The Matter-Radiation Interactions in Extremes (MaRIE) Project

38th International Free-Electron Laser Conference

New Lasing & Status of Projects II

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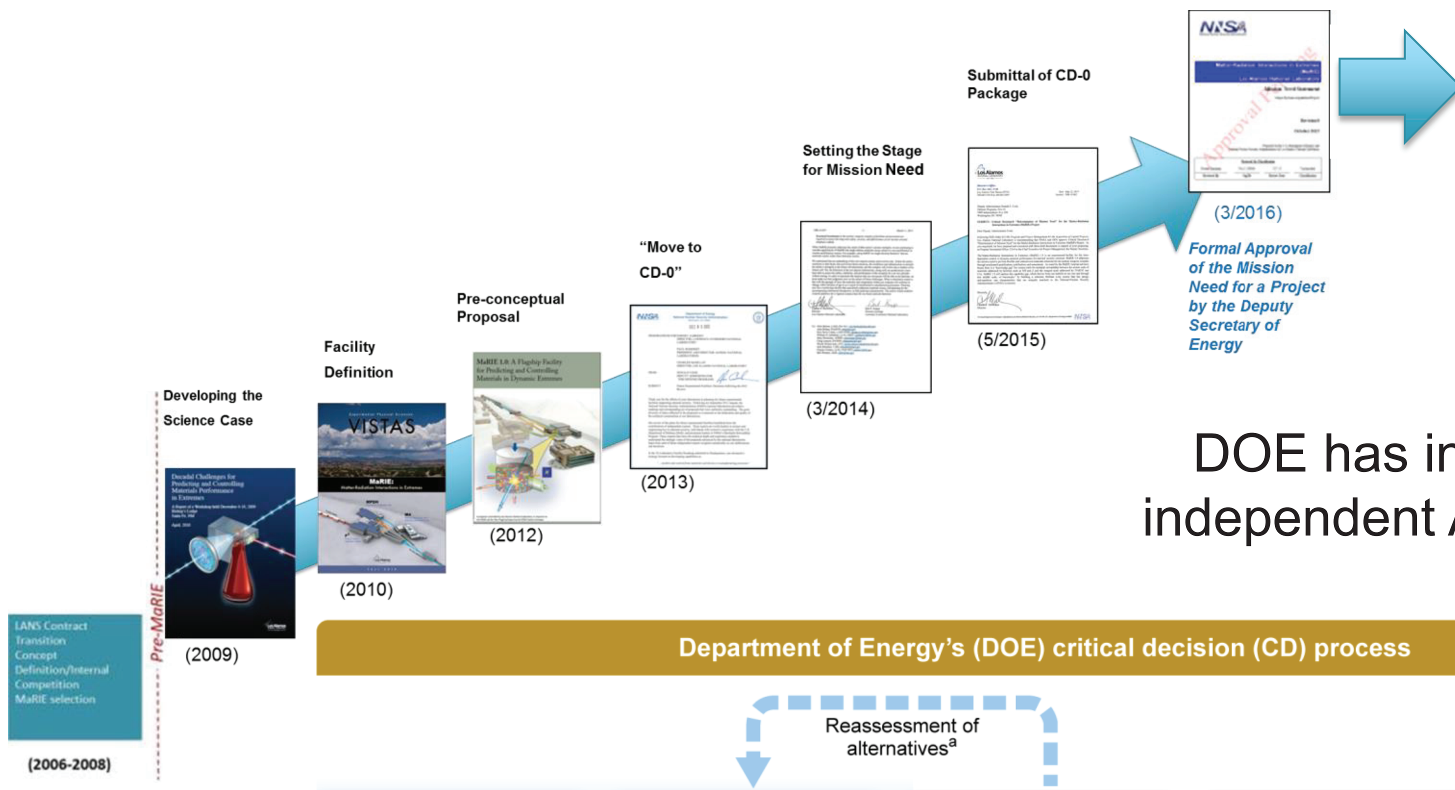
LA-UR-17-27460

The Laboratory has been working toward our vision of MaRIE since the contract transition and attained CD-0 in March, 2016

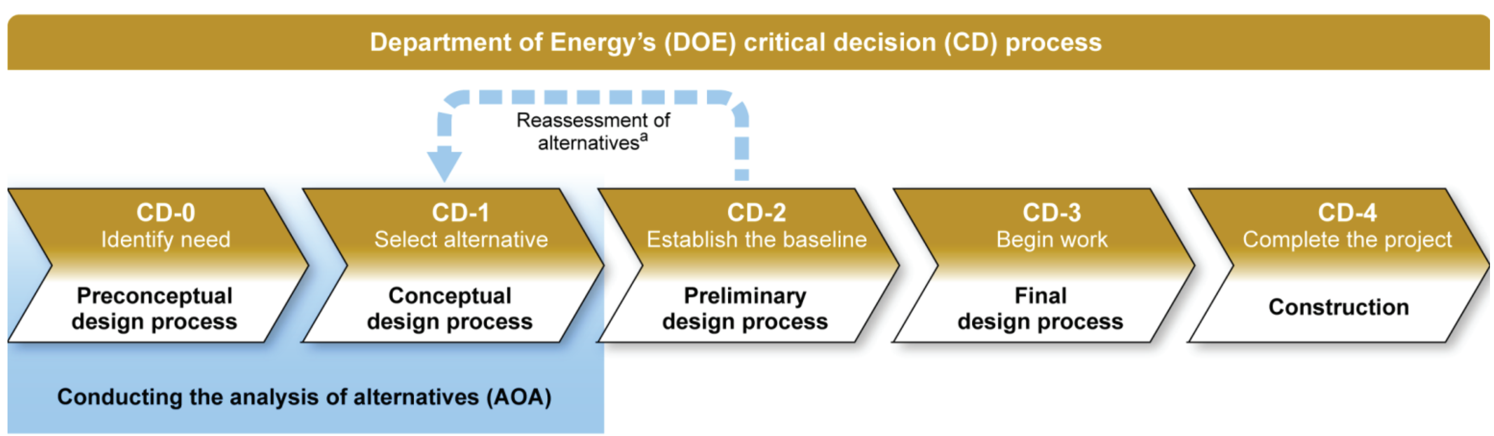


CD-1

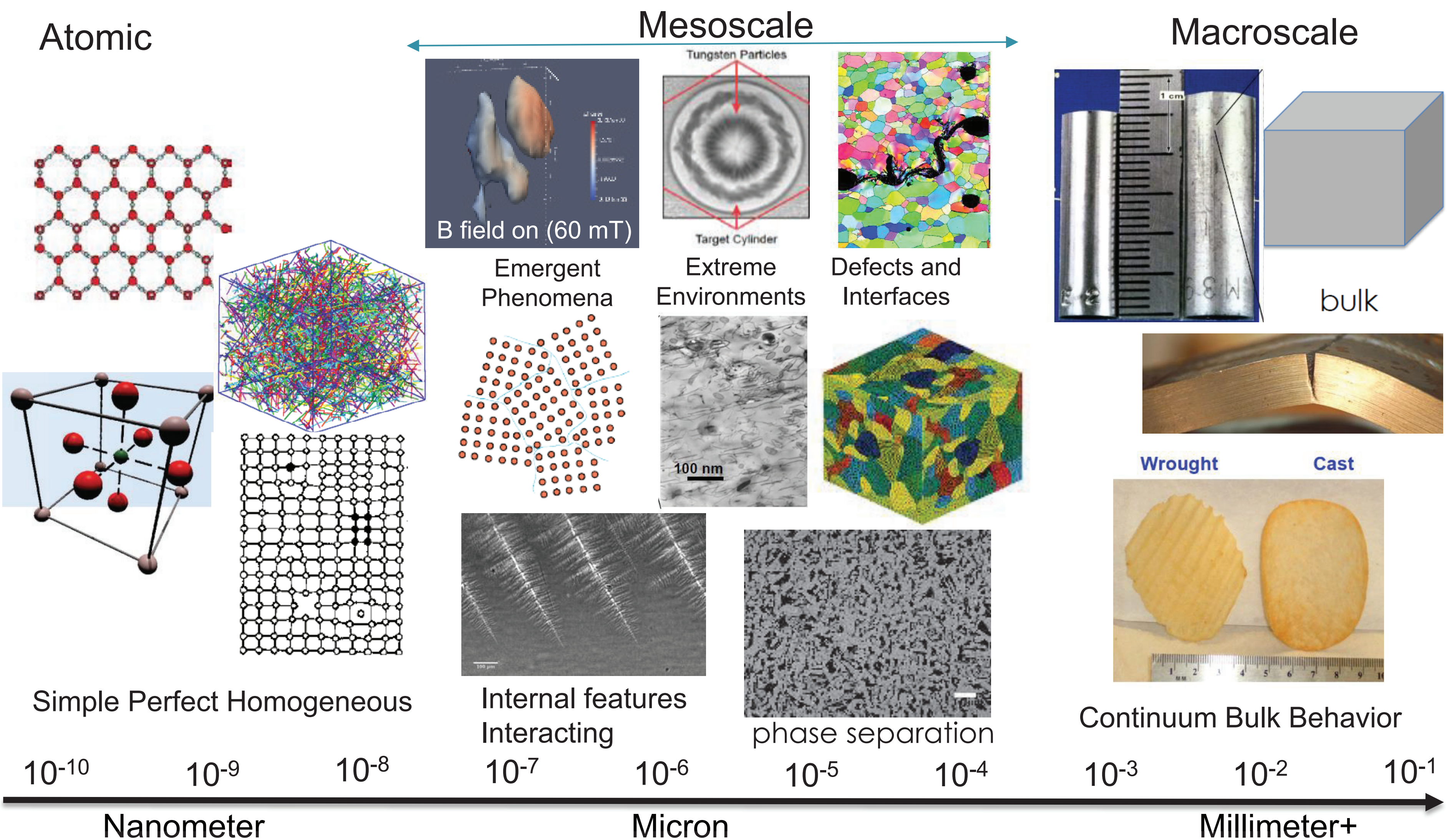
- AoA
- Conceptual Design

(2016 - *)

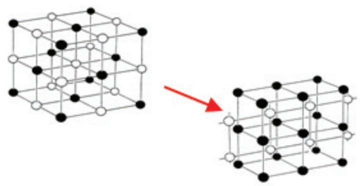
DOE has initiated the independent AoA process



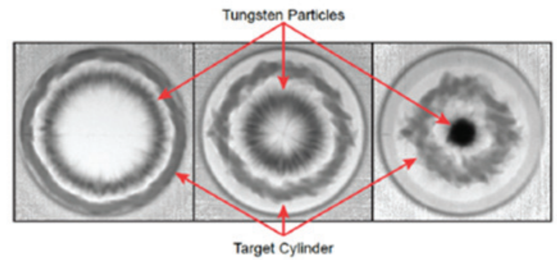
MaRIE focuses on bridging atomic scales and the bulk continuum

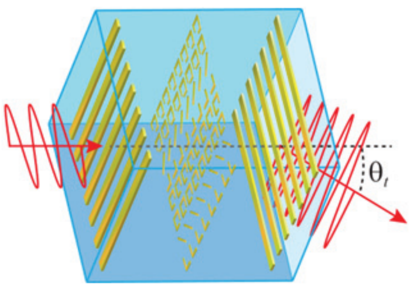


MaRIE will provide critical data to understand materials performance in dynamic environments and to guide advanced manufacturing.

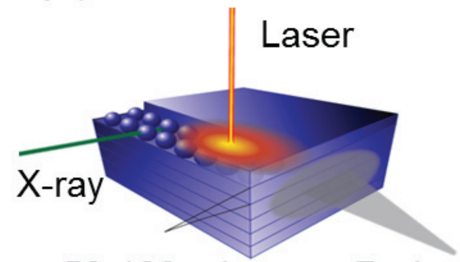


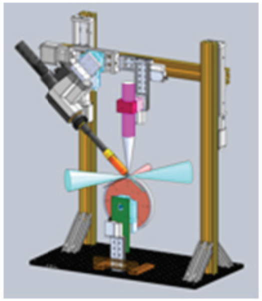
ps – 100 ns
Phase Transformations





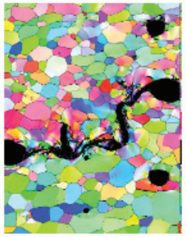
ns – 100 ns
Shock transit across grain;
Hydrodynamic instability



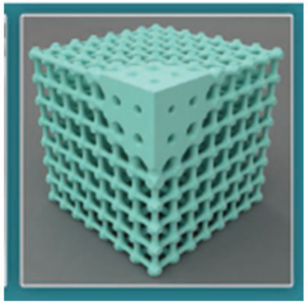


100 ns – 10 μs
Shock transit across sample

50-100 microns pRad beam



10 μs – 1 ms
Thermal pulse evolution



10 s – 10 hour
Additive manufacturing build

months – years
Aging effects

The envelope of common technical requirements for the probes to be able the make SFR measurements has been affirmed by an independent review

Mission Need – Gaps in Knowledge → **Scientific Functional Requirements**

	Metals and Age Aware performance	HE certification and qualification	Turbulent Materials Mixing	Casting
Spatial resolution	<100 nm - 20 μm	< 100 nm - 20 μm	100 nm	< 1 μm – 100 μm
Field of View	100 μm - 1 mm	100 μm - 2 mm	1 mm	0.3 mm – 1 cm
# of frames	~ 30	~ 30	~ 30	1000 per second
min pulse sep	< 300 psec	< 500 psec	1 nsec	10 nsec
macropulse length	5 μsec	7 μsec	15 μsec	1 msec
sample thickness	> 250 μm	> 10 μm – 6 cm	1 – 10 cm	0.1 to 10 mm
repetition rate	< 1 Hz	< 1 Hz	10 Hz	10 Hz
max pulse length	< 1 ps	< 1ps	< 1 ns	< 100 ps
lattice measurement	0.1%	0.2%	-	0.01%
species	Be - Pu	Typically C, H, O, N	Noble gases, Ga, Be	Actinides
density	1%	3%	2%	1%

Defining parameters

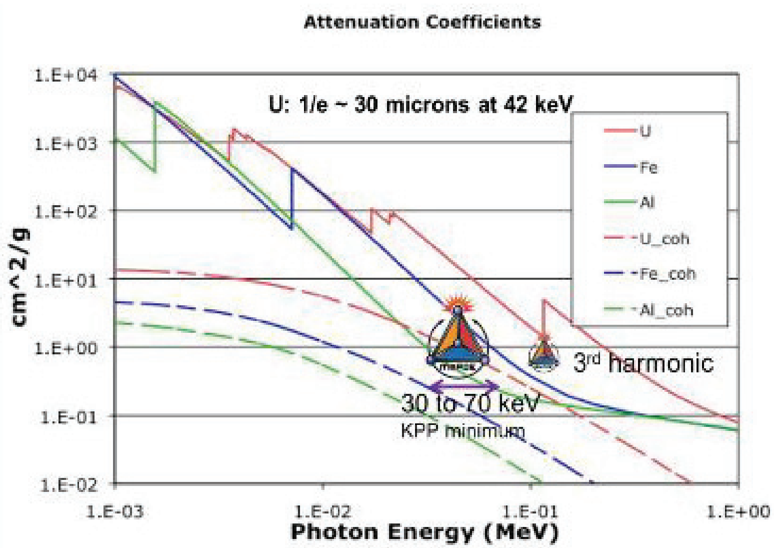
Though mission need is the primary reason for CD-0, CD-0 also requires a cost and schedule estimate

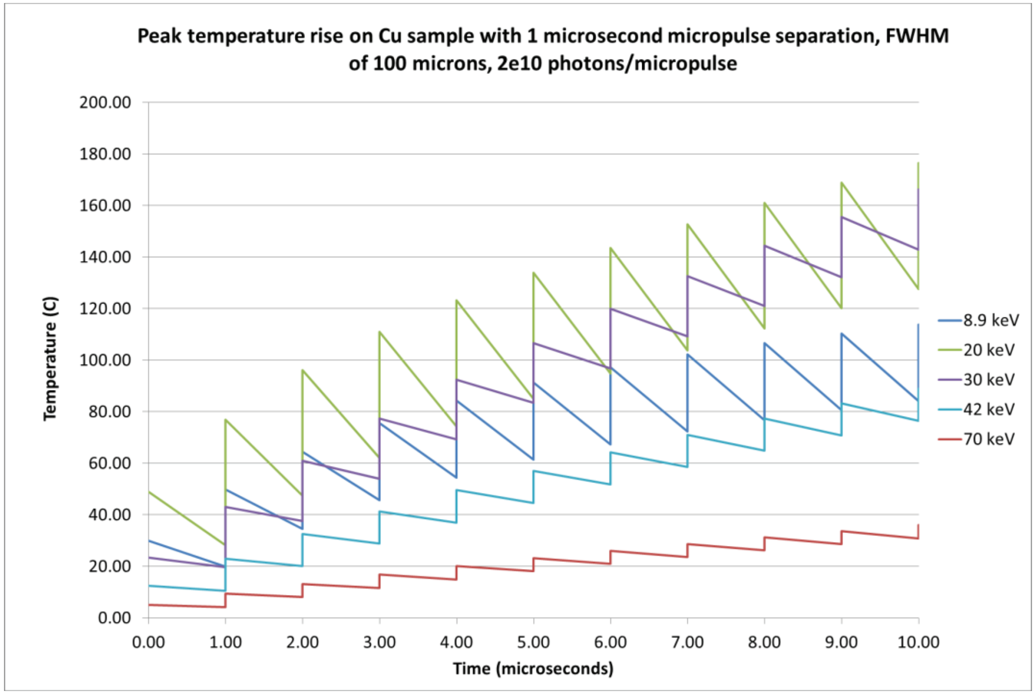
- **A pre-conceptual reference design, a "plausible alternative", with the aforementioned characteristics needed to be developed for the schedule and budget estimate.**

- **We reviewed a wide range probe techniques, x-ray tubes, CBS, 3rd generation light sources, etc., that could possibly address the wide range of requirements.**

- **An XFEL can meet the envelope of requirements (coherent brilliance, penetration, time format, probe heating) for an x-ray light source and so was used for the pre-conceptual reference design.**

Unique characteristic 1: high energy x-rays allow measuring bulk high-Z properties by maximizing elastic scattering for diffraction and minimizing absorptive heating.

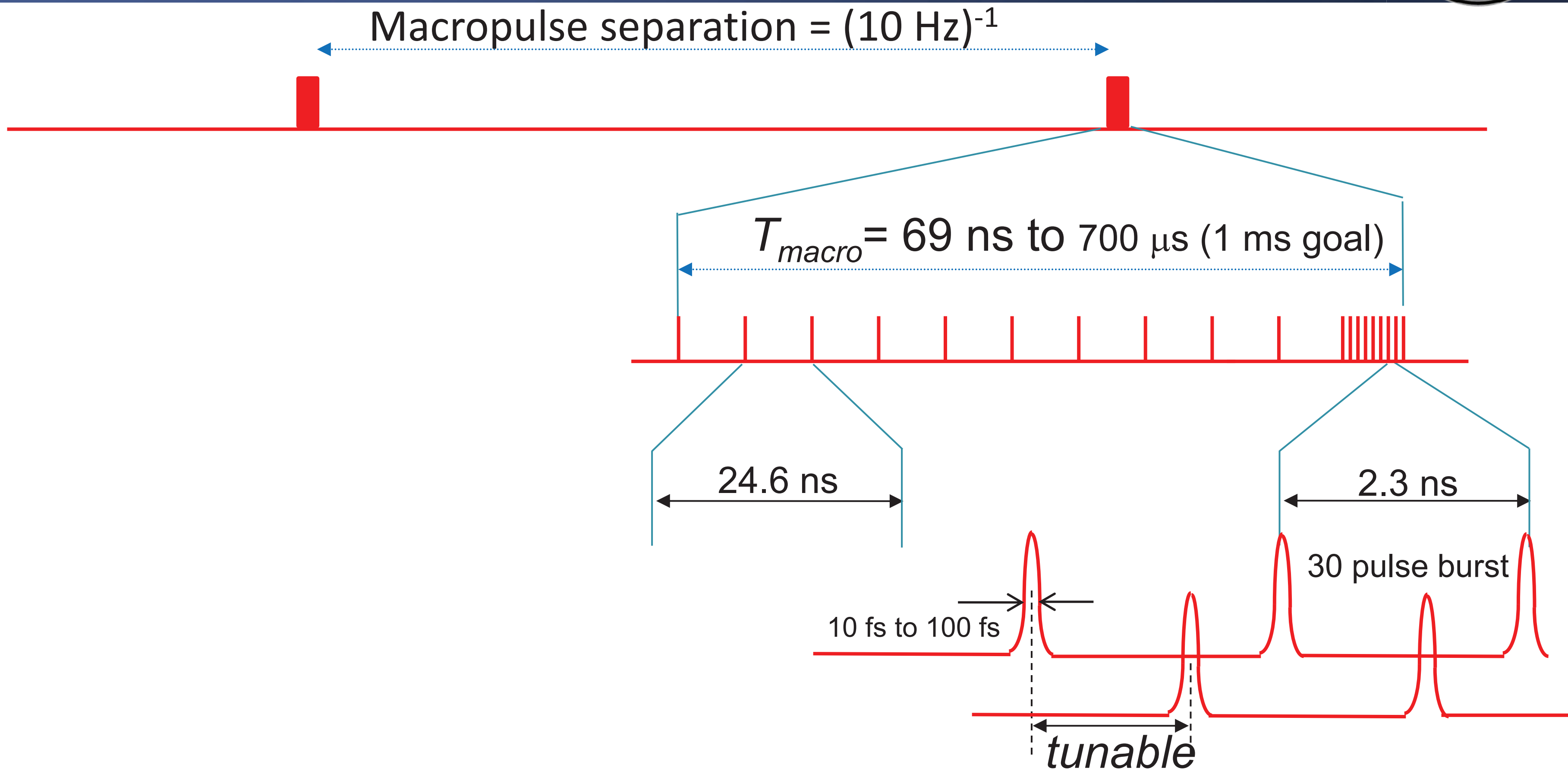




A key design requirement, that will be central to balance of cost, risk, and performance, will be the threshold and objective x-ray energy.

J. L. Barber *et al.*, Phys. Rev. B **89** (2014) 184105

Unique Characteristic 2: Time-dependent control of the mesoscale requires an innovative and flexible electron pulse structure that can span from electronic/ionic (sub-ps) through acoustic (ns) to shock transit (μs) to thermal (ms) event time scales



We plan on using an optical split and delay to generate sub-ns pulse separation

Requirements on repetition-rate and duty cycle are also critical!

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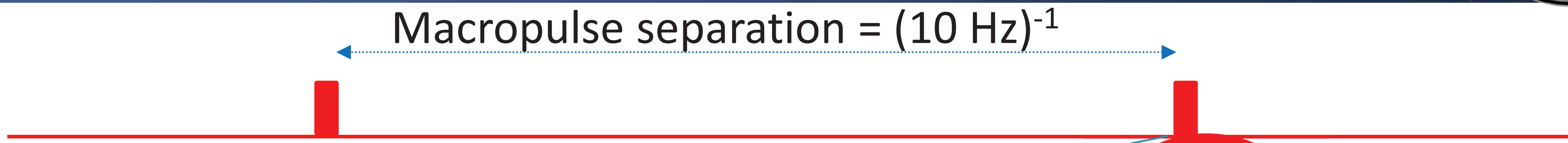
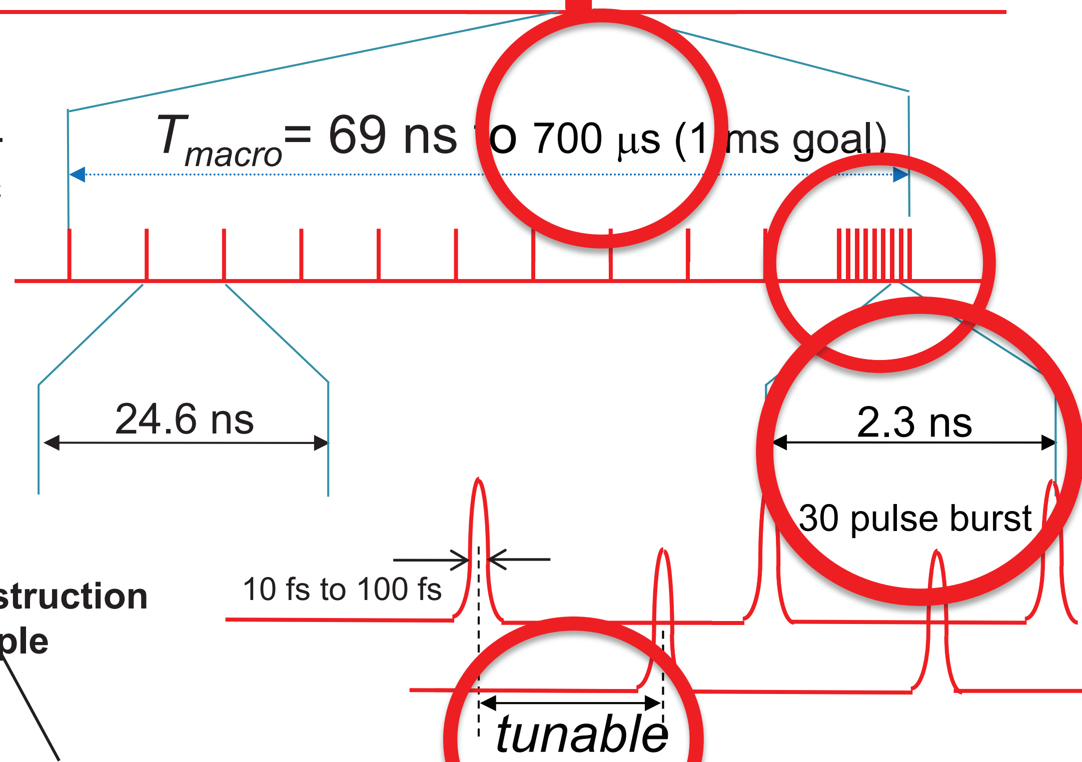
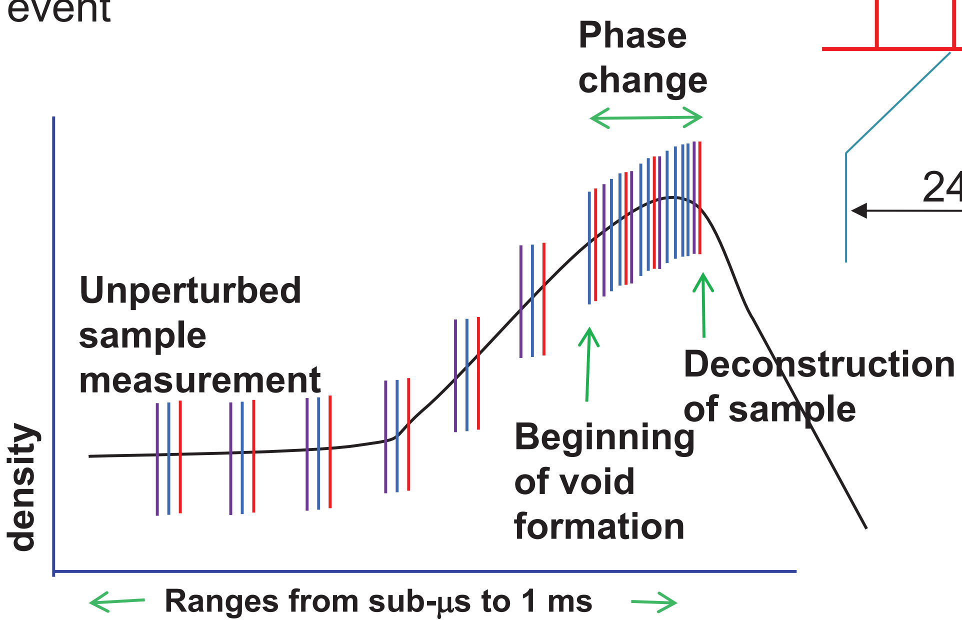


MaRIE multiplexes 42-keV x-ray photons (blue), 12-GeV electrons (purple), and 0.8-GeV protons (red) during a single dynamic event





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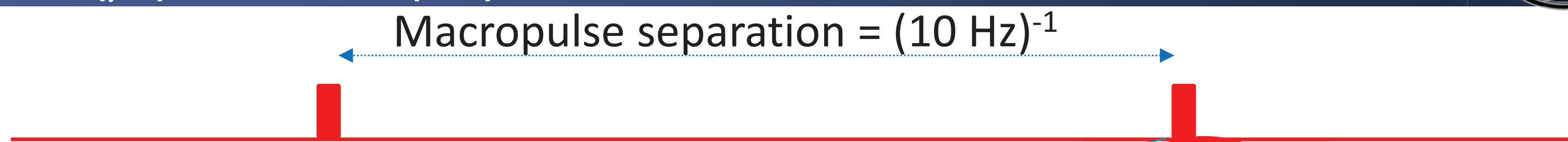

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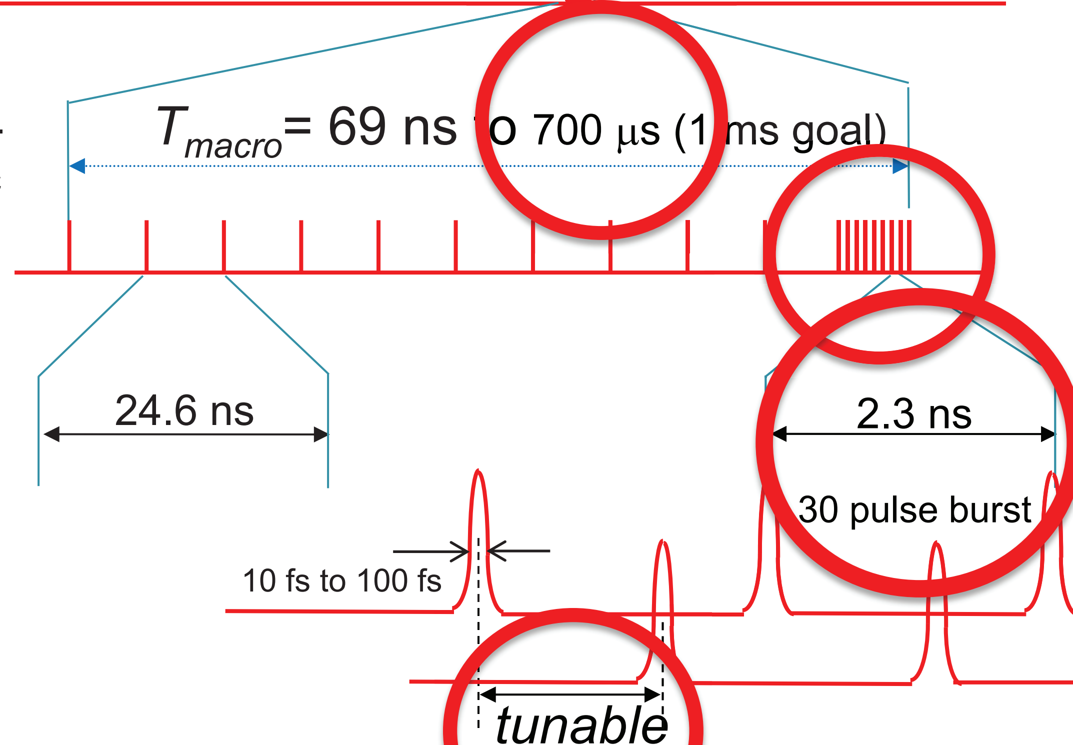

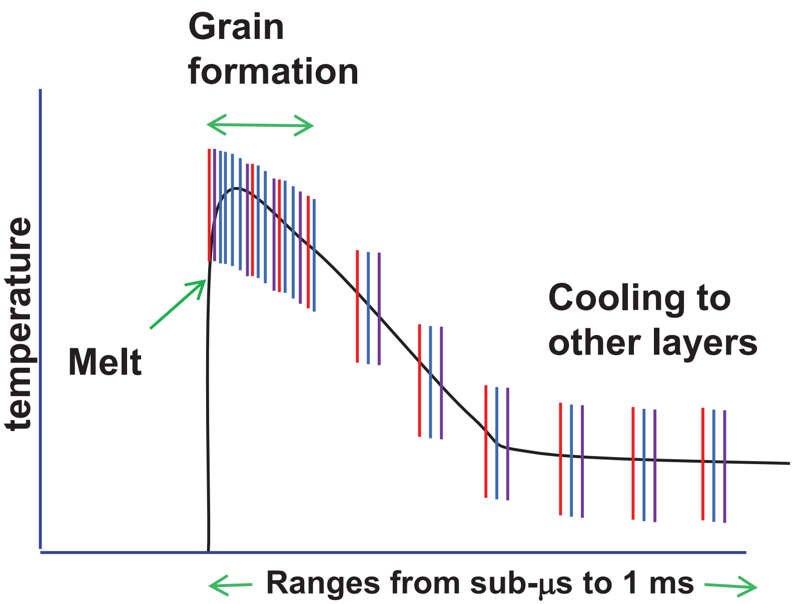

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Photon Facility Functional Requirements led to a pre-conceptual reference design for the electron beam

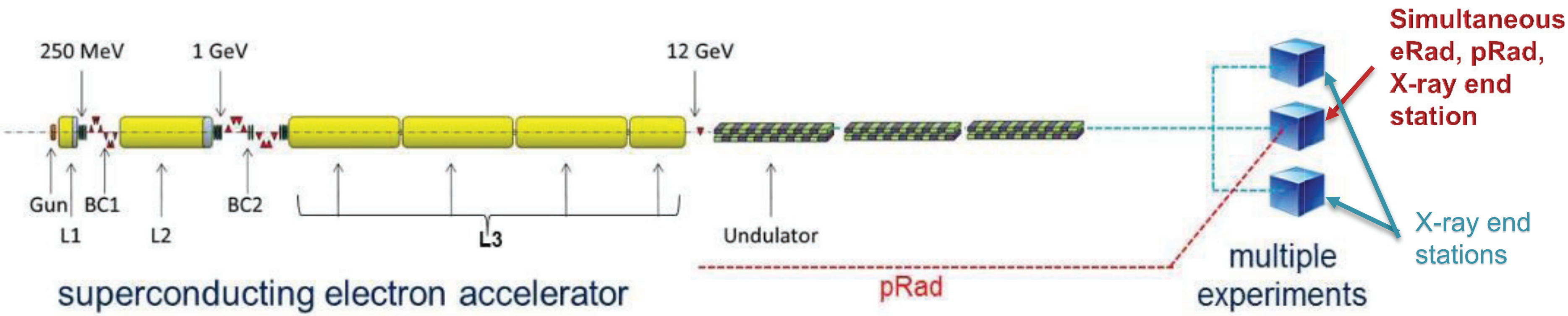
Photon Requirements (FFRs)	
Design energy is normally top of range (keV)	5 to 42 (42 to 126 at 3^{rd} harmonic)
Photons per image	$2x10^{10}$ ($5x10^{10}$ total per micropulse, $1x10^{8}$ at 3^{rd} harmonic)
Energy Bandwidth ($\Delta E/E$)	$2x10^{-4}$ to $<10^{-5}$
Divergence	≤ 10 μrad
Pulse length	≤ 100 fs

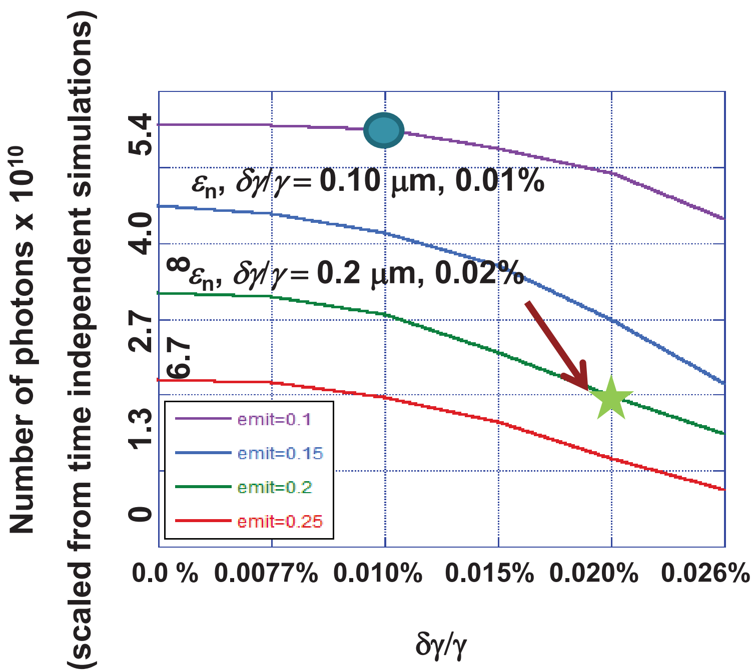
Electron beam FFRs			
Energy	12 GeV	Electron source	Photo-injector
Linac fundamental frequency	1.3 GHz	Maximum macropulse duration	1 ms
Linac type	Super-conducting	Macropulse to macropulse energy variation	≤ 0.02%
SC L-band cavity gradient	31.5 MV/m	Pulse energy variation within a macropulse	≤ 0.01%
Maximum beamline angle	2.0 degrees @ 12 GeV	12 GeV FWHM micropulse length	33 fs

XFEL electron beam FFRs			
Pulse charge	0.2 nC	Normalized rms slice emittance	≤ 0.2 micron
Slice energy spread	≤ 0.02%	Micropulses per macropulse	30
Macropulse repetition rate	10 Hz	Min micropulse separation	2.3 ns
eRad electron beam FFRs			
Pulse charge	1 nC	Normalized emittance	<1000 microns
Microbunch energy spread	≤ 0.02%	Macropulse repetition rate	10 shots per day
Micropulses per macropulse	10	Min micropulse separation	23 ns

The FFRs will be revisited after completion of the AoA and as part of the Conceptual Design

The end result of the process is an XFEL pre-conceptual reference design document





Accelerator Design Goal

Baseline for FEL simulations

We have 150 m tunnel contingency to go to 15 GeV in the future; worth ~2x photons or ~70 keV energy upgrade capability

We have plans in place to address the Critical Technology Elements (CTEs) that could have a major impact on MaRIE performance

Should an XFEL be chosen as the preferred alternative then the following technology gaps must be addressed to attain the required performance:

- Photoinjector emittance: Relevant measurements at other facilities and a test stand at LANL
- Beam energy spread: Relevant measurements at other facilities
  - Wakefield effects last longer or are stronger than anticipated
  - Coherent Synchrotron Radiation (CSR) suppression
  - Microbunch instability suppression
  - Dechirper energy correction
- Distributed seeding: Relevant measurements at other facilities
- End-to-end modeling and simulation: Incorporates results from the above demonstrations and confirms performance

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Presently funded CTEs are source independent and required to attain the full facility benefit. Several will have a major impact on the facility layout: High-Energy and Ultrafast Imaging Cameras, Multidimensional Dynamic Imaging techniques, Bulk Thermometry of Dynamic Materials, Development of Charged Particle Radiography for the Study of Small and Fast Physical Processes; also identified are X-ray Optics, and Long-Pulse Laser Technology Development.

Los Alamos National Laboratory is committed to enabling the strategic vision for MaRIE

- **As the Project progresses, we will be looking to fund collaborative research to identify and reduce technical risk, decrease cost, and expand performance that builds on the expertise and resources at existing facilities.**

- **LANL is using indirect funding to continue to generally support congruent Lab Capabilities in mesoscale materials, accelerators – many of these efforts are being presented at this conference.**

- **A facility is needed for designing and making advanced materials to meet 21st-century national security and energy security challenges.**