Generation and Characterization of High Brightness Electron and Photon bunches

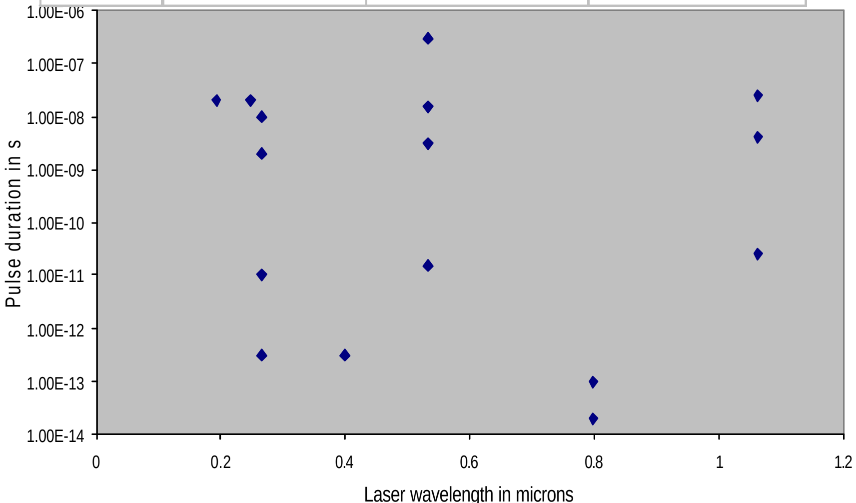
Outline of the talk

- Resources in the lab
- High Brightness electron source
  - Photocathode studies
  - High peak current source
  - High average current source
  - High peak and average current source
- High Brightness photon source
- Detector
  - Electron
  - Photon

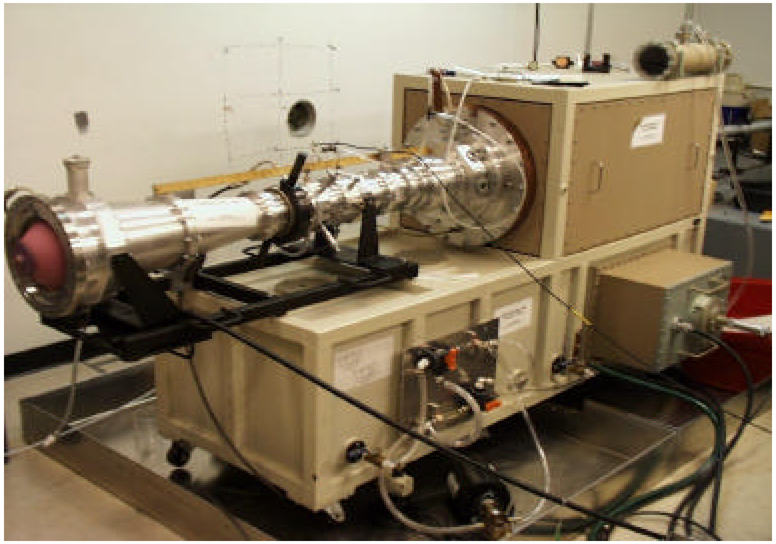
Resources

Laser Systems

Laser type	Wavelength (nm)	Pulse duration s	Energy per pulse
Ti:sapphire	0.798	1.00E-14	3.00E-09
Ti:sapphire	0.798	1.00E-13	4.00E-09
Ti:sapphire	0.798	1.00E-14	3.00E-09
	0.798	4.23E-13	5.00E-04
	0.399	3.00E-13	2.00E-04
	0.266	2.50E-13	8.00E-05
YAG	1.064	2.50E-11	2.50E-02
	0.532	1.50E-11	1.00E-02
	0.266	1.00E-11	1.00E-03
	1.064	2.50E-08	4.50E-01
	1.064	4.00E-09	4.50E-01
	0.532	3.00E-09	2.00E-01
	0.532	1.50E-08	2.00E-01
	0.266	1.00E-08	5.00E-02
	0.266	2.00E-09	5.00E-02
excimer	0.248	2.00E-08	2.00E-01
	0.193	2.00E-08	1.00E-01
YLF	0.532	3.00E-07	6.00E-03



HV Pulse Generators



Voltage:	Up to 1 MV, and 5 MV
Pulse duration:	~1 ns
Synchronizable to external trigger	
Jitter:	Down to 500 ps (1 MV system)
Field gradient:	> 1 GV/m without breakdown

Requirements For High Brightness

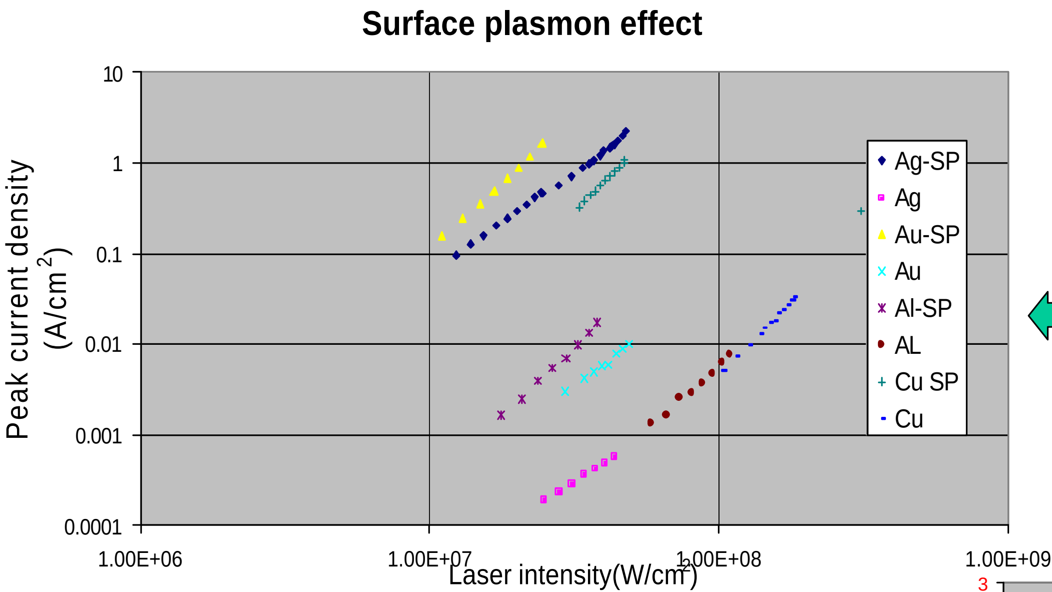
Brightness $\propto$ Charge/phase space volume

$$\propto Q/\Delta x \, \Delta y \, \Delta t \, \Delta p_x \, \Delta p_y \, \Delta E$$

- **High charge**
- **Short bunch**
- **Small spot size, Small energy spread and divergence**

- Choice of cathode
- High Efficiency and lifetime
- Reduction/maintenance of Phase Space volume

Photocathode Research

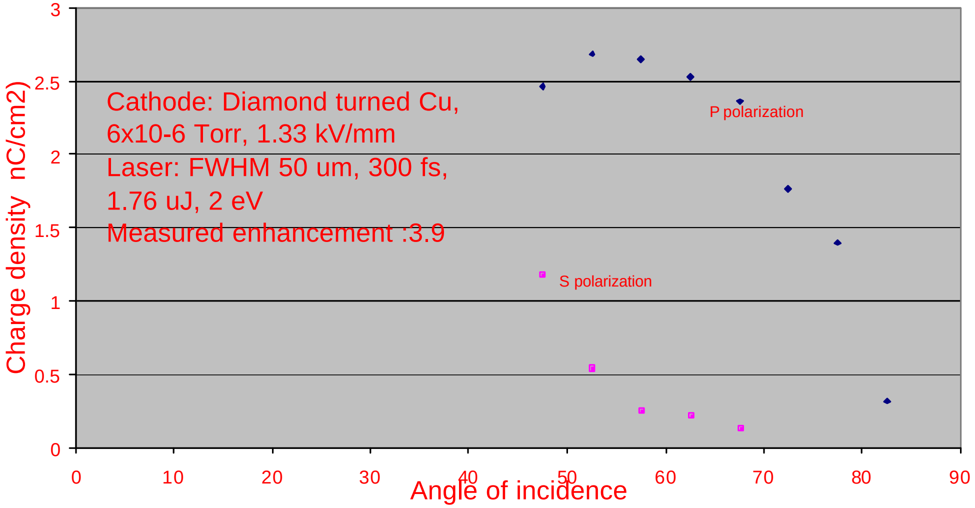


Multiphoton process

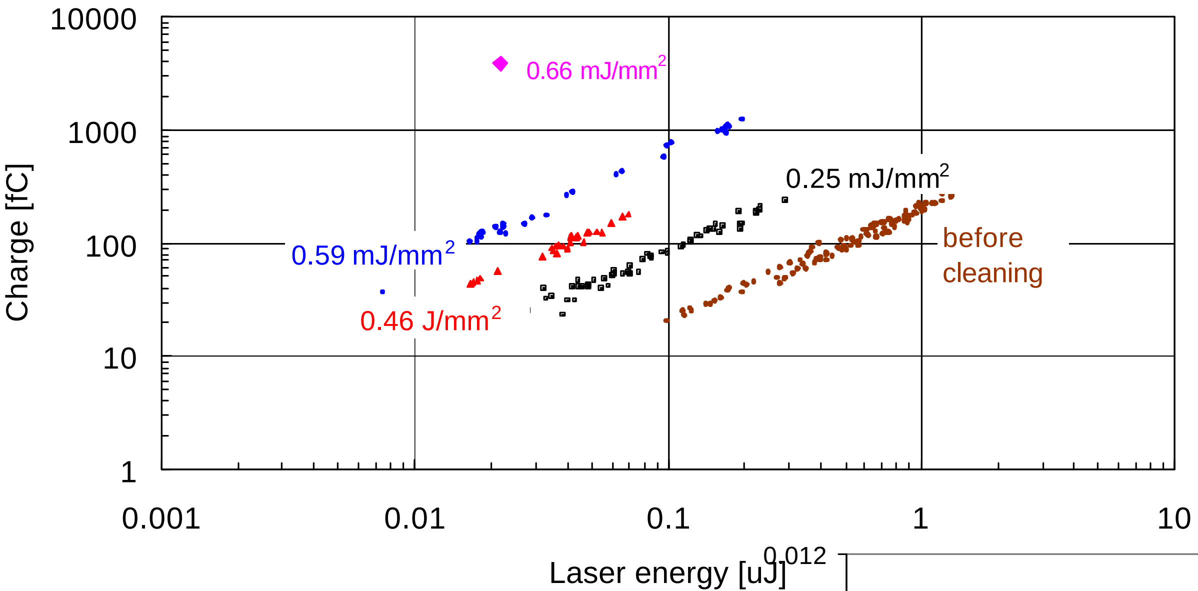
Surface Plasmon enhanced emission

Enhancement due to increased absorption

Photon field enhanced emission

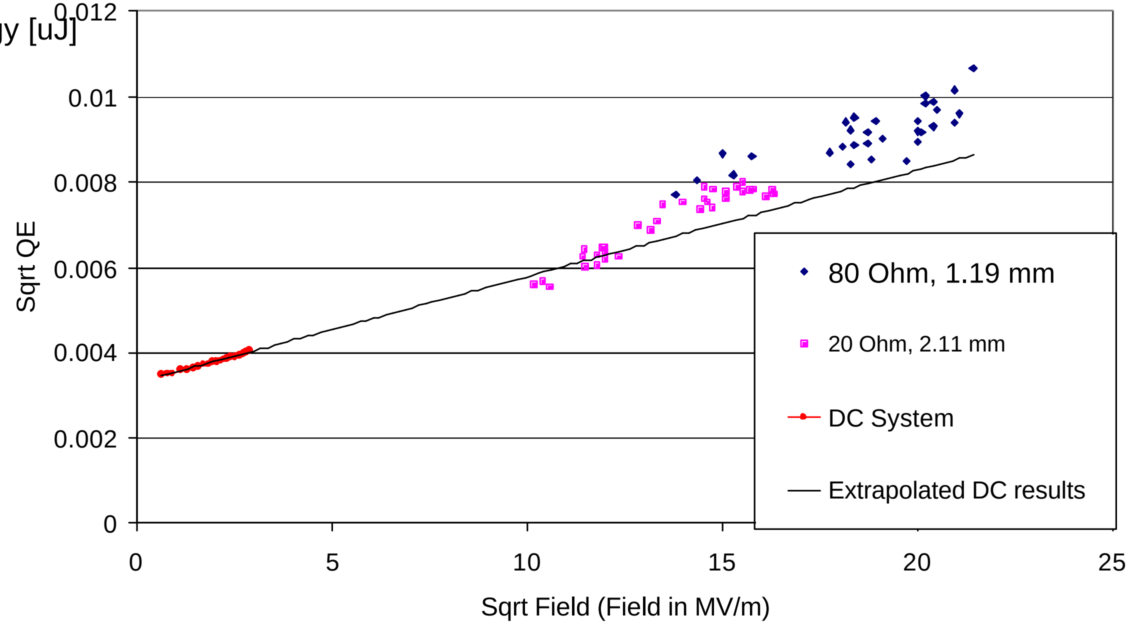


Surface Preparation

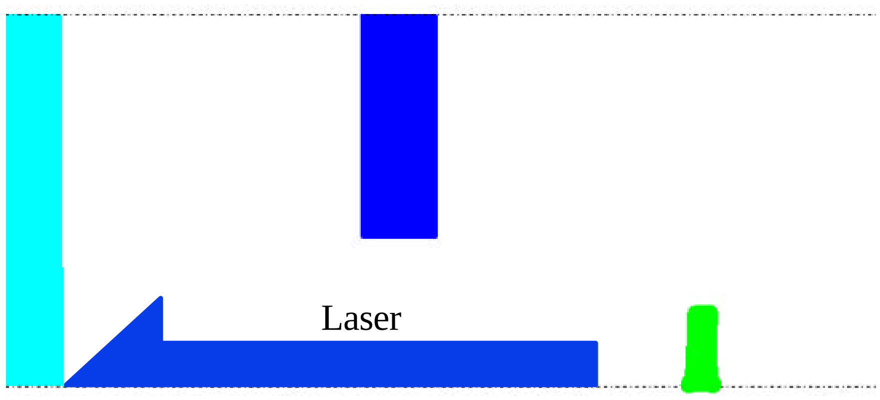


Nb, laser cleaning

Cu, Schottky effect



Principle Behind Photoinjector

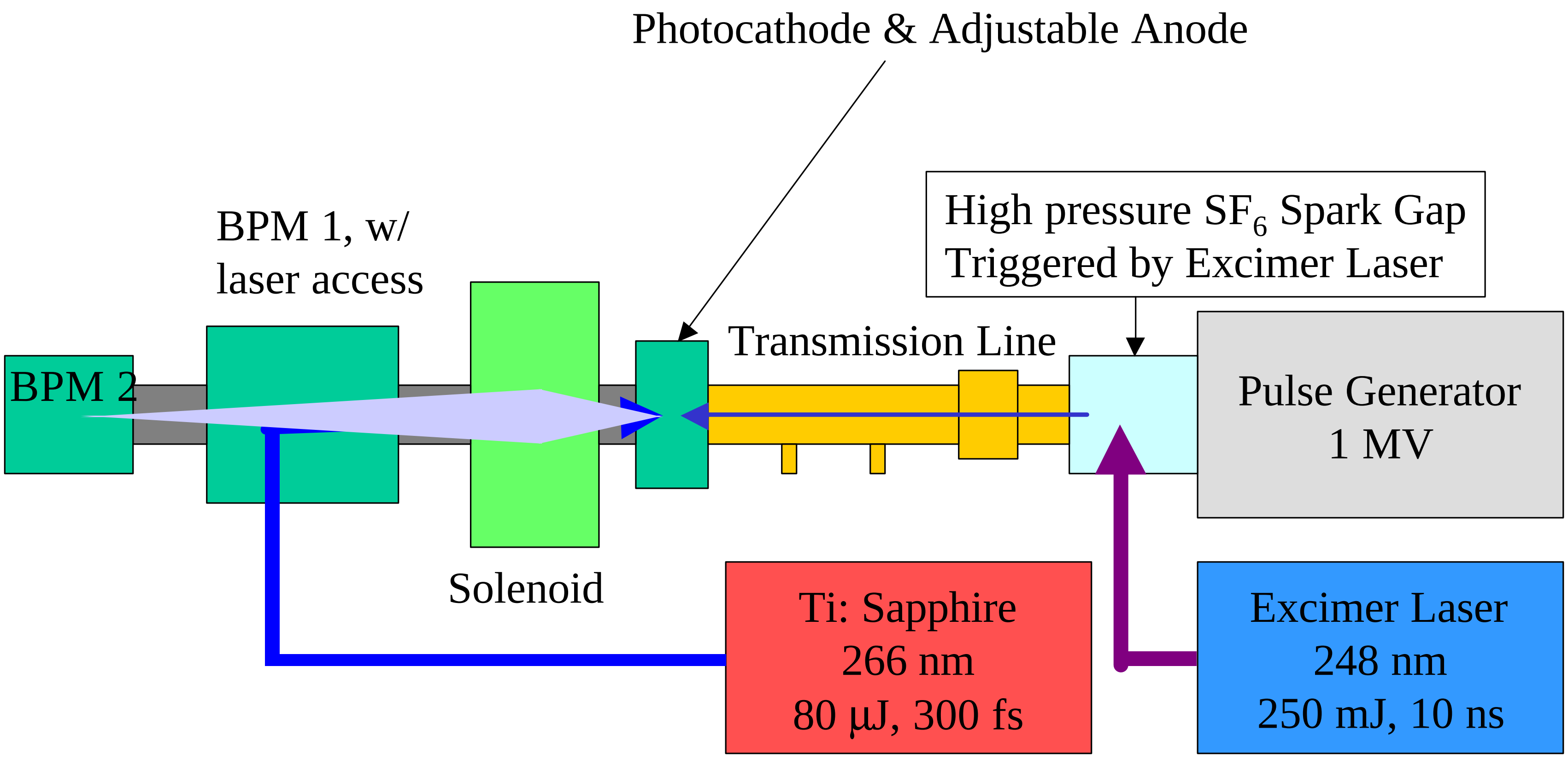


Charge profile at the cathode determined by the laser

Charge profile at interaction point determined by laser and transport

High Peak, Low Average Current Injectors

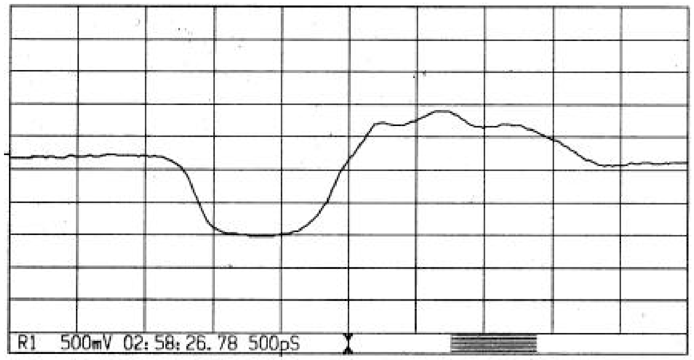
Pulsed Power Injector



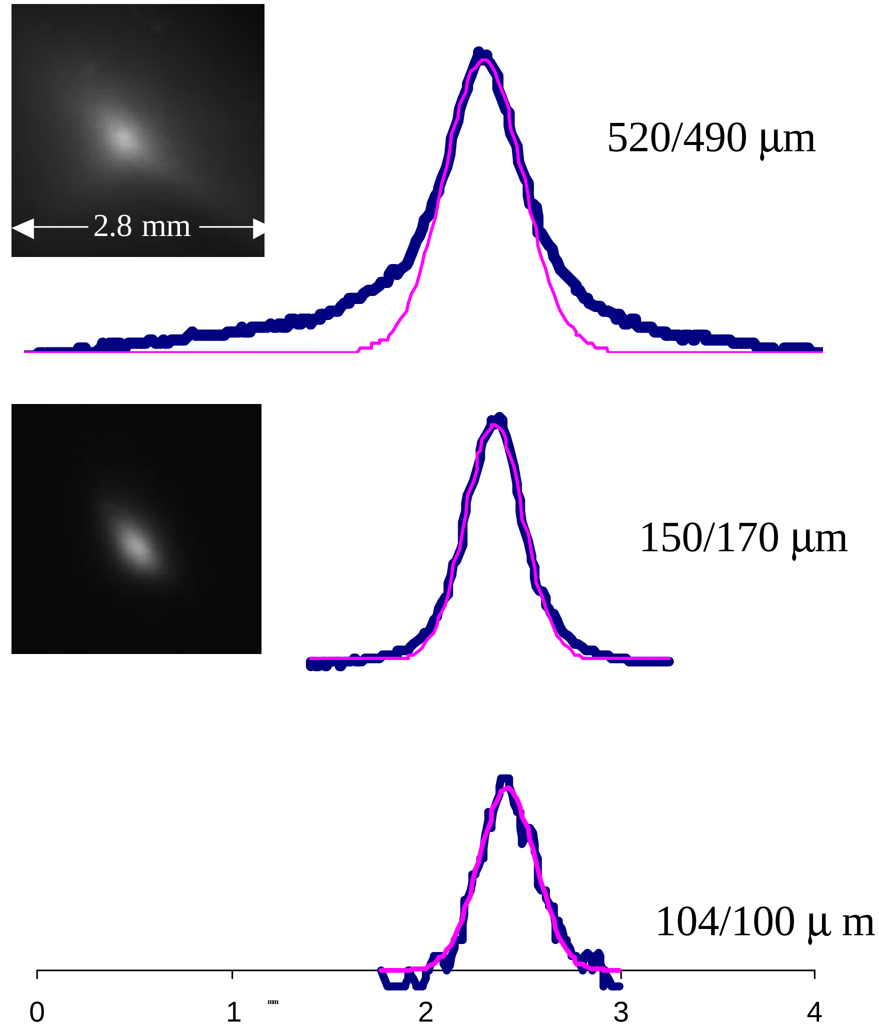
High gradient: up to 1 GV/m Þ Higher charge, lower space charge effects

Constant Voltage in space and time Þ No variation due to field

Wide range of laser pulse duration: 300 fs to 1 ns



Typical Voltage Pulse



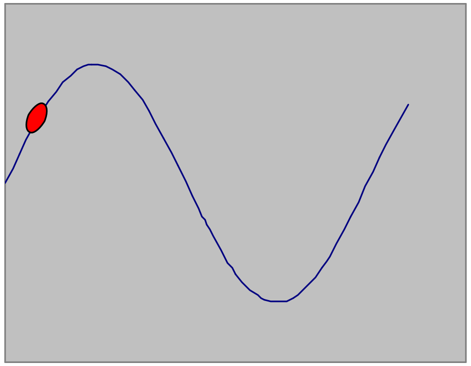
Results

Up to 60 pC, 300 fs, > 100 kA/cm^2

1 pC, 2.3 kA/cm^2, 1.2±0.7 mm-mrad

0.2 pC, 85 ❍m, 0.6±0.4 mm-mrad

RF injector: RF accelerating field



ATF injectors:

Y, Cu, Mg cathodes

266 nm, ~10 ps, up to 3 Hz laser

2.876 GHz, >100 MV/m at cathode

Up to 1 nC, 10 ps, 100 A peak current, ~ 3 kA/cm^2, few nA average current, 1 mm mrad

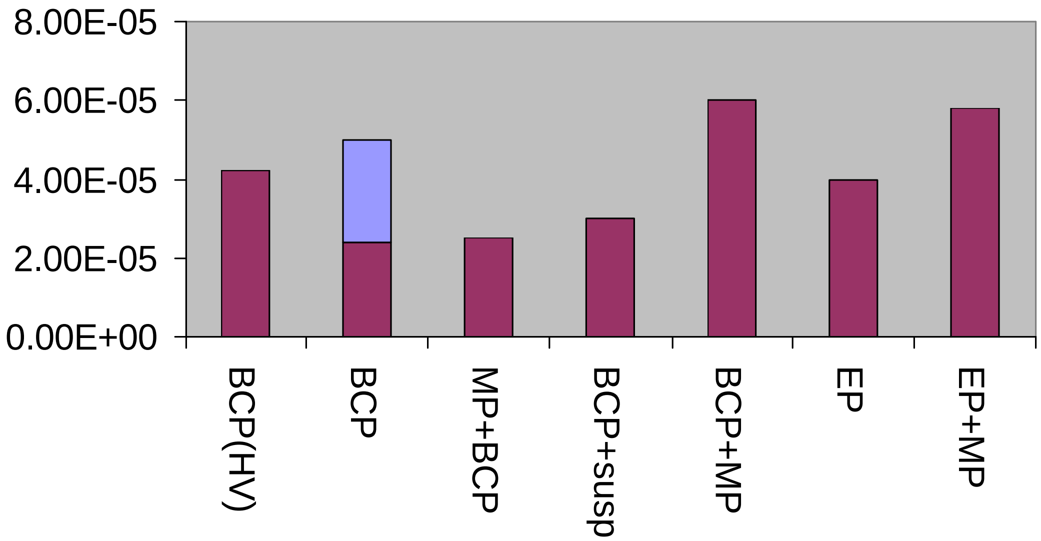
Similar systems in BNL, US and worldwide

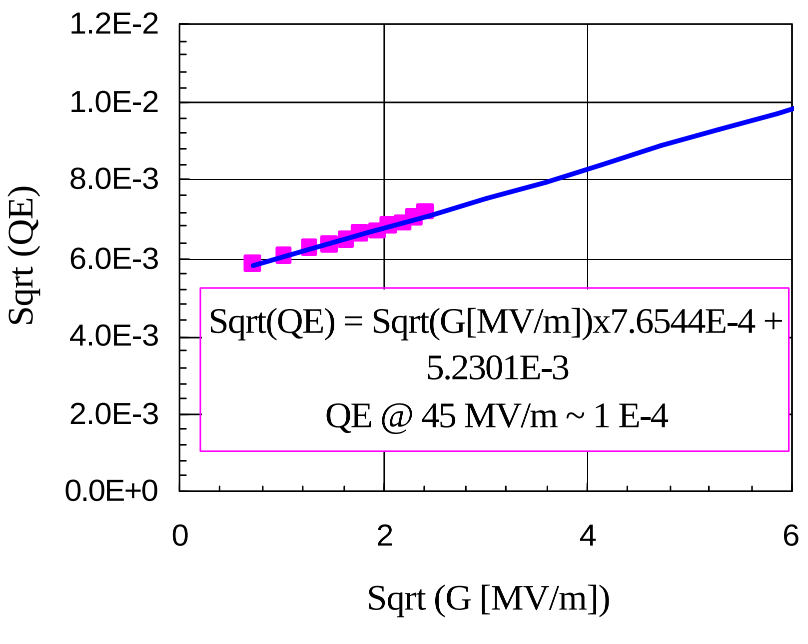
High Average, Low Peak Current RF Injector

Issues

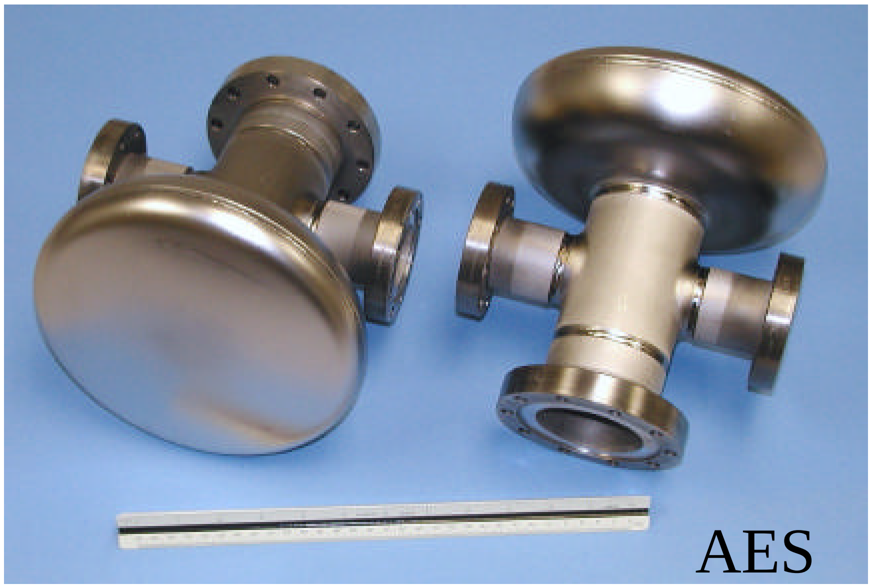
RF Power Þ Superconducting cavity

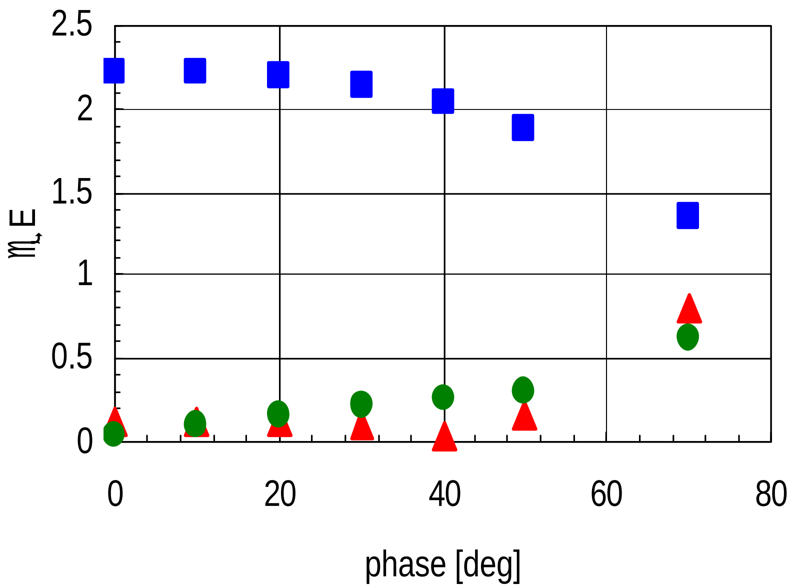
Laser Power Þ High QE





Cavity Design and simulations





½ CELL, 1.3 GHz CAVITY, Domed end wall for stiffness, 3.5 mm Nb electro formed and welded. Thickness optimized for thermal loading.

PARMELA simulation

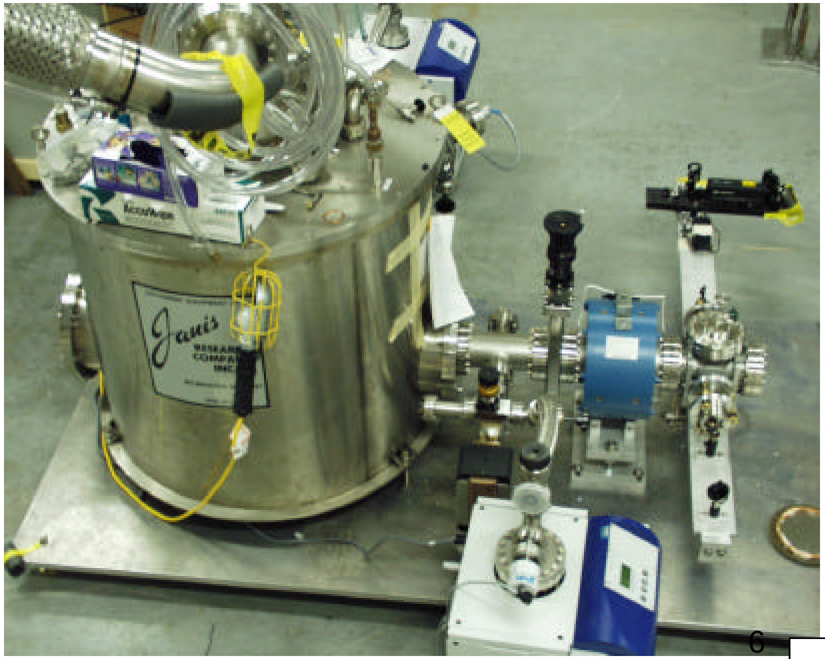
? Longitudinal emittance in keV deg,

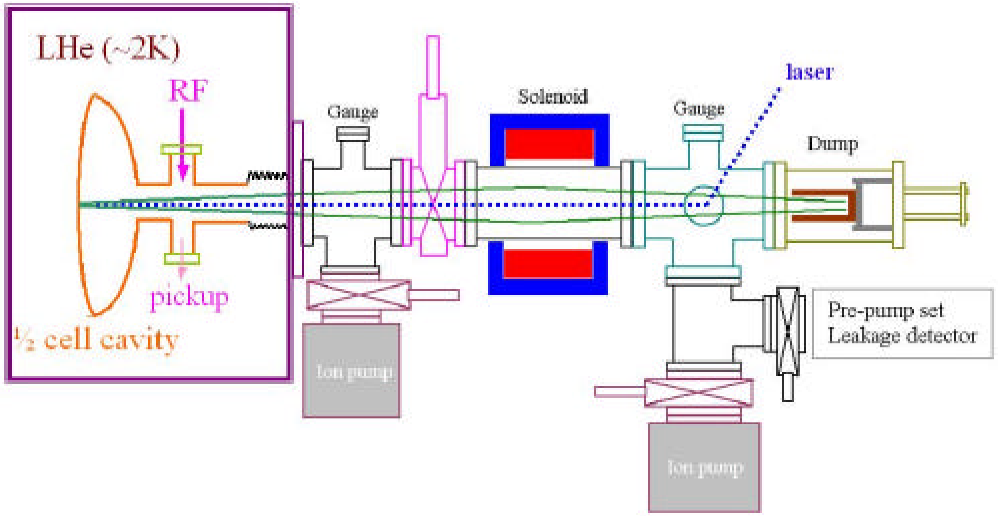
? Transverse emittance in mm mrad,

¦ Energy in MeV

Collaboration between IO, CAD, AES

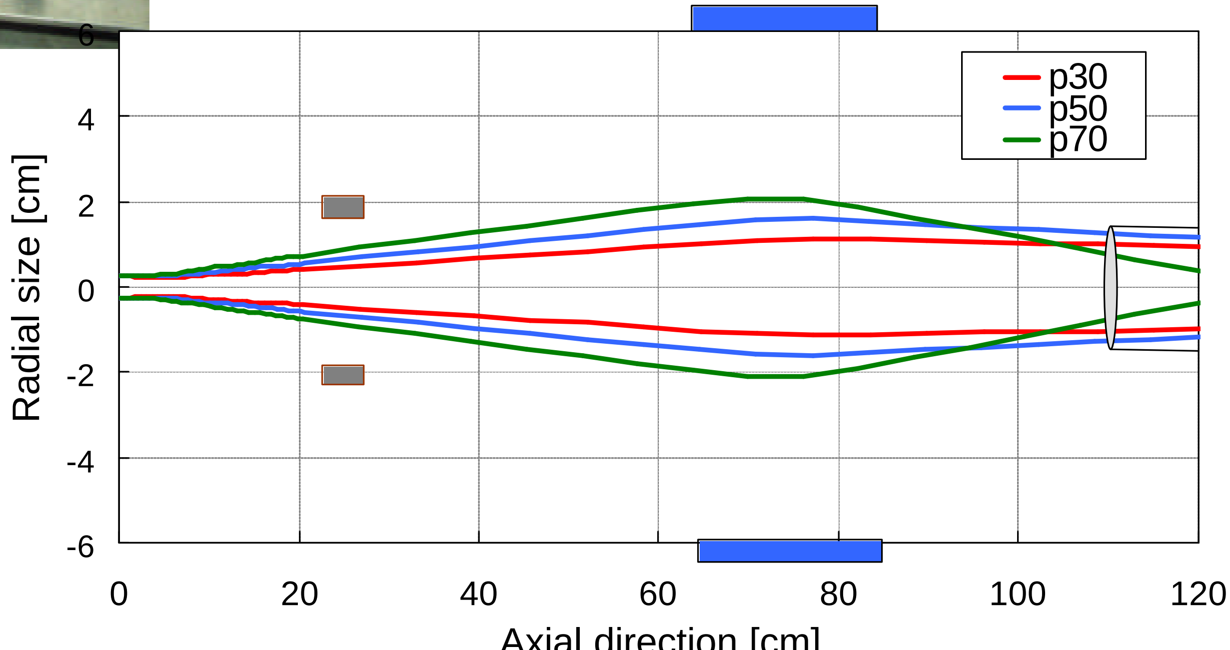
ELECTRON BEAM TRANSPORT LINE





Full e-beam size (6σ, 99% particles) along line

Q=1pC, R=1.2mm, Ec=43MV/m, B=600Gs



Cooled down to 4K

Measured Frequency: 1.3 GHz

Measured Q:10^7

High Average and Peak Current Injector

E beam Requirements for Cooling

Charge per bunch:	5-10 nC
Bunch length:	30 ps
Peak current:	>300 A
PRF:	~9.4 MHz
Average current:	~100 mA

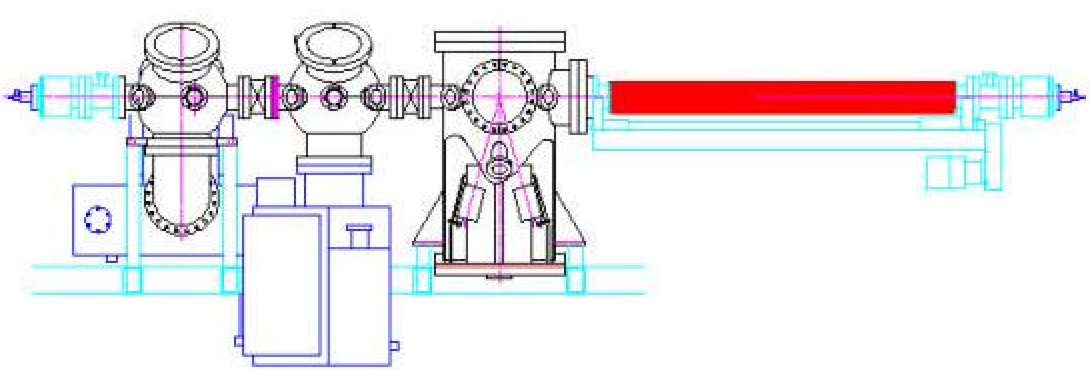
Photocathode requirements

Efficiency: >1%

Long Life time

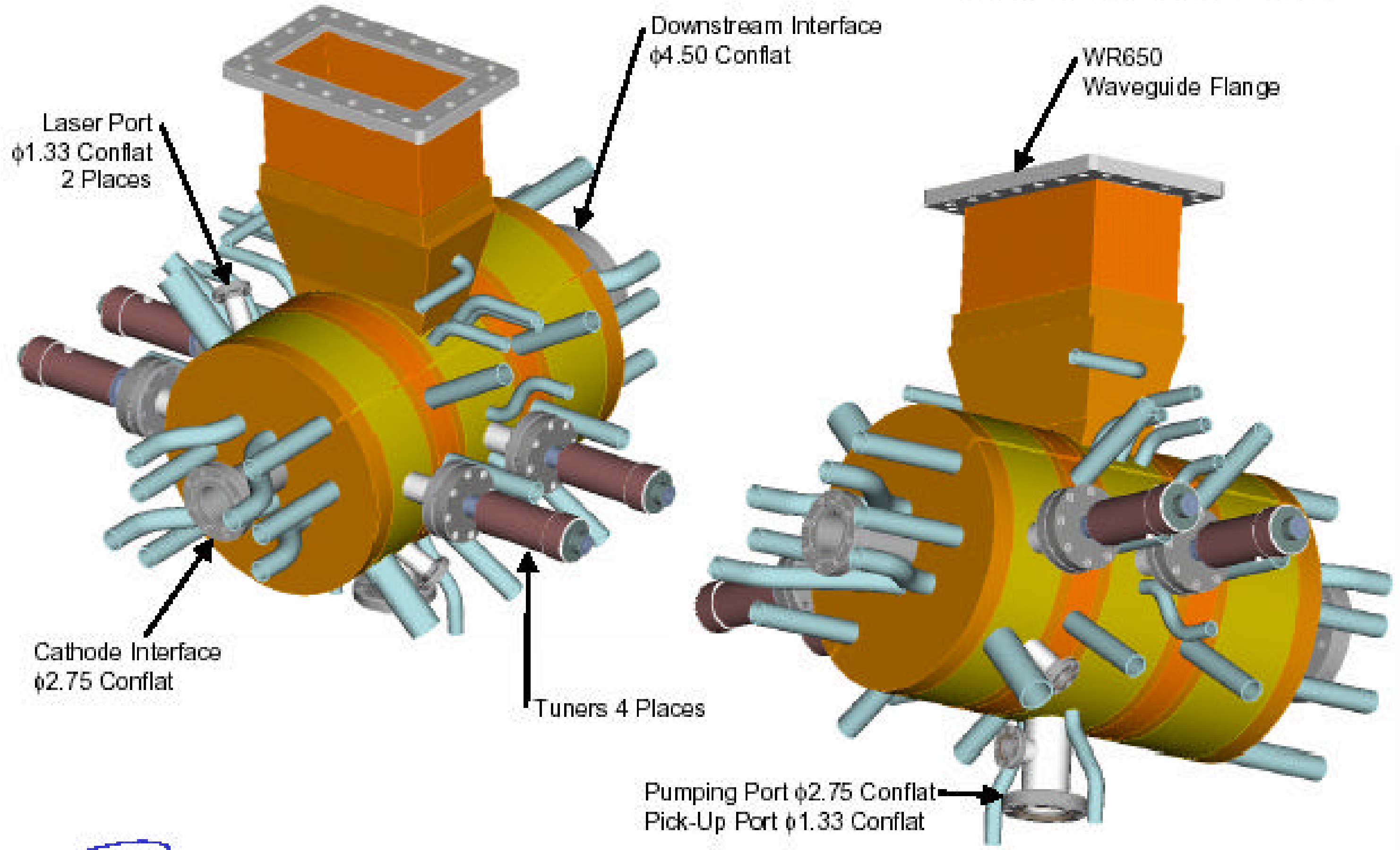
Insensitive to contaminants

High current capability

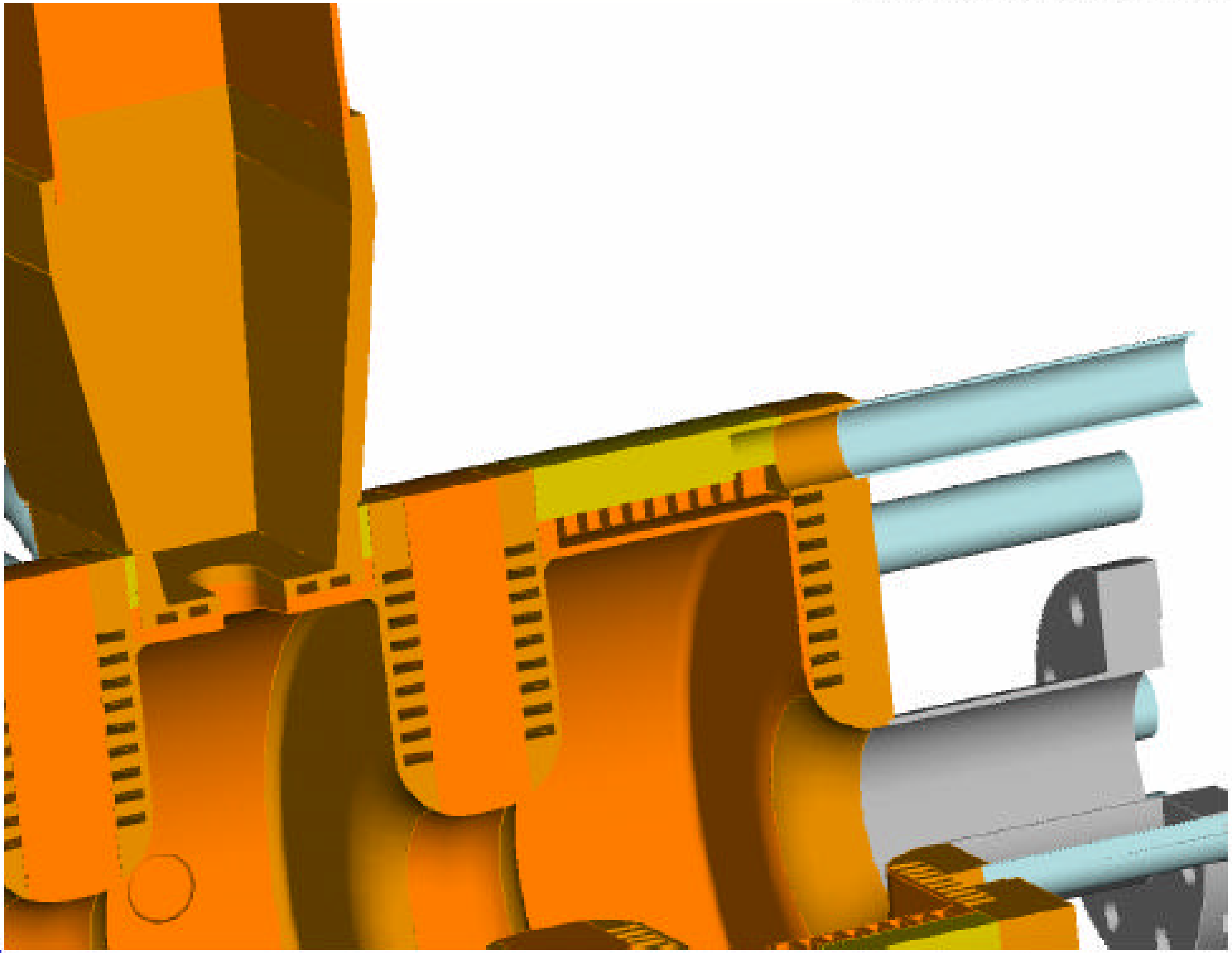


Collaboration between CAD, IO and AES

Complete Assembly - 2.6 Cell, 1.3 GHz



Detail View - Last Cell Cooling



High Harmonic Radiation in VUV, XUV

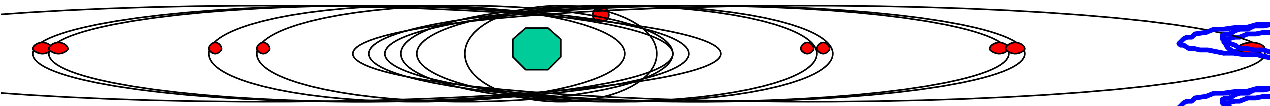
- Conventional Approach:
- Electric field of laser is small perturbation to atomic field
- Pulse duration is long compared to periodicity of the laser

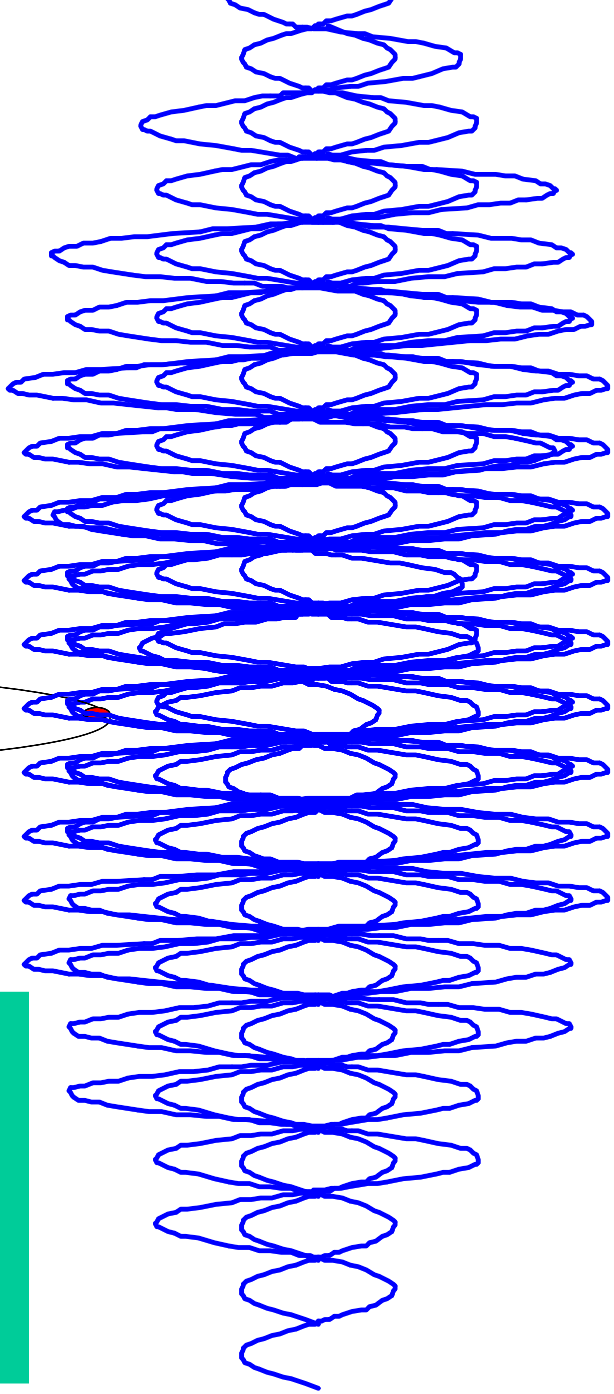
But

Consider a 800 nm laser of 1 mJ energy, 20 fs FWHM, focused to 10 ❍m diameter spot size

Peak optical field ~ $7*10^{11}$V/m

~ 7 optical cycles in FWHM





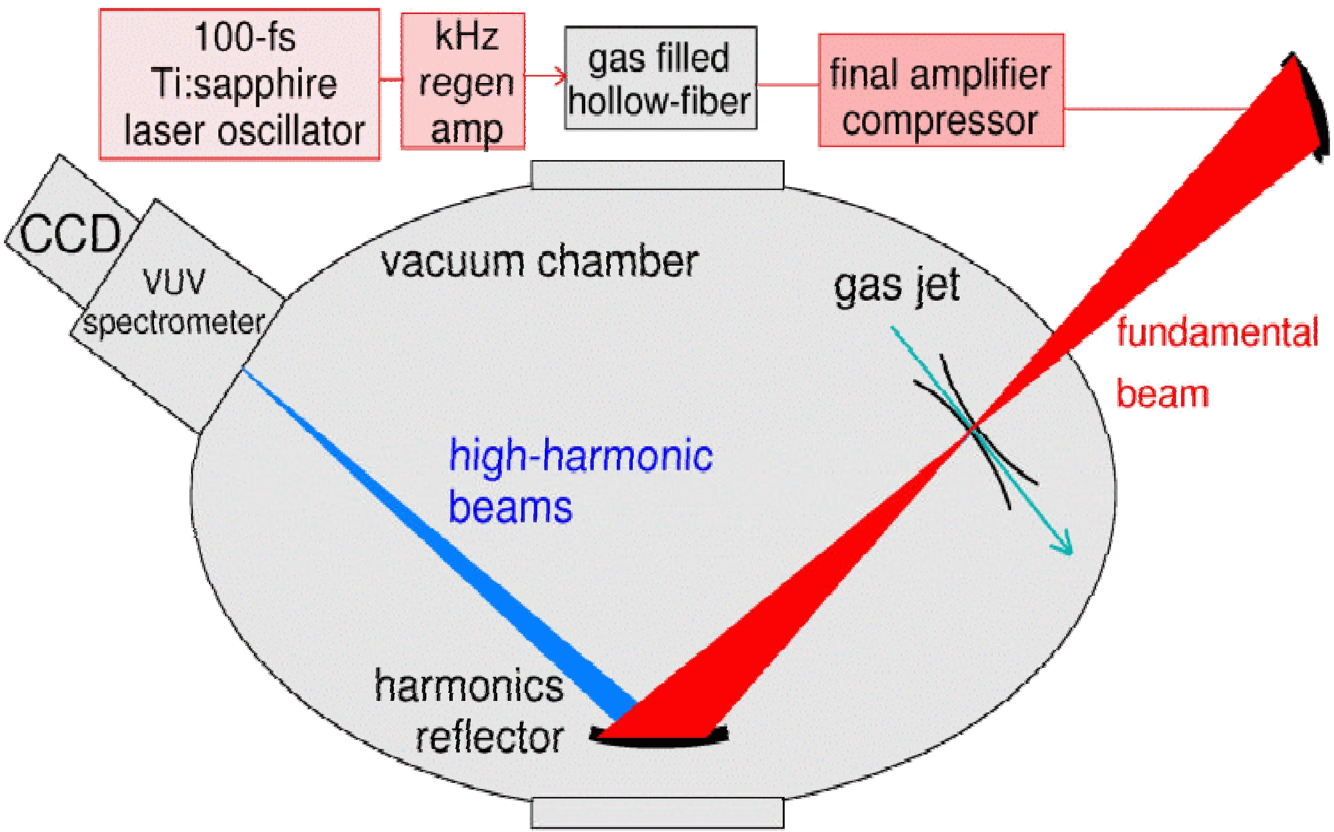
Emission characteristics:

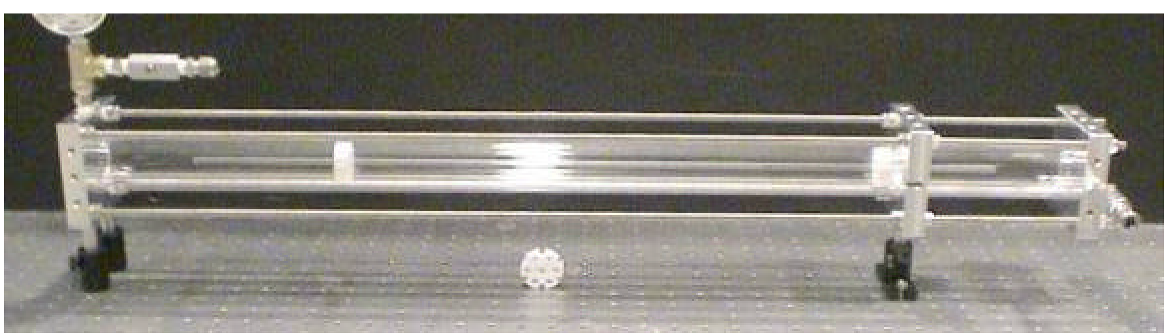
Coherent

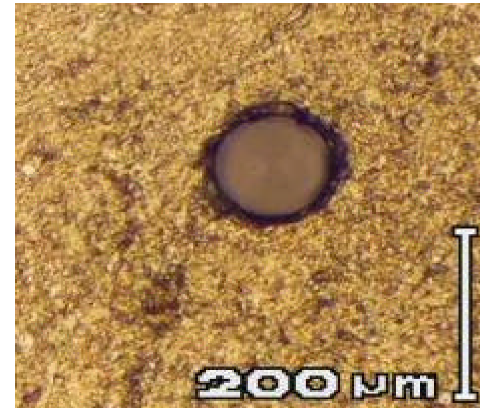
Harmonic of fundamental

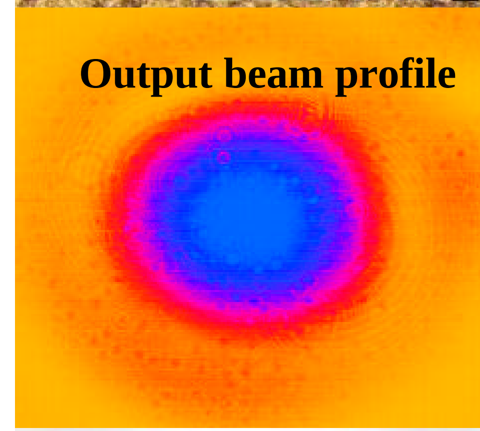
Highest photon energy depends on ionization potential

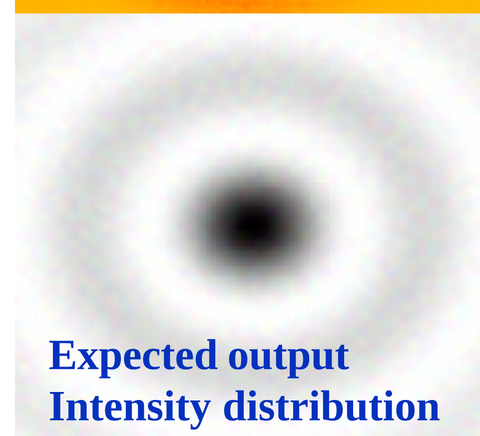
Number of photons depend on interacting particles



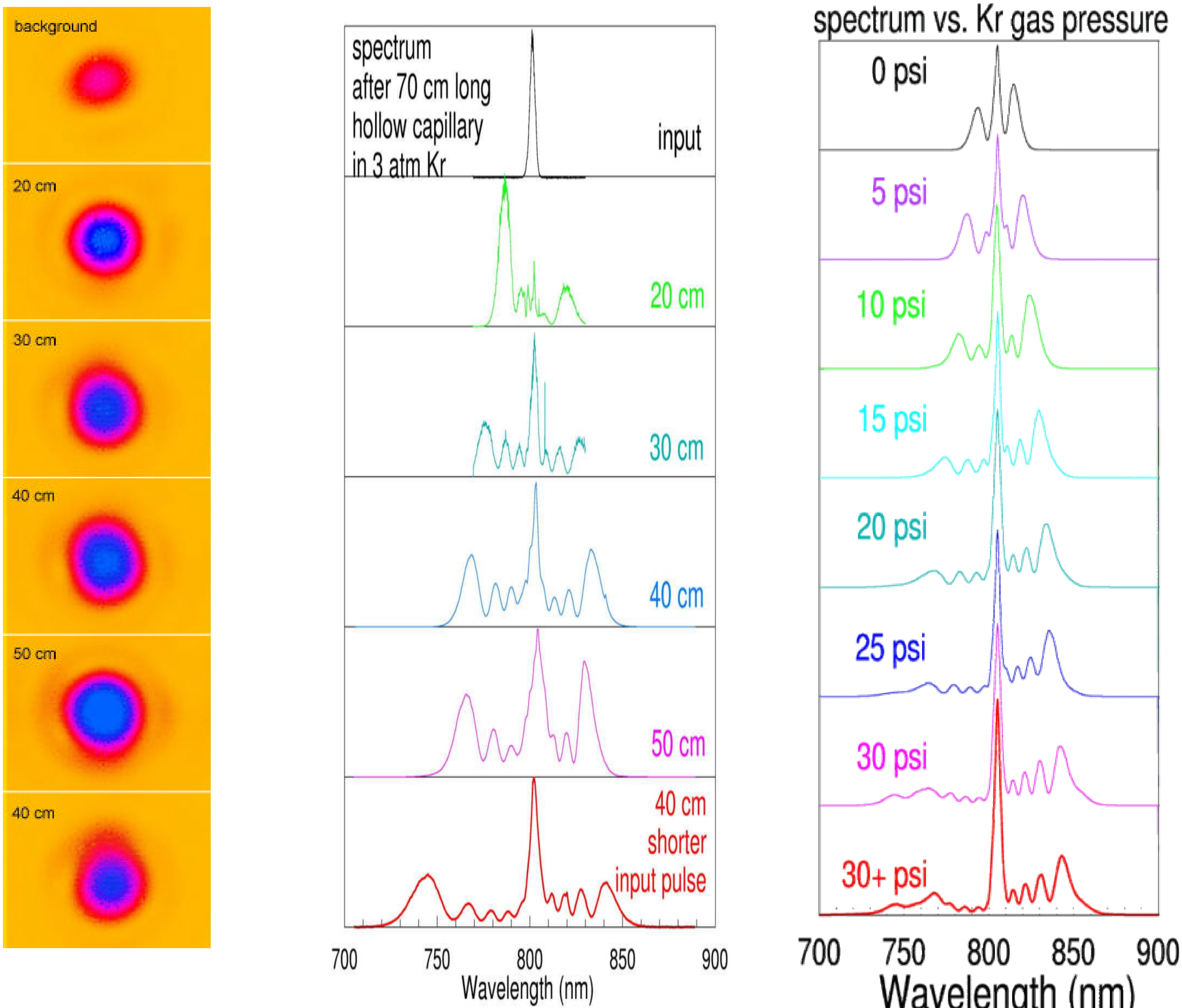






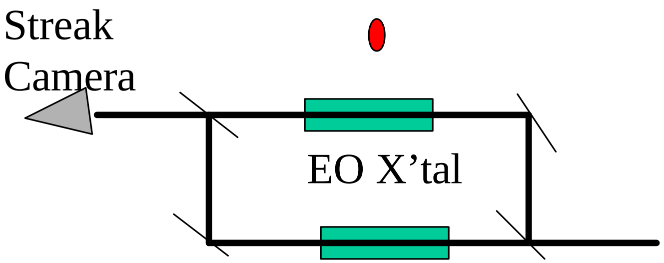


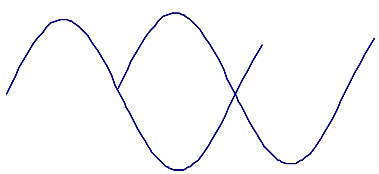
Collaboration between IO, NSLS, BU



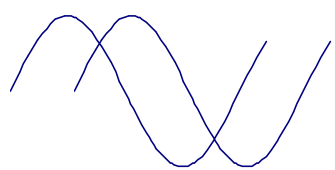
background
20 cm
30 cm
40 cm
50 cm
40 cm
spectrum
after 70 cm long
hollow capillary
in 3 atm Kr
input
20 cm
30 cm
40 cm
50 cm
40 cm
shorter
input pulse
700
750
800
850
900
Wavelength (nm)
spectrum vs. Kr gas pressure
0 psi
5 psi
10 psi
15 psi
20 psi
25 psi
30 psi
30+ psi
700
750
800
850
900
Wavelength (nm)

Electron Bunch Length Measurements

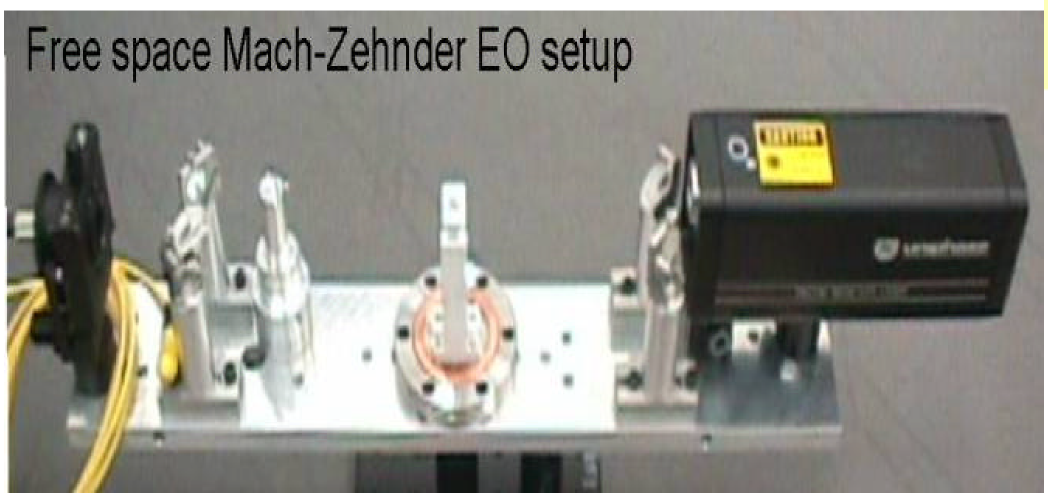


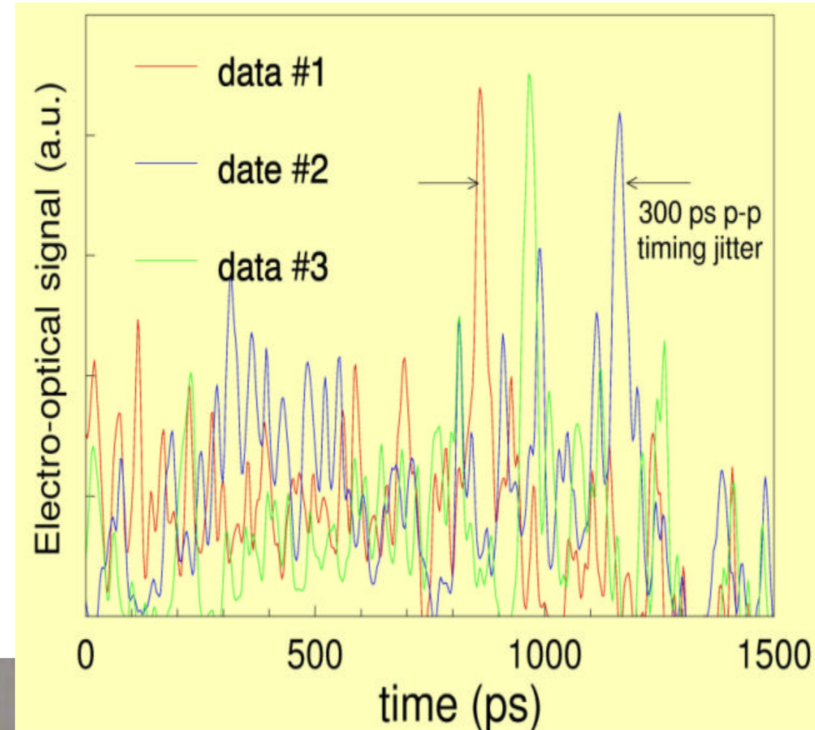


E beam off



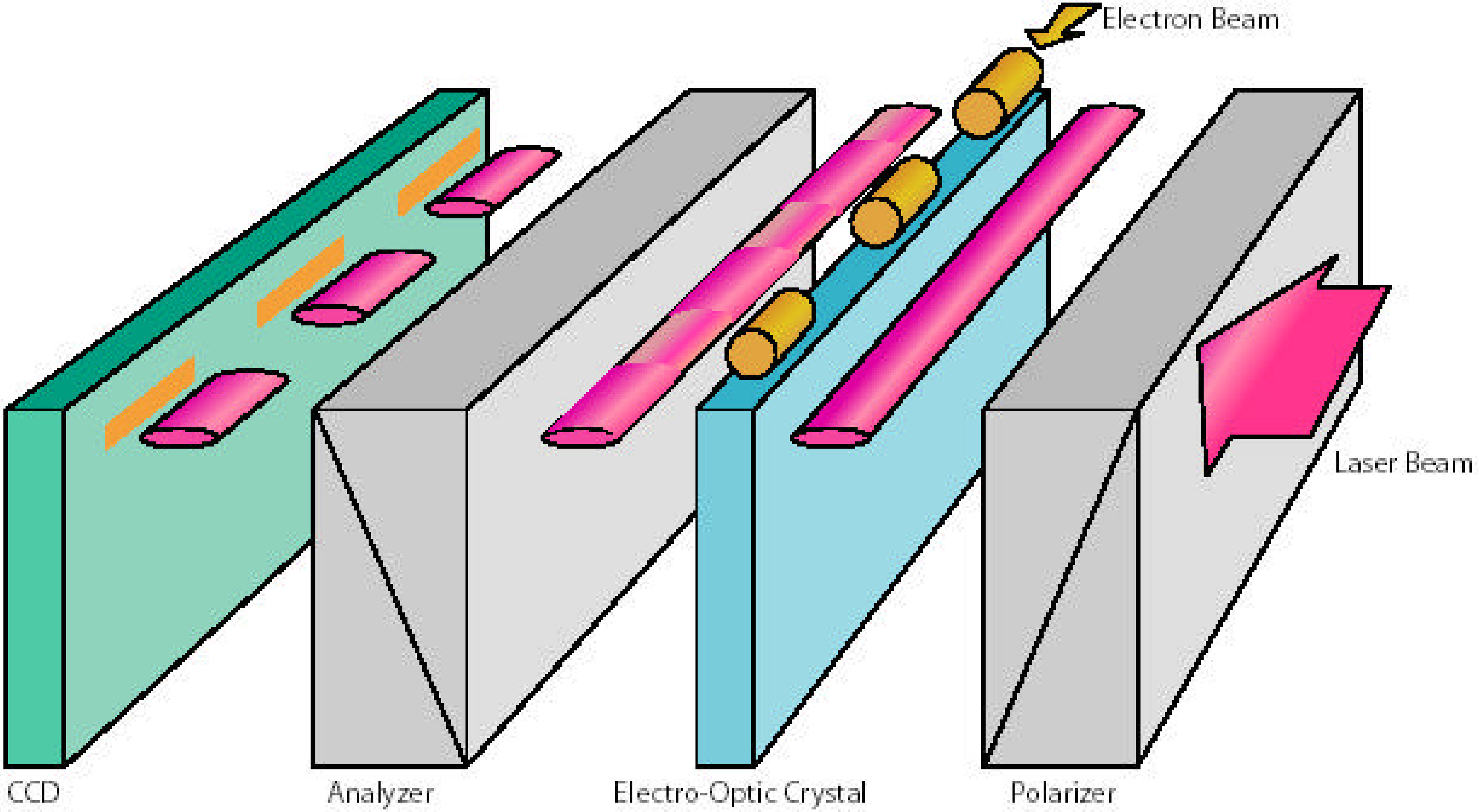
E beam on





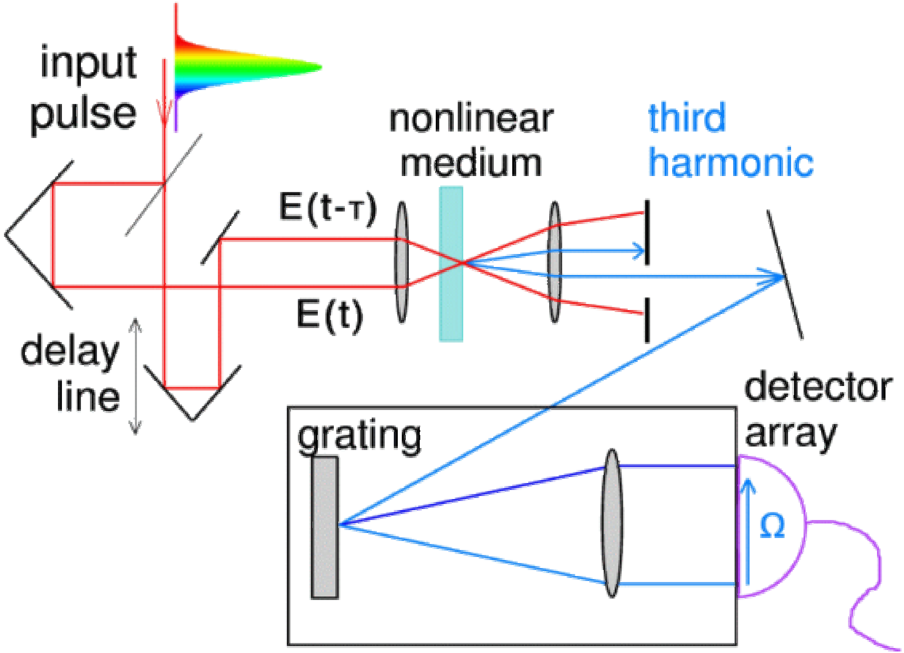
Collaboration between IO,Physics, CAD, Montclair, UCLA

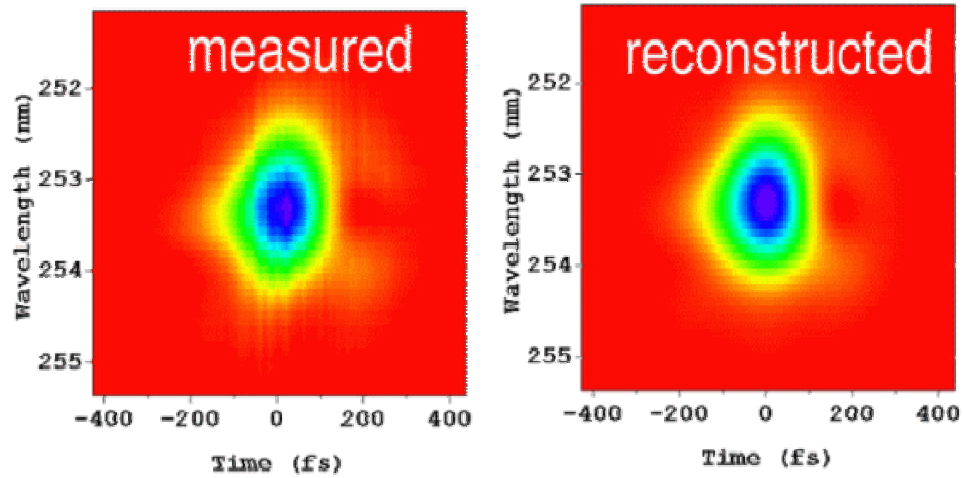
Schematic to measure subps e$^-$ bunches

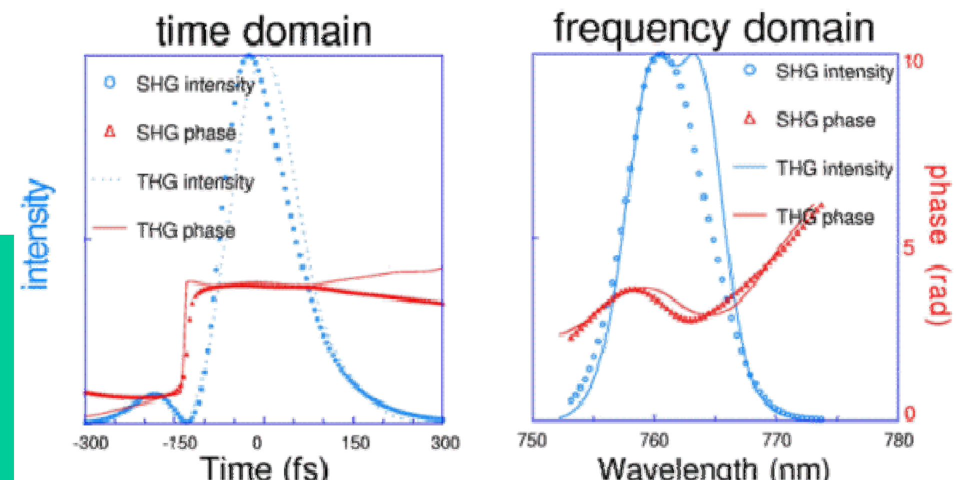


Measurement of Ultrafast Photon bunches

Frequency-Resolved Optical Gating (FROG): Surface Third Harmonic Generation







- *No direction of time ambiguity*
- *Third-harmonic enhanced at interface*
- *Potential for sub-femtosecond pulse measurements*

Collaboration between IO and Sandia National Laboratory

Active Programs in

- ✓Generation of High Brightness Electron beams
- ✓Generation of High Brightness VUV, XUV photons
- ✓Measuring electron bunch lengths below 1 ps
- ✓Measuring photon bunch lengths in fs regime