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Time-tagged photon imaging
for
trace gas measurement
using
cavity enhanced absorption spectroscopy

J. M. Hallam & J. S. Lapington, Space Research Centre
S. M. Ball, Department of Chemistry
University of Leicester

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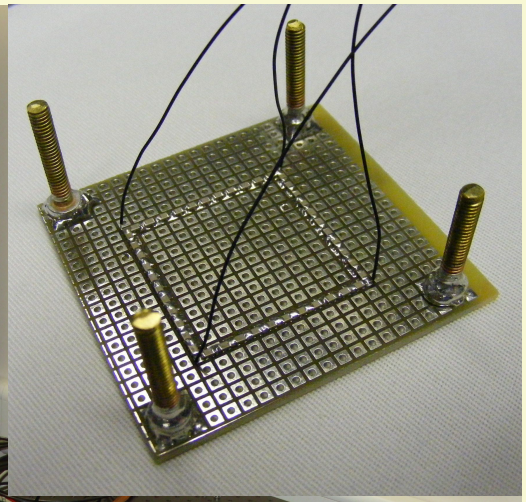
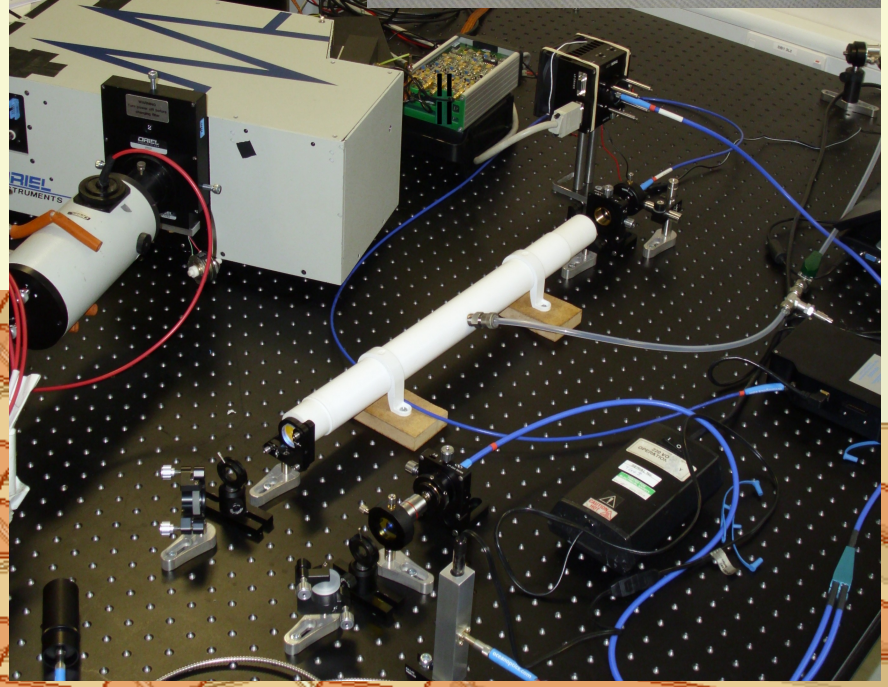
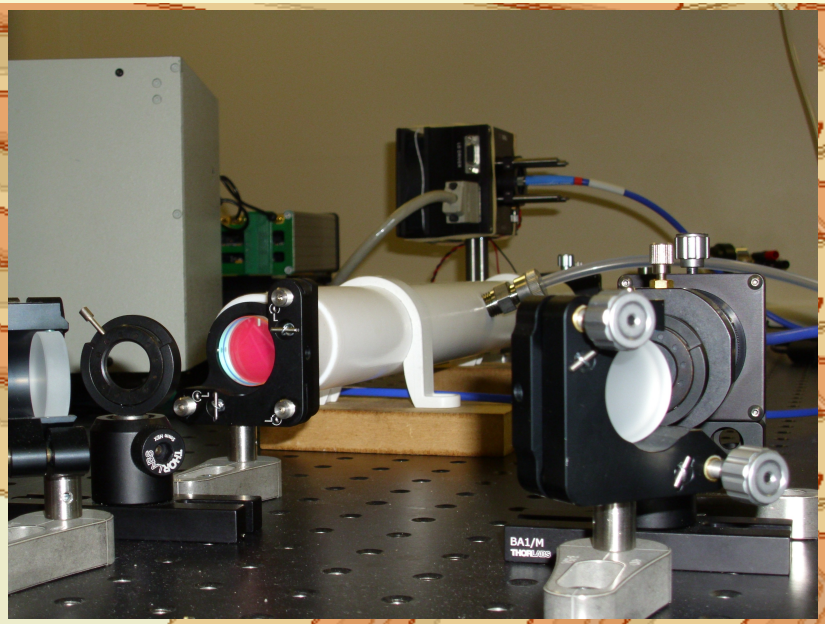
Outline

- Absorption Spectroscopy
- Cavity Enhanced
- Imaging with capacitive readout
- Capacitive readout design







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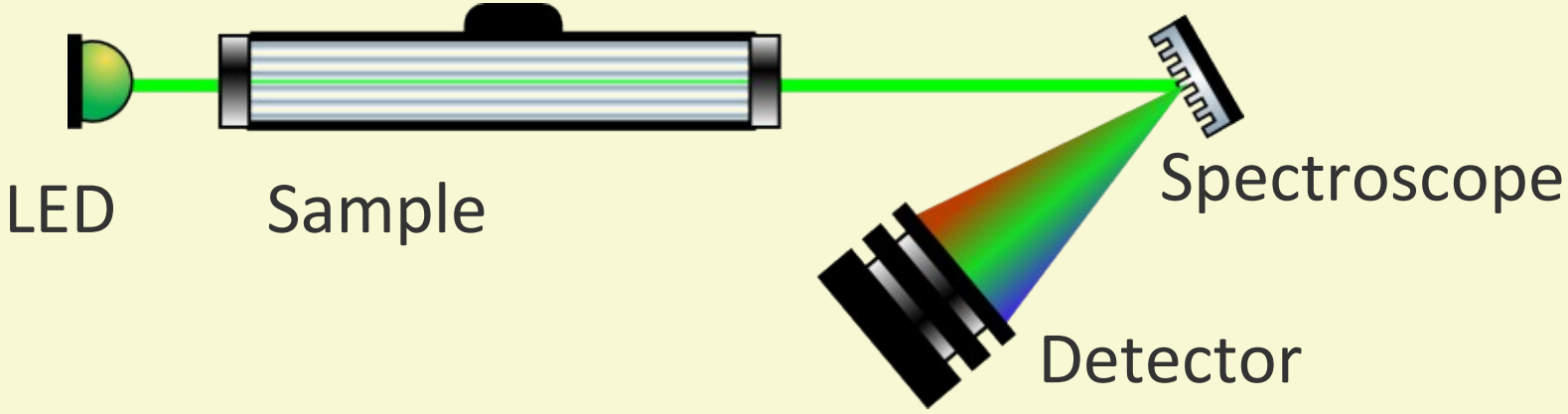
Absorption Spectroscopy

- Trace gas measurements...
  - NO_2 (air quality/exhaust fumes)
  - I_2 (biogenic seaweed emission)
  - NO_3 & N_2O_5 (night-time chemistry, nitrate aerosols)
  - Water dimer, water continuum (climate feedback)



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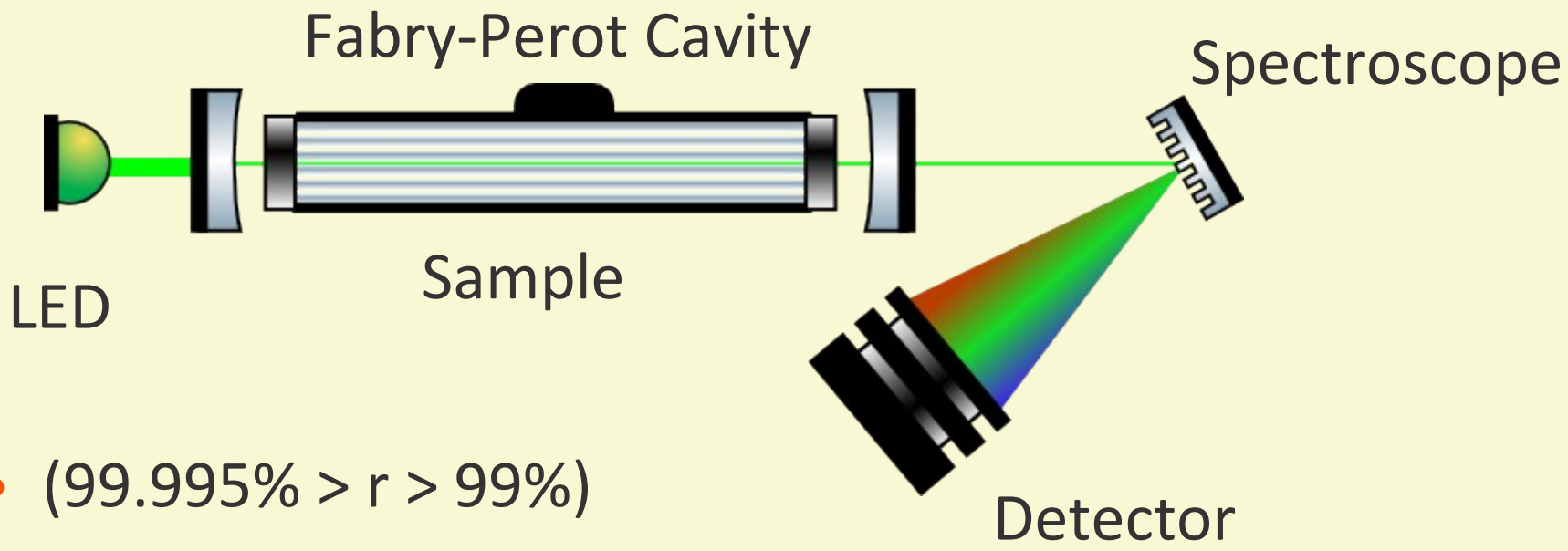
Cavity Enhanced

- Goal: Detect atmospheric NO_2 at the part-per-billion level
- Long path length: Use Fabry-Perot cavity



- (99.995% > r > 99%)

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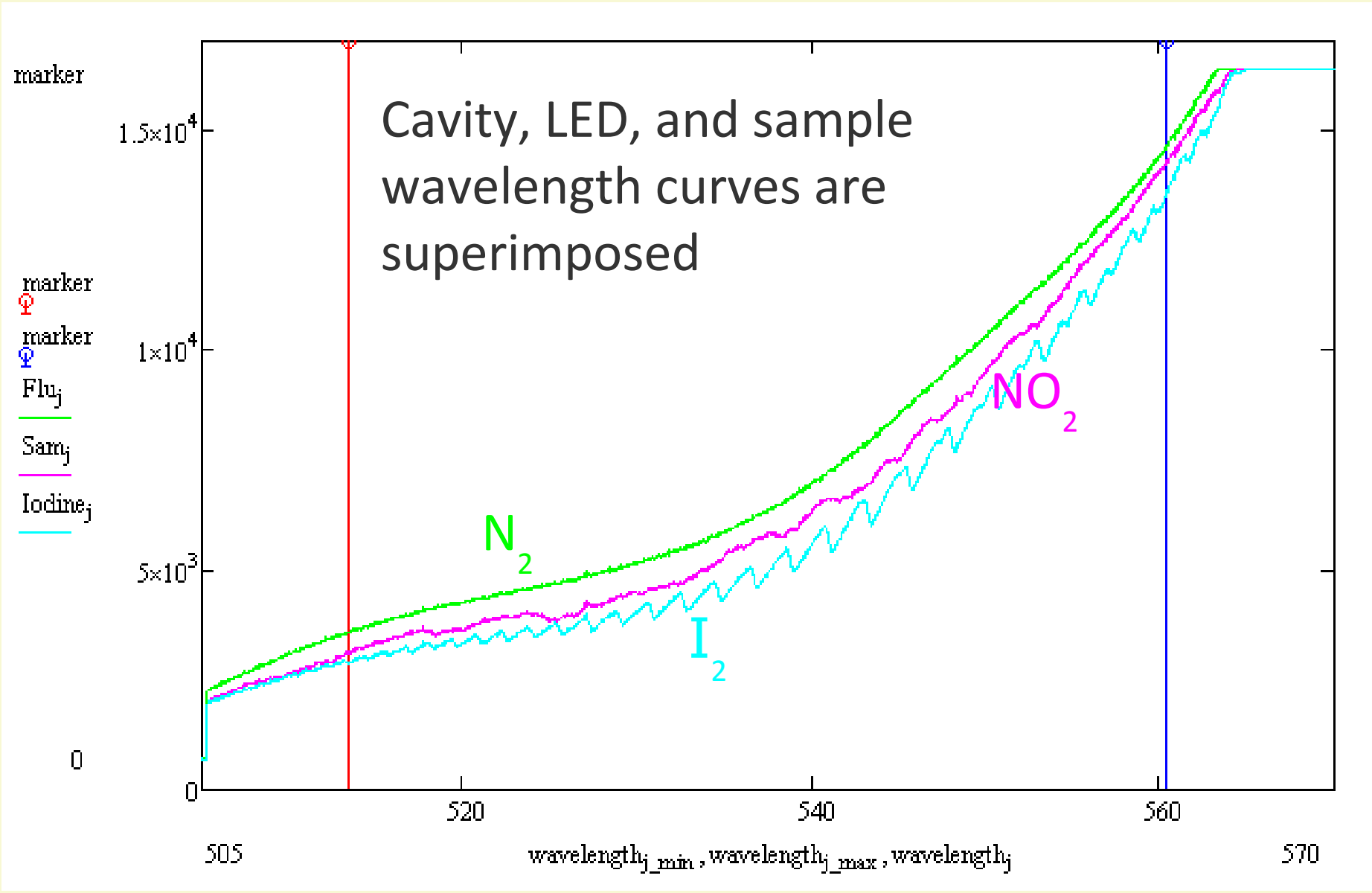

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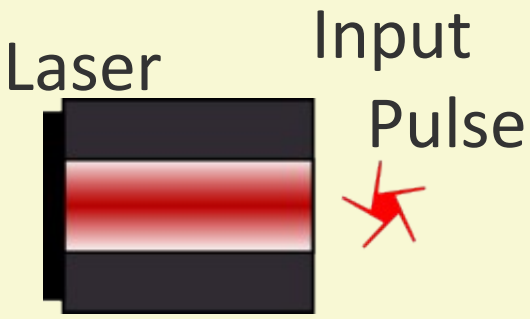
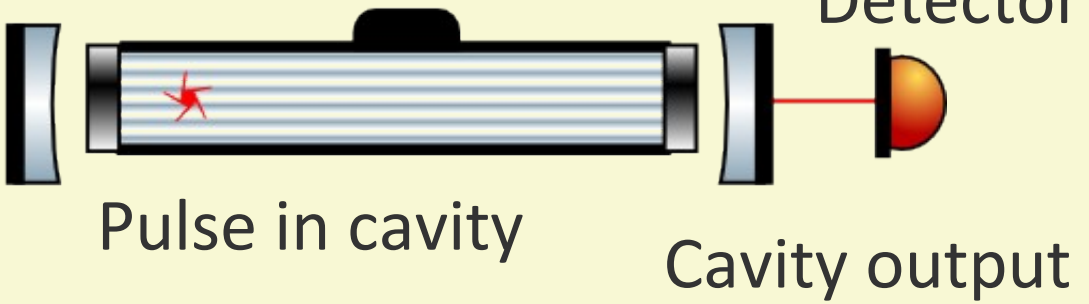
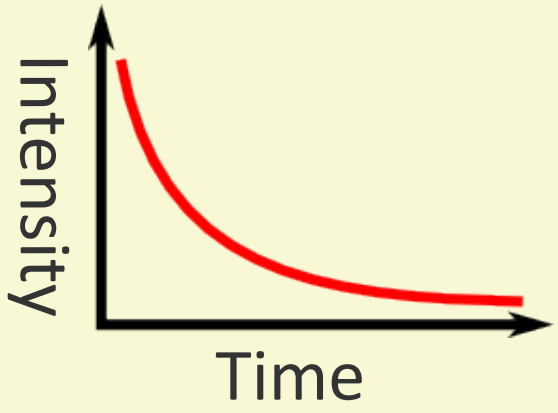
Cavity RingDown Spectroscopy

- Using a pulsed coherent light source





- Cavity output tails off exponentially
- Loss of spectral information
- Low sampling rate



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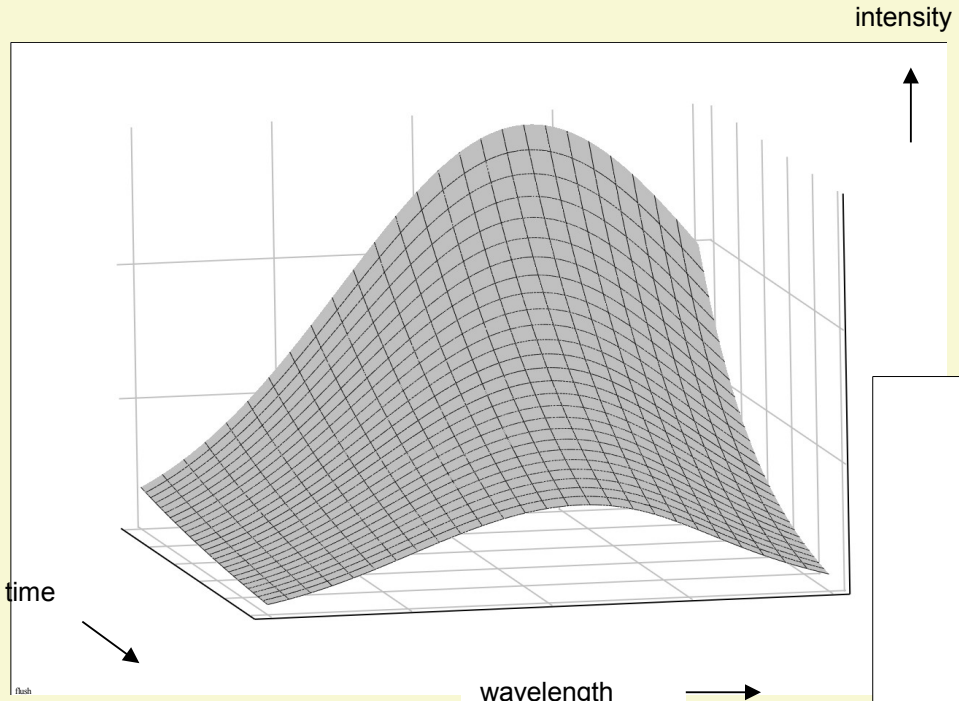
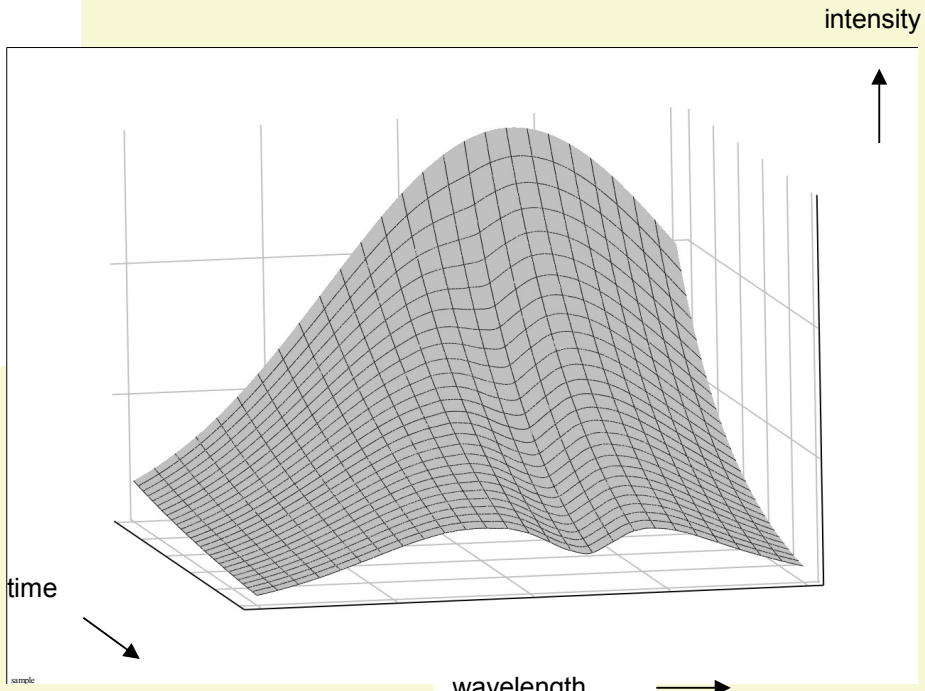
Empty cavity



Cavity + sample



[Ball '09]

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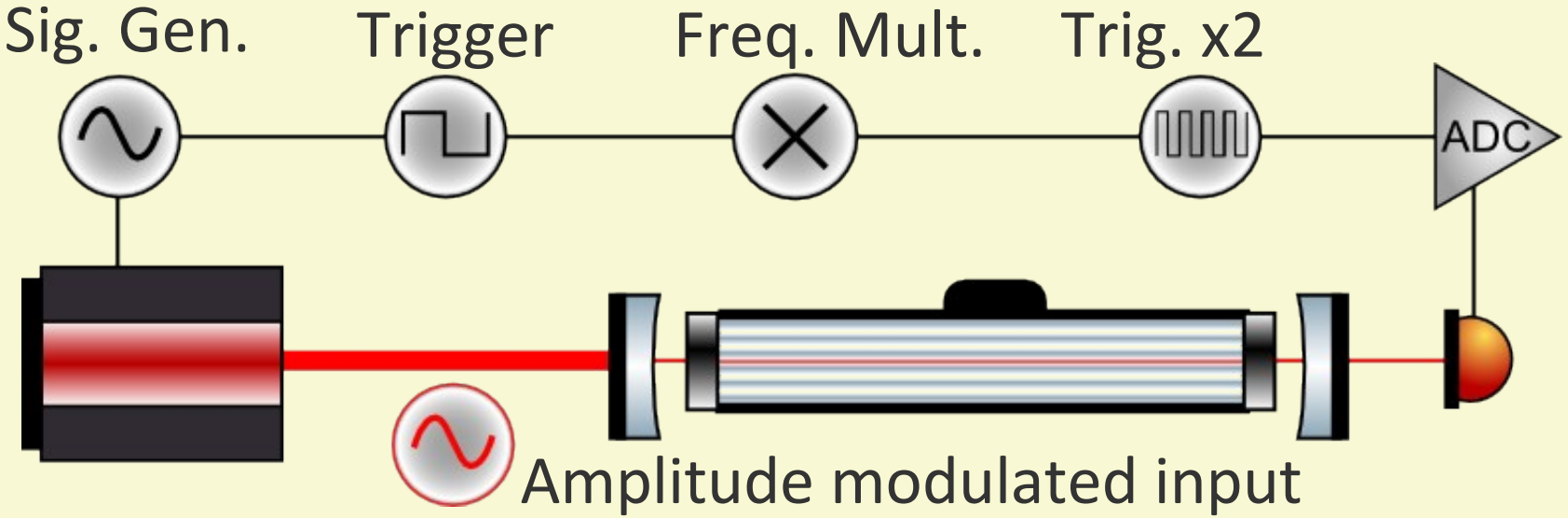
Continuous CRDS[Engeln '96]



- Demodulation extracts the phase delay ϕ
- From which we obtain ringdown time τ
- $\tan\phi = -2\pi f\tau \quad (= 1)$

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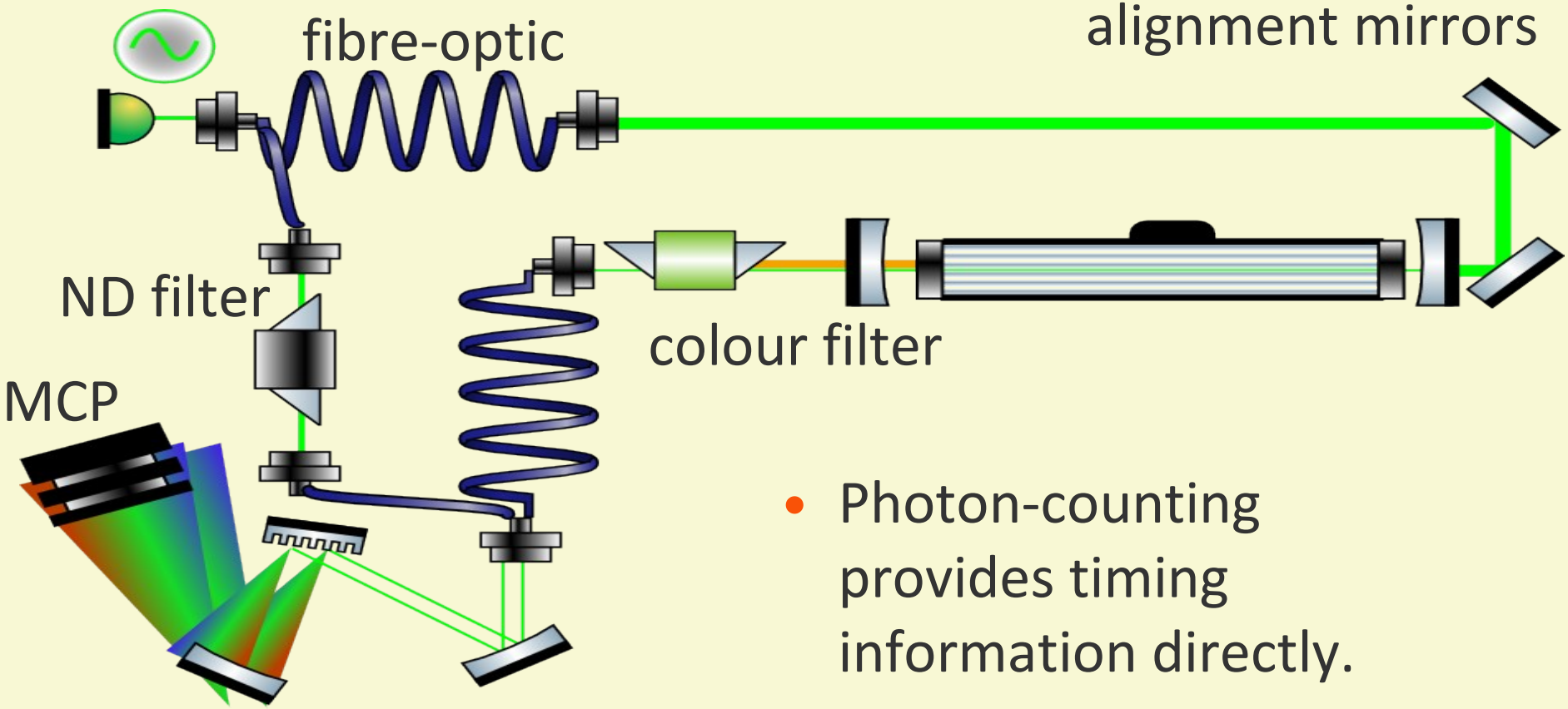
BroadBand Cavity Enhanced Absorption Spectrometry (BBCEAS)



- Photon-counting provides timing information directly.

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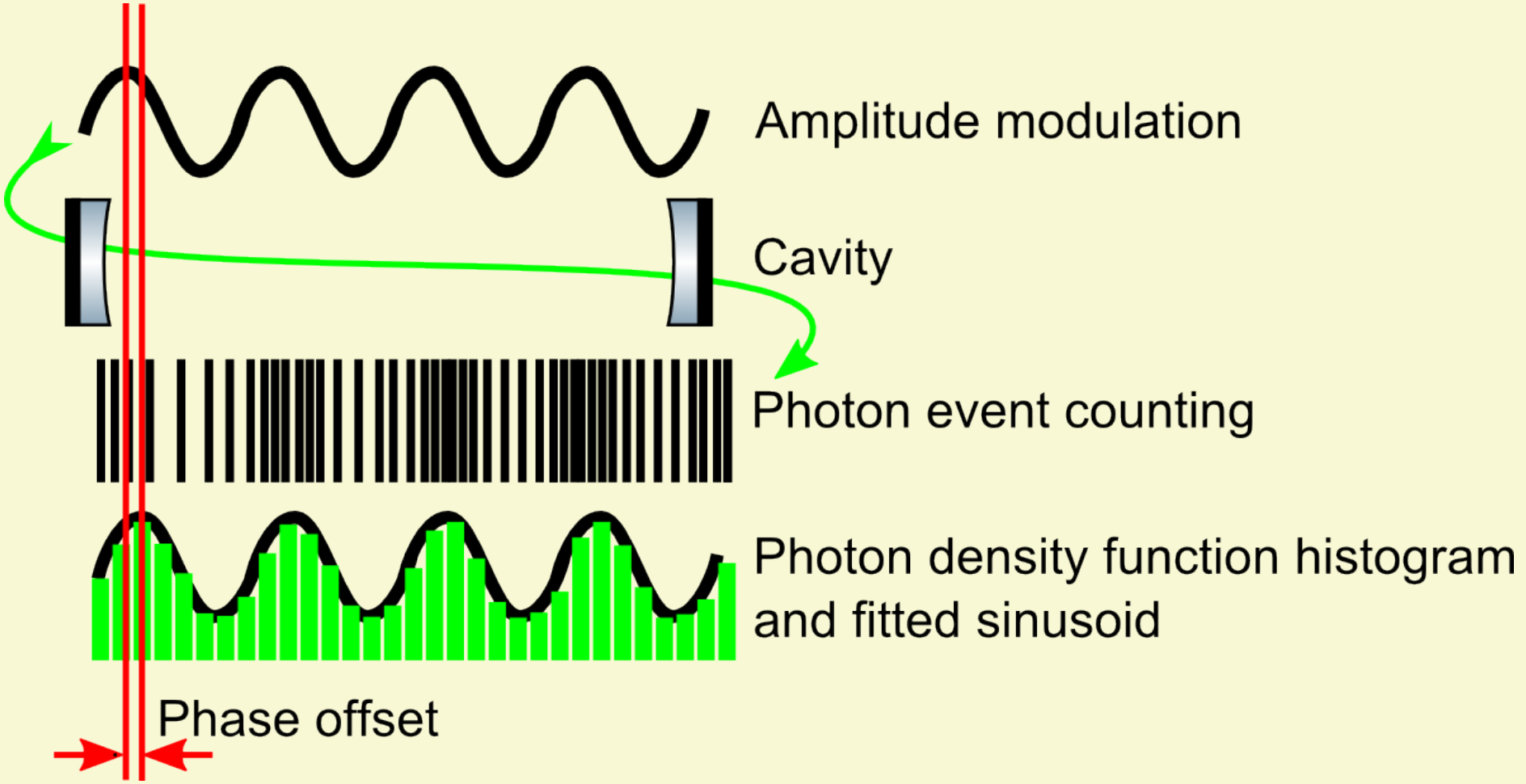
BroadBand Cavity Enhanced Absorption Spectrometry (BBCEAS)



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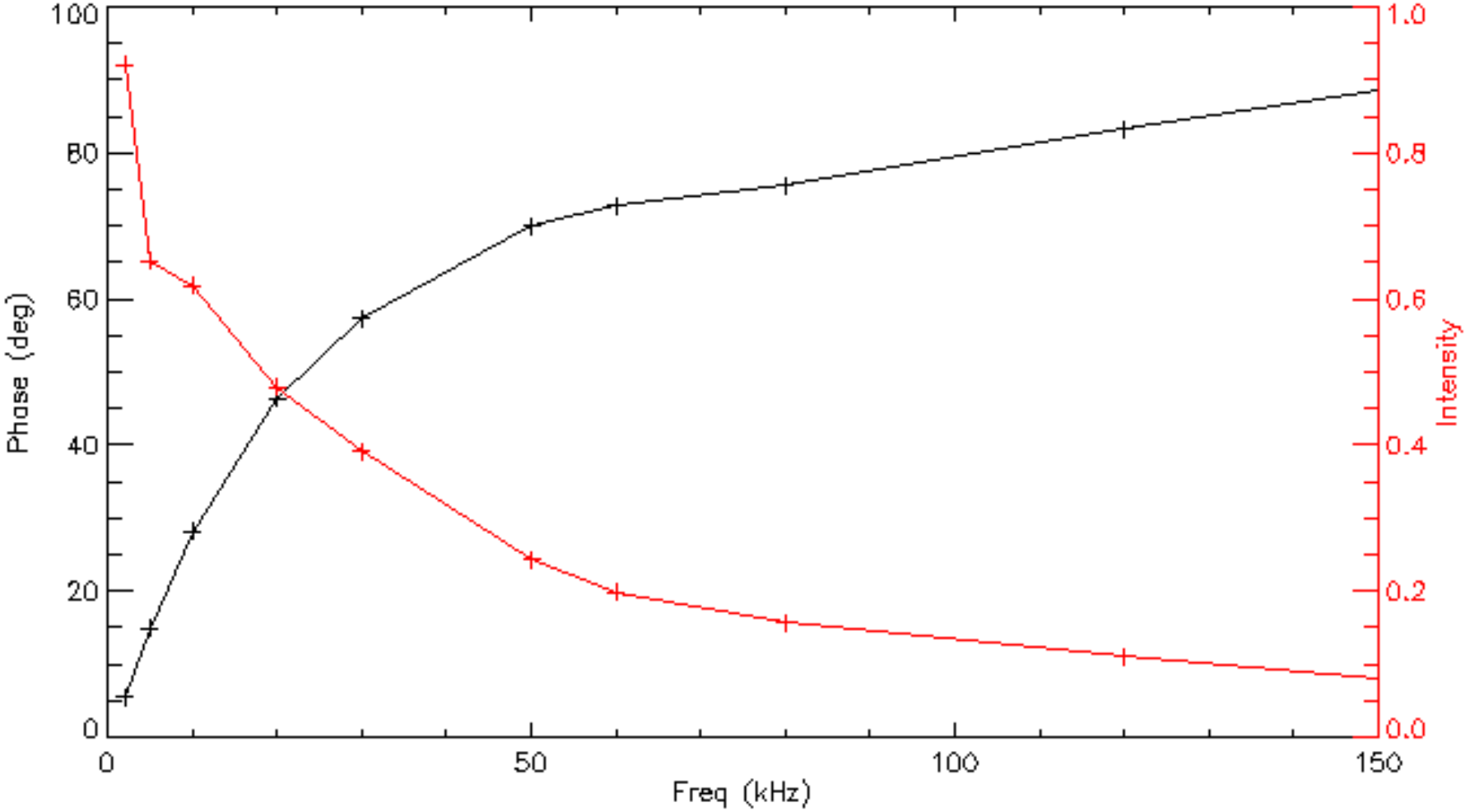
Phase shift and intensity over modulation frequency



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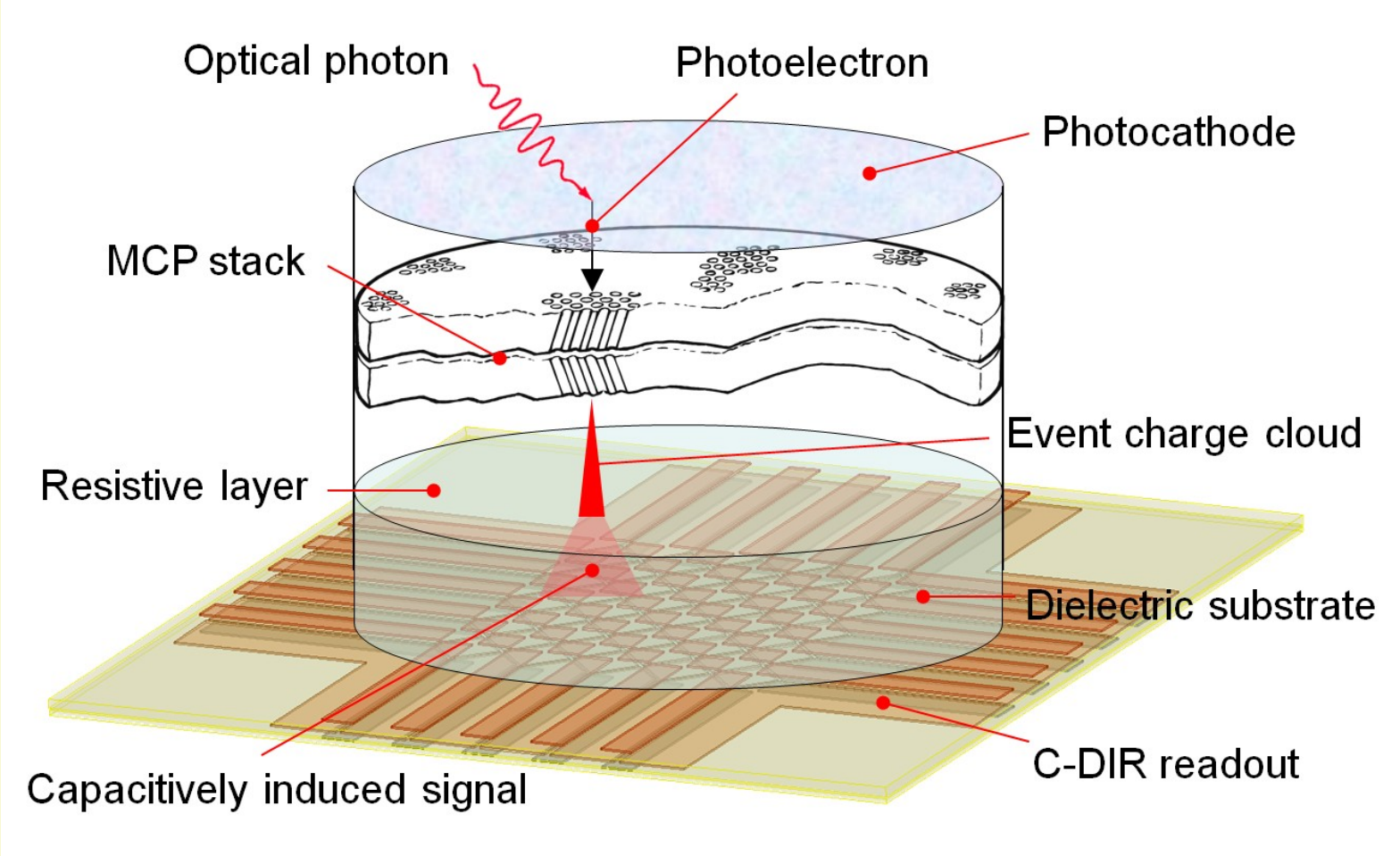
MCP and Capacitive Readout



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Capacitive Readout Advantages

- Capacitive coupling – no resistive noise, no bias resistors, separate from MCP vacuum
- No geometric charge division – no partition noise
- High-speed – MCP limited timing
- Only electronic noise, dominated by preamp input capacitance
- Simple linear algorithm to decode position
- Excellent linearity - >80% anode dynamic range

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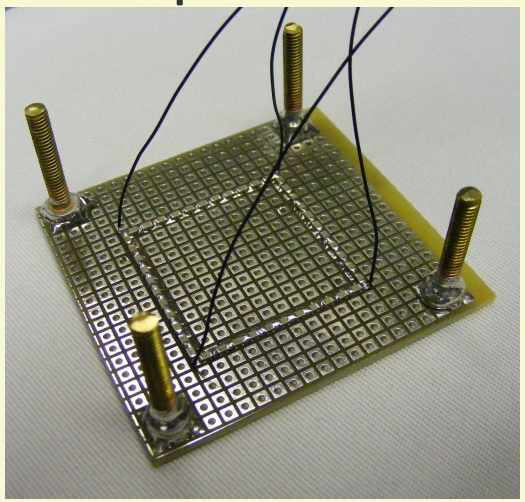
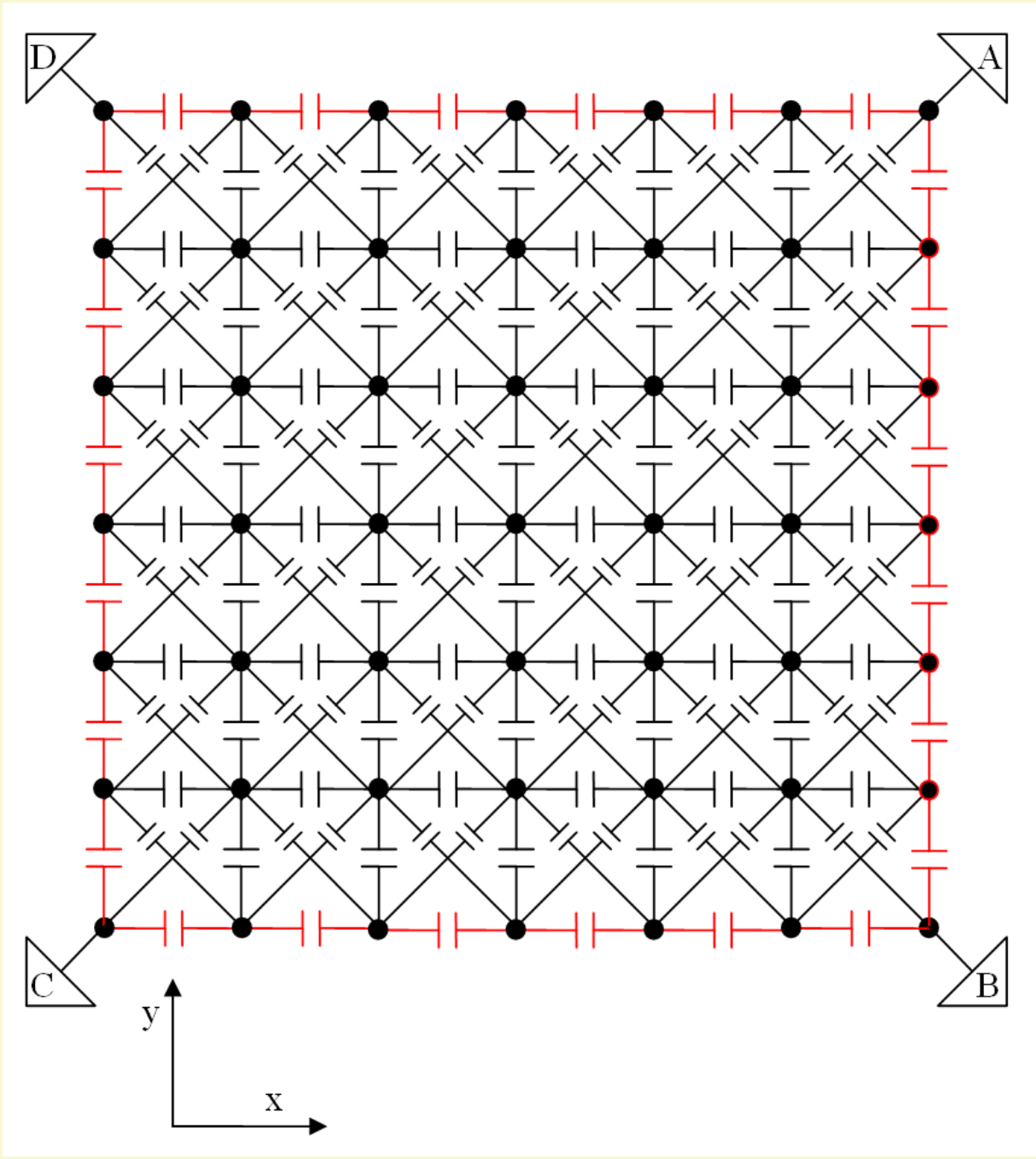
Capacitive Readout

- Increased edge capacitance
- Horizontal and vertical capacitance emphasized





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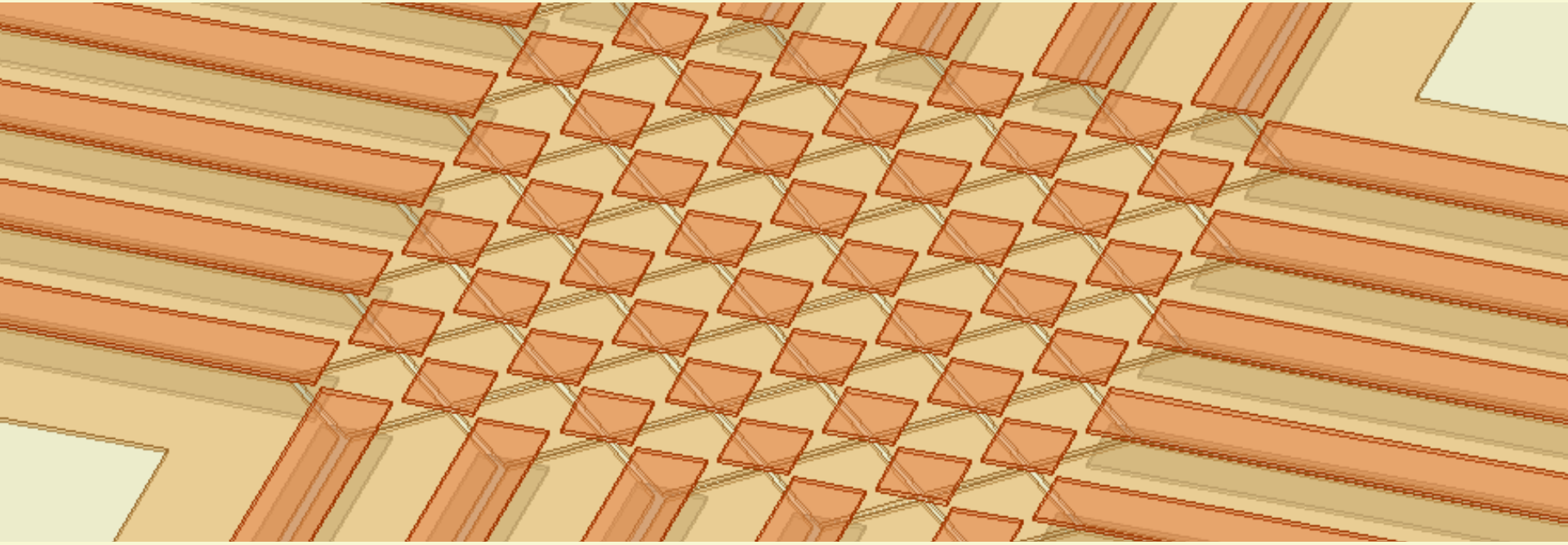
New Capacitive Readout Design

- Capacitance built-in to pattern geometry – no discrete components



- 25 x 25 mm^2 C-DIR finite-element modelled with 8pF pattern capacitance

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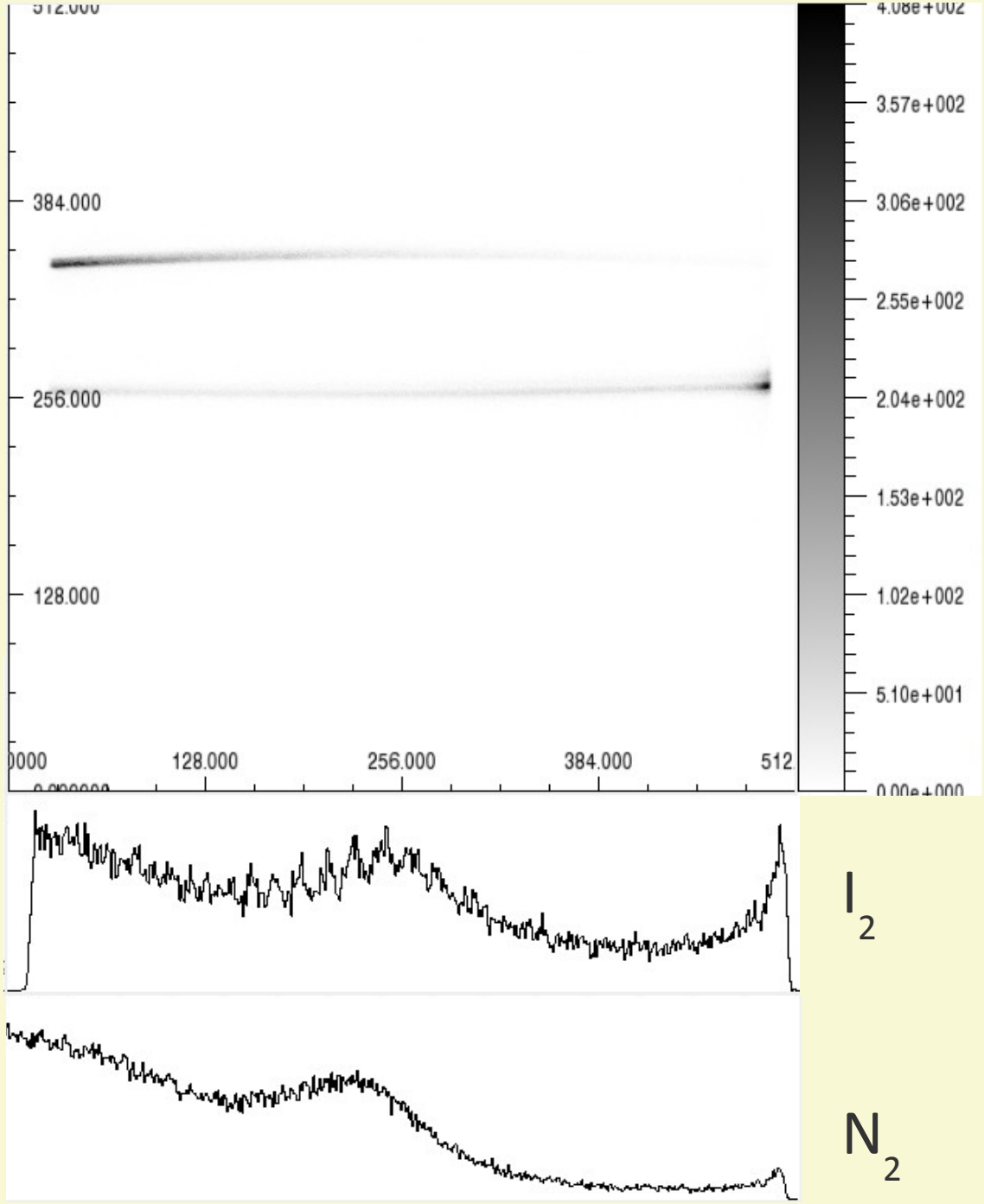
Imaging detector

- Single-channel cavity (N_2 flush with I_2 contamination) output image
- Histogram across image, showing I_2 absorption spectrum from N_2 base spectrum



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Conclusions

- BBCEAS is a powerful, flexible and simple technique for point atmospheric studies
  - Time-resolution measures cavity ringdown allowing cavity-calibration in the field
  - Spectral resolution allows different species and concentrations to be identified together
- Our imaging, photon counting detector has read out broadband spectra from both cavity and reference beams at high sensitivity, with spectral and time resolution

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Bibliography & Acknowledgements

Ball, S., Jones, R., 2009, 'Broadband cavity ring-down spectroscopy', (Chapter 3, Berden,. G, Engeli, R., Cavity Ring-Down Spectroscopy: Techniques and Applications), Blackwell Publishing

Engeln, R., Vonhelden, G., Berden, G., & Meijer, G. 1996, 'Phase shift cavity ring down absorption spectroscopy', Chemical Physics Letters, 262, 105

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