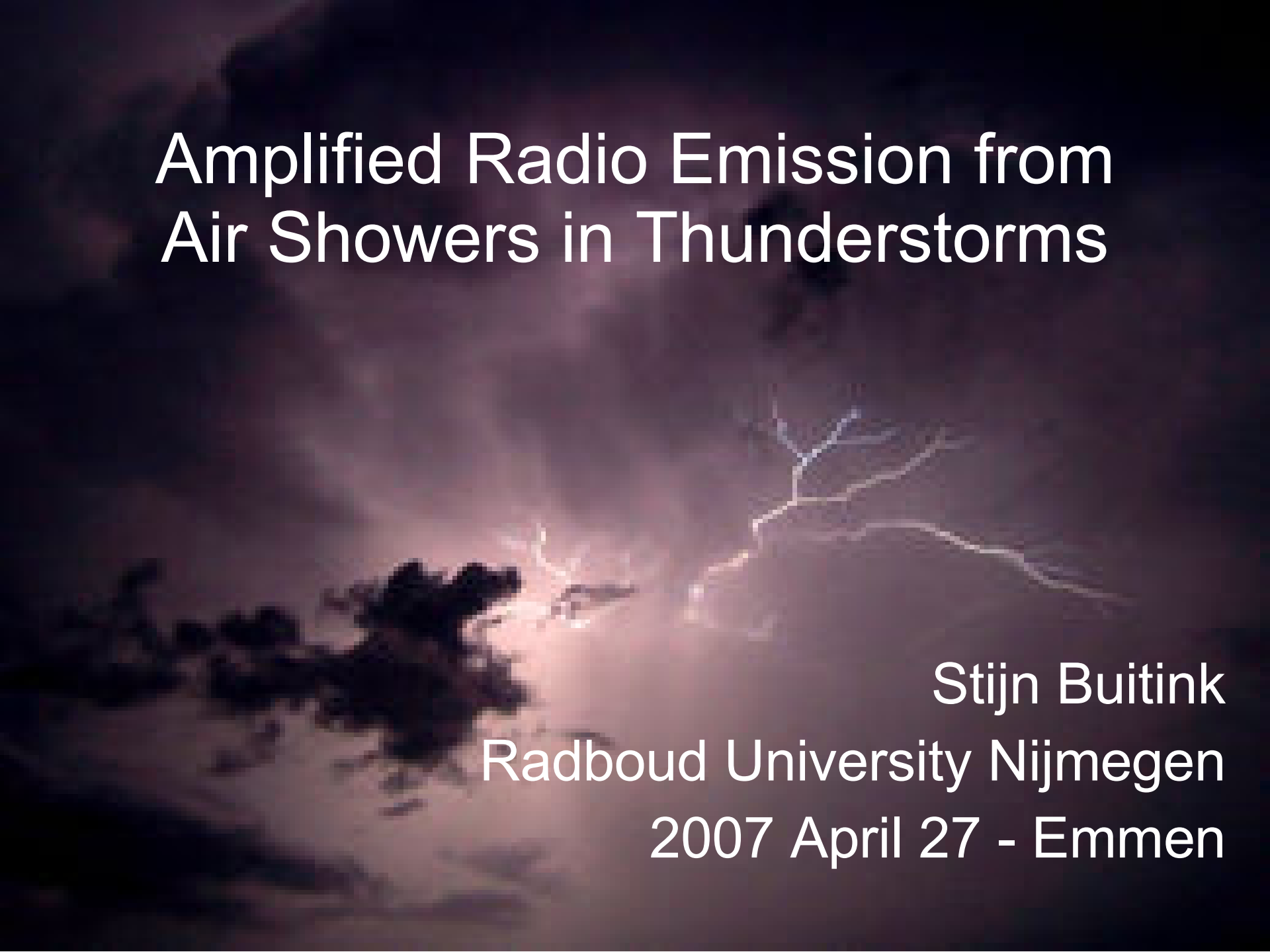


# Amplified Radio Emission from Air Showers in Thunderstorms

Stijn Buitink
Radboud University Nijmegen
2007 April 27 - Emmen

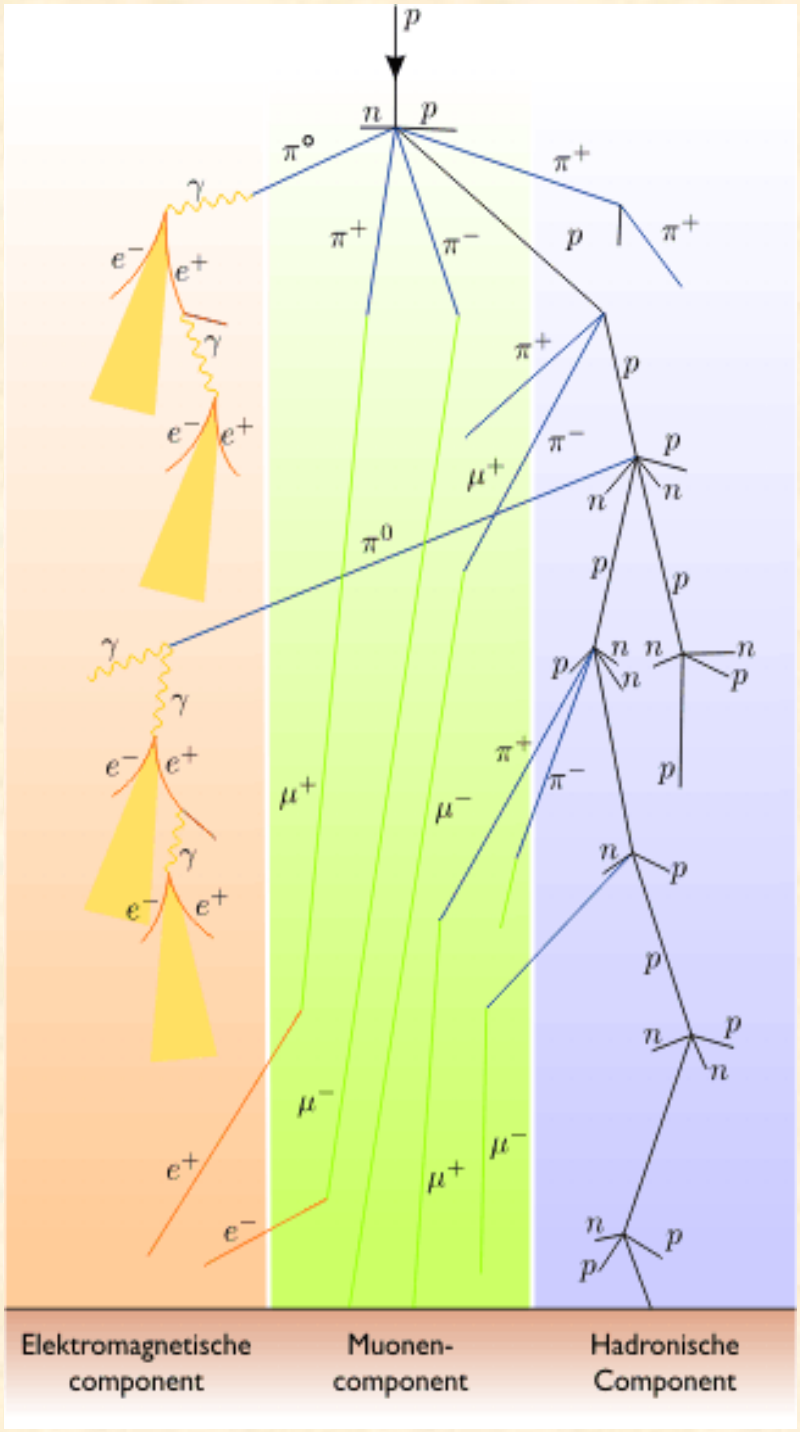
# Outline

- Part I: Emission mechanism
- Part II: LOPES thunderstorm results
- Part III: Other thunderstorm research

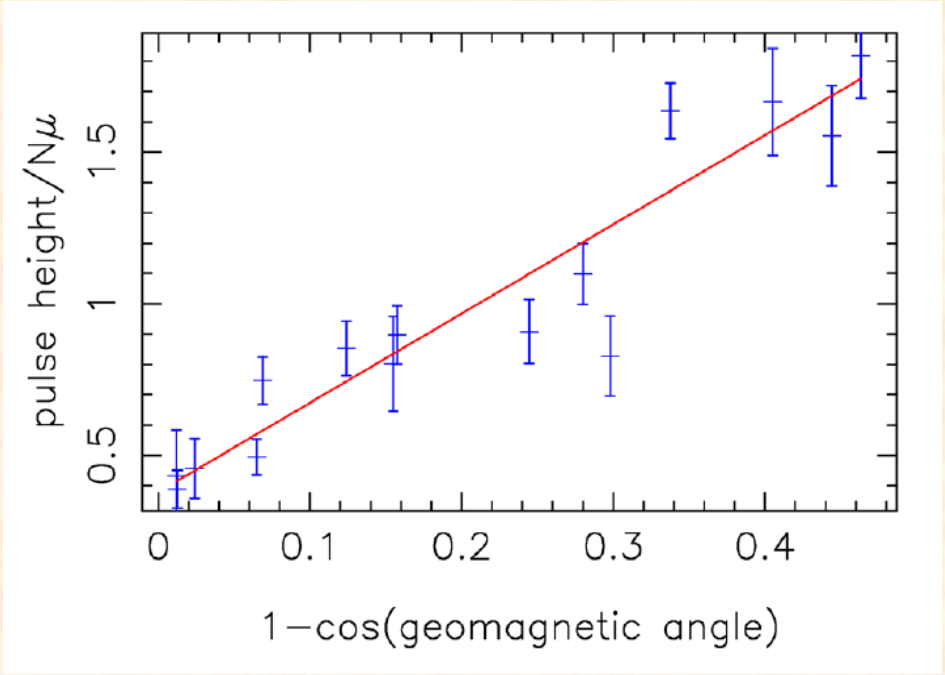
# Part I: Emission Mechanism

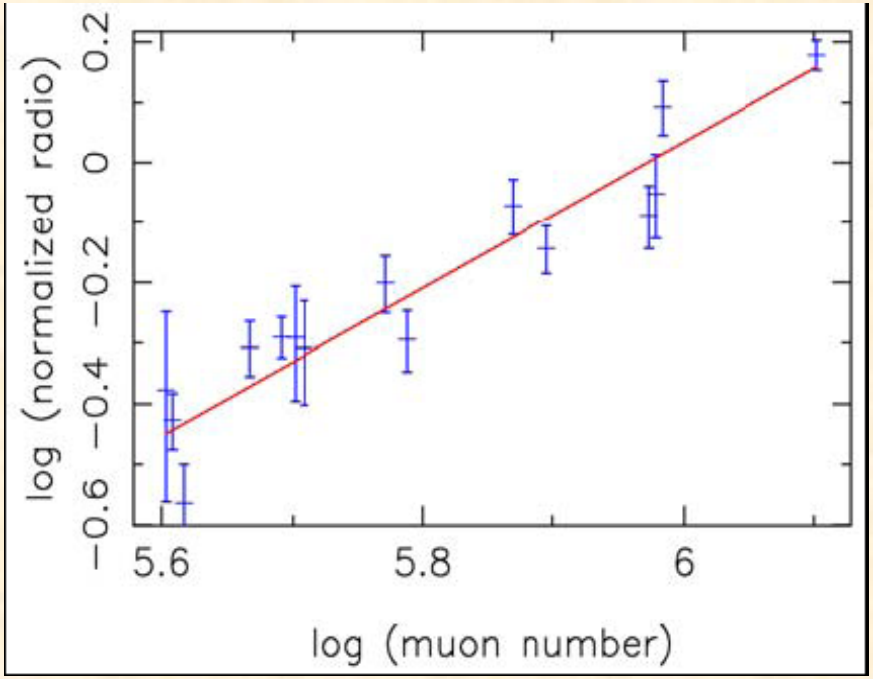
# Air Showers

- Created by high energy cosmic rays
- Electromagnetic component contains electron-positrons pairs
- Radio emission by synchrotron radiation



# Radio Emission from Air Showers

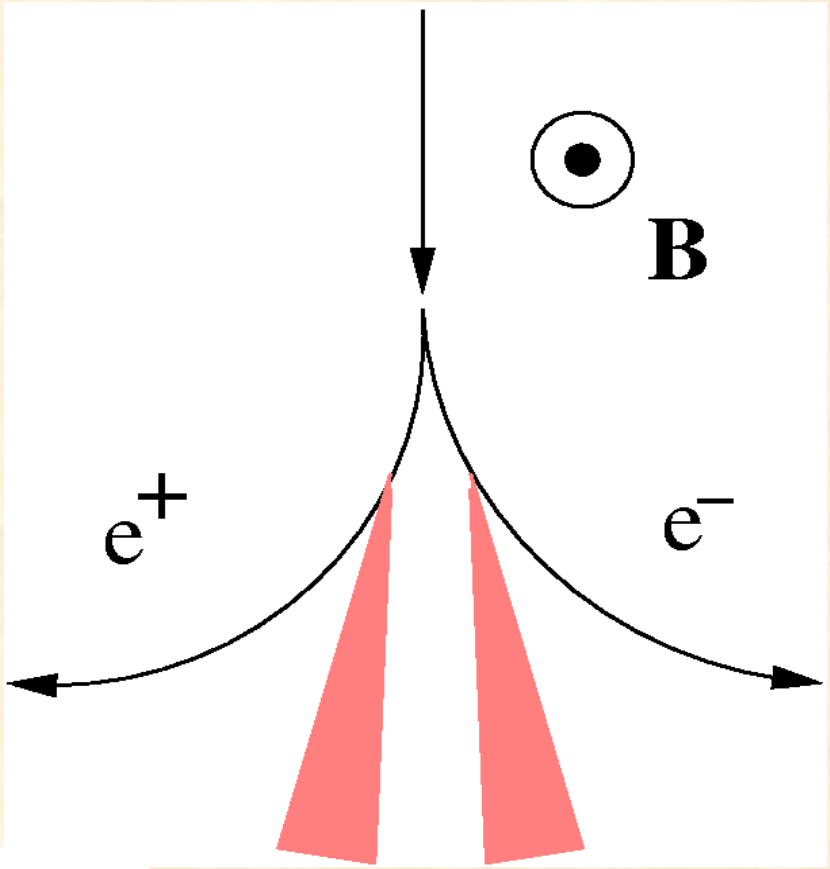



- Emission driven by Earth's magnetic field
- …how about atmospheric electric fields?

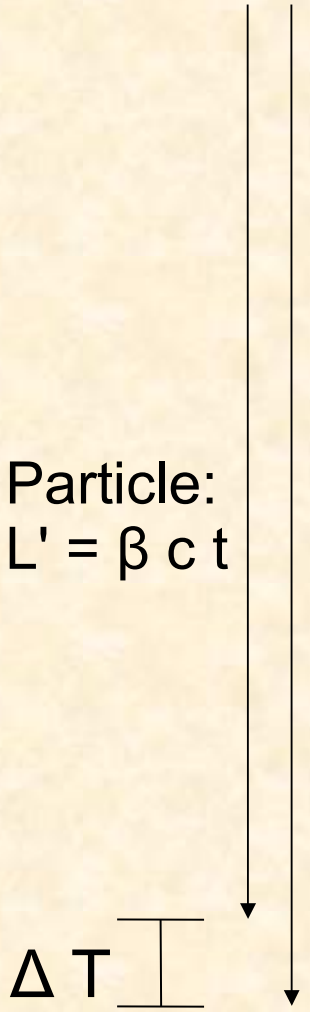
# Emission mechanism

- Geosynchrotron
- Same sign for $e^+/e^-$
- Pulse height:
  $E \sim \gamma^3 F_\perp$



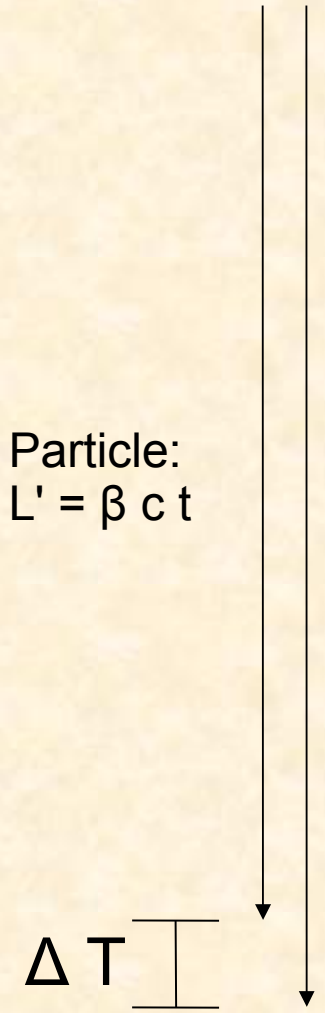

$$\boldsymbol{E}(\boldsymbol{x},t) = \frac{e}{c}\left[\frac{\boldsymbol{n}\times\left[(\boldsymbol{n}-\boldsymbol{\beta})\times\dot{\boldsymbol{\beta}}\right]}{(1-\boldsymbol{\beta}\cdot\boldsymbol{n})^3 R}\right]_{\text{ret}}$$

# Coherency

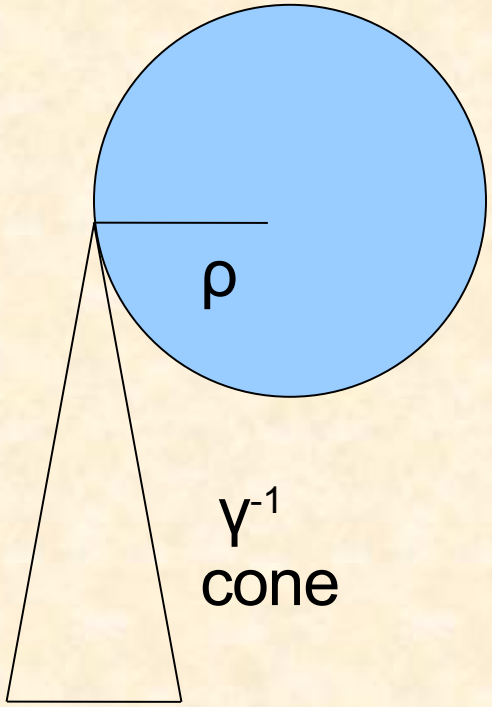



- Total shower length L (few kilometers)
- $\Delta x = (c/n)\, t - \beta\, c\, t$
  $\approx L / 2\gamma^2$
- $\Delta T = L / 2\gamma^2 c \sim 10^{-8}$ s

# Coherency

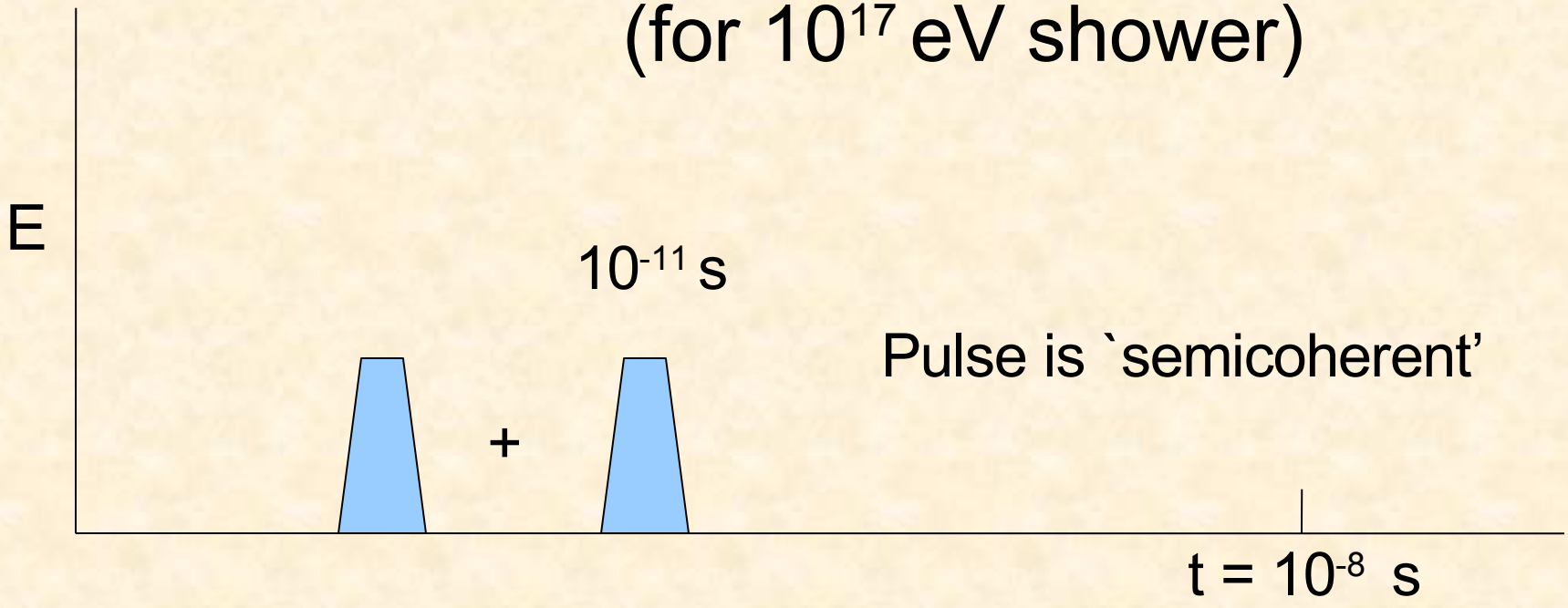



- $\Delta T = L / 2\gamma^2 c \sim 10^{-8}$ s
- Radation visible for observer $\Delta t = \pi\rho / c\gamma^3 \sim 10^{-11}$ s

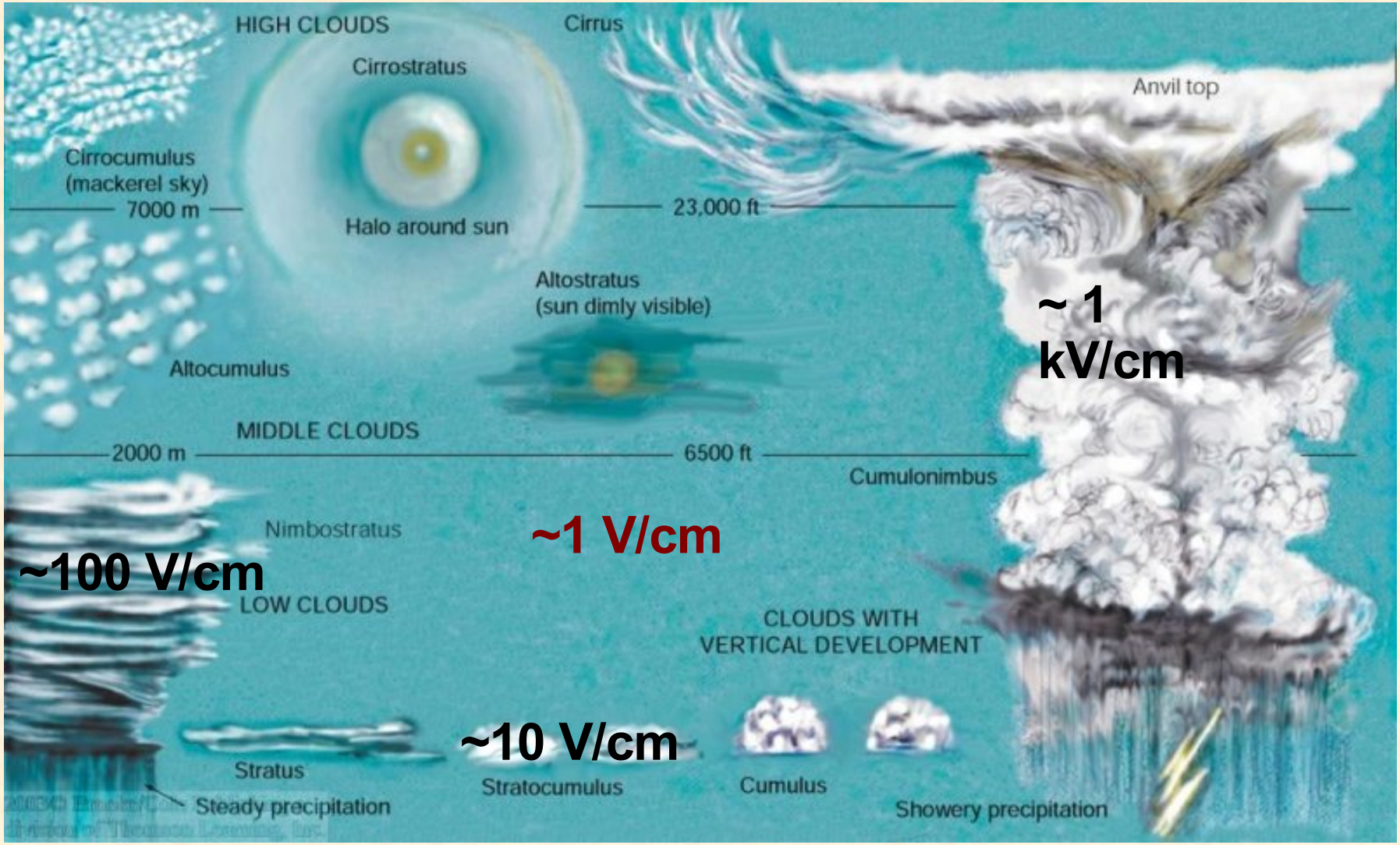


# Coherency

- $\Delta T = L / 2\gamma^2 c \sim 10^{-8}$ s
- $\Delta t = \pi\rho / c\gamma^3 \sim 10^{-11}$ s
- Number of pairs: $N \sim 10^8$ (for $10^{17}$ eV shower)

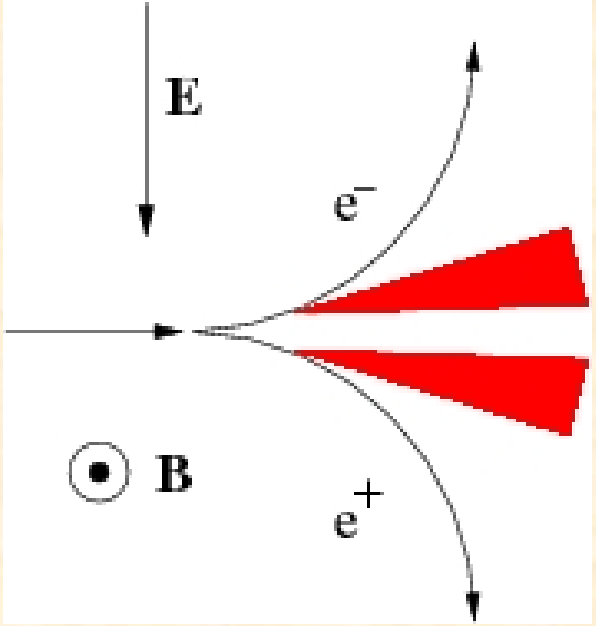


# Electric fields in atmosphere



# Electric field

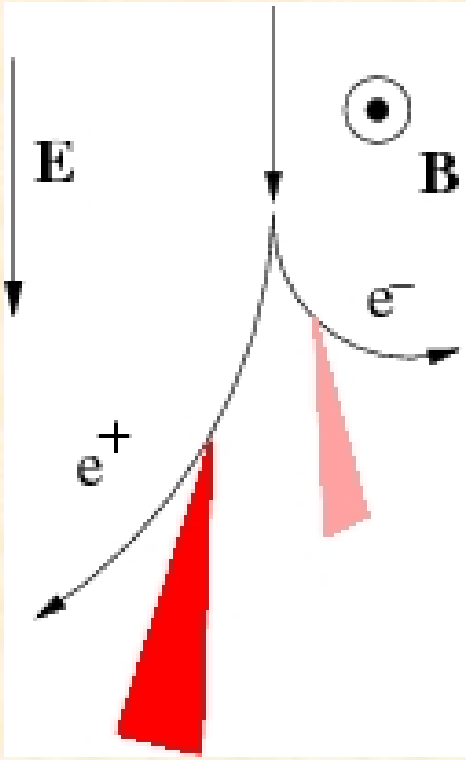
- *Case 1: Perpendicular*
  Increase in $F_{\perp}$



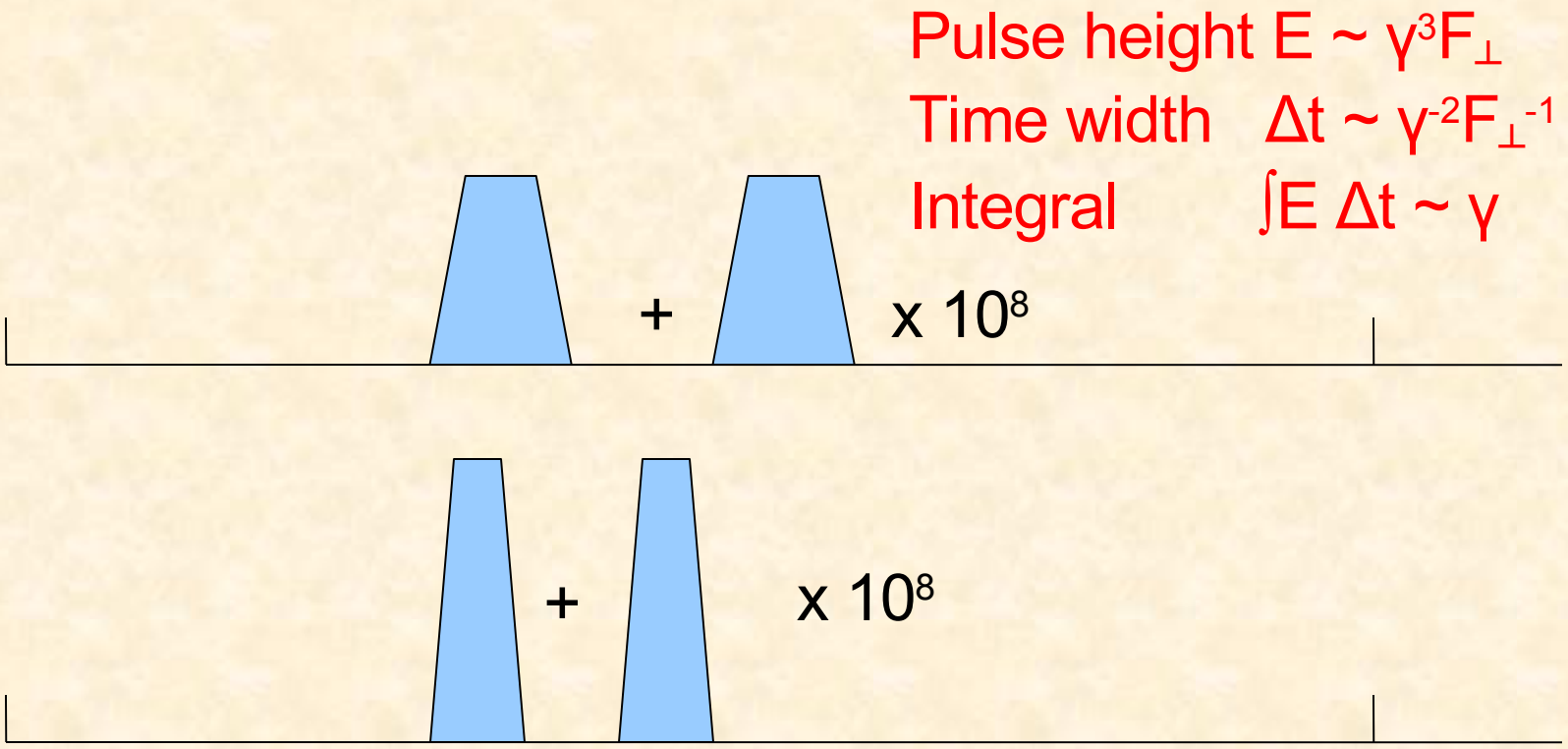

- *Case 2: Linear*
  $e^+$ : Increase in γ

  $e^-$ : Decrease in γ

  (Radiation by $F_{\parallel}$ is suppressed by a factor $\gamma^2$)



# Amplification of shower ?

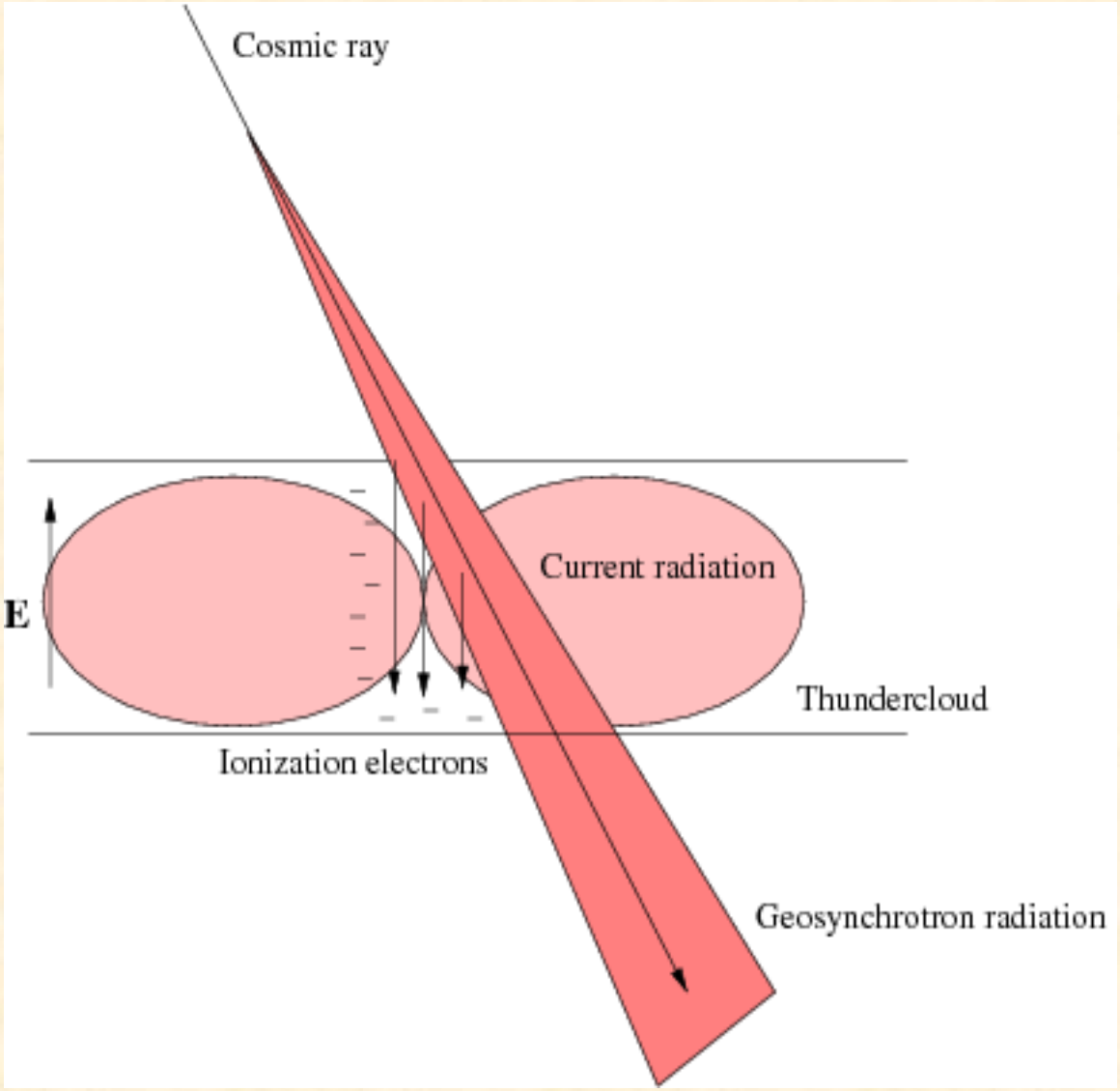



-Amplification by linear acceleration more efficient

-Shower development crucial

-Monte Carlo simulation in progress

# Runaway breakdown radiation



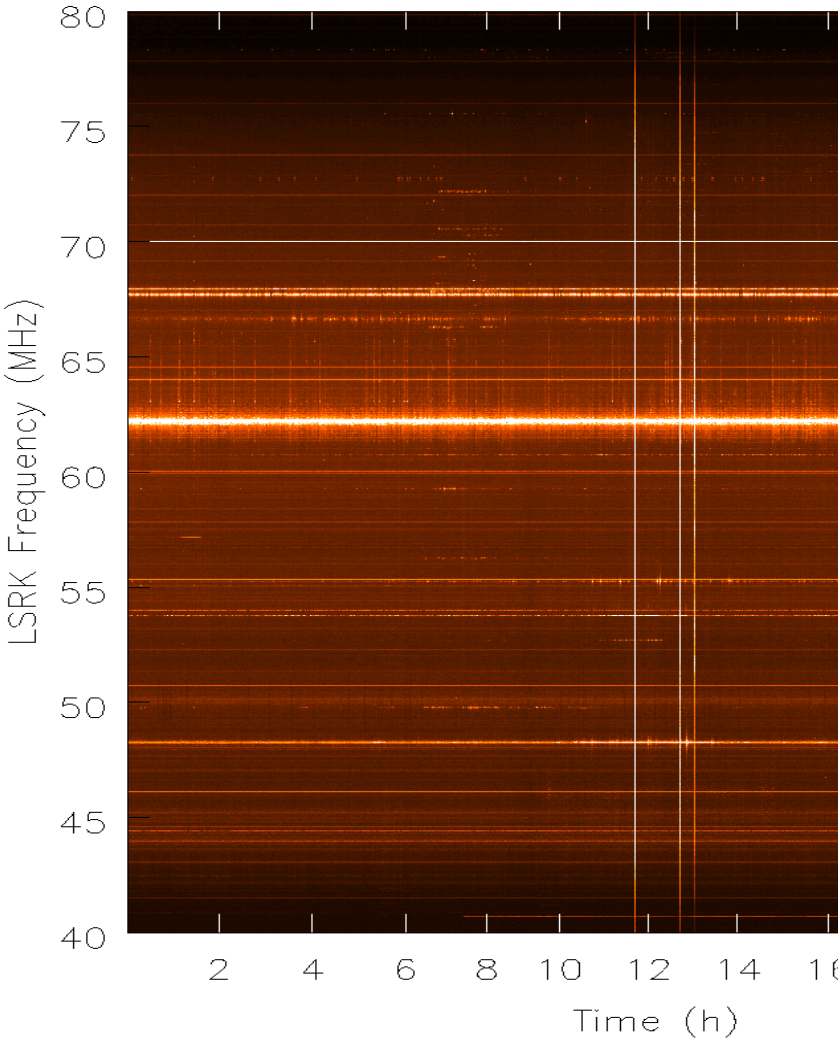

- Current Pulse Radiation
- Pulse width ~ 100-300 ns

  (dependent on attachment time of electrons to oxygen)

# Part II: LOPES thunderstorm results

# Data Analysis

- 3 selections of 2004 LOPES data
- - Cloudless
  - Nimbostratus
  - Thunderstorms

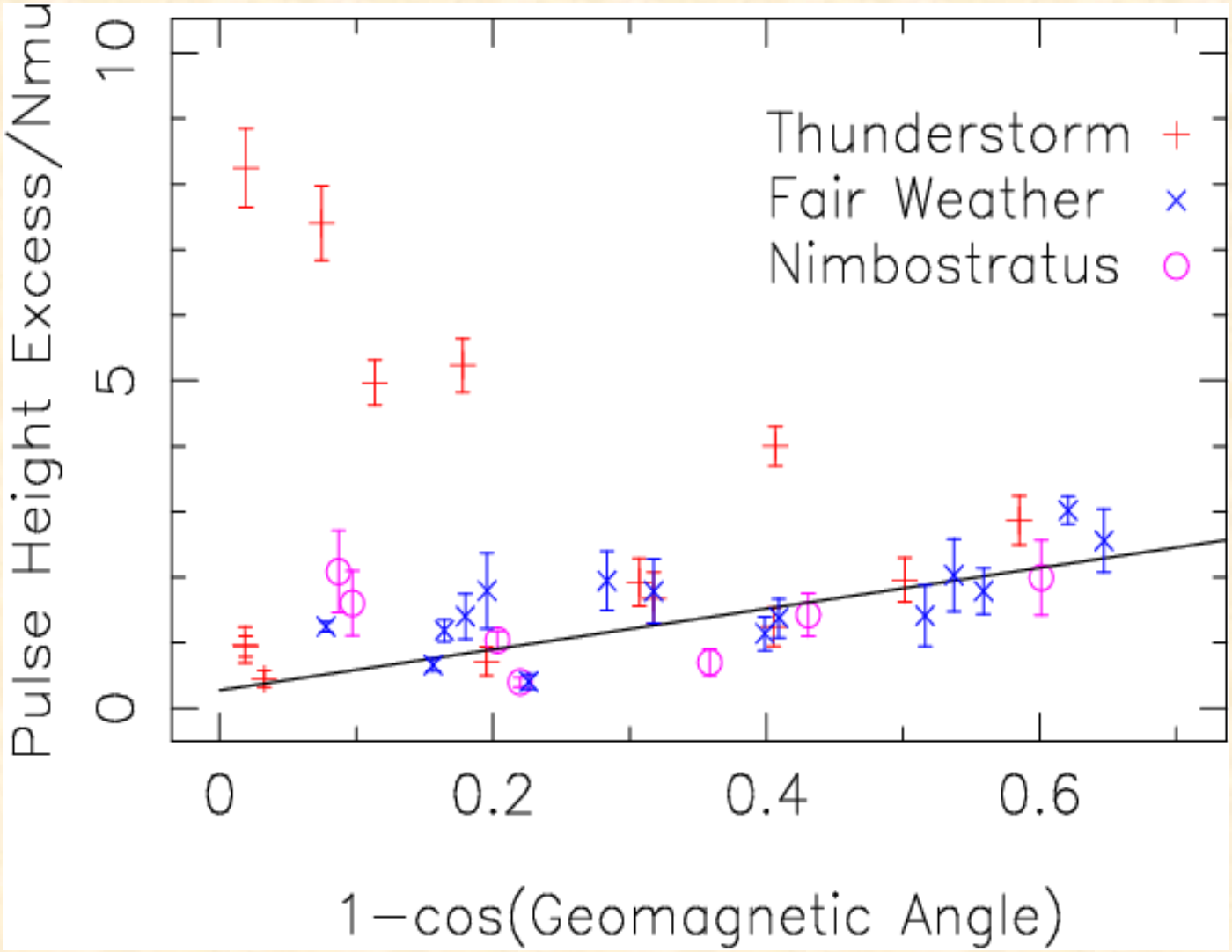


# Statistics

- No pre-selection on high energy
  → low detection ratio !!

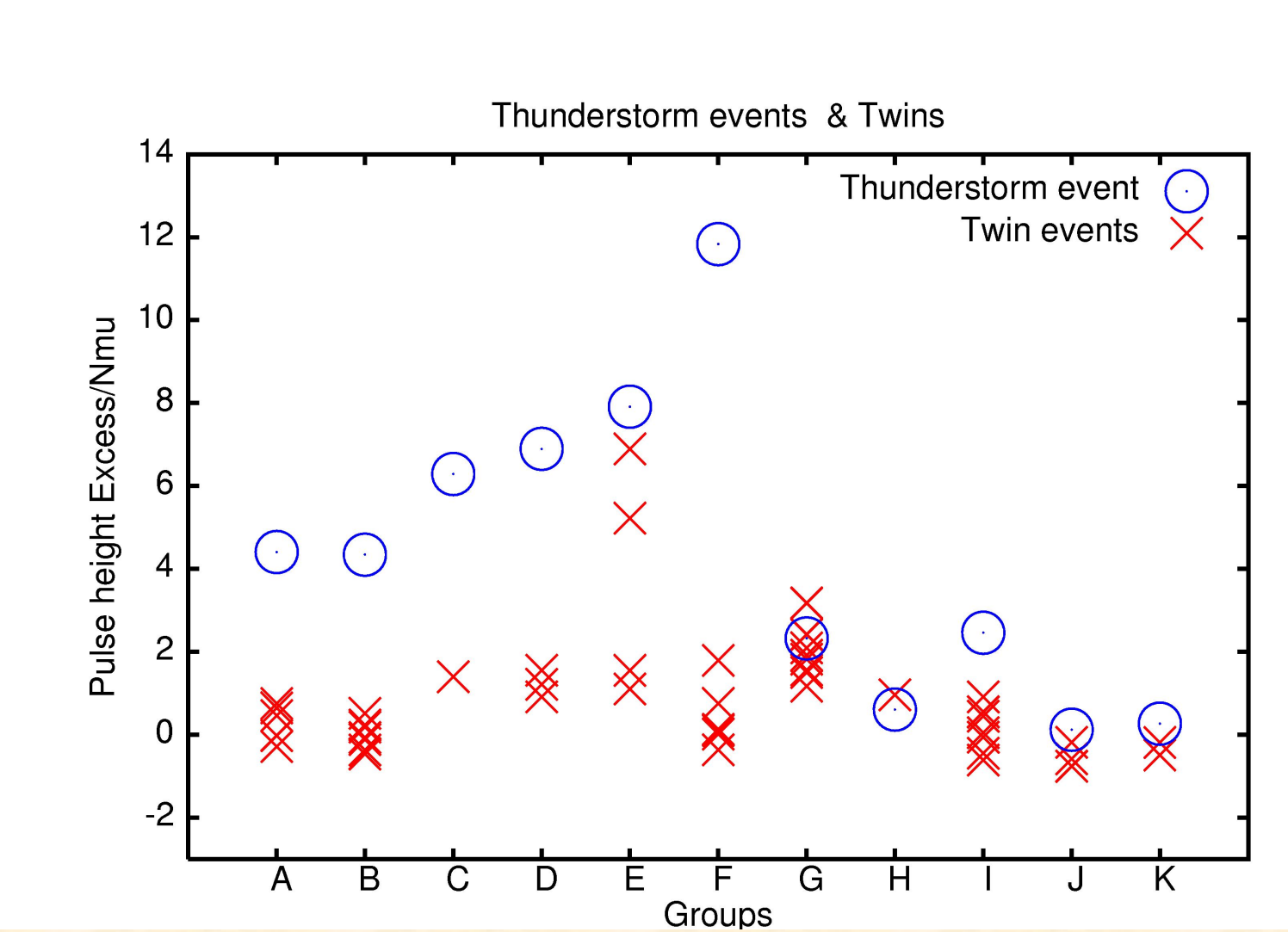
- Fair Weather: 9455 → 15 (0.16 %)
- Nimbostratus: 2659 → 7 (0.26%)
- Thunderstorm: 3510 → 14 (0.40%)

# Results




Buitink et al. 2007, A&A (in press)

# Results: twin groups




Buitink et al. 2007, A&A (in press)

# What causes amplification?

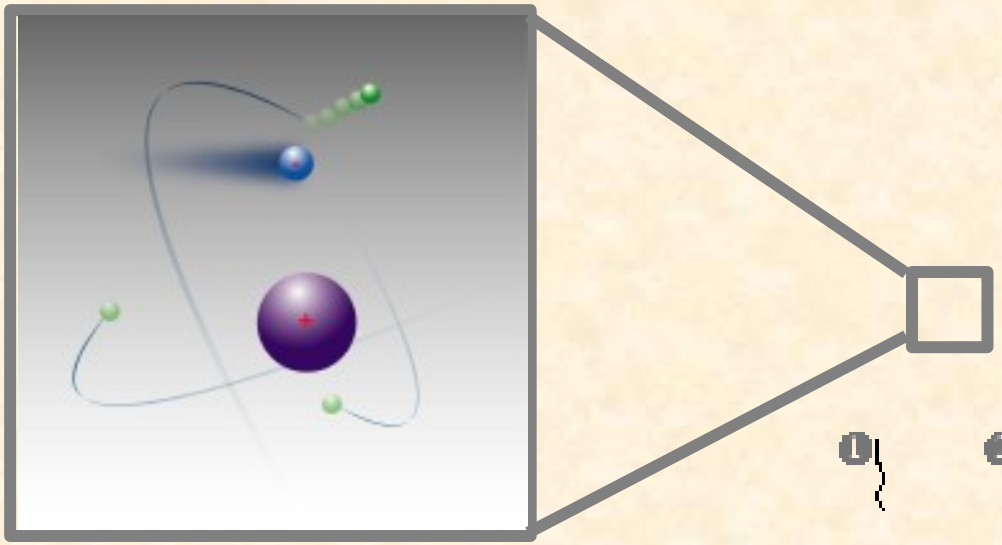
| Geosynchrotron + E-field | Ionization current |
| --- | --- |
| Emission is beamed forward | Emission is radiated in all directions |
| Emission is east-west polarised | Emission is polarised in plane of current |
| Time width ~ 50 ns | Time width ~ 100-300 ns |

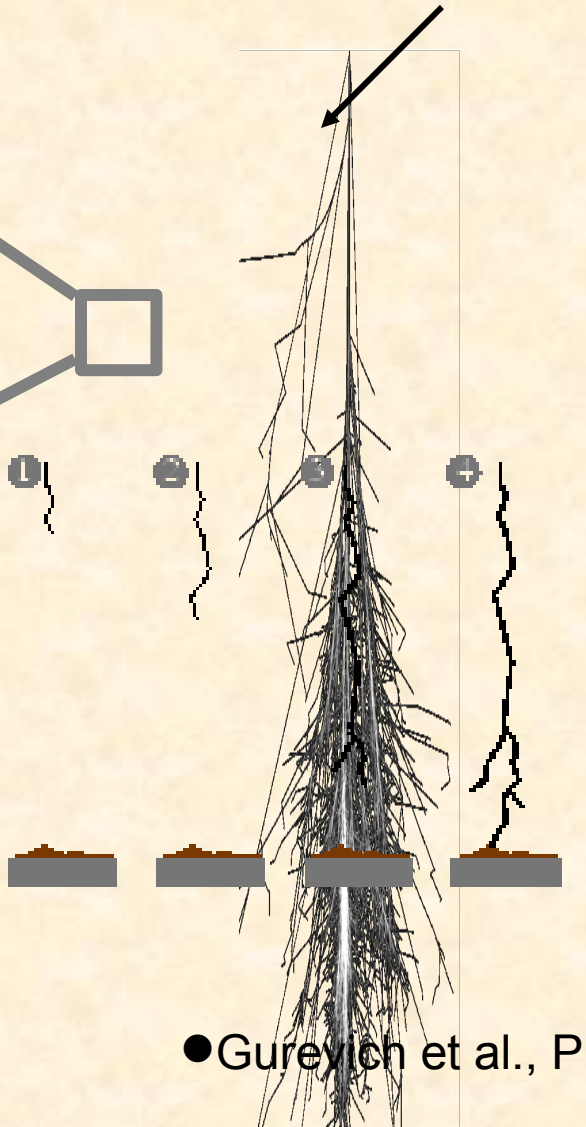
Observed width favours modified geosynchrotron emission

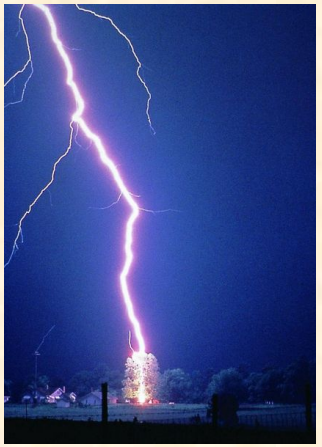
More information with LOFAR

# Part III: Other thunderstorm research

# Lightning triggering by air showers





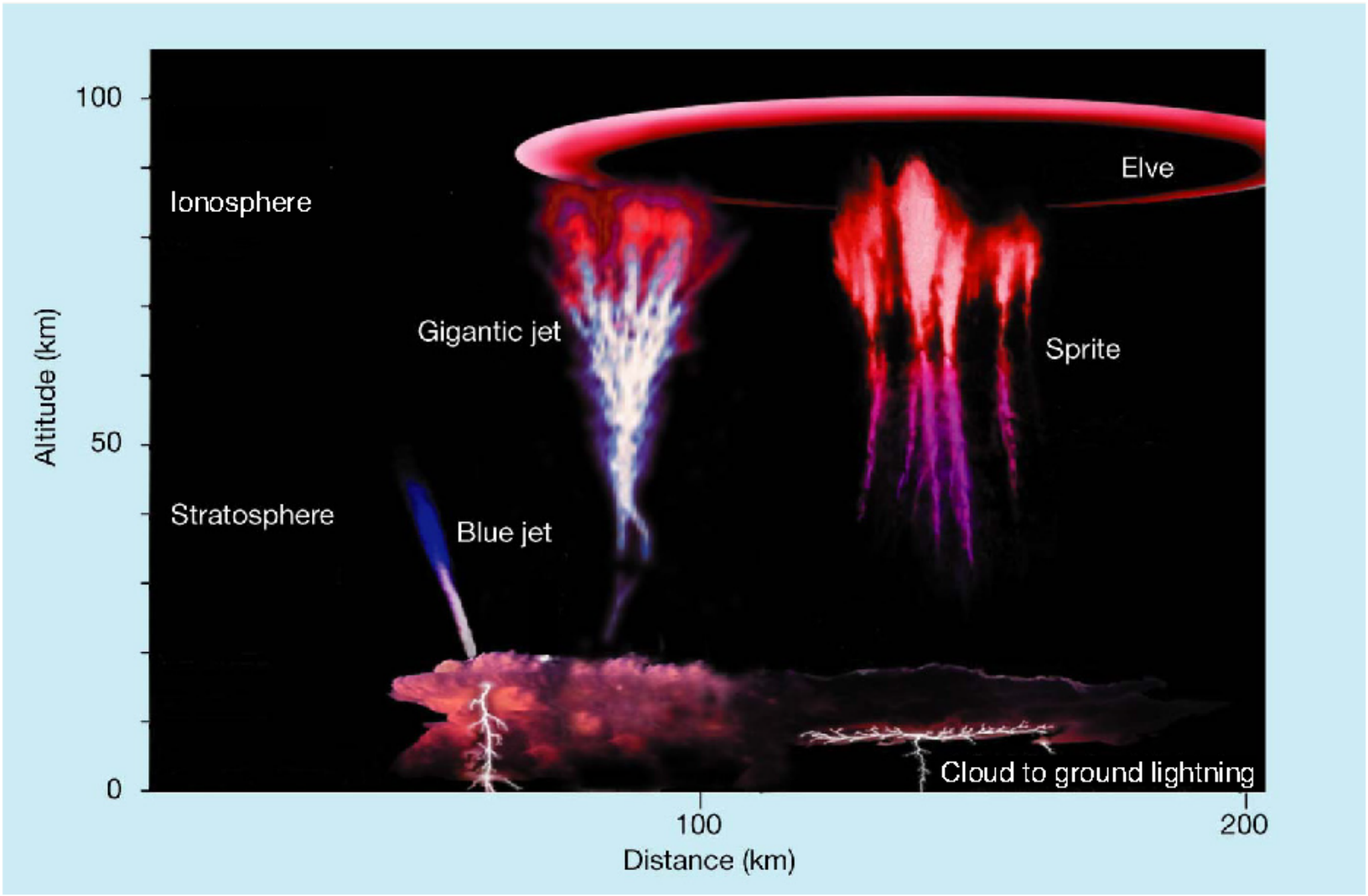


- Gurevich et al., Phys. Let. A, 2004

# Lightning imaging

Lars Baehren

# Lightning initiation / Sprites




[Pasko, Nature, 423, 927-929, 2003]

# Summary

- Atmospheric electric fields effect air shower emission … but only strong fields
- This reduces duty cycle only slightly
- During thunderstorms a variety of interesting experiments can be performed

***Enjoy the weather !!***