AE52: Beam Manipulation by Self-Wakefield at the ATF

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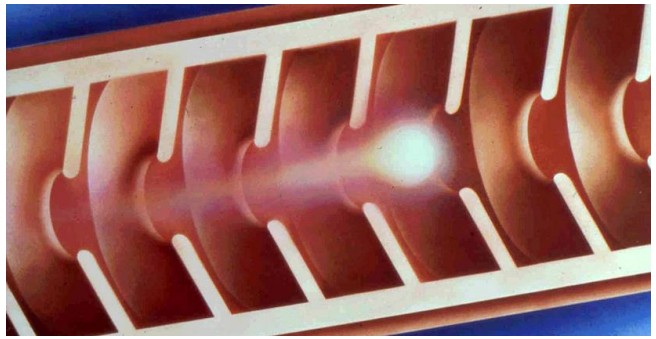
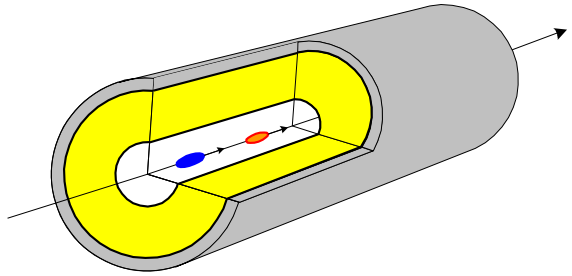
Euclid Techlabs LLC

• AE52 - Beam manipulation by self-wakefield

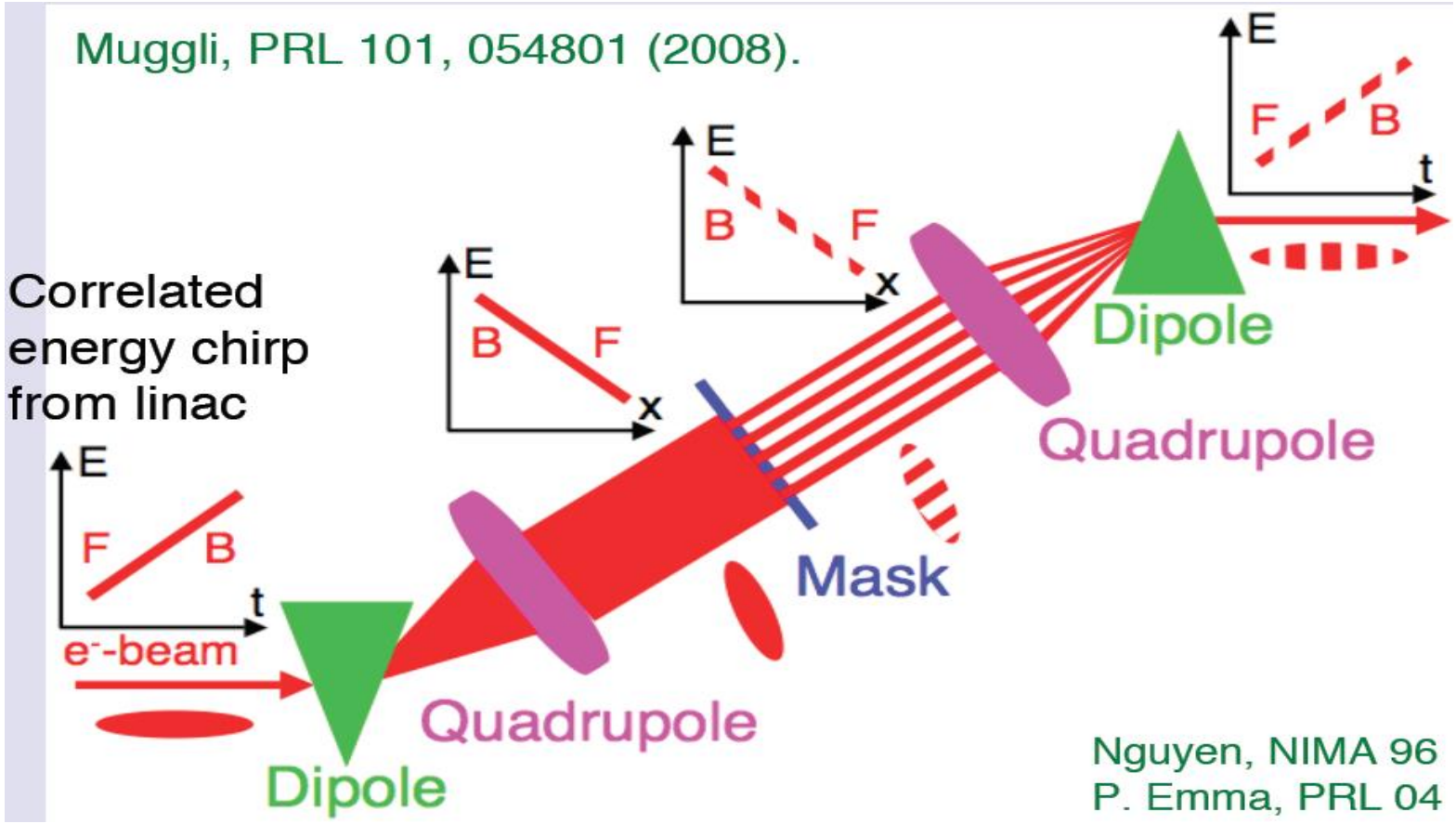
- Various structures
  - dielectric loaded, corrugated, single mode, multimode
- Study of wakefield (/THz)
- Study of self-wakefield
  - Dechirper, energy modulation, transformer ratio

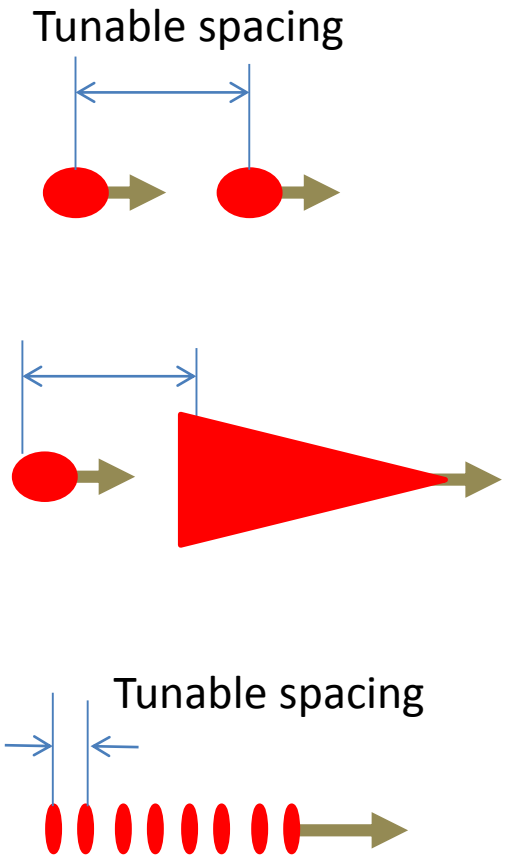




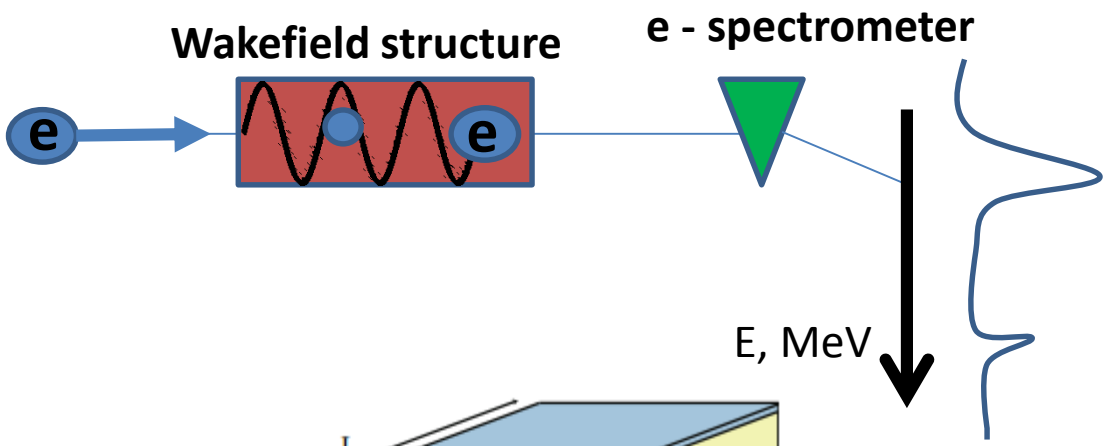
$$W_Z(z) \approx \frac{Q}{a^2} \exp\left[-2\left(\frac{\pi\,\sigma_z}{\lambda_n}\right)^2\right]\cos(kz)$$

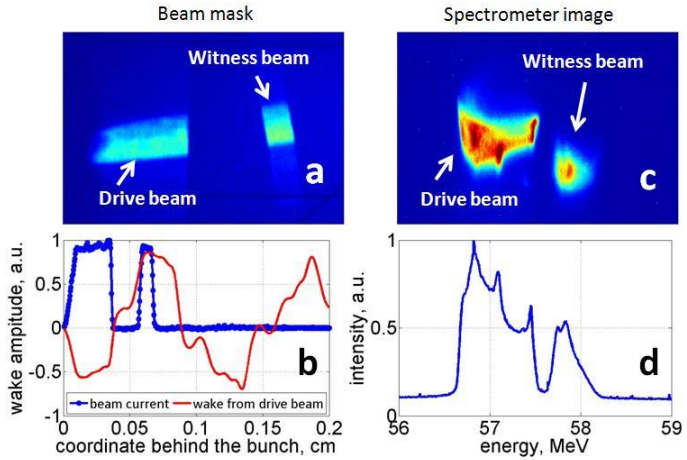
Beam shaping

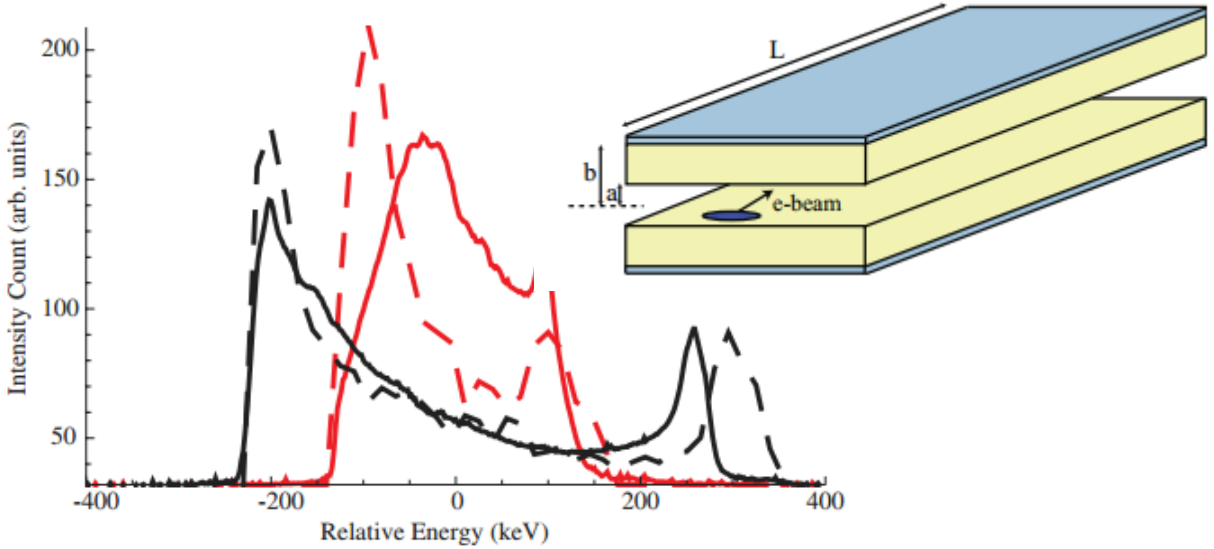


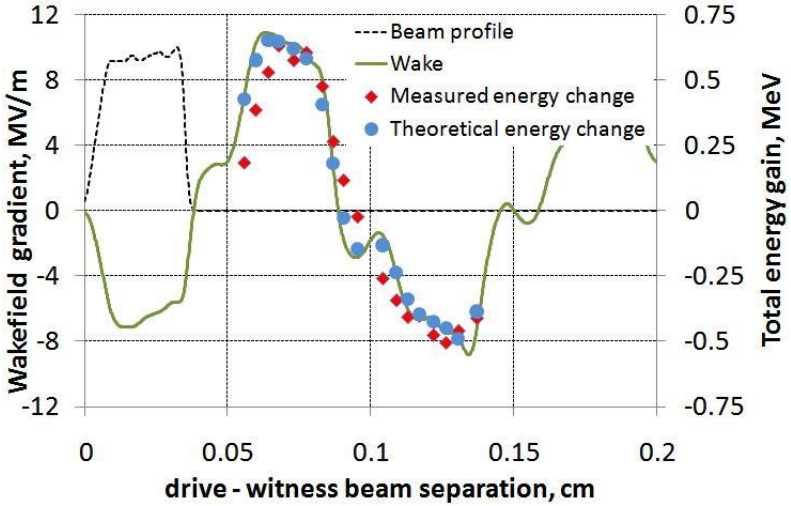


Collinear wakefield acceleration









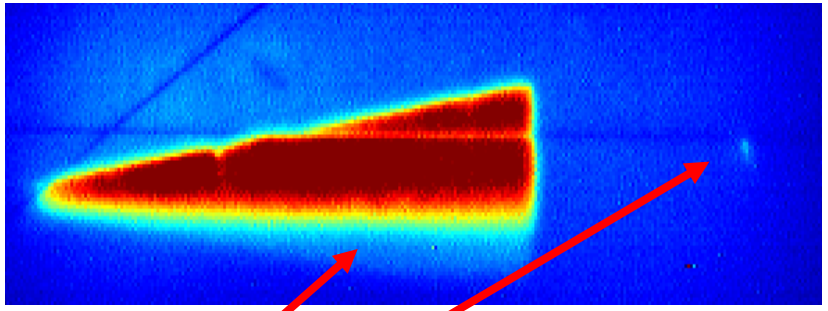
G. Andonian et.al PRL 108, 244801 (2012)

S. Antipov, et.al, Appl. Phys. Lett. 100, 132910 (2012)

euclid TECHLABS

Transformer ratio measurement at ATF

Beam profile after the mask in a dogleg

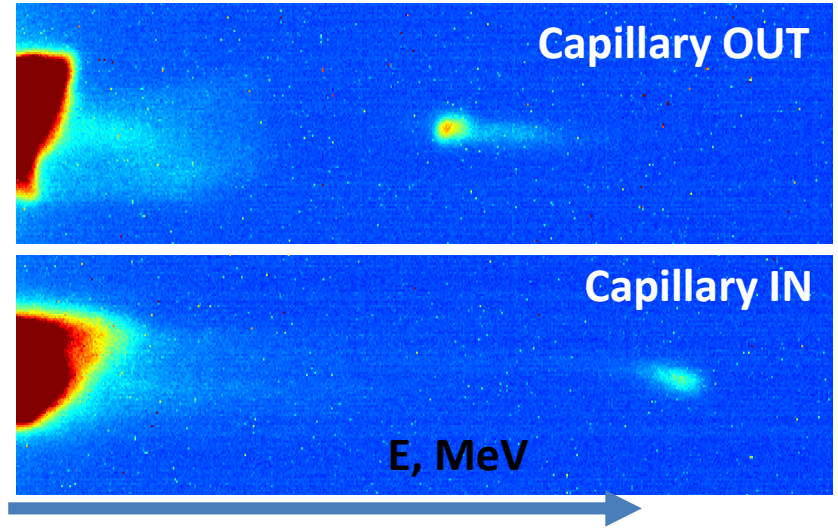


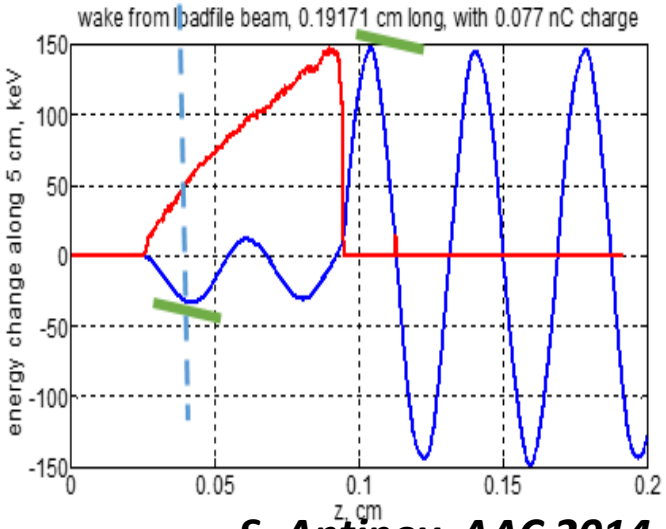
Drive (77 pC) and witness (3.5 pC)

Theoretical: 4.5

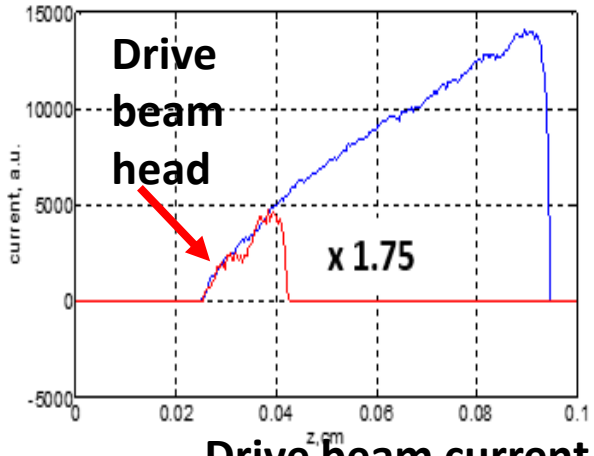
Measured: 3.5

- Small witness beam: spectrometer



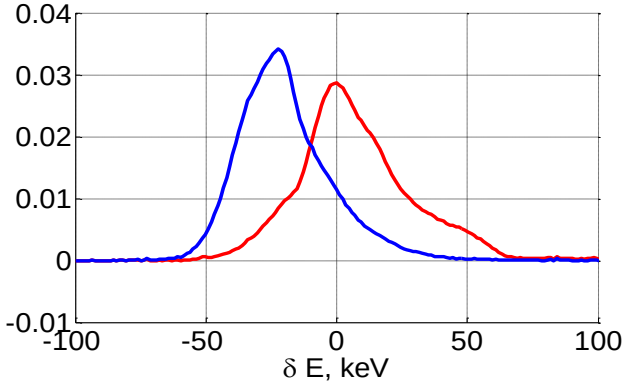


S. Antipov, AAC 2014



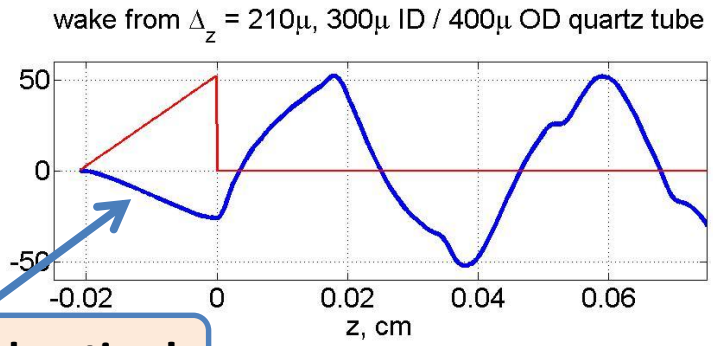
Drive beam current

Drive head energy loss (21keV)



Energy Chirp Correction Experiment at ATF

Triangular-shaped (current) beam with energy chirp

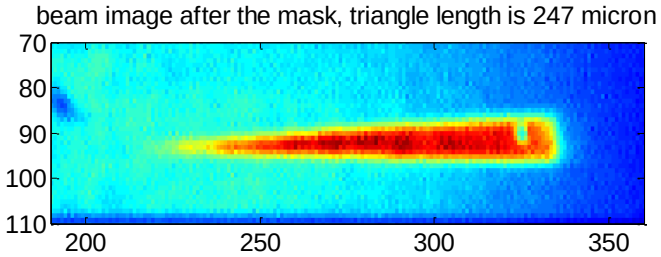


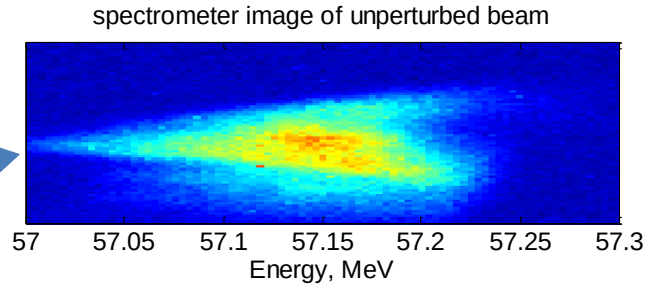
Self-deceleration!

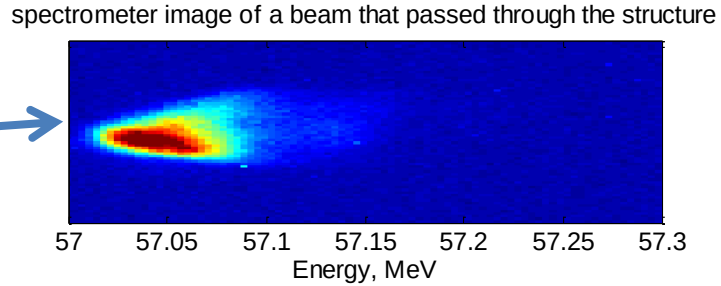
Chirp corrector – passive wakefield tube: dielectric loaded waveguide

Spectrometer image of the original beam

Spectrometer image after chirp corrector

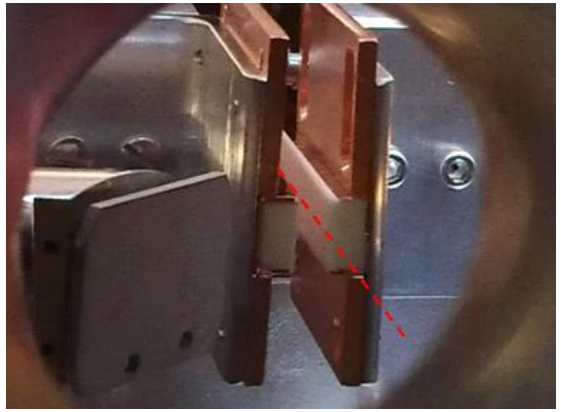




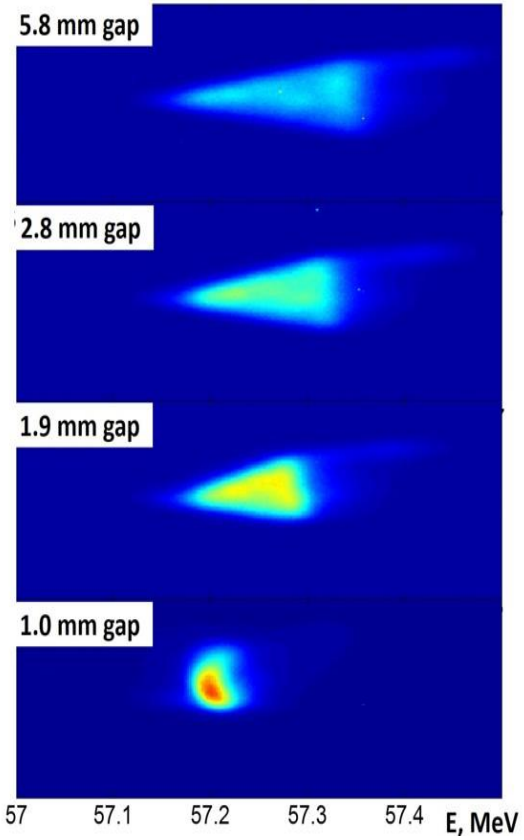


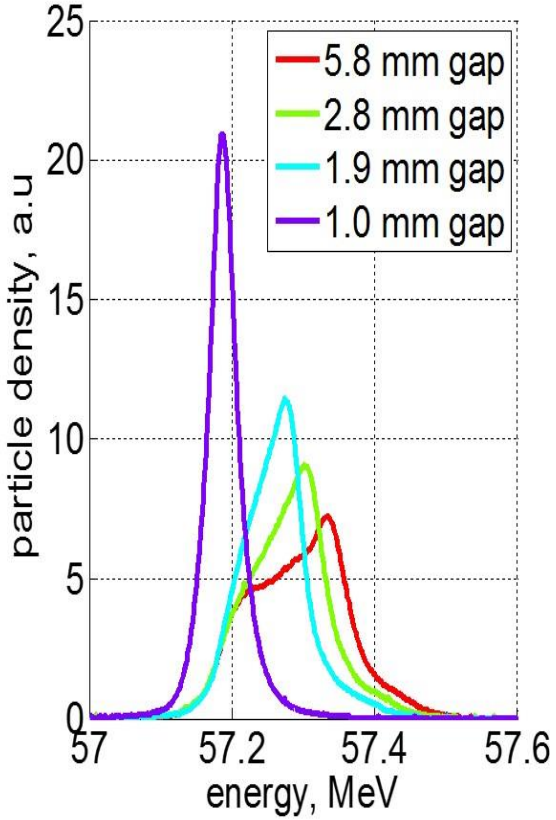
S. Antipov, C. Jing, M. Fedurin, W. Gai, A. Kanareykin, K. Kusche, P. Schoessow, V. Yakimenko, and A. Zholents, Phys. Rev. Lett. 108, 144801 (2012)

Tunable Energy Chirp Correction Experiment at ATF



dechirper: multimode rectangular dielectric loaded waveguide with tunable beam gap



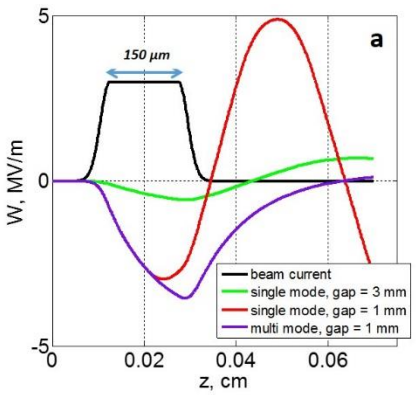


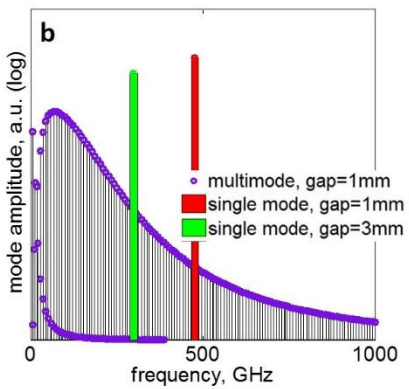
S. Antipov, S. Baturin, C. Jing, M. Fedurin, A. Kanareykin, C. Swinson, P. Schoessow, W. Gai, and A. Zholents, Phys. Rev. Lett. 112, 114801 (2014)

Triangular-shaped (current) beam with energy chirp
Correlated energy spread was removed by closing the dechirper gap

Semiconductor dechirper - collimator!

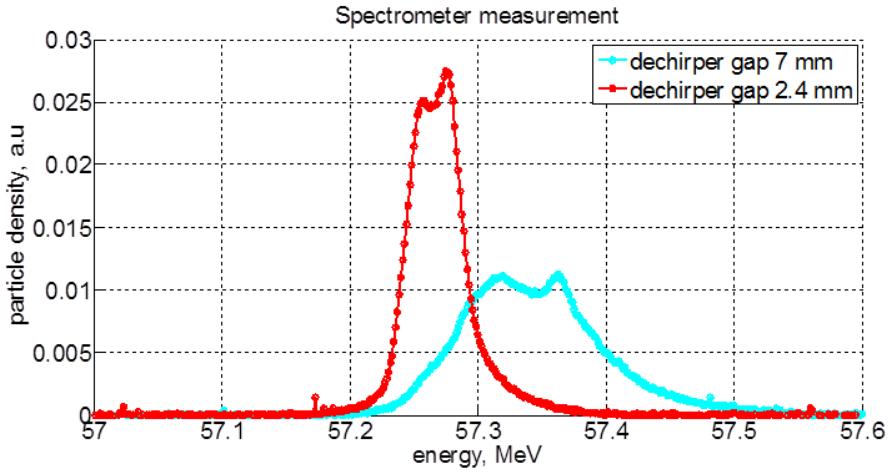
Dechirpers tested	ATF Ceramic	PAL Copper	ATF Silicon
Q, pC	54	150	90
Structure, L, m	0.1	1	0.1
Gap size, mm	1	5	2.4
ΔE, keV	165	175	90
Strength, MeV/mm/m/nC	61	2.7	33





S. Antipov IPAC 2016

- Semiconductor – resistivity for charge drain
- Balance between σ and ε
- Silicon – doping, radiation hard
- In the experiment: 5kOhm × cm resistivity but skin depth is 35 mm
- **Propose: Dechirper – Collimator!**

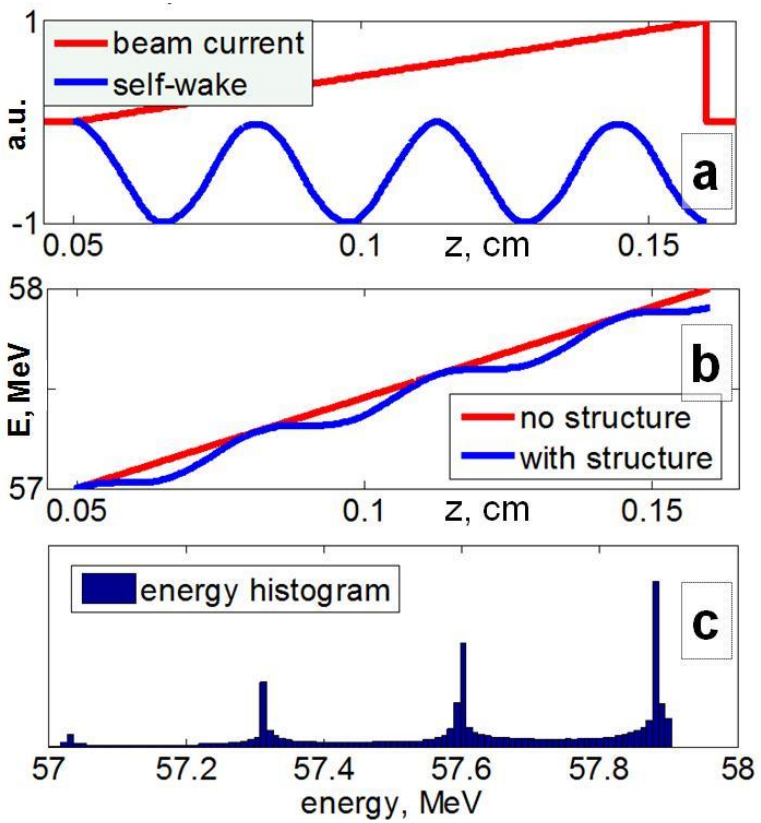


With A. Zholents (APS)

Observation of energy modulation at ATF

Periodic self-deceleration!

simulation

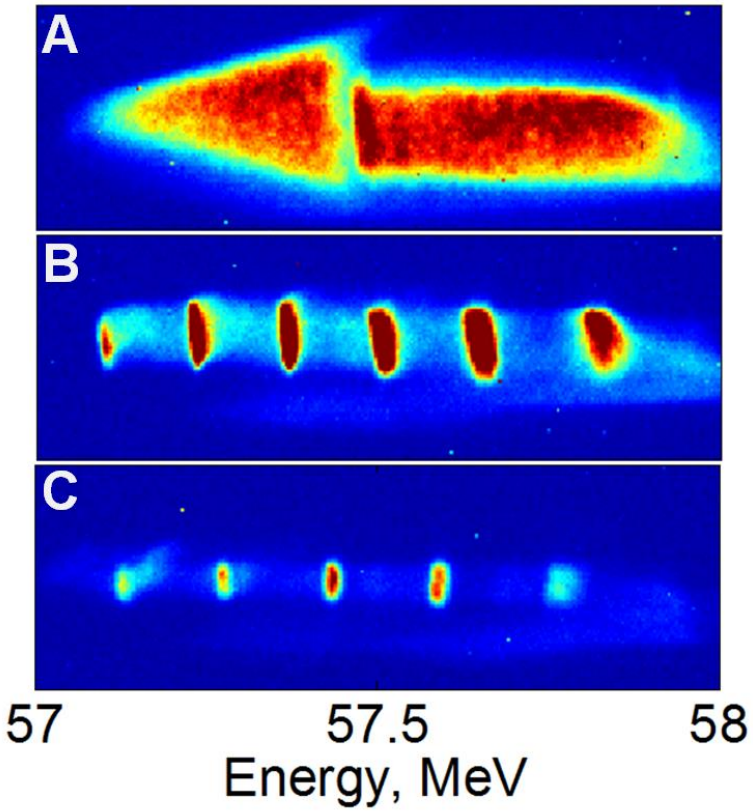


Measurement: spectrometer

Original chirped beam →

0.95 THz structure →

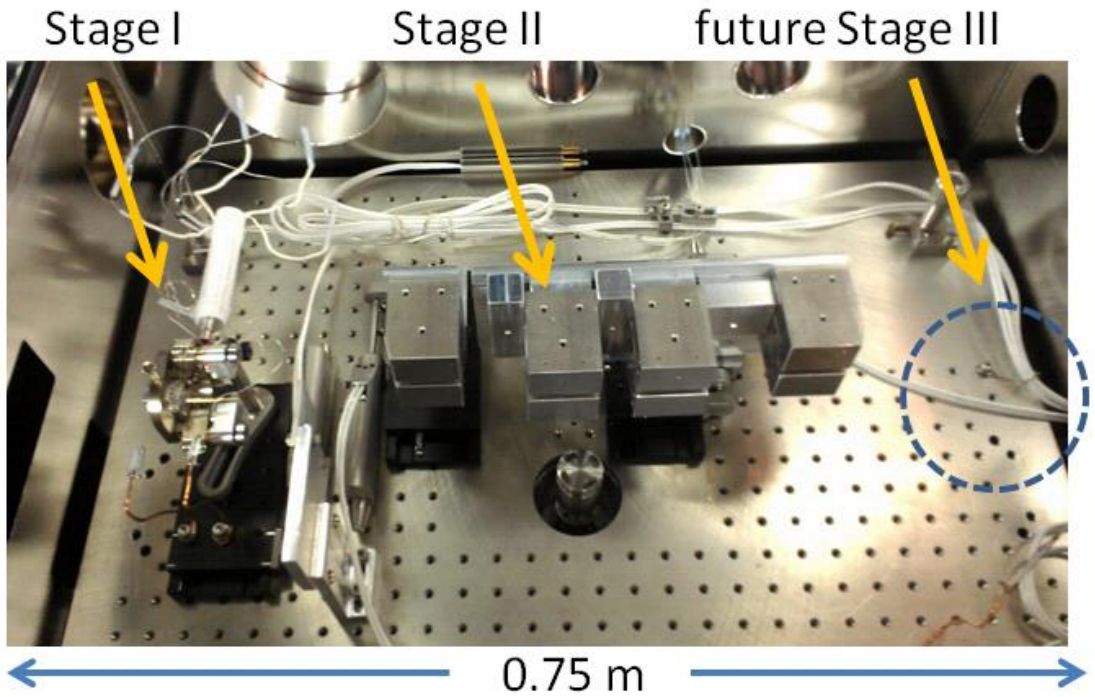
0.76 THz structure →



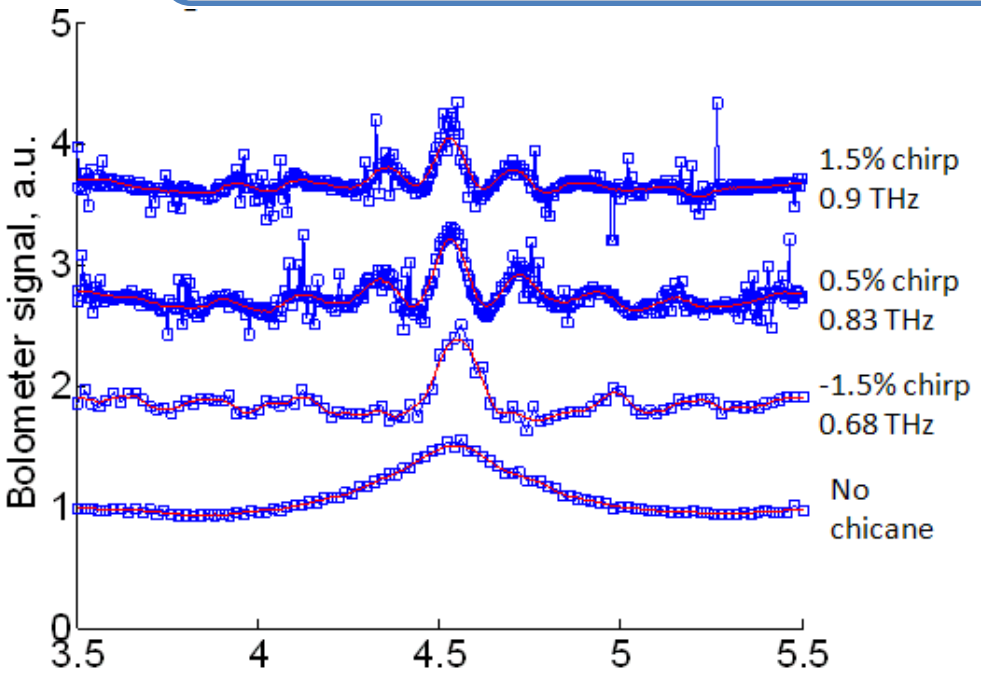
S. Antipov, et.al., Phys. Rev. Lett. 108, 144801 (2012)

Sub-picosecond bunch train production at ATF

PM chicane is used to convert energy modulation into density modulation



CTR interferometry shows that THz periodicity can be tuned by energy chirp



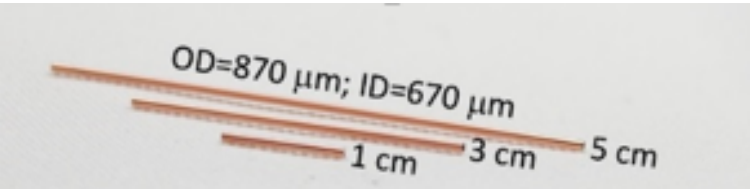
S. Antipov, et. al., Phys. Rev. Lett. 111, 134802 (2013)

We proposed a high power terahertz radiation source based on this scheme (electron beam wakefields). A third stage, yet another dielectric tube will be installed after chicane to coherently extract THz power from the bunch train

THz generation at ATF

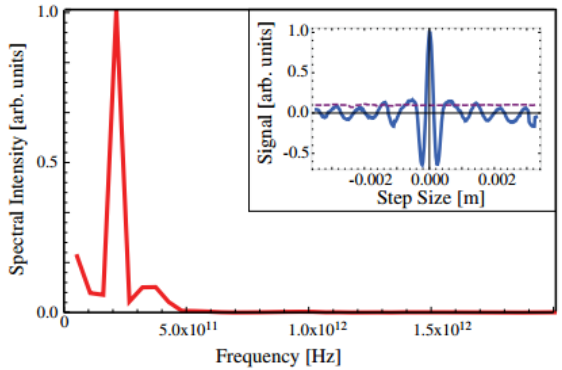
THz generation at ATF

Dielectric loaded waveguide



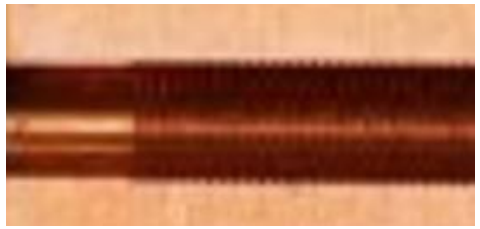
Numerous measurements by UCLA and Euclid

Bragg structure



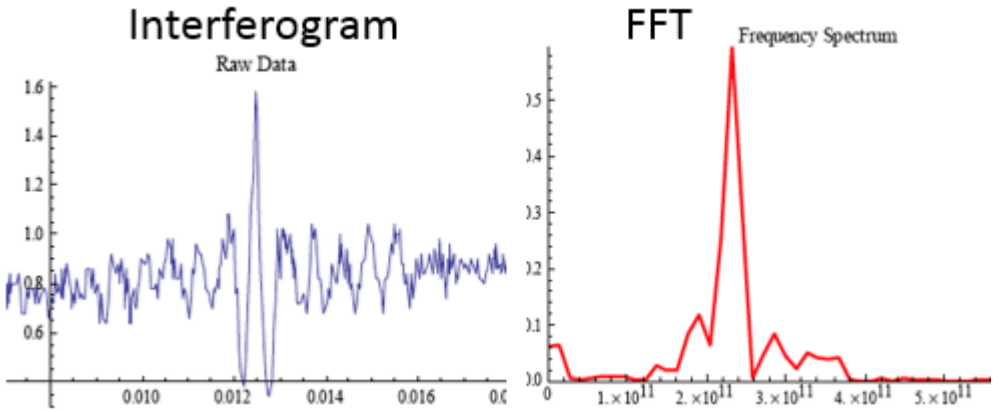
G. Andonian, PRL 113, 264801 (2014)

Corrugated waveguide



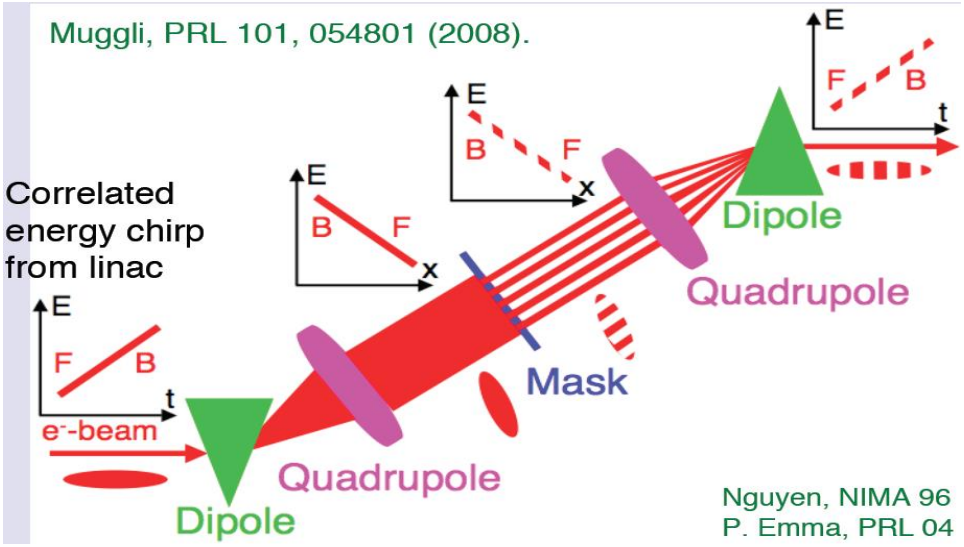
K. Bane (SLAC), S. Antipov
NIM-A, Volume 844, 1
February 2017, Pages 121-128

Woodpile structure

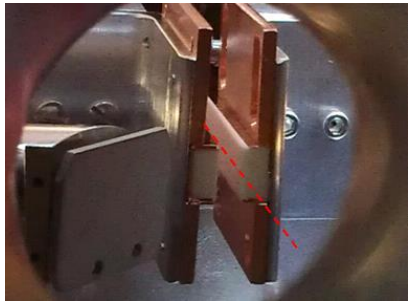


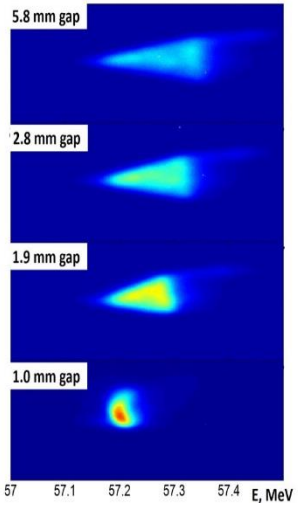
G. Andonian, P.Hoang, UCLA

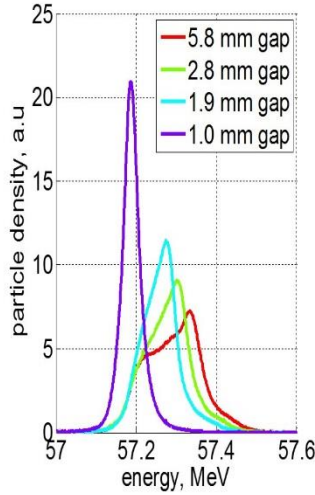
Tunable: f = 0.1 – 2 THz, BW = 1-100%



Dielectric Dechirper – multimode wake
Corrugated Dechirper – single mode wake

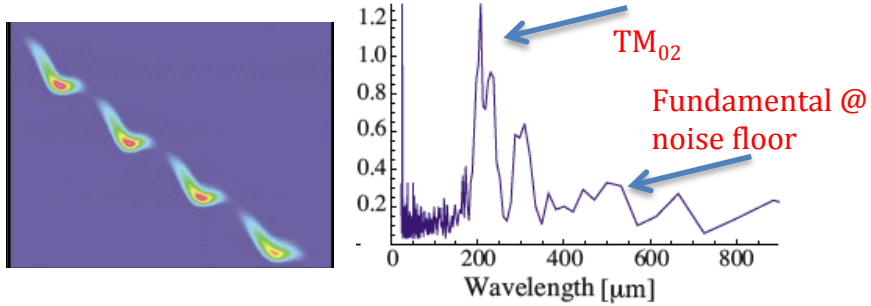




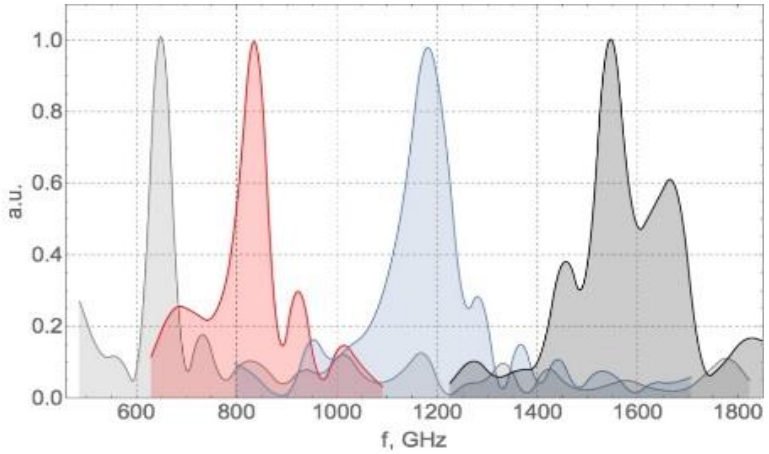


S. Antipov, et.al. , Phys. Rev. Lett. 112, 114801 (2014)

Bunch train – multimode structure interaction

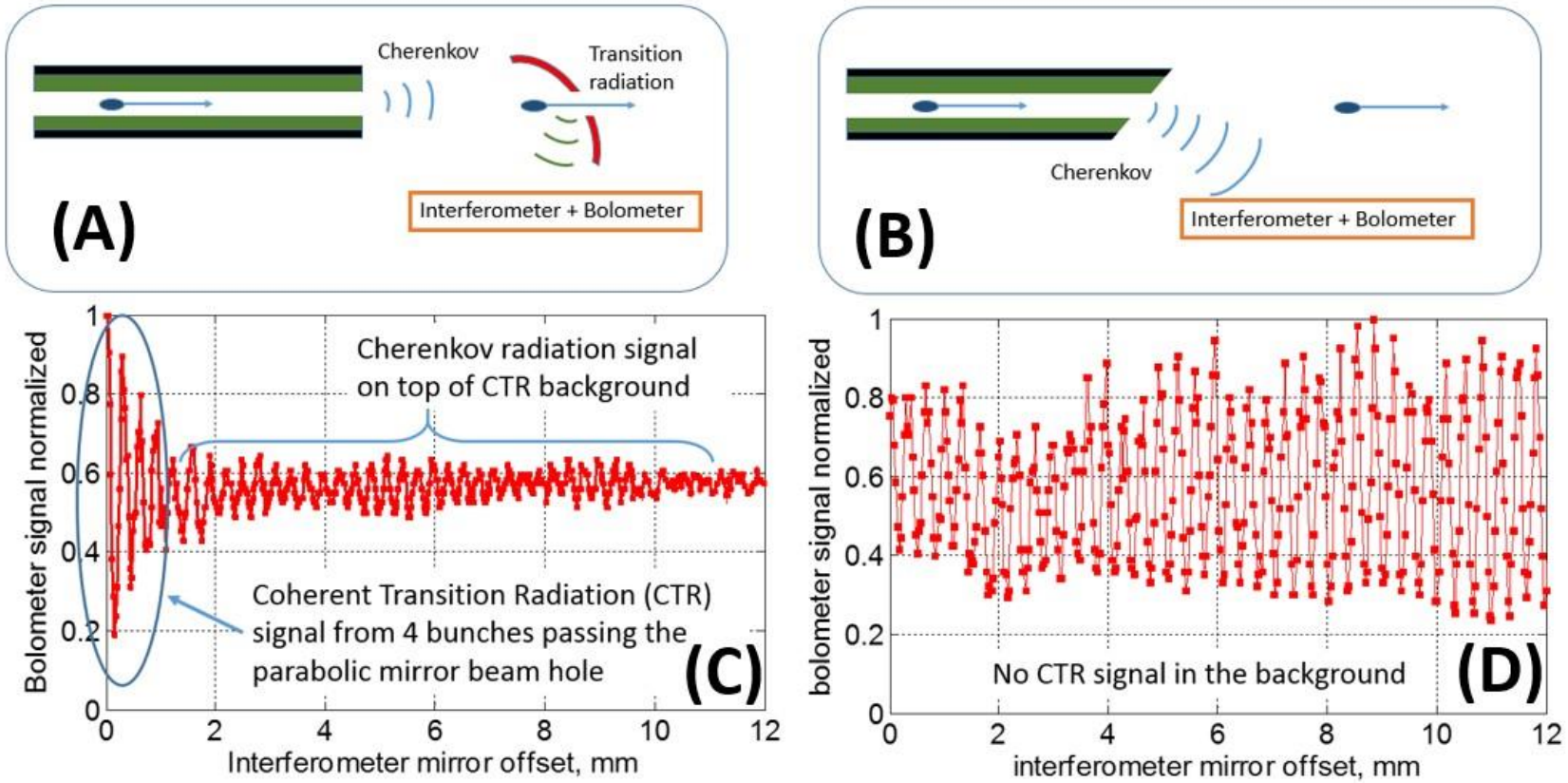


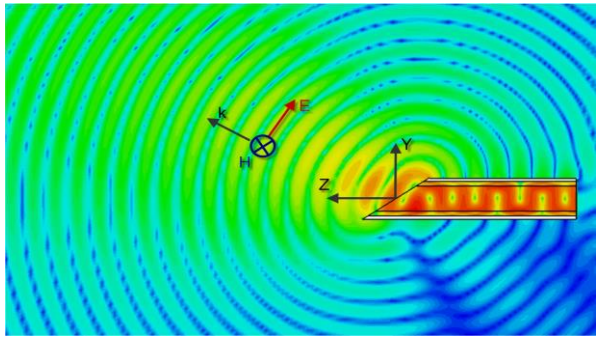
G. Andonian et al., APL 98, 202901 (2011)

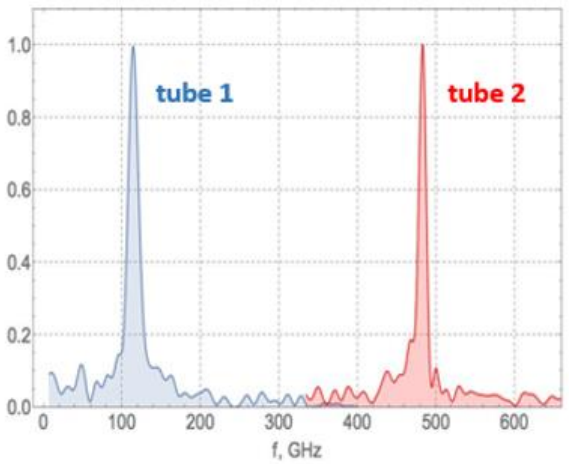


S. Antipov et al., IPAC 2015

Efficient power extraction



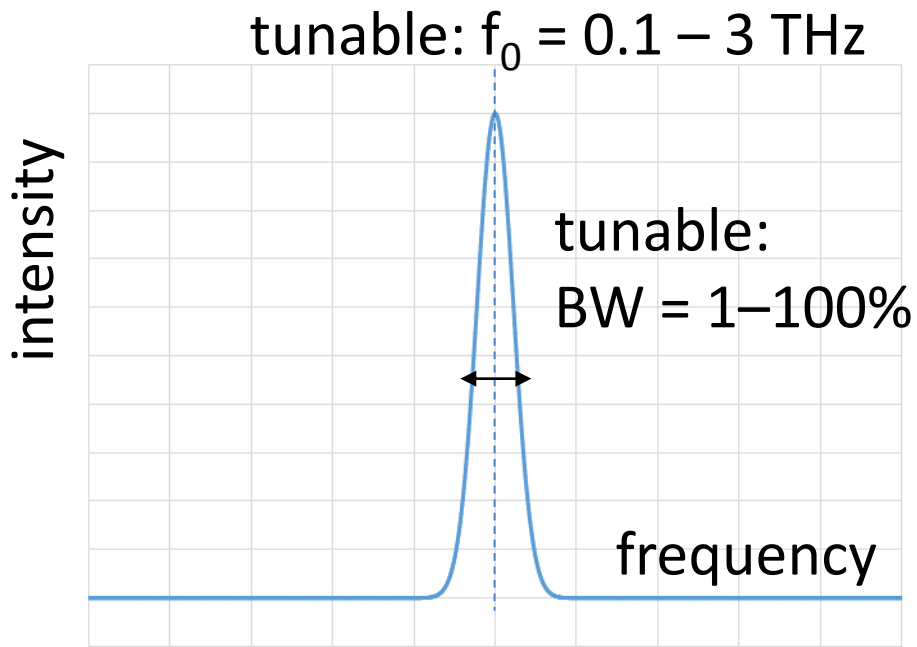


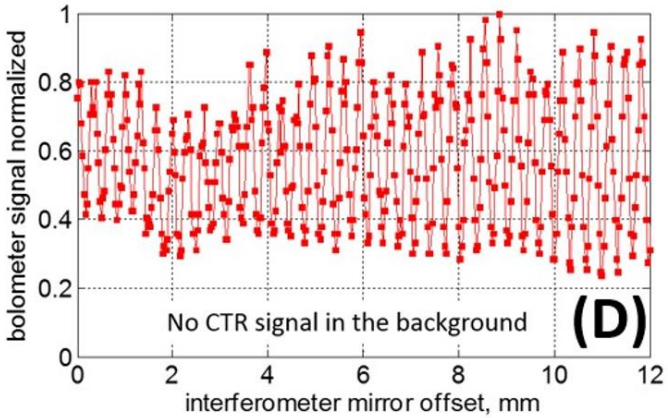


S. Antipov, et.al. Appl. Phys. Lett. 109, 142901 (2016)

0.5 THz, 10uJ – outside the beamline available for experiments

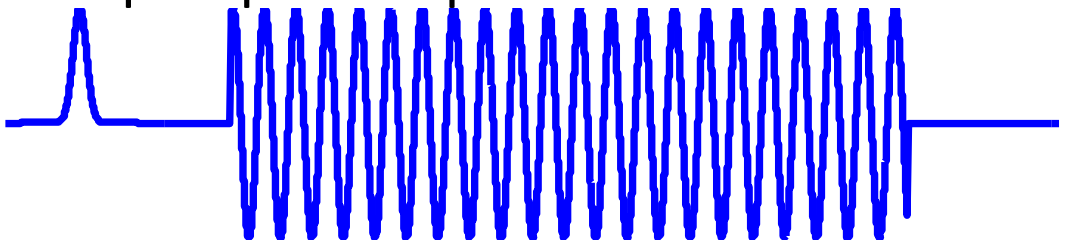
THz parameters attainable at the ATF





Actual measurement at ATF. Efficient THz extraction. 10uJ
S. Antipov, et.al. Appl. Phys. Lett. 109, 142901 (2016)

- Frequency tunable 0.1 – 3 THz
  - 0.4 – 12.4 meV photons
- Bandwidth tunable: 1 – 100%
  - 100% - single cycle
  - 1% - 100 oscillations in a signal
- Energy in a pulse outside beamline ~10μJ
- Peak power ~ 100kW
- THz pump – THz probe available:

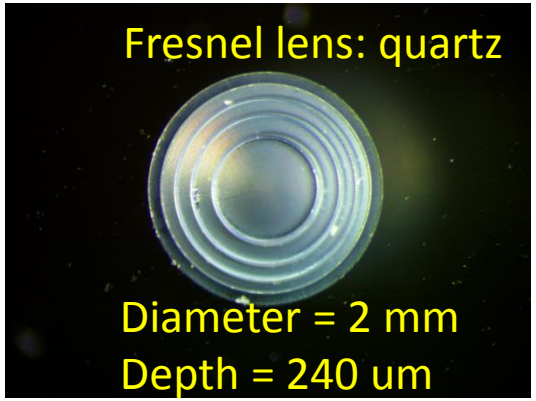


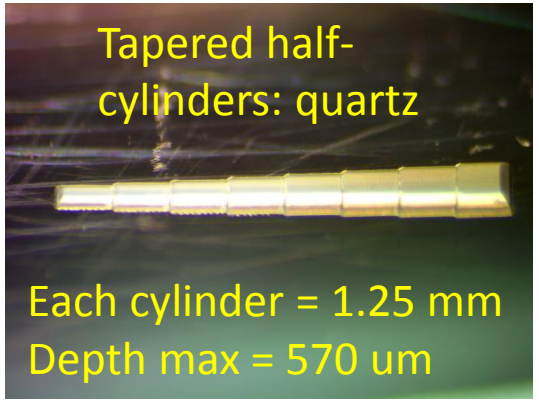
AE52 Summary

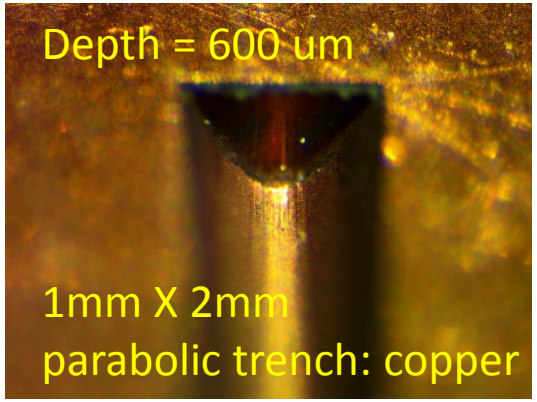
<u>Large number of experiments over the years:</u>

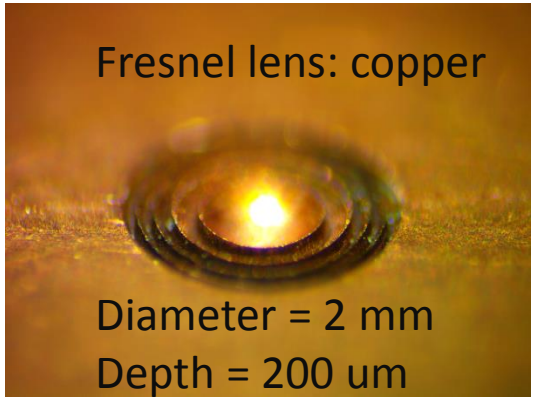
- Wakefield mapping
- Beam energy modulation
- Microbunching
- Tunable dechirping
- Enhanced transformer ratio measurement
- Numerous THz measurements:
  - DLA – cylindrical, planar
  - Corrugated structure (with K.Bane (SLAC))
  - Selective mode excitation in a multimode structure
  - Efficient power extraction
- Multistage THz generation experiment – limited by electron-optics and complex alignment

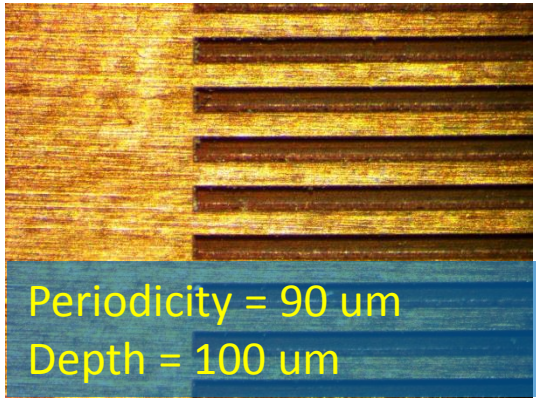
Laser Ablation Examples





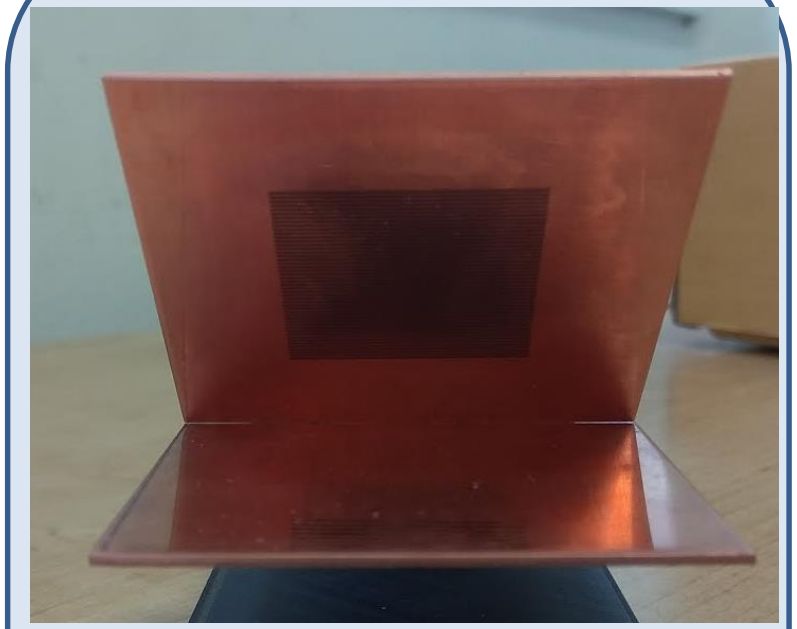




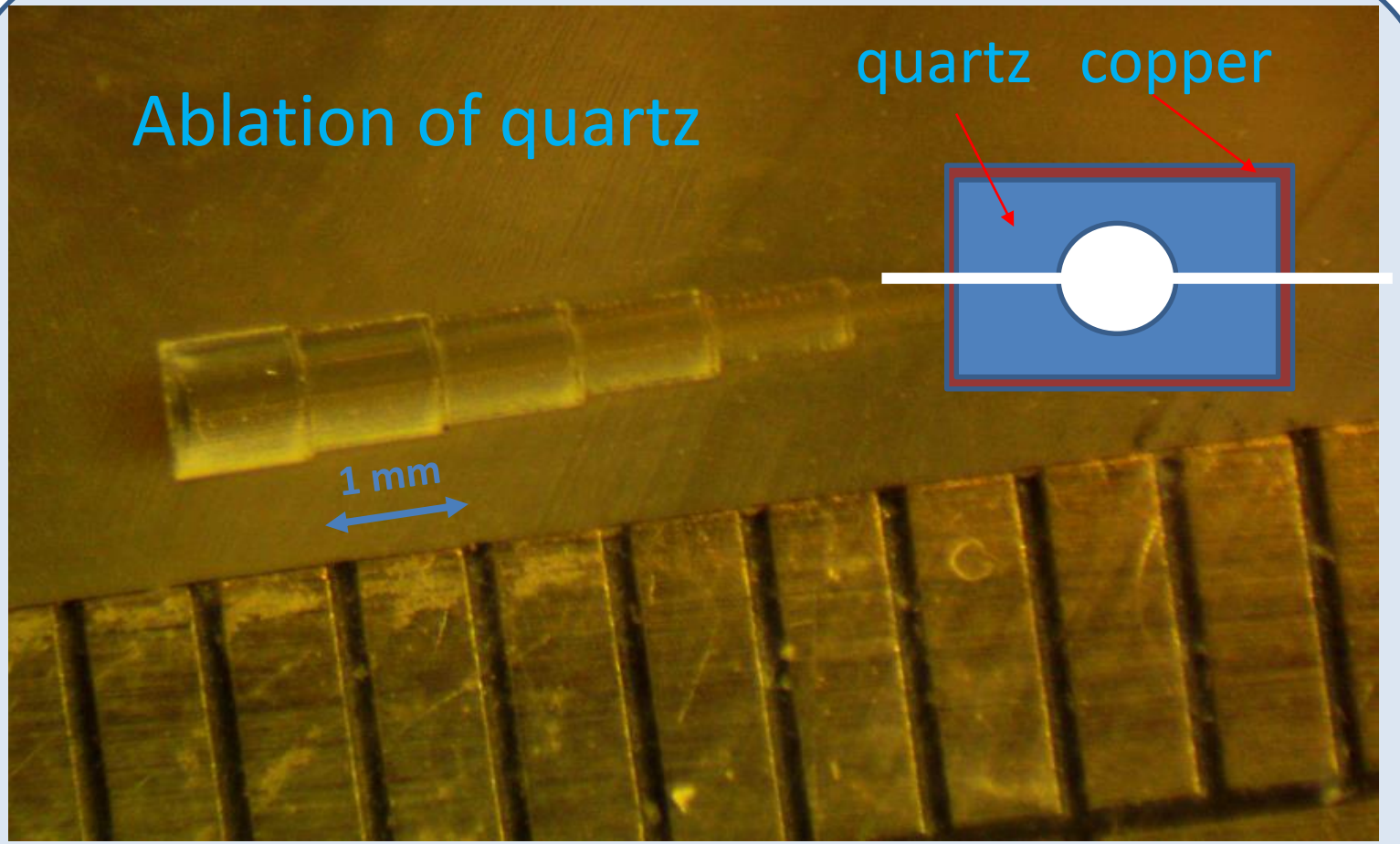


diamond, quartz, copper, tungsten

Femtosecond laser ablation for next generation wakefield structures



Groove polarizer: linear → circular (300 GHz)



Future plans

- Next generation wakefield / THz structures
- THz manipulation (polarization, detection …)
- THz “user” experiment (possible complementarity to UED program?)

Acknowledgements

- **Accelerator User Facility Team** (ATF-BNL)
- Wei Gai, Sasha Zholents (ANL)
- E. Gomez, R. Kostin, S. Kuzikov (Euclid)
- D. Wang, L. Yan (Tsinghua)
- D. Schegolkov, E. Simakov (LANL)

Electron Beam Requirements

Parameter	Nominal	Requested Experiment Parameters
Beam Energy (MeV)	50-65	*57 MeV*
Bunch Charge (nC)	0.1-0.5	*500 pC*
Compression	Down to 100 fs (up to 1 kA peak current)	*Motorized beam masking*
Transverse size at IP (sigma, um)	30 – 100 (dependent on IP position)	*75 um*
Normalized Emittance (um)	1 (at 0.3 nC)	*1-2 um*
Rep. Rate (Hz)	1.5	*1.5 Hz*
Trains mode	Single bunch	*Single bunch*

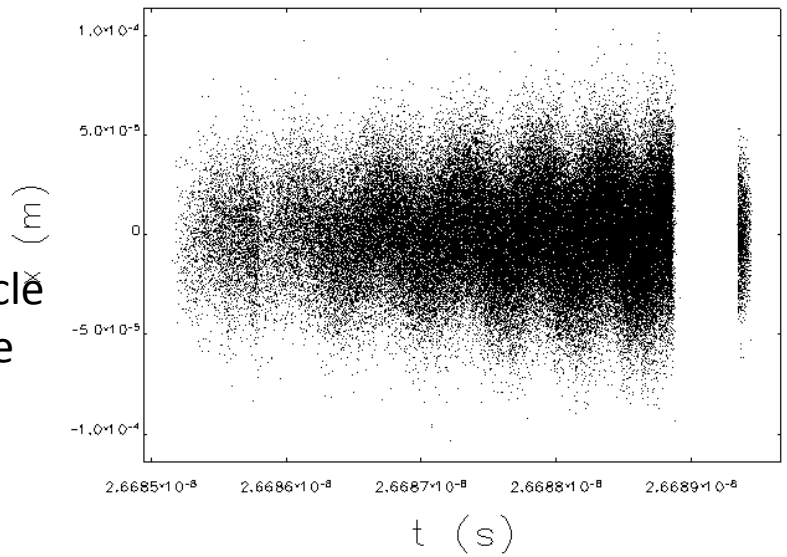
Special Equipment:

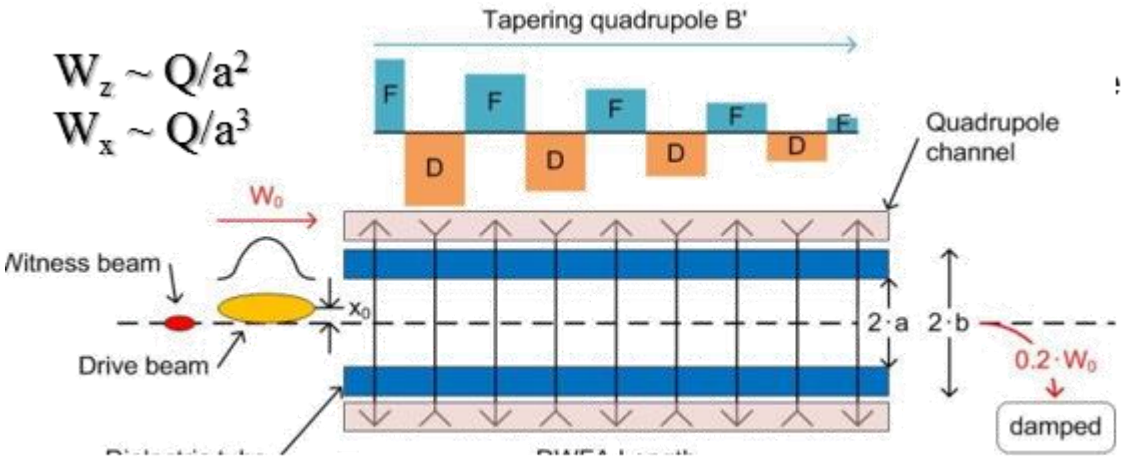
bolometer/interferometer setup required

Multi-meter collinear wakefield acceleration

Use of **FODO lattice** for beam confinement

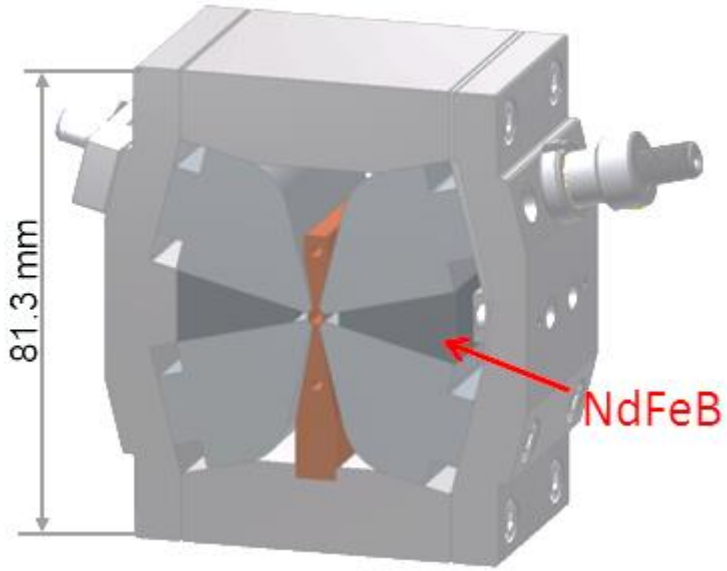
BNS damping, i.e., use of drive beam energy chirp to desynchronize transverse particle oscillations and thus reduce the resultant transverse electric wakefield





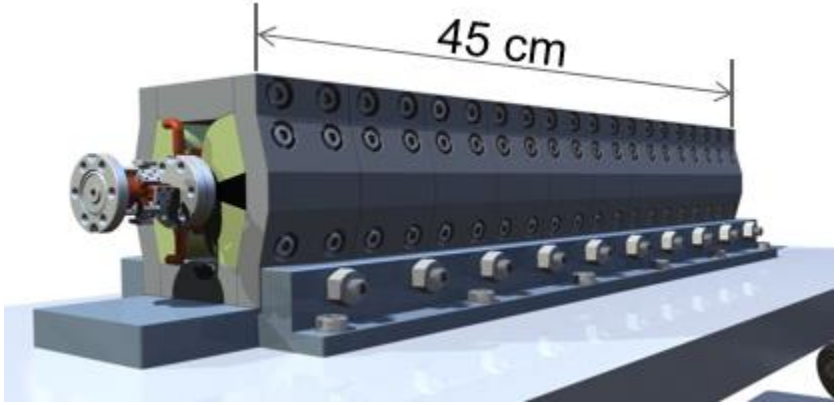
Dielectric channel imbedded into *quadrupole wiggler*

D. Shegolkov, E. Simakov (AAC 2014)



High gradient hybrid quad

- Bore radius = 1.5 mm.
- Peak gradient = 0.96 T/mm.
- Sub-micron precision in the magnetic center position.
- Length = 40 mm.
- Weight = 2.5 kg.
- Magnetic force between top and bottom parts = 30.5 kg.



N. Strelnikov, A. Zholents

Collaboration: APS-AWA-Euclid-LANL