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Bringing Better Pixels to UHD with Quantum Dots

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Nanosys Inc., Milpitas, CA

About Nanosys

- World's leading supplier of Quantum Dots, a unique and highly differentiated light emitting material which is transforming the display industry
- Located in Silicon Valley, Nanosys was the first company to focus on Quantum Dots for electronics starting in 2001
- Highest volume manufacturer with over 4 tons of QD Concentrate delivered to customers, enough for more than one million 60" class TVs, and annual capacity to service more than 6 million 60" class TVs per year
- World's Premier QD Patent Portfolio with 223 worldwide patents granted & 90 pending
- ~100 employees

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Business Model

Manufacture and sell Quantum Dot materials

Design and license Quantum Dot display components to key partners

Continue to develop innovative display technologies

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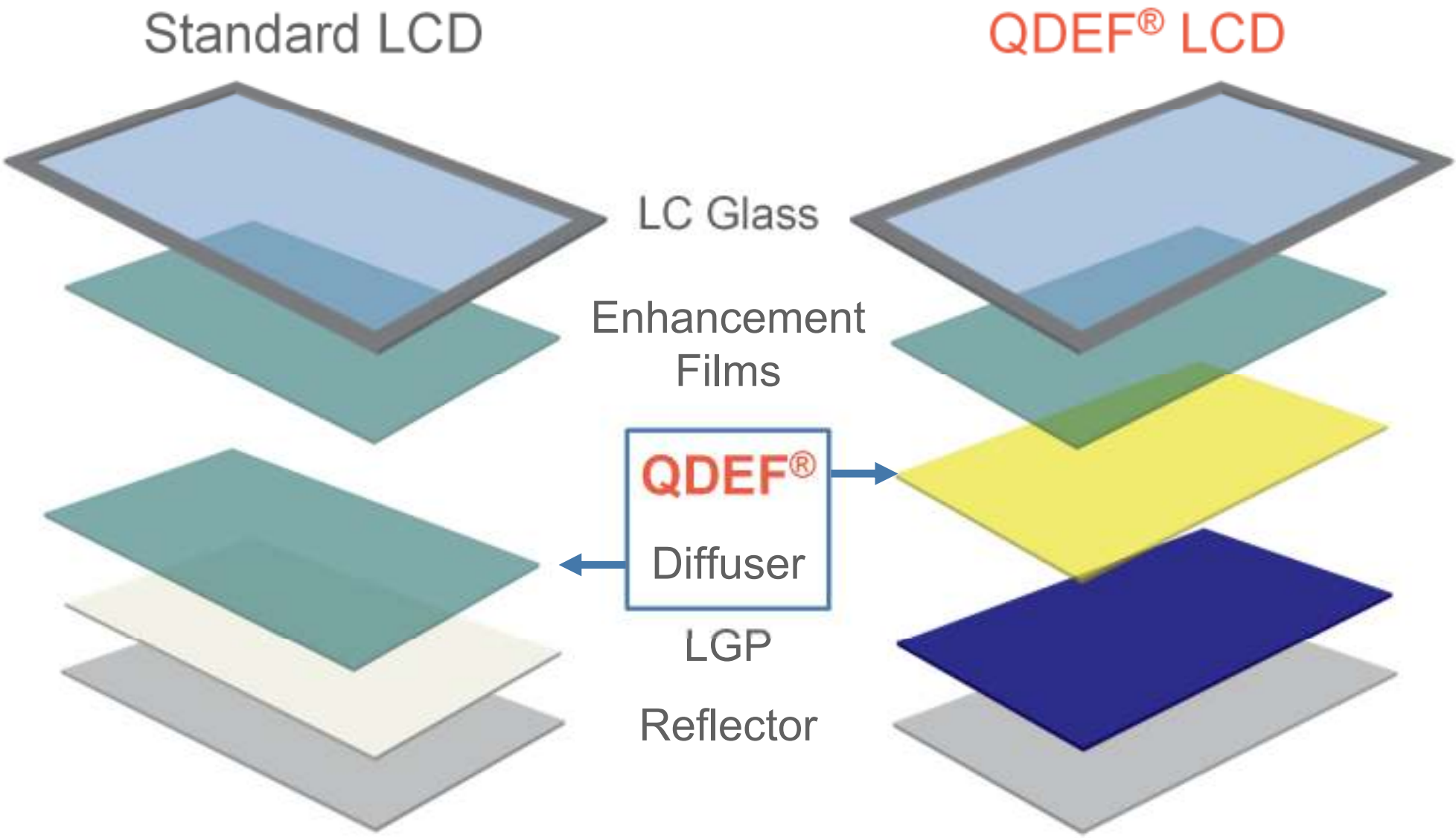
QDEF® designed to be cost neutral with simple "drop-in" manufacturing process



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Outline

- Background Information
  - UHD and the requirements for better pixels
- Improving LCD Pixels to Achieve rec.2020 requirements
  - Creating Primary Colors in LCDs
  - Using CdSe Quantum Dots to create an optimized spectrum for rec.2020
  - Rec.2020 Demonstration using QD Film in LCD
  - Other types of Quantum Dots
  - Further optimizations to achieve 100% rec.2020 performance
- Conclusions

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What is UHD?

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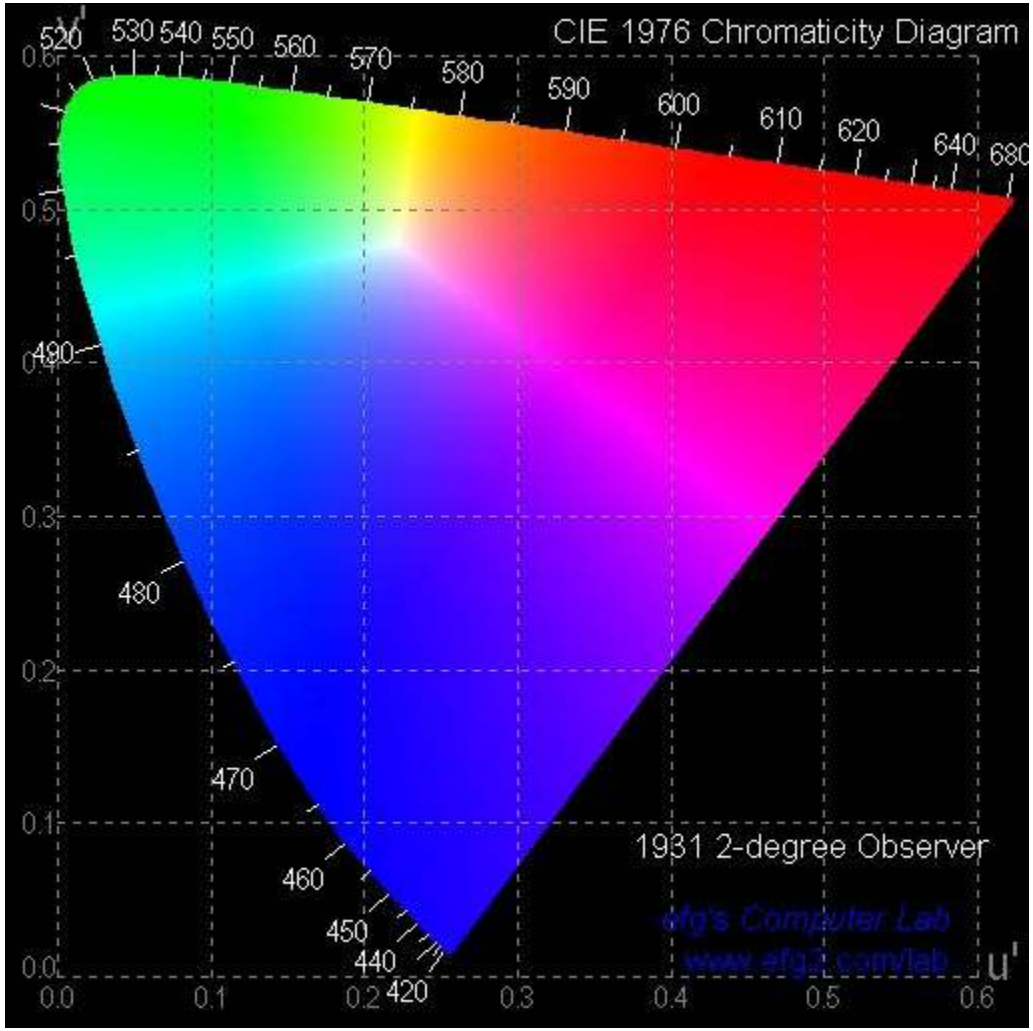
Colors Seen by the Human Eye
Color Gamut – 1976 CIE Diagram



- International Commission on Illumination (CIE) diagram shows all the colors that can be seen by the human eye
- Theoretical Limit for ***Wide Color Gamut System Colorimetry***
  - Beyond this, colors are imaginary
- Points on the color locus correspond to monochromatic light with different wavelengths

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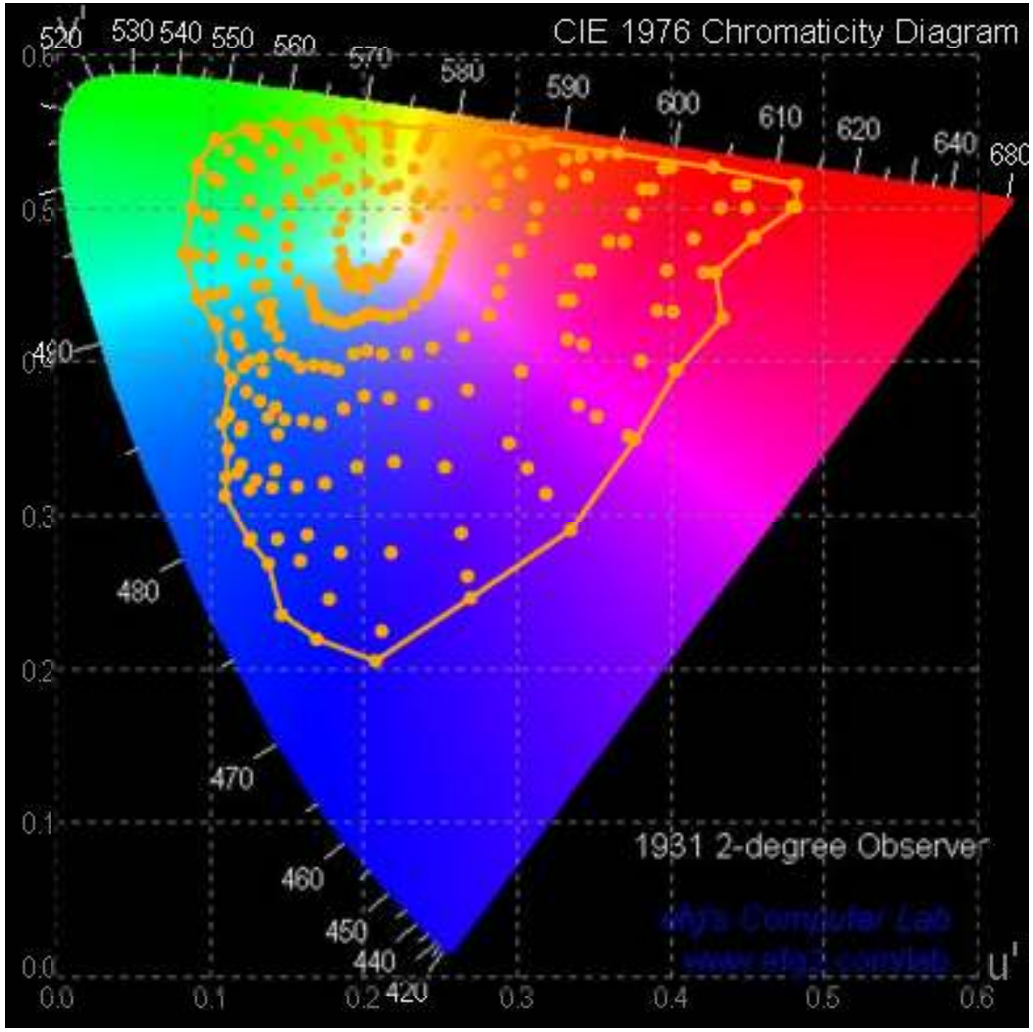
Colors Measured from Real Objects from Reflective Surfaces -- Pointer's Gamut



"The Gamut of Real Surface Colors", M.R.Pointer, Color Research and Application 5 (1980).

- Pointer's gamut: colors measured from reflections off real objects
  - Pointer's gamut covers 46% of color space that can be seen by the human eye
  - Practical Requirement for ***Wide Color Gamut System Colorimetry***
- Some man-made colors, (e.g., LEDs, Computer Graphics) are outside of Pointer's gamut

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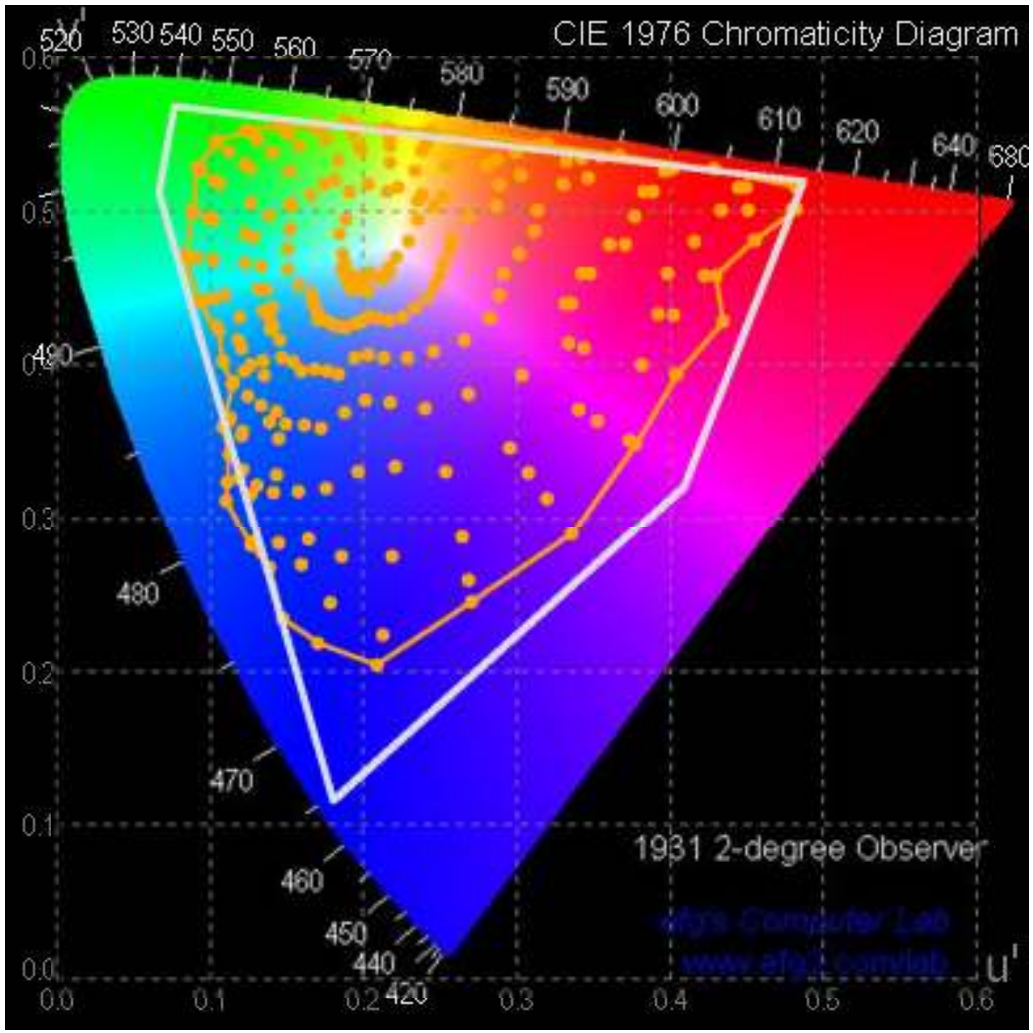
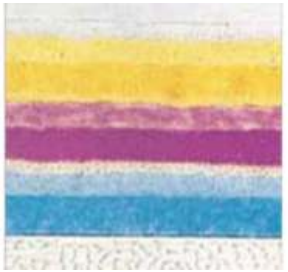
Film Color Space (Typical)



- Color film has at least three silver halide grain layers, each made sensitive to different colors by the addition of dyes which adsorb to the surface of the silver salts
- Film covers most of Pointer's gamut



Blue Light Recording Layer

Green Light Recording Layer

Red Light Recording Layer

Film structure

Source: Kodak

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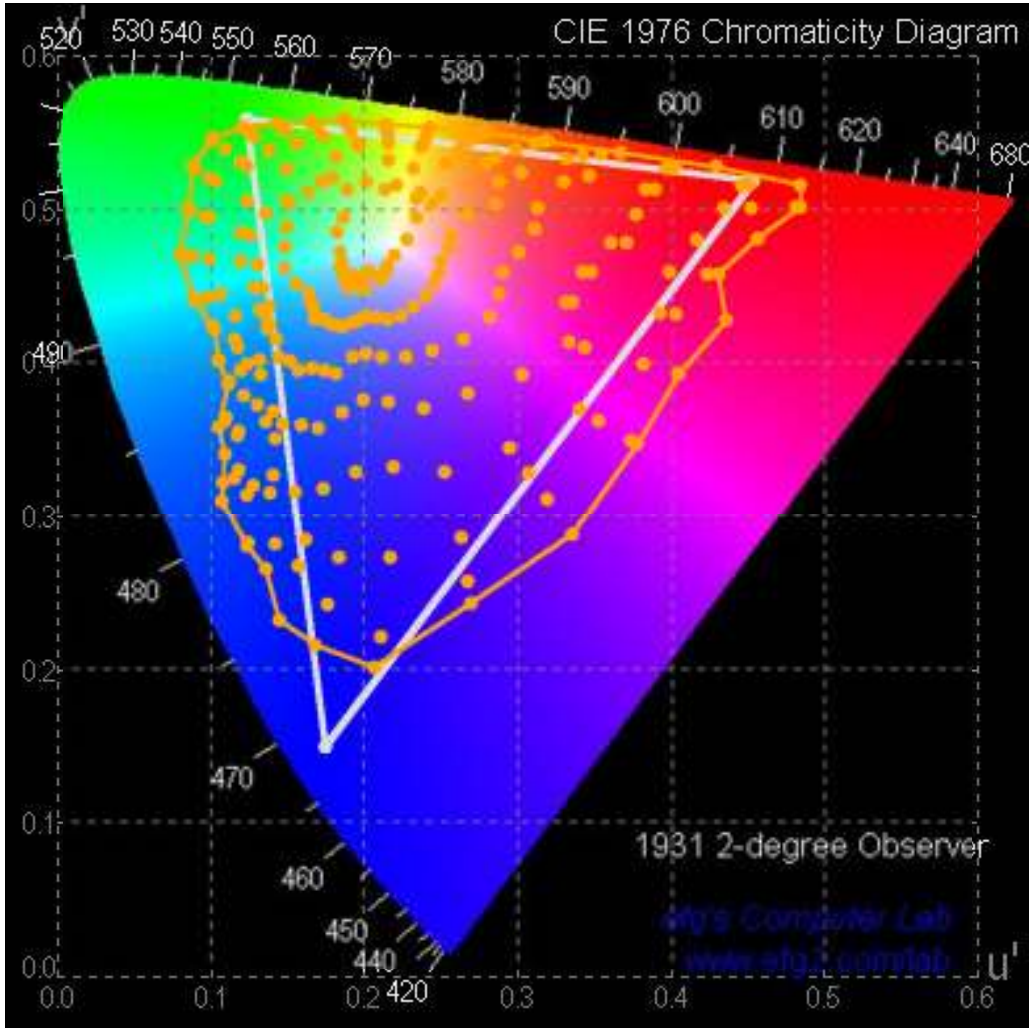
sRGB (Rec. 709) Color Space



- The color standard for most of today's displays is sRGB (Rec.709.) This is the standard for HD broadcast and is the most common in use on the Internet.
- sRGB covers 33% of color space for the human eye and only covers 70% of Pointer's gamut
  - You don't feel like you are there.

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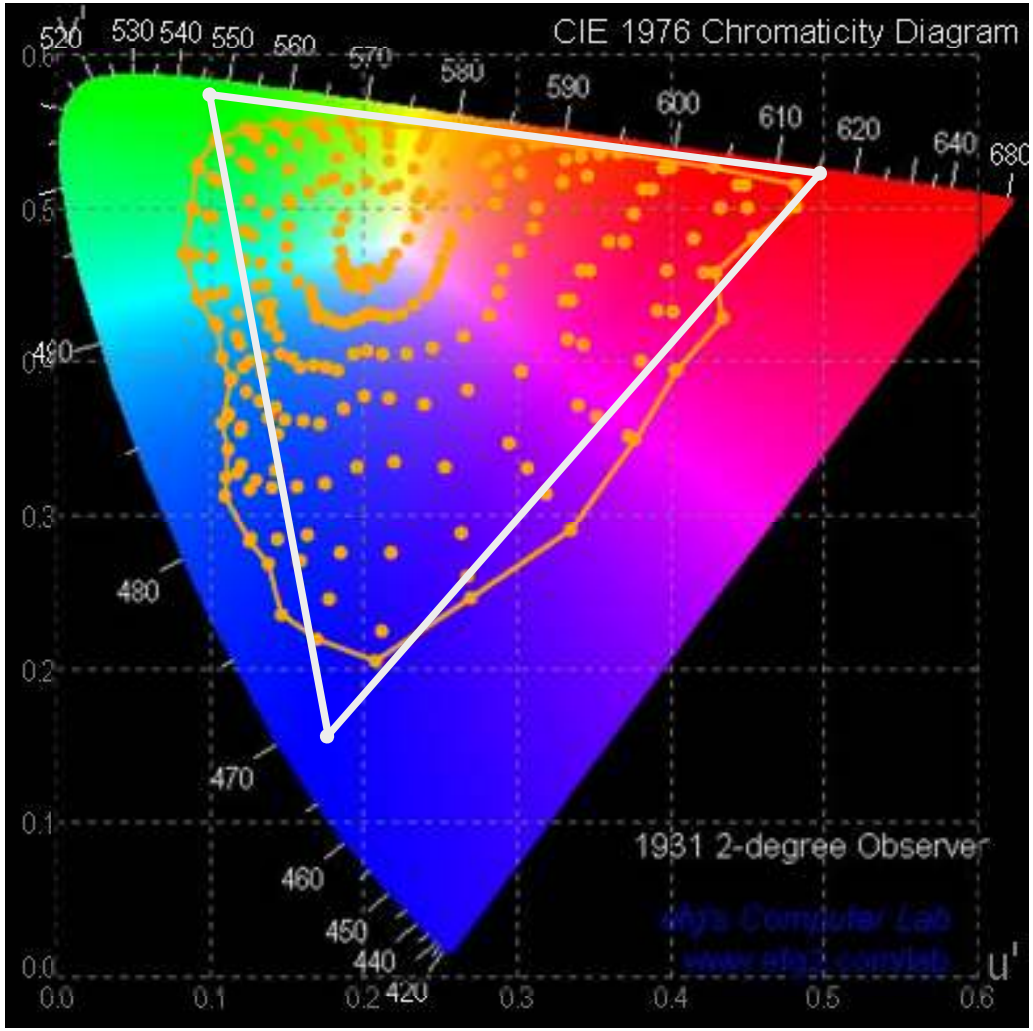
DCI-P3



- The DCI-P3 color space is part of a voluntary specification for digital cinema projectors in controlled environments, between Disney, Fox, Paramount, Sony, Universal and Warner Bros.
- The DCI-P3 color space covers 41.7% % of color space for the human eye and only covers 85.5%of Pointer's gamut
- Support for DCI-P3 color content in consumer or broadcast devices is absent today

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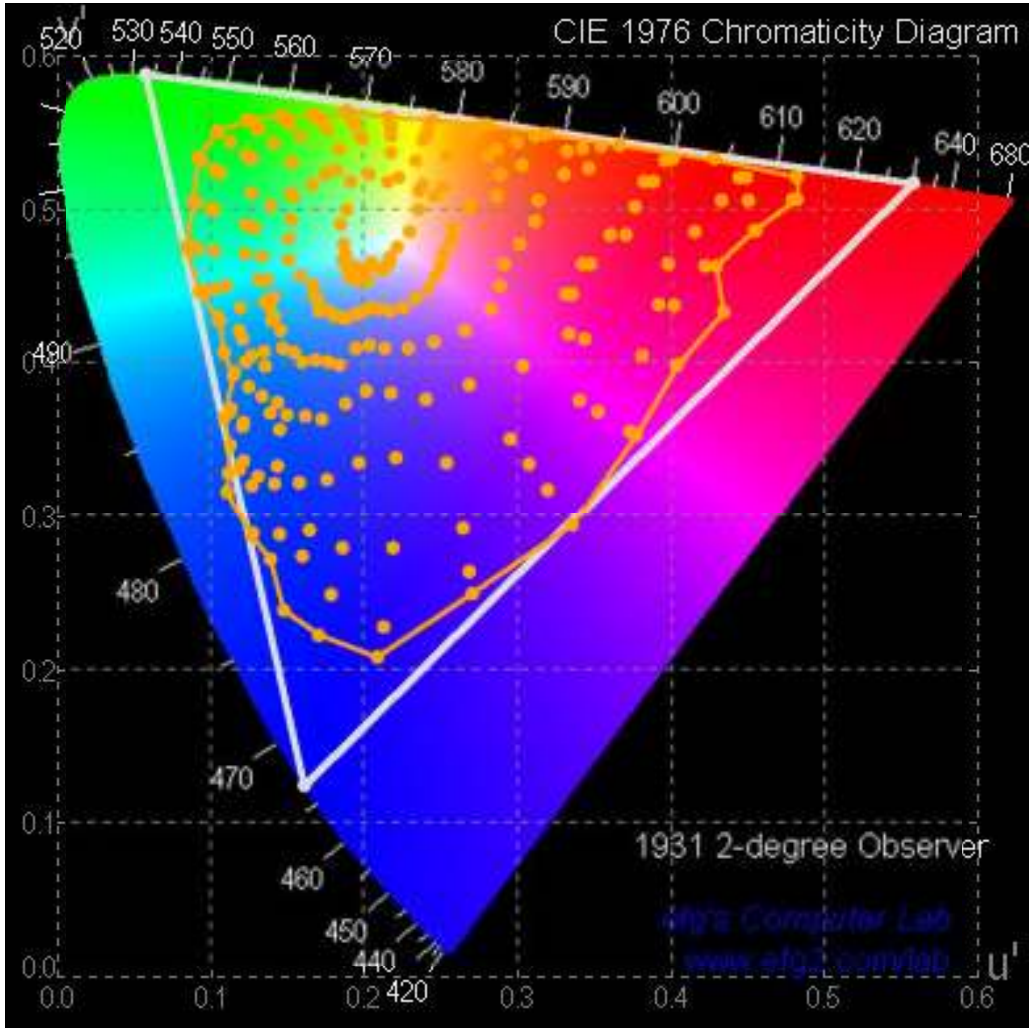
Colors for Ultra-High Definition TV – Rec.2020



- Rec.2020 is the UHD-TV color standard
  - Covers 76% of color space seen by human eye
  - Covers ~100% of Pointer's gamut
- Combined with higher pixel resolution (4K and 8K), higher dynamic range and 22.2 multi-channel sound UHD-TV will make you feel like you are really there
- Currently, only laser-based rear projection DLP TVs can deliver close to Rec.2020 color gamut
  - Mitsubishi LaserVue

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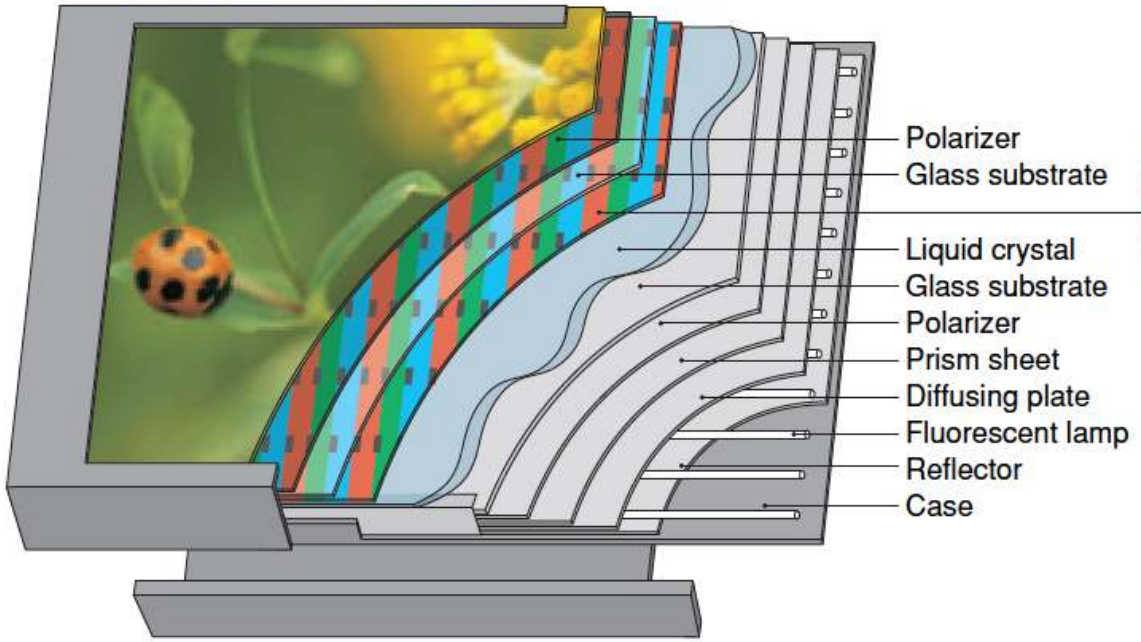
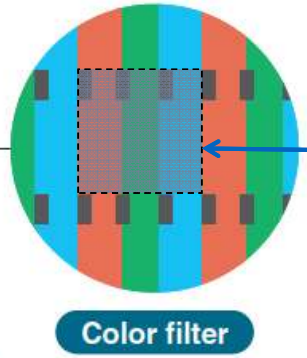
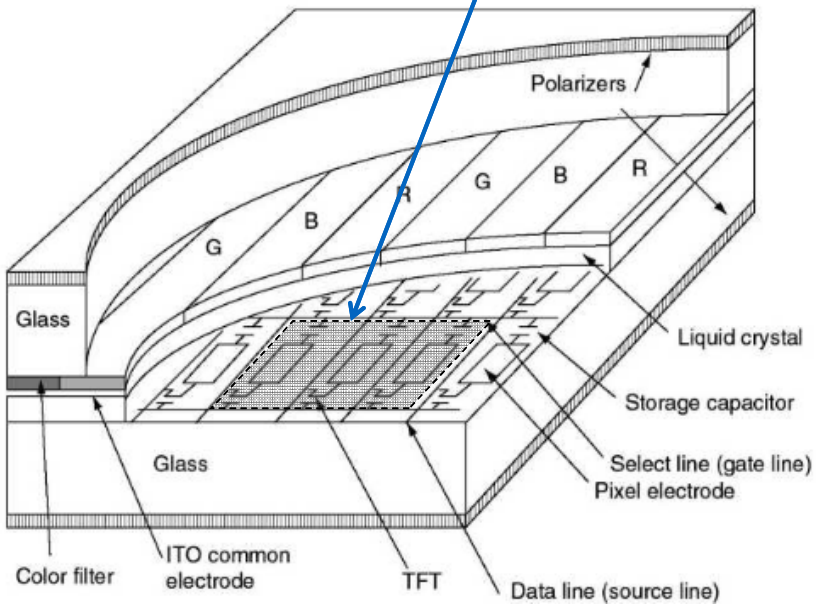
Creation of Primary Colors in LCD





1 pixel



- In LCD, each pixel consists of R, G, and B sub-pixels
- By using white backlights and color filters, R/G/B primary colors are created

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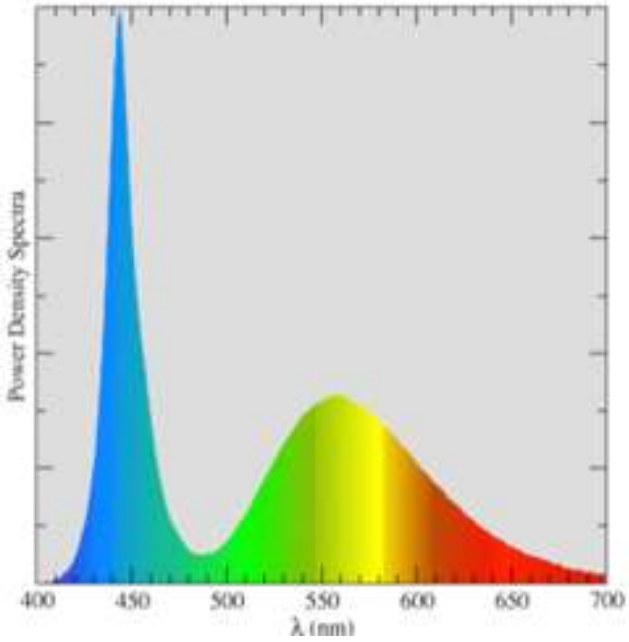
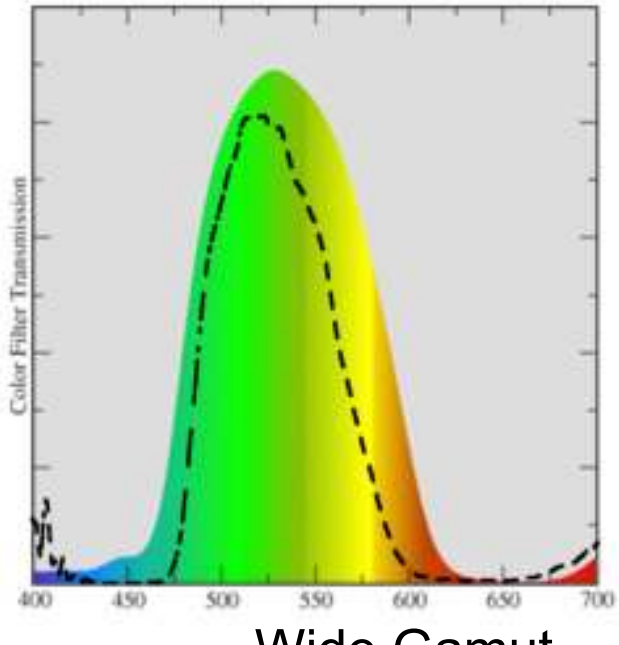
Creating Primary Colors using White LEDs for Standard & High Color Gamut. Example: Green

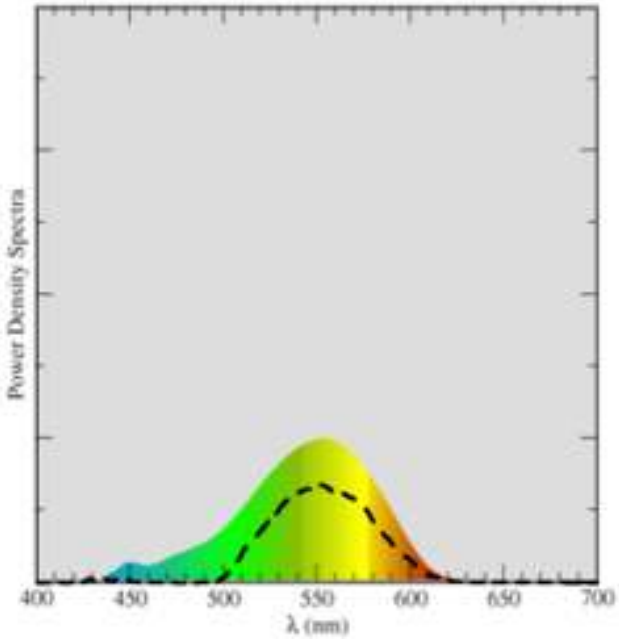
Backlight Spectrum



Green Color Filter



Green Spectrum



– – – – Wide Gamut

- Narrow band-pass color filters need to be used to carve out the primary color from a broad white light source
- For high color gamut displays, even narrower-band color filters need to be used. More light is thrown away

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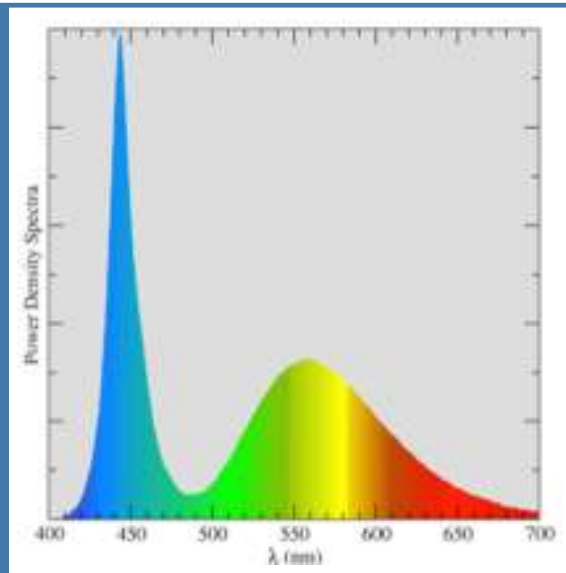
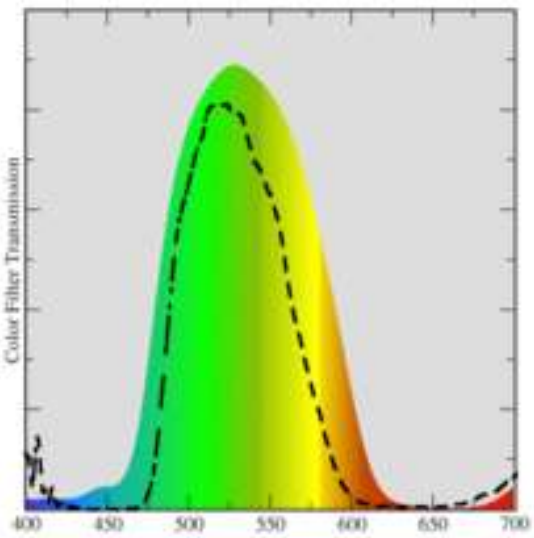
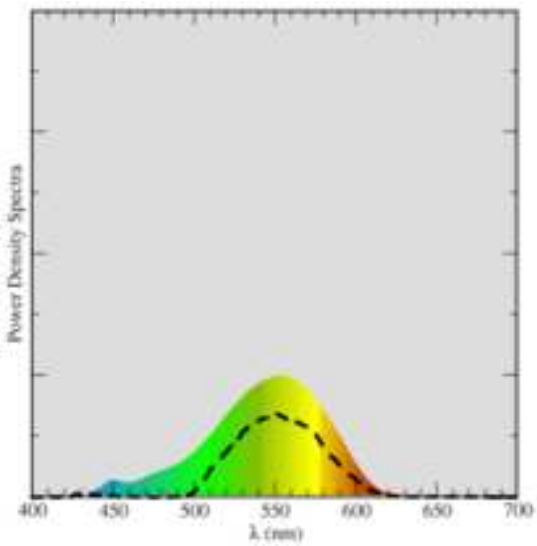
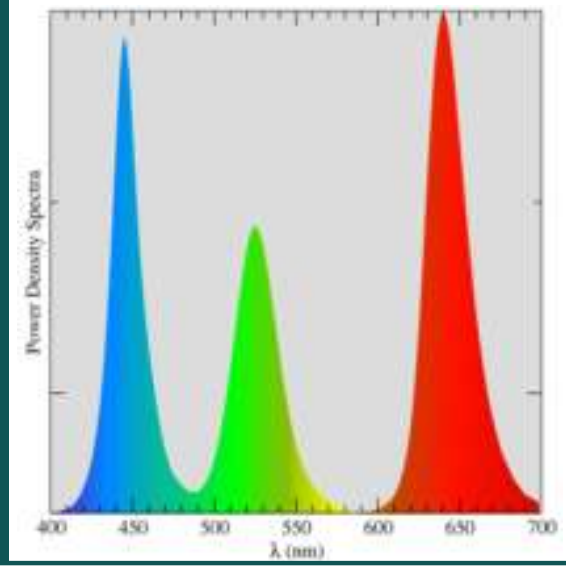
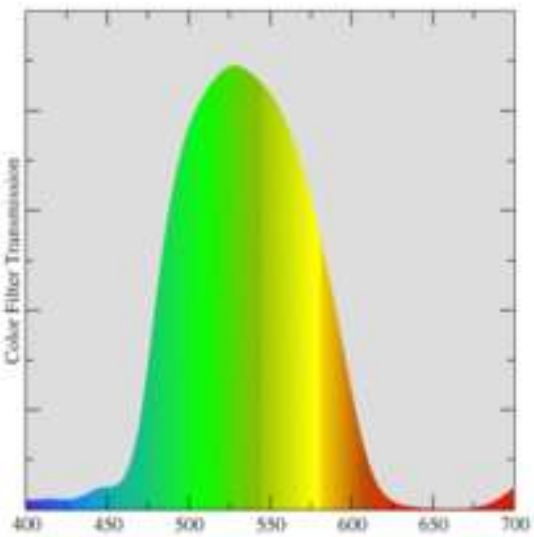
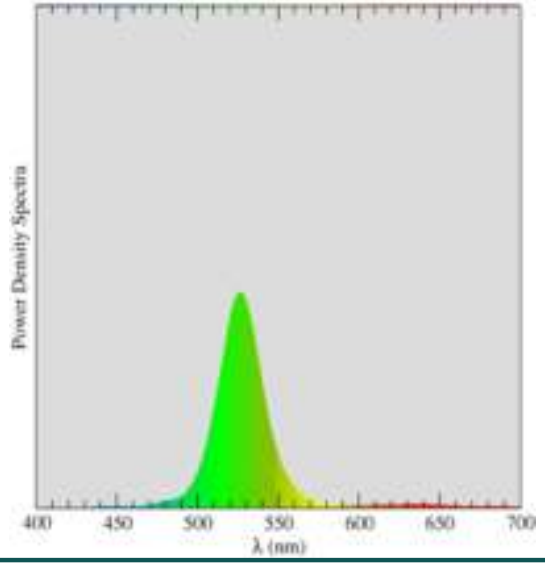
Creating Primary Colors using QDs

Color Filters Only Need to Filter Out Other Peaks – Example Green

	Backlight Spectrum	Green Color Filter	Green Spectrum
White LED			
Blue LED + QD			

— — — - Wide Gamut

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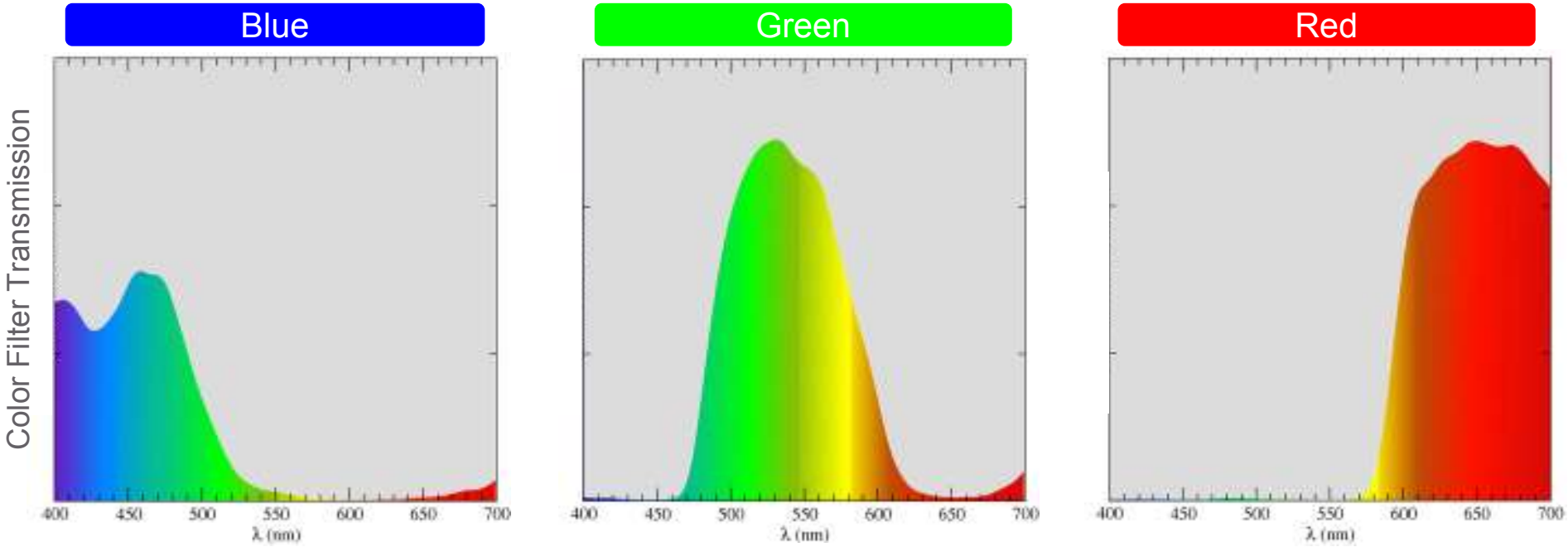
Existing LCD Color Filters



- For this demonstration, we used existing LCDs with mainstream color filters

- These color filters are designed for sRGB using white LEDs with broad-band yellow phosphor

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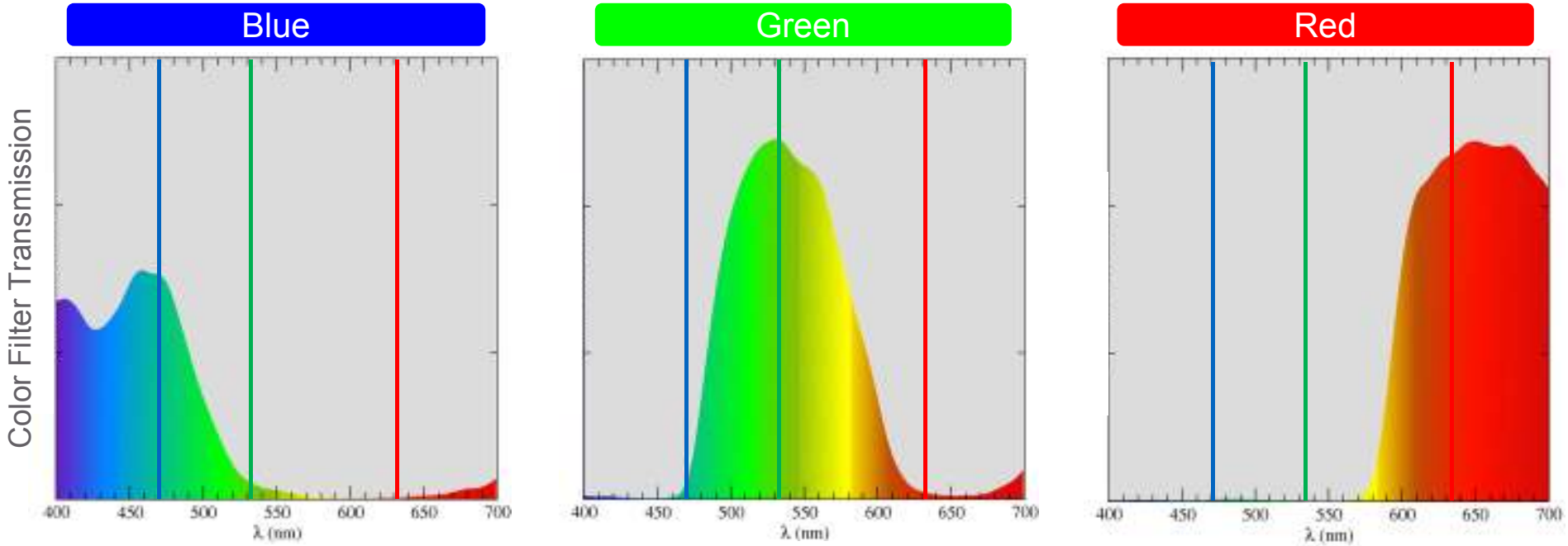
Existing CFAs with rec.2020 Ideal Wavelengths



- The ideal wavelengths for Rec2020 are monochromatic sources at 467nm, 532nm and 630nm

- But monochromatic sources are expensive

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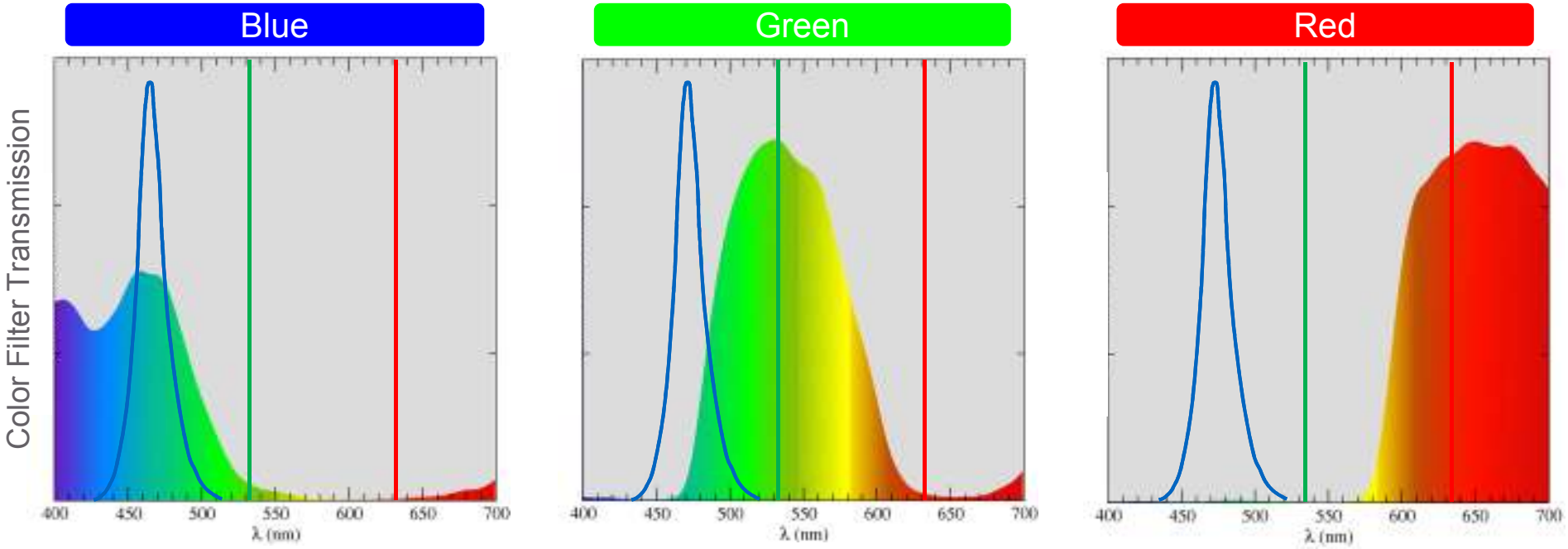
Current CFAs and Blue LED Spectra at rec.2020 Primary Wavelengths



- If we substitute a GaN blue LED for the blue primary source at 467nm, the blue → green crosstalk is unacceptable with these color filters.

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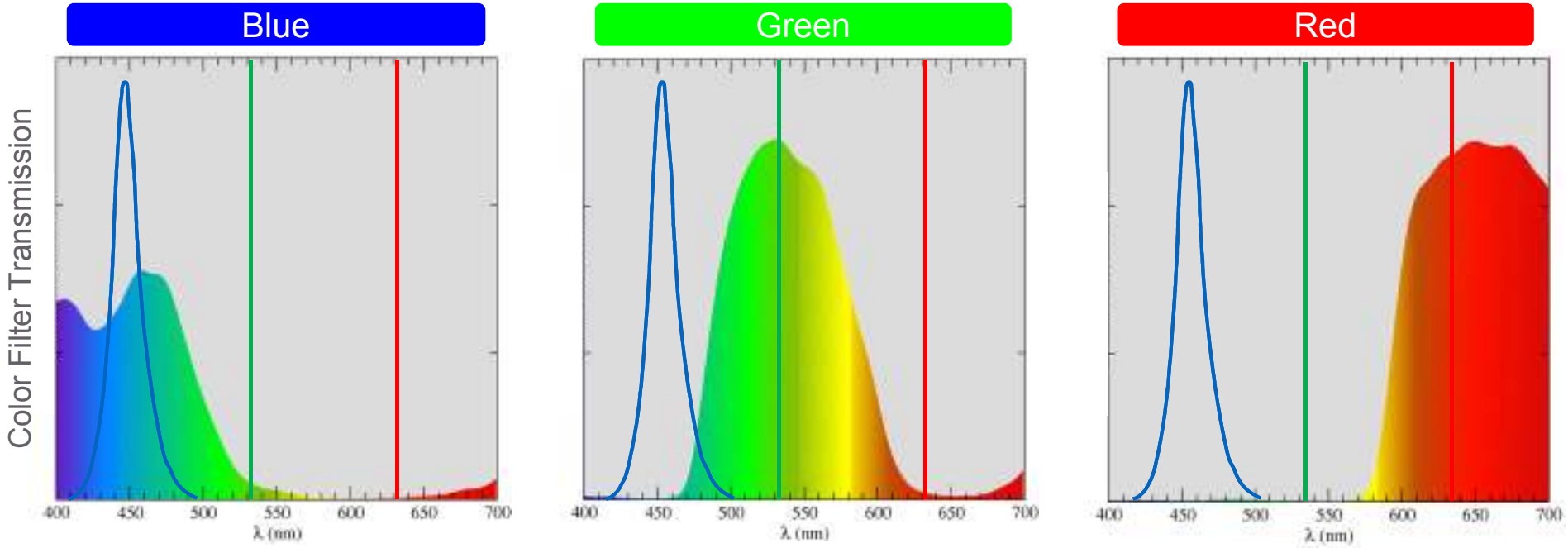
Address Blue Primary Leakage into Green by Moving Blue Deeper



- We can address this by slightly moving the peak of the blue primary to minimize the green color channel crosstalk. Doing so will sacrifice some of the rec.2020 coverage as the blue will not be in the correct location, but we can also compensate for this elsewhere to some degree.

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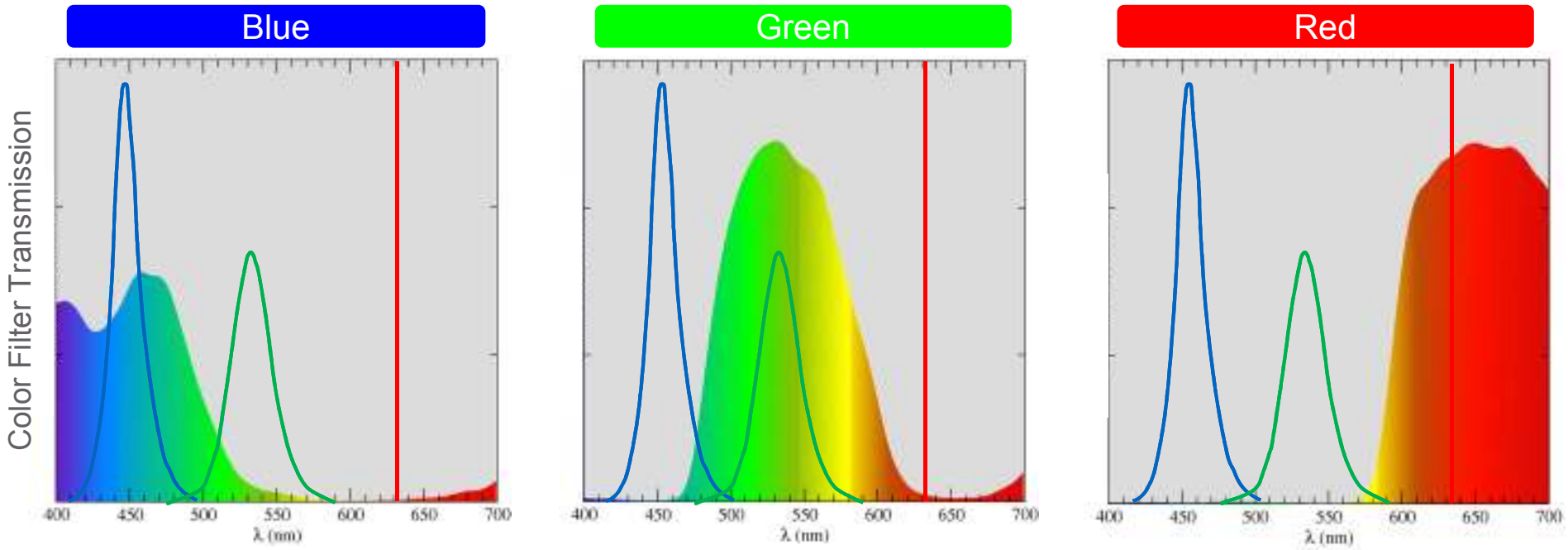
Place Green Primary with QD at <30nm FWHM



- If we then replace the monochromatic green source with a green using a QD emission spectra, we see that we have some cross-talk of the green into the blue. This can be tuned to optimize the blue by moving the green.

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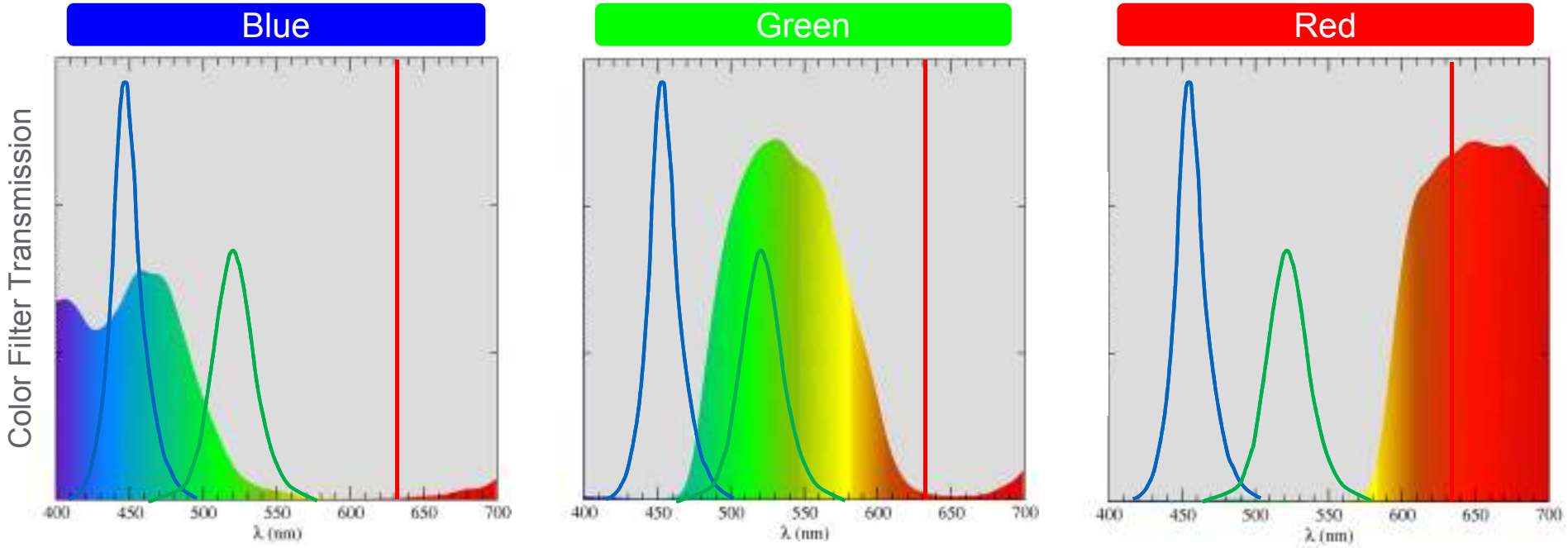
Slightly Blue Shift Green to Compensate for Shifting Blue



- By moving the green primary deeper, we can increase the green-blue cross talk in the blue, and while the effect is a more distributed primary, the result is that we shift the blue primary back red slightly and improve its location on the cie diagram.

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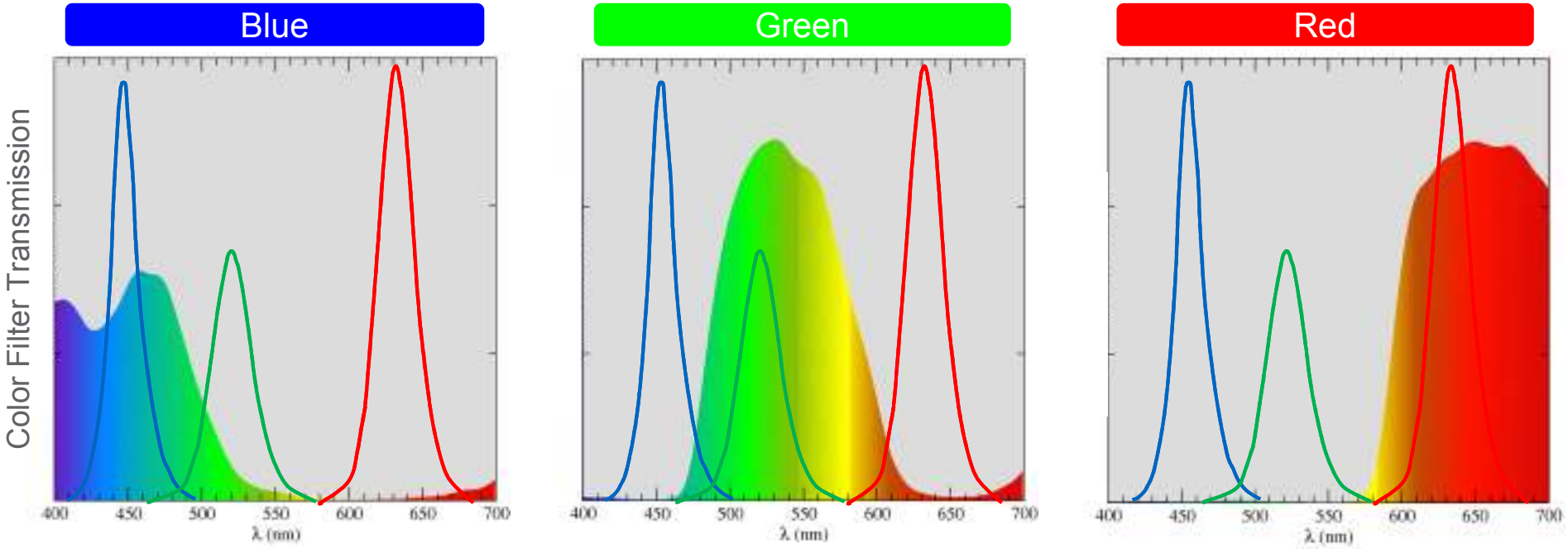
Place Red Using QD with FWHM < 30nm



- Using a narrow red QD emission, we can easily place the primary at the rec2020 primary of 630nm

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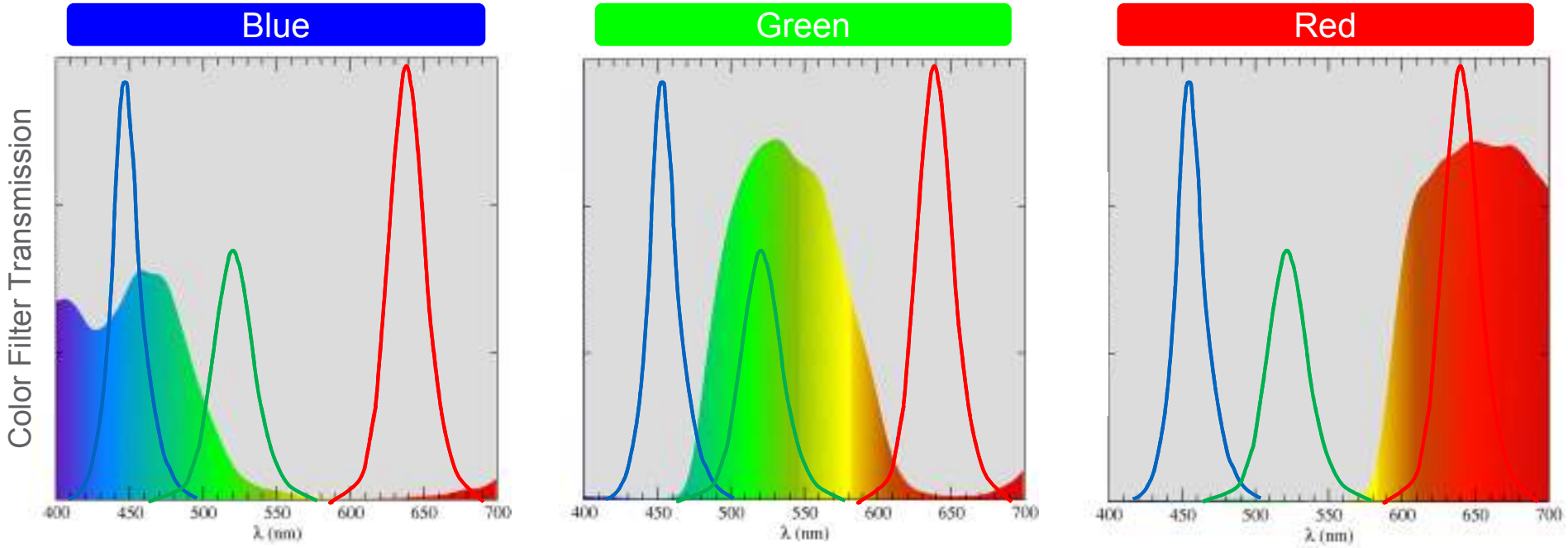
Use final tuning to optimize red location



- Final simulation of the effect of the red primary on overall Rec2020 coverage show that a slight increase in the red will improve the system performance.

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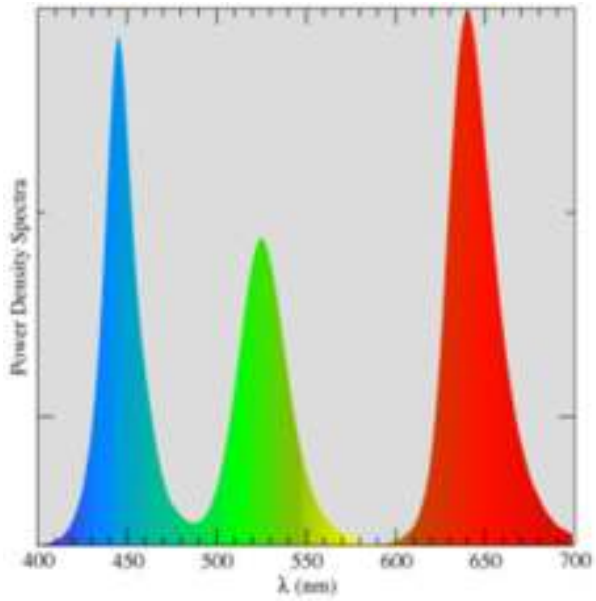
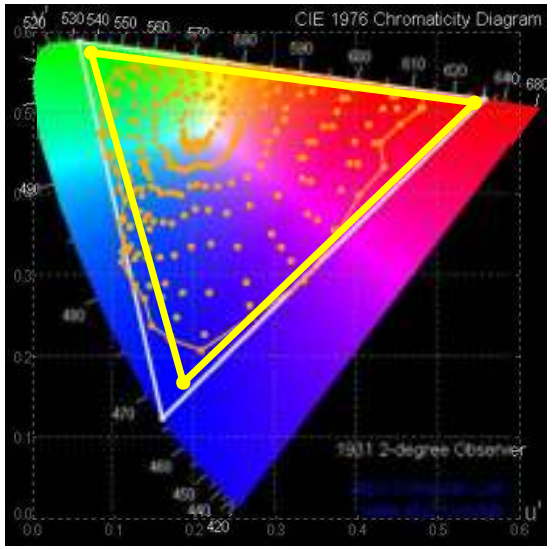
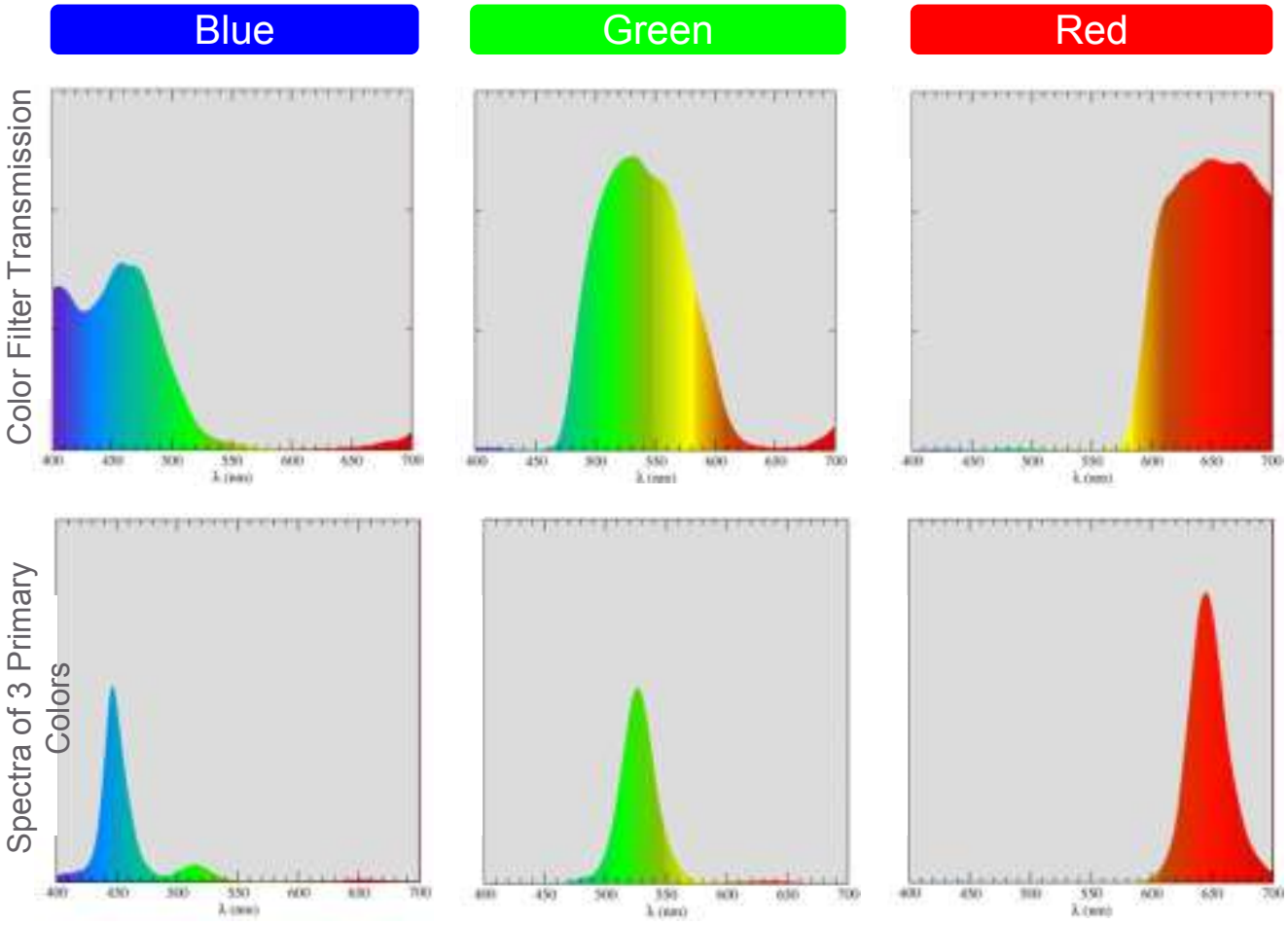
Final result is >90% Rec2020







Blue = 447nm Green = 526nm Red = 640nm

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Ultra-Book Demo – Edge-Lit

Control Unit
sRGB

QD Demo
90% rec.2020

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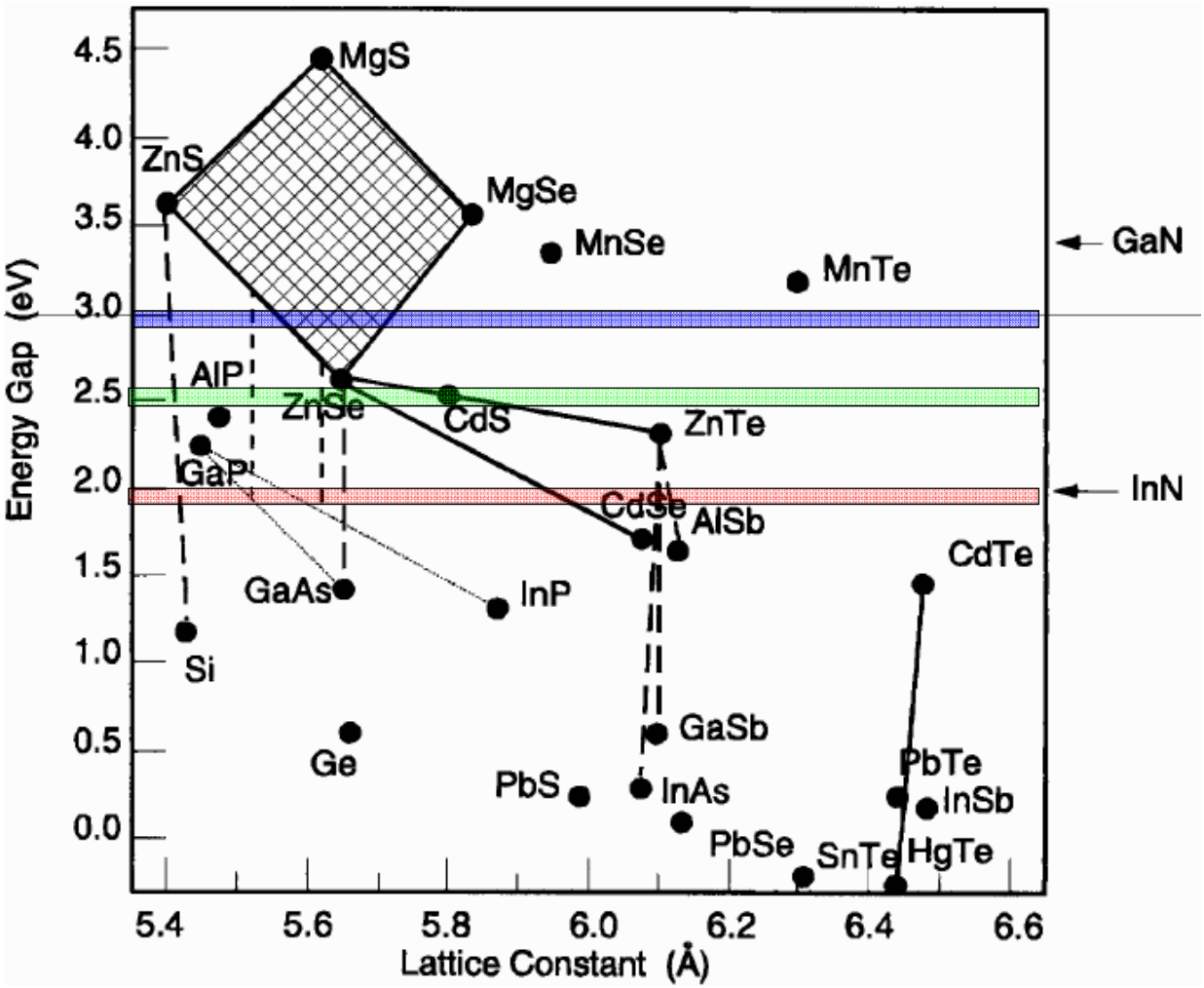
Limitation of Non-CdSe Quantum Dots

- Very limited semiconductor materials choices for efficient light emission in the visible
  - Bulk material emission in near IR
  - Direct band-gap
- Candidates for QD core
  - CdSe
  - GaAs
  - InP (In-based)
    - Very small crystals. Difficult to achieve:
      - FWHM <30nm
      - Thick shell (stability)
      - Low wavelength green



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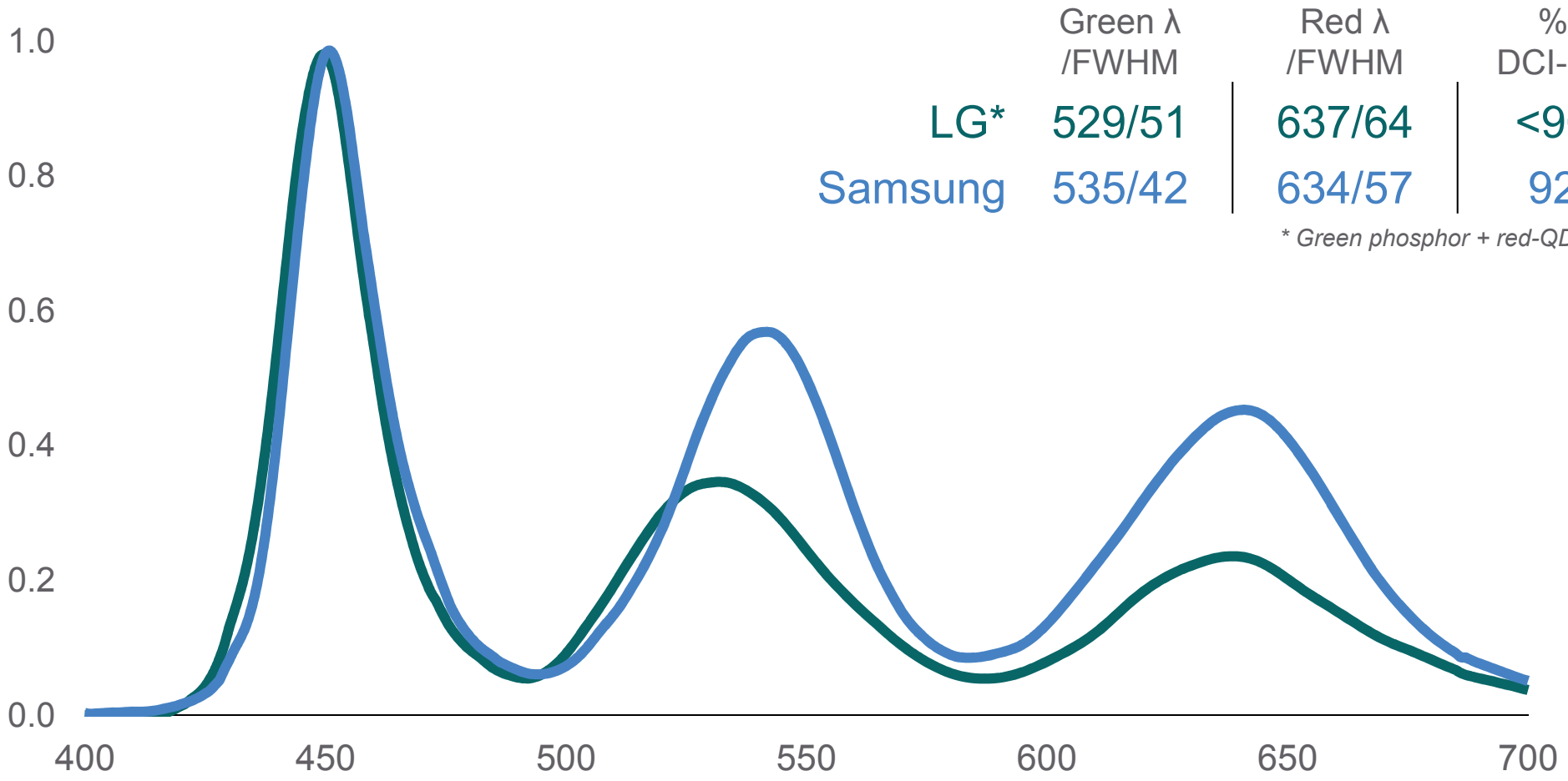
Non-CdSe Quantum Dots



	Green λ /FWHM	Red λ /FWHM	% DCI-P3
LG*	529/51	637/64	<90
Samsung	535/42	634/57	92

** Green phosphor + red-QD film*

- **LG & Samsung spectra taken from CES TV demos**

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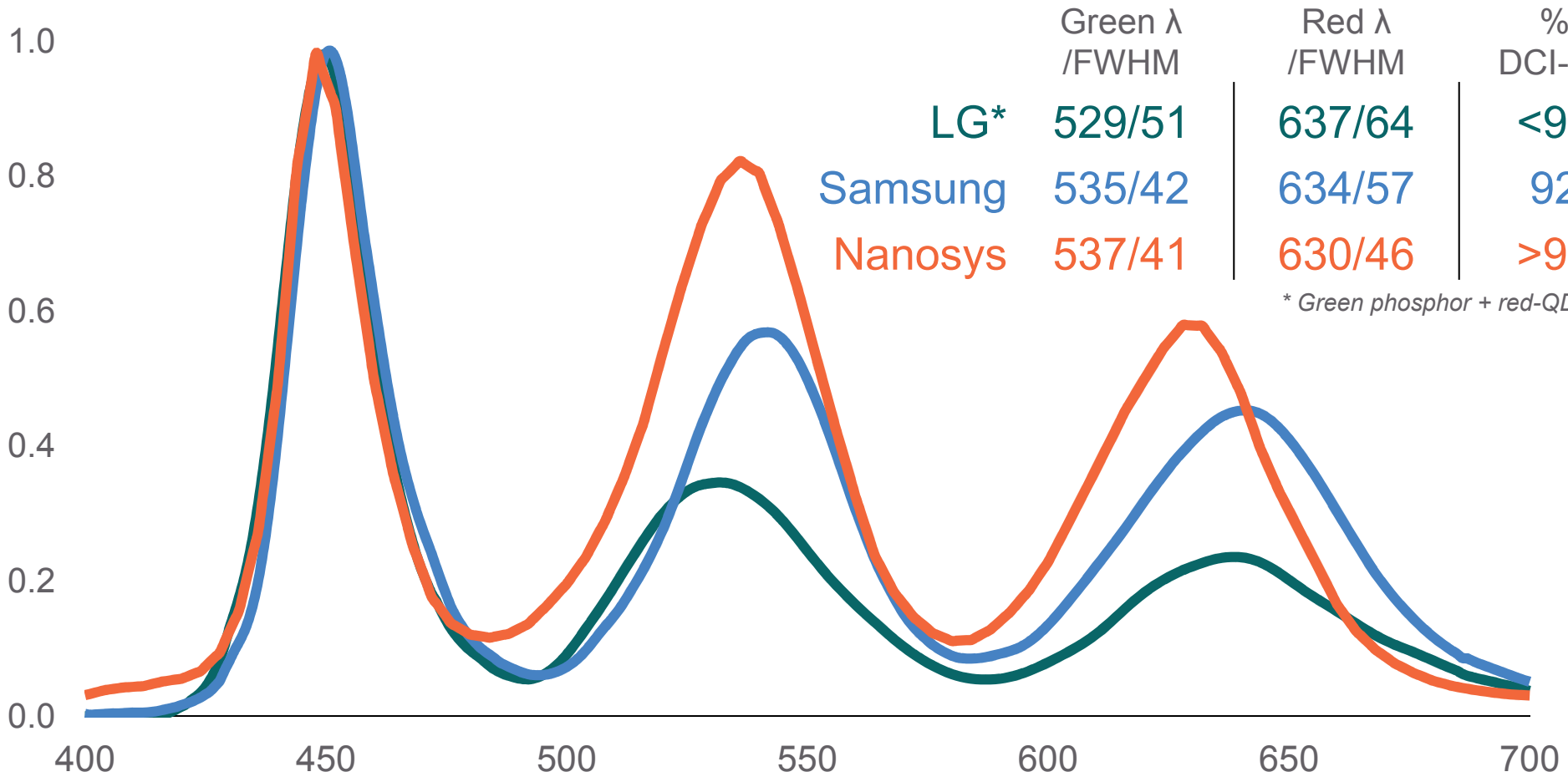
NNSY Non-CdSe Quantum Dots



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LG*	529/51	637/64	<90
Samsung	535/42	634/57	92
Nanosys	537/41	630/46	>99

** Green phosphor + red-QD film*

- **LG & Samsung spectra taken from CES TV demos**
- **Nanosys Non-CdSe QDs have narrower FWHM**

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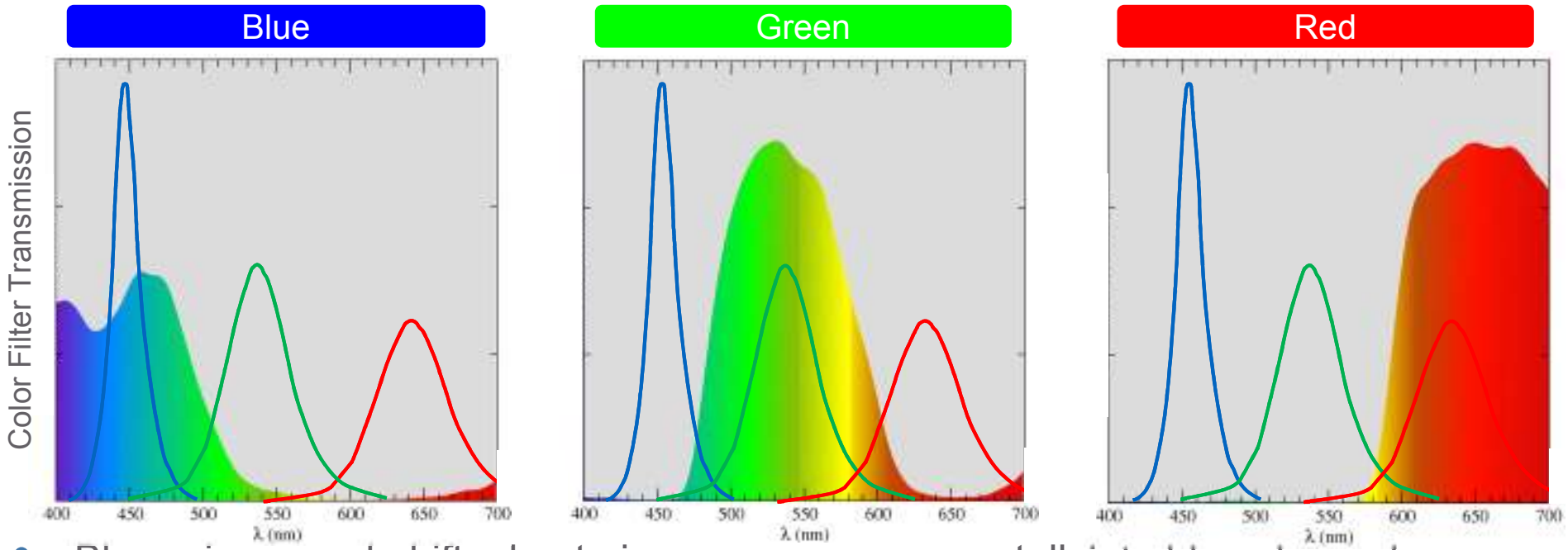
Using Nanosys Non-CdSe QDs for Rec2020



- Blue primary red-shifts due to increase green cross-talk into blue channel.
- Green primary broadens and red shifts from broader green and broader red FWHM
- Red primary blue shifts. Can be compensated by moving red even deeper but decreases photopic brightness by ~1%/nm.

- Impossible to reach >82% Rec2020 coverage without lower peak green wavelength and major improvement in FWHM or major change in CFA
- D65 also very challenging to hit

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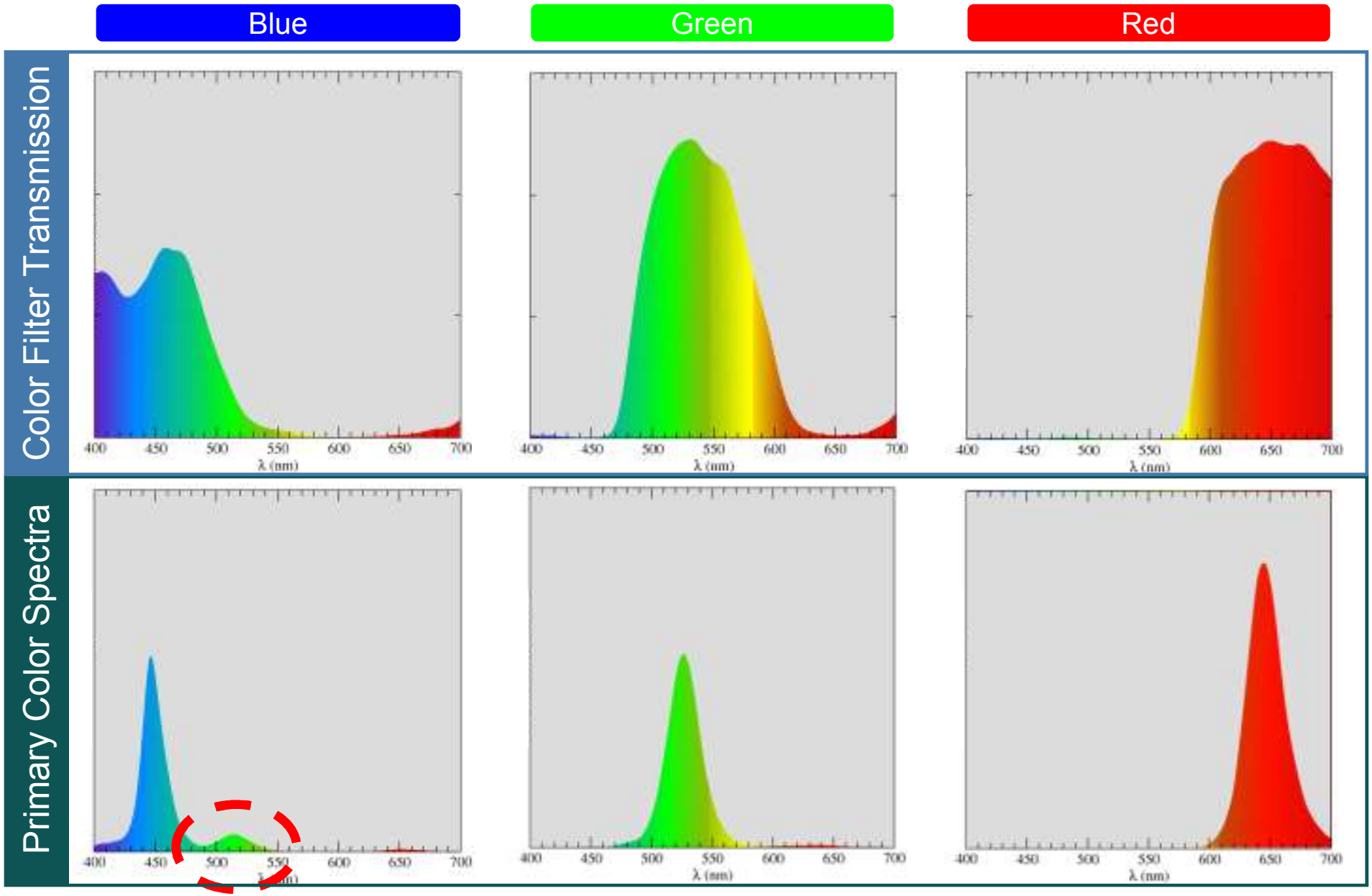
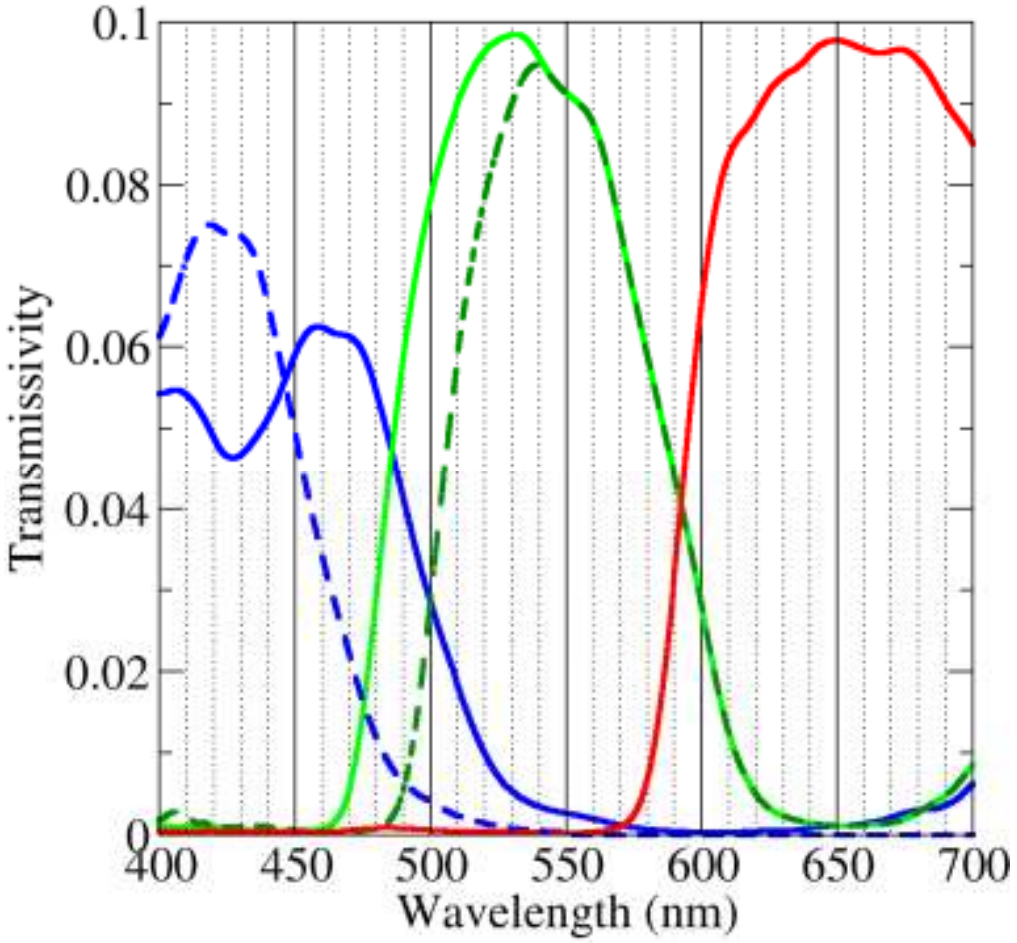
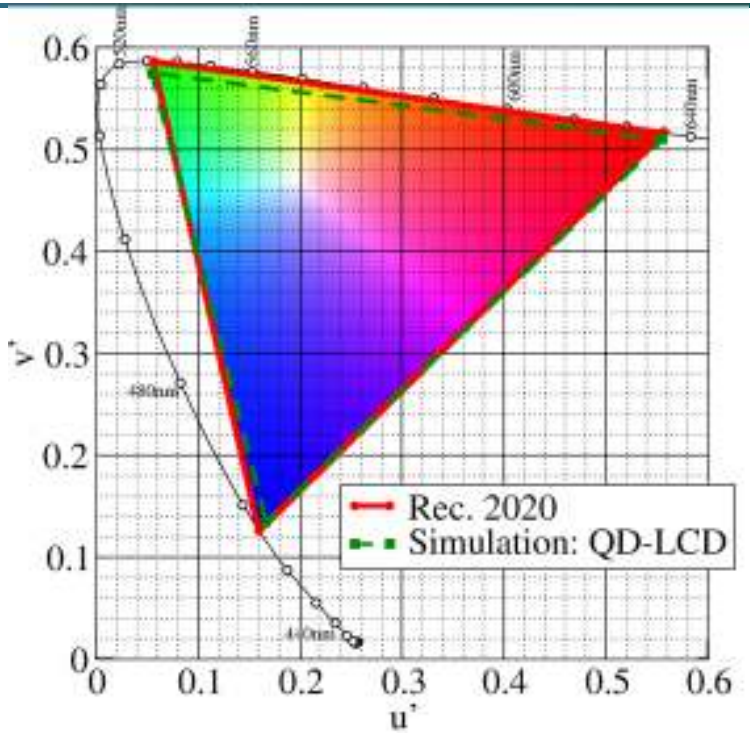
Limitation from Current Color Filters = 94% Rec.2020



Getting >95% Rec.2020 with QDs



Solid lines: Current CF72
Dashed lines: Proposed CFs



- To further improve Rec.2020 coverage beyond 95%, both blue and green color filters need to change
  - Better separation of the blue and green peaks
  - Combine with spec change or definition change to slightly different primary peaks to enable 100% compliance

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Conclusions

- Rec.2020 LCD demonstrated using CdSe QD film with >90% coverage of target gamut
  - Today's mainstream CF72 color filters are used
  - With color filter modifications to better separate blue & green peaks, >95% Rec.2020 can be achieved using CdSe QDs
- CdSe QD film offers the only practical & cost effective solution for UHD-TVs with rec.2020 color gamut & high dynamic range
- Quantum Dots have already emerged from a novelty material to a commercial product. QDs and QD film are being manufactured on large scale with robust supply chain for the LCD industry

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Thank You!

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