Hybrid concept for SWGO
SST-1M @ SWGO

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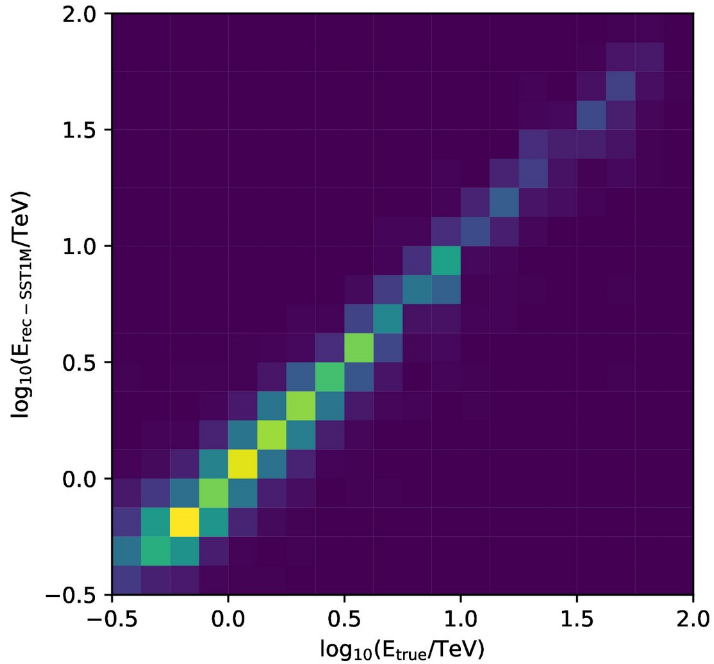
Advantages of SWGO+SST

- **Energy calibration**
- Two+ SST-1M telescopes = **stereo reconstruction**
  - → possibility to test directional reconstruction
- **Gamma-hadron separation**
  - → independent gammaness estimator – checks of SWGO gamma flagging
- **Multi-parameter studies**
  - → on the hybrid subset a lot of additional information – interesting for CR
  - → study systematic differences between interaction models
- **Follow-up observations**
  - → SST-1M with better angular resolution could observe transients
- **Lowering energy threshold of SST-1M**
  - → high altitude + SWGO helps with shower axis determination @ low E
  - → possibility to study Cherenkov light from primary CR particles

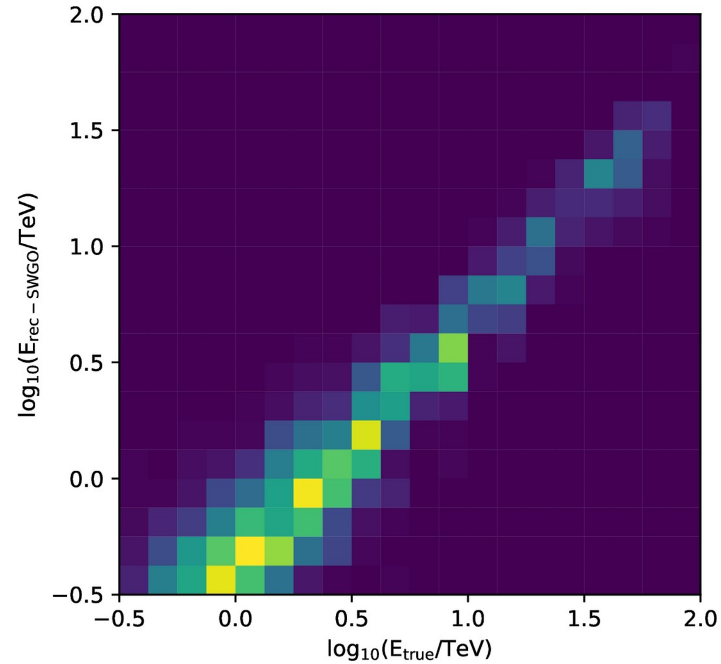
Energy calibration of SWGO

- Idea summarized in HAP-22-007 – **Auger-like calibration**
  - → targeted to specify the energy scale – IACTs have different systematics
  - → detailed simulation of SWGO response in HAWCsim + HAWCrec

SST-1M + SWGO core energy migration



Energy migration from HAWCrec – clear bias



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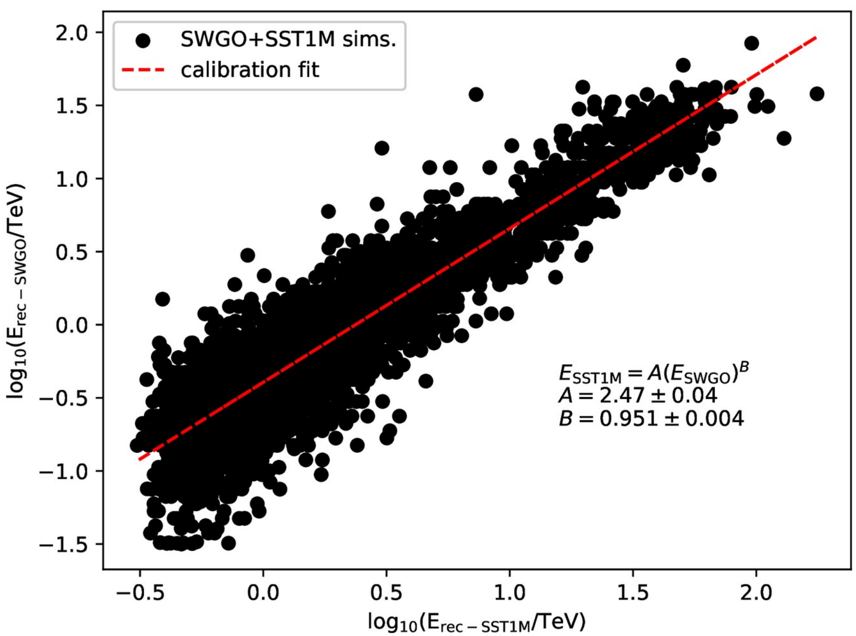
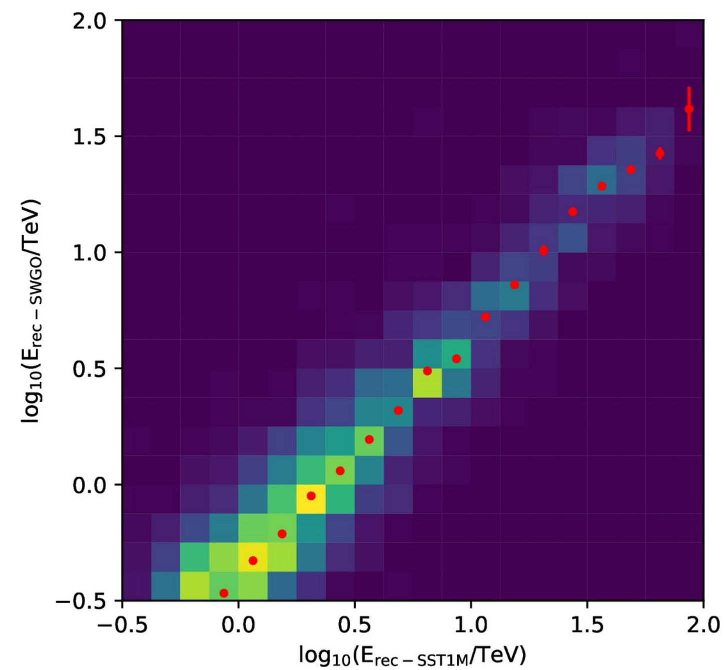
Calibration curve from hybrid sims.

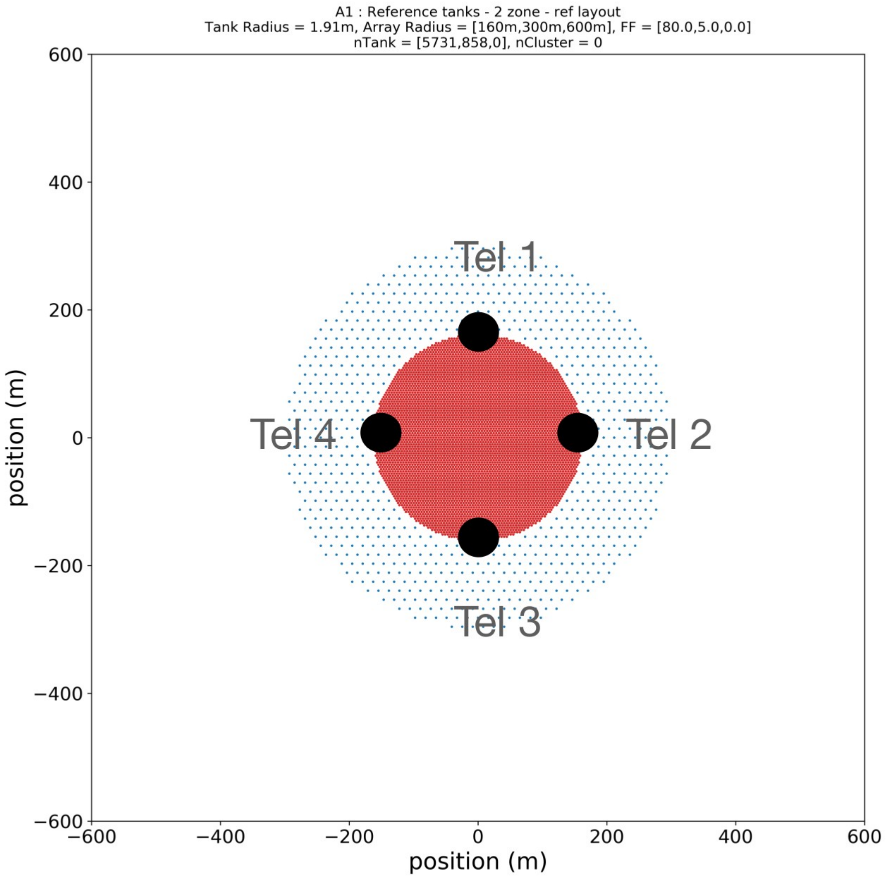


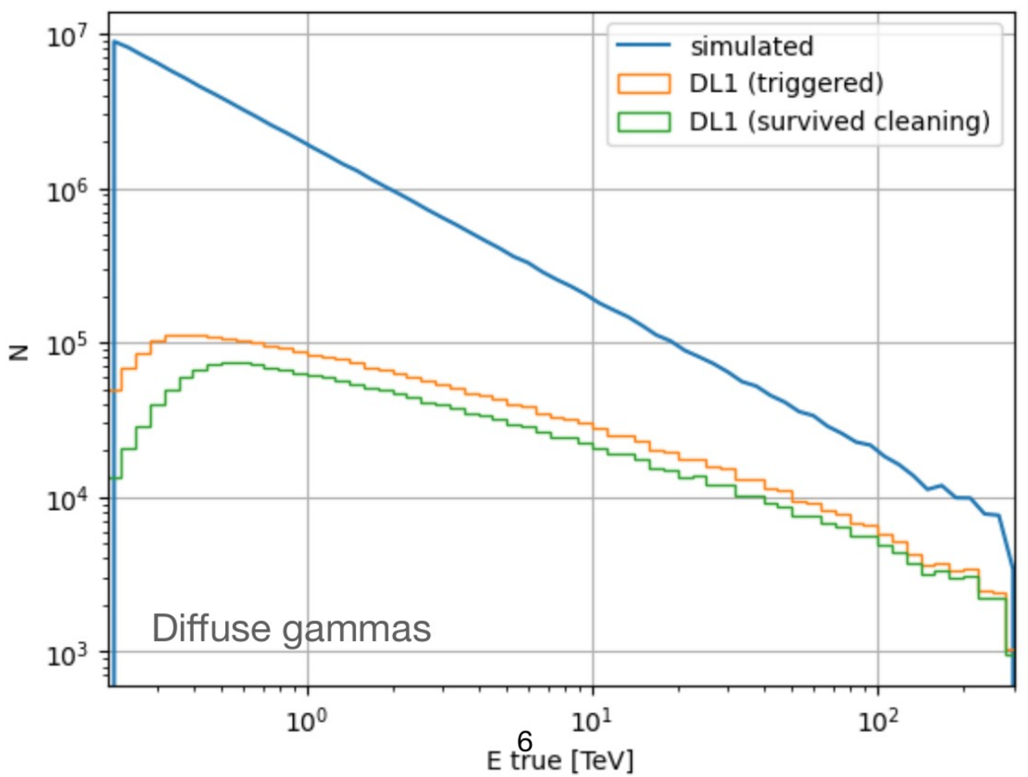
Correlation between HAWCrec and SST-1M



SST-1M mono performace

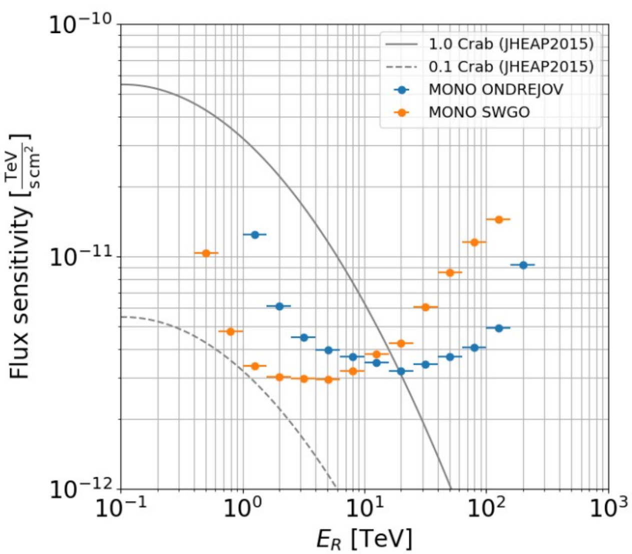
- CORSIKA + sim_telarray
  - Four SST-1M telescopes with mono trigger, averaged over 4 tels.

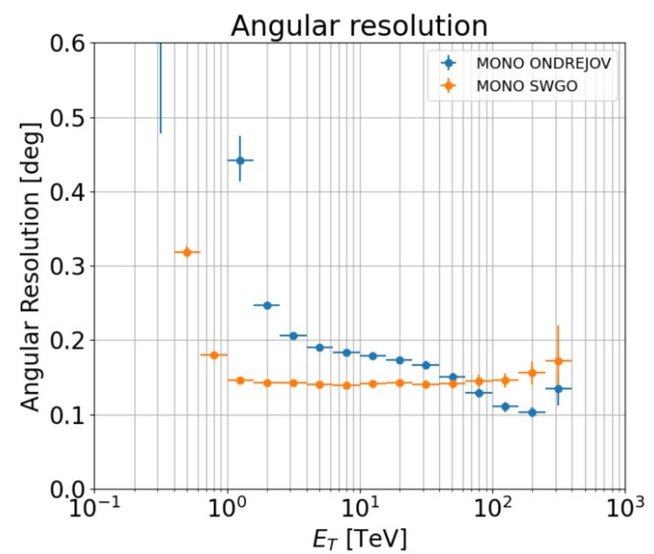


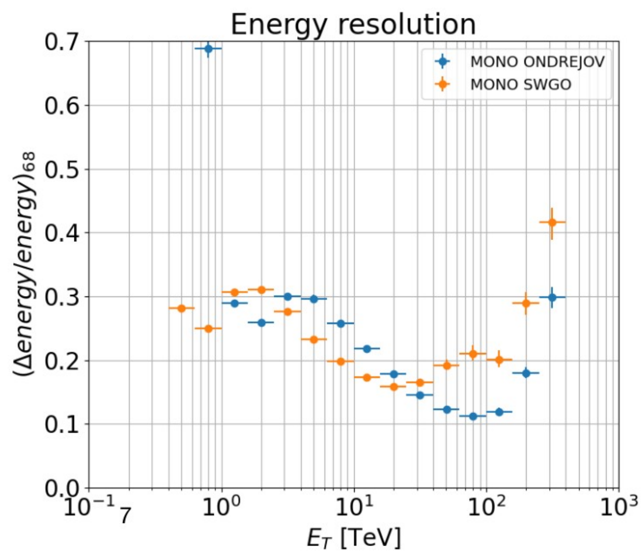


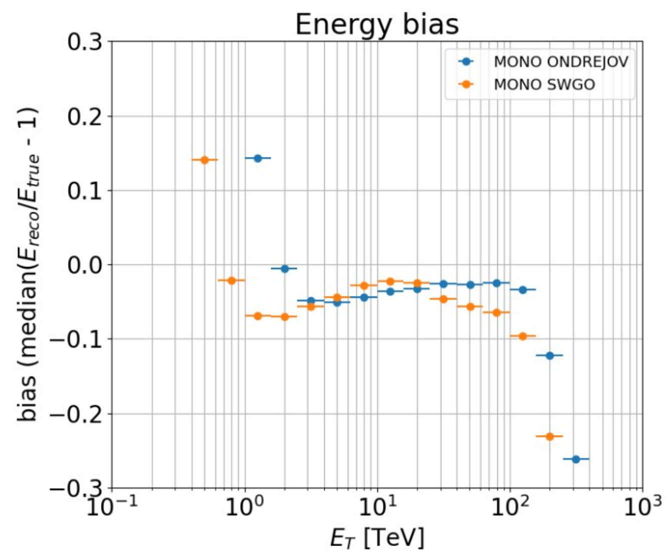
SST-1M mono performace

- Comparison between Ondřejov and SWGO site (4500 m a.s.l.)



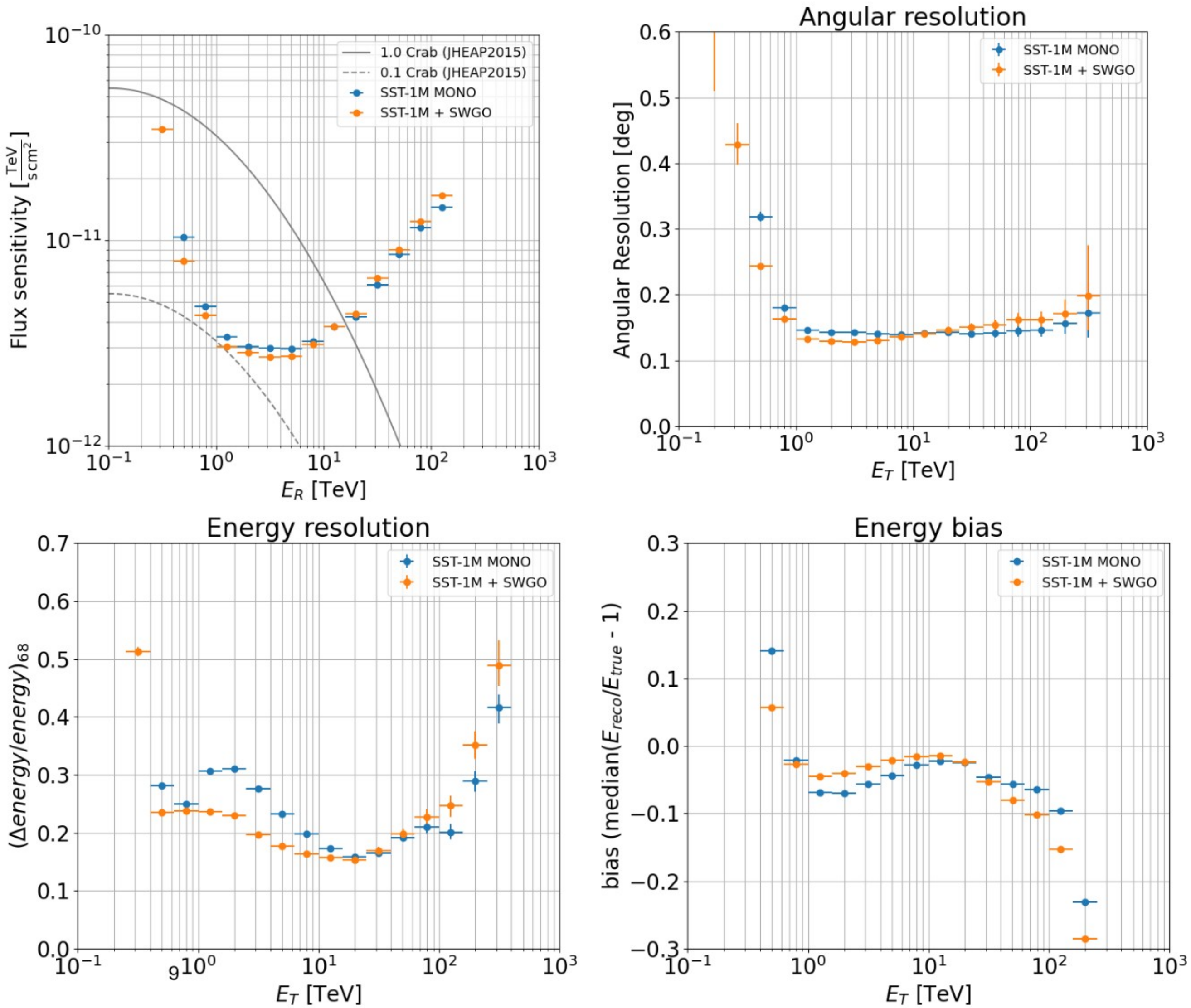






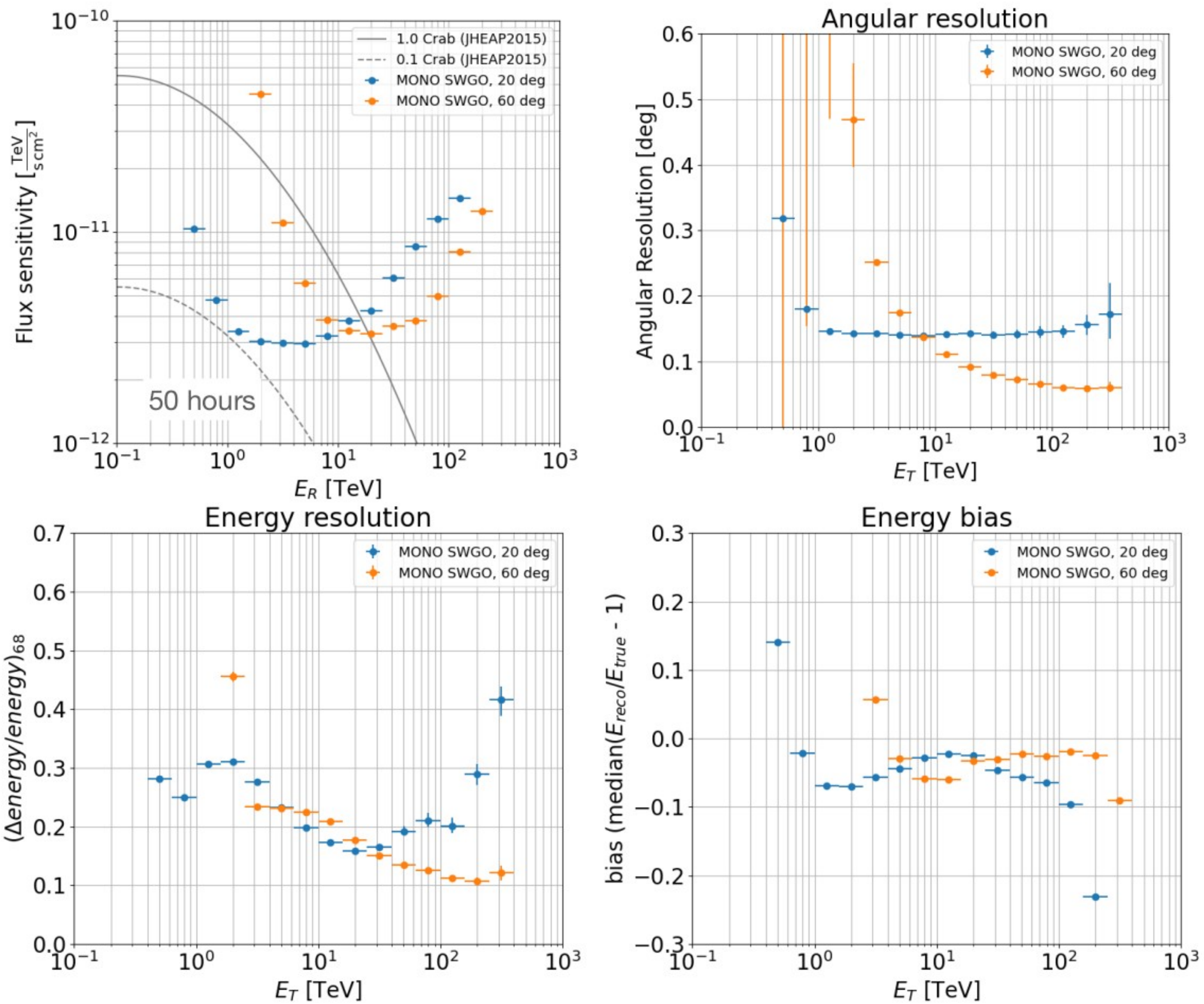
SST-1M mono + SWGO

- Change of performance when SWGO core added to SST-1M rec.



SST-1M mono @ SWGO site

- Change of performance with zenith angle – 20° and 60°



SST-1M mono @ SWGO site

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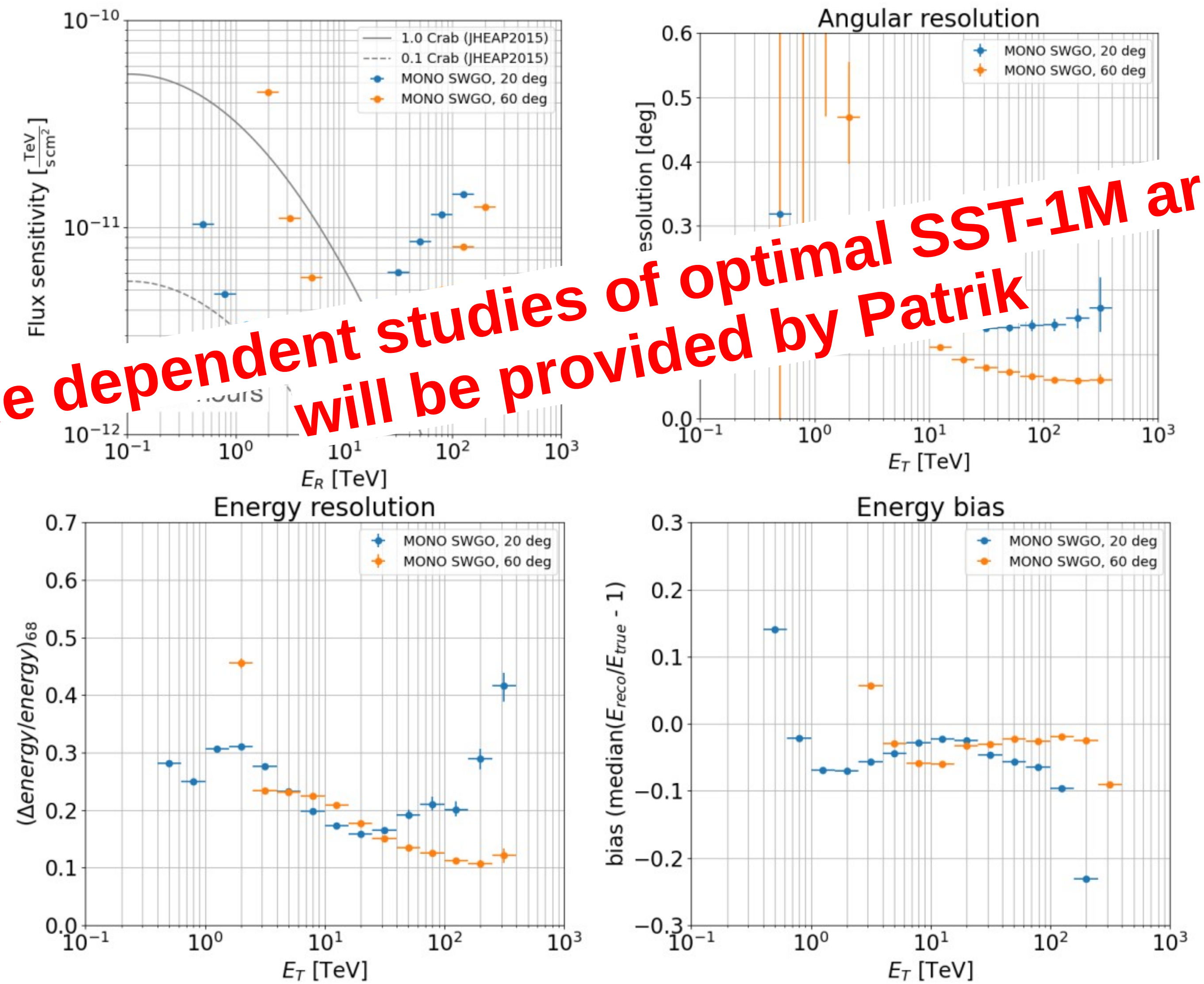
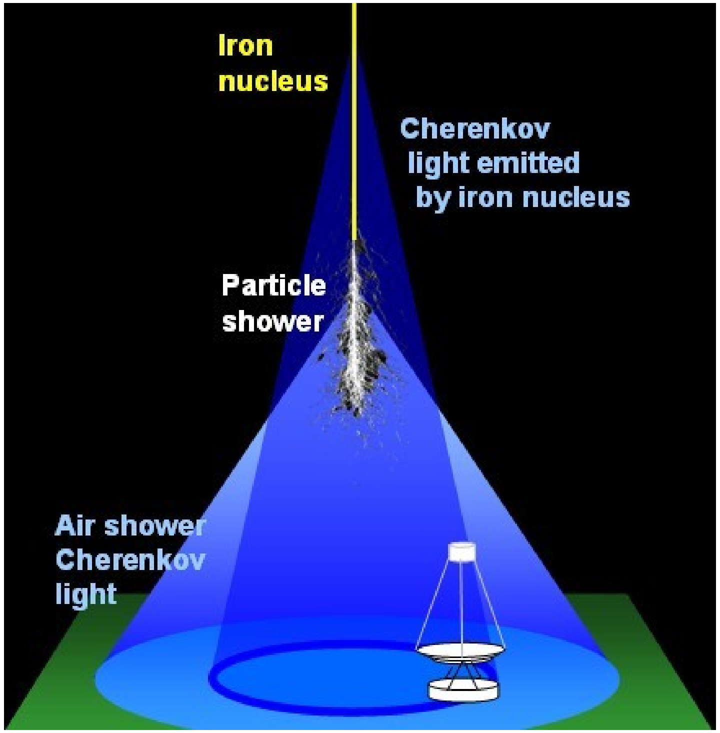
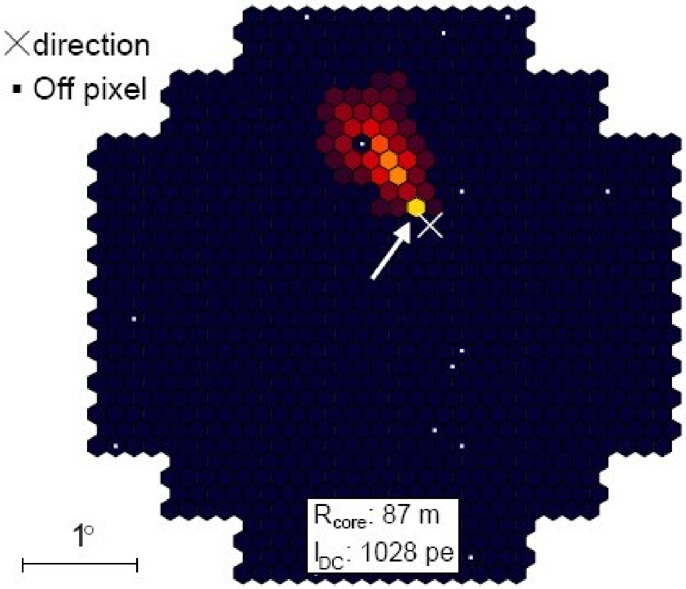


Altitude dependent studies of optimal SST-1M array layout will be provided by Patrik

Mass separation using SST-1M

- Two possible **methods** available with **IACT**
  - → direct **Cherenkov** radiation from **primary CR particle**
  - → utilizing **Hillas parameters**





credits to the H.E.S.S collaboration

Cherenkov from primary CR

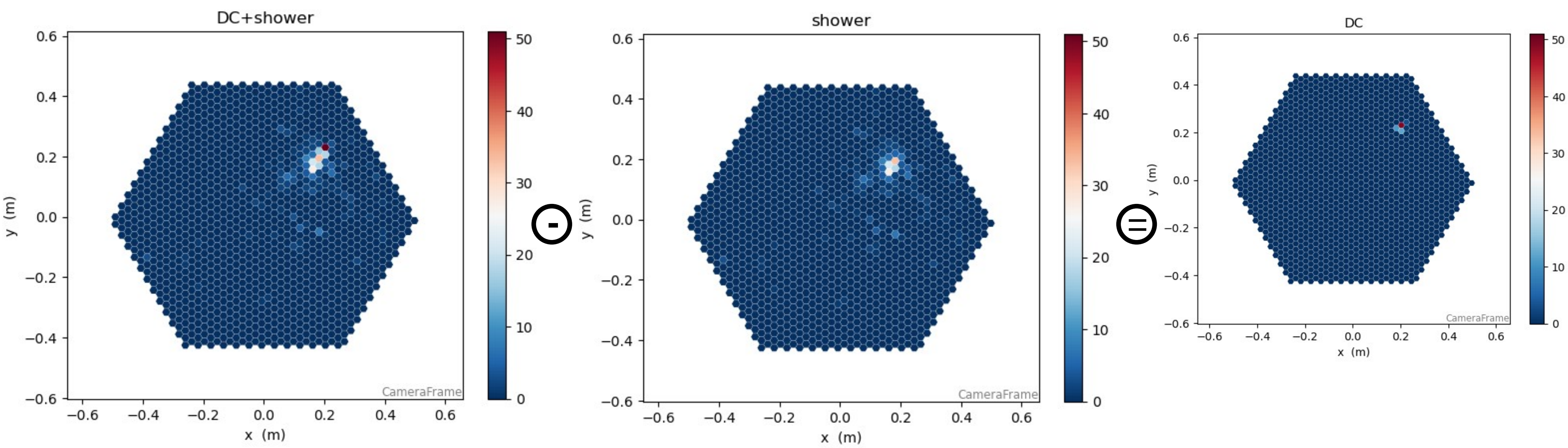
- Number of Cherenkov photons from Frank-Tamm formula
  - proportional to Z^2, unlike X_{max} which is ~ln(A)
  - almost independent of energy in relativistic regime

$$\frac{d^2N}{dx\,d\lambda} = \frac{4\pi^2 z^2 e^2}{hc\lambda^2}\left(1 - \frac{1}{n^2\beta^2}\right) = \frac{2\pi z^2}{\lambda^2}\alpha \sin^2\Theta_C$$

- Simulations needed to asses if it can be detected
  - CORSIKA – special mode to flag photons from primary CR
  - sim_telarray – modified to produce useful results
    - issue with random number generator...

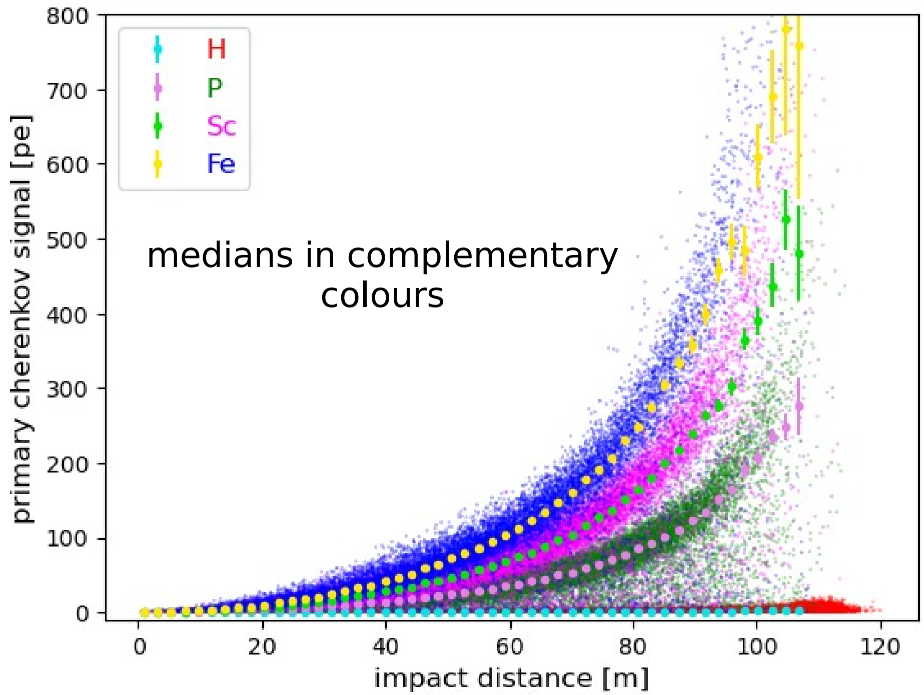
Result of simulations

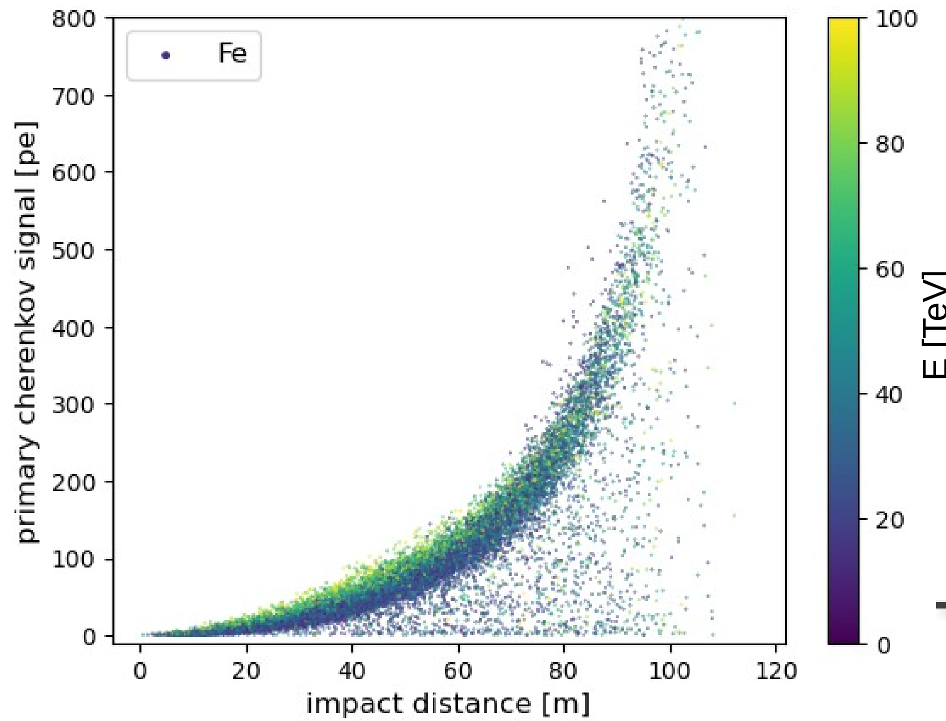
- Two classes of events – subtracted to get the signal from primary
  - → all the light from primary (DC) + subsequent shower
  - → only light from the shower



Impact distance and Z^2 dep.

- 4 classes of primaries simulated
  - → Protons ($^{1}_{1}H$), Phosphorus ($^{31}_{15}P$), Scandium ($^{45}_{21}Sc$), Iron ($^{56}_{26}Fe$)
  - → equal distance in Z^2
  - → 0.4-100 TeV, E^{-2}, θ=20°, altitude 4700 m a.s.l.
  - → signal from primaries increases with impact distance



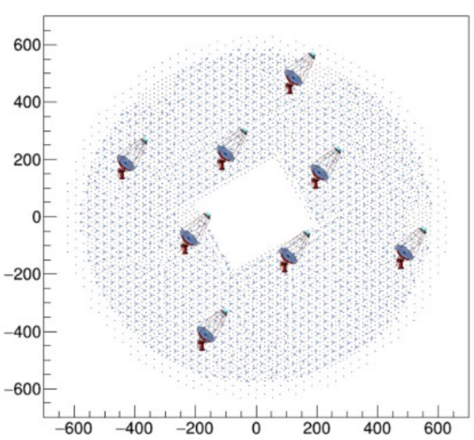


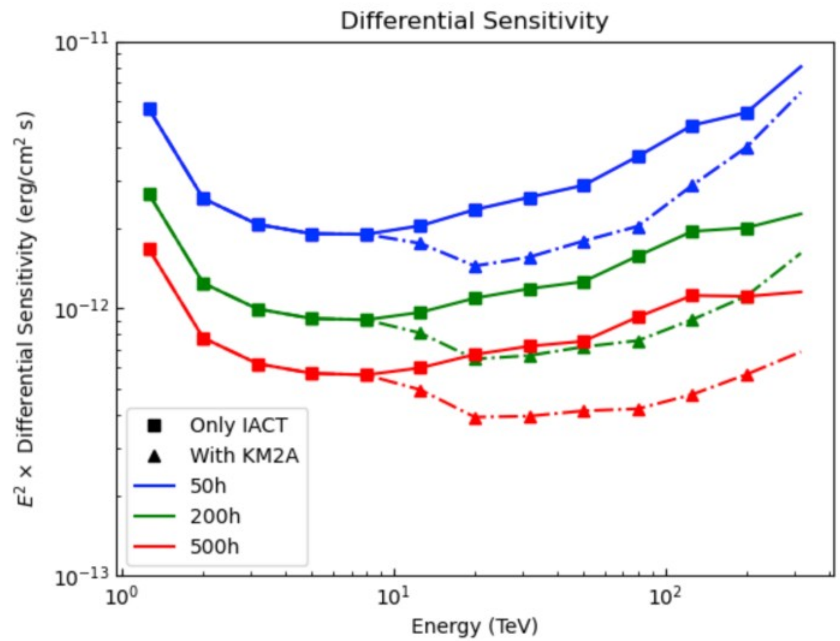
Conclusions

- Mutual benefit between SWGO and SST-1M
- Nice setup for cosmic-ray and gamma-ray studies
- LHASSO will have an array of IACTs in the near future!

LHAASO + IACT (Zhang et al. 2024, [2402.11286])

- 6-m telescopes
- ground array only used to improve g/h separation



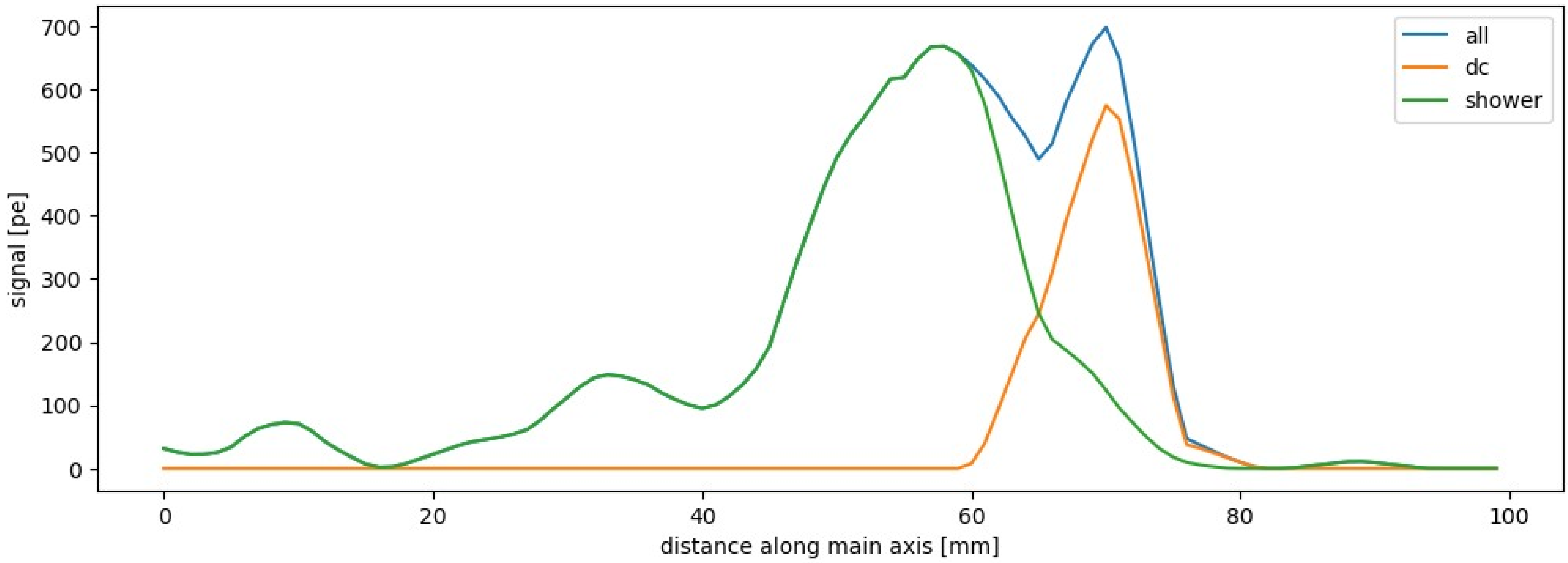


Work still in progress

Primary determination

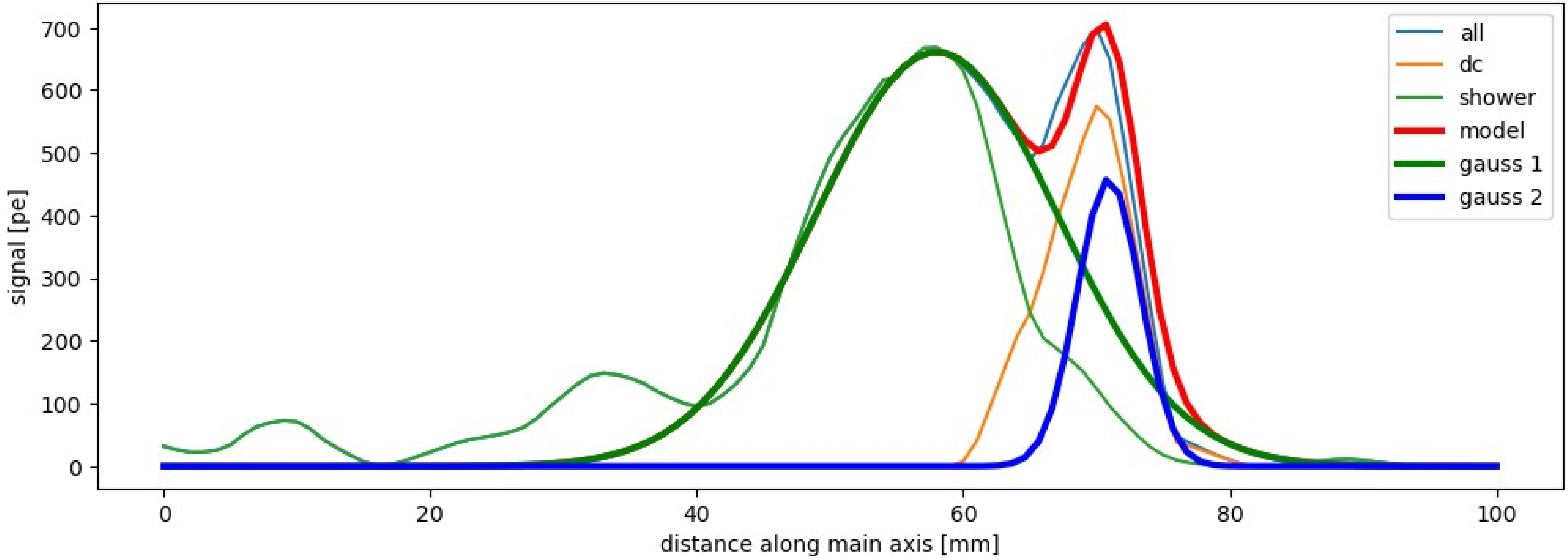
- To determine the primary we ideally need
  - → impact distance - well known (thanks also to SWGO array)
  - → Cherenkov signal from primary - can we estimate?

signal in pixels projected to the major axis of the Hillas ellipse



Signal determination

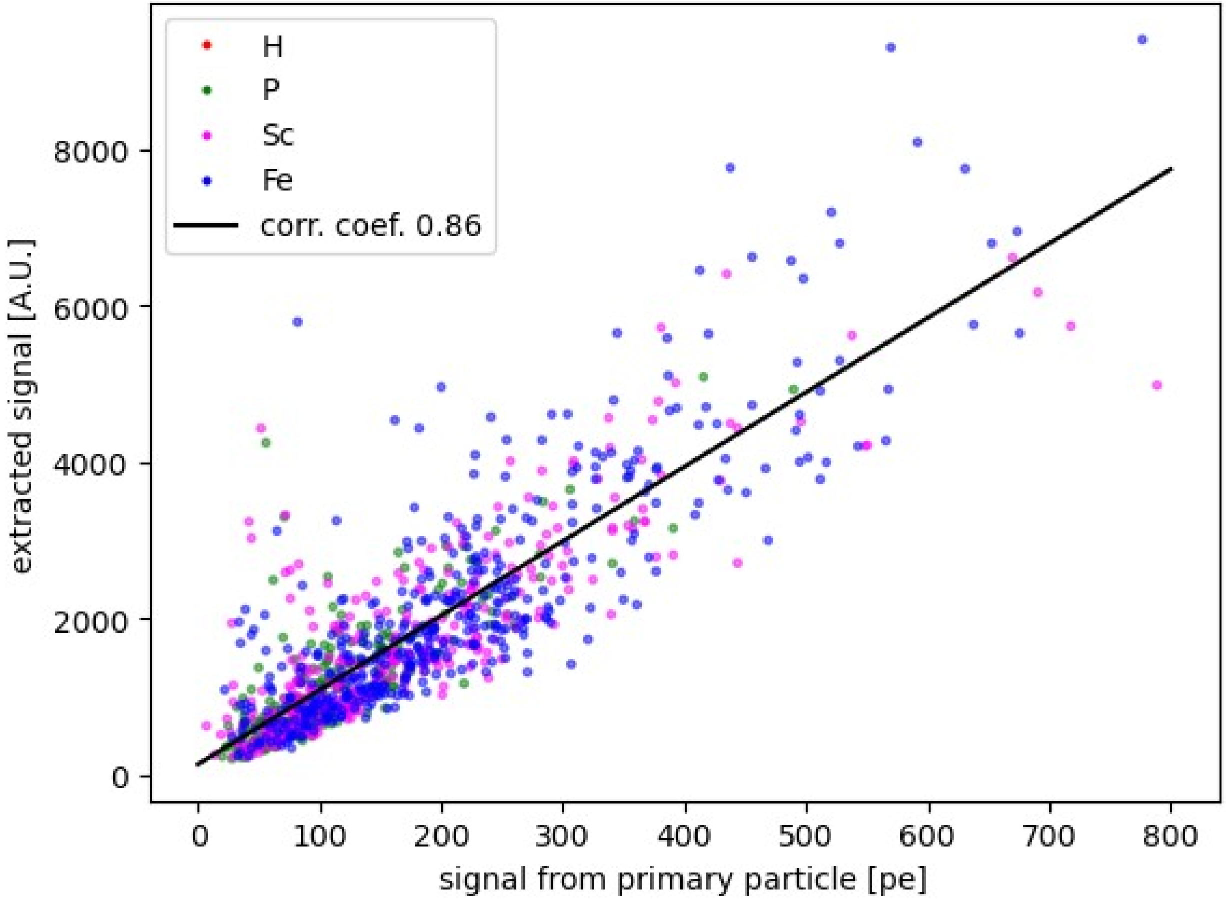
- Can we estimate the signal from primary?
  - project signal to the major axis of the Hillas ellipse
  - fit the profile by appropriate function (*very first try below*)
  - extract the area of Cherenkov-related peak



Signal determination

◎ Can we estimate the signal from primary?

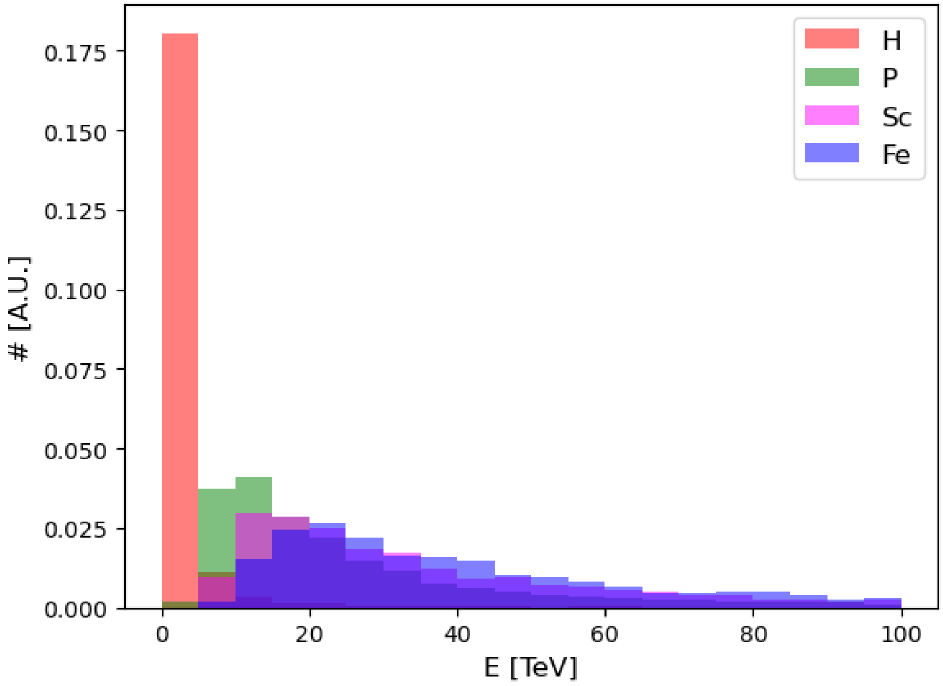
→ extracted signal correlates with primary-Cherenkov signal

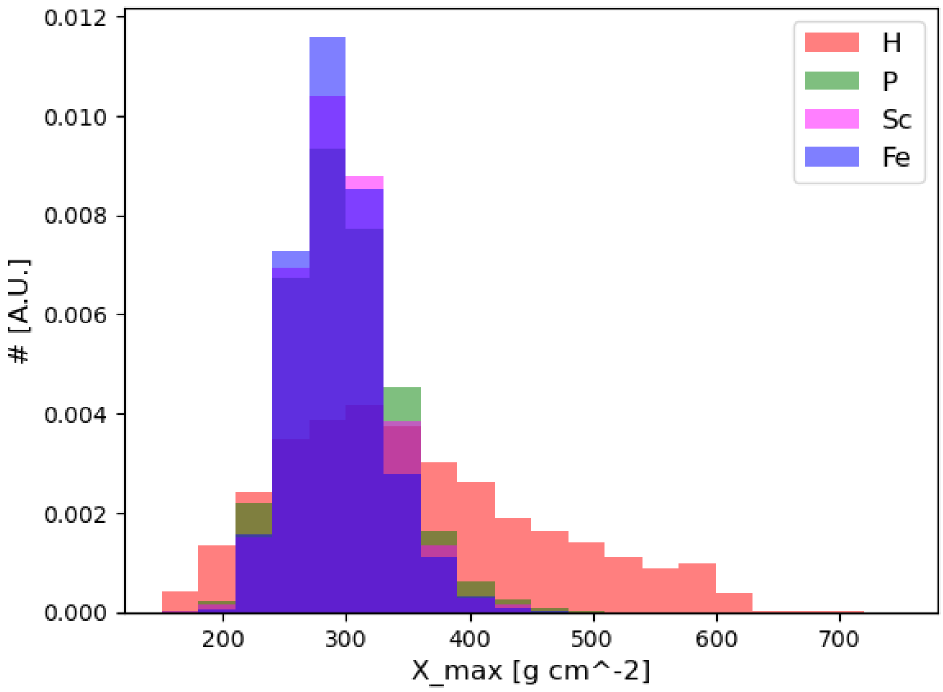


more work needed to make it precise

Sampled distributions

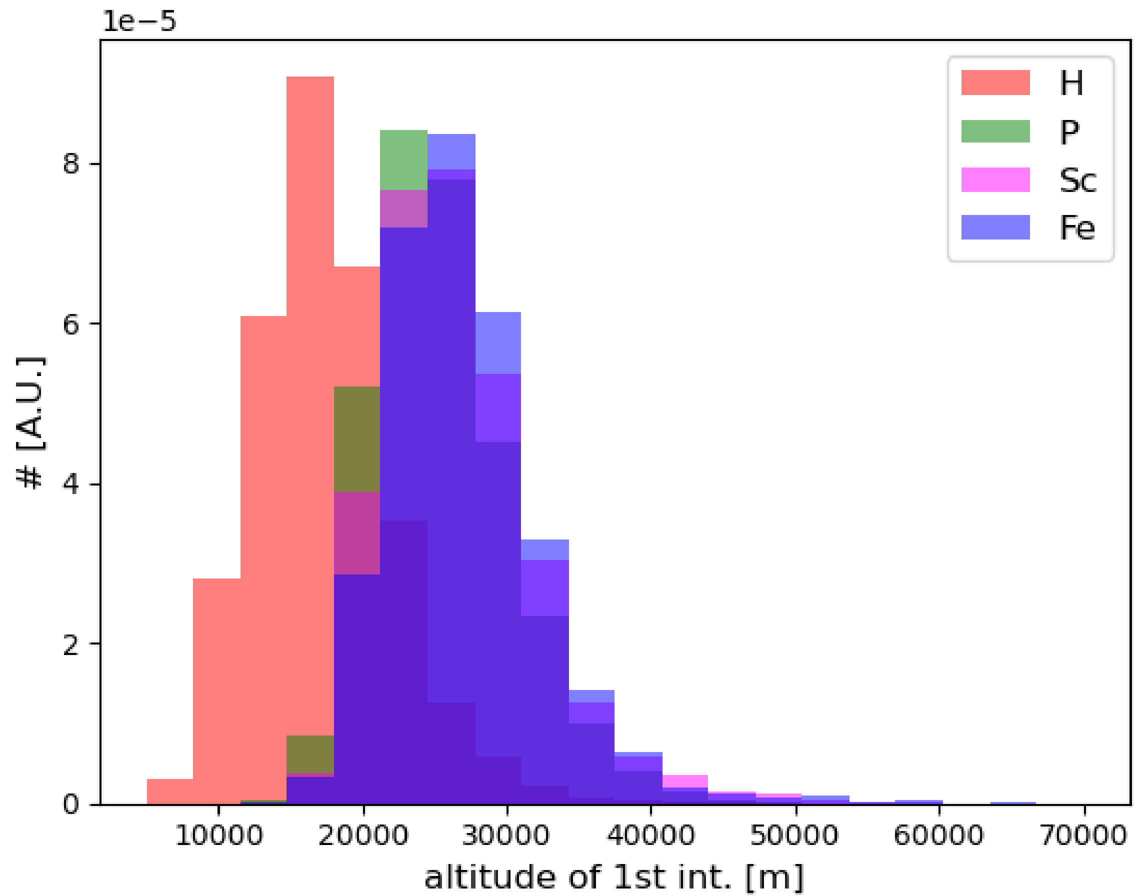
- Primary separation seems feasible
- What showers do we actually see in primary Cherenkov?
- Events with at least 1 pe from primary Cherenkov:





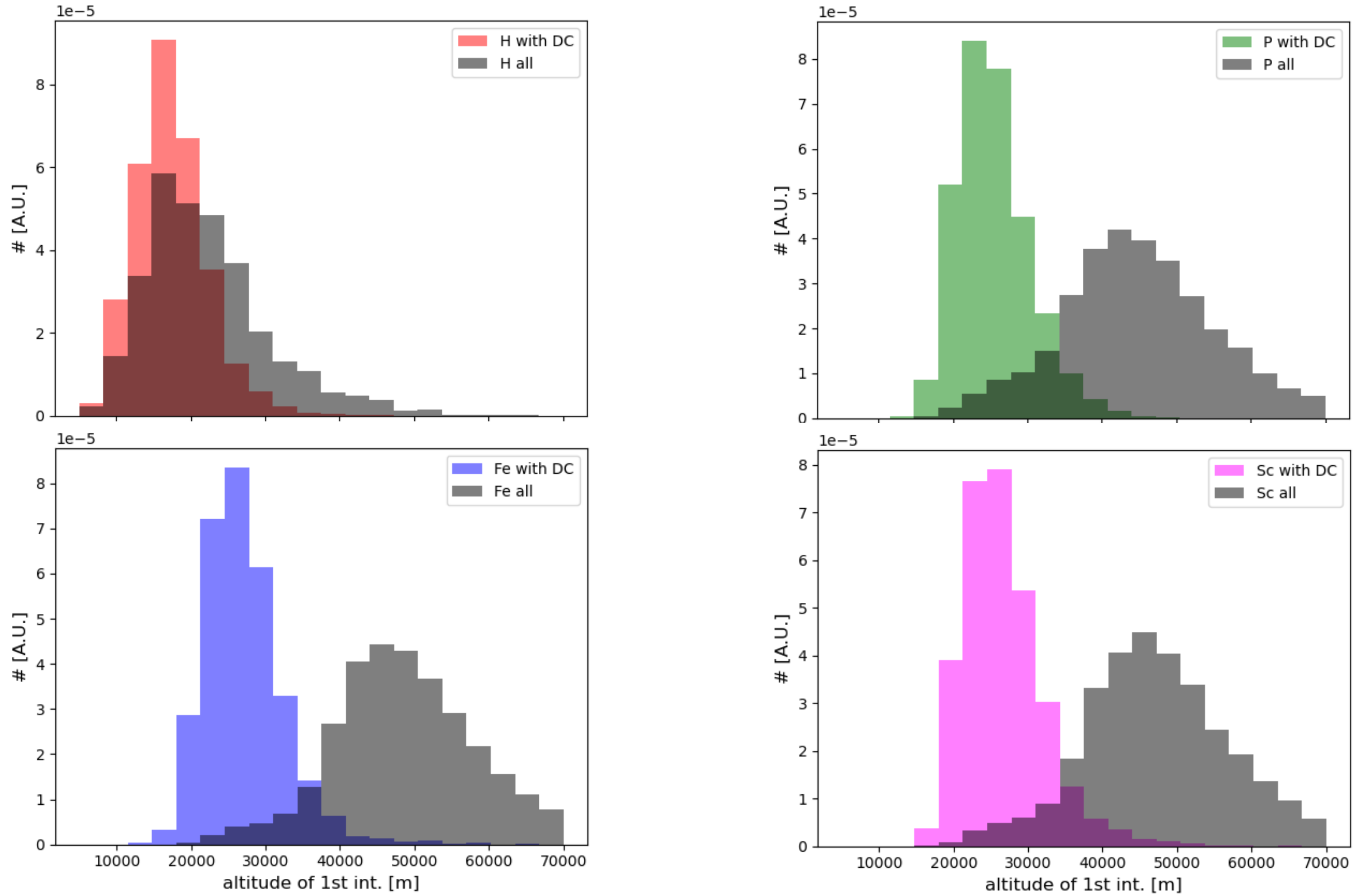
Sampled distributions

- Why so many protons at low energy?
  - → the depth of the first interaction



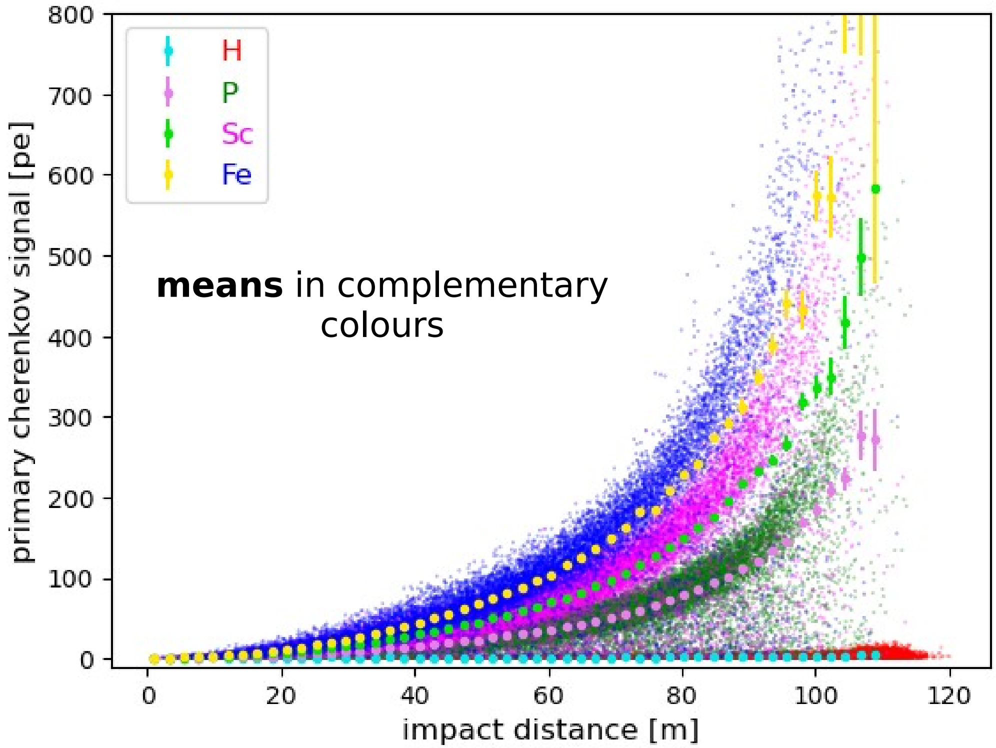
Sampled distributions

- Heavier primaries are sampled similarly – similar int. depth
- Low energy protons (H) present but with almost no signal



Backup

◎ Means of Cherenkov signal distributions are slightly shifted w.r.t. medians due to tails - to be studied



75 m < impact distance < 80 m