The UCLA/LLNL Inverse Compton Scattering Experiment: PLEIADES

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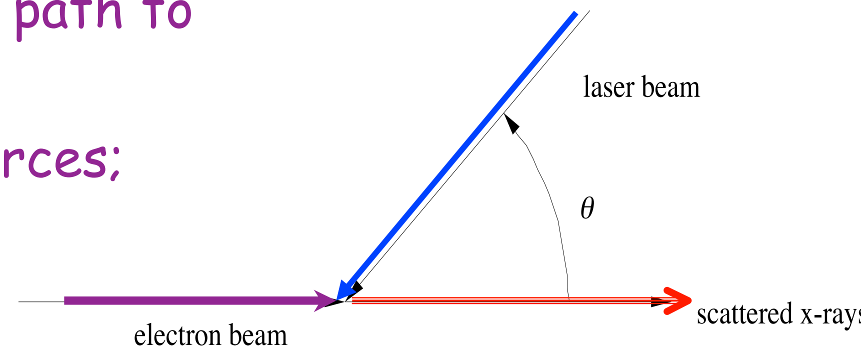
Introduction

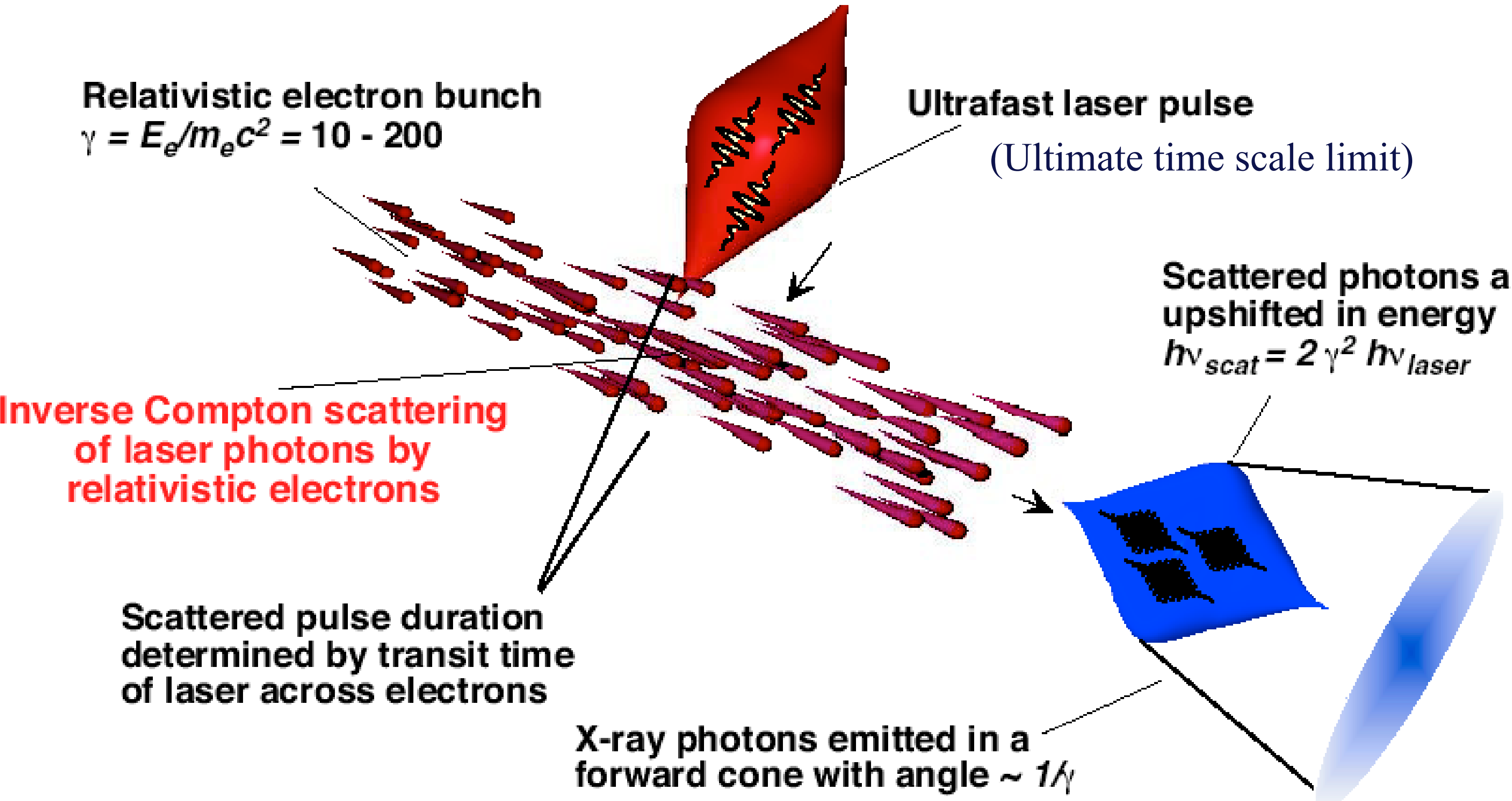
UCLA

- Inverse Compton scattering provides a path to 4th generation x-ray source
- Doppler upshifting of intense laser sources; “monochromatic” source
- Intense electron beam needed
- Extremely diverse uses
  - High energy density physics (shocks, etc.)
  - High energy physics
    - Polarized positron sourcery
    - Gamma-gamma colliders
  - Medicine
    - Diagnostics (dichromatic coronary angiography)
    - Enhanced dose therapy



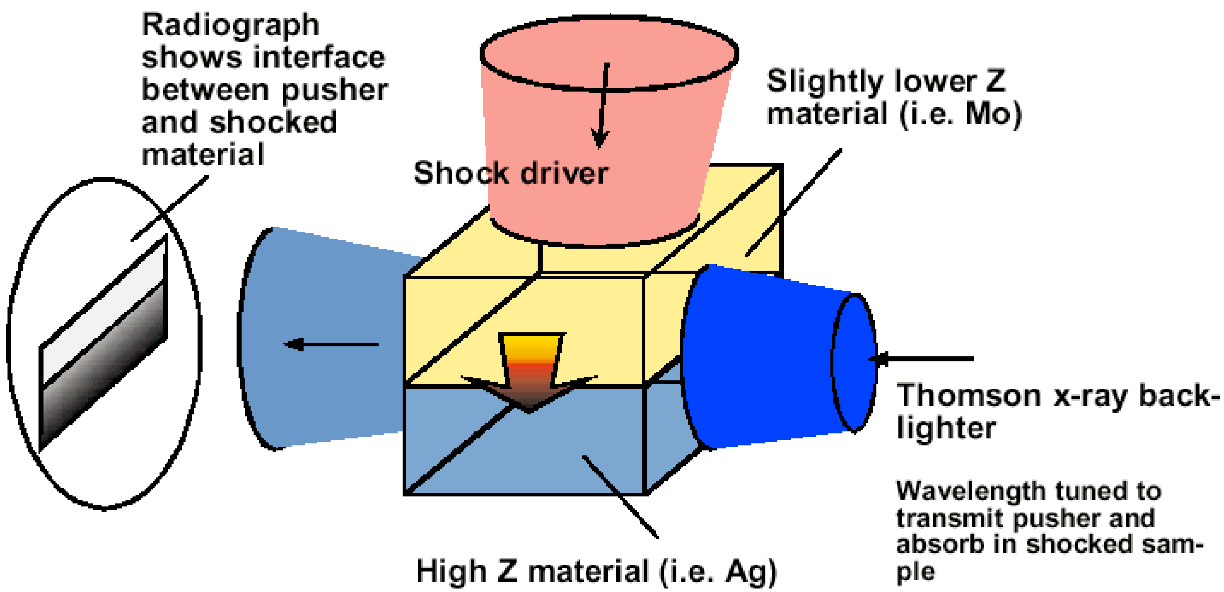
$$\lambda_\gamma \cong \lambda_L / 2(1+\cos(\theta))\gamma^2$$

Inverse Compton process

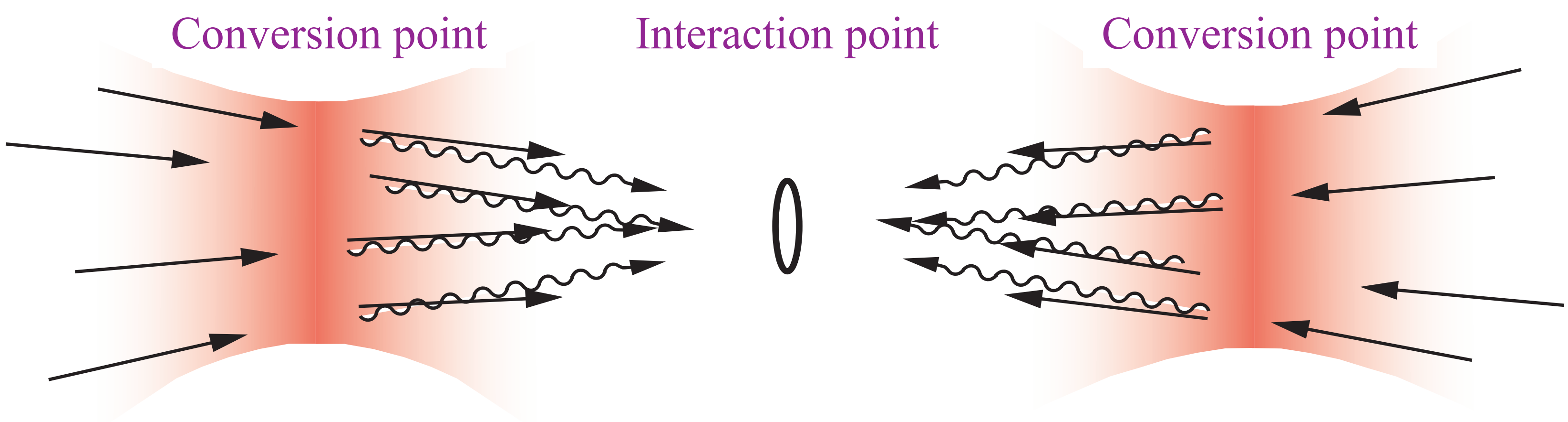


Shock physics

- Fundamental material studies for ICF, etc.
- Pump-probe systems with high power lasers
- EXAFS, Bragg, radiography in fsec time-scale.



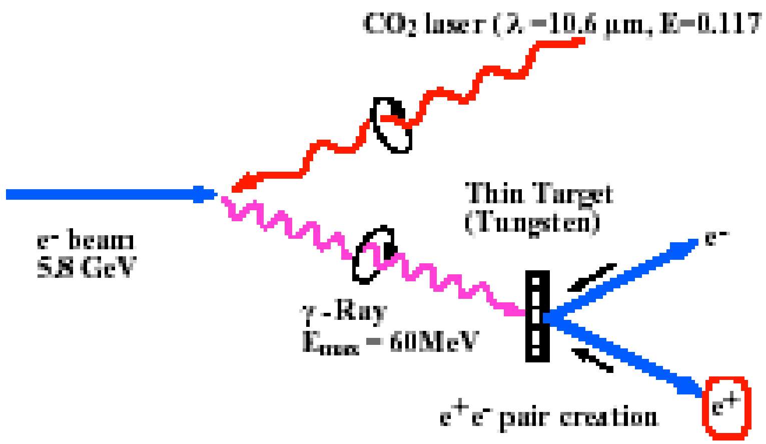
HEP 1: Gamma-Gamma collisions

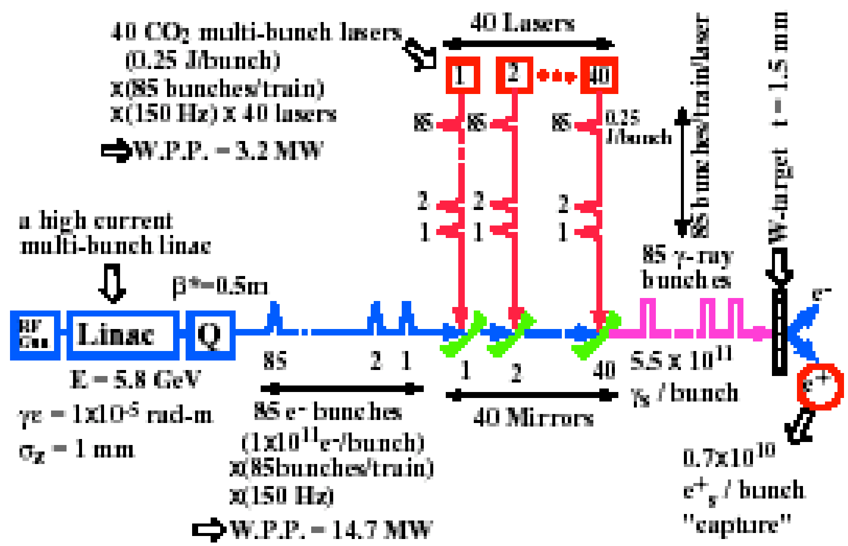


- Start with an electron linear collider
- Collide the electron bunches with a laser pulse just before the IP to produce high energy photons (100's GeV)
- Requires:
  - Lasers
    - Pulses of 1J / 1ps @ 11,000 pulses / second
  - Optics
    - Focus pulses inside the IR without interfering with the accelerator or detector

HEP 2: Polarized Positron Sourcery

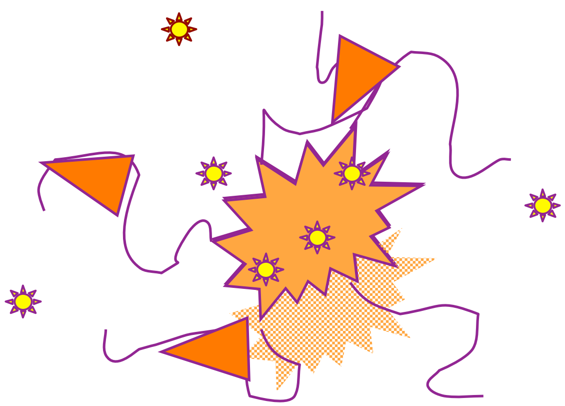
UCLA



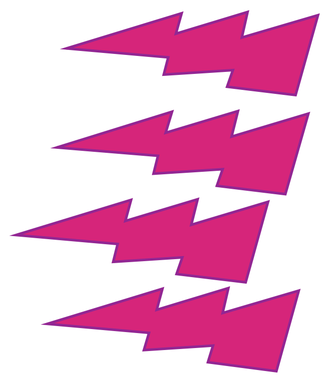


- Start with an 2-7 GeV electron linac (dependent on photon choice)
- Collide the electron bunches with a circularly polarized laser pulse to produce high energy photons (<u>100 MeV</u>)
- Convert gammas W target to obtain the positrons
- Requires:
  - Lasers
    - Pulses of 1J / 1ps @ 11,000 pulses / second

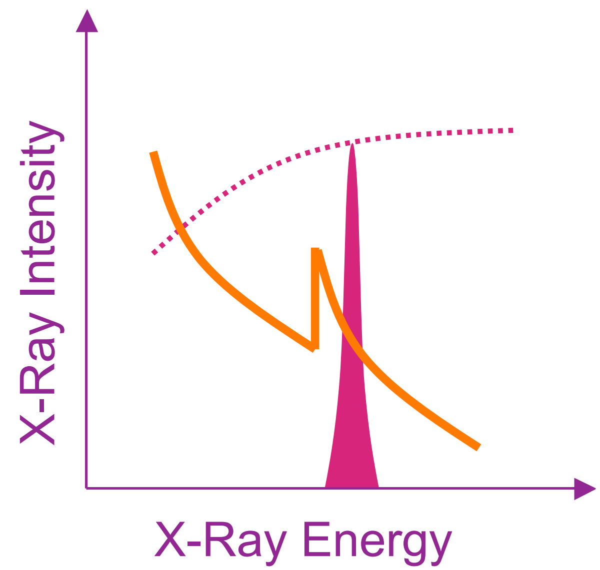
Monochromatic cancer therapy



Tagged Agents Imaged by Noninvasive X-Ray Absorption or Diffraction Spectroscopy

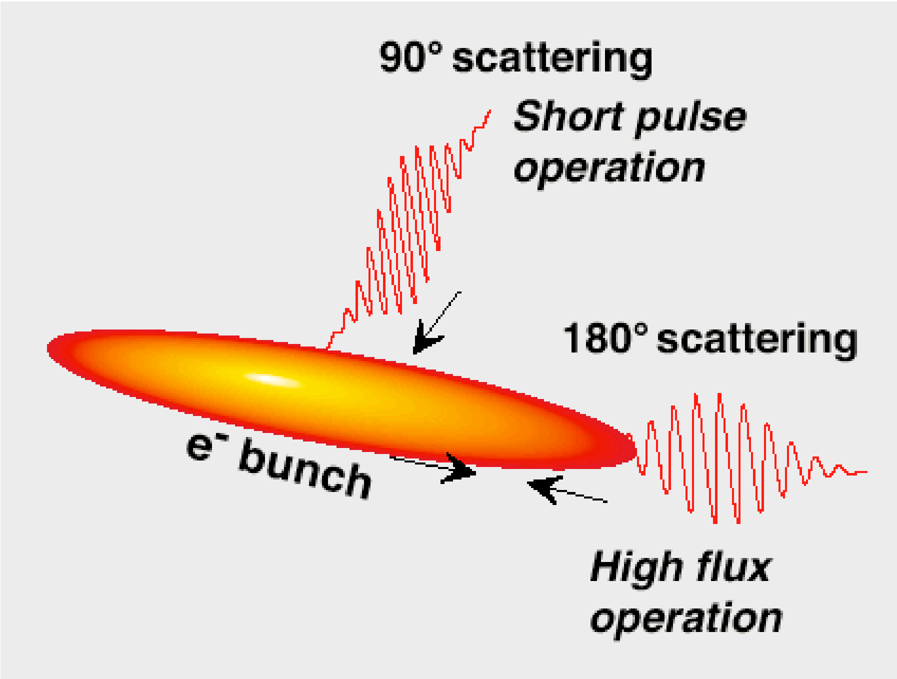


Intensity Increased to Deliver Localized Radiation Dose



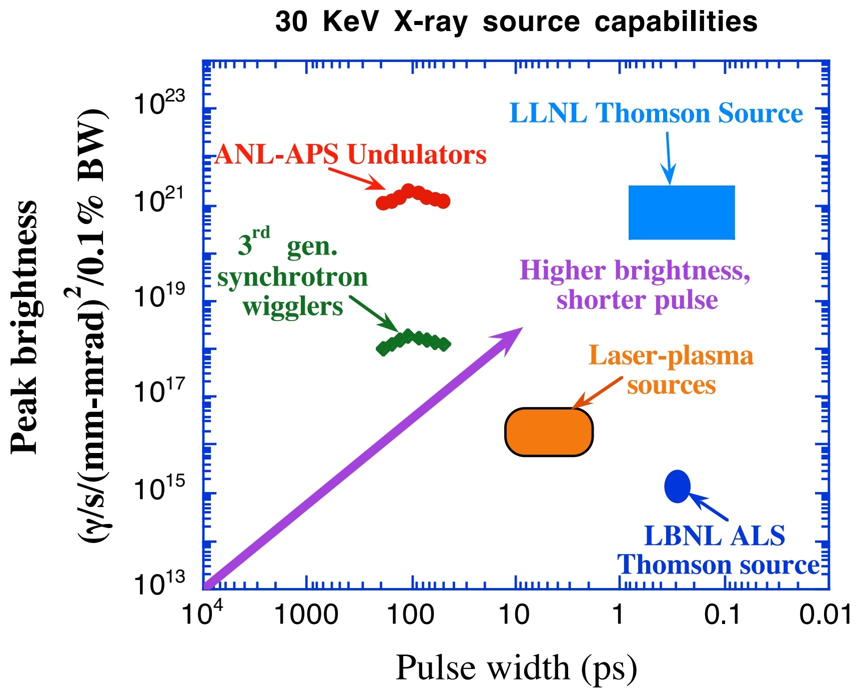
K-edge (~30 keV)

Choice of time structure



90° Scattering	180° Scattering
10 - 100 keV 50 - 100 fs pulse width ~10^8 γ/pulse (10% bandwidth)	20 - 200 keV < 10 ps pulse width ~10^9 γ/pulse (10% bandwidth)

The PLEIADES source

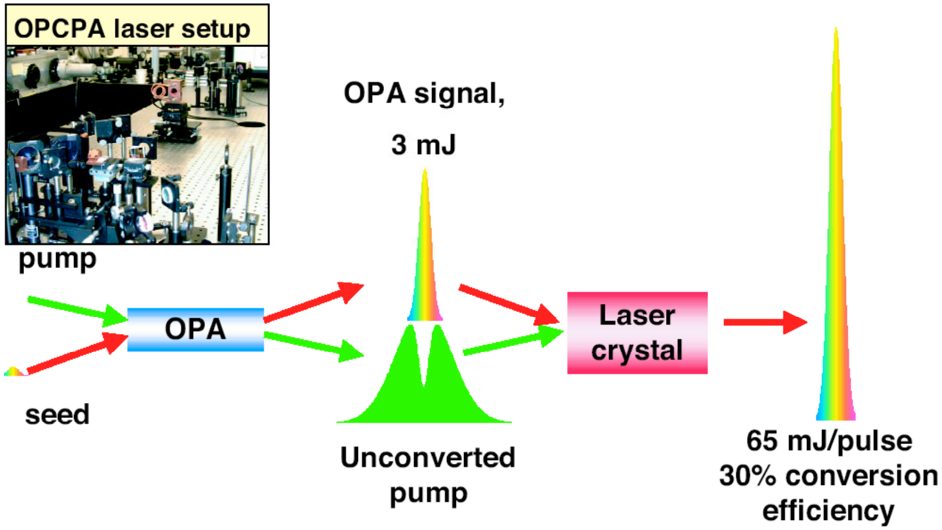


$$\lambda_{sc} = \frac{\lambda_l}{2\gamma^2(1-\beta\cos\psi)}\left[1 + a_l^2 + (\gamma\theta)^2\right]$$

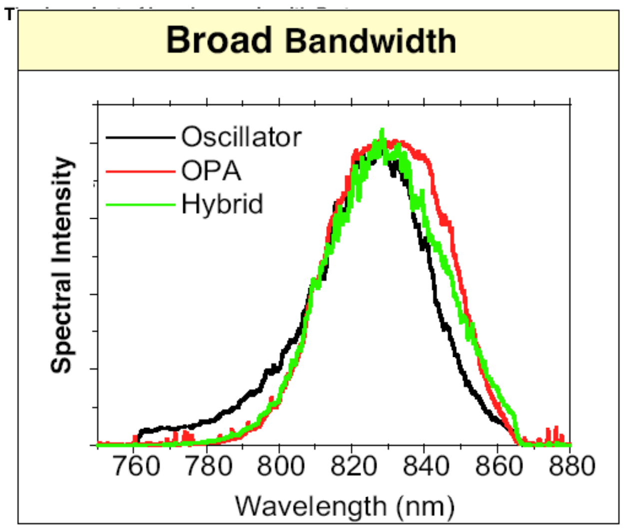
Brightness limited by energy?

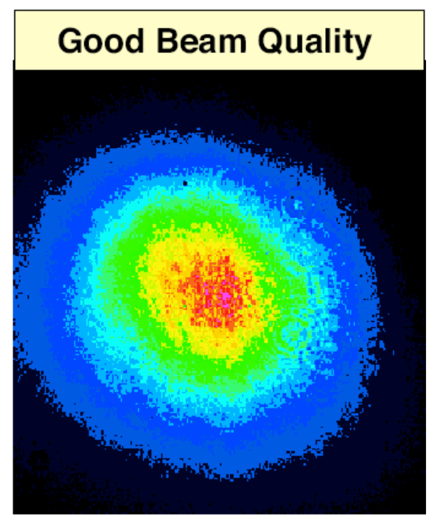
- **P**icosecond **L**aser-**E**lectron **I**nter**A**ction for **D**ynamic **E**valuation of **S**tructures
- Joint project between LLNL and UCLA
- High brightness photoinjector linac source
  - 1 nC, 1-10 ps, 35-100 MeV
- **FALCON** laser
  - 10 TW, >50 fs, 800 nm source
- Up to 1E9 x-ray photons per pulse
- Photon energy tunable > 30 kV

The FALCON laser



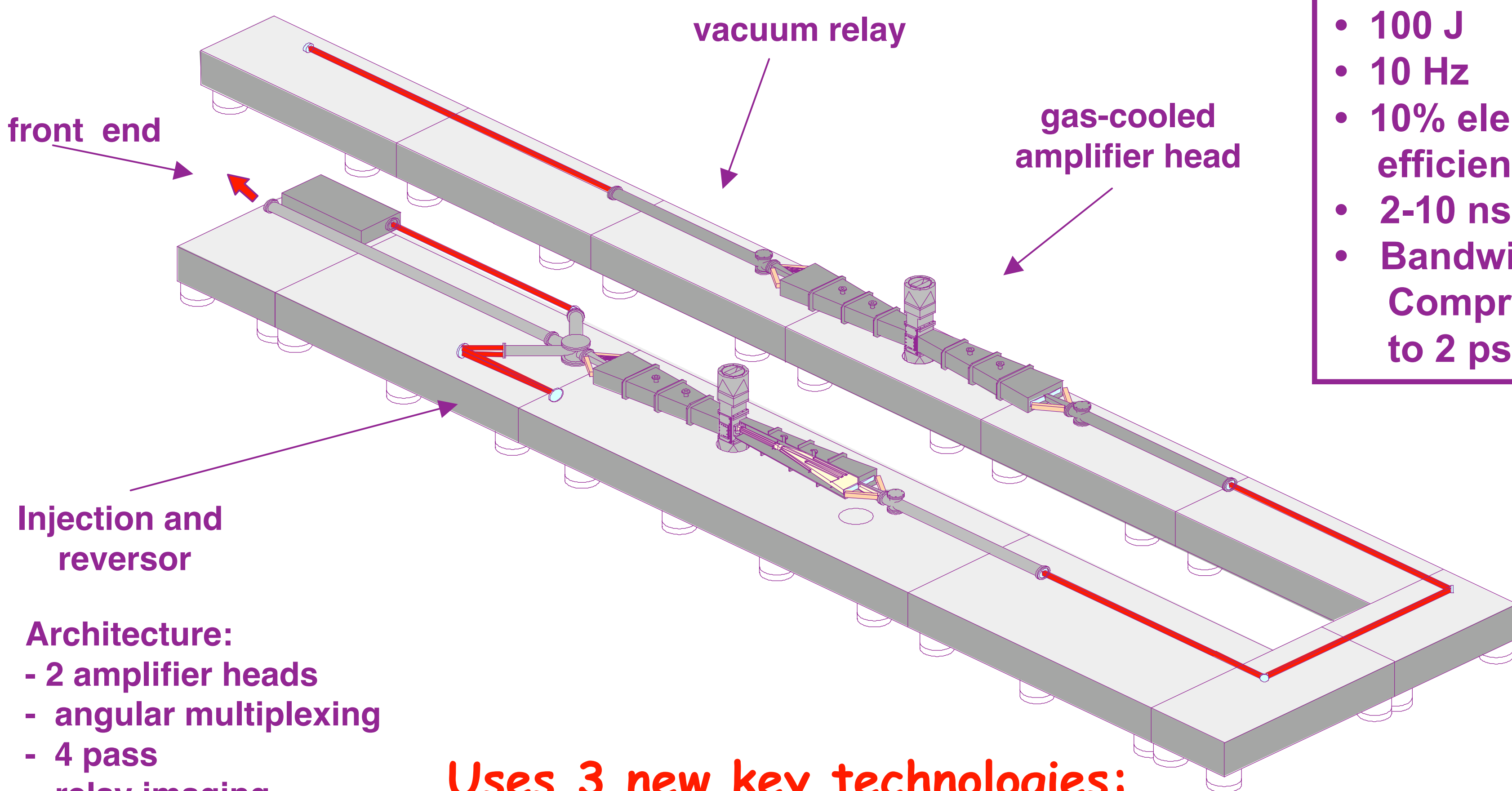
LLNL advanced technology





Scaling to HEP application:LLNL Mercury laser

Goals:
- 100 J
- 10 Hz
- 10% electrical efficiency
- 2-10 ns
- Bandwidth to Compress to 2 ps

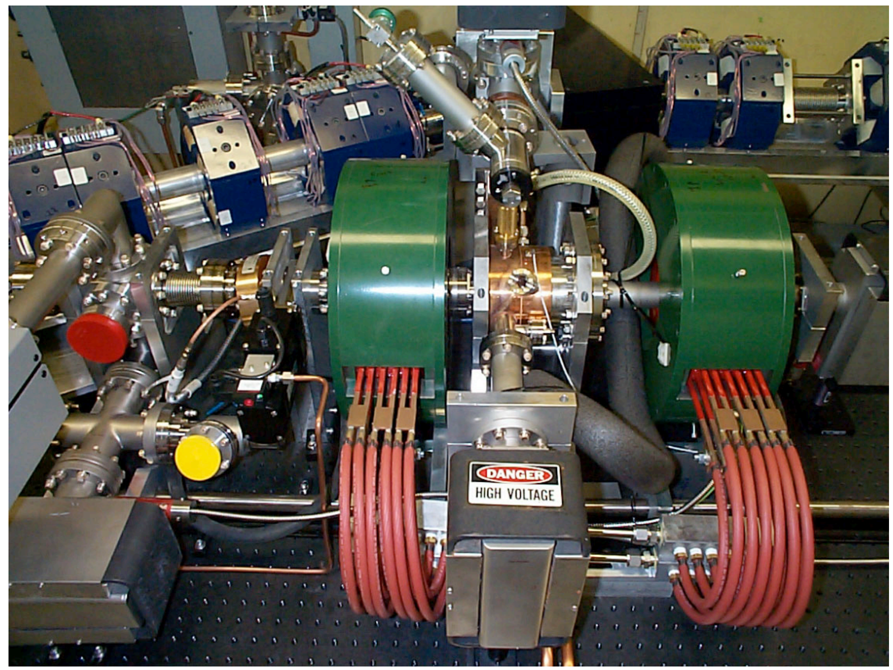


Architecture:
- 2 amplifier heads
- angular multiplexing
- 4 pass
- relay imaging
- wavefront correction

Uses 3 new key technologies:
gas cooling, diodes, and Yb:S-FAP crystals

RF Photoinjector

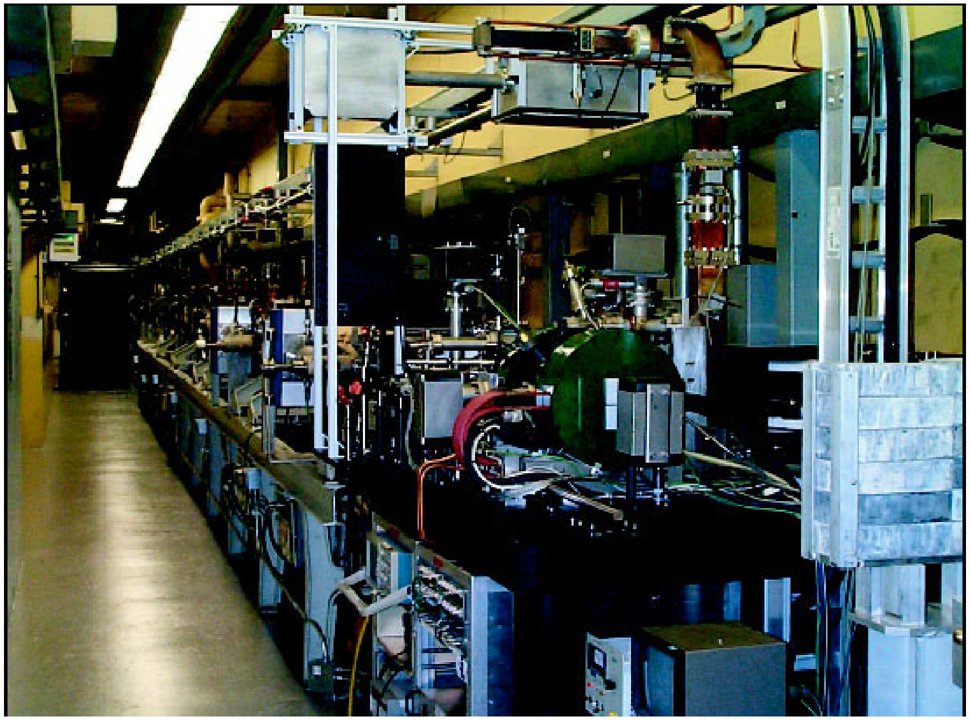
- UCLA responsibility
- 1.6 cell high field S-band (a la SPARC)
  - 2854.5 MHz(?!)
  - Run up to 5.2 MeV
- All magnets from UCLA
  - Solenoids
  - Bypass quads/dipoles
  - Final focus
    - High field electromagnets
    - PMQ system!



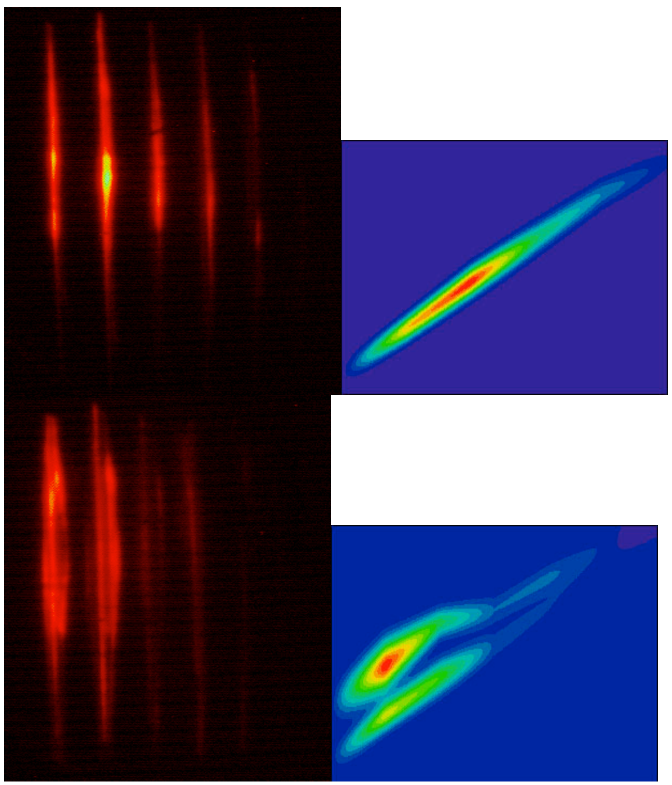
Photoinjector and bypasss

Electron linac

- 35 year old 120 MeV travelling wave linac
- High average current thermionic source for positron production
- 4 linac sections
- Solenoid focusing around each section



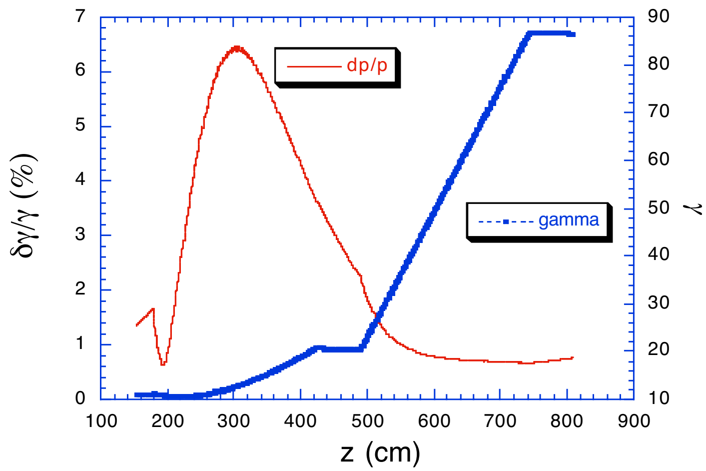
Velocity bunching for increased current (Serafini/Ferrario proposal)

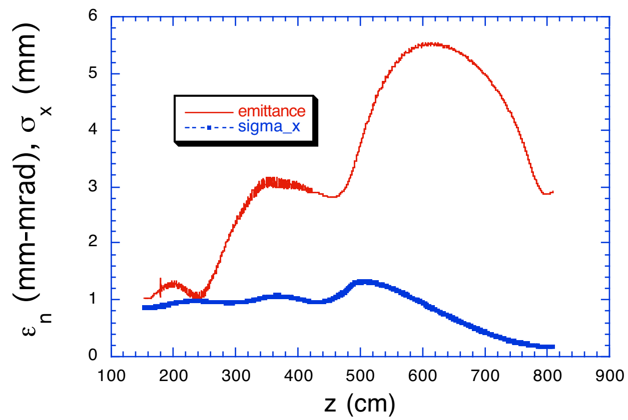


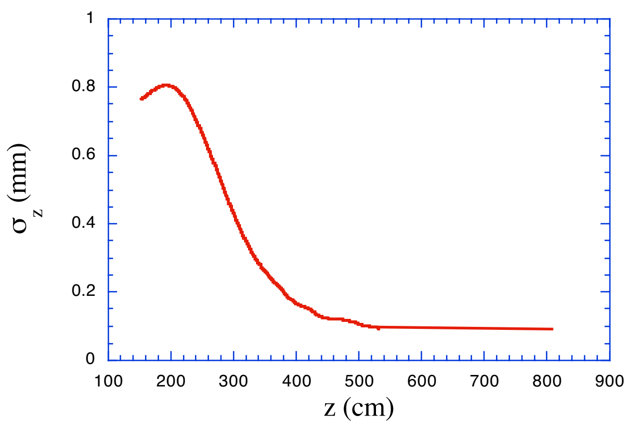
Multi-slit phase space measurement at Neptune showing bifurcation in chicane

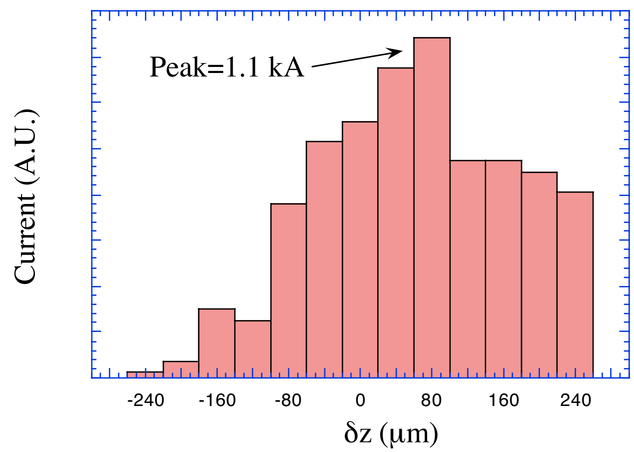
- Enhanced photon brightness
- Avoid problems of magnet chicane bunching
- Emittance control *during bunching* using solenoids around linacs
- Bunching effectively at lower energy
  - Lower final energy spread
  - Better final focus…

PARMELA simulations of velocity bunching



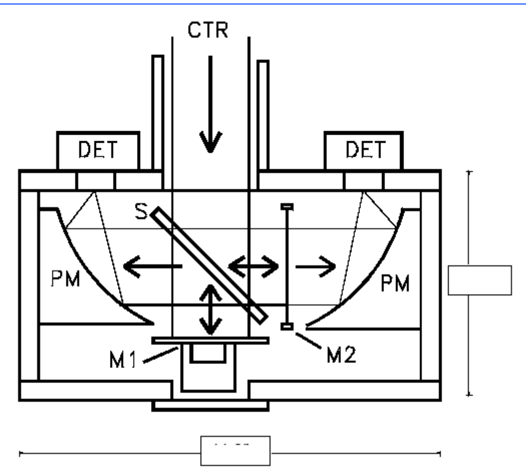


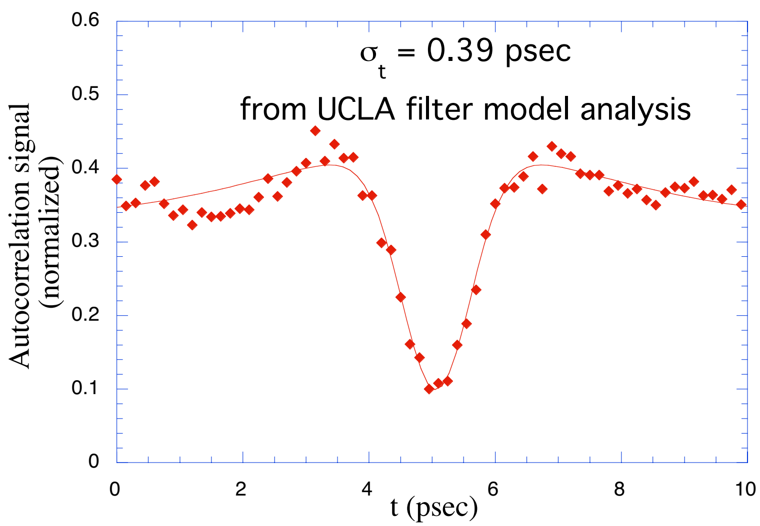




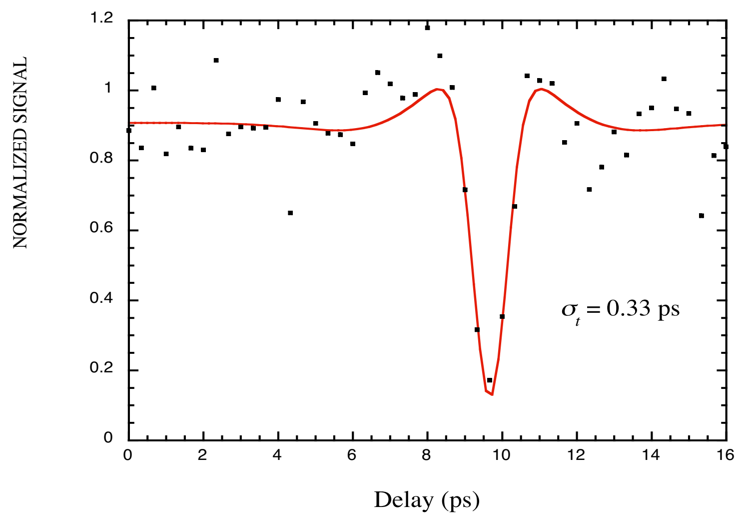
Velocity bunching measurements

- Over factor of 12 bunching shown in CTR measurements
- Better than Neptune "thin-lens" performance
- Next measurements: emittance control



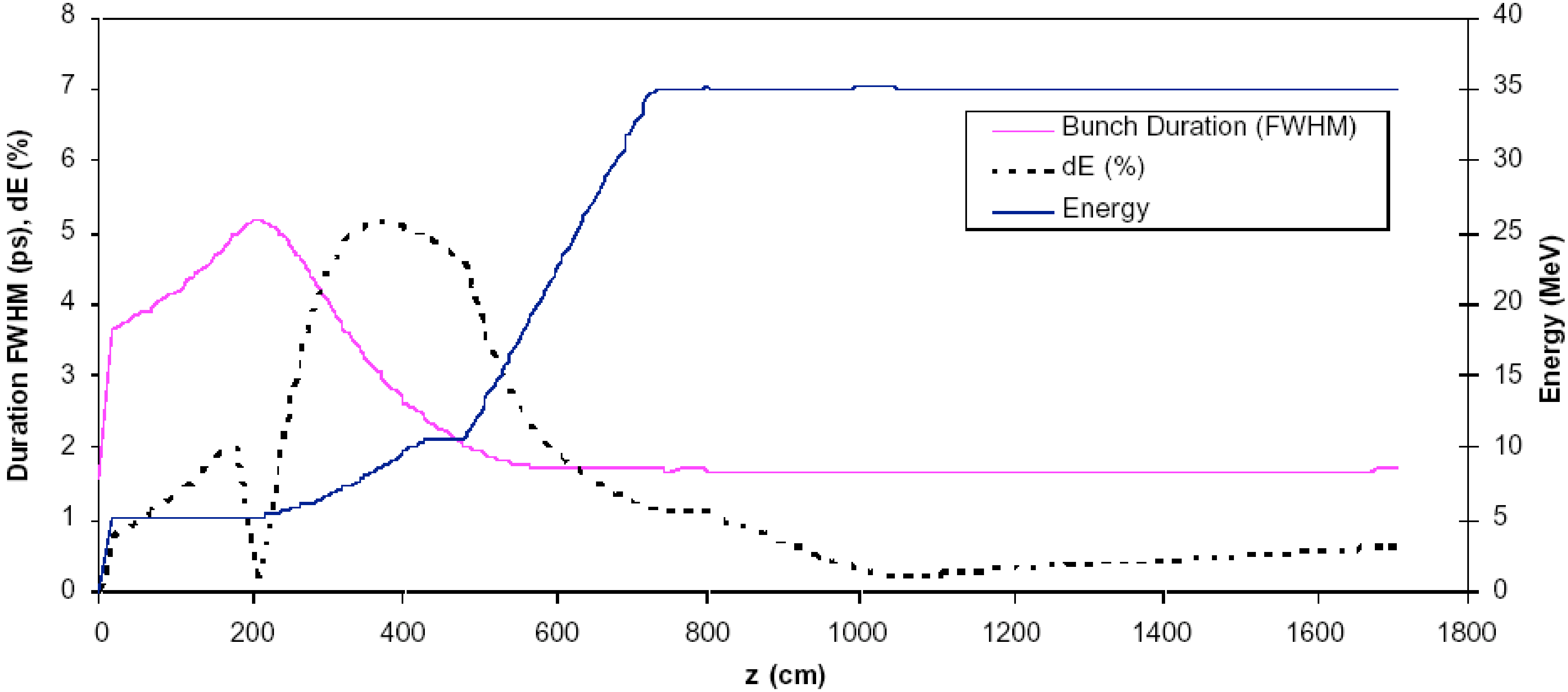


Neptune measurements (PWT "thin lens", no post acceleration)

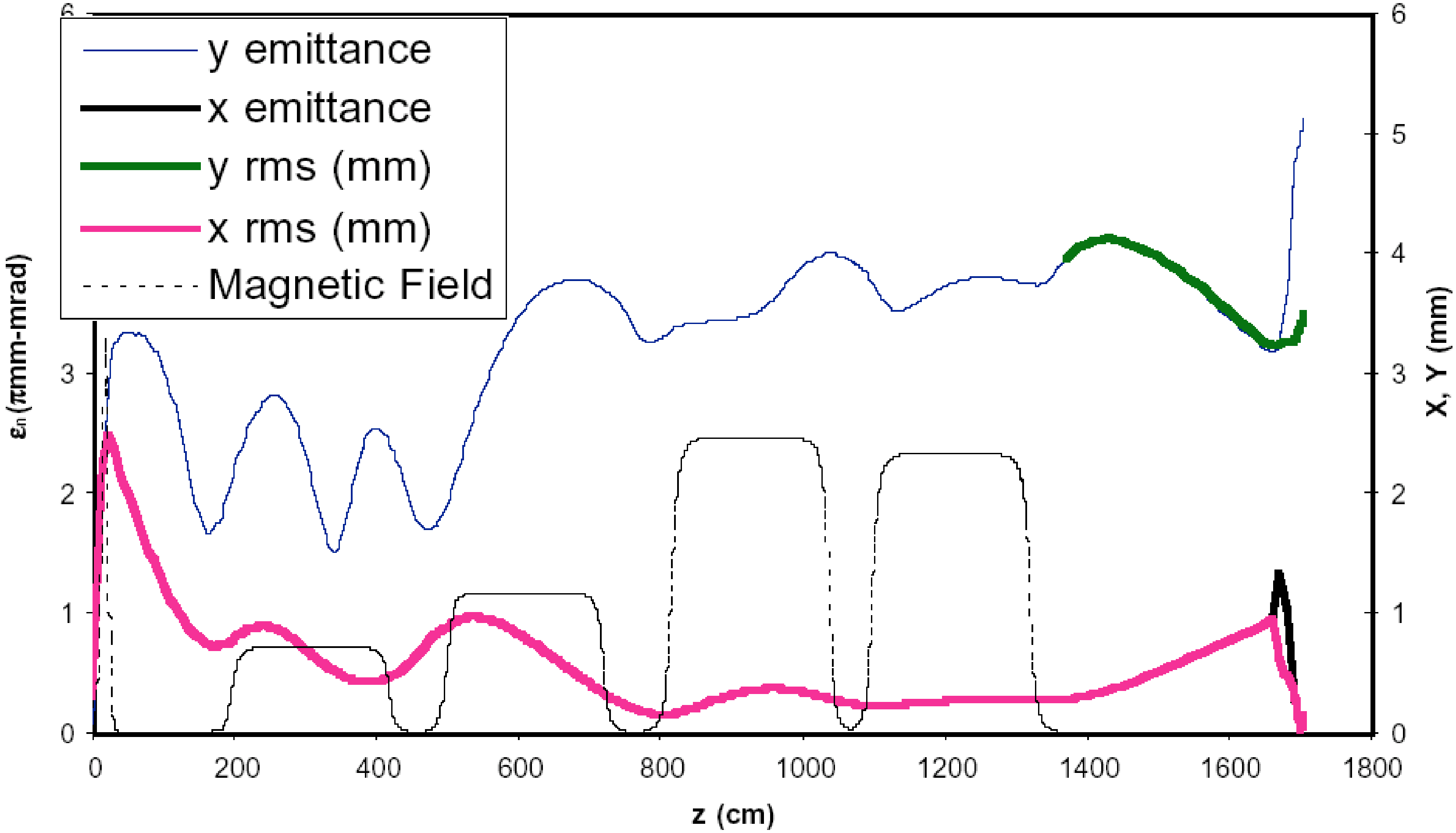


Recent measurement of velocity bunching at LLNL PLEIADES

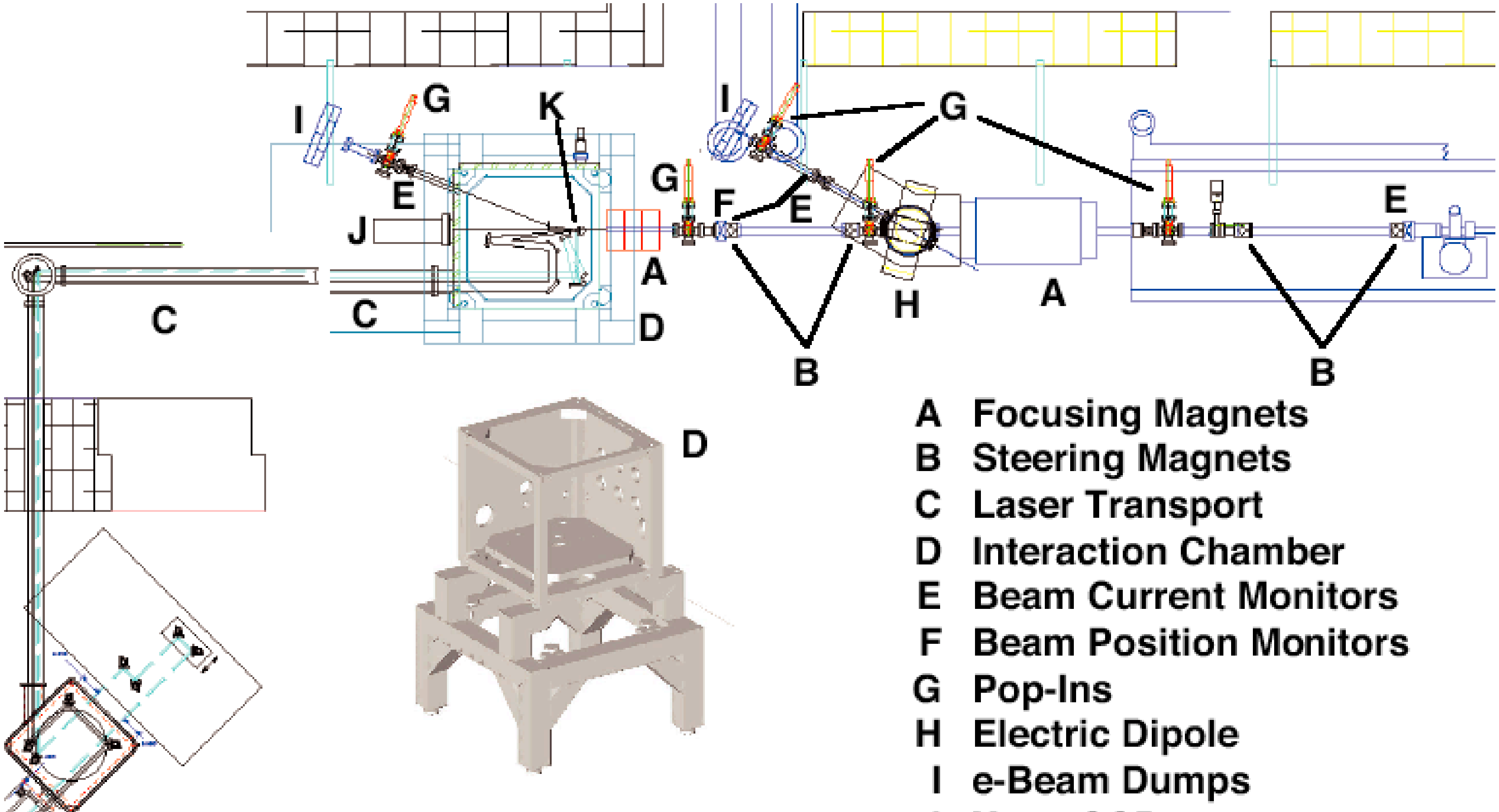
Start-to-end simulations with final focus…



RMS beam envelope and emittance control



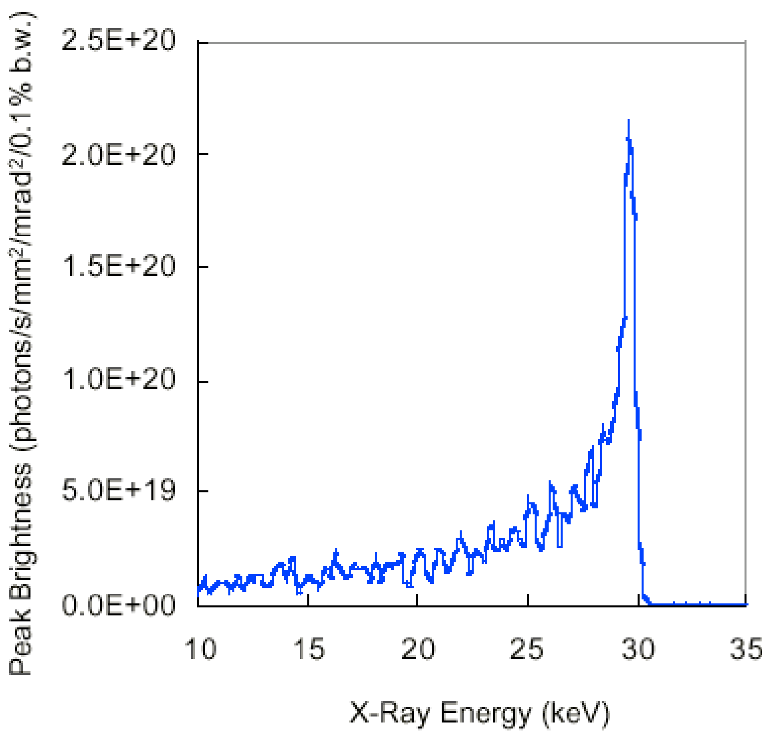
Interaction region



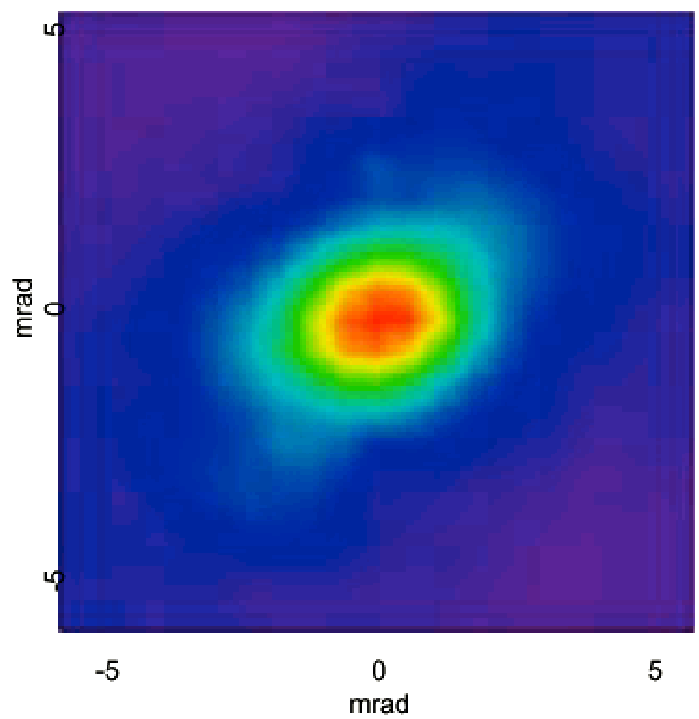
A Focusing Magnets
B Steering Magnets
C Laser Transport
D Interaction Chamber
E Beam Current Monitors
F Beam Position Monitors
G Pop-Ins
H Electric Dipole
I e-Beam Dumps
J X-ray CCD
K OTR foil
L Bend Magnets

Expectrum

- Linear 3D scattering code (Hartemann)
- Start-to-end with PARMELA…



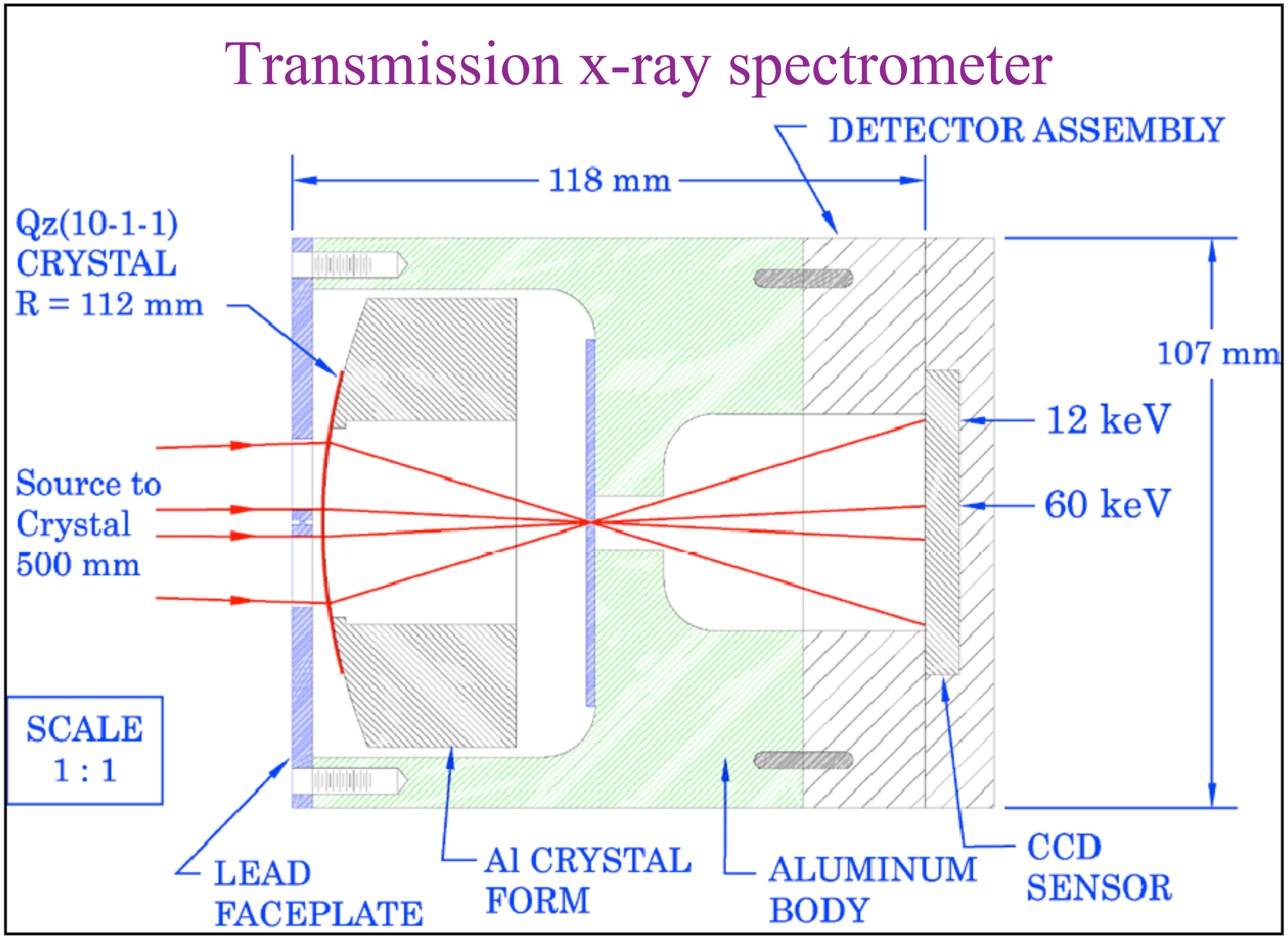
Expected spectrum



Expected image at CCD (far-field)

Advanced X-ray diagnostics (LLNL/UCLA)

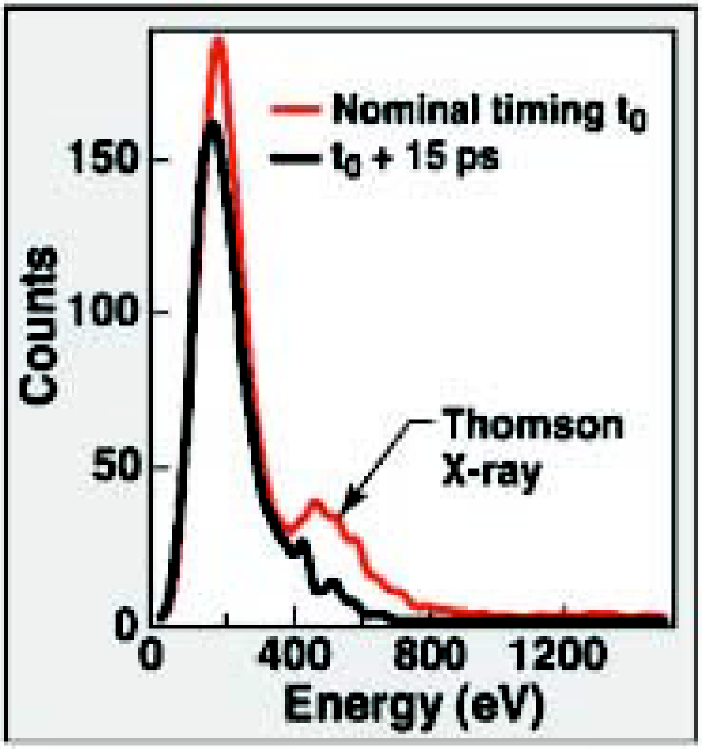
UCLA



-Transmission spectrometer

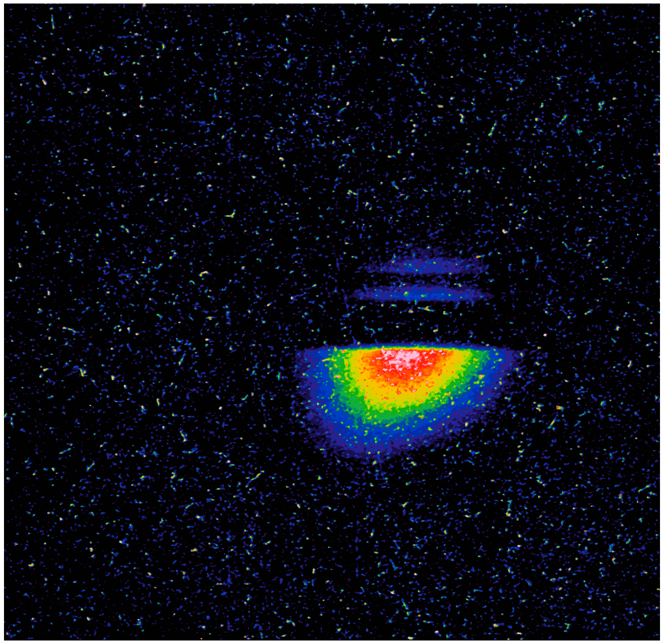
-Aiming also for LCLS work

First light results



Timing worked out with gun only…

Now up to 1E6 photons!



Masked x-ray CCD image

How do we improve this performance? Final focus…

The problem of the final focus

UCLA

- Luminosity demands small beams

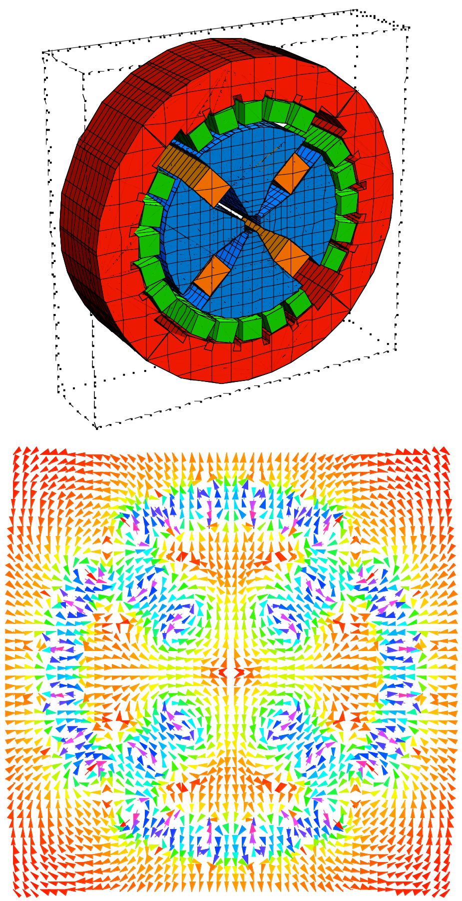
$$N_\gamma = \left[\frac{N_l N_{e-}}{4\pi\sigma_x^2}\right]\sigma_{th}$$

- Compression gives large energy spread
  - Chromatic aberrations
  - Demagnification limit

$$\frac{\sigma^*}{\sigma_0} = \sqrt{\frac{1+\left(\frac{\beta_0}{f}\right)^2\left(\frac{2\sigma_{\delta p}}{p}\right)^2}{1+\left(\frac{\beta_0}{f}\right)^2\left[1+\left(\frac{2\sigma_{\delta p}}{p}\right)^2\right]}} \underset{\left\{\frac{\beta_0}{f} >> \frac{p}{\sigma_{\delta p}}\right\}}{\cong} \frac{2\sigma_{\delta p}}{p}$$

  - Cannot remove chromatic aberrations with sextupoles, etc. Transport too long, costly…
- Quadrupole strength problem
  - Cannot expand beam; space-charge "decompensation" (also with sextupoles)
  - Very attractive option: permanent magnet quadrupoles

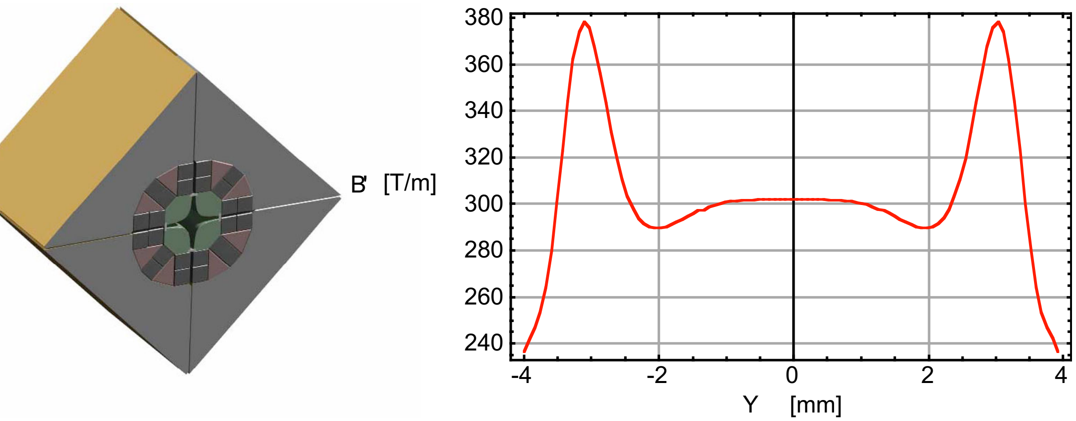
Permanent magnet quadrupoles



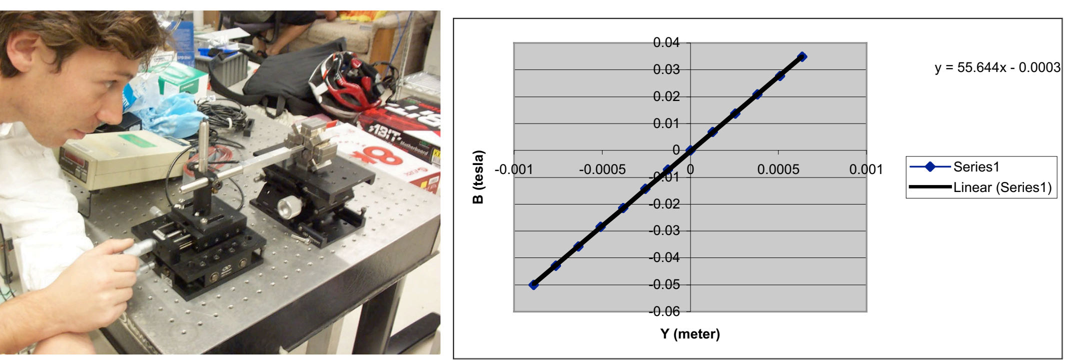
Halbach ring-tuned quad for NLC
(UCLA/FNAL/SLAC project), with field map

- PMQs stronger than EMQs
  - >500 T/m v. <25 T/m
- PMQs are quite difficult to tune
  - Need to tune system from 35 to 100 MeV!
  - Tradeoffs between tunability, strength, centerline stability

High, fixed field PMQ design?



Moderate field hybrid iron-yoke PMQ design

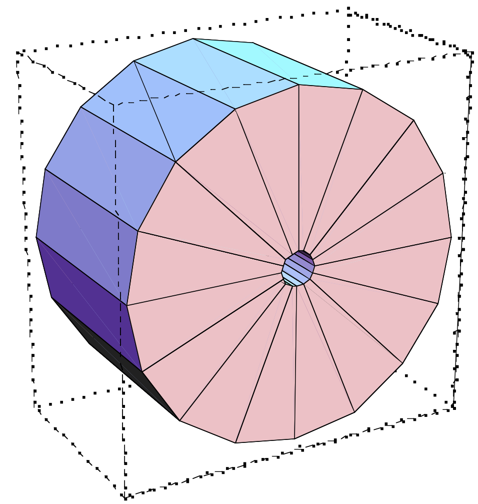


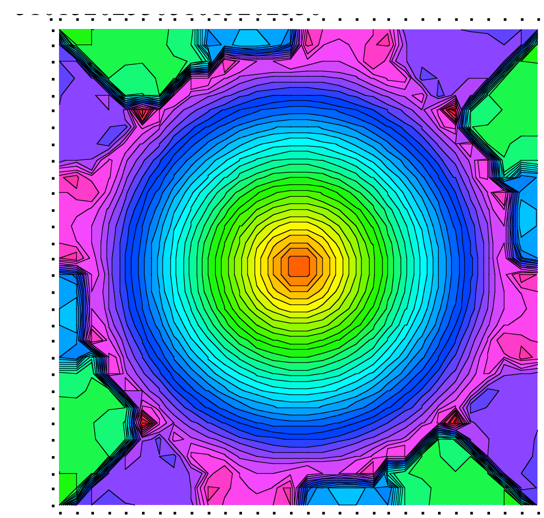
Scaled hybrid PMQ for Neptune

- We decided to *not adjust strength* of PMQs… only *change longitudinal position*
- We have reinvented camera optics…
- Need over 300 T/m for PLEIADES
  - Set by minimum energy of 35 MeV
- Some experience already at UCLA in PM design
  - Quads
  - Undulators

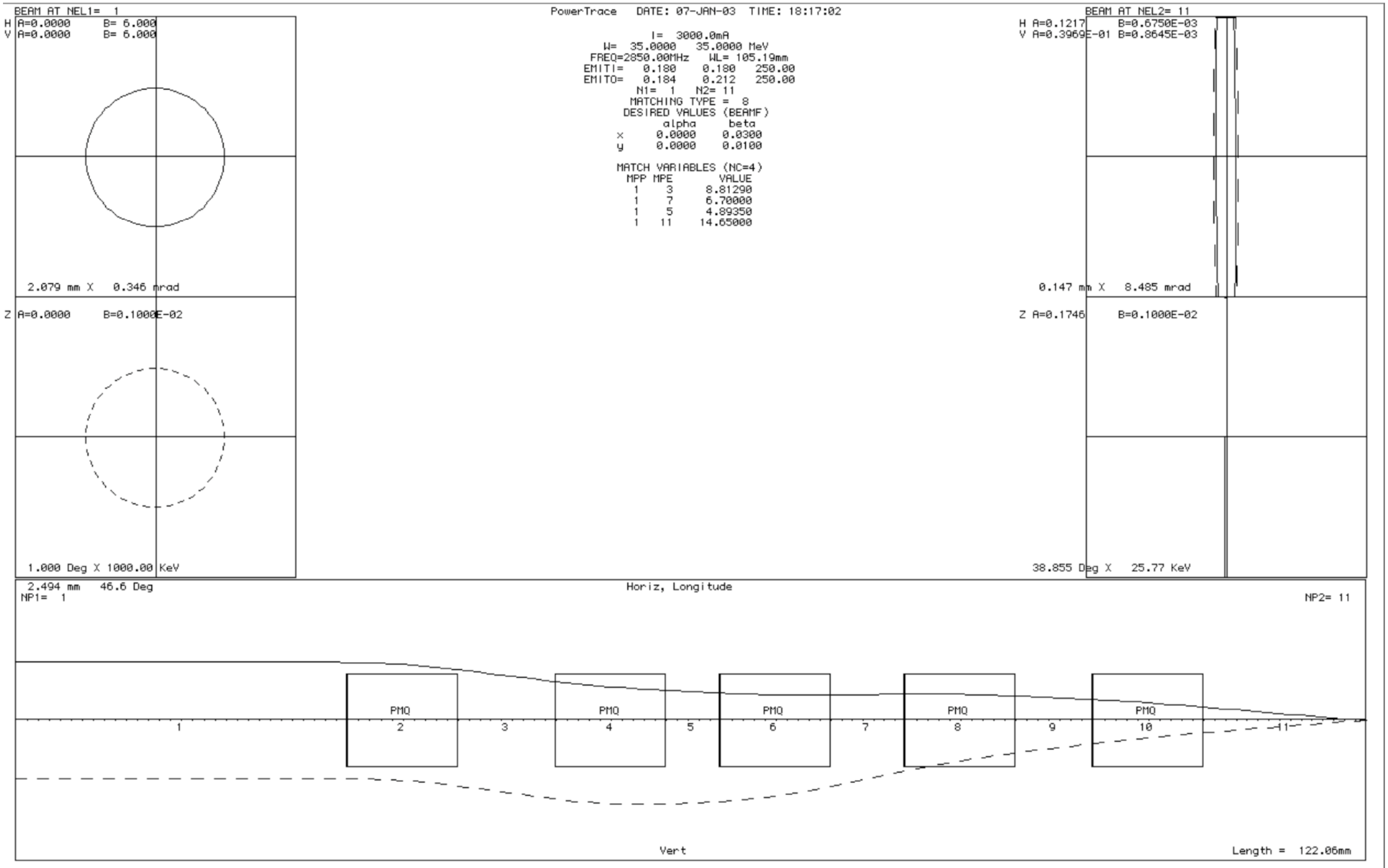
The Pizza-pie PMQ

- Can obtain >500 T/m with 8 mm ID
- Linearity good over 80% of aperture
- Self/mutual forces small
- Designed at UCLA
- Under construction by industrial PM company

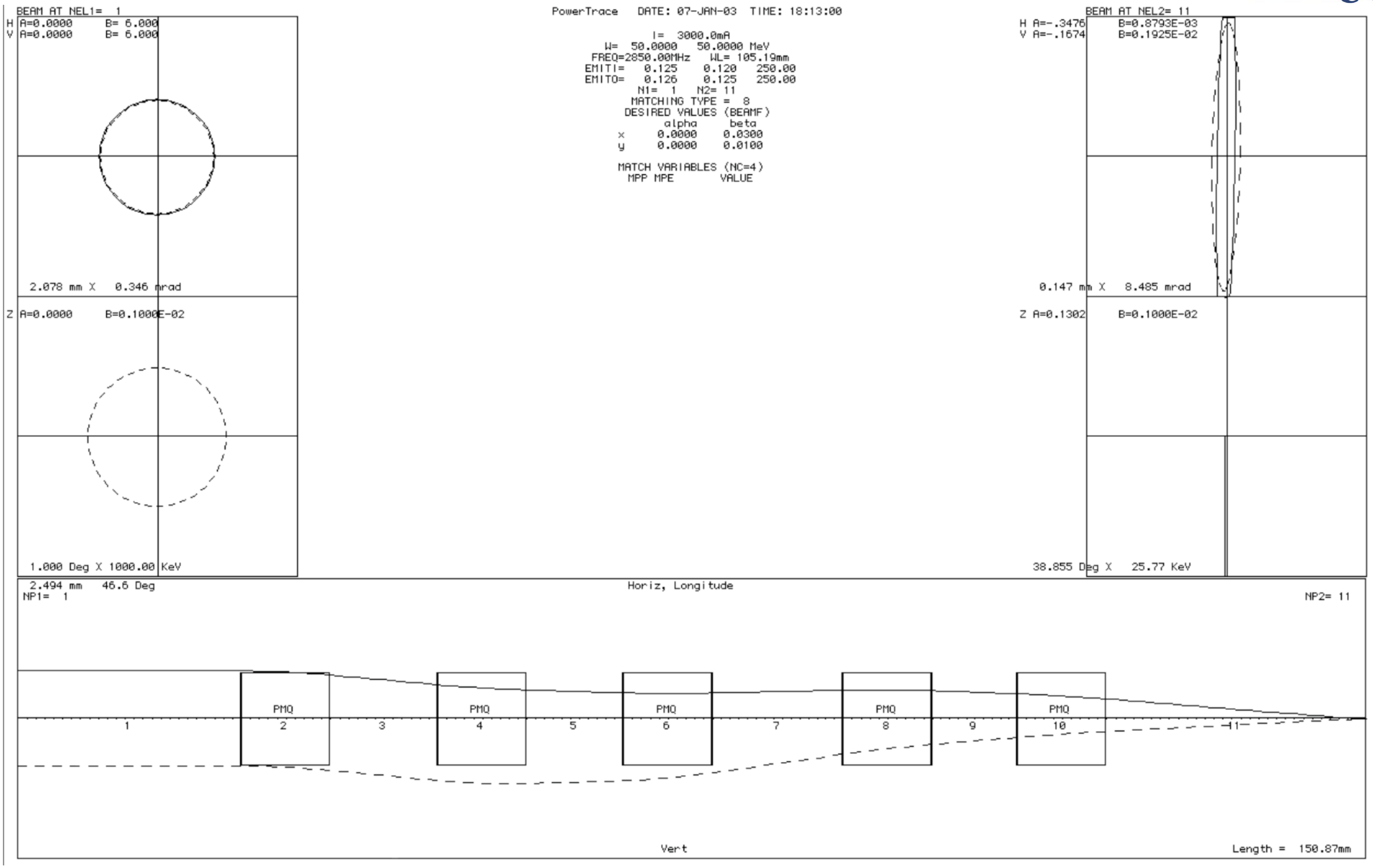




Beam dynamics with 5 PMQ configuration (35 MeV)

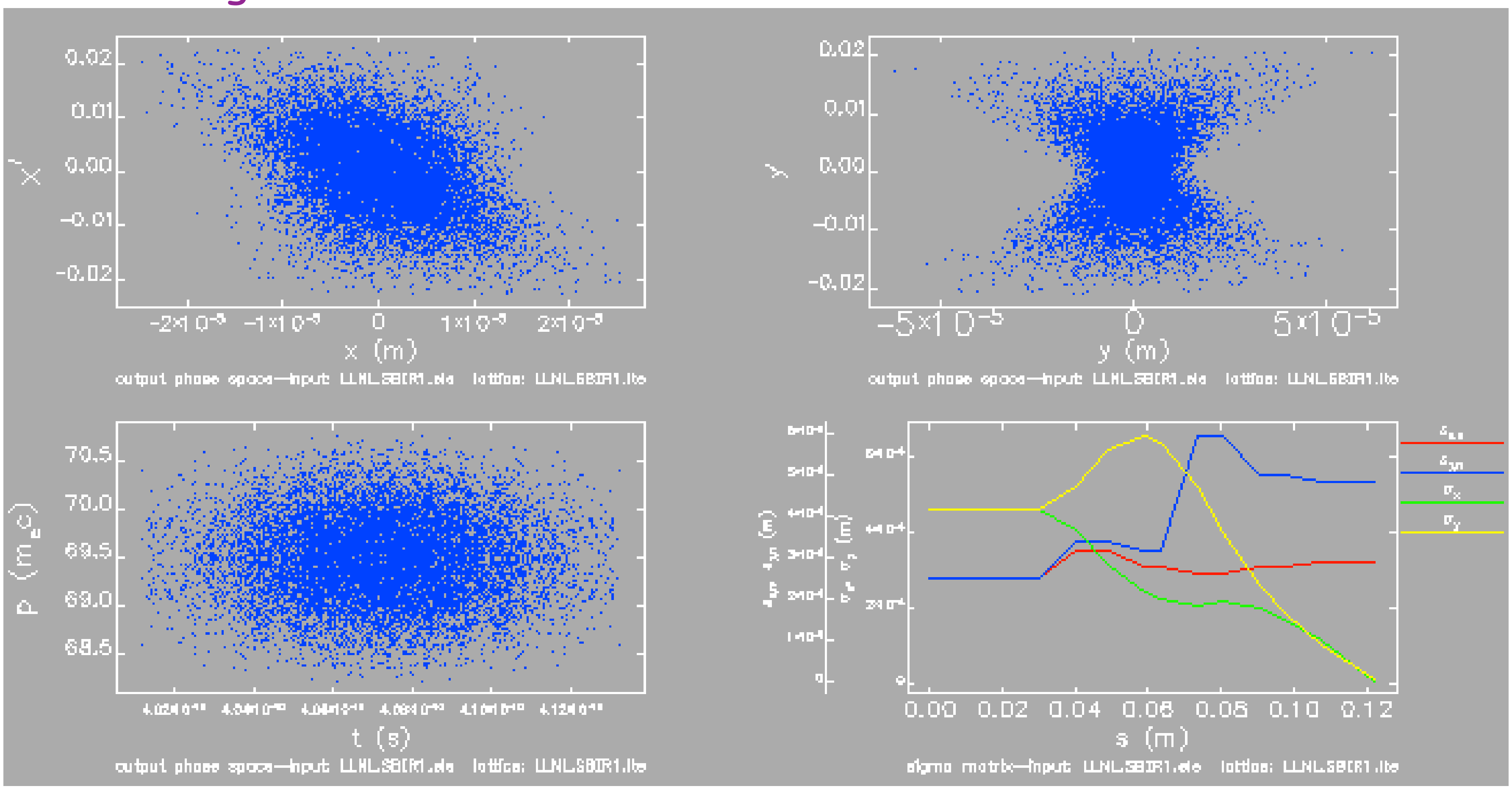


Beam dynamics with 5 PMQ configuration (50 MeV)

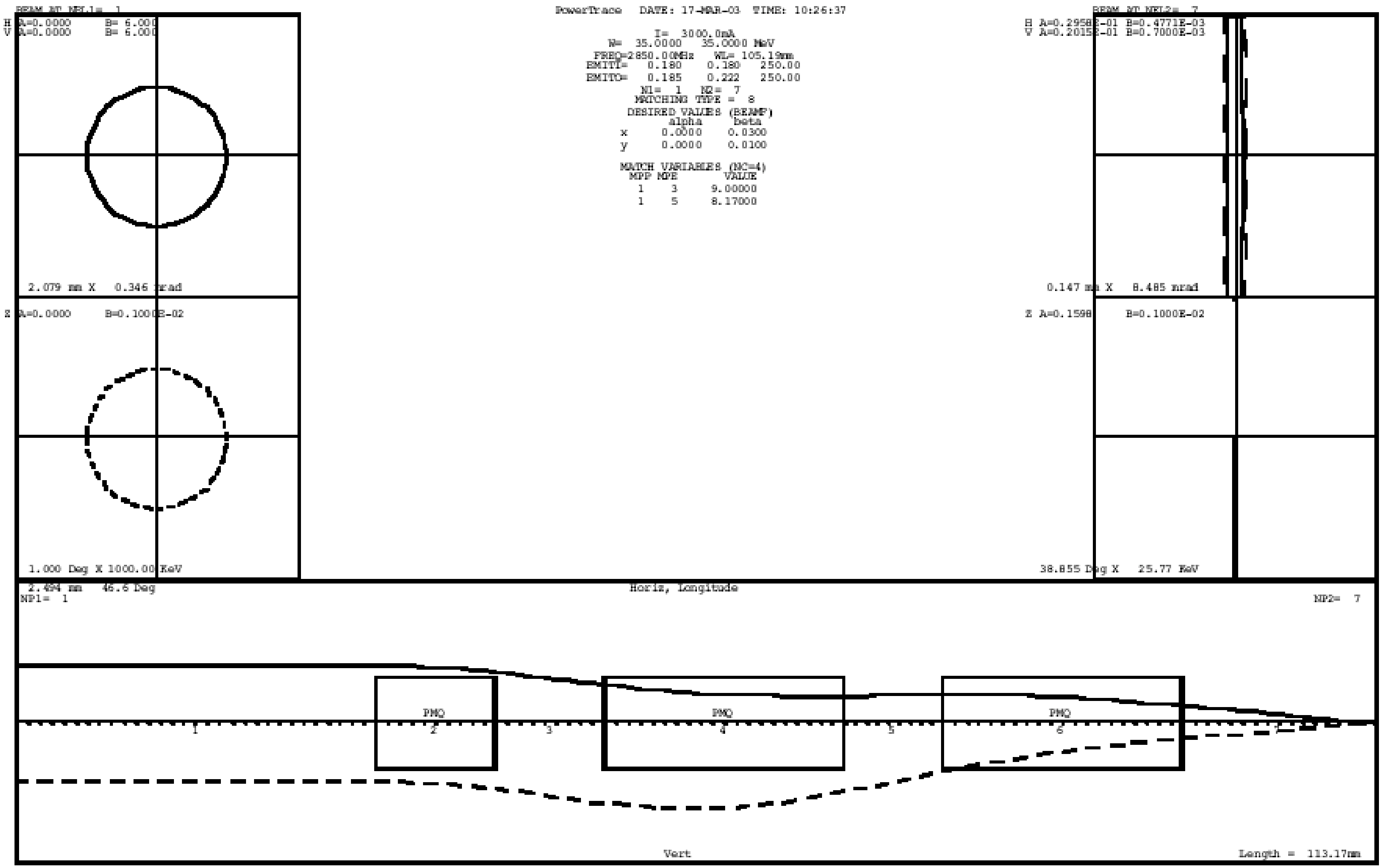


Elegant simulations of FF

- 5x7 micron spots at 35 MeV!
- Emittance growth from aberrations notable in vertical dimension

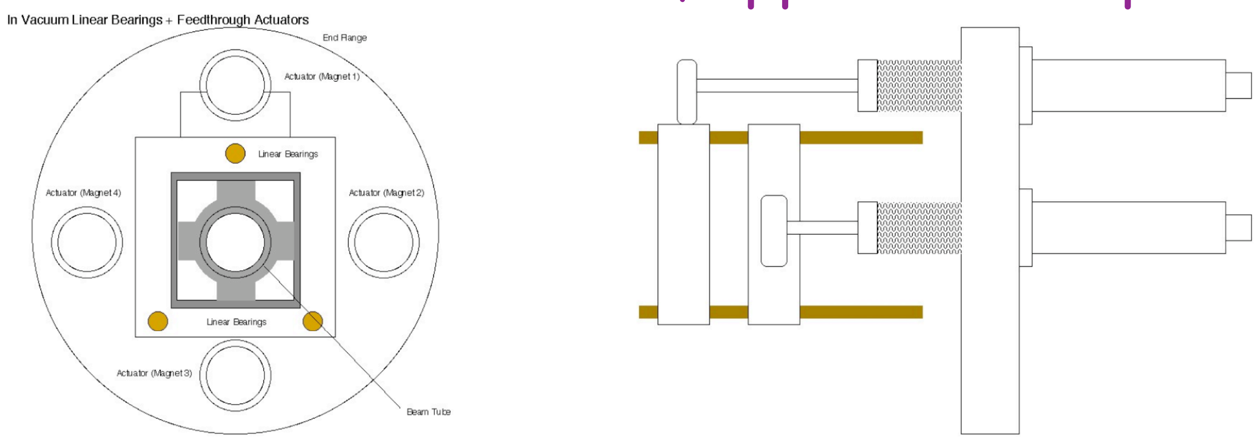


Works with only 3 quads… better for moving!



Near term future for UCLA at PLEIADES

- Final engineering of PMQ movers
- Velocity bunching with emittance control (July 03)
- Commissioning of PMQ system (August 03)
- Commissioning of x-ray spectrometer (Sept. 03)
- On to nonlinear Thomson, application experiments…



Clutched moving system for PMQ final focus

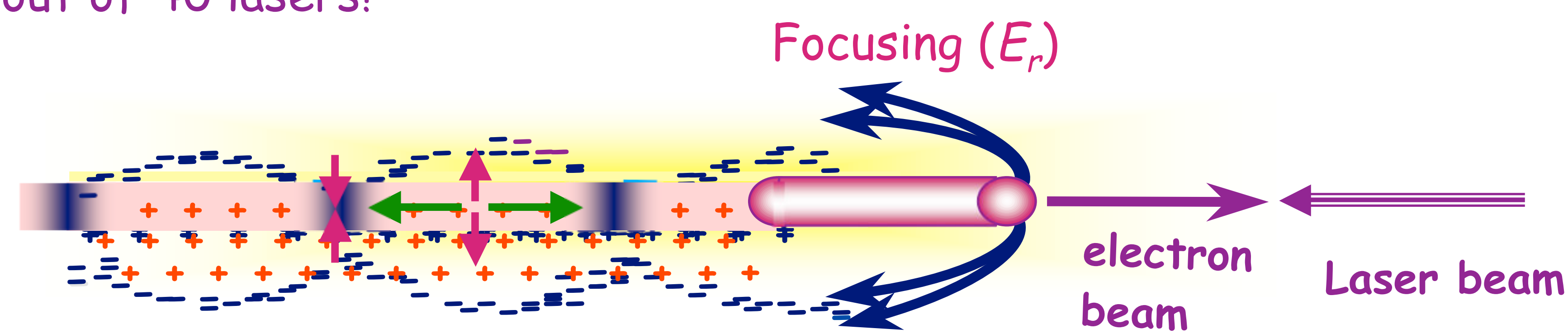
New directions

UCLA

- Desire to extend applications to UCLA campus
  - California NanoSystems Institute
- Use of SPARC or other higher energy facilities
- Competitive field; we need new ideas!

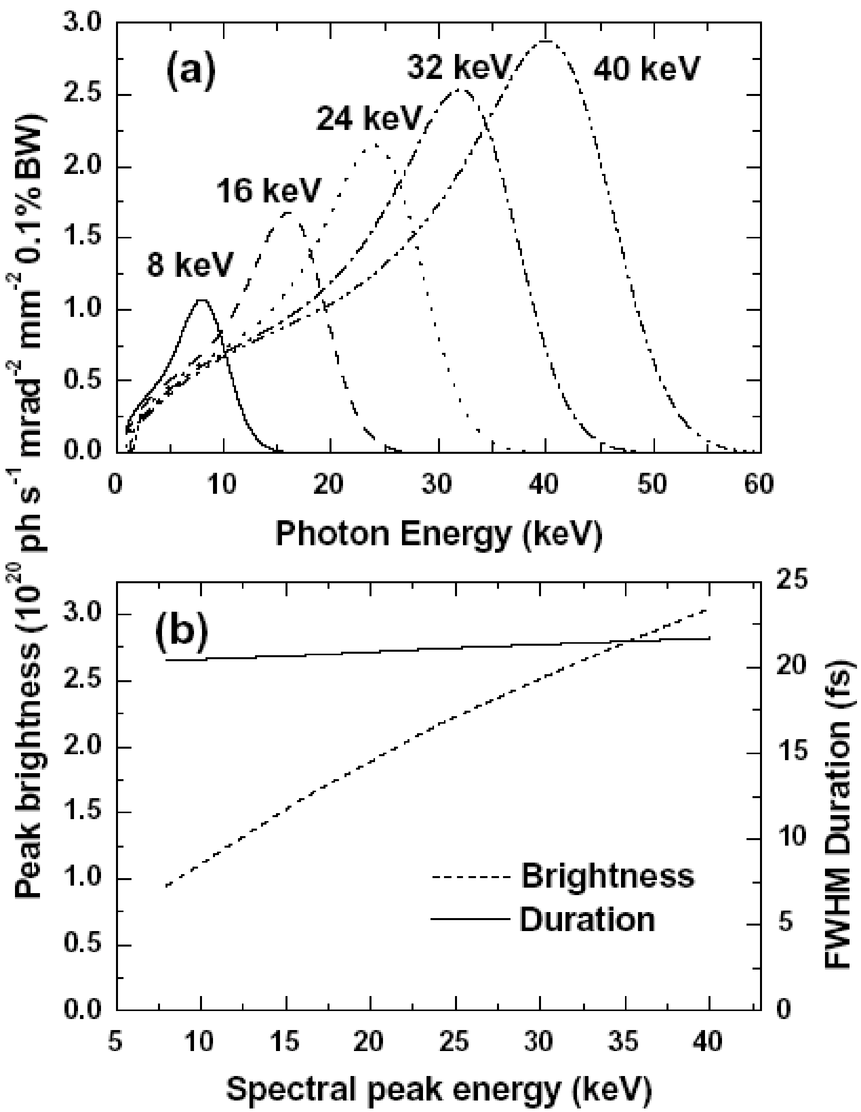
New directions 1: PEICS

- Need more photons, especially for medicine/HEP
- We have gotten small spot sizes; we need to keep them small
- Guiding high power beams only with plasma!
- Beam creates own channel; also forms a fiber for the laser. Plasma Enhanced Inverse Compton Scattering.
- Use very high charge, long electron beam…
- Studying very seriously the polarized positron source; eliminate 39 out of 40 lasers!



New directions 1: SAICS

- Need higher brightness with short pulse length
- Specific problem SPARC is at too high energy
- Small Angle Inverse Compton Scattering
- Small angle gives
  - Lower photon energy with high energy e-beam; small angle x-rays!
  - Luminosity challenges, but *higher brightness*
  - fs pulse lengths
  - Larger spectral width



Example for SPARC

UCLA

- "Medical" photons (33 keV)
- Moderate energy is excellent regime

nput:
eam $U_{e-} = 200\ \mathrm{MeV}$ $\beta_{e-} = 5\ \mathrm{mm}$ $\varepsilon_n = 2\ \mathrm{mm\text{-}mrad}$ $\sigma_t = 0.5\ \mathrm{ps}$

Laser $\lambda_L = 800\ \mathrm{nm}$ $U_L = 1\ \mathrm{J}$ $\tau_L = 100\ \mathrm{fs}$ $Z_r = 0.4\ \mathrm{mm}$

Crossing angle $\boxed{\phi = 21.5\ \mathrm{deg}}$ (not that small…)

Output $\tau_{sc} = 106\ \mathrm{fs}$ $N_{sc} = 7 \times 10^7$ $\left(dE/E\right)_{sc} = 3.4\%$

Very high brightness at this energy!