The LLNL Fusion Energy Program and its Directions

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on
Heavy Ion Fusion and High Energy Density Physics
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LBNL and LLNL

Slides from:
Edmund J. Synakowski (LLNL FEP Leader)
at: Fusion Power Associates Meeting, September 27 - 28, 2006

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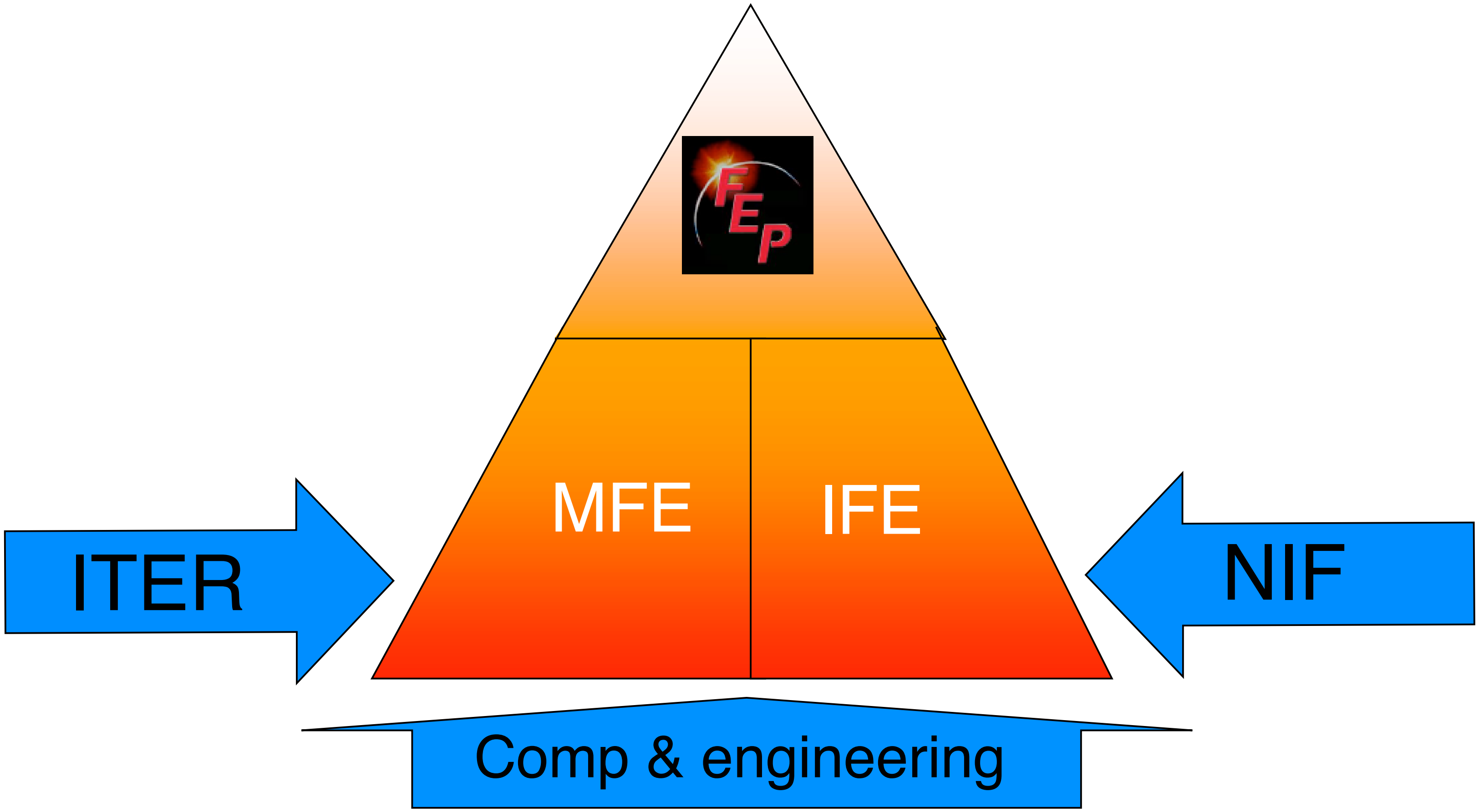
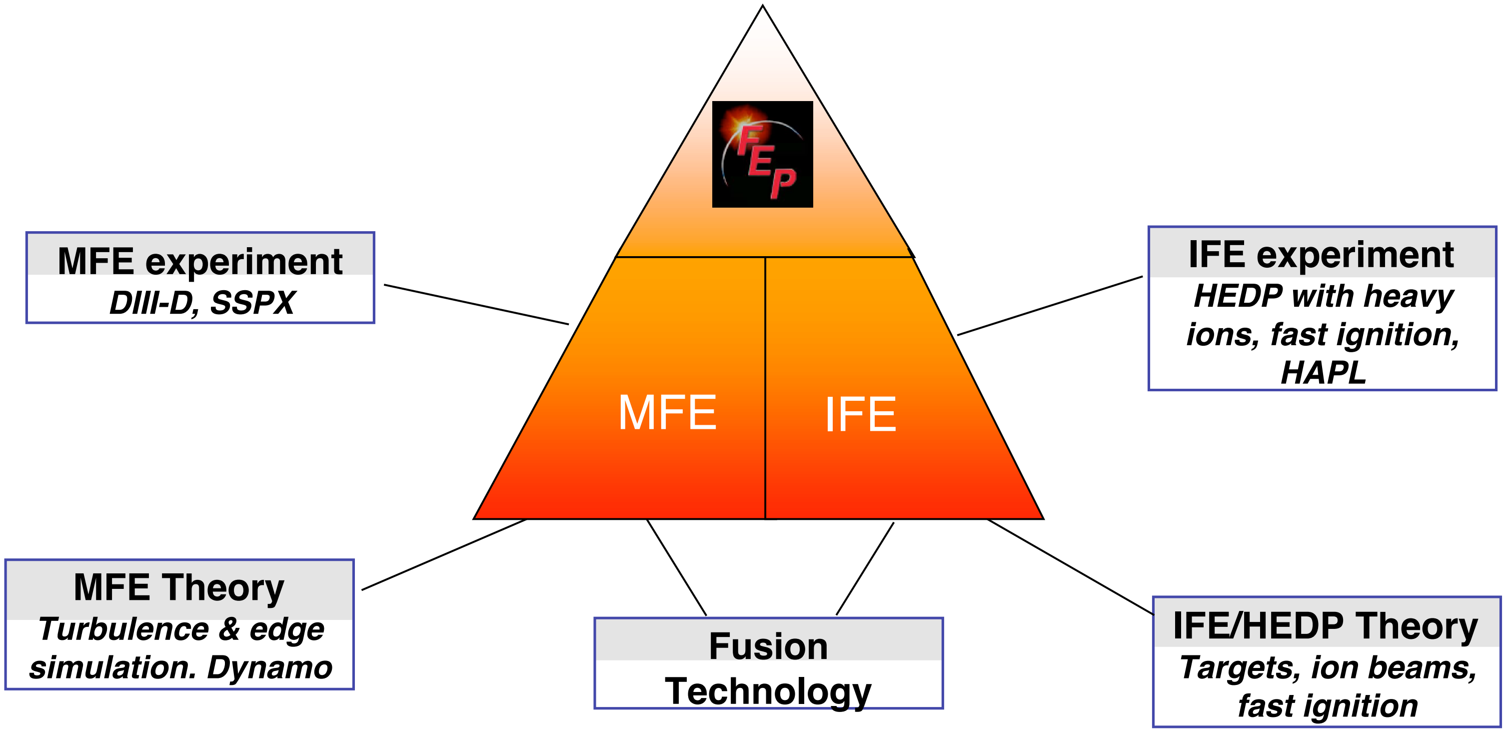
The LLNL FEP research & resources enable broad contributions to fusion energy research

- Vision and present structure of the LLNL FEP
- MFE, including ITER and the role of LLNL capabilities
- IFE opportunities: NIF and present research elements

The long-range vision for the LLNL Fusion Energy Program: leadership roles in both MFE and IFE, buoyed by ITER, NIF science, and LLNL's broad capabilities



The present structure: LLNL FEP research portfolio is diverse



- **Magnetic**: Tokamaks (DIII-D, NSTX) and self-organized systems (SSPX). Boundary and current density measurements. Turbulence theory and simulation, SOL transport. MFE systems technology, including neutronics
- **Inertial**: Target design. High energy density physics: fast ignition, heavy ion fusion through collaboration (Virtual National Laboratory with LBL, PPPL, LLNL), HAPL. IFE systems technology, including neutronics
- LLNL resources in engineering and computation available

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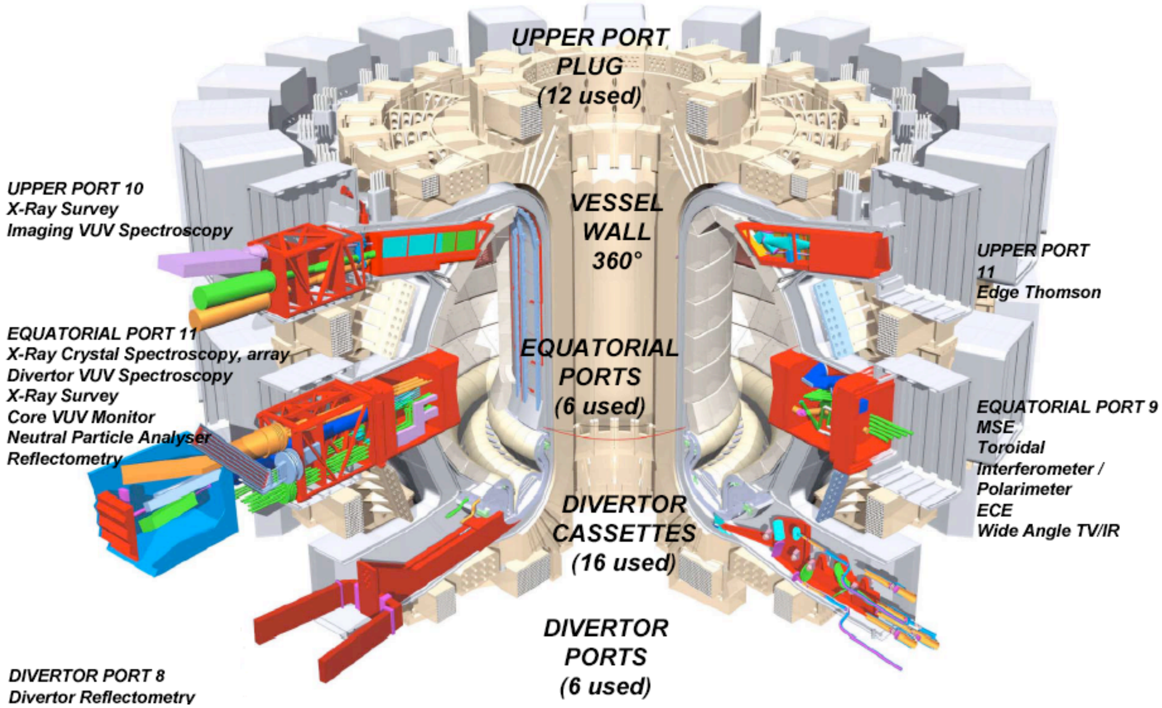
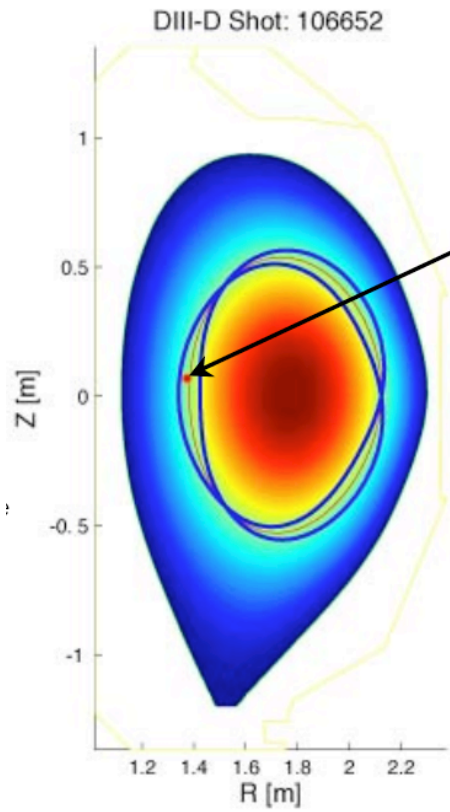
- IFE opportunities and research elements

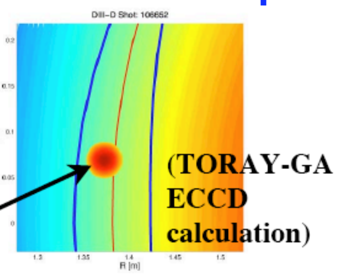
We are pursuing an LLNL role in ITER physics through diagnostics



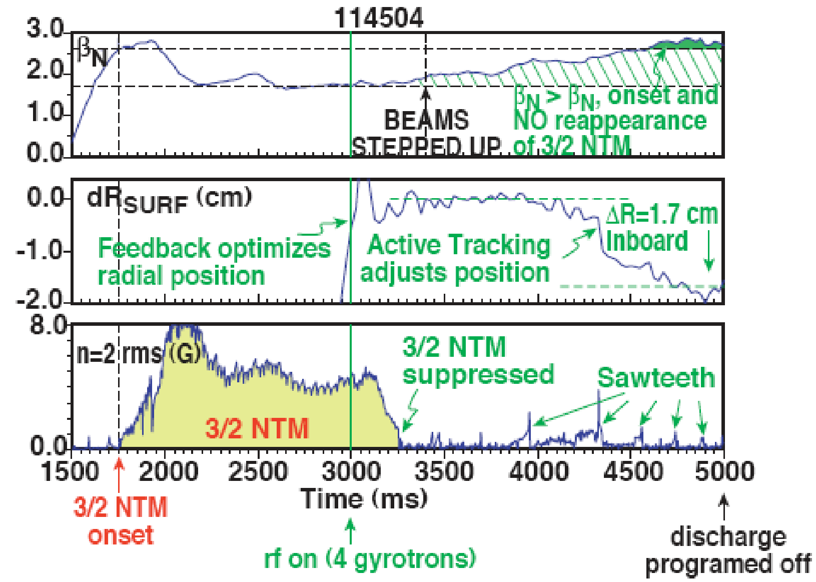
- Current density measurements (MSE) a U.S. task, with LLNL FEP interest
- Infrared camera measurements (boundary) a U.S. task, with FEP interest
- The diagnostic choices are born from leadership on DIII-D
- Port integration, testing of interest to LLNL

The LLNL experience with MSE on DIII-D has high impact and includes integration to plasma control, important for optimizing ITER performance





- ECCD FWHM ~2 cm ~50% of island width
- Uncertainty in calculated ECCD location < 1 cm
- Precision of q-surface location < 1 cm



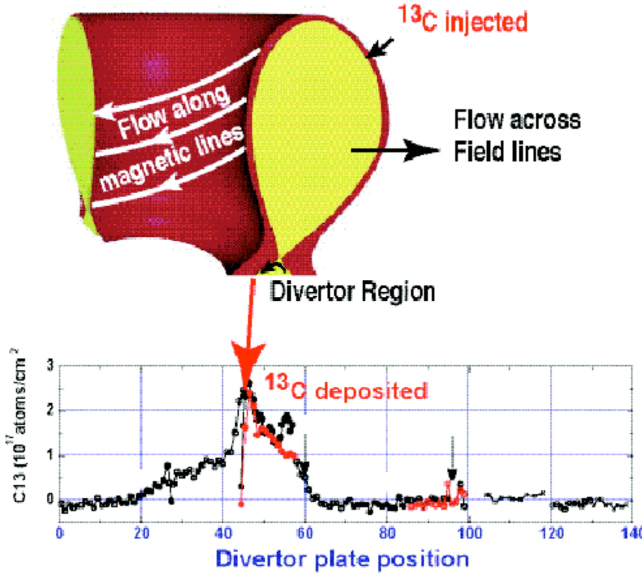
- Active feedback on DIII-D (LaHaye) - Suppression of tearing modes demonstrated
- LLNL modeling tools capable of ITER control system modeling
  - Have developed plasma control simulator developed using CORSICA as a central element.
  - History: CORSICA used in EDA to design ITER PF coils

ITER's boundary physics needs are advanced by the LLNL FEP

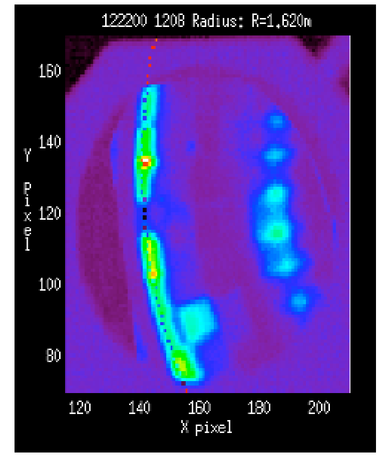
Experiment:

- A major DIII-D focus. Work includes SOL transport, including ^{13}C transport, edge ergodization, pedestal physics, heat fluxes
- LLNL researchers key participants in ELM control/mitigation studies at General Atomics.
- Partnership with PPPL on NSTX in fueling, divertor spectroscopy, and boundary modeling

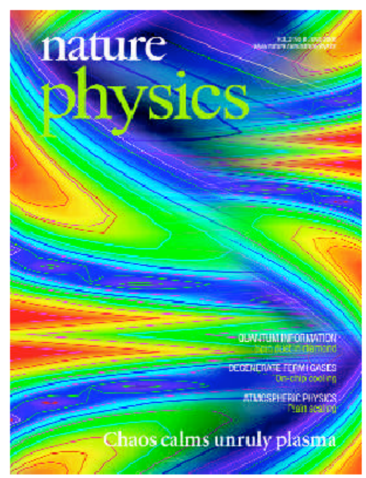
^{13}C transport

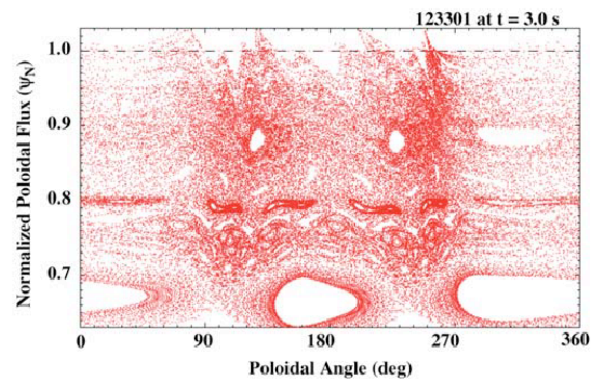


Surface temperature measurements (Lasnier)



ELM Control



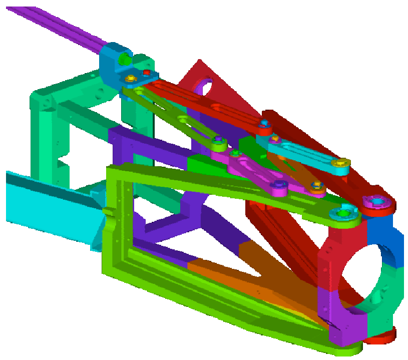


Evans (GA)

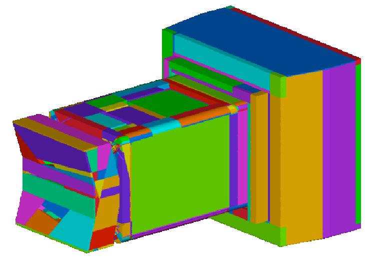
LLNL offers its resources to lead the U.S. effort in port plug integration

- Recognition of a new age in diagnostic requirements for tokamaks- the system has to work when delivered
- Neutronics expertise in -house.
- An Engineeering Directorate that has a long history of delivering complex projects of this scale, and having them work first time

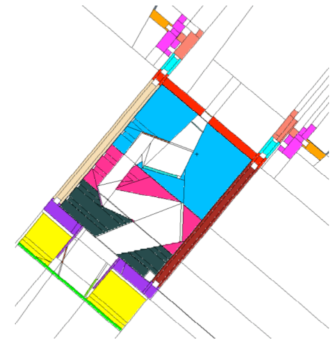
Leverage from NIF work



Performing neutronics calculations for diagnostic design assumptions starting with ITER CADs



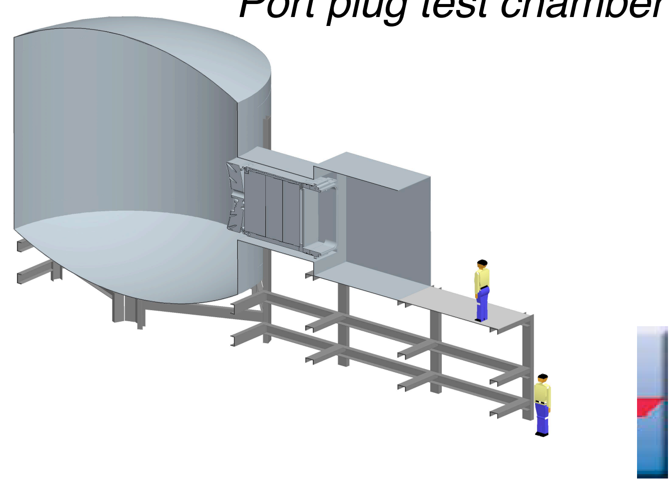
MSE



Candidate high bay

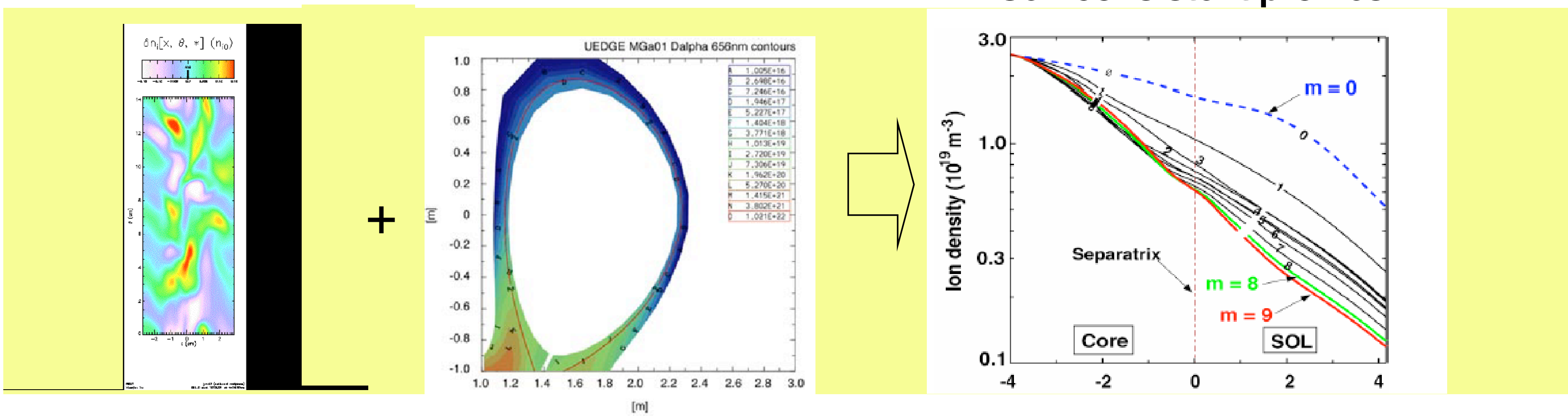
B432 has been identified as a potential sit for the Port Integration and Test Facility

Port plug test chamber



LLNL aims to develop a predictive capability of edge dynamics for ITER

BOUT code **UEDGE transport modeling** **Self-consistent profiles**



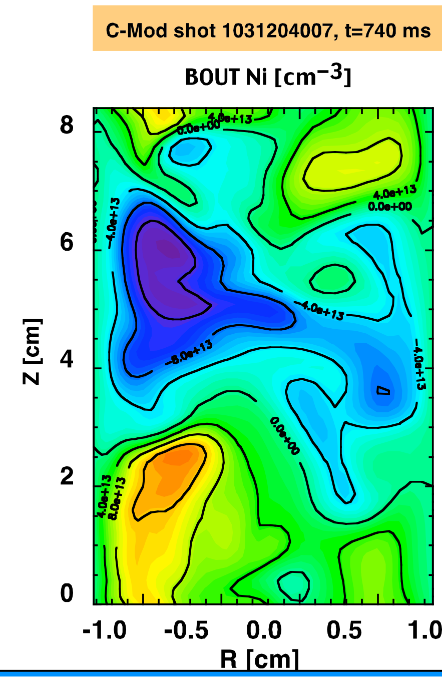
- First work to self-consistently couple boundary turbulence simulations with boundary transport

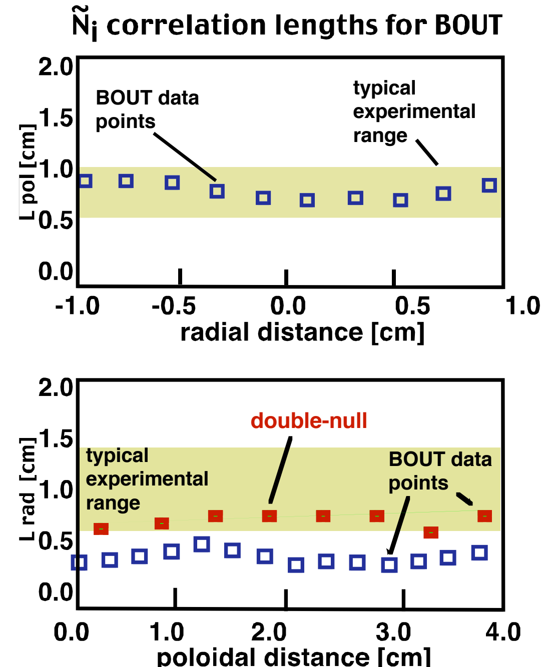
- *Edge Simulation Laboratory and edge gyrokinetics*: joint OFES effort with OASCR builds on internal TEMPEST code development
  - LLNL lead, with GA, LBNL, UCSD, PPPL, UCB

- LLNL resources: FEP collaboration with Center for Advanced Scientific Computing

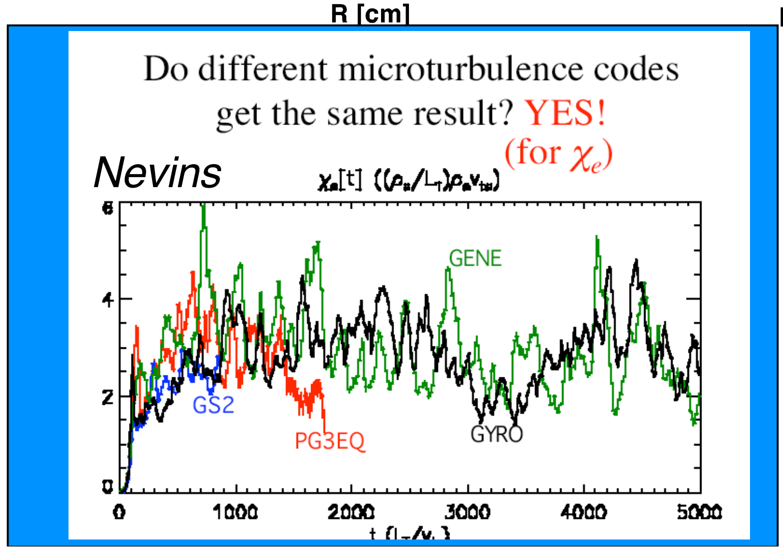
The LLNL program is committed to validation and verification of simulation

- Edge: theory & experiment
  - Up-down asymmetry now realizable
  - Simulations readily compared with turbulence imaging





- Core: theory & theory
  - Led ETG benchmarking study
  - Highlights need for careful consideration of particle noise
  - Essential as simulations become more and more "like experiment" in complexity



C-Mod, BOUT correlation lengths brought into agreement with fully 2-D code upgrade

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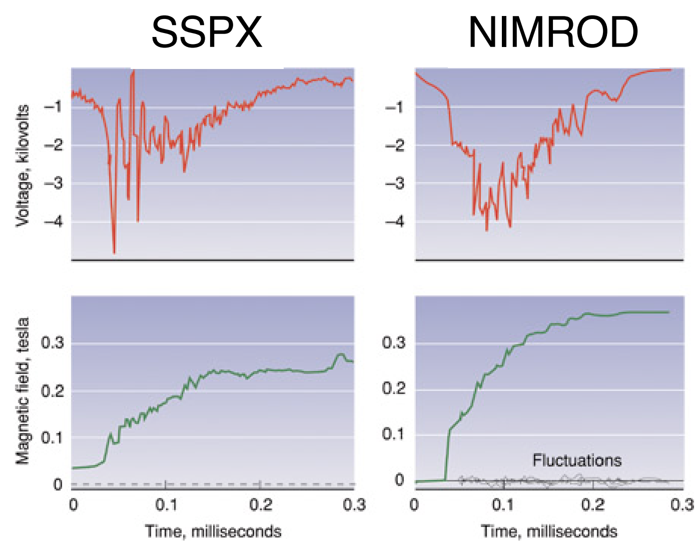
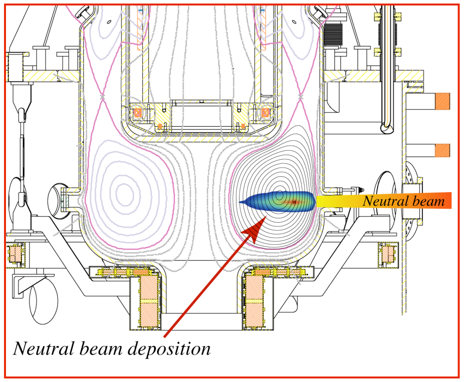
SSPX has an effective interplay with leading MHD simulations to increase understanding and to develop new operating scenarios

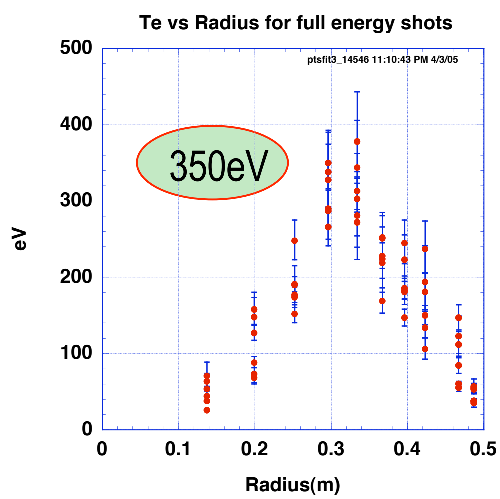
- Computational theory is guiding the experimental planning, not just describing it

- Modular cap bank upgrade enables longer pulses, larger field generation ==> platform for NBI & basis for flexible laboratory to study and assess
  - the promise of the spheromak itself
  - helicity transport & dynamo formation
  - reconnection physics
  - coronal mass ejection physics
  - hyperresistivity relevant to tokamaks

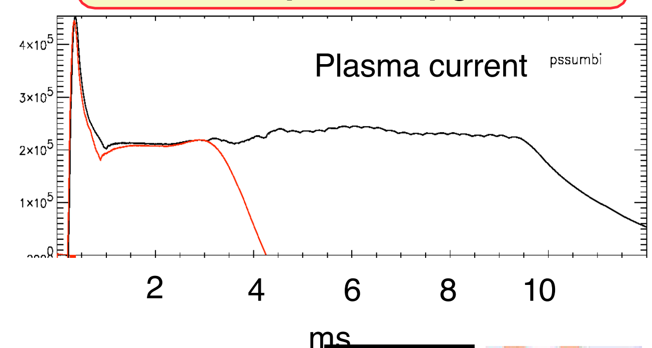


NBI heating operational FY08





Pulse length extended with modular cap bank upgrade



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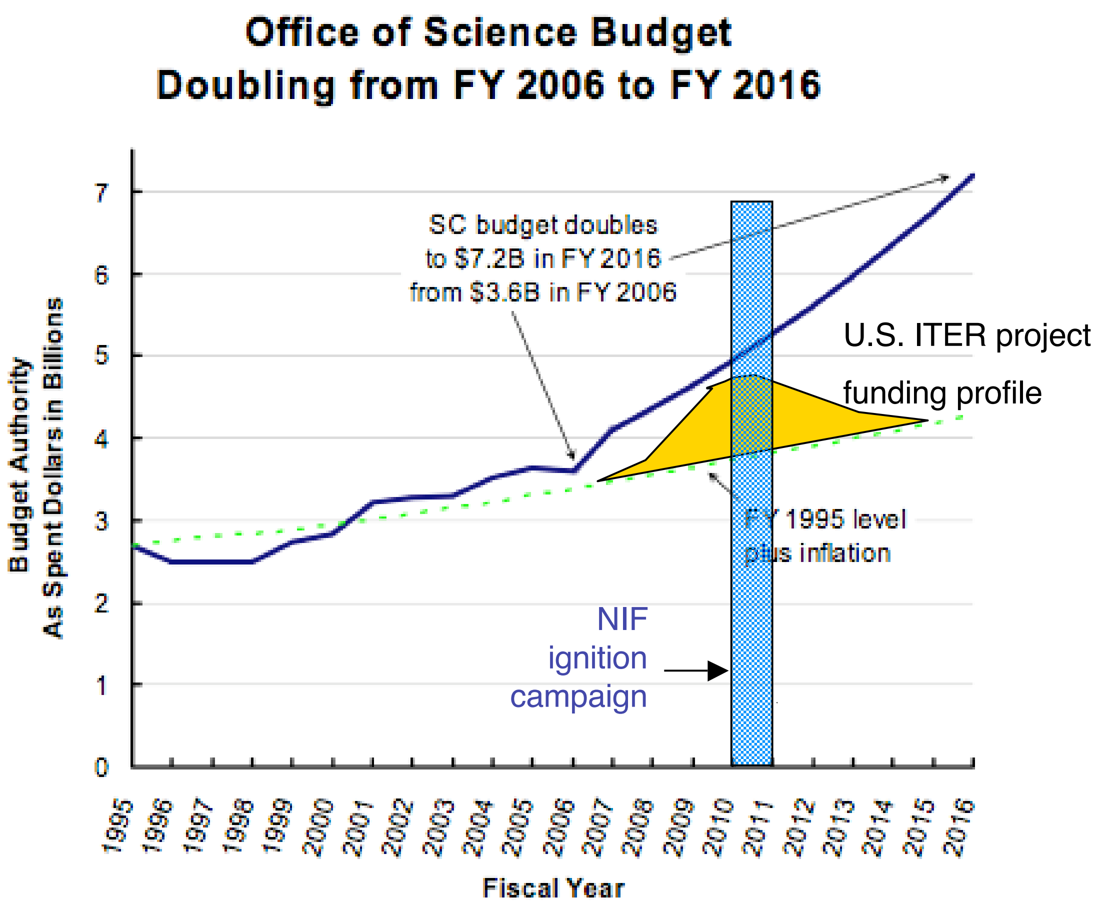
Opportunity for IFE: NIF success, hoped-for physical science funding, and ITER construction funding roll-off

But then a question: "What is your energy strategy?"

- NIF ignition campaign projected to occur with rising physical sciences budget, ITER project funding roll-off

- NIF success, then headlines read, "*Promise for limitless energy!*"

- The challenges are
  - making it up the hill of ITER spending growth
  - Having necessary elements in place near-term for a clear storyline after 2011



We are working with the community towards a meeting this spring (likely April) to sharpen an IFE 20 year vision

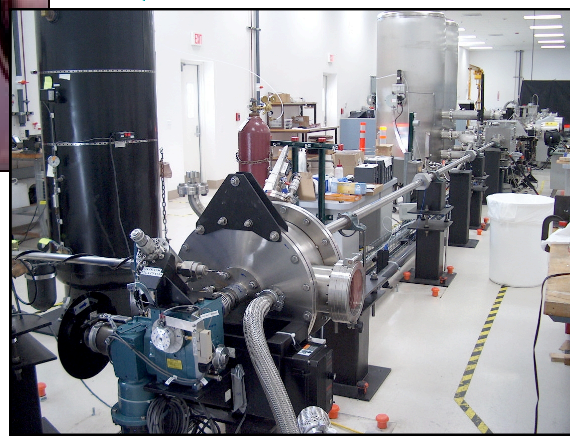
IFE research at LLNL has many facets to support such a strategy

Activities include

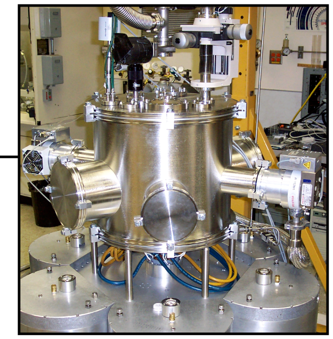
- HAPL program
- Heavy ion fusion
  - The HIFS VNL
  - Advanced accelerator design
- Target design & laser/plasma interactions
- Fast ignition
- Systems technology

The High Average Power Laser (HAPL) program addresses many elements critical to the success of IFE

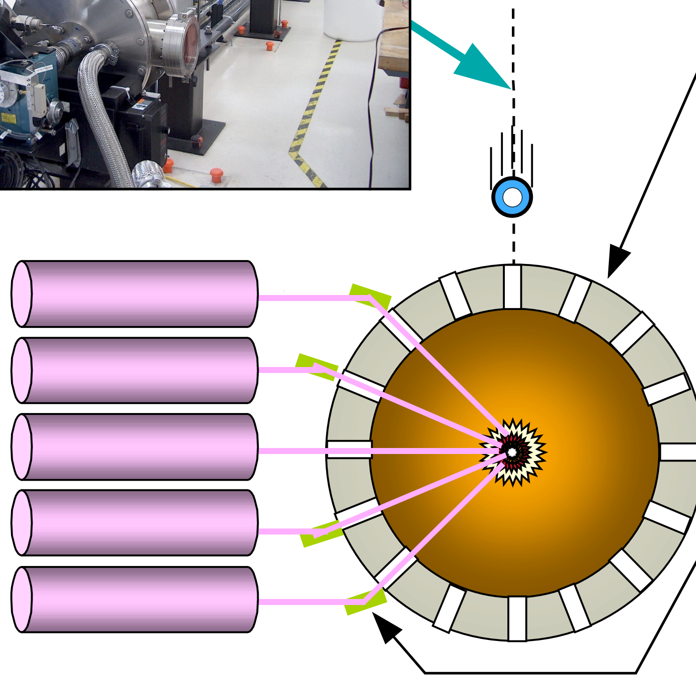
Target, Design, and Fabrication
NRL, LLE, LLNL, GA, LANL, SCHAFER



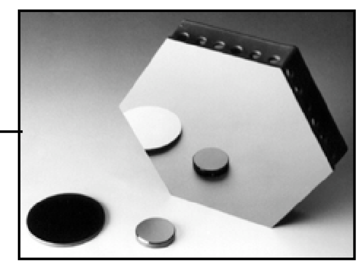
Target Injection
GA, LANL



Chambers
SNL, LLNL, WISC, UCSD, ORNL, UCLA



Laser Drivers
LLNL: DPSSL (Mercury)
NRL: KrF (Electra)



Final Optics
LLNL, LANL, UCSD

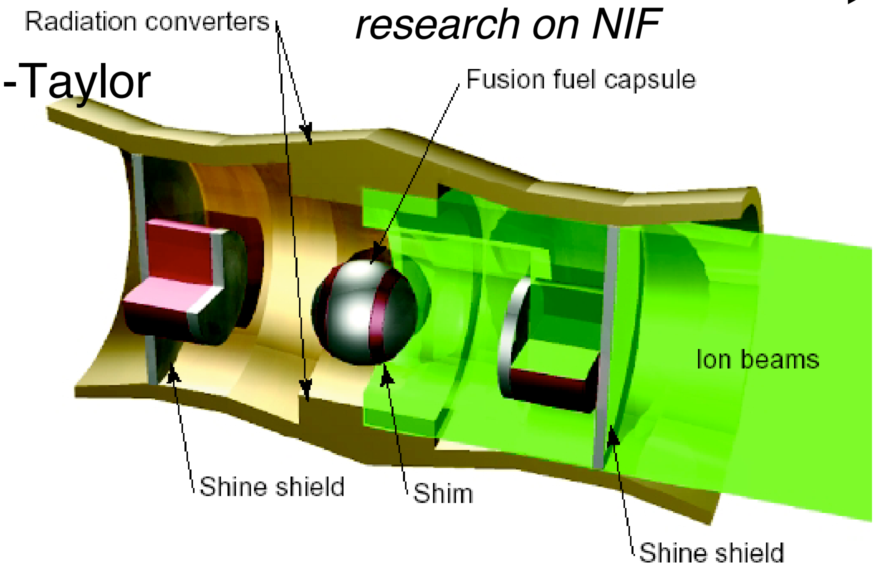
From C. Bibeau (LLNL)

The FEP theory efforts contribute directly to the science of NIF ignition

In the last 8 years, the following are examples of discoveries that have been made that have their origins within the LLNL FEP:

- Identified minimum kinetic energy required for ignition vs. drive pressure, adiabat, and implosion velocity. Sets ignition requirements for NIF
- Studied robustness of targets w.r.t. Rayleigh-Taylor & implosion velocity.
- Designed and fielded capsules (with SNLA and GA) that have increased robustness to asymmetries
- Proposed radiation shine shields to improve radiation symmetry in holhraums.
- Proposed use of low density materials in holhraum walls to reduce hydrodynamic losses.

HIF will benefit from the target physics research on NIF →



e.g. Callahan & Tabak, Nuclear Fusion 39, 883 (1999)

Heavy ion fusion science VNL is ready for WDM studies and has advanced the science of accelerators

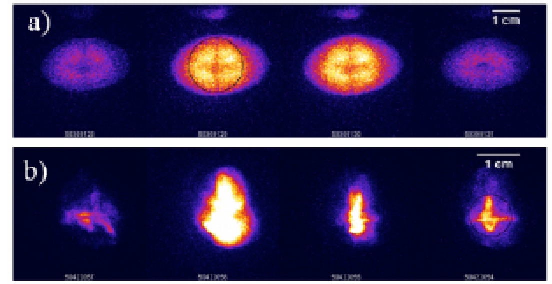
- With LBL & PPPL
- Developing experimental plan to utilize access to WDM regime in 2008
- Drift compression, electron cloud work are recent research highlights

Drift compression experiments at NDCX

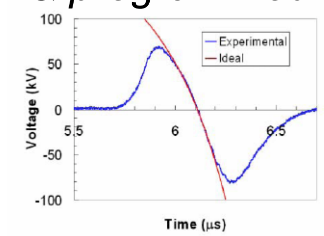
Radial focus

Non-neutralized

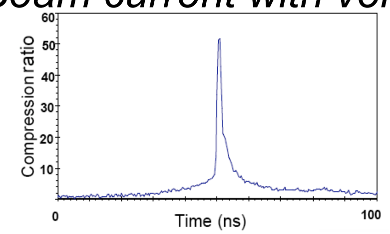
neutralized



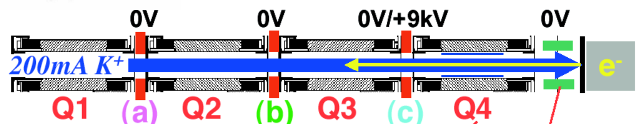
Ideal & programmed tilt

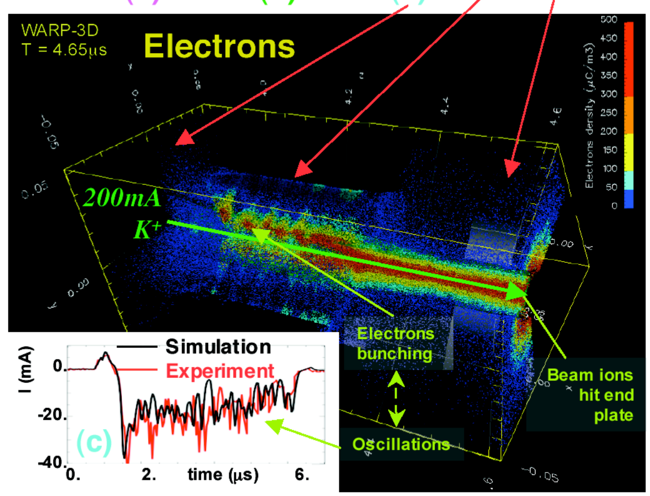


Beam current with velocity tilt



V&V: electron cloud measurements & simulation





Roy et al., Phys. Rev. Lett. 95, 234801 (2005)

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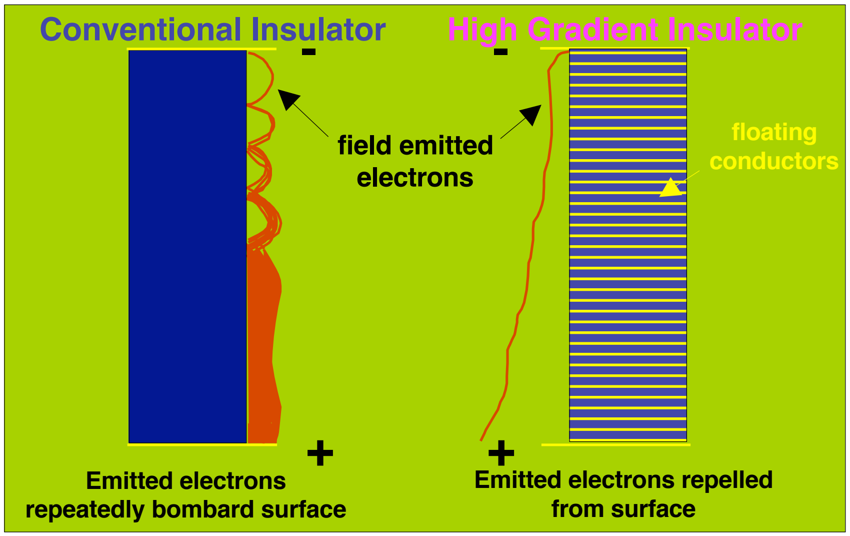
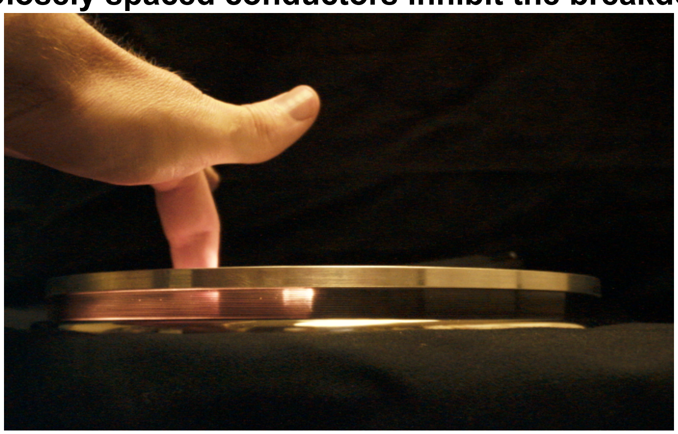
High gradient cells may be a foundation for a new, compact heavy ion accelerator

- *Beam physics group, LLNL*

Dielectric Wall Accelerator (DWA) incorporates pulse forming lines into a high gradient cell with an insulating wall

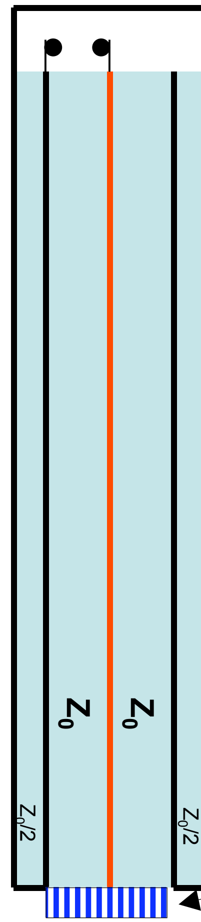


Closely spaced conductors inhibit the breakdown process

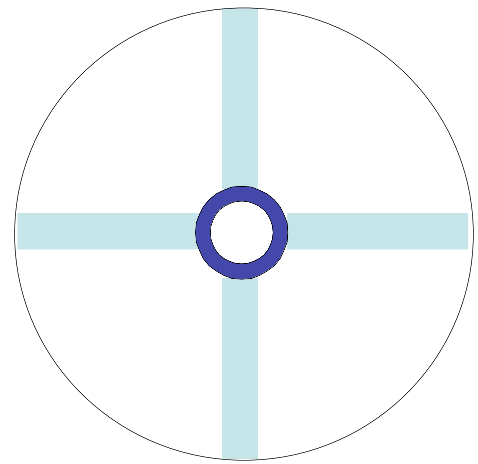


HGI structure forms a periodic electrostatic focusing system for low energy electrons

Leopold, et. al., IEEE Trans. Diel. and Elec. Ins. 12, (3) pg. 530 (2005)

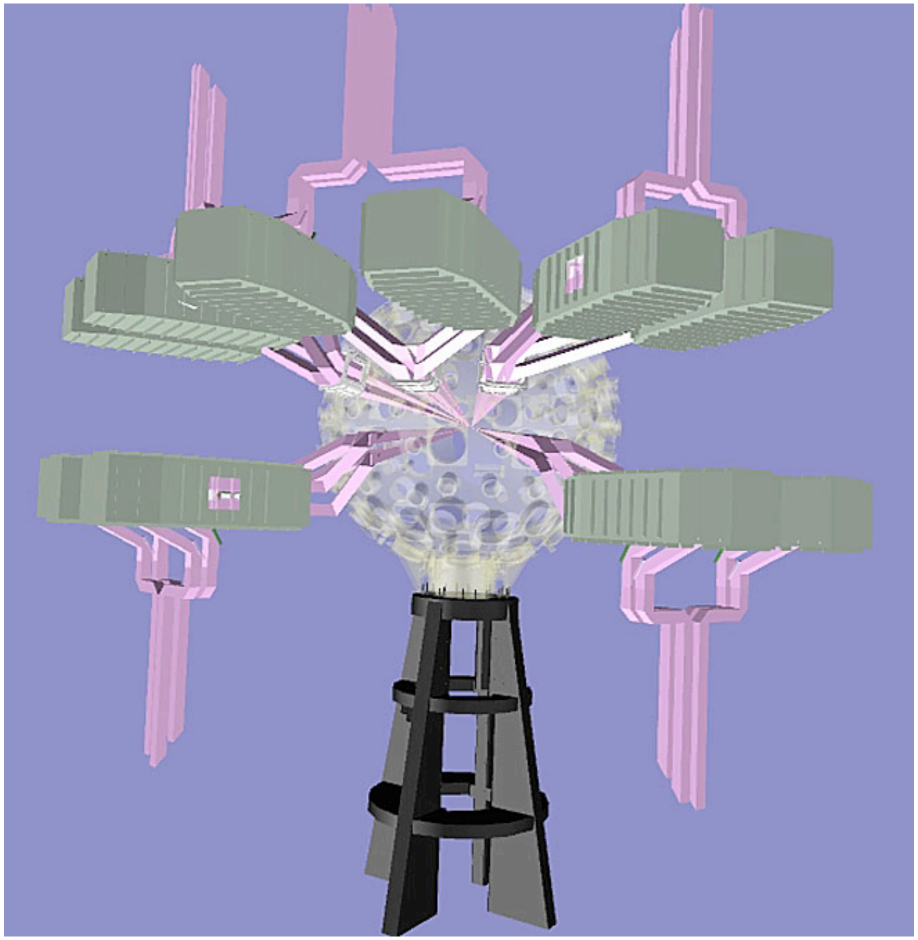


High gradient cell with potential for >10 MV/M



High gradient insulator

NIF could be adapted to demonstrate high gain fast ignition

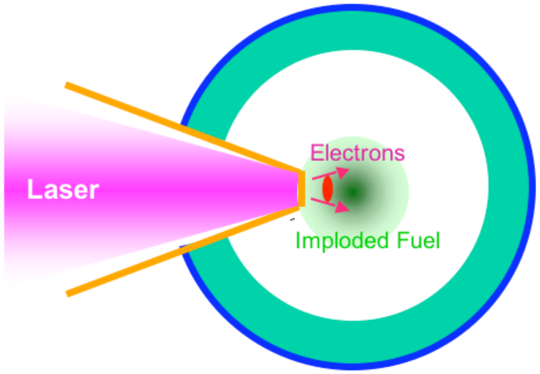


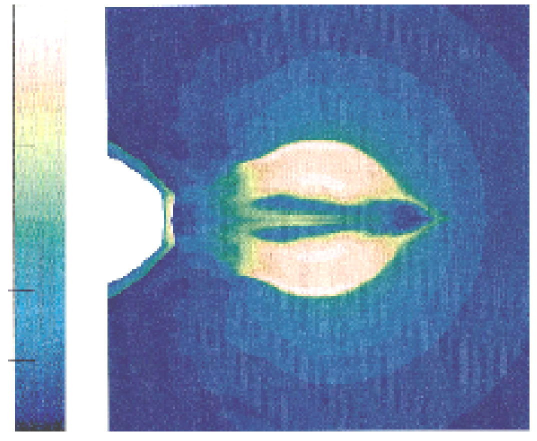
Advanced Radiography Capability (ARC) would provide the tools: petawatt lasers for radiography backlighting

Fast ignition may be a critical strategic element for ignition, and certainly for IFE

- The FEP has run time aimed at fast ignition physics on Titan (LLNL; recently commissioned), RAL (UK), in preparation for operations on Omega EP (U. Rochester) in '08

- FI brings extensive university collaboration to LLNL through the OFES, FSC and ILSA (including 16 students / postdocs from UCD,UCSD and OSU)





•Ist hydro design by S Hatchett, M Tabak et al. Anomalous Abs. Conf. April 2000

Titan
Two beams 350J ,10 ps, 1kJ ,1 ns

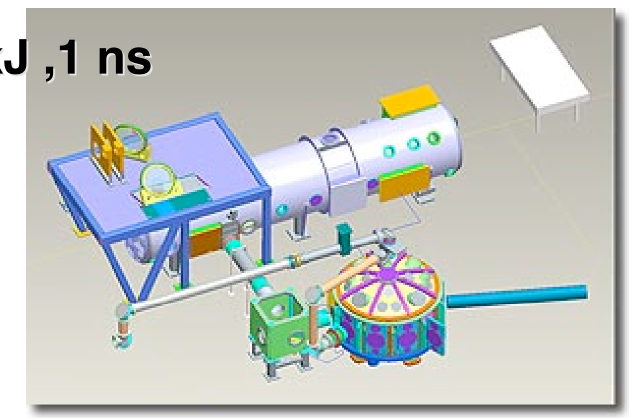


Illustration of the laser bay and target area of the two-beam Titan laser.

The LLNL FEP research & resources enable broad contributions to fusion energy research

- The lab offers its resources for advancing fusion energy
- Major experiment efforts and theory focal points in MFE are well aligned with ITER needs
- A validation and verification focus of the LLNL FEP benefits both theory and experiment. A leading example is with SSPX, where theory guides experimental choices.
- There is an obligation and opportunity to leverage the attention afforded to IFE by NIF success. LLNL seeks to work with the national community to define an IFE vision

End