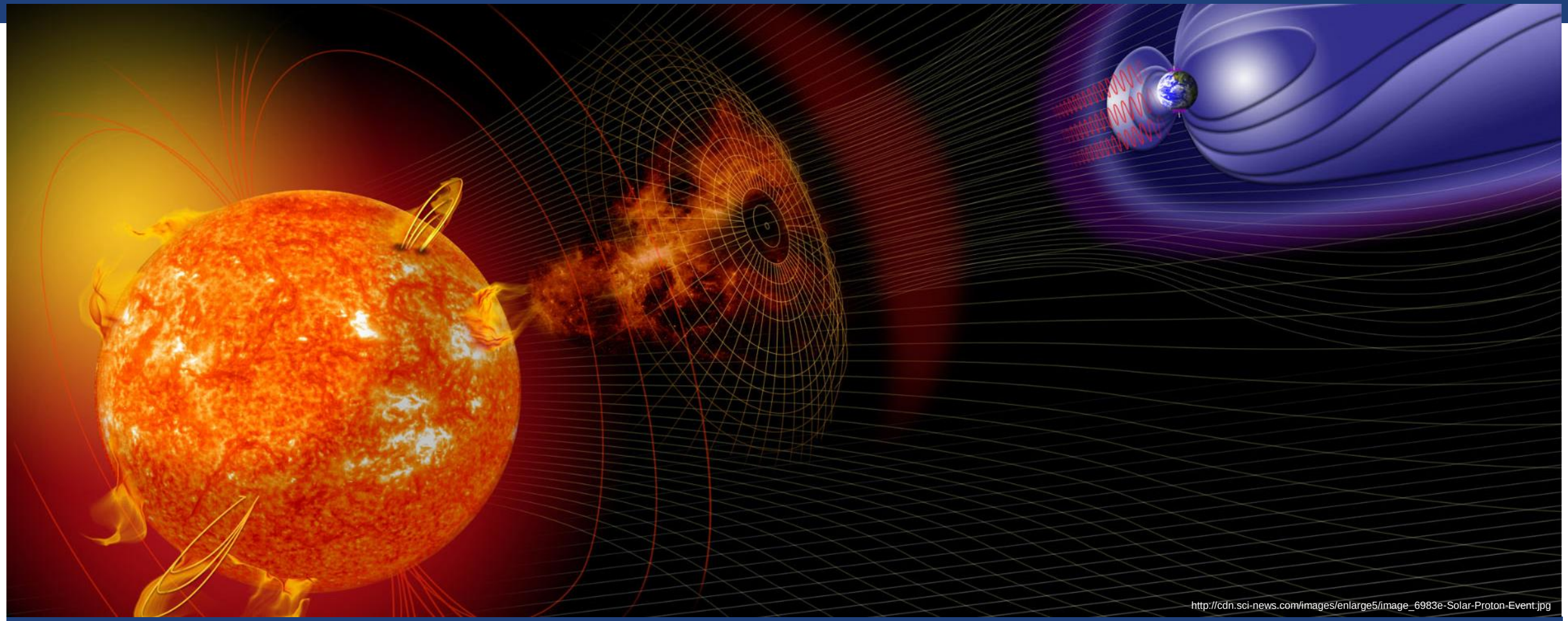
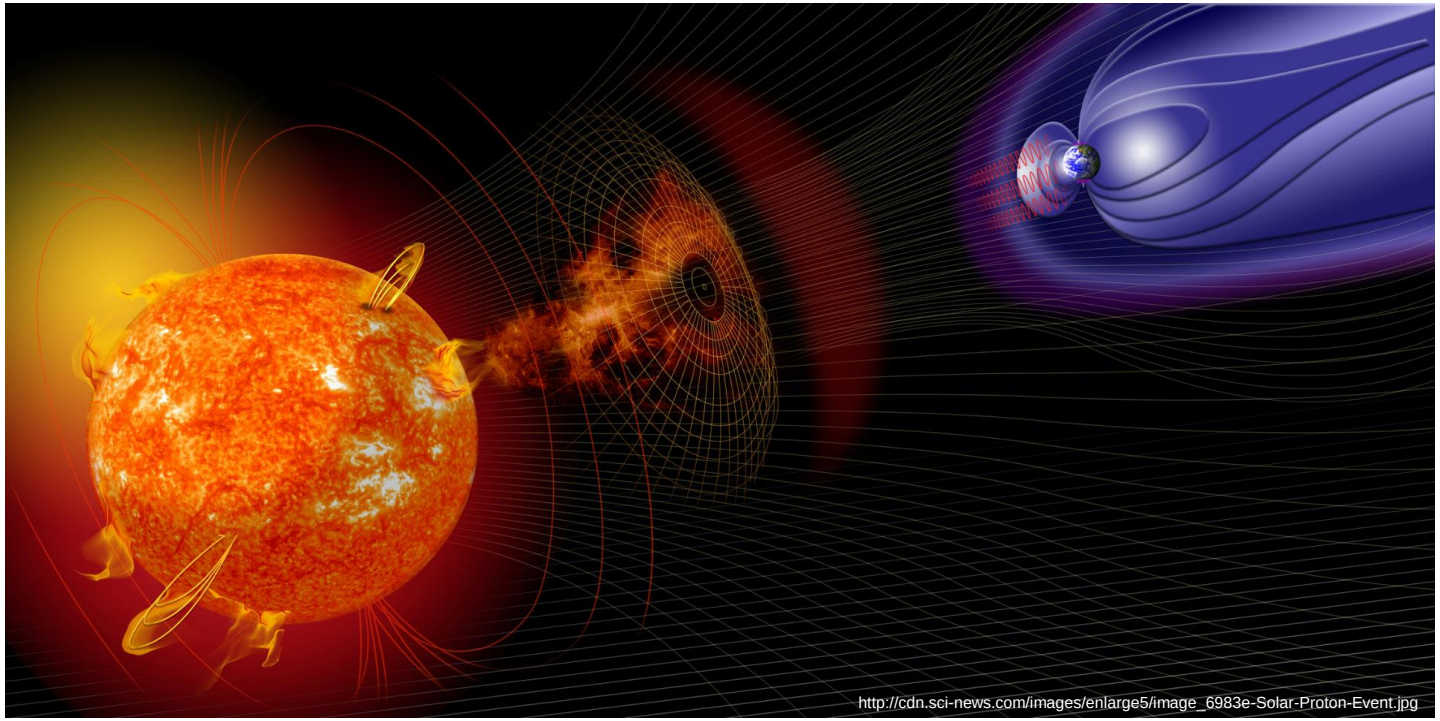



# Detection of solar proton events by using radiocarbon in tree-rings

Nicolas Brehm, Marcus Christl, Hans-Arno Synal, Raimund Muscheler, Florian Adolphi, Alex Bayliss, Timothy Knowles, Emanuelle Casanova, Kurt Nicolussi, and Lukas Wacker

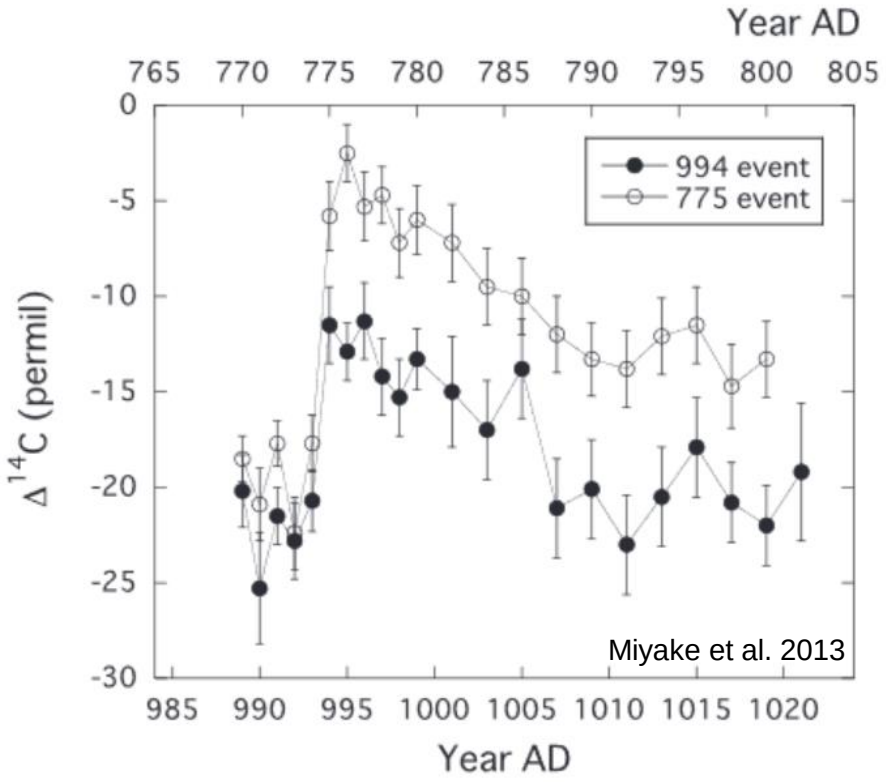
# Solar energetic particle (SEP) events

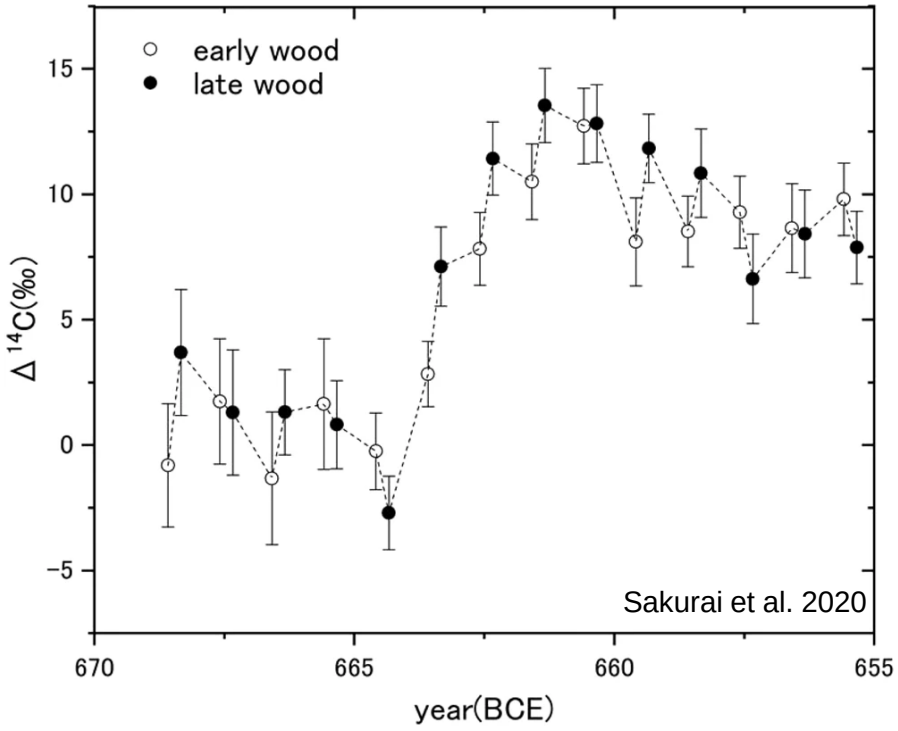
- **Sun irregularly expels large amounts of particles (solar flares)**
- **Solar energetic protons (SEP) induce radionuclide production spike**



# Solar energetic particle (SEP) events

**3 events were so far detected by using radionuclides (775 AD, 993 AD and 664 BC)**

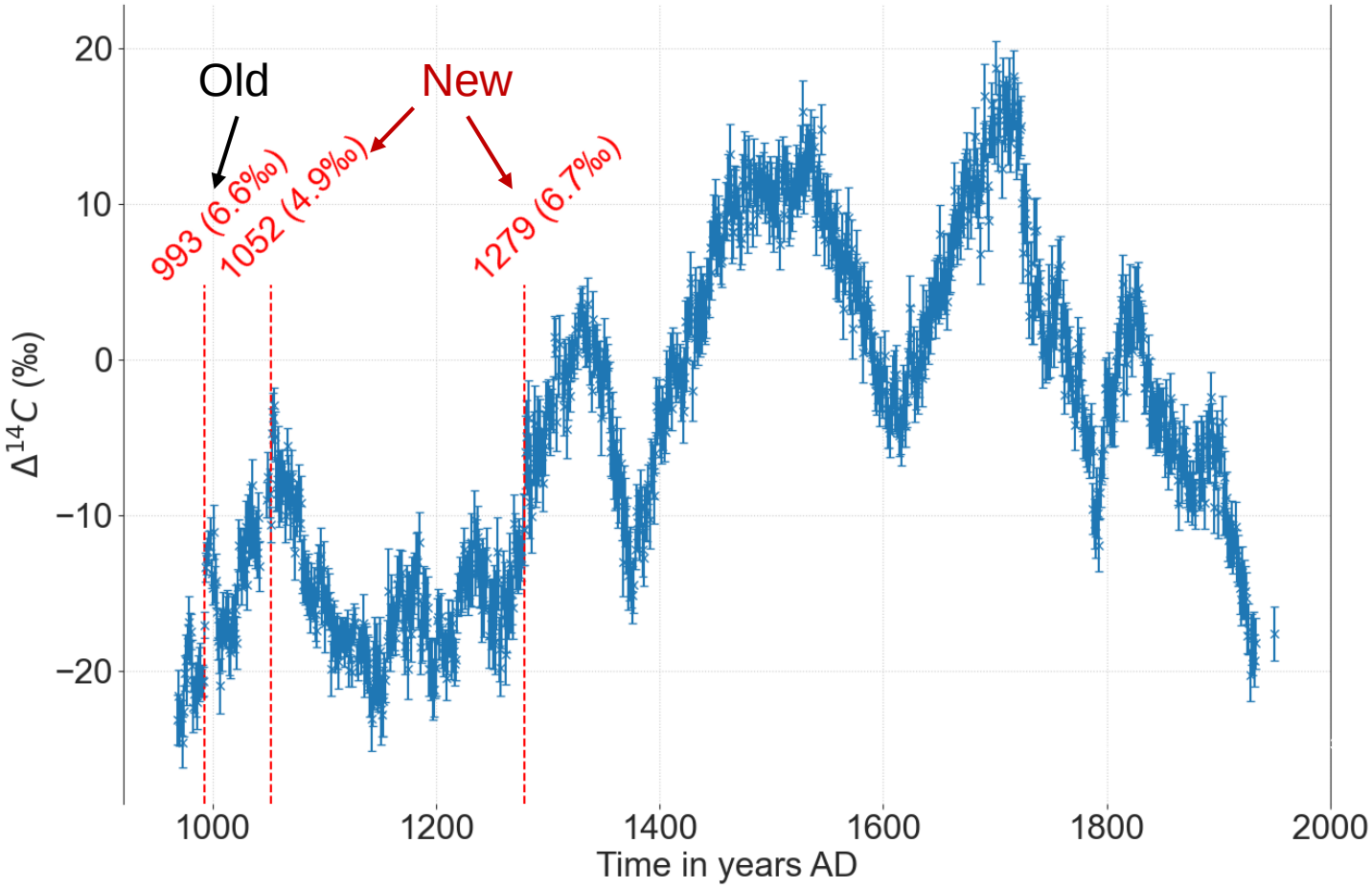


# Solar energetic particle (SEP) events during the last 1000 years

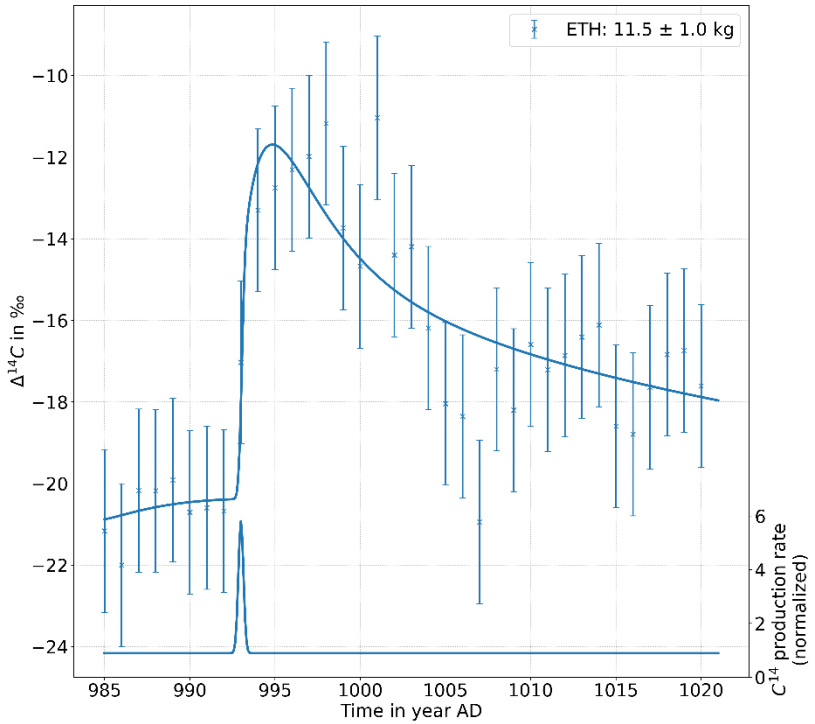
- **2 new abrupt increases in $\Delta^{14}C$ (more than 4.5‰) found in annual 1000 yr record!**
- **Now 3 events per 1000 yr?**

**Maybe more than expected?**

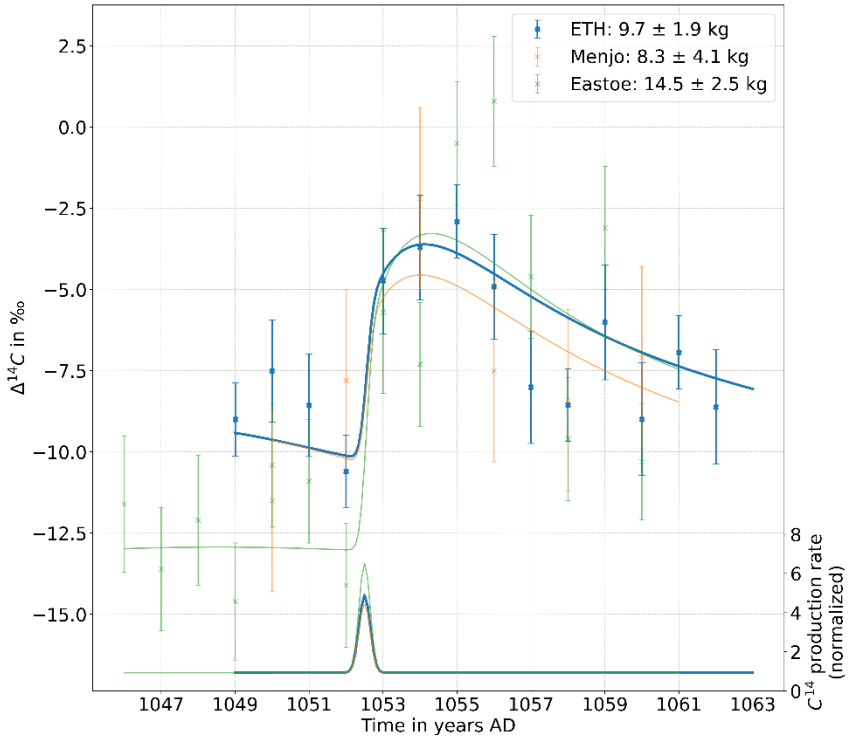


# Modelling of events for the last 1000 years

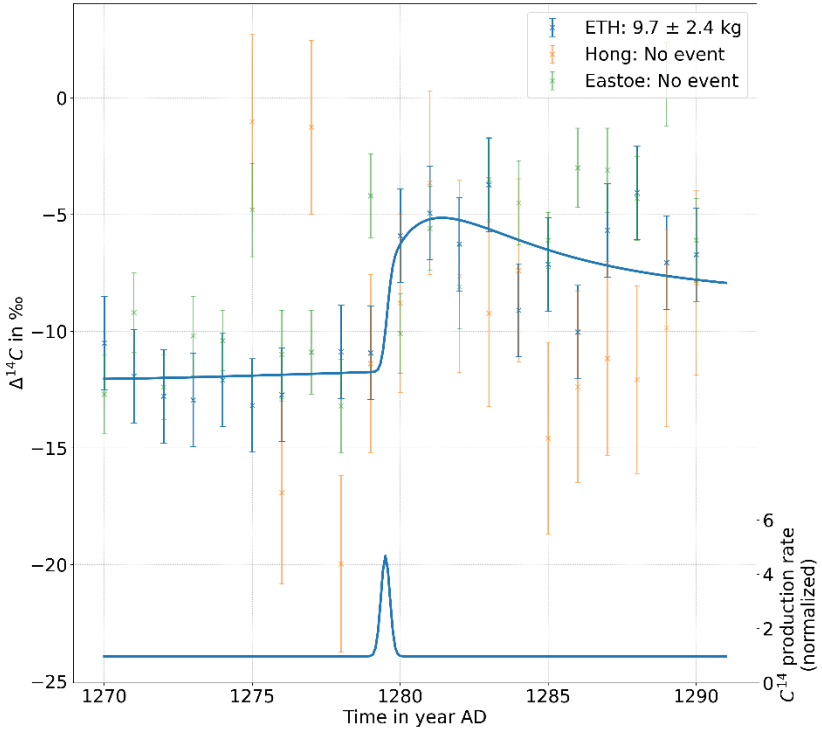
## 993 Event




## 1052 Event




## 1279 Event



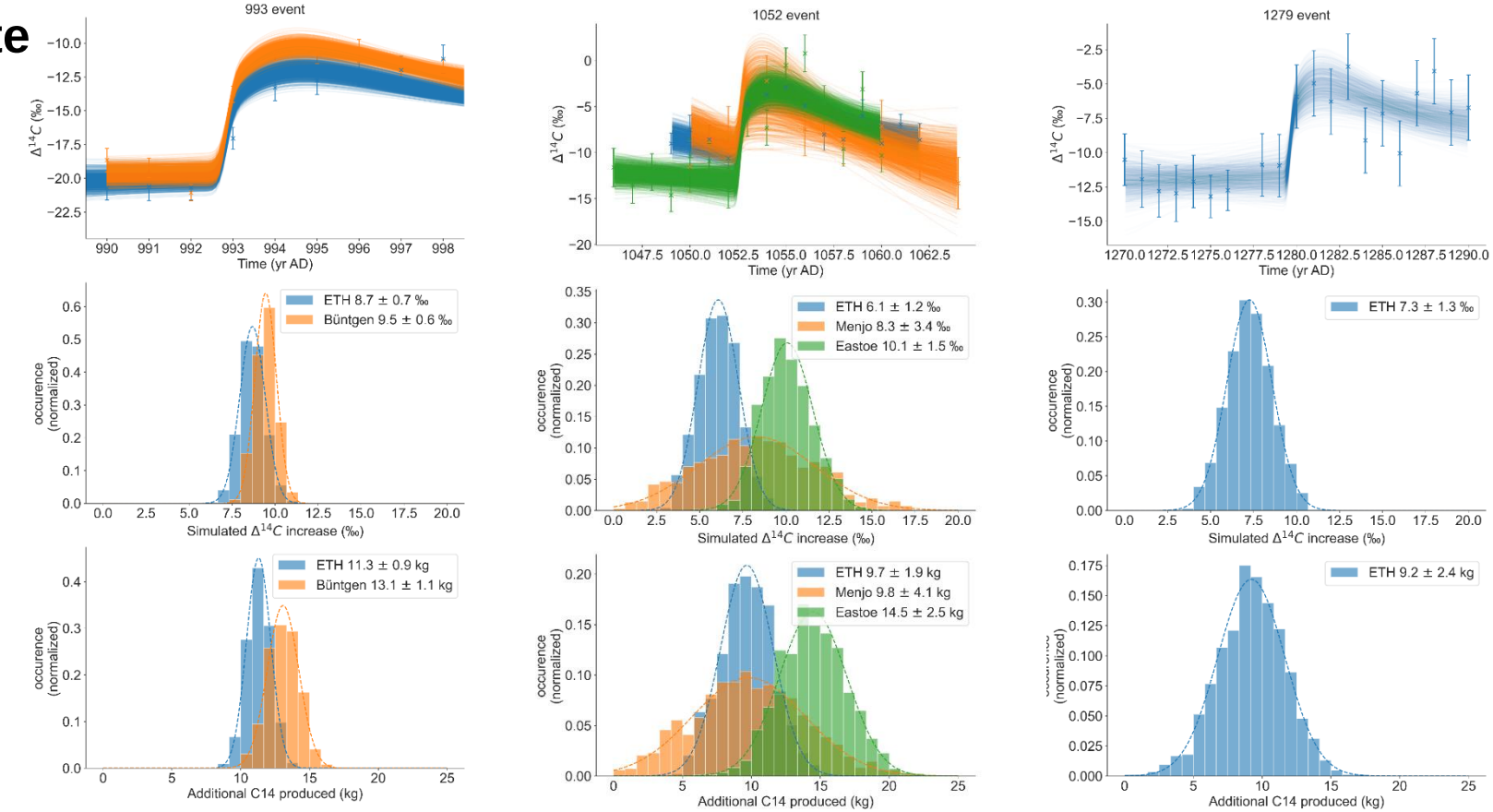

- **3 events are similar in amplitude, production more than double for one year (average annula $^{14}C$ production 6.6 kg)**

# Monte Carlo simulation

**Evaluation with 1000 Monte Carlo simulations to estimate:**

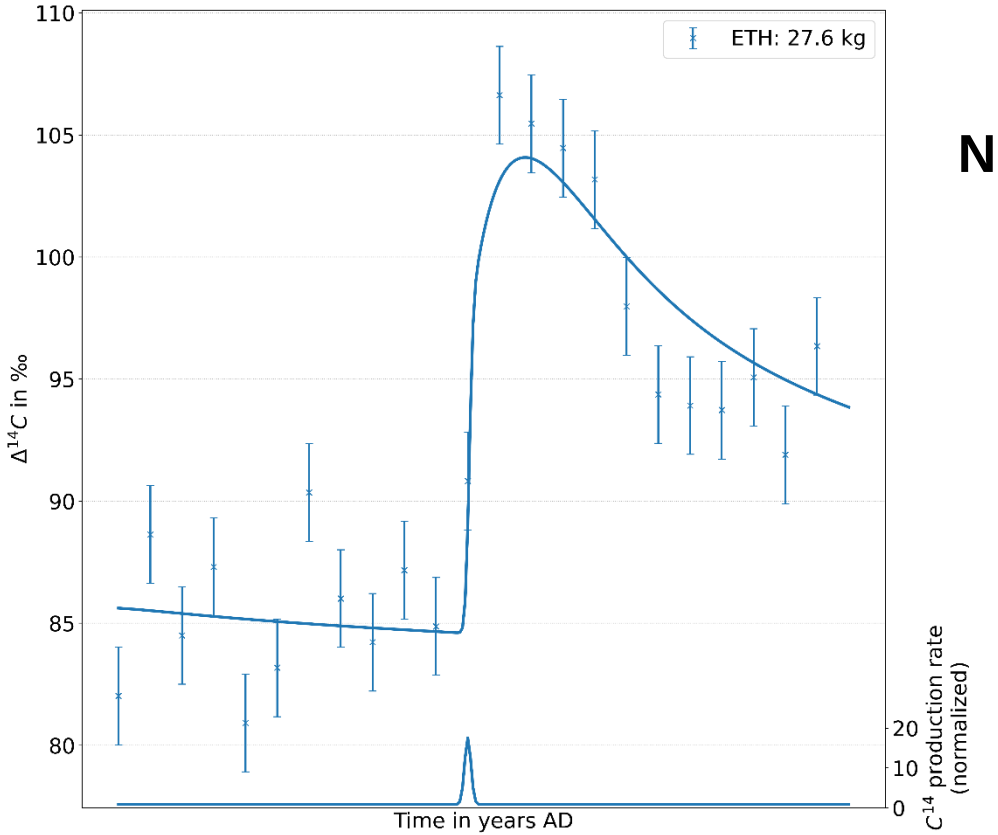
- **$\Delta^{14}C$ increase**
- **$^{14}C$ production due to event** (in addition to annual production due to cosmic rays)

*Modelled data:*
- *ETH Zürich*
- *Eastoe et al. 2019*
- *Menjo et al. 2005*



# Two new events around 9000 BP, and 7000 BP?

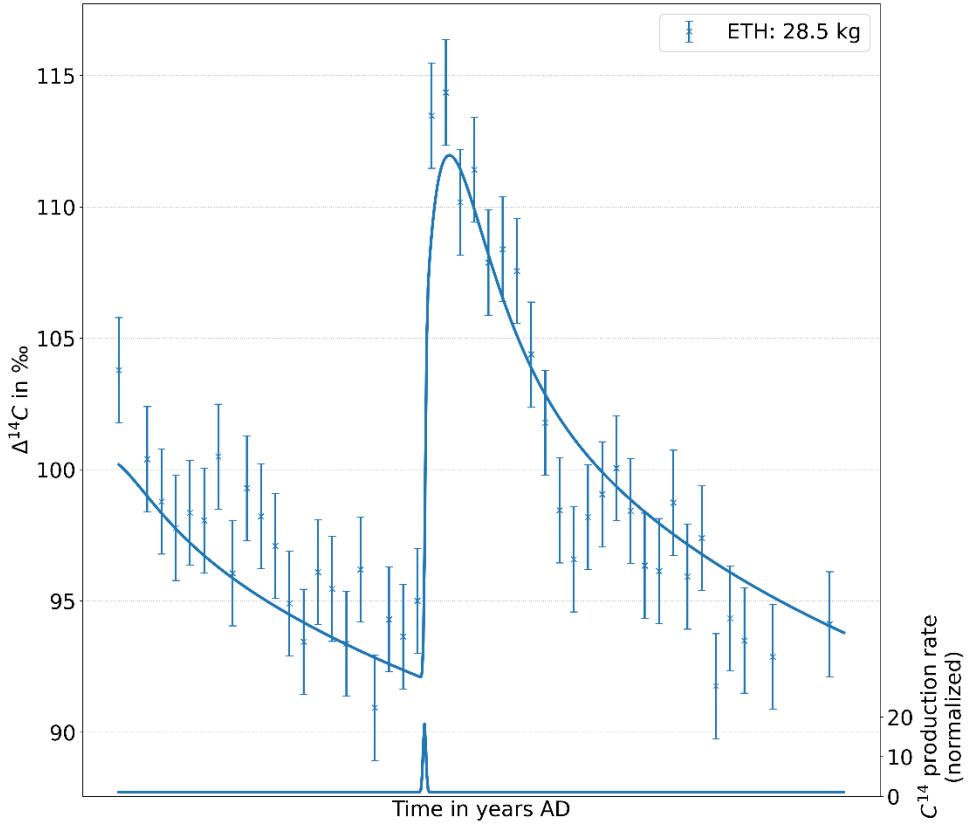
## 9000 BP



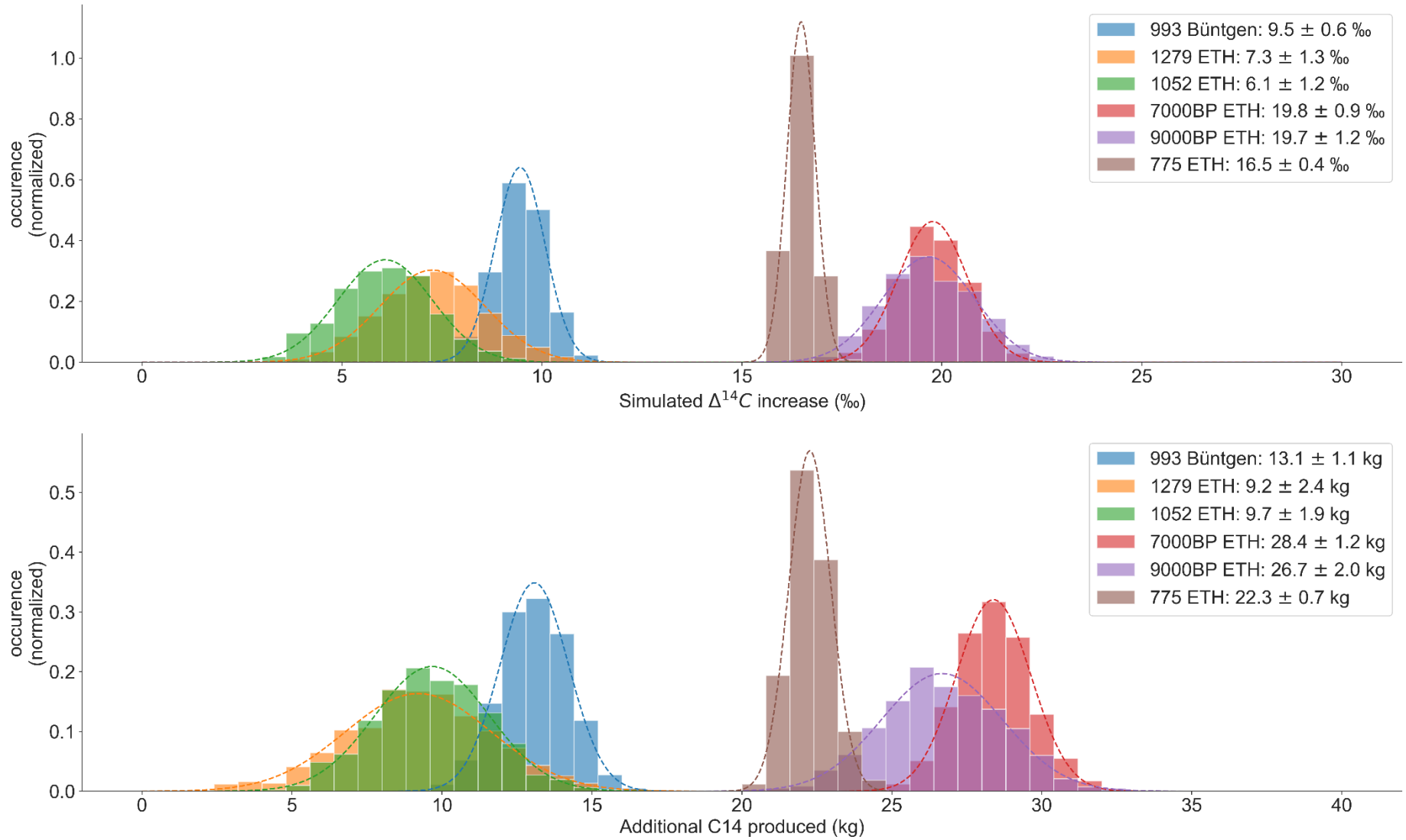

**Nearly 20‰ Δ¹⁴C increase!!**

**Stronger than 775 AD event?**

## 7000 BP



# Comparison



# Conclusions

- **With high-precision $^{14}C$ measurements more, weaker events can be detected (over last 1000 yr)**

- **Also more strong events can be expected further back in time! (that could not be identified by the previously available measurements)**

***What if this happens again today?***

- **Radiation may interrupt communication**
- **Computers may fail (in airplanes)**
- **Health problems…**