Energy resolved positron and hadron spectrum produced by a negative stepped lightning leader

Christoph Köhn[1], Ute Ebert[1,2]

2.5.2014

[1] Centrum Wiskunde & Informatica (CWI), Amsterdam
[2] Department of Applied Physics, Eindhoven University of Technology

11 January 2011 Last updated at 08:34

Antimatter caught streaming from thunderstorms on Earth

Other species?

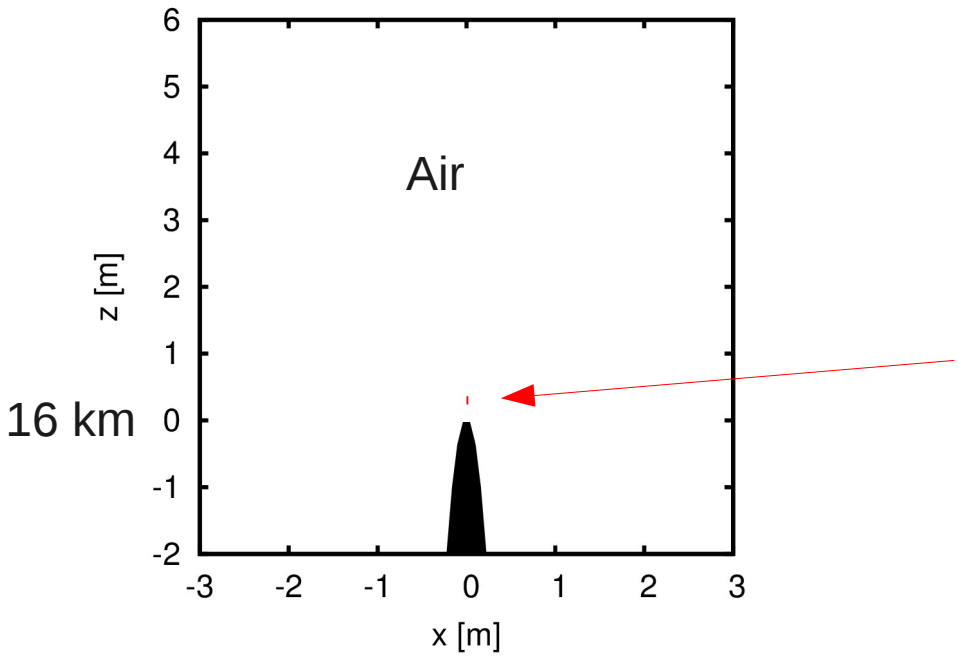
By Jason Palmer
Science and technology reporter, BBC News, Seattle

Electrons racing up electric field lines give rise to light, then particles, then light

A space telescope has accidentally spotted thunderstorms on Earth producing beams of antimatter.

Related stories

Modelling



A hot, propagating and stepping plasma channel transporting charge through air

Here: L = 4 km, r = 1 cm

- Electron(s) 30 cm ahead of leader tip
- Calculate electric field of leader
- Accelerate electrons in this field

[Xu, Celestin and Pasko, Geophys. Res. Let., vol. 39, L08801, 2012]

Motion of electrons

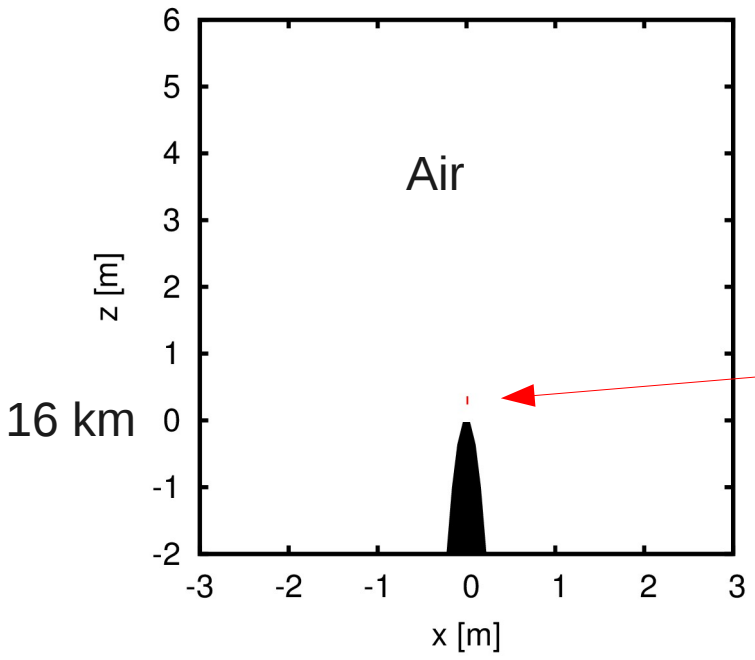
3D relativistic Monte Carlo code

Free motion between collisions

Differential cross sections to model collisions:

- Elastic scattering
- Ionization
- Excitations
- Attachment (Dissociative and three body)
- Bremsstrahlung
  - Electron - nucleus
  - Electron - electron

Modelling



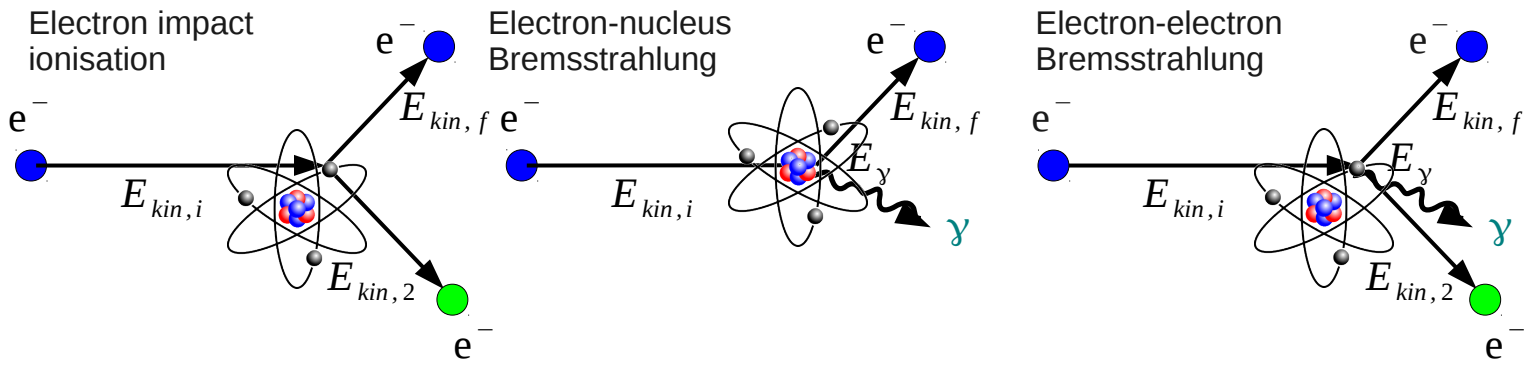
A hot, propagating and stepping plasma channel transporting charge through air

Here: L = 4 km, r = 1 cm

- Electron(s) 30 cm ahead of leader tip
- Calculate electric field of leader
- Accelerate electrons in this field
- Create new electrons and Bremsstrahlung photons

[Xu, Celestin and Pasko, Geophys. Res. Let., vol. 39, L08801, 2012]

Source of electrons and photons



$$e^- + A \rightarrow e^- + A^+ + e^-$$

[Y. K. Kim, J. Paulo Santos, 2000. Phys. Rev. A, vol. 62, 052710]

$$e^- + A \rightarrow e^- + A + \gamma$$

[C. Koehn and. U. Ebert, 2014. Atmos. Res., vol. 135-136, pp. 432-465]

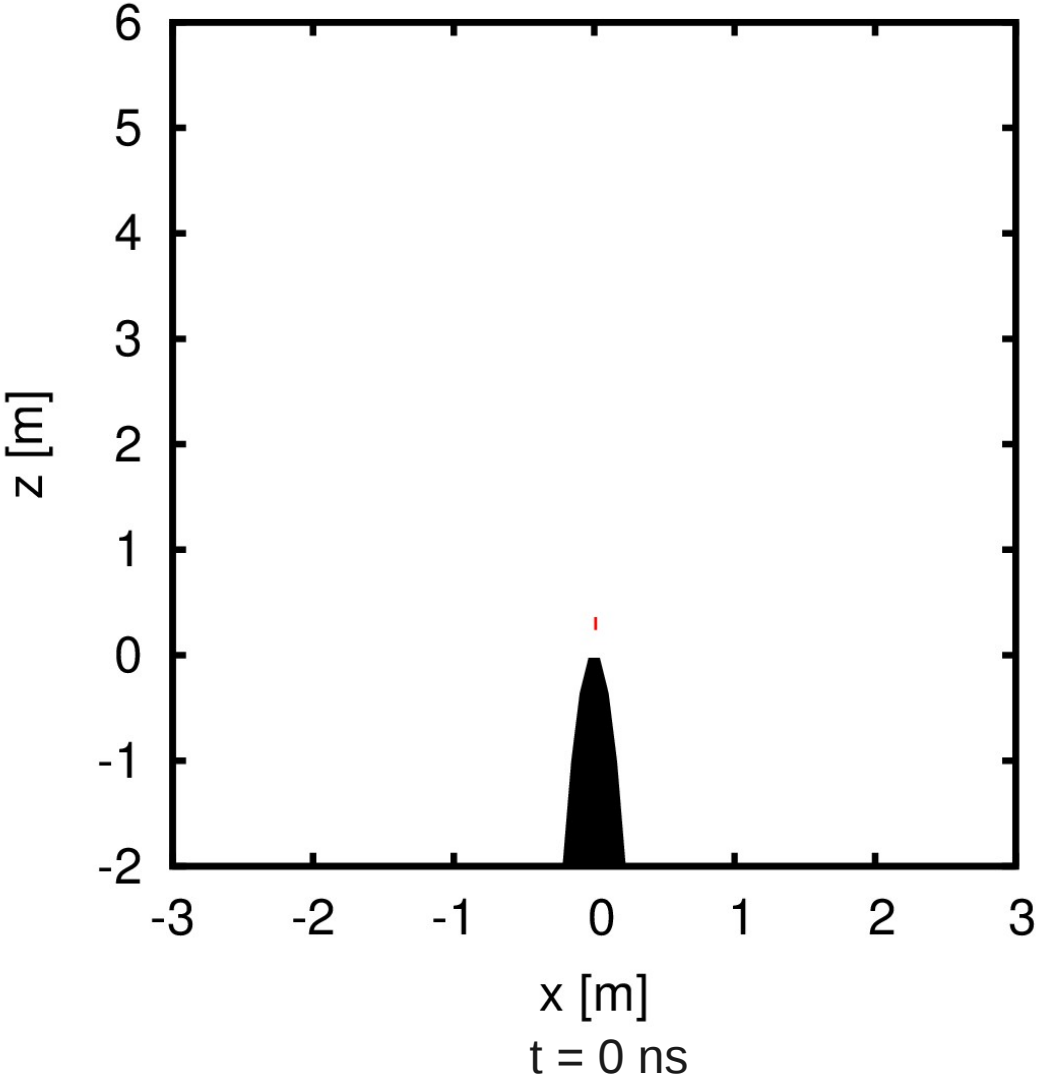
$$e^- + A \rightarrow e^- + A^+ + e^- + \gamma$$

[F. Tessier and I. Kawrakow, 2007. NIM Phys. Res. B, vol. 266, pp. 625-634]

Collaboration with A. Mangiarotti, previously CERN, now Brazil

Dominant for energies above 1 MeV
=> Enrichment of high-energy electrons
=> More high-energy photons

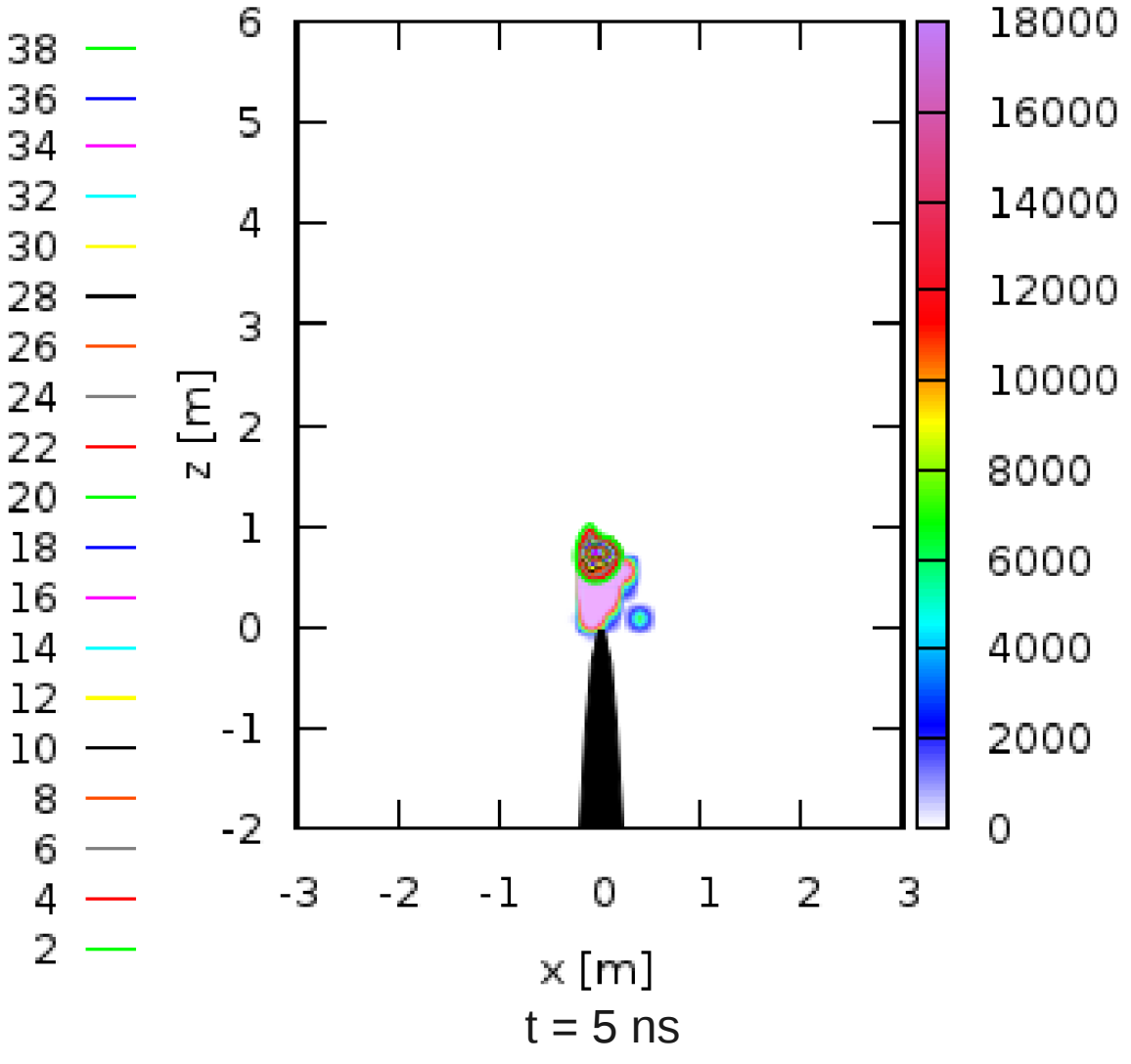
Temporal evolution of electrons



[C. Koehn et al., 2014. The importance of electron-electron Bremsstrahlung for terrestrial gamma-ray flashes, electron beams and electron-positron beams. Revised for J. Phys. D.: Appl. Phys.]

Temporal evolution of electrons

Electron density > 1 MeV [1/m³]

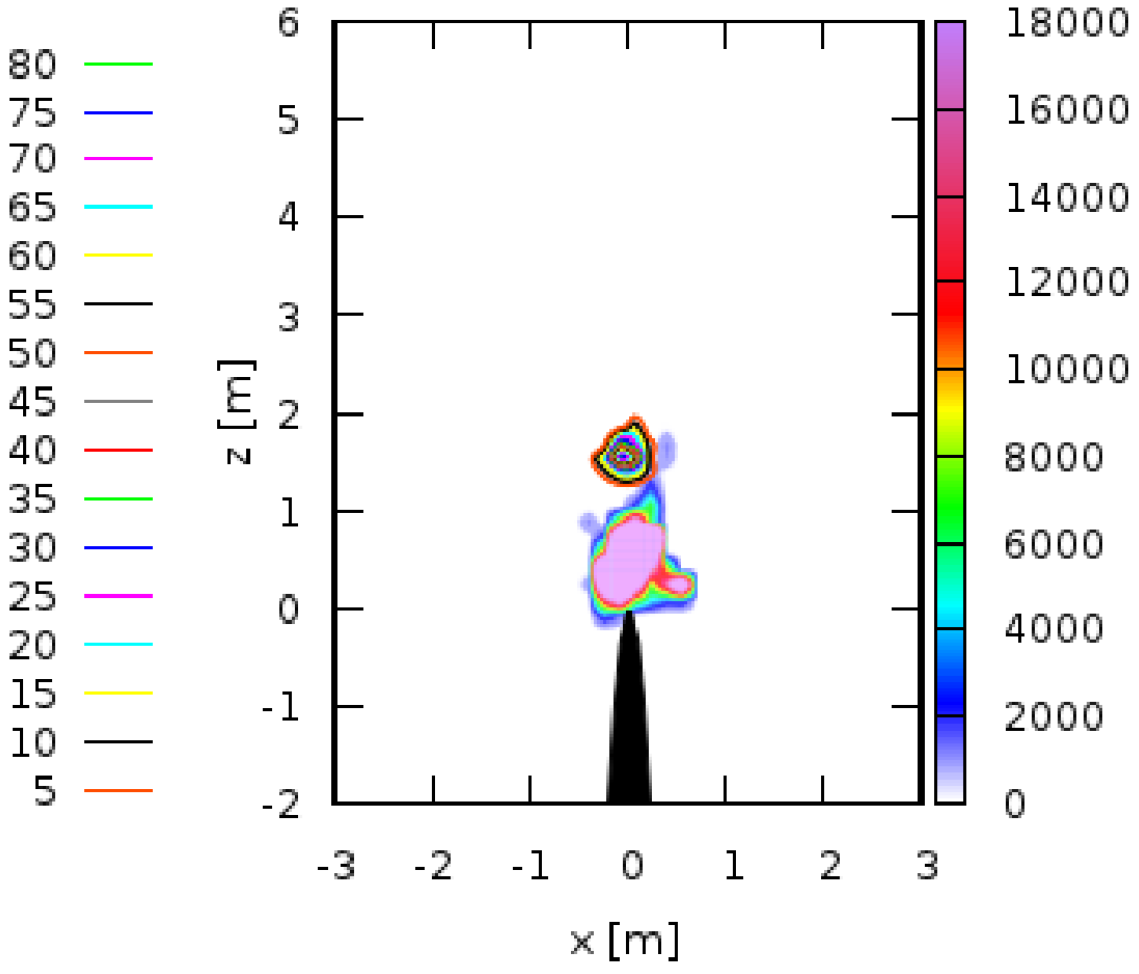


Electron density < 1 MeV [1/m³]

[C. Koehn et al., 2014. The importance of electron-electron Bremsstrahlung for terrestrial gamma-ray flashes, electron beams and electron-positron beams. Revised for J. Phys. D.: Appl. Phys.]

Temporal evolution of electrons

Electron density > 1 MeV [1/m³]

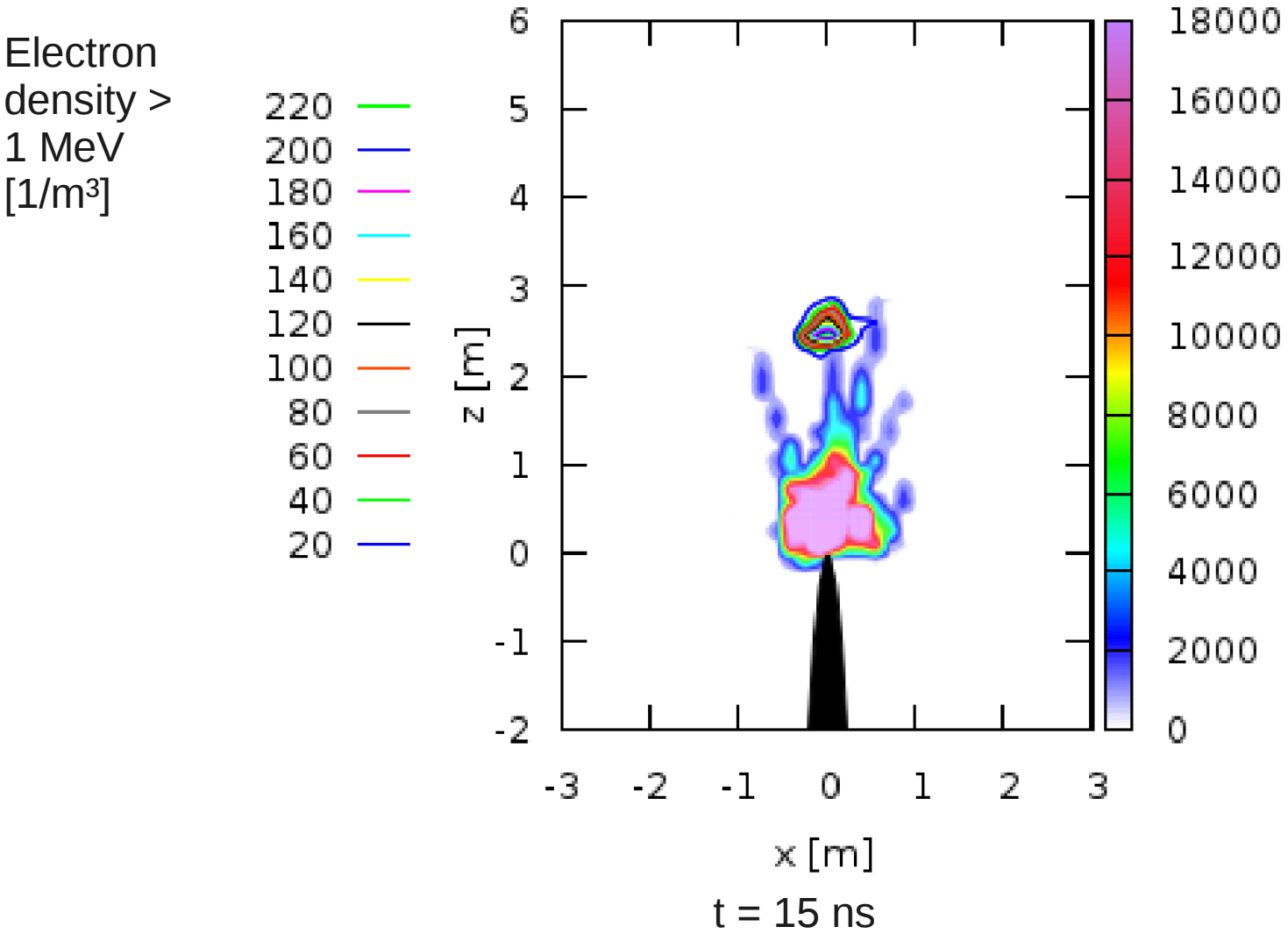


t = 10 ns

Electron density < 1 MeV [1/m³]

[C. Koehn et al., 2014. The importance of electron-electron Bremsstrahlung for terrestrial gamma-ray flashes, electron beams and electron-positron beams. Revised for J. Phys. D.: Appl. Phys.]

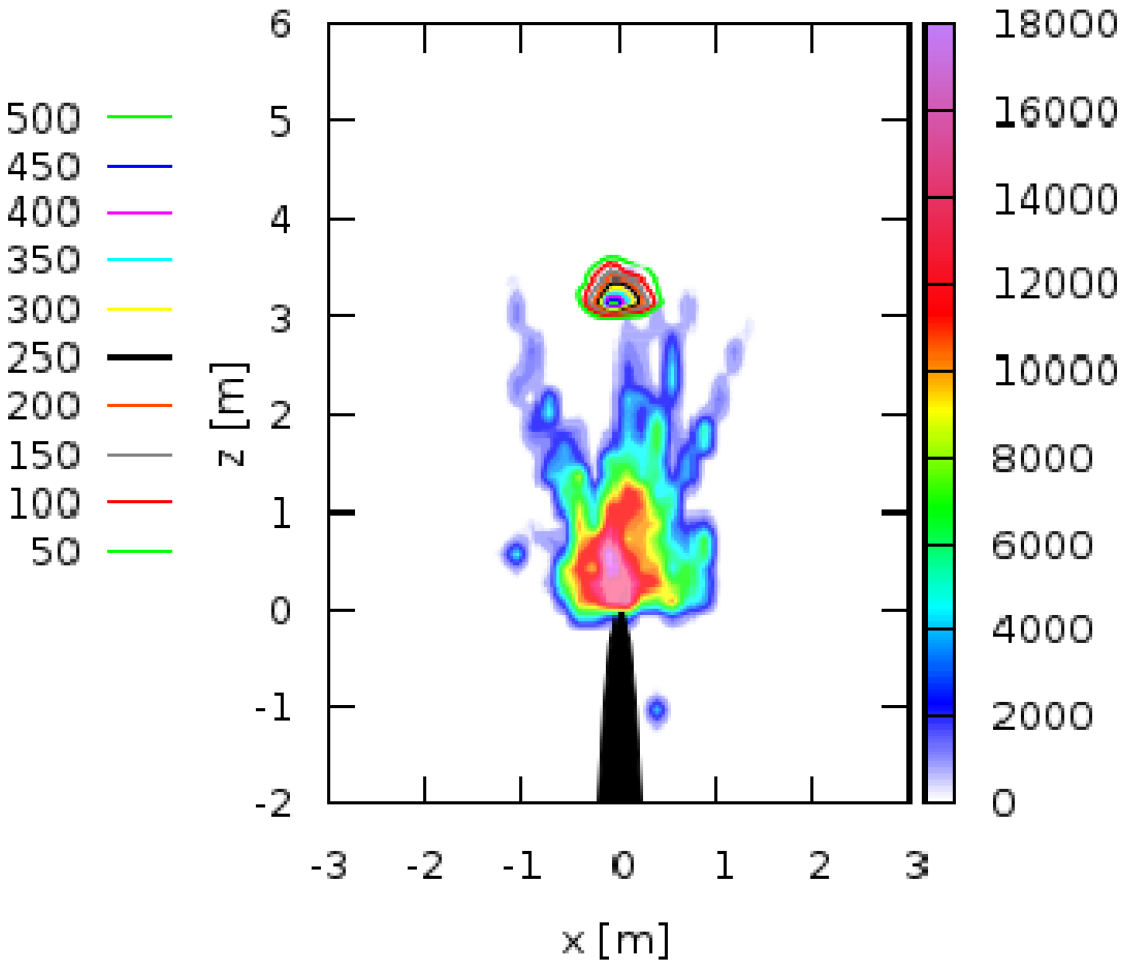
Temporal evolution of electrons



[C. Koehn et al., 2014. The importance of electron-electron Bremsstrahlung for terrestrial gamma-ray flashes, electron beams and electron-positron beams. Revised for J. Phys. D.: Appl. Phys.]

Temporal evolution of electrons

Electron density > 1 MeV [1/m³]



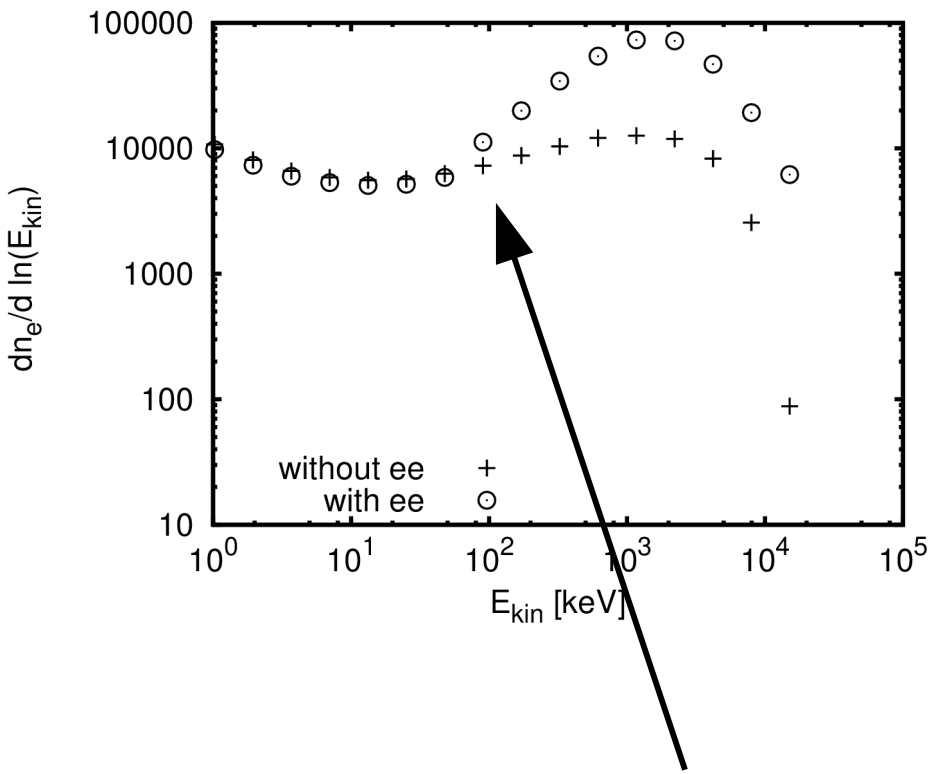
t = 20 ns

Electron density < 1 MeV [1/m³]

[C. Koehn et al., 2014. The importance of electron-electron Bremsstrahlung for terrestrial gamma-ray flashes, electron beams and electron-positron beams. Revised for J. Phys. D.: Appl. Phys.]

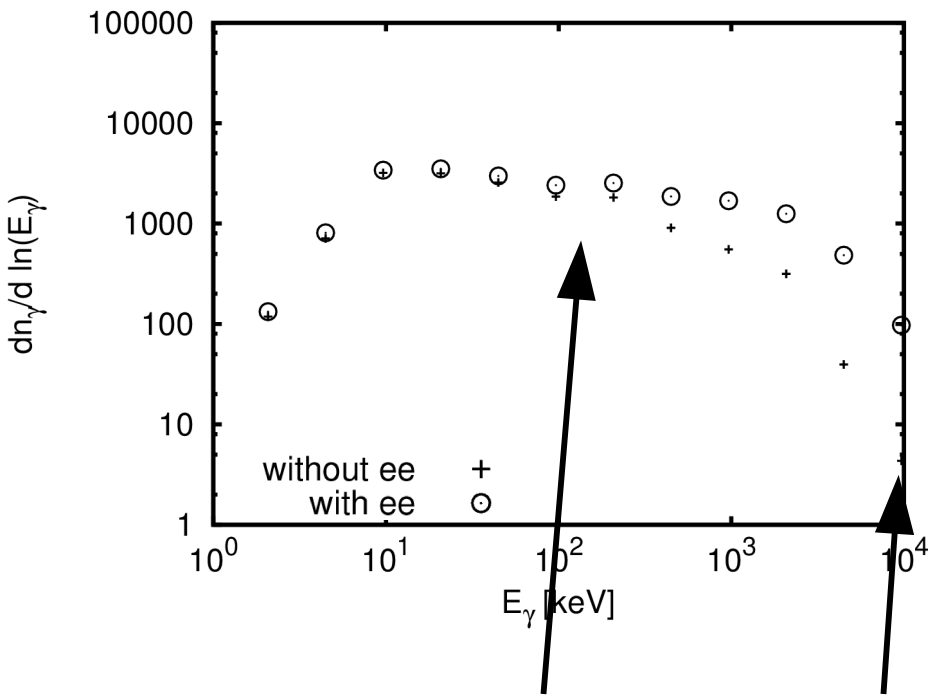
Electron and photon distributions

Electron distribution (t = 24 ns)



Enrichment of electrons above 100 keV

Photon distribution (t = 24 ns)

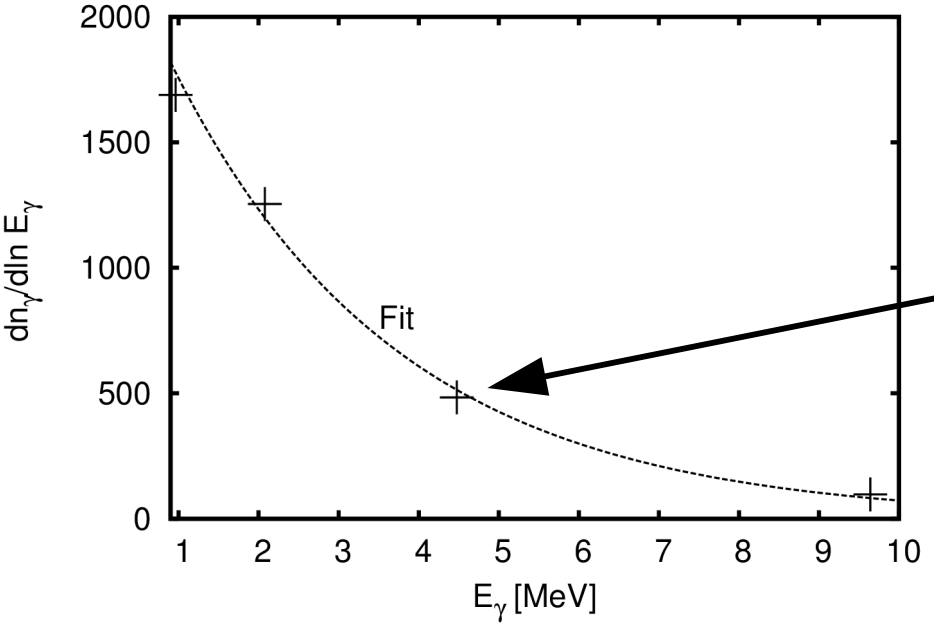


More photons above 100 keV

Dominates spectrum at 10 MeV

[C. Koehn et al., 2014. The importance of electron-electron Bremsstrahlung for terrestrial gamma-ray flashes, electron beams and electron-positron beams. Revised for J. Phys. D.: Appl. Phys.]

From photons to positrons



Fit spectra to an exponential

$$n_\gamma\left(E_\gamma[\mathrm{eV}]\right) \sim e^{-\frac{E_\gamma}{3\,\mathrm{MeV}}}$$

Extrapolate to 40 MeV

Motion of photons

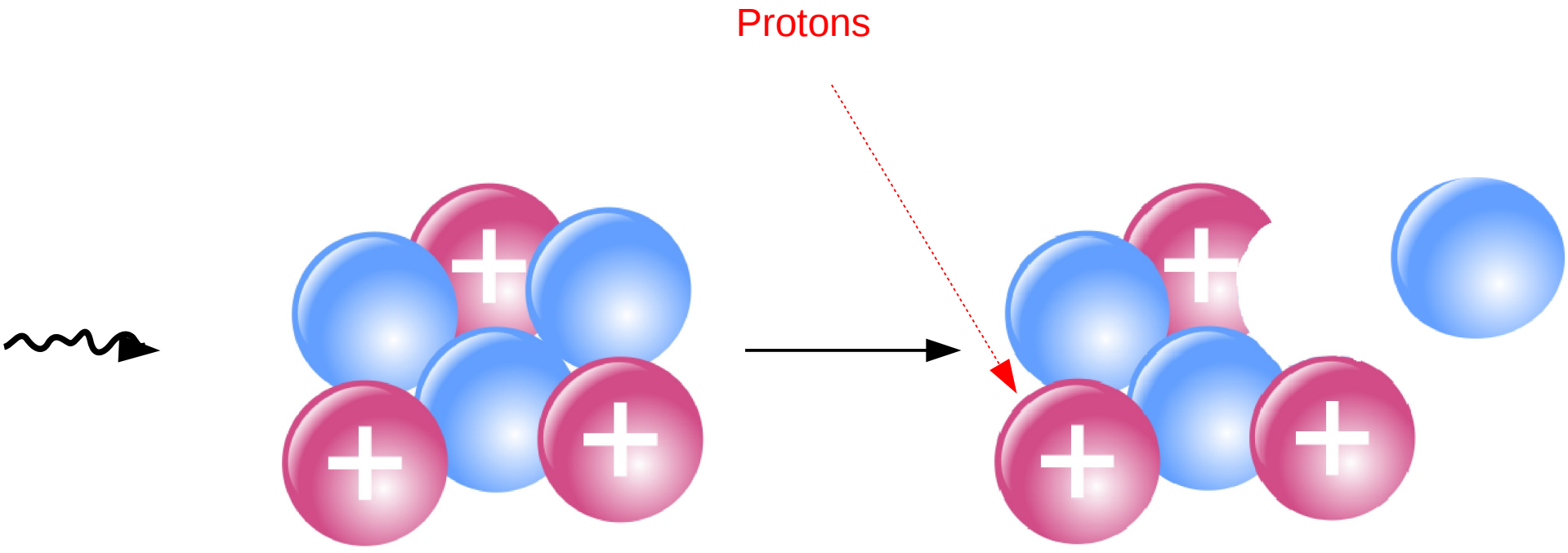
3D Monte Carlo code

Free motion between collisions

Differential cross sections to model collisions:

- Photo ionization (Photons disappear)
- Compton scattering
- Pair production (Photons disappear)
- Neutron production (Photons disappear)
- Proton production (Photons disappear)
- Rayleigh scattering

Photoproduction of hadrons

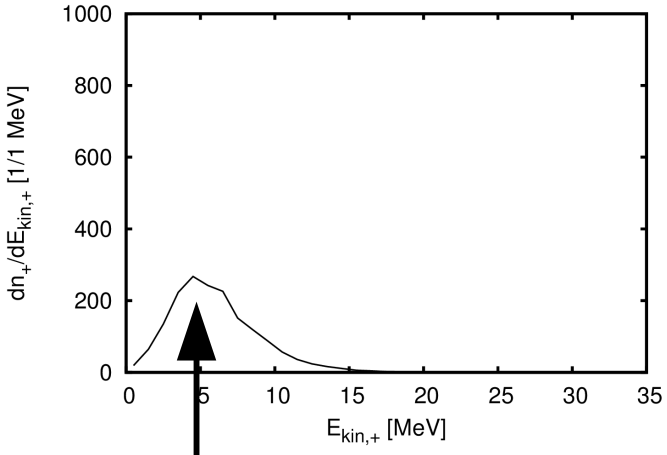


Binding energy of a nucleus approx. 8 MeV

[E.G. Fuller, 1985. Photonuclear reaction cross sections for C, N and O. Physics reports, vol. 127, pp. 185-231]

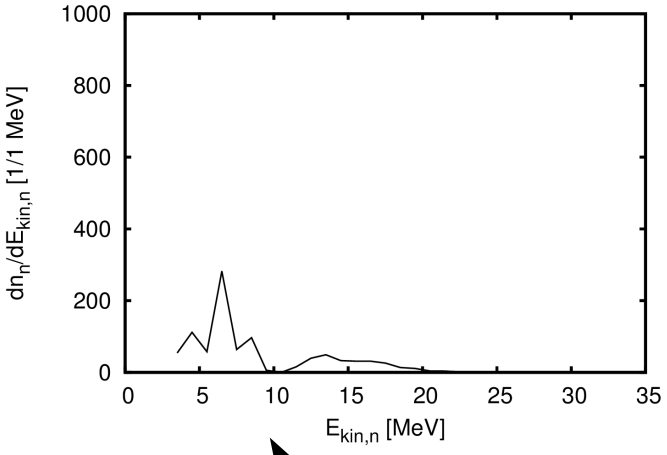
Energy distributions t=1 µs

Positrons:

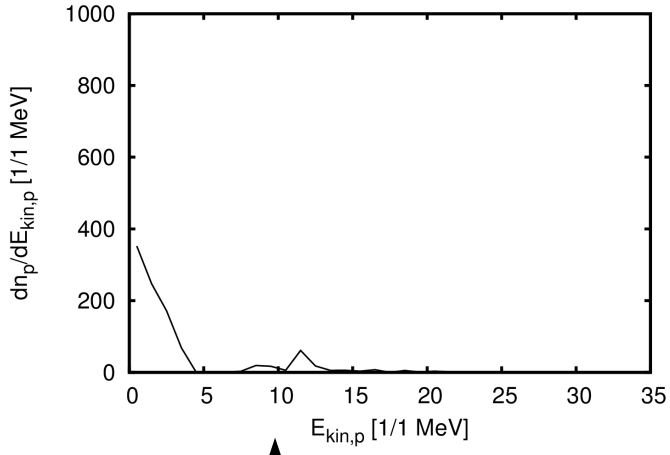


Maximum at 5 MeV

Neutrons:



Protons:

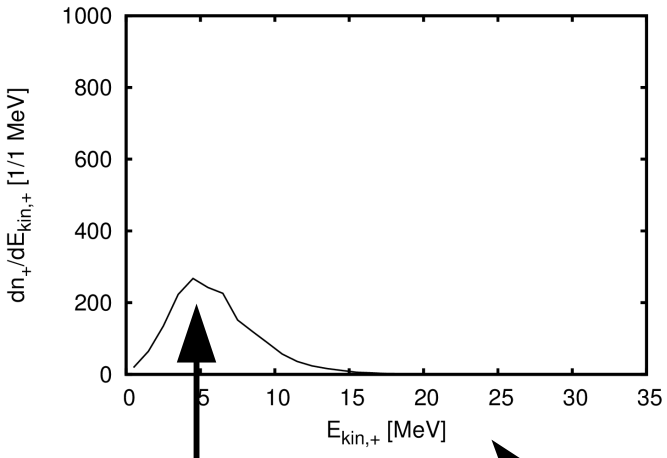


Discrete energies because of cross sections

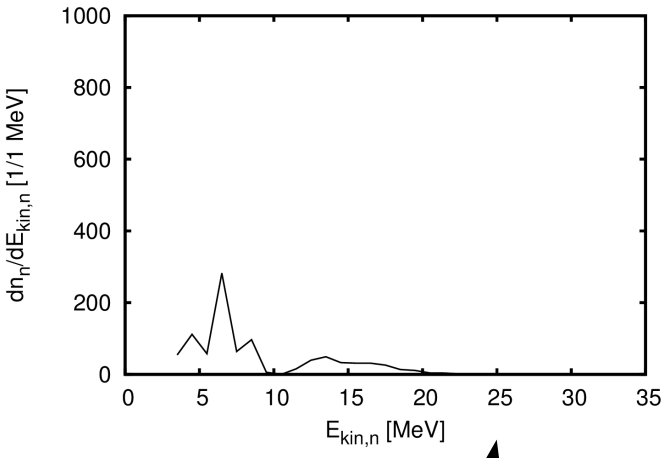
[C. Koehn and U. Ebert. Calculation of positron and hadron beams form a negative lightning leader stepping upwards. In prep.]

Energy distributions t=1 µs

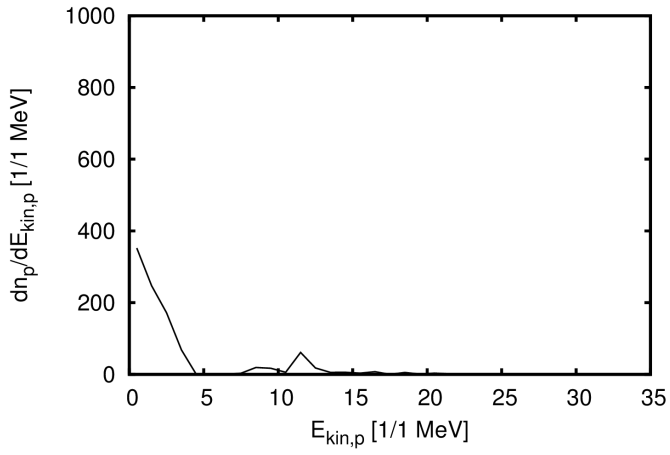
Positrons:



Neutrons:



Protons:



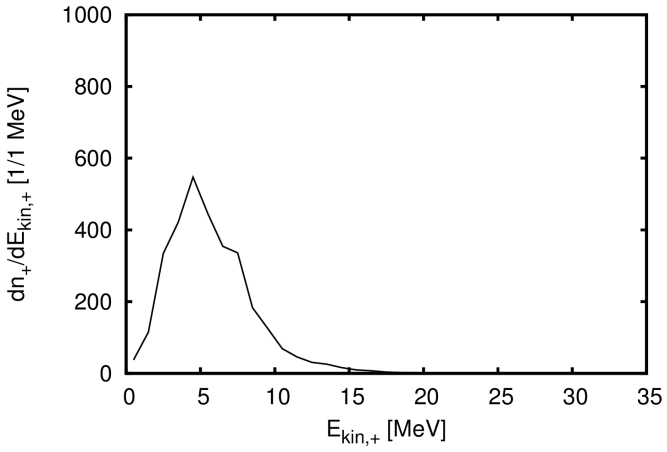
Maximum at 5 MeV

Energies up to tens of MeV

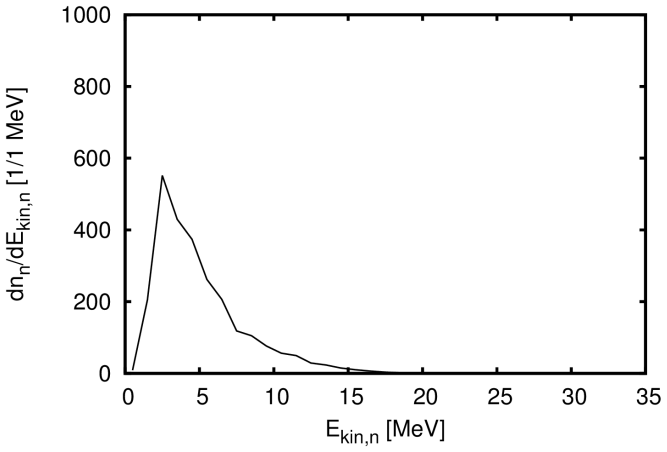
[C. Koehn and U. Ebert. Calculation of positron and hadron beams form a negative lightning leader stepping upwards. In prep.]

Energy distributions t=0.5 ms

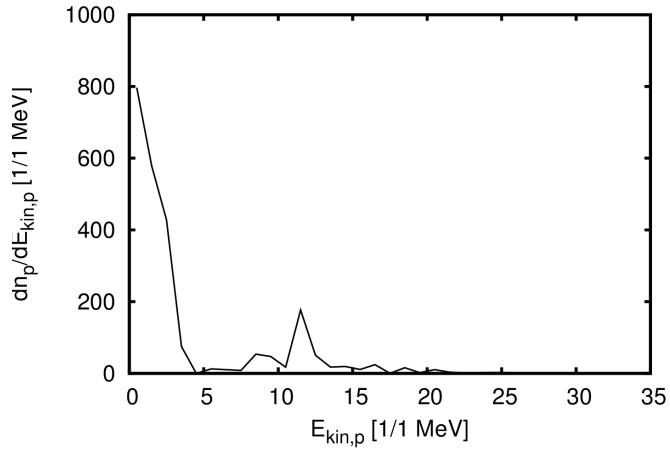
Positrons:



Neutrons:



Protons:



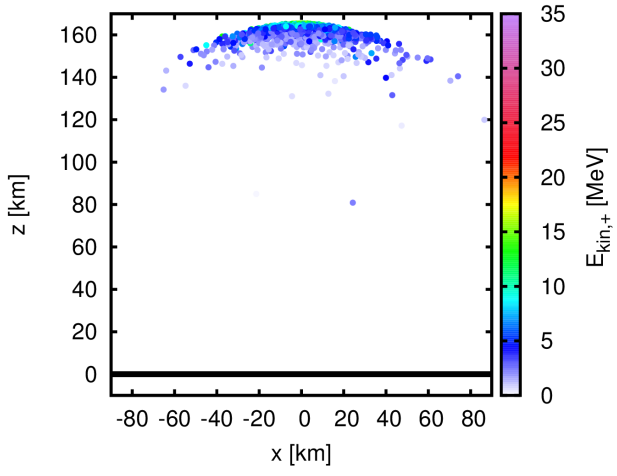
Neutron distribution smooths out

No significant change for positrons and protons

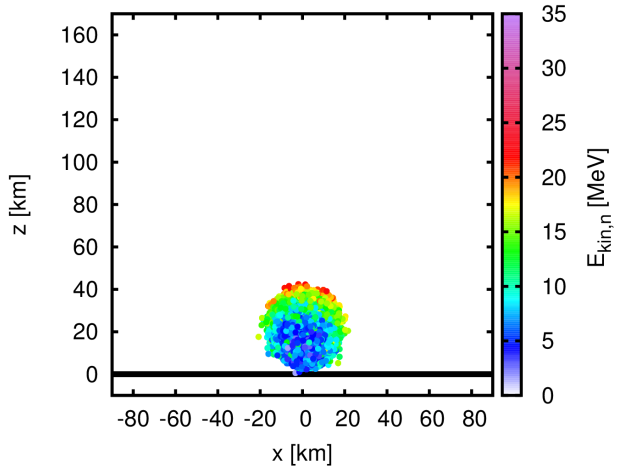
[C. Koehn and U. Ebert. Calculation of positron and hadron beams form a negative lightning leader stepping upwards. In prep.]

Spatial distribution t=0.5 ms

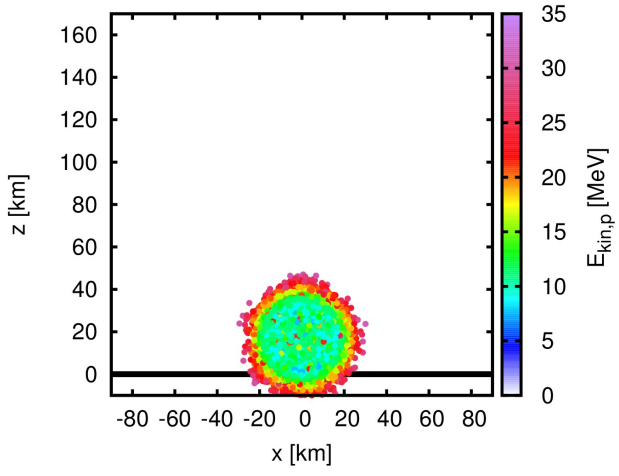
Positrons:



Neutrons:



Protons:

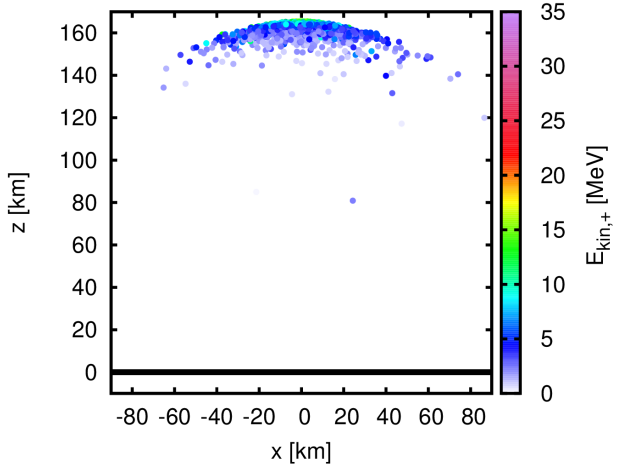


[C. Koehn and U. Ebert. Calculation of positron and hadron beams form a negative lightning leader stepping upwards. In prep.]

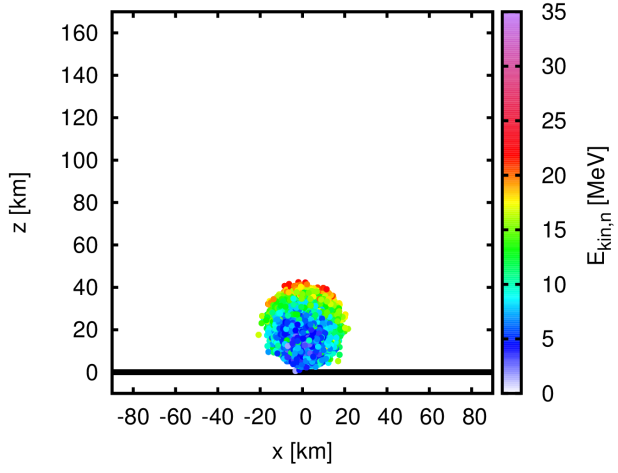
Conclusion

- Significant contribution from ee Bremsstrahlung
- Positrons and hadrons:

Positrons:



Neutrons:



Protons: