



# Beam Diagnostics for Plasma Accelerators

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# Overview

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- Introduction
- A new beam profile analysis algorithm for radiative diagnostics for micron scale beams
  - Application to OTR
- Applications of a DMD in optical beam diagnostics
  - High dynamic range imaging and halo imaging (Past/Current)
  - Phase space mapping, Interferometry, Fourier plane filtering (Current/Future)
- Novel non-invasive bunch length THz diagnostic
- Supersonic gas jet based profile monitor
- Spin-off beam diagnostics company, D-Beam

# Introduction

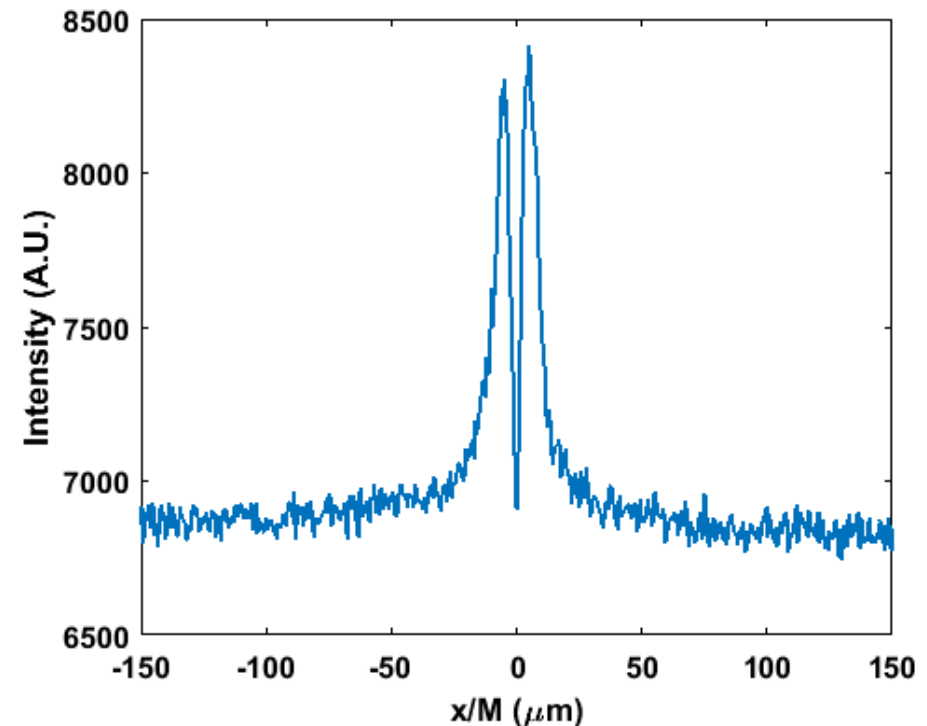
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- Quasar group specialises in diagnostics for particle accelerators.
- From the University of Liverpool, which in turn is a member of the Cockcroft Institute.
- Cockcroft Institutes specialises in accelerator research.
- Presented is an overview of our research which is most relevant to EuPRAXIA and plasma accelerators as a whole:
  - Innovative
  - Non-invasive
  - Low cost

# New Analysis Algorithm for OTR...

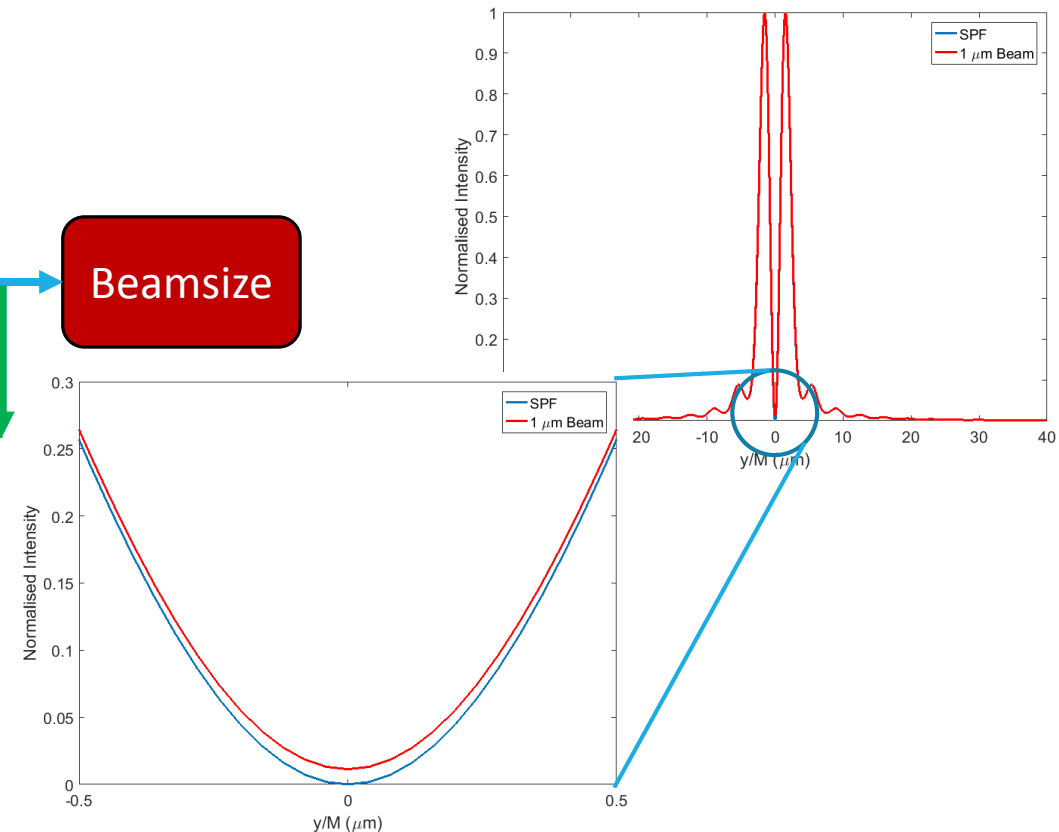
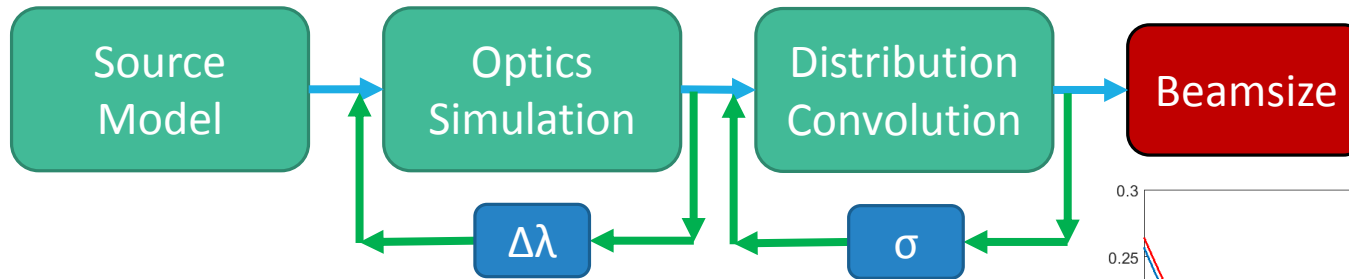
- New technique retrieves transverse beam profile from OTR images where traditional techniques fail.
- New algorithm uses optical simulations to further increase resolution to sub-micrometre.
- Applied to the case of OTR from  $\mu\text{m}$  scale electron beams at ATFII, KEK.

- Vertical scan of OTR produced by a  $1\ \mu\text{m}$  beam.
- Beam size/distribution is obscured by the OTR SPF (Single Particle Function).
- Visibility is dependent on beam size.



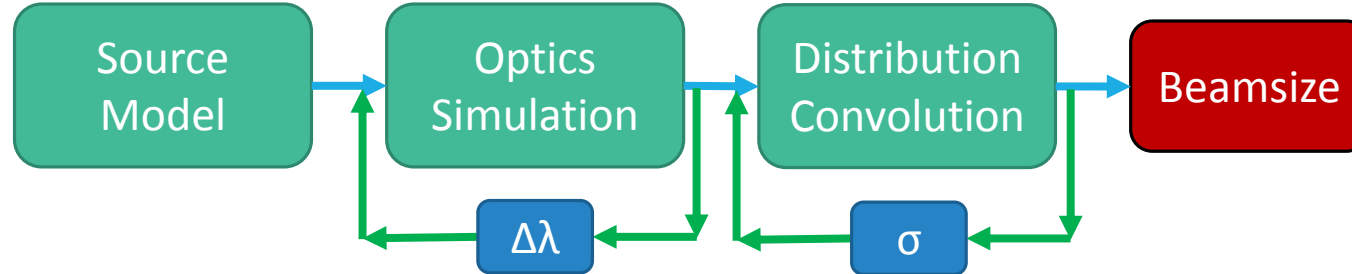
# New Analysis Algorithm for OTR...

- Use Zemax Optical Studio to propagate OTR source distribution through known optics.
- Convolve result with estimated beam distribution.
- Vary parameters of distribution to match data.



# ...just OTR?

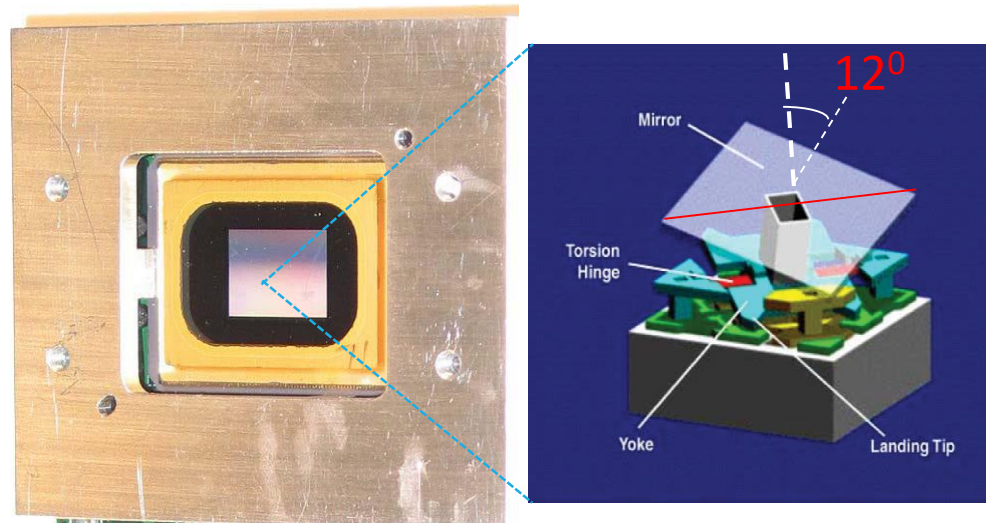
- Due to the modular design, each stage of algorithm is independent of the others.
- Therefore any source, any optics and any beam distribution can be studied.



- ATFII is a specific case, therefore some alterations will be required for other applications.
- Currently analysing data from our last trip to KEK.
- Future studies:
  - Apply algorithm to ODR/OSR imaging.
  - Apply algorithm to angular distribution studies.
  - Investigate use in THz.

# Imaging with a DMD

- DMD (Digital Micro-mirror Device) is an array of individually addressable mirrors.
- Each mirror is  $10 \times 10 \mu\text{m}$ , and can be set to either on ( $+12^\circ$ ) or off ( $-12^\circ$ ).
- Can be used to produce optical masks.

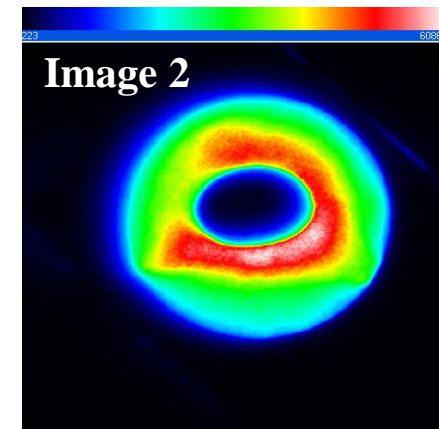
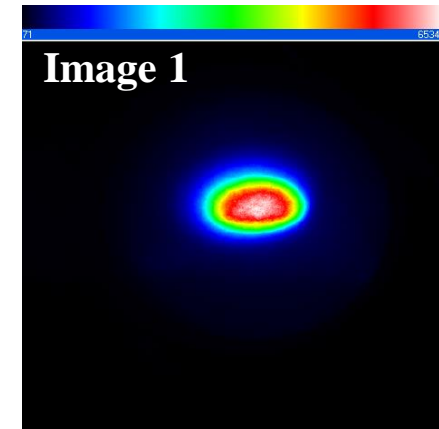
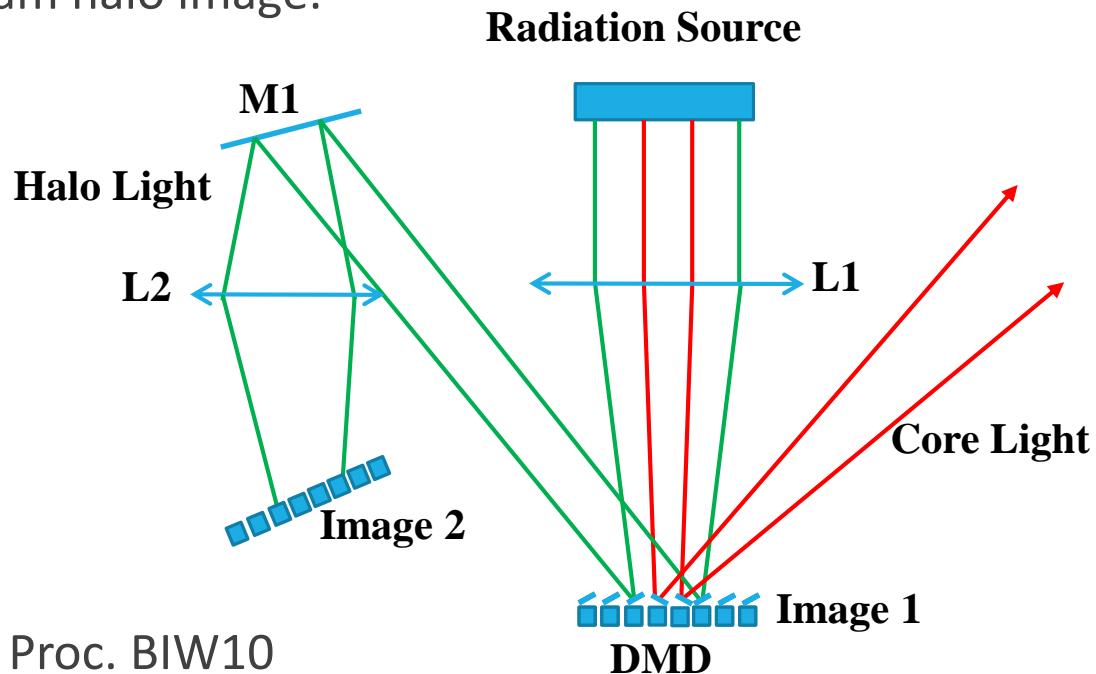


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# Halo imaging with a DMD

- A single mask can be used to produce a beam halo image – beam size.
- Beam is imaged and a mask is fit on the DMD to the most intense region.
- The beam is then imaged again with a longer exposure to produce a beam halo image.

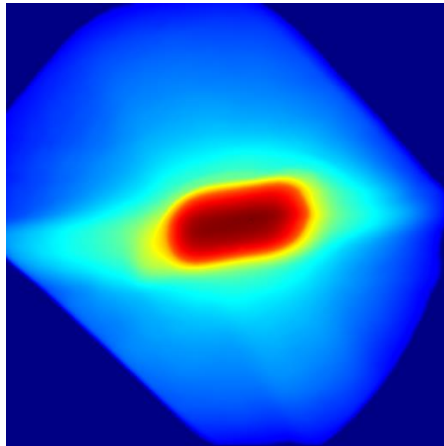




# HDR imaging with a DMD

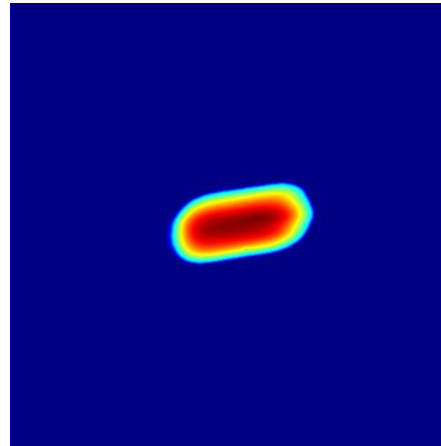
- By extending the halo imaging process, HDR (High Dynamic Range) imaging is possible.
- Masks are iteratively fit to the most intense regions of longer and longer exposures.
- By combining these images it is possible to produce  $>10^6$  dynamic range.

$(1 - 10^{-6})$



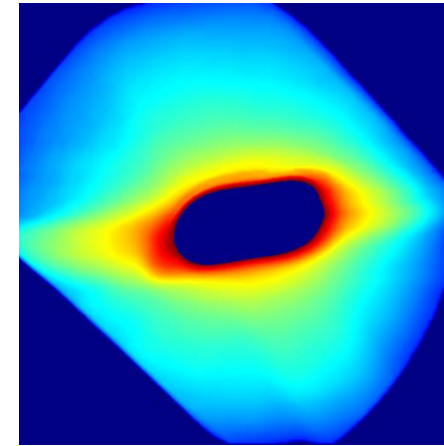
$$E_{Total} \equiv \int_S J(x, y) dx dy$$

$(1 - 10^{-2})$



$$E \sim 0.99 E_{Total}$$

$(10^{-2} - 10^{-6})$

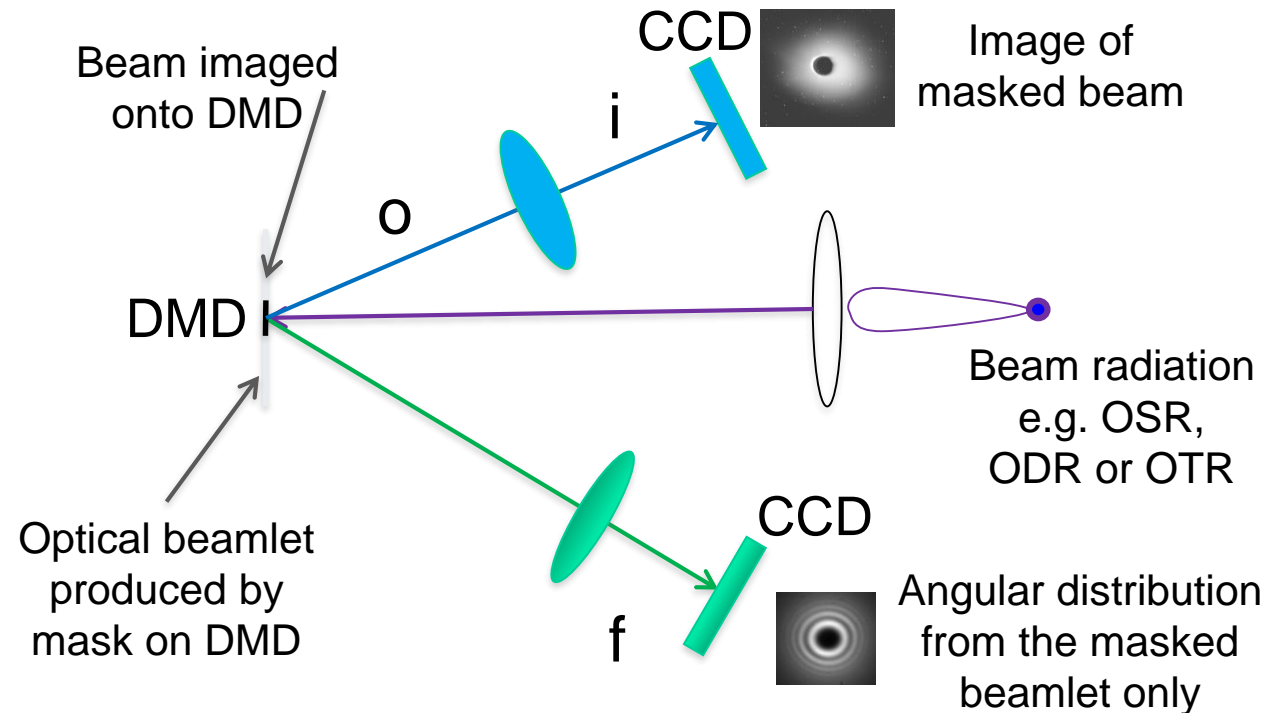


$$E \sim 0.01 E_{Total}$$

H. Zhang et al. Proc. IPAC2012

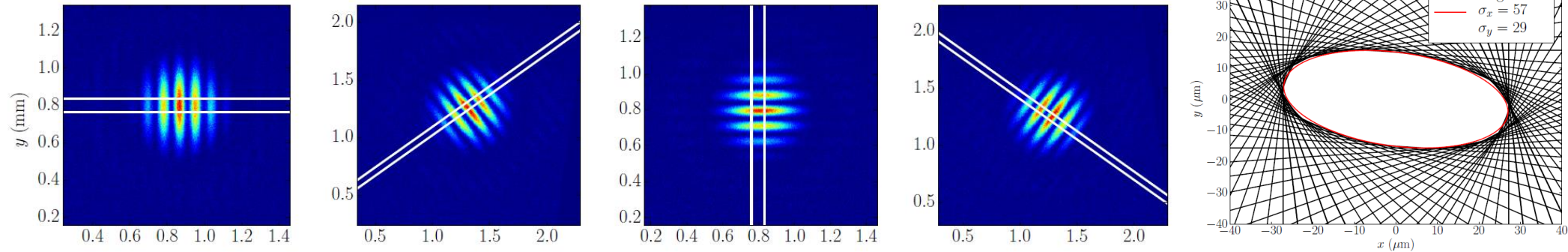
# Phase space mapping with a DMD

- Optical equivalent of standard pepper pot technique.
- Current status/plans:
  - Modelling DMD in Zemax Optical Studio.
  - Studying effects of mask size/shape on resolution of the imaging system (PSF).
  - Build and test performance of OPSM at a real accelerator.



# Interferometry with a DMD

- OSR passes through a rotating double pinhole and is imaged.

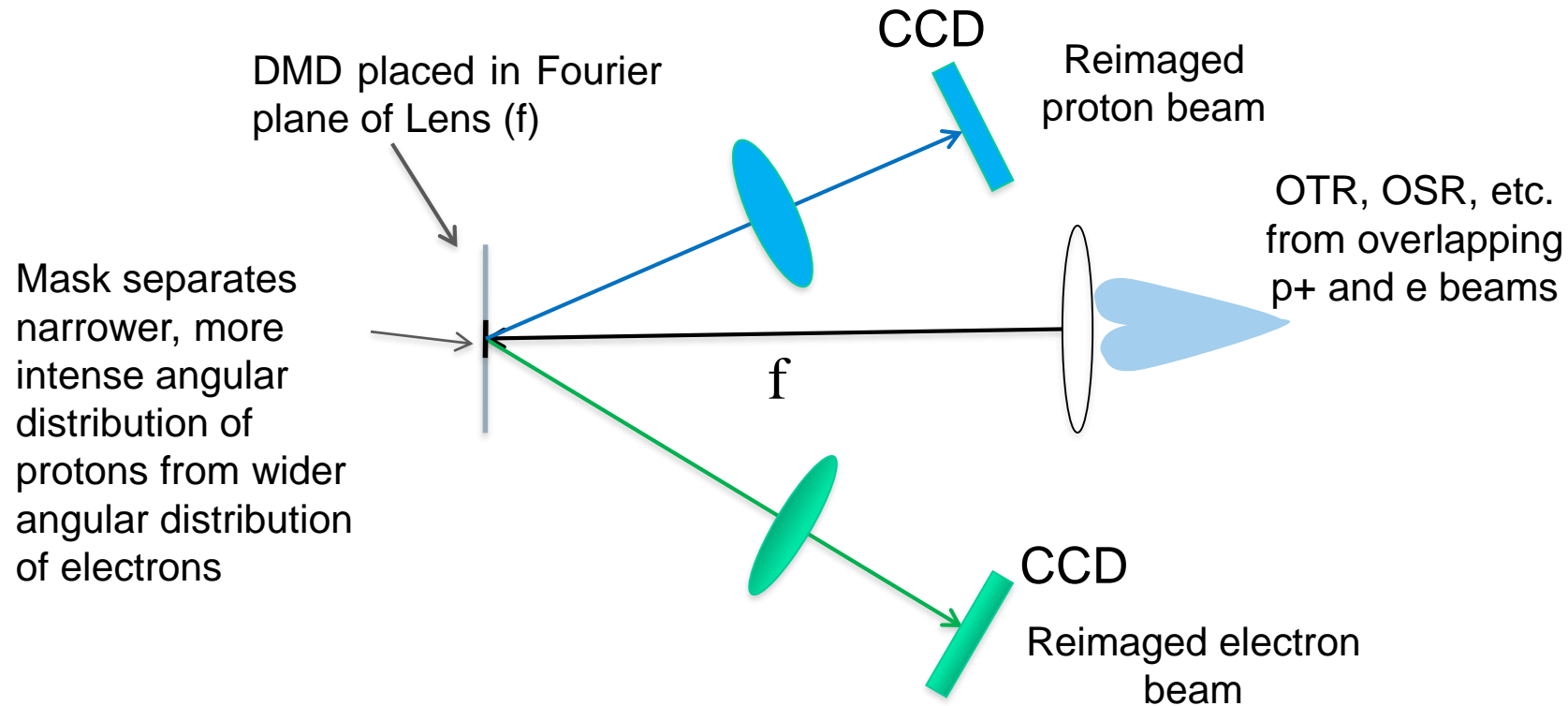


L. Torino et al. Proc. IBIC16

- Resolution limited by the separation of the pinholes.
- Can use DMD to create a double pinhole.
  - Separation of pinholes can be reduced to  $\sim 10 \mu\text{m}$ . Improved resolution.
  - Update rate on DMD mirrors much quicker than rotating mechanical device.

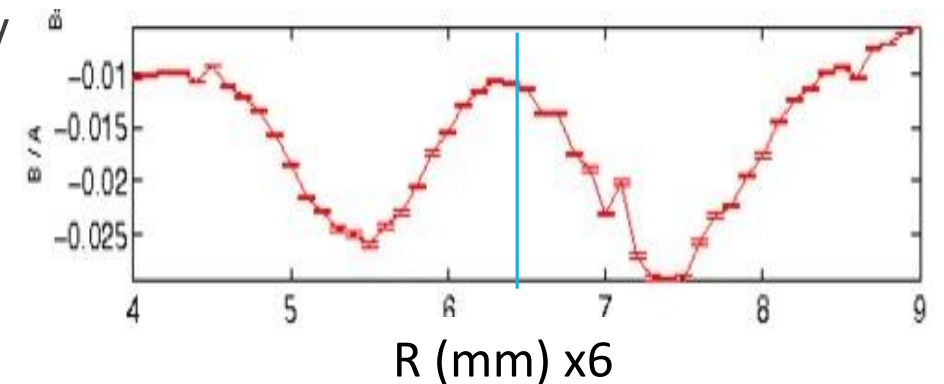
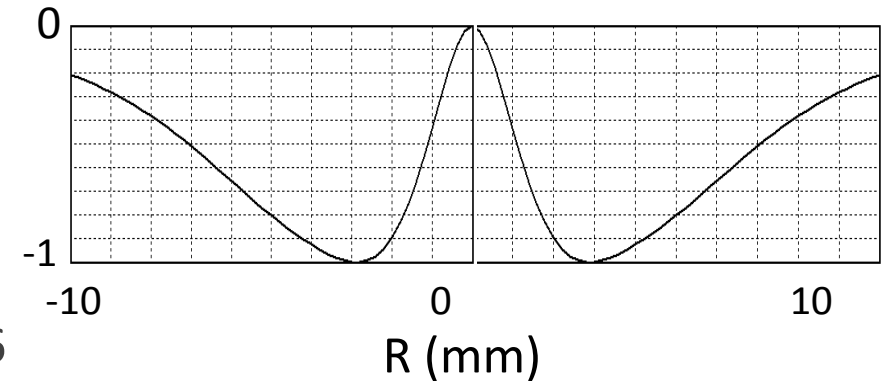
# Fourier Plane Filtering with a DMD

- Simultaneous proton beam, electron beam imaging - proposed for AWAKE.



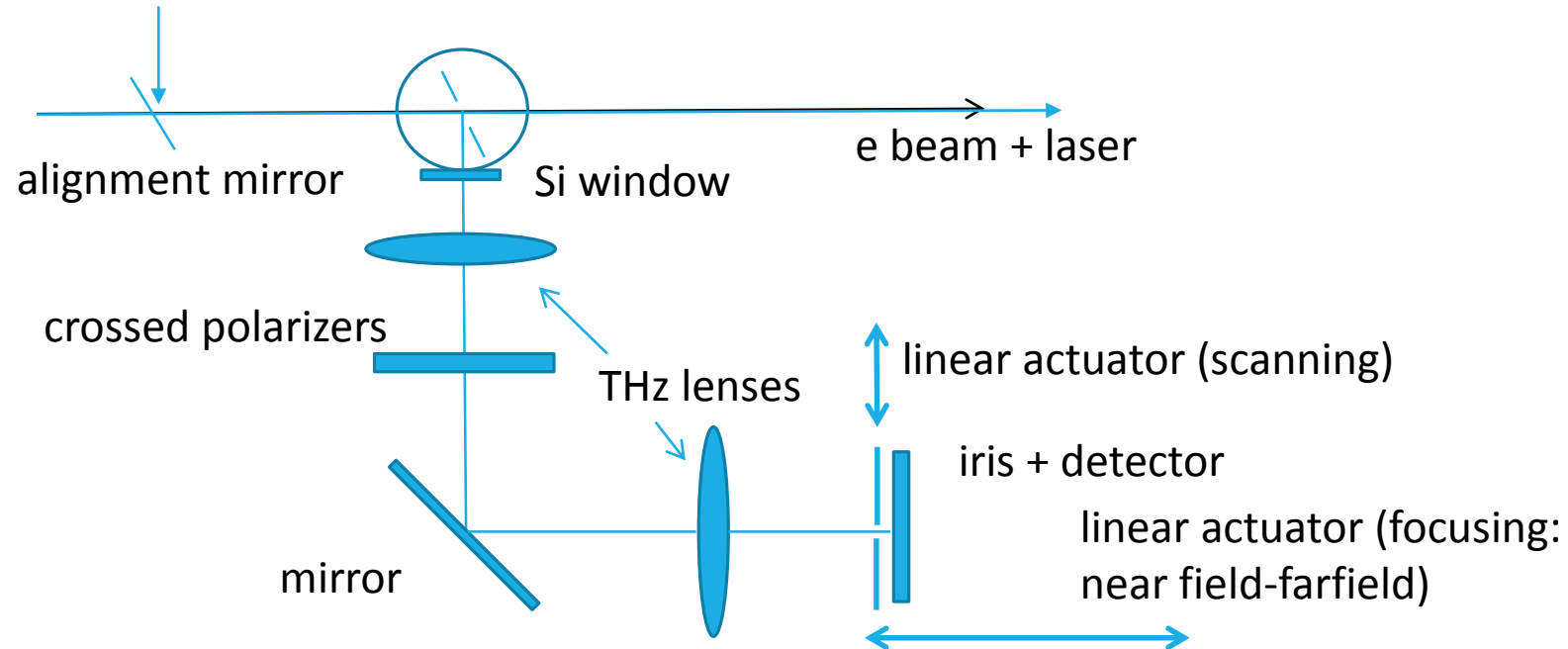
# Non-invasive bunch length THz diagnostic

- CTR/DR angular distribution normally studied for bunch length monitoring.
- New method uses CTR/DR image peak-to-peak separation:
  - Less interference from upstream sources
  - More intense than angular distribution
  - Easier to setup optical system
  - Works on beams comparable in size to the SPF
- CDR experiments at SLAC-FACET conducted in April 2016
  - Peak-to-peak separation found did not match theory
  - Calibration or theory error
  - Needed simulations of CDR



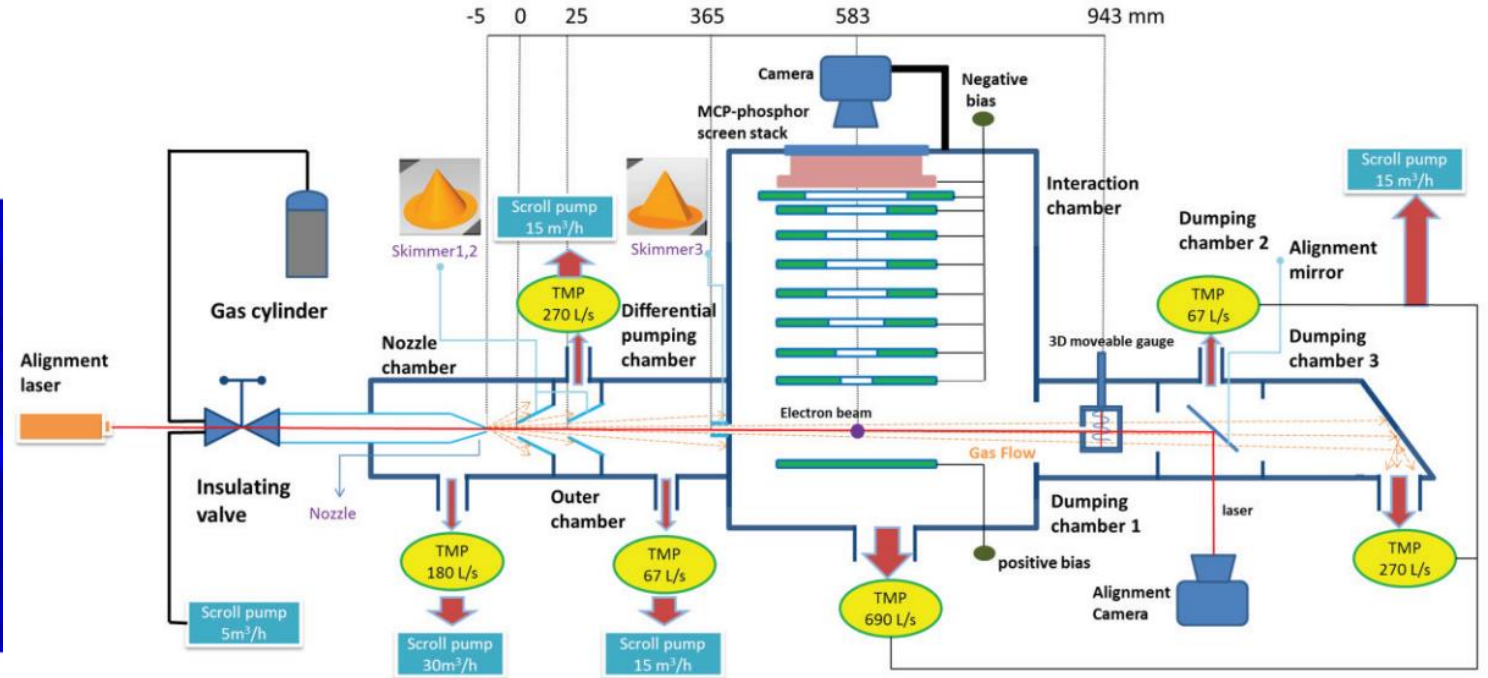
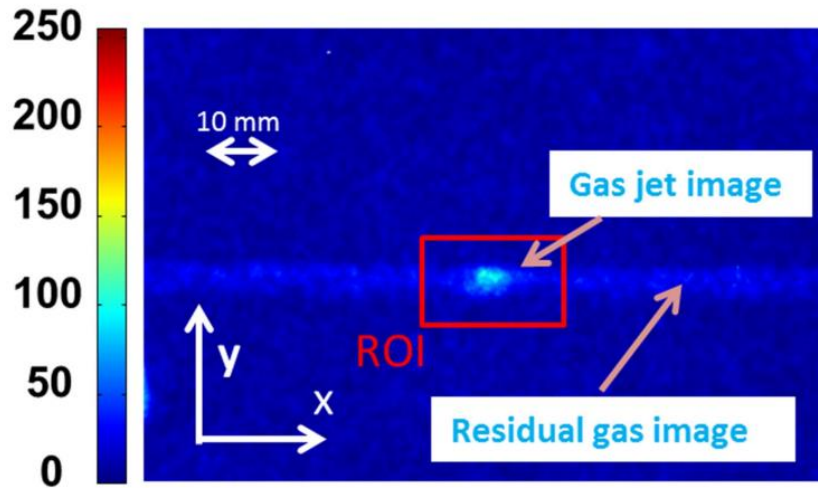
# Non-invasive bunch length THz diagnostic

- Simulations have been carried out and setup has been adjusted accordingly.
- Follow up experiment happening imminently at PSI SwissFEL.



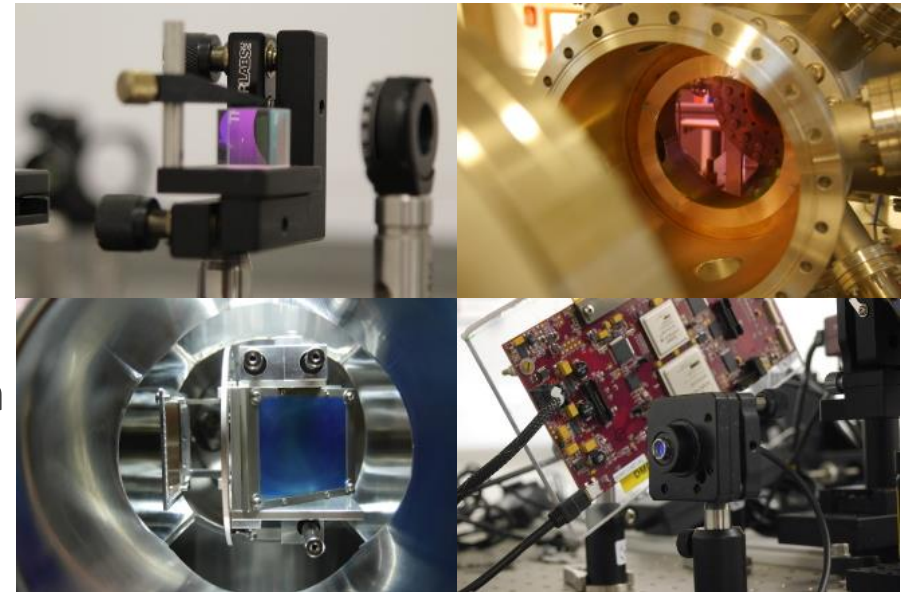
# Supersonic gas jet based profile monitor

- A beam profile monitor based on a supersonic gas jet curtain has been designed and implemented at the Cockcroft institute.
- Can be run in two modes:
  - Ion collection
  - Fluorescence



# D-Beam

- Spin-off company of the Quasar group.
- Goal is to provide beam diagnostics which have been developed as reliable and cost-efficient techniques for use at accelerator facilities.
- Can currently provide:
  - Optical fibre based BLMs (Cherenkov radiation).
  - RF cavity diagnostics.
  - Light transport systems
  - Laser self-mixing analysis for gas jets characterisation
- [D-beam.co.uk](http://D-beam.co.uk) ( email: [A.Alexandrova@d-beam.co.uk](mailto:A.Alexandrova@d-beam.co.uk) )





# Thank you

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