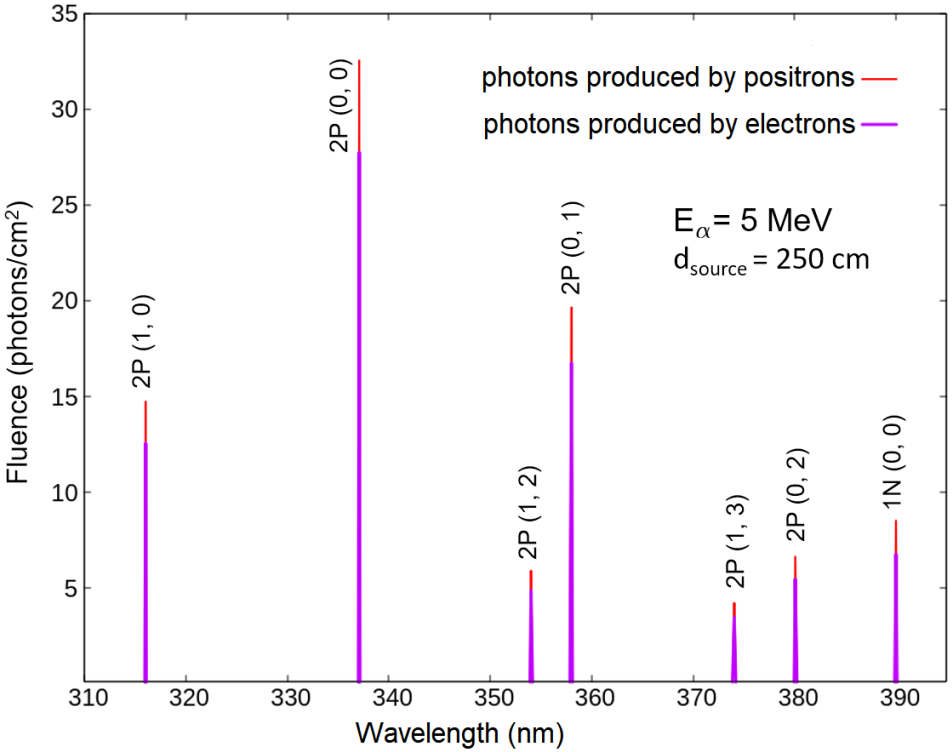


Fig. 8 . *Radioluminescence induced by electrons and positrons from cosmic rays*

Simulations and results

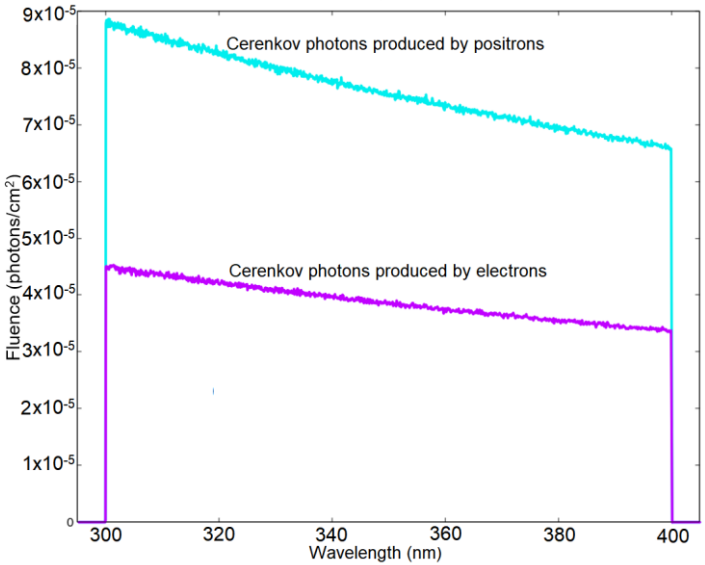


Fig. 9. *Cerenkov photons produced by beta in air*

- Beta particles from cosmic rays moving through the atmosphere with a velocity larger than the speed of light in air emit Cerenkov light
- This light can be emitted in the interest interval (300 ÷ 400) nm

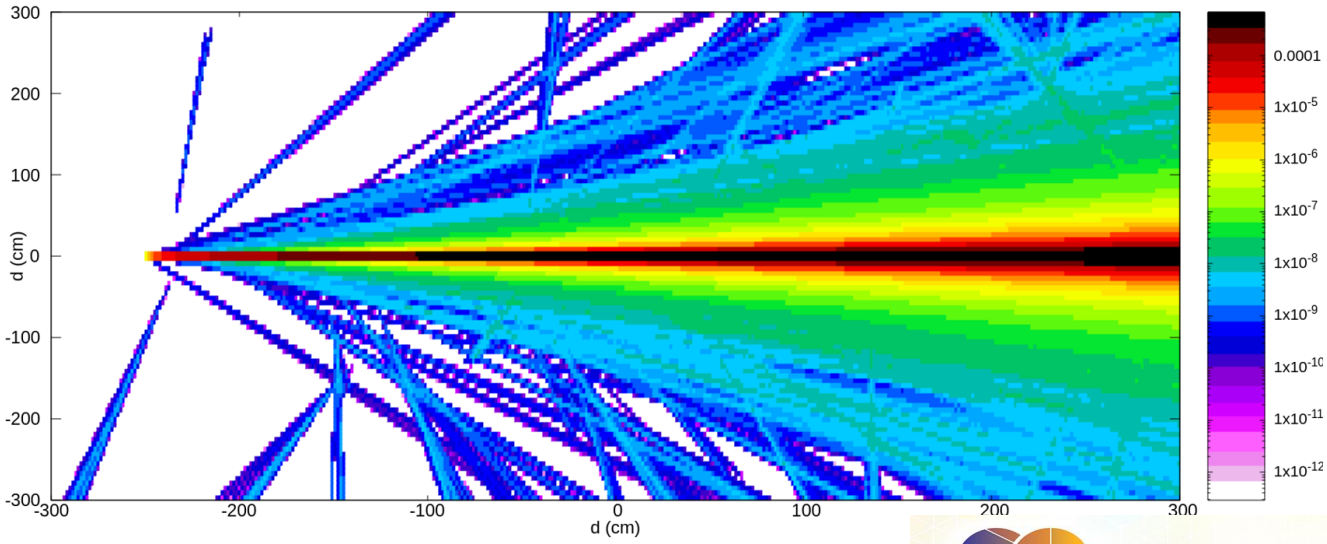


Fig 10. *Cerenkov photons density*

Simulations and results

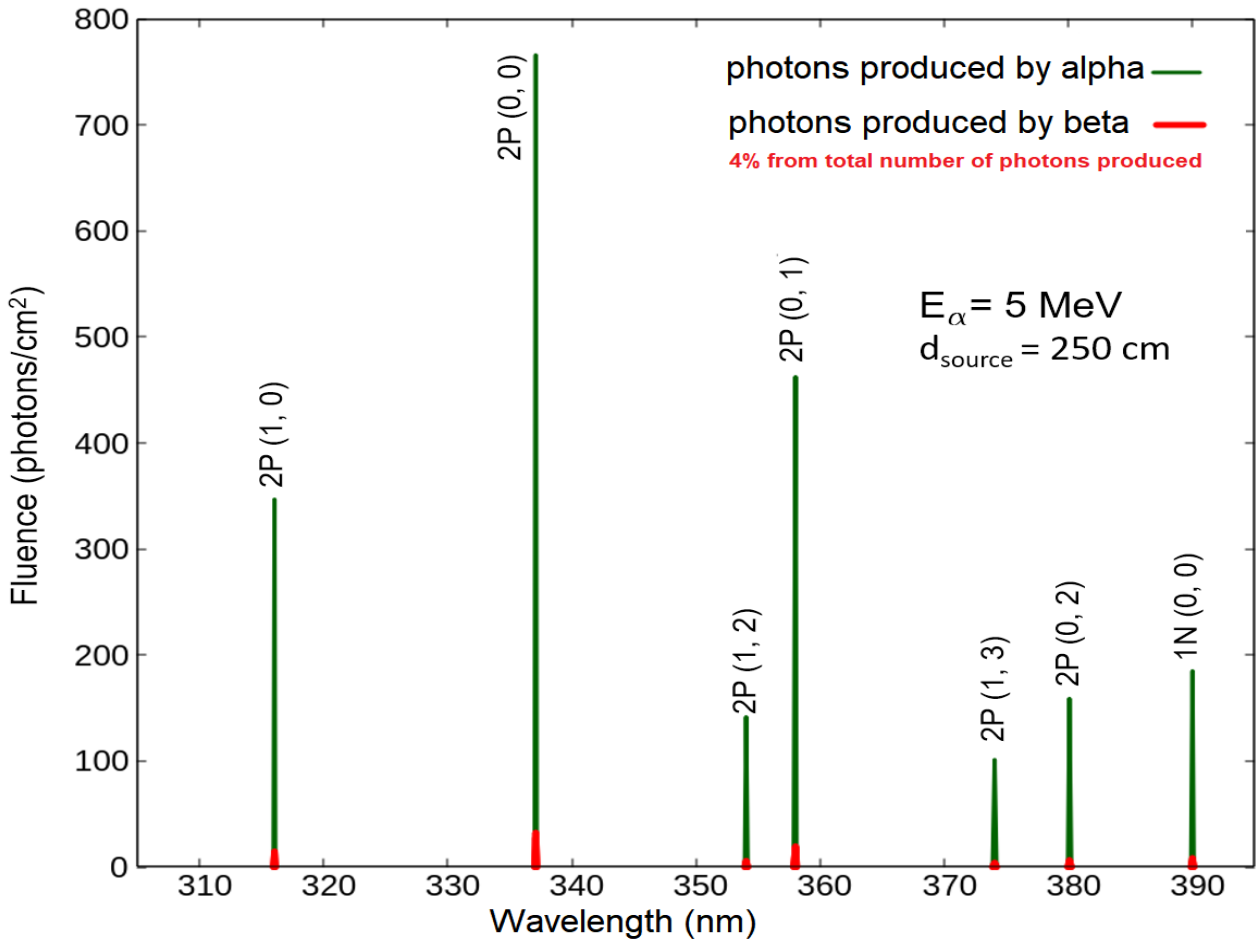


Fig 11. *Simulated radioluminescence emission spectrum of air excited by alpha and beta particles*

- Cerenkov photons produced by cosmic rays are negligible
- The background induced by beta particles from cosmic ray has a small contribution (4%) to the total number of photons per unit area

Conclusions

- **Modelled results indicate air fluorescence to be applicable in the detection of apha emitting source**
- **From the simulations we obtained the Cerenkov and beta induced radioluminescence spectra**
- **Air fluorescene is well suited for the detection and localisation of alpha emitters**
- **Further study needs to be done for other background sources**

Thank you for your attention!

Acknowledgements:

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