Presentation at EAAC'15, Elba, Italy
September 13-19, 2015

Advanced Acceleration and THz Generation by Dielectric Based Structures: ANL/BNL/Euclid Collaboration.

A.Kanareykin for

Euclid TechLabs LLC, Gaithersburg MD USA

in collaboration with

Argonne National Laboratory/AWA and APS, Chicago IL USA

Brookhaven National Laboratory/ATF, Brookhaven NY USA

Collaboration

Euclid Techlabs LLC: S.Antipov, C.Jing, S,Baryshev, J. Qiu, P. Schoessow, S.Baturin, R.Conecny;

Argonne National Lab/
- **AWA**: W.Gai, M. Conde, J.G.Power,
- **APS**: A.Zholents, N.Strelnikov

Brookhaven National Lab/ATF: K. Kusche, M. Fedurin.

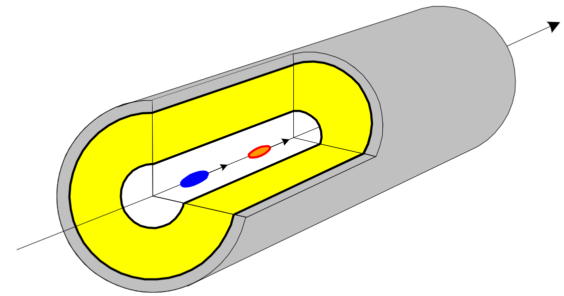
Outline

- AWA Facility
- Collinear wakefield acceleration for FEL
- A linear collider: short pulse, staging
- THz generation with the dielectric based structures
- Energy chirp compensation
- UNCD FE Cathode
- Summary

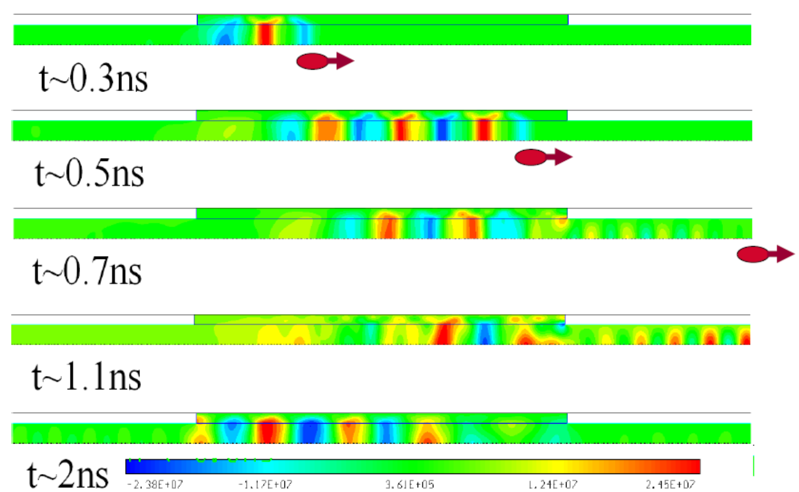
Why Dielectric Based Accelerator ?

Dielectric based accelerator advantages:

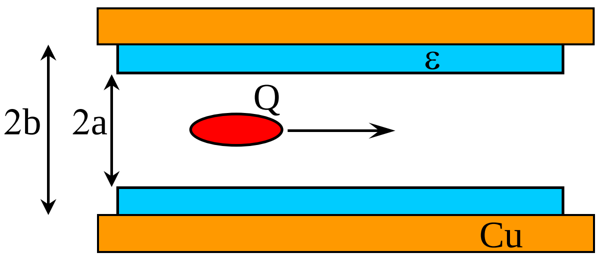
- ❑ design simplicity: no tight tolerances – 2D structure
- ❑ E_z field magnitude is flat along the cross-section;
- ❑ GHz,THz structures at ~ 0.5-1.0 GV/m gradient
- ❑ enables tuning;
- ❑ reduced BBU instability;
- ❑ diamond thermal conductivity
- ❑ …..



Wakefield (beam→structure)



Cherenkov Wakefields & Dielectric Structures



$$W_Z(z) \approx \frac{Q}{a^2} \exp\left[-2\left(\frac{\pi\,\sigma_z}{\lambda_n}\right)^2\right]\cos(kz)$$

$$\sigma_r = \left(\frac{\varepsilon_N}{\gamma}\beta\right)^{1/2}$$

Direct Wakefield Acceleration:

- **AWA with Advanced Accelerator P5 Report**
- **BNL/ATF**
  SLAC/FACET Presented
- **LBNL/BELLA**

A Strategic Plan for Accelerator R&D in the U.S. Accelerating Discovery

http://science.energy.gov/~/media/hep/hepap/pdf/Reports/Accelerator_RD_Subpanel_Report.pdf

9.1.1: Facilities at National Laboratories

FACET is a proposal-driven user facility at SLAC for developing advanced acceleration concepts. First among these is electron beam-driven PWFA with the beam having the …

BELLA is an LWFA experiment at LBNL utilizing a large 40-J, 1-Hz laser. It also employs a 10-Hz terawatt-level laser, TREX, in its research program. Significant progress has been made in accelerating electron beams up to > 4 GeV with …

The **Argonne Wakefield Accelerator (AWA)** facility at ANL has been built to demonstrate the two-beam concept and key technologies of wakefield generation by high-charge beams in dielectric cylinders (DWFA). Research is concentrated on operation at 200 MV/m to 400 MV/m gradients in the frequency range of 20 GHz to 60 GHz. The recently commissioned AWA upgrade can deliver a 75-MeV beam with up to 10 pulses of 100-nC charge with a few picosecond pulse length and a beam power within the macro pulse of 10 GW at a repetition rate of 60 Hz.

BNL's **Accelerator Test Facility (ATF)** is a highly productive user facility funded via DOE's Accelerator Stewardship program. Experiments at the ATF are proposal-driven and some are funded by GARD. It provides synchronized high-brightness electron-beams and high-power laser-beams to …

P5 Report

Particle Physics Project Prioritization Panel

"The **Argonne Wakefield Accelerator (AWA)** facility at ANL has been built to demonstrate **the two-beam concept and key technologies of wakefield generation by high charge beams in dielectric** cylinders (DWFA). Research is concentrated on operation **at 200 – 400 MV/m gradients in the frequency range of 20 – 60 GHz.** The recently commissioned AWA upgrade can deliver a **75 MeV drive beam with up to 10 pulses of 100 nC charge with a few picosecond pulse length** and a beam power within the macro pulse of 10 GW at a repetition rate of 60 Hz".

euclid TECHLABS

A Strategic Plan for Accelerator R&D in the U.S. Accelerating Discovery

9.1.4: Dielectric Wakefield Acceleration

DWFA has been pursued for a few decades by the Argonne Wakefield Accelerator (AWA) group in the cm-wavelength and 100-MV/m regime and by dedicated experiments at FACET and the ATF which explore the mm-wave-to-THz spectral region and GV/m fields. The AWA concept is to

9.2: Opportunities and Challenges

9.2.2: Dielectric Wakefield Acceleration

Dielectric wakefield accelerators may offer a possible approach to deliver ~1 GV/m gradients. With the expected closure of the CLIC Test Facility 3 at CERN, the AWA would be the only facility designed to conduct two-beam accelerator tests at cm wavelengths. To reach mm wavelengths at

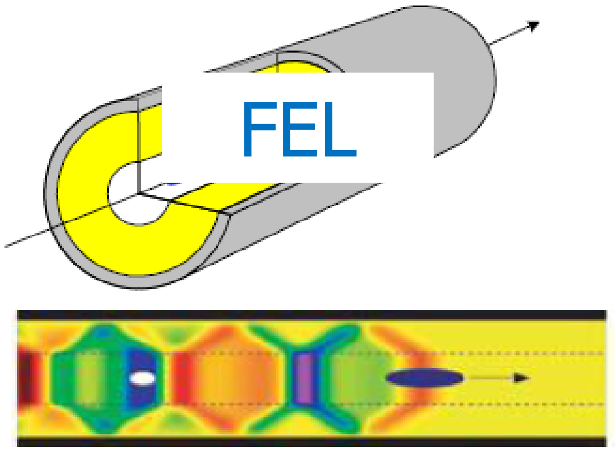
"…Dielectric Wakefield Accelerator DWFA **has been pursued for a few decades by the Argonne Wakefield Accelerator (AWA) group in the cm-wavelength and 100 MV/m regime** and by dedicated experiments at FACET and the ATF which explore the mm-wave-to-THz spectral region and GV/m fields…".

"…With the expected closure of the CLIC Test Facility 3 at CERN, **the AWA would be the only facility designed to conduct two-beam accelerator tests at cm wavelengths…".**

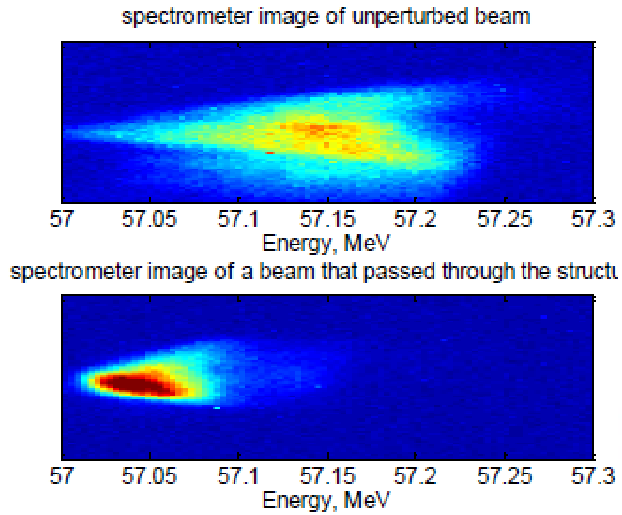
euclid TECHLABS

Example of Applications of Wakefields

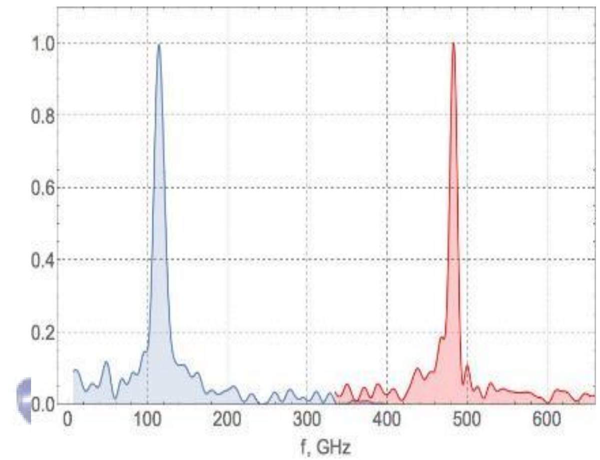
Collinear wakefield acceleration



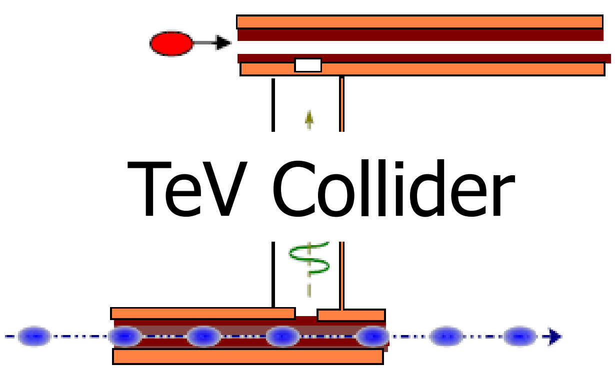
Energy chirp correction



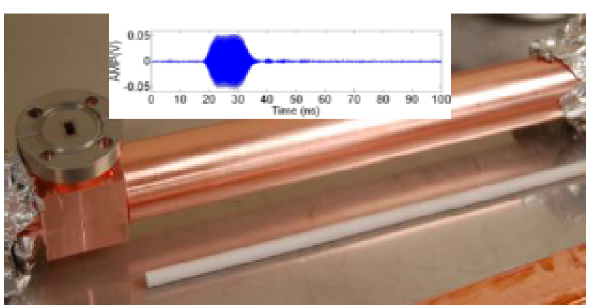
THz Radiation



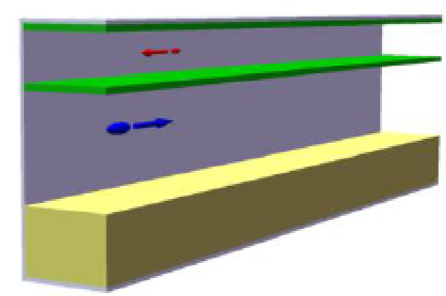
Two Beam Acceleration



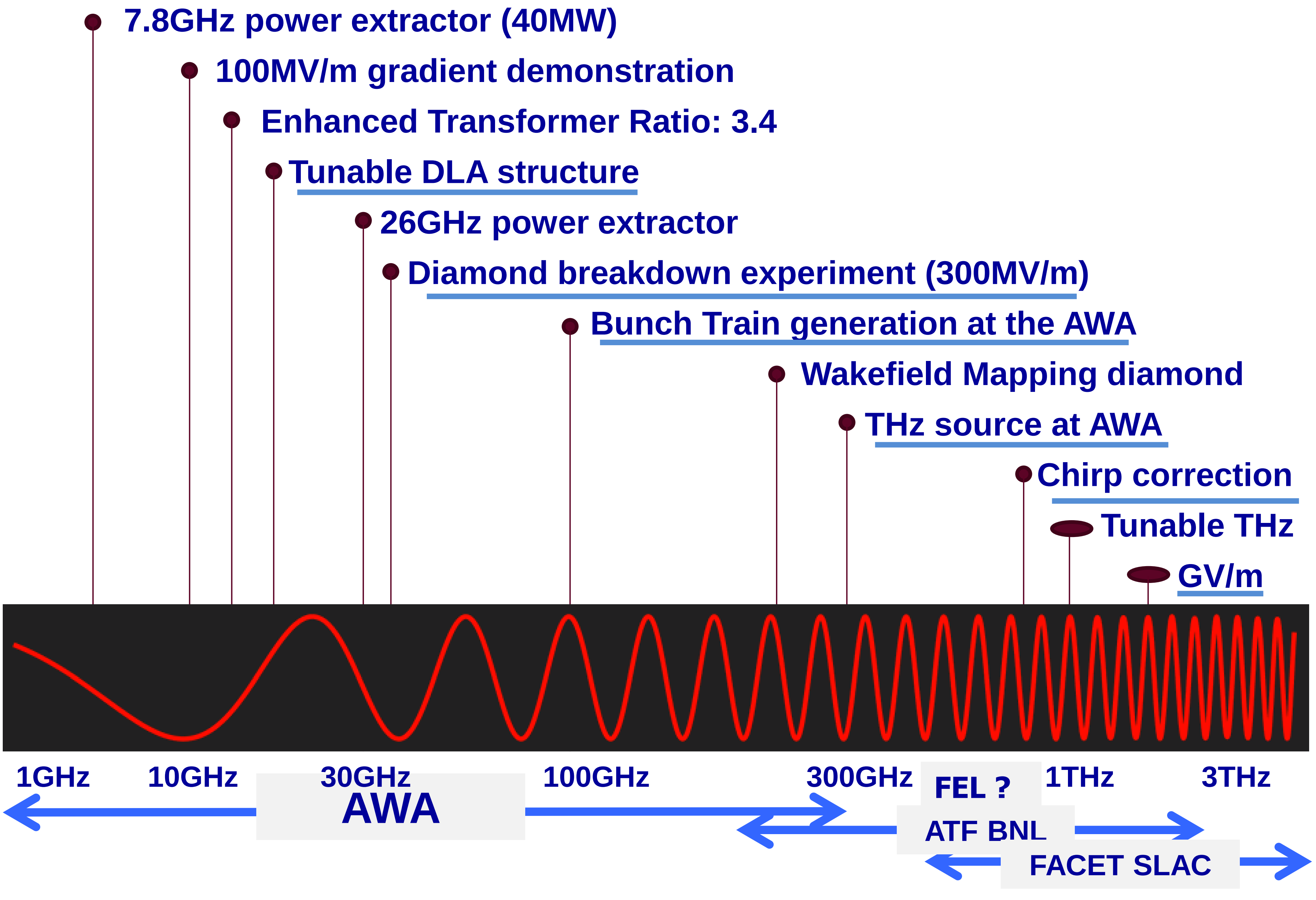
High power RF source



Wakefield undulator



Our work across the spectrum and applications

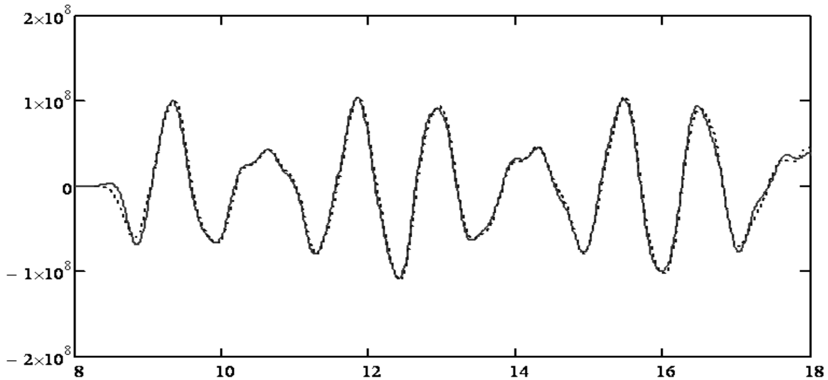


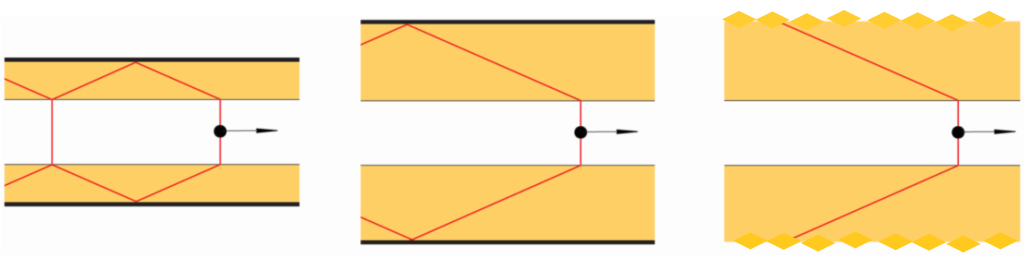
Cherenkov Radiation from Short Relativistic Bunches: General Approach

S. S. Baturin[1,*] and A. D. Kanareykin[1,2]
[1]St. Petersburg Electrotechnical University LETI, St. Petersburg, Russia 197376
[2]Euclid Techlabs, LLC, Solon, Ohio 44139, USA
(Received 22 September 2013; published 17 November 2014)

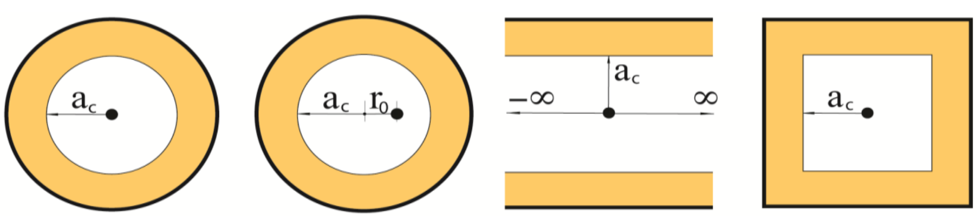
In recent years new interest in Cherenkov radiation has arisen based on progress in its new applications like biomedical imaging, photonic structures, metamaterials, and beam physics. These new applications require Cherenkov radiation theory of short bunches to be extended to rather more complicated media and structures than considered originally. We present a new general approach to the analysis of Cherenkov

Cherenk aveguide
is analyzed path. We



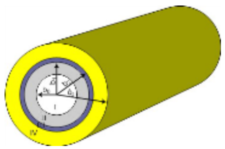


(a) (b) (c)

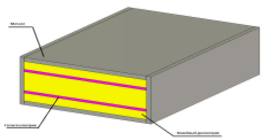


(a) (b) (c) (d)

Waveguide

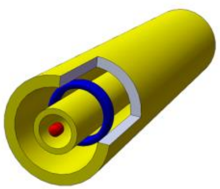


Rectangular

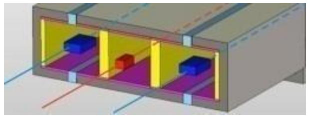


Multibunch

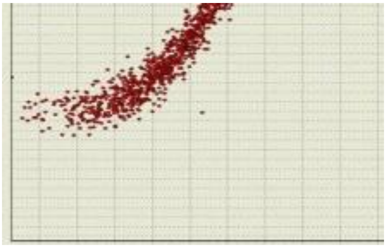
Annular



Multizone.

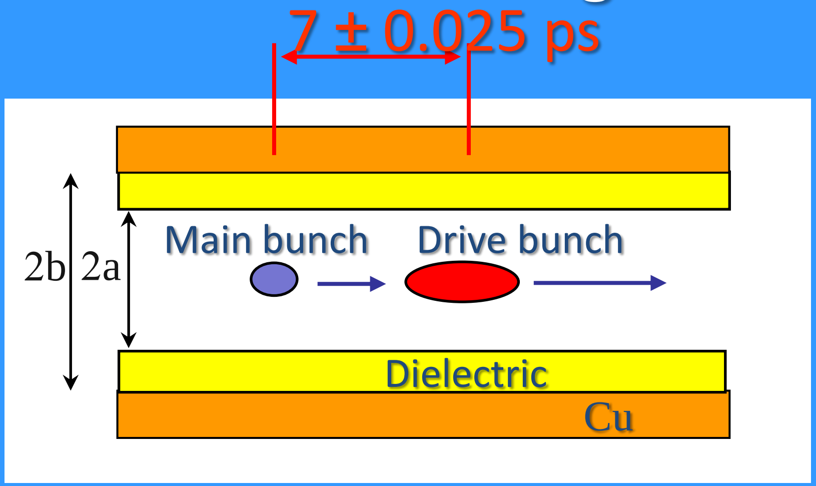


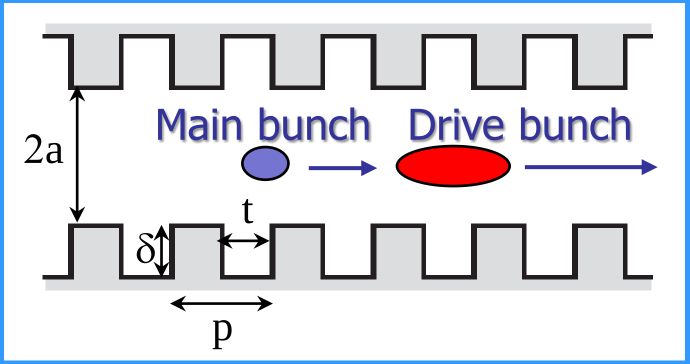
Beam Breakup (BBU)



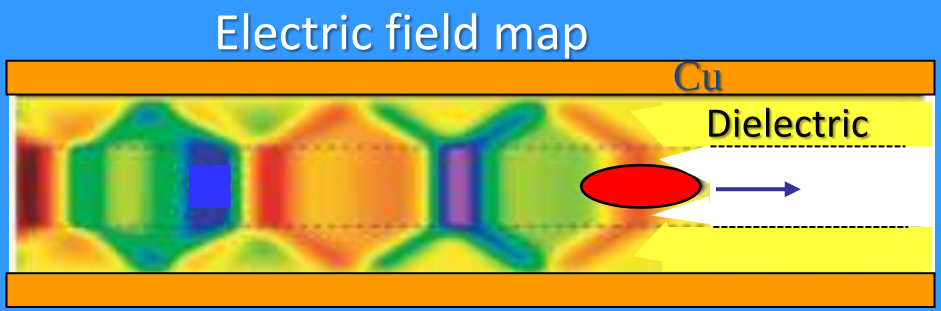
Collinear acceleration in a hollow dielectric channel or corrugated wall waveguide*

Talk by A.Zholents





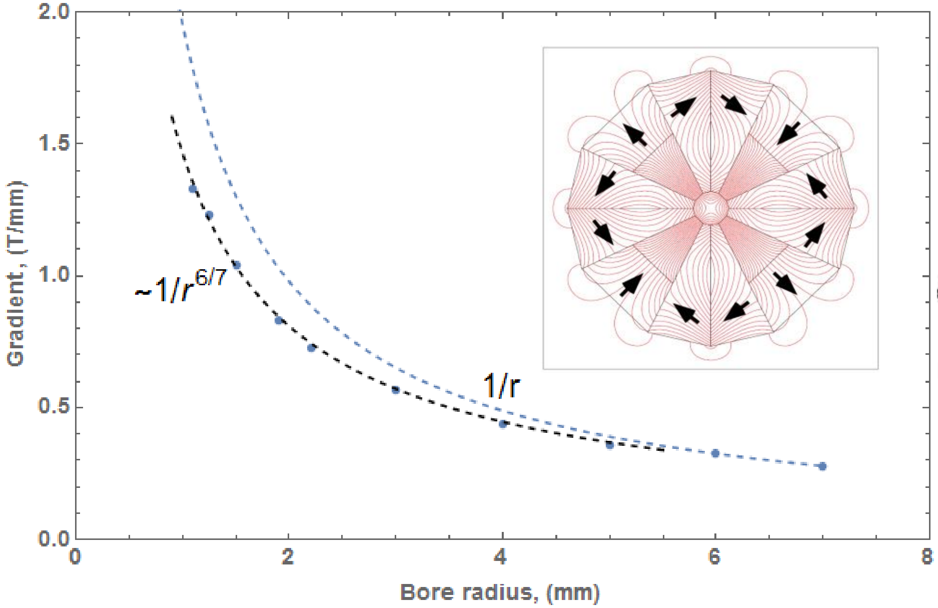
Drive and Main from the same source bunch→ minimal timing jitter

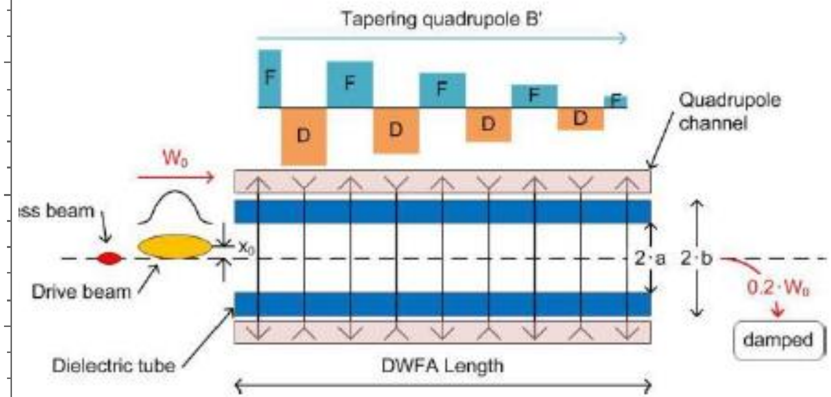


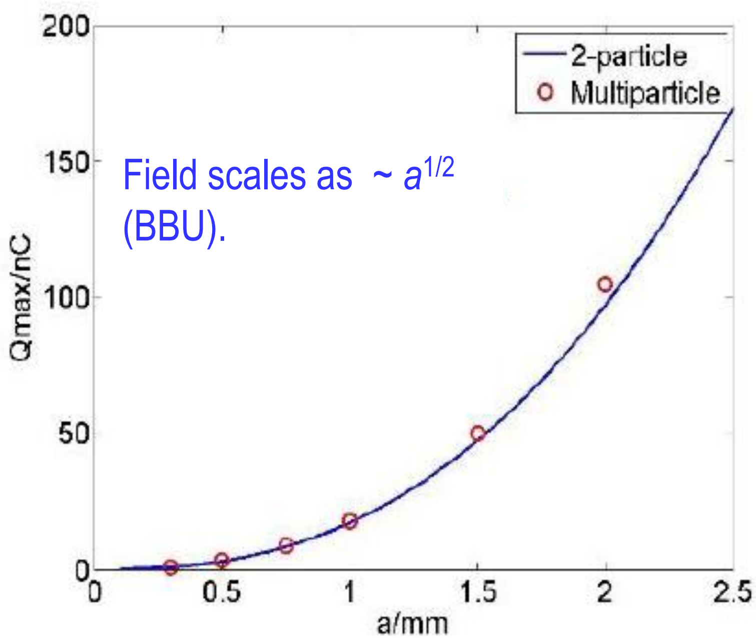
group velocity = (0.7-0.9)c

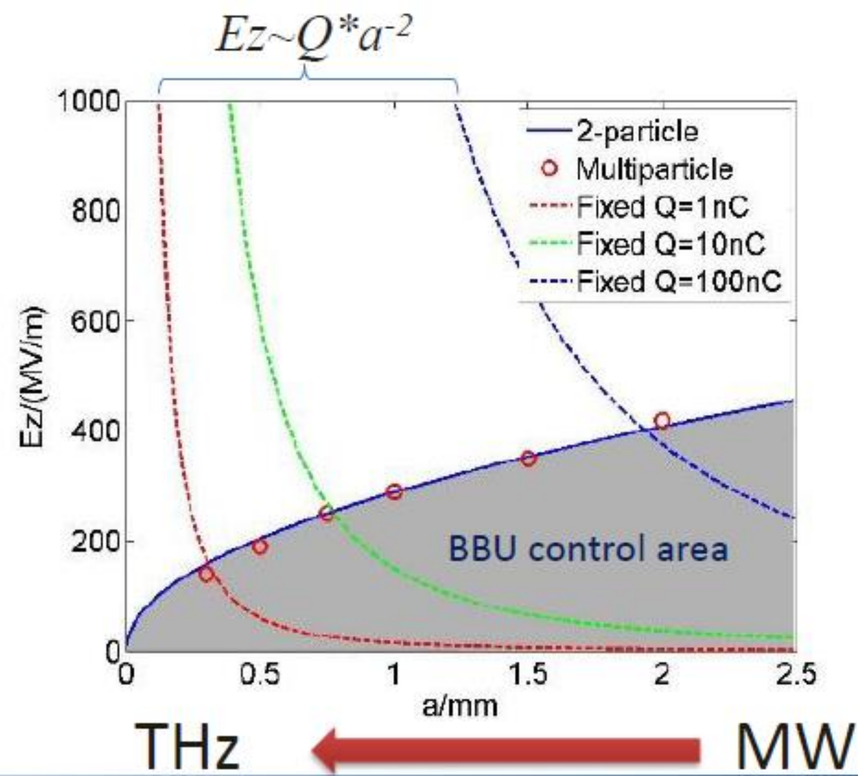
- **Low cost device (likely)**
- **Potential for:**
  - **high field gradients**
  - **high wall plug power efficiency**
  - **high bunch repetition rate**

*) G. A. Voss and T. Weiland, DESY M-82-10, 1982; K. L. F. Bane, P. Chen, P. B. Wilson, SLAC-PUB-3662,1985; W. Gai et al. Phys. Rev. Lett. 61, 2756,1988.





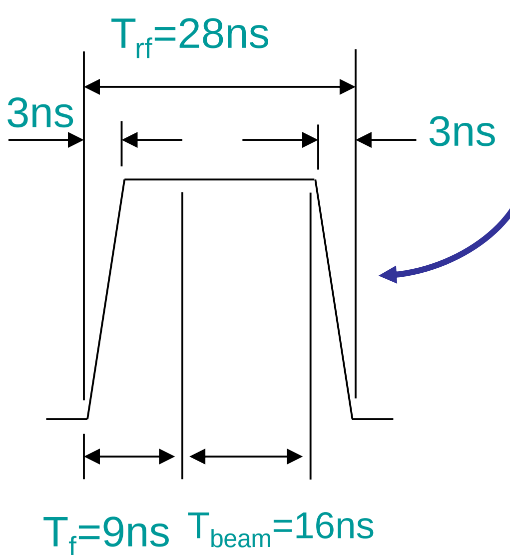




Chen Li, et al, submitted to PRSTAB (2014)

DWA Based Collider Concept

1) using a two beam acceleration scheme in the main linacs to avoid the slow rise time of klystrons;
2) using broadband accelerating structures;
3) main linac design with a relatively large group velocity and relatively short length to reduce the filling time;
4) main linac design with a relatively high frequency and optimal beam loading to improve rf-to-beam efficiency.



RF pulse structure

- fast rf rise time (<3ns) → Broadband (>150MHz)
- less filling time → Large (~10%c) Vg.

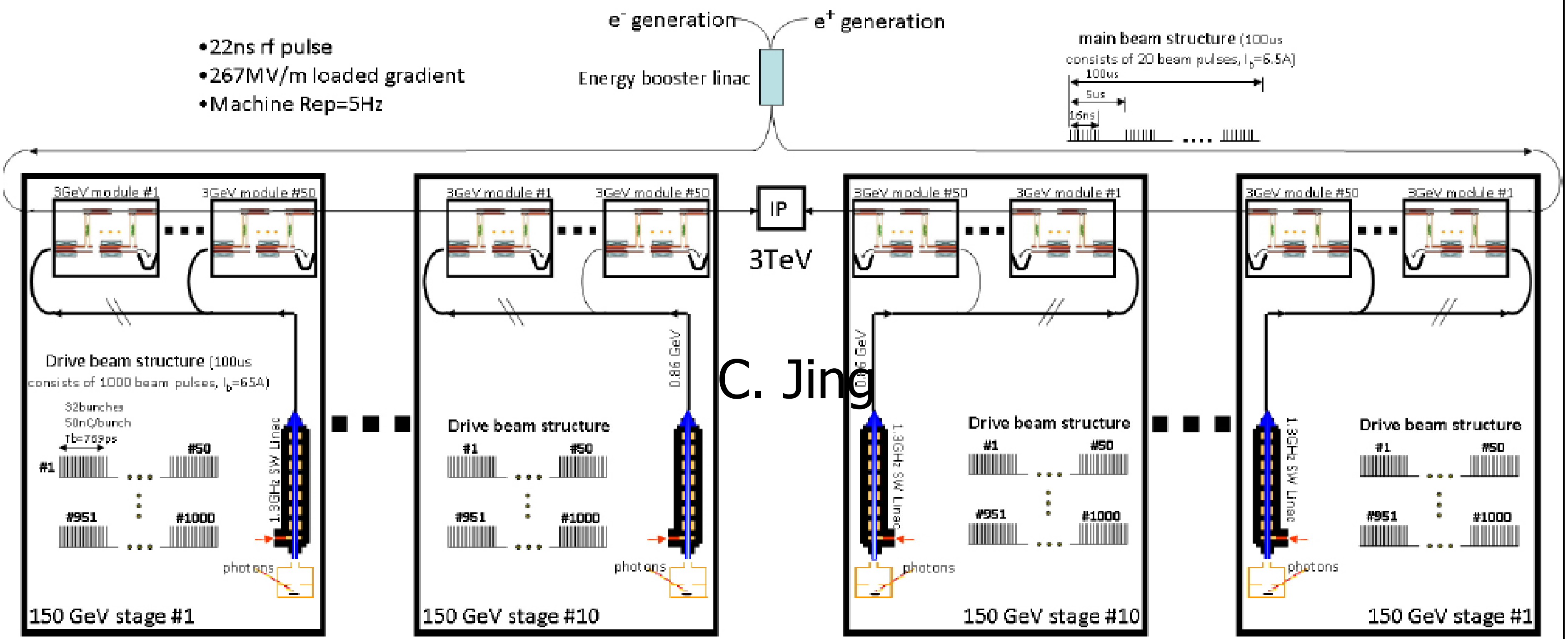
$$\eta_{bRF} = \frac{I_{beam} E_{load} L_s}{P_{rf}} \times \frac{T_{beam}}{T_{rf}} = 26\%$$

(I_{beam} = 6.5A, E_{load} = 267MV/m, L_s = 0.3m, T_{beam} = 16ns, P_{rf} = 1.264GW, T_{rf} = 25ns)

*W. Gai, M. Conde, J.G.Power and C.Jing. 2010, Proc.Int.Part. Accel.Conf. IPAC'10, Kyoto, p.3428.

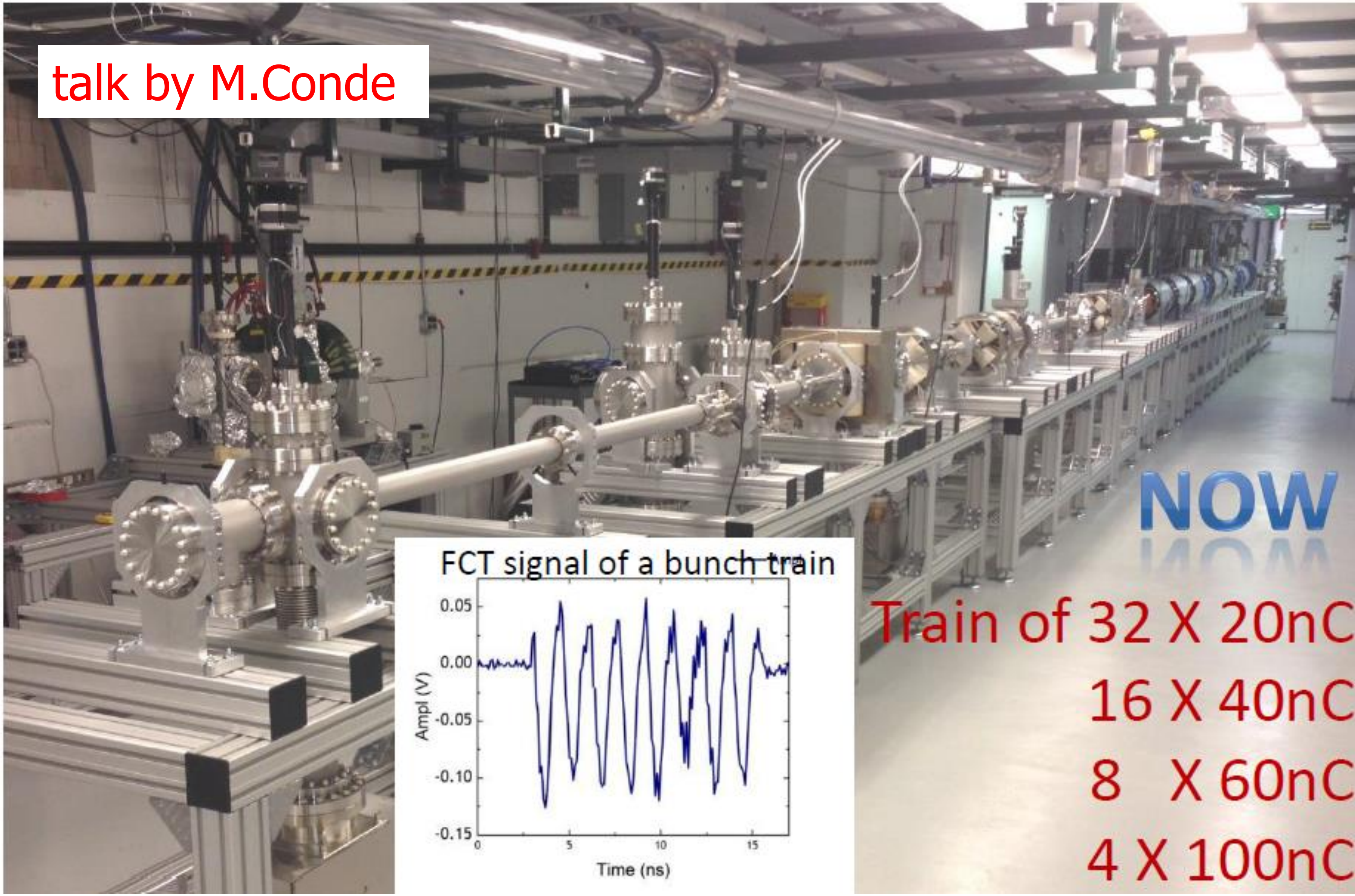
Argonne 26GHz 3TeV Flexible Linear Collider

C. Jing, Proceedings of IPAC2013, Shanghai, China, 1322



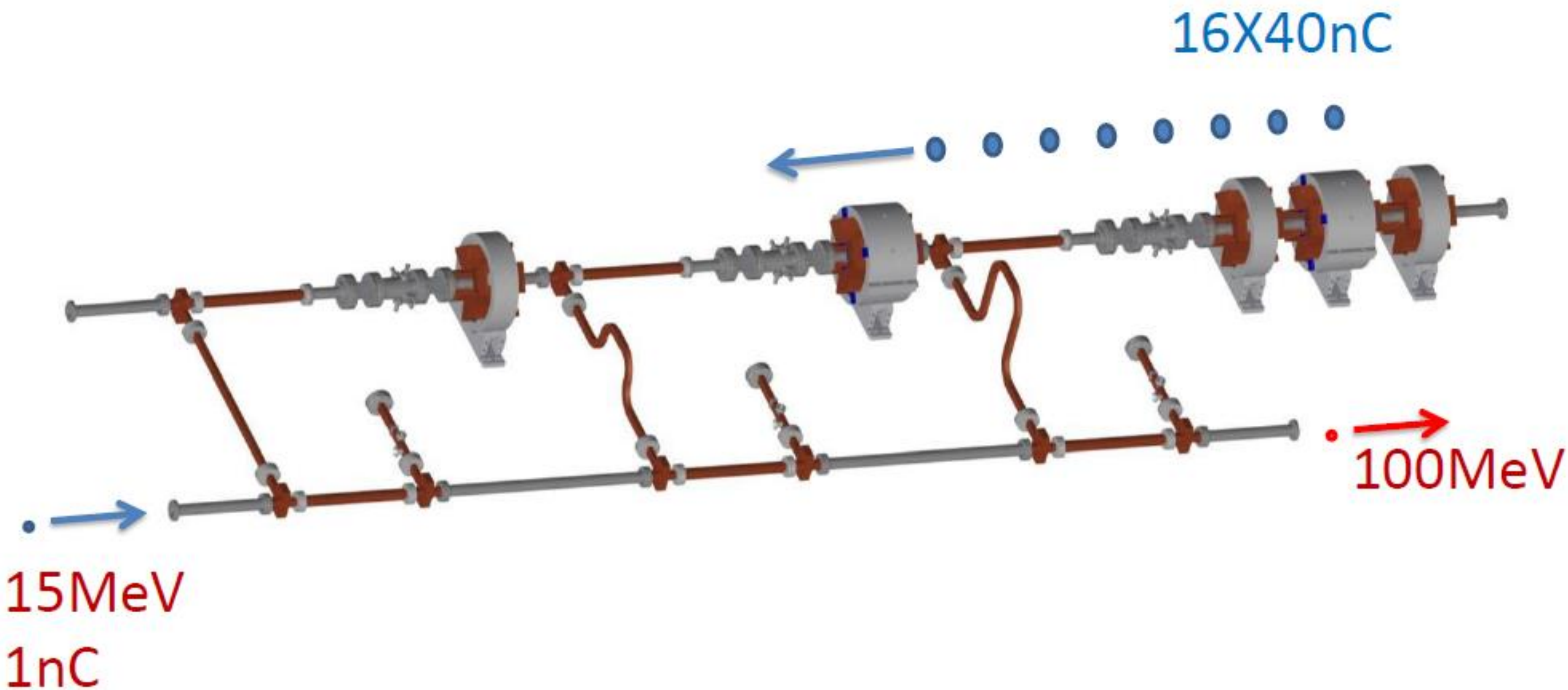
Average drive beam power (1.5TeV, e^-)	68.8 MW
Average main beam power (1.5TeV, e^-)	15.6 MW

AWA 75MeV μC Beamline --- a drive for GW RF Power

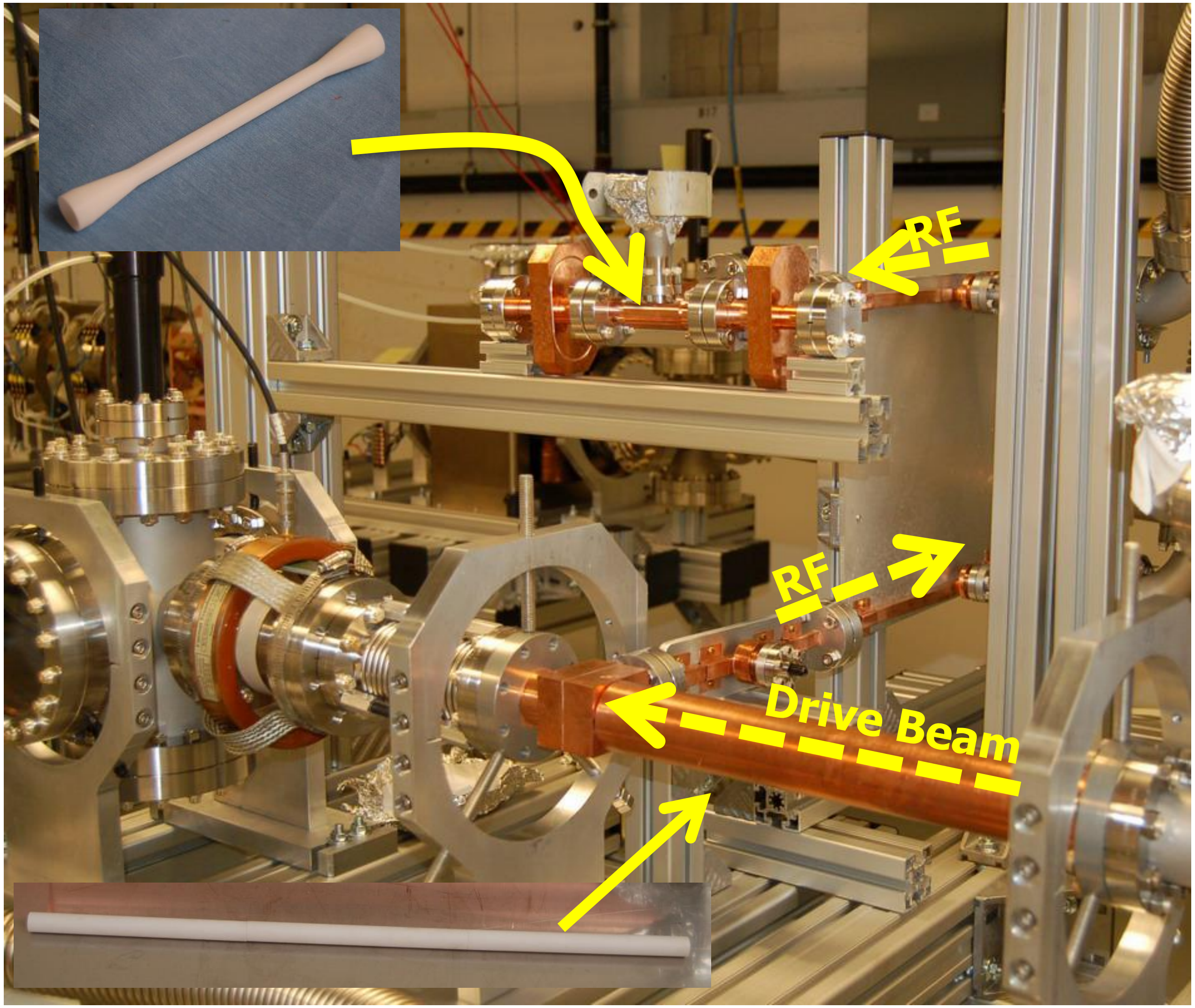


Staging Demonstration

Two Beam Acceleration at AWA



High power rf test of 26GHz Dielectric Loaded Accelerator using RF pulses extracted from the AWA Drive Beam



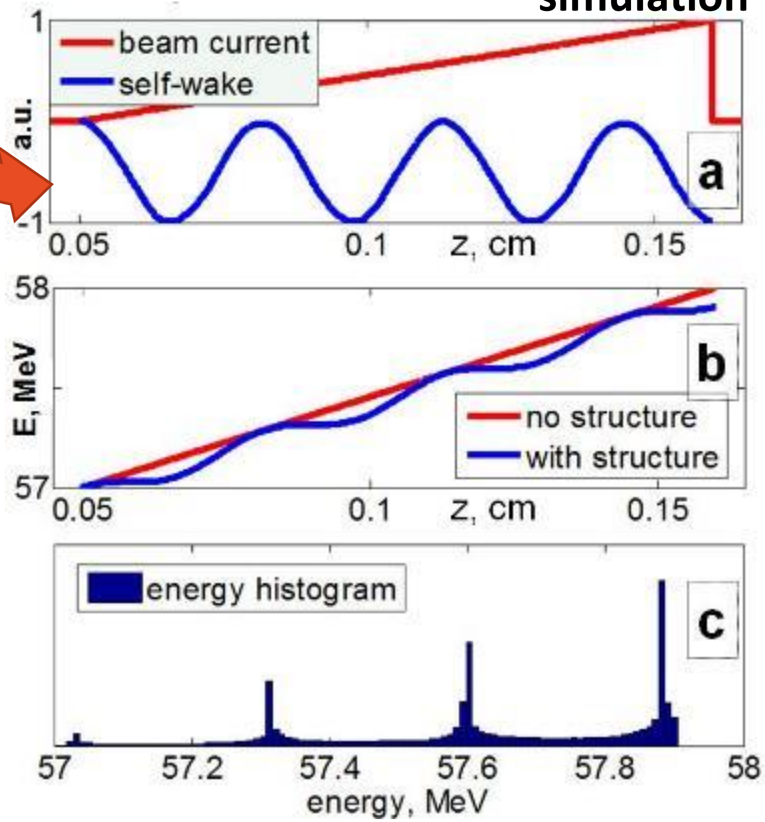
- 37MW max RF power measured out of Power Extractor.
- Equivalent to 54MV/m gradient in DLA structure.
- No breakdowns were observed.
- RF pulse is 5ns~15ns depending on the #s of bunches in a train.

Relativistic beam energy modulation

BNL/ATF

Periodic self-deceleration!

simulation

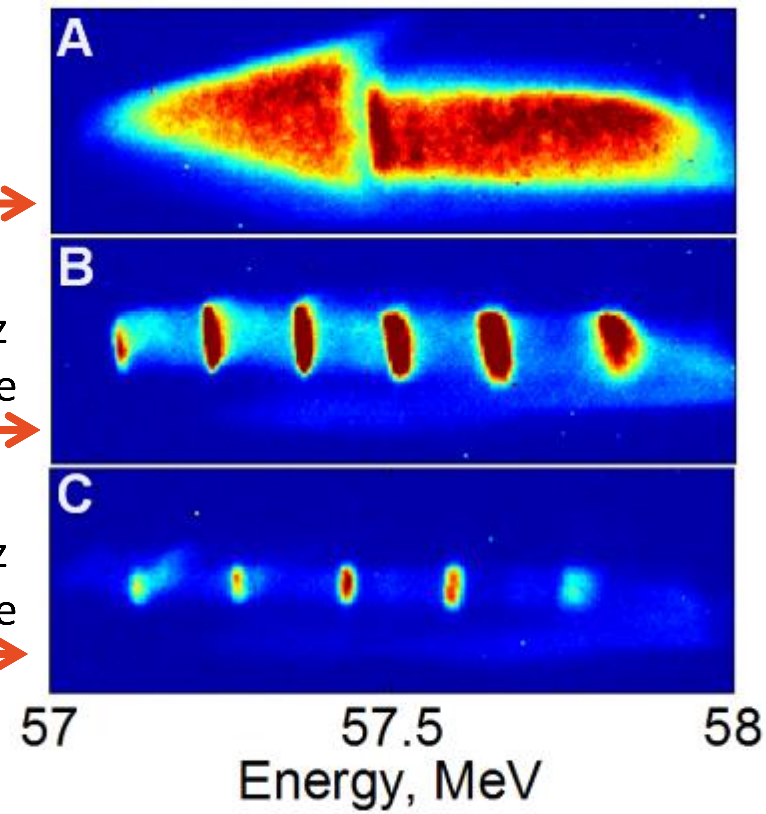


Measurement: spectrometer

Original chirped beam

0.95 THz structure

0.76 THz structure



No ballistic bunching!

S. Antipov, et. al., Phys. Rev. Lett. 108, 144801 (2012)

High power beam-based THz source

Stage I

S. Antipov, C. Jing et. al. Phys. Rev. Lett. 108, 144801 (2012)

Energy modulation via self-wakefield

Stage II

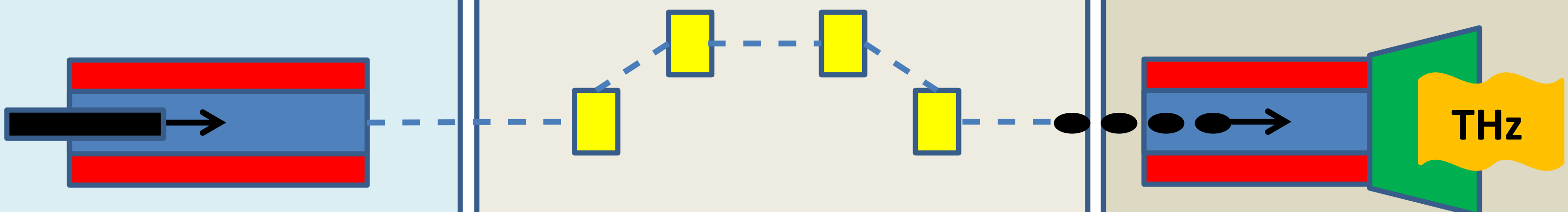
D. Xiang et. al. Phys. Rev. Lett. 108, 024802 (2012)
S. Antipov, et al. to be published

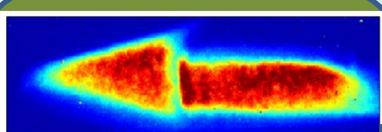
Chicane energy modulation conversion to bunch train

Stage III

G. Andonian et. al. Appl. Phys. Lett. 98, 202901 (2011)

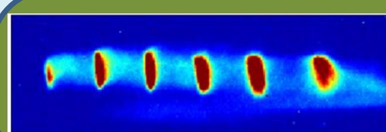
THz radiation wakefield structure





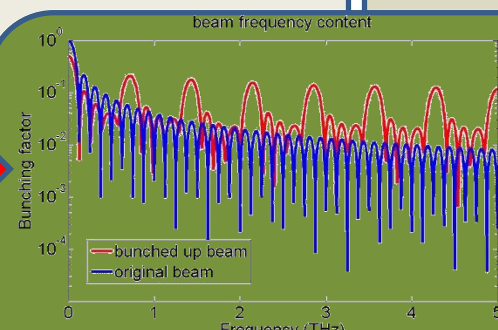
Measured beam spectrum

Energy chirped rectangular beam



Measured beam spectrum

Energy modulated rectangular beam



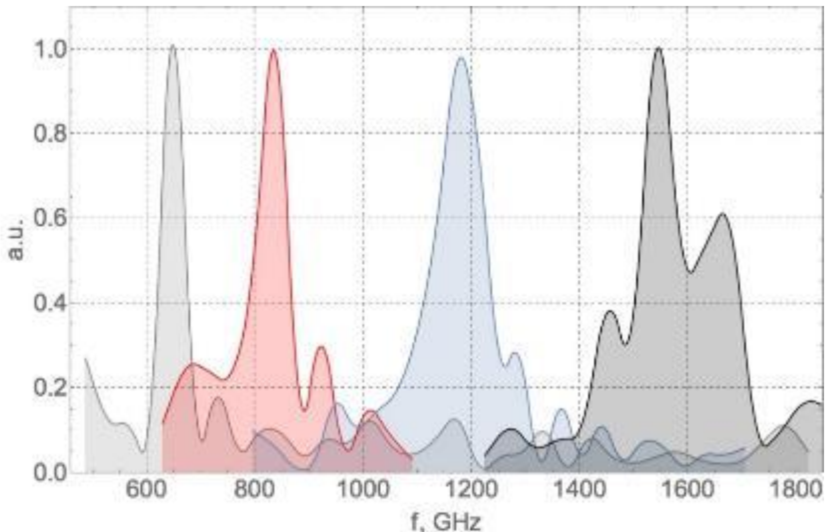
Bunch train frequency content

Tunable 100% source: Range: 0.3-1.5 THz
Pulse bandwidth: 1%
Energy in pulse: ~ mJ

Flexible: each step has a tuning range

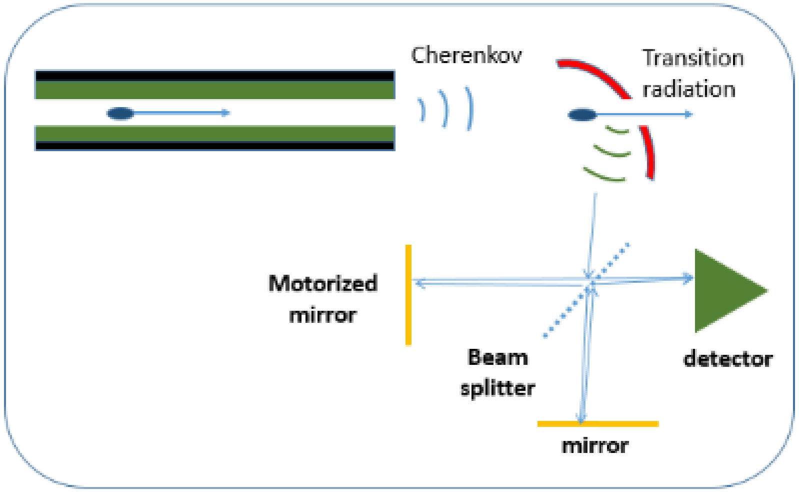
S.Antipov et al. Phys. Rev. Lett.

Multimode structure selective excitation **BNL/ATF**

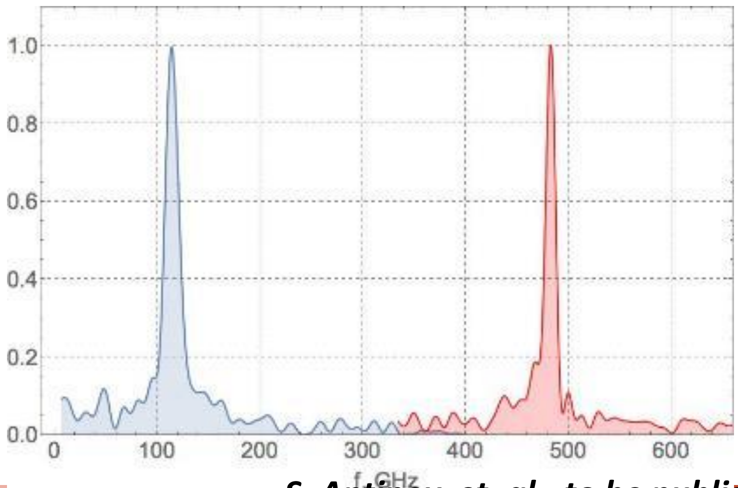


S. Antipov, et. al., IPAC (2015)

G. Andonian et al. APL 98, 202901,2011

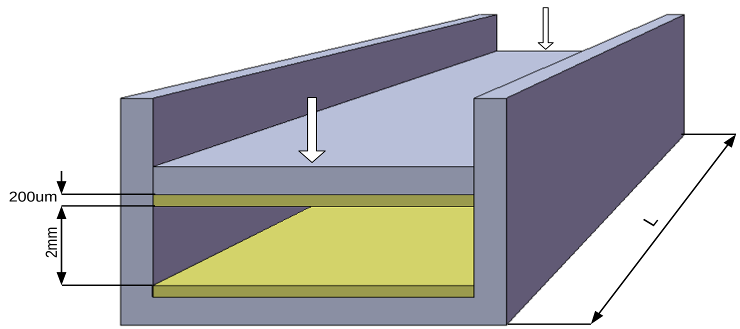


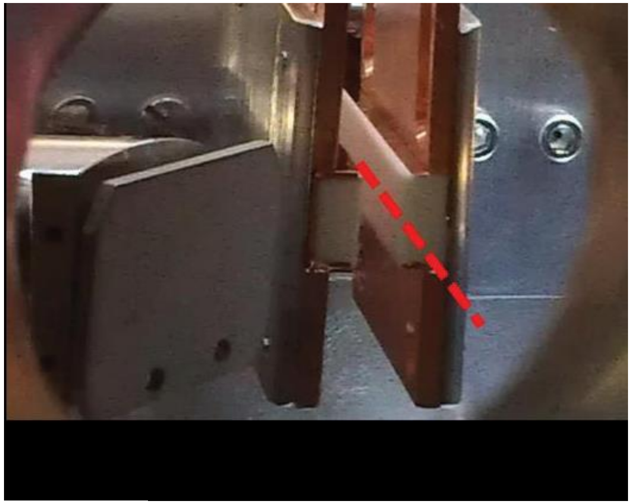
- Tuning the e-beam spacing we selectively excite $TM_{0,N}$ modes in a multimode structure
- Recently we improved signal – noise ratio by efficient power extraction from the THz structure
- Spectral characterization is limited by interferometer scanning range

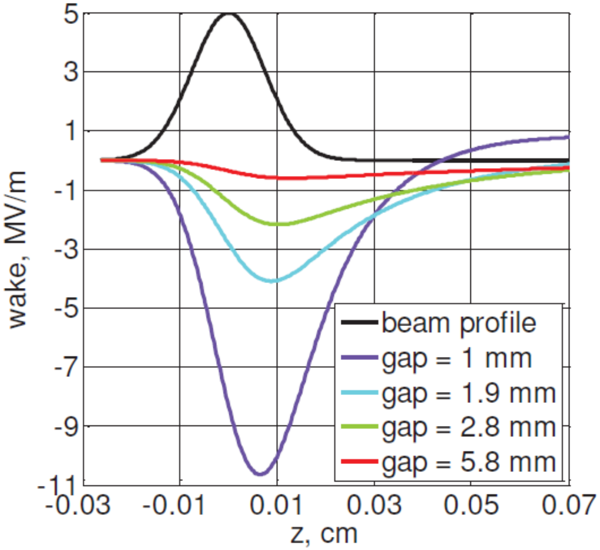


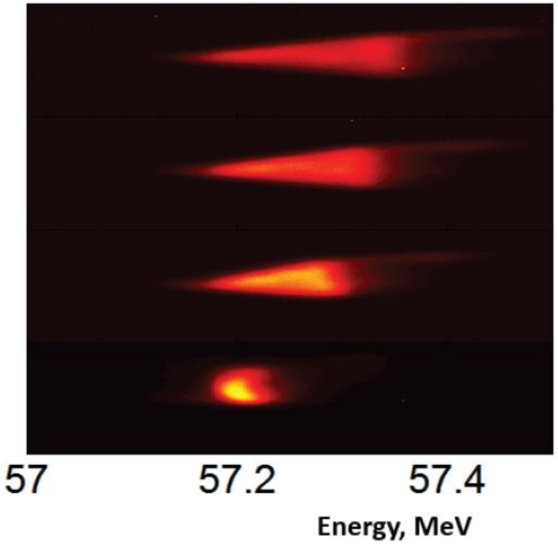
S. Antipov, et. al., to be published

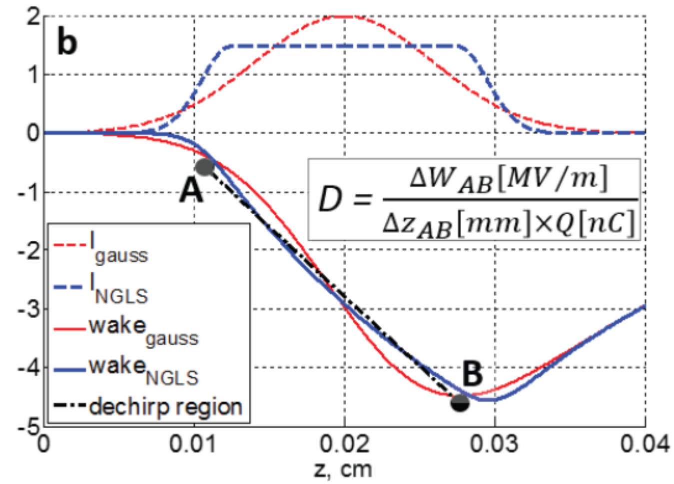
Tunable FEL Energy Chirp Correction





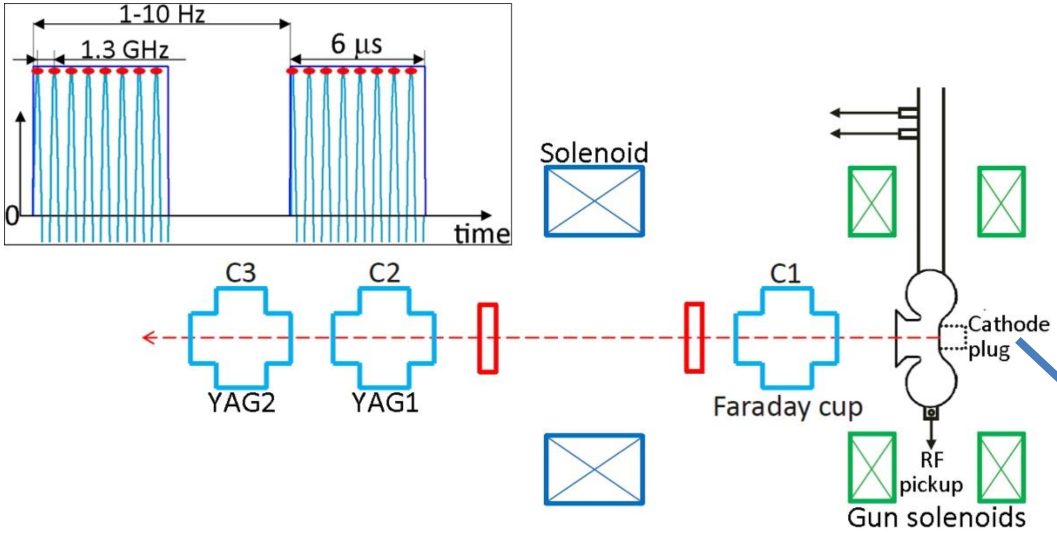


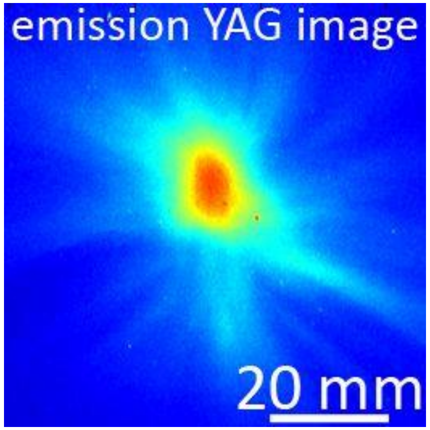


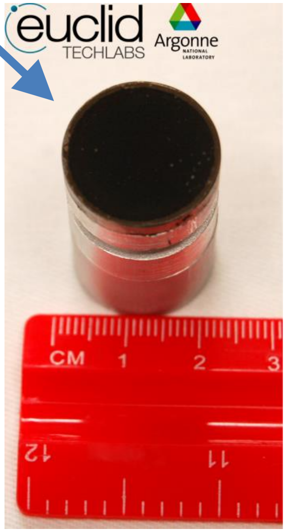


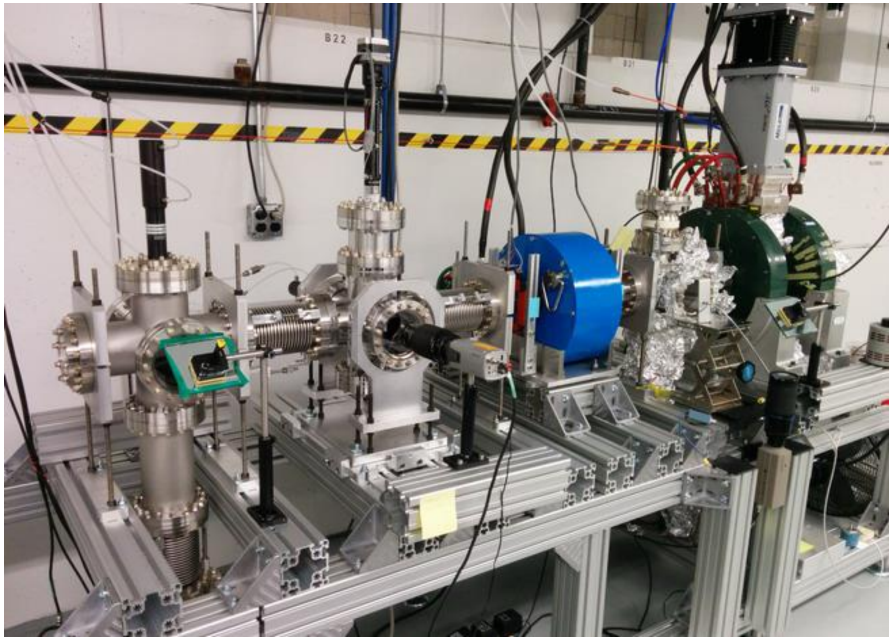
S. Antipov et al. Phys. Rev. Lett. 112, 114801 (2014).

Field Emission UNCD Cathode







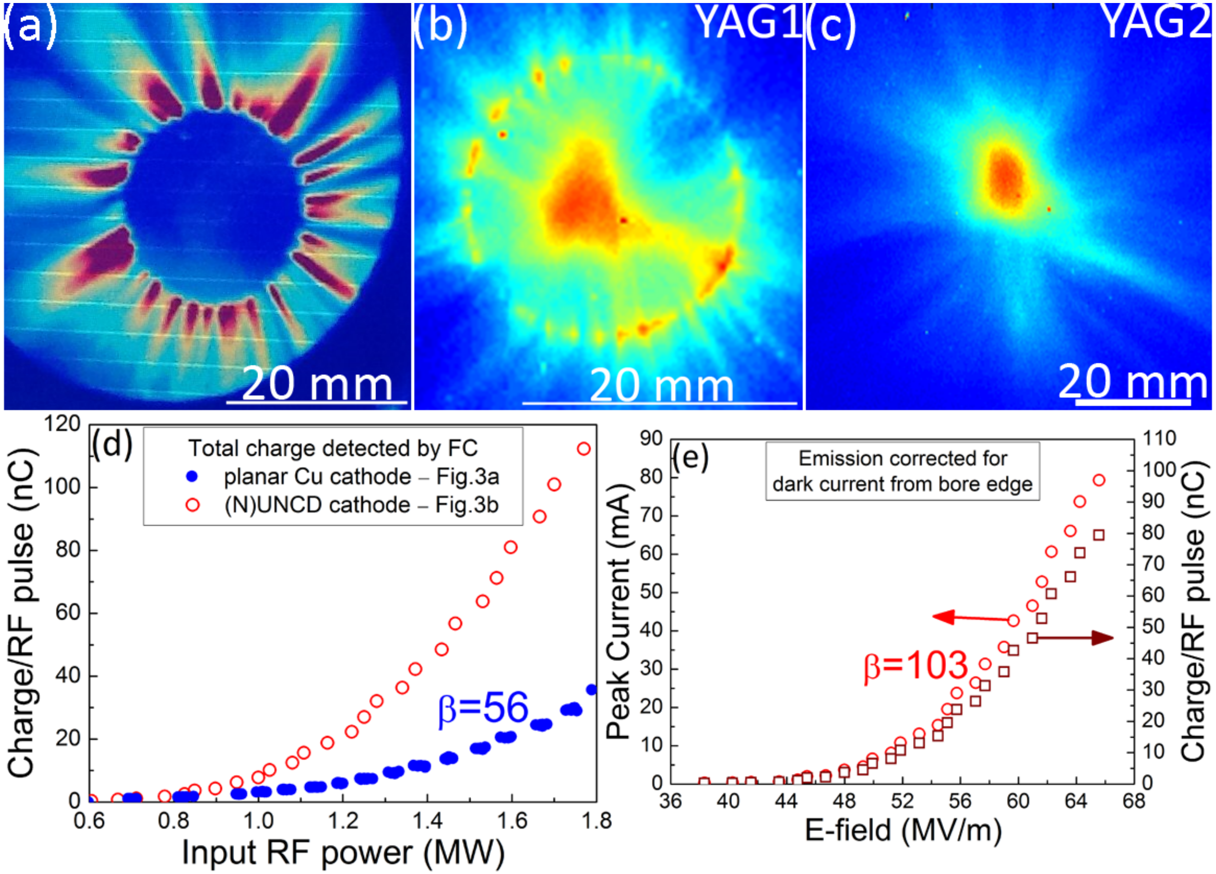


Test-stand @ AWA ANL

Electron emission seen by YAGs and Faraday cup

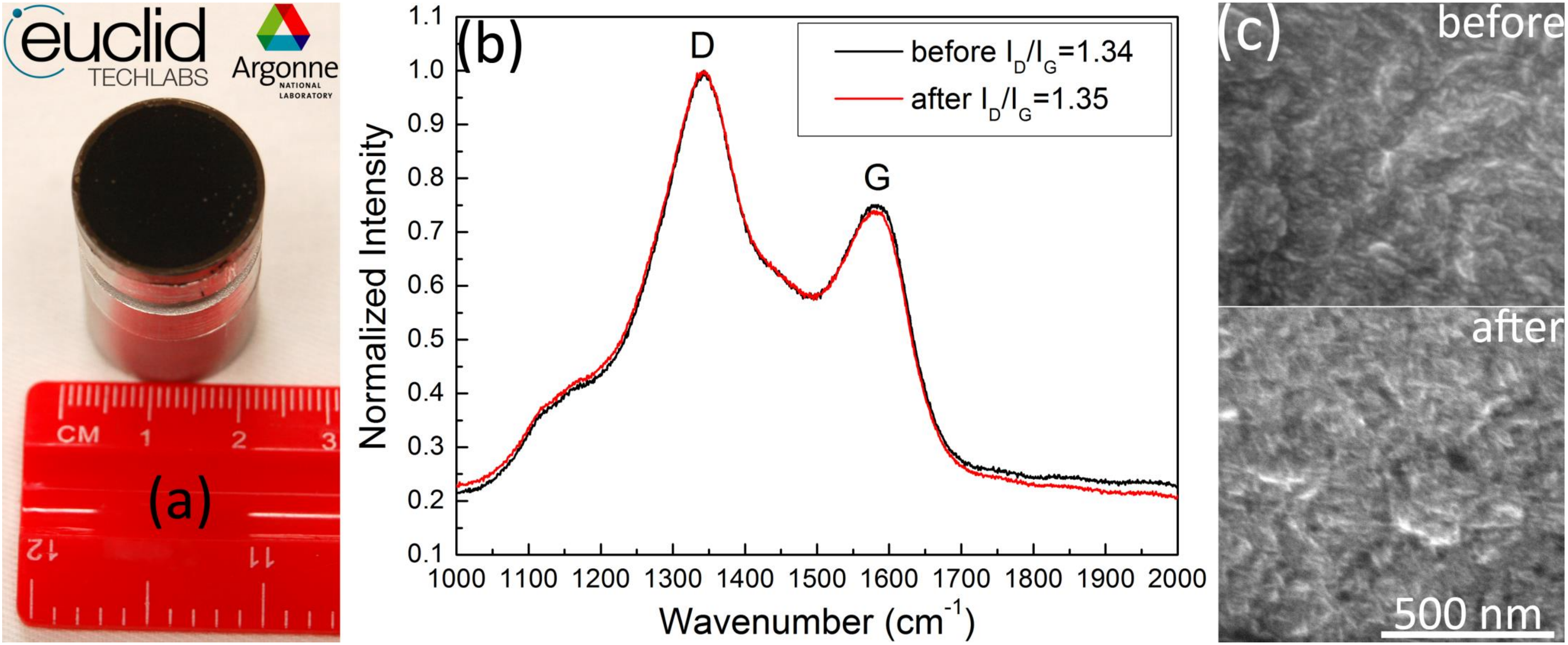
At surface gradients 45-65 MV/m,

peak currents of 1-80 mA (equivalent to 0.3-25 mA/cm^2)



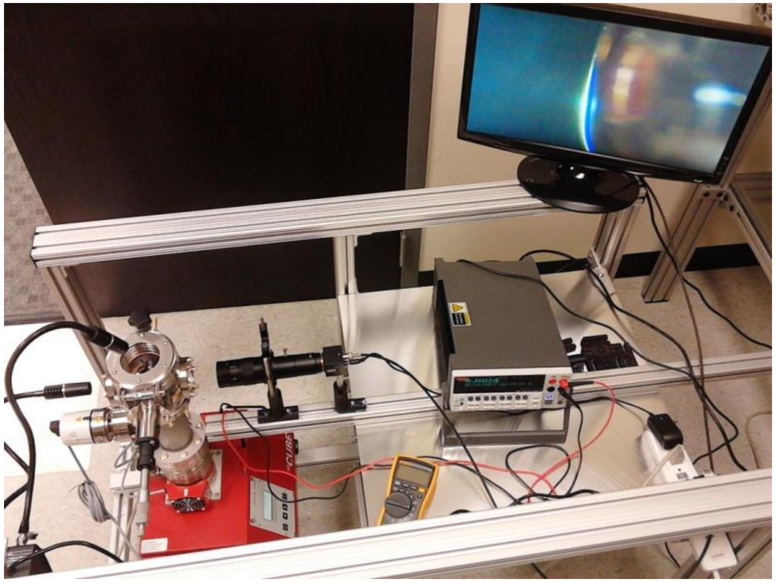
Time(s)/RF pulses/GHz oscillations	Peak current (mA) at 45 MV/m	Peak current (mA) at 55 MV/m	Peak current (mA) at 65 MV/m
0 s/0/0	1.56 ± 0.08	19.54 ± 0.98	79.37 ± 3.97
3600 s/36×10^3/288×10^6	1.47 ± 0.07	19.24 ± 0.96	79.26 ± 3.96

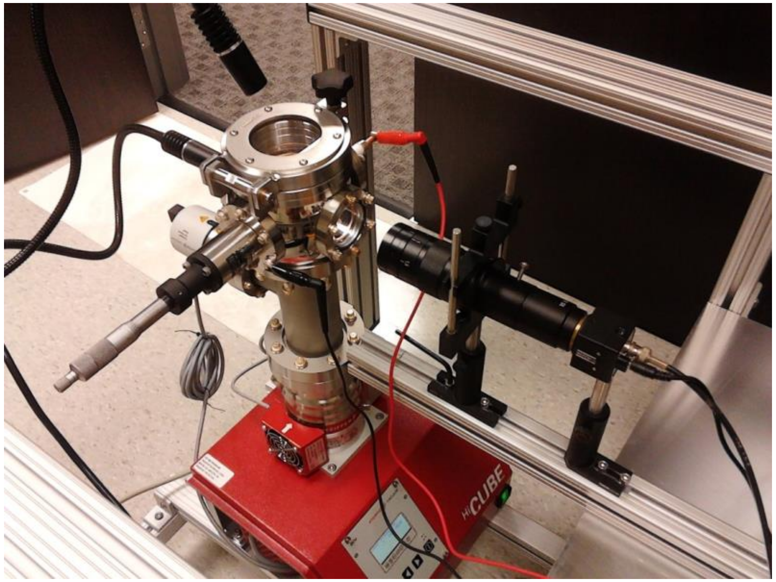
Surface examination before and after the test

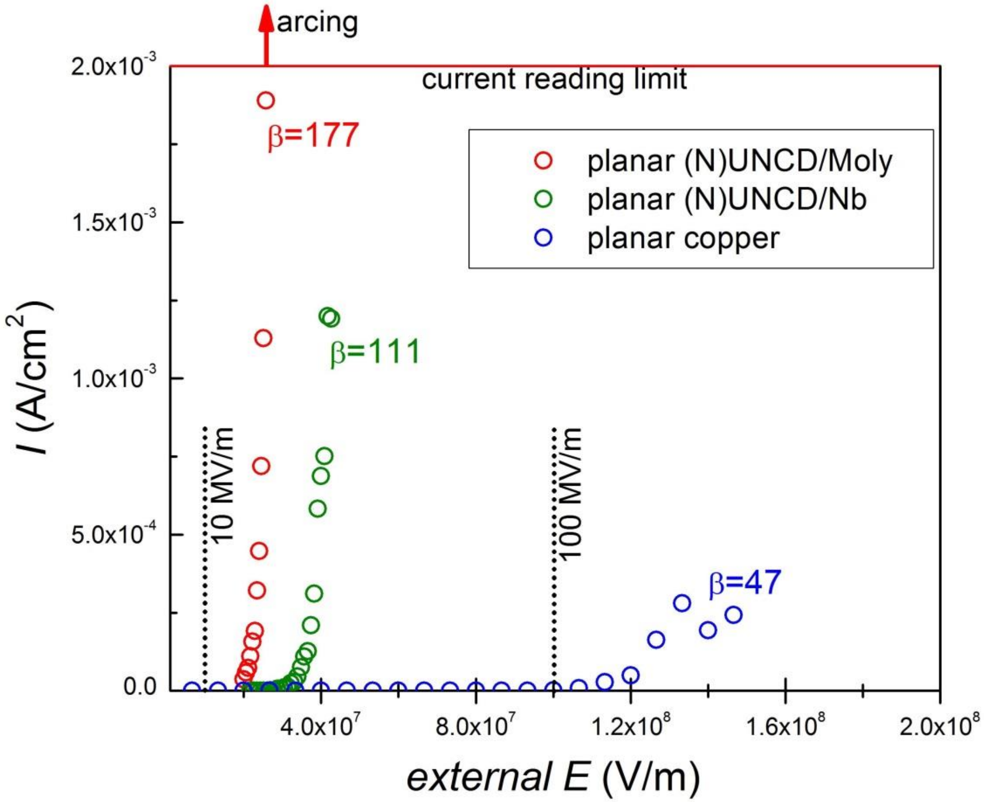


Patent Euclid/ANL is pending

Direct current field emission test-stand

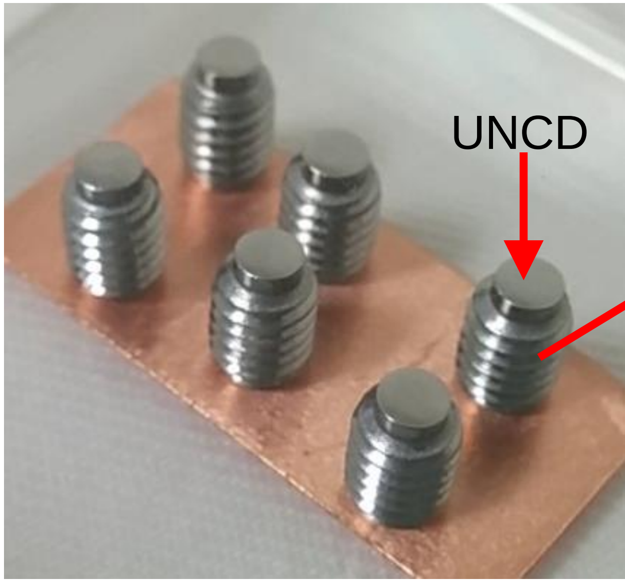


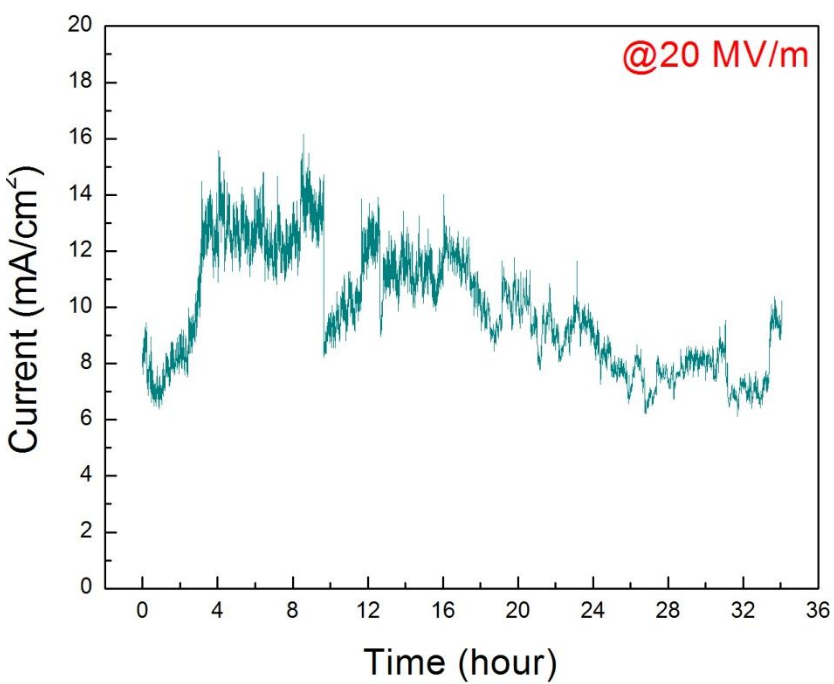




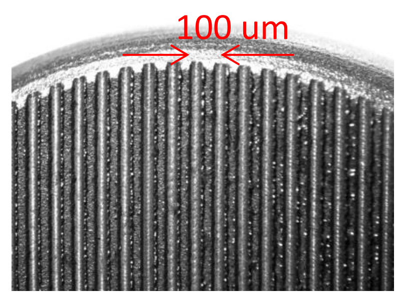
Experimentally demonstrated that UNCD on metal turn-on field is ~ 10 MV/m; current reading limit is 100 um, high current testing is underway.

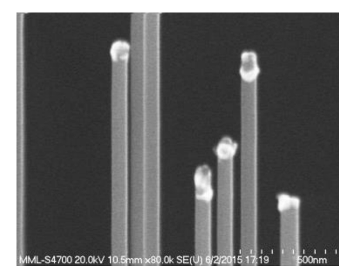
Assembly on 2.75” CF and initial time stability test





UNCD Deposition





SUMMARY

- Structure based THz wakefield accelerator technologies is nearly mature to be used in the large scale future facilities.
- New ideas and new applications of structure based THz wakefield technologies are greatly explored lately, and more to come
- We are interested in new experimental ideas/collaborations for our GHz/THz beam-based facilities.