# Brainstorming session
# Plasma Based Accelerators

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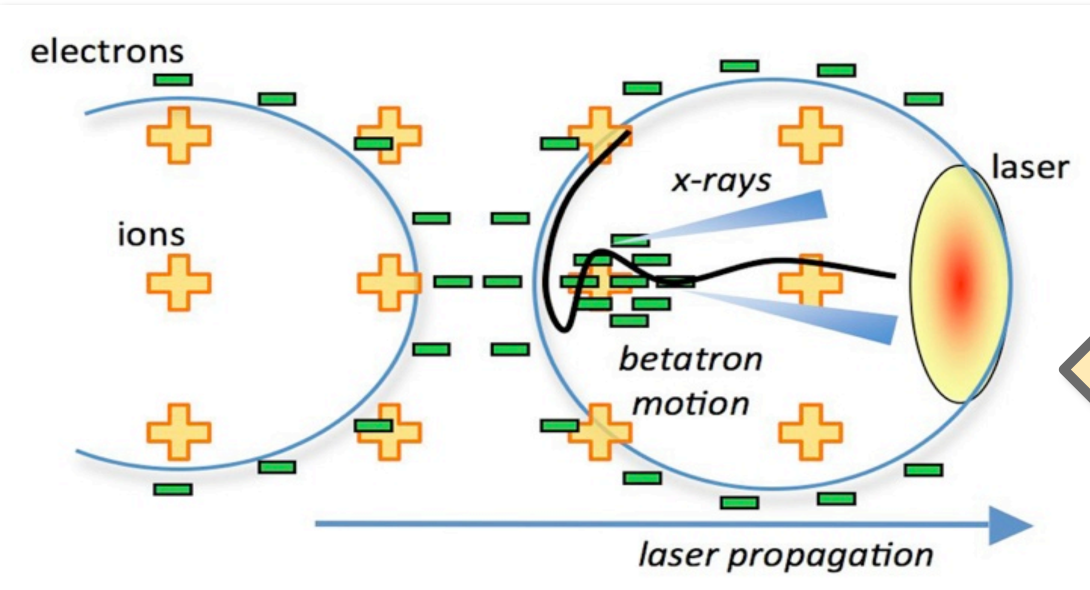
*ADRD meeting -- DOE-BES*
*Annapolis, Md*
*August 22-23, 2011*

# OUTLINE

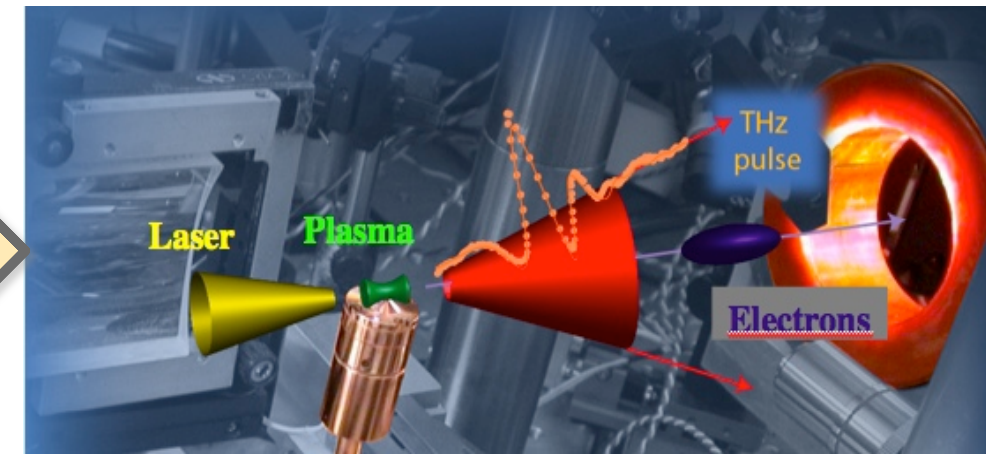
- Laser plasma accelerators -- this presentation
- Plasma wakefield accelerators:
  - E-beam driven
  - Largely similar plasma-beam interaction physics compared to laser driver (with important differences):
    - Some of what is in this talk applies as well
  - Talks by:
    - Eric Colby (SLAC)
    - Vitaly Yakimenko (BNL)
- Discussion (throughout talks as well)

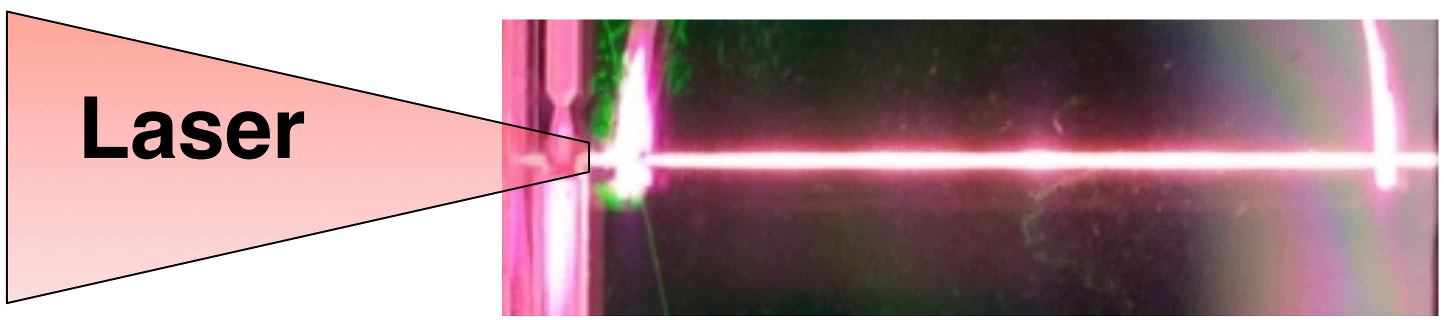
# Hyperspectral radiation from THz to Gamma Ray (+electrons and protons/neutrons), synchronized and ultra-short

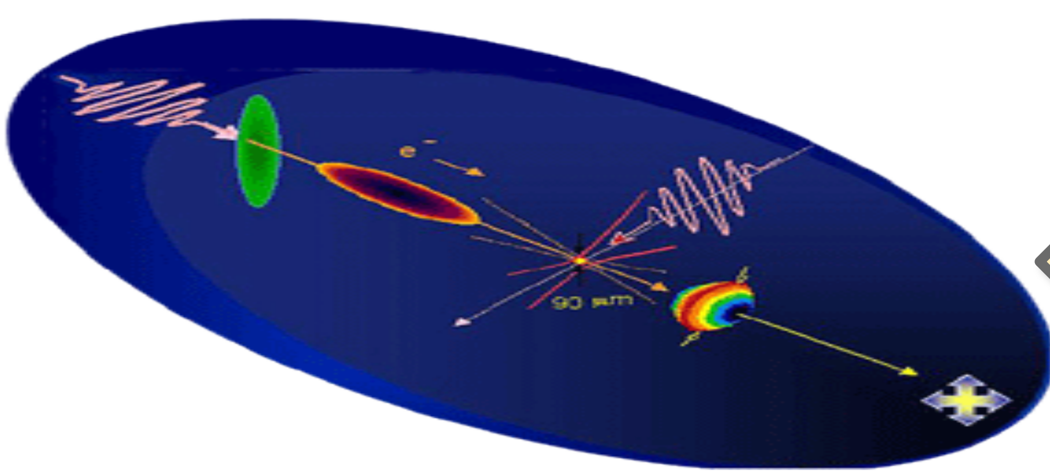
Betatron radiation during acceleration – Multi keV



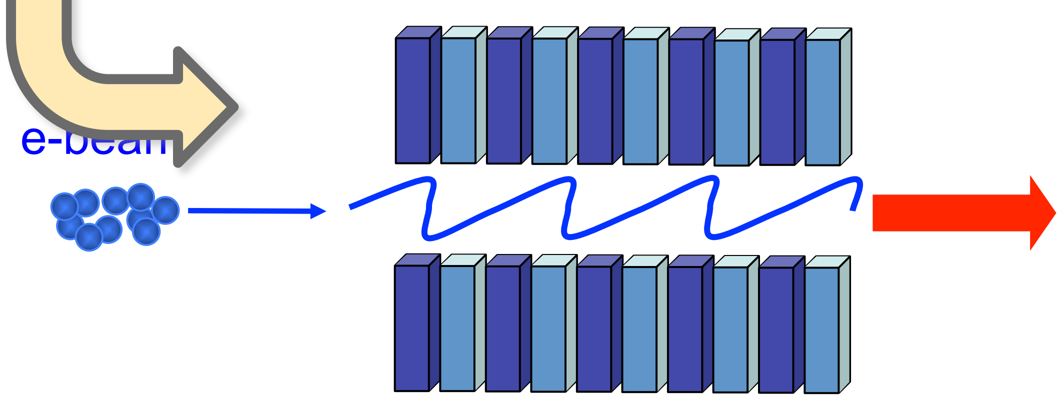

Transition radiation from beam exiting plasma – MV/cm THz



Thomson Scattering – Multi keV/ MeV x-ray/gamma ray

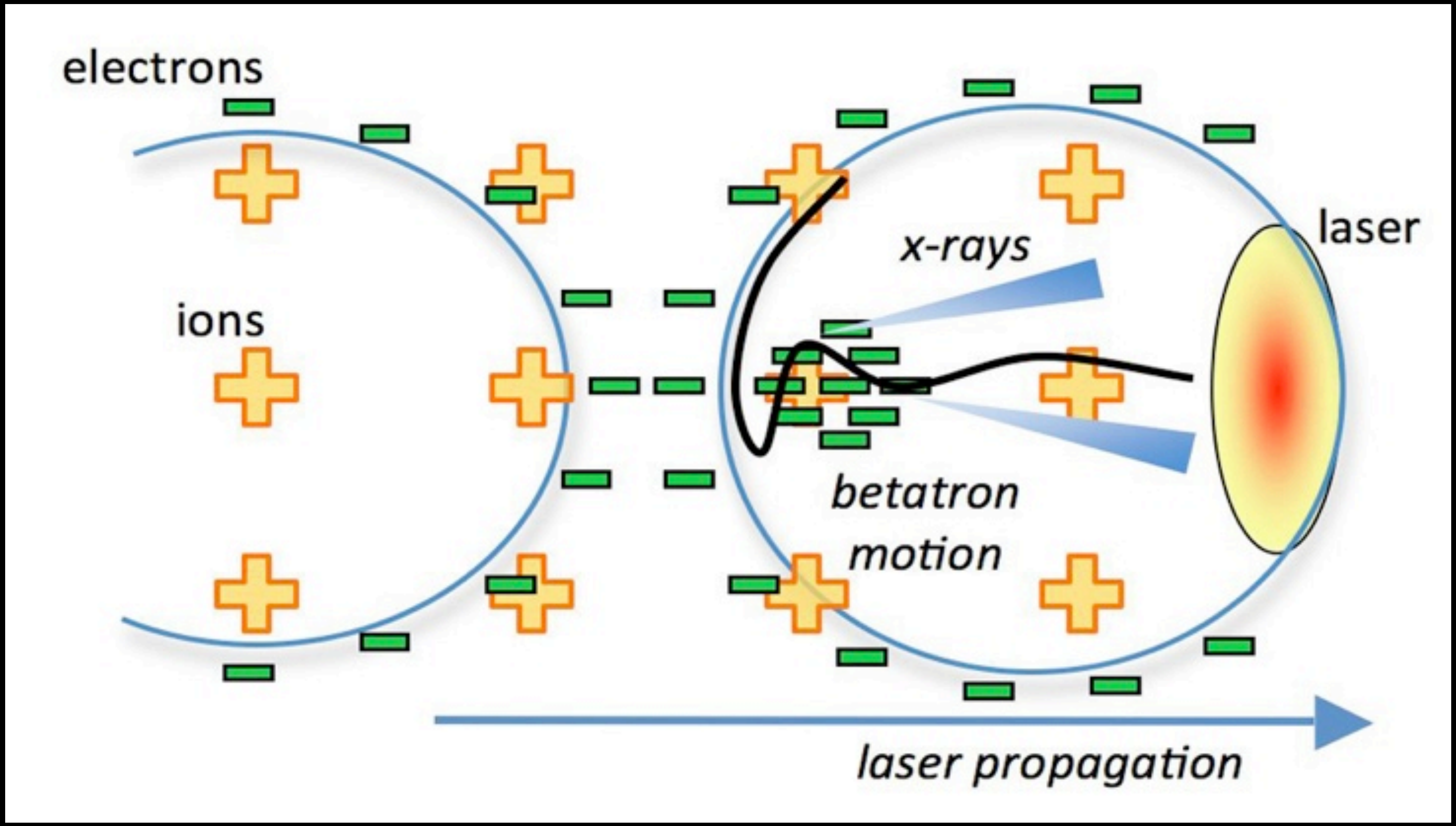


Free Electron Laser-> XUV, x-ray

# X-rays from betatron source

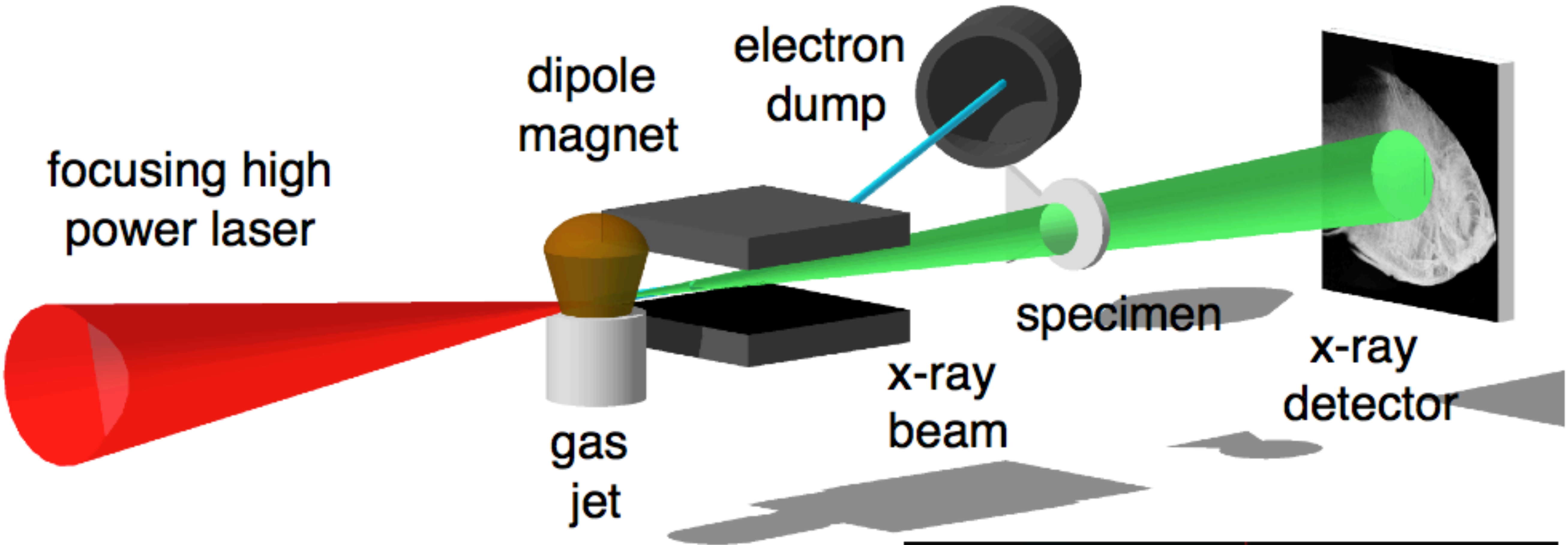
- Incoherent
- Few keV to 10's of keV to MeV
  - Seen from PWFA's and LPA's
- Ultra-short x-rays (fs), synchronized
- Bunch diagnostic:
  - X-ray spectrum carries information about the electron beam inside the undulator (plasma ion column)
  - Beam size inside plasma can be sub-micron
- Biological imaging application

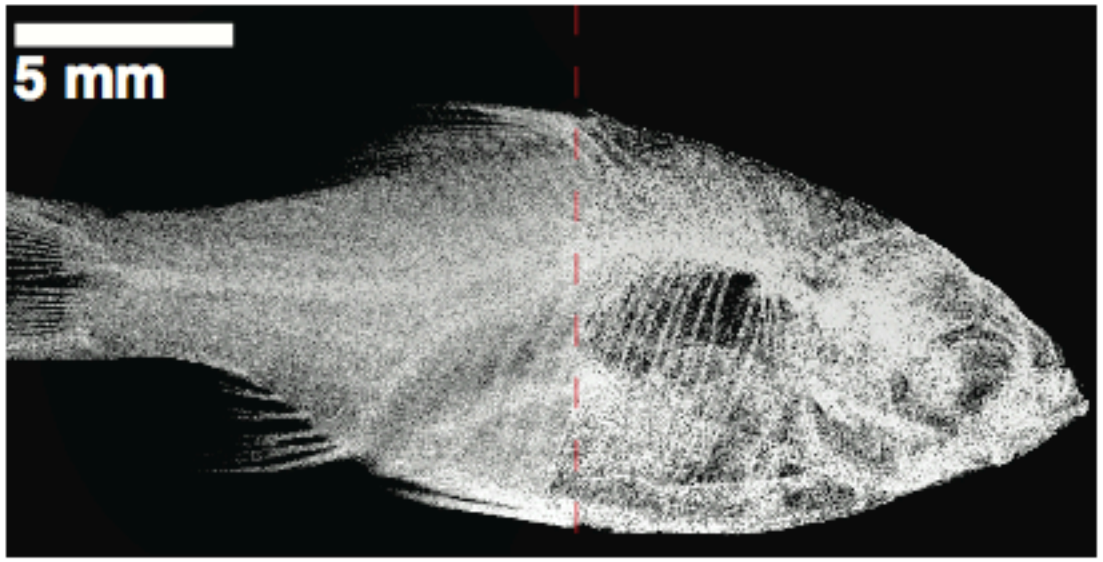
# X-ray emission from betatron motion provides information of electron beam size inside LPA




- ✓ Bunch radiates x-rays
- ✓ Wiggler parameter is determined by bunch radius:
  - $K = \gamma k_\beta r_\beta \propto \gamma^{1/2} n_e^{1/2} r_\beta$
- ✓ Measuring x-rays provides bunch information

# Imaging of Biological Specimens




- contact radiograph of tetra fish
- specimen and camera ~3m from source



S Kneip et al., Nat. Phys. **10**, 980 (2010)
S Kneip et al., arXiv 1105.2517v1 (2011)
S Kneip et al., APL, accepted (2011)

Imperial College London

# Imaging of Biological Specimens

| | |
|---|---|
| laser power | 60-100 TW |
| pulse duration | 32 fs |
| spot size | 11 um |
| plasma density | $8 \times 10^{18}$ cm$^{-3}$ |
| plasma length | 5 mm |
| electron energy | 230±70 MeV |
| beam charge | 0.1 - 0.3 nC |
| x-ray source size | 1-3 um |
| K parameter | ~5 |
| divergence | 5-15 mrad |
| photon number | $10^7$-$10^8$ |
| critical energy | 29±13 keV |
| peak brightness* | 1 $10^{22}$ |

*ph/s/mm$^2$/mrad$^2$/0.1%BW

MichiganEngineering

S Kneip et al., Nat. Phys. **10**, 980 (2010) S Kneip et al., arXiv 1105.2517v1 (2011)

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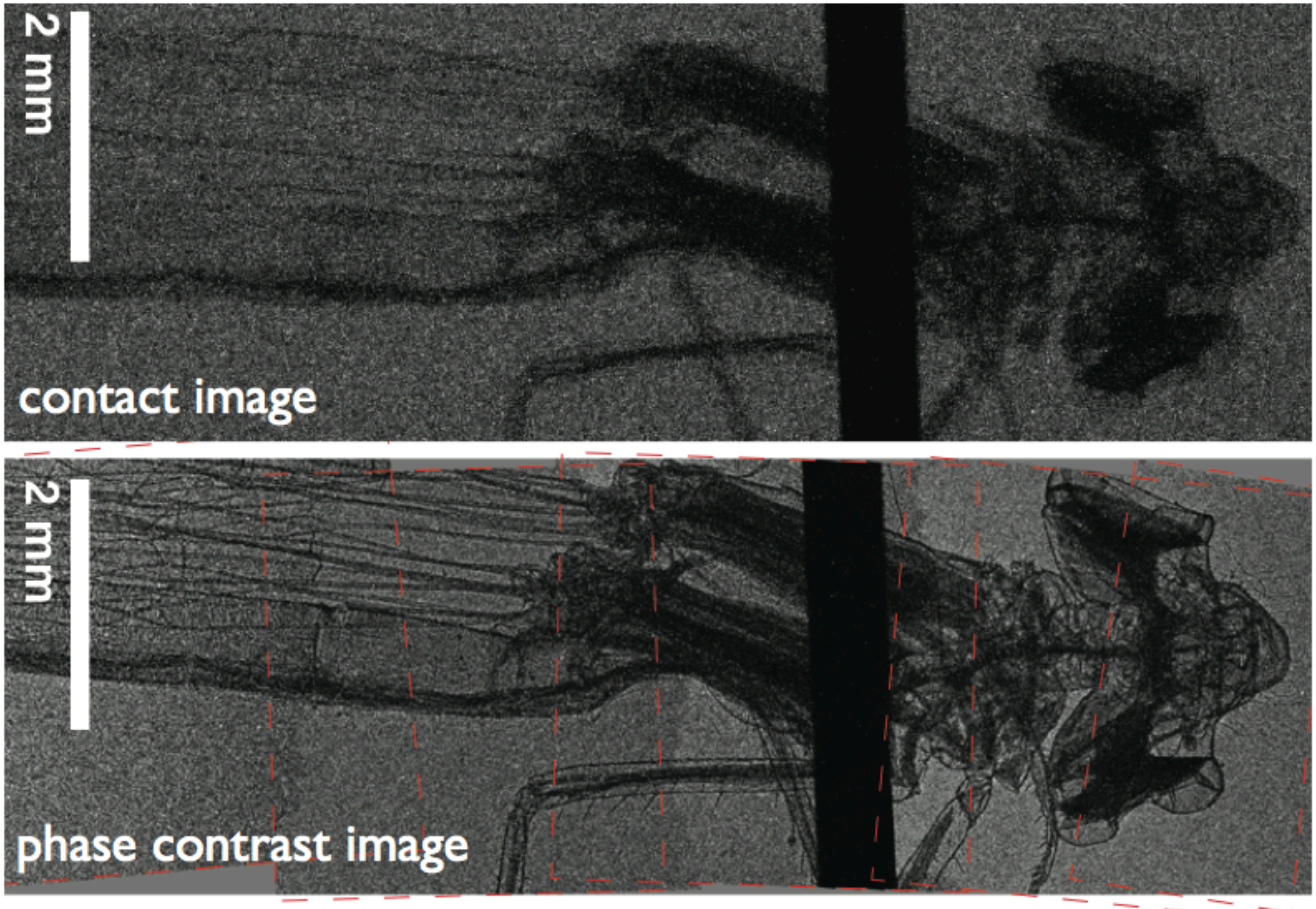
# Imaging of Biological Specimens




- specimen and camera ~3m from source
- specimen ~0.5m and camera ~1.8m from source



S Kneip et al., Nat. Phys. **10**, 980 (2010)
S Kneip et al., arXiv 1105.2517v1 (2011)
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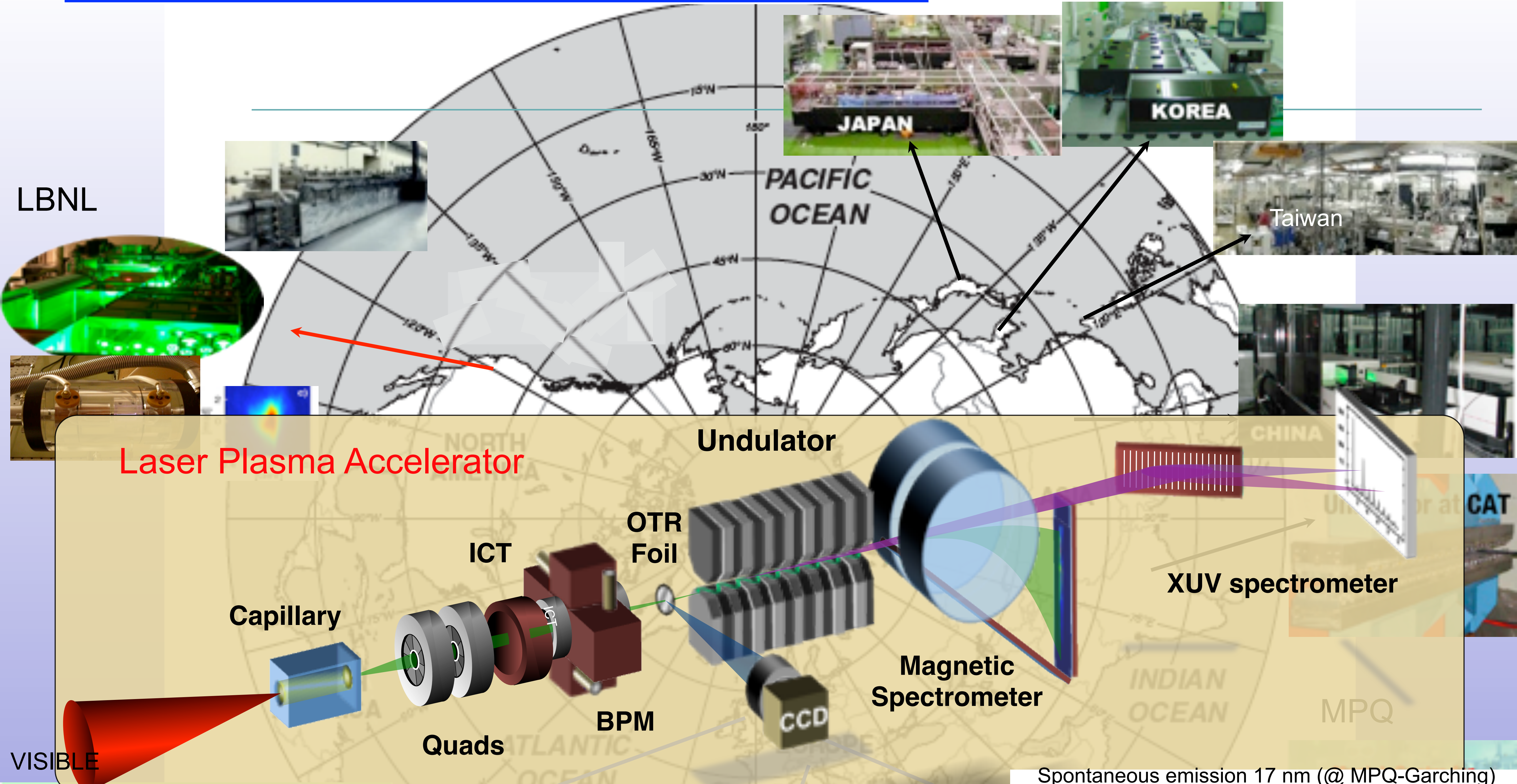
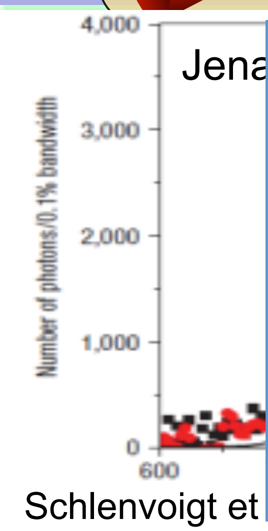
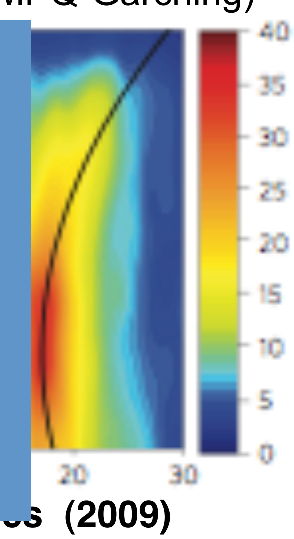
# World-wide effort aimed at FEL using laser accelerator




## Main challenges:

- ➡ Beam quality:
- ➡ Tuning, energy spread, emittance, peak current
- ➡ Seeding for temporal coherence

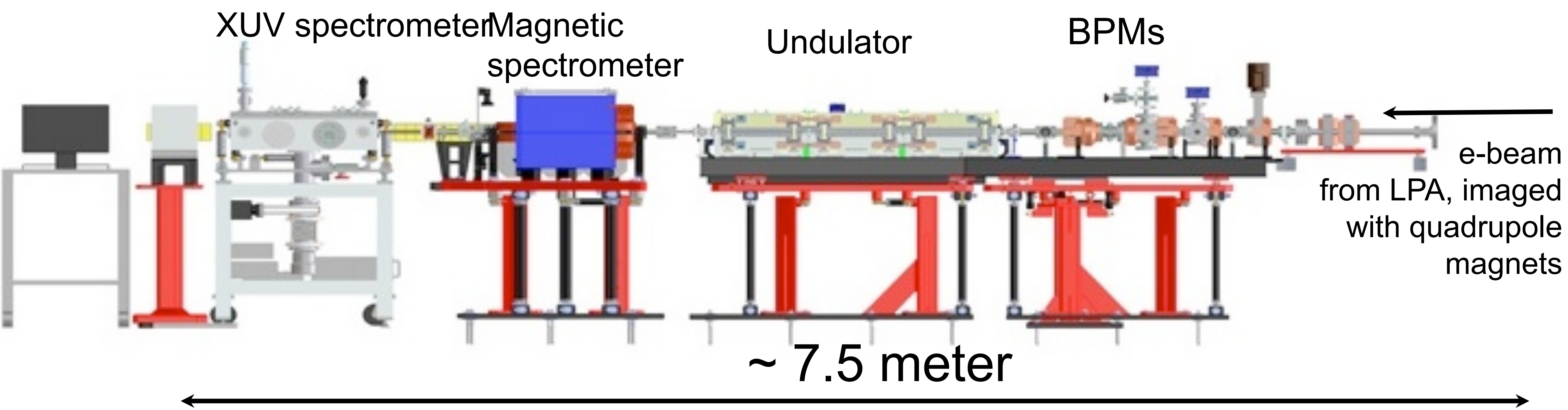


# Fully coherent XUV-FEL based on LPA Technology

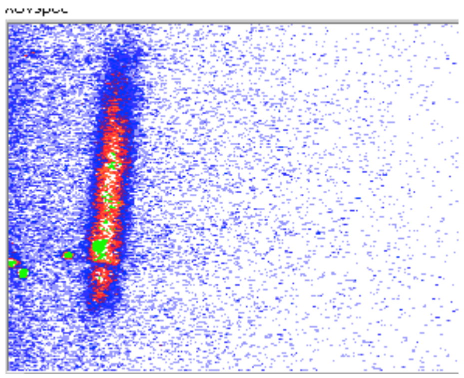
- Latest results:
  - Spontaneous emission seen in visible (Schlenvoight et al., Nature Physics 2008) and XUV (Fuchs et al., Nature Physics 2009)
  - Tuning techniques, stability improvement
    - Colliding pulse injection
    - Longitudinal density tailoring for phase velocity/trapping control
  - Normalized emittance: <0.2 micron
  - Observation of coherent optical transition radiation >4 meter from LPA
  - First light from undulator at LBNL
- Next steps:
  - FEL gain measurements
  - Seeding with laser produced high harmonics

# First XUV light seen from undulator

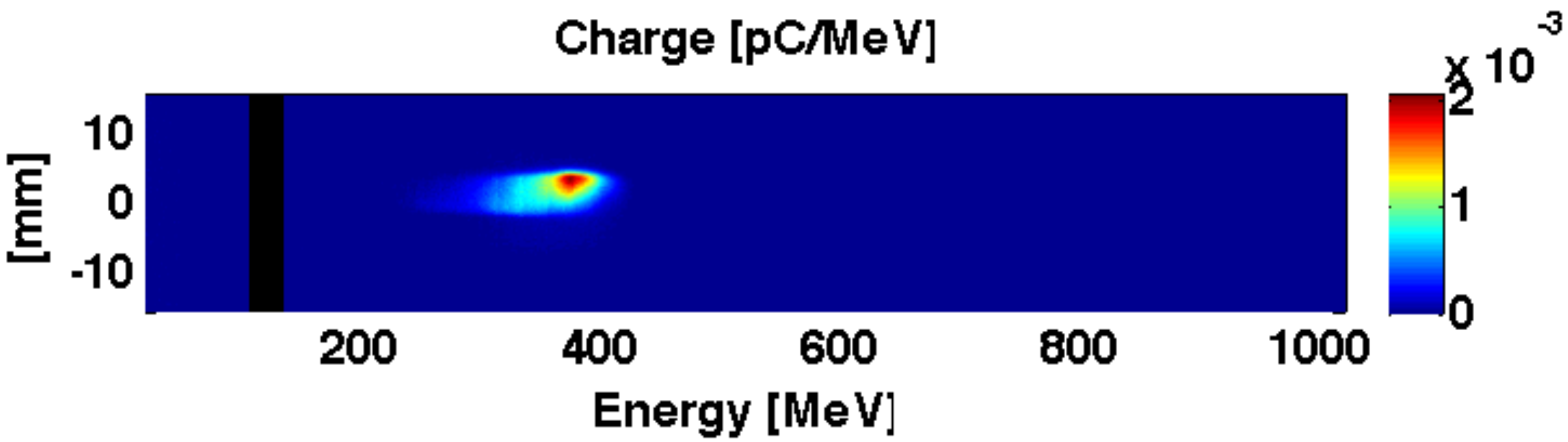
- Undulator based single shot diagnostic for e-beam
- Uses gas jet + capillary based LPA
- Beam is imaged onto undulator using permanent magnet quads



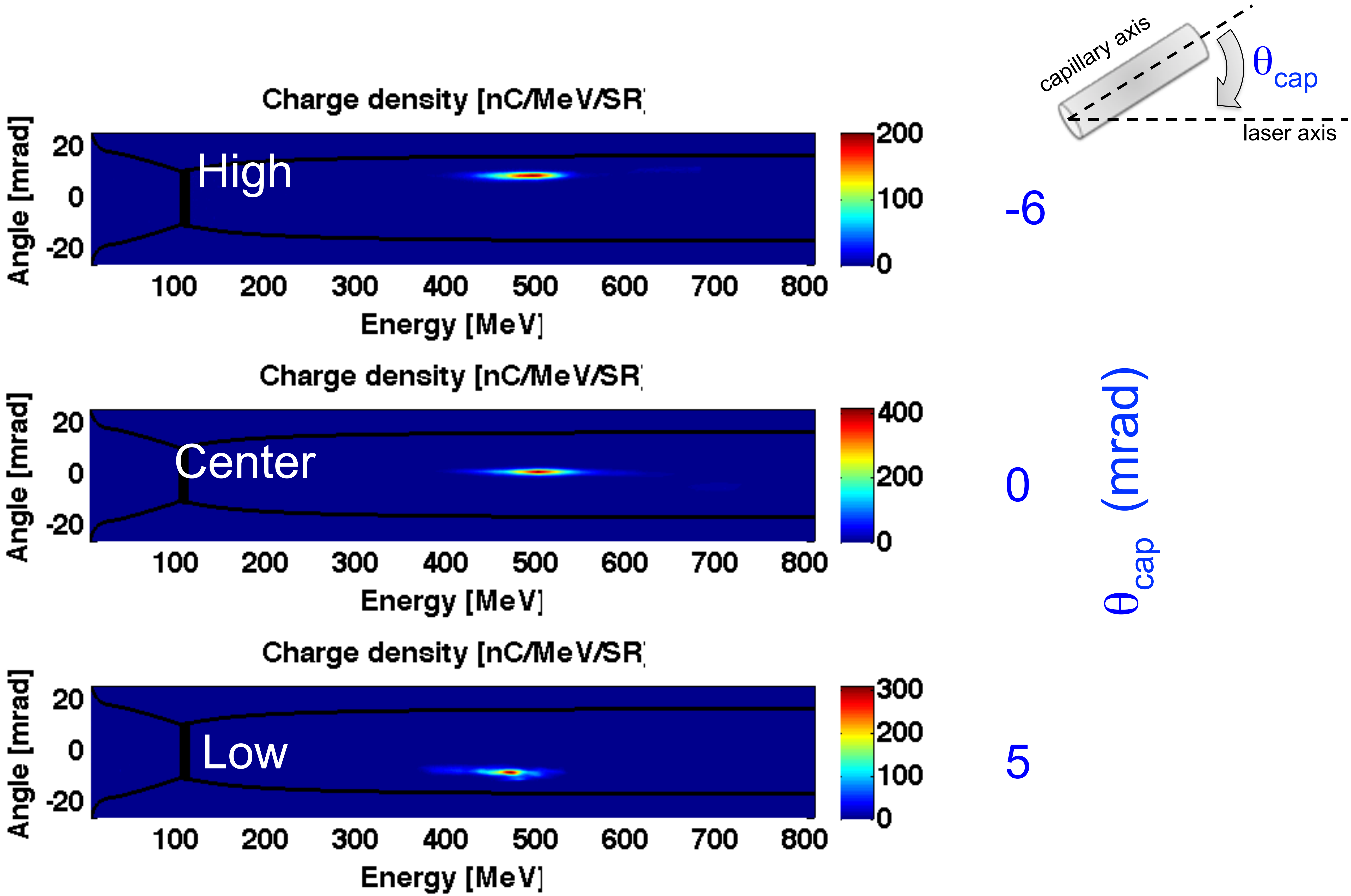

XUV light



Electron beam spectra



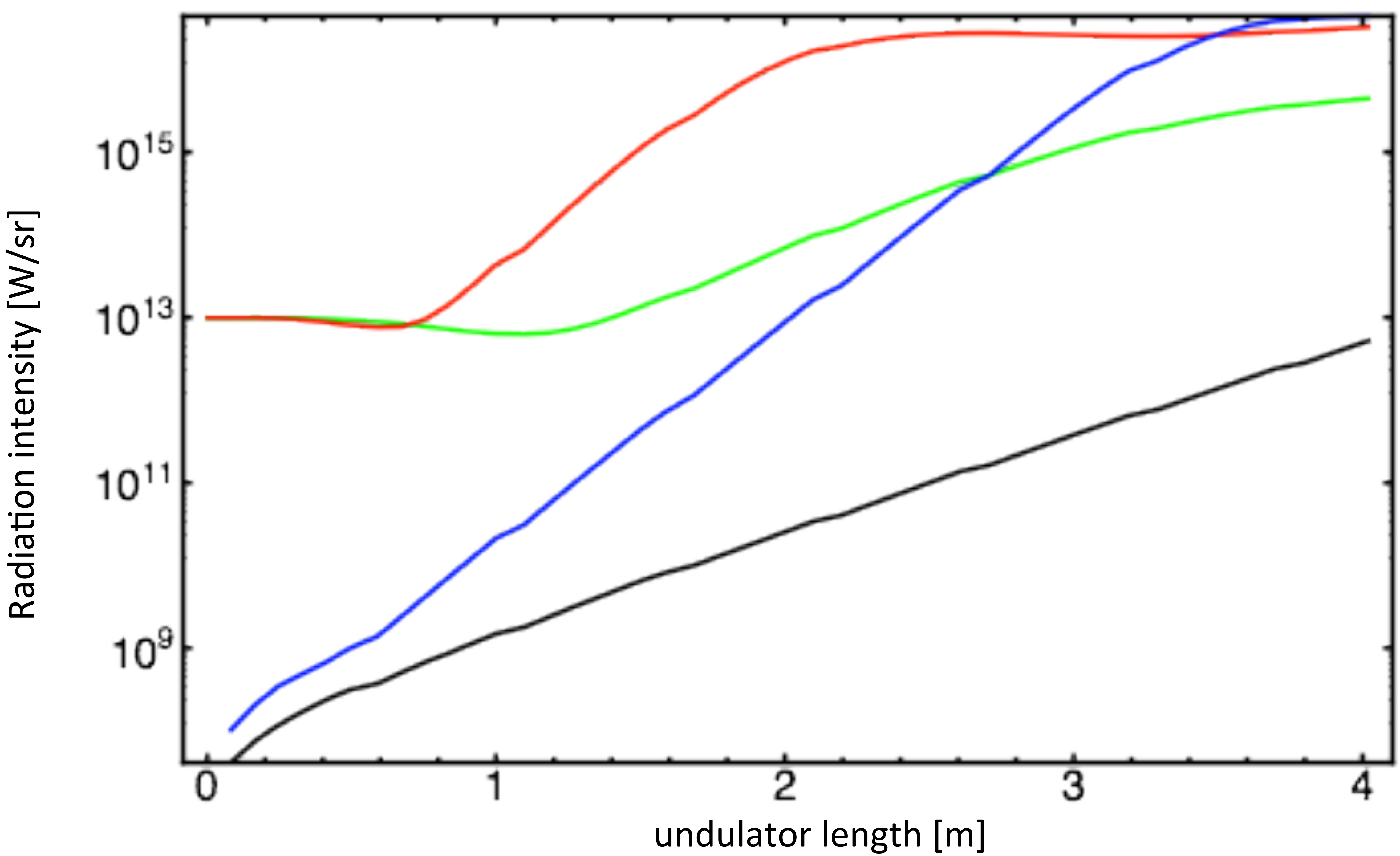
# Electron beam can be steered using plasma channel alignment



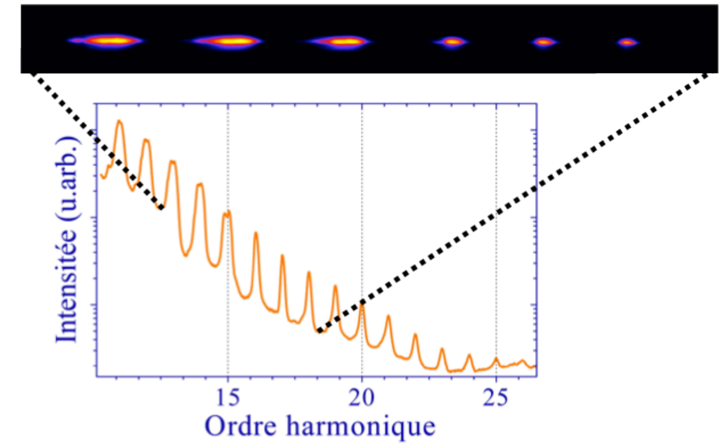
# Ultra-low emittance reduces constraints on other beam parameter -- Seeding should allow saturation in ~ 2meter

Undulator: K=1.25, 2.18 cm
Beam: 308 MeV, 0.2 micron emittance, 0.5%,
21 fs FWHM (1.5kA=30pC)

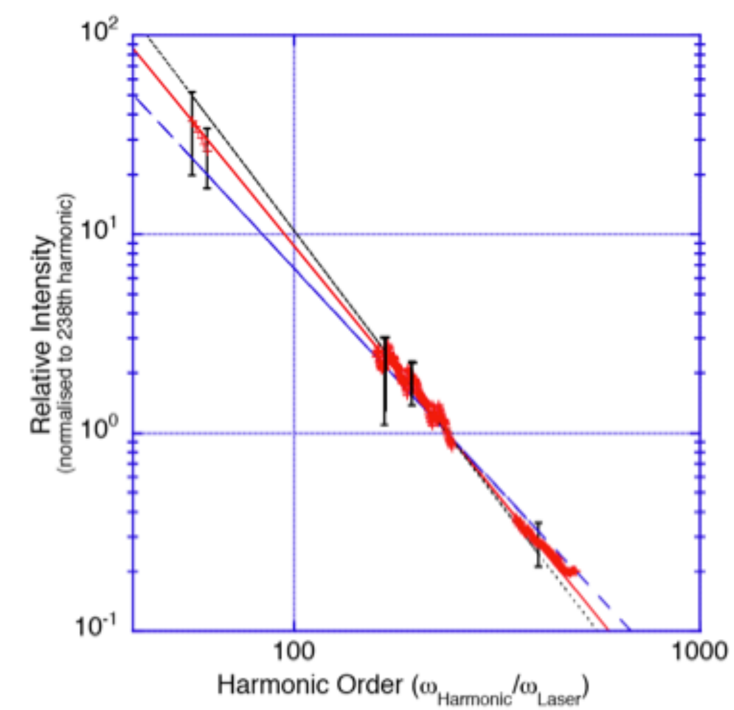
Fundamental wavelength: 53 nm
FEL parameter (5 kA): $5 \times 10^{-3}$
HHG seed ($15^{th}$): 1 MW, 0.1 mrad, 8.5 fs RMS



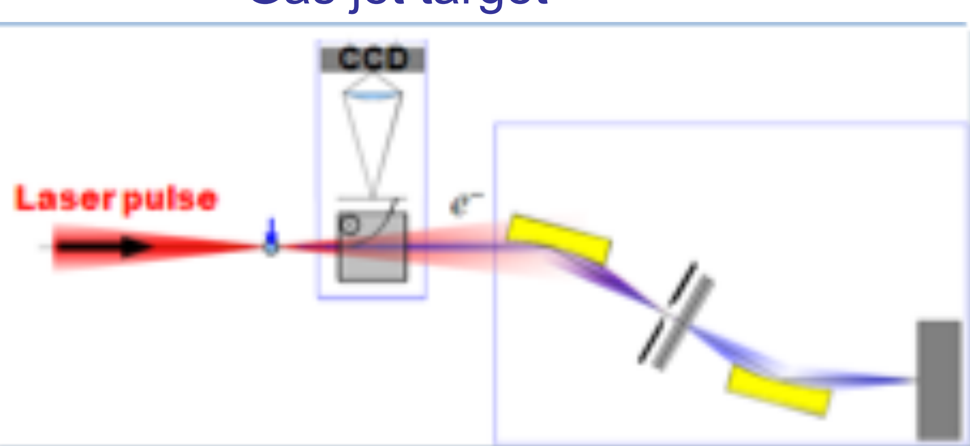
# New plasma based high harmonic emission physics is being discovered

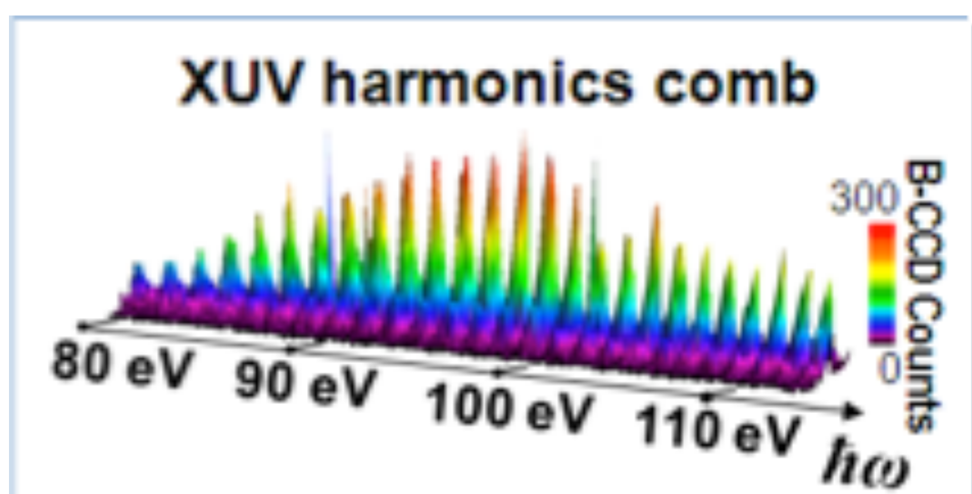


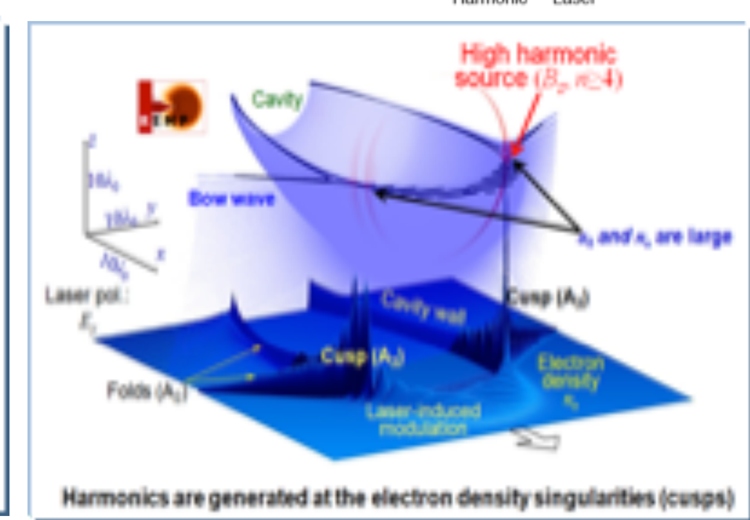

- Coherent wake excitation
  - Thaury et al., Nature Physics 2007
  - $10^{16}$ - $10^{17}$ W/cm$^2$
  - Solid target
- Relativistic oscillating mirror
  - Dromey et al., Nature Physics 2006
  - $>10^{18}$ W/cm$^2$
  - Solid target



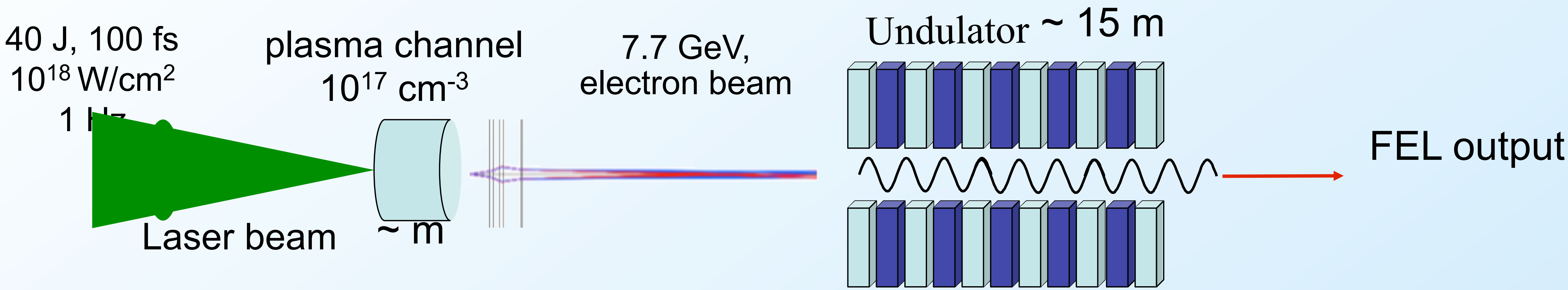

- Plasma shocks in underdense plasmas
  - S.V. Bulanov et al., 2011
  - $>10^{18}$ W/cm$^2$
  - Gas jet target



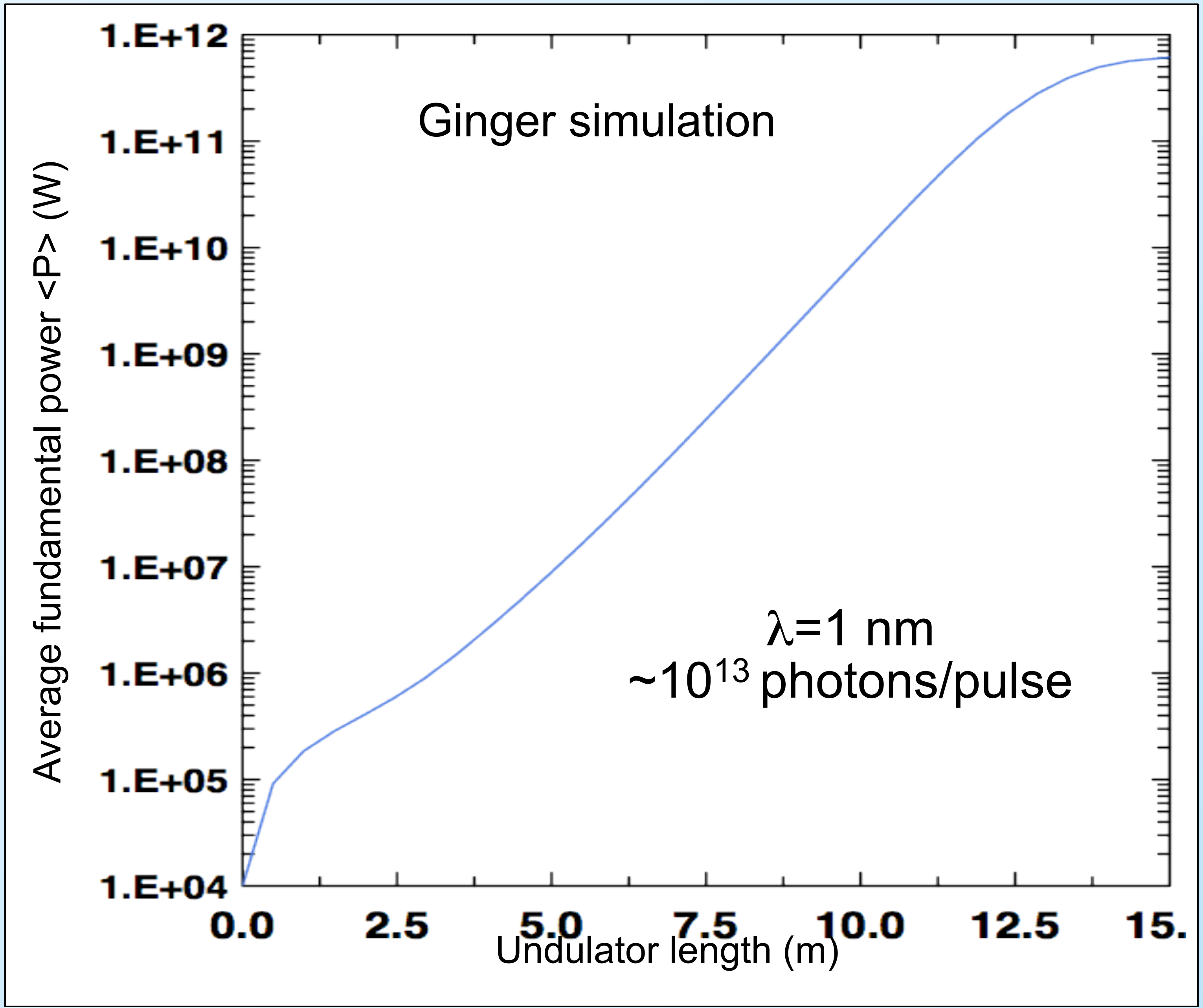



# Case study: Laser-plasma accelerator driven soft x-ray FEL at 1 nm



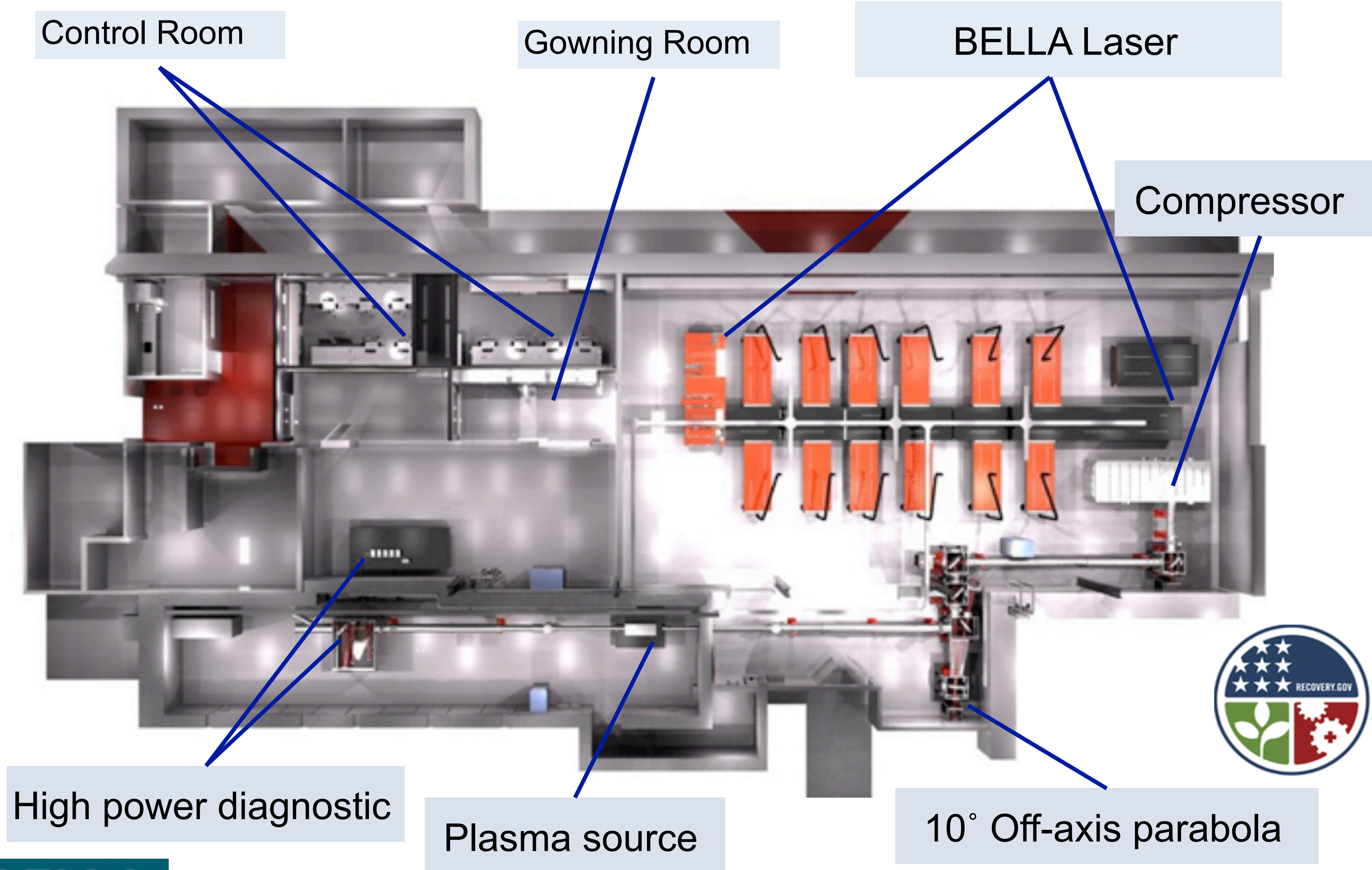

LPA electron beam:

| | |
|---|---|
| Beam energy | 7.7 GeV |
| Peak current | 30 kA |
| Bunch length | 20 fs |
| Relative energy spread | $10^{-3}$ |
| Normalized emittance | 1 micron |



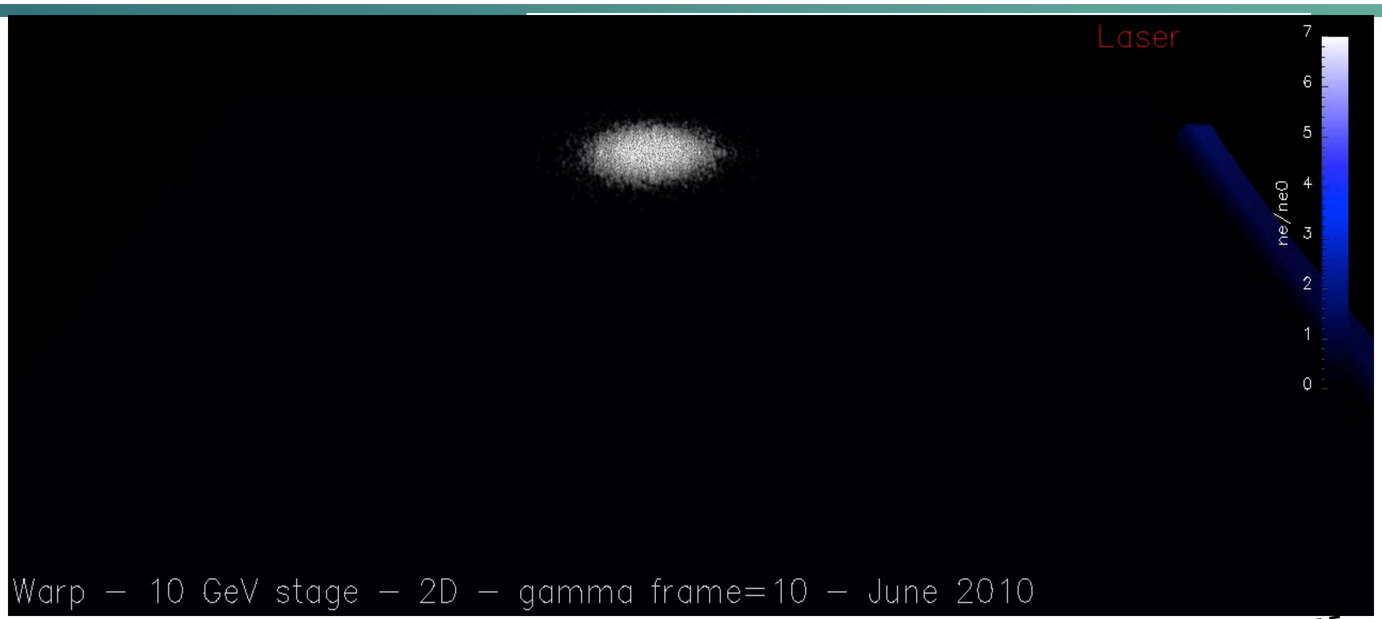

Requires nominal
10 GeV LPA

# BELLA Facility: state-of-the-art PW-laser for laser accelerator science

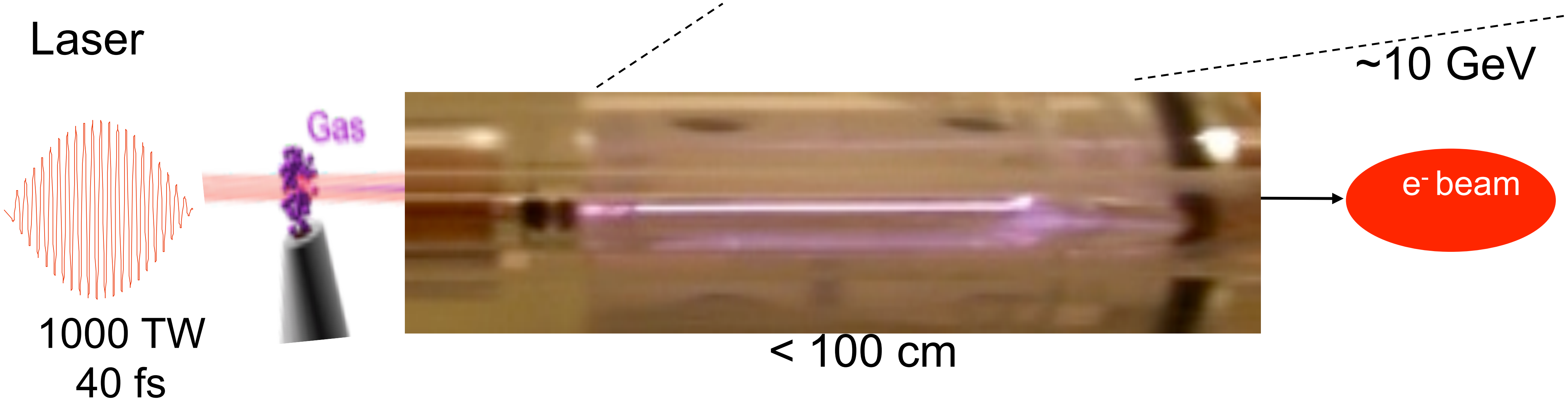


# BELLA laser opens significant opportunities

Lorentz boosted frame simulation
Full 1 m BELLA stage -- major advance
Courtesy of J.-L. Vay




2013 Experiments




- Accelerator science studies
- 10 GeV Module for collider, (10 GeV, beam optimization, efficiency etc…)
- Positron production; plasma wakefield acceleration, etc…
- Driver for FEL

W. Leemans et al., AAC2010 Proceedings

# Observations

- Laser/plasma based sources:
  - Hyperspectral source -- laser plasma accelerator technology (and science!)
    - Coherent (THz - IR, visible - XUV/soft x-ray):
      - FEL experiments underway, with seeding
      - Lots of innovation taking place in high harmonic sources
    - Incoherent (hard x-rays, gamma rays)
    - Electrons:
      - Magnetic switching, electron injection - MeV to GeV beams
      - PoP 10 GeV experiments starting in 2012
- Laser technology
  - Up to PW-class lasers commercially available but rep rate low (1-10 Hz)
  - Need strategy and technology for high average power
    - ICFA-ICUIL Joint taskforce workshops and white paper in progress
- Small/medium scale facility
  - Agile test platform: development of FEL concepts (including seeding, fs bunch diagnostics and beam manipulation), technology development, reconfigurable/ flexible, training of students, postdocs etc...
  - Fs pump-probe science (see e.g. F. Parmigiani's talk)
    - Center piece of ELI Hungary and ELI Czech Republic

# Strawman Facility Design

- Linac costs near nothing – build multiple linacs and beam lines driven by single laser or multiple lasers
- With laser cost decreasing and performance increasing: power each beam line with its own laser