# Prospects and interest of observing high-altitude horizontal air showers with suborbital detectors

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7th International Symposium on Ultra High Energy Cosmic Rays

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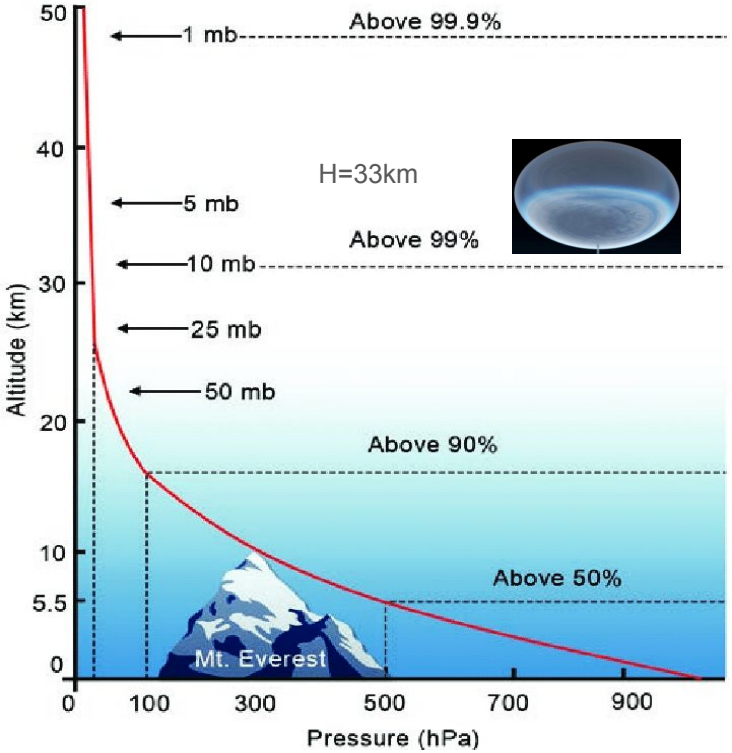
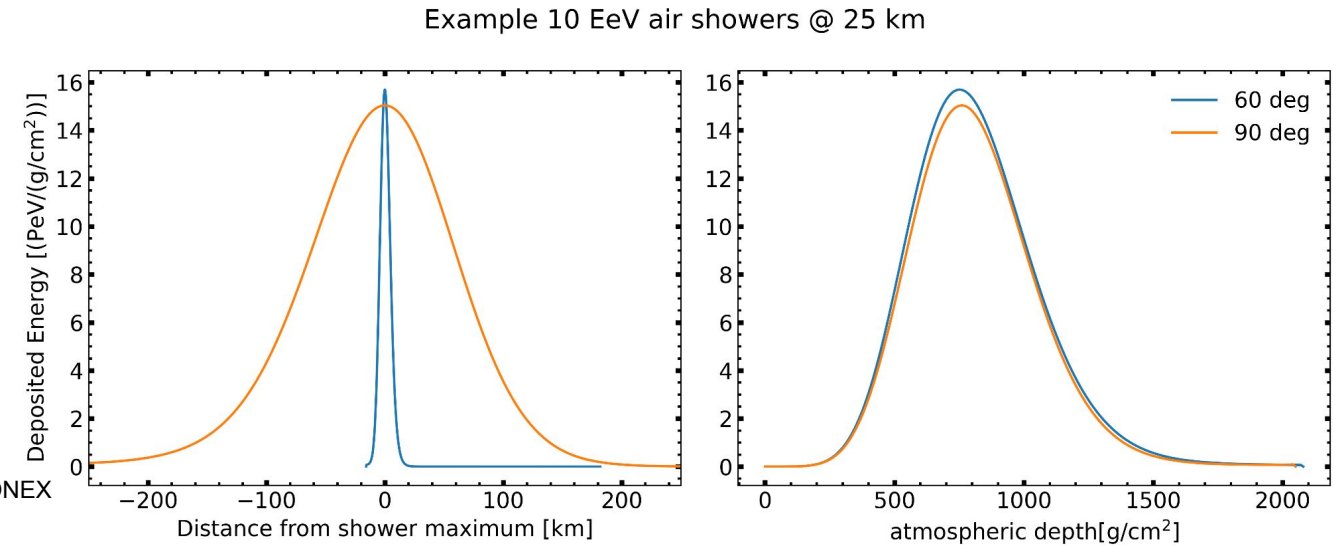
# A unique observing geometry




- Balloons at 33 km altitude are above 99% of the atmosphere
- Rarefied atmosphere leads to elongated shower development (off-axis, fluorescence observation)
- Detector in the middle of active shower development for some showers (on-axis, Cherenkov)

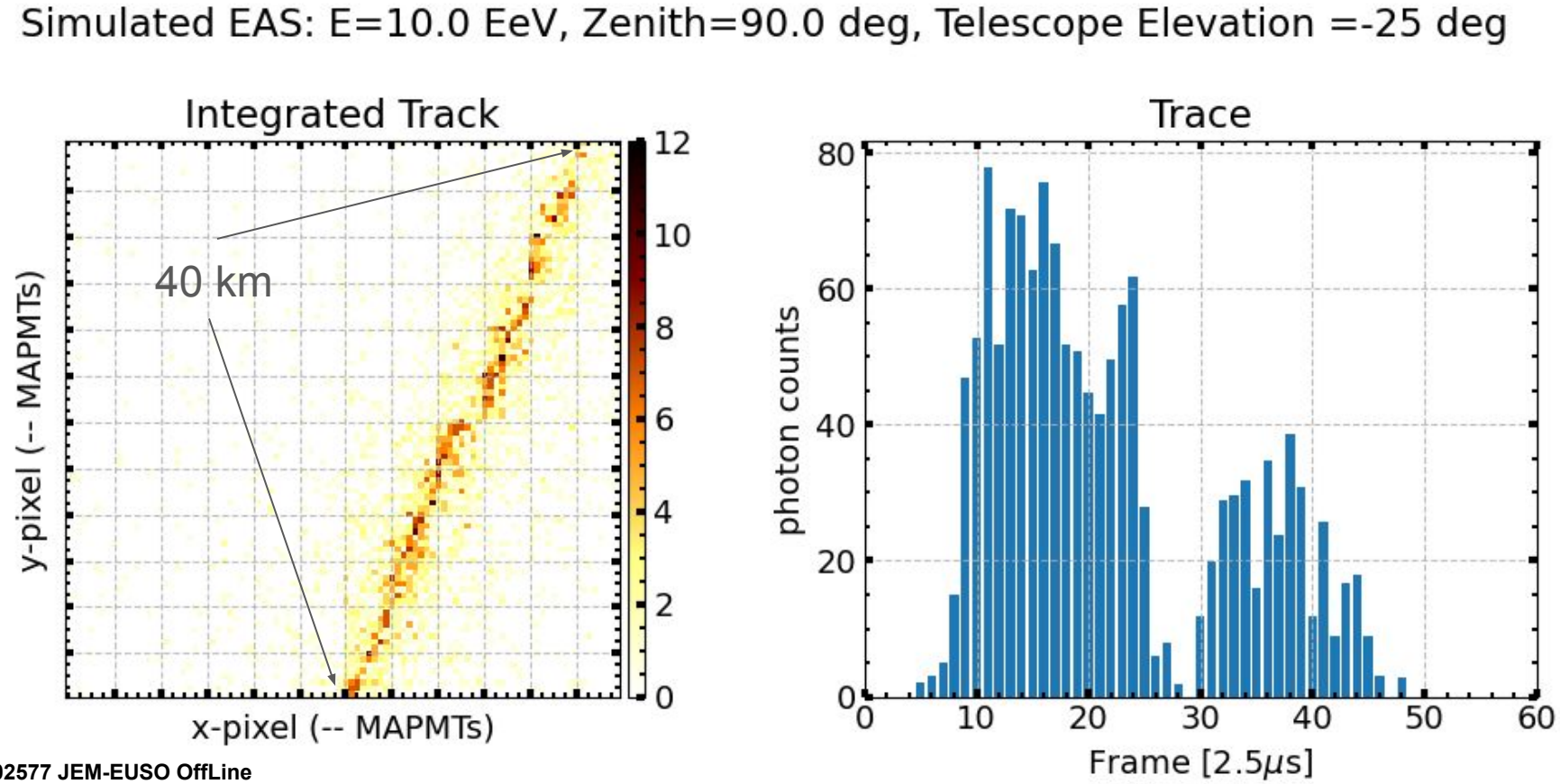
# Benefits of elongated geometry

- Small features of longitudinal profile can be resolved (~g/cm^2 per pixel)
- Composition analyses can rely on all information from shower, not just Xmax
- Potential to have stronger event-by-event mass discrimination
- Potential



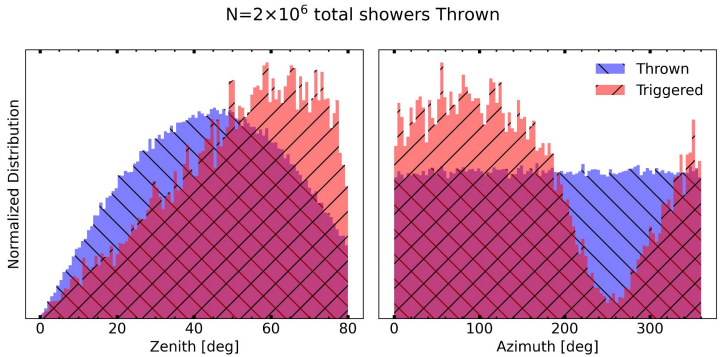

**arXiv:astro-ph/0606564** CONEX

# Example of an observable fluorescence shower

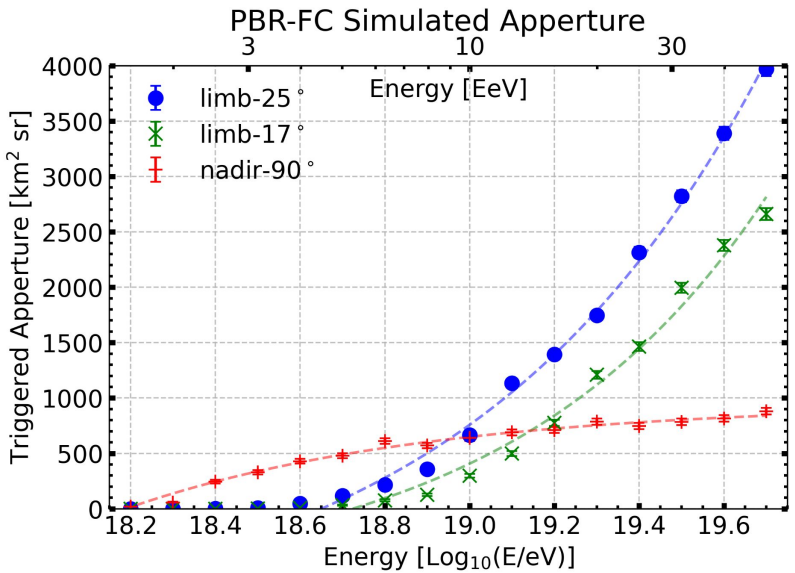


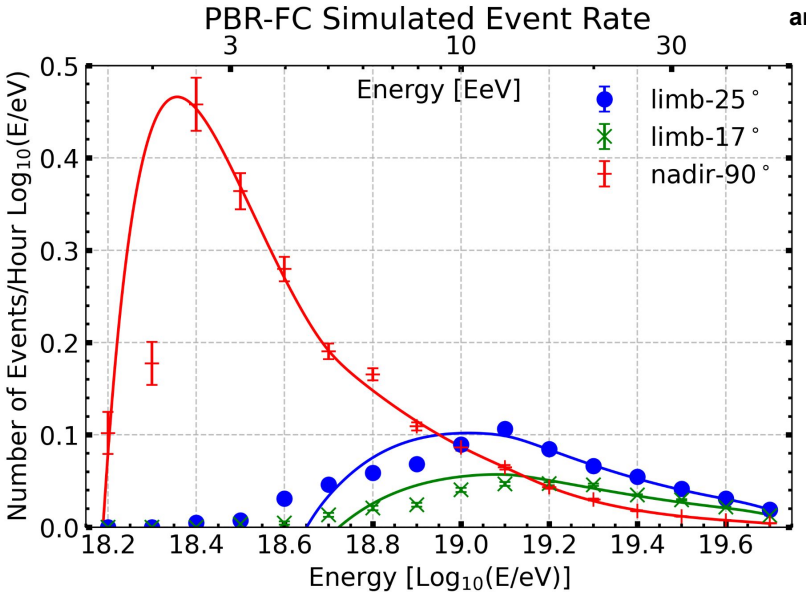

arXiv:2309.02577 JEM-EUSO OffLine

# Feasibility of observation



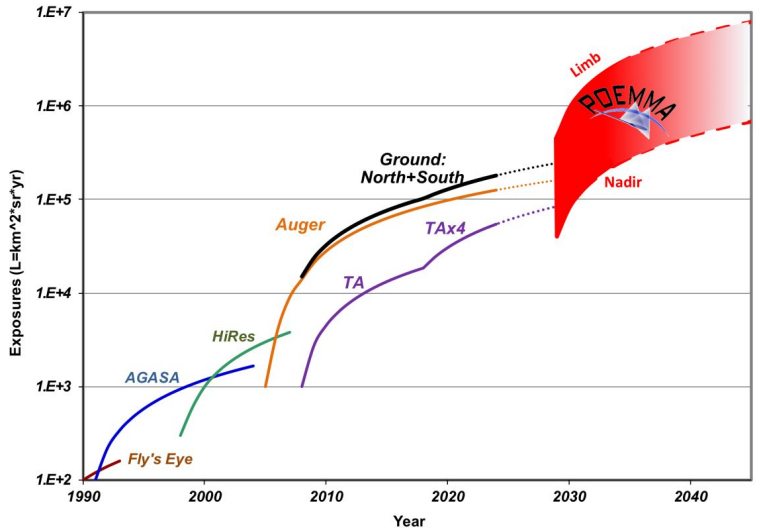

- Realistic energy range for observations
- Bias towards more inclined showers
- Increasing aperture at E>50 EeV

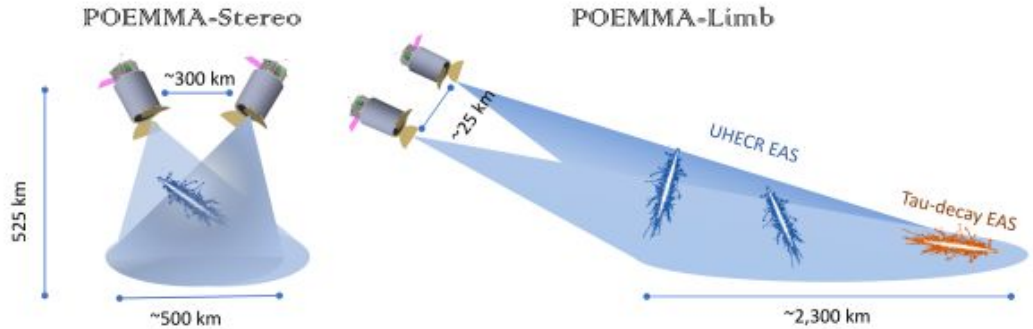



arXiv:2406.13673

# Proof of concept for future (space) missions



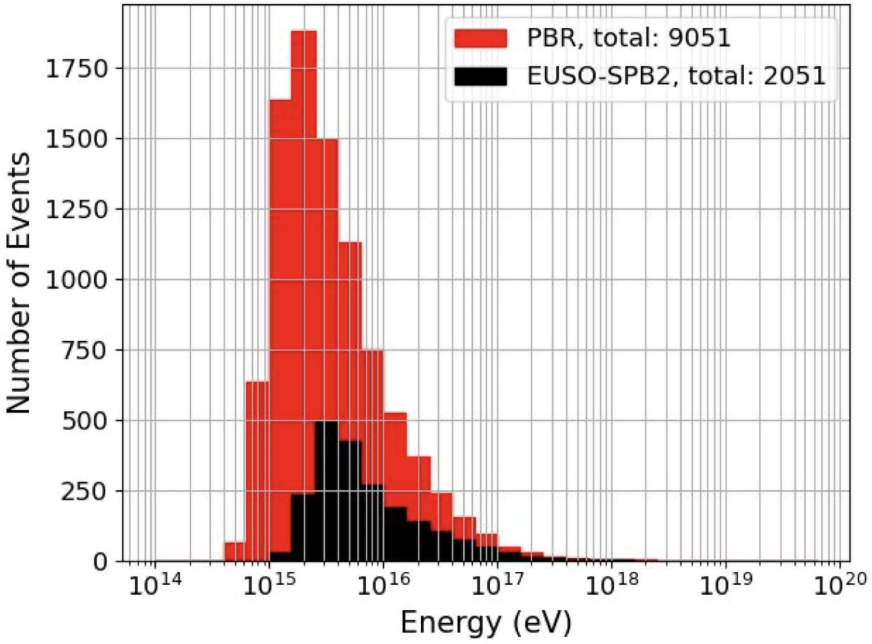




- Balloon expects a few (<10) events of this type
- A long duration satellite missions would expect to observe many
- Even larger FoV to observe the shower development
- PBR should provide a proof of concept for this observation technique

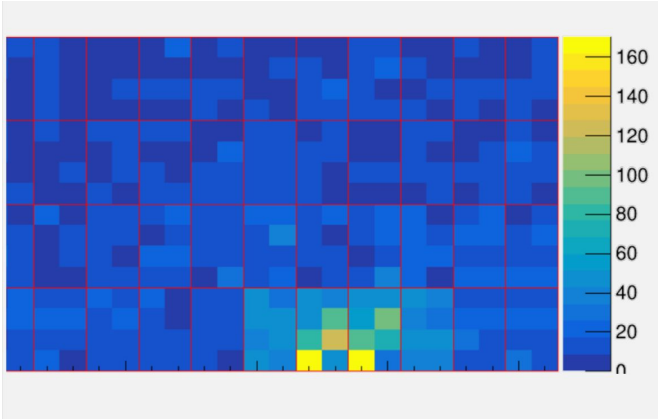
arXiv:2012.07945

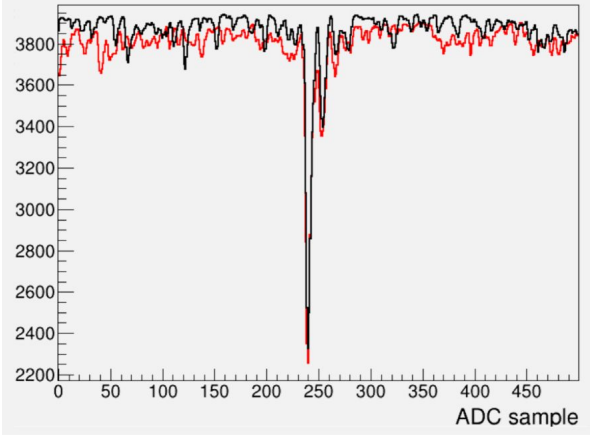
# On axis measurements

- Bifocal Cherenkov light observation
- Proven technique (SPB2)
- Expected larger number of events (3 orders of magnitude)

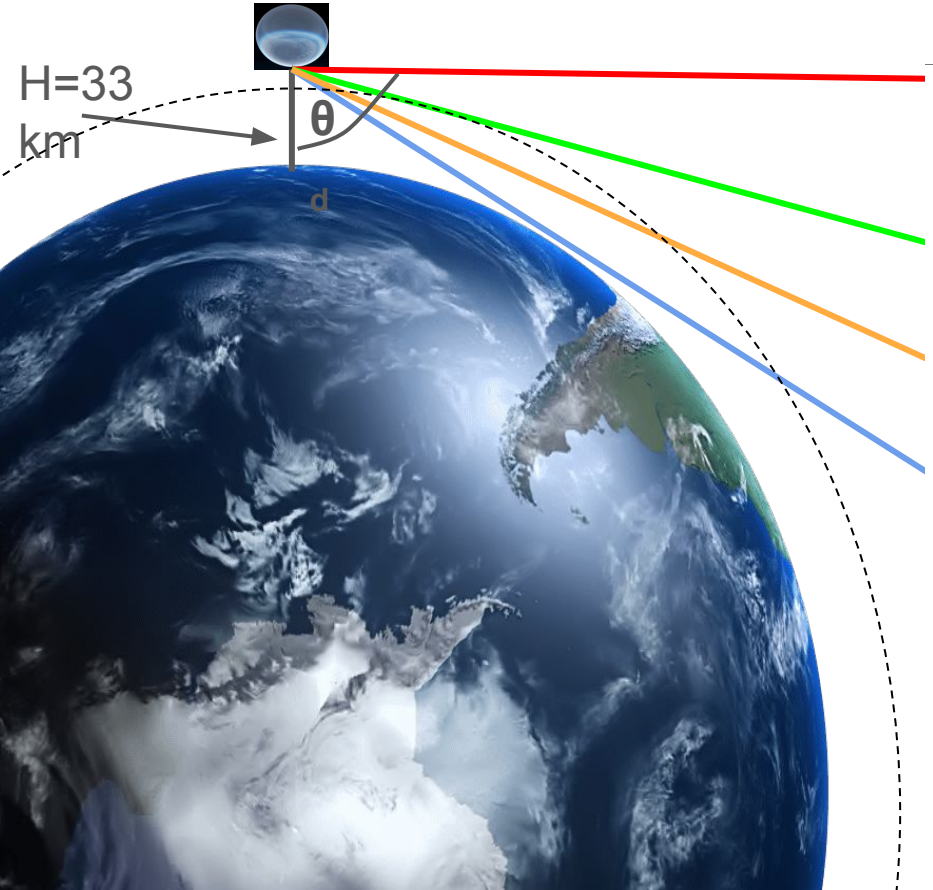


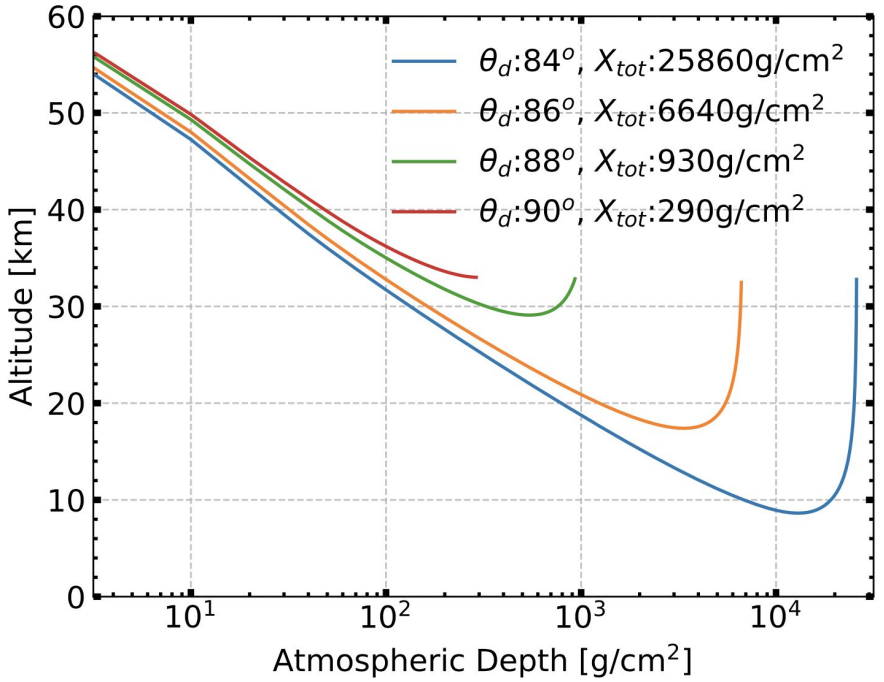

arXiv:2308.15628



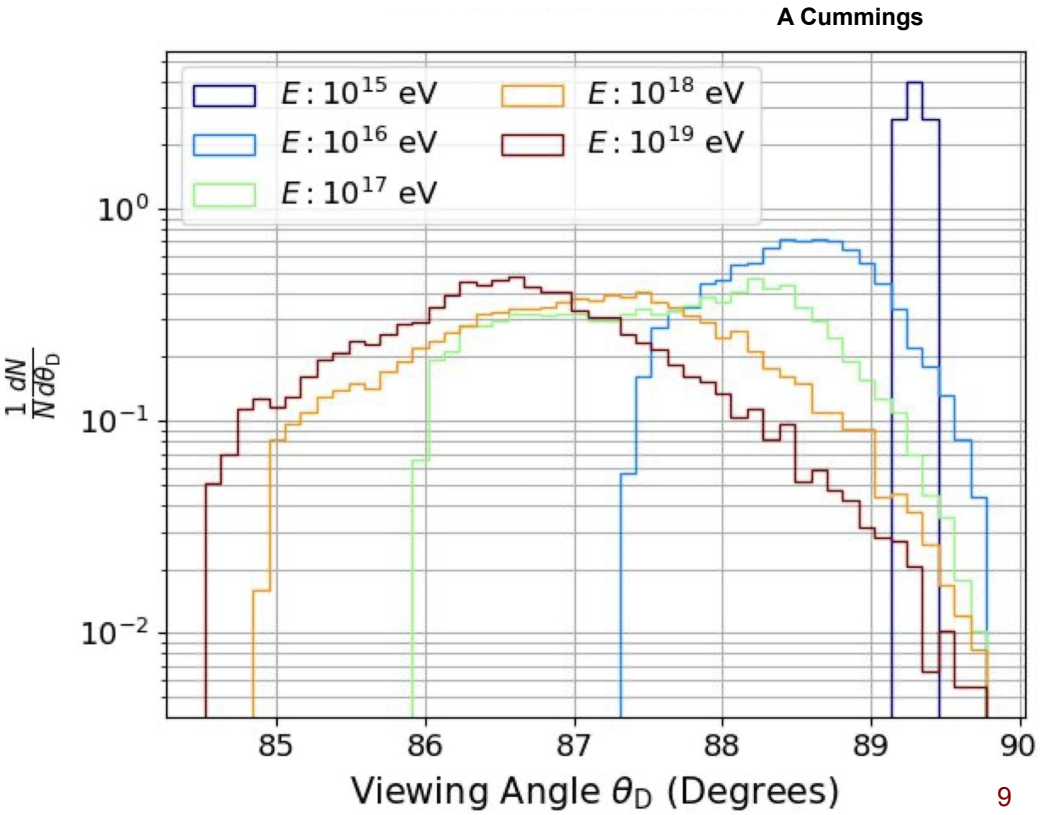
# Change in slant depth vs angle



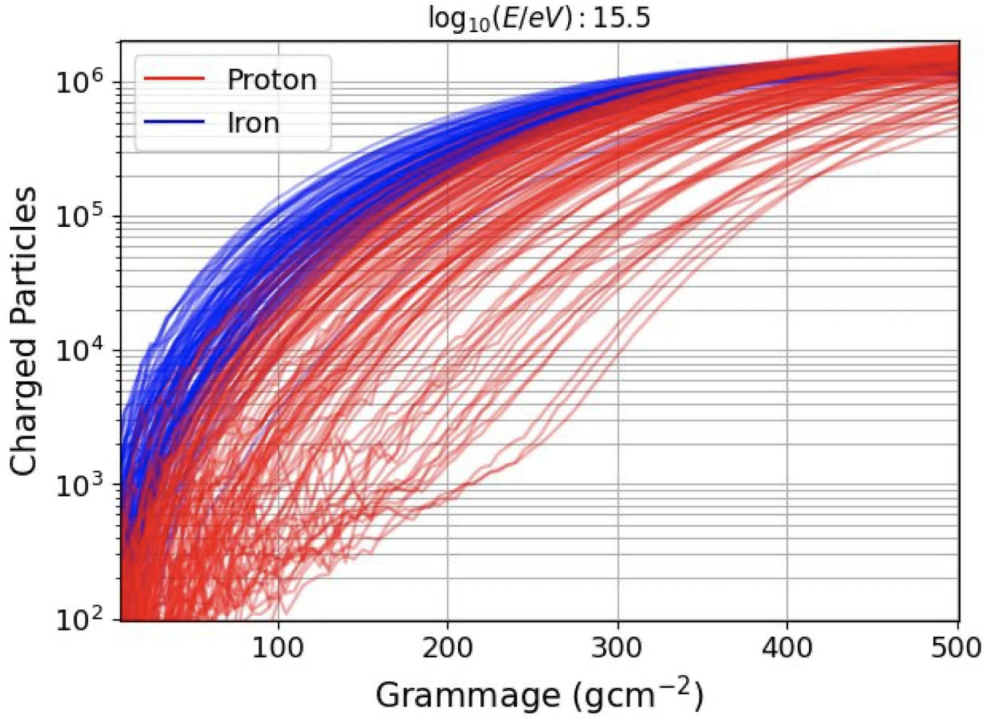
# Atmosphere as a cosmic ray energy filter

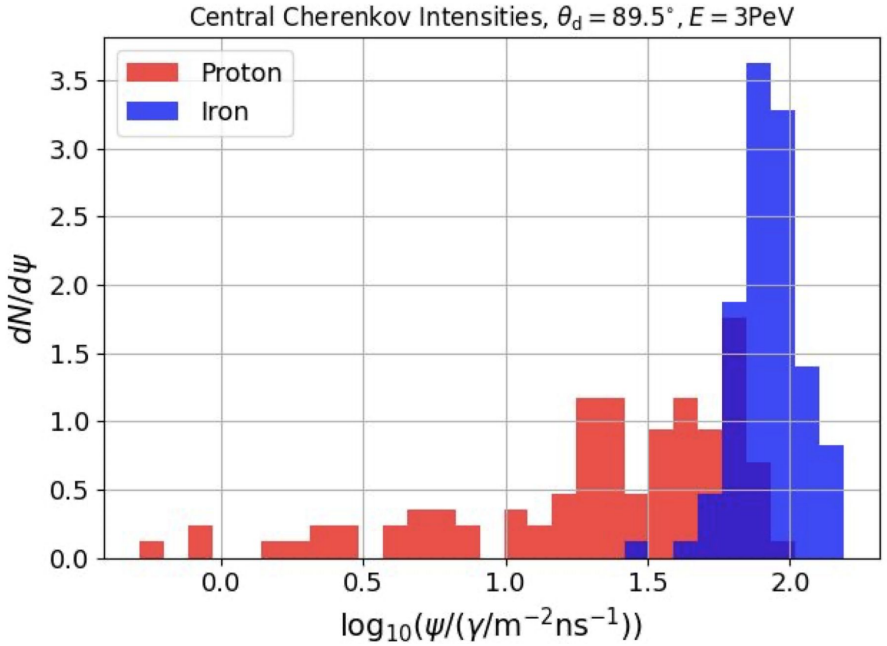
- Higher energy showers can penetrate through more atmosphere
- Provides an independent handle on the energy spectrum
- “Slope” of spectrum with angle provides a handle on composition evolution



# Difference in shower development across primaries

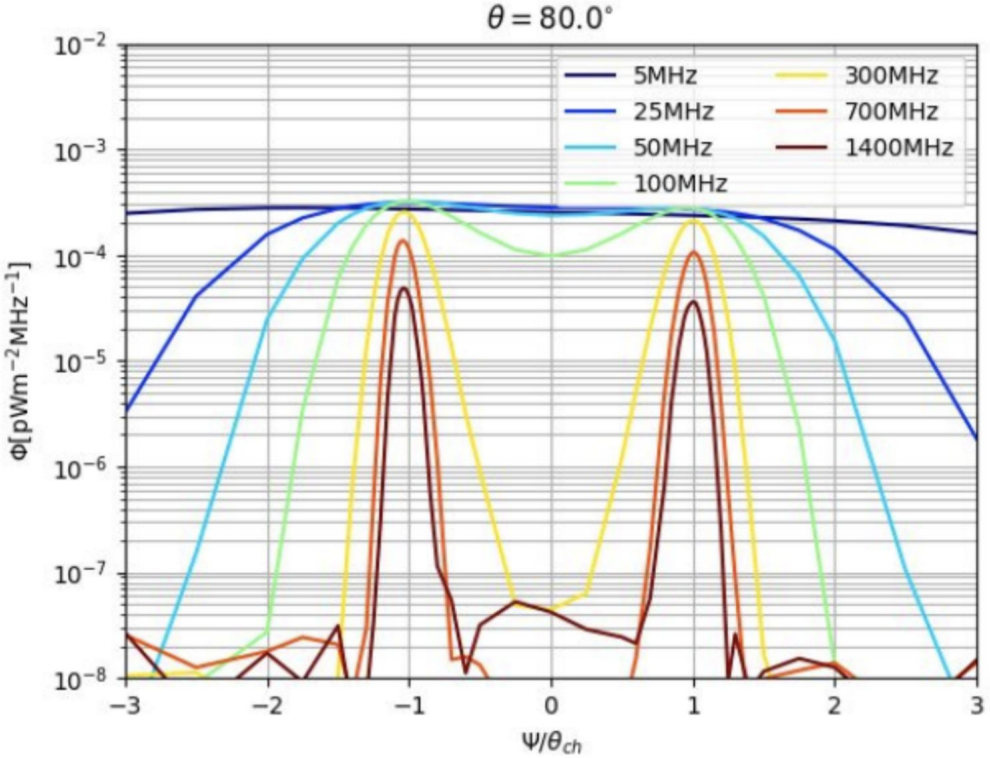
Peak charged particle intensity (and Chernenkov light intensity) per solid angle varies by ~ factor of 2 between iron and proton

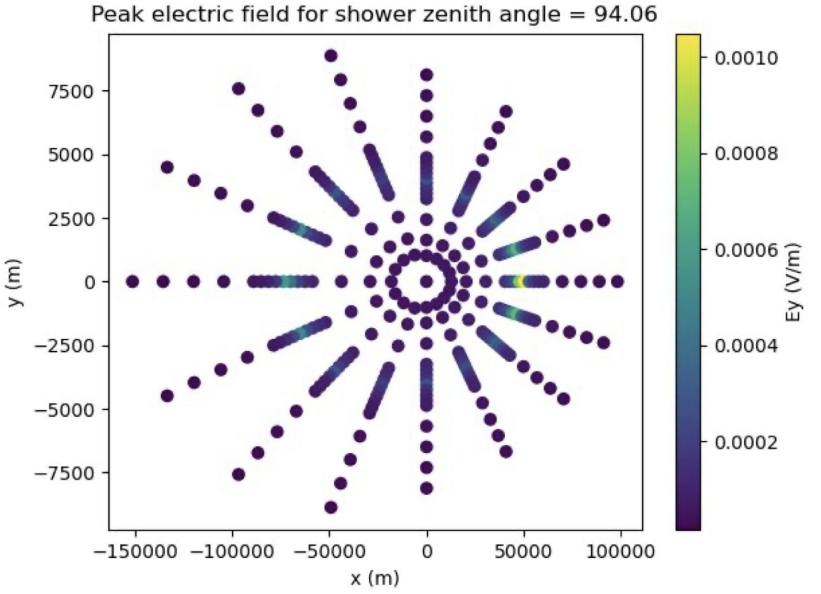


# Hybrid measurements possible with optical and radio

- Can help break degeneracy between position relative to shower axis and energy -> higher energy resolution

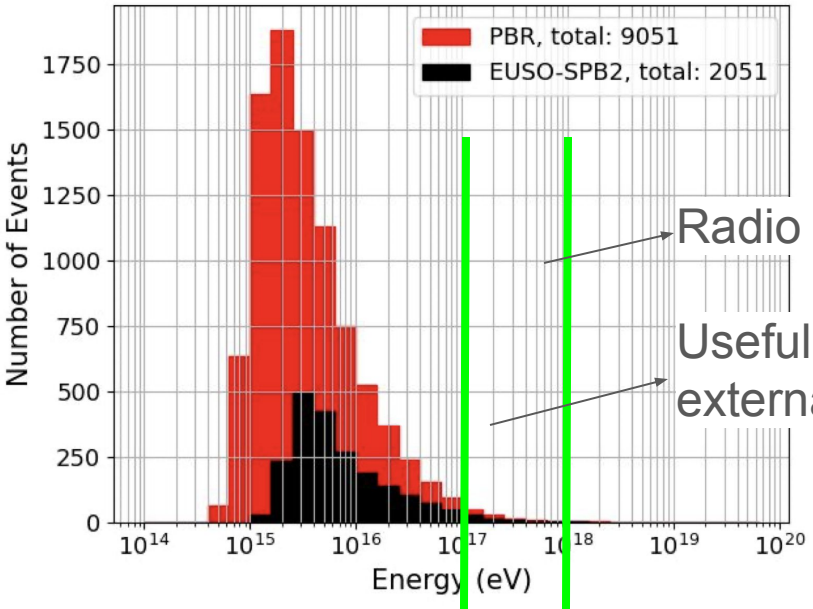


# Difficulties of radio observations

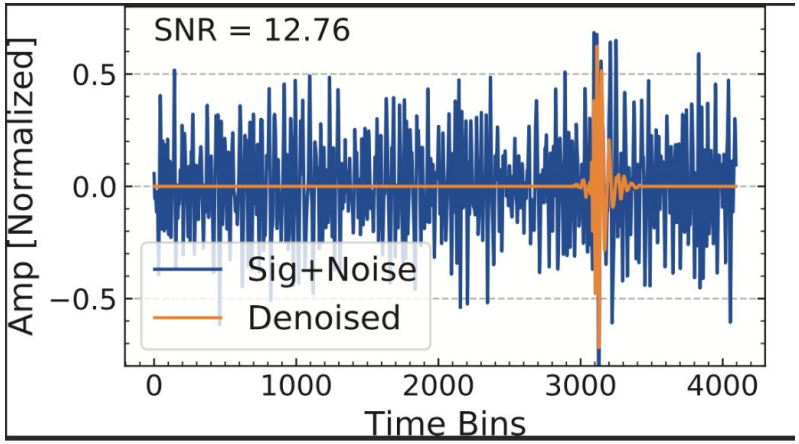
https://pos.sissa.it/395/417/

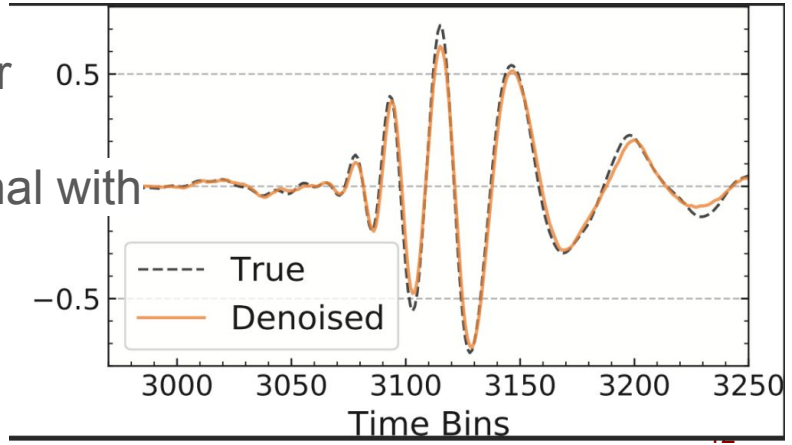
- Limited to high energy events
- Will need to rely on machine learning denoising techniques



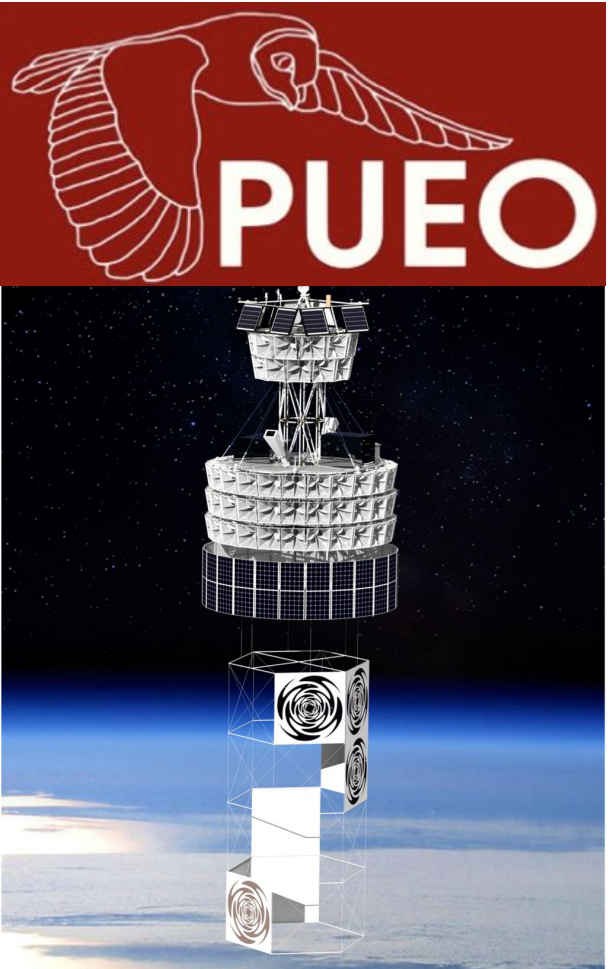

Radio self trigger

Useful radio signal with external trigger



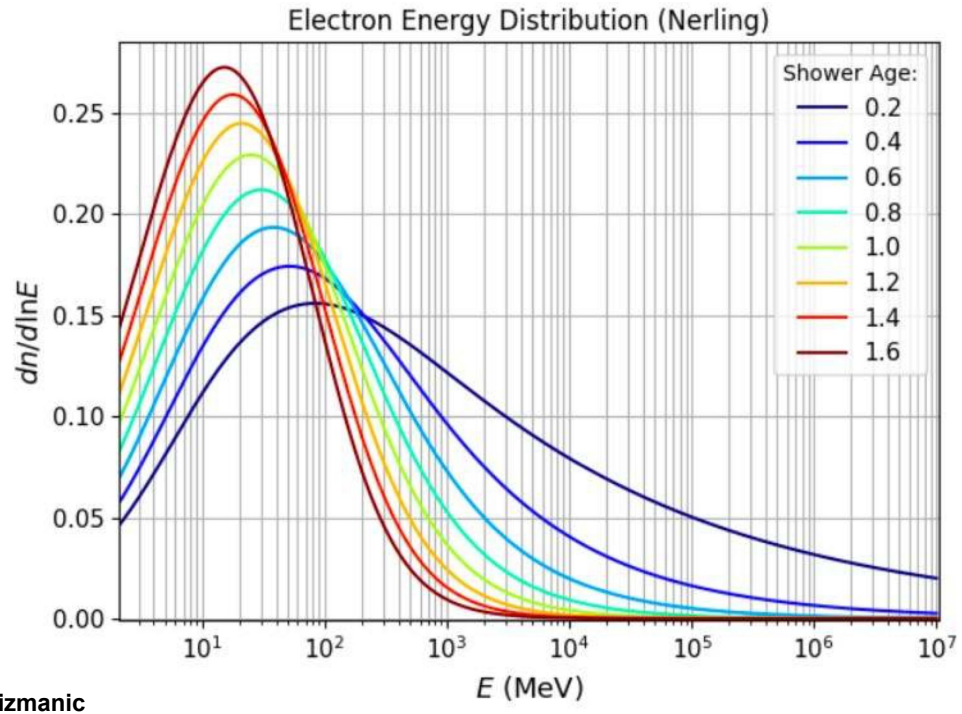
# Other balloon bourne radio measurements




- Payload for Ultra-High Energy Observations (PUEO)
- Planned to launch in 13 months
- Low frequency instrument (similar to PBR) triggered off of main instrument
- Cosmic rays are background (to neutrinos) but will provide insights into the observation technique

https://pos.sissa.it/444/1031/

# Possible measurement of x-rays

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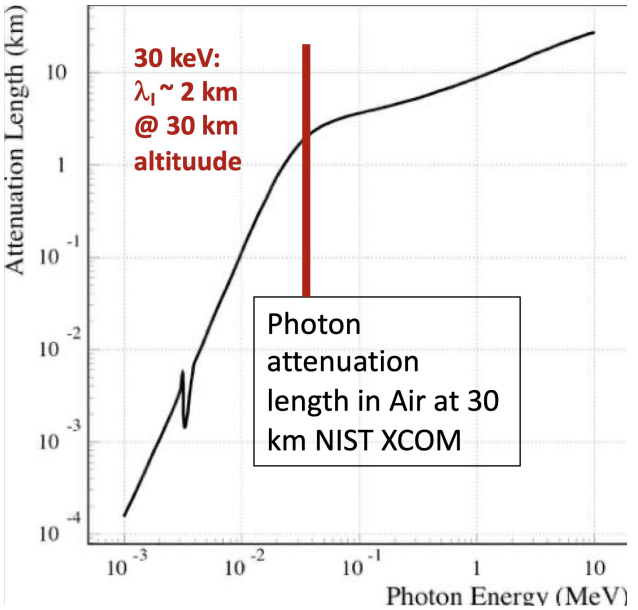
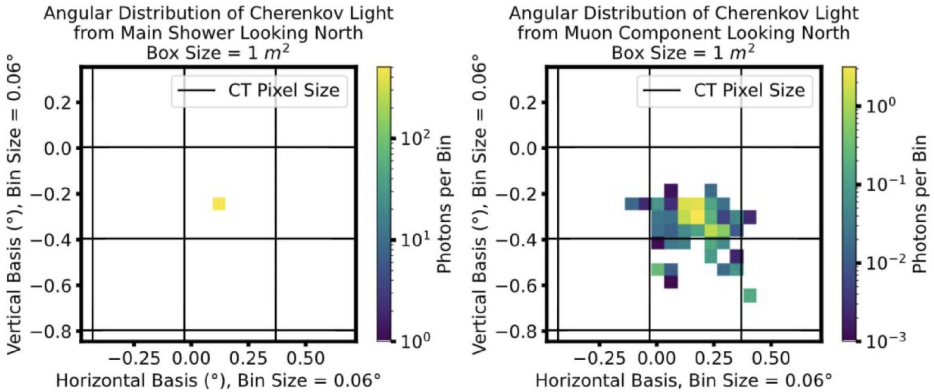



Simultaneous measurement of x-rays with shower validates understanding of shower development

$0.02 \times 10^4$ [electrons] × 104 [X-rays/electron] = $2 \times 10^6$ [Brem X-rays]
$2 \times 10^6 / 2.5 \times 10^5$ [cm2] ≈ **10 Brem photons/cm2**

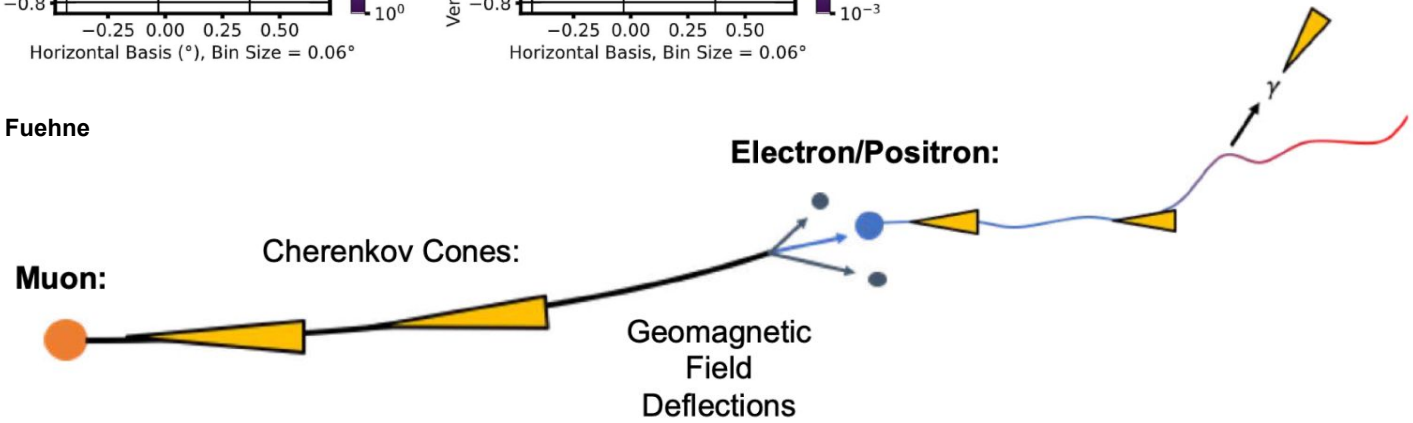
# Muon deflections in Earth's magnetic field

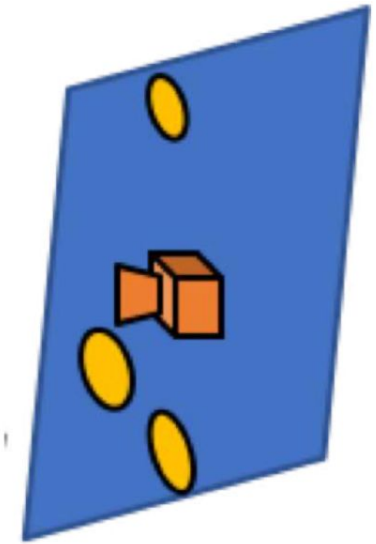



Deflections of early-shower muons in geomagnetic field broadens signal

Effect should depend on azimuthal orientation of detector

D Fuehne



# Summary

- High altitude balloons provide a unique observing environment for extensive air showers
- POEMMA Balloon with Radio will leverage many techniques to exploit its position on top of the atmosphere
- These measurements will serve as a proof of concept for future space based missions and possibly shed insights into shower development