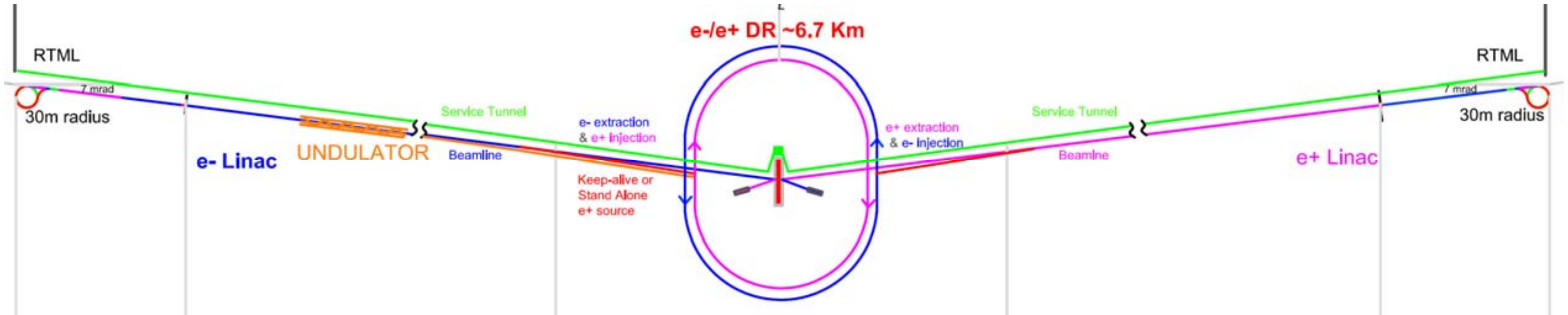
ILC
Reference Design Report

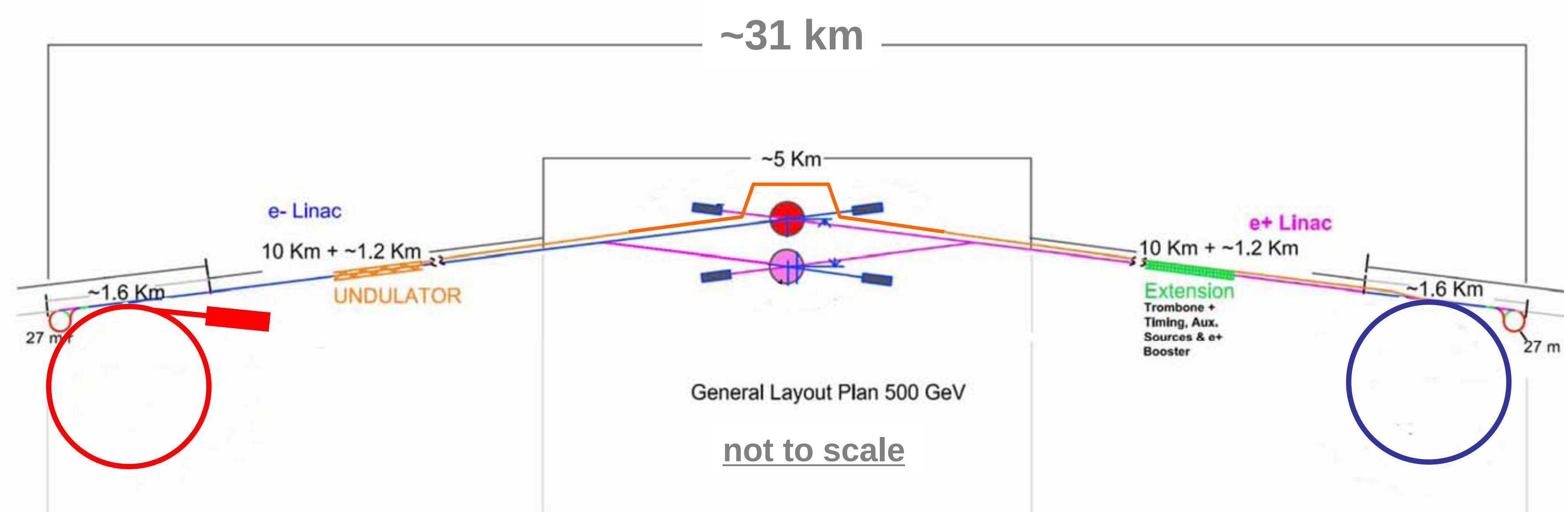


Barry Barish

8-Feb-07

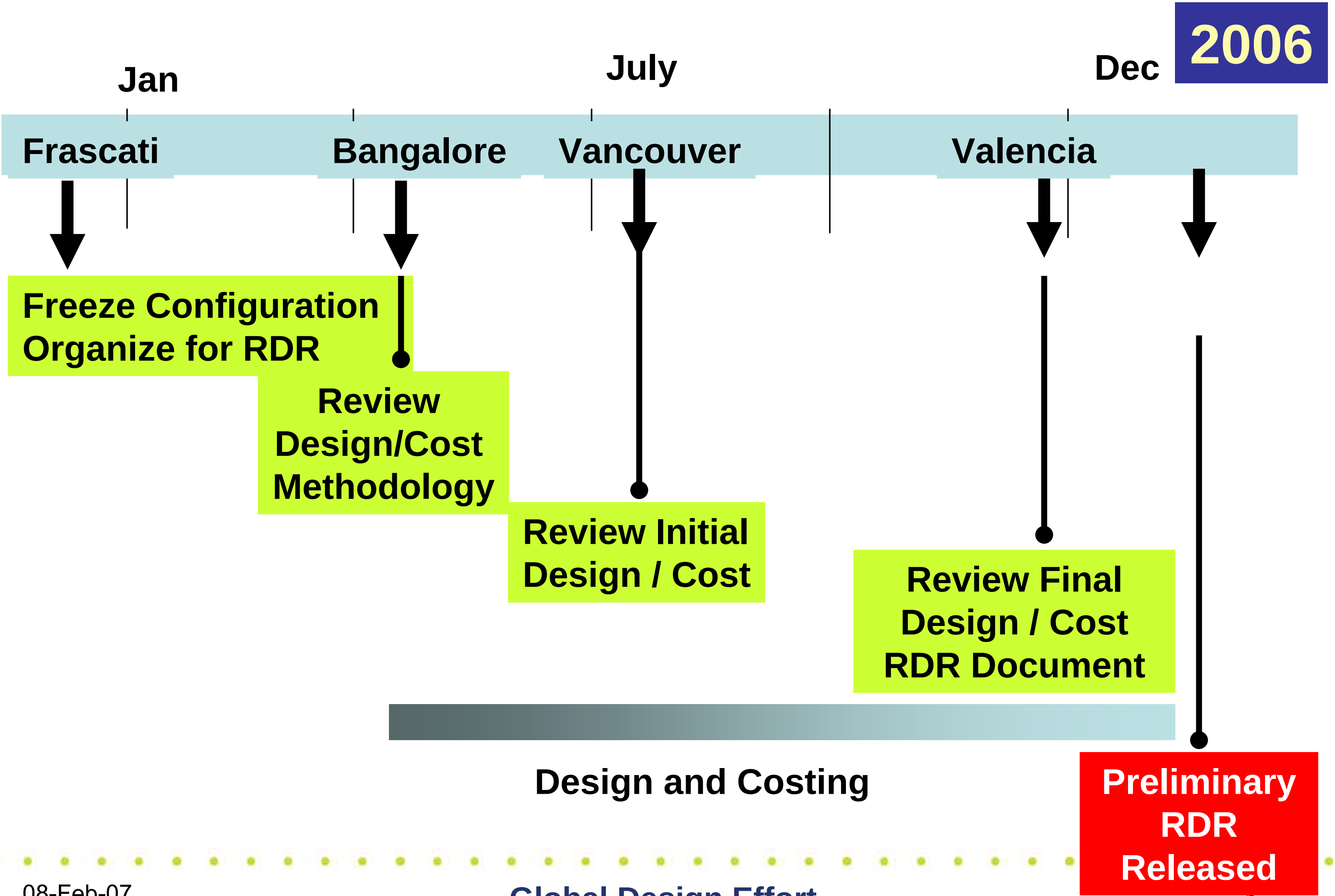
1st Milestone - ILC Baseline

Baseline Configuration -- Dec 2006



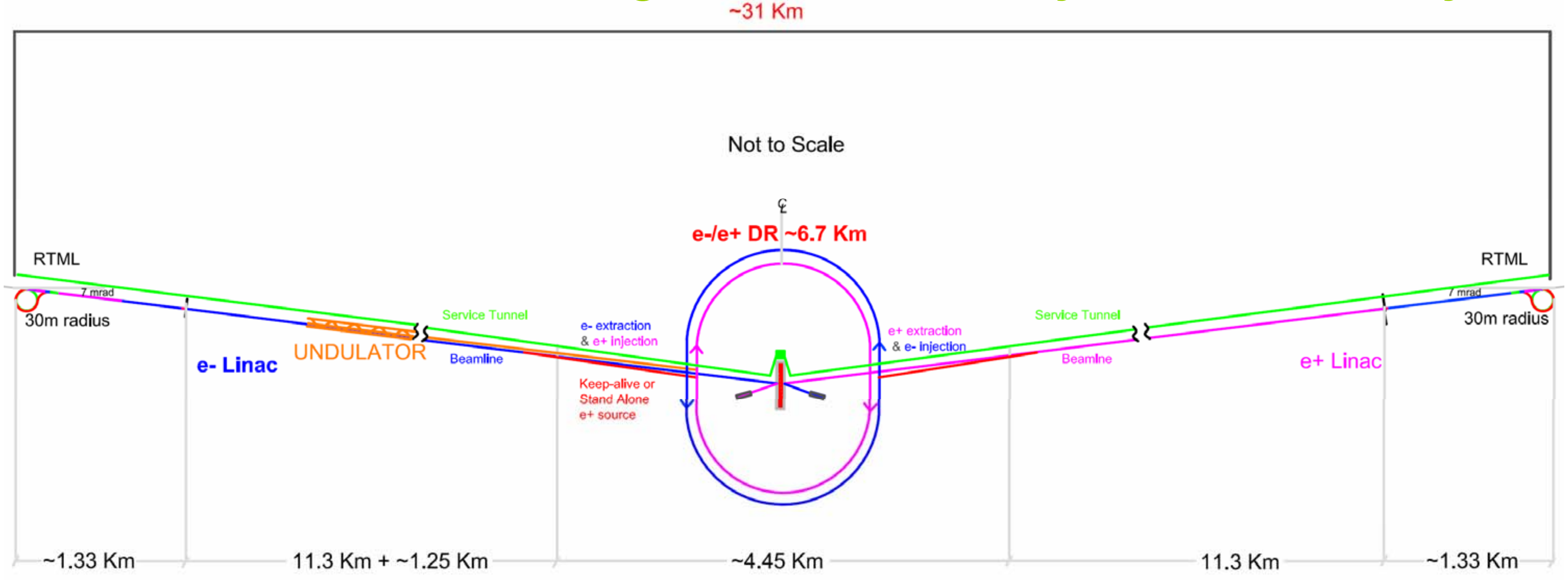
Documented in Baseline Configuration Document

Baseline to a RDR



2nd Milestone – ILC Reference Design

- 11km SC linacs operating at 31.5 MV/m for 500 GeV
- Centralized injector
  - Circular damping rings for electrons and positrons
  - Undulator-based positron source
- Single IR with 14 mrad crossing angle
- Dual tunnel configuration for safety and availability



RDR Design

Max. Center-of-mass energy	500	GeV
Peek Luminosity	~$2x10^{34}$	$1/cm^2s$
Beam Current	9.0	mA
Repetition rate	5	Hz
Average accelerating gradient	31.5	MV/m
Beam pulse length	0.95	ms
Total Site Length	31	km
Total AC Power Consumption	~230	MW

RDR vs ILC Physics Goals

- E_{cm} adjustable from 200 – 500 GeV
- Luminosity → $\int Ldt$ = 500 fb^{-1} in 4 years
- Ability to scan between 200 and 500 GeV
- Energy stability and precision below 0.1%
- Electron polarization of at least 80%

- The machine must be upgradeable to 1 TeV

The RDR Design meets these "requirements," including the recent update and clarifications of the reconvened ILCSC Parameters group!

Parameters Report Revisited

- **The ILCSC Parameters Group has given updated selected clarification on accelerator requirements, based on achieving ILC science goals:**
  - **Removing safety margins in the energy reach is acceptable but should be recoverable without extra construction. The max luminosity is not needed at the top energy (500 GeV), however …..**
  - **The interaction region (IR) should allow for two experiments ….. the two experiments could share a common IR, provided that the detector changeover can be accomplished in approximately 1 week.**

RDR Cost Estimating

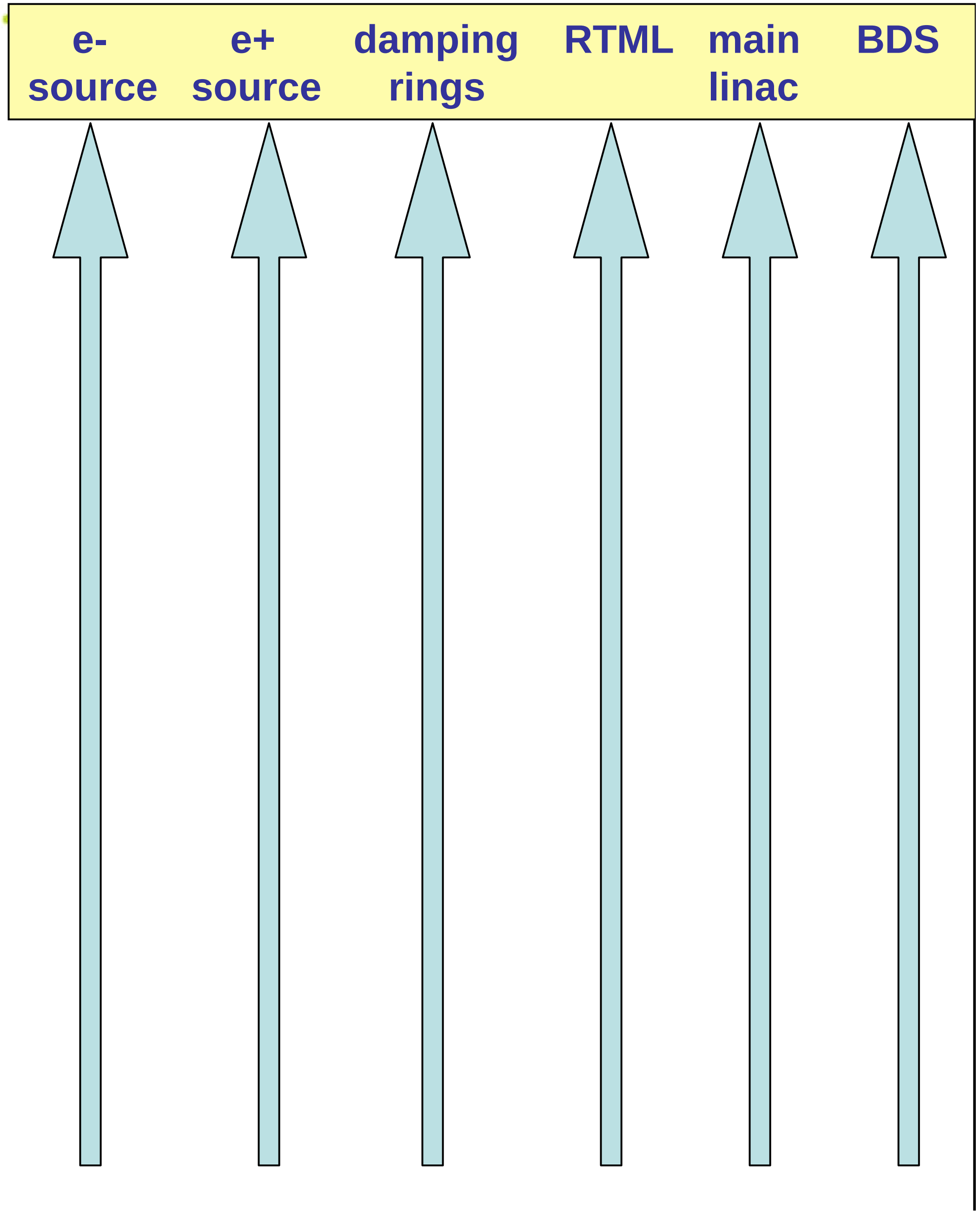
- "Value" Costing System: International costing for International Project
  - Provides basic agreed to "value" costs
  - Provides estimate of "explicit" labor (man-hr)]
- Based on a call for world-wide tender:
  lowest reasonable price for required quality
- Classes of items in cost estimate:
  - Site-Specific: separate estimate for each sample site
  - Conventional: global capability (single world est.)
  - High Tech: cavities, cryomodules (regional estimates)

Vancouver Cost Data

System description	July 18, 2006 - Cost Estimates received for								Regional		
	common	e-	e+	DR	RTML	ML	BDS	Exp	Am	Asia	Eur
e- Source		√									
e+ Source			√								
DR				√							
RTML					√						
Main Linac											
BDS							√				
Com, Op, Reliab											
Control System	√	√	√	√	√	√	√				
Cryogenics		√	√	√ *	√	√	√ *				
Convent. Facilities	√	√	√	√	√	√	√ *	√	√	√	√
Installation	√	√	√	√	√	√	√				
Instrumentation	√	√	√	√	√	√	√				
Cavities				√					√		√
Cryomodules		√	√		√	√			√	√	√
RF	√	√	√	√	√	√			√	√	√
Magnets & PS				√ *			√ *				
Dumps & Collim		√	√	√	√		√				
Vacuum		√	√	√	√	√	√				
Accel Phys											

√ = complete, √ * = almost complete, missing something minor

Cost Roll-ups



Area Systems

Technical Systems

Vacuum systems

Magnet systems

Cryomodule

Cavity Package

RF Power

Instrumentation

Dumps and Collimators

Accelerator Physics

Global Systems

Commissioning, Operations & Reliability

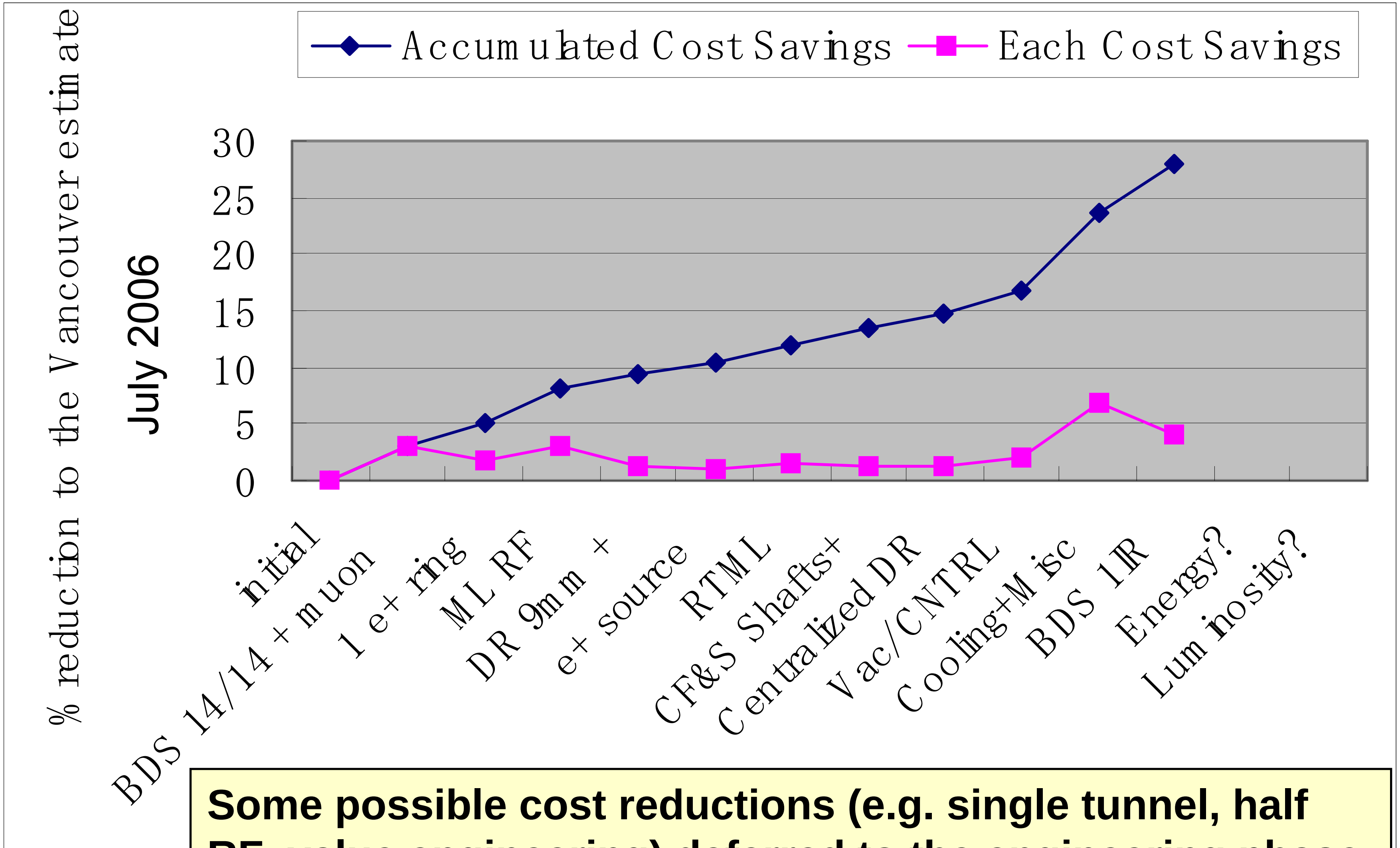
Control System

Cryogenics

Cost-Driven Design Changes

Area		RDR MB	CCR	CCB	approx. Δ$
BDS	2´14mr IRs	supported	14	YES	~170 M$
	Single IR with push-pull detector	supported	23	YES	~200 M$
	Removal of 2nd muon wall	supported	16	YES	~40 M$
ML	Removal of service tunnel	**rejected**			~150 M$
	RF unit modifications (24 ® 26 cav/klys)	supported			~50 M$
	Reduced static cryo overhead	supported	20	YES	~150 M$
	Removal linac RF overhead	supported			~20 M$
	Adoption of Marx modulator (alternate)	**rejected**			~180 M$
RTML	Single-stage bunch compressor	**rejected**			~80 M$
	Miscellaneous cost reduction modifications	supported	19	YES	~150 M$
Sources	Conventional e+ source	**rejected**			<100M$
	Single e+ target	supported	*in prep*		~30 M$
	e- source common pre-accelerator	supported	22	YES	~50 M$
DR	Single e+ ring	supported	15	YES	~160 M$
	Reduced RF in DR (6 ® 9mm σ_z)	supported	*in prep*		~40 M$
	DR consolidated lattice (CFS)	supported	*in prep*		~50 M$
General	Central injector complex	supported	18(19)	YES	~180 M$

Evolving Design → Cost Reductions



Some possible cost reductions (e.g. single tunnel, half RF, value engineering) deferred to the engineering phase

RDR Design & “Value” Costs

The reference design was “frozen” as of 1-Dec-06 for the purpose of producing the RDR, including costs.

It is important to recognize this is a snapshot and the design will continue to evolve, due to results of the R&D, accelerator studies and value engineering

The value costs have already been reviewed twice

- **3 day “internal review” in Dec**
- **ILCSC MAC review in Jan**

Summary
RDR “Value” Costs

Total Value Cost (FY07)

4.87B ILC Units - Shared

+

1.78B ILC Units - Site Specific

+

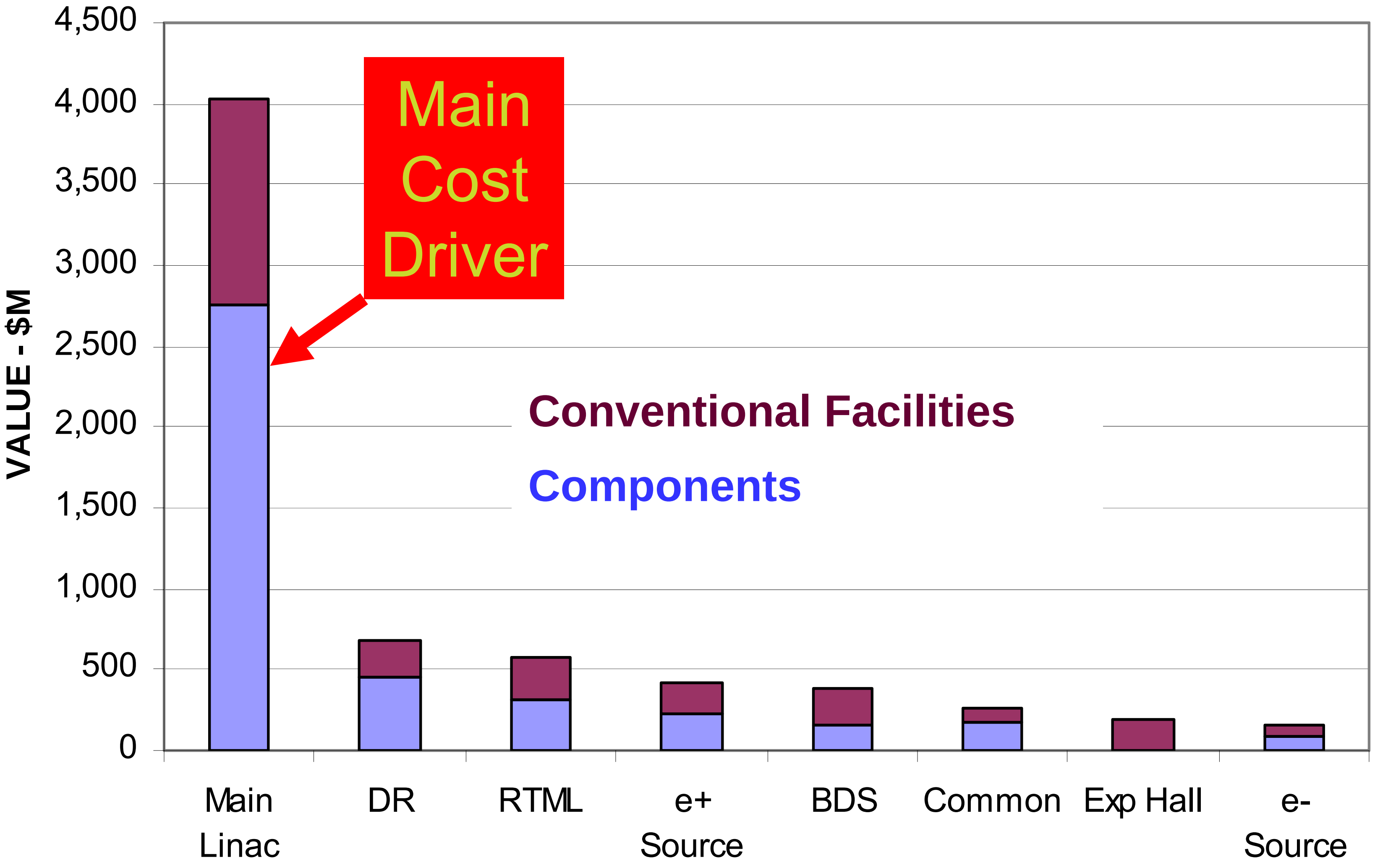
13.0K person-years

(“explicit” labor = 22.2 M person-hrs @ 1,700 hrs/yr)

For this estimate

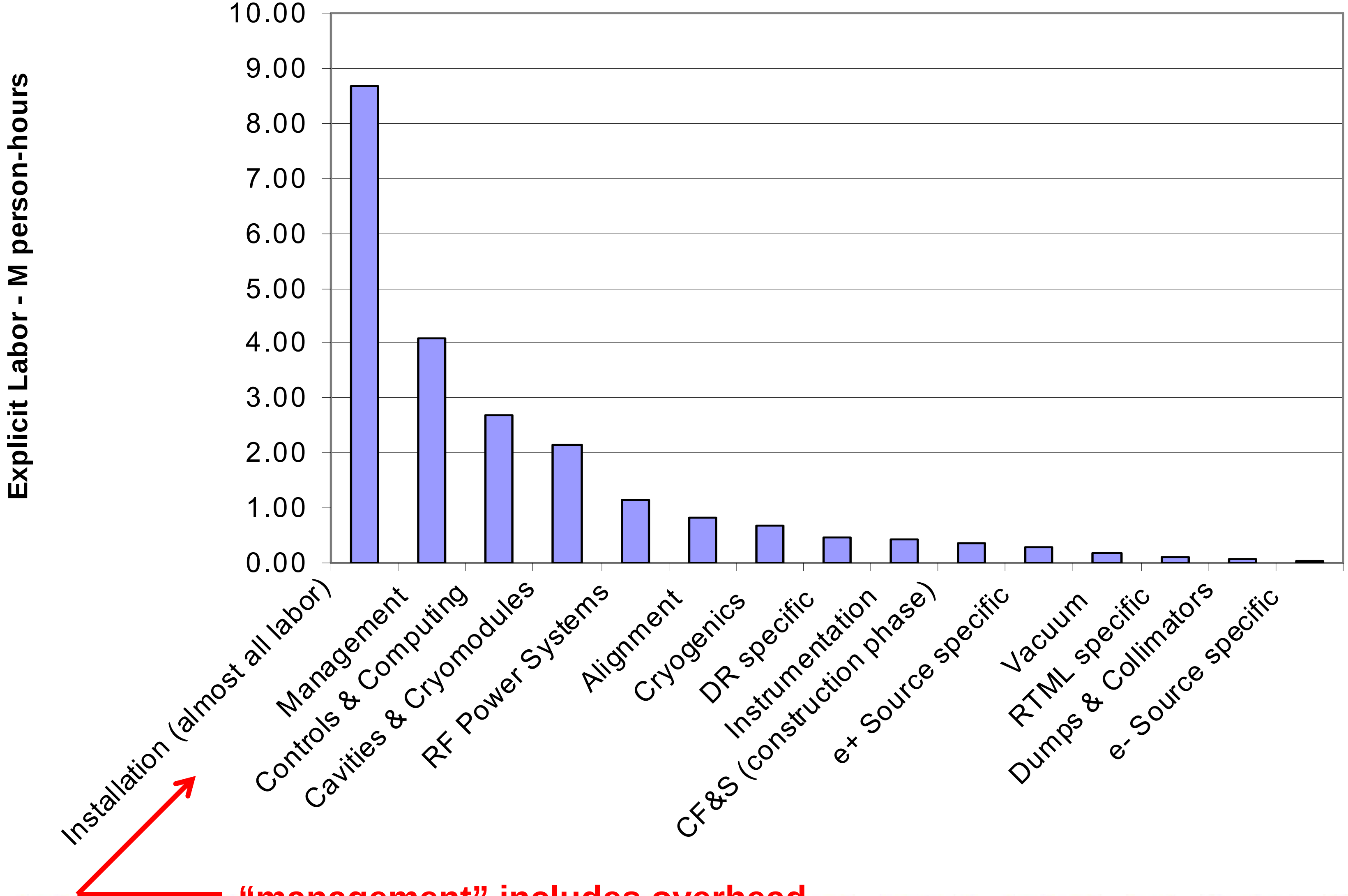
1 ILC Unit = 1 US 2007$ (= 0.83 Euro = 117 Yen)

ILC Value – by Area Systems



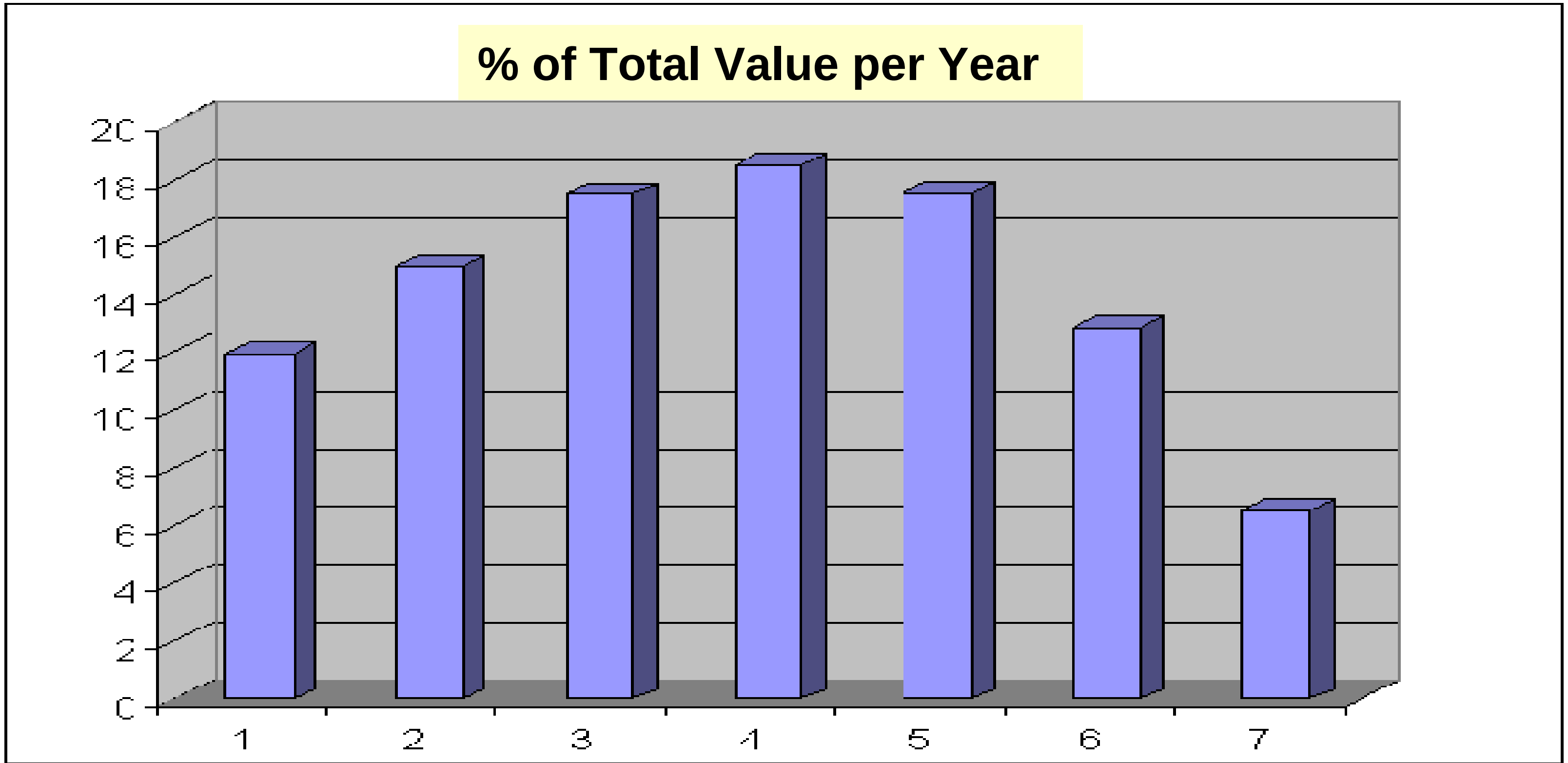
Explicit Manpower

13 K person-yrs = 22 M person-hrs



"management" includes overhead

Value Funding Profile



We are not using integrated cost/schedule tools yet; but it appears feasible to develop a realistic funding profile

How Good is our Cost Estimate?

- Methodology (value costing) is a practical way of developing agreed to “international” costing.
  - **Strength: Good scheme for evaluating value of work packages to divide the project internationally**
  - **Weakness: Difficult to sort out real regional difference from differences due to different specifications, etc**

- We have spent ½ year, developing methodology, good WBS dictionary, technical requirements and costing data requested. We spent another ½ year doing cost vetting and cost / performance optimization. VERY COMPLETE COST ANALYSIS FOR THIS STAGE IN THE DESIGN

Sanity Checks

Comparison with TESLA costs

	TESLA TDR / M€	Scaled TESLA TDR / M$	ILC RDR / M$	Difference / M$
Total Cost	**3136**	**5018**	**~6500**	**~1500**
Civil Facilities	676	1082	2437	1355
Underground Buildings	383	613	1070	457
Surface Buildings	44	70	168	98
Consultant Engineering	10	16	160	144
Power Distribution	34	54	275	221
Water Cooling	70	112	374	262
Cryogenic System	162	260	567	307
Cryo Plant*	12 x 11	12 x 17	10 x 34.3	139

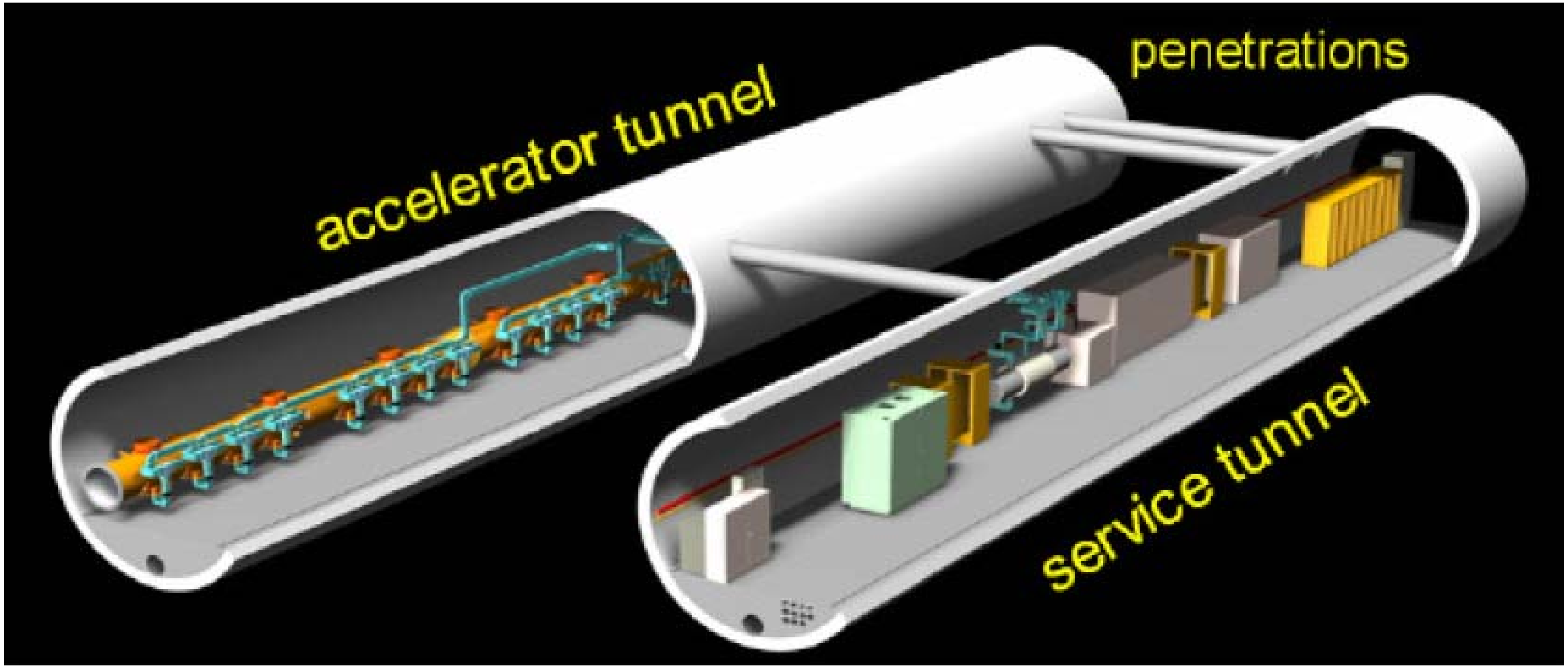
*TESLA: 6 x 4.3 kW @ 2 K

ILC: 10 x 3.5 kW @ 2 K

XFEL: 2.45 kW @ 2 K; 34.35 M€ for Cryogenic System

The difference is primarily in conventional facilities

Main Linac Double Tunnel



- Three RF/cable penetrations every rf unit
- Safety crossovers every 500 m
- 34 kV power distribution

Cost Driver – Conventional Facilities

72.5 km tunnels ~ 100-150 meters underground

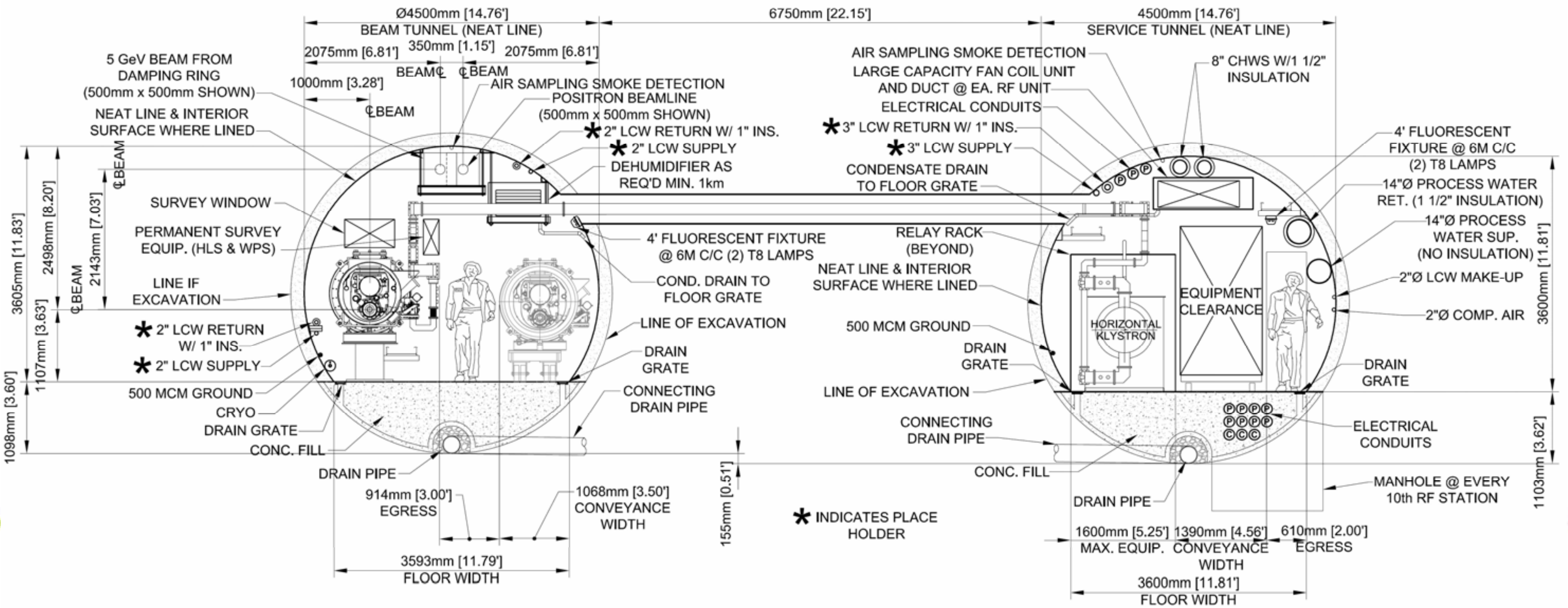
13 major shafts $\geq$ 9 meter diameter

443 K cu. m. underground excavation: caverns, alcoves, halls

92 surface "buildings", 52.7 K sq. meters = 567 K sq-ft total

Main Linac Tunnels

- Design based on two 4.5m tunnels
  - Active components in service tunnel for access
  - Includes return lines for BC and sources
  - Sized to allow for passage during installation
  - Personnel cross-over every 500 meters



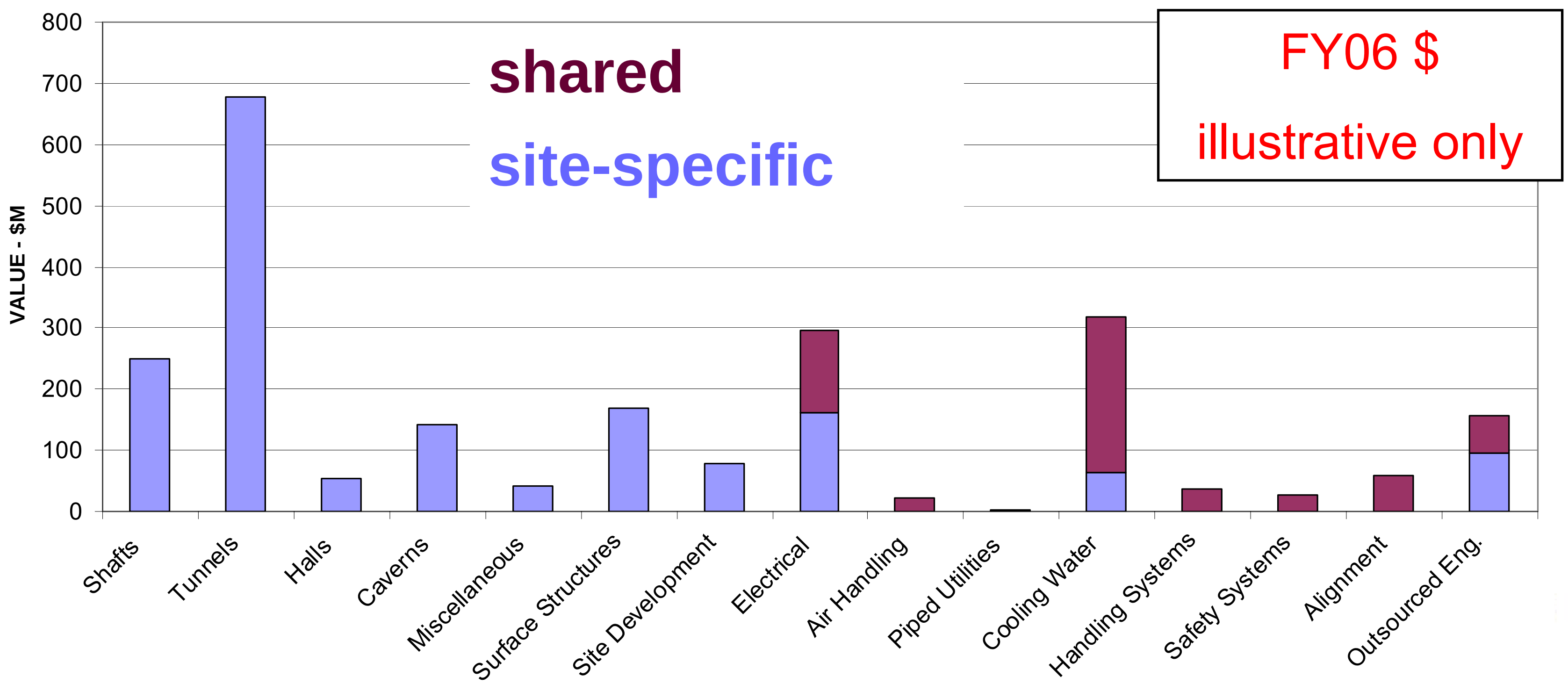
Conventional Facilities

Regional Comparisons :

Quote 2007$ – Escalate 2006$ by 10.6% U.S (Turner); 2-3 % other regions

ASIA	TOTAL COST=	$2,247,562	CIVIL ONLY=	$1,377,765
AMERICA	TOTAL COST=	$2,540,439	CIVIL ONLY=	$1,648,052
EUROPE	TOTAL COST=	$2,493,066	CIVIL ONLY=	$1,608,407

Yen to US $	0.0085714
Euro to US $	1.2
Euro to Yen	140
US to Yen	116.7



How Good is our Cost Estimate?

- Cost Estimate is ~ 30% level over the RDR concept. However, there are some important limitations:
  - **The estimate is for a concept or reference design, not an engineering design.**
  - **The design will evolve, giving concerns of future cost growth. We believe this can be compensated for by deferred potential gains from value engineering**
  - **Major Cost Drivers: Conventional facilities need actual site(s) for better estimates (e.g. safety, one tunnel, shallow sites, etc)**
  - **Major Cost Drivers: Main Linac limited because of proprietary information, regional differences, gradient, uncertainties regarding quantity discounts, etc**

- Risk analysis will be undertaken following this meeting

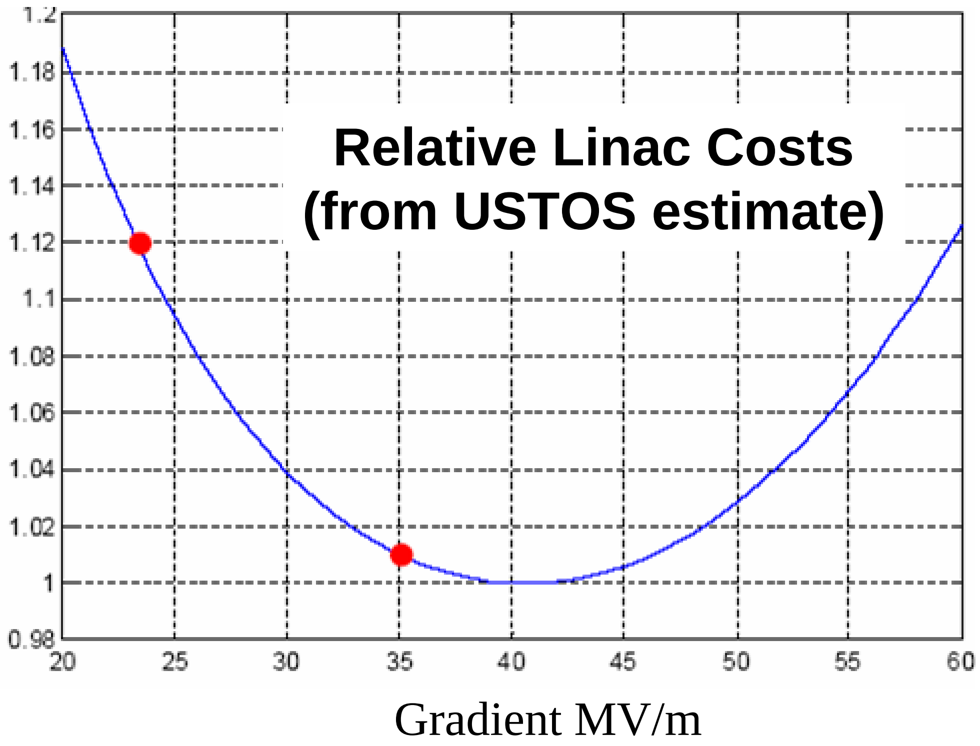
Cost Driver - The Main Linac

Subdivision	Length (m)	Number
Cavities (9 cells + ends)	1.326	14,560
Cryomodule (9 cavities or 8 cavities + quad)	12.652	1,680
RF unit (3 cryomodules)	37.956	560
Cryo-string of 4 RF units (3 RF units)	154.3 (116.4)	71 (6)
Cryogenic unit with 10 to 16 strings	1,546 to 2,472	10
Electron (positron) linac	10,917 (10,770)	1 (1)

- Costs have been estimated regionally and can be compared.
  - **Understanding differences require detail comparisons – industrial experience, differences in design or technical specifications, labor rates, assumptions regarding quantity discounts, etc.**

Main Linac Gradient Choice

- Balance between cost per unit length of linac, the available technology, and the cryogenic costs
- Optimum is fairly flat and depends on details of technology
- Current cavities have optimum around 25 MV/m



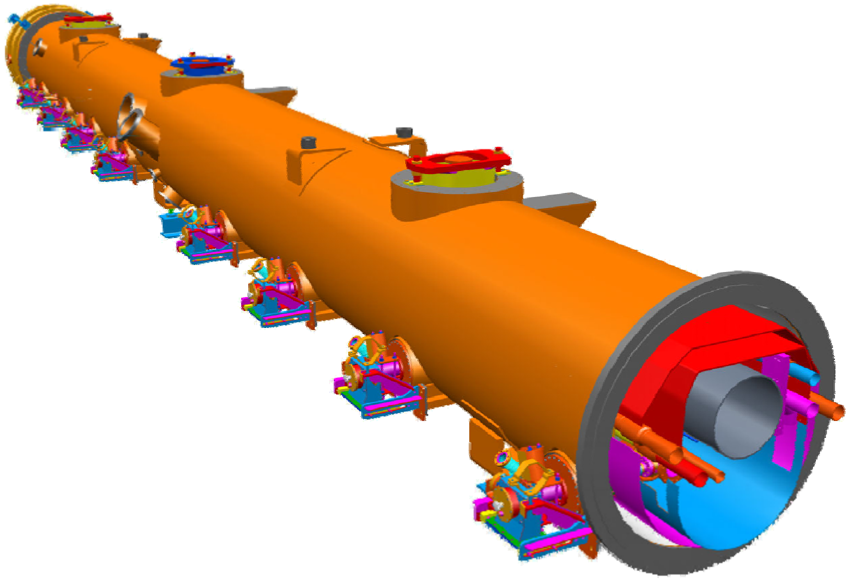
	Cavity type	Qualified gradient MV/m	Operational gradient MV/m	Length Km	Energy GeV
initial	TESLA	35	31.5	10.6	250
upgrade	LL	40	36.0	+9.3	500

Cost Impact of Lower Gradient

- We have given high priority to S0 Cavity R&D program to demonstrate baseline 31.5 MV/m
- Cost impact of running the ILC linacs with a range of gradients (22-34 MV/m with an average of 28 MV/m)
  - **assumes the power to the cavities is adjustable (one time only)**
- The Main Linac cost increases by 11.1% and the ILC cost increases by 6.7% assuming Main Linacs are 60% of the ILC cost.

From Chris Adolphsen

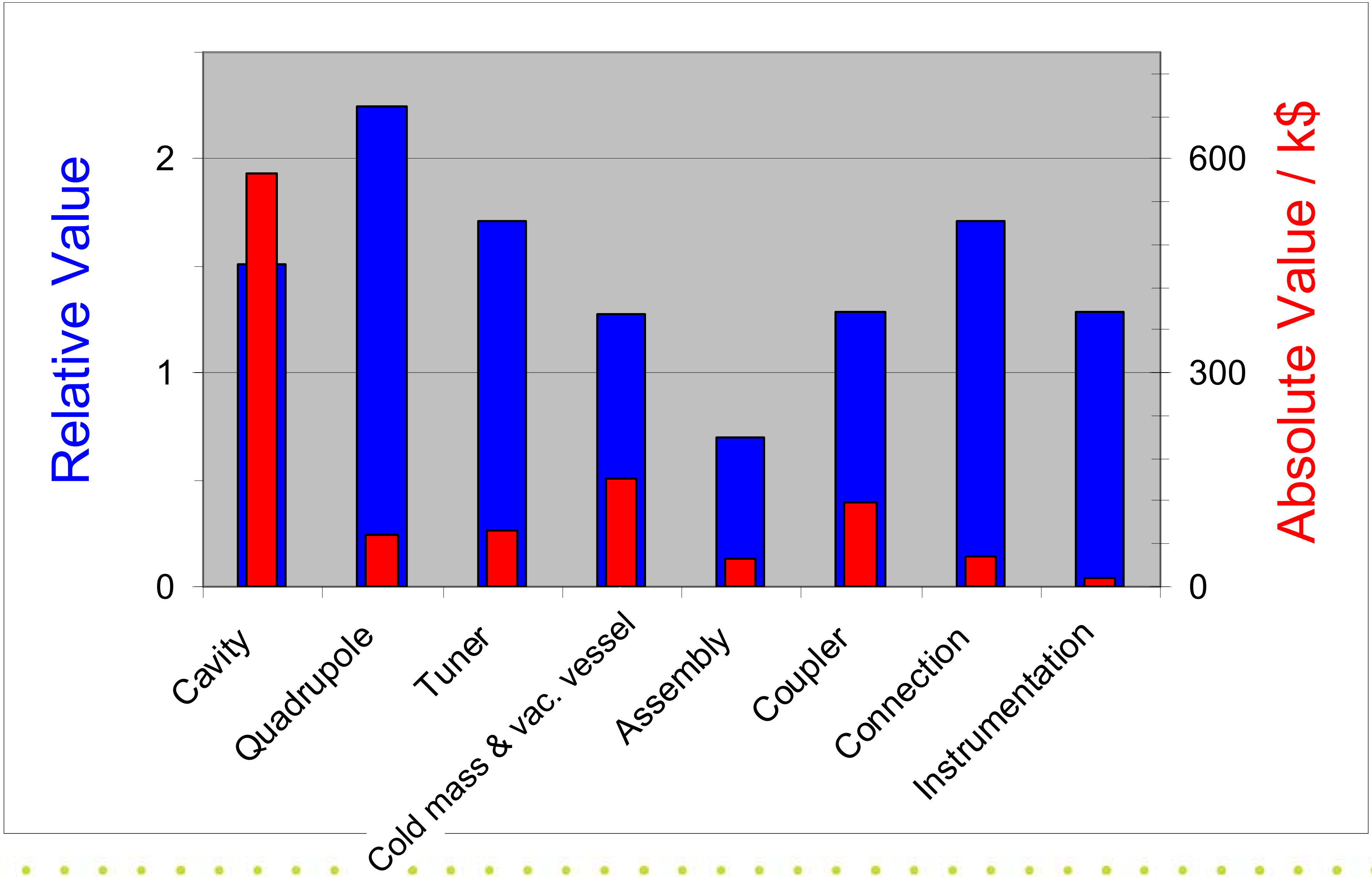
Cryomodule Value Estimates



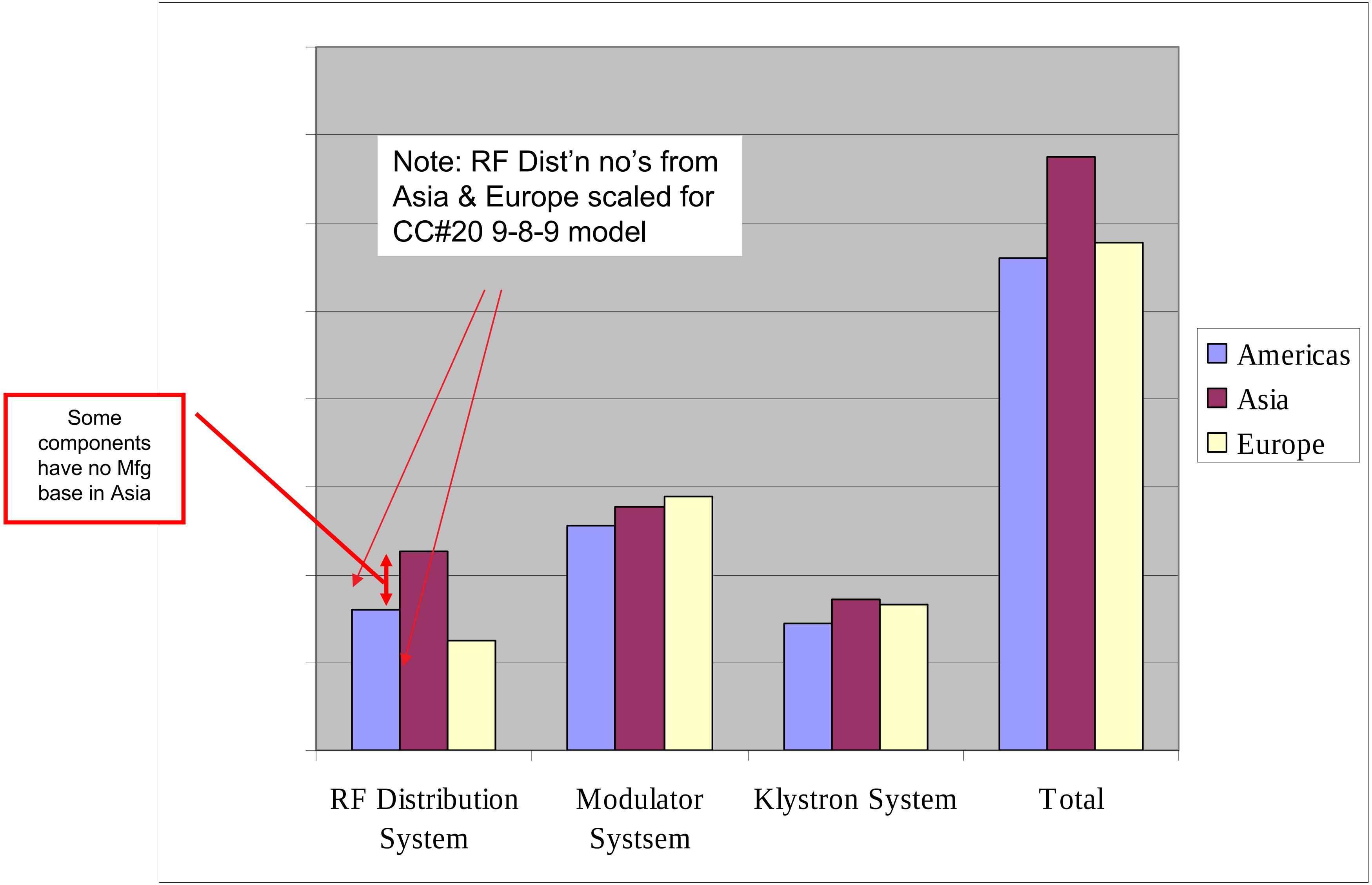
TESLA cryomodule

4^{th} generation prototype ILC cryomodule

American vs European Estimate



Cost of High Level RF by Region



RDR Report

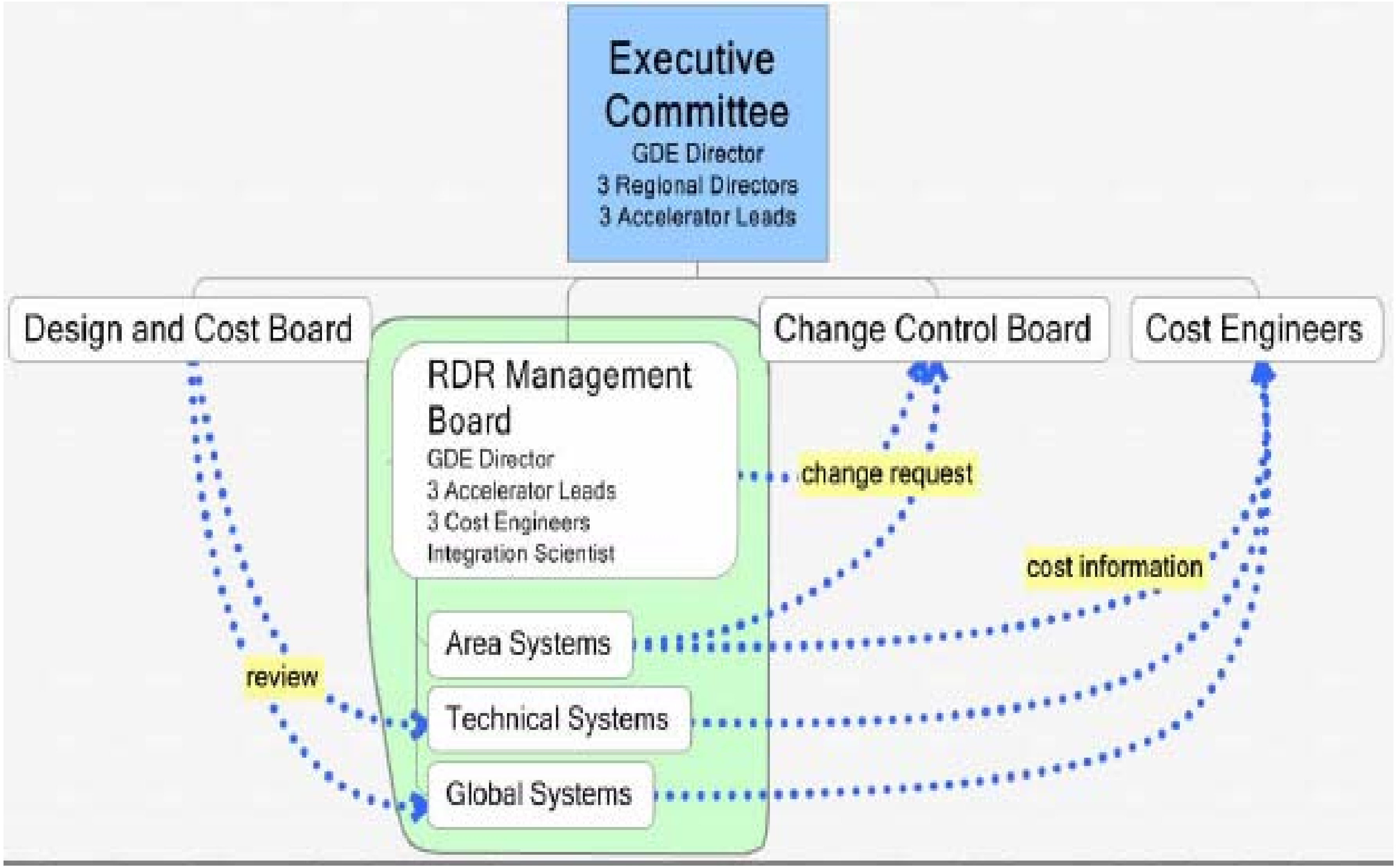
- Three Documents will be presented to the joint ICFA – ILCSC meeting tomorrow, then will be posted

  http://www.linearcollider.org/

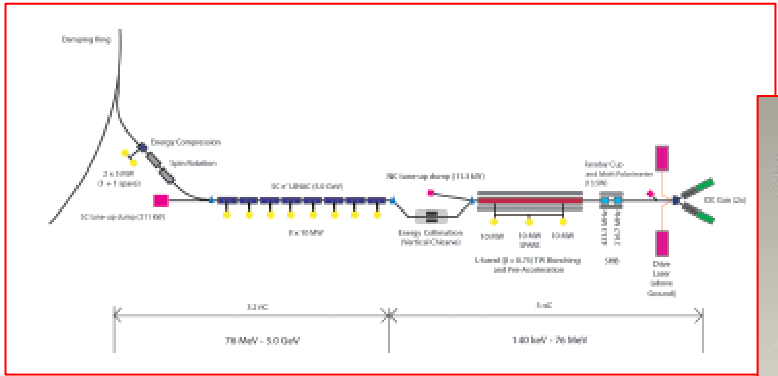
  - **RDR Overview – (Stand alone and Chapter 1)**
  - **Draft Reference Design Report**
  - **The International Linear Collider - *"Gateway to the Quantum Universe"***

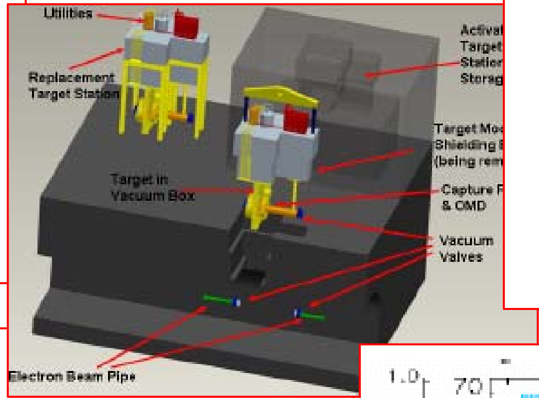
- **Thanks to all that have contributed! A fantastic accomplishment**

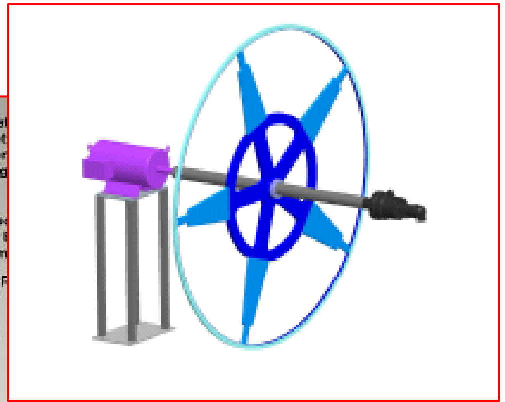
RDR Overview – Chapter 1

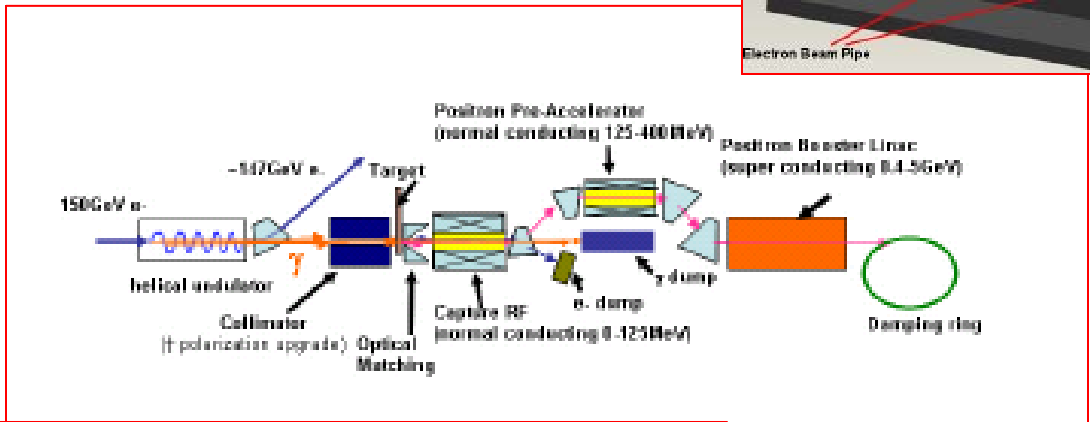


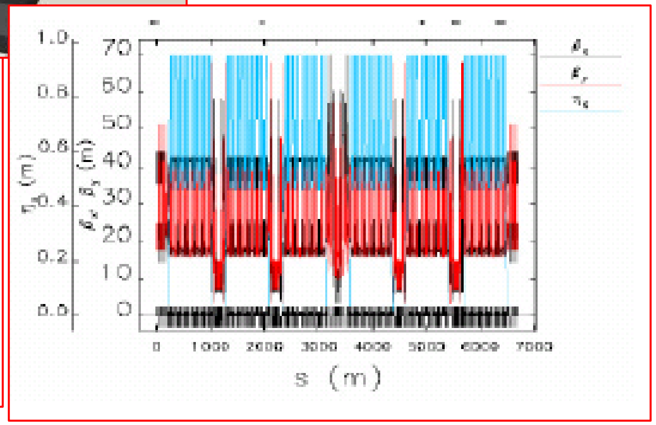
RDR Report – Accelerator Description

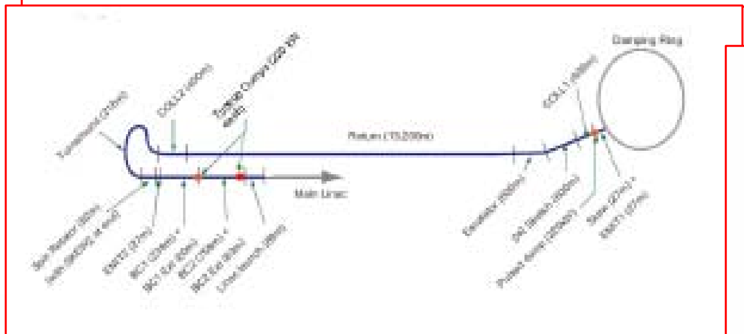


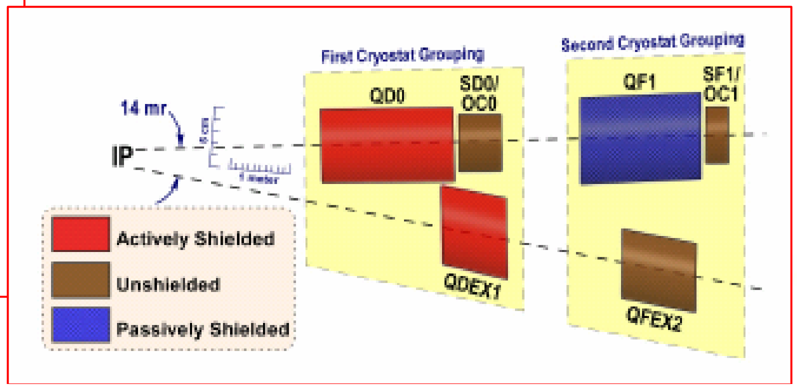






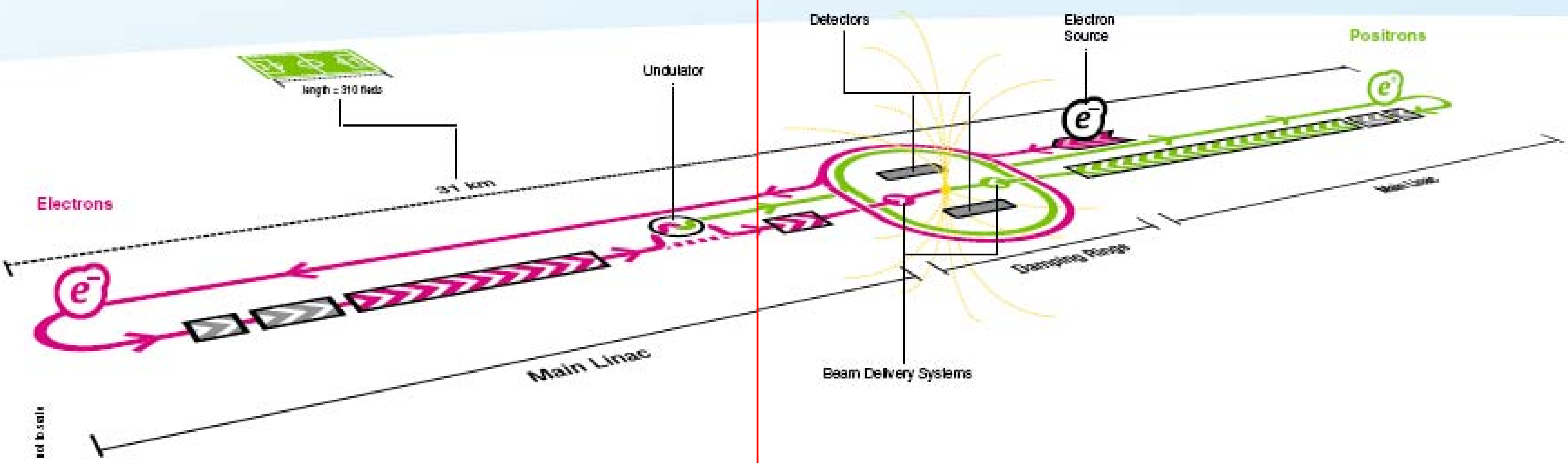






+ Main Linac

RDR Companion Document



The ILC – a step-by-step guide

Electrons

To produce electrons we will fire high-intensity, two-nanosecond light pulses from a laser at a target and knock out billions of electrons per pulse. We will gather the electrons using electric and magnetic fields to create bunches of particles and launch them into a 250-metre linear accelerator that boosts their energy to 5 GeV.

Positrons

Positrons, the antimatter partners of electrons, do not exist naturally on earth. To produce them we will send the high-energy electron beam through an undulator, a special arrangement of magnets in which electrons are sent on a "roller-coaster" course. This turbulent motion will cause the electrons to emit a stream of X-ray photons. Just beyond the undulator the electrons will return to the main accelerator, while the photons will hit a titanium-alloy target and produce pairs of electrons and positrons. The positrons will be collected and launched into their own 250-metre 5-GeV accelerator.

The damping rings

When created, neither the electron nor the positron bunches are compact enough to yield the high density needed to produce copious collisions inside the detectors. We will solve this problem by using seven-kilometre-circumference damping rings, one for electrons and one for positrons. In each ring, the bunches will repeatedly traverse a series of wigglers, devices that causes the beam trajectories to "wiggle" and emit photons. This process makes the bunches more compact. Each bunch will spend approximately two tenths of a second in its damping ring, circling roughly 10,000 times before being kicked out. Magnets will keep the particles on track and focussed in their circular orbits around the ring. Upon exiting the damping rings the bunches will be a few millimetres long and thinner than a human hair.

The linacs

We will use two main linear accelerators ("Linacs"), one for electrons and one for positrons, each 12 kilometres long, to accelerate the bunches of particles toward the collision point. Each accelerator consists of superconducting cavities nestled within a series of cooled vessels to form cryomodules. The modules use liquid helium to cool the cavities to -271°C, only slightly above absolute zero, to make them superconducting. We will launch travelling electromagnetic waves into the cavities to "push" the particles through, and accelerate them to energies up to 250 GeV. Each electron and positron beam will then contain an energy of about 1 kilojoule, which corresponds to an average beam power of roughly 10 megawatts.
The whole process of production of electrons and positrons, damping, and acceleration will repeat five times every second.

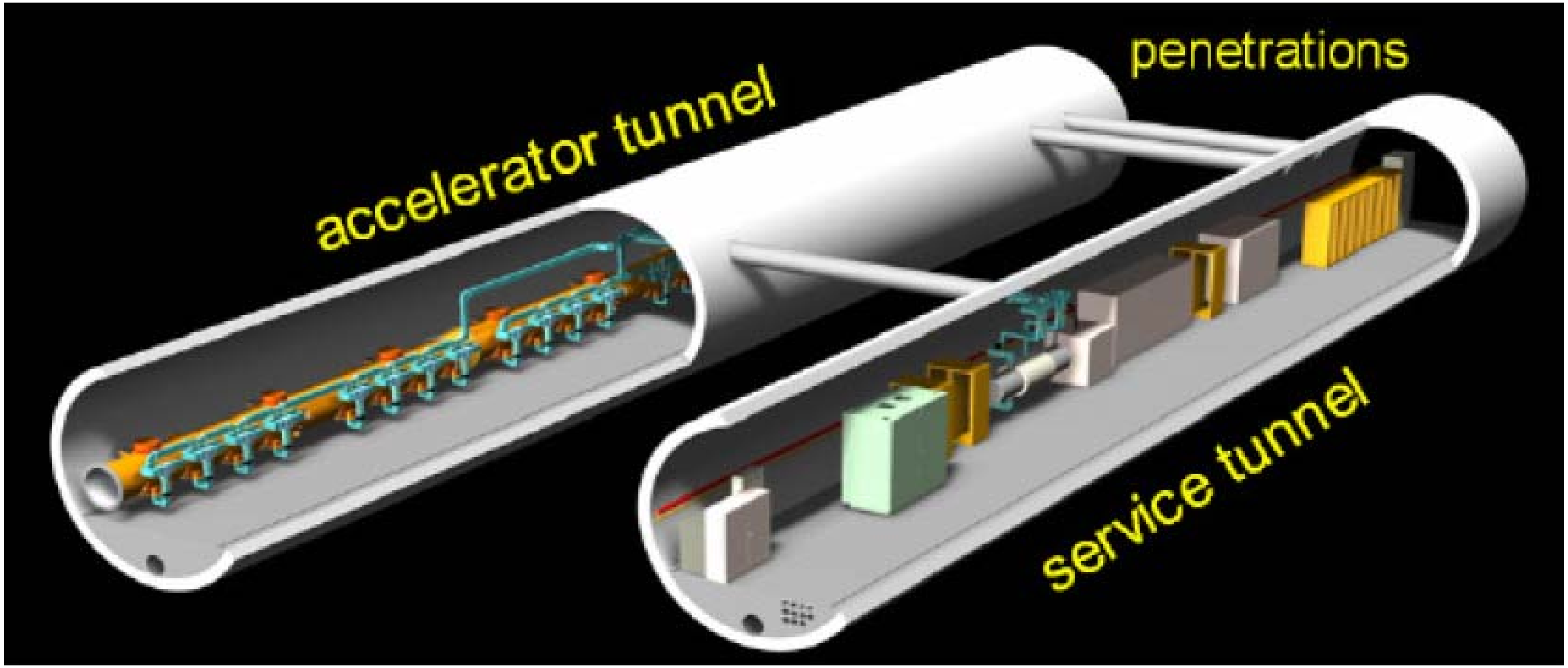
The beam delivery systems

In order to maximise the luminosity we will then focus the bunches to extremely small sizes. We will use a series of magnets, arranged along two 2-kilometre beam delivery systems on each side of the collision point, to focus the beams to a few nanometres in height and a few hundred nanometres in width. The beam delivery systems will scrape off stray particles in the beams and protect the sensitive magnets and detectors. Magnets will steer the electrons and positrons into head-on collisions.

The detectors

Travelling towards each other at nearly the speed of light, the electron and positron bunches will collide with a total energy of up to 500 GeV. We will record the spectacular collisions in two giant particle detectors. These work like gigantic cameras, taking snapshots of the fleeting particles produced by the electron-positron annihilations. The two detectors will incorporate different but complementary state-of-the-art technologies to capture this precious information about every particle produced in each collision. Having these two detectors will allow vital cross-checking of the potentially-subtle physics discovery signatures.

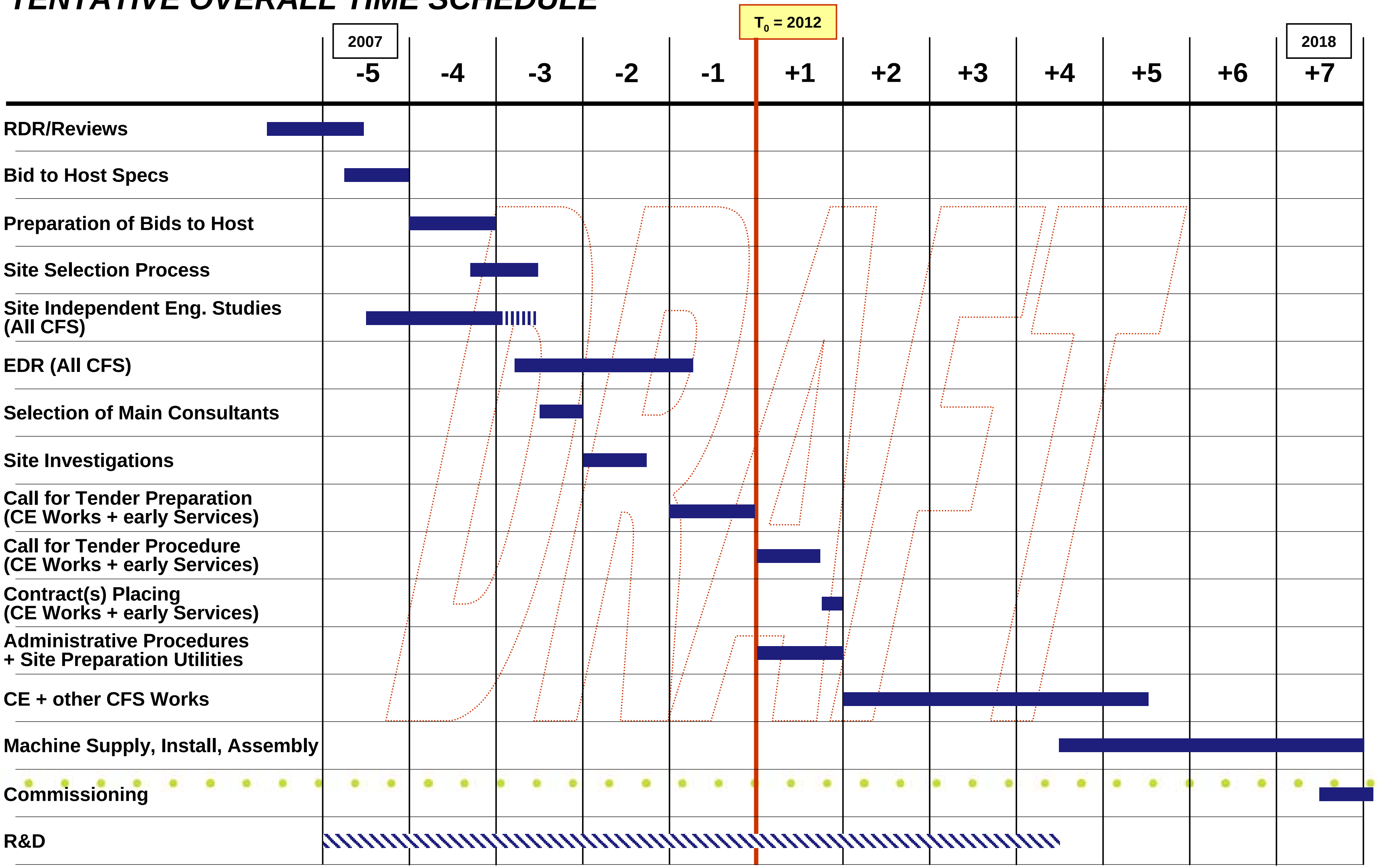
Main Linac Double Tunnel



- Three RF/cable penetrations every rf unit
- Safety crossovers every 500 m
- 34 kV power distribution

CF&S Project Schedule

TENTATIVE OVERALL TIME SCHEDULE



Summary & Final Remarks

- We have produced the ILC RDR as planned!
- The design is completely consistent with the ILCSC physics goals and parameters
- We have produced a first version of the draft RDR that will be presented to ICFA / ILCSC tomorrow