Progress in Alternate Chambers Activities

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LLNL’s chambers work is divided into four main areas

_ ☐ Magnetic deflection

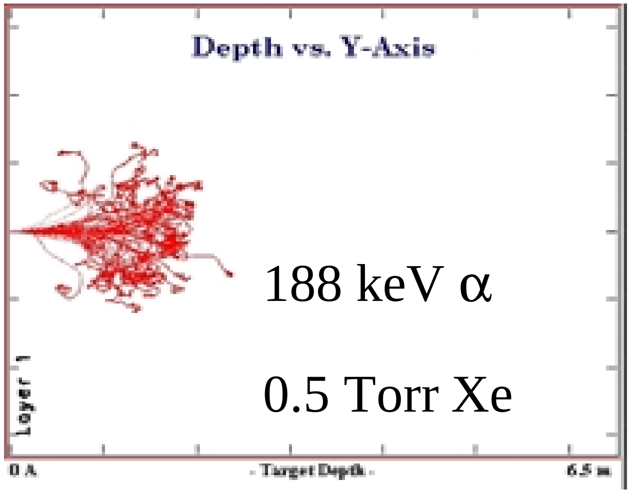
_ ☐ Implementation issues for fast ignition

_ ☐ Molecular dynamics simulations for graphite

☐ Safety & environment

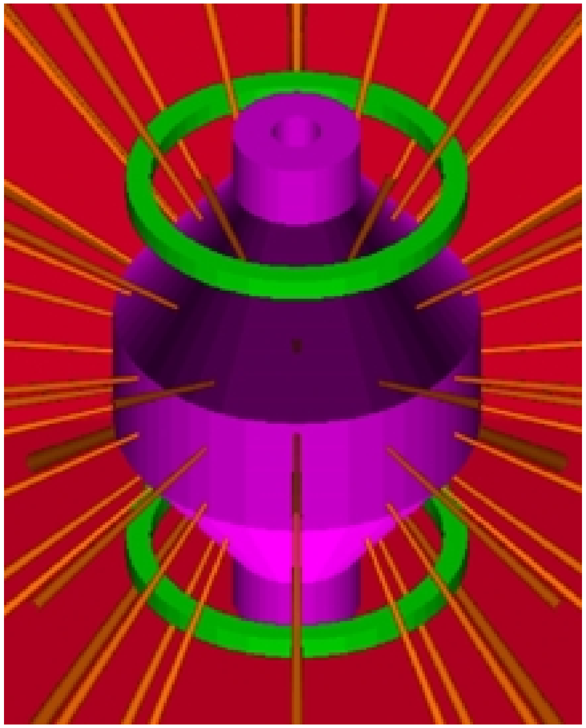
Introduction to magnetic deflection

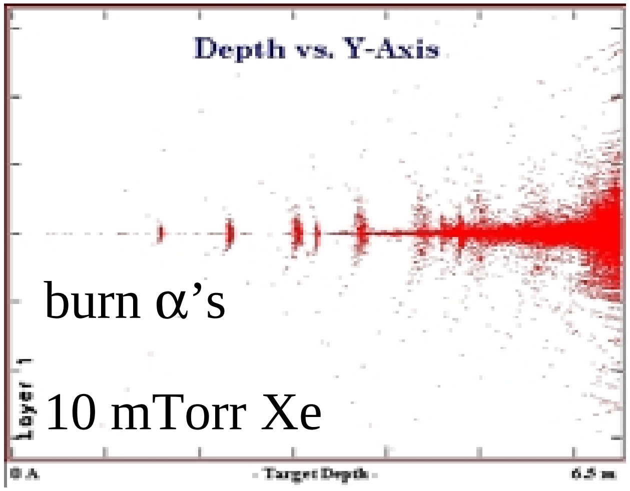
- ☐ As discussed Thursday, energetic ions will reach first wall/optics due to need for low gas pressures
- ☐ Multiple “radiation damage” issues, but exfoliation is sufficient to cause serious problems; could result in loss of ~2 μm/h



188 keV α

0.5 Torr Xe





burn α’s

10 mTorr Xe

Magnetic deflection progress is picking up

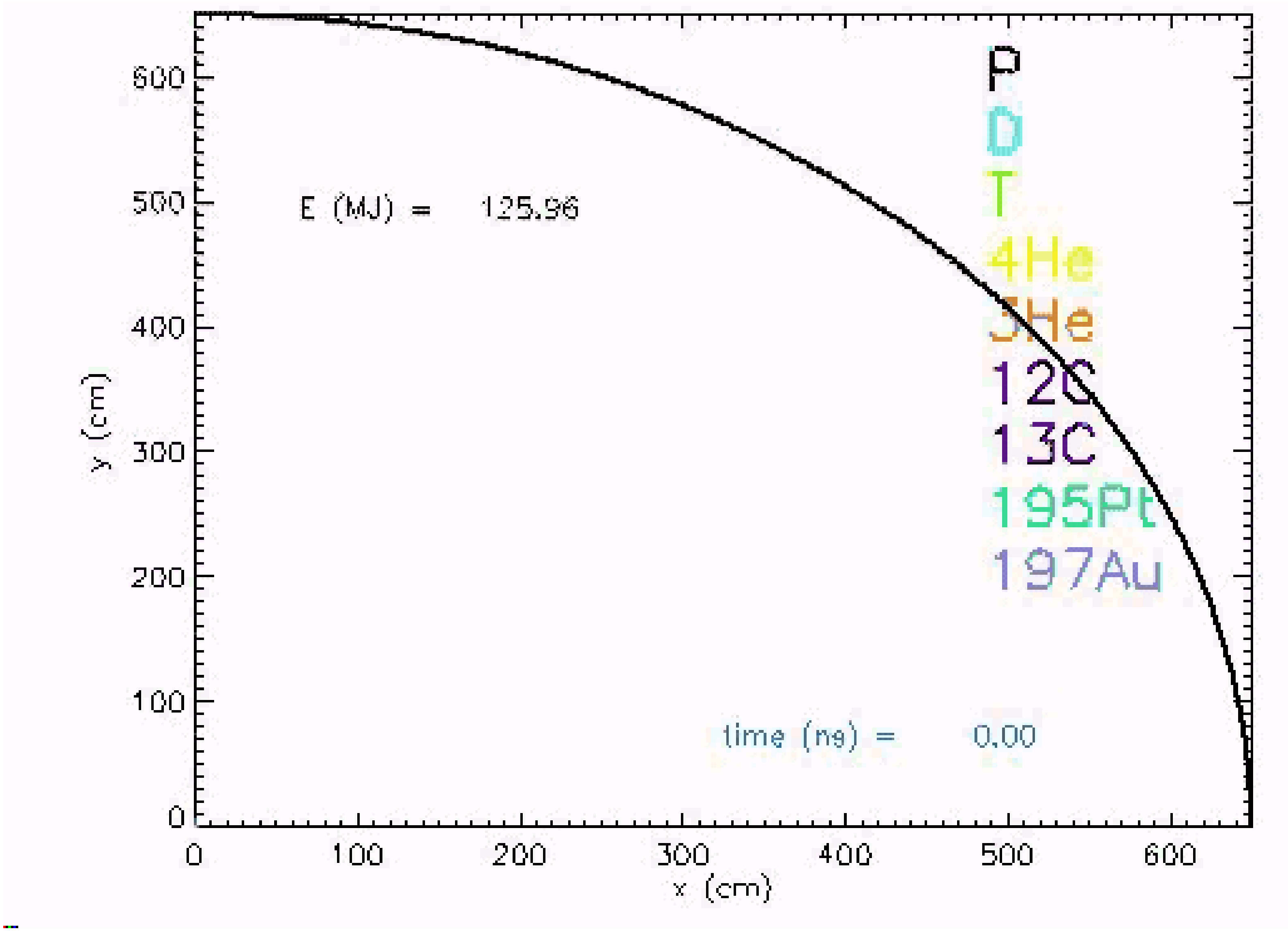
- ☐ Original plan was to run ion-only simulations as screening tool:
  - – Code assigns e^- infinite mass; don't "blow a bubble"
  - – When e^- turned on, time steps and mesh size get prohibitively small

- ☐ Forced us to reconsider our simplistic plans → consulted with MFE colleagues; following most recommendations:
  - – Including much more analytical work
  - – Designing set of good 2-D calcs
  - – Bringing up MHD code

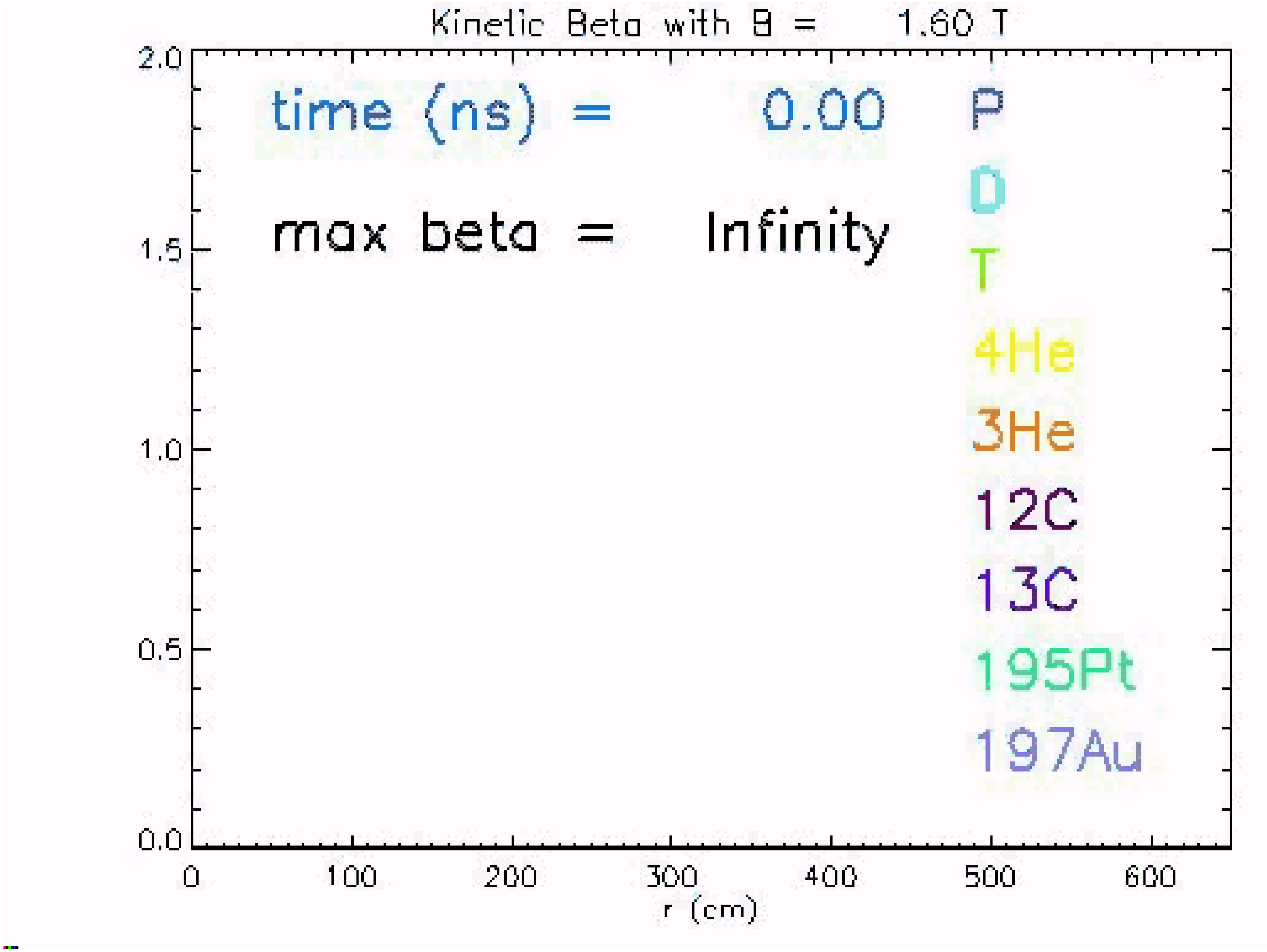
Magnetic deflection, (Cont’d.)

- First, 3-D PIC calcs started with 30-cm-radius plasma at very high (uniform) density → conditions severely stressed the code
- Realized that early time history would be ~unaffected by fields due to tremendous plasma pressures → should be able to start problem at later time, after some initial expansion
- Consulted with John Perkins, René Raffray, and Don Haynes to get better understanding of target emissions as f(t)
- Developed “concentric shells” model as tool to understand time-of-flight expansion, which tells us most of what we need to know

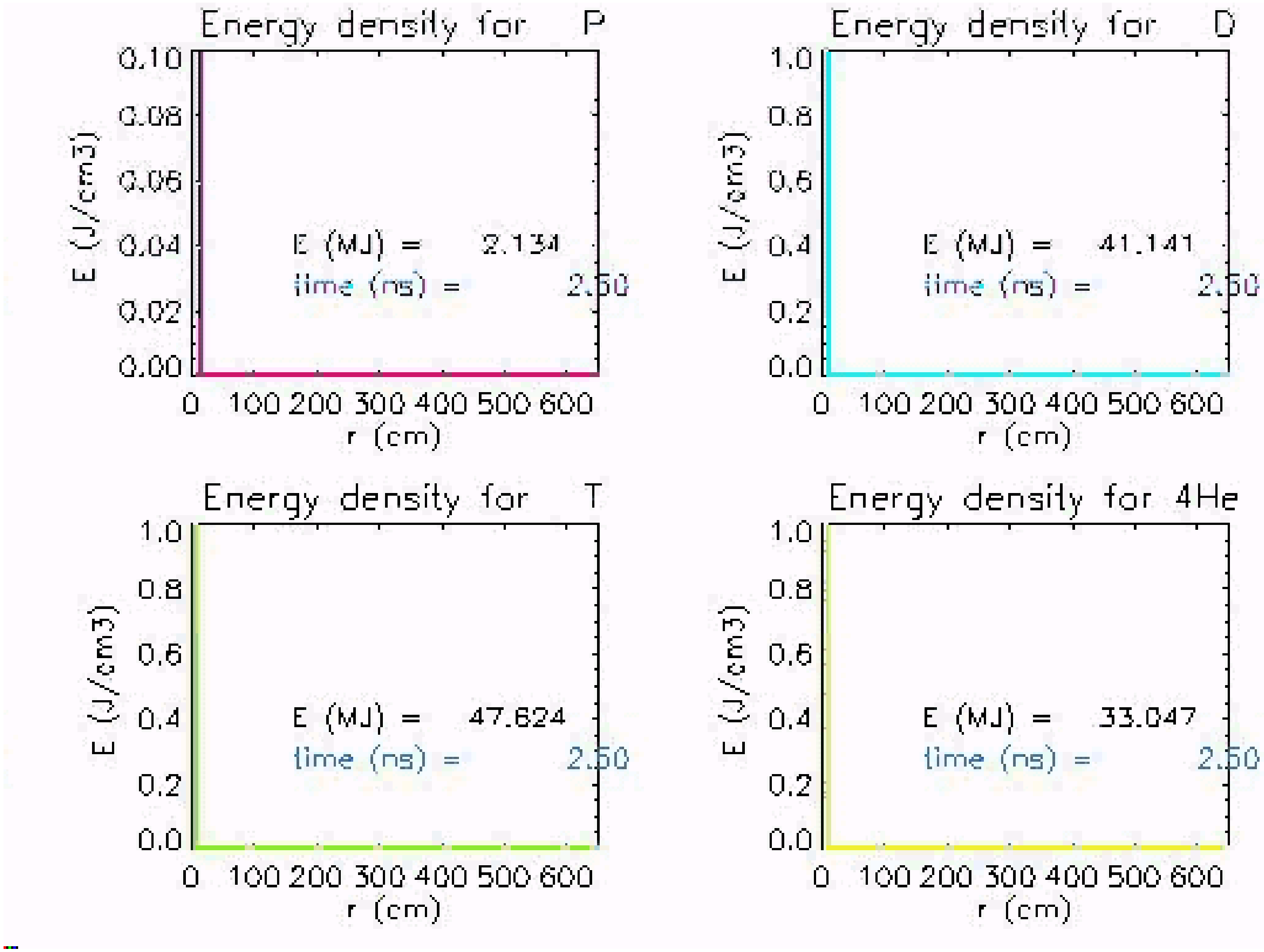
The concentric shell model provides us with a visualization of the ion threat



The kinetic B is calculated as a function of radius and type of particle



We plan to use this model to help decide which particles need to be "picked up" when



Other issues have been/are being addressed

- Concern about Bremsstrahlung has been addressed:
  - Used Dolan relation for Bremsstrahlung power loss at plasma stagnation: $P_{Brem} = 5 \_ 10^{-37} Z_{eff} n_e^2 T_e^{1/2} \sim 7$ MW
  - Assumed full thermalization @ stagnation
  - Suggests this is not an issue for magnetic deflection
  - Conclusion needs to be revisited using concentric shell model

Other issues (Cont'd.)

- First cut at charge exchange reactions, which could produce neutrals that would defeat our system, has been completed:
  - $n_0 = 3.5 \_ 10^{14}$ cm^{-3}
  - Cross sections:
    - $H^+ + Ar \rightarrow H \approx 1.0 \_ 10^{16}$ cm^2
    - $H+ + Kr \rightarrow H \approx 1.2 \_ 10^{16}$ cm^2
    - Assume same for $\sigma_{DT+ \rightarrow DT}$
  - $\nu_{DT+ \rightarrow DT} = n_0 \, v_i \, \sigma_{DT+ \rightarrow DT} = 1.9 \_ 10^{17}$ s^{-1}
  - Translates into ~24 cm distance between charge exchange reactions → needs to be evaluated in more detail

Additional calculations are underway and/or planned

- 2-D PIC calculations are also quite slow; Perkins (advanced fuel) calculation will be repeated as performance & timing benchmark for the two codes

- 2-D MHD calculations will be performed using TRACK2 (Charlie Hartmann to help on this):
  - Examine bubble size & exit size at appropriate downstream distances
  - Address growth of flutes from initial perturbation

- Several magnet layouts analyzed (cusp, mirror, uniform field)

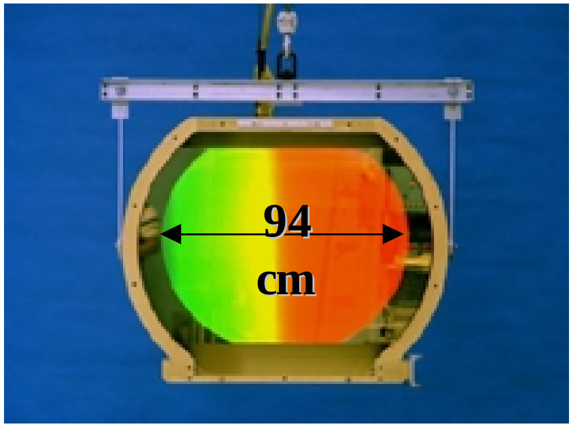
- Simple shielding analyses completed:
  - Nuclear heating (recirculating power issue) and radiation damage likely to be doable
  - Activation of NbTi or Nb_3Sn will be issue (fails to meet Class C)
  - Bromberg showed very interesting HTS data at last ARIES meeting; consider these?

We are currently assessing final optics options for FI laser IFE

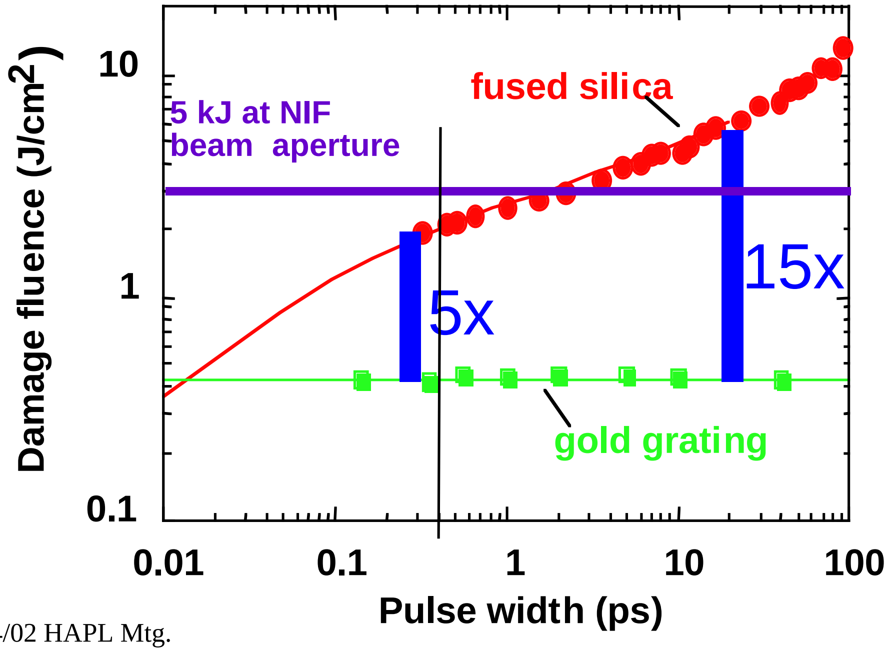
- Compression beam requirements similar to hot spot ignition (but may not require uniform illumination)
- However, petawatt ignitor beams require development of high energy, short-pulse compatible gratings and focusing optics
- Need to develop an appropriate solution for FI final optics layout
  - optimum stand off-distance compatible with spot size requirement (~ 30 μm)
  - optics damage threshold for high intensity laser
  - potential target directional output (case of cone-focused design)
- Need to understand the various final optics options
  - Parabolic mirrors: conventional option, metal or dielectric coated gratings
  - Fresnel lenses: still have some development issues
  - Plasma mirrors: target using built-in mirror combined with permanent thin fused silica gratings may be the most adequate
  - GIMMs, GILMMs

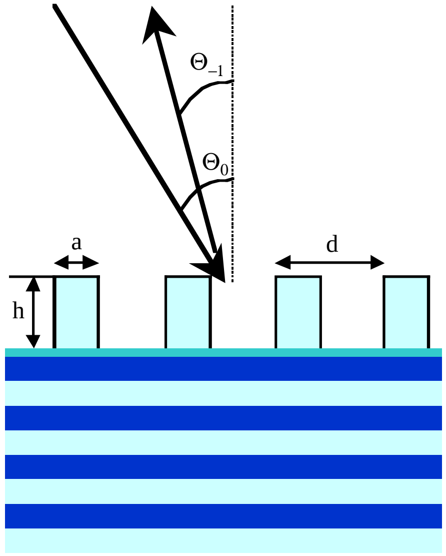
Conventional option would use large scale metal or dielectric coated gratings

- ☐ Petawatt laser in LLNL used large scale metallic gratings
- ☐ However, available metallic gratings do not have sufficient laser damage threshold for use in FI
- ☐ Multi-layer dielectric and SiO_2 transmission gratings are currently being designed and tested



Petawatt-scale gold-coated grating



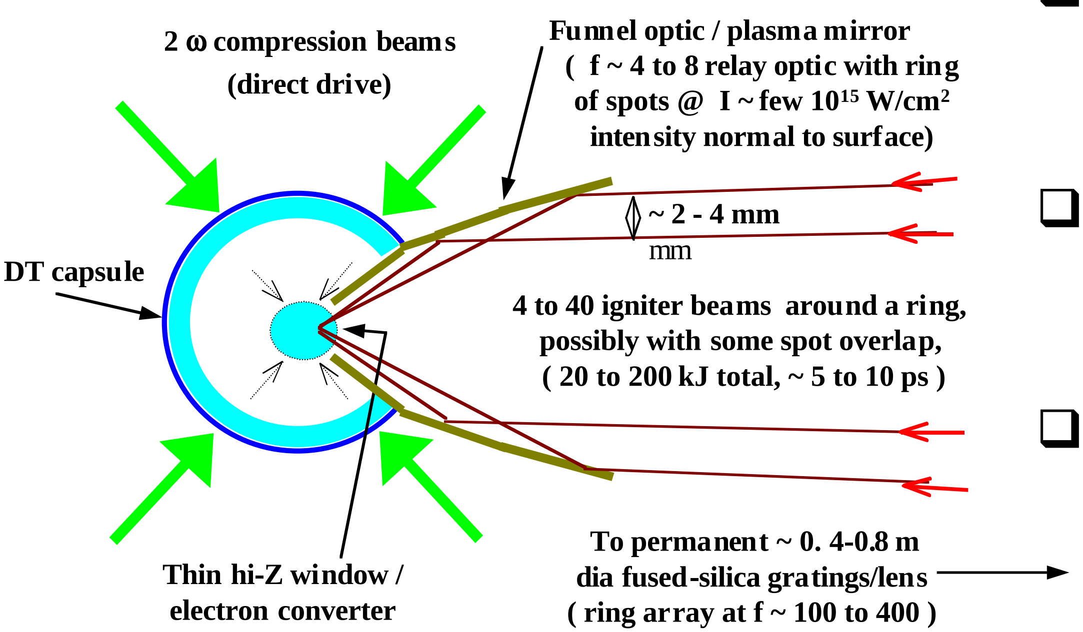


Multilayer Grating Structure

Optics protection from target emissions should consider plasma mirrors or GILMMs

- ❑ Target emissions (directional in case of cone-focused target) can limit the minimum stand off distance for the optics

- ❑ Large diameter gratings with long stand-off distance could be combined with parabolic plasma mirrors to focus the beams



2 ω compression beams (direct drive)

Funnel optic / plasma mirror (f ~ 4 to 8 relay optic with ring of spots @ I ~ few 10^{15} W/cm^2 intensity normal to surface)

DT capsule

~ 2 - 4 mm

mm

4 to 40 igniter beams around a ring, possibly with some spot overlap, (20 to 200 kJ total, ~ 5 to 10 ps)

Thin hi-Z window / electron converter

To permanent ~ 0. 4-0.8 m dia fused-silica gratings/lens (ring array at f ~ 100 to 400) →

- ❑ Also, a GILMM has been suggested for robust final optics of a laser IFE power plant

- ❑ Grazing incidence angle will enlarge the size of optics, layout for FI needs to be addressed

- ❑ More analyses are needed to address acoustic vibrations and film smoothness

Summary and directions for fast ignition work

- ☐ Fast ignition offers many potential advantages for IFE:
  - High gain at low driver energy
  - Lower COE and/or small size plants
  - Reduced constraints on target fab and injection
  - Possibility of using advanced fuels

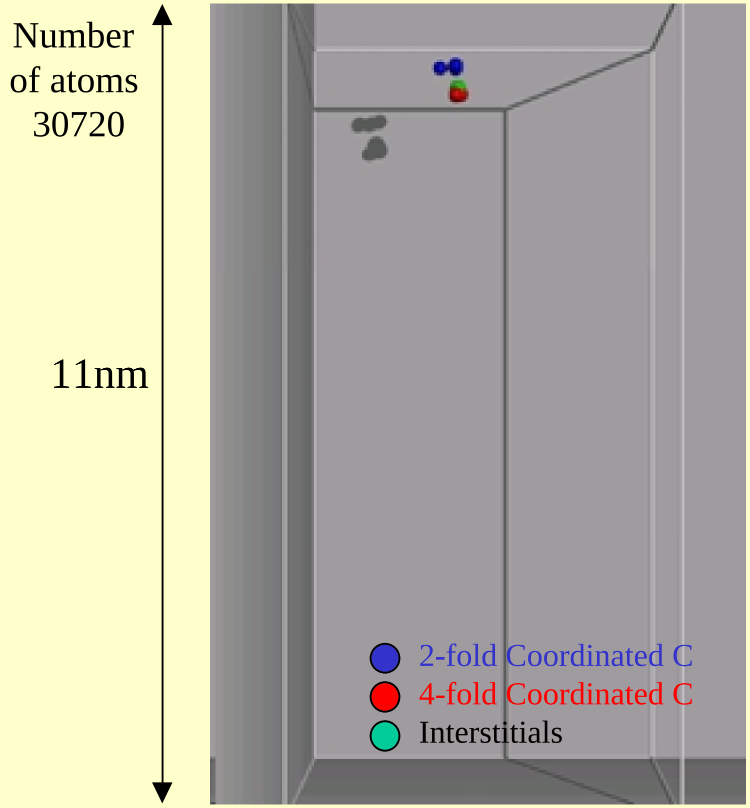
- ☐ Significant work is needed to address numerous issues related to implementation (target design, fabrication, injection, beam focusing and timing, final optics)

- ☐ Important R&D effort is required in the final optics development for ignitor beams:
  - Numerical modeling
  - Sub-scale fabrication
  - Damage testing
  - Optical characterization

Atomistic Modeling of Defect production during Neutron Irradiation of Graphite

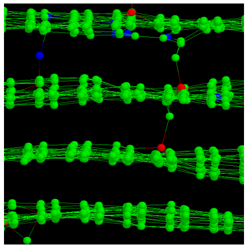
Interatomic Potential: Brenner (bond-order potential)

Recoil Energies: 1 and 2 keV

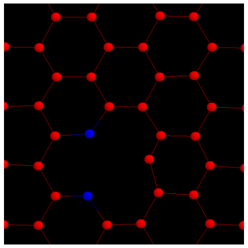


Defects identified

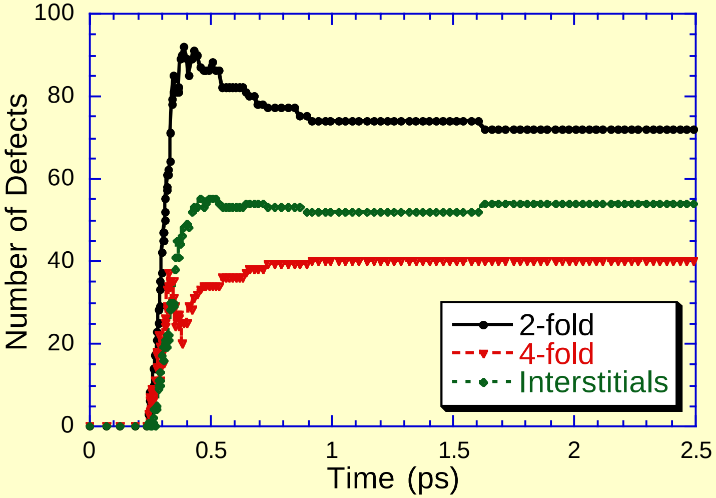
Interstitials: C between layers



Vacancies in planes

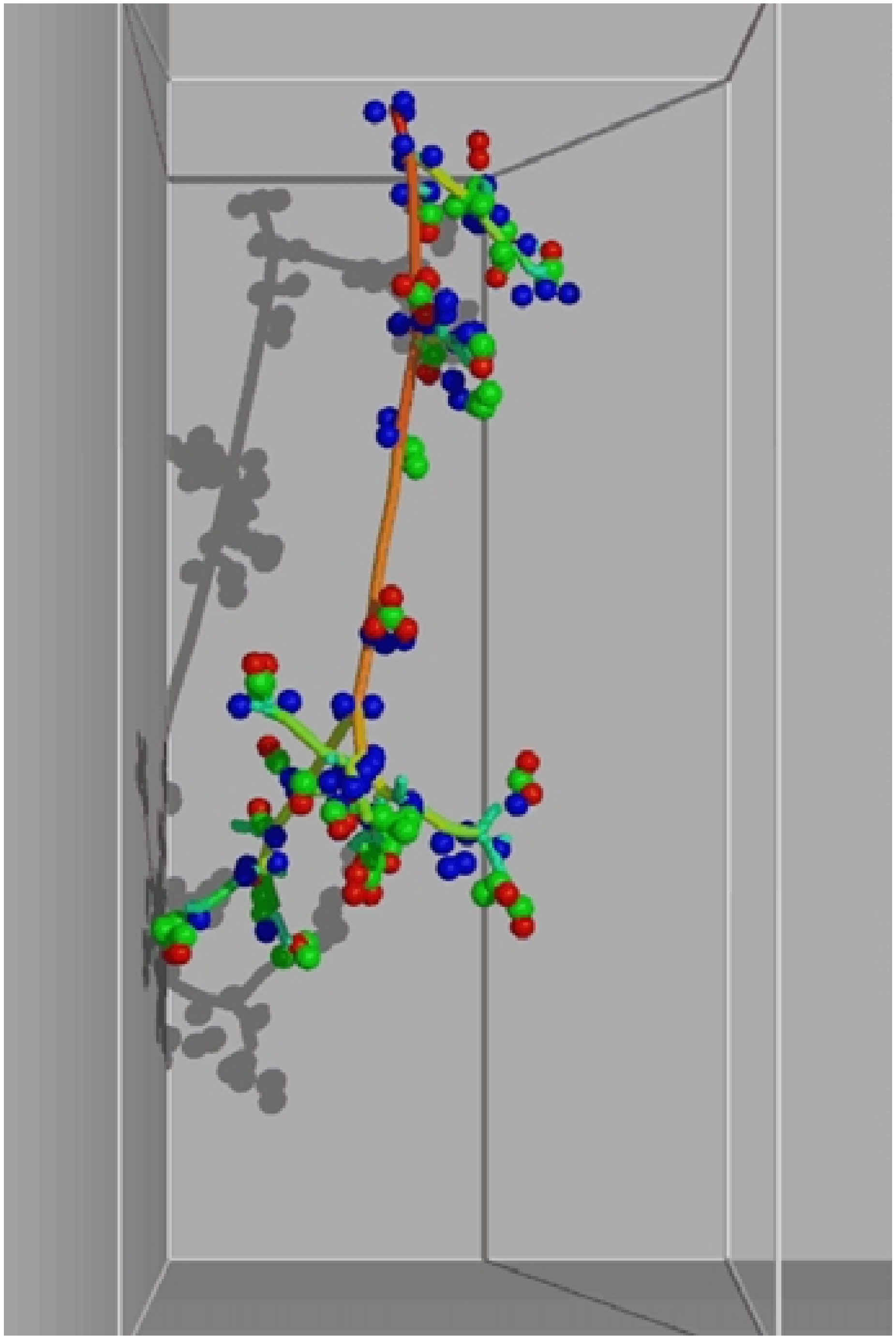


1 keV recoil Defect Evolution



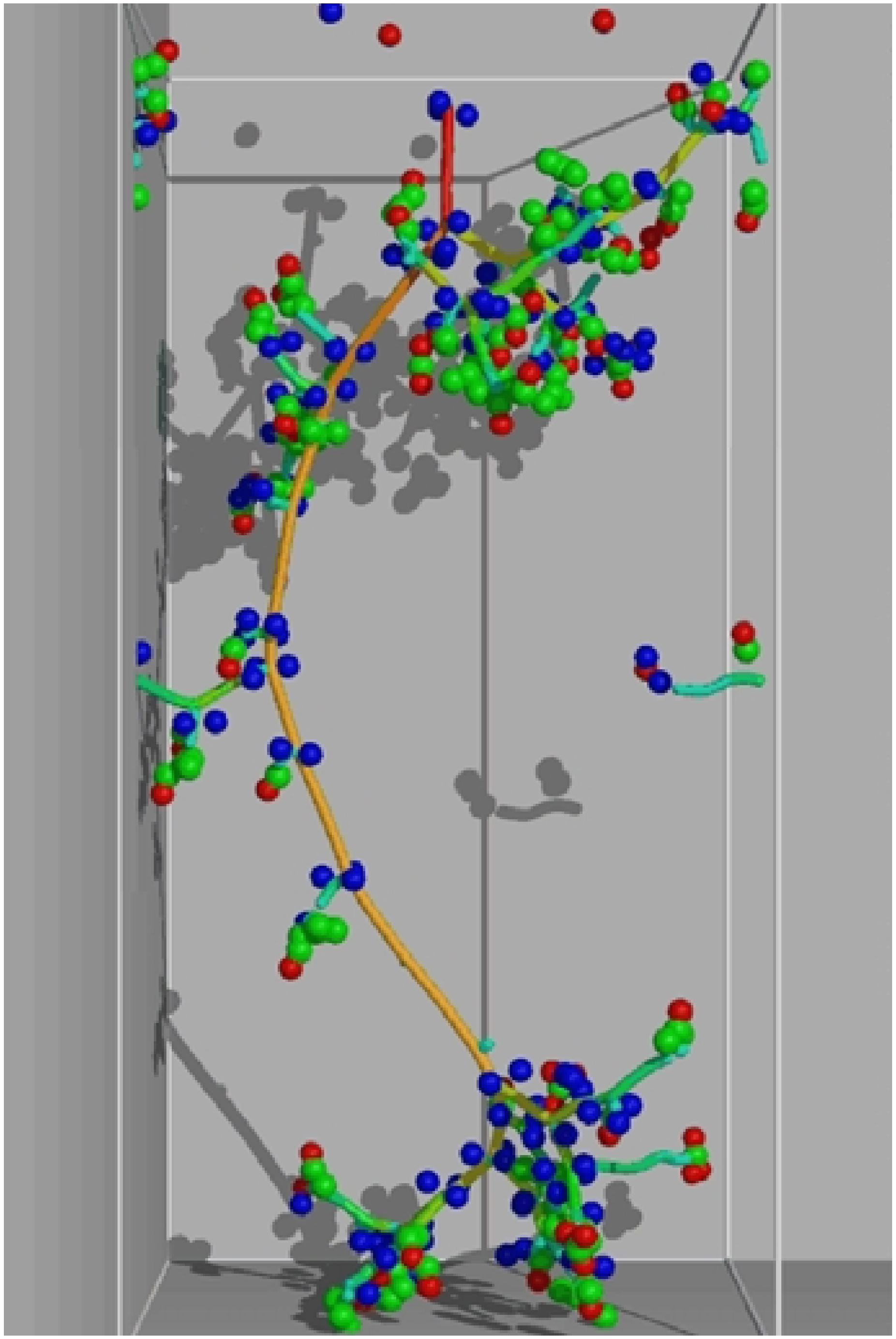
Started to quantify number and type of defects produced during irradiation: 1keV recoil results in 24 vacancies, 2keV recoil 55 vacancies

Molecular dynamics simulation of 1 keV PKA in graphite



🔵 2-fold Coordinated C
🔴 4-fold Coordinated C
🟢 Interstitials

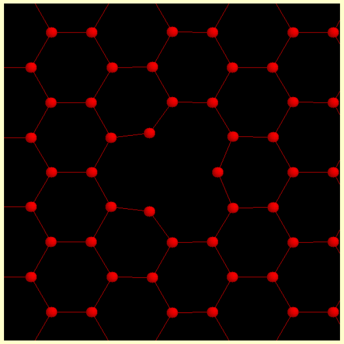
Molecular dynamics simulation of 2 keV PKA in graphite



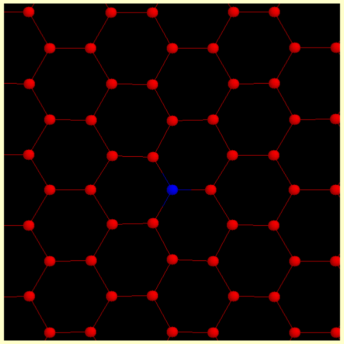
- ● 2-fold Coordinated C
- ● 4-fold Coordinated C
- ● Interstitials

Defect Energetics provide information about trapping sites for H, T and D

Single Vacancy in Graphite

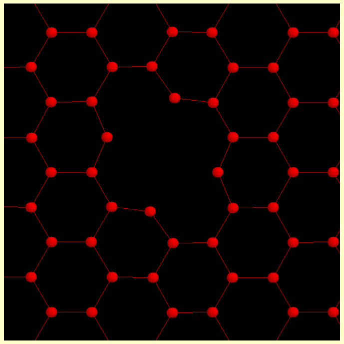


H on a Vacant site in Graphite

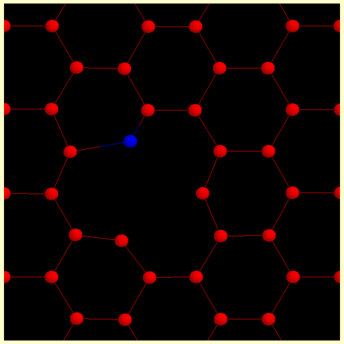


De-trapping energy of a H from a Vacant site = 3.8 eV

Di-vacancy Structure in Graphite



H on a Di-Vacancy



Binding Energy = 3.2 eV

We are quantifying the number of H atoms that can be accommodated per vacancy cluster as a function of cluster size to account for the total retention

Summary

- Magnetic deflection design effort is currently focused on attempting to make problem tractable:
  - Concentric shell model to be used to initialize problem
  - Charge exchange needs t be addressed in detail

- Fast ignition has multiple options for the final optic, but issues such as directional output, stand-off distance vs. spot size, and optics damage at high intensities need to be better understood

- MDS work is making nice progress; Zeroing in on number of stables defects and number of tritium atoms that can be accommodated (trapped) vs. cluster size