Photonuclear reactions triggered by lightning discharges in a Japanese winter thunderstorm

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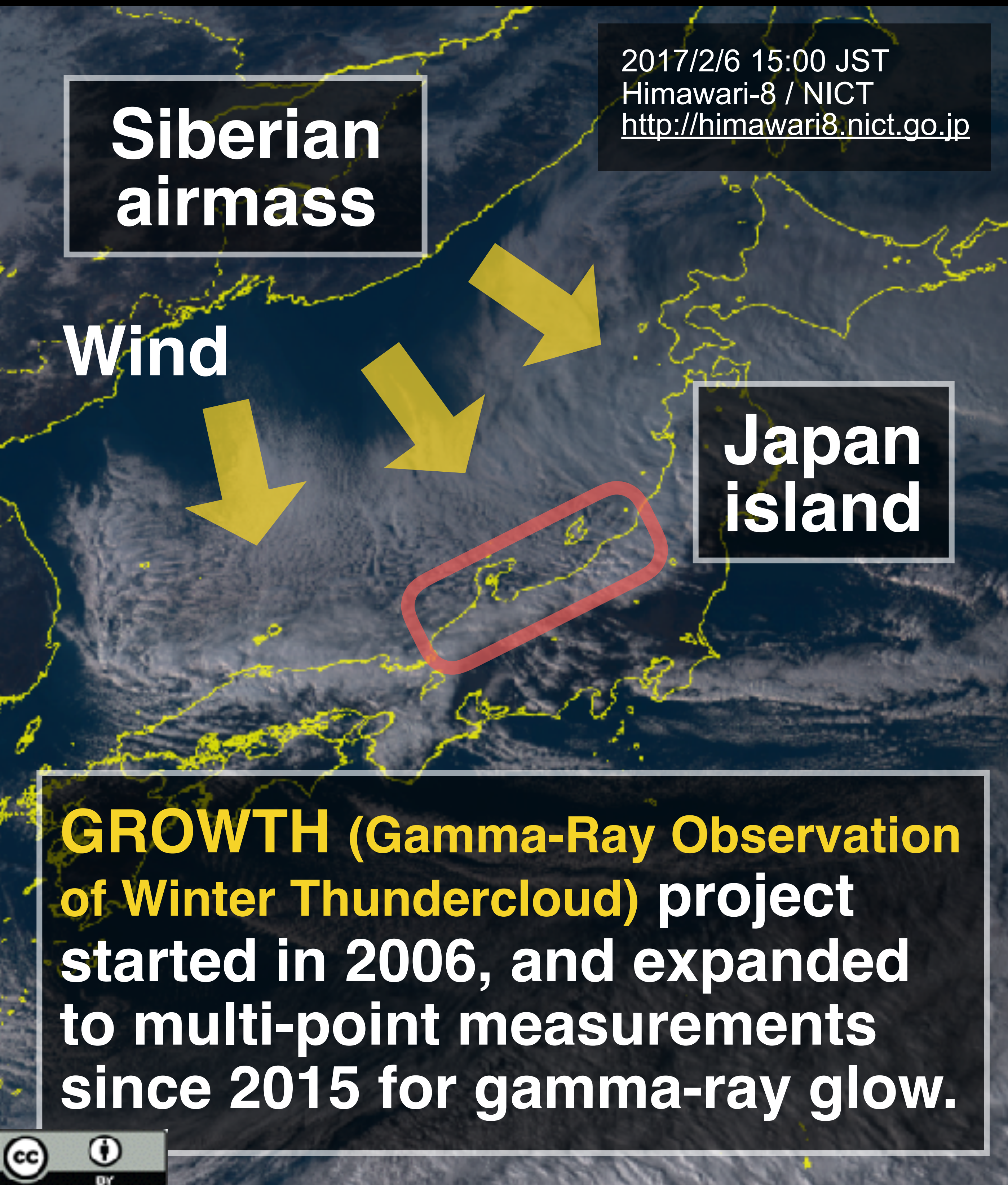
Enoto et al., *Nature* 551, 481 (2017)

Photo at Fukui, Japan by Otowa Electric Co., Ltd. / Masako Tanaka

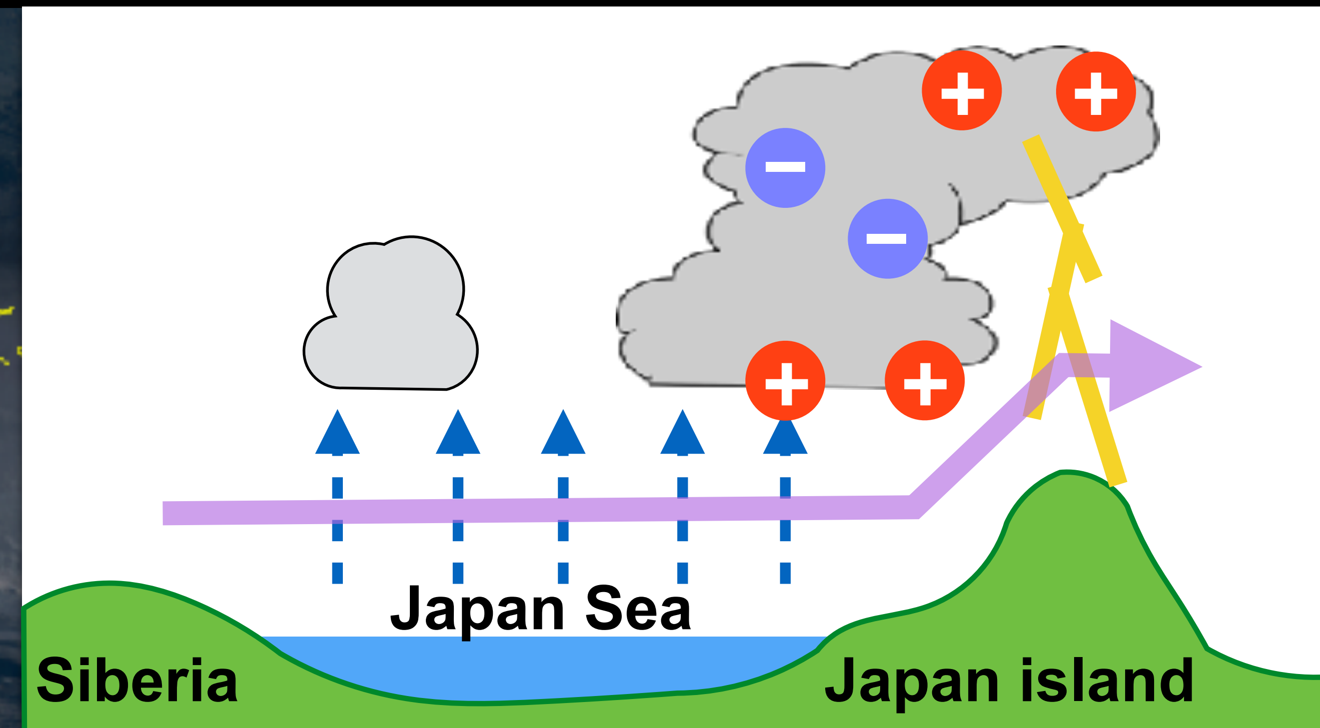
EGU2018-3798, 14:00-14:15, April 10, 2018, Vienna, Austria, “Atmospheric Electricity, Thunderstorms, Lightning and there effects” (NH1.2/AS1.14/SSS13.43)

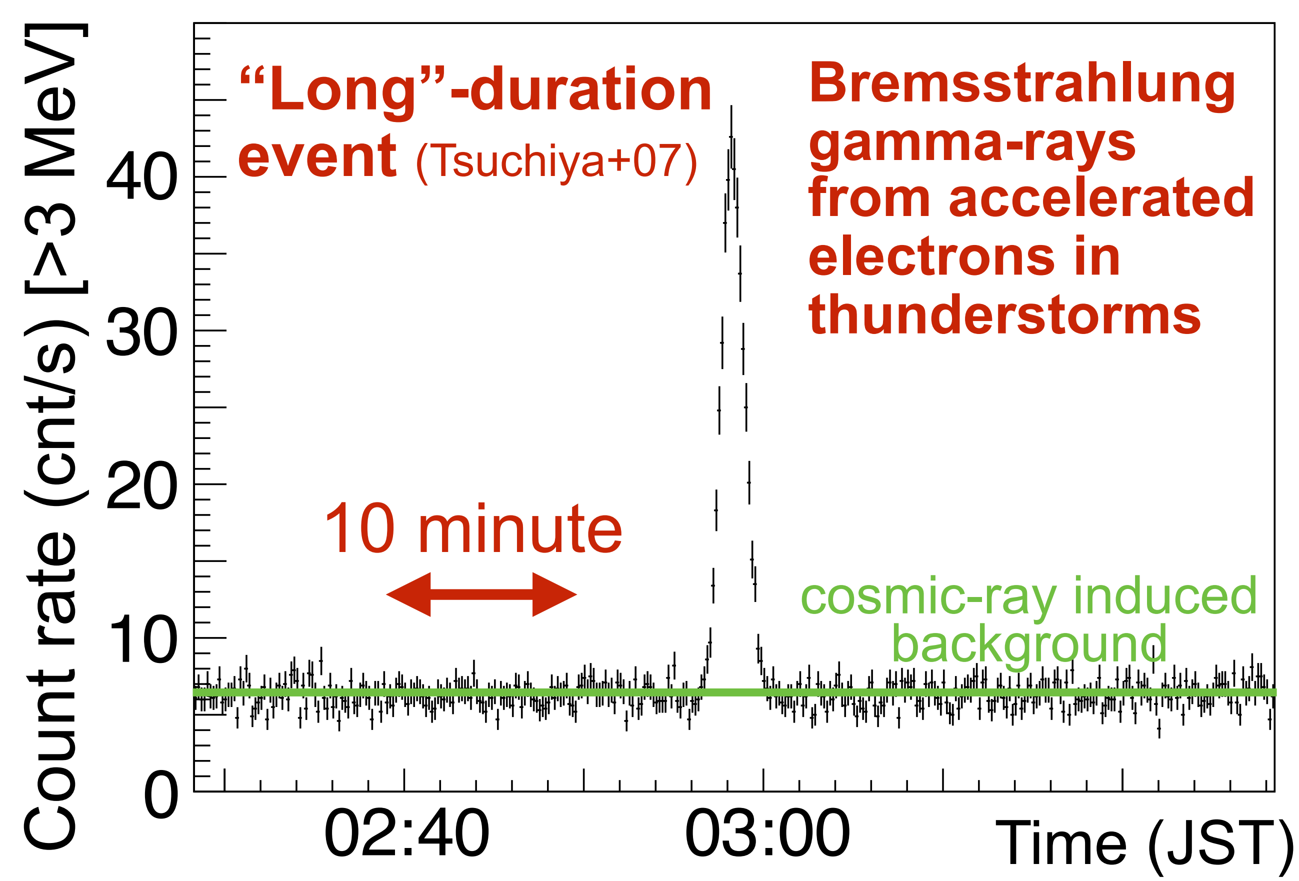
Winter thunderstorm and lightning in Japan

low altitude (<1 km), powerful lightning, frequent positive discharge
Ideal for observing the high-energy atmospheric phenomena



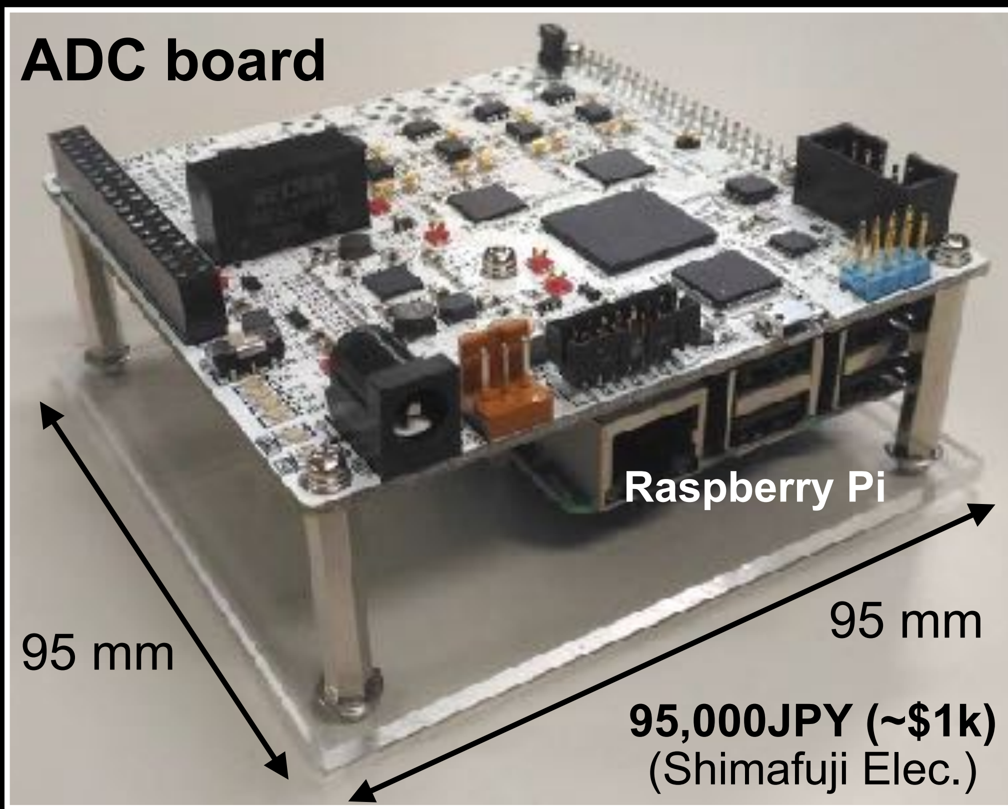
GROWTH (Gamma-Ray Observation of Winter Thundercloud) project started in 2006, and expanded to multi-point measurements since 2015 for gamma-ray glow.



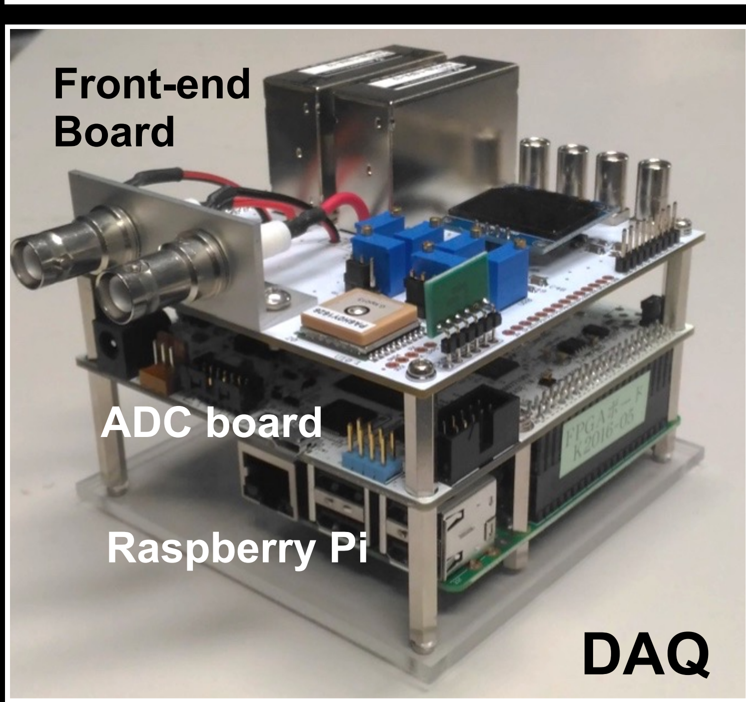


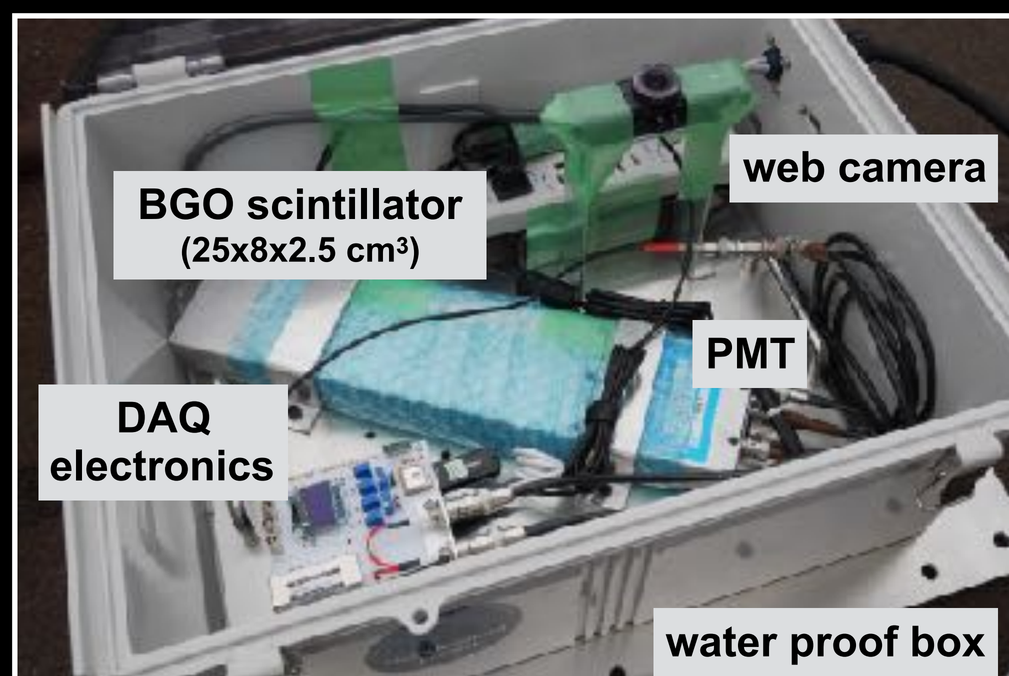
Radiation detectors for mapping observations

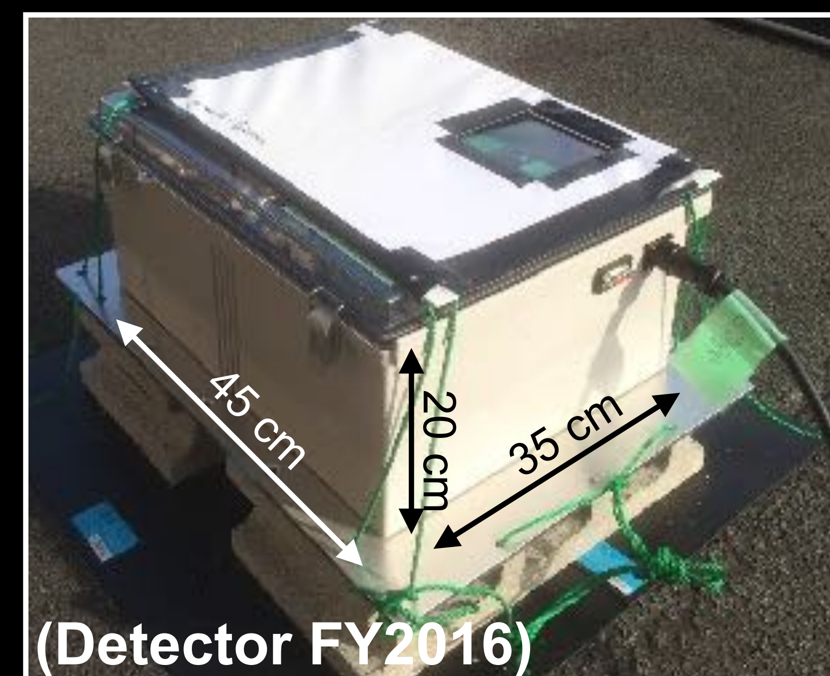
A new stand-alone, low cost, and high-performance data acquisition (DAQ) system was developed; e.g., FPGA board of 4 channel 50 MHz, 12 bit ADC



- Gamma-rays detected with BGO scintillators
- Recorded with energy and GPS time tag
- Environmental sensors (temperature, pressure, etc)
- Mobile data transfer & remote control
- Deployed at local high schools, universities
- Supported by academic crowdfunding, and aiming at distributing to citizen scientists







Wada, Master thesis of the University of Tokyo, "Construction of the multi-point observation network for thundercloud gamma-rays"
(ref) FPGA/ADC board specification http://ytkyk.info/blog/2016/09/04/growth-fpga-adc-board/

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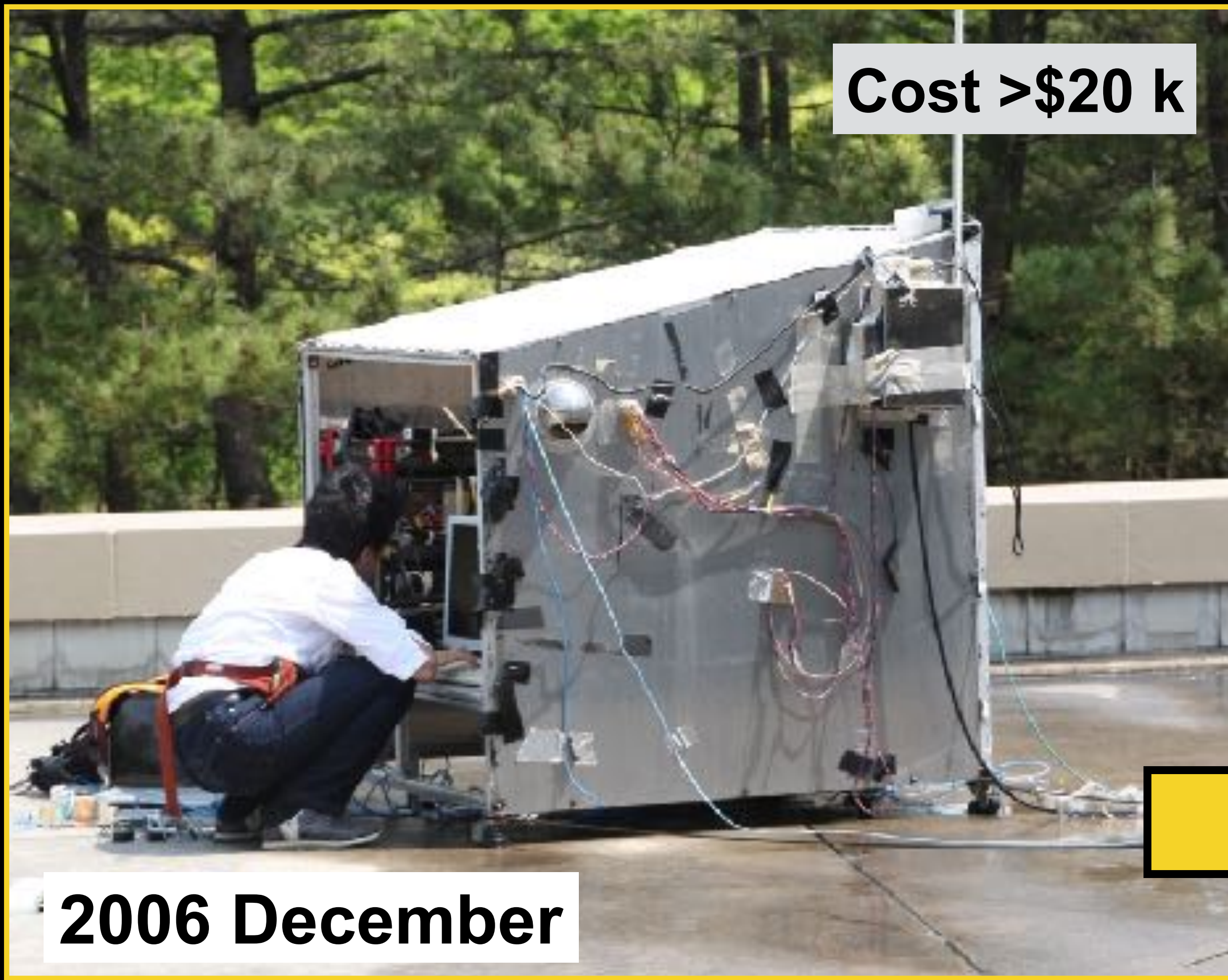

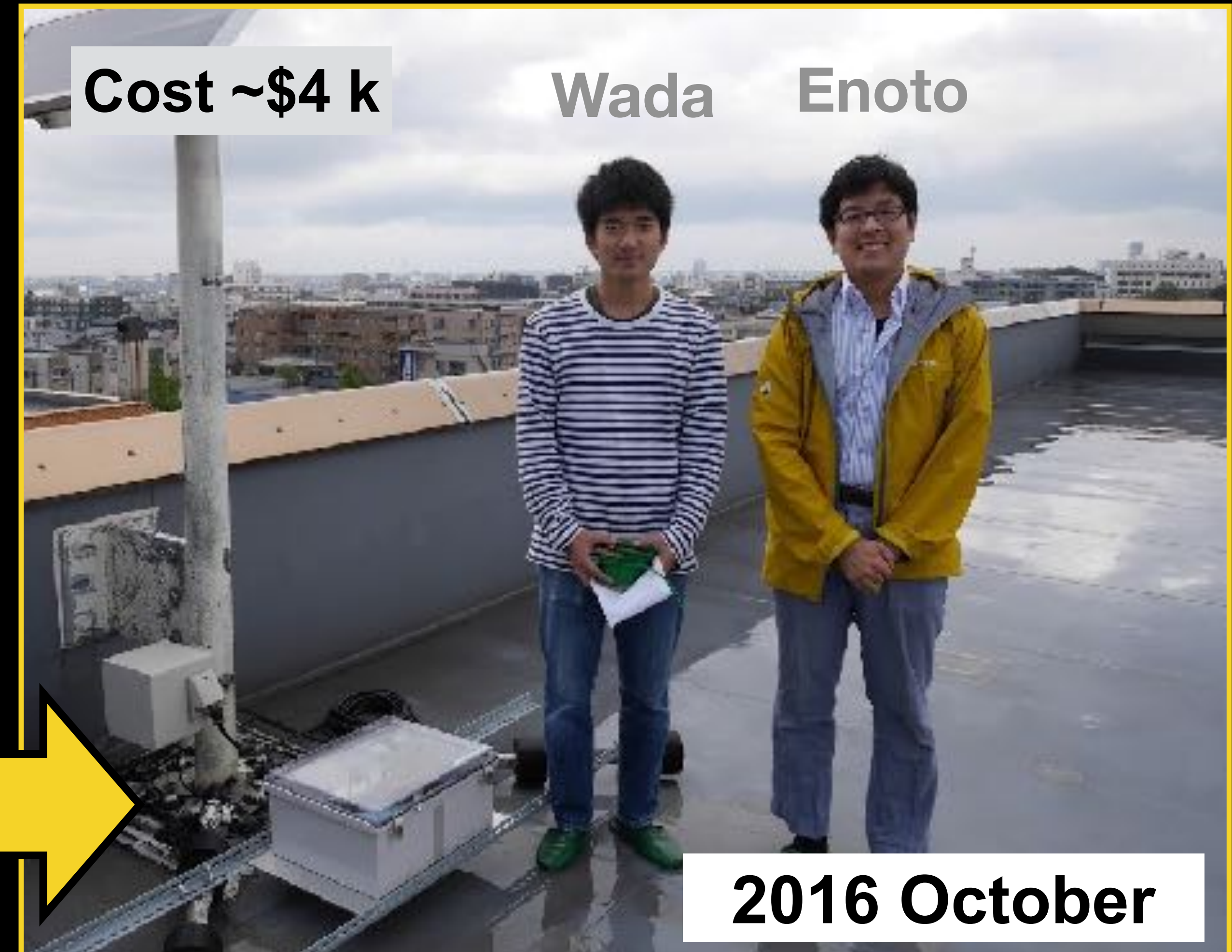

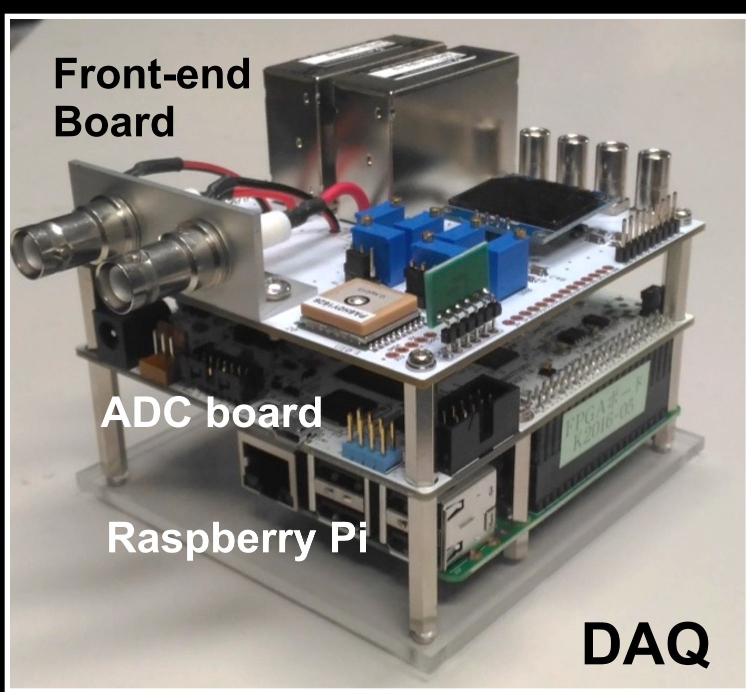

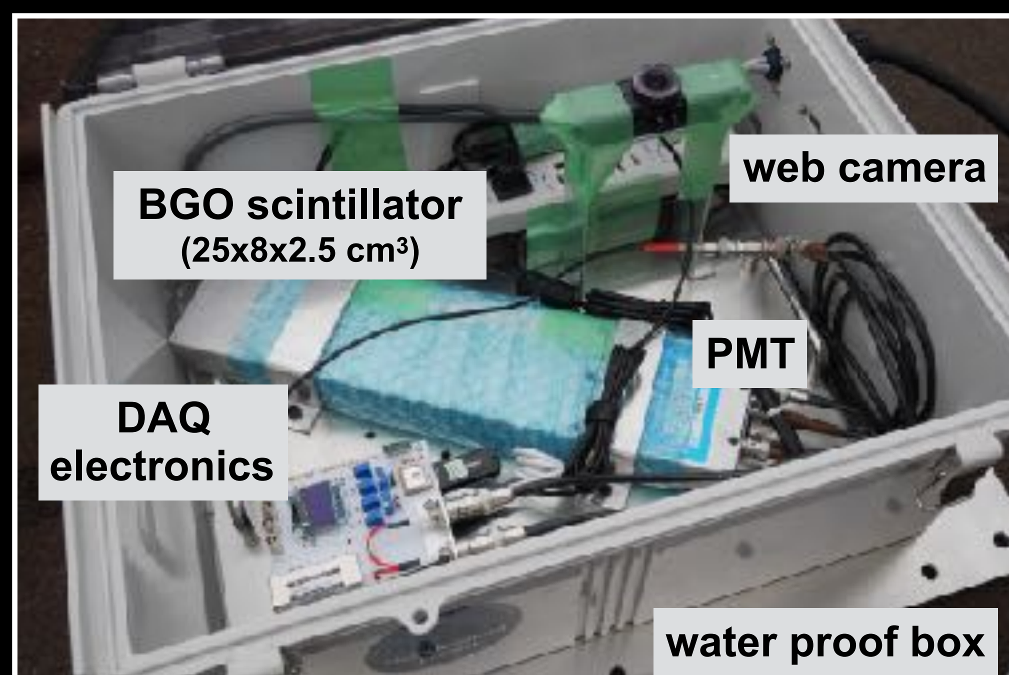

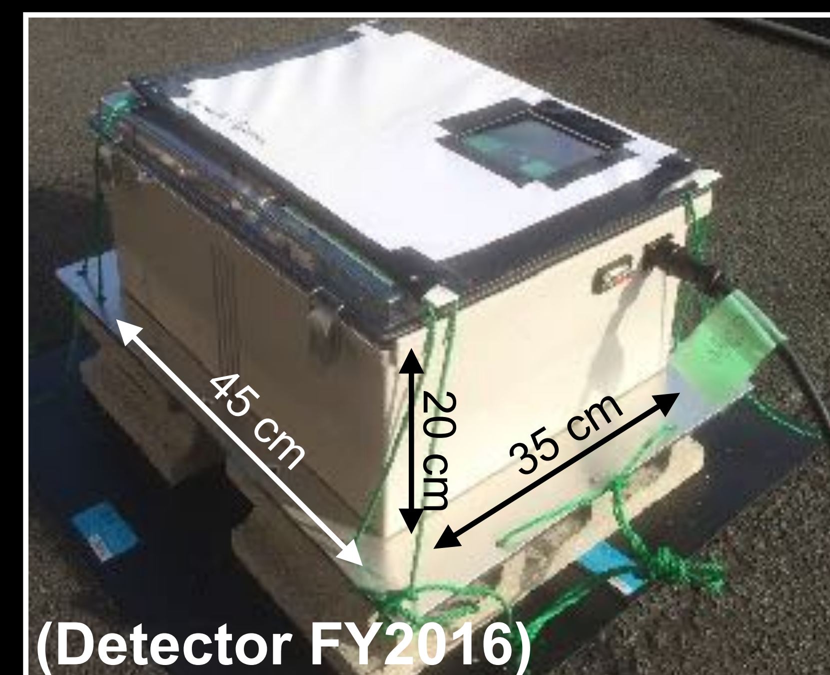

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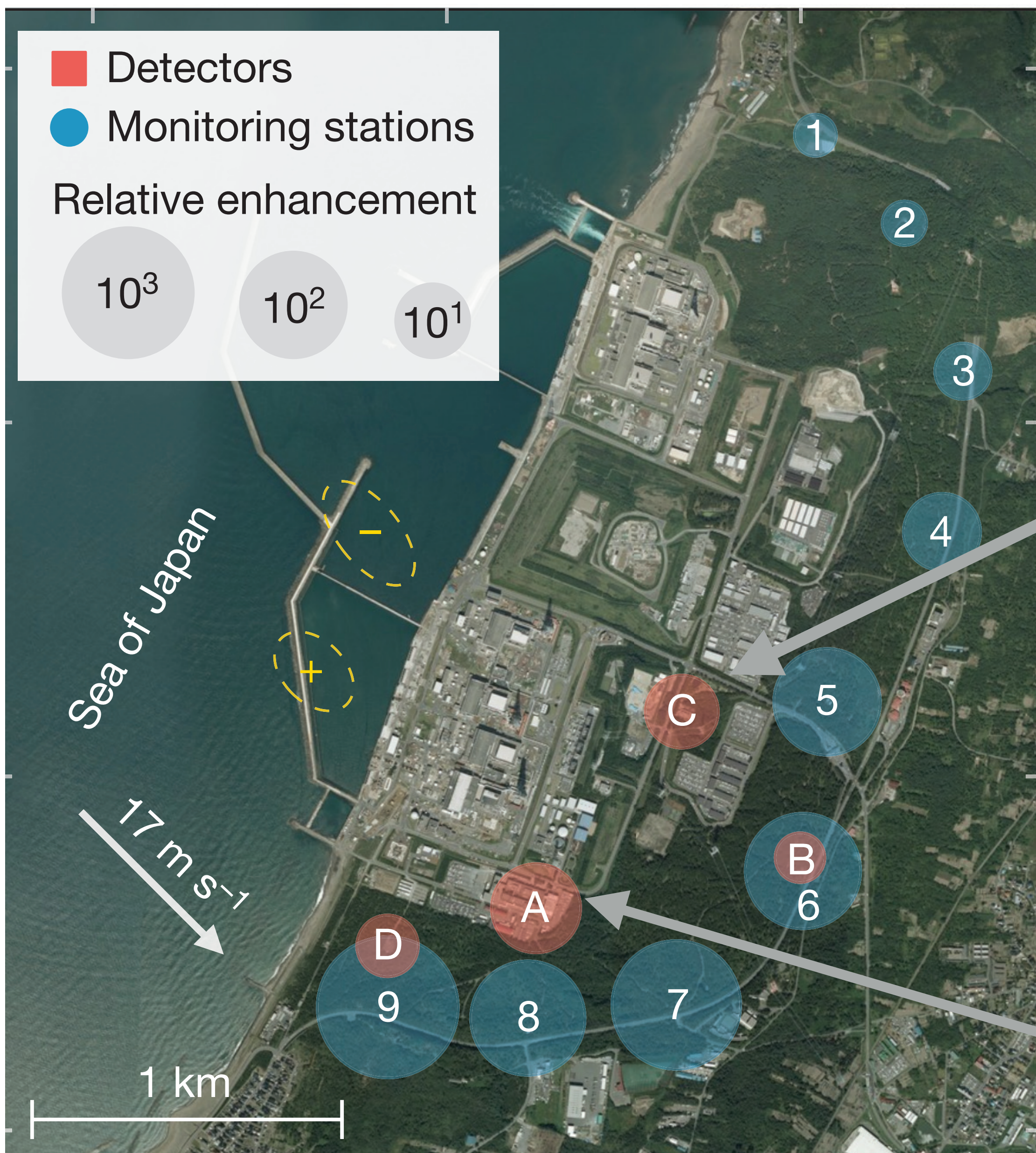
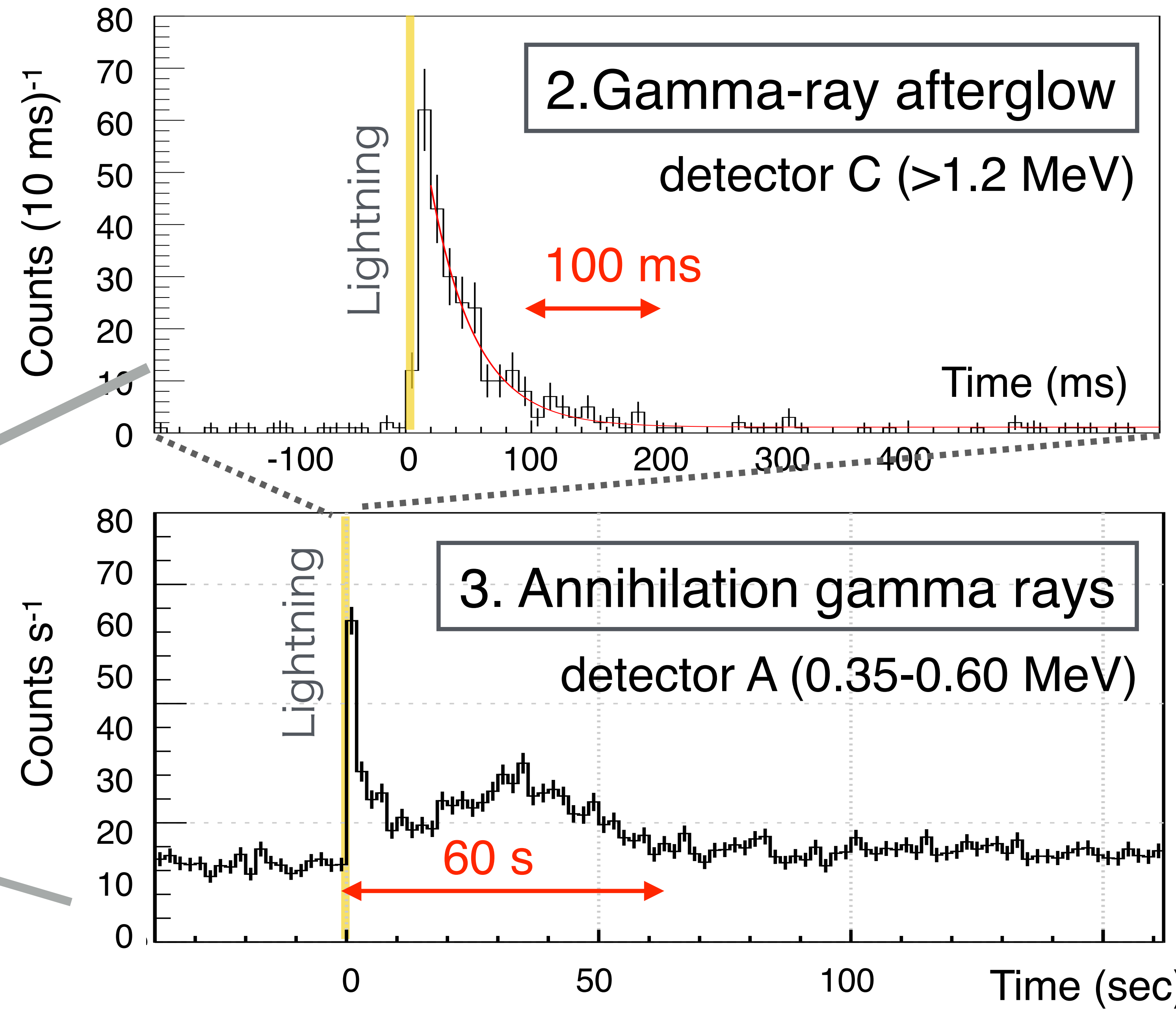
Short-duration burst associated with lightning

on February 6, 2017, 17:34:06, at Kashiwazaki station had three components

1. **Intensive initial spike** (<~a few milliseconds, exceeds 10 MeV)
2. **Gamma-ray afterglow** (<~100 ms, <10 MeV)
3. **Delayed annihilation gamma rays** (~minute, at 0.511 MeV)





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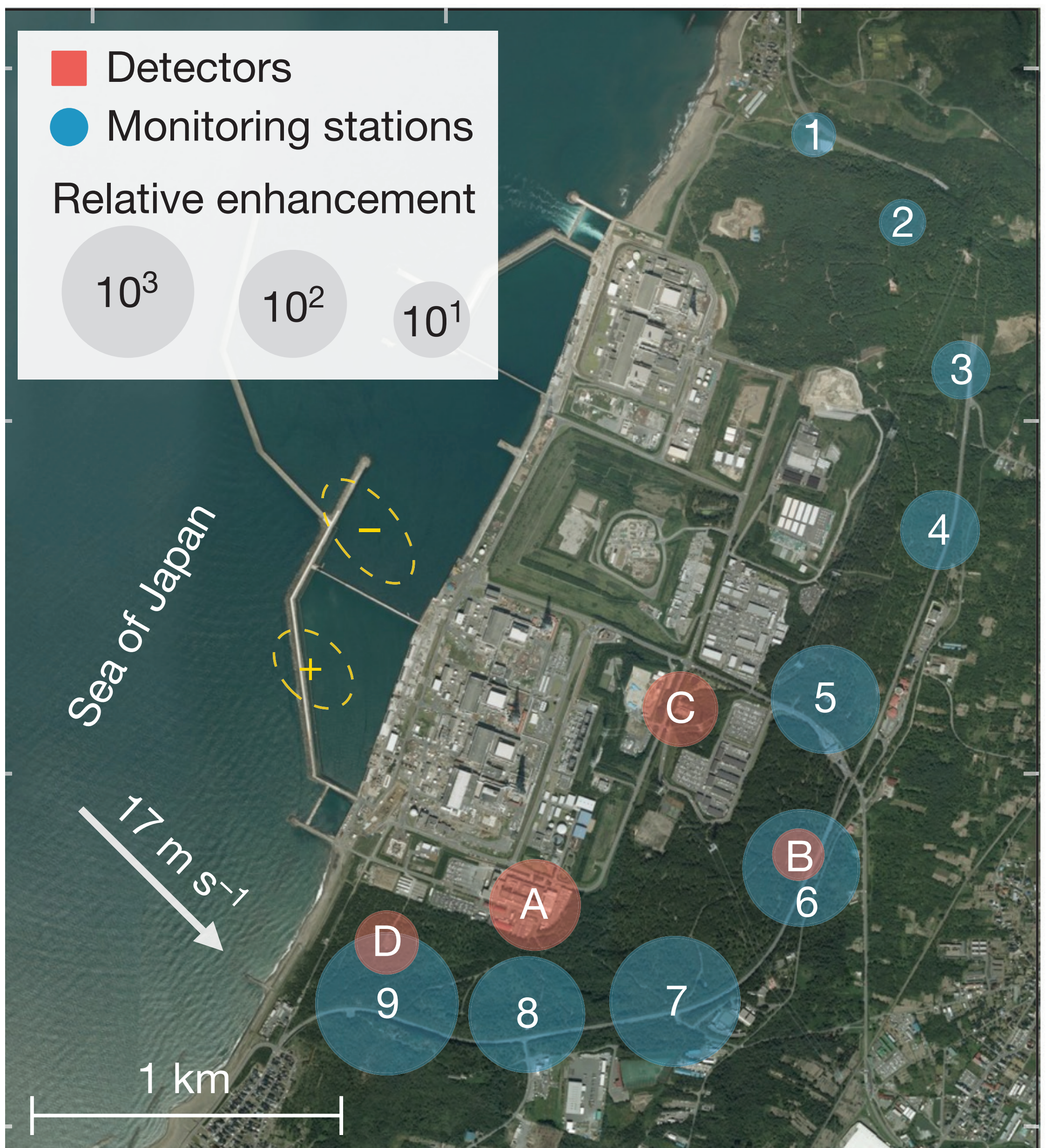
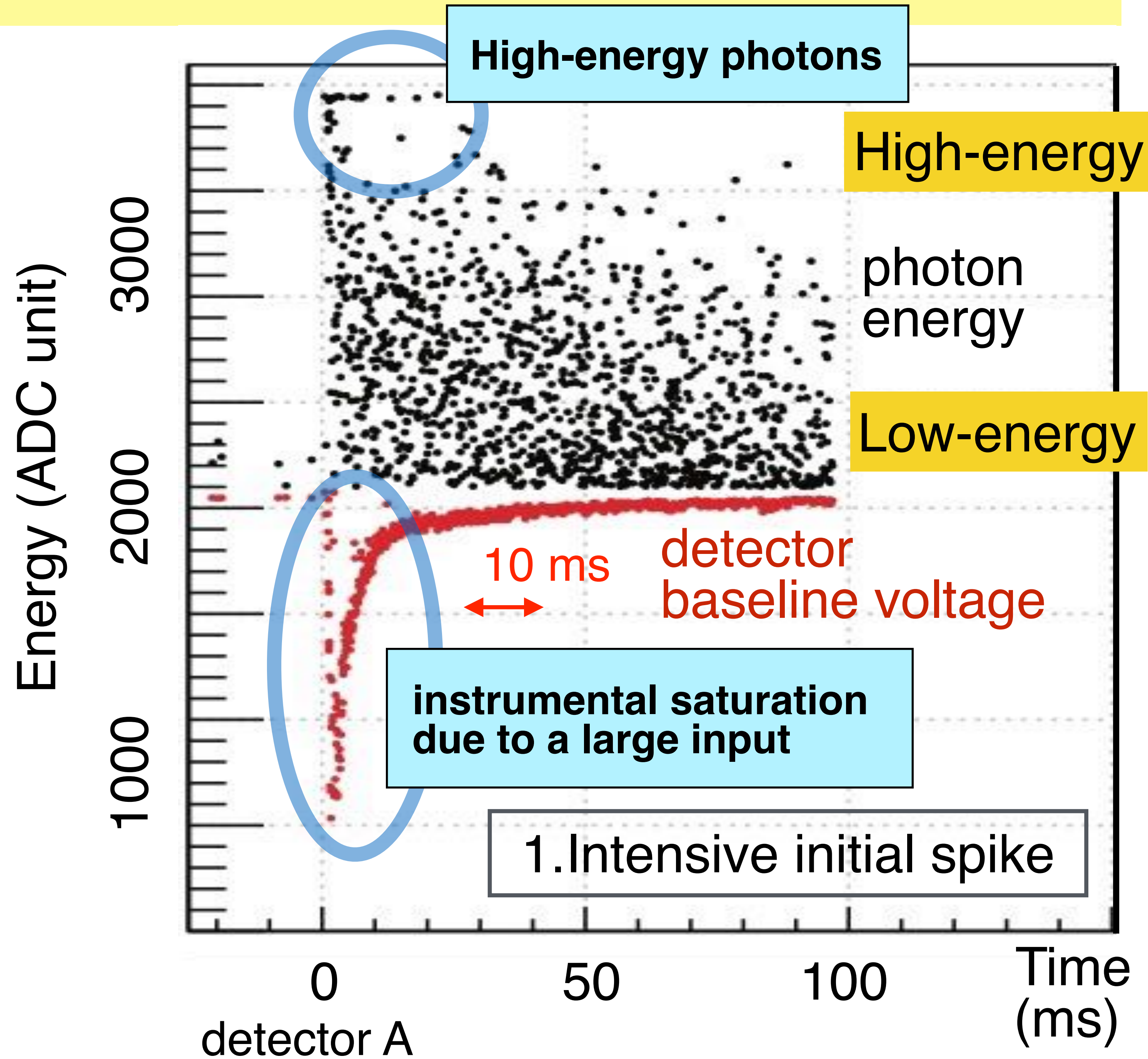
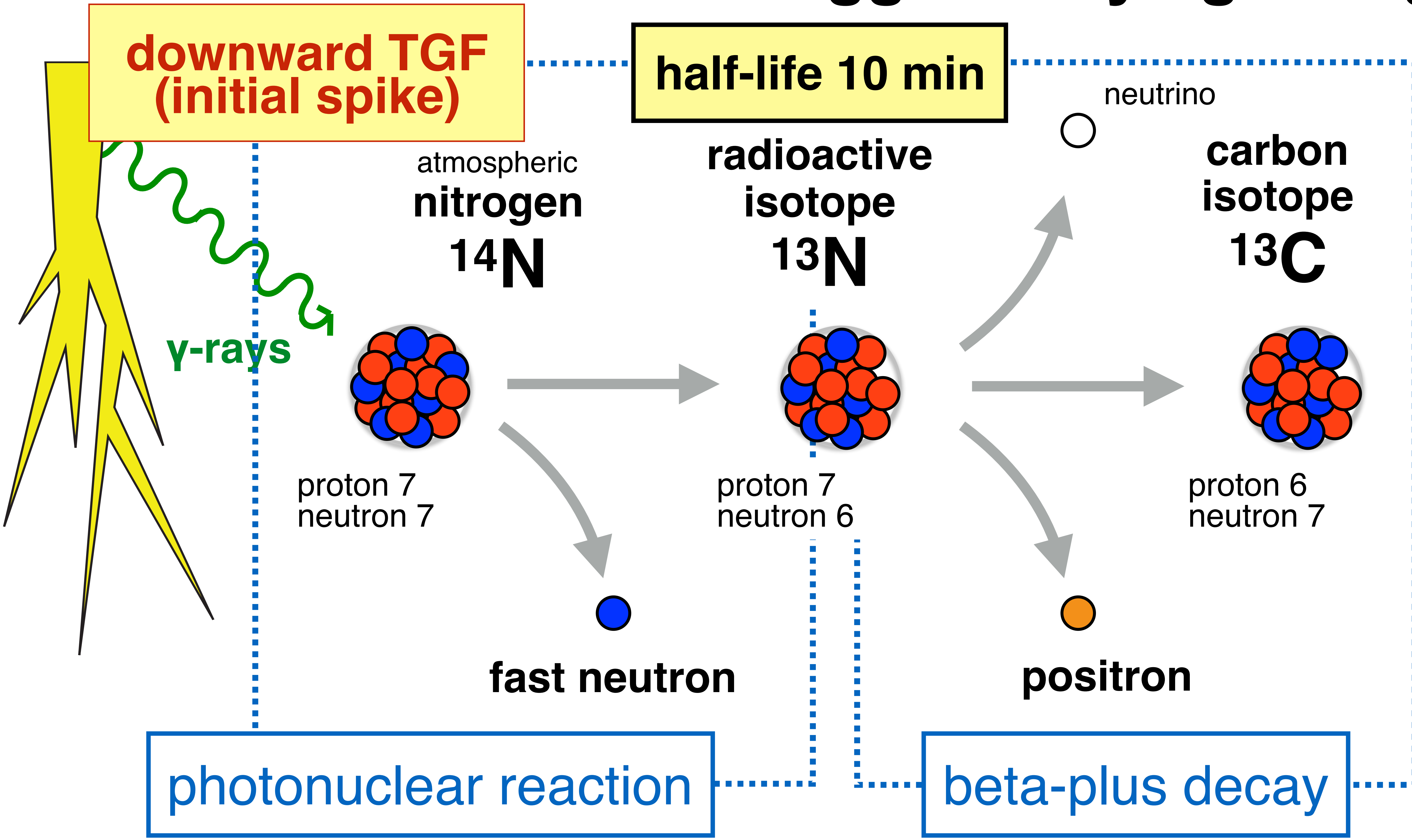




Photonuclear reactions triggered by lightning



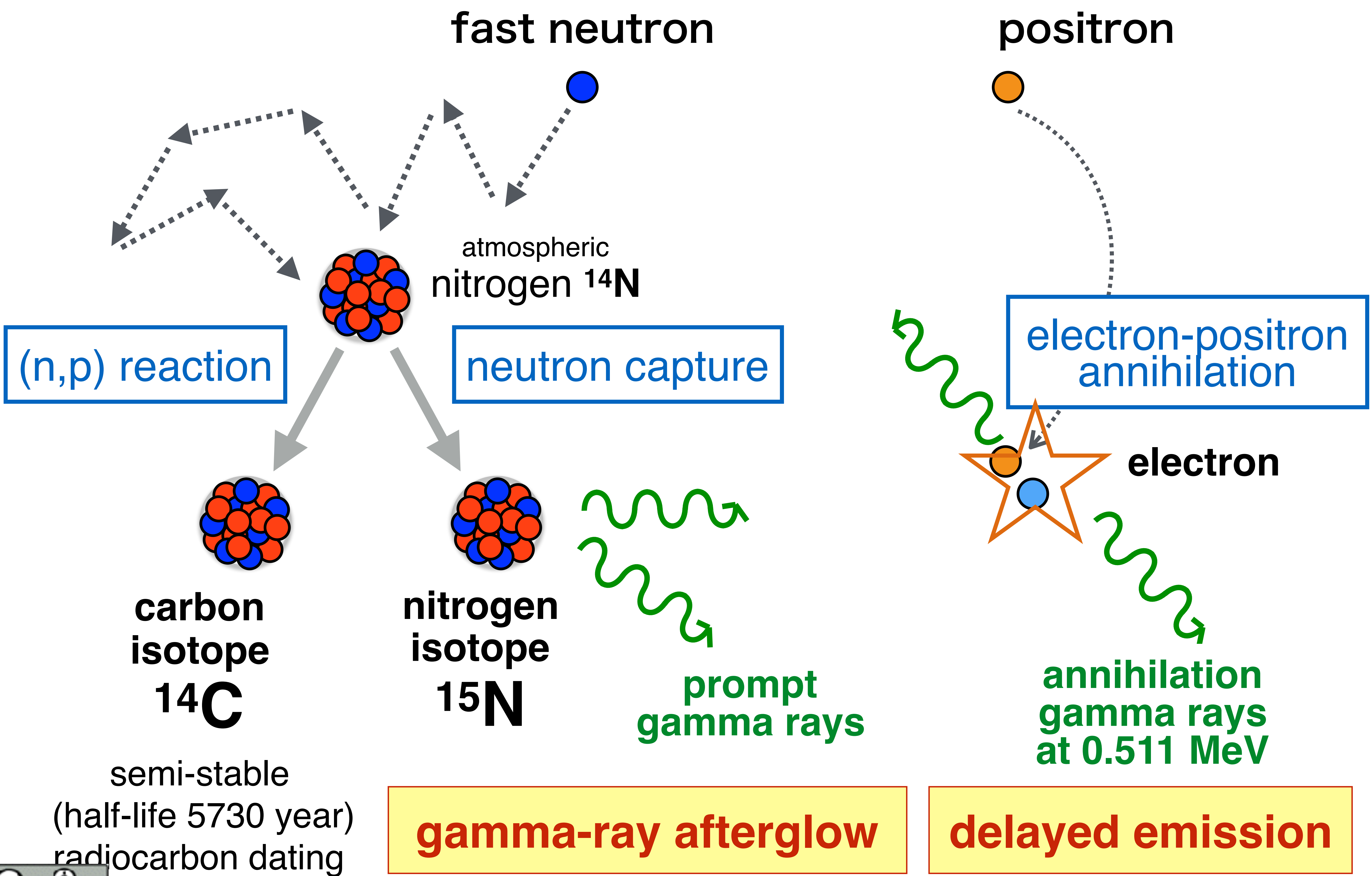
$$\gamma + {}^{14}N \rightarrow {}^{13}N + n$$

$$ {}^{13}N \rightarrow {}^{13}C + e^{+} + \nu$$
$$(p \rightarrow n + e^{+} + \nu)$$

fast neutron

positron

Gamma rays from neutron and positrons



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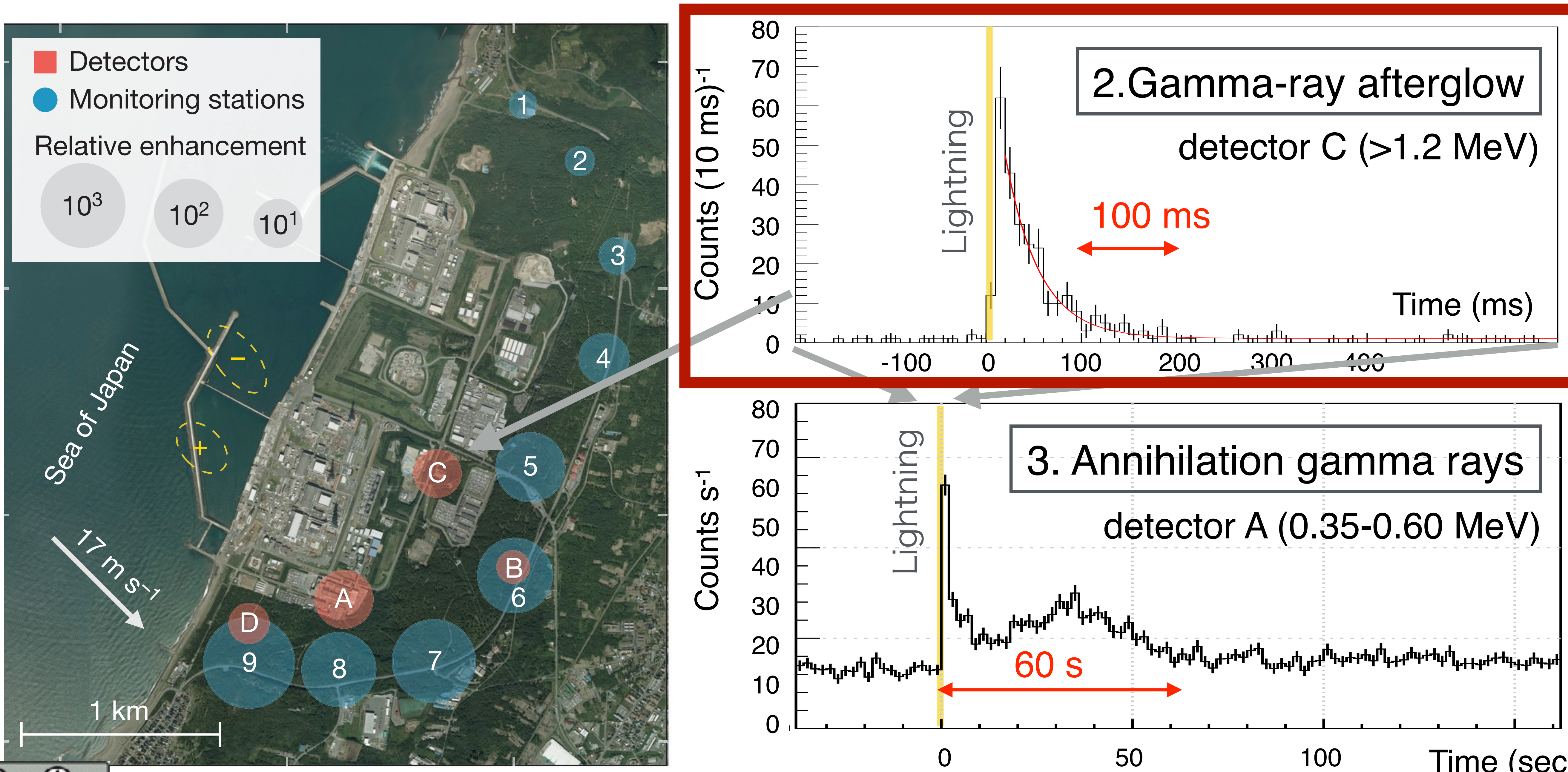
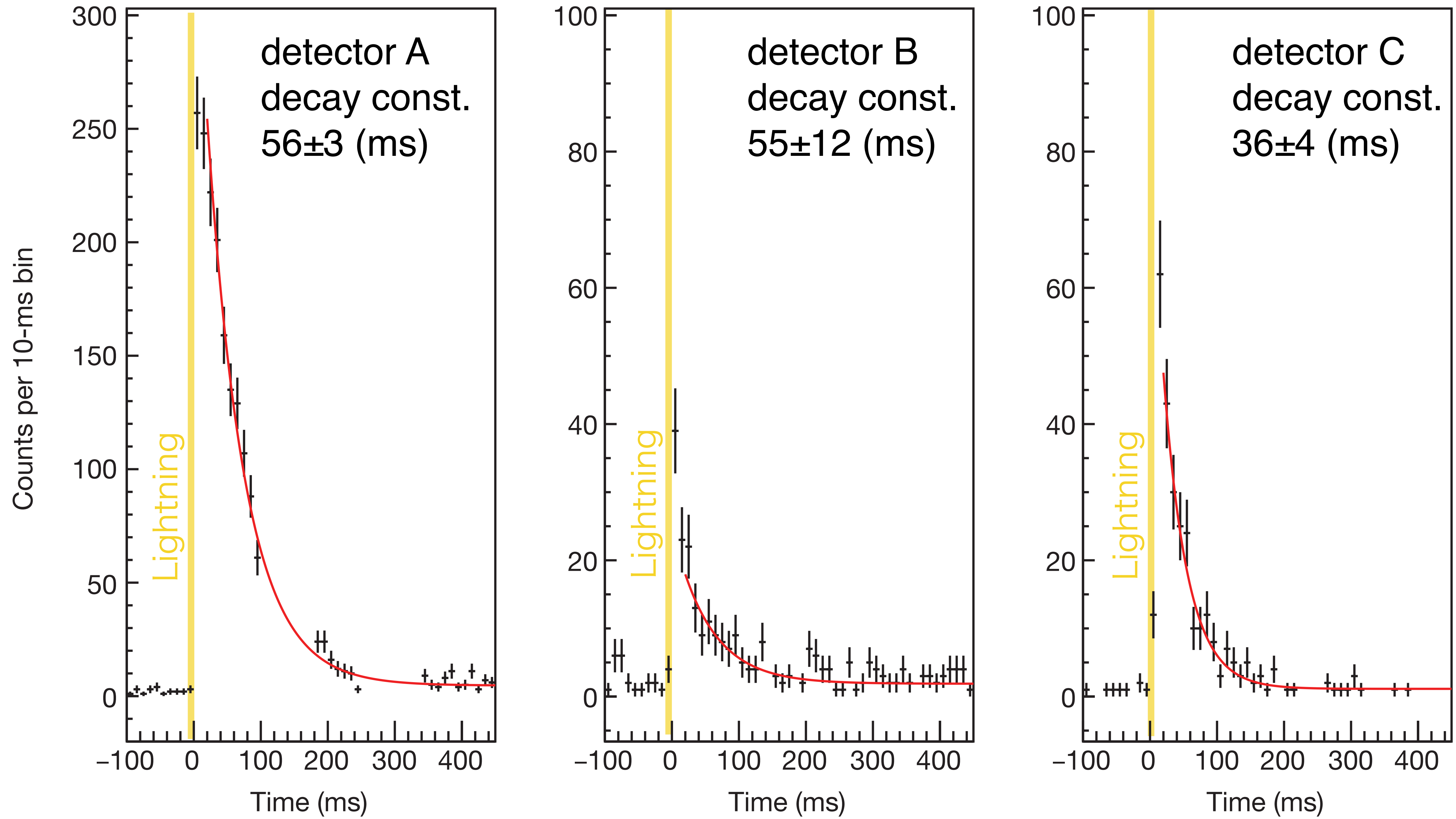


Neutrons make the gamma-ray afterglow



- Exponential decay constant of the sub-second afterglow is consistent with the theoretical prediction ~56 ms of the neutron thermalisation.

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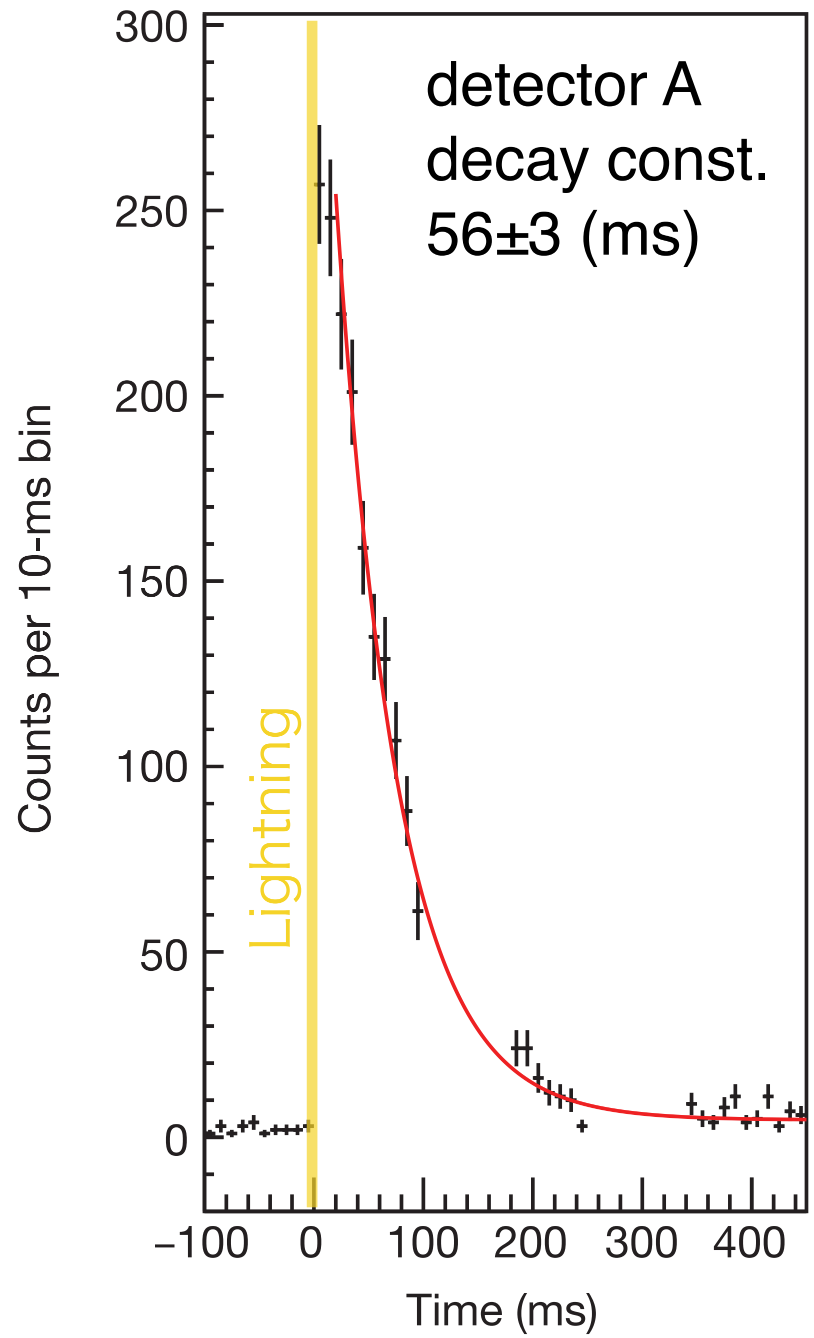

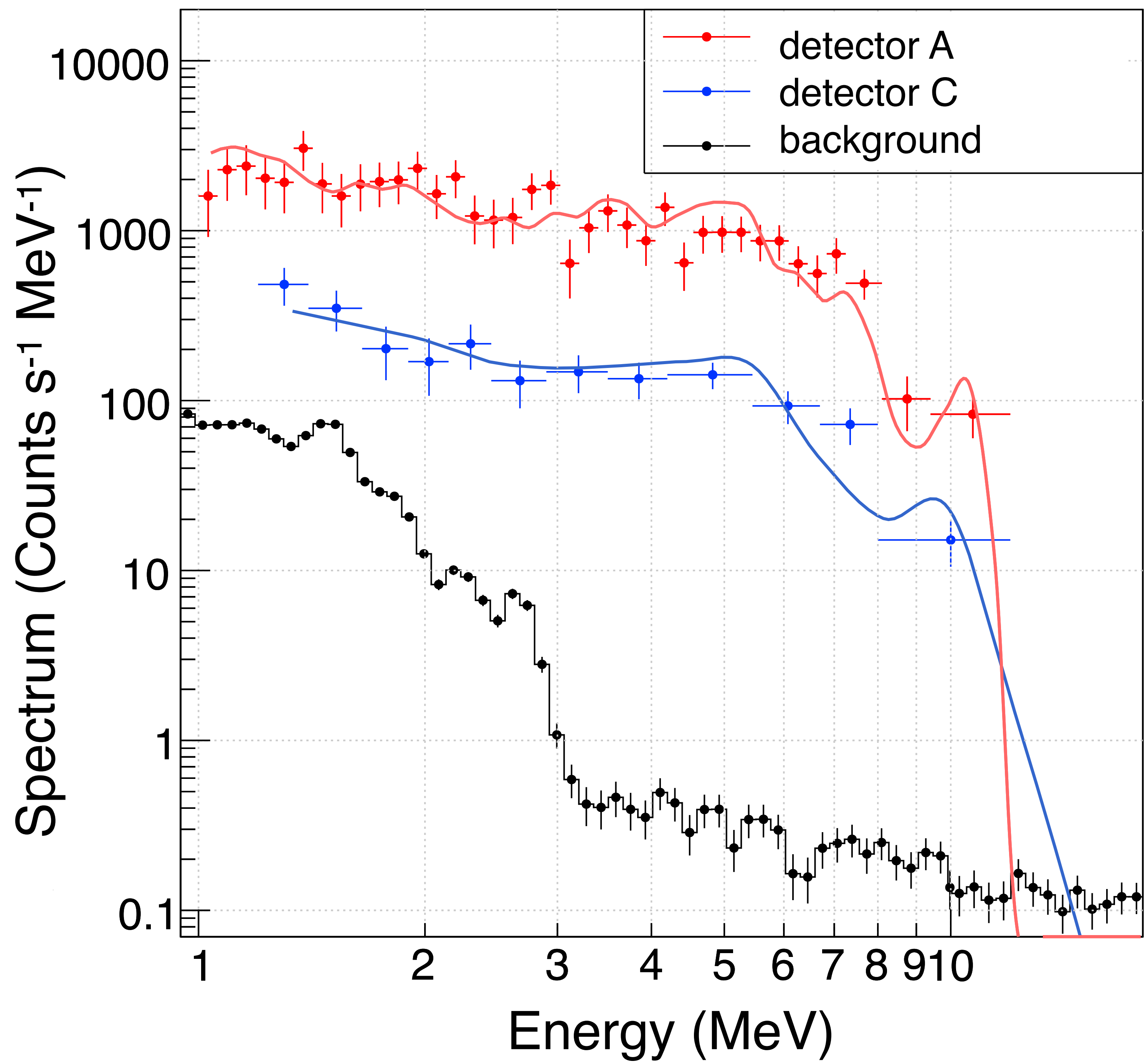

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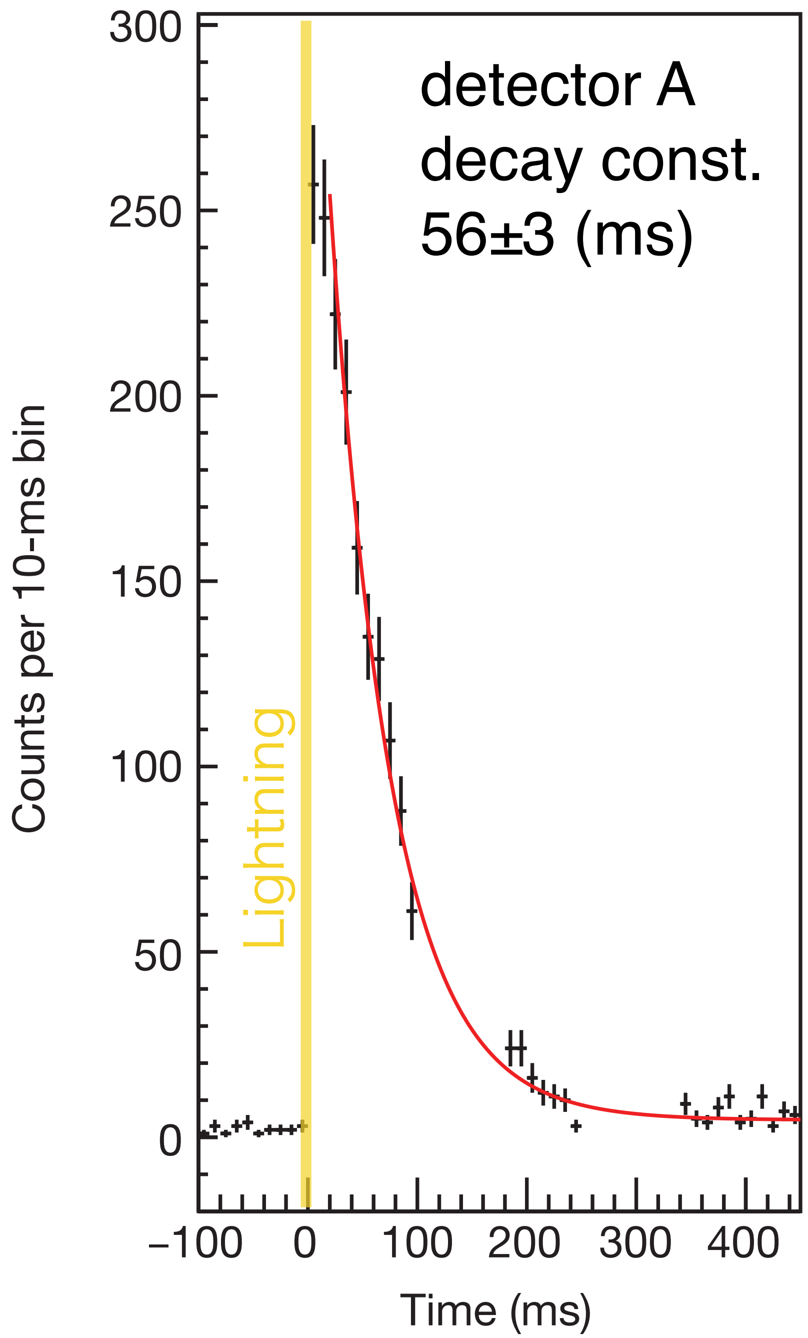

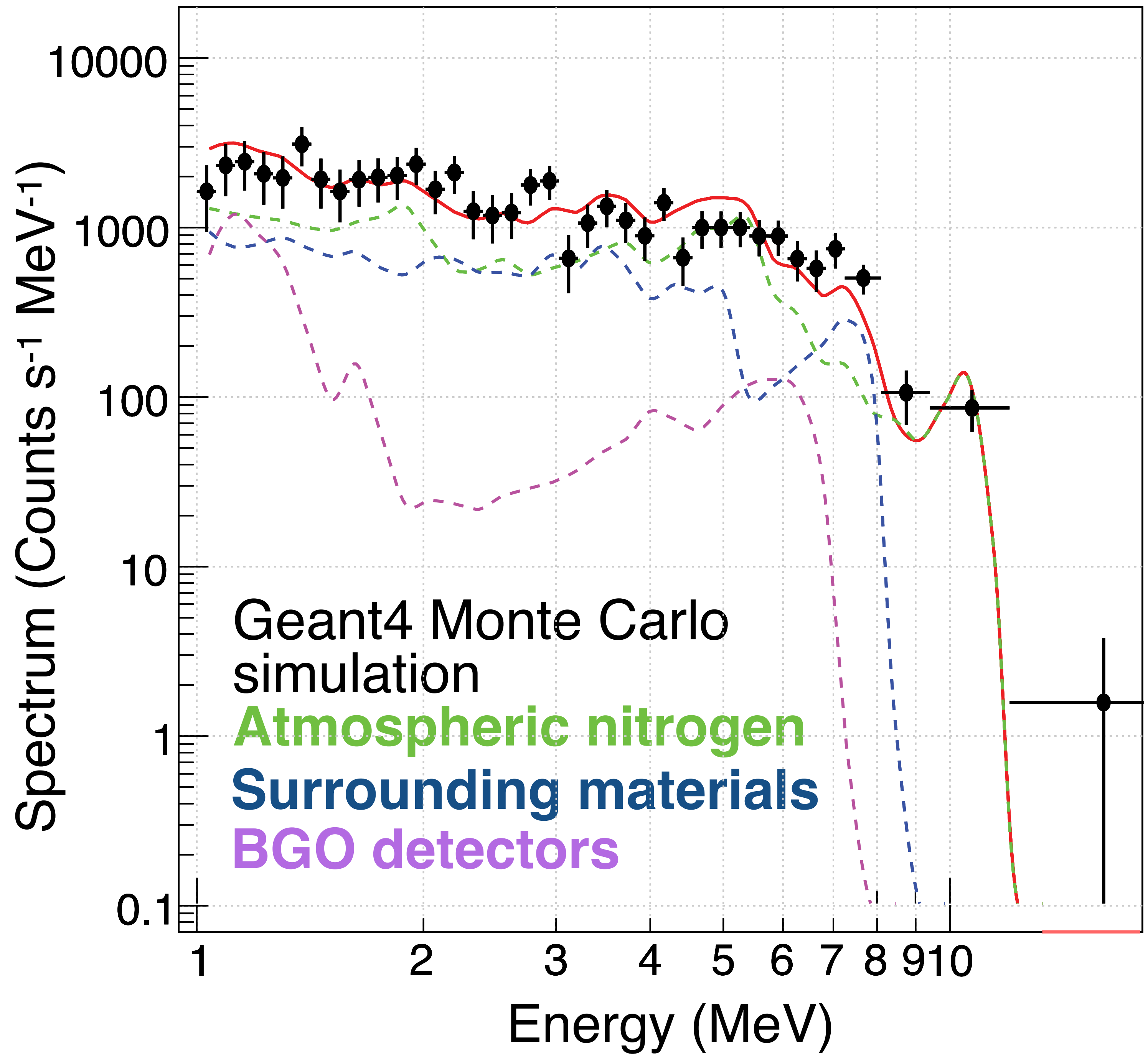

- Exponential decay constant of the sub-second afterglow is consistent with the theoretical prediction ~56 ms of the neutron thermalisation.
- Spectrum with a sharp cutoff at 10 MeV is well explained by prompt gamma rays from atmospheric nitrogens and surrounding materials.

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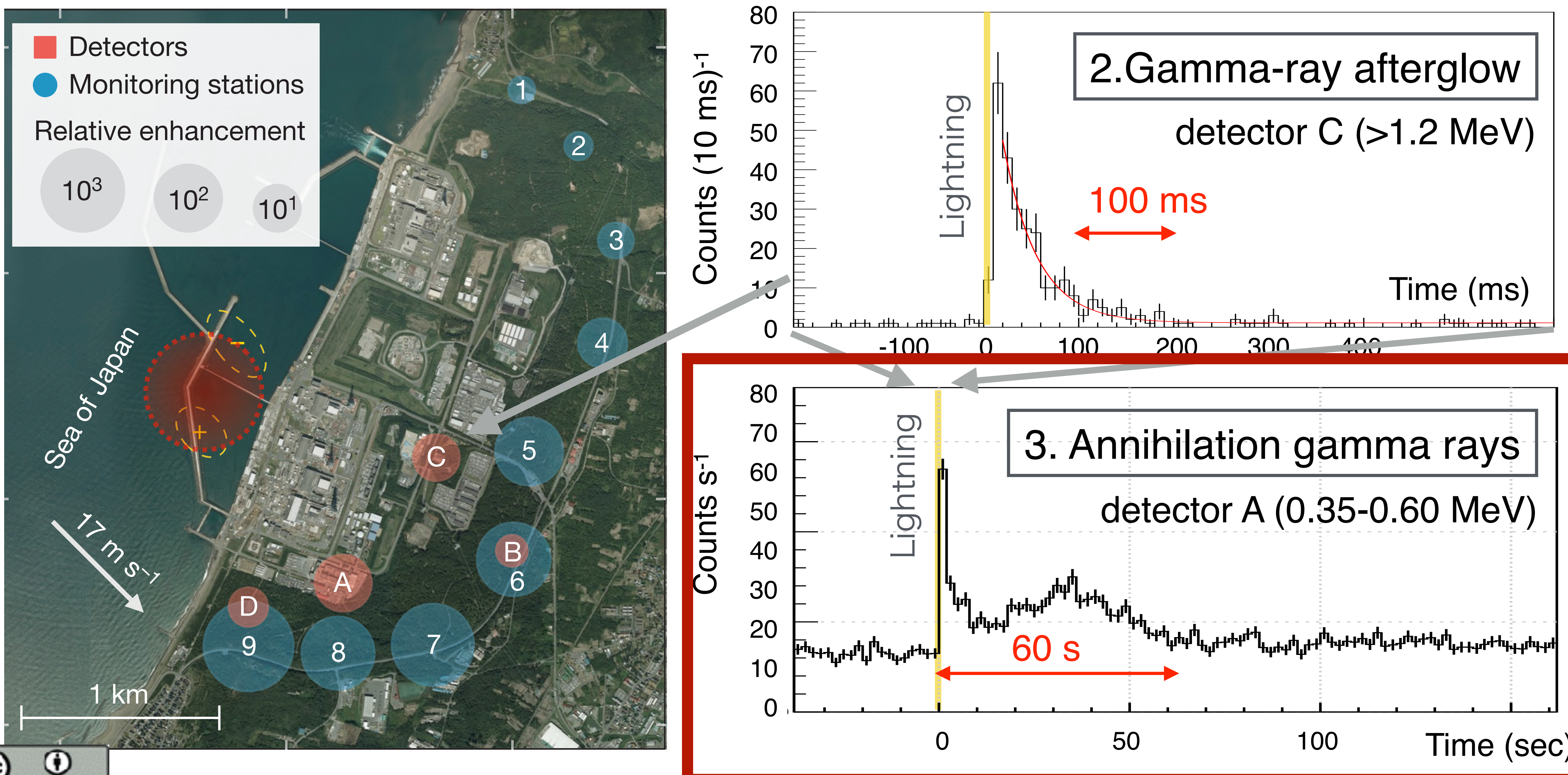
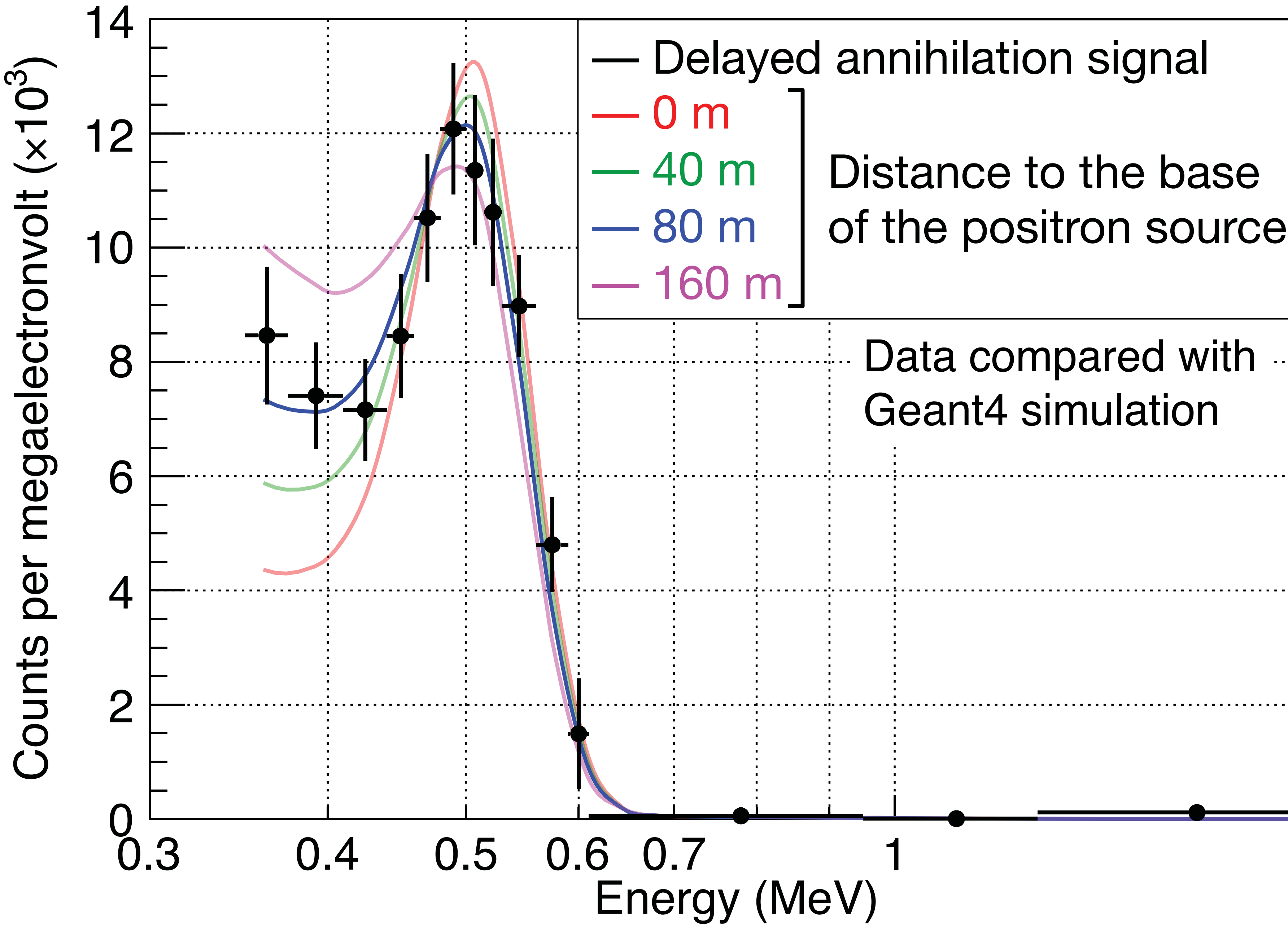
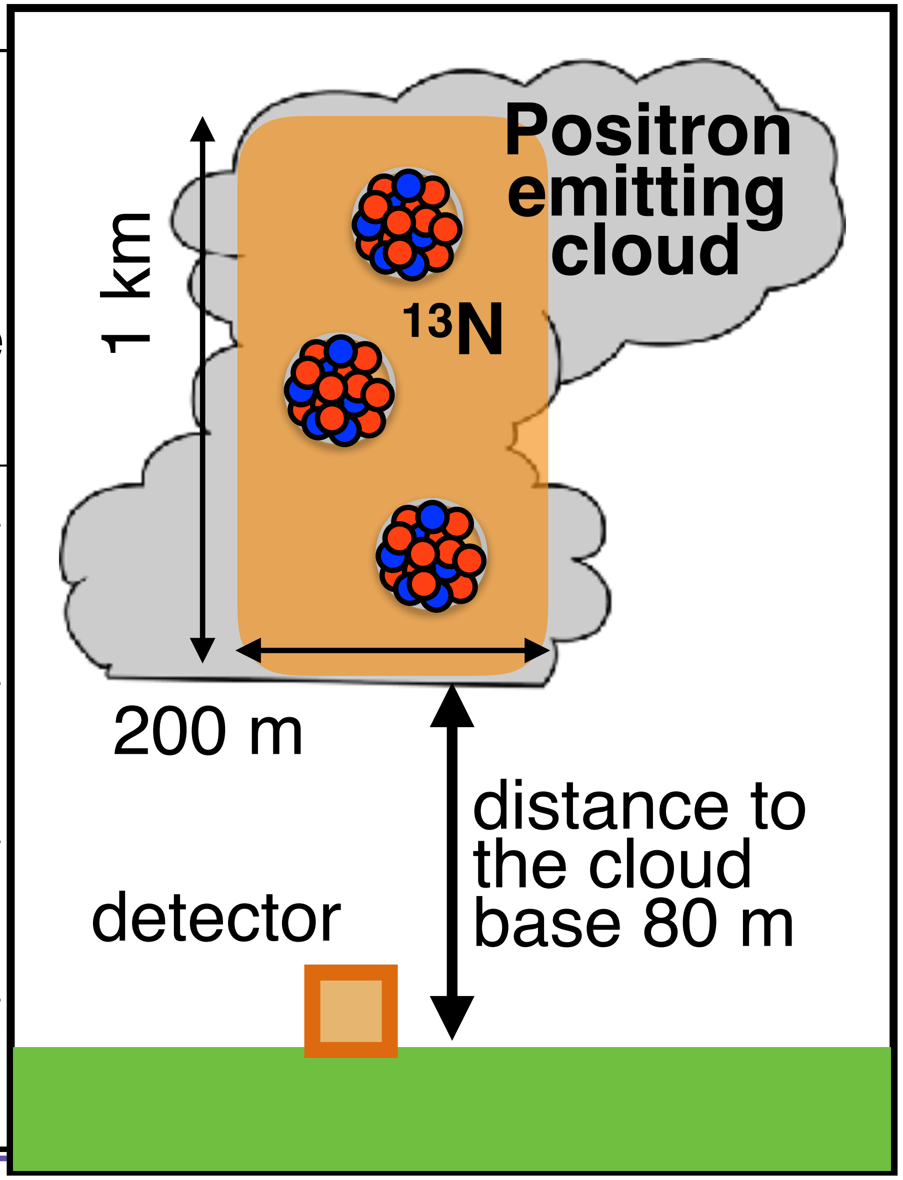


Positron annihilation signal at 0.511 MeV

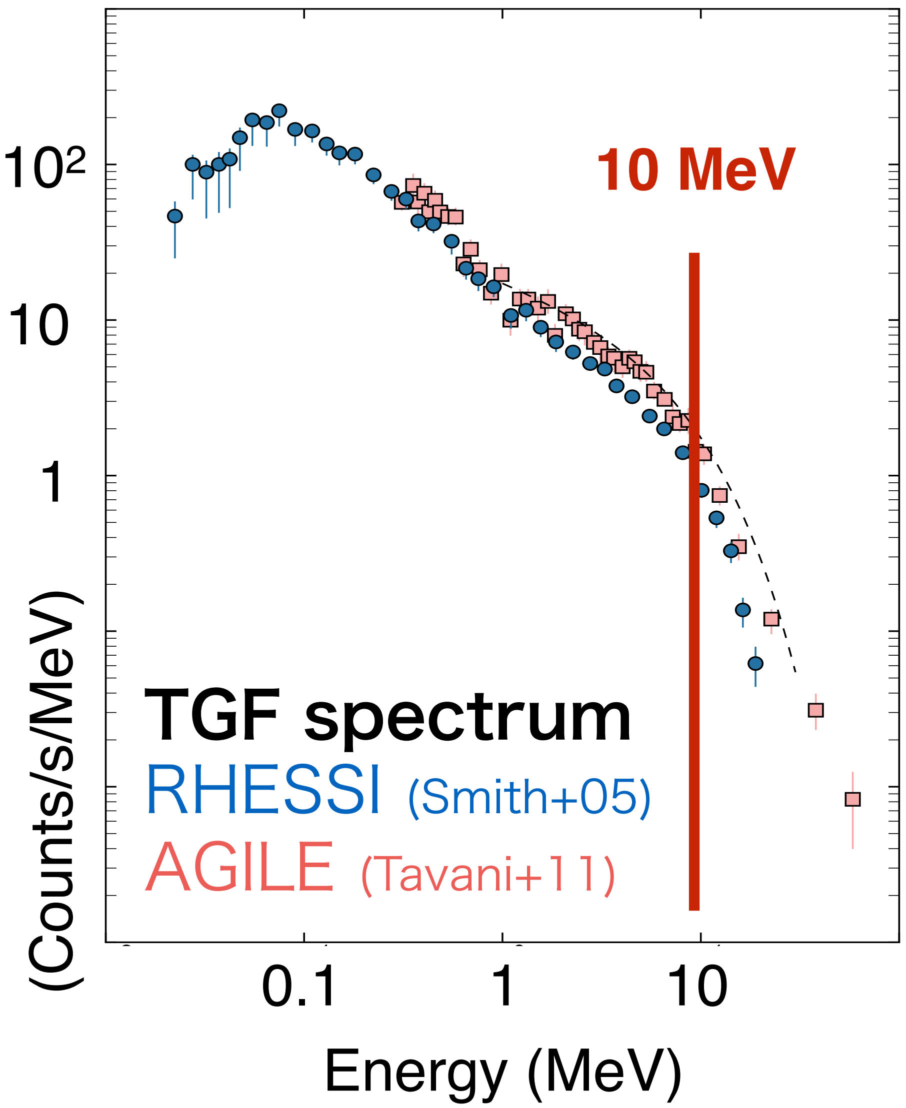
- The ~35 sec delay is consistent with the cloud moving from the lightning.
- The duration ~13 sec (1σ) x wind speed ~17 m/s → emission size ~200 m

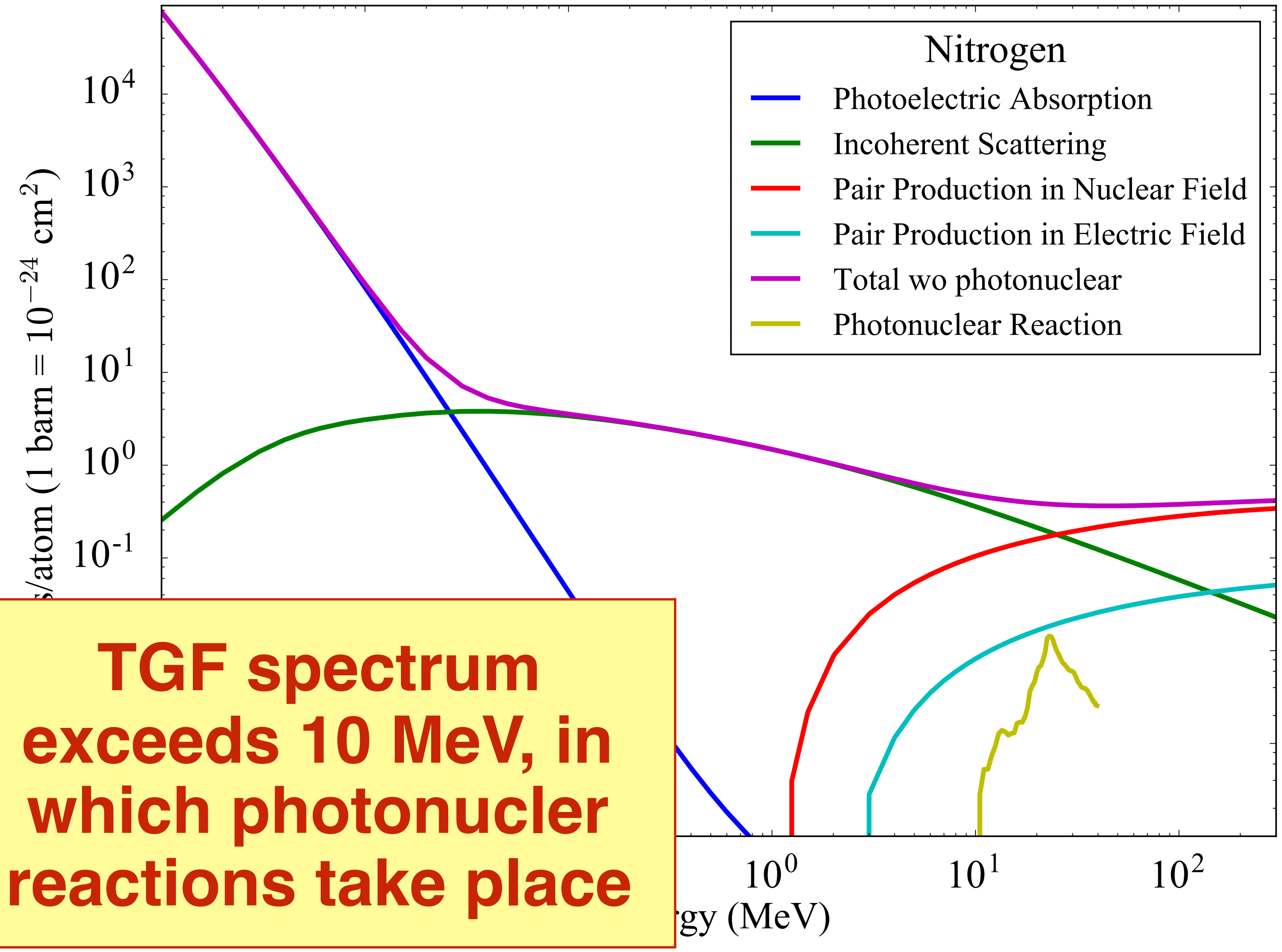




- Relative intensity of the 0.511 MeV emission line and continuum below it gives a distance to the base of the positron-emitting cloud: ~80 m
- A lightning-triggered photonuclear event produces 4×10^{12} neutrons.

Discussion





TGF spectrum exceeds 10 MeV, in which photonucler reactions take place

Estimated number of neutron 4×10^{12} produced by photonuclear reaction is within predicted range of 10^{11-15} (Babich+10, Carlson+14)**.**

- Atmospheric oxygen also contributes to the lightning photonuclear reactions.
- Can explain past reports of 0.511 MeV (Umemoto+2016) and neutrons (Bowers+2017).
- Lightning produces atmospheric ^{13}N, ^{15}N, ^{13}C, and ^{14}C isotopes.

Summary

- **GROWTH project has been observing high-energy atmospheric phenomena in the Japanese winter thunderstorm and lighting since 2006. We are also aiming at expanding to citizen science.**

- **We provided unequivocal evidence for the lightning-triggered photonuclear reactions of atmospheric nitrogen $^{14}N+\gamma \rightarrow {}^{13}N+n$; (1) downward terrestrial gamma-ray flash, (2) gamma-ray afterglow of thermalised neutrons, and (3) annihilation gamma-ray signal at 0.511 MeV from the beta-plus decay of ^{13}N.**

- **Lightning provides channels to generate carbon isotopes.**

Enoto, Wada, Furuta et al., *Nature* 551, 481 (2017)

Selected as one of the Top 10 Physics Breakthroughs of 2017 by Physics World magazine, IOP Publishing Ltd

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