Status of linear collider designs:

Electron and positron sources

Design overview, principal open issues

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Electron sources- for 500 GeV CM machines

Parameter	**TESLA**	**NLC**	**CLIC**
Cycle rate (Hz)	5	120	200
Bunches/train	2820	192	154
Bunch spacing (ns)	337	1.4	0.67
Particles/bunch(x10^{10})	4	0.8	0.625
Total charge/train (nC)	18,048	246	165
Average beam current (μA)	90	30	31
Average beam current during train (mA)	91	915	1600
Polarization (%)	80	80	75
Rms normalized emittance (μm)	40	100	7
Bunch length FWHM (mm)	8	10	7
Energy spread (%)	1	2	5
Source output energy (MeV)	500	80	190

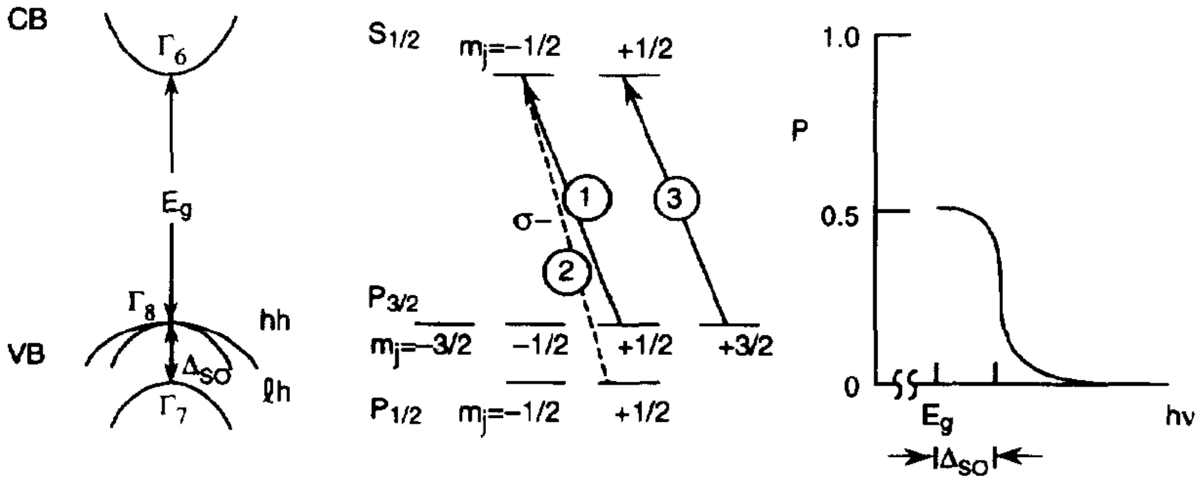
Polarized electron guns

- All projects require ~80% polarization and plan on a polarized electron gun .
- All projects will use a DC photocathode source using strained GaAs as the photocathode.
- The vacuum requirement for strained GaAs is very stringent ($<10^{-12}$ Torr), and the negative electron affinity (NEA) surface is very sensitive to field emission. This is incompatible (to date) with an rf gun.

Polarized electron gun- GaAs cathode

- Bulk GaAs can be an efficient photoemitter when it is p-doped and the photoemitting surface is coated with Cs.
- The p-doping and Cs lower the vacuum level below that of the conduction band, producing a ”negative electron affinity” (NEA) surface.
- Photons absorbed in the bulk promote electrons to the conduction band, which diffuse to the NEA surface and are emitted
- If the photons have the right energy and are circularly polarized, the emitted electrons will be polarized.
- The polarization can be enhanced by growing a thin “strained” layer of p-doped GaAs on top of bulk $GaAs_{1-x}P_x$

(a) GaAs



(b) GaAs – GaAs$_{1-x}$ P$_x$

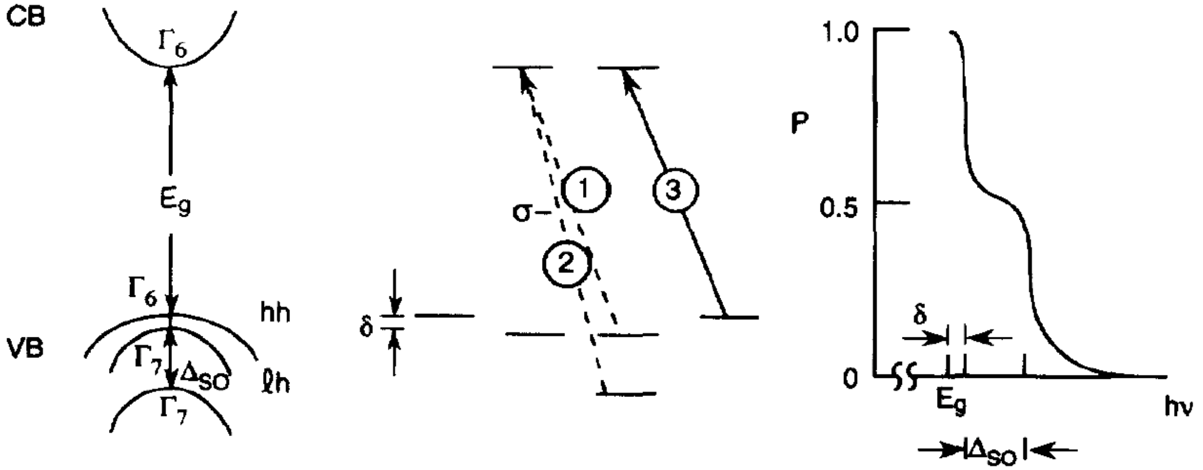


Fig. 3. Energy level diagram and transition probabilities at Γ point. Only the transitions for σ-excitation are shown. (a) For GaAs, the solid-line transitions are for $E_g < h\nu < (E_g + \Delta)$. (b) For GaAs–GaAs$_{1-x}P_x$, the solid-line transitions are for $E_g < h\nu < (E_g + \delta)$.

Polarized electron guns

- For the DC guns, the output energy is in the range of 120-200 keV. The field gradient at the cathode is a few MV/m, and the charge per bunch is a few nC. The normalized emittance is in the range of 40-100 mm-mrad, because of the low field gradient.
- The linear collider DC gun is very similar to the DC gun used at the SLC, but requires a higher current output.

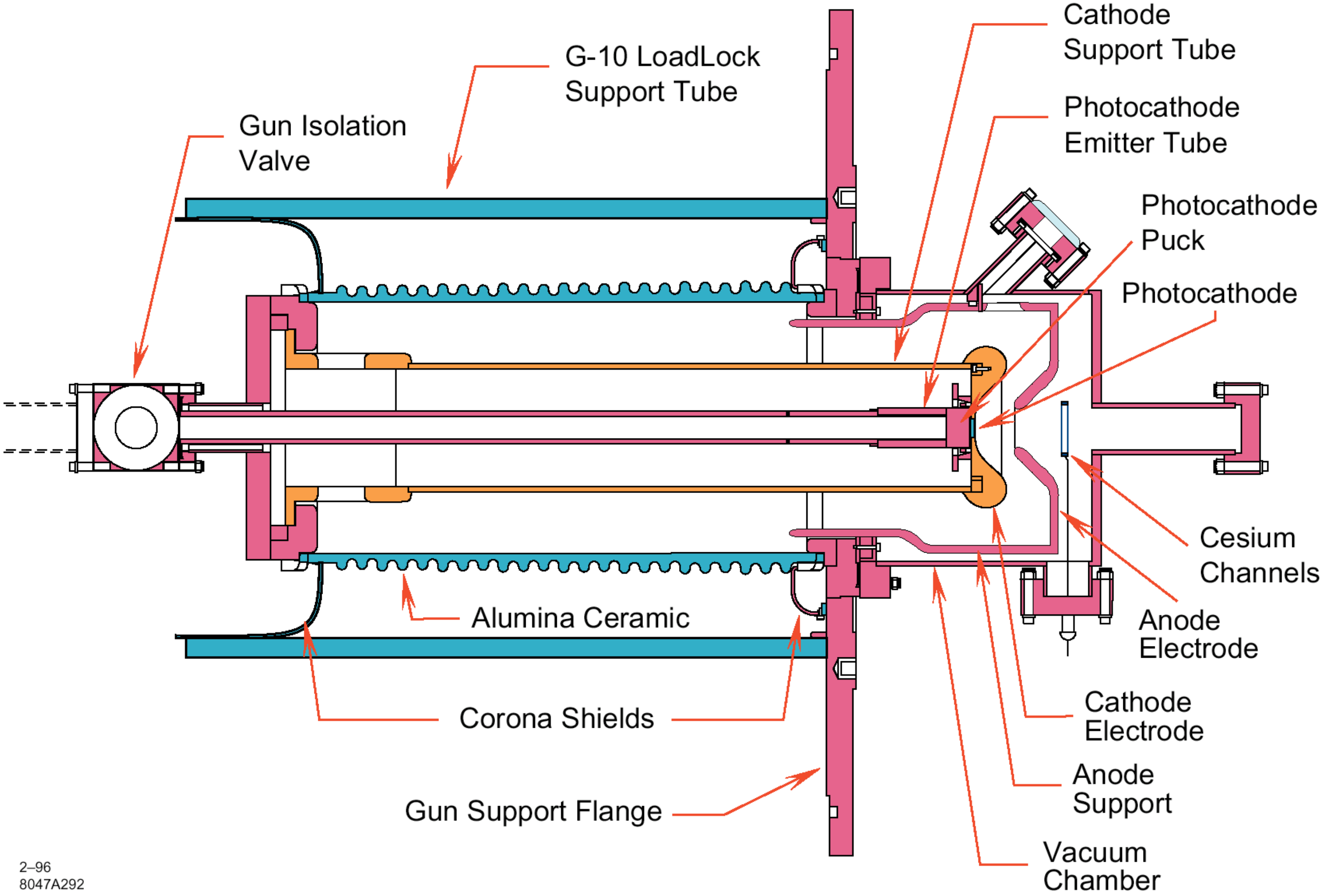


Figure 2-2. *Cross section of the SLC polarized electron gun (loadlock not shown).*

Polarized electron guns
-laser system-

- Baseline laser system: Ti:Sapphire circularly polarized laser at ~800 nm, pumped with mode-locked Nd:YLF .
- Spot radius on cathode of about 1 cm, about 4 μJ of energy required per bunch. (50-100 mW of average power).
- Stability required is (0.5%, 5%), (NLC/JLC and CLIC, TESLA) (pulse to pulse variation in laser intensity). Circular polarization >99%.

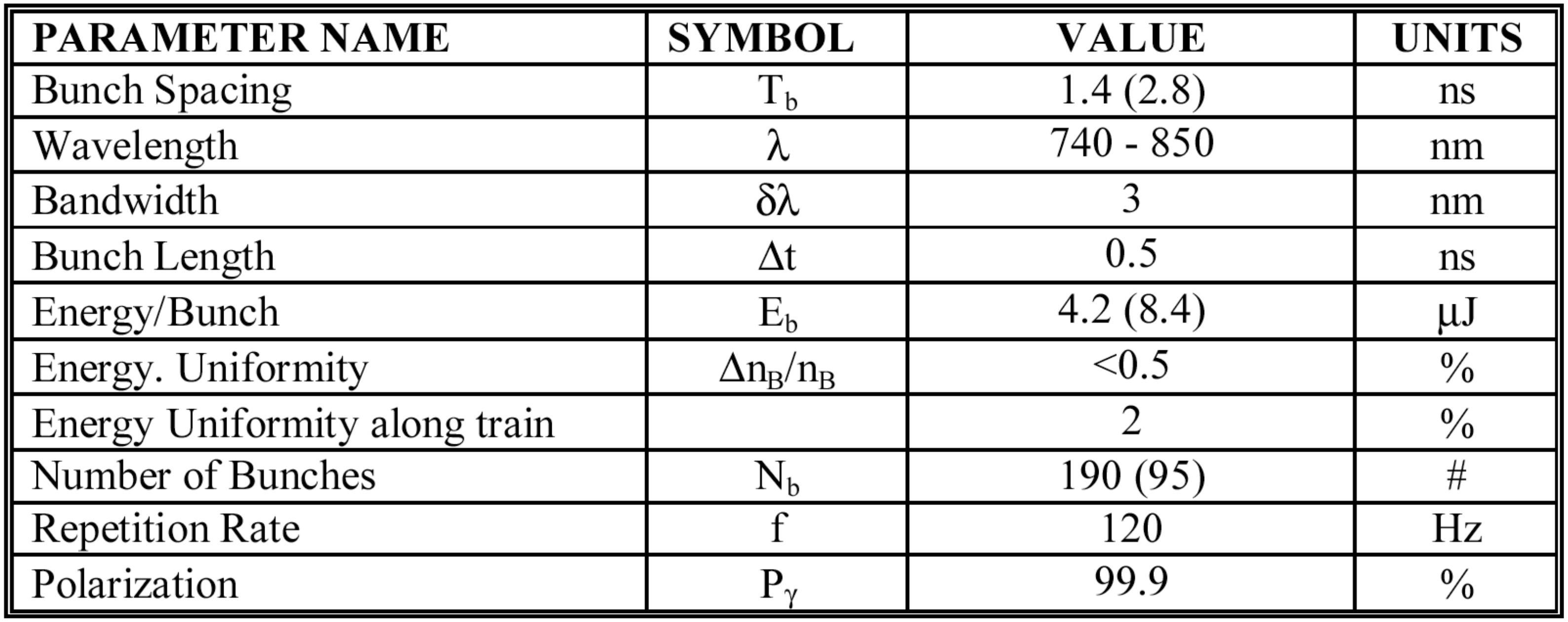


Table 5.2: Polarized electron source laser system parameters

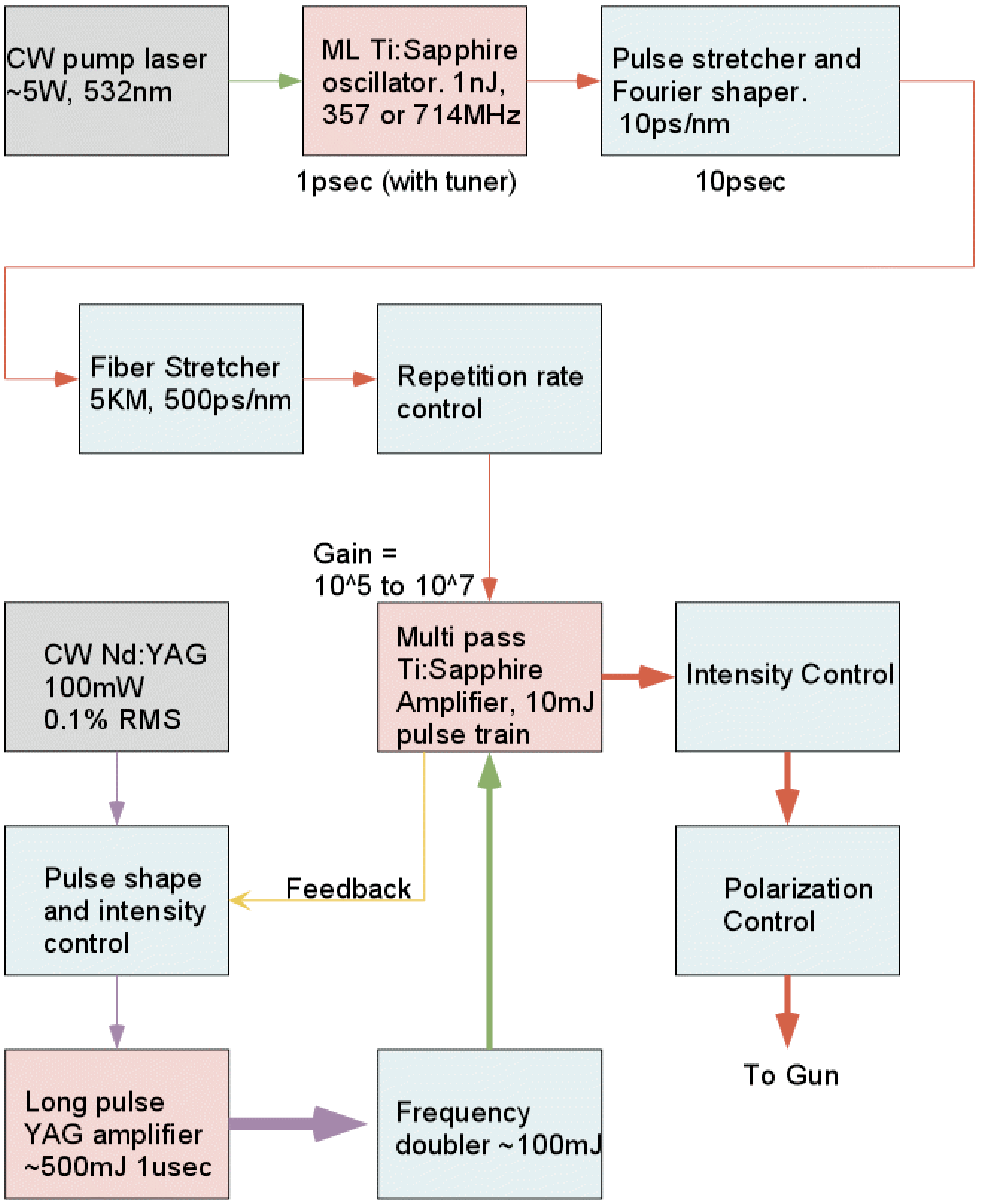
PARAMETER NAME	SYMBOL	VALUE	UNITS
Bunch Spacing	T_b	1.4 (2.8)	ns
Wavelength	λ	740 - 850	nm
Bandwidth	$\delta\lambda$	3	nm
Bunch Length	Δt	0.5	ns
Energy/Bunch	E_b	4.2 (8.4)	µJ
Energy. Uniformity	$\Delta n_B/n_B$	<0.5	%
Energy Uniformity along train		2	%
Number of Bunches	N_b	190 (95)	#
Repetition Rate	f	120	Hz
Polarization	P_γ	99.9	%

NLC/JLC Polarized gun laser system

Parameter	TESLA 500	TESLA 800
Wavelength	780 to 850 nm tunable to < 10 nm	
Train rep. rate	5 Hz	3 Hz
Polarisation	circular switchable	
Pulse Train Structure:		
Pulse train length	950 μs	850 μs
No. of pulses per train	2820	4500
Pulse spacing	337 ns	189 ns
Pulse energy	4.6 μJ	3.2 μJ
Pulse length	700 ps to 2 ns (sigma)	
Spot radius on cathode	10 mm (flat top)	
Synchronization	to reference RF signal	
Phase stability	< 200 ps (rms)	
Energy stability	< 5 % (rms)	
Control	fully remote	
Maintenance down time	<1 %	

Table 4.2.3: *Basic specification of the laser system for the polarised electron source. The differences in the pulse train structure for TESLA-500 and TESLA-800 are shown.*

NLC Source Laser Block Diagram



CW pump laser
~5W, 532nm

ML Ti:Sapphire
oscillator. 1nJ,
357 or 714MHz

1psec (with tuner)

Pulse stretcher and
Fourier shaper.
10ps/nm

10psec

Fiber Stretcher
5KM, 500ps/nm

Repetition rate
control

Gain =
10^5 to 10^7

Multi pass
Ti:Sapphire
Amplifier, 10mJ
pulse train

Intensity Control

Polarization
Control

To Gun

CW Nd:YAG
100mW
0.1% RMS

Pulse shape
and intensity
control

Feedback

Long pulse
YAG amplifier
~500mJ 1usec

Frequency
doubler ~100mJ

Polarized Electron guns-issues

- The average current required during the train for NLC/JLC and CLIC exceeds the GaAs “cathode charge limit” and requires cathode development.
- The NLC/JLC and CLIC laser pulse-to-pulse stability requirement is very challenging. The requirements were, however, met for the SLC source.
- For TESLA, the long bunch train is a challenge for Ti:Sapphire laser systems. (Short lifetime -3.2 μs- and thermal lensing)
- The emittance required for CLIC is rather small for a DC gun.

Prebunching and acceleration- TESLA

- For TESLA, the beam from the gun is prebunched to 3.4 mm in 108 and 433 MHz bunchers, then solenoid focused and accelerated to 76 MeV in warm 1.3 GHz rf cavities.
- There are significant thermal loads on the warm rf, because of the long (1ms) pulse-0.5% duty cycle.
- Subsequently, the beam is accelerated to 500 MeV with 1.3 GHz scrf for transfer to the electron injector.
- The electron injector is a 1.3GHz scrf linac which takes the beam to 5 GeV for damping ring injection.

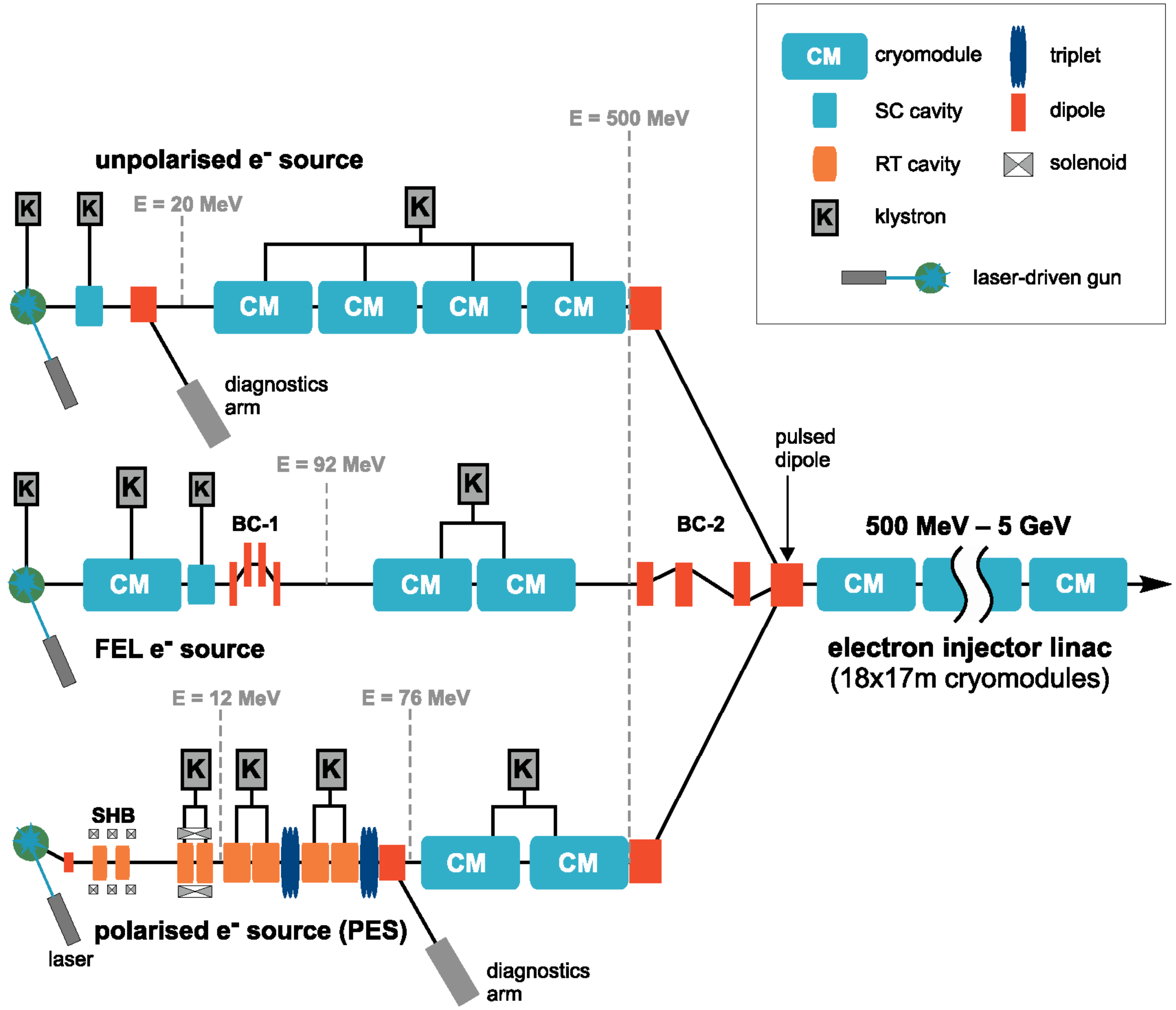


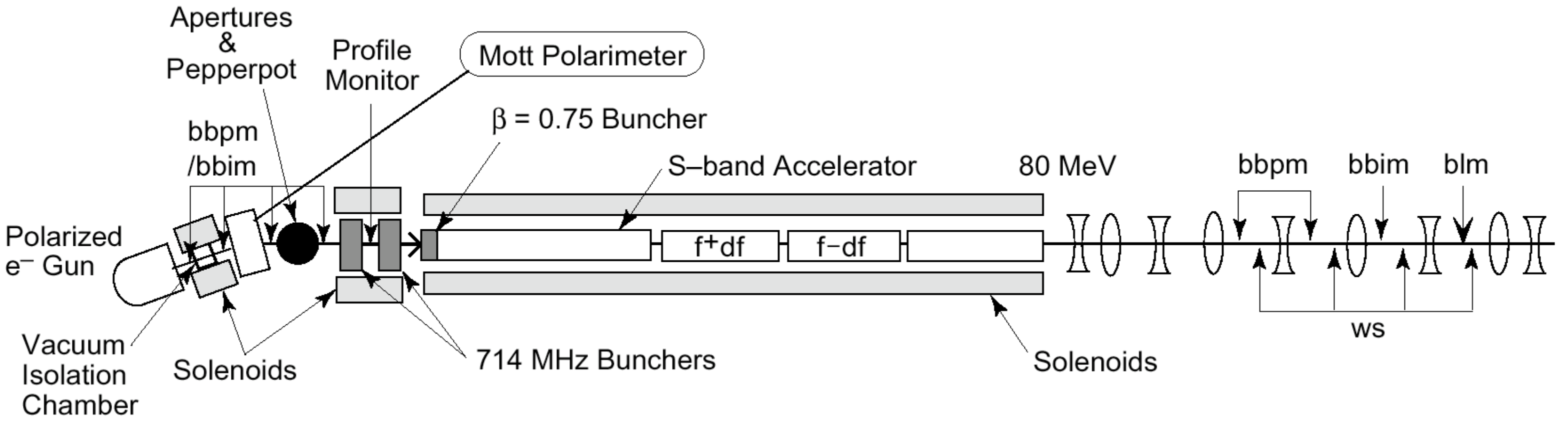
Figure 4.2.1: *Schematic of the electron injector complex (see relevant sections for details). Note that not all components are shown.*

TESLA Electron source

Prebunching and acceleration-NLC/JLC

- For NLC/JLC, the beam is bunched to 5 mm in a 714 MHz subharmonic cavity and accelerated to 80 MeV in a solenoid focused 3 GHz warm linac.
- It is then injected into a standard 3 GHz warm rf linac and accelerated to 2 GeV for injection into the damping ring.

Polarized Source Electron Injector



NLC/JLC electron source

Prebunching and acceleration-CLIC

- For CLIC, the beam from the DC gun is pre-accelerated to 10 MeV using a solenoid-focused system, then accelerated to 190 MeV in 1.5 GHz pre-injector
- It is further accelerated to 2 GeV @1.5 GHz for injection into the damping ring.

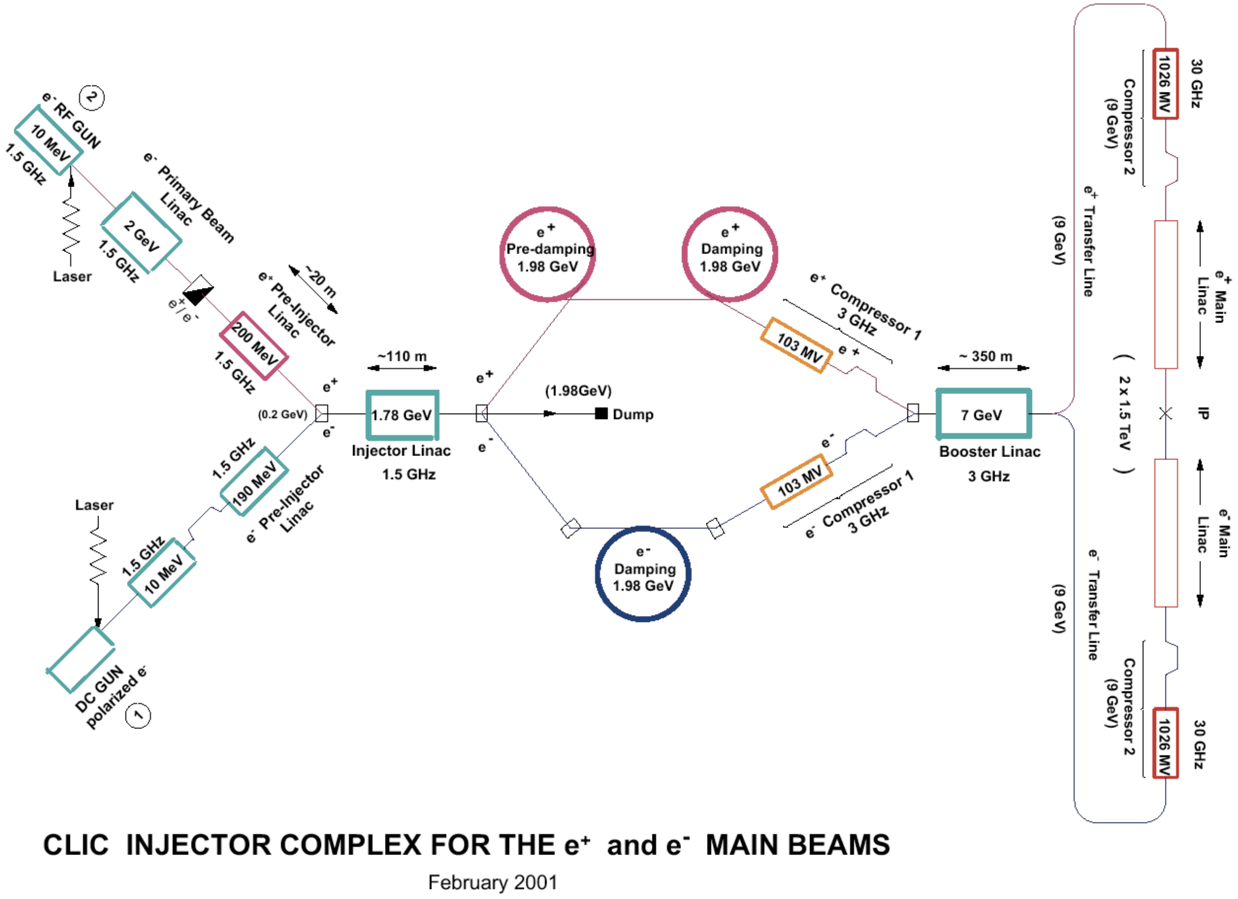


Figure 2: CLIC injector complex for the e$^+$ and e$^-$ main beams.

Positron sources-500 GeV CM machines

Parameter	**TESLA**	**NLC**	**CLIC**
Cycle rate (Hz)	5	120	200
Bunches/train	2820	192	154
Bunch spacing (ns)	337	1.4	0.67
Particles/bunch($x10^{10}$)	2	0.9	0.84
Total positrons/train ($x10^{12}$)	56	1.73	1.25
Incident beam energy (GeV)	150-250	6.2	2
Target/thickness (r.l.)	1xTi/0.4	3xWRe/4	2xWRe/4
Yield($e+/e^-$)	1-2	1	0.7
normalized emittance (edge) (mm)	20	30	90
Bunch length FWHM (mm)	5	15	7
Energy spread (%)	7	15	10
Source output energy (MeV)	300	250	200

Positron sources

- NLC/JLC and CLIC use "conventional" sources-positrons are produced by electromagnetic showers generated by a high energy (few GeV) electron beam impinging on a high-Z (tungsten-rhenium) thick target
- From SLC experience, the limit (due to thermal stress) on the maximum tolerable instantaneous energy density deposit in such a target by a high energy electron beam is about 50 J/g.
- In order to limit the energy density to below this value for NLC/JLC and CLIC, multiple target/capture systems must be used.

Positron source:NLC/JLC

- A 6 GeV electron beam is generated in a 3 GHz rf linac. This is targeted on a 4 radiation length W-Re target. The resulting positrons are captured in an adiabatically matched solenoid field (peak 5.8 T), and solenoid-focused and accelerated to 250 MeV in a 1.5 GHz linac.
- They are further accelerated in a conventional 1.5 GHz rf linac to 2 GeV, for injection into the positron pre-damping ring. The injected yield is 1 positron/electron.
- There will be four target/capture systems, of which 3 will be used simultaneously, using rf separated beams.

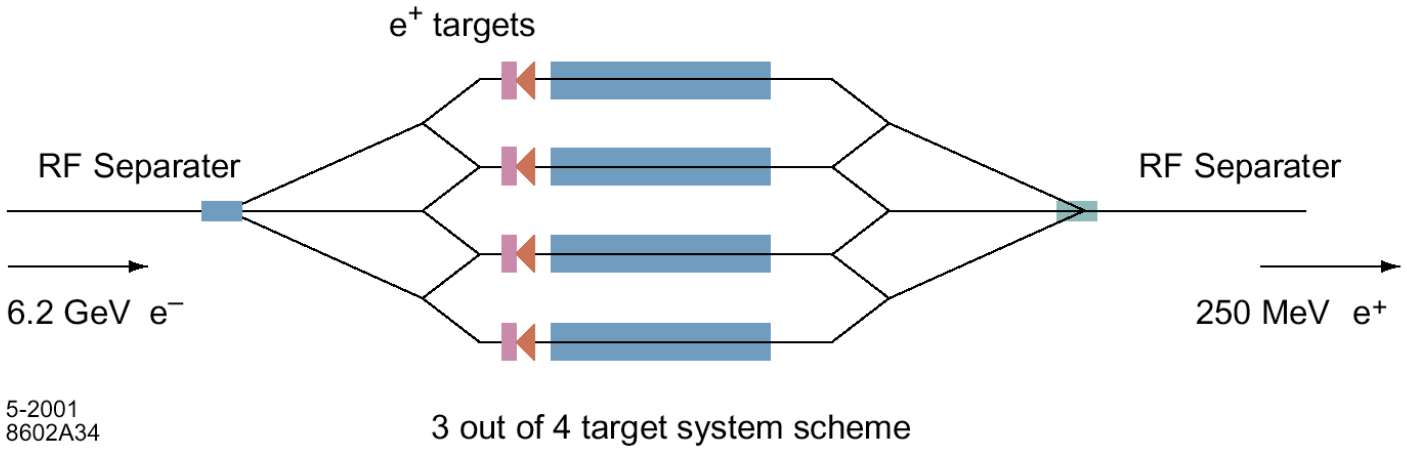


Figure 1.11: Schematic of the conventional e^+ production system

Positron source:CLIC

- A 2 GeV electron beam is generated in a 1.5 GHz rf linac. This is targeted on a 4 radiation length W-Re target. The resulting positrons are captured in an adiabatically matched solenoid field (peak 6 T), and solenoid-focused and accelerated to 200 MeV in a 1.5 GHz linac.
- They are further accelerated in a conventional 1.5 GHz rf linac to 2 GeV, for injection into the positron pre-damping ring. The injected yield is 0.7 positron/electron.

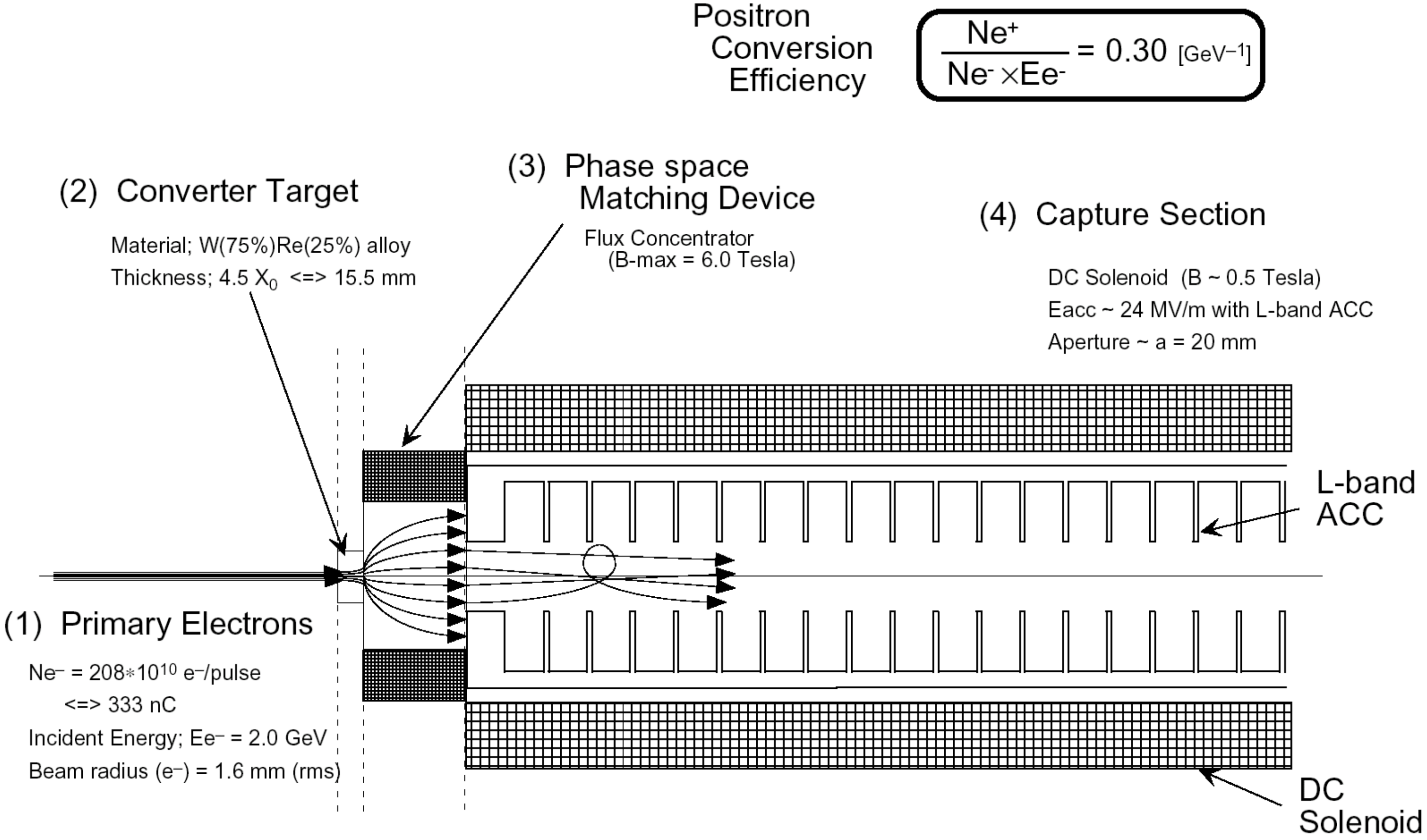


Figure 4: CLIC e^{+} generator

Table 4: Energy density for CLIC target compared with SLAC results

Parameters	Units	SLAC Exp. (sample B1)	CLIC
Beam energy	[GeV]	24.4	2.0
Ne^- per pulse	[10^{10} e^-]	8.0	208.0
Beam size	[mm]	0.91 (x), 0.35 (y)	1.6 (r)
Target thickness	[χ_0]	5.4	4.5
Target material		$W_{75}Re_{25}$	$W_{75}Re_{25}$
Density per area	[10^{12} GeV/mm^2]	1.95	0.52
Peak density per vol.	[10^{10} GeV/mm^3]	0.93	0.64
Incident beam energy	[10^{10} GeV/mm^2 χ_0]	7.2	3.3
Beam density	[kJ/kg]	76	53

Positron source-TESLA

- Total positrons/train: (56, 1.73, 1.25) x10^{12} for TESLA, NLC/JLC, CLIC, (in 950, 0.27, 0.10) μs
- Target peak thermal stress due to electron beam energy deposition limits the rate at which positrons can be produced from direct electron beam showers: TESLA parameters are out of reach.

Positron source-TESLA

- Positrons are produced at TESLA from electromagnetic showers generated in a thin target by 30 MeV photons generated by passing a 250 GeV electron beam through a long (100 m) 14-mm period wiggler.(B=0.75 T, K=1)
- For positron production by photons, the target length optimizes at 0.4 radiation lengths and is not a strong function of Z.
- This allows the use of Ti as the target material, which has high heat capacity, higher strength, and more ductility, than W-Re. It can survive the thermal shock generated by the showers in which the positrons are produced. It must still be rotated at high speed (50 m/s) to spread the energy deposition over a wide region.

Positron Source-TESLA

- The positrons are collected in using an adiabatic matching device (peak field 6 T) and solenoid focused and accelerated in a 250 MeV 1.5 GHz warm linac. They are then accelerated to 5 GeV and transported to the damping ring.
- The phase space from the target is large but less than with a conventional system, and consequently a pre-damping ring is not required.
- The injected yield varies from 2 positrons/electron for a primary beam energy of 250 GeV, down to 1 positron/electron at 150 GeV.

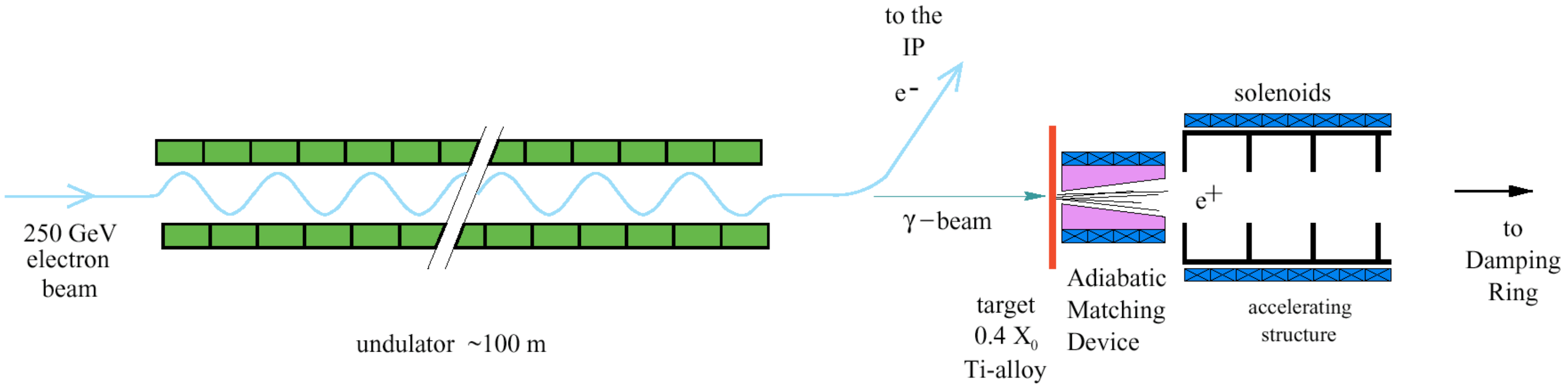


Figure 12: Sketch of the positron source layout.

Undulator	
peak field	0.75 T
period length	14.2 mm
gap height	5 mm
γ-spot size on target	0.7 mm
photon beam power	135 kW
Target	
material	Ti-alloy
thickness	1.42 cm ($0.4X_0$)
pulse temperature rise	420 K
av. power deposition	5 kW
Adiabatic Matching Device	
initial field	6 T
taper parameter	$30\,\mathrm{m}^{-1}$
end field	0.16 T
capture cavity iris radius	23 mm
General	
capture efficiency	16%
No. of positrons per electron	2
norm. e^+-beam emittance	0.01 m
total energy width	±30 MeV
required D.R. acceptance	0.048 m

Table 4.3.3: *Overview of the positron source main parameters.*

Positron source- TESLA:pros and cons

- Pros:
  - High flux
  - Smaller final phase space
  - Polarized positrons are possible if circularly polarized photons are generated in a helical undulator
- Cons:
  - Not fully prototyped
  - Electron beam slightly degraded by undulator-energy spread increases from 0.15% to 0.3%.
  - Requires at least 150 GeV electrons->special measures required for CM energies below 300 GeV (e.g., 50 GeV transfer line for operation at Z_0).