Applications of NLC X-Band Technology Including a Compact XFEL

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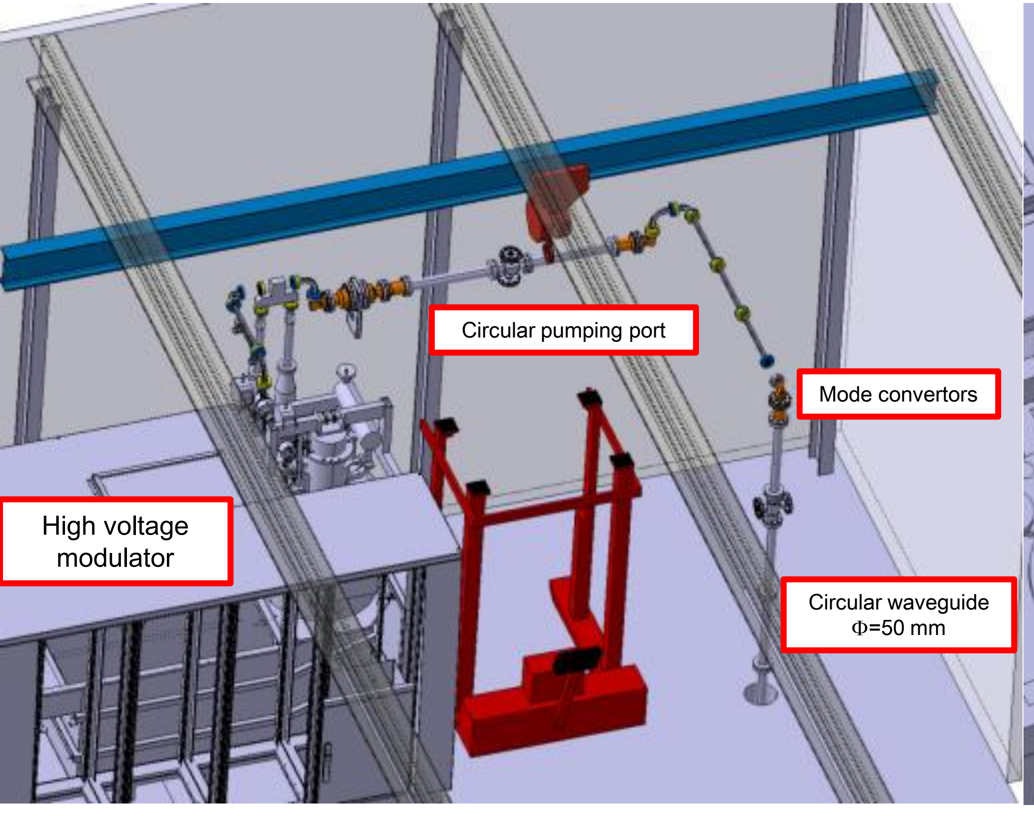
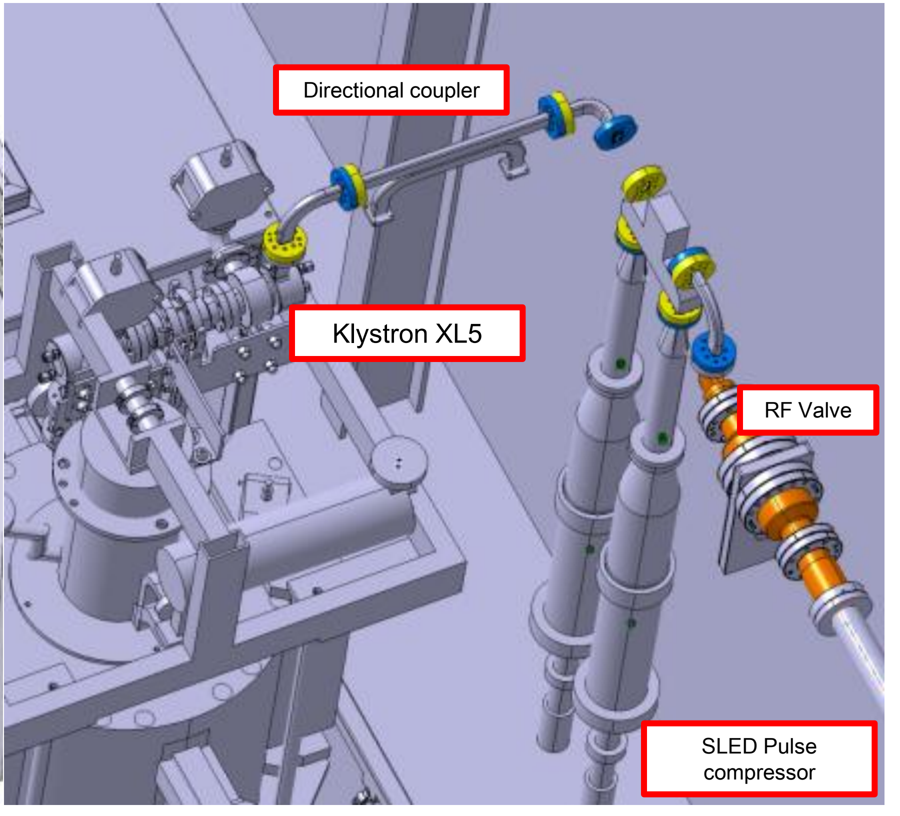
High Power (Multi-MW) X-Band Applications

- Energy Linearizer
  - Single Structure: in use at LCLS, planned for BNL, PSI, Fermi/Trieste and SPARX/Fascati
- Deflecting Cavity for Bunch Length Measurements
- CERN Linear Collider Structure Development
- 100’s of MeV to Many GeV Linacs
  - LLNL 250 MeV linac for gamma-ray production
  - SLAC 600 MeV energy ‘dither’ linacs for LCLS II
  - LANL 6-20 GeV linac for an XFEL source to probe proton-matter interactions
  - SPARX 1-2 GeV X-Band linac for their FEL
  - SLAC study of a 6 GeV Linac for a Compact XFEL (CXFEL) source

CERN/CLIC X-band Test-Stand
(Under Construction)





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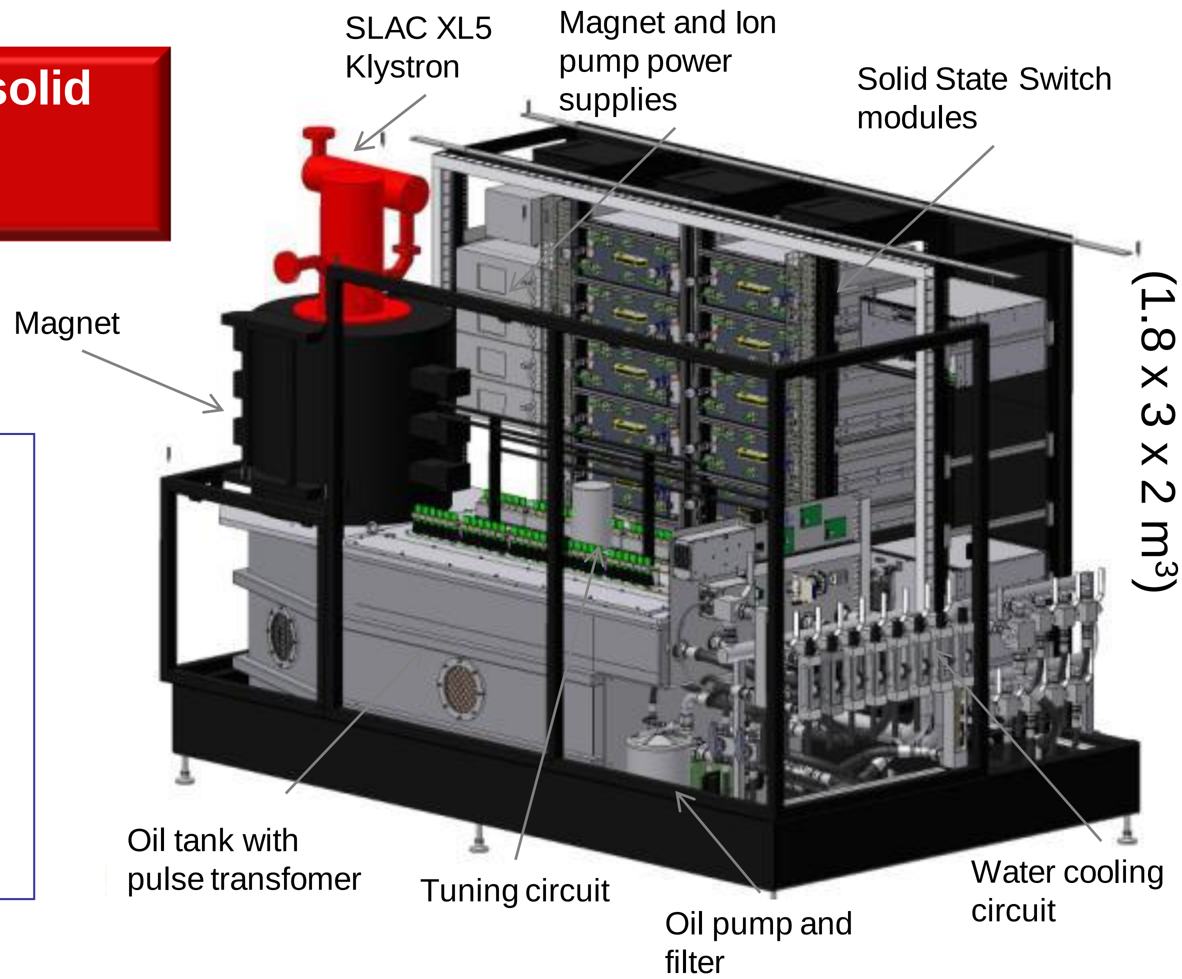
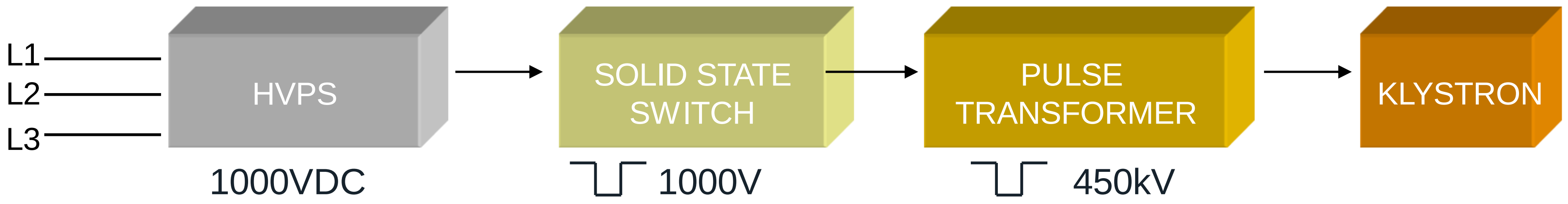
High Voltage Modulator

Development of a new solid state modulator by SCANDINOVA



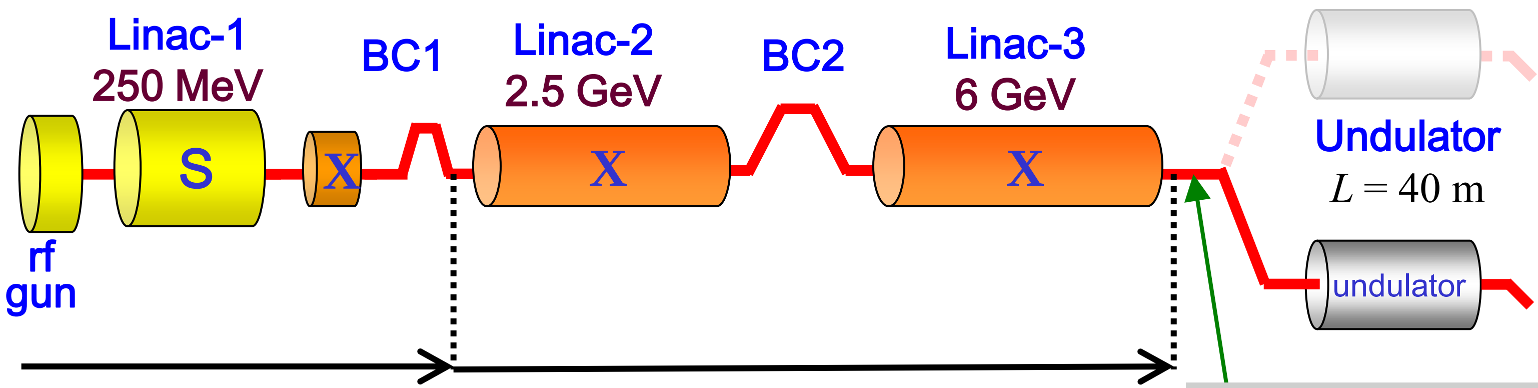
Specification :	
High Voltage :	450 kV
Current :	335 A
Flat pulse length:	1.5 µs
Pulse length at 50%:	2.3 µs
Repetition rate:	50 Hz
HV ripple:	0.25 %
Pulse to pulse stability:	0.1 %



Compact X-Ray (1.5 Å) FEL

Parameter	**Symbol**	***LCLS***	**CXFEL**	**Unit**
Bunch Charge	Q	250	250	pC
Electron Energy	E	14	6	GeV
Emittance	$\gamma\varepsilon_{x,y}$	0.4-0.6	0.4-0.5	μm
Peak Current	I_{pk}	3.0	3.0	kA
Energy Spread	σ_E/E	0.01	0.02	%
Undulator Period	λ_u	3	1.5	cm
Und. Parameter	K	3.5	1.9	
Mean Und. Beta	$\langle\beta\rangle$	30	8	m
Sat. Length	L_{sat}	60	30	m
Sat. Power	P_{sat}	30	10	GW
FWHM Pulse Length	ΔT	80	80	fs
Photons/Pulse	N_γ	2	0.7	10^{12}

X-band Linac Driven Compact X-ray FEL



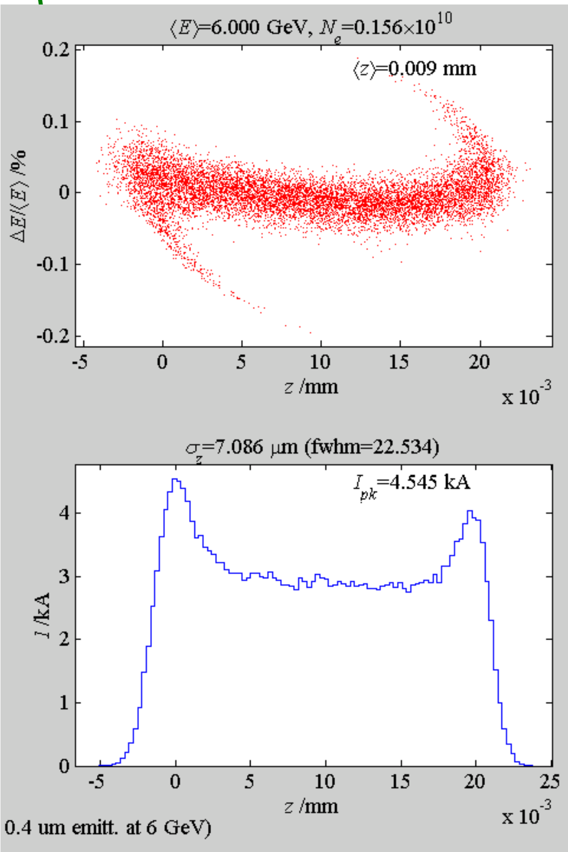
LCLS-like injector

L ~ 50 m

250 pC, $\gamma\varepsilon_{x,y} \approx 0.4\ \mu m$

X-band main linac+BC2

G ~ 70 MV/m, L ~ 150 m



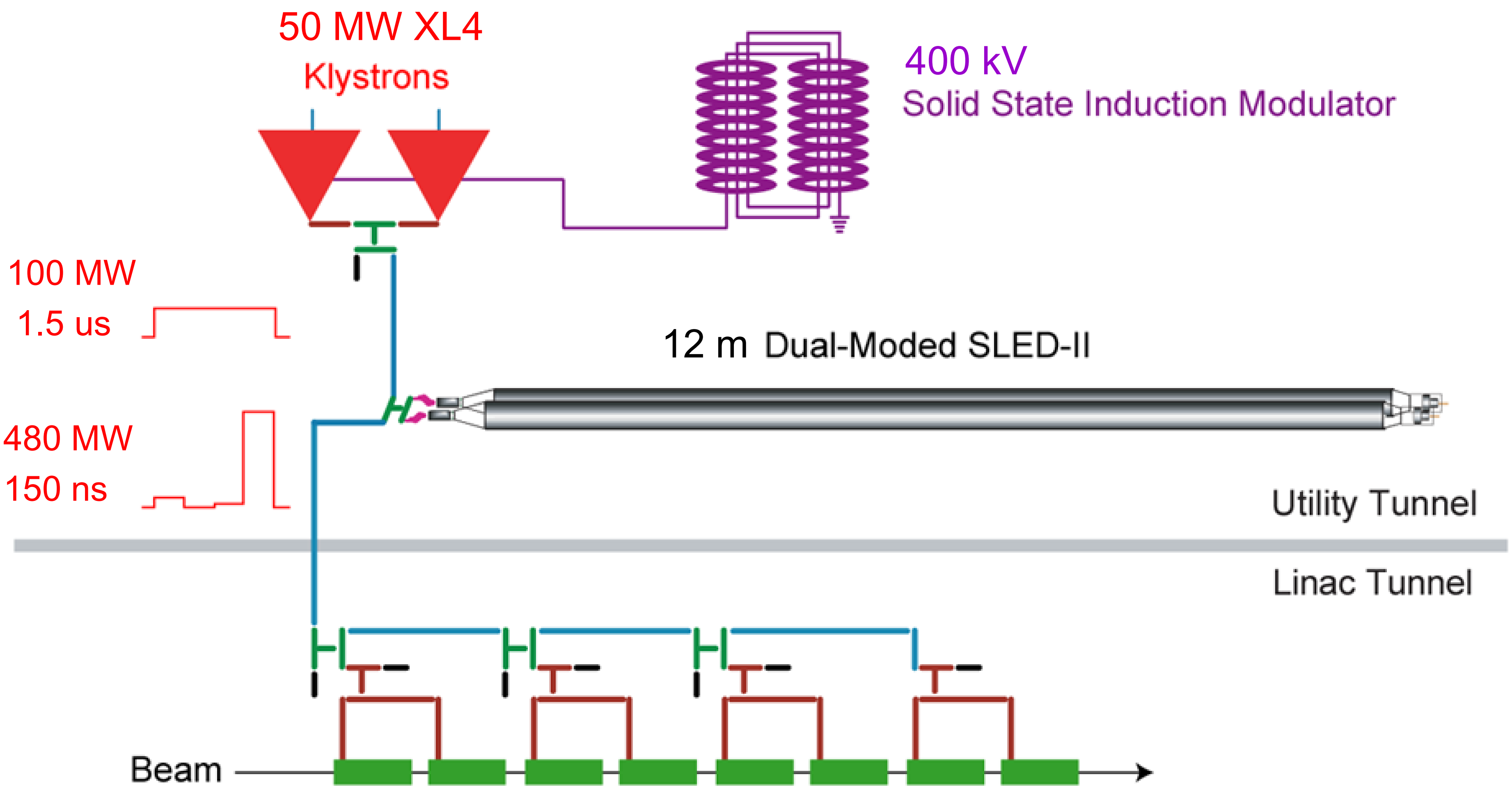
- Use LCLS injector beam distribution and H60 structure (a/λ=0.18) after BC1
- LiTrack simulates longitudinal dynamics with wake and obtains 3 kA “uniform” distribution
- Similar results for T53 structure (a/λ=0.13) with 200 pC charge

Operation Parameters

	Units	CXFEL	NLC
Final Beam Energy	GeV	6	250
Bunch Charge	nC	0.25	1.2
RF Pulse Width*	ns	150	400
Linac Pulse Rate	Hz	120	120
Beam Bunch Length	μm	7	110

* Allows ~ 50-70 ns multibunch operation

Layout of Linac RF Unit



Nine T53 Structures (a/λ = 13%) or Six H60 Structures (a/λ = 18%)

NLC RF Component Costs

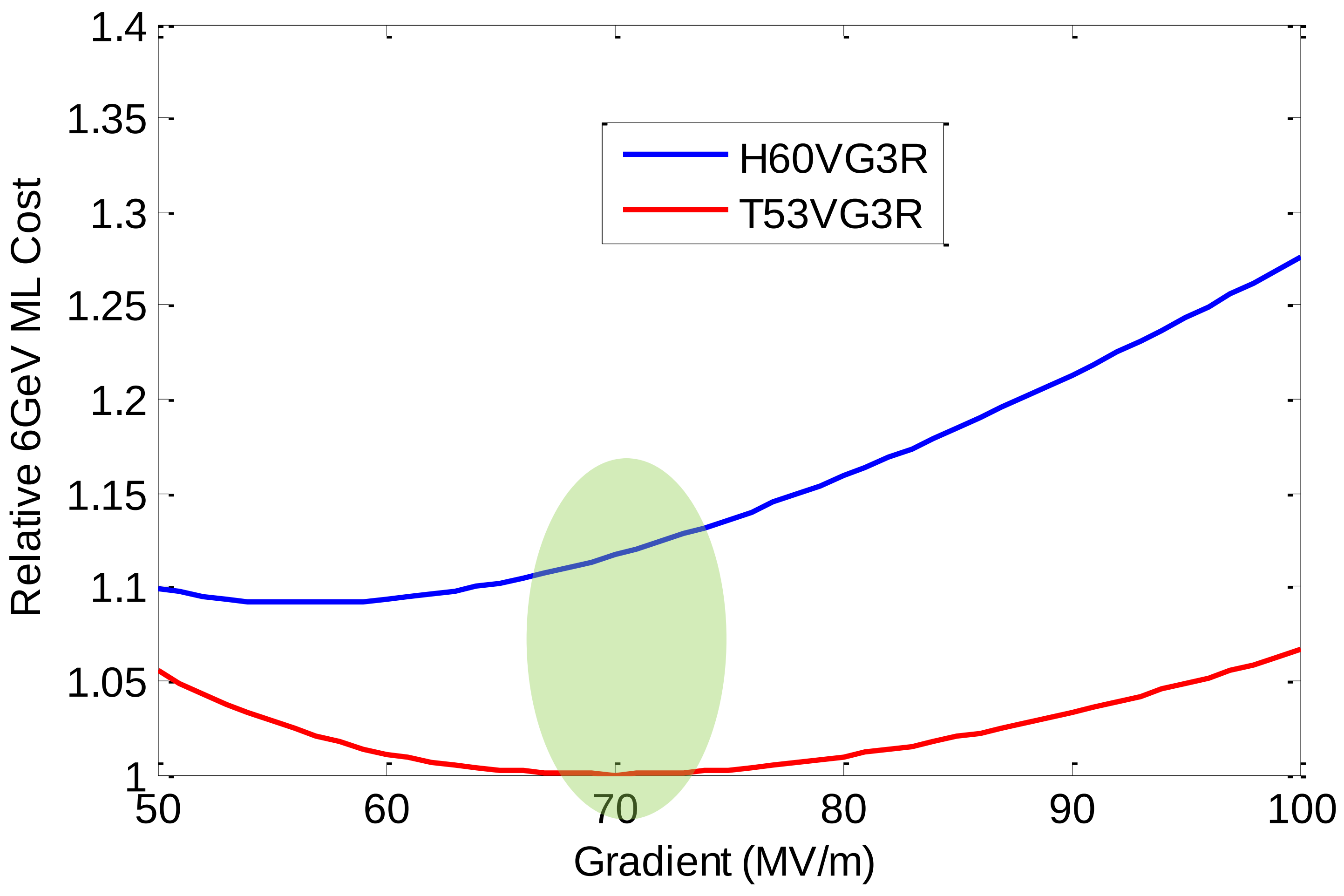
(2232 RF Units)

Cost (k$) per Item	
LLRF	26.1
Modulator	83.7
Klystron	56.6
TWT	13.3
SLED-II	242.3
Structures	21.5

For the 6 GeV CXFEL, assume the cost per item will be 4 times higher. For 70 MV/m operation:

	Units	T53	H60
Total RF units		18	24
X-Band Linac Length	m	122	108
Total Accelerator Length	m	192	178
X-Band Linac Cost	M$	56	62

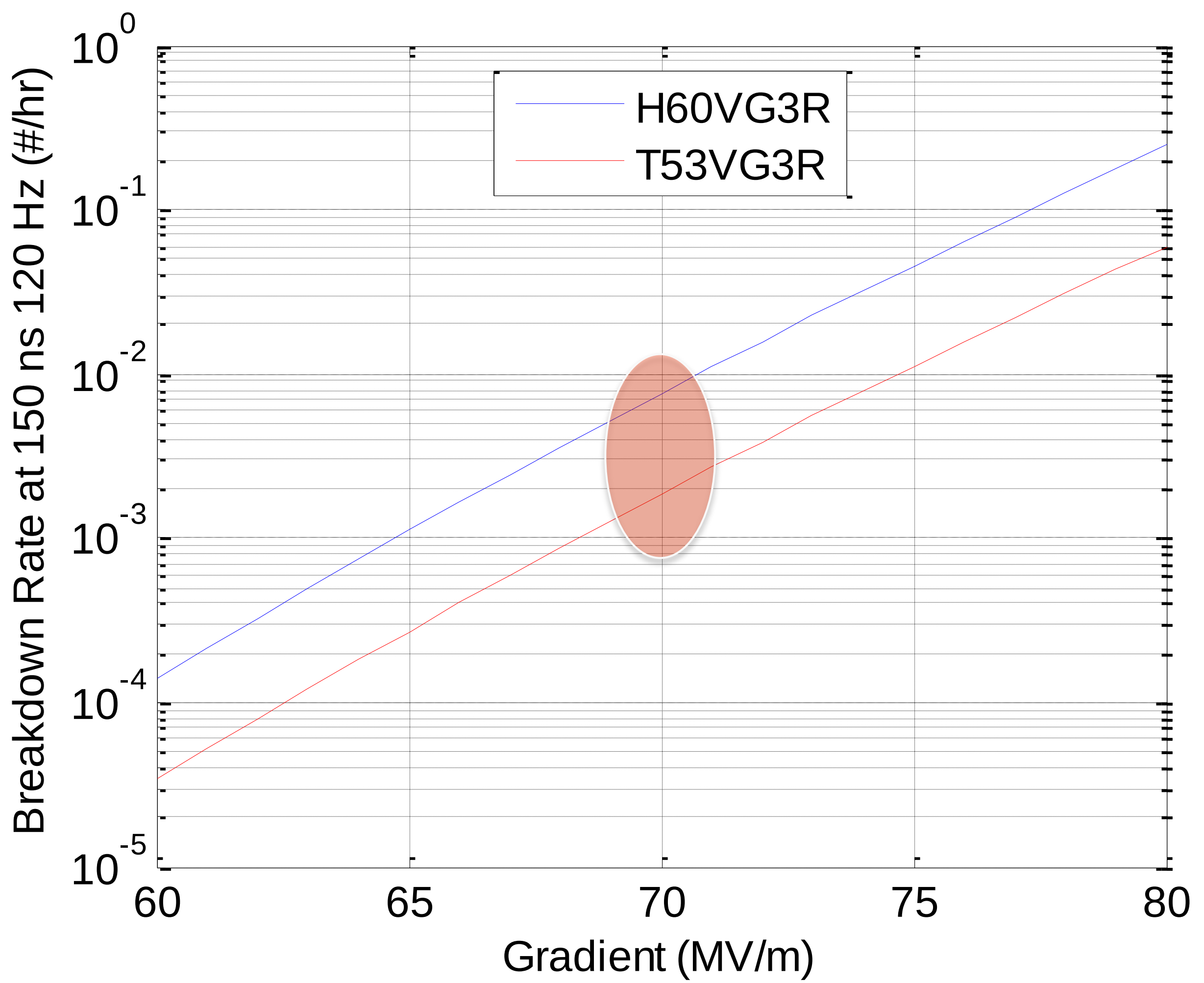
Gradient Optimization



Assuming 1) Tunnel cost 25 k$/m, AC power + cooling power 2.5 $/Watt

2) Modulator efficiency 70%, Klystron efficiency 55%.

Structure Breakdown Rates with 150 ns Pulses



At 70 MV/m, Expect Rate Less Than 0.01/hr at 120 Hz

1) H60VG3R scaled at 0.2/hr for 65 MV/m,400 ns, 60Hz
2) T53VG3R scaled at 1/hr for 70 MV/m, 480 ns, 60 Hz
3) Assuming BDR ~ G^{26}, ~ PW^6

Single Bunch Wake Tolerances

- In both Linac-2 and Linac-3, short-range transverse wakefields in H60 are not a major issue in that:

    - An injection jitter equal to the beam size yields a 1% emittance growth in Linac-2 and .003% growth in Linac-3

    - Random misalignments of 1 mm rms, assuming 50 structures in each linac, yields an emittance growth of 1% in Linac-2, 0.1% in Linac-3.

- With the T53 structure, the jitter and misalignment tolerances are about three times tighter for the same emittance growth.
- The wake effect is weak mainly because the bunches are very short.

X-Band Revival

- The 15 year, ~ 100 M$ development of X-band technology for a linear collider produced a suite of robust, high power components.
- With the low bunch charge being considered for future XFELs, X-band technology affords a low cost, compact means of generating multi-GeV, low emittance bunches.
  - Gradients of 70-100 MV/m possible vs ~ 25 MV/m at S-Band and ~ 40 MV/m at C-Band
- The number of XFELs is likely to continue to grow (e.g., normal conducting linacs being considered in Korea and China).
- To expand X-band use, need to have components industrialized and a small demonstration accelerator built, such as the 150 MeV C-band linac at Spring-8 in Japan where they have done light source studies.