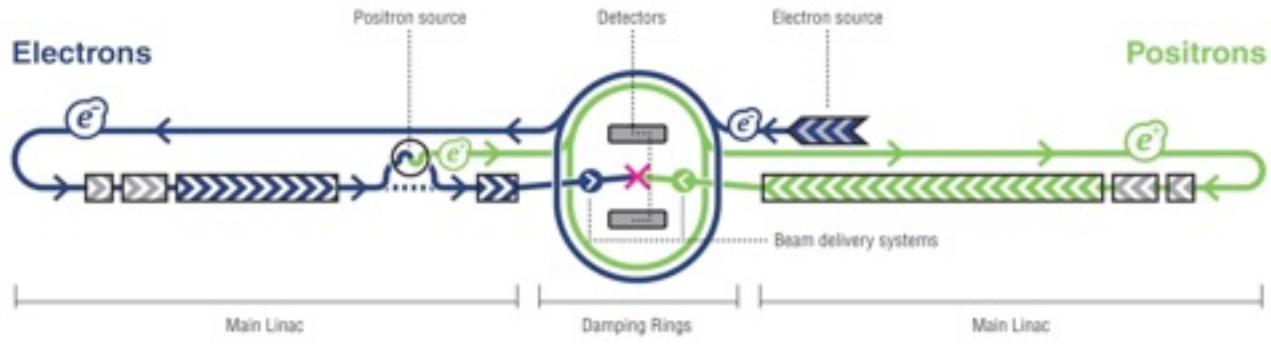
Linear Collider

E.Elsen



R&D for CLIC
ILC Global Design Effort

XXXIX International Meeting on Fundamental Physics,
Feb 7-11, 2011, Canfranc (Huesca)

A clearly defined (European) Strategy

- The LHC will be the energy frontier machine for the foreseeable future, maintaining European leadership in the field; *the highest priority is to fully exploit the physics potential of the LHC, resources for completion of the initial programme have to be secured such that machine and experiments can operate optimally at their design performance.* A subsequent major luminosity upgrade (SLHC), motivated by physics results and operation experience, will be enabled by focussed R&D; *to this end, R&D for machine and detectors has to be vigorously pursued now and centrally organized towards a luminosity upgrade by around 2015.*

- In order to be in the position to push the energy and luminosity frontier even further it is vital to strengthen the advanced accelerator R&D programme; *a coordinated programme should be intensified, to develop the CLIC technology and high performance magnets for future accelerators, and to play a significant role in the study and development of a high-intensity neutrino facility.*

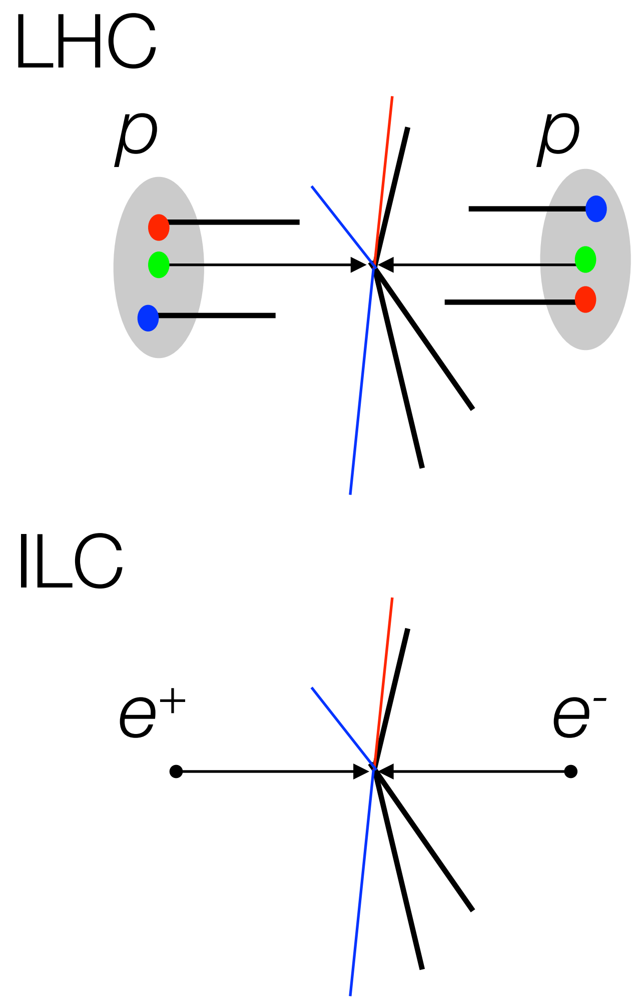
- It is fundamental to complement the results of the LHC with measurements at a linear collider. In the energy range of 0.5 to 1 TeV, the ILC, based on superconducting technology, will provide a unique scientific opportunity at the precision frontier; *there should be a strong well-coordinated European activity, including CERN, through the Global Design Effort, for its design and technical preparation towards the construction decision, to be ready for a new assessment by Council around 2010.*

Paths towards the Terascale

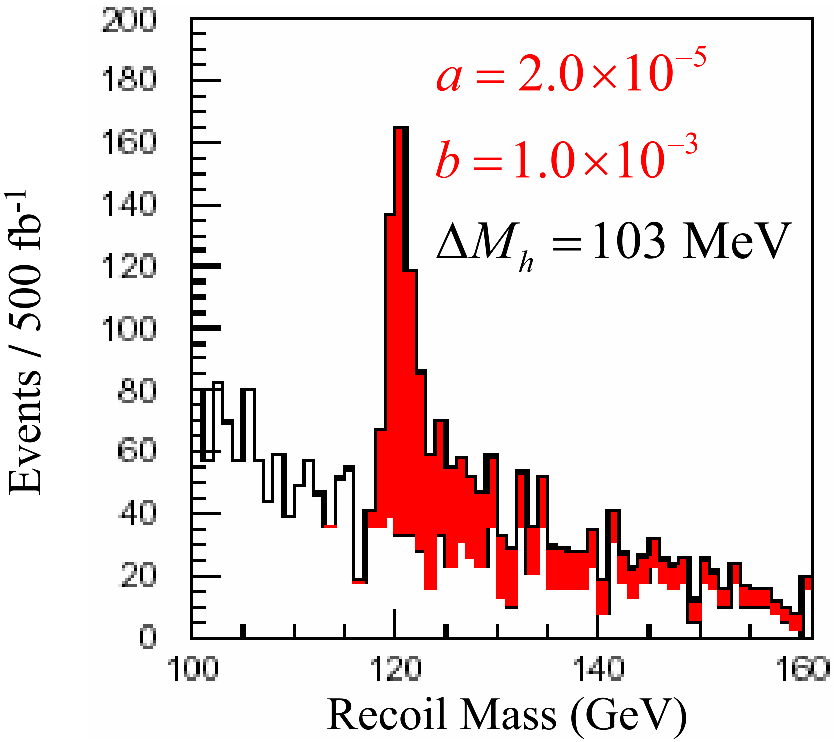
- **Collision Energy**
  - high accelerating gradient
- **Collider**
  - two counter-running beams
    (effectively two accelerators)
- **Luminosity**
  - many interesting production cross sections are small
    s-channel $\sigma \sim 1/s$

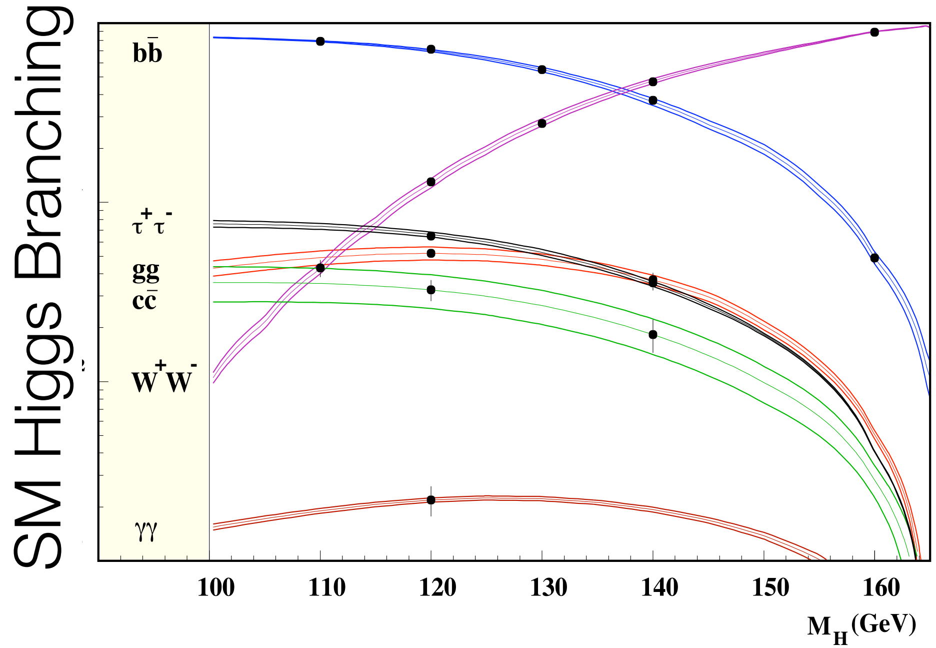
e$^+$e$^-$ versus pp

- LHC
  - Discovery machine
  - strongly interacting initial state
  - parton distribution results in an inherent scan
- ILC
  - elementary particles
  - energy, angular momentum well defined
  - democratic particle production
  - information of the final state almost fully captured in the detector



Higgs Reconstruction and Branching Ratios

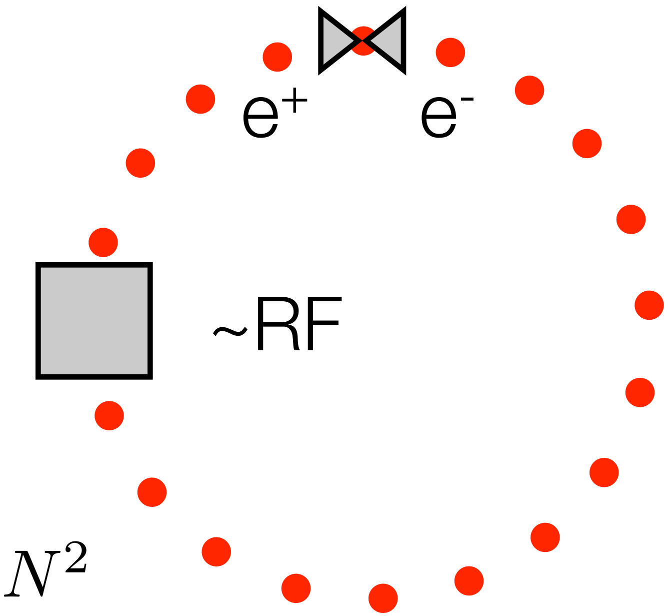




An e^+e^- Linear Collider will disentangle the new physics through precision measurements

Circular accelerators for electrons?

- Synchrotron as a collider
  - relatively little RF-power to be installed
    - same accelerating section used again and again (LEP/LHC: $f_{rep} \sim$ 11 kHz)
  - many bunches n_b
    - Duty cycle at
      LHC $f_{rep}*n_b \sim$ 40 MHz
      LEP $f_{rep}*n_b \sim$ 44 kHz
- for electrons:
  Synchrotron radiation imposes practical limit on maximum energy!

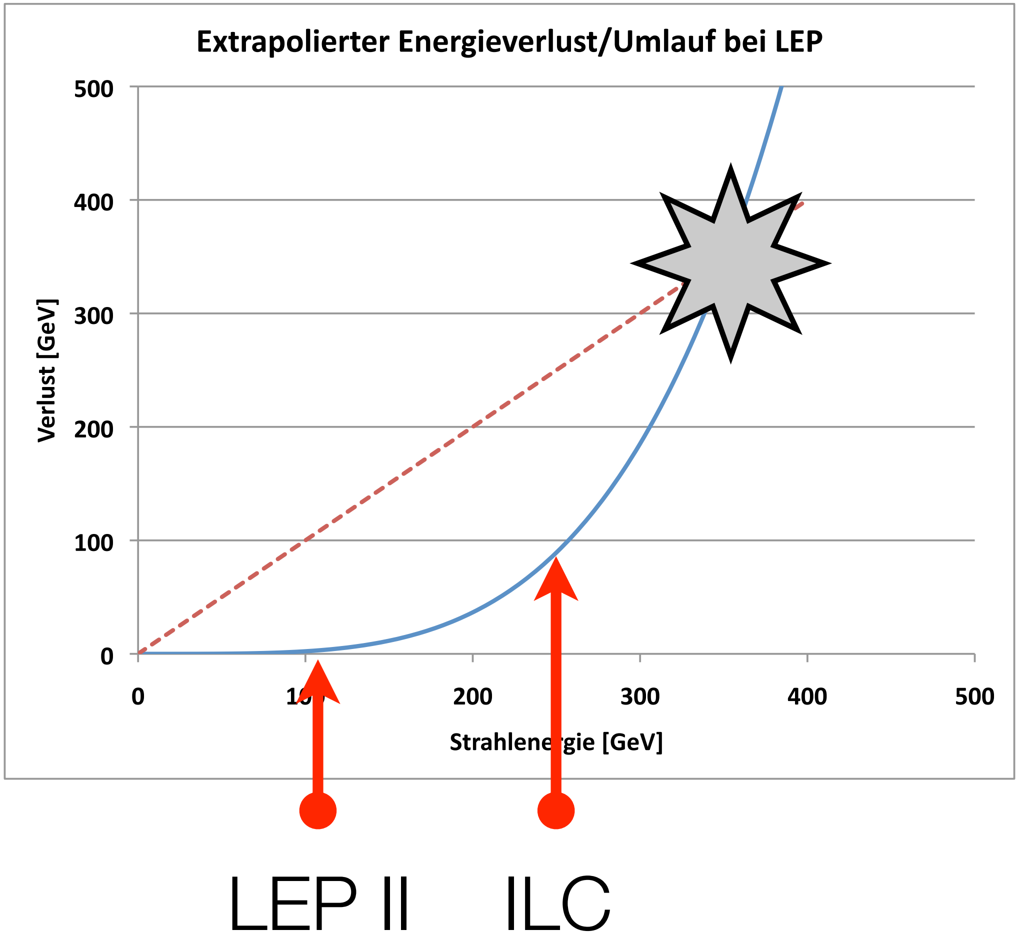


$$\mathcal{L} = f_{rep} \frac{n_b N^2}{4\pi\sigma_x\sigma_y}$$

$$\Delta E_{\mathrm{rep}} \propto \frac{1}{\rho}\left(\frac{E}{m}\right)^4$$

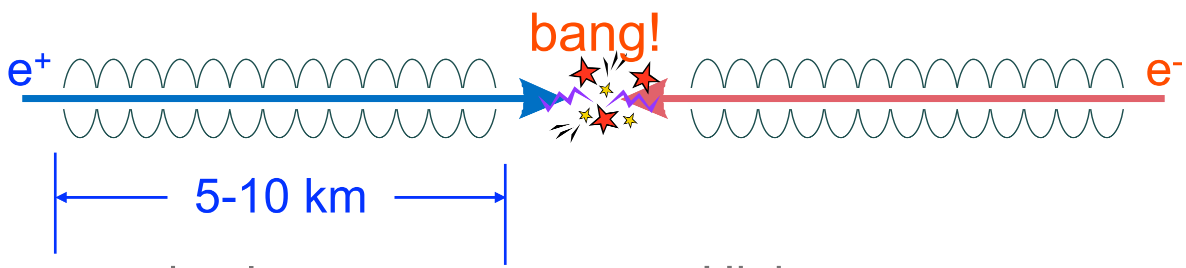
Use of LEP/LHC rings for e^+e^-?

- Energy loss E>100 GeV
  (a considerable fraction of the beam energy)
  - momentum acceptance for the ring!
  - for E>300 GeV practically all energy radiated in one turn



⇒ Future of electron accelerators is linear

Requirements for a Linear Collider



- Bunches are used only once
    - extremely strong focusing
    - repetition rate
    - high gradient
- High power
    - Stability requirements
    - realistic treatment of beam power and heat
    - dimensions of facility

	LEP	ILC
$\sigma_x \times \sigma_y$	130 × 6 [µm²]	500 × 5 [nm²]
N^*f_{rep}	4*11 kHz	3000*5 Hz

…a brief excursion into the past

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

M. Tigner

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

Nuovo Cimento 37 (1965) 1228

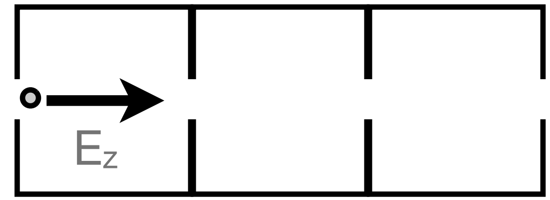
While the storage ring concept for providing clashing-beam experiments ([1]) is very elegant in concept it seems worth-while at the present juncture to investigate other methods which, while less elegant and superficially more complex may prove more tractable.

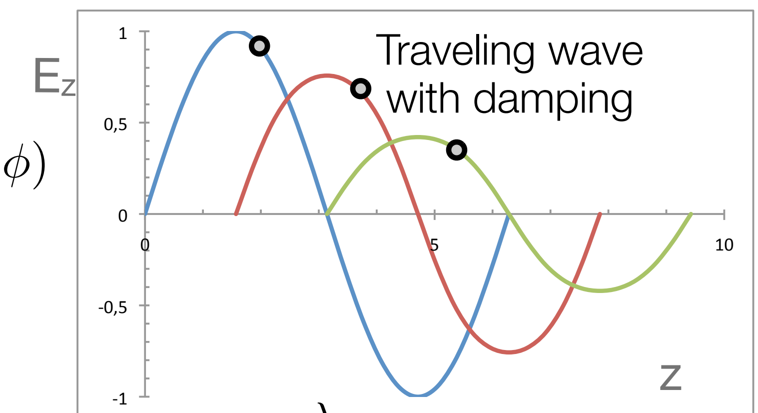
Up to now only one collider has been built in Linac-Technology: SLC

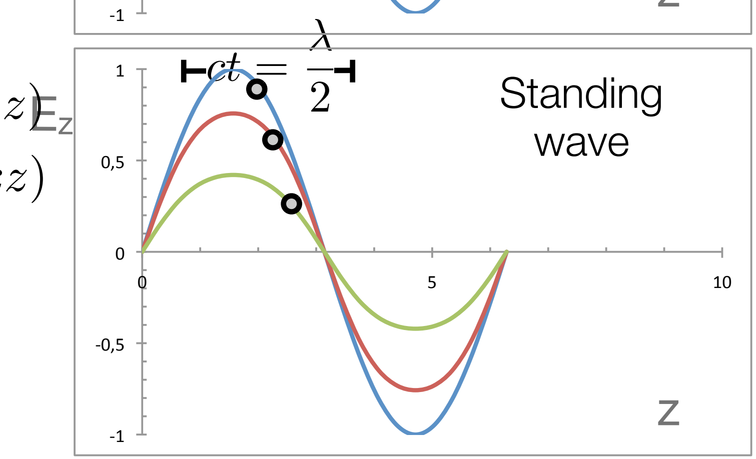
Concepts of RF acceleration

- Resonator required for
    - longitudinal component E_z
    - matching of phase velocity
- Two concepts
    - **Traveling wave** $$E_z = E_0 \cos(\phi)$$
        - Bunch gains energy from field and reduces wave amplitude
    - **Standing wave** $$E_z = E_0 \sin(\omega t + \phi) \sin(kz) = E_0 \sin(kz + \phi) \sin(kz)$$
        - Bunch experiences acceleration corresponding to the average field; field largely unaffected

Resonator







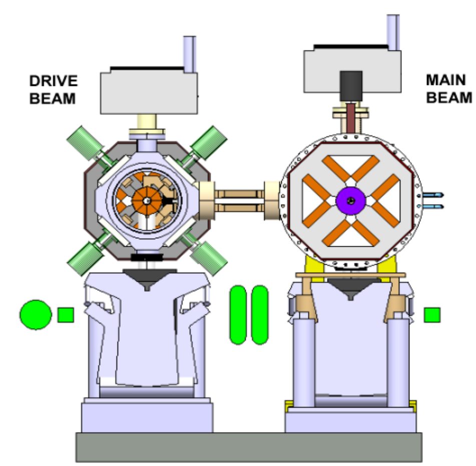
Generation of RF power

- Klystron
  - velocity modulation of an electron beam in an external field results in a density modulatation of the electron beam
  - Electrical field is coupled into wave guide

10 MW

Thales CPI Toshiba

- Wakefield
  - The field of a moving charged is coupled into a suitable resonator.

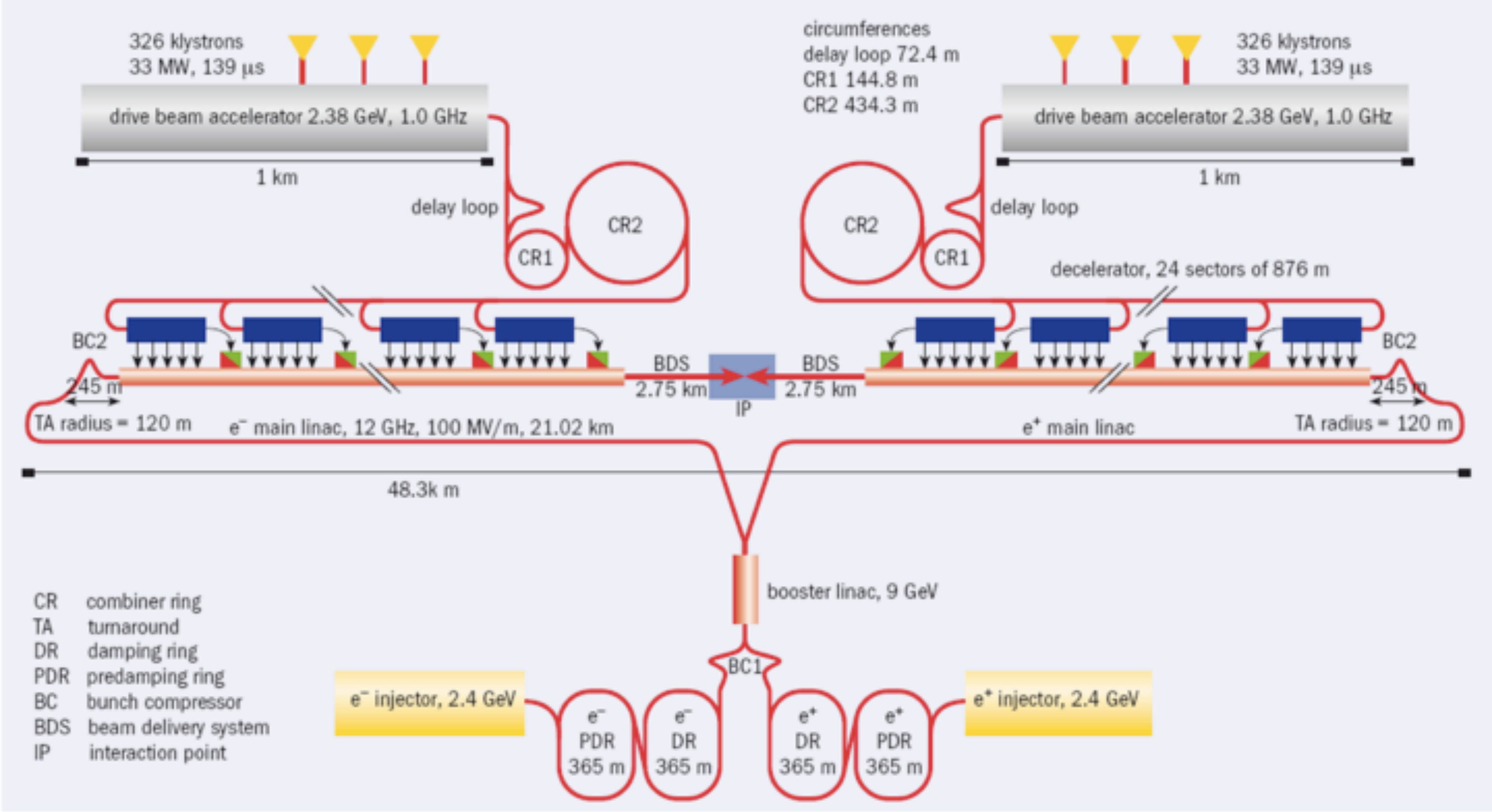


R&D for the
Compact Linear Collider CLIC

W.Schnell: A Two-stage RF Linear Collider using a Superconducting Drive Linac, CERN-LEP-RF/86-06 and Proc. Symposium on Advanced Accelerator Concepts, Madison. 1986, AIP Conf. Proc. 156

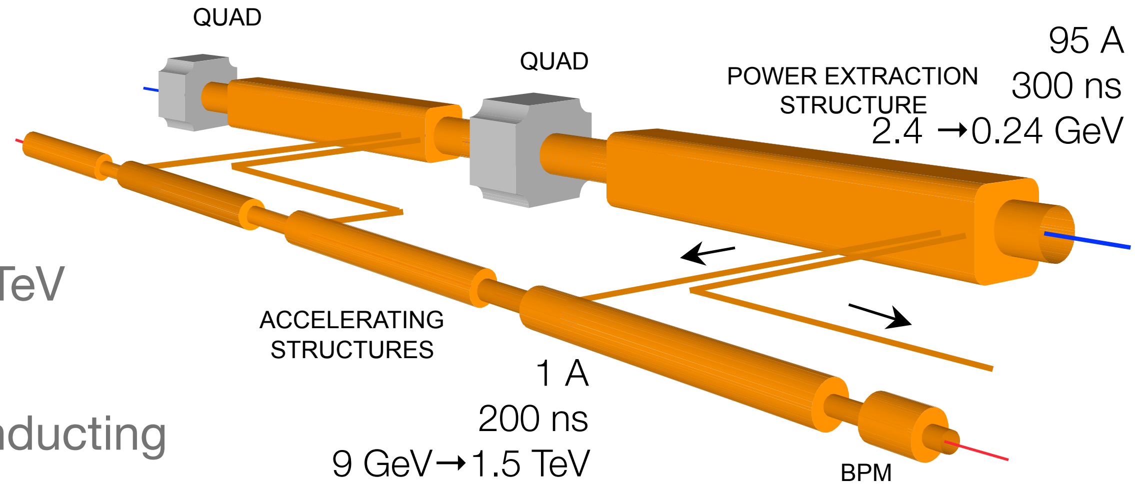
Example for wakefield acceleration

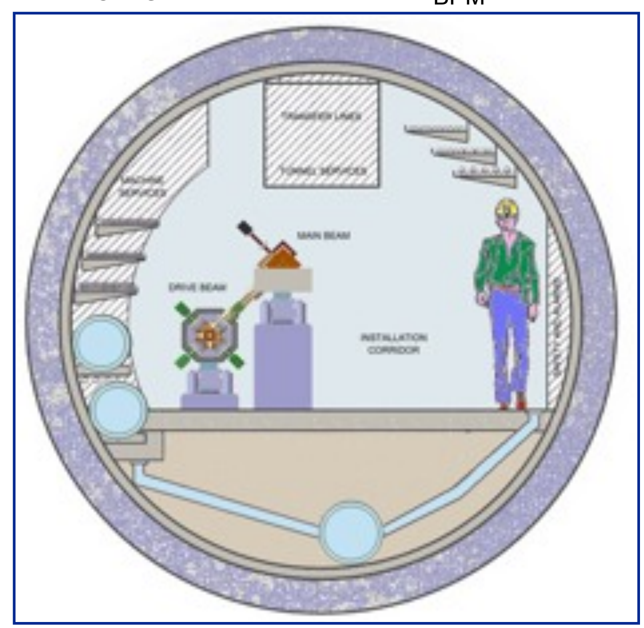
CLIC Layout for 3 TeV



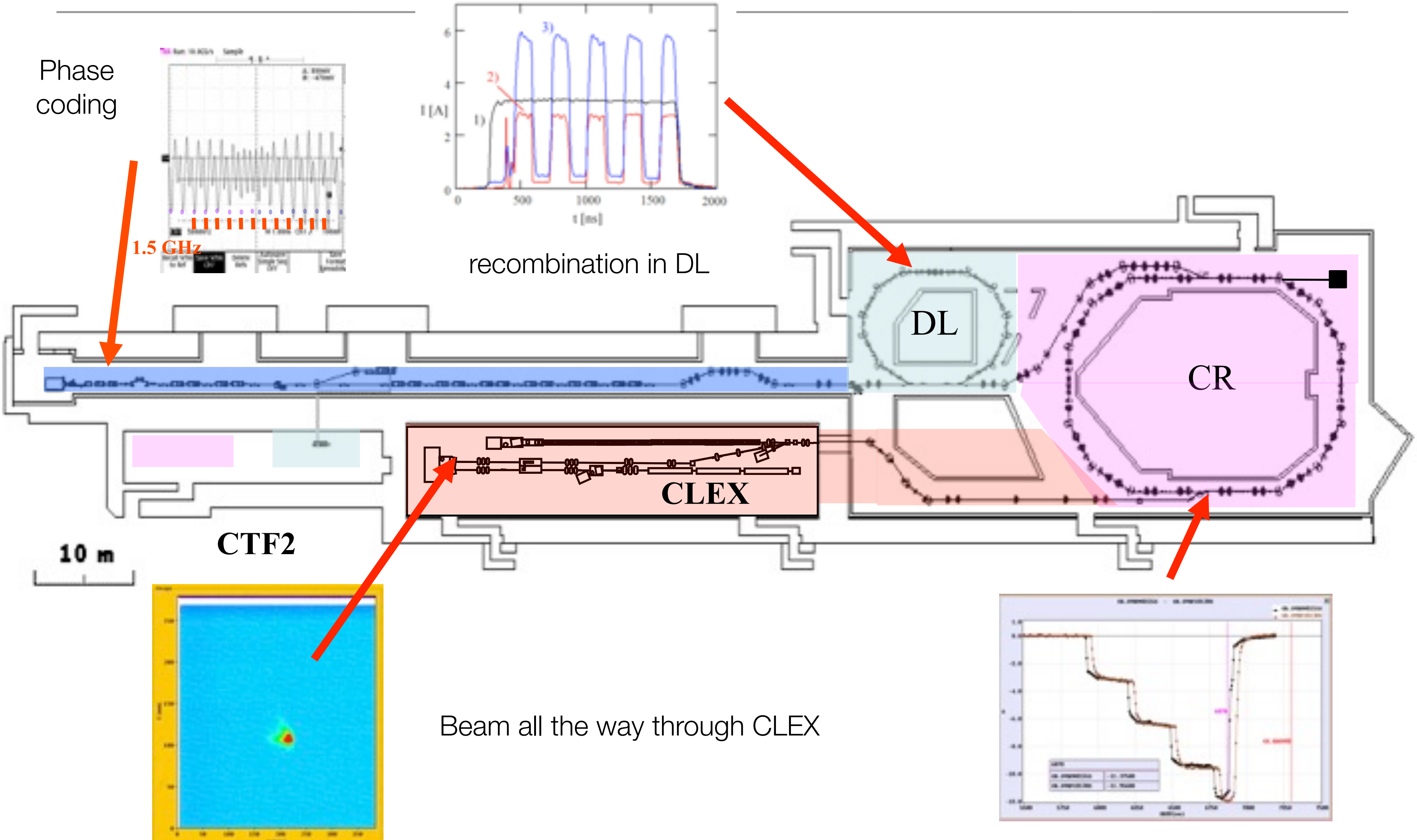
CLIC Characteristics

- High gradient >100 MV/m
  - Compact collider;
    total length ~ 50 km for 3 TeV
  - Acceleration in normal conducting structures @ 12 GHz
- Accelerating Field generated by high current drive beam parallel to main beam
  - field efficiently generated "just in time"
  - drive beam generated efficiently





CLEX – CLIC Experiment



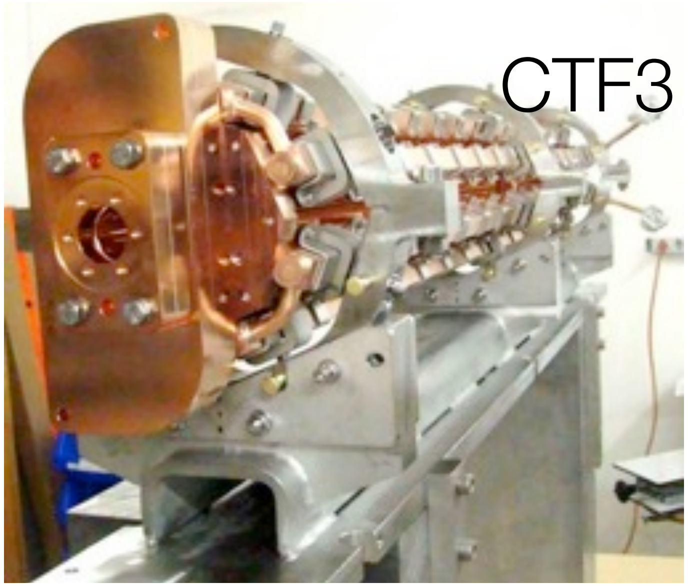
Phase coding

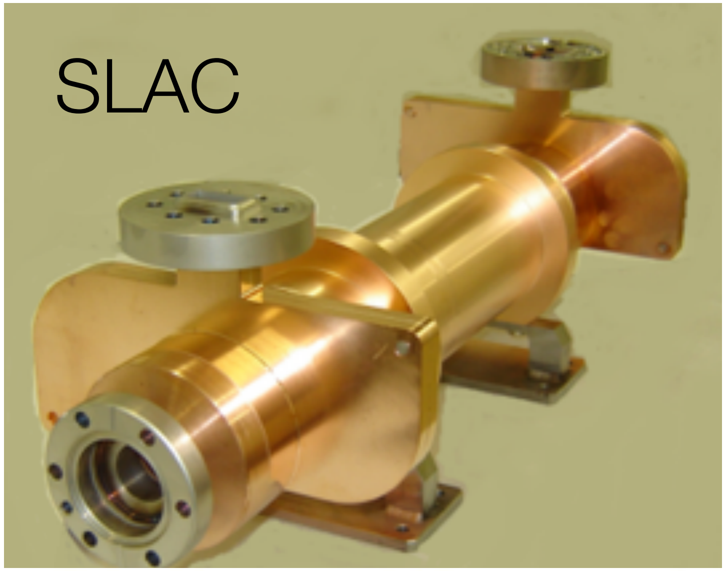
recombination in DL

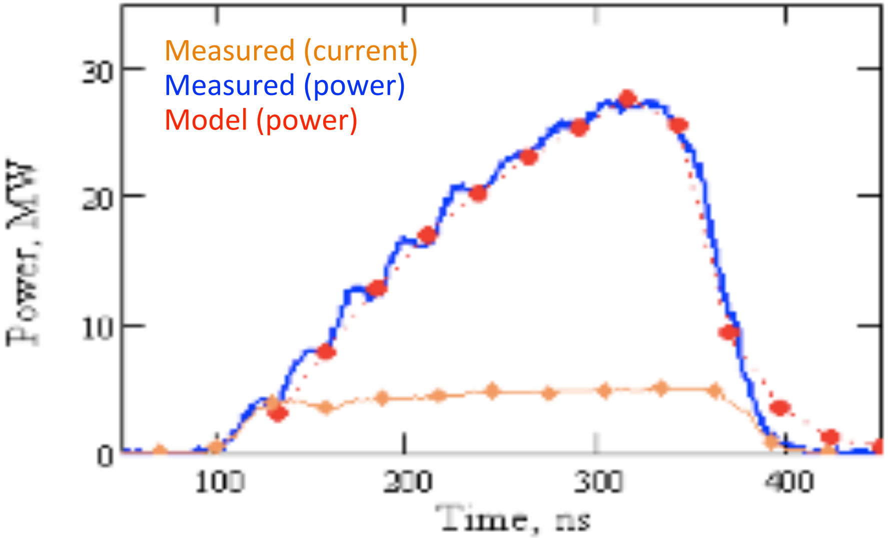
Beam all the way through CLEX

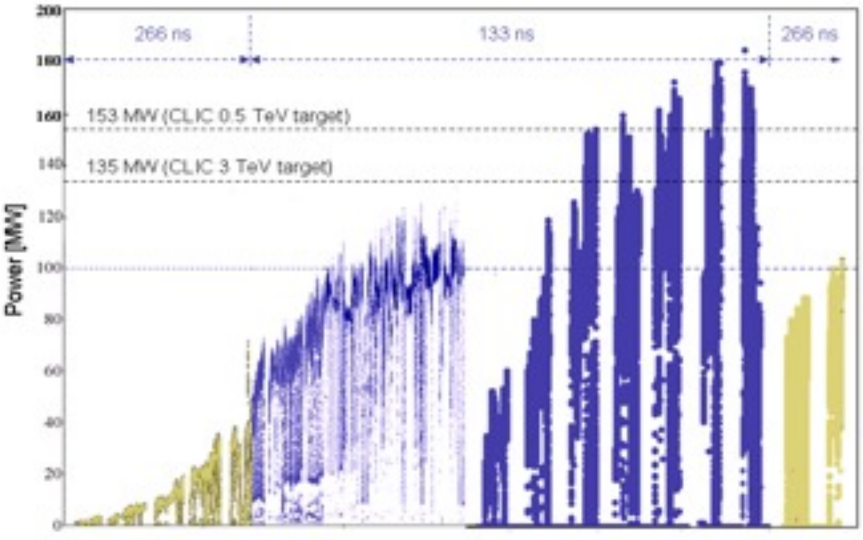
Factor 4 interleaving in CR

Power Extraction and Transfer Structure (PETS)



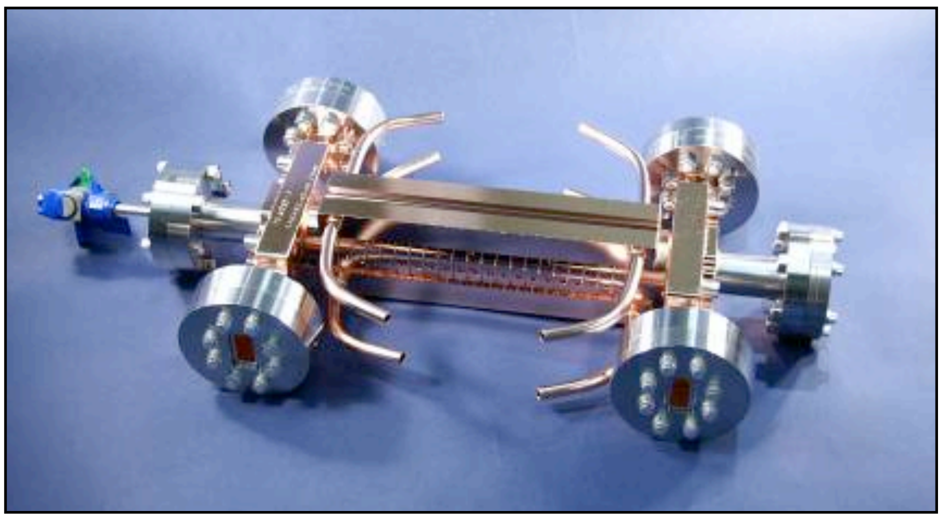


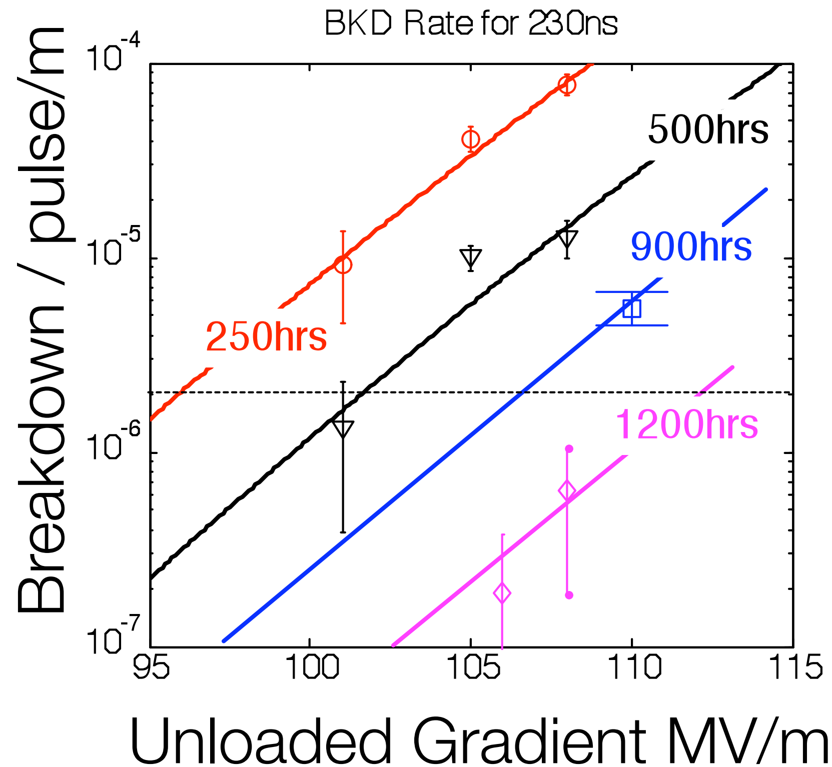




Performance of Accelerating Structures

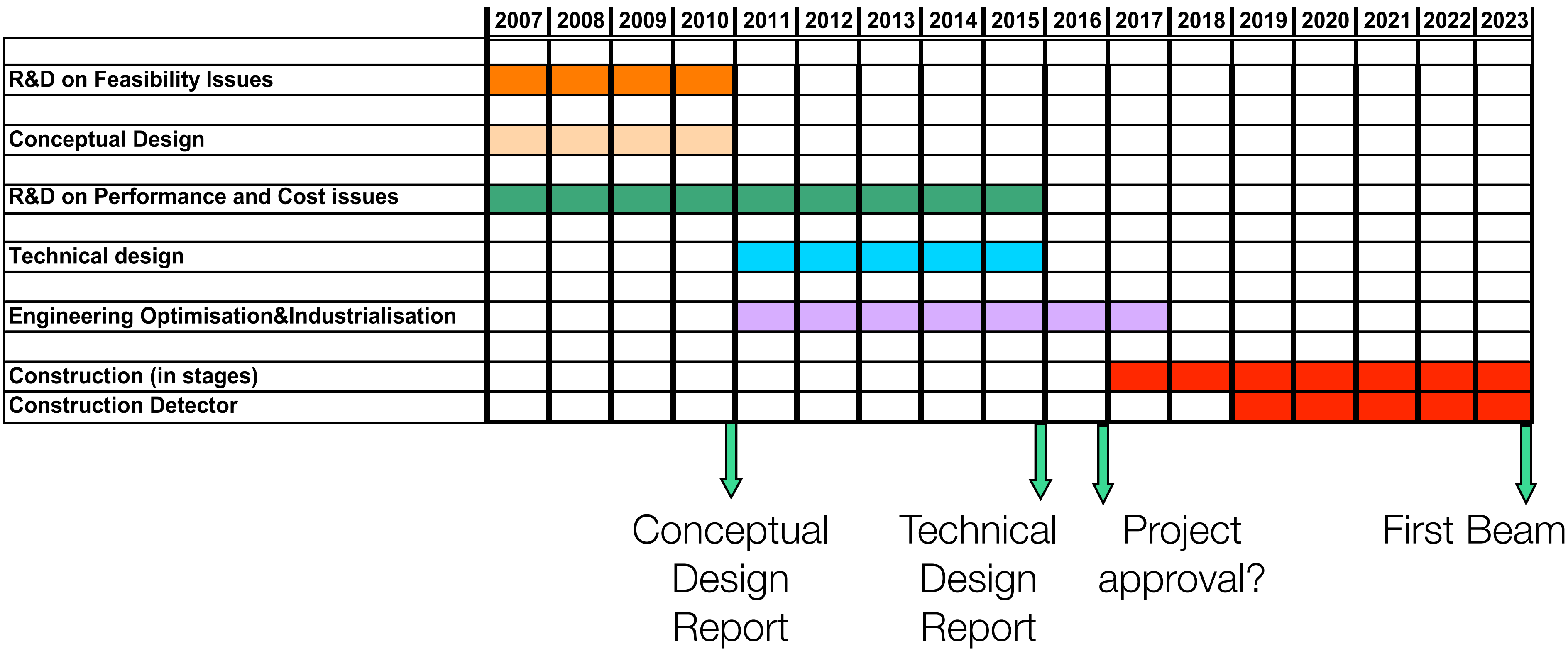
- Built @ CERN
- Tests @ SLAC





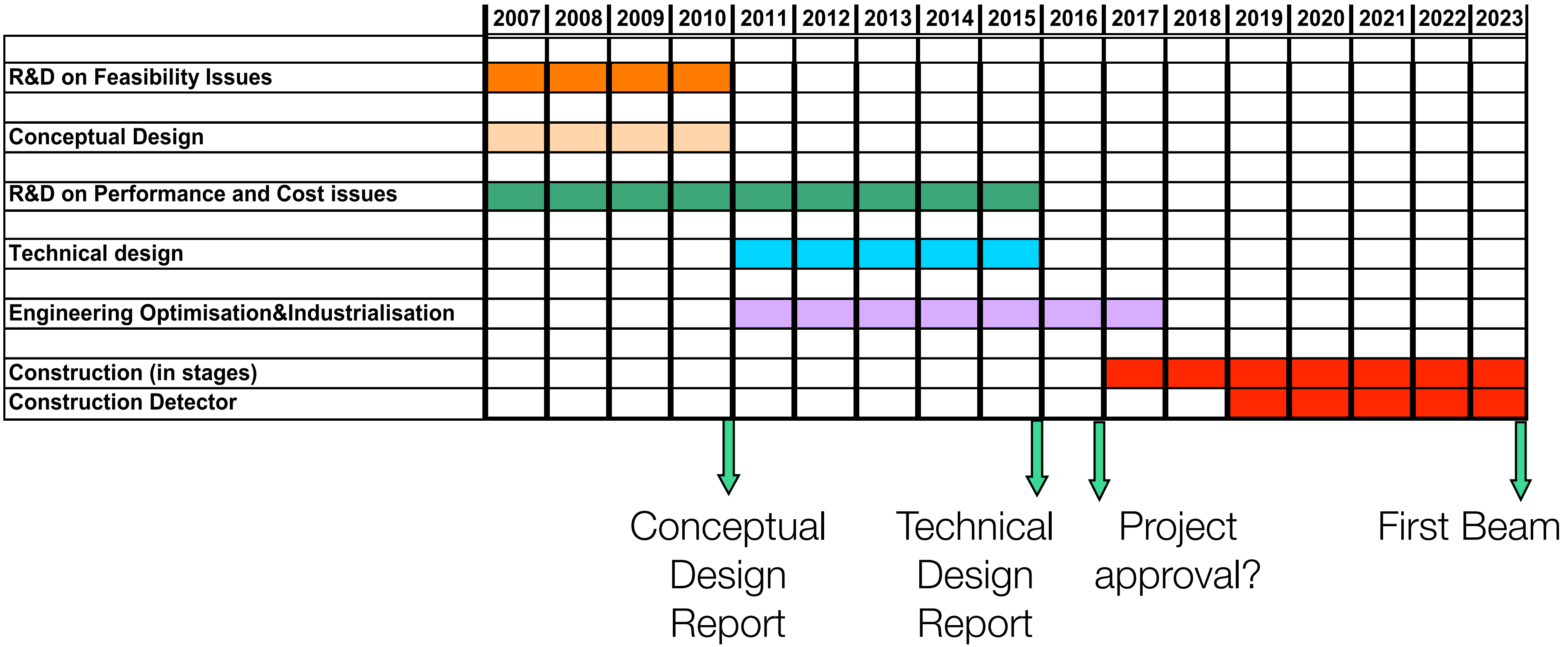
CLIC requires breakdown rates $<10^{-7}$

Tentative long-term CLIC scenario Shortest, Success Oriented, Technically Limited Schedule (2008)



- System tests
  - Drive beam handling
  - Power transfer on a large scale

Tentative long-term CLIC scenario Shortest, Success Oriented, Technically Limited Schedule (2008)



- System tests
  - Drive beam handling
  - Power transfer on a large scale

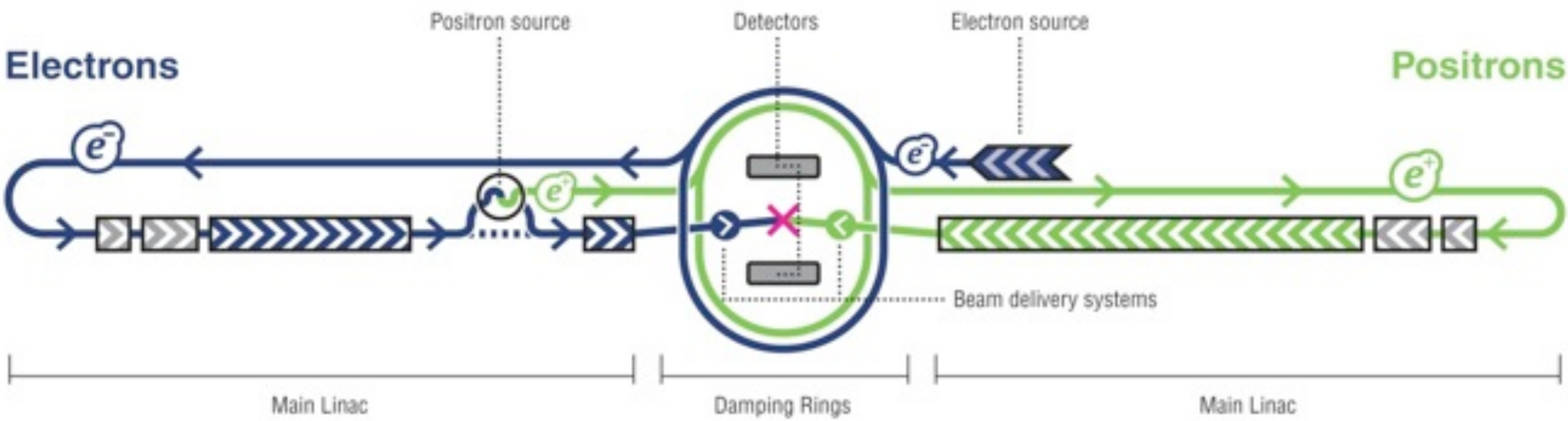
Verification of syste

International Linear Collider (ILC)
Global Design Effort

B. Wiik et al., A proposal to construct and test superconducting RF structures for linear colliders,
TESLA Report 93-01, DESY 1993

Acceleration by standing waves

ILC Layout



- Superconducting linear accelerators of 10 km
  - Nominal average gradient 31.5 MV/m

The Global Design Effort* (GDE)

Americas

Labs

ANL
BNL
FNAL
JLAB
LANL
LBNL
LLNL
SLAC
TRIUMF

Universities/Institutes

Colorado Univ.
Cornell
FSU
Iowa Univ.
MSU
Notre Dame Univ.

3 Regions
16 Countries
76 Institutes

Europe

labs

Budker
CEA/Saclay
CERN
CIEMAT
CNRS
STFC Daresubry Lab.
DESY
ESRF
GSI
INFN
JINR
LAL-Orsay
PSI

Universities/Institutes

Abertay Univ.
Berlin HU
Birmingham Univ.
Cambridge Univ.
Dundee Univ.
Durham
IFIC
IPJ
IPN-Orsay
IPPP Durham
Krakow
Lancaster Univ.
LAPP-Annecy
Legnaro
Liverpool Univ.
Manchester Univ.
Mannheim
Oxford Univ.
RHUL
Rostock

Asia

labs

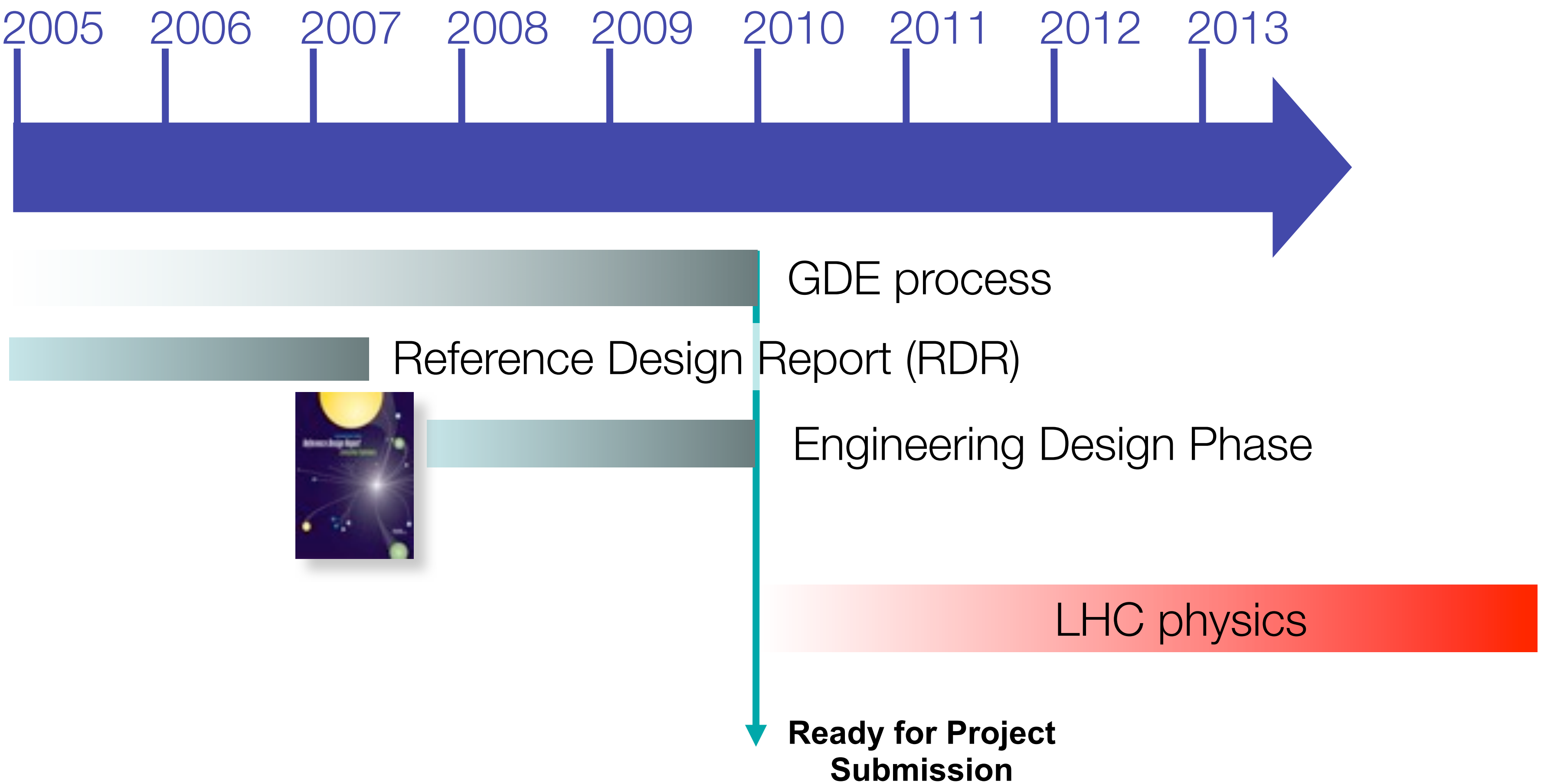
BARC
IHEP
IUAC
KEK
RRCAT
Tsinghua Univ.
VECC

Universities/Institutes

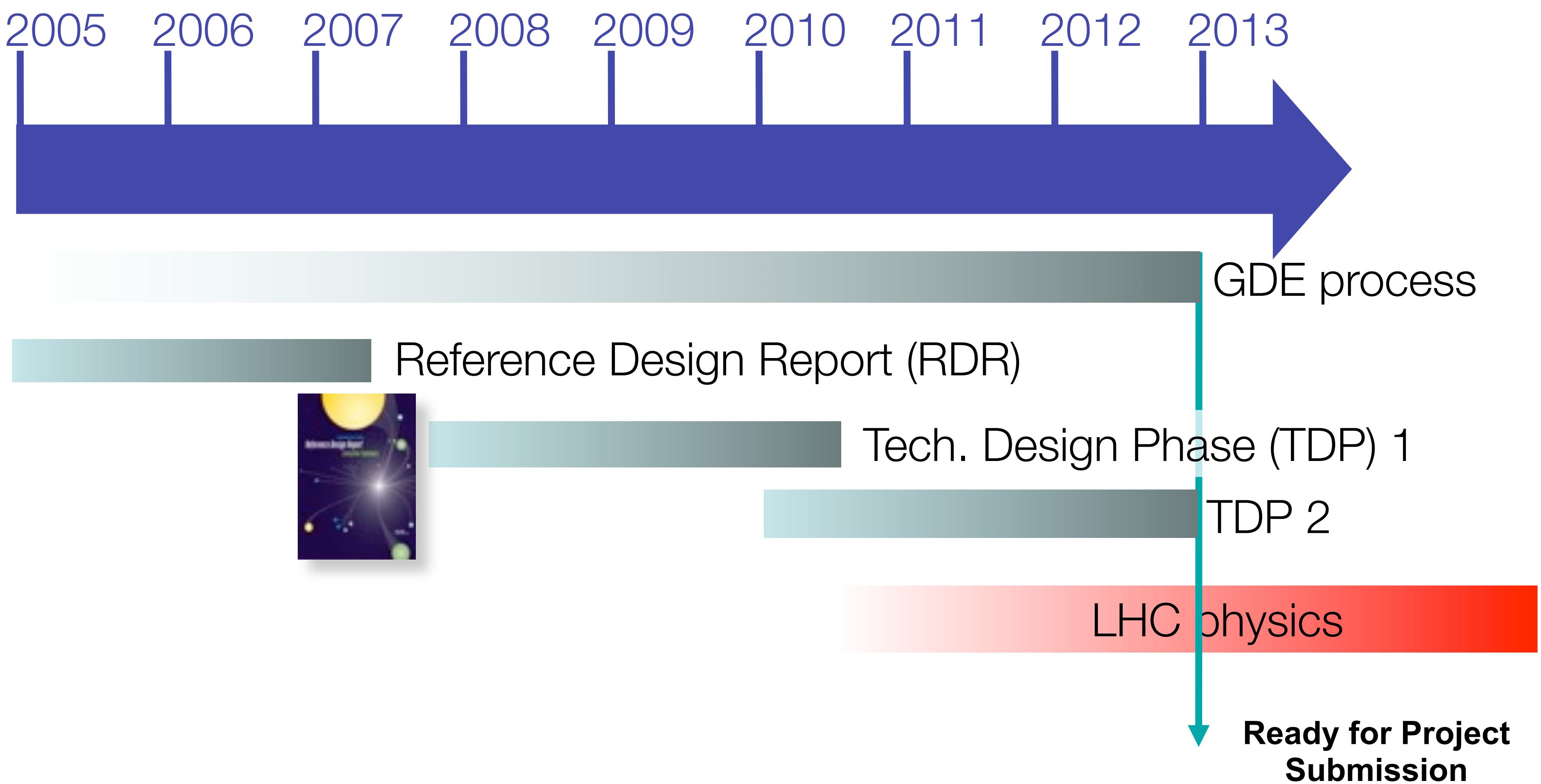
Hiroshima Univ.
KNU
Nagoya Univ.
PAL
TIFR
Tohoku Univ.
Tokyo Univ.
Univ. Delhi

*Based on known participation and received expressions of interest

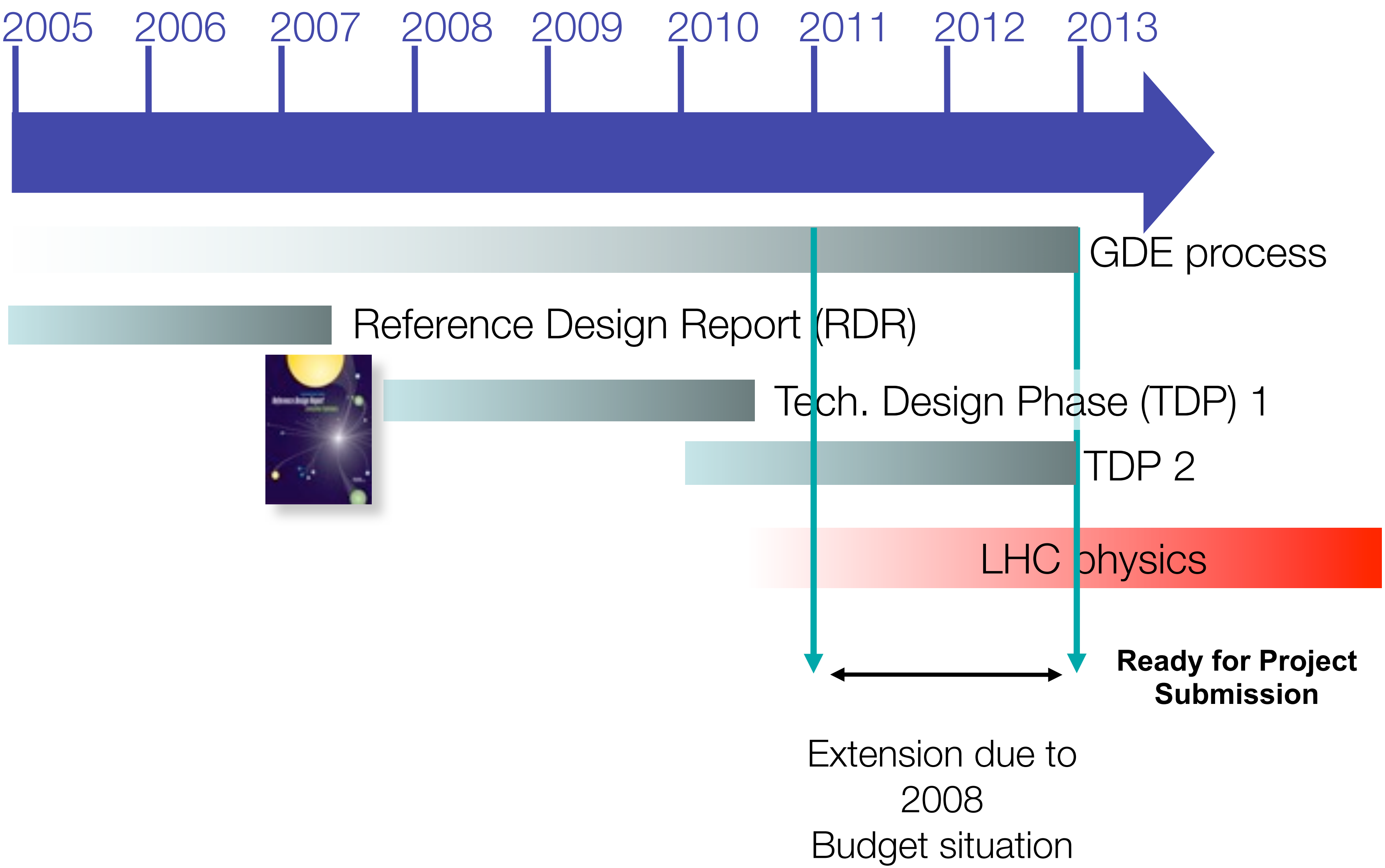
GDE ILC Timeline (2008)



GDE ILC Timeline (current)



GDE ILC Timeline (current)



TD Phase 1 & 2: The R&D Plan

- Stated TDP Goals:
  - Updated ILC design
  - Results of critical risk-mitigating R&D
  - Updated VALUE estimate and schedule
  - Project Implementation Plan

ILC Research and Development Plan for the Technical Design Phase

Release 4

July 2009

ILC Global Design Effort

Director: Barry Barish

Prepared by the Technical Design Phase Project Management

Project Managers: Marc Ross, Nick Walker, Akira Yamamoto

TD Phase Stated Priorities (R&D Plan)

Risk Mitigating R&D

- SCRF Technology (e.g. gradient)
- Damping ring electron cloud
- ...

Beam Test Facilities

- ATF / ATF 2 (KEK)
- CesrTA (Cornell)
- TTF/FLASH (DESY)
- ...

Machine Design / Cost

- CFS / Value Engineering
- Accelerator Design & Integration

Global SCRF Technology

Global SCRF Technology

Implicit <u>but critical</u> GDE goal:

Promote development of 1.3GHz nine-cell expertise & infrastructure in <u>all three regions</u>

<u>Major progress</u> in infrastructure development in all three regions

Global SCRF Technology: ASIA

Global SCRF Technology: ASIA

Global SCRF Technology: AMERICAS

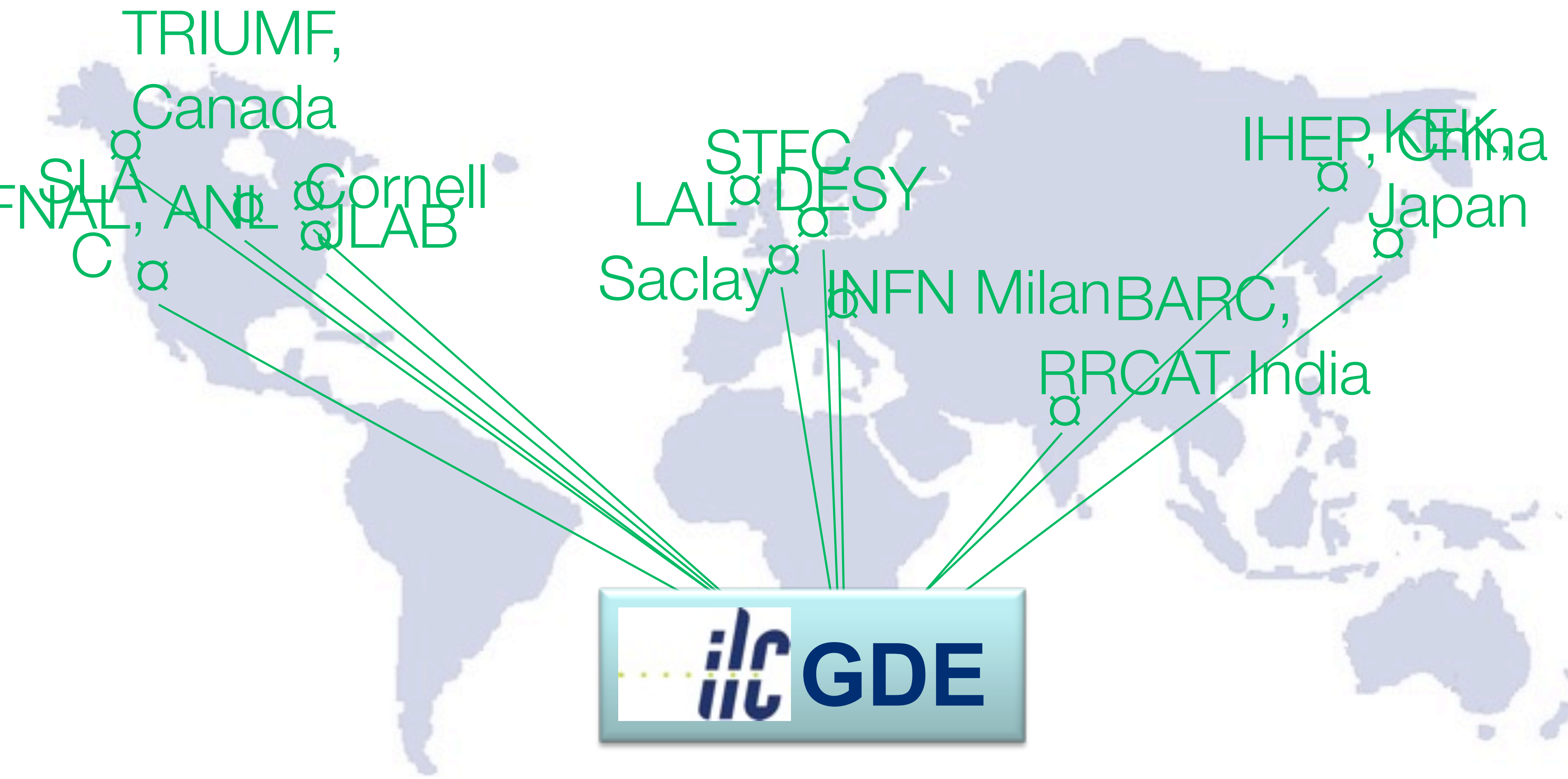
Global SCRF Technology: AMERICAS

Global SCRF Technology: EUROPE

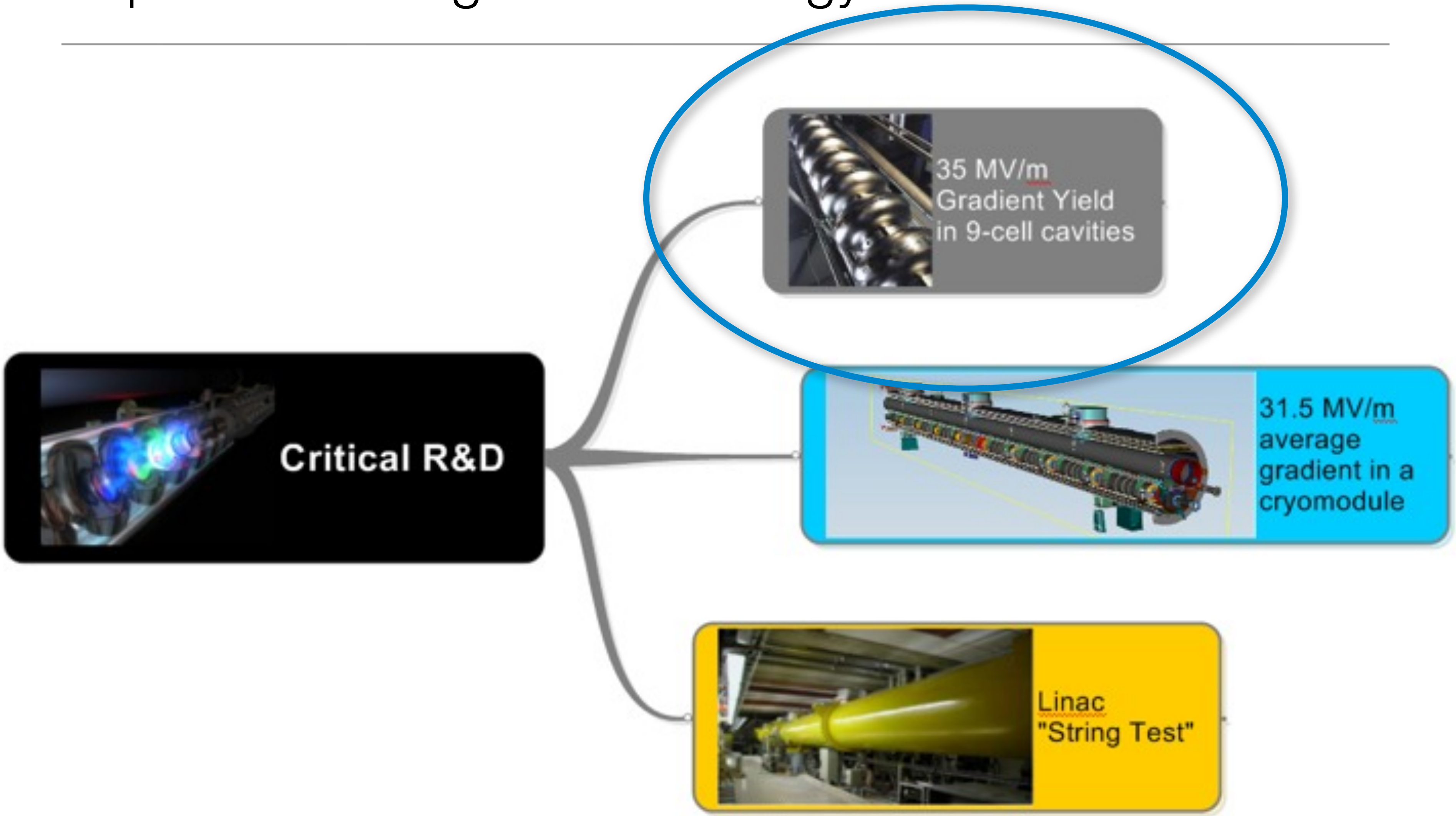
Global SCRF Technology: EUROPE

Global SCRF Technology

Global SCRF Technology



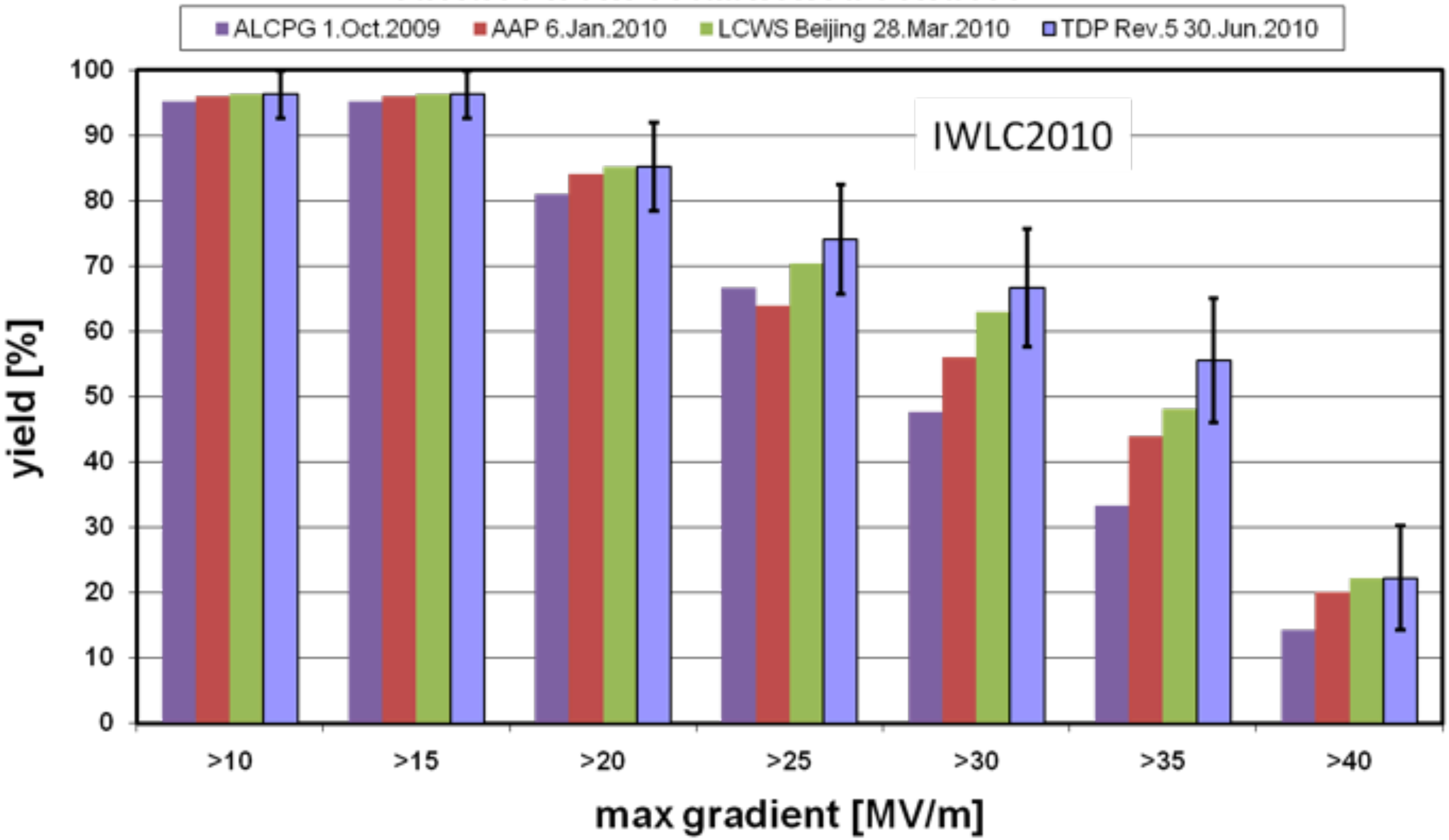
Superconducting RF Technology



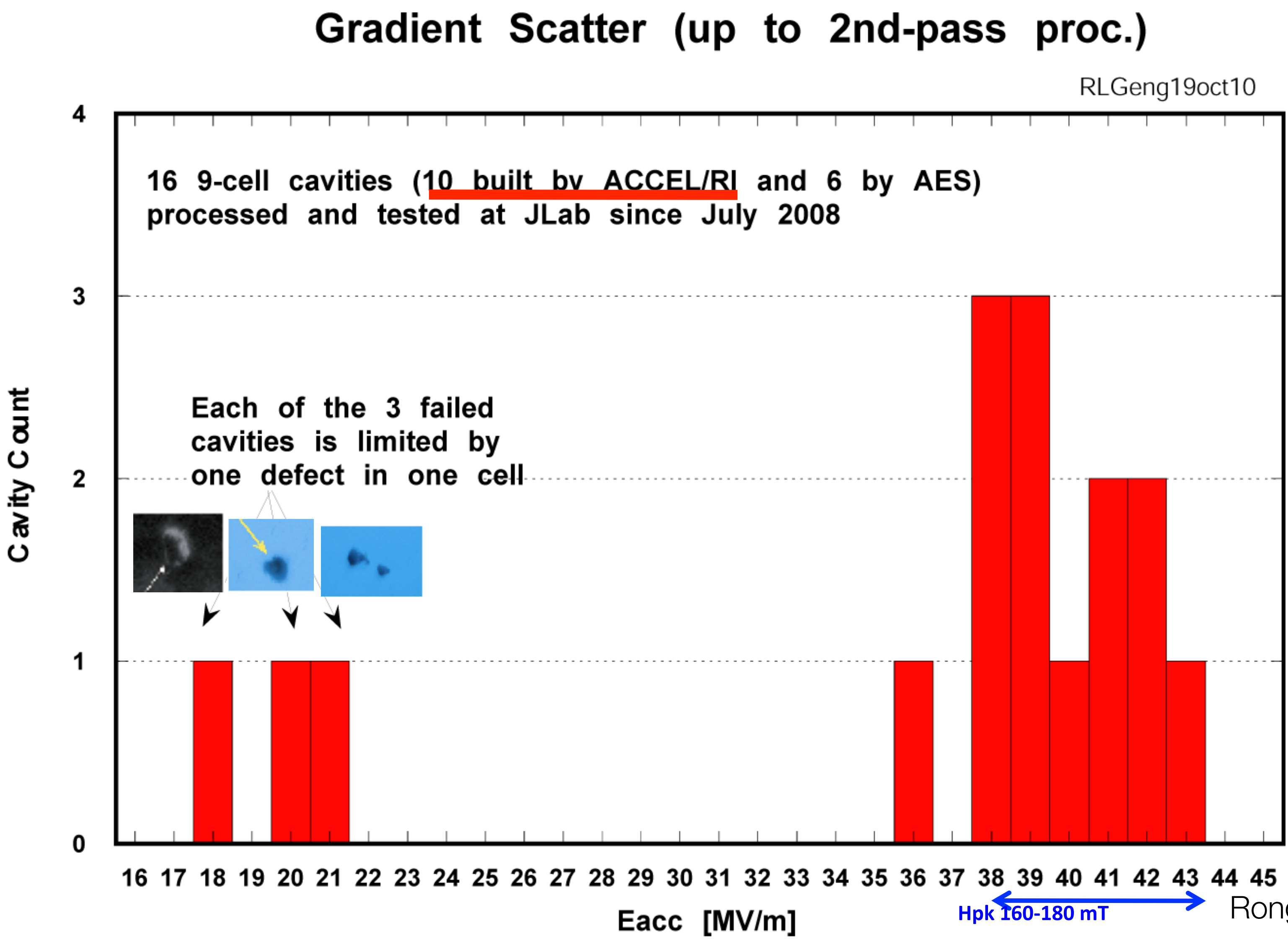
SCRF Priority R&D: Gradient

- Gradient: single biggest cost driver
- RDR baseline:
  - ≥35 MV/m vertical (acceptance) test
  - ≥31.5 MV/m average operational gradient
- Proof of principle of gradient achieved
  - Many single-cells
  - Tens of 9-cells
  - Operational acceleration demonstrated (TTF/FLASH)
- GDE Focus on mass-production yield and cost
  - TDP-1 goal: ***process yield*** 50%
  - TDP-2 goal: ***production yield*** 90%

Progress Towards High-Gradient Yield

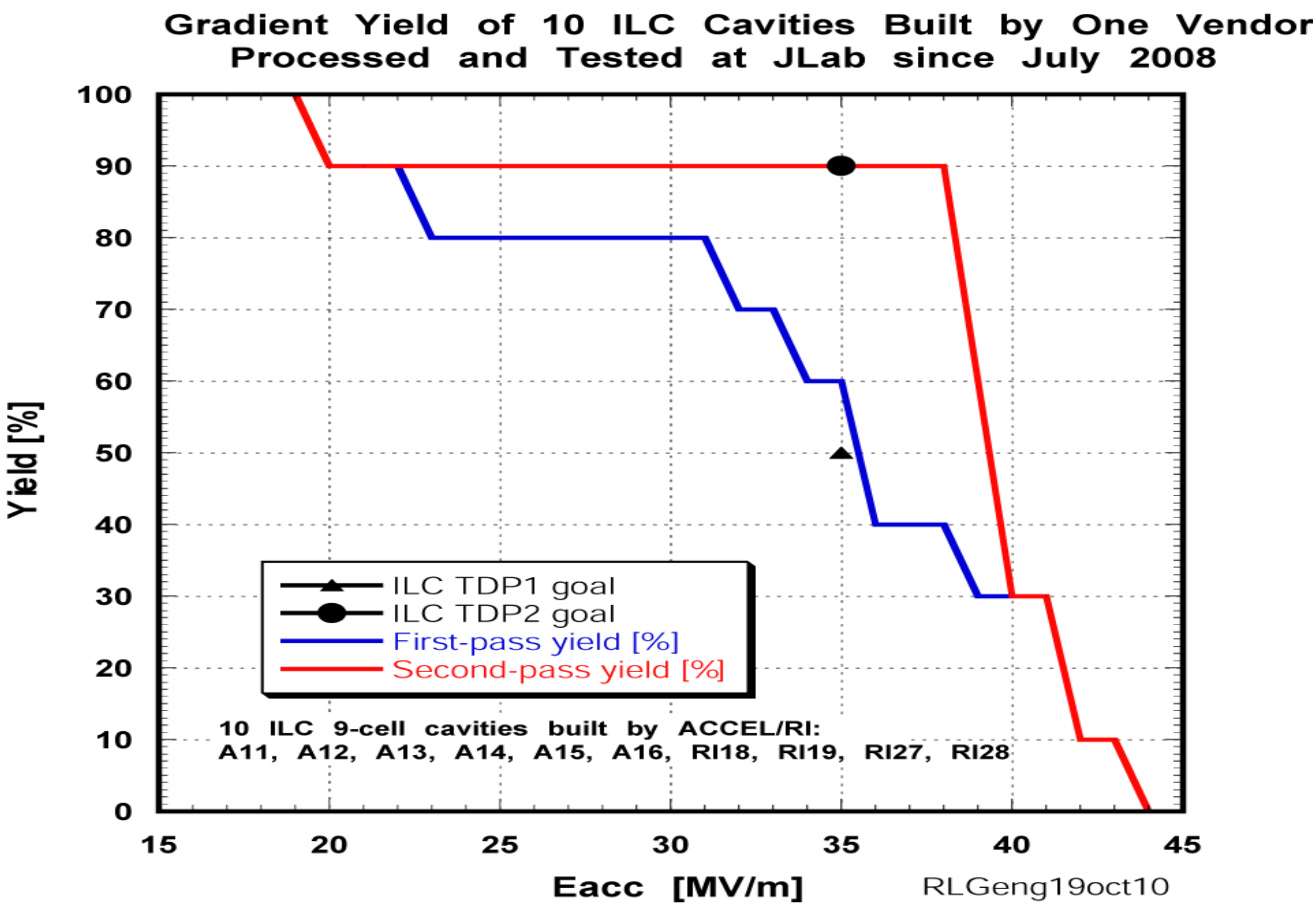


Recent Production of cavities at JLAB

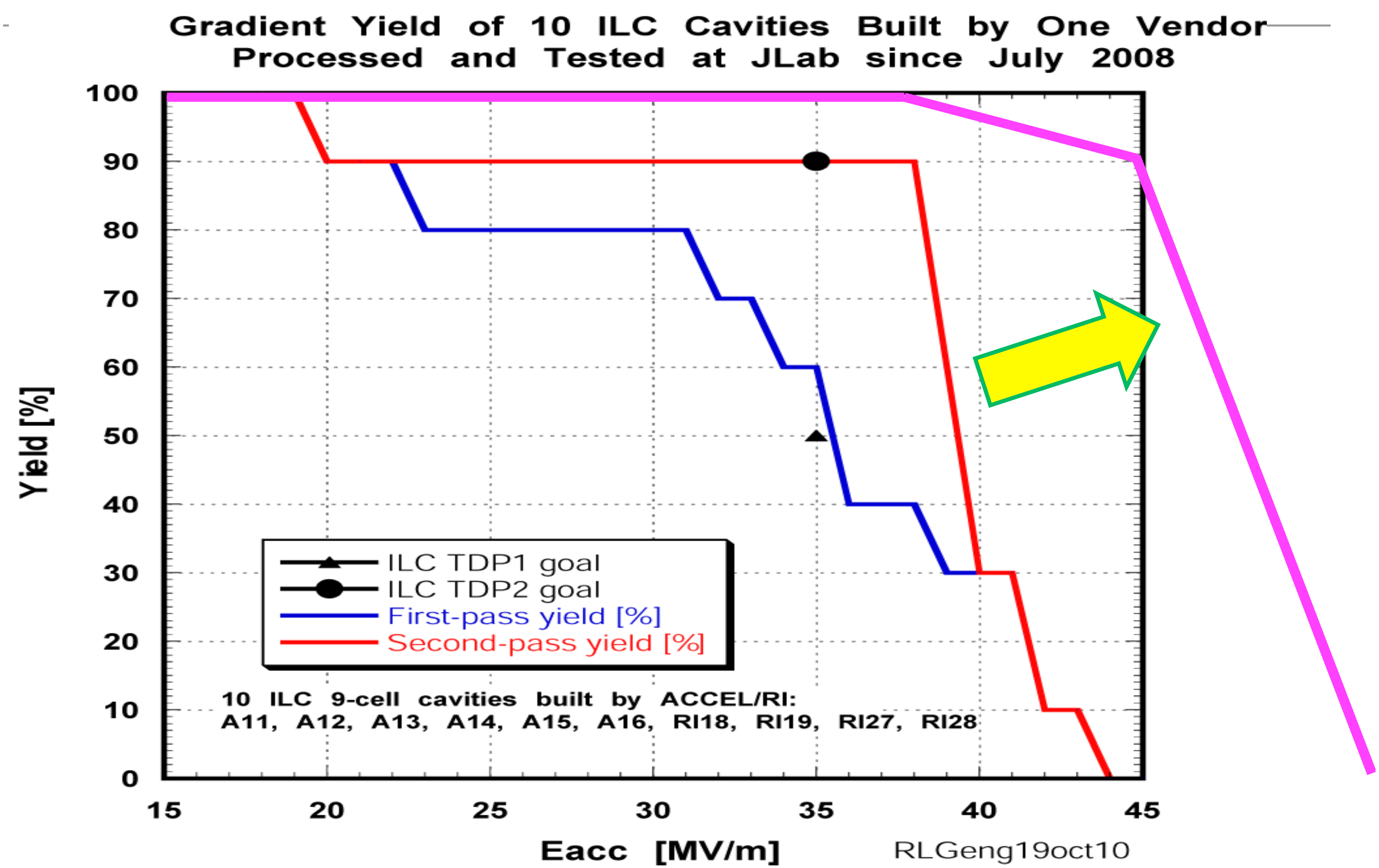


Rongli Geng

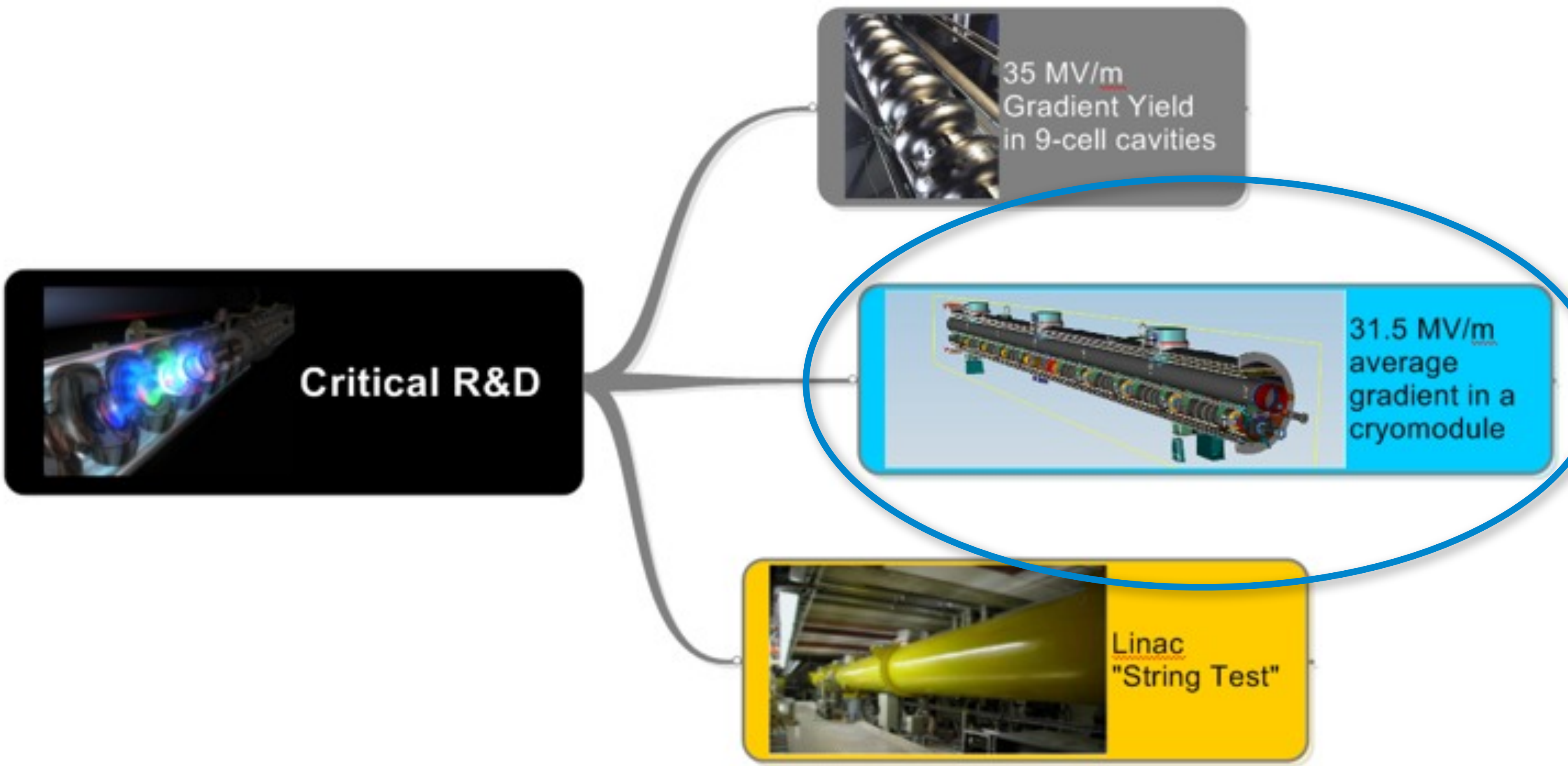
Statistics of small sample production



Statistics of small sample production



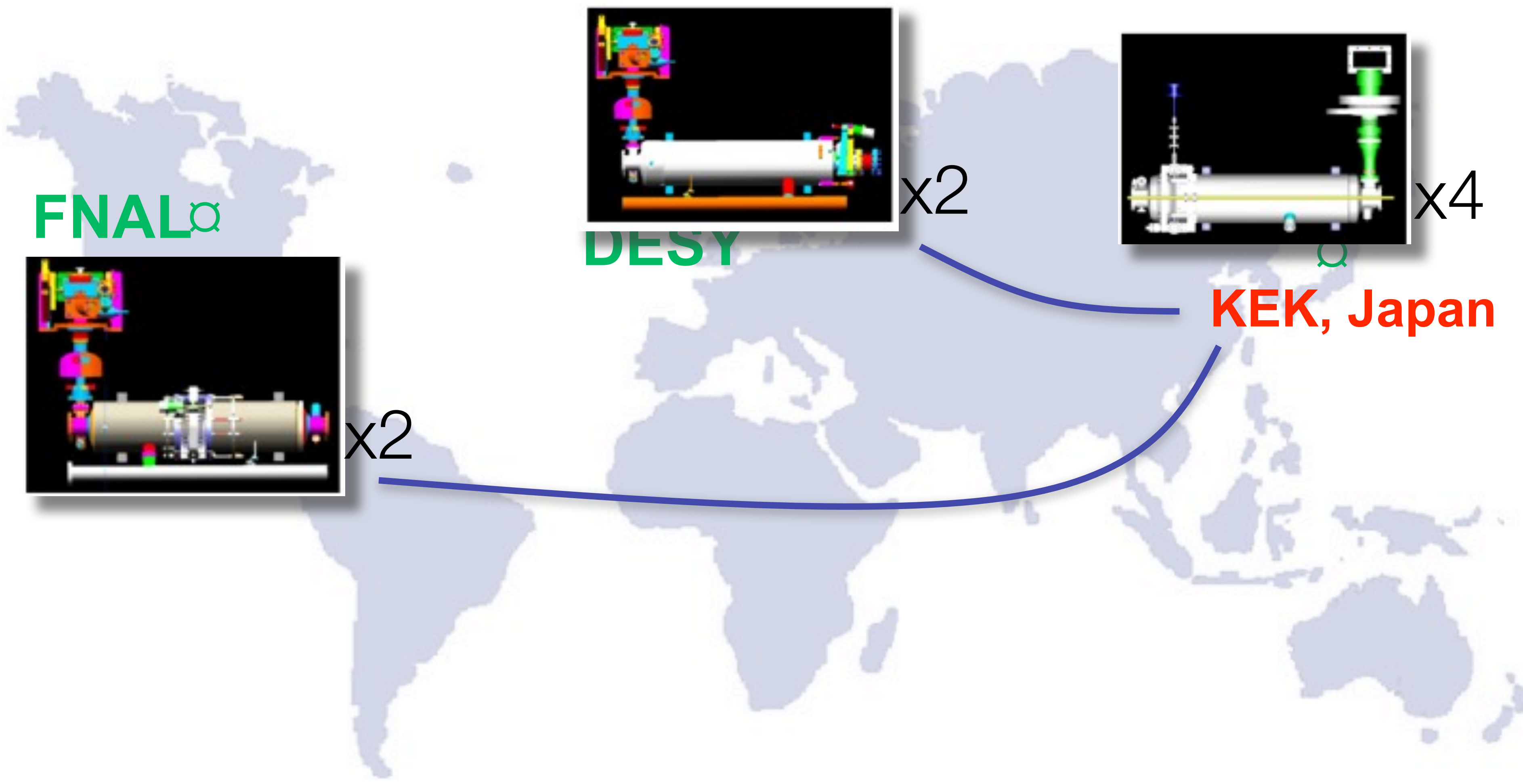
Superconducting RF Technology



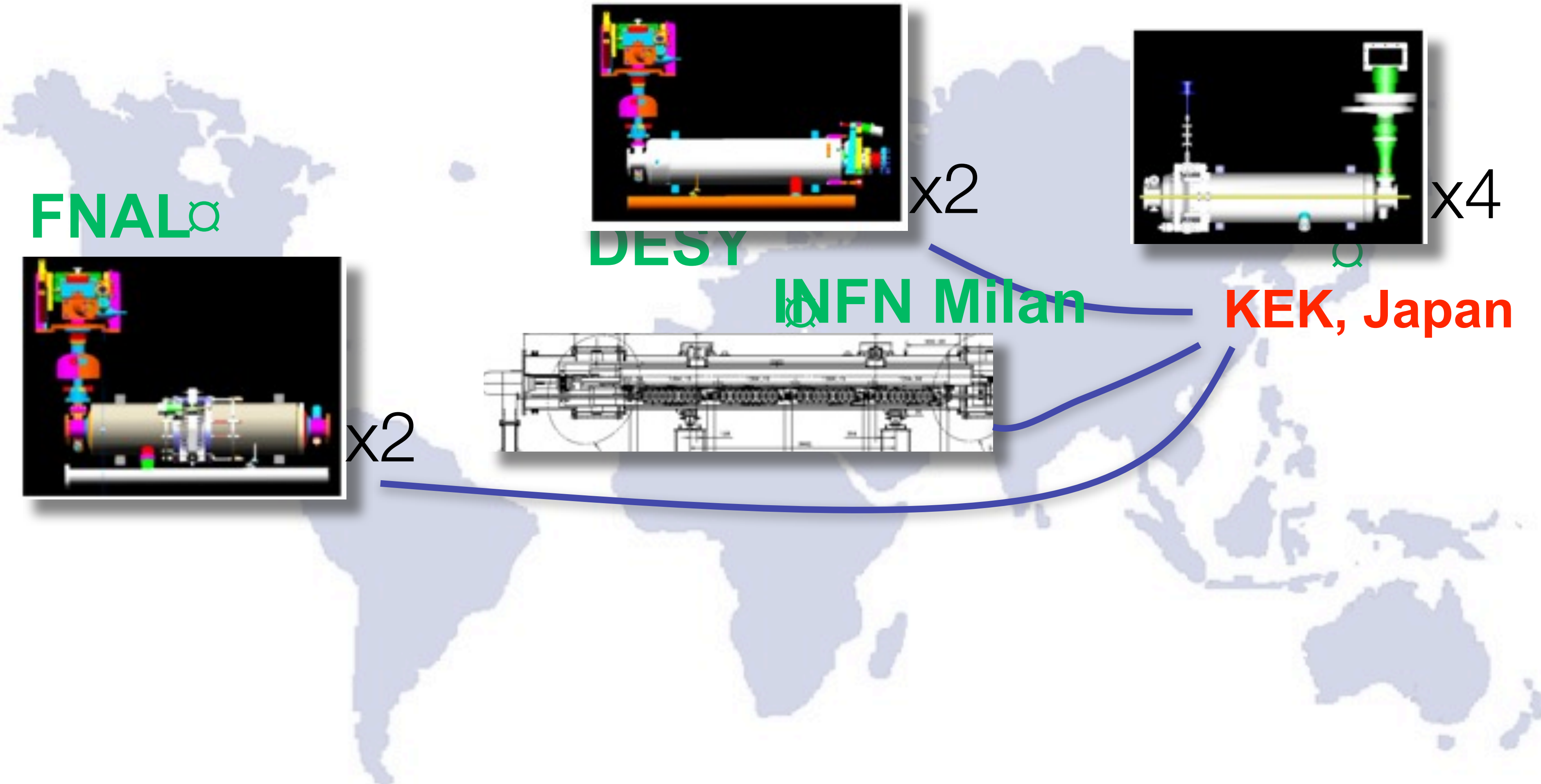
S1-Global Collaboration

S1-Global Collaboration

S1-Global Collaboration

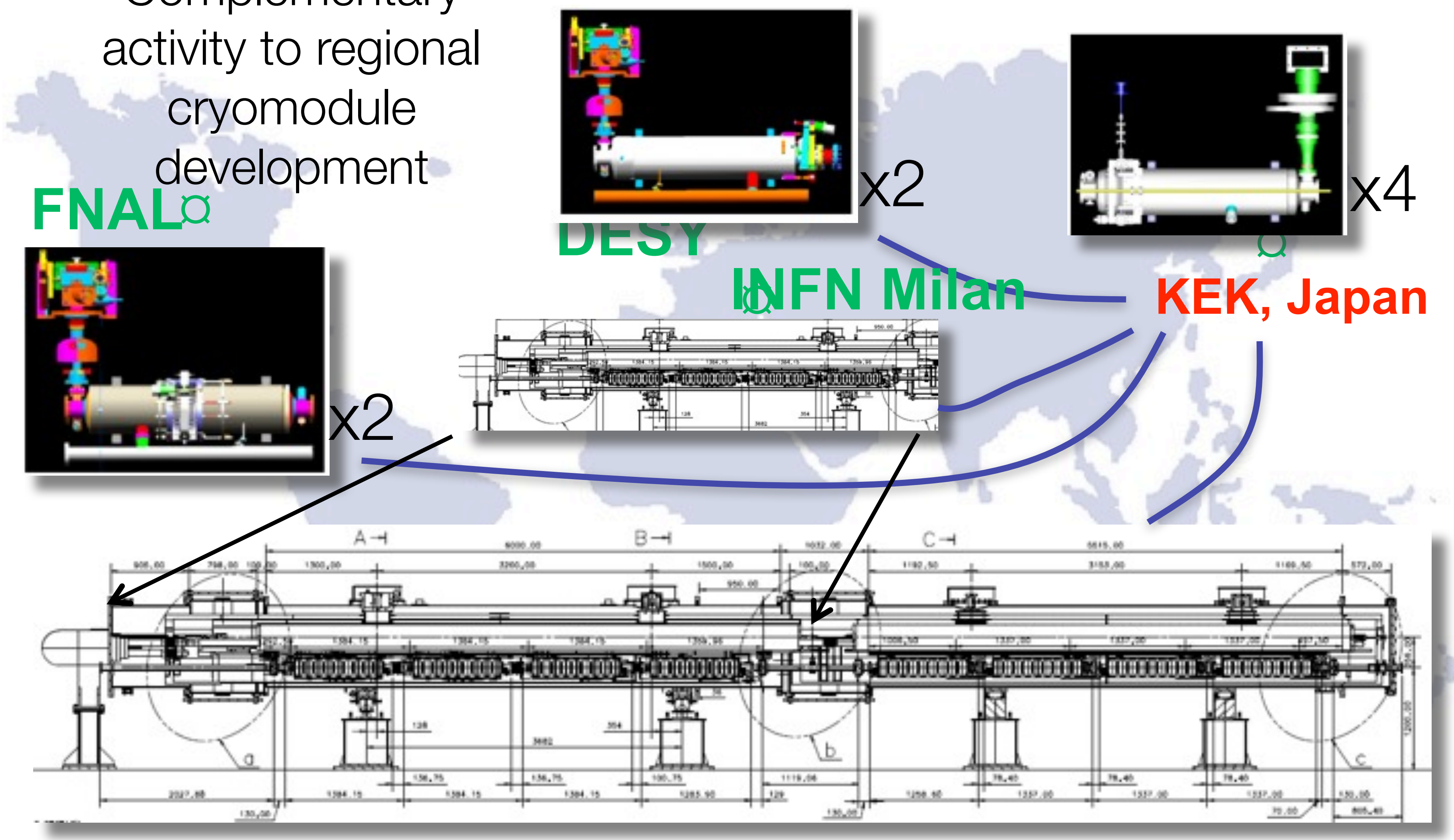


S1-Global Collaboration



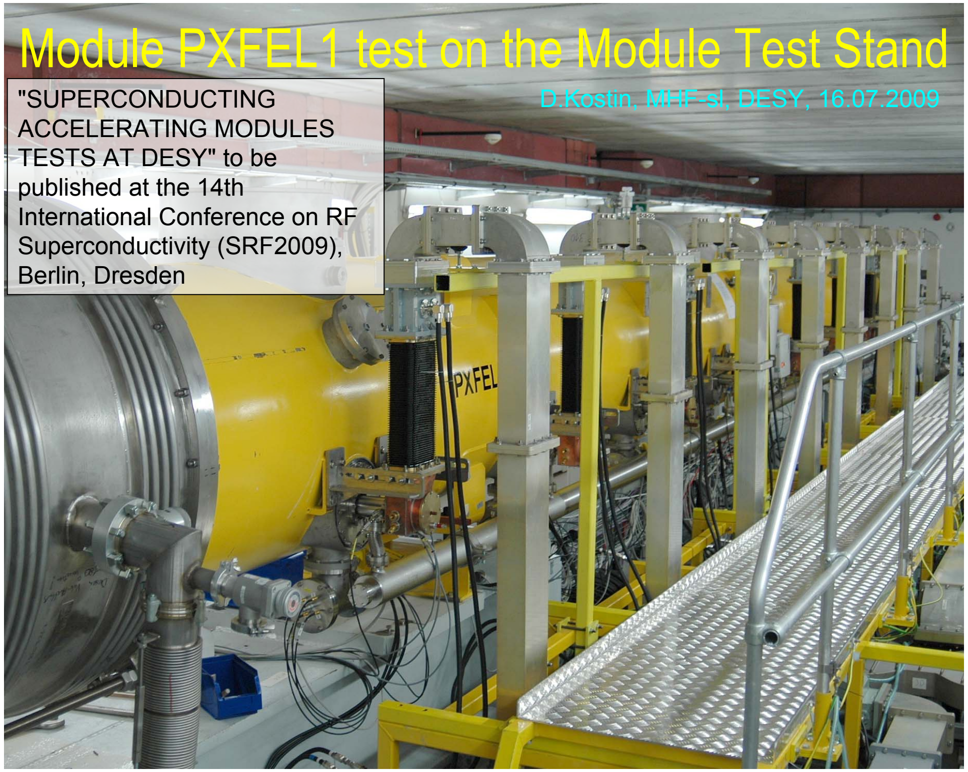
S1-Global Collaboration

Complementary activity to regional cryomodule development

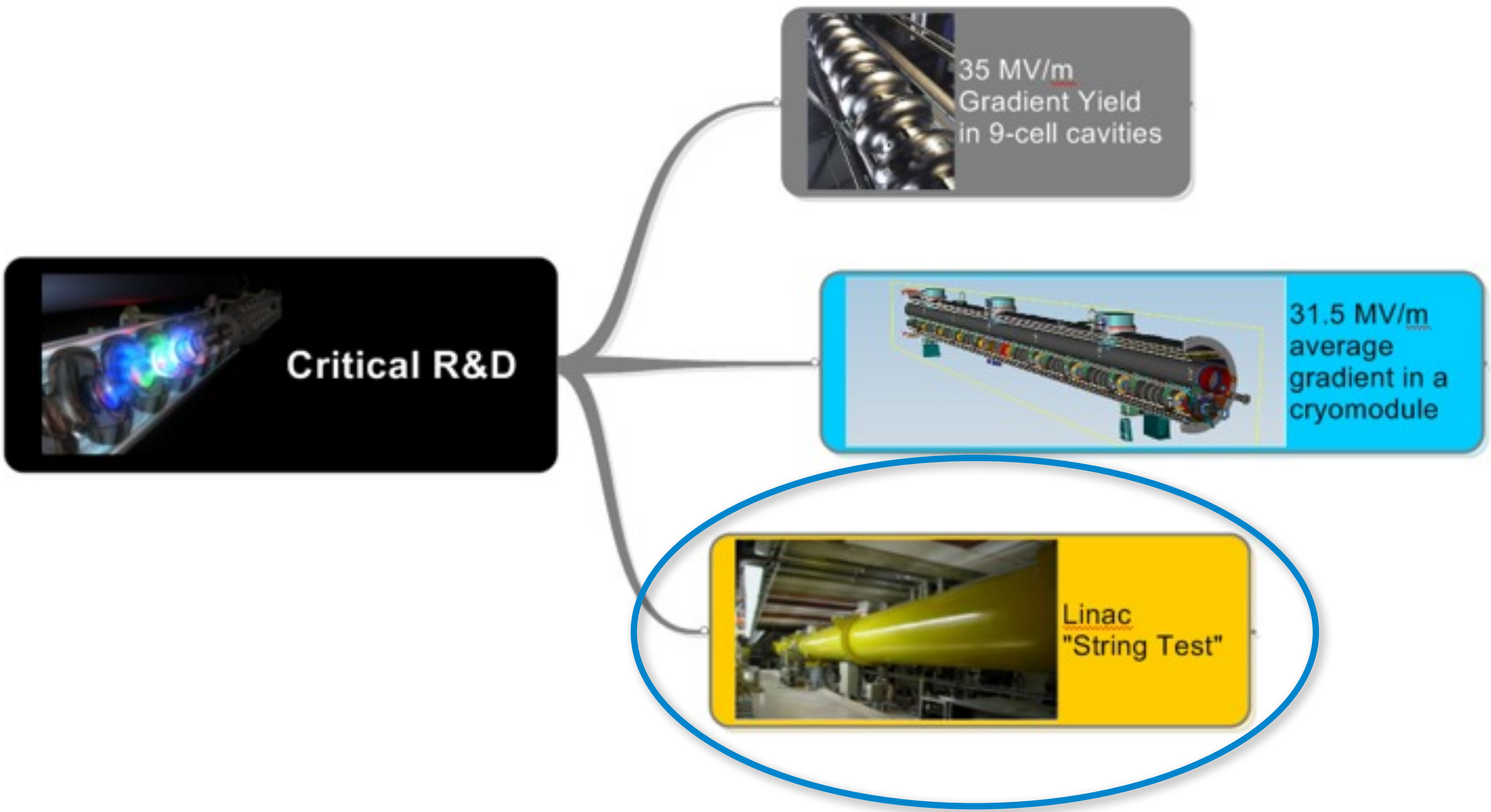


Acceptance test of last installed FLASH Module

- Cavity test before assembly: 34.75 MV/m
- Cavities in module 32.5 MV/m
- Operation in FLASH at 30 MV/m and 10 Hz
- FLASH energy increase to 1.2 GeV
- Collaboration of IHEP/Beijing, CEA-IRFU/Saclay, IN2P3-LAL/Orsay, INFN/Milano, CIEMAT/Madrid und DESY



Superconducting RF Technology



SRF Test Facilities

SRF Test Facilities

STF (phase I & II)
Under construction
first beam 2011
ILC RF unit test by 2013

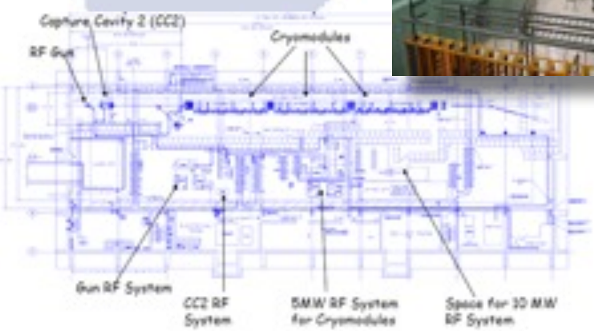
SRF Test Facilities

NML facility
Under construction
first beam 2010
ILC RF unit test ~2012

STF (phase I & II)
Under construction
first beam 2011
ILC RF unit test by 2013

SRF Test Facilities

FNAL

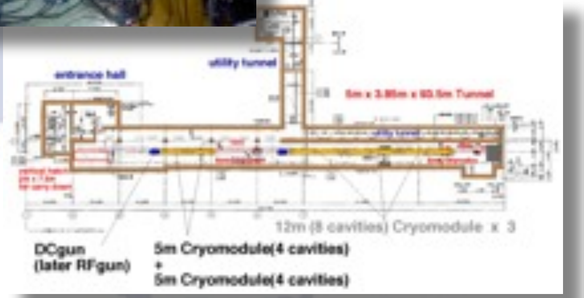


NML facility
Under construction
first beam 2010
ILC RF unit test ~2012

DESY

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

KEK, Japan

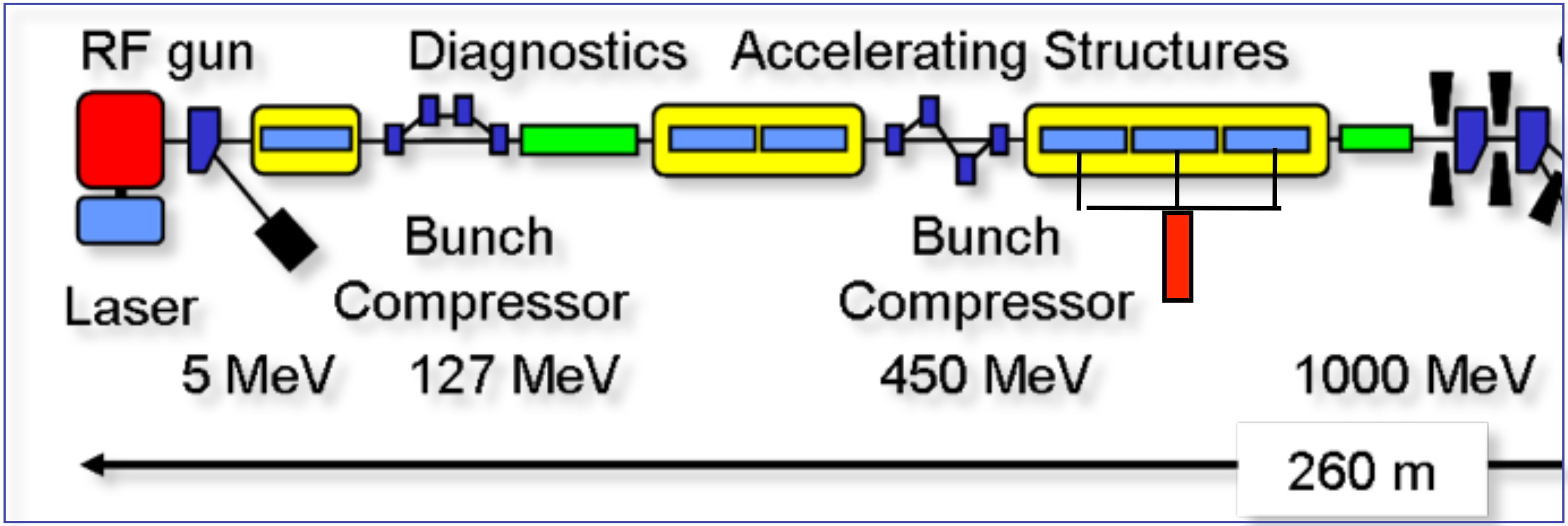


STF (phase I & II)
Under construction
first beam 2011
ILC RF unit test by 2013

A string test in each region

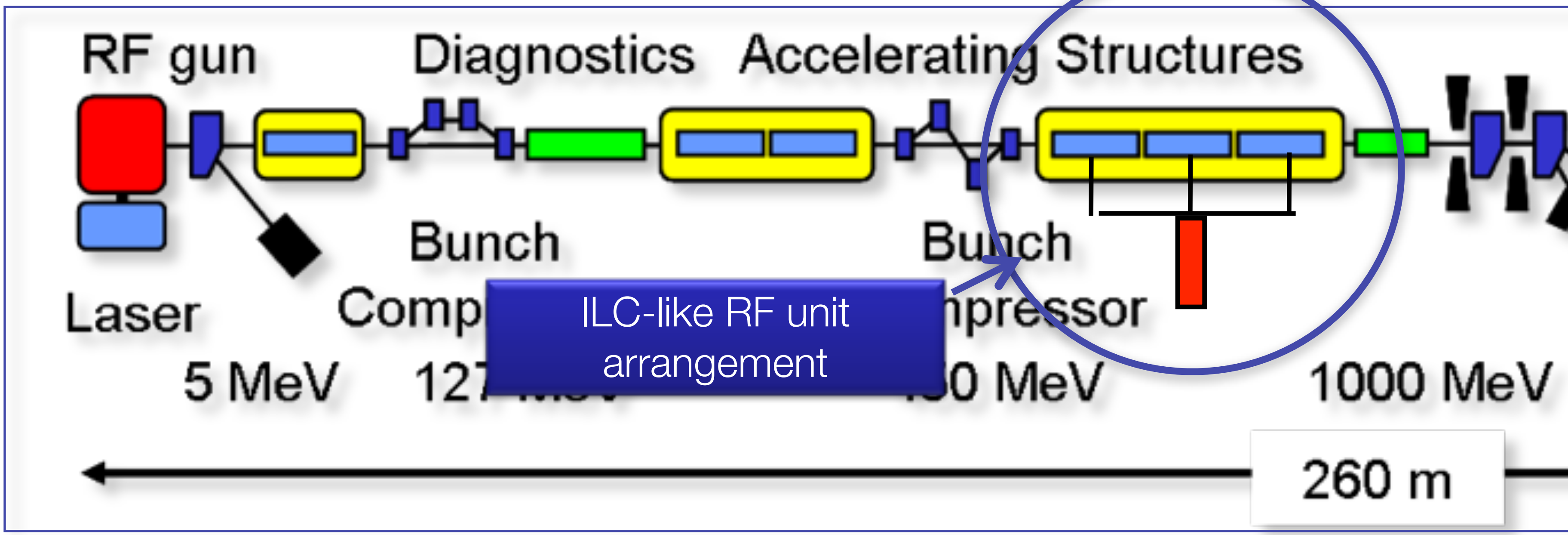
- **Complementary testing:**
  - Each region must develop industry and must develop ‘ownership’ of this critical technology
- **No one system will exactly represent the baseline reference design RF unit design (before 2012)**
  - FNAL: beam format [under review]
  - KEK: number of cryomodules [1 (of 3) by end 2012]
  - DESY: gradient [~27MV/m average over 3 cryomodules]
- **Strategy must account for infrastructure limitations and construction schedules at each of the three main linac test facilities under development.**

9mA Experiments in TTF/FLASH



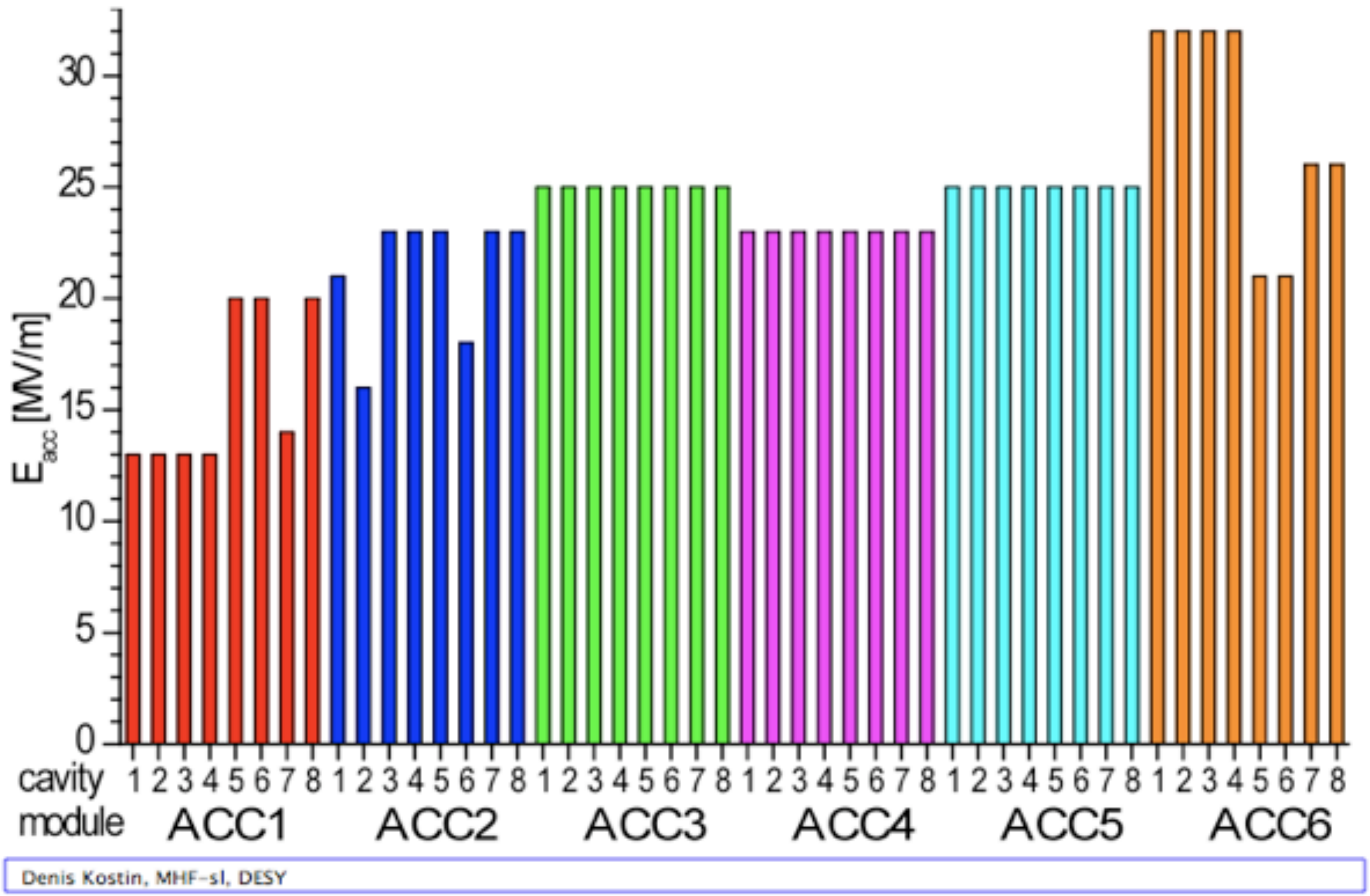
		XFEL	ilc	FLASH design	FLASH experiment
Bunch charge	nC	1	3.2	1	3
# bunches		3250*	2625	7200*	2400
Pulse length	μs	650	970	800	800
Current	mA	5	9	9	9

9mA Experiments in TTF/FLASH

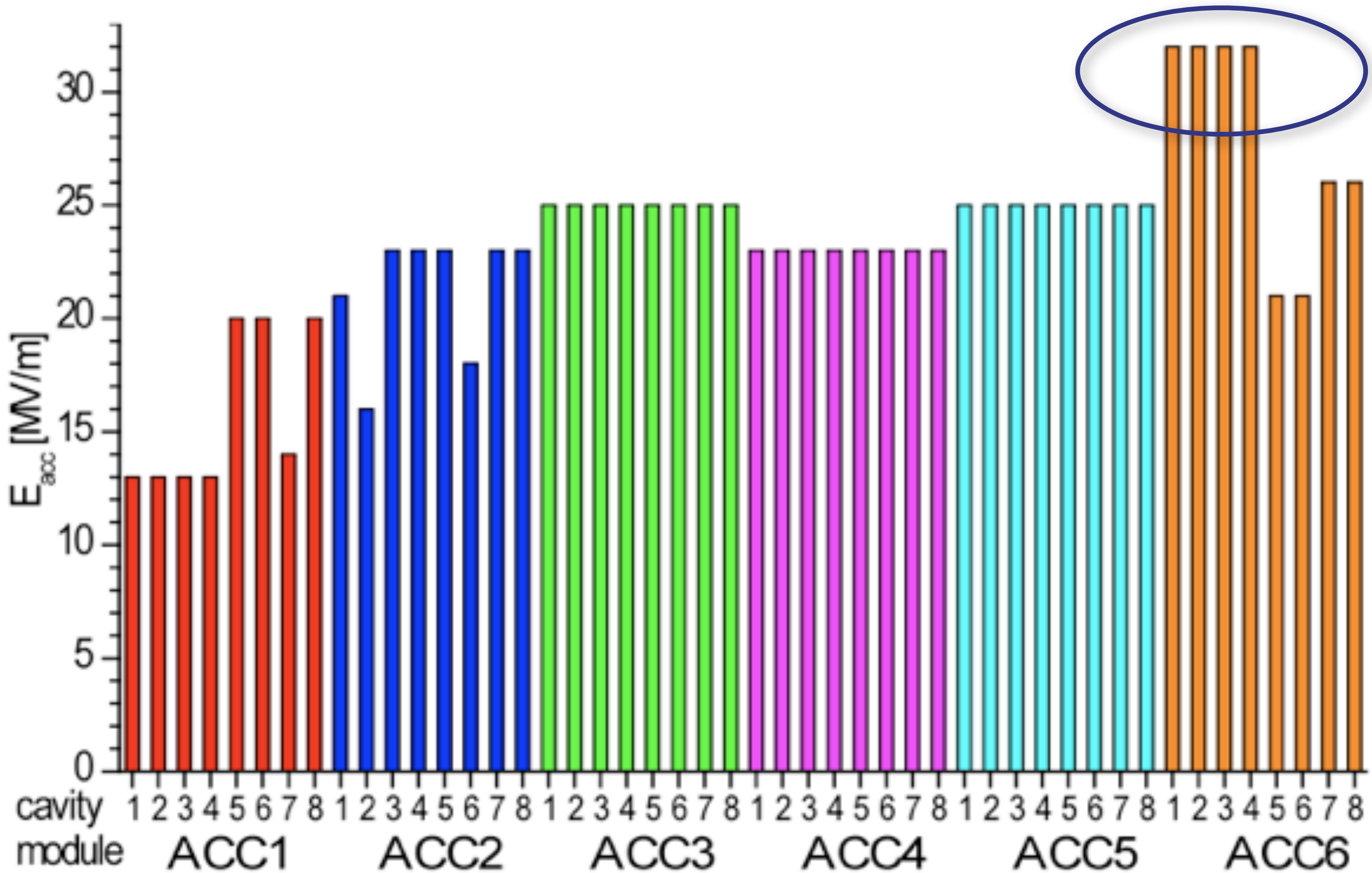


		XFEL	ILC	FLASH design	FLASH experiment
Bunch charge	nC	1	3.2	1	3
# bunches		3250*	2625	7200*	2400
Pulse length	μs	650	970	800	800
Current	mA	5	9	9	9

FLASH Gradient limits



FLASH Gradient limits

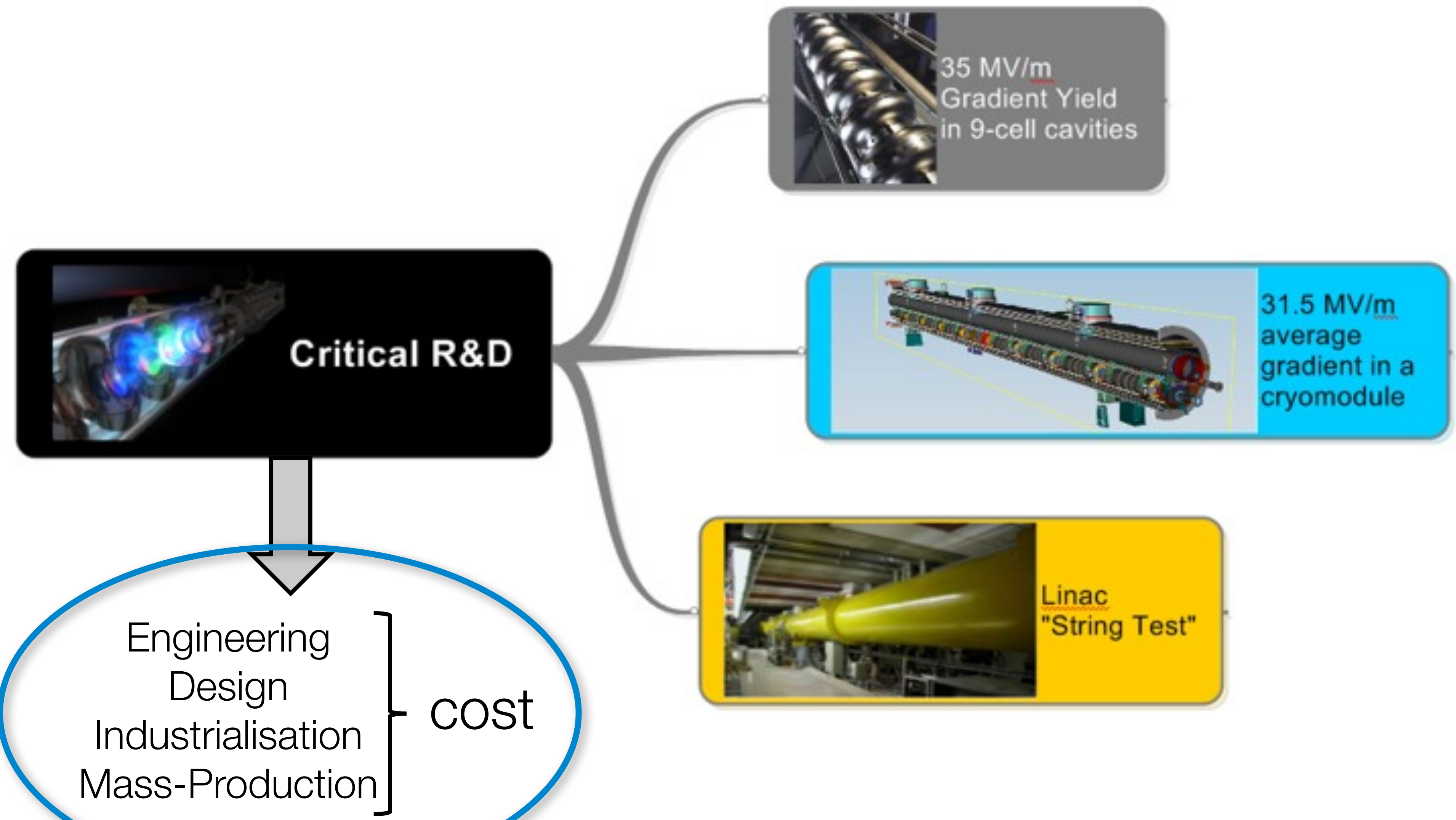


Denis Kostin, MHF-sl, DESY

Global plan for SCRF R&D

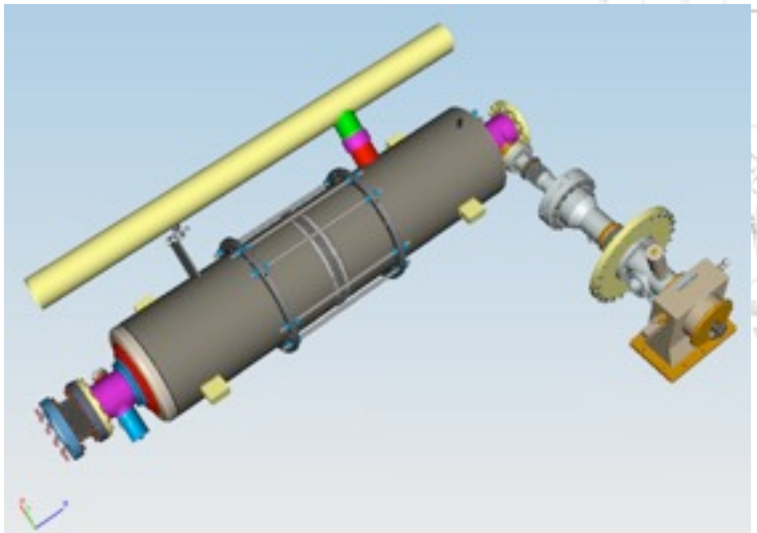
Calendar Year	2007	2008	2009	2010	2011	2012
Technical Design Phase	TDP-1				TDP-2	
Cavity Gradient R&D to reach 35 MV/m		Process Yield **> 50%**			Production Yield **>90%**	
Cavity-string test: with 1 cryomodule			**Global collab. for <31.5 MV/m>**			→
System Test with beam 1 RF-unit (3-module)		FLASH (DESY)			STF2 (KEK) NML (FNAL)	

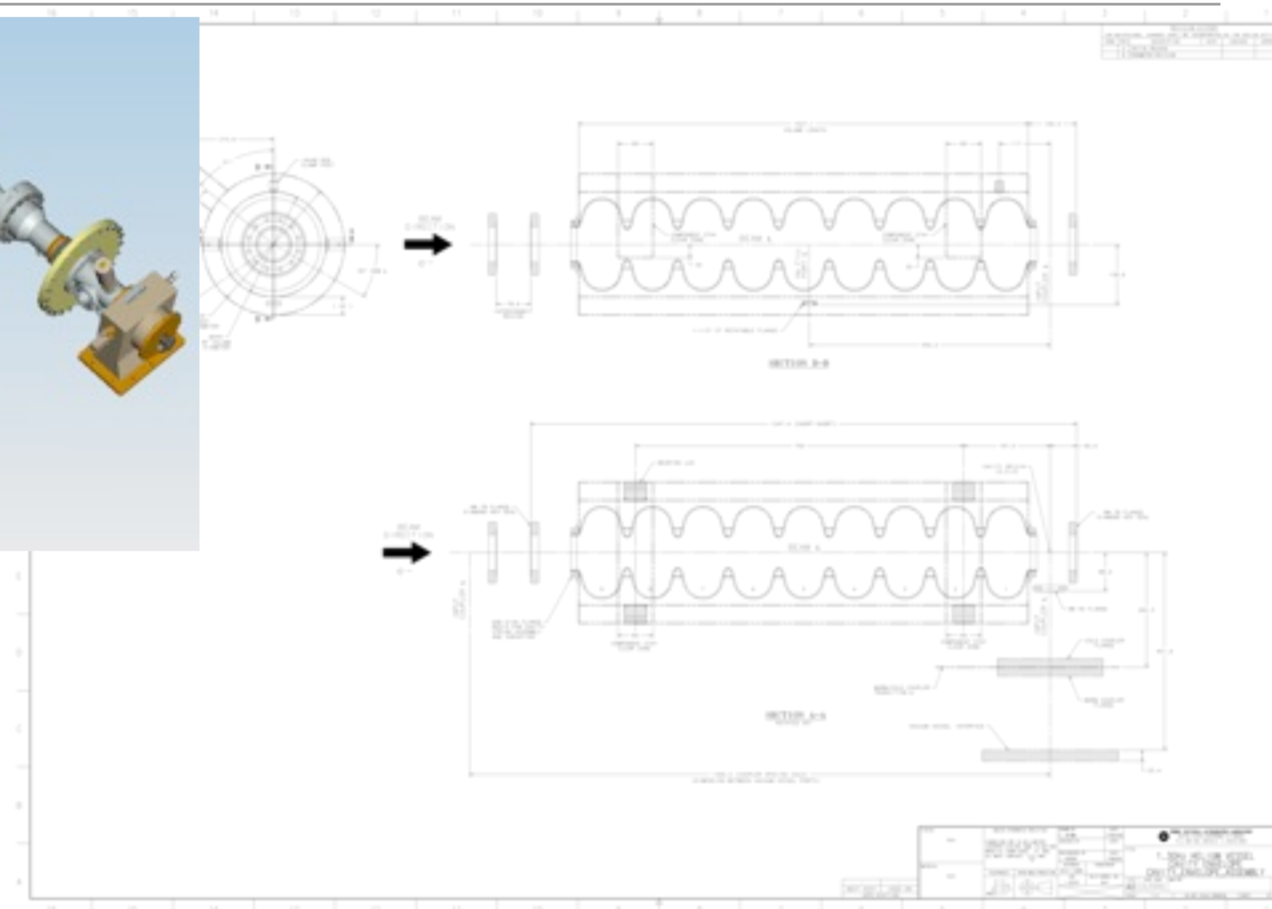
Superconducting RF Technology



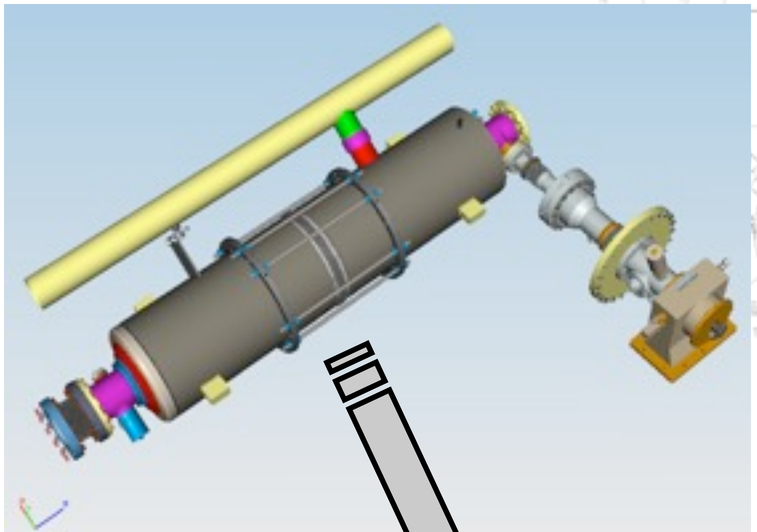
Cavity: Plug-compatible interface

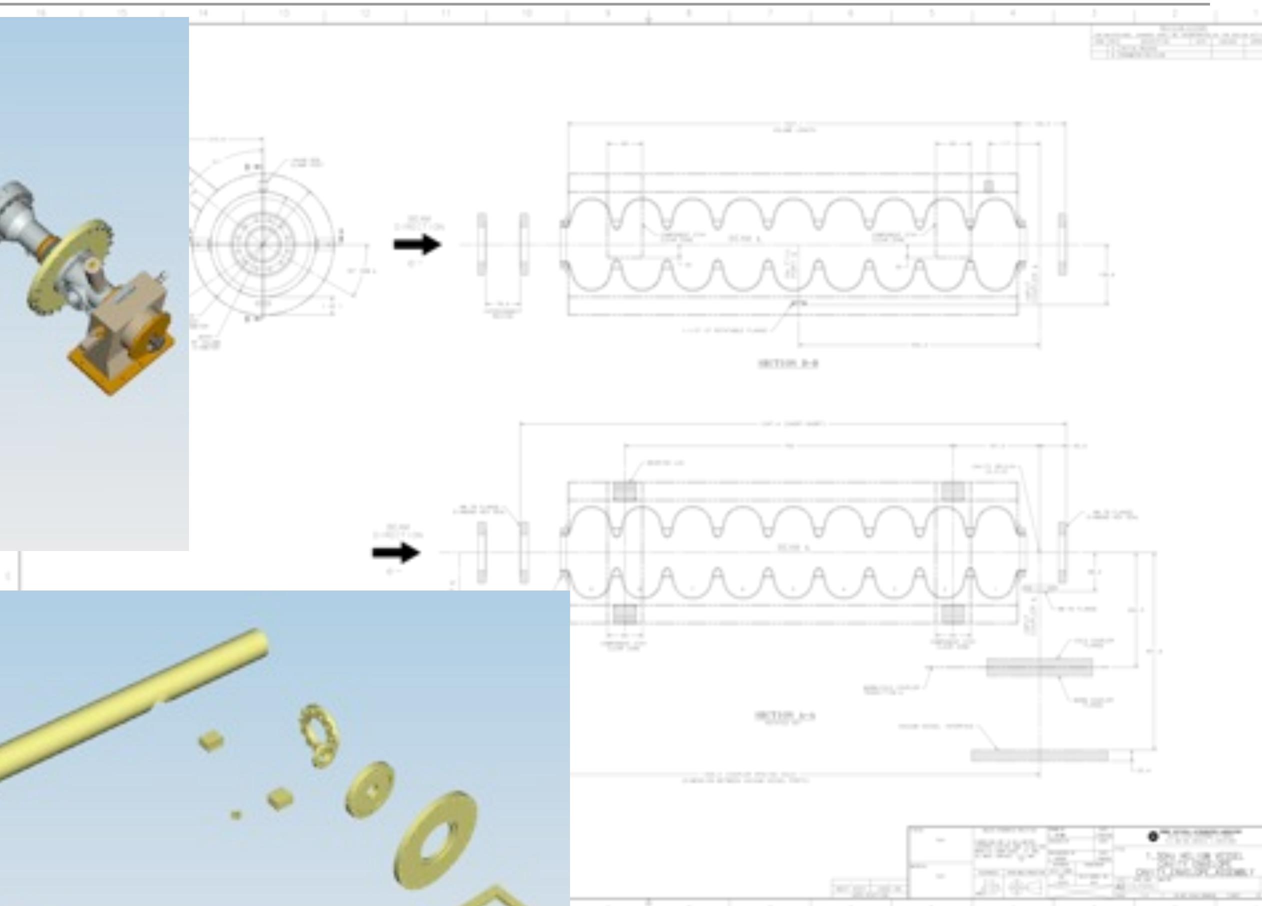
Cavity: Plug-compatible interface

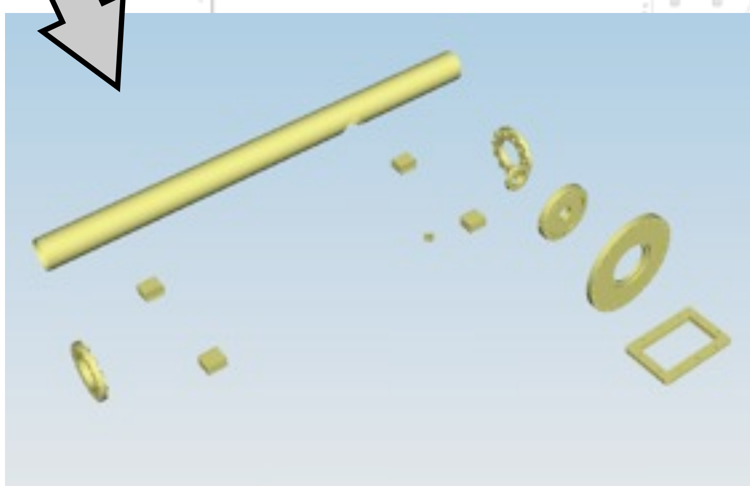




Cavity: Plug-compatible interface

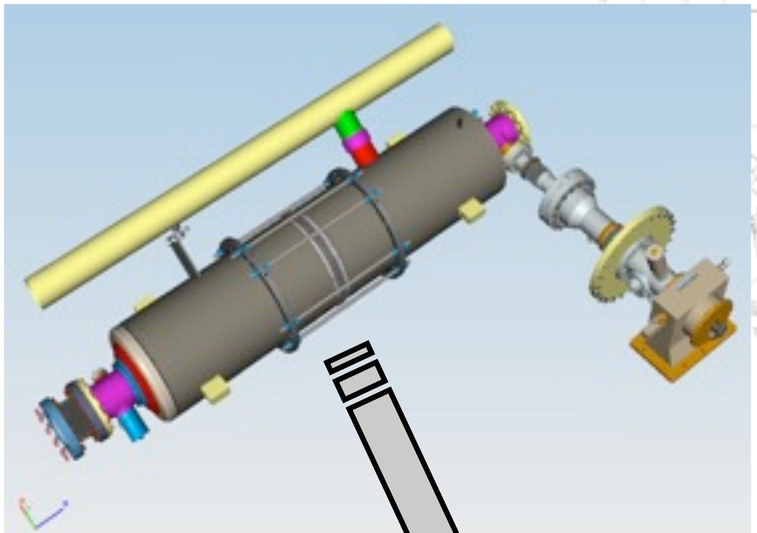




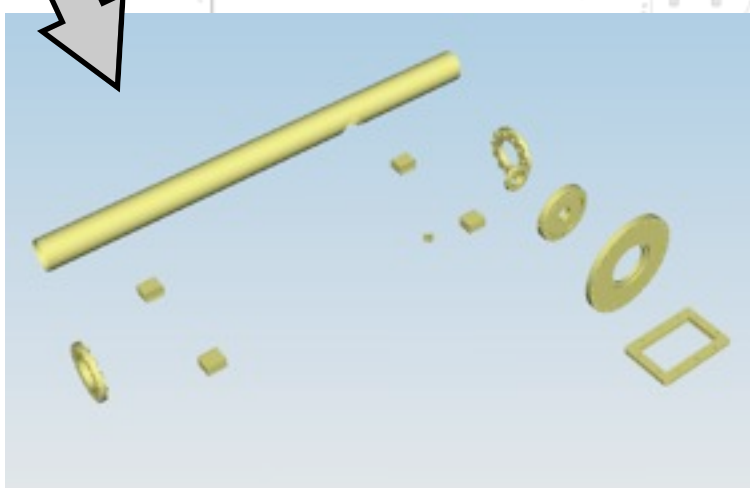


Component interfaces are reduced to the minimum necessary to allow for system assembly

Cavity: Plug-compatible interface



- Allow innovative R&D to continue
  - e.g. novel cavity shapes
- Allow quasi-independent regional development of cost-effective manufacture
- Set boundary conditions and maintain focus



Component interfaces are reduced to the minimum necessary to allow for system assembly

Rapid transition from R&D to construction project

Toward Industrialization

- Global status of Industries
  - Research Instruments and Zanon in Europe
  - AES, Niowave, PAVAC in Americas
  - MHI in Asia

Project Scope	Cavities	Prod.	
European XFEL	~800	2 years	~1 cavity / day
Project X	~400	3 years	~2 cavities/ week
ILC	~15,500	4 years	~20 cavities / day
(÷ 3 regions			~7 cavities / day)

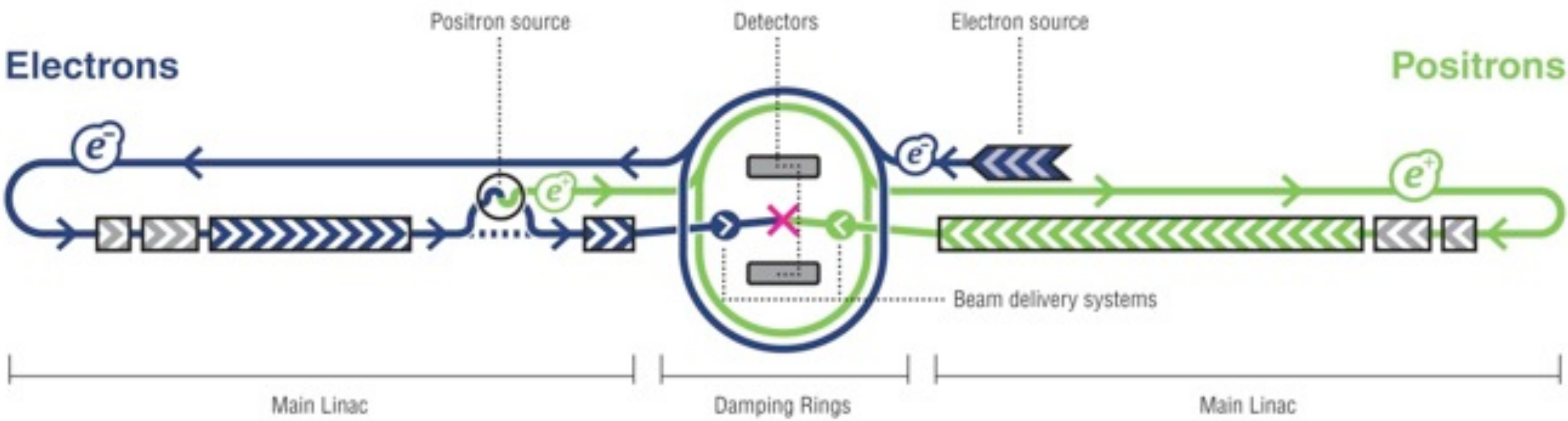
- Industrial Capacity: status and scope
  - No company currently has required ILC capacity
  - Understand what is needed (and cost) by 2012

Industrialization and cost reduction

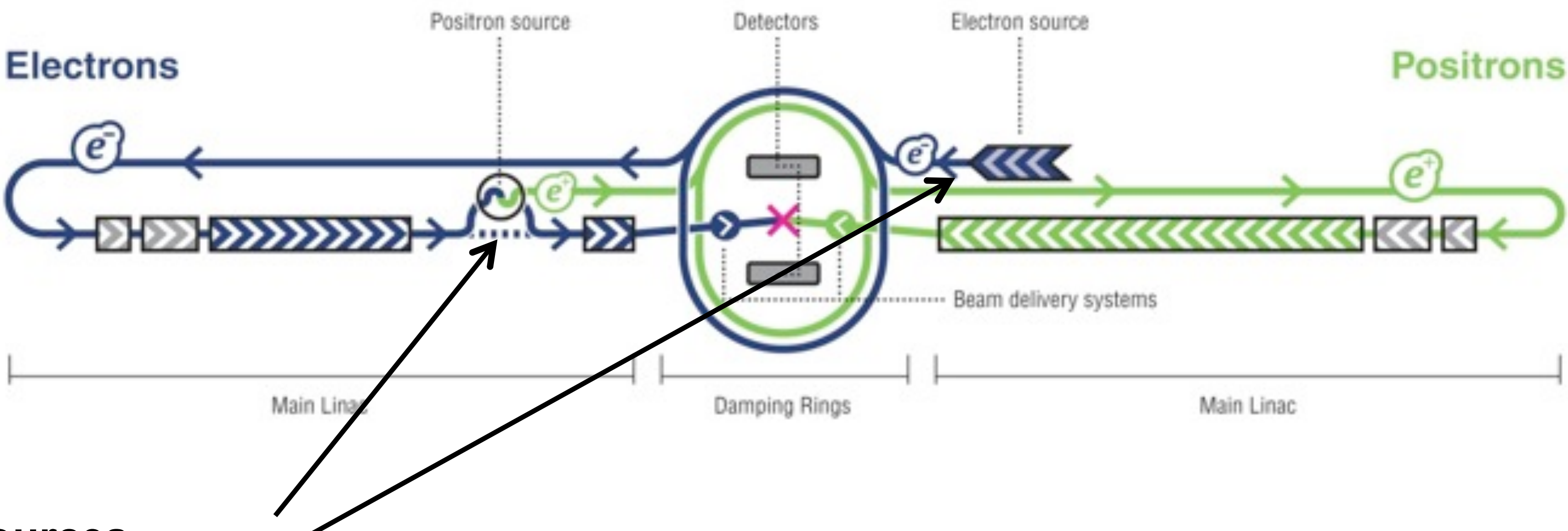
- Re-visit previous effort, and update the cost-estimate for production
  - Review the RDR cost estimate (was based on TESLA)
  - Include recent R&D experience (industry/lab)
- Encourage R&D Facilities for industrialization
  - Develop cost-effective manufacturing, quality control and cost-reduction in cooperation with industry
- Reflect the R&D progress for cost-reduction
  - Baseline ⇒ Forming, electrob-beam welding, assembly work…

ILC: more than just SCRF

ILC: more than just SCRF



ILC: more than just SCRF



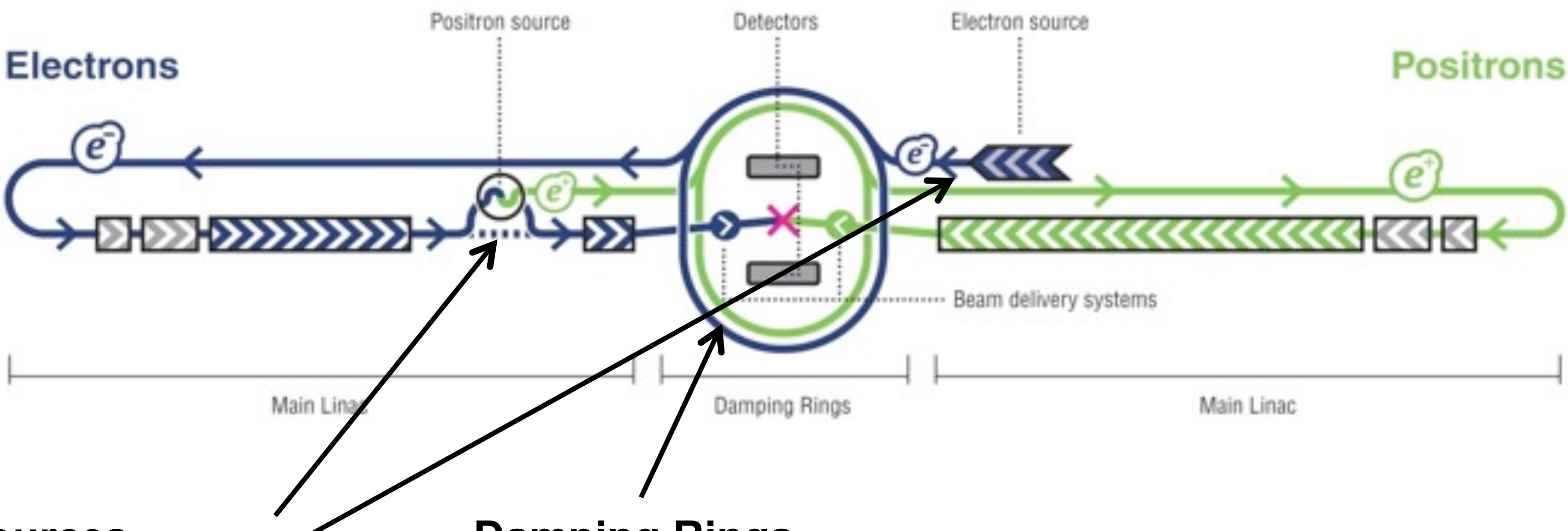
Sources

-Positron production

-Polarised electrons

-…

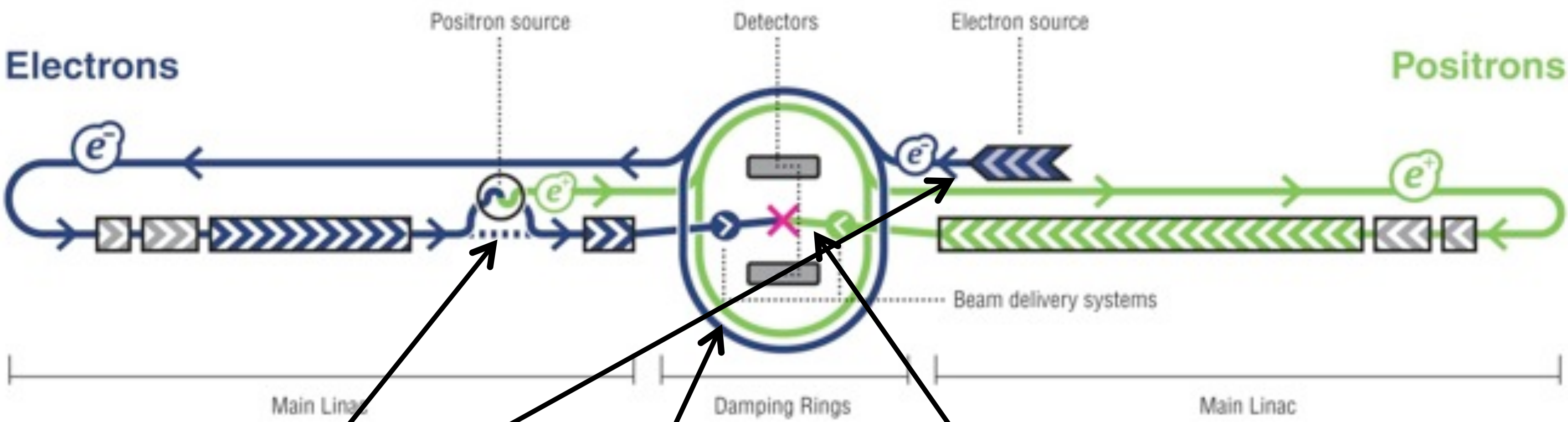
ILC: more than just SCRF



Sources
-Positron production
-Polarised electrons
-…

Damping Rings
-Electron cloud
-Fast kickers
-Low emittance tuning
-…

ILC: more than just SCRF

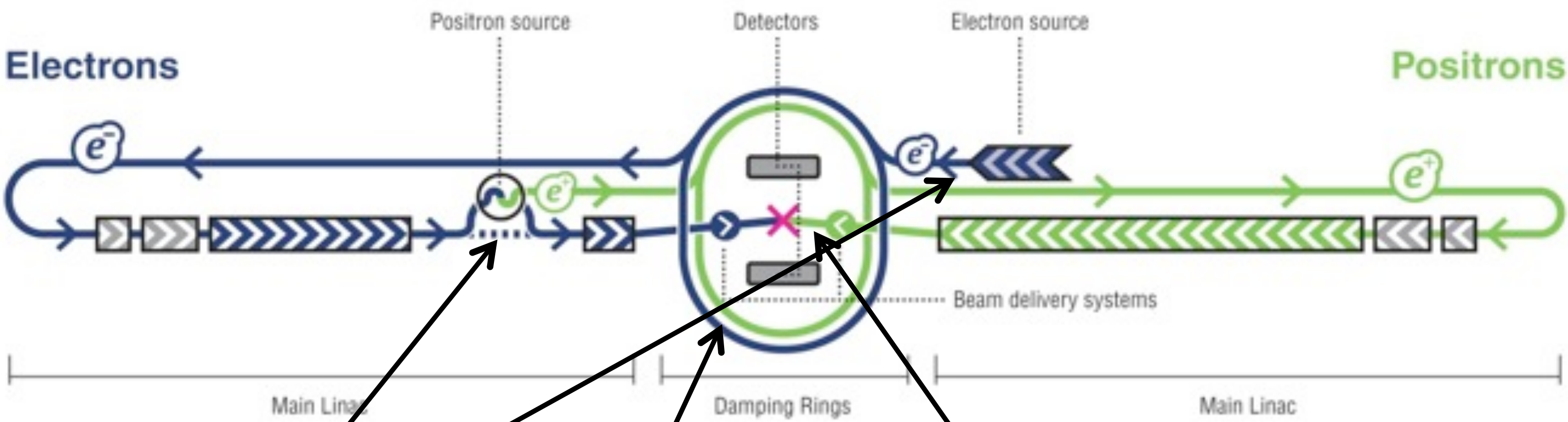


Sources
- -Positron production
- -Polarised electrons
- -…

Damping Rings
- -Electron cloud
- -Fast kickers
- -Low emittance tuning
- -…

Beam Deliver System / MDI
- -Optics / demagnification
- -FD design
- -Stability & feedbacks
- -Detector integration
- -…

ILC: more than just SCRF



Sources
- -Positron production
- -Polarised electrons
- -…

Damping Rings
- -Electron cloud
- -Fast kickers
- -Low emittance tuning
- -…

Beam Deliver System / MDI
- -Optics / demagnification
- -FD design
- -Stability & feedbacks
- -Detector integration
- -…

Beam Test Facilities

(Non-SRF) Beam Test Facilities

(Non-SRF) Beam Test Facilities

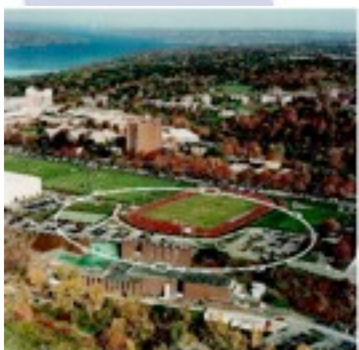
CesrTA (Cornell)
electron cloud
low emittance

(Non-SRF) Beam Test Facilities

KEK, Japan

Cornell

INFN Frascati



CesrTA (Cornell)
electron cloud
low emittance

DAϕNE (INFN Frascati)
kicker development
electron cloud

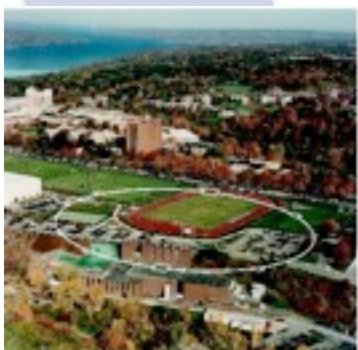
(Non-SRF) Beam Test Facilities

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

KEK,
Japan

Cornell

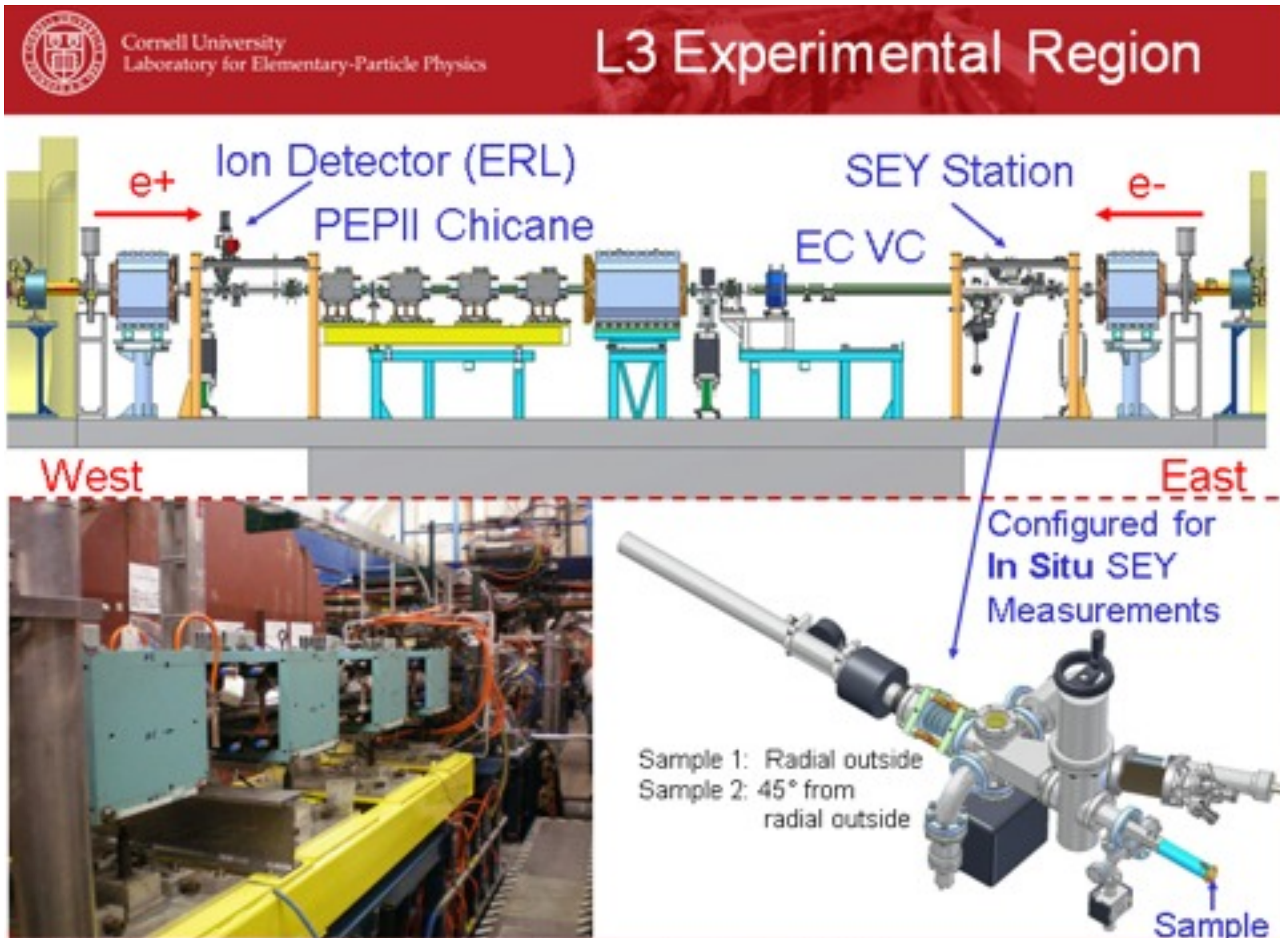
INFN Frascati



CesrTA (Cornell)
electron cloud
low emittance

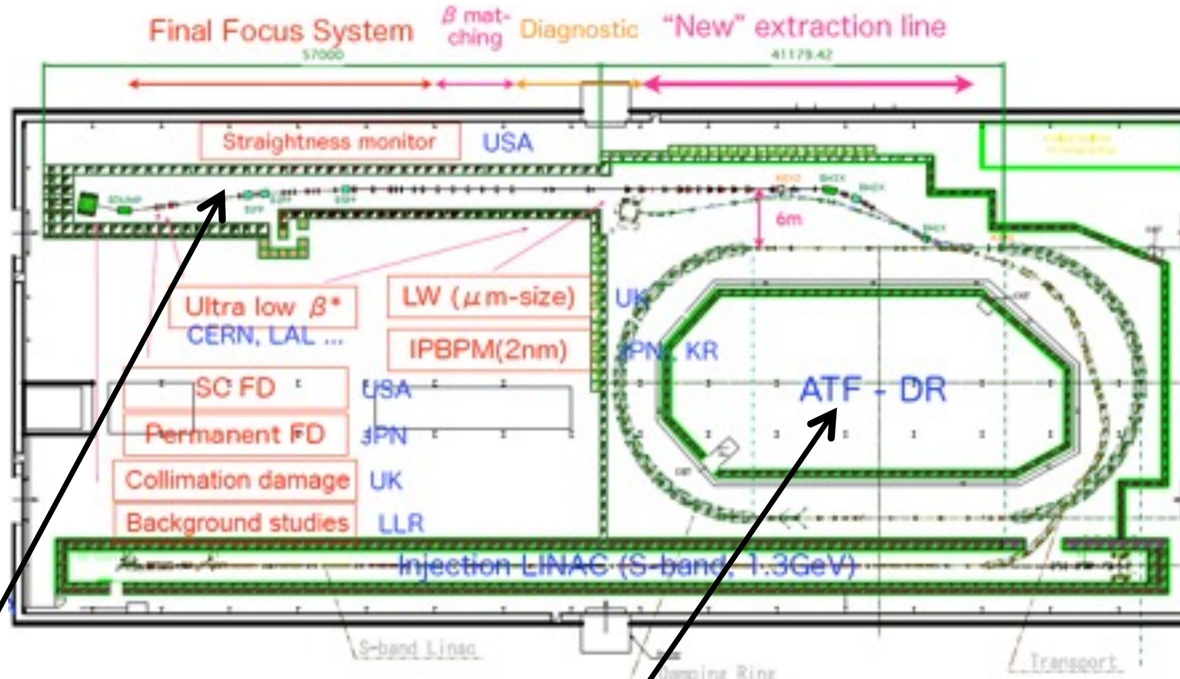
DAϕNE (INFN Frascati)
kicker development
electron cloud

Example: e-cloud & CesrTA (Cornell)



- e-cloud: high-priority risk mitigating R&D
- Cornell SLAC KEK INFN…
- CesrTA: dedicated test facility to
  - Test e-cloud suppression techniques
  - Benchmark and develop theoretical understanding (codes)
  - Develop low-emittance tuning techniques

Example: ATF & ATF2 (KEK)



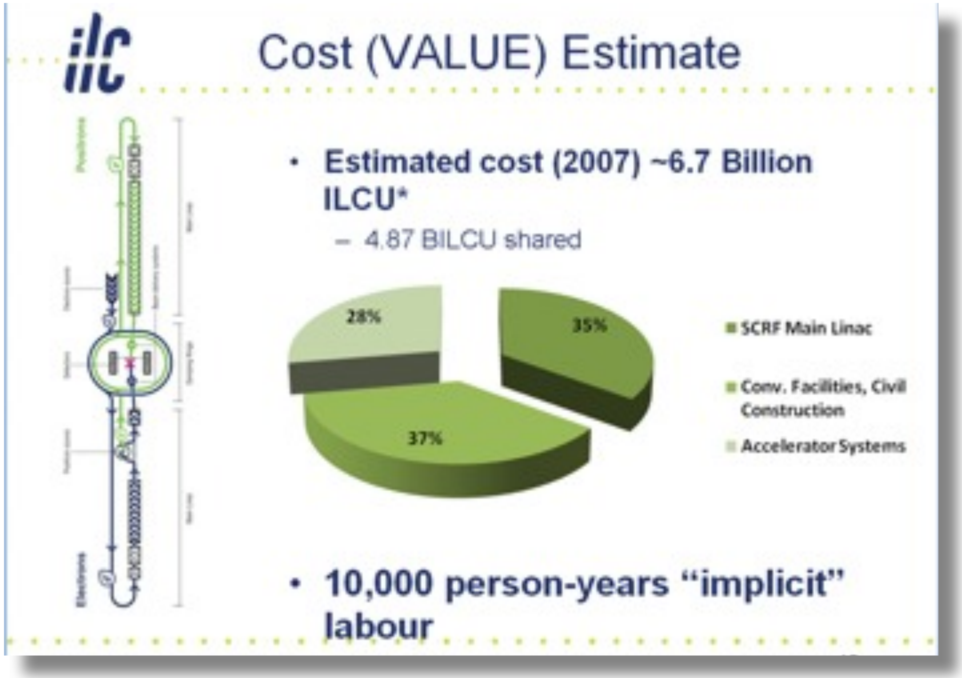
<u>ATF2 (Final Focus)</u>

- Demonstration of demagnification / compact optics
- Vibration stabilisation
- Instrumentation

<u>ATF (Damping Ring)</u>

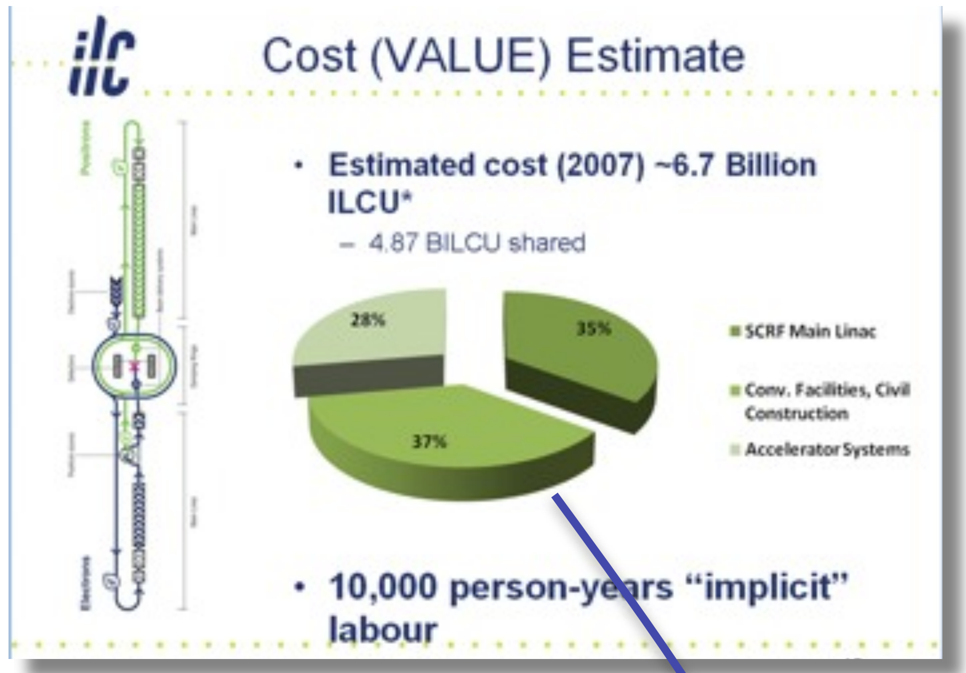
- Demonstration of ultra-low emittance (2pm) and its stability
- Fast kicker (beam) tests

Integration & Design Activities



Integration & Design Activities

- Primary TD Phase Deliverable:
  - Updated design
  - Updated VALUE estimate
- RDR sound base-line
  - Mature, ***but***
  - Conservative



- Use 'additional' time to look at options
  - Cost not performance driven
  - CFS cost-driver ⇒ reduce underground volume

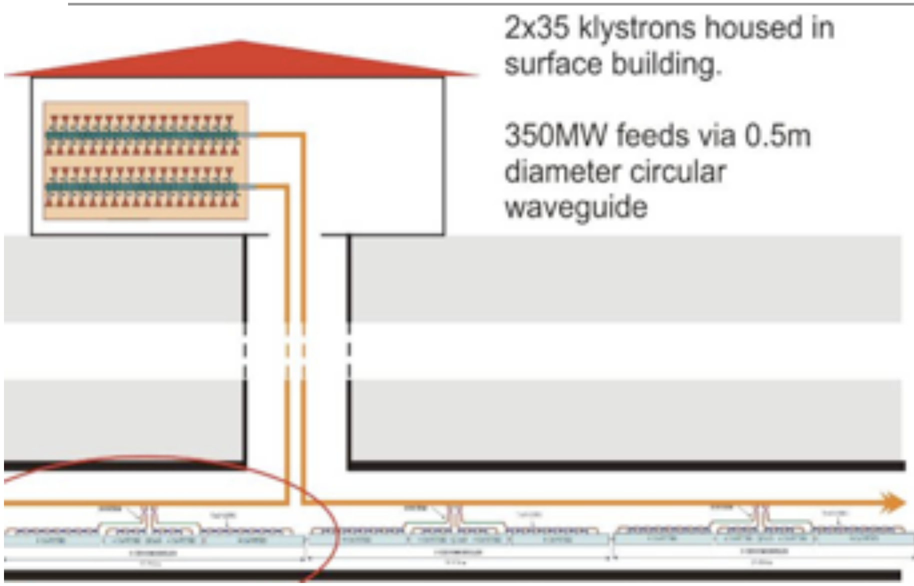
Cost-Driver Design Studies

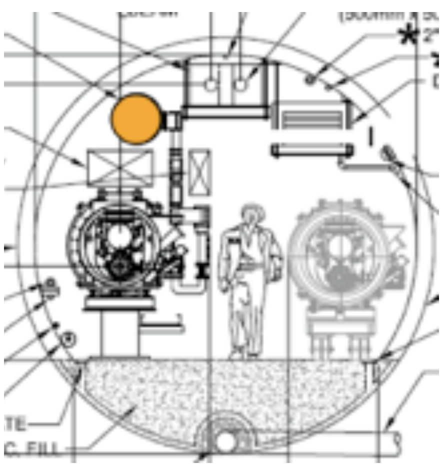
- Single Tunnel Configuration(s)
- Reduced Beam Power
  - less RF,
  - smaller DR
- Central Injector Housing Integration
  - Sources sharing tunnel with BDS
- CFS: Value Engineering

Power In
Power Out
Underground Volume

10-15% TPC

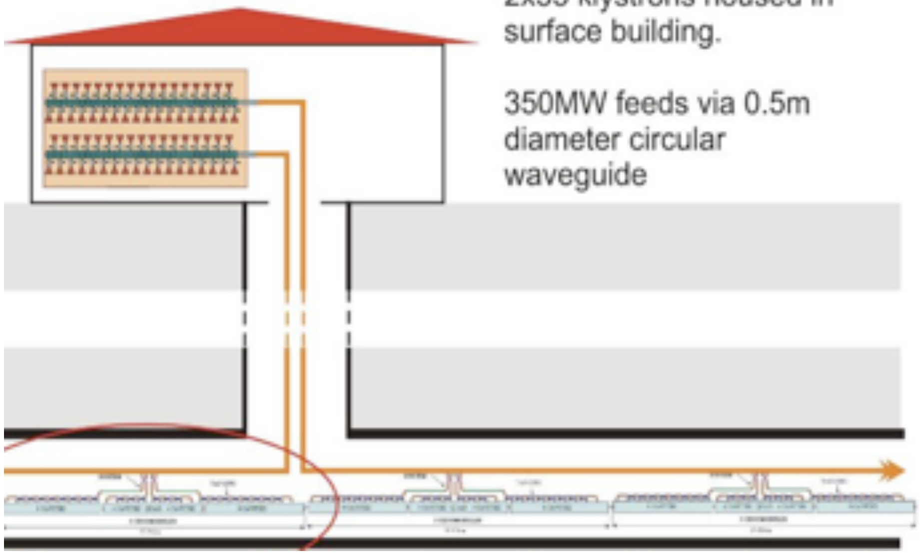
Novel RF Distribution Concepts





Klystron Cluster
(SLAC)

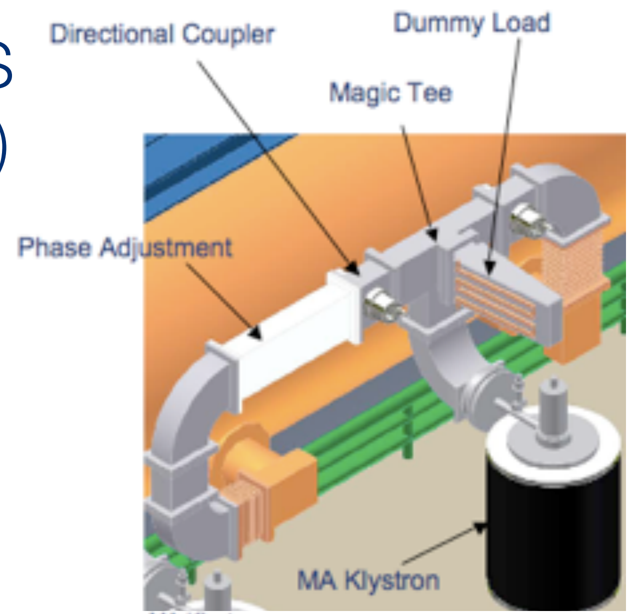
Novel RF Distribution Concepts

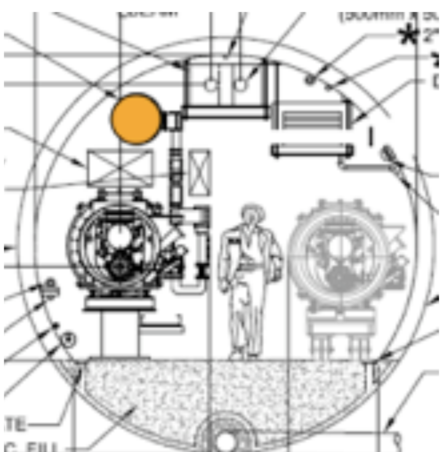


2x35 klystrons housed in surface building.

350MW feeds via 0.5m diameter circular waveguide

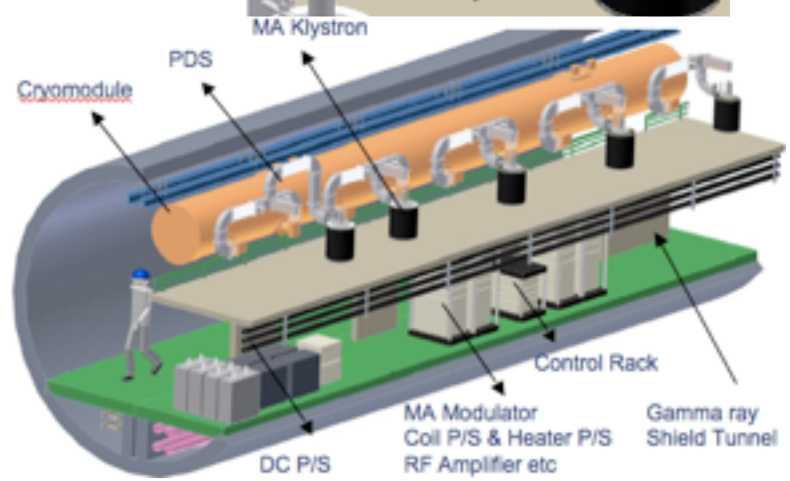
DRFS (KEK)



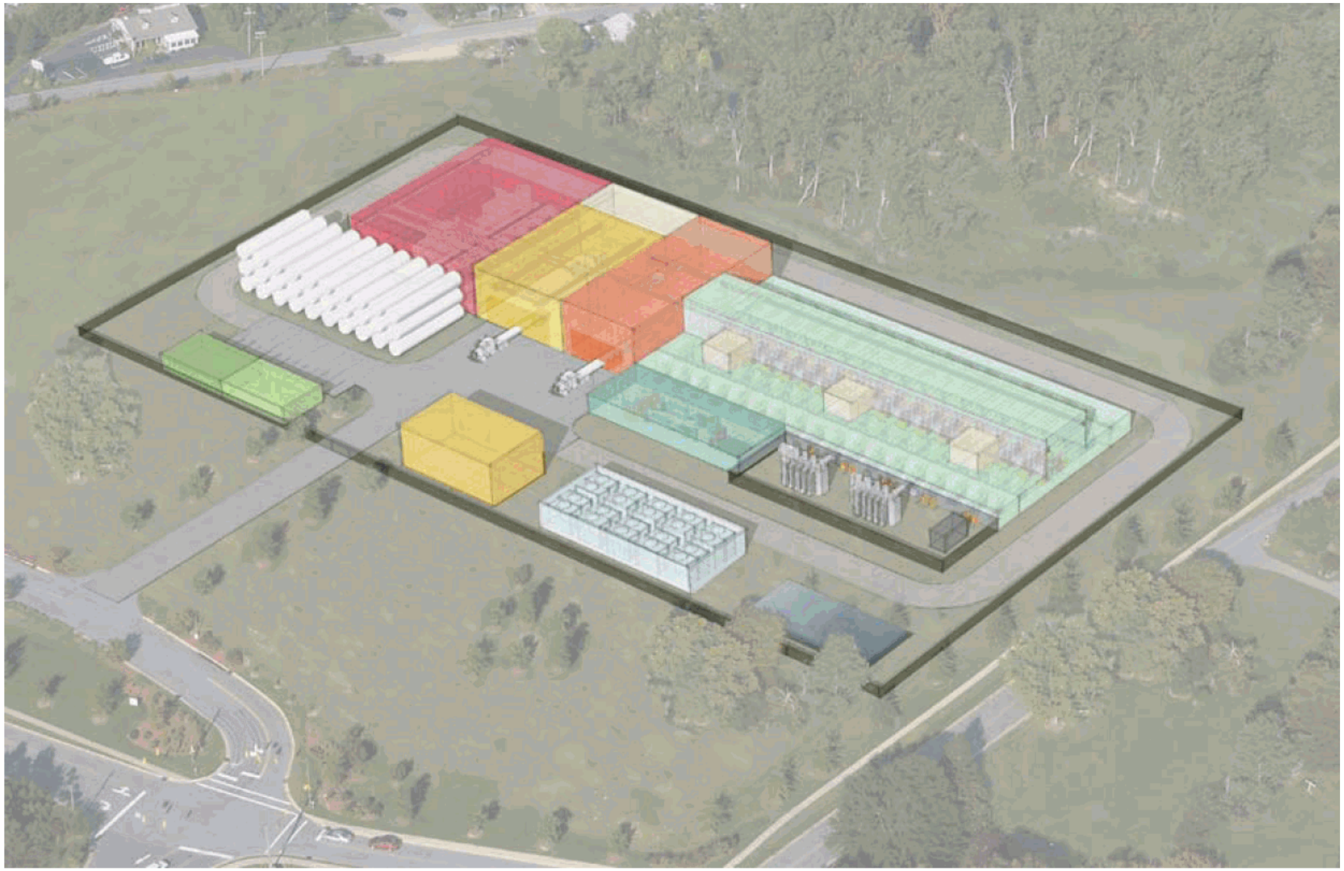


Klystron Cluster (SLAC)

Single Tunnel Solutions

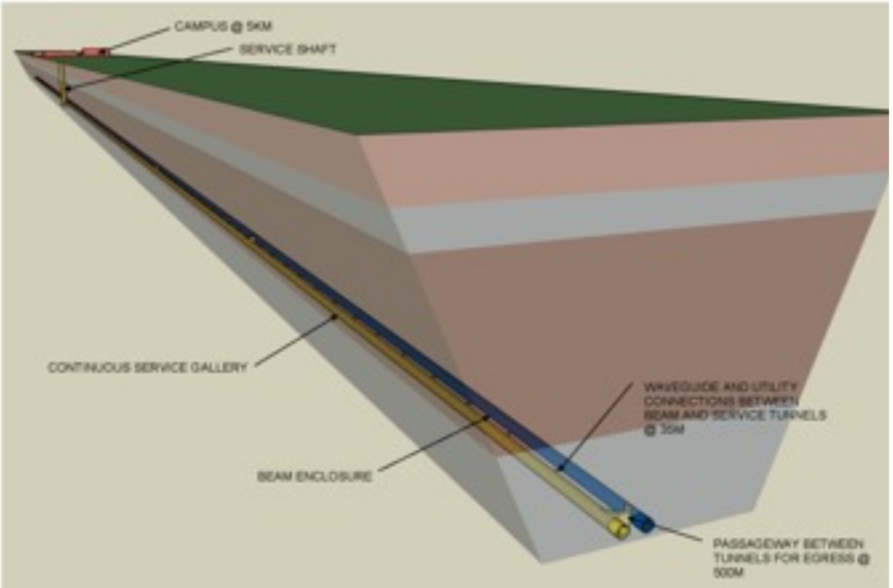


Klystron Cluster System – Surface Building

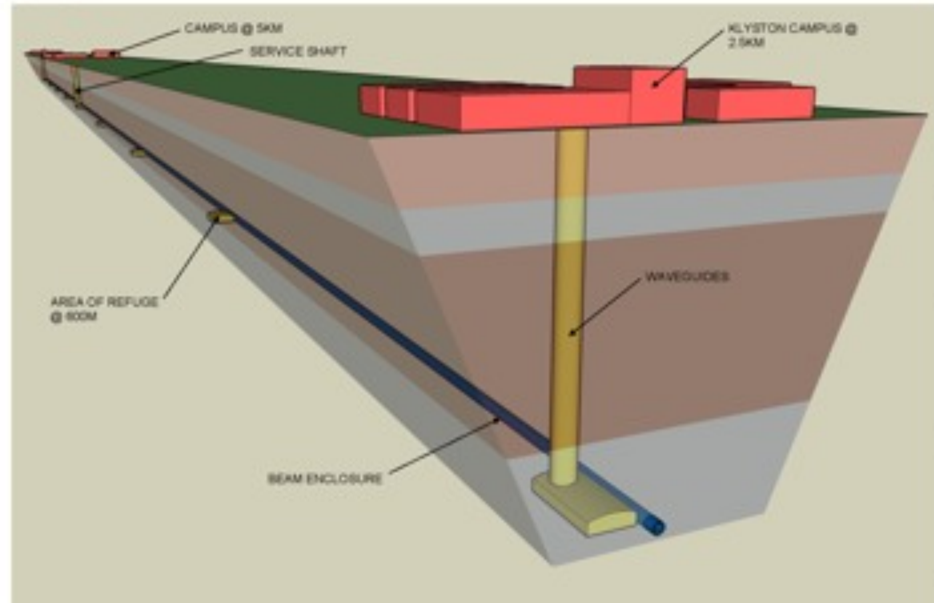


RF UNIT BUILDING	CRYO BUILDING	ADMIN
SURFACE PROCESS COOLING DI PLANT	SHAFT ACCESS BUILDING	WORKSHOP
FAN-HOUSE	SUPPORT	LOADING BAY

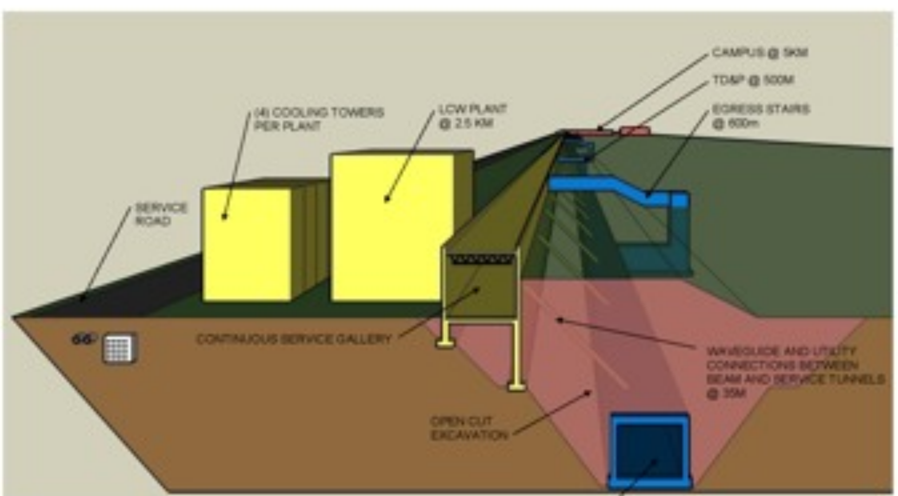
TWIN DEEP TUNNELS; VERTICAL ACCESS



SINGLE DEEP TUNNEL; VERTICAL ACCESS

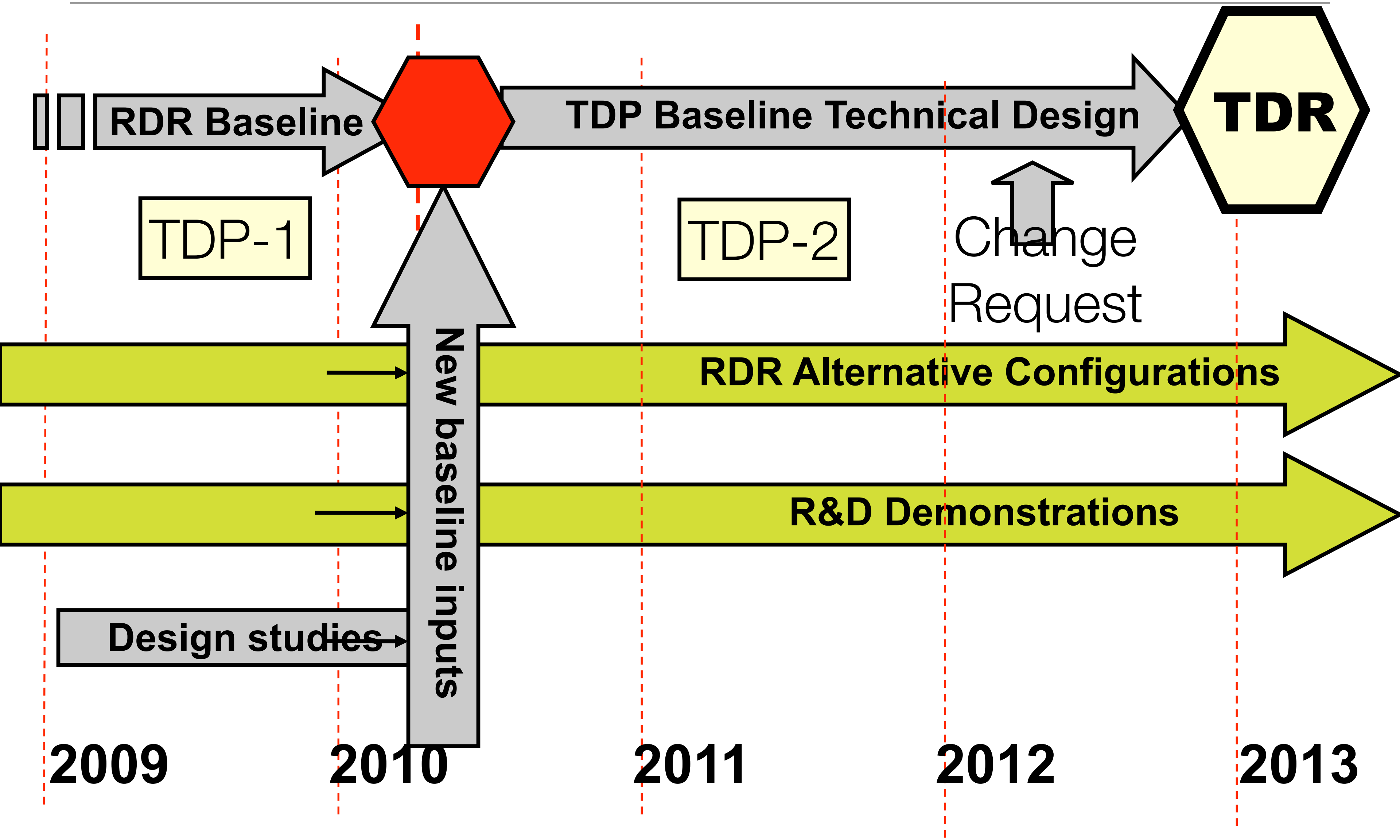


ENCLOSURE IN OPEN CUT EXCAVATION; CONTINUOUS SERVICI



Linac Tunnel configurations – 3 of 7 under study

Technical Design Phase and Beyond



Summary ILC

- Significant progress on all identified priority R&D (despite 2008 funding crises)
- Primary focus maintained on SCRF (Cost driver)
  - Development in all three regions
    - Significant progress on gradient yield
    - Demonstration of high-gradient cryomodule and plug compatibility
    - No full “ILC-spec” string test within TDR time-scale
- Major Beam Test Facility addressing (non-SCRF) risk mitigating R&D
  - CesrTA – e-cloud
  - ATF2 BDS/MDI issues
- Design and integration activities (including CFS) focusing on updating baseline for TD Phase 2
  - Site variants being studied

Updated design for ILC will be ready by 2012

Common R&D Activities for ILC & CLIC

- Many technical aspects are independent of acceleration technology and can be addressed in common
- EUROTeV, a 27 M€ design study for a TeV Linear Collider, encompassed both ILC and CLIC during its project duration 2005–2008
- Test facilities such as ATF/ATF2 naturally serve ILC and CLIC purposes
- It is hence natural to collaborate on a world-wide basis by the establishment of common working groups

CLIC – ILC Working Groups

	CLIC	ILC
Physics & Detectors	L.Linssen, D.Schlatter	F.Richard, S.Yamada
Beam Delivery System (BDS) & Machine Detector Interface (MDI)	D.Schulte, R.Tomas Garcia E.Tsesmelis	B.Parker, A.Seryi
Civil Engineering & Conventional Facilities	C.Hauviller, J.Osborne.	J.Osborne, V.Kuchler
Positron Generation (new)	L.Rinolfi	J.Clarke
Damping Rings (new)	Y.Papaphilipou	M.Palmer
Beam Dynamics	D.Schulte	A.Latina, K.Kubo, N.Walker
Cost & Schedule	H.Braun (P.Lebrun), K.Foraz, G.Riddone	J.Carwardine, P.Garbincius, T.Shidara

Summary LC

- any new very large-scale project of HEP will have to await
  - the successful start-up of LHC and √
  - the first physics harvest (√)
- towards the end of 2012 hence appropriate time to
  - decide on construction of a 0.5 TeV ILC that is upgradeable to 1 TeV
- or / and
  - focus on the multi-TeV region from the start
    - Advance the CLIC concept to maturity