What Can Elves Tell Us About Very Strong Lightning?

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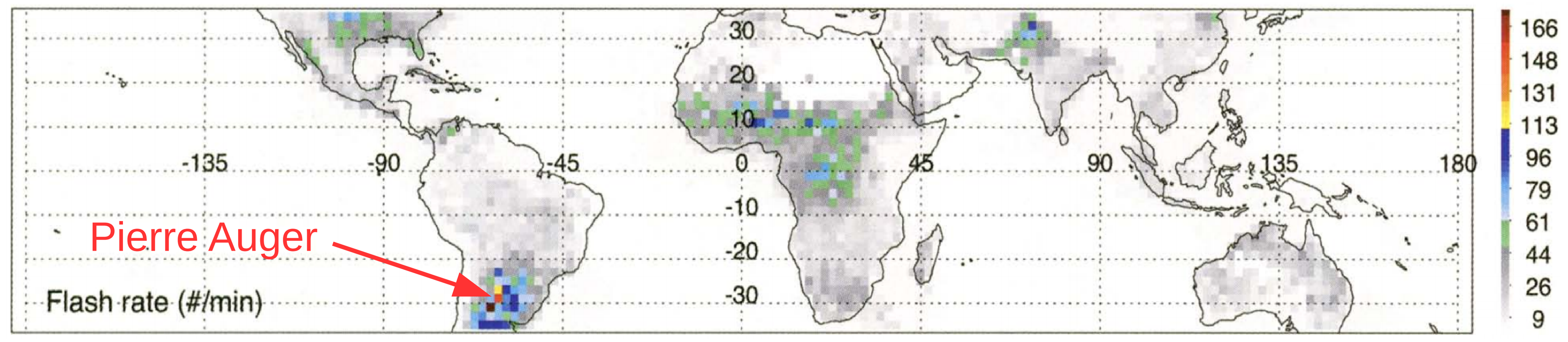
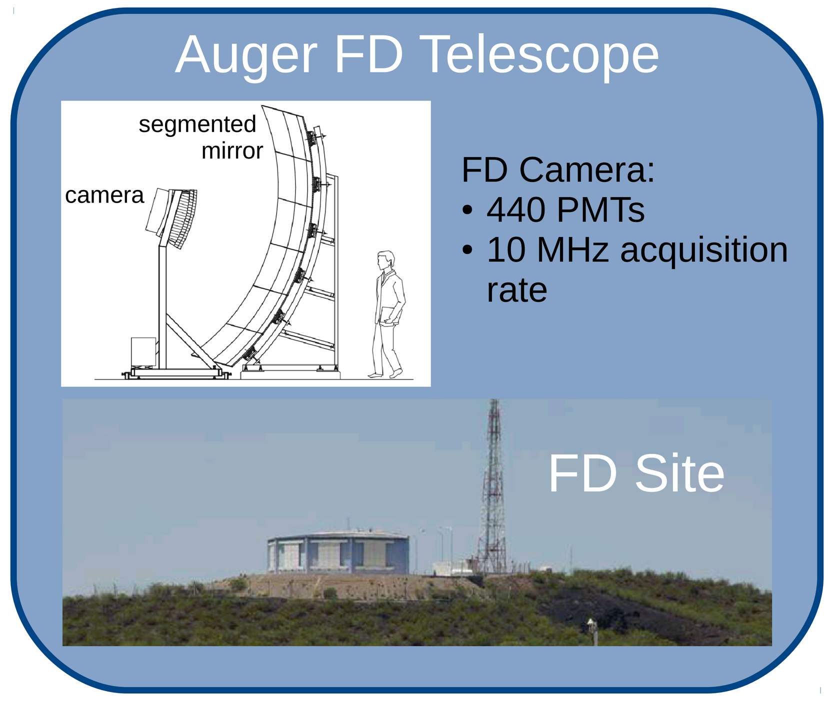
Motivation

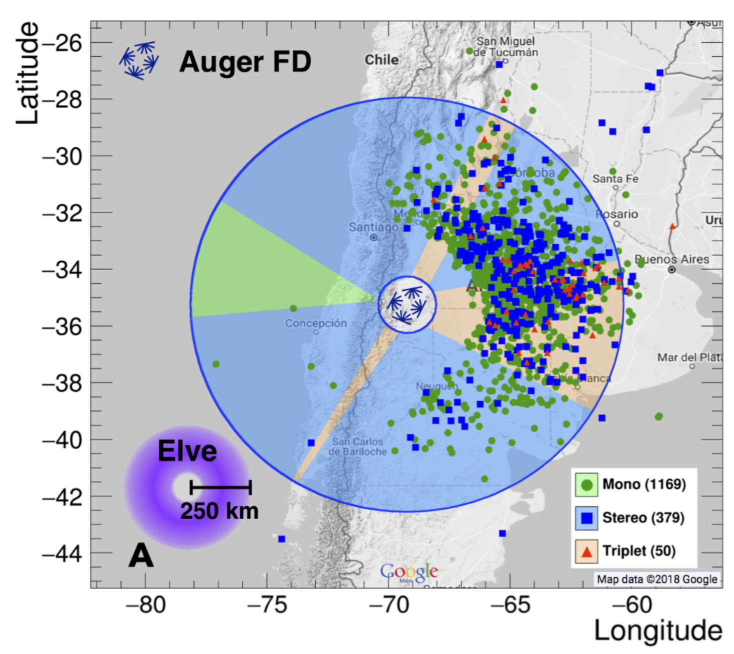
1) Argentina has some of the world's strongest lightning.
2) The Pierre Auger Cosmic Ray Observatory monitors this region.
3) Lightning can be dangerous, so it is important to study.



Auger Observatory

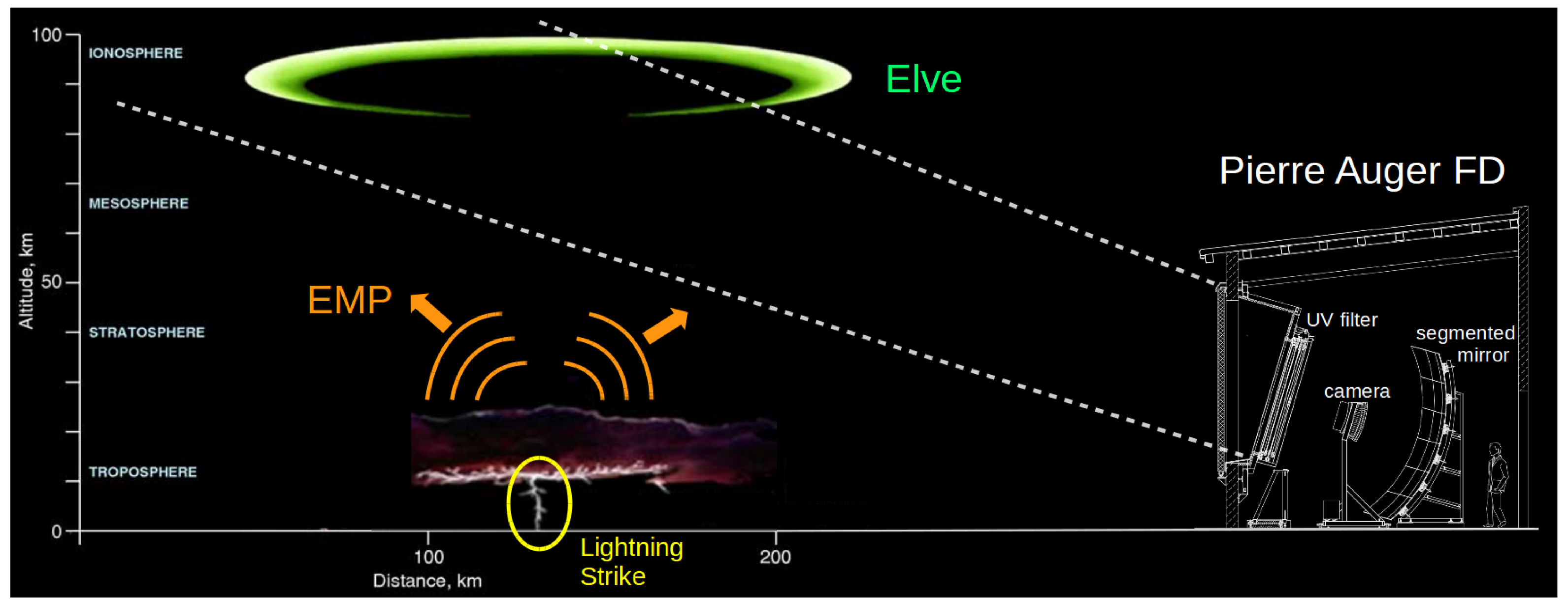
- The Pierre Auger fluorescence detector (FD) records UV fluorescence.
- FD is made up of four sites with six telescopes each (24 total).



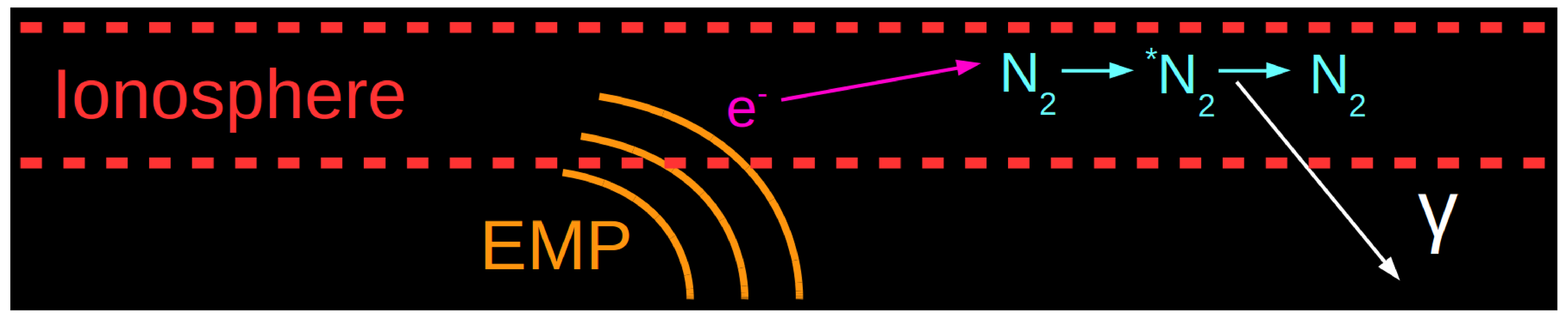


Elves

- Elves are a class of transient luminous events that occur in the ionosphere above strong lightning.
- The fast current flow in lightning is modeled as a Hertzian dipole and creates an EMP.
- Elves are a result of the interaction between this EMP and the ionosphere.
- Elves: **E**mission of **L**ight and **V**ery Low Frequency perturbations due to **E**lectromagnetic Pulse **S**ources



- What is actually happening in the ionosphere?

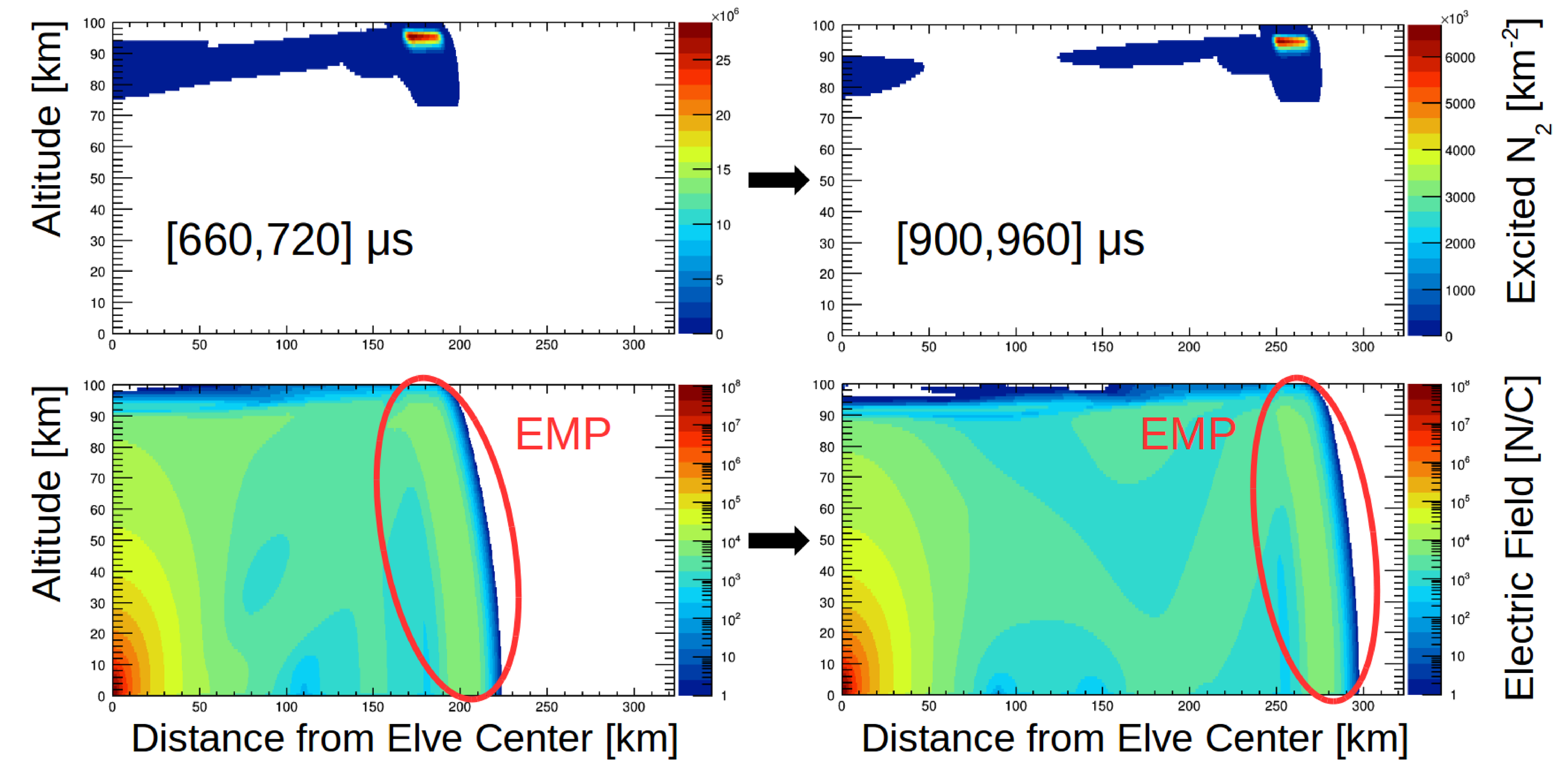


Elve Simulation

- Models the lightning strike, EMP, and interactions with the ionosphere.
- Numerically propagates Maxwell's Equations and the Langevin equation:

$$\epsilon_0 \frac{\partial \mathbf{E}}{\partial t} = \nabla \times \mathbf{H} - \mathbf{J}_{\text{tot}} \qquad \mu_0 \frac{\partial \mathbf{H}}{\partial t} = \nabla \times \mathbf{E} \qquad \frac{\partial \mathbf{J}_n}{\partial t} + \nu_n \mathbf{J}_n = \overrightarrow{\omega_{c,n}} \times \mathbf{J}_n + \omega_{p,n}^2 \epsilon_0 \mathbf{E}$$

- Can we see elves from this simulation? Yes! The excited N_2 follows the EMP.



Sensitivity Study

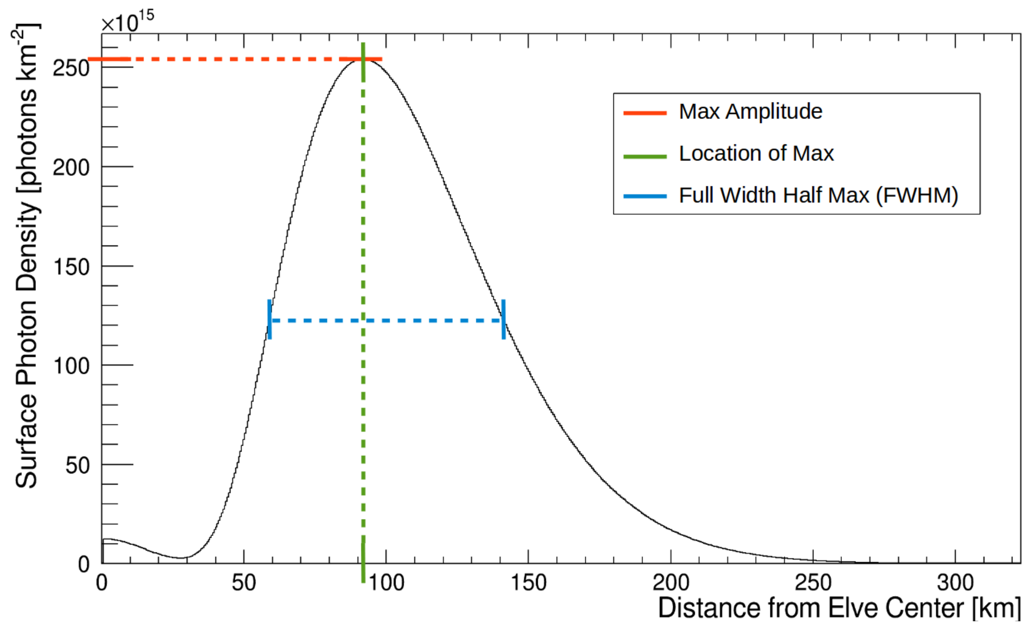
Which lightning parameters affect elve structure the most?

Simulation Input: Lightning Parameters

Simulation Output: Elve Parameters

Parameter Name
Peak Current
Channel Length
Return Stroke Speed
Rise Time
Fall Time
Height of Emission / Ionosphere
Continuing Current

- Each of these parameters is varied over a specific range.
- Range selected through literature review and simulation study.



- Integrate excited nitrogen over **altitude** and **time**.
- This gives us **surface photon density**.
- Information reduced to two dimensions.
- Chosen metrics shown on plot.

References

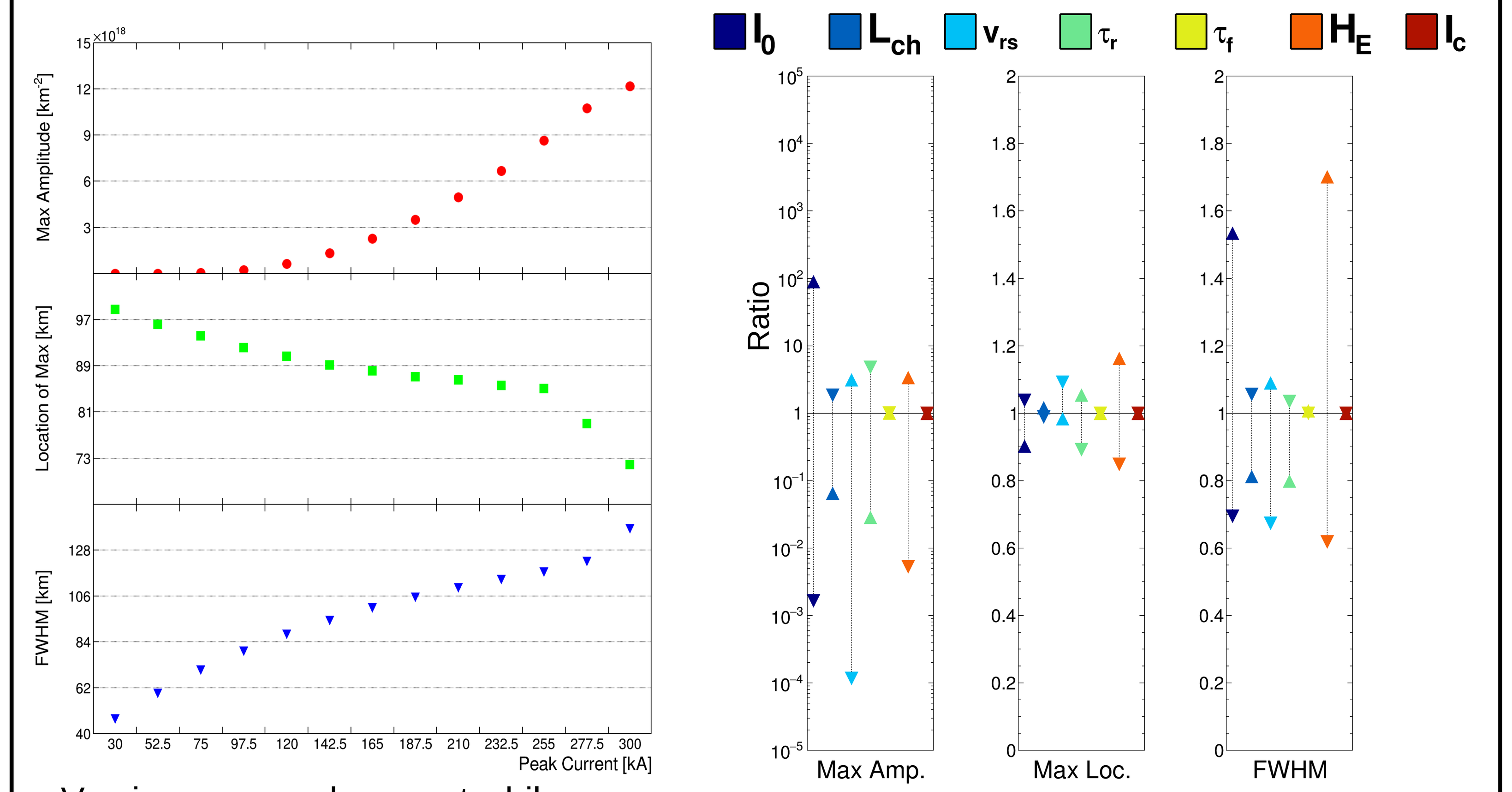
[1] E. J. Zipser et al., "Where are the most intense thunderstorms on Earth?," Bull. Am. Meteorol. Soc., vol. 87, no. 8, pp. 1057–1072, Aug. 2006.

[2] J. Abraham, P. Abreu, M. Aglietta, and ..., "The fluorescence detector of the Pierre Auger Observatory," Nucl. Instruments Methods Phys. Res. Sect. A Accel. Spectrometers, Detect. Assoc. Equip., vol. 620, no. 2–3, pp. 227–251, Aug. 2010.

[3] Warrilow, Chrissy. "Transient Luminous Events: Sprites, Jets and Elves Are Mysteries in the Sky (PHOTOS)." The Weather Channel, 27 Aug. 2014, weather.com/news/news/transient-luminous-events-mysteries-sky-20130731.

[4] R. A. Marshall, "An improved model of the lightning electromagnetic field interaction with the D-region ionosphere," J. Geophys. Res. Sp. Phys., vol. 117, no. A3, p. n/a-n/a, Mar. 2012.

Sensitivity Results

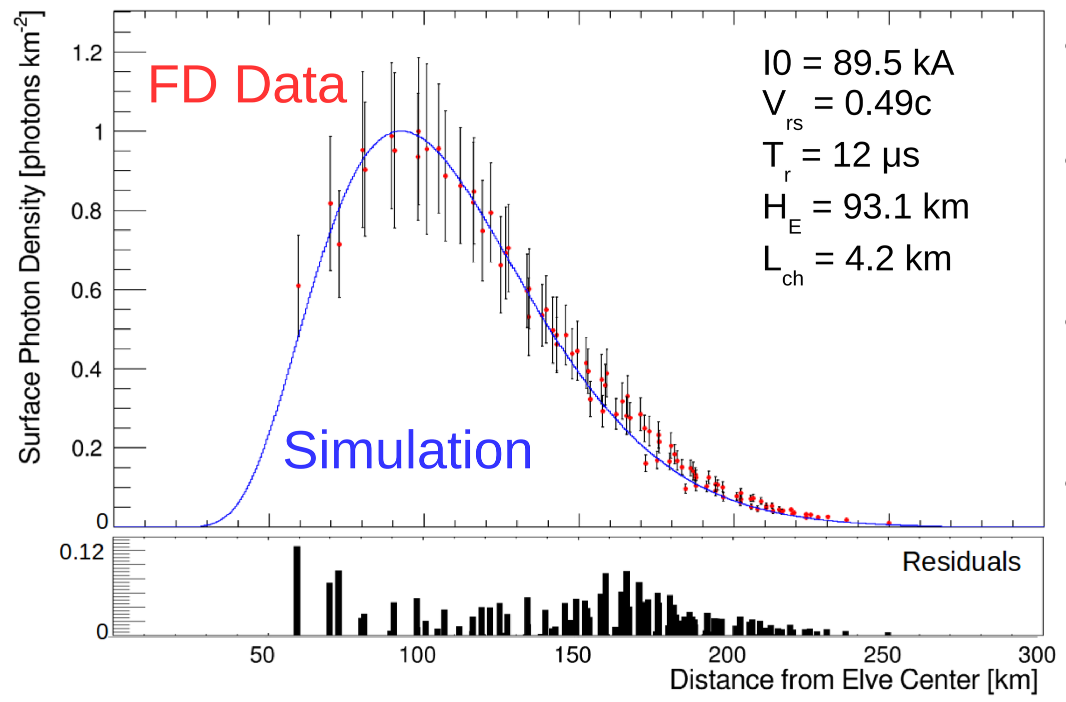


- Varying over peak current while keeping other parameters constant.
- Clearly sensitive to peak current.
- Note the turn on point in amplitude @ 120 kA.

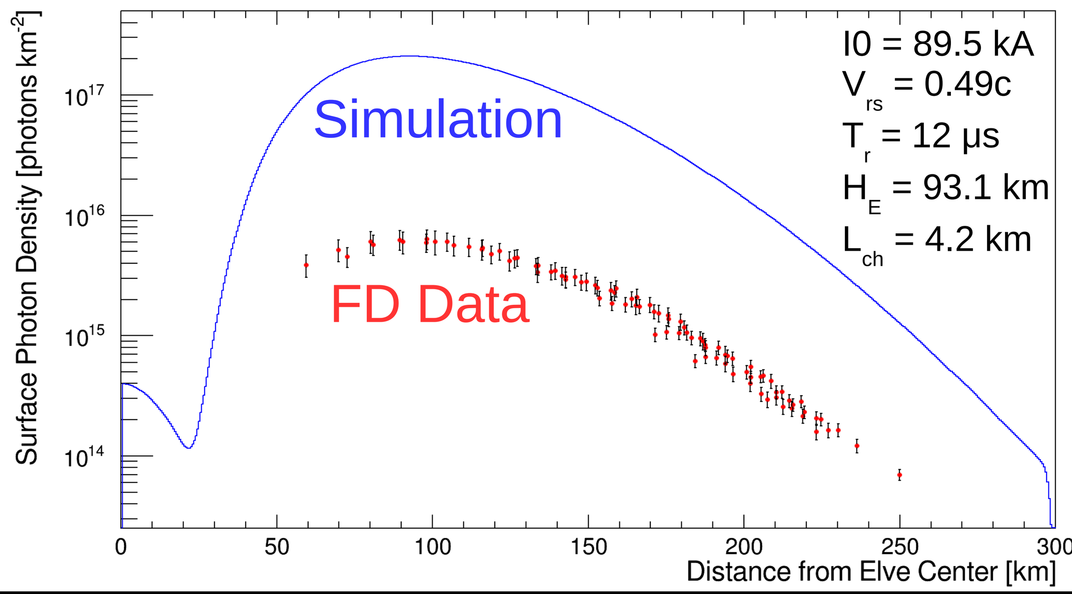
- ▲: output param at max value of input param divided by output param at nominal value of input param.
- Larger ratios = sensitive to that parameter

Simulation vs. Data

- Sensitivity study + X^2 minimization → attempt to match simulation to data.



- Each red dot is an FD pixel.
- Both plots are **normalized** to their respective maximums.
- Shape of simulation (Location of Max, FWHM) matches data well.
- Reduced chi squared: $\chi^2_\nu = 3.48$ with $\nu = 51$



- Without normalization, Max Amplitude is off by ~2 orders of magnitude.
- Possible causes:
  1) Surface density reconstruction
  2) EMP simulation

Conclusions

1) Lightning can be dangerous, so it is important to study.
2) We are using elves to look at lightning in a very novel way.

- Very bright elves means that peak current is greater than 120 kA.
- Better understanding of how lightning affects elve shape and amplitude.
- Simulation can create accurate surface density profiles.
- Problem with amplitude needs to be resolved.

Parameter	Sensitive to this Parameter?
Peak Current	Very
Channel Length	Somewhat
Return Stroke Speed	Very
Rise Time	Somewhat
Fall Time	No
Height of Ionosphere	Very
Continuing Current	No