Heading Down the Profiling Rabbit Hole

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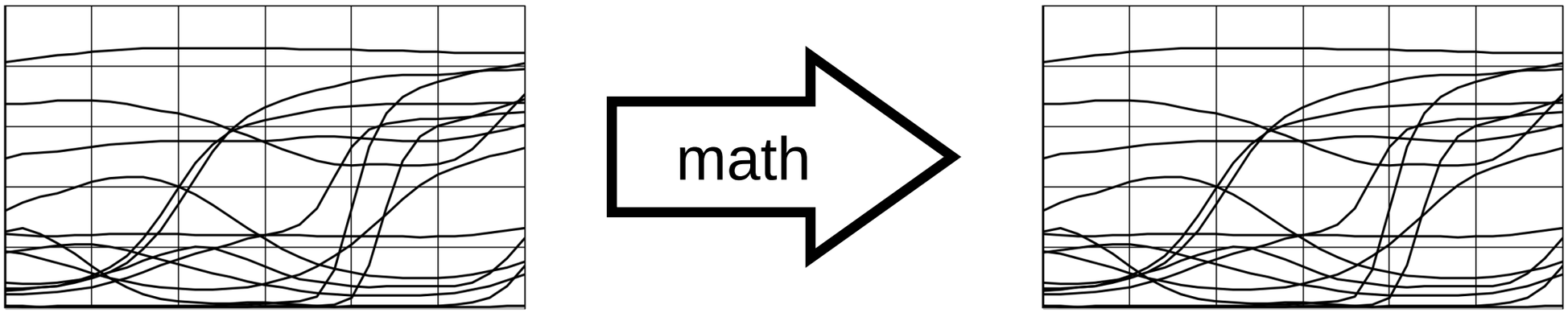
Profiling

profiling (n) ˈ*prō-fī-liŋ*

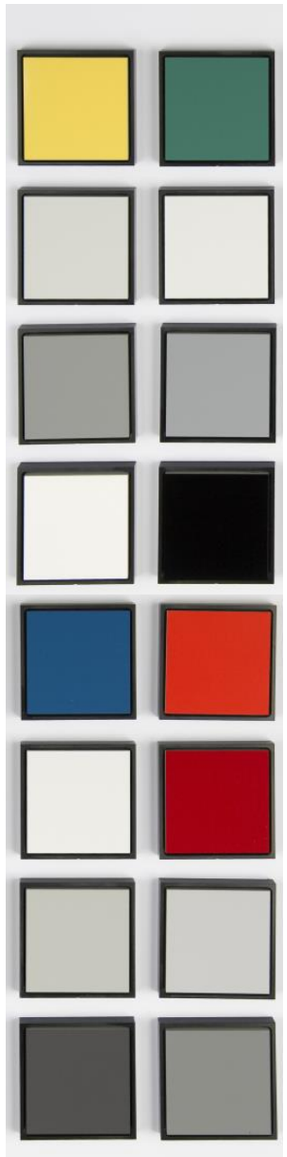
1. The act or process of extrapolating information about a person based on known traits or tendencies.

2. The art and science of coercing a defensible mathematical model into accurately transforming one set of spectra into another.

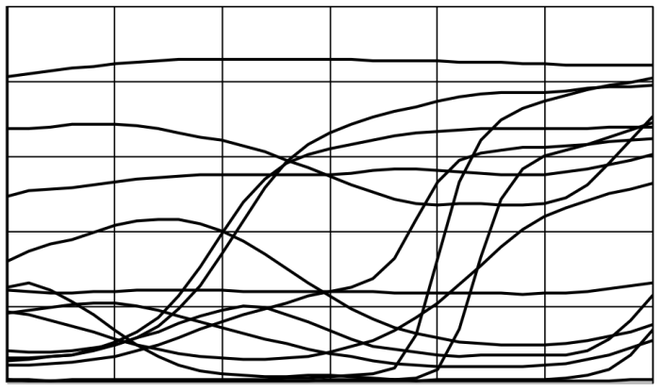


test instrument reference instrument

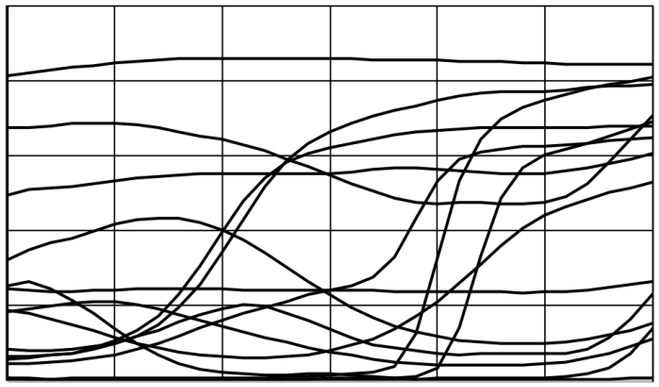
Profiling: Model fitting



reference standards
(measured on both)



reference instrument



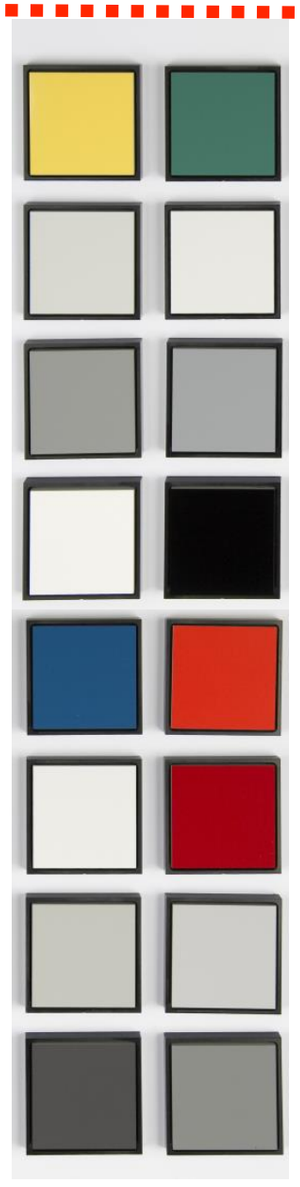
test instrument

parameter
starting
values

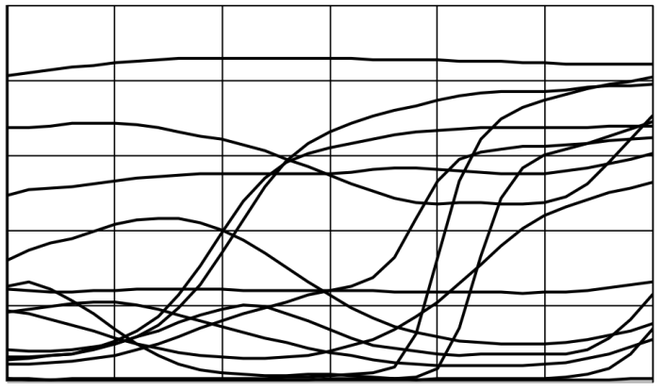
optimization
engine

model
parameters

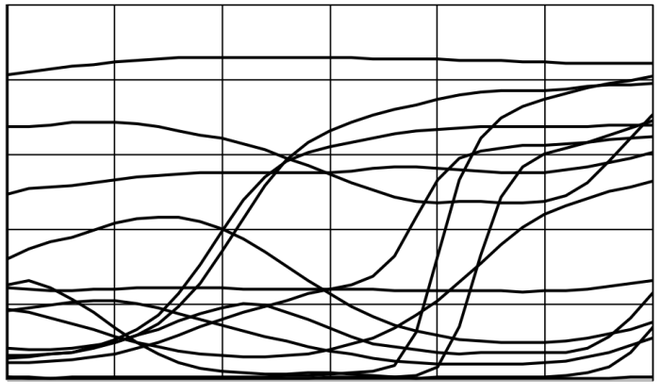
Profiling: Model fitting



reference standards (measured on both)



reference instrument



test instrument

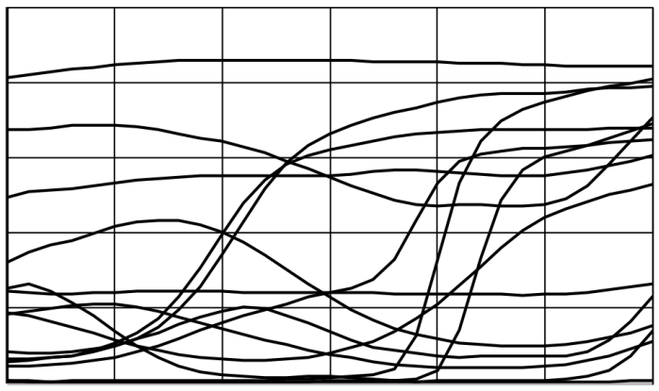
parameter starting values

optimization engine

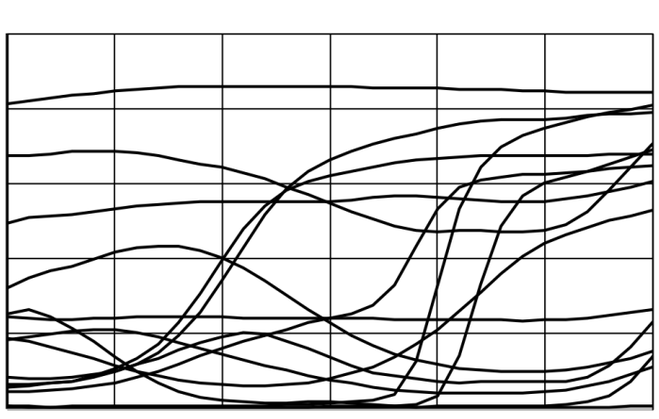
model parameters

These all can affect the model parameters

Profiling: Model Application



reference instrument

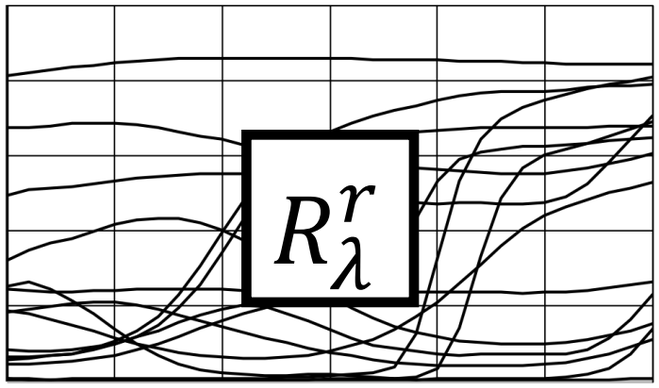


test instrument

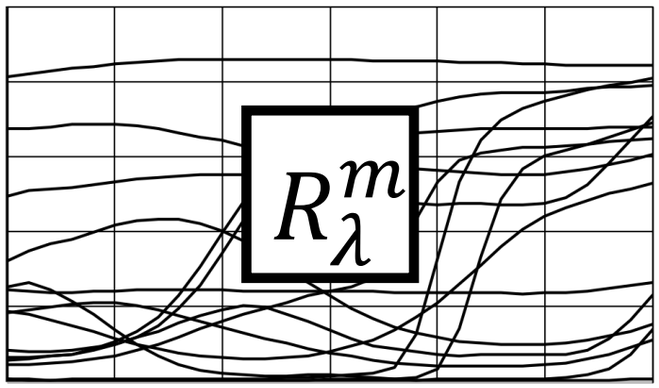
model parameters

The goal is to transform the measurements of the test instrument into those that *would have* been made on the reference instrument.

Profiling: Model fitting



reference instrument



test instrument

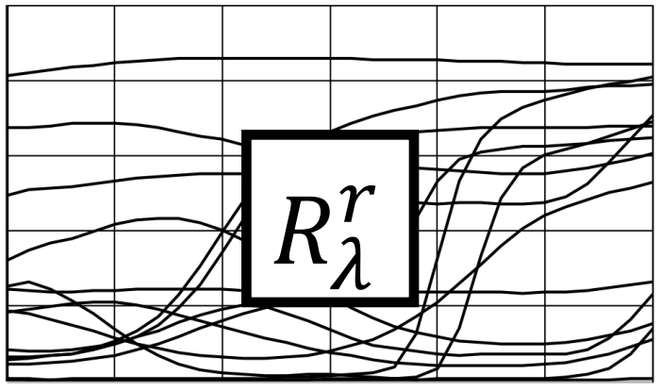
Minimize RMS spectral difference using MS Excel Solver

$$\begin{vmatrix} \beta_{0,\lambda} \\ \beta_{1,\lambda} \\ \beta_{2,\lambda} \end{vmatrix}$$

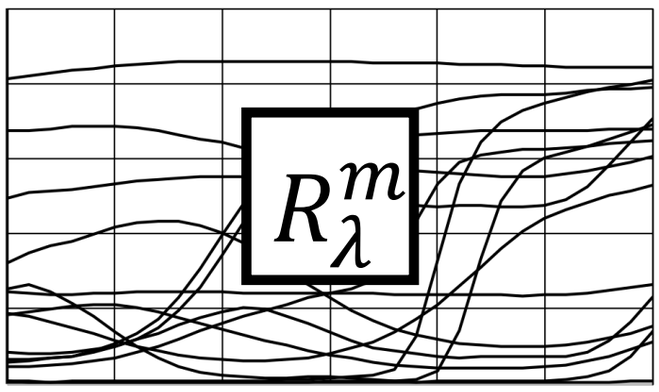
model parameters

$$R_\lambda^m - R_\lambda^r = \beta_{0,\lambda} + \beta_{1,\lambda} R_\lambda^m + \beta_{2,\lambda} \frac{dR_\lambda^m}{d\lambda}$$

Profiling: Model fitting



reference instrument



test instrument

No claim this is the best model or method!
It is consistently applied here.

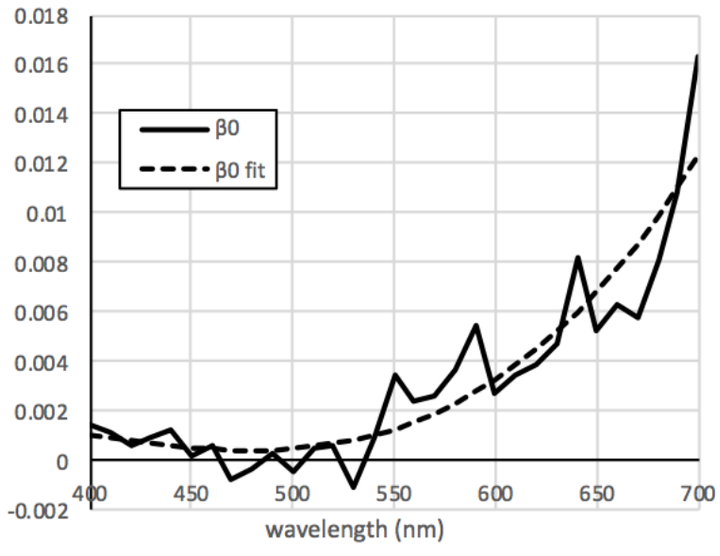
$$R_\lambda^m - R_\lambda^r = \beta_{0,\lambda} + \beta_{1,\lambda} R_\lambda^m + \beta_{2,\lambda} \frac{dR_\lambda^m}{d\lambda}$$

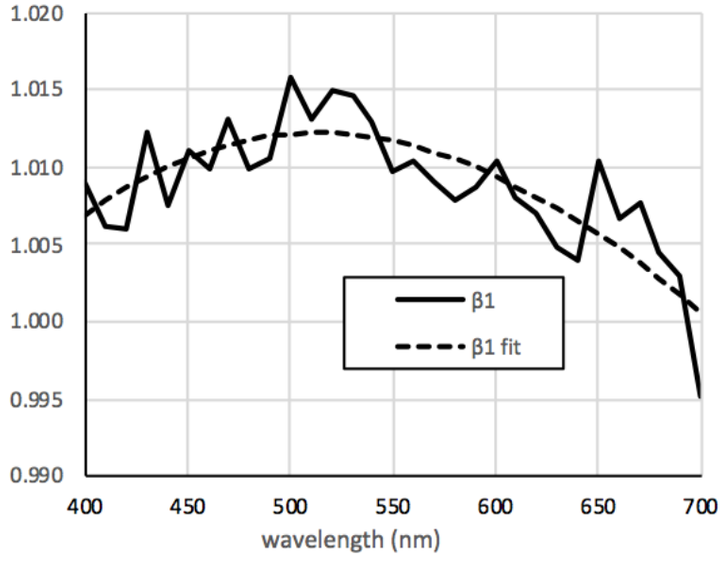
$$\begin{vmatrix} \beta_{0,\lambda} \\ \beta_{1,\lambda} \\ \beta_{2,\lambda} \end{vmatrix}$$

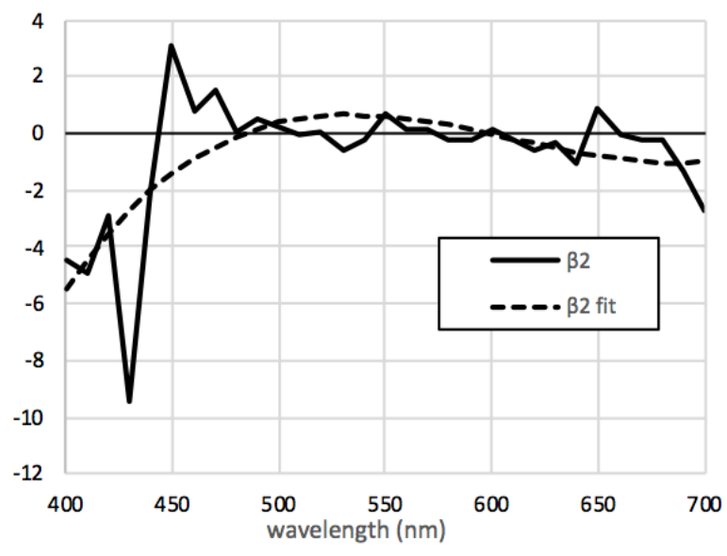
model parameters

Profiling: Model fitting

Parameterized model
Cubic polynomial fit to each spectral β parameter







Reduces number of model parameters from 93 to 12.
n = 20 samples x 31 wavelengths = 620

Profiling: Experiment

Glossy Ceramic Tile Set (20)
Diffuse sintered PTFE (20)

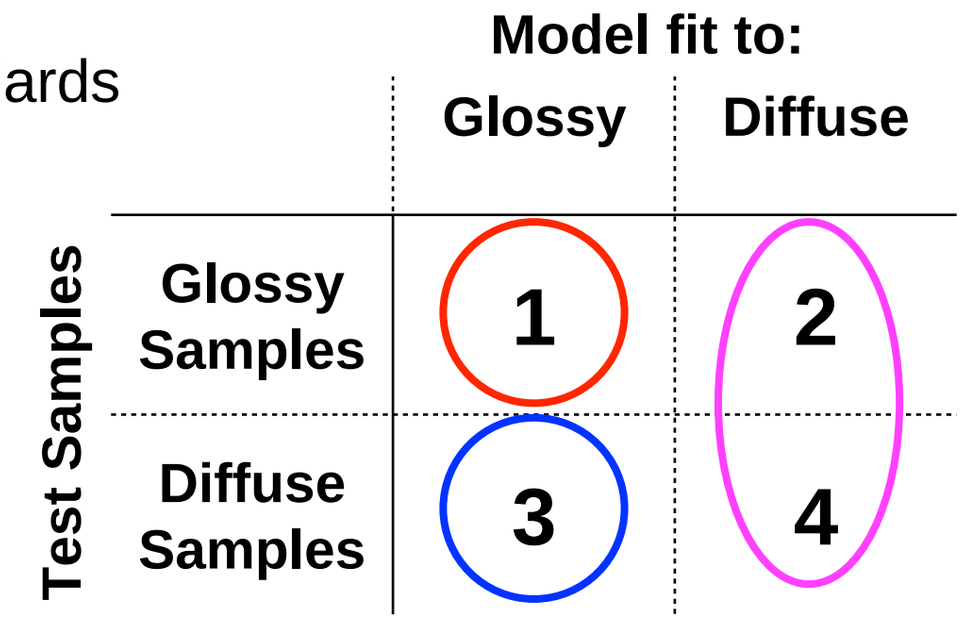
Two hemispherical instruments, d:0°. One reference, one test instrument.
Configured for specular component excluded.

Three bidirectional instruments, 45°:0°. One reference, two test instruments.
Reference and one test are larger area, overfilled geometry. One is small area, and subject to significant translucency error.

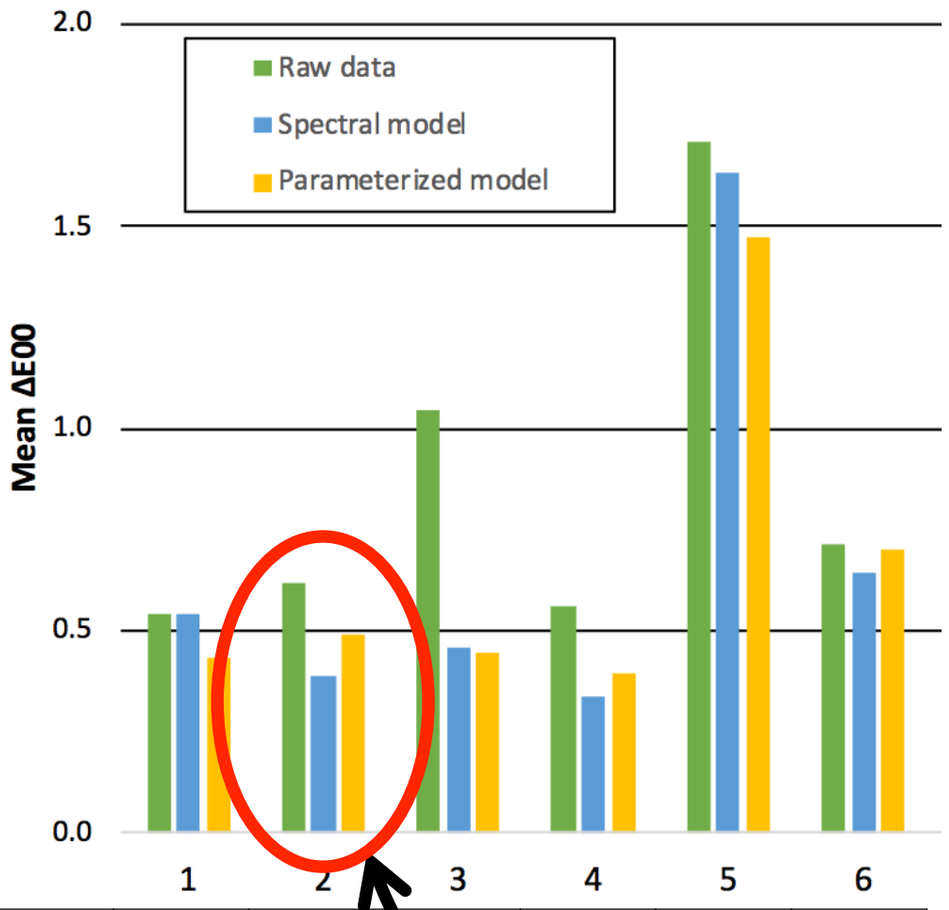
Model fitting using glossy or diffuse standards
Model application using glossy or diffuse standards

Two tests use like standards and samples (1,4)
Two test use different standards and samples (2,3)

The case we usually hear about
The case that is often applied
Diffuse standards not often used for profiling



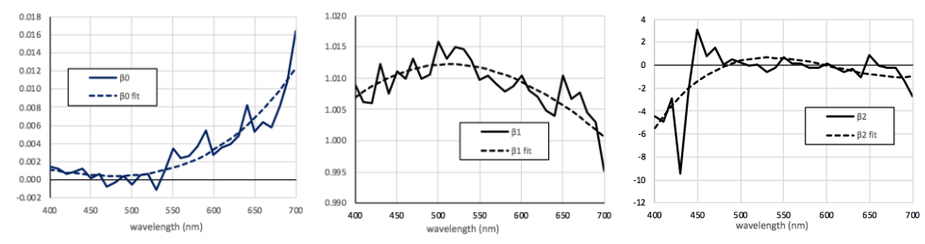
Profiling: Results



instr	45:0 (1)	45:0 (1)	d:8	d:8	45:0 (2)	45:0 (2)
	GLOSSY	MATTE	GLOSSY	MATTE	GLOSSY	MATTE

VS

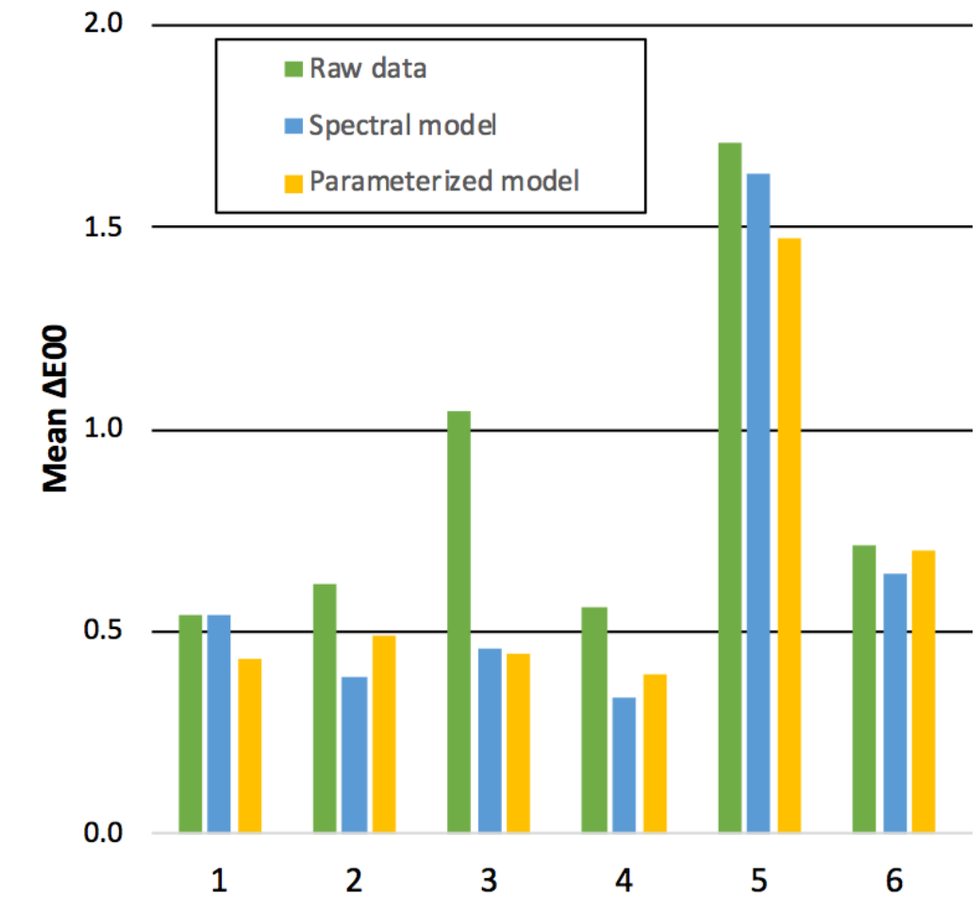
$$R_\lambda^m - R_\lambda^r = \beta_{0,\lambda} + \beta_{1,\lambda} R_\lambda^m + \beta_{2,\lambda} \frac{dR_\lambda^m}{d\lambda}$$



All plots are mean ΔE00 for the entire data set.

We “expect” behavior like this

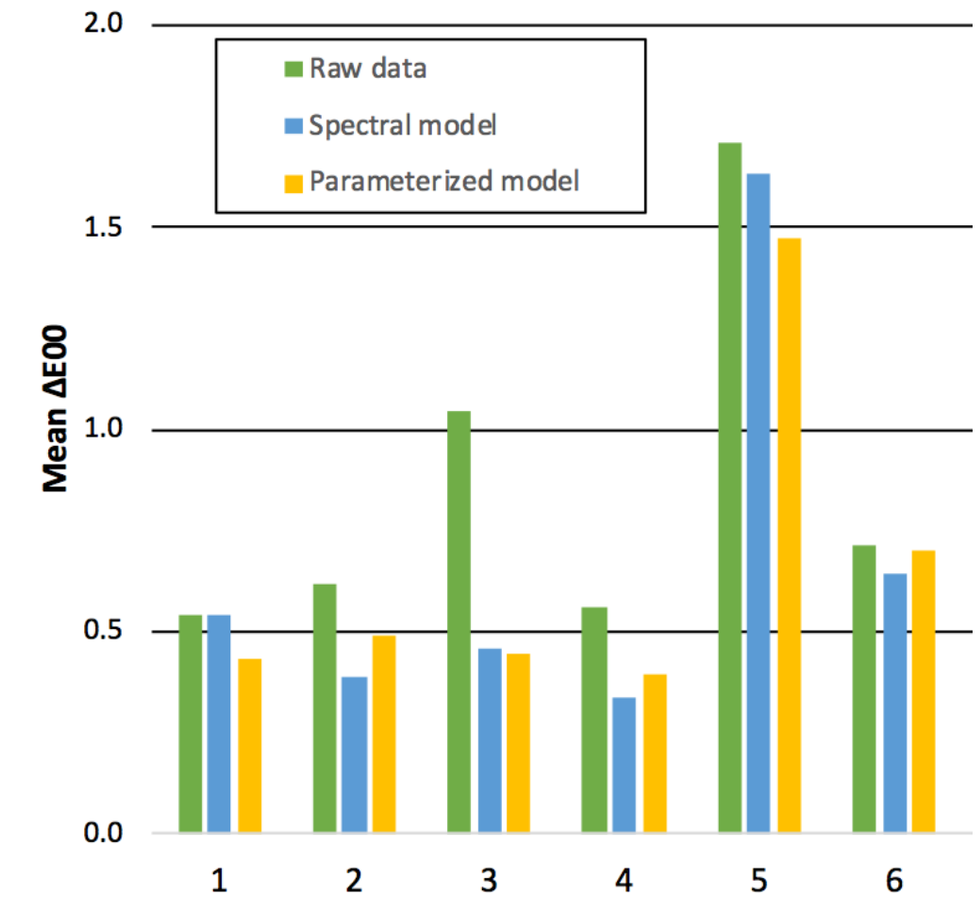
Profiling: Results



instr	45:0 (1)	45:0 (1)	d:8	d:8	45:0 (2)	45:0 (2)
	GLOSSY	MATTE	GLOSSY	MATTE	GLOSSY	MATTE

Instruments match well initially, little model improvement

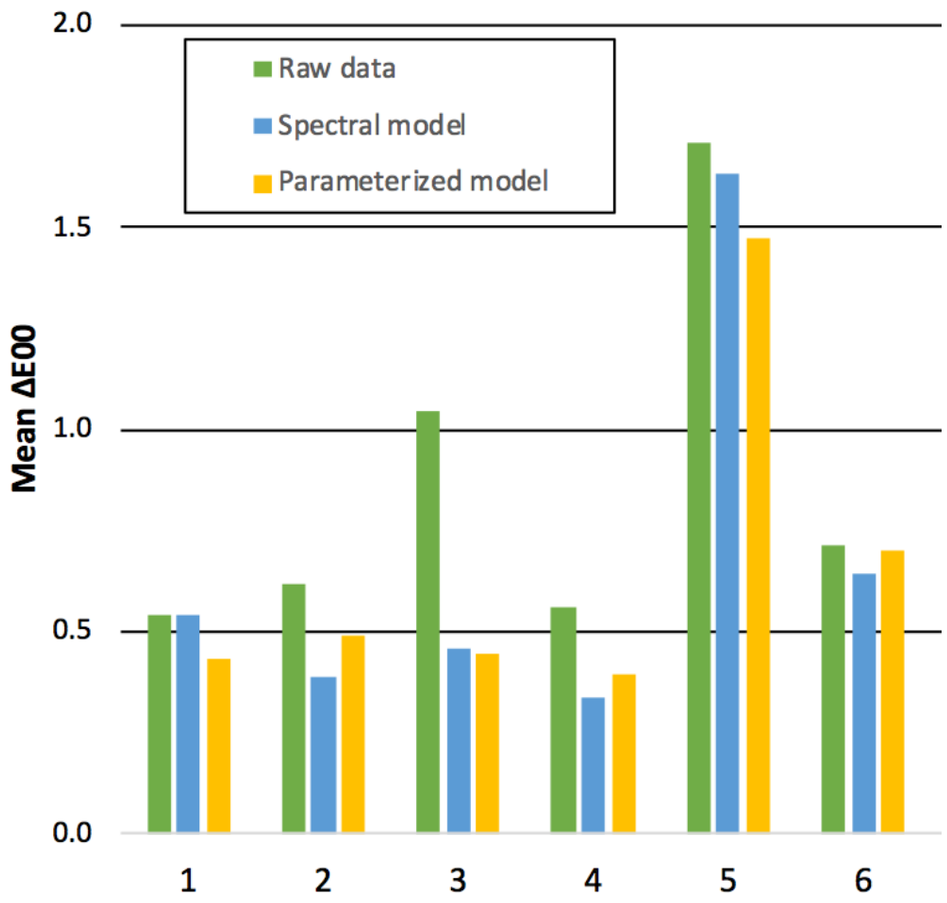
Profiling: Results



instr	45:0 (1)	45:0 (1)	d:8	d:8	45:0 (2)	45:0 (2)
	GLOSSY	MATTE	GLOSSY	MATTE	GLOSSY	MATTE

Glossy tiles improved considerably.
Matte samples less so.

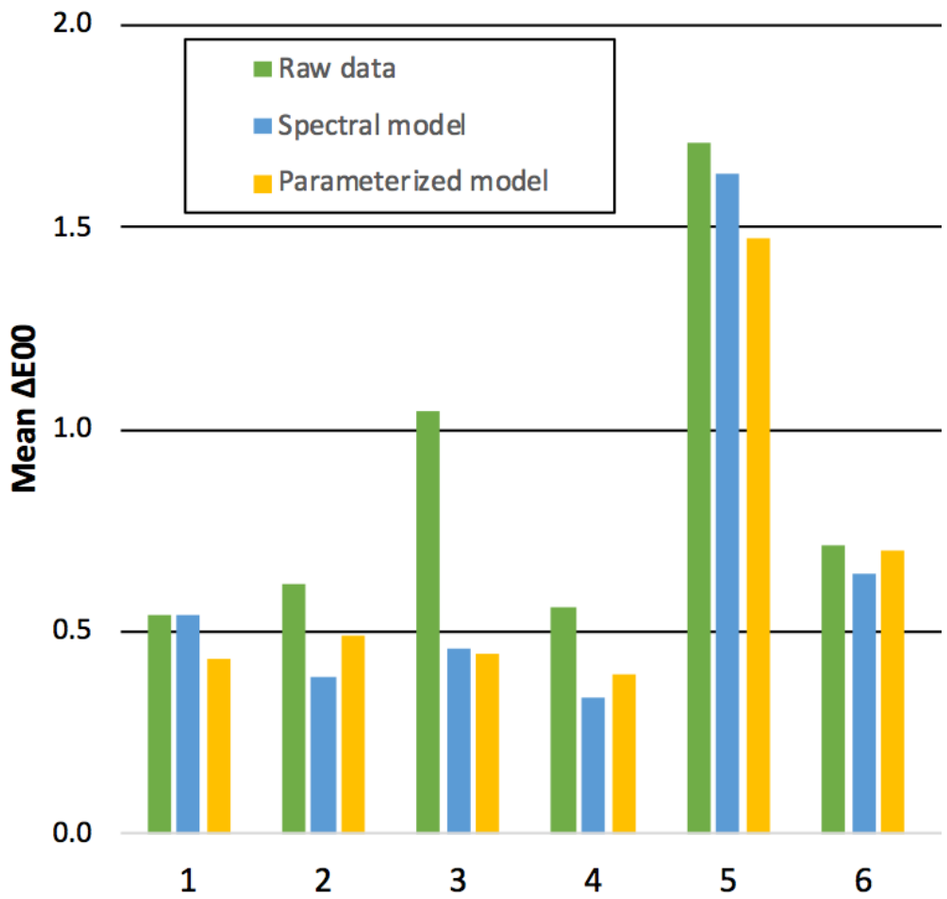
Profiling: Results



instr	45:0 (1)	45:0 (1)	d:8	d:8	45:0 (2)	45:0 (2)
	GLOSSY	MATTE	GLOSSY	MATTE	GLOSSY	MATTE

Glossy tiles hard to match (translucency?)
Matte samples are reasonable.

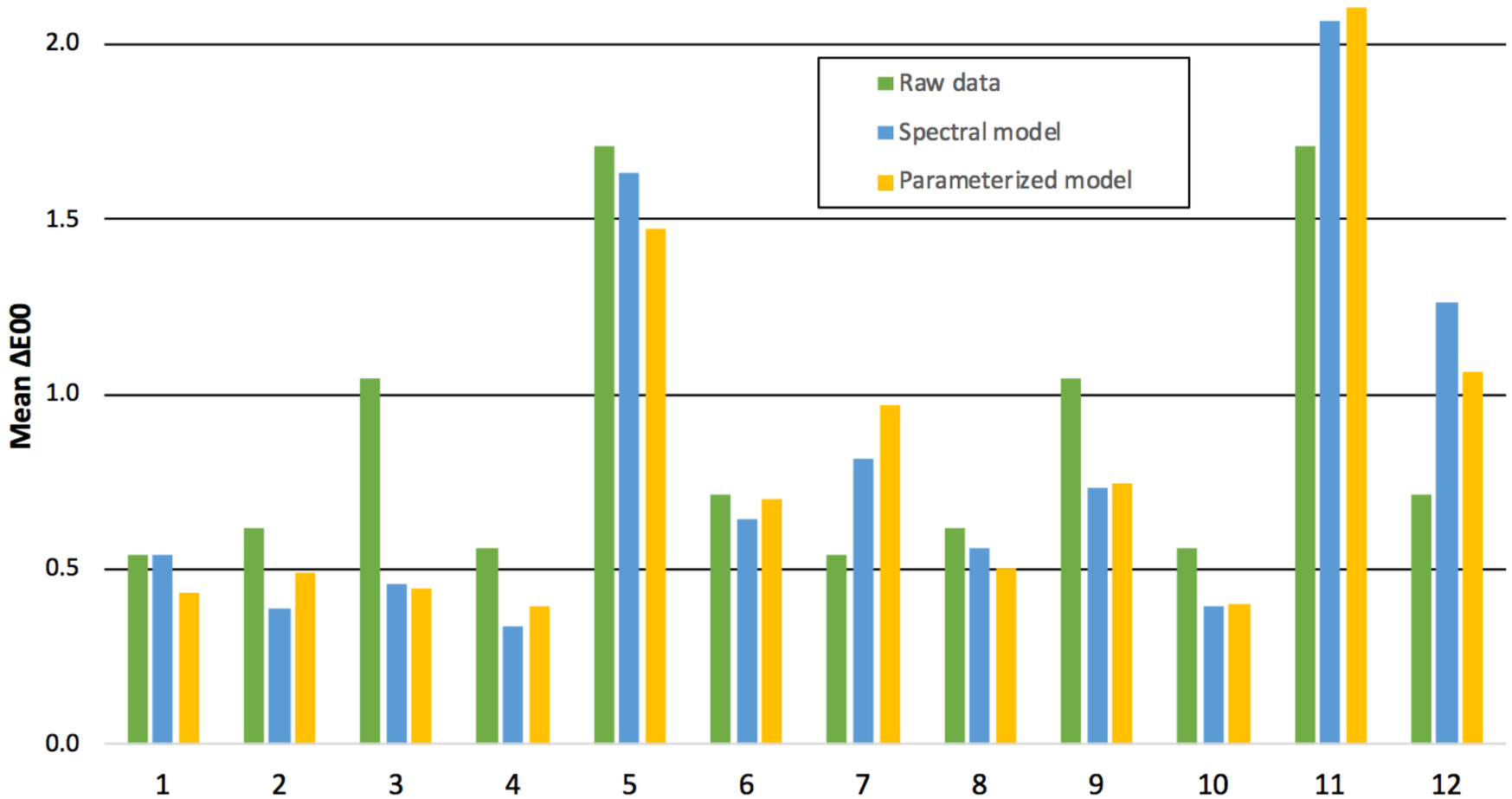
Profiling: Results



instr	45:0 (1)	45:0 (1)	d:8	d:8	45:0 (2)	45:0 (2)
	GLOSSY	MATTE	GLOSSY	MATTE	GLOSSY	MATTE

Overall matte standards profile as well or better than glossy standards.

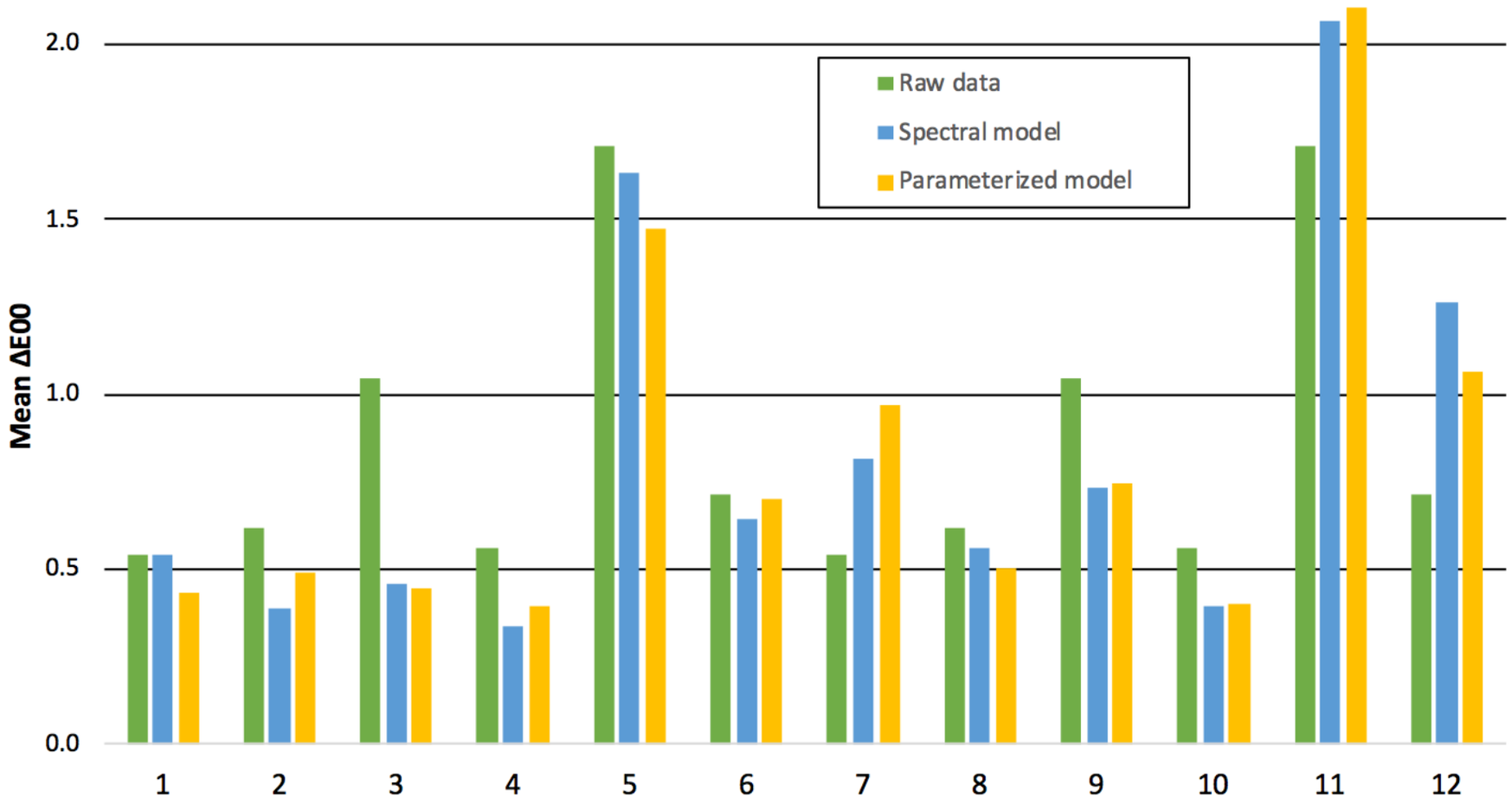
Profiling: Results



instr	45:0 (1)	45:0 (1)	d:8	d:8	45:0 (2)	45:0 (2)	45:0 (1)	45:0 (1)	d:8	d:8	45:0 (2)	45:0 (2)
model	GLOSSY	MATTE	GLOSSY	MATTE	GLOSSY	MATTE	MATTE	GLOSSY	MATTE	GLOSSY	MATTE	GLOSSY
sample	GLOSSY	MATTE	GLOSSY	MATTE	GLOSSY	MATTE	GLOSSY	MATTE	GLOSSY	MATTE	GLOSSY	MATTE

Models *degrade* performance for glossy samples when matte samples used as reference

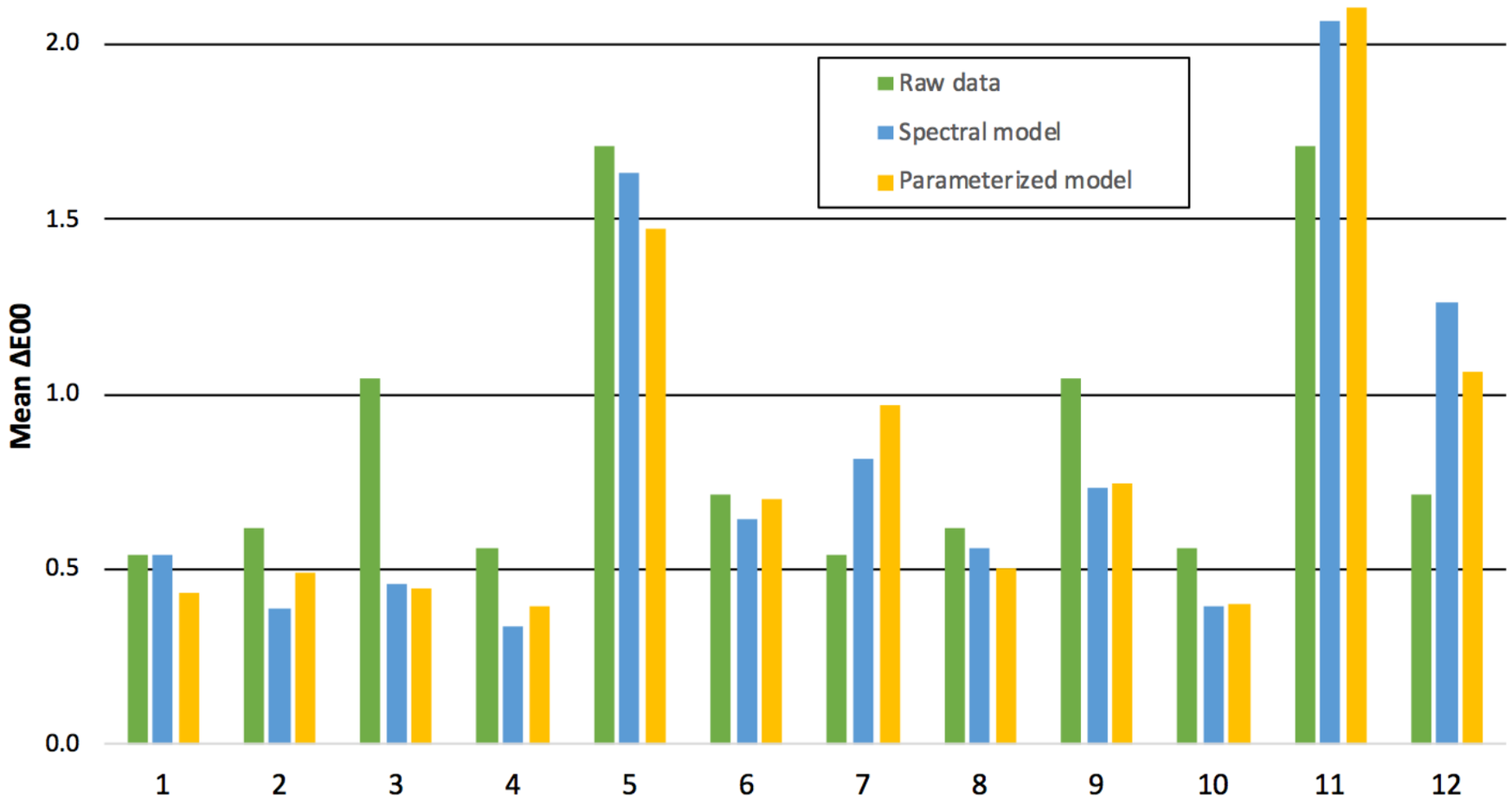
Profiling: Results



instr	45:0 (1)	45:0 (1)	d:8	d:8	45:0 (2)	45:0 (2)	45:0 (1)	45:0 (1)	d:8	d:8	45:0 (2)	45:0 (2)
model	GLOSSY	MATTE	GLOSSY	MATTE	GLOSSY	MATTE	MATTE	GLOSSY	MATTE	GLOSSY	MATTE	GLOSSY
sample	GLOSSY	MATTE	GLOSSY	MATTE	GLOSSY	MATTE	GLOSSY	MATTE	GLOSSY	MATTE	GLOSSY	MATTE

Models based on glossy standards improve performance *slightly* for matte samples.

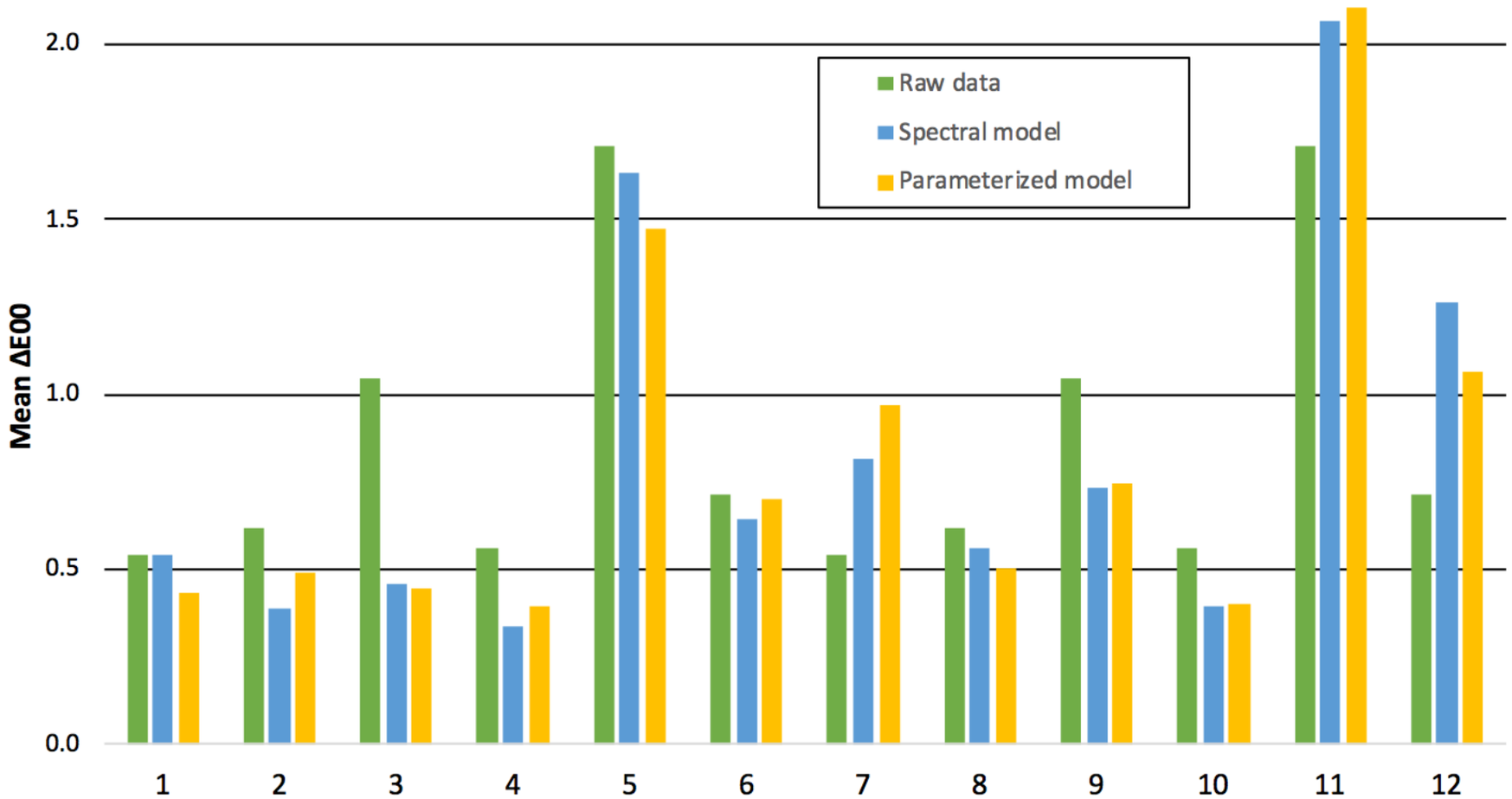
Profiling: Results



instr	45:0 (1)	45:0 (1)	d:8	d:8	45:0 (2)	45:0 (2)	45:0 (1)	45:0 (1)	d:8	d:8	45:0 (2)	45:0 (2)
model	GLOSSY	MATTE	GLOSSY	MATTE	GLOSSY	MATTE	MATTE	GLOSSY	MATTE	GLOSSY	MATTE	GLOSSY
sample	GLOSSY	MATTE	GLOSSY	MATTE	GLOSSY	MATTE	GLOSSY	MATTE	GLOSSY	MATTE	GLOSSY	MATTE

Models based on matte standards improve performance *somewhat* for glossy samples.

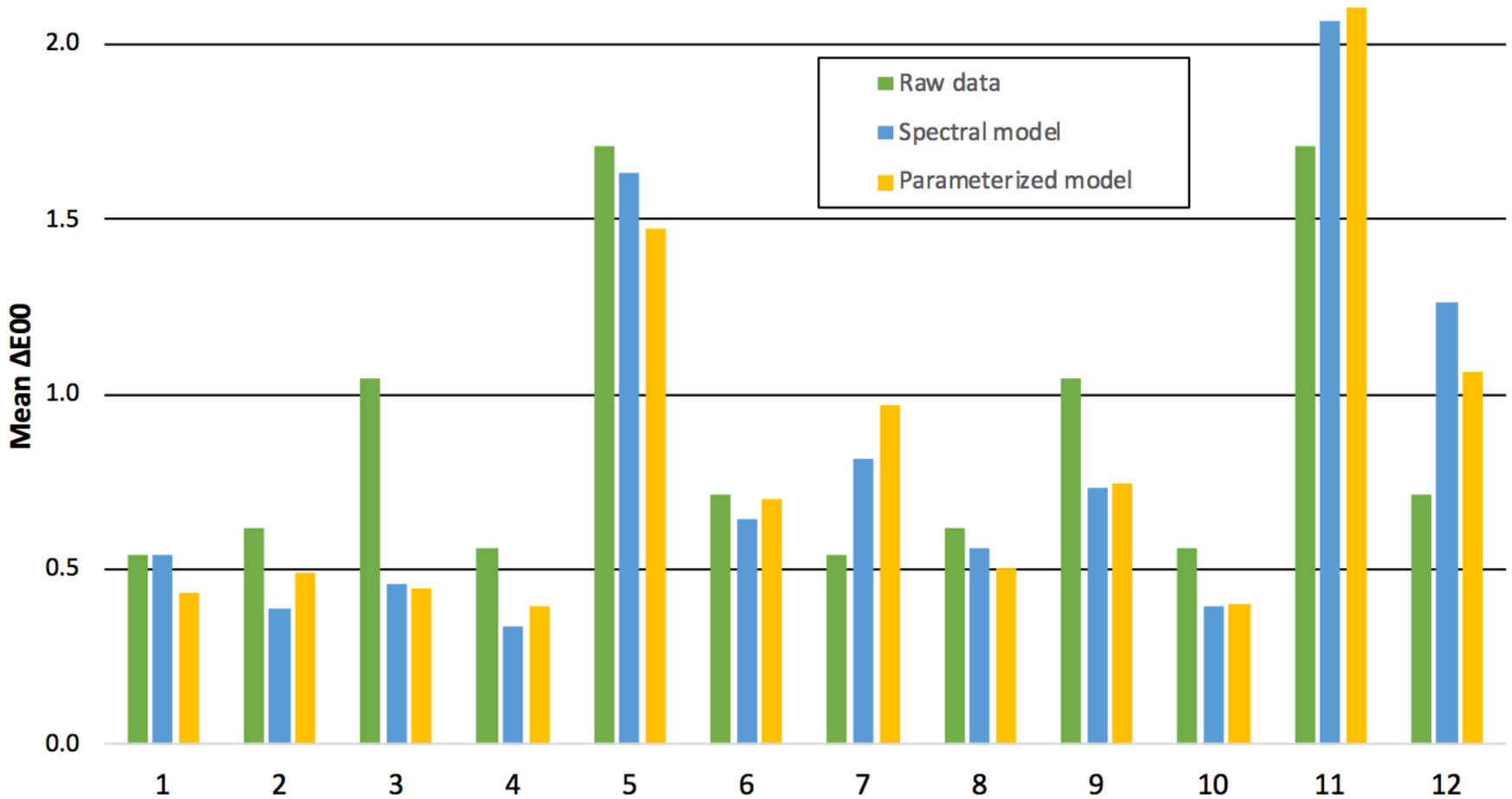
Profiling: Results



instr	45:0 (1)	45:0 (1)	d:8	d:8	45:0 (2)	45:0 (2)	45:0 (1)	45:0 (1)	d:8	d:8	45:0 (2)	45:0 (2)
model	GLOSSY	MATTE	GLOSSY	MATTE	GLOSSY	MATTE	MATTE	GLOSSY	MATTE	GLOSSY	MATTE	GLOSSY
sample	GLOSSY	MATTE	GLOSSY	MATTE	GLOSSY	MATTE	GLOSSY	MATTE	GLOSSY	MATTE	GLOSSY	MATTE

Models perform *poorly* for glossy samples when matte samples used as reference

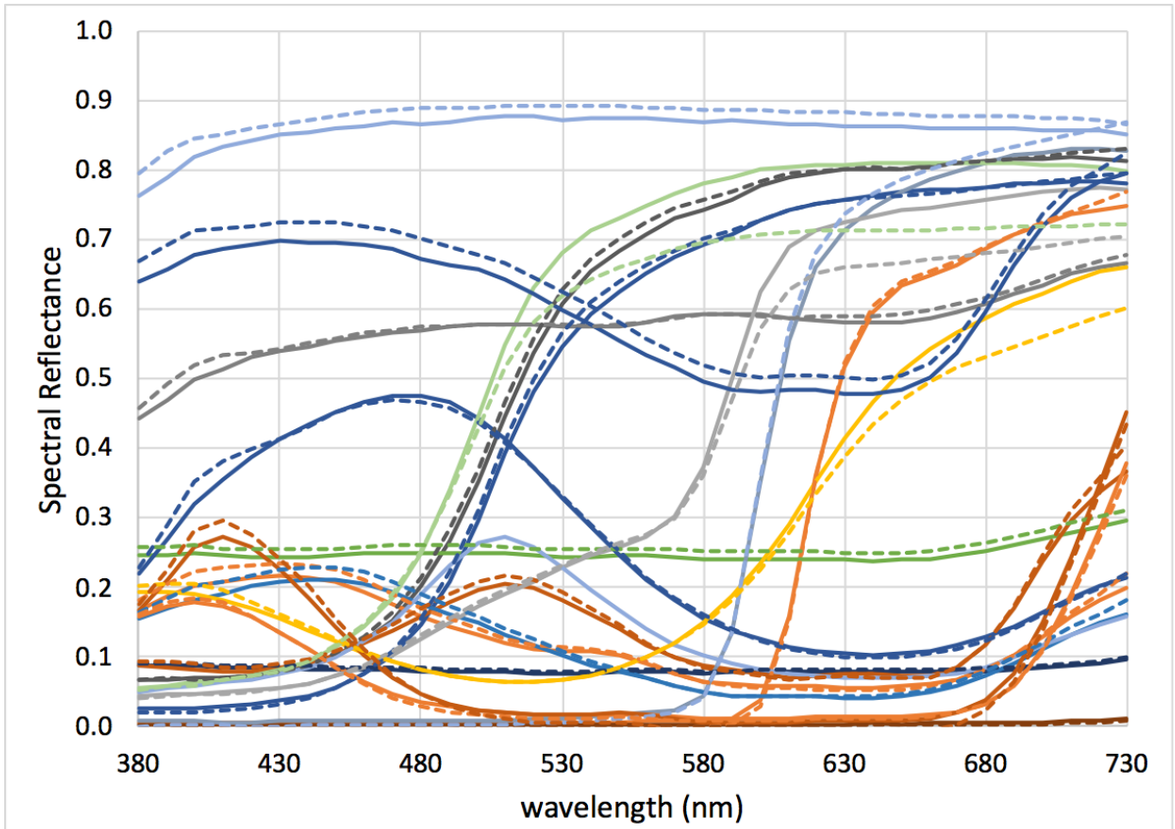
Profiling: Results



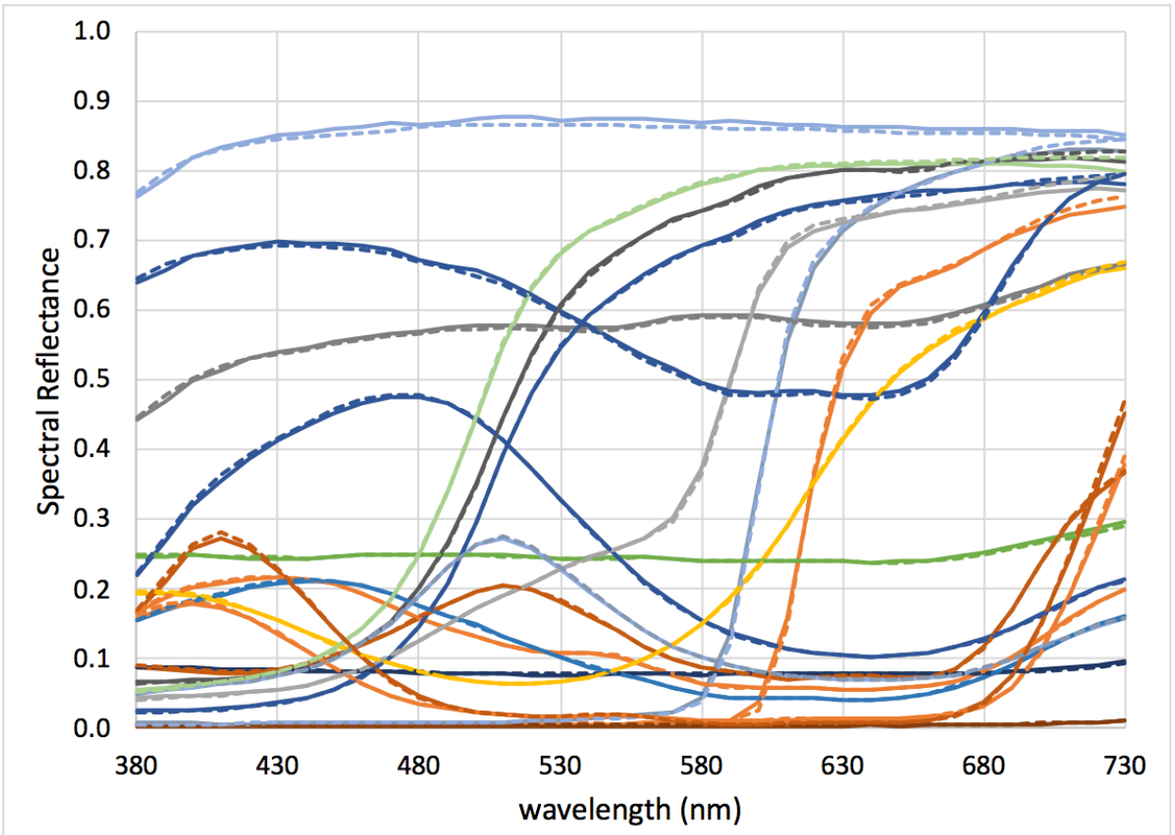
instr	45:0 (1)	45:0 (1)	d:8	d:8	45:0 (2)	45:0 (2)	45:0 (1)	45:0 (1)	d:8	d:8	45:0 (2)	45:0 (2)
model	GLOSSY	MATTE	GLOSSY	MATTE	GLOSSY	MATTE	MATTE	GLOSSY	MATTE	GLOSSY	MATTE	GLOSSY
sample	GLOSSY	MATTE	GLOSSY	MATTE	GLOSSY	MATTE	GLOSSY	MATTE	GLOSSY	MATTE	GLOSSY	MATTE

Models *degrade* performance for matte samples when glossy samples used as reference

A Tale of Two 45:0 Devices



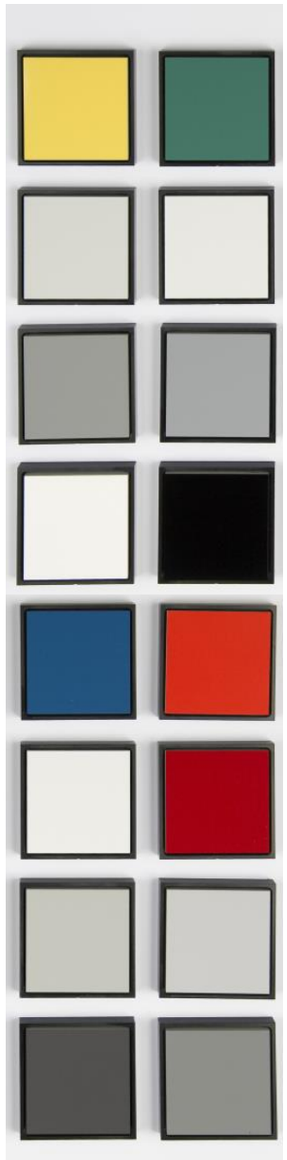
small measurement port



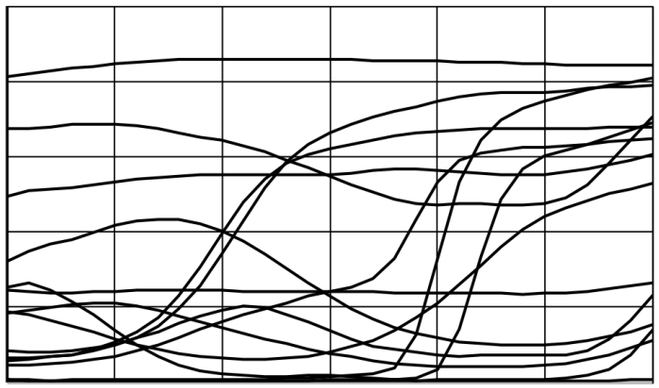
medium overfilled measurement port

Glossy sample set.
Solid lines are reference instrument.

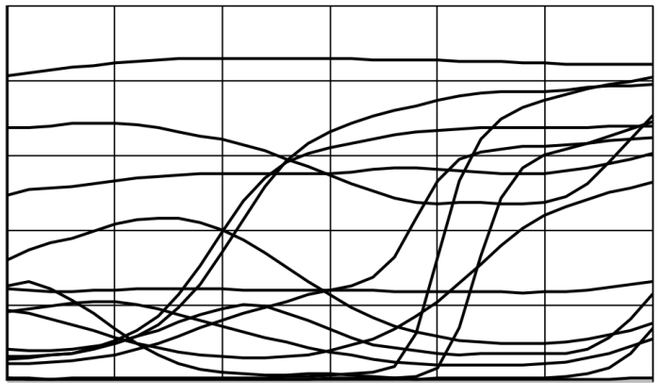
The Rabbit Hole?



reference standards
(measured on both)



reference instrument



test instrument

parameter
starting
values

optimization
engine

Which reference standards?
Which model?
Which parameters?
What starting values?

model
parameters

$$R_\lambda^m - R_\lambda^r = \beta_{0,\lambda} + \beta_{1,\lambda} R_\lambda^m + \beta_{2,\lambda} \frac{dR_\lambda^m}{d\lambda}$$

Conclusions

- Be careful with average color difference. Consider including weighted max color difference, and/or weighted RMS spectral difference.
- Small area devices may only be able to be profiled against other small area devices.
- Profiling using diffuse reference standards is useful in some cases, provided the other concerns are addressed (cleaning and handling).
- The performance of the parameterized model is quite good given its simplicity.
- The optimization is often an exercise in which verification standards you want to perform well. This is not necessarily bad if your measurement samples are consistent and similar.

Thank you

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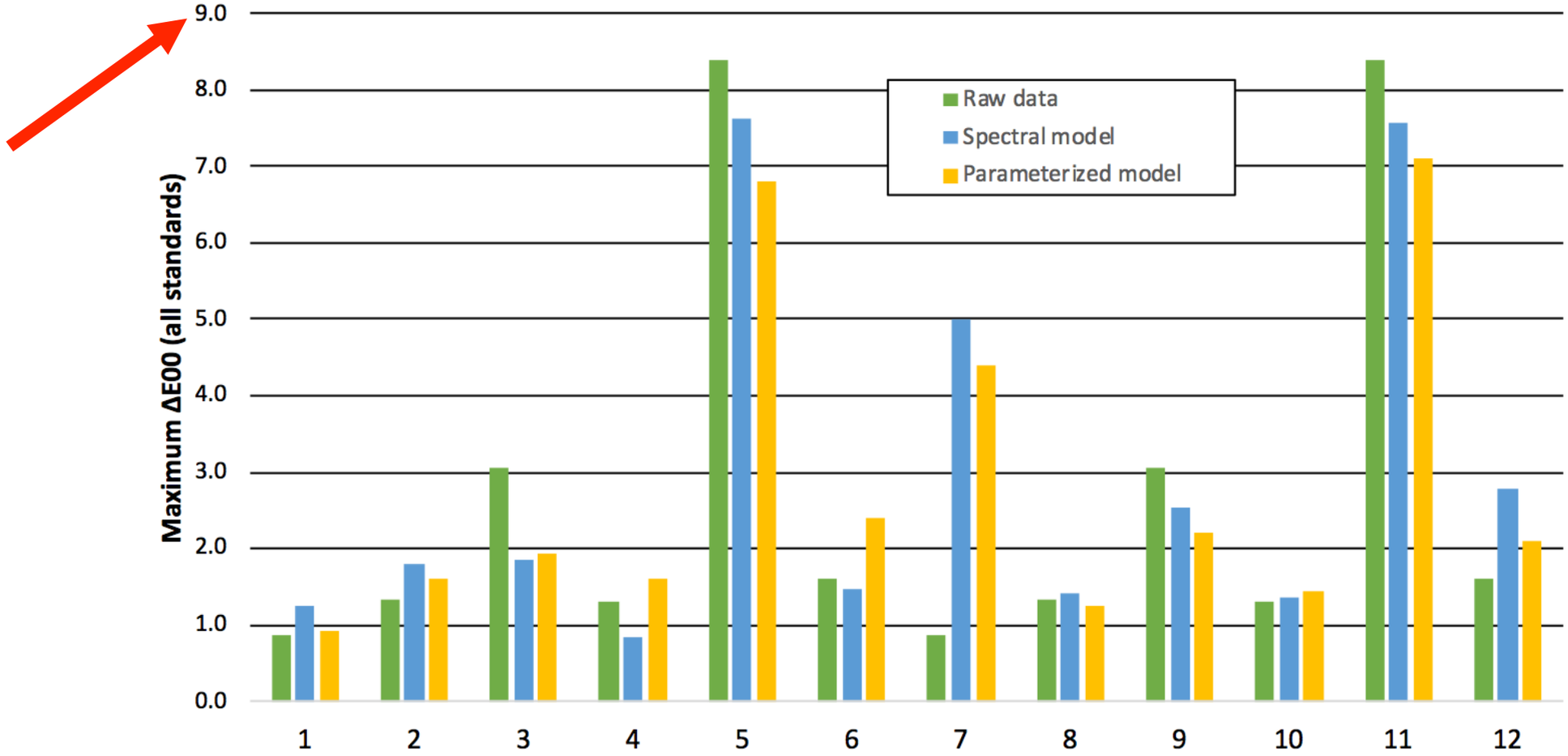
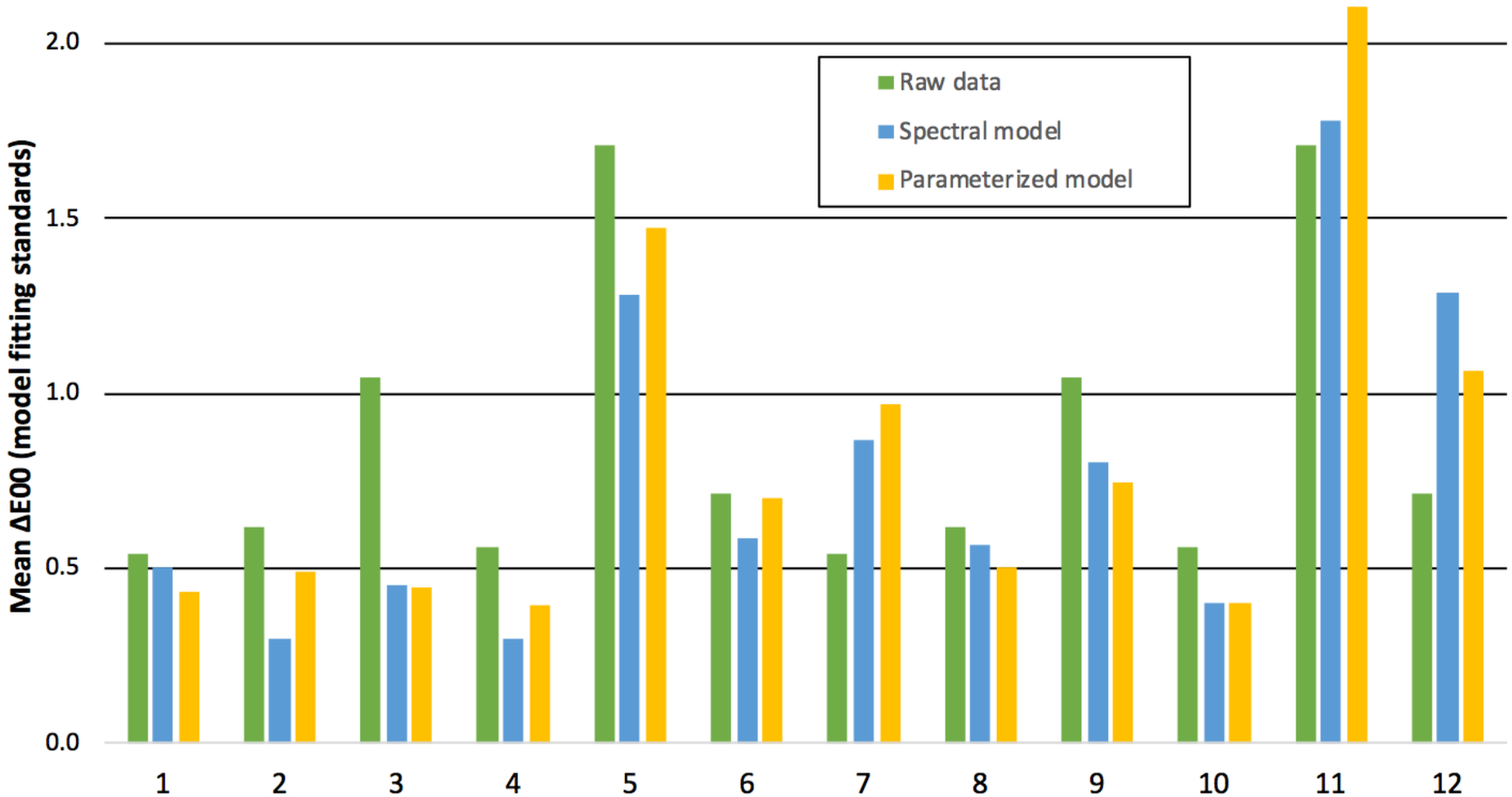
ROCHESTER

Profiling: Max ΔE00



instr	45:0 (1)	45:0 (1)	d:8	d:8	45:0 (2)	45:0 (2)	45:0 (1)	45:0 (1)	d:8	d:8	45:0 (2)	45:0 (2)
model	GLOSSY	MATTE	GLOSSY	MATTE	GLOSSY	MATTE	MATTE	GLOSSY	MATTE	GLOSSY	MATTE	GLOSSY
sample	GLOSSY	MATTE	GLOSSY	MATTE	GLOSSY	MATTE	GLOSSY	MATTE	GLOSSY	MATTE	GLOSSY	MATTE

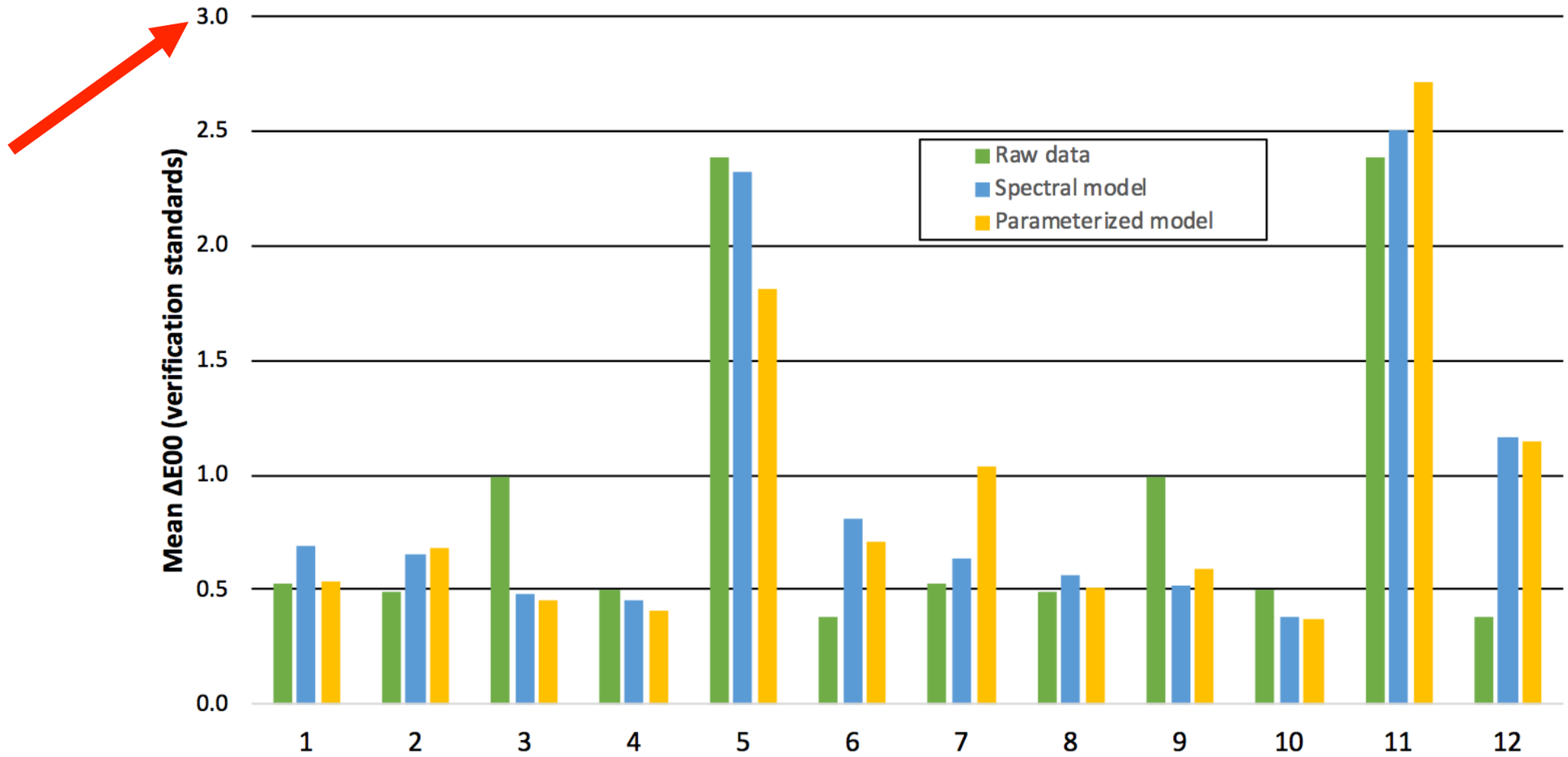
Profiling: Fitting Standards



instr	45:0 (1)	45:0 (1)	d:8	d:8	45:0 (2)	45:0 (2)	45:0 (1)	45:0 (1)	d:8	d:8	45:0 (2)	45:0 (2)
model	GLOSSY	MATTE	GLOSSY	MATTE	GLOSSY	MATTE	MATTE	GLOSSY	MATTE	GLOSSY	MATTE	GLOSSY
sample	GLOSSY	MATTE	GLOSSY	MATTE	GLOSSY	MATTE	GLOSSY	MATTE	GLOSSY	MATTE	GLOSSY	MATTE

Results from the standards used for the model fitting

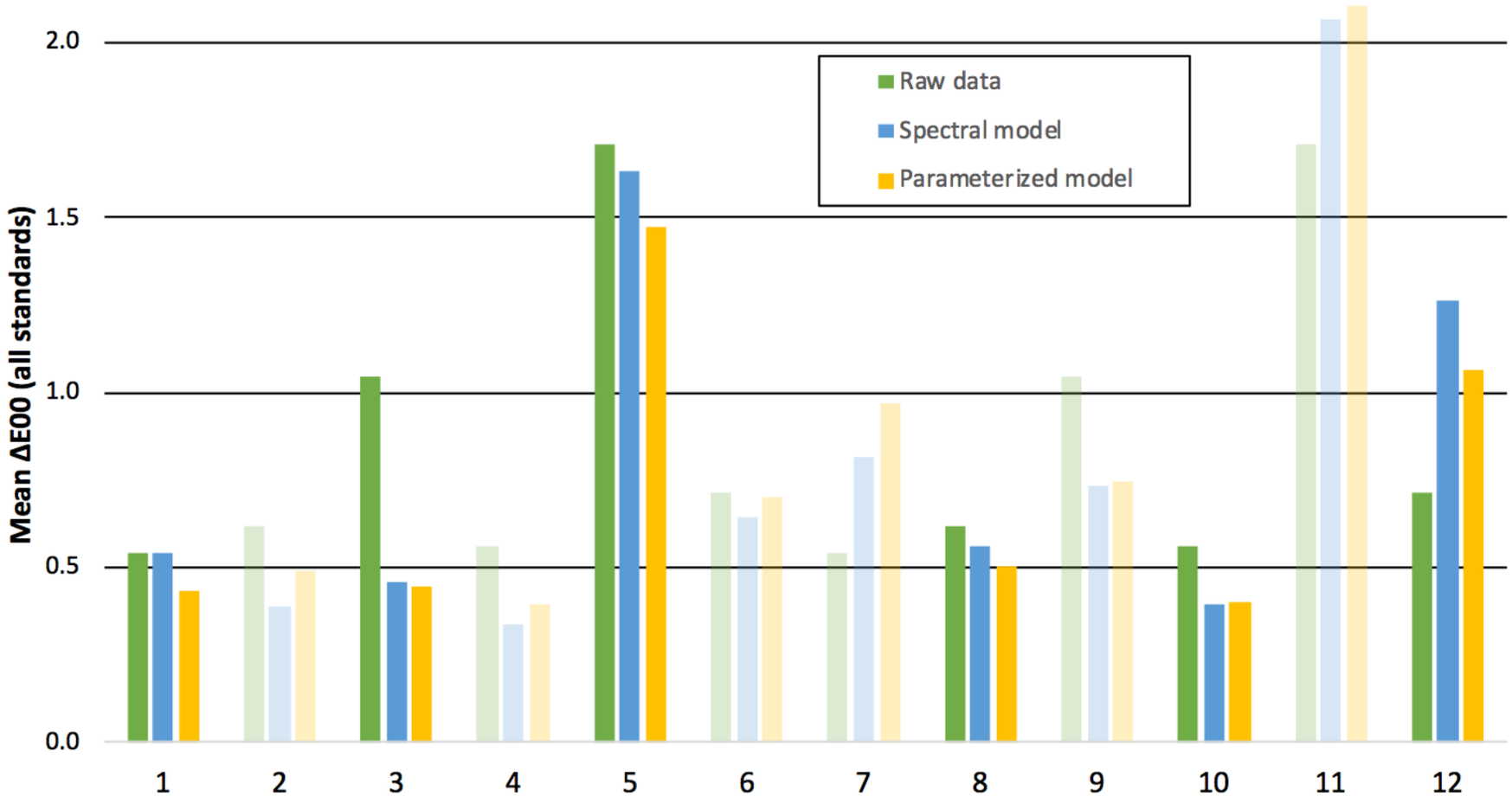
Profiling: Verification Standards



instr	45:0 (1)	45:0 (1)	d:8	d:8	45:0 (2)	45:0 (2)	45:0 (1)	45:0 (1)	d:8	d:8	45:0 (2)	45:0 (2)
model	GLOSSY	MATTE	GLOSSY	MATTE	GLOSSY	MATTE	MATTE	GLOSSY	MATTE	GLOSSY	MATTE	GLOSSY
sample	GLOSSY	MATTE	GLOSSY	MATTE	GLOSSY	MATTE	GLOSSY	MATTE	GLOSSY	MATTE	GLOSSY	MATTE

Results from the standards used for the model verification.
These were not included in the model fitting.

Profiling: Results



instr	45:0 (1)	45:0 (1)	d:8	d:8	45:0 (2)	45:0 (2)	45:0 (1)	45:0 (1)	d:8	d:8	45:0 (2)	45:0 (2)
model	GLOSSY	MATTE	GLOSSY	MATTE	GLOSSY	MATTE	MATTE	GLOSSY	MATTE	GLOSSY	MATTE	GLOSSY
sample	GLOSSY	MATTE	GLOSSY	MATTE	GLOSSY	MATTE	GLOSSY	MATTE	GLOSSY	MATTE	GLOSSY	MATTE

Most industrial applications use glossy tiles for calibration and model fitting.