Maximization of energy deposition in GGAG crystal with the W, Pb and Cu coating

International Workshop “SPD at NICA-2019”

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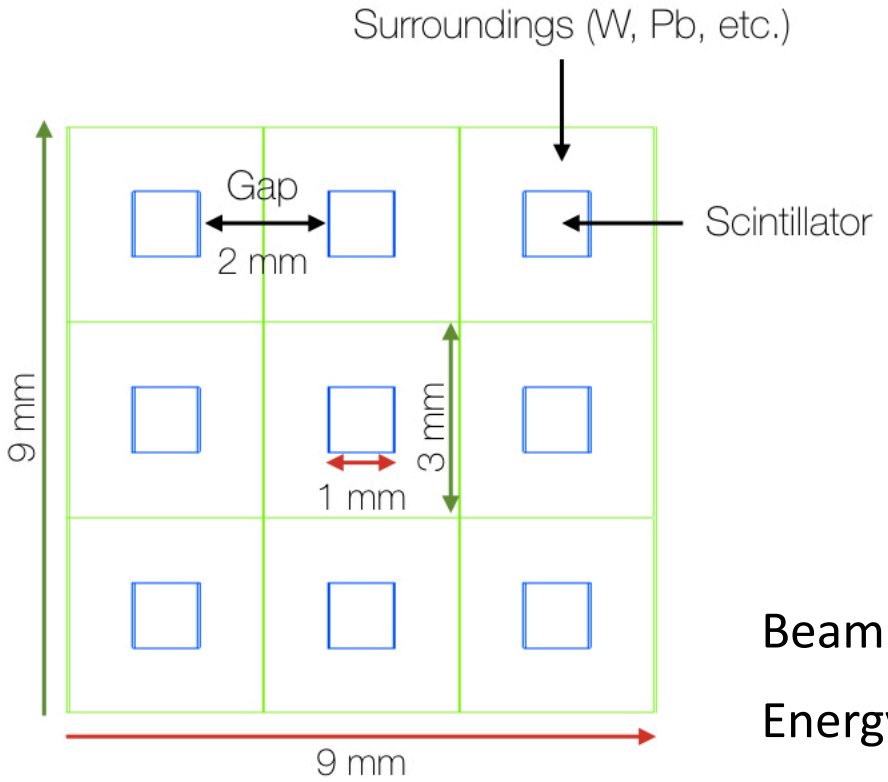
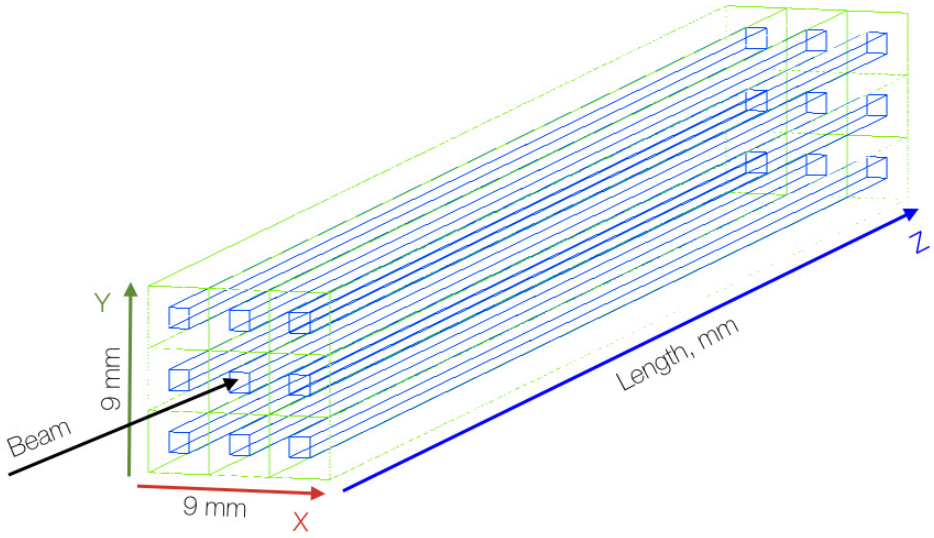
NICA (Nuclotron-based Ion Collider fAcility)
SPD (Spin Physics Detector)

- Beam: from protons and polarized deuterons to very massive gold ions
- Heavy ions will be accelerated up to kinetic energy of 4.5 GeV per nucleon, the protons – up to 12.6 GeV.

Spaghetti Calorimeter GEANT4 setup



Used matrix 243x243 mm
(81x81 cell)



Beam is phonons

Energy range: $500 \div 6000$ MeV

Length range: $10 \div 50$ cm

Surrounding: Scintillator, WCu, Pb, WPb, W

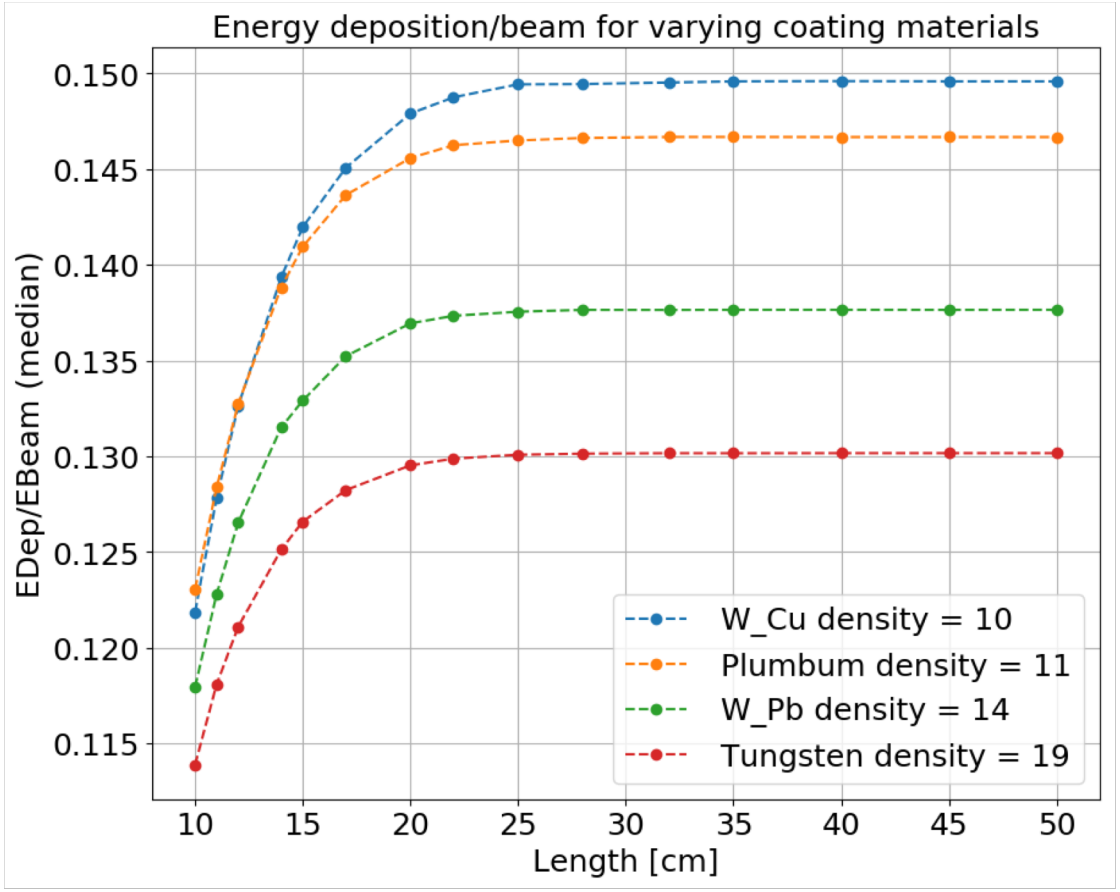
Scintillator Restrictions

- The scintillator is made of Gadolinium Gallium Aluminum Garnets (GGAG) crystal.
- Usage of the pure crystal is impractical and economically not feasible.
- The typical SPACAL consists of GGAG cells coated with heavy metal alloys

Energy deposition were maximized by varying coating materials and length of the SPACAL

Material	Formula	Density, g/cm^3
GGAG	$Gd_3Ga_3Al_2O_{12}$	6
WCu	25% Cu; 75% W	10
Pb	Pb	11
WPb	50% Pb; 50% W	14
W	W	19

Optimal Length = 25 cm



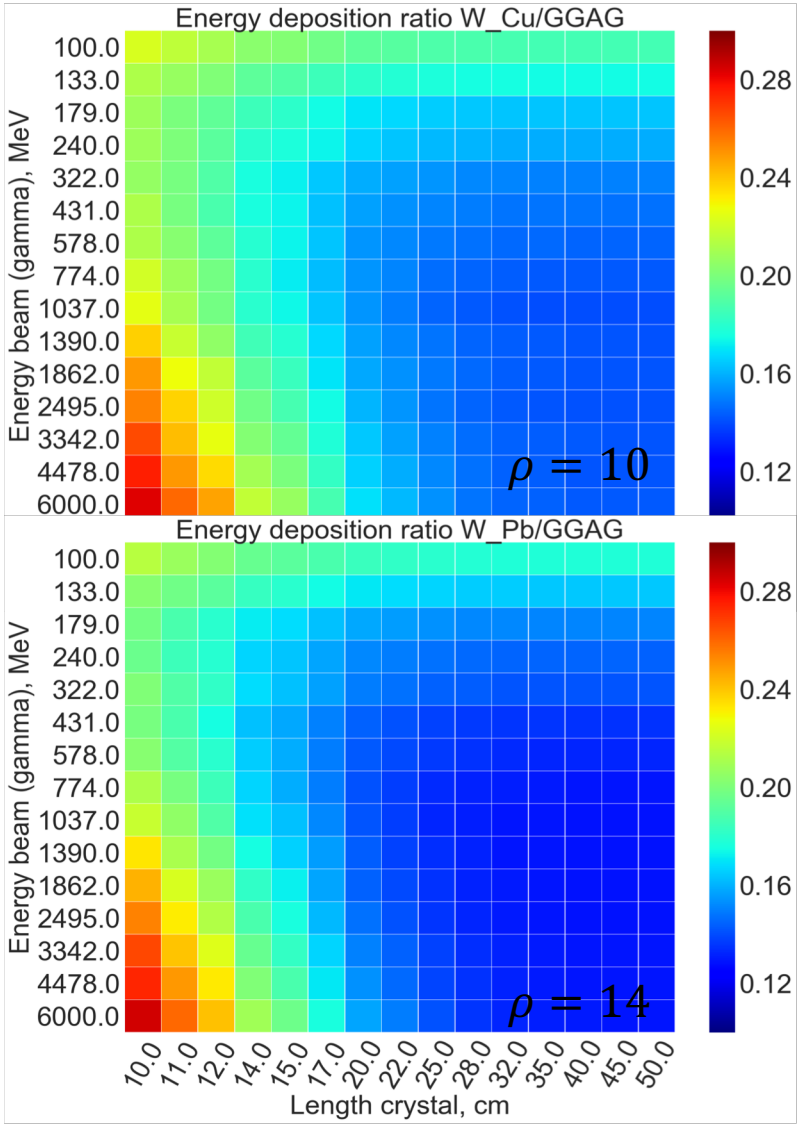
Tungsten has the **lowest** optimal length

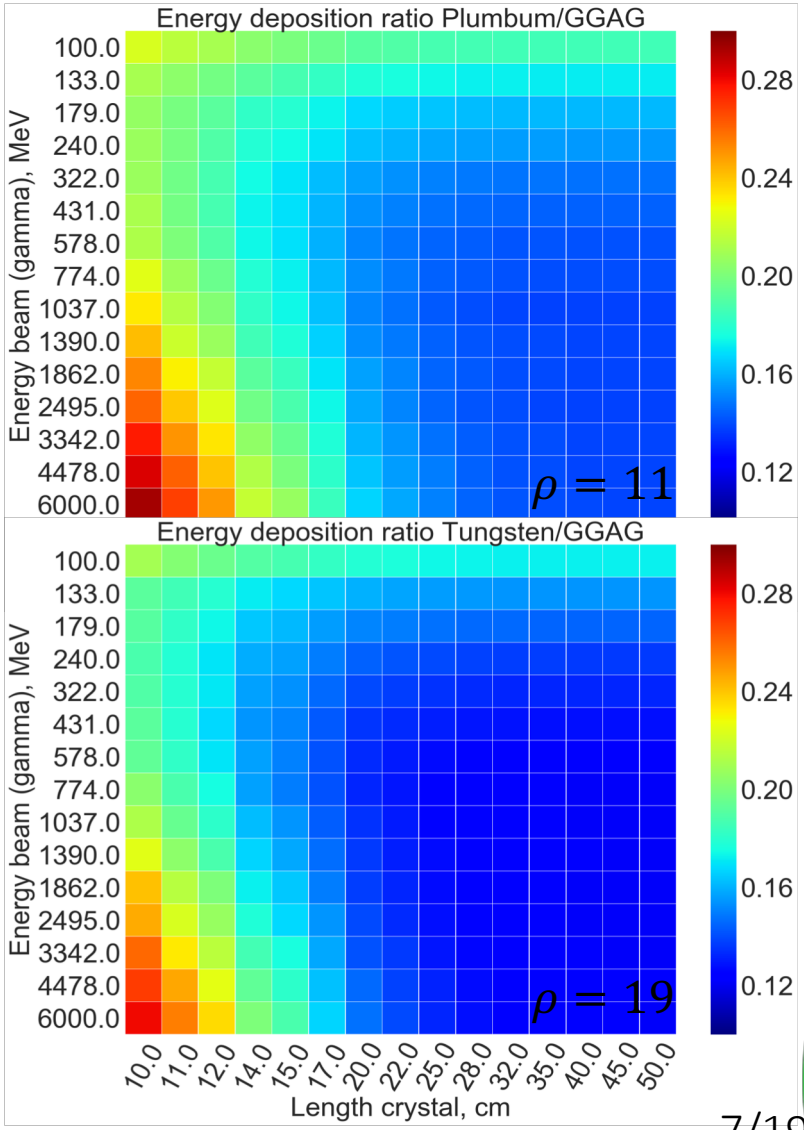
WCu is the **most effective**

Optimum length is **25** cm.

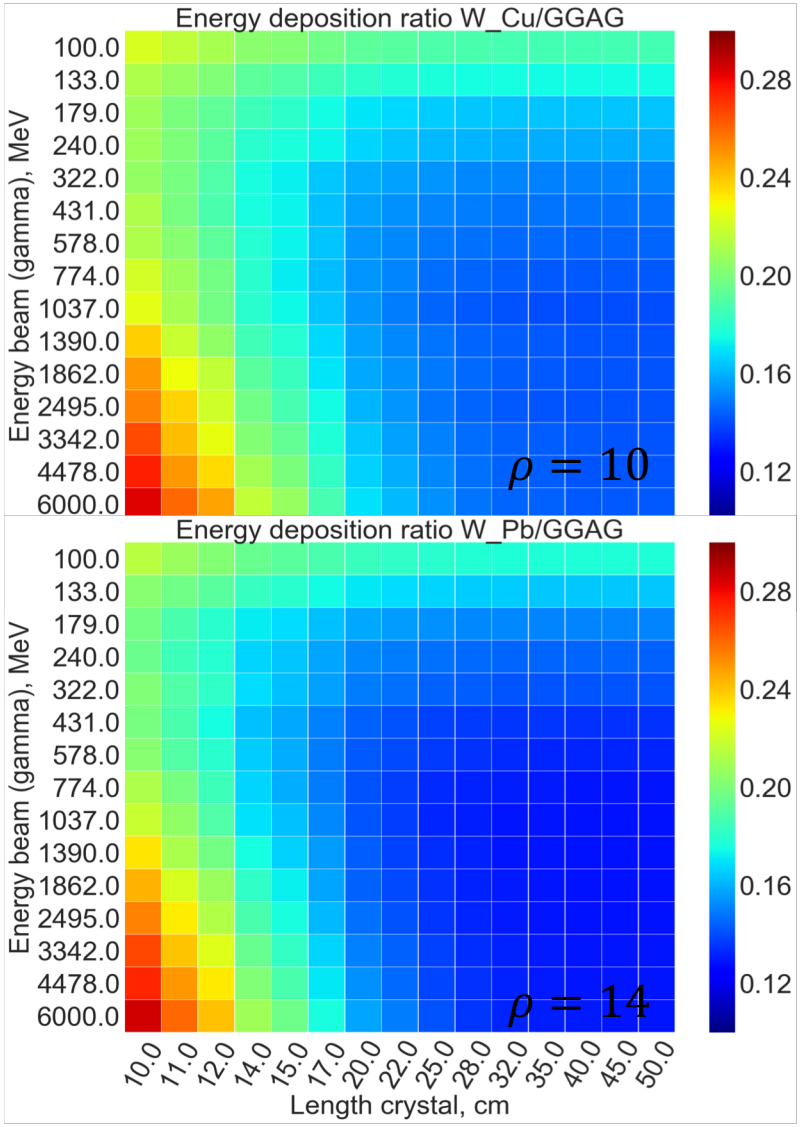
Max. length is **17** cm but this value is not much worse

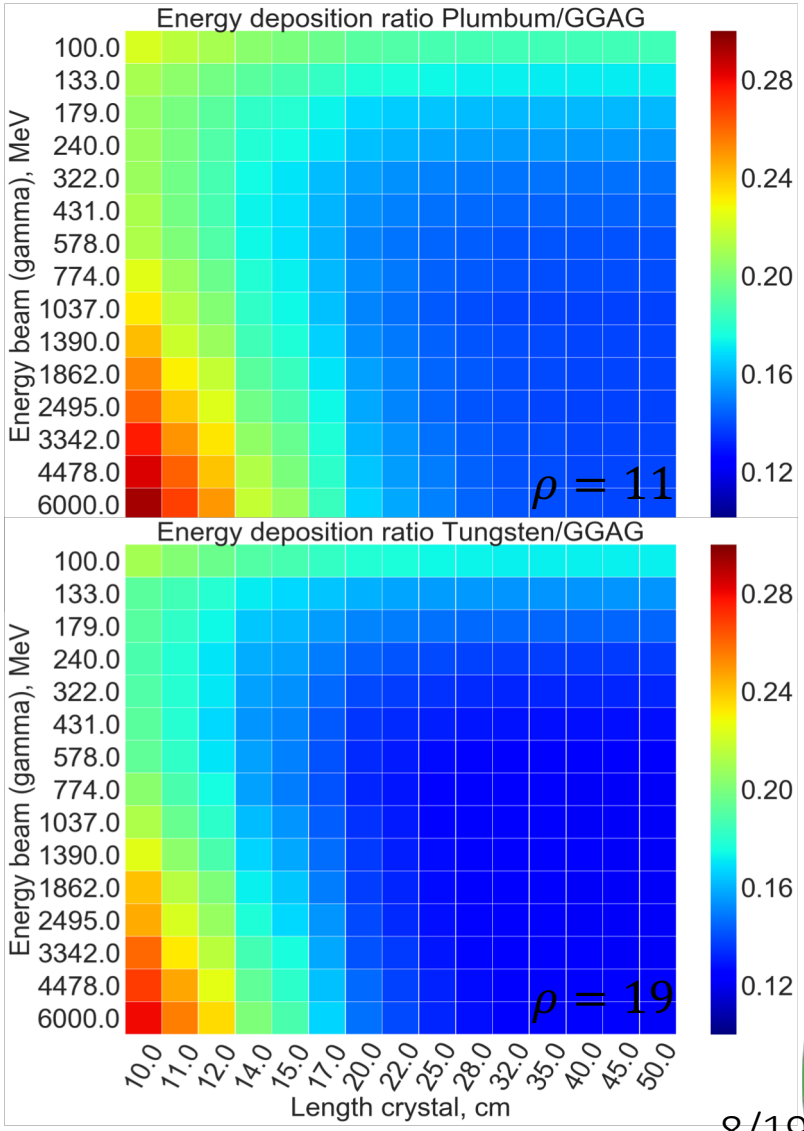
Short crystals in the coating are similar to GGAG because ED is low



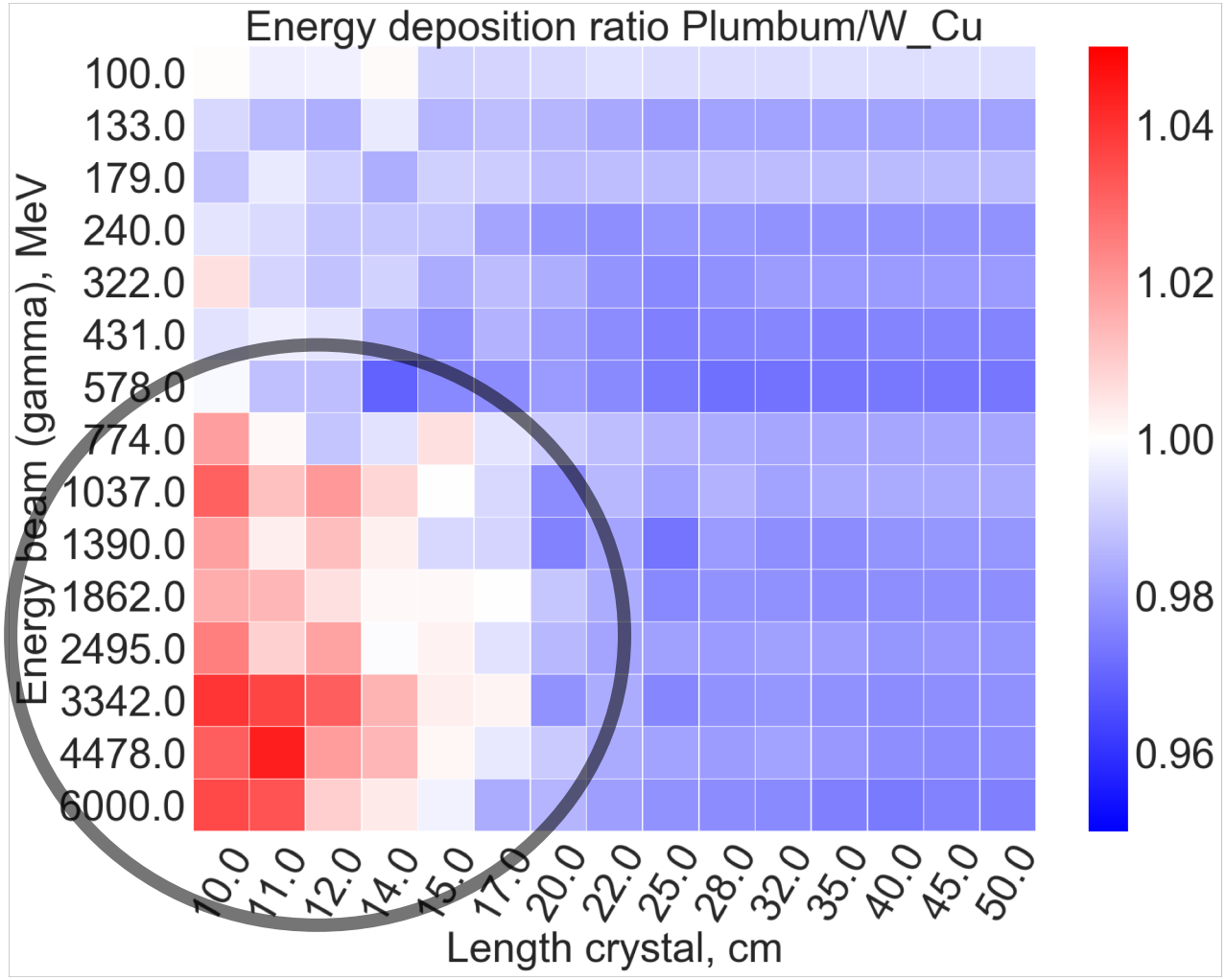


At greater lengths and energies, about 80% −85% of the energy dep is lost, since the ratios of a pure crystal to a crystal with a coating are 1 mm^2 to 8 mm^2



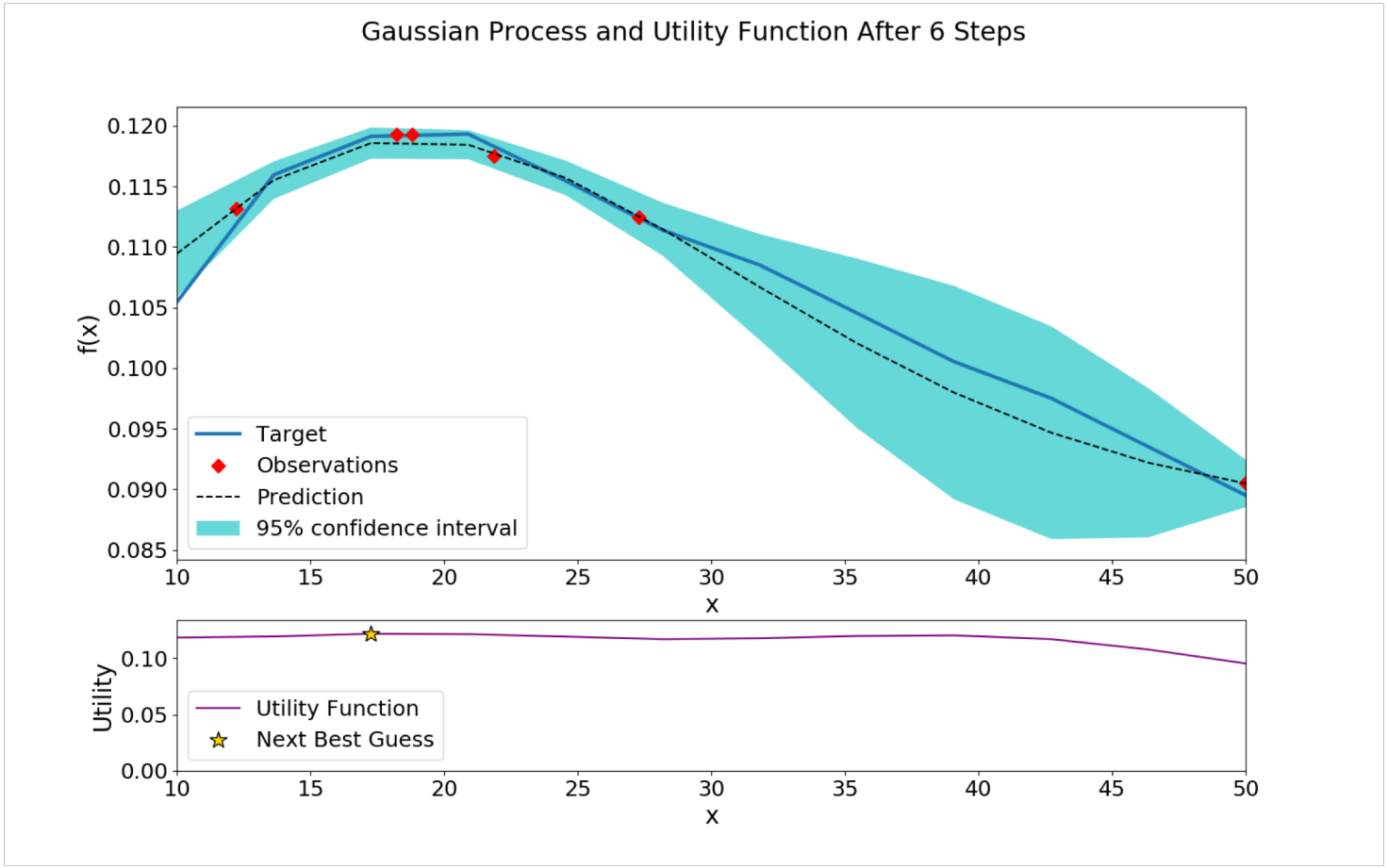


Max difference between Pb WCu = 5%



Pb coating preferable for **short** (< 15 cm) detectors
W_Cu coating preferable for **long** (> 15 cm) detectors

Automatic search of the optimal length



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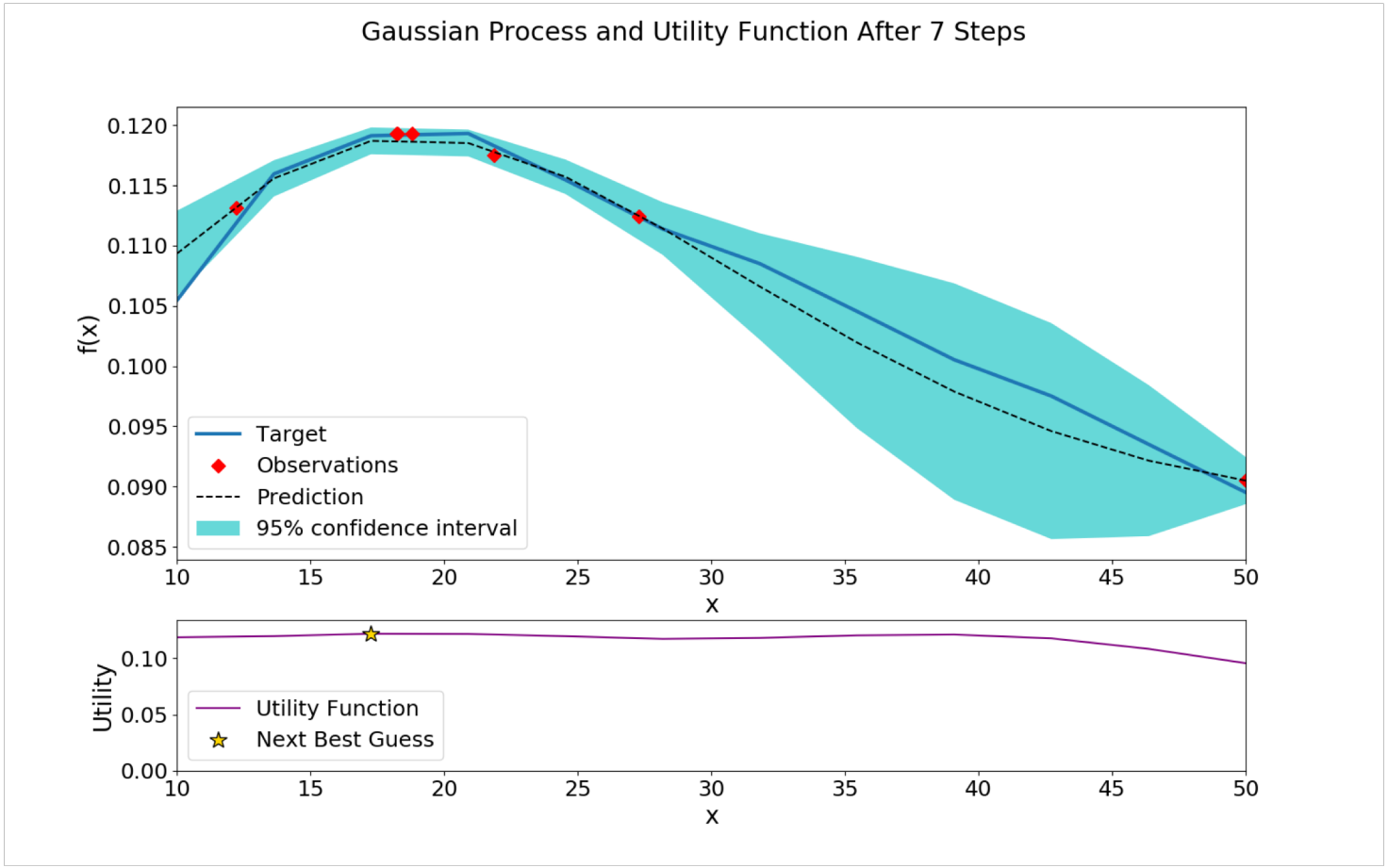

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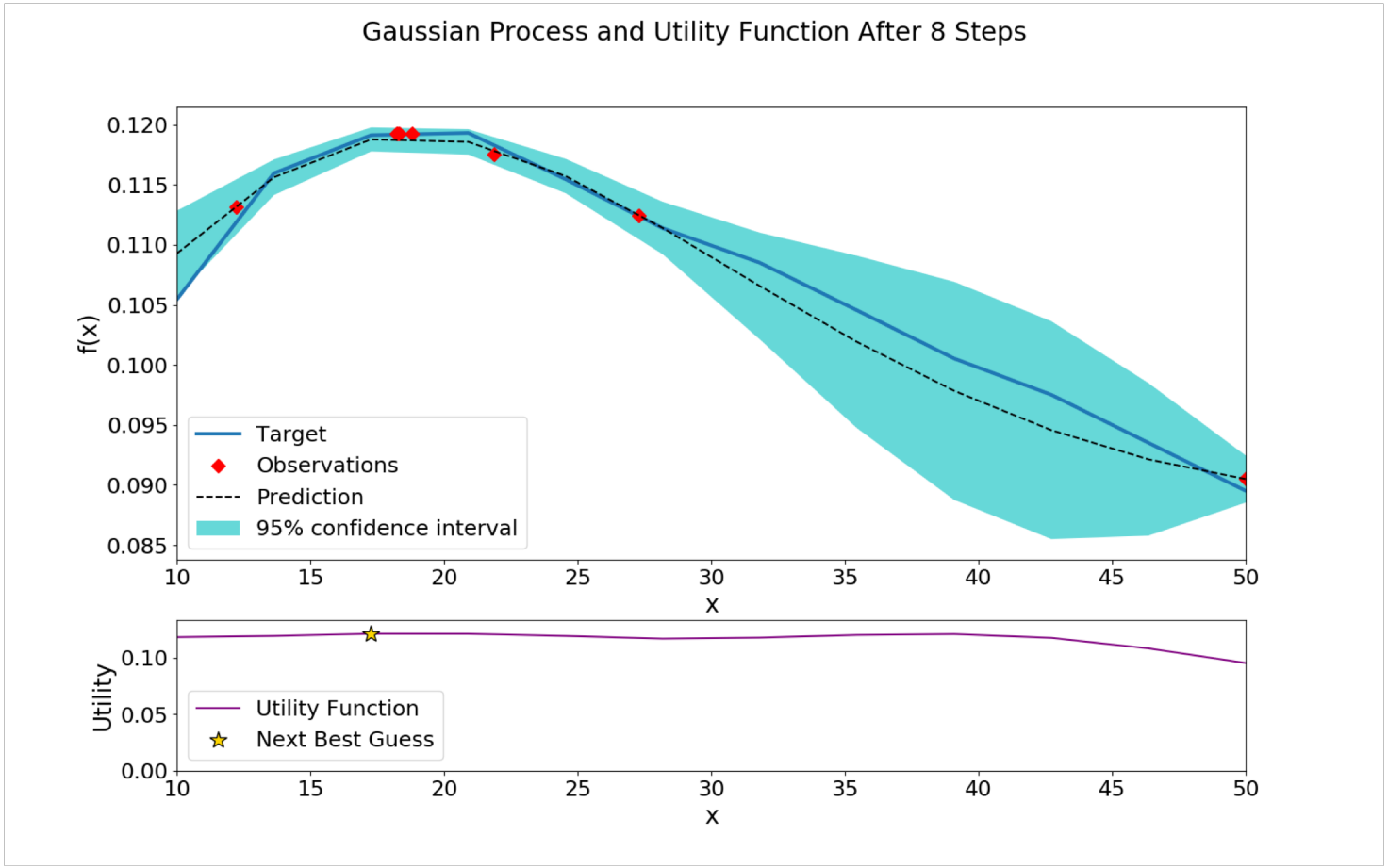

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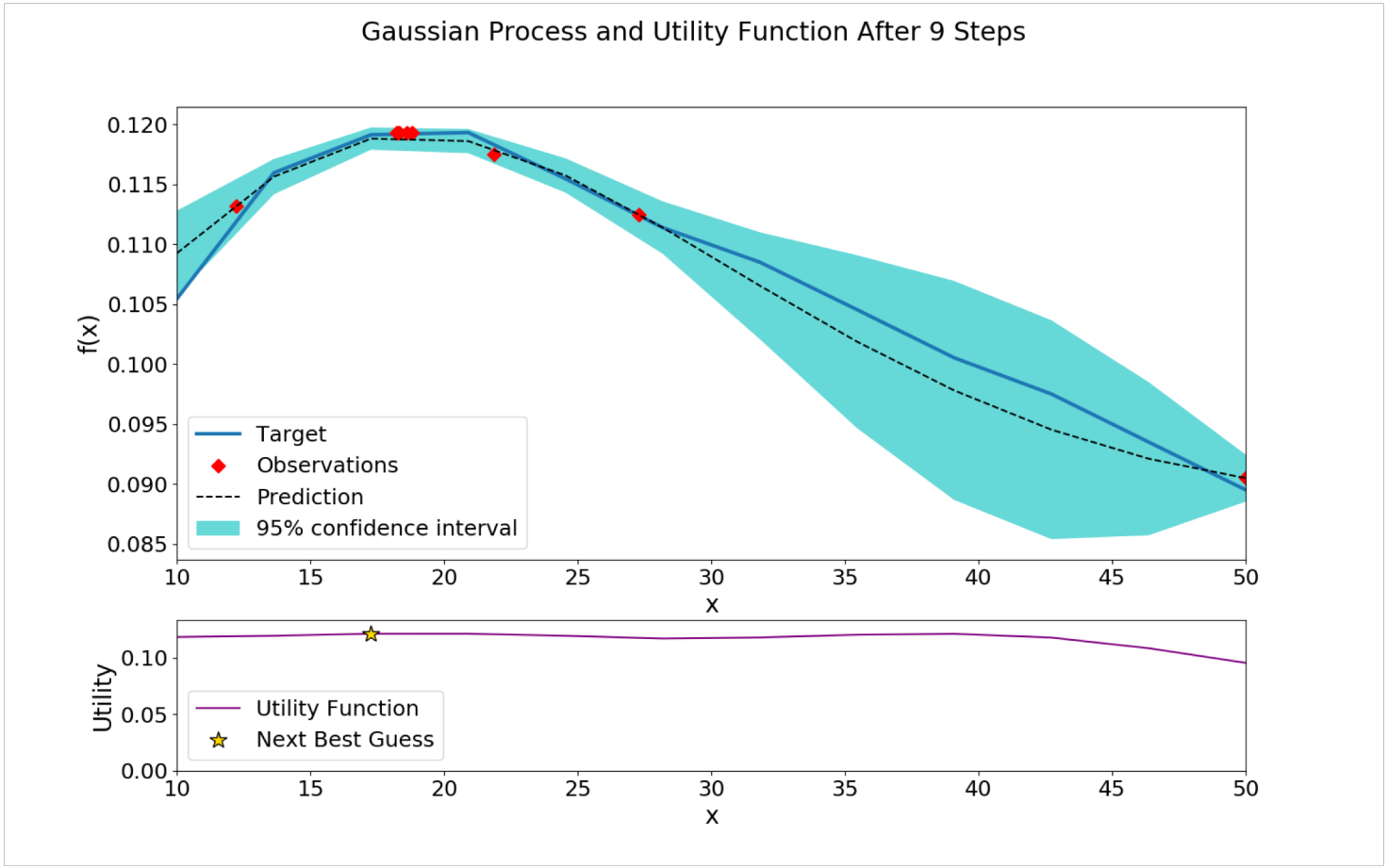

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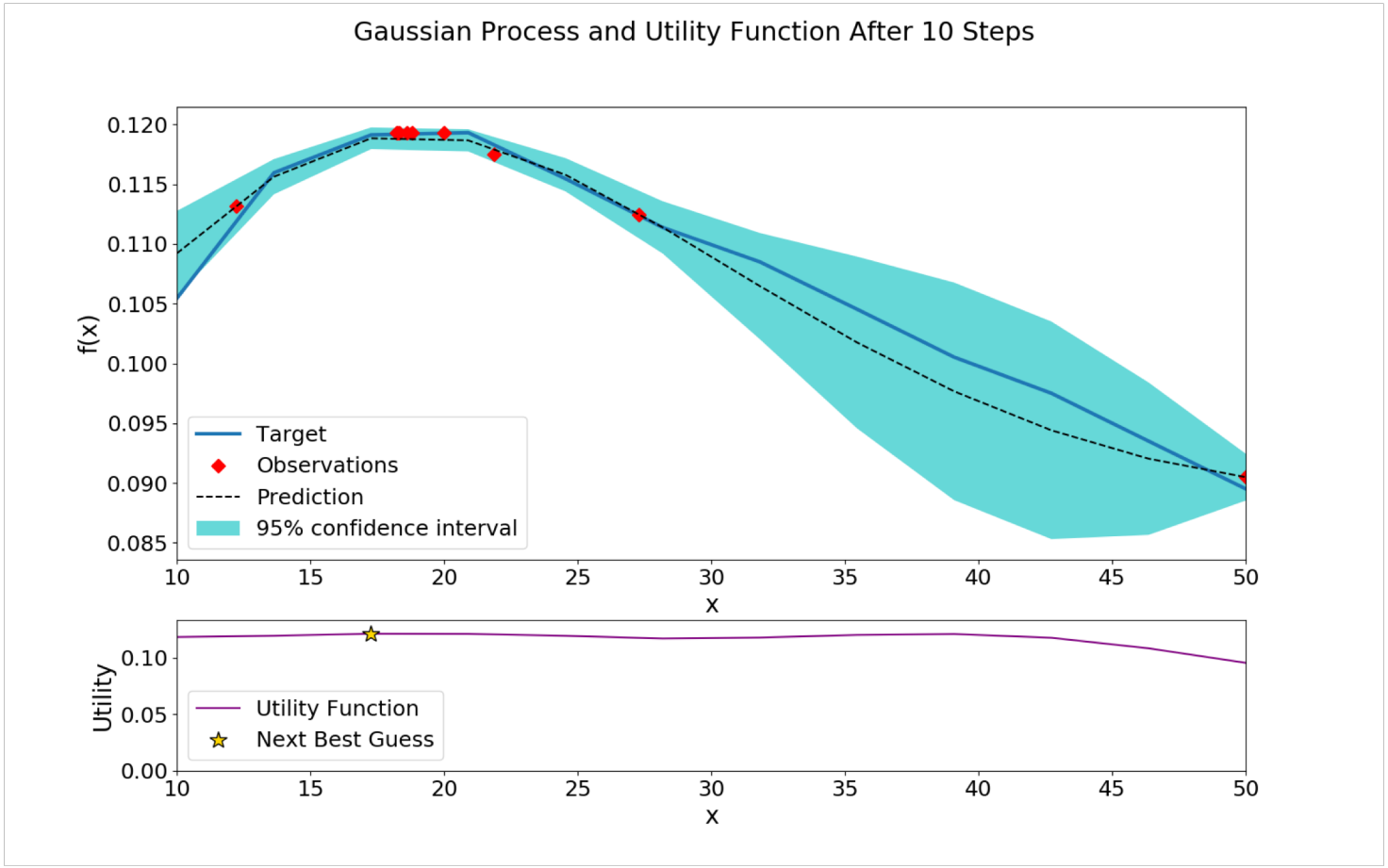

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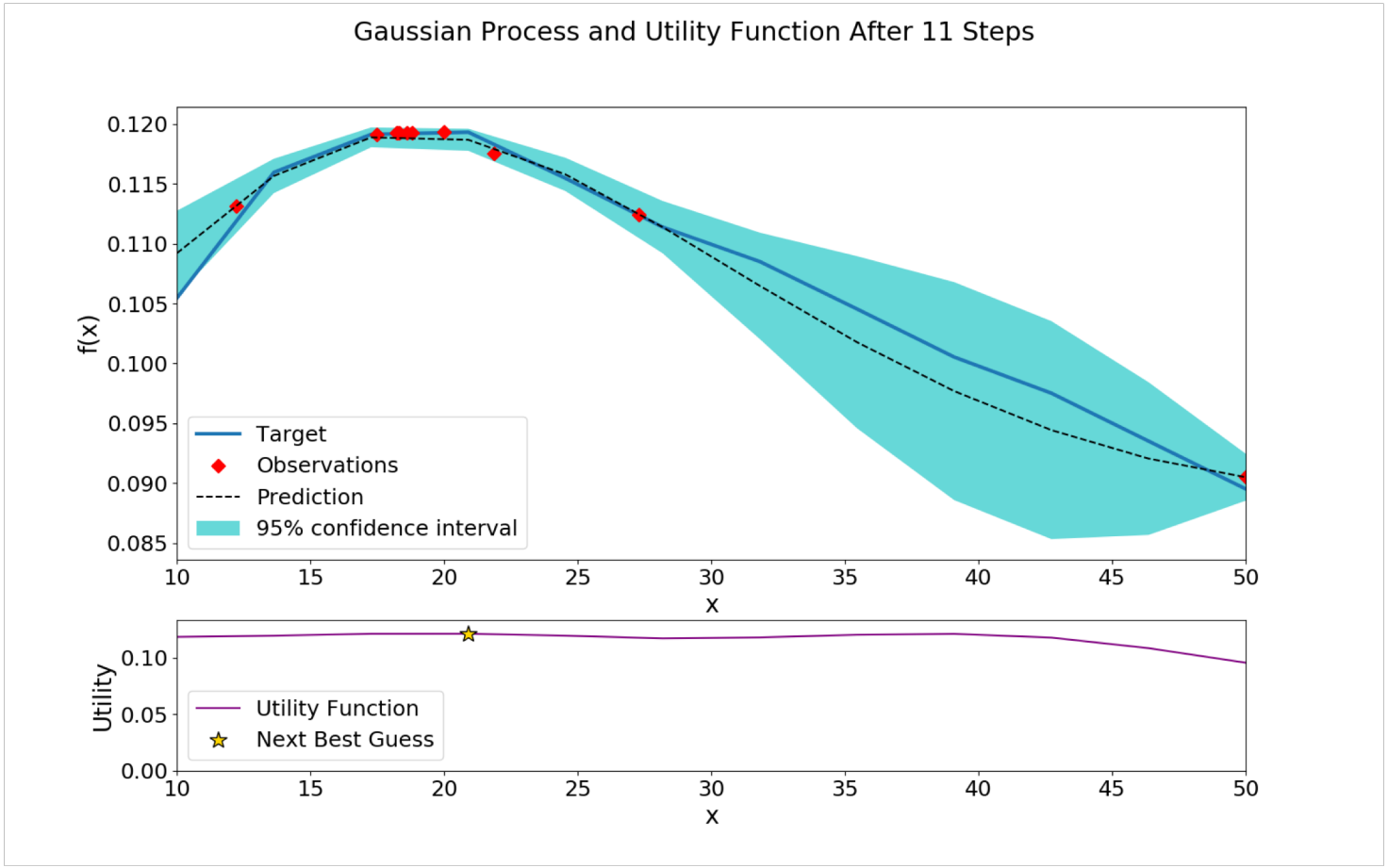

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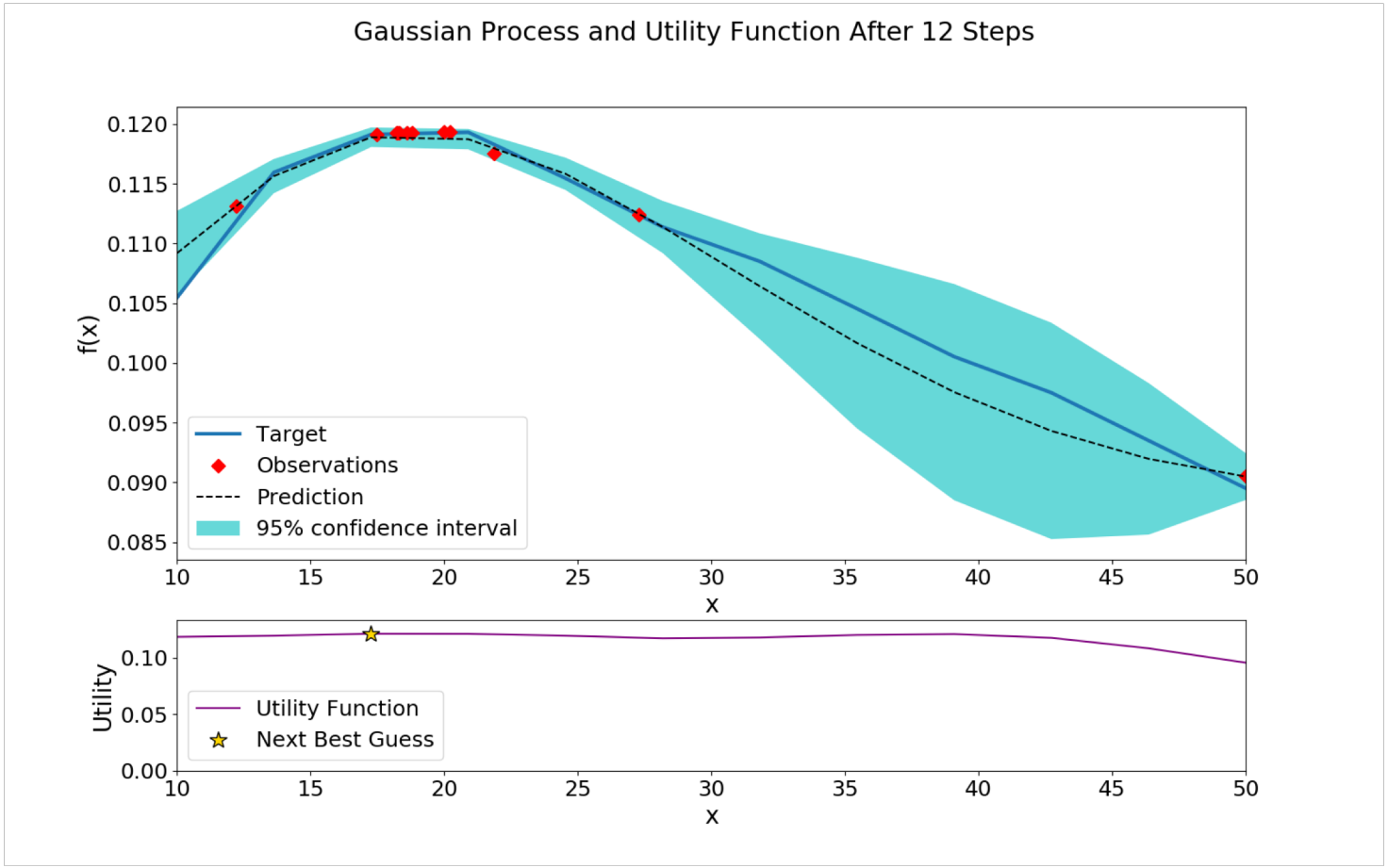

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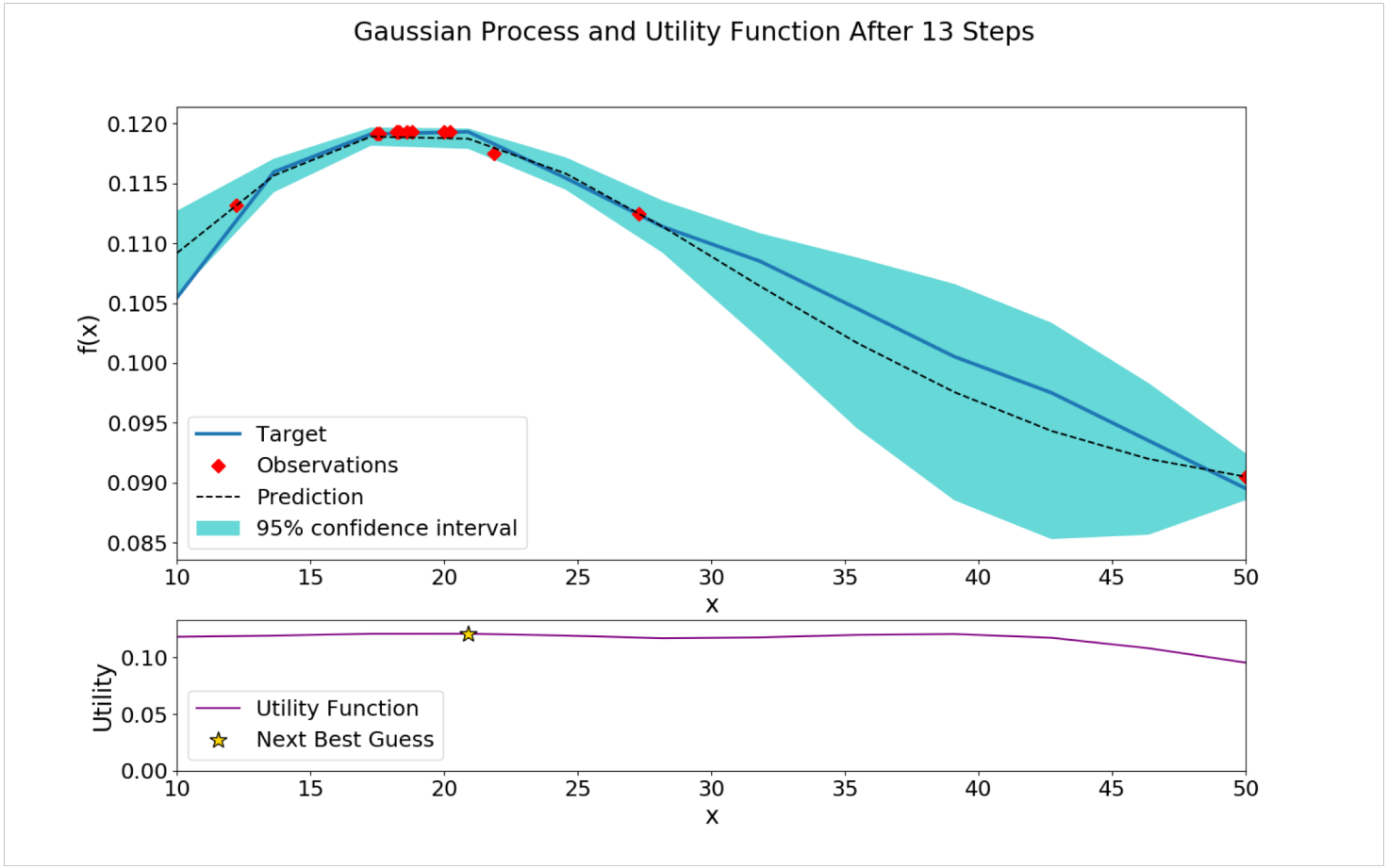

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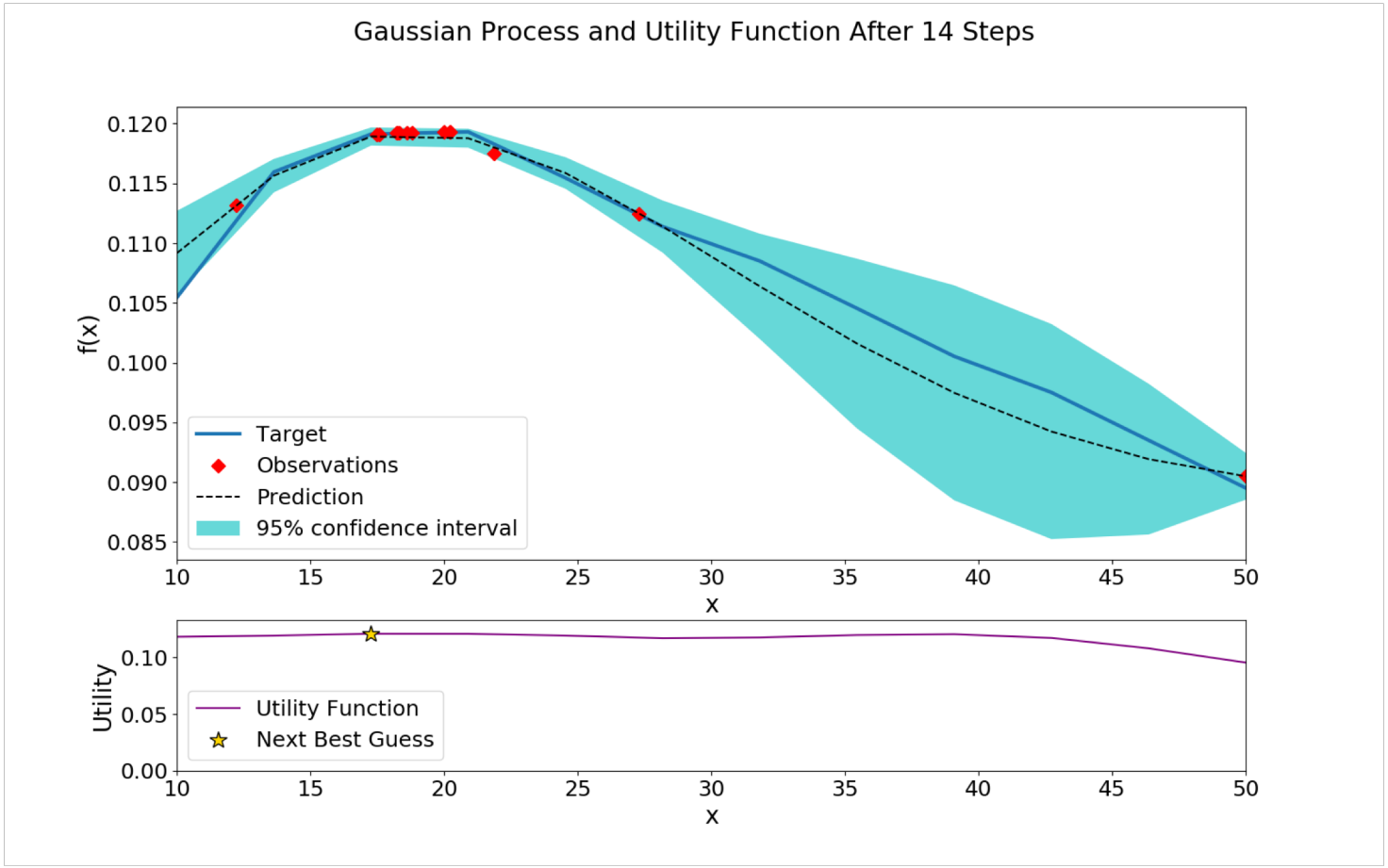

Conclusions

- The optimal length of the SPACAL detector is about 25 cm
- ED coated GGAG / ED pure GGAG is about 15%
- Pb coating preferable for l < 15 cm
- W_Cu coating preferable for l > 15 cm
- Future Plans: use the multi dimentional (Bayesian) optimization to find optimal crystal parameters (gap, shape, length, material) in space

Thank you for attention!

How to calculate density (mass ratio)?

V — *volume*
m — *mass*
d_2 — *fraction*

$$V_1 = \frac{m(1-d_2)}{\rho_1} \qquad V_2 = \frac{md_2}{\rho_2}$$

$$\rho_{1+2} = \frac{m}{V_1 + V_2} = \frac{1}{\frac{1-d_2}{\rho_1} + \frac{d_2}{\rho_2}} = \frac{\rho_1 + \rho_2}{\rho_2(1-d_2) + \rho_1 d_2}$$

Properties GGAG

Properties Optical/Scintillation	Units	Value
Wavelength (Max. Emission)	nm	520
Wavelength Range	nm	475 - 800
Decay Time	ns	50 - 150
Light Yield	photons/keV	40 - 60
Photoelectron Yield	% of NaI(Tl)	TBA
Radiation Length	cm	TBA
Optical Transmission	µm	TBA
Transmittance	%	TBA
Refractive Index		1.9 @540nm
Reflection Loss/Surface	%	TBA
Neutron Capture Cross-section	barns	TBA

Properties Mechanical	Units	Value
Chemical Formula		$Gd_3Al_2Ga_3O_{12}$
Density	g/cm^3	6.63
Atomic Number (Effective)		54.4
Melting Point	°C	1850
Thermal Expansion Coeff.	C^{-1}	TBA x 10^{-6}
Cleavage Plane		None
Hardness	Mho	8
Hygroscopic		No
Solubility	$g/100gH_20$	N/A

Bayesian optimization

- Bayesian optimization is a sequential design strategy for global optimization of black-box functions that doesn't require derivatives.
- Since the objective function is unknown, the Bayesian strategy is to treat it as a random function and place a over it. The prior captures beliefs about the behaviour of the function. After gathering the function evaluations, which are treated as data, the prior is updated to form the posterior distribution over the objective function. The posterior distribution, in turn, is used to construct an acquisition function (often also referred to as infill sampling criteria) that determines the next query point.
- In Bayesian statisticsposterior probabilityrandom event or an uncertain proposition[is the conditional probability that is assigned after the relevant evidence or background is taken into account.

About SPACAL

- SPACAL now: LAA(CERN) programme to develop new High Energy Physics experimental techniques.