ILC Machine Overview and Critical R&D

ALCPG Meeting

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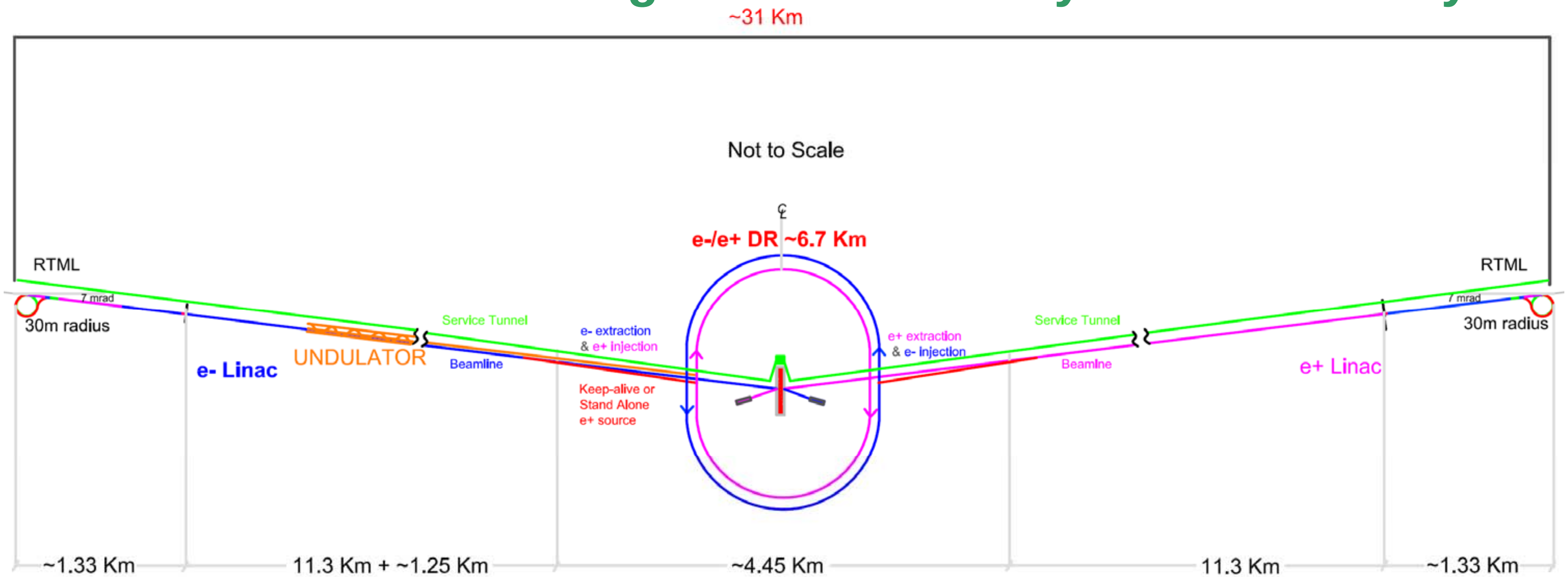
ILC Schematic

- 11km SC linacs operating at 31.5 MV/m for 500 GeV
- Centralized injector
  - Circular damping rings for electrons and positrons
  - Undulator-based positron source
- Single IR with 14 mrad crossing angle
- Dual tunnel configuration for safety and availability



ILC Parameters

- Overall parameters
  - 2e34 peak luminosity
  - 75% collider availability → 500 fb^{-1} 1st four years
  - 9.0 mA average current during beam pulse
  - 0.95 ms beam pulse and 1.5 ms rf pulse length
  - 5 Hz operation and 230 MW power consumption
- Beam parameter ranges defined for operability
  - 1000 to 6000 bunches
  - 1e10 to 2e10 per bunch
  - Beam power between 5 and 11 MW
  - Bunch length: 200 to 500 um at IP
  - IP spots sizes: $\sigma_x \sim 350 - 620$ nm; $\sigma_y \sim 3.5 - 9.0$ nm

ILC Beam Parameters

	Nominal	Low N	Large Y	Low P
Repetition rate frep (Hz)	5	5	5	5
Number of particles per bunch N (10^{10})	2	1	2	2
Number of bunches per pulse nb	2625	5120	2625	1320
Bunch interval in the main linac tb (ns)	369.2	189.2	369.2	480
in units of RF buckets	480	246	480	624
Average current in the main linac Iave (mA)	9	9	9	6.8
$\gamma\varepsilon x$ at IP (mm·rad)	10	10	12	10
$\gamma\varepsilon y$ at IP (mm·rad)	0.04	0.03	0.08	0.035
Beta function at IP βx (mm)	20	11	11	11
Beta function at IP βy (mm)	0.4	0.2	0.6	0.2
R.m.s. beam size at IP σx (nm)	639	474	474	474
R.m.s. beam size at IP σy (nm)	5.7	3.5	9.9	3.8
R.m.s. bunch length σz (μm)	300	200	500	200
Disruption parameter Dx	0.17	0.11	0.52	0.21
Disruption parameter Dy	19.4	14.6	24.9	26.1
Beamstrahlung parameter Yave	0.048	0.05	0.038	0.097
Energy loss by beamstrahlung δ_B	0.024	0.017	0.027	0.055
Number of beamstrahlung photons n_γ	1.32	0.91	1.77	1.72
Luminosity enhancement factor H_D	1.71	1.48	2.18	1.64
Geometric luminosity Lgeo 10^{34} cm^{-2} s^{-1}	1.2	1.35	0.94	1.21
Luminosity L 10^{34} cm^{-2} s^{-1}	2	2	2	2

ILC Energy Upgrade Path

- Linac energy upgrade path based on empty tunnels hard to 'sell'
  - **Empty tunnels obvious cost reduction**
- Lower initial gradient increases capital costs
- Baseline has tunnels for 500 GeV cms with a linac gradient of 31.5 MV/m
- Geometry of beam delivery system adequate for 1 TeV cms
  - **Require extending linac tunnels past damping rings, adding transport lines, and moving turn-around → ~50 km site**

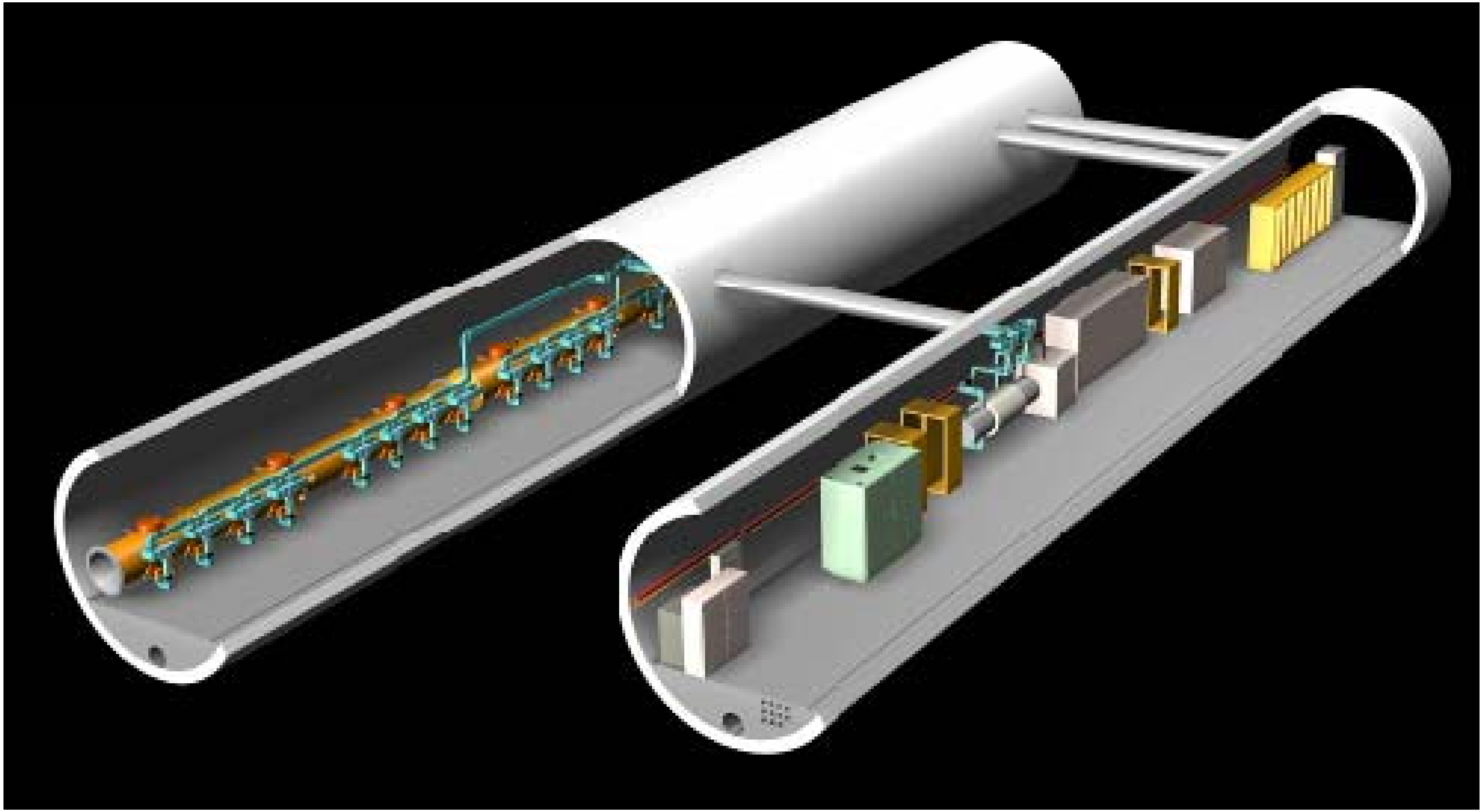
ILC Availability Issues

- ILC is ~10x larger than previous accelerators
- Aiming at an availability of ~75%
- Predict very little integrated luminosity using standard accelerator MTBFs and MTTRs
  - **Stringent requirements on component and sub-system availability**
    - Improvements ~10x on magnets, PS, kickers, etc
  - **Drives choices such as redundant power and particle sources and dual linac tunnels**
  - **Still has potential for significant impact on project cost in either direction**

Main Linac Features

- Linacs roughly 11km in length with ~280 rf units
  - **13 GeV → 250 GeV**
- Accelerating gradient 31.5 MV/m @ 9.0 mA
- Each rf unit consists of 3 cryomodules:
  - **2 modules with 9 SC cavities and one with 8 cavities; 8-cavity module has SC quadrupole/BPM**
  - **All modules are 12.65 meters in length**
  - **RF power source: Bouncer-type modulator with pulse transformer & 10 MW Multi-beam klystron**
  - **RF distribution system ~310kW per cavity**
- Effective filling factor is ~67%

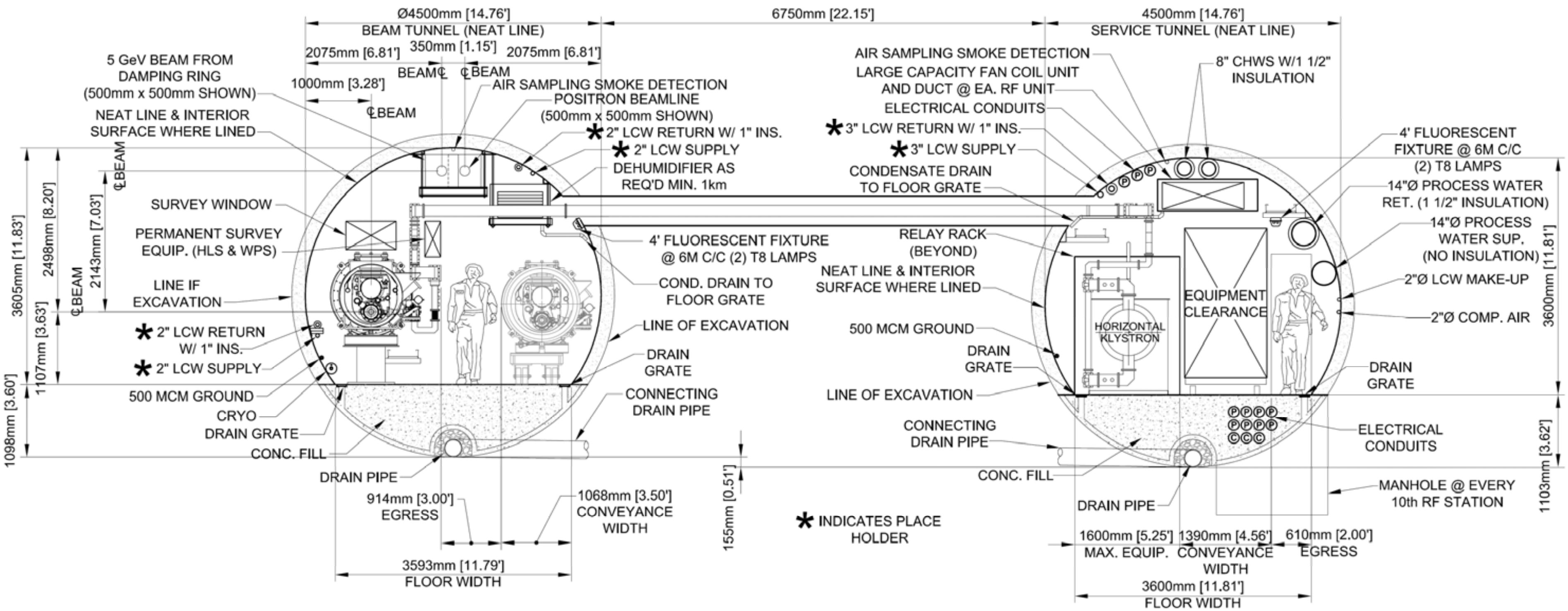
Conceptual ML Tunnel View



Global Design Effort

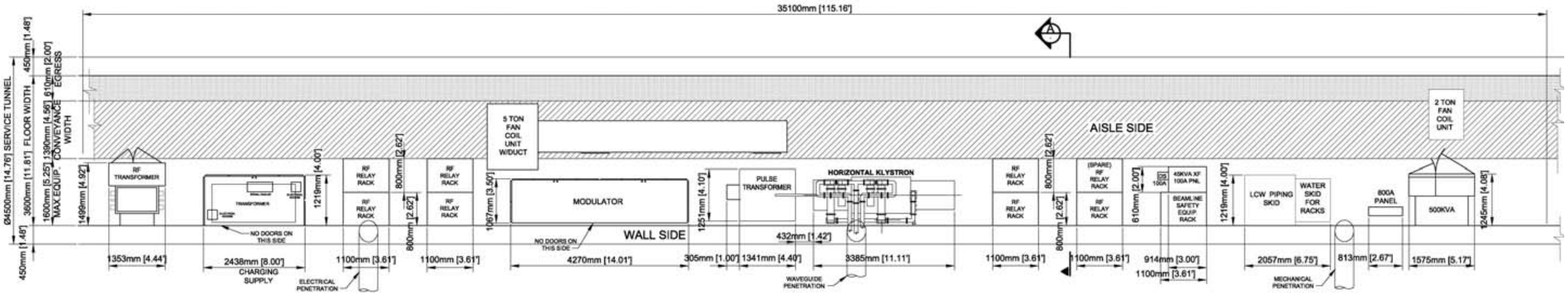
Main Linac Tunnels

- Design based on two 4.5m tunnels
  - Active components in service tunnel for access
  - Includes return lines for BC and sources
  - Sized to allow for passage during installation
  - Personnel cross-over every 500 meters

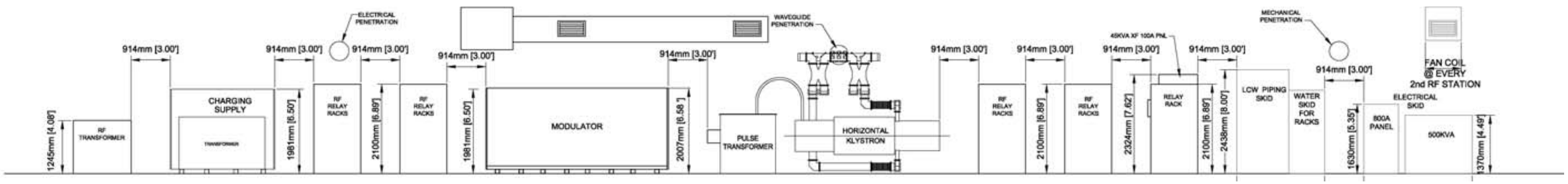


Main Linac Tunnels (2)

Service tunnel Rf Unit – Plan view

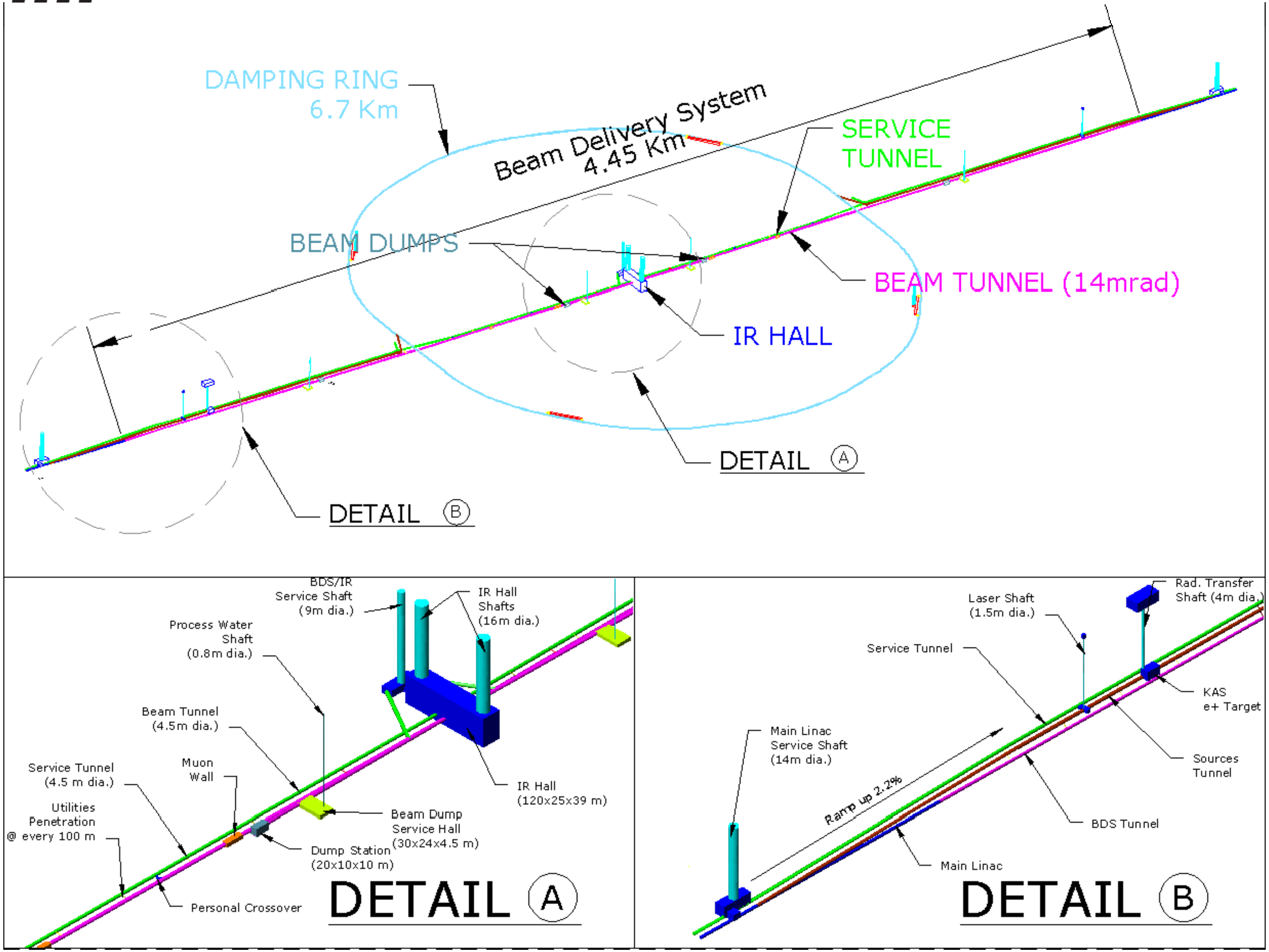


Service tunnel Rf Unit – Elevation view



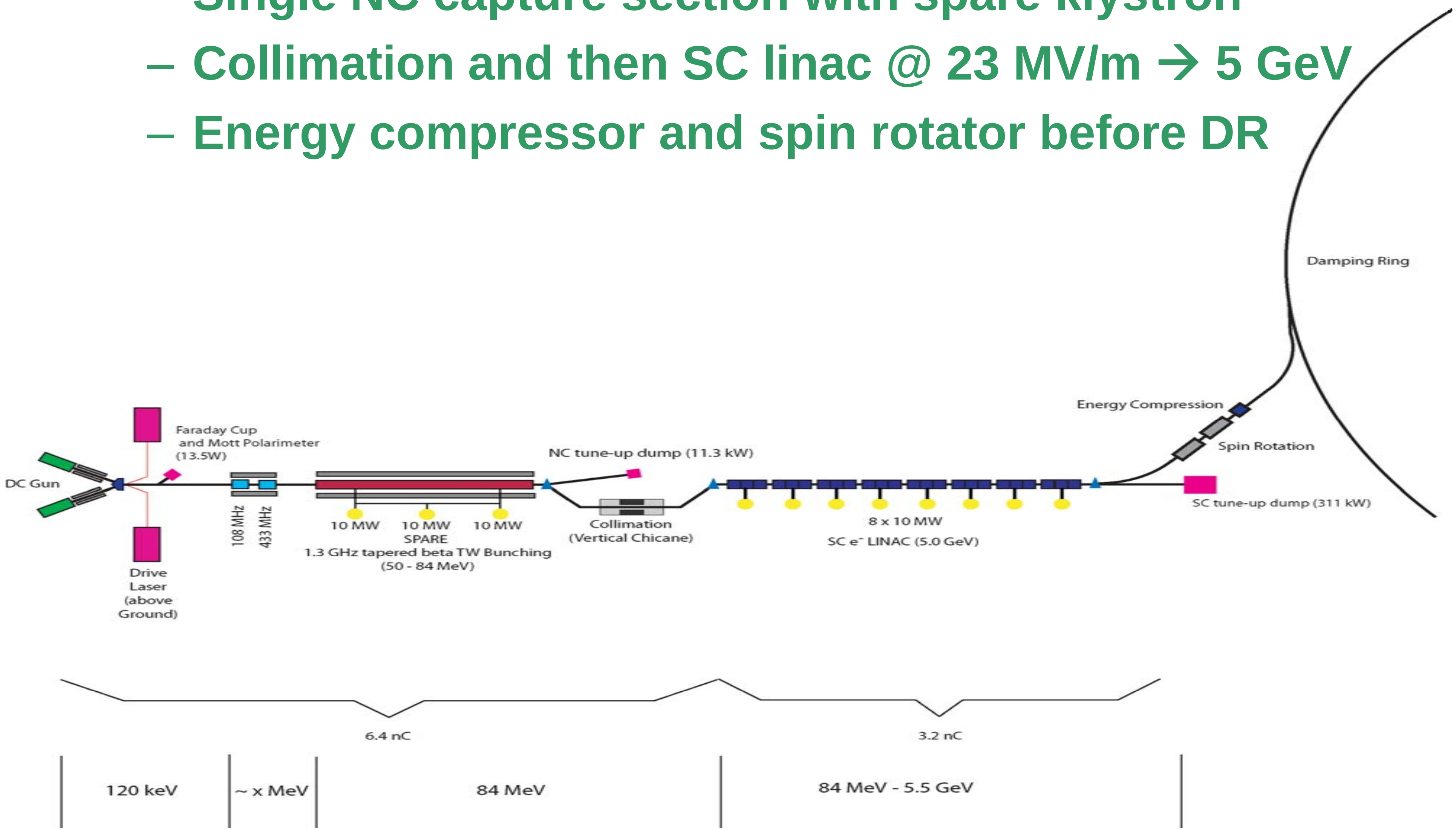
Note lengths show obsolete 35 meter rf unit – presently 38 meters

Centralized Injector



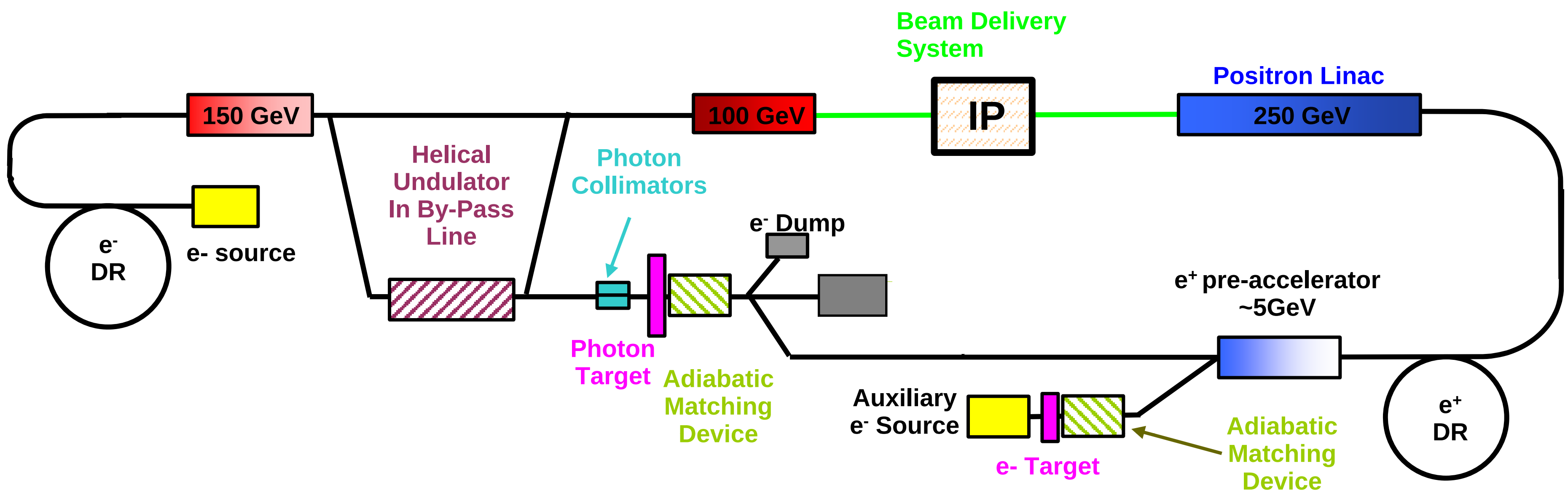
ILC Polarized Electron Source

- Dual 140kV guns and dual polarized laser systems
- Single NC capture section with spare klystron
- Collimation and then SC linac @ 23 MV/m → 5 GeV
- Energy compressor and spin rotator before DR



Positron Source

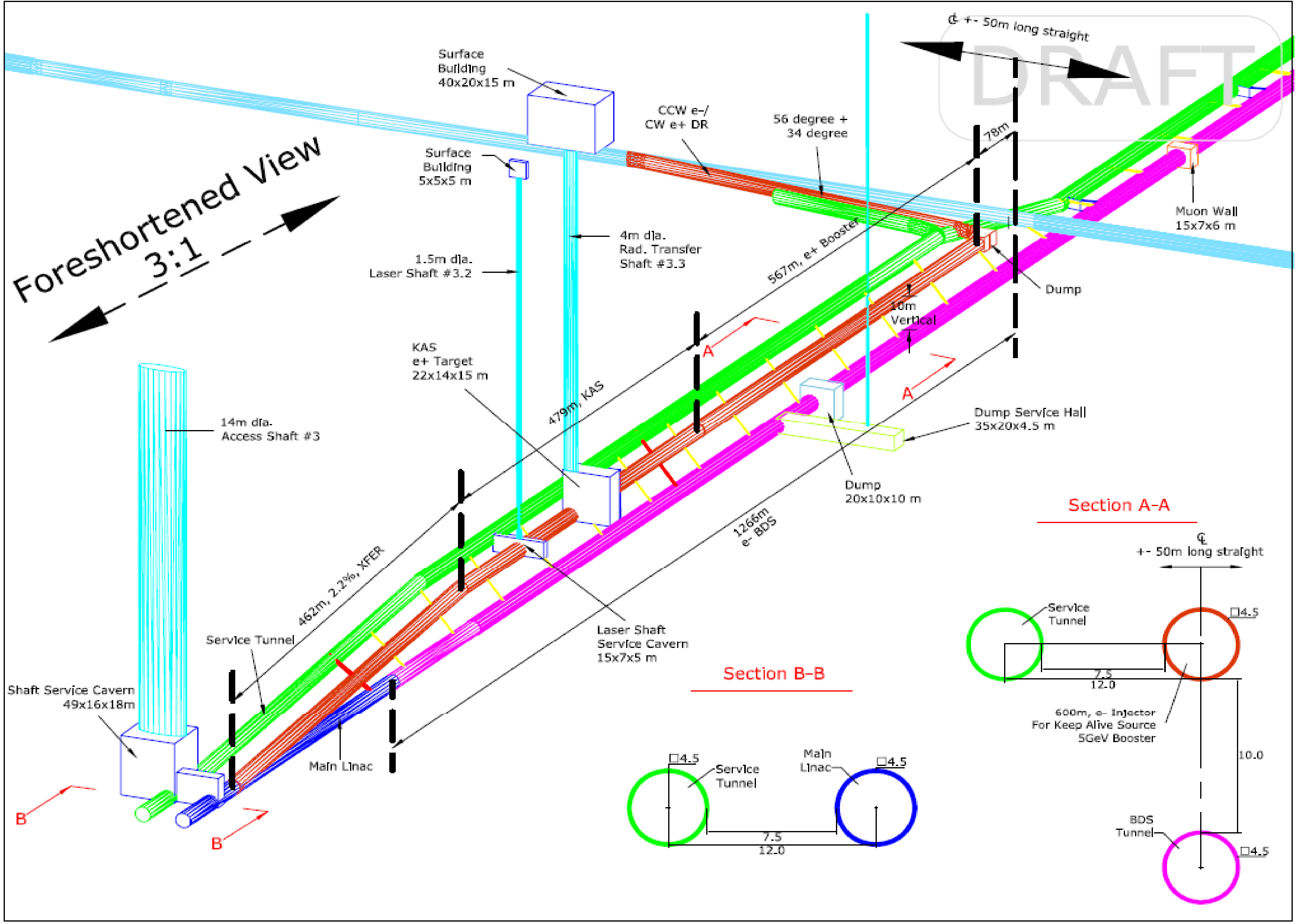
- Undulator-based positron source
  - ~100 meter undulator with K=1; λ = 1cm; 6mm aperture
  - Easy upgrade to produce polarized positrons
- Undulator located at 150 GeV in electron linac
  - Eases operational issues when changing IP energy
- Two e+ production stations including 10% keep alive



Schematic not updated for centralized injector

Central Positron Source

Global Design Effort

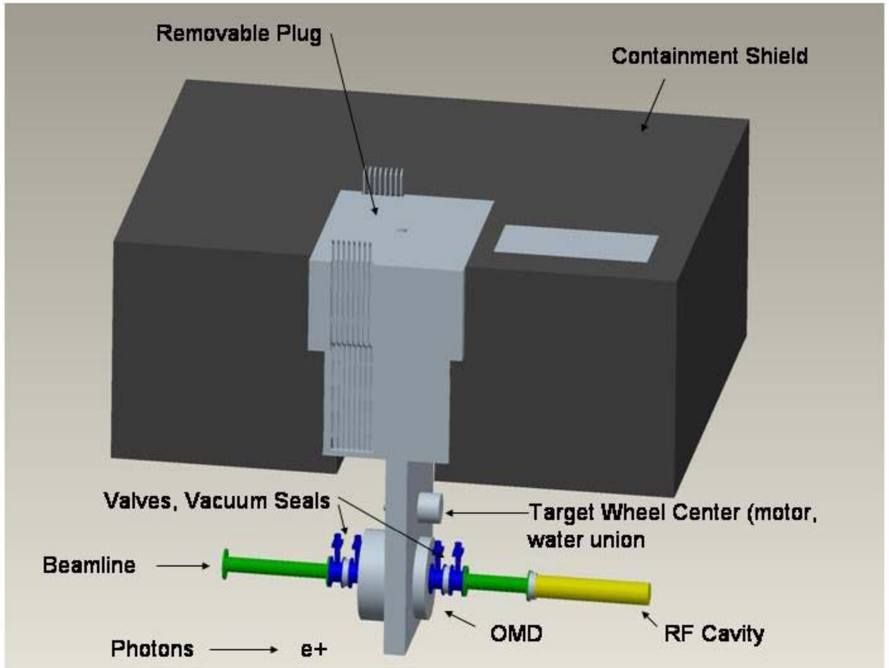


Current schematics have tunnels vertically offset

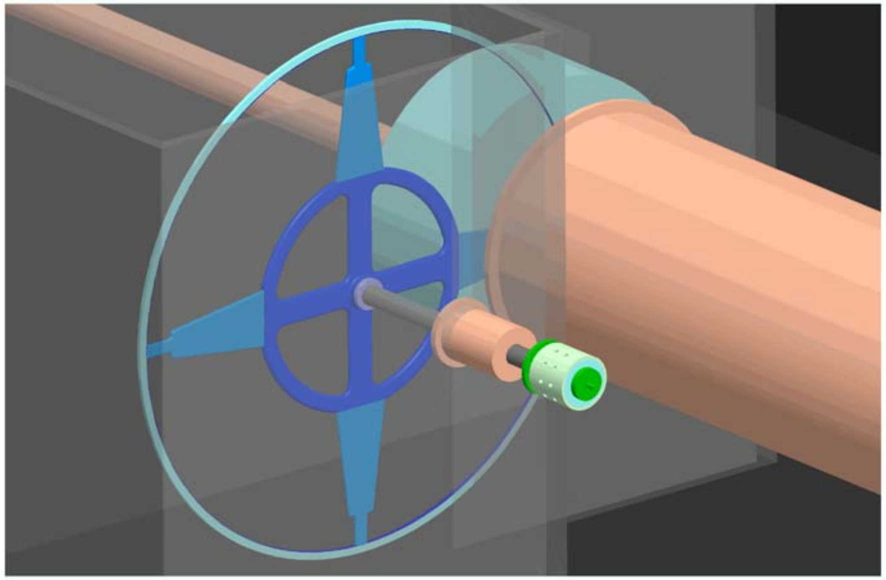
Positron Target

- Large positron flux required
  - **Large diameter Ti target wheel rotated at ~500 rpm**
  - **Limited lifetime due to radiation damage**
    - Remote handling needed – hot cells located at surface
  - **Immersion in 6~7T OMD field improves yield by ~50%**

Target and OMD removable unit



Spinning Target Wheel w/ dc OMD



Damping Ring Requirements

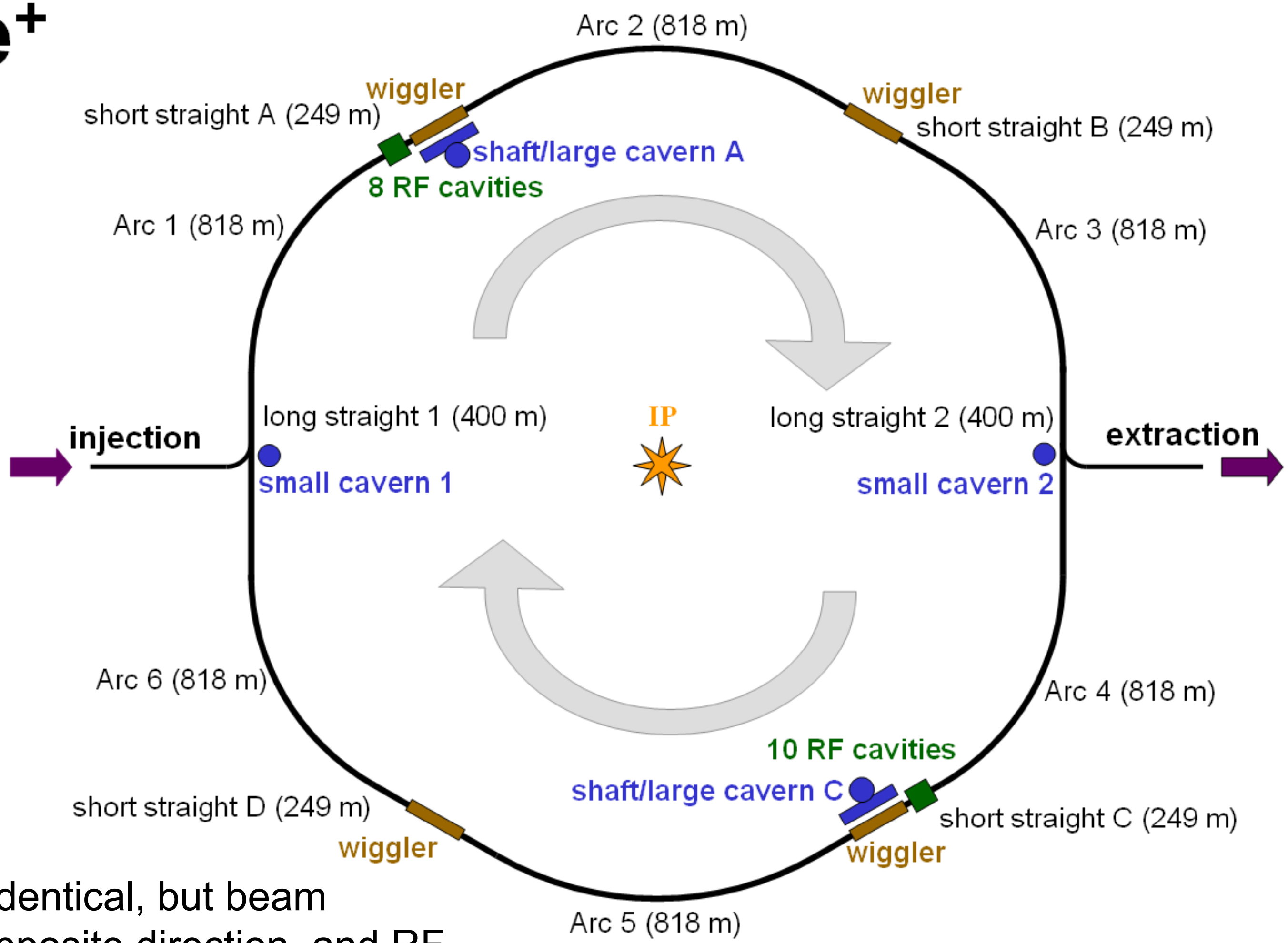
- Compress 1 ms linac bunch train in to a "reasonable size" ring
  - **Fast kicker (rise and fall time ~3ns)**
- Damping of $\gamma\varepsilon_{x,y}$= 10^{-2} m-rad positron beams to ($\gamma\varepsilon_x$, $\gamma\varepsilon_y$)=(8×10^{-6}, 2×10^{-8}) m-rad
  - **Low emittance, diagnostics**
- Cycle time 0.2 sec (5 Hz rep rate)→ τ = 25 ms
  - **Damping wiggler (~200 meters of 1.6 T wiggler)**
- ~2700 bunches, 2×10^{10} electrons or positrons per bunch, bunch length= 9 mm
  - **Instabilities (classical, electron cloud, fast ion)**
- Beam power > 200 kW
  - **Injection efficiency, dynamic aperture**

Damping Ring Parameters

Circumference	6695 m			
Beam energy	5 GeV			
Average current	400 mA			
Number of bunches	2767	3646	4346	5782
Bunch spacing	6.2 ns	4.6 ns	3.1 ns	3.1 ns
Bunch population	2.0×10^{10}	1.5×10^{10}	1.3×10^{10}	1.0×10^{10}
Normalized natural emittance	0.53 nm			
Natural bunch length	9 mm			
Natural energy spread	0.13%			
RF voltage	23 MV			
RF frequency	650 MHz			
Momentum compaction	4.2×10^{-4}			
Damping times	25.7 ms (x,y); 12.9 ms (z)			

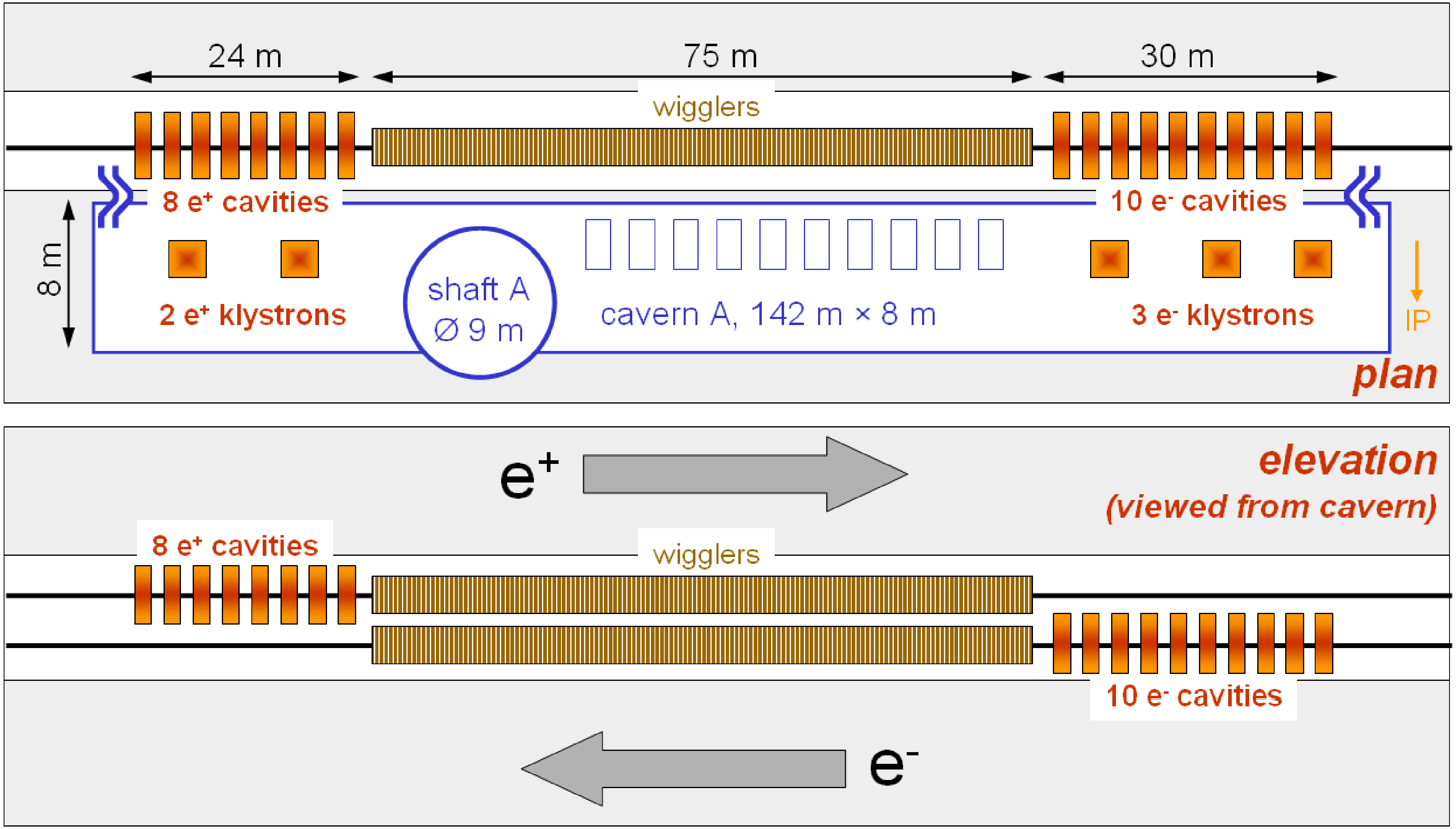
Damping Ring Schematic

e^+



e^- footprint is identical, but beam circulates in opposite direction, and RF cavities are always upstream of the wiggler.

Damping Ring Alcove

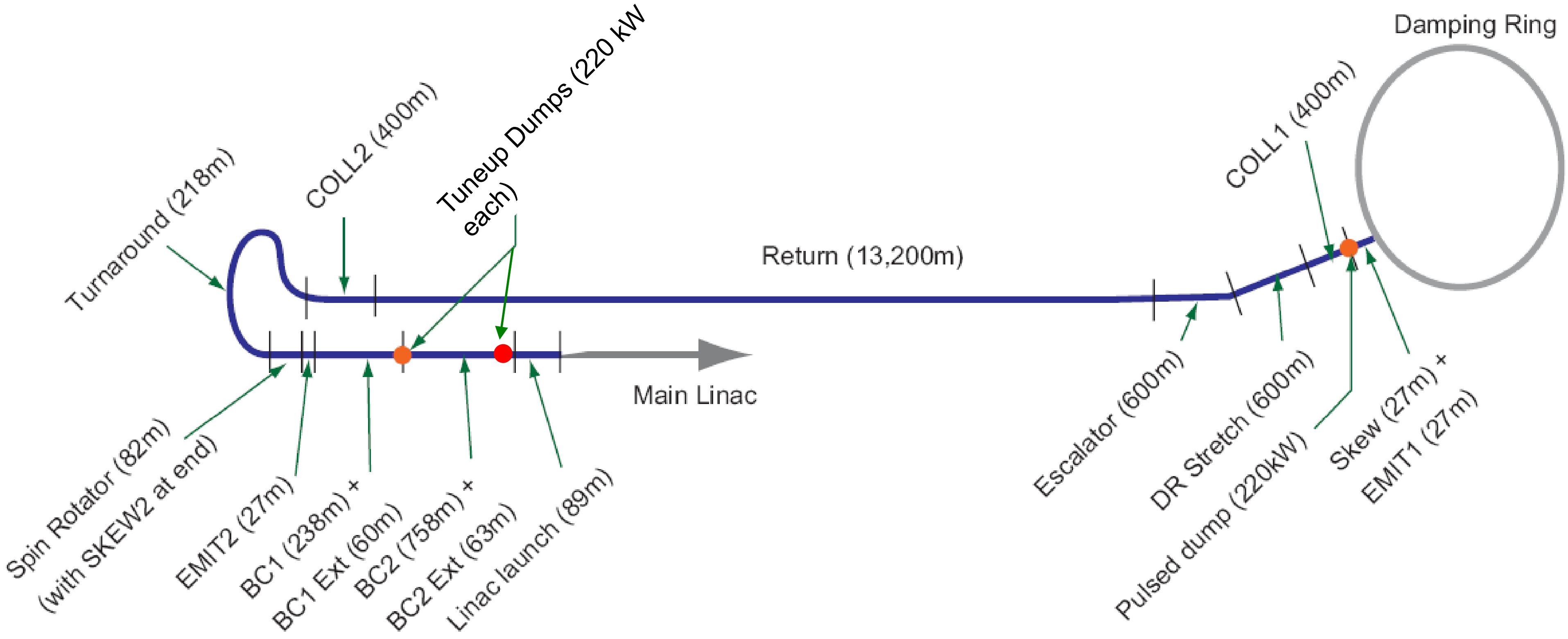


Ring To Main Linac

- Transport beam from central DR complex to main linac injection, ~15 km away
  - **Focusing lattice matched to linac periodicity**
  - **20 nTorr vacuum pressure**
- Collimation of halo from damping ring
  - **Avoid accelerating halo to high energies**
- Spin Rotation
- Dual stage bunch compressor
  - **9mm from DR → 200 ~ 300 um in main linacs**
- Diagnostic and correction elements
- Largely conventional components

Ring To Main Linac: Schematic

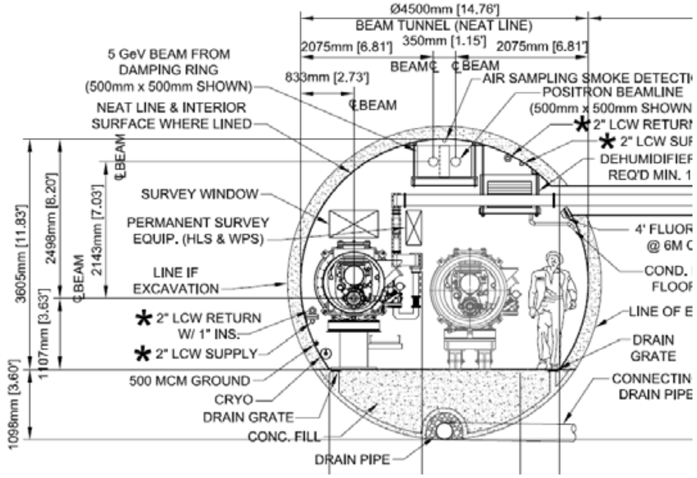
Global Design Effort



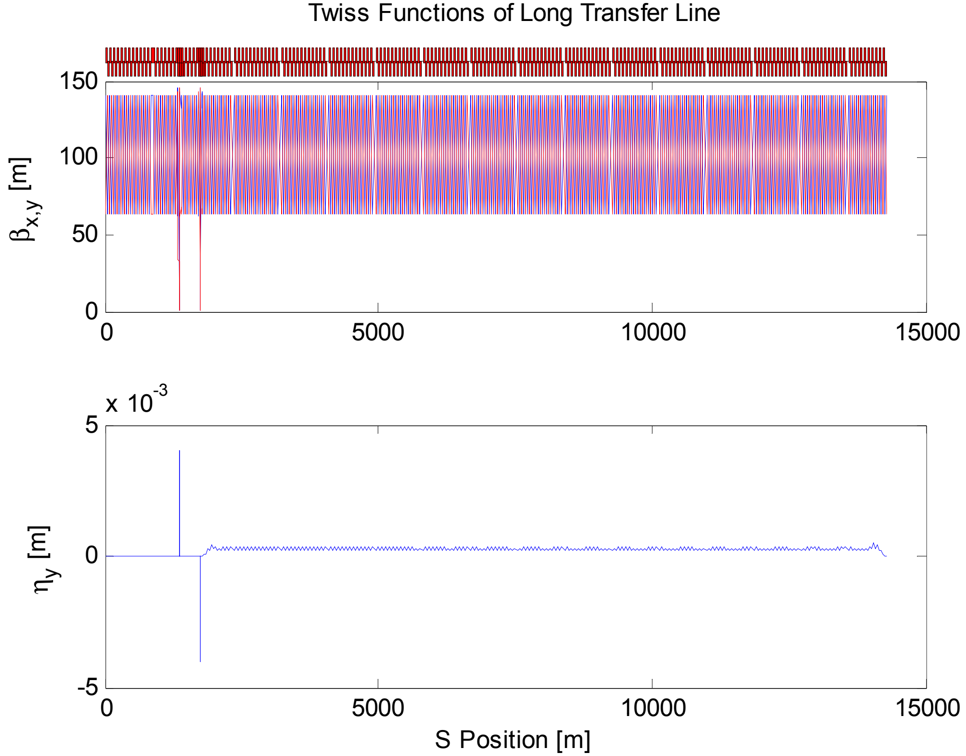
Note: Exact lengths of sub-beamlines still being finalized.

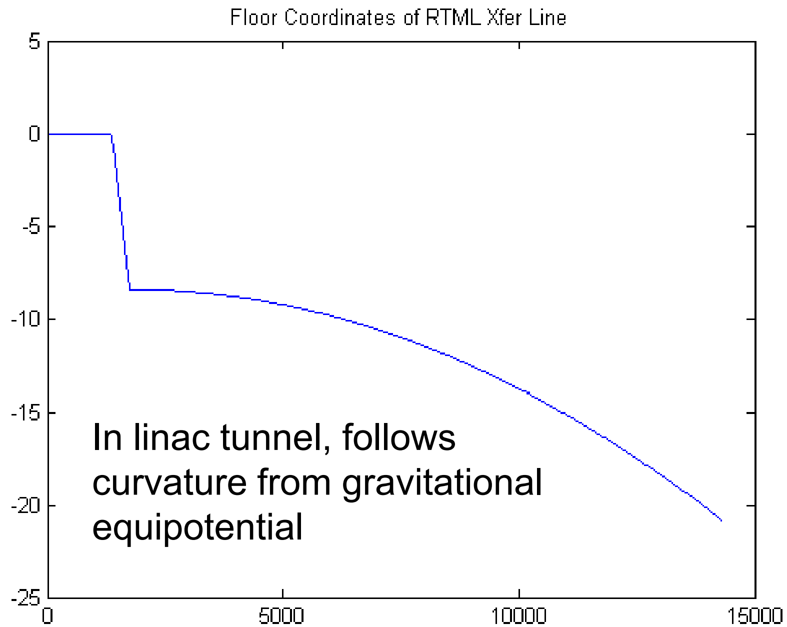
RTML Return Line

- Transport low emittance beam



38 m quad spacing, 45° FODO cell except in vertical arcs





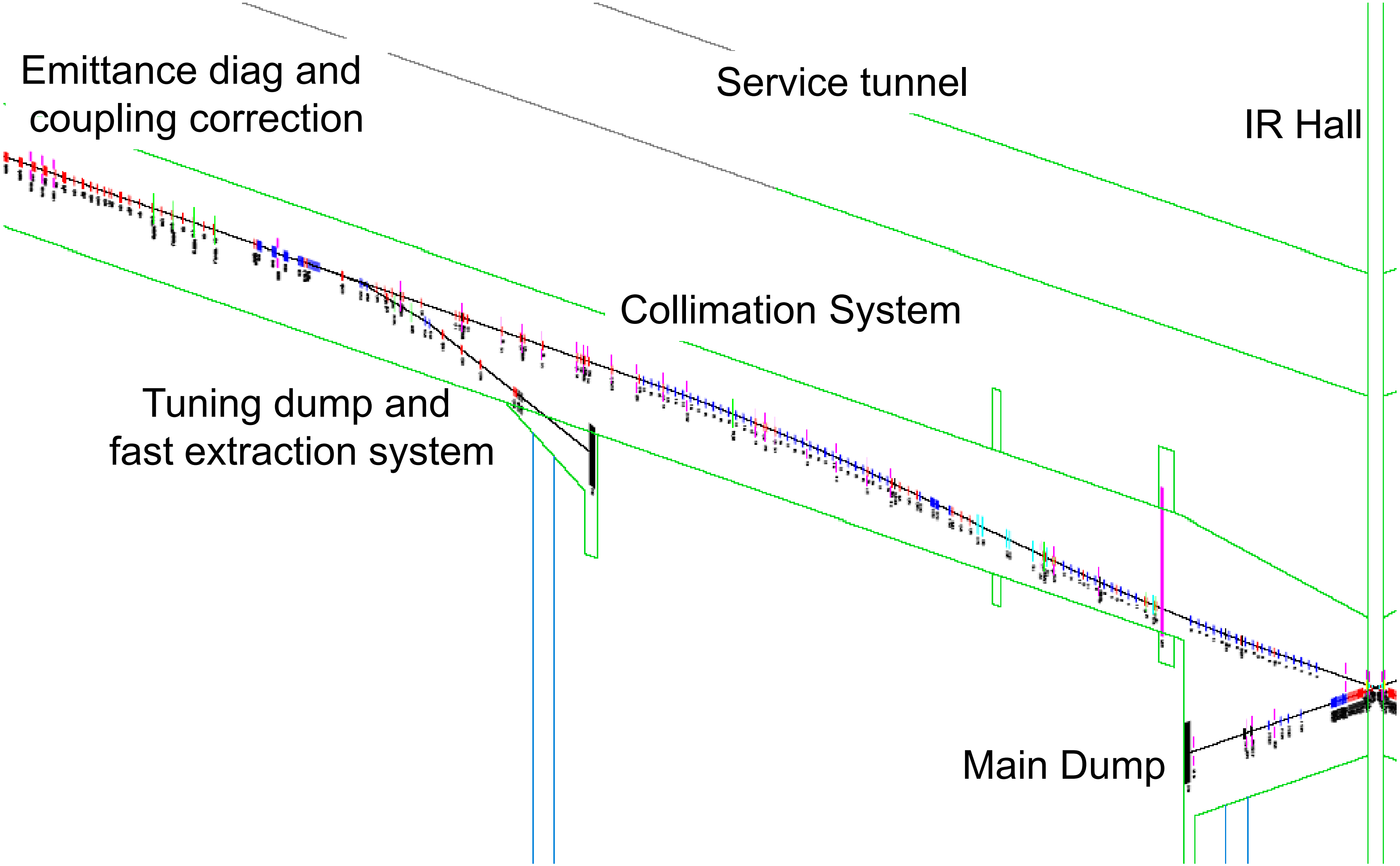
Beam Delivery System

- Functional requirements:
  - Post-linac emittance and energy diagnostics
  - Coupling correction section
  - Halo collimation and Machine Protection
  - Tuning dump and fast extraction dump
  - Final focus system
    - IP beta functions of β_x = 10~20 mm and β_y = 200~400 um
  - Interaction region with 14 mrad crossing
    - IR hall large enough for two detectors in a push-pull mode
    - Surface buildings for detector assembly
  - Low loss extraction lines to main dumps (11 MW)
- Roughly 2.2 km per side

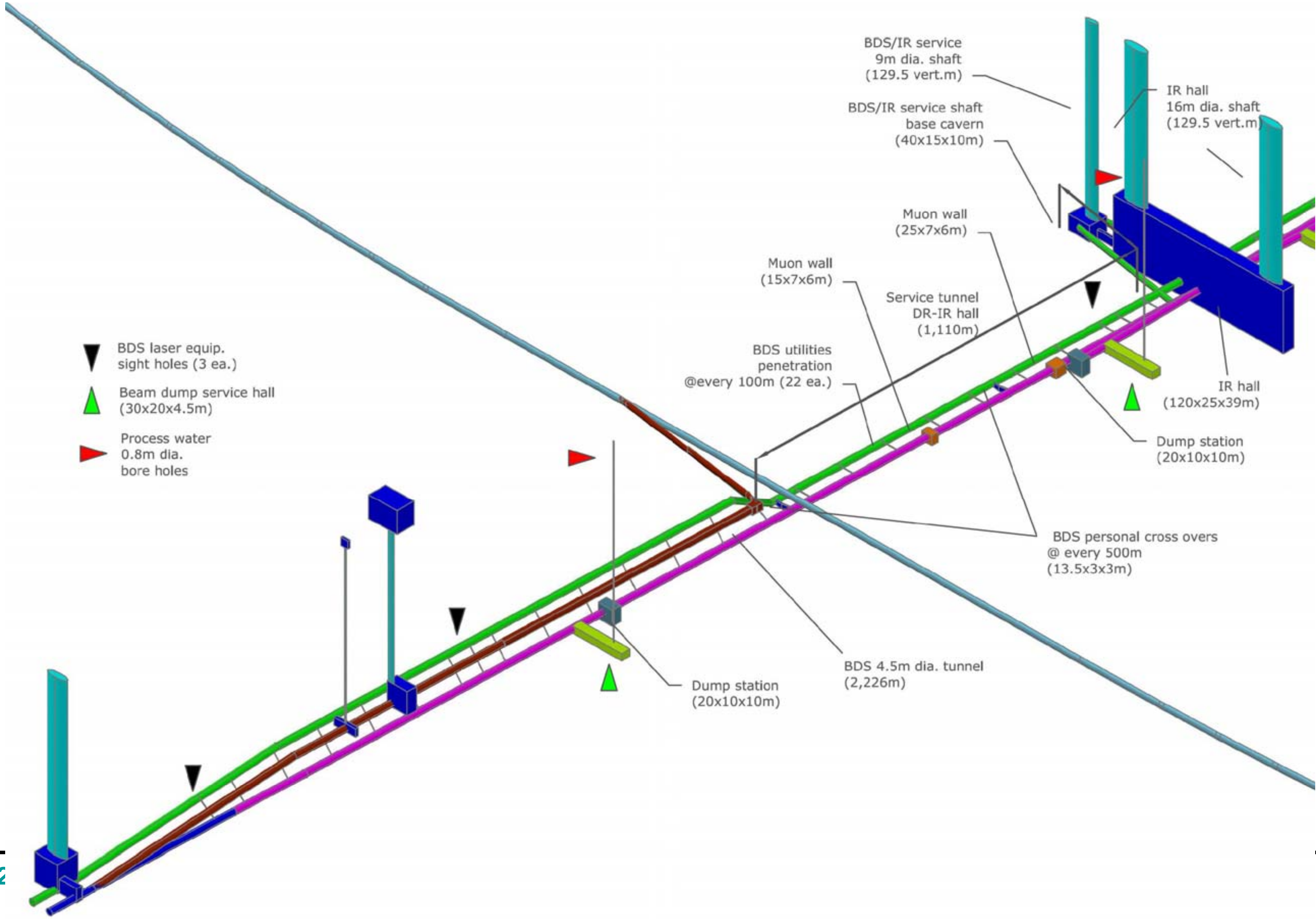
BDS Features

- Mostly conventional components
  - **Many conventional magnets, high resolution BPMs and magnet movers**
  - **Vacuum spec between 50 nTorr and 1 nTorr**
  - **SC IR quads, large muon spoiler walls, high power dumps**
- Service tunnel for safety and hardware access
  - **Personnel cross-over every 500 m like linacs**
  - **Utility penetrations every 100 meters (10% linac)**
- Single large IR hall
  - **Detector assembly largely done on surface**

BDS Magnet Layout



BDS Civil Schematic



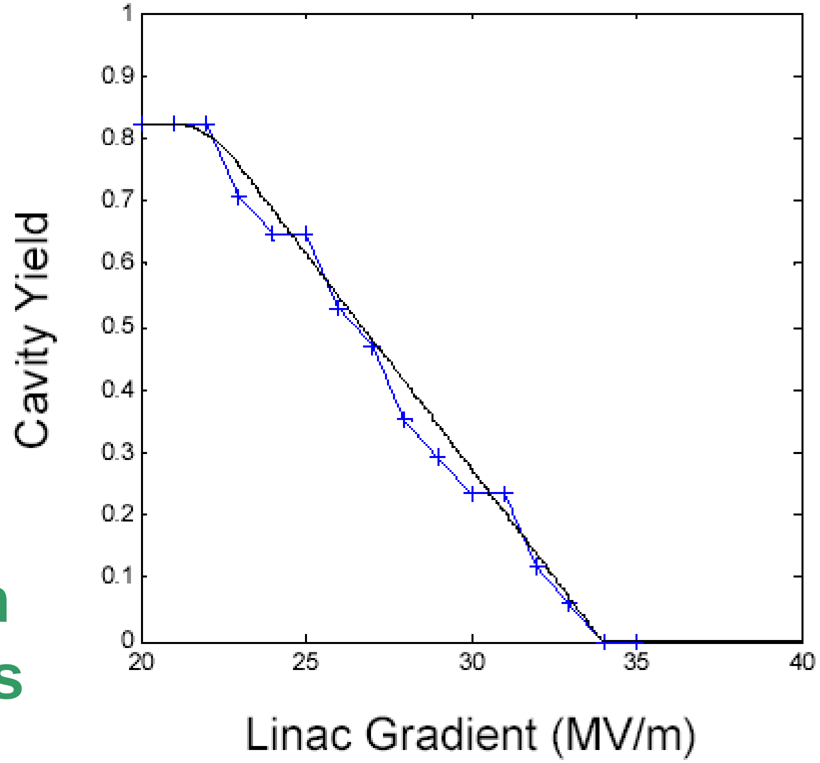
Critical R&D

- Large amount of R&D and engineering needed
- Largest impact on layout or cost:
  - **Main linac SC cavity gradient and yield**
  - **Main linac rf power sources and LLRF**
  - **Damping ring kicker, electron cloud, and RF**
  - **BDS interaction region: push-pull, final magnets, and crab cavity**
- Other major cost or performance issues:
  - **Main linac CM design and heat loads**
  - **Main linac quadrupole; BDS collimators**
  - **Wakefields in linac and BDS**
  - **DR instabilities; e+ source undulator/target/OMD**

Cavity Gradient

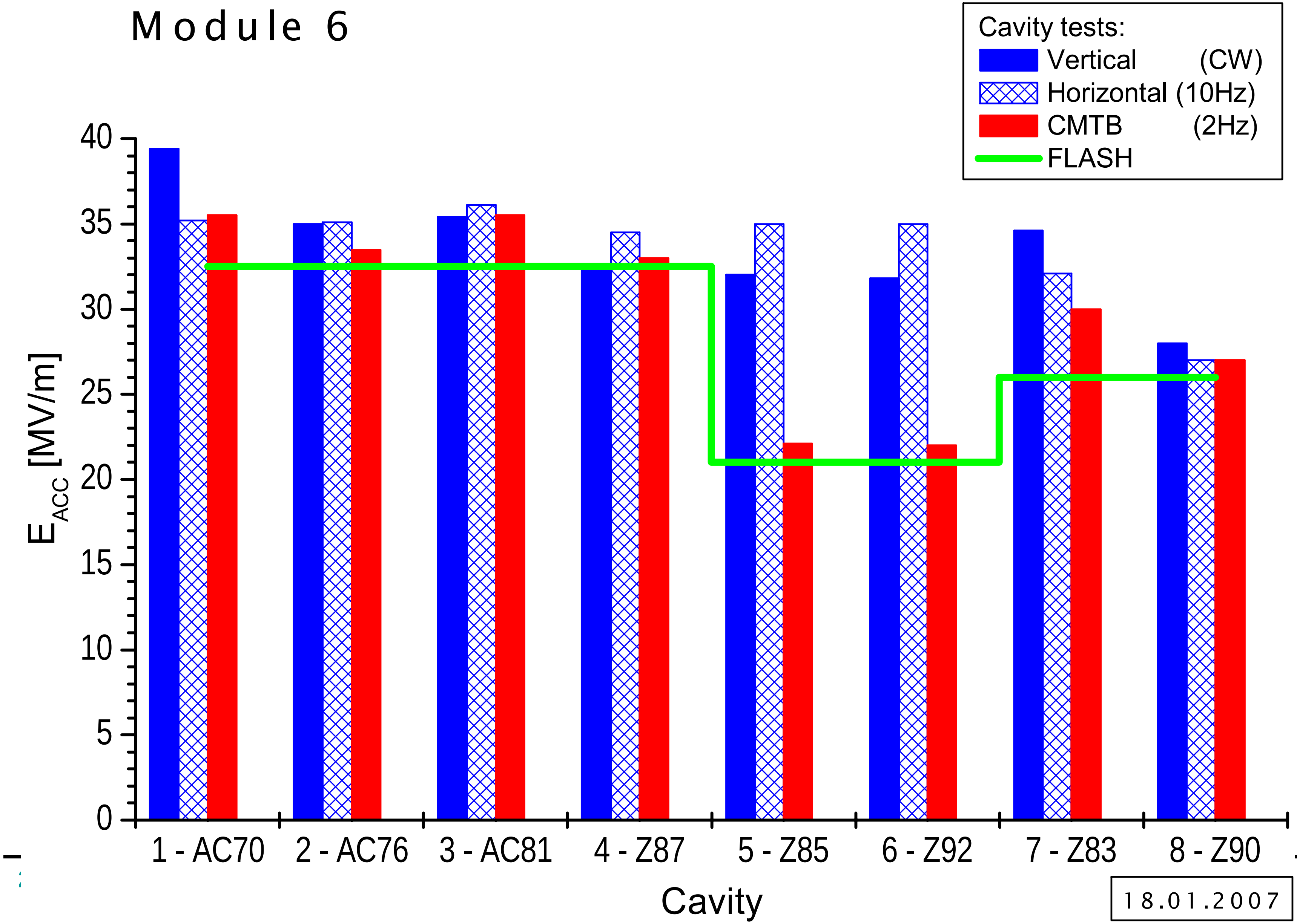
- Cost of ILC is a strong function of the linac grad
- Recent cavity production has had large spread
  - **Design based on 35 MV/m cavities yielding 31.5 MV/m**
  - **Present variation would increase cost ~7%**
- Potential for significant improvement
  - **R&D in understanding gradient variation**
  - **S0/S1 getting statistics on the processing techniques**

Yield estimate from processing of 17 Zanon cavities



Cavity Gradient (DESY)

Module 6



18.01.2007

Cavity Gradient (Jlab)

Jefferson Lab

Summary of Recent Vertical Test Data

By J. Mammosser (JLab)

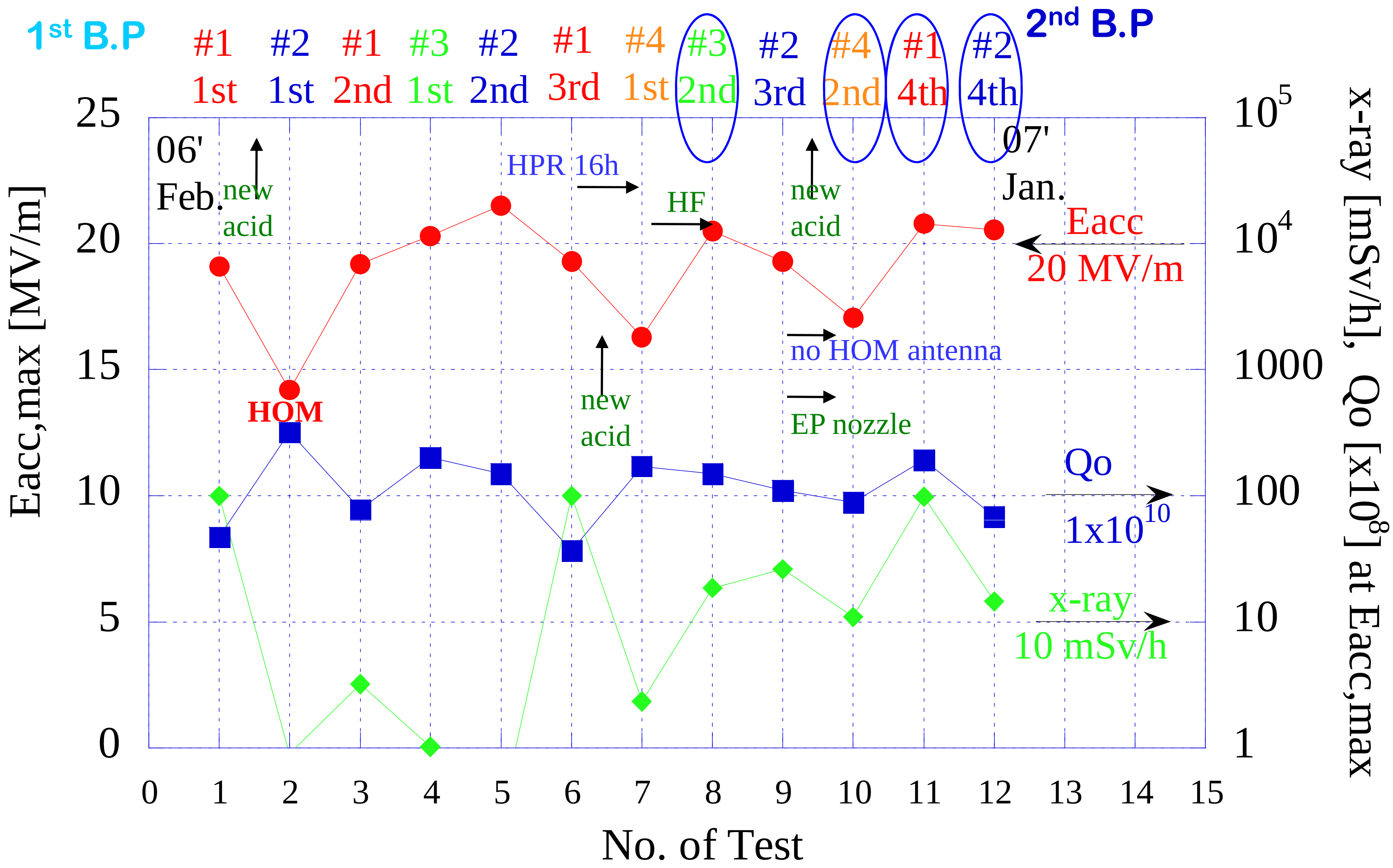
Qualification Runs				Qualification								
Test Date	Cavity #	Purpose of test	Processing Performed	Low Field Qo 5MV/m	Max Gradient (MV/m)	Q at Max	Rad onset	Max Rad (mRem/hr)	Limit	Q-disease	Mode Excited	Grad_excited
12/12/2006	A6	First qualifying test	EP20um,Degrease,HPR,Bake 120,100K soak 3days	2.00E+10	19.4	3.22E+09	17.3	0.3	Cable	No	not checked	
1/10/2007	A7	Second qualifying test	EP20um,Degrease,HPR,Bake 120	1.92	39.5	8.90E+09	28.3	100	unknown	NA	not checked	
			Soak at 100K 8 hours							yes	not checked	
			Warmup to 300K, cooldown	1.92E+10	41.25	8.00E+09	25.3	298	Quench	No	7/9th	24
1/23/2007	A6	Second qualifying test	EP20um,Degrease,HPR,Bake 120	1.66E+10	29.14	8.20E+09	none	none	Quench	NA	none	

Passband Excitation

Cavity Gradient (KEK)

Global Design Effort

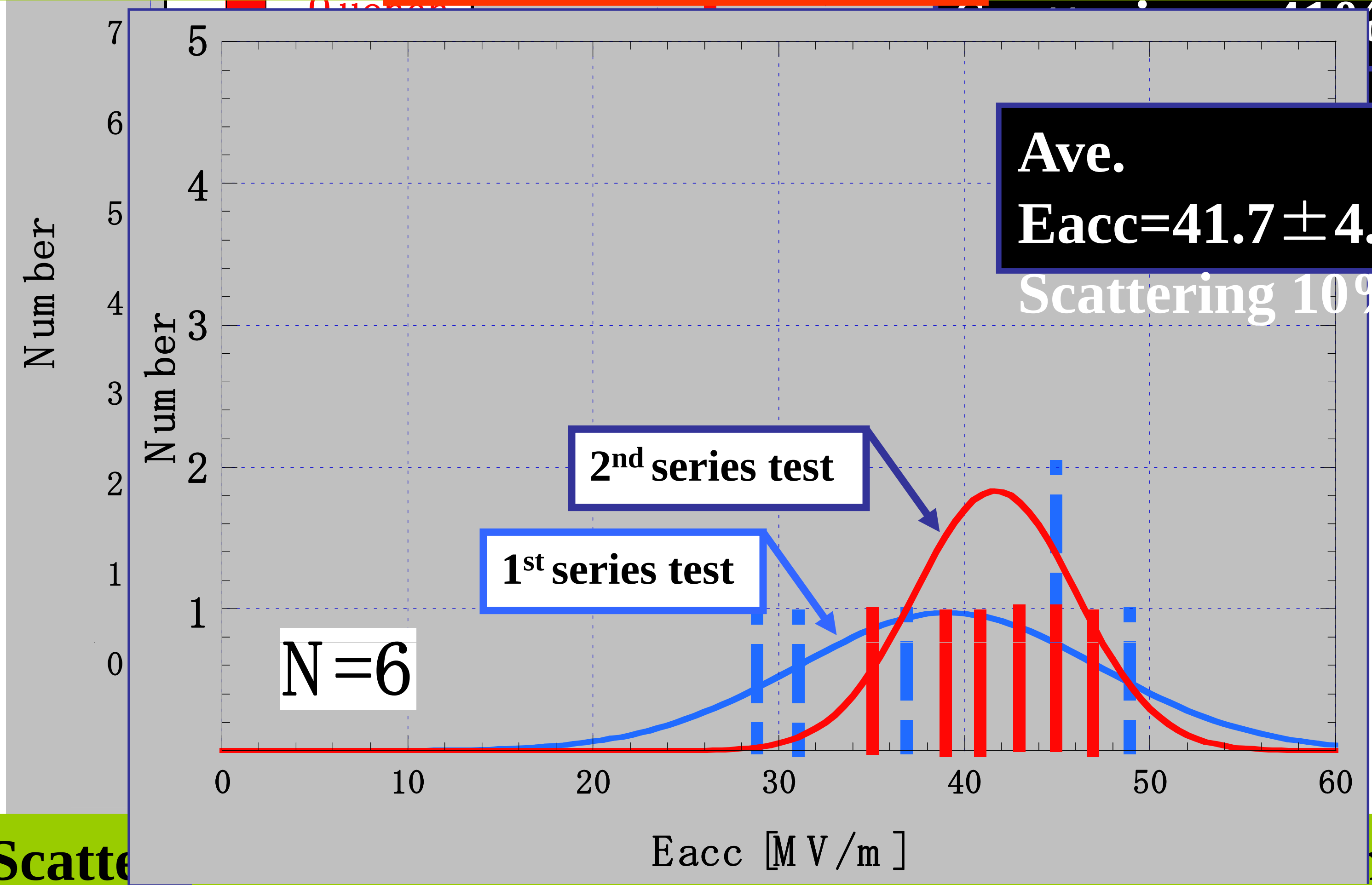
Summary of Vertical Tests (12 tests for 4 cavities)



Cavity Gradient (Single Cell)

Global Design Effort

KEK new recipe : CBP+CP+Anneal+EP(80μm, tank) +EP(3μm, fresh EP acid) + HF + HPR + Baking



Ave.
Eacc=41.7±4.4MV/m
Scattering 10

Scatte… mistakes
of cavity EP(3um, fresh EP acid) reduced the scattering.
ing.

RF Cryomodules

- Big development programs at FNAL and KEK
- Type-4 CM design pursued by international team
- Fermilab has been putting together infrastructure
  - **FNAL to assemble kit from DESY in CY07 and tested in NML**
  - **Build an additional Type-3 CM by mid-FY08**
  - **Construct two new Type-4 CM by end of FY09**
- KEK has started assembling STF
  - **Most infrastructure complete**
  - **2 cavities installed in CM to be tested in April**
  - **8 cavities to be tested in April**

RF Power Sources

- Modulator development is focused on Marc Generator modulator
  - Recent demonstration of for pulse length and full voltage
  - Adding additional protection before full power tests
  - Working on venier boards for pulse flattening
- Work on adjustable tap-off to handle variation in cavity gradient
  - Reduces cost impact of gradient variation from 15% to ~7%
- Developing lower cost klystron
  - Plug compatible with MBK

Damping Ring R&D

- Damping ring circumference depends on bunch spacing → kickers, electron cloud, and ion instab.
- Demonstrated necessary kicker timing
  - **Need ~3ns rise and fall for Low N parameters**
  - **R&D focused on developing a real system**
- Large effort to understand electron cloud and develop chambers with low SEY
  - **Simulations everywhere**
  - **Chambers being tested at KEK and SLAC**
    - Initial results are quite encouraging ➔ 2 e+ rings → 1 ring
  - **Need to test robustness of solutions and verify performance with ILC-like conditions**

Summary

- Complete design for the ILC
  - Recent scope reductions to reduce cost ➔ mostly self-consistent
- Reference Design Report mostly complete
  - Draft to be updated in April
  - RDR cost review at Saclay/Orsay in May
  - Final release planned for mid-summer
- R&D program is making good progress
  - Working hard on understanding and improving SC gradient and on other RF topics for cost reduction
  - Damping ring and BDS R&D programs established
  - ILC MAC to review R&D program at FNAL in April
- Hope to have PM in place for EDR by LCWS