# *Progress update on emittance diagnostics for Run 2c*

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AWAKE

# Overview

- **Overview of emittance diagnostics**
- **Setup of experiments at CLEAR – Oct 2023**
- **Preliminary images and analysis**
- **Next steps**
- **Integration ideas at AWAKE**


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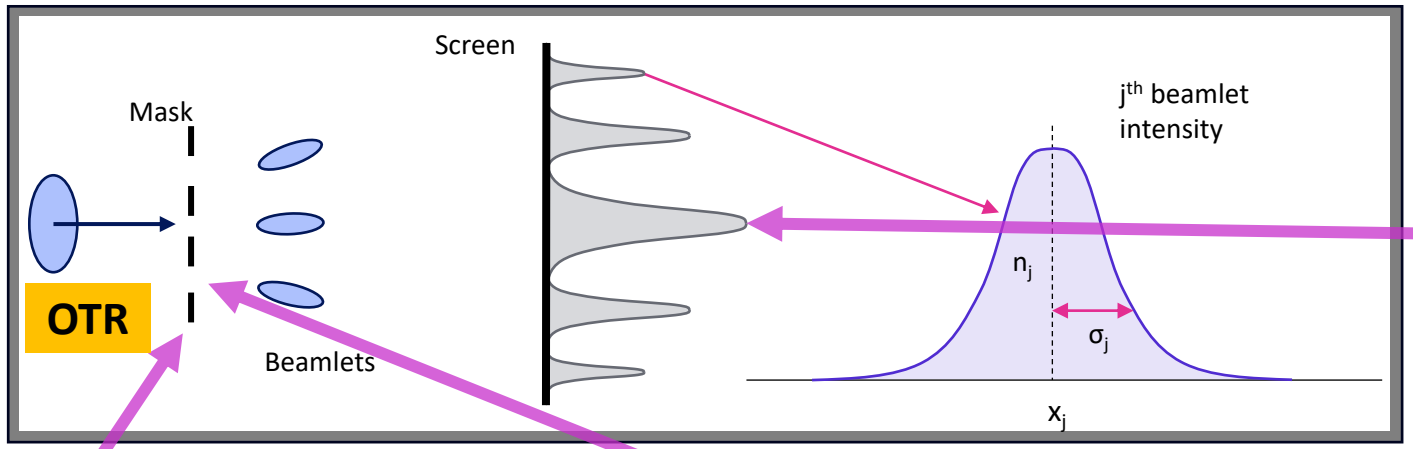
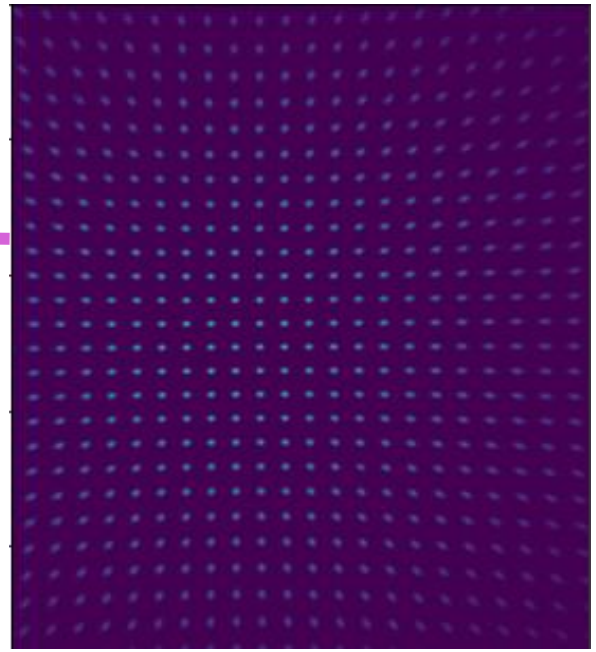
# Emittance diagnostics

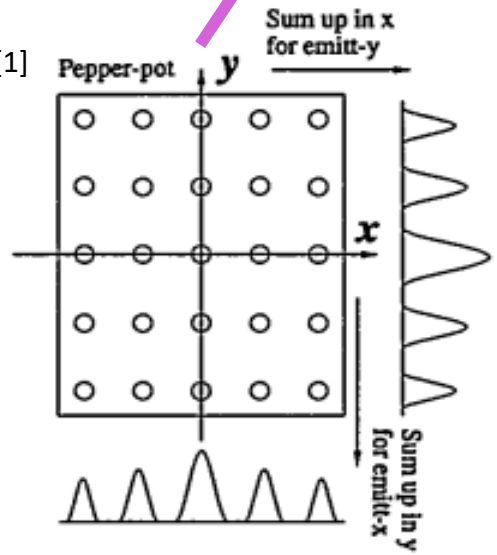
- **Optical versions of slit/pinhole scans and pepper-pot**
- **Two methods under investigation:**
  - **DMD – Digital Micro-mirror Device**
  - **MLA – Micro Lens Array**
- **Initial testing with transition radiation (OTR)**
  - **Thin screens can be used with minimal impact on >1GeV beams**
  - **Future tests planned with non-invasive OSR**

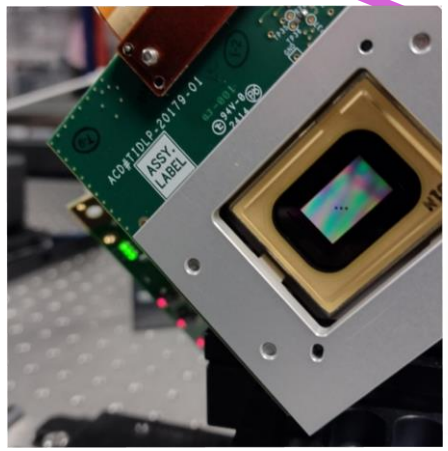
# Pepperpot emittance measurements



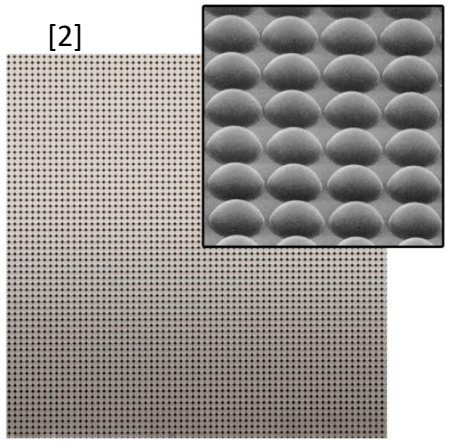



[1]



[2]



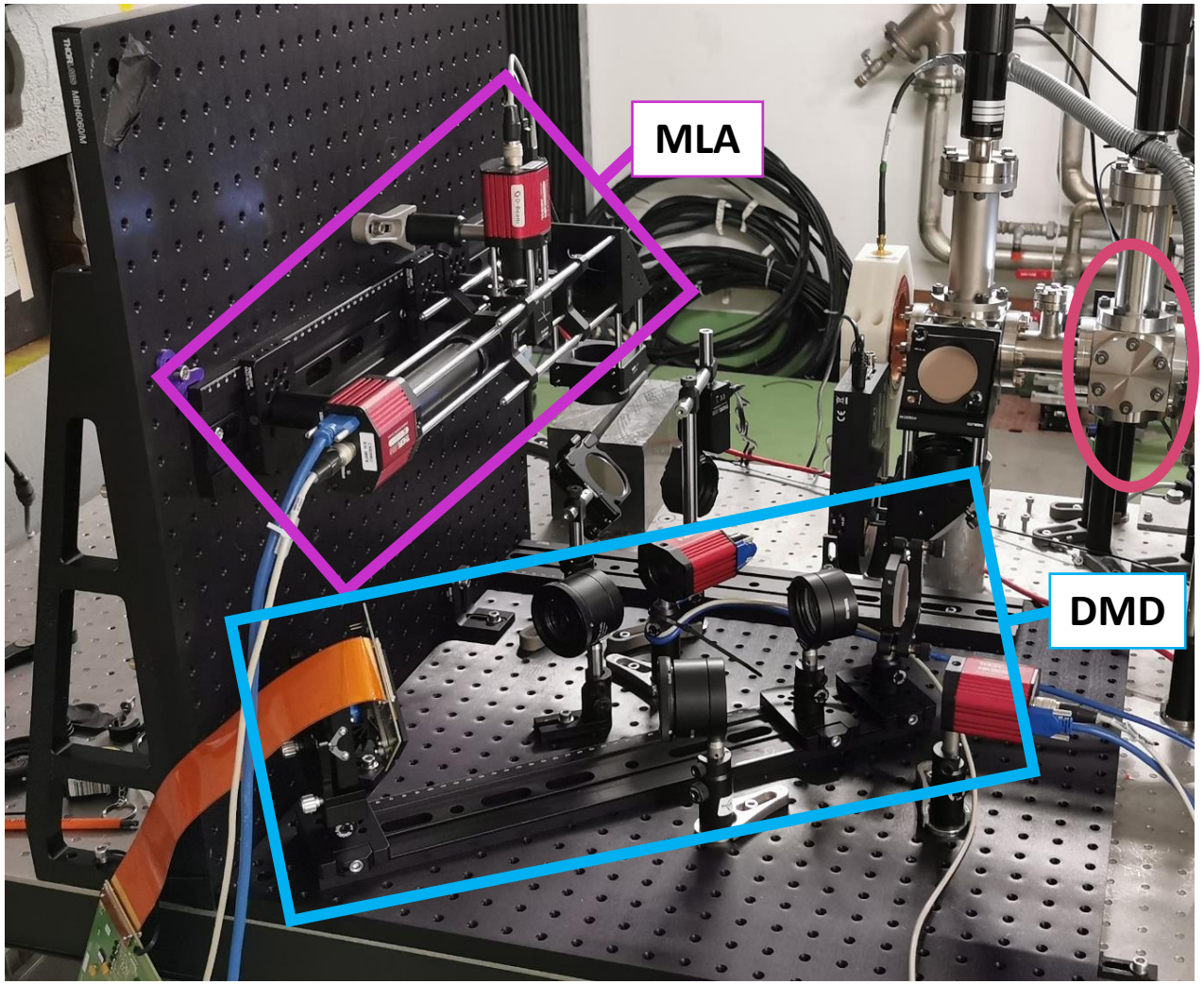
[2]https://www.thorlabs.com/newgrouppage9.cfm?objectgroup_id=2861

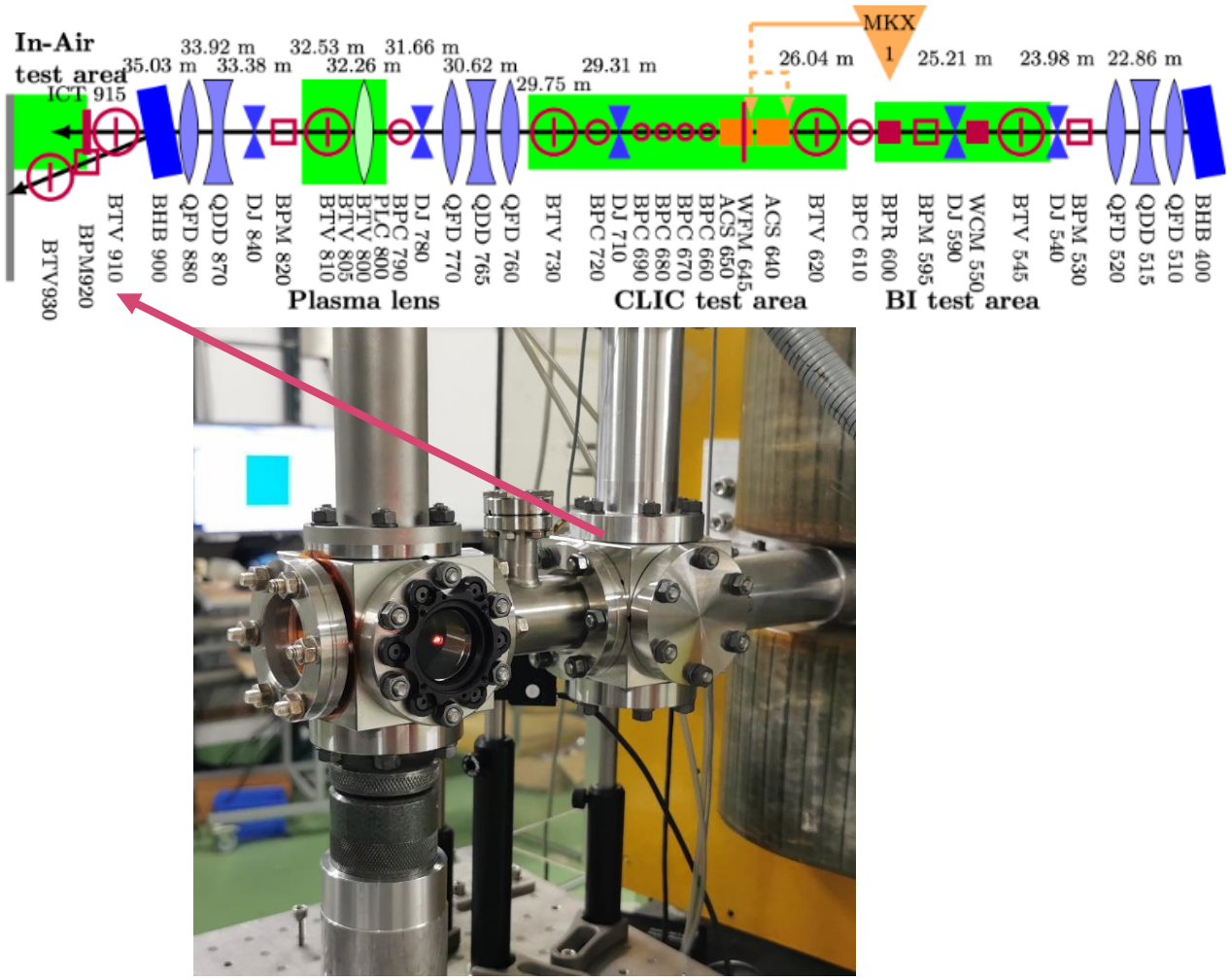
$$\epsilon_x^2 = \langle x^2 \rangle \langle x'^2 \rangle - \langle xx' \rangle^2 \quad [1]$$

$$\approx \frac{1}{N^2}\left\{\left[\sum_{j=1}^{p} n_j(x_{sj}-\bar{x})^2\right]\left[\sum_{j=1}^{p}\left[n_j\sigma_{x_j'}^2 + n_j(\bar{x_j'}-\bar{x'})^2\right]\right] - \left[\sum_{j=1}^{p} n_j x_{sj}\bar{x_j'} - N\bar{x}\bar{x'}\right]^2\right\}$$

[1] M. Zhang, "Emittance Formula for Slits and Pepper-pot Measurement", FERMILAB-TM-1988, Oct. 1996

# Experimental setup





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# Measurements at CLEAR

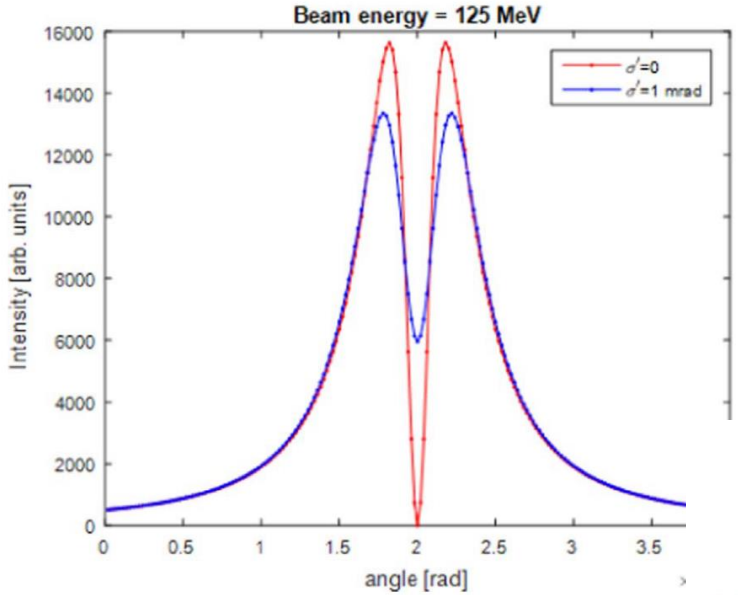



**Fig. 2.** Line profile of the OTR angular distribution for 125 MeV electron different angular spreads.

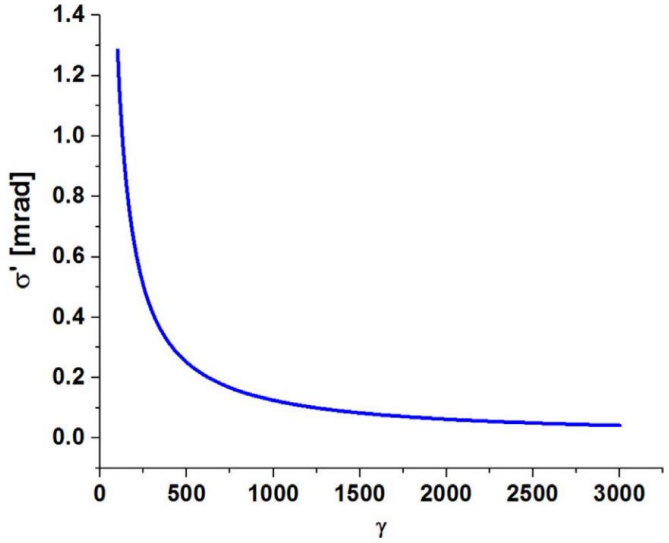
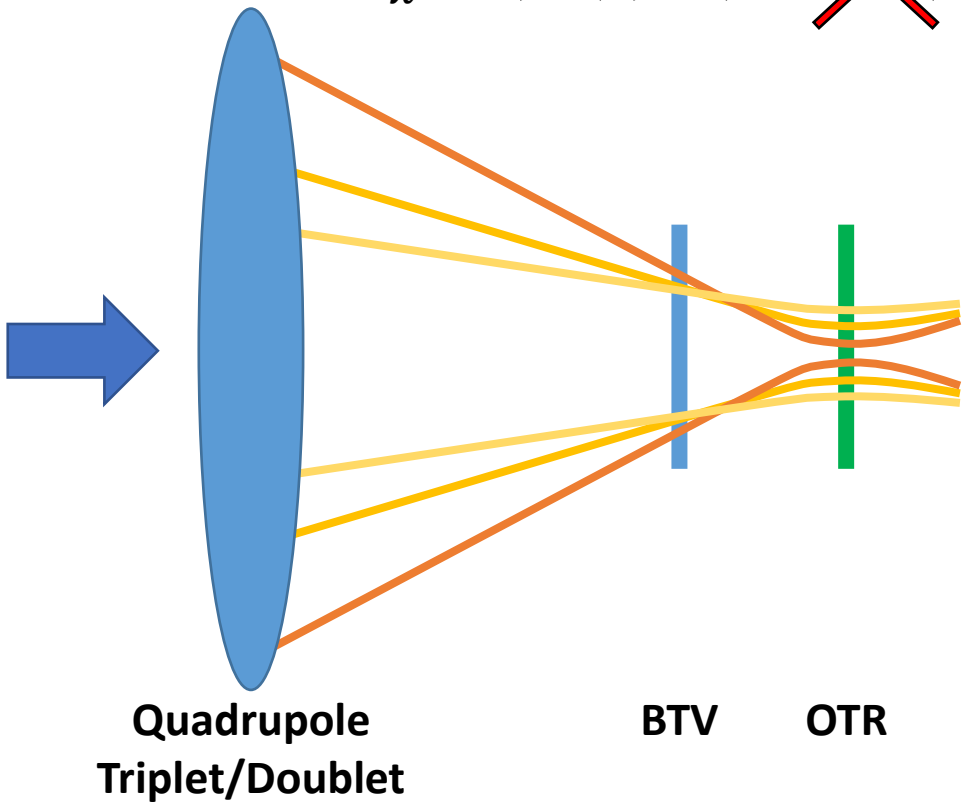



**Fig. 3.** Resolution limit for the beam divergence vs beam energy.

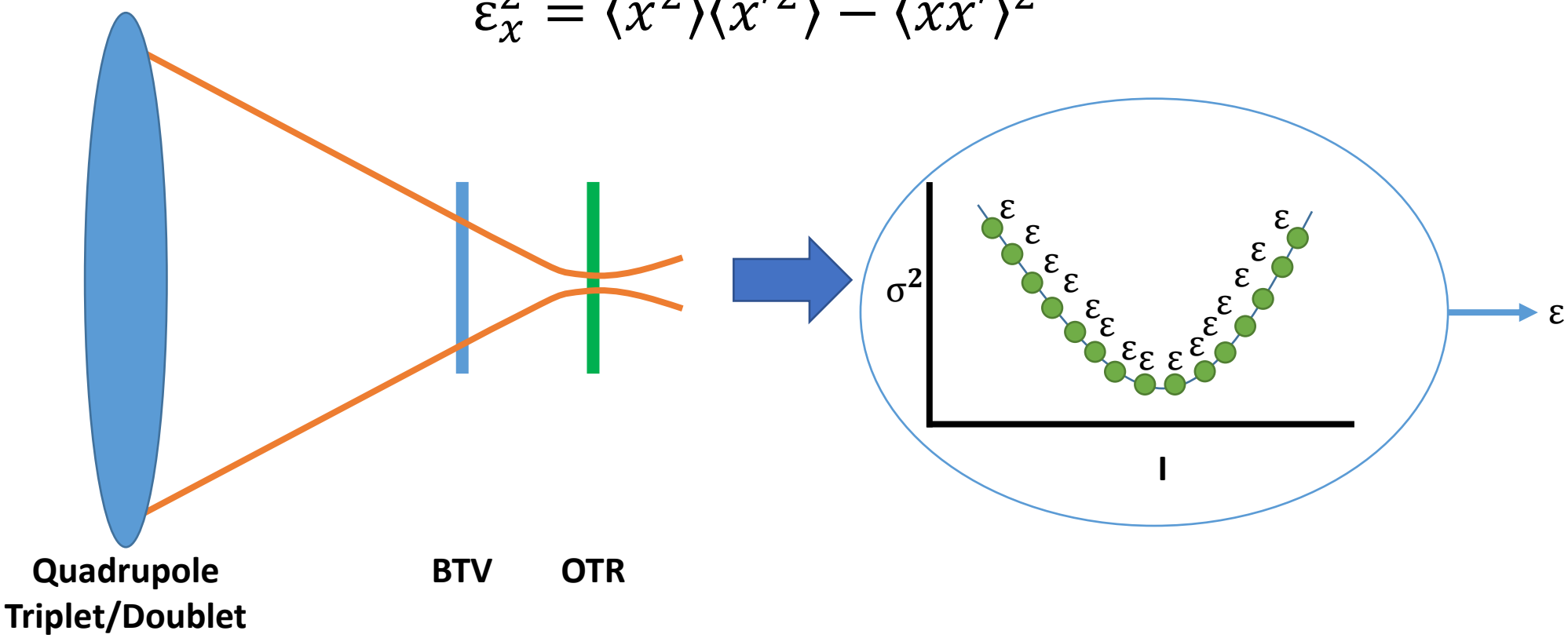
[3]

$$\varepsilon_x^2 = \langle x^2 \rangle \langle x'^2 \rangle - \langle xx' \rangle^2$$



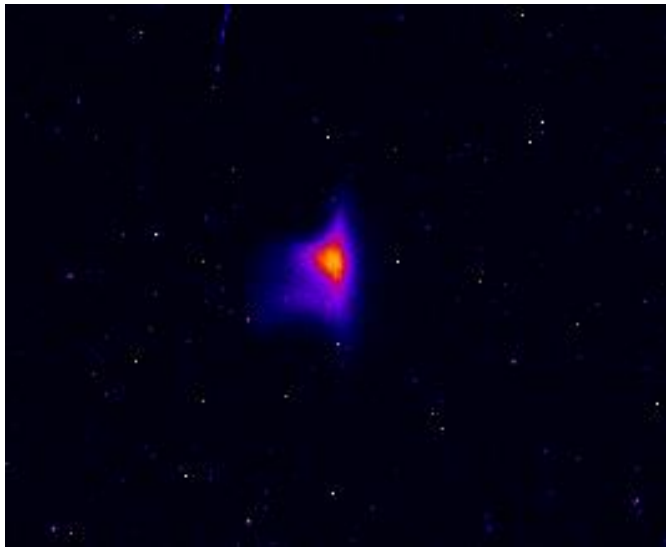
# Measurements at CLEAR

$$\varepsilon_x^2 = \langle x^2 \rangle \langle x'^2 \rangle - \langle xx' \rangle^2$$

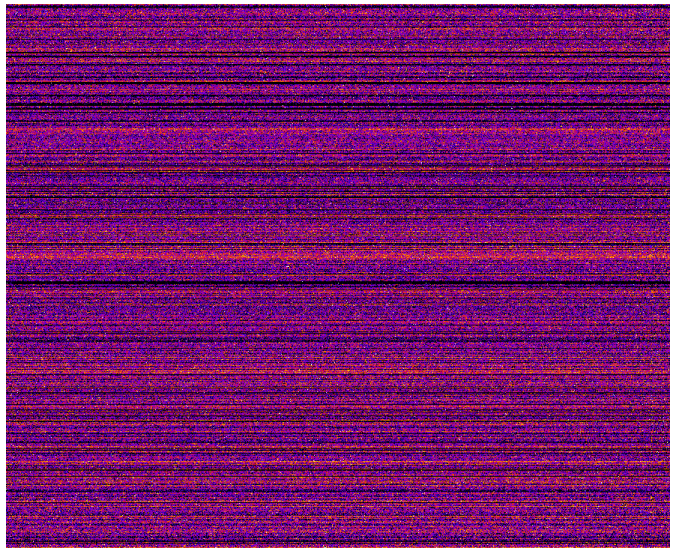


# Preliminary images - DMD

**3 bunches – 700 pC 204 MeV**

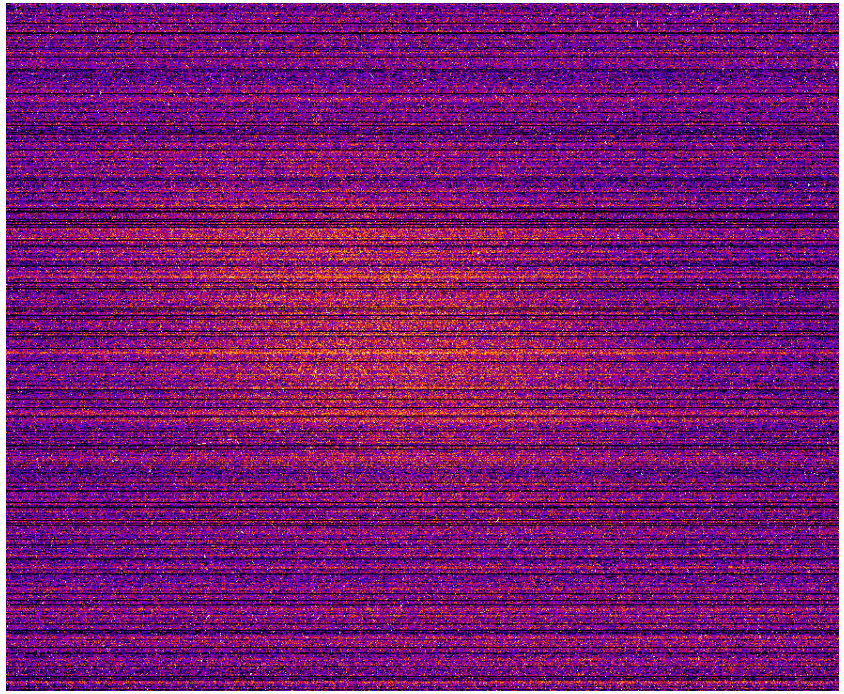


**Spatial**



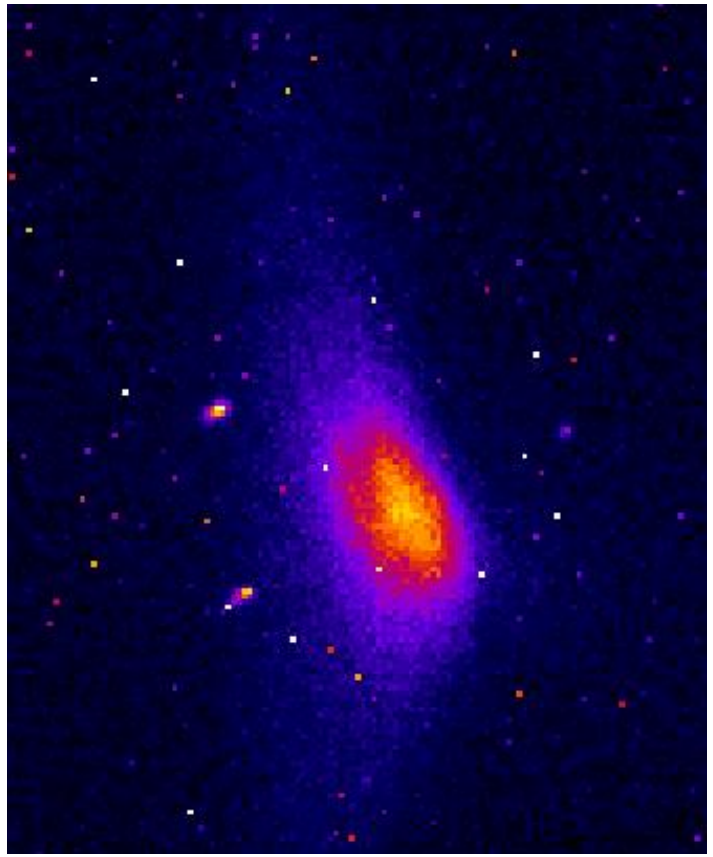
**Angular**

**22 bunches – 4 nC 204 MeV**

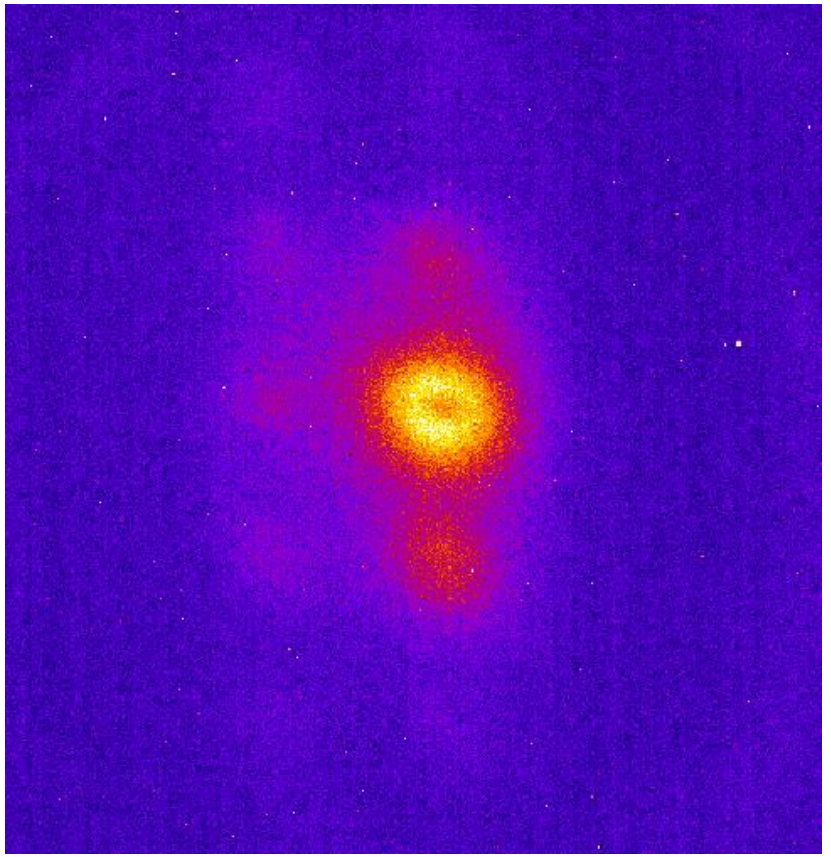


# Preliminary images - MLA

**3 bunches – 700 pC 204 MeV**



**Spatial**



**Angular**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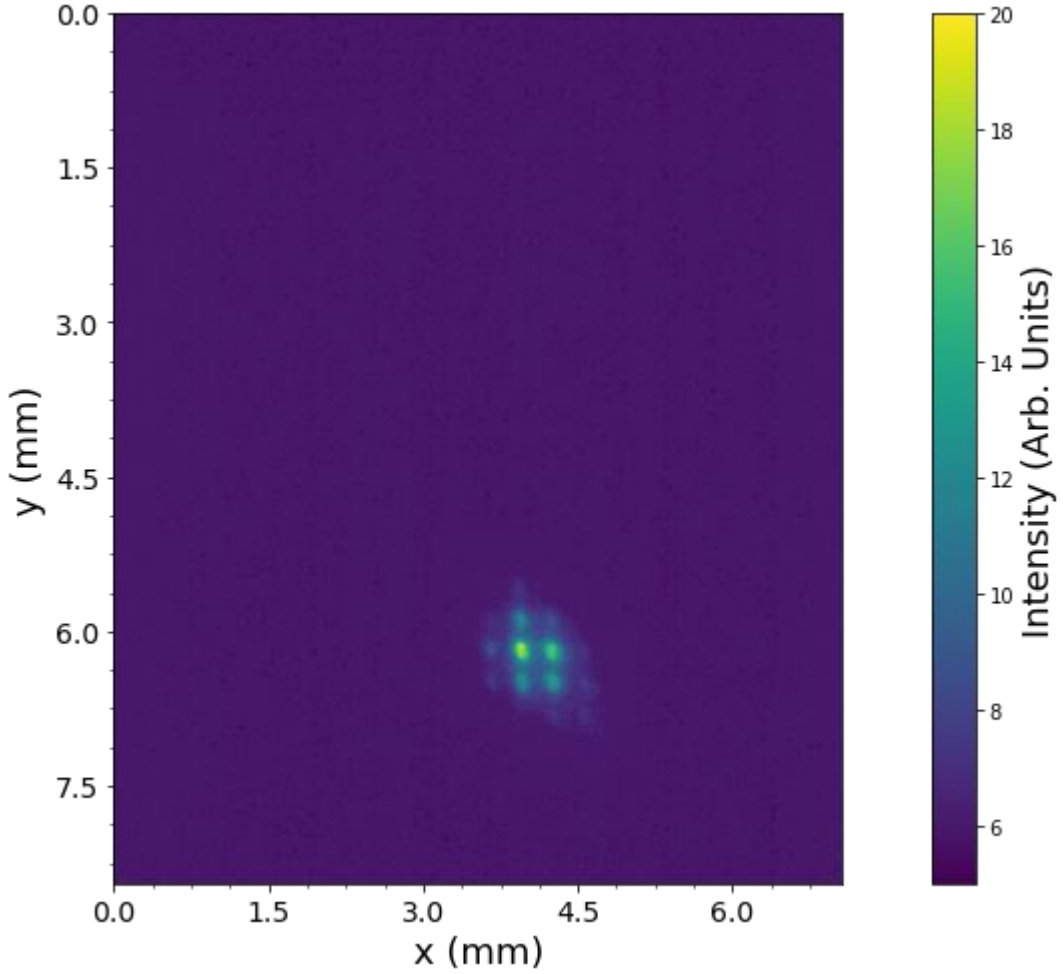
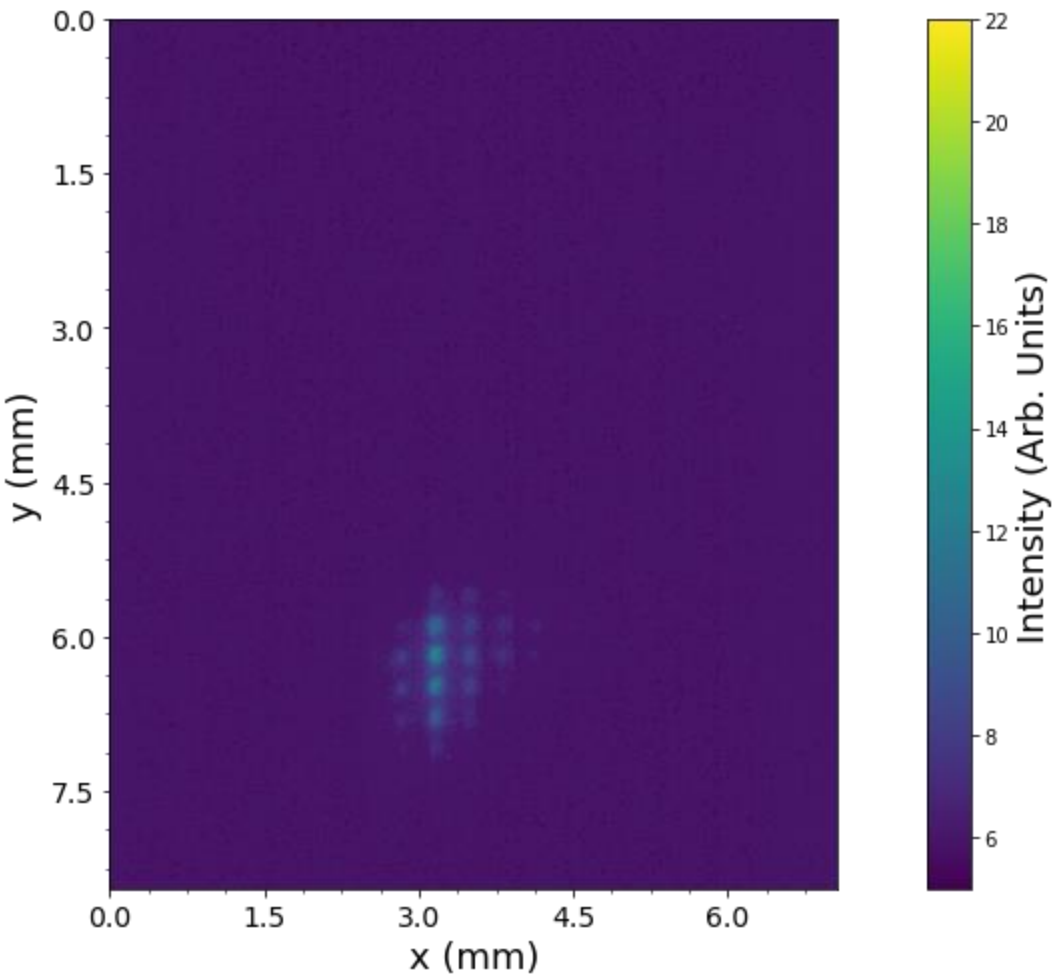
# MLA single shot emittance



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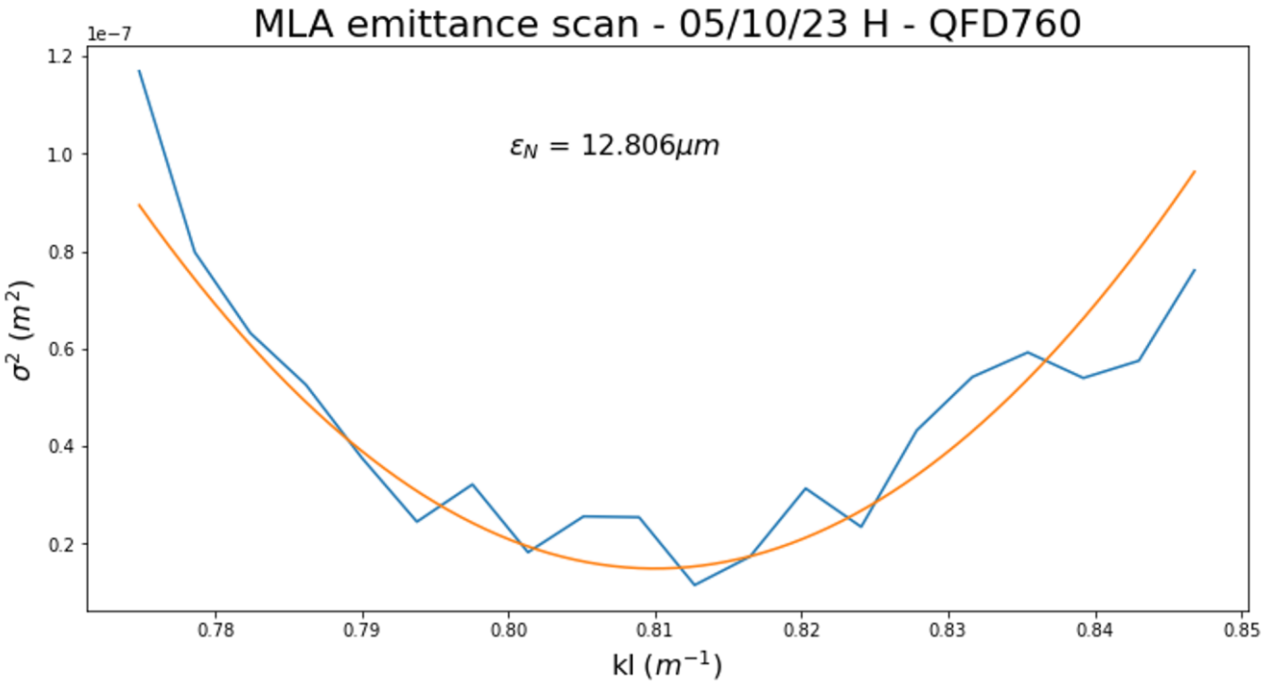
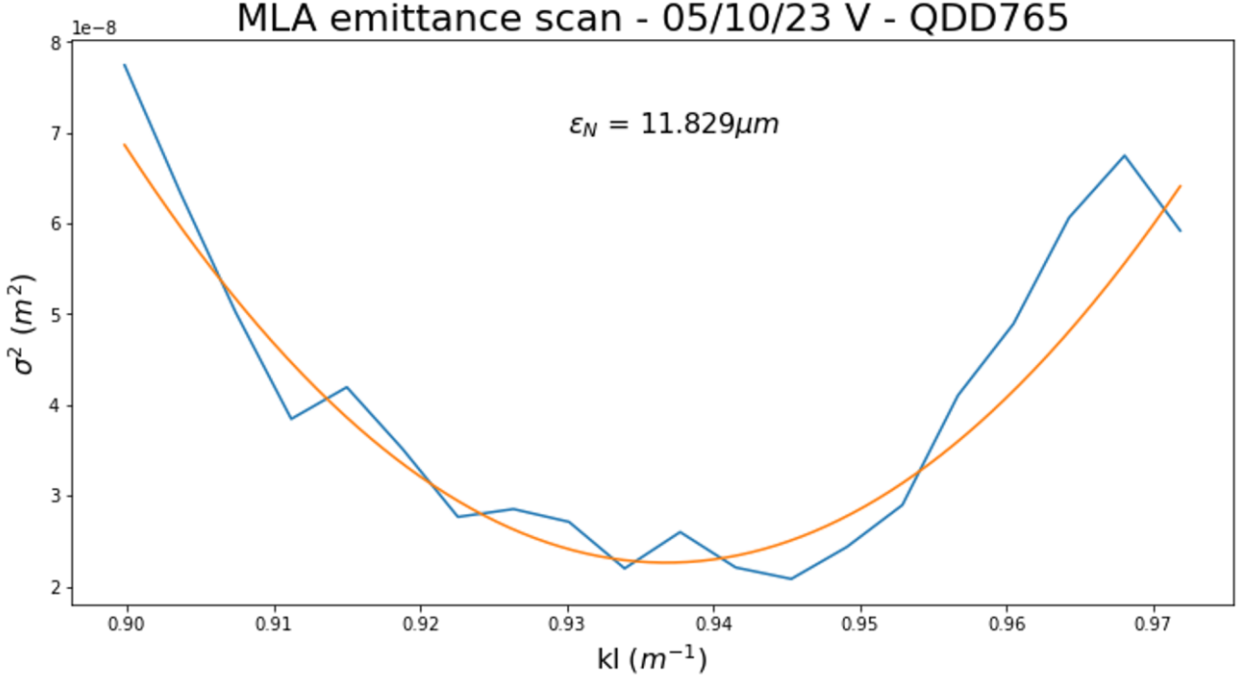
# MLA quad scans



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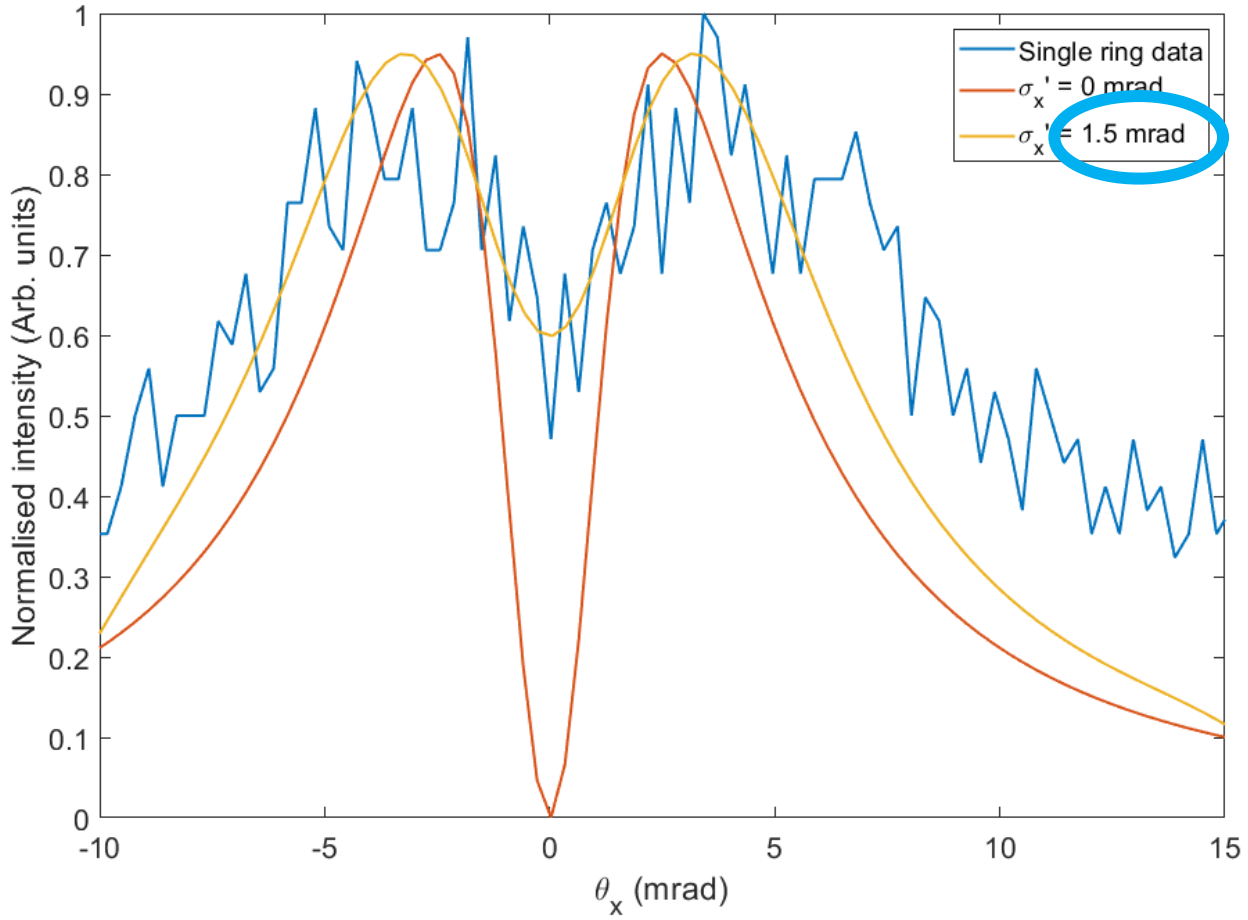
# Single-shot emittance

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$$\approx \frac{1}{N^2} \left\{ \left[ \sum_{j=1}^{p} n_j (x_{sj} - \bar{x})^2 \right] \left[ \sum_{j=1}^{p} [n_j \sigma_{x_j'}^2 + n_j (\bar{x_j'} - \bar{x'})^2] \right] - \left[ \sum_{j=1}^{p} n_j x_{sj} \bar{x_j'} - N \bar{x} \bar{x'} \right]^2 \right\}$$



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# Next steps and outlook

- **Finish analysis of MLA data and quantify resolution and operation range**
- **Identified improvements to DMD system – need implementing and testing in lab**
- **Return to CLEAR to test DMD improvements – Q2**
- **Return to CLEAR to test MLA improvements and operation with OSR – Q4**
- **Testing systems at CLARA FEBE**
- **Application of ML and MLE-ML model to betatron radiation diagnostic (UCLA and UoM)**

# Next steps and outlook

**Possible integration scenarios**

- **Pre-plasma**
  - **OTR off existing/planned screens**
    - DMD or MLA, depending on requirements
  - **OSR from dipole in $e^-$ beam line (virtual diagnostic)**
    - Viewport from within the dipole or an off-axis screen to extract downstream
- **Post-plasma**
  - **OTR on common beamline will not work given $p^+/e^-$ intensity difference**
    - Beam separation (for HEP applications?)
  - **OSR from spectrometer dipole?**
    - Again, any dipoles in potential separation optics could be used
  - **Would require MLA or future single-shot version of DMD**


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# Thanks for listening, any questions?

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*AWAKE collaboration 12/03/2024*