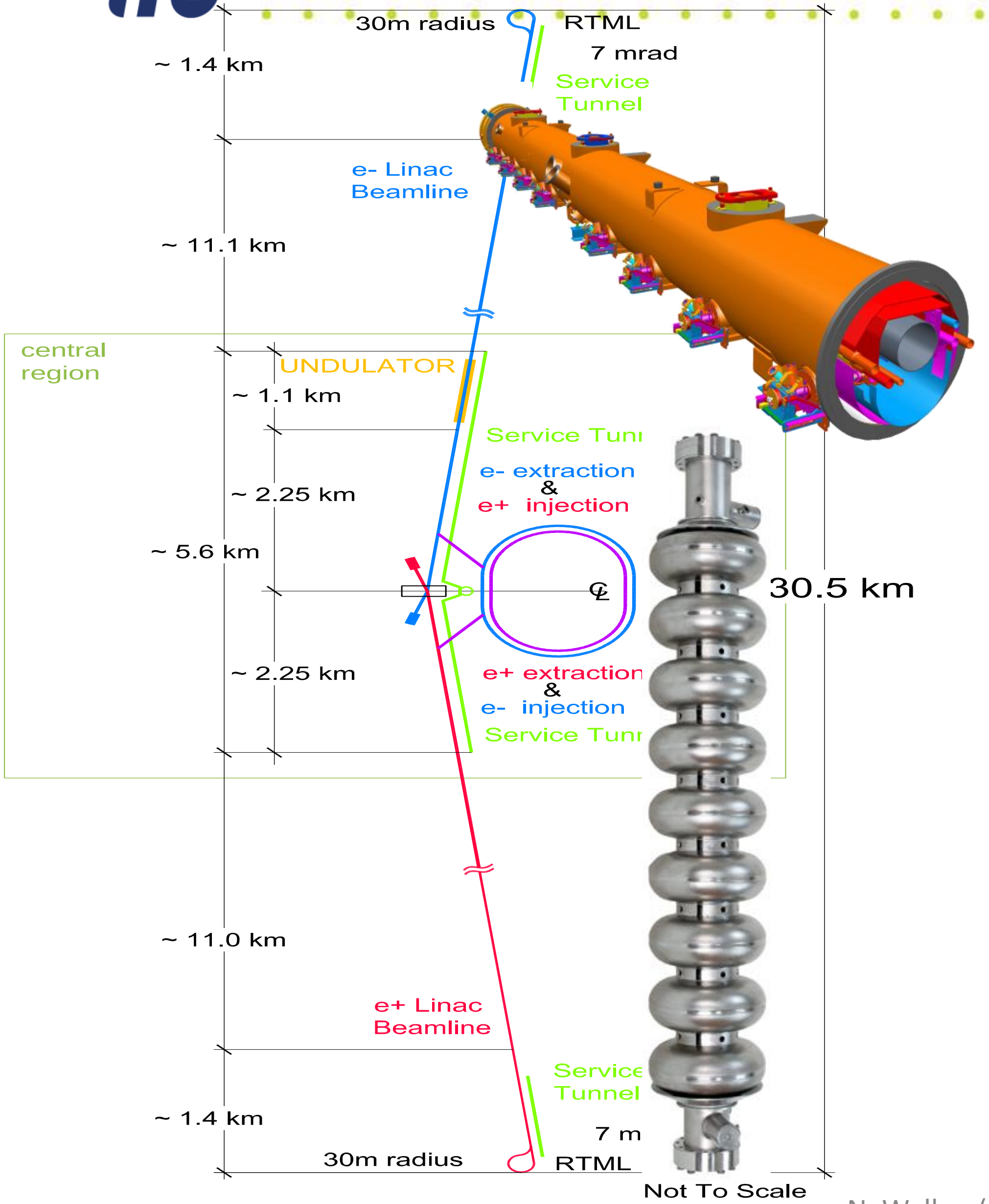
The ILC Accelerator Complex

Nick Walker – DESY/GDE

International Linear Collider – A Worldwide Event
12 June 2013
CERN, Geneva, Switzerland.

ILC in a Nutshell



- 200-500 GeV E_{cm} e^+e^- collider $L \sim 2\times10^{34}\ cm^{-2}s^{-1}$
  - upgrade: ~1 TeV
- SCRF Technology
  - 1.3GHz SCRF with 31.5 MV/m
  - 17,000 cavities
  - 1,700 cryomodules
  - 2×11 km linacs
- Developed as a truly global collaboration
  - **G**lobal **D**esign **E**ffort – **GDE**
  - ~130 institutes
  - http://www.linearcollider.org/ILC

500 GeV Parameters

Physics

Max. E_{cm}	500 GeV
Luminosity	1.8×10^{34} $cm^{-2}s^{-1}$
Polarisation (e-/e+)	80% / 30%
δ_{BS}	4.5%

Beam (interaction point)

tiny emittances
nano-beams at IP
strong beam-beam

σ_x / σ_y	574 nm / 6 nm
σ_z	300 μm
$\gamma\varepsilon_x$ / $\gamma\varepsilon_y$	10 μm / 35 nm
β_x / β_y	11 mm / 0.48 mm
bunch charge	2×10^{10}

...ructure)

High-power high-current beams. Long bunch trains.
→ SCRF

Number of bunches / pulse	1312
Bunch spacing	554 ns
Pulse current	5.8 mA
Beam pulse length	727 μs
Pulse repetition rate	5 Hz

Accelerator (general)

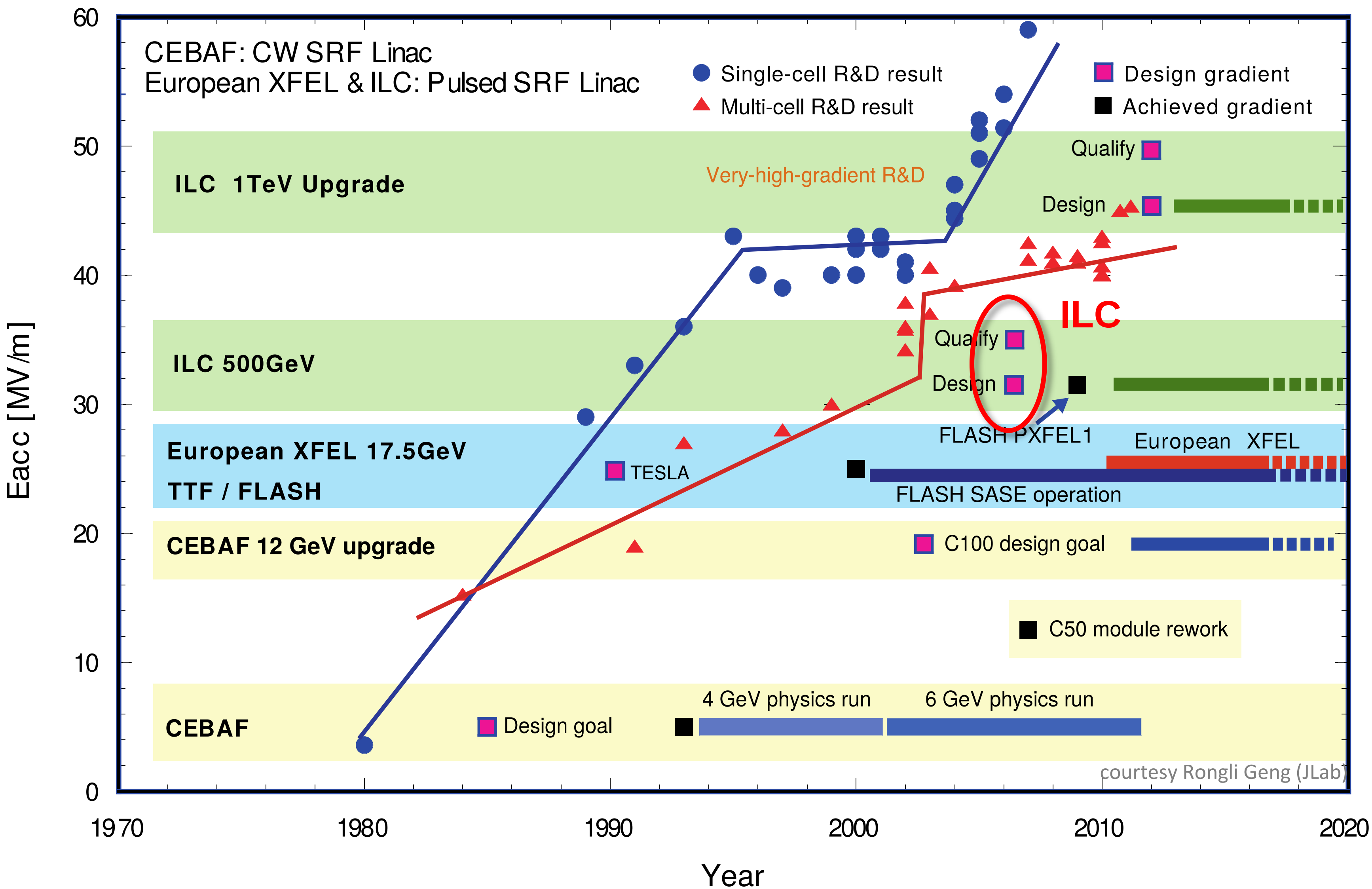
Average beam power	10.5 MW (total)
Total AC power	163 MW
(linacs AC power	107 MW)

1.3 GHz Superconducting RF Cavity

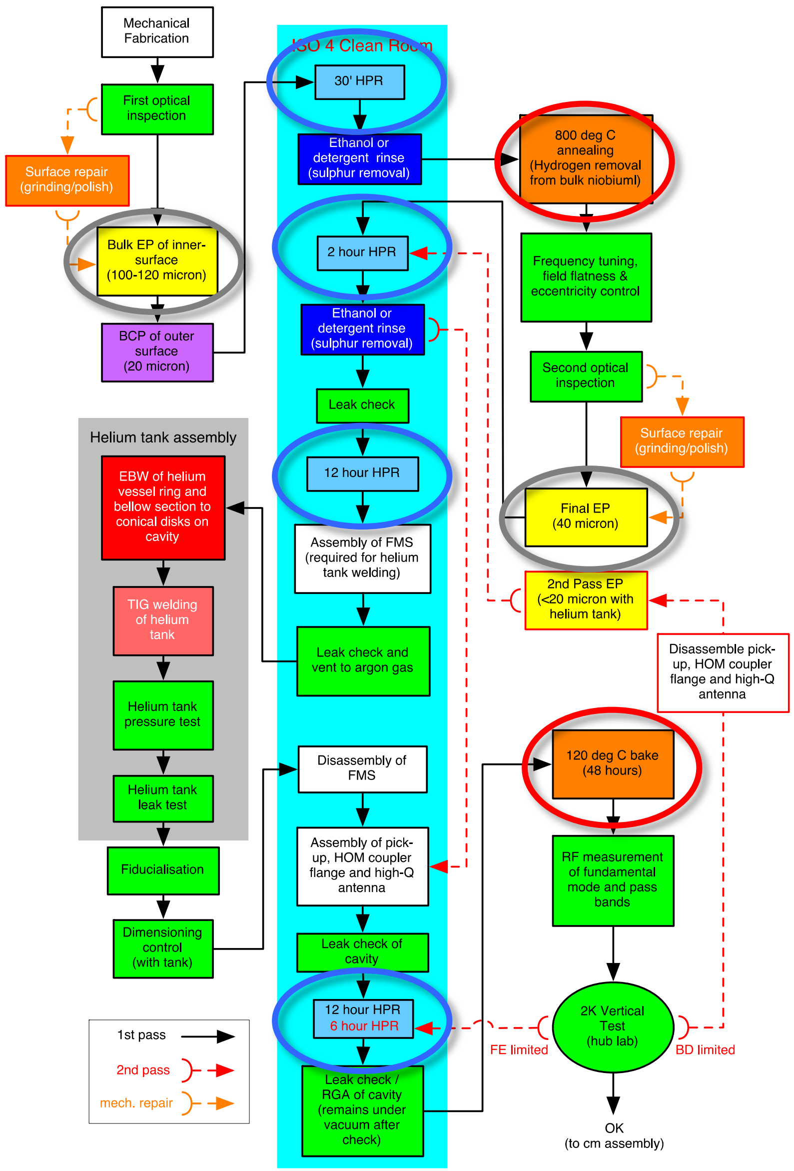
- solid niobium
- standing wave
- 9 cells
- operated at 2K (LHe)

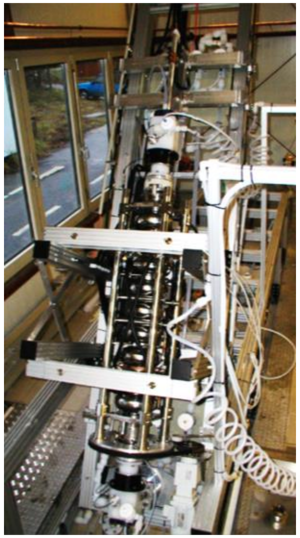
- 35 MV/m
- $Q_0 \geq 10^{10}$

The Quest for High Gradient

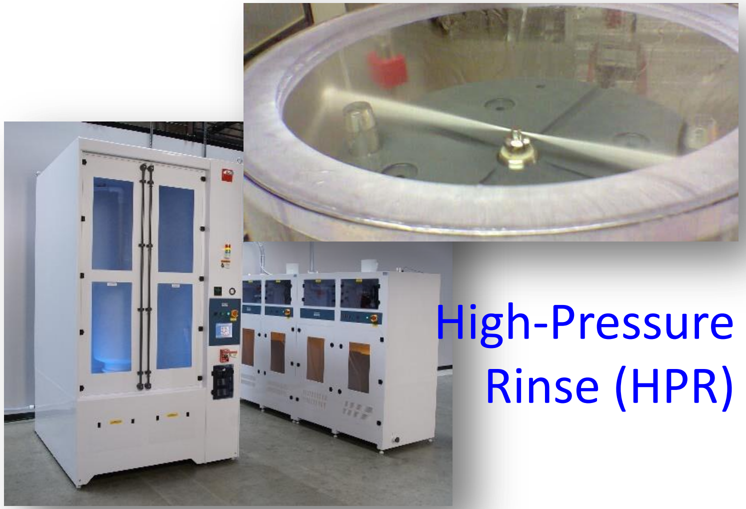


Road to High Performance





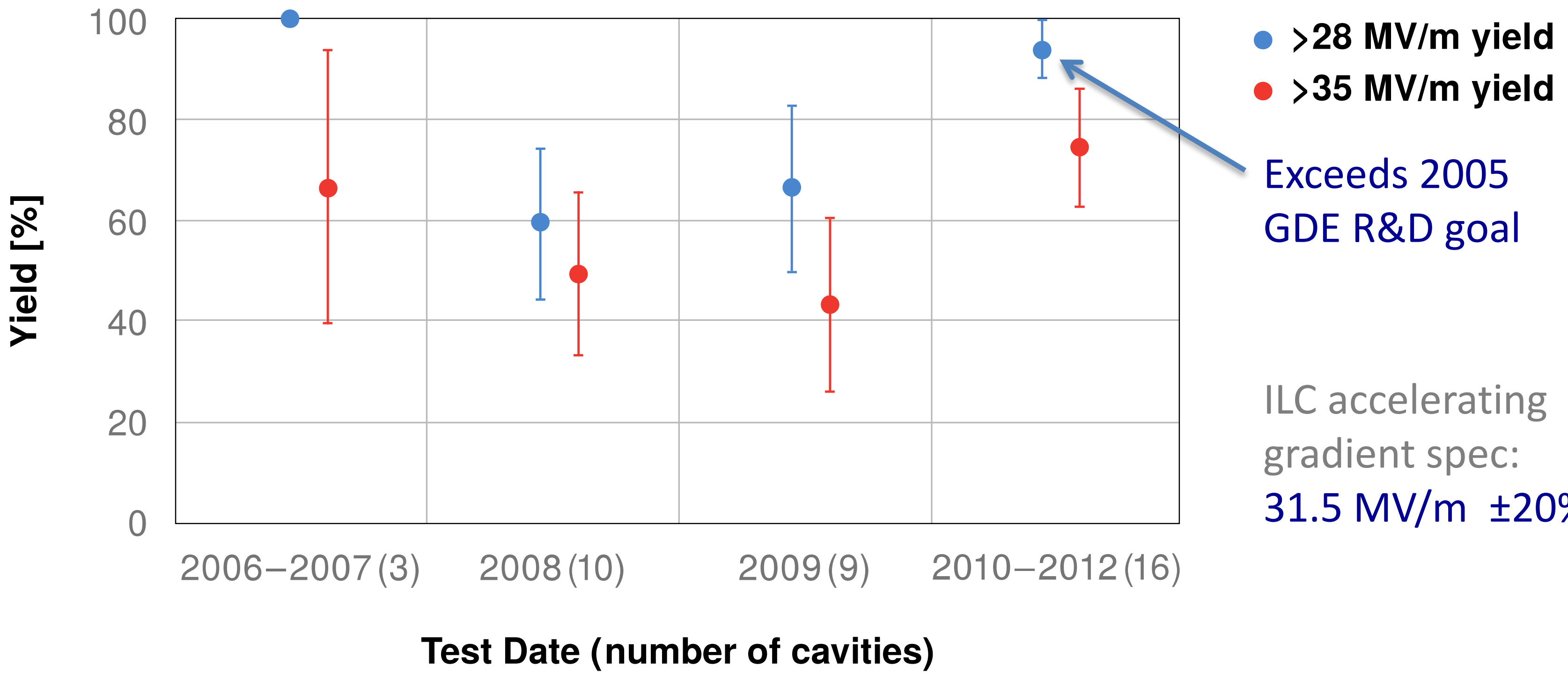
Electropolishing



High-Pressure Rinse (HPR)

800° C annealing and 120° C baking

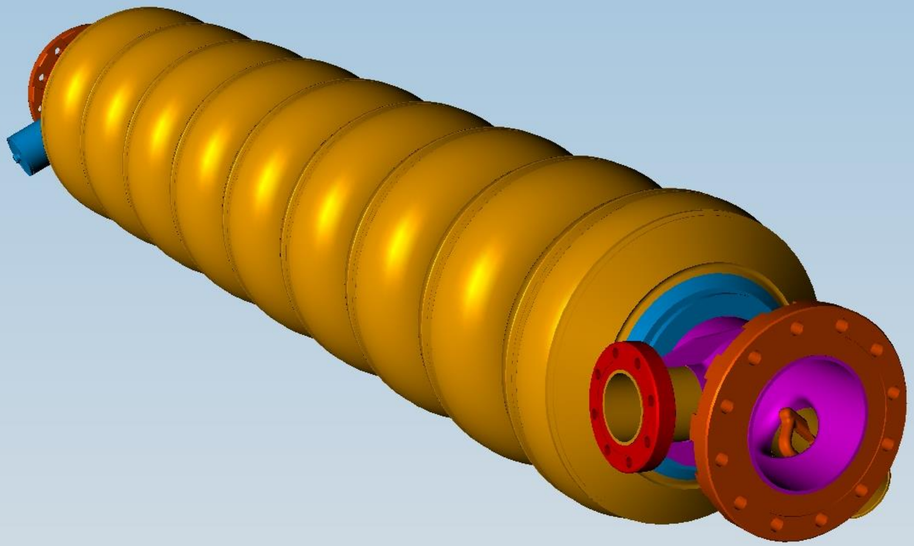
Worldwide gradient R&D



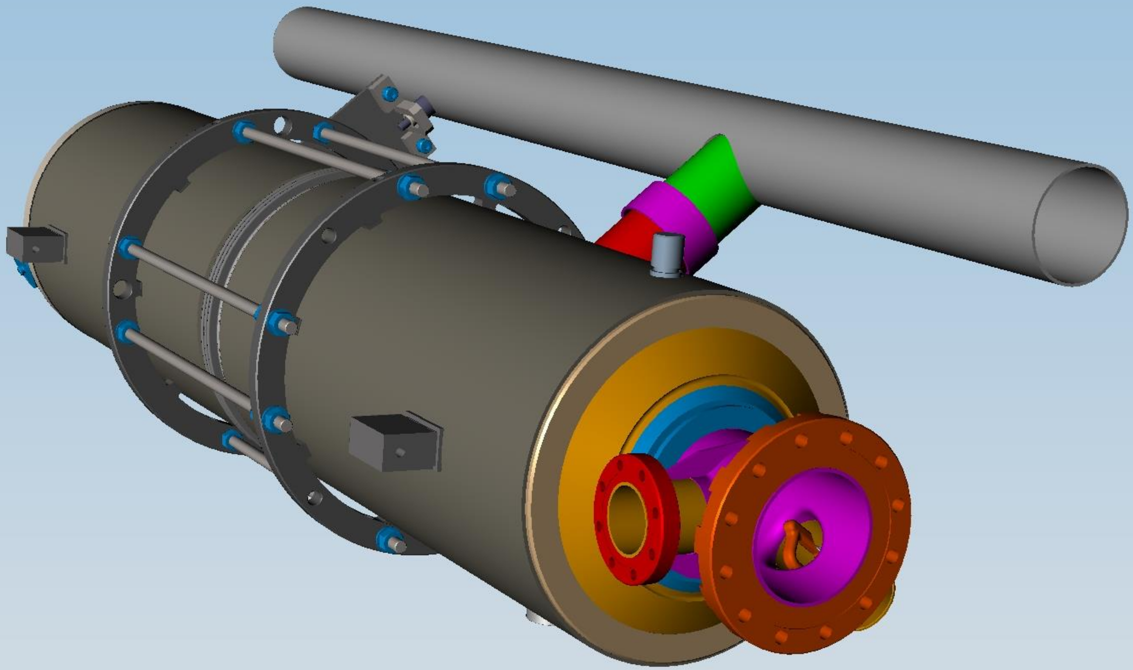
ILC accelerating gradient spec:
31.5 MV/m ±20%

GDE global database	Asia – KEK; Europe – DESY; US – JLab, FNAL, ANL
Qualified cavity vendors	Asia – 2; Europe – 2; US – 1

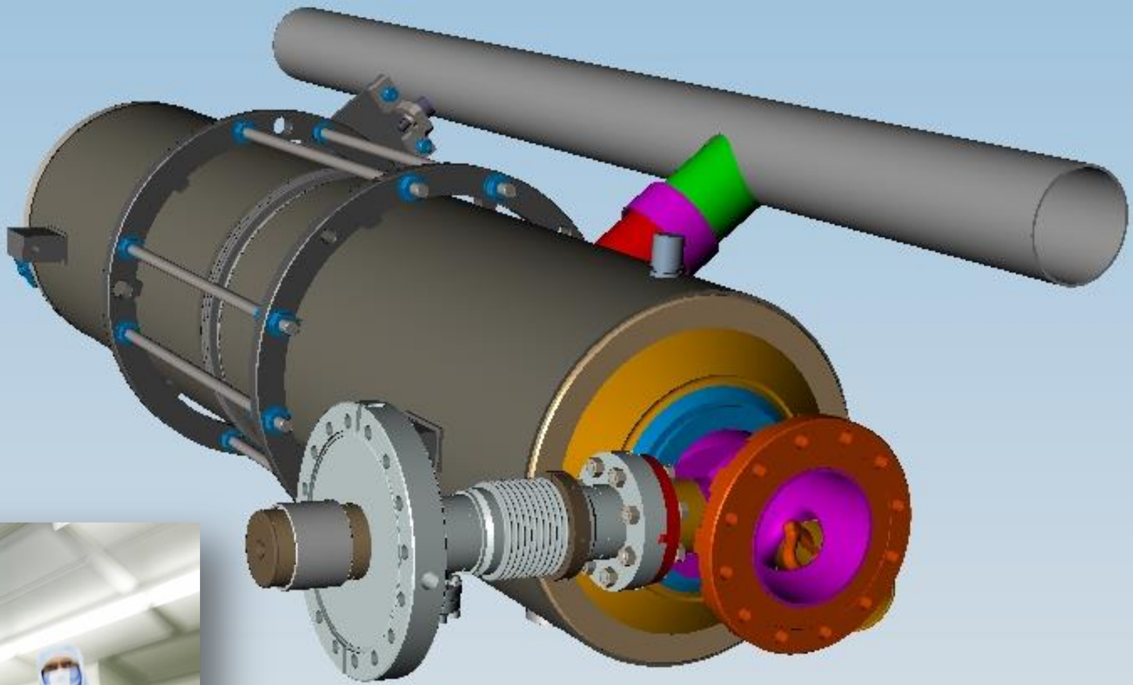
Cryomodule construction



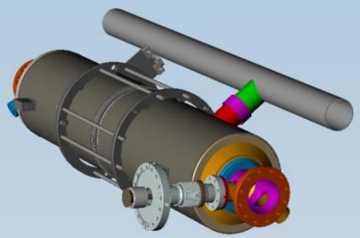
Cryomodule construction



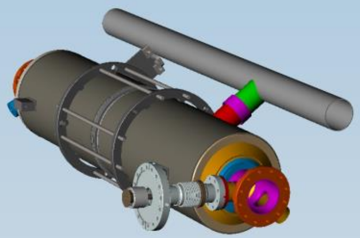
Cryomodule construction



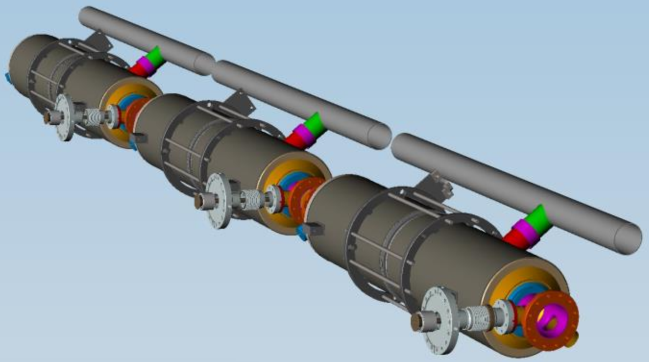
Cryomodule construction



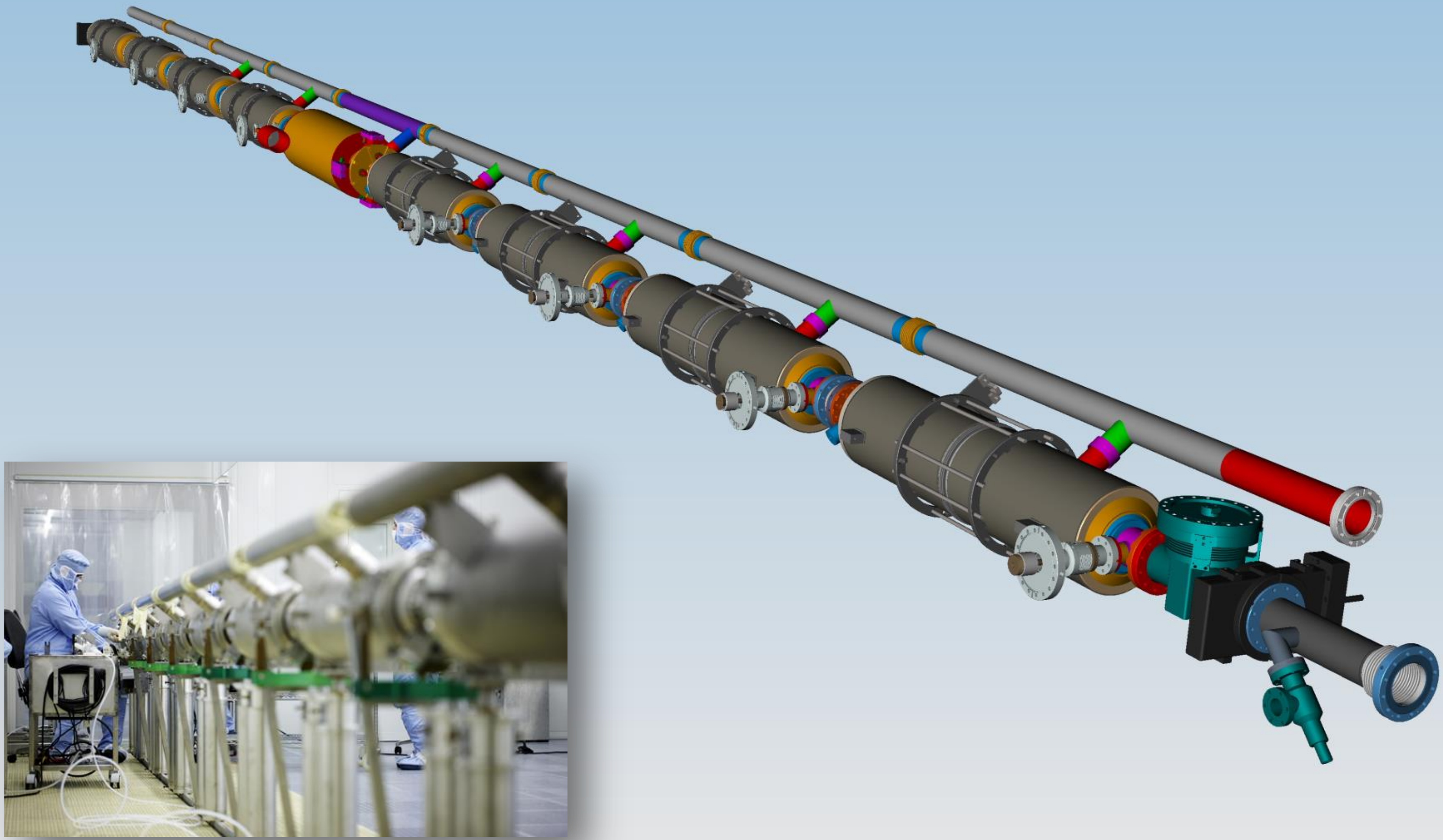
Cryomodule construction



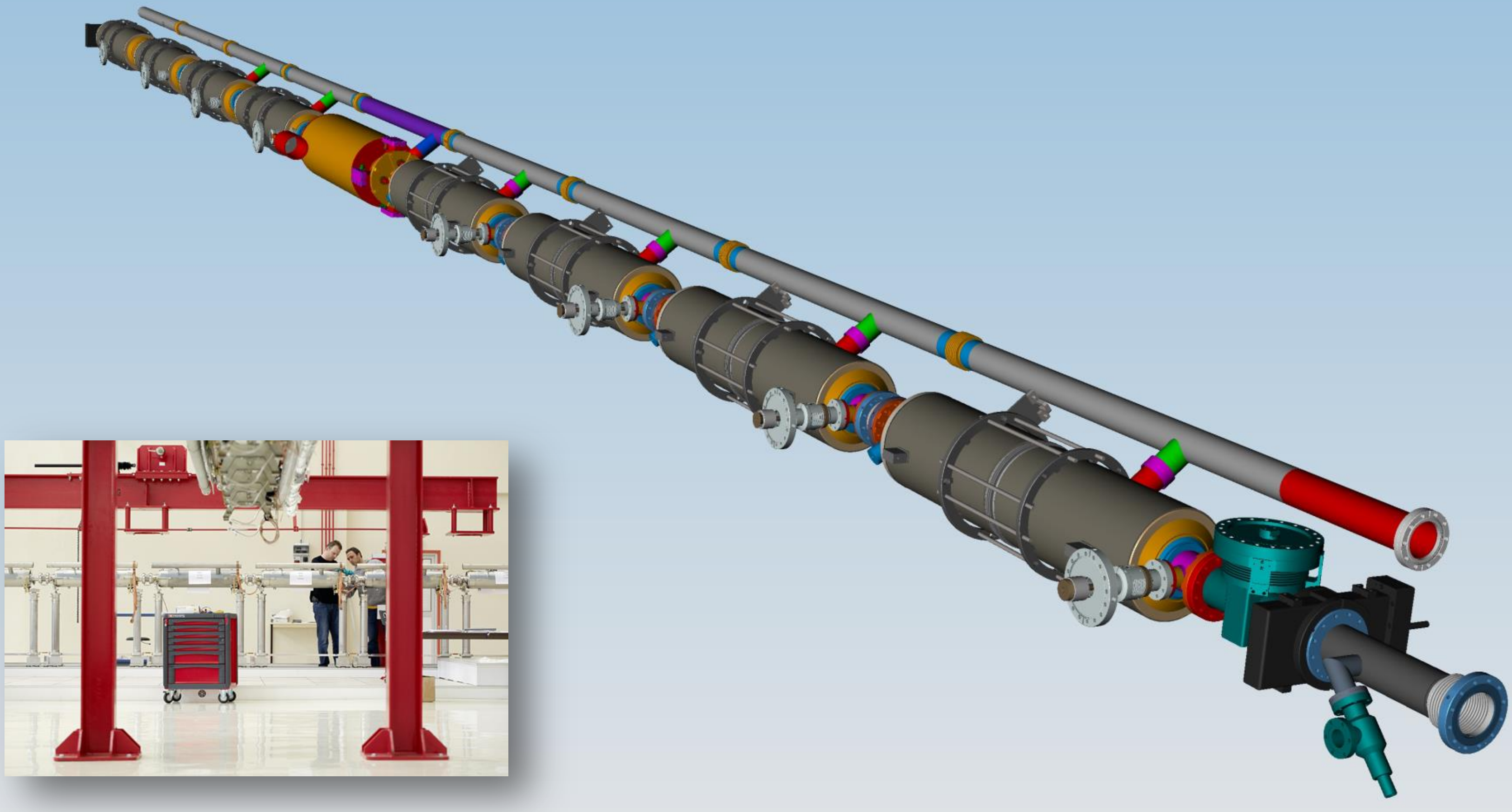
Cryomodule construction



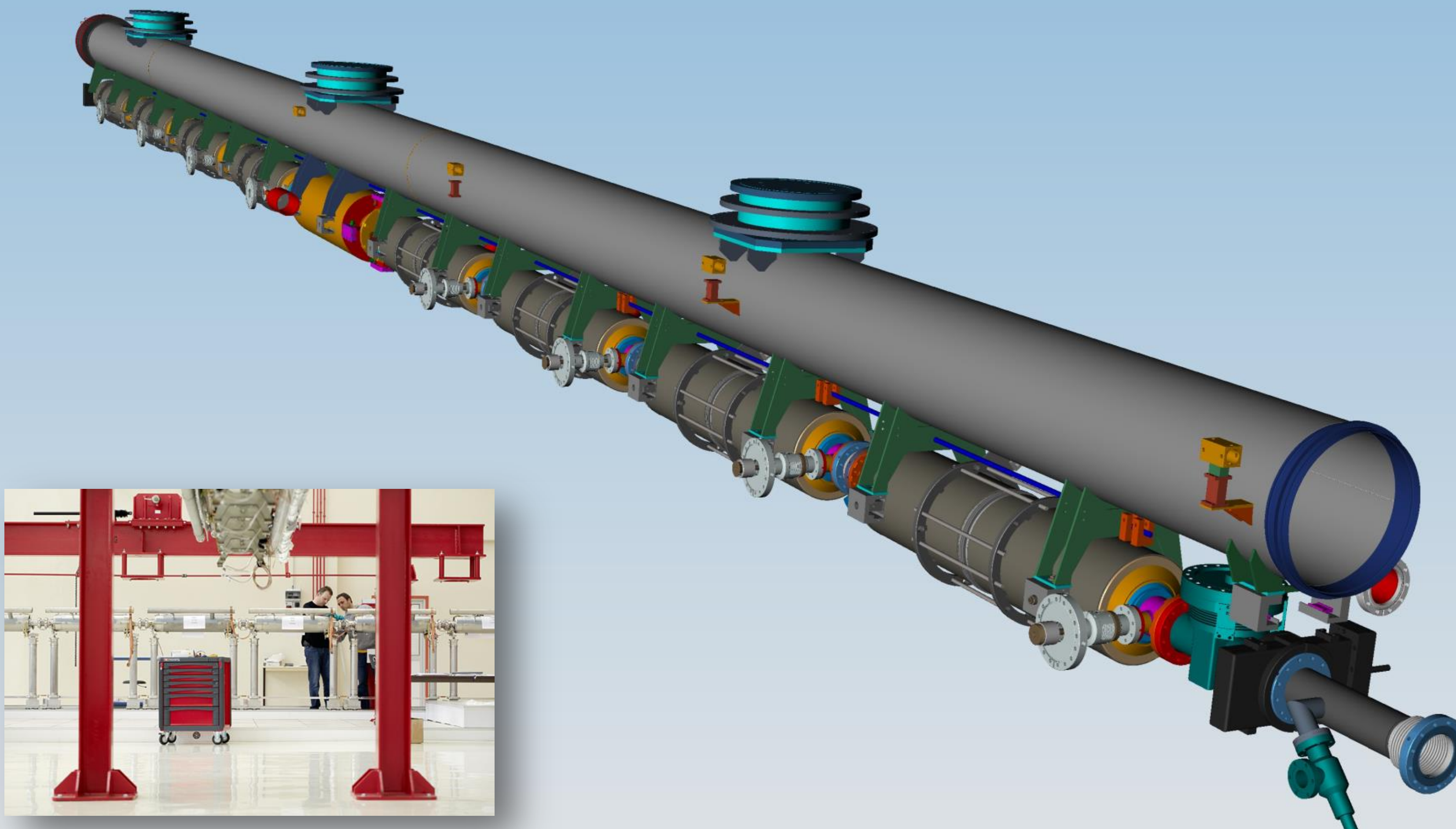
Cryomodule construction



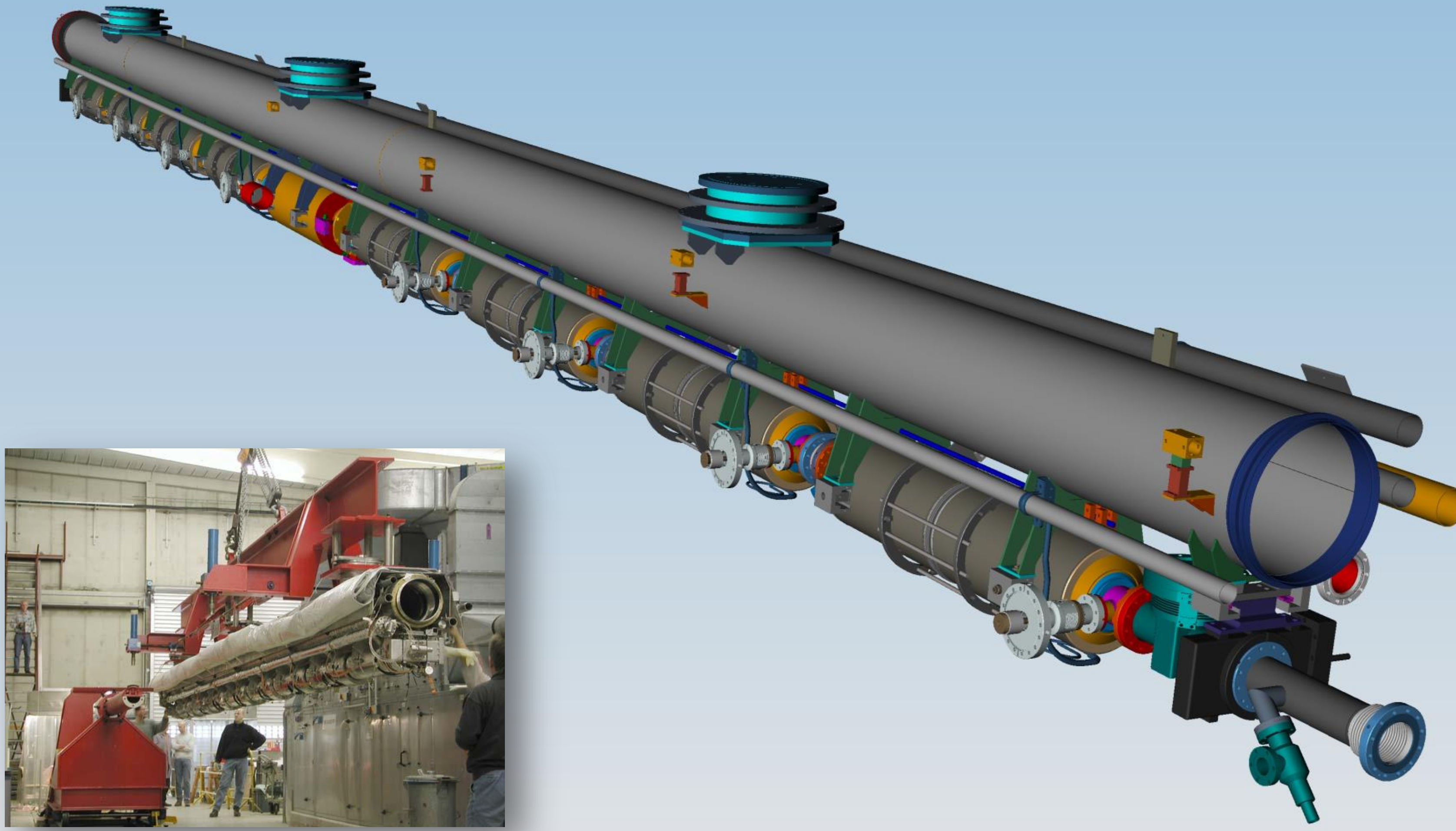
Cryomodule construction



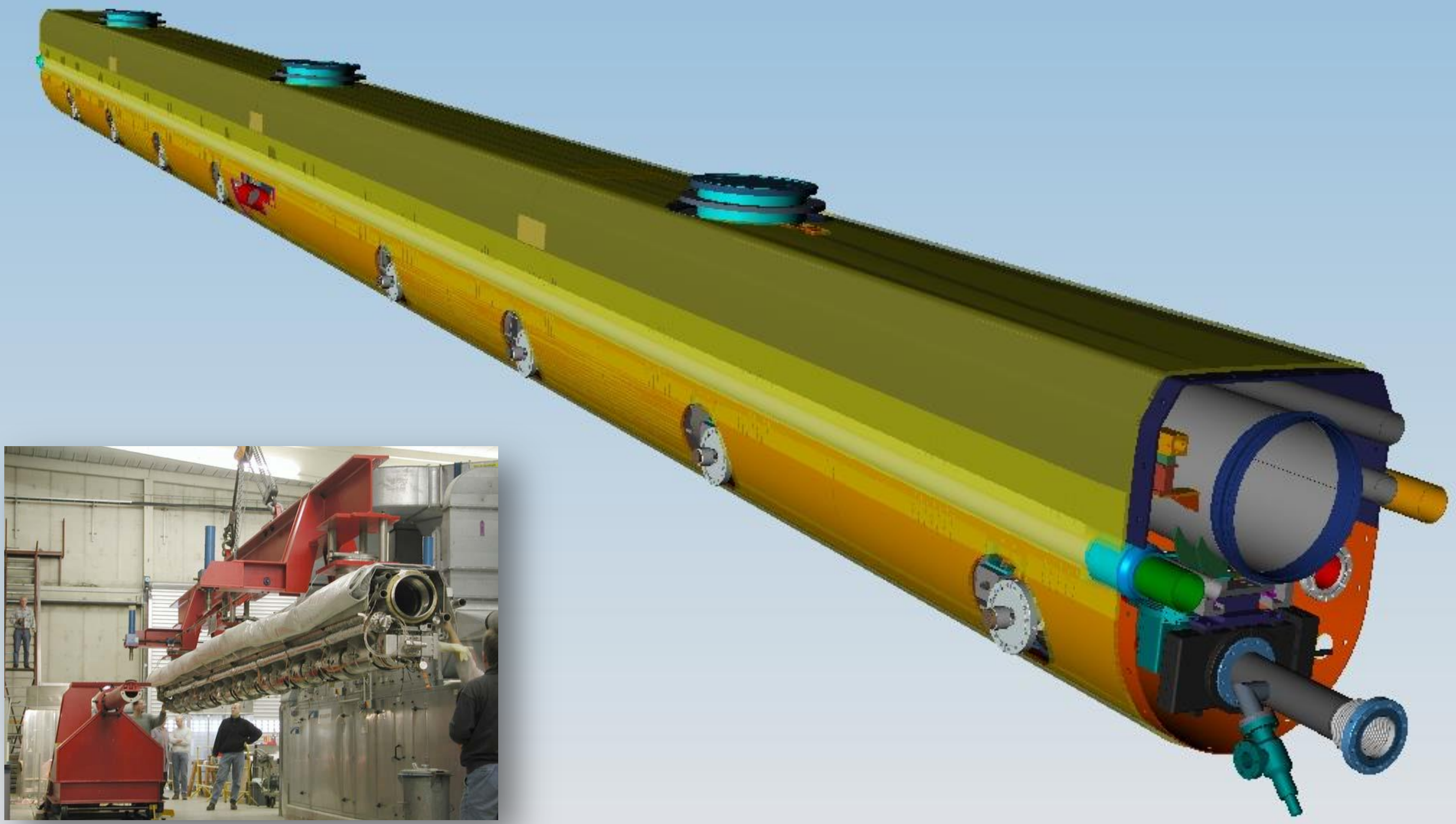
Cryomodule construction



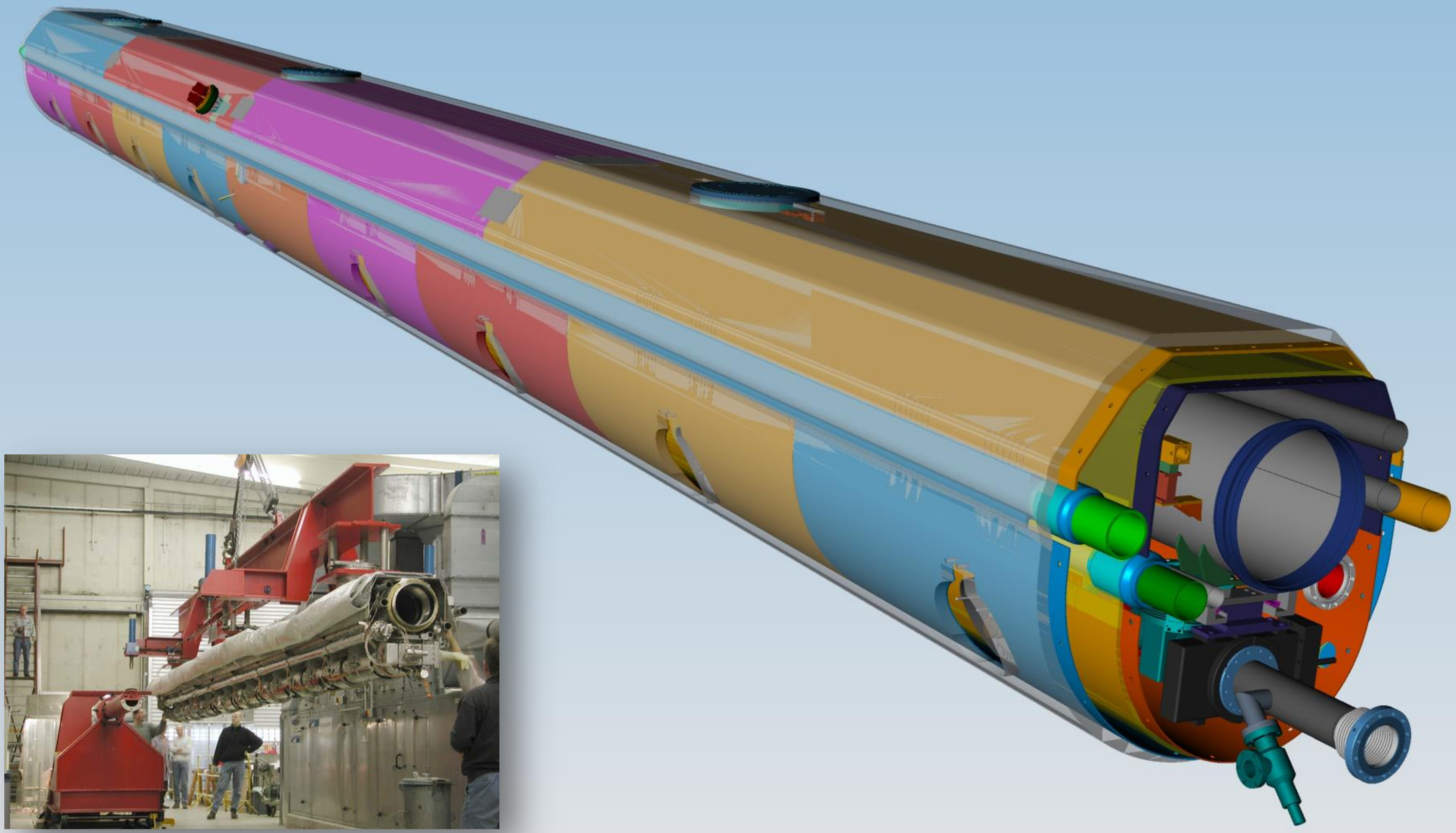
Cryomodule construction



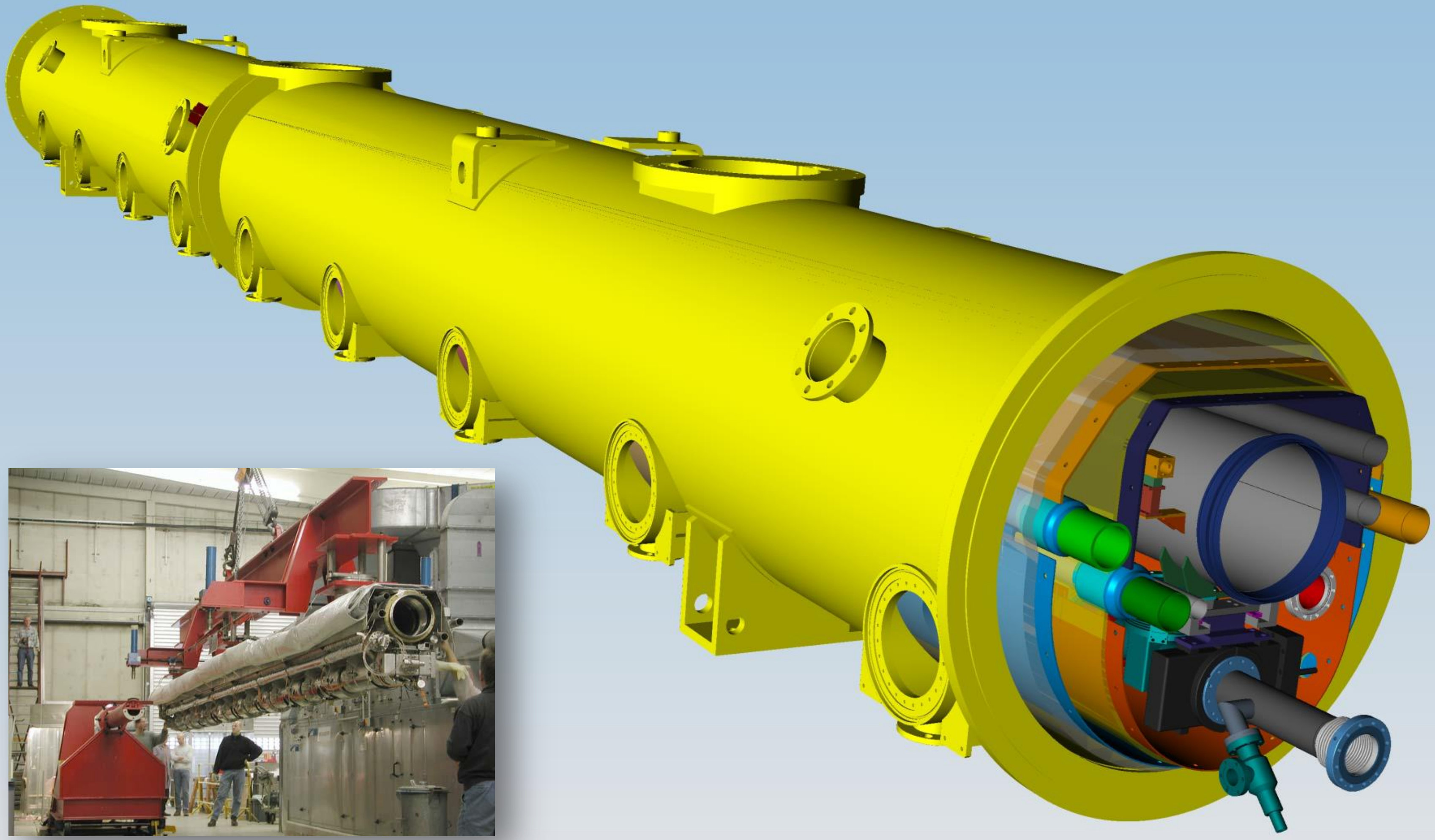
Cryomodule construction



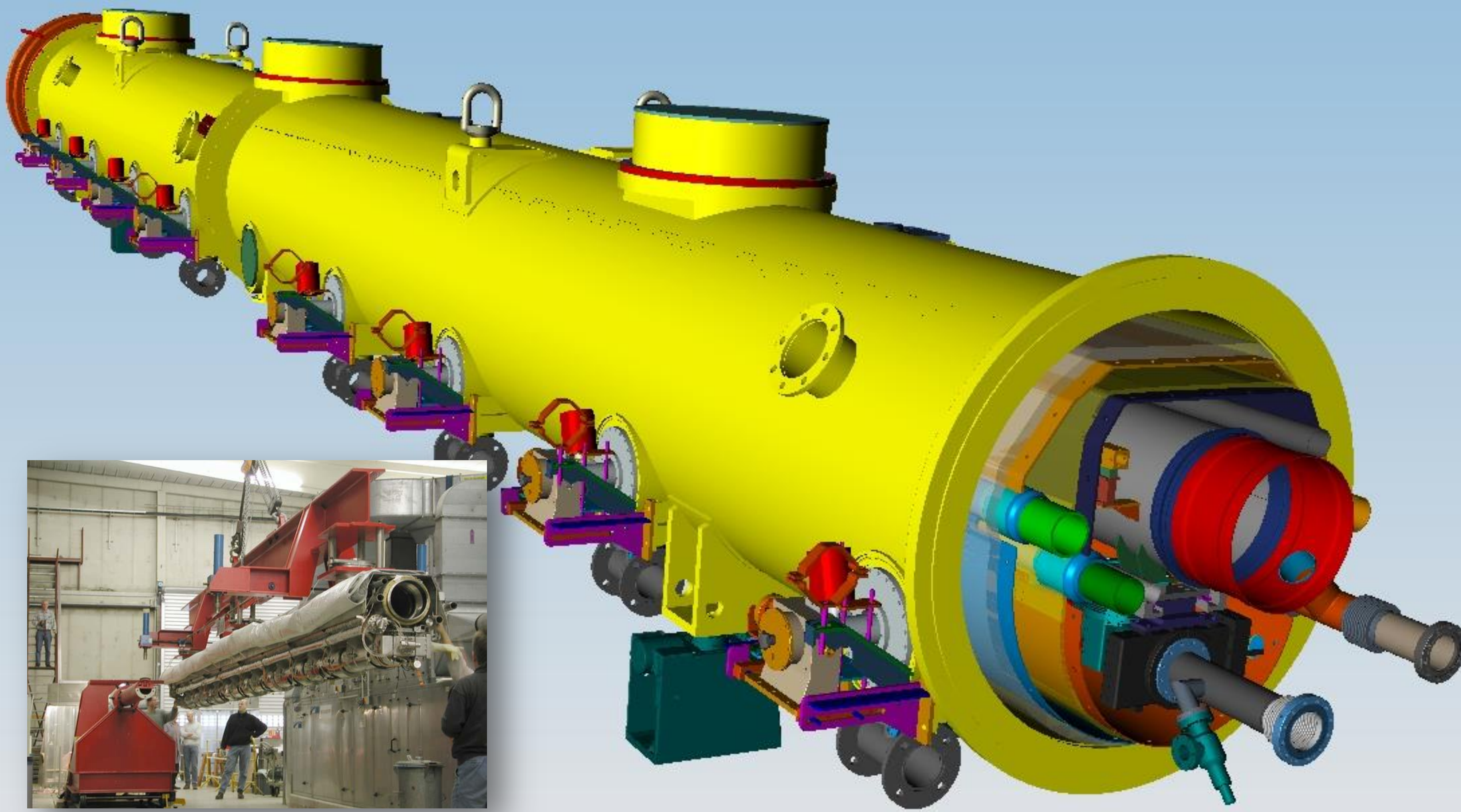
Cryomodule construction



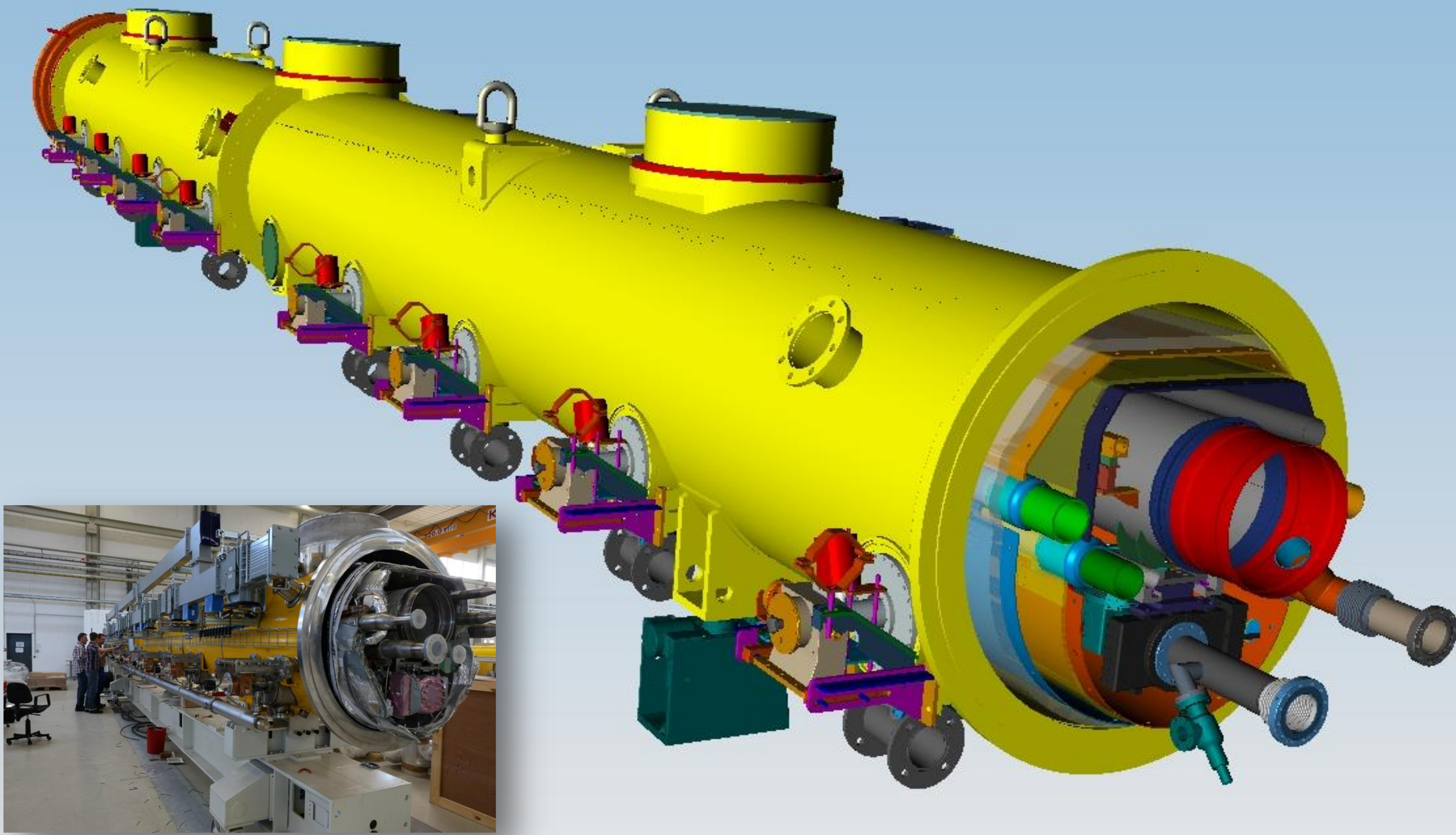
Cryomodule construction



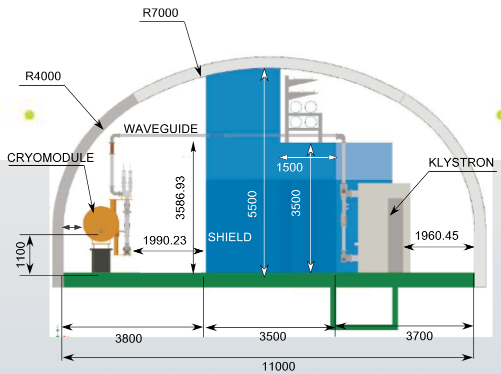
Cryomodule construction

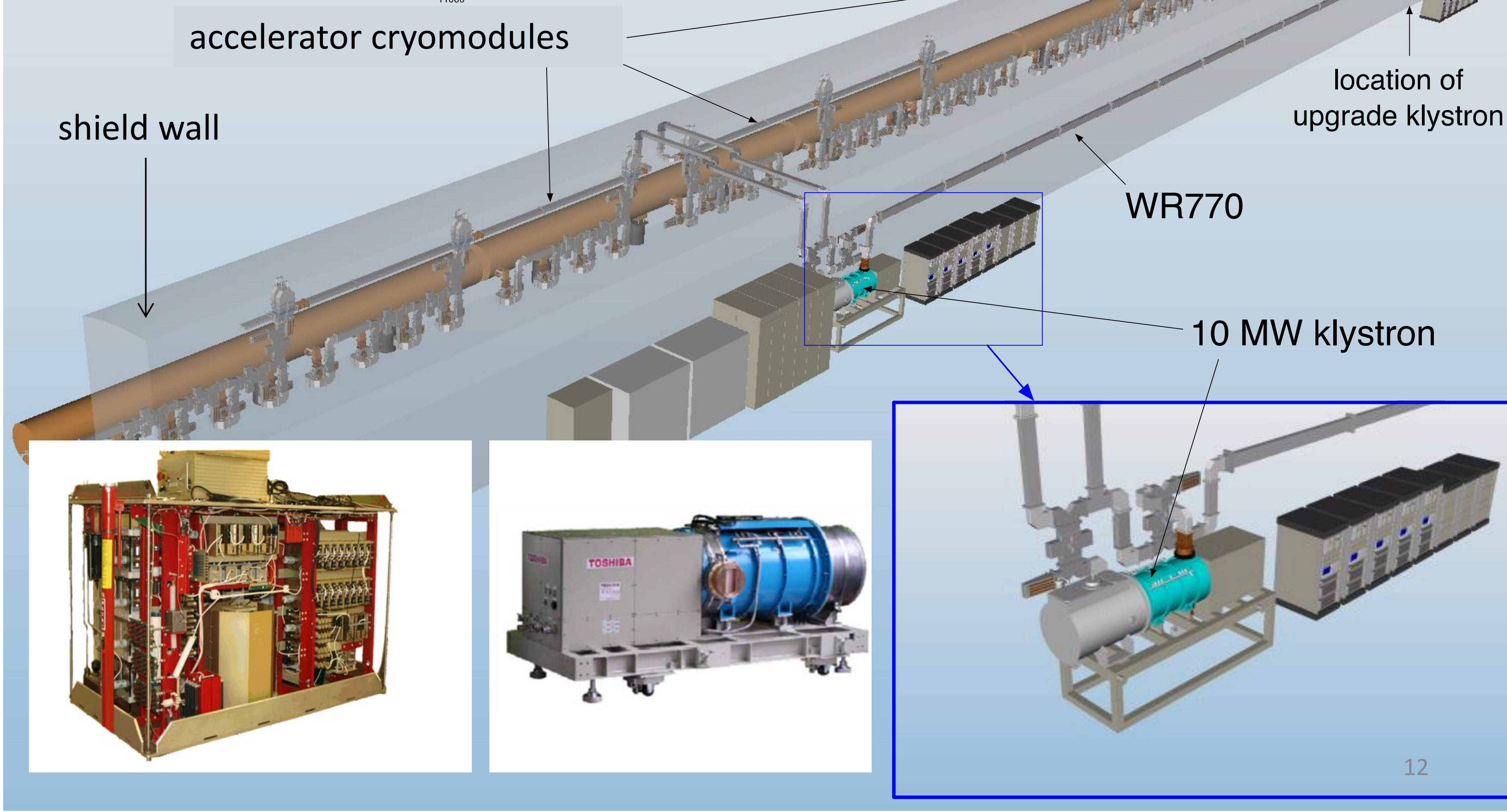


Cryomodule construction



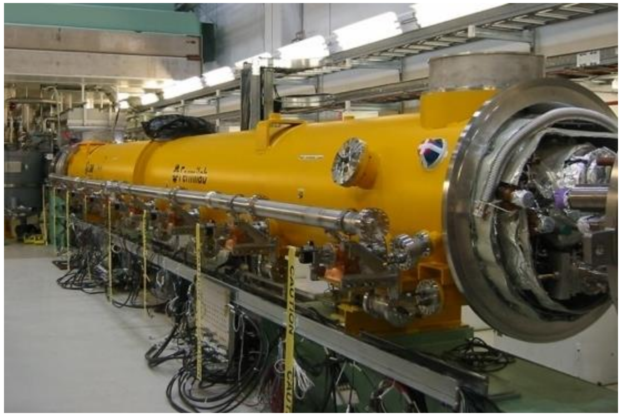
RF Power Generation





shield wall removed

Worldwide Cryomodule Development



CM1 at FNAL NML module test facility

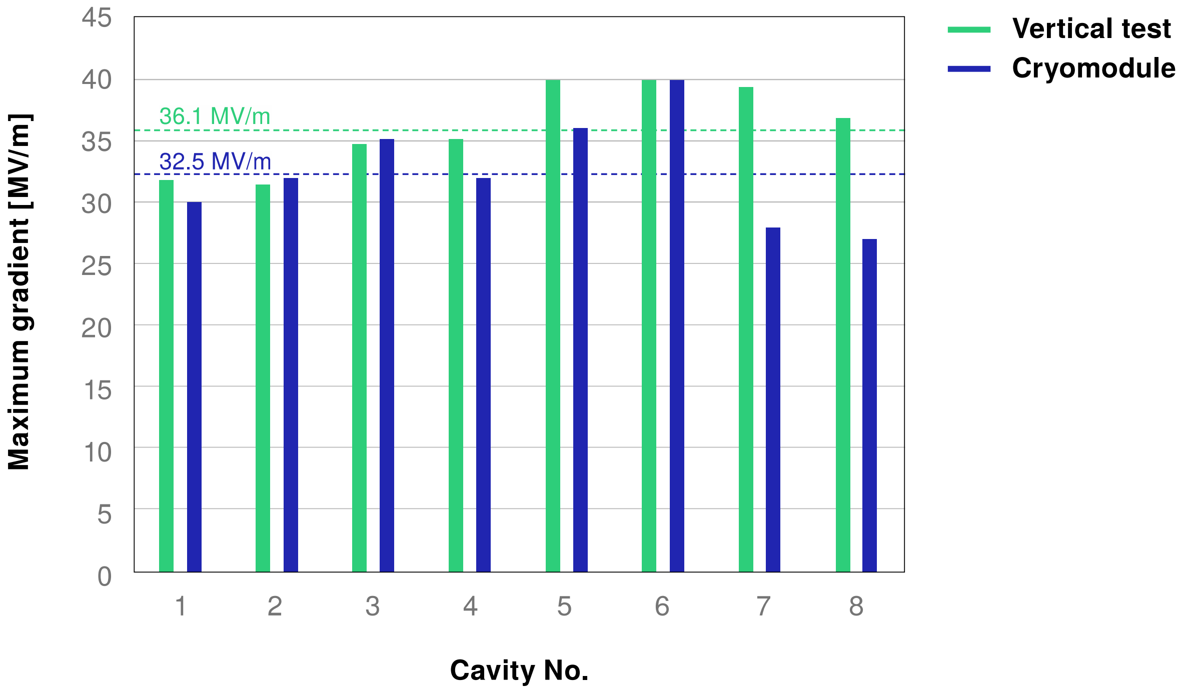
S1 Global at KEK SRF Test Facility (STF)

PXFEL 1 installed at FLASH, DESY, Hamburg

Worldwide Cryomodule Development

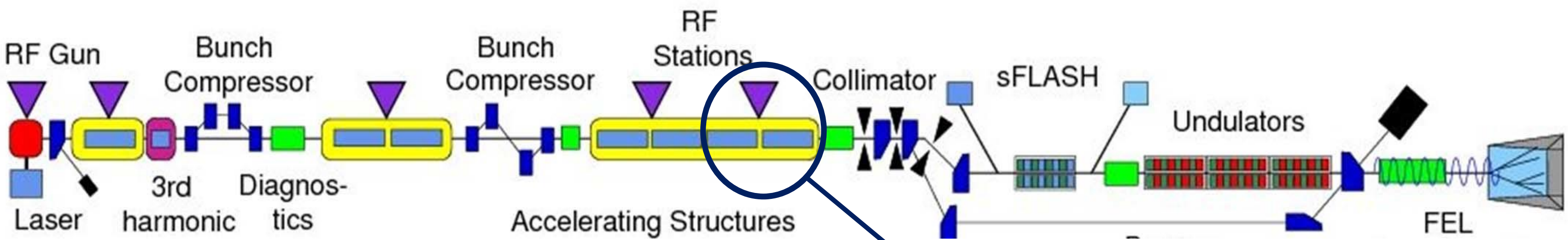
PXFEL 1 installed at FLASH, DESY, Hamburg

Worldwide Cryomodule Development

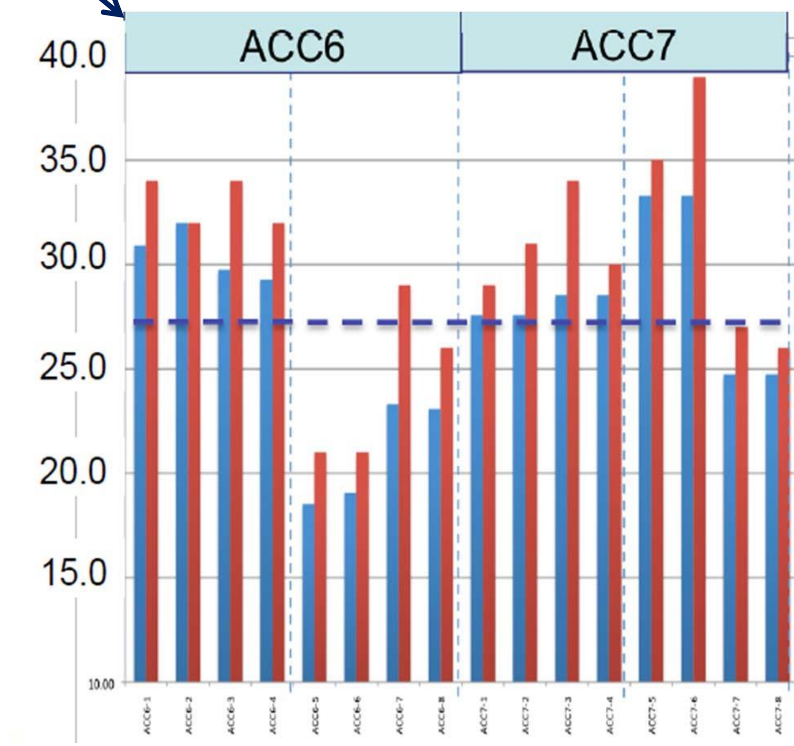


PXFEL 1 installed at FLASH, DESY, Hamburg

FLASH@DESY 9mA Experiment



		XFEL	ILC (upg.)	FLASH design	9mA studies
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



Many basic demonstrations:

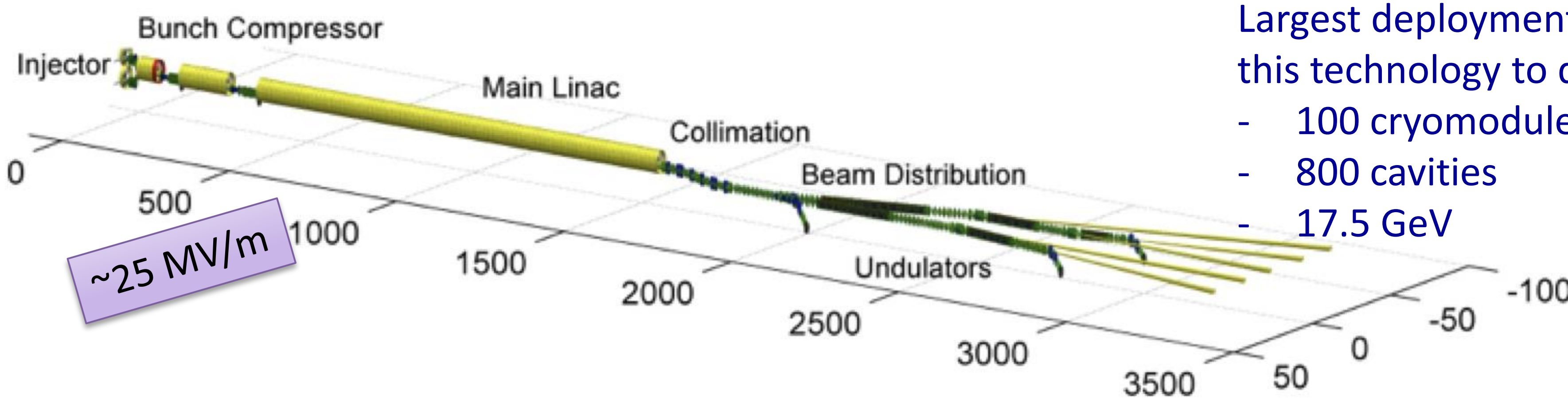
- heavy beam loading with long bunch trains
- operation close to quench limits
- klystron overhead etc.

Development (LLRF & controls):

- tuning algorithms
- automation
- quench protection etc.

European XFEL @ DESY

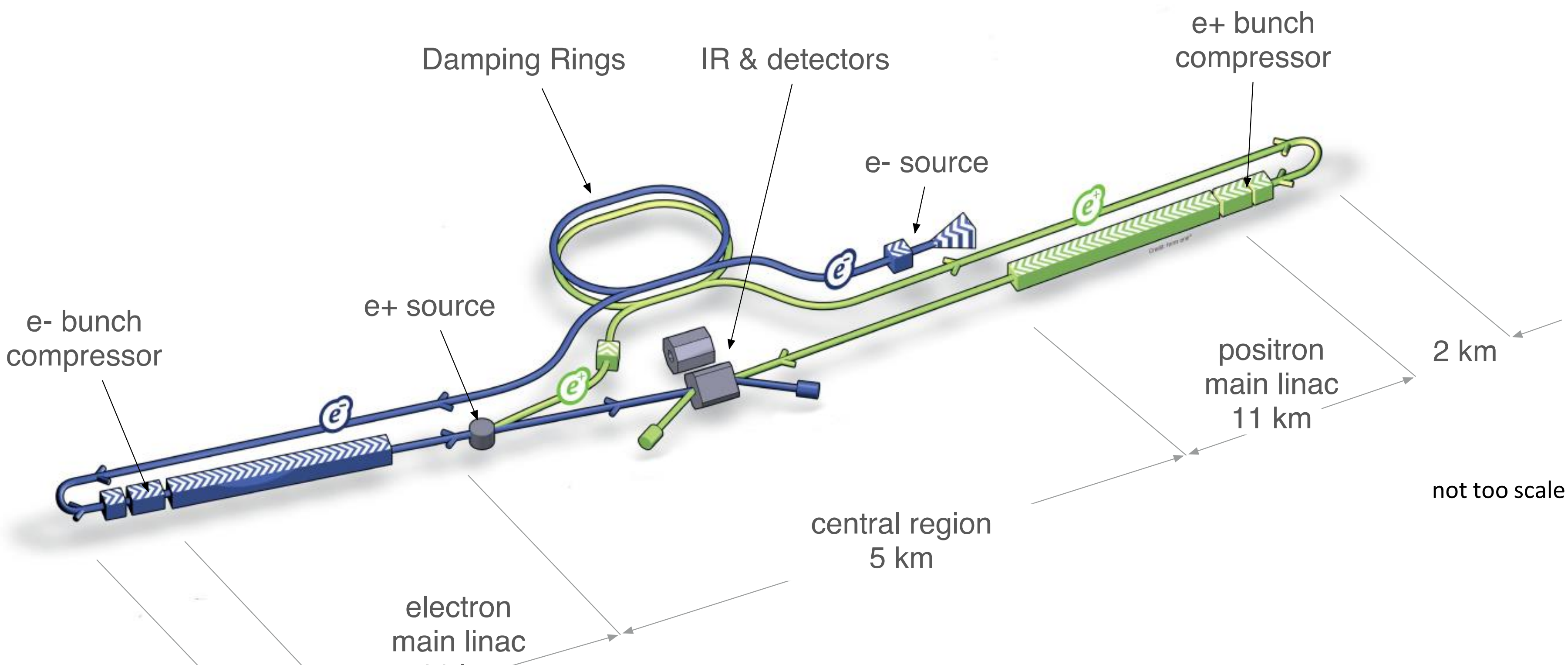
Largest deployment of this technology to date
- 100 cryomodules
- 800 cavities
- 17.5 GeV



Institute	Component Task
CEA Saclay / IRFU, France	Cavity string and module assembly; cold beam position monitors
CNRS / LAL Orsay, France	RF main input coupler incl. RF conditioning
DESY, Germany	Cavities & cryostats; contributions to string & module assembly; coupler interlock; frequency tuner; cold-vacuum system; integration of superconducting magnets; cold beam-position monitors
INFN Milano, Italy	Cavities & cryostats
Soltan Inst., Poland	Higher-order-mode coupler & absorber
CIEMAT, Spain	Superconducting magnets
IFJ PAN Cracow, Poland	RF cavity and cryomodule testing
BINP, Russia	Cold vacuum components

The ultimate 'integrated systems test' for ILC. Commissioning with beam 2nd half 2015

Beyond the SCRF Main Linacs

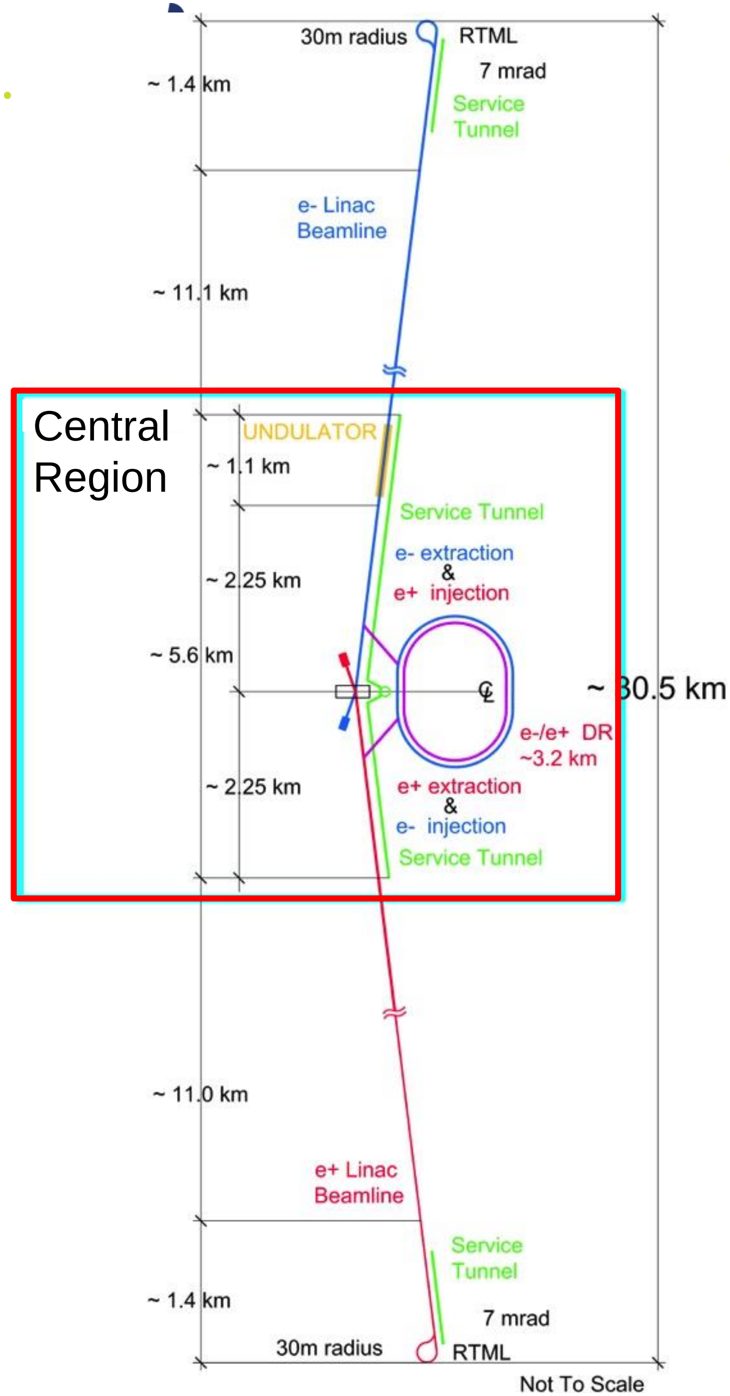


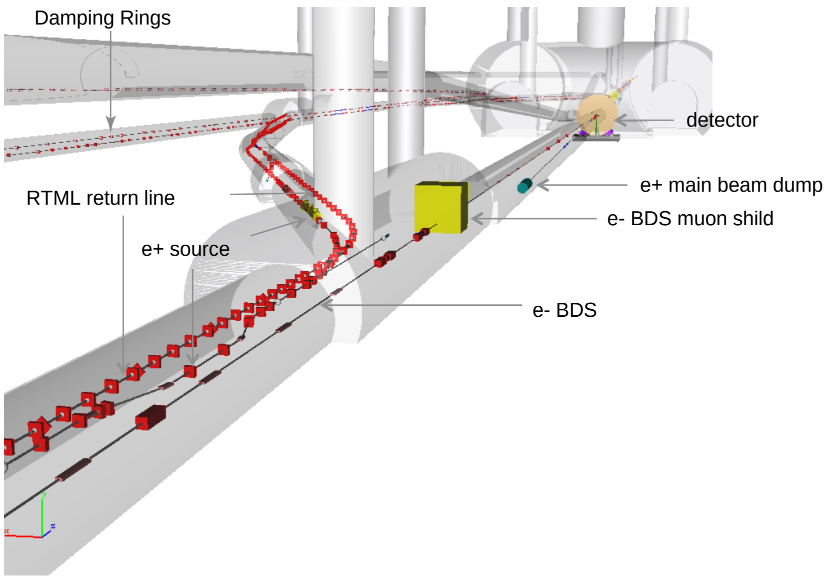
- injectors (sources and damping rings)
- final focus system and interaction region

Central Region

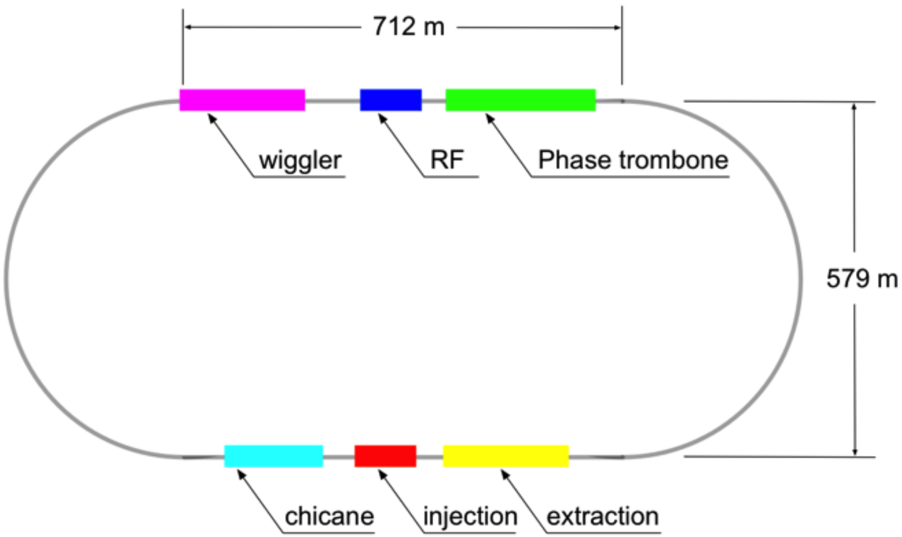
- 5.6 km region around IR
- Systems:
  - electron source
  - positron source
  - beam delivery system
  - RTML (return line)
  - IR (detector hall)
  - damping rings
- Complex and crowded area

common tunnel





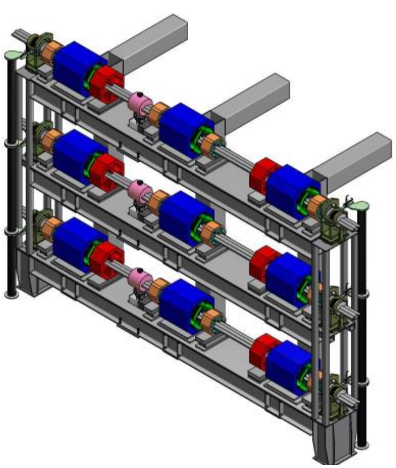
Damping Rings



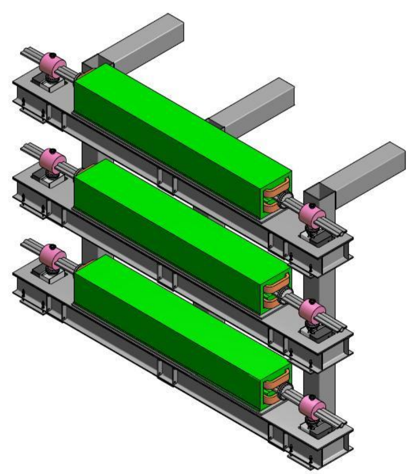
Positron ring (upgrade)

Electron ring (baseline)

Positron ring (baseline)



Arc quadrupole section



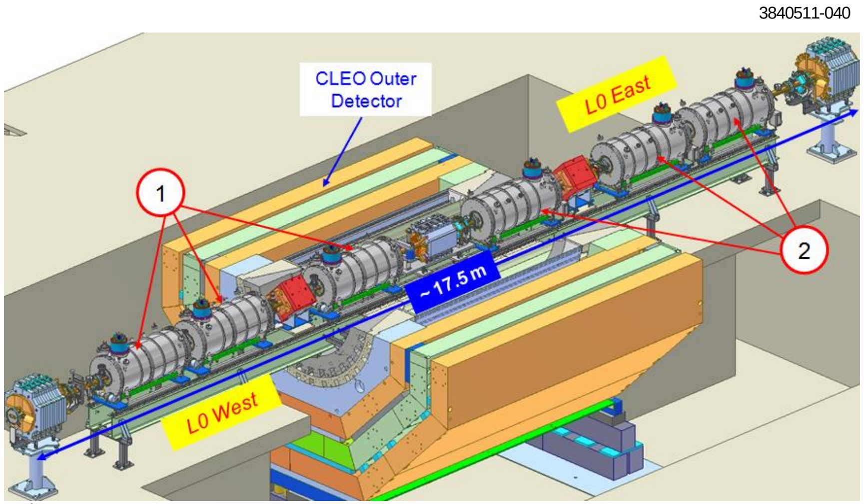
Dipole section

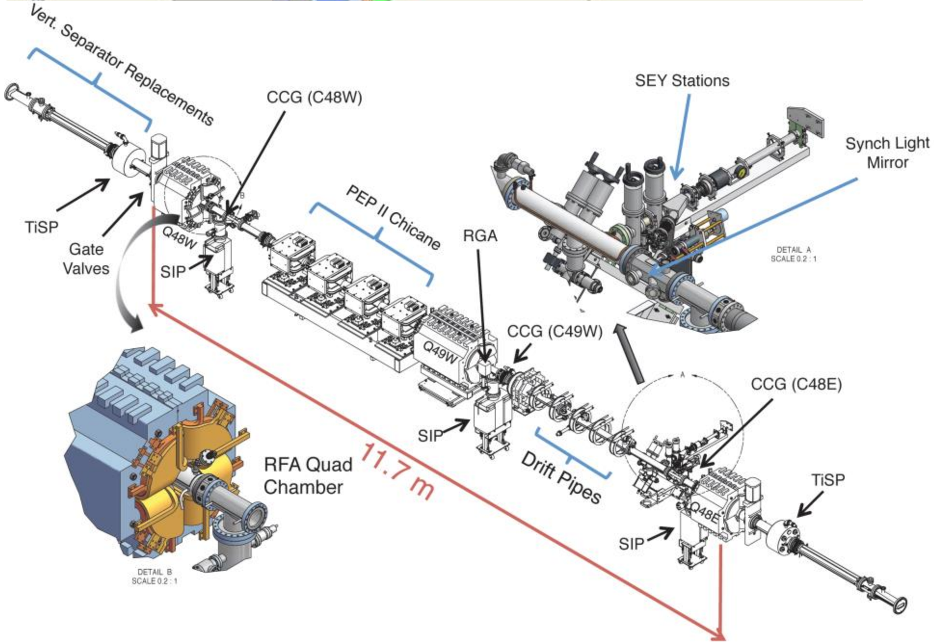
Circumference		3.2	km
Energy		5	GeV
RF frequency		650	MHz
Beam current		390	mA
Store time		200 (100)	ms
Trans. damping time		24 (13)	ms
Extracted emittance	x	5.5	µm
(normalised)	y	20	nm
No. cavities		10 (12)	
Total voltage		14 (22)	MV
RF power / coupler		176 (272)	kW
No.wiggler magnets		54	
Total length wiggler		113	m
Wiggler field		1.5 (2.2)	T
Beam power		1.76 (2.38)	MW

Values in () are for 10-Hz mode

Many similarities to modern 3rd-generation light sources

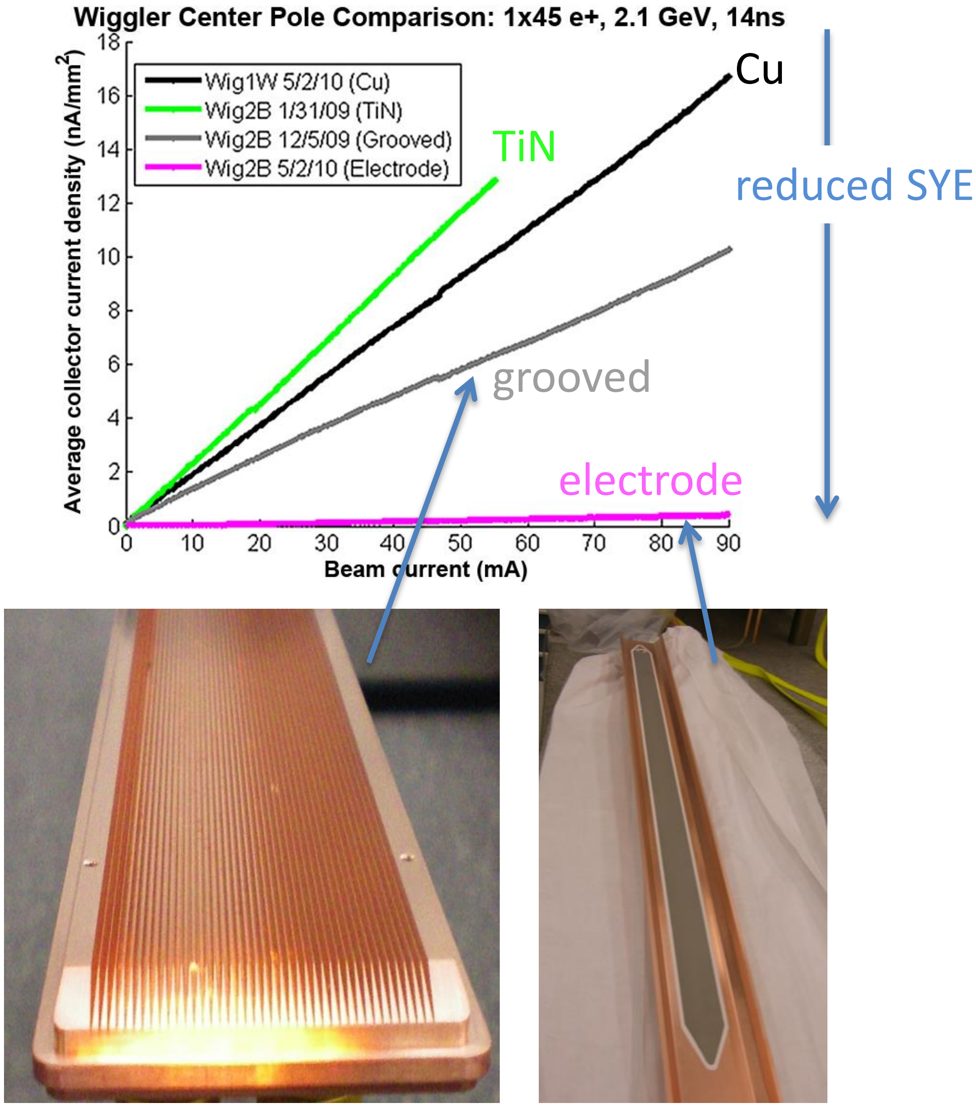
Critical R&D: Electron Cloud





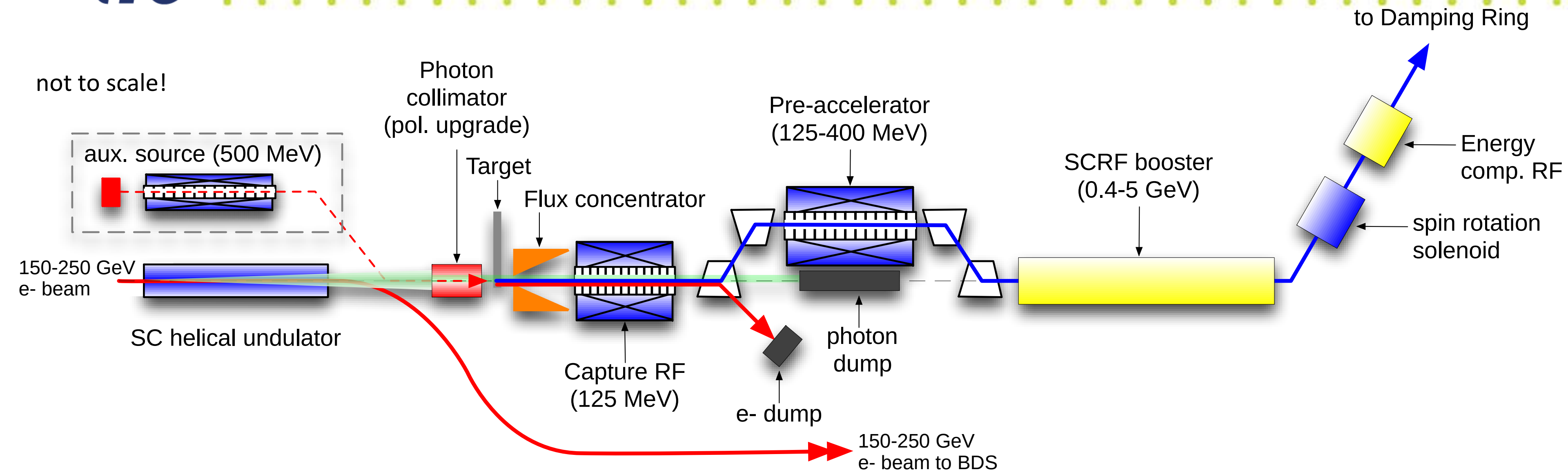
- Extensive R&D programme at CESR, Cornell (CesrTA)
- Instrumentation of wiggler, dipole and quad vacuum chambers for e-cloud measurements
  - RFA
- low emittance lattice

Critical R&D: Electron Cloud

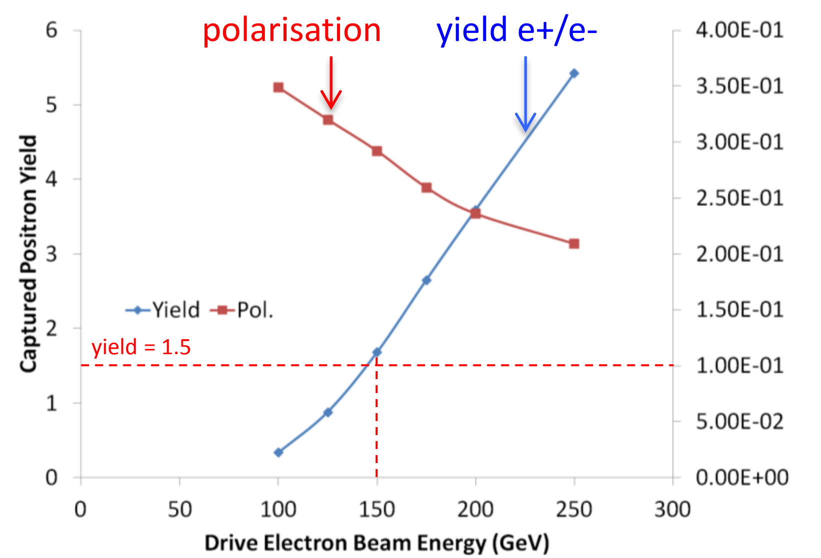


- Extensive R&D programme at CESR, Cornell (CesrTA)
- Instrumentation of wiggler, dipole and quad vacuum chambers for e-cloud measurements
  - RFA
- low emittance lattice
- Example: wiggler vacuum chamber
- Benchmarking of simulation codes
  - cloud build-up
  - beam dynamics (head-tail instabilities)

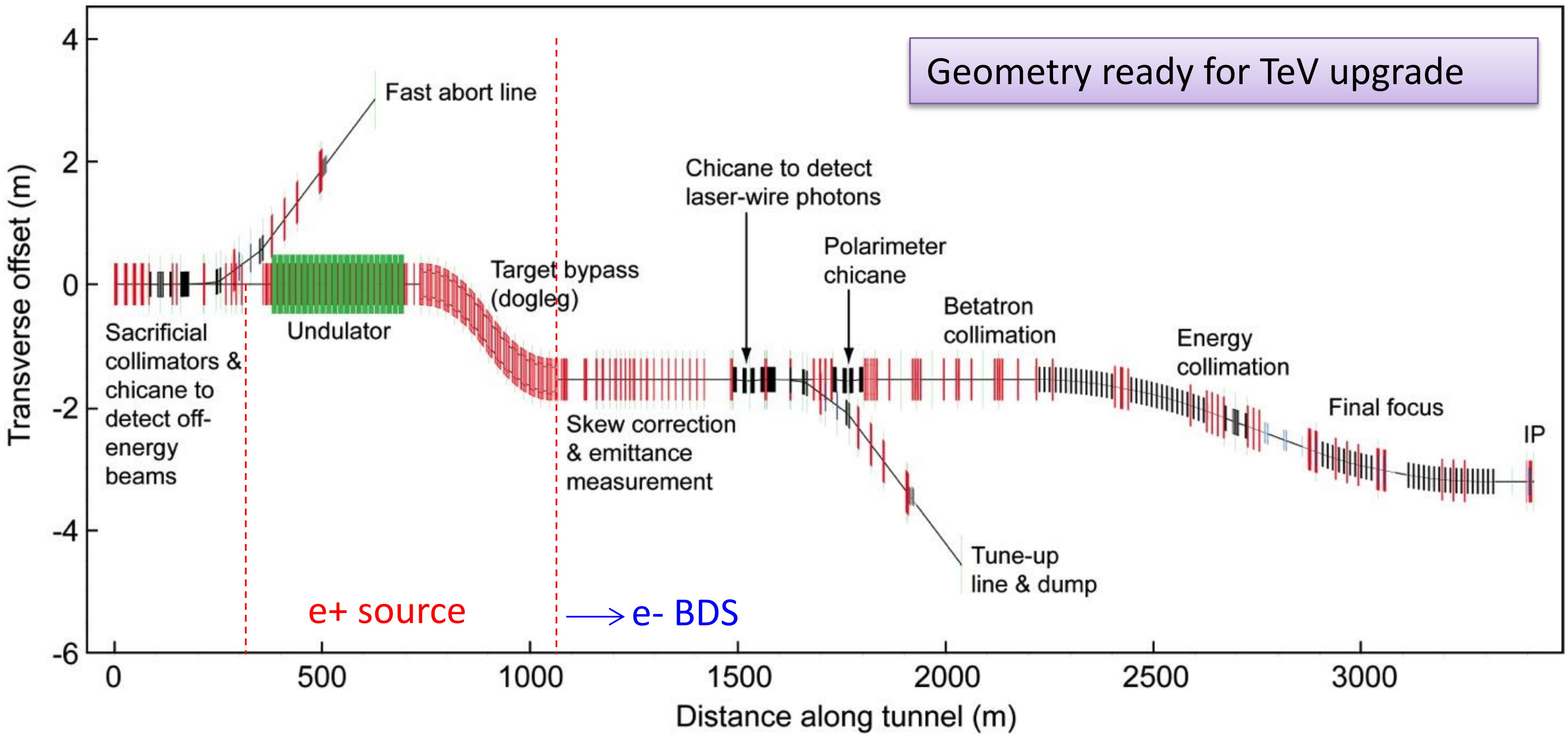
Positron Source (central region)



- located at exit of electron Main Linac
- 147m SC helical undulator
- driven by primary electron beam (150-250 GeV)
- produces ~30 MeV photons
- converted in thin target into e+e- pairs



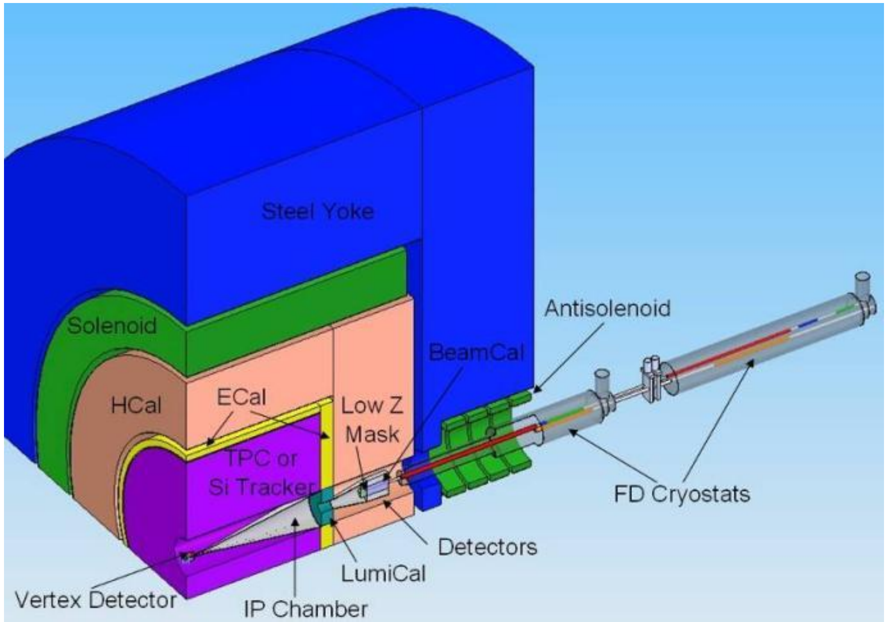
Beam Delivery System and MDI

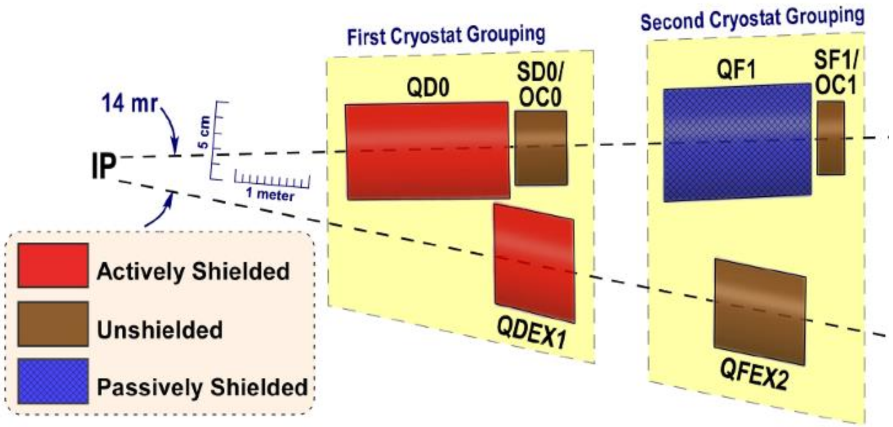


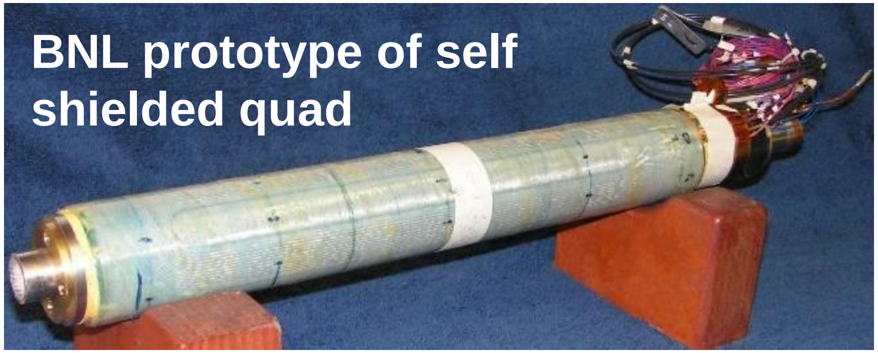
electron Beam Delivery System

IR region (Final Doublet)

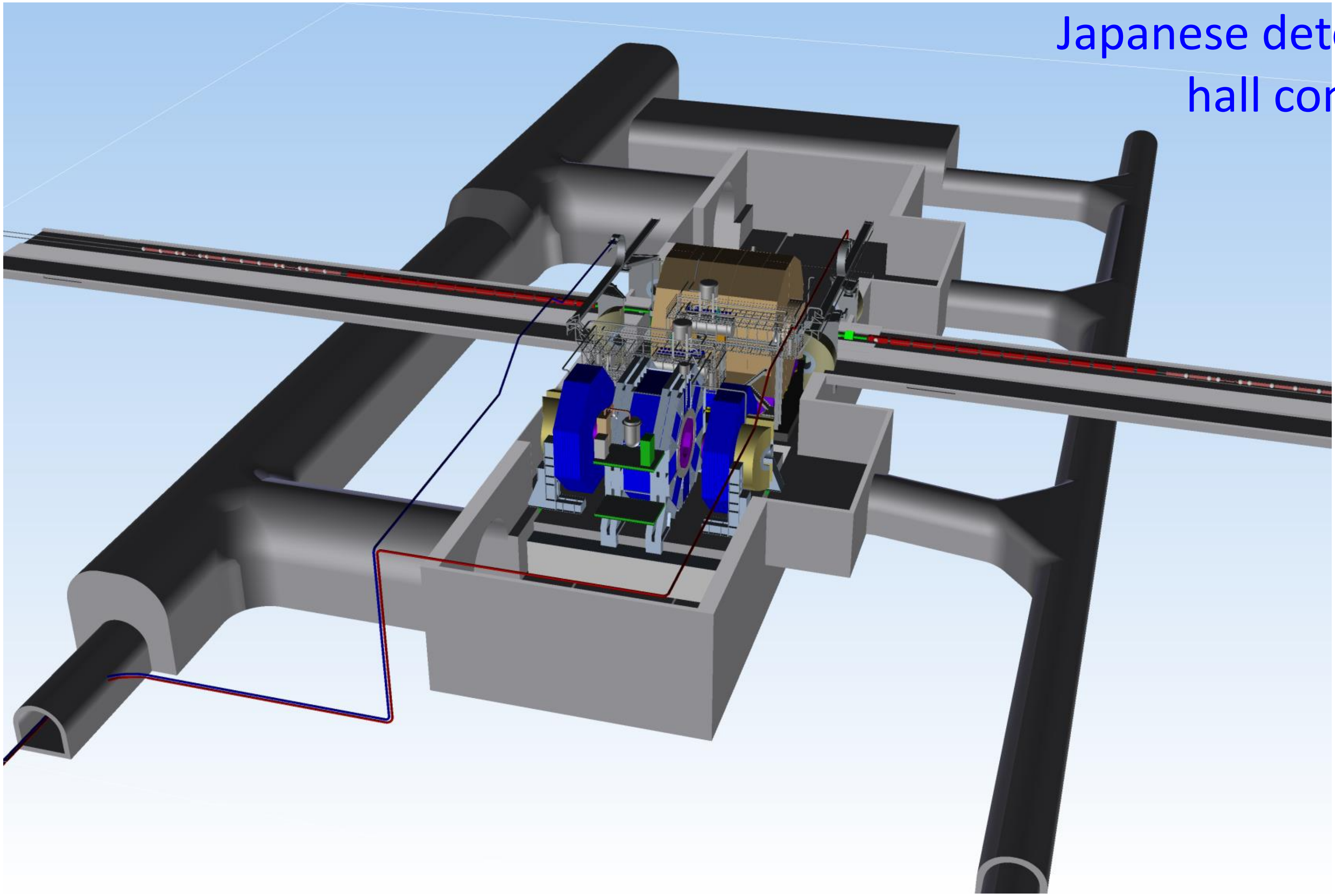
- FD arrangement for push pull
  - different L*
  - ILD 4.5m, SiD 3.5m
- Short FD for low E_{cm}
  - Reduced β_x*
    - increased collimation depth
  - "universal" FD
    - avoid the need to exchange FD
    - conceptual - requires study
- Many integration issues remain
  - requires engineering studies beyond TDR
  - No apparent show stoppers





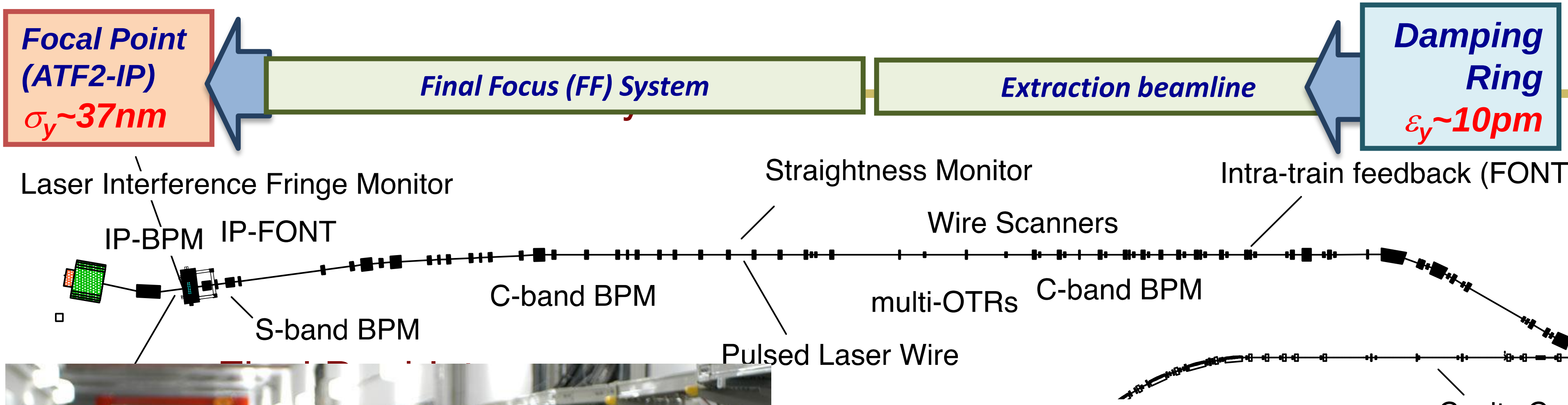


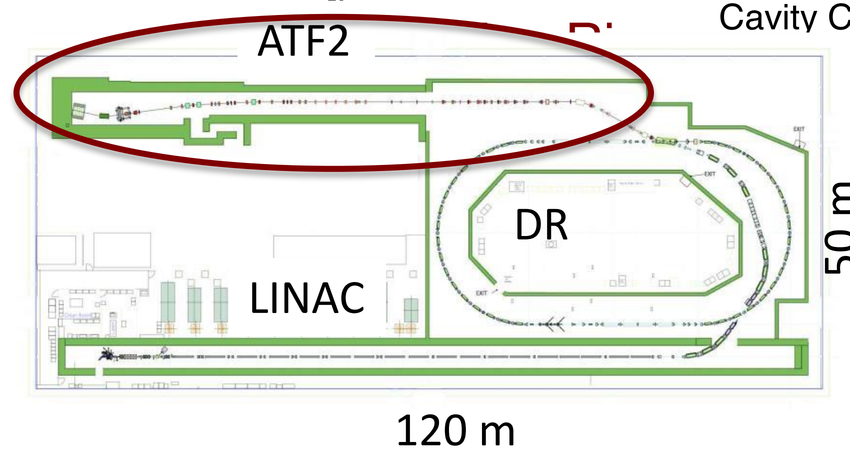
MDI (Detector Hall)



Japanese detector hall concept

Final Focus R&D: ATF2 @ KEK



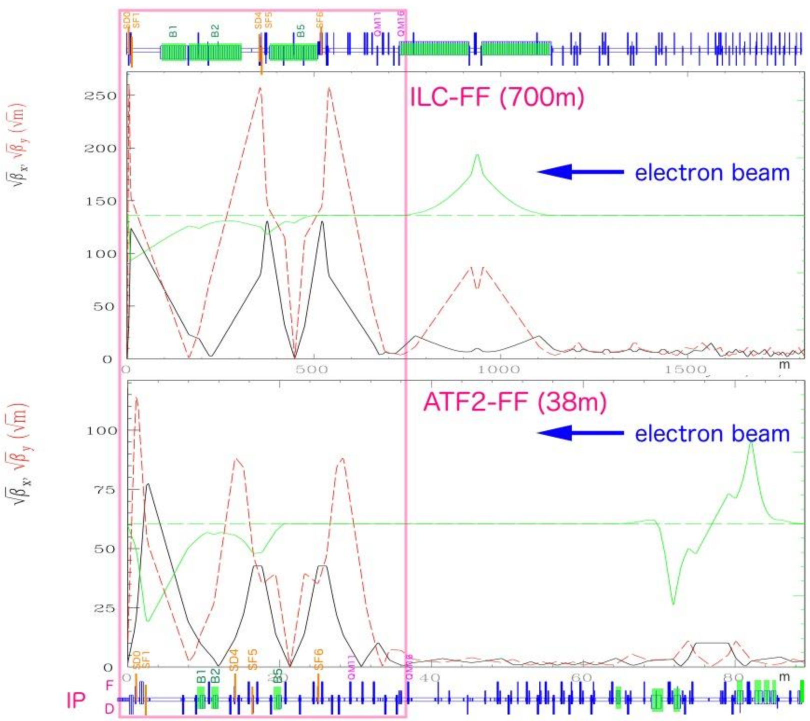


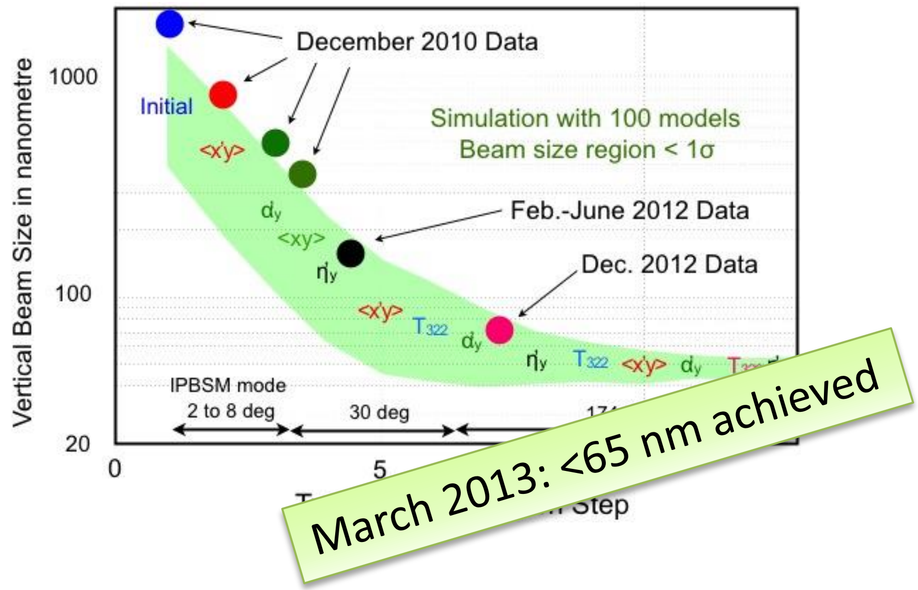
Formal international collaboration

Final Focus R&D: ATF2 @ KEK

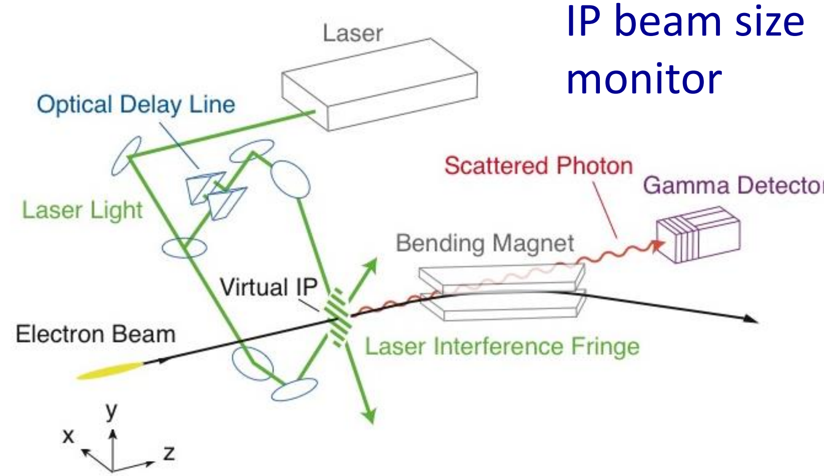
Test bed for ILC final focus optics

- strong focusing and tuning (37 nm)
- beam-based alignment
- stabilisation and vibration (fast feedback)
- instrumentation





IP beam size monitor



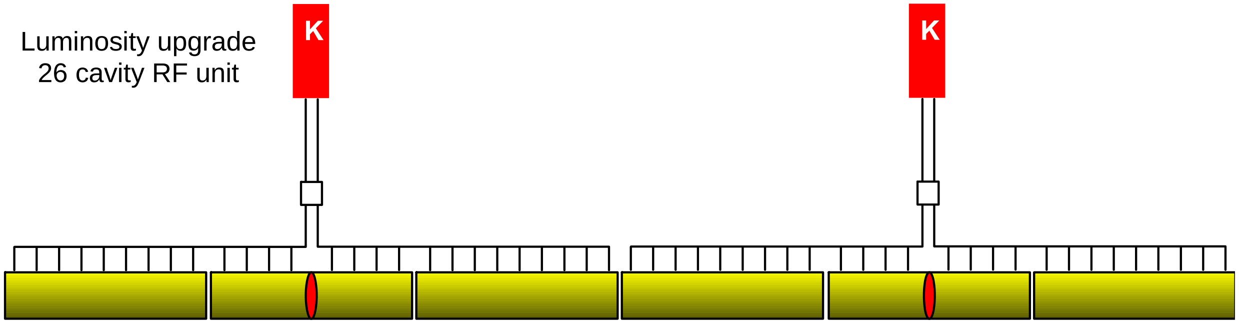
Beyond the Baseline

Luminosity Upgrade

- Concept: increase n_b from 1312 → 2625
  - Reduce linac bunch spacing 554 ns → 336 ns
- Doubles beam power → ×2 $L = 3.6\times10^{34}\ cm^{-2}s^{-1}$
- AC power: 161 MW → 204 MW (est.)
  - shorter fill time and longer beam pulse results in higher RF-beam efficiency (44% → 61%)

Luminosity Upgrade

Adding klystrons
(and modulators)

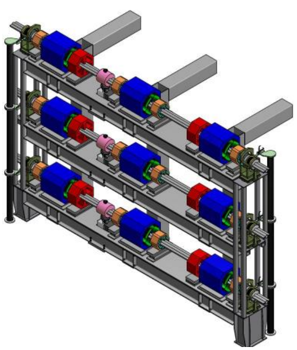


Damping Ring:

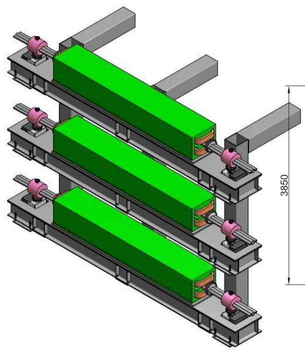
Positron ring (upgrade)

Electron ring (baseline)

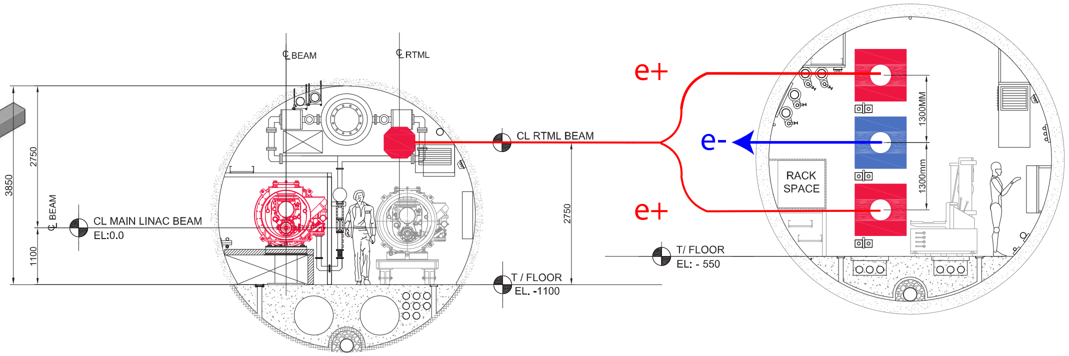
Positron ring (baseline)



Arc quadrupole section



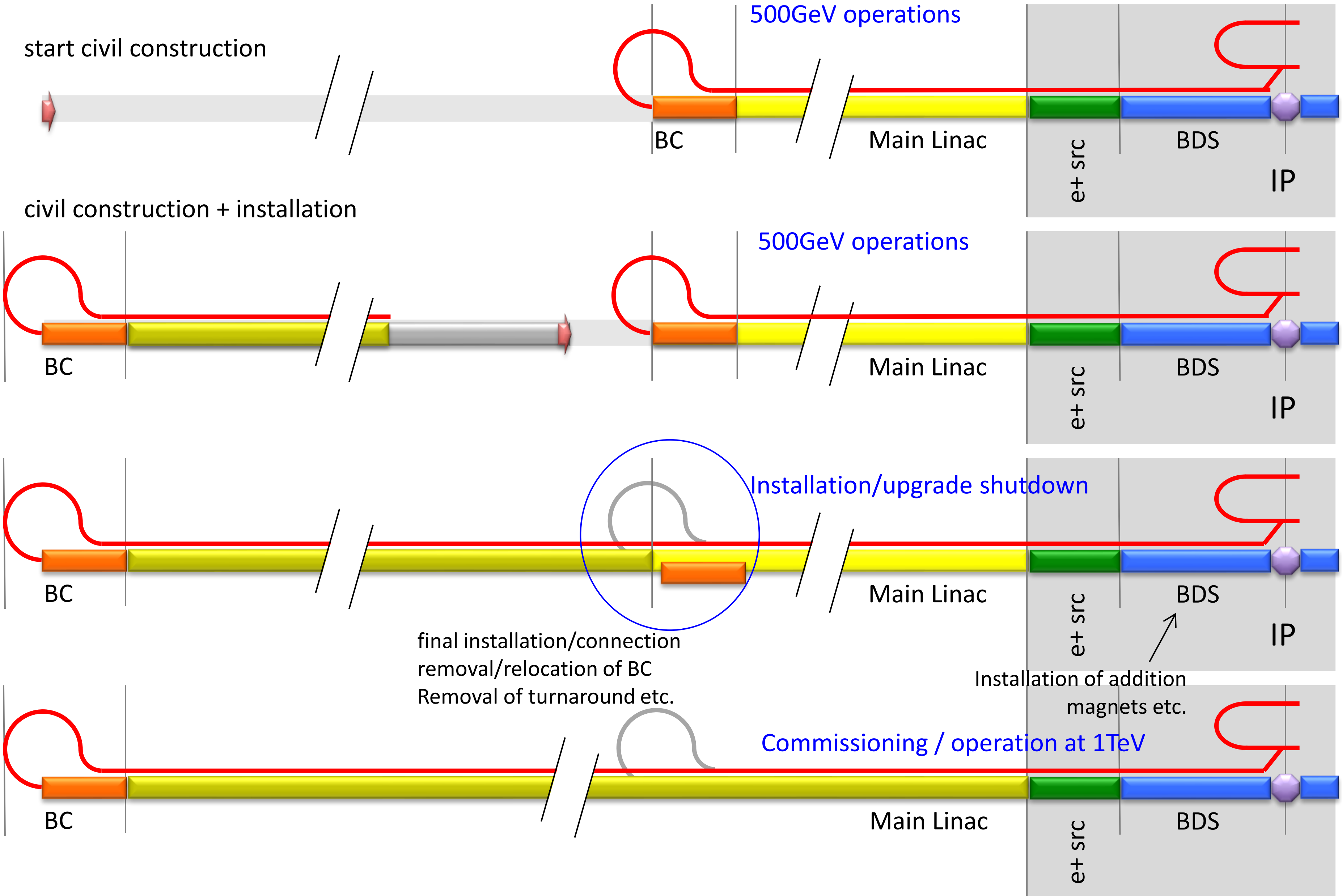
Dipole section



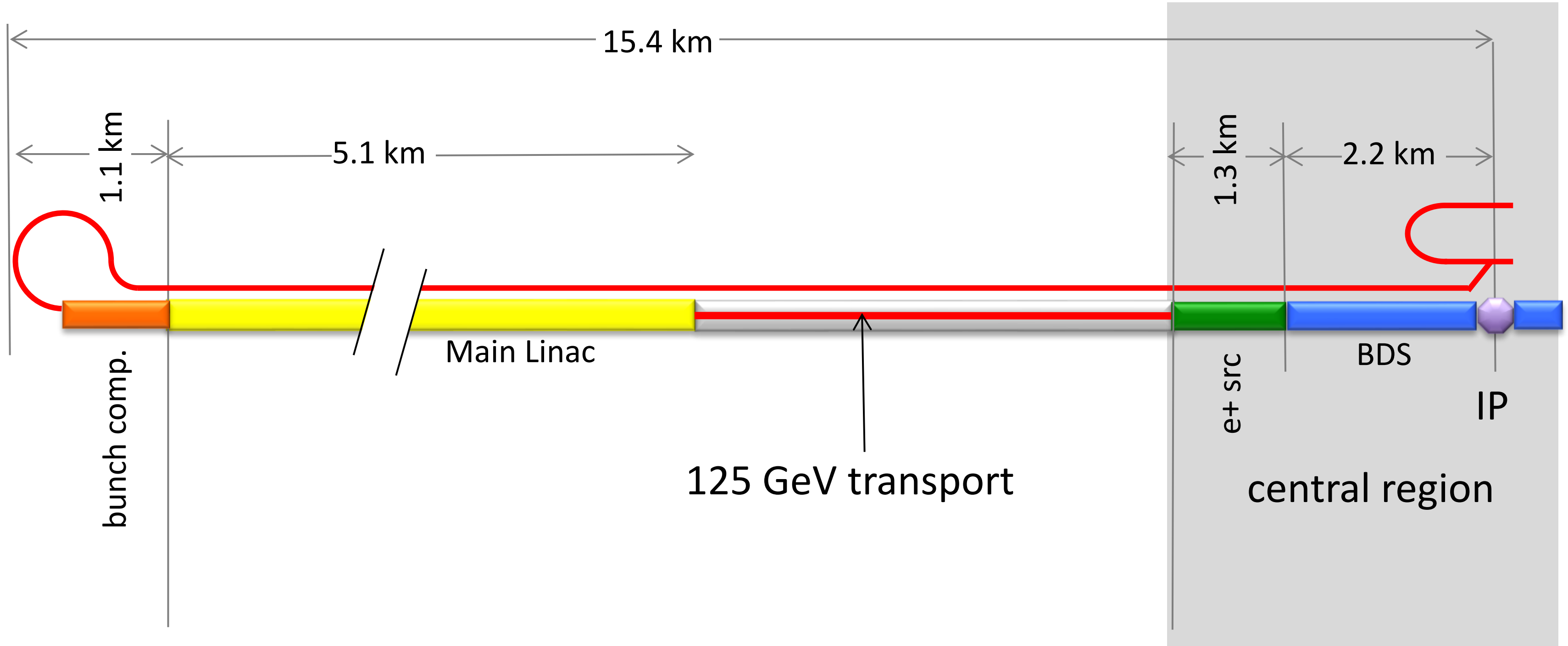
Main Linac Tunnel

Damping Ring Tunnel

Energy (TeV) upgrade



250 GeV staged LHF



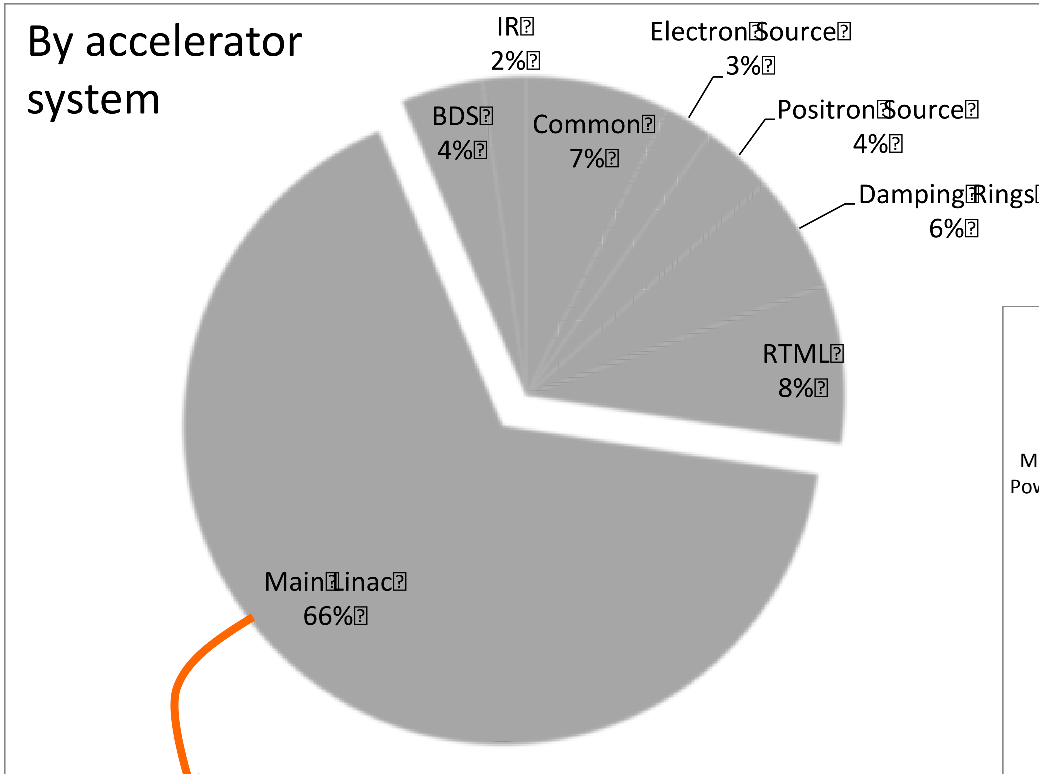
Half the linacs
Full-length BDS tunnel & vacuum (TeV)
½ BDS magnets (instrumentation, CF etc)
5km 125 GeV transport line

quasi-adiabatic energy upgrade?

TDR Value Estimate

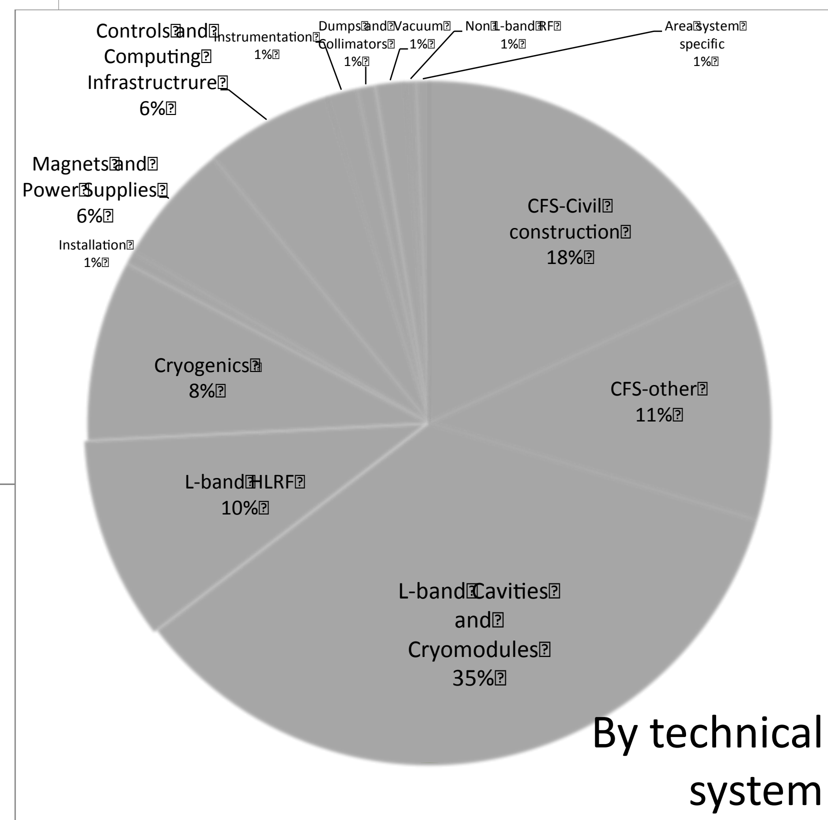
7.8 Billion ILCU
22.6 Million person-hours

TDR Value Estimate



7.8 Billion ILCU
22.6 Million person-hours

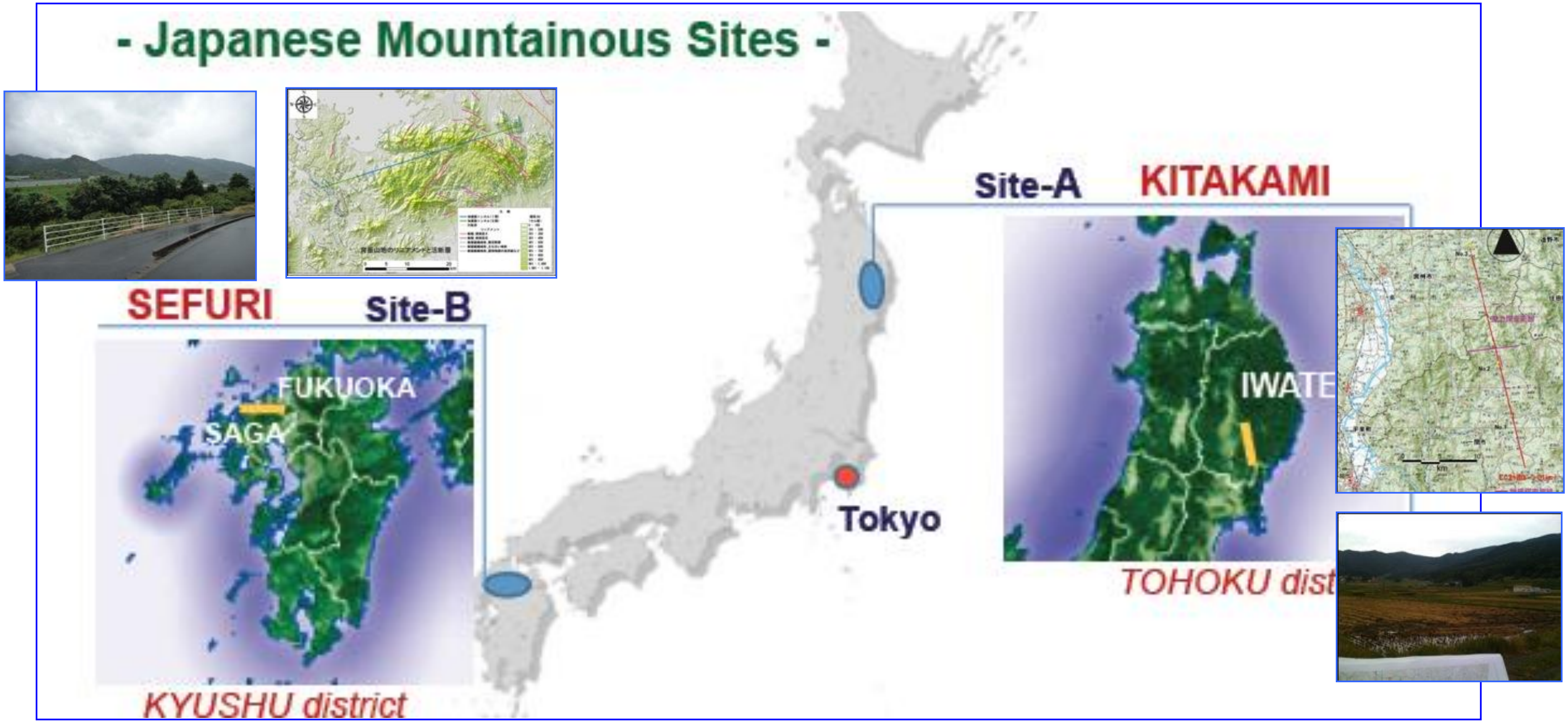
CFS-Civil construction	10%
CFS-other	6%
L-band Cavities and Cryomodules	32%
L-band HLRF	9%
Cryogenics	7%
Controls	2%
TOTAL Main Linac	**66%**



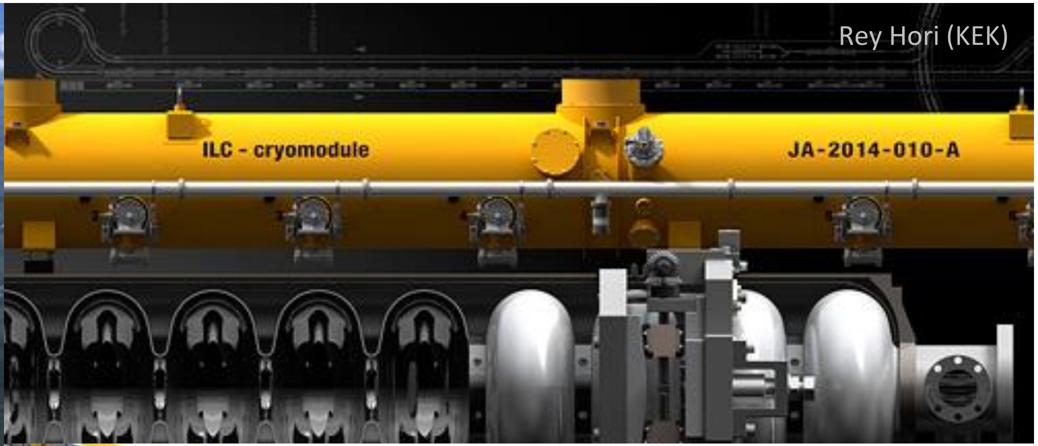
Unsung Heroes

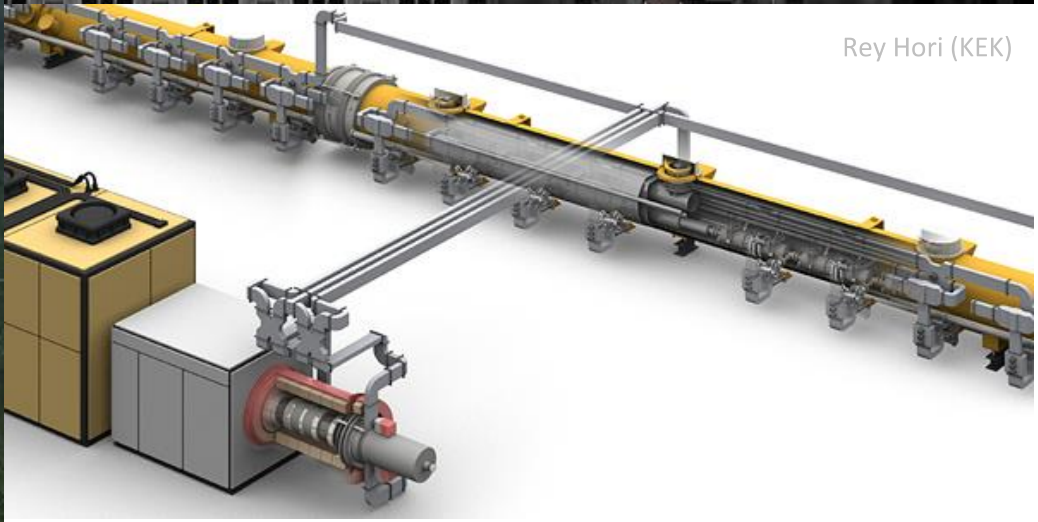
- Not high-tech
- But equally important and *challenging*
- And 30% of the total project cost!

Looking towards the East



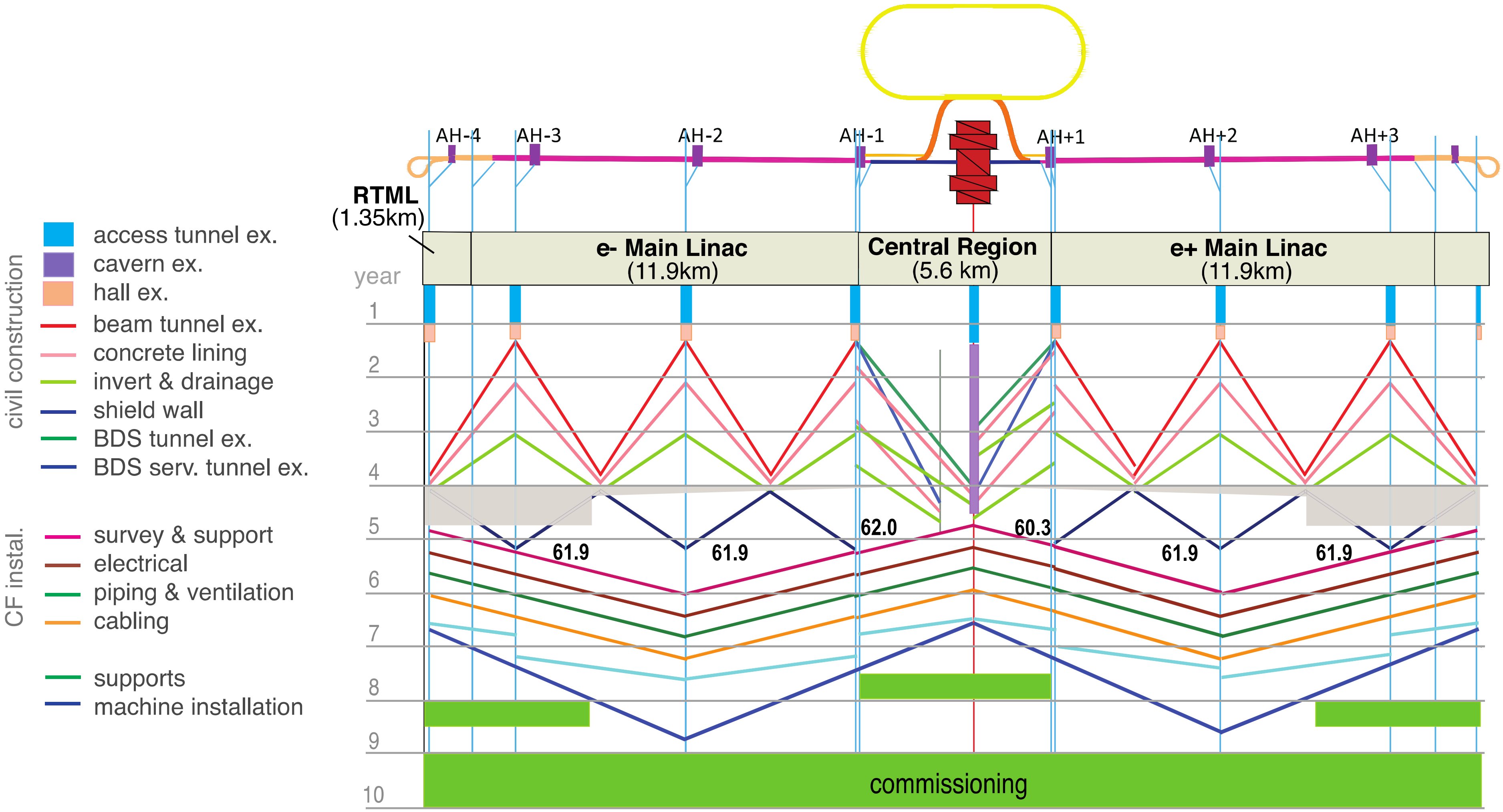
Thank you for your attention ☺





Backup / spares

Example Construction Schedule



TeV Parameters (2 sets)

Beam energy	GeV	500	
Collision rate	Hz	4	
Number of bunches		2450	
Bunch population	$\times 10^{10}$	1.74	
Bunch separation	ns	366	
Pulse current	mA	7.6	
RMS bunch length	mm	0.25	0.225
Electron RMS energy spread		0.08	0.09
Positron RMS energy spread		0.04	0.05
Electron polarisation	%	80	
Positron polarisation	%	30	
Horizontal emittance	mm	10	
Vertical emittance	nm	30	
IP horizontal beta function	mm	22.6	11.0
IP vertical beta function	mm	0.25	
IP RMS horizontal beam size	nm	481	335
IP RMS veritcal beam size	nm	2.8	
Luminosity	$\times 10^{34}$ cm^{-2}s^{-1}	**3.6**	**4.9**
Fraction of luminosity in top 1%		0.6	0.4
Average energy loss		0.06	0.11
Number of pairs per bunch crossing	$\times 10^{3}$	200	383
Total pair energy per bunch crossing	TeV	1338	3441

P_{AC} constrained ≤300 MW

shorter bunch length
(within BC range)

horizontal focusing main difference

low and high beamstrahlung