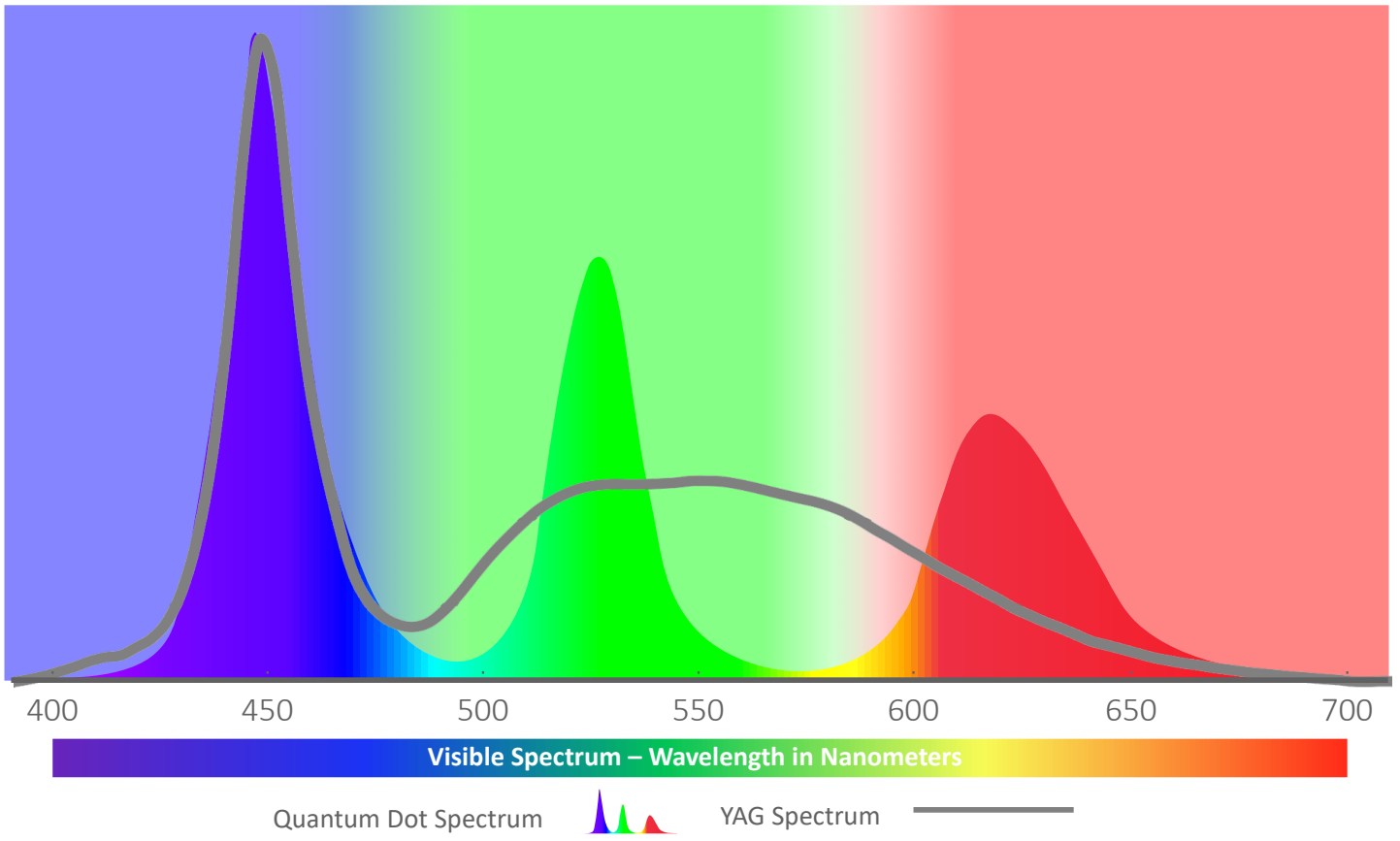
QDEF BACKLIGHT COMPARED TO YAG

QDEF RGB spectrum produces much more light in each color channel compared to YAG

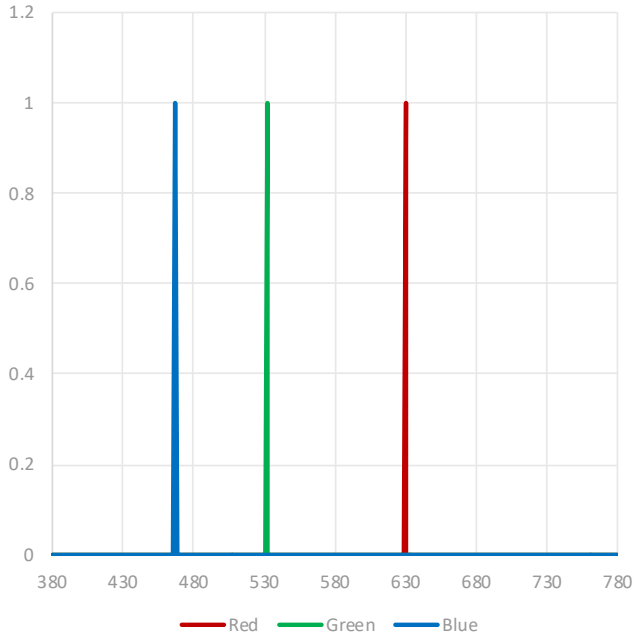


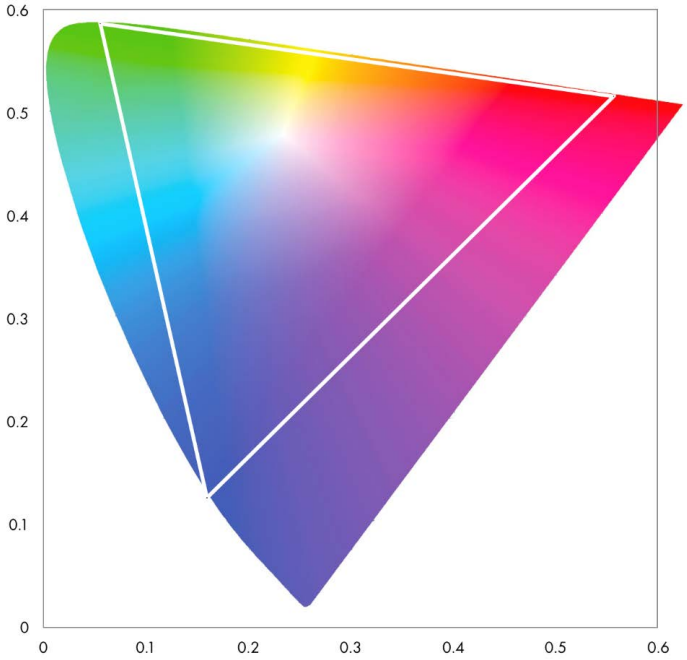
QDEF: HOW TO ACHIEVE HIGH COLOR GAMUT

- In Photoemissive displays, color filters and QD FWHM both have a major impact on gamut coverage

Let’s examine what is required to achieve high levels of BT.2020 color

HOW TO ACHIEVE HIGH BT.2020 COLOR GAMUT?





- The BT.2020 gamut color primaries are 467nm, 532nm, and 630nm
- But the gamut assumes true monochromatic sources (~1nm FWHM)
- Broader emitters are “inside” the triangle, not on the perimeter

BT.2020 GAMUT: IMPACT OF COLOR FWHM

So what happens with real world emitters?

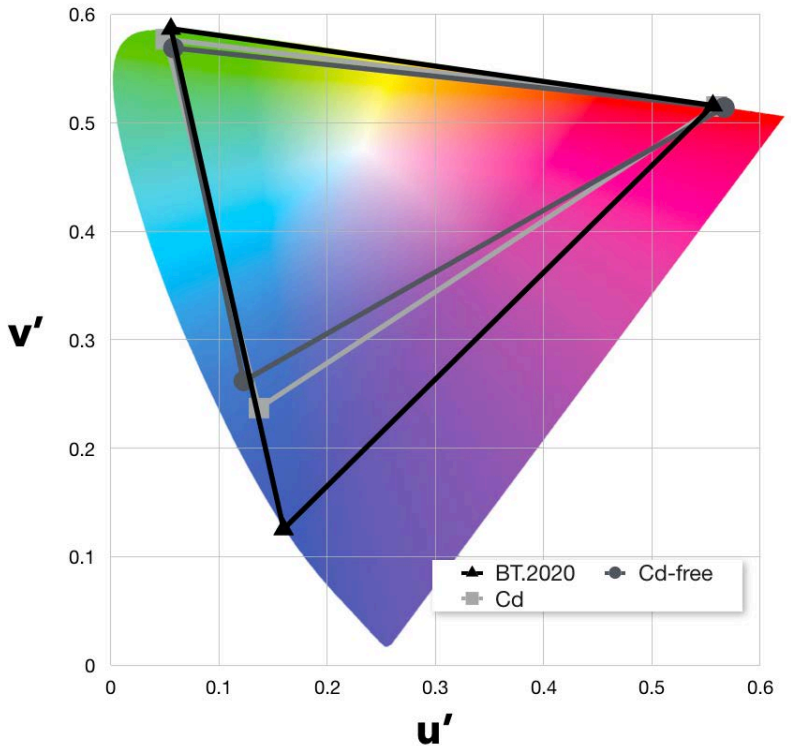
- Let's look at typical optical characteristics:
  - Blue LED: 20nm FWHM
  - Cd-Free QD: 39nm FWHM for green, 42nm FWHM for red
  - Cd-based QD: 22nm FWHM for green, 20nm FWHM for red

And use them for optical modeling of gamut…

BT.2020 GAMUT: IMPACT OF COLOR FWHM

Gamut using Standard Color Filters at BT.2020 Wavelengths

- BT.2020 Gamut coverage:
  - For Cd-free: 67.1%
  - For CdSe: 74.3%
- Green and Red color points still close, but blue color point very poor, due to color filter light leakage

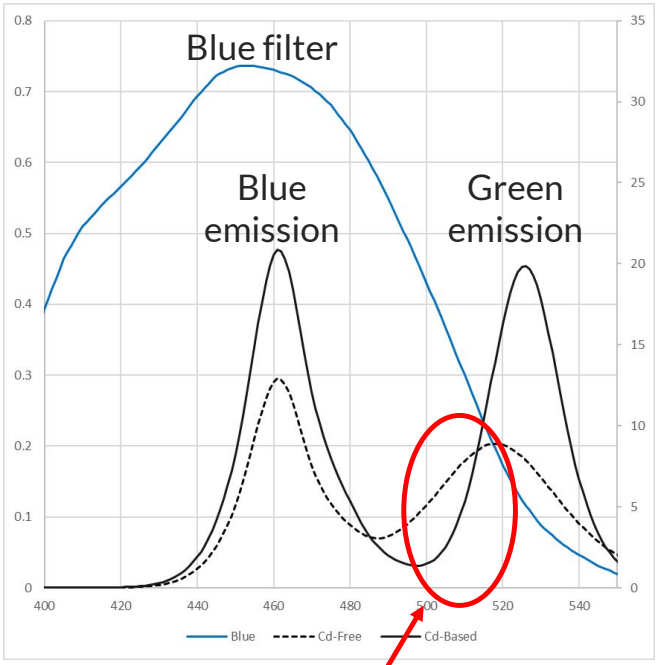


BT.2020 GAMUT: IMPACT OF COLOR FILTERS

Effect of Standard Color Filters at BT.2020 Wavelengths

- Large leakage of green emission through the blue color filter

- Gamut can be improved by adjusting peak wavelengths (spreading the colors out further).

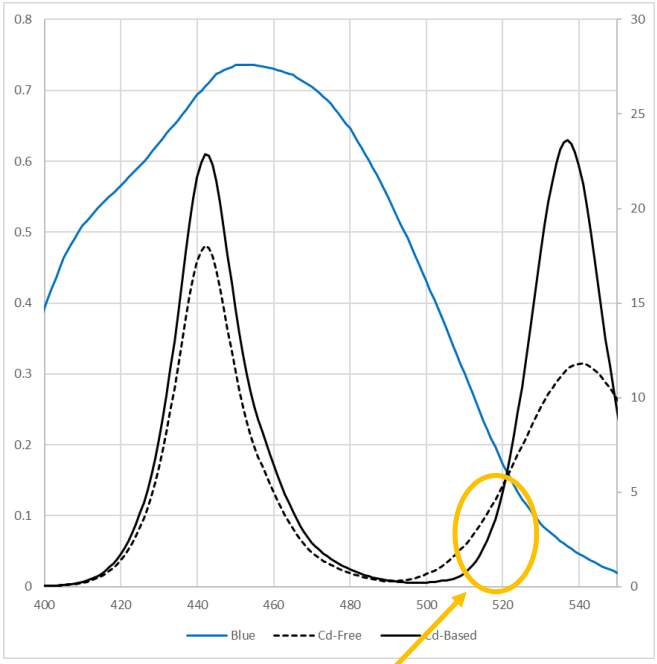


Blue color filter transmits significant green emission

BT.2020 GAMUT: IMPACT OF COLOR FILTERS

BT.2020 Gamut coverage with re-optimized wavelengths

- Optimizing wavelengths improves things significantly
  - Cd-Free: 84.5%
  - Cd-Based: 88.0%
- But gamut is still well below optimum, primarily due to green still leaking through blue color filter
- Optimization of gamut is a compromise between a correct blue primary (467 nm) and minimization of green leakage into the blue color channel.

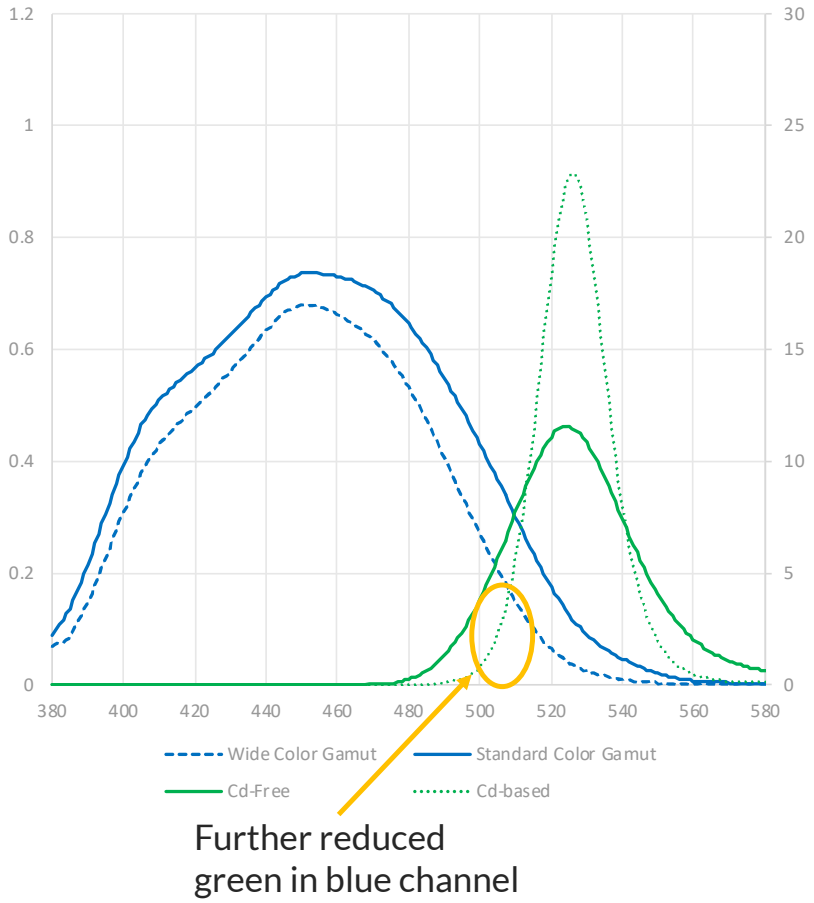


Moved emission wavelengths reduces green in blue channel

BT.2020 GAMUT: IMPACT OF COLOR FILTERS

What about “wide color gamut” filters?

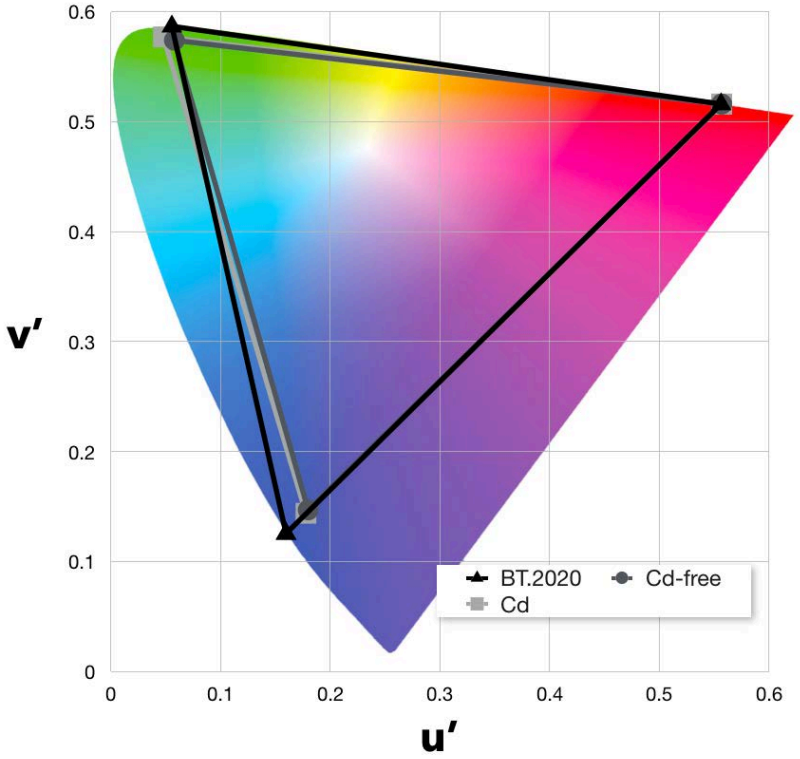
- Wide Color Gamut color filters reduce crosstalk, but typically at the expense of light output
- For blue color filter, “wide color gamut” filter usually the same filter material just at a higher concentration



BT.2020 GAMUT: IMPACT OF COLOR FILTERS

Wide Color Gamut Filters with Optimized Wavelengths

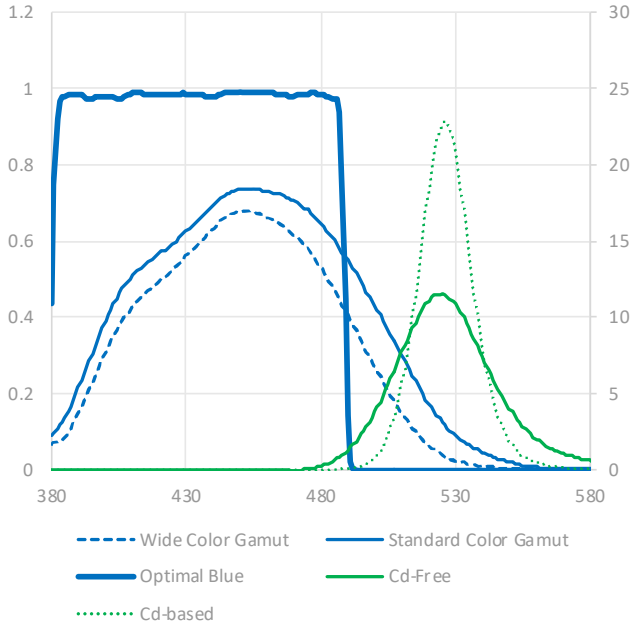
- For Cd-free: 91.9%
- For Cd: 94.3%
- Filters are the still major limitation
- Blue color point furthest from BT2020 coordinate
- Brightness somewhat compromised compared to typical color filters



BT.2020 GAMUT: IMPACT OF COLOR FILTERS

What if we could use an ideal blue color filter?

- With a high quality bandpass filter for blue only (and using standard color filters for green and red)
- BT.2020 Coverage
  - For Cd-free: 95.4%
  - For Cd: 97.4%



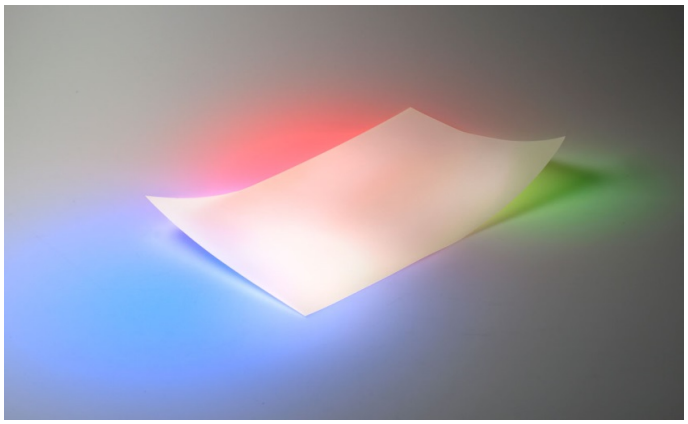
Improving the blue color filter is the single largest factor for increasing the gamut coverage in photoenhanced QD technology

QDEF: THE PATH TO BT.2020

- Conclusion on BT.2020 gamut coverage:
  - Gamut coverage is limited by cross-talk in color filters:
    - Red BT.2020 color point is reached with current color filters
    - Green color filter does limit gamut somewhat;
  - But upgrading the blue color filter alone yields nearly complete BT.2020 color gamut coverage even with standard green and red color filters. This would have a major impact on LCD display performance

HYPERION™ QUANTUM DOTS: A HYBRID OF INP AND CDSE

- Hyperion™ Quantum Dots are created by combining green CdSe and red InP
  - Green CdSe QD composition engineered to have very low cadmium content.
  - Ligand and adhesive matrix were designed to be compatible with both material systems
  - Result: Excellent gamut coverage and RoHS compliance at 70-95 ppm cadmium
  - SID named Hyperion 2017 Display Component of the Year.
  - Numerous QD displays today use Hyperion.



Specifications:
FWHM: Green 23nm
FWHM: Red: 39nm
Cadmium conc: <95ppm
>90% BT.2020 coverage

NANOSYS QDEF PERFORMANCE COMPARISON

Gamut coverage of NNSY products using WCG color filters

		Cd-based	Low-Cd (Hyperion)	Cd-free (InP)
Gamut Coverage	DCI-P3 coverage (CIE1976)	>99%	>99%	>99%
	Adobe RGB coverage (CIE1976)	>99%	>99%	>99%
	NTSC area (CIE1931)	>100%	>100%	>100%
	BT.2020 coverage (CIE1976)	92%	91%	88%
Relative Brightness		100%	96-98%	91-94%

- To reach >90% BT.2020, Cd-free QD emission needs to be narrower: G: 33nm, R: 35nm FWHM
- Note: Different color gamuts have different relative brightness. BT.2020 will always be dimmer than a smaller gamut because of the deeper red color point.