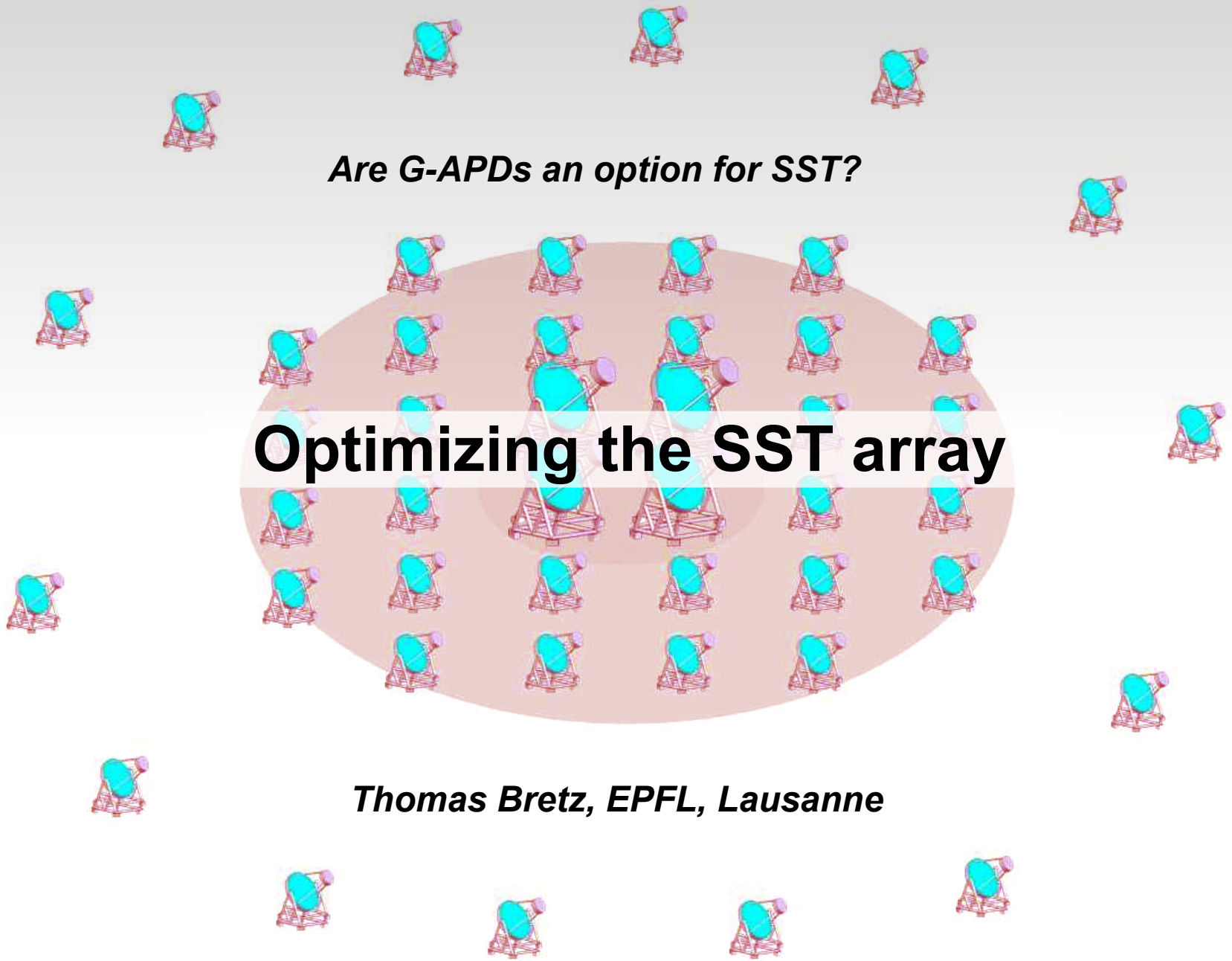
ÉCOLE POLYTECHNIQUE
FÉDÉRALE DE LAUSANNE

Are G-APDs an option for SST?

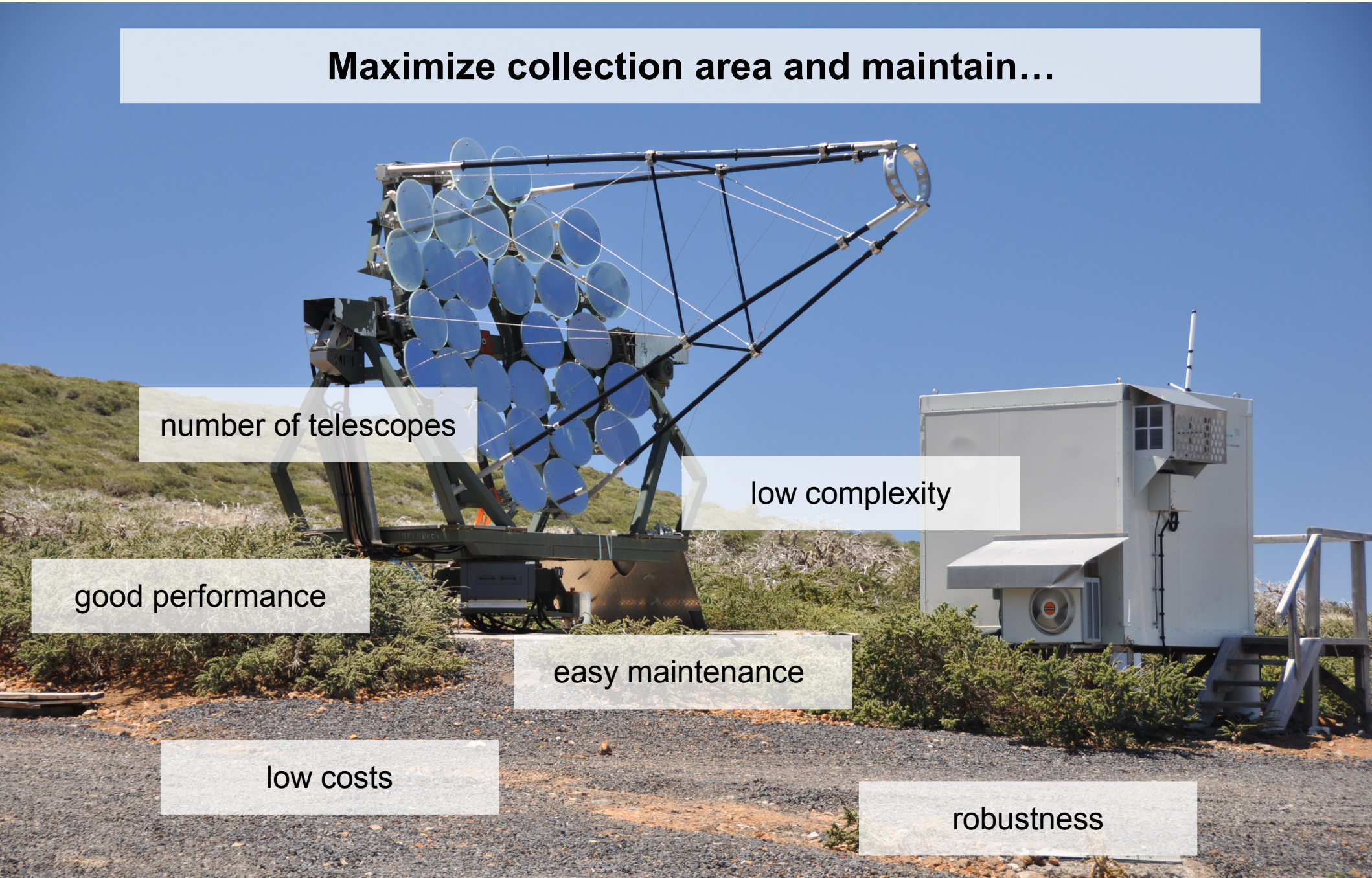


Optimizing the SST array

Thomas Bretz, EPFL, Lausanne

Small size telescopes

Maximize collection area and maintain…



Small size telescopes

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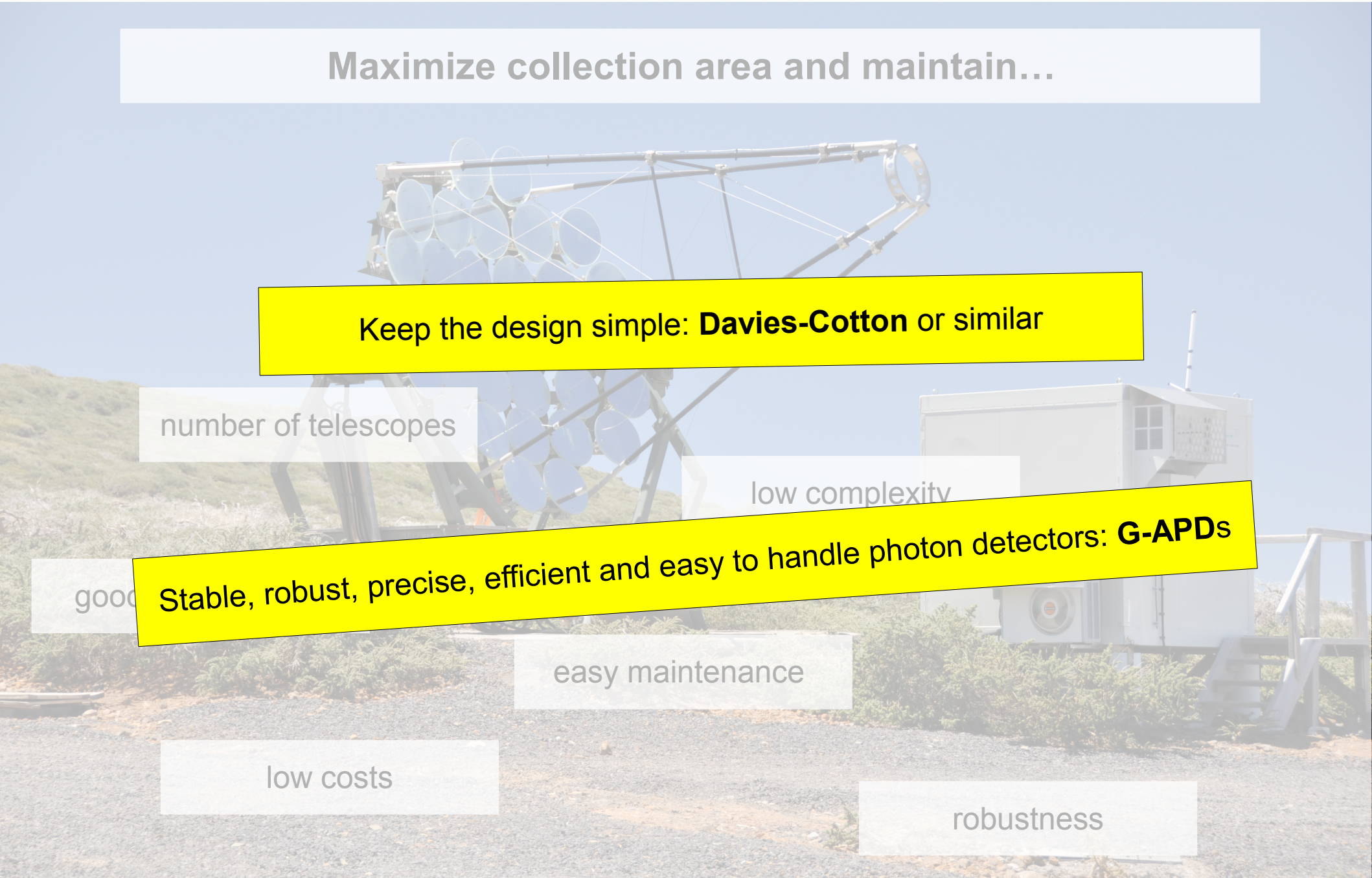


Keep the design simple: **Davies-Cotton** or similar

number of telescopes

low complexity

good

Stable, robust, precise, efficient and easy to handle photon detectors: **G-APDs**

easy maintenance

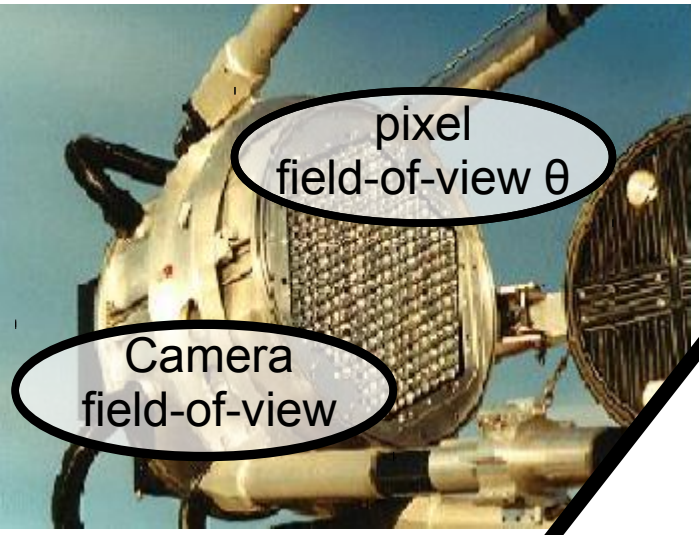
low costs

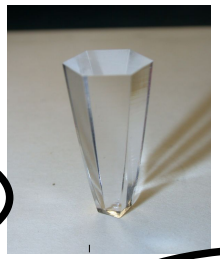
robustness

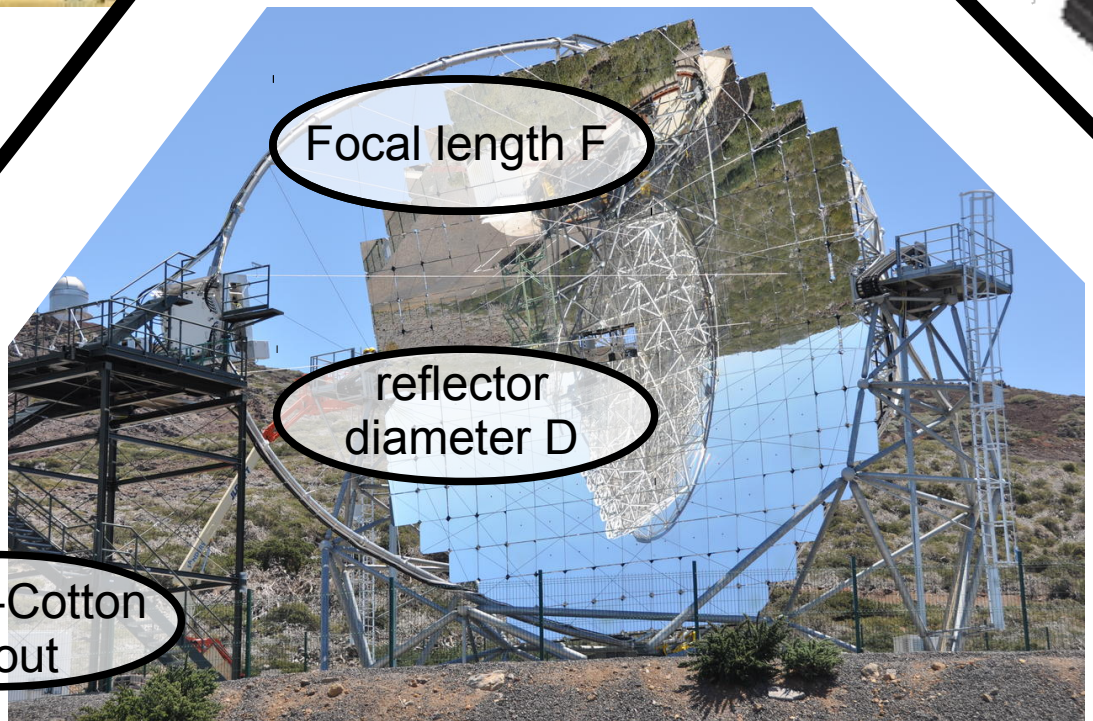
Telescope design / Array layout

- Problem: HUGE phase space
  - Pixel field-of-view
  - Mirror diameter
  - Focal length
  - Number of telescope
  - Distance between telescopes
  - ...

Telescope properties







Photon detector properties

Free parameter

pixel field-of-view θ

Requirement

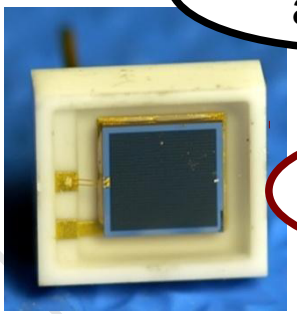
Camera field-of-view

unknown

pixel phys. area A

defined

photo sens. area a



Requirement

use G-APDs

angular acceptance φ

defined

unknown

Focal length F

reflector diameter D

unknown

Requirement

Davies-Cotton layout

Constraints from light concentrators

Free parameter

pixel field-of-view θ

Requirement

Camera field-of-view

unknown

pixel phys. area A

defined

photo sens. area a

Requirement

use G-APDs

Winston formula

A, α ↔ a, φ

unknown

Focal length F

angular acceptance φ

defined

reflector diameter D

unknown

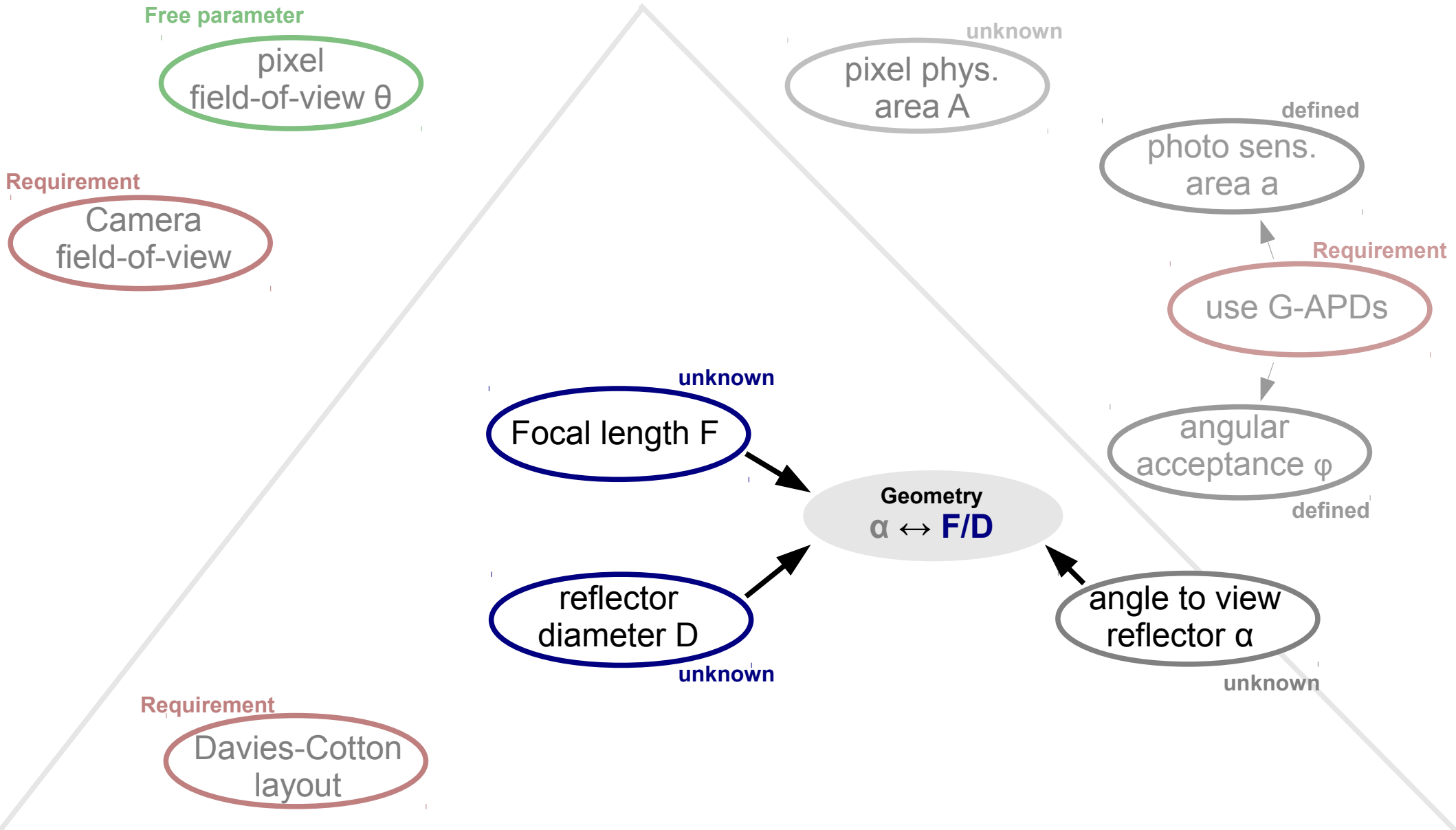
angle to view reflector α

unknown

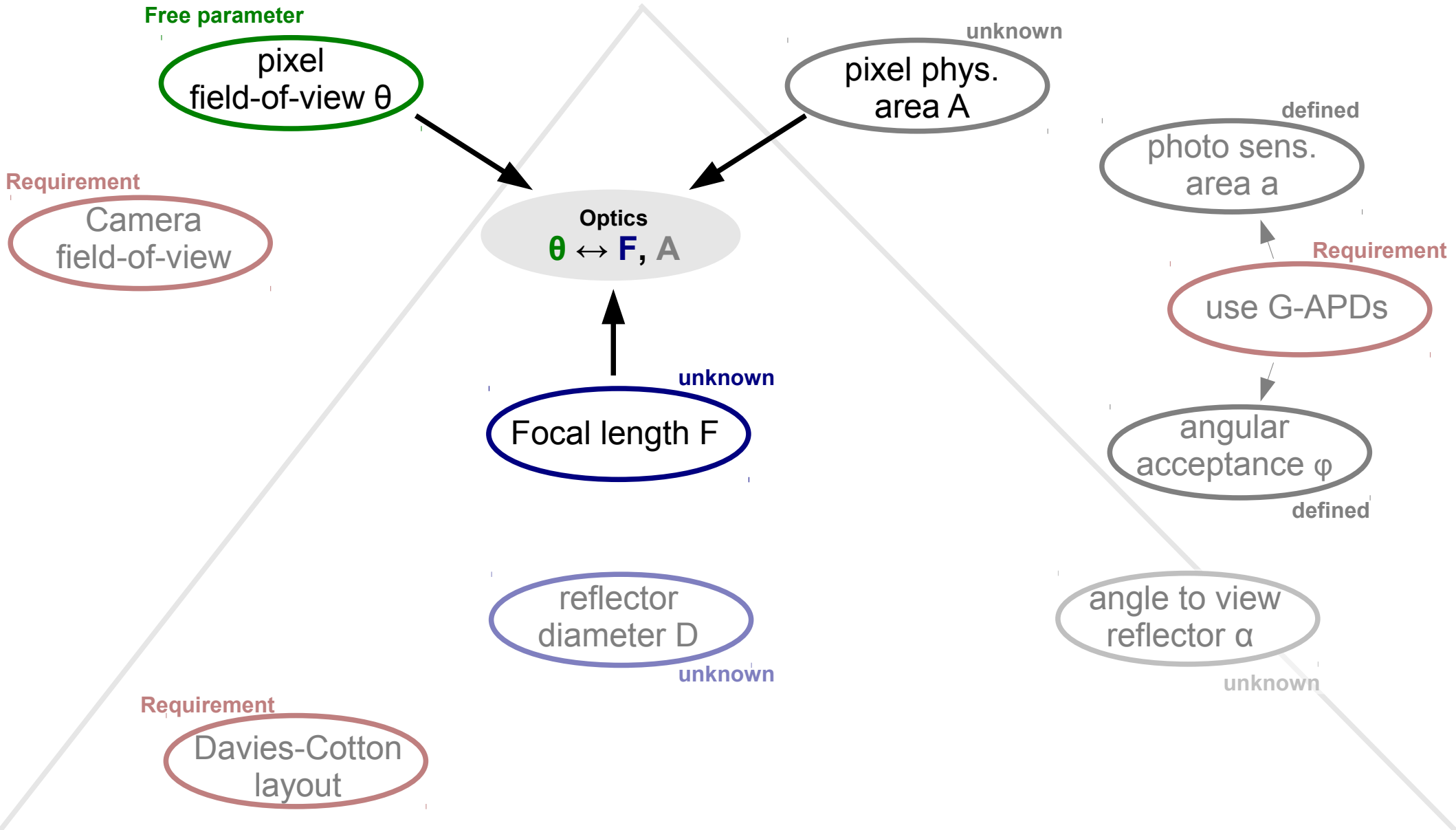
Requirement

Davies-Cotton layout

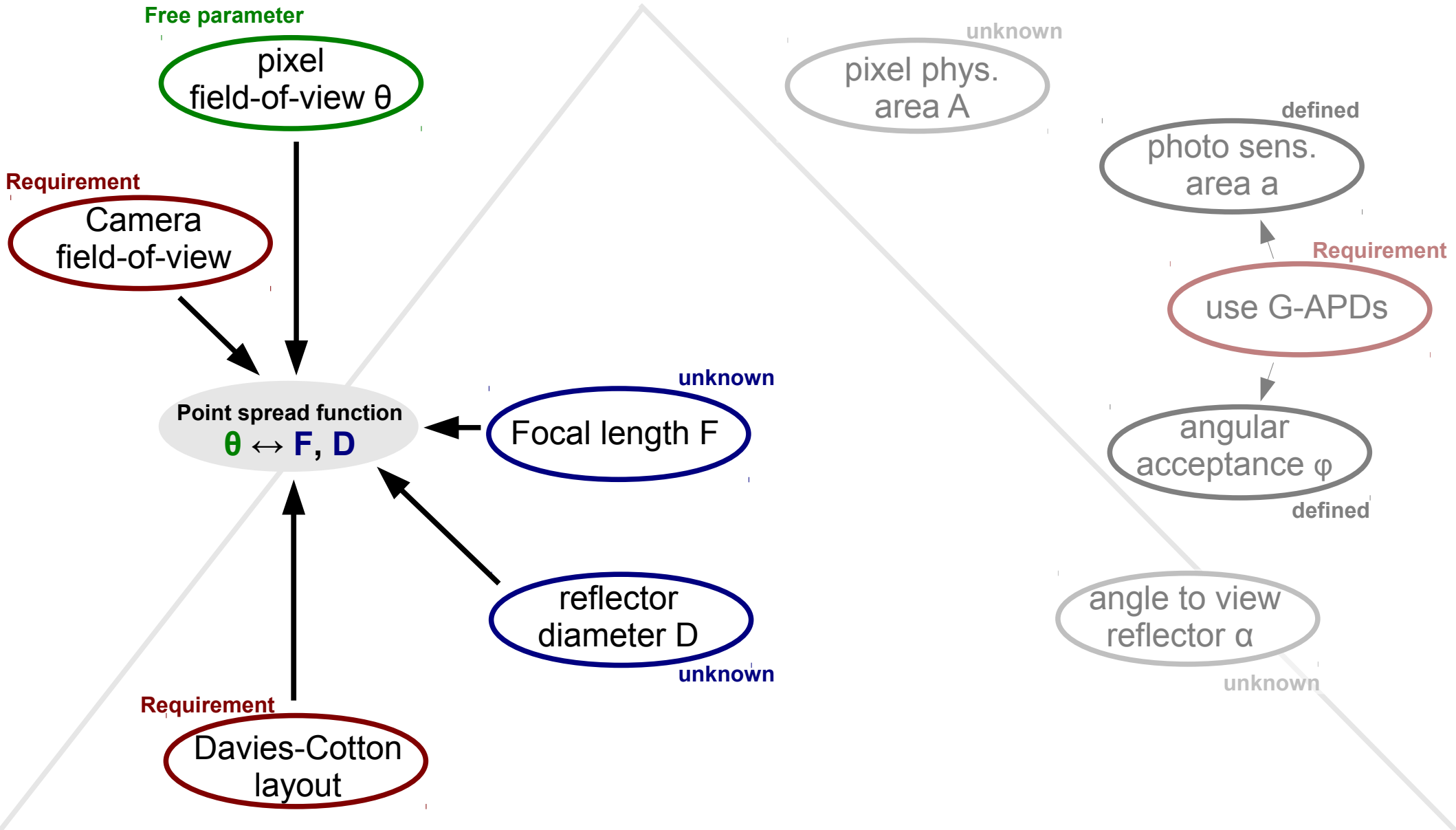
Geometrical relation



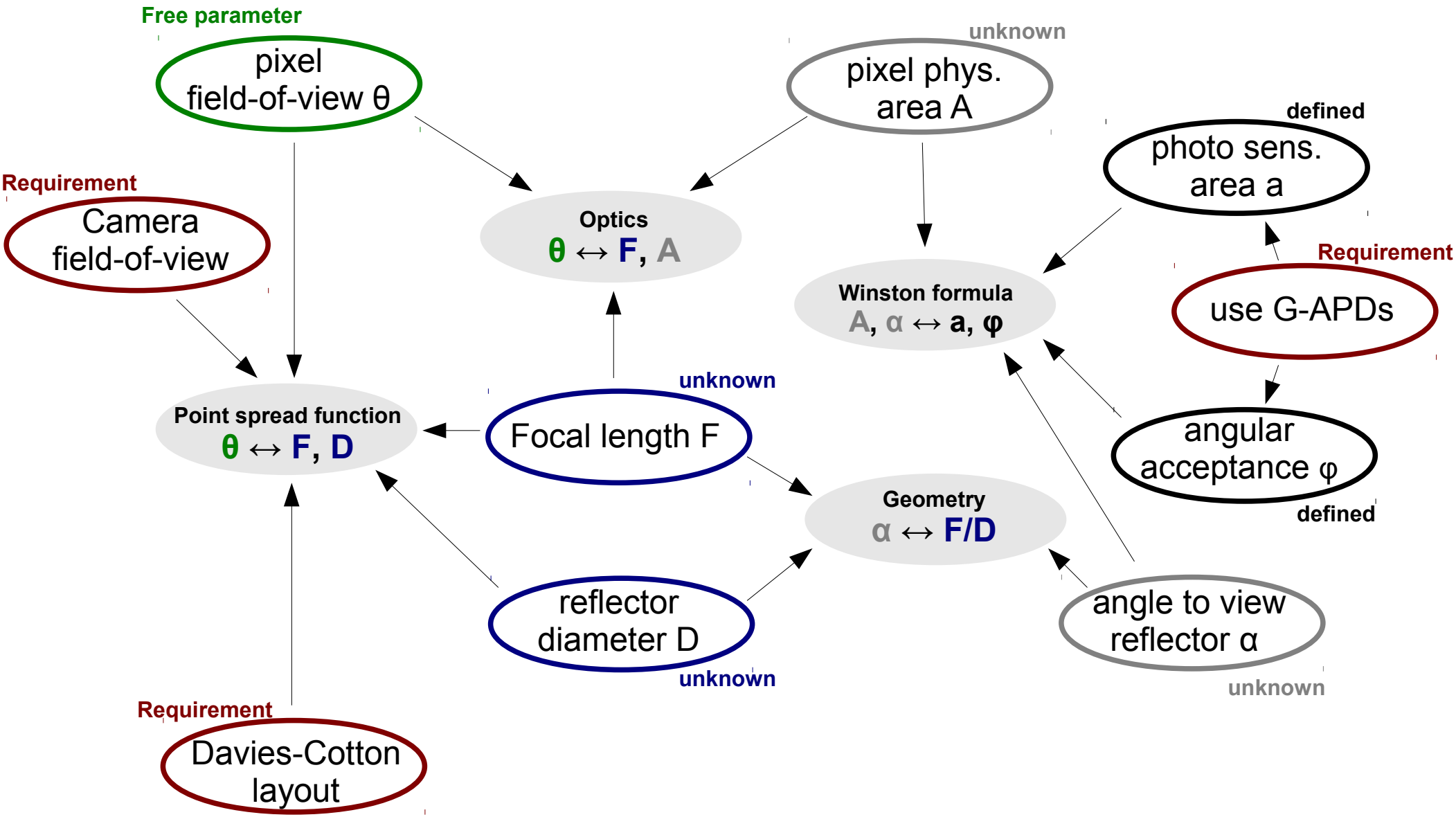
Optics


Free parameter
pixel
field-of-view θ
unknown
pixel phys.
area A
defined
photo sens.
area a
Requirement
Camera
field-of-view
Optics
θ ↔ F, A
Requirement
use G-APDs
unknown
Focal length F
angular
acceptance φ
defined
reflector
diameter D
unknown
angle to view
reflector α
unknown
Requirement
Davies-Cotton
layout

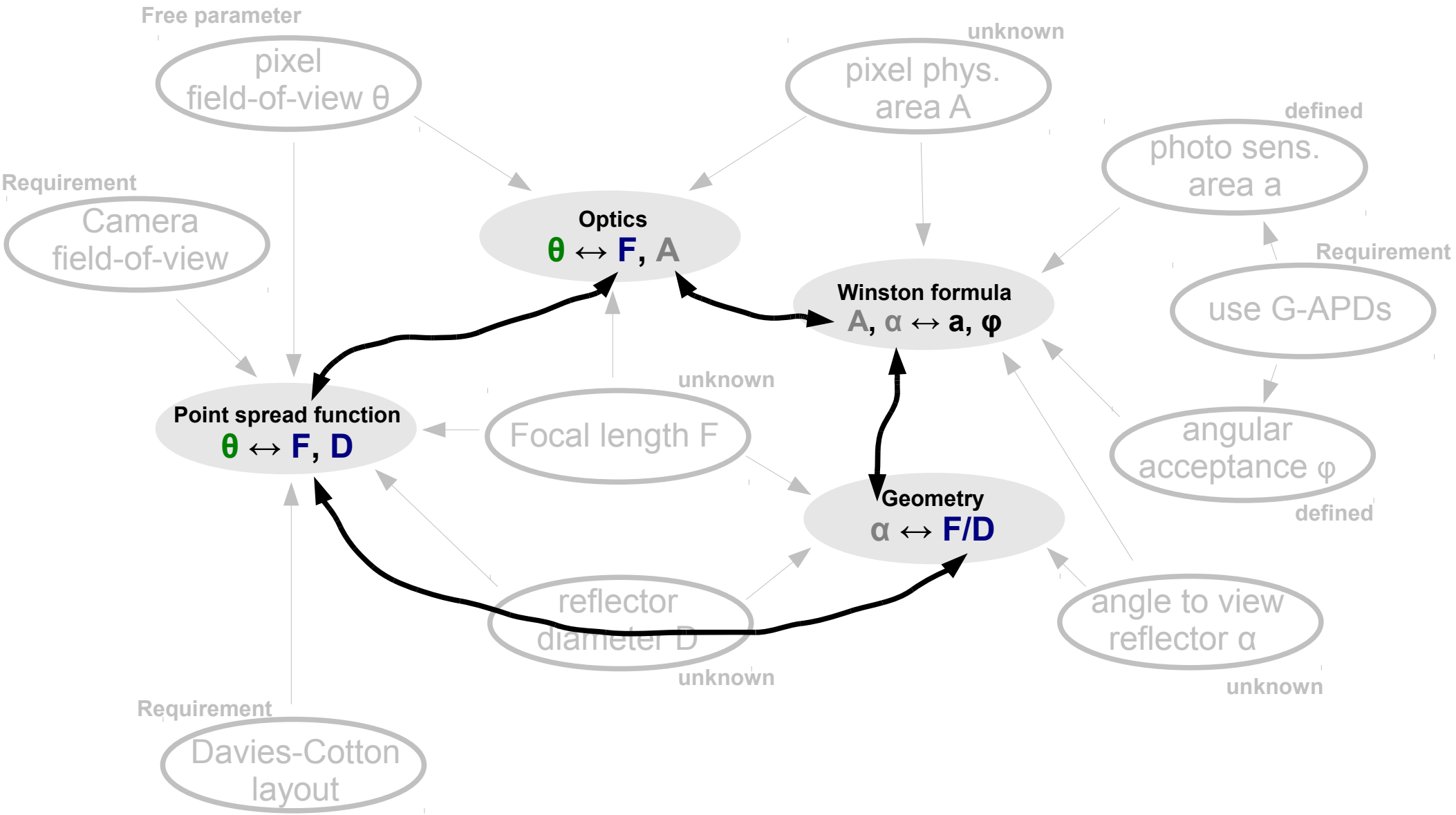
Reflector quality



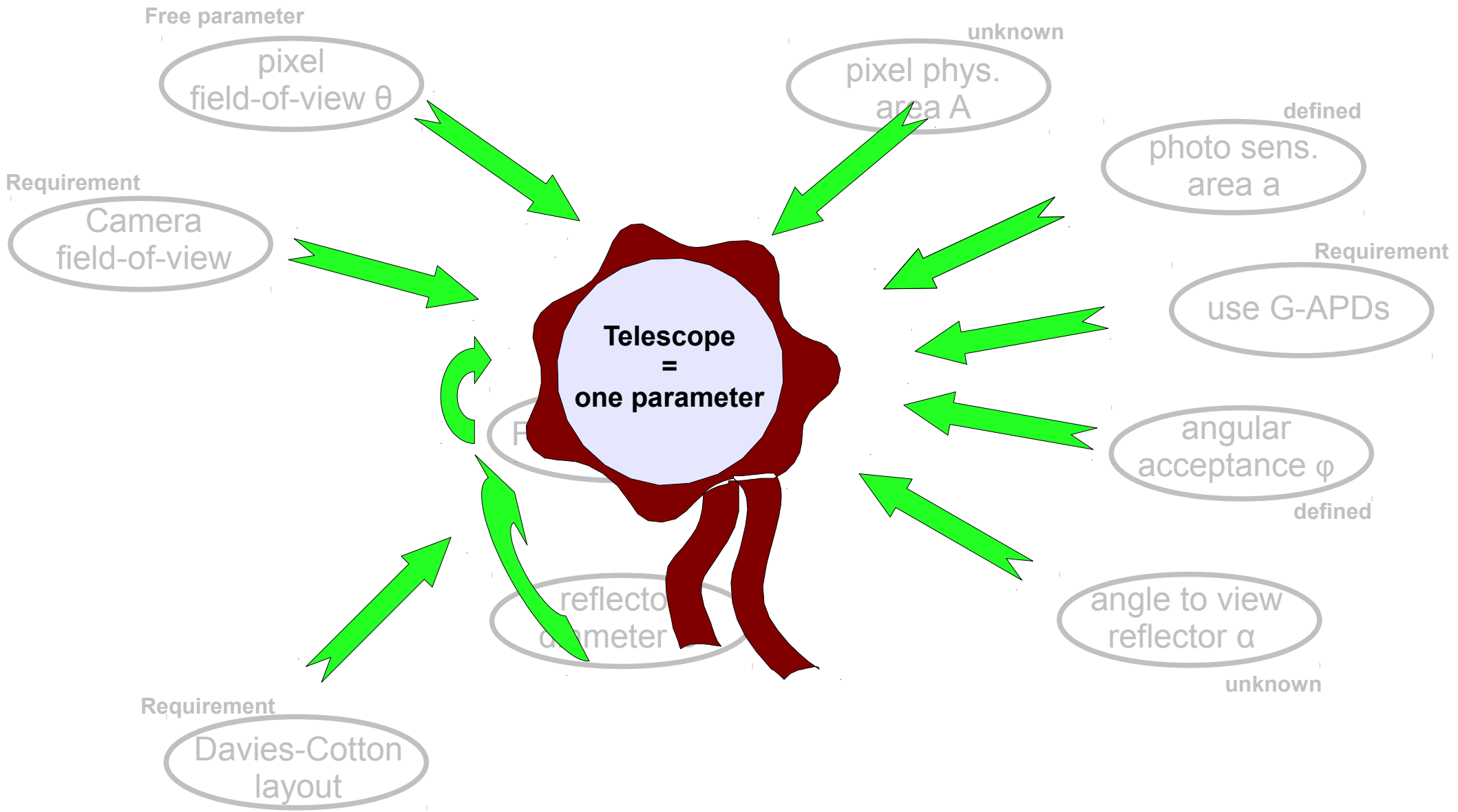
Relations – an overview



Relations – reduction



Relations - reduced

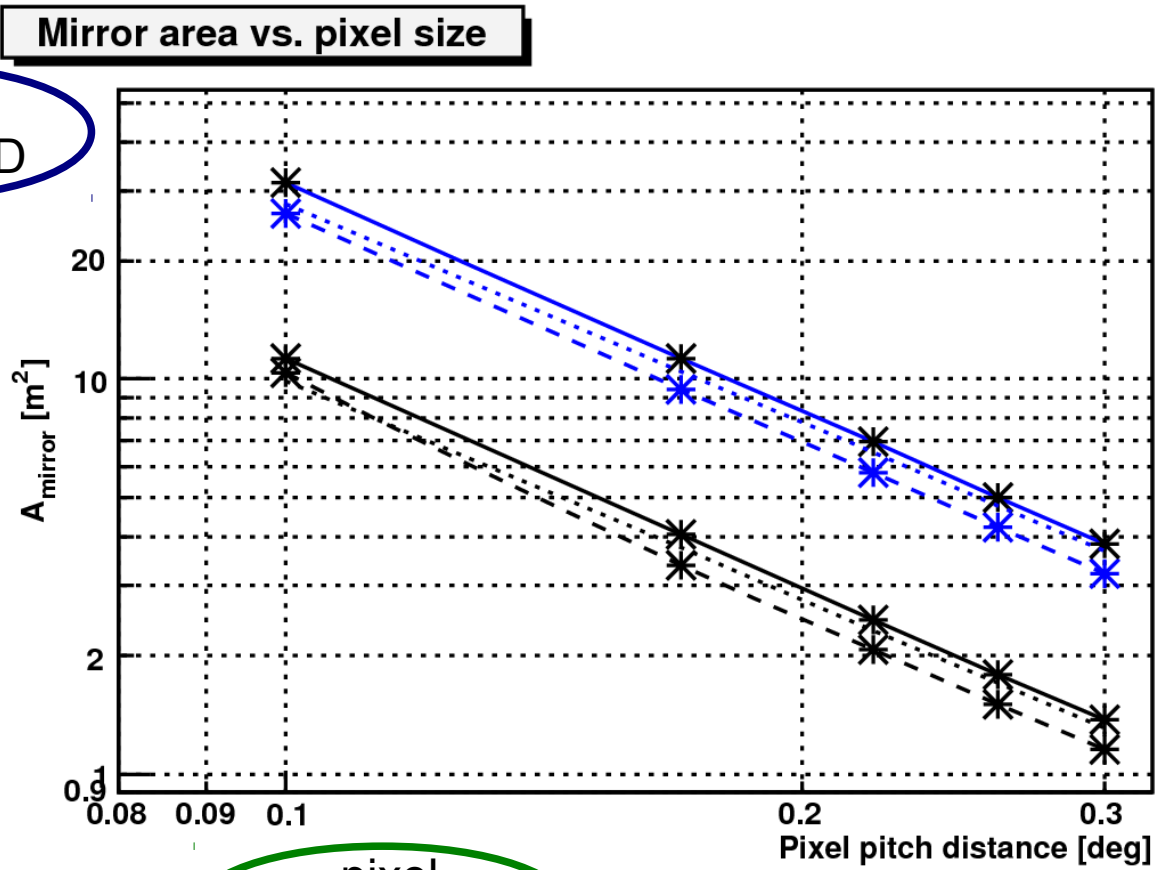


Telescope design - result

reflector diameter D

Camera field-of-view

FoV = 8°



pixel field-of-view θ

use G-APDs

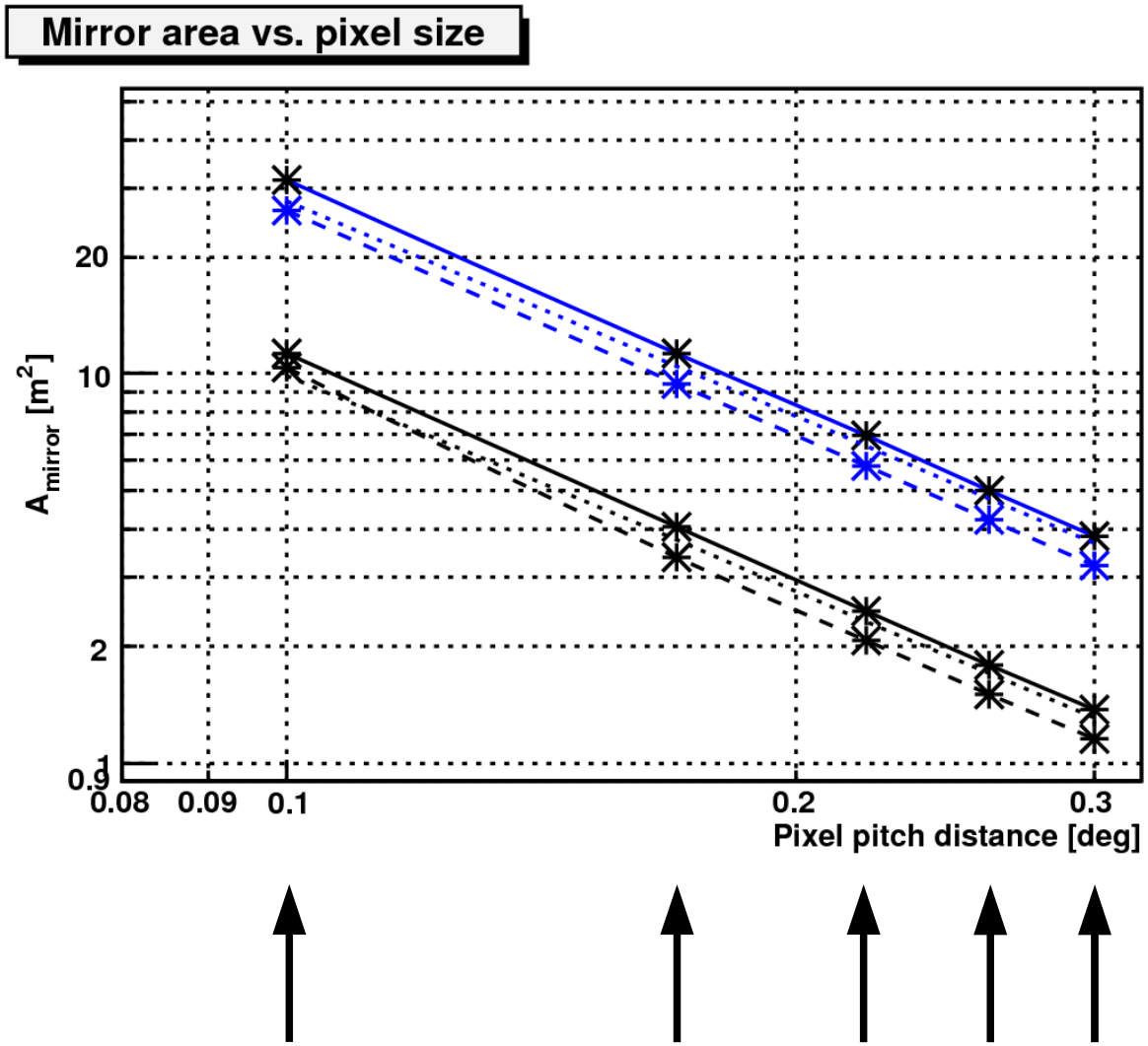
5mm x 5mm (in prep.)

3mm x 3mm (available)

Mirror area and **pixel-FoV** are **correlated** and define all other telescope properties!

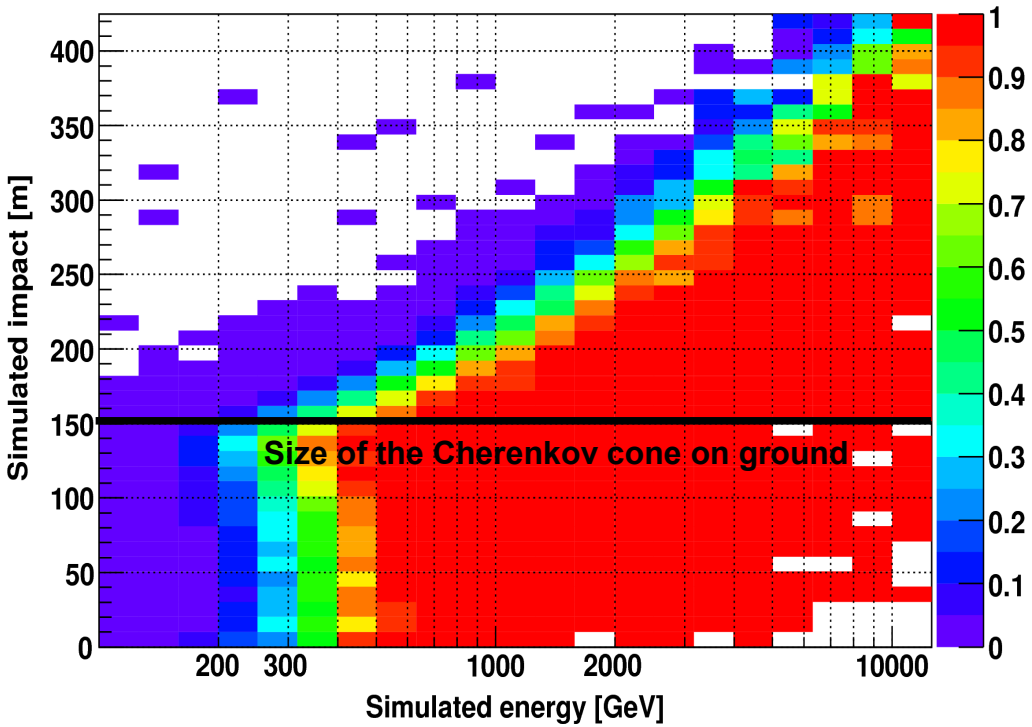
Array layout

Telescope design - simulations



Do a Monte Carlo simulation for these telescopes

Efficiency



Simulation of a few telescope setups

Zd=30°

Trigger efficiency versus

- energy
- impact

parametrization / fit

pitch distance

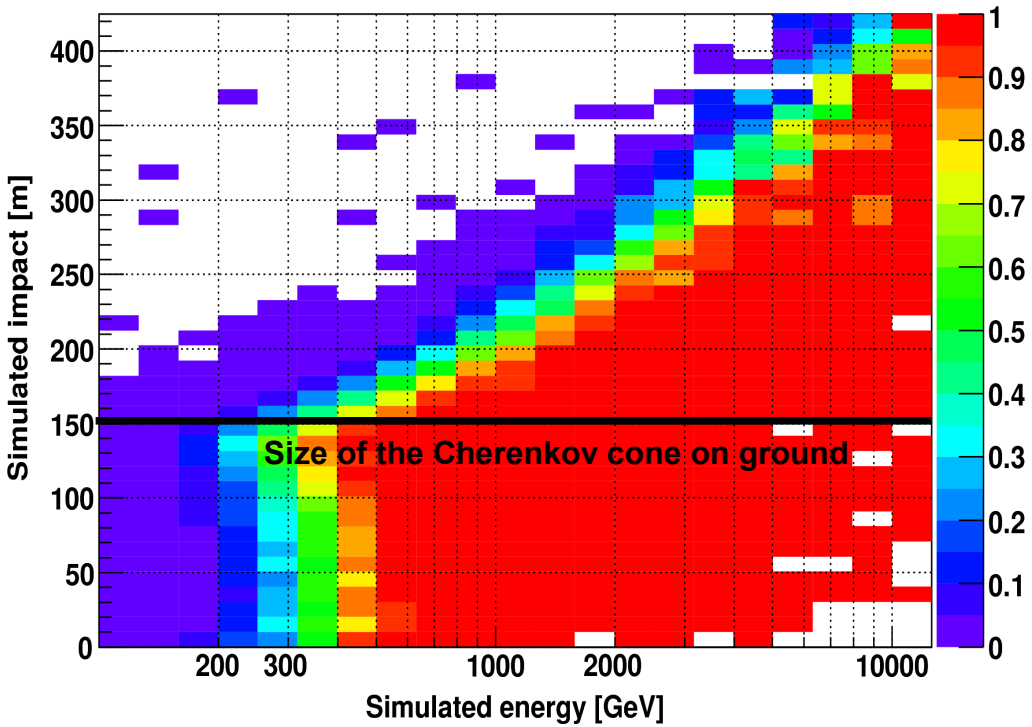
num. telescopes

Toy-MC

Trigger efficiency for an array of telescopes (e.g. multiplicity 3)

effective collection area vs. energy

Efficiency parametrization



$$\epsilon(E,I) = 1 - \frac{1}{\left(\frac{E}{E_0(I)}\right)^{k} + 1}$$

$$E_0(I) = \begin{cases} e_0 & \text{for } I < I_0 \\ e_0\left(\frac{I}{I_0}\right)^{m} & \text{for } I > I_0 \end{cases}$$

Simulation of a few telescope setups

↓

Trigger efficiency versus
- energy
- impact

↓

parametrization / fit

pitch distance, num. telescopes

↓

Toy-MC

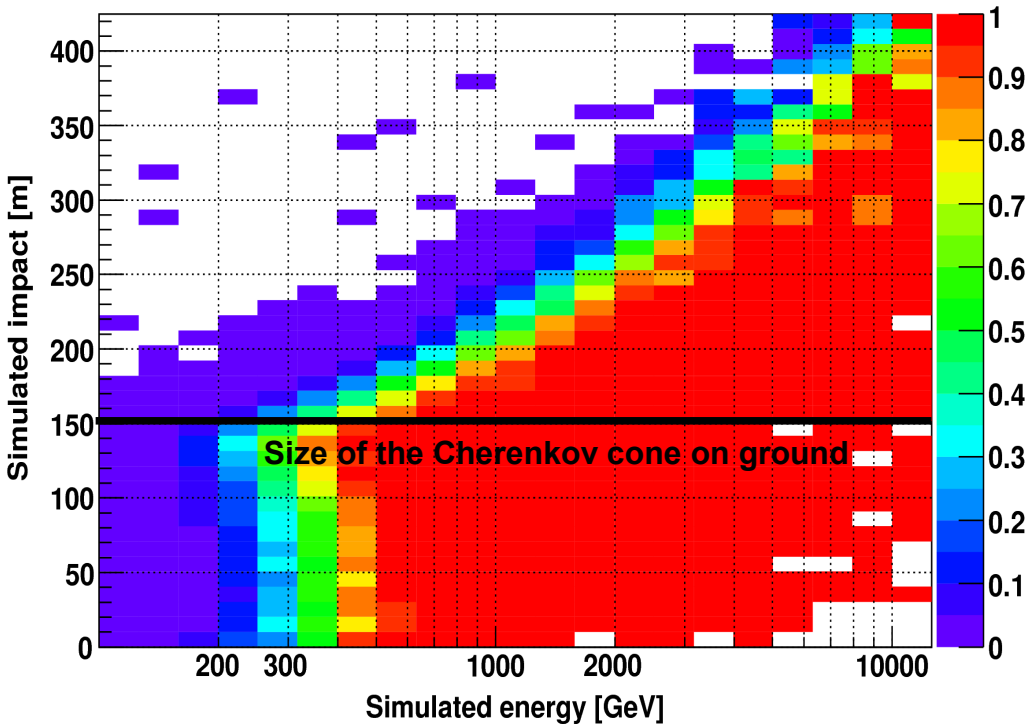
↓

Trigger efficiency for an array of telescopes (e.g. multiplicity 3)

↓

effective collection area vs. energy

Array simulation



Simulation of a few telescope setups

↓

Trigger efficiency versus
- energy
- impact

↓

parametrization / fit

pitch distance — num. telescopes

↓

Toy-MC

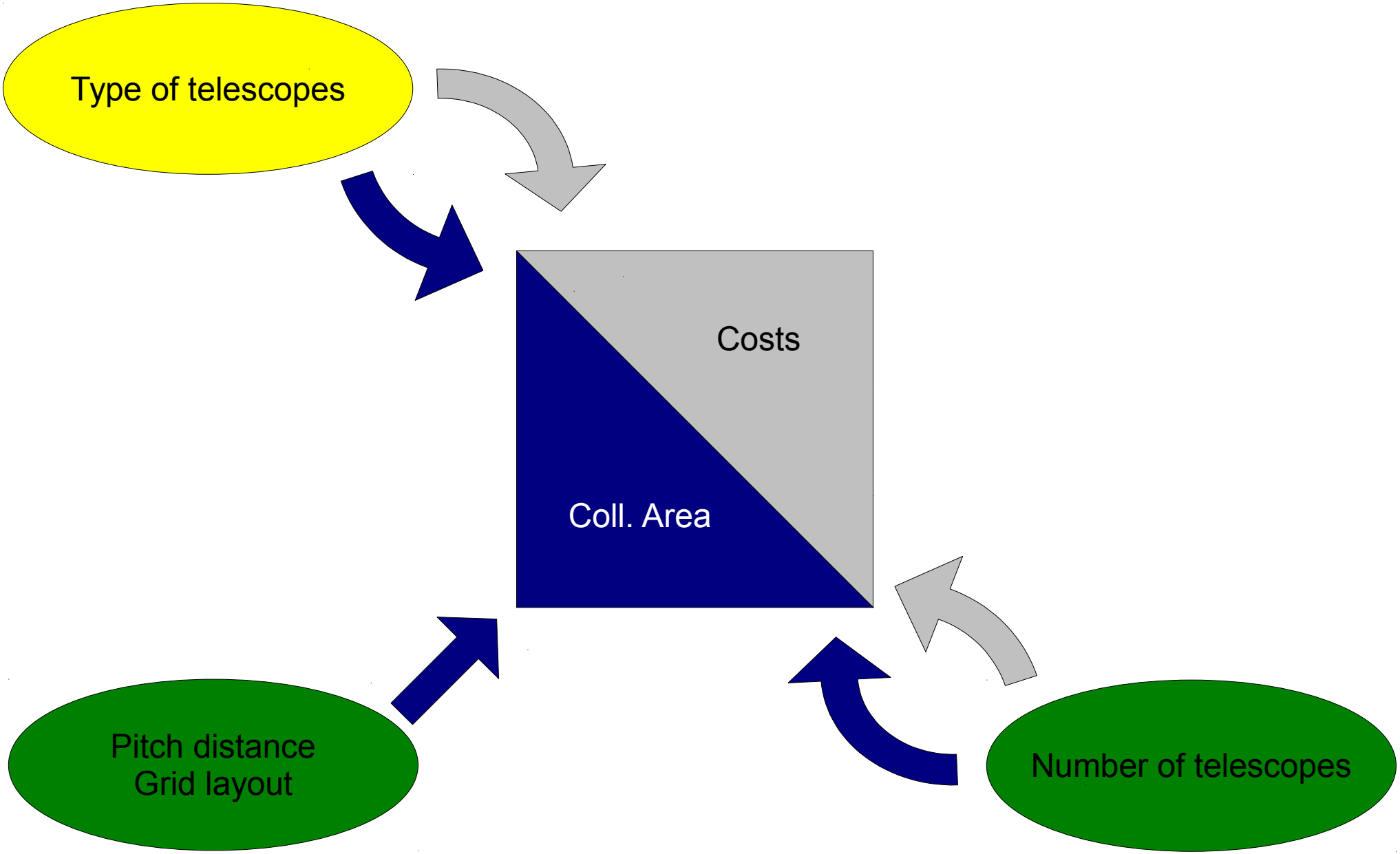
↓

Trigger efficiency for an array of telescopes (e.g. multiplicity 3)

↓

effective collection area vs. energy

Array optimization - Correlations



Array optimization - Correlations

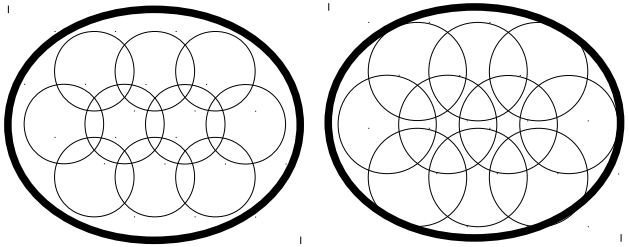
Type of telescope

Costs scales with (*rough estimate*)

+ Camera:	number of channels	**N**
+ Reflector:	reflector diameter	**D²**
+ Mount:	reflector size	**D³**

Energy threshold
- decr. with reflector size
- incr. with pixel-fov

O(100) telescopes: small dependence of the eff. area from the reflector size



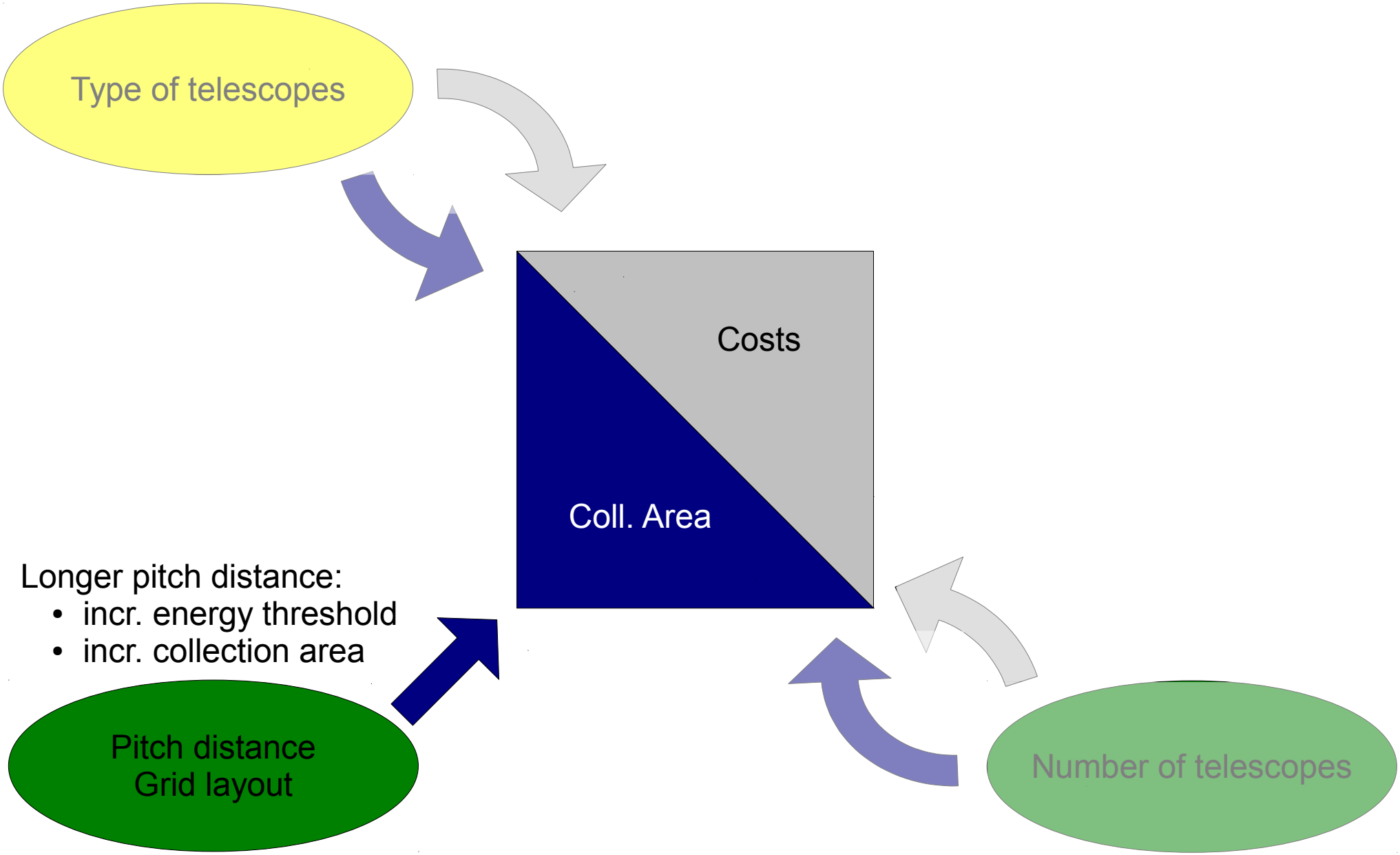
Costs

Coll. Area

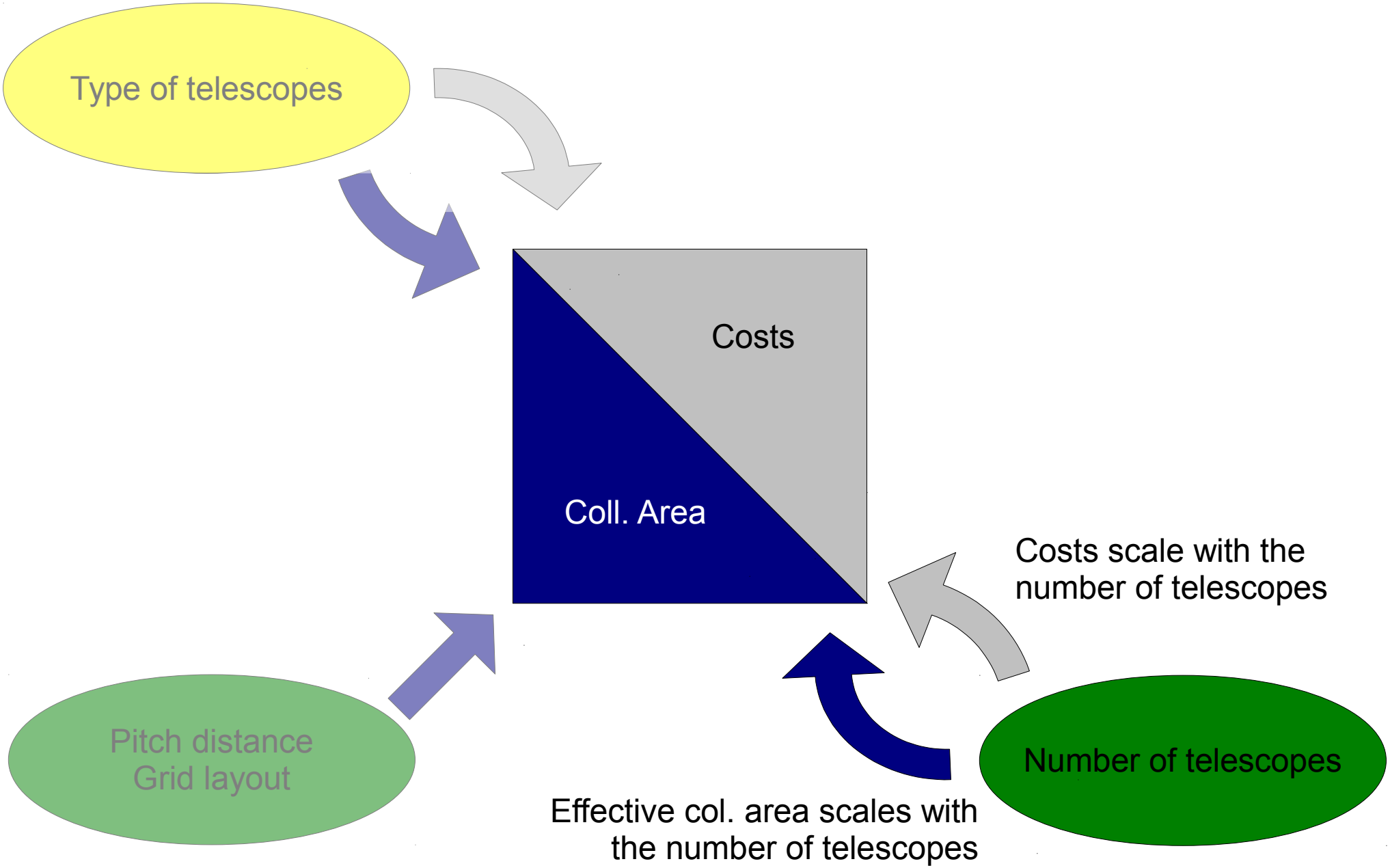
Pitch distance
Grid layout

Number of telescopes

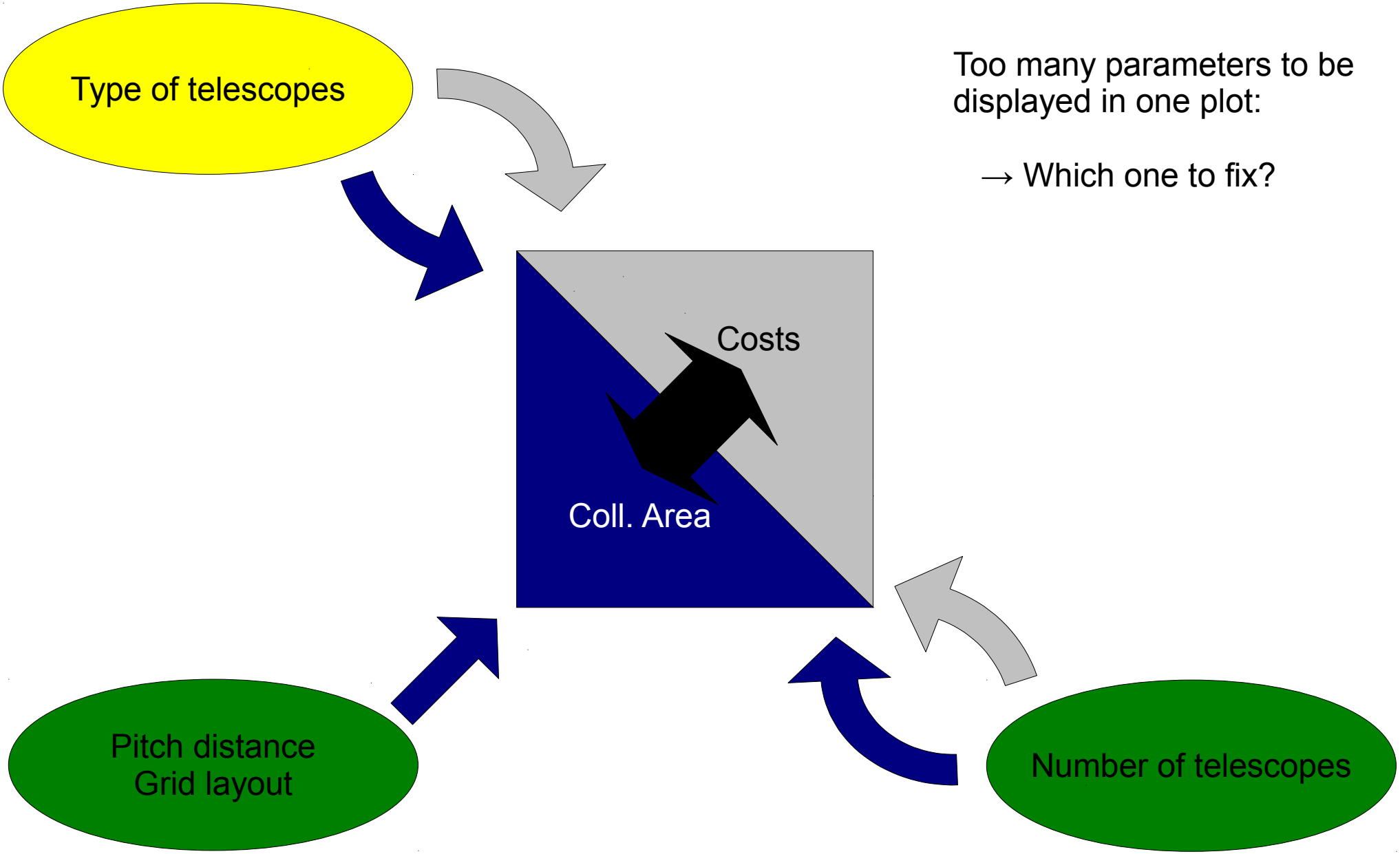
Array optimization - Correlations



Array optimization - Correlations



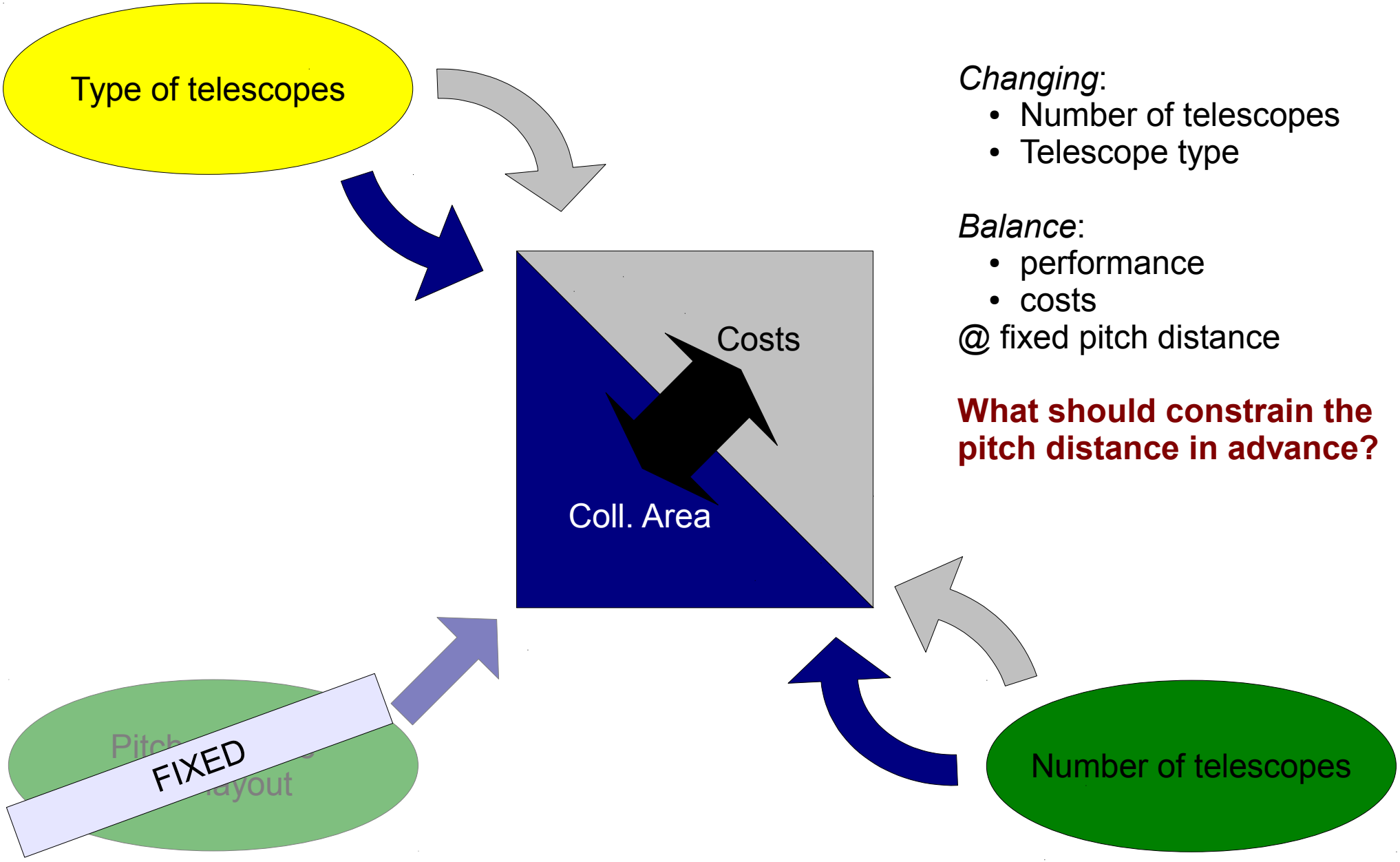
Array optimization



Too many parameters to be displayed in one plot:

→ Which one to fix?

Array optimization



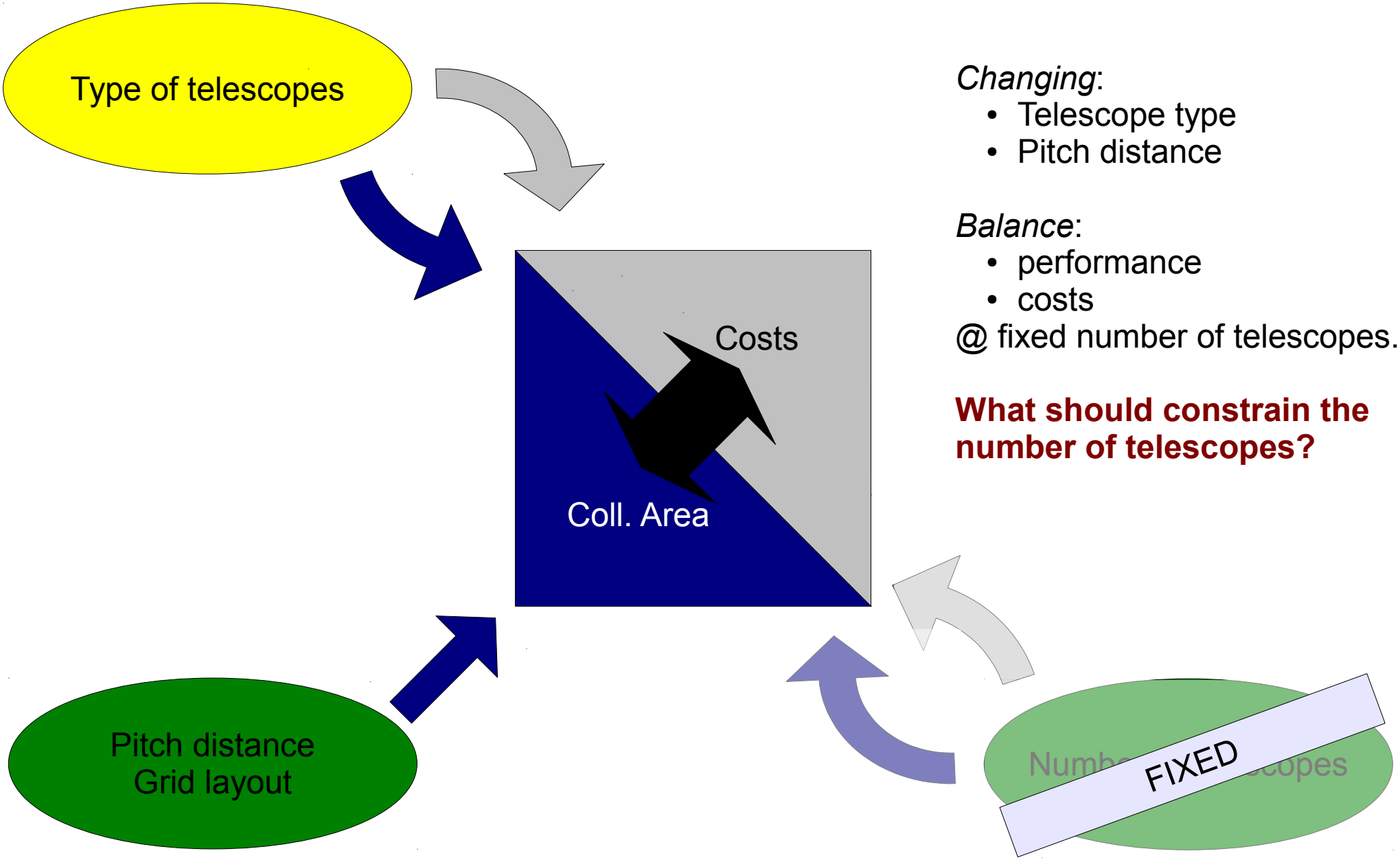
Changing:
- Number of telescopes
- Telescope type

Balance:
- performance
- costs

@ fixed pitch distance

What should constrain the pitch distance in advance?

Array optimization



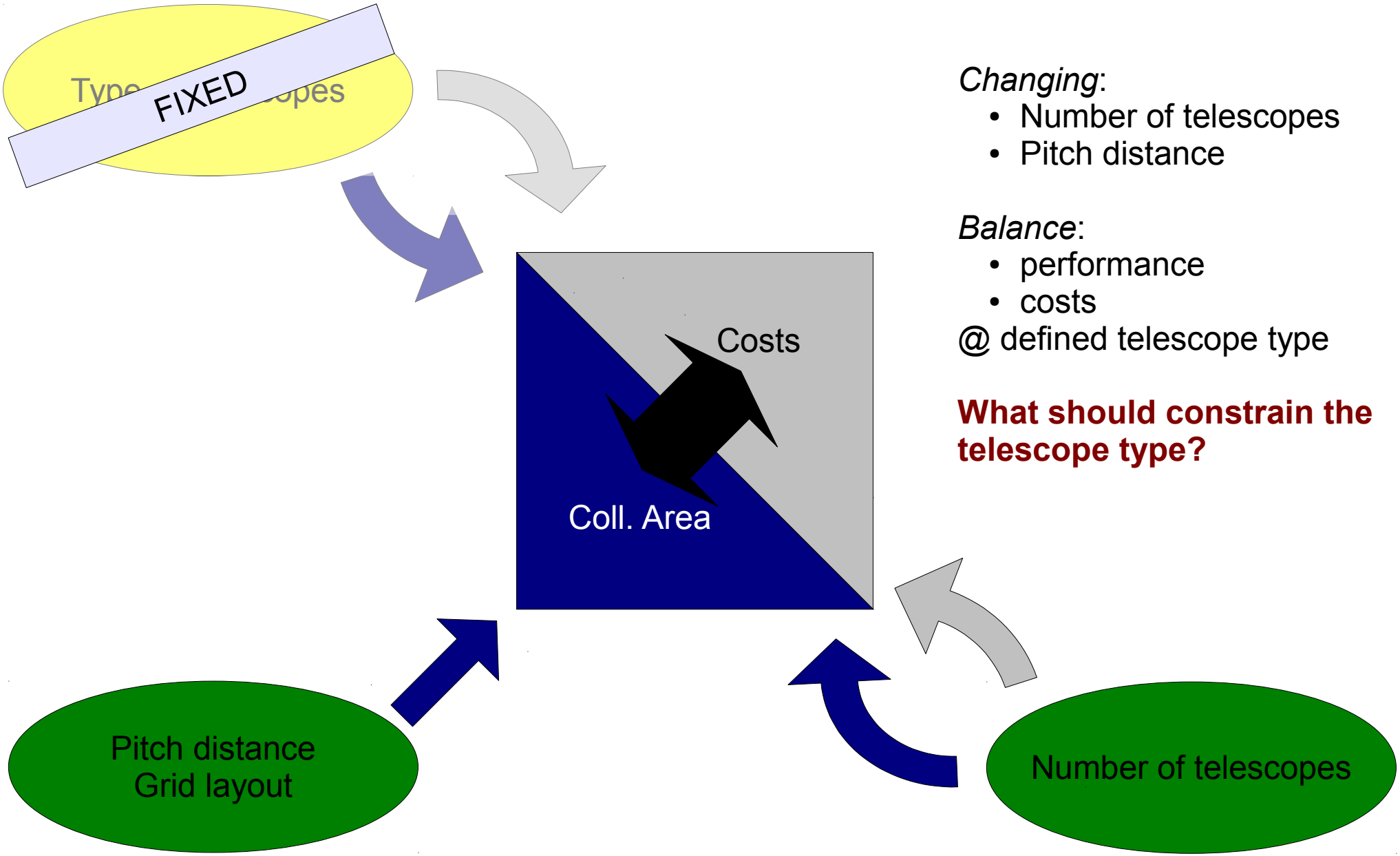
Changing:
- Telescope type
- Pitch distance

Balance:
- performance
- costs

@ fixed number of telescopes.

What should constrain the number of telescopes?

Array optimization



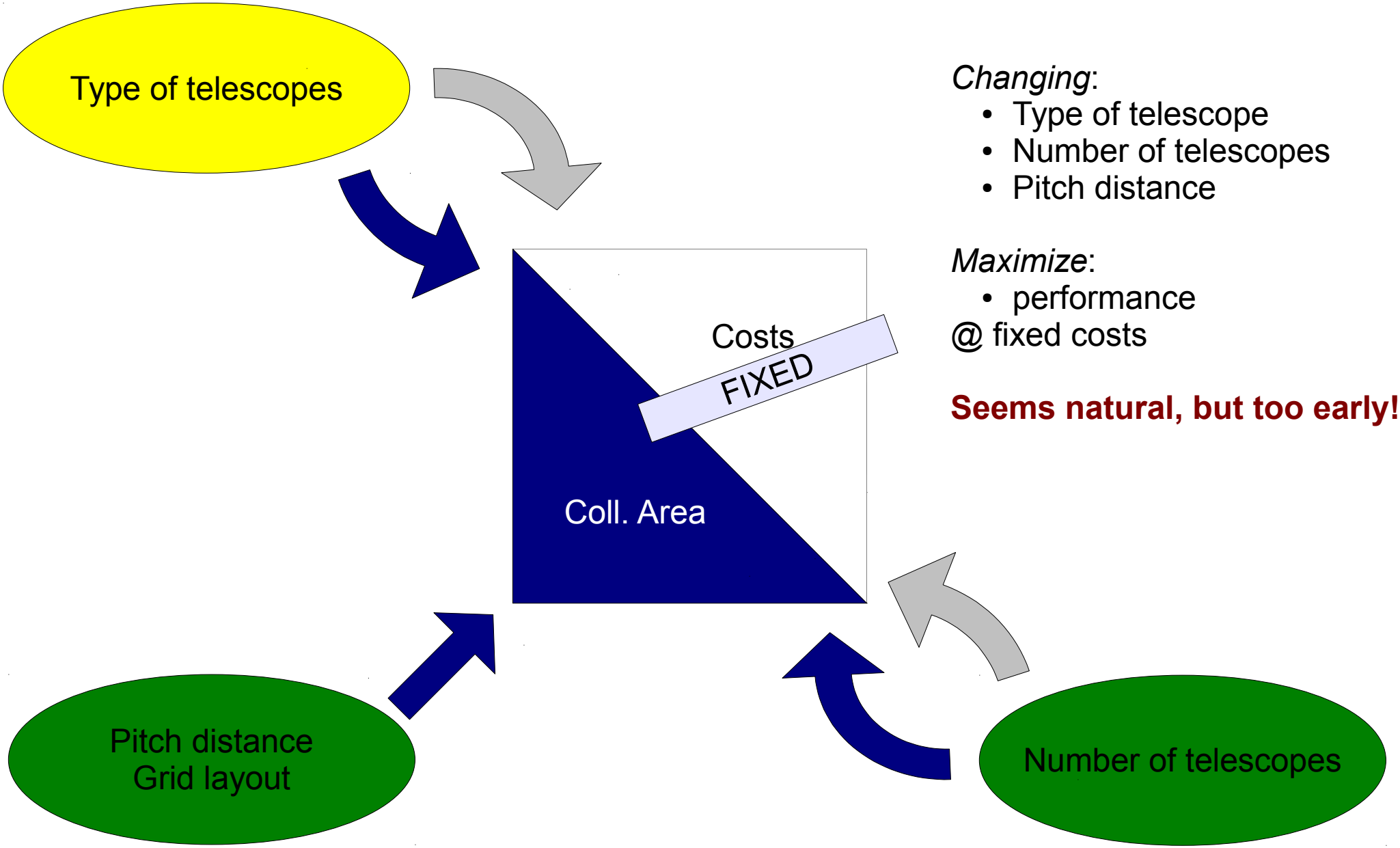
Changing:
- Number of telescopes
- Pitch distance

Balance:
- performance
- costs

@ defined telescope type

What should constrain the telescope type?

Array optimization



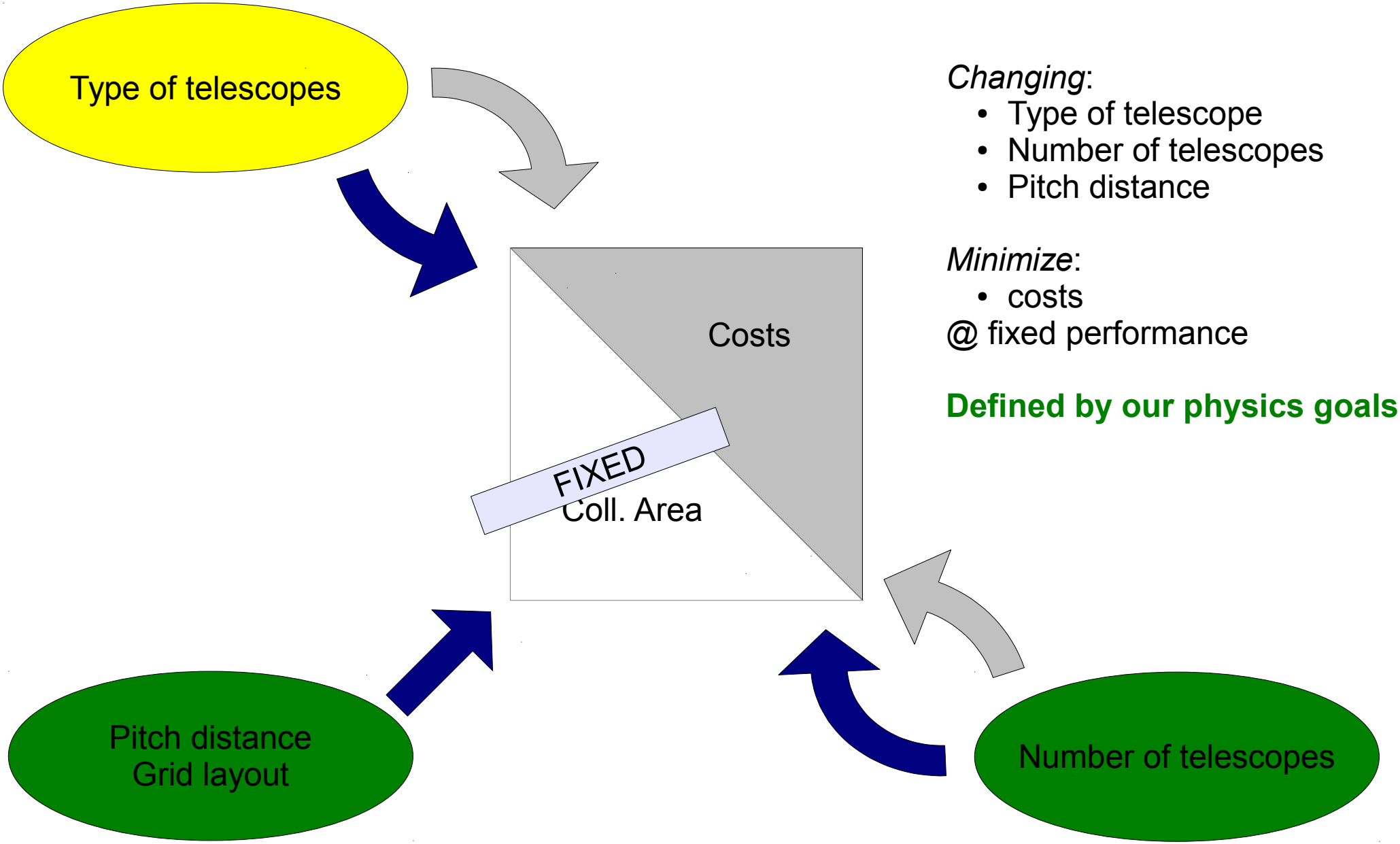
Changing:
- Type of telescope
- Number of telescopes
- Pitch distance

Maximize:
- performance

@ fixed costs

Seems natural, but too early!

Array optimization



Changing:
- Type of telescope
- Number of telescopes
- Pitch distance

Minimize:
- costs

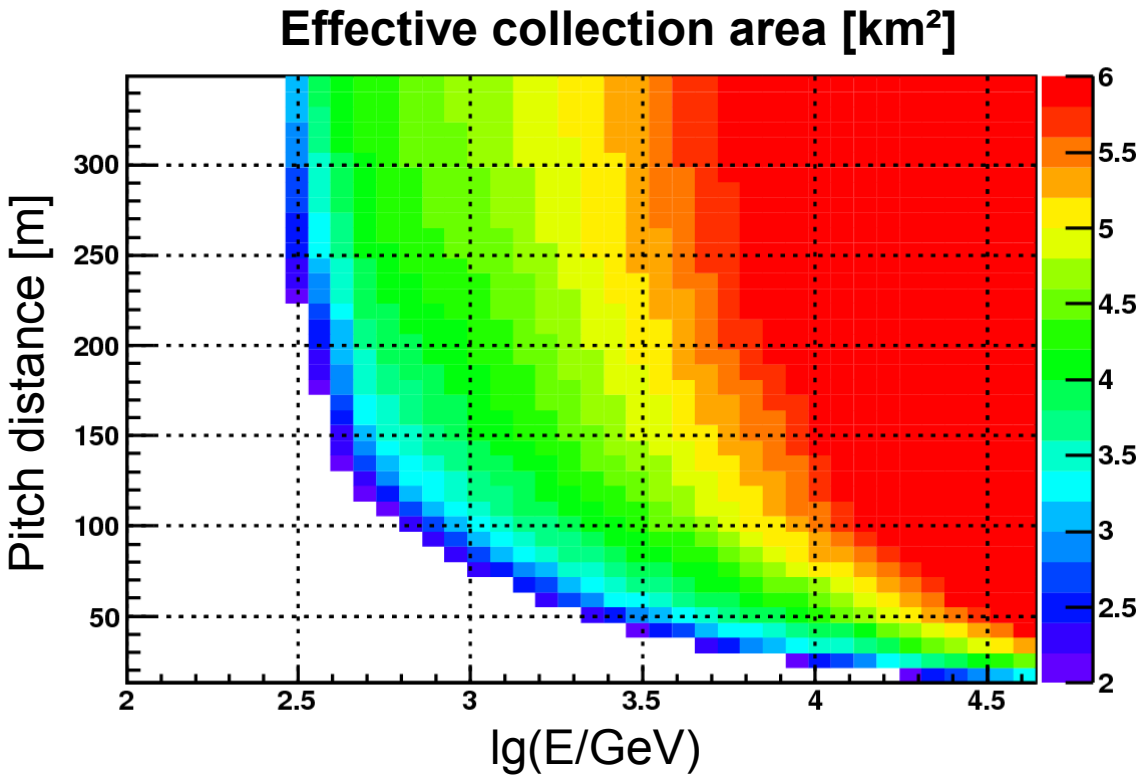
@ fixed performance

Defined by our physics goals!

Fixed Ground Area

Telescopes of one type placed in an area of 4km²
(expectation: eff. area close to 4km²)

How to choose?



- 5mm G-APD, FoV 0.17°
- Multiplicity >= 3
- Zd = 30°
- H = 2200m a.s.l.
- La Palma atmosphere

Fixed Ground Area

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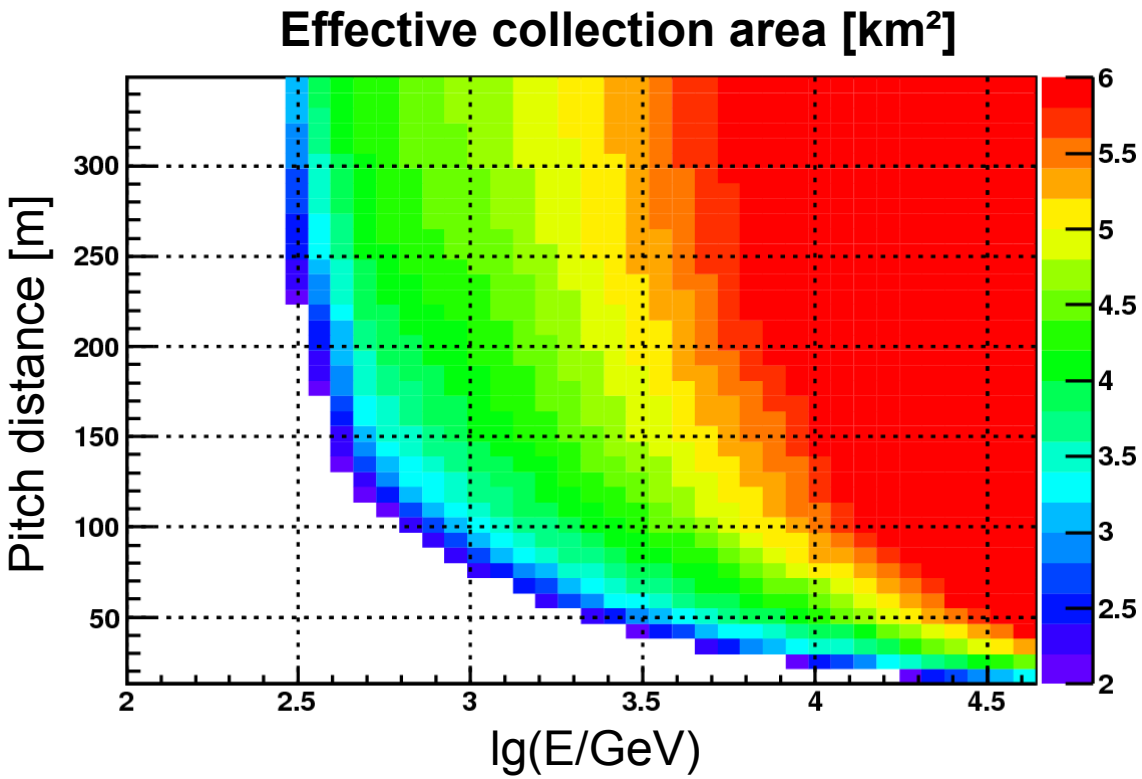

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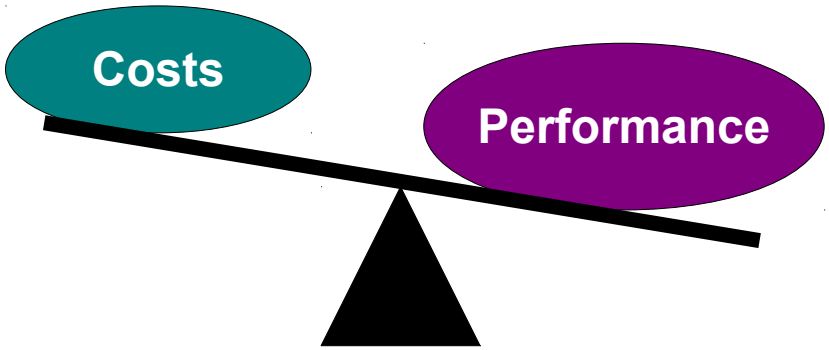


pitch distance too large
→ showers don't trigger
→ performance decreases

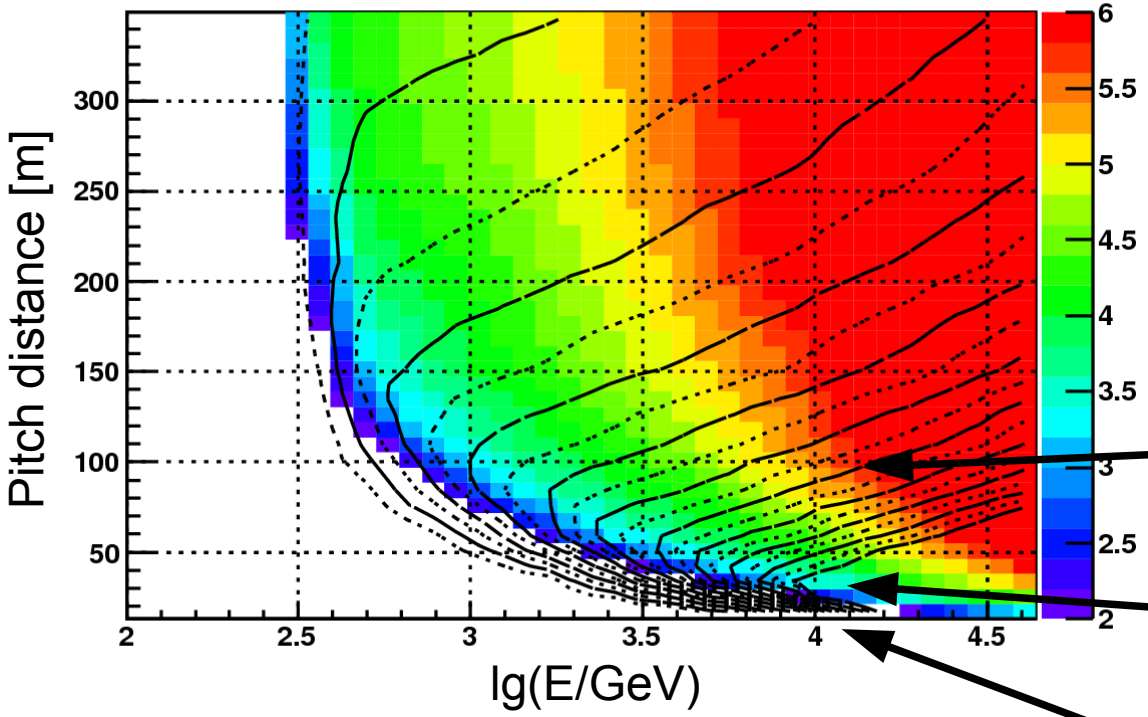
optimum in between

pitch distance too short
→ more tel. trigger than necessary
→ costs too high

Fixed Ground Area

Telescopes of one type placed in an area of 4km²
(Pitch distance → num. of telescopes)

Effective collection area per telescope [km²] = efficiency



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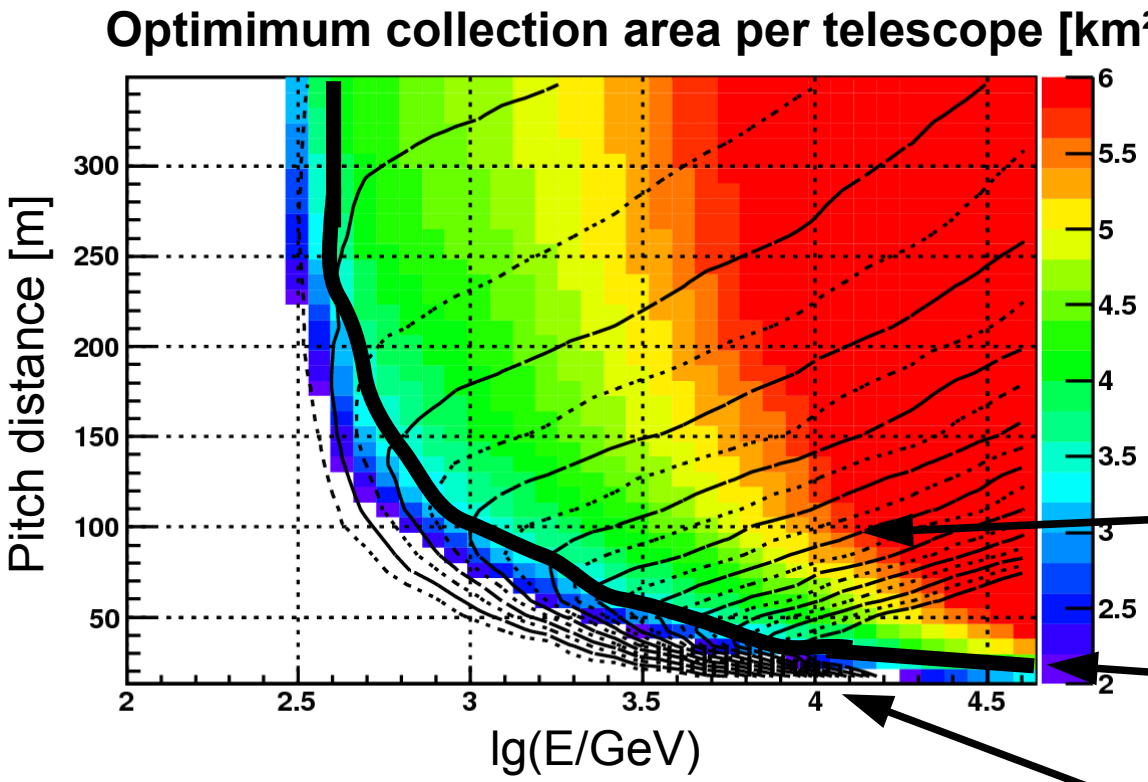
Fixed Ground Area

Telescopes of one type placed in an area of 4km²
(Pitch distance → num. of telescopes)



pitch distance too large
→ showers don't trigger
→ performance decreases

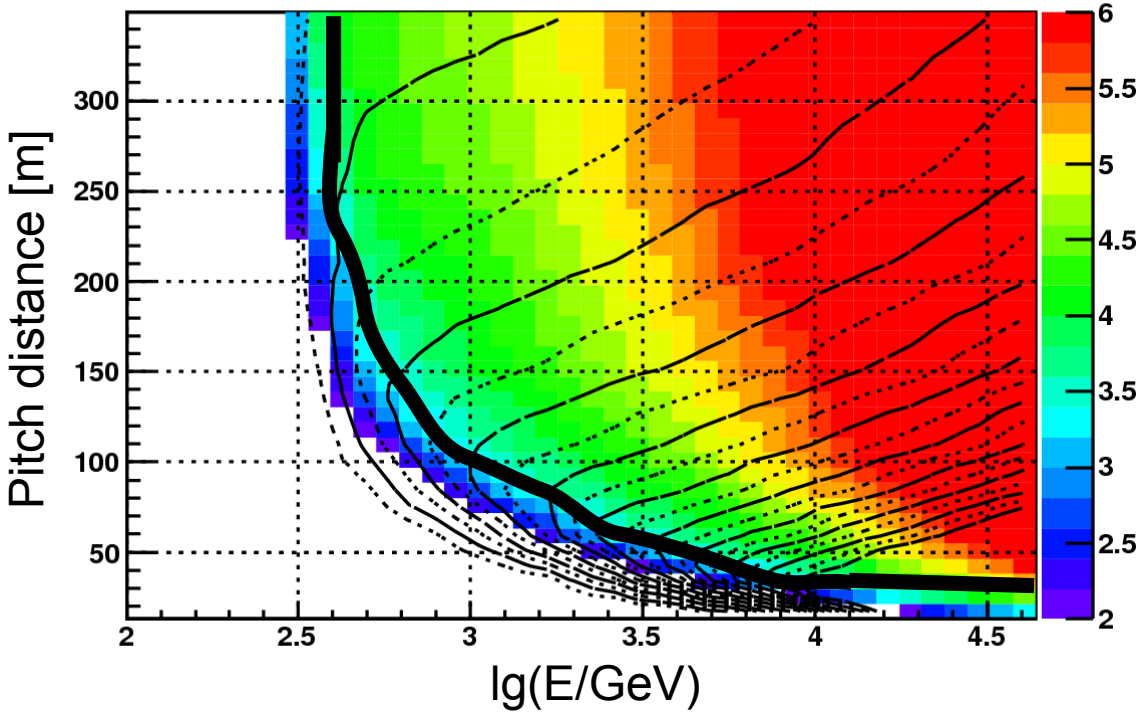
optimum in between

pitch distance too short
→ more tel. trigger than necessary
→ costs too high

Fixed Ground Area

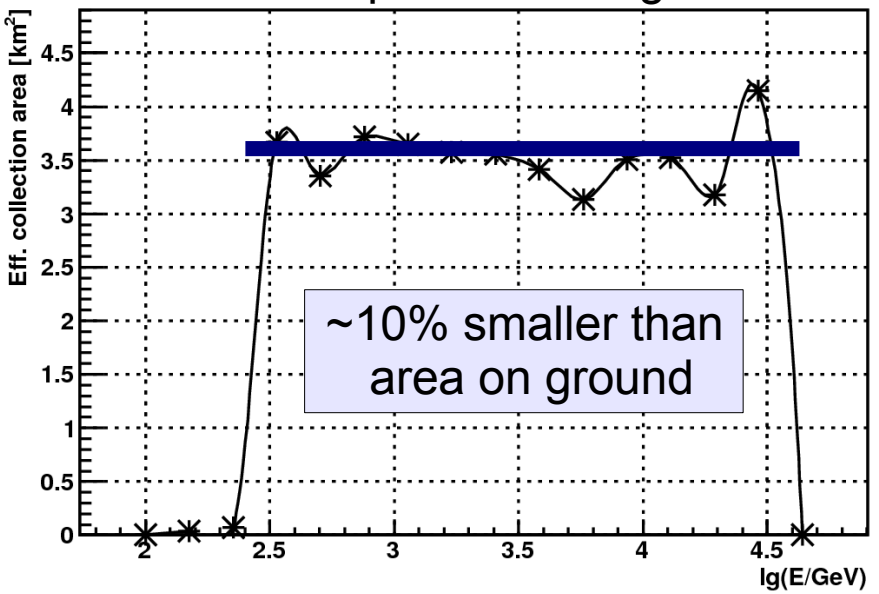
Telescopes of one type placed in an area of 4km²
(Pitch distance → num. of telescopes)

Optimimum collection area per telescope [km²]

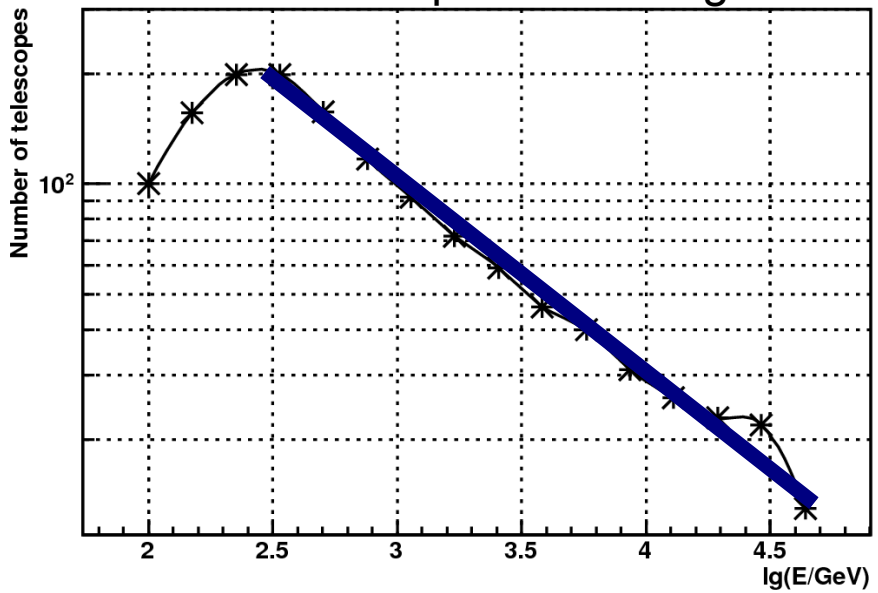


Do it for all telescope configurations!

Eff. area for optimum configuration



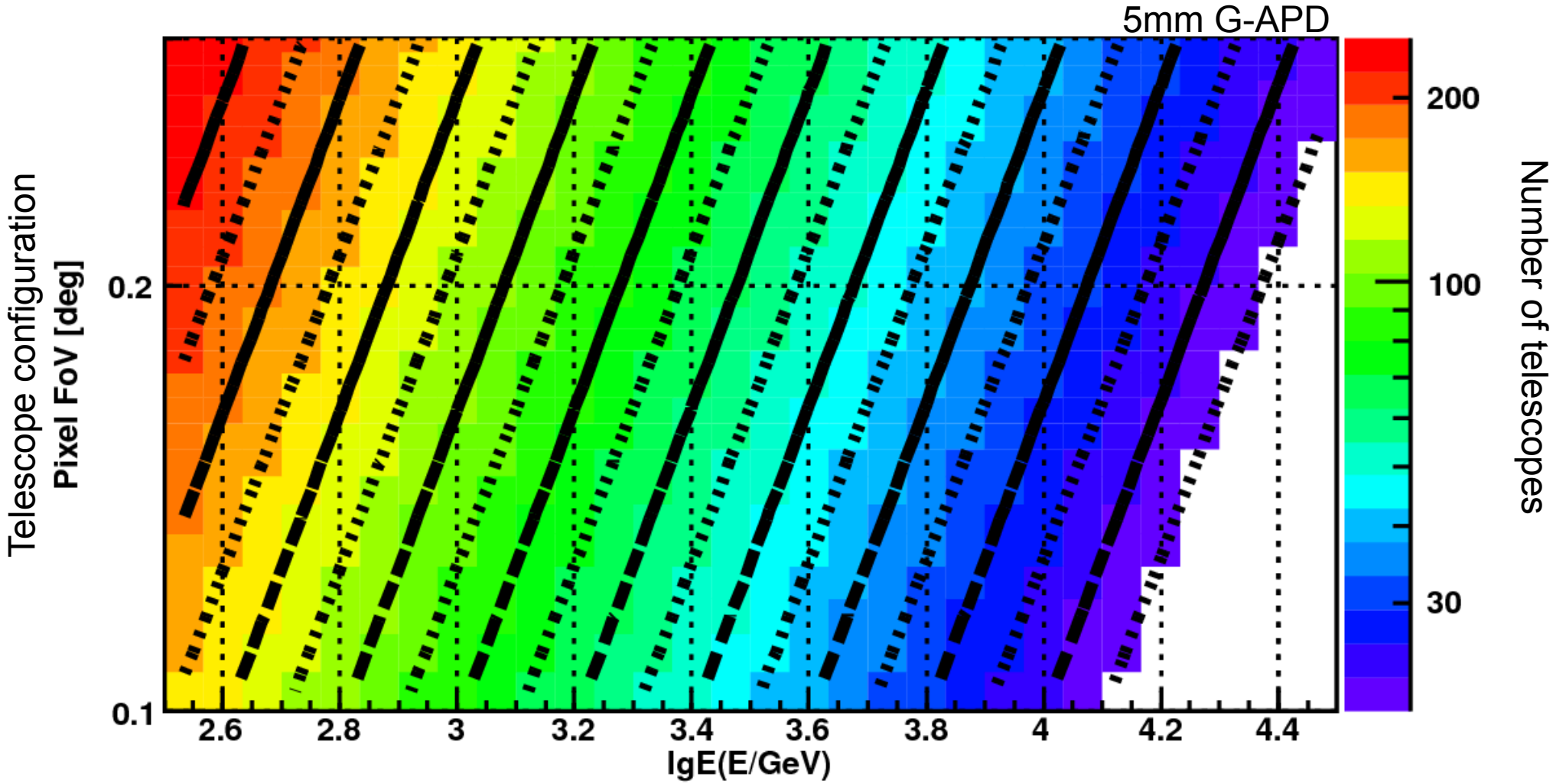
Num. of tel. for optimum configuration



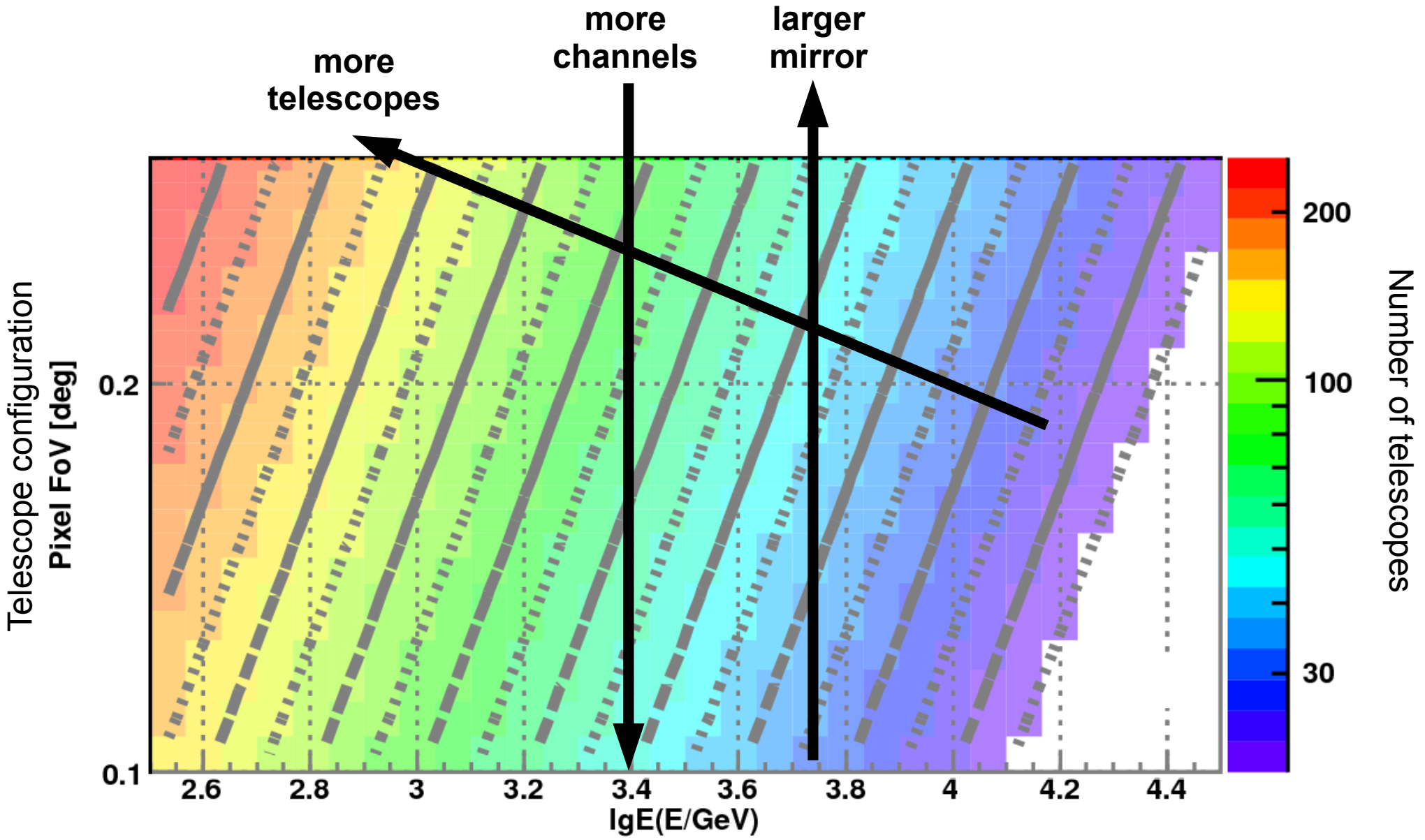
Array layout – a result

Number of telescope needed to reach an effective collection area of ~4km² for

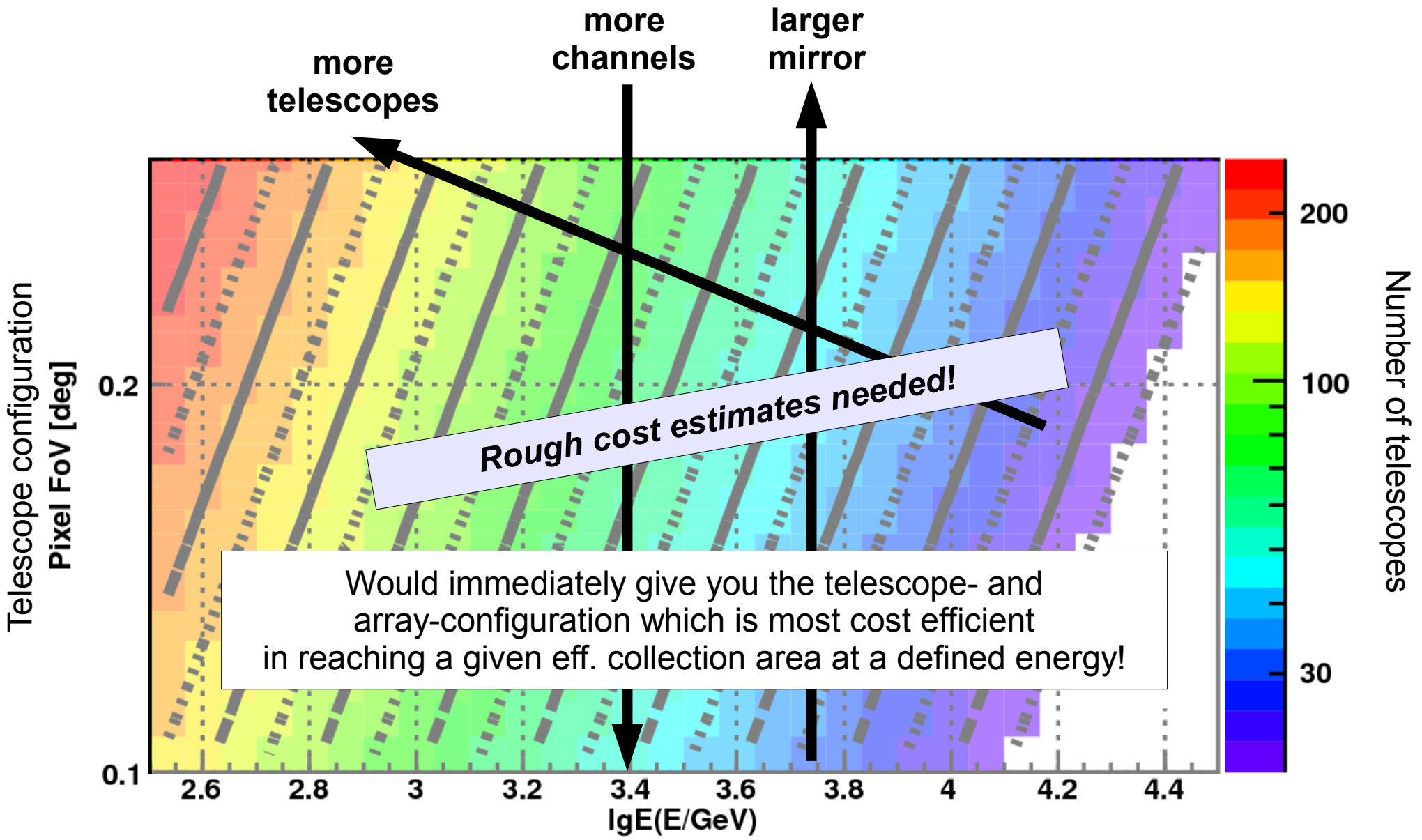
- a given telescope type (pixel FoV)
- at a given energy



Array layout – equal eff. area



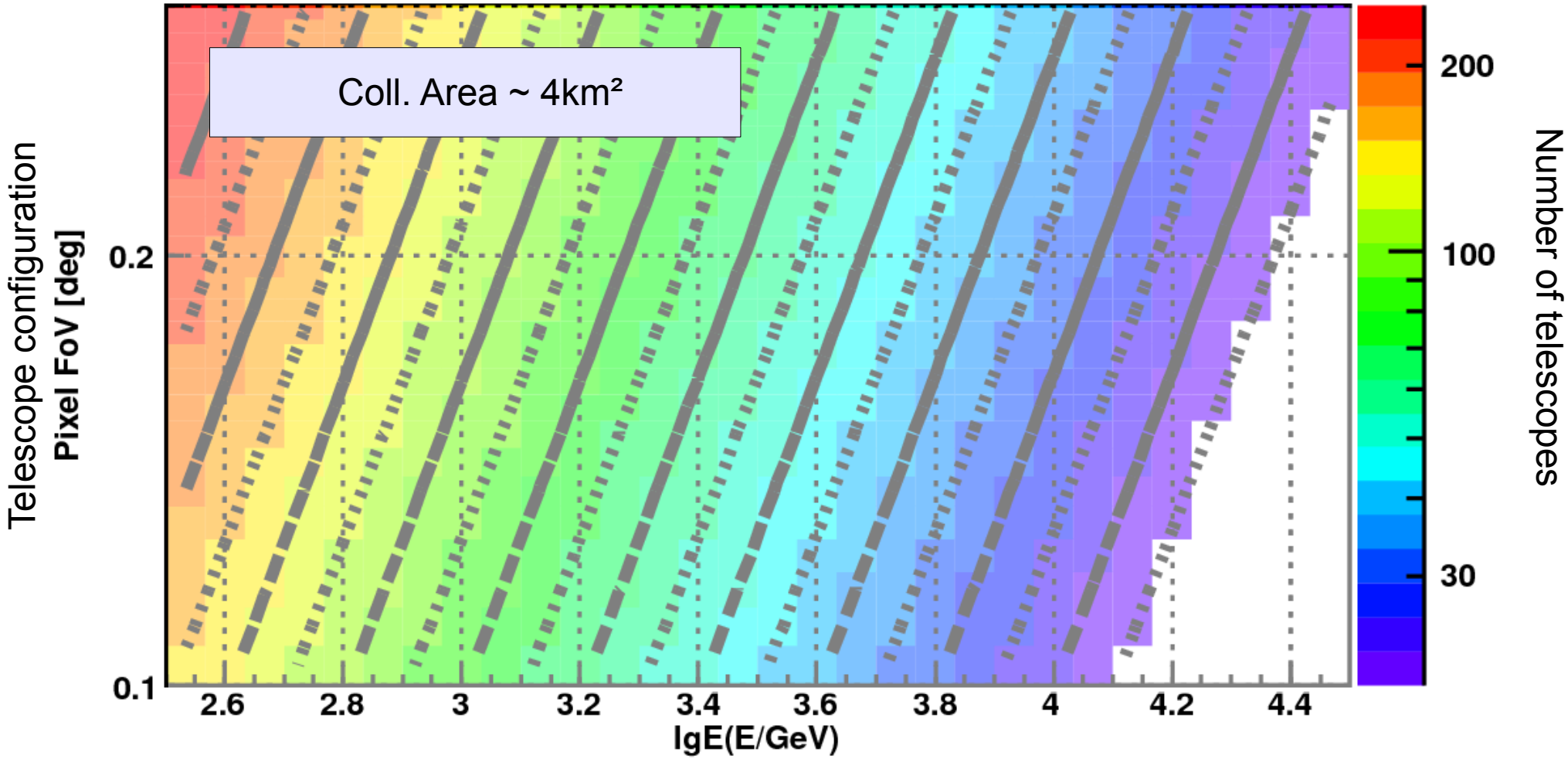
Array layout – equal eff. area



Array layout – a result

Number of telescope needed to reach an effective collection area of ~4km² for

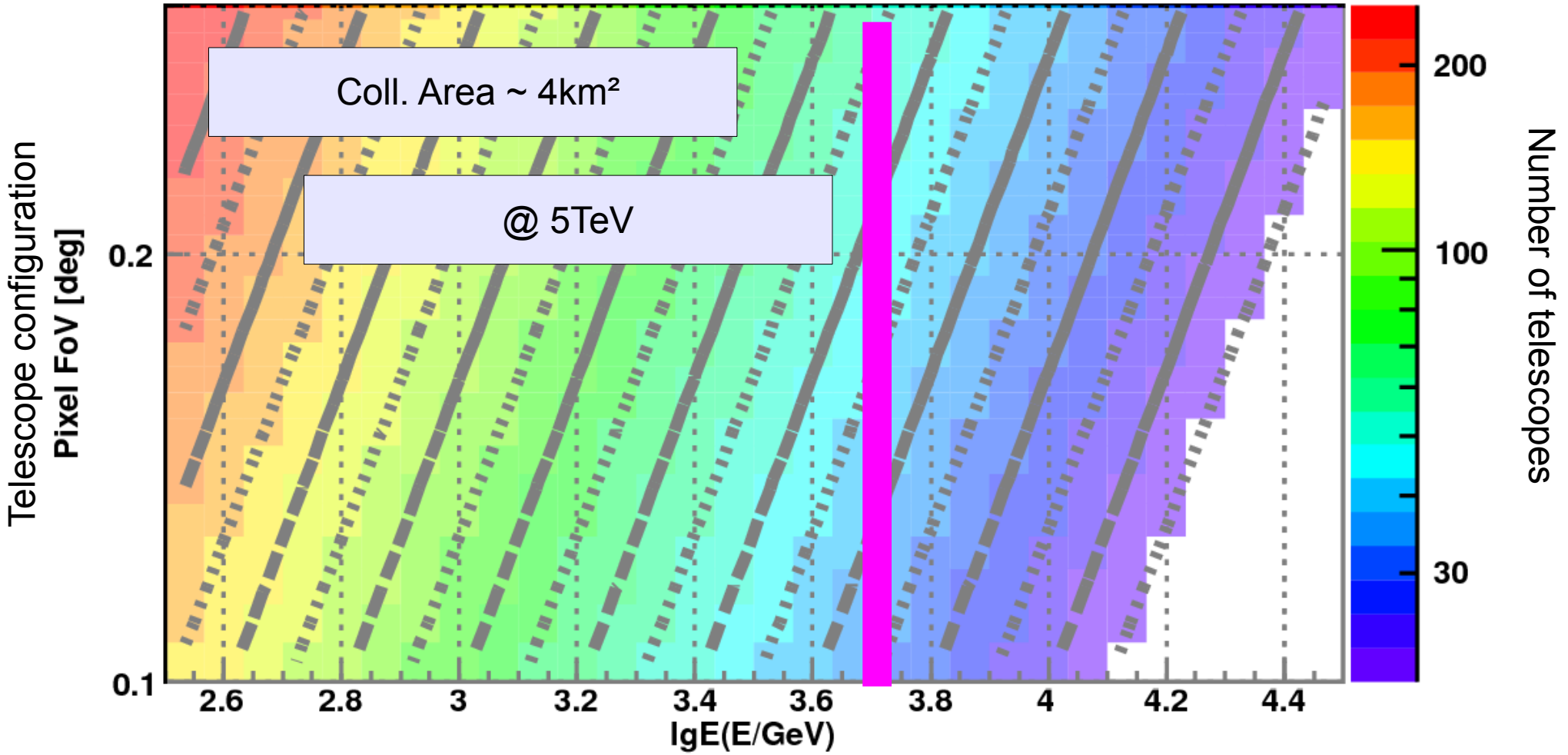
- a given telescope type (pixel FoV)
- at a given energy



Array layout – a result

Number of telescope needed to reach an effective collection area of ~4km² for

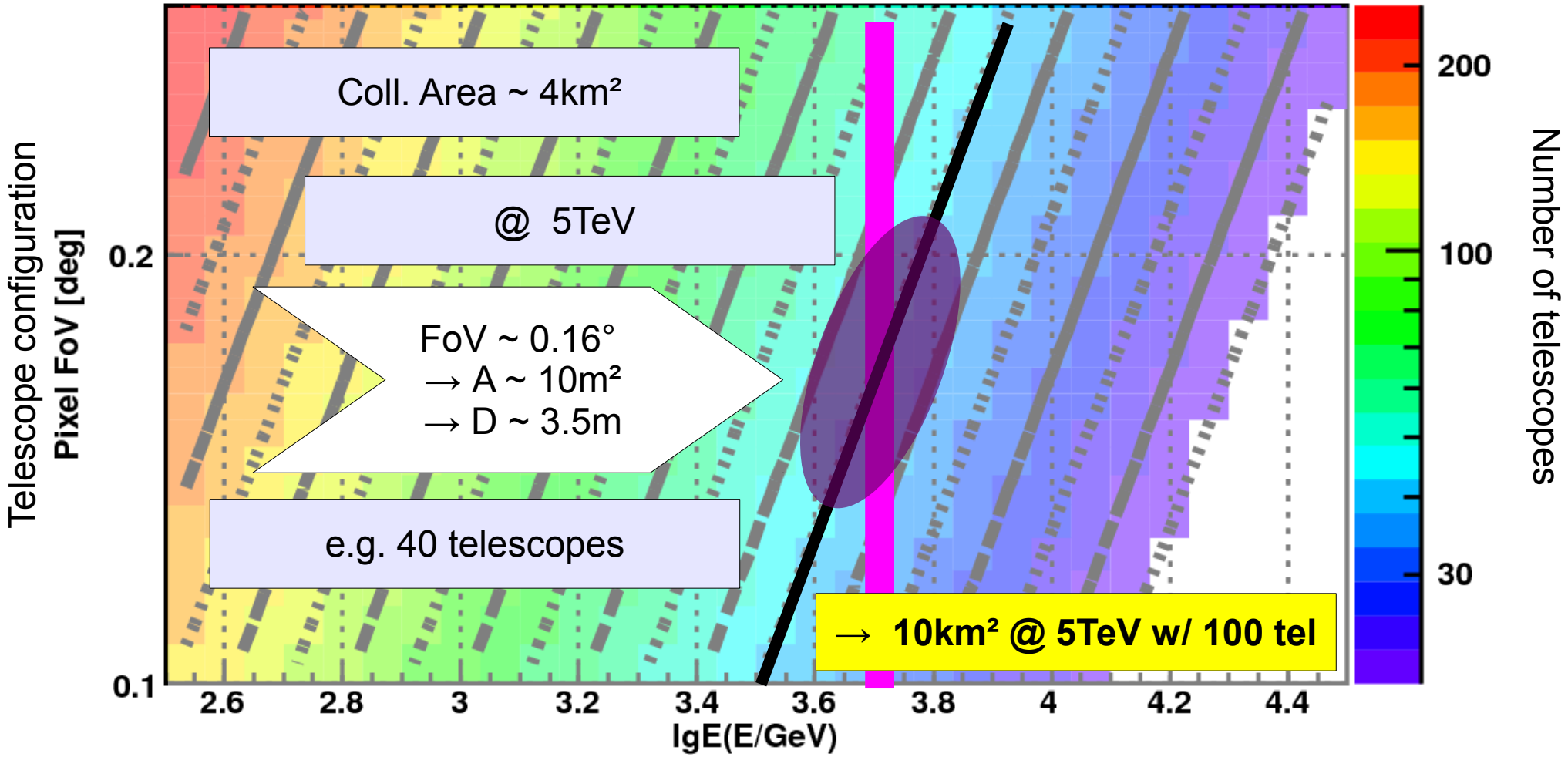
- a given telescope type (pixel FoV)
- at a given energy



Array layout – an example

Number of telescope needed to reach an effective collection area of ~4km² for
- a given telescope type (pixel FoV)
- at a given energy

<u>Example</u>: Instead of finding least costs we define a fixed number of telescopes (40)!



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Conclusions

- **The huge phase space to design our telescope could be reduced to a single variable!**
  (assuming that the photon detector is well defined)

- Monte Carlo studies for this phase space were performed for
  - G-APDs (3mm, 5mm) with solid cones
  - Zd = 30°
  - La Palma atmosphere

- It is possible to find the most cost efficient solution (telescope type and array layout) for a given collection area at a given energy
  (or to maximize the collection area at a given energy and given expenses)

- **The studies have shown that G-APD with a Davies-Cotton reflector are an option!**