# Astro-particle in MODE

First MODE workshop on Differentiable Programming

# Outline

- **Theory**
  - Cosmology
  - Astrophysics

Parameter Estimation

- **Experiment**
  - Gravitational waves detectors
  - Cherenkov telescopes (CTA)
  - Radio neutrino telescopes (IC)

# Parameter Estimation

Use **automatic differentiation** (AD) to do parameter inference in high-dimensional models.

- Frequentist: Use gradient descent to minimise the likelihood function (AD is an alternative to finite differences algorithms).
- Bayesian: Hamiltonian MC to estimate the posterior distribution function.
- Likelihood-free or Simulation based inference: Likelihood is not tractable or unknown then use a neural network to predict the likelihood or the posterior (K. Cranmer et al. review 1911.01429)

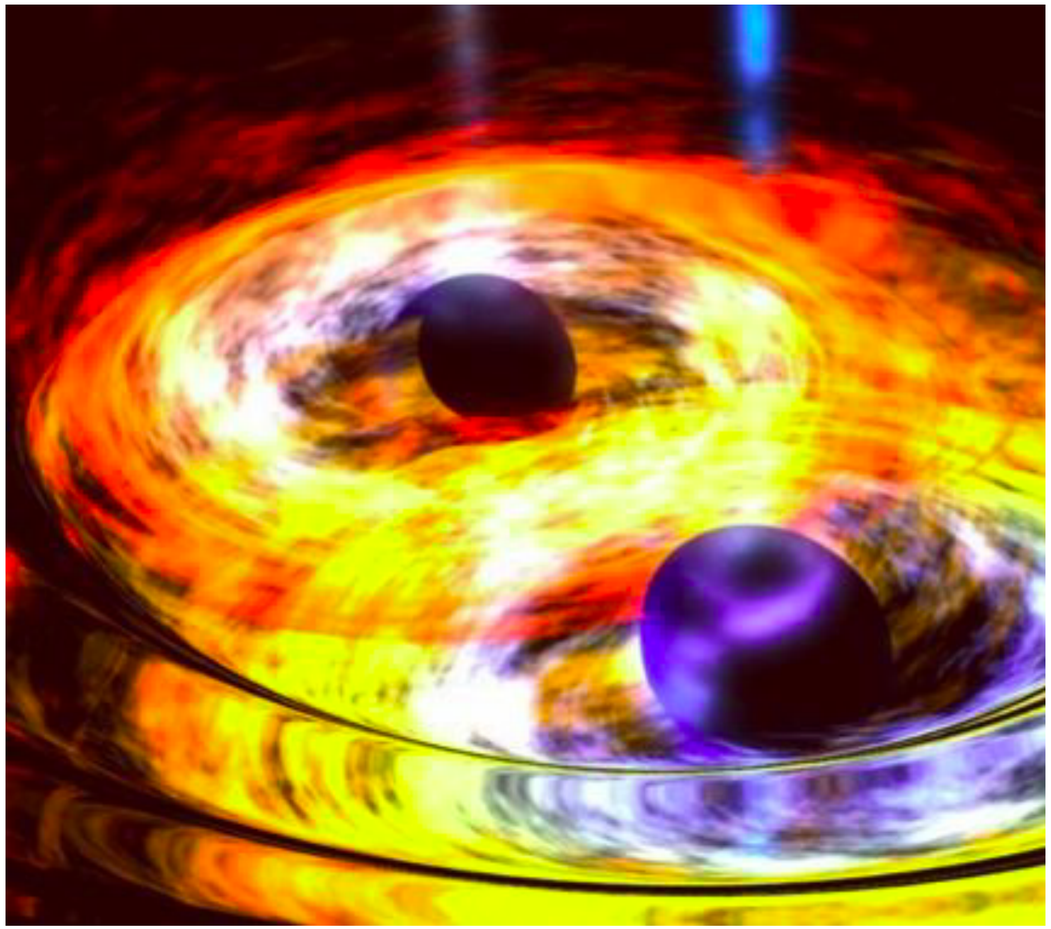
# Gravitational Waves

## On going

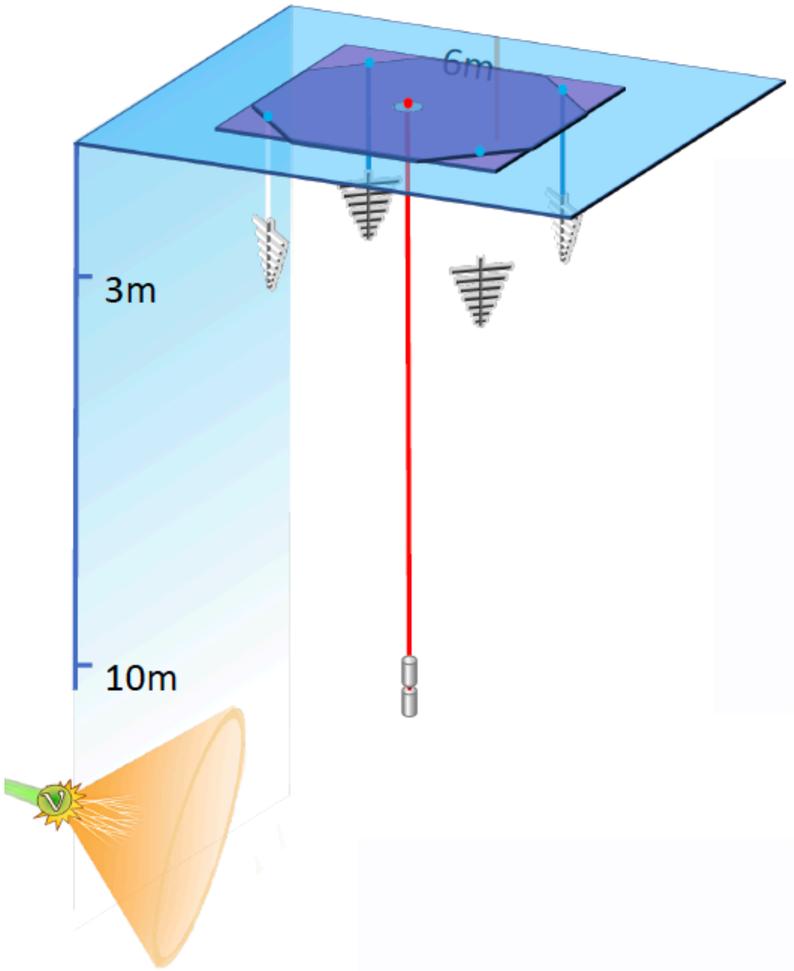
- Parameter estimation: Simulation-free inference
- Anomaly detection: glitch recognition & signal detection (Kaggle challenge)

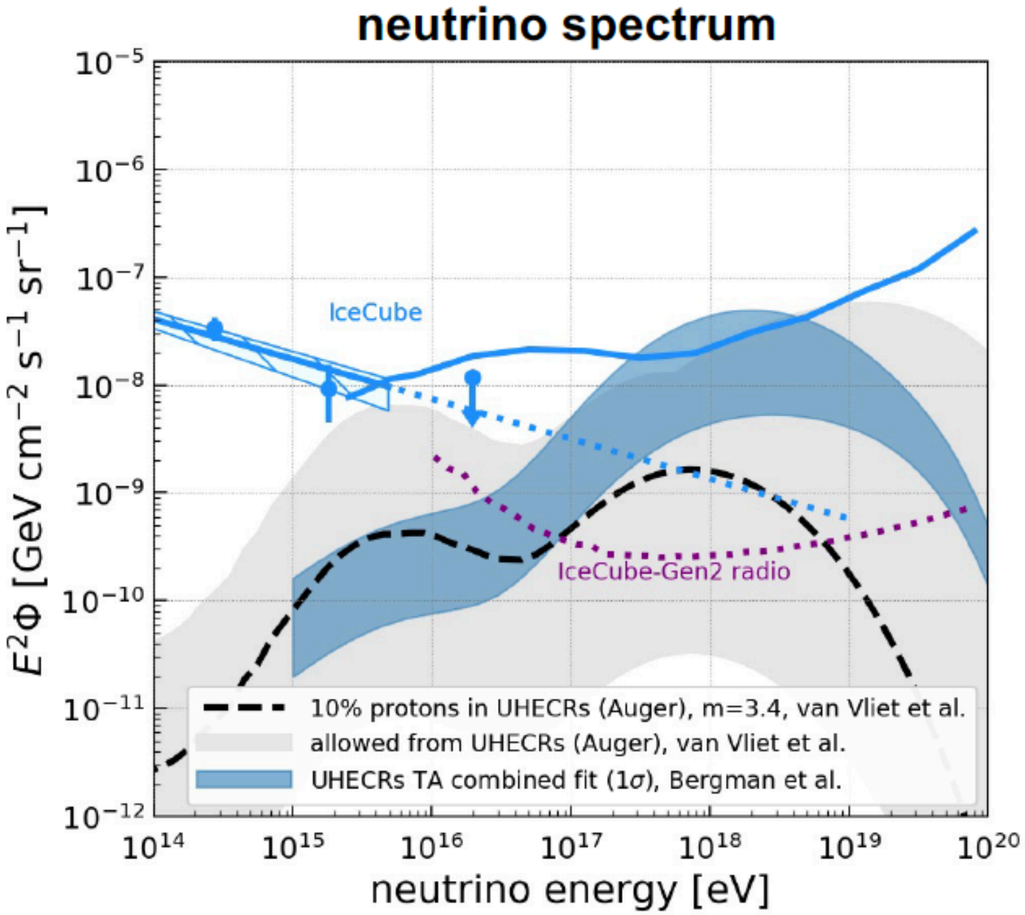
## Future

- Detector optimisation for a new generation of gravitational waves detectors ?



# Radio Detectors for High Energetic Neutrinos




optical

radio

# Optimization for Radio Detectors

**Parameters to optimize**

- Station spacing and layout
- Station layout
  - number of antennas
  - position of antennas
  - type of antennas
  - orientation of antennas
- Trigger

**Objective**

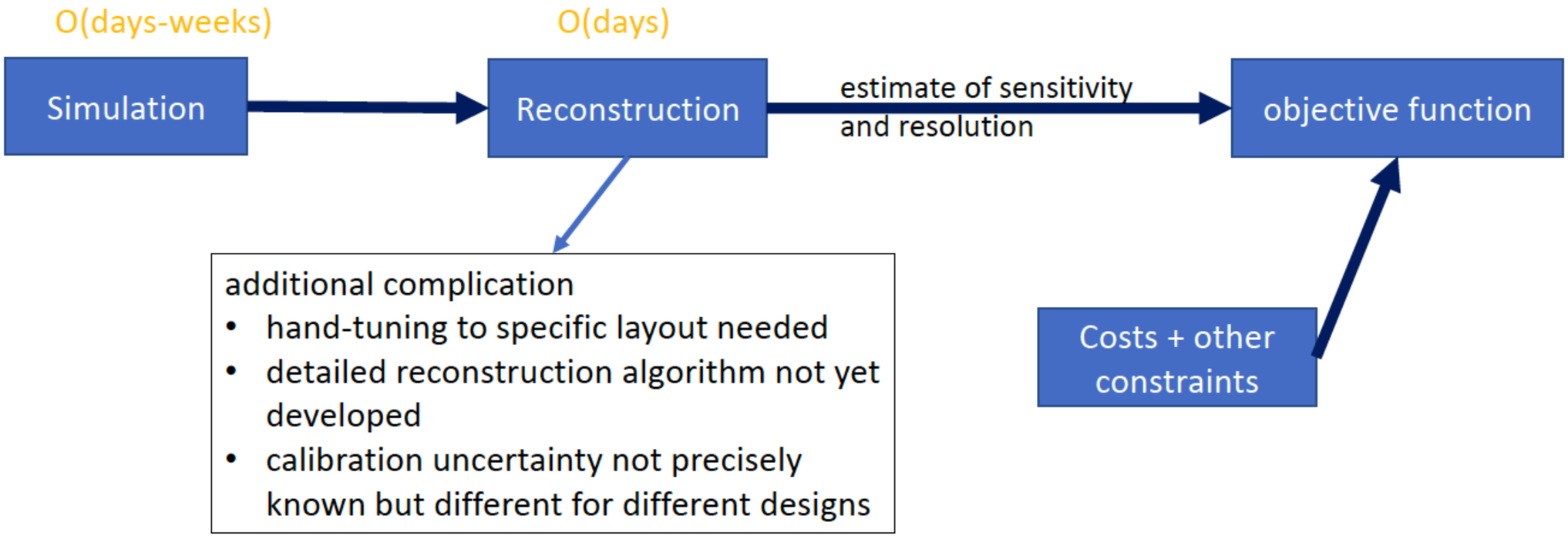
- Neutrino sensitivity (i.e. effective area)
- Resolution
  - Energy, Direction, Flavor
- But also: Robustness against systematic uncertainties
  - Redundancy in measurments
- Also: Ability to reject rare background

**+ costs,**
**deployment constraints,**
**engineering constraints,**

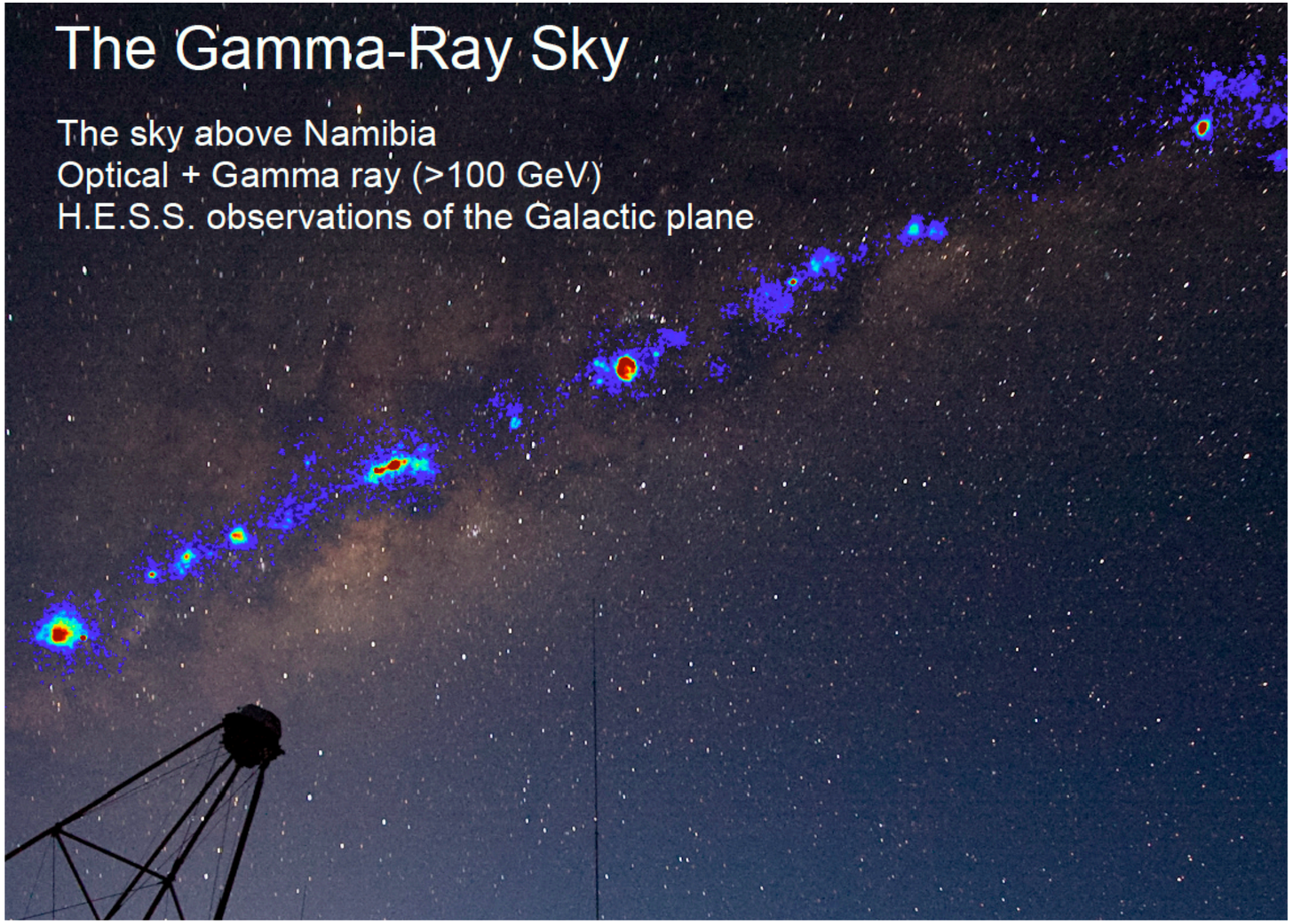
diverse science program
different optima for
different science cases

# Optimization Pipeline

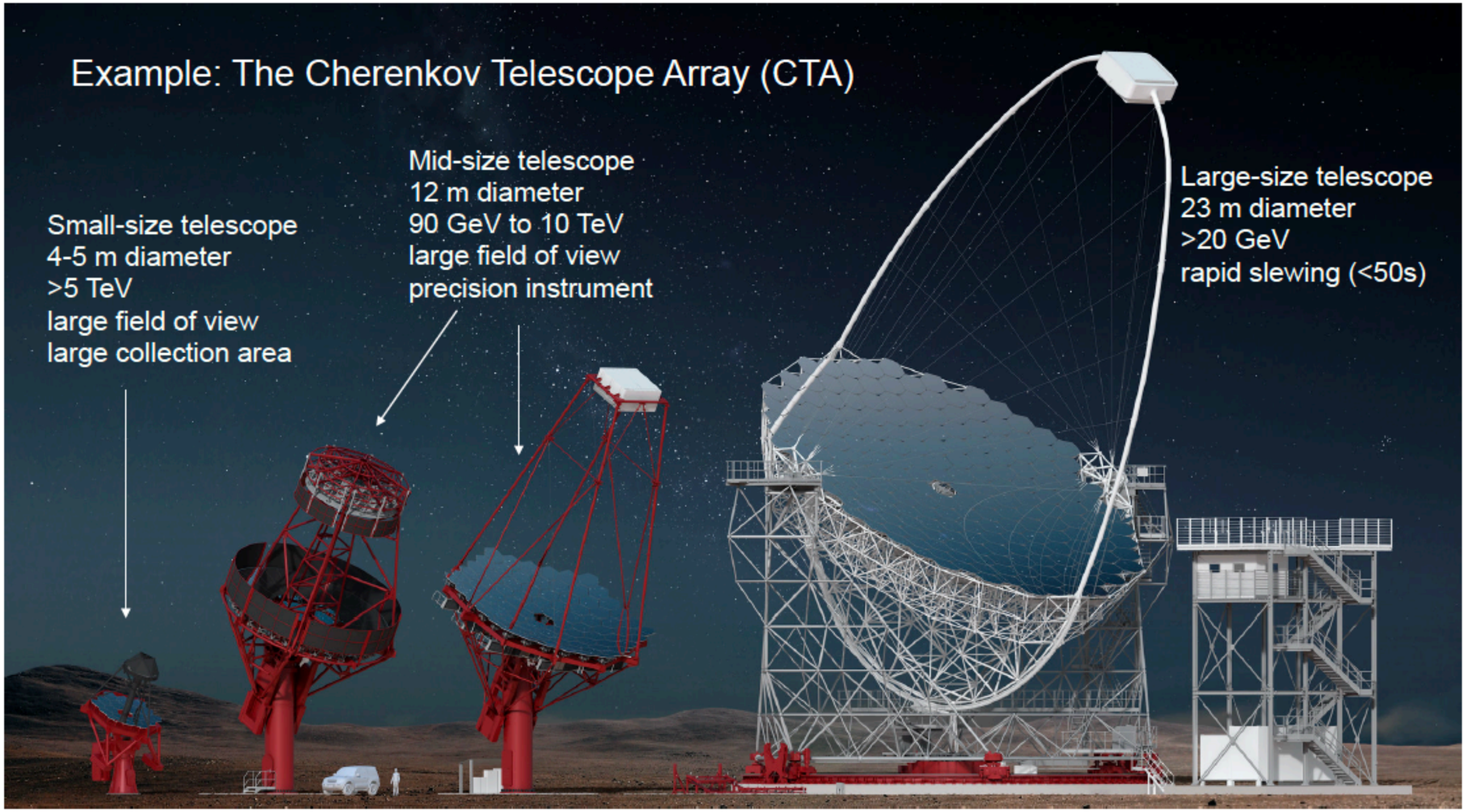
For each detector design:



# Cherenkov telescopes (CTA)



# Architecture



# Cherenkov telescopes (CTA)

## Optimisation Procedure

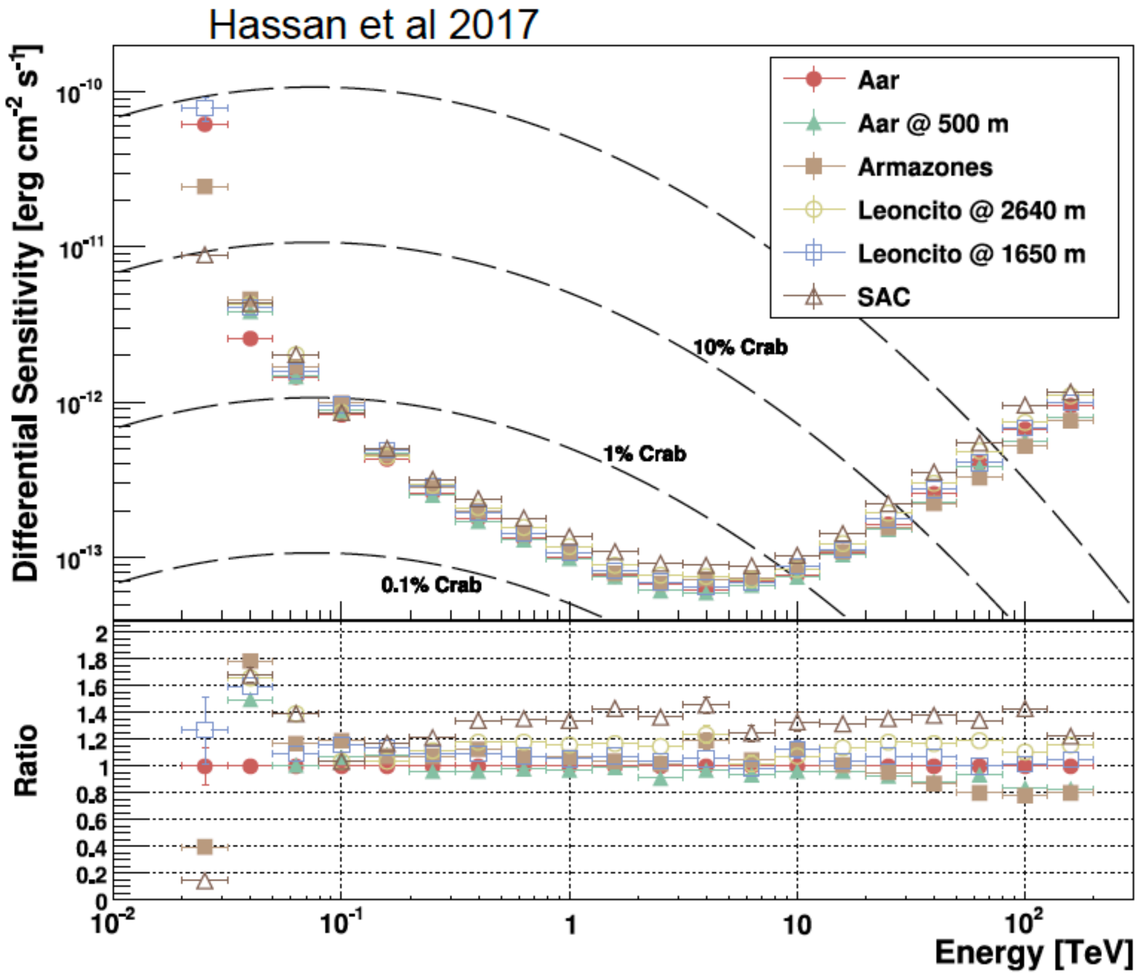

- **large parameter space to optimise**
  (close to 100D…)

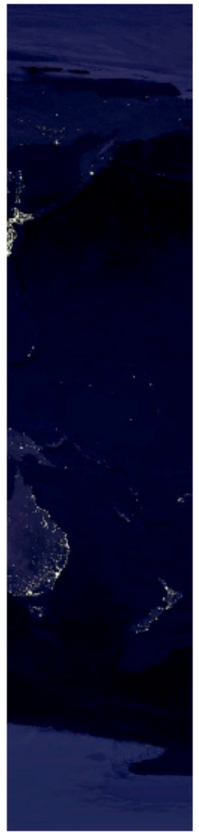
- **“optimise” by common sense, first principle, guessing, brute force walk through the parameter space, green-table decisions**
  - split into smaller problems (if possible)

- **MC simulations and analysis**
  - detailed Monte Carlo Simulation of shower, telescope optics, trigger, and digitisation
  - image analysis, stereo reconstruction, background suppression including training of machine learners

- **discussion of technical and science teams on what is the ‘best’**

# Atmosphere effects



**For doing optimisations order 100 billion events have to be generated => 1.5 Petabyte**

# That’s all