The MIT Bates X-Ray Laser Project

Townsend Zwart
MIT Bates Linac

Science Driven Performance

Scope of Initial Proposal

Recent Activities at Bates: Visitors and Workshop

Facility Parameters

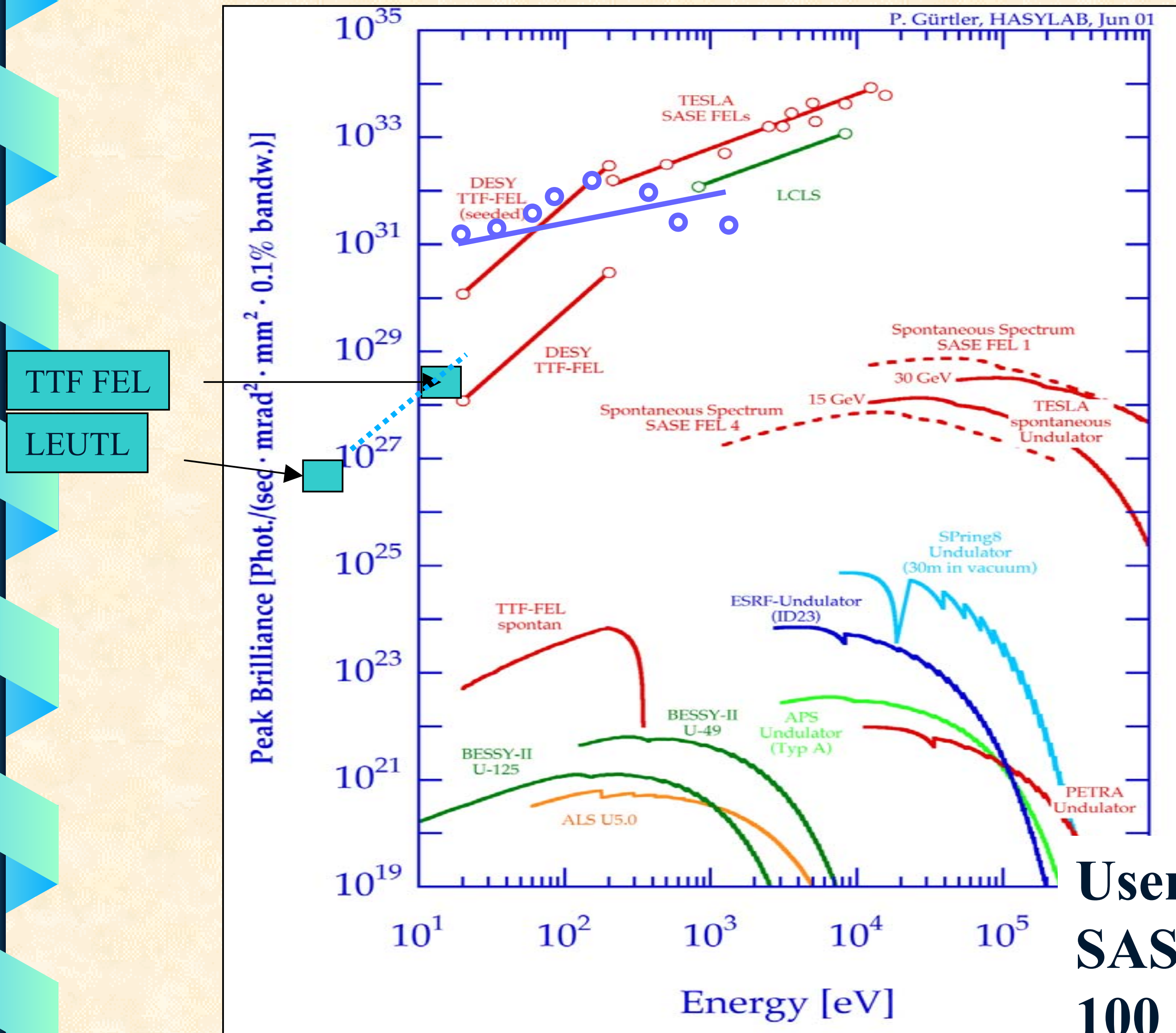
Use of Existing Bates Linac (100-30 nm FEL)

0.5-100 nm Bates/Greenfield X-Ray Laser

Upgrade Path

Conclusions & Future Plans

Science Driven Performance



User Facility
SASE
100 - 0.5 nm
Multiple Beam lines

This is a Peak Brilliance Machine

Photon Energy/Pulse: 5 GW ·200 fs = 1 mJ

Maximum Electron Current: 1 MHz ·500 pC = 500 uA

P_{avg} < 1 kW

Compare to P_{avg} ~ 5 kW from one APS Undulator.

The challenge is to build an efficient machine which will distribute the pulses in a way that is experimentally useful. Considerations include pump probe requirements, time of flight requirements, signal averaging requirements etc...

Time Averaged Brilliance will still be good

LCLS type duty factor/beamline to begin: 100 Hz · 200 fs = 2×10^{-11}

Average Brilliance: 2×10^{20} Compare APS Undulator A: 4×10^{19}

Scope of Initial Proposal

Three year design study which will assess:

Scientific Impact and Opportunities of 100 - 0.5 nm Laser User Facility

Readiness of Technology for Construction of such a Facility

Three year study will deliver:

Optimized Greenfield Design of X-Ray Laser Facility

Site Specific Details for Implementation of X-Ray Laser at MIT-Bates

Three year study will also support:

Involvement of other Laboratories and Institutions

A series of workshops to achieve the above goals

Educational Opportunities for Students and Professionals in
the field of X-Ray Lasers

A Few People on the MIT Bates X-Ray Laser Project Team

F. Wang

D. Moncton

M. Farkhondeh

A. Zolfaghari

S. Sobcynski

J. van der Laan

C. Tschalar

E. Ihloff

Recent Visitors to MIT Bates

Norbert Holtkamp 5/20/2002:

"Superconducting structures are the clear choice for high beam power facilities."

Bob Kustom 5/21/2002:

"Don't use so many klystrons."

Dave Dowell 5/30/2002:

"The gun for such a facility is a non-trivial problem. Lower frequency for higher duty factor."

X.J. Wang 5/31/2002:

"Guns may be optimized at lower bunch charges, 100 pC vs 1 nC. The laser for such a facility is in hand. "

Mike Borland 6/7/2002:

"You should worry about CSR and compression. Paul Emma has written code to tell you where to put the bunch compressors."

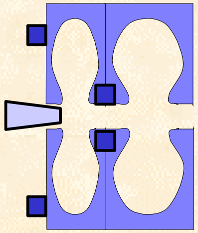
Efim Gluskin 6/13/2002:

"The undulators for FEL photon wavelengths between 1 and 100 nm are straightforward."

Bill Graves 6/14/2002:

"I see no principle problem in the construction of such a facility."

June 19-20 Bates X-Ray Laser Workshop



Attendees:

Y. Cho, J. Galayda, J. Hastings, K. J. Kim, S. Krinsky, S. Milton, D. McWhan, L. Rivkin, J. Schneider, G. Shenoy, T. Shintake

Topics:

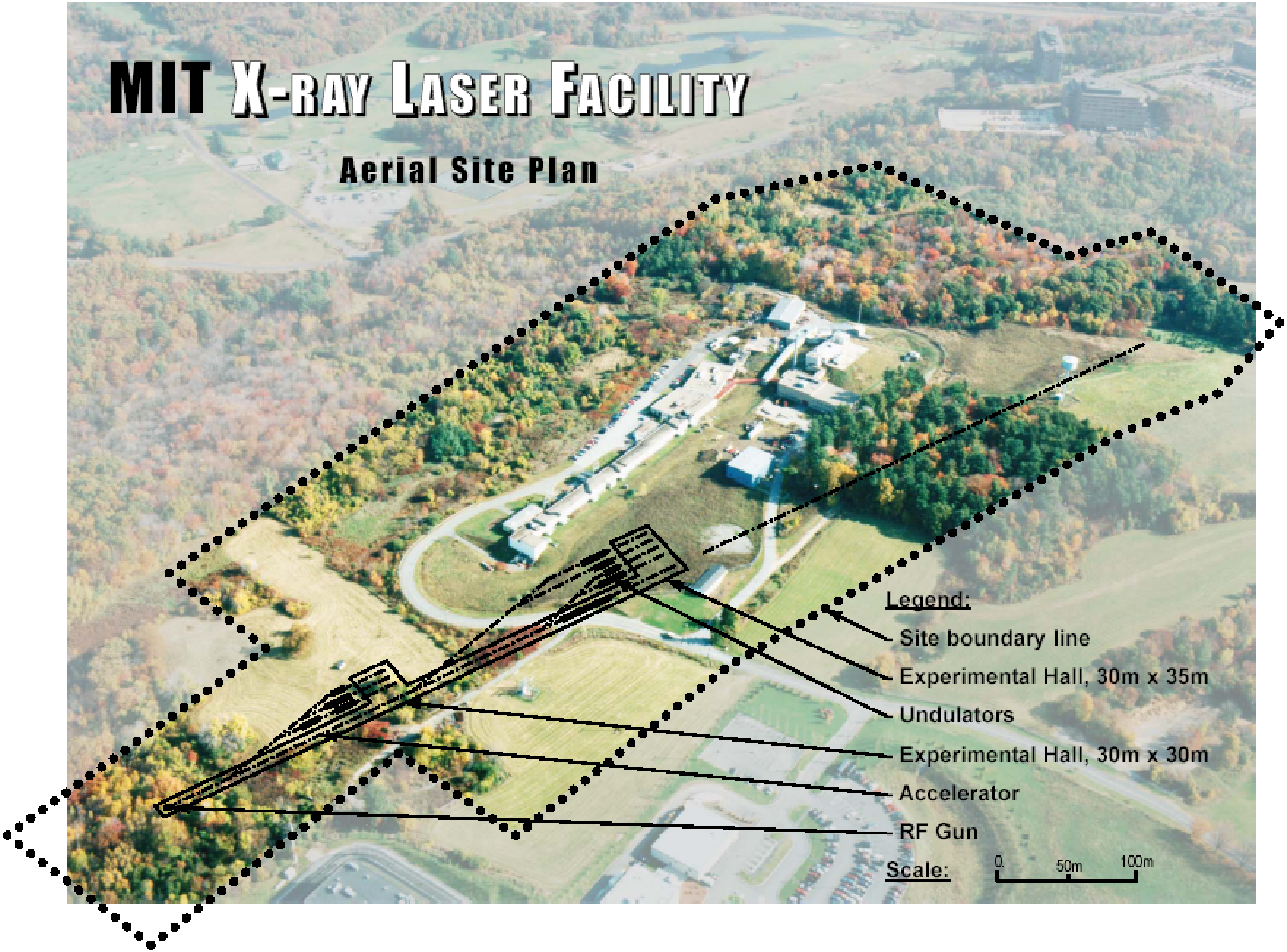
FEL Theory
Technology Considerations
Scientific Impact
Straw Proposal

Bates Xray Laser Parameters

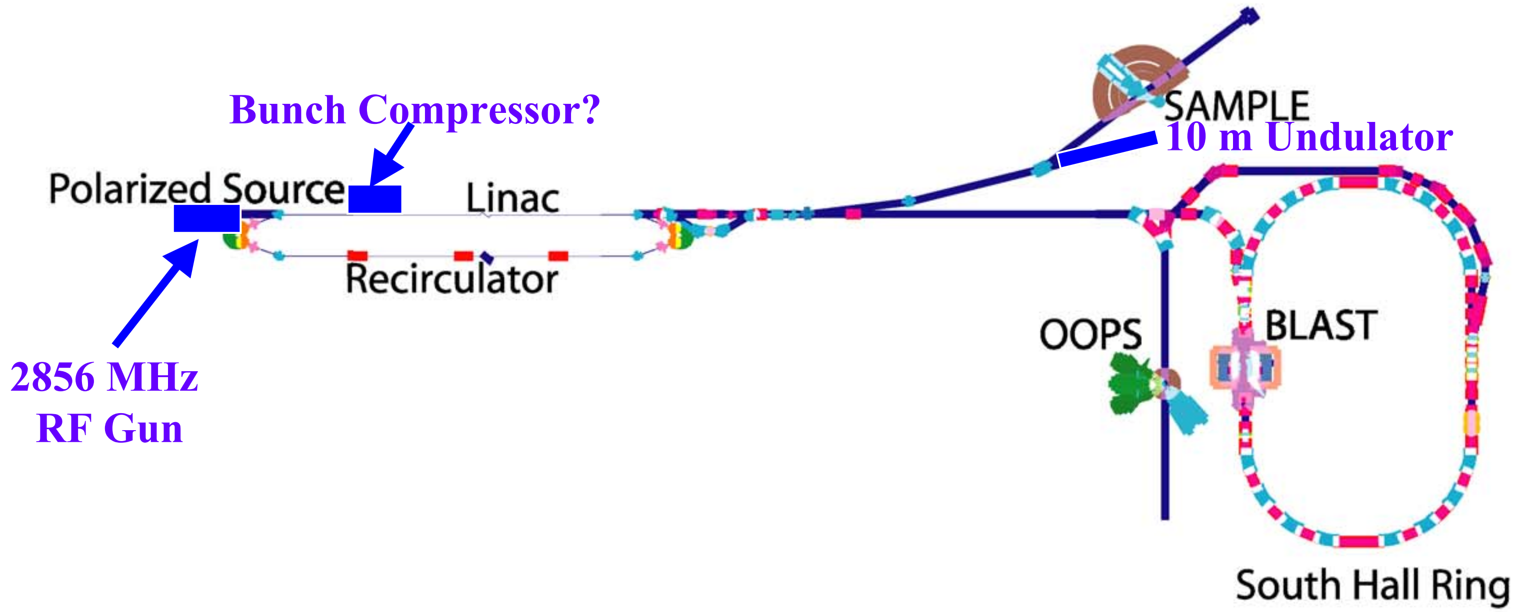
λ	100 - 0.5	nm	
Beam Energy	3.8	GeV	
Linac Freq.	1.3	GHz	(Tesla SC Structure)
Linac Gradient	20	MeV/m	
Active Linac Length	192	m	(24 Cryomodules)
Linac/Facility Length	400	m	
Avg. Current	<10	uA	(Beam Power < 10% RF Power)
Duty Factor	10	%	
Rep. Rate	1	Hz	(Quasi CW)
AC Installation	5	MW	

Bates Xray Laser Parameters cont.

Gun Freq	1.3	GHz	Copper 0.1% DF
Bunch Charge	500	pC	
Emittance	1	um	
Bunch Spacing	1	us	(Inside 10 us macropulse)
Laser Pulse Width	4	ps	DUVFEL Laser
Peak Current	2	kA	
ΔE/E	0.02	%	
# Undulators	8		(Allows ~20 Limited by Cost)
Undulator Period	3-6	cm	
Undulator K	1.17/2.8		
Undulator Lengths	6-30	m	


MIT X-ray Laser Facility
Aerial Site Plan
Legend:
Site boundary line
Experimental Hall, 30m x 35m
Undulators
Experimental Hall, 30m x 30m
Accelerator
RF Gun
Scale:
0
50m
100m

Bates with a DUV Laser
Post BLAST - Pre X-Ray Laser



John Galayda: "The use of the existing Bates facility better look like falling off a log because it won't be as easy as you think it is."

Bates DUV Stage 2005-2010

- Existing Linac 550 MeV could provide radiation to ~ 80 nm .
- RF Gun must be installed. This gun could be identical to the LCLS gun.
- Construct ~10-20 m Undulator (LEUTL,TTF) on the 14 ° line.
- Additional Compressor may be required. Remove one 7 m linac section at ~200 MeV.
- Use existing Chicane, R_{56}=35 mm/%, and the last linac section for compression. Compression factor of eight.
- Establish user base and demonstrate Higher Harmonic Generation
- The recirculator may be used to see how well the beam properties can be preserved, study CSR, and possibly generate SASE radiation at 30 nm
- The recirculator may also be configured for compression. (cf I.V. Bazarov)
- Use this facilty post BLAST, pre XFEL, 2005-2010?

Technology Exists Today for 0.5 nm

- **Guns:**

  Adequate performance has been demonstrated. Room for continuing R&D and improvement. Not a costdriver.

- **Compression:**

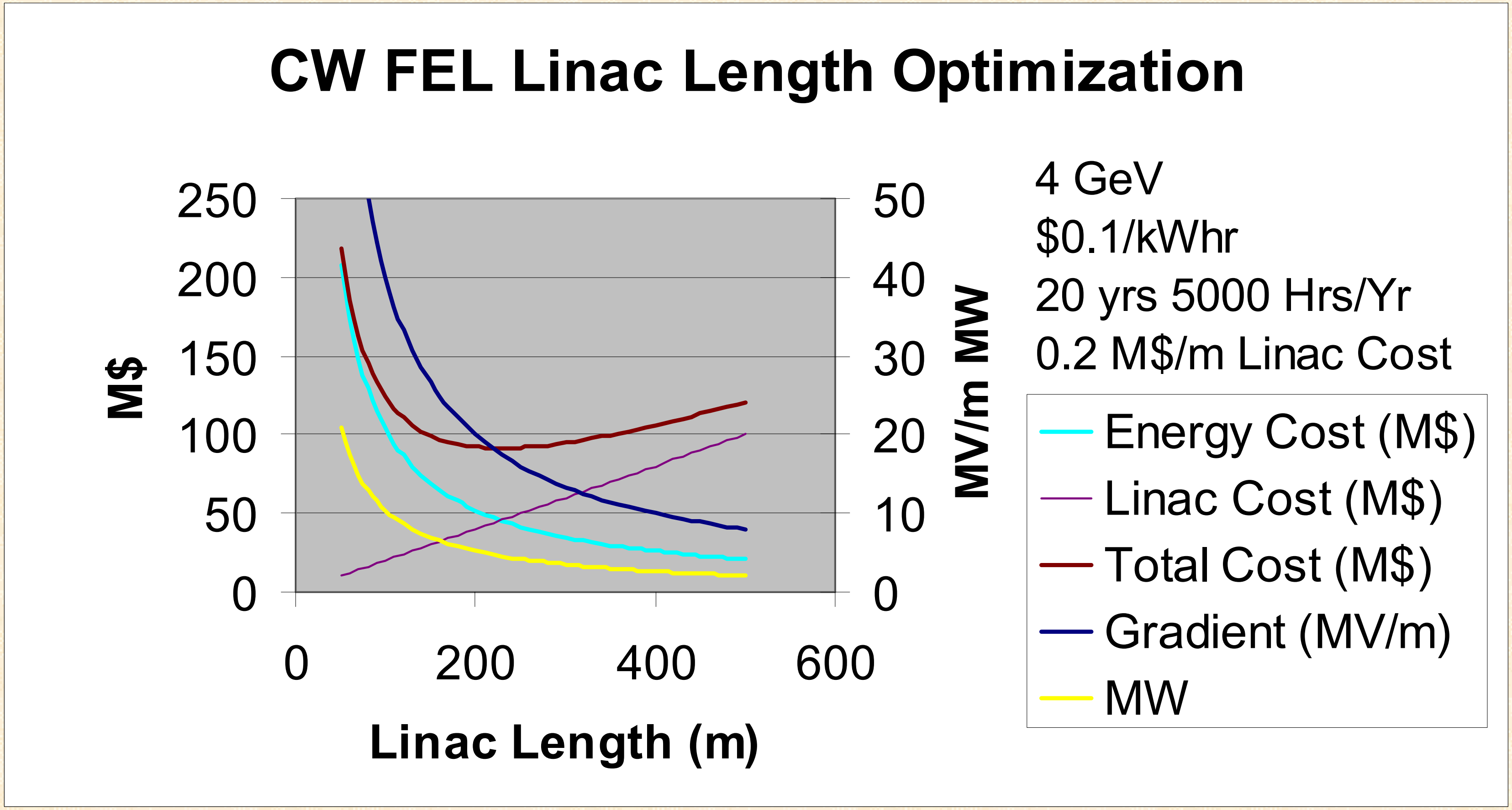
  Adequate performance has been demonstrated. Needs careful study and simulation for optimization. Experimental data on CSR effects would be useful. Not a cost driver.

- **Linac:**

  Successful operation at Tesla Test Facility, JLAB. Capital cost driver.

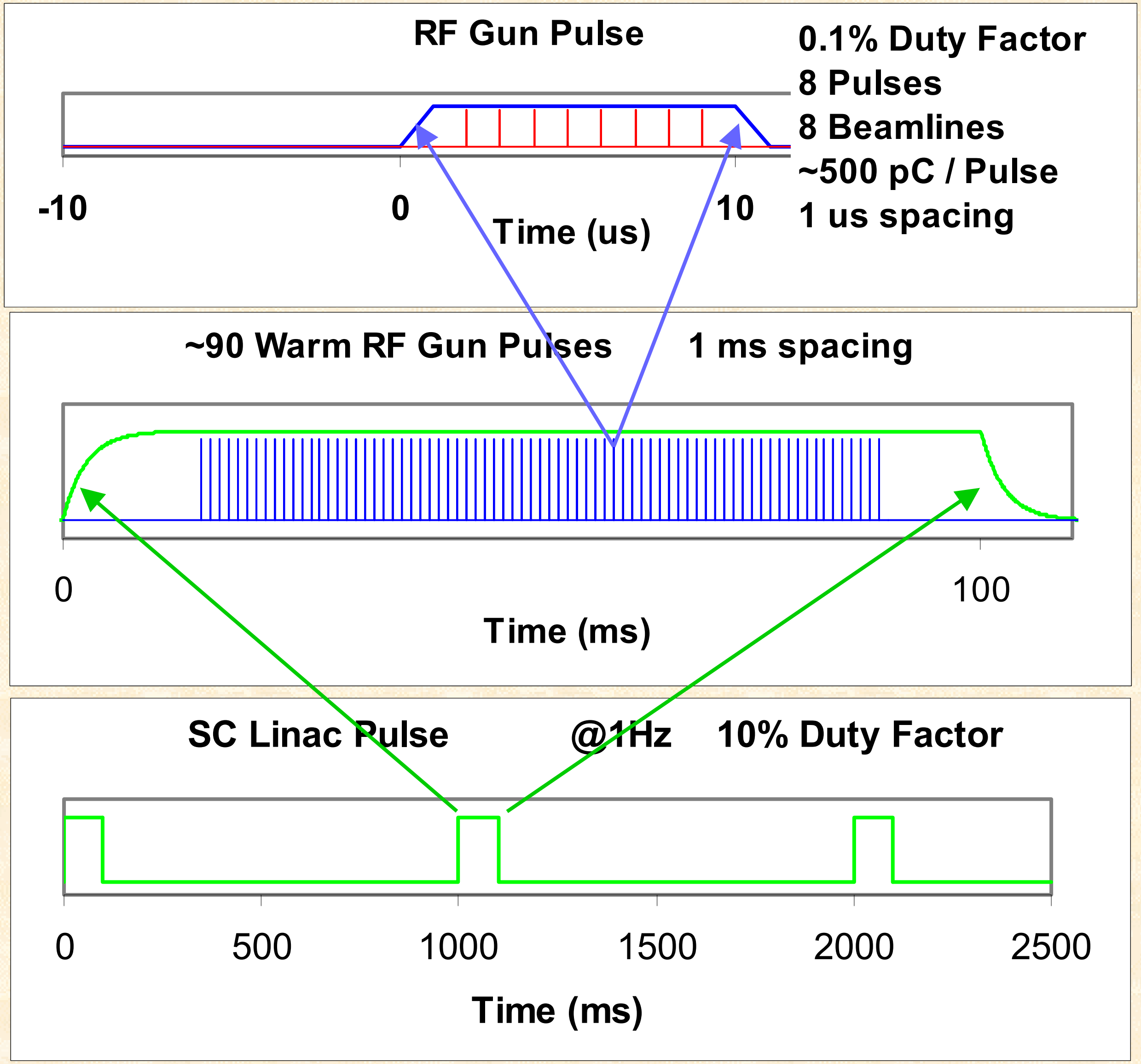
- **Undulator:**

  Well established. Successful experience at LEUTL, TTF. Make use of investment in LCLS design. Capital Cost driver.



CW FEL Linac Length Optimization
250
200
150
100
50
0
M$
50
40
30
20
10
0
MV/m MW
0
200
400
600
Linac Length (m)
4 GeV
$0.1/kWhr
20 yrs 5000 Hrs/Yr
0.2 M$/m Linac Cost
Energy Cost (M$)
Linac Cost (M$)
Total Cost (M$)
Gradient (MV/m)
MW

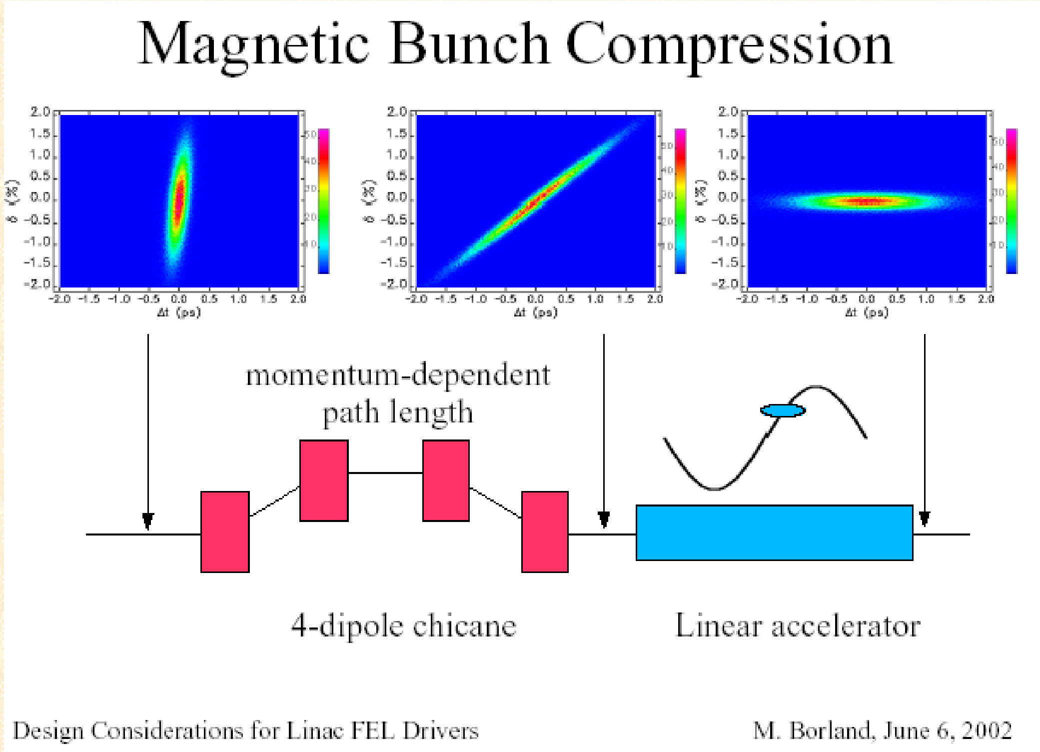
Pulse Structure
Quasi - CW



Pulse Structure

- Allows the use of normal conducting RF Gun
- Allows Higher Q_{ext} and thus lowers installed RF Power
- Permits use of Ferrite Extraction Kickers
- Duty Factor of 10 % allows the use of the highest Gradients

Optimized Compression Scheme



Courtesy Mike Borland

1) **Accelerate Hard Early**

2) **Chirp Before the Energy becomes too high**

3) **Finish Compression before first extraction beamline**

4) **Keep Deflection Angles Small due to CSR Effects**

---> Compressors located at 200 MeV and 1000 MeV ?

AC Budget

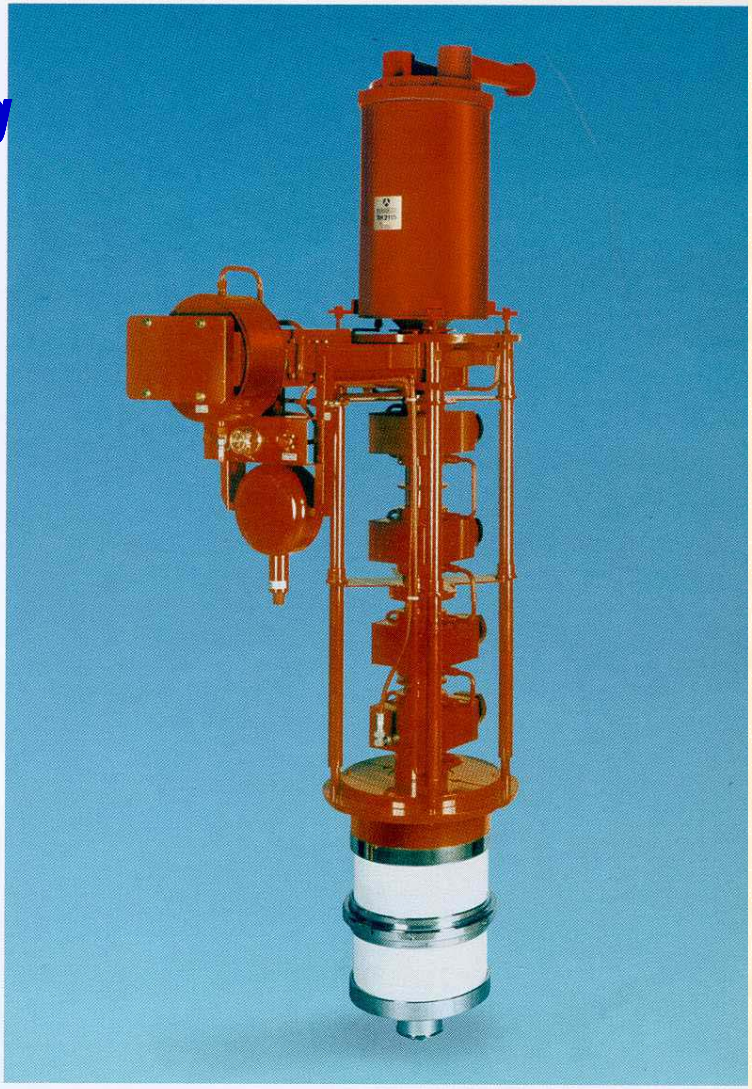
$$P_{RF} = \frac{V^2}{2 \cdot 1038 \cdot Q_{Ext} L} \qquad P_{RF\_Heat} = 15 \cdot \left(\frac{V}{15MV/m} \right)^2 W @ 2K \qquad \cancel{P_{Beam} = VI}$$

$\boxed{<40\ \text{kW}}$

External Q	**1.5e7**		**cf TESLA 3e6**
Fill Time	**2.5**	**ms**	**cf TESLA 0.5**
Rep Rate	**1**	**Hz**	
Pulse Length	**100**	**ms**	
DF	**10**	**%**	**cf TESLA 0.7%**
RF Power Pk/Avg	**7/0.7**	**MW**	
RF AC Power Pk/Avg	**17/1.7**	**MW**	
Heat Load @ 2K Static	**0.07**	**kW**	
Heat Load @ 2K Active Pk/Avg	**6**	**kW**	
Refrigerator Power Pk/Avg	**6/0.6**	**MW**	
Cryo + RF Wall Plug Power Avg	**2.4**	**MW**	

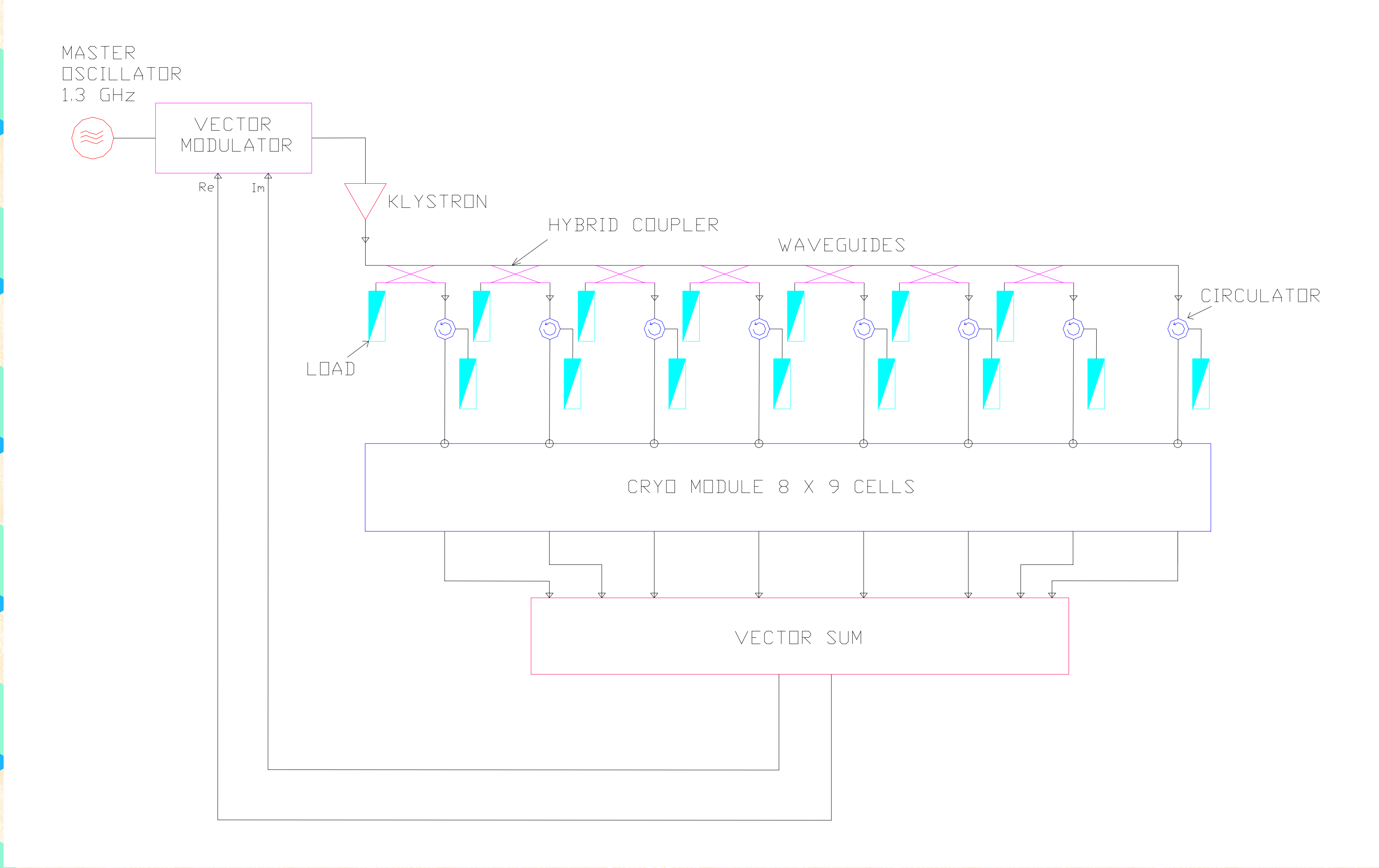
2.5 MW peak - 150 kW av.
at 1.3 GHz

24 Klystrons
250 kW Peak - 25 kW avg
1 Klystron/1 Cryomodule



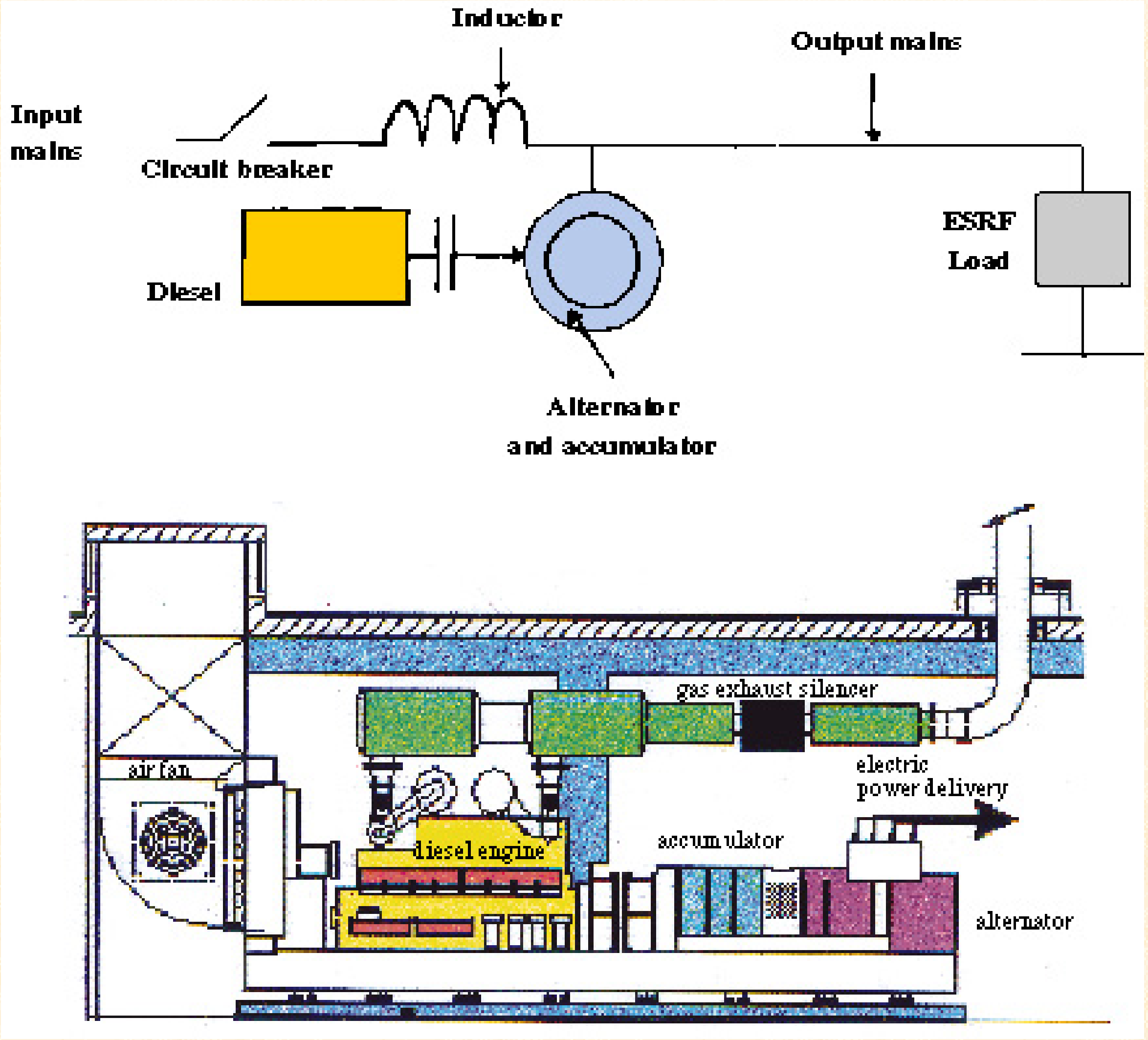
- Modulating anode
- High power in long pulse duration (1 ms)
- High gain: 43 dB typical
- Good efficiency: 47% typical
- High reliability, long life

One Klystron/Cryomodule



Energy Storage and AC Line Decoupling

(Bill North)



ESRF: 5 MW for 5 seconds

X-Ray Laser RF: ~3 MW for 100 ms @ 1 Hz

No line noise! Fewer Power Failures.

Efim Gluskin 6/13/2002:

"The undulators for FEL photon wavelengths between 1 and 100 nm are straightforward.

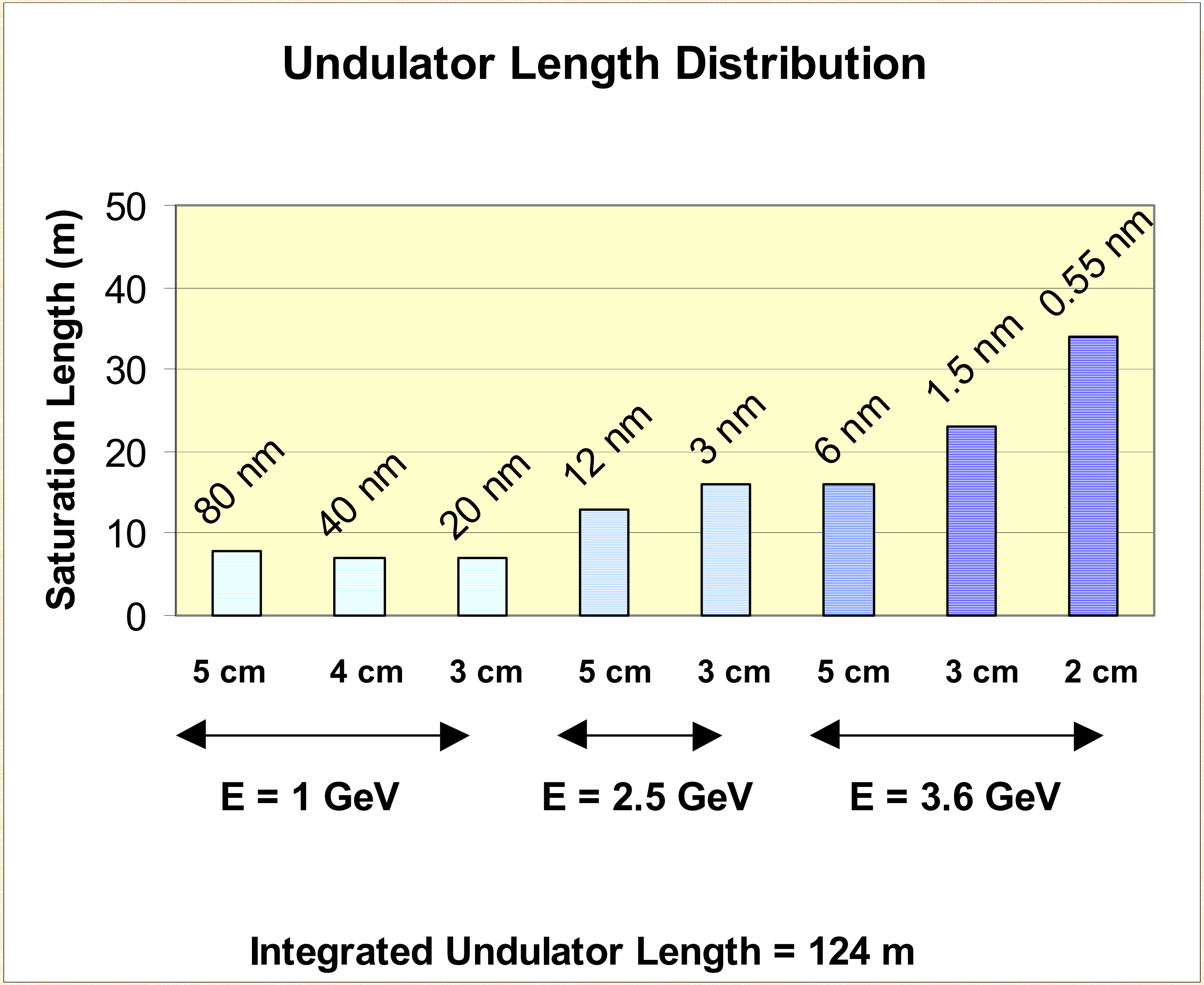
$$\lambda = \frac{\lambda_u}{2\gamma^2}\left(1 + \frac{K^2}{2}\right)$$

λ_u - Undulator period

K - Undulator parameter

γ - Relativistic factor

Many Optical Beamlines



Thanks to M. Xie and S. Milton

Upgrade Path

Additional Users

Increased Time Averaged Brilliance

Shorter Wavelengths

- **Facility would allow additional beamlines as funding permits.**

- **SC Linac would allow use of full 10% duty factor as gun technology matures. Time averaged Brilliance could surpass what is available at today's 3rd generation light sources.**

- **Linac could be extended while proposed facility is operational.**

Conclusions

The Technology Exists today to Build a user X-Ray Laser Facility with photon wavelengths between 0.5 and 100 nm.

This facility would consist of:

A High Brightness, RF Gun
A 192 m ~3.8 GeV Superconducting 1.3 GHz Electron Linac
2 or 3 Stations of Magnetic Compression
8 Photon Beamlines

This facility would make optimum use of existing technology and be constructed in a way that can evolve to produce higher time averaged brilliance and shorter wavelengths as technology improves.

Brighter Guns
Additional Beamlines
Shorter Period Undulators (SC structures)
Longer Linac

This project envisions a 2-4 year design stage followed by a 4-6 year construction stage and would be available for science between 2010 - 2012.