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Development of the I-BEAT: Ionoacoustic Diagnostic for Laser-Driven Ion Sources

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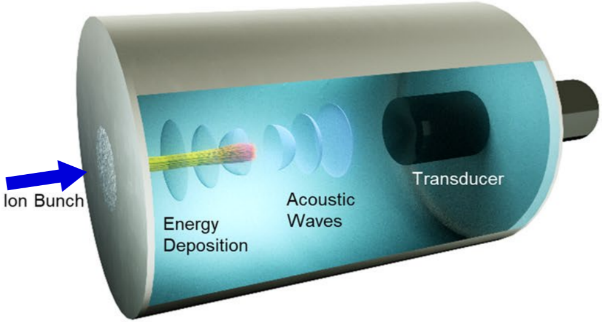
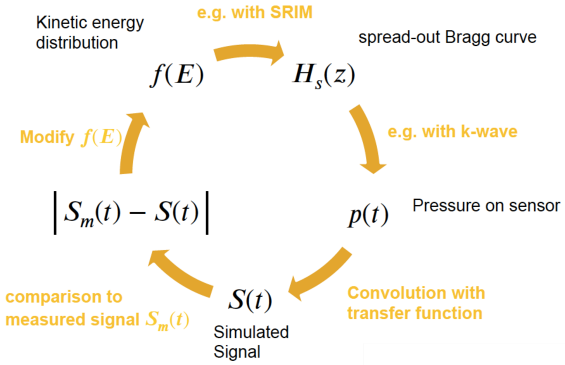
Concept

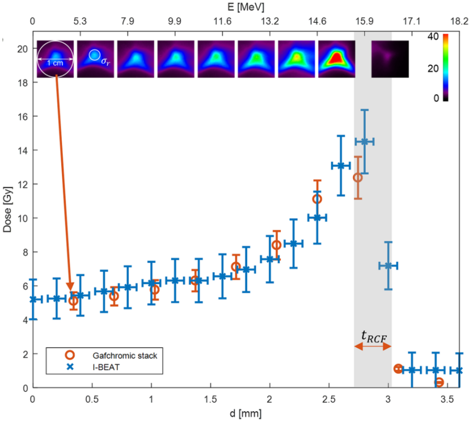


- Ions deposit their energy in a water reservoir
- Energy deposition leads to localized heating
- A pressure wave originates from gradients in thermal expansion
- Ultrasonic signal is recorded by a transducer

Fig: Haffa et al., 2019

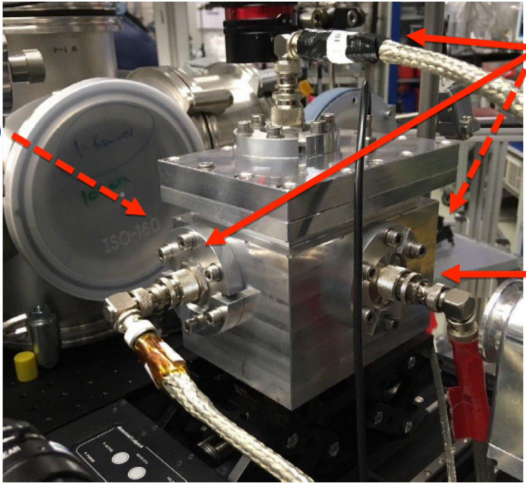
Spectral (1D) Reconstruction



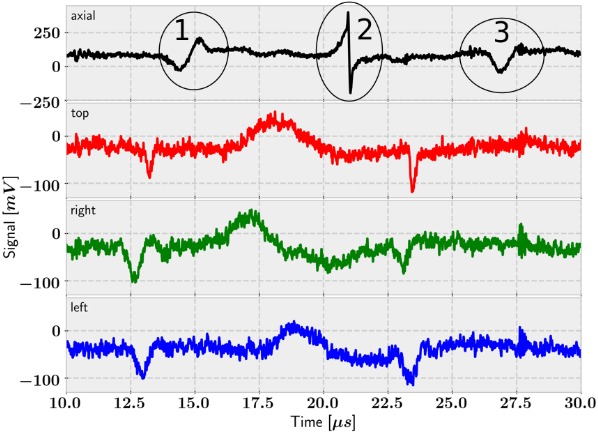


Left: Jörg Schreiber; Right: Haffa et al, 2019

Steps to 3D Reconstruction



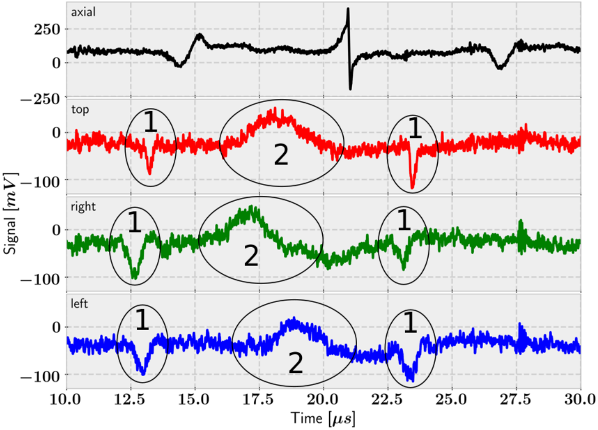
Steps to 3D Reconstruction



Axial Information

- Three distinct features:
  1. Signal of the Bragg peak
  2. Signal of the ions passing the entry window
  3. Reflection of the Bragg peak signal at the entry window
- Mean energy estimation by signal runtime: 29 MeV
- Comparison with ToF: 30 MeV

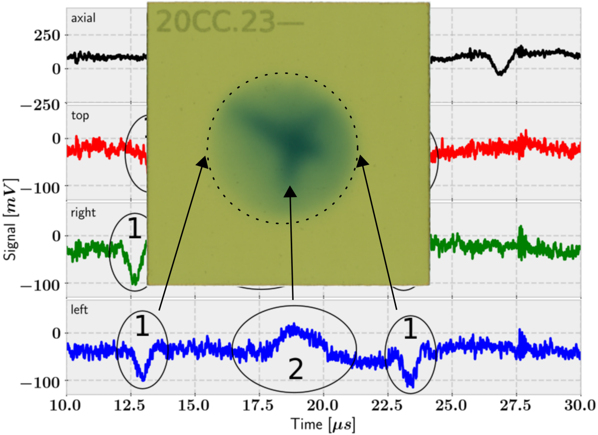
Steps to 3D Reconstruction



Lateral Information

- Two distinct features:
  1. Sharp dip corresponding to the entry aperture
  2. Wide peak corresponding to internal beam structure
- Beam aperture estimation by signal runtime: 15 mm (Aperture of ToF entry: 14 mm)
- Lateral positioning better than 500 μm

Steps to 3D Reconstruction



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Conclusion

- Good energy resolution
- Measurement of lateral beam profile
- Good lateral beam position resolution
- High repetition rate
- Online data acquisition and parameter estimation
- EMP resistant
- Radiation hard
- Cheap and compact

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HZDR: F. Kroll, F.-E. Brack, J. Metzkes-Ng, A. Nossula, M. Reimold, M. Umland, K. Zeil, S. Bock, R. Gebhardt, T. Püschel, U. Schramm

References

- Haffa et al: I-BEAT: Ultrasonic method for online measurement of the energy distribution of a single ion bunch (2019), Sci. Rep. 9, 6714
- Assmann et al: Ionoacoustic characterization of the proton Bragg peak with sub millimeter accuracy (2015), Med. Phys. 42, 567-574

Energy deposition (heating function H) as source term for wave equation:

$$\left(\nabla^2 - \frac{1}{c_s^2}\frac{\partial^2}{\partial t^2}\right) p(\vec{r}, t) = -\frac{\Gamma}{c_s^2}\frac{\partial}{\partial t} H(\vec{r}, t)$$

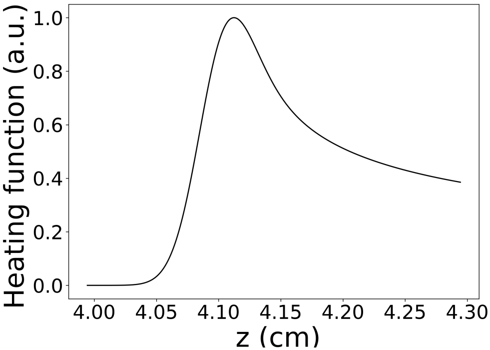
with Grüneisen parameter Γ and sound (phase) velocity c_s.
General solution:

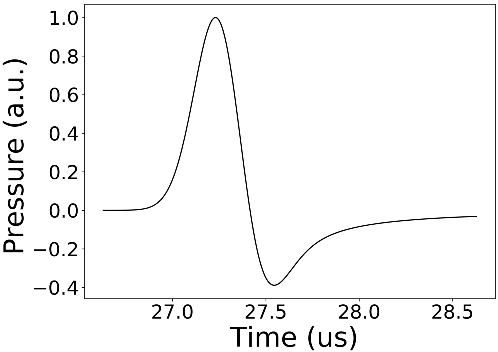
$$p(\vec{r}, t) = \frac{\Gamma}{c_s^2}\frac{\partial}{\partial t}\int d^3\vec{r}\,'\frac{1}{|\vec{r} - \vec{r}\,'|} H\left(\vec{r}\,', t - \frac{|\vec{r} - \vec{r}\,'|}{c_s}\right)$$

Assuming instantaneous dose deposition and detector in far field:

$$p(t) \propto \frac{\partial H(z)}{\partial z}\Big|_{z=-ct}$$

Example (30 MeV, Transducer at z = 0, entry window at z = 5 cm):



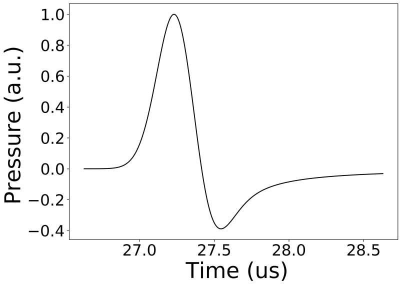


Detector Response

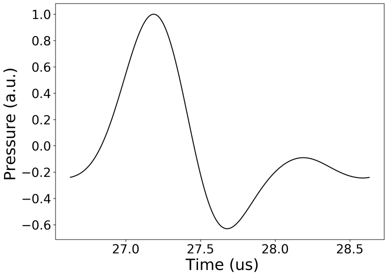
The measured signal S is the real pressure p convoluted with the transfer function T:

$$S(t) = p(t) * T(t)$$

Initial signal:

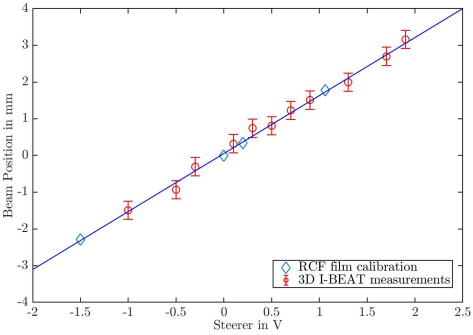


After convolution with transfer function:



Lateral Measurements at MLL Tandem (Garching)

Lateral Position



Lateral Beamprofile