# Accelerator-Driven High Energy Density Physics Workshop-Motivation and Purpose

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## Motivation and Purpose:

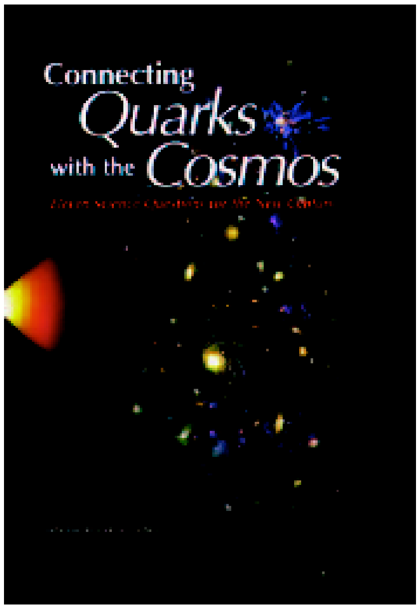
- **Explore issues and opportunities for accelerator-driven HEDP**
- **Provide input to HIF-VNL program on key questions:**

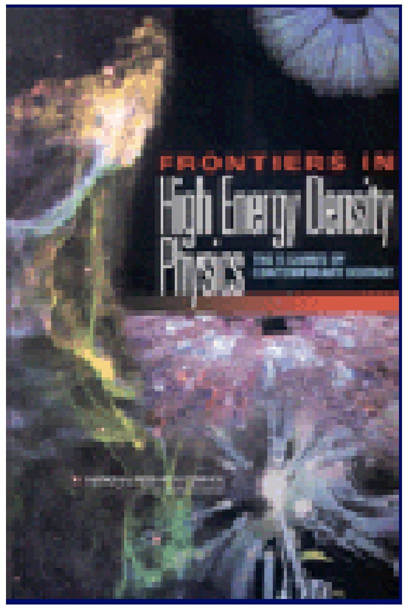
***-How can the heavy ion program contribute to HEDP? (Ray Orbach-DOE)***

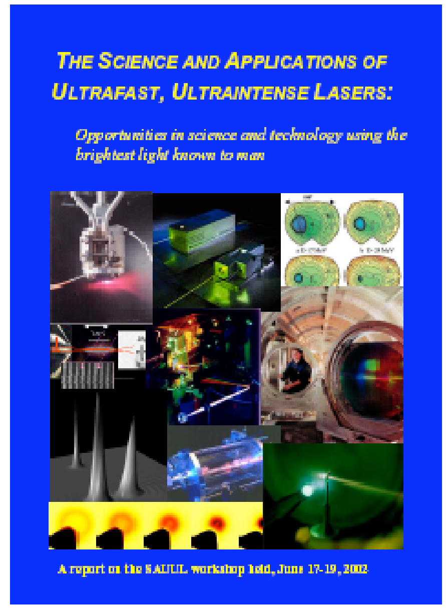
***-How can heavy ion beams be compressed to the high intensities required for creating high energy density matter and fusion ignition conditions? (National Task Force-HEDP & Fusion Energy Science Advisory Committee)***

***-What are competing approaches for accelerator-driven HEDP (VNL-PAC)***

# Washington interest in high energy density physics has grown due to several recent landmark reports….




*FRONTIERS FOR DISCOVERY IN*

*HIGH ENERGY DENSITY PHYSICS*

*Prepared for*

Office of Science and Technology Policy

National Science and Technology Council

Interagency Working Group on the

Physics of the Universe

*Prepared by*

National Task Force

on High Energy Density Physics

*July 20, 2004*

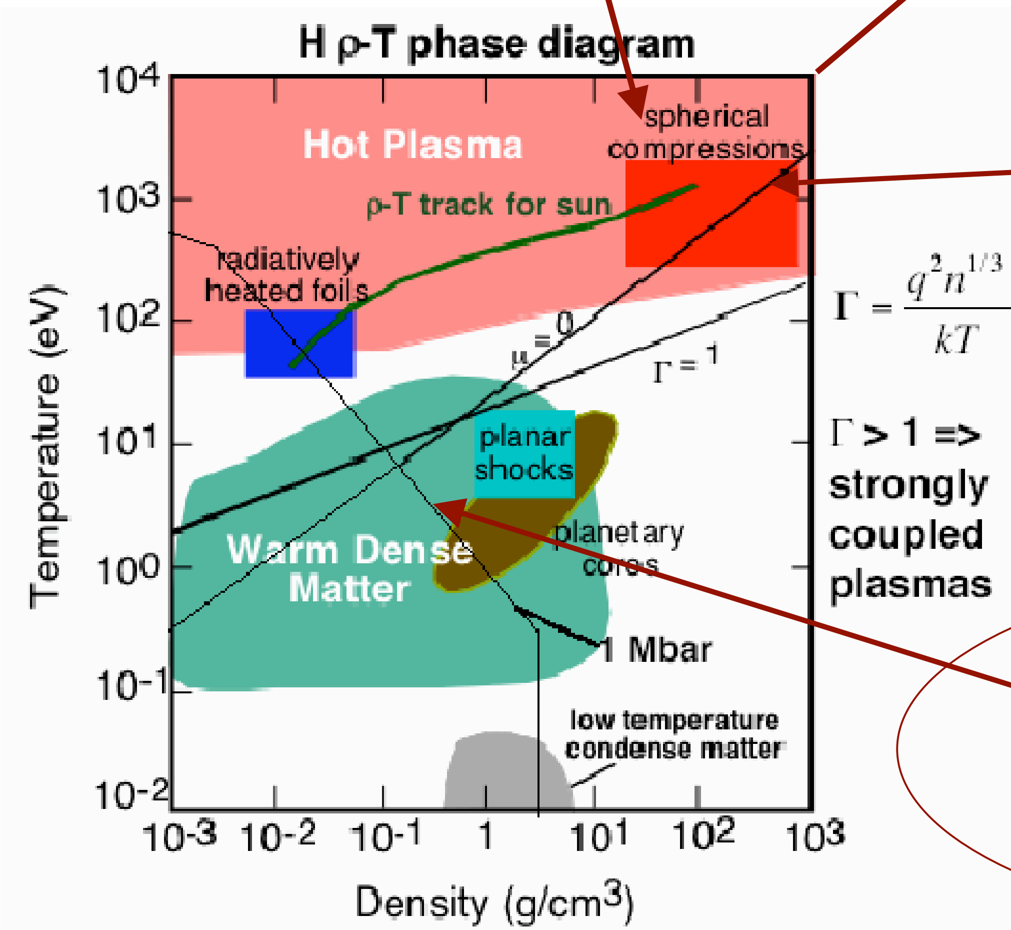
## …but there are constraints on physical science spending (OSTP/OMB)

## →implies refocusing some programs (like HIF) towards HEDP

# HEDP has rich discovery potential. Different agencies (NNSA, HEP, OFES, NSF..) are seeking different niches in the broad HEDP parameter space that can be synergistic with traditional program science goals

**Fast igniter relativistic plasmas**

**Quark-gluon plasmas**
***(off scale in this chart)***




**Fusion: Burning plasma propagation in dense fuel**

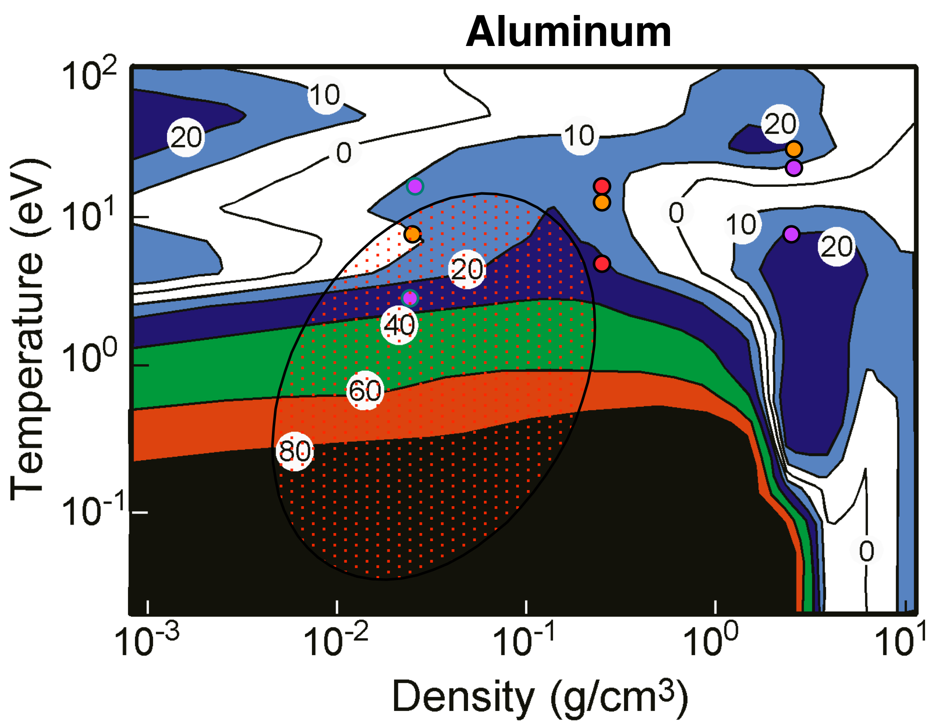
***Most relevant for this workshop:***

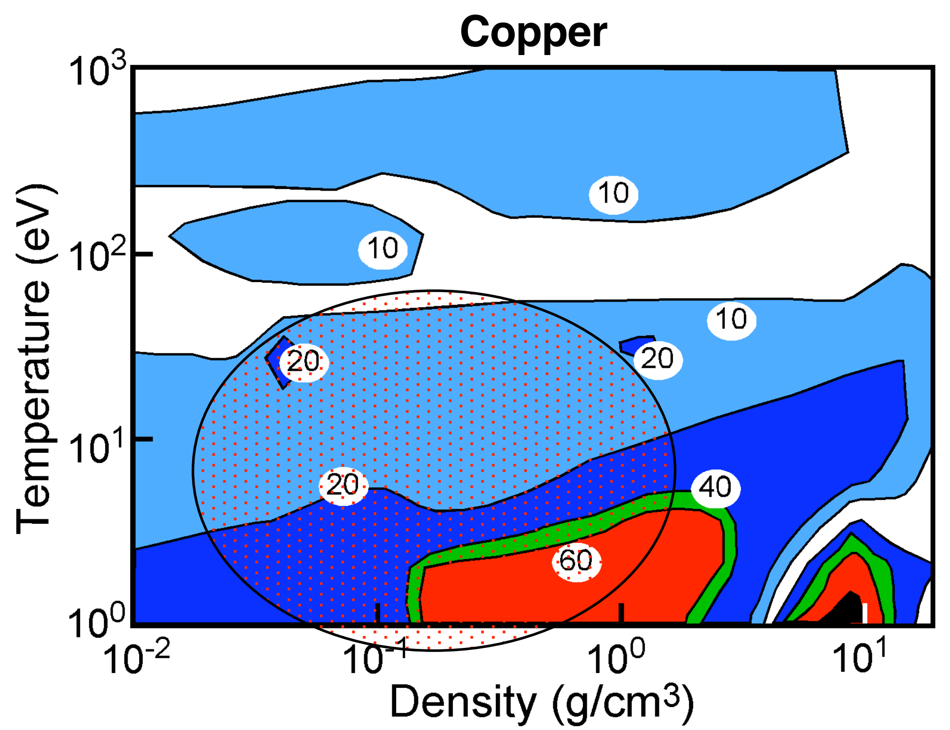
***Strongly-coupled plasmas:***
***Many ab-initio equation of state and opacity theories remain unresolved for existing laser-shock heating data***

**HEDP definition: U> $10^{11}$ J/m$^3$; P> 1 Mbar; kT > 1eV**

# Dense, strongly coupled plasmas $10^{-2}$ to $10^{-1}$ *below* solid density are potentially productive areas to test EOS models

**Contours of % differences in pressure for different EOS theories**




- **EOS Differences > 80% are common**
- **Measurements are *essential* for guidance**
- **Where there is data the models agree!!**
  - **Data is along the Hugoniot - single shock □-T-P response curve**

**(slide courtesy of Richard Lee- see White Paper )**

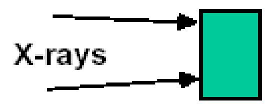
# Multi-agency-supported HEDP science would benefit from a variety of facilities offering different tools, shots on demand, and different convenient locations for students

***An Office of Fusion Science-supported program in compressing ion beams and focusing chambers can complement NNSA/other-supported facilities for High Energy Density Physics.***

- Foils preheated by hard x-rays

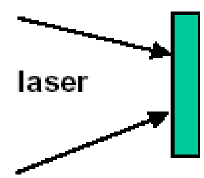

XFEL heating (LCLS) → small energy/volumes (~1 μm radius, ~0.1 μm thickness) may limit diagnostic accuracy. Poor coupling to lower Z.

- Supersonically heated foams or low Z materials (thermal x-rays)



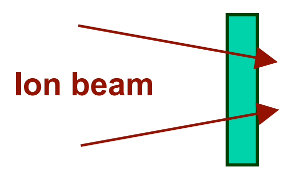

MJ of soft-x-rays available on Z but limited number of shots

- Shock compressed and heated thin foils




Lasers absorb at critical density << solid density→ large density/ pressure gradients

- **Focus of this workshop: Developing tailored (Bragg-peak) ion beams for heating targets**




Fast heating of a solid with penetrating ions →more volume, lower gradients→ more accurate EOS

***The HIF-VNL PAC (Aug 5 2004) urged we also consider developing HEDP targets, chambers and diagnostics in parallel exploiting existing drivers (e.g., Z, LCLS, ETA, etc.)***

## Ten-year plan* to address the compelling question:
## *How can heavy ion beams be compressed to the high intensities required for creating high energy density matter and fusion ignition conditions?*

| Science Areas | FY05 | FY06 | FY07 | FY08 | FY09 | FY10 | FY11 | FY12 | FY13 | FY14 | FY15 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| High Brightness Beam Transport | 4 quadrupoles 4 solenoids | | Upgrades (larger and/or moremagnets) | | | Upgrades of injectors and diagnostics to further reduce beam temperature | | | | | |
| Longitudinal Beam Compression | 10x compression | | 100x compression with 10x focusing | | | Active beam correction experiments to explore potential 1000x compressions | | | | | |
| Focusing onto Targets | Large plasma source | | Plasma lens and time dependent corrections | | | Advanced focusing experiments e.g., induced self-pinching | | | | | |
| Beam-Target Interactions | | | Target design and fast beam diagnostics | | | Beam energy loss and deposition profiles, target $T_e$ (t) $n_e$(t) diagnostics and modeling | | | | | |
| Advanced Theory and Simulations | Source to target models | | | | | Source through target models | | | | | |
| Estimated resource needs | $12 M/yr | | $14M/yr | | | $16M/yr | | | | | |

**2yr Milestones:**
A2: 10x neutralized compression
B2: Gas/electron limits in 4 magnets

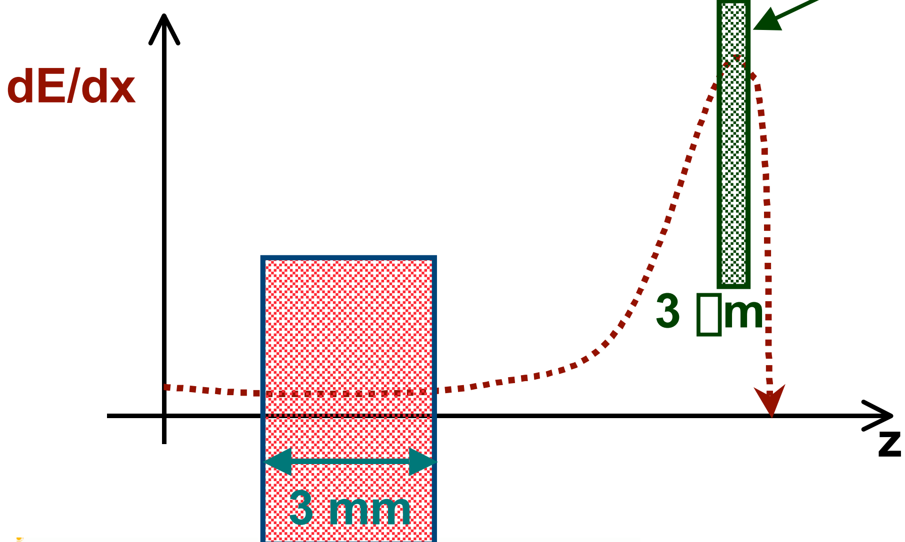
**5yr Milestones**
A5: 100x neutralized compression and focusing
B5: Gas/electron predictive capability for HEDP accelerators

**10yr Objective:**
Beam and target physics knowledge base for heavy-ion-driven HEDP user facility

****from National HEDP Task Force*** **→*New facilities must consider alternative approaches***

## The German and US heavy-ion programs have complementary approaches to HEDP. HEDP is the common near term goal, but fusion remains a long term goal.

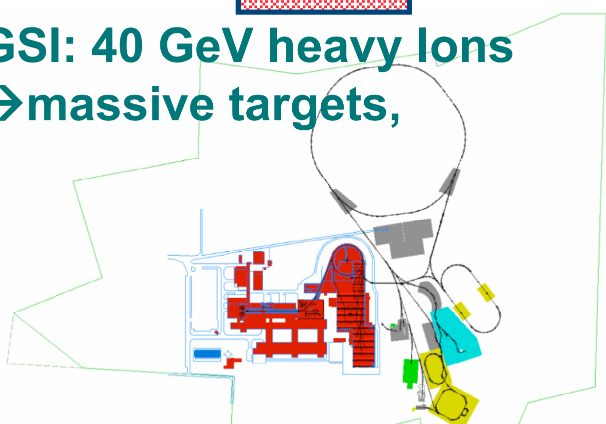
**Ion energy loss rate in targets**




**Maximum dE/dx *and* uniform heating at Bragg peak** (L. R. Grisham, *Moderate Energy Ions for High Energy Density Physics Experiments,* Physics of Plasmas, in press (2004).

**→Te > 10 eV for 30J, 30 MeV LBNL HEDP accelerator.**

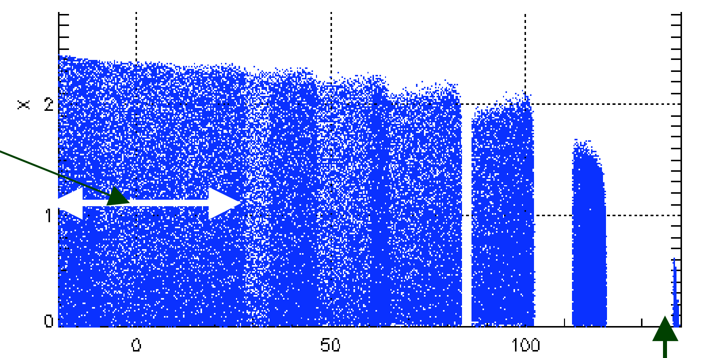
**GSI: 40 GeV heavy Ions →massive targets,**



**→Te < 1 eV @ 1 kJ**

**Simulation of dramatic ion pulse compression in a plasma pre-filled-solenoid**

**Initial bunch length**




**>50,000X intensity increase at focus**

## Combining low Bragg peak energy, target energy densities >$10^{11}$ J/$m^3$, and pulses shorter than target expansion times (<1 ns) leads to >$10^{13}$ ions/cm incident on target (see John Barnard's talk) →New challenges:

→Requires focusing in neutralizing plasma (otherwise high perveance > 0.1 !)

→Requires perveance x longitudinal compression ratios > 0.1 upstream

| □(g/cm$^3$)(%solid) | 0.027 (1%) | | | 0.27 (10%) | | | 2.7 (100%) | | |
|---|---|---|---|---|---|---|---|---|---|
| Foil length (□) | 480 | | | 48 | | | 4.8 | | |
| kT (eV) | 3.1 | 4.8 | 15 | 4.2 | 7.3 | 18 | 5.9 | 12 | 22 |
| □□ | 1.1 | 2.1 | 2.7 | 0.56 | 1.7 | 2.6 | 0.56 | 1.2 | 2.5 |
| $□_{ii}=Z^{*2}e^2n_i^{1/3}/kT$ | 0.45 | 1.1 | 0.95 | 0.30 | 0.63 | 1.4 | 0.30 | 0.70 | 1.6 |
| $N_{ions}/(r_{spot}/1mm)^2$ /$10^{12}$ | 1 | 3 | 10 | 1 | 3 | 10 | 1 | 3 | 10 |
| □t (ns) | 84 | 48 | 27 | 3.8 | 2.2 | 1.2 | 0.04 | 0.03 | .014 |
| U (J/m$^3$)/$10^{11}$ | .015 | .045 | 0.15 | 0.15 | 0.45 | 1.5 | 1.5 | 4.5 | 15 |

**Example: Neon Z=10, A=20.17, $E_{min}$=7.7 MeV, $E_{center}$=12.1 MeV, $E_{max}$=20.1 MeV □$z_{min}$ = 40 m**

(Eq. of state, Z*: Zeldovich and Raizer model from R.J. Harrach and F. J. Rogers, J. Appl. Phys. **52**, 5592, (1981).)

## Guidance on hardware costs: fusion program budgets have been ~ flat for the last decade→ what price tags might OFES accept?

- In 1999 the HIF program proposed a 300 M$, 200 MeV multiple beam induction linac for a fusion-driver prototype. Response: OFES told us to stop designing and proposing such a facility.

- In 2002 and 2004, the HIF program proposed a 50M$, 5 MeV single beam induction linac for fusion driver beam physics. Response: OFES encouraged us to present our plans, and then told us there wouldn't be money for it for 10 years.

- In March 2004, we proposed $4 M hardware to upgrade an existing facility to reach HEDP conditions by FY09. Response: OFES said "Don't be afraid to ask for that kind of money".

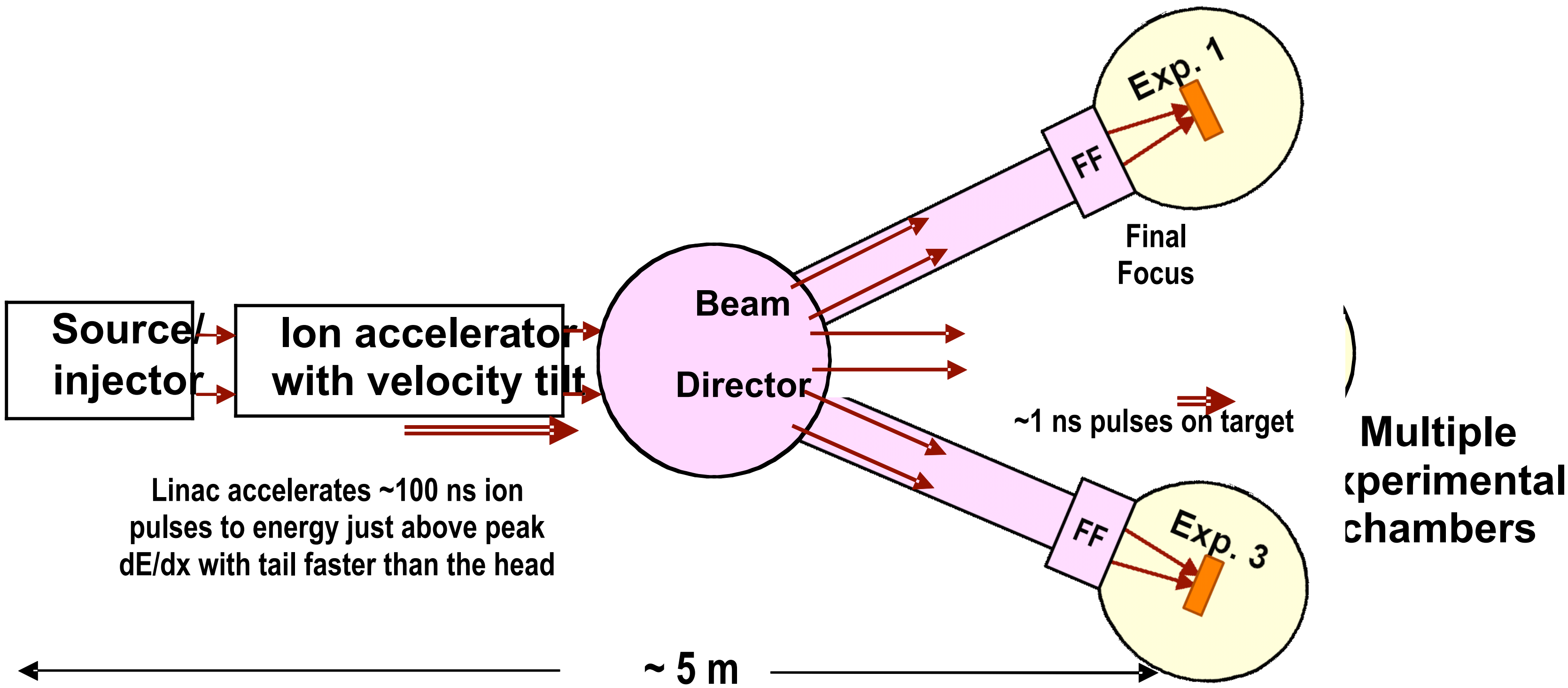
*→We should be able to raise $50 M in less than 10 years, if our research shows a unique combination of desirable attributes for a dedicated HEDP user facility are achievable.*

## In evaluating alternative accelerators for HEDP, please assess the combination of desirable attributes of each: (see white paper distributed)

- **Precise control and uniformity of energy deposition;**
- **Large sample sizes compared to diagnostic resolution volumes;**
- **A benign environment for diagnostics (low debris and radiation background);**
- **High shot rates (10/hour to 1/second) and multiple beamlines/target chambers;**
- **Sites with easy access for broad participation by university scientists and students; and with the technical support for designing and fielding targets for qualified experiments.**

***→Even if there was an existing facility possessing all these attributes, but most shots were reserved for other programs, the science could still benefit from a new facility dedicated to HEDP.***

# The scientific productivity of any accelerator option for HEDP would be greatly enhanced if there were a way to quickly switch the beam between multiple target chambers: please consider switching!



**Thank you all for coming!**

**Put on your thinking caps!**

**We look forward to learning new ways to meet the HEDP challenge!**