ASTA User/PAC Meeting

Nano-Channeling Acceleration Research @ ASTA

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9: 15 – 9:30 Am, July 24, 2013

Opportunities with Crystal Technology for Accelerators

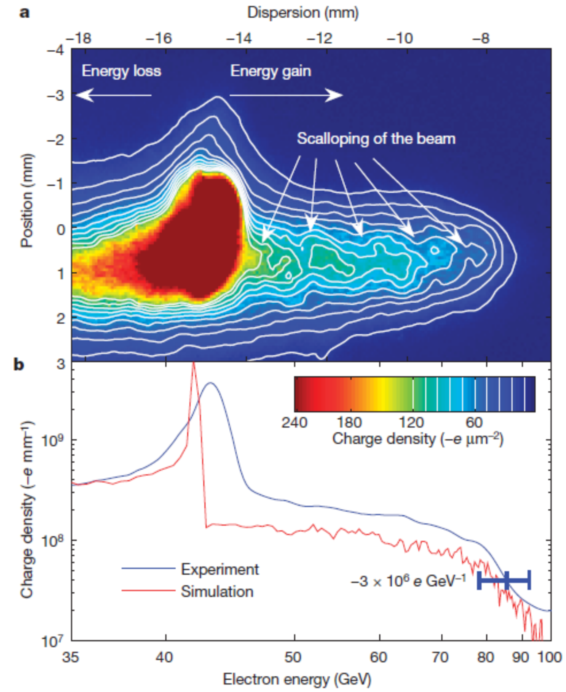
High Gradient Acceleration in Plasma Gas

$$E_0 = \frac{m_e c \omega_p}{e} \approx 100[\frac{GeV}{m}] \cdot \sqrt{n_0[10^{18} cm^{-3}]}$$

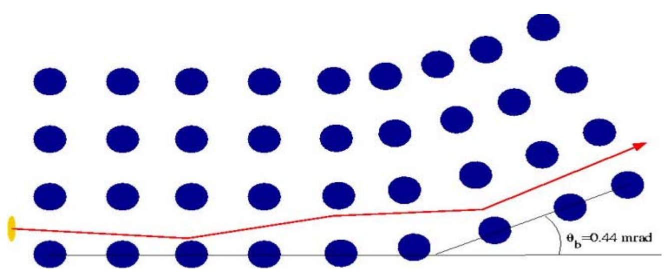
$10^{17} – 10^{18}cm^{-3}$ → 30 ~ 100 GeV/m

→ *Energy spectrum of the electrons (FFTB @ SLAC) (top) energy spectrum of the electrons in the 35 – 100 GeV range. (head: 43 GeV, tail: 85 GeV) (bottom) projection of the image in (top), shown in blue. The simulated energy spectrum is shown in red.*

Nature 445, 741-744 (2007)



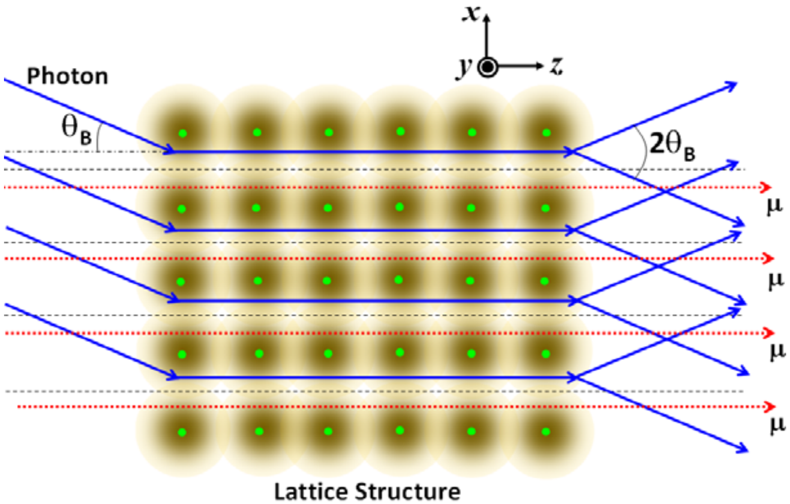
Accelerate channeled particles using plasma waves in crystal:



$10^{19} – 10^{22}cm^{-3}$ → 0.3 ~ 10 TeV/m

- **Very stable, can be used for**
  - **deflection/bending (*works*)**
  - **focusing (*works*)**
  - **acceleration (*if waves excited*)**

- **Laser-Driven Acceleration**



→ **T. Tajima and M. Cavenago, Phys. Rev. Lett. 59, 1440 1987**

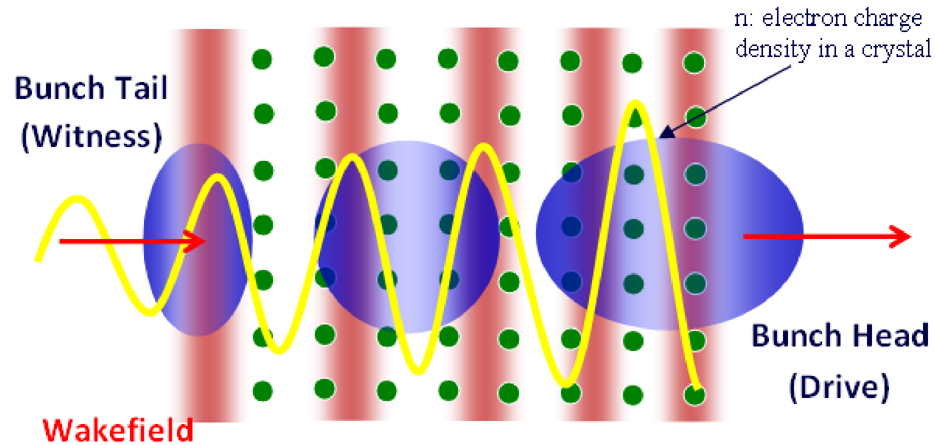
- **Particle species: proton/muon**
- **Driving Source: External Laser Pumping**
- **Required Laser Specs**

  - **Diffraction Resonance (λ_ν < *a, a:* lattice constant)**

    → **Energy: 40 keV (hard X-ray)**

  - **$E_l < E_\nu < E_b$ (E_l: Energy Loss, E_b: Atomic Binding Energy)** → **Power: > 3 GW**

- **Beam-Driven Acceleration**

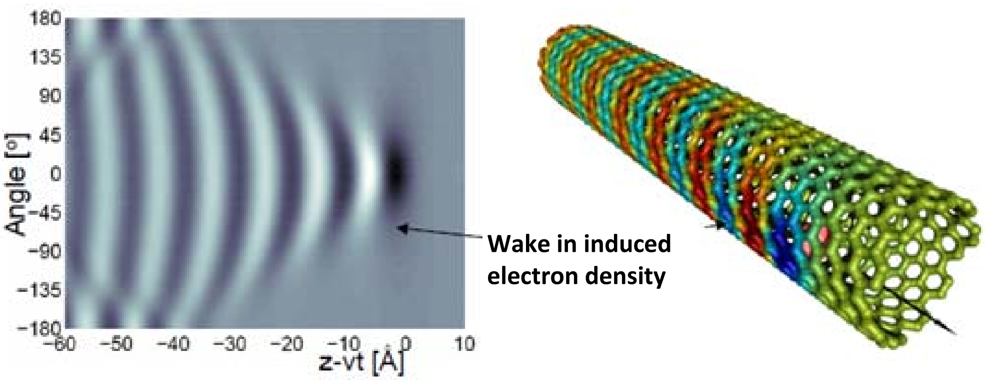


→ **P. Chen and R. J. Noble, AIP Conf. Proc. 156, 222 1987**

- **Particle species: electron/positron**
- **Driving Source: Particle Bunch (Self-Acceleration)**
- **Required Beam Specs**

  - **Bunch Length: $\leq \lambda_p$**
  - **Spot size: $\geq \lambda_p$**

CNTs for Channeling Acceleration



Zoran Miskovic, "Prospects of on channelling through carbon nanotubes", REM talk

- **Nanostructure (e.g. CNT) vs Crystal**

(1) A size of a channel is readily controllable up to micron. The larger channel can
→ decrease de-channeling rates
→ increase acceptance angles
→ mitigate laser energy/power requirement

(2) Thermally and mechanically stronger than crystals, steels, or even diamonds (*sp*2 bond > *sp*3 bond)
→ Higher durability in extremely intense channeling radiation/acceleration

Nanotubes for HG Accelerator Application

[1] B. Newberger, T. Tajima, F. R. Huson, W. Mackay, B. C. Covington, J. R. Payne, Z. G. Zou, N. K. Mahale, and S. Ohnuma, in *Proceedings of the 1989 Particle Accelerator Conference*, Chicago, IL, edited by F. Bennett and J. Kopta IEEE, New York, 1989, p. 630

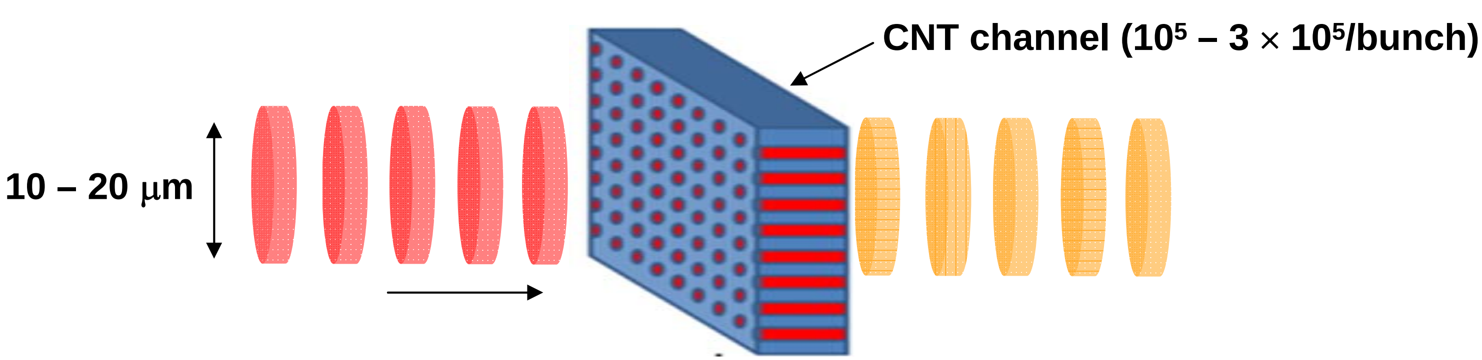
[2] L. A. Gevorgyan, K. A. Ispiryan, and R. K. Ispiryan, Pis'ma Zh. Eksp. Teor. Fiz. 66, 304 1997, JETP Lett. 66, 322 1997

[3] B. Rau and R. A. Cairns, Phys. Plasmas 7, 3031 2000

[4] S. V. Bulanov, F. F. Kamenets, F. Pegoraro, and A. M. Pukhov, Phys. Lett. A 195, 84 1994

[5] N. Saito and A. Ogata, Phys. Plasmas 10, 3358 2003

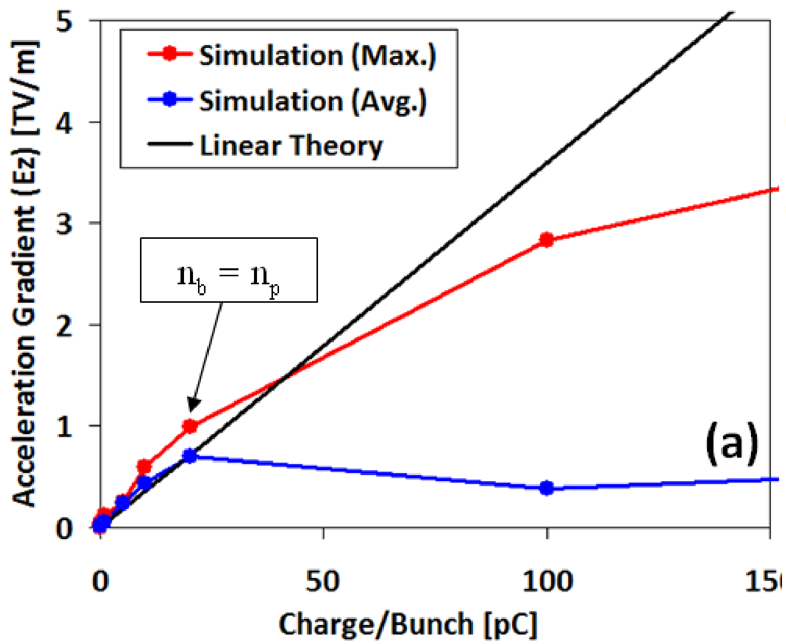
[6] M. Murakami, and M. Tanaka, Appl. Phys. Lett. 102, 163101 (2013)

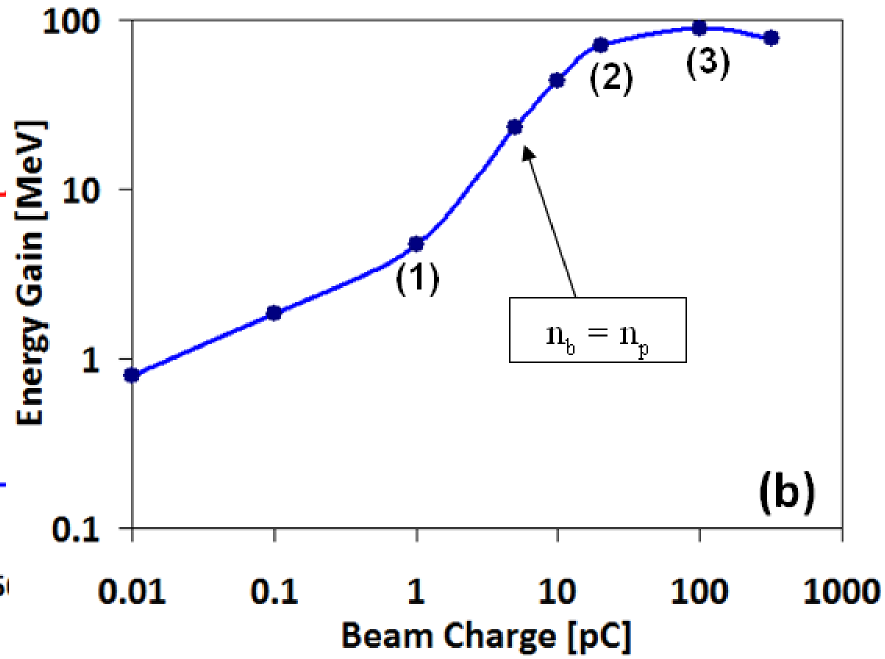


Gain Analysis of Low Density at 50 MeV

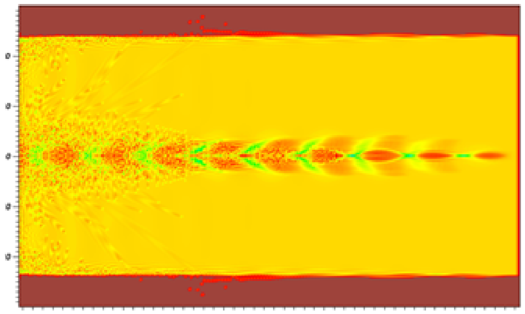
- Beam Energy = 50 MeV
- Bunch-to-Bunch Distance = 10 μm
- # of Bunches = 10
- Bunch Length (RMS) ~ 2 μm
- Channel Charge Density = 10^{19} cm^{-3}
- Channel Length = 100 μm

Simulation: Vsim (VORPAL 6.25): "Beam-Driven Wakefield Simulator"

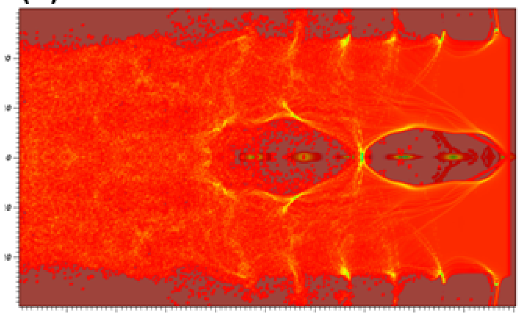




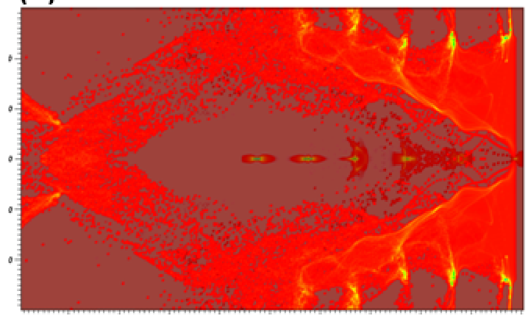
(1)



(2)

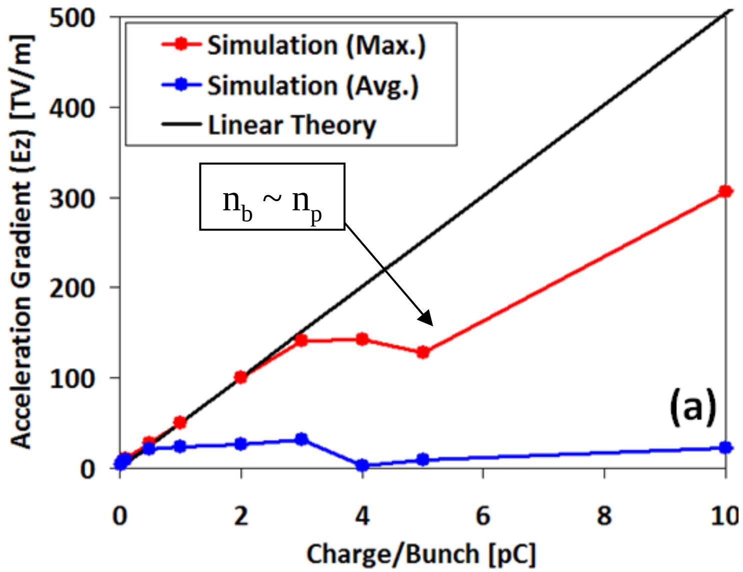


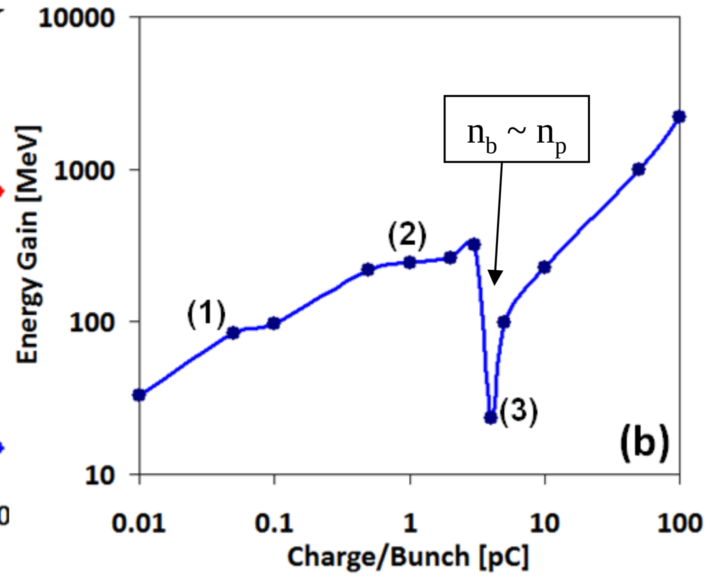
(3)

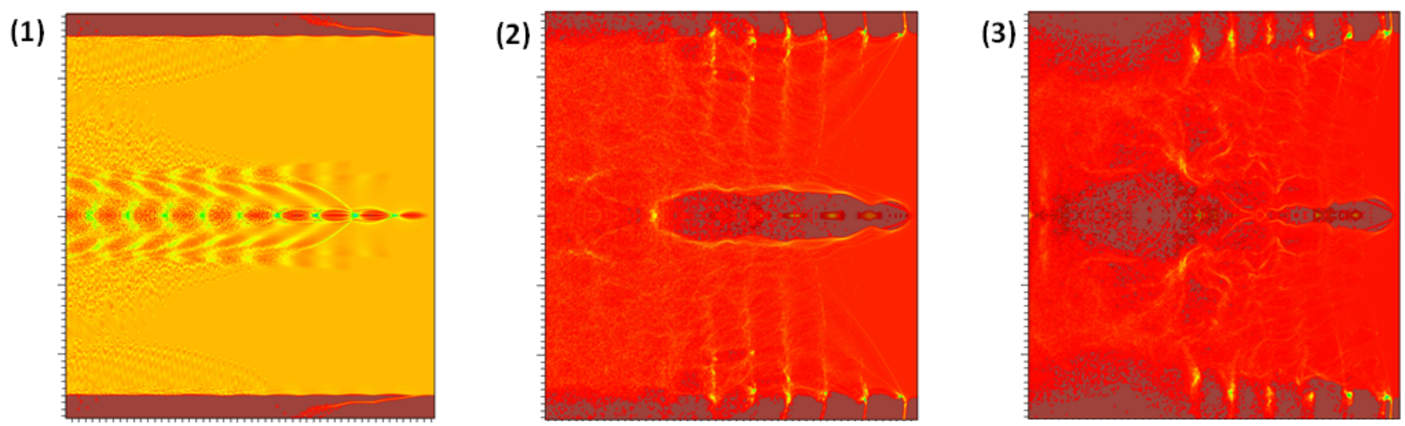


Gain Analysis of High Density at 200 MeV

- Beam Energy = 200 MeV
- Bunch-to-Bunch Distance = 0.267 μm
- # of Bunches = 10
- Bunch Length (RMS) ~ 27 nm
- Channel Charge Density = 1.6×10^{22} cm^{-3}
- Channel Length = 2.67 μm

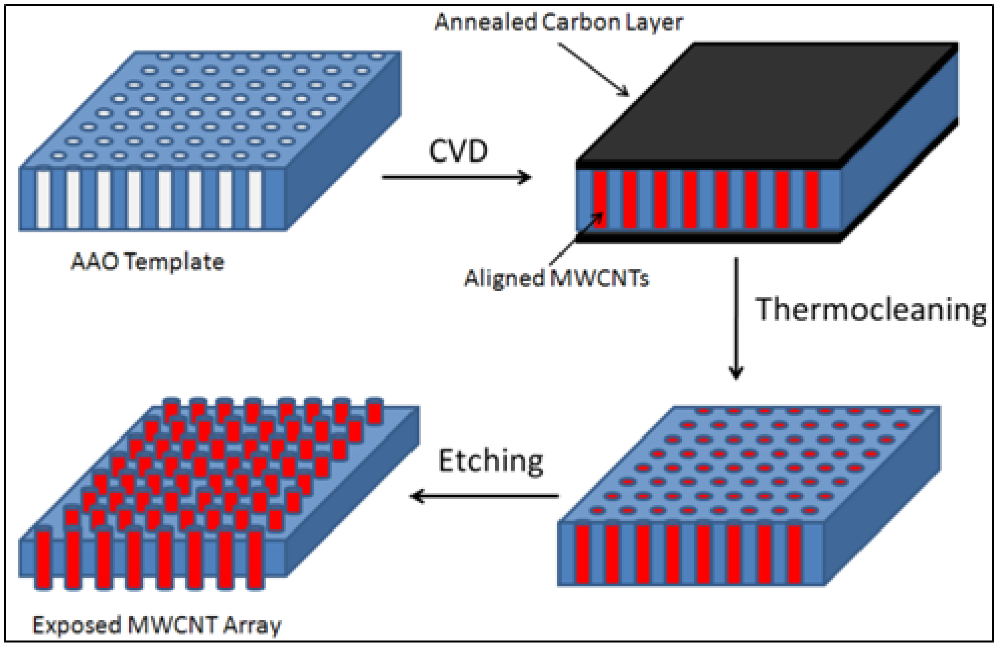


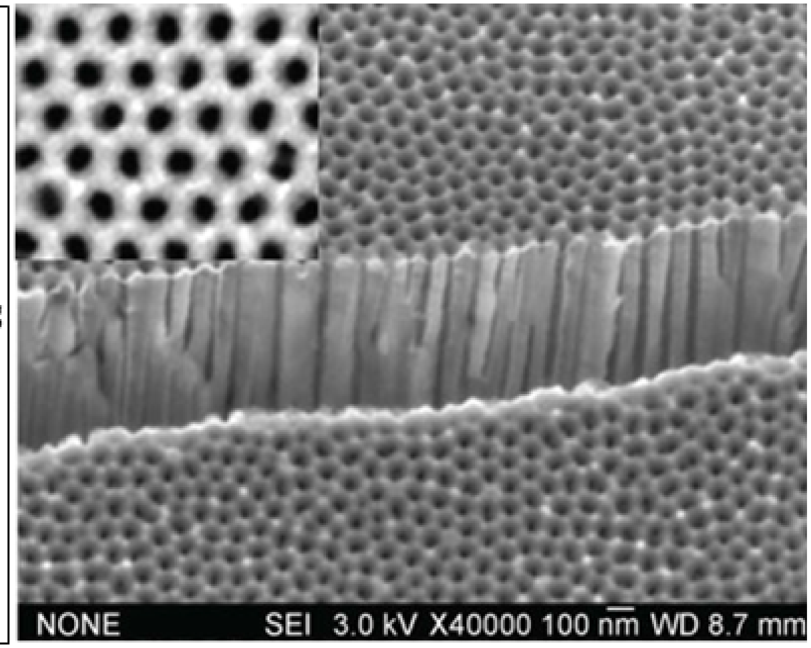




Fabrication of Test Devices

Anodic Aluminum Oxide (AAO) Template Technique (MWCNT)





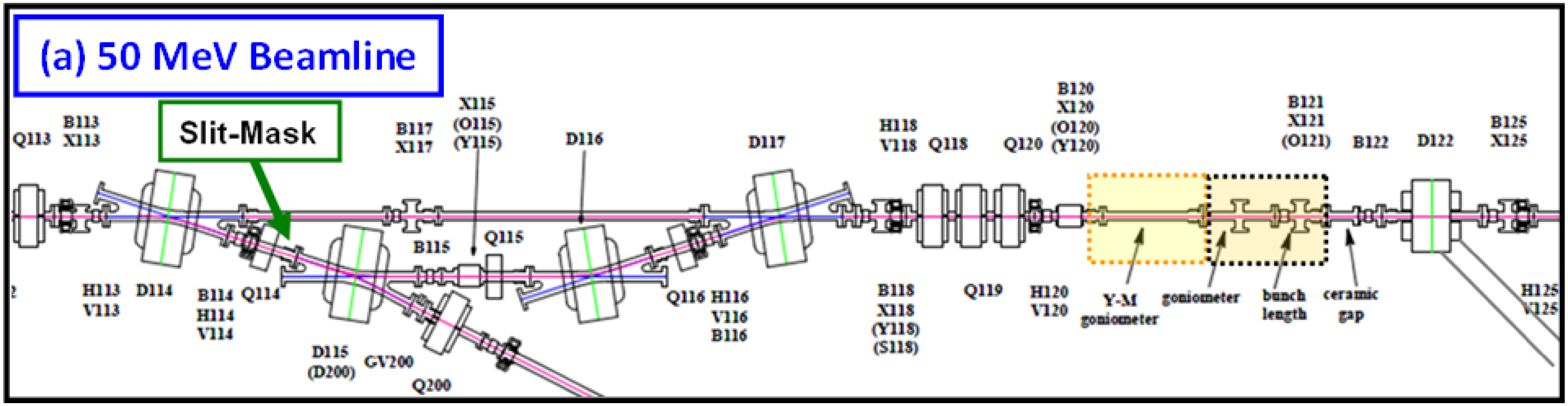
The AAO film has uniform and straight nano-size channels with a tailored length and diameter. The length, diameter, and density of the as-synthesized CNTs can be uniformly tailored because of the controllability of the pore texture of AAO template.

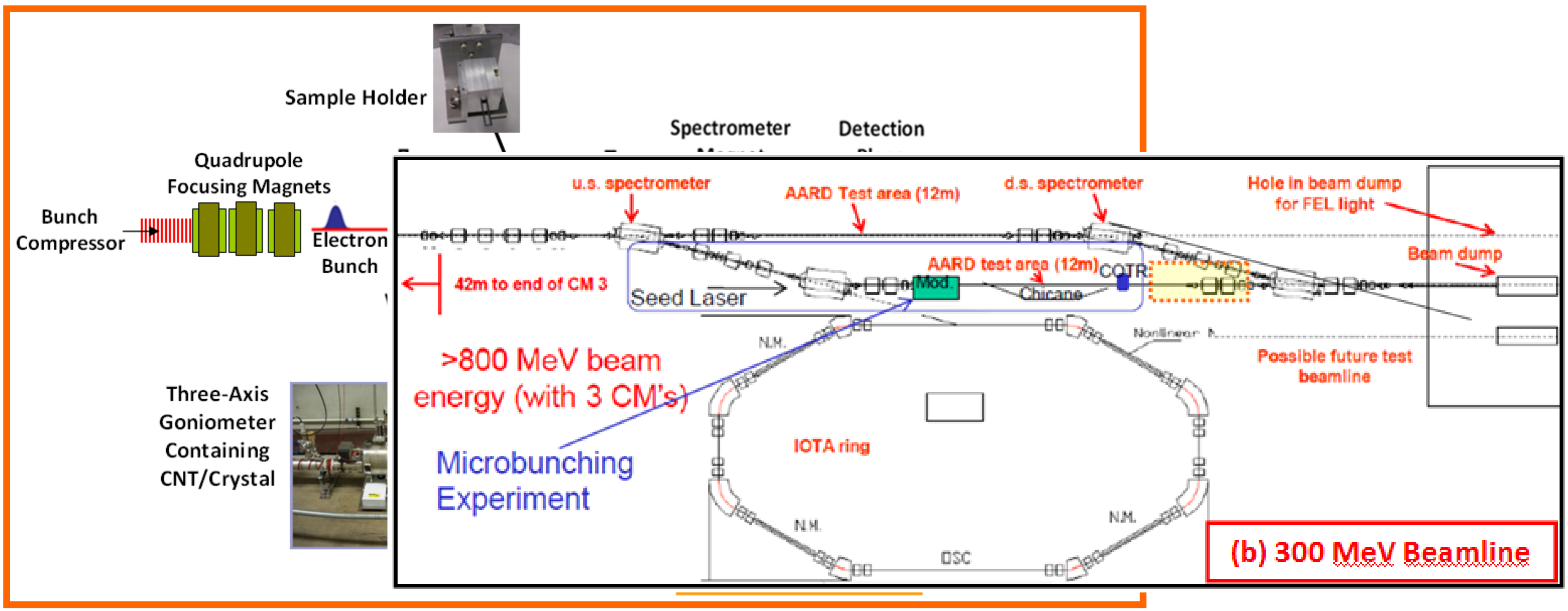
→Width: ~ sub-micron
→Length: 50 ~ 100 micron

Tao Xu of NIU (Dept. of Chemistry) has a full set of hands-on equipment to process growth of MWCNTs on an AAO template.

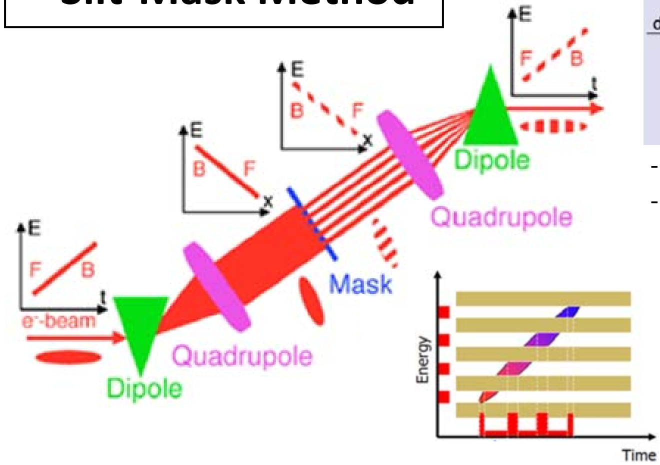
[1] Masuda H, Hasegwa F, Ono S. J Electrochem Soc, 197, 144: L127–L130
[2] Martin C R. Chem Mater, 1996, 8: 1739–1746
[3] Kyotani T, Tsai L F, Tomita A., Chem Mater 1995, 7: 1427–1428
[4] Kyotani T, Tsai L F, Tomita A., Chem Mater 1996, 8: 2109–2113
[5] Chen Z, Zhang H G., Soc, 2005, 152: D227 –D231
[6] Thompson G E., Thin Solid Films, 1997, 297: 192–201

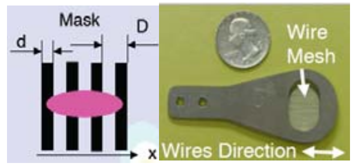
Experiment Layout





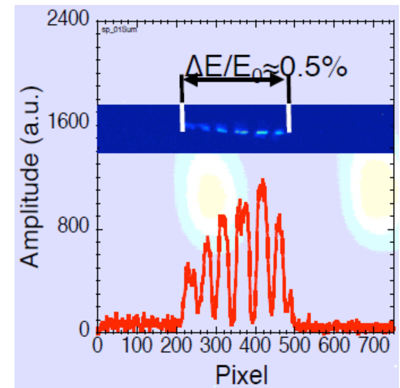
• Slit-Mask Method





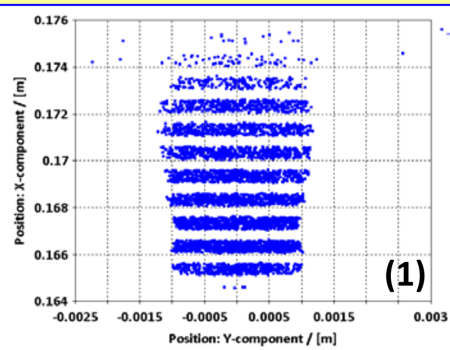
- D = 1,270 μm
- d = 508 μm (T = 60 %)

Exp. Parameters @ BNL-ATF

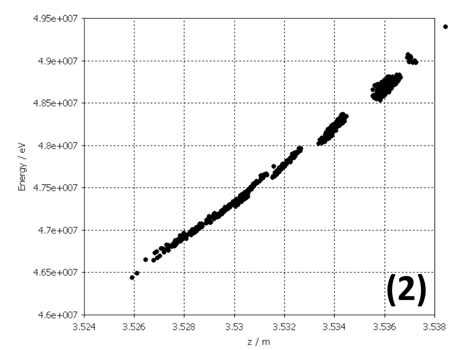


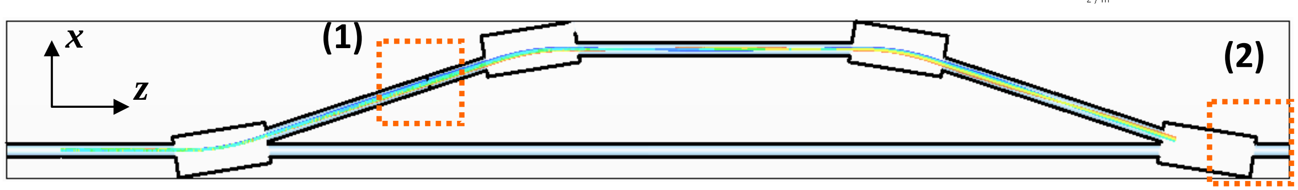
P. Muggli, et. al., PRL 101, 054801 (2008)

• Slit-Mask Microbuncher @ ASTA – 50 MeV Beamline



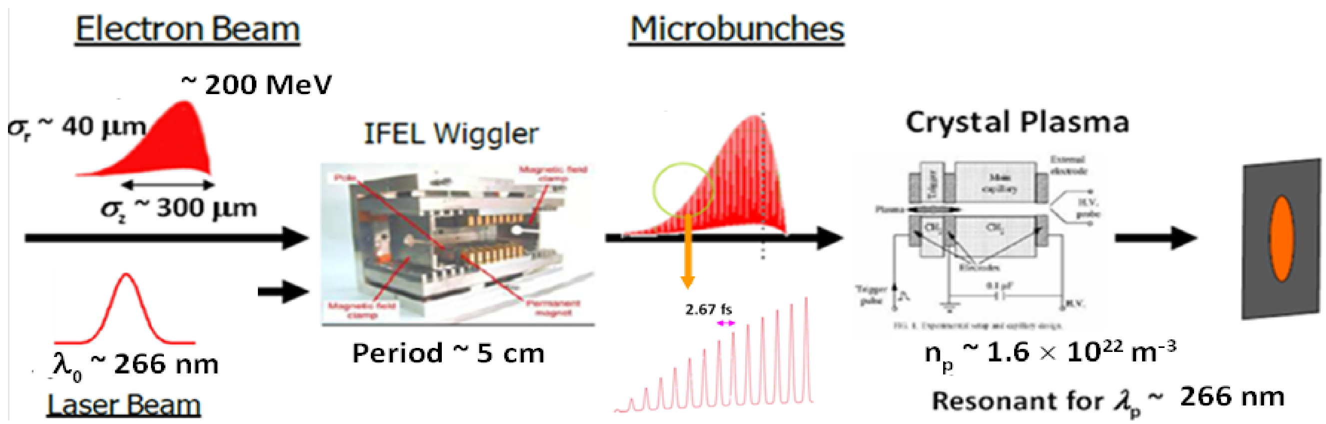
- D = 100 μm
- d = 50 μm (T = 50 %)





Micro-bunch Generation Technique (2): IFEL

- **IFEL Method**



Phase #	Beam Energy (MeV)	Laser Fundamental (nm)	Und. Period (cm), K, n	Microbunching Harmonics (nm)
1a	44.5	800	2.18, 1.2, 3	400,266, 200
1b	44.5	800	2.18, 1.2, 3	100,90,80
2	200	266	5,1.2,1	48, 29,26
	250	800	20, 1.36,1	400,266,200,80
2	500	--	5,1.2,1	---
2	500	266	5,1.2,3	48,29,26
3-HGHG	900	TBD	TBD	
4-SASE	900	--	1.1,0.9,1	3

A. Lumpkin, ASTA-Proposal

Beam Parameter/Personnel Involved/Other Opportunity

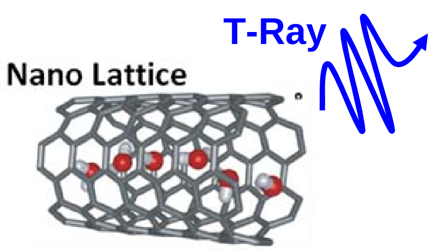
- **Required Beam Parameters (TBO)**

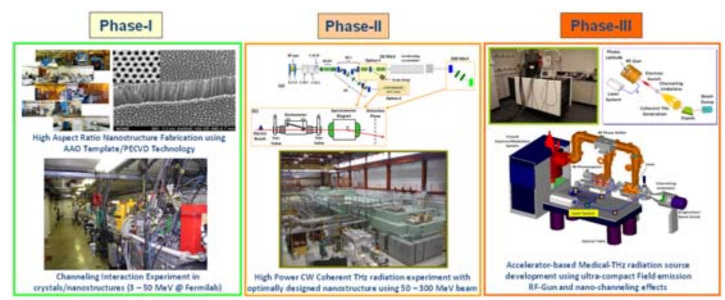
- **Personnel Involved (TBD)**

	Planning	Experiment	Diagnostics	Analysis	Simulation
Y. M. Shin	V	V		V	V
T. Xu		V			
J. C. Thangaraj			V		
V. Shiltsev	V			V	
D. Still		V			
K. A. Carlson		V			
A. Grabenhofer				V	V

Y. M. Shin: Accelerator Physicist
T. Xu: Nano-Fabrication Expert
J.C. Thangaraj: Beam Diagnostics/Microbunching Experimentalist
V. Shiltsev: Crystal R&D Expert
K. A. Carlson/D. Still: Engineering Physicists
A. Grabenhofer: NIU Graduate

- **Other Opportunity – Coherent THz Source Development**





- Collaboration with Muonsinc/Jlab (F. Marhauser, G. Flanagan, R. Johnson)

Summary

- **Why Channeling Acceleration Research is important….??**

→ ***Because It Offers New Opportunities for Accelerator Technology in Energy Frontier***

- **TeV/m Acceleration Gradient → Stable High Energy Gain**
- **Strong Beam focusing**
- **High Energy/High Intensity Beam Control → Fast Cooling**

- **Why ASTA…??**

→ ***Because it Supplies High Quality Electron Source for Advanced Accelerator R&D***

- **High Brightness Beam**
- **Wide Range of Beam Shaping Flexibility (EEX, Flat Beam Formation, etc)**
- **Stable Operation**

- **What Next…??**

→ ***Plan, Design, Assemble, Install, Test, Analyze….***

- **Crystal Channeling Accelerator Can be a Breakthrough for future PeV Collider!**

Acknowledgement

(1) We thank Dean Still and Kermit Carlson for Technical Support and for Relocating Goniometers and Electronics from E0/D0 to ASTA
(2) We thank Alex Lumpkin for sharing his suggestion on micro-bunching
(3) We thank Philippe Piot for helpful discussion and support for the proposal and Chris Prokop for sharing his ASTA simulation design parameters.