Single shot thermal emittance measurement in photoinjectors

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Outline

- Introduction to the technique
- Proof of principle experiment
- Application to cathode study
- Summary

Thermal emittance

The key to high brightness electron linacs

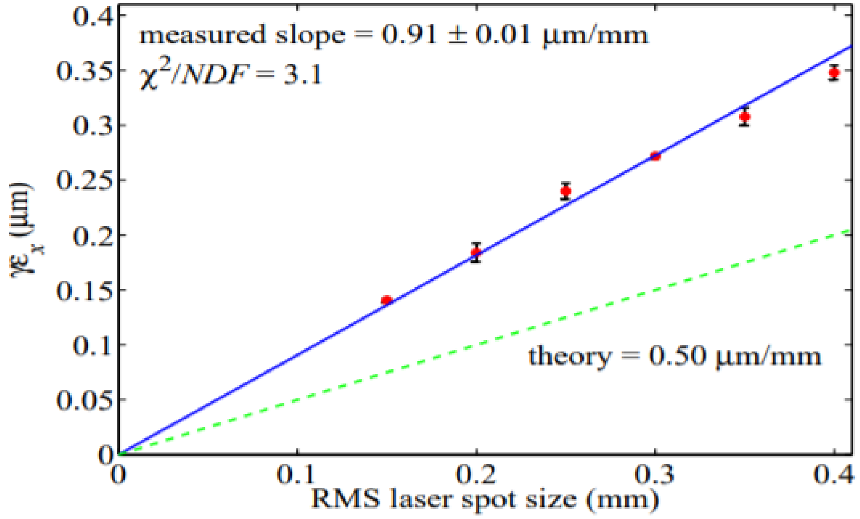
- Electron source already carries emittance from their emission mechanism
  - $\varepsilon_{thermal} = \sigma_{beam} * \frac{\sigma_{px}}{m_0 c}$

    Transverse beam size at cathode

    Transverse momentum spread at cathode

  - Best photoinjectors are dominated by thermal emittance
    - Beamline optimized emittance compensation
    - Good laser shaping & high gun gradient
  - Maximum emission brightness $\sim \frac{E_{emission}}{\sigma_{px}^2}$
    - Thermal emittance is more effective than gradient
- Conventional thermal emittance measurement is not easy
  - Fit emittance to laser size
  - Time consuming and vulnerable to errors

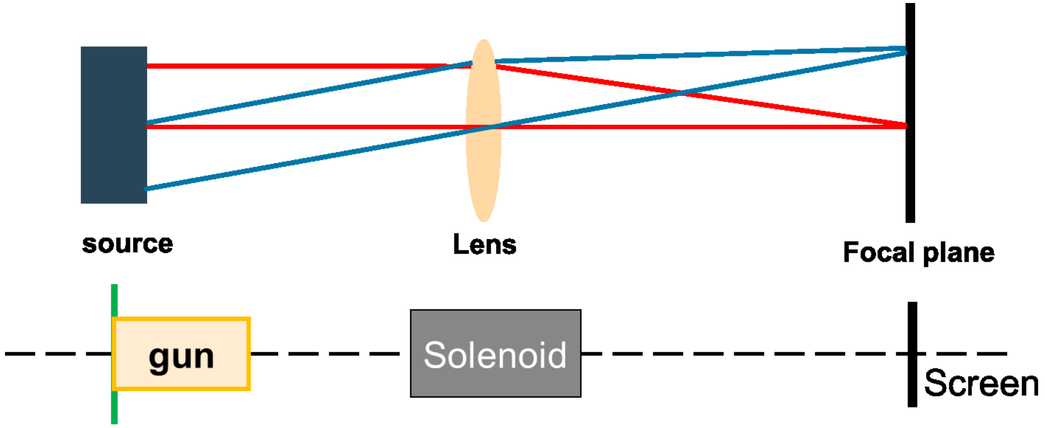
LCLS-II measurement



Single shot cathode transverse momentum measurement

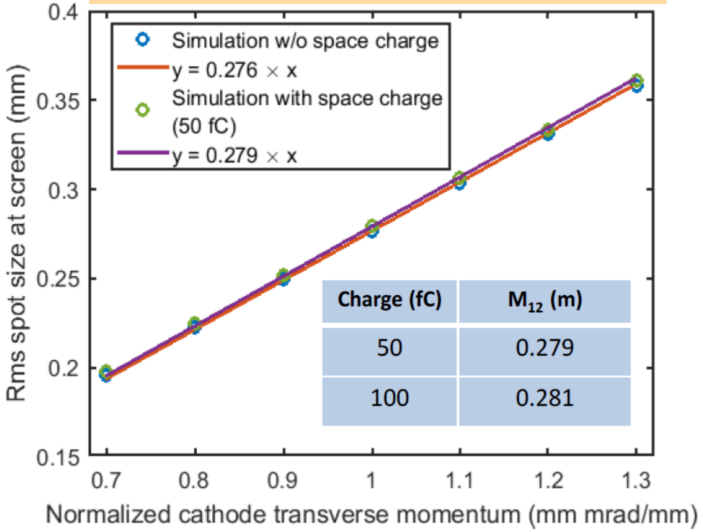
Basic idea

- Imaging transverse momentum to position
  - Linear dynamics at low charge
    - $x_2 = R_{11}x_1 + R_{12}x_1'$
  - Tune gun solenoid to zero R_{11}
    - $\sigma_{scr} = M_{12}\frac{\sigma_{px}}{m_0 c}$



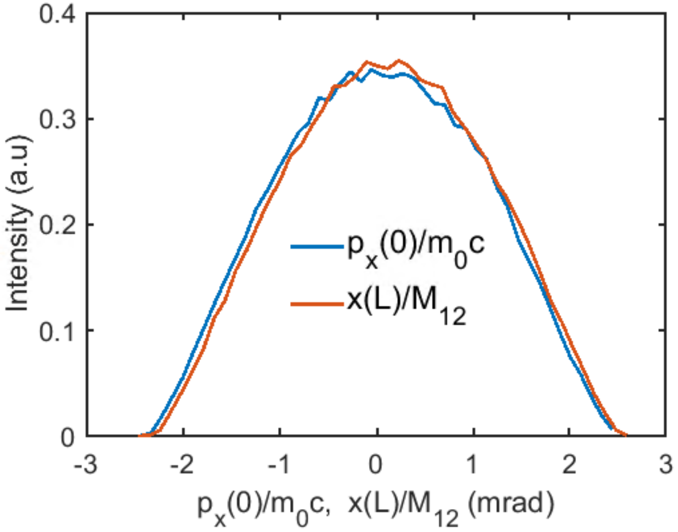
- Simulation proof using the PITZ injector at DESY

Linearity check when R_{11}=0



Charge (fC)	M_{12} (m)
50	0.279
100	0.281

Distribution check



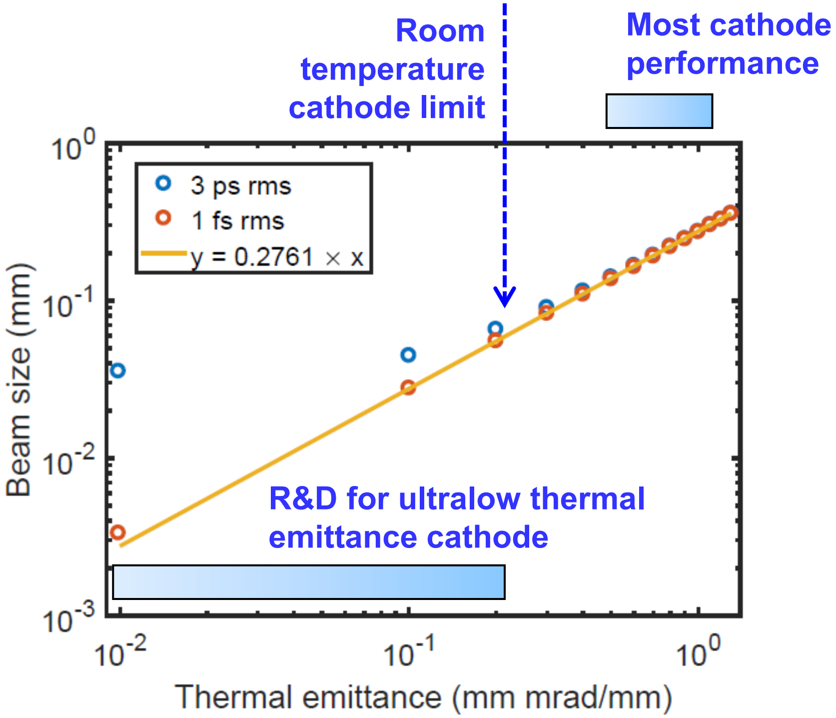
Limitation of the method

RF emittance & solenoid field abberation

- RF emittance growth in the PITZ gun

$$\varepsilon_{RF} \approx \frac{eE_0}{2m_0c^2}\sigma_x\sigma_\phi \cos\phi_f \sqrt{\sigma_x^2 + x_0^2}$$

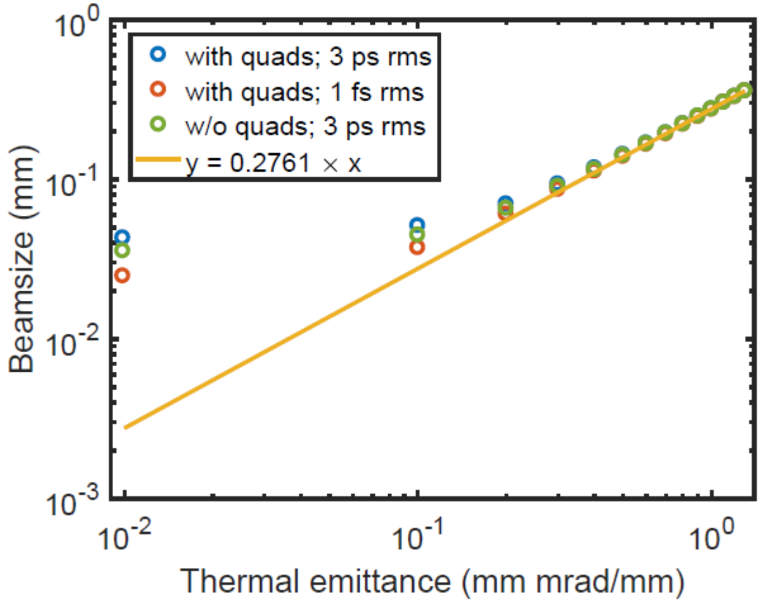
Beam size   Bunch length   Beam offset



- Emittance growth due to solenoid quadrupole aberration

$$\varepsilon_{\text{coupled}} = \beta\gamma \frac{\sigma_{x,\text{sol}}\sigma_{y,\text{sol}}}{f_a} |\sin 2(KL + \alpha_a)|$$

Focal length of quad error   Larmor angle   Effective angle of the rotated quadrupole



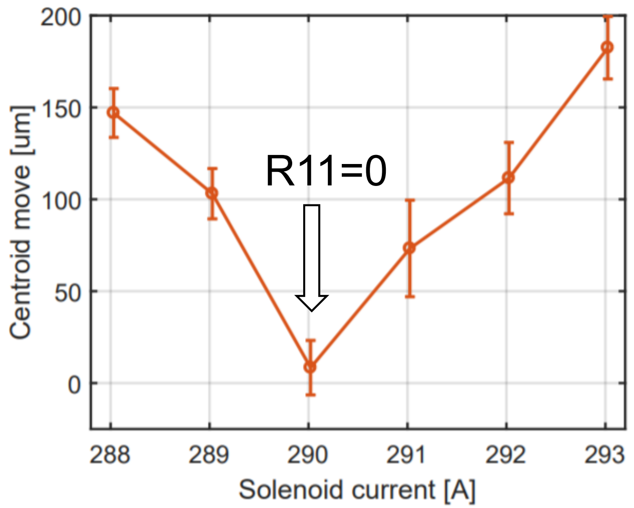
Quad focal length ~50 m in this simulation

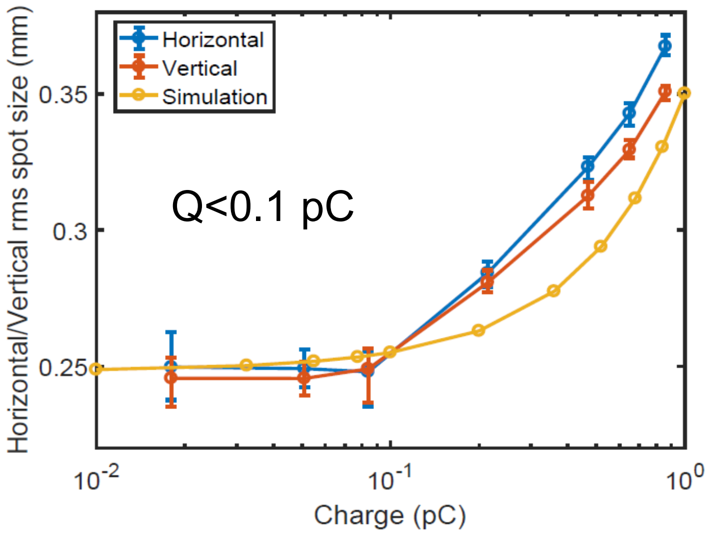
It can be corrected with weak quadrupoles.

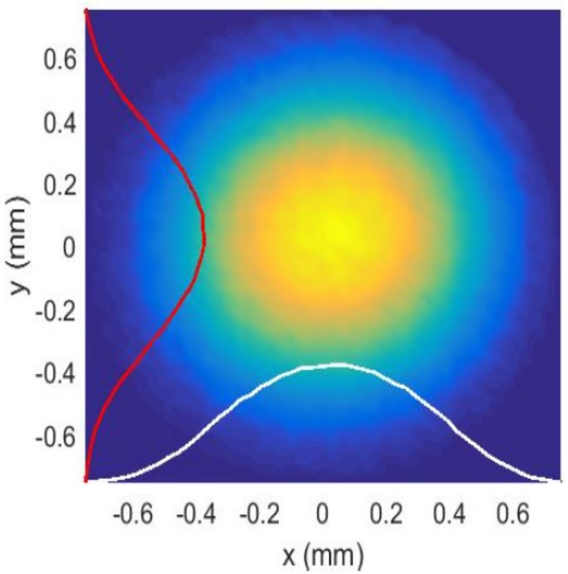
Proof of principle experiment at PITZ

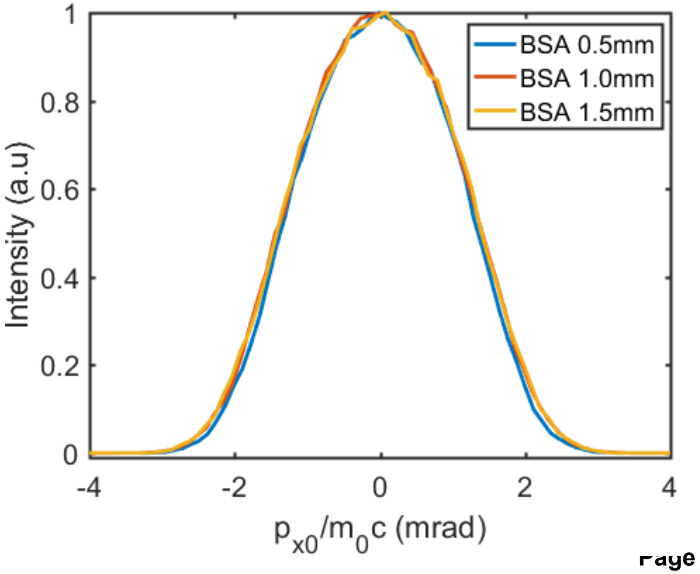
Step by step

- Experiment settings
  - Gun: 5.8 MeV/c
  - Laser: 6 ps FWHM, 1 mm diameter
  - Screen: ~5 meter from cathode
- Tune $R_{11} = \frac{dX_{scr}}{dX_{laser}} = 0$
  - Move the laser on cathode
  - Measure beam movement on screen
- Minimize space charge effect
  - Measure beam size vs charge
  - Q<0.1 pC
- Beam size vs laser size at R11=0
  - Laser diameter 0.5/1.0/1.5 mm
  - Beam size does not change on screen







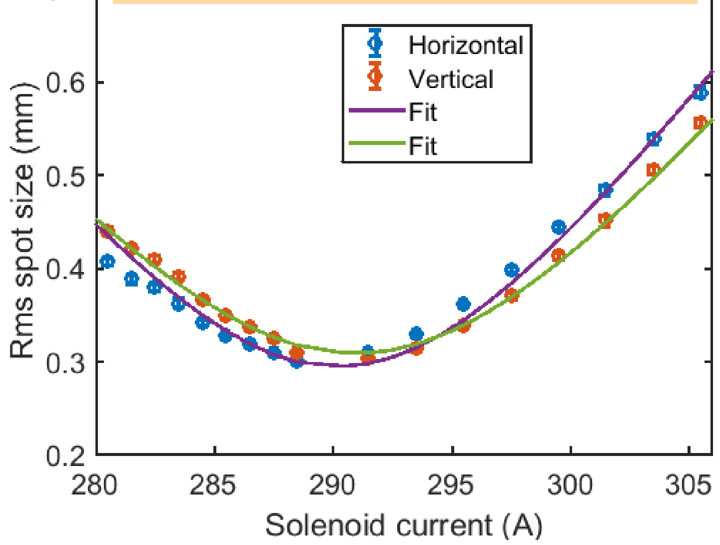


Proof of principle experiment at PITZ

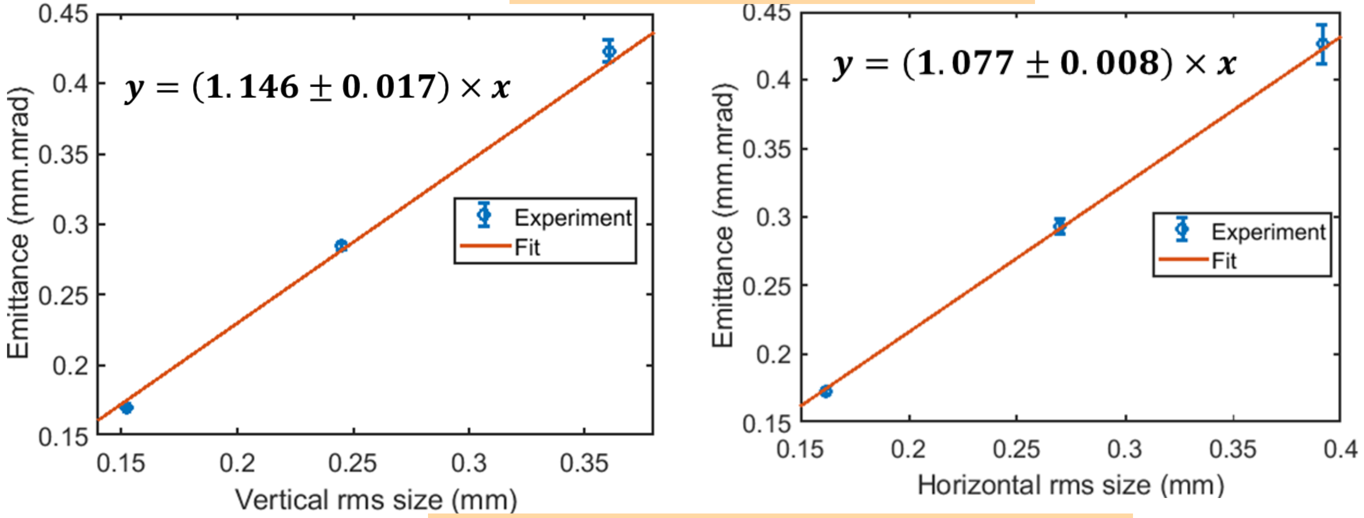
Cross check with conventional method

- Solenoid scan based emittance fitting
  - **1.11±0.01** mm.mrad/mm
- Result by transverse momentum imaging
  - **1.10±0.01** mm.mrad/mm

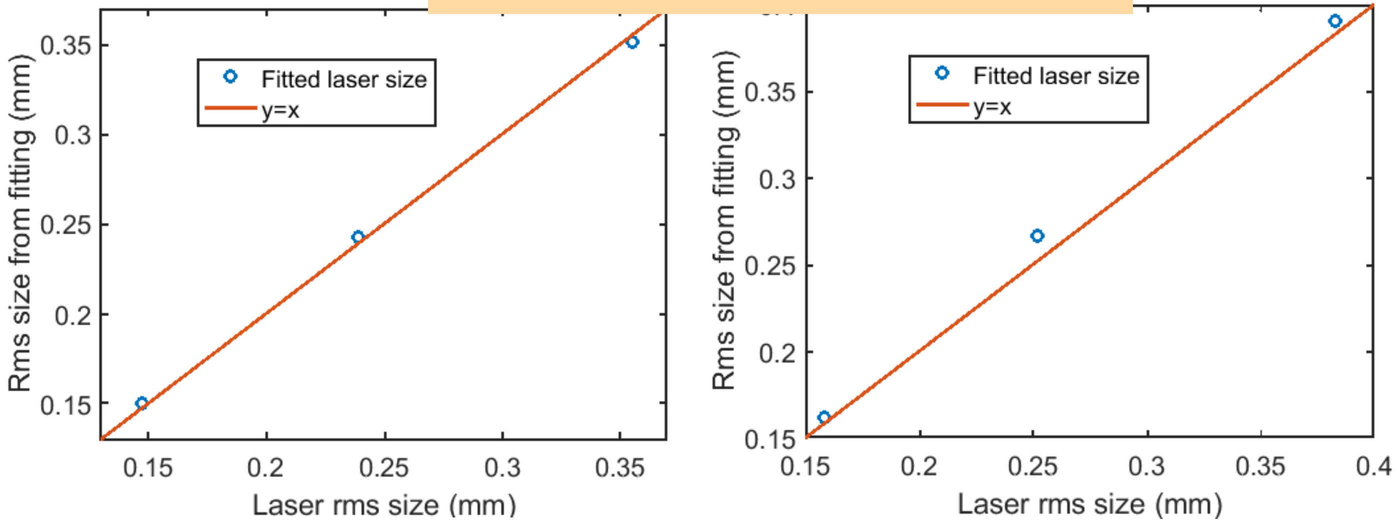
Solenoid scan for 1mm laser



Emittance vs laser size fit

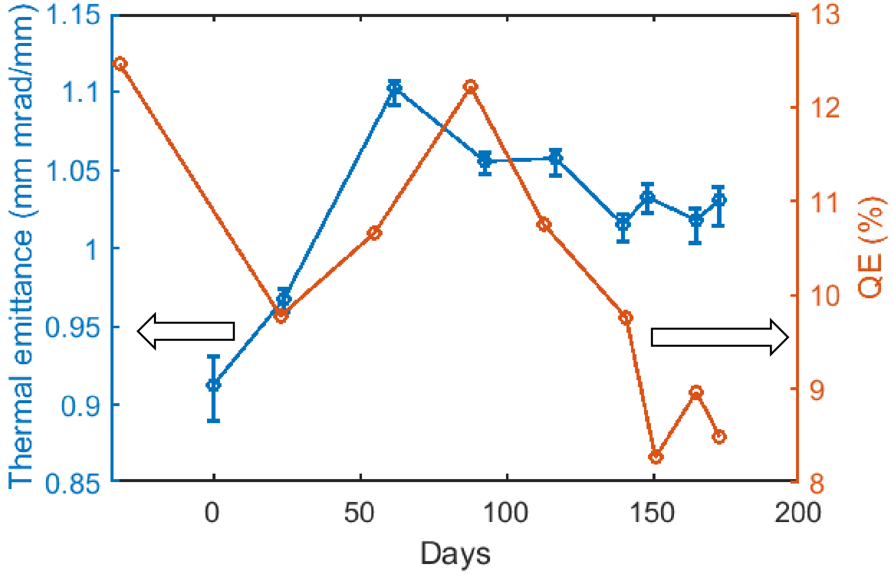


Fitted laser size vs measured laser

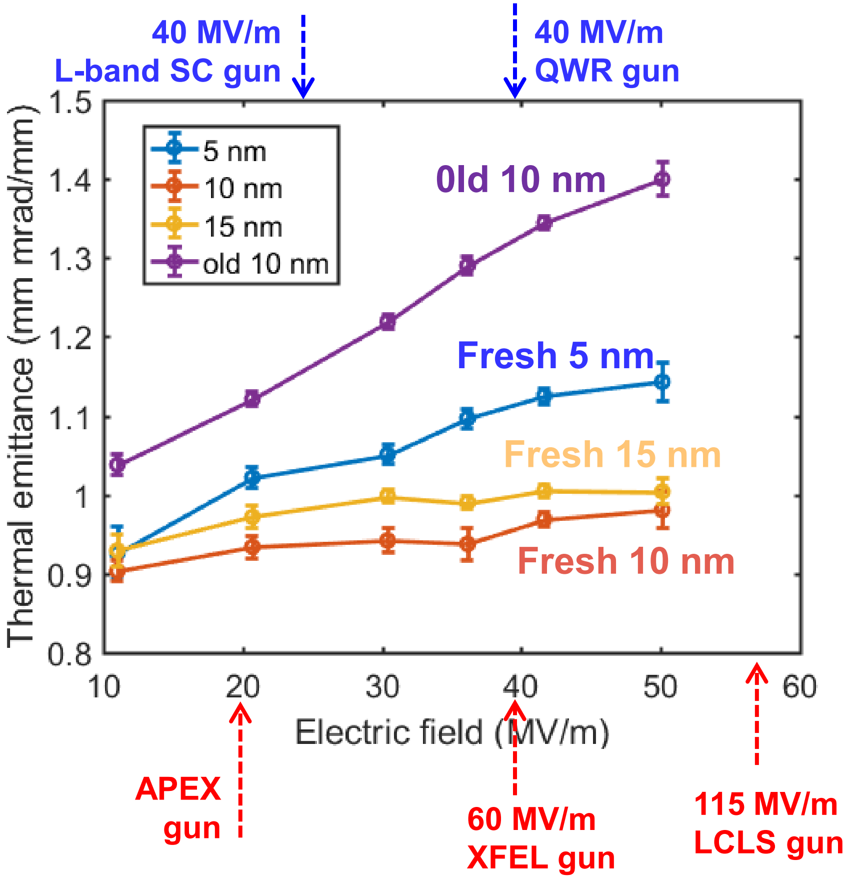


Application to cathode study

- Cathode properties monitoring
  - Reduced beam time for such task



- Cathode thermal emittance
  - Vs emission field
  - Vs cathode thickness



$$\sim \frac{E_{emission}}{\sigma_{px}^2}$$

Application to cathode study

Thermal emittance map

- RF emittance growth when beam is off axis

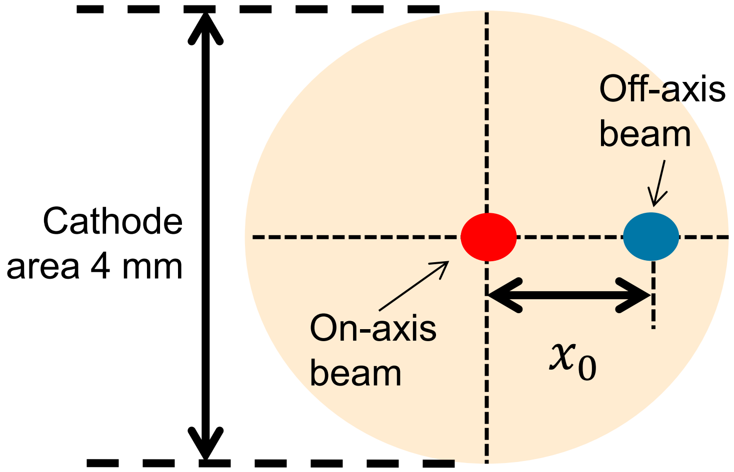
$$\varepsilon_{RF} \approx \frac{eE_0}{2m_0c^2}\sigma_x\sigma_\phi\cos\phi_f\sqrt{\sigma_x^2+x_0^2}$$

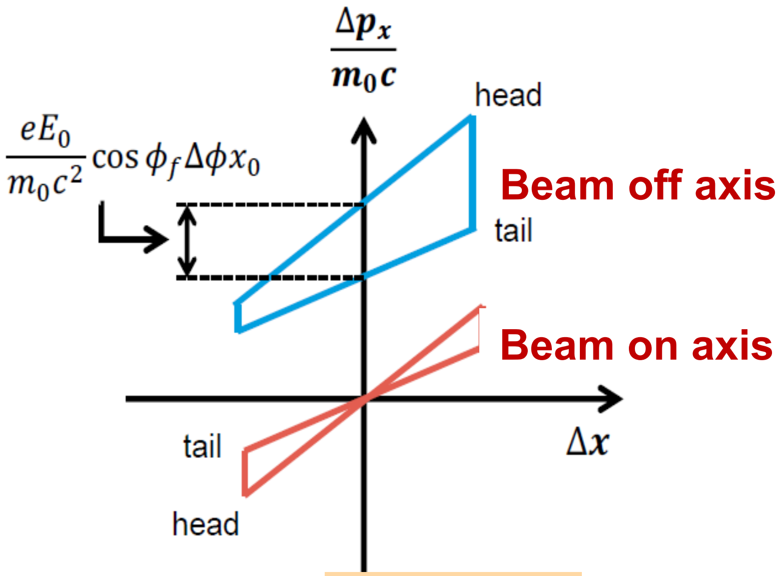
Beam size

Bunch length

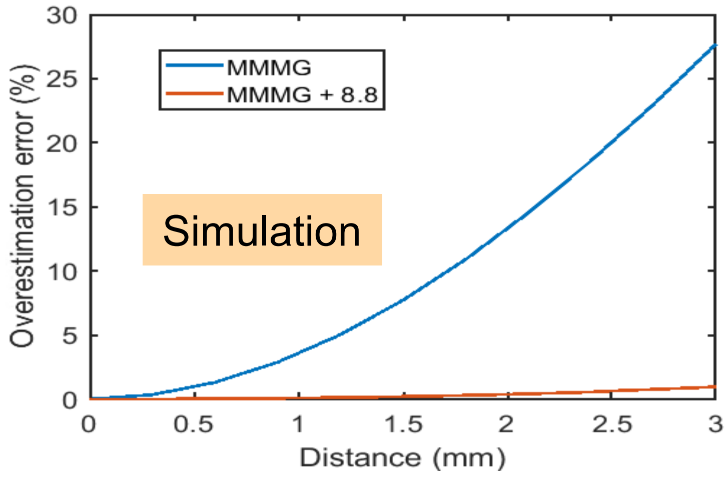
Beam synchronous phase: $\omega t_f - kz_f + \phi_{RF}$

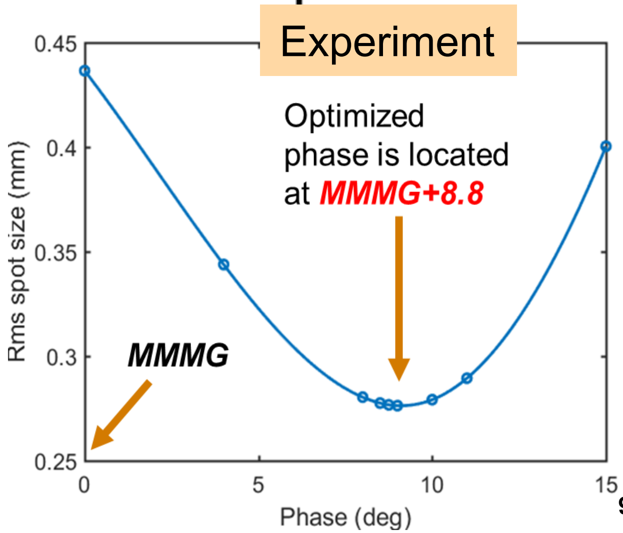
Beam offset





- How to find the right phase
  - Put beam off cathode center
  - Simulation:
    - Phase for min emittance
  - Measurement @R_{11}=0
    - Minimum beam size



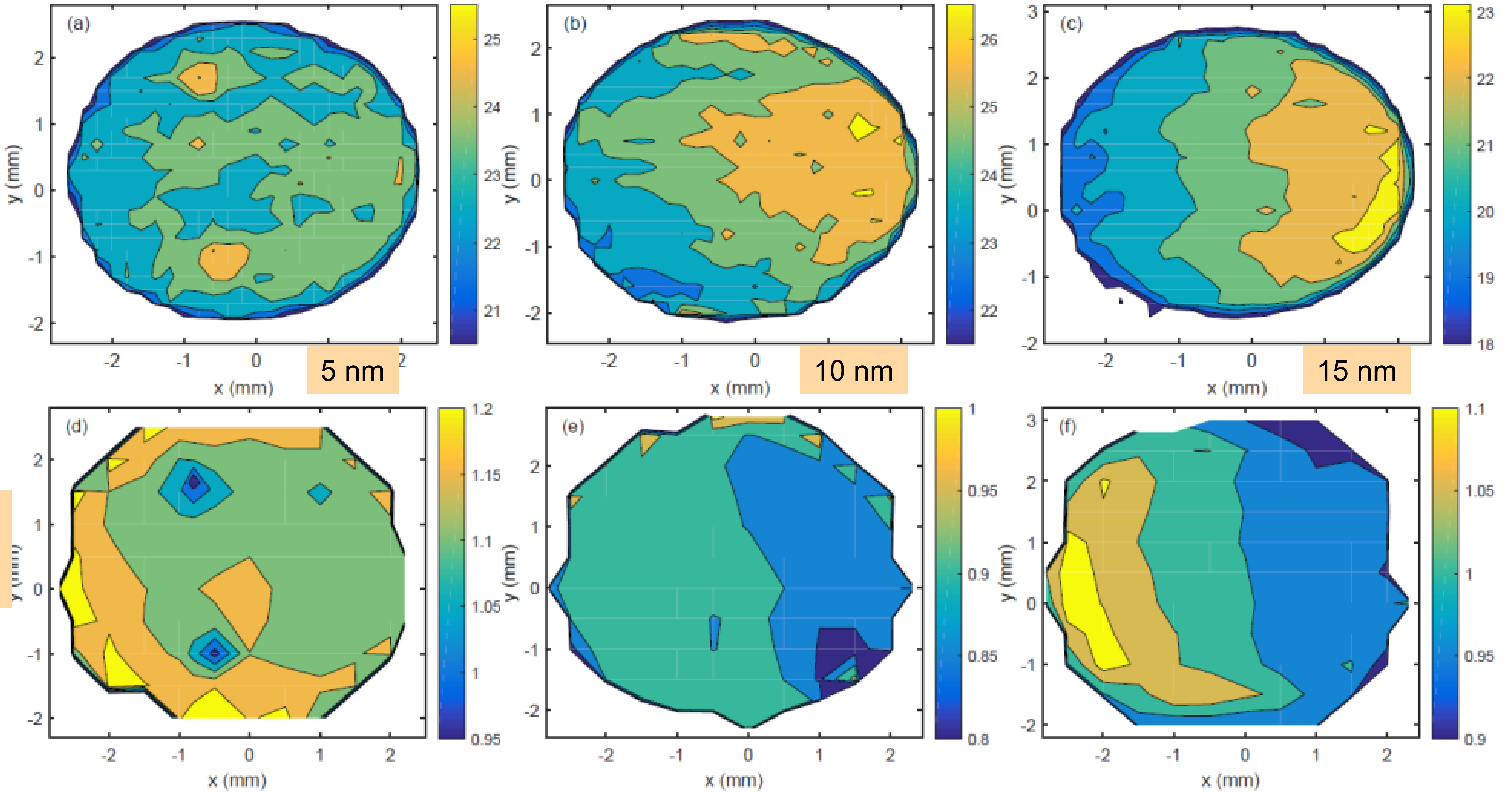


Application to cathode study

Thermal emittance map vs QE map

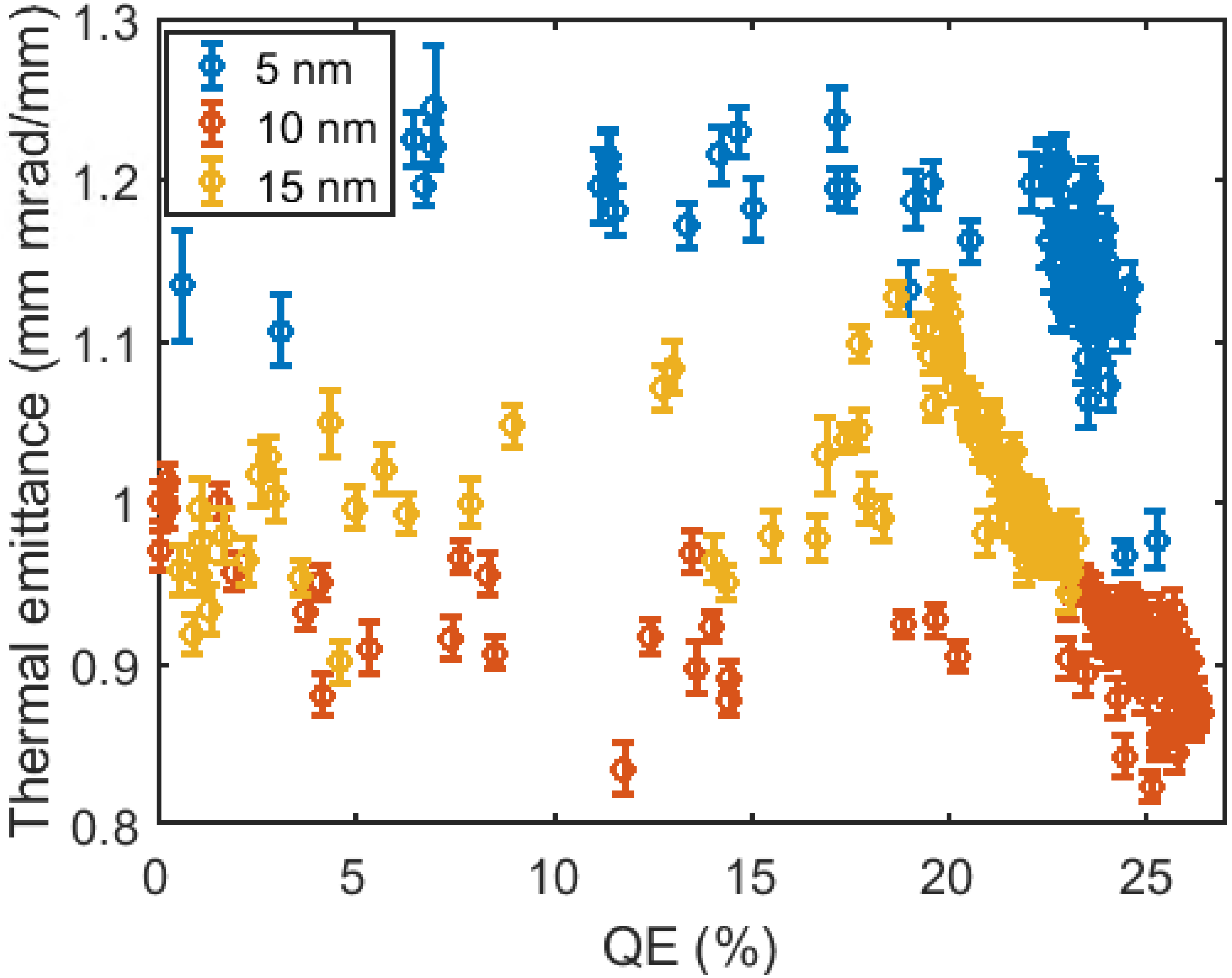
QE map

Thermal emittance map



Application to cathode study

Thermal emittance vs QE



Negatvie correlation?

Contradicts conventional understanding:
High QE, high emittance.

Summary

- A single shot cathode transverse momentum imaging technique is introduced.
  - Time efficient, reduce error in experiment

- Proof of principle tested at DESY PITZ beamline.

- Applications for cathode studies
  - Long term monitoring of cathode emittance
  - Cathode characterization vs emission field
  - Cathode mapping

Thanks for your attention !