One-vs-Two Tunnel Tradeoffs
(America's Specific)

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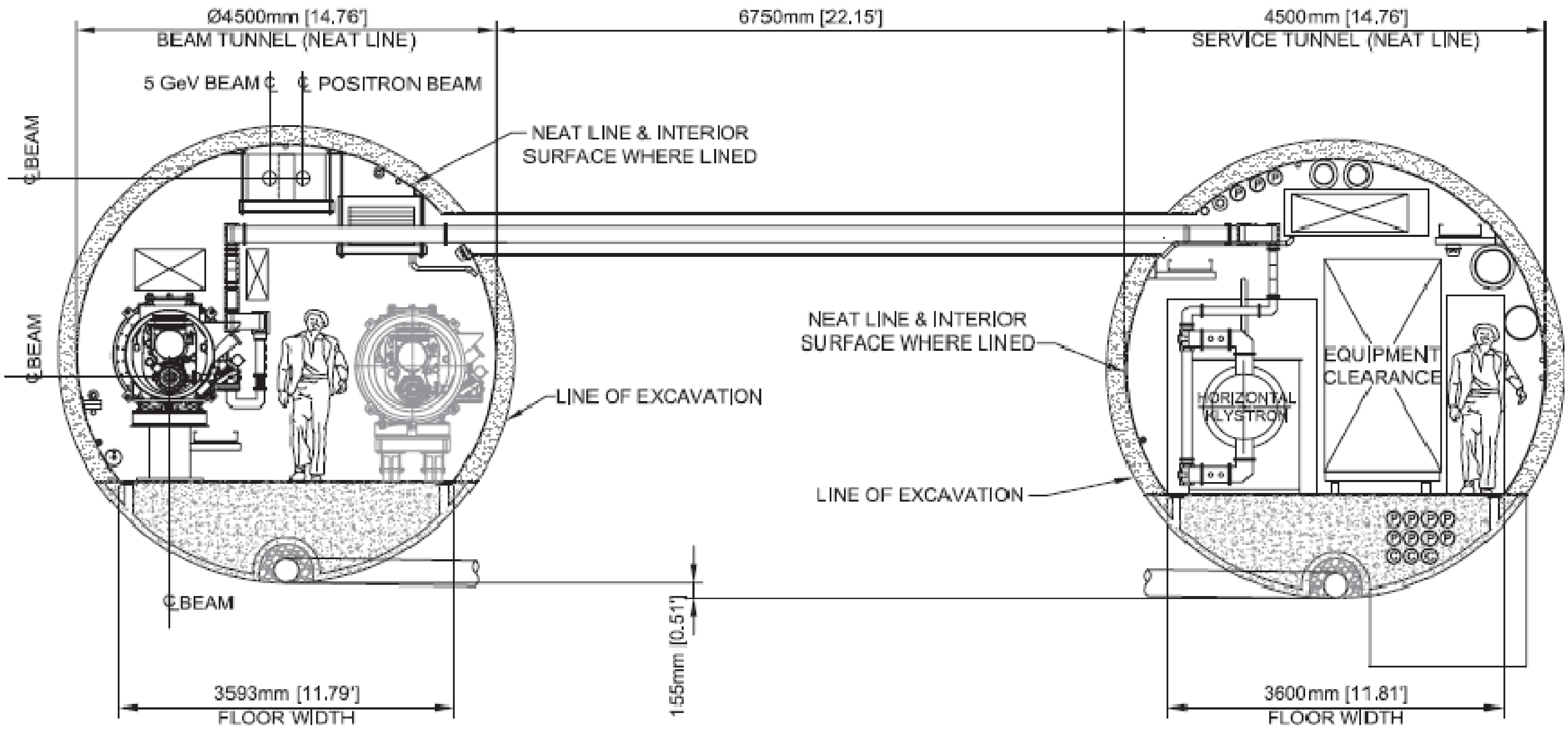
General Considerations

- Advantages of one tunnel
  - Lower cost from eliminating one tunnel, penetrations and cross connects.
- Disadvantages of one tunnel
  - Decreases availability – ameliorate with better HA designs (increase MTBF's) and/or more energy overhead. Increases risk of not achieving sufficient reliability.
  - Electronics exposed to dark current and beam induced radiation – requires rad hard designs and/or extensive shielding.
  - Cryomodules exposed to temperature gradients (from air heating) and increased vibration, which may compromise performance.
  - Installation more constrained, will likely take longer.
  - Limited access during operation requires "fire-drill" forced downtime maintenance mode instead of orderly replacement at any time. Also it slows commissioning and makes difficult gradual improvements and debugging of subtle problems.

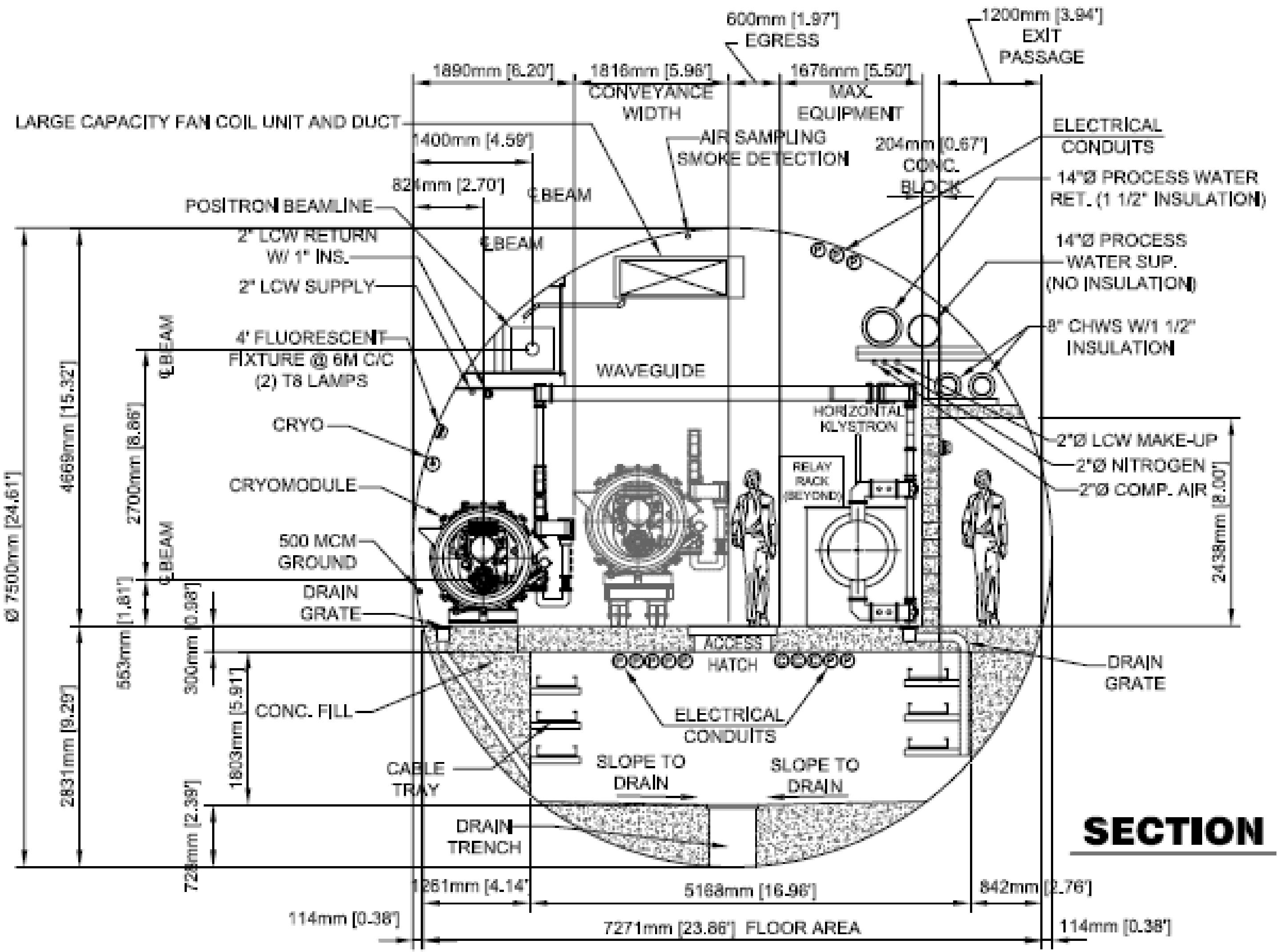
Compare 3 Layouts

- Baseline design: Two 5 m tunnels separated by 7.5 m
  - Each includes 0.7-0.9 m space for egress
  - Cross connects every 500 m for fire safety
- One 7.5 m tunnel
  - 0.6 m space for egress
  - 1.4 m brick enclosure for fire safety
  - Very spacious (easy to add radiation shielding)
- One 5.2 m tunnel w/liner: like XFEL proposal
  - 0.6 m space for egress
  - Fire wall every 600 m and smoke-activated venting system (not known if allowed in US).
  - All rf components fit longitudinally in tunnel without change in dimensions

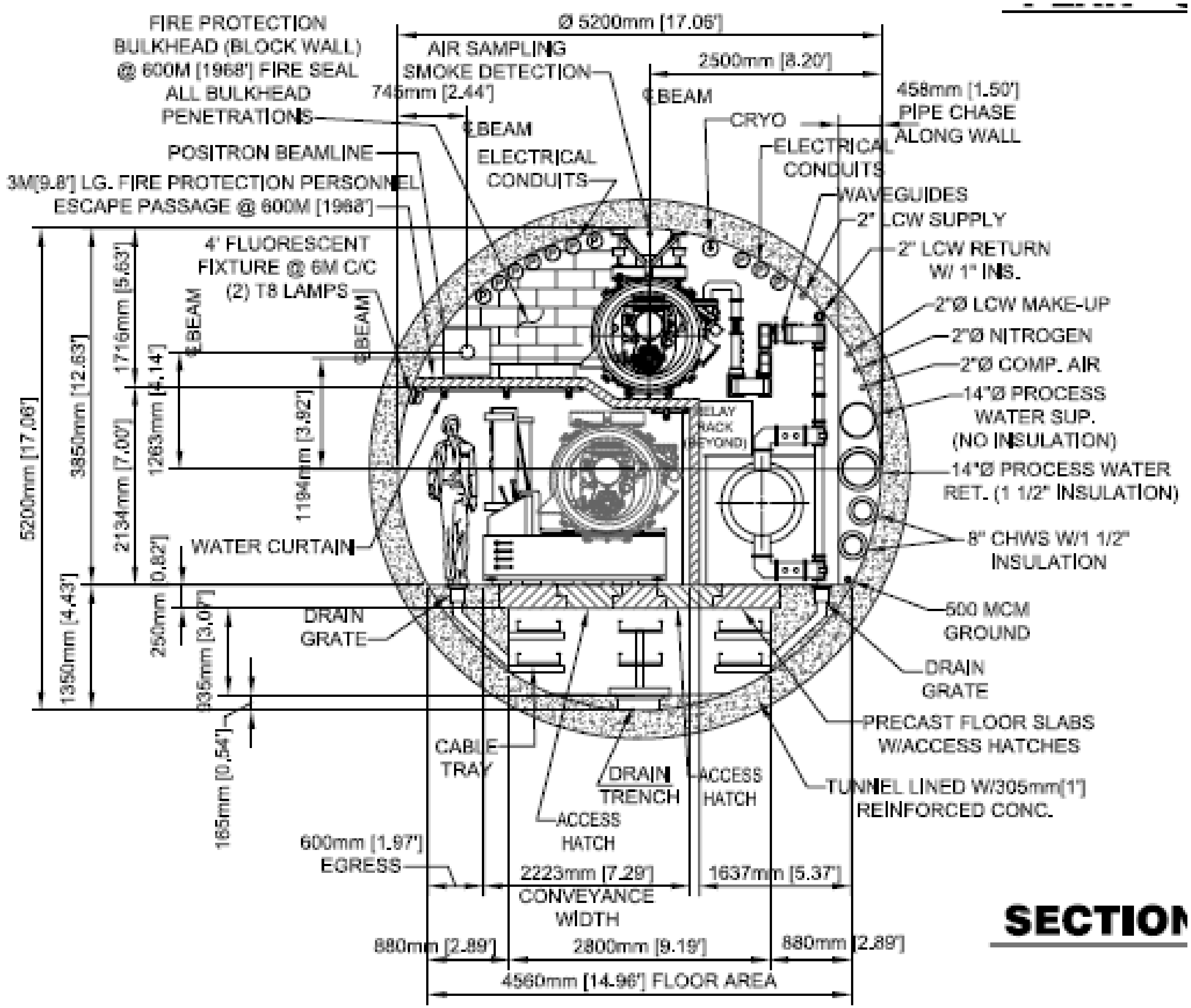
ILC Baseline Linac Tunnel Layout



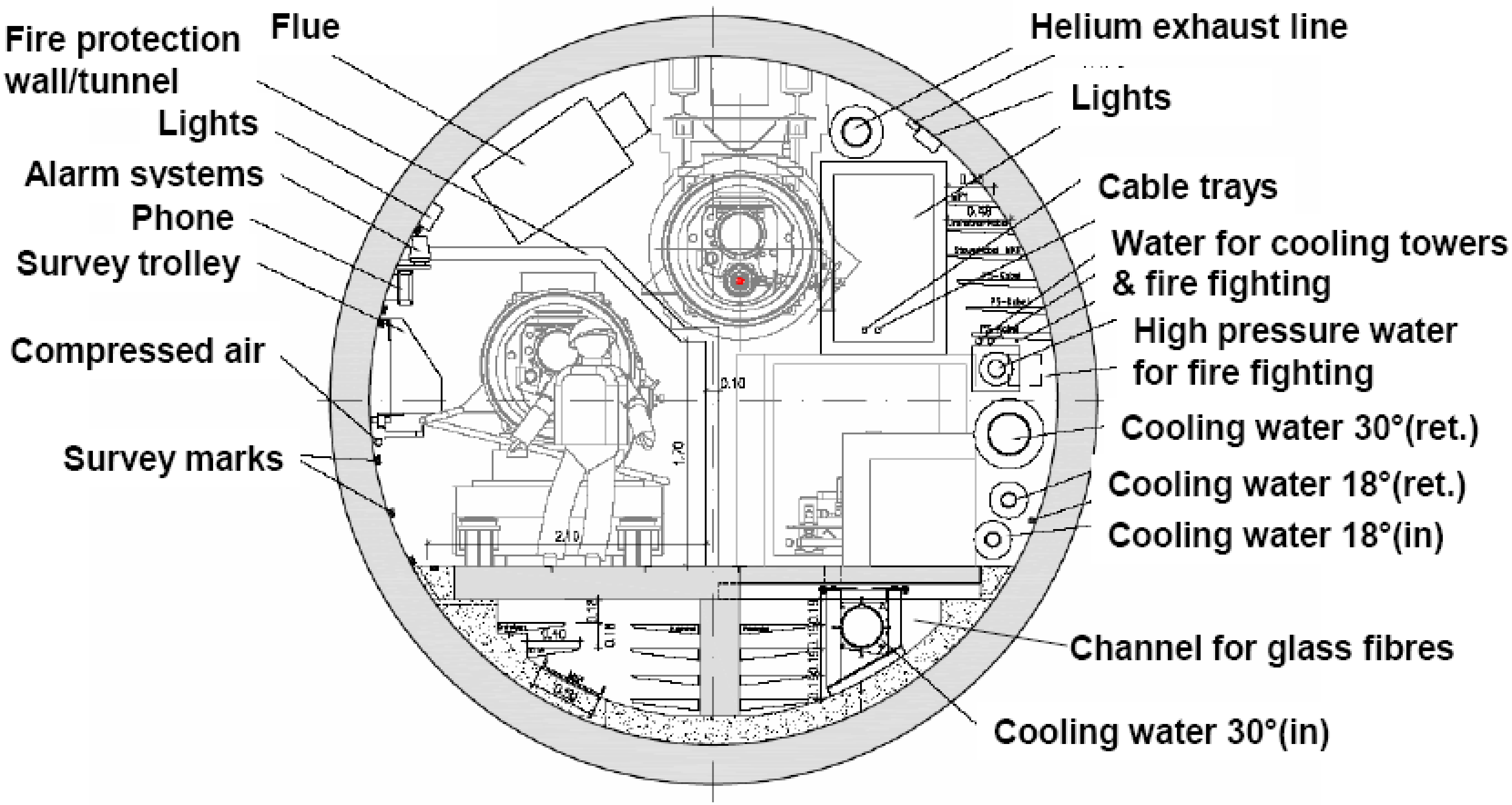
7.5 m Diameter Single Tunnel



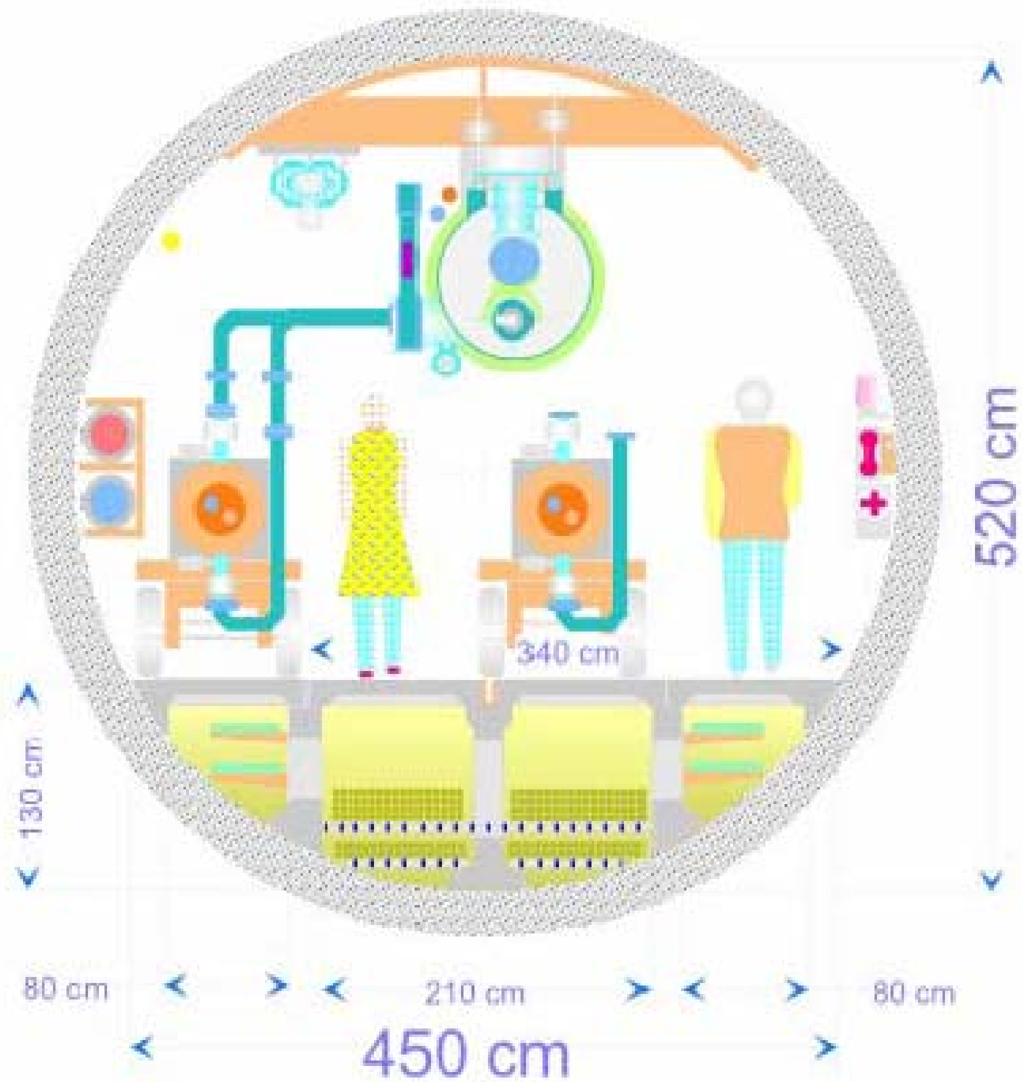
5.2 m Diameter Single Tunnel



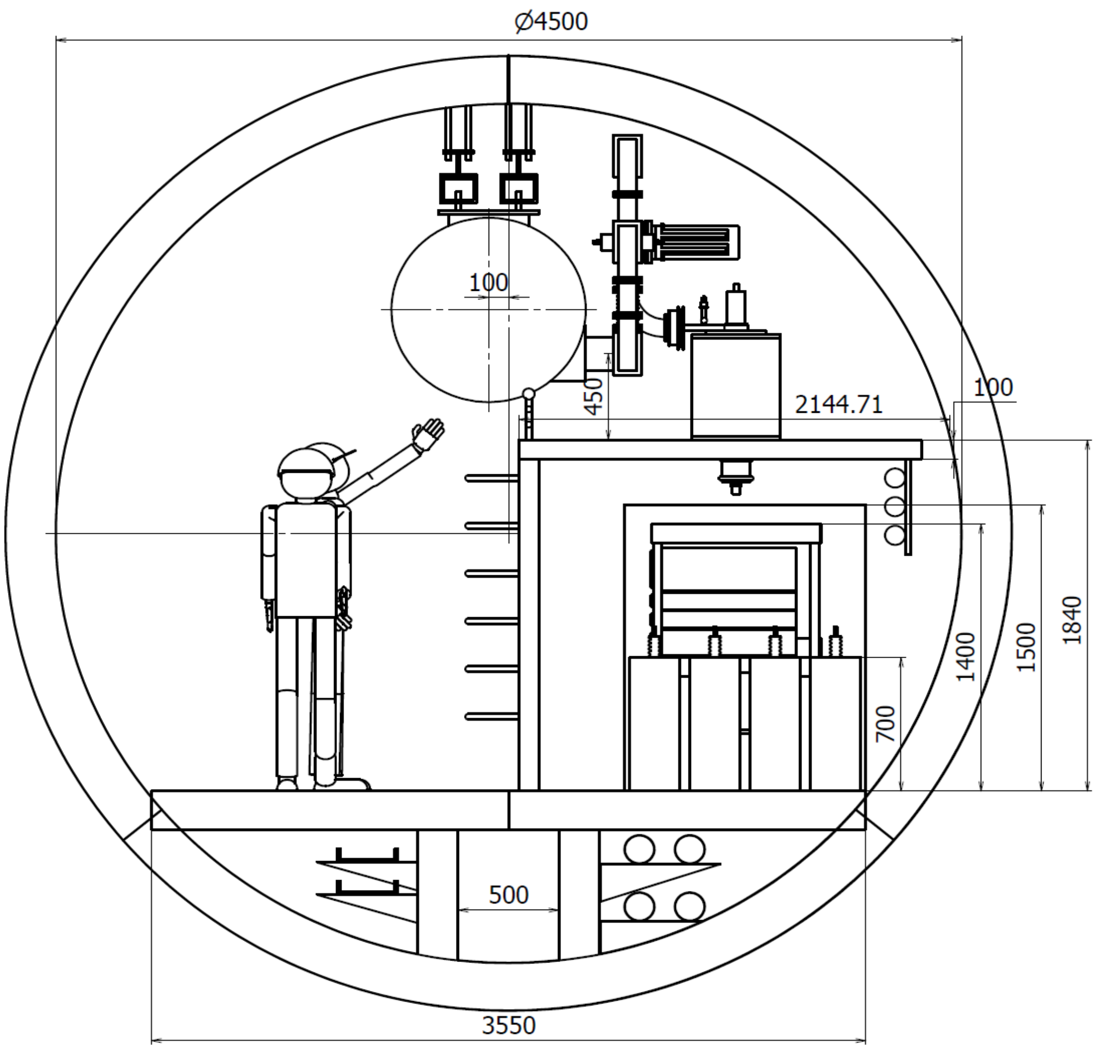
XFEL Single Tunnel (5.2 m ID)

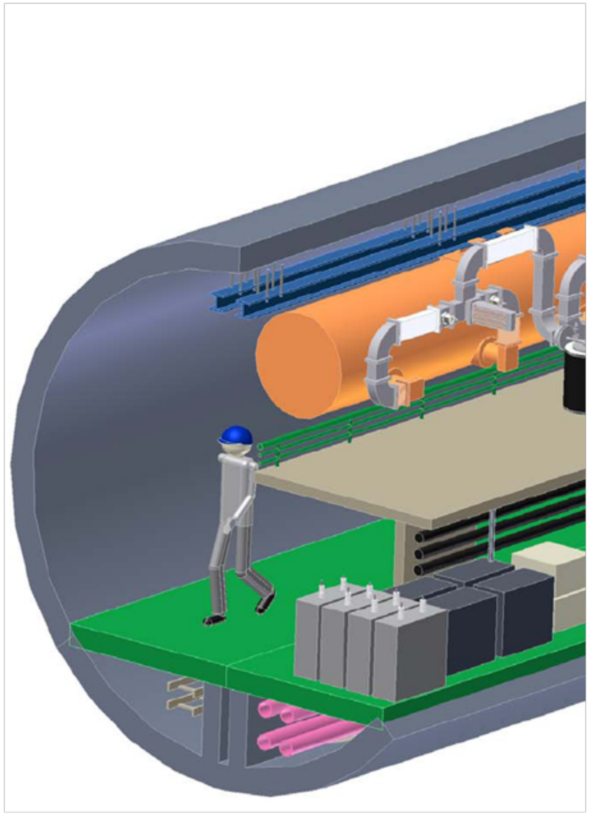


TESLA Single Tunnel for ITRP

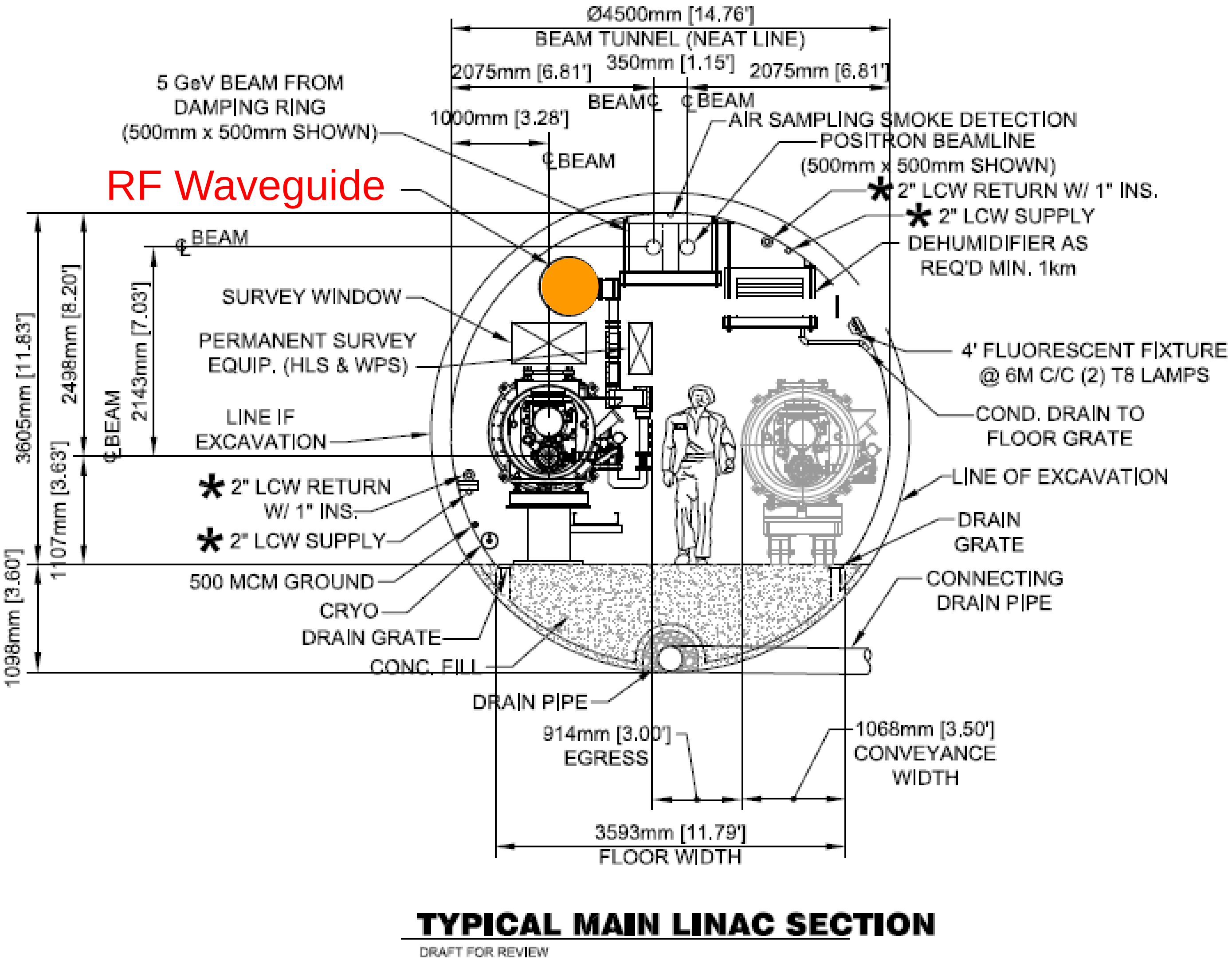


Distributed RF System





Klystron Cluster Scheme



Modulator Layout

- TESLA/XFEL assume modulator pulser unit located in surface buildings every 5 km.
- Could likely be implemented in any the 3 layouts just discussed.
- Advantages
  - Allows easy maintenance during machine operation.
  - Does not expose modulator electronics to radiation in single tunnel cases.
  - High power AC distribution no longer in tunnel.
- Disadvantages
  - Additional 100 M$ (?) cost for cables and buildings.
  - Cable installation costly & cable MTBF becomes an issue.
  - R&D required to develop 120 kV pulse transport if new modulator designs used.

Tunnel Neutron Radiation

TESLA Answer to ITRP Question 10

- Fast neutrons will cause single event upset (SEU) but not permanent damage to low power electronics such as computers. The total neutron dose in TESLA is expected to be < 10e12 neutrons/ cm^2 in 20 years (at surface of cryomodule).
- Measurements with standard PCs in TTF I and FPGAs and SRAM in LINAC II (here we have similar conditions as in the TESLA Linac) have shown that SEU may be at a rate of 10 - few hundred events per day.
- Maxell industries has developed a SEU immune processor board (SCS750 available in Q4 04, price 9,200 $) for flight system. We can apply similar software/hardware strategies to make the electronics immune to SEU.

Tunnel Gamma Radiation

TESLA Answer to ITRP Question 10

- The maximum expected gamma dose rate at the surface of the cryomodule is 10 Rad/hour or 65 kRad/year (based on a maximum cryo-load of 0.1 W/m).
- The damage level for a typical digital signal processor is 3 - 10 kRad. For all electronics in the LLRF system for example we can assume safe operation up to a total does of 1 kRad.
- Assuming 100,000 hours of operation (20 years) the worst case scenario would require shielding of a factor of 1000 corresponding to approximately 0.8 m of concrete or 8 cm of lead shielding. Considering the strong forward angle of the emitted gamma radiation the required shielding can be easily installed around the electronic racks.

B. Mukherjee 12/07 Estimate

SHIELDED RADIATION DOSE FIGURES FOR XFEL

For the total XFEL operation time of 80000h (10 y)

SHIELDING: 10 mm Lead and 3 mm Borated Polyethylene foil

Gradient : 22.5 MV. m^{-1} (Routine operation)

Gamma Dose (shielded): 6 Gy
Neutron kerma (unshielded): 0.031Gy (remain unchanged)
***Number of SEU in 1 MB bq4017MC-70 SRAM (shielded): ~ 8.0**

Gradient : 30 MV. m^{-1} (Worst Case Scenario)

Gamma Dose (shielded): 760 Gy
Neutron kerma (unshielded): 0.050 Gy (remain unchanged)
***Number of SEU in 1 MB bq4017MC-70 SRAM (shielded): ~ 10**

*** Using the SEU Cross Section of 2.3×10^{-13} $cm^2.bit^{-1}$ (D Makowski, PhD Thesis, 2006, DMCS, TU Lodz, Poland and experimentally estimated thermal neutron cut off factor of 10^{-4}.**

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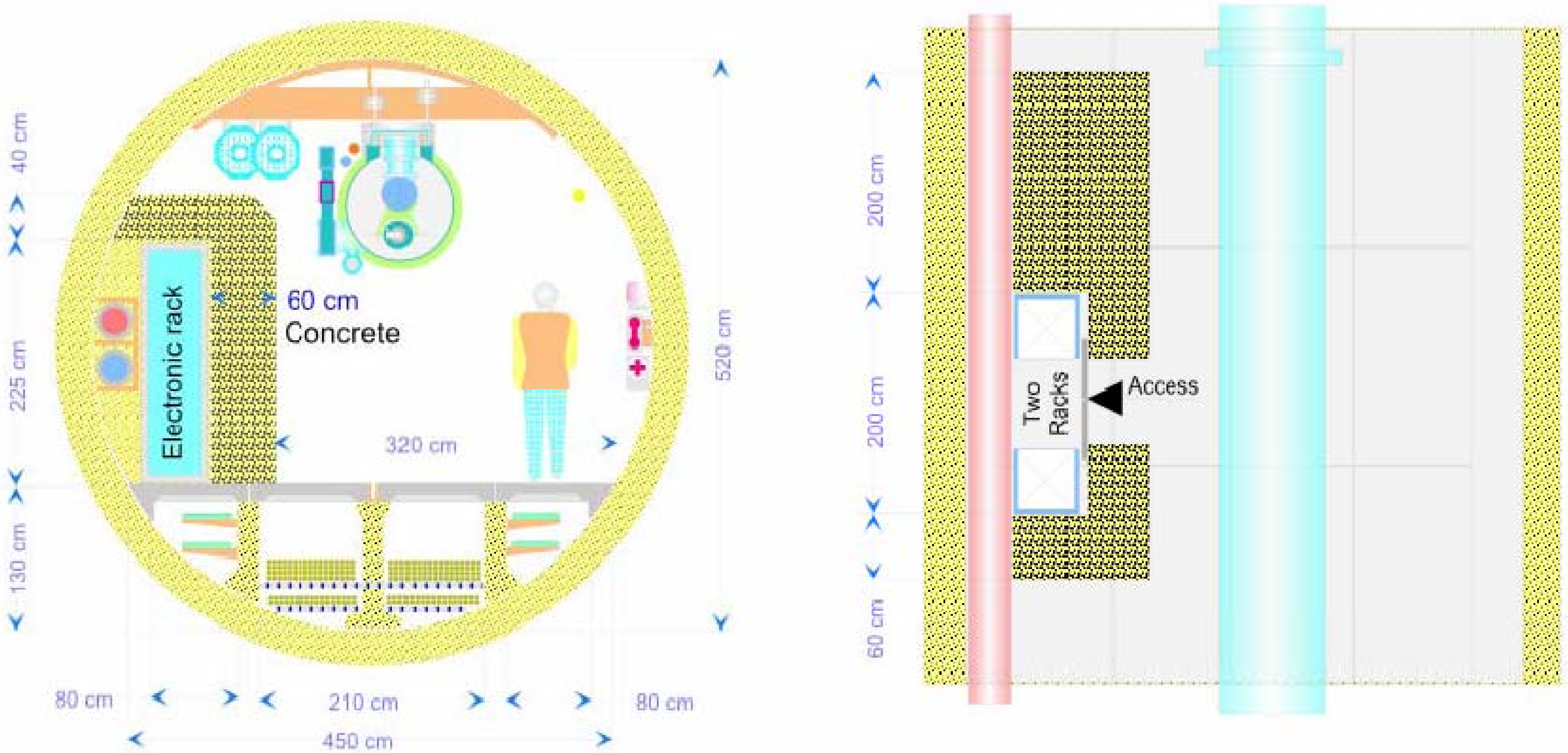
TESLA Tunnel Shielding

TESLA Answer to ITRP Question 10



XFEL TDR (Ch 4) on Radiation

- ‘The racks housing the preamplifier, auxiliary power supplies and interlock [for the rf system] will be shielded by lead thus protecting the electronic components in these devices from radiation’.
- ‘The [LLRF] system must be also immune to Single Event Upsets (SEU), i.e. a spontaneous bit flip caused e.g. by radiation’.
- ‘The overall XFEL injector and linac reliability and availability are a serious issue. As far as systems are placed inside the linac tunnel, they must be designed in a robust fashion since they are not accessible during operation. The potential for radiation damage is an added risk’.
- ‘Main objective is to perform a [radiation exposure] test which allows learning what type of problems might occur in the XFEL linac tunnel and what shielding and hardware and software design measures can be taken to guarantee reliable performance of the electronics’.

Controls Summary

- One tunnel could be done, but with technical & operational consequences, and with (likely significant) increases in controls/LLRF construction costs:
  - Radiation environment will cause single event upsets and equipment lifetime issues.
  - It will be more difficult to get the same availability.
  - There could be important performance issues.
- Controls and LLRF architectures may have to change significantly to mitigate the technical impacts.
- Will require significant pre-construction R&D.
- We will need additional information from DCB to put bounds on the cost increase and to assess the technical impact.
- The lack of equipment access creates difficulties for commissioning, machine optimization, and downtime mitigation that cannot be over-stated. This is hard to quantify in terms of construction cost.

Availability Impact

- Machine uptime predicted to decrease from 78% to 64% if nothing is done to further improve the availability of the tunnel components.
- To maintain a 78% availability with a single tunnel would require increasing the MTBF’s of a number of components by factors of 3 to 10.
- To avoid ~ 150 khr or longer MTBF’s for the klystrons and modulators, which are probably not possible, need to increase energy overhead in the linac by 3% (i.e., from 3% to 6%) at a cost of about 180 M$.

Needed MTBF Improvements

Device	Improvement factor **A** for 2 tunnel conventional e+ source	Improvement factor **B** for 1 tunnel undulator e+ source, 6% energy overhead	Improvement factor **C** for 1 tunnel undulator e+ source, 3% energy overhead	Nominal MTBF (hours)
magnets - water cooled	**20**	20	20	1,000,000
power supply controllers	**10**	**50**	50	100,000
flow switches	**10**	10	10	250,000
water instrumention near pump	**10**	10	**30**	30,000
power supplies	**5**	5	5	200,000
kicker pulser	**5**	5	5	100,000
coupler interlock sensors	**5**	5	5	1,000,000
collimators and beam stoppers	**5**	5	5	100,000
all electronics modules	**3**	**10**	10	100,000
AC breakers < 500 kW		**10**	10	360,000
vacuum valve controllers		**5**	5	190,000
regional MPS system		**5**	5	5,000
power supply - corrector		**3**	3	400,000
vacuum valves		**3**	3	1,000,000
water pumps		**3**	3	120,000
modulator			**3**	50,000
klystron - linac			**5**	40,000
coupler interlock electronics			**5**	1,000,000
linac energy overhead		**3%**		3%

Summary

- For the Americas Main Linac tunnels, would save 200-250 M$ with the 7.5 m or 5.2 m single tunnel layouts relative to the baseline (Vic will provide more detail). The TESLA group response to ITRP Question 22 says 350 M Euro would saved for a 1 TeV machine.
- If increase energy overhead 3% to allow more realistic klystron and modulator MTBFs, cost will be about 180 M$.
- If add shielding or alcoves to allow off-the-shelf electronics, cost will likely be 60-120 M$.
- There will also be additional costs associated with increasing component MTBFs, providing heat and vibration isolation, and installing, commissioning and maintaining the linacs (the increase is both in capital and operating costs).