TRIUMF

CANADA'S NATIONAL LABORATORY FOR PARTICLE AND NUCLEAR PHYSICS

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Electron Linac

Accelerator design for ½ MW photo-fission driver based on TESLA 1.3 GHz SCRF technology

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LABORATOIRE NATIONAL CANADIEN POUR LA RECHERCHE EN PHYSIQUE NUCLÉAIRE ET EN PHYSIQUE DES PARTICULES

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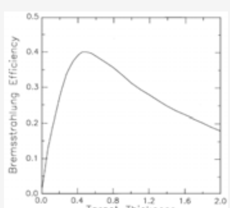
Photo-fission *a la* Bill Diamond



Production efficiency high: one γ-photon for three electrons (30 MeV)

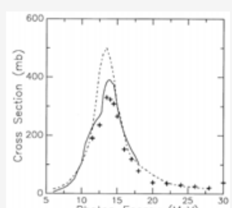
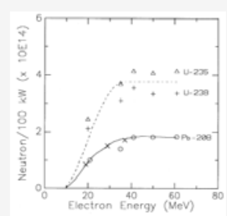


Photo-fission cross-section high for 15 MeV γ due to GDR

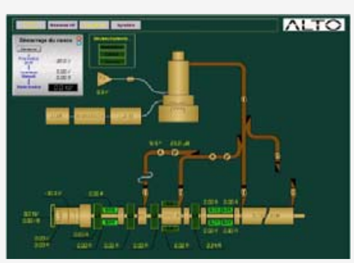


Neutron/fission yield saturates above 40 MeV

^{91}Kr production rate provides a reference point between Diamond's estimate and meaurements at *Alto* using LIL (LEPP Injector Linac at Orsay)

Estimate: 3×10^8 of ^{91}Kr/s/μA electrons

Measurement: 2×10^6 of ^{91}Kr/s/μA extracted from UC target and trapped on cold finger.



Conclusion: A 500 kW electron beam could produce 4-7 $\times10^{13}$ fissions/second from a ^{238}U target, leading to copious neutron-rich isotopes.

Beam Specification

Bunch charge (pC)	16
Bunch repetition rate (GHz)	0.65
Radio frequency (GHz)	1.3
Average current (mA)	10
Kinetic energy (MeV)	50
Beam power (MW)	0.5
Duty Factor	100%

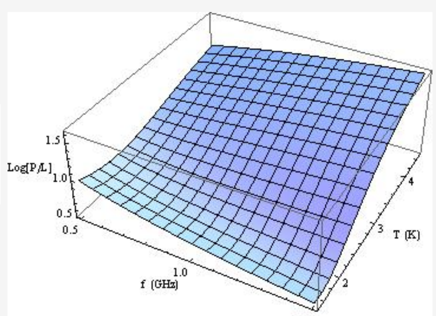
Bunch vital statistics	inject	eject
Normalized emittance (µm)	<30π	<100π
Longitudinal emittance (eV.ns)	<20π	<40π
Bunch length (FW), inject (ps)	<170	>30
Energy spread (FW)		<1%

The requirement: 50 MeV × 10 mA = ½ MW beam power eliminated on target.

Why SCRF? High duty factor or c.w. operation inconceivable with NC cavities – for 50 MeV, need 2-4 MW c.w. RF power!

Cost scales as Power/Length
@ constant gradient =

$$\frac{c\, E0^2 \left(Rdc + \frac{A\, e^{-\frac{B}{T}} f^2}{T}\right)(-T + Ts)}{2\, f\, T\, \eta^2}$$



1.3 GHz @ 2 K is
cost minimum

H.A. Schwettman, Low Temperature Aspects of a Cryogenic Accelerator, IEEE Trans. Nuc. Sci. June 1967

1.3 GHz SCRF cavities have been in development for >30 years, starting with 27 m long 50 MeV SCA at Stanford.

Impediments to high Q and gradient were: (1) multipactor (MP); and (2) surface purity/treatment.

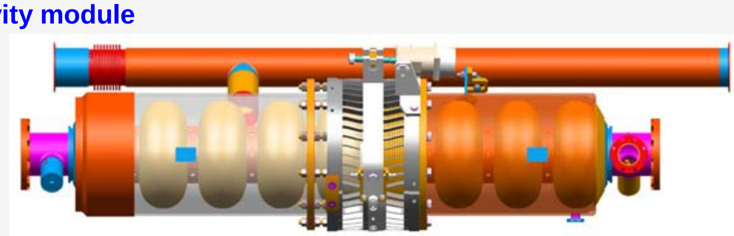
MP: is a regenerative electron emission instability (avalanche); and was cured by introduction of spherical-shaped cells (1979).

Improvements in surface preparation are ongoing; measures include clean rooms, HT bake, BCP, EP, HPR, etc.

With major impetus from LEP, CEBAF & TESLA, etc, technology is now mature with gradients >20 MV/m routine.

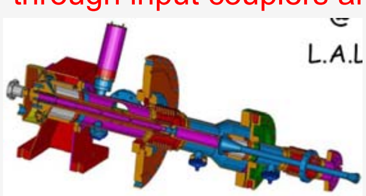
TTF/ILC 9-cell cavity

ILC cavity module



Commonality of ILC with Fission driver stops here

Fission Driver: 500 kW CW RF power has to propagate through input couplers and cavities to beam

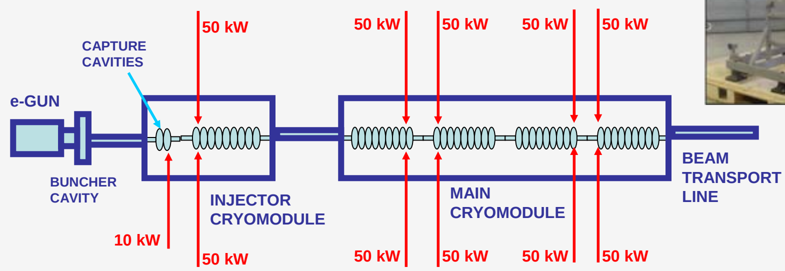


TTF3/ILC input coupler: ≤16kW average power

Cornell ERL input coupler: ≤60kW average power

E-linac power distribution

Five 130 kW klystrons



ILC	
9 cavity/cryomodule; 9 cell/cavity	Average current 0.04 mA
1 input coupler/cavity; 31 MV/m gradient	Average power 16 kW/cavity
2 HOM coupler/cavity	Duty factor 0.5%

Fission Driver	
4 cavity/cryomodule; 9 cell/cavity	Average current 10 mA
2 input coupler/cavity; 10 MV/m gradient	Average power 100 kW/cavity
1 HOM absorbr/cavity	Duty factor 100%

CW operation has other challenges:

- Higher heat load in all RF components: cavity, input coupler, HOM coupler/absorber, etc
- Limited choice of c.w. klystrons, c.w. couplers

	Fission driver, 10 MV/m 4 cavity	ERL 20 MV/m 4 cavity	TESLA TDR 23.4 MV/m 12 cavity
RF Load (W)	41.6	166.4	4.95
2K Sum (W)	44.4	251.5	9.05
5K Sum (W)	29.1	34.5	15.94
Input Couplers	713	265	80.9
80K Sum (W)	717.6	601.2	183.02

CW related (RF Load, 2K Sum)

Beam power related (Input Couplers, 80K Sum)

2K & 80K sums are almost 4× TESLA values

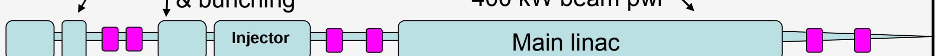
CW operation has also some benefits:

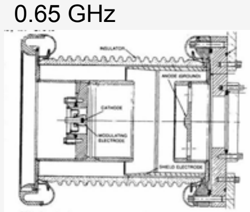
- No periodic beam-load transients
- No periodic Lorentz-force detuning
- Little or no need for piezo actuators
- LLRF simpler in principle
- Ideal for targets - avoid thermal cycling/ shocking of target
- Lower bunch charge – lower HOM excitation.

All relaxed c.f. ILC (applies to the first four items)

Rossendorf ELBE cavity

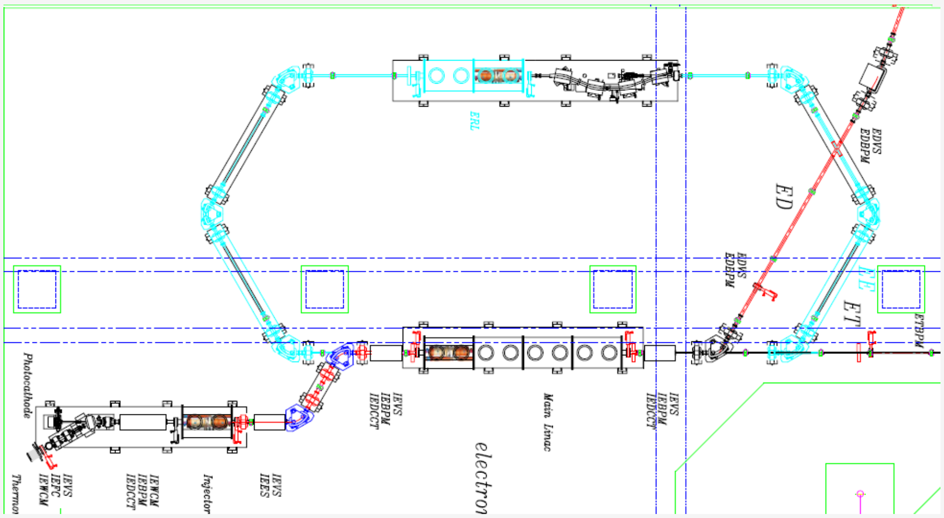
Baseline Design



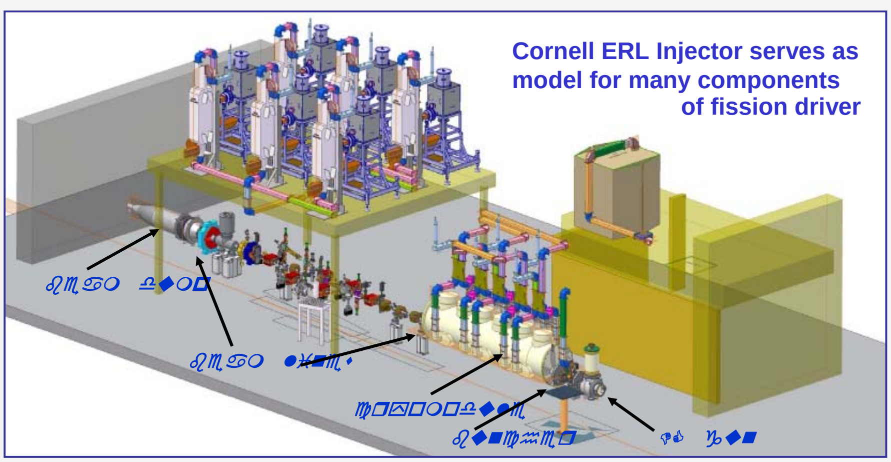


NIST/NIKHEF /JLab design

Division into injector and main linacs allows upgrade path (after 2015) to test-bed for RLA (Recirculating Linear Accelerator) or ERL (Energy Recovery Linac)



The path-finders for c.w. high-power, high-current linacs are the Energy Recovery Linac (ERL) based light-sources, particularly their injector linacs – (no energy recovery)



Fission driver specification more relaxed than for ERL or ERL injector – many reasons!

- FEL-based light source at ERLs need 6D high-brilliance beams & careful emittance preservation.
- Fission driver has no such requirement - eliminates beam on target, so beam brilliance immaterial.

	Daresbury ERLP	JLab IR-FEL (1.5 GHz)	Cornell ERL Injector	ILC	Fission driver
Charge/bunch (pC)	80	135	80	100	8
Bunch length (ps)	1-2	0.2-2	2	2	40
Emittance (μm) normalized	1-2	<30	1	3/.03	30
Bunch rep' rate (MHz)	81.25	75	1300	3	1300
Macro-pulse rep' rate (Hz)	20	c.w.	c.w.	5	c.w.
Beam energy (MeV)	40	80-200	10	300/cryo	50

bunch repetition rate sets the fine-structure of the beam frequency spectrum.

Electron Source

ERL: Photonic gun – expensive, high maintenance, 10^{-11} torr

Fission driver: Thermionic gun – inexpensive, low maintenance, 10^{-9} torr. (Gun is gridded *a la* FELIX at NIKHEF and modulated at 0.65 GHz.)

HOM excitation and HOM power – scale as Q^2

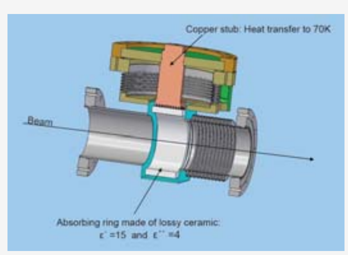
By design, issue much reduced in fission driver.

ERL: High charge (Q) and short bunch → large HOM power, ferrite absorbers (one/cavity) in beam pipe, etc.

Fission driver: Low bunch charge, beam frequency spectrum lines only at 0.65 GHz multiples

Long bunches → beam spectrum rolls off at 20 GHz.

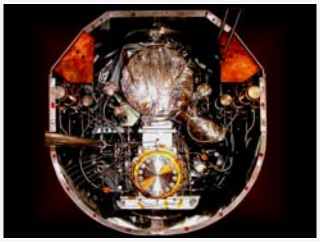
XFEL-type ceramic HOM absorbers



Elinac will use/adapt existing equipment designs wherever possible

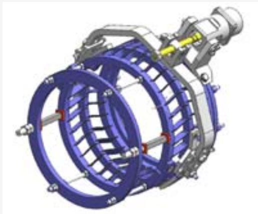
- NIST/NIKHEF Triode gun
- ELBE NC buncher cavity
- TTF/ILC 9-cell cavities
- Cornell/CPI 50 kW couplers (CW variant of ILC coupler)
- e2V 130 kW klystrons
- XFEL HOM absorbers

As shown above



Cornell cryostat
(CW variant of TTF cryostat)

Tuner: Costing based on INFN blade/coaxial tuner



Elinac Summary

L-band SCRF technology provides cost effective approach to MW-class fission driver.

There are cell, cavity, input coupler, HOM damper, tuner, klystron, IOT, cryostat and BPM designs all pre-existing – eliminates substantial R&D & cost.

C.W. operation poses some challenges c.f. TESLA/ILC – but these are being met by ERL light source designs.

Indeed, some of the fission driver specifications are more relaxed than for ILC and/or ERLs.