MANUFACTURE AND TESTING OF OPTICAL SCALE ACCELERATOR STRUCTURES FROM SILICON AND SILICA*

R. Joel England

SLAC National Accelerator Laboratory

Stanford, Tech-X, MPQ, Incom, Purdue, UCLA

IPAC 2012

Tues May 22, 2012

*Work supported by U.S. Department of Energy under Grants DE-AC02-76SF00515, DE-FG06-97ER41276 and by DARPA Grant N66001-11-1-4199

Who Are We?

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Ken Soong
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Behnam Montazeri
Ken Leedle
Chia-Ming Chang
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Brian Schwartz
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Max Planck Institute
Peter Hommelhoff
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UCLA
Gil Travish
Josh McNeur
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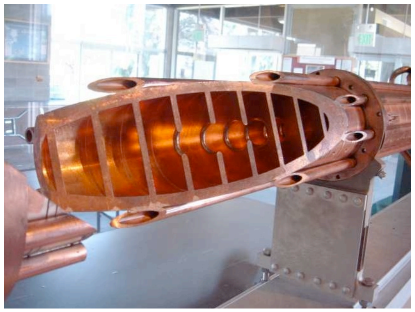
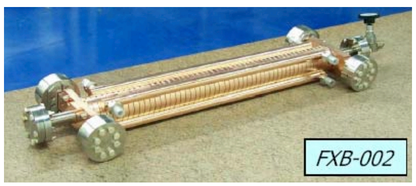
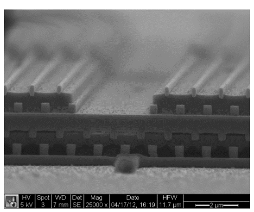
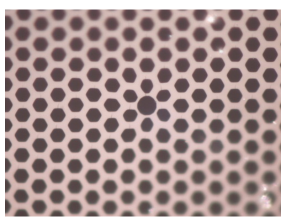
Purdue Univ.
Minghao Qi
Chunghun Lee
Yi Xuan
Li Fan
Leo T. Varghese

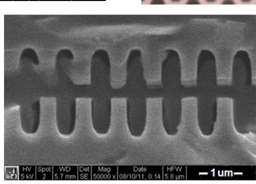
Dielectric Laser Accelerator Concept











S-Band RF

x 1/4

X-Band RF

x 10^{-4} !

Optical to IR

smaller RF structures:

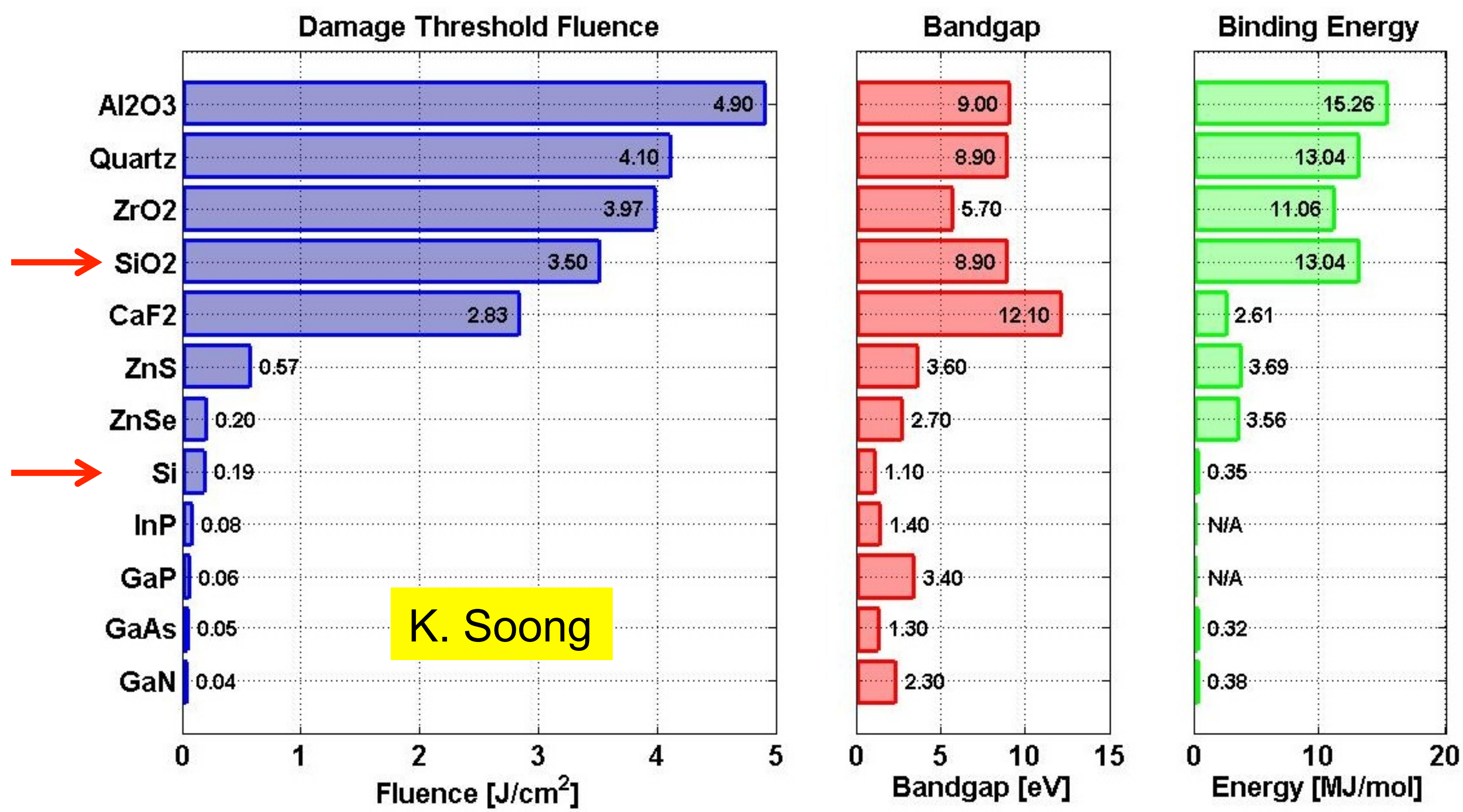
- higher gradient
- machining tolerances
- transverse wakefields
- breakdown ($E_z \leq 100$ MV/m)

laser-driven microstructures

- lasers offer high rep rates, strong field gradients (>1 GV/m), commercial support
- dielectrics: high breakdown threshold (1-5 GV/m)

Laser Damage Threshold - Results

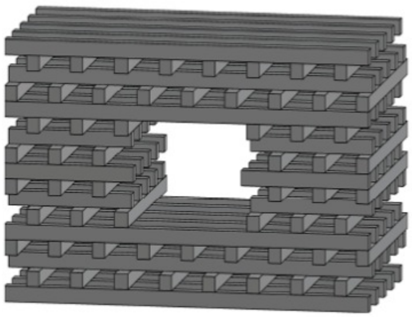
Ti:Sapph Laser wavelength: 800nm; Pulse length: 1ps;



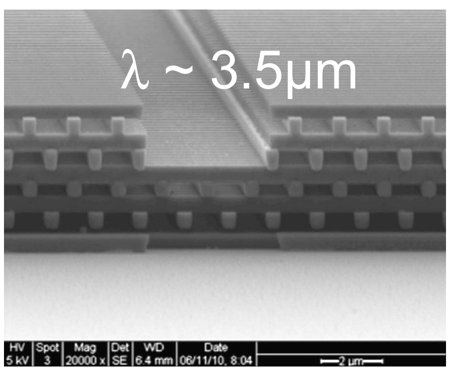
Structure Fabrication Studies

3D

image courtesy B. Cowan

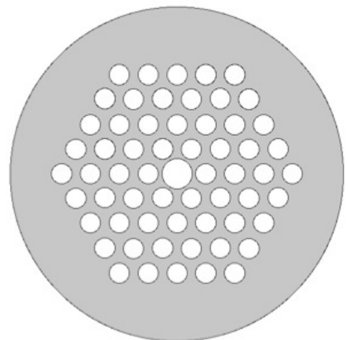


C. McGuinness

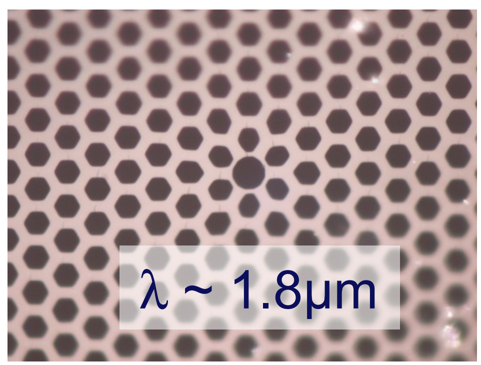


"woodpile" silicon photonic crystal (C. McGuinness)

2D



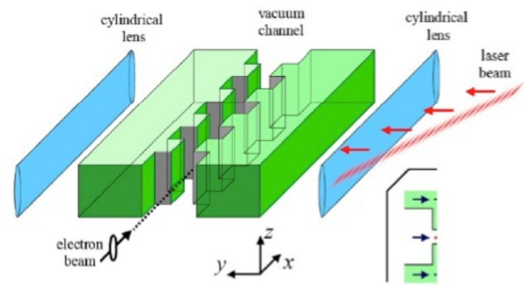
J. Spencer



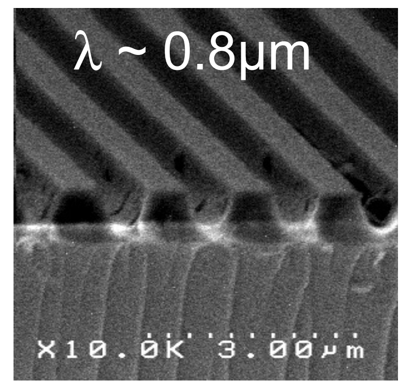
photonic crystal borosilicate fibers (J. Spencer/Incom Inc)

1D

img courtesy T. Plettner



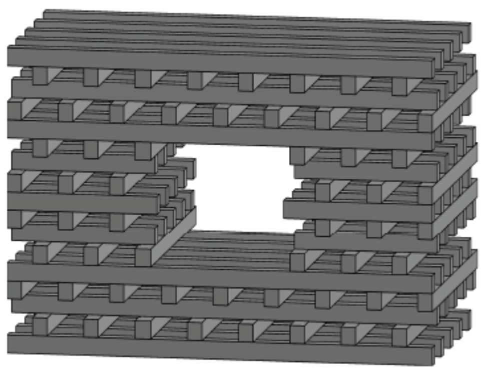
E. Peralta



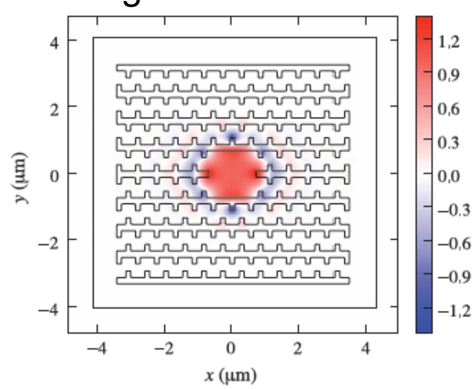
dual silica grating accelerator (E. Peralta)

Silicon Woodpile Structure

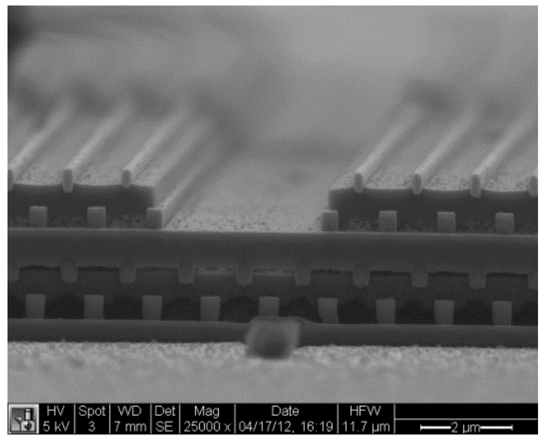
simulation of accelerating mode



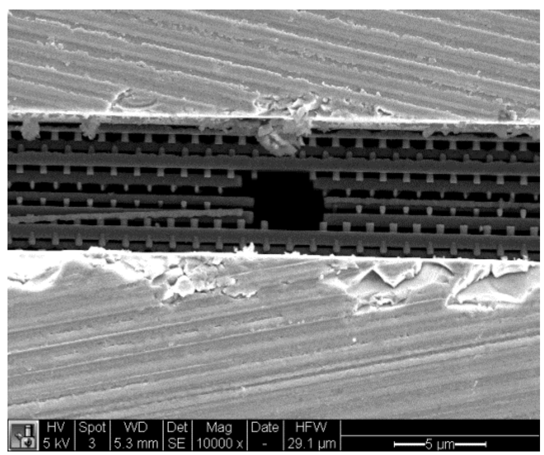
max gradient ~ 400 MV/m

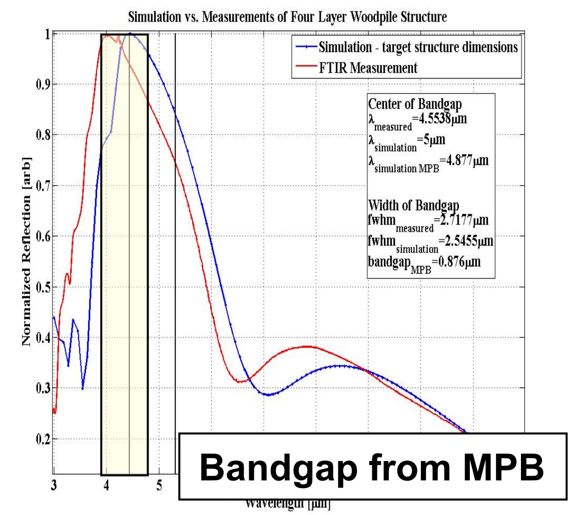


B. Cowan, Tech-X



images courtesy of C. McGuinness





17-layer structure built with ~400nm "logs" by photolithography
Suitable for 3.5 μm wavelength drive laser (Ti:Saph laser + OPA)

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Dielectric Fiber Accelerator

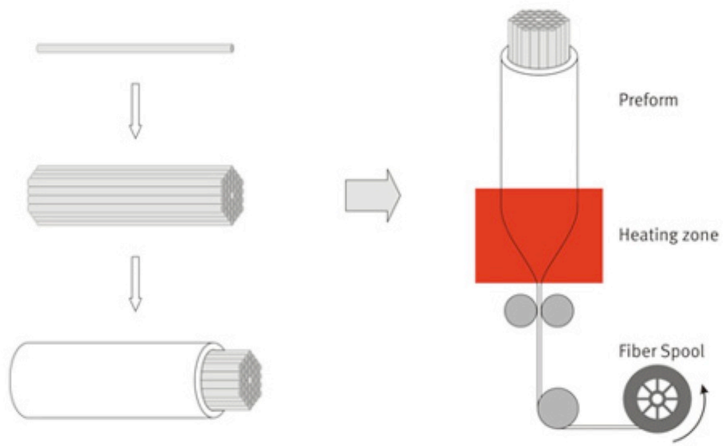
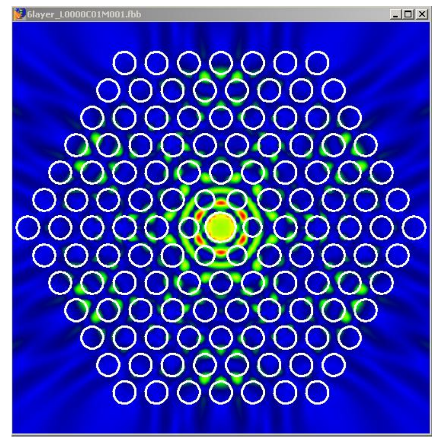


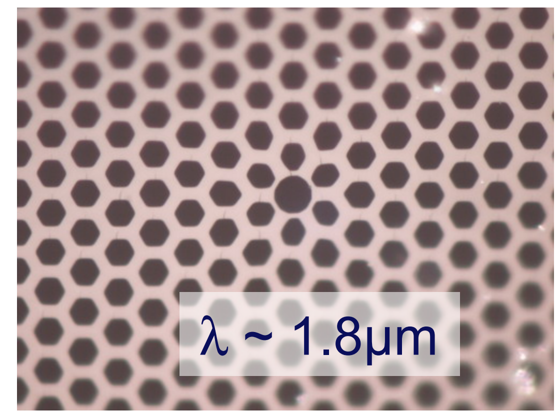
Image Attribution: Crystal-Fibre, Inc.

Example CUDOS mode

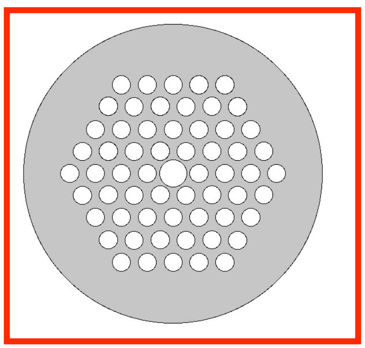


B. Noble, J. Spencer

central hole is beam channel and accelerating mode guide



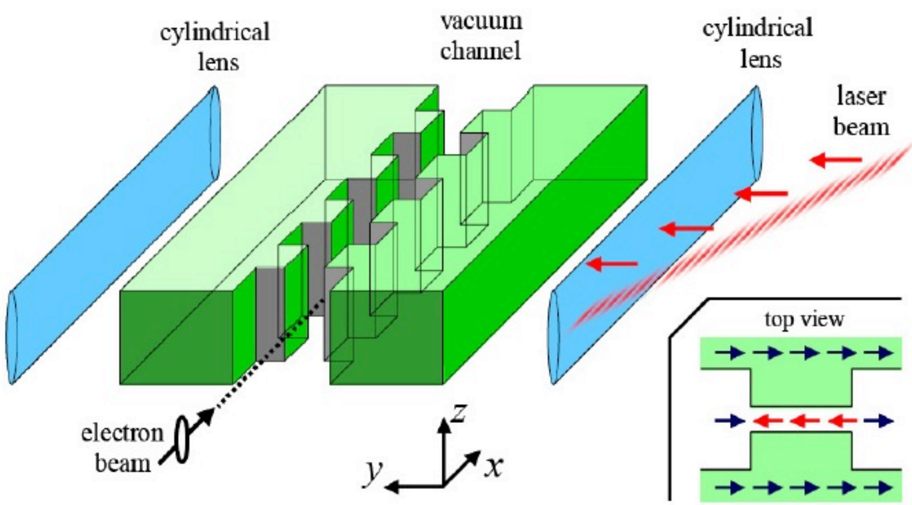
borosilicate PBG fiber prototype, via SBIR with Incom Inc.



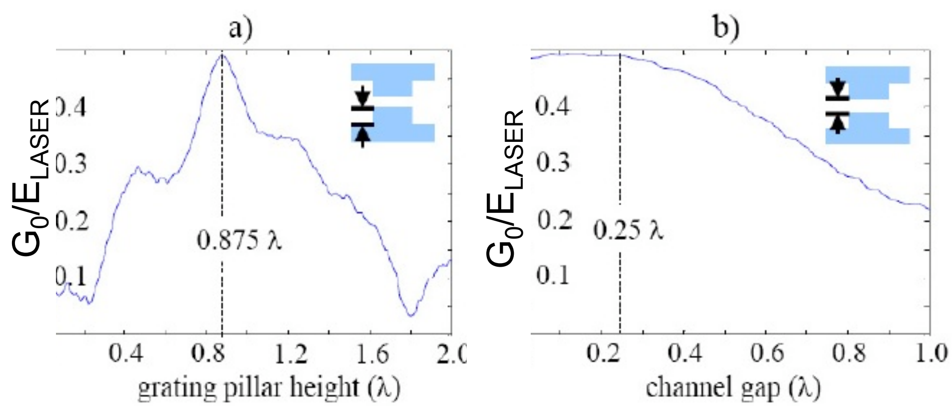
PBG fiber with central defect aperture ~ 0.68 λ; G_0 ~ 2.5 GV/m

X. E. Lin, PRSTAB **4**, 051301 (2001)

Grating-Based Planar Structure



T. Plettner, et al. PRST-AB **9**, 111301 (2006).

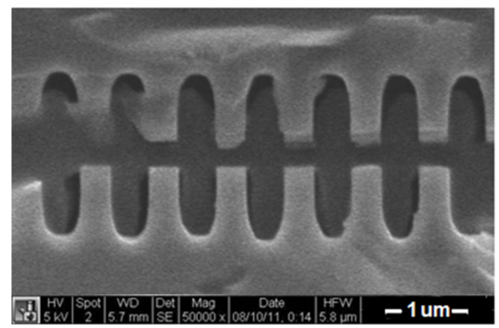


SiO_2 planar gratings with side-coupled laser and flat beam.

Periodic phase reset of the EM field results in a large accelerating gradient over many periods.

damage threshold for SiO_2 >3 GV/m @ 1ps

$G_{0,max}$ ~ 1GV/m

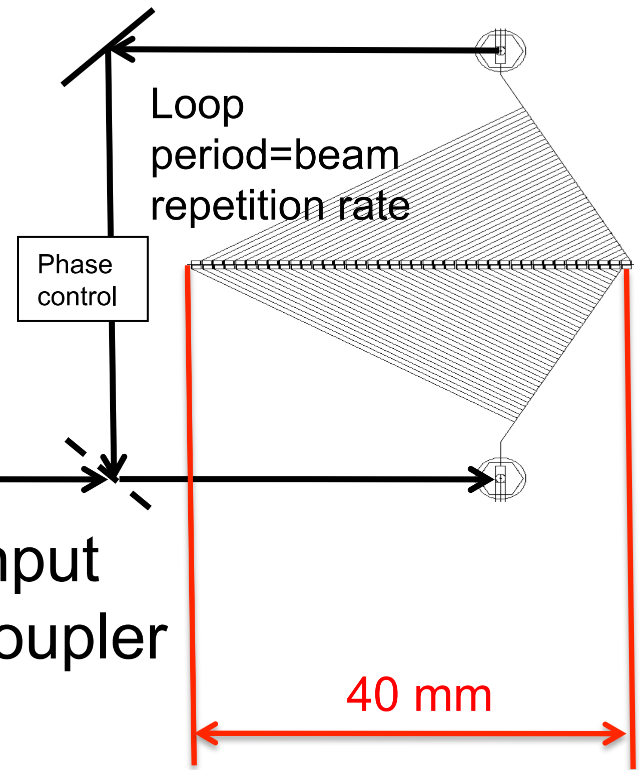


E. Peralta, recently fabricated prototype structure

Multi-Stage Layout Concept

A Multi-Stage "Module" Driven by One Laser

recycling the laser energy allows laser-ebeam efficiency up to ~ 40% [Siemann, PRSTAB (2004)].

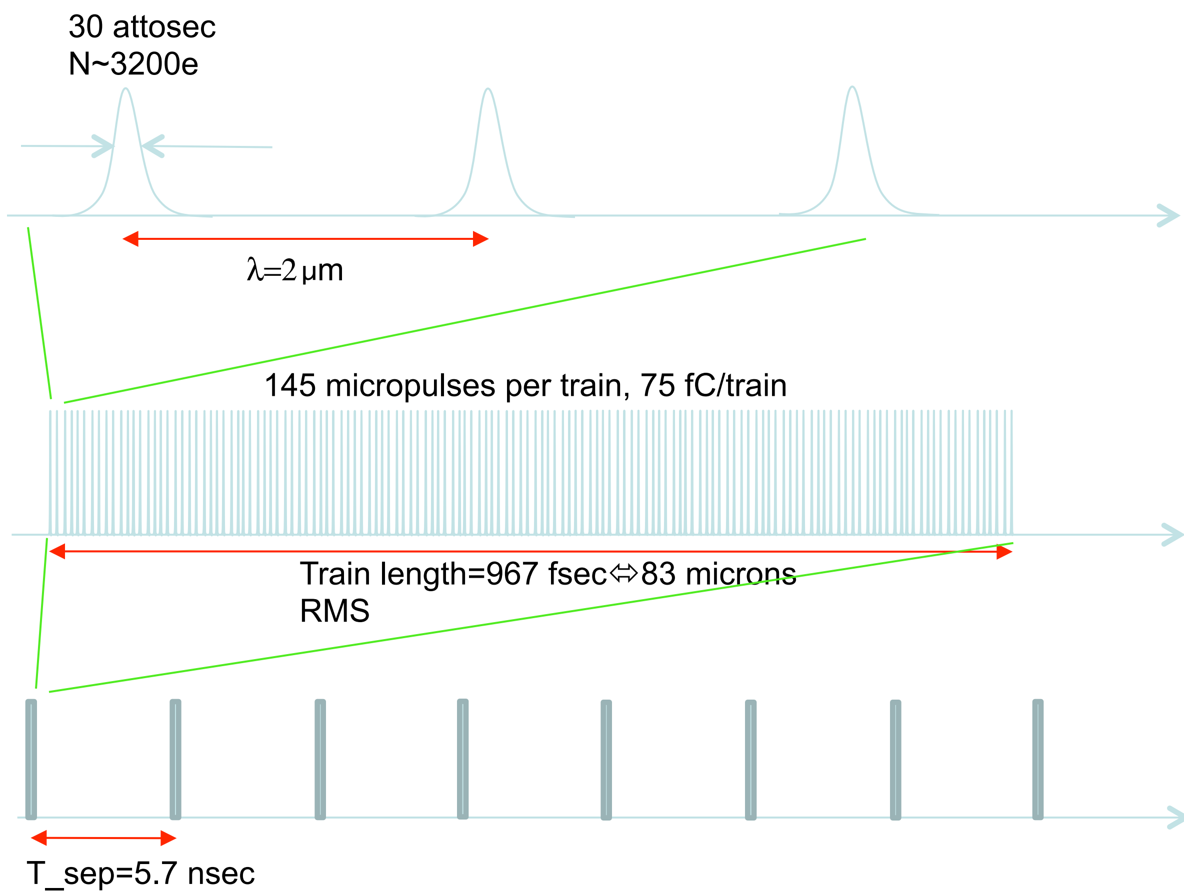


40 PBG Structures driven through a waveguide split/ delay network from a common fiber feed

Thulium fiber laser $\lambda = 2\,\mu m$

E. R. Colby, R. J. England, R. J. Noble, "A Laser-Driven Linear Collider: Sample Machine Parameters and Configuration", PAC 2011.

E-Beam Pulse Format



E. R. Colby, R. J. England, R. J. Noble, "A Laser-Driven Linear Collider: Sample Machine Parameters and Configuration", PAC 2011.

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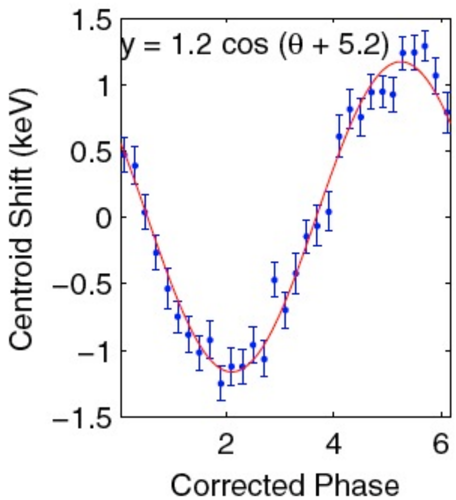
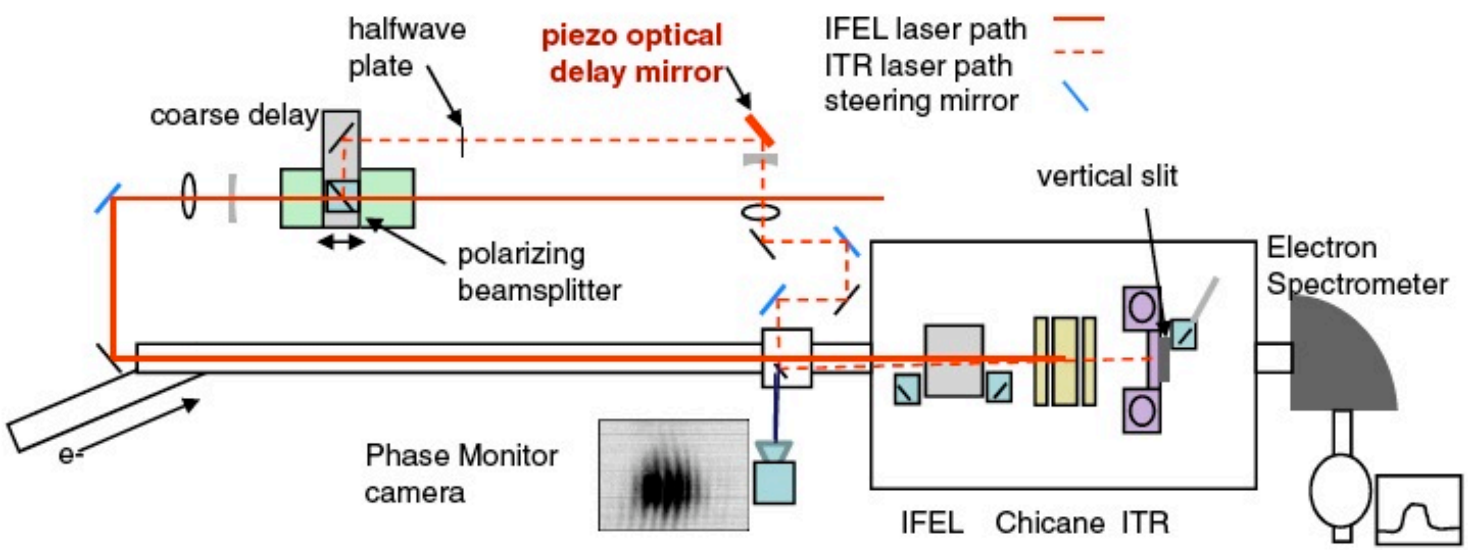
Prior Work: Net Acceleration



Net laser acceleration of 1.2 keV demonstrated for **400 attosec microbunches** using inverse transition radiation (ITR) at a metal foil.

C.M.S. Sears, et al. "Production and characterization of attosecond electron bunch trains," PRST-AB **11**, 061301 (2008)].

C.M.S. Sears, et al. "Phase stable net acceleration of electrons from a two-stage optical accelerator." PRST-AB **11**, 101301 (2008).



Collider Parameters

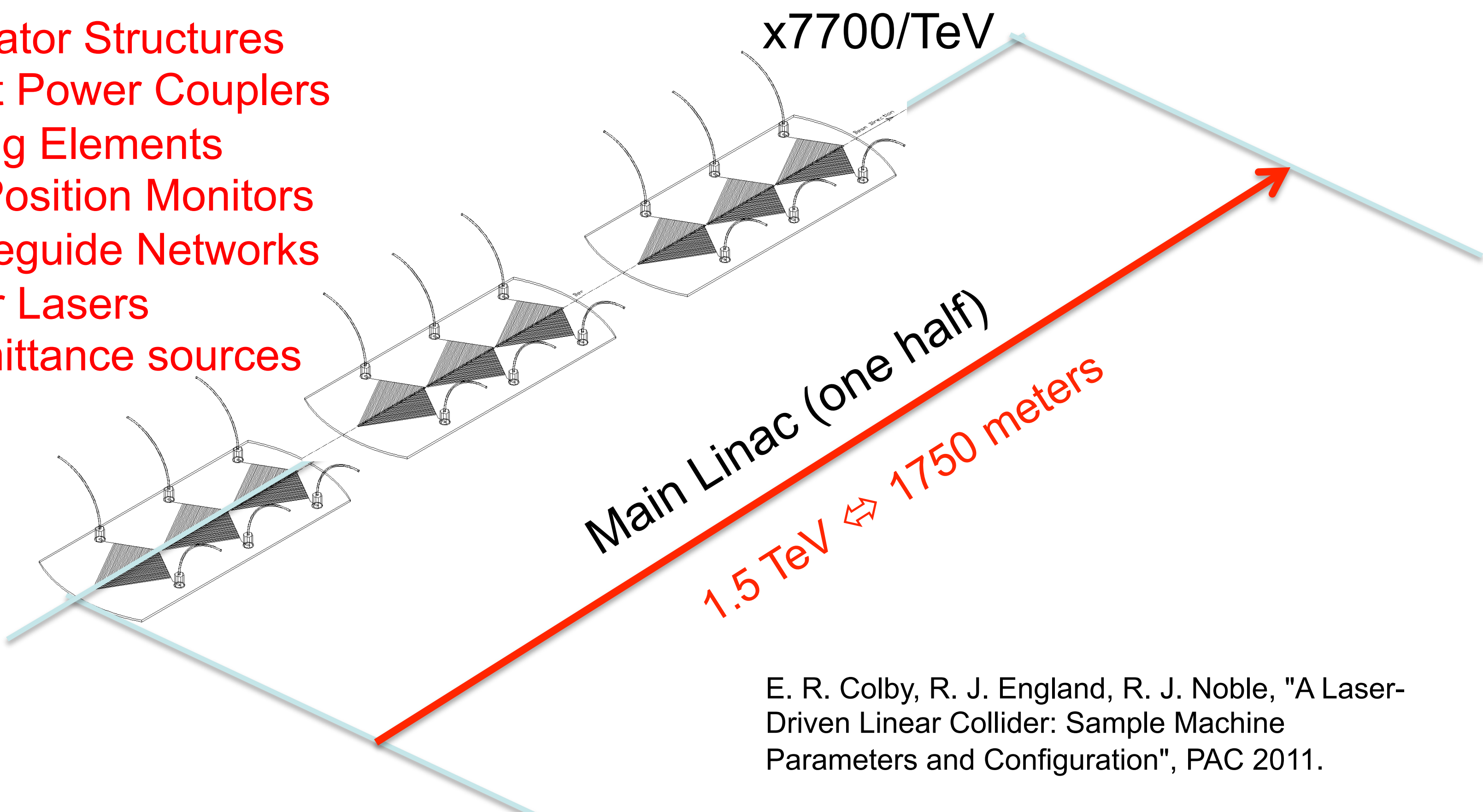
	Traditional RF	DLA
Source	Klystron (Microwaves)	Commercial μJ Class IR Laser
Wavelength	2-10 cm	1-10 μm
Bunch Length	1-5 ps	1-100 attosec
Bunch Charge	1-4 nC	1-10 fC
Required Emittance	0.1-1 μm	1-10 nm
Rep Rate	1-1000 Hz	1-10 MHz
Confinement of Mode	Metal Boundaries	Photonic Crystal (1D, 2D, 3D)
Material	Metal	Dielectric
Max Unloaded Gradient	30-100 MV/m	0.5-2 GV/m
Power Coupling Method	Critically-coupled Metal WG	Free-space /Silicon WG
Luminosity (cm^-2/s) *	1.70E+35	1.05E+36
Beamstrahlung E-loss (%) *	**53**	**4.4**
Wall Plug Power (MW) *	540	390

* For 10TeV c-o-m collider scenario, based on numbers from Report of ICFA-ICUIL 2010 Joint Task Force on Ultra-High Intensity Lasers, Ch. 1. RF numbers extrapolated from ILC parameters scaled to higher luminosity.

Multi-Stage Layout Concept

Train of Integrated Modules on Silicon Wafers

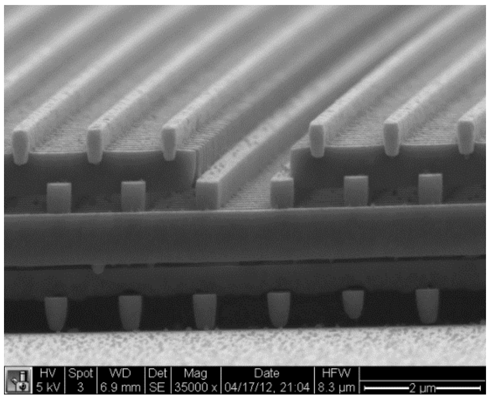
Accelerator Structures
Efficient Power Couplers
Focusing Elements
Beam Position Monitors
IR Waveguide Networks
IR Fiber Lasers
Low-emittance sources
...

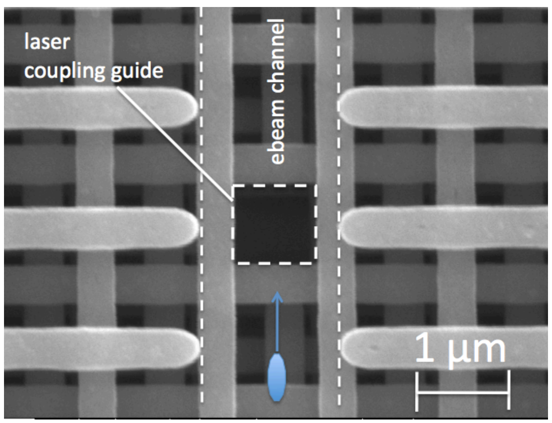


E. R. Colby, R. J. England, R. J. Noble, "A Laser-Driven Linear Collider: Sample Machine Parameters and Configuration", PAC 2011.

Accelerator Subcomponents

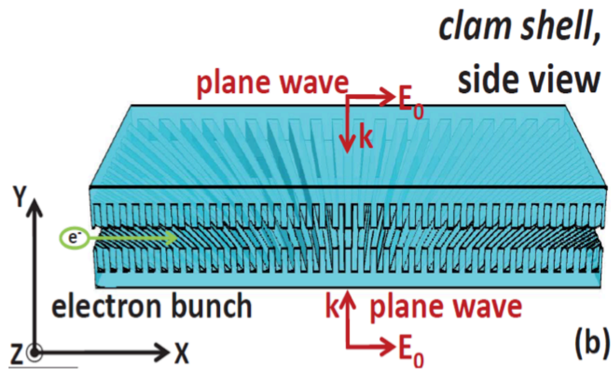
Efficient Coupler Designs



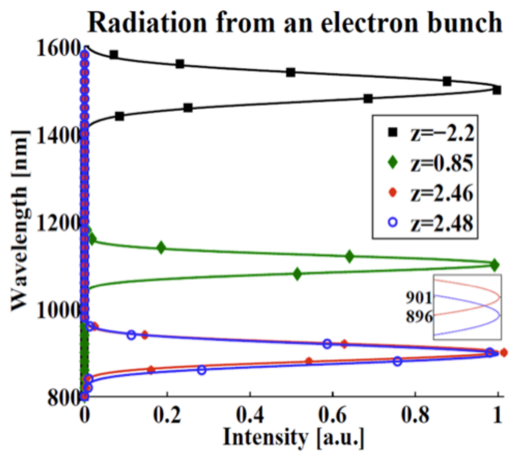


C. McGuinness. Z. Wu

BPMs



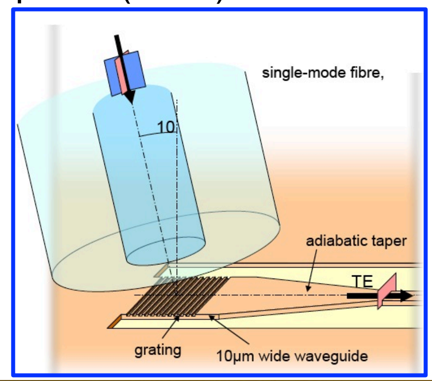
K. Soong

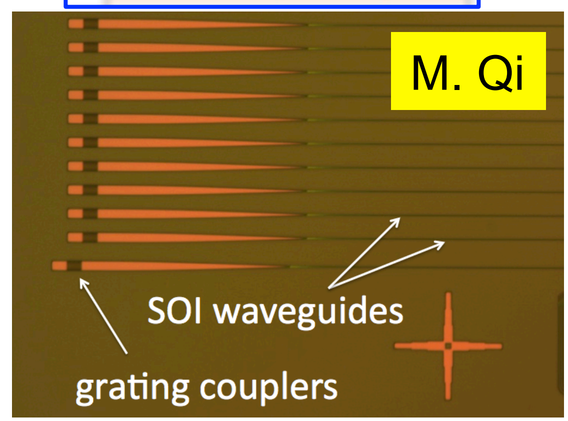


K. Soong, et al. *Optics Letters*, Vol. 37, Issue 5, pp. 975-977 (2012)

Fiber couplers Waveguide Networks

Taillaert, et al., JQE 38(7), p.949 (2002)

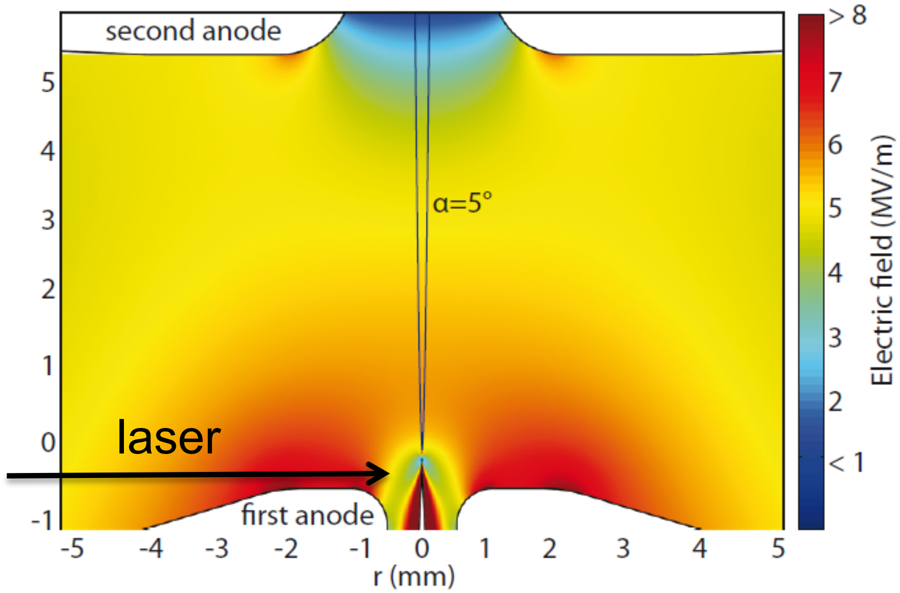


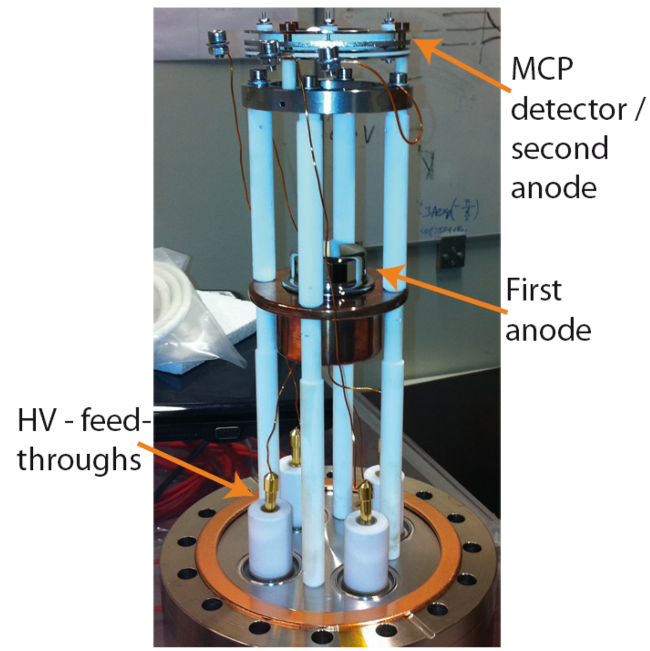


Supertip Emitter Source Development

Dr. Peter Hommelhoff, Johannes Hoffrogge, (MPQ)

• Optimized 30 keV structure found with the help of FDTD eletric field simulations and particle tracking. Result:

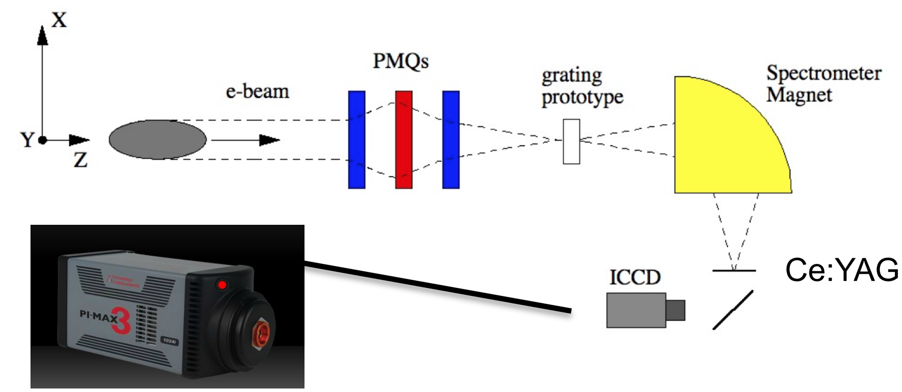




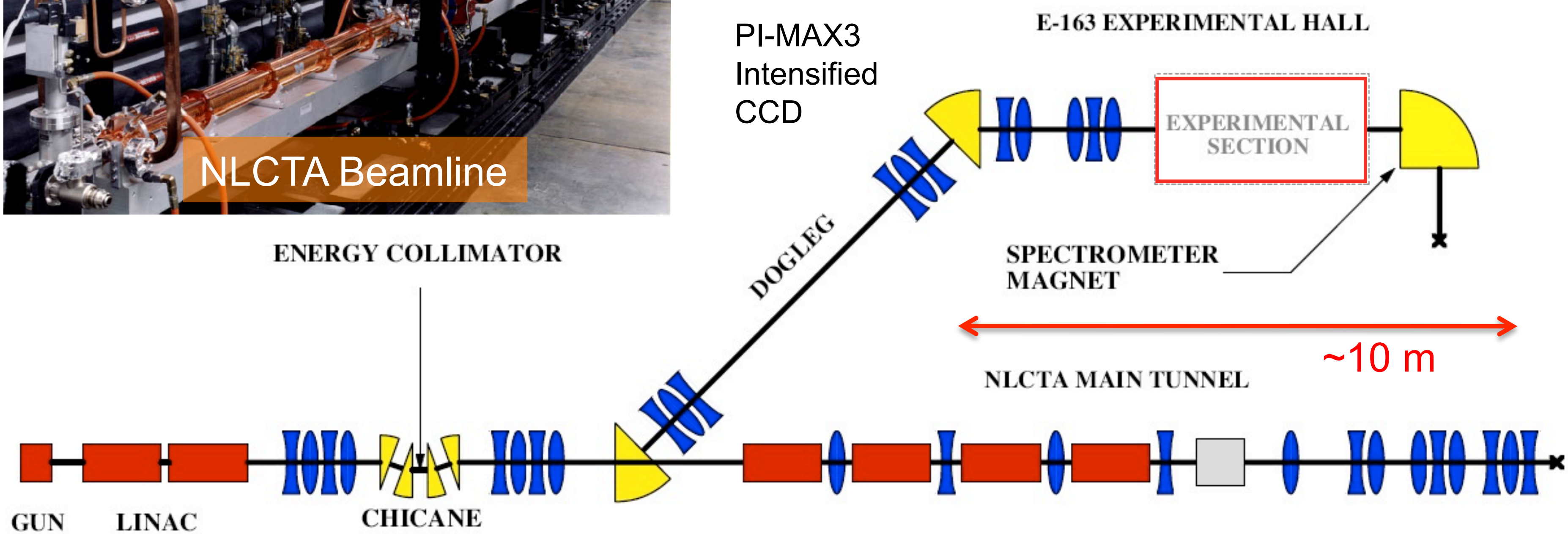
Tip pointing through one anode, with second anode a few mm away (left). With this geometry, the field on electrons' path never drops below ~4MV/m

Next Linear Collider Test Accelerator

E163: A facility for testing laser-driven accelerator structures.
Beam energy = 60MeV; σ_t = 1ps; σ_E = 0.1%

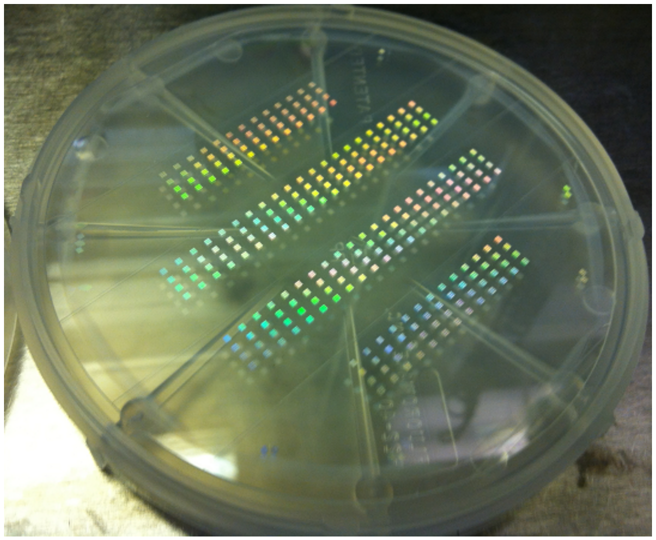


PI-MAX3
Intensified
CCD

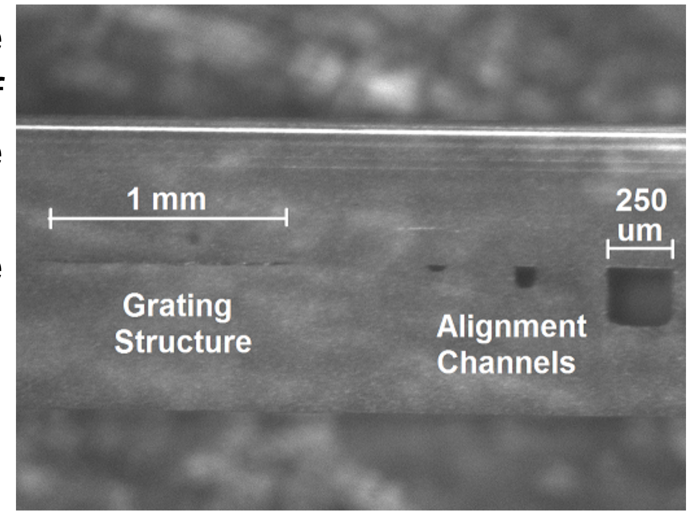


First Beam-Test Prototypes

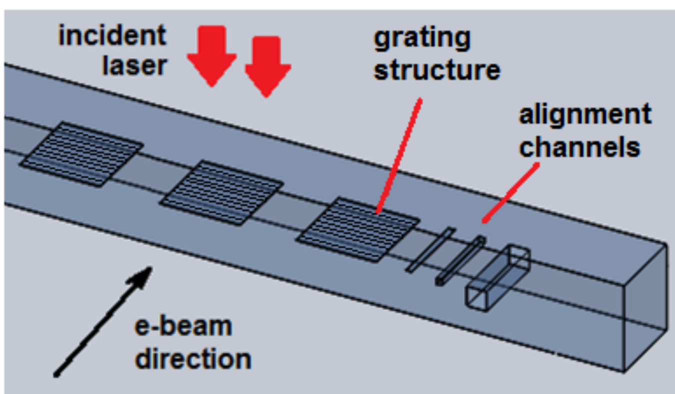
Bonded wafers



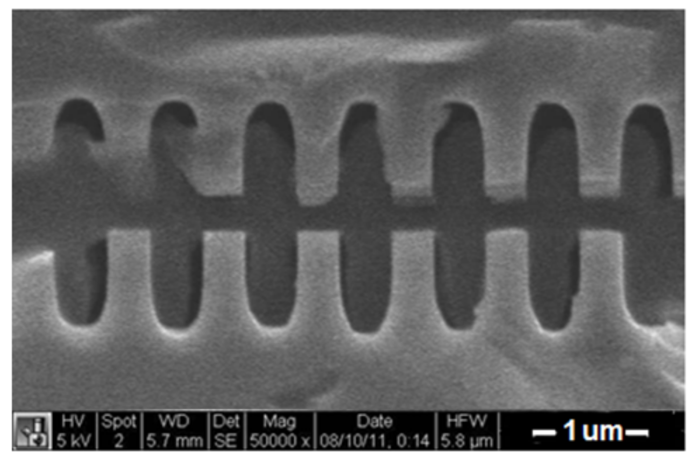
Microscope image of front face of diced sample



Wafer is diced into individual samples for e-beam tests.



SEM image of sample cross-section



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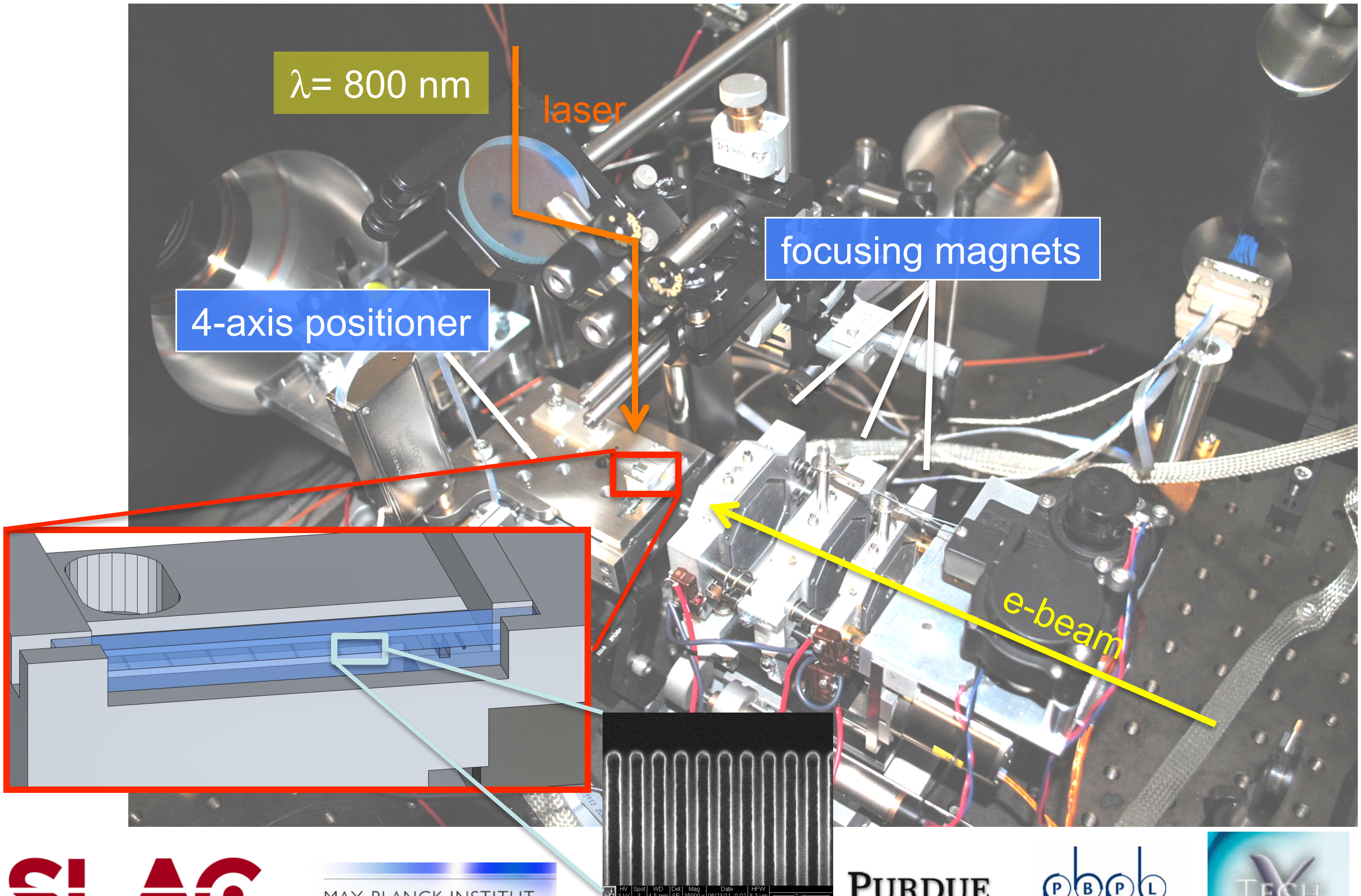
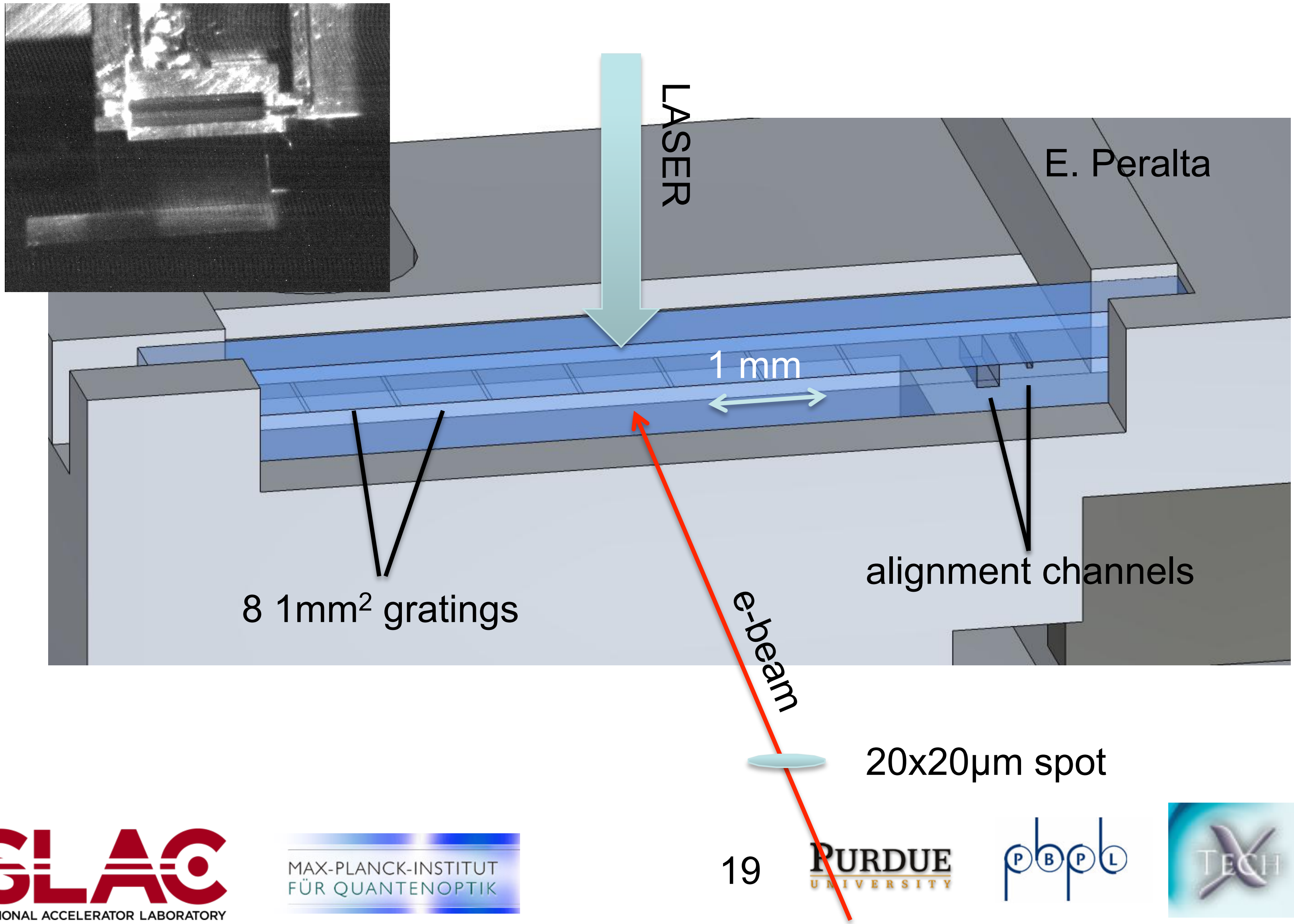
slide courtesy E. Peralta

Experiment Vacuum Setup

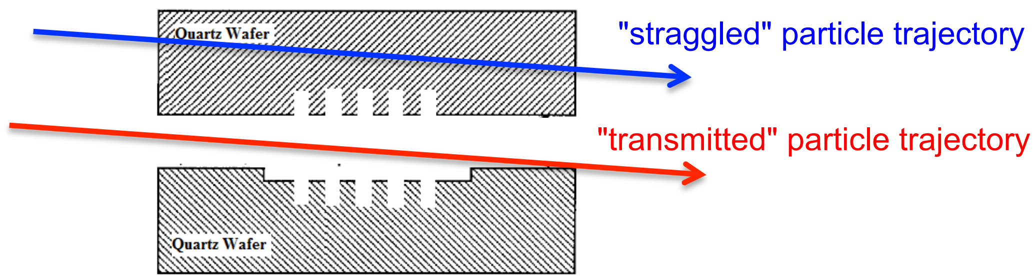


E. Peralta

Interaction Point Schematic

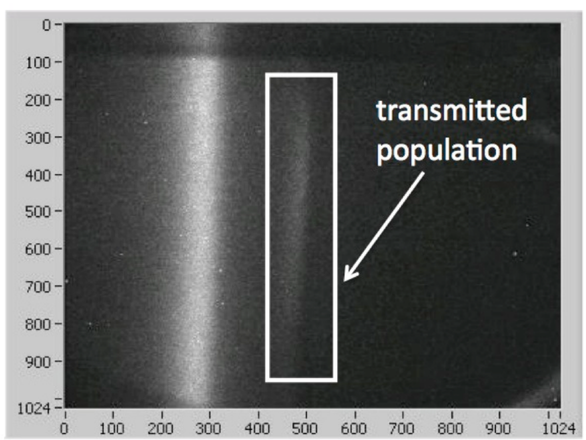


Electron Energy Spectrum

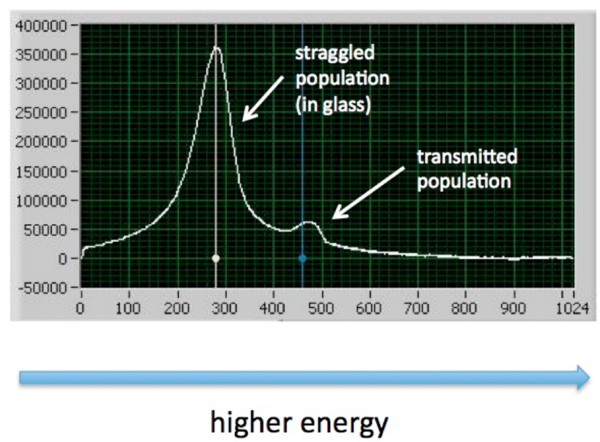


[cartoon: image not to scale]

spectrometer camera image



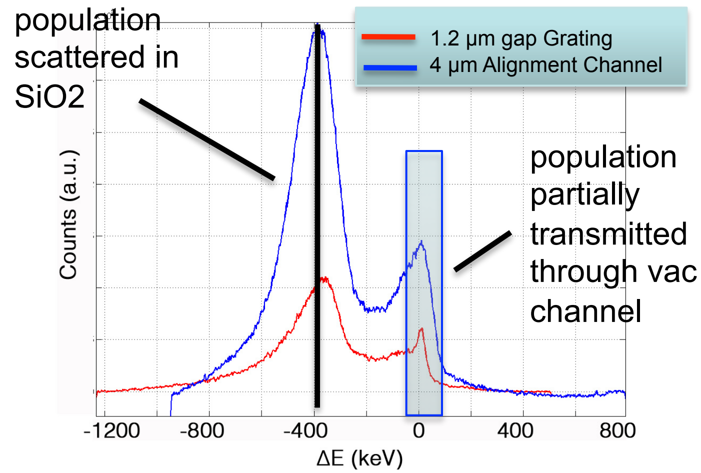
electron energy spectrum

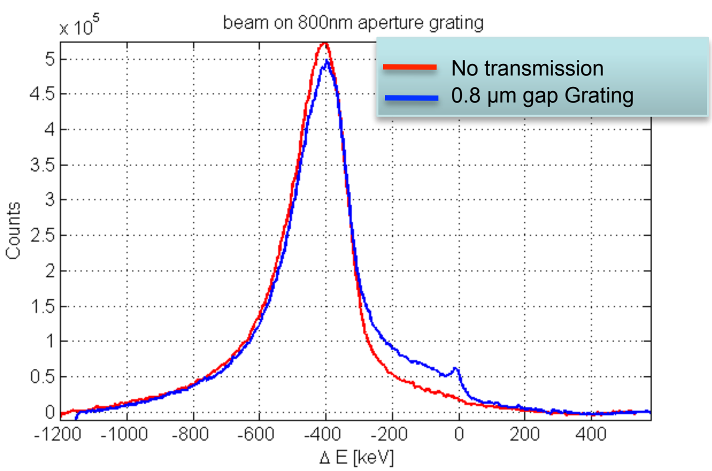


~ 400 keV peak separation consistent with collisional stopping power of SiO_2

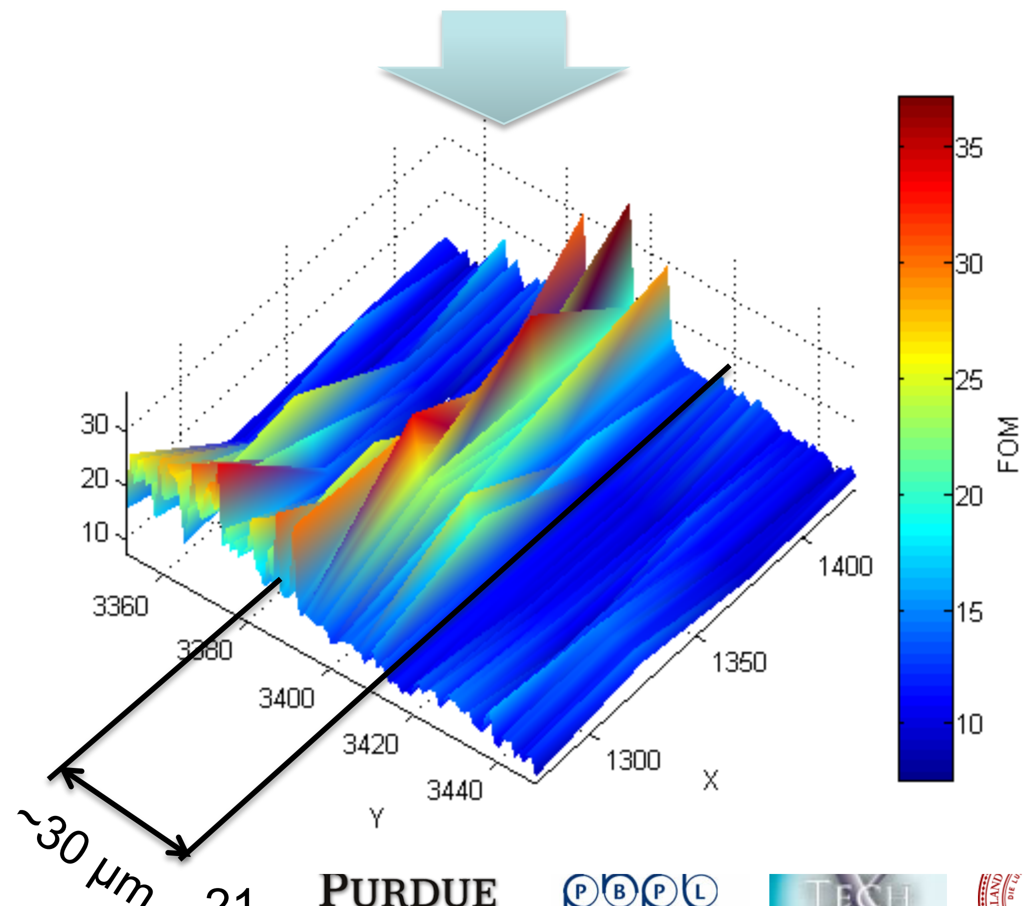
First observed transmission through the grating structures (1.2 μm gap).
Acceleration will manifest as a "broadening" of the transmitted distribution.

Transmission Spectra





Transmission metric: peak detect + gated integral over region near ΔE = 0.



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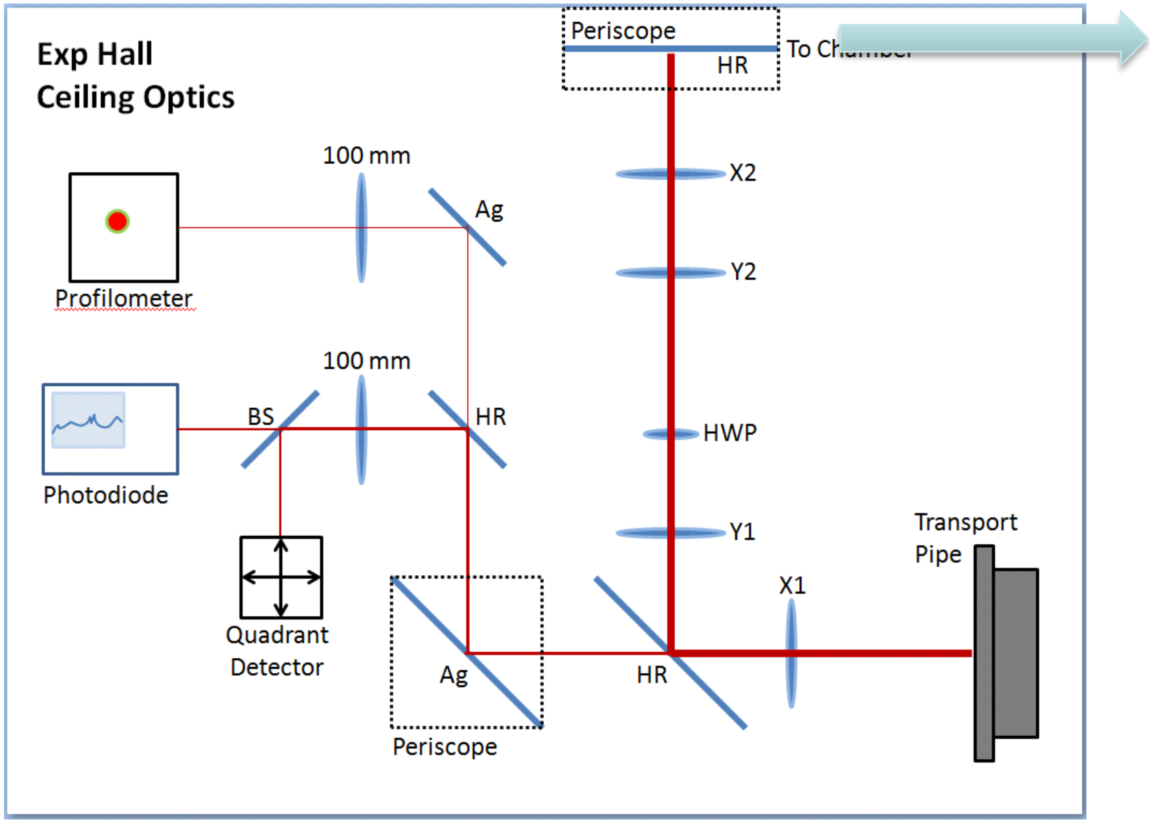
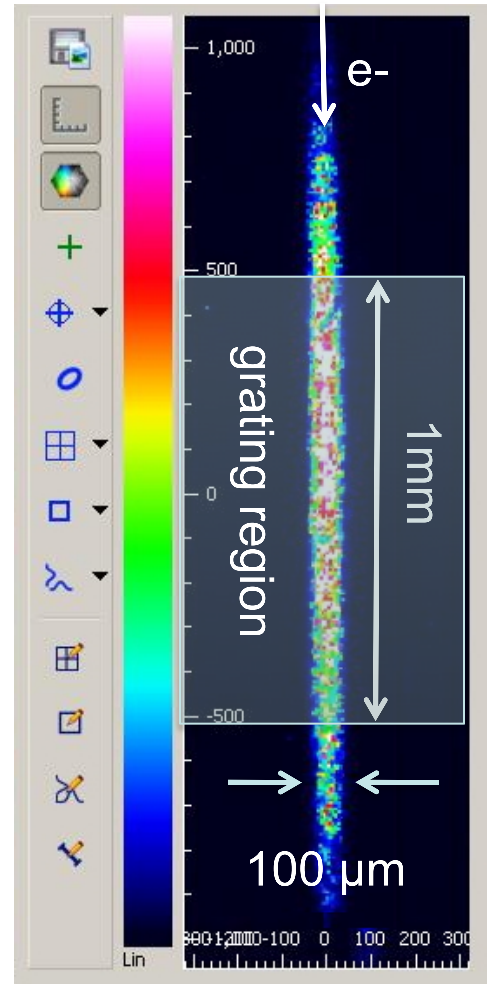
IR Optics

IR Optics on Ceiling of Experimental Hall



Profilometer Image at the Interaction Point



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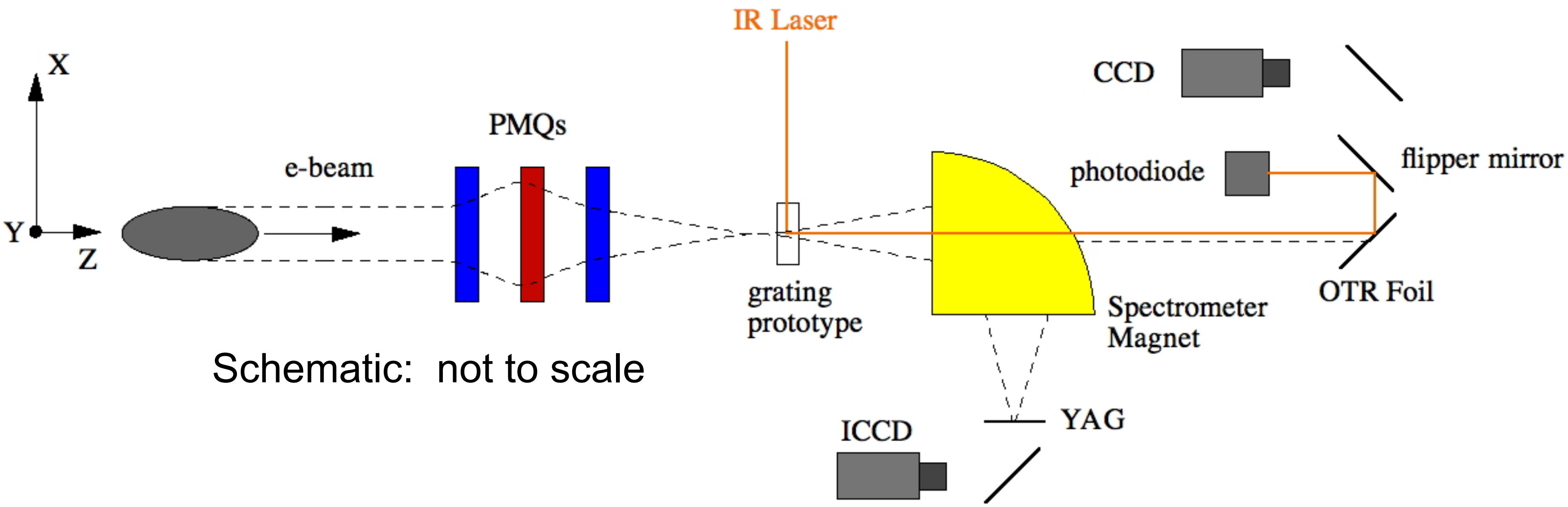
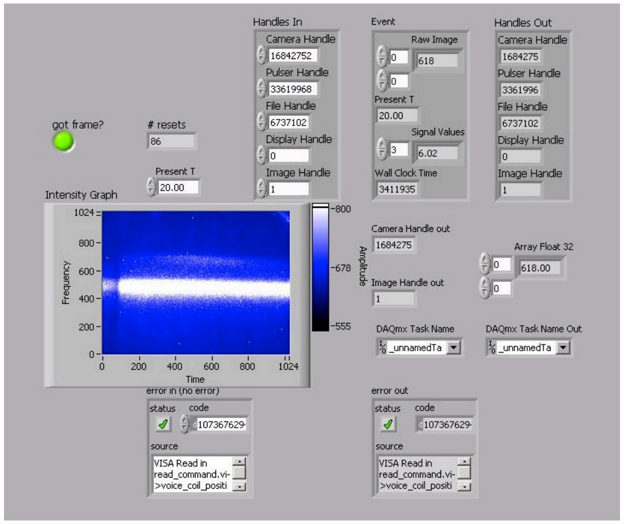
Timing Overlap



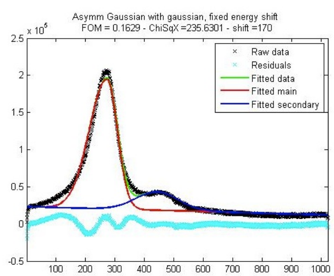
Schematic: not to scale

- Gross timing overlap (~50ps level): using OTR foil and fast photodiode
- Fine timing overlap (~ps level): will use the interaction signal (detection of energy modulation of the beam spectrum) itself to cross-correlate electron and laser beams at the IP

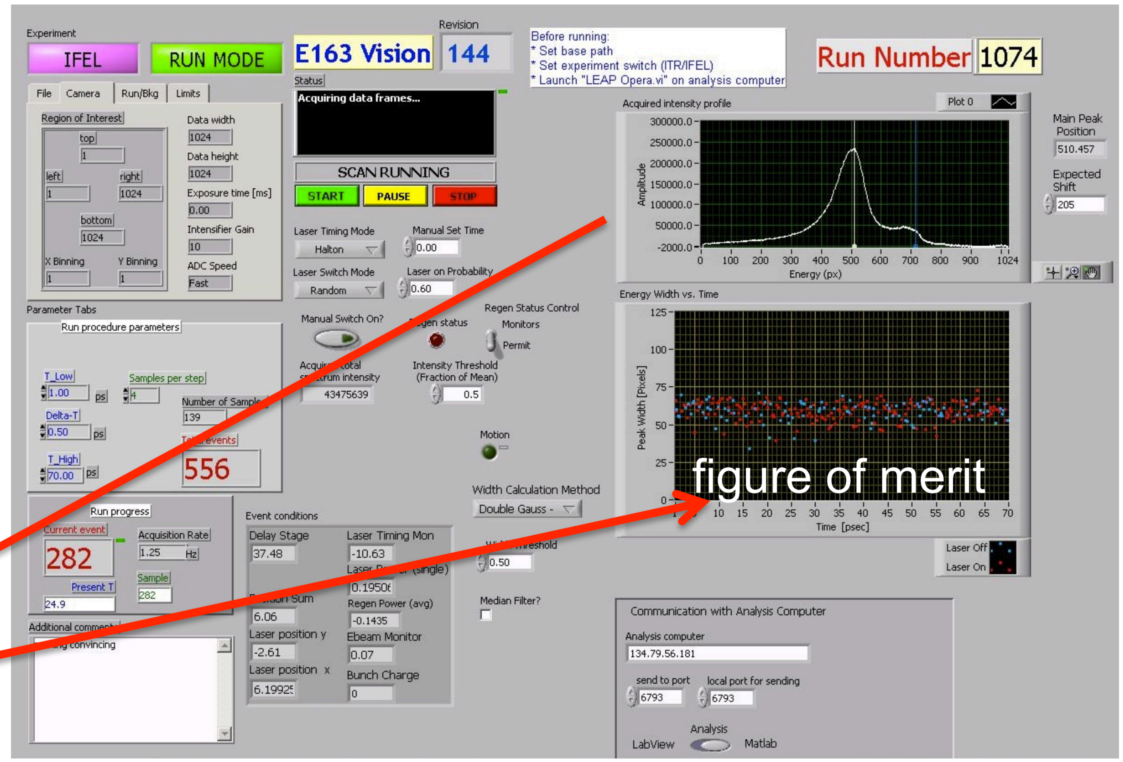
Online Data Analysis



ICCD Camera acquisition
at spectrometer screen

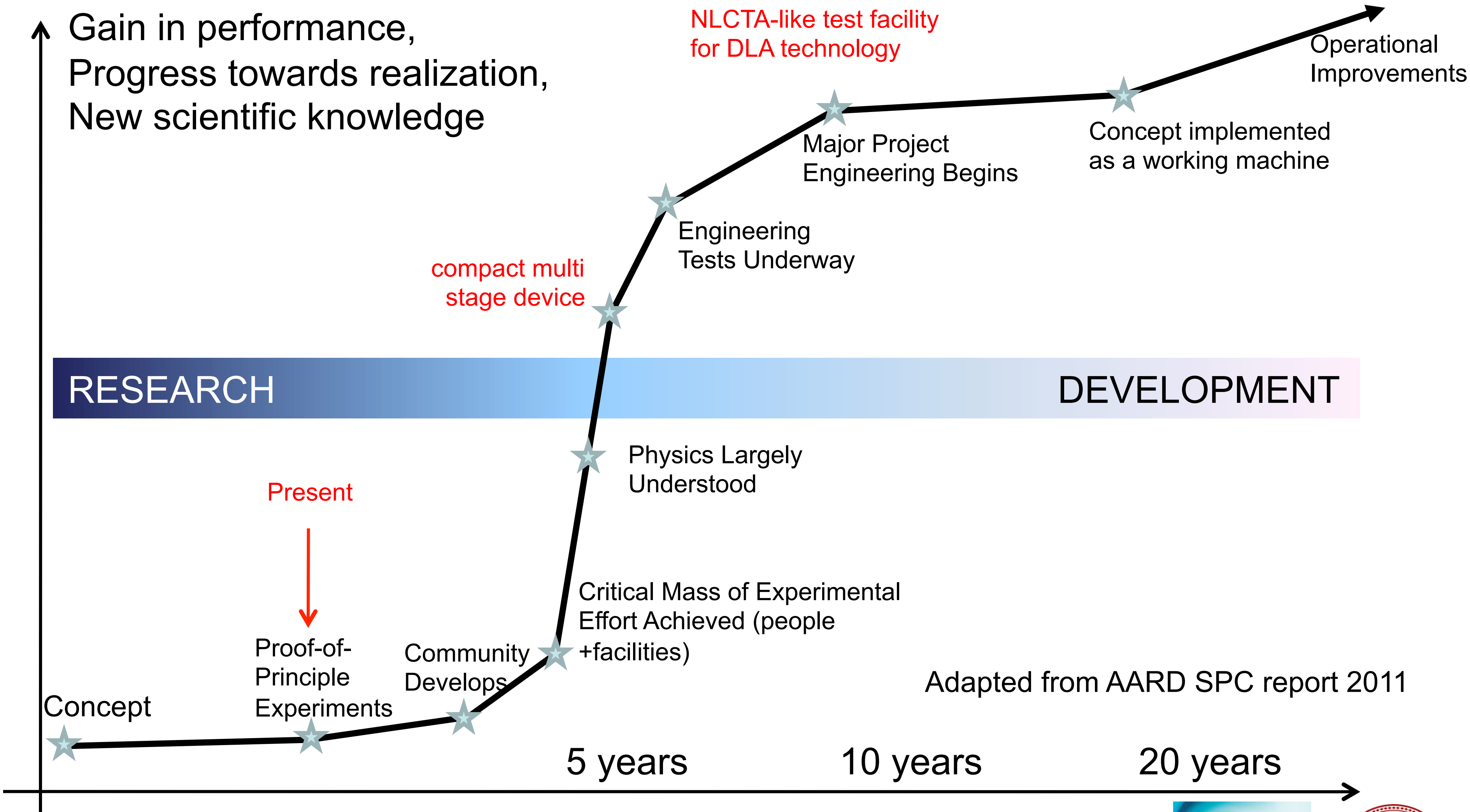


online fitting of the distribution



online data collection and analysis

Long-Term Timeline



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Thank You!