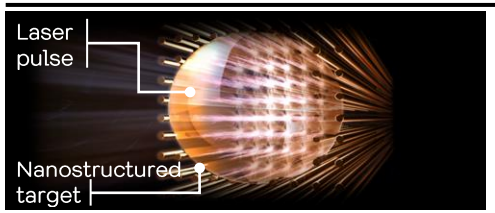
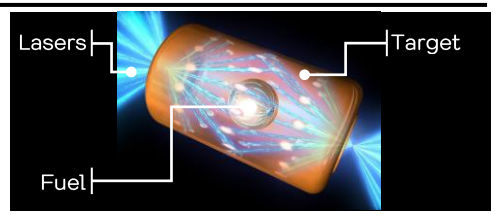
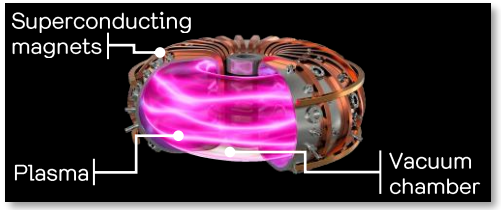
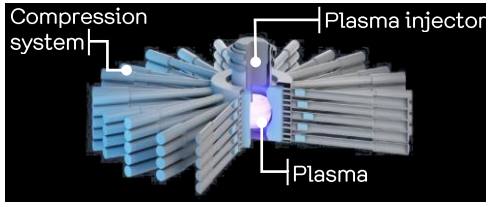
MarvelFusion

Energy for Humanity

Overview Fusion Approaches

Pursuing inertial fusion energy leveraging ultrashort-pulsed lasers and nanofabricated targets

	Inertial Fusion Energy		Magnetic Fusion Energy	Magneto-Inertial Fusion
				
Companies	MarvelFusion	FOCUSED ENERGY, XCIMER	GAUSS FUSION, Proxima Fusion	HELION, generalfusion
Approaches	• Direct Drive Volume Ignition	• Indirect Drive • Direct Drive Fast Ignition	• Tokamak • Stellarator	• Magnetized Target Fusion • Field Reversed Configuration
Confinement	***Ultrashort***-pulsed lasers (fs)	***Short***-pulsed lasers (ps-ns)	***Superconducting*** magnets	e.g. ***Pistons***
Fuel	***Mixed fuels (inc. pB11)***	***DT***	***DT***	***DT, DHe3***

About Marvel Fusion

4 years underway and well-positioned

2019 ***Founded*** in Munich

>€60M ***Private funding*** secured

>70 ***Employees*** with >20 nationalities

>2,000 ***Experiments*** at existing laser facilities

Shareholders

EARLYBIRD

BLUE YARD

PRIMEPULSE

+ individuals from

ATHOS Venture GmbH

Possible. VENTURES

USV

Google

Note: 1) incl. SPRIN-D funding of EUR 45M

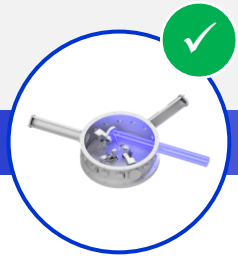
Technical Roadmap

Technical proof-of-concept in execution as milestone for power plant

Existing Facilities

1x scientific laser

Demonstration of fusion physics

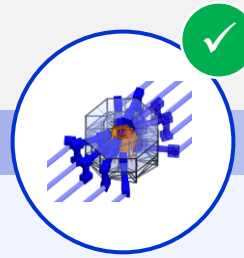


2019-Today

Technical Proof-Of-Concept

2x industrial lasers

Demonstration of technology



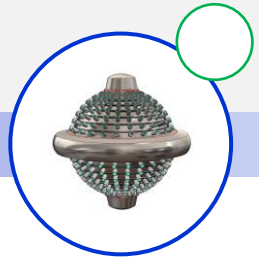
2026+

Most capable short-pulse laser facility and only laser facility tailored to commercial fusion technology

Prototype

100's industrial lasers

Integrated engineering and system design (100 MW)



2032+

Commercial Plant

100's industrial lasers

Cost-effective and reliable baseload power (300-800 MW)

2035+

Partnerships

Parallelization of tech development and physics demonstration through partnerships

SIEMENS energy

Partnership since ***2021 on energy conversion systems and engineering***

BASF

Partnership since ***2022*** on ***material science and nanostructure technology***

THALES

Partnership since ***2022*** on ***ultrashort-pulsed, high-power lasers and components***

Laser Facilities

CALA

eli nuclear physics

COLORADO STATE UNIVERSITY

TEXAS The University of Texas at Austin

RISE HUB (funded by DOE)

XCIMER

Los Alamos NATIONAL LABORATORY

GENERAL ATOMICS

COLORADO STATE UNIVERSITY

Stanford University

UNIVERSITY OF ILLINOIS URBANA-CHAMPAIGN

Cornell University

U.S. NAVAL RESEARCH LABORATORY

Our Team

Team with expertise and track record across key capabilities

Moritz von der Linden
Chief Operating Officer
20+ years of experience in successfully founding and managing the high-tech companies ***360T and CRX***

Heike Freund
Chief Operating Officer
Former Partner in McKinsey's Operations practice, serving mainly automotive, machinery and high-tech businesses

Dr. Georg Korn
CTO, Co-Founder
Former Technology Director at ELI[1], 10+ years experience in direct drive laser fusion with spherical compression

Prof. Dr. Siegfried Glenzer
Science Advisor & Board Member
Stanford professor for plasma physics, former plasma physics lead at NIF (LLNL), E.O. Lawrence award recipient

Prof. Dr. Hartmut Ruhl
Lead Scientist
Professor for computational and plasma physics at LMU. Expert in quantum transport theory and laser fusion processes

Dr. Marius Schollmeier
Director Experiments
Former Principal Scientist at Sandia National Laboratory in the USA with a focus on Laser-Plasma interaction

Prof. Dr. Gérard Mourou
Chairman of Science Council

Dan Nebe
Director Operations

Dr. Erhard Gaul
Director Laser Systems

Michael Ehrmanntraut
Senior Manager Engineering

Dr. Nicolas Burkardt
Director Finance

Prof. Dr. Barbara Sandfuchs
Director Legal

Marija Kose
Director People

Dr. Karl-Georg Schlesinger
Science & Strategy, Co-Founder

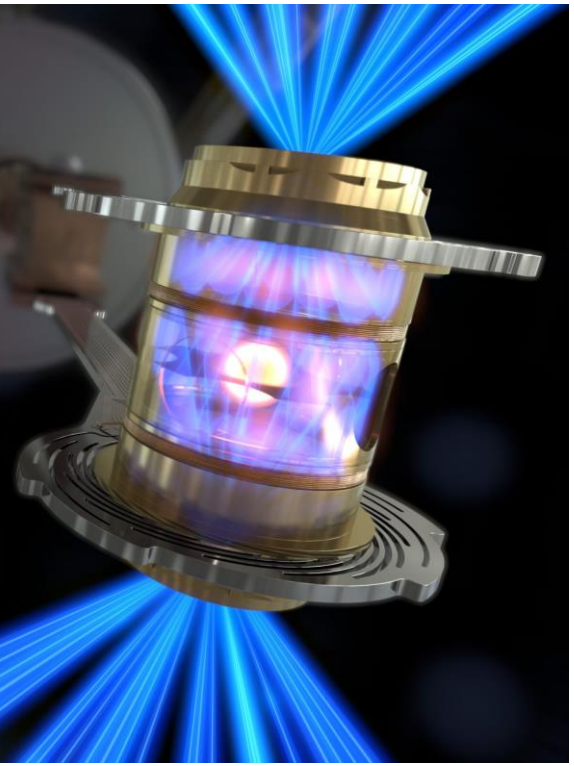
>40% PhDs

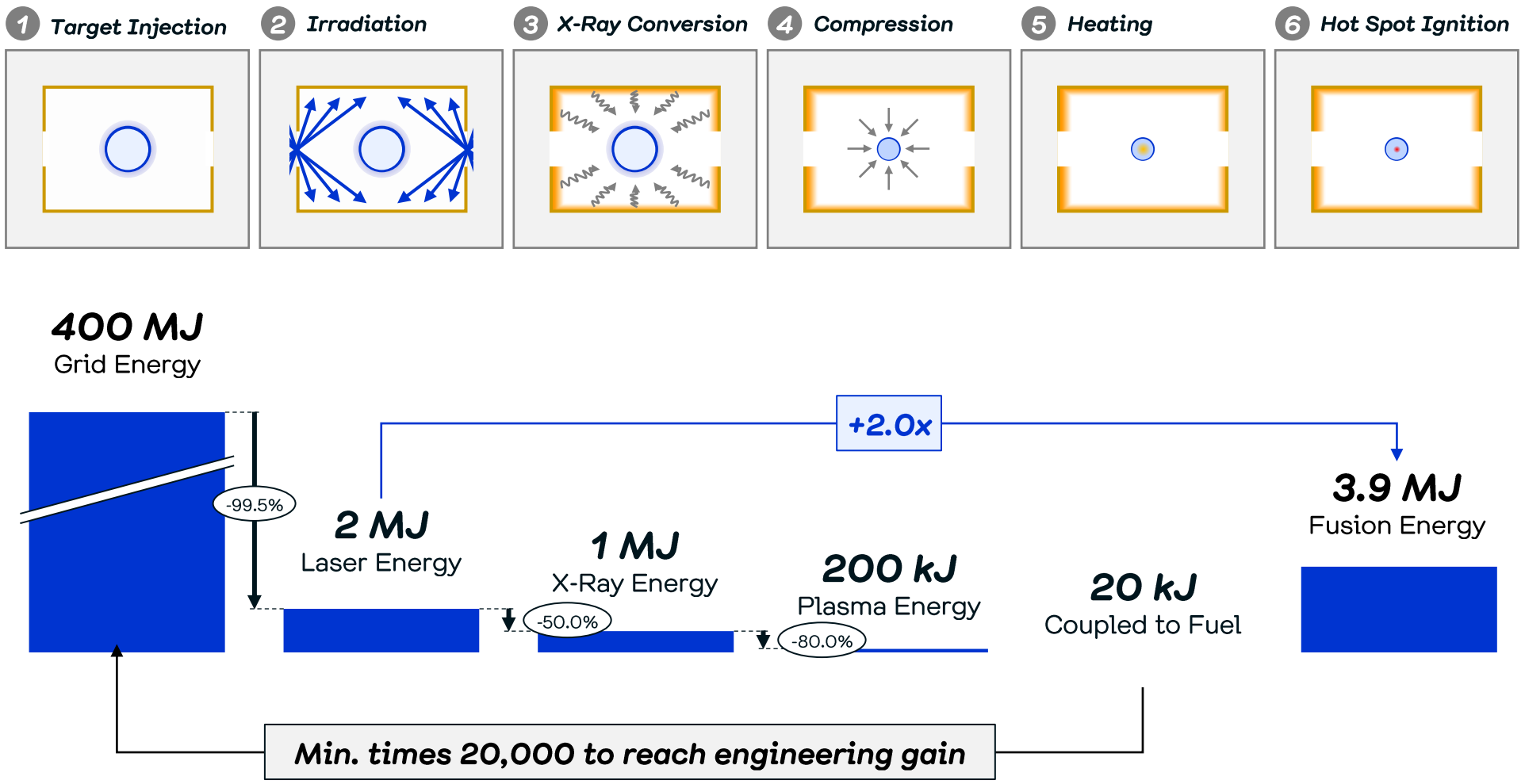
>20 Nationalities

Note: 1) "ELI" – Extreme Light Infrastructure laser facility in Prague, housing the world's largest and most advanced laser infrastructure

National Ignition Facility

NIF approach showed way to ignition but lacks energy efficiency



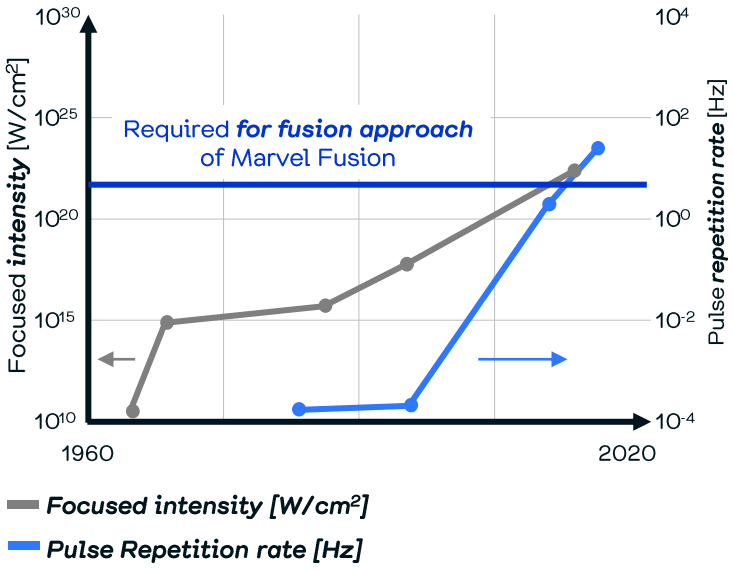


Why Now?

Recent technology leaps are enabling the approach

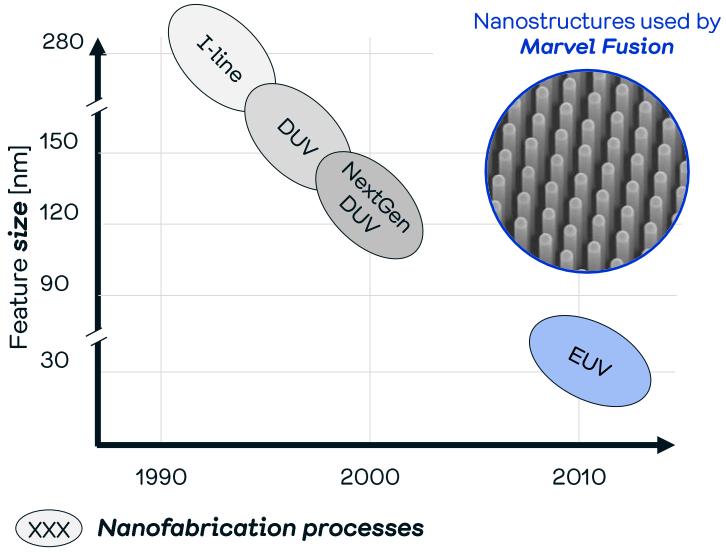
Laser Properties Available

Laser properties have reached required level due to Nobel Prize-winning invention



Feature Sizes Producible

Advanced nanofabrication technologies allow for production of nanostructured targets at scale



Opening a New Fusion Regime

Ultrashort-pulsed lasers and nanostructured targets offer key advantages for reaching commercial fusion

20x improved laser efficiency[1] vs NIF

30x more compact laser design[2]

100x improved laser-target coupling[3] vs. NIF

100% solid, non-cryogenic, non-toxic target

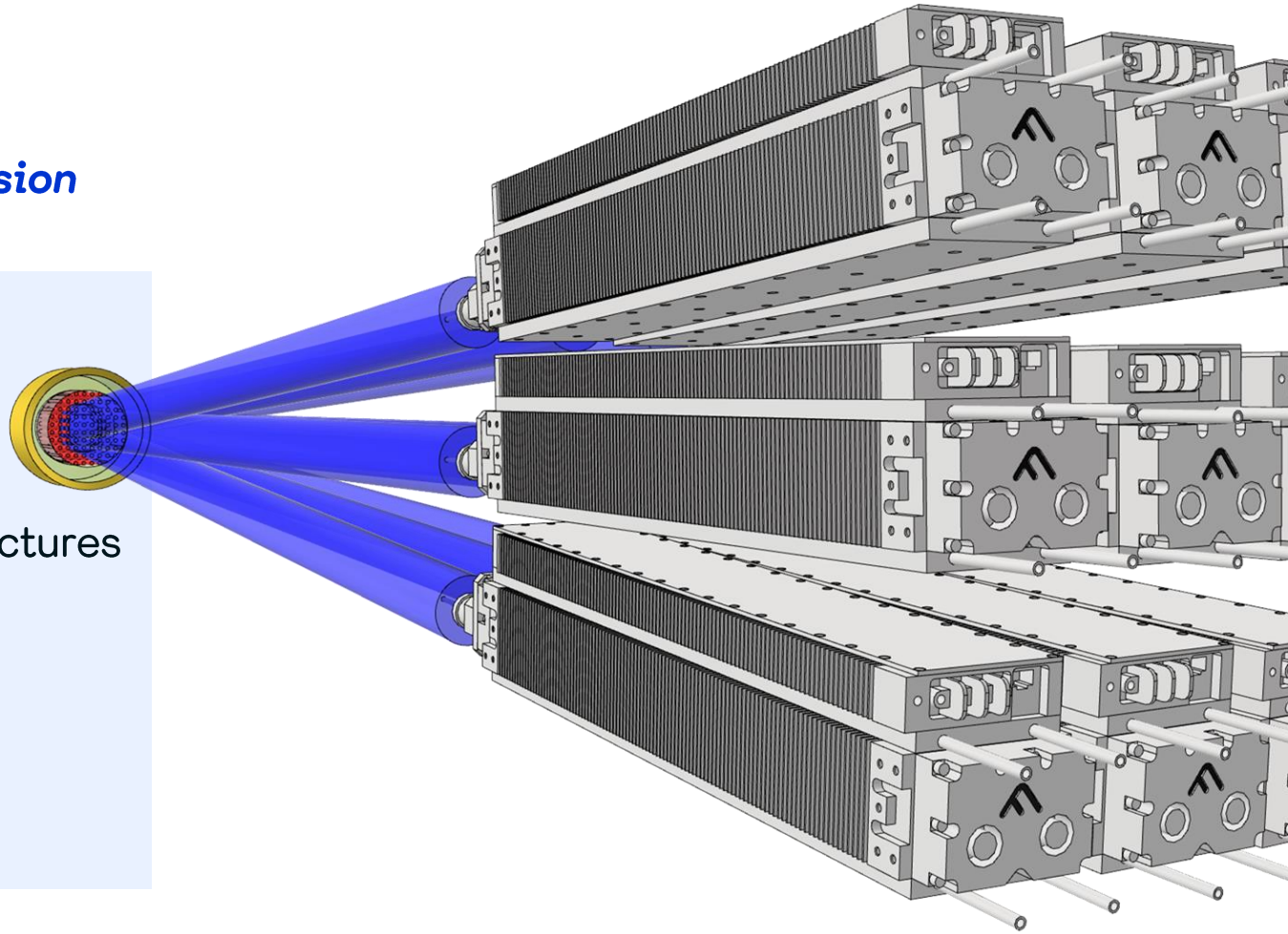
Notes: 1) NIF laser is at approximately 1% wall-plug efficiency; 2) 10m² stackable laser system vs 300m² for a comparable laser system; 3) 100x more laser energy can be coupled into the ions due to the use of nanostructured fuel targets

Our Approach

Ultrahigh-power deposition and efficient laser-fuel coupling

Direct drive, ultrafast, high intensity laser driven fusion concept:

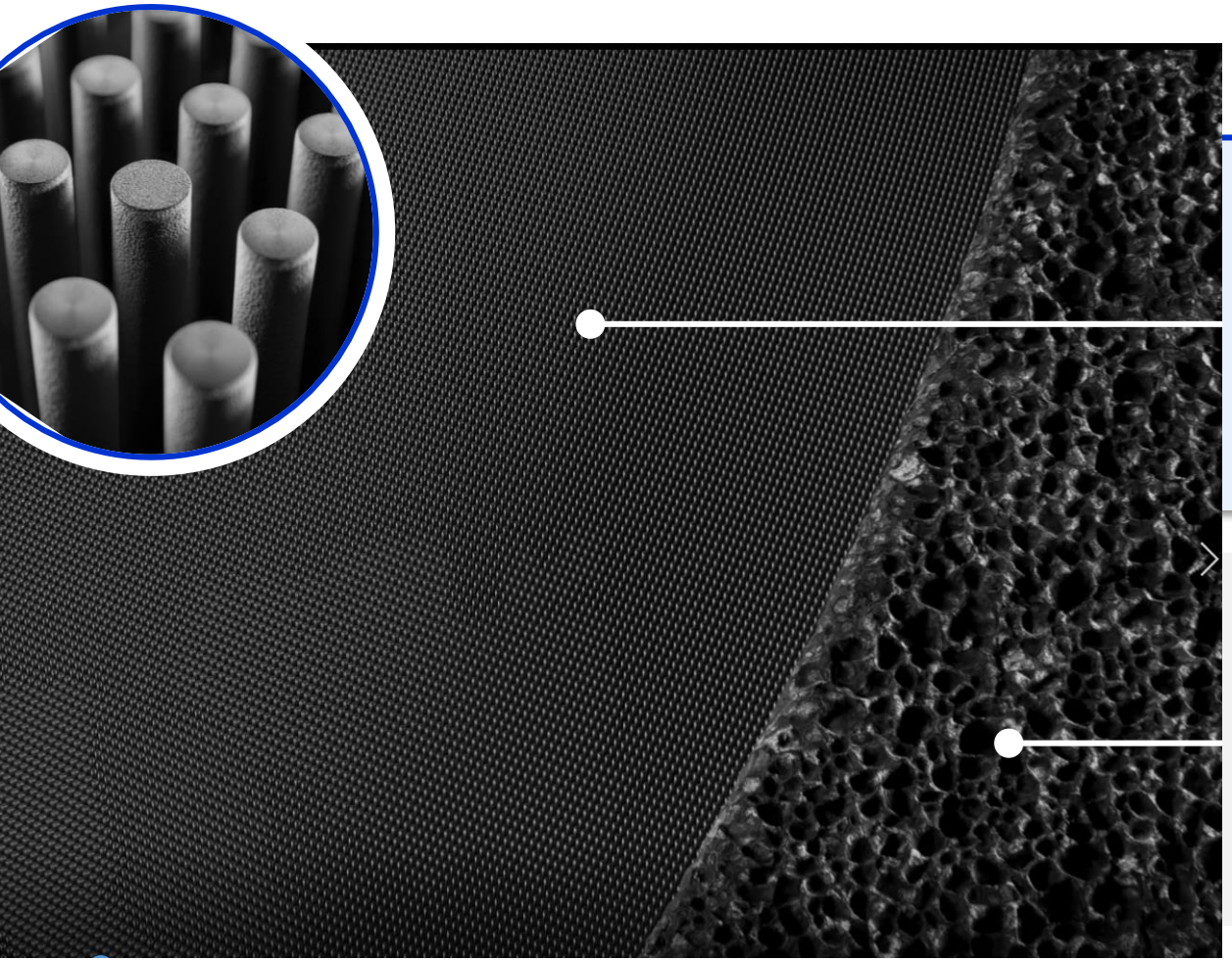
- Ultra-high energy and ***power densities***
- ***Arrays*** of ultrashort, high-contrast laser pulses
- High laser-fuel ***coupling efficiency*** due to nanostructures
- Ensemble of ***mixed fuel*** types
- Absence of fuel ***pre-compression***
- Path to ***economically viable*** power plants



Reference: H. Ruhl and G. Korn, arXiv:2306.03731 and references therein

Our Approach

Nano Accelerator technology as key innovation, facilitating a 100x improved laser-energy conversion



Stage 1:
Nano Accelerator

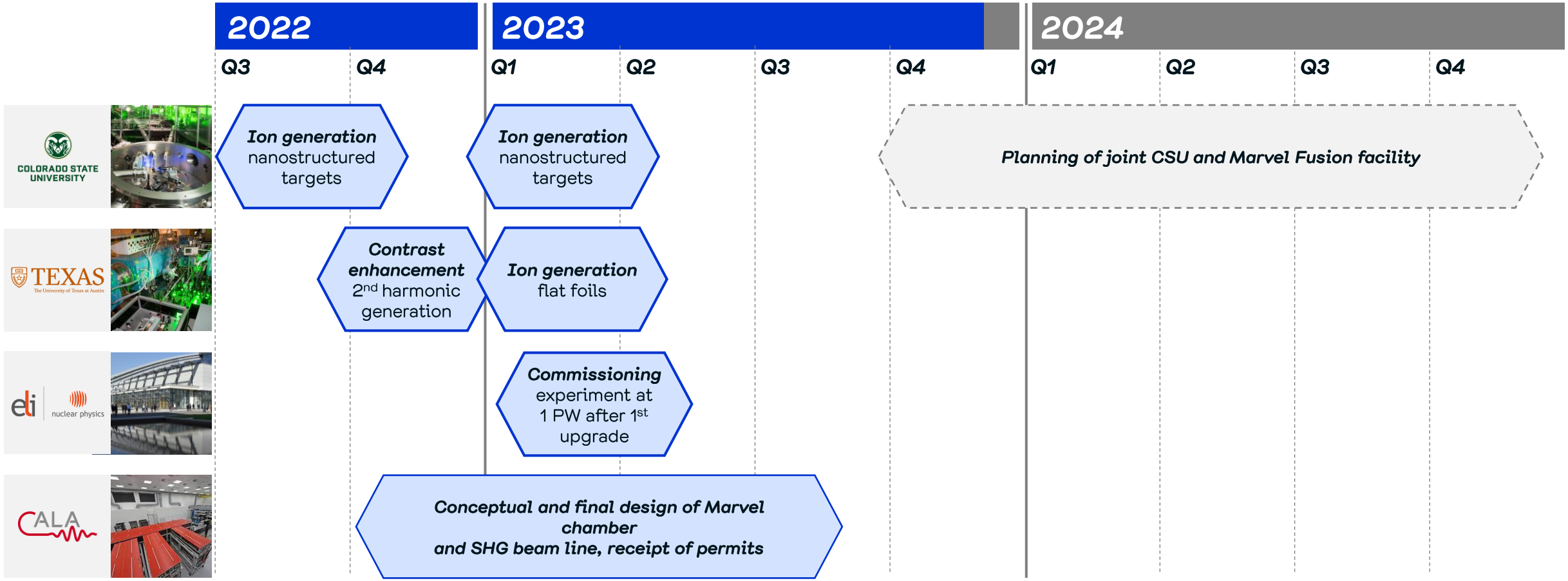
1. ***Laser Absorption***
2. ***Ion Acceleration***

Stage 2:
Fusion Fuel

3. ***Ion Energy Deposition***
4. ***Heating and Ignition***

Experimental Roadmap

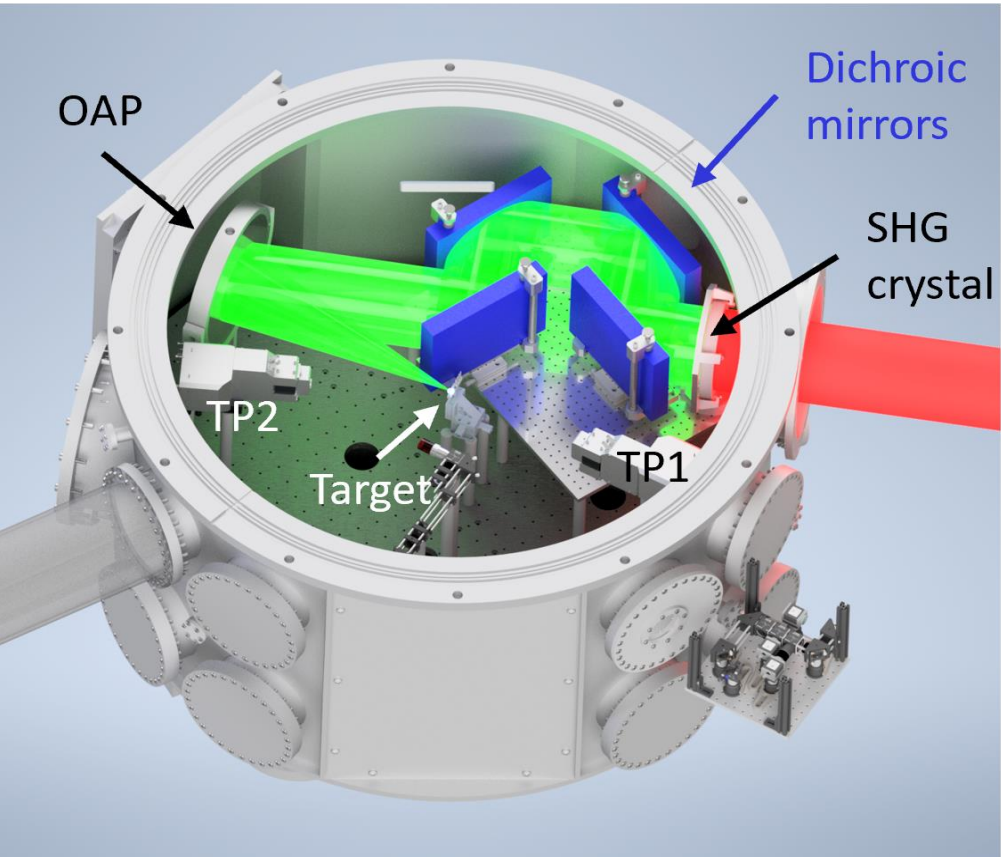
Validated physics drivers of concept at existing PW laser facilities

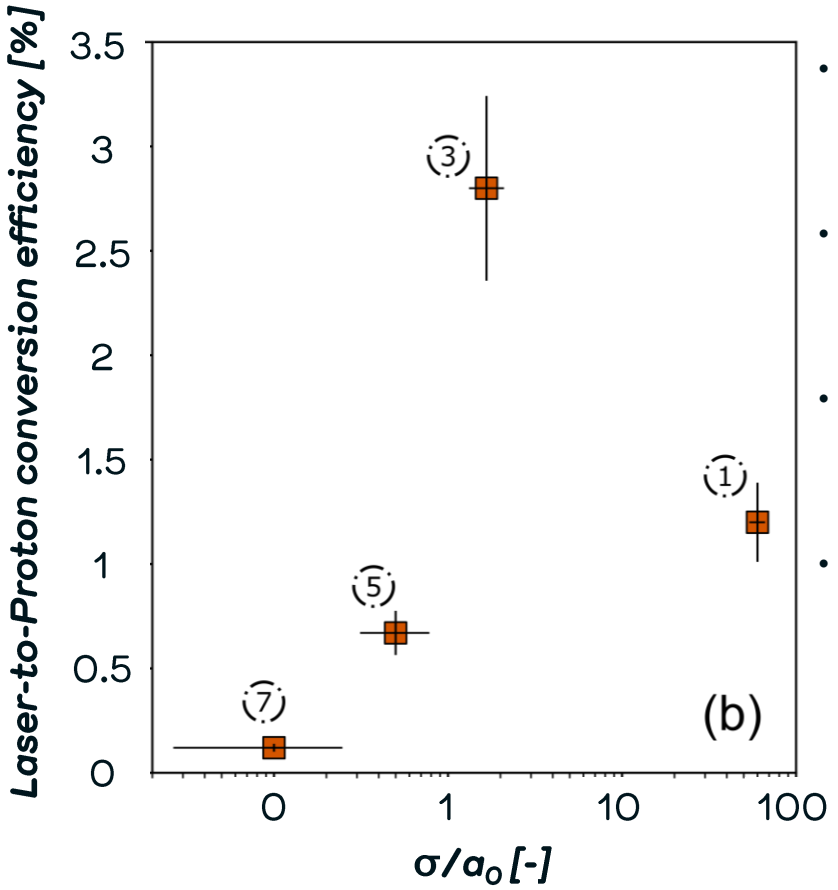


Results Experiments

Efficient particle acceleration from foils using 100-femtosecond laser pulses

TEXAS
The University of Texas at Austin





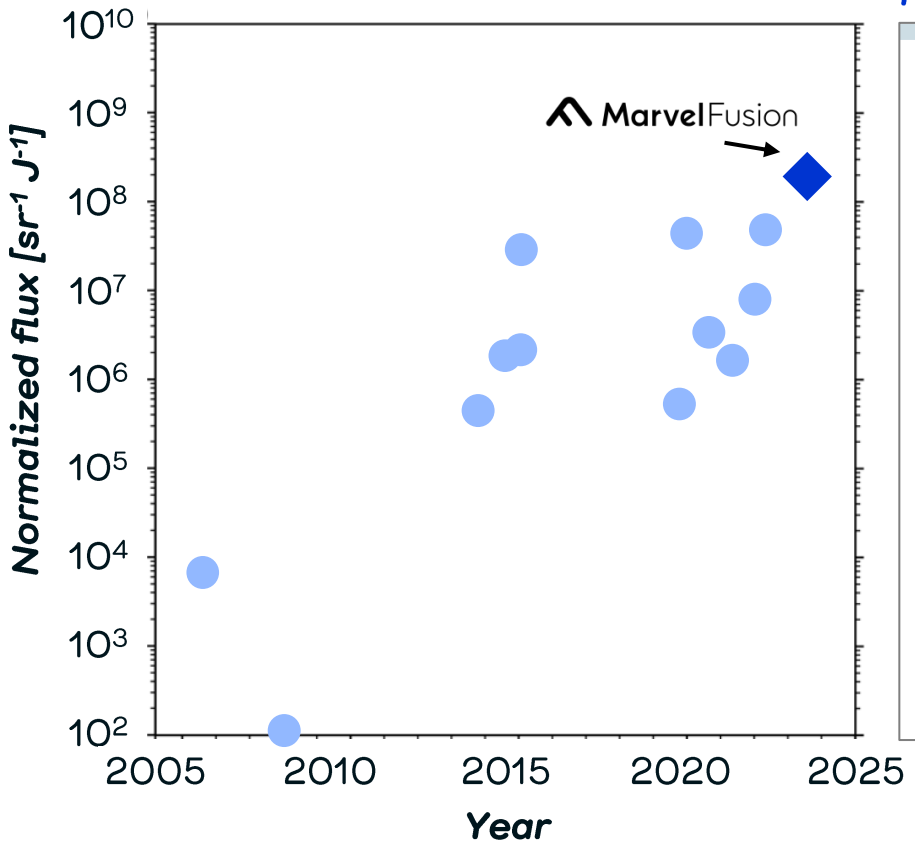
- Demonstrate that ***laser parameters are suitable*** to shoot nanometer thin foils
- Demonstrated ***efficient coupling of energy*** to foils with thickness on the order of 10 nanometers
- ***Scientific paper*** on experiments is in preparation and will shortly be submitted
- A laser-to-ion energy ***conversion efficiency of >50%*** is predicted in simulations of nanostructured targets[1]

Note: Experiment supported by LaserNetUS grant
Reference: B. Gonzalelz-Izquierdo et al., submitted

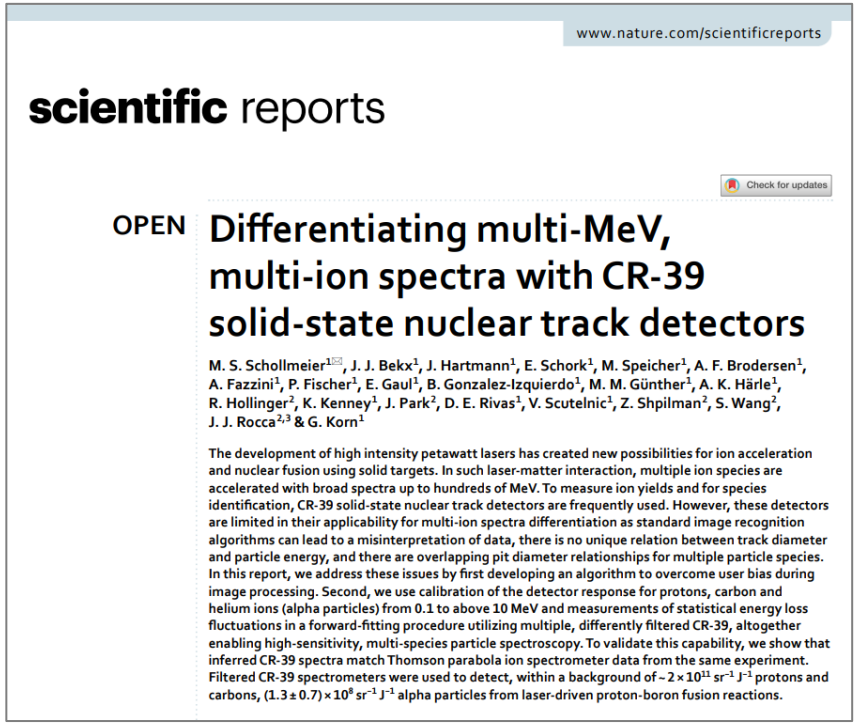
Results Experiments

Demonstrated record efficiency in triggering proton-Boron fusion

COLORADO STATE UNIVERSITY



Publication in Nature Scientific Reports



www.nature.com/scientificreports

scientific reports

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OPEN

Differentiating multi-MeV, multi-ion spectra with CR-39 solid-state nuclear track detectors

M. S. Schollmeier[1✉], J. J. Bekx[1], J. Hartmann[1], E. Schork[1], M. Speicher[1], A. F. Brodersen[1], A. Fazzini[1], P. Fischer[1], E. Gaul[1], B. Gonzalez-Izquierdo[1], M. M. Günther[1], A. K. Härle[1], R. Hollinger[2], K. Kenney[1], J. Park[2], D. E. Rivas[1], V. Scutelnic[1], Z. Shpilman[2], S. Wang[2], J. J. Rocca[2,3] & G. Korn[1]

The development of high intensity petawatt lasers has created new possibilities for ion acceleration and nuclear fusion using solid targets. In such laser-matter interaction, multiple ion species are accelerated with broad spectra up to hundreds of MeV. To measure ion yields and for species identification, CR-39 solid-state nuclear track detectors are frequently used. However, these detectors are limited in their applicability for multi-ion spectra differentiation as standard image recognition algorithms can lead to a misinterpretation of data, there is no unique relation between track diameter and particle energy, and there are overlapping pit diameter relationships for multiple particle species. In this report, we address these issues by first developing an algorithm to overcome user bias during image processing. Second, we use calibration of the detector response for protons, carbon and helium ions (alpha particles) from 0.1 to above 10 MeV and measurements of statistical energy loss fluctuations in a forward-fitting procedure utilizing multiple, differently filtered CR-39, altogether enabling high-sensitivity, multi-species particle spectroscopy. To validate this capability, we show that inferred CR-39 spectra match Thomson parabola ion spectrometer data from the same experiment. Filtered CR-39 spectrometers were used to detect, within a background of ~ 2×10^{11} sr^{-1} J^{-1} protons and carbons, $(1.3 \pm 0.7) \times 10^{8}$ sr^{-1} J^{-1} alpha particles from laser-driven proton-boron fusion reactions.

- ***Addressed issues in CR-39 detector analysis*** for ion spectroscopy by developing algorithms to overcome user bias during data processing
- ***Filtered CR-39 spectrometers were used to detect (1.3 ± 0.7) × 10^{8} sr^{-1} J^{-1} alpha particles*** from laser-driven proton-Boron fusion reactions, within a background of ~2 x 10^{11} sr^{-1} J^{-1} protons and carbons.
- ***Record alpha particles from proton-Boron fusion*** – the highest efficiency published to date

Upcoming Experiments

Dedicated target chamber and CALA upgrade finalized in 2024

CALA

Upgrade CALA expected to be finalized by Q3 '24

- Implemented ***Second Harmonic Generation*** to increase laser contrast and built optical system in own target chamber
- ***All-year access*** to one of the world's most powerful laser systems to perform flagship experiments
- Dedicated experimental setup for ***testing of new targets and online diagnostics*** at high rep rates and highest intensities
- Prototype testing of ***in-house designed equipment*** and development of automation controls and logic

Laser Technology

High efficiency, high contrast, compact, ultrashort-pulsed laser driver in development

1. ***Highly efficient driver lasers with wall plug efficiencies η_d= 0.1-0.2***
2. Marvel Fusion OPCPA-technology with ***subsequent broadband amplification***
3. ***Directly diode-pumped solid-state materials for broadband amplifier*** – High energy storage capabilities of > 1 MJ in 1 m^3 of Yb and/or Nd-doped materials
4. ***Broadband amplifiers supporting sub-100 fs pulse duration*** allowing efficient energy extraction and cooling
5. Non-CPA enables broadband ***low coherence direct drive ICF nanosecond compression concepts***
6. ***Compact industrial standard laser*** is being developed for future industrial mass production

Technology Demonstrator

Technical proof-of-concept started as milestone for powerplant

$150M Public-Private Partnership

COLORADO STATE UNIVERSITY MarvelFusion

2019-today

Existing Facilities

Demonstration of fusion physics

2026+

Proof-Of-Concept

Demonstration of technology

2032+

Prototype

Integrated engineering and system design (100 MW)

2035+

Commercial Plant

Cost-effective and reliable baseload power (300-800 MW)

Technology Demonstrator

Completion of the proof-of-concept facility planned by 2027

Proof-of-concept facility

- Signed ***$150M Public-Private Partnership*** between Marvel Fusion and Colorado State University to develop ***a world-leading laser facility***
- ***Marvel Fusion*** leads the development of two short-pulsed laser systems suitable for use in future powerplants
- ***CSU*** contributes funding for the facility's infrastructure, diagnostics and auxiliary systems

1. Enables ***capital lean execution*** of technology roadmap
2. Capable of ***demonstrating all key physics*** relevant to MF's concept
3. Testing of ***technology under power plant conditions,*** e.g., target injection, 10 Hz laser operation


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