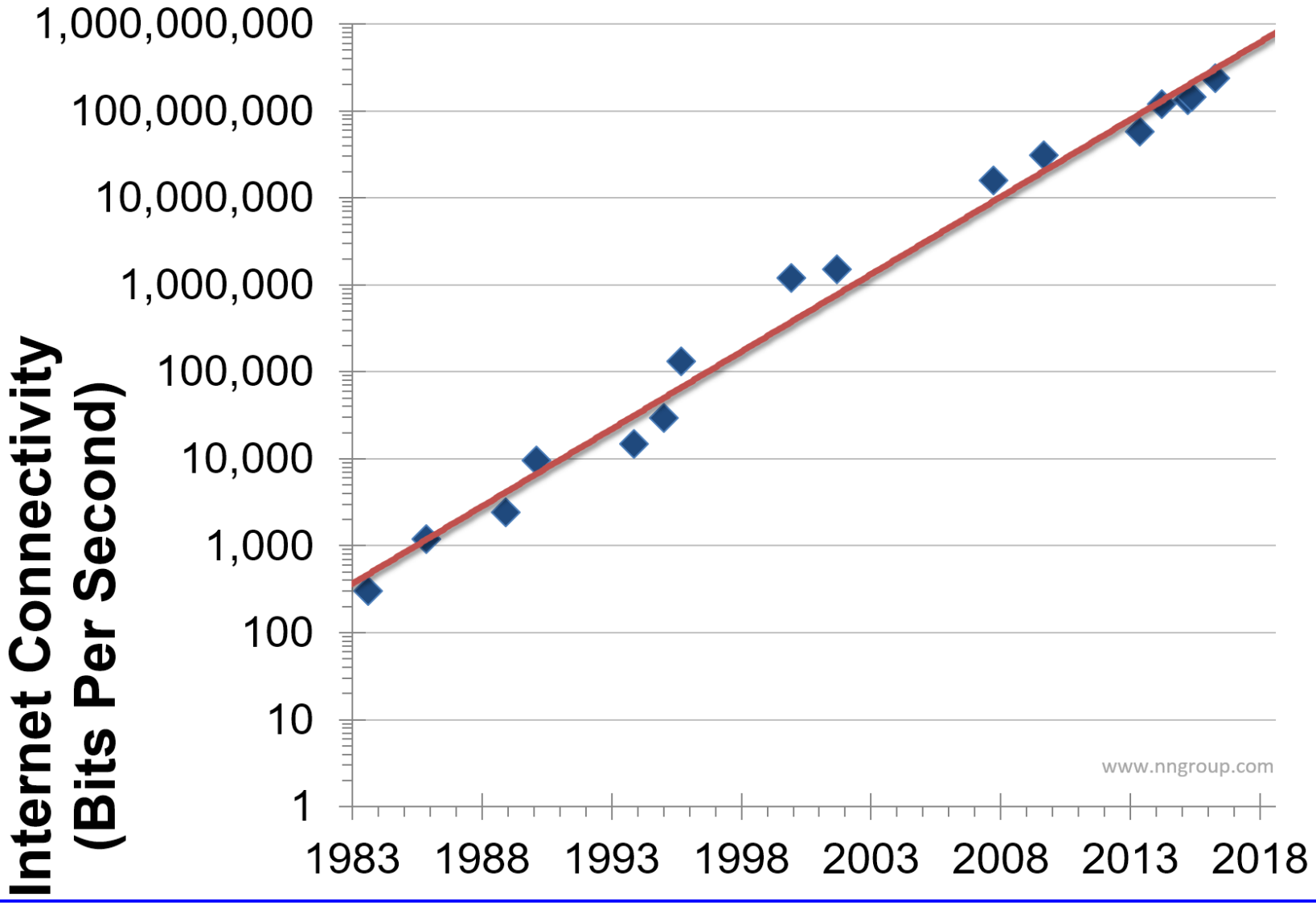
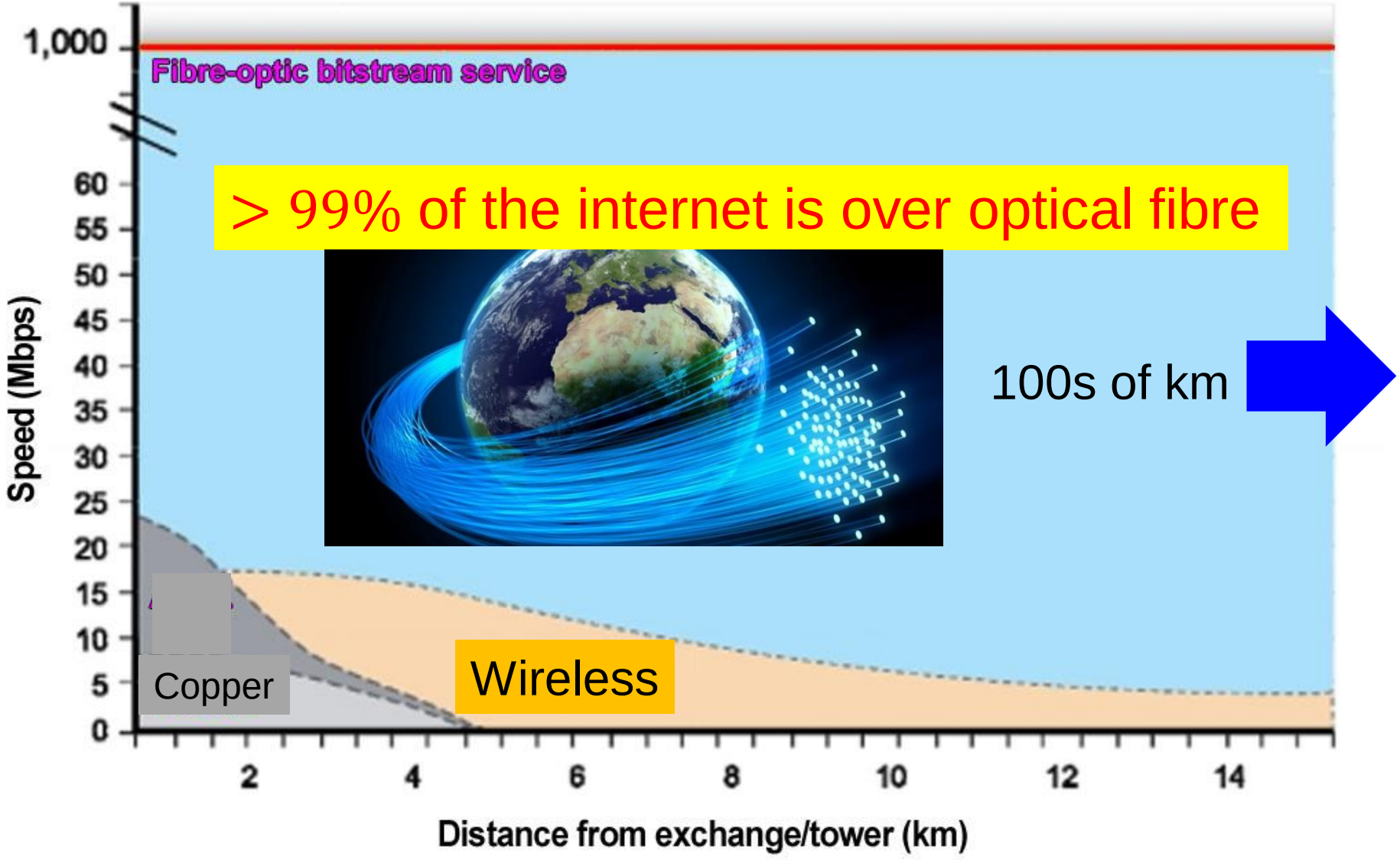
Final Year Projects in Integrated Photonics

Integrated Photonics Group

The Internet – not slowing yet

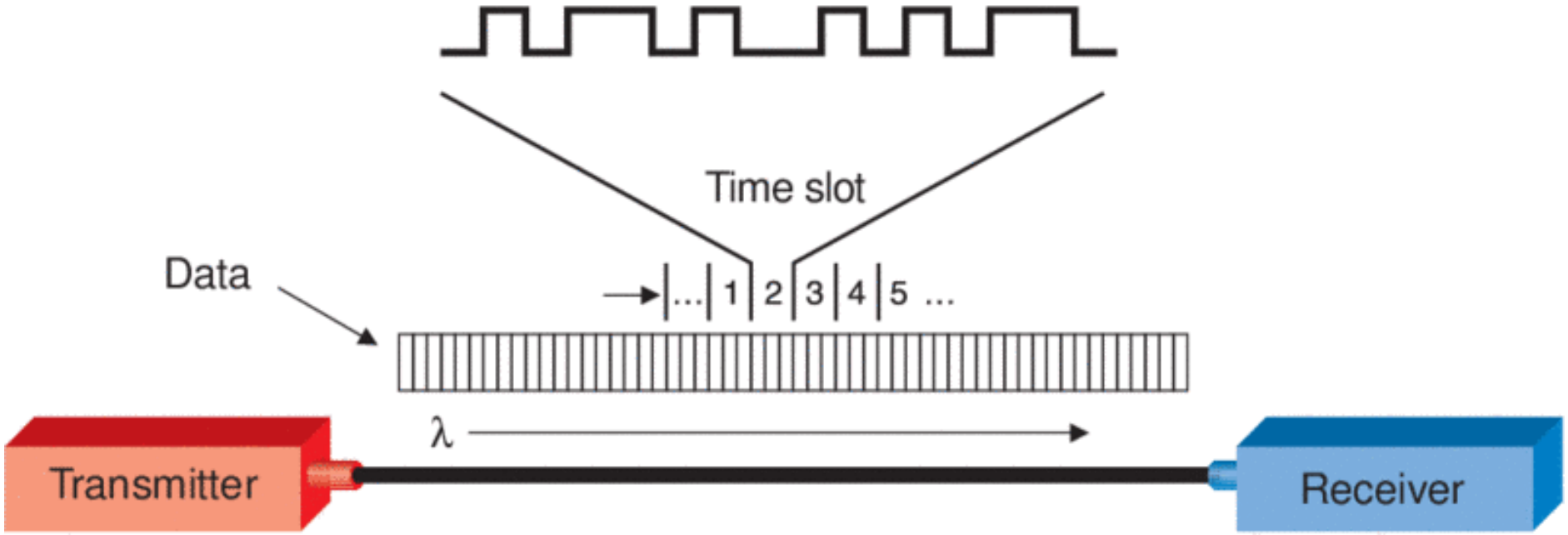


Optical vs. Copper vs. Wireless



How is light used?

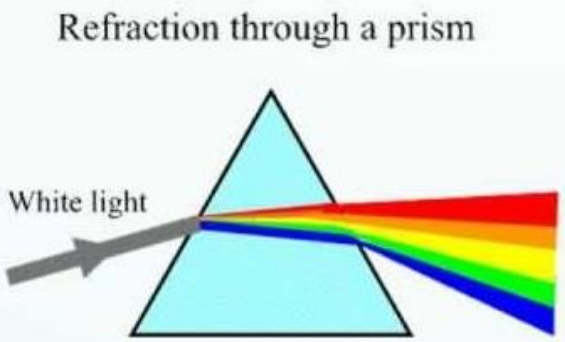
Light is turned on and off, for digital ones and zeros

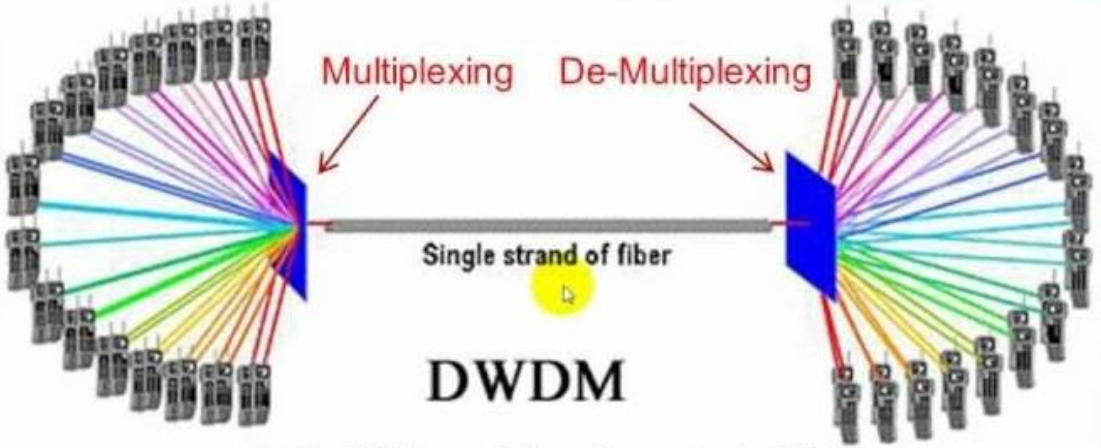


Then, multiple colours can also be used…

What is WDM?

WDM = Wavelength Division Multiplexing

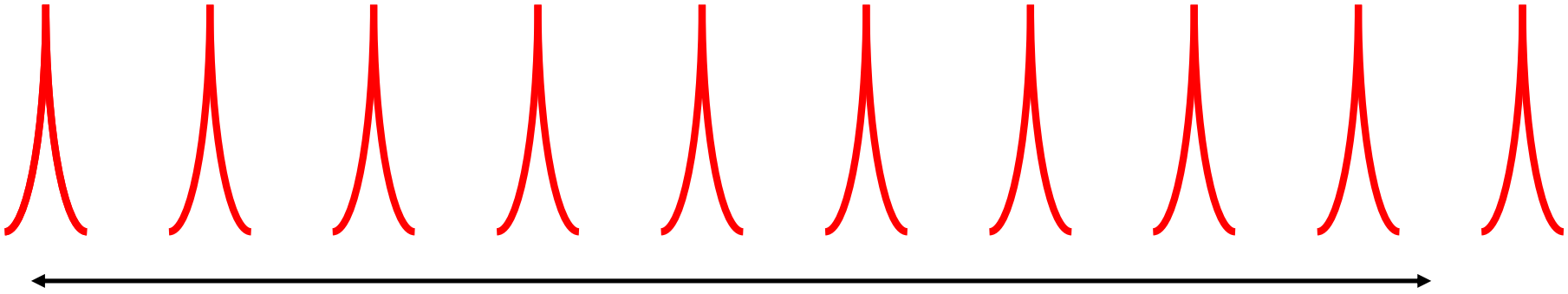




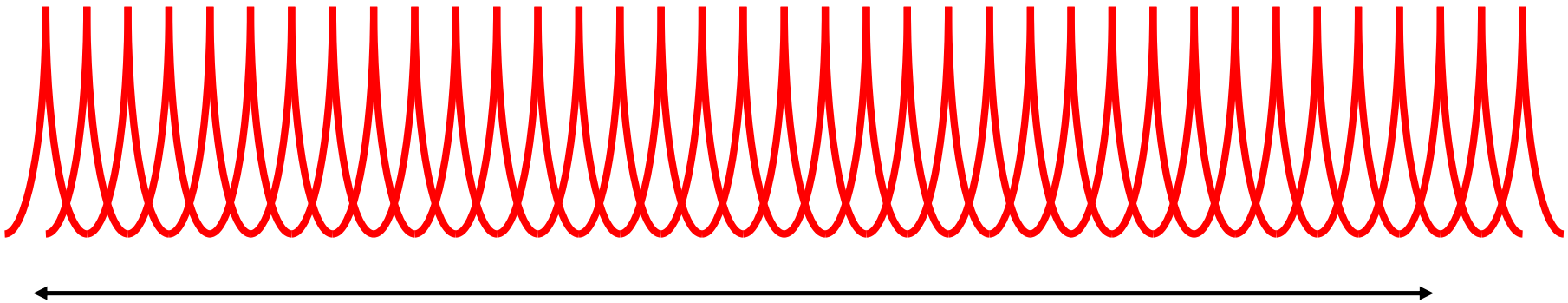
WDM is used on fiber optics to increase the capacity of a single fiber

Can we just keep adding more wavelengths at higher data rates?

Increase the number of colours?



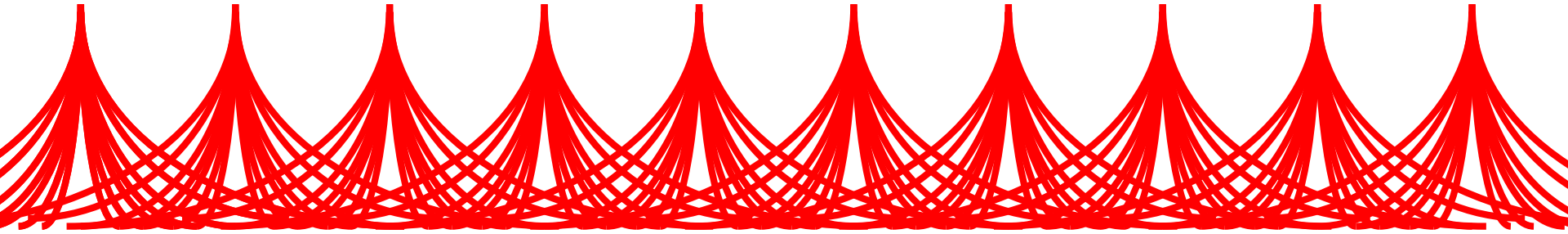
Available space in optical fibre



The channels eventually interfere!

Increase the data rate?

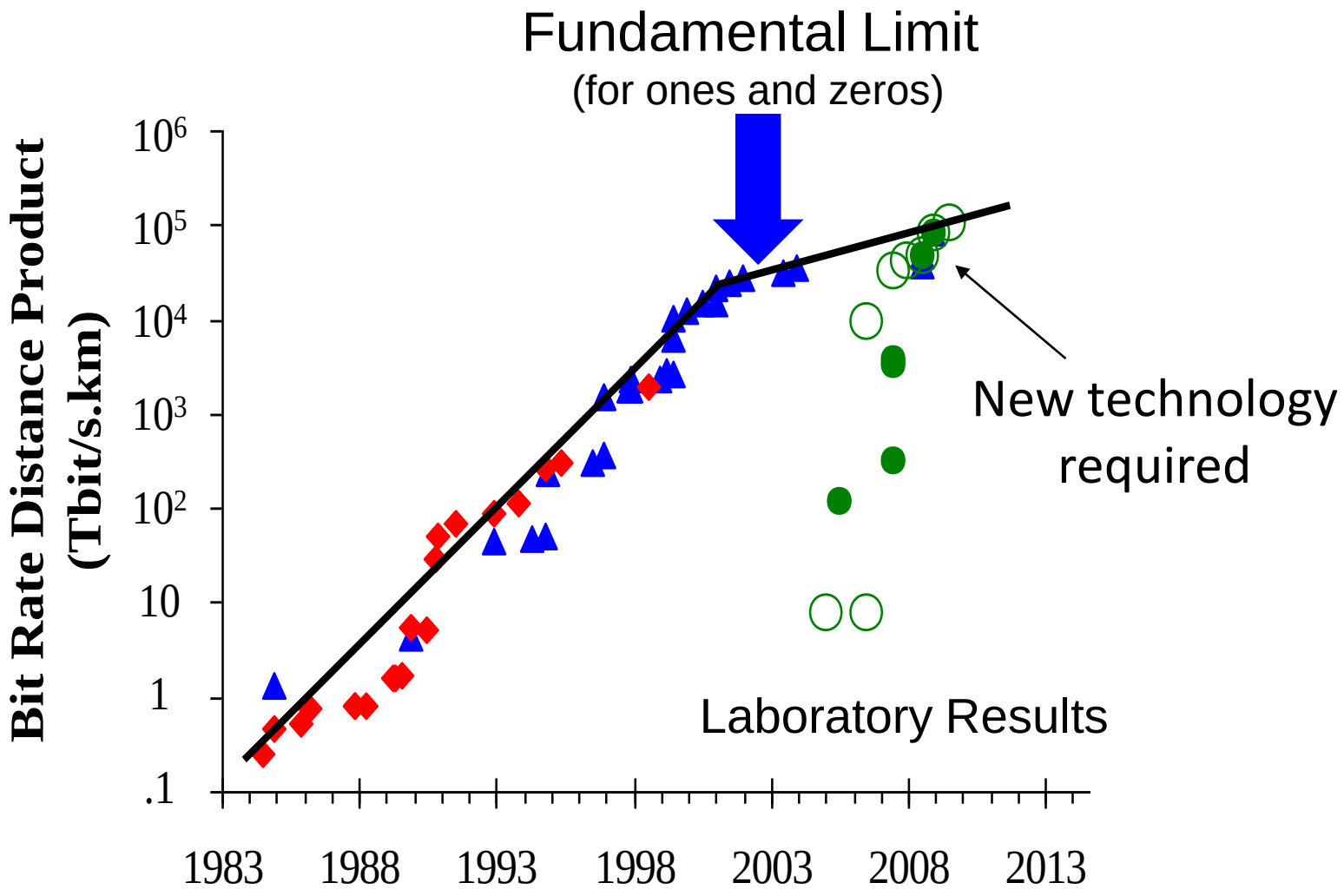
$$\Delta E \Delta t \geq \frac{\hbar}{2} \qquad E = h\nu \qquad \Delta t \downarrow \quad \Delta \nu \uparrow$$



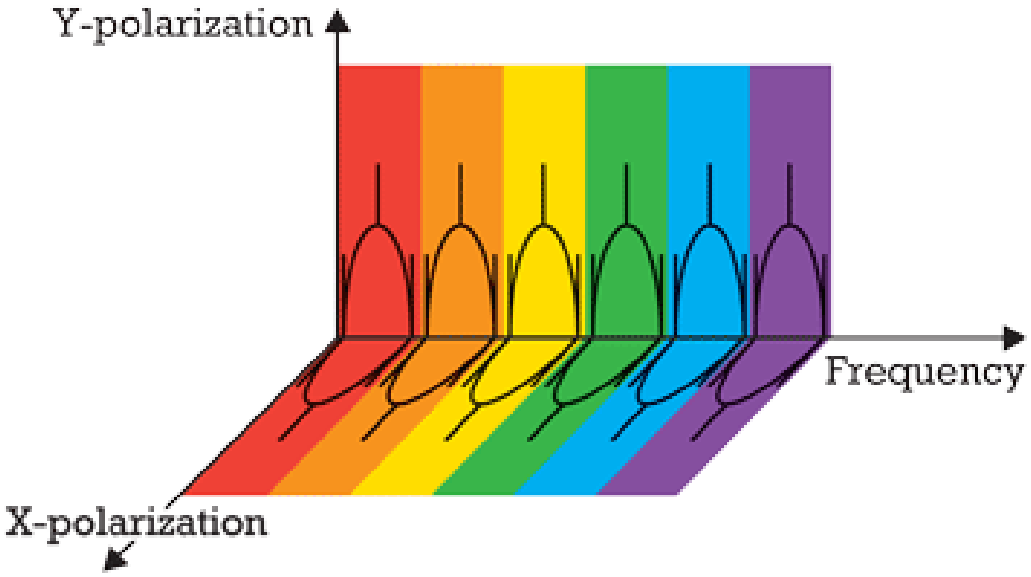
Available space in optical fibre

The channels eventually interfere!

The end is near…



What improvements are possible?

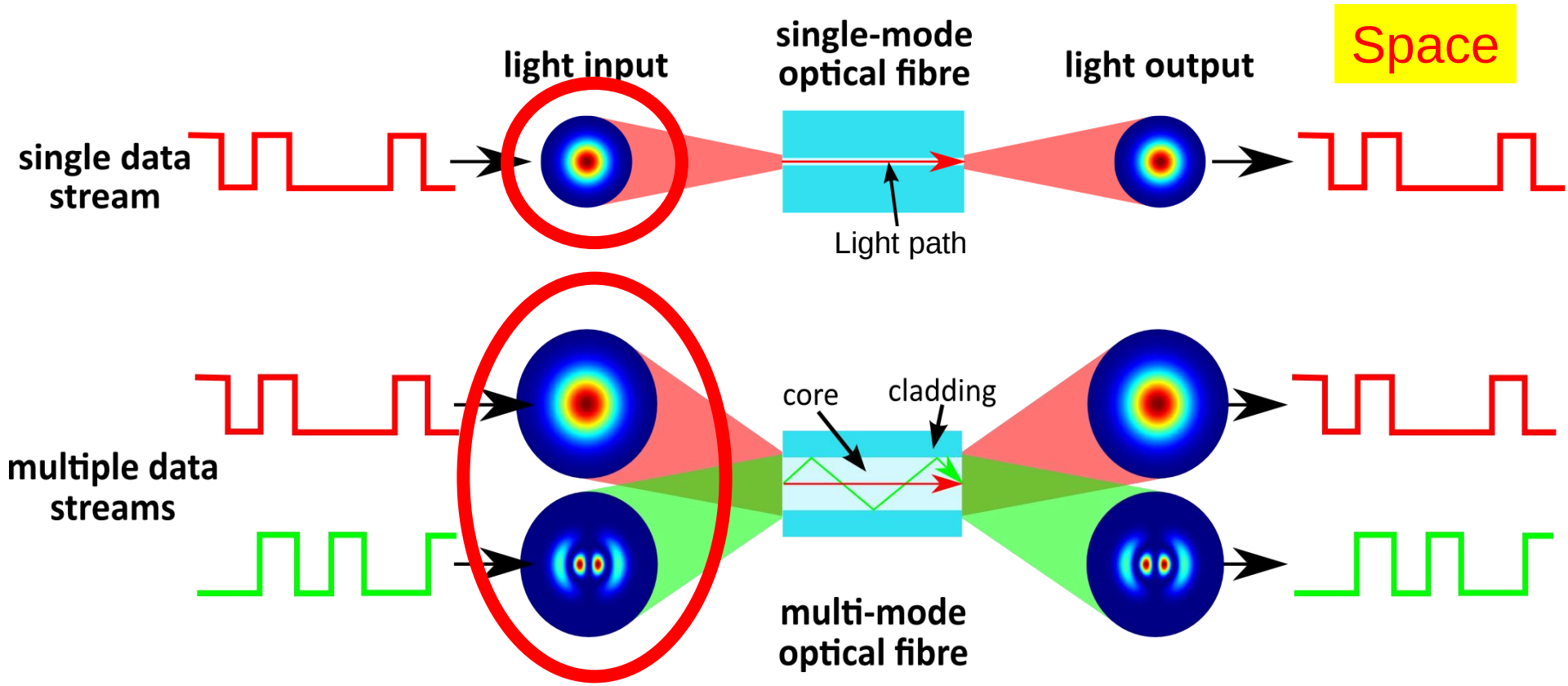


Polarisation

Use 2 orthogonal polarisations:

- Increases bandwidth by 2x
- Done (boring)

What improvements are possible?

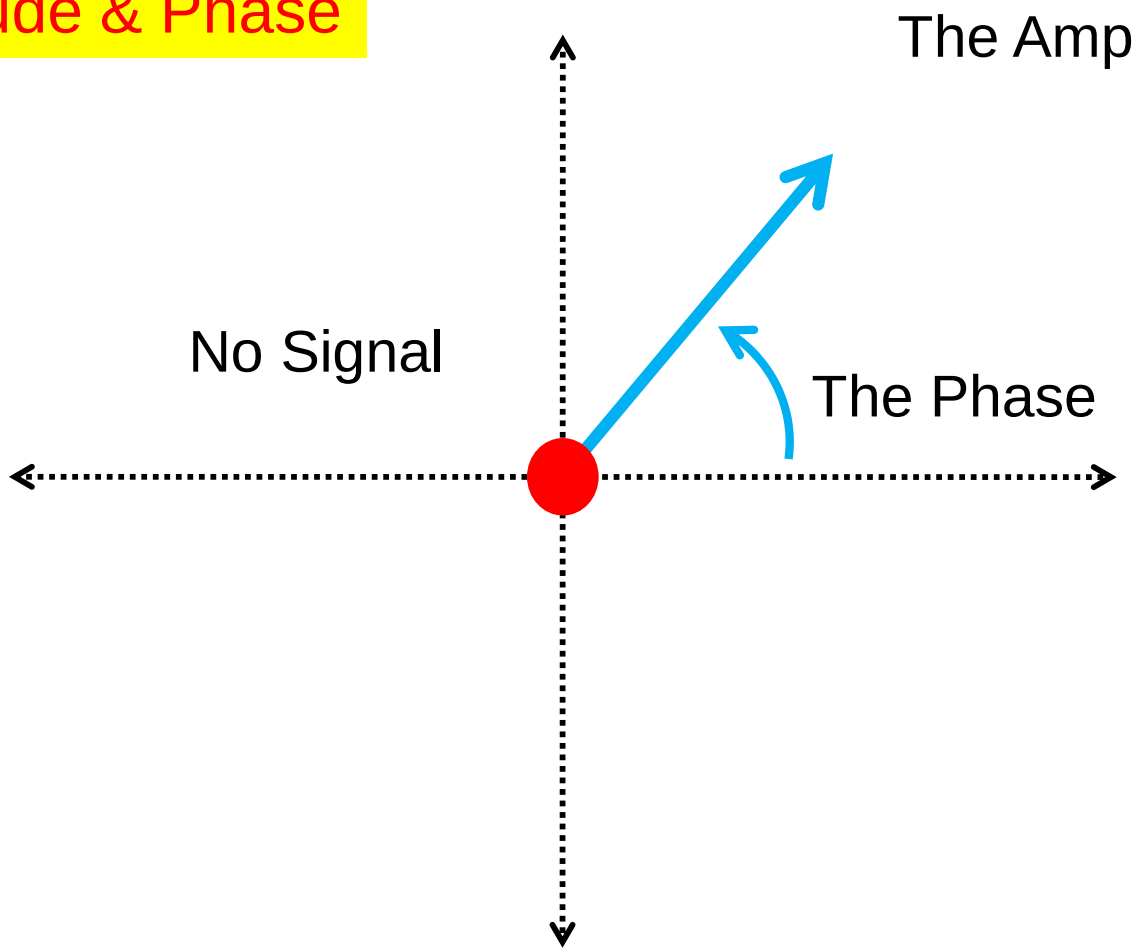


Use N orthogonal modes of optical fibre:

- Increases bandwidth by N
- Very current, very expensive

What improvements are possible?

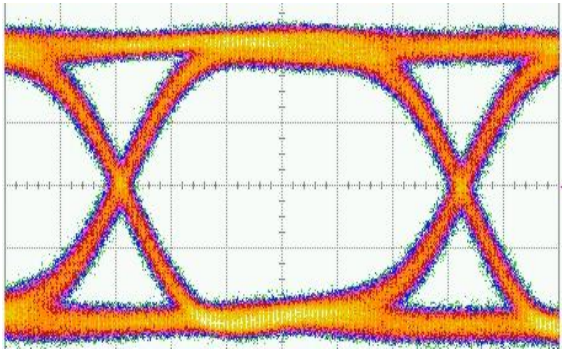
Amplitude & Phase



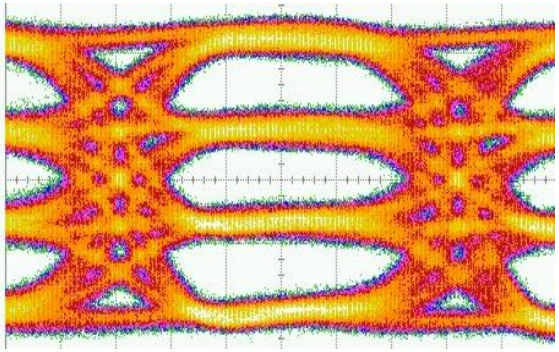
What improvements are possible?

Amplitude & Phase

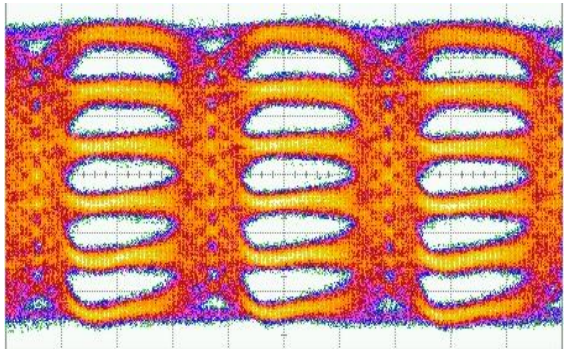
2bits/pulse

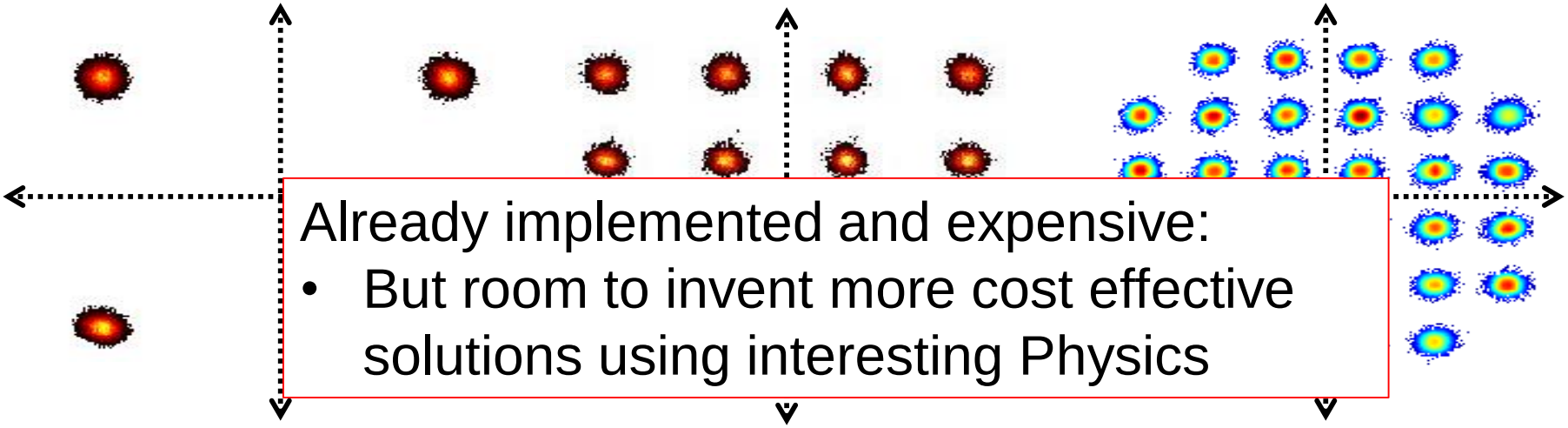


4 bits/pulse



5 bits/pulse



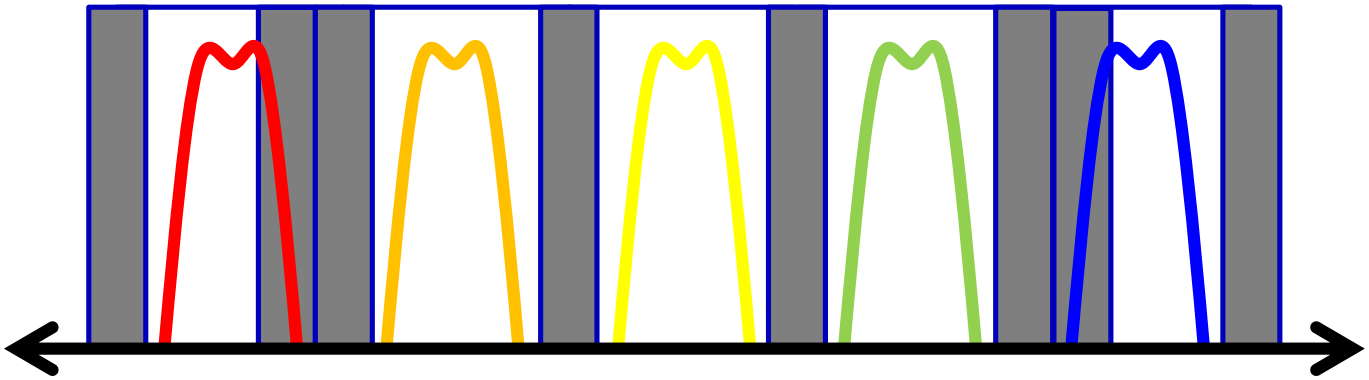


Already implemented and expensive:

- But room to invent more cost effective solutions using interesting Physics

What improvements are possible?

Coherence



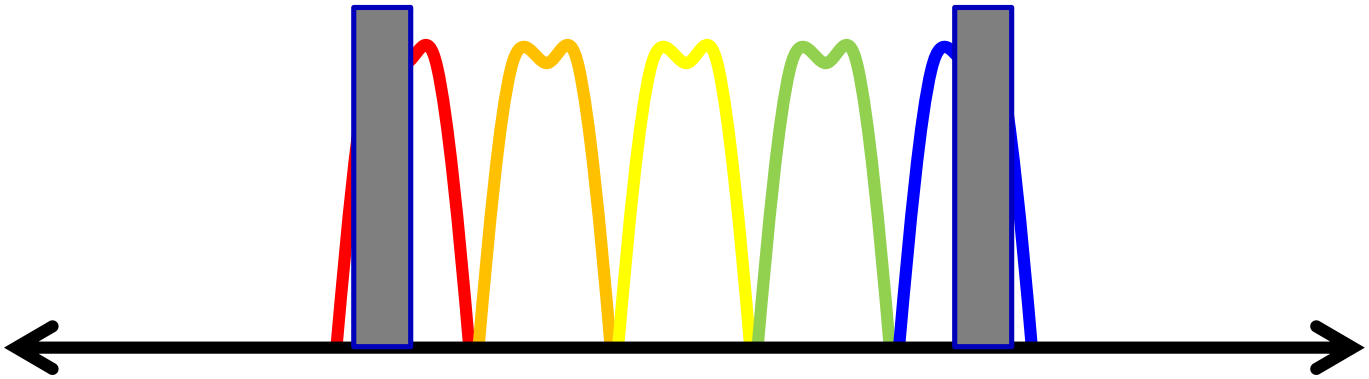
Available Frequency

Separate Channels

What improvements are possible?

Coherence

Requires coherent optical comb

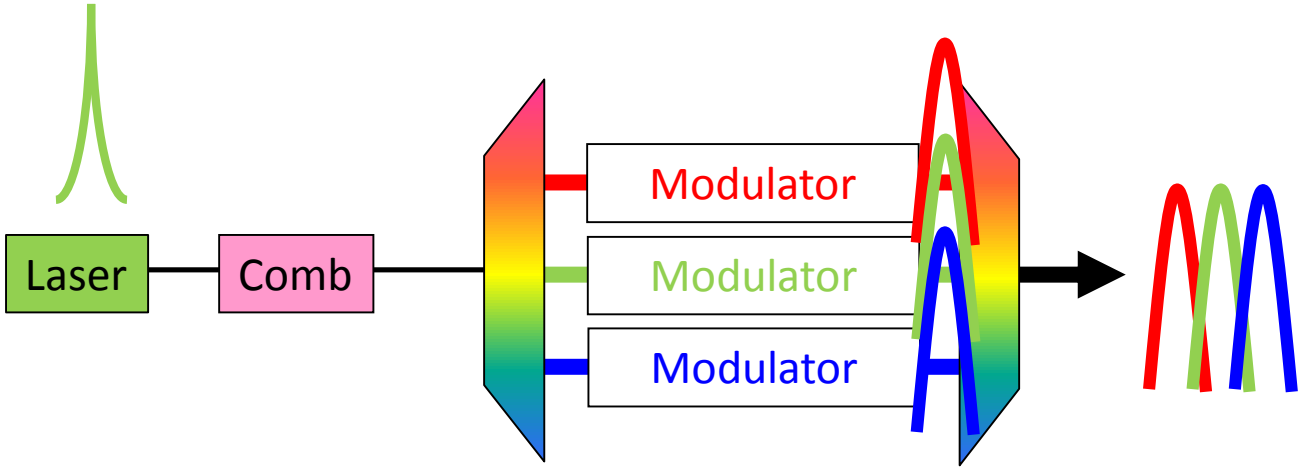


Available Frequency

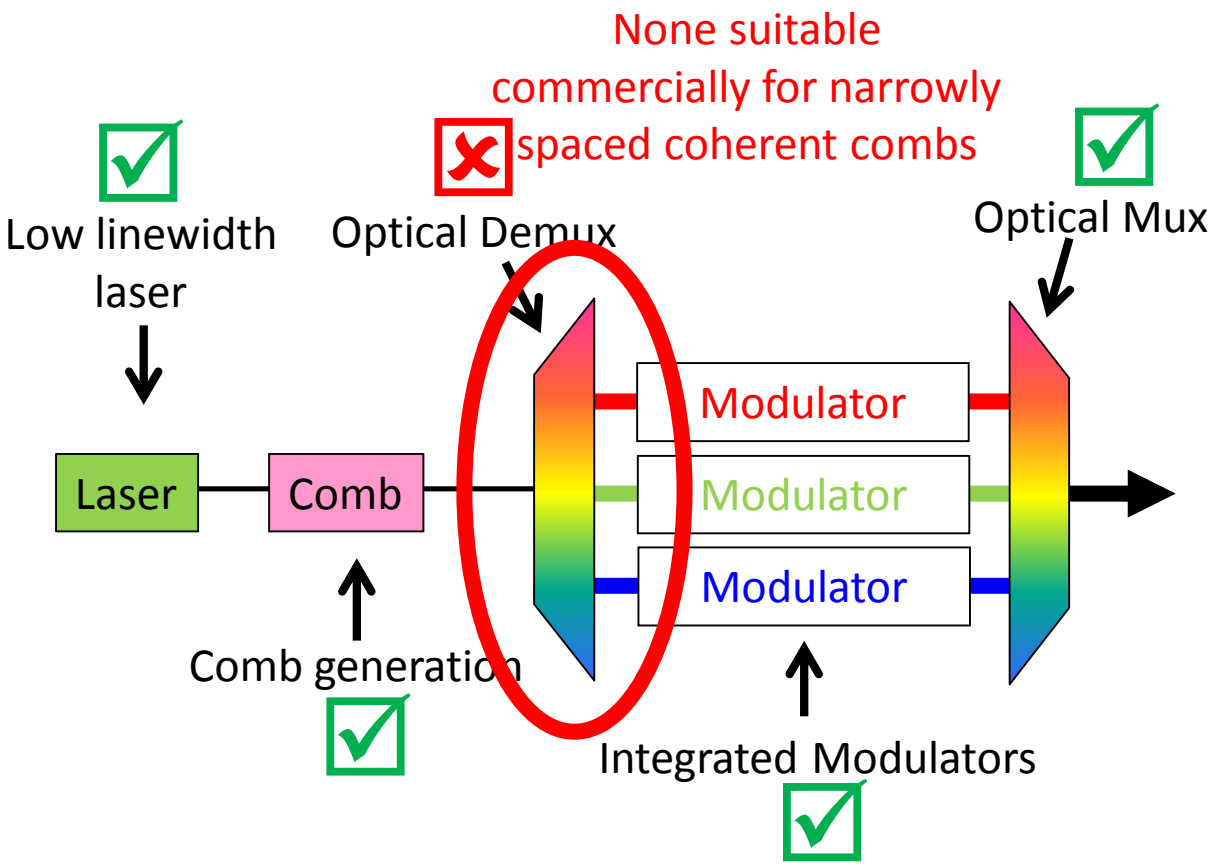
No current commercial solutions:

- Focus of research group

What we want on a single chip



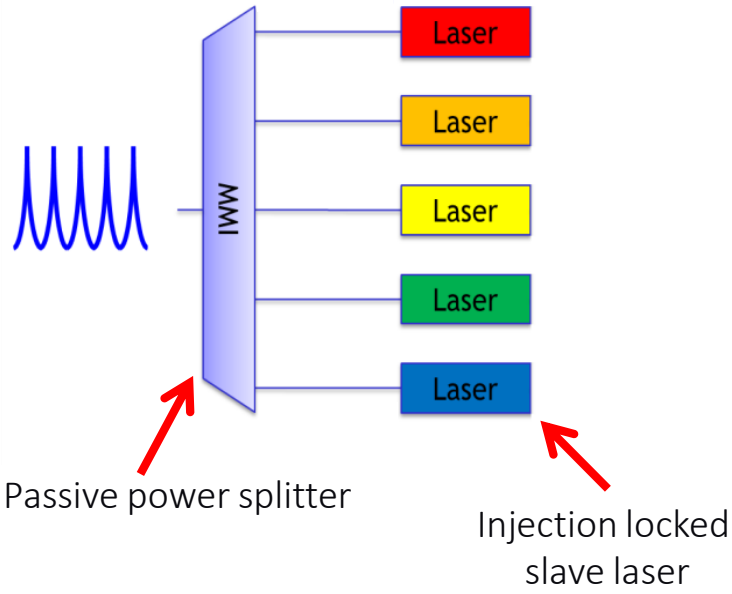
Required components

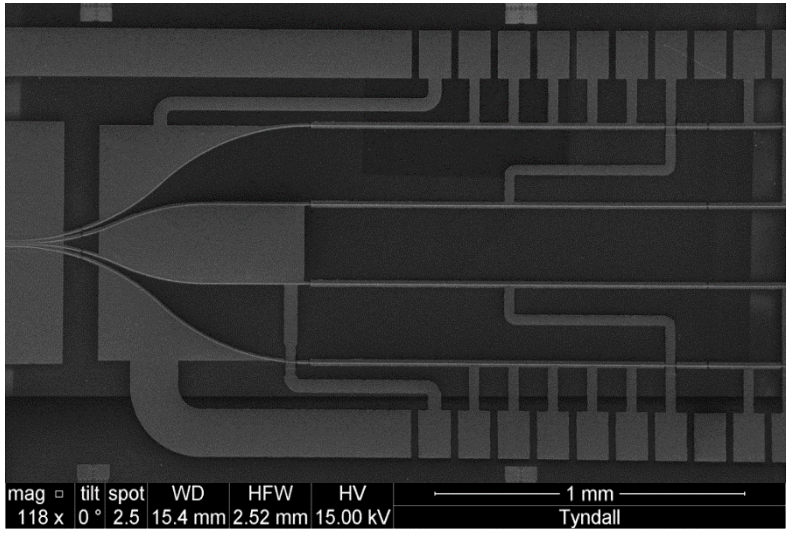


Design of Integrated Optical Demultiplexers

The current design of the integrated optical demultiplexers works by:

1. Passively splits the injected comb using a Multimode Interferometer (MMI)
2. Injection locks a slave laser to each line in the optical comb.

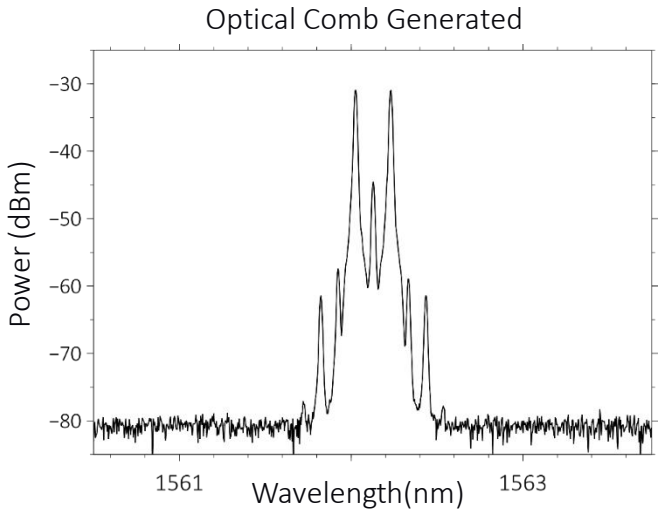


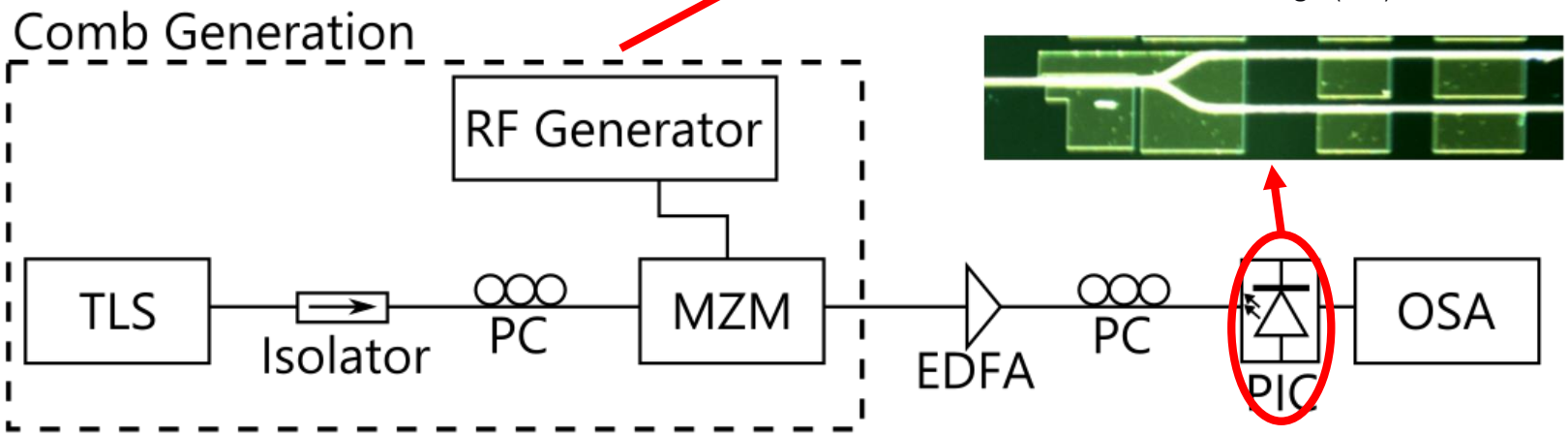


SEM image of a 1x4 MMI integrated with slotted Fabry-Pérot slave lasers

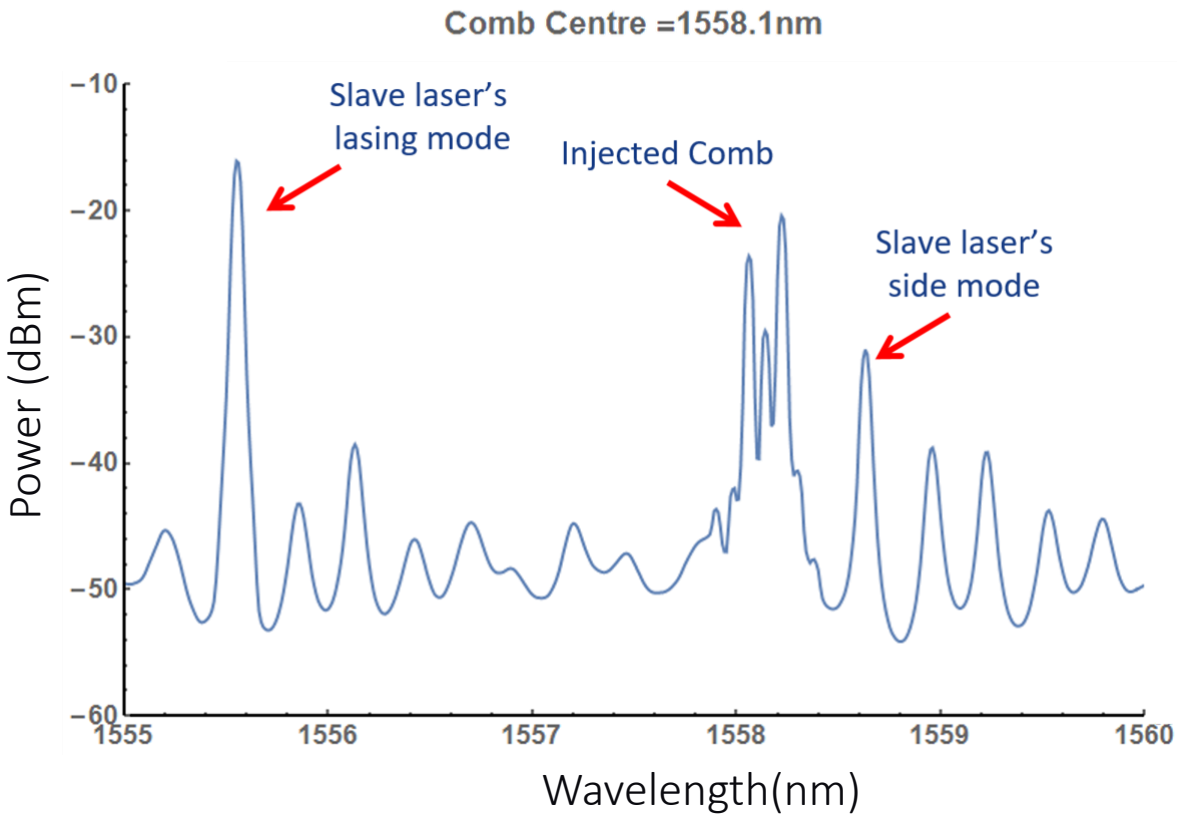
Laser injection locking

TLS: Tuneable laser source
PC: Polarization controller
MZM: Mach-Zehnder modulator
EDFA: Erbium doped fibre amplifier
PIC: Photonic integrated circuit
OSA: Optical spectrum analyser

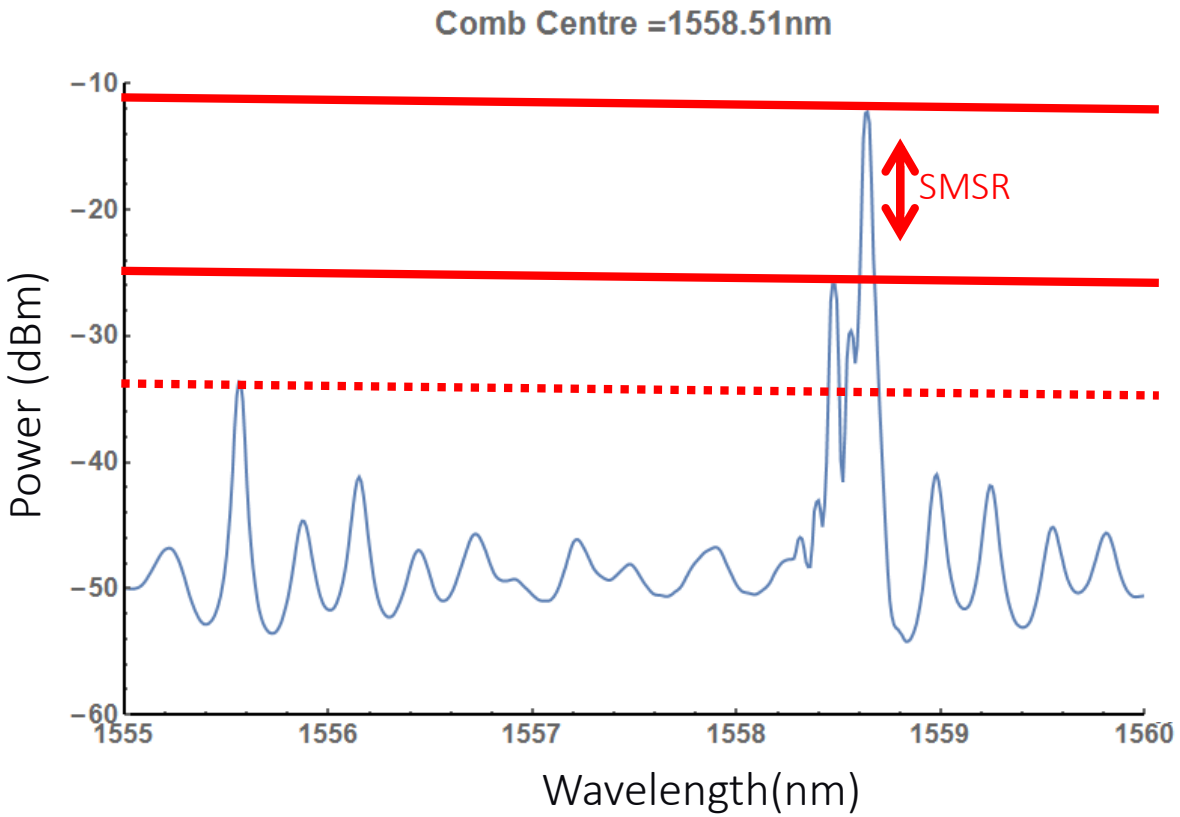




Laser injection locking



Laser injection locking



Theoretical model

- The complex expression $\frac{d}{dt}\widetilde{E_s}$ for the slave laser's filed was split into real and imaginary parts:

$$\frac{d}{dt}E_s(t) = \frac{1}{2}G_N(N(t) - N_{th})E_s(t) + \sum_j E_j \cos\left(\delta\omega_j - \phi_s(t)\right) \quad (1)$$

$$\frac{d}{dt}\phi_s(t) = \frac{1}{2}\propto_H G_N[N(t) - N_{th}] + \sum_j \frac{E_j}{E_s(t)} \sin\left(\delta\omega_j - \phi_s(t)\right) \quad (2)$$

- The carriers were modelled by:

$$\frac{d}{dt}N(t) = R_p - \frac{N(t)}{\tau_s} - G_N[N(t) - N_{th}]E_s(t)^2 - \frac{1}{\tau_p}E_s(t)^2 \quad (3)$$

- Equations (1), (2) and (3) were solved numerically using a 4th Order Runge-Kutta method.
- A fast Fourier transform was then used to obtain the spectral information.

Types of Projects

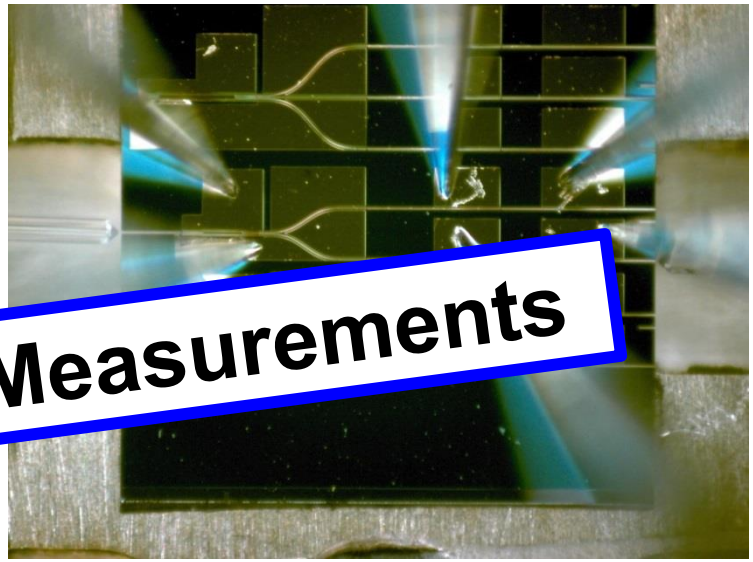
- Simulation:
  - Solving analytical equations
  - Based on existing code
  - Requiring code development
- Experimental
- Mix of Experiment and Theory

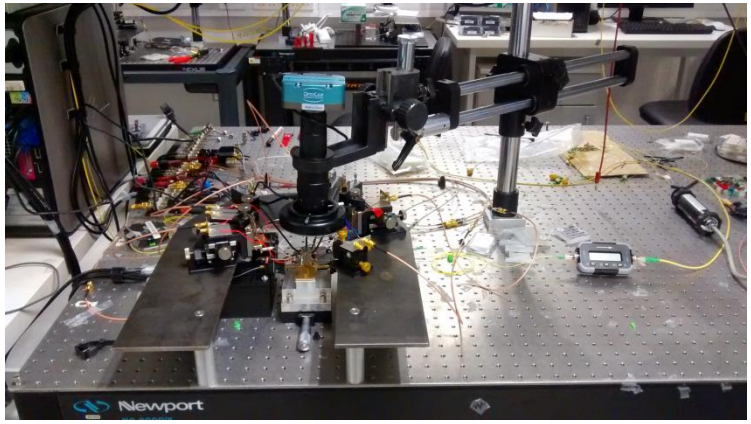
Laser Testing

Develop LabView based characterisation of diode lasers including:

- Electrical
- Optical
- Gain

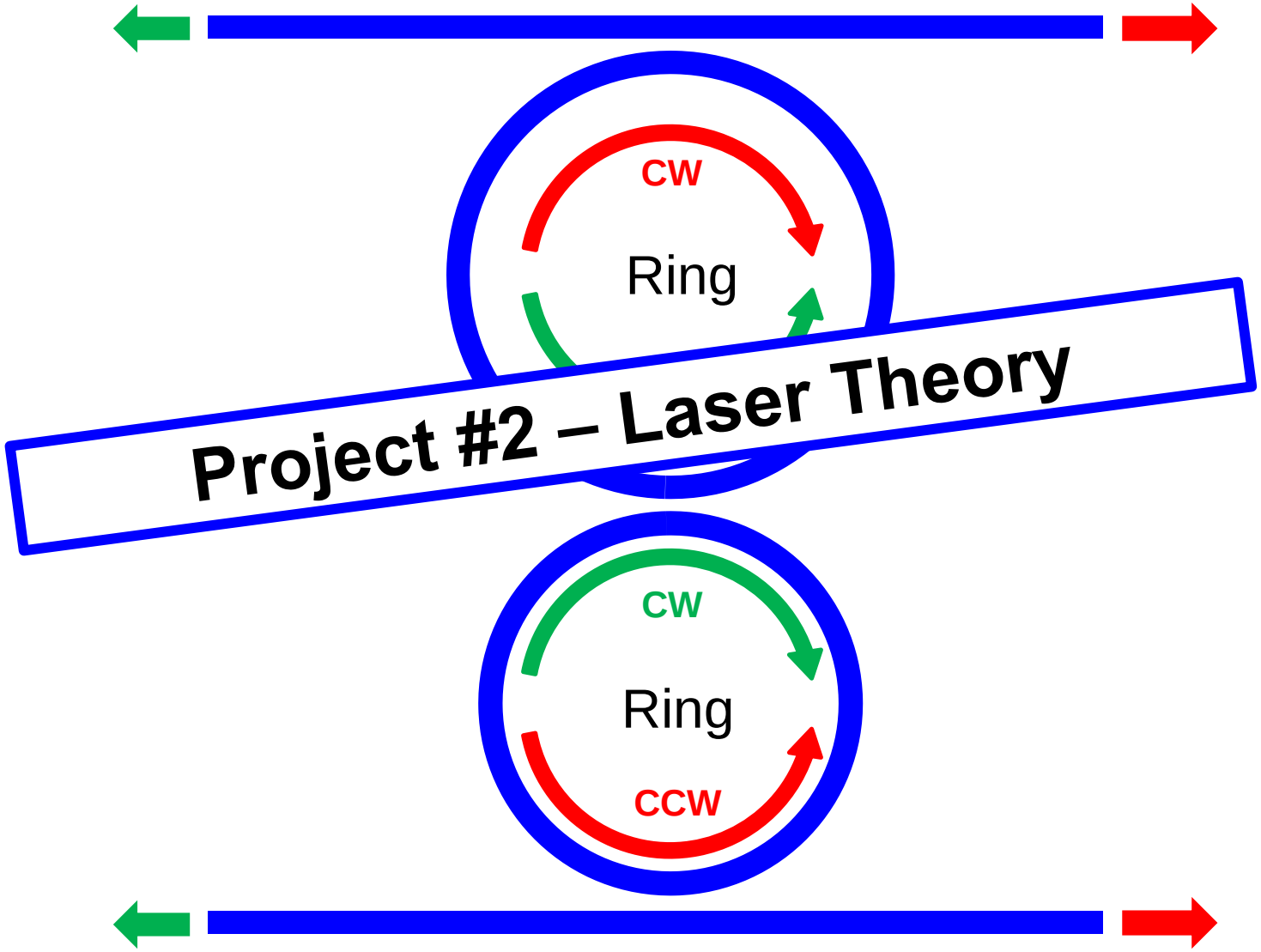
Project #1 – Laser Measurements





Possible theoretical simulation and analysis addition available.

A ring laser



Laser linewidth

$$\Delta E \Delta t \geq \frac{\hbar}{2} \quad \Rightarrow \quad \Delta \nu \Delta t \geq \frac{1}{4\pi}$$

How long does an electromagnetic wave retain mathematical perfection?

$$E = E_0 e^{i(kx-\omega t)}$$

Δt_c : Coherence time

$\Delta l_c = c\Delta t_c$: Coherence length

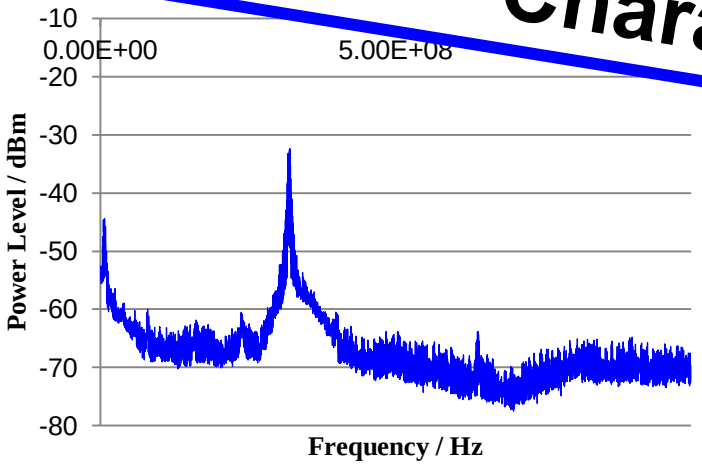
$\Delta \nu_c$: Linewidth

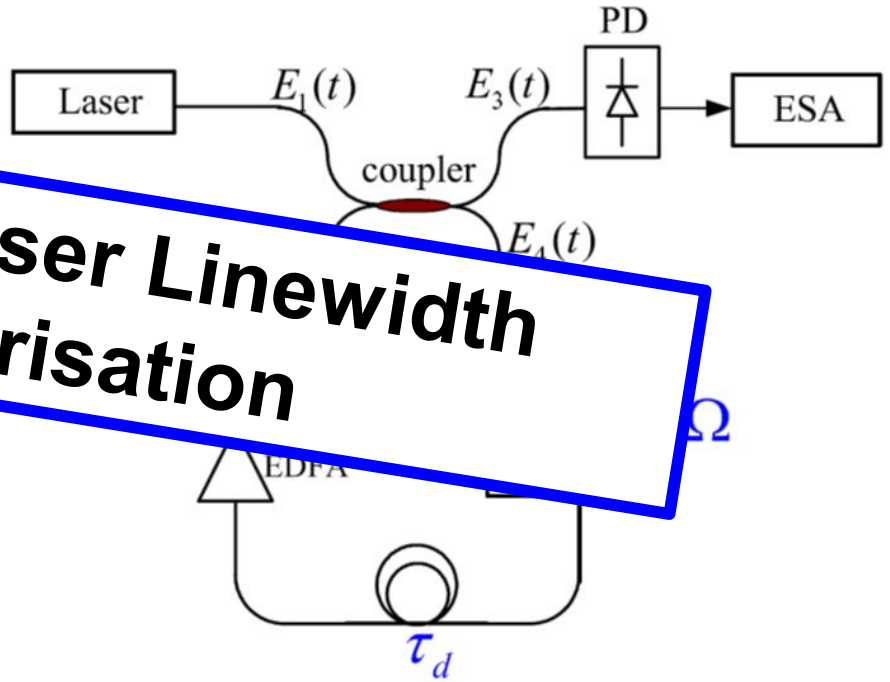
Laser Linewidth Characterisation

Student will learn to characterize noise of and measure laser linewidth:

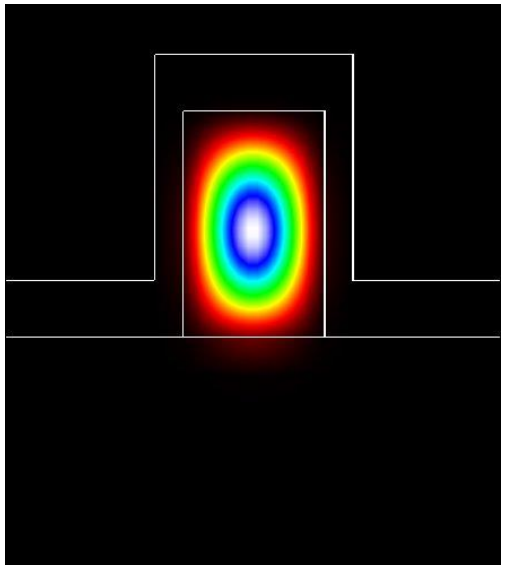
- Using loss-compensated recirculating delayed self-heterodyne interferometer (LC-RDSHI)
- Sources of Noise in
  - E… …t Equipment
  - C…

Project #3 –Laser Linewidth Characterisation

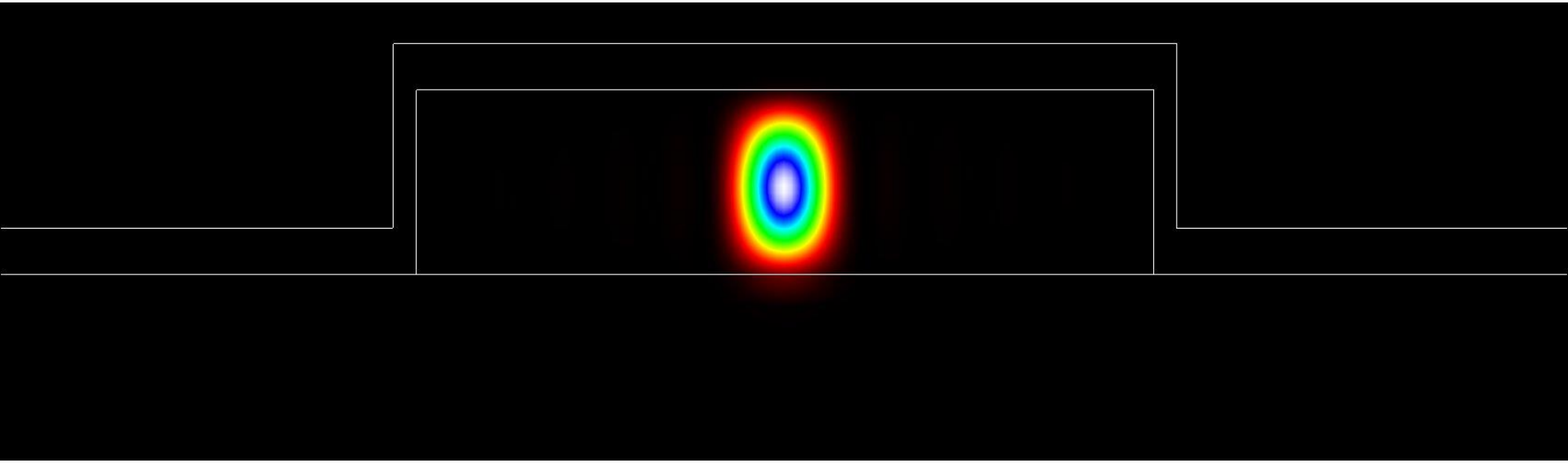




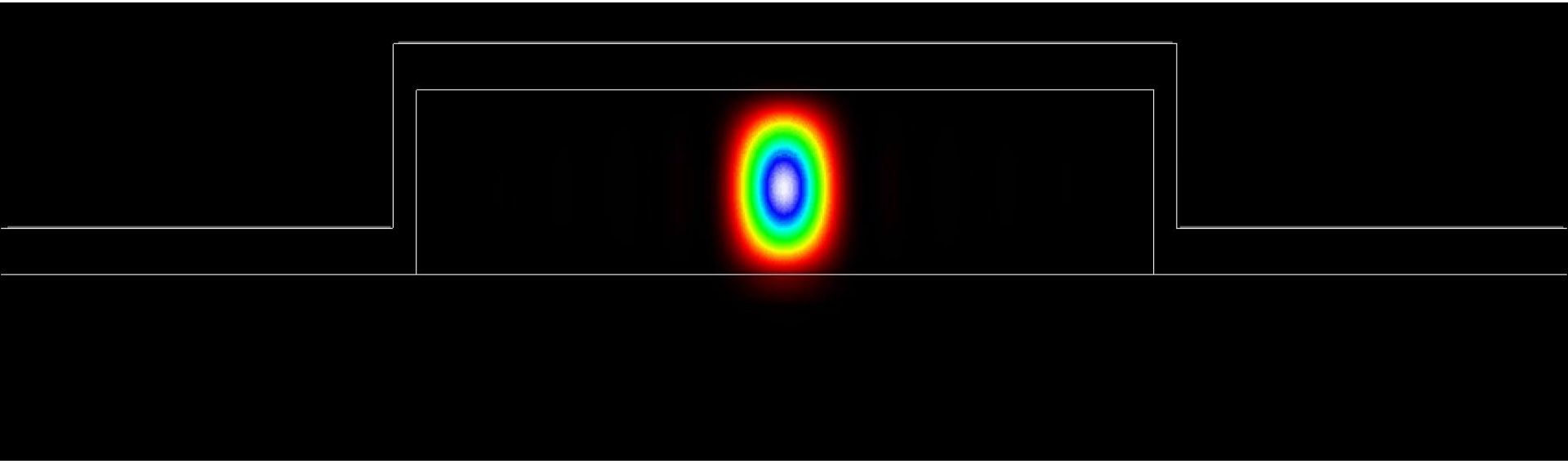
Starting Mode in Waveguide



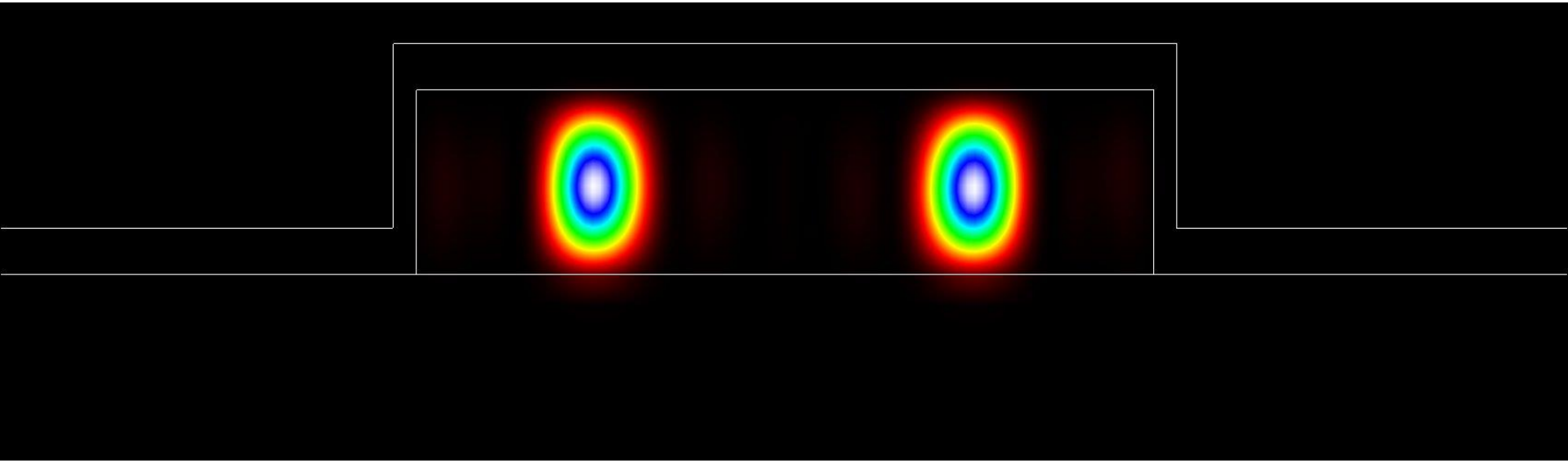
Starting Mode enters larger region



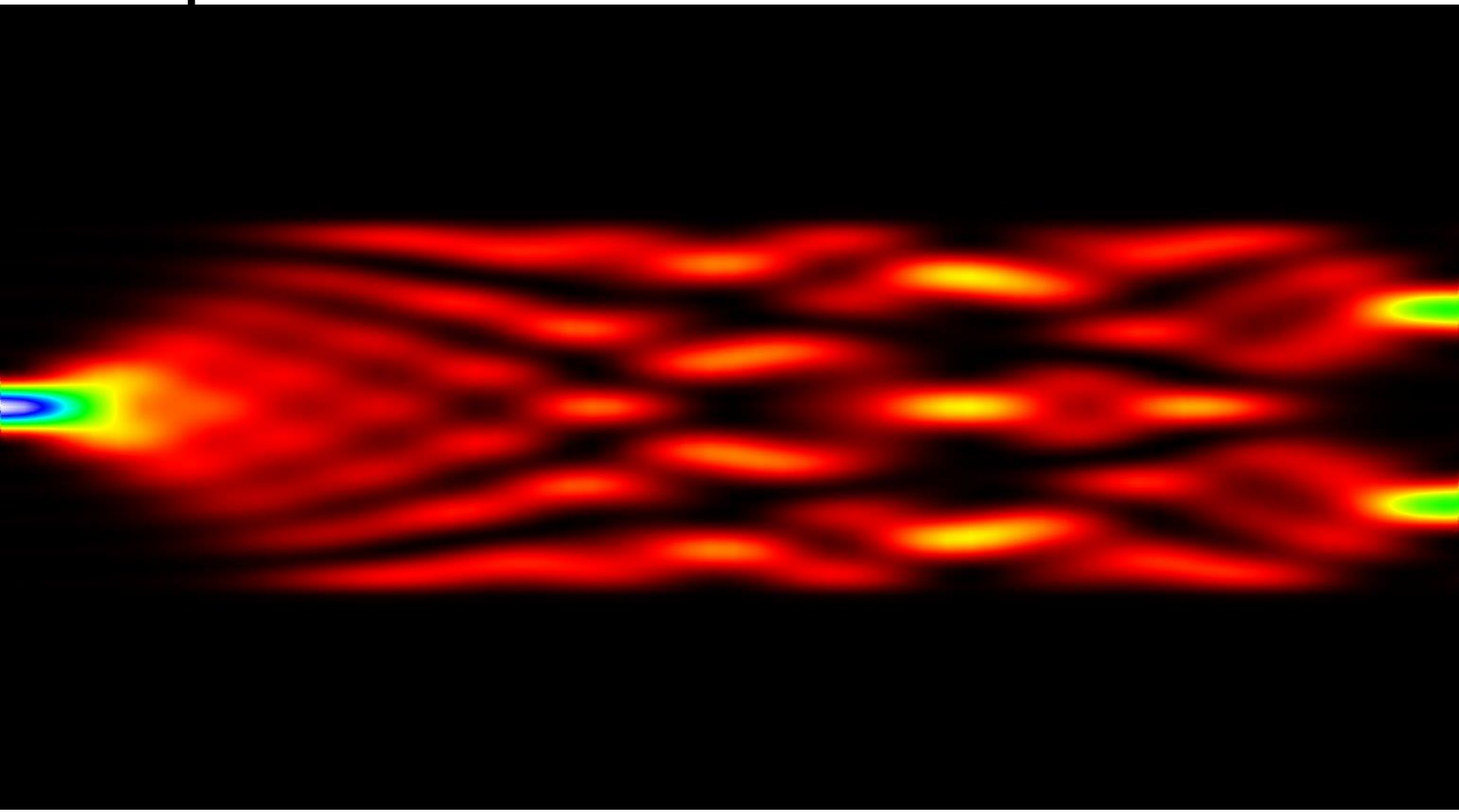
Light Propagates through device



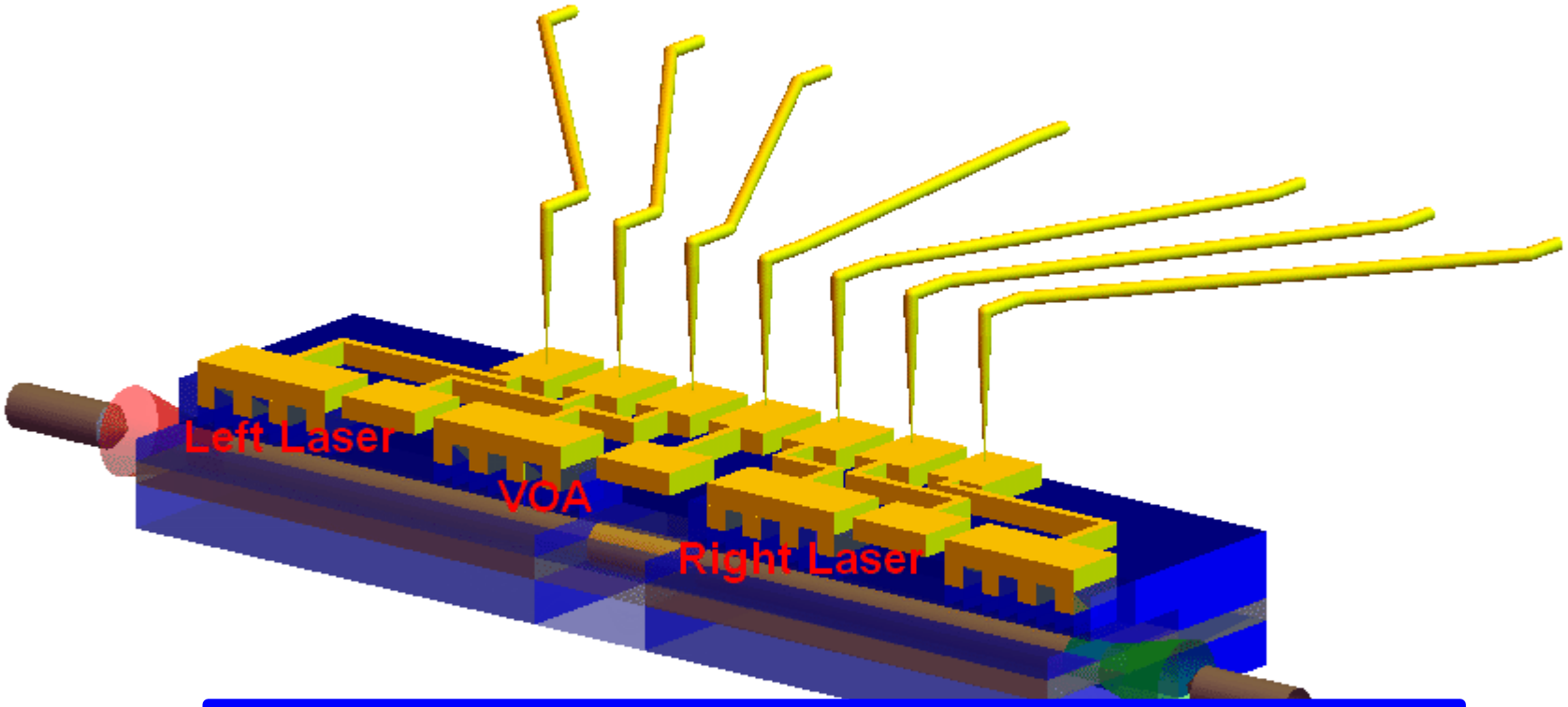
Starting Mode exits in two pieces



Top View

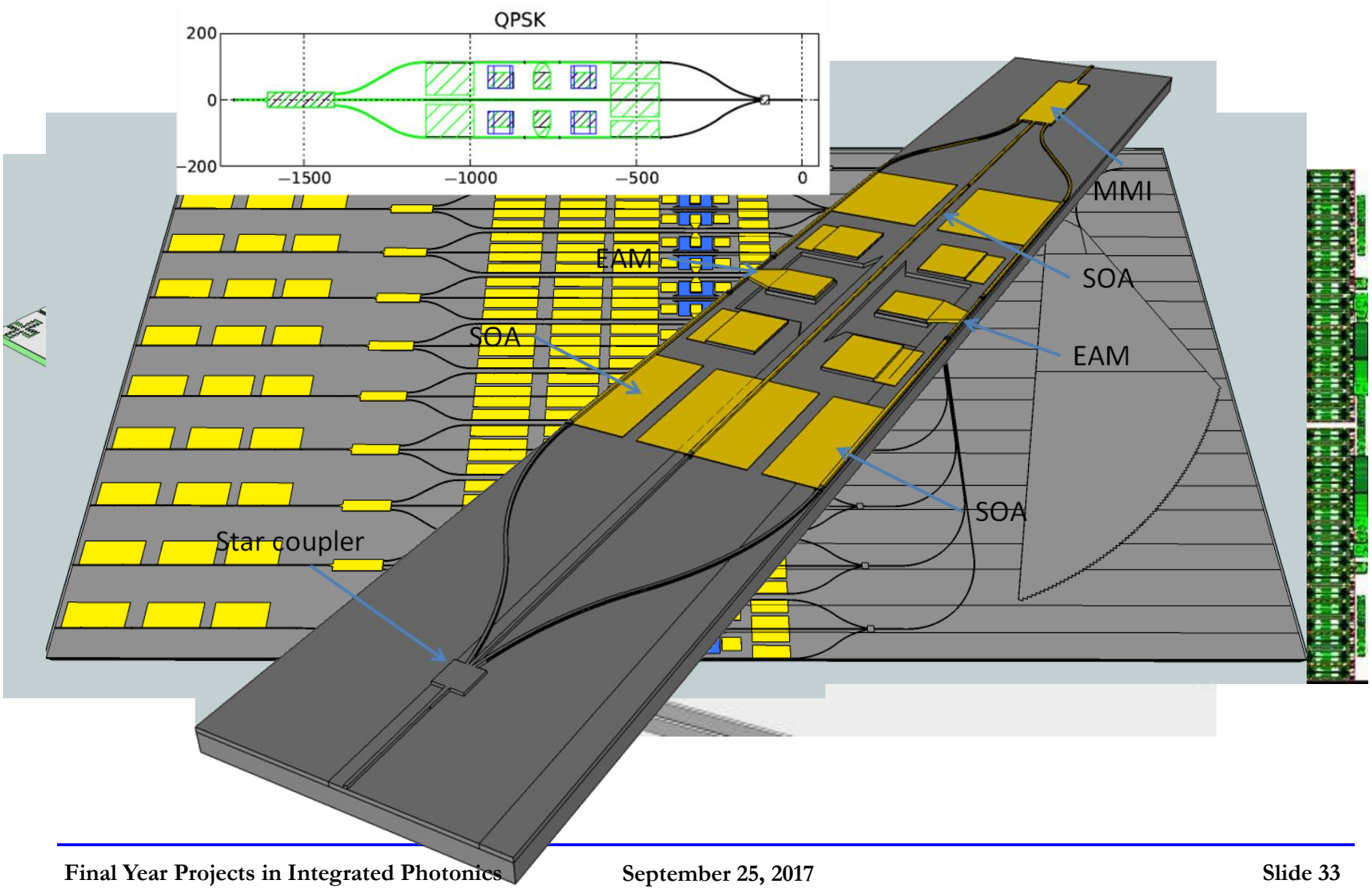


Laser-laser interactions



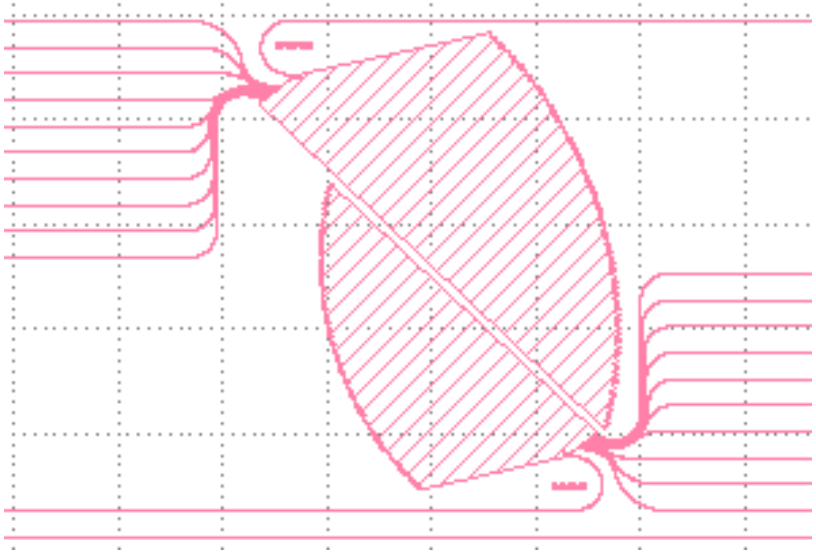
Project #4 – Optical Simulations (more than one topic possible)

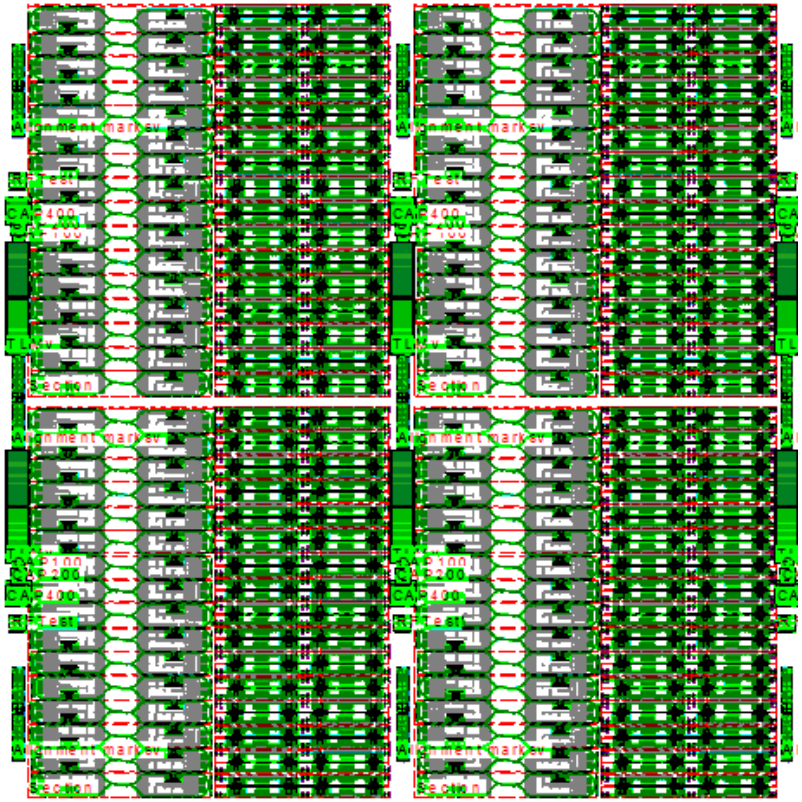
PICdraw – Custom Design tool

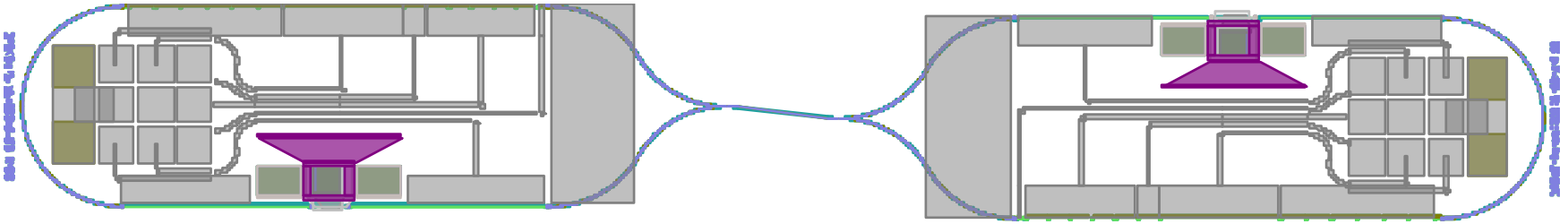


Mathematical based design

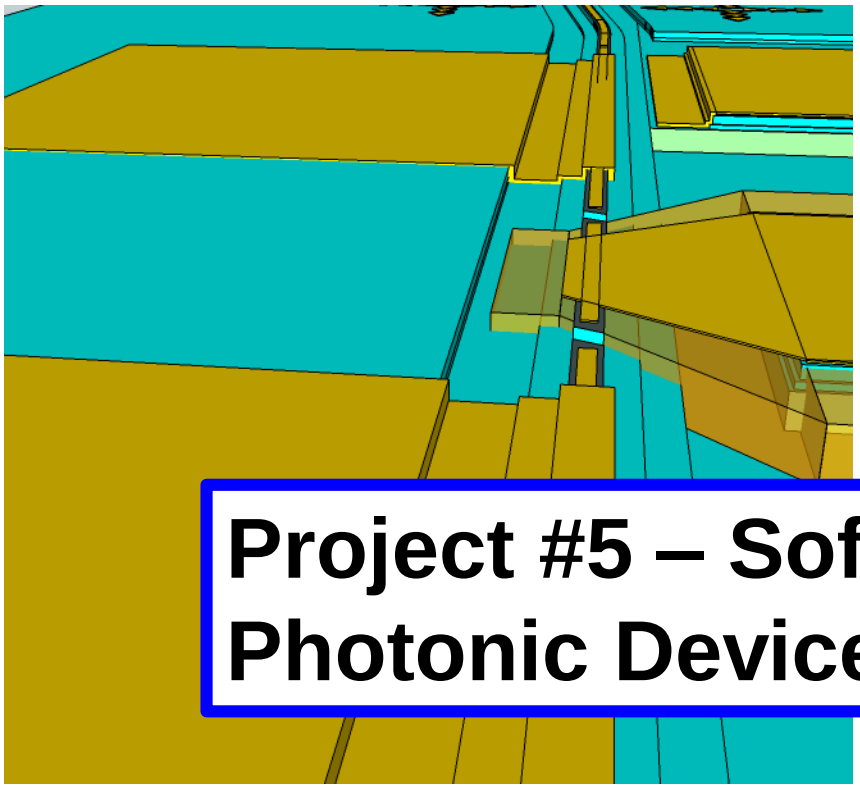
- Custom software used to design the complex devices

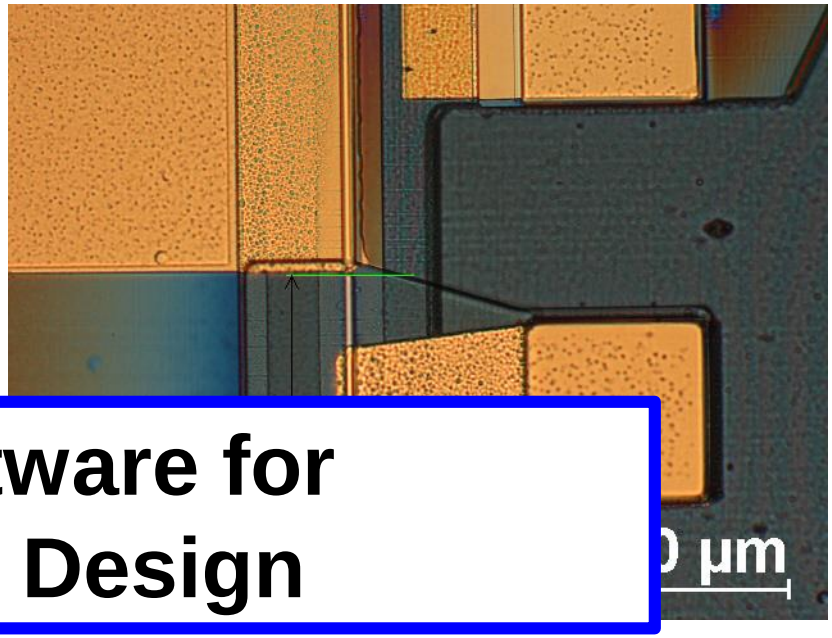






Simulation and fabrication of complex photonic devices



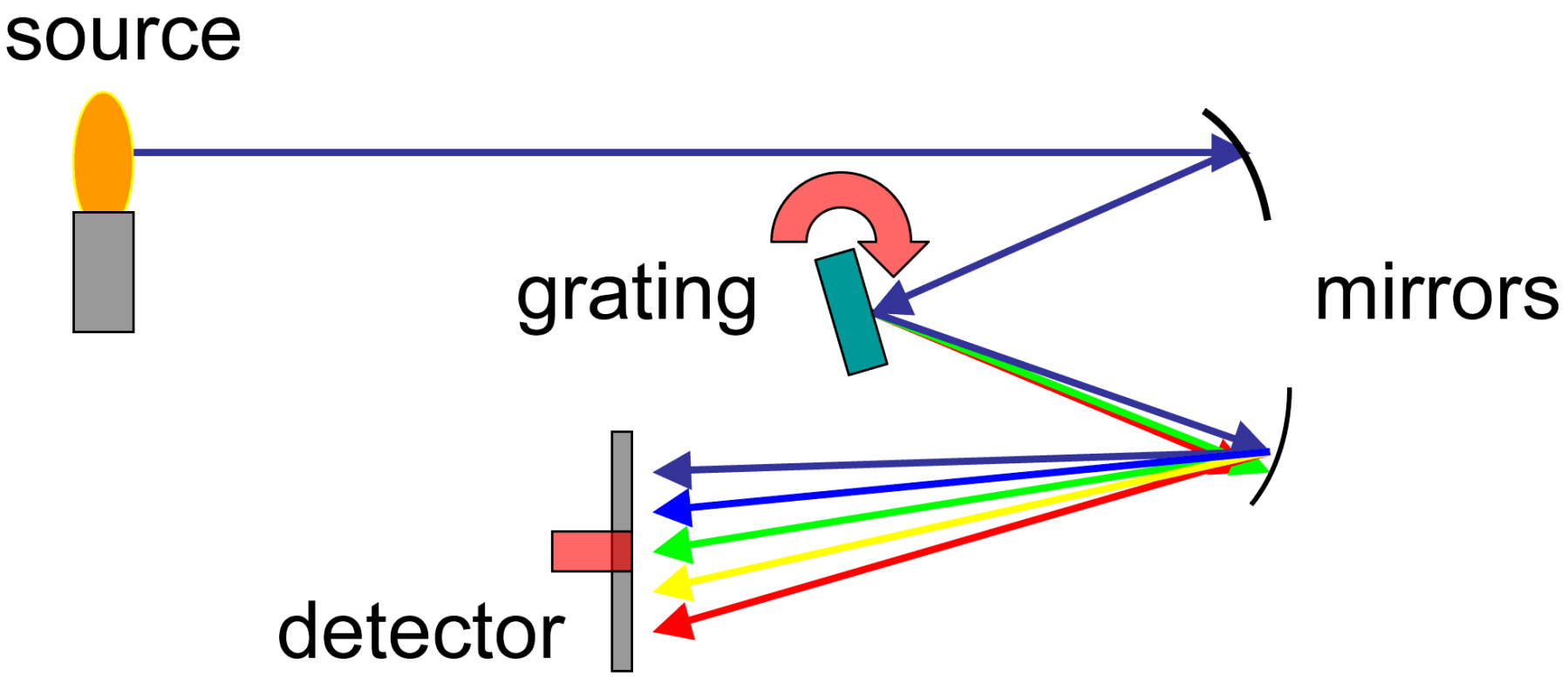


Project #5 – Software for Photonic Device Design

Get your hands dirty?

Project #6 – Making Stuff
(come and talk to me…)

e.g. Czerny-Turner spectrometer



6 possible project areas:

		Experiment	Theory	Programming
1	Laser Measurements	Yes	possible	LabView
2	Laser Theory	No	Yes	likely
3	Laser Linewidth	Yes	Yes	LabView
4	Simulations	No	Yes	likely
5	Optical design tools	No	Yes	C++
6	Making things	Yes	?	?

Please contact me if you have any questions about any of the project options.