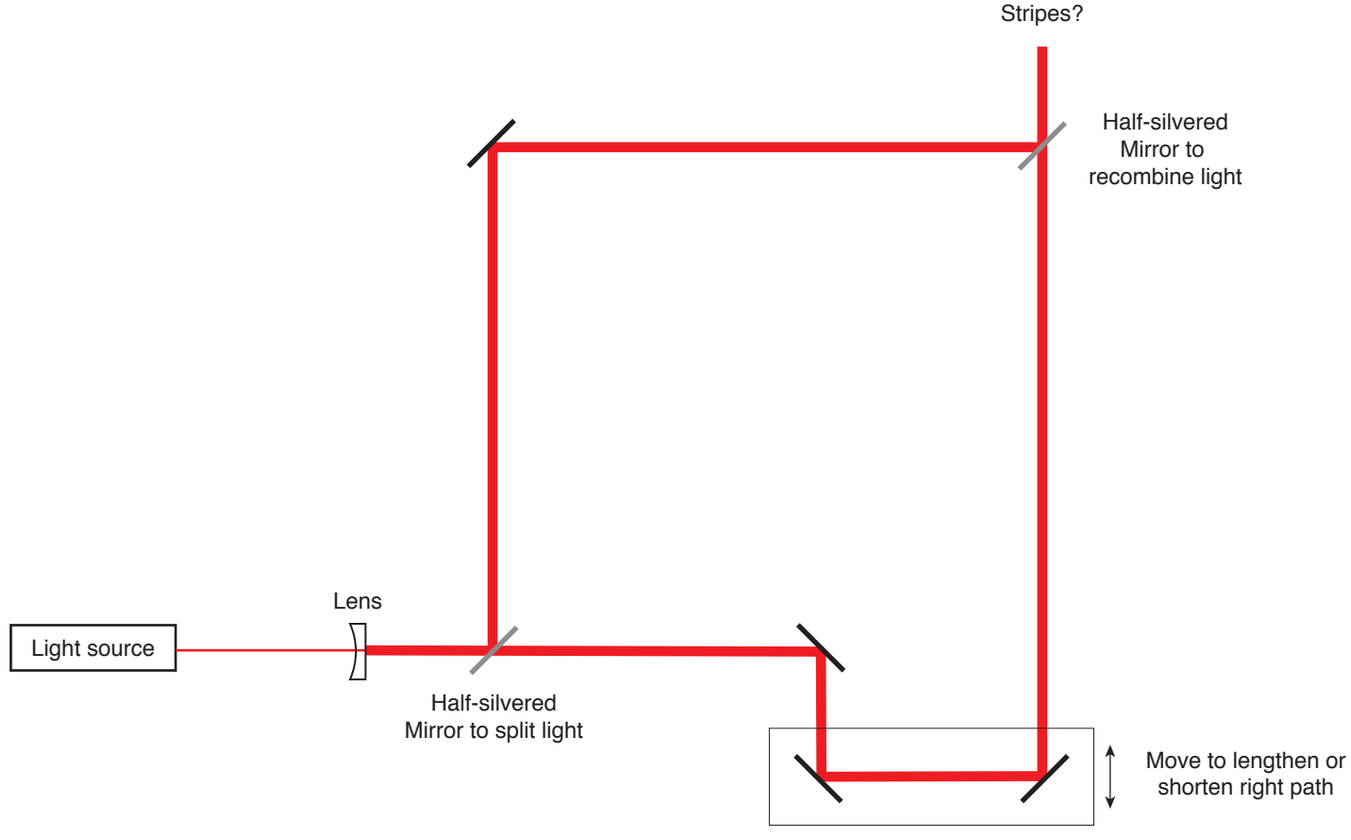
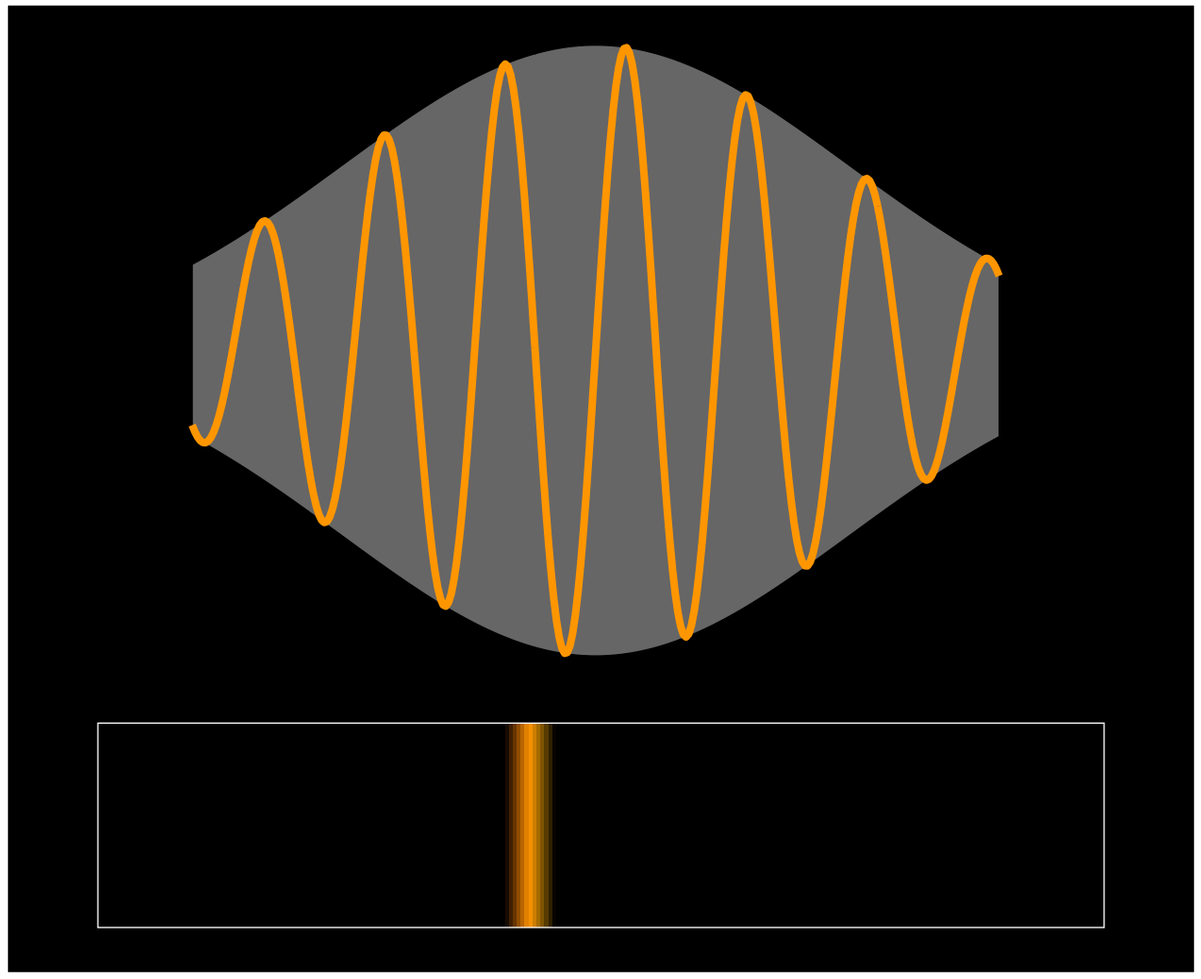
Particle Introverts & Extroverts

Stripes fade

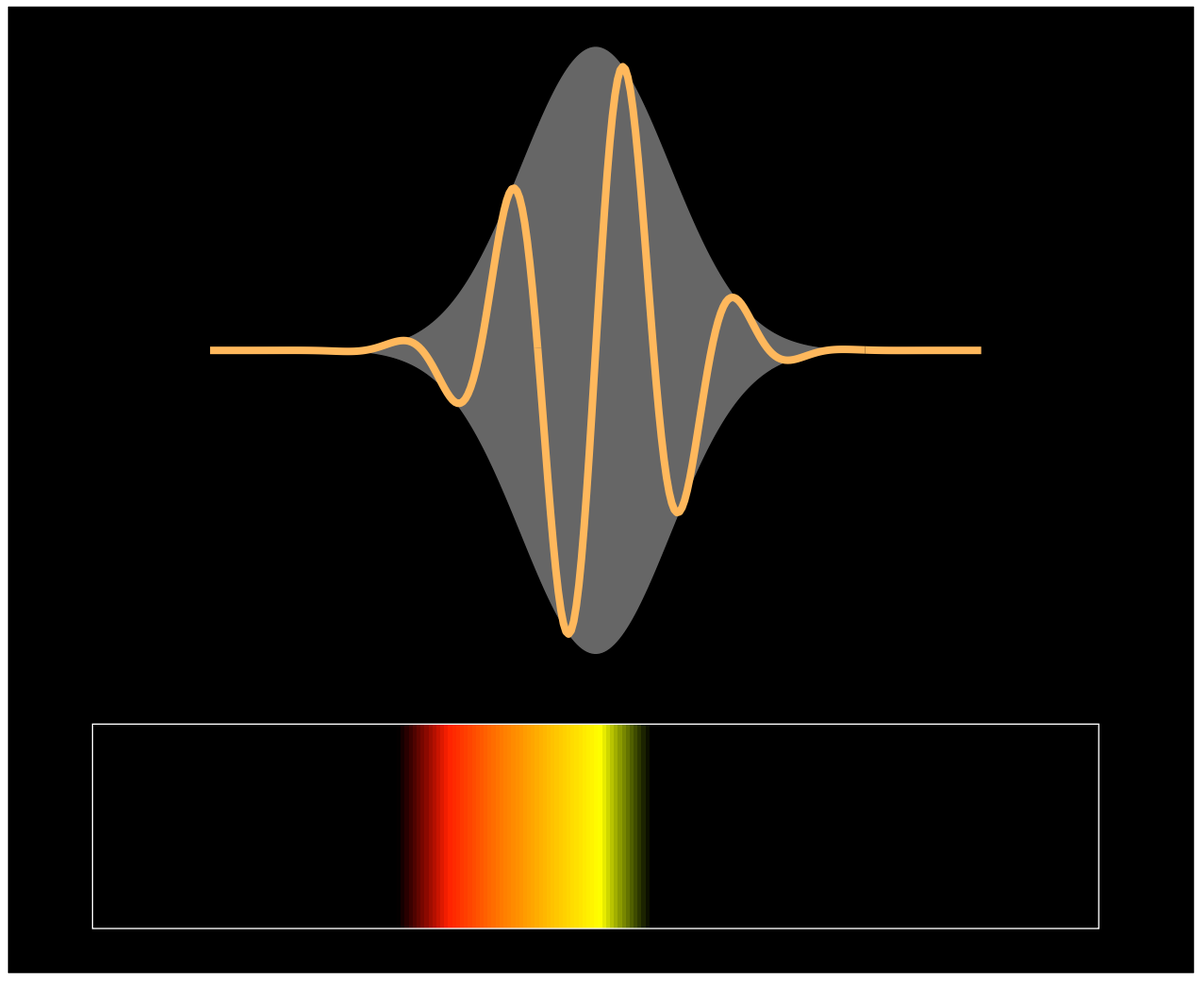
- Sometimes very quickly (white light; microns)
- Sometimes very slowly (fancy lasers; km)



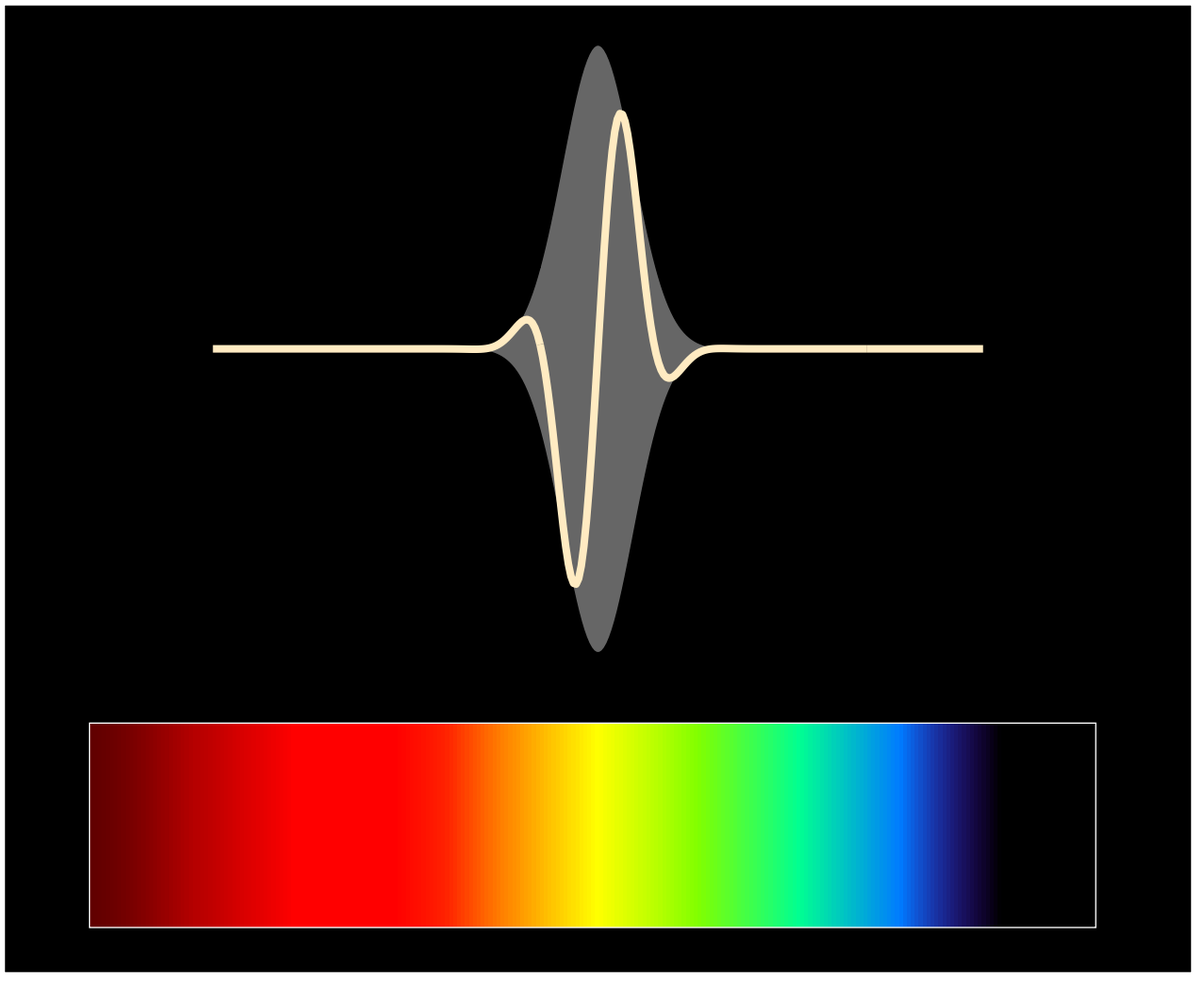
Long ripple, narrow color



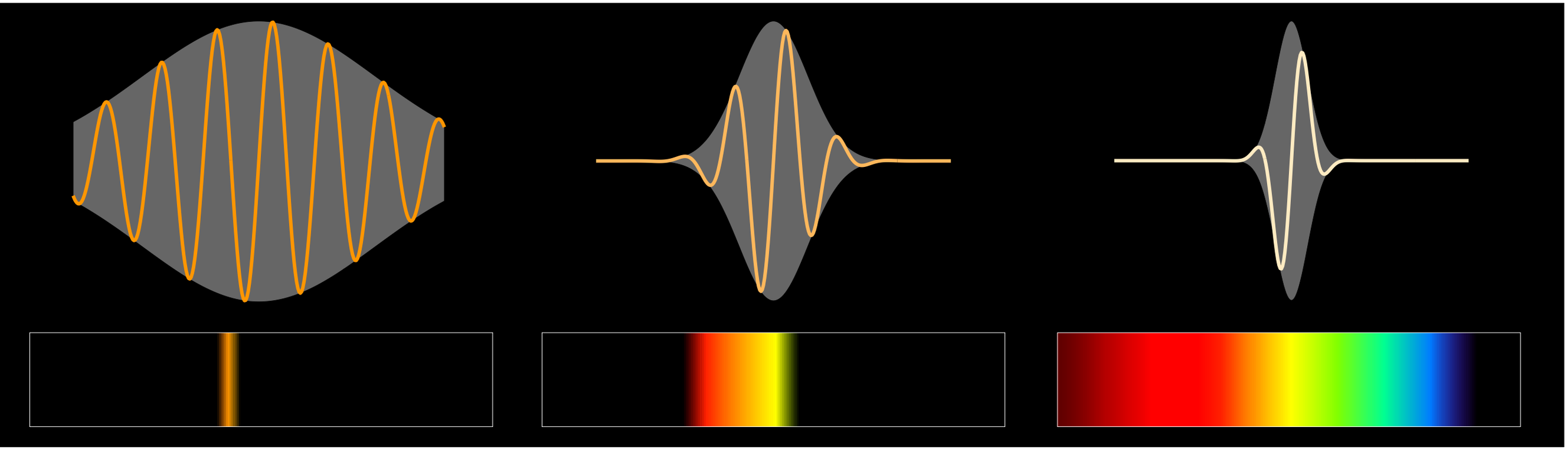
Med ripple, medium color range



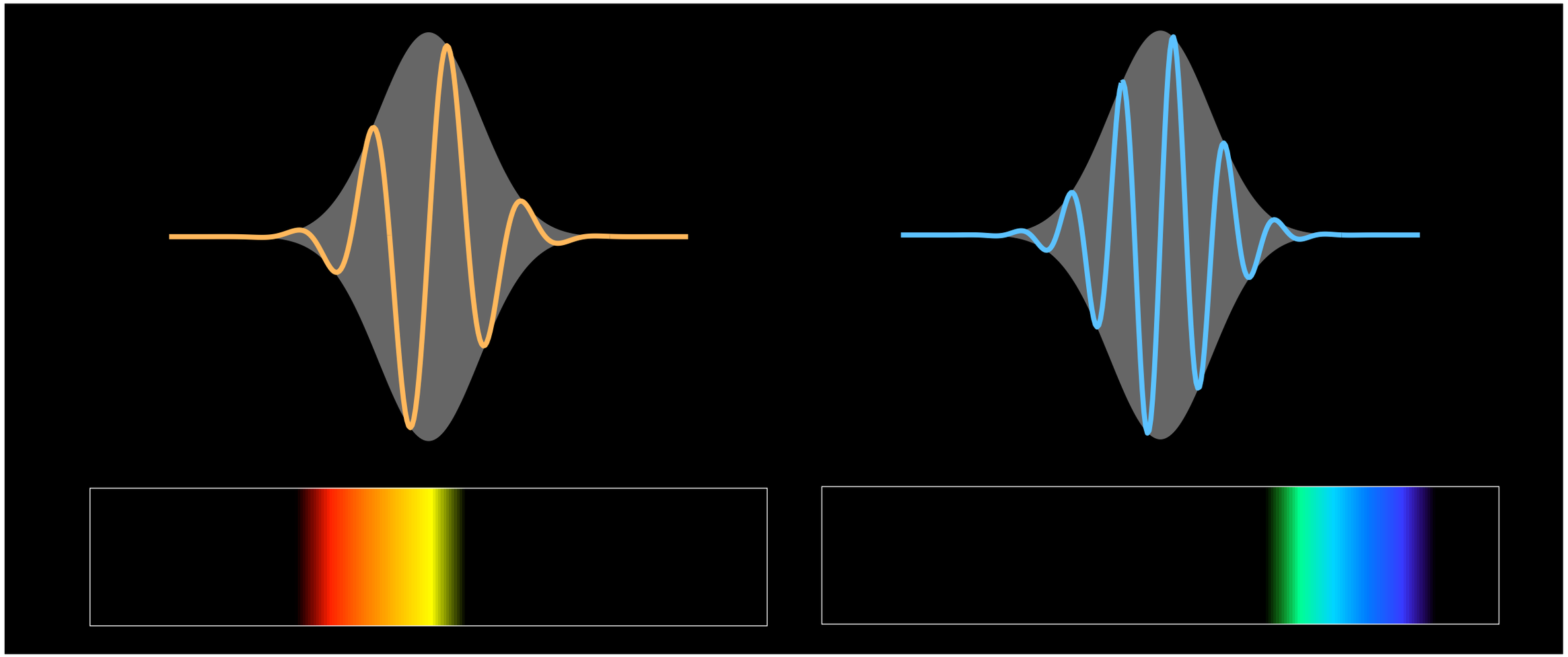
Short ripple, wide color range



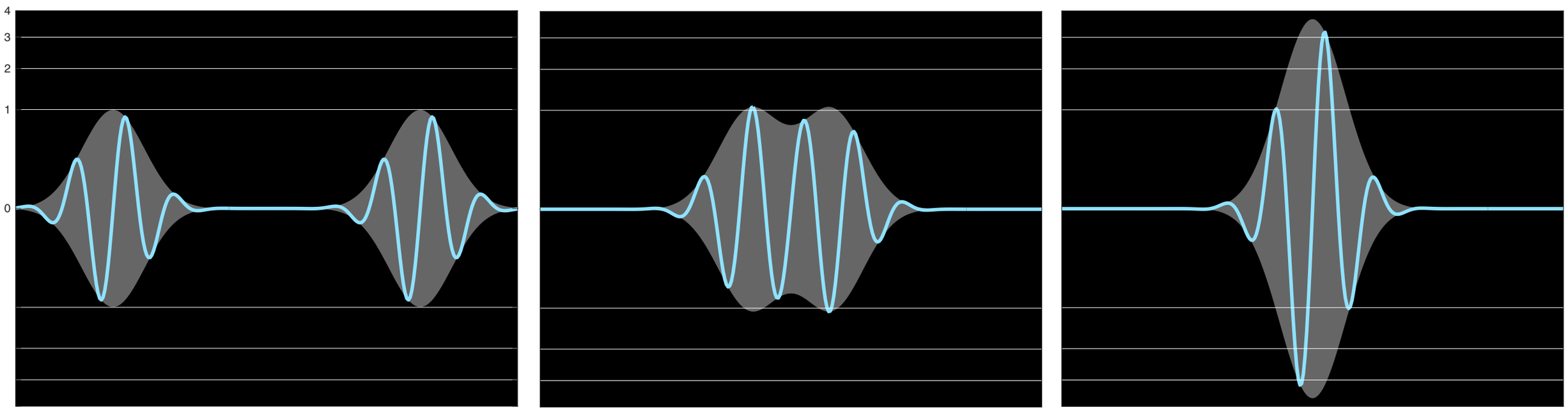
Ripple length



Can have any color



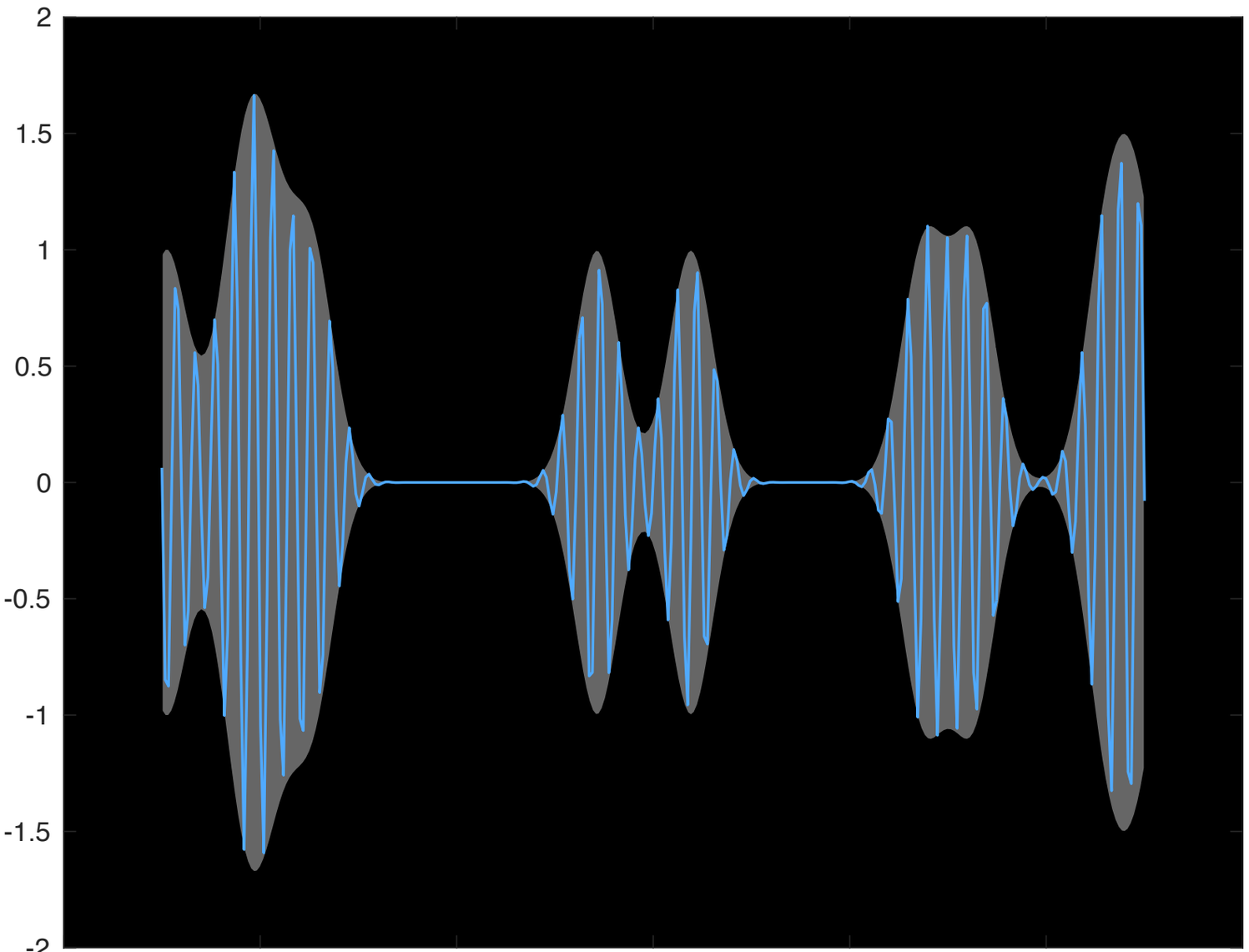
What happens if particles overlap?


4
3
2
1
0

Take starlight with perfectly random photon arrivals (ripples), and squeeze the light ripples onto a fiber

Photons interacting

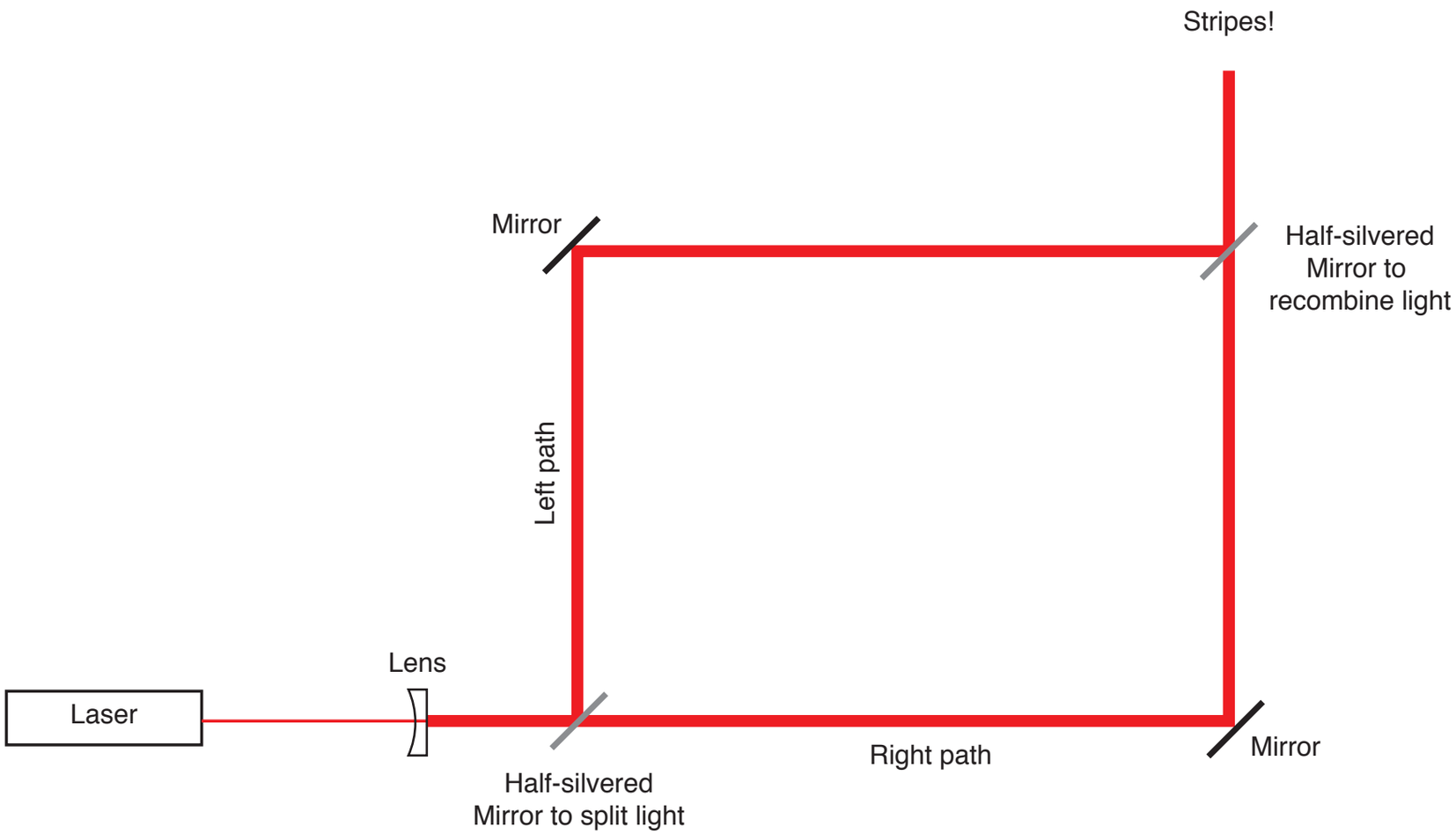
- Photons randomly put on a fiber don’t arrive randomly spaced
- They like to hold hands and ‘bunch’



Repeat all previous experiments with different particles types

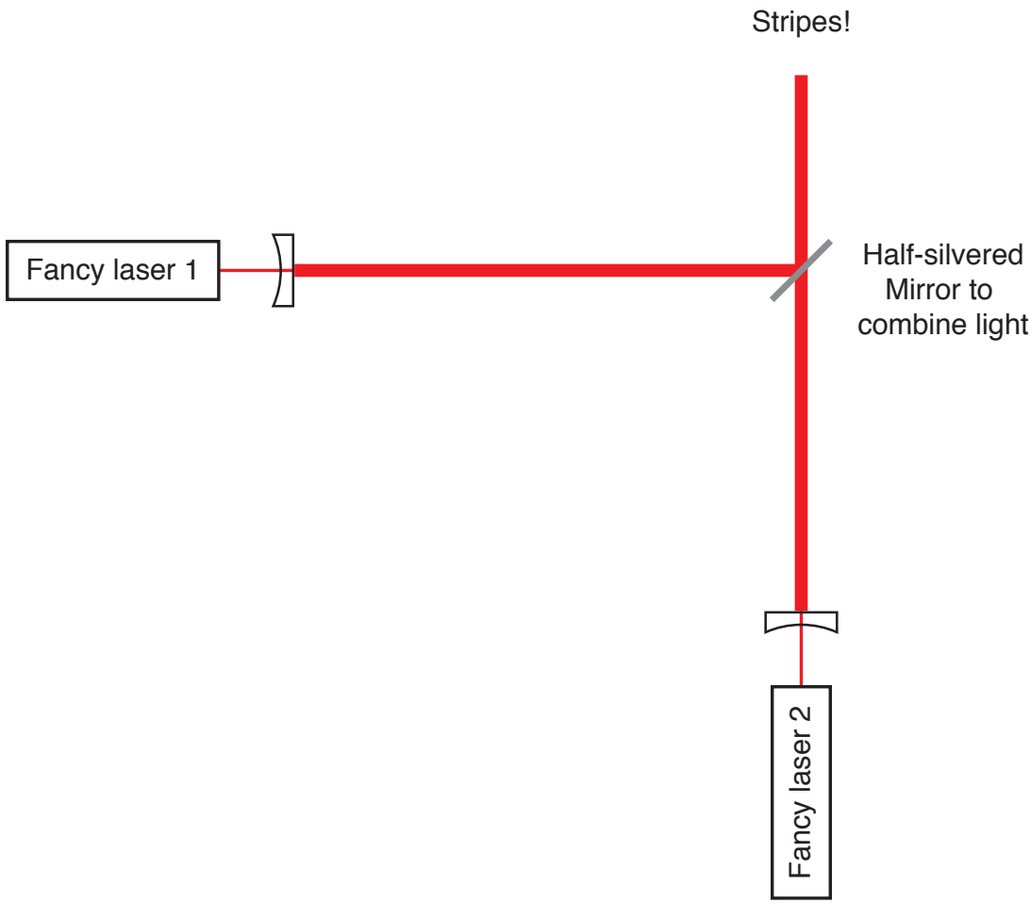
Particles move as waves and take both paths

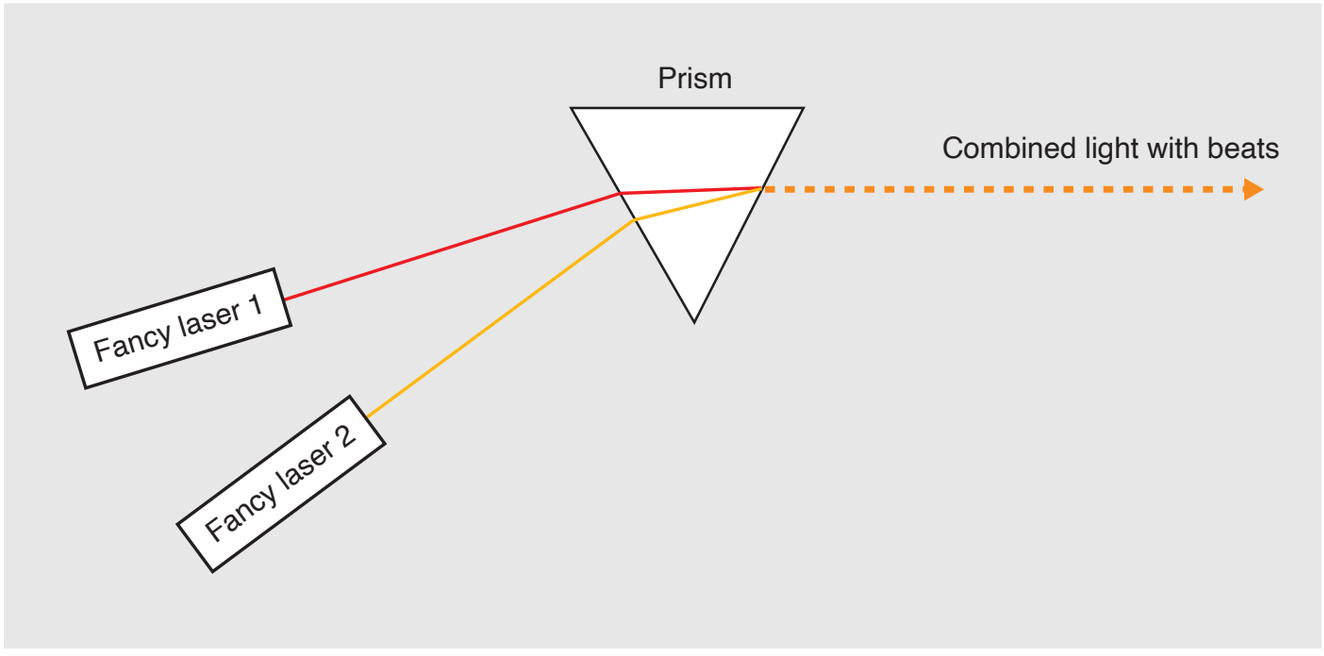
Particles interact with themselves



✓ **True for all particles**

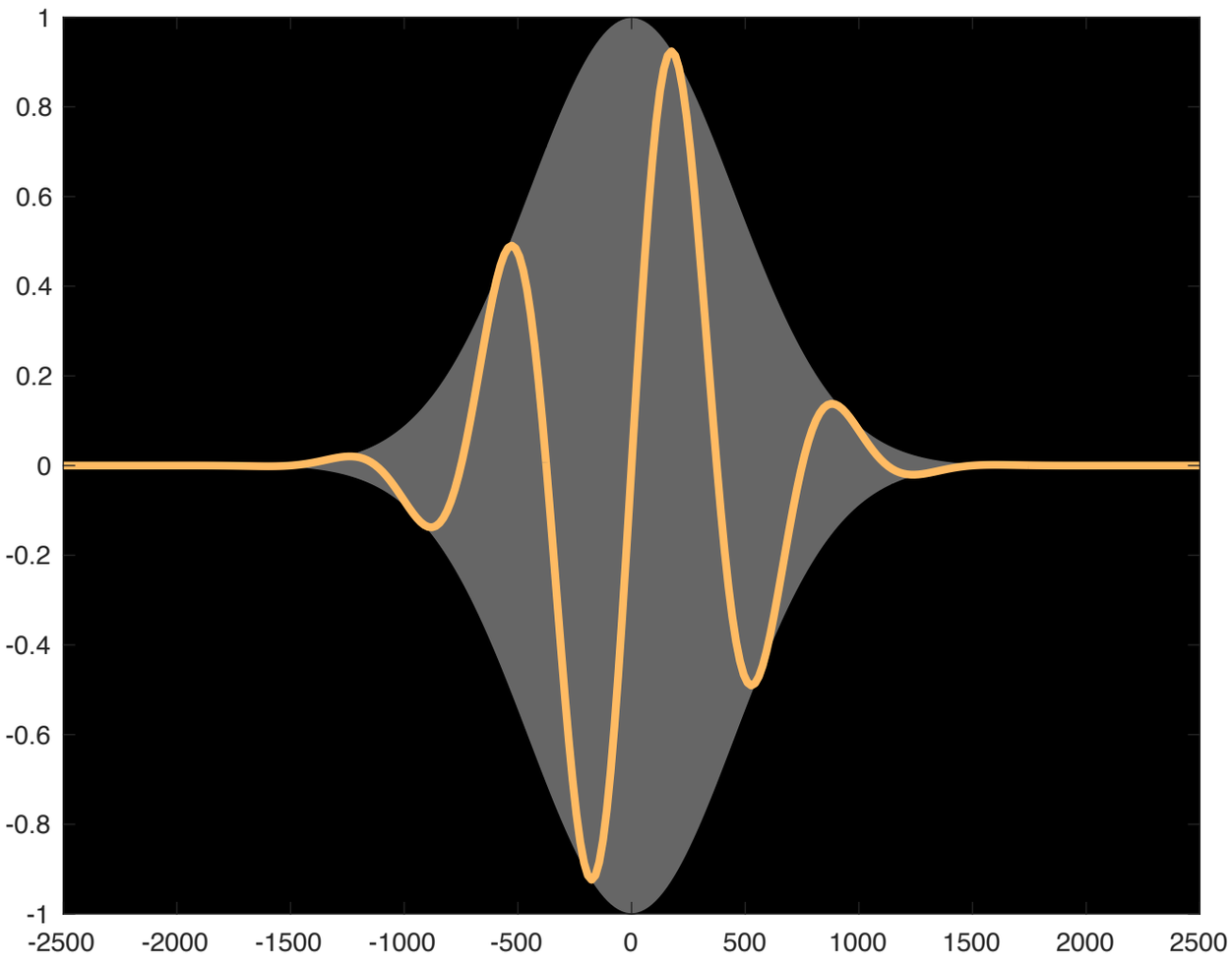
Particles mix with other particles

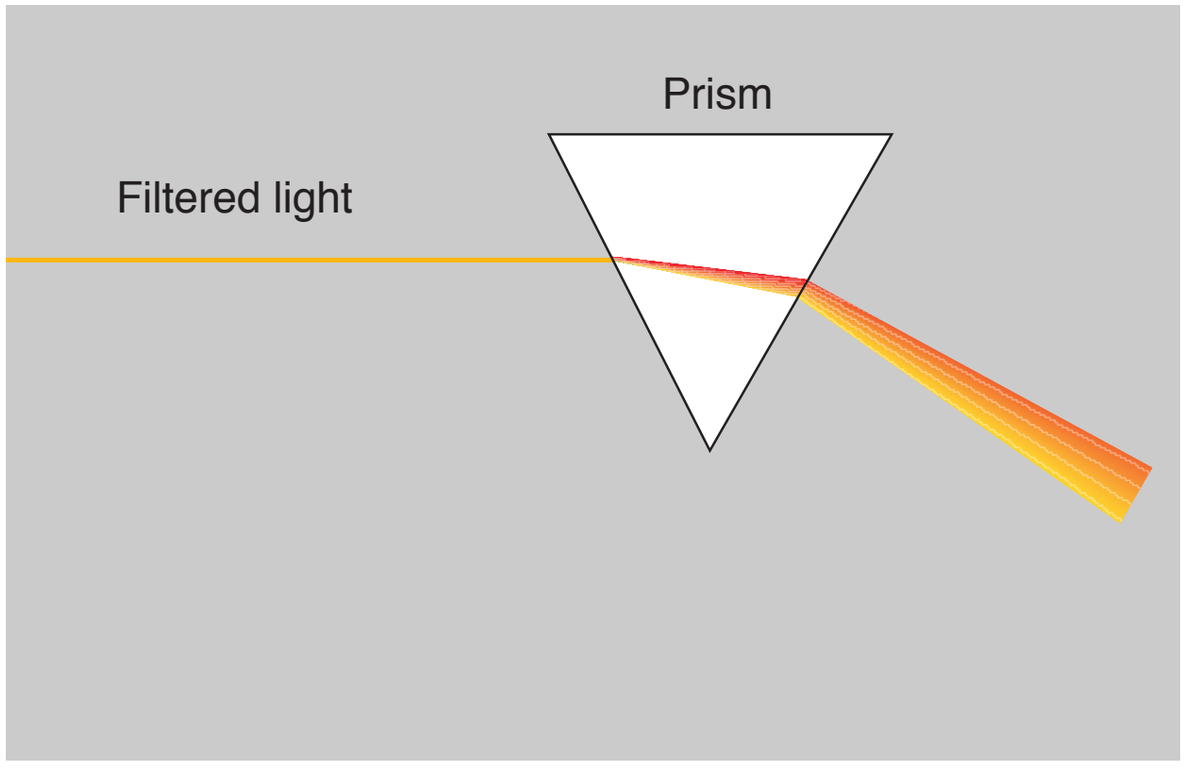




True for all particles

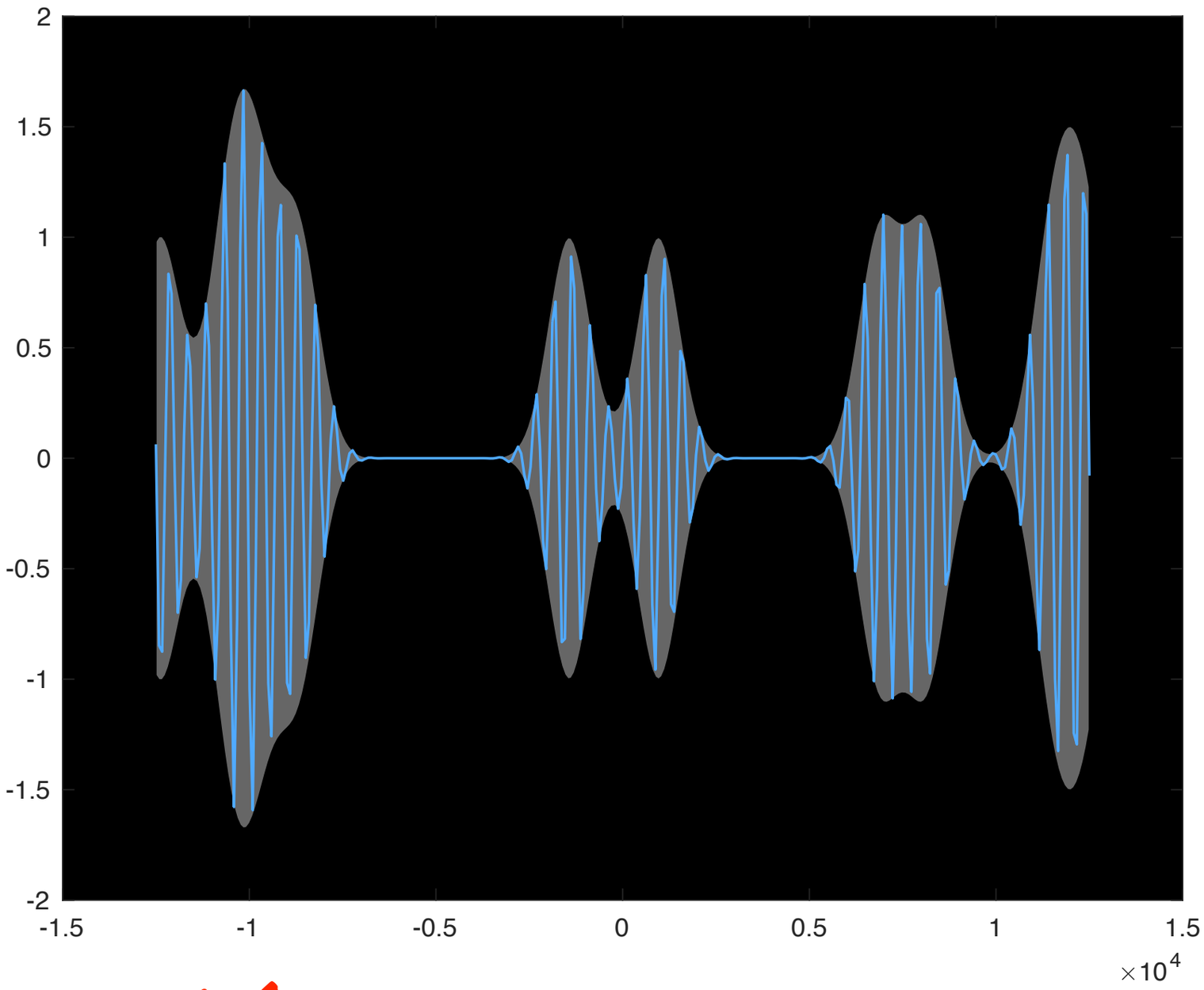
Ripple length depends on range of color





True for all particles

Particles like to hold hands and ‘bunch’



✗ **Not true for all particles!**

Particle introverts & extroverts

- Some particles like to hold hands and bunch: extroverts
- Some particles avoid each other and ‘anti-bunch’: introverts

Extroverts (bunch)

- Photons, gluons, pions
- Are called ‘bosons’

Introverts (anti-bunch)

- Neutrons, protons, electrons, quarks
- Are called ‘fermions’

All particles are either introverts or extroverts

No particles will arrive randomly in time (bunch or anti-bunch)

One additional trick

- Introvert fermions can pair up to act like a bosons (extroverts)

- Fermions are much friendlier with a wingman

    - Pions have 2 quarks (fermions), but behave like boson

    - Protons & Neutrons have 3 quarks, so behave like fermion

- Bosons cannot be made to act like fermions

Favorite experiment

- Cool Helium to less than one millionth of a degree above absolute zero
- Drop onto a detector
- He^4 has 6 fermions (2 protons, 2 neutrons, 2 electrons), bunches like a boson
- He^3 has 5 fermions (2 protons, 1 neutrons, 2 electrons), anti-bunches like a fermion

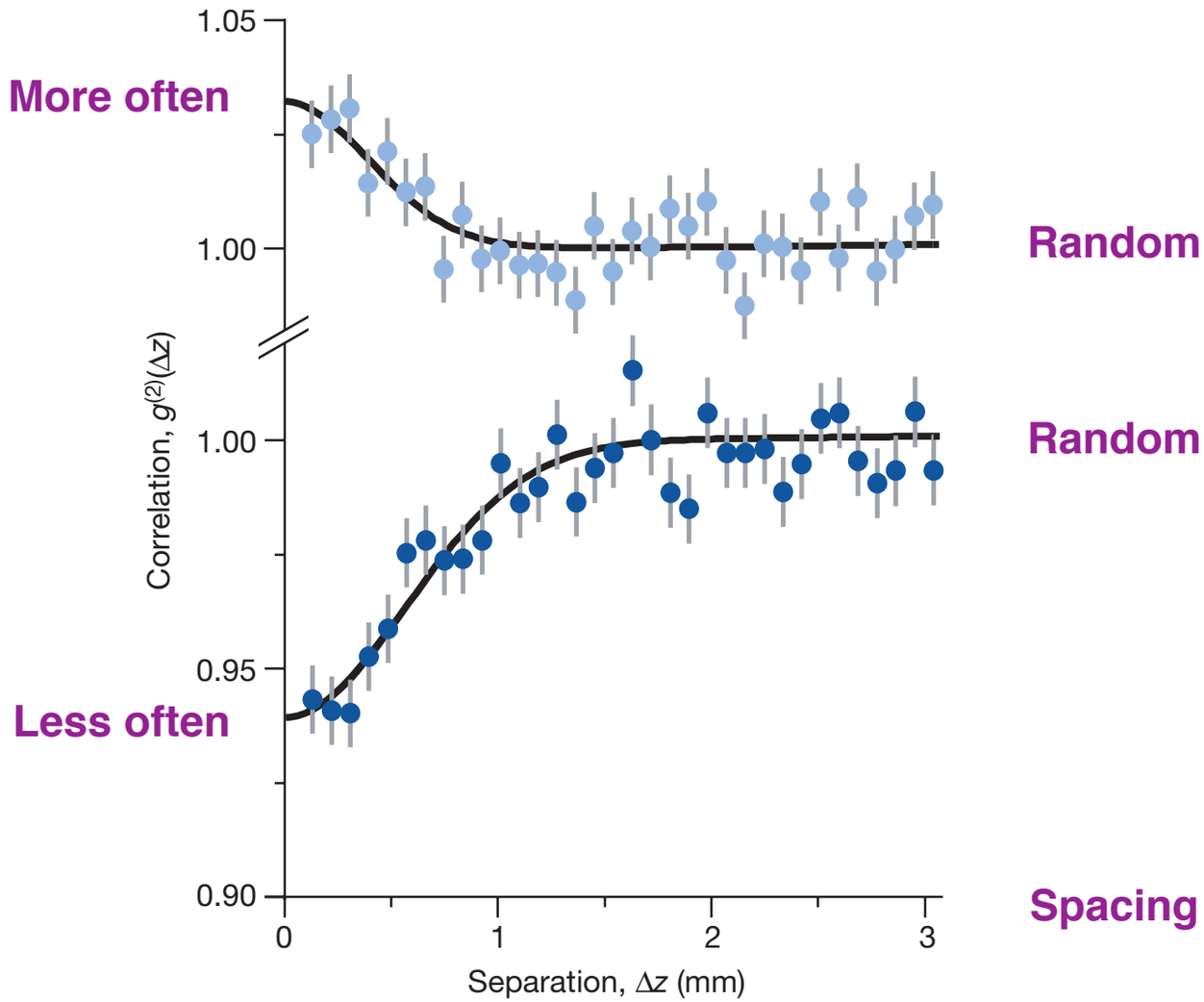


Figure 2 | Normalized correlation functions for ^{4}He* (bosons) in the upper plot, and ^{3}He* (fermions) in the lower plot. Both functions are measured at the same cloud temperature (0.5 μK), and with identical trap parameters. Error bars correspond to the square root of the number of pairs in each bin. The line is a fit to a gaussian function. The bosons show a bunching effect, and the fermions show antibunching. The correlation length for ^{3}He* is expected to be 33% larger than that for ^{4}He* owing to the smaller mass. We find 1/e values for the correlation lengths of 0.75 ± 0.07 mm and 0.56 ± 0.08 mm for fermions and bosons, respectively.