EUSO-TA ground based fluorescence detector: analysis of the detected events

Francesca Bisconti (JEM-EUSO Coll.)
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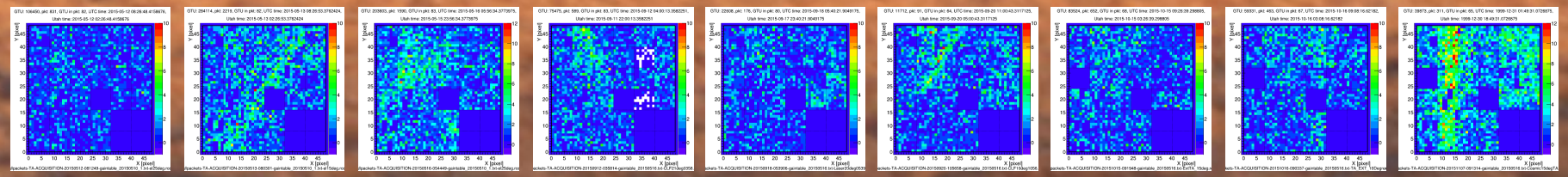


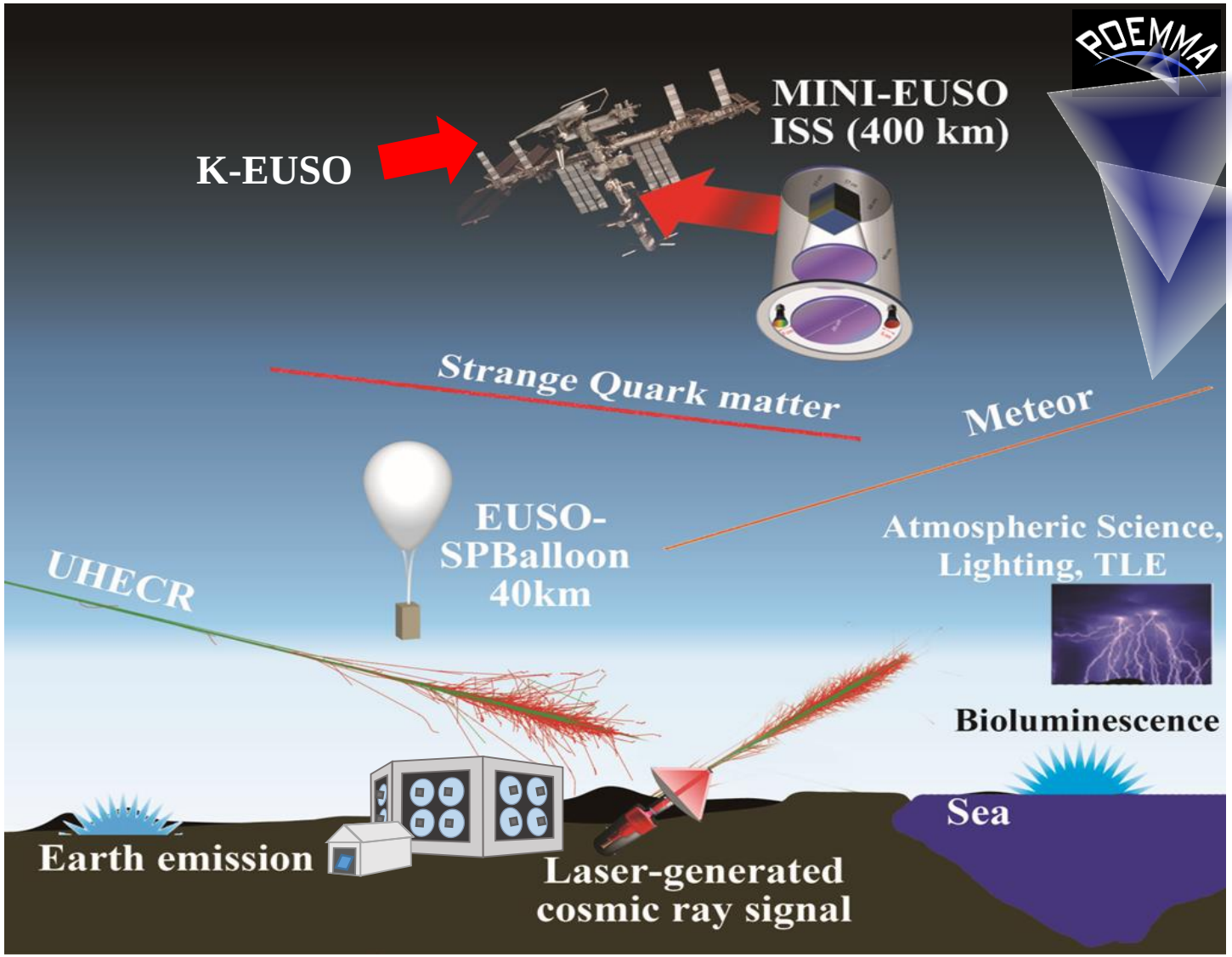
Overview

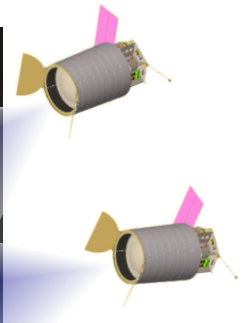
- Overview of the **JEM-EUSO program**
- Overview of the **EUSO-TA experiment**
- Description of the **detected cosmic ray events**
- **Simulation** results
- Method for the estimation of the **energy threshold of the JEM-EUSO detectors**
  - Correction for the actual part of the shower observed by ESUO-TA, rather than the whole shower
  - Correction for the atmospheric transmission

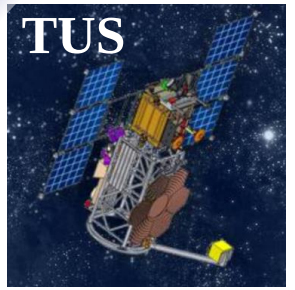
JEM-EUSO Program

Joint Experiment Missions for Extreme Universe Space Observatory

- EUSO-TA (2013)
- EUSO-Balloon (2014)
- TUS (2016)
- EUSO-SPB (2017)
- Mini-EUSO (2019)
- EUSO-SPB2 (2022)
- K-EUSO (2023+)
- POEMMA (2029+)

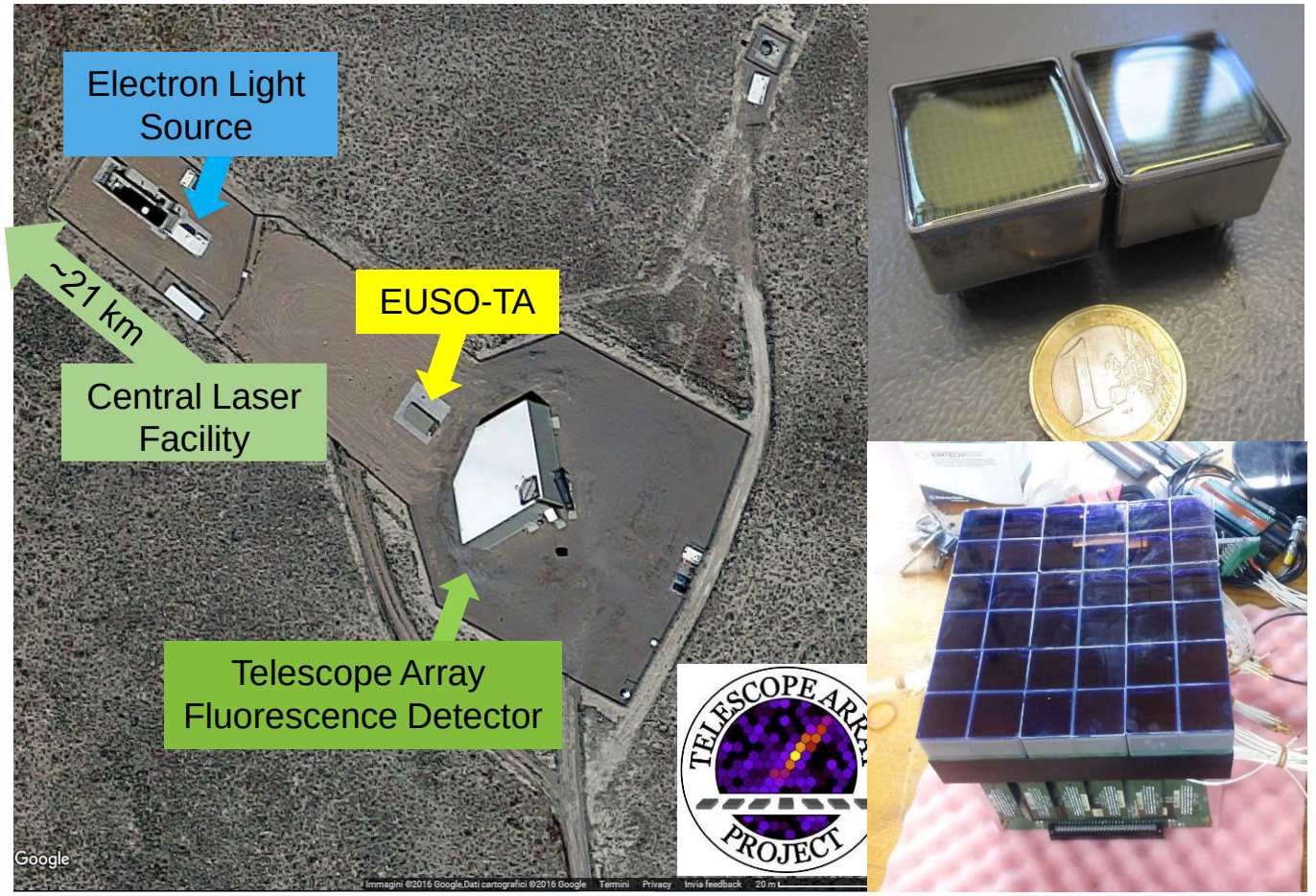






Ground based experiment EUSO-TA
at Telescope Array site

- **Location:**
  Telescope Array site, Utah, USA,
  in front of the **Black Rock Mesa**
  fluorescence detector station
- **Characteristics:**
  - **Focal surface**:
    36 Multi-Anode PMTs ⇨ 2304 pix.
  - **Optics**: 2 Fresnel lenses
  - **Field of view**: 10.5°
  - **Time resolution:** 2.5 μs
- **Main purposes:**
  - **Tests** of the JEM-EUSO system
  - **Detection of cosmic rays**



Events in the EUSO-TA's field of view

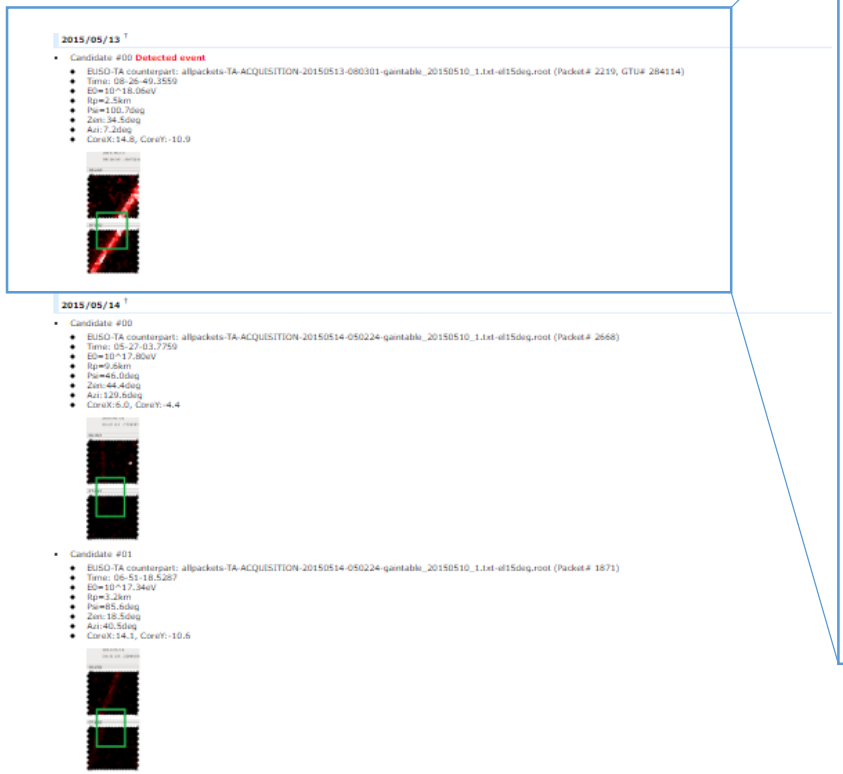
Telescope Array provided:

→ External trigger

→ List of events in the EUSO-TA's FOV

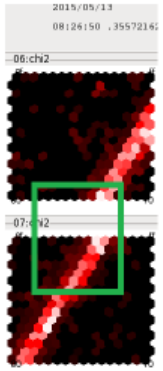
and **reconstruction parameters**

In total 110 events



2015/05/13 †

- Candidate #00 **Detected event**
  - EUSO-TA counterpart: allpackets-TA-ACQUISITION-20150513-080301-gaintable_20150510_1.txt-el15deg.root (Packet# 2219, GTU# 284114)
  - Time: 08-26-49.3559
  - E0=10^18.06eV
  - Rp=2.5km
  - Psi=100.7deg
  - Zen:34.5deg
  - Azi:7.2deg
  - CoreX:14.8, CoreY:-10.9



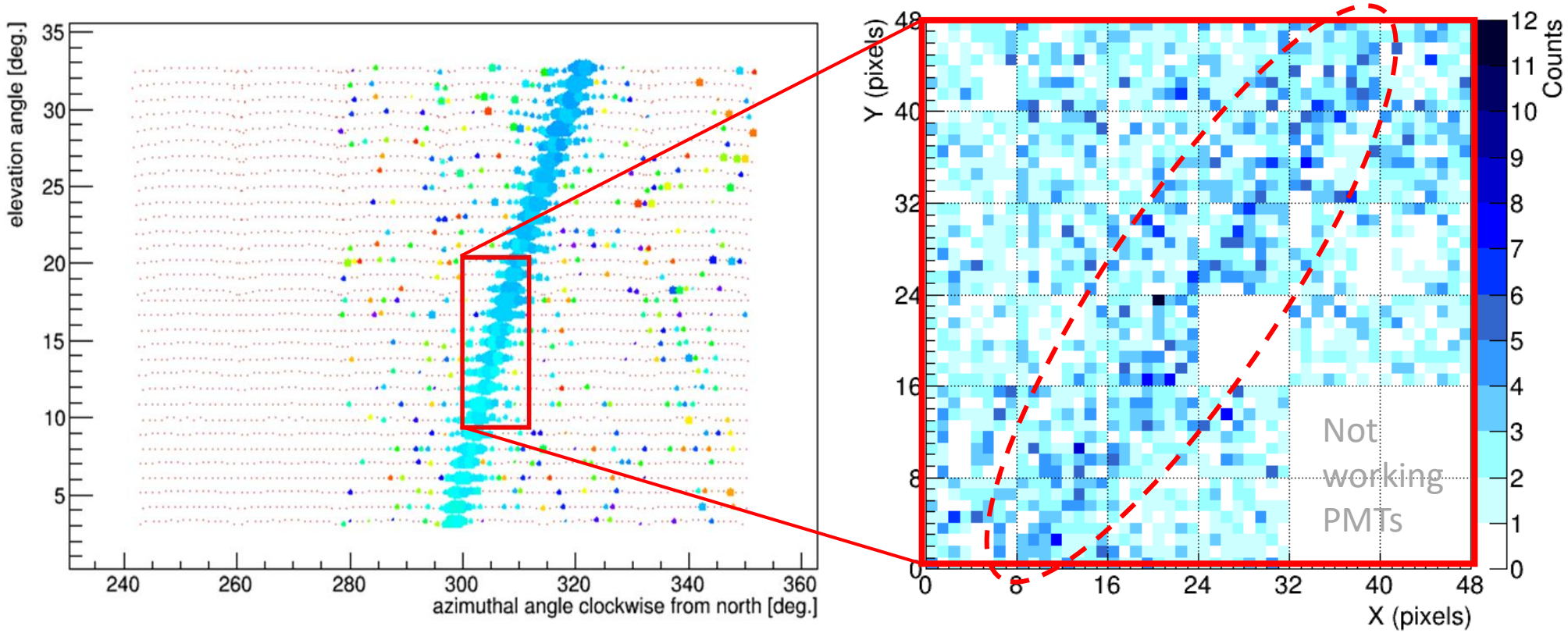
Example of detected cosmic ray shower

Telescope Array

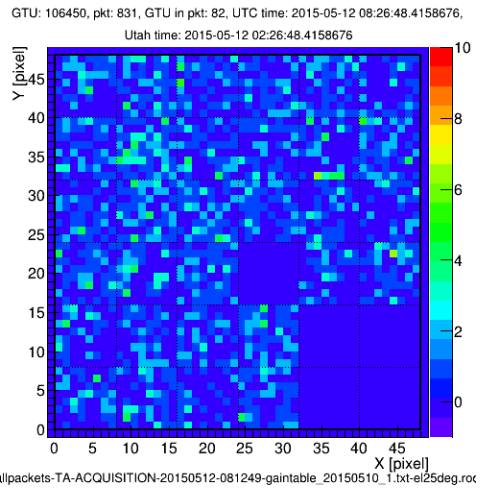
- Time resolution = 100 ns (image over 51.2 μs)
- Pixel FOV = 1°

EUSO-TA

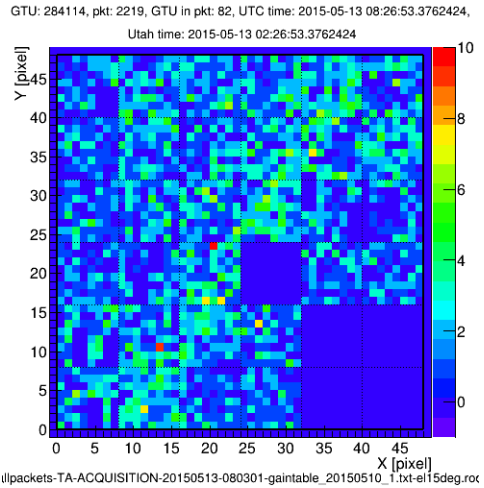
- Time resolution = 2.5 μs
- Pixel FOV = 0.19°



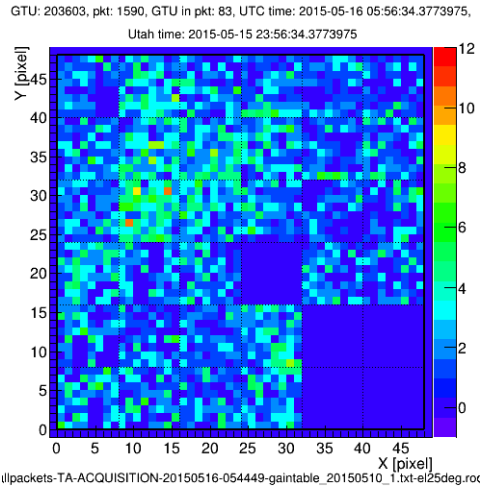
CR events detected in 2015



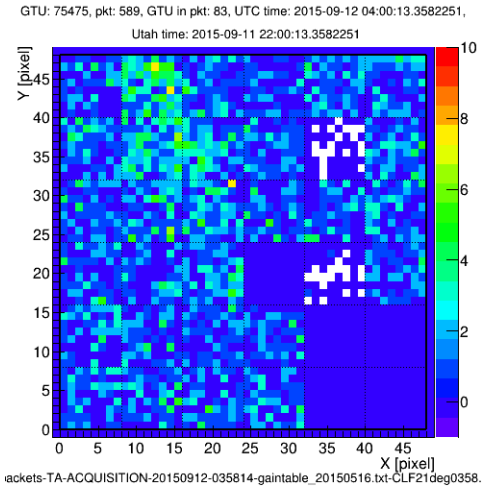
1. logE = 18.69
   Rp = 8.3 km
   Zen = 56.9°, Azi = 15.7°



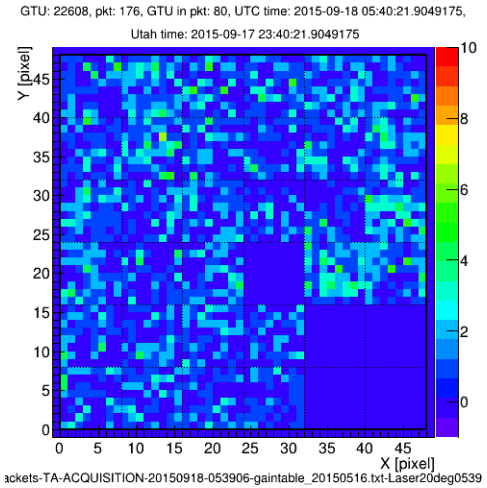
2. logE =18.06
   Rp = 2.5 km
   Zen = 34.5°, Azi = 82.8°



3. logE = 18.20
   Rp = 0.8 km
   Zen = 62.9°, Azi = 27°



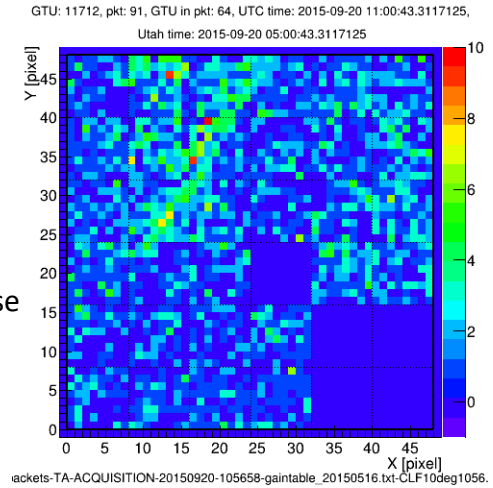
4. logE = 18.05
   Rp = 5.0 km
   Zen = 29.5°, Azi = 254.9°



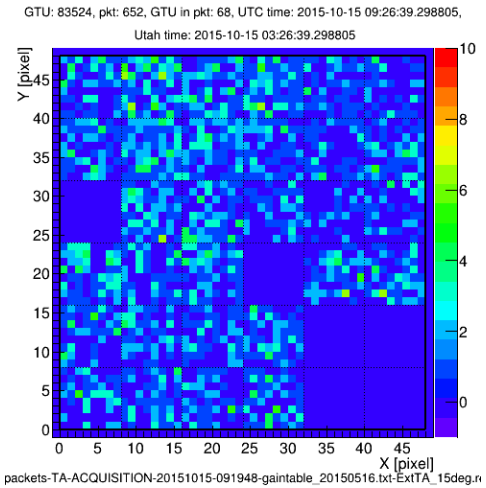
5. logE = 18.51
   Rp = 9.1 km
   Zen = 60.4°, Azi = 169.3°

Azimuth
from East
Counterclockwise

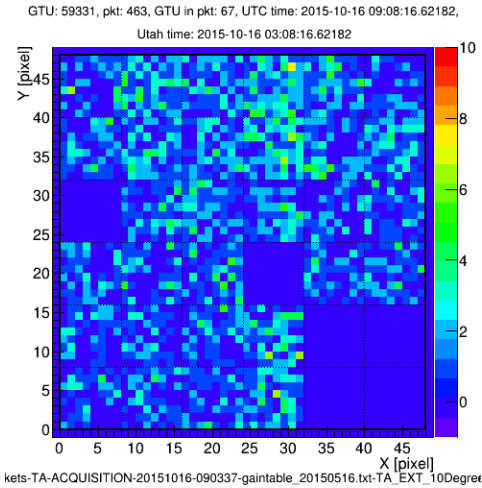
Azimuth
EUSO-TA
143.5 deg



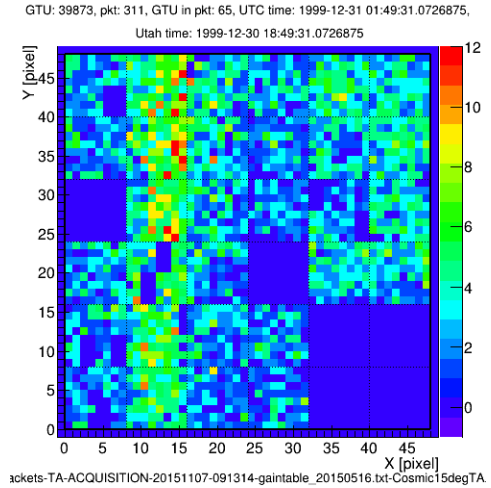
6. logE = 18.38
   Rp = 6.7 km
   Zen = 41.2°, Azi = 114.8°



7. logE = 18.52
   Rp = 9.0 km
   Zen = 40.6°, Azi = 210.5°



8. logE = 17.71
   Rp = 1.7 km
   Zen = 10.6°, Azi = 130.5°



9. logE = 18.42
   Rp = 2.6 km
   Zen = 8.1°, Azi = 8°

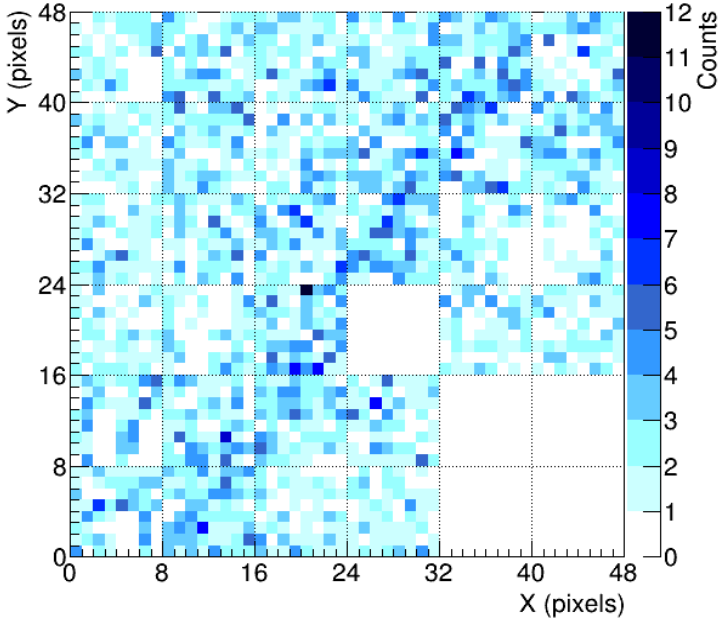
Simulation performance and results

Simulation of the detected events provided:

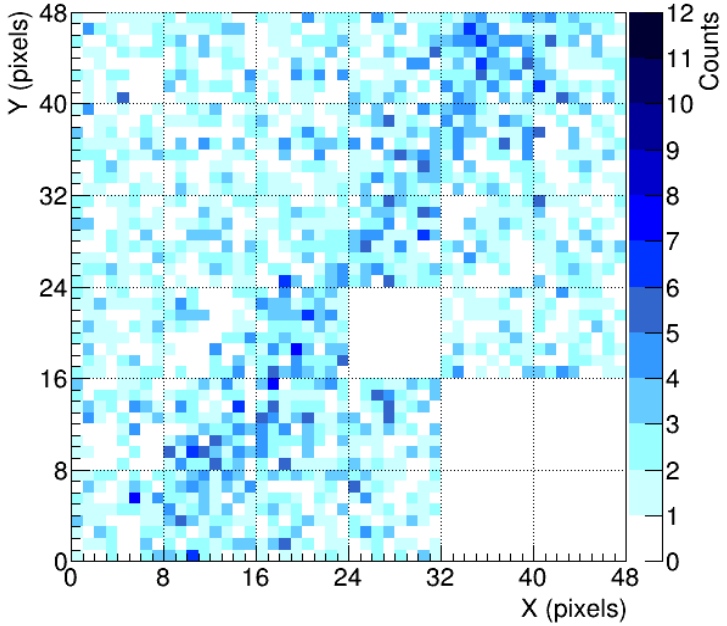
- Information on the photon's production mechanism
- Information on the efficiency of the detector and detector's subsystems

Example of comparison between simulated and detected cosmic ray air shower

Data



EUSO-Offline simulation



General results from the simulation of detected events

Photon origin

- Fluorescence: 65-80%
- Scattered Cher.: 13-34%
- Direct Cher.: 1-10%

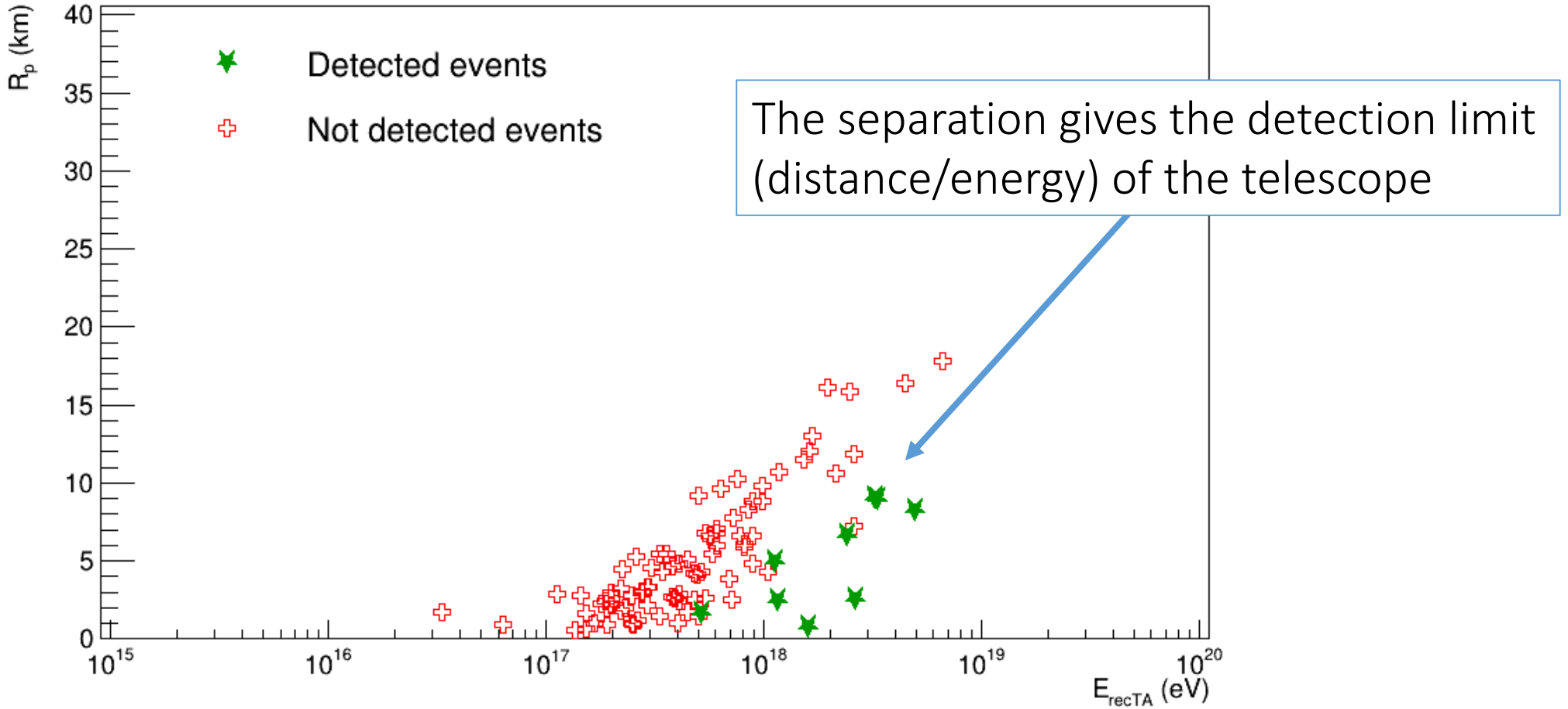
⇨ Depend on **geometry**

Efficiencies

- Lens transmiss.: ~16%
- Sensors: 25-27%
- Overall: 4-5%

⇨ Depend on **distance** and **energy** (e.g. pile-up pixels)

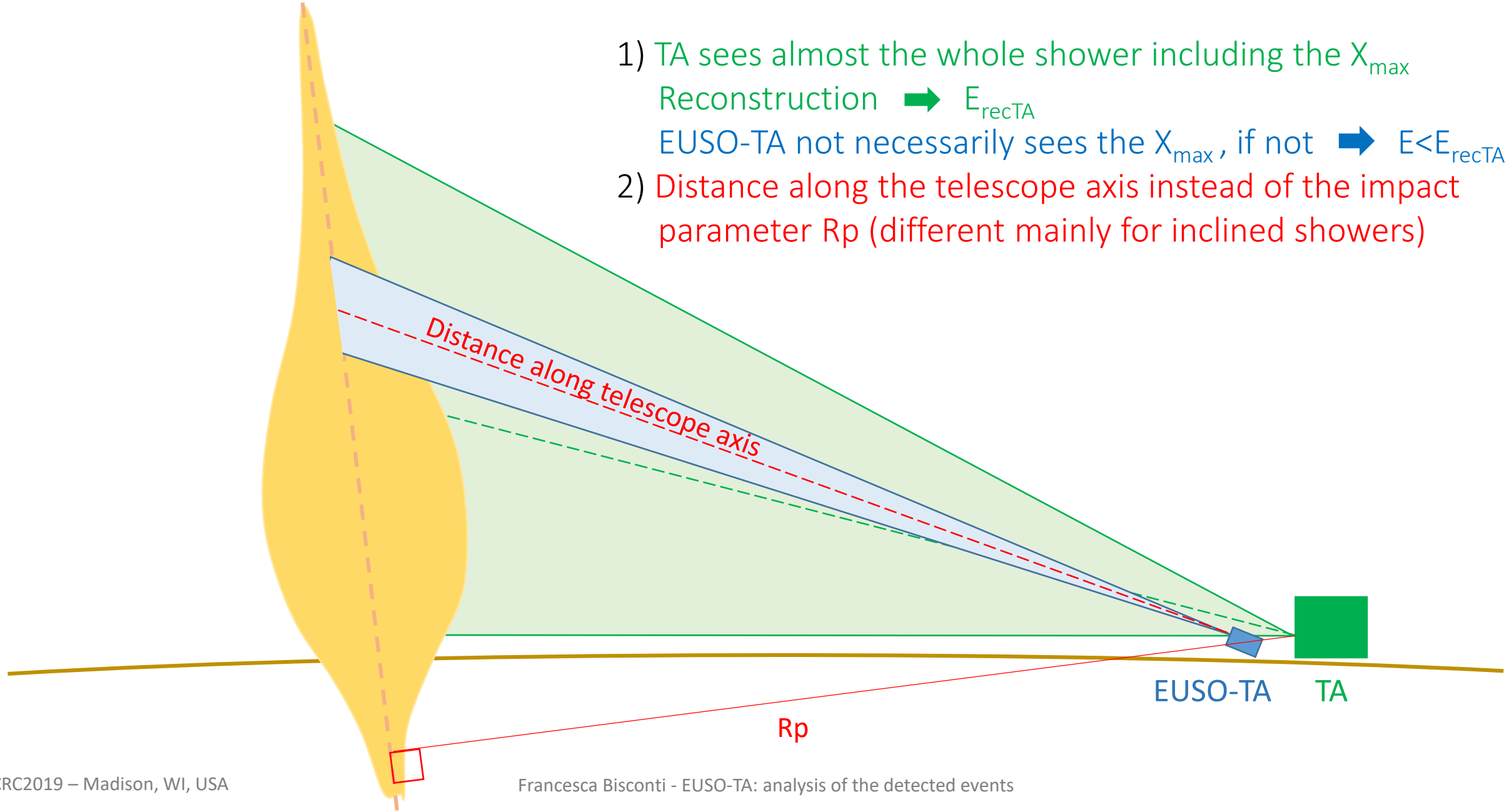
Impact parameter – Reconstructed energy (by TA)



- Total of events which crossed the EUSO-TA field of view: 110 (→ 18 discarded because on edge of PDM or on inefficient MAPMTs) → 92 events in the analysis
- Detected events: 9 (small pixels' size optimized for observations from space + time resolution of 2.5 μs decreases the signal/noise ratio + 0.2 μs dead time inside each 2.5 μs of acquisition time)

Equivalent energy of the showers

1) TA sees almost the whole shower including the X_{max}
   Reconstruction ➡ E_{recTA}
   EUSO-TA not necessarily sees the X_{max} , if not ➡ $E<E_{recTA}$
2) Distance along the telescope axis instead of the impact parameter Rp (different mainly for inclined showers)



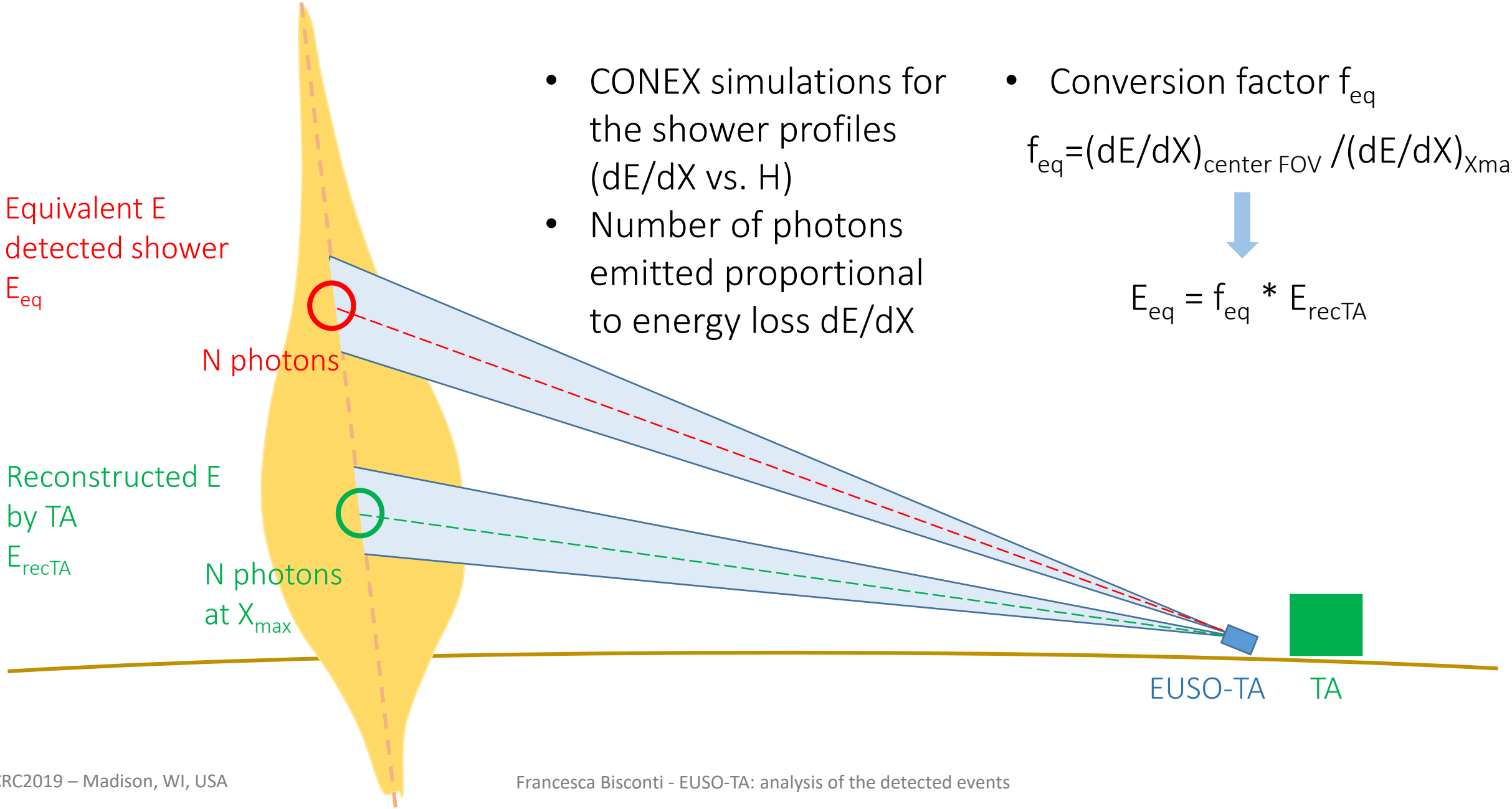
Equivalent energy of the showers

- CONEX simulations for the shower profiles (dE/dX vs. H)
- Number of photons emitted proportional to energy loss dE/dX

- Conversion factor f_{eq}

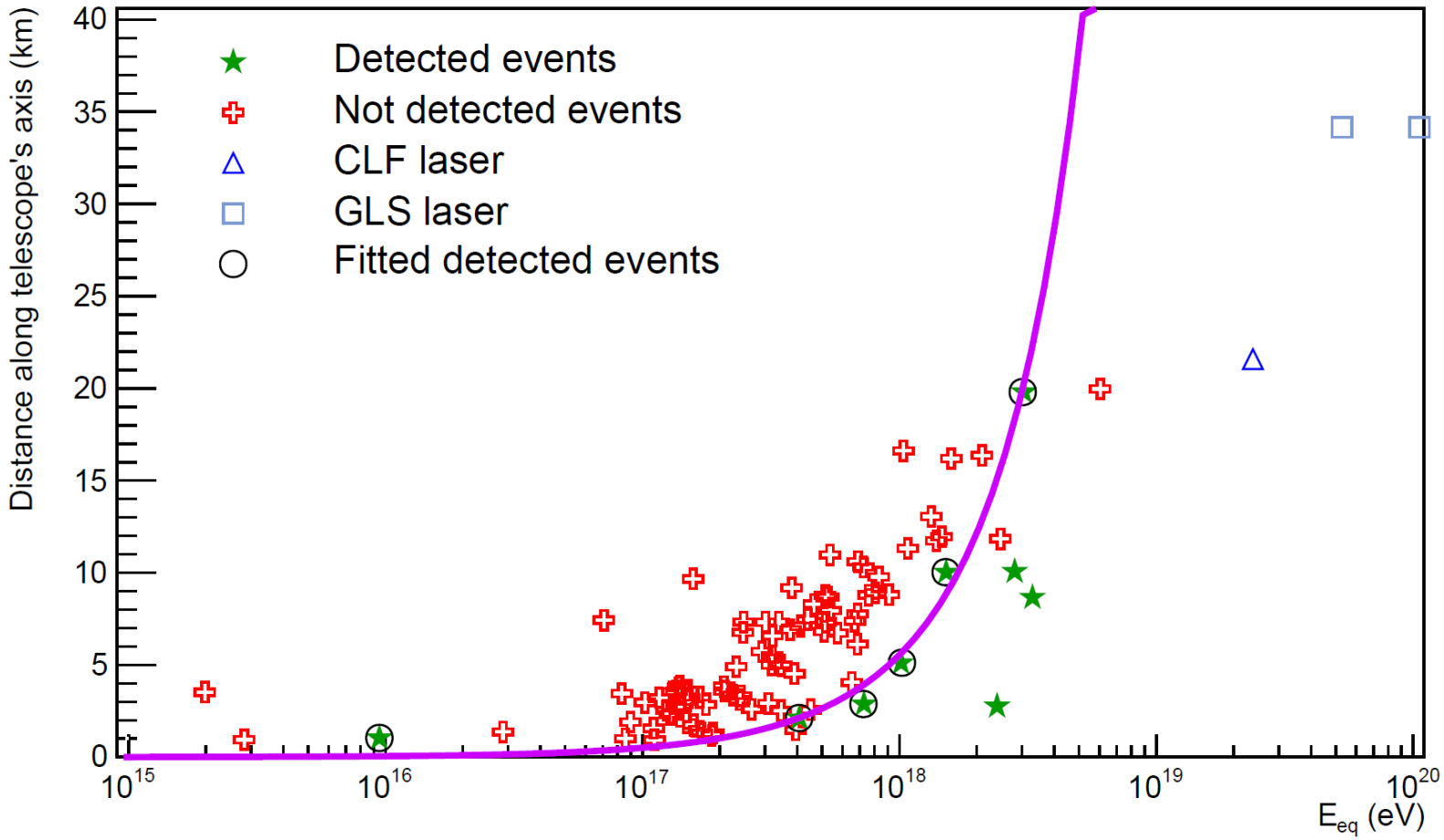
$$f_{eq}=(dE/dX)_{\text{center FOV}} /(dE/dX)_{Xmax}$$

$$E_{eq} = f_{eq} * E_{recTA}$$



Distance shower axis along the telescope axis vs equivalent energy

G. Abdellaoui et al., Astropart. Phys. 102, 98-111 (2018)



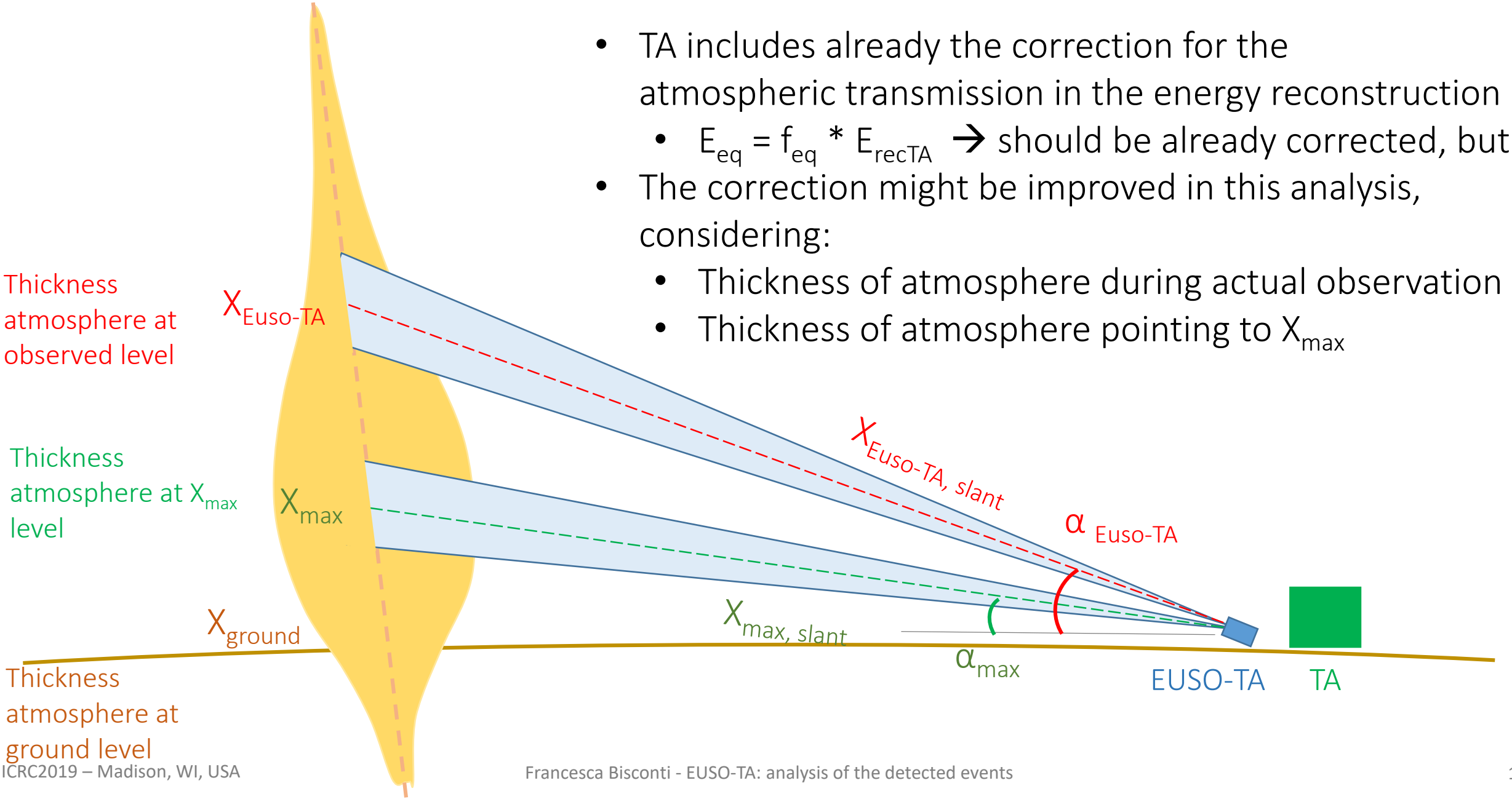
Line:

→Does not have a physical meaning

→Gives idea of distance and energy of observable showers

Photon transmission by the atmosphere

- TA includes already the correction for the atmospheric transmission in the energy reconstruction
  - $E_{eq} = f_{eq} * E_{recTA}$ → should be already corrected, but
- The correction might be improved in this analysis, considering:
  - Thickness of atmosphere during actual observation
  - Thickness of atmosphere pointing to X_{max}

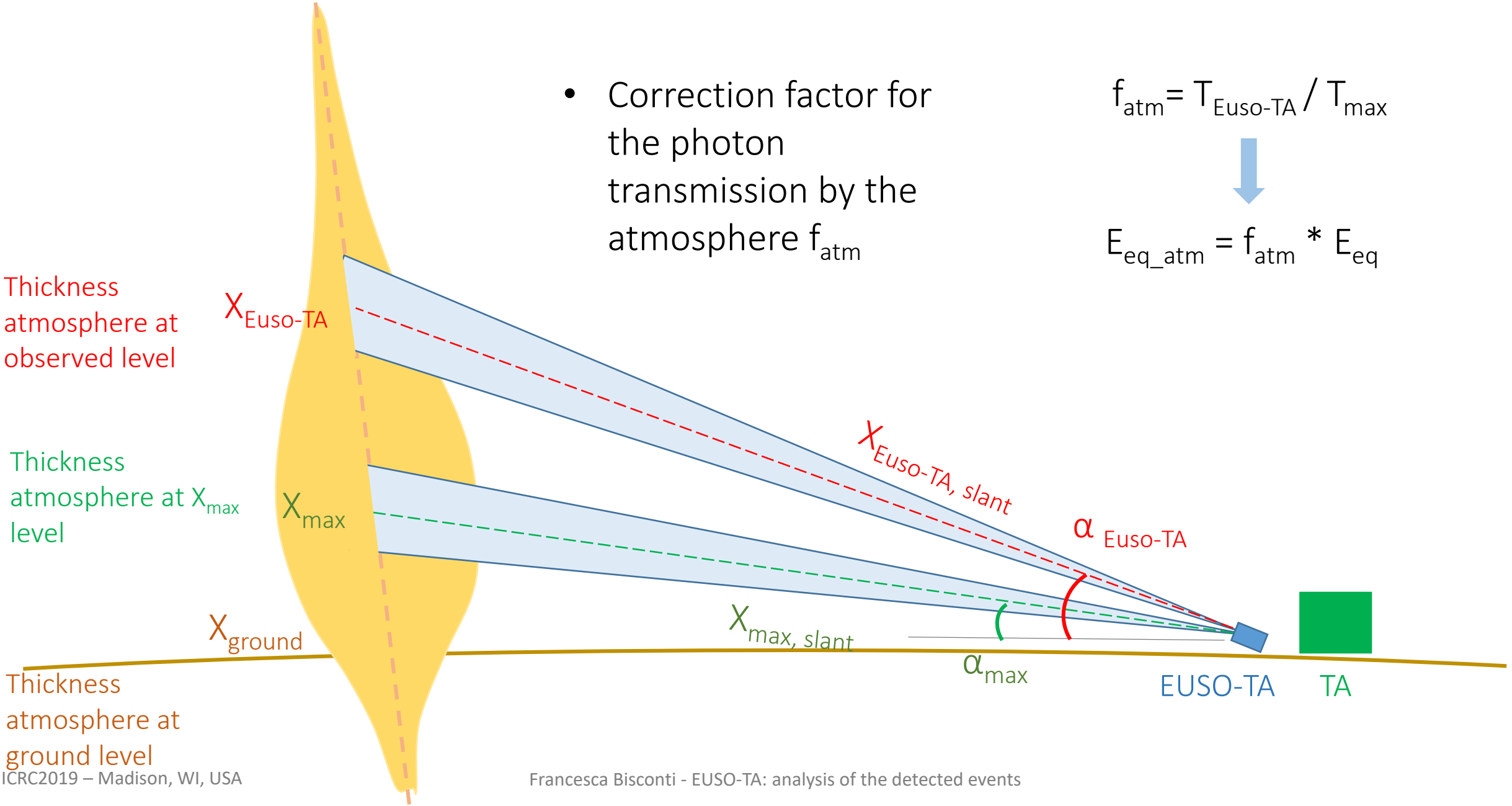


Photon transmission by the atmosphere

- Correction factor for the photon transmission by the atmosphere f_{atm}

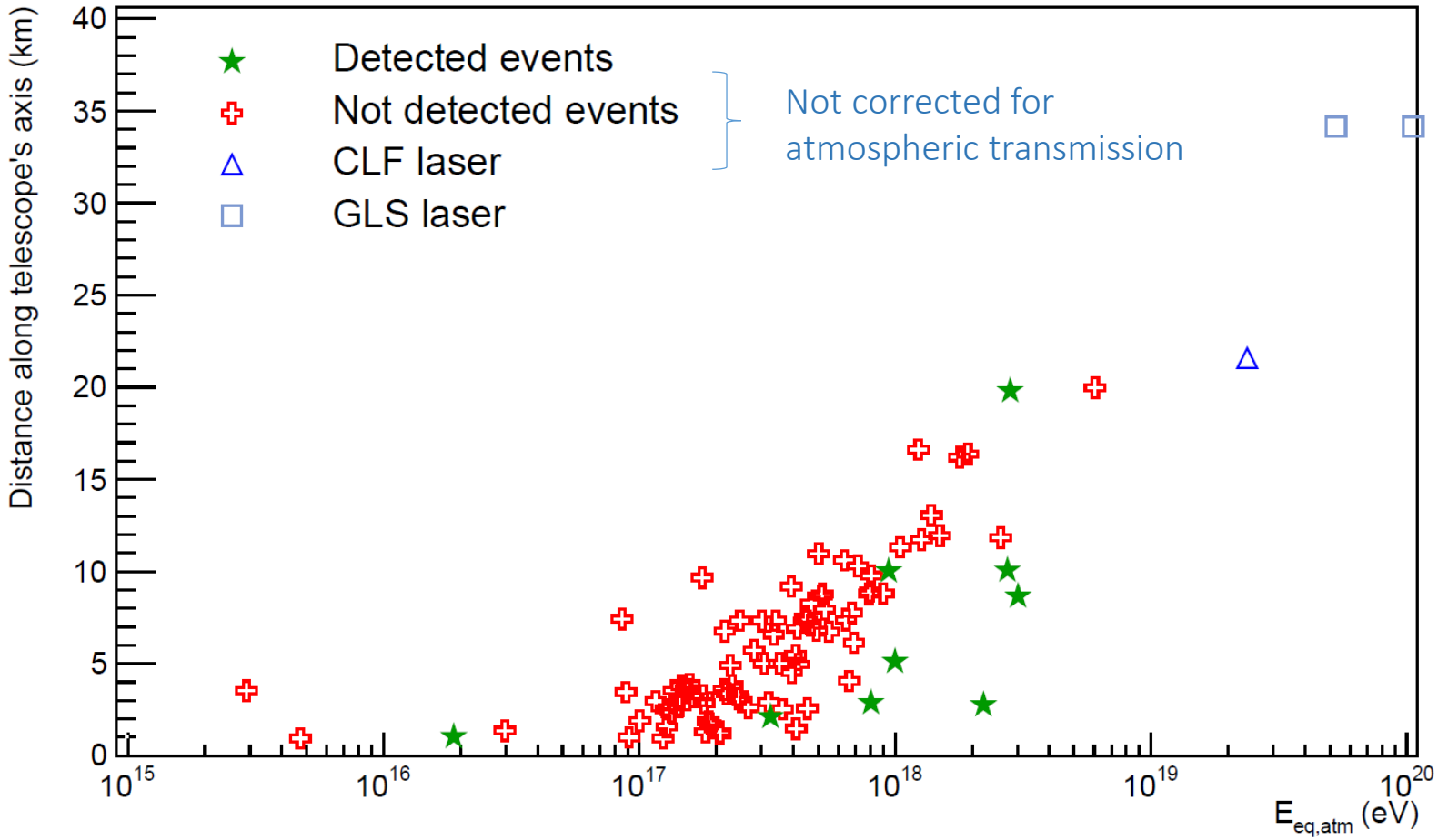
$$f_{atm} = T_{Euso\text{-}TA} / T_{max}$$

$$E_{eq\_atm} = f_{atm} * E_{eq}$$



Distance shower axis along the telescope axis vs equivalent energy

with correction for atmospheric transmission



← Preliminary
Work ongoing

Summary

- **Simulation of the cosmic ray events:**
  - Study of the light components producing the signal
  - Efficiency of the detector (overall and subsystems)

- **Study of the detection capabilities of the JEM-EUSO experiments using the events detected and not detected by EUSO-TA**
  - Energy correction for actual portion of the shower observed rather than the whole shower including X_{max}
  - Energy correction for the atmospheric photon transmission
  - Separation between detected and undetected cosmic ray event is in agreement with measurements of lasers

- **More statistics of events and laser observations with EUSO-TA-2 will improve the estimation of the energy threshold**, useful also for balloon- and space-based experiments

Backup slides

Photon transmission by the atmosphere

H→X from Linsley parametrization – from CORSIKA

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========================= ATMOSPHERE ========================

 ( US STANDARD ATMOSPHERE PARAMETERIZED BY LINSLEY )
 HEIGHT H IN KM GIVES THICKNESS OF ATMOSPHERE T IN G/CM**2
H =  -5.8...  4.0 KM ---> X = -1.86556E+02 + 1.2227E+03 * EXP( -H / 9.9419E+00)
H =   4.0... 10.0 KM ---> X = -9.49190E+01 + 1.1449E+03 * EXP( -H / 8.7815E+00)
H =  10.0... 40.0 KM ---> X =  6.12890E-01 + 1.3056E+03 * EXP( -H / 6.3614E+00)
H =  40.0...100.0 KM ---> X =  0.00000E+00 + 5.4018E+02 * EXP( -H / 7.7217E+00)
H = 100.0...112.8 KM ---> X =  1.12829E-02 - H / 1.0000E+04
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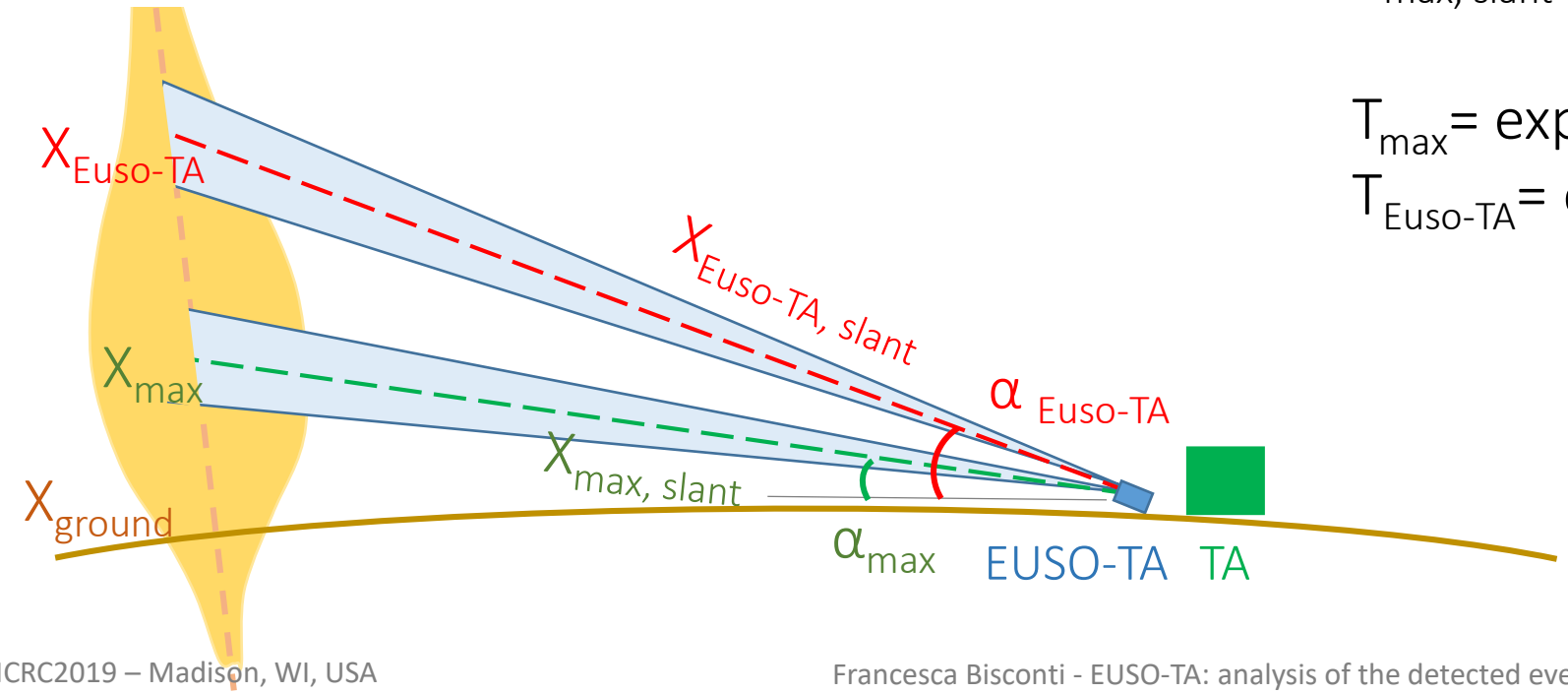


T = transmission atmosphere = exp(-X/ Λ)

Λ = Mean free path Rayleigh scattering

$\Lambda(350\ nm)=1700\ g/cm^2$

$X_{Euso-TA,\ slant}=(X_{ground}-X_{Euso-TA})/\sin\alpha_{Euso-TA}$

$X_{max,\ slant}=(X_{ground}-X_{max})/\sin\alpha_{max}$

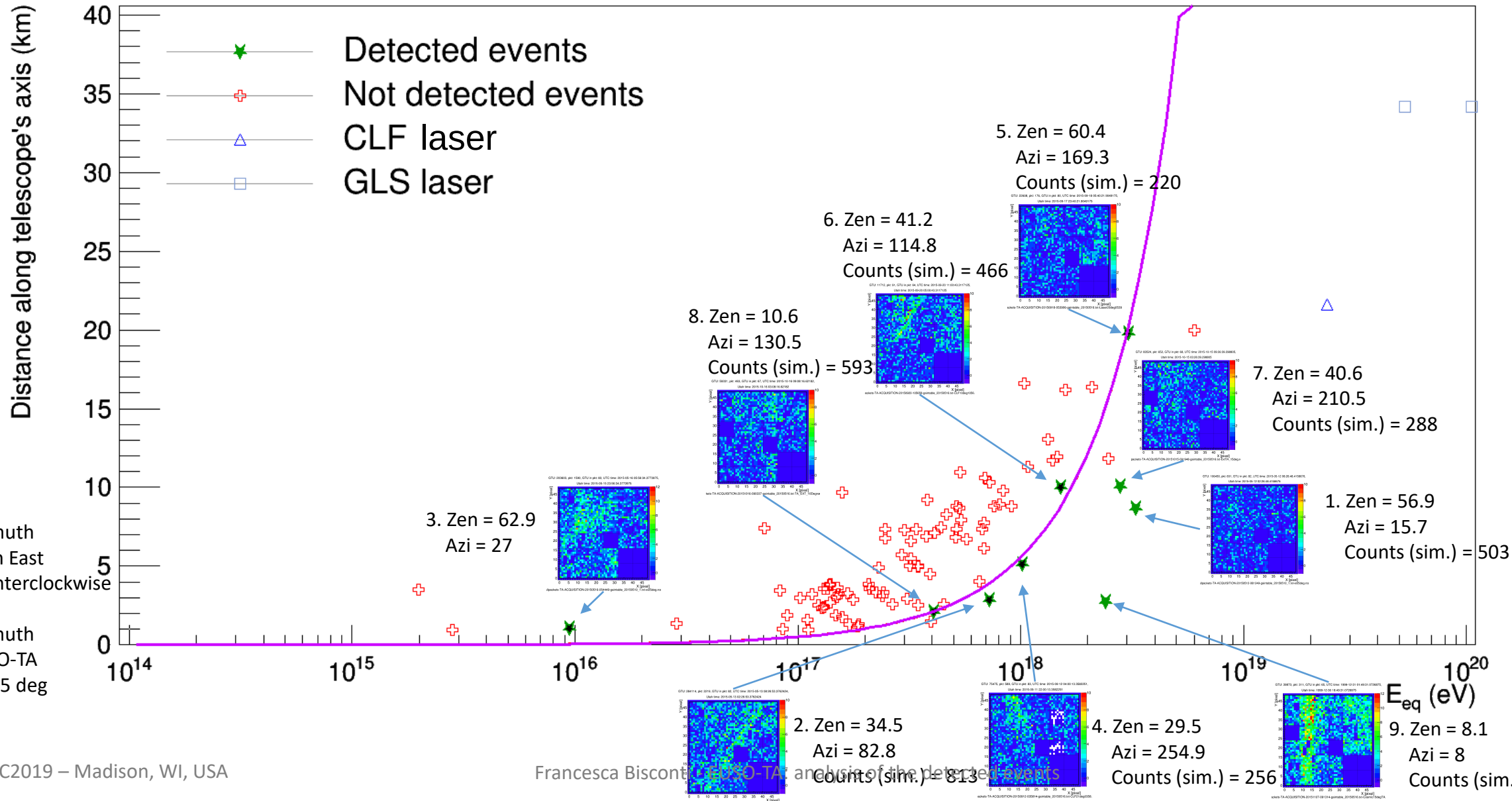
$T_{max}= \exp(-X_{max,\ slant}/\Lambda(350nm))$

$T_{Euso-TA}= \exp(-X_{Euso-TA,\ slant}/\Lambda(350nm))$

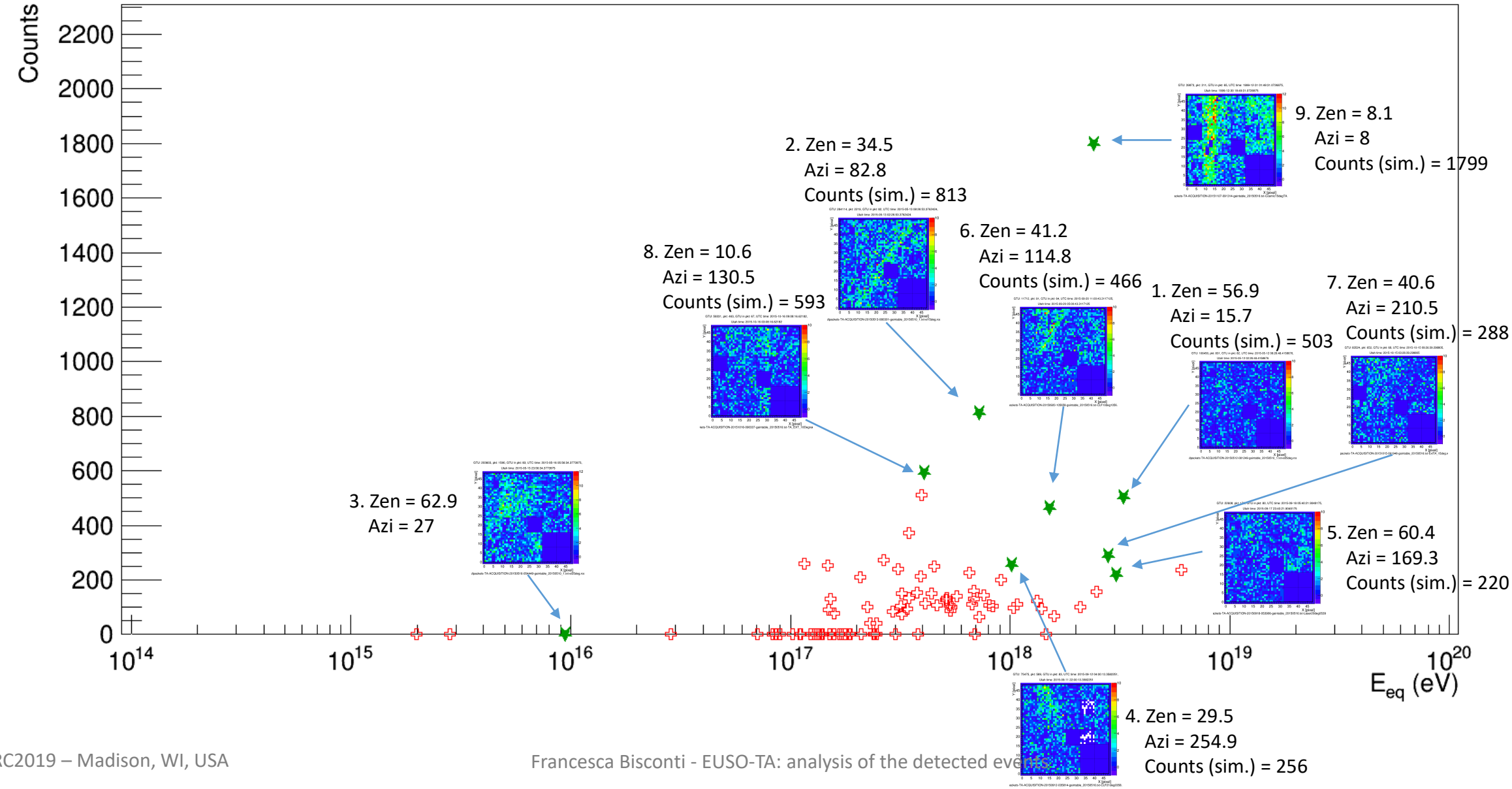
$f_{atm}= T_{Euso-TA} / T_{max}$

$E_{eq\_atm} = f_{atm} * E_{eq}$

$E_{equivalent}$ – Distance along telescope axis



Counts - $E_{equivalent}$



Counts - Distance along telescope axis