Accelerator Physics Challenges of the International Linear Collider

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July 15, 2005
12th International Workshop on RF
Superconductivity, Ithaca, NY

*Supported by the National Science Foundation

Physics parameters for the ILC

- E_{cm} adjustable from 200 – 500 GeV
- Luminosity $\int L dt$ = 500 fb^{-1} in 4 years
- Energy stability and precision below 0.1%
- Electron polarization of at least 80%
- The machine must be upgradeable to 1 TeV

Key accelerator physics challenge: achieving the linear collider luminosity

$$L\left[10^{34}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}\right]\approx 121\left(N_\gamma H_D\right)\frac{P_b[\mathrm{MW}]}{E_b[\mathrm{GeV}]}\frac{1}{\sigma_y[\mathrm{nm}]}$$ (flat beams)

- **Maximize the beam power-**
  - Limited by the wall plug power and rf -> beam power efficiency
- **Minimize the vertical beam size at the IP**
  - Limited by the beam emittance provided by the injector, emittance dilution in the linac, and the final focus optics.
- **Stabilize the vertical beam position at the IP**
  - Limited by component physical motion (natural ground motion, man-made sources) and EM field fluctuations
- **Achieve the required availability**

Linear collider luminosity parameters

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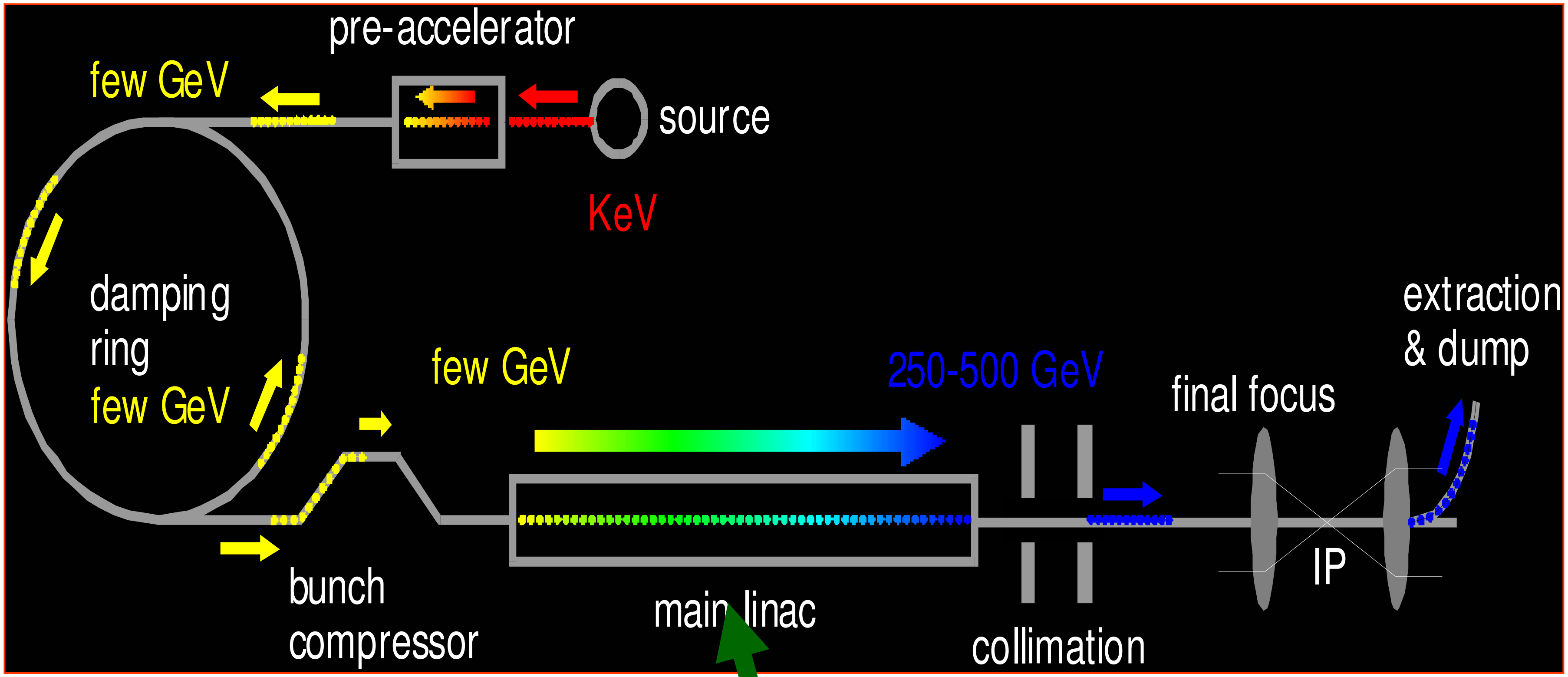
Parameter	SLC	ILC
Beam energy [GeV]	46	250
Beam power/beam [MW]	0.035	11.3
Vertical rms beam size at IP [nm]	650	5.7
Beamstralung photons/electron N_γ	1.1	1.3
Disruption enhancement H_D	2.1	1.7
Luminosity [10^{33} cm^{-2} s^{-1}]	0.003	20

Design Starting Point



Superconducting RF Main Linac

Design focus: generating and colliding high power, low emittance beams

- **Beam generation:** positron source
- **Emittance reduction:** damping rings
- **High efficiency acceleration and emittance preservation:** superconducting linacs
- **Beam delivery:** beam transport, demagnification, collision maintenance, spent beam disposal

Positron source challenges

Generating a high flux of positrons: high power target design and engineering

Capturing the flux: adiabatic matching systems, long pulse normal conducting RF systems

Operational flexibility

Providing a polarization option

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Positron source options

Conventional source

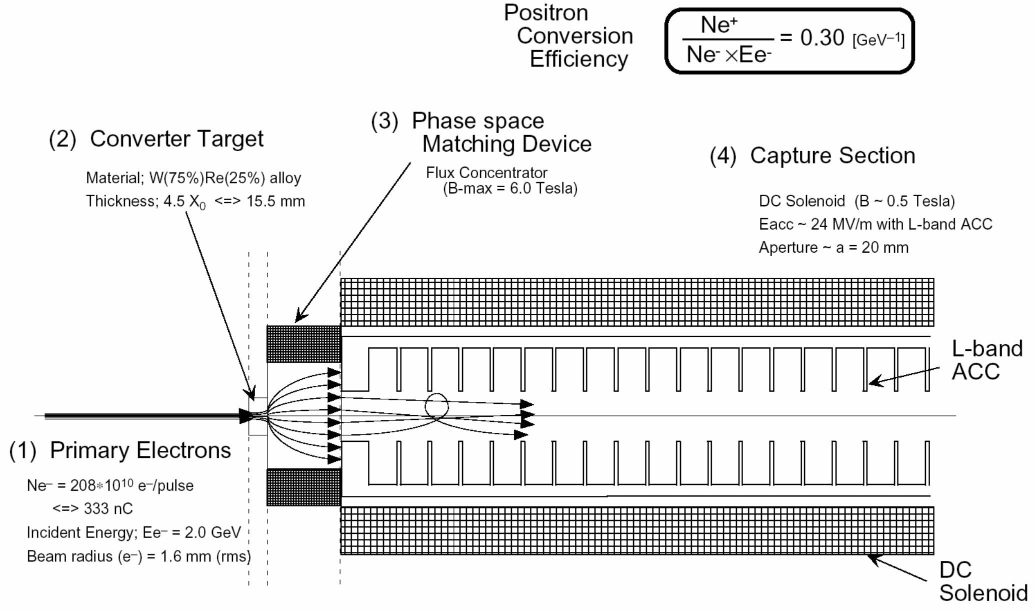
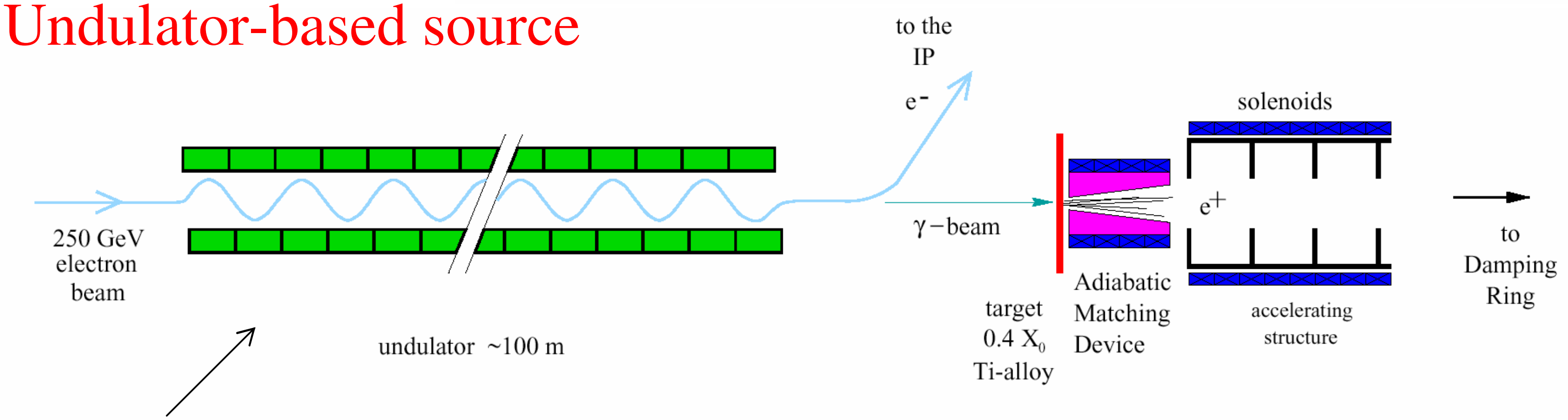


Figure 4: CLIC e^+ generator

Undulator-based source



B=0.75 T
5 mm gap

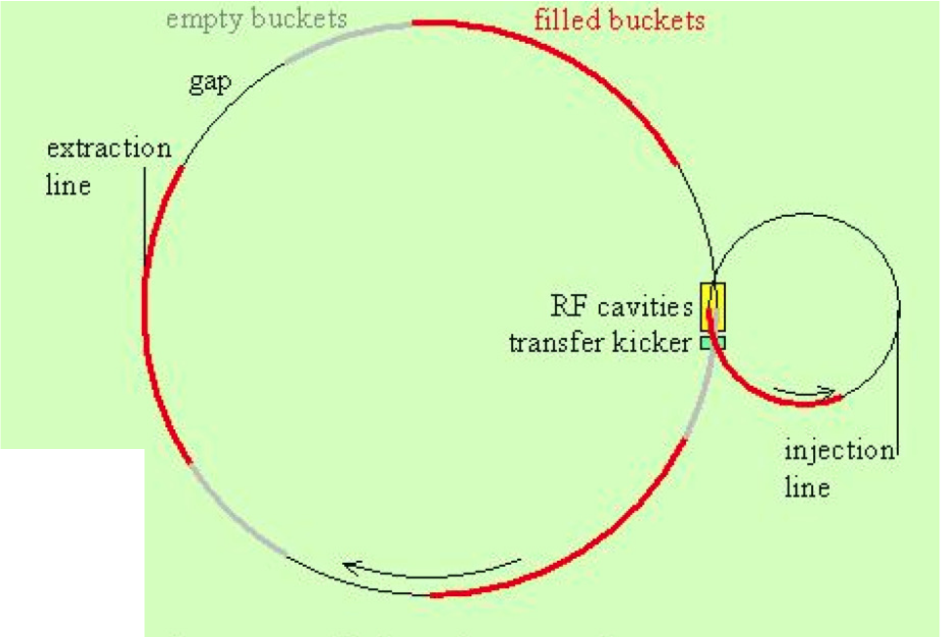
Figure 12: Sketch of the positron source layout.

Damping ring challenges

- **Bunch train compression:** requires fast kicker (<20 ns r.t.)
- **Collective effects**: interaction of the stored beams with residual gas ions (fast ion instability); with photoelectrons generated by the synchrotron radiation (electron cloud); space charge
- **Achieving low vertical emittance:** requires a high degree of orbit control and beam-based alignment. ATF at KEK has achieved a vertical emittance of 4 pm. ILC requirement is 2 pm.
- **Dynamic aperture:** Magnetic lattice design requires extensive use of wiggler magnets. The dynamic aperture is limited primarily by sextupole and wiggler nonlinearities.
- **Beam jitter:** Ground motion and vibration of ring magnets must be controlled; extraction devices must be very stable (kicker relative field variation $<10^{-3}$).

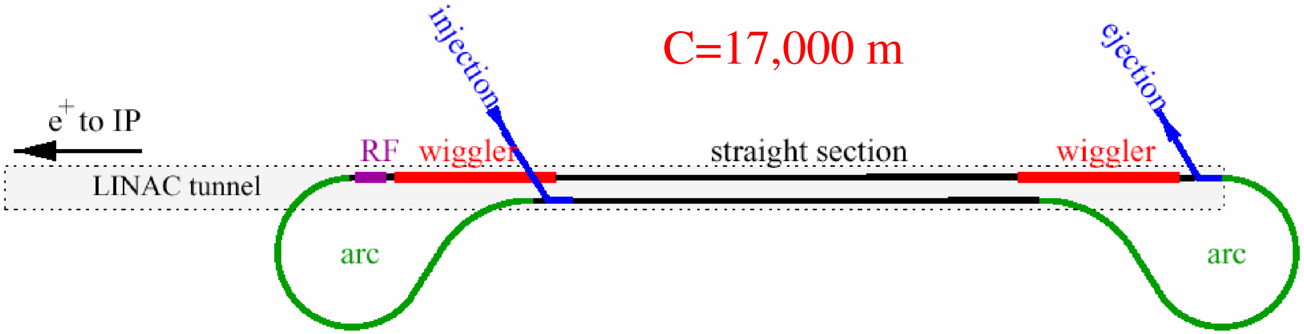
Damping Ring options

6 km Fermilab ring



TESLA: 17 km ring

TESLA DR layout (the “dog-bone”)

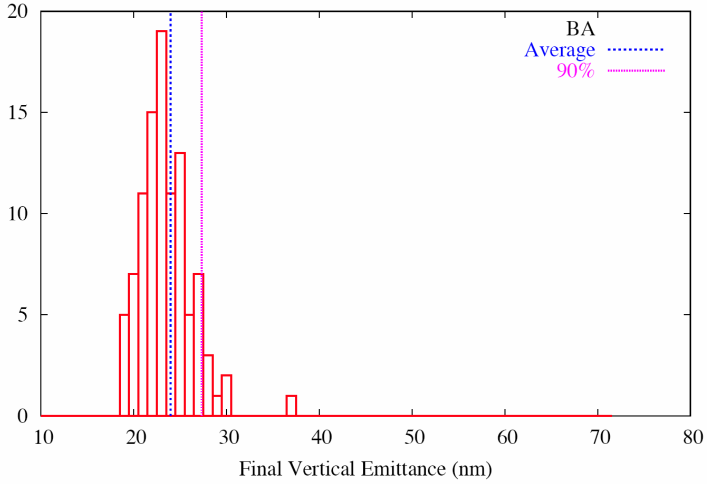


Main linac challenges

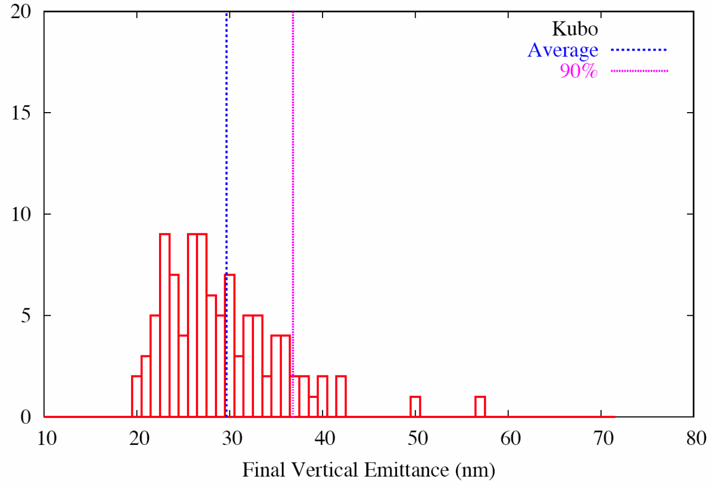
- **Linac technology development**
  - Efficient transfer of power to the beam (superconducting structures), affordability, very high reliability.
  - Design flexibility to adapt to technology advances.

- **Linac beam dynamics**
  - Very small vertical emittances must be accelerated in very long linacs with small vertical emittance growth (~20 nm) and small beam jitter (~0.1σ).
  - This requires control of wakefields (low-frequency structures) and precise beam-component alignment.
  - Beam-based alignment, requiring reliable, high performance, large-scale instrumentation and sophisticated algorithms, is essential.

Emittance preservation in the linac

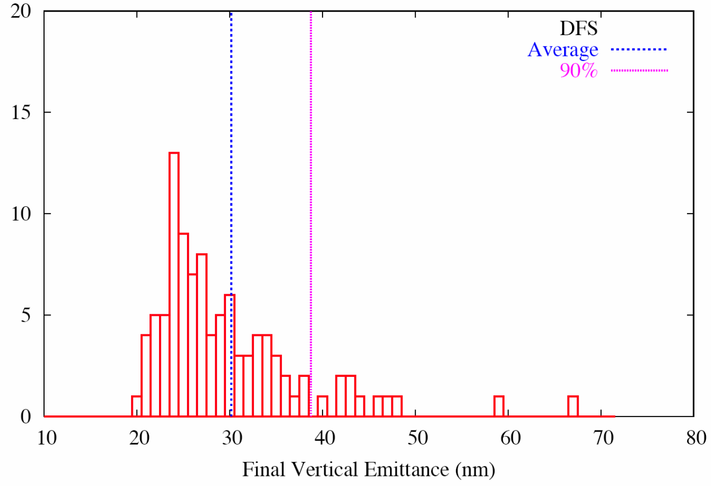


Ballistic Alignment with Design Misalignments



Kubo Method with Design Misalignments

Error	Tolerance	With Respect To...
Quad Offset	300 μm	Cryostat
Quad tilt	300 μrad	Cryostat
BPM Offset	300 μm	Cryostat
BPM Resolution	10 μm	True Orbit
RF Cavity Offset	300 μm	Cryostat
RF Cavity Pitch	200 μrad	Cryostat
Cryostat Offset	200 μm	Survey Line
Cryostat Pitch	20 μrad	Survey Line

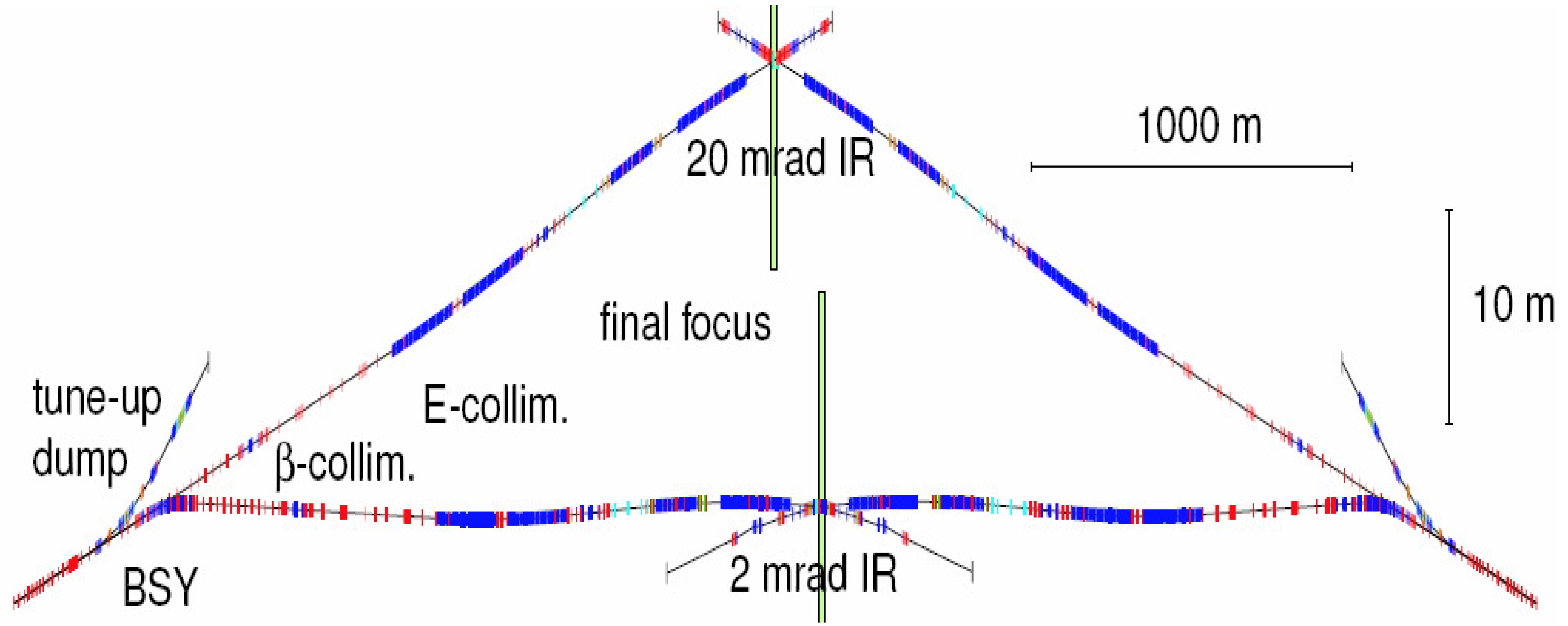


Dispersion Free Steering with Design Misalignments

Beam delivery systems-challenges

- Transport the high-energy beam from the end of the main linac to the interaction point
- Transport the post-collision spent beam and beamstralung to the dumps
- Provide collimation for control of backgrounds
- Provide machine protection systems for errant beams
- Provide collision point maintenance through the use of fast feedback systems (inter-train and intra-train)

ILC Strawman BDS Layout



Mark Woodley

ATF-2 Test Facility at KEK

Goals of ATF2

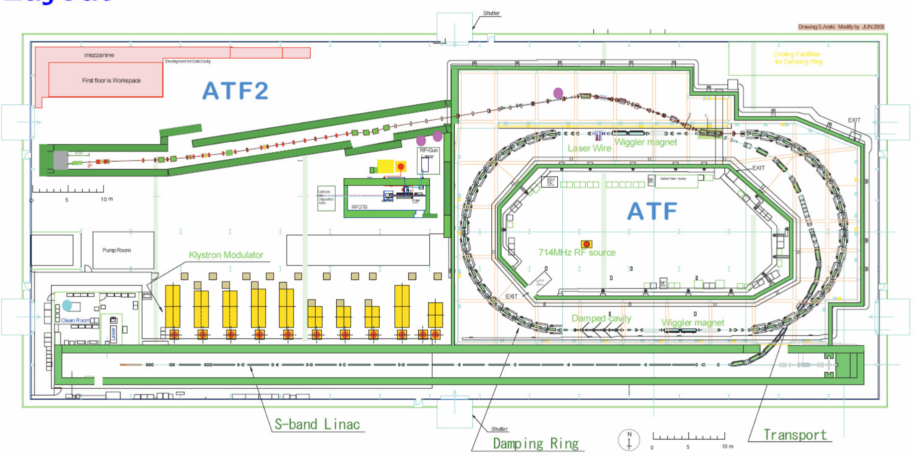
(**A**) Achievement of beam size ∼37nm

- (**A1**) Demonstration of a compact final focus system based on local chromaticity correction scheme
- (**A2**) Maintenance of the small beam size

(**B**) Control of beam position

- (**B1**) Demonstration of beam orbit stabilization with nano-meter precision at IP.
- (**B2**) Establishment of beam jitter controlling technique at nano-meter level with ILC-like beam

Layout



- So-called optimal layout: Total length of FFS ≈ 36m
- Plus diagnostics section and beam-dump

Conclusions

- Linear colliders require extensive efficient RF systems, capable of accelerating high power beams (~MW) with small beam spot sizes (~nm).
- Achieving nm scale beam spots requires generating high intensity beams of electrons and positrons, damping the beams to ultra-low emittance in damping rings, transporting the beams to the collision point without significant emittance growth or uncontrolled beam jitter, and disposing cleanly of the spent beams.
- Based on experience with SLC and simulations, there are designs which can satisfy the luminosity goals, but reaching these goals will require solving a number of challenging problems in accelerator physics and technology.