

# Color Theory – Part 4

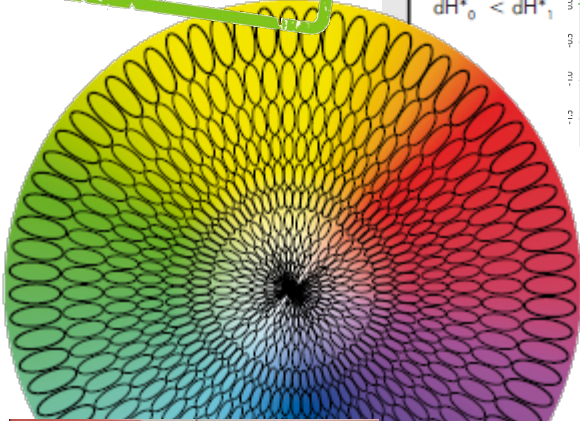
Color Tolerances

# Color Theory – Part 4

## Color Tolerances

**FAIL**

**PASS**



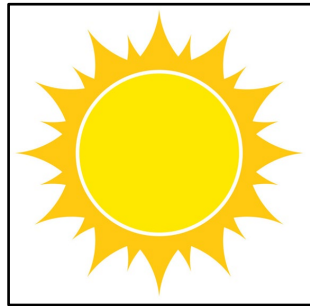
Batch Name	CIE L	CIE a	CIE b	CIE C	CIE h	Mean Date
BAT 10	70.10	25.46	63.07	68.02	68.02	66.03 27-Mar-02
BAT 11	70.28	31.38	69.65	76.39	65.75	27-Mar-02
BAT 12	71.67	28.61	66.82	72.51	66.76	27-Mar-02
BAT 13	70.17	28.89	65.74	71.81	66.27	27-Mar-02
BAT 14	70.66	28.33	65.96	71.78	66.76	27-Mar-02
BAT 15	69.87	30.24	66.24	72.82	65.46	27-Mar-02
BAT 16	70.43	28.58	66.69	72.56	66.80	27-Mar-02
BAT 17	69.25	28.73	64.01	70.16	65.83	27-Mar-02
BAT 18	71.26	30.41	66.50	73.12	65.43	27-Mar-02
BAT 19	70.42	29.27	65.73	73.95	66.06	27-Mar-02
BAT 2	69.86	30.30	66.60	73.17	65.54	27-Mar-02
BAT 20	71.26	29.48	67.34	73.52	66.36	27-Mar-02

Tolerance	Illuminant	Parameter	Value	P/F
CieLab	D65 10	CIE DE P/F Tol.	1.00	Fail

# Review - A Colorimetric Description

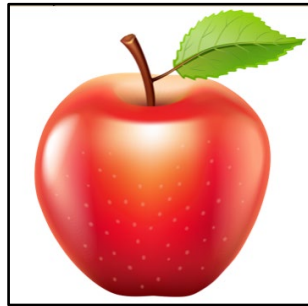
*Defining a numerical system for color perception*

We have described the visual color perception process by showing how the light source, object and observer are together responsible for color perception.



Natural Daylight

**X**



Object (Apple)

**X**

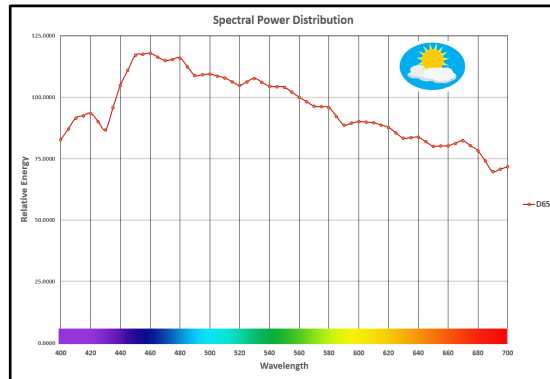


Human Observer

**=**

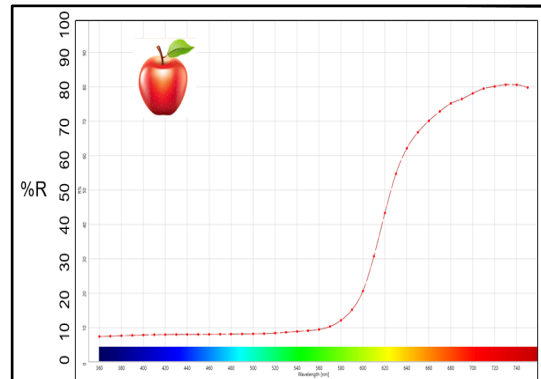
**Color Perception**

With the Standard Observer, we can now develop a numerical specification:



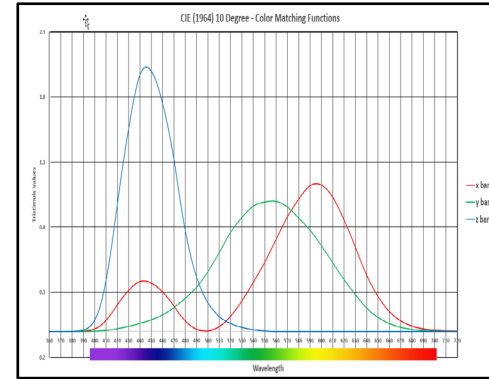
Daylight Illuminant  
Numerical Data

**X**



Reflectance Curve  
Numerical Data

**X**



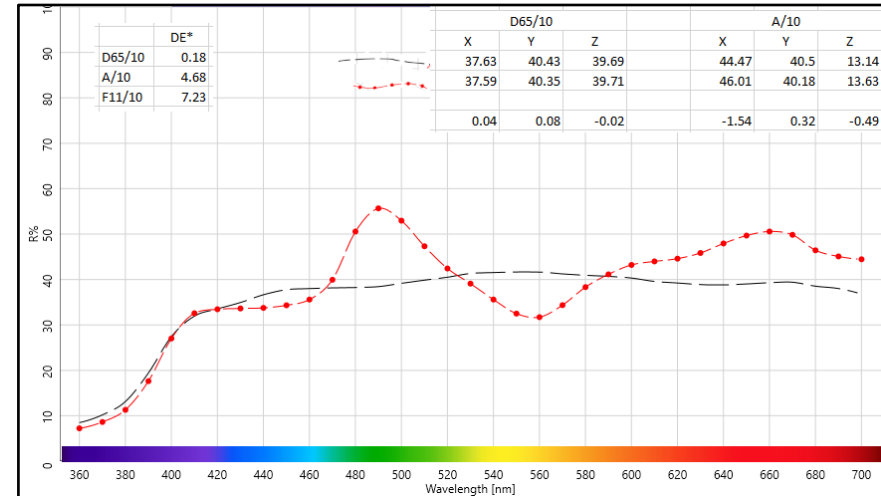
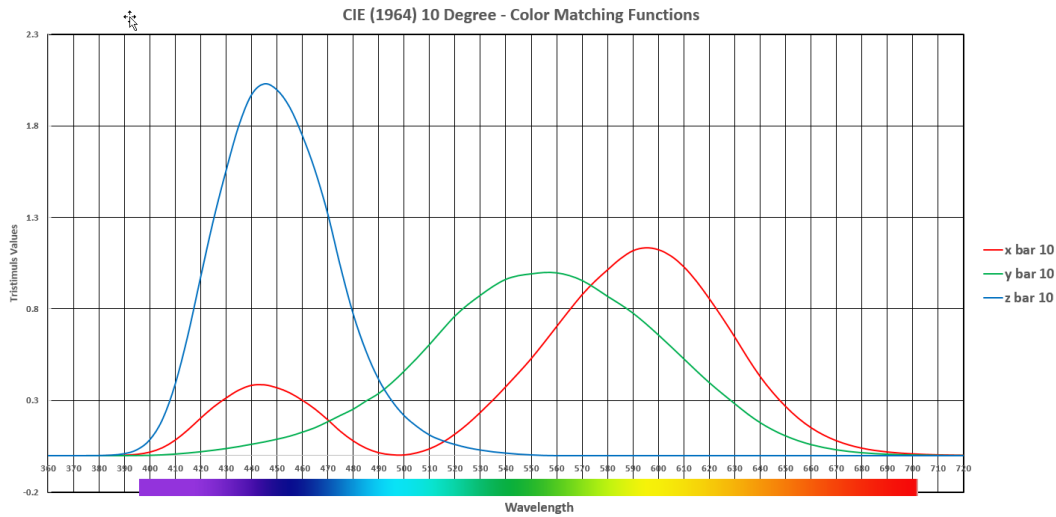
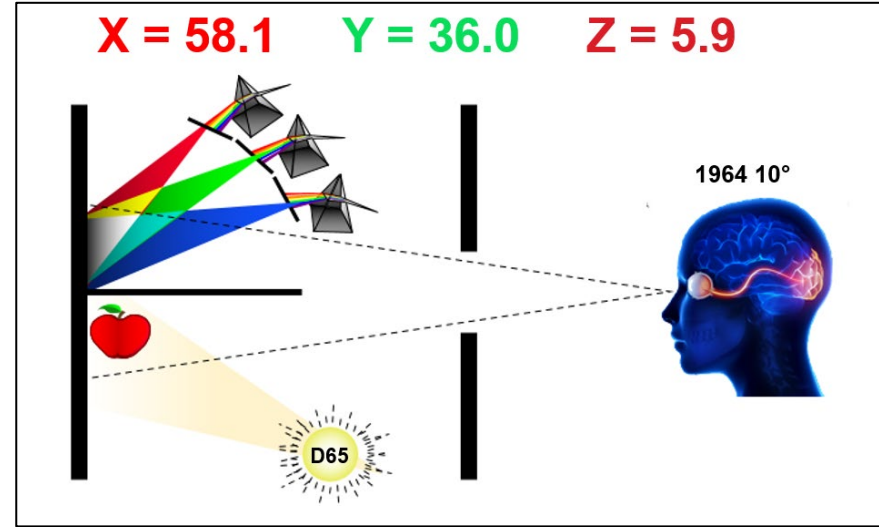
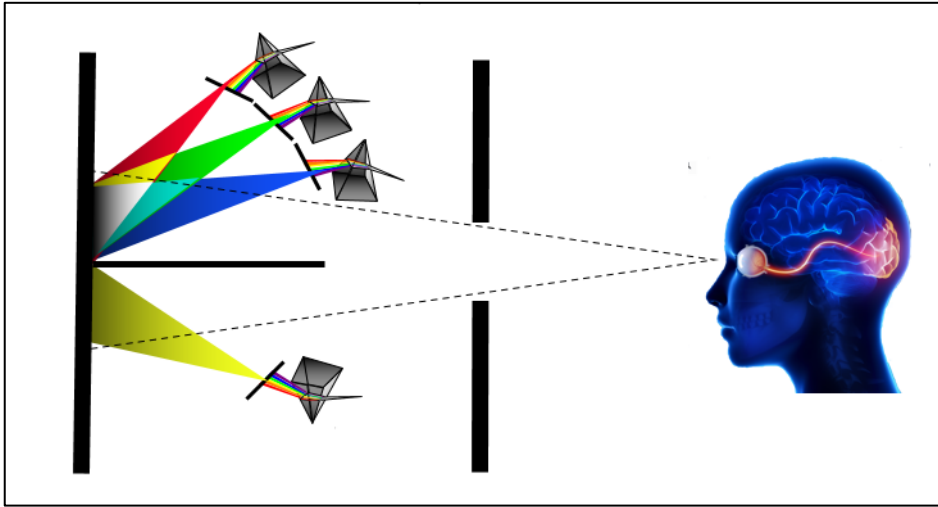
CIE Standard Observer  
Numerical Data

**=**

**Colorimetric Description**

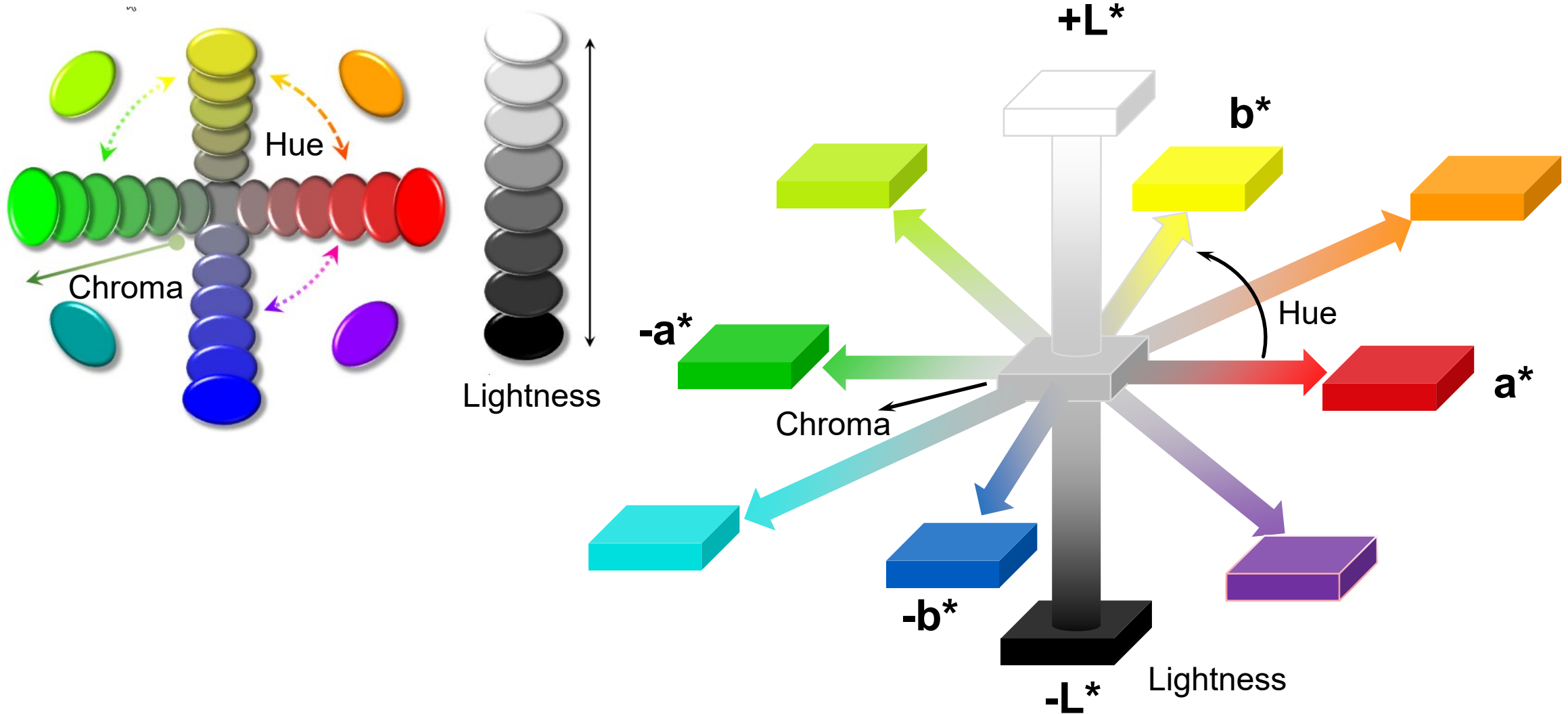
# Review

## Standard Observer / Metamerism



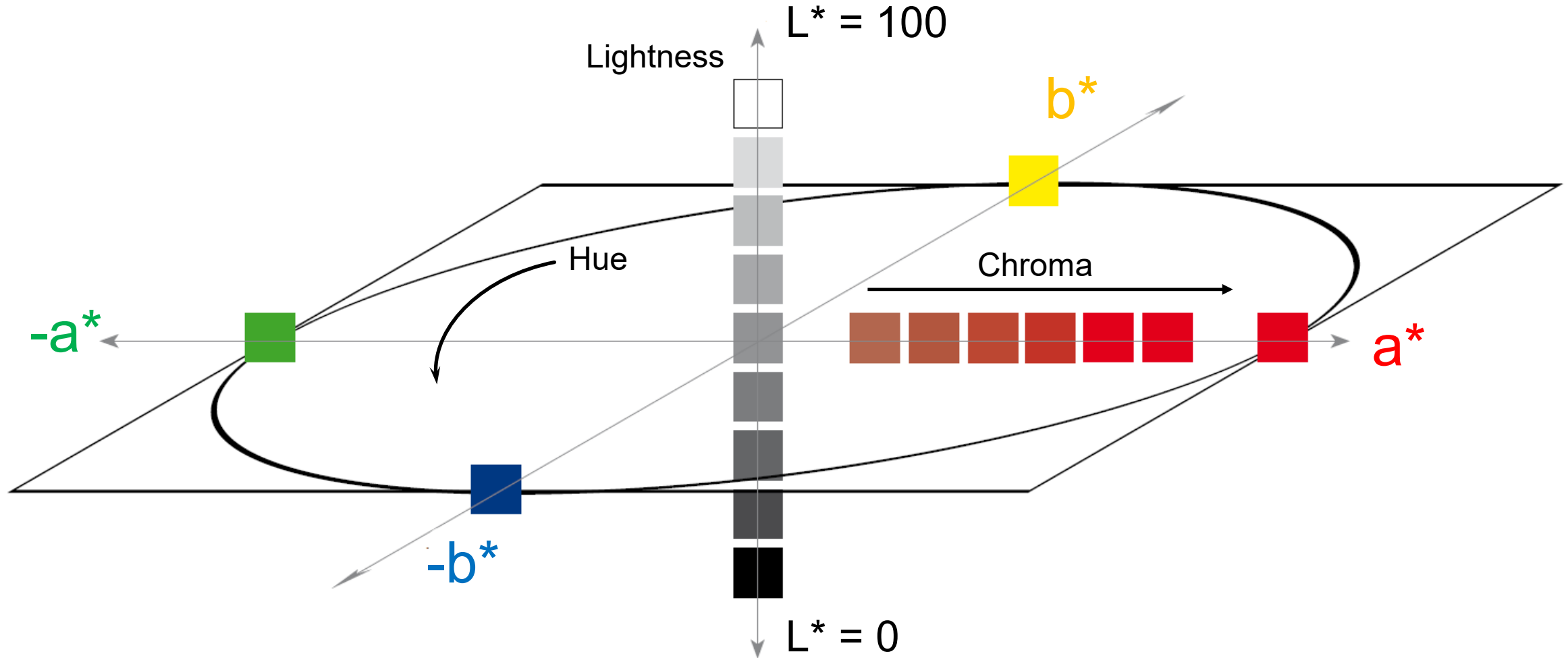
# Review - CIELAB

## 3 Dimensions of Color – Hue, Chroma, Lightness



# Review - CIELAB

CIE  $L^*a^*b^*$  Color Space

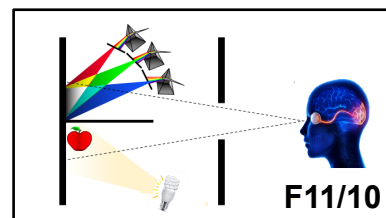
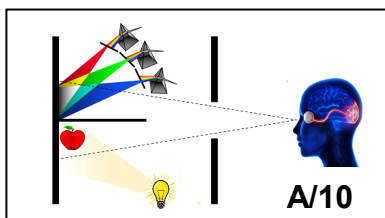
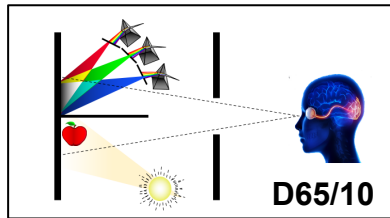


# Review - CIELAB Color Difference

Red Apple 1 and Red Apple 2



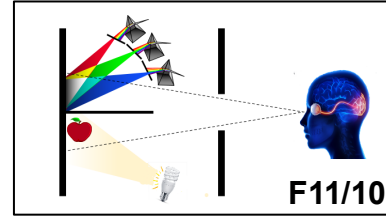
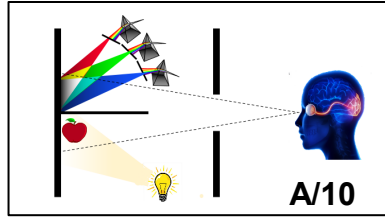
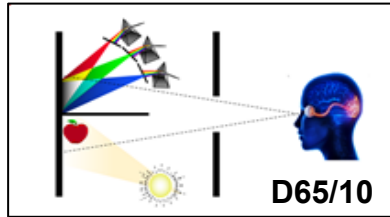
Red Apple 1



Current Illumi	Std. Name	Std. CIE X	Std. CIE Y	Std. CIE Z	Std. CIE L	Std. CIE a	Std. CIE b	Std. CIE C	Std. CIE h
D65 10 Deg	Red Apple 1	21.65	13.60	9.29	43.65	48.50	14.38	50.58	16.51
A 10 Deg		34.21	18.83	3.06	50.49	51.01	26.02	57.26	27.03
F11 10 Deg		26.83	15.91	5.58	46.86	47.48	20.42	51.68	23.27



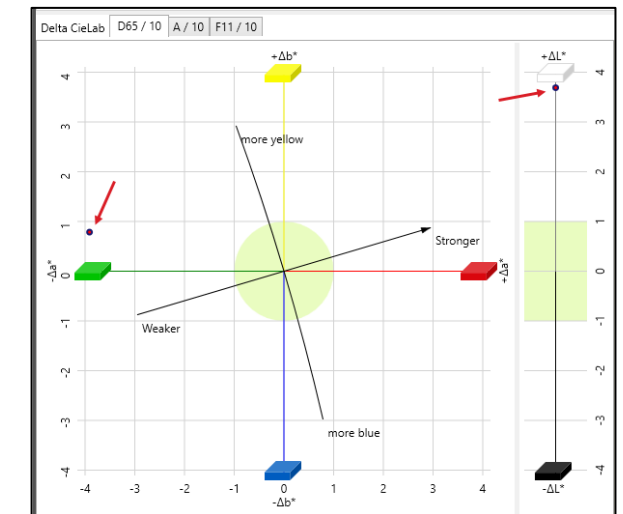
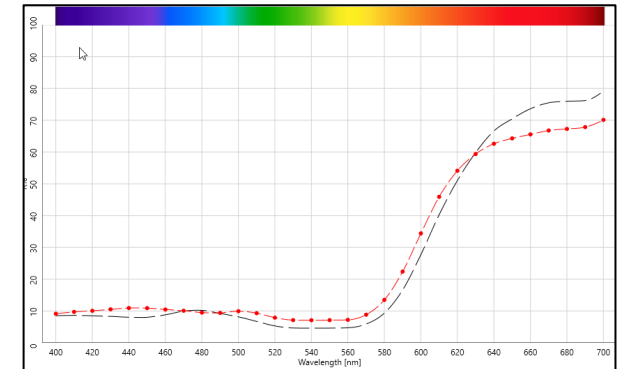
Red Apple 2



Current Illumi	Batch Name	Batch CIE X	Batch CIE Y	Batch CIE Z	Batch CIE L	Batch CIE a	Batch CIE b	Batch CIE C	Batch CIE h
D65 10 Deg	Red Apple 2	24.30	16.28	11.16	47.34	44.58	15.16	47.09	18.78
A 10 Deg		37.04	21.62	3.62	53.62	46.57	26.30	53.49	29.45
F11 10 Deg		30.77	19.11	6.90	50.82	45.29	20.79	49.84	24.66

CIELAB Color Difference – DL\*, Da\*, Db\*, DC\*, DH\*, DE\*

Current Illumi	Batch Name	CIE DL	CIE Da	CIE Db	CIE DC	CIE DH	CIE DE
D65 10 Deg	Red Apple 2	3.69	-3.92	0.78	-3.50	1.93	5.44
A 10 Deg		3.13	-4.44	0.28	-3.78	2.34	5.44
F11 10 Deg		3.96	-2.19	0.37	-1.85	1.23	4.54



# Update - Color Difference

CIELAB Polar Coordinates –  $DL^*$ ,  $DC^*$ ,  $DH^*$

$$C^* = (a^{*2} + b^{*2})^{1/2}$$

$$h = \tan^{-1} (b^*/a^*)$$

$$DL^* = L^*_{BAT} - L^*_{STD}$$

( + is lighter )  
( - is darker )

$$DC^* = C^*_{BAT} - C^*_{STD}$$

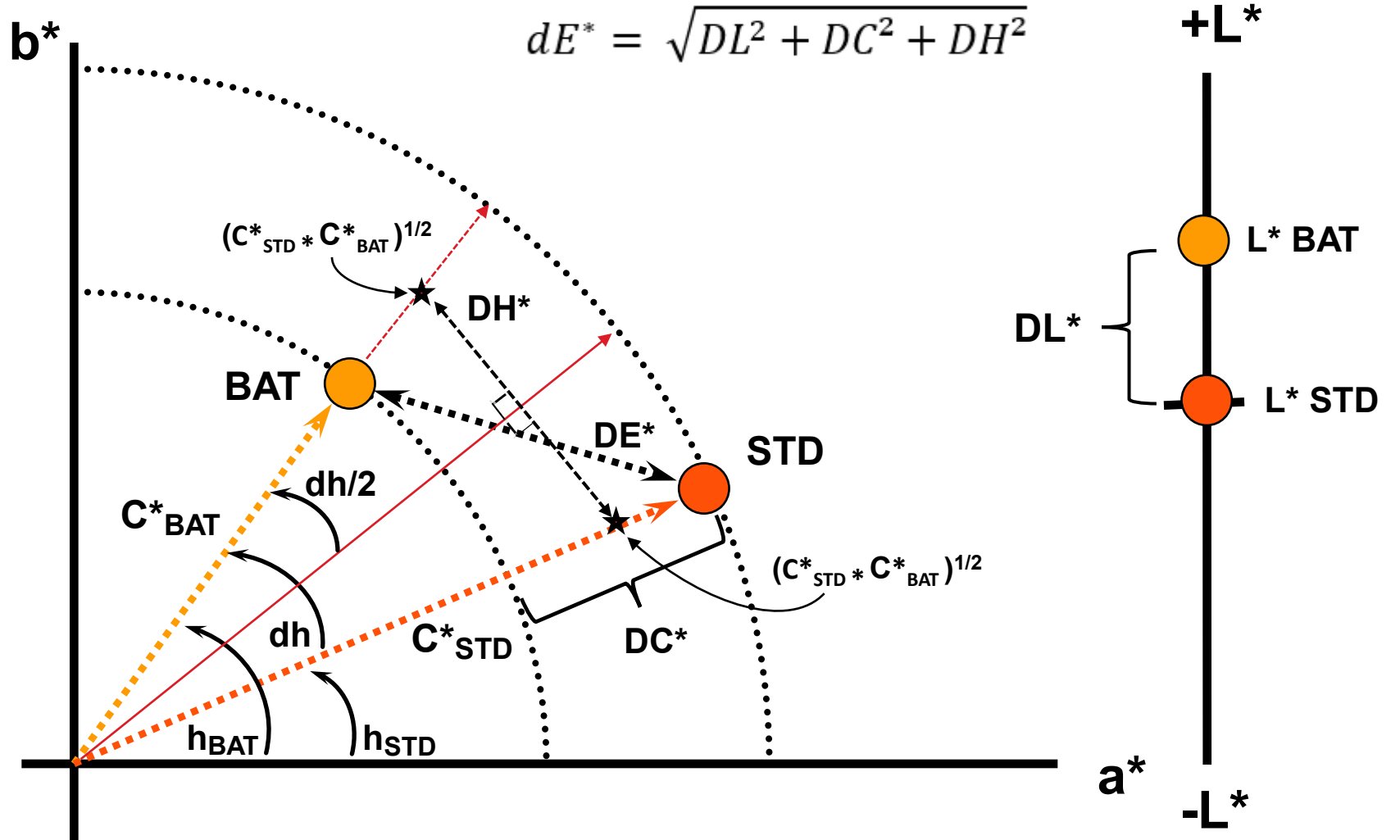
( + is more chroma )  
( - is less chroma )

$$dh = h_{BAT} - h_{STD}$$

$$DH^* = 2(C^*_{STD} * C^*_{BAT})^{1/2} \sin (dh/2)$$

( + is counter-clockwise )

$$DE^* = (DL^2 + DC^2 + DH^2)^{1/2}$$





# Color Tolerances

## *Acceptability versus Perceptibility*

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Perceptibility defines a just-noticeable difference between a standard and a batch.

Acceptability is the largest acceptable difference between a standard and a batch.

Color tolerances are the colorimetric limits that define when a product is acceptable.

Realistic tolerances are usually based on the maximum acceptable color difference rather than on a minimum perceptible difference.

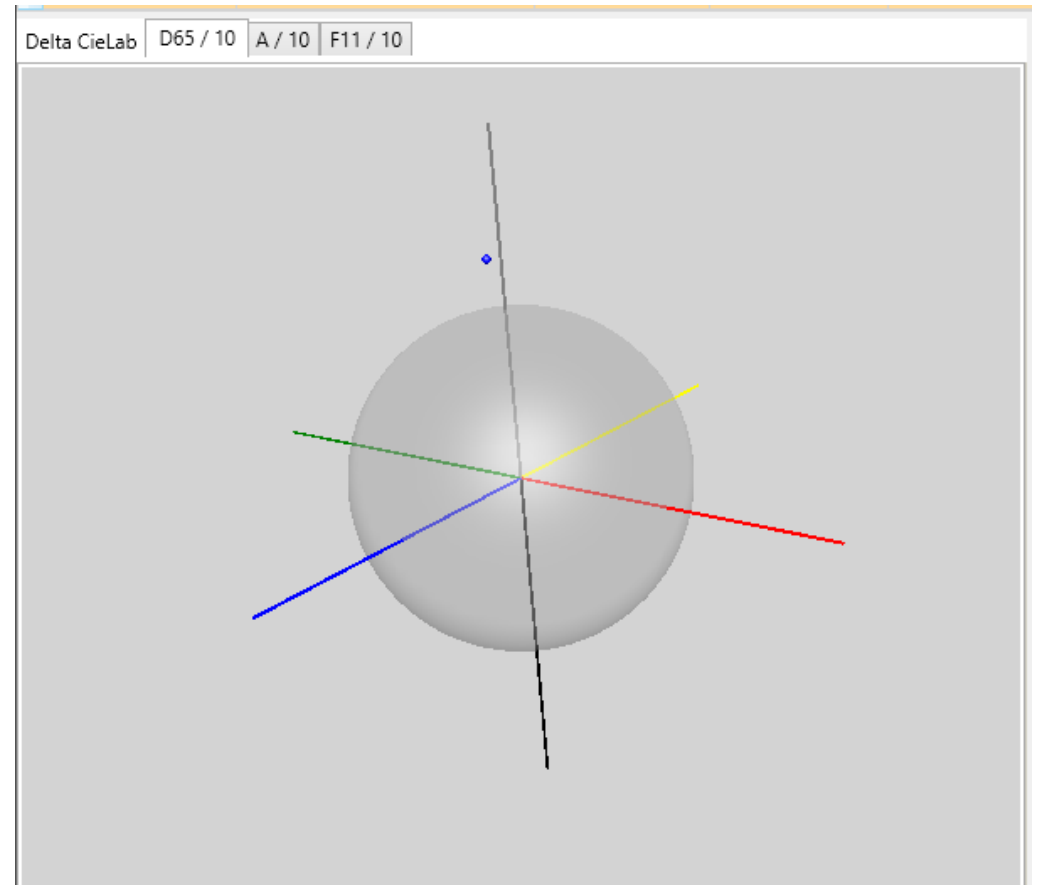
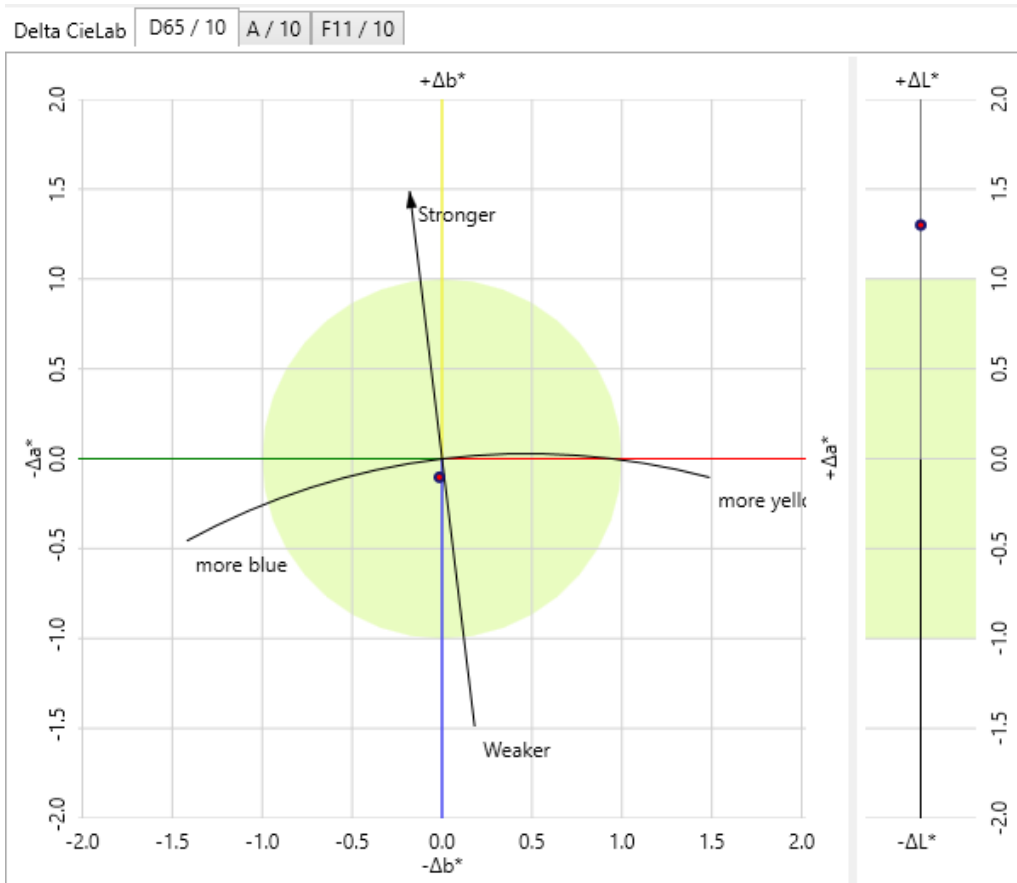
A color tolerance is the amount of color difference or variation that is commercially acceptable.

Color tolerances will vary across industries. A good tolerance represents a compromise between the capability of the process and the customer's requirements.

# DE\* Tolerance

Defines a Sphere in CIELAB Color Space

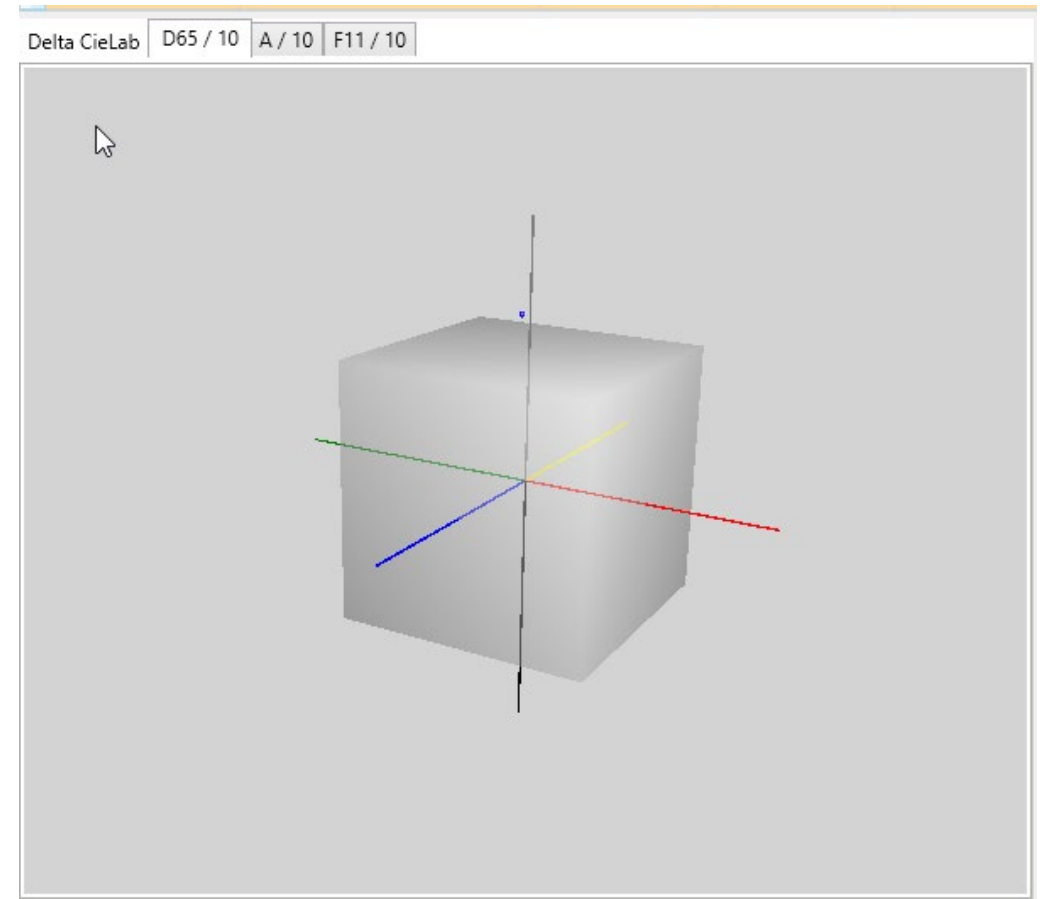
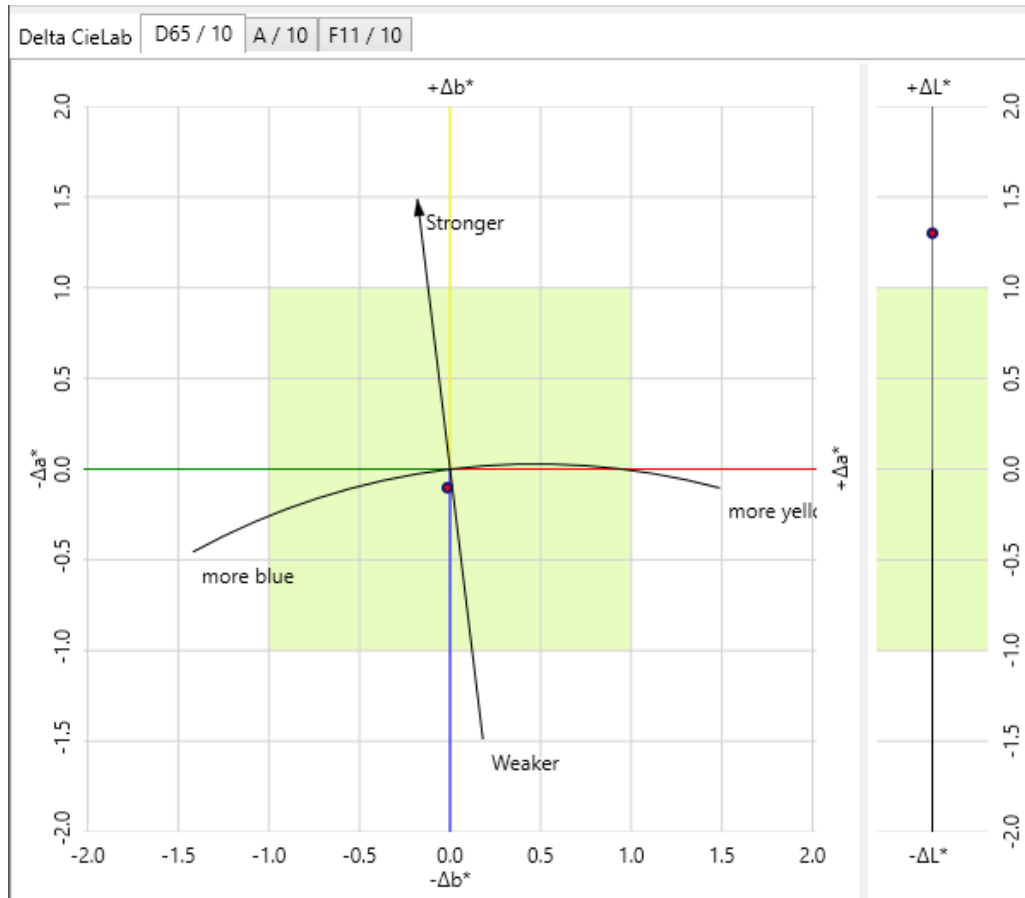
DE\* tolerance of 1.0 defines a sphere with a radius of 1.0 CIELAB Units.



# DE\* Tolerance

*Defines a Box in CIELAB Color Space*

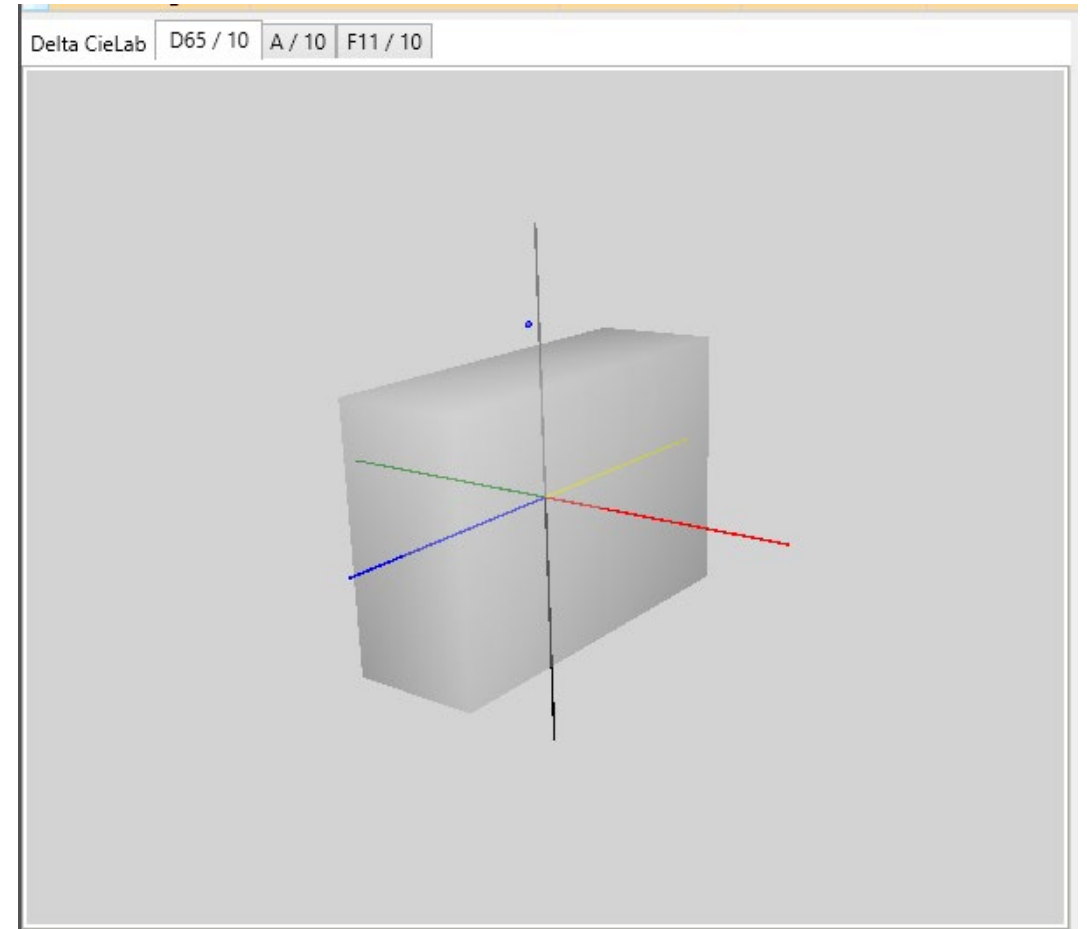
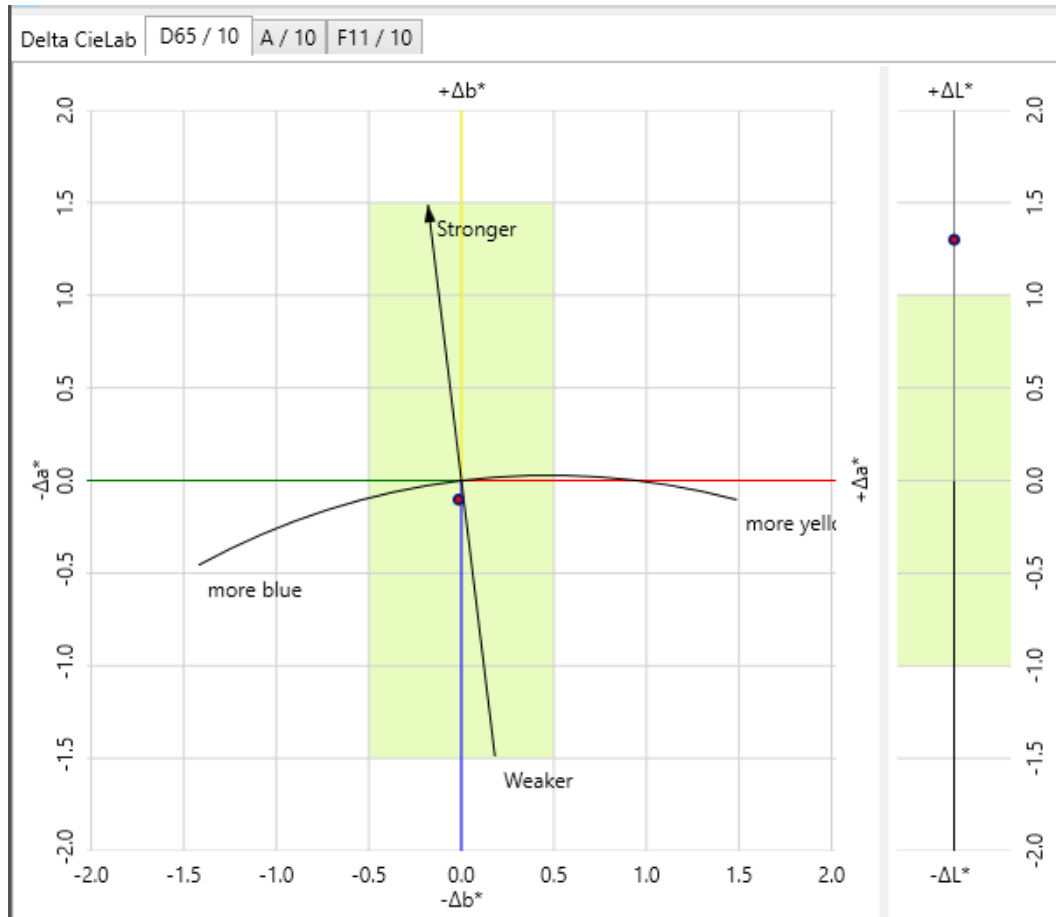
DL\*, Da\*, Db\* tolerance of 1.0 defines a box in CIELAB space.



# DE\* Tolerance

*Defines a Box in CIELAB Color Space*

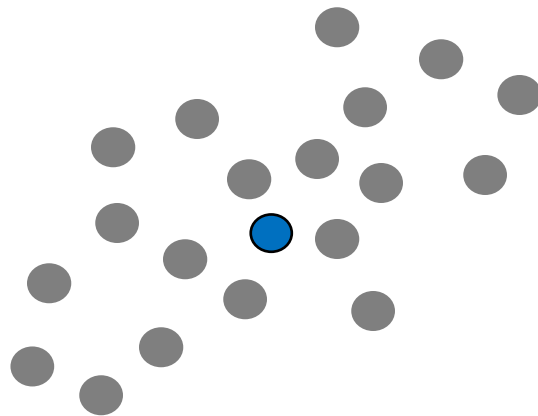
Tolerance  $DL^* = \pm 1.0$ ,  $Da^* = \pm 0.5$ ,  $Db^* = \pm 1.5$  defines a box in CIELAB space.





# Tolerance Determination

*From Historical Batch Data*

$b^*$



-  Standard
-  Batches

Batches to the Standard  
shown in  $a^*/b^*$  plane.

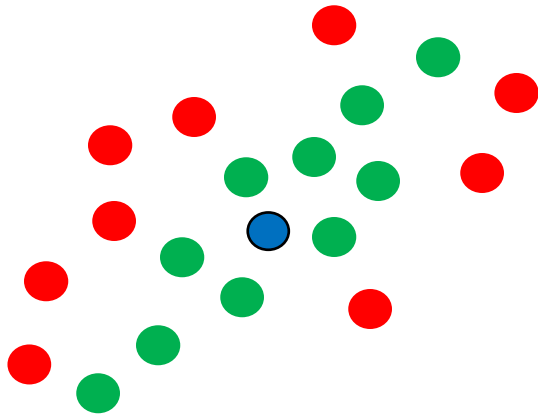





$a^*$

# Tolerance Determination

*Visually Evaluate Each Batch as Pass or Fail*

$b^*$



-  Standard
-  Pass
-  Fail

Batches are marked either as visually acceptable (Pass) or unacceptable (Fail).

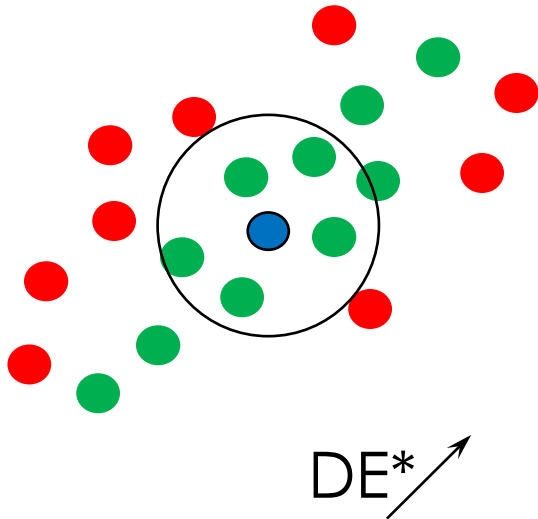


$a^*$

# Tolerance Determination

$DE^*$  - Spherical Tolerance

$b^*$



 Standard

 Pass

 Fail

 Tolerance Limit

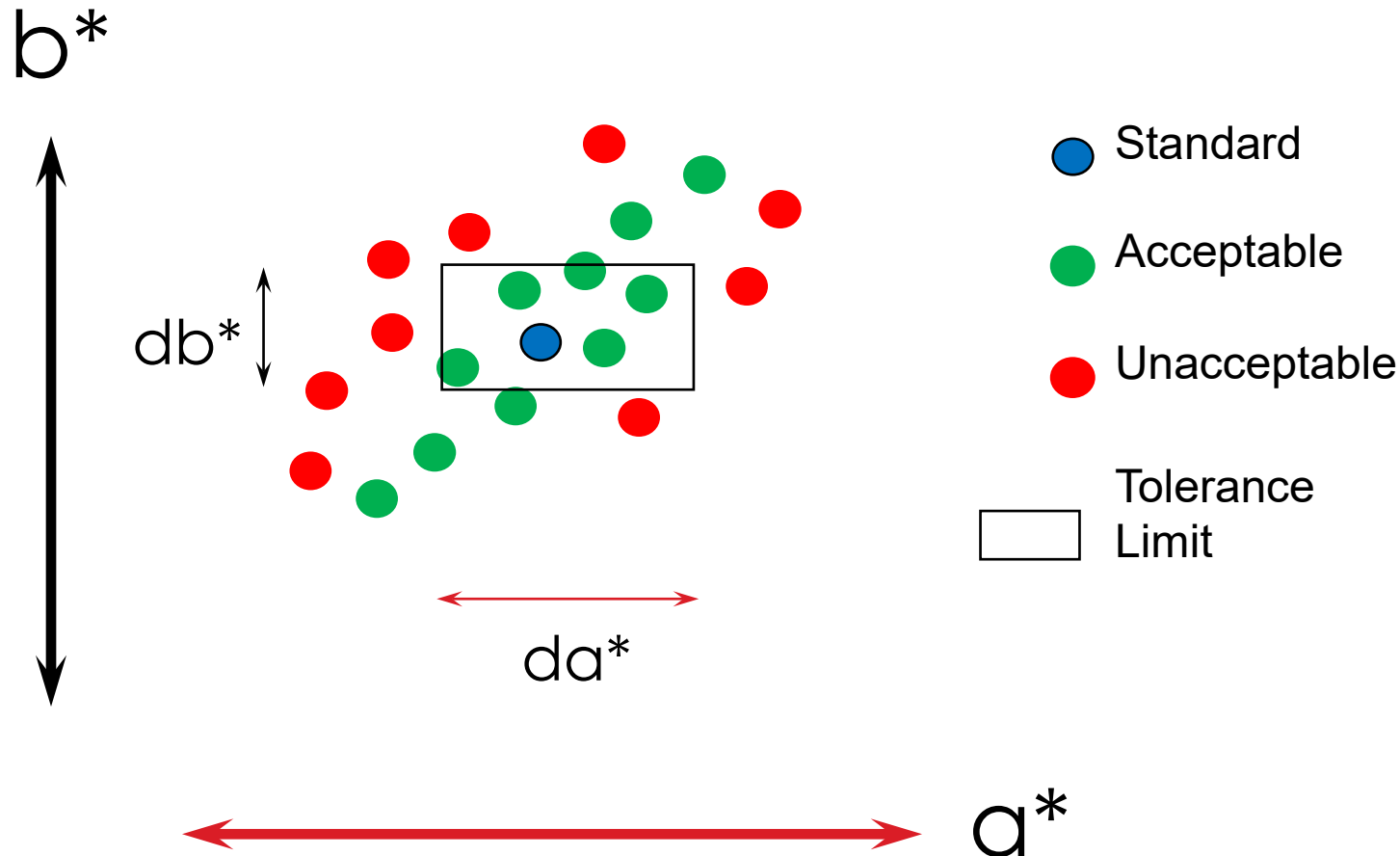
A single  $DE^*$  value cannot include the Pass batches and exclude the Fail batches.



$a^*$

# Tolerance Determination

*Rectangular  $DL^*$   $Da^*$   $Db^*$*

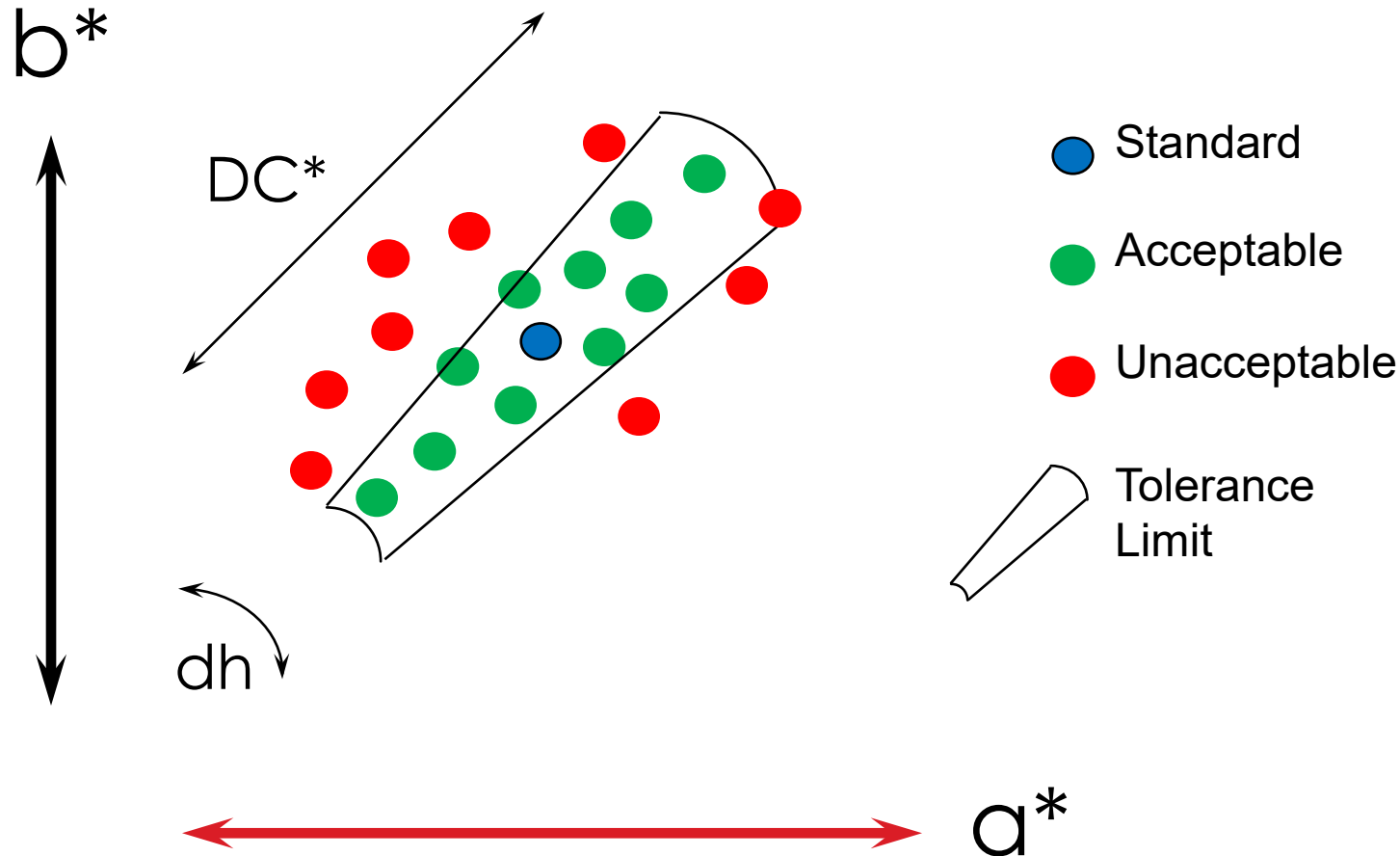


A rectangular  $da^*$  and  $db^*$  value cannot include acceptable batches and exclude unacceptable batches.



# Tolerance Determination

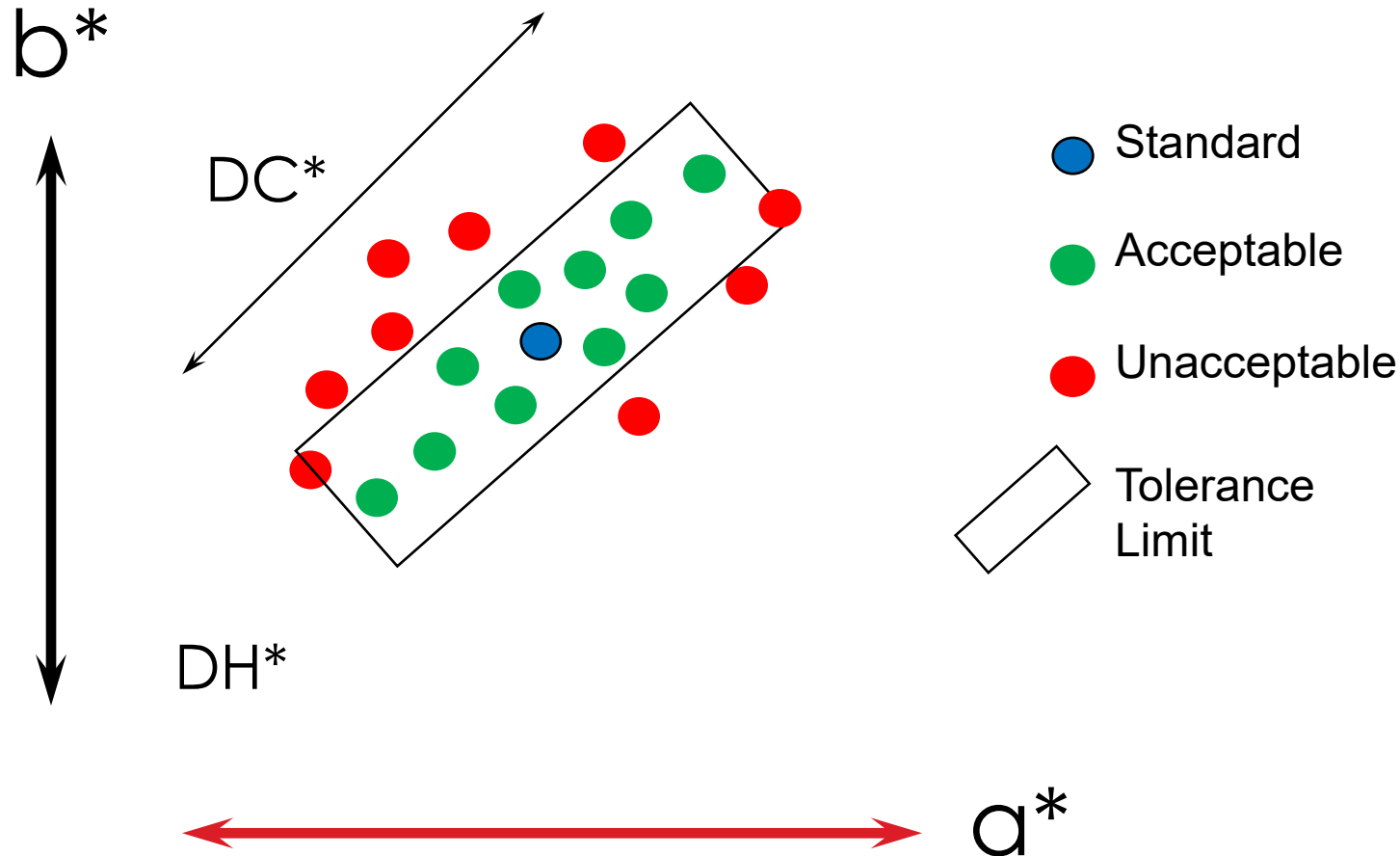
Polar  $L^* C^* h$



A tolerance based on  $dh$  and  $DC^*$  gets close but still can't quite get there.

# Tolerance Determination

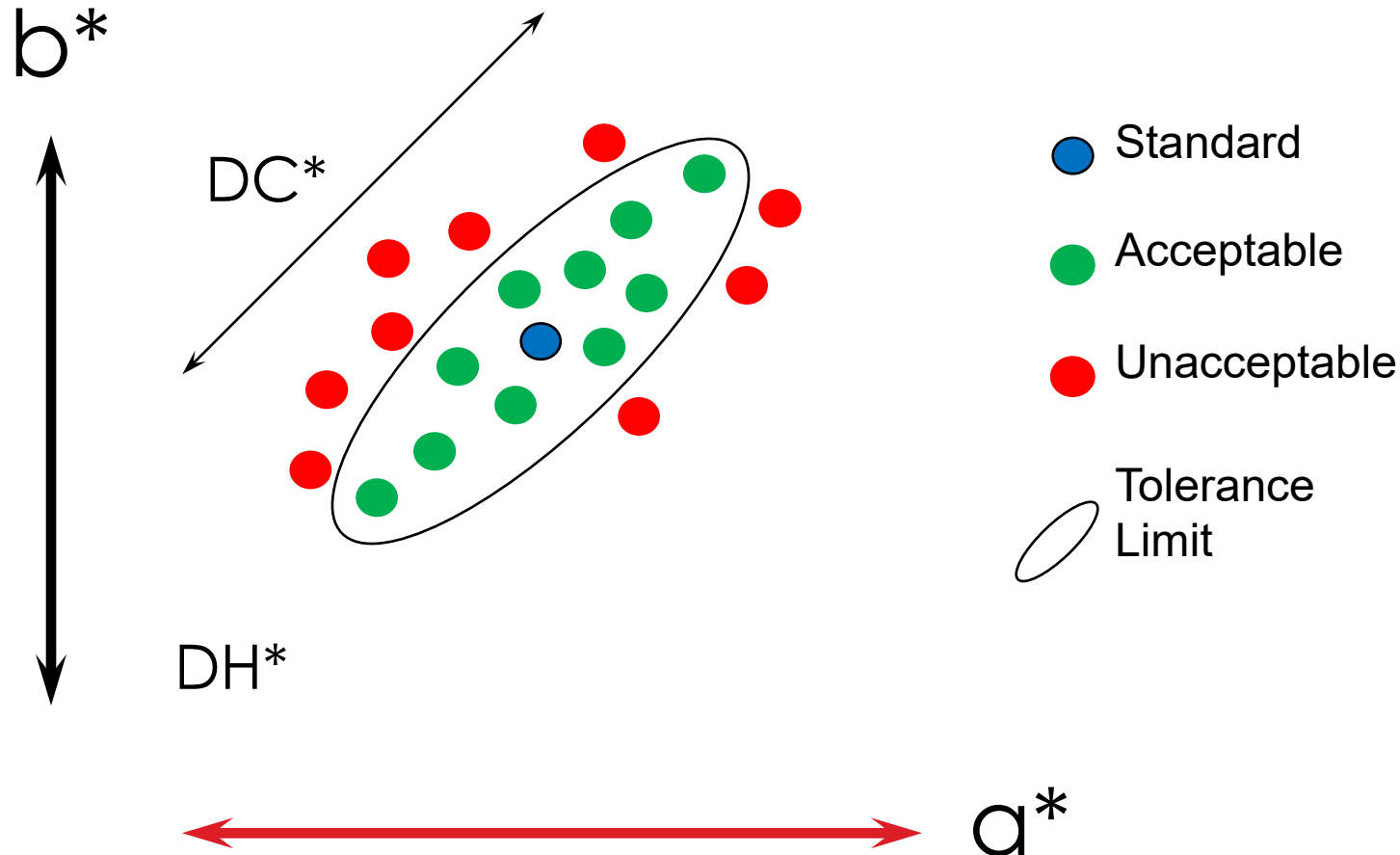
Rectangular  $L^* C^* H^*$



A tolerance based on  $DH^*$  and  $DC^*$  also gets close but still can't quite get there.

# Tolerance Determination

Ellipsoidal  $L^* C^* H^*$

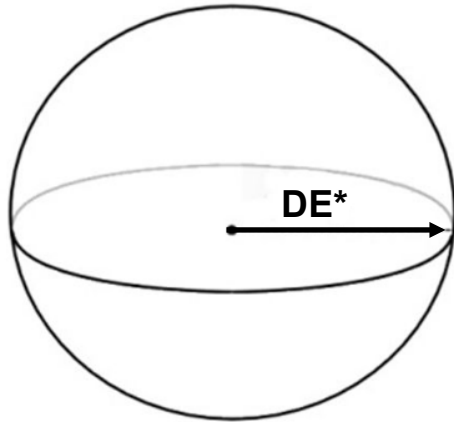


An ellipsoidal tolerance based on  $DH^*$  and  $DC^*$  can include the acceptable batches and exclude the unacceptable ones.

# CMC Color Difference Equation

Ellipsoidal Tolerancing

DE\*



$$\Delta E_{CMC(l:c)}^* = \left[ \left( \frac{\Delta L^*}{l S_L} \right)^2 + \left( \frac{\Delta C_{ab}^*}{c S_C} \right)^2 + \left( \frac{\Delta H_{ab}^*}{S_H} \right)^2 \right]^{1/2}$$

$S_L$  = Lightness Tolerance

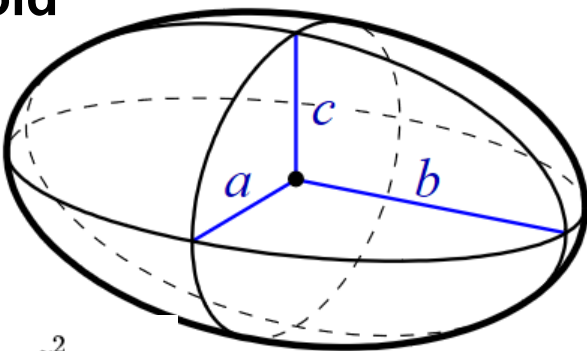
$S_C$  = Chroma Tolerance

$S_H$  = Hue Tolerance

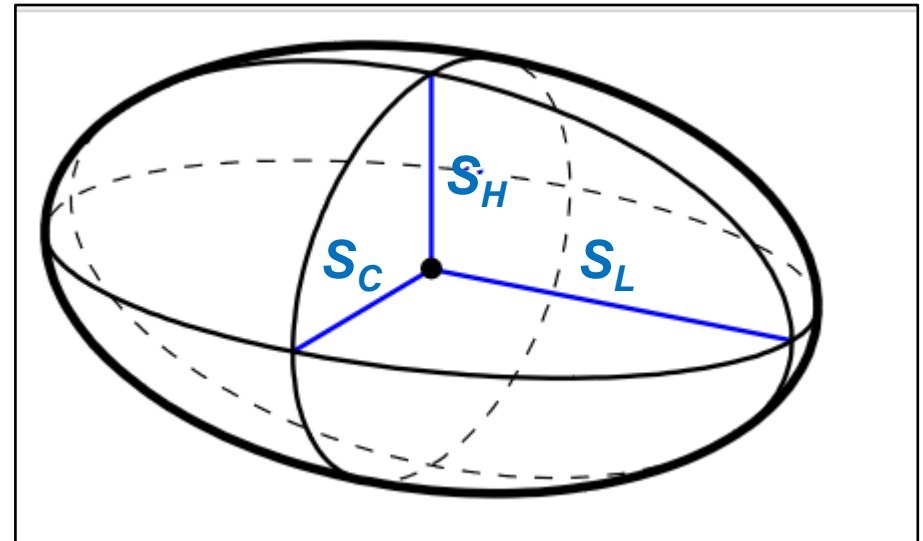
$l$  = Lightness Adjustment Factor

$c$  = Chroma Adjustment Factor

Ellipsoid



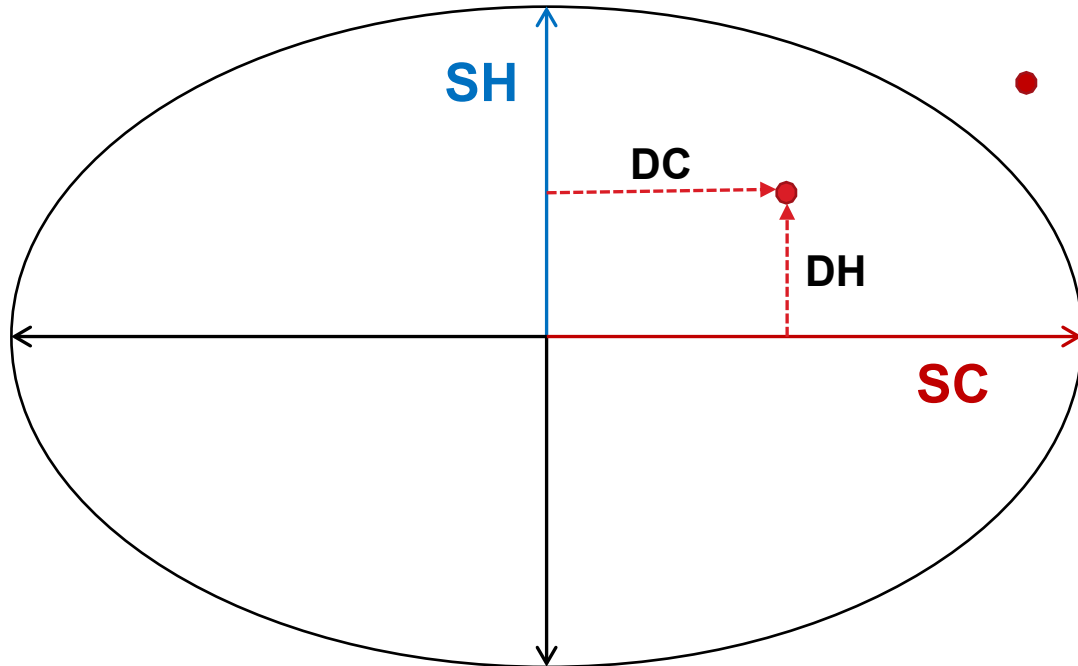
$$\frac{x^2}{a^2} + \frac{y^2}{b^2} + \frac{z^2}{c^2} = 1$$



# CMC Color Difference Equation

Pass/Fail Considerations

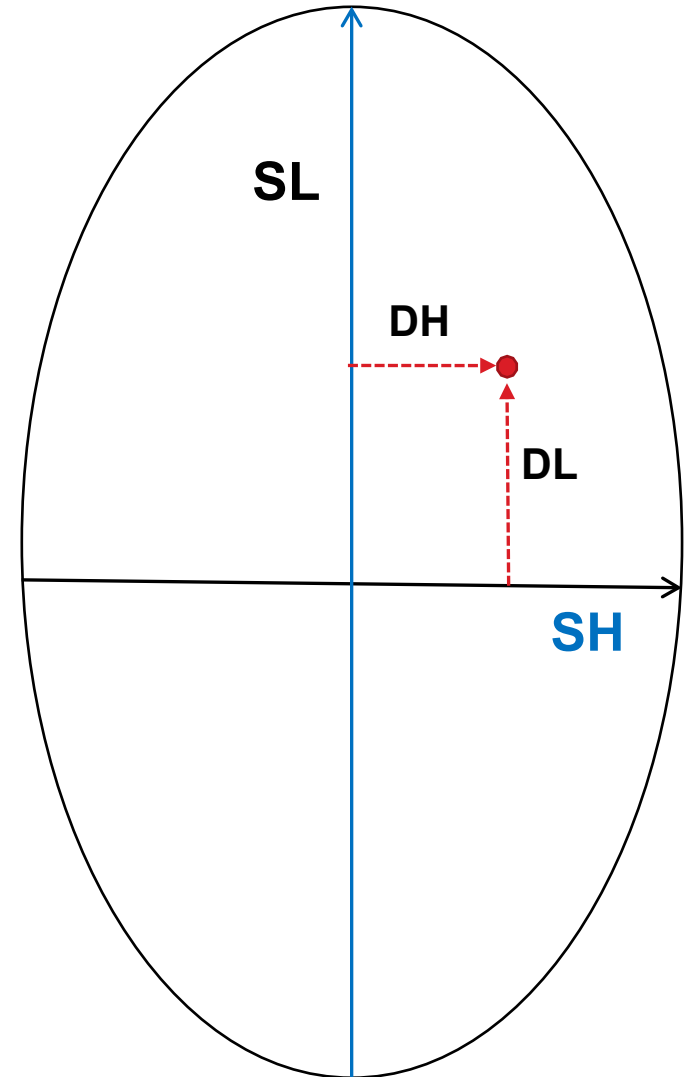
$$\Delta E_{CMC(l:c)}^* = \left[ \left( \frac{\Delta L^*}{lS_L} \right)^2 + \left( \frac{\Delta C_{ab}^*}{cS_C} \right)^2 + \left( \frac{\Delta H_{ab}^*}{S_H} \right)^2 \right]^{1/2}$$



**DL\* / SL**

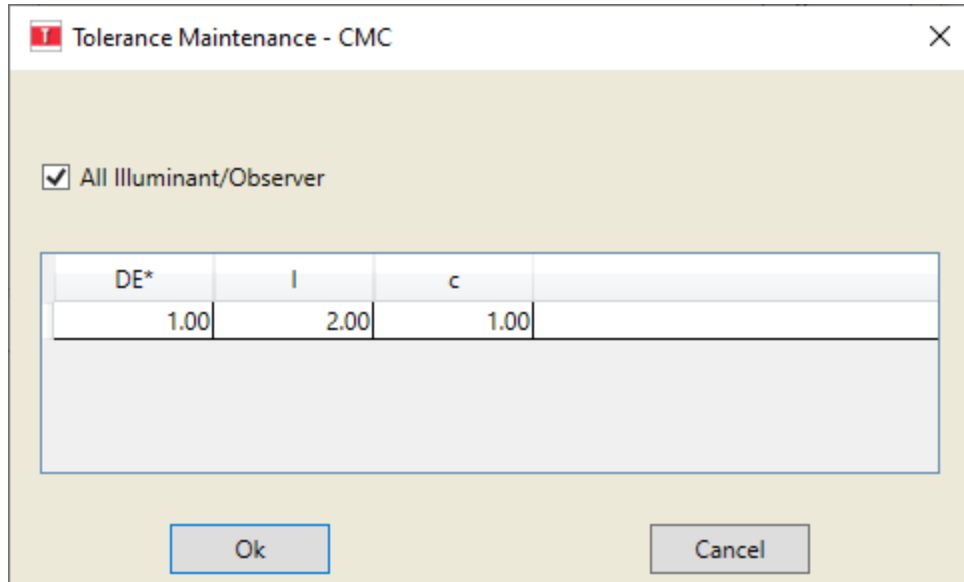
**DC\* / SC**

**DH\* / SH**



# CMC Color Difference Equation

Meaning of the Value of the CMC DE



$$\Delta E_{CMC(l:c)}^* = \left[ \left( \frac{\Delta L^*}{l S_L} \right)^2 + \left( \frac{\Delta C_{ab}^*}{c S_C} \right)^2 + \left( \frac{\Delta H_{ab}^*}{S_H} \right)^2 \right]^{1/2}$$

$$\Delta E_{CMC}^* = 1.0$$

Batch is on surface of ellipsoid.

$$\Delta E_{CMC}^* < 1.0$$

Batch is inside ellipsoid (Pass)

$$\Delta E_{CMC}^* > 1.0$$

Batch is outside ellipsoid (Fail)

***l*** = Lightness Factor

Allows adjustment of  $\Delta L^*$  Semi-axis

***c*** = Chroma Factor

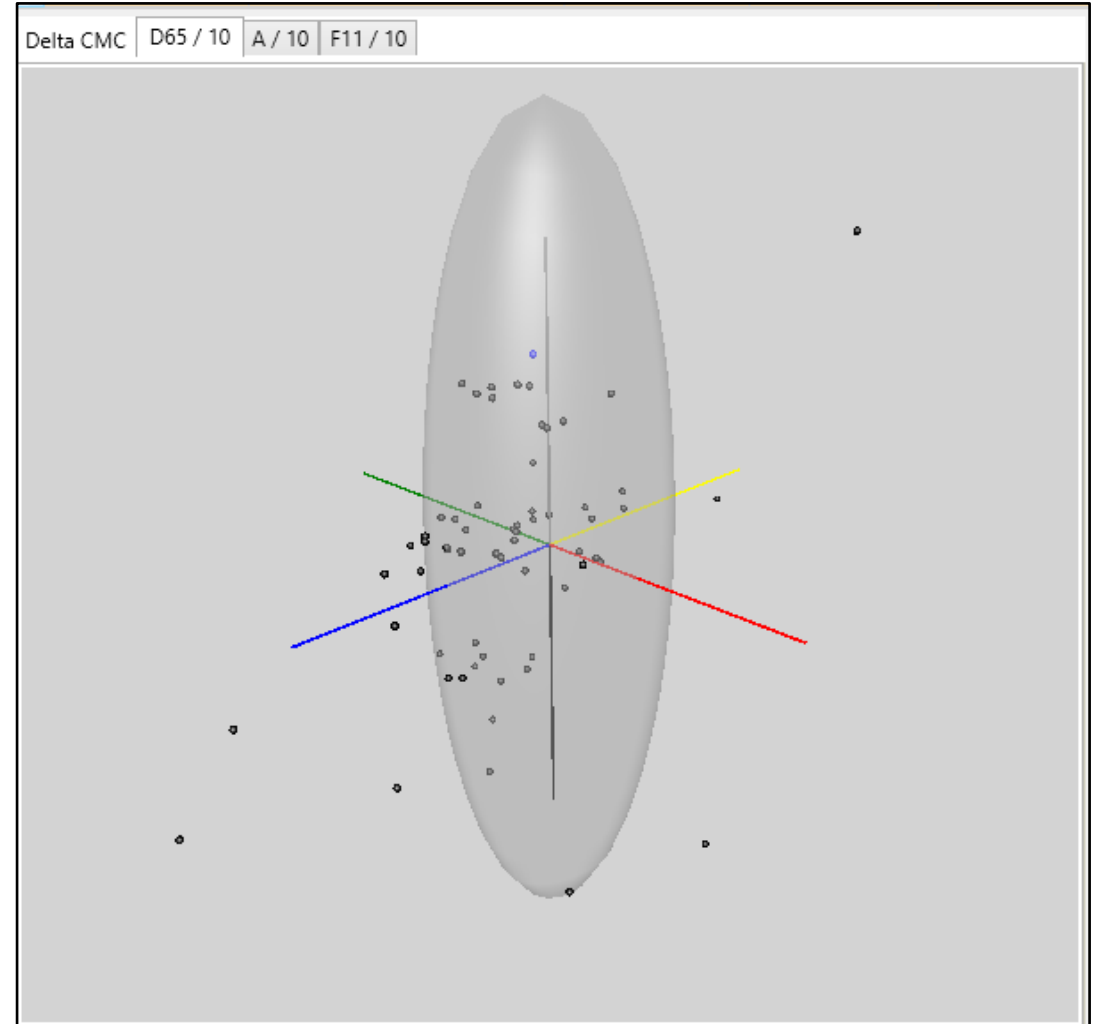
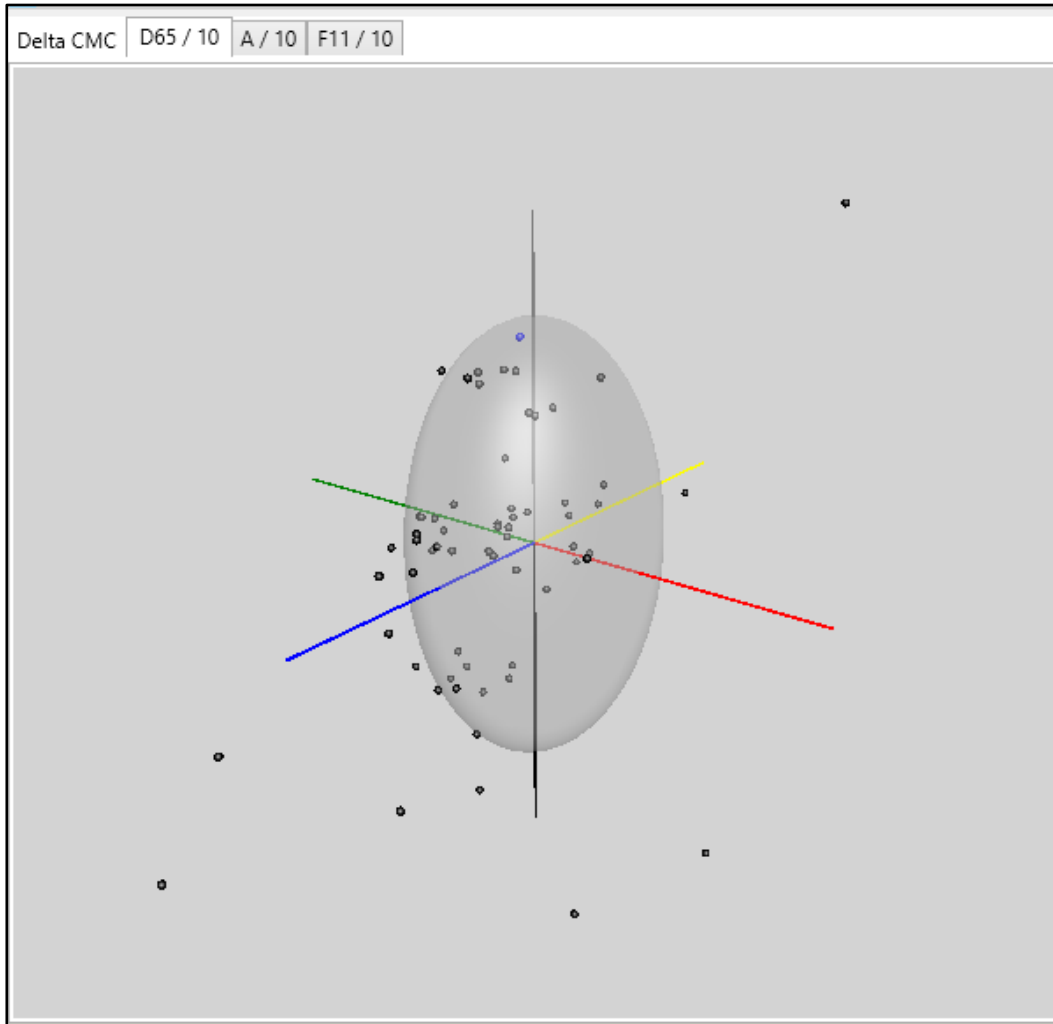
Allows adjustment of  $\Delta C^*$  Semi-axis

# CMC Color Difference Equation

*Changing the Value of the CMC Lightness Factor from 1 to 2*

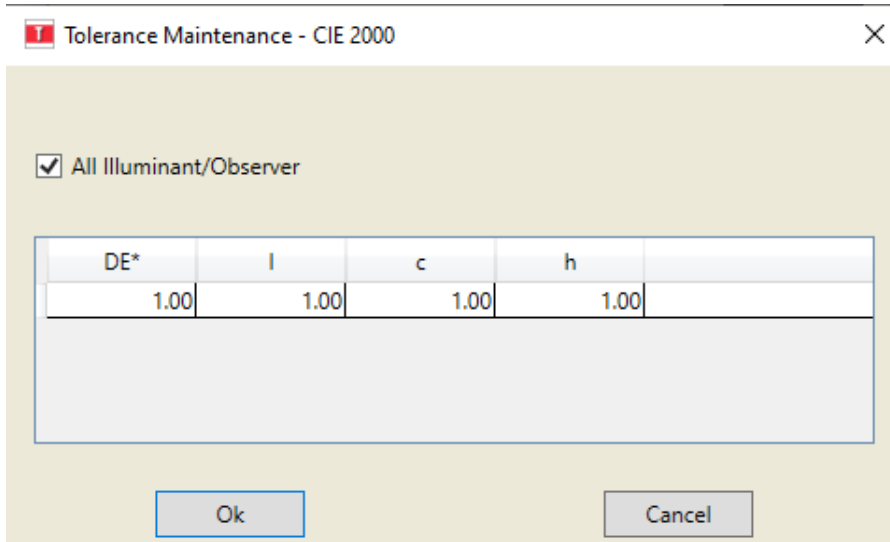
$l = 1$   $c = 1$

$l = 2$   $c = 1$



# CIE 2000 Color Difference Equation

Meaning of the Value of the CIE 2000 DE



$$\Delta E_{00}^* = \sqrt{\left(\frac{\Delta L'}{k_L S_L}\right)^2 + \left(\frac{\Delta C'}{k_C S_C}\right)^2 + \left(\frac{\Delta H'}{k_H S_H}\right)^2 + R_T \frac{\Delta C'}{k_C S_C} \frac{\Delta H'}{k_H S_H}}$$

Includes lightness, chroma and hue weighting factors  
Improved gray colors  
Improved performance for blue colors using rotational factor

$K_L$  = Lightness Factor  
Allows adjustment of  $DL^*$  Semi-axis

$K_C$  = Chroma Factor  
Allows adjustment of  $DC^*$  Semi-axis

$K_H$  = Hue Factor  
Allows adjustment of  $DH^*$  Semi-axis

$S_L$  = Lightness Tolerance

$S_C$  = Chroma Tolerance

$S_H$  = Hue Tolerance

$DE_{00}^* = 1.0$   
Batch is on surface of ellipsoid.

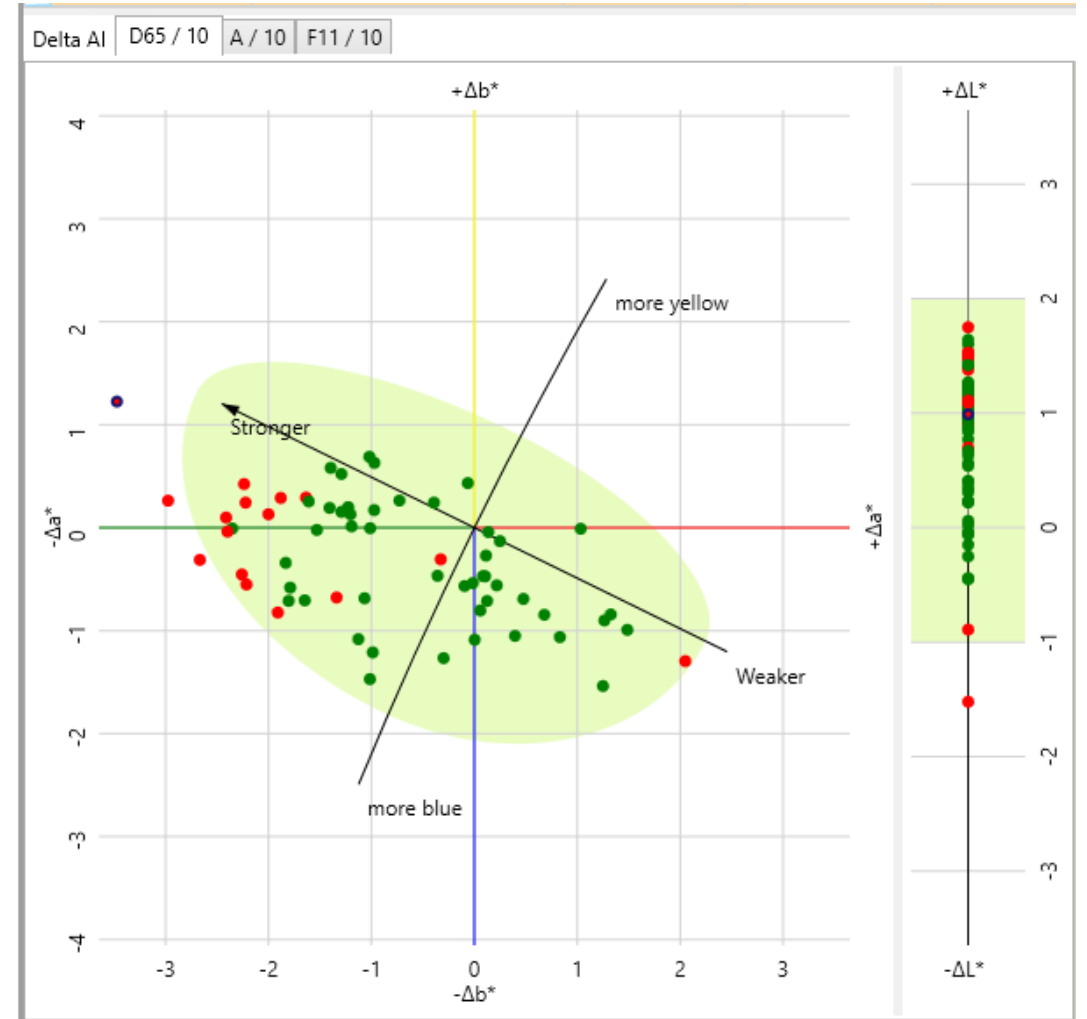
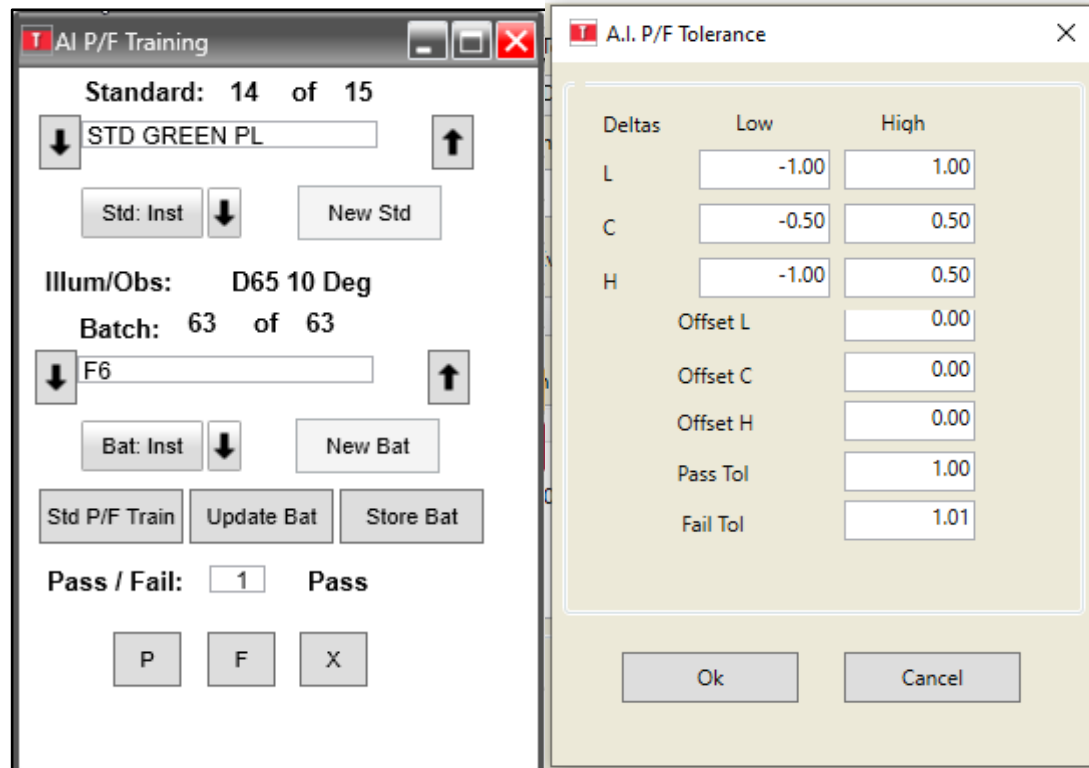
$DE_{00}^* < 1.0$   
Batch is inside ellipsoid (Pass)

$DE_{00}^* > 1.0$   
Batch is outside ellipsoid (Fail)



# AI Pass/Fail

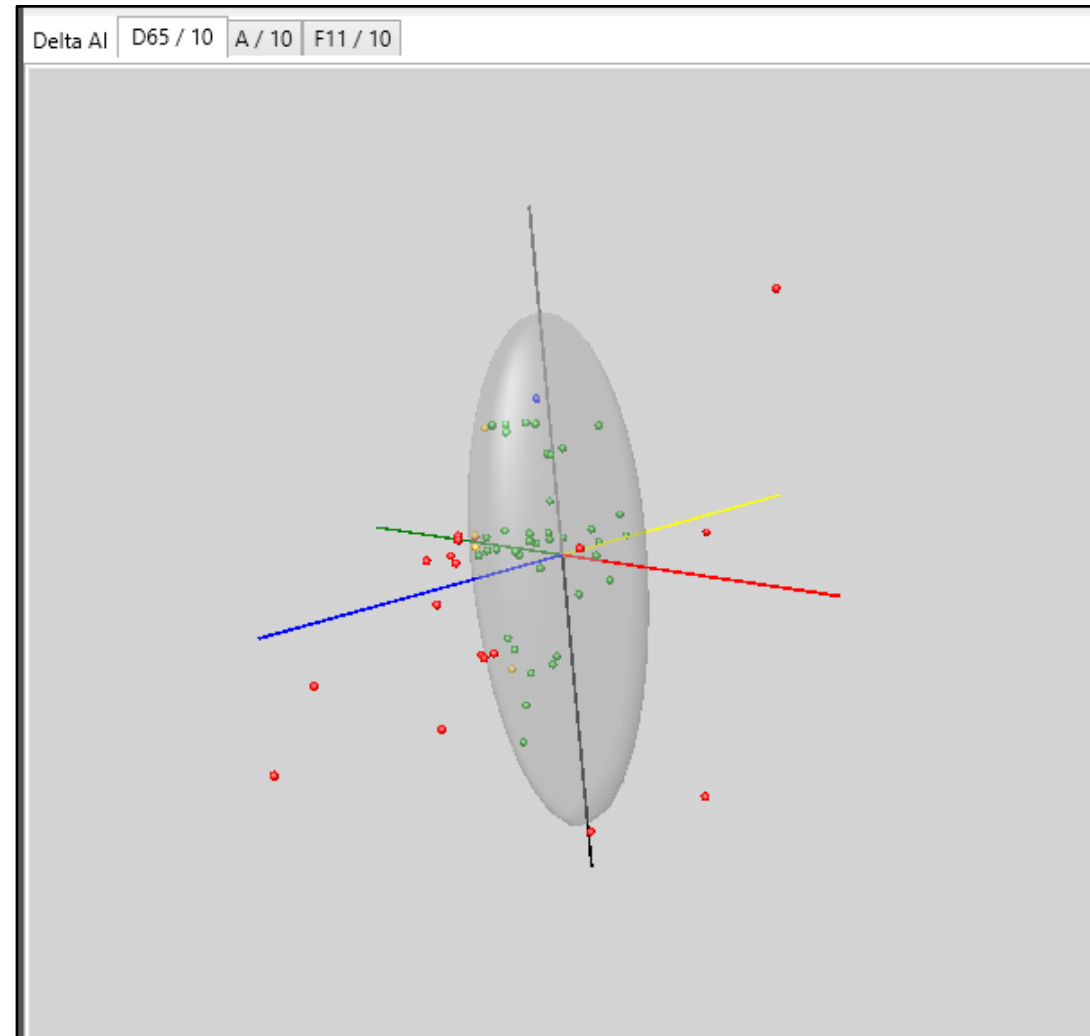
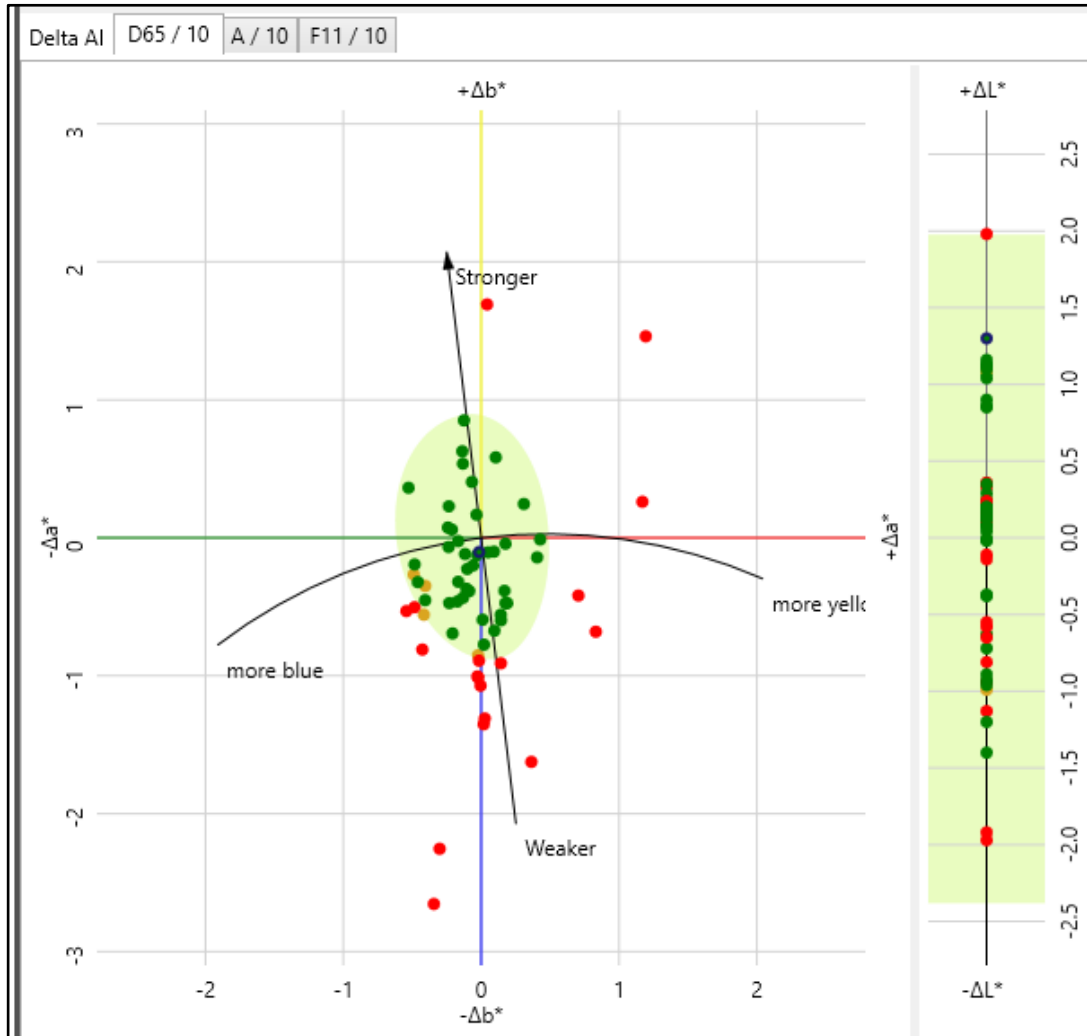
Computer Generated Tolerance Based on Visual Acceptability



User can mark each batch as either a pass or fail and the program will try to create an ellipsoid that includes the pass samples and excludes the fail samples.

# AI Generated Tolerance

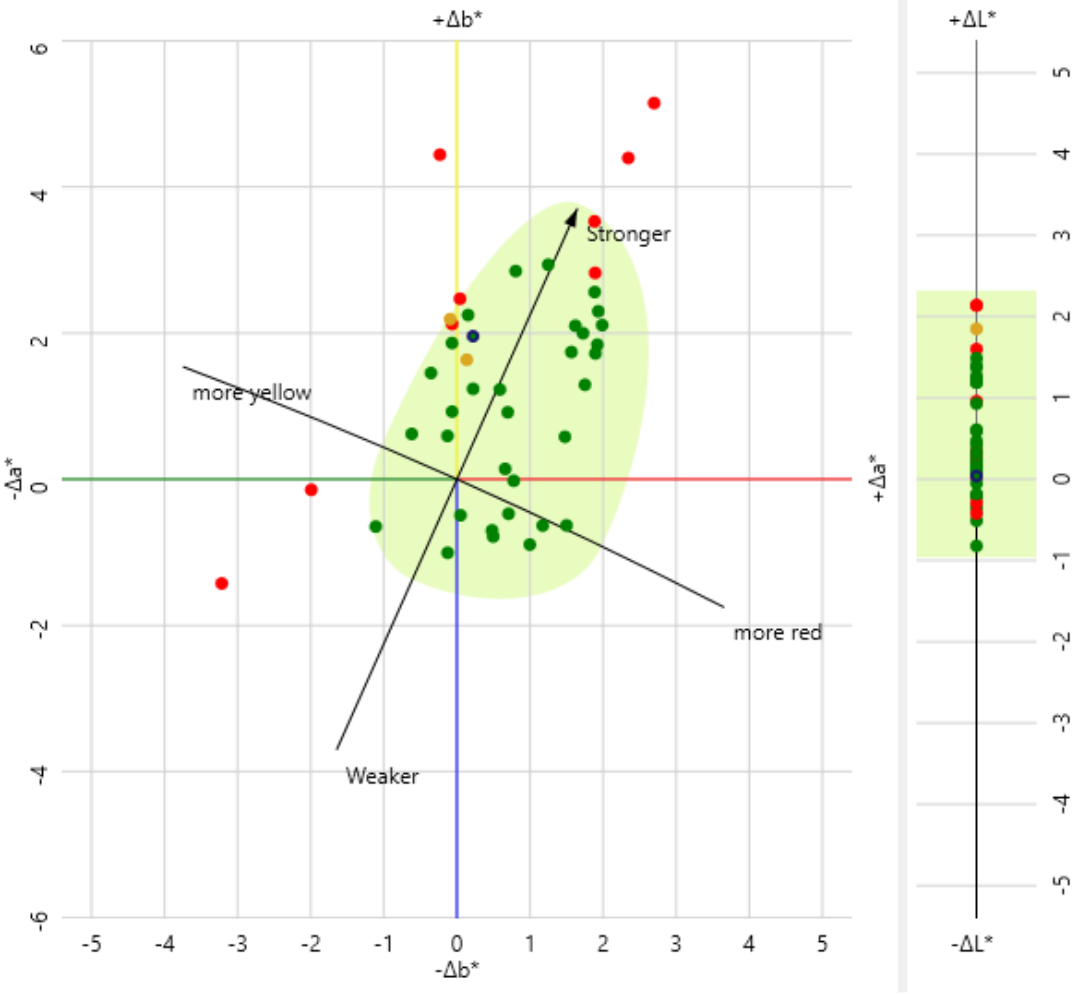
Light Gray Sample



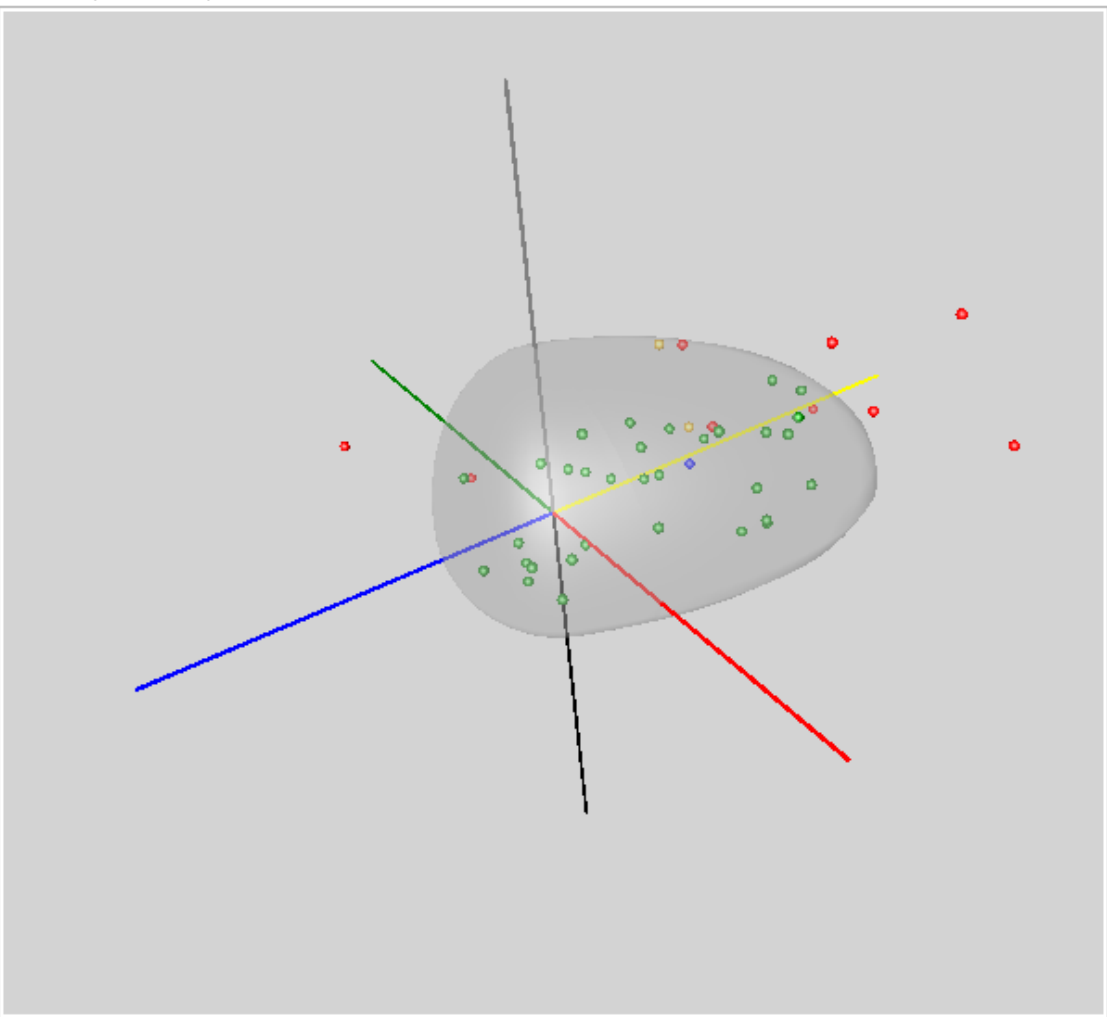
# AI Generated Tolerance

*Yellow Gold Sample*

Delta AI D65 / 10 A / 10 F11 / 10

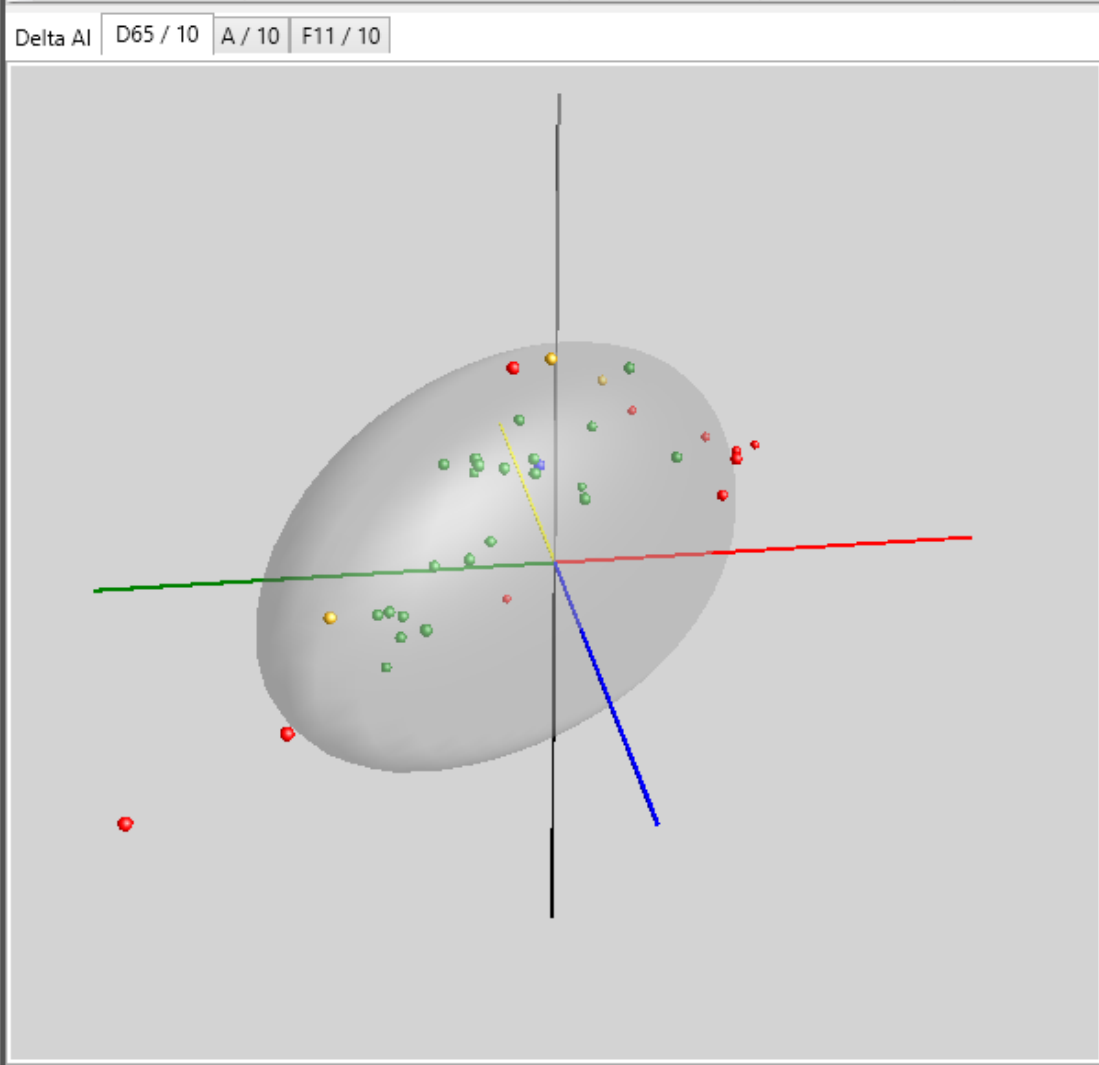
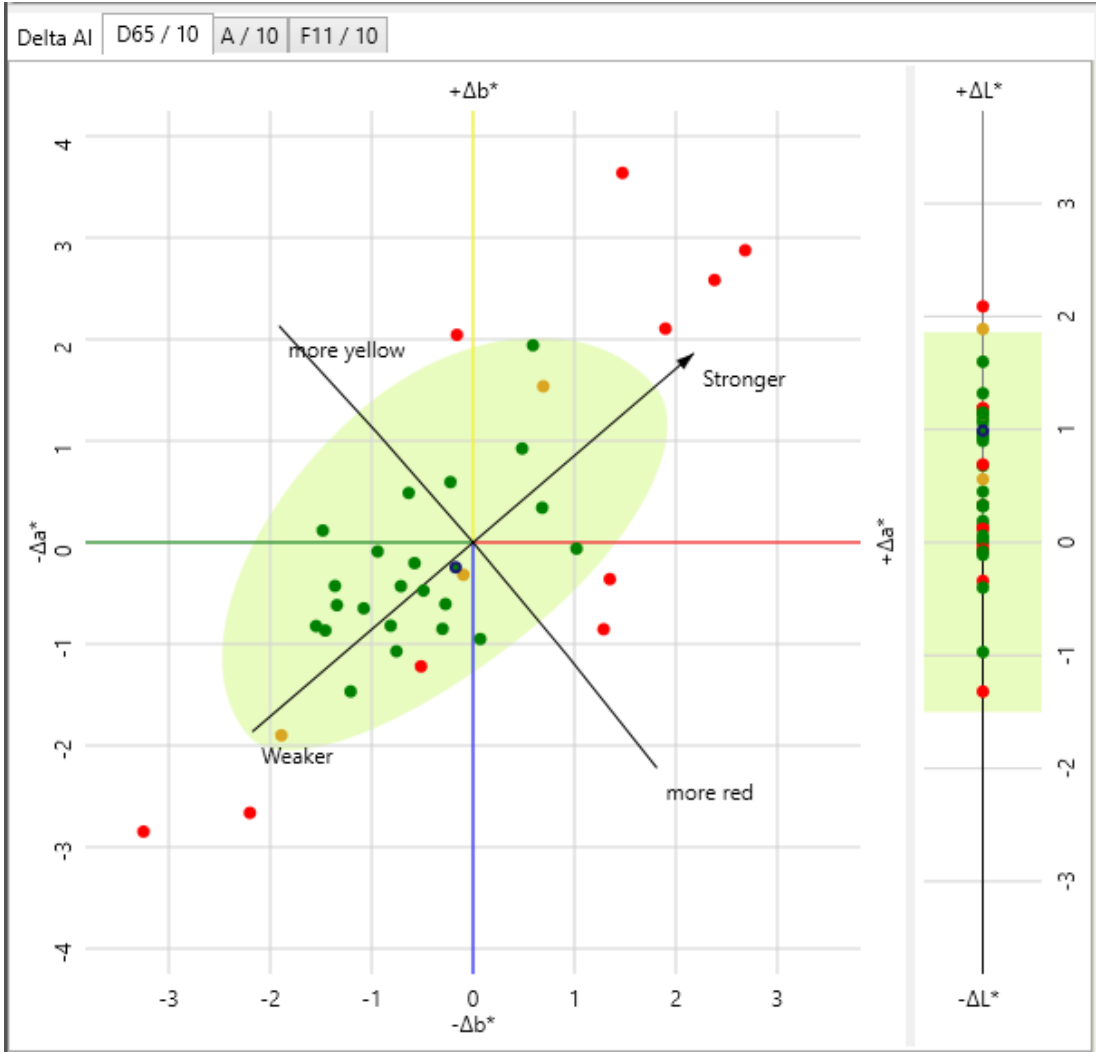


Delta AI D65 / 10 A / 10 F11 / 10



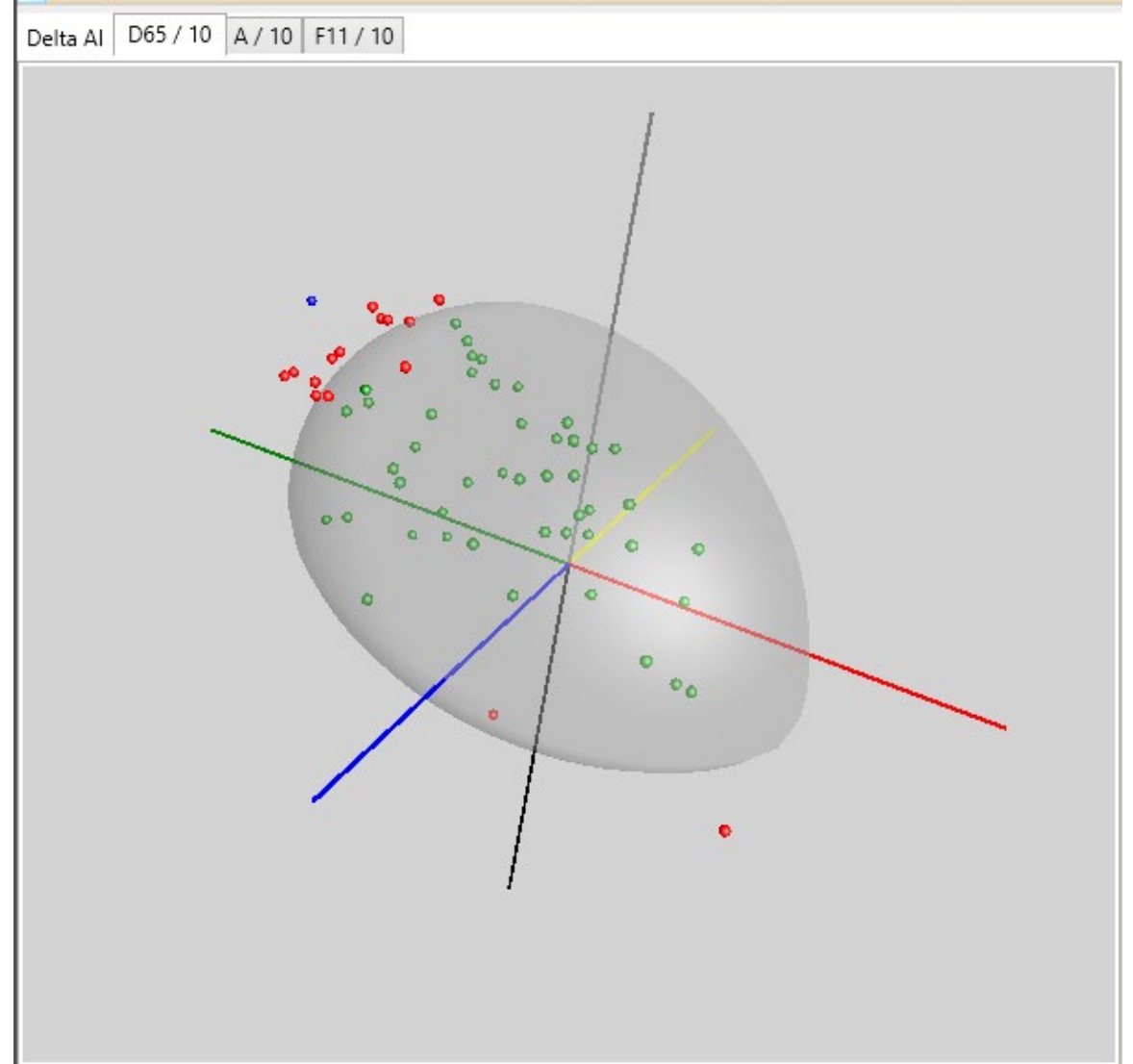
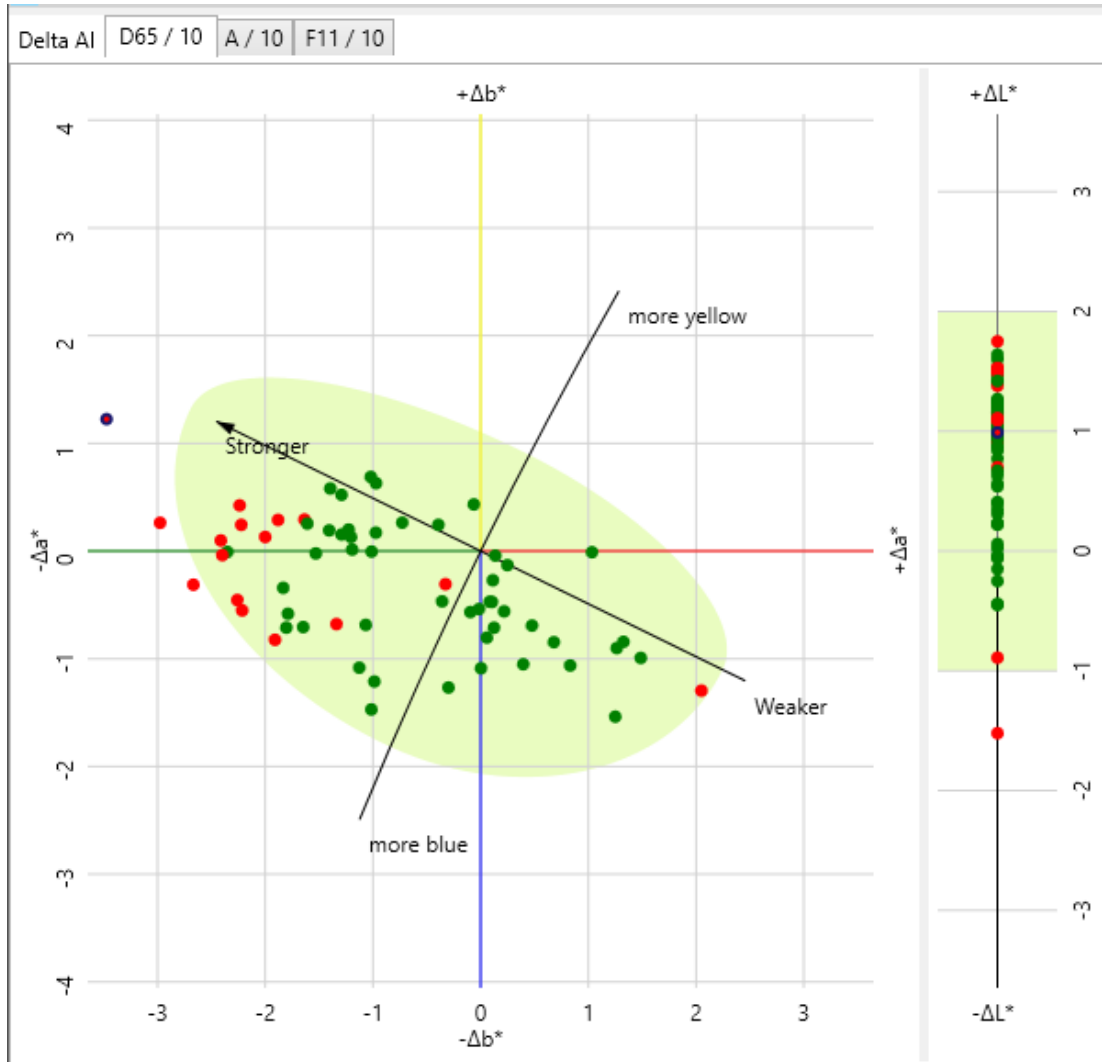
# AI Generated Tolerance

Orange Sample



# AI Generated Tolerance

Green Sample



# Demo

## Datacolor TOOLS examples

# Webinar – Questions and Comments

CMC vs CIE2000

Are the differences between them worth changing?

Are there negatives where CIE2000 isn't as good?

What if mill is using CMC and Retailer is using CIE2000?

Different DE\*'s – CIELAB, CMC, CIE2000, DIN99, CIE94 – What to use?

If Spectrophotometer uses D65 light source, does the illuminant for Lab need to be specified?

Cases where DE is very close, but samples are visually far apart.

Cases where DE is very large, but samples look good?

Color difference most accurate for color matching?

Metamerism in architectural coatings?

DE\* calculated by DL\*,Da\*,Db\* same as by DL\*,DC\*,DH\*? Yes.

DE's to different materials, any limitations?

Vector direction in color space?

# Next session:

We will talk about visual and instrumental evaluations

Instrument Geometry

Integrating Sphere – d/0, 0/d

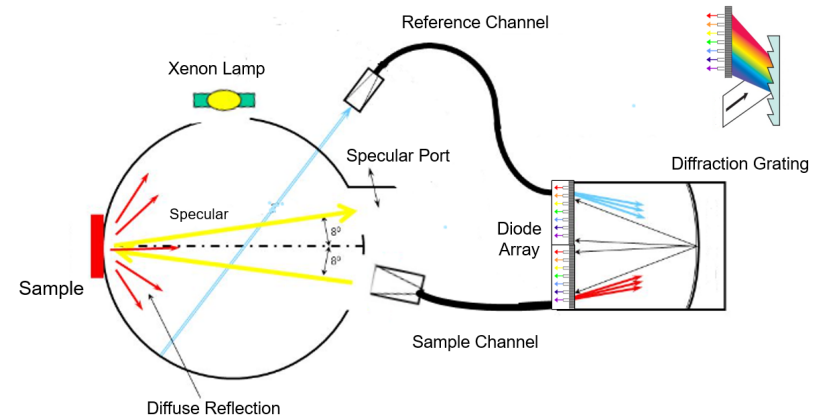
SCI, SCE

45/0, 0/45

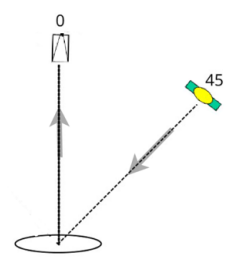
Visual Evaluation

Light Booths

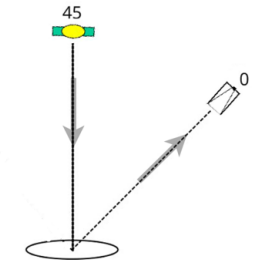
Follow-up on Questions



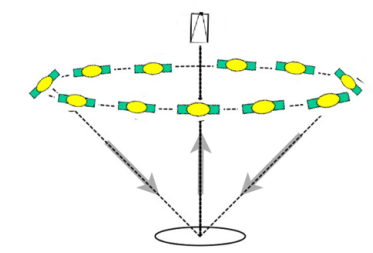
**45/0**



**0/45**



**45/0**  
Circumferential





## Want to learn more?

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Sign up at [Datacolor Academy](#) for classroom style lectures and demonstrations covering useful color topics in select venues around the globe

Some useful reading material:

[Do You Know How Humans See Color?](#)

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