LINEAR COLLIDER COLLABORATION

ILC Accelerator

A 25-year effort towards an e^+e^- collider

Nan Phinney

SLAC

ILC Worldwide Event, Fermilab, June 12, 2013

(Many slides courtesy of Marc Ross, Akira Yamamoto, Barry Barish)

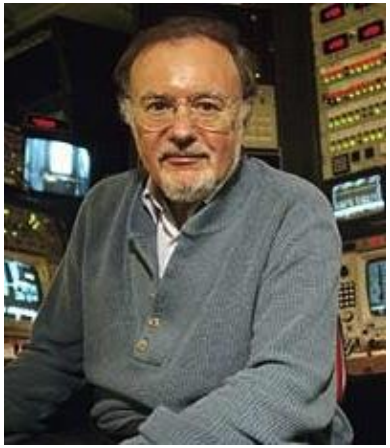
The Beginning – *an idea*

A Possible Apparatus for Electron-Clashing Experiments (*).

M. Tigner

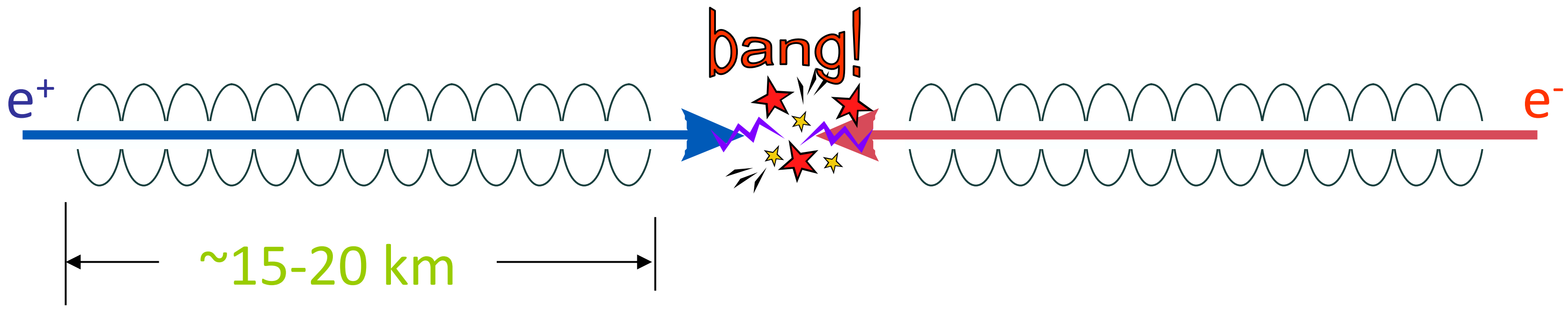
Laboratory of Nuclear Studies. Cornell University - Ithaca, N.Y.

M. Tigner,
Nuovo Cimento 37 (1965) 1228



"While the storage ring concept for providing clashing-beam experiments ([1]) is very elegant in concept it seems worth-while at the present juncture to investigate other methods which, while less elegant and superficially more complex may prove more tractable."

Two Linacs, No Bends!



For a E_{cm} = 1 TeV machine:

Effective gradient G = 500 GV / 15 km

= 34 MV/m real-estate gradient

Cost scaling:	storage ring	$\$_{tot} \propto E^2$
	linear collider	$\$_{tot} \propto E$

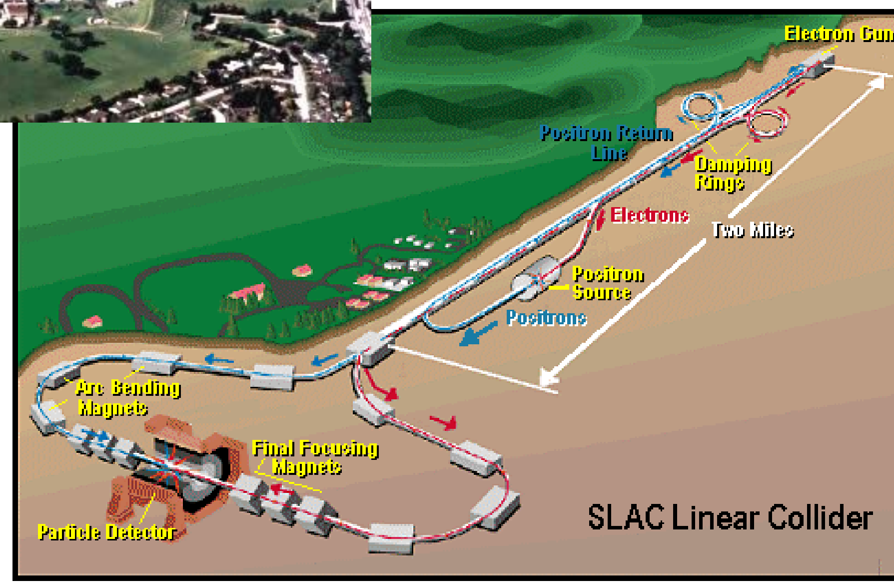
The real Beginning was *at SLAC*

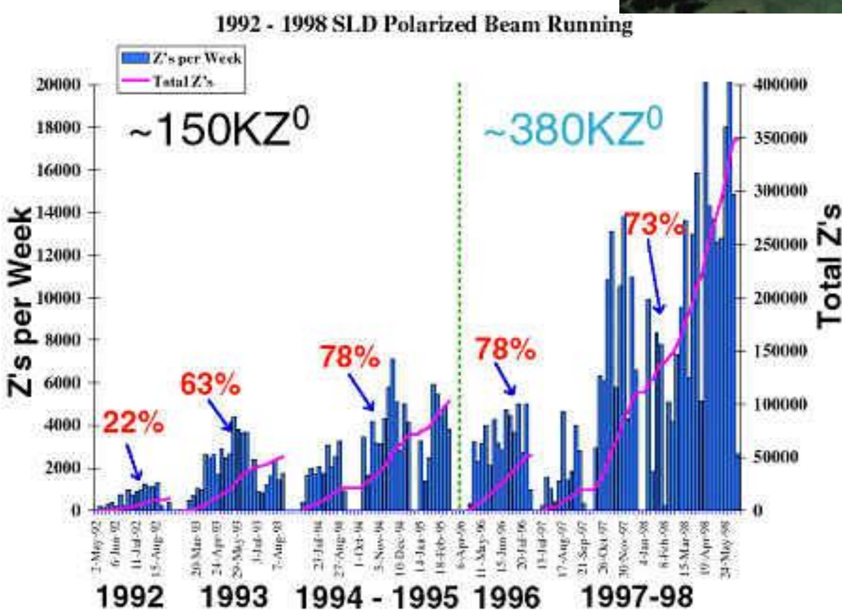
Burt Richter

SLAC Linear Collider (SLC)

1988-1998

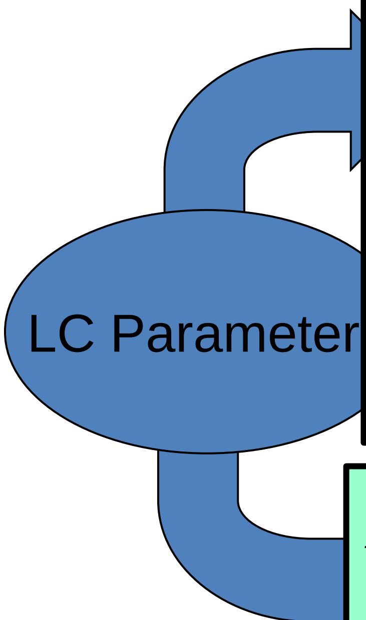
A proof of principle





Achieved $\sigma^x \times \sigma^y$ = 1/3 of design

Linear Collider Design Issues



L – Luminosity: Effectiveness of collider
N – particles in a bunch
n_b – bunches in a machine pulse
f_{rep} – pulses per second
$\sigma_{x,y}$ – x (and y) beam sigma at IP
H_D – disruption of one beam caused by the fields of the other

E_{CM} – collision Center of Mass Energy
b_{fill} – the fraction of the machine length actually used for acceleration
L_{linac} – the length of the linac
G_{RF} – the average accelerating gradient

The *Luminosity* Issue

- **High Beam Power**
  - **High current (n_b N)**
  - **High efficiency ($P_{RF} \rightarrow P_{beam}$)**
- **Small IP vertical beam size**
  - Small emittance ε_y
  - strong focusing (small β^*_y)

The *Luminosity* Issue

- **High current (n_b N)**
- **High efficiency ($P_{RF} \rightarrow P_{beam}$)**

Superconducting
RF Linac
Technology

(SCRF)

- Small emittance ε_y
- strong focusing (small β^*_y)

the Big Jump from SLC to ILC:

LINEAR CO

In Beam Power (P_{beam}) X 100,
collision beam size (σ^*_y) 1/100
and Luminosity (L) X 10^4

SLC / ILC Comparison

	SLC	ILC	
E_{cm}	100	500	GeV
P_{beam}	0.04	5	MW
σ^*_y	500	6	nm
$\delta E/E_{bs}$	0.03	4	%
L	**3×10^{-4}**	**1.8**	**10^{34} cm^{-2}s^{-1}**

1^{st} LC Technology Review - 1994

Only one scheme (of 8) was superconducting

E_{cm}=500 GeV

	TESLA	SBLC	JLC-S	JLC-C	JLC-X	NLC	VLEPP	CLIC
f [GHz]	1.3	3.0	2.8	5.7	11.4	11.4	14.0	30.0
$L \times 10^{33}$ [$cm^{-2}s^{-1}$]	6	4	4	9	5	7	9	1-5
P_{beam} [MW]	16.5	7.3	1.3	4.3	3.2	4.2	2.4	~1-4
P_{AC} [MW]	164	139	118	209	114	103	57	100
$\gamma\varepsilon_y$ [$\times 10^{-8}$m]	100	50	4.8	4.8	4.8	5	7.5	15
σ_y^* [nm]	64	28	3	3	3	3.2	4	7.4

2nd LC Technology Review - 2002

E_{cm}=500 GeV

Not Represented

Not Ready

	TESLA	SBLC	JLC-S	JLC-C	JLC-X/NLC	VLEPP	CLIC
f [GHz]	1.3			5.7	11.4		30.0
$L\times10^{33}$ [$cm^{-2}s^{-1}$]	34			14	20		
P_{beam} [MW]	11.3			5.8	6.9		
P_{AC} [MW]	140			233	195		[illegible]
$\gamma\varepsilon_y$ [$\times10^{-8}$m]	3			4	4		1
σ_y^* [nm]	5			4	3		1.2

International Technology Review Panel

International Committee for Future Accelerators (ICFA) representing major particle physics laboratories worldwide convened a panel to choose the collider technology.

In Beijing 2004, ICFA accepted the ITRP recommendation.

- Chose ILC accelerator technology (SCRF)
- Determined ILC physics design parameters
- Formed Global Design Effort and Mandate (TDR)

By late 2004: only ILC and CLIC

LINEAR COLLIDER

E_{cm}=500-1000 GeV

	ILC	SBLC	JLC-S	JLC-C	JLC-X/NLC	VLEPP	CLIC
f [GHz]	1.3						30.0
$L \times 10^{33}$ [$cm^{-2}s^{-1}$]	≥20						21
P_{beam} [MW]	5-23						4.9
P_{AC} [MW]	140-300						175
$\gamma\varepsilon_y$ [$\times 10^{-8}$m]	3-8						1
σ_y^* [nm]	3-8						1.2

ILC and CLIC: 2013

E_{cm}=500-1000 GeV

	ILC	SBLC	JLC-S	JLC-C	JLC-X/NLC	VLEPP	CLIC
f [GHz]	1.3						11.4
$L \times 10^{33}$ [$cm^{-2}s^{-1}$]	18						23
P_{beam} [MW]	5						4.9
P_{AC} [MW]	160						257
$\gamma\varepsilon_y$ [$\times 10^{-8}$m]	3						1
σ_y^* [nm]	6						1.2

This talk

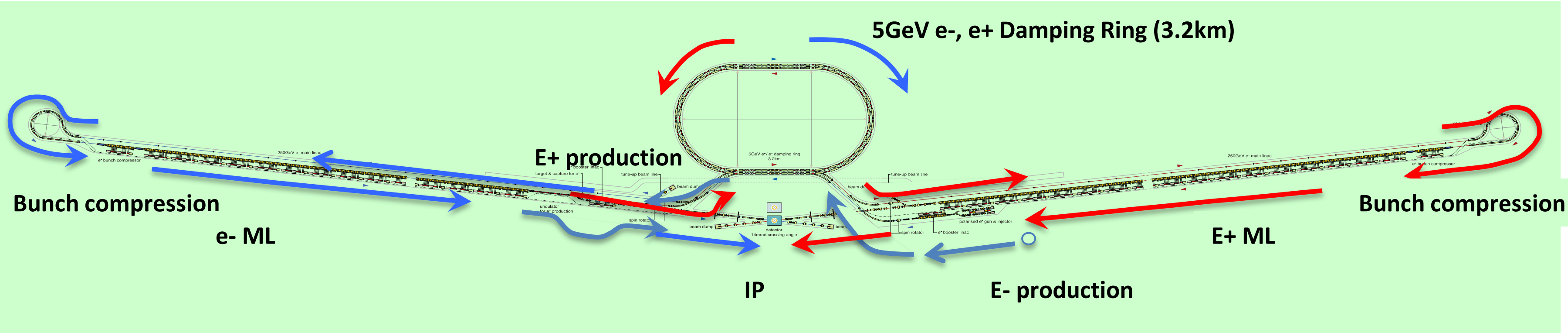
Closer, but still ***Not Ready***

25 year – long effort towards a very high performance e+ / e- collider

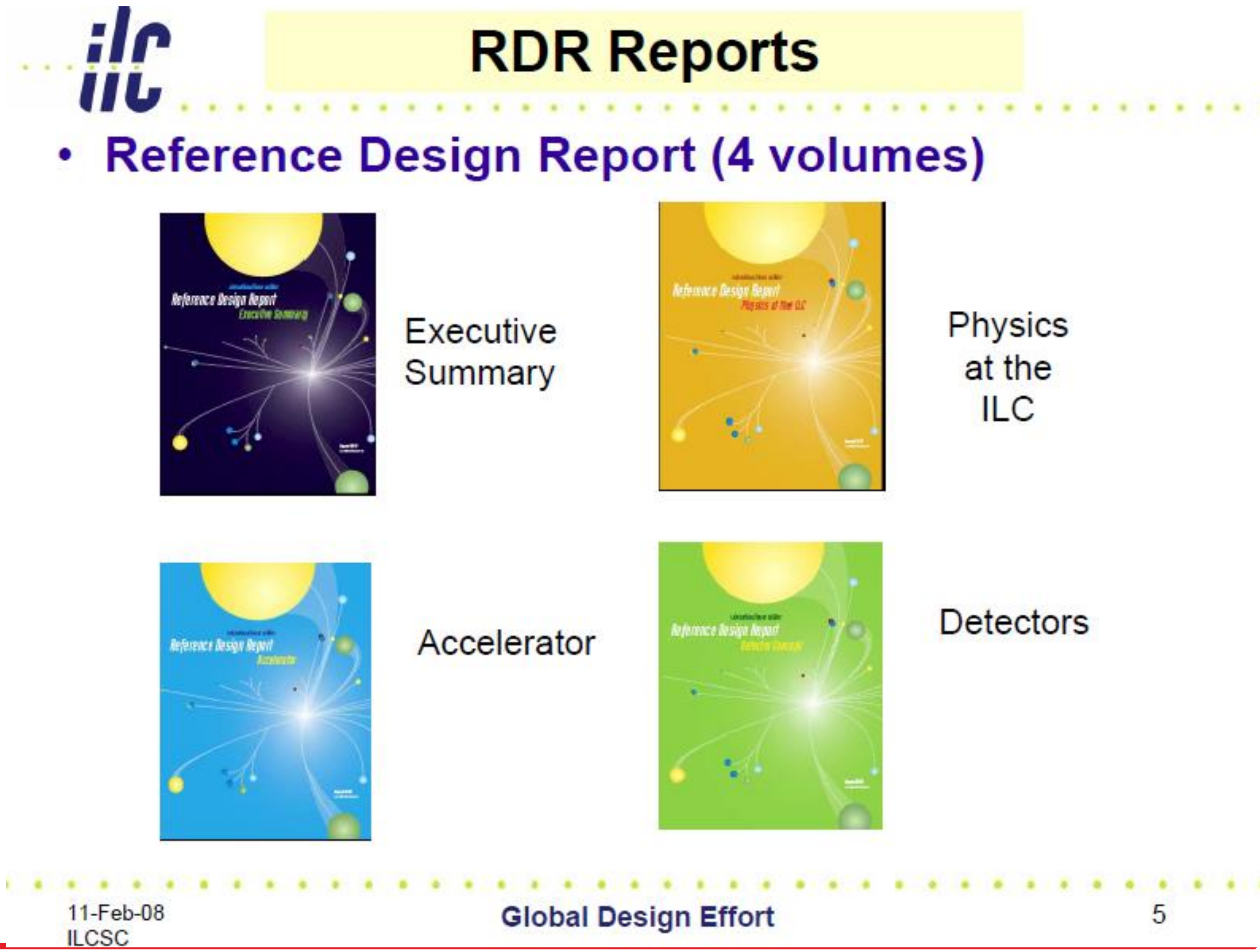
Year	1987	1992	1998	2004	2006	2012
Phase	SLC @ SLAC		LC Design		Global Design Effort - ILC	
500 GeV Linear Collider R & D	8 schemes		4		2 →	
Comparative Reviews		Technology Review 1995	Technology Review 2002	International Technology Review Panel 2004		'General issues' ILC/CLIC
Beam Test Facilities - Linac (cost-driver)	(SLAC)		NLCTA, TTF / FLASH			NML, STF, CTF
Beam Test Facilities - Emittance		FFTB	ATF		CesrTA	ATF2

Requirements from Physics Experiments

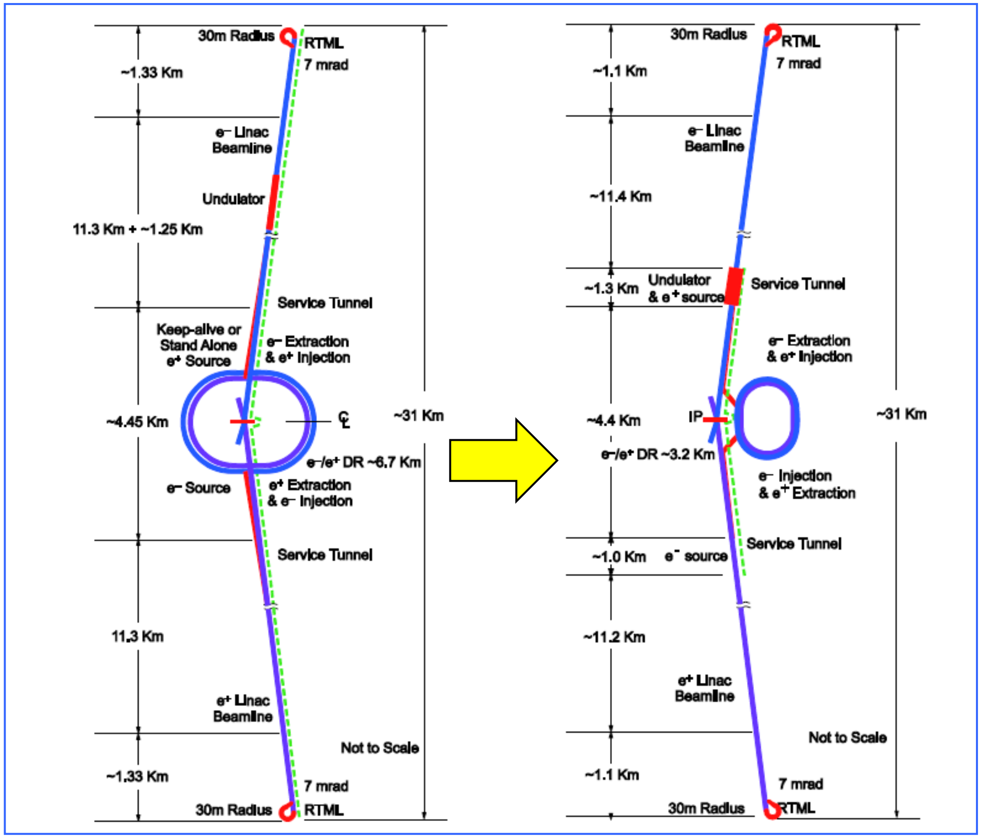
- **Basic requirements:**
  - Luminosity : $\int Ldt = 500\ fb^{-1}$ in 4 years
  - E_{cm} : 200 – 500 GeV and the ability to scan
  - E stability and precision: < 0.1%
  - Electron polarization: > 80%
- **Extension capability:**
  - Energy upgrade: 500 → 1,000 GeV



Reference Design - 2007

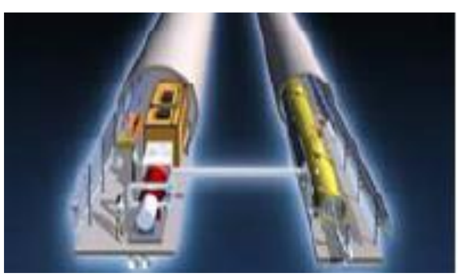


RDR (2007) to TDR (2012)

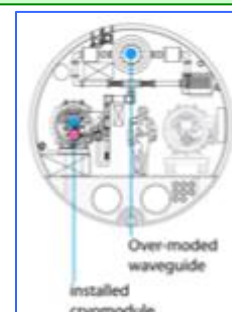


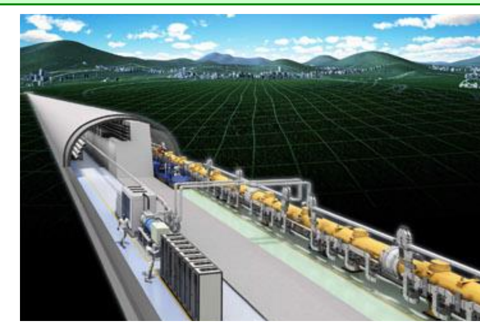
Cost Containment Effort

- **Single acc. Tunnel**
- **Reducing # bunches**
  - w/ smaller damping rings
- **Allowing gradient spread**
  - 31.5 MV/m +/- 20 %,
- **Site-dependent RF system:**
  - Clustered on surface (KCS),
  - Distributed in tunnel (DKS)



RDR'07 →
(Reference Design Rep.)
TDR'12
(Technical Design Rep.)





Flat-land or Mountainous Tunnel Design

Major R&D Efforts in TD Phase

SCRF technology and beam acceleration：

- Cavity Gradient required：31.5 MV/m
  - ILC SCRF cavity R&D
    - Effort for ~ 7 x Gradient (KEK-TRISTAN, CERN-LEP)
    - Gradient Progress ： < 37 MV/m> （Record：46 MV/m at DESY)
    - System engineering： S1-Global program with global effort
- Industrialization of cavity production

Electron Cloud Mitigation (CESR-TA)

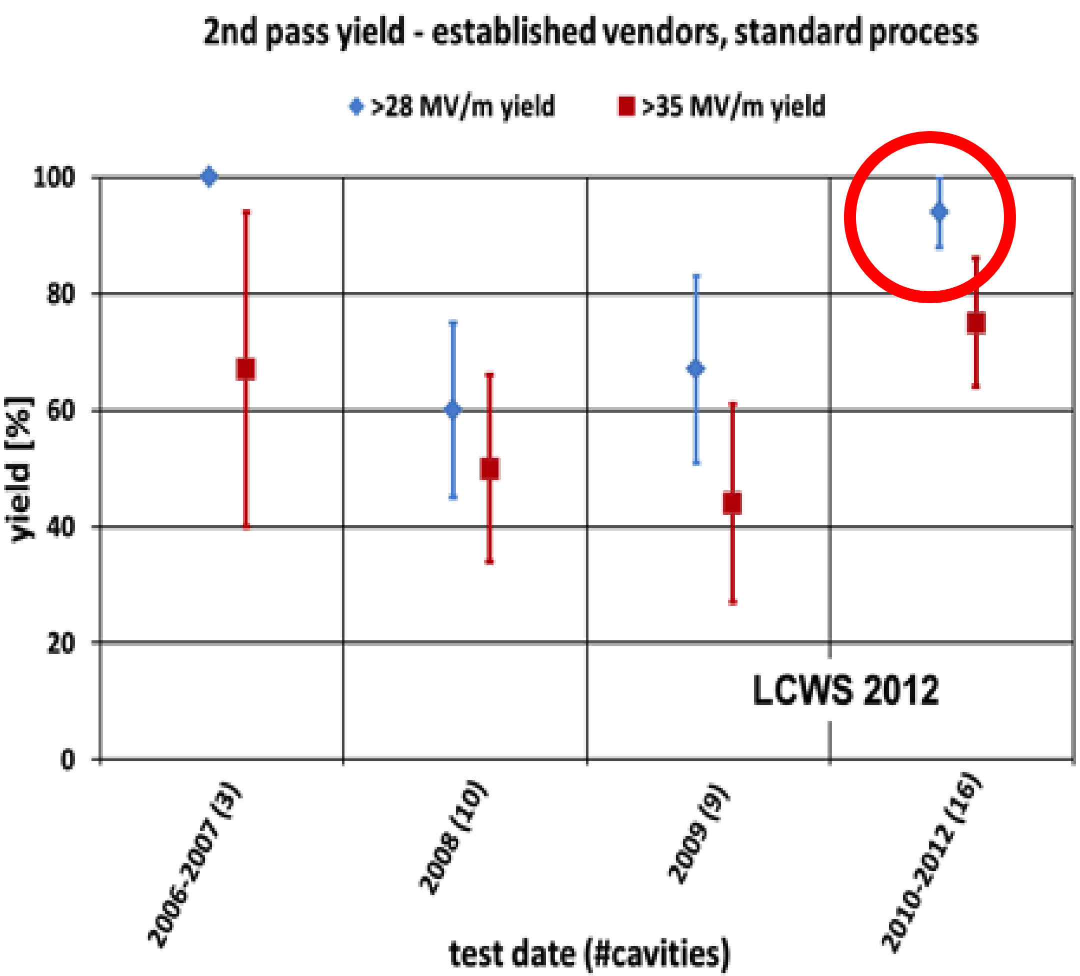
Nano-beam handling :

- ILC requires a beam size ~ 6 nm (vertical) and stability ~2nm:
  - Progress in KEK-ATF2:
    - achieved ~70 nm (at 1.3 GeV),
    - corresponding to 10 nm (at 250 GeV, ILC)

Global Plan for SCRF R&D

Year	07	2008	2009	2010	2011	2012
Phase	TDP-1			TDP-2		
Cavity Gradient in vert test to reach 35 MV/m	→ Yield 50%			→ Yield 90%		
Cavity-string to reach 31.5 MV/m, with one-cryomodule		Global effort for string assembly and test (DESY, FNAL, INFN, KEK)				
System Test with beam acceleration		FLASH (DESY) , NML/ASTA (FNAL) QB, STF2 (KEK)				
Preparation for Industrialization			Production Technology R&D			
Communication with industry:	1st Visit Vendors (2009), Organize Workshop (2010) 2nd visit and communication, Organize 2nd workshop (2011) 3rd communication and study contracted with selected vendors (2011-2012)					

Progress in SCRF Cavity Gradient



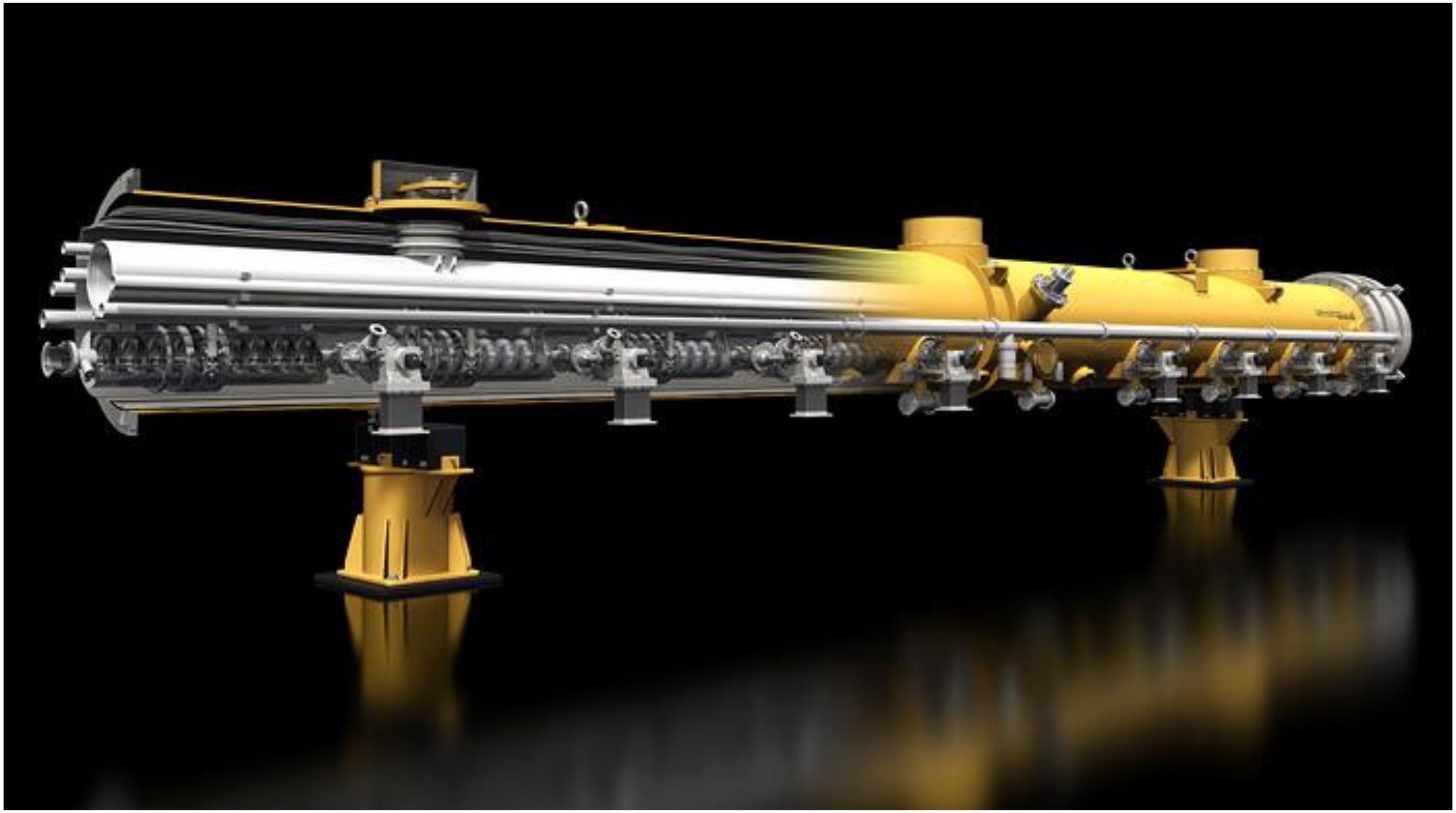
Production yield:
94 % at > 28 MV/m,

Average gradient:
37.1 MV/m

reached in 2012

ILC Cryomodule

- **12.6 m long; 1 m diameter**
  - (Similar to LHC dipole)
  - 8 cavities w / SC quad magnet in middle



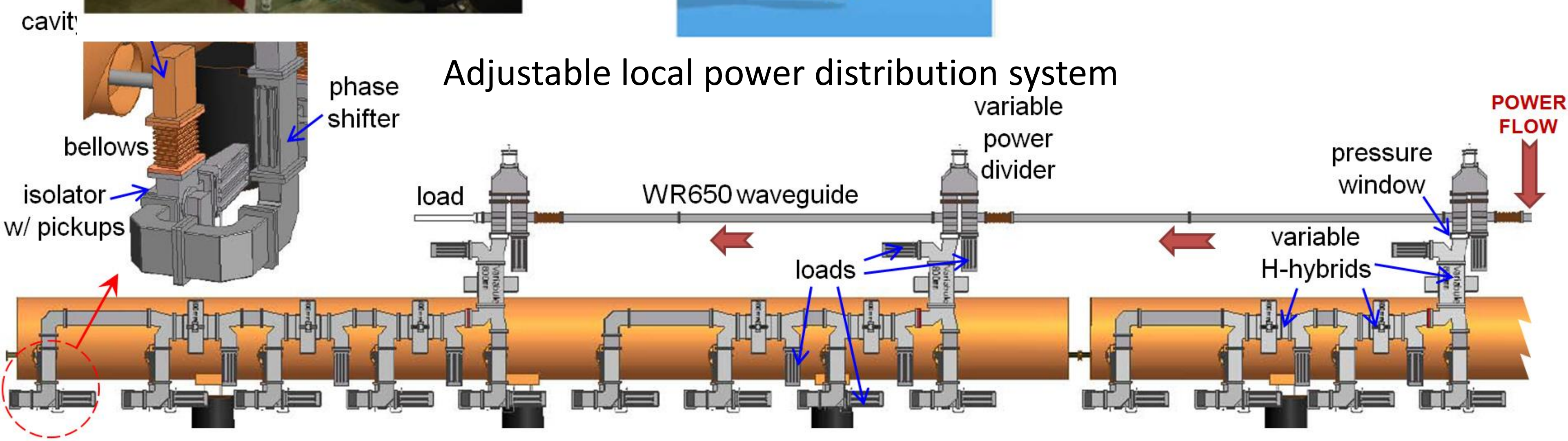
View along main linac:

RF Power Source and Distribution

Marx modulator

10MW MB Klystron

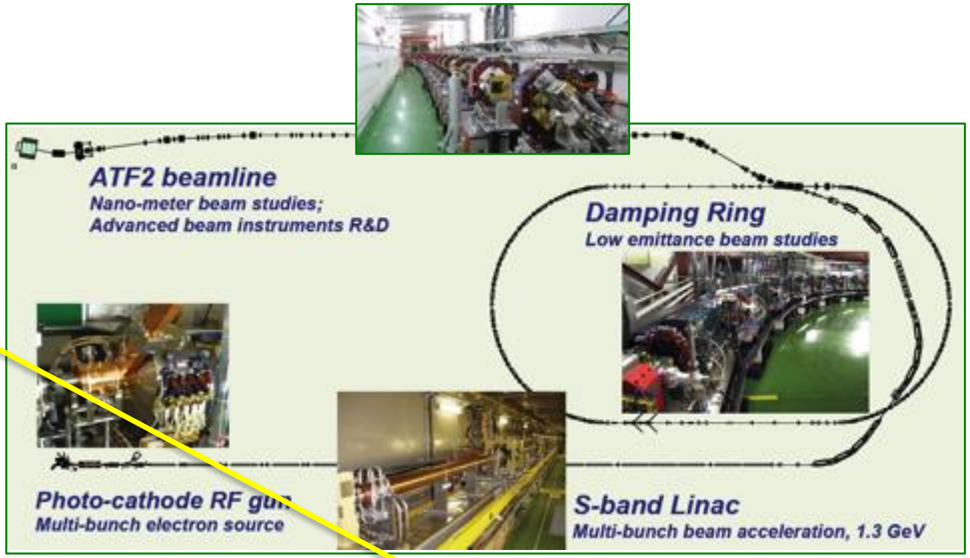
Adjustable local power distribution system

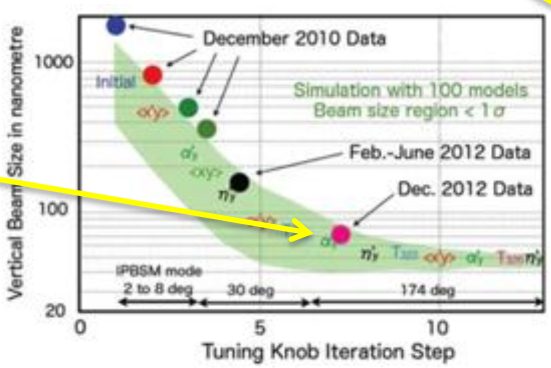


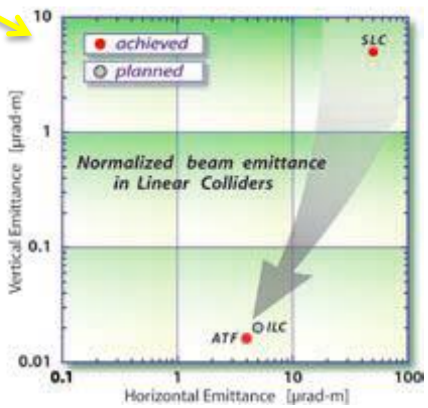
KEK-ATF : Progress

Ultra-small beam

- **Low emittance : KEK-ATF**
  - Achieved the ILC goal (2004).
- **Small vertical beam size : KEK ATF2**
  - Goal = 37 nm,
    - 160 nm (spring, 2012)
    - ~70 nm (Dec. 2012) at low beam current







Global Cooperation for ILC Accelerator Beam Demonstration

TTF/FLASH (DESY) ~1 GeV
ILC-like beam ILC RF unit
(* lower gradient)

STF (KEK) operation/construction
ILC Cryomodule test： S1-Global
Quantum Beam experiment

CesrTA (Cornell)
electron cloud
low emittance

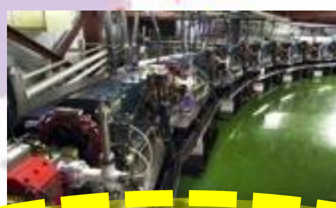
DESY

INFN Frascati

KEK, Japan

FNAL

Cornell



DA$^{\Phi}$NE (INFN Frascati)
kicker development
electron cloud

ATF & ATF2 (KEK)
ultra-low emittance
Final Focus optics
KEKB electron-cloud

NML facility ILC RF unit test
Under construction

Technical Design Report Completed

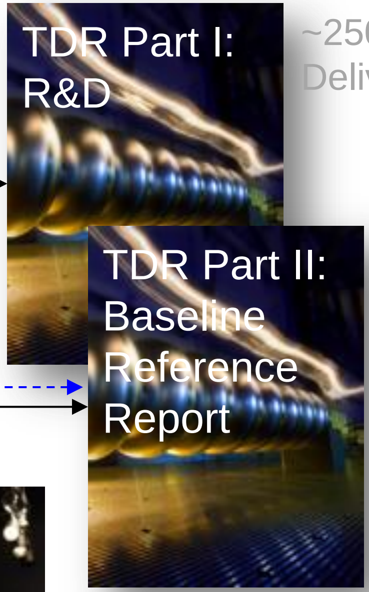
2007

2011

2013*

ILC Technical Progress Report (“*interim report*”)

AD&I



~250 pages
Deliverable 2

~300 pages
Deliverables 1,3 and 4

Reference Design Report

Technical Design Report

* end of 2012 – formal publication early 2013

Japanese plans for a “Science City”

What's next?

20 years from 1st idea to 1st prototype SLC

25 more years to a complete ILC design

2013

- TDR complete, Technical- and Cost-Reviews done
- Linear Collider Collaboration is being formed
- Japan plans to select a site this summer

2013-2016

- Prepare a proposal to the funding agencies

2016 →

The ILC is Good to Go

Quote from ILCSC chair Jonathan Bagger at LC2013 DESY