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Short Intense Ion Pulses for Radiation Effects Research Using NDCX-II and BELLA-i

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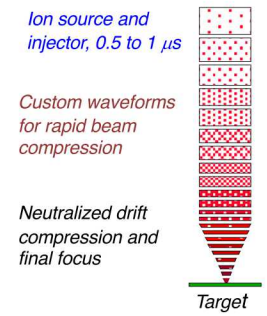
Abstract: *Intense, pulsed ion beams can deliver large neutron-equivalent doses in a few nanoseconds and enable tests of dose rate effects of ionizing radiation on materials and electronics. We give an updated description of two facilities at Lawrence Berkeley National Laboratory capable of delivering ion pulses for these applications. The NDCX-II induction linac provides pulses of 1 MeV protons and helium ions. Laser-plasma acceleration of ions with the BELLA petawatt laser provides protons and heavy ions up to 8 MeV to date.*

NDCX-II Accelerator Delivers Intense, ns Ion Pulses

- The induction linac delivers up to 1.2 MeV proton and He ions with peak currents of ~1 A/mm² in nanoseconds long pulses.
- Other species can also be accelerated.
- We have generated ~2 to 20 ns ion pulses with beam spots of ~3 mm² and up to 3x10¹² ions/pulse/cm² [1].
- NDCX-II's intense ion beam pulses enable new studies of high dose-rate effects. Controlled dose 100 – 10⁵ Gy.



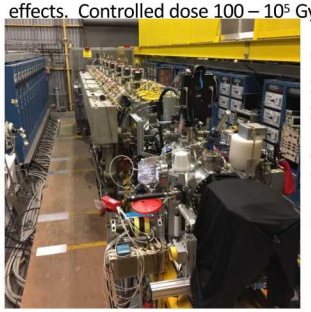
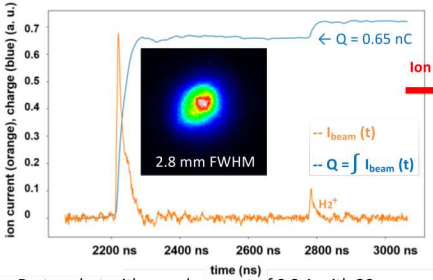


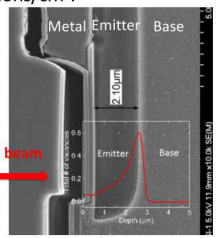
Photo of the NDCX-II induction linac at Berkeley Lab (ca. 12 m long)



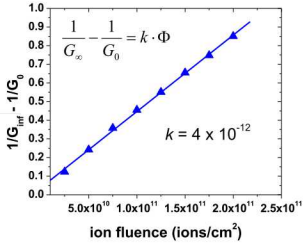
Proton shot with a peak current of 0.2 A with 20 ns FWHM. The proton energy is 1 MeV with a range in silicon of 16 um.

Radiation Effects Studies with Intense Pulses of 1 MeV Helium Ions at NDCX-II

- We have explored the effects of high ion flux, short pulse irradiation on the Messenger-Spratt damage factor using Microsemi 2N2907 pnp transistors.
- We have applied an ion flux of 10^{18} – 10^{19} ions/cm²/s per ~10 ns long helium ion pulse (1 MeV).
- We have measured late-time gain degradation as a function of ion fluence for a series of irradiations up to 2.5x10¹¹ ions/cm².



End-of-range ion irradiations target the base-emitter junction, where damage leads to gain degradation. Ion pulses simulate pulsed neutron irradiation [2].



Example of a measured Messenger-Spratt curve to determine the damage constant Microsemi2N2907 pnp transistors [3].

References:
[1] P. Seidl, et al., Nucl. Instr. Meth. A 800, 98 (2015) and Laser and Particle Beams 35, 373 (2017)
[2] B. A. Aguirre, et al., IEEE Trans. Nucl. Sci. 64, 190 (2017)
[3] B.A. Ludewigt et al., JRERE 36, 97 (2018)
[4] A. J. Gonsalves, et al. Phys. Rev. Lett. 122, 084801 (2019)
[5] S. Steinke, Q. Ji, S. Bulanov, et al., in preparation
[6] J. van Tilborg, et al., Phys. Rev. Lett. 115, 184802 (2015)

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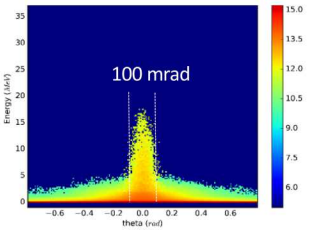
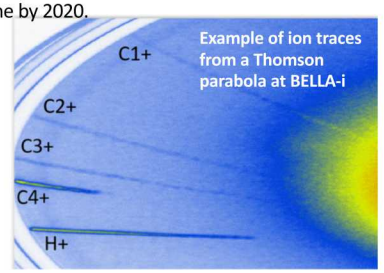
BELLA-i: Laser-driven Ion Acceleration

- BELLA-i is an initiative for High Energy Density Plasma Science with the BELLA peta watt laser at Berkeley Lab. It delivers, e.g., 1-10 J/cm² proton pulses (8 MeV)
- The BELLA Ti:sapphire laser can deliver up to 40 J in 32 fs to solid targets at 1 Hz [4].
- We have now started ion acceleration experiments with laser intensities up to ~2x10¹⁹ W/cm² and a beam spot with 100 micron diameter [5].
- Plans: implement a plasma lens to focus and transport laser-accelerated ions for radiation effects studies [6] and achieve E >50 MeV with a new short focal length laser beamline by 2020.

Simulated carbon ion pulse





NDCX-II and BELLA-i Capabilities

- Short, intense ion pulses from NDCX-II and BELLA-i are available for studies of high dose-rate damage effects to simulate neutron damage for evaluation of radiation hardness of electronics and materials.

	NDCX-II	BELLA-i
Ion species	He, also protons, d, high Z gases	protons, d, carbon, any high Z ion
Ion energy, MeV	0.5 to 1.2	~0.5 to 15
pulse length, ns	2 to 20	~0.1 to 3
Ions per pulse	10^{10} to 10^{11}	~10^{12}
Ion beam spot, mm²	2 to 100	0.5 to 100 (expected from simulations)
Repetition rate	~1/min	up to 1 Hz (target limited)
Shots per day	>100	>>100

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