Introduction to dielectric wakefield acceleration

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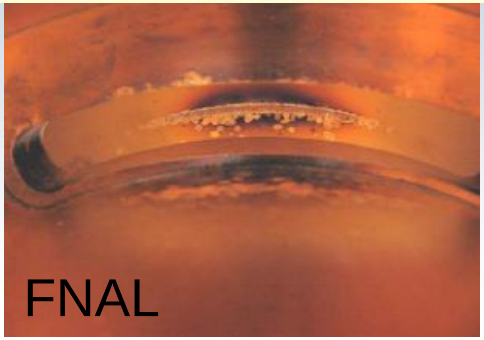
April 6, 2015

A problem for conventional accelerators

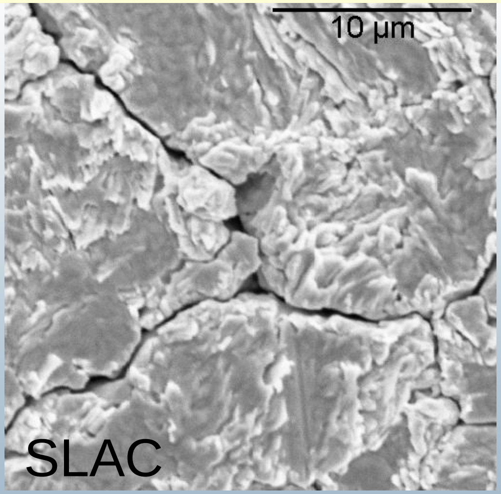
The challenge

- Microwave (rf) cavities are commonly used to accelerate beams
- They can suffer from:
  - field-emission & multipactoring
  - surface damage
  - breakdown
  - Above effects seem to be enhanced in the presence of a magnetic field
- New paths for acceleration?

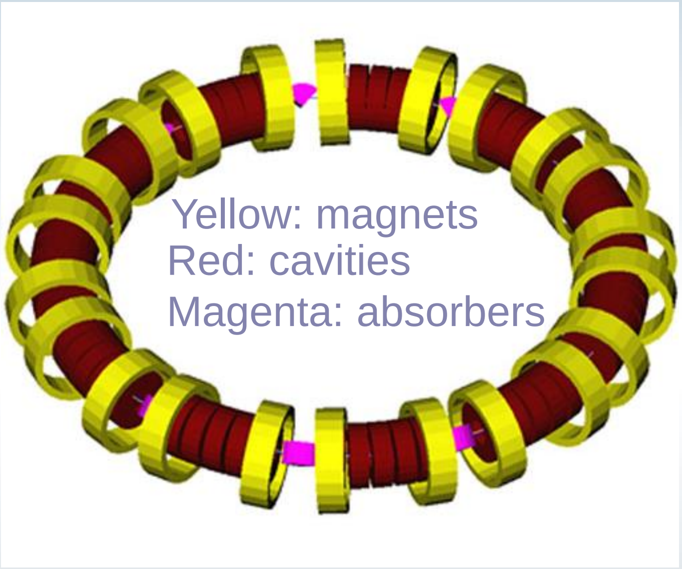
Damage in a 805 MHz

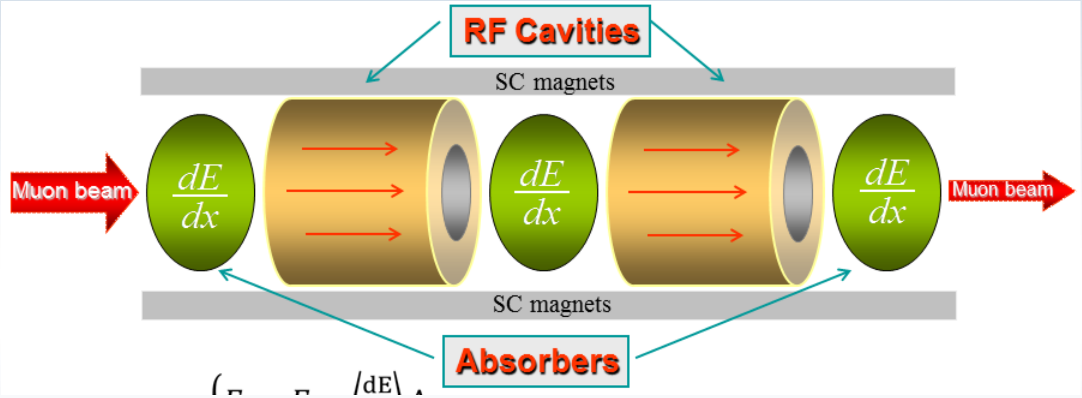


Damage in a 11.4 GHz



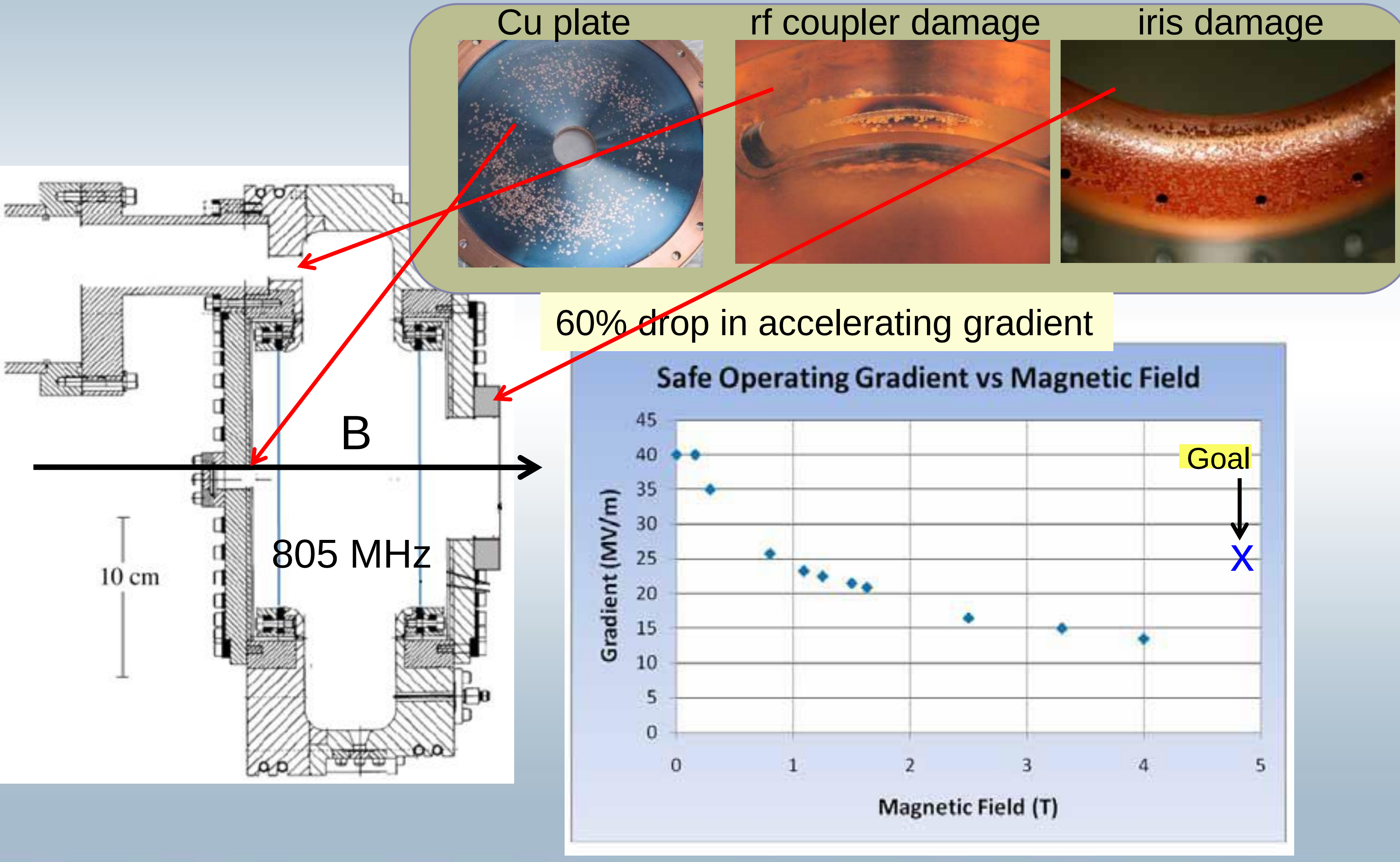
Recall muon ionization cooling…





- Muon beams are cooled via ionization cooling
- Requires rf cavities to operate within multi-Tesla magnetic fields
- Typical values: 805 MHz cavities in 2-5 T fields!

Example of rf breakdown



Further reading

- Nice review paper on breakdown with emphasis on contributions from the magnetic field in the process

rf breakdown with external magnetic fields in 201 and 805 MHz cavities

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(Received 8 September 2008; published 12 March 2009)

- More B-field specific:

Contents lists available at ScienceDirect
Nuclear Instruments and Methods in Physics Research A
journal homepage: www.elsevier.com/locate/nima
ELSEVIER

Effects of external magnetic fields on the operation of high-gradient accelerating structures

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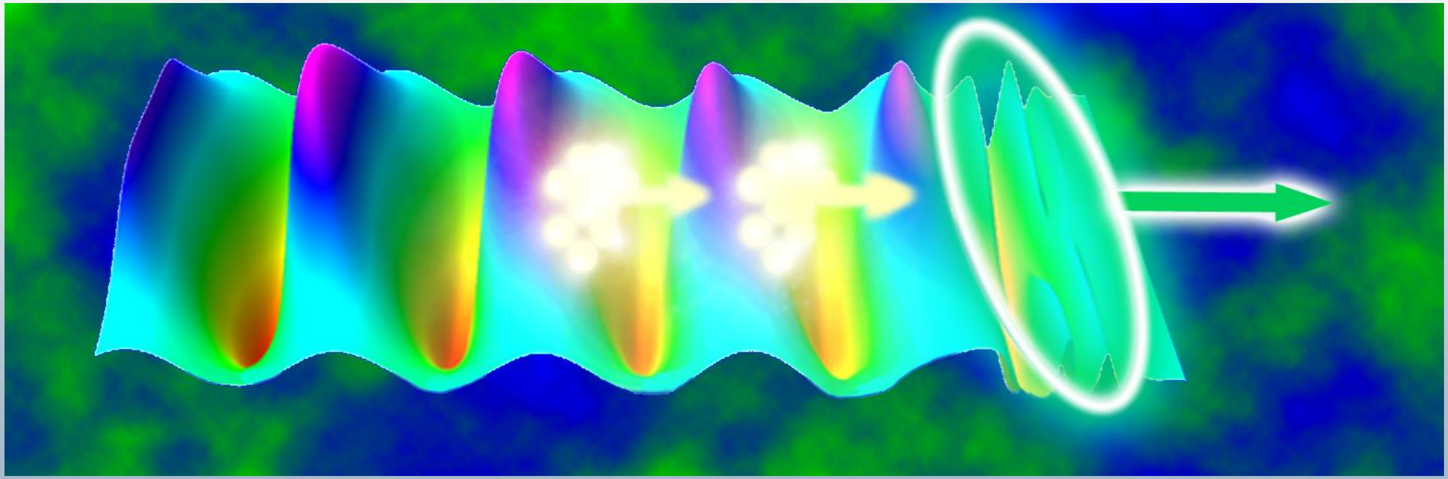
- More: Just “google”: “rf cavities, breakdown, SLAC”

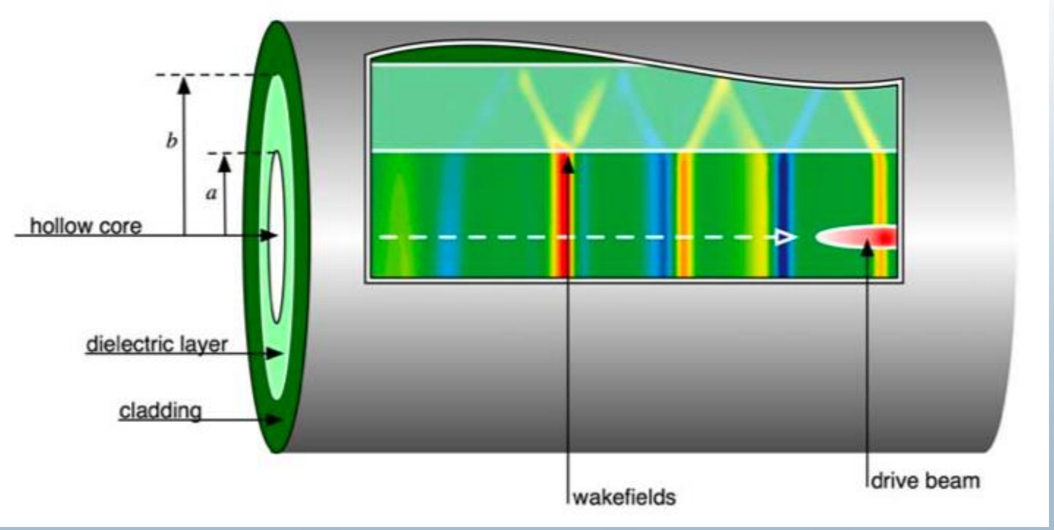
Treatment: Wakefield acceleration

- Many types
  - Plasma wakefield acceleration (PWA)
  - laser wakefield acceleration (LWA)
  - dielectric wakefield acceleration (DWA)
- Focus of this talk is on DWA



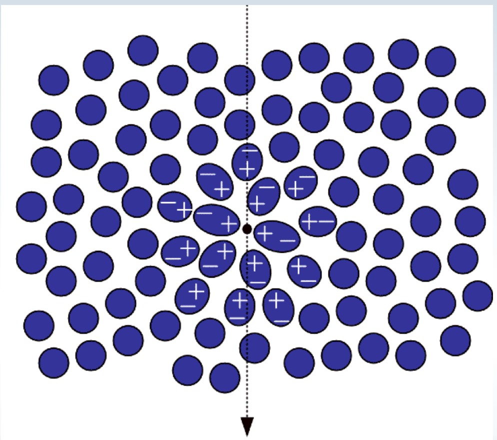
Dielectric wakefield acceleration

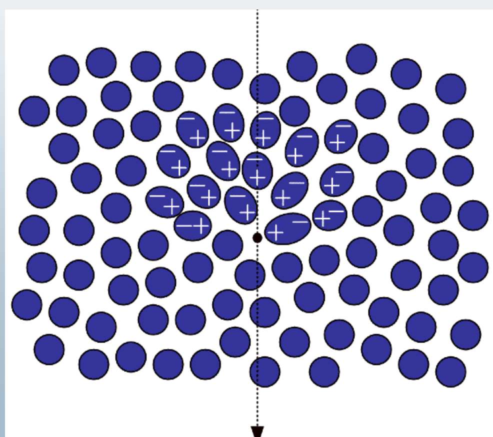
- In a dielectric wakefield accelerator, electromagnetic power is radiated by an ultra-short, intense "driving" electron bunch propagating in a hollow dielectric fiber. This power is then used to accelerate another "witness" bunch.
- Has shown to produce GV/m acceleration gradients.

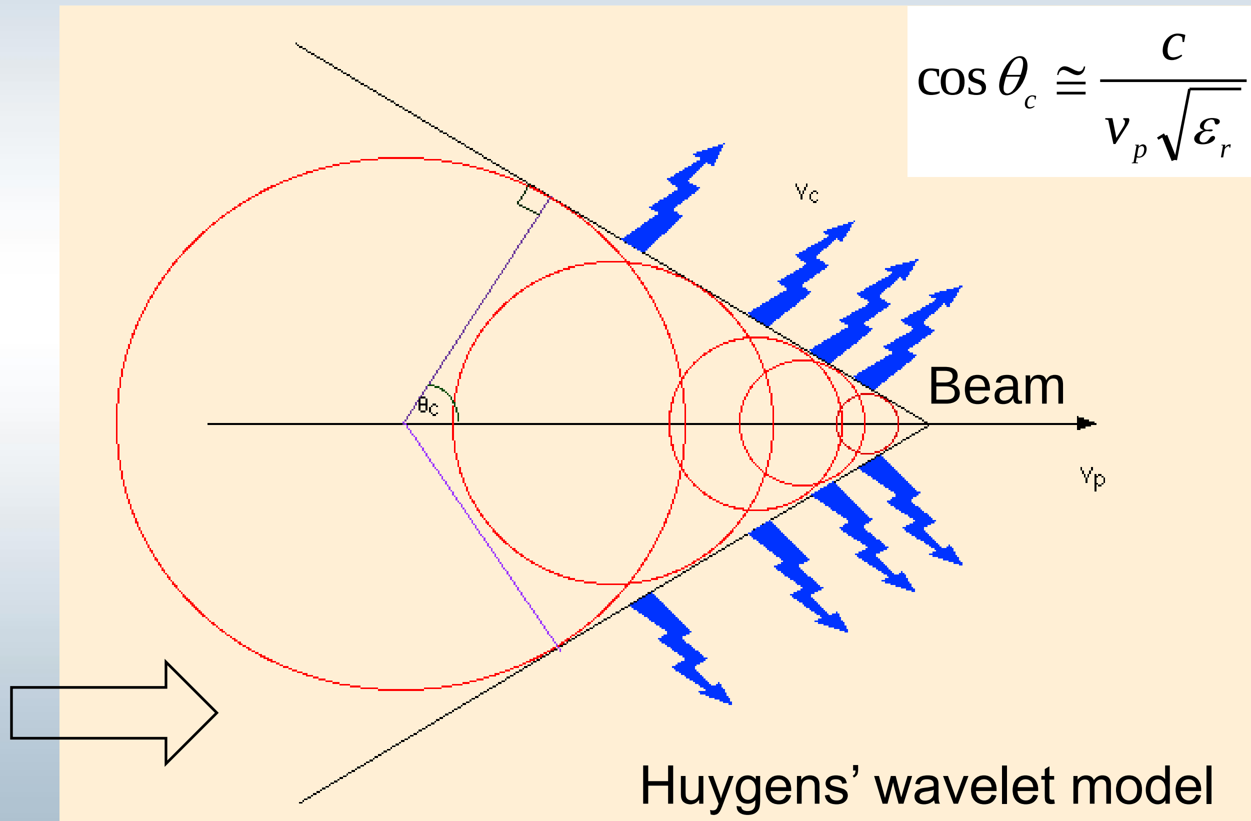


The “wake” mechanism

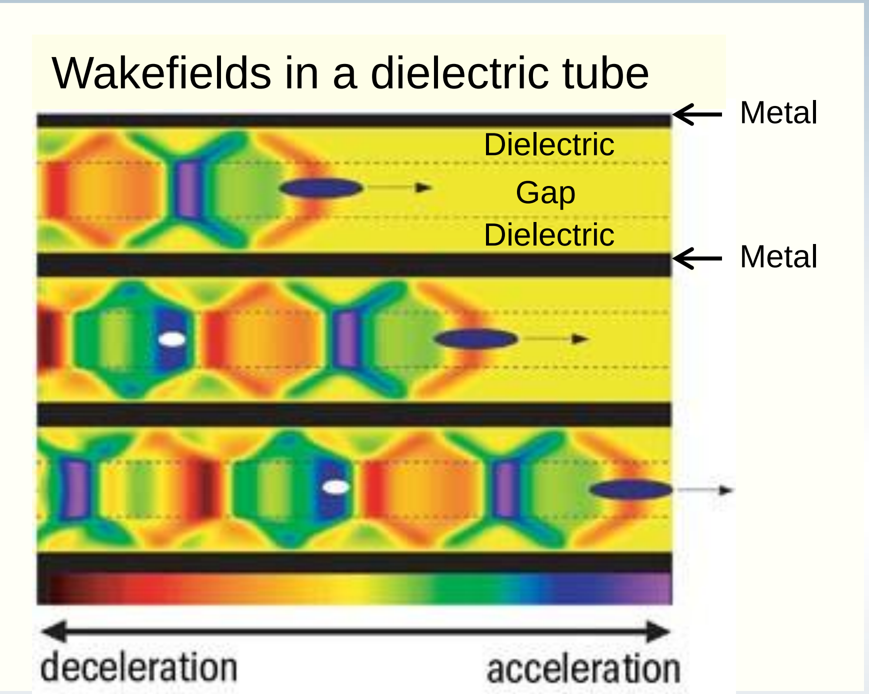
- Cherenkov radiation:







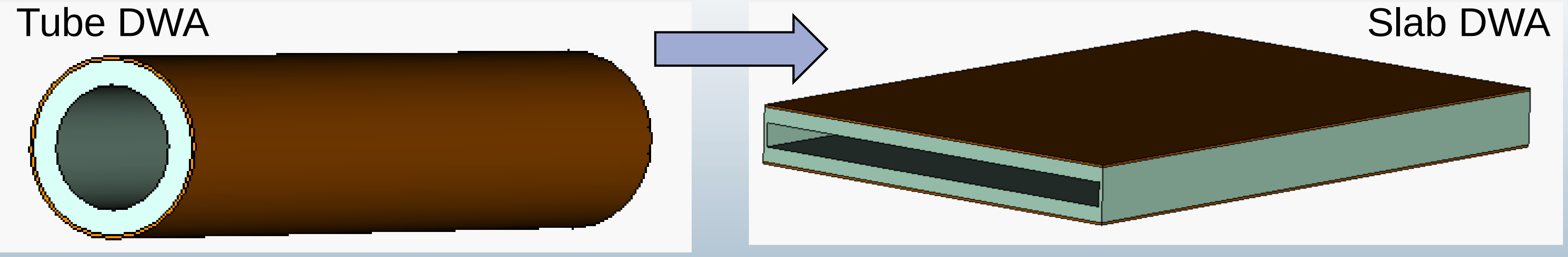
The concept



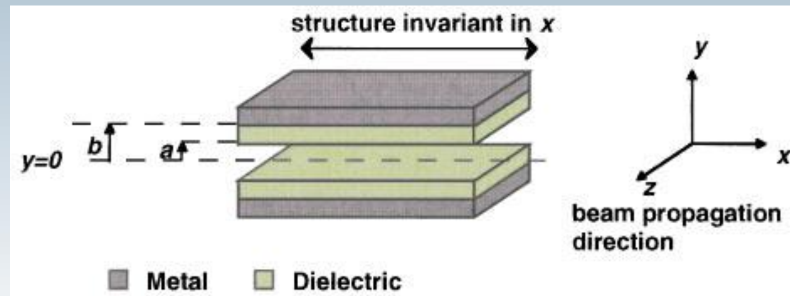
- Dielectric wakefield accelerator:
  - The radiated electric field propagate towards the outer boundary of the structure at the Cherenkov angle and reflected back to wards the center axis where a second beam is accelerated
  - Typical transverse size: a few 100-500 µm

Advantages of slab DWA geometries

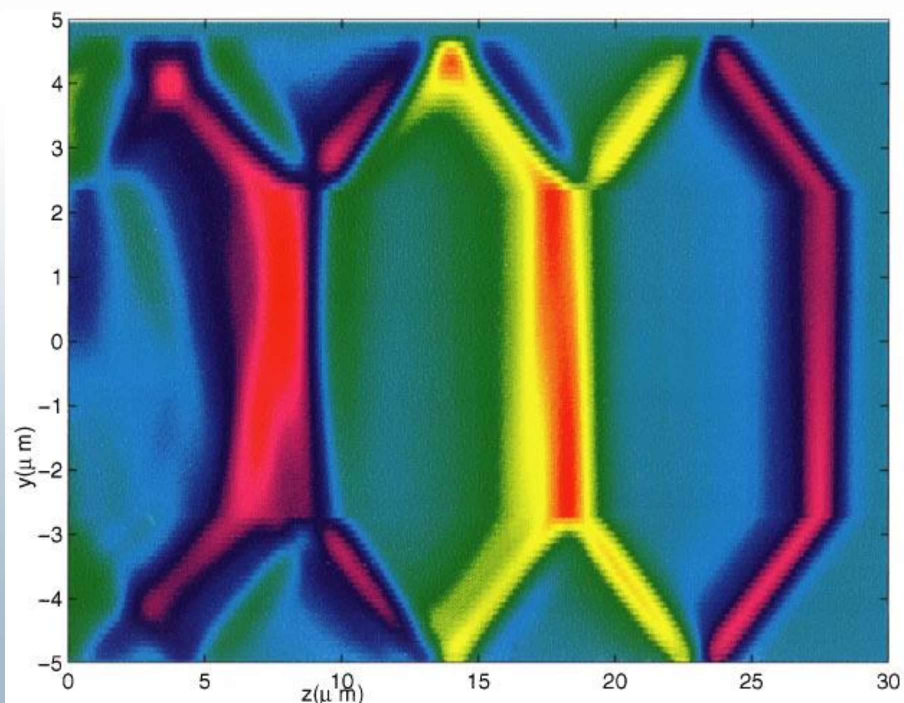
- Many experiments rely on a tube-shaped DWA
- Exploration of slab-shaped geometries maybe beneficial:
  - **Better tuning:** The operating parameters of the slab can be easily adjusted by moving the side walls
  - **No transverse wakefields:** Strong suppression of transverse wakefields.

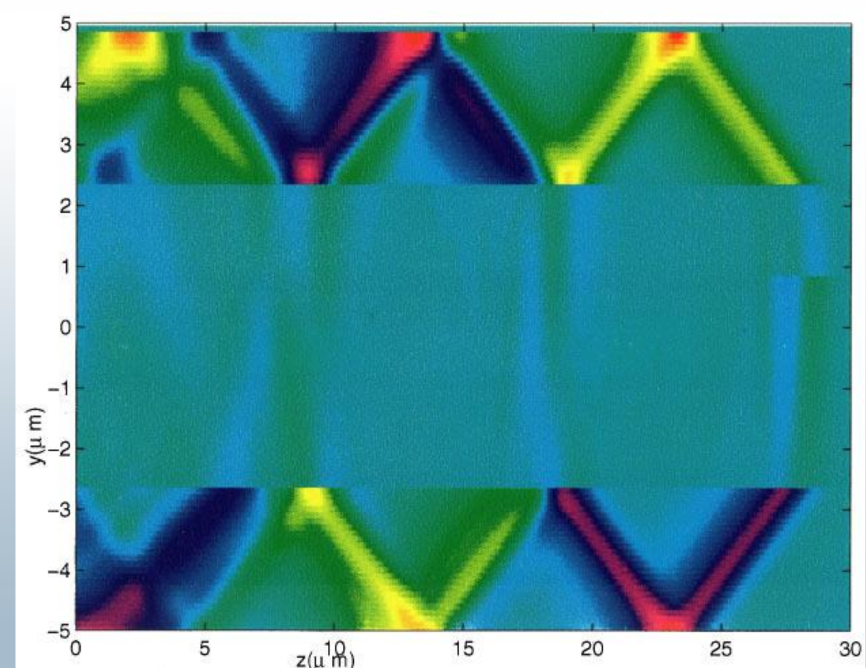


Wakefields in a slab DWA (1)

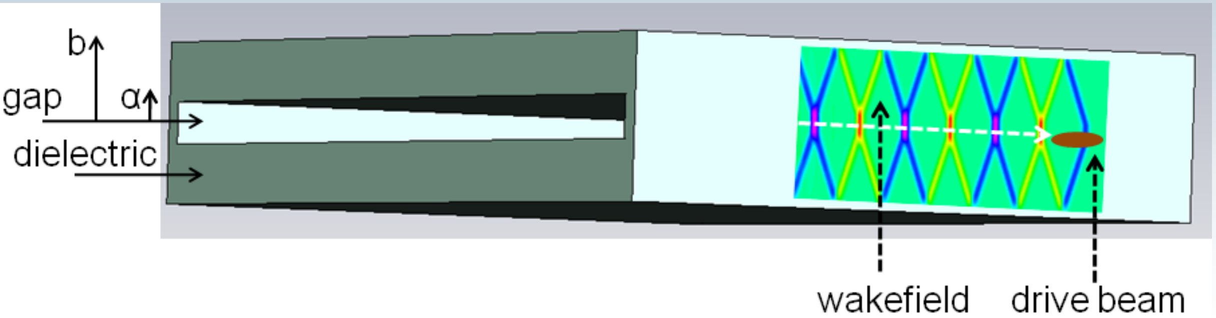


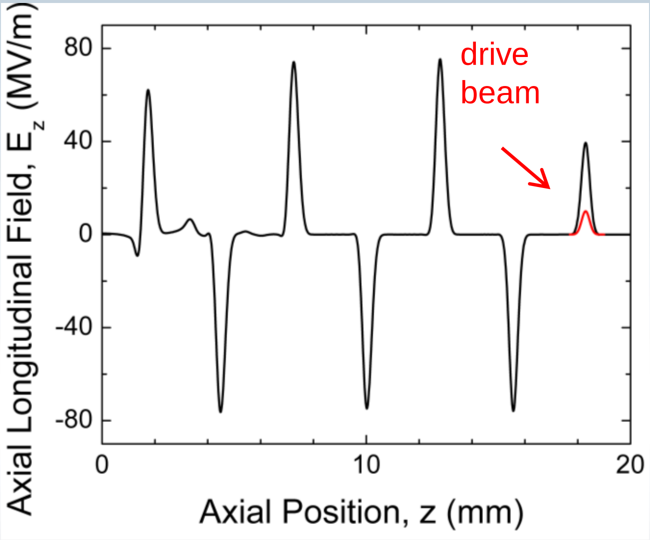
- Longitudinal wakefield
- Transverse wakefield





Wakefield in a slab DWA (2)

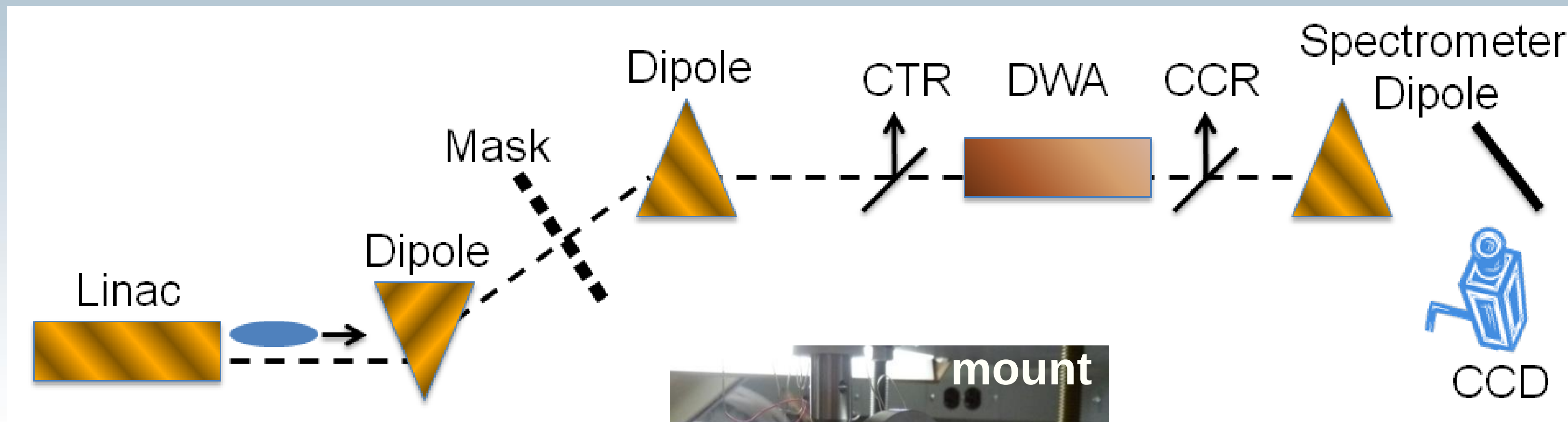


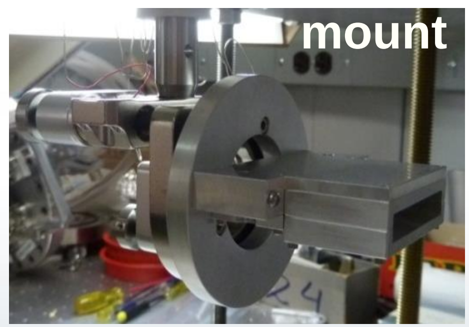


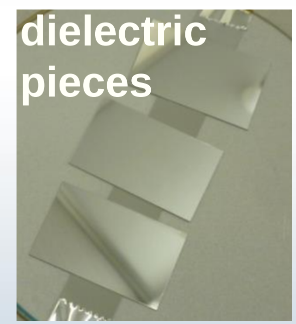
- Electron bunch drives Cerenkov wake in slab:
  - Wakefield accelerate the trailing bunch
  - Dependent on the structure properties
  - Peak accelerating field:
  - The radiated energy is concentrated in discrete modes corresponding to the eigenmodes of the structure

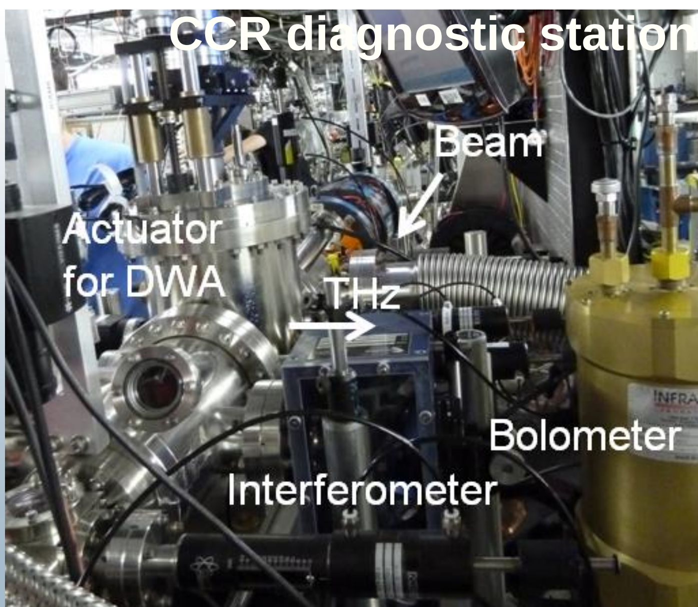
$$E_{z,acc} = \frac{Q}{\varepsilon_0 \left(a + 2\pi\sigma_z \frac{\varepsilon_r}{\sqrt{\varepsilon_r - 1}} \right)}$$

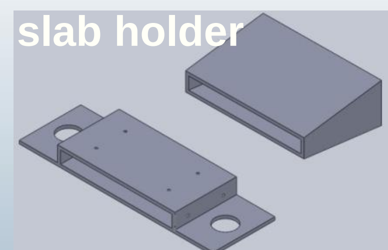
Experimental tests at ATF (BNL)

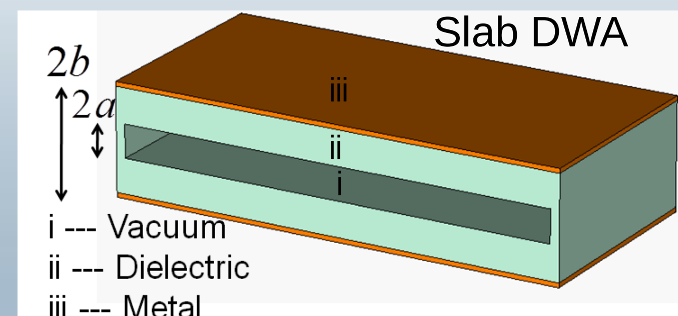




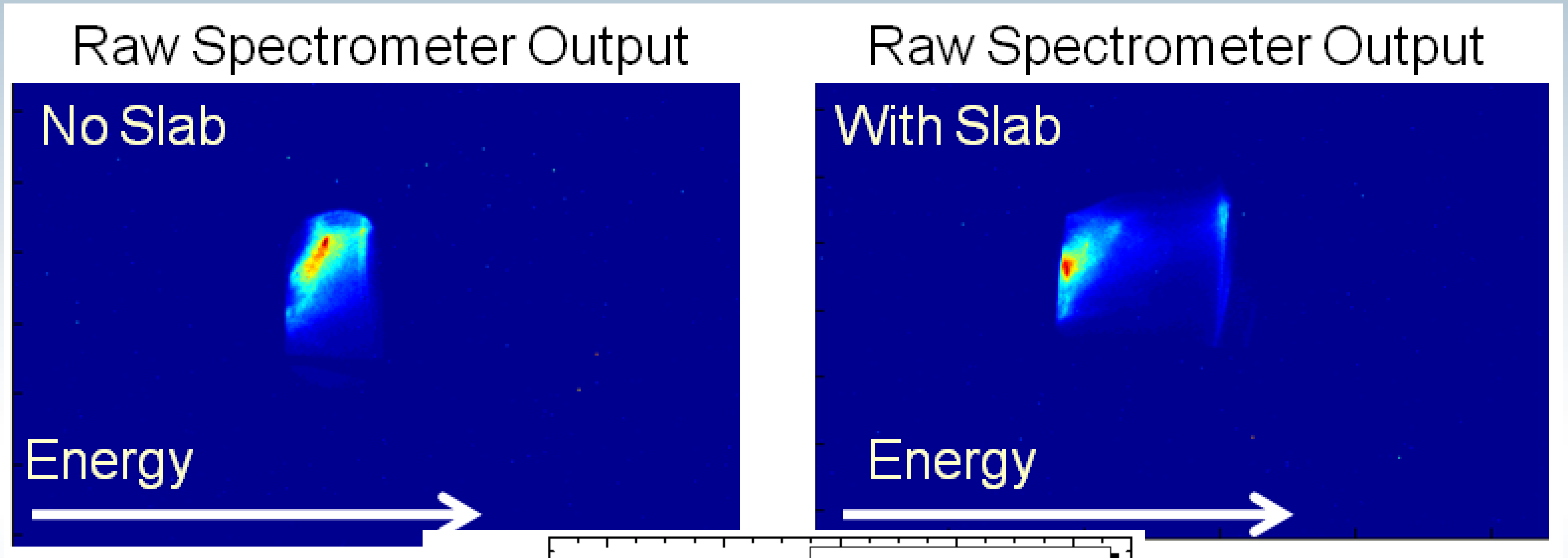


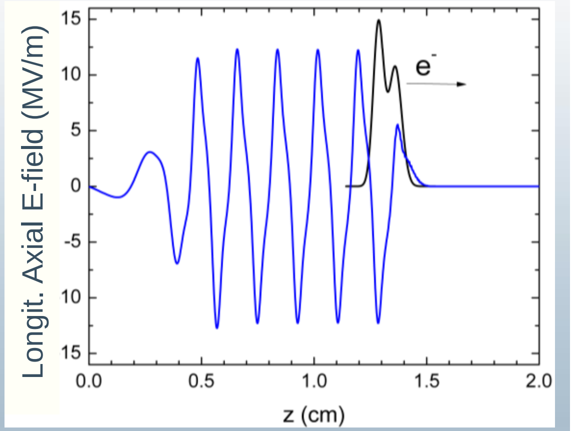


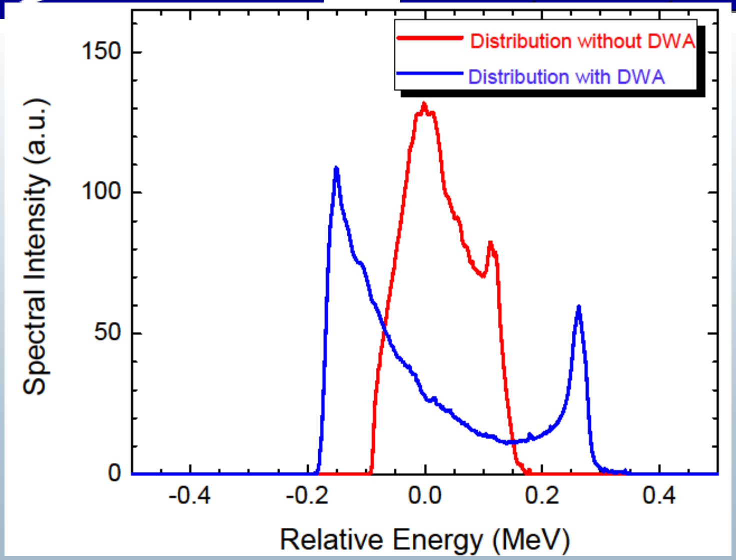




Demonstration of acceleration







More reading

- There are many papers recently in this area. Here is one of them:

Dielectric Wakefield Acceleration of a Relativistic Electron Beam in a Slab-Symmetric Dielectric Lined Waveguide

G. Andonian,[1] D. Stratakis,[1] M. Babzien,[2] S. Barber,[1] M. Fedurin,[2] E. Hemsing,[3] K. Kusche,[2] P. Muggli,[4] B. O'Shea,[1] X. Wei,[1] O. Williams,[1] V. Yakimenko,[2] and J.B. Rosenzweig[1]

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[2]*Accelerator Test Facility, Brookhaven National Laboratory, Upton, New York 11973, USA*
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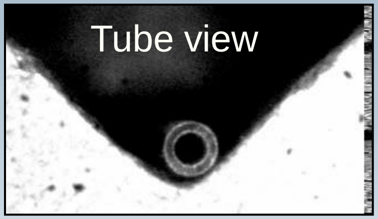
[4]*Max-Planck-Institut für Physik, Munchen, Germany*

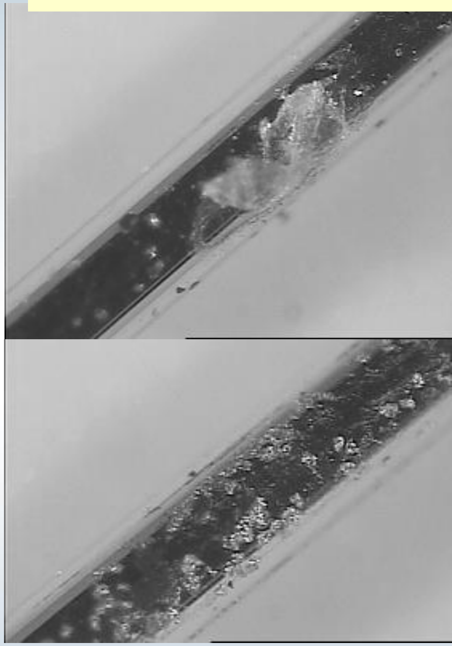
(Received 12 October 2011; published 15 June 2012)

We report first evidence of wakefield acceleration of a relativistic electron beam in a dielectric-lined slab-symmetric structure. The high energy tail of a ~60 MeV electron beam was accelerated by ~150 keV in a 2 cm-long, slab-symmetric SiO_2 waveguide, with the acceleration or deceleration clearly visible due to the use of a beam with a bifurcated longitudinal distribution that serves to approximate a driver-witness beam pair. This split-bunch distribution is verified by longitudinal reconstruction analysis of the emitted coherent transition radiation. The dielectric waveguide structure is further characterized by spectral analysis of the emitted coherent Cherenkov radiation at THz frequencies, from a single electron bunch, and from a relativistic bunch train with spacing selectively tuned to the second longitudinal mode (TM_{02}). Start-to-end simulation results reproduce aspects of the electron beam bifurcation dynamics, emitted THz radiation properties, and the observation of acceleration in the dielectric-lined, slab-symmetric waveguide.

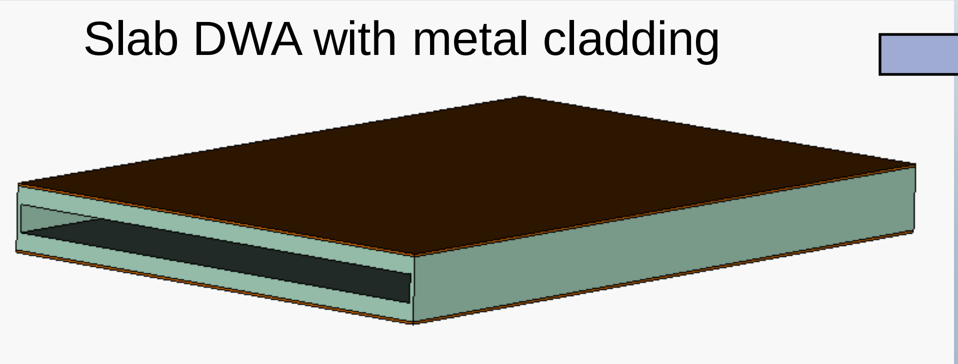


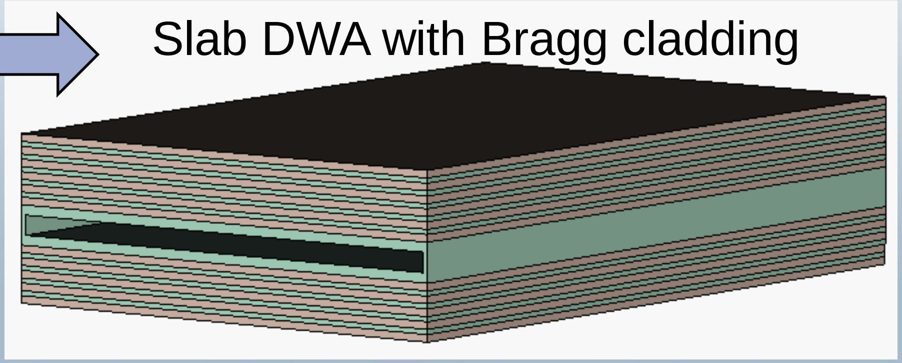
Perfecting the geometry

Metal evaporation seen in Al tubes



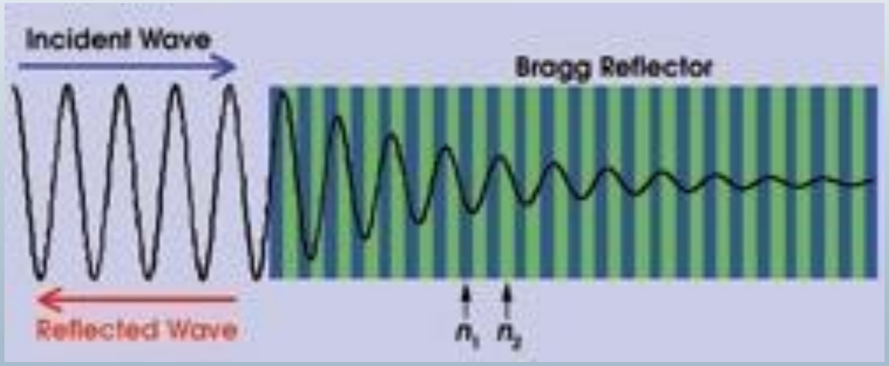
- Previous experiments showed that an electron beam can vaporize the aluminum cladding in a quartz-made DWA
- Explore alternate designs that allow mode confinement without metal: Bragg fibers



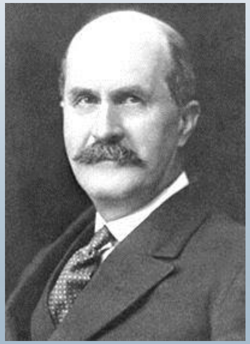


Bragg cladding concept

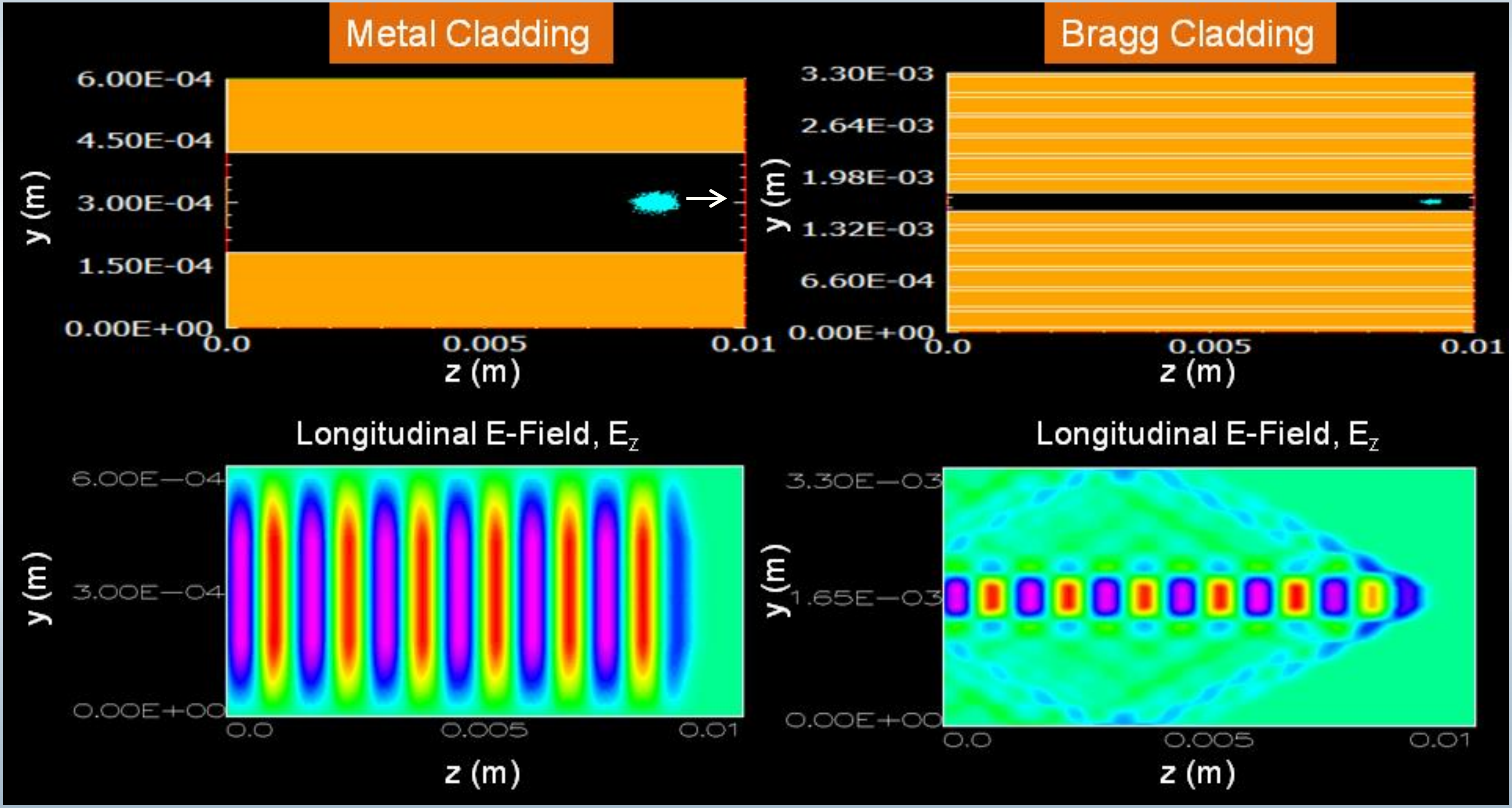
- Multi-layer stack of alternate high and low index films
- All reflected components from the interfaces interfere constructively, which results in a strong reflection.
- The strongest reflection occurs when each material of the two is chosen to be a quarter of wavelength thick



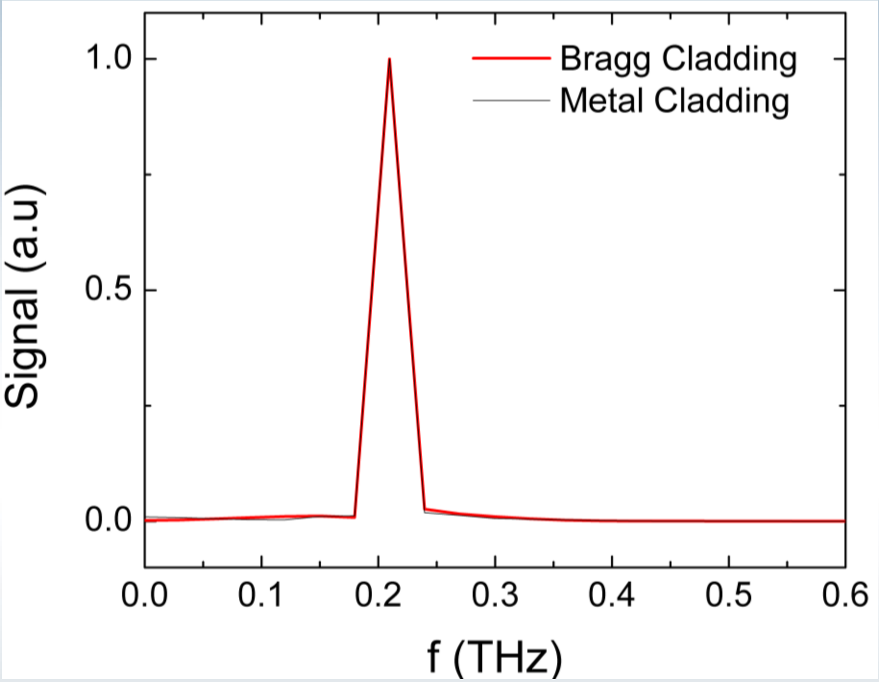
Sir William H. Bragg

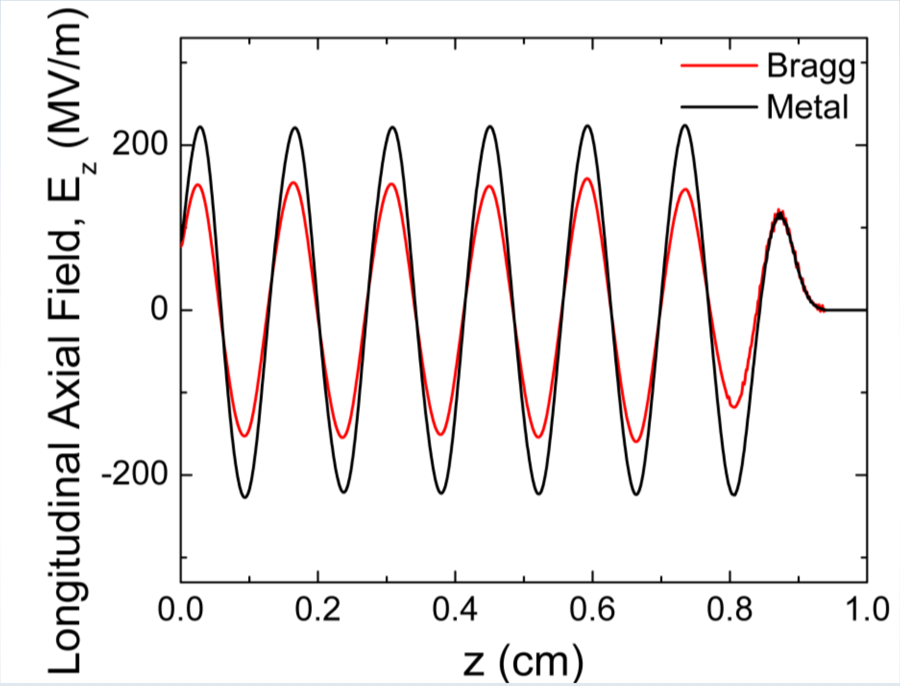


OOPIC predictions for Bragg structures



OOPIC predictions for Bragg structures





- In comparison to metal cladding, the Bragg cladding:
  - Confines the same fundamental mode (TM_{01})
  - Achieves peak field that is weaker by 30%

Summary (DWA)

- Acceleration in wake driven dielectric structures may offer a promising path to achieve GV/m gradients
- Slab geometries seem advantageous as they can pass more charge and mitigate transverse wakefields
- An experiment was carried out to demonstrate acceleration with a dielectric slab
- A method to eliminate metal cladding was proposed based on Bragg reflector and simulations results look promising