Linear Collider: Lecture Two
Obtaining the Energy
Ron Ruth

- **Outline of this Lecture**
  - **Choice of Collision Energy**
  - **Acceleration Basics**
  - **Comparison of Technologies**
  - **TESLA**
  - **C-Band**
  - **NLC/JLC**
  - **CLIC and Two-Beam LCs**
  - **Summary**

Choice of Energy

- **You have heard about the world consensus that the next linear collider should begin with an energy of about ½ TeV and be upgradable to about 1 TeV.**
- **The TESLA and NLC designs both address this range. (TESLA up to 800 GeV)**
- **The CLIC approach uses two-beam acceleration and higher frequency to get up to 3 TeV.**
- **They also put forward upgrades to 5 TeV.**
- **The community is putting forward a decade of energy reach for the next plus next generation linear colliders (0.5 to 5 TeV)**
- **This lecture will focus primarily on the lower energy accelerators.**
- **However, we will conclude with multi TeV options for linear colliders.**

Accelerator Technology Choices

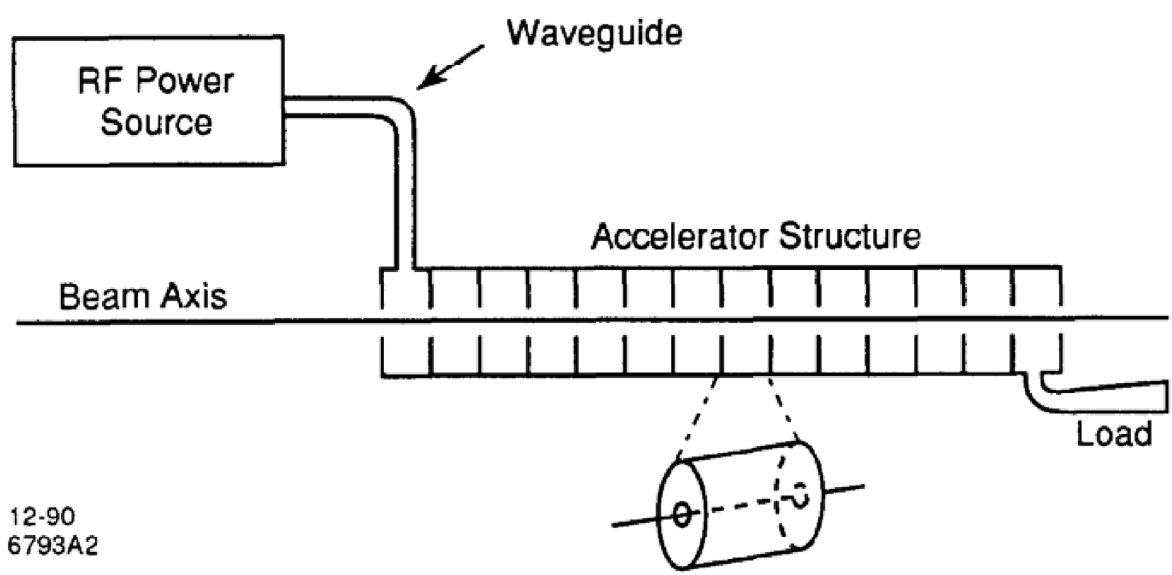
- **There are two main choices of acceleration technology which are being pursued.**
  - **Superconducting Accelerator Structures**
  - **Room temperature high-conductivity (copper) structures.**
- **Within the room temperature category there are several alternative approaches based on different frequencies.**
  - **S-band (SLC, DESY) f = 3 GHz**
  - **C-band (KEK) f = 5.7 GHz**
  - **X-band (SLAC/KEK) f = 11.4 GHz**
  - **CLIC (CERN+collab) f = 30 GHz**
- **The superconducting approach is followed by a collaboration of many institutions which are led by DESY.**
  - **L-Band (TESLA collab, DESY) f = 1.3 GHz**

Acceleration Basics

- **The total energy gain in a linear collider is provided by a linear accelerator with almost all of the linear length occupied by accelerator structure.**
- **The total energy gain is just**

$$E = E_0 + G_z L$$

- **We can think of Gz as the longitudinal accelerating field in a structure of length L, or as an average including the fill factor with L being the length of the linac.**



Energy Extraction

- **The diagram shows a travelling wave structure with phase velocity of c and some charateristic group velocity.**
- **In contrast to a circular collider, electron acceleration takes place near the crest of the RF with only a small phase offset.**

$$\Delta E = G_z L \cos(\varphi)$$

- **The particle bunch also induces a decelerating field behind it.**

$$G_{wake} = -2kq \cos(\omega z / c)$$

- **For a particle on crest this just reduces the accelerating field behind the bunch. The single bunch efficiency is**

$$\eta_0 = 1 - \frac{\left(G_z - 2kq\right)^2}{G_z^2} \cong \frac{4kq}{G_z}$$

Energy Spread Compensation

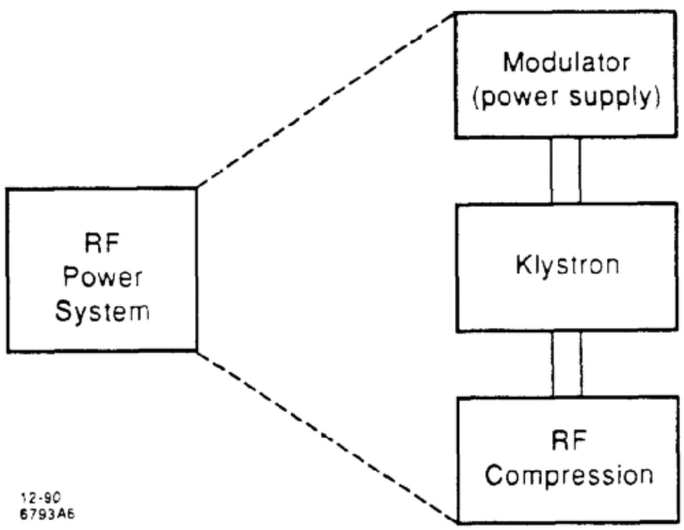
- **The head of the bunch feels the full acceleration while the tail has a reduced field. In the linear approximation (short bunch)**

$$\Delta E_{ave} = (G_z - kq)L_s \qquad \Delta E_{spread} = \pm kqL_s$$

- **This spread can be compensated by a small phase offset provided the single bunch only extracts a percent or less of the energy.**
- **This seems to imply that trailing bunches get less acceleration.**
- **They will unless some technique is used to compensate this effect.**
- **The technique is to run the accelerator in a <u>temporary steady state</u>.**
- **Match the input of RF power into the structure with the extraction of RF power by the beam so the average gradient is maintained over the train of bunches.**

The Radio Frequency Power Source

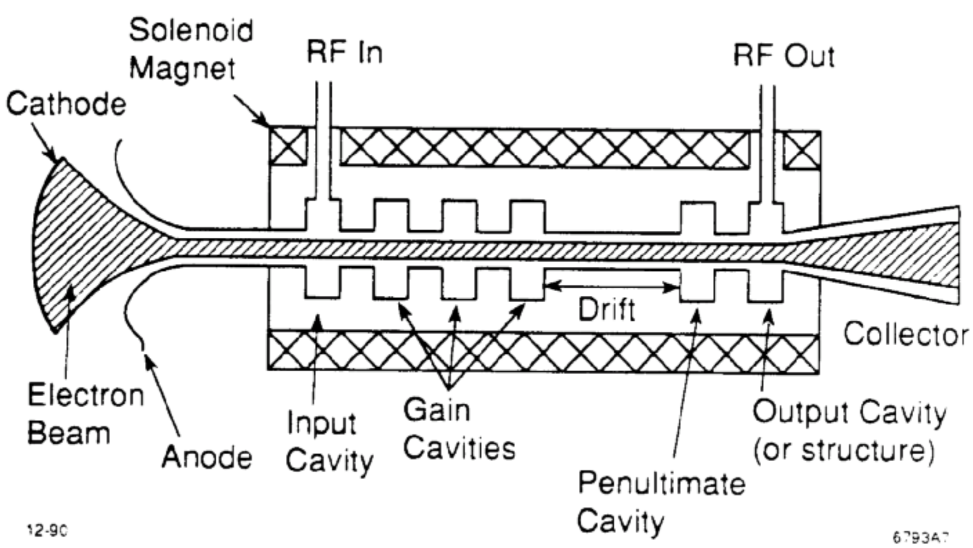
- **The RF power system converts the power from the grid to pulsed power at the desired RF frequency.**
- **The details of the pulse structure are different for different designs, but a common arrangement is**



- **The modulator provides the basic pulse structure and energy storage with capacitors and inductors**
- **The klystron is an efficient RF amplifier.**
- **The RF compression trades pulse length for peak power.**

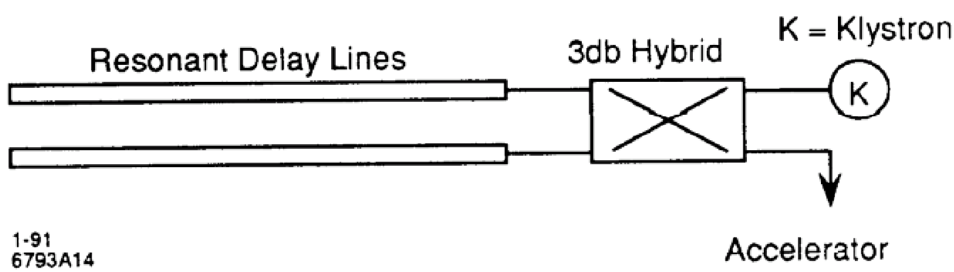
The Klystron

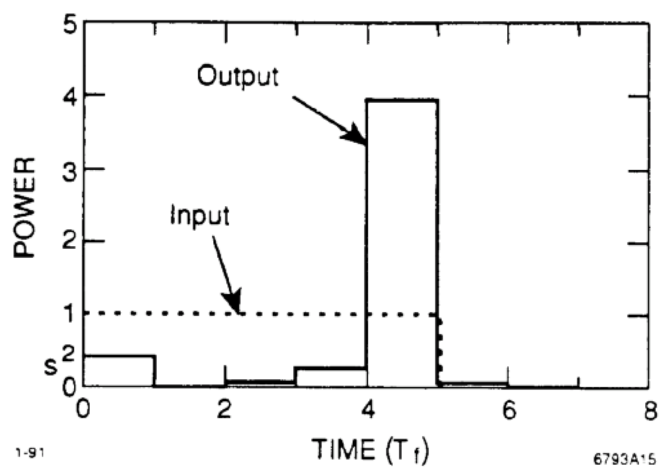
- **The klystron modulates a high current electron beam with a small RF signal.**
- **This causes the beam to bunch which drives cavities downstream which further bunch the beam.**
- **The bunching process culminates after a special penultimate cavity in the output cavity or structure.**
- **The fields induced by the beam are at a phase which causes the bunches to decelerate transferring their energy to the RF wave.**



The RF Compression System

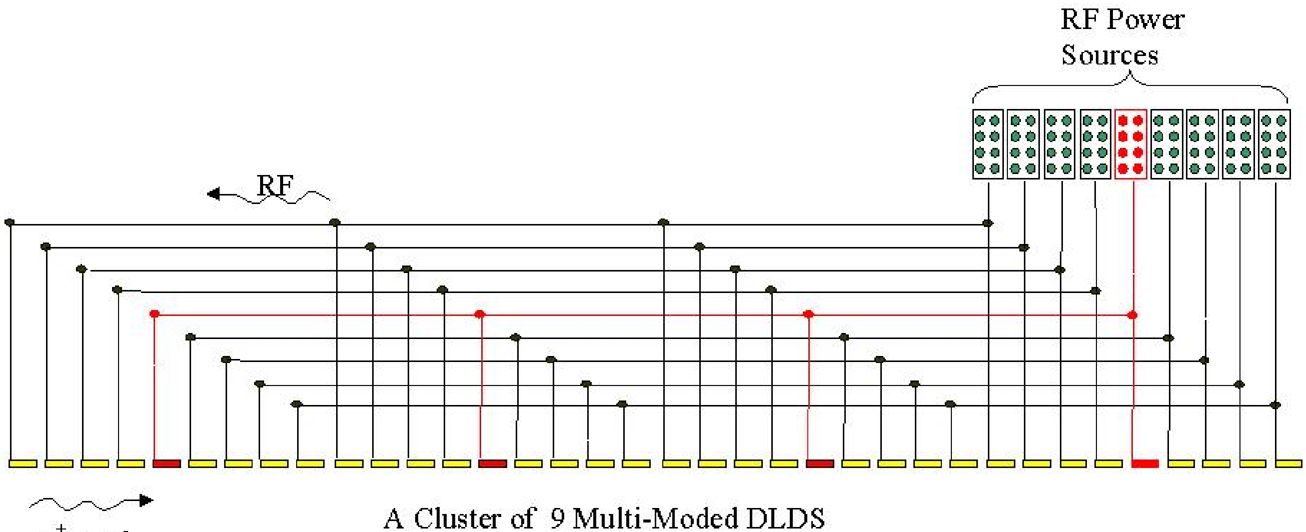
- **The object of the RF compression system is to obtain a short high power RF pulse when given a long lower power pulse.**
- **The serves to match the capabilities of the klystron/modulator system with the necessary pulse length and power for the accelerator.**
- **The type shown below is called SLEDII.**
- **The energy is stored in resonant delay lines prior to delivery to the structure.**



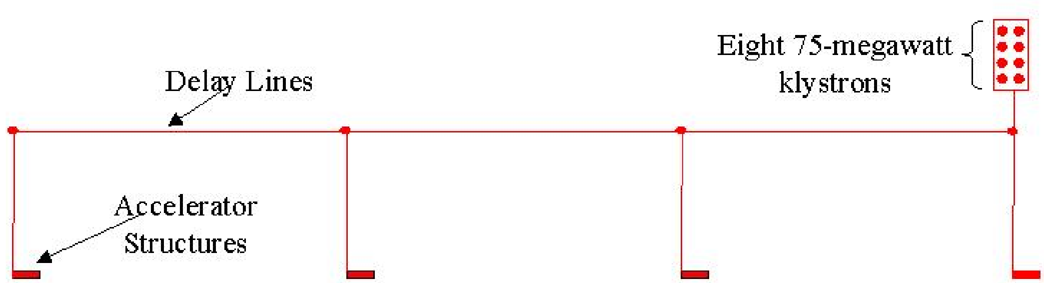


Other 'Compression' Schemes, DLDS

- **DLDS stands for Delay Line Distribution System**
- **The idea is to combine power then chop it up in time slices which are shipped upstream to arrive when they are needed.**



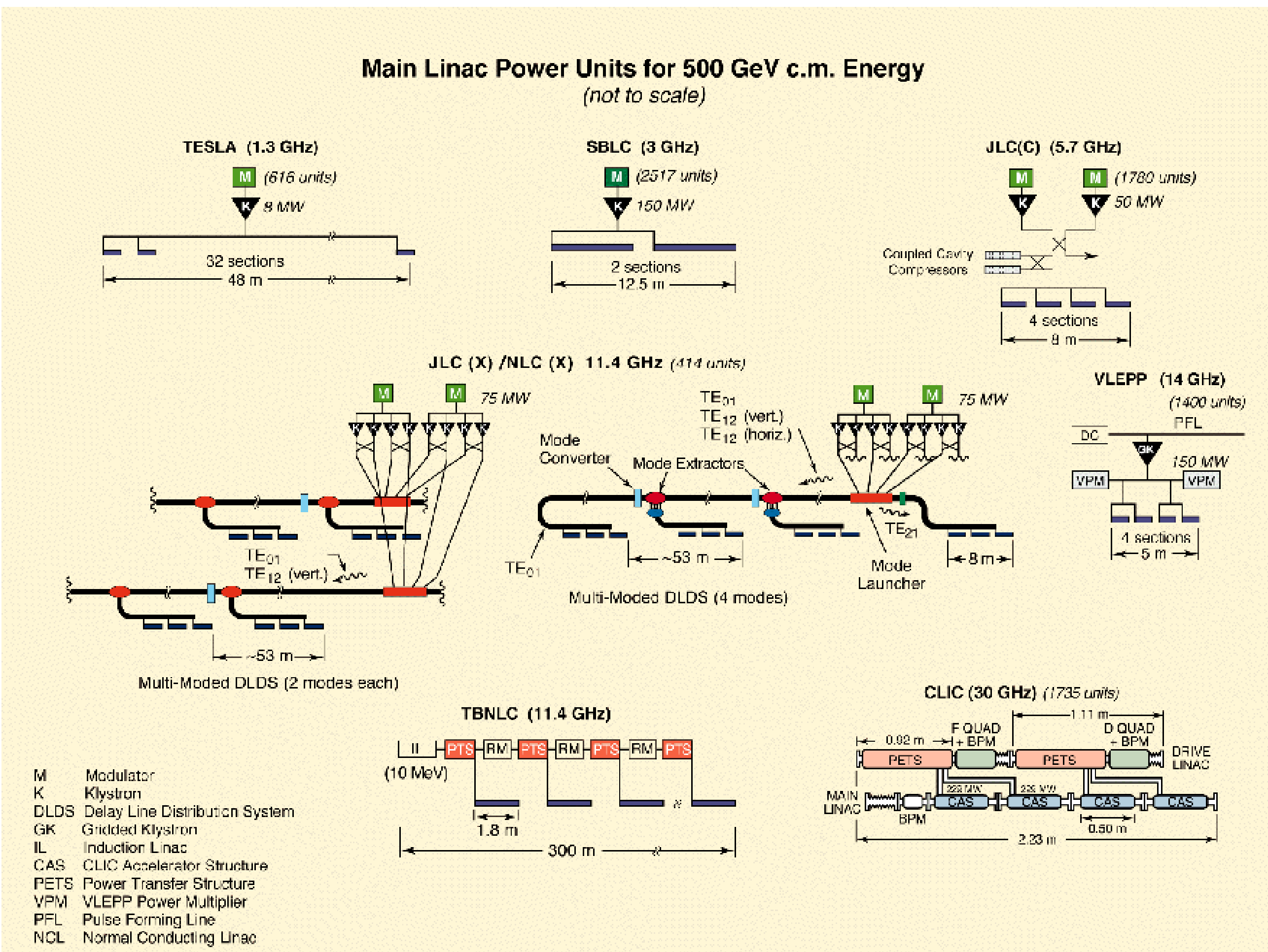
A Cluster of 9 Multi-Moded DLDS Sections



A Single Multi-Moded Delay Line RF Distribution System

A View of all the possibilities

- **There are various incarnations of these basics as shown below**



- **For a better view of this figure let’s go here**
- Power Sources.ppt

Standing Back to View Common Traits

- **ALL linear accelerators are transformers**
  - **DC -> High energy, low current beam**
- **Pulse compression and energy storage are critical**

- **TESLA**
  - **11 MW, 5 Hz, 2.3 MJ/pulse, 1 msec pulse**
- **NLC**
  - **4.5 MW, 120 Hz, 40 kJ/pulse, 300 nsec pulse**
- **C-Band**
  - **2.9 MW, 100 Hz, 30 kJ/pulse, 250 nsec pulse**
- **CLIC (0.5)**
  - **4.8 MW, 200 Hz, 25 kJ/pulse, 100 nsec pulse**
- **CLIC (3.0)**
  - **11 MW, 75 Hz, 140 kJ/pulse, 100 nsec pulse**

Energy Storage in Each Scheme

- **TESLA**
  - **Capacitors, DC-> 1msec**
  - **SC Cavity**
- **C-Band**
  - **Caps, DC-> 2.5 microsec**
  - **High Q RF Cavity -> 2500 -> 250 nsec**
- **NLC**
  - **Caps, DC-> 1.5 microsec**
  - **Low loss Delay lines -> 1500 -> 350 nsec**
- **CLIC (Two-Beam)**
  - **Caps, DC-> 75 microsec**
  - **Beam, -> 75 microsec->n x 100 nsec**

- **Fundamentally all acceleration methods need a High Q storage medium to efficiently accomplish the time compression part of the 'transformer'. In the chain it is just prior to acceleration.**

Why So Many Choices?

- **TESLA- 20 MV/m**
  - **Focused on the lowest energy, 1/2 TeV**
  - **Low wakefield due to large aperture**
  - **Challenges of cost and gradient**
  - **Limited energy reach (~800 GeV)**
- **C-Band ~30/40 MV/m**
  - **Focused on lowest energy**
  - **Closest to Conventional S-band Technology**
  - **Tighter tolerances, limited energy reach**
- **NLC ~55/70 MV/m**
  - **Optimized for 1 TeV (0.5 to 1.5)**
  - **New X-Band technology ~ S-Band Tech.**
  - **Tighter tolerances**
- **CLIC (Two-Beam) ~150 MV/m**
  - **Focused on Multi-TeV energy**
  - **High frequency, tightest tolerances and New Two-Beam Technique**
  - **Gradient limits and testing Two Beam?**

Technology Tour

- **To get a feel for superconducting technology lets look at TESLA**
  - **TESLA technology tour.ppt**

- **To get a feel for warm technology lets look at C-Band and then NLC/JLC.**
  - **C-Band Technology Tour.ppt**
  - **NLC technology tour.ppt**

- **To understand Two-Beam we will discuss CLIC and Two-Beam upgrades to NLC**
  - **Two Beam digression.ppt**

Summary

- **A quote from the Snowmass working group and agreed to by key participants of the group.**
  - **"The NLC/JLC-X and TESLA designs and technology are sufficiently developed and either could be used to build a 500 GeV collider. The performance limitations are well understood and the measures which must be taken to achieve the design performance at a high level of confidence are precisely defined. The R&D on the X-band will take another 3 to 4 years, i.e. 2004, before being ready for large-scale industrial production. Similarly, TESLA will be ready in 2 to 3 years, i.e. 2003. In both cases, final engineering R&D should be performed in the framework of a funded project."**
- **The high energy physics community, especially the young generation has a great opportunity to open the door to precision physics which begins at the electroweak scale and could extend to multi TeV energy.**
- **This opportunity has been provided by more than a decade of world-wide research on and experience with linear colliders.**
- **Do not fail to take the opportunity.**