Bulk Deuterium Acceleration in the Light Sail Regime

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Outline

- Radiation Pressure Acceleration. Theory
- Experimental Setup
- Ion vs Neutron Spectroscopy
- Parameter Scaling
- The problem with transparency
- Simulations
Motivation

- A fast-neutron source has a wide range of applications, but limited access to facilities

- Laser-driven sources appear as a possible solution
  - Neutron sources based on TNSA have been the most studied, but suffer its limitations
  - Slow ion energy scaling and lack of bulk species

- Radiation Pressure Acceleration appears as an alternative given its advantages
  - Acceleration of bulk ions, fast scaling, more directional
RPA. Theory

Radiation Pressure
\[ P = (2R + A) \cdot I / c \]

Hole-Boring Ion acceleration

laser

Target

Pushed-electrons sheath + ions
Characteristics of the source

- Quasi-monoenergetic spectrum
- Ion energy $E \propto \left( a_0^2 \tau_p / \chi \right)^\alpha \equiv \left( E_{\text{laser}} / \rho_{\text{target}} l_{\text{target}} \right)$
- Bulk ions accelerated
Experimental Setup

TPS Configuration

- Pinhole
- Dipole yoke
- Electrode
- Ion beam
- Differential Filter

TPS Configuration (A. Alejo et al., Rev. Sci. Instr. 85(9), 2014)

Vulcan PW (Nd:Glass) 200±50 J

Plasma Mirror

Target

TPS

Neutron collimators

Correlation of Spectra

ions

neutrons

Deuterons flux (D/(MeV/n)/sr)

Energy (MeV/n)

Neutron flux (n/(MeV/n)/sr)

Energy (MeV)

- 10 μm CD
- 400 nm CD
- 320 nm CD
- 195 nm CD
- 90 nm CD

- 10 μm, on axis
- 400 nm, on axis
- 320 nm, on axis
- 195 nm, on axis
- 90 nm, on axis
Highly-dense deuteron bunch travelling together long time

\[ Y_n \approx \frac{\tau_{\text{burn}}}{2} \int n_d^2 \cdot \langle \sigma v \rangle \, dV \]

Still doesn’t explain 90nm
Energy scaling

As reported by S. Kar et al (PRL 109, 2012)

Theoretical

Deuteron (SL)

Proton (SL)

90nm ~Flat spectrum

Self Induced Transparency
Transparency constraint

• Low-density targets are prone to early transparency
  • Deformation of the target
  • Relativistically induced transparency ($n_{c,\text{rel}} = \gamma n_{c,0}$)
  • Need of a sacrificial ion species

• Solution: New target to spot those problems
  • Compensate the relativistic correction increasing the number of electrons
  • Incorporate high-Z ions, which will sacrifice while the low-Z species stay bunched

→ Thin targets with gold layer deposited at the rear
Correlation of Spectra

ions

- 10 μm CD
- 400 nm CD
- 320 nm CD
- 195 nm CD
- 90 nm CD
- 90 nm CD + 5nm Au

neutrons

- 10 μm, on axis
- 400 nm, on axis
- 320 nm, on axis
- 195 nm, on axis
- 90 nm, on axis
- 90nm+5nm Au
Energy scaling

Theoretical
Deuteron (ML)
Proton (ML)
Deuteron (SL)
Proton (SL)
Energy scaling

Theoretical Deuteron (ML)
Proton (ML)

Theoretical*
Neutron (ML)

$E_{bunch}$ (MeV/n)

$E_{n,max}$ (MeV)

$a_0^2 \tau_p / \chi$

 ions

 neutrons
Flux scaling

On-axis Neutron Flux (n/sr)

Laser Intensity (W/cm²)

- P. Norreys PPCF 1998
- L. Williangle, POP, 18, 083106, 2011
- C. Zulick, APL, 102, 124101 (2013)
- F. Floux, PRA, 1, 821, 1970
- Kodama PPCF, 41, A419, 1999

See S. Kar et al., arXiv:1507.04511 for more scalings and references.
Simulation - 320nm

Electric Field

Density Profile

Opaque

TNSA+Bunch

Bunched
320nm. Ion spectra

Experimental

2D PIC Simulation

Energy of spectral bunch recovered

Important TNSA component
Simulation - 90nm

Electric Field

Density Profile

Early transparency

TNSA + Plateau
90nm. Ion spectra

Experimental

2D PIC Simulation

Spectral Plateau

Still bunched
Simulation - 90nm+Gold

**Electric Field**

**Density Profile**

*Recovered opacity*

*Reduced TNSA*
90nm+Au. Ion spectra

Experimental

2D PIC Simulation

Improved bunch shape + high energy
Conclusions

- RPA is an intrinsically good mechanism for neutron generation
  - Flux can be further increased including a catcher
- SIT limits the capabilities of RPA
  - Multi-layer targets can help extending LS range to low-density materials
- Neutron spectroscopy allows to retrieve hard-to-get information about interaction itself

Thank you for your attention