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Modeling the 511 keV background enhancement events observed in thunderstorms

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EGU 2018, April 10th

EGU2018-7279

UNIS The University Centre in Svalbard

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positrons

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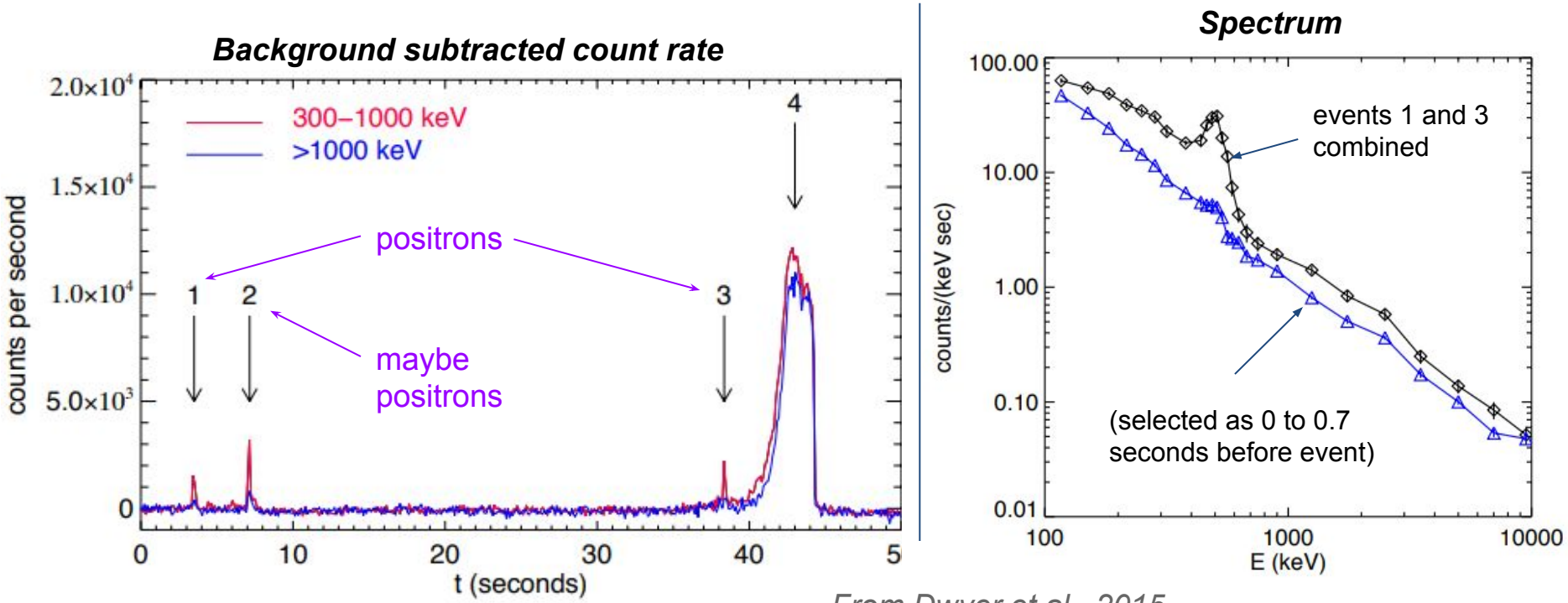
1. Observations of positron events from aircrafts flying inside thunderstorms
   - ADELE
   - ILDAS
2. Investigating the hypothesis that these events are due to cosmic rays secondary particles interacting with thunderstorms electric fields

ADELE positron event

- Reported in *Dwyer et al., 2015 "Positron clouds within thunderstorms", J. Plasma Phys.*
- Gulfstream V aircraft flew over southeast coast of Georgia (USA)
- Entered the upper part of an active thunderstorm cell at **~12 km altitude**



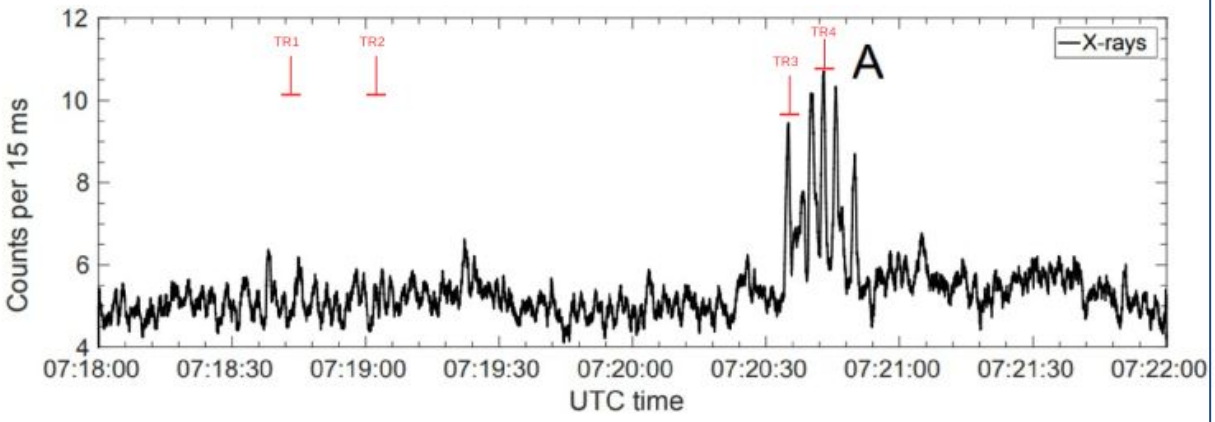
From Dwyer et al., 2015

- **~10 time increase of the 511 keV line compared to the *background***
- few hypothesis discussed, but ***no clear explanation found***

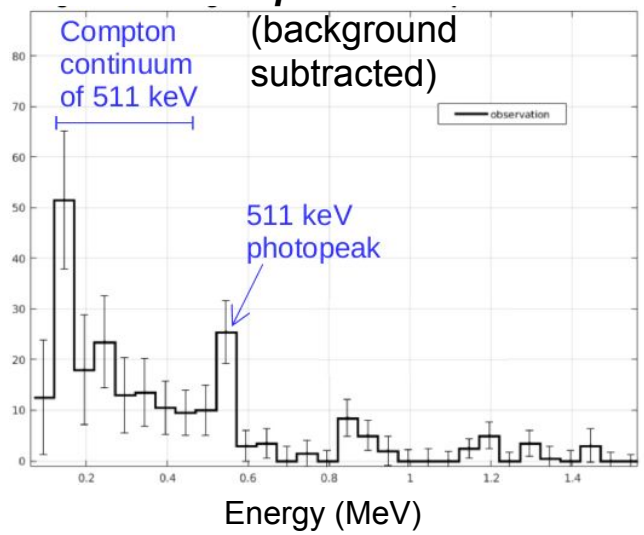
ILDAS positron event

- Reported in *Kochkin et al., 2017 AGU Fall Meeting presentation, and Kochkin et al., 2018 "In-flight observation of positron annihilation by ILDAS", JGR Atmos.* Under review.
- A-340 aircraft, intentionally flew through a thunderstorm, over Northern Australia
- ~12 km altitude

counts VS time



Spectrum (background subtracted)



- **~3-4 time increase of 511 keV photon flux compared to the background.**

- Could these events be due to the **enhancement of cosmic ray secondary particles** by **thunderstorms' electric fields** ?

→ **We can try to answer to this question using simulations**

- *Several previous works modeled the interactions of cosmic rays with thunderstorms, including McCarthy and Parks (1992,JGR) Chilingarian et al. (2013, EPL), Cramer et al. (2017, JGR),* among others.

Positron and electron flux modifications

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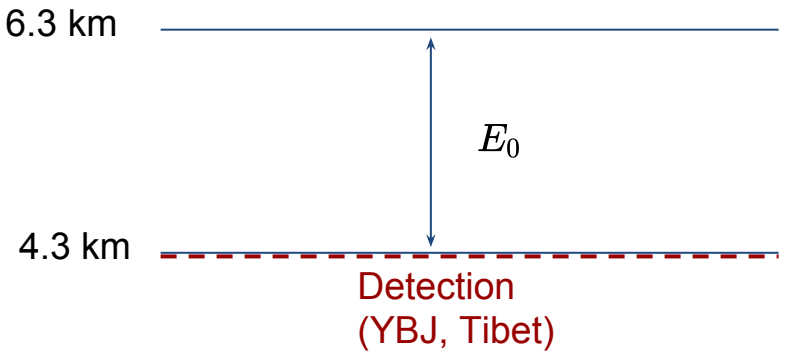
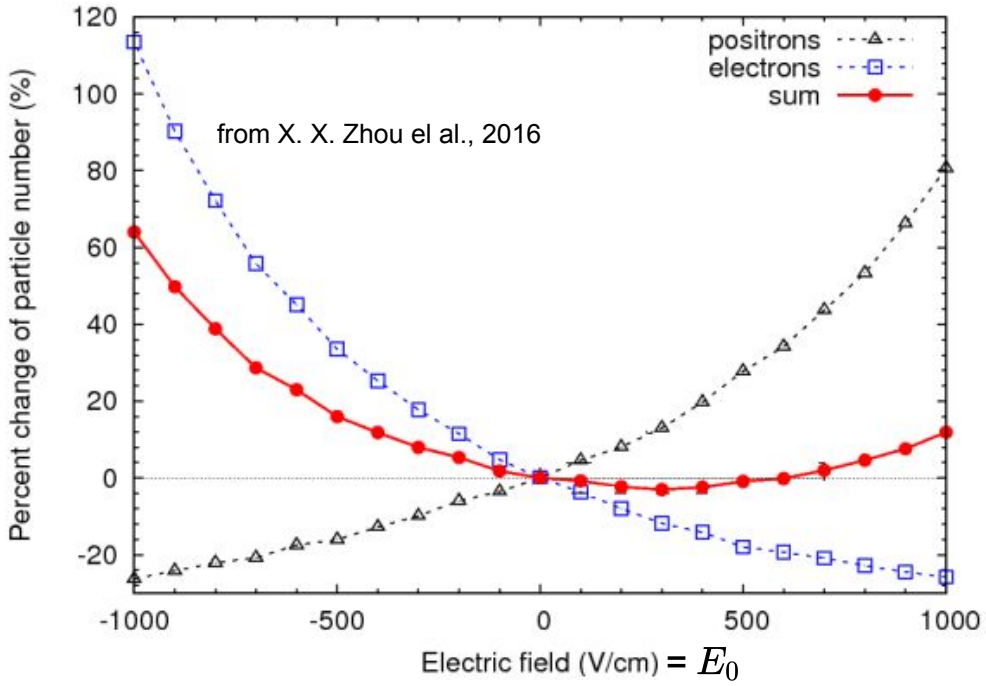
- Presented in *X. X. Zhou et al., "Effect of near-earth thunderstorms electric field on the intensity of ground cosmic ray positrons/electrons in Tibet" , 2016, Astroparticle Physics*
- Uses **CORSIKA** Monte-Carlo code
- Cosmic ray showers are *fully simulated* (i.e. starting from high energy protons)
- Energy threshold of 100 keV



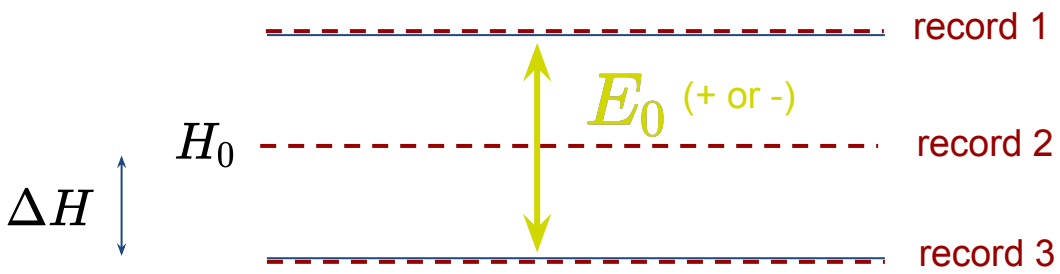
$$E_{RREA} = 1.6\ \mathrm{kV/cm}\ @\ \mathrm{H} = 5.3\mathrm{km}$$



- Mechanism : **increase** (or reduction) ***path length*** **of charged particles due to thunderstorm electric field, therefore more** (or less) **can reach the detector**
- Very interesting effect. It raises questions :
  - **How does it change with altitude ?** (12 km)
  - **For higher E-fields, how high can it reach ?** (if E-field close to RREA threshold)

Our modeling attempt

• Calculating **variation of cosmic ray electron, positron and photon fluxes due to thunderstorms E-fields.**



• Compared to *Zhou et al.* :
- very different modeling strategy,
- we push the model to higher altitudes and larger E-fields

- ***Geant4* based** (CERN's reference Monte-Carlo code for high energy particles tracking)
- Air density profile from the well known ***MSIS-E-90 model***
- Cosmic rays secondaries randomly sampled from the ***PARMA code :***
  - From *T. Sato et al., "Development of PARMA: PHITS based Analytical Radiation Model in the Atmosphere" (2008, Rad. Res.)*
  - Based on simulation from the PHITS (Heavy Ion Transport code System) model
  - Fits very well observational data
  - **We converted PARMA data to probability density functions in order to sample random cosmic rays** (random variables : **type**, **altitude, direction** and **energy**)

Results : Comparison with Zhou et al.

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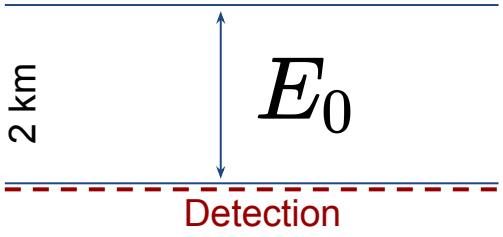
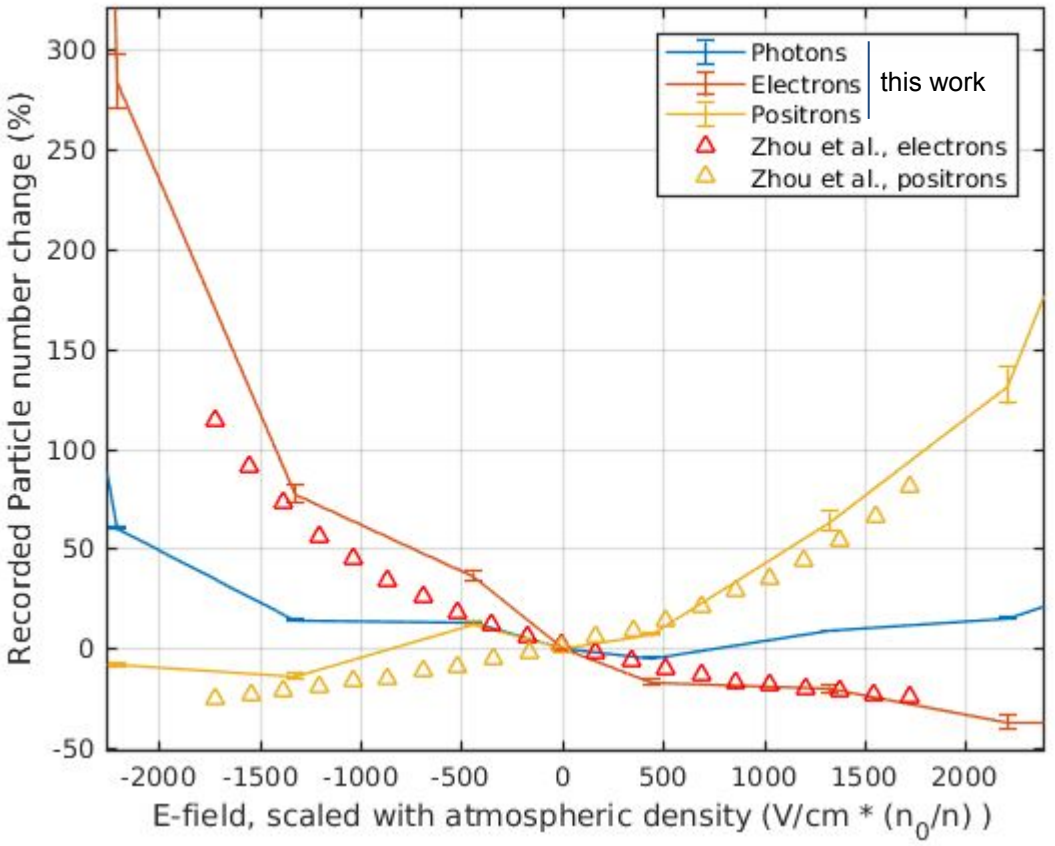
RREA threshold
~ 2800 V/cm
at sea level





- **Approximately scales with density**
- **The two models are fairly consistent** (~10 % difference for positrons on positive side)

Results : Hypothetical ILDAS / ADELE configuration

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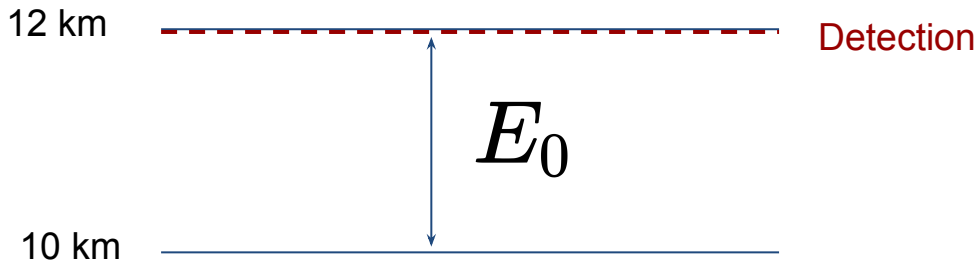

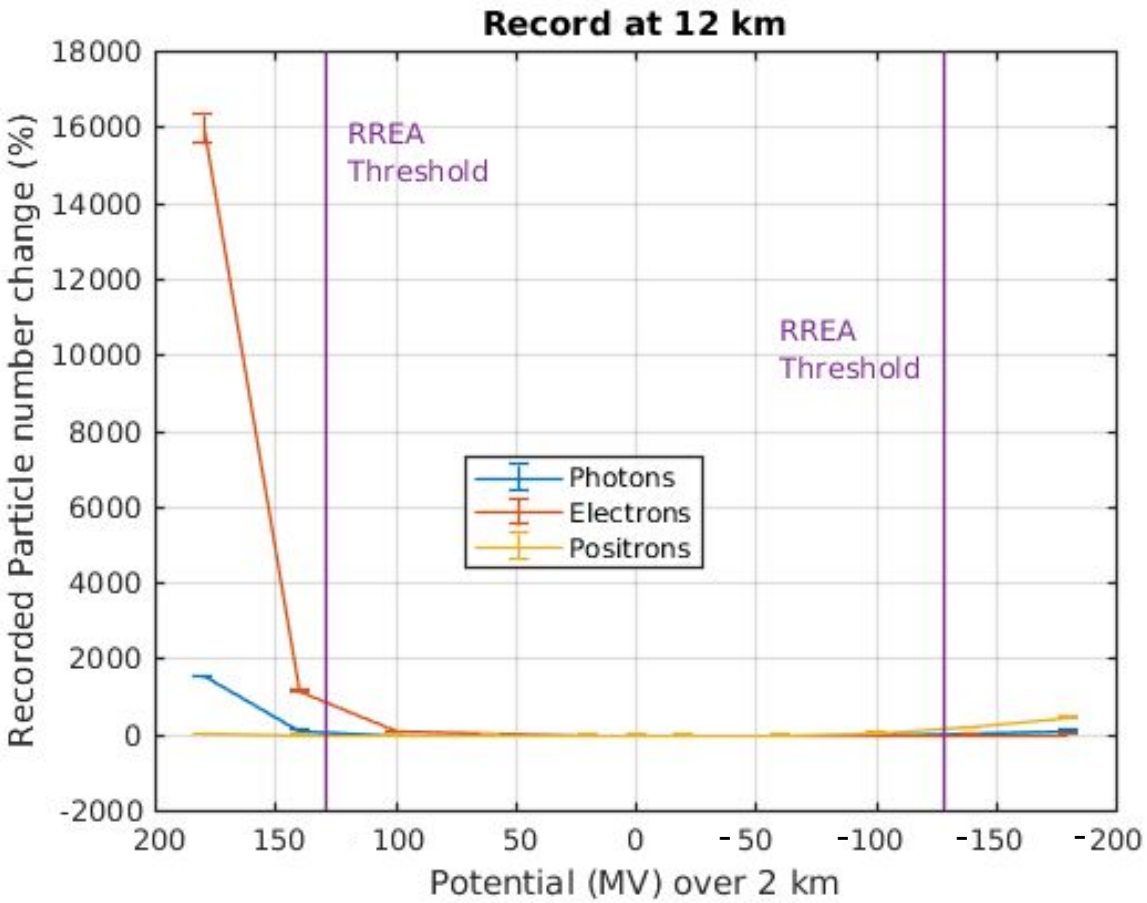

RREA threshold
~ 130 MV / 2 km

Results : Hypothetical ILDAS / ADELE configuration

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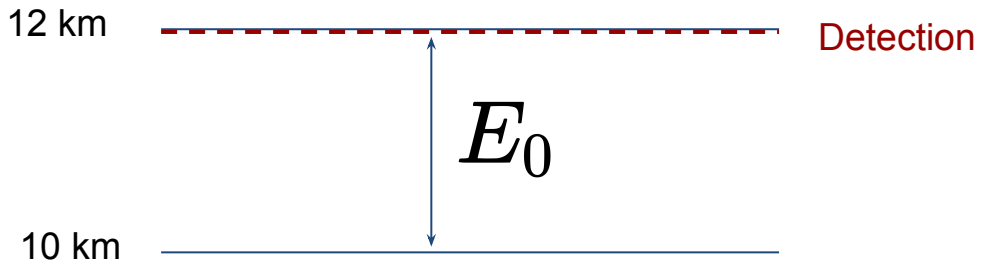

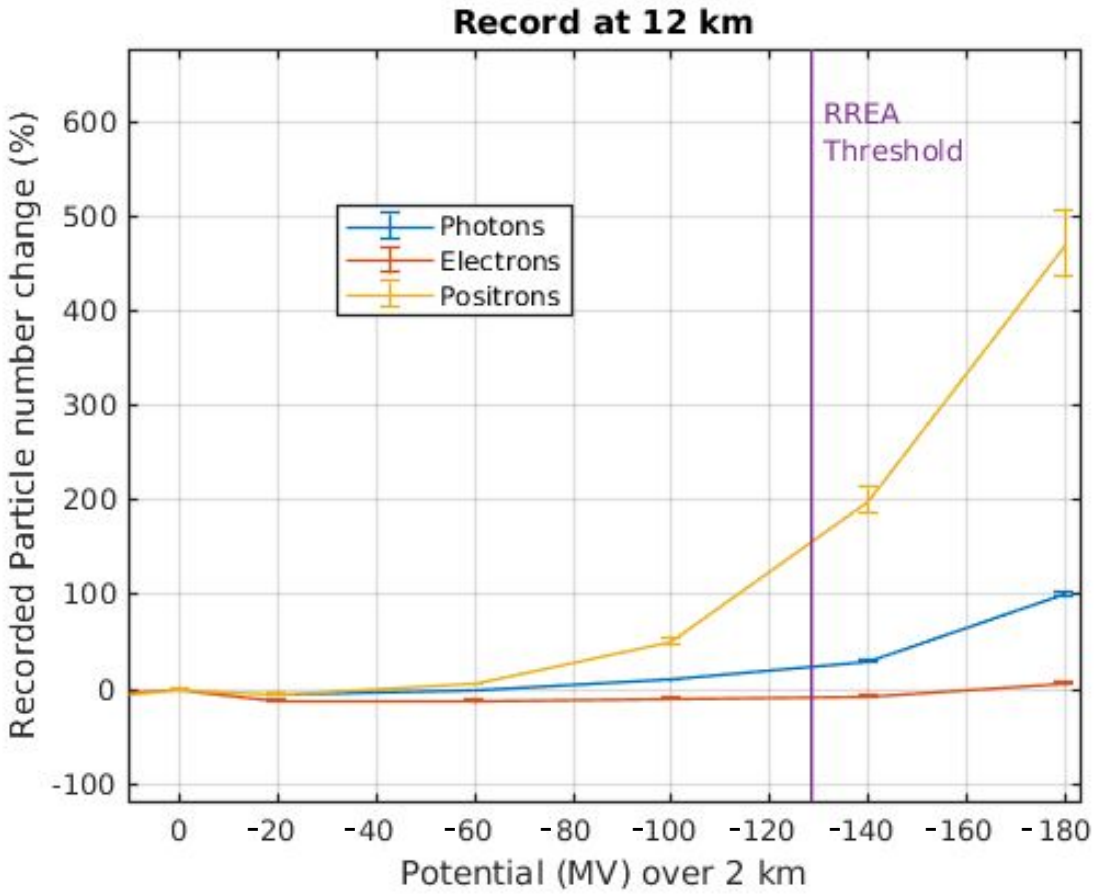

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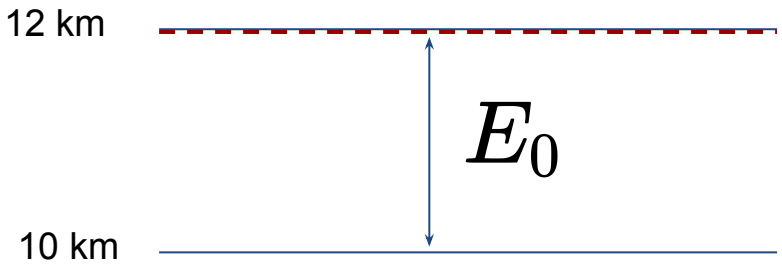

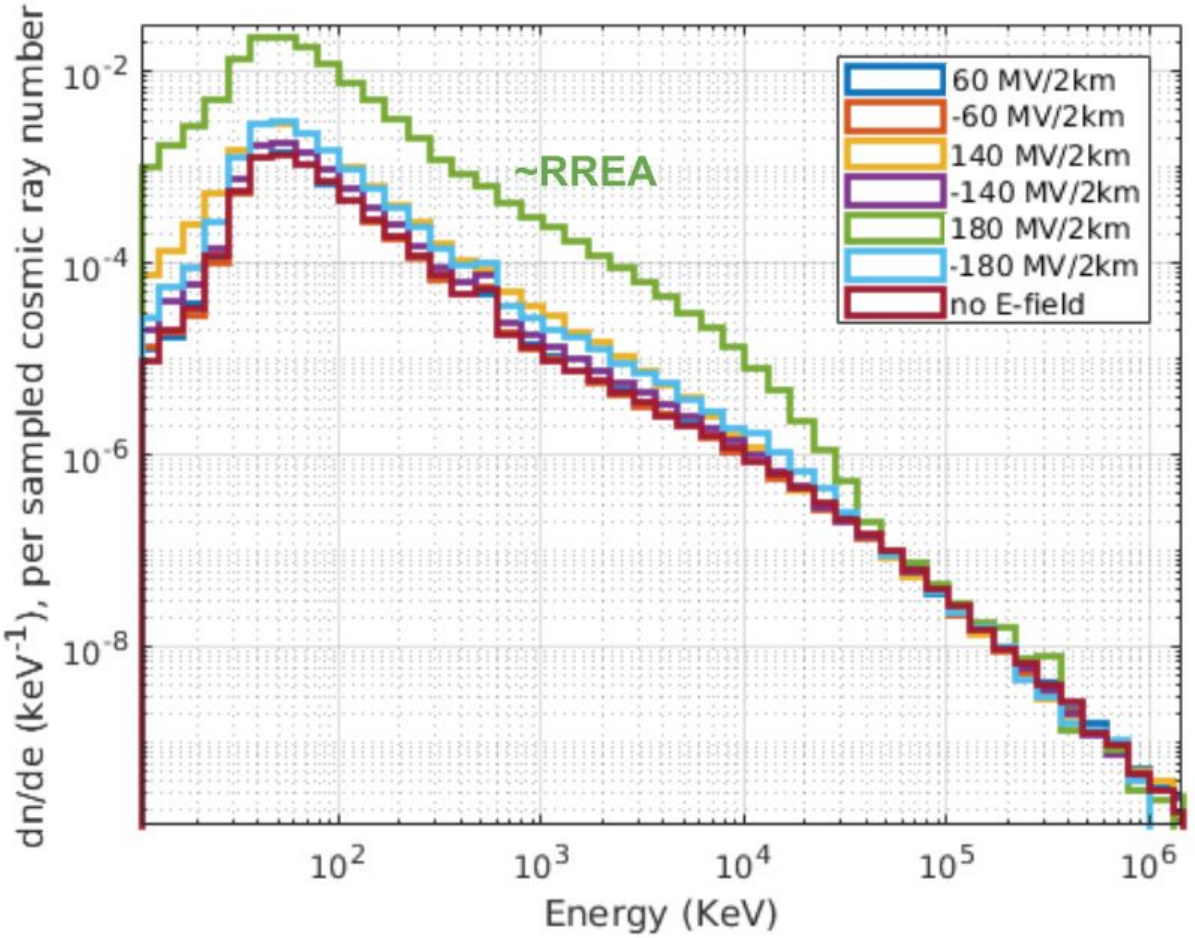

511 keV line seems not increasing as in the ADELE or ILDAS observations

We have to take into account the effect of the aircraft (positrons should be stopped and annihilate on it) **and the response of the detectors.**

Conclusions / Discussion

• Promising preliminary results, but **work in progress**

• Using a different modeling strategy, we tested the mechanisms presented in *Zhou et al, 2016*, who showed that cosmic ray secondary charged particles fluxes can be strongly affected by thunderstorms electric fields.

• Confirmation that **positron fluxes** (cosmic ray secondaries) at a given altitude **can be significantly affected by surrounding thunderstorms' electric fields**

• **The positron flux increase we obtained is consistent with *Zhou et al, 2016.***
• **Its magnitude approximately scales with density**

• In a geometrical configuration close to *ILDAS* and *ADELE* (12 km altitude), it seems possible to obtain a **variation of positron flux** of **+160%** for E-field slightly below RREA threshold, and **+500%** for E-field 40% above RREA threshold.

→ **Observed positron enhancement events may be due to the modulation of cosmic ray secondaries by thunderstorm's complex electric fields** (work in progress, e.g. we must include the response of the aircraft)

• May explain the "positron pulses" detected by ILDAS (3 to 4 times increase of 511 keV background)
• ADELE event is more challenging (10 times increase)

THANK YOU FOR YOUR ATTENTION