# Progress on proton acceleration from a hydrogen gas jet

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# Benefits of a gas jet as an ion beam source

- Pure (compared to solid targets which become quickly covered in impurities)
- Can employ H, He and other species difficult to make in other targets
- Allows changing target material quickly
- Can run at high repetition rate

# Benefits from combining gas jet with a $CO_2$ laser

- Due to $\lambda$ =10 $\mu$m, $n_{cr} = \varepsilon_0 m\omega_0^2/e^2 = 10^{19}$ cm$^{-3}$ is 100 times lower than  for a solid sate laser.
Gas-jets easier to make at this density allowing to operate hydrogen jet (proton source) in the most efficient, near-critical regime where maximum ion acceleration has been observed (foam targets) and RPA has been predicted.

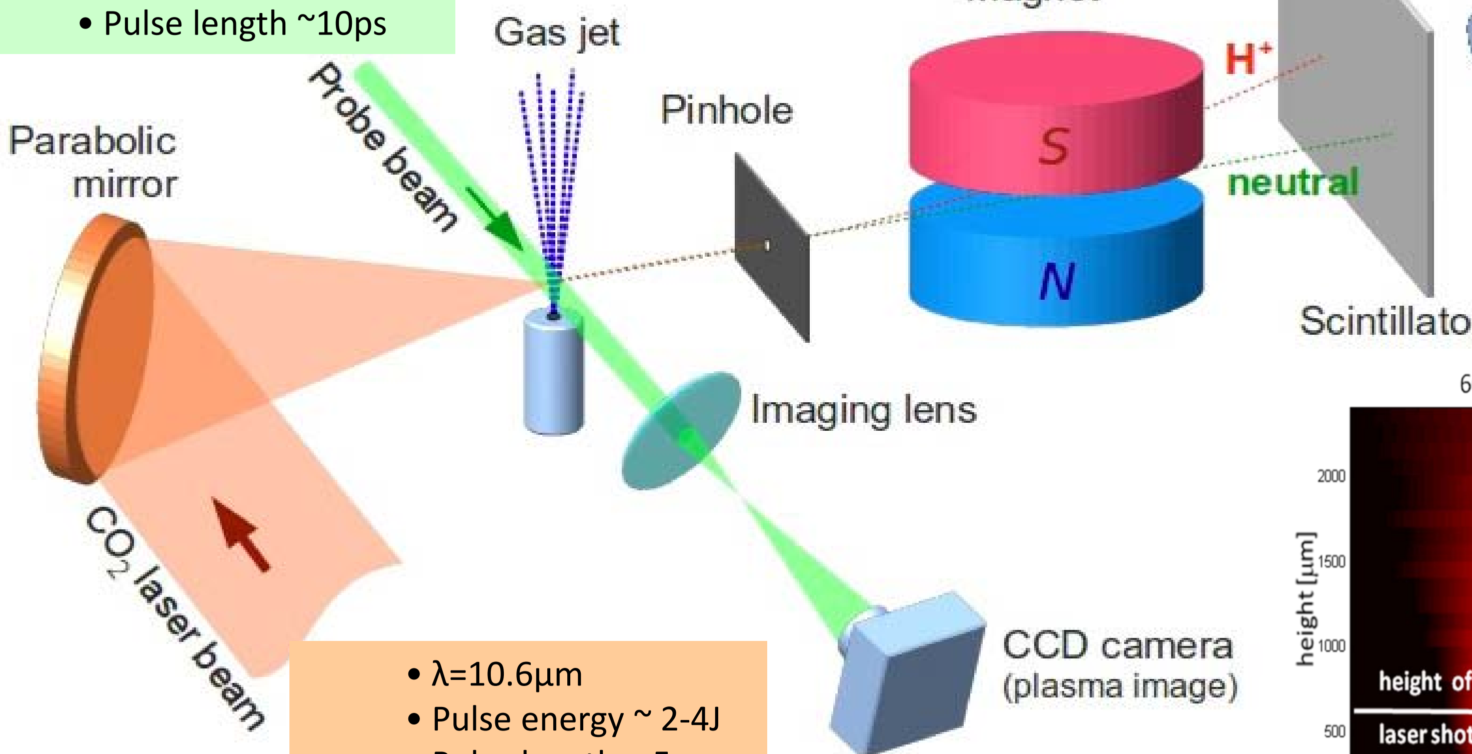
- Possibility for optical probing of overdense interactions.

For 532nm, $n_{cr}$ ~ 4x10$^{21}$ cm$^{-3}$ (easy transmitted through the gas jet)

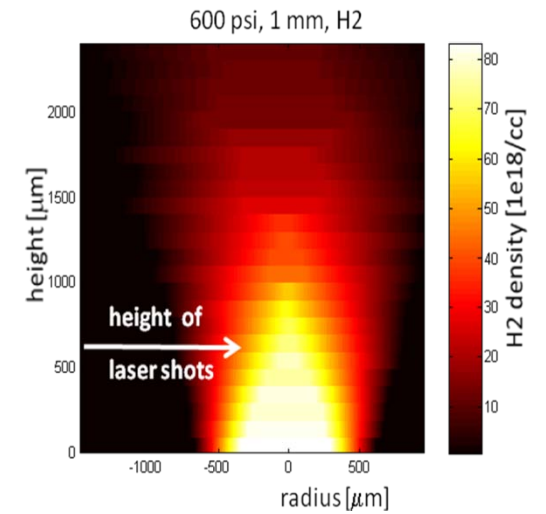
# BNL experiment with gas jet

- Nozzle 0.5-1mm
- Backing press.: 115 - 1100psig
- $1.3n_{cr} - 12.3n_{cr}$

- 2ω Nd:YAG, λ=532nm
- Pulse energy ~ 200μJ
- Pulse length ~10ps




- λ=10.6μm
- Pulse energy ~ 2-4J
- Pulse length ~ 5ps
- Focal spot $w_0$= 60μm
- I ~ $5x10^{15}W/cm^2$



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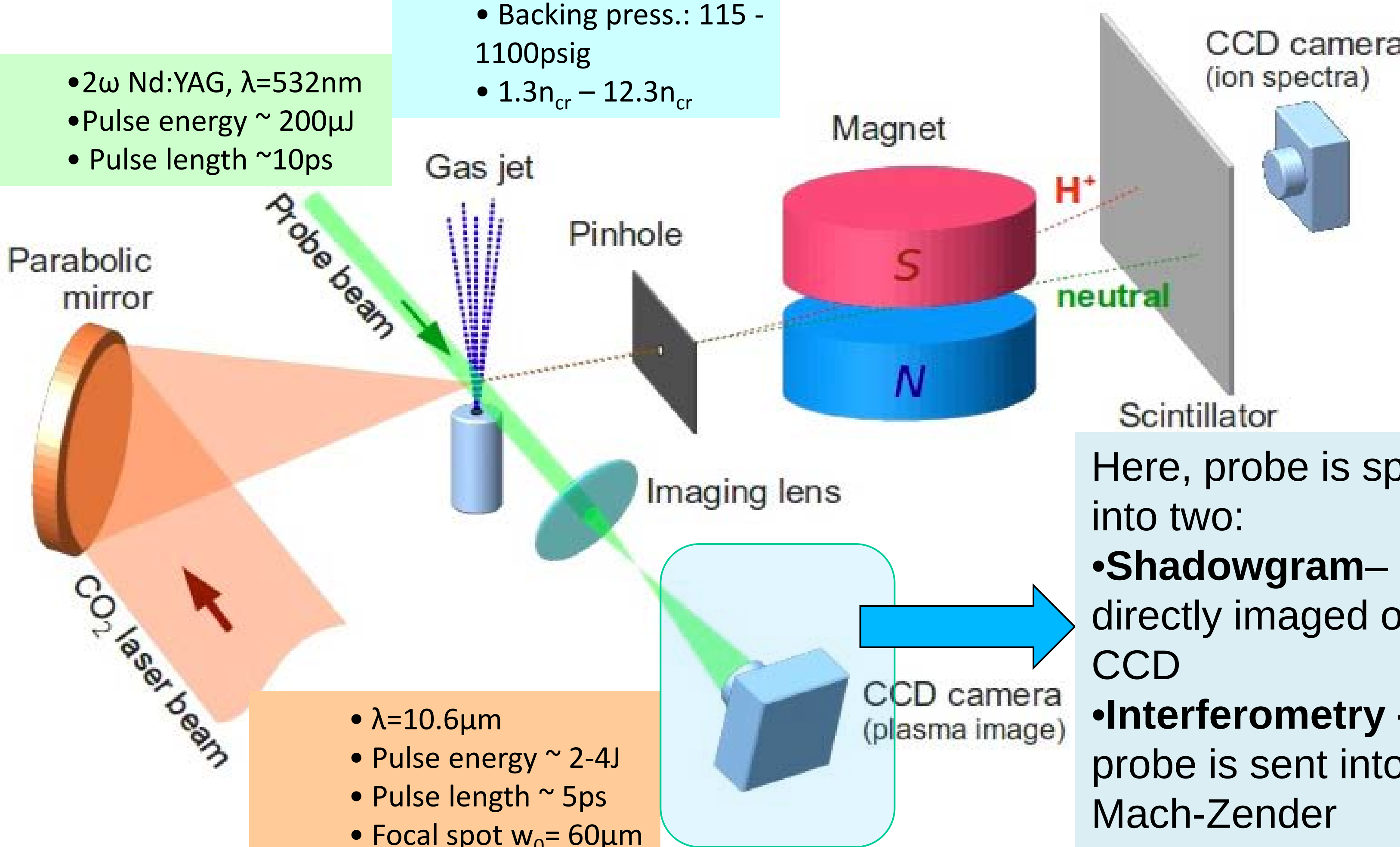


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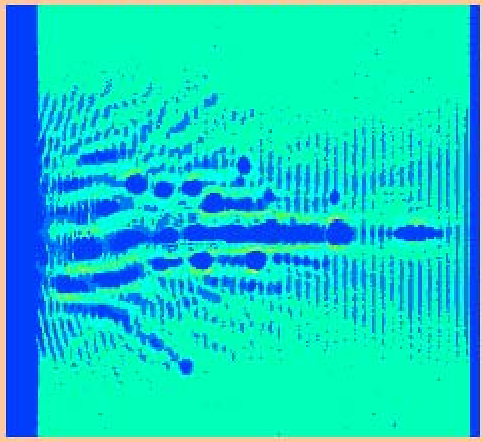
Here, probe is split into two:
- **Shadowgram**– directly imaged onto CCD
- **Interferometry –** probe is sent into a Mach-Zender interferometer and overlapped with itself

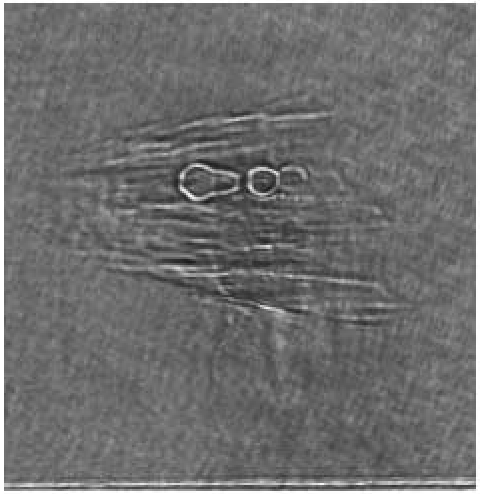
# Wealth of non-linear phenomena observed

simulation

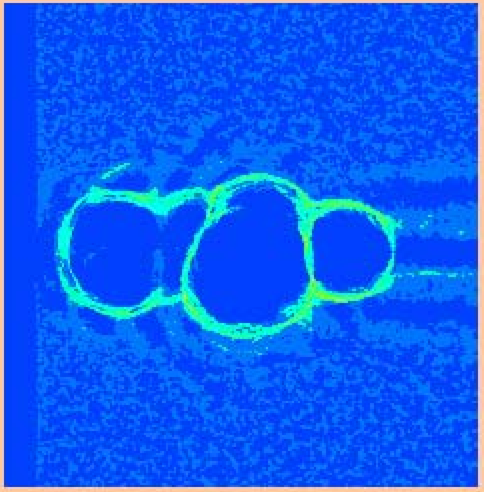
experiment

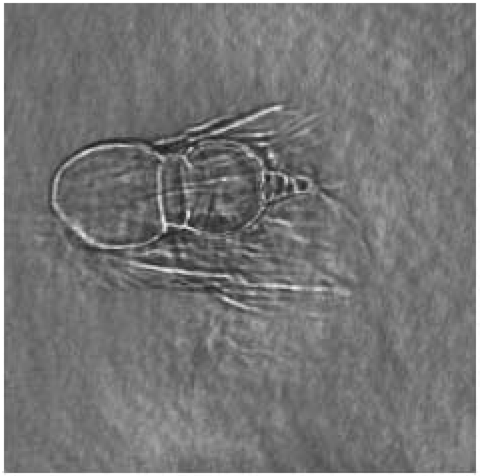
Plasma filaments and solitons



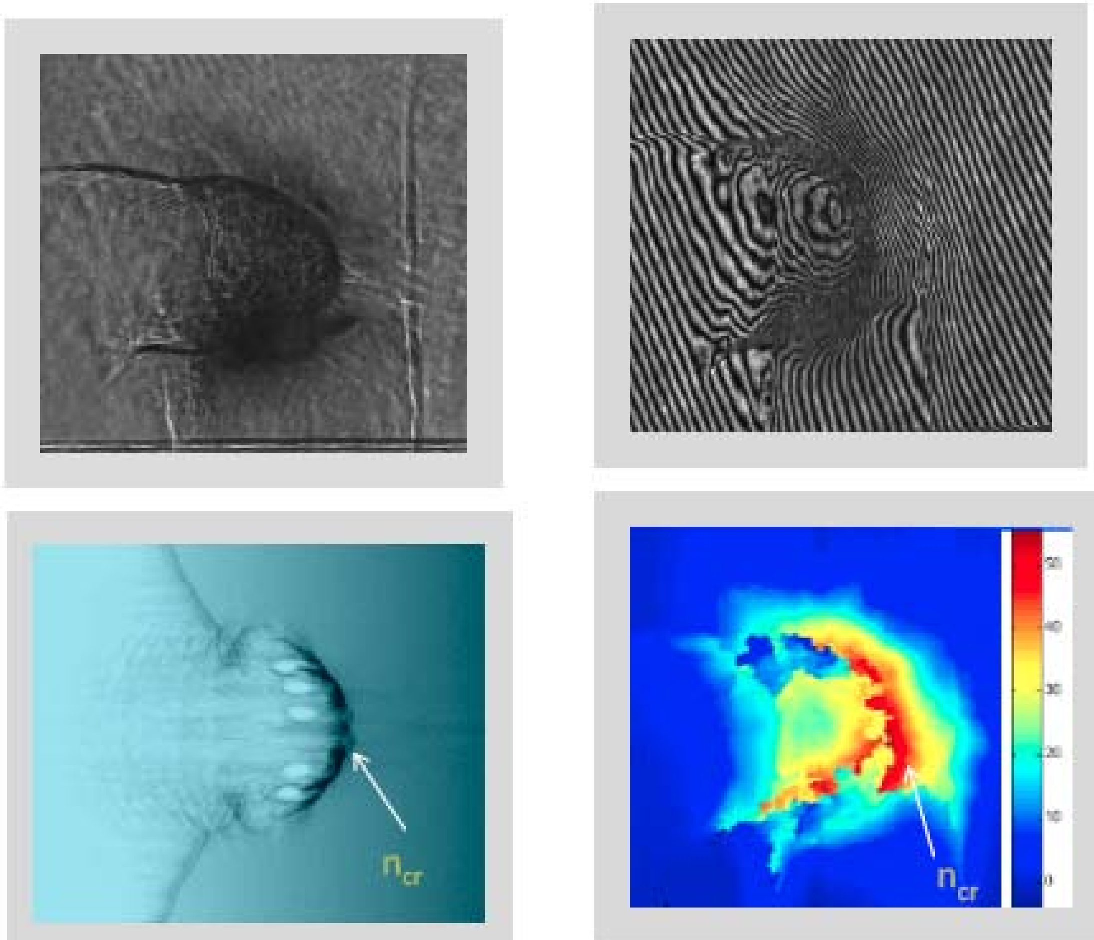


Solitons expand and combine into post-solitons at the ion time scale



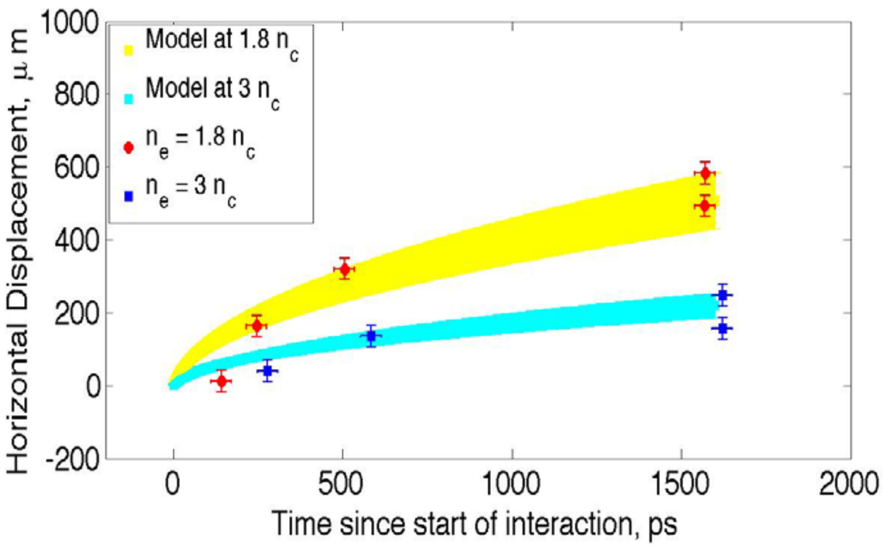


# Hole boring by radiation pressure

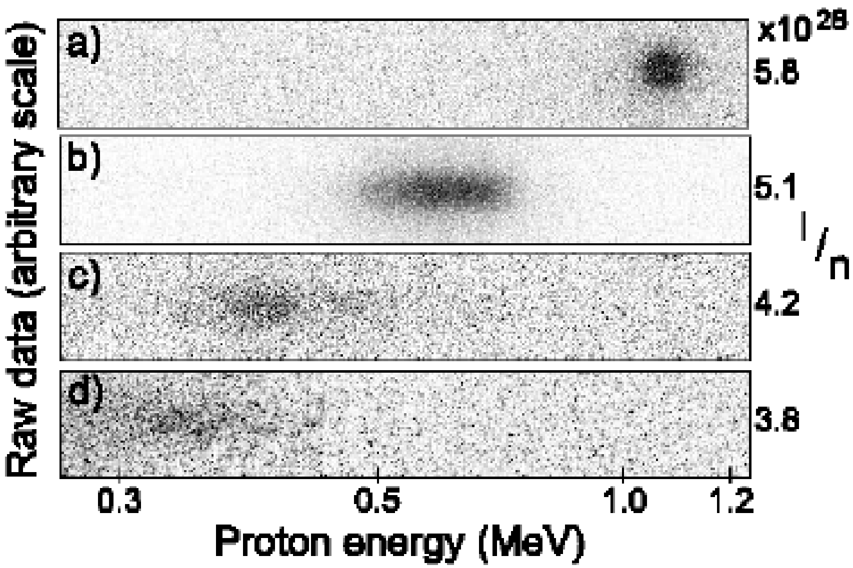



• Plasma discontinuity represents a shock with the critical surface moving at $\sim I/n$.

# Trend of increasing proton energy with $I/n$



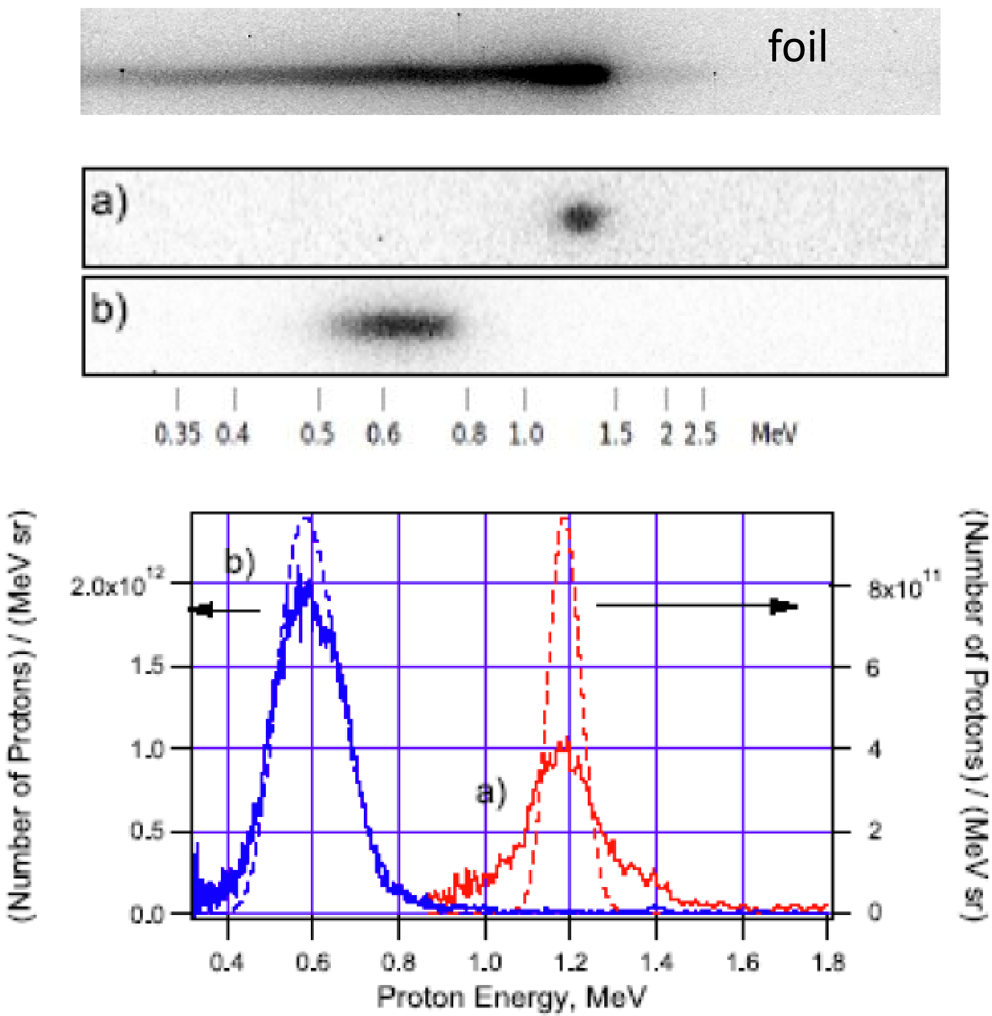

- For opaque plasma ($n>n_{cr}$), the radiation pressure, $P=2I/c$, initially pushes plasma electrons into the target.
- Space charge field pulls along ions setting up an electrostatic shock moving at hole boring velocity $v=(2I/\rho c)^{1/2}$




- Stationary ions in advance of the shock get accelerated by the same space charge field effectively bouncing off the shock front.*
- Associated with it proton energy $E=½m(2v)^2=4I/nc$

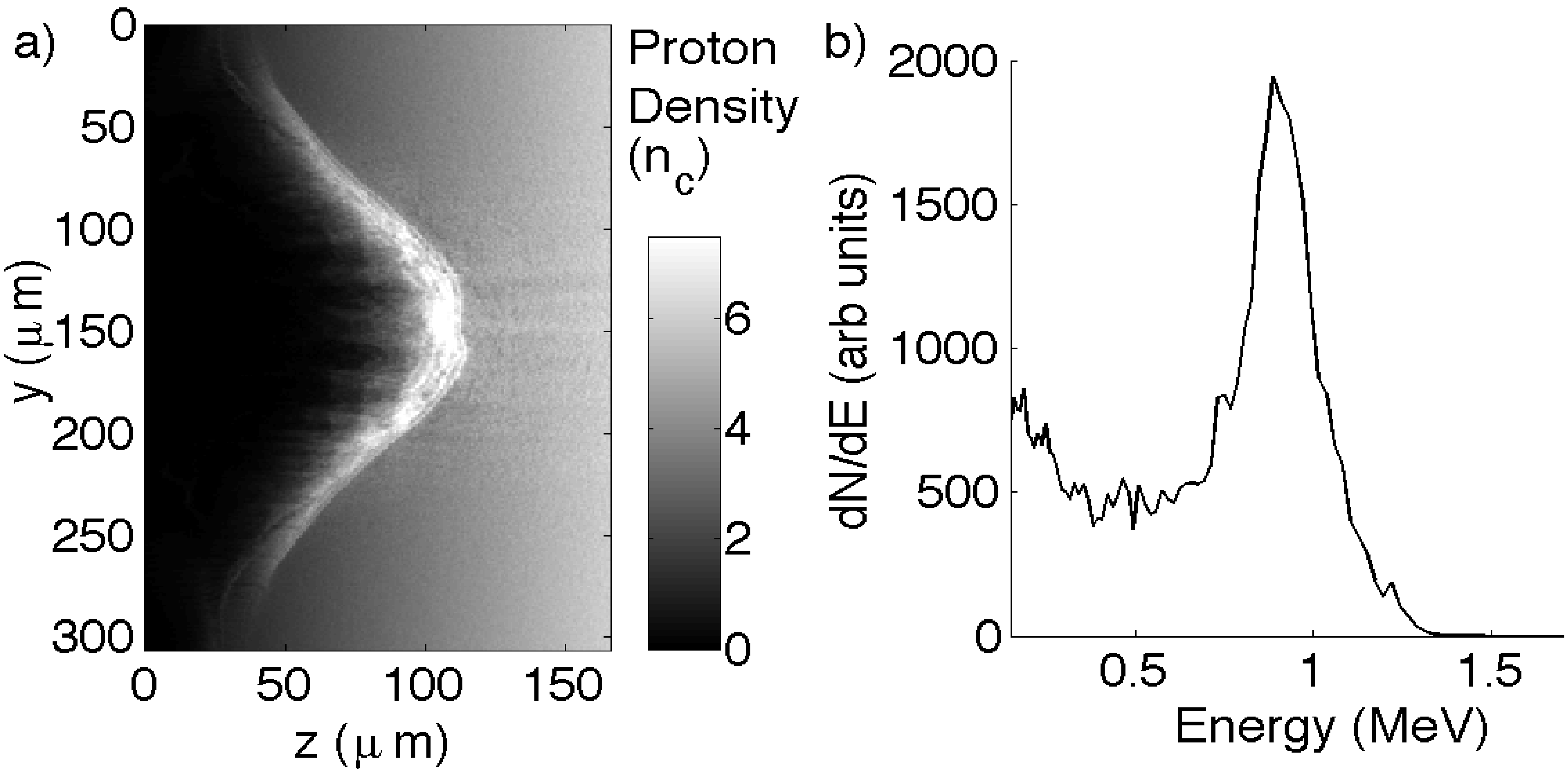
* PRL 92, 015002 (2004)
PRL 93, 155003 (2004)

# Narrow energy spread




- Proton beams observed with consistently narrow energy spread.
- Deconvolution with spectrometer instrument function to determine energy spread of beams.
- Energy spread down to ~ 4% → significantly narrower than previously observed.
- ~ $2x10^{12}$protons/MeV/sr → 1000 brighter than previous modulated spectra.
- Geometrical emittance
  $\varepsilon$=0.16 $\mu$m-rad
- Normalized emittance
  $\varepsilon_n=\beta\gamma\varepsilon$ =8 nm-rad

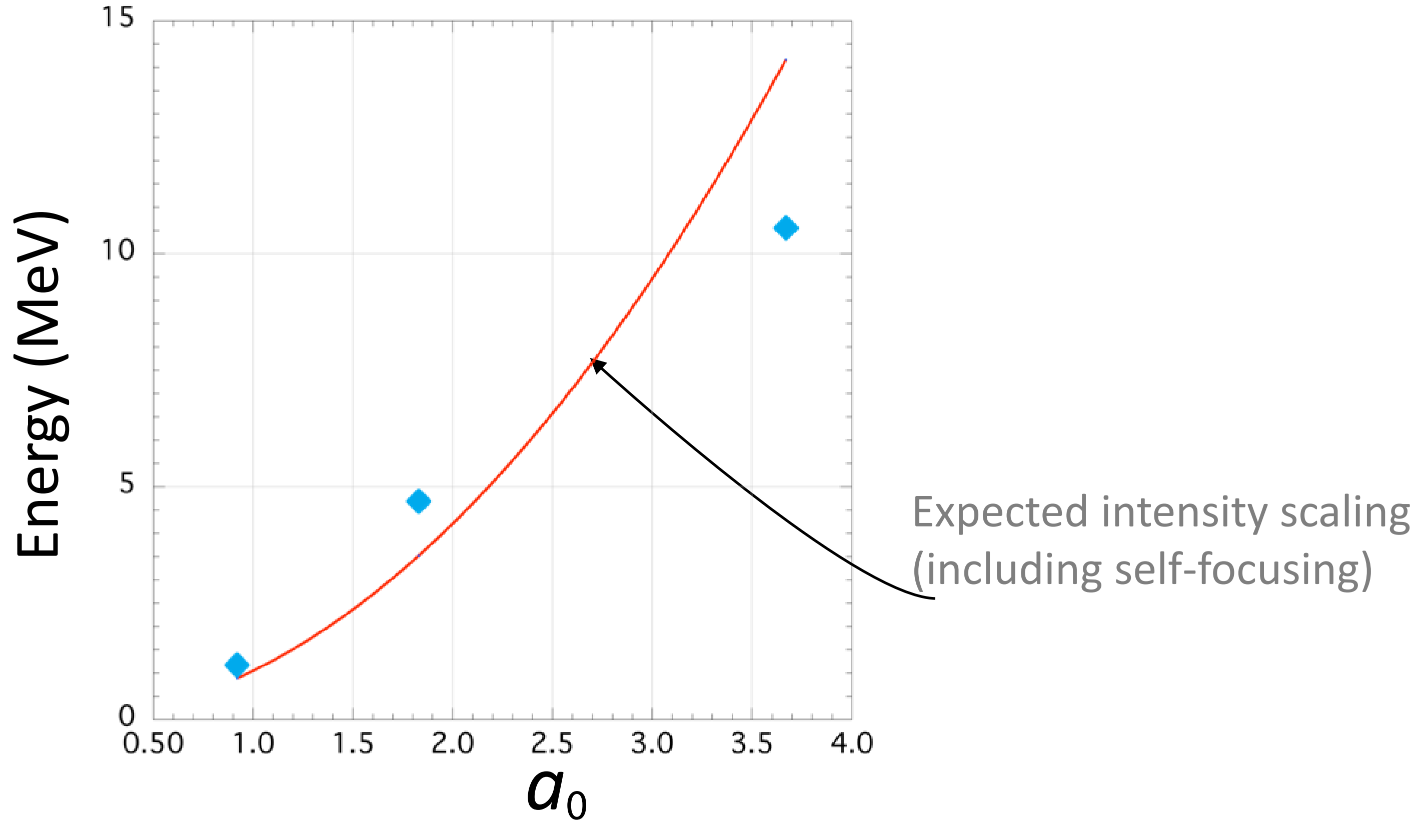
# Simulation




Simulation Conditions:

| | |
|---|---|
| Laser: | Target: |
| $a_0$= 0.6 | Ionised $H_2$ |
| $\tau_L$= 6ps | Triangular density profile |

# Future prospects




- Peak energies expected to increase with increasing $a_0$
- $a_0$ = 1.5 easily achievable by changing to faster focusing
- higher $a_0$ conceivable with planned laser upgrades

# Additional investigations

- As well as intensity scaling, we plan to measure:
- Angular distribution of ion beam
- Acceleration of different ion species
- Investigation of influence of double pulses
- Investigation of influence of polarization
- Investigation of micro-gas targets