Simulation of particle interactions in a high intensity radio-frequency quadrupole for molecular hydrogen ions

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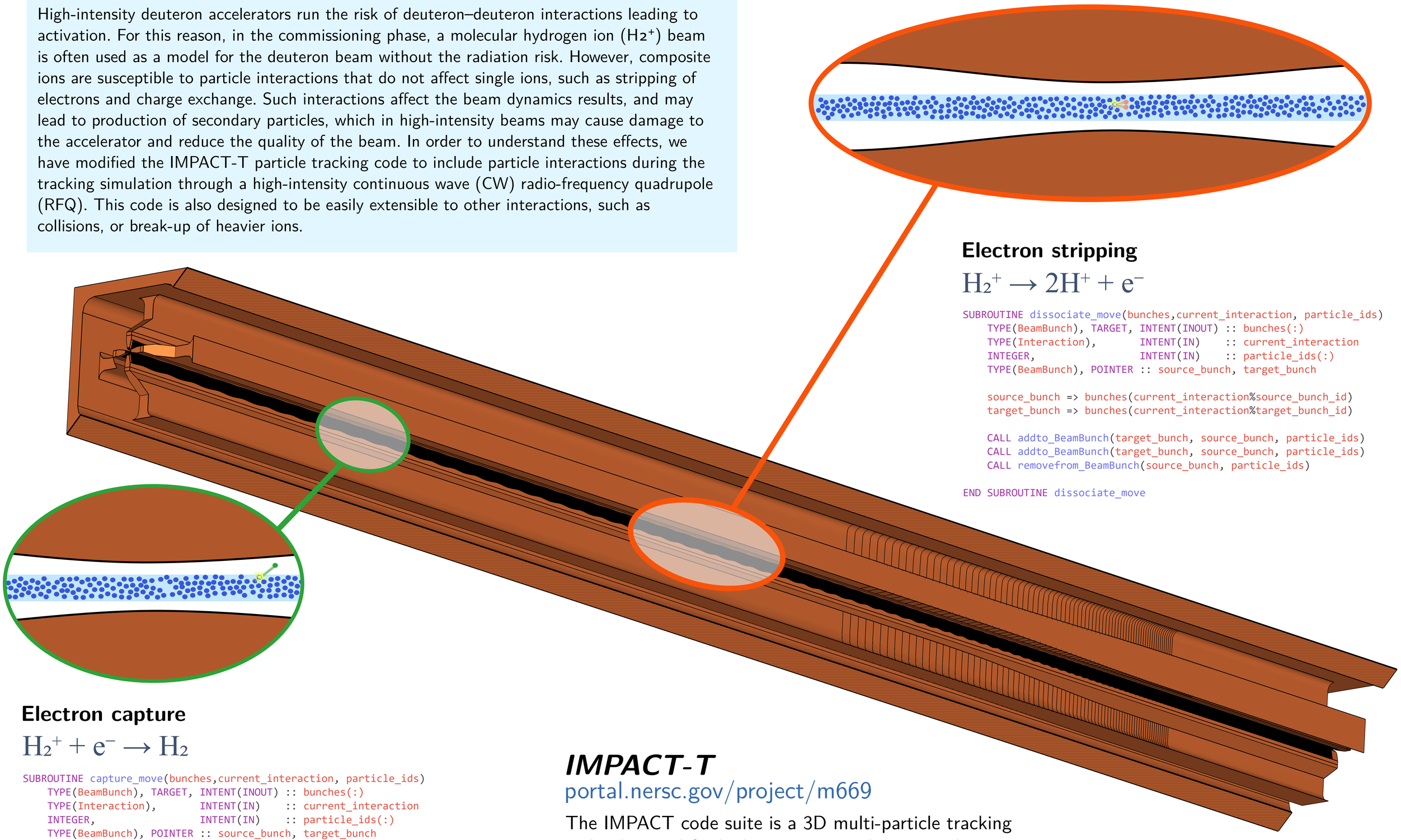
Abstract

High-intensity deuteron accelerators run the risk of deuteron–deuteron interactions leading to activation. For this reason, in the commissioning phase, a molecular hydrogen ion ($H2^+$) beam is often used as a model for the deuteron beam without the radiation risk. However, composite ions are susceptible to particle interactions that do not affect single ions, such as stripping of electrons and charge exchange. Such interactions affect the beam dynamics results, and may lead to production of secondary particles, which in high-intensity beams may cause damage to the accelerator and reduce the quality of the beam. In order to understand these effects, we have modified the IMPACT-T particle tracking code to include particle interactions during the tracking simulation through a high-intensity continuous wave (CW) radio-frequency quadrupole (RFQ). This code is also designed to be easily extensible to other interactions, such as collisions, or break-up of heavier ions.



Electron capture

$$H_2^+ + e^- \longrightarrow H_2$$

```
SUBROUTINE capture_move(bunches,current_interaction, particle_ids)
    TYPE(BeamBunch), TARGET, INTENT(INOUT) :: bunches(:)
    TYPE(Interaction),       INTENT(IN)    :: current_interaction
    INTEGER,                 INTENT(IN)    :: particle_ids(:)
    TYPE(BeamBunch), POINTER :: source_bunch, target_bunch

    source_bunch => bunches(current_interaction%source_bunch_id)
    target_bunch => bunches(current_interaction%target_bunch_id)

    CALL addto_BeamBunch(target_bunch, source_bunch, particle_ids)
    CALL removefrom_BeamBunch(source_bunch, particle_ids)

END SUBROUTINE capture_move
```

Electron stripping

$$H_2^+ \longrightarrow 2H^+ + e^-$$

```
SUBROUTINE dissociate_move(bunches,current_interaction, particle_ids)
    TYPE(BeamBunch), TARGET, INTENT(INOUT) :: bunches(:)
    TYPE(Interaction),       INTENT(IN)    :: current_interaction
    INTEGER,                 INTENT(IN)    :: particle_ids(:)
    TYPE(BeamBunch), POINTER :: source_bunch, target_bunch

    source_bunch => bunches(current_interaction%source_bunch_id)
    target_bunch => bunches(current_interaction%target_bunch_id)

    CALL addto_BeamBunch(target_bunch, source_bunch, particle_ids)
    CALL addto_BeamBunch(target_bunch, source_bunch, particle_ids)
    CALL removefrom_BeamBunch(source_bunch, particle_ids)

END SUBROUTINE dissociate_move
```

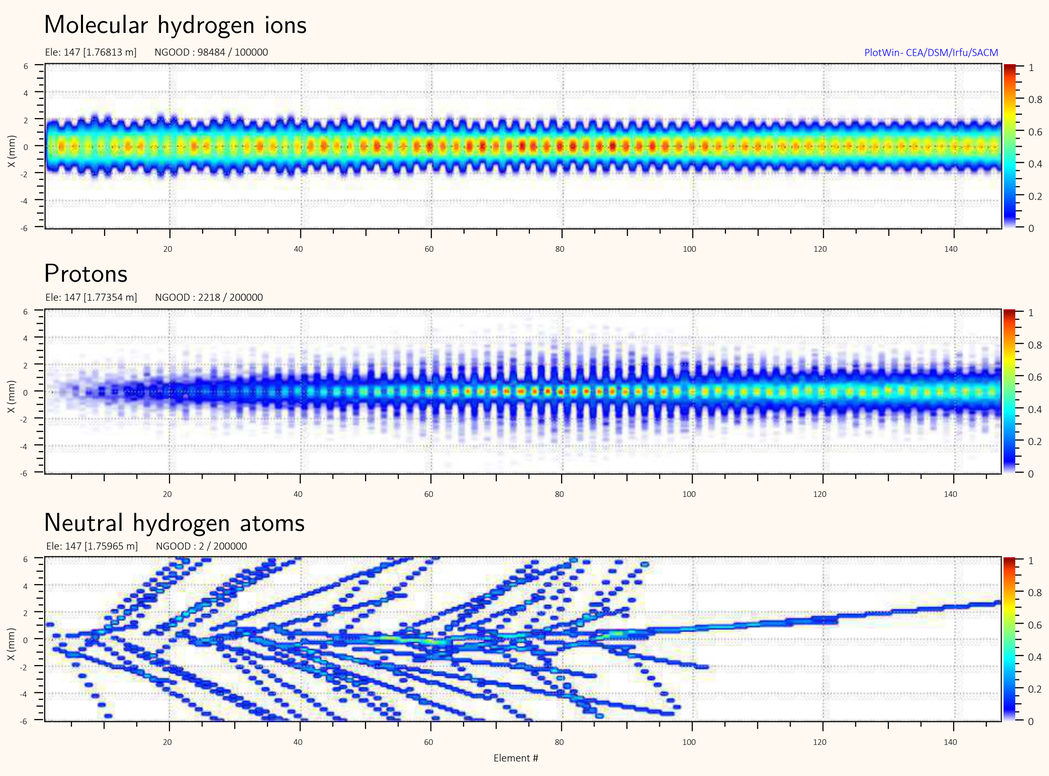
IMPACT-T

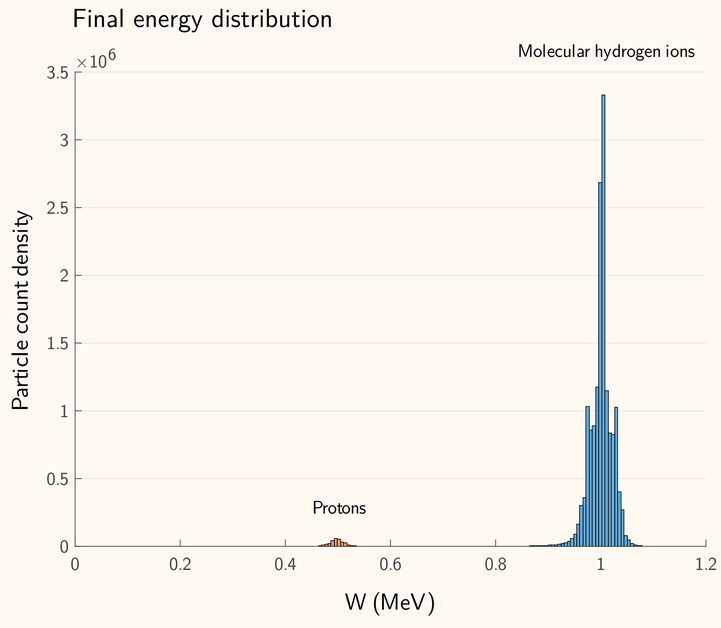
portal.nersc.gov/project/m669

The IMPACT code suite is a 3D multi-particle tracking code, designed for high intensity accelerator applications. It uses the particle-in-cell (PIC) method of modelling space-charge effects, and runs in parallel for scalability.

Particle tracking results

Accelerating 50 mA of molecular hydrogen ions from 50 keV to 1 MeV through a 1.8 m RFQ in CW mode using 100,000 macroparticles.





These results show approximately 1.5% of molecular hydrogen ions interacting in one way or another, with a small peak at half energy for protons and a few losses to neutral atoms.

Conclusions

Using reported cross-sections, we found that with a vacuum level of 10^{-6} Pa in the beam pipe, losses due to such interactions should be negligible.
This doesn't match with our experience, in that molecular hydrogen beams often exhibit slightly higher loss rates than equivalent deuteron beams in the same RFQ. A full Monte Carlo implementation would be a more robust algorithm for investigating this discrepancy.

We hope to follow up these simulations with some experimental tests using a molecular hydrogen in an existing high intensity RFQ. We are also looking at other codes that could complement *IMPACT-T* for these investigations, such as *OPAL*, which already implements both a Monte Carlo algorithm and a PIC space-charge algorithm, but as yet does not have an RFQ module.

The interaction code is not specific to molecular hydrogen beams, and future work could also include modelling break-up of heavy ions into constituent parts, interactions with electron clouds in a beam pipe, or other particle interactions during acceleration. Future work could also investigate different types of accelerating structures using the same interactions module.

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