U.S. DEPARTMENT OF ENERGY | Office of Science

NSTX-U

Fast Burst Laser System for Laser Scattering Measurements

Ahmed Diallo[1]

in collaboration with

B.P. LeBlanc[1], L.F. Delagdo-Aparicio[1],
D. J. Den Hartog[2], M. Borchardt[2],
D. Holly[3], J. Ambuel[3], P. Robl[3], D. Wahl[3], and A. Laundrie[3]

[1] Princeton Plasma Physics Laboratory
[2] University of Wisconsin - Madison
[3] UW-Madison Physical Sciences Laboratory

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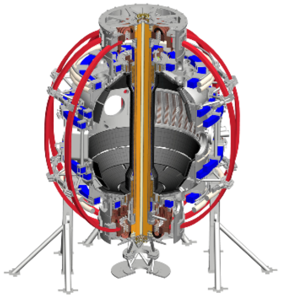
PSL | W | PPPL



Motivation: Locally resolve the electron density & temperature to probe various fast physical phenomena via Thomson scattering

- Low temperature (< 10 eV) plasma benefits from Langmuir probe access with its potential perturbation to the local plasma.

- High temperature plasma routinely probe the plasma via laser scattering for local measurements.

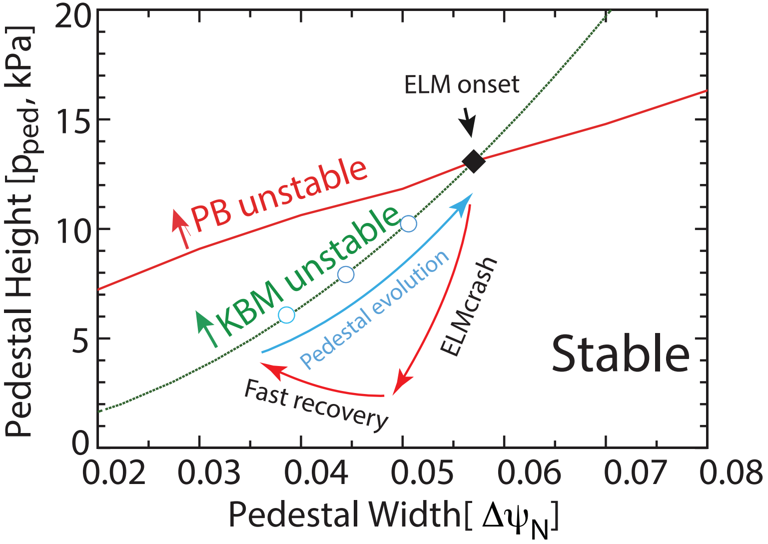
H-mode pedestal dynamics and onset of edge localized modes are still ongoing research

Stability code suite(EPED) predicts pedestal pressure height and width

- based on two key limiting instabilities
  - non-local peeling–ballooning (P–B)mode ➝ trigger for edge-localized mode (ELM)
  - nearly local kinetic ballooning modes (KBMs) ➝ regulate transport between ELMs

Connor, PoP (1998); Wilson, PoP (2002); Snyder, PoP (2001); Snyder, NF (2011)

Type I ELM cycle cartoon



ELM physics is thought to be localized to the pedestal.

Both ELM onset and pedestal recovery are on microseconds and milliseconds time scale.

Impurity transport physics in H-mode

- Very strong neoclassical inward pinch drives **rapid** cross-field transport of impurities into the core.

- Rapid ELM events produce convective outward expulsion of impurities.

Need to diagnose these fast processes by acquiring both high-speed impurity measurements and **fast** ne, Te measurements

All impurity measurements **rely on electron profiles** (ne, Te)

Thomson scattering is central to many analyses in fusion devices

- Thomson scattering has since been a robust and accurate approach for density & temperature local measurements.
- *Limitations:*
  - Temporal resolution has been limited to tens of Hz @ Joule level energies.
  - Increase of this repetition rate is usually achieved by interleaving multiple lasers.
  - Difficult to scale in order to achieve kHz rep rate.
- Both in low and high temperature plasmas, fast transient physics require kHz rep rate lasers.

Outline

- Two approaches to achieve fast temporal resolution.
  - Thin disk

    Immune to thermal lensing and capable of 1 kHz @ Joule levels - ongoing work
  - Flashlamp (this talk)

    Limited to fast burst but capable to achieve tens of kHz at joule level energies

- Characterization of the fast pulse burst laser system.

- Benefits of synergy between TS and modern x-ray-based Te measurement.

Fast Thomson scattering measurements can be achieved using a pulse burst laser system (PBLS)

- PBLS has been pioneered at Madison Symmetric Torus (MST).

D J Den Hartog, J R Ambuel, M T Borchardt, J A Reusch, P E Robl, and Y M Yang
Journal of Physics: Conference Series 227 (2010) 012023

- On NSTX-U, we plan to **A** extend the pulse duration and, **B** add a baseline mode to increase the regular (60 Hz) TS temporal resolution.
  - PBLS will be an upgrade to the existing TS system.

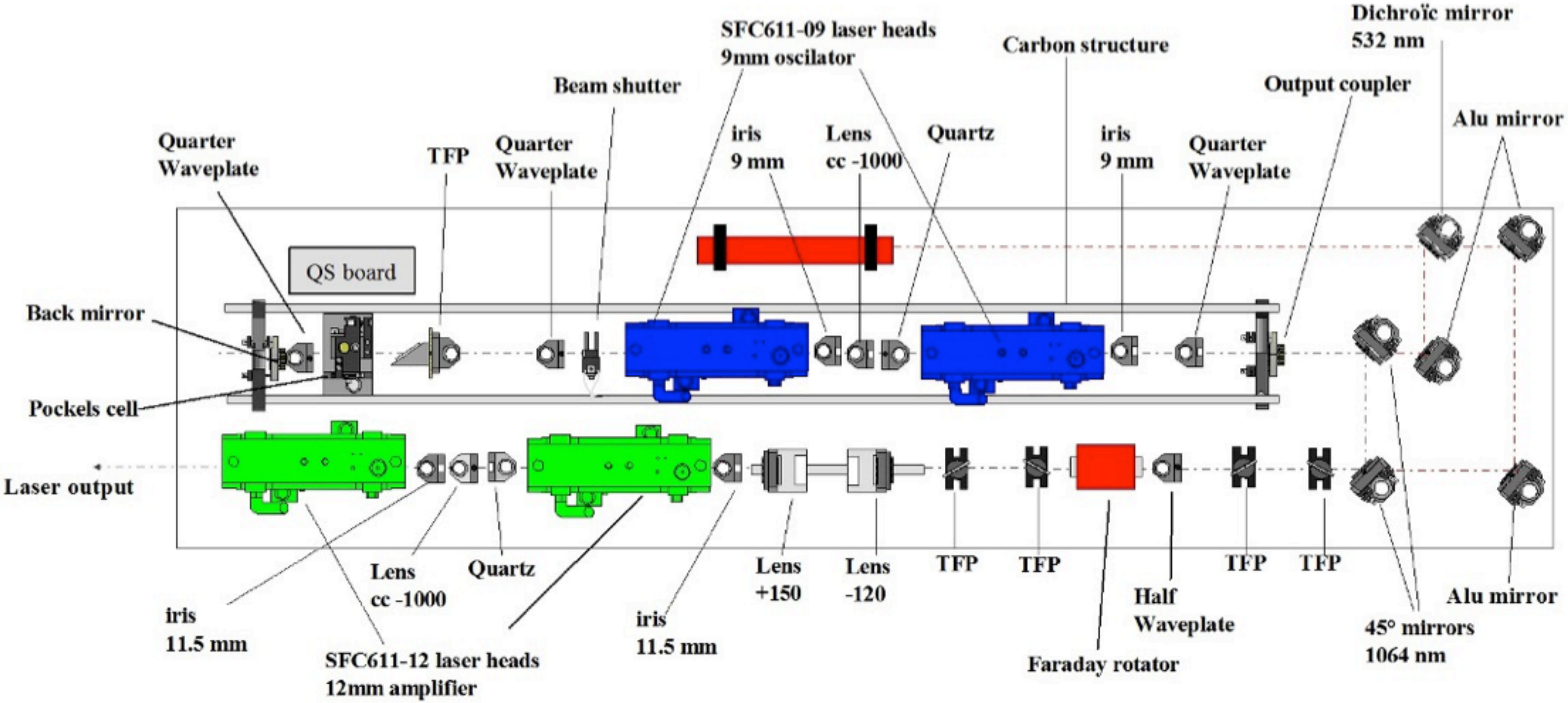
- PBLS will offer new time resolved measurements capabilities to tackle a wide range of physics.
  – ELM onset physics (≲ 1ms).
  – MHD, e.g., kink and tearing modes (~ sub ms).
  – Disruption physics (~ sub ms)
  – L-H transition (≲ 1 ms).
  – Probe the electron distribution induced by RF.
  – Fast ion physics, e.g., density and temperature displacements induced by TAE modes.
  – Edge turbulence (few kHz).

Pulse burst laser - Design specifications

- Pulse energy ⇛ 1.5 J per pulse.
  - Pulse width ⇛ 10 ns (FWHM)
  - Beam diameter ⇛ 10 mm @ 0.5 mrad
- Three modes of operation.
  - Base mode @ 30 Hz to be compatible with the current NSTX-U rep rate
  - Slow burst mode: 1 kHz rep rate for 50 ms.
  - Fast burst mode: 10 kHz rep rate for 5 ms.

  } **Limited by thermal lensing** (slow and fast burst modes)
- Take advantage of Nd:YAG larger rod diameter (9 & 12 mm) for thermal inertia.

Quantel laser head provides large diameter rods to increase the thermal inertia

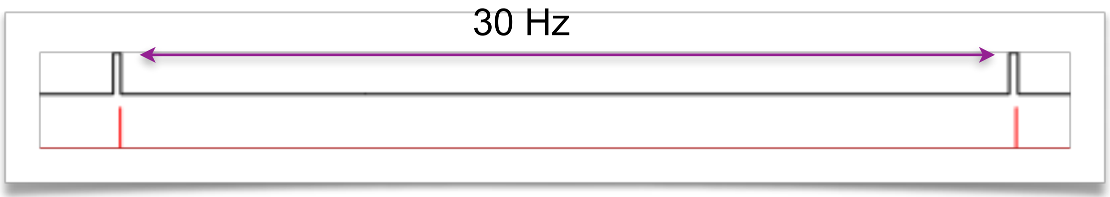


Three of modes of operation have been implemented

Baseline

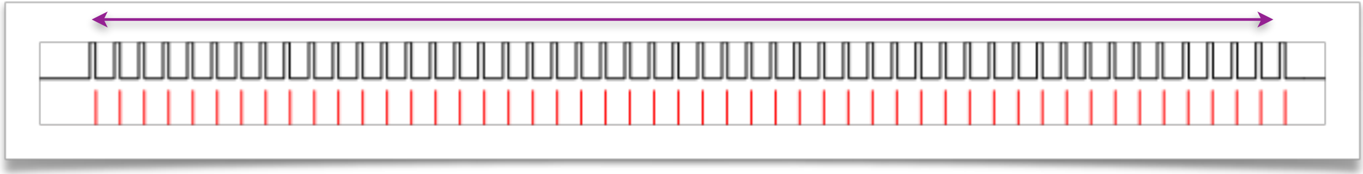
Flashlamp

Q-switch

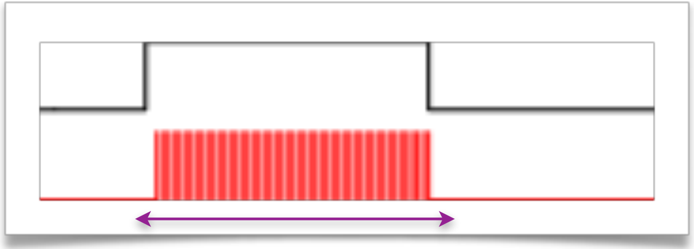


1 kHz for 50 ms

Slow burst



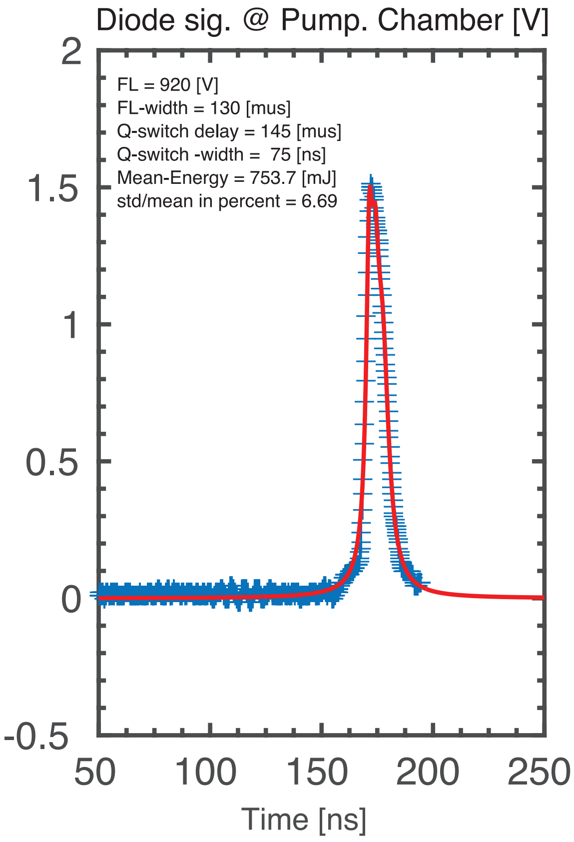
Fast burst



10 kHz for 5 ms

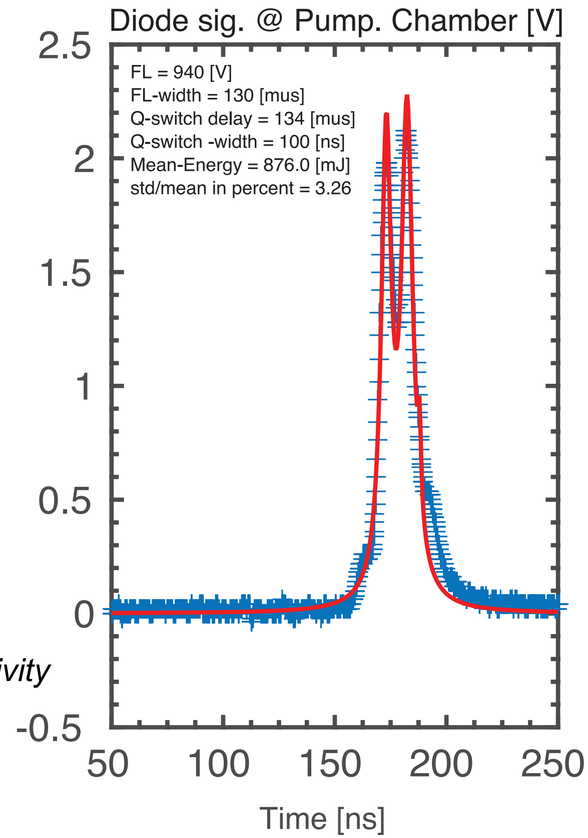
Slow and fast can also be **triggered** on demand

Two types of pulse shape have been observed at the exit of the oscillator

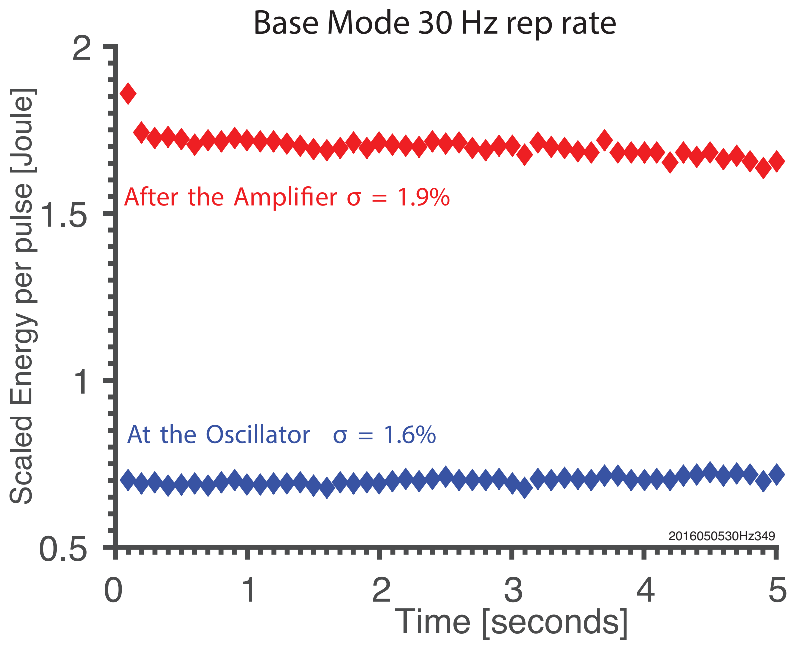


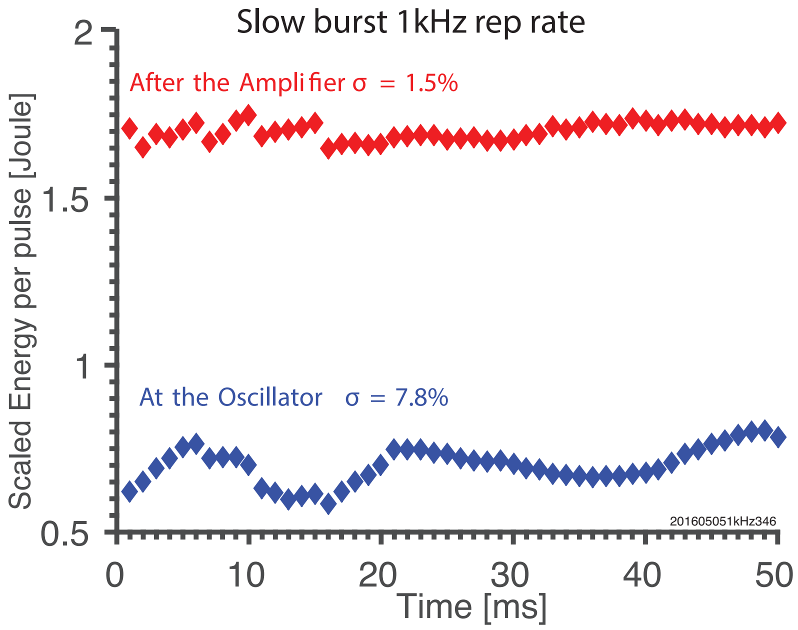
- Single and double hump pulses.
- Minimal impact of the NSTX-U TS analysis.

Laser head can in principle produce a stable single-hump pulse by optimizing the oscillator output coupler reflectivity (subject of future upgrade)

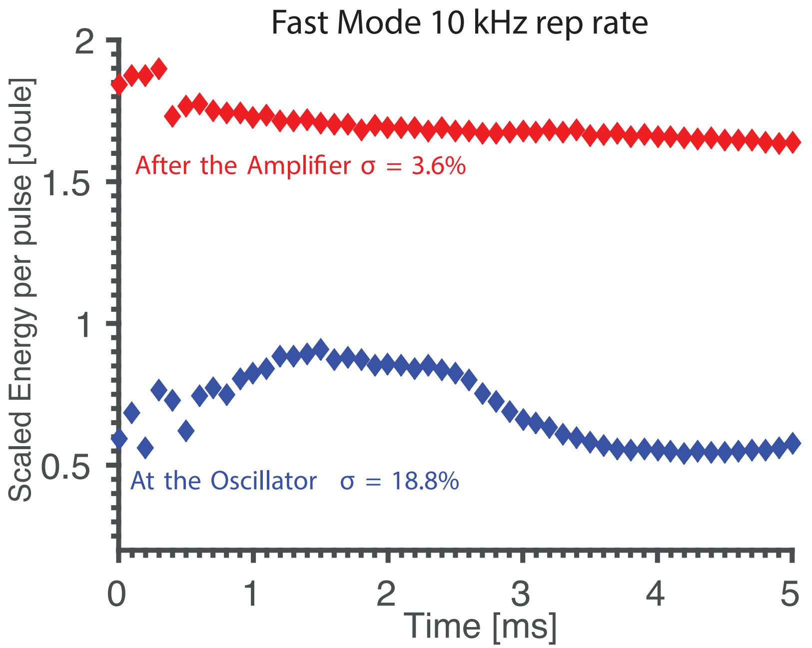


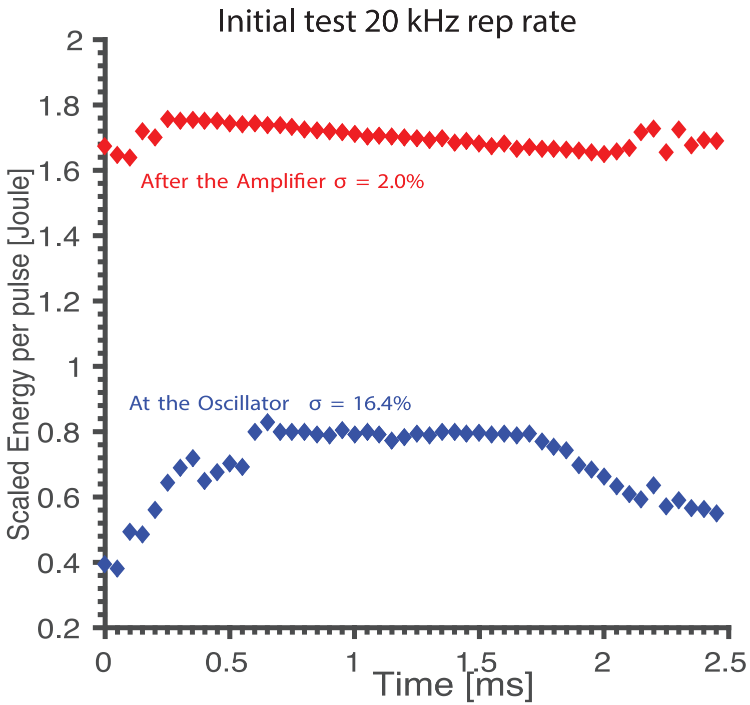
Energy levels needed for the base and slow burst modes were achieved



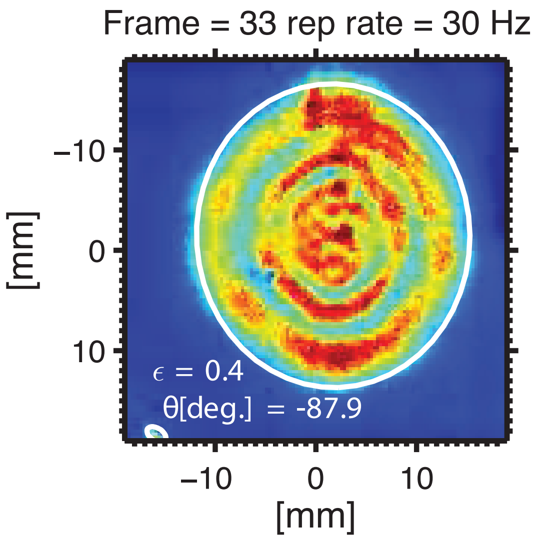


Similar reproducibility are obtained for two fast bursts scenarios: 10 kHz & 20 kHz





Base mode exhibits good beam profile far field stability
(Imaging a reticle at 8.5 m)

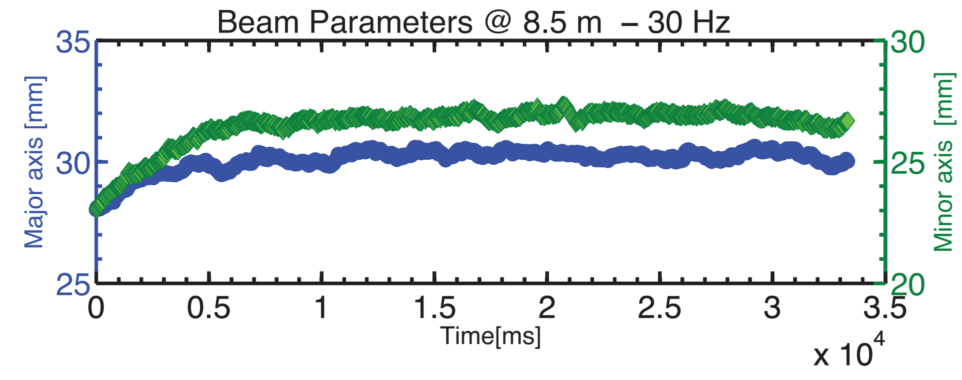


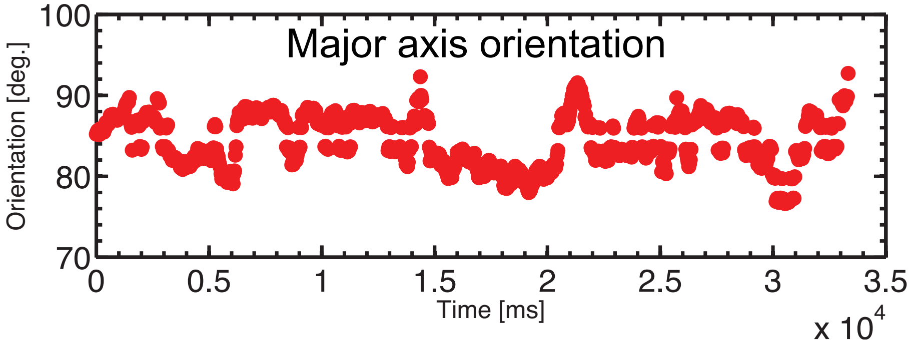
Key beam profile parameters

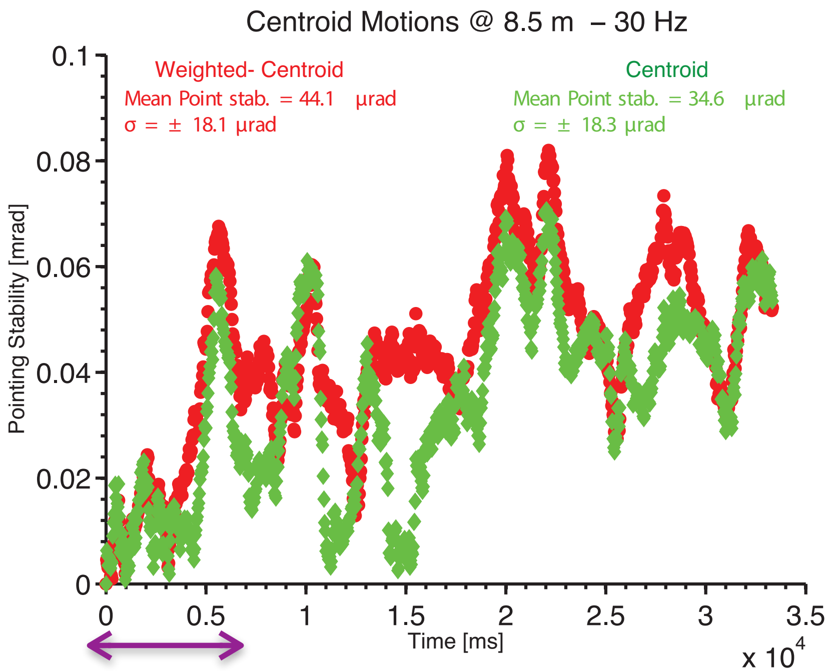
Major & minor axis
Tilt of major axis
Pointing stability

Thanks to R. Perkins, M. Jaworski, F. Scotti for the initial assistance in operating the camera.

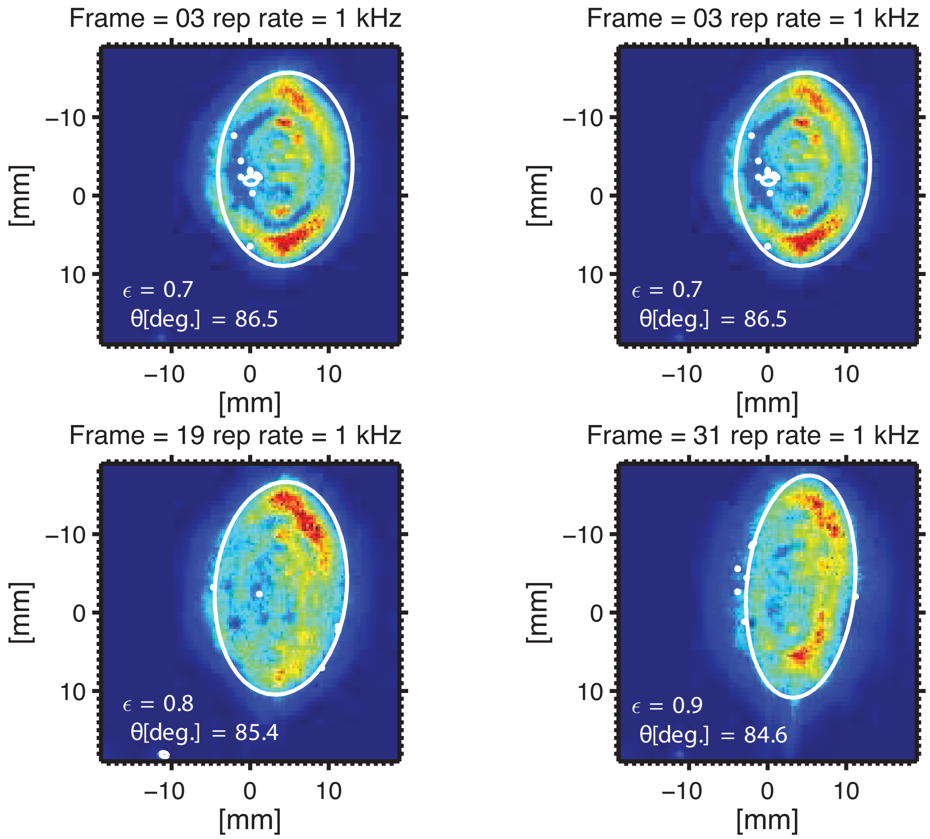
Summary of beam parameters in far field field for base mode: Major (vertical) axis and orientation, minor (horizontal) axis, pointing properties



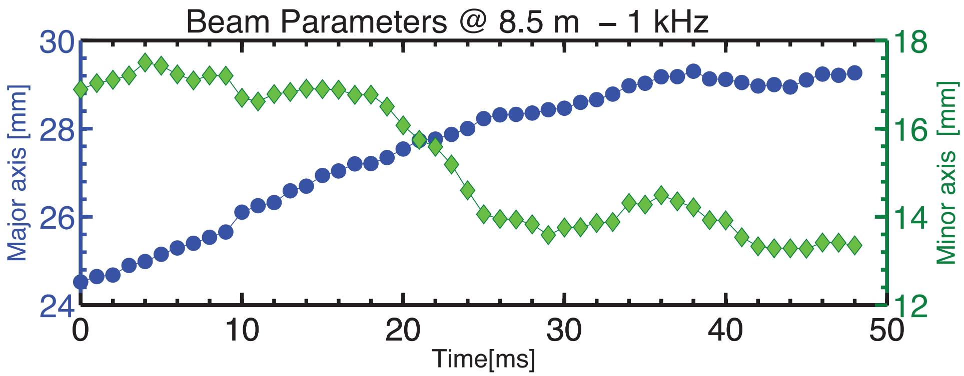


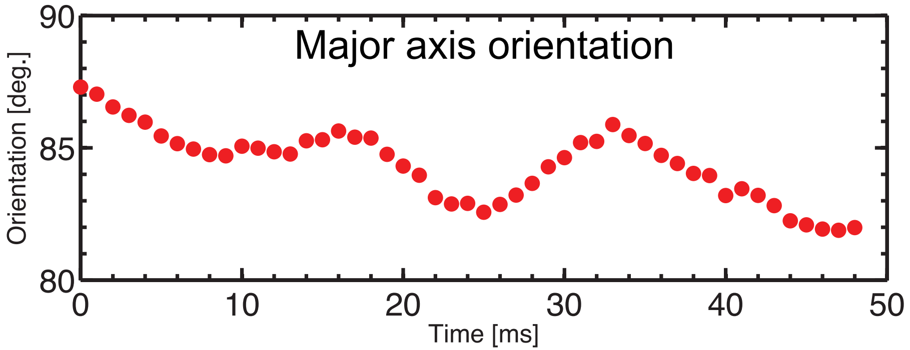


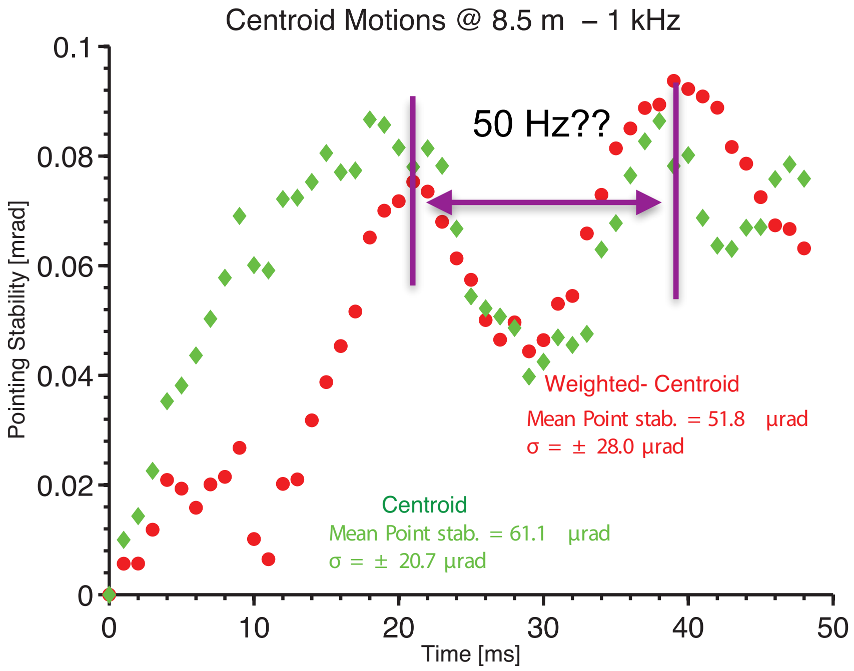
Slow burst mode exhibits an elongated beam profile in the far field *(still under investigation)*



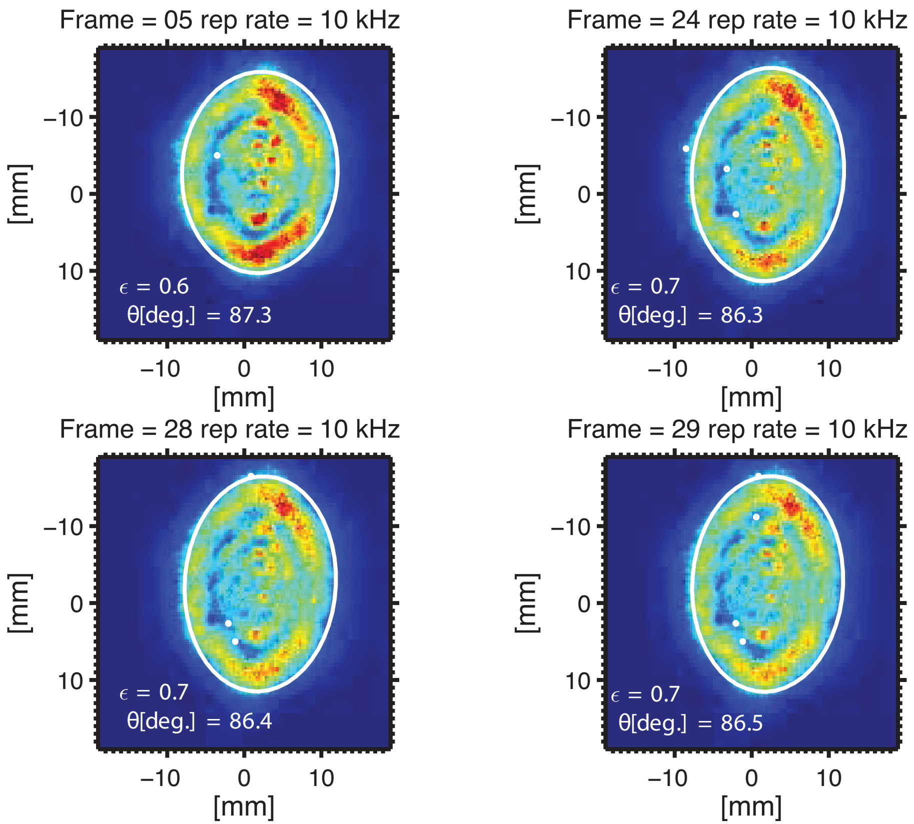
Summary of beam parameters in far field field for slow burst
Major (vertical) axis and orientation, minor (horizontal) axis, pointing properties



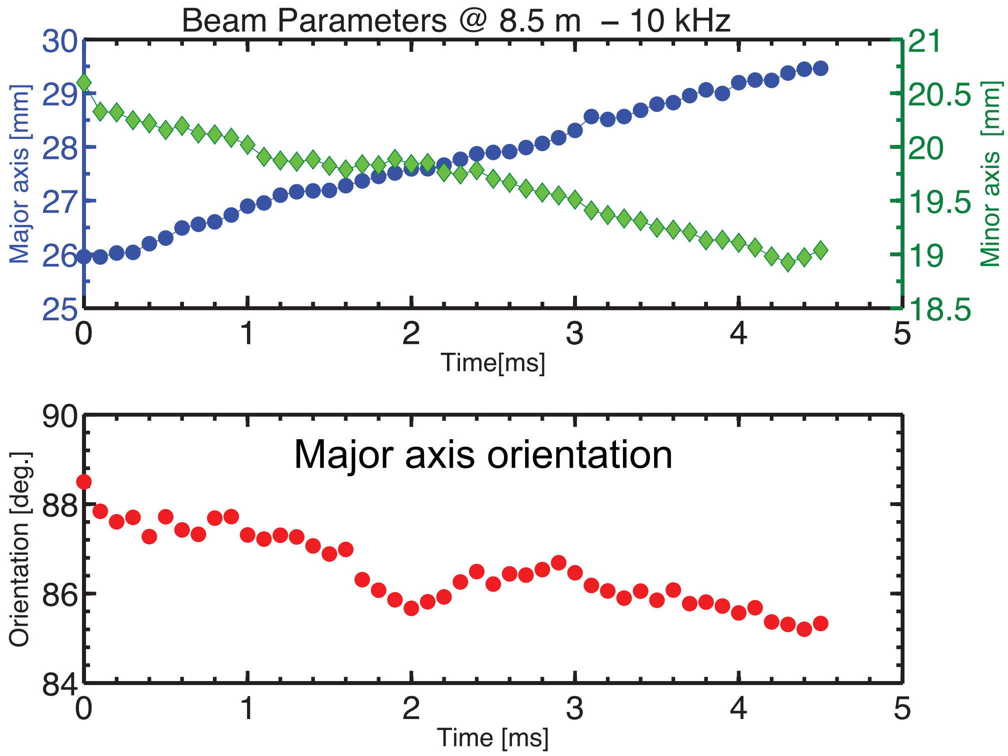


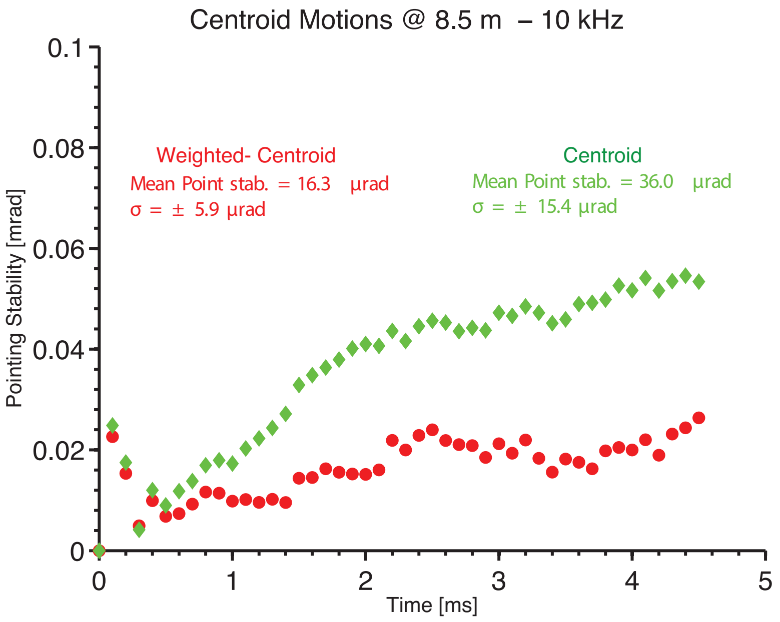


Fast burst mode has acceptable far-field beam properties



Summary of beam parameters in far field field for fast burst
Major (vertical) axis and orientation, minor (horizontal) axis, pointing properties





Outline

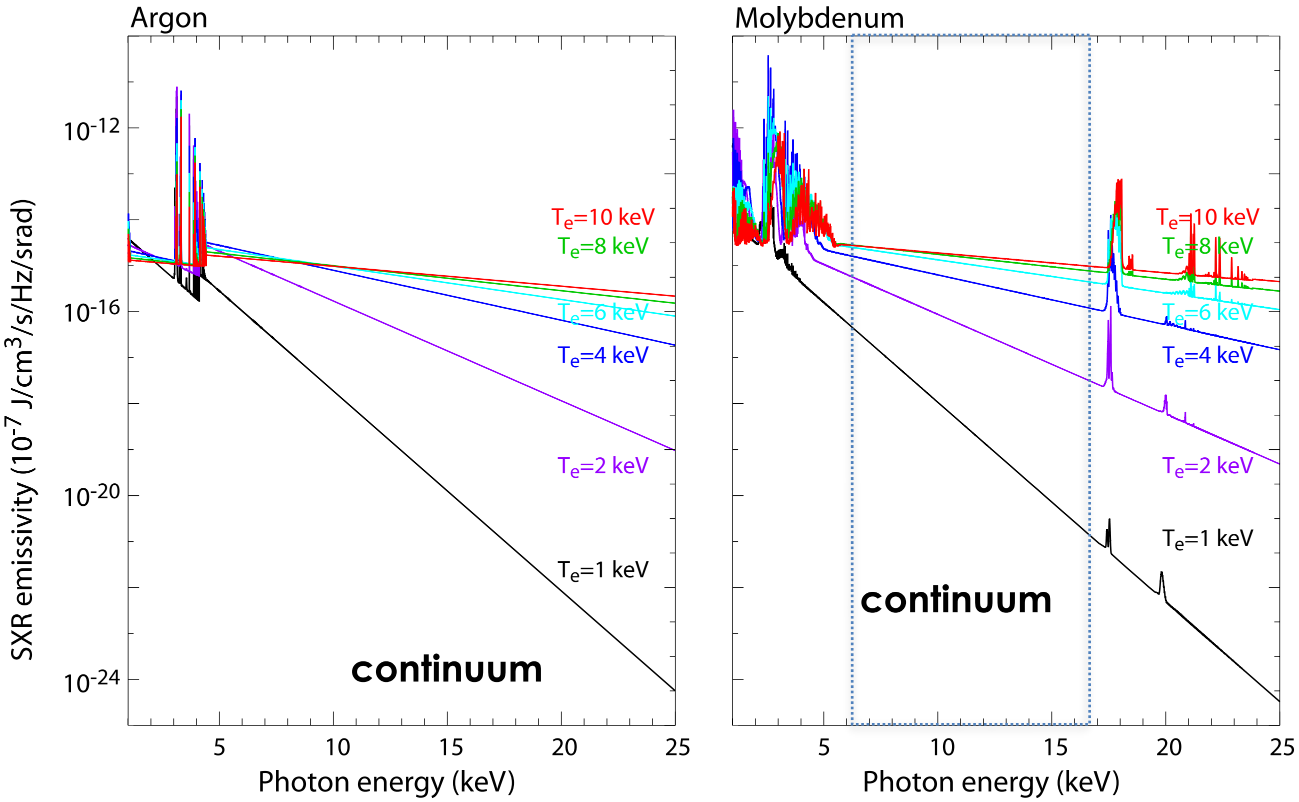
- Two approaches to achieve fast temporal resolution
  - Thin disk
    - Immune to thermal lensing and capable of 1 kHz @ Joule levels - ongoing work
  - Flashlamp

    This talk
    - Limited to fast burst but capable to achieve tens of kHz at joule level energies

- Characterization of the fast pulse burst laser system

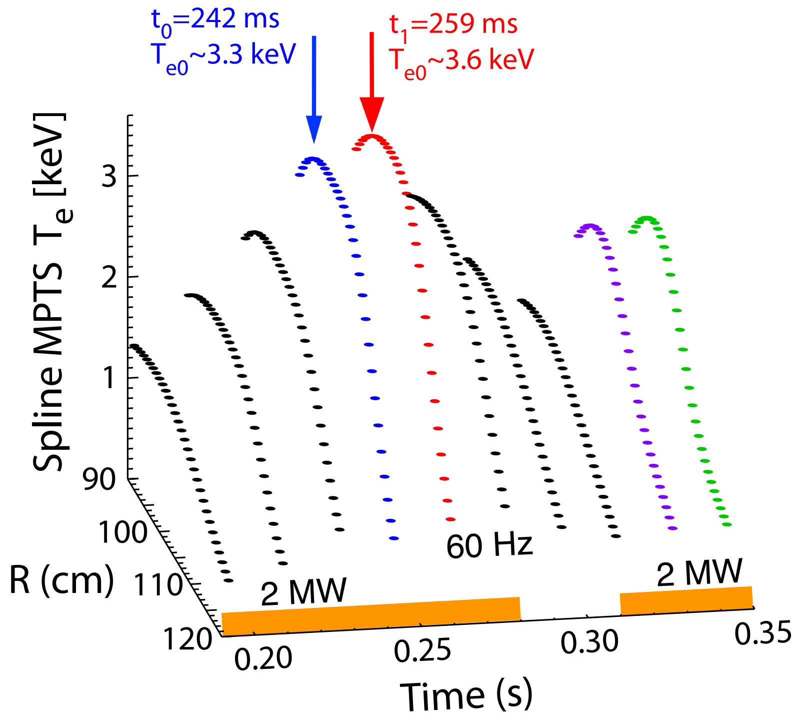
- **Benefits of synergy between TS and modern x-ray-based Te measurement.**

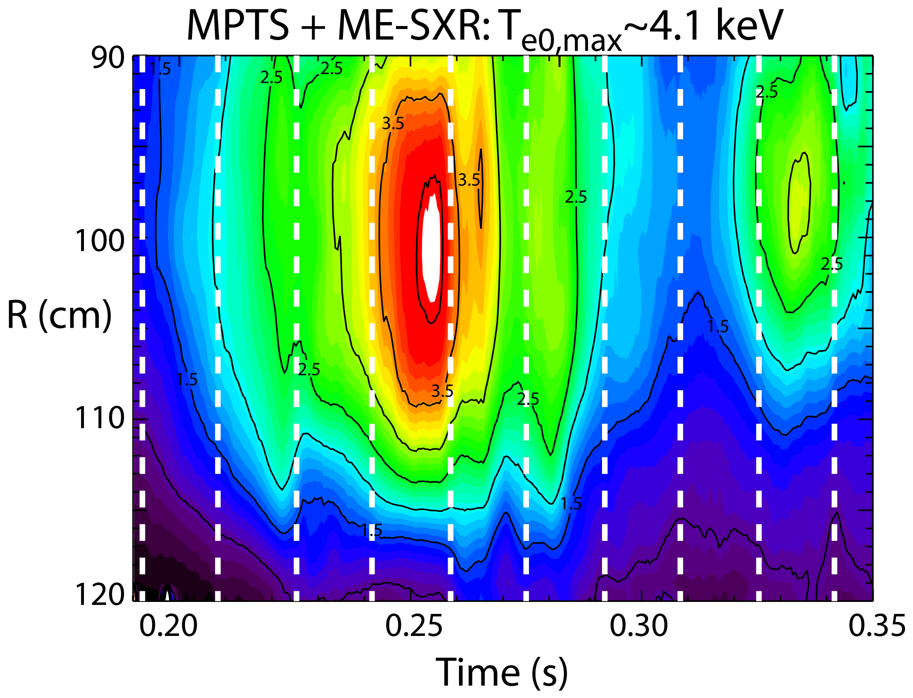
From sampling the continuum from Ar and Mo, T_e and $n_e^2 Z_{eff}$ can be determined



- Medium- and high-Z impurities can be found in tokamaks and stellarators.
- Continuum radiation is sampled using modern detectors.
- T_e, n_Z/n_e and δZ_{eff} can be inferred from the continuum.

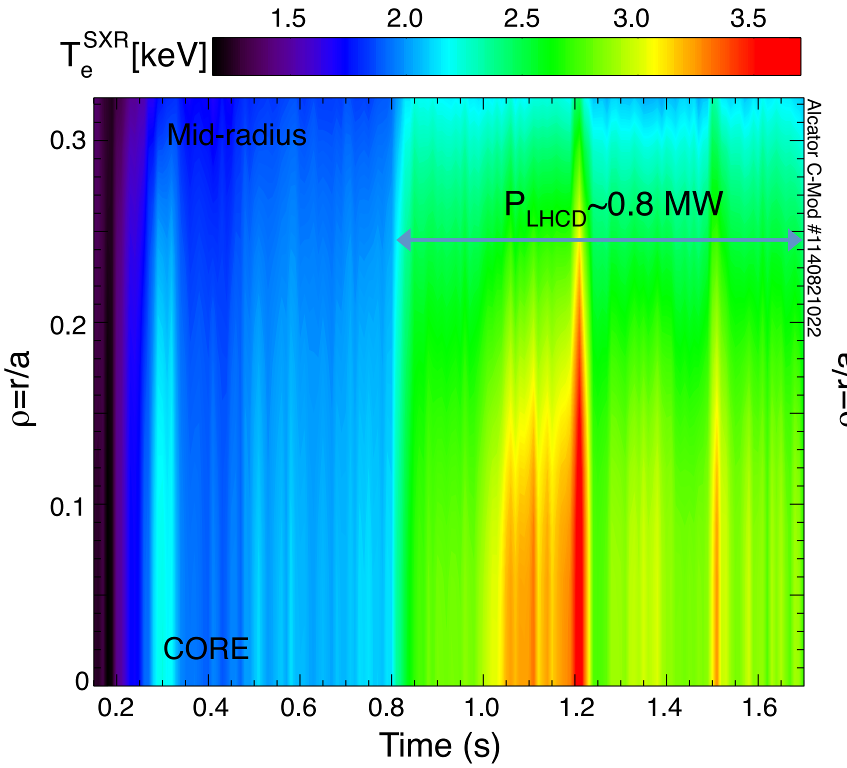
Fast Te measurements using the continuum in combination with Thomson scattering has been demonstrated in NSTX

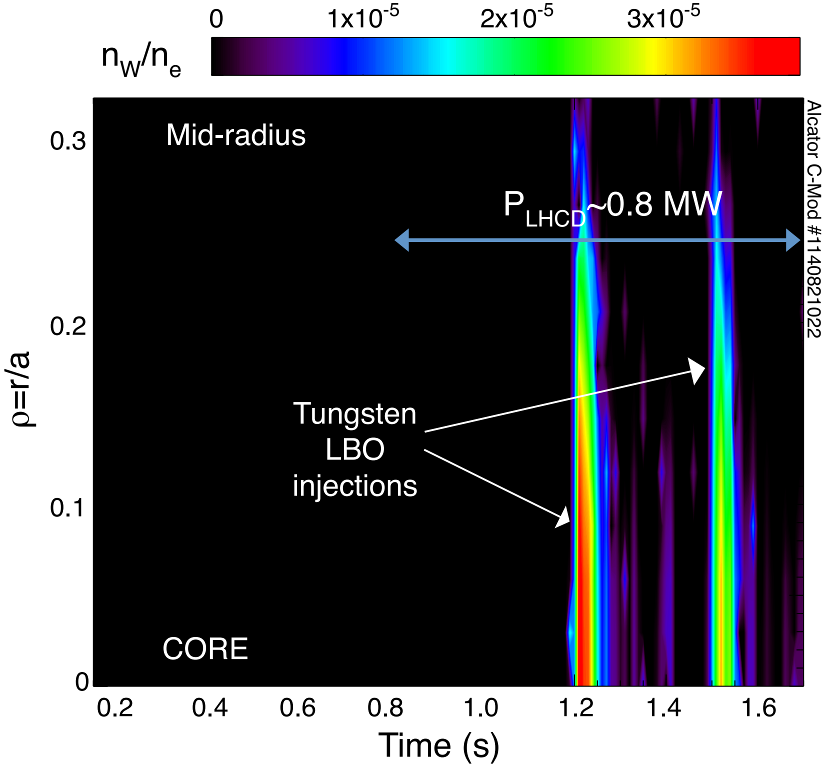




- However, these measurements are constrained by photon statistics up to 10 kHz.

On C-mod Continuum and line-emission can constrain T_e and n_Z/n_e





From the fast TS, in combination with SXR measurements, the impurity densities can be measured with high temporal

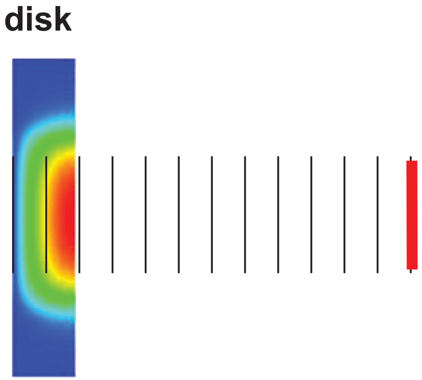
Summary and outlook

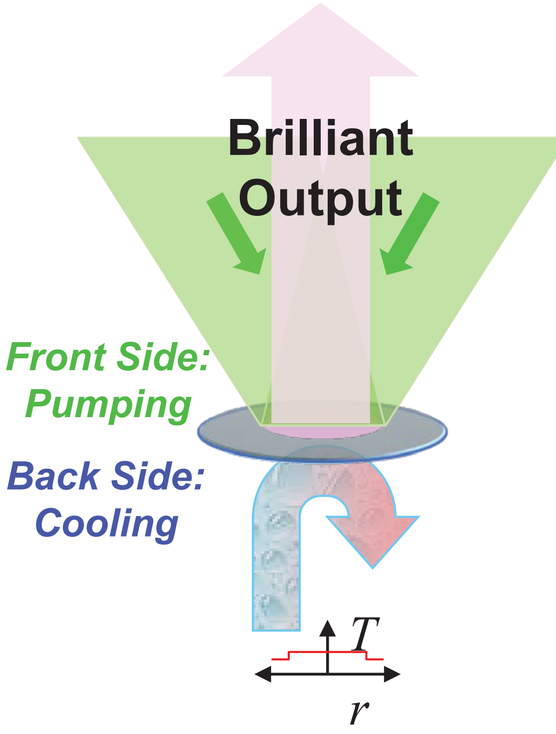
- Good progress in the R&D of the fast laser system for NSTX-U.
  - Capable of operating at up to 20 kHz in burst mode
- Such laser system will open new research opportunities in fast phenomena present in fusion devices.
  - ELM physics, impurity transport, L-H physics, and fast ion physics etc..
  - Note this system can be extended to diagnose physics phenomena in low temperature plasma such as spokes.
- PBLS will offer new time resolved measurements capabilities to tackle a wide range of physics.
  – ELM onset physics ($\lesssim$ 1ms).
  – MHD, *e.g.*, kink and tearing modes (~ sub ms).
  – Disruption physics (~ sub ms).
  – L-H transition ($\lesssim$ 1 ms).
  – Probe the electron distribution induced by RF.
  – Fast ion physics, *e.g.*, density and temperature displacements induced by TAE modes.
  – Edge turbulence (few kHz).

The burst capability can be applied to low temperature plasma!

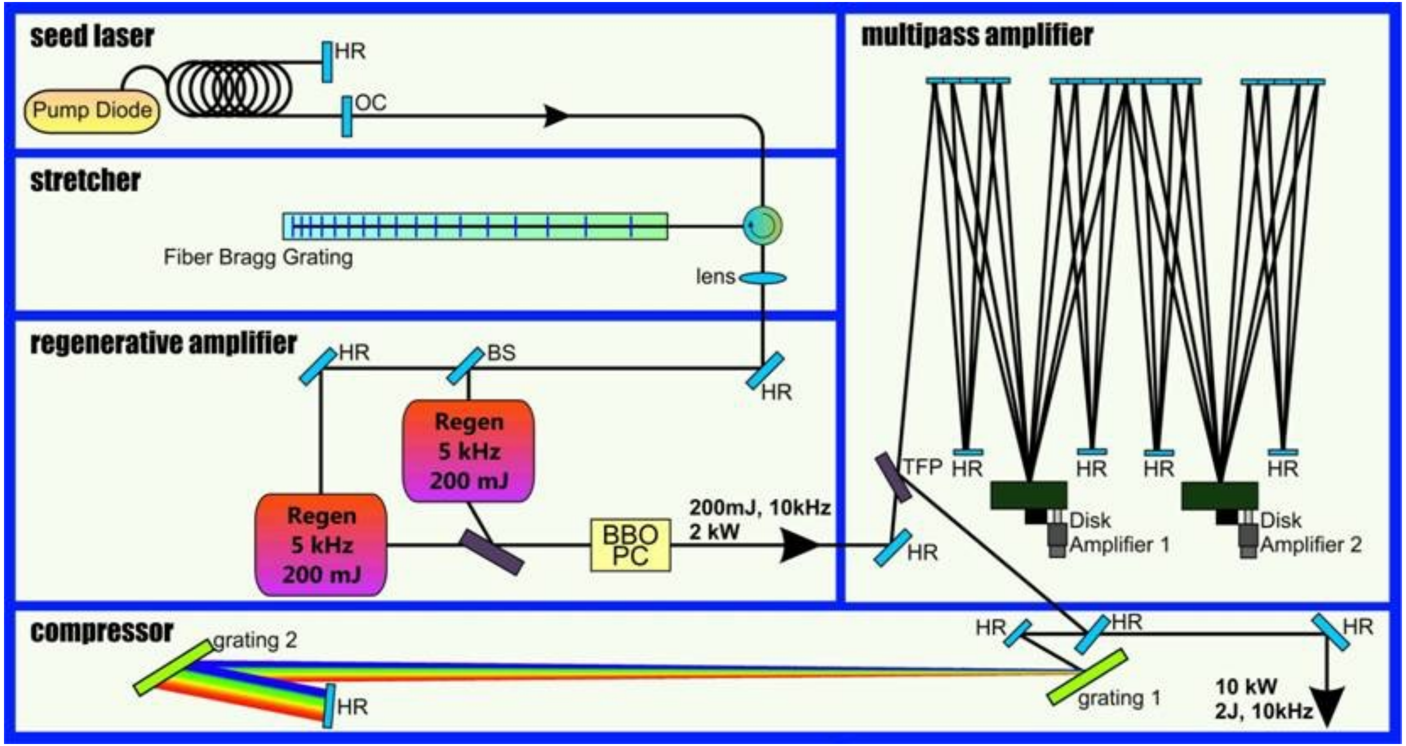
Competing approach: Disk laser principle

- Uniaxial heat flux: Low thermal lensing
- High brightness
- Low brightness constraints for pump diodes
- High gain saturation: Insensitive to back reflections
- Scalability by increase of beam cross section
- Negligible nonlinearities at high peak powers





Current technologies support thin disk based laser system for a continuous 10 kHz @ 2J



Courtesy TRUMPF