# Main Linac Layout –
## Two variants for two different types of sites

M. Ross

*Project Advisory Committee Review*

*13 December, 2012*

*KEK*

# Mandate from RDR

Chapter 7.1 (The Scope of the Engineering Design Phase)

"… design the conventional construction and site-specific infrastructure in enough detail to provide the information needed to allow potential host regions to estimate the technical and financial risks of hosting the machine, including local impact, required host infrastructure, and surface and underground footprints …"

# Global Value Engineering

- **Civil construction is a cost driver**
  - (27% Value estimate)
- **R & D results must support a *cost-optimized linac layout* solution balancing:**
  - Underground construction
  - Utilities
  - High level RF generation
  - HLRF distribution

  Linac Conventional Facilities and HLRF
- **Key issues:**
  - Cost containment → ***remove second tunnel boring***
  - Accessibility of HLRF equipment during operation → ***availability and energy overhead***
  - Safety → ***egress***

# Outline

- **Superconducting Linac Schematic**

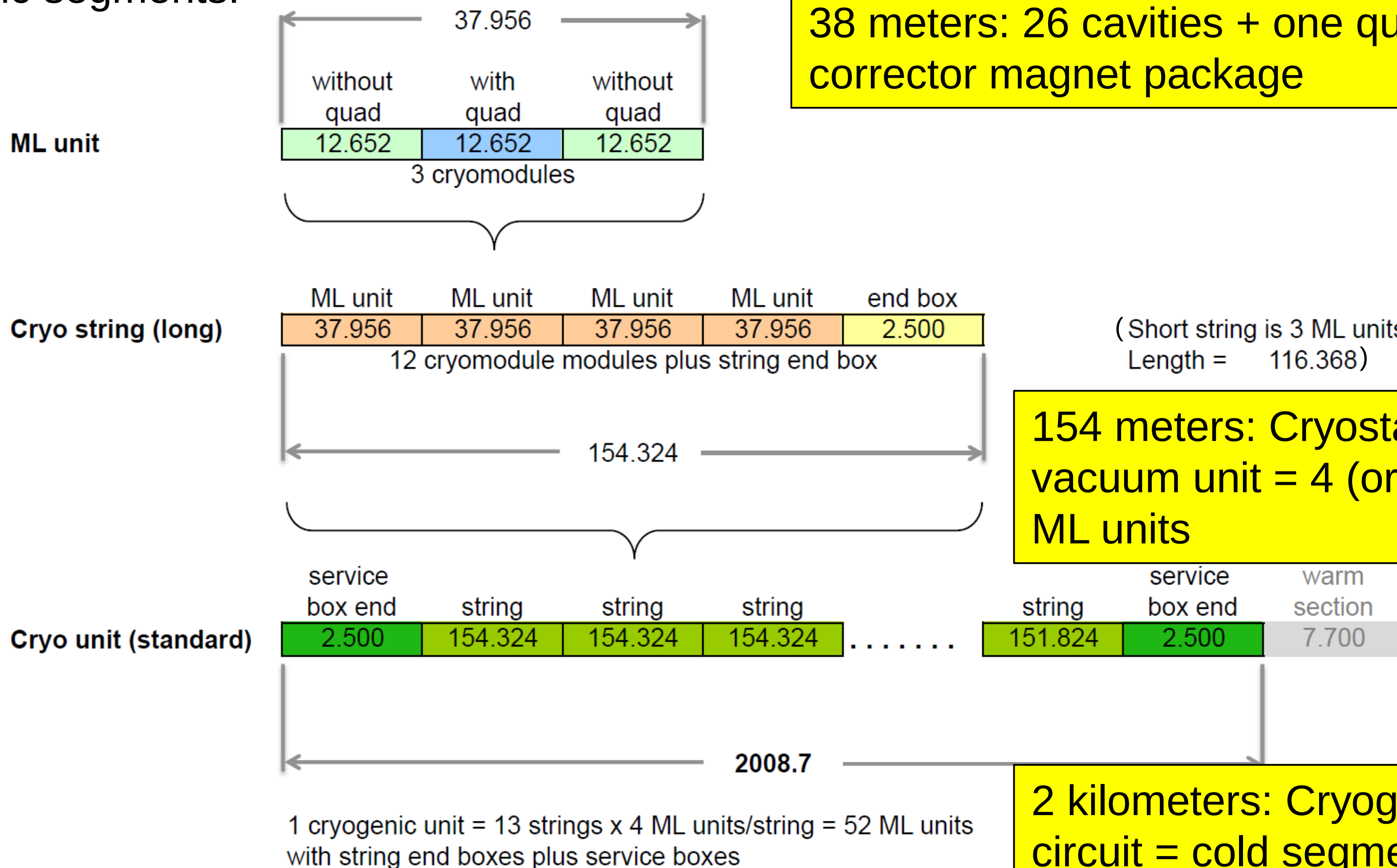
**Two *Main Linac* Layouts:**

- **Mountainous Region**
  - Civil Construction
  - HLRF Distribution, Detailed schematic
- **Flat Terrain**
  - Civil Construction
  - HLRF Distribution, Detailed schematic

- **Cryogenics**
- **Availability / Overhead / Operations**
- **Radiation exposure and**
- **Heat Load / AC Power**

# Superconducting linac schematic:

3 basic segments:

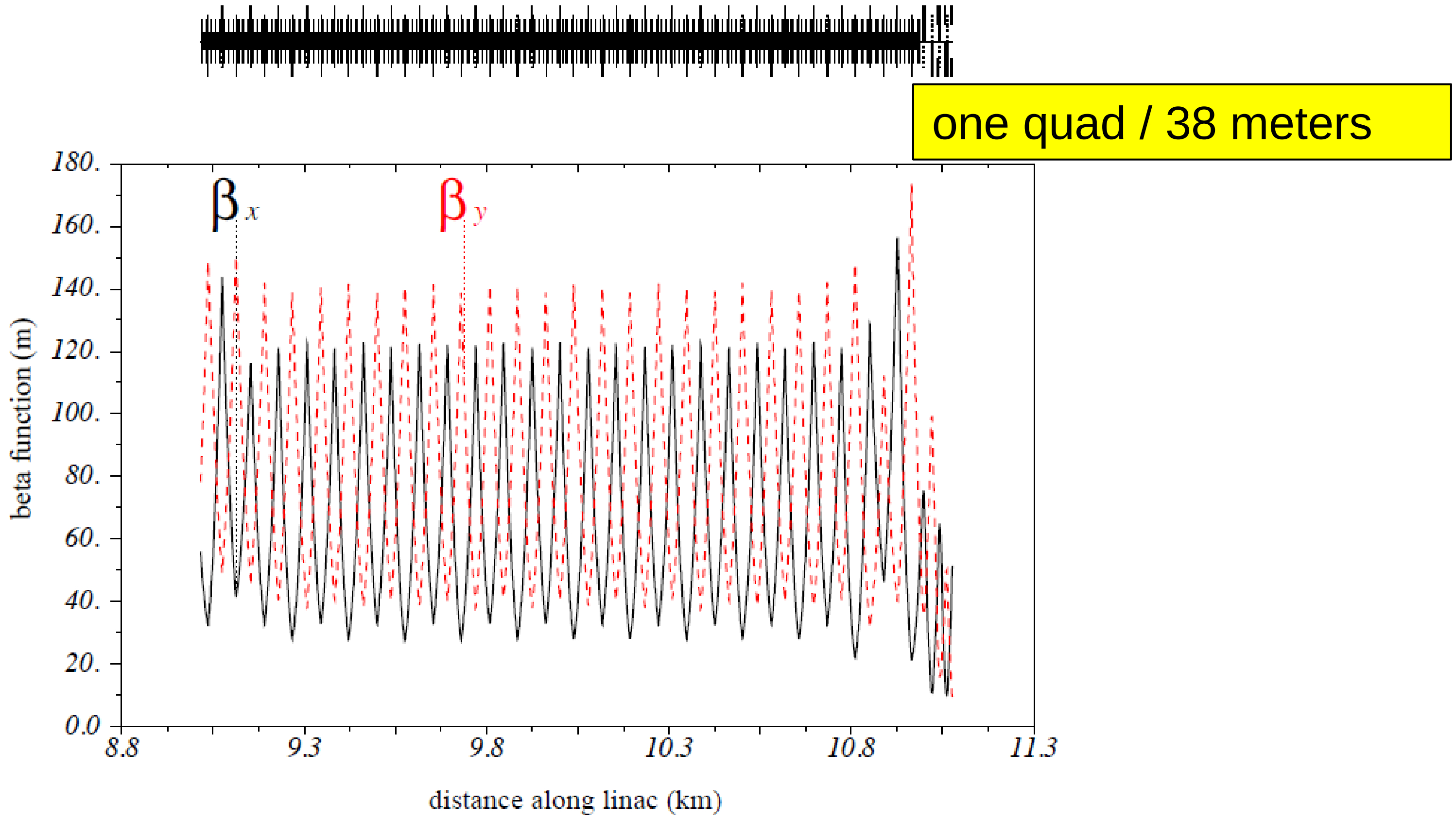



38 meters: 26 cavities + one quad / corrector magnet package

154 meters: Cryostat vacuum unit = 4 (or 3) ML units

2 kilometers: Cryogenic circuit = cold segment

# Linac Lattice




Lattice functions for last cryo-unit (2.008 km) with post-linac collimation

# Two Types of sites considered:

**Mountainous Region (MR)**

**(e.g. Japan)**

Features:

- No access to surface above tunnel
- Little surface construction
- Underground construction technology: blasting preferred in hard rock
- Tunnel depth variation

**Flat Terrain (FT)**

**(e.g. CERN or Fermilab)**

Features:

- Access to surface above tunnel
- Surface construction
- Underground construction: TBM preferred in soft (CERN) or moderately hard (Fermilab) rock
- Little tunnel depth variation

# Two Design Solutions for HLRF and Utilities:

## Mountain Region

'self-contained' main linac HLRF system with limited surface construction and limited surface connections

- Distributed Klystron (DKS)
- Similar to deep twin-tunnel RDR (2007)

## Flat Terrain

'tightly-linked' main linac system with extensive surface construction and HLRF distribution system

- Klystron Cluster (KCS)
- Quasi-new technology based on over-moded transmission of very high power RF
- R & D program

Linac Designs (cryomodules/optics) equivalent


**Candidate site in northeastern Japan**
**Tohoku 'Mountain Region'**

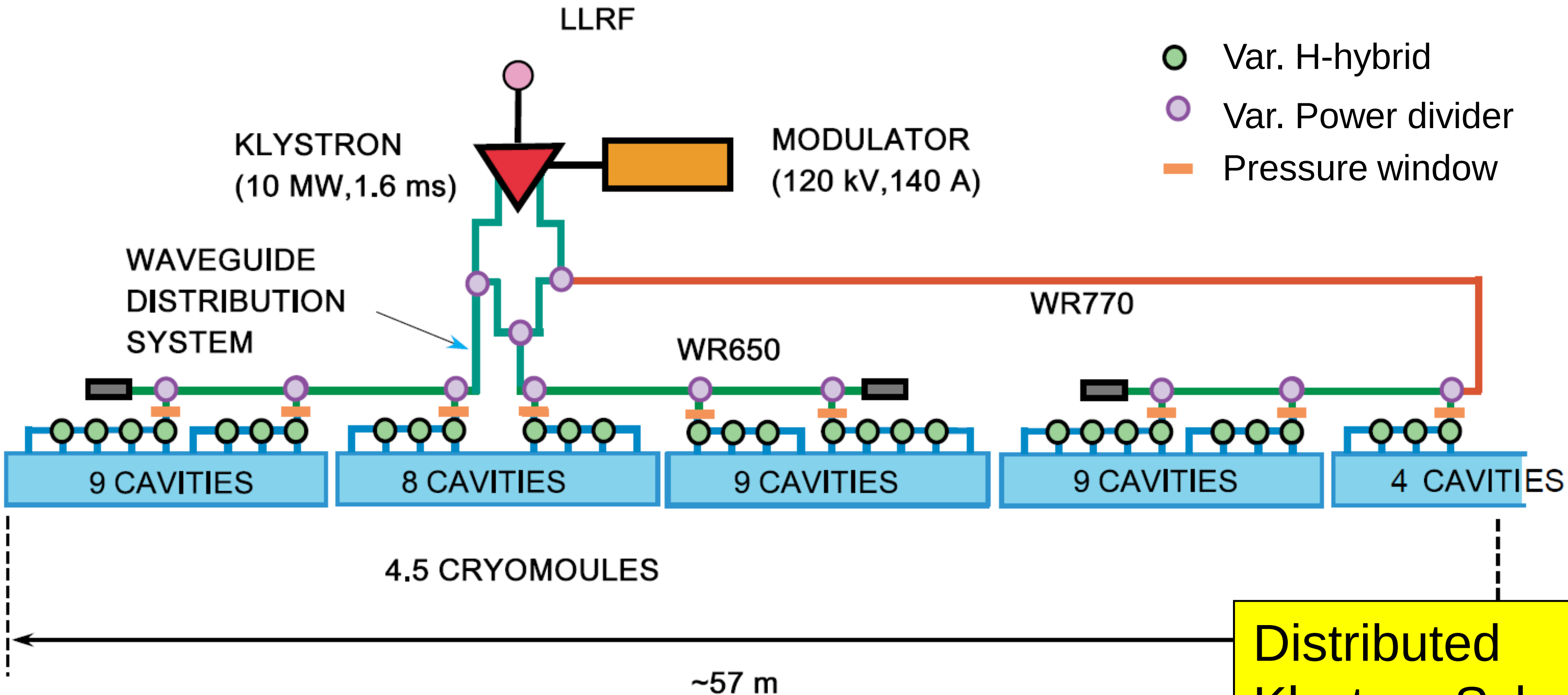
(Photo taken100 km north of Sendai.)

The ILC alignment would be 50 to 400 meters below these hills.

## Candidate site in western Japan Sefuri 'Mountain Region'

(Photo taken 30 km from Fukuoka; ~80 km east of Nagasaki).
The ILC would be 50 to 800 m below these hills.

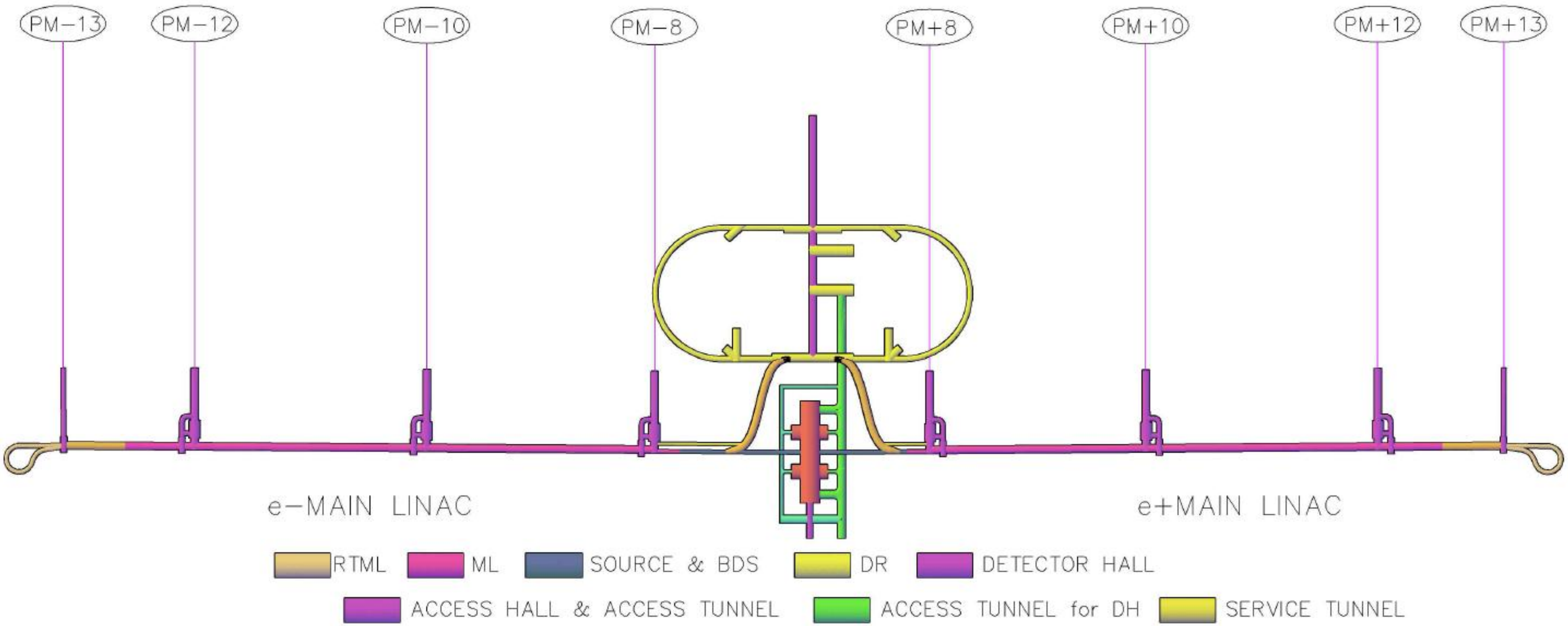
# MR Linac + HLRF (Japan)




Distributed Klystron Scheme → **DKS**

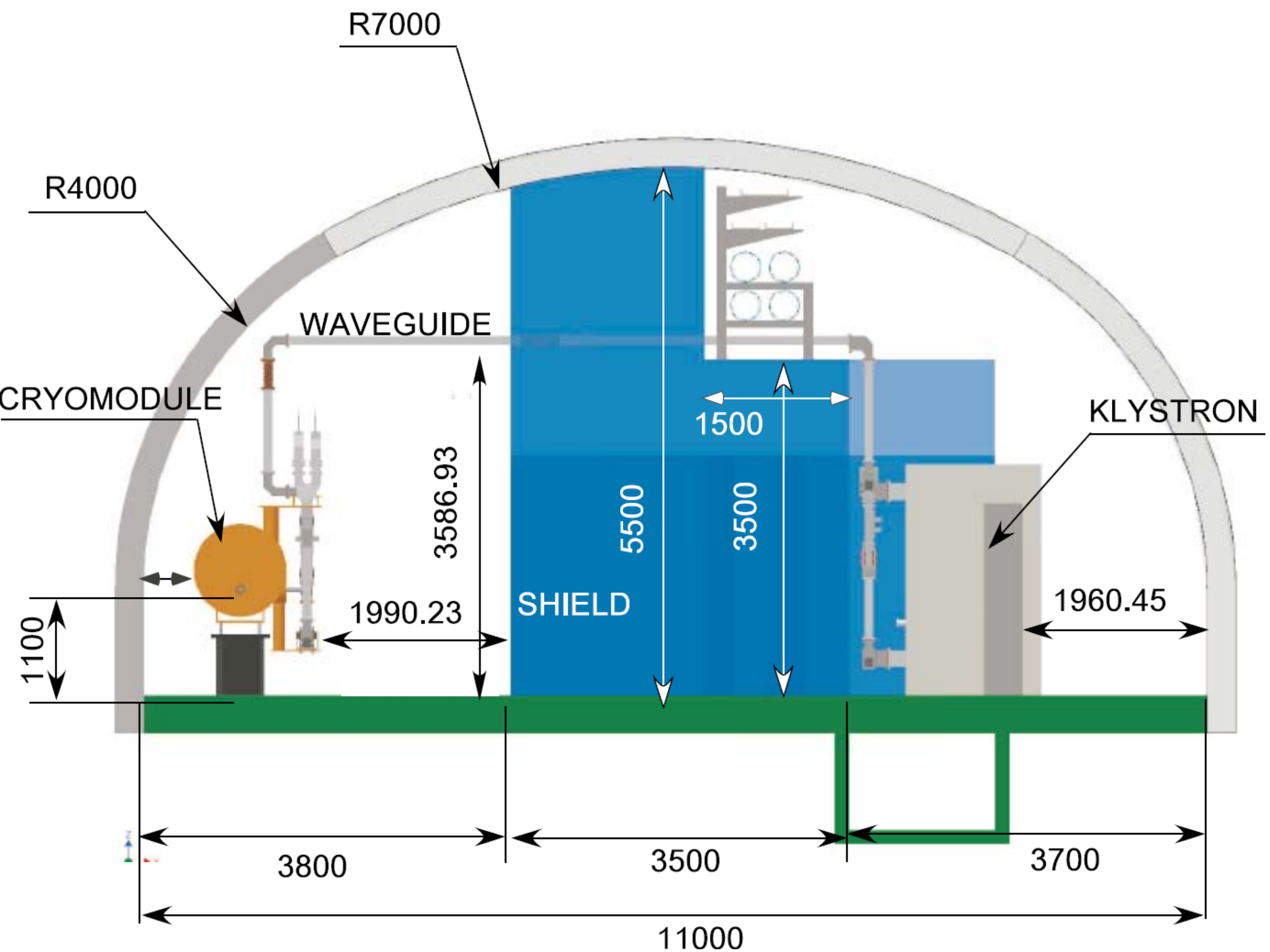
- Similar to 2007 RDR layout
- 1.5 ML Units
- 39 cavities: 9 8 9 9 4 // 4 9 9 8 9 // …

# MR Civil Layout



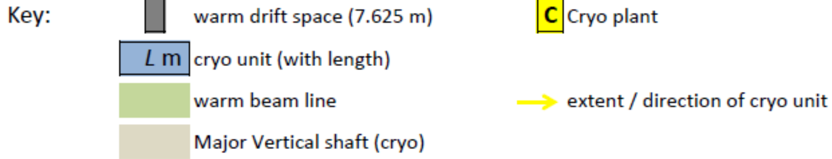

- **Six access tunnels / access halls**
  - 3 each per linac
  - Tunnels typically 1 km long, 10% grade
  - Details depend on site alignment
  - Access halls ~ 180 x 20 m

# MR Linac tunnel cross-section:

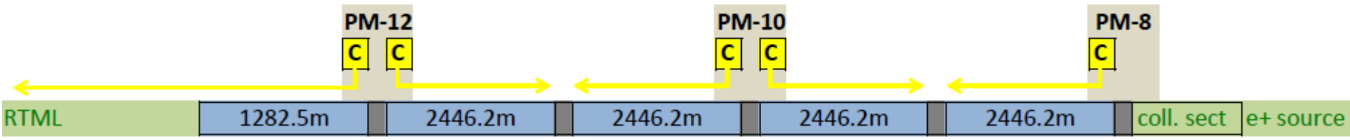



- **Personnel can occupy klystron area during operation**
  - Radiation analysis later in presentation
- **Cross-over paths for egress (500 m)**
- **11 m wide x 5.5 m high**
  - dimensions in mm

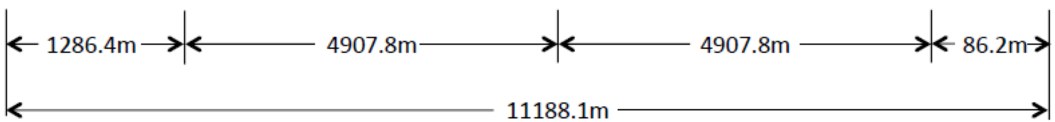
# MR Linac: Modules, Strings and HLRF



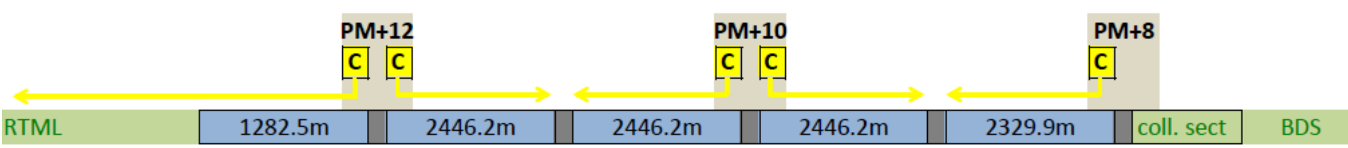

**Electron Linac**



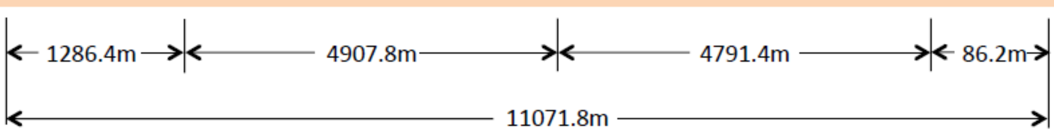

| | tot. | | | | | |
|---|---|---|---|---|---|---|
| Long strings | 0 | 0 | 0 | 0 | 0 | 0 |
| Short strings | 95 | 11 | 21 | 21 | 21 | 21 |
| Cold boxes | 90 | 10 | 20 | 20 | 20 | 20 |
| ML units | 285 | 33 | 63 | 63 | 63 | 63 |
| Cryomodules | 855 | 99 | 189 | 189 | 189 | 189 |
| RF stations | 190 | 22 | 42 | 42 | 42 | 42 |
| Beam Energy | 15 | 42.9 | 96.3 | 149.7 | 203.0 | 256.4 GeV |




**Positron Linac**

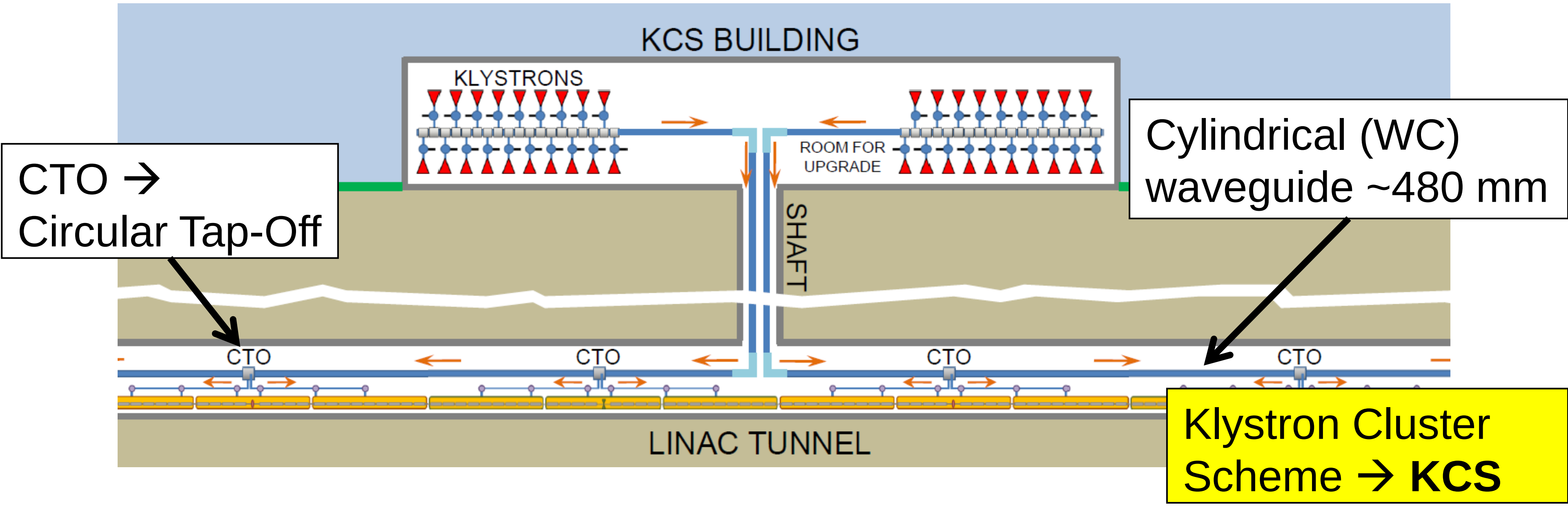



| | tot. | | | | | |
|---|---|---|---|---|---|---|
| Long strings | 0 | 0 | 0 | 0 | 0 | 0 |
| Short strings | 94 | 11 | 21 | 21 | 21 | 20 |
| Cold boxes | 89 | 10 | 20 | 20 | 20 | 19 |
| ML units | 282 | 33 | 63 | 63 | 63 | 60 |
| Cryomodules | 846 | 99 | 189 | 189 | 189 | 180 |
| RF stations | 188 | 22 | 42 | 42 | 42 | 40 |
| Beam Energy | 15 | 42.9 | 96.3 | 149.7 | 203.0 | 253.8 GeV |




- 1701 ML cryomodules
- 378 ML Klystrons total for both linacs

# FT Linac + HLRF (CERN/Fermilab)

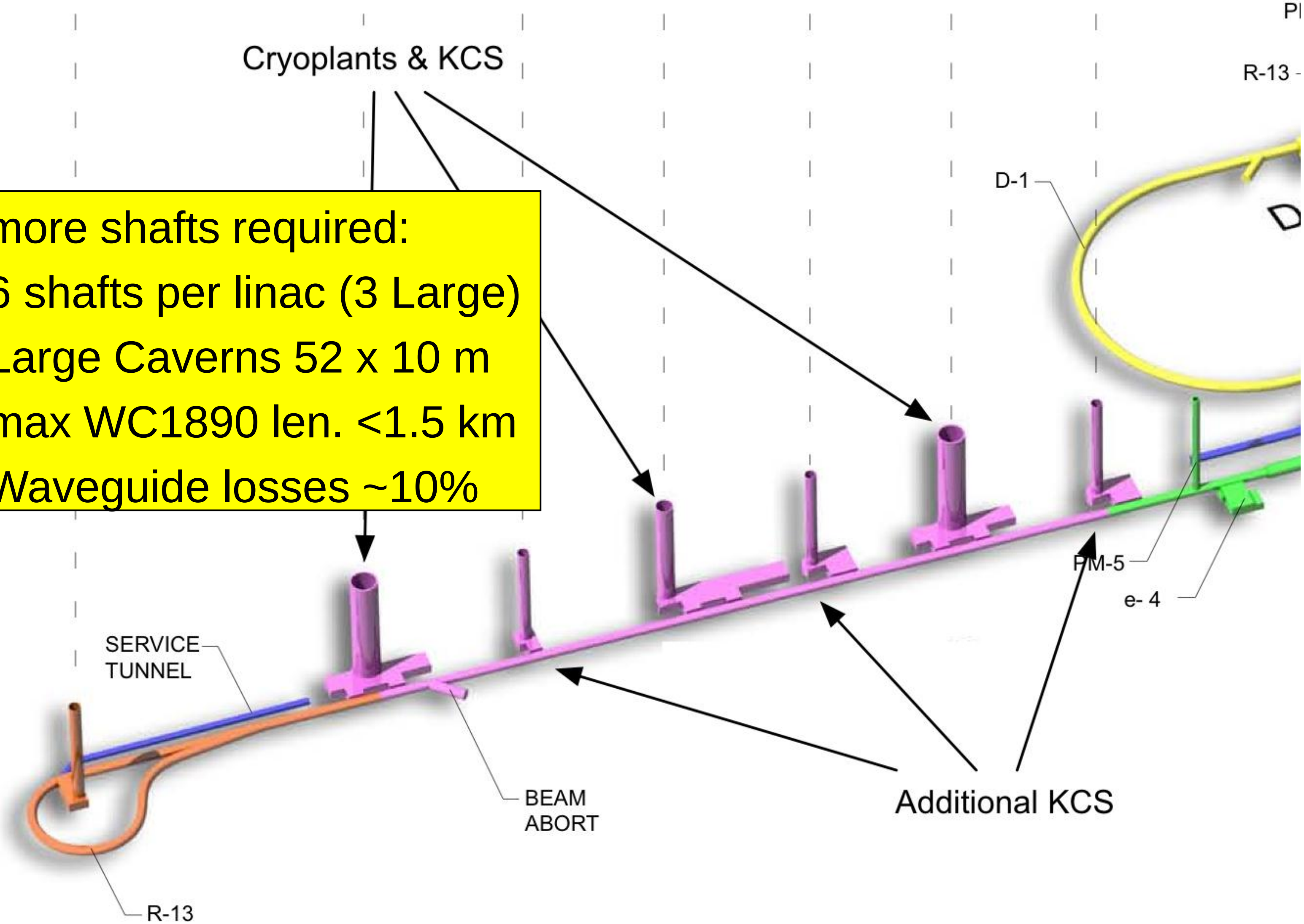



- Power distribution using over-moded waveguide (WC1890 @ 2 bar gauge pressure)
  - **Low loss, (8.5%/km), high power transmission**
- Similar technology to X-band (NLC / JLC)
- clusters of klystrons housed in surface buildings

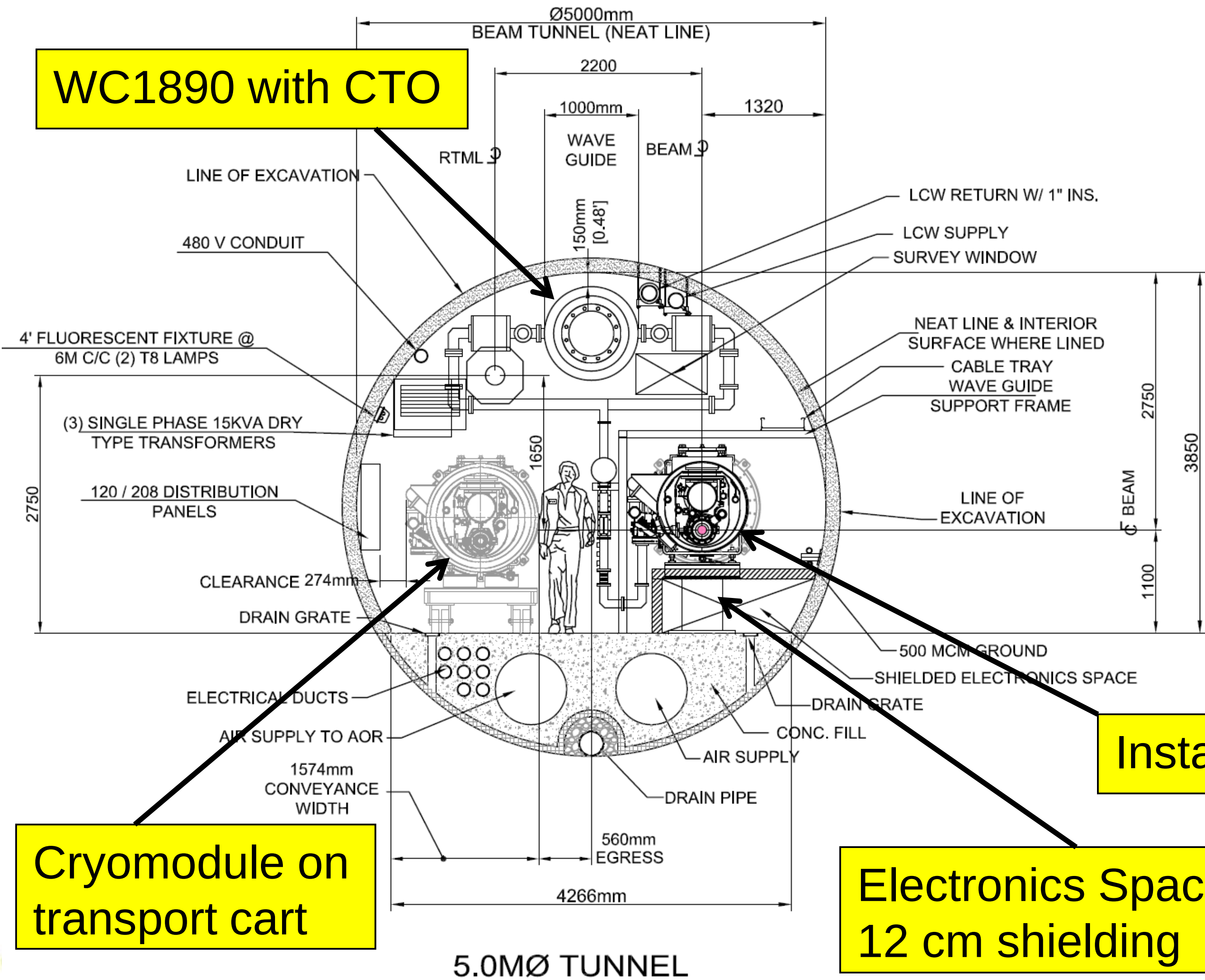
# FT Civil construction

2x more shafts required:

- 6 shafts per linac (3 Large)
- Large Caverns 52 x 10 m
- max WC1890 len. <1.5 km
- Waveguide losses ~10%

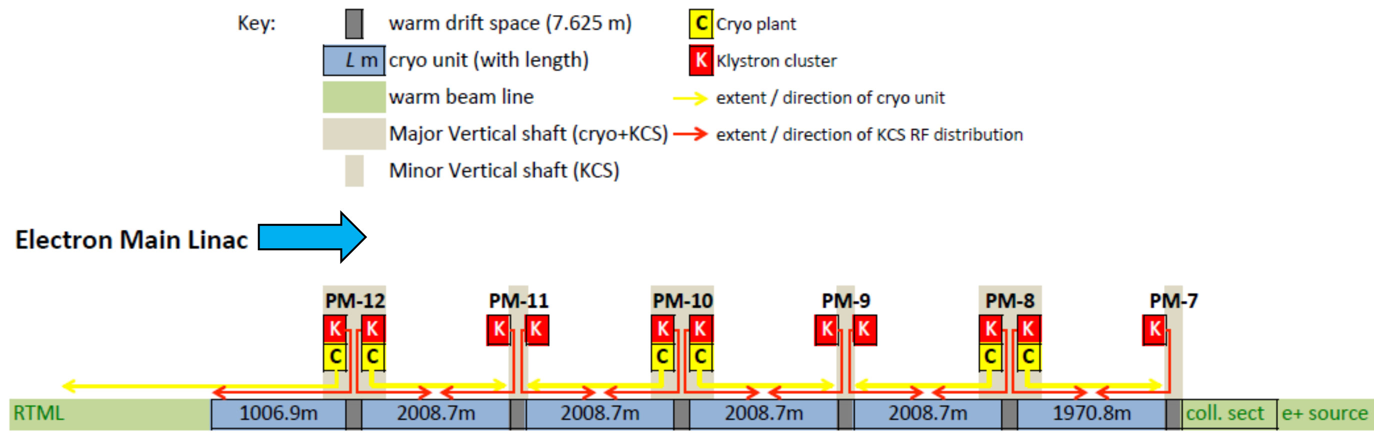


# FT Linac tunnel cross-section




- **No high power equipment in tunnel**
  - Instrumentation and control racks only
- **'Area of Refuge' mid-way between access shafts (~1000 m)**
- **5 m diameter (3.8 m high)**

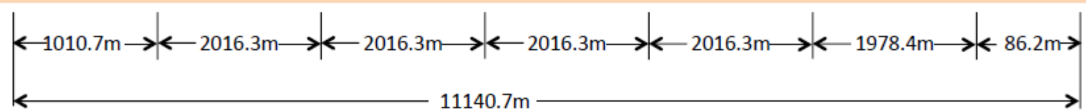
# FT Linac: Modules, Strings, Clusters and HLRF

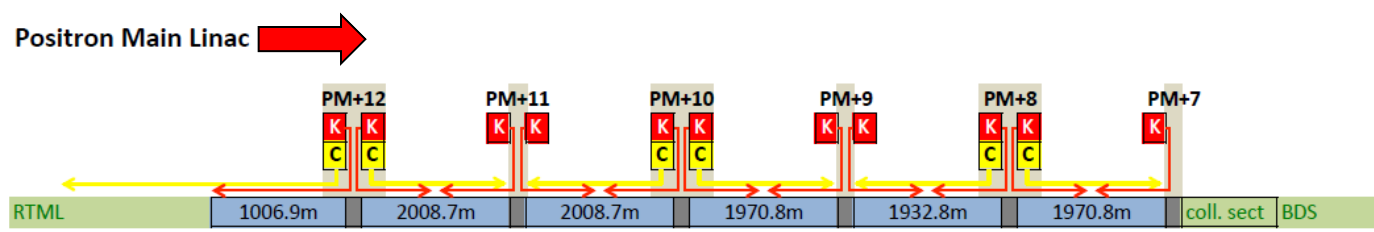



| | tot. | | | | | | |
|---|---|---|---|---|---|---|---|
| Long strings | 69 | 5 | 13 | 13 | 13 | 13 | 12 |
| Short strings | 3 | 2 | 0 | 0 | 0 | 0 | 1 |
| Cold boxes | 66 | 6 | 12 | 12 | 12 | 12 | 12 |
| ML units | 285 | 26 | 52 | 52 | 52 | 52 | 51 |
| Cryomodules | 855 | 78 | 156 | 156 | 156 | 156 | 153 |

| | tot. | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CTOs | 285 | 26 | 26 | 26 | 26 | 26 | 26 | 26 | 26 | 26 | 26 | 25 |
| Klystrons/Mod. | 208 | 19 | 19 | 19 | 19 | 19 | 19 | 19 | 19 | 19 | 19 | 18 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Beam Energy | 15 | 37.0 | 81.1 | 125.1 | 169.1 | 213.2 | 256.4 GeV |

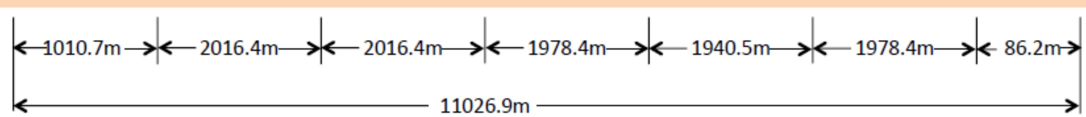



| | tot. | | | | | | |
|---|---|---|---|---|---|---|---|
| Long strings | 66 | 5 | 13 | 13 | 12 | 11 | 12 |
| Short strings | 6 | 2 | 0 | 0 | 1 | 2 | 1 |
| Cold boxes | 66 | 6 | 12 | 12 | 12 | 12 | 12 |
| ML units | 282 | 26 | 52 | 52 | 51 | 50 | 51 |
| Cryomodules | 846 | 78 | 156 | 156 | 153 | 150 | 153 |

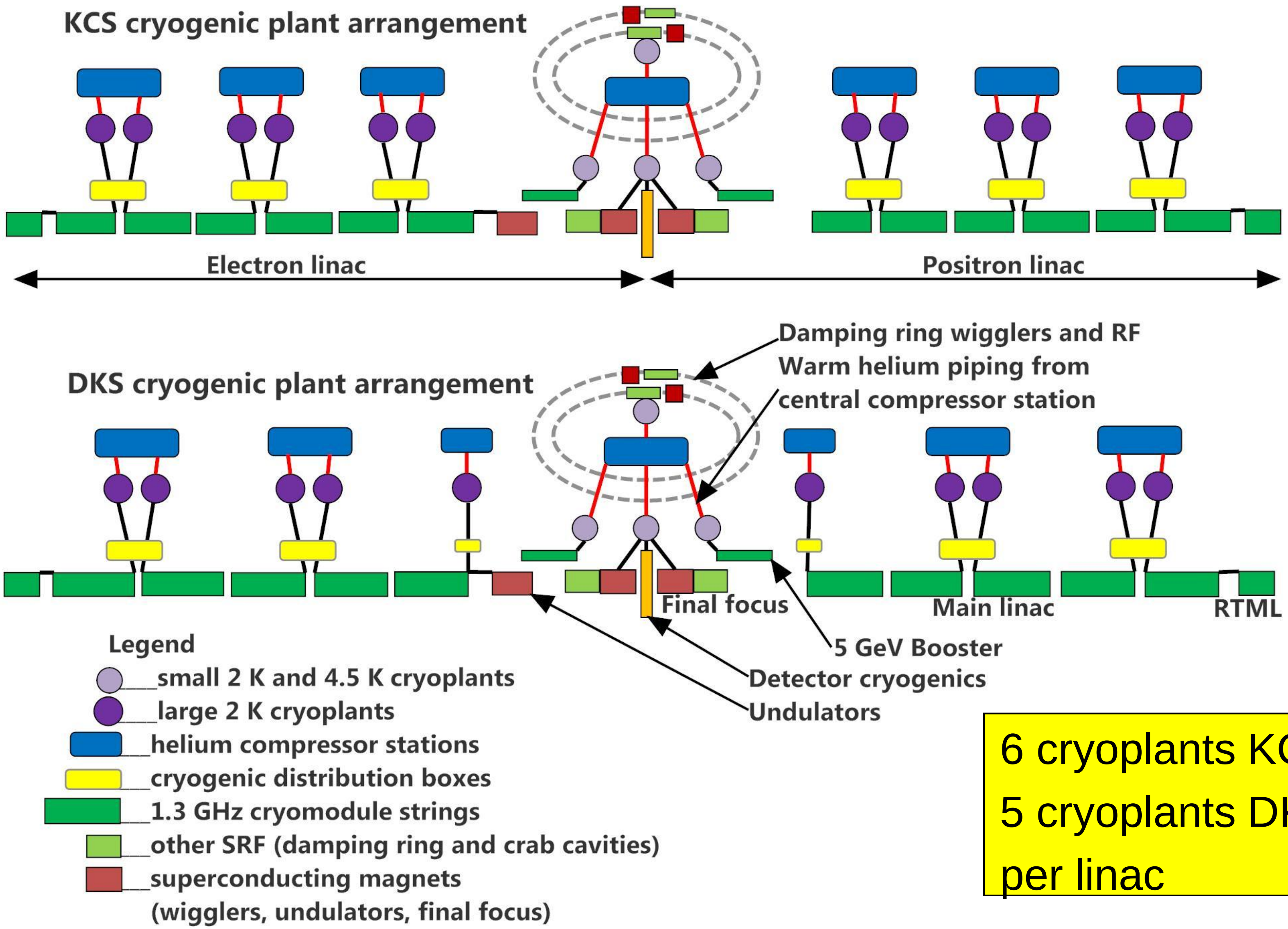
| | tot. | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CTOs | 282 | 26 | 26 | 26 | 26 | 26 | 26 | 25 | 25 | 25 | 25 | 26 |
| Klystrons/Mod. | 205 | 19 | 19 | 19 | 19 | 19 | 19 | 18 | 18 | 18 | 18 | 19 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Beam Energy | 15 | 37.0 | 81.1 | 125.1 | 168.3 | 210.6 | 253.8 GeV |




- 413 ML Klystrons total for both linacs
- KCS requires 9% more klystrons than DKS
- ~even cluster spacing

# Cryogenics




6 cryoplants KCS
5 cryoplants DKS
per linac

# Energy Overhead

- **1.4% energy overhead adopted**
  - (ILC nominal energy 253.5 GeV)
  - Provides margin for failure / degradation in cryomodule
- **Good HLRF system accessibility is required.**
- **Needed 'energy overhead' assumed to compensate for worst-performance component:**
- **Tuner (electro – mechanics inside cryostat) and Power Coupler failures can reduce linac energy and may accumulate since repair is very time-consuming**
- **→ Worst-performance component expected to be electro mechanical cavity tuner system**
- ***Important R & D for post-TDR.***

# Linac Availability

- **Linac availability simulated for four schemes(Including DKS-RDR and KCS)**
  - Confirmed assumption that tuner is greatest concern
- **Assume tuner system MTBF is 10^6 hour**
  - implies a failure every 2½ days
  - 3.5% of the linac would be unavailable (average)
  - (with a 5-year linac cryomodule maintenance cycle)
  - Assume no acceleration by a cavity with a failed tuner (worst case).
- **Tuner MTBF target: 10^7 hours.**
  - Roughly consistent with availability goal
  - Nominal energy operation with design margin of 1.4%
- ***Ongoing R & D and work with E XFEL***

# Operations

189 KW peak delivered to average cavity

## KCS

**67% RF power to beam**

**(189+92 KW generated *per cavity*)**

| | | KW peak | % of total |
|---|---|---|---|
| Single Klystron output | | 10,000.0 | |
| N cavities 26*26/19 | 35.6 | Per cavity 281.1 | 100% |
| Klystron margin | | 276.7 | 98% |
| KCS main / shaft loss | | 240.0 | 85% |
| LPDS loss | | 220.8 | 79% |
| LLRF Overhead | | 206.4 | 73% |
| Extra power for ±20% | | 189.2 | 67% |

## DKS

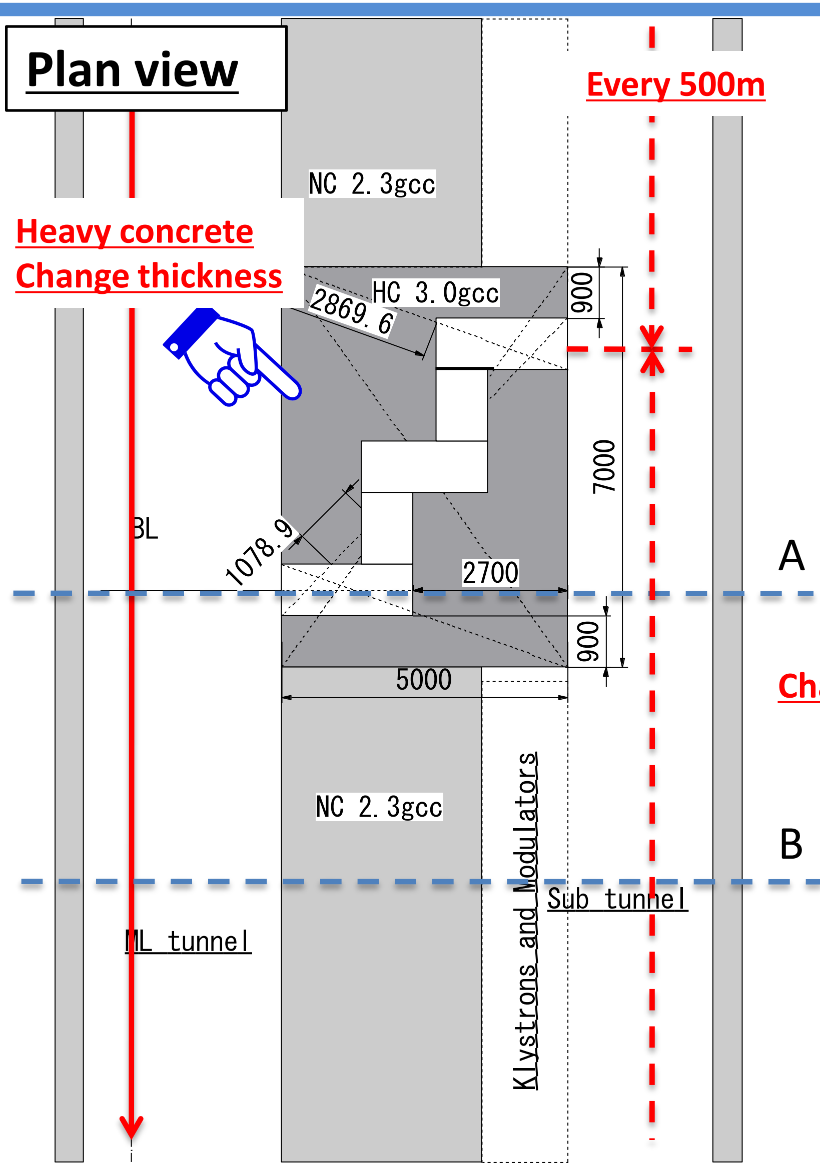
**74% RF power to beam**

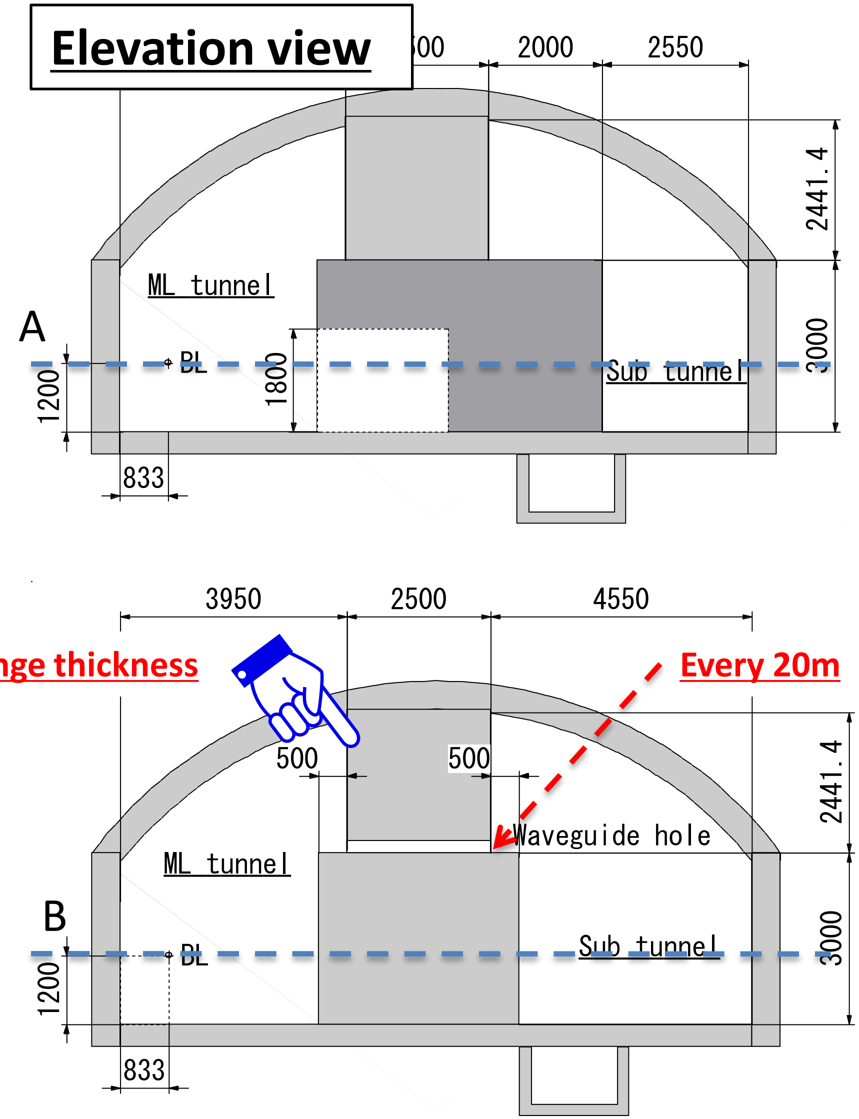
**(189 + 67 KW generated *per cavity*)**

| | | KW peak | % of total |
|---|---|---|---|
| Single Klystron output | | 10,000.0 | |
| N cavities | 39.0 | Per cavity 256.4 | 100% |
| Klystron margin | | 251.9 | 98% |
| LPDS loss | | 226.0 | 88% |
| LLRF Overhead | | 211.2 | 82% |
| Extra power for ±20% | | 189.2 | 74% |

# MR Tunnel access during operation – radiation exposure analysis:

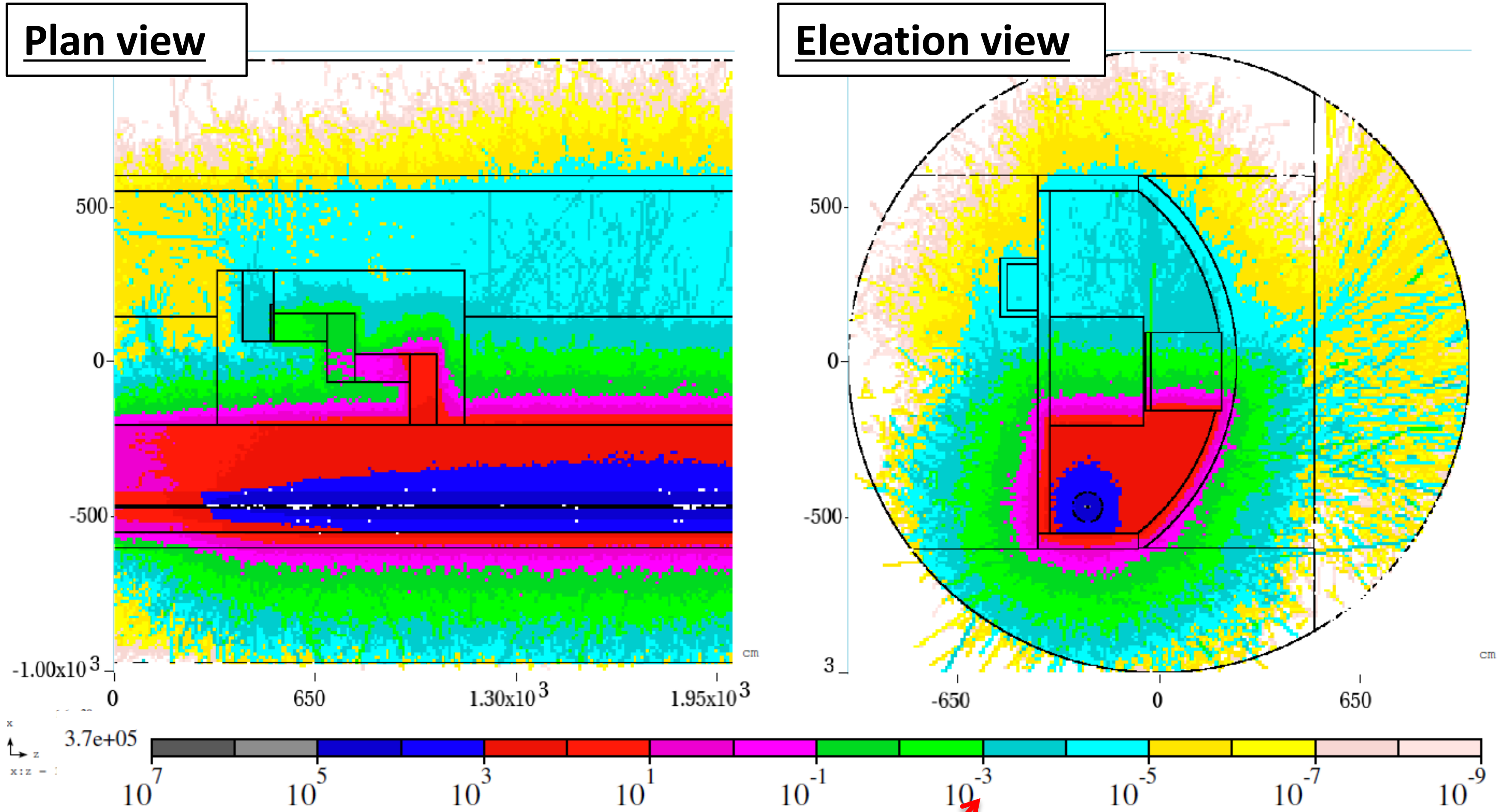
# Personal passage way+ Waveguide hole



# MR Tunnel access during operation – radiation exposure analysis (2):

## Dose rate for 1 W/m uniform loss

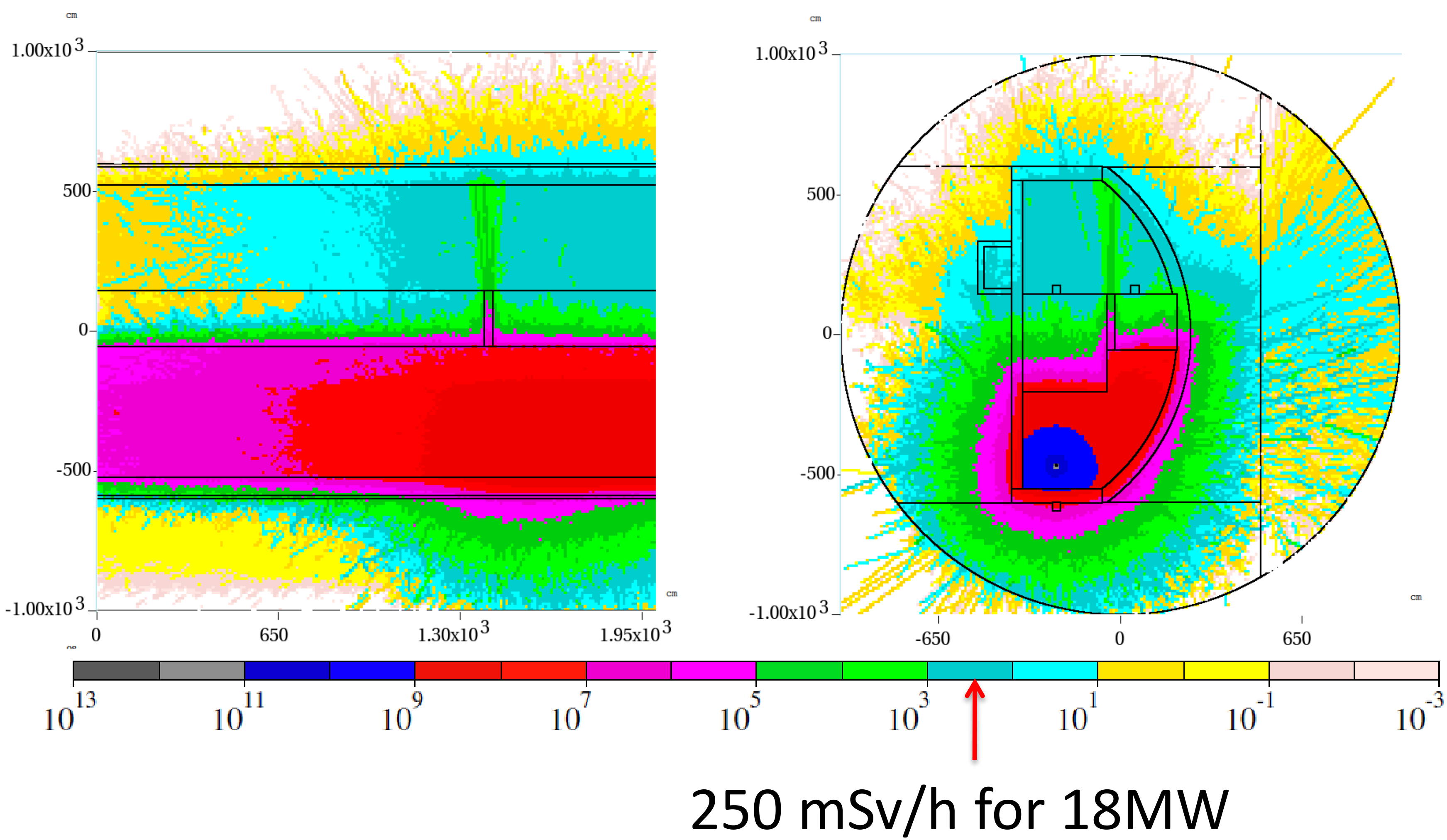



1 μSv/h for 1 W/m

< 20 μSv/h

# MR Tunnel access during operation – radiation exposure analysis (3):

## Dose rate for 18 MW point loss



# Heat Load and Power Flow

## Surface

| COMPONENTS IN THE SURFACE per ML unit | Average Heat Load (KW) | To LCW<br>Heat Load to LCW Water (KW) | to CHW<br>Racks Heat Load (KW) | To AIR<br>Heat Load to Air (KW) |
|---|---|---|---|---|
| RF Components x (413 ) | | | | |
| RF Charging Supply | 2.39 | 1.7 | | 0.7 |
| Switching power supply | 5.5 | 3.3 | | 2.2 |
| Filament Transformer | 0.79 | 0.6 | | 0.2 |
| Marx Modulator | 4.96 | 3.0 | | 2.0 |
| Klystrn Scket Tank / Gun | 0.99 | 0.8 | | 0.2 |
| Focusing Coil (Solenoid ) | 1.68 | 1.6 | | 0.1 |
| Klystron Collector | 38.43 | 37.1 | | 1.3 |
| Klystron Body & Windows | 3.37 | 3.4 | | |
| CTOs & combining Loads/circulators | 11.71 | 9.4 | | 2.3 |
| Relay Racks (Instrument Racks) | 3.0 | 0 | 3 | 0.0 |
| Subtotal surface RF& NonRF unit Only (for 1 RF) | | 60.74 | 3.0 | 9.1 |

## Tunnel

| COMPONENTS IN THE TUNNEL ( per ML unit | | | | |
|---|---|---|---|---|
| RF Components (x 567) | | | | |
| RF Pipe in Shaft (shaft & bends) | 1.89 | 1.7 | | 0.2 |
| Relay Racks (Instrument Racks) | | 5 | | 0.0 |
| Main tunnel Wvgde & local wvgd | 12.23 | 11.6 | | 0.6 |
| Distribution Edn Loads & Cavity Reflection loads | 31.80 | 31.30 | | 0.5 |
| Subtotal Tunnel RF& NonRF unit Only (for 1 RF) | | 49.62 | | 1.3 |

Waste heat:

- for each klystron station (surface) and
  - 73 kW
- for each ML 3 cryomodule unit (tunnel)
  - 50 kW
  - 1.3 kW to tunnel air
- 740 kW to air (ML total)
- air / water fraction
  - 33 W/meter to air
  - Does not include 'cooling' due to cryomodules (~ 150 W 10% reduction)

(KCS)

# FT and MR AC Power

| System | Flat Topography AC power (MW) | Mountain Topography AC power (MW) |
|---|---|---|
| Modulators | 58.1 | 52.1 |
| Other RF system and controls | 5.8 | 5.5 |
| Conventional facilities | 13.3 | 16.4 |
| Cryogenics | 32.0 | 32.0 |
| Total | 109.2 | 106.1 |

Asia (MW)

| Accelerator section | RF Power | Racks | NC magnets | Cryo | Conventional | | Total |
|---|---|---|---|---|---|---|---|
| | | | | | Normal | Emergency | |
| $e^-$ sources | 1.28 | 0.09 | 0.73 | 0.80 | 1.47 | 0.50 | 4.87 |
| $e^+$ sources | 1.39 | 0.09 | 4.94 | 0.59 | 1.83 | 0.48 | 9.32 |
| DR | 8.67 | | 2.97 | 1.45 | 1.93 | 0.70 | 15.72 |
| RTML | 4.76 | 0.32 | 1.26 | | 1.19 | 0.87 | 8.40 |
| Main Linac | 52.13 | 4.66 | 0.91 | 32.00 | 12.10 | 4.30 | 106.10 |
| BDS | | | 10.43 | 0.41 | 1.34 | 0.20 | 12.38 |
| Dumps | | | | | 0.00 | 1.21 | 1.21 |
| IR | | | 1.16 | 2.65 | 0.90 | 0.96 | 5.67 |
| TOTALS | 68.2 | 5.2 | 22.4 | 37.9 | 20.8 | 9.2 | 164 |

Tunnel Lengths and volumes

# Summary:

Asia

| Accelerator section | Length(m) | Volume ($m^3$) |
|---|---|---|
| $e^-$ source (beam) | 368 | 17,757 |
| $e^-$ source (service) | 223 | 4,881 |
| $e^+$ source (beam) | 1,678 | 67,364 |
| $e^+$ source (service) | 1,523 | 33,351 |
| Damping Ring | 3,239 | 120,352 |
| RTML | 3,305 | 200,237 |
| Main Linac | 22,425 | 1,395,754 |
| BDS (beam) | 3,847 | 184,019 |
| BDS (service) | 3,102 | 67,915 |
| TOTAL | 39,710 | 2,091,630 |

Europe

| Accelerator section | Length (m) | Volume ($m^3$) |
|---|---|---|
| $e^-$ source (beam) | 368 | 18,522 |
| $e^-$ source (service) | 618 | 9,828 |
| $e^+$ source (beam) | 1,678 | 84,329 |
| $e^+$ source (service) | 2,203 | 35,038 |
| Damping Ring | 3,239 | 91,571 |
| RTML (beam) | 3,305 | 74,546 |
| RTML (service) | 1,955 | 31,090 |
| Main Linac | 22,168 | 470,782 |
| BDS (beam) | 3,847 | 193,379 |
| BDS (service) | 3,847 | 61,183 |
| TOTAL | 43,228 | 1,070,268 |

- Two configurations:
- Mountain Region Tunnel lengths
  - **(e.g. Japan)**
- Flat Terrain Tunnel lengths
  - **(e.g. CERN / Fermilab)**

High Level RF to be presented by S. Fukuda

- Conventional Facilities / Siting to be presented by V. Kuchler and A. Enomoto