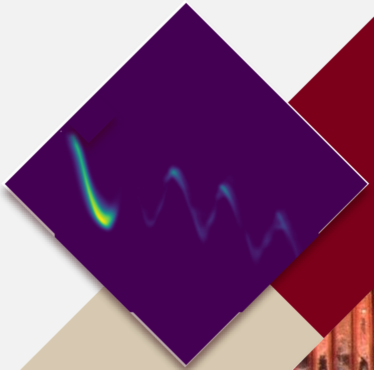
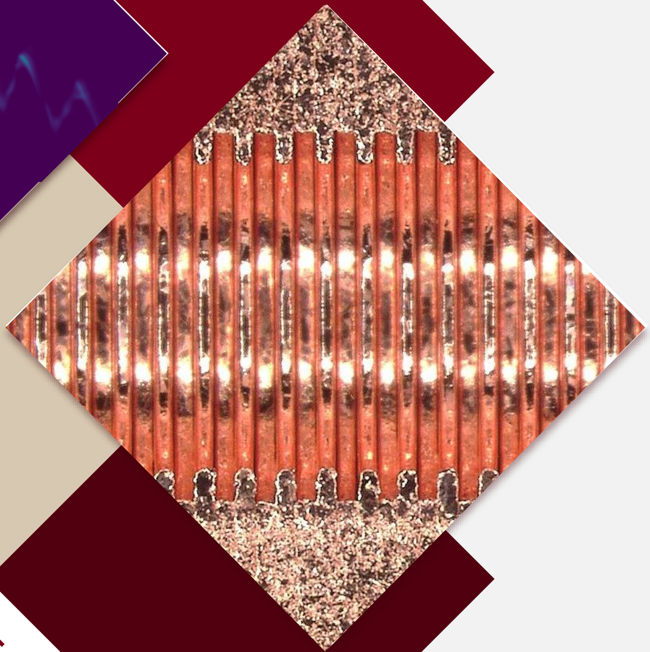
WG4 : Novel structure acceleration

Advanced Accelerator Concept Workshop 2024

July 21~26, NIU Naperville Regional Center, IL, USA

Status and plan for beam-driven THz wakefield structure





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In Collaboration with

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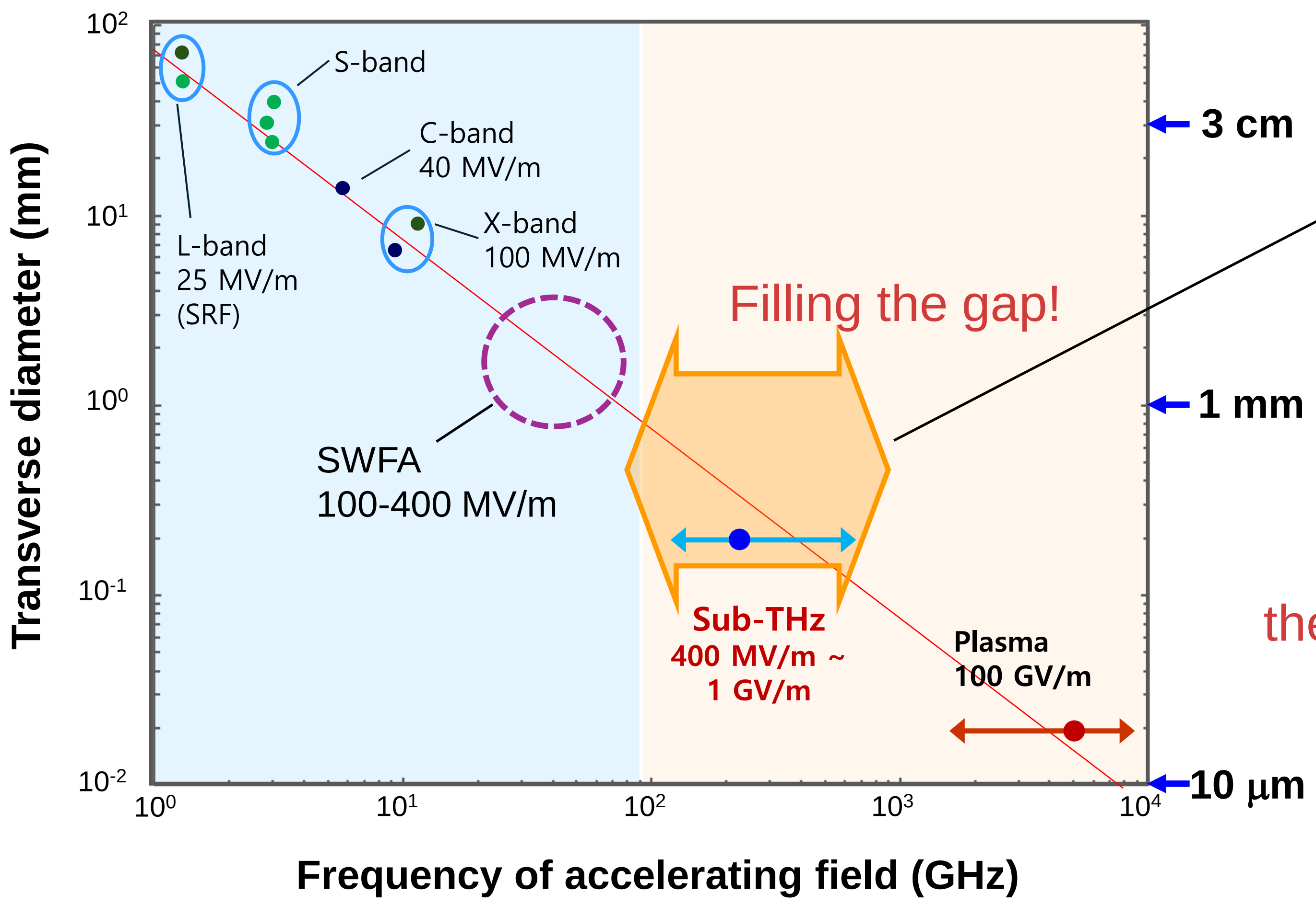
Contents

Motivation and goals

Motivation

Accelerator Size · Accelerating Gradient · RF Frequency



Could be…
- Higher gradient than GHz-SWFA
- Higher stability than plasma
- Compatible with nC charges

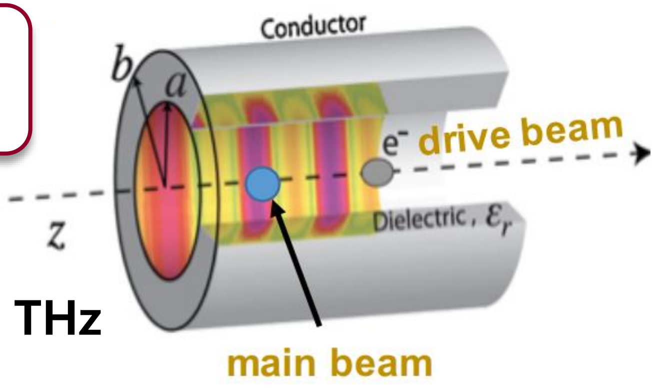
One of major challenges is the fabrication of micro-structures

Beam-driven THz acceleration

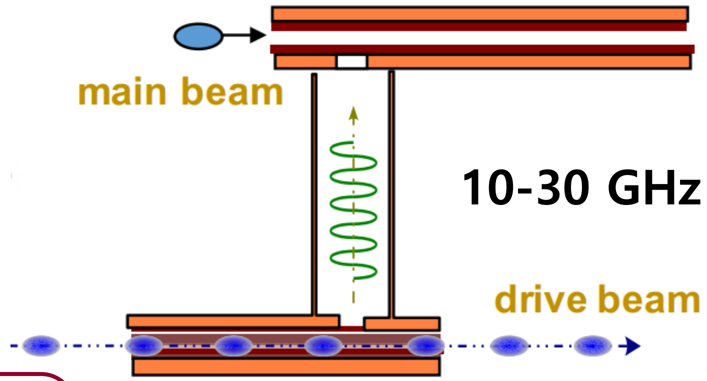
Easier to achieve
high-gradient than TBA

Difficulties from co-propagation
Drive beam manipulation needed

CWA



0.1-1 THz



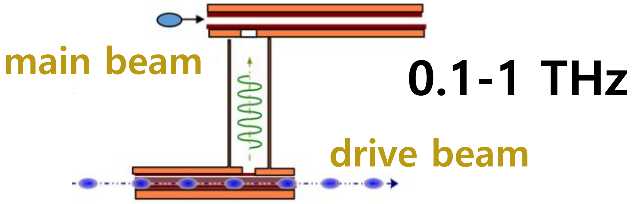
TBA

More mature than CWA

Limited gradient
Need two beamlines
Need high-charge bunch train

It could be a collection of advantages

- Higher gradient than GHz-TBA
- No co-propagation is needed
- No drive manipulation is needed
- Need to **tiny two** beamlines
- **A few to tens** of nC bunch train is needed

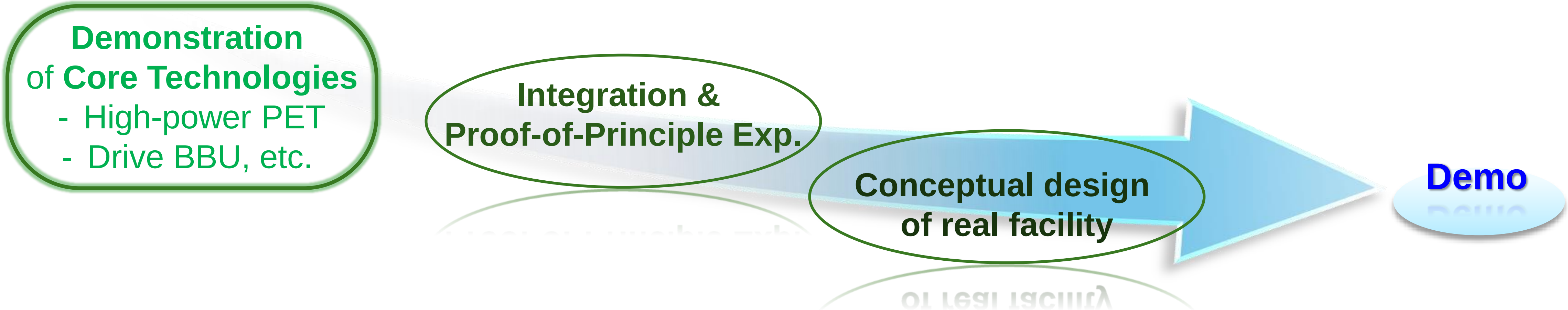


But, it still has several major concerns

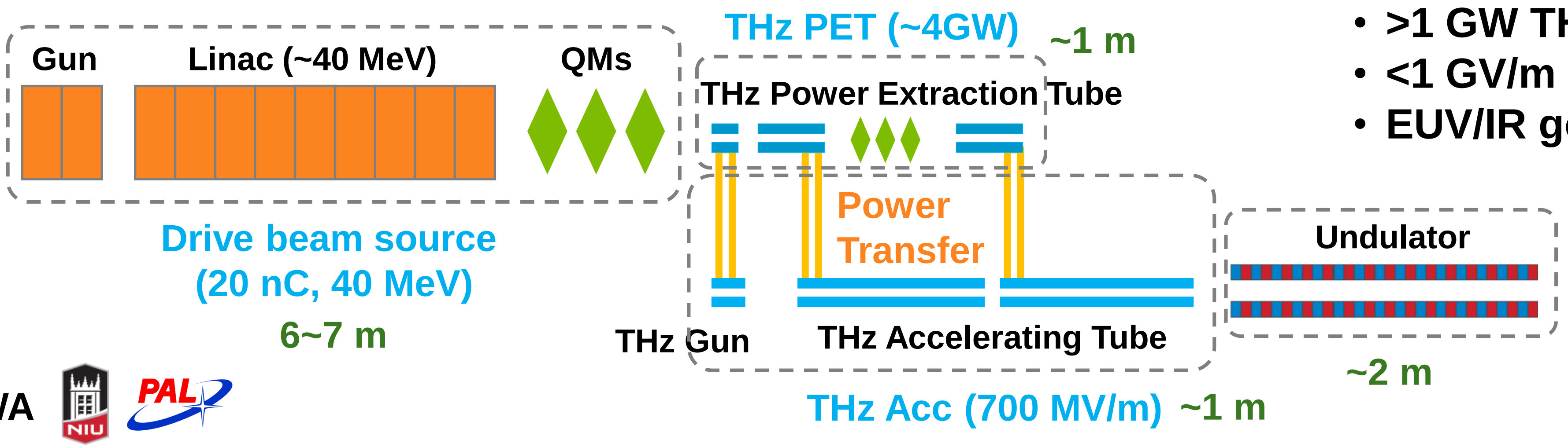
- **BBU** could be harder to handle
- Power extraction, transport, and injection could be **lossy**
- **Structure fabrication** is not straightforward

General plan and Concept of demo facility

- **The R&Ds on Core Technologies for THz-TBA :** Simulation, Design, Fabrication, Demonstration, etc.
- **Integration** of developed core technologies will be verified by **EUV generation** using THz-TBA.



Layout for Demo Facility - Total : 10 m



- **>1 GW THz power**
- **<1 GV/m gradient**
- **EUV/IR generation**

To Do List : R&Ds

Demonstration

High-power
- single PET (~4 GW)

High-gradient
- single pair (700 MV/m)

2-PET propagation
(~4 GW each)

Staged acceleration

EUV generation

Beam dynamics

Drive bunch train

PET optics
- 2-PET
- 30 PET

Short-pulse TW simulation

General lattice design

RF

Structure R&D

Fabrication R&D

PET-ACC design

Power extraction

Power injection

Power transfer

Gun R&D

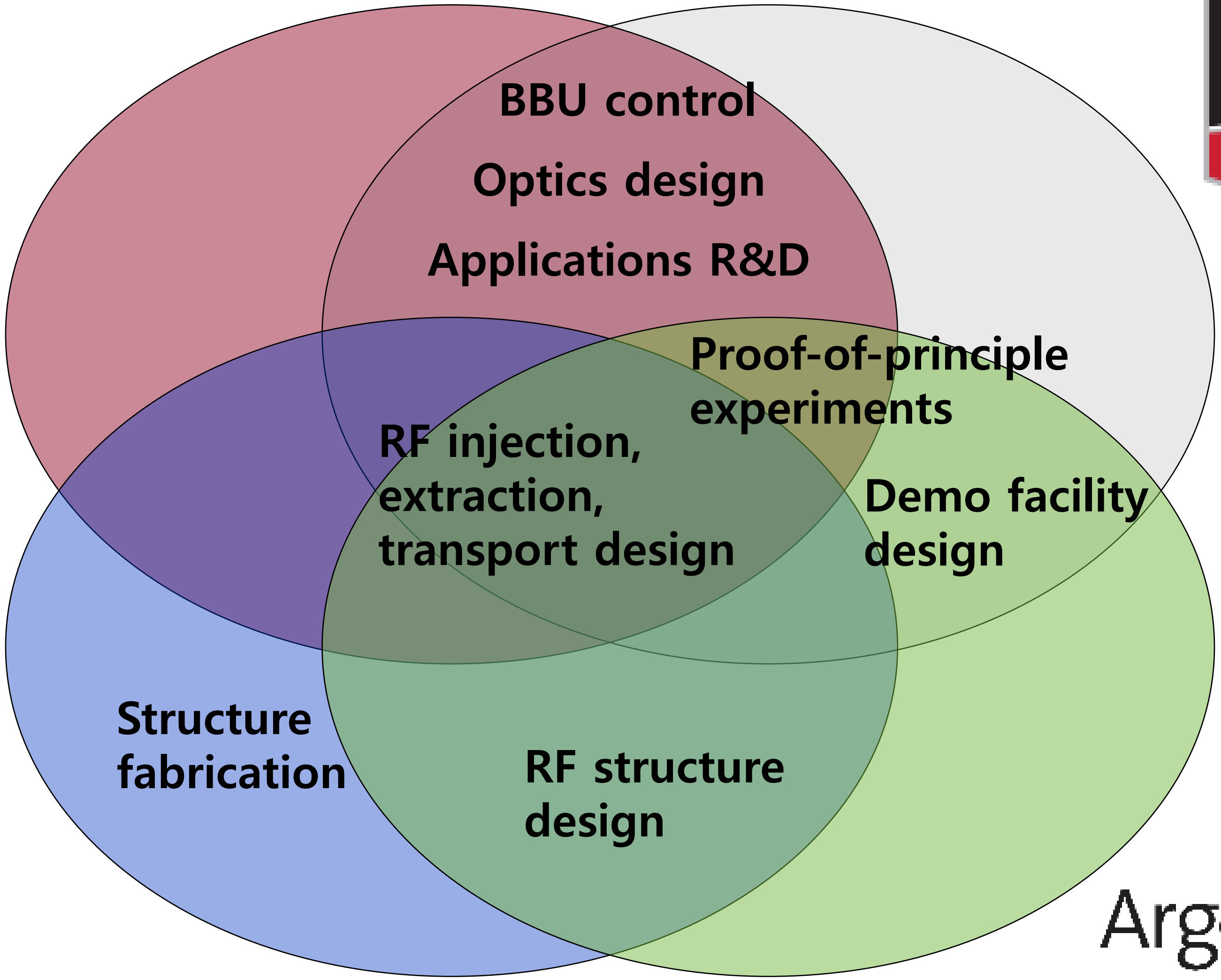
Gun type R&D

Gun design

Beam generation demo

High brightness demo

Global collaboration

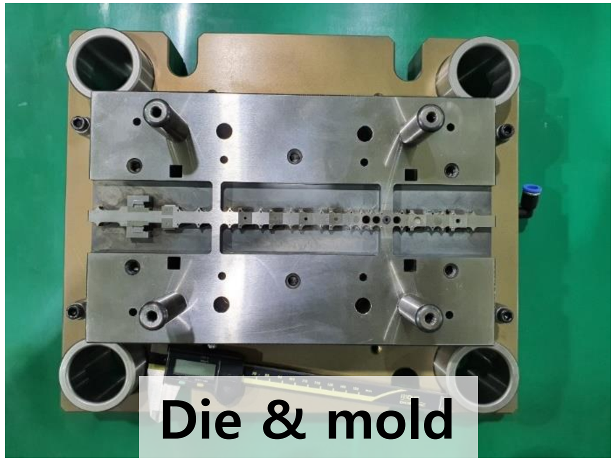


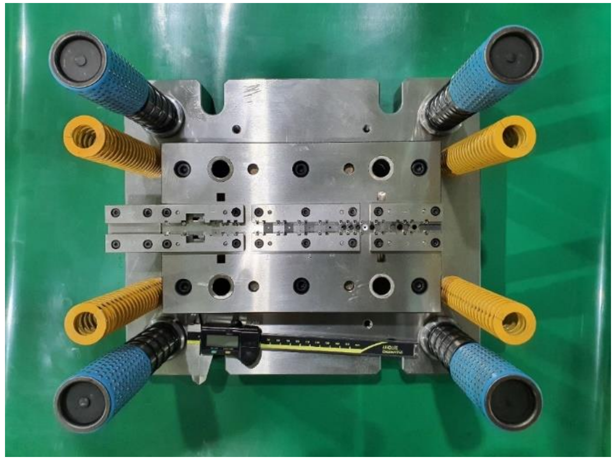
Previous experiment results

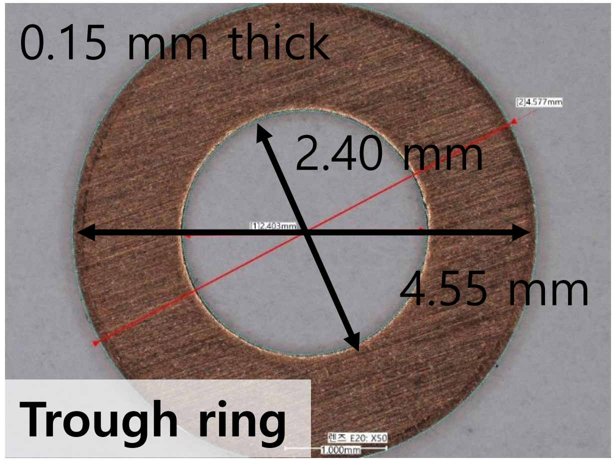
Development of the fabrication method and its experimental verification

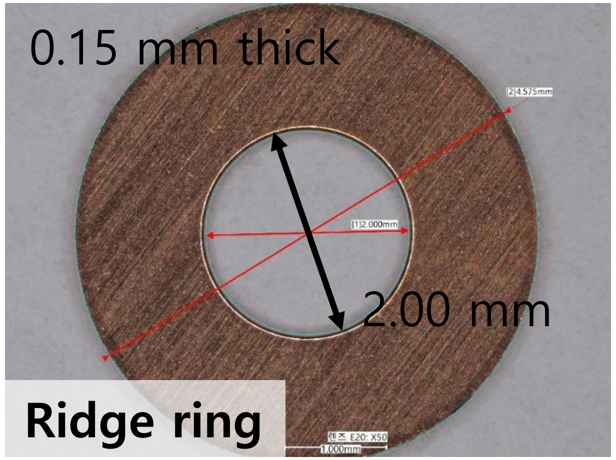
Fabrication method I : Die stamping & Disk Stacking

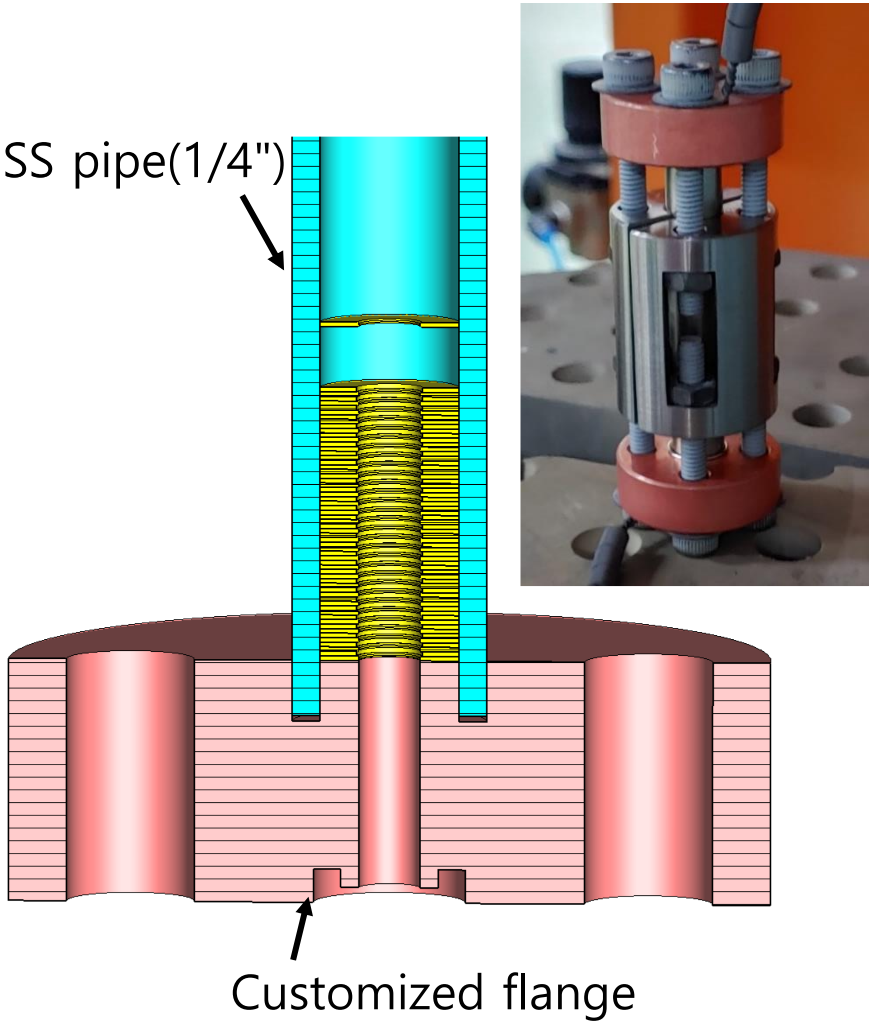
- We chose disk-stacking method to fabricate corrugated waveguide ⇒ suitable for mass-production.
- Disks are slightly curved due to the stamping ⇒ Outer structure provided appropriate pressure for contact.







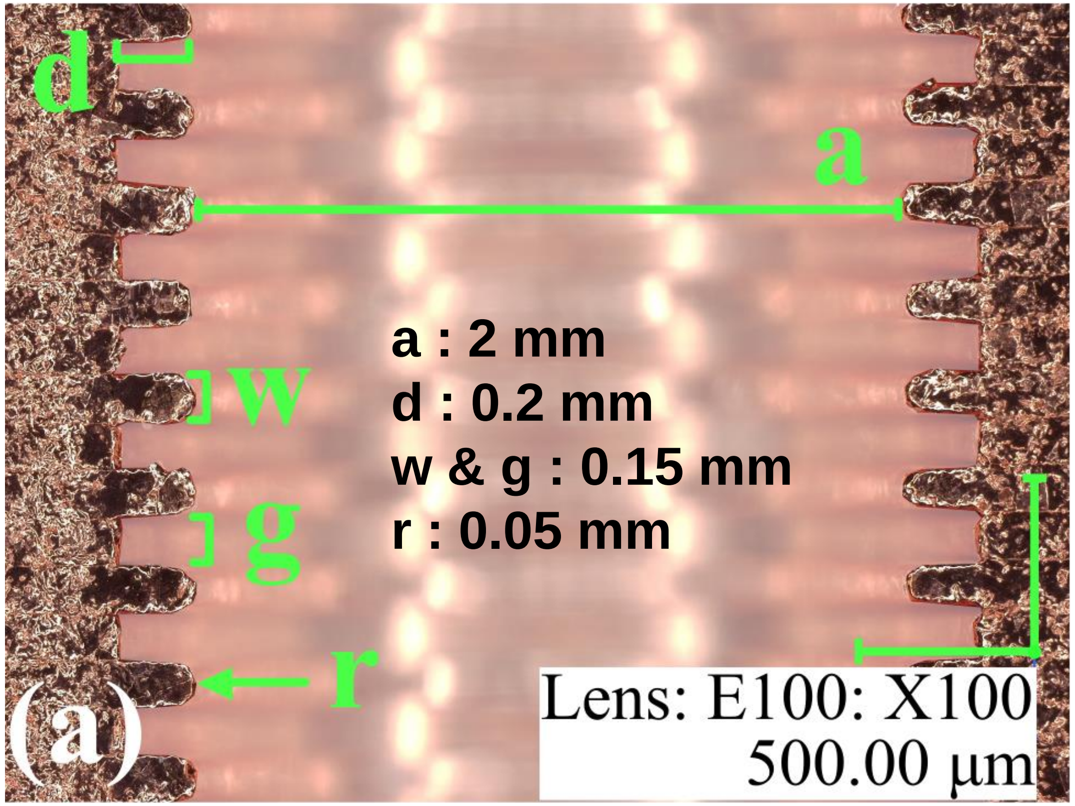




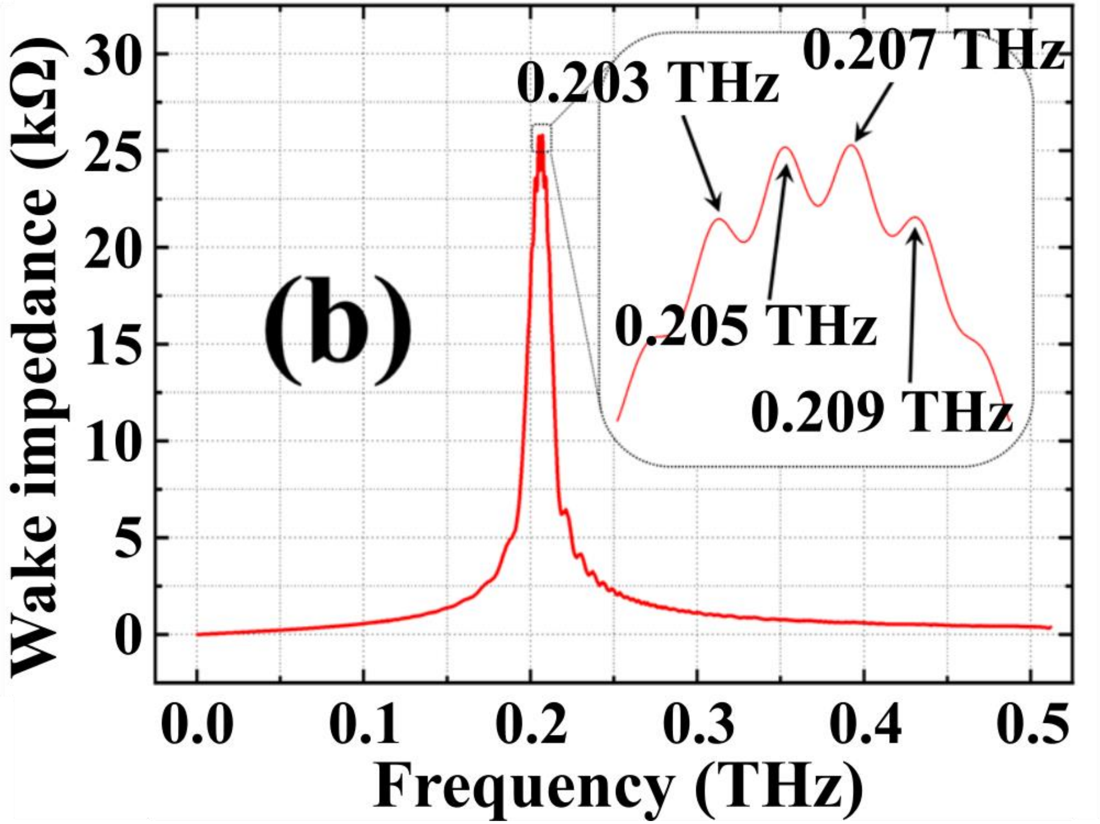
Fabricated structure and simulated spectrum

- Structure was successfully fabricated.
- Structure was designed to be compatible with ~0.2 THz.

Fabricated corrugated structure



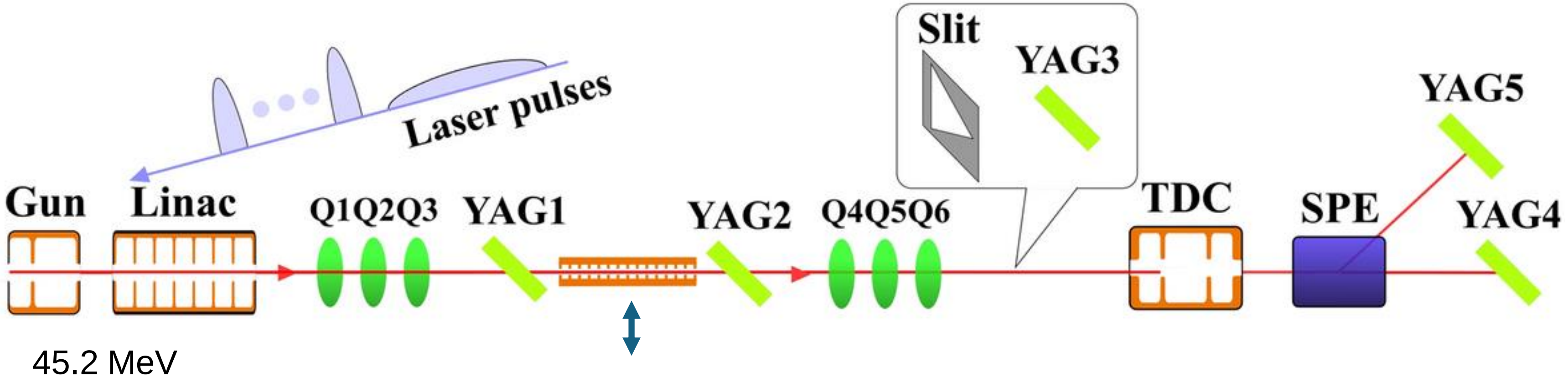
Wake Impedance (CST simulation)



(ref. H. Kong et. al., Scientific Reports 13:3207 (2023))

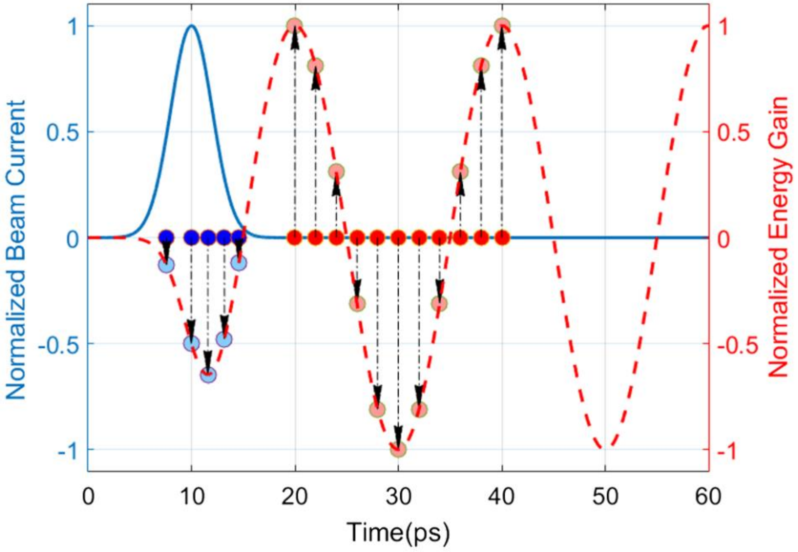
Beamline layout and wakefield diagnostics

Layout of Beamline



Diagnostics for measuring longitudinal & transverse wakefields

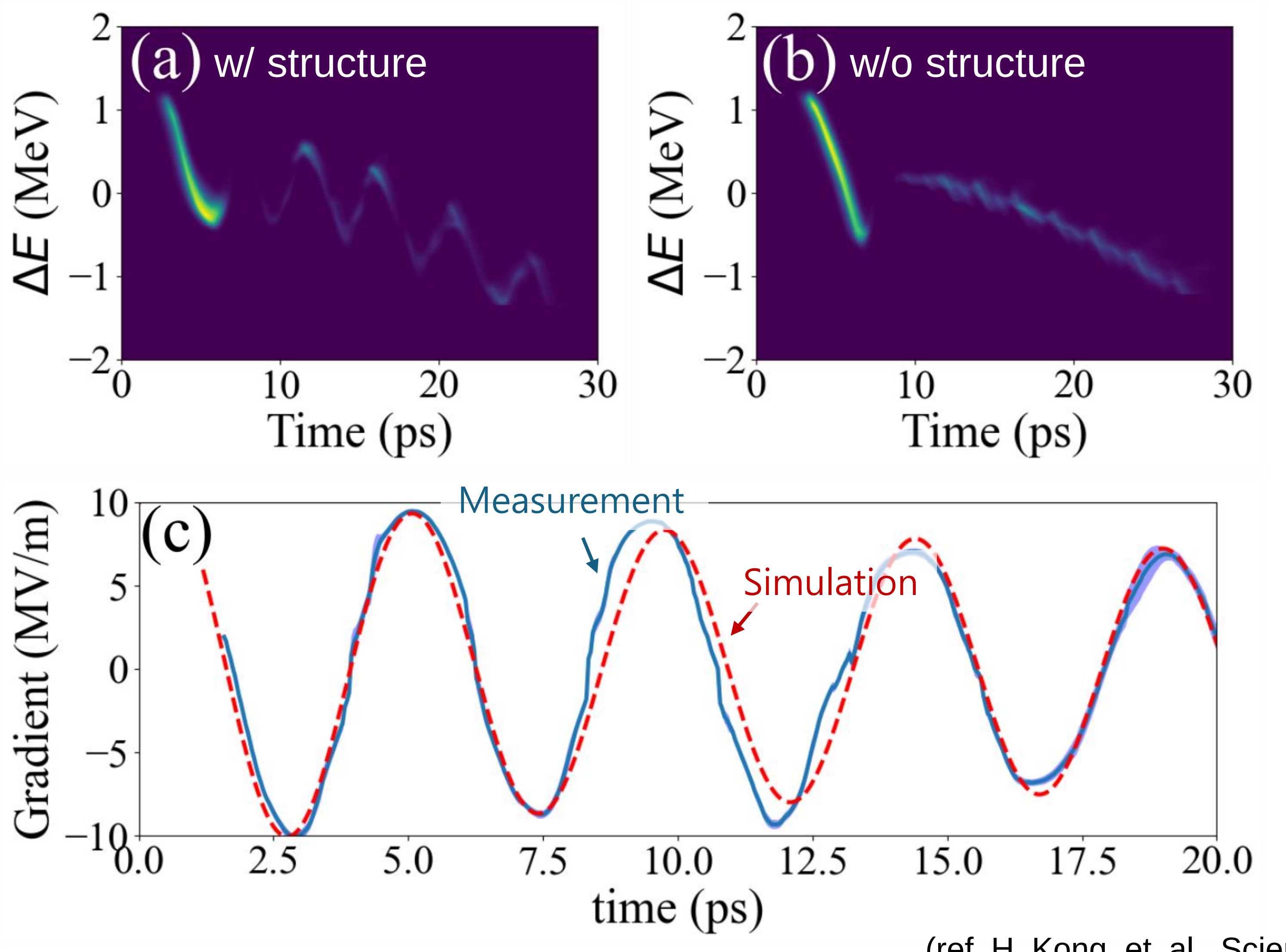
- We used a long witness beam as a probe.
- The strength of the wakefield can be evaluated from the witness beam's energy or transverse position changes.
- Comparison of the witness beam energy with and without the structure provides wakefield pattern.
- Longitudinal phase spaces with and without the structure were measured.
- t-x plane with and without the structure were measured, and horizontal centroids for each time was found.



(ref. H. Kong et. al., Scientific Reports 13:3207 (2023))

Longitudinal wakefield measurement

Longitudinal phase spaces



Accelerating Gradient of Wakefield

Drive Beam
Charge : ~ 1 nC
Bunch length: 1.1 ps rms

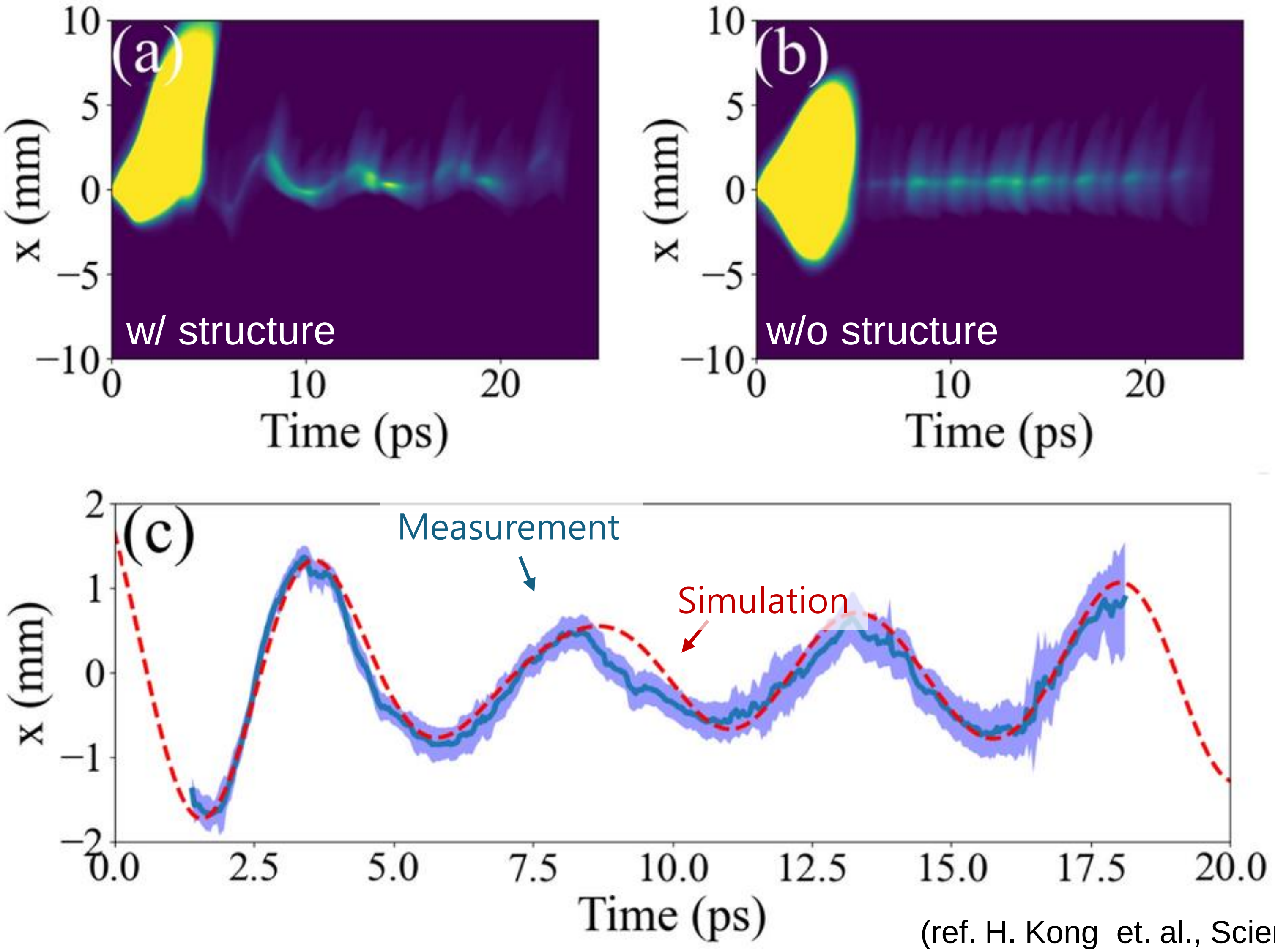
Peak Acc. Gradient
9.4 MV/m/nC with a single bunch
→ Expected >35 MV/m/nC with four bunches

(ref. H. Kong et. al., Scientific Reports 13:3207 (2023))

Transverse wakefield measurement

Transverse distribution in time

Transverse Wakefield



(ref. H. Kong et. al., Scientific Reports 13:3207 (2023))

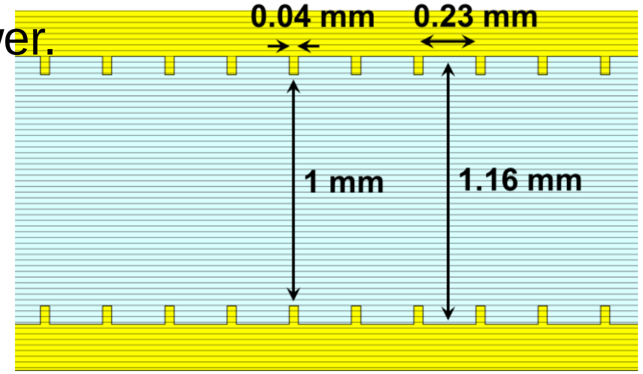
Toward GW power generation

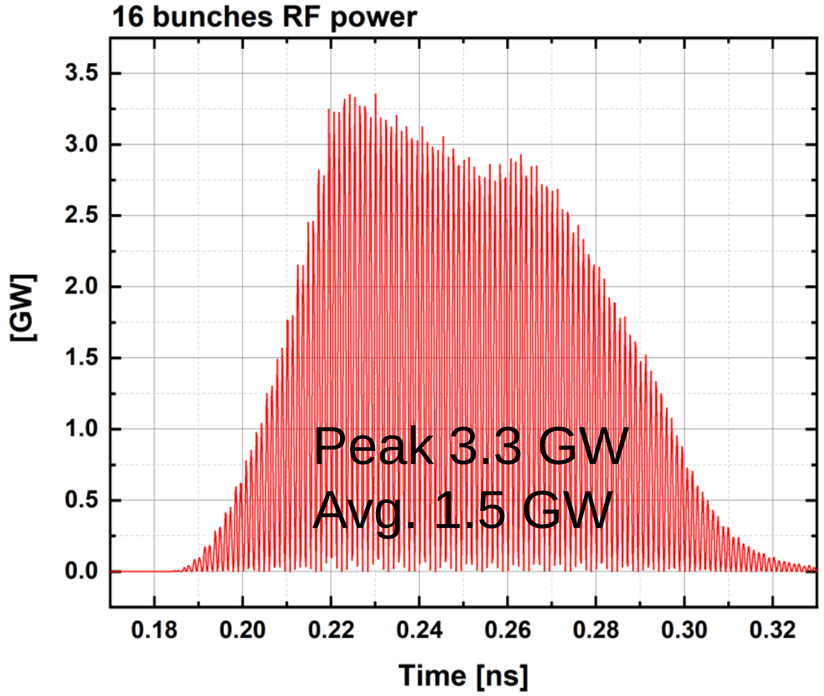
Status of experiment preparation for high-power generation

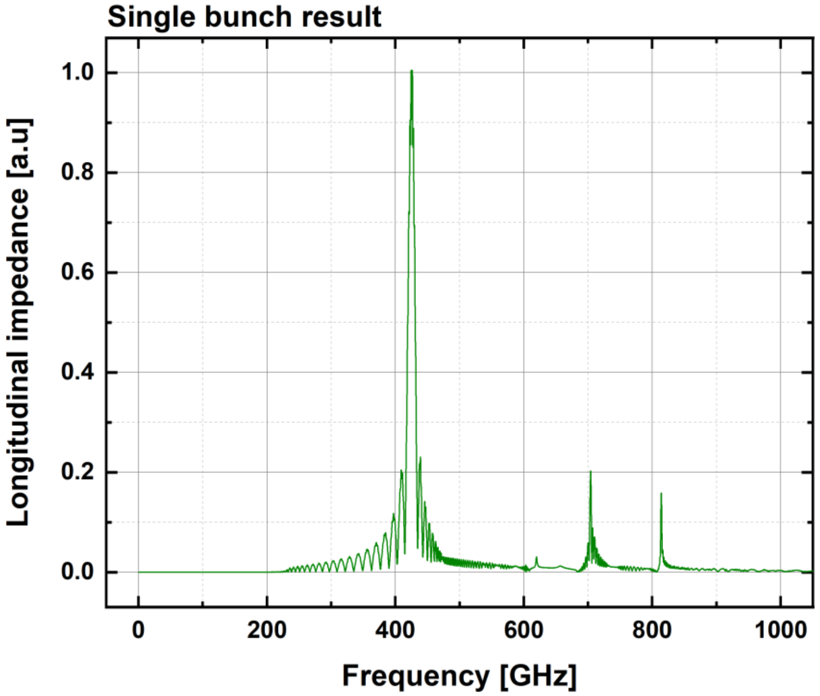
Structure design

(Courtesy of H. Kong)

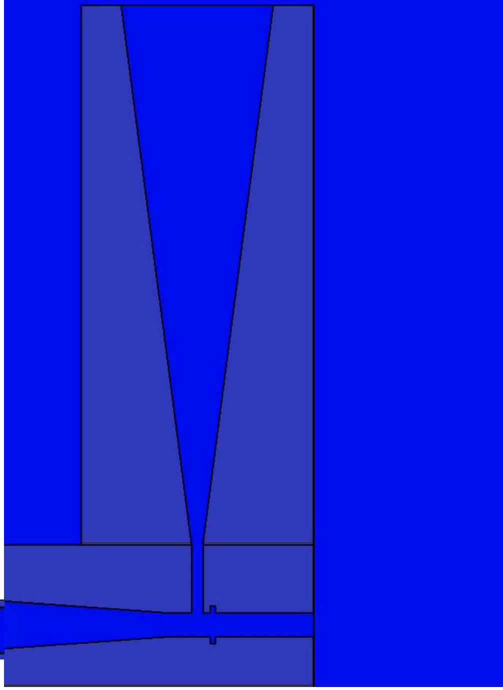
- Structure parameters were optimized to obtain GW power.
- Peak power of 3.3 GW is expected from a bunch train with 16 bunches and 1 nC/bunch.







The extraction options are under consideration

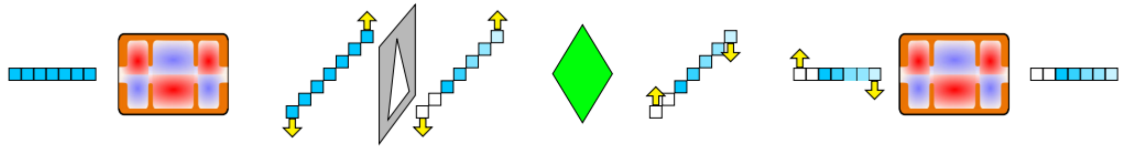


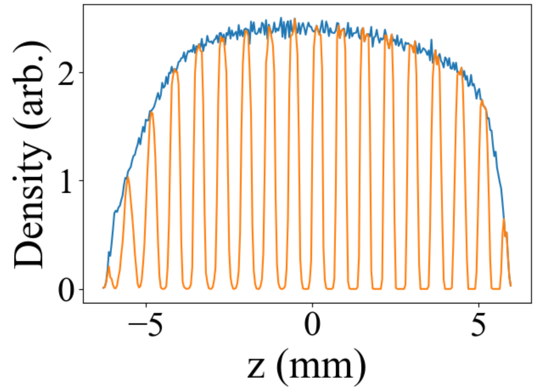
Preparation Drive beam shaping

(Courtesy of G. Ha)

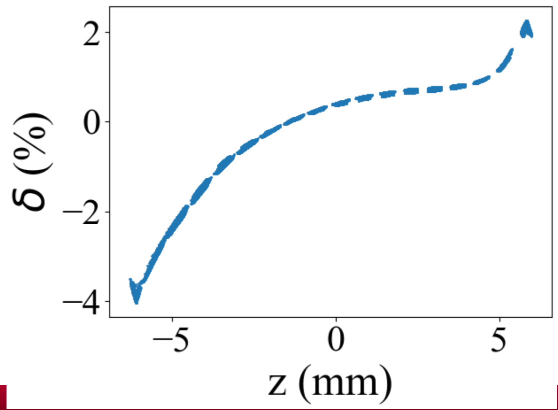
TDC-shaping

(Transverse Deflecting Cavity TDC)





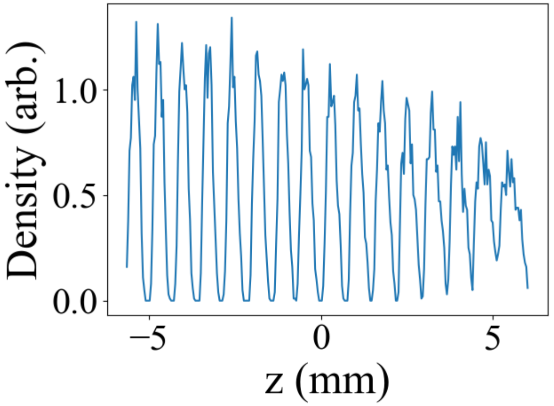
- High quality shaping
- Starting from 35 nC,
  15.4 nC remains (T: 44%)
- Low form factor
  (high form factor is available but more losses)



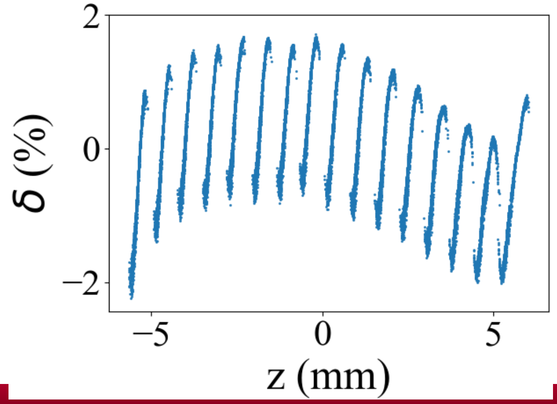
- Each micro-bunch has small energy spread
- Bunch-to-bunch has energy deviation
  (controllable up to some level)
- Needs 2-3 powerful TDCs

Laser-shaping

Laser shaping showed surprisingly good quality, so chose laser-shaping result as input



- (relatively) low quality shaping
- 19.2 nC, emittance is 2/3 of TDC-case
- Low form factor
  (high form factor is not available)



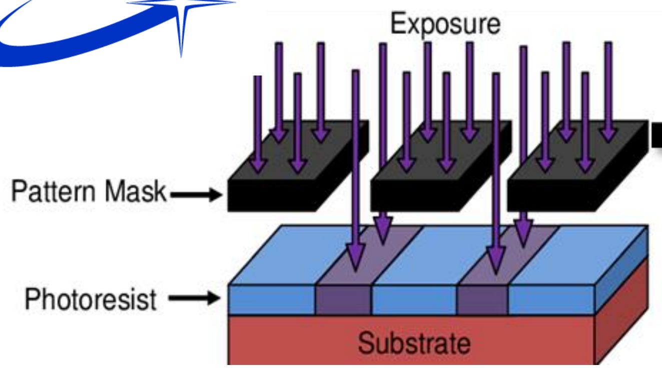
- Each micro-bunch has huge energy spread
- Bunch-to-bunch has small energy deviation
- Large laser split-delay stages

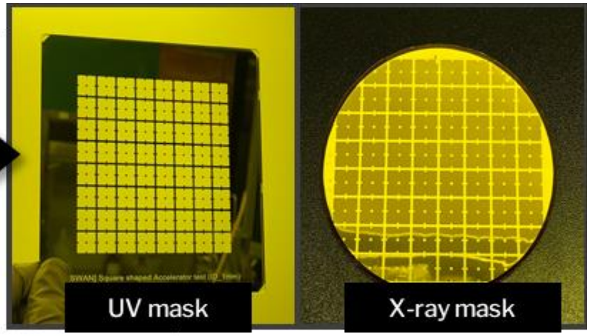
Structure fabrication

(Courtesy of J.-H. Kim)

- For the higher quality disk fabrication, we adopt LIGA.

PLS-II 9D beamline

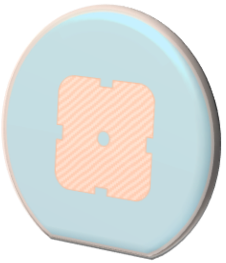




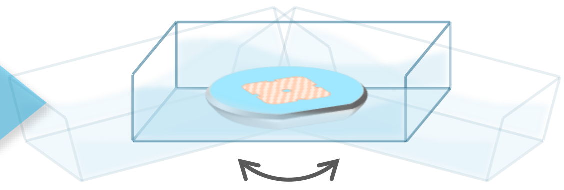
UV Lithography for 40μm thickness

X-ray Lithography for 230μm thickness

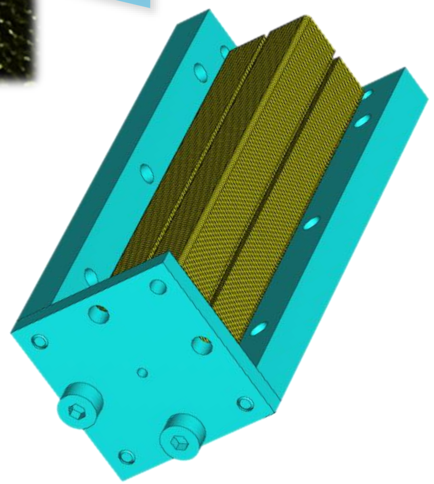
Expose to X-ray

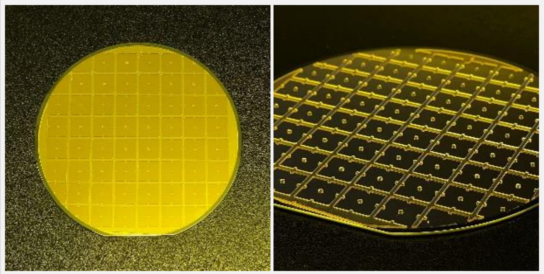


Before development

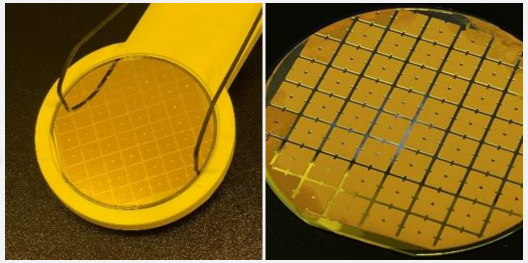


Development

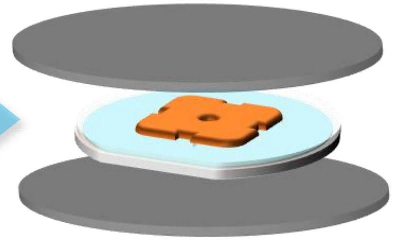




Patterned substrate



Electro-forming



Double side polishing

Summary

- THz-TBA could be an interesting new way to take advantage of THz-CWA and GHz-TBA.
- KU-PAL-NIU-ANL collaborate to develop core methods and technologies to realize THz-TBA and their integration.

- 0.2 THz structure was successfully fabricated via die stamping and disk stacking method.
- Wakefields from 0.2 THz structure the fabricated structure was experimentally characterized.

- Fabrication of 0.4 THz structure is ongoing using LIGA method for a higher quality.
- Bunch train with 16 bunches having 1 nC each will be generated using laser pulse train.
- The peak power of 3.3 GW is expected from upcoming experiment.