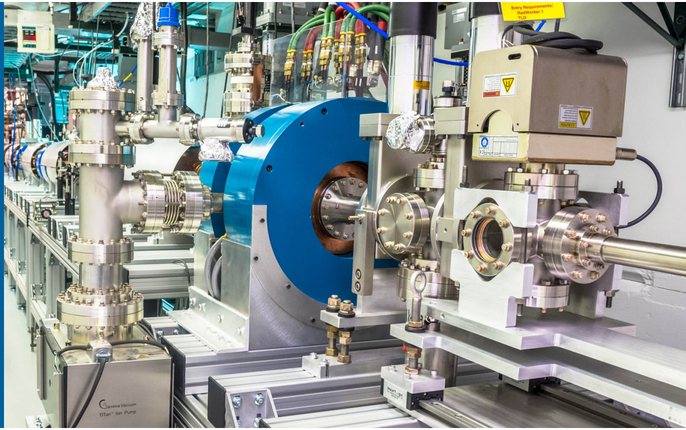
PROGRESS REPORT ON AN X-BAND ULTRA-HIGH GRADIENT PHOTOINJECTOR



GONGXIAOHUI CHEN
on behalf of joint efforts from AWA, Euclid Techlabs and NIU

08/10/2023

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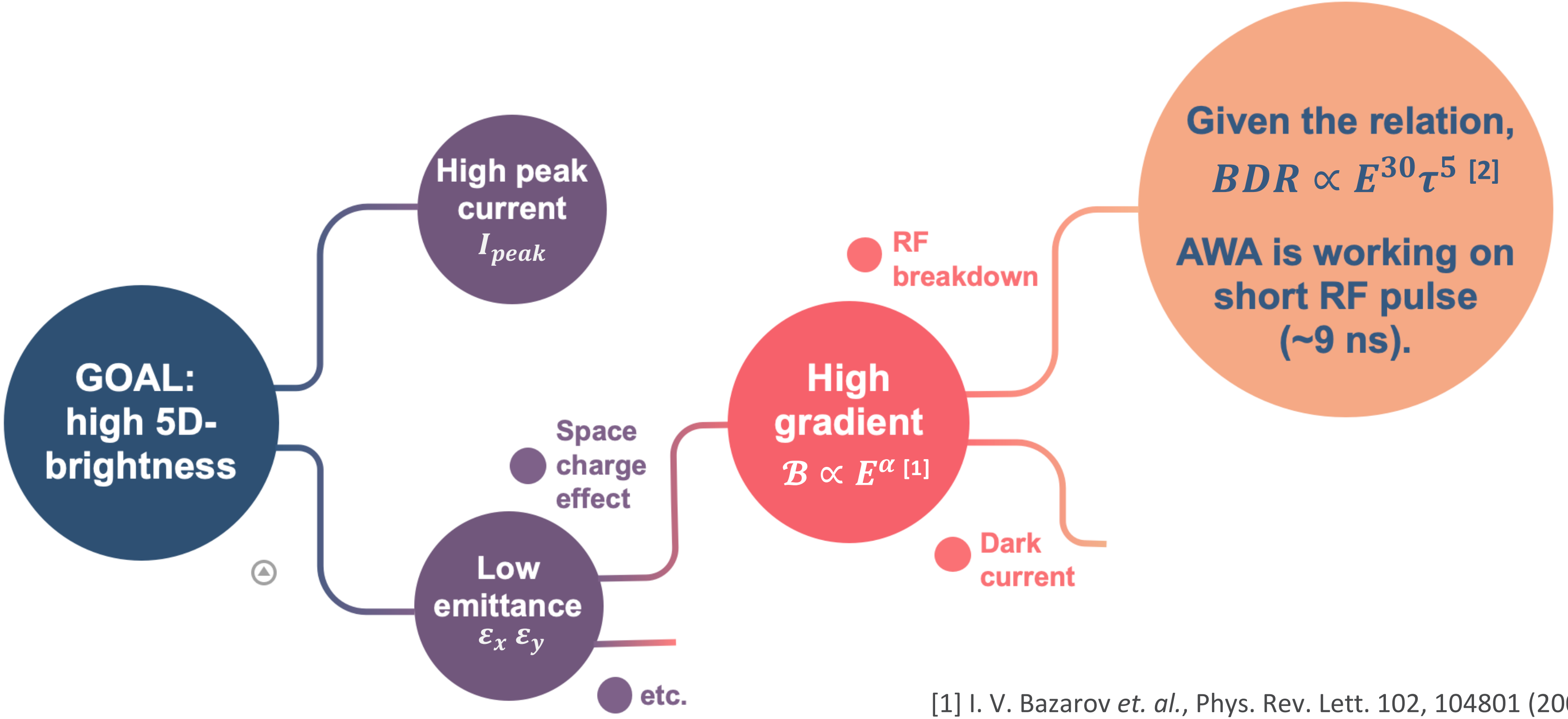
OUTLINE

- Motivation
- Brief introduction to the Xgun
  - Rf properties
  - Xgun test history since 2019
- Overview on the upcoming Xgun experiment: *studies on the fundamentals of photoemission at high gradient*
  - Simulations of beam dynamics
- Future work:
  - preliminary design of new Xgun (w/ removable cathode stock)

OUR APPROACH TO HIGH BRIGHTNESS

Motivation

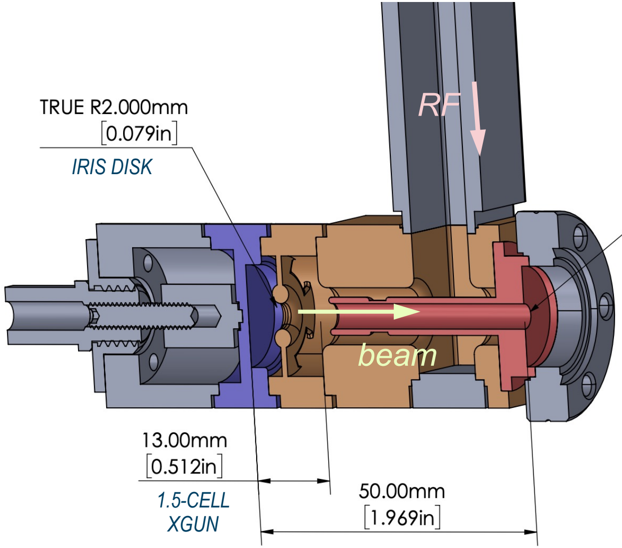


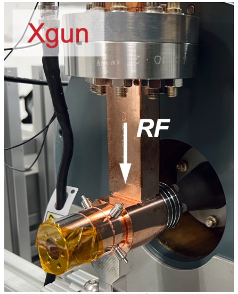
[1] I. V. Bazarov *et. al.*, Phys. Rev. Lett. 102, 104801 (2009).
[2] A. Grudiev *et. al.*, Phys. Rev. ST-AB, 12, 102001 (2009).

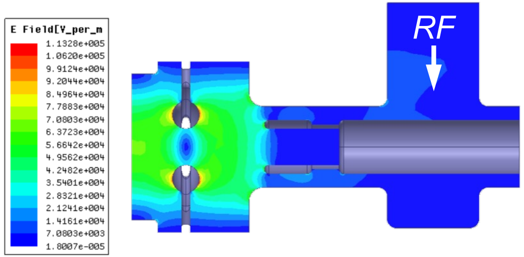
SHORT PULSE XGUN DESIGN

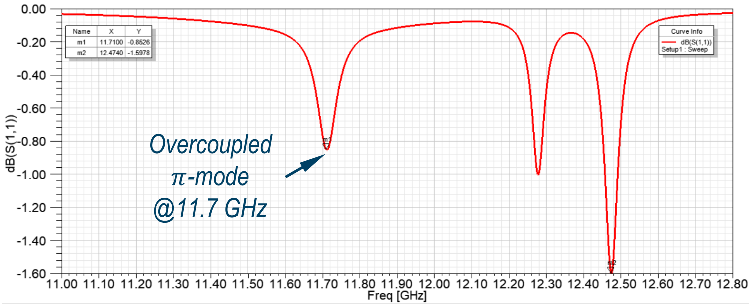
Brief introduction

- X-band 1.5-cell rf gun (Xgun)
- Operate on π-mode @11.7 GHz
- Strongly over-coupled
  - Short fill-time
  - Q_load≈180
- Cathode is the Cu backwall of the Xgun cavity





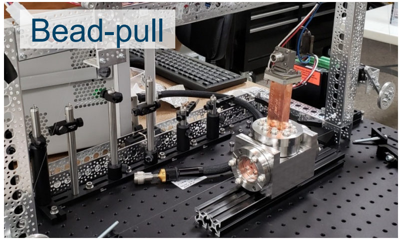


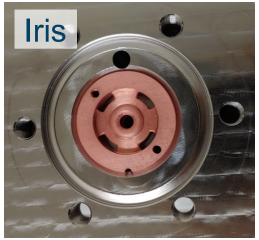


XGUN TEST HISTORY

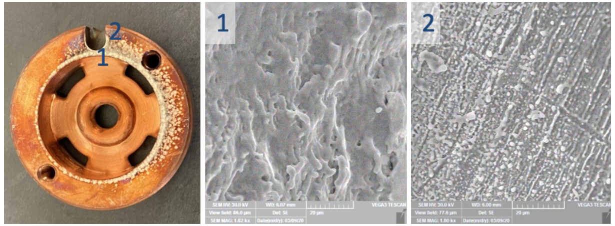
Prototype I - brazeless (2019)

- Cold test performed
- High power rf test performed
- Disassembled and examined for BDs



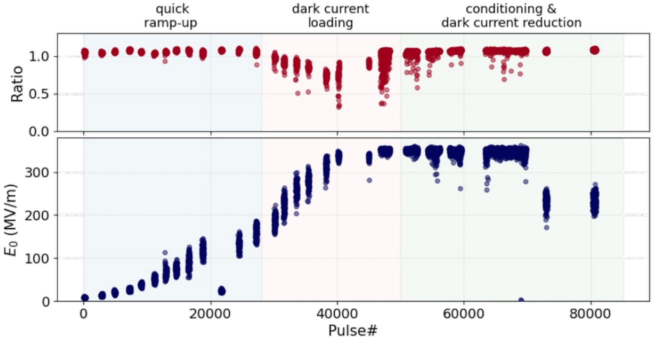


Iris after rf test + SEM

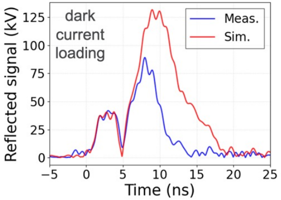


Prototype II - brazed (2020 - present)

- Cold test performed
- **1st high power rf conditioning** (Nov. 2020):
  - Achieved 350 MV/m within 70k pulses.
  - A dark current loading region observed.
  - No observable dark current after conditioning.



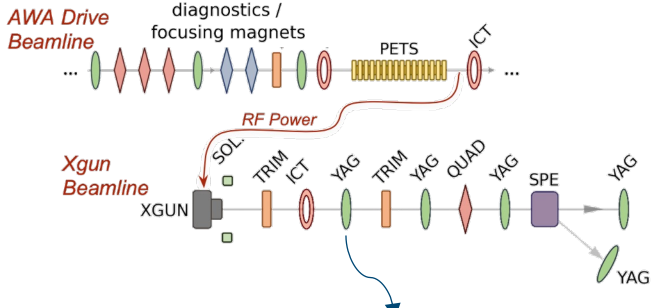
$$Ratio = \frac{V_{ref\_meas}}{V_{ref\_sim}}$$

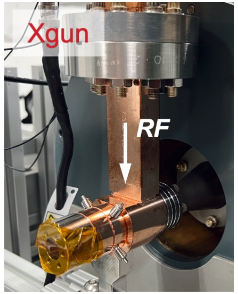


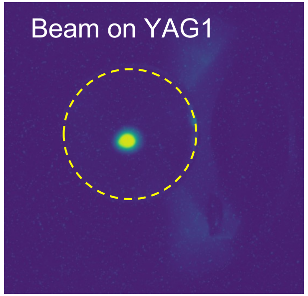
XGUN TEST HISTORY

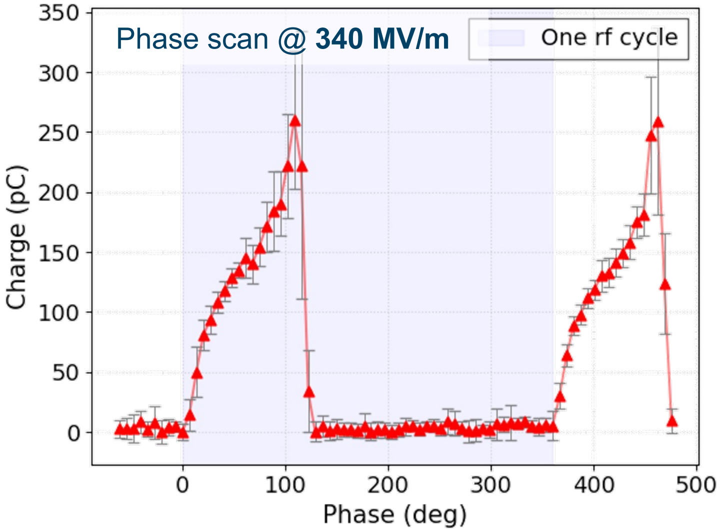
Prototype II - brazed (2020 - present) cont'd

- **1st beam test** (Dec. 2021):







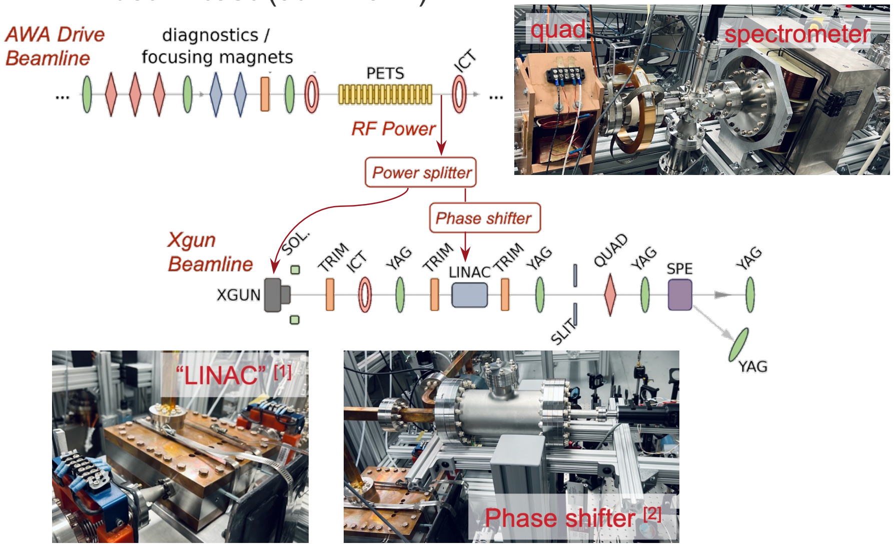


- Unconventional strong Schottky effect.
- Beam energy characterized (~3% fluctuation).
- High gradient (**388 MV/m**) verified.

XGUN TEST HISTORY

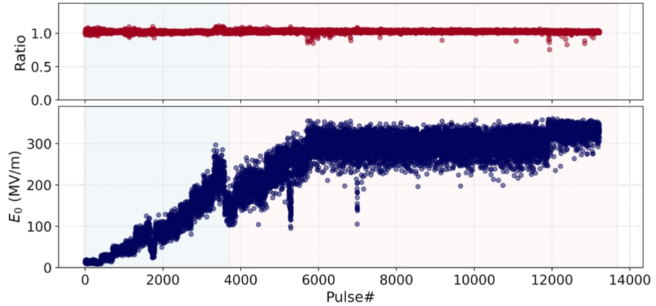
Prototype II - brazed (2020 - present) cont'd

- **2nd beam test** (Jun. 2022):



- ○ Beam energy characterized with LINAC.
- ○ Preliminary emittance measured at low gradient (280 MV/m).
- ○ However, random BDs were found during the beam test.

- **2nd high power rf test** (Oct. 2022):



- ○ Did not observe dark-current loading.
- ○ The Xgun stays **alive and robust** after being fully conditioned.

Other prototypes (summer 2021)

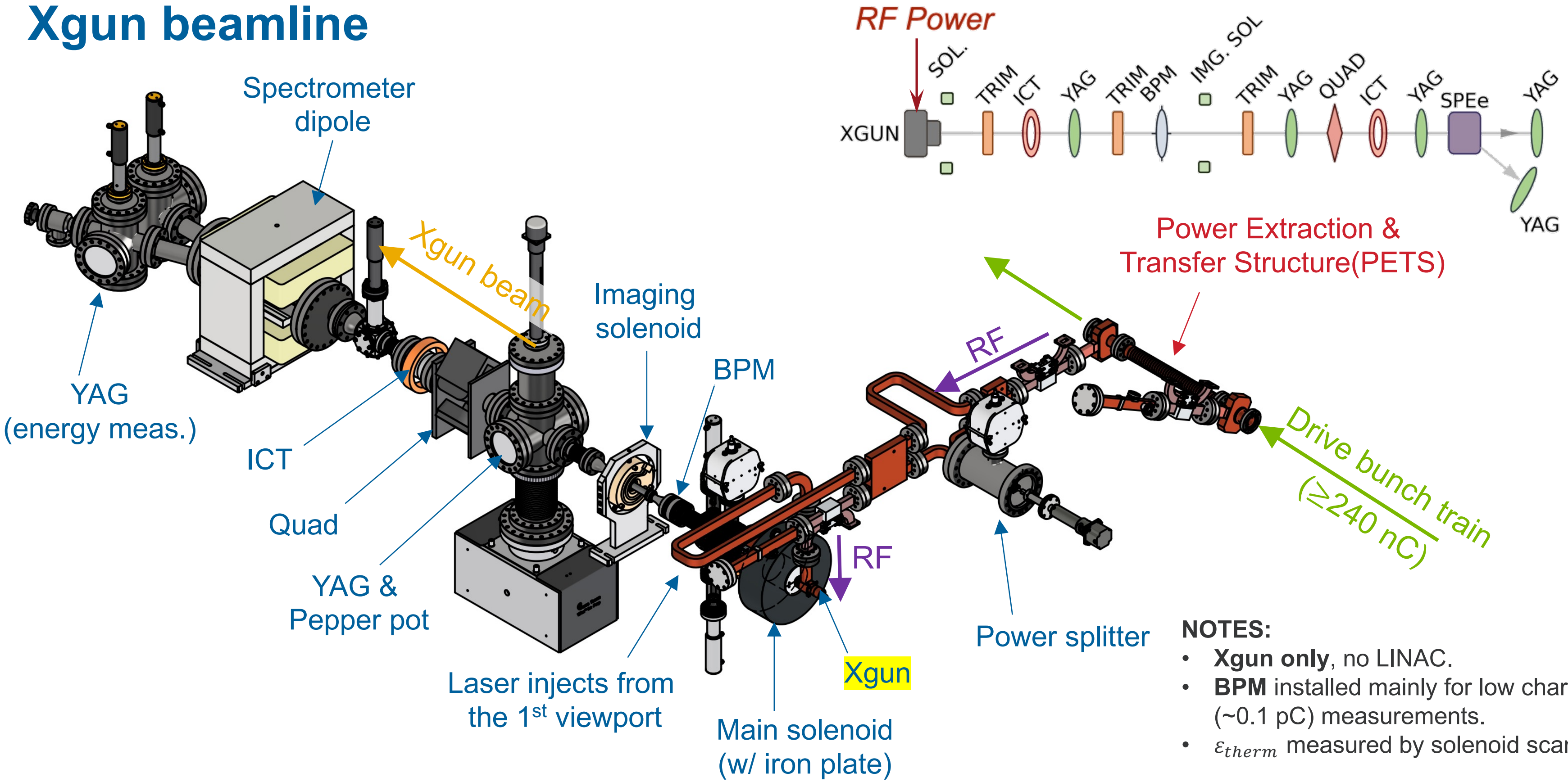
- Brazed version
- Cold tested and high power rf tested
- Fabrication defects found

OVERVIEW ON THE UPCOMING EXPERIMENT

- **GOAL:** study the fundamentals of photoemission
  1. Schottky studies @ different Xgun gradients
     - Measure QE
     - Characterize beam energy
  2. Thermal emittance measurements @ different Xgun gradients
     - Prep: beam dynamics simulations

EXPERIMENTAL SETUP

Xgun beamline



NOTES:

- **Xgun only**, no LINAC.
- **BPM** installed mainly for low charge (~0.1 pC) measurements.
- ε_{therm} measured by solenoid scan.

SIMULATIONS FOR ε_{therm} MEASUREMENTS

Rf effect (ε_{rf})

Given the relation:

$$\varepsilon_x = \sqrt{\varepsilon_{therm}^2 + \varepsilon_{rf}^2 + \varepsilon_{optics}^2 + \varepsilon_{sc}^2}$$

where,

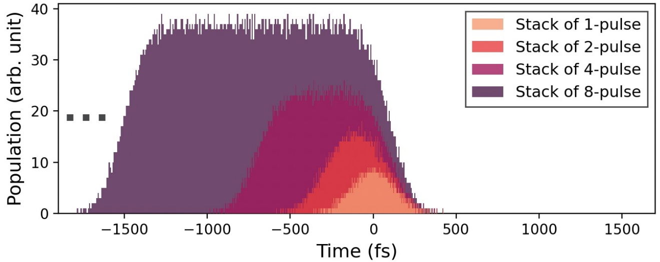
ε_{therm} - thermal emittance, an intrinsic property of cathode material.

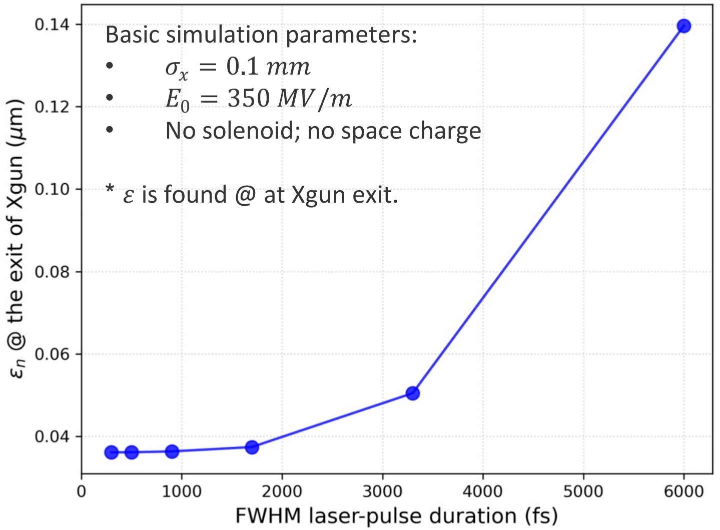
ε_{rf} - rf emittance ($\propto \sigma_x^2 \sigma_z^2$)

ε_{optics} - emittance growth term from solenoid aberrations

ε_{sc} - emittance growth term from space charge effects

At AWA, laser pulse length can be adjusted from 300 fs (FWHM) to 6 ps by pulse stacking.

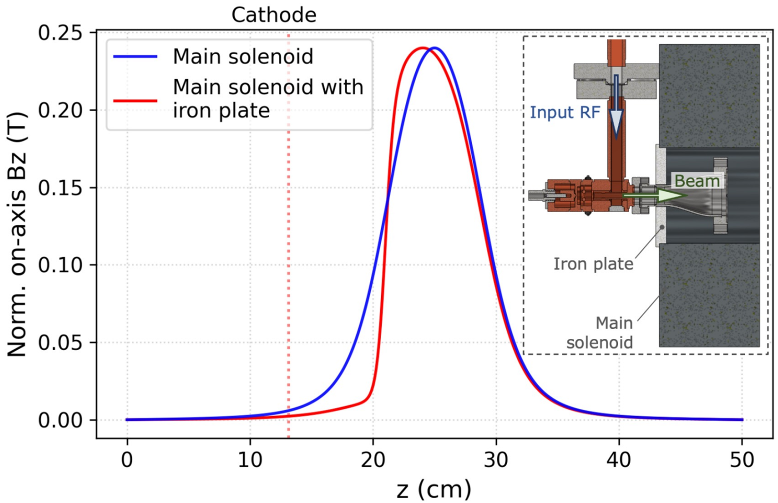


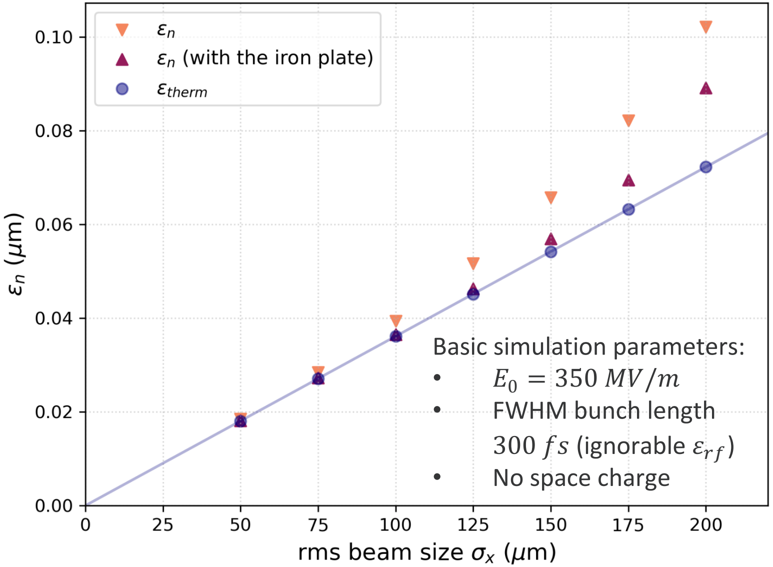


- $\varepsilon_{rf} \propto \sigma_x^2 \sigma_z^2$
- Pulse length needs to be $\leq 900\ fs$ to avoid a noticeable impact on the emittance.

SIMULATIONS FOR ε_{therm} MEASUREMENTS

Solenoid modification and solenoid effect (ε_{optics})





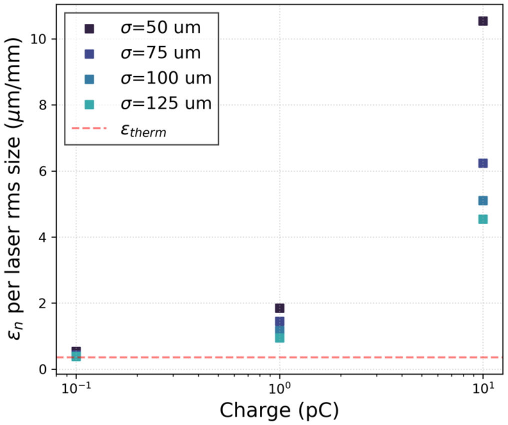
- A non-zero B_z was found on the cathode surface.
- Design and added an iron plate, then on cathode B_z drops to < 22 Gauss.

- Iron plate helps on the resulting emittance.
- $\varepsilon_{chromatics} \propto \sigma_x^2$, $\varepsilon_{spherical} \propto \sigma_x^4$
- To avoid solenoid effects (e.g., $\varepsilon_{chromatic}$ and $\varepsilon_{spherical}$), σ_x needs to be ≤ $125\ \mu m$.

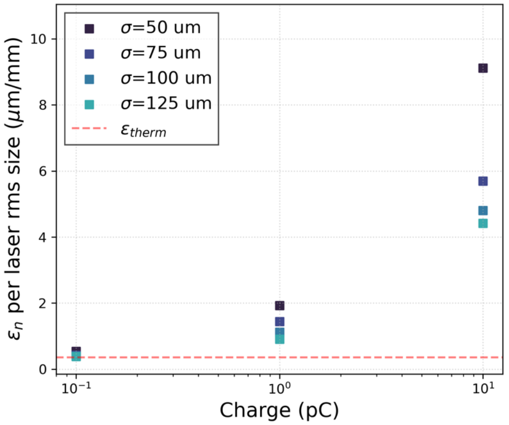
SIMULATIONS FOR ε_{therm} MEASUREMENTS

Space charge effect (ε_{sc})

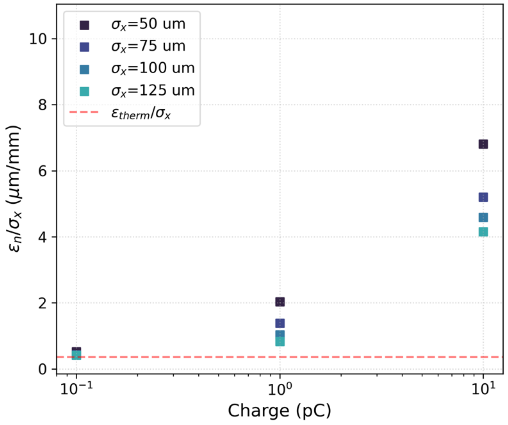
charge vs. $\varepsilon_n/\sigma_{x,y}$
laser duration (τ_p): 300 fs



charge vs. $\varepsilon_n/\sigma_{x,y}$
τ_p : 500 fs



charge vs. $\varepsilon_n/\sigma_{x,y}$
τ_p : 900 fs



- Again, $\varepsilon_x = \sqrt{\varepsilon_{therm}^2 + \varepsilon_{rf}^2 + \varepsilon_{optics}^2 + \varepsilon_{sc}^2}$
- By the definition, thermal emittance (ε/σ_x) is only material dependent, and should converge to a constant level below a certain charge threshold

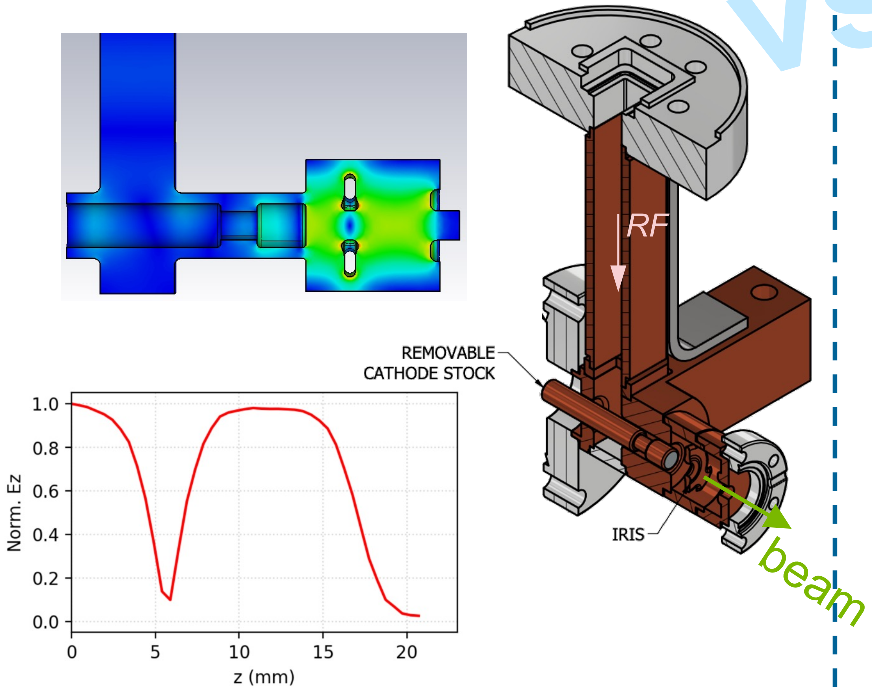
- Considering the constraints on the bunch length (≤ 900 fs) and the transverse beam size (σ_x ≤ 125 μm), to avoid space charge effect, charge needs to be ~0.1 pC.

NEW XGUN DESIGNS

1.5 cell vs. 2.5 cell (?); with removeable cathode

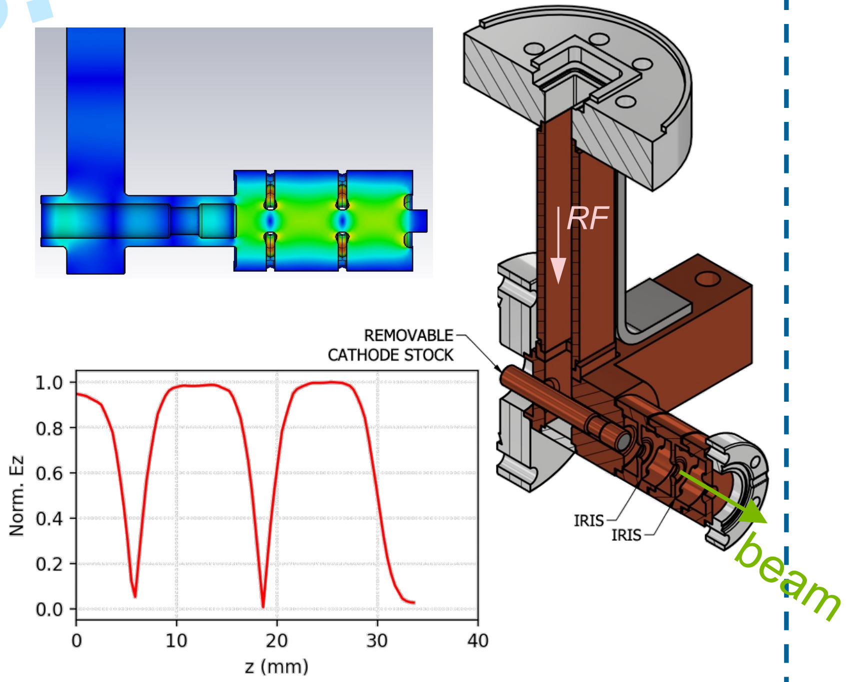
New Xgun is designed by Sergey Kuzikov and Ernie Knight at Euclid TechLabs.

1.5 cell

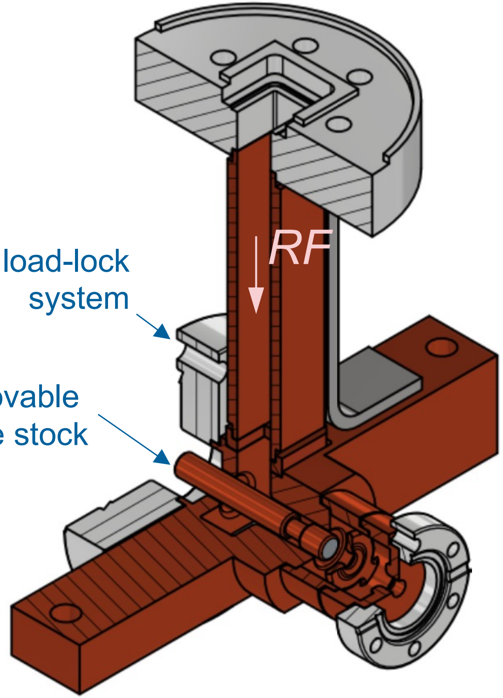


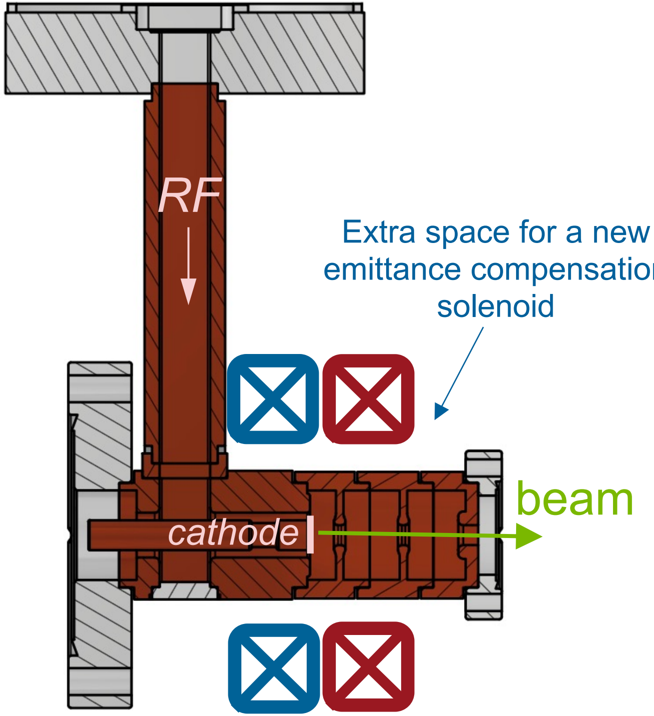
vs.

2.5 cell



NEW SOLENOID





New Xgun is designed by Sergey Kuzikov and Ernie Knight at Euclid TechLabs.

CONCLUSION

- Characterized parameters of Xgun, include:
    - High gradient ~400 MV/m
    - Energy fluctuation (~3%)
    - Robustness, no BDs after fully conditioned
    - Preliminary beam emittance with less-ideal LINAC
- Next experiment has been reviewed, and will focus on the study of fundamentals of photoemission at high gradients.
- New designs of the Xgun have been proposed, aims to include:
    - Removable cathode stock for different cathode materials.
    - Extra space for a new emittance compensation solenoid.

BIG THANKS TO OUR TEAM!

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