ILC Main Linac Issues and Evolving SRF Test Facilities

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Fermilab

for the Global Design Effort

International Linear Collider

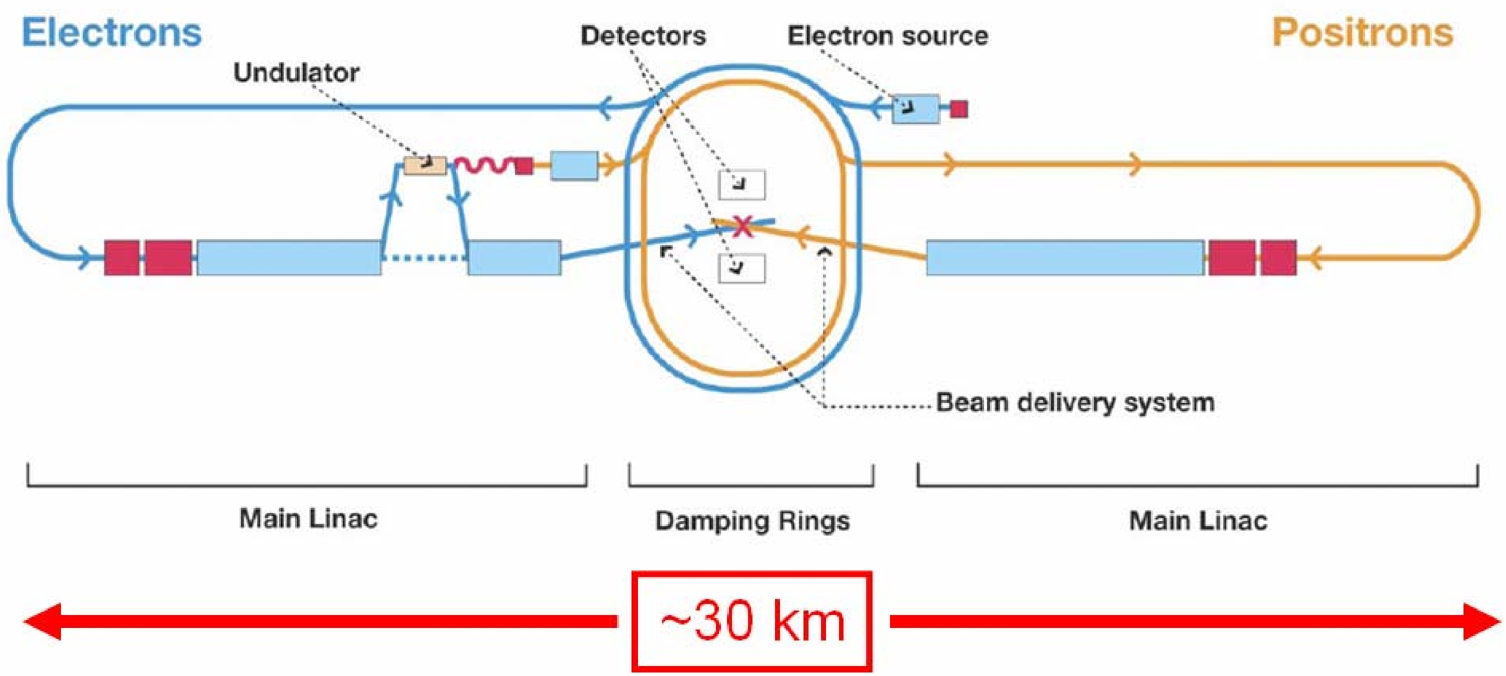
New energy frontier machine proposed for HEP

Parameters

- Electron-Positron Collider
- 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

Overview

- The ILC is based upon a Superconducting Radio Frequency (SRF) linacs of unprecedented scope (length=23 km, 1680 Cryomodules, 14,560 SRF cavities, 31.5 MV/m)



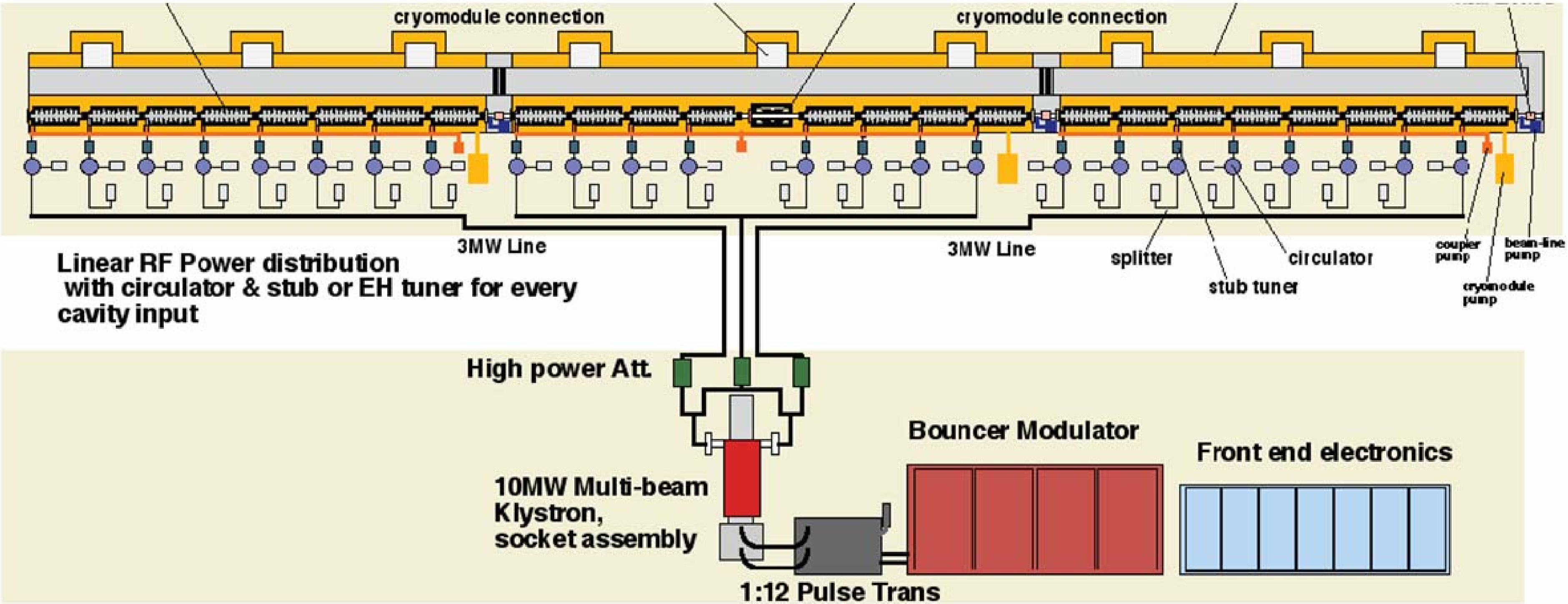
ILC ML Beam Parameters

Parameter	Value	Parameter	Value
Initial Beam energy	15 GeV	Initial $\gamma\varepsilon_x$	8.4 μm
Final Beam energy	250 GeV	Final $\gamma\varepsilon_x$	9.4 μm
Particles per Bunch	2×10^{10}	Initial $\gamma\varepsilon_y$	24 nm
Beam Current	9.0 mA	Final $\gamma\varepsilon_y$	34 nm
Bunch Spacing	369 ns	σ_z	0.3 mm
Bunch train length	969 μs	Initial σ_E/E	1.5%
Number of bunches	2625	Final σ_E/E	0.1%
Pulse repetition rate	5 Hz	Beam phase wrt RF crest	5°

Average beam power is 11 MW / beam ➔ wall plug to beam efficiency is crucial ➔ Superconducting RF

ML basic building block

ILC RF Unit: 3 CM, klystron, modulator, LLRF

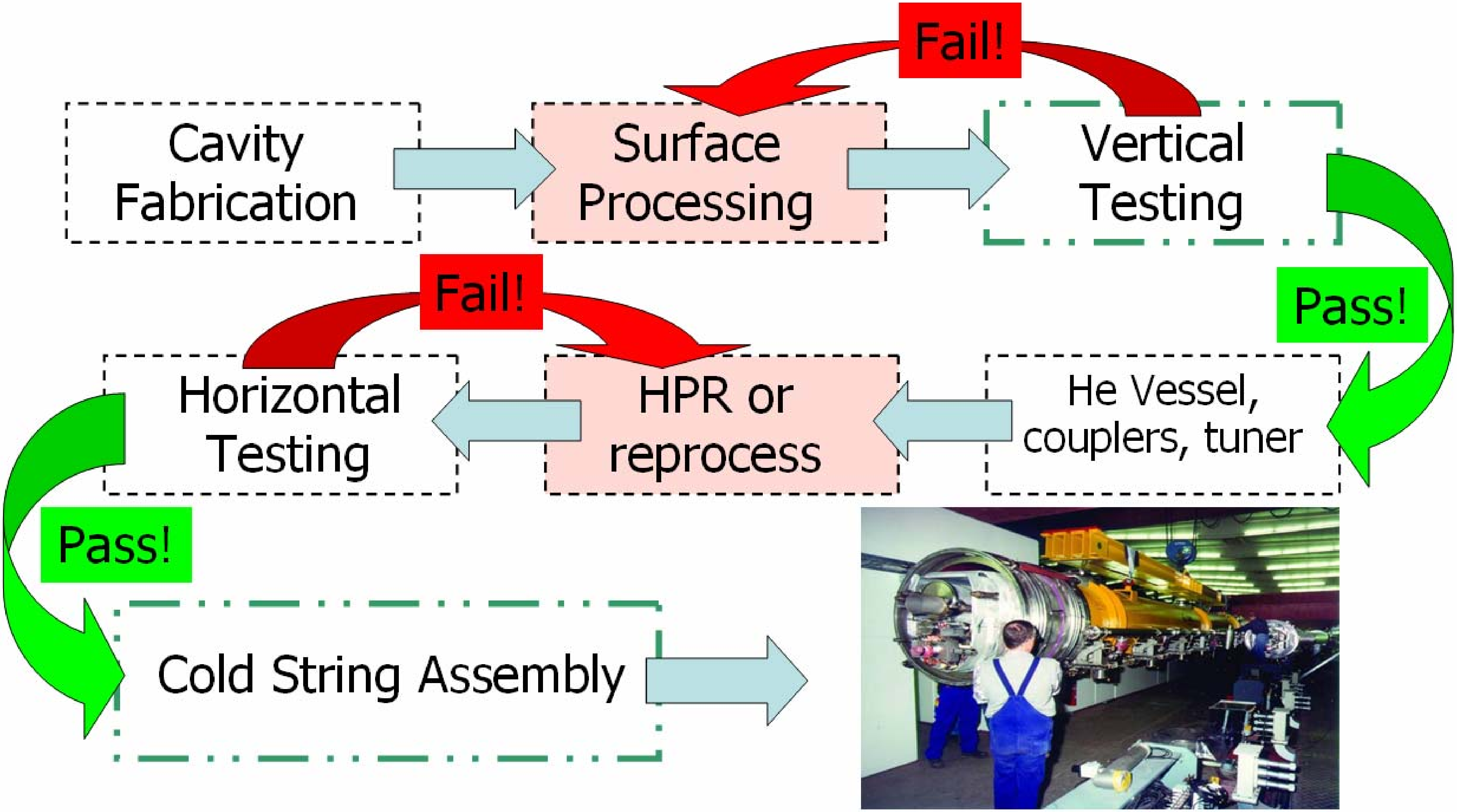


Baseline design now has 2 CM with 9 cavities, 1 CM with 8 cavities + quad

Issues for ILC linac

- Key issues for ILC Physics
  - Machine Energy, Luminosity, Availability
- Technical Challenges
  - Achieving high gradient in SRF cavities with a reproducible process
  - Building cryomodules with these cavities that meet ILC specification
  - Developing a reliable and efficient RF power source
  - Industrialization of high volume components
  - Cost !
- The Global Design Effort is addressing these challenges via a worldwide R&D program with specific goals
- Key to achieving these goals are evolving ILC Development and Test Facilities, the subject of this talk

Cavity/CM process and Testing



Plan… Develop in labs then transfer technology to industry

SCRF Infrastructure

- This process requires extensive infrastructure
- Bare cavities
  - Fabrication facilities (Electron beam welder, QC, etc)
  - Surface treatment facilities BCP & Electro-polish facilities (EP)
  - Ultra clean H_20 & High Pressure Rinse systems
  - Vertical Test facilities (Cryogenics + low power RF)
- Cavity Dressing Facilities (cryostat, tuner, coupler)
  - Class 10/100 clean room
  - Horizontal Test System (cryogenics and pulsed RF power)
- String Assembly Facilities
  - Large class 10/100 clean rooms, Large fixtures
- Cryo-module test facilities
  - Cryogenics, pulsed RF power, LLRF, controls, shielding, etc.
  - Beam tests ➔ electron source (RF unit test facilities)

Cavity and Cryomodule Goals

- The GDE has established project wide R&D goals for ILC cavities and cryomodules (labeled as S0,S1,S2)
- S0 goal: Establish a process & controls to reliably achieve 35 MV/M in bare cavity tests (80% yield)
- S1 goal: Complete an ILC Cryomodule with all cavities at working at accelerating gradients >31.5 MV/M (Average)
- S2 goal: Demonstrate a fully qualified ILC RF unit
- Achieving these goals requires extensive SRF infrastructure & a coordinated International R&D program

Goals of ILC RF Unit Tests

From S2 task force report

- Demonstrate an RF unit operating at ILC specifications
- Understand RF control issues
  - RF phase and beam energy control
  - Cavity gradient spread that can be handled by LLRF
  - RF fault recognition and recovery software
- Demonstrate beam based feedback schemes
  - steering, energy, and intra-train feedback
- Measure
  - CM static and dynamic heat loads ,cavity dark current, etc
- Determine component MTBF and other CM weaknesses before large scale industrial production
- Test transport & interoperability of CM from different regions

ILC RF unit test facilities will address these issues

Regional ILC R&D efforts

- 3 Regions currently involved
  - Europe: Primarily DESY but also Italy, France, U.K., and growing efforts in Russia and at CERN
  - Asia: Primarily KEK, but growing efforts in India, Korea, China
  - Americas: FNAL, SLAC, TJNL, Cornell, ANL, LBNL, LLNL, LANL, MSU, Triumf, etc
- Can't cover it all… focus on Main Linac beam test facilities (DESY, KEK, FNAL)

Europe

DESY R&D Activities

The TESLA collaboration centered at DESY developed the SRF technology adopted for ILC. DESY is the world leader

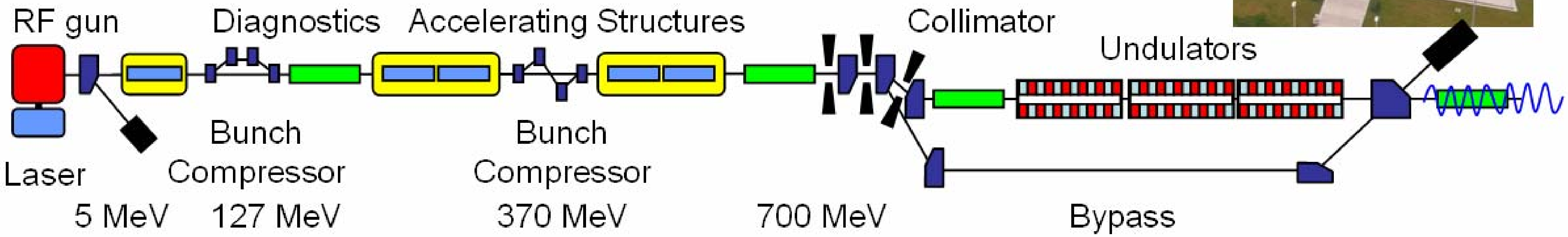
- Cavity R&D
  - 9 cell TESLA shape (baseline for ILC)
  - Electropolishing development
  - Large grain Nb, hydroformed
- Cryomodule and RF power Development
- TTFII/Flash ~ RF unit test facility for XFEL
- Industrialization of SRF technology

TTFII/FLASH/XFEL (DESY)

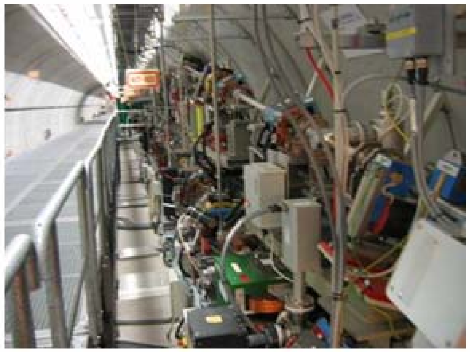
- TTFII/FLASH
  - TTFII: was originally a test facility for TESLA (ILC)
  - TTFII SRF linac now drives VUV-FEL (FLASH) providing light for BES users
  - Machine time still available as ILC test facility
- XFEL (European Project)
  - Recently approved for construction at DESY
  - 20 GeV SRF linac driven light source
- DESY Facilities (ramping up in support of XFEL)
  - Cavity fabrication, processing, test facility upgrades
  - Cryomodule fabrication → industrial training for XFEL

FLASH Overview



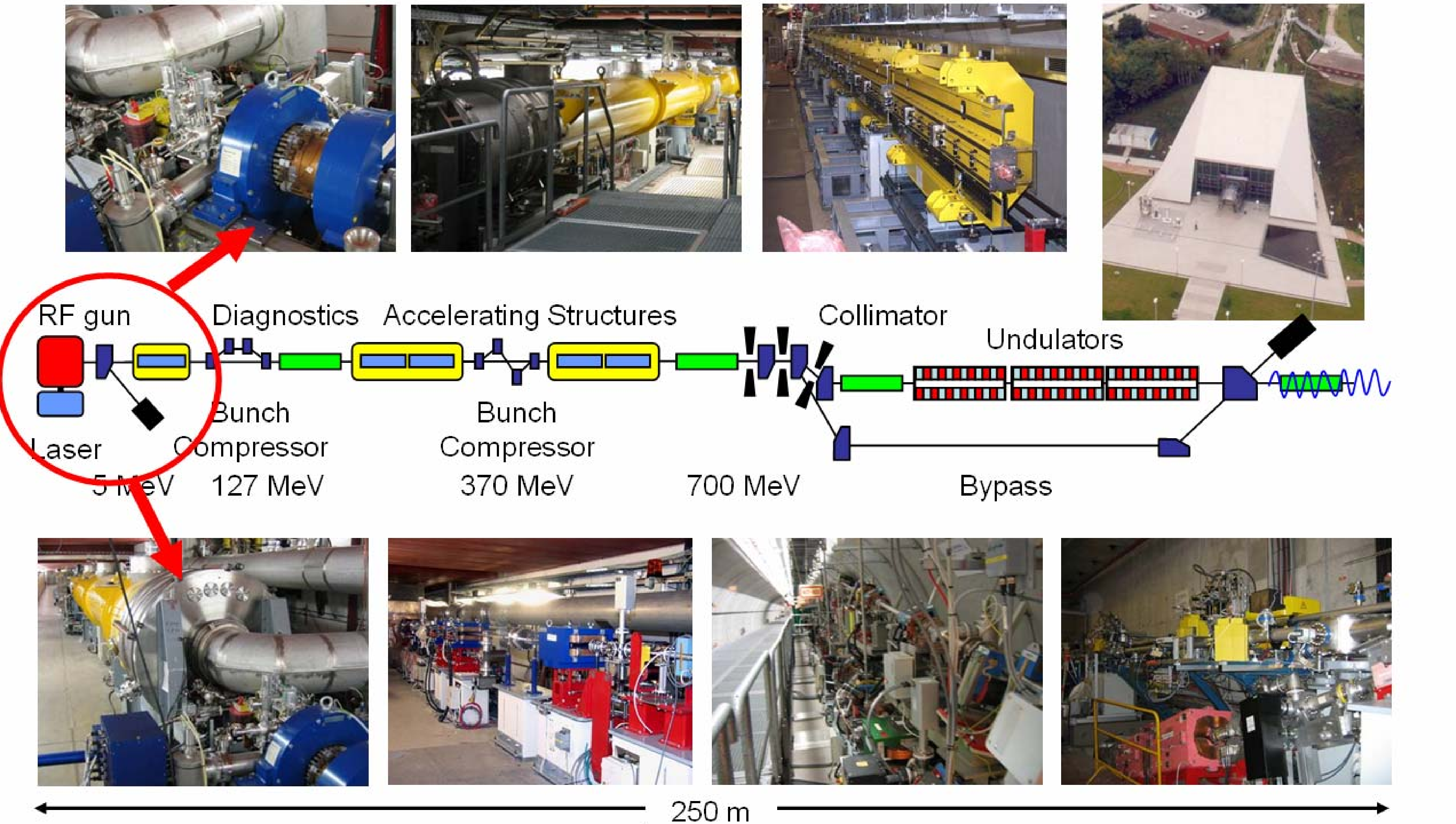








250 m

FLASH Overview



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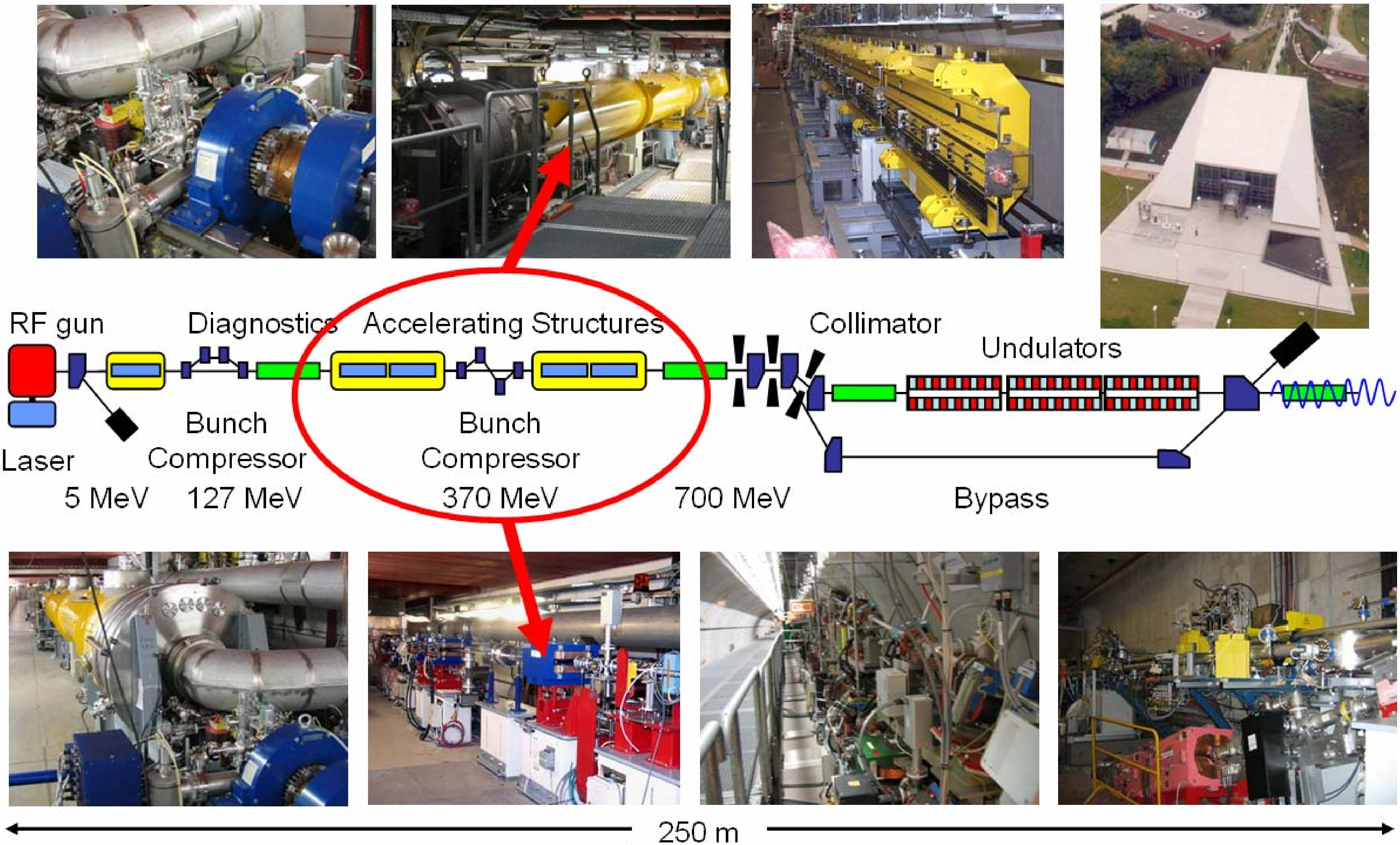

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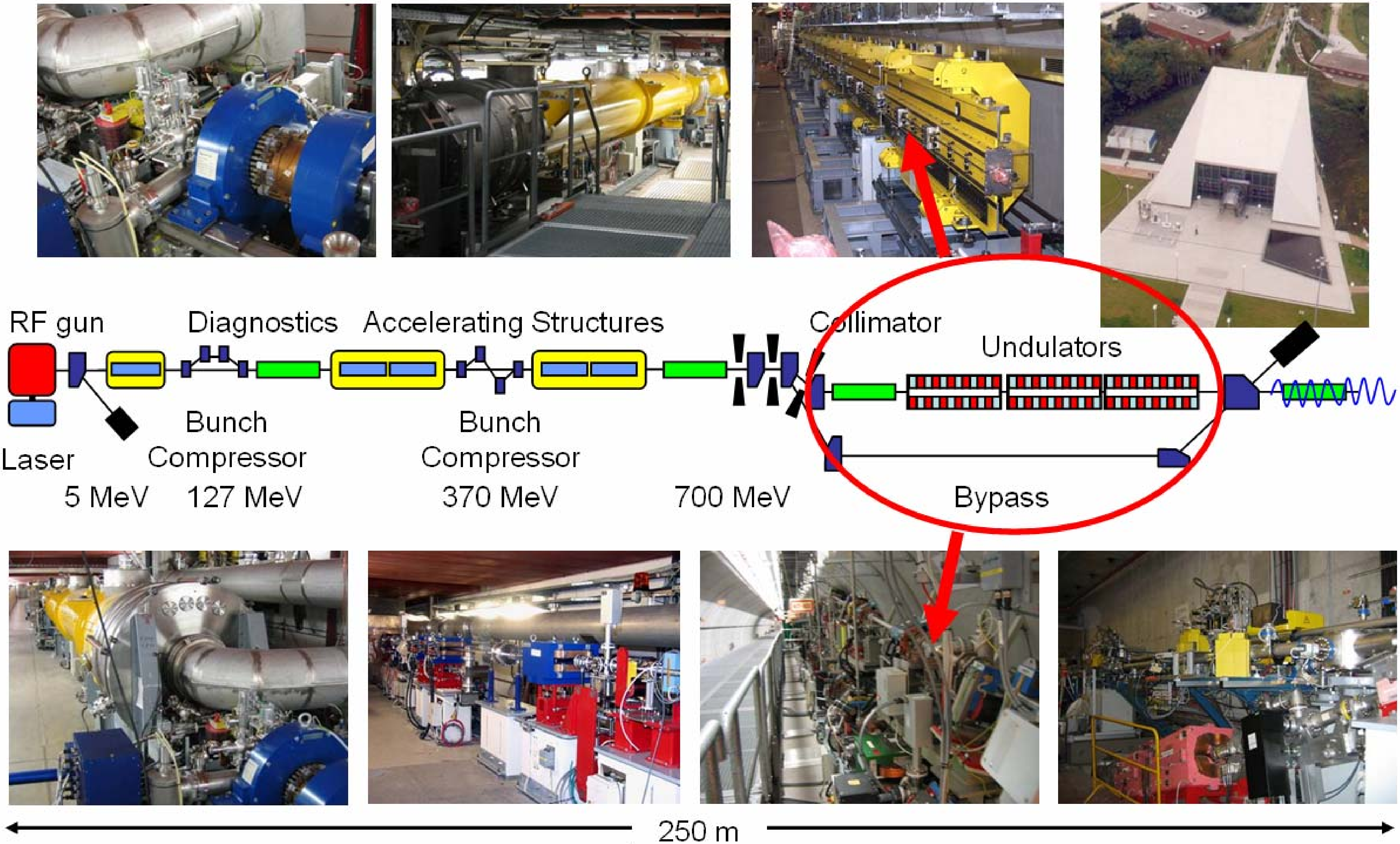

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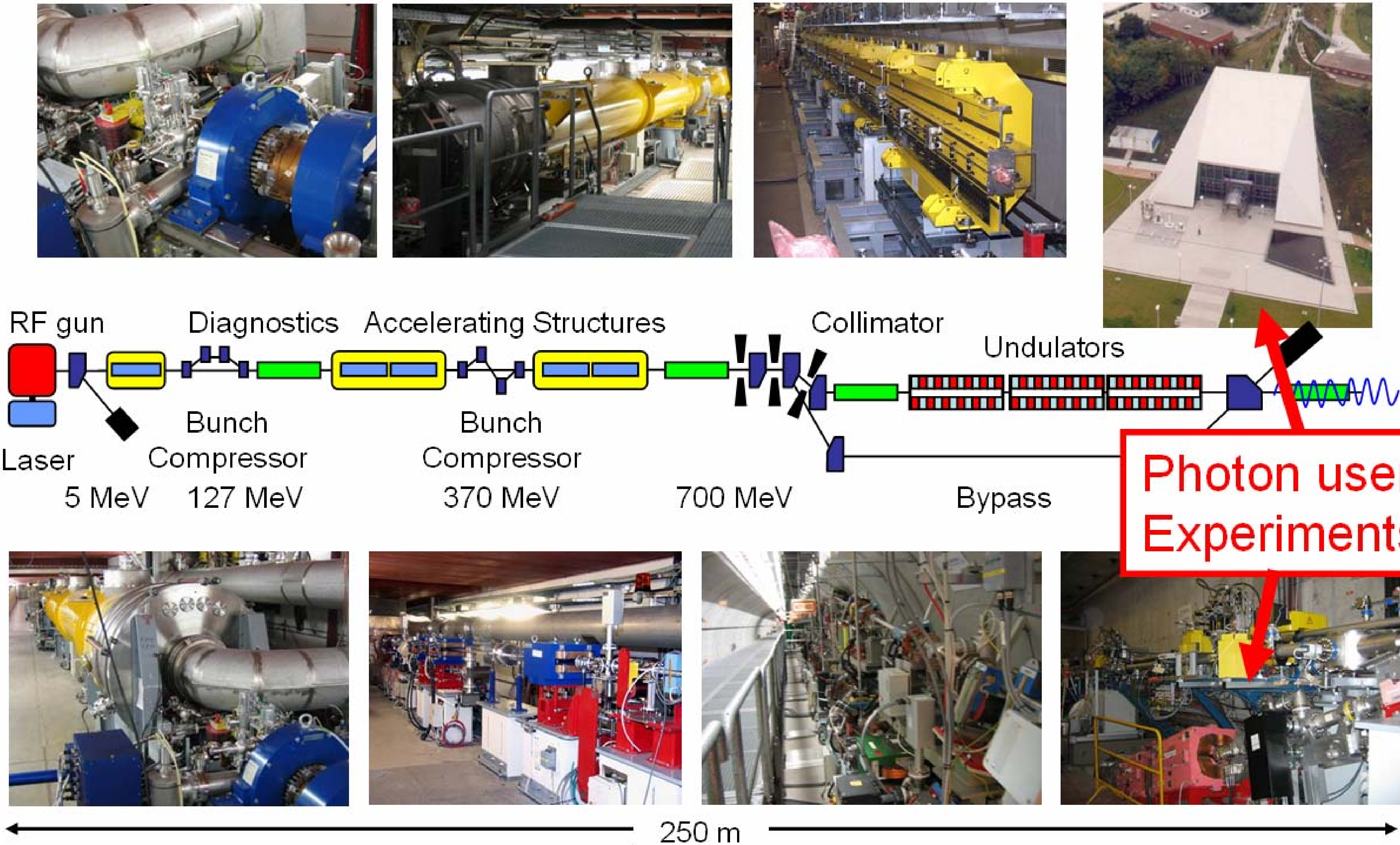
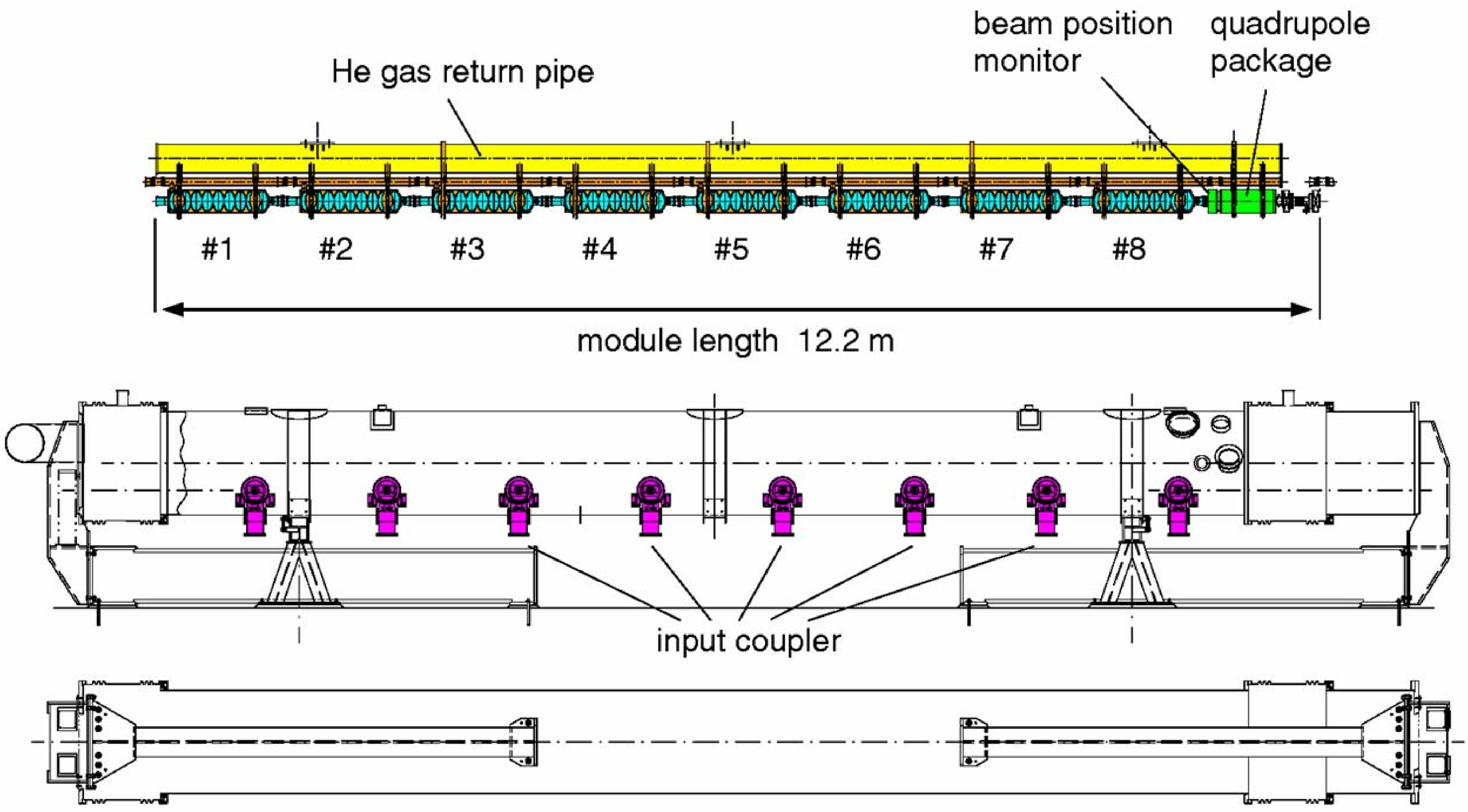


FLASH uses TESLA CM's



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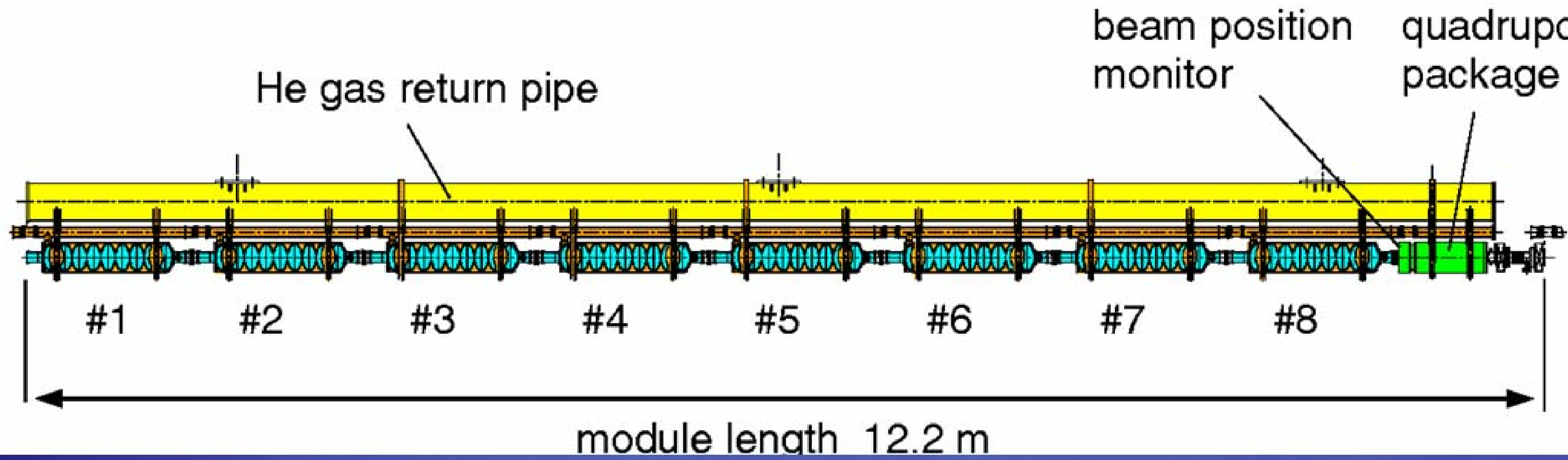
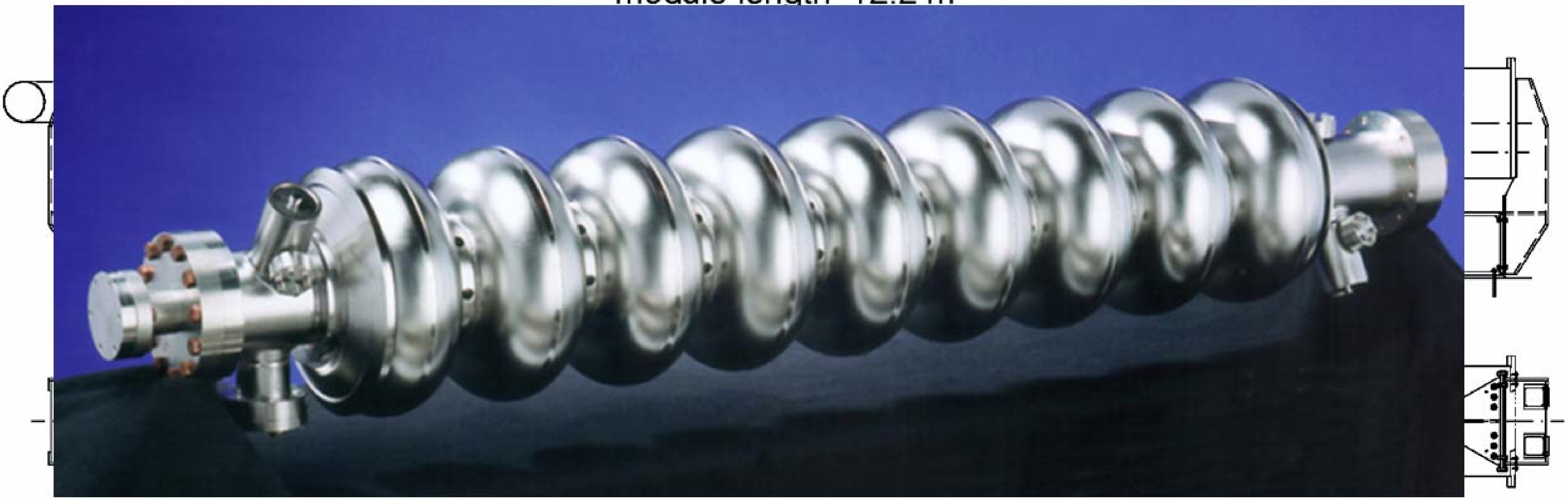


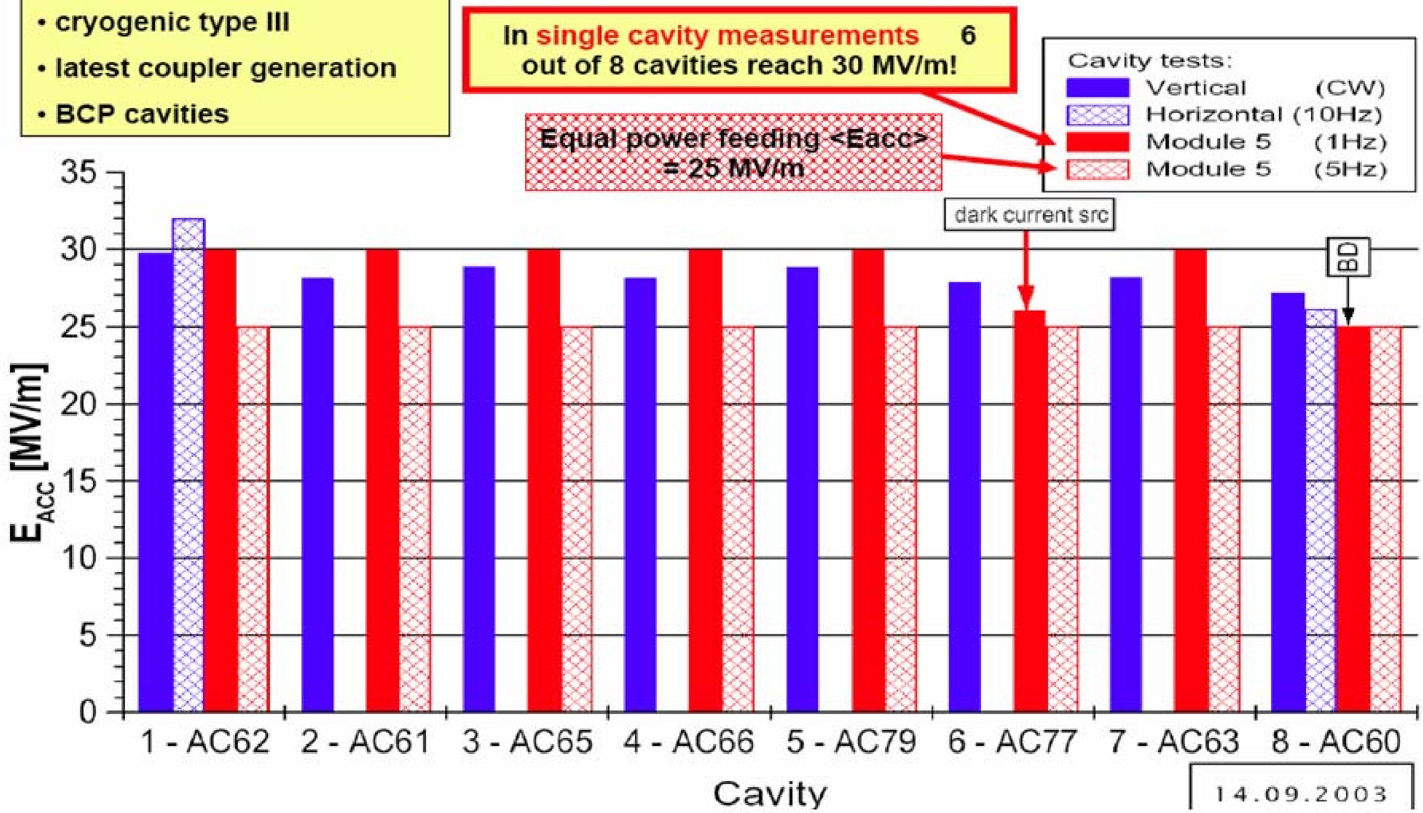


FLASH uses TESLA CM's

Performance of Recent CM #7

Europe

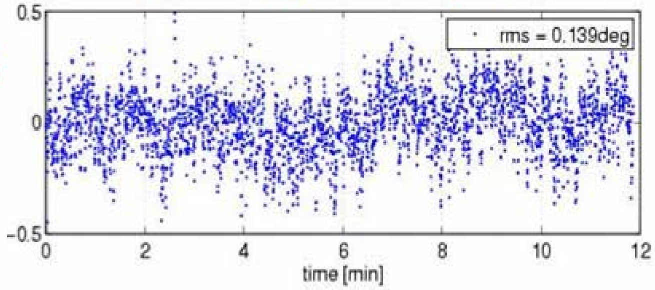
A State-of-the-art module
- cryogenic type III
- latest coupler generation
- BCP cavities



- Recent CM experience
  - CM 6 had 5 cavities over 30 MV/M (but 2 went down WRT HTS)
  - CM 7 had 6 of 8 cavities above 30 MV/M (encouraging)

TTFII/FLASH

- ILC related performance:
  - Operations: 13% unscheduled down time (mostly RF sys)
  - Phase stability: 0.14° of 1.3 GHz or 300 fs
  - dE/E = 2.4 10^{-4} measured at 127 MeV

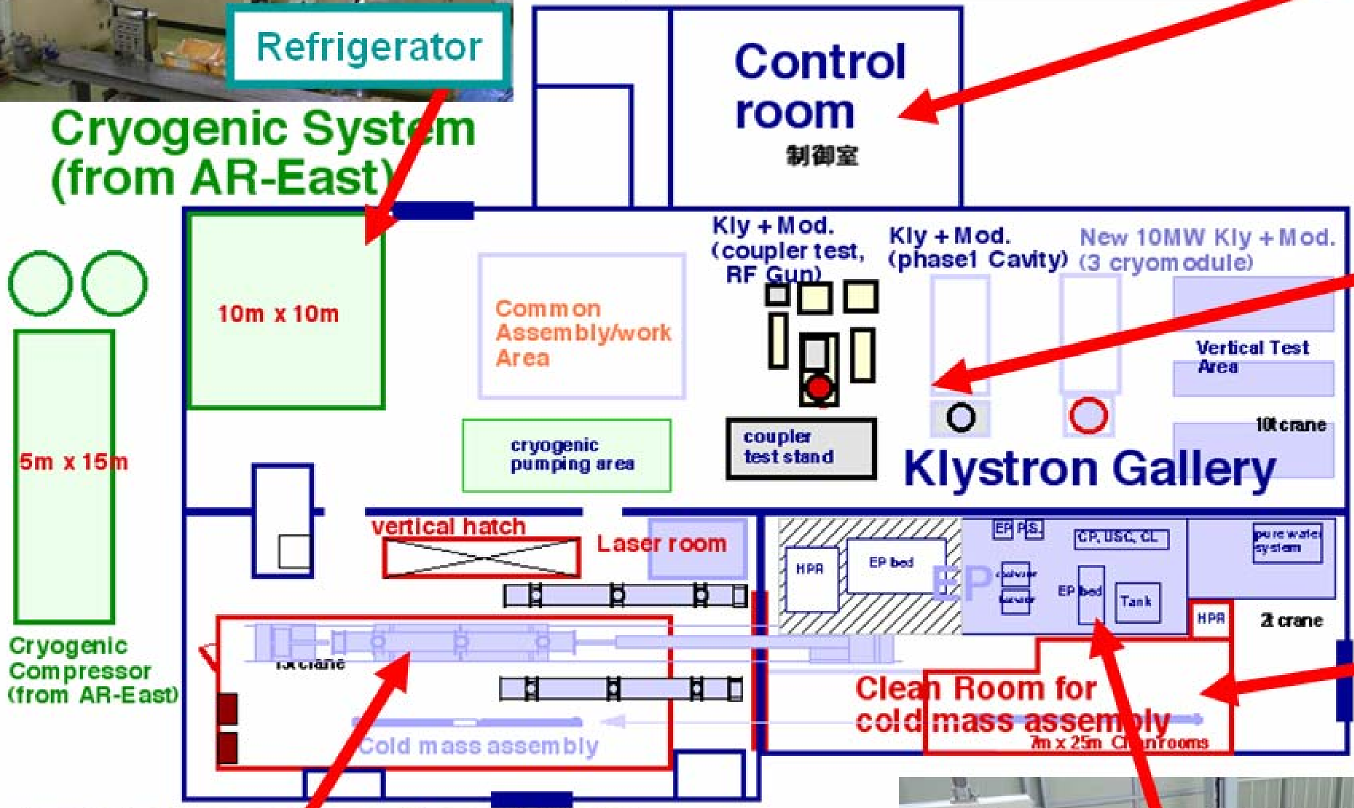


- Plans:
  - Add 6th CM, beam energy → 1 GeV/c
  - Improve electron gun (reduce dark current)
  - Add 3rd harmonic CM (FNAL), doubles FEL light output
- FLASH operations, ILC studies, Construct XFEL !!!
  - ~30% of time is available for Accel dev and ILC R&D

STF (Asia)

- Superconducting Test Facility (STF)
  - Location: KEK, Japan
  - Purpose: General SRF test facility in support of the ILC
  - Status: Under construction
- Facilities
  - Cavity fabrication, processing, test
  - ILC module fabrication
  - ILC module test facility
  - Plan: Evolve into RF unit test facility

STF Facility KEK



Clean Rooms

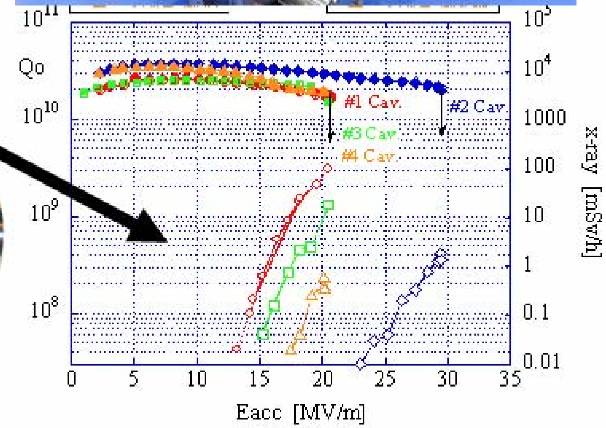
STF R&D Activities (Asia)

- Cavity R&D
  - 9 cell TESLA shape (baseline for ILC)
  - 9 cell Ichiro cavities (goal = higher Eacc)
  - Seamless cavities (hydroformed)
  - Single cell EP R&D
- Cryomodule & RF Power development
- ILC RF unit test facility
- Industrialization of SRF technology

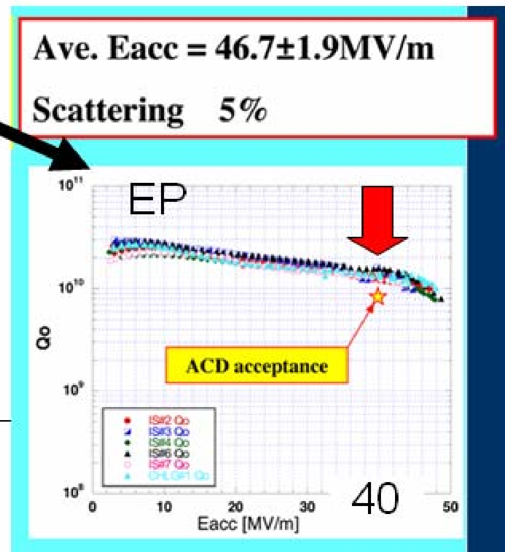
Cavity R&D at KEK

Asia

- 4 Tesla Shape cavities
- Processed and vertical tested
- 3 cavities achieved ~20 MV/m
- 1 achieved 30 MV/m, installed in CM
- Performance limited by field emission



- 4 Ichiro cavities
- Reentrant design lowers B at fixed Eacc
- Single cells: 6 examples all > 40 MV/M
- But… so far 9 cells are only 12-20 MV/M
- Limited by multipacting in end groups
- End groups removed→1 achieved 29 MV/M
- One 19 MV/m Ichiro cavity installed in CM



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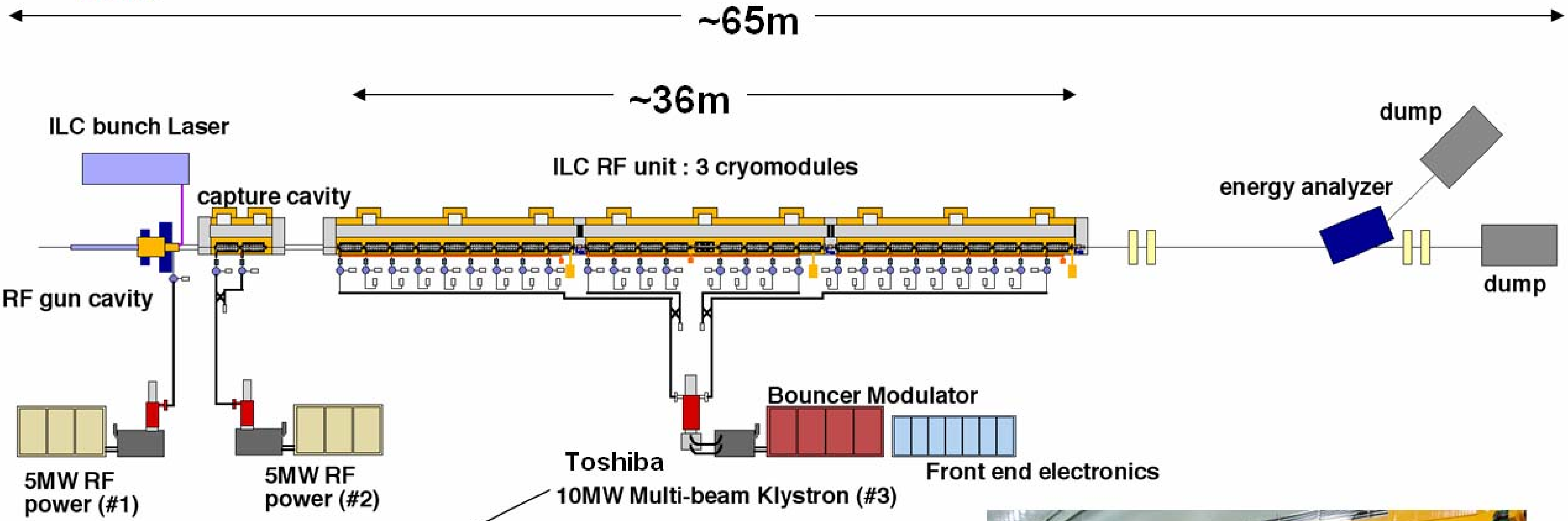
STF Plan

- **Phase 1 (2005-07)** Develop SRF cavities & infrastructure
  - Two types of cavities: TESLA and Ichiro (35 → 45 MV/m)
  - Start with two 4 M cryostats (access to STF tunnel)
  - 1 cavity in each short cryostat Now !
  - 4 cavities in each short cryostat Sep 2007
  - Improved cavities Apr 2008
- **Phase 2 (2008 – 10) Develop ILC Main Linac RF unit**
  - Built Cryomodule test facility
  - CM Fabrication 2009-10
  - Build RF power test infrastructure now-2010
  - RF unit test 2011
- **In parallel with phase 1,2**
  - GDE S0 task force (demonstrate 35 MV/M gradient)
  - Industrialization

Plan of STF Phase 2 beam line



- **Phase 2 Beam (2011)**
  - 2 SC beam capture cavities
  - RF gun, (collab with FNAL)
  - Bunch charge, structure, and current similar to ILC

Existing Short Cryomodules

R&D Activities (Americas)

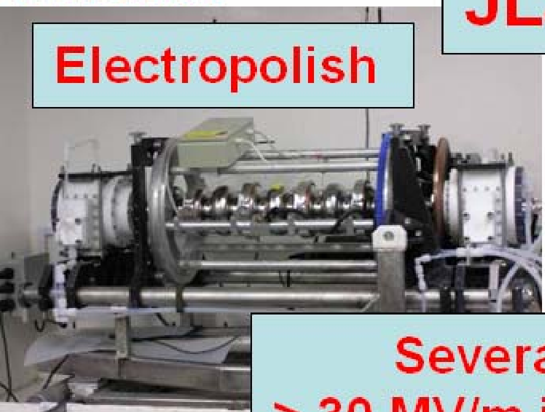
- Cavity R&D
  - 9 cell TESLA shape (baseline for ILC)
  - Large grain Nb (TJNL, FNAL)
  - Electropolishing (Cornell, TJNL, ANL/FNAL)
- Cryomodule design & fabrication (FNAL)
- RF power development (SLAC)
- ILC RF unit test facility (FNAL)
- Industrialization just starting

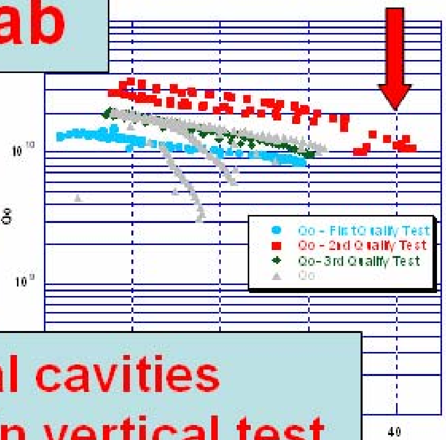
U.S. Cavity R&D = National effort

Americas

JLab

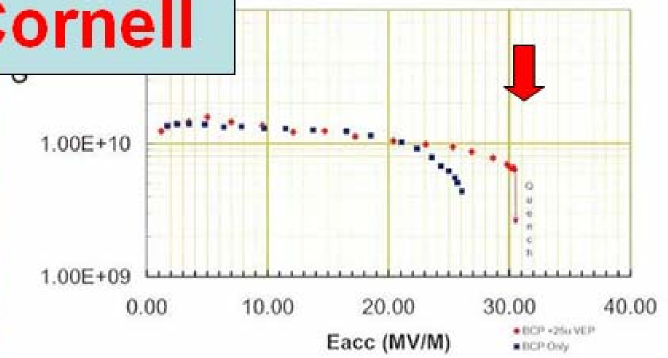
Electropolish





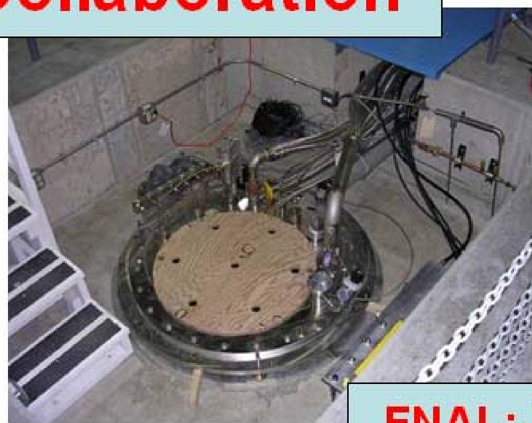
Several cavities
> 30 MV/m in vertical test

Cornell



Vertical EP

ANL/FNAL Collaboration



ANL: New clean rooms,
state-of-the-art EP

FNAL: New Vertical
Test Facility

Horizontal Test System (FNAL)

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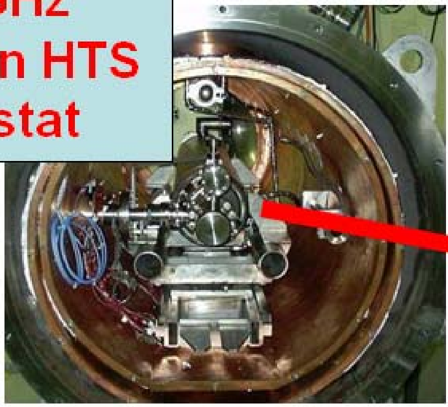
- After vertical test extensive cavity handling ensues
  - Cavity welded inside He vessel
  - Cavity opened to install main coupler
  - Tuner added

  "Dressing"
- Horizontal Test
  - First test of the cavity with high pulsed RF power
  - R&D Test bed: tuners (slow), couplers, LLRF, etc.
- NEW HTS facility is nearly complete at FNAL

1.3 GHz Cavity in HTS Cryostat



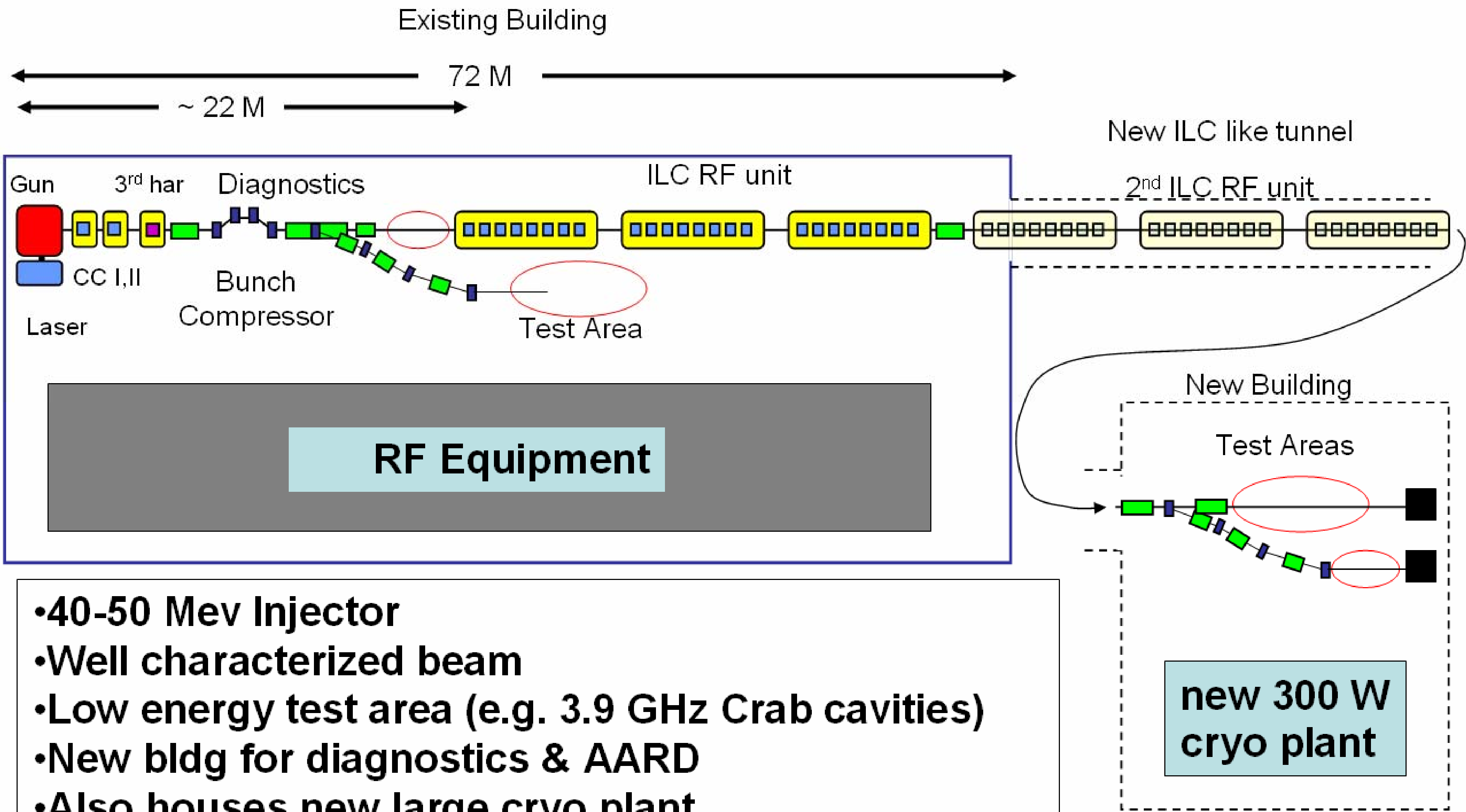
HTS Cryostat

RF Power for HTS

ILCTA (FNAL)

- ILC RF unit test facility
- Location: Fermilab "New Muon Building" (NML)
- Goal: Address the GDE "S2 Goals"
  - Demonstrate a complete ILC RF unit with ILC-like beam
  - Also crab-cavity R&D, diagnostics development, personnel training, and advanced accelerator R&D.
- ILC-like beam
  - 3.2 nC/bunch @3 MHz
  - Up to 3000 bunches @ 5Hz
  - Bunch length: 300-μm rms
  - Injector Energy: 30-40 MeV (to avoid over focusing in ILC CM)
  - To understand CM need "known" beam parameters @ CM entrance and exit→ good diagnostics

ILCTA_NM (FNAL)



- •40-50 Mev Injector
- •Well characterized beam
- •Low energy test area (e.g. 3.9 GHz Crab cavities)
- •New bldg for diagnostics & AARD
- •Also houses new large cryo plant

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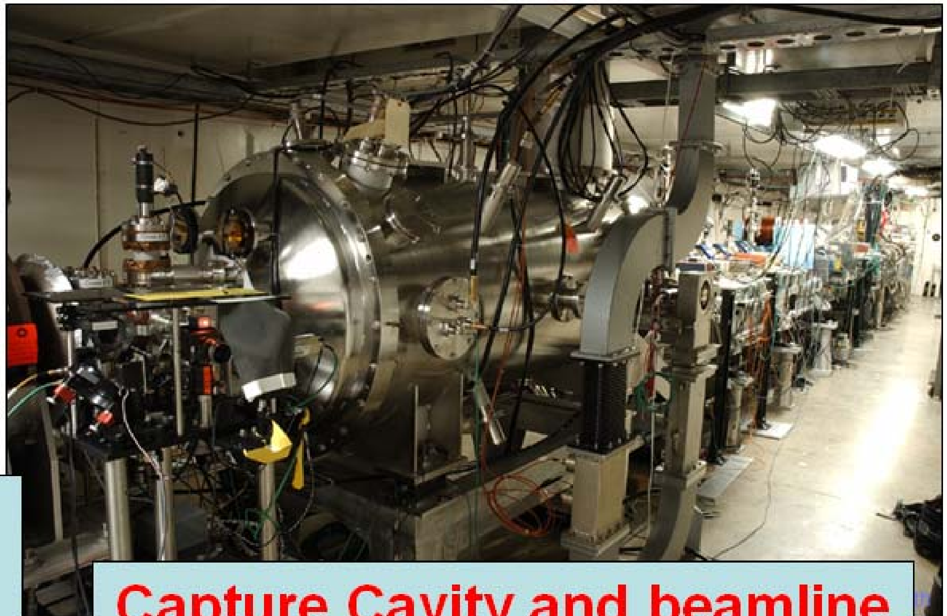
A0 Photo Injector

- The A0 Photo Injector built in collaboration with DESY as part of the TESLA collaboration (essentially a copy of TTFI)
- In operation since late 90's
- Two klystron-based RF systems power the RF Gun & Capture Cavity
- Built a second capture cavity (CCII) using high gradient DESY cavity
- A0 RF assets and CCII will be moved to NML in 2008

RF Gun prior to solenoid installation



Capture Cavity and beamline

Capture Cavity-II

ILCTA Plans

- Effort is Funding limited→ phased approach
- Cryomodule delivery
  - 1st (Type 3+) cryomodule built from "kit" of DESY parts in late 2007
  - 2nd (Type 3+) CM – 2008 built with U.S. processed cavities
  - 3rd (ILC Type 4) CM – 2009 all U.S. components
  - Replace all three CMs with ILC Type 4+ in FY2010
- FY07: Start as a Cryomodule Test Stand
- FY08: move A0 photoinjector, start civil construction for new bldg
- FY09: 1st beam operation, 2-3 CM, low rep rate operations
- FY10: replace all 3 CM with ILC type CM
- FY11: install new refrigerator, ILC RF Unit operations
- Collaboration: DESY, INFN, ANL, Cockroft, NIU, Rochester, KEK

ILCTA_NML@FNAL

ilc Americas

NML Building

NML: June 07

Cavities for 1st CM @ FNAL

1st of 2 refrigerators each 60 W@1.8K

Parts for 1st CM at DESY

FNAL Clean Room & CM assembly Area

Summary

- The International Linear Collider will employ an SRF linac of unprecedented scope
- Cavities & Cryomodules are cost drivers for ILC
- There are many issues to be addressed to demonstrate the required performance for ILC
- All three regions have mounted large R&D programs to explore these issues (I apologize for omissions)
- Extensive infrastructure is needed to support this R&D and ILC industrialization
- Large scale RF unit test facilities are a key
- Lots of progress & ambitious plans