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Recent Results on Acceleration Mechanisms and Beam Optimization of Laser-Driven Proton Beams

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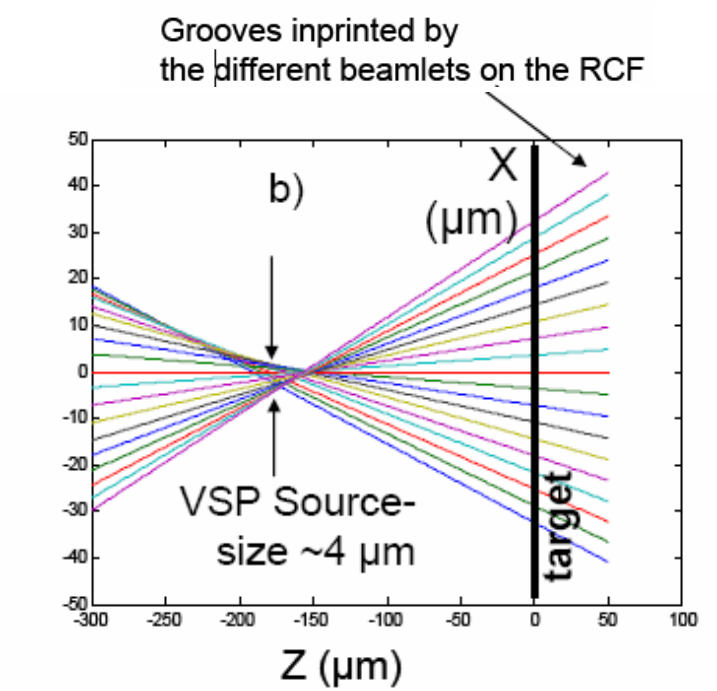
Actual characteristics

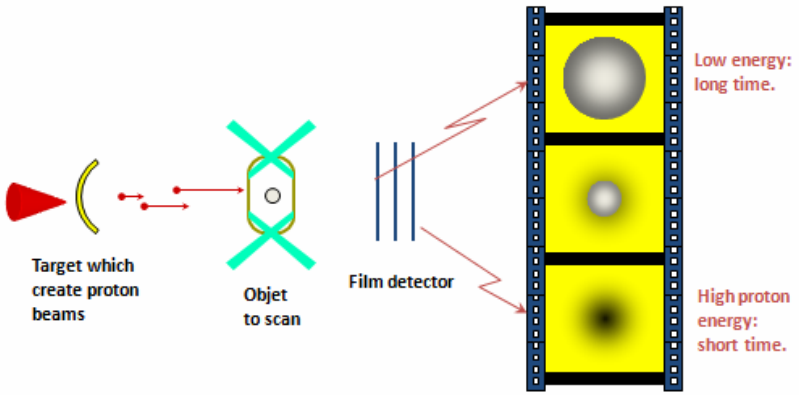
- Low emittance beam: 0.015 mm.mrad
- Laminarity: virtual source size of 4 µm
- Short bunch duration: few picoseconds



- High proton numbers: 10^{11}-10^{13} per bunch
- High energy:
  Up to 60 MeV

Applications

- Warm dense matter generation: high current and large spectra
- Plasma field radiography: large spectra

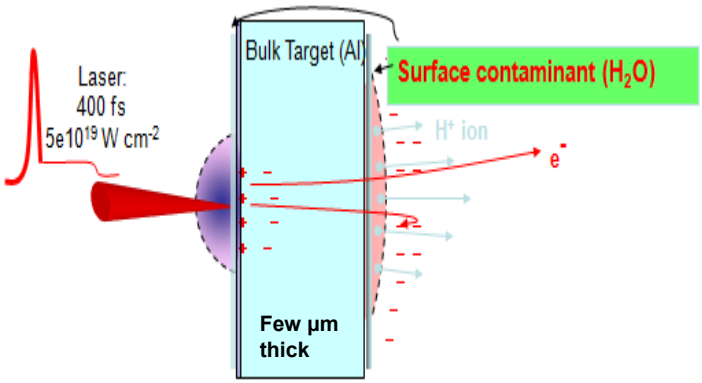


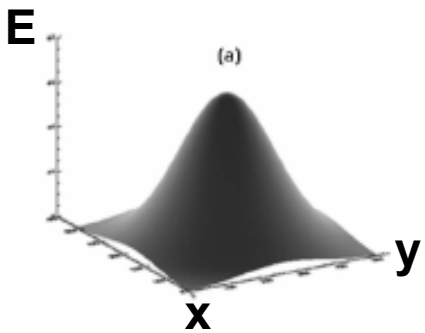
- Compact accelerator system: laminarity, emittance, cost and facility size.

mechanism

Predominant mechanism:

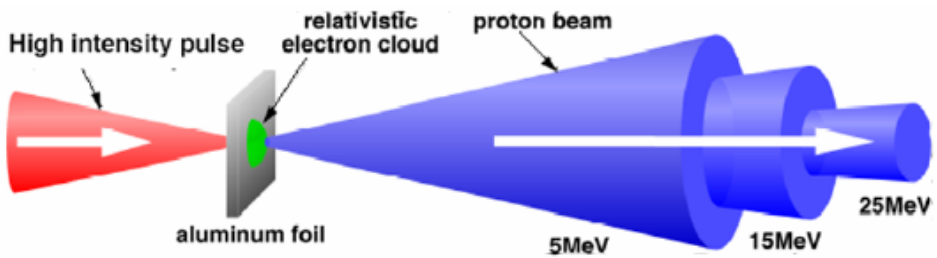
Target Normal Sheath Acceleration





Electron sheath

Electrons crossing target



Beam divergence depends on proton energy

Paths toward beam optimisation

- Increased laser intensity:
  - ⇨ Improved laser parameters **limited by laser development**
  - ⇨ Reduced focal spot **limited by diffraction and experiment geometry**
- Reduced electrons dilution:
  - ⇨ Limited lateral size target
  - ⇨ Reduced target thickness

  } **Need for high contrast laser**
- Increased laser absorption:
  - ⇨ New interaction regimes
  - ⇨ New kind of target

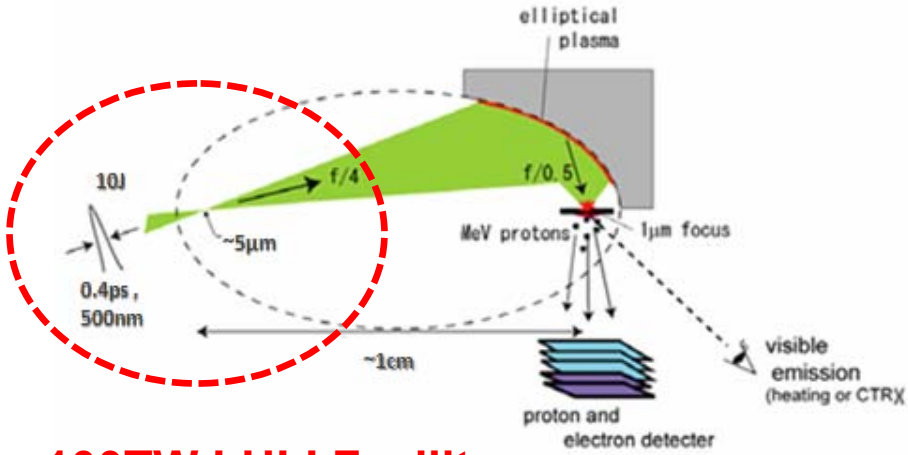
Laser intensity increase using Elliptical plasma mirror (using a 400fs laser pulse)

Reduced spot size:

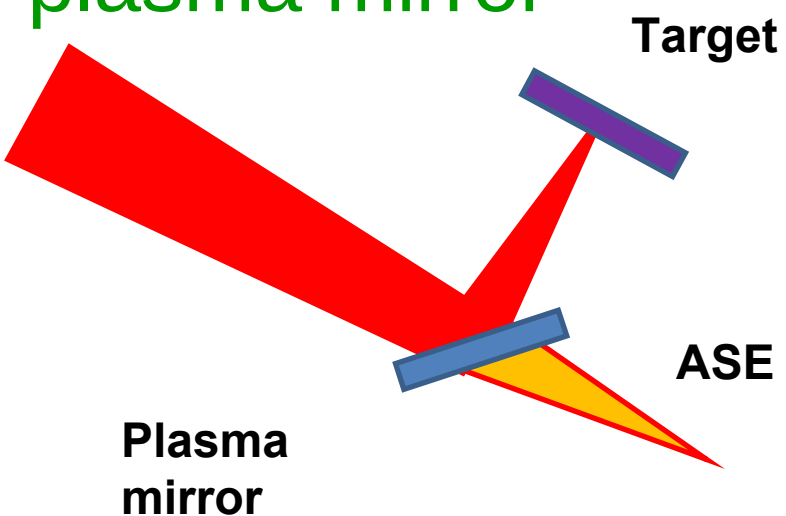
very short focal length

Increased contrast ratio:

plasma mirror

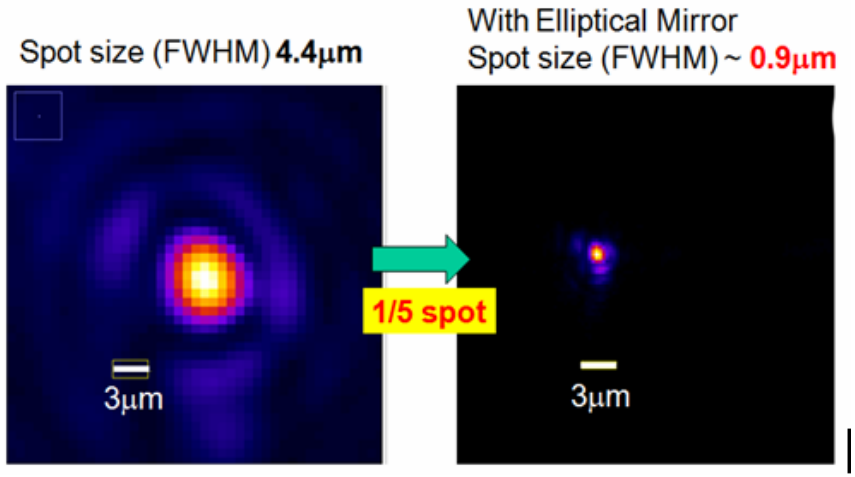


100TW LULI Facility



Reflectivity increases abruptly when Intensity is high enough :

Amplified Spontaneous Emission is reduced



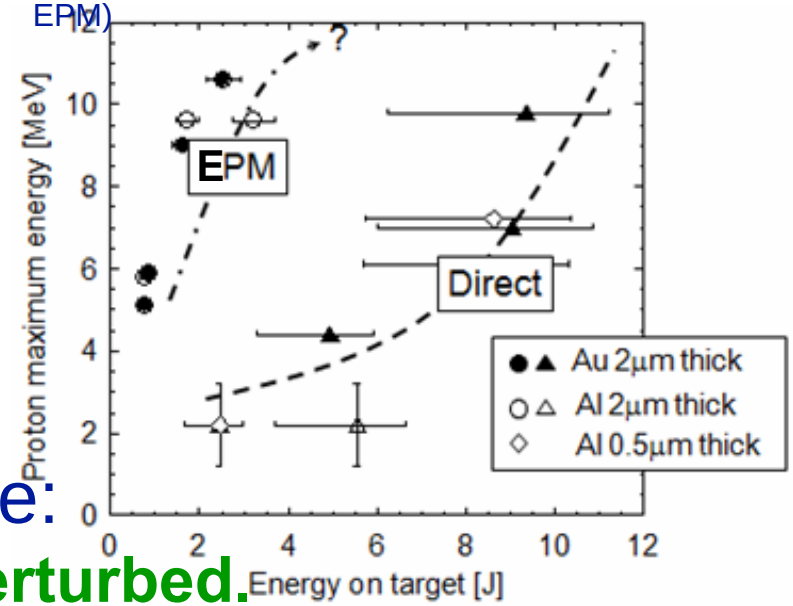
Laser focal spot is reduced

Laser intensity is increased (~70% energy is losed on EPM)

I_{laser}=1.10^{19} W.cm^2

I_{laser}=8.10^{19} W.cm^2

Protons beam energy is increased



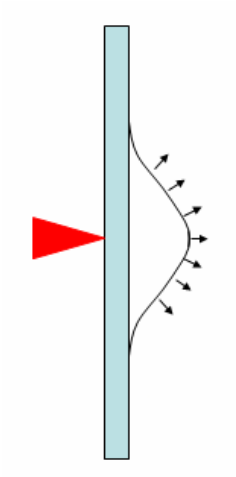
- Acceleration seems to saturate:

  Plasma mirror surface gets perturbed.

- At the same intensity, small focal spot is less efficient:

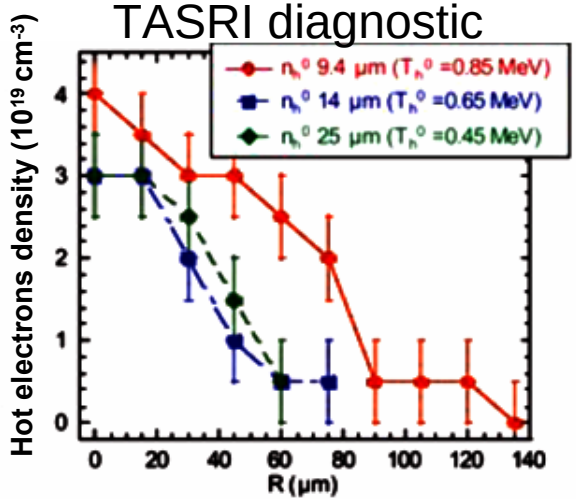
  Lateral spreading likely to increase.

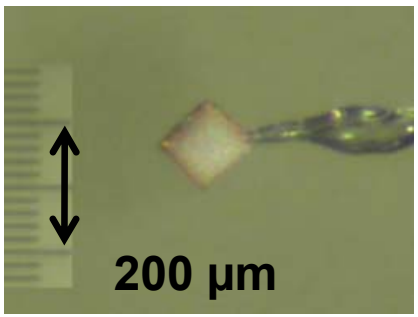
Electron confinement using reduced lateral size target (using a 400fs laser pulse)



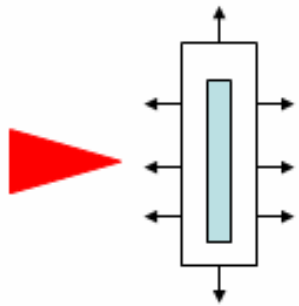
Lateral expansion sheath is about 100 µm

TASRI diagnostic





Lateral expansion is blocked

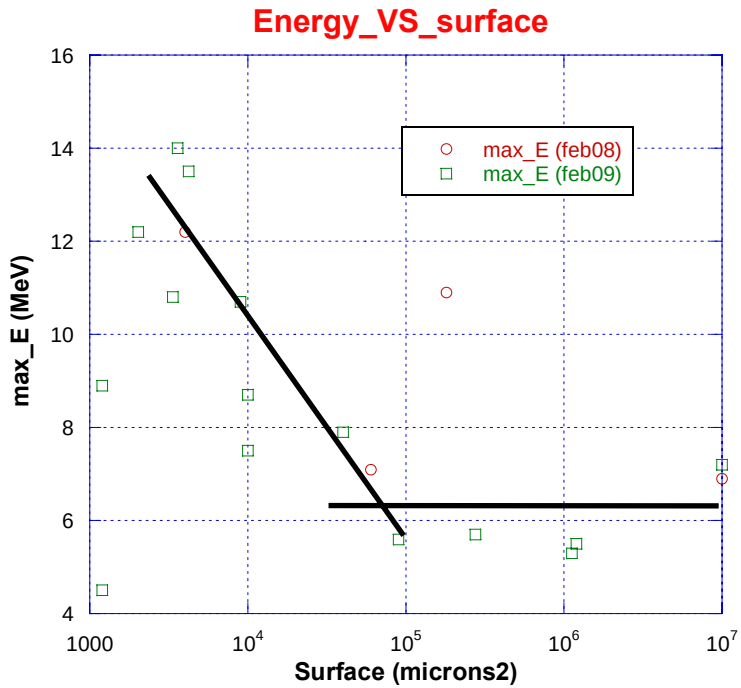


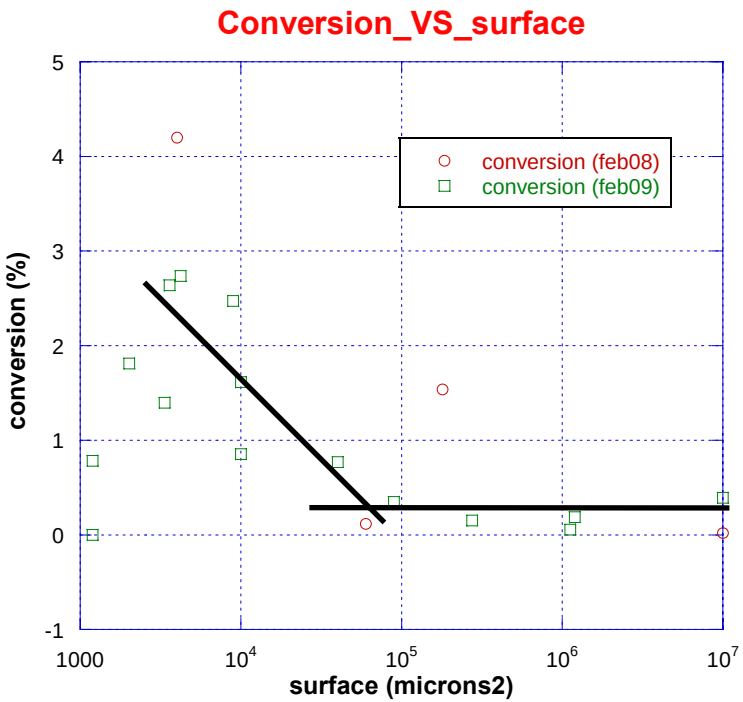
Electron sheath is confined if target size < “natural” sheath size

When target surface is less than 0,1 mm^2 we increase ...

2µm thick target

... Proton energy





... Conversion rate

S. Buffechoux, submitted (2009)

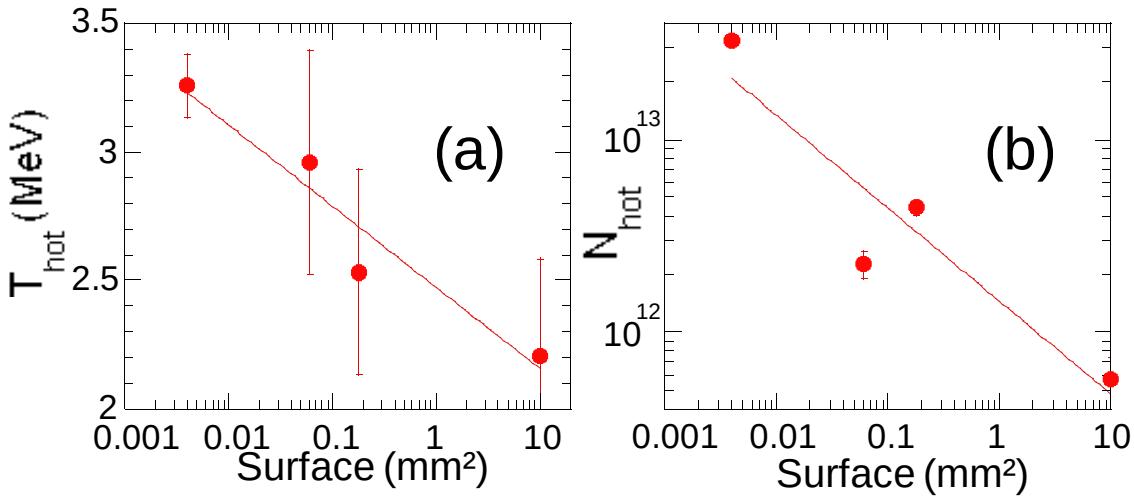
Electron sheath parameters are improved

Fluid model:

J. Fuchs et al., Nature Physics **2**, 48 (2006).

$$dN/dE = 1.3 N_{hot} c_s / [c(2Ek_B T_{hot})^{1/2}] \exp(-[2E/(k_B T_{hot})]^{1/2})$$

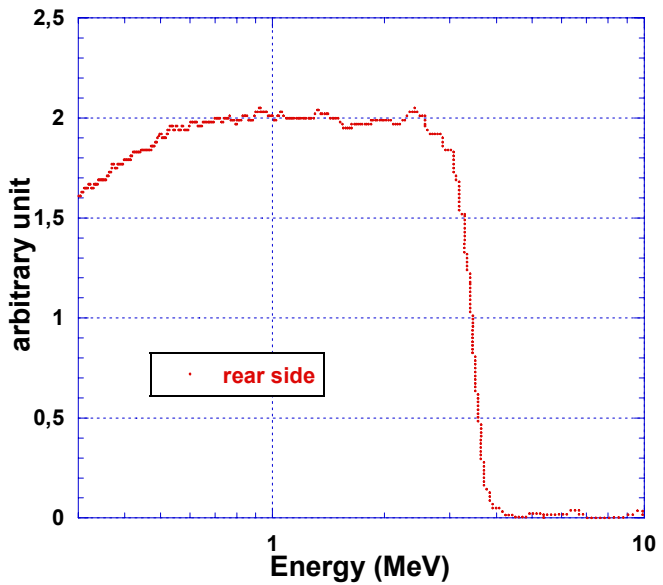
N_{hot}: height; T_{hot}: slope



Coupling between laser and plasma is increased

Using 25fs laser pulse duration

- High laser intensity with only few Joules
- 10 Hz repetition rate
- High contrast ratio



Time Of Flight diagnostic

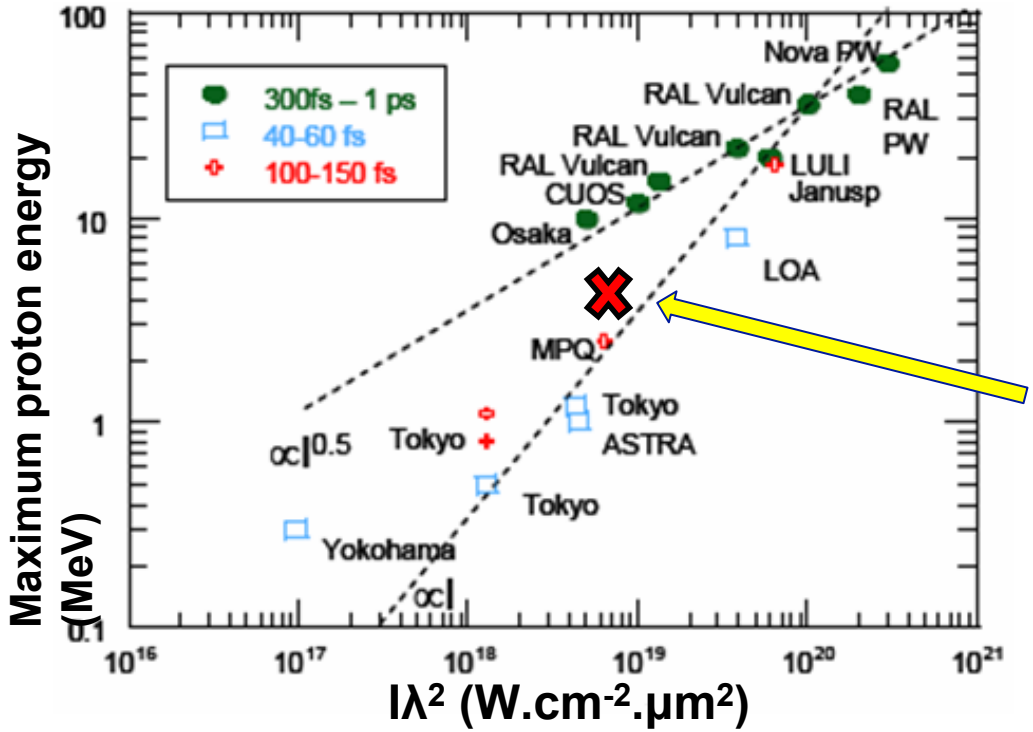
With plasma mirrors:

- 220 mJ on target
- 6,5µm target thickness

4 MeV

(ALLS- INRS facility)

Comparing with others laser facilities around the world



ALLS-INRS Facility (25fs)

Using very thin target (less than 1μm), with high laser contrast:

expect to increase significantly proton

Conclusion

All the above-shown different approaches demonstrate feasible optimization paths for proton beams acceleration.

Other paths toward energy increase:

- **Using coating or foam target: increase absorption.**
- **Using several beams: modify electrons acceleration.**
- **Using circular polarisation: RPA regime.**

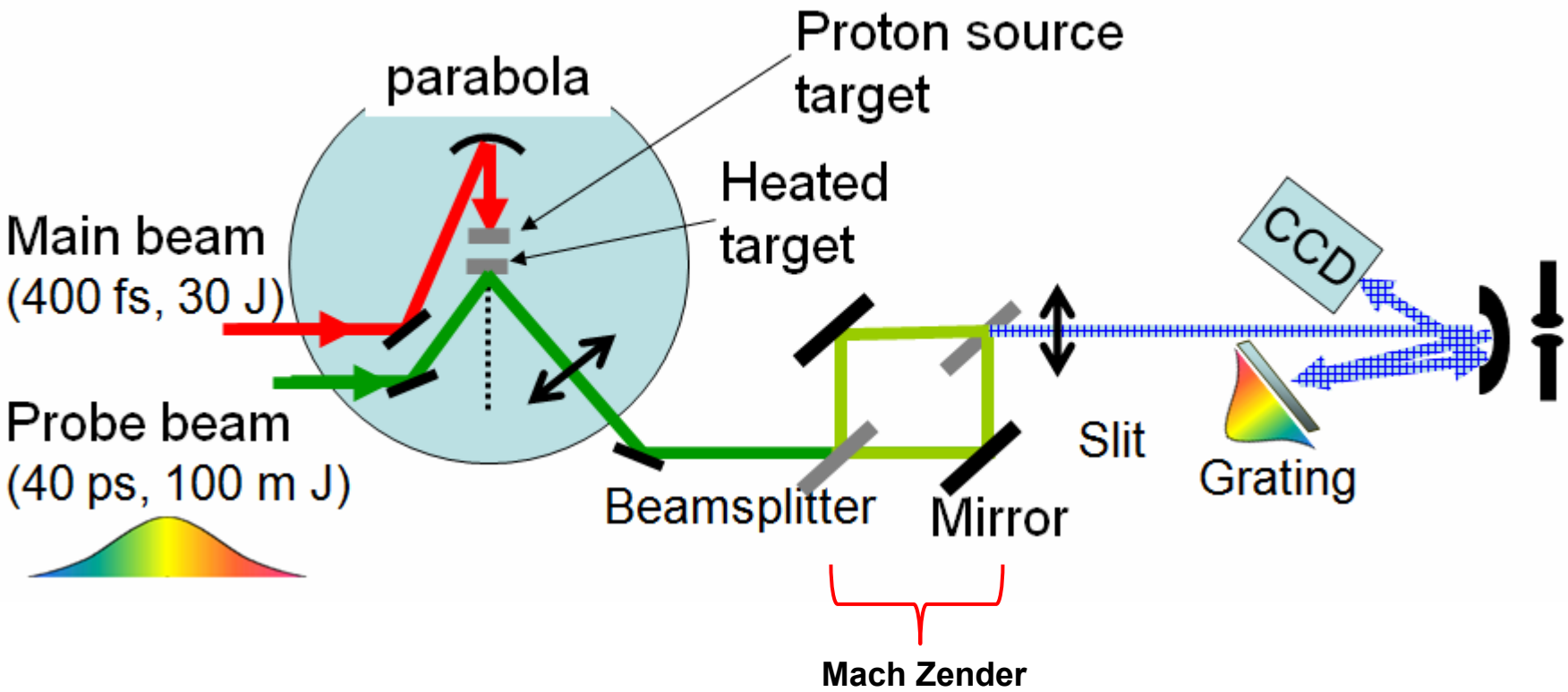
Laser driven protons acceleration becomes more and more interesting :

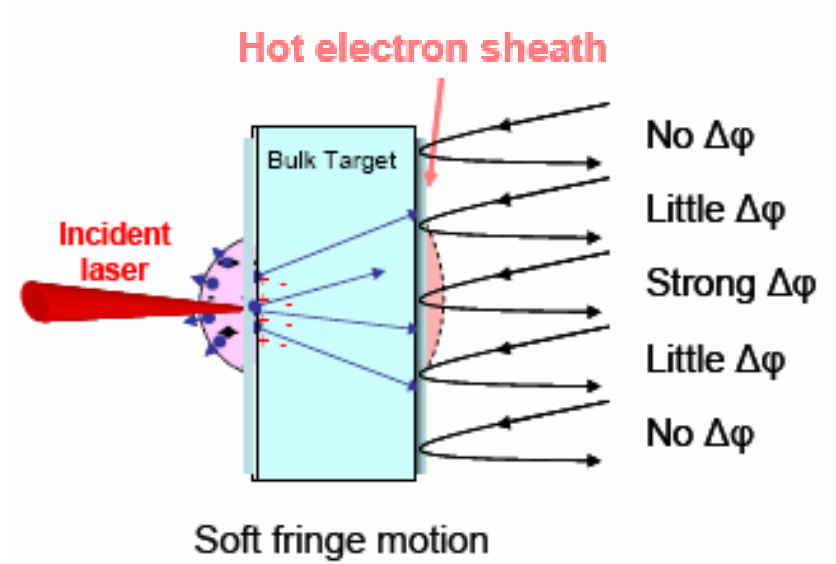
- **laser development.**
- **Better understanding in proton acceleration mechanism.**

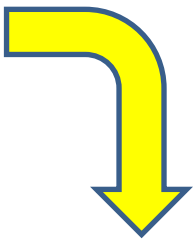
Thank you for your attention

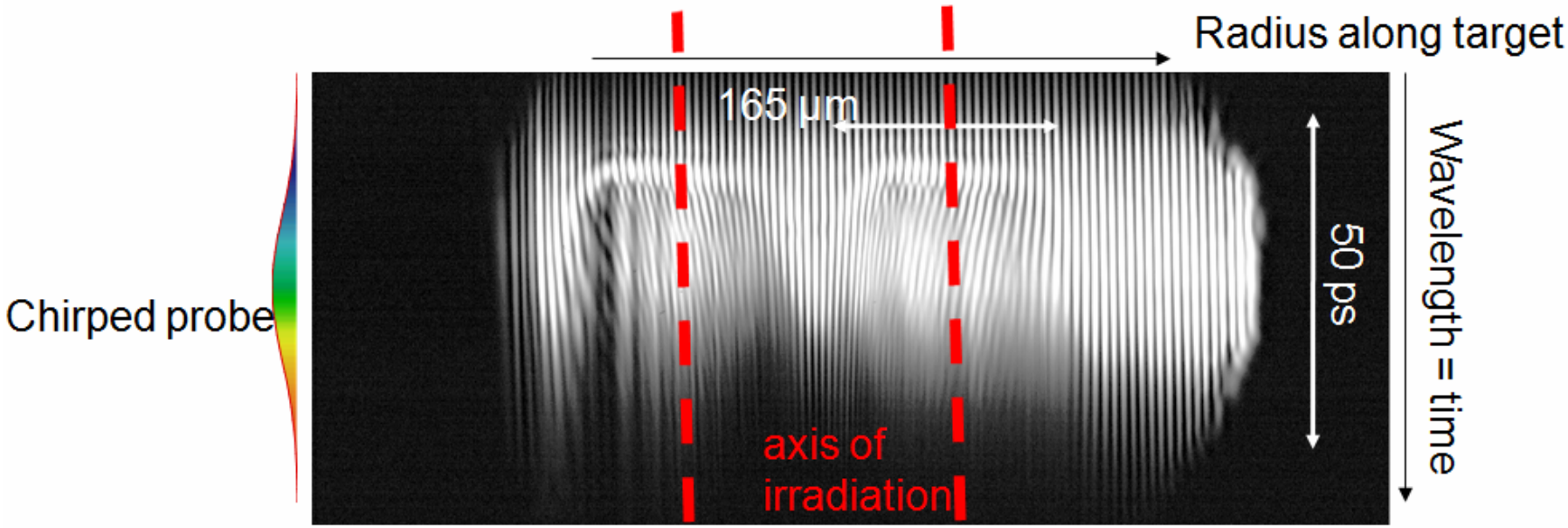
Any questions?

Time And Space Resolved Interferometry




Hot electron sheath
Bulk Target
Incident laser
No Δφ
Little Δφ
Strong Δφ
Little Δφ
No Δφ
Soft fringe motion




Radius along target
165 μm
50 ps
Wavelength = time
Chirped probe
axis of irradiation