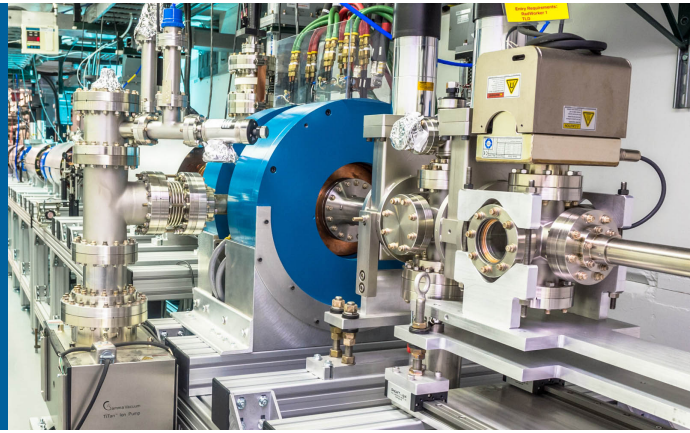
PROGRESS REPORT ON AN X-BAND sub-GV/m PHOTOINJECTOR



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

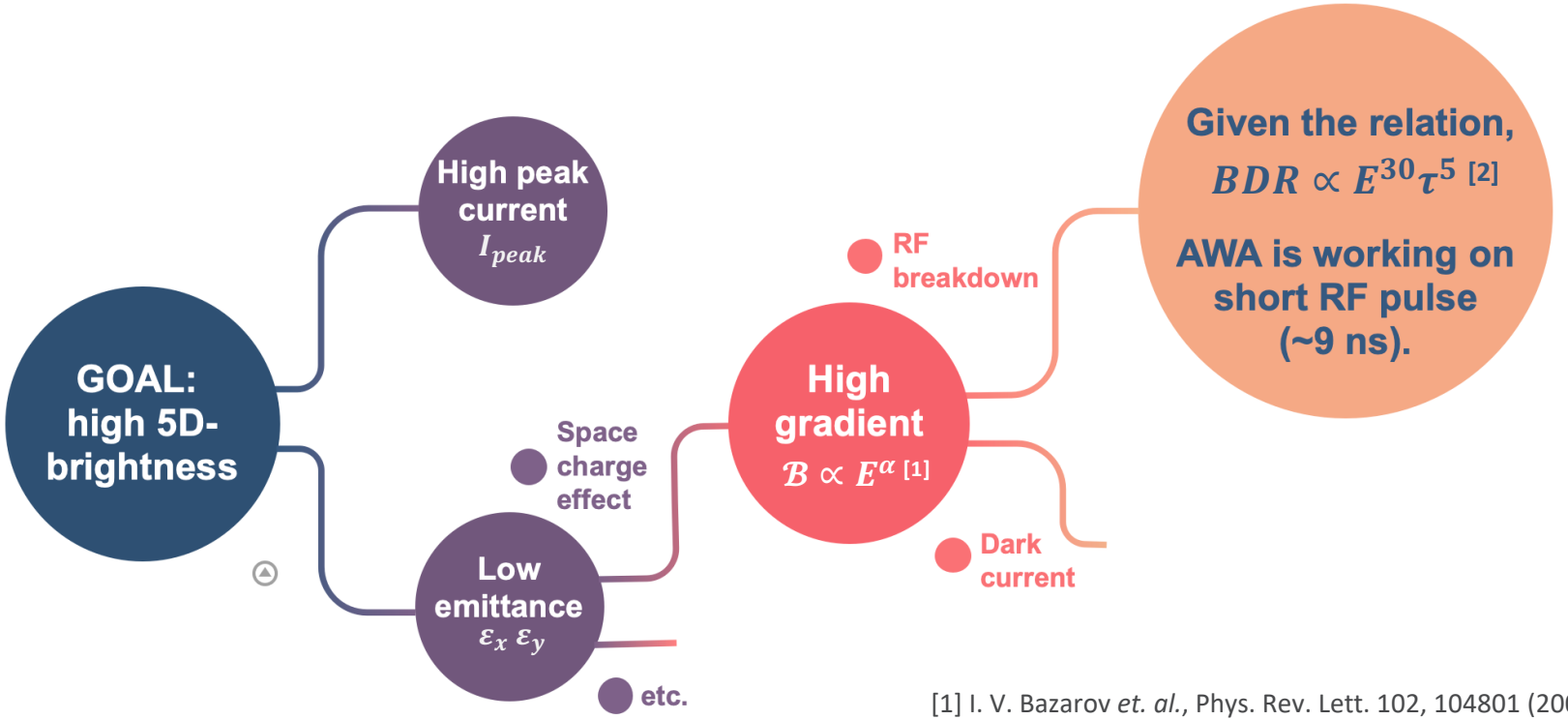
11/08/2022

OUTLINE

- Motivation
- Brief introduction to the Xgun
- 1st beam test of Xgun only
  - Beam energy characterization
- 2nd beam test of Xgun with LINAC
  - Preliminary emittance measurement
  - Troubleshooting
- Near-future plan and the long-term plan of Xgun

OUR APPROACH TO HIGH BRIGHTNESS

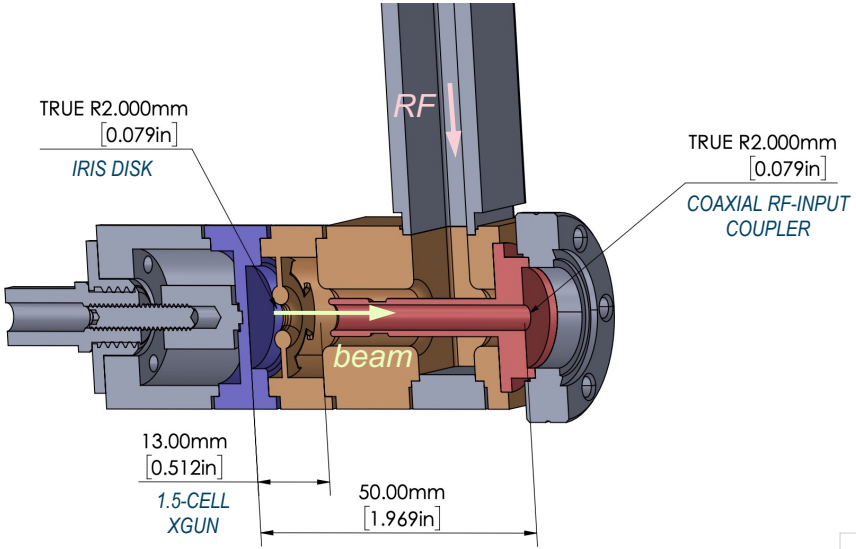
Motivation

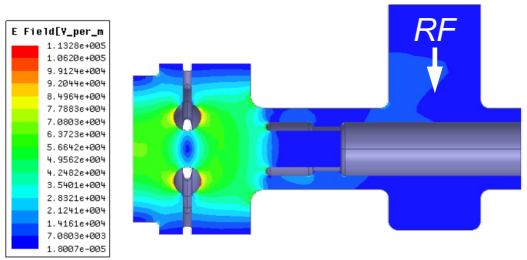


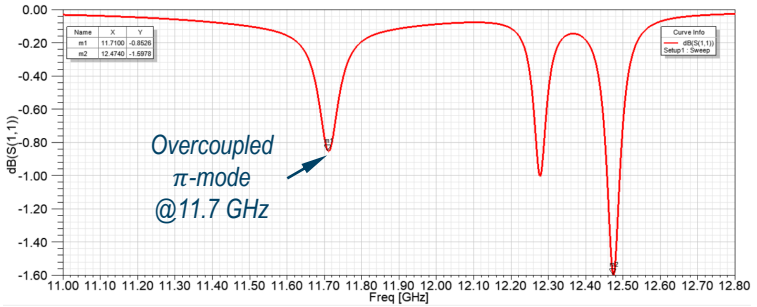
[1] I. V. Bazarov *et. al.*, Phys. Rev. Lett. 102, 104801 (2009).
[2] A. Grudiev *et. al.*, Phys. Rev. ST-AB, 12, 102001 (2009).

SHORT PULSE XGUN DESIGN

- 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

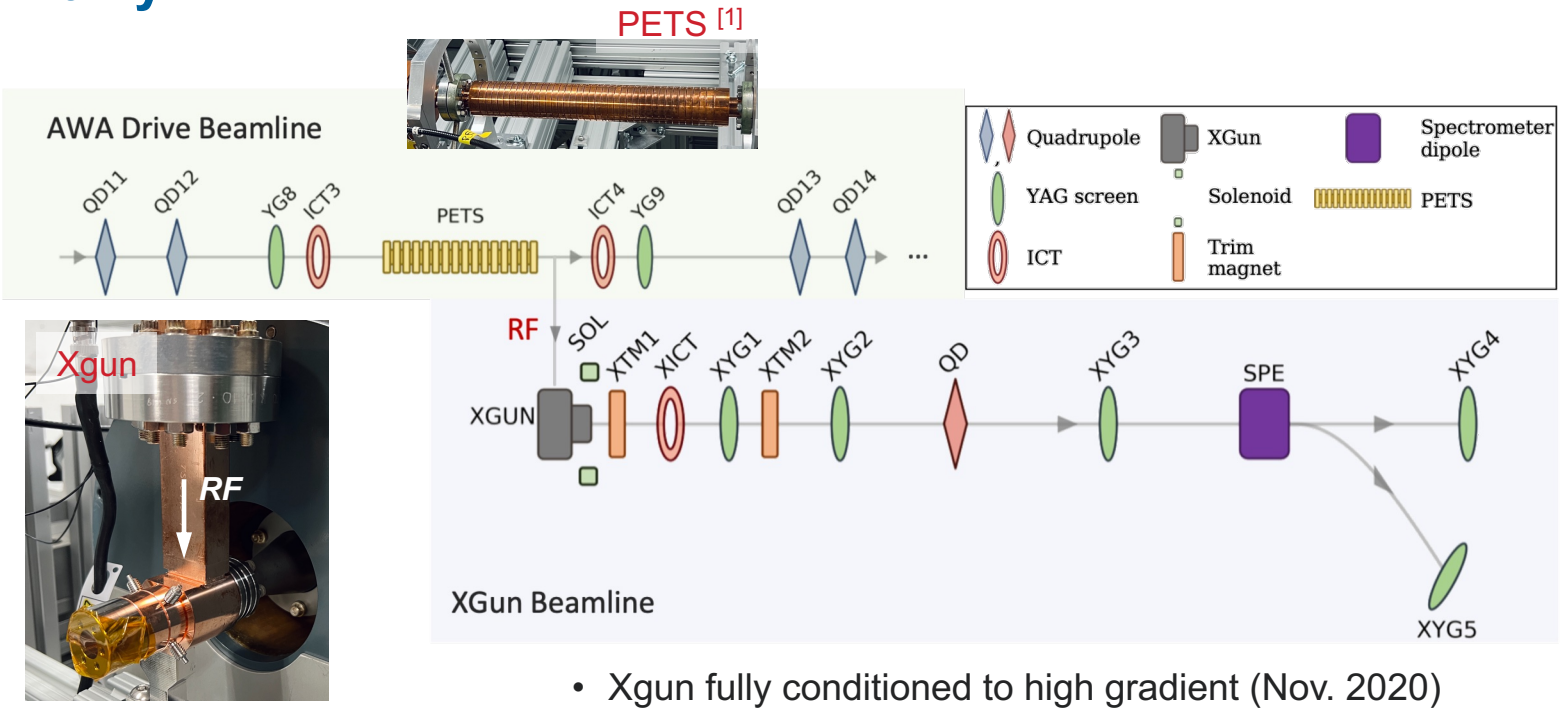






1ST BEAM TEST LAYOUT

Xgun only

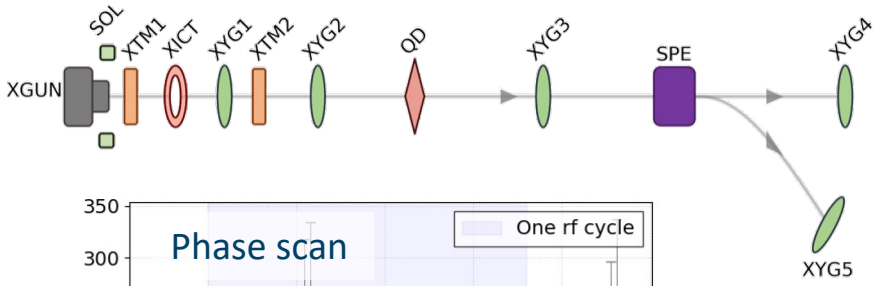


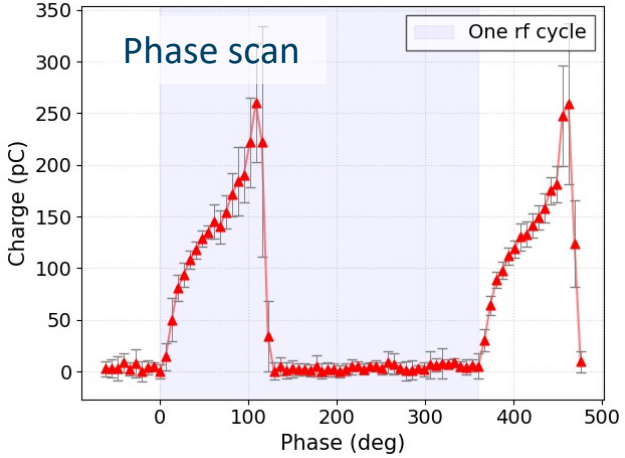
- Xgun fully conditioned to high gradient (Nov. 2020)
  - achieved 350 MV/m within 70k pulses [2]
- Beam energy characterization

[1] J. Shao *et. al.*, doi:10.18429/ JACoW- IPAC2019-MOPRB069 (2019)
[2] W.H.Tan *et. al.,* Phys. Rev. Accel. Beams 25, 083402, August 2022 (2022)

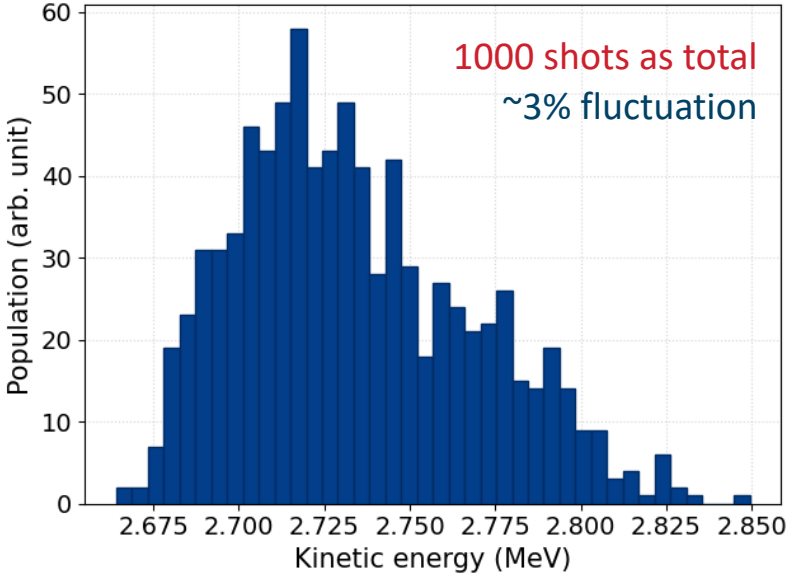
BEAM ENERGY CHARACTERIZATION

1st beam test





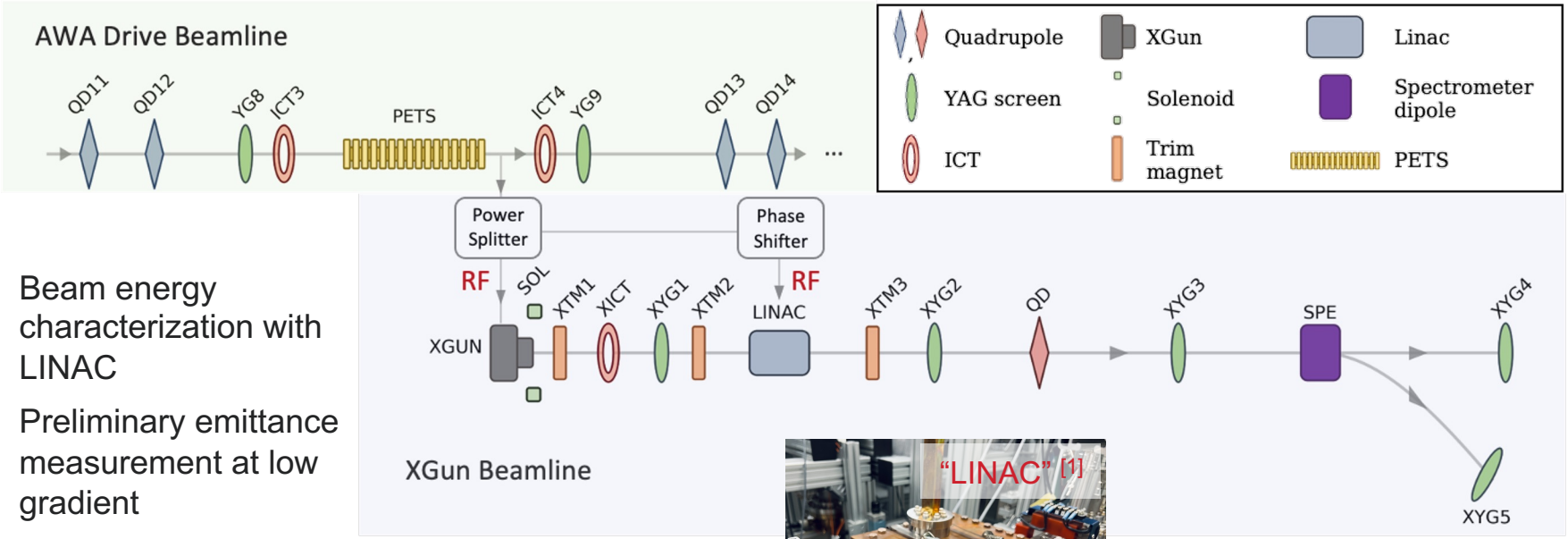
- Xgun phase scan @**340 MV/m**
- Evidence of strong Schottky effect



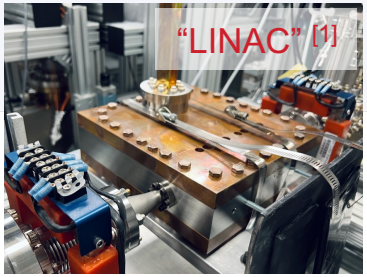
- Energy measured by the spectrometer dipole
- ~3% fluctuation, likely due to the drive charge instability and laser RF phase jitter in the drive linac.
- Max achieved gradient is **388 MV/m** from the beam energy measurement

2ND BEAM TEST LAYOUT

Xgun with linac installed



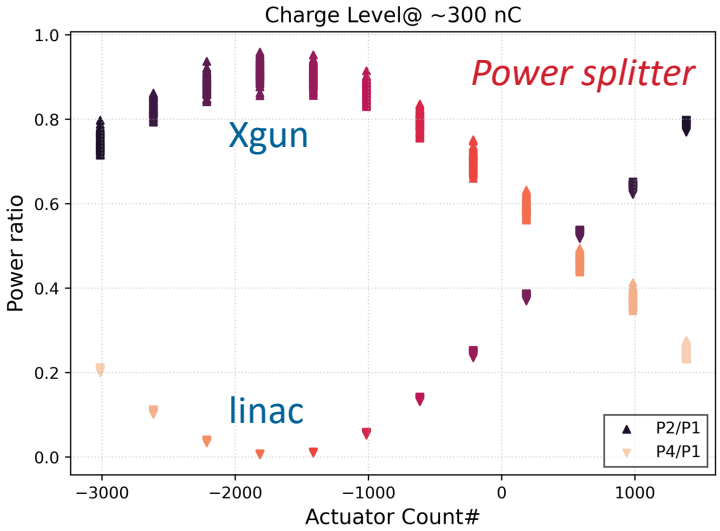
- Beam energy characterization with LINAC
- Preliminary emittance measurement at low gradient

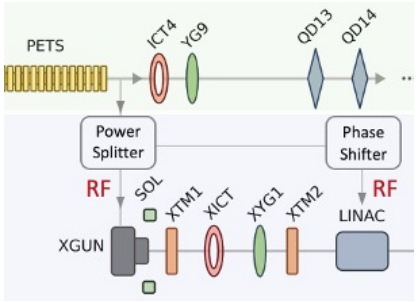


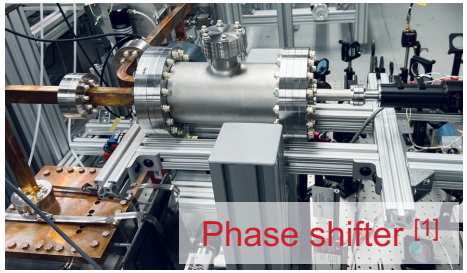
[1] S. Antipov *et. al.*, doi:10.18429/ JACoW-IPAC2021-MOPAB152 (2021)

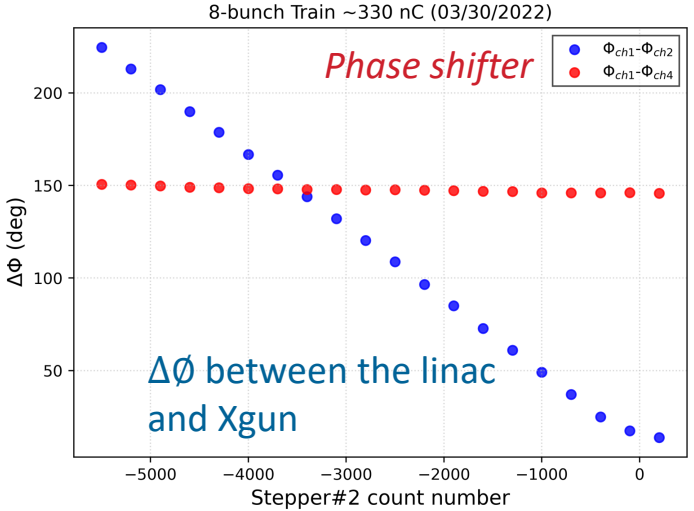
POWER SPLITTER AND PHASE SHIFTER TEST

Prep for 2nd beam test









- Both components were tested with high power (>200 MW)
- Power splitter (power level):
  - 0-100% power variation
- Phase shifter:
  - >180 deg phase shift

[1] Sergey Kuzikov *et. al.,* doi:10.18429/JACoW-IPAC2022-MOPOMS013 (2022)

XGUN EMITTANCE CHARACTERIZATION

- Beam optimizations towards lowest emittance
- Preliminary emittance measurement
- Troubleshooting

XGUN BEAM DYNAMIC SIMULATIONS

Optimization towards lowest emittance

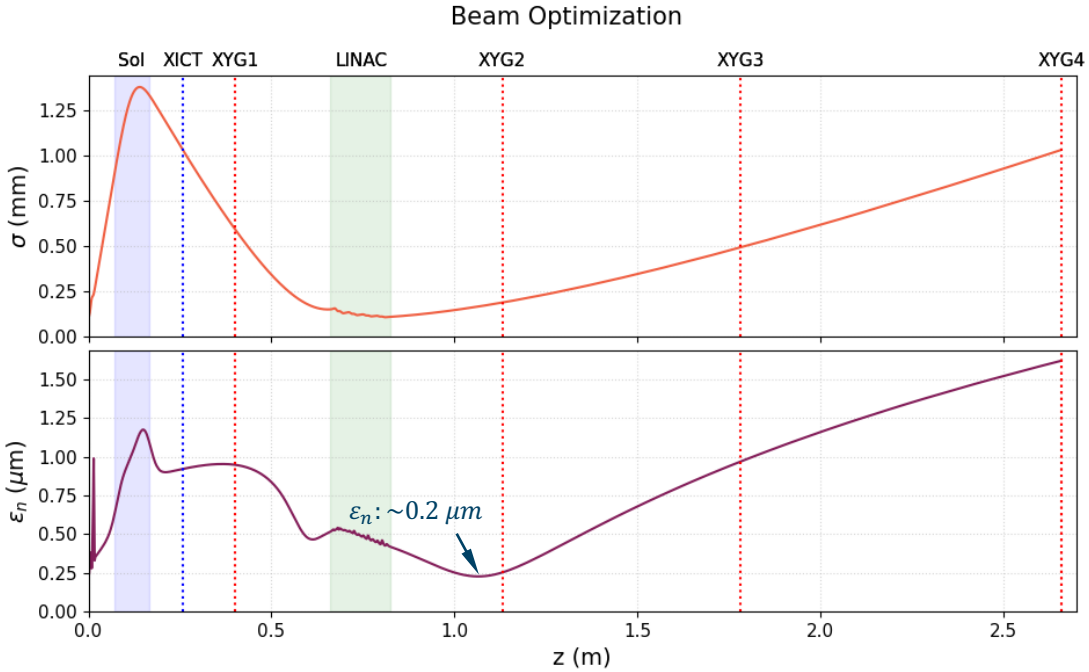


Table 1: List of optimized parameters

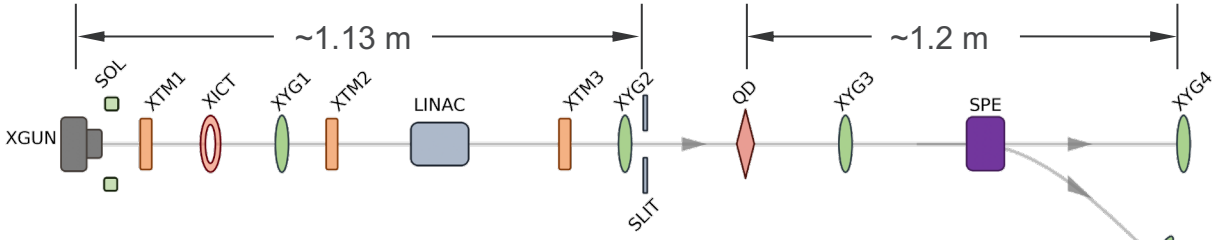
Parameter	Value	Unit
Laser spot rms size	96	μm
Laser rms duration	3	ps
Beam charge	100	pC
RF gun peak E-field	350	MV/m
RF gun phase	−1.159	deg
Linac peak field	142.2	MV/m
Solenoid B-field	0.299	T
Final beam energy	9.8	MeV
Final beam transverse emittance	0.2	μm

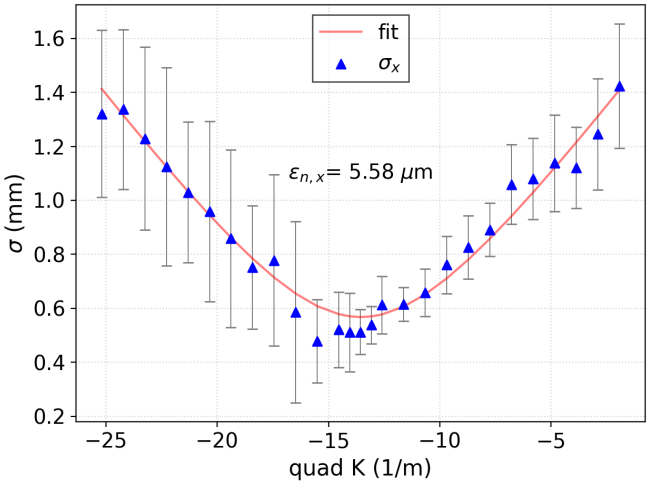
Optimization was only done based on the available hardware (limited resources).

* Part of the simulation work can be found in W. H. Tan *et. al.,* doi:10.18429/JACoW-IPAC2021-THPAB129 (2021)

PRELIMINARY EMITTANCE MEASUREMENT

2nd beam test





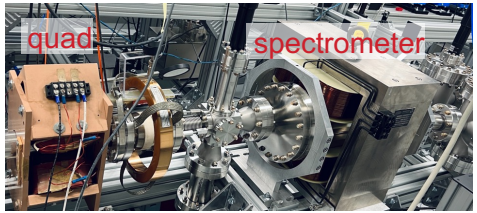
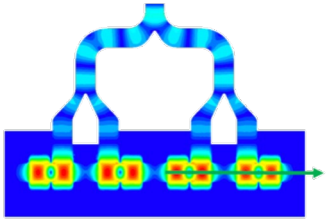


Table 1: List of the operating parameters

Parameter	Value	Unit
Laser σ_x	0.189	mm
Laser σ_y	0.234	mm
Laser bunch length (FWHM)	300	fs
Xgun peak E-field	280.0±3	MV/m
Xgun phase [1]	31.8	degree
Bunch charge	44.9±10	pC
Solenoid B-field	0.202	T
Linac peak field	86.9±2	MV/m



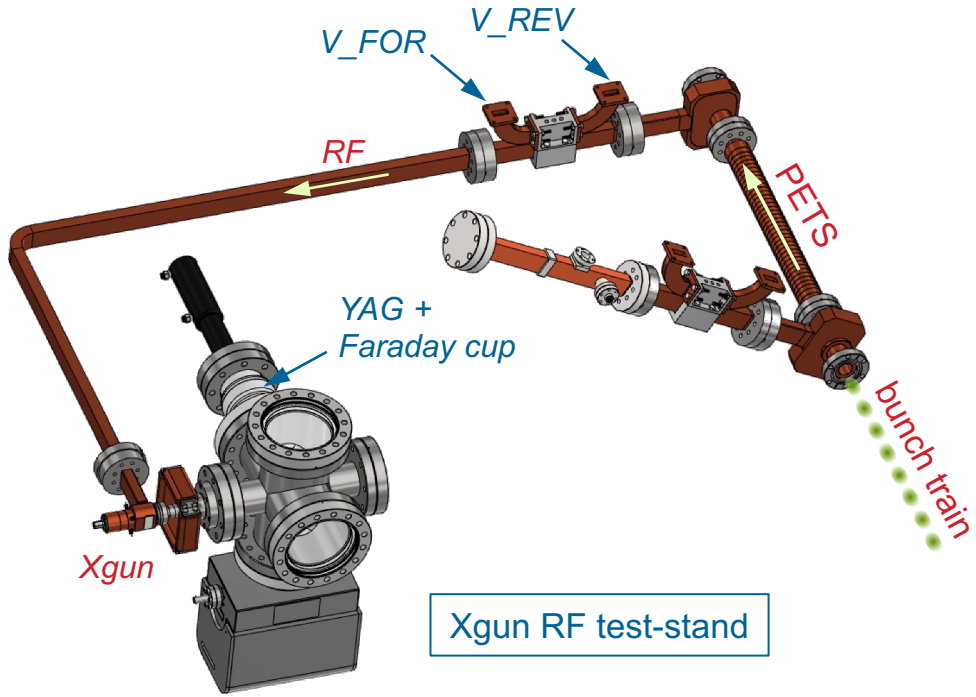
- Emittance was measured by quad scan:
  - $\varepsilon_{n,x} = 5.58\ \mu m$
  - $\varepsilon_{n,y} = 11.26\ \mu m$ (due to geometry asymmetry of the linac)
  - Kinetic energy: 5.9 MeV
- This is a preliminary test. Xgun was not operated at optimized parameters.

REVIEW ON THE PRELIMINARY ε MEAS.

Issues in the 1st ε measurement:

1. Non-ideal LINAC geometry
   - New LINAC design is proposed
2. Less-ideal solenoid
   - New solenoid design is under review
3. Unknown BDs happened randomly and prevent us reaching to a higher optimized gradient
   - *Xgun has been damaged?*

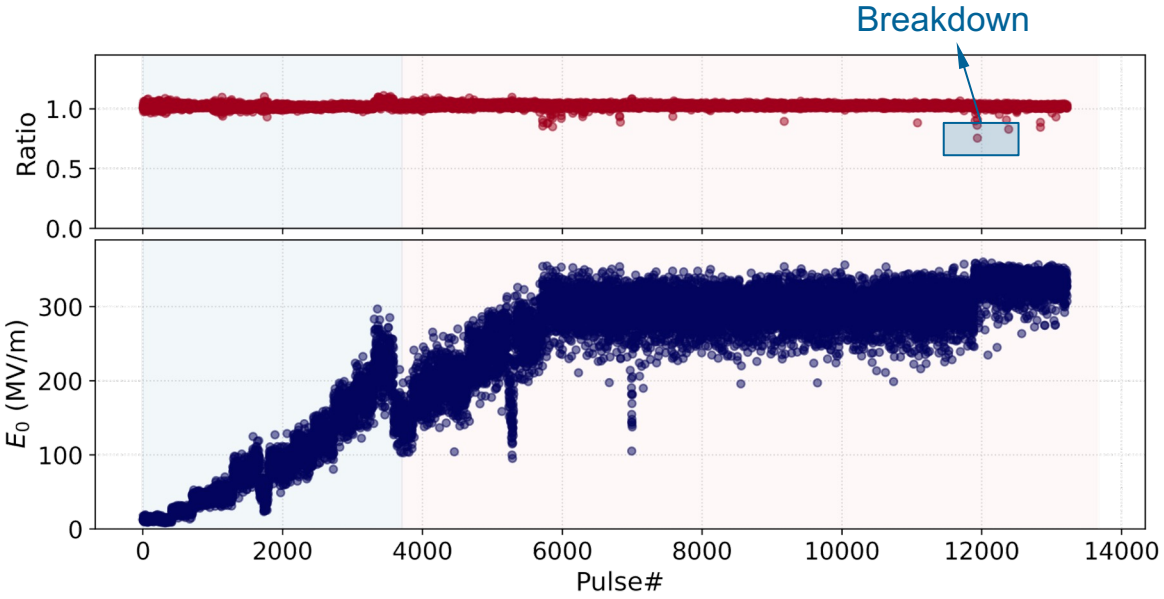
Decided to vent the beamline and do more inspections on the Xgun.



Xgun RF test-stand

XGUN DAMAGE TEST

Xgun high power test/re-conditioning

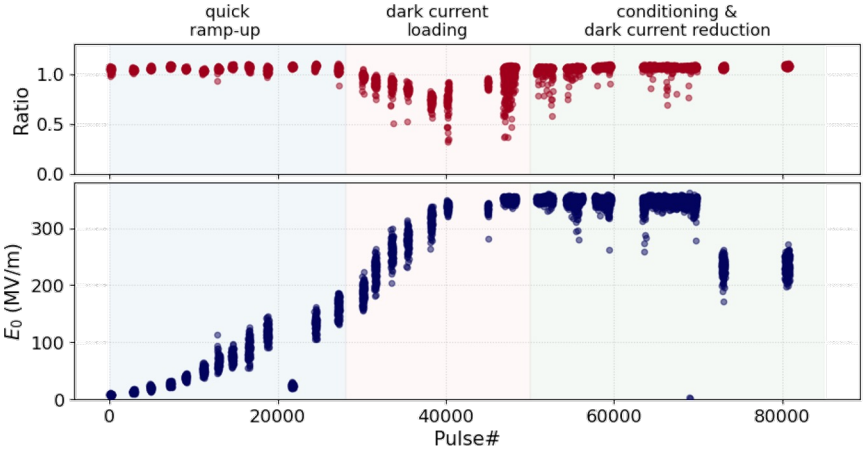


- $Ratio = \frac{V_{ref\_meas}}{V_{ref\_sim}}$
- Conditioned to > **350 MV/m** with only a few BD noticed at high gradient level.
- Xgun is still in good shape.
- The previously observed BDs were found to be related to the *insufficient* vacuum pumping speed.

GUN RF CONDITIONINGS

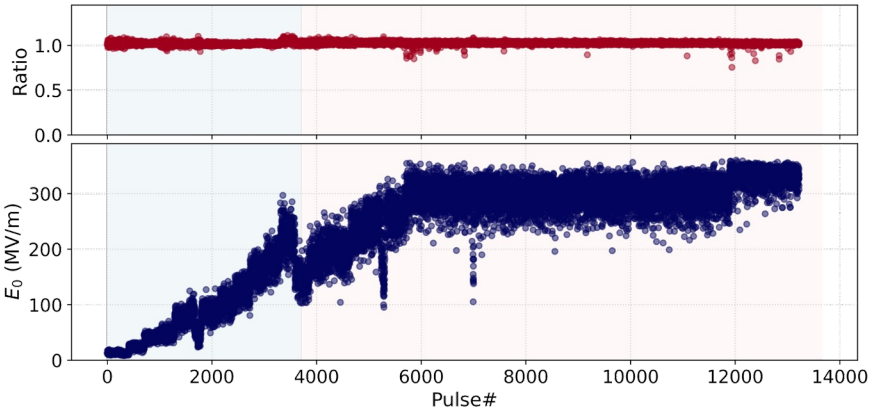
Comparison on two conditioning processes

1st Xgun conditioning (Nov. 2020):



- Conditioning process is quick.
- A dark current loading region observed.
- No observable dark current after conditioning.
- Achieved 350 MV/m within 70k pulses.

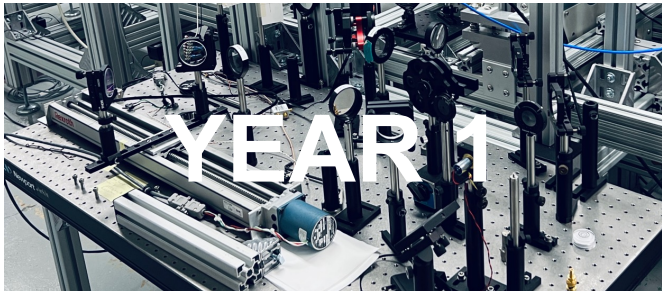
2nd Xgun conditioning (Oct. 2022):



- Xgun has been disassembled occasionally for the beamline construction and exposed to the air quite frequently.
- Did not observe dark-current loading.
- The Xgun stays alive and robust after being fully conditioned.

FUTURE PLAN

The ultra high-gradient path towards high brightness



Investigating the fundamentals of photoemission in the high-field regime.

- Upgrade to a tunable laser (optical parametric amplifier) to control photon energy.
- Dec. 2022 - Jan. 2023 (scheduled):
  - Re-construct the beamline to improve the pumping speed
  - **Schottky studies** with better laser profile
  - **Thermal emittance measurements** as function of gradient and photon energy using the existing AWA PC gun.
- More studies are planed for the next year..

Generating High-brightness beam.

- Add an X-band RF cavity to beamline.
- Acceleration and emittance compensation at high (~100 pC) charge. Beam characterization.
- Design an upgraded X-band RF PC gun with removable cathode plug and new solenoid.

Characterizing low-MTE cathode at high gradient.

- Fabricate and commission the upgraded RF gun.
- Characterize promising cathodes at high gradient (QE, MTE, response time, etc.).
- Investigate the possible compression of the bunch using velocity bunching in the LINAC.

CONCLUSION

- High gradient achieved ~400 MV/m
- Beam energy characterized
- Preliminary emittance measured at limited resources (re-purposed linac, solenoid, etc.)
- Xgun surface is still robust and has good environmental tolerance.

BIG THANKS TO OUR TEAM!

Scott Doran (AWA)
Seongyeol Kim (AWA)
Wanming Liu (AWA)
John Power (AWA)
Charles Whiteford (AWA)
Eric Wisniewski (AWA)
Gwanghui Ha (was at AWA, now at NIU)
Jiahang Shao (was at AWA, now at IASF)

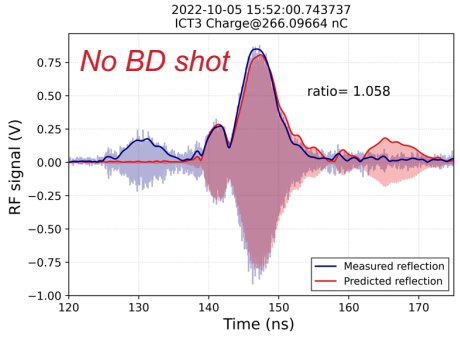
Chunguang Jing (Euclid Techlabs / AWA)
Ernie Knight (Euclid Techlabs)
Sergey Kuzikov (Euclid Techlabs)
Pavel Avrakhov (Euclid Techlabs)
Sergey Antipov (was at Euclid Techlabs, now at PALM Scientific)

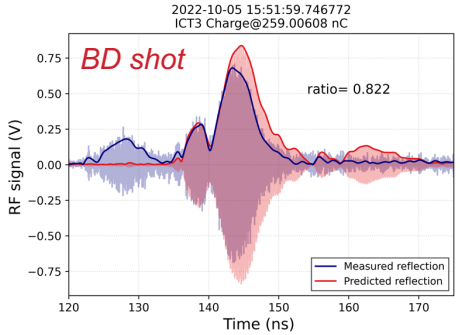
Xueying Lu (NIU / AWA)
Philippe Piot (NIU / AWA)
Wei Hou Tan (was at NIU, now at KLA)

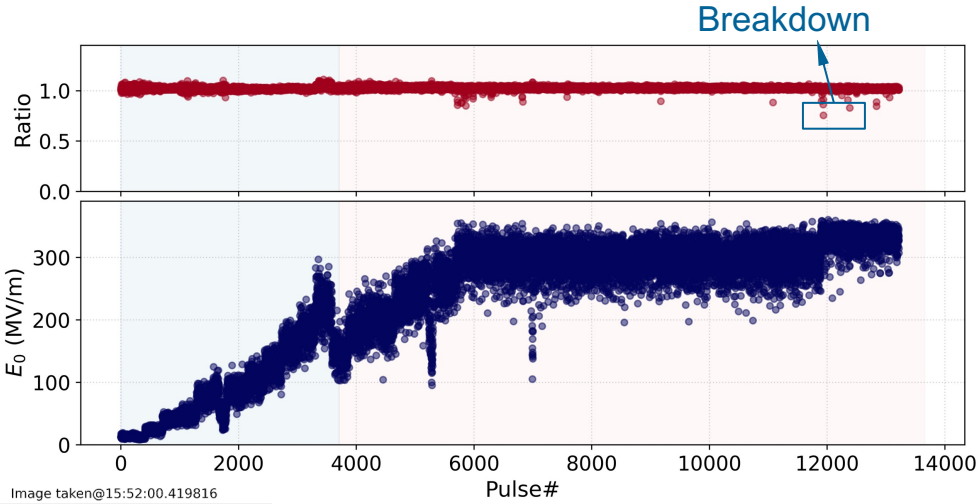
BACKUP

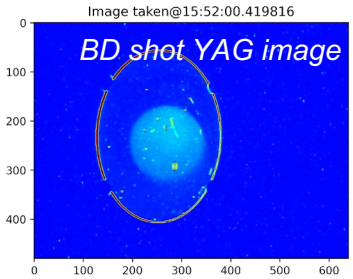
XGUN DAMAGE TEST

Oct. 2022 - Xgun high power test/re-conditioning





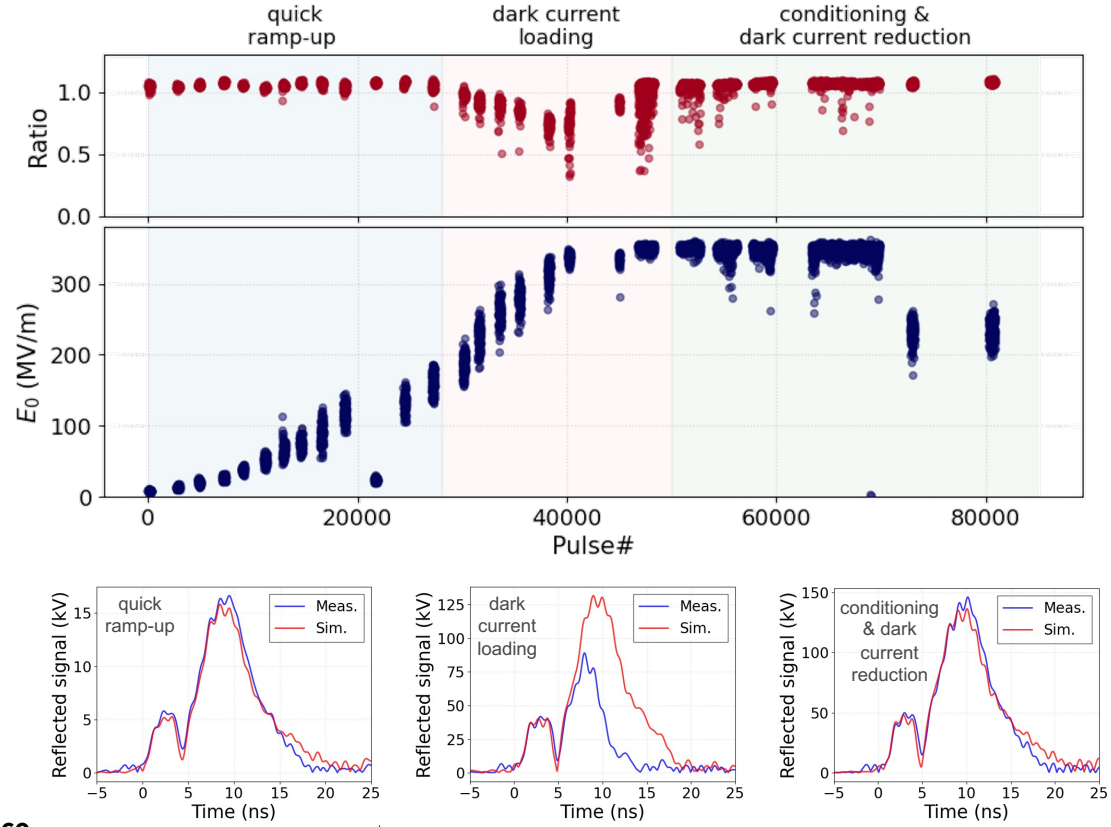




- $Ratio = \frac{V_{ref\_meas}}{V_{ref\_sim}}$

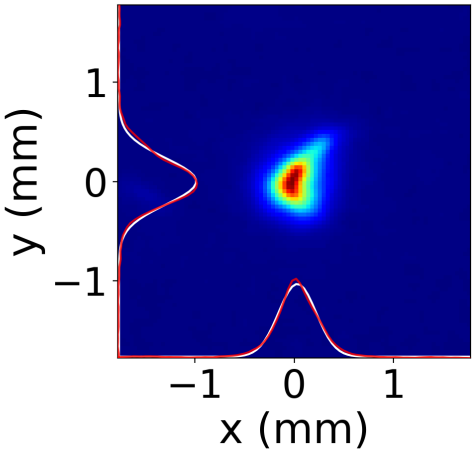
INITIAL XGUN RF CONDITIONING

Nov. 2020



- Conditioning process is fairly quick.
- Achieved 350 MV/m within 70k pulses.
- No observable dark current after fully conditioning.

LASER FOR EMITTANCE MEAS.



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