

# SELECTION OF TRANSVERSE DIAGNOSTICS TO MEASURE FEW-MICRON BEAM MODULATIONS IN THE NANOPATTERNED MICROBUNCHING EXPERIMENT

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## ABSTRACT

A nanopatterned microbunching collaboration has been formed to test the production of electron microbunches by rotating transverse beamlets into the longitudinal plane using the emittance exchange (EEX) beamline of the Argonne Wakefield Accelerator (AWA). This mechanism has been suggested, such as by the Compact X-ray Free-Electron Laser (CXFEL) group at Arizona State University, to hold the potential to make short-wavelength free-electron lasers (FELs) more compact. Our collaboration will pattern AWA's 44 MeV electron beam with a TEM grid to produce micro-scale beamlets that will become micro-to-nano scale microbunches in the longitudinal plane. Characterizing an array of beamlets with a modulation period at the few micron scale and a low, single pC scale total charge presents challenges in achieving the necessary transverse resolution and signal strength. These proceedings will detail the diagnostics explored to characterize these transverse modulations. We will discuss the merits and challenges of each approach in relation to our application, and progress towards demonstrating these desired diagnostics.

## NANOPATTERNED MICROBUNCHING EXPERIMENT

For the Nanopatterned Microbunching Experiment, we need to resolve 3  $\mu\text{m}$  separated beamlets. The smallest beam we can measure with our current diagnostics is  $\sigma = 40 \mu\text{m}$ , despite a camera resolution of 5-6  $\mu\text{m}$ .

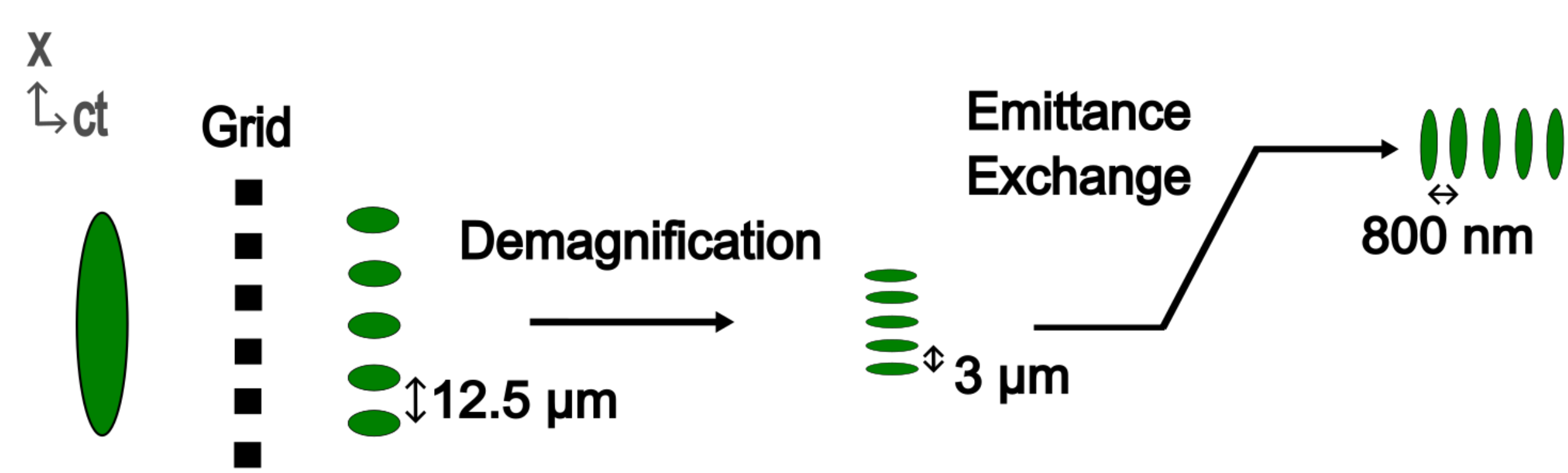
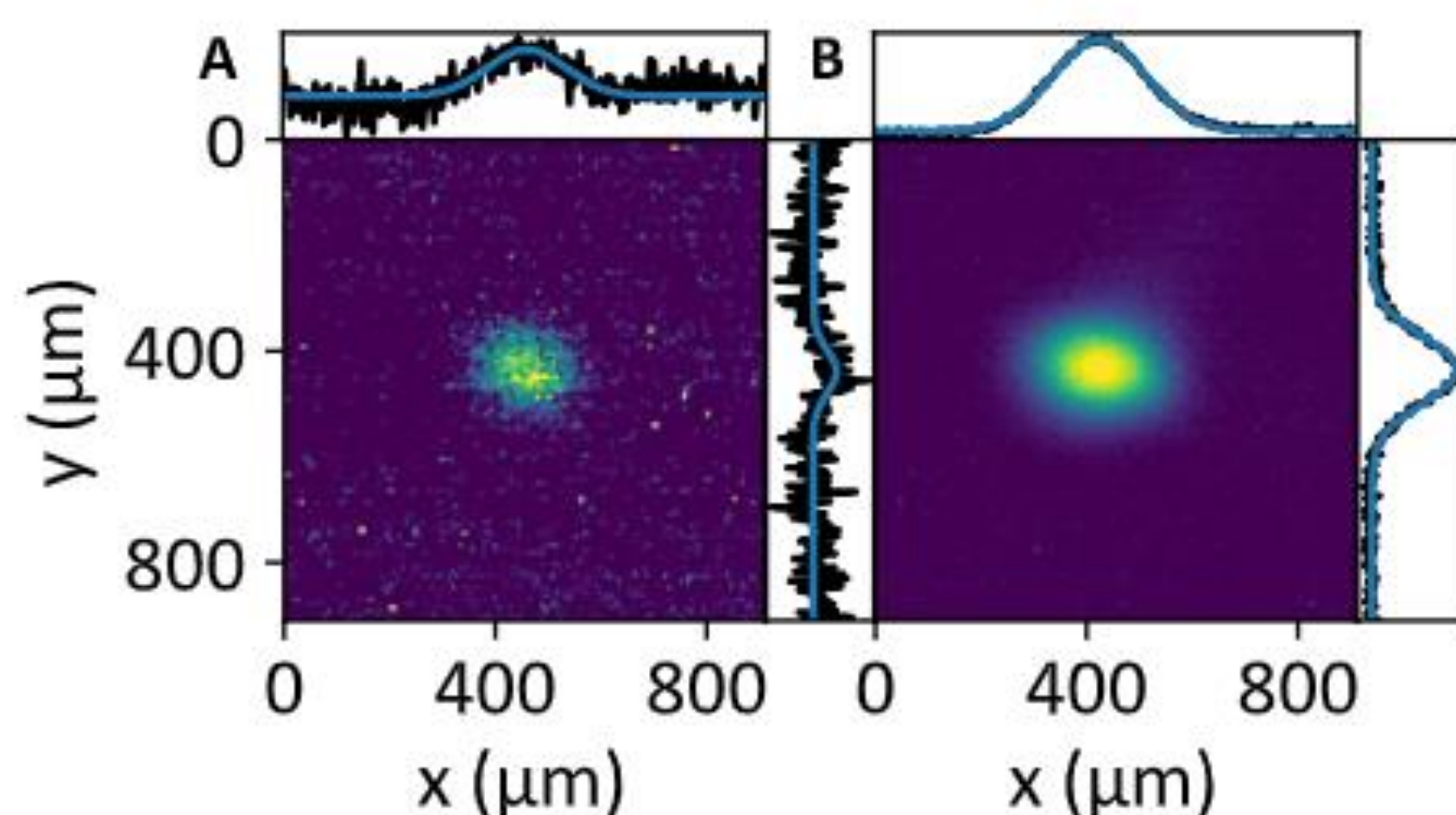


Figure 1: Nanopatterned Microbunching Experiment Overview [1,2]. 44 MeV electrons from the AWA drive line are scattered by a 12.5  $\mu\text{m}$  TEM grid, creating transverse beamlets that are then demagnified with quadrupoles [3] to 3  $\mu\text{m}$ , and converted through emittance exchange to 800  $\mu\text{m}$  microbunching.

Figure 2: Electron beam measurements at AWA on a 100  $\mu\text{m}$  thick YAG:Ce screen.

A) 0.3 pC beam charge,  $\sigma_x = 74 \mu\text{m}$ ,  $\sigma_y = 40 \mu\text{m}$ , B) 3 pC beam charge,  $\sigma_x = 88 \mu\text{m}$ ,  $\sigma_y = 62 \mu\text{m}$ . The imaging system (BFLY-PGE-23S6M-C Blackfly camera and Nikon AFFX 200mm f/4D IF-ED Lens, with a 381 mm extension between the lens and camera) had a calibration of 1.3  $\mu\text{m}/\text{pixel}$ , and a resolution of 6.2  $\mu\text{m}$  as measured on a USAF target.



## REVIEW OF TRANSVERSE DIAGNOSTICS OF MEV-SCALE ELECTRON BEAMS

Table 1: High-resolution transverse electron diagnostics close to 44 MeV, 1 pC.

\* $\sigma = \text{FWHM}/(2\sqrt{2} \ln 2)$  for Gaussian  
\*\* $\sigma = \text{FW}/(2\sqrt{3})$  for flat-top

Method	Material	Beam Size, $\sigma$ ( $\mu\text{m}$ )	Beam Energy (MeV)	Charge (pC)	Facility	Refs
Scintillator	YAG, 20 $\mu\text{m}$ thick	5	8	0.02	UCLA Pegasus	[4]
	YAG, 100 $\mu\text{m}$ thick	15	7-250	6	PSI SwissFEL Injector Test Facility	[5], Fig 47
	YAG, 200 $\mu\text{m}$ thick	14	7	<1	PSI SwissFEL Injector Test Facility	[6-9]
	LYSO, 200 $\mu\text{m}$ thick	1.4	855	(250 pA CW)	University of Mainz, MAMI	[10]
Optical Transition Radiation (OTR)	Al-coated mirror	14	50	250	BNL-ATF	[11]
	Al-coated Si	0.75	1280	1600	KEK ATF2	[12]
Wire Scan	Gold, 900 nm wide	0.434	300	<1	PSI SwissFEL	[13, 14]
	Gold, 1 $\mu\text{m}$ wide	2	50-155	0.2	DESY ARES Test Stand	[15]
Slit Scan	Tungsten, 10 $\mu\text{m}$ wide	~50	20	250	DESY PITZ	[16]
Knife-Edge Scan	Si, Coated	0.0015*	0.1	(0.2 nA CW)	NTT Corp (Lithography)	[17]
	SiN and Au Film	0.4	0.75	(200 fA CW)	LBNL HIRES	[18]
	"Metal"	3.9	4.2	0.0015	SLAC UED	[19]
Electron Beam Moiré	Nickel mesh, 106 $\mu\text{m}$ period	15**	0.003	-	Shenzhen University (Image Conversion Tube)	[20]

## FUTURE WORK

- Scintillator – 20  $\mu\text{m}$  thick YAG for fast, coarse tuning ( $\sigma > 5 \mu\text{m}$ )
- Slit Scan – 1  $\mu\text{m}$  wide slit in 2-4  $\mu\text{m}$  thick Ni w/ SS support for fine tuning ( $\sigma \approx 1 \mu\text{m}$ )
- Knife-Edge Scan – edge of 60  $\mu\text{m}$  thick gold for fine tuning ( $\sigma \approx 1 \mu\text{m}$ )

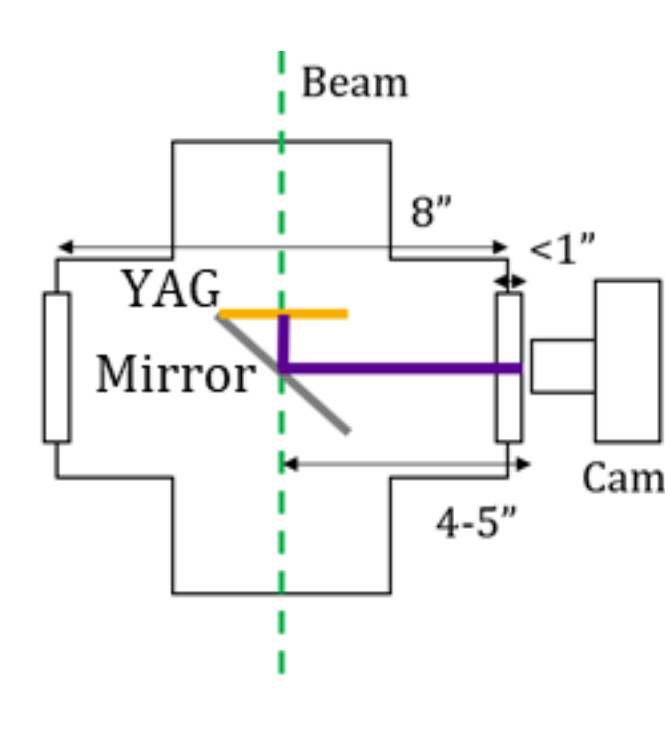
## ACKNOWLEDGEMENTS & REFERENCES

This work is supported by the U. S. Department of Energy, under contract No. DE-AC02-06CH11357.  
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## TRANSVERSE DIAGNOSTIC METHODS

### Screen Imaging Methods

#### Scintillators



Scintillators can produce single-shot 2D images. Resolution is limited by screen thickness;  $\sigma \approx 5 \mu\text{m}$  for 20  $\mu\text{m}$  thick YAG.

Figure 3: AWA Imaging Cross. Electron beam hits scintillator at normal incidence. Camera working distance (purple) is 165 mm.

Multiple Coulomb Scattering:

$$\theta_{rms} = \frac{13.6 \text{ MeV}}{\beta p c} z \sqrt{\frac{x}{X_0}} \left[ 1 + 0.038 \ln \left( \frac{x}{X_0} \right) \right] \quad y_{rms} = \frac{d\theta_{rms}}{\sqrt{3}}$$

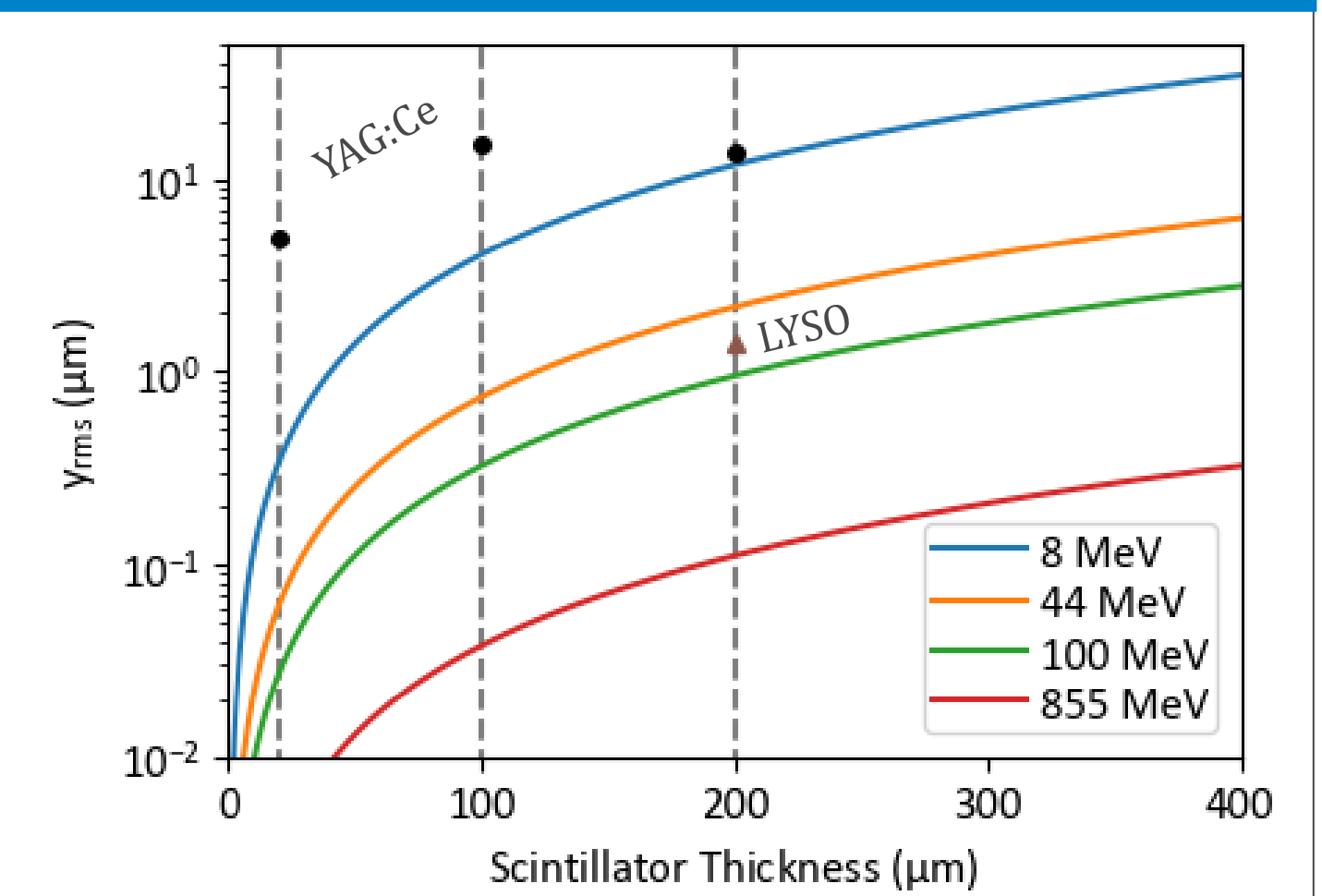


Figure 4: Electron resolution limit on a YAG:Ce screen. Screen thicknesses of 20  $\mu\text{m}$ , 100  $\mu\text{m}$ , and 200  $\mu\text{m}$  are indicated by dashed lines. Markers give examples from Table 1.

### Optical Transition Radiation (OTR)

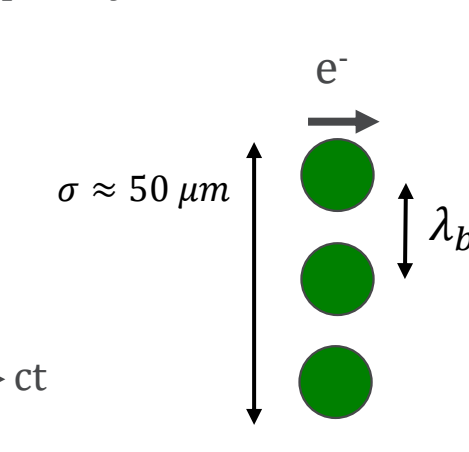
Light is produced as electrons cross into region with different refractive index. 2-lobed radiation structure can give a 5-10  $\mu\text{m}$  blur on a typical screen. Difficult to fit this when imaging a beamlet array.

### Occlusion Scanning Methods

High resolution,  $\sigma \approx 1 - 5 \mu\text{m}$ , but slower, multi-shot measurements.

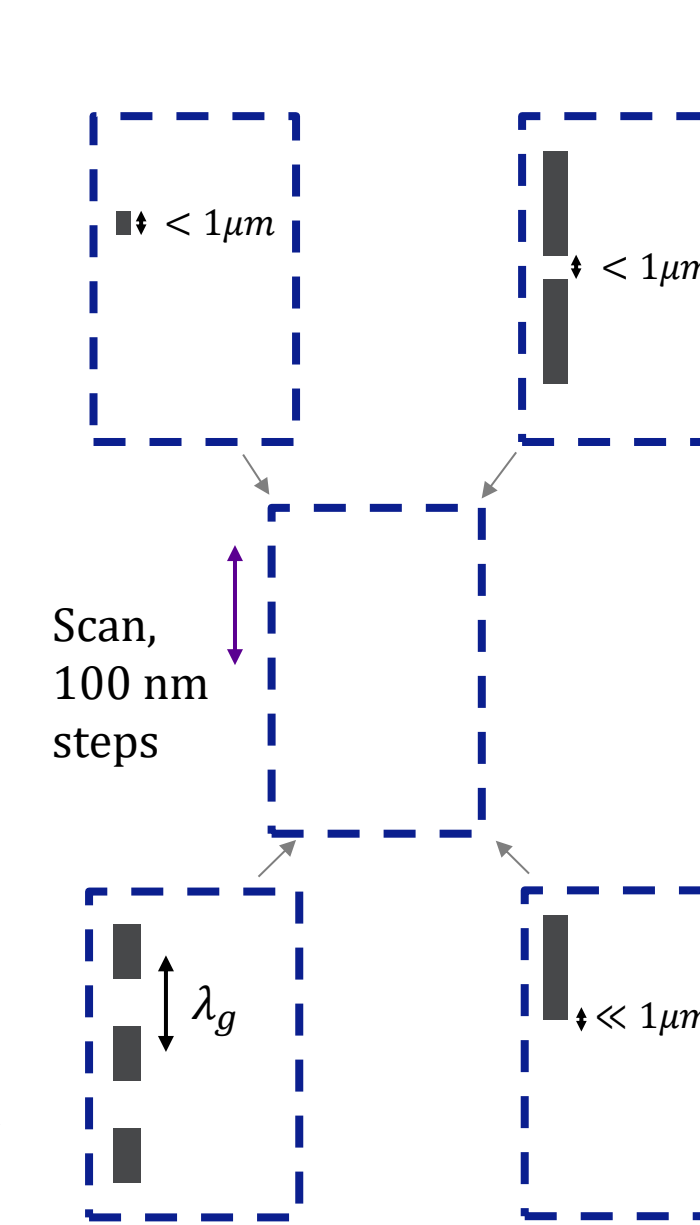
#### Wire Scan

Common at high energies where electrons are scattered at low angles ( $\theta \sim 1/\gamma$ ) and secondary radiation is high. Difficult to measure a small dip on strong direct beam, so scattered beam typically measured.



#### Grid Scan

Enhanced signal when  $\lambda_b = \lambda_g$ . Requires a precise match between grid and beamlet array.



### Electron Beam Moiré

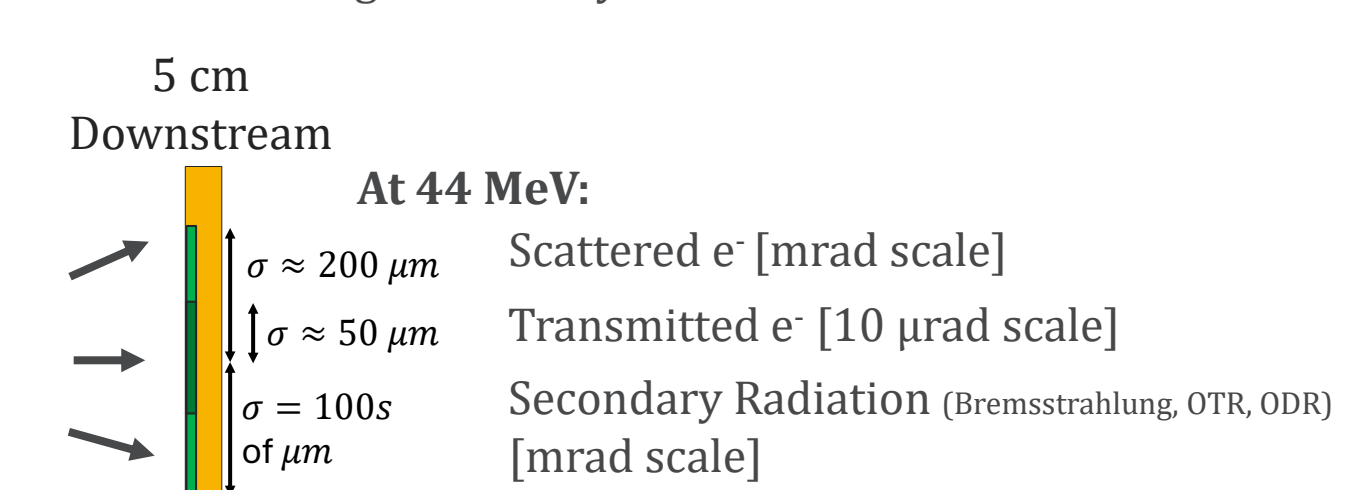
Scatter off grid to produce long-wavelength features that are resolvable on a screen in a single-shot.

$$\lambda_m = \frac{\lambda \lambda'}{\sqrt{\lambda'^2 \sin^2 \alpha + (\lambda' \cos \alpha - \lambda)^2}}$$

Figure 5: Moiré pattern feature sizes for beamlet spacing  $\lambda$ , grid period  $\lambda'$  and relative angle  $\alpha$ .

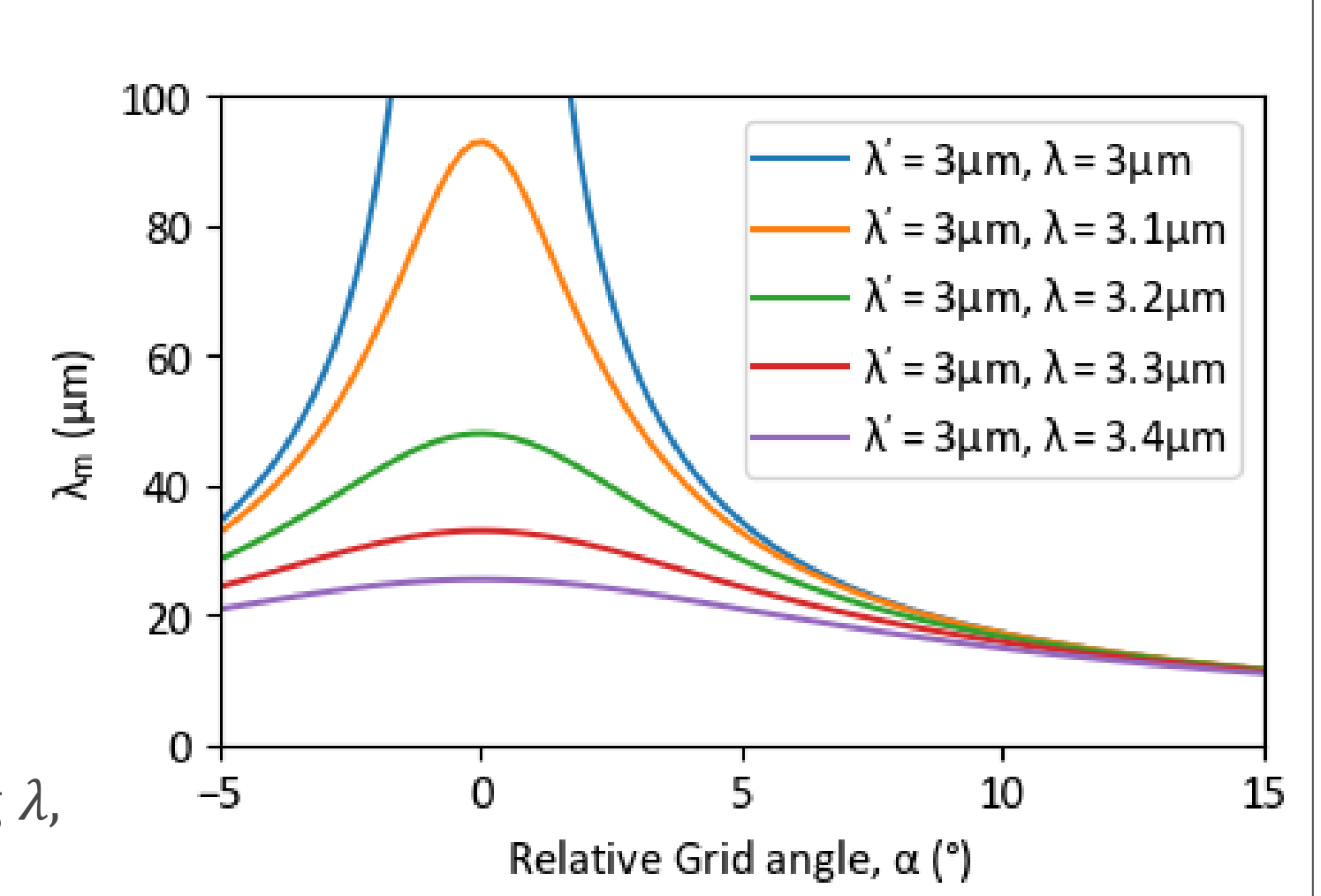
#### Slit Scan

Not commonly used for high transverse resolution measurements, but common for emittance measurements. At 44 MeV, measuring the direct beam may be feasible. Radiation backgrounds may be 10-20%.



#### Knife-Edge Scan

Measure direct or scattered beam; could be difficult to get sufficient dynamic range.



Swapping in/out grids of varying sizes will allow us to tune the demagnifier beamline in stages.

Grid	$\lambda_{grid}$ ( $\mu\text{m}$ )	$\lambda_{beamlet}$ ( $\mu\text{m}$ )	$\sigma_{grid}$ ( $\mu\text{m}$ )	$\sigma_{beamlet}$ ( $\mu\text{m}$ )
G2000HSG	12.5	3	1.88	0.45
G1000HSG	25	6	5.49	1.32
G200G	125	30	26.01	6.24
G75G	340	81.6	82.37	19.77