The Baseline Configuration

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RDR Matrix

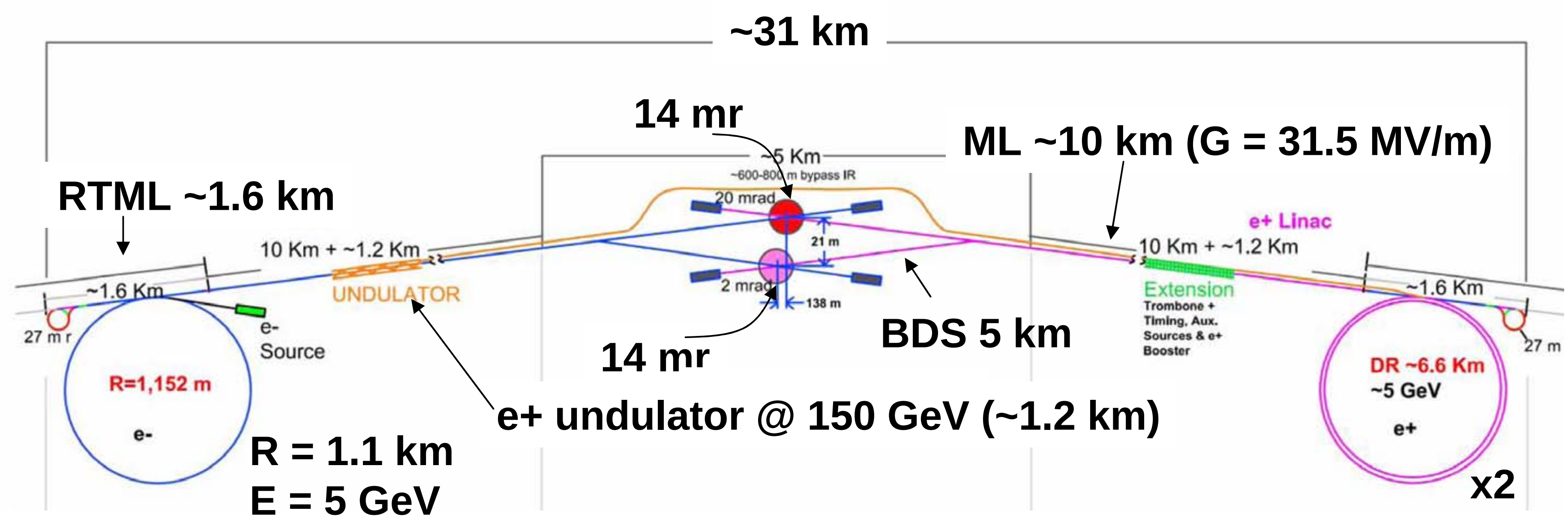
- Matrix of Area Systems and Technical Systems to develop cost estimate
  - International representation in all working groups

	Area Systems					
	e- source	e+ source	Damping Rings	RTML	Main Linac	BDS
		Kiriki	Gao	ES Kim	Hayano	Yamamoto
			Guiducci		Lilje	Angal-Kalinin
	Brachmann	Sheppard	Wolski	Tenenbaum	Adolphsen	Seryi
	Logachev		Zisman		Solyak	
Technical Systems						
Vacuum systems	Suetsugu	Michelato	Noonan			
Magnet systems	Sugahara		Thomkins			
Cryomodule	Ohuchi	Pagani	Carter			
Cavity Package	Saito	Proch	Mammosser			
RF Power	Fukuda		Larsen			
Instrumentation	Urakawa	Burrows	Ross			
Dumps and Collimators	Ban		Markiewicz			
Accelerator Physics	Kubo	Schulte				
Global Systems						
Commissioning, Operations & Reliability	Teranuma	Elsen	Himel			
Control System	Michizono	Simrock	Carwardine			
Cryogenics	Hosoyama	Tavian	Peterson			
CF&S	Enomoto	Baldy	Kuchler			
Installation	Shidara	Bialwons	Asiri			

The ILC Accelerator

- 2^{nd} generation electron-positron Linear Collider
- Parameter specification
  - **E_{cms} adjustable from 200 – 500 GeV**
  - **Luminosity → $\int L dt$ = 500 fb^{-1} in 4 years**
  - **Ability to scan between 200 and 500 GeV**
  - **Energy stability and precision below 0.1%**
  - **Electron polarization of at least 80%**
  - **Options for electron-electron and γ–γ collisions**
  - **The machine must be upgradeable to 1 TeV**
- Three big challenges: energy, luminosity, and cost

Schematic of the Baseline



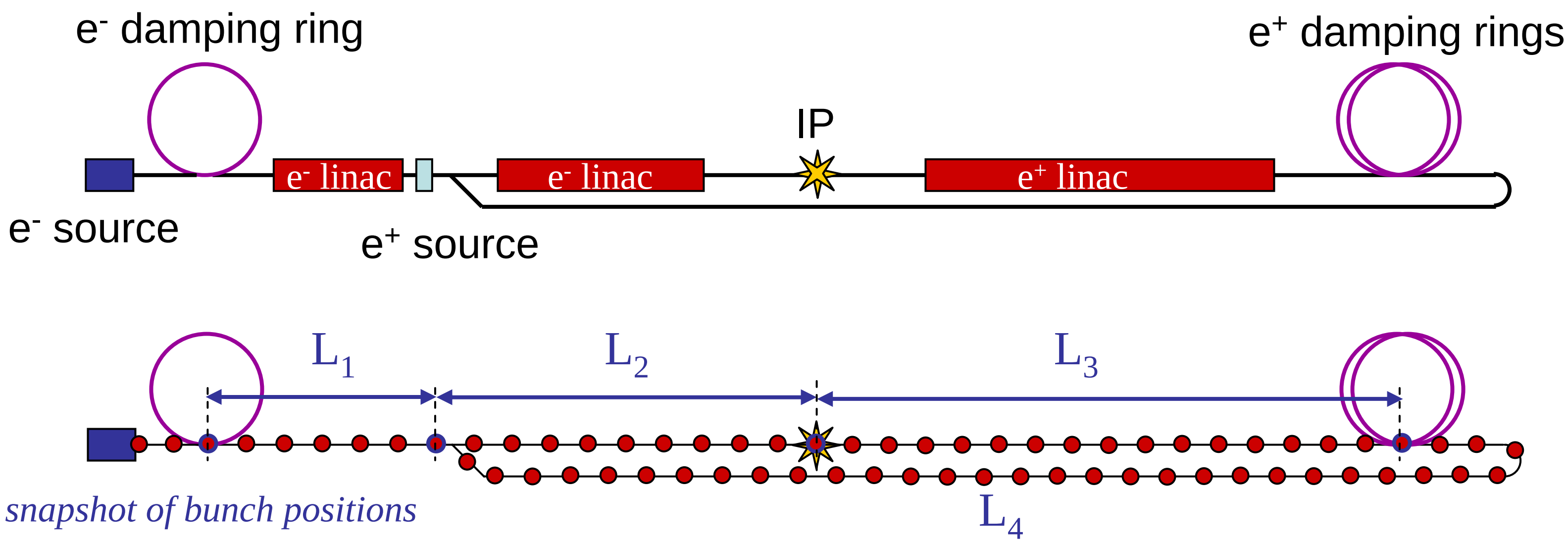
not to scale

Major Differences since April 2006

- Adopted a solution for the e+ timing problem
  - **1.2 km insert into e+ linac that adjusts the path length for the e+ DR injection for greatest flexibility**
  - **Also a ~100 m to adjust path length between two interaction regions and to allow fine tuning**
- Adopted a BDS with two 14 mrad crossing angle beamlines instead of 2 and 20 mrad
  - **The 2 & 20 mrad solution was more technically challenging and costly (mainly due to difficulties with the 2 mrad extraction line)**
  - **Detectors are located at same z location**

Timing Issues

- The undulator positron source makes timing harder
  - **Positron bunches must be injected into empty buckets in the e+ damping rings**
  - **Most flexible option is to re-inject into empty bucket → delay n ring turns**
  - **Present design is off by ~2.5 km → add 1.2 km insert into e+ linac – also need flexibility for 2 IRs**



Parameter Plane

- Parameter plane established
  - **TESLA designed for 3.4e34 but had a very narrow operating range**
    - Designed for single operating point
  - **ILC luminosity of 2e34 over a wide range of operating parameters**
    - Bunch length between 500 and 150 um
    - Bunch charge between 2e10 and 1e10
    - Number of bunches between ~1000 and ~6000
      - Significant flexibility in damping ring fill patterns
      - Vary rf pulse length
      - Change linac currents
    - Beam power between ~5 and 11 MW
  - **Thought to have small cost impact – to be checked**

Example Parameter Sets

Parameter range established to allow operating optimization

		nom	low N	lrg Y	low P	High L
N	$\times 10^{10}$	2	1	2	2	2
n_b		2820	5640	2820	1330	2820
$\varepsilon_{x,y}$	μm, nm	9.6, 40	10, 30	12, 80	10,35	10,30
$\beta_{x,y}$	cm, mm	2, 0.4	1.2, 0.2	1, 0.4	1, 0.2	1, 0.2
$\sigma_{x,y}$	nm	543, 5.7	495, 3.5	495, 8	452, 3.8	452, 3.5
D_y		18.5	10	28.6	27	22
δ_{BS}	%	2.2	1.8	2.4	5.7	7
σ_z	μm	300	150	500	200	150
P_{beam}	MW	11	11	11	5.3	11

Luminosity Overhead

- Concern that the design has 2.5x *L* overhead
  - **Linear colliders have limited operating space**
  - **Many parameters are already at the limit**
    - Beam power, gradient, DR emittances, …
  - **Additional parameter space is primarily gained by focusing harder**
    - Requires shorter IP bunch lengths or causes a large increase in IP disruption → some cost impact in BC
  - **High luminosity parameters push everything to the design limit – unlikely to achieve *L***
    - Beamstrahlung increases and degrades luminosity cleanliness while complicating BDS operation
  - **Significant cost savings in low Power design**

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**

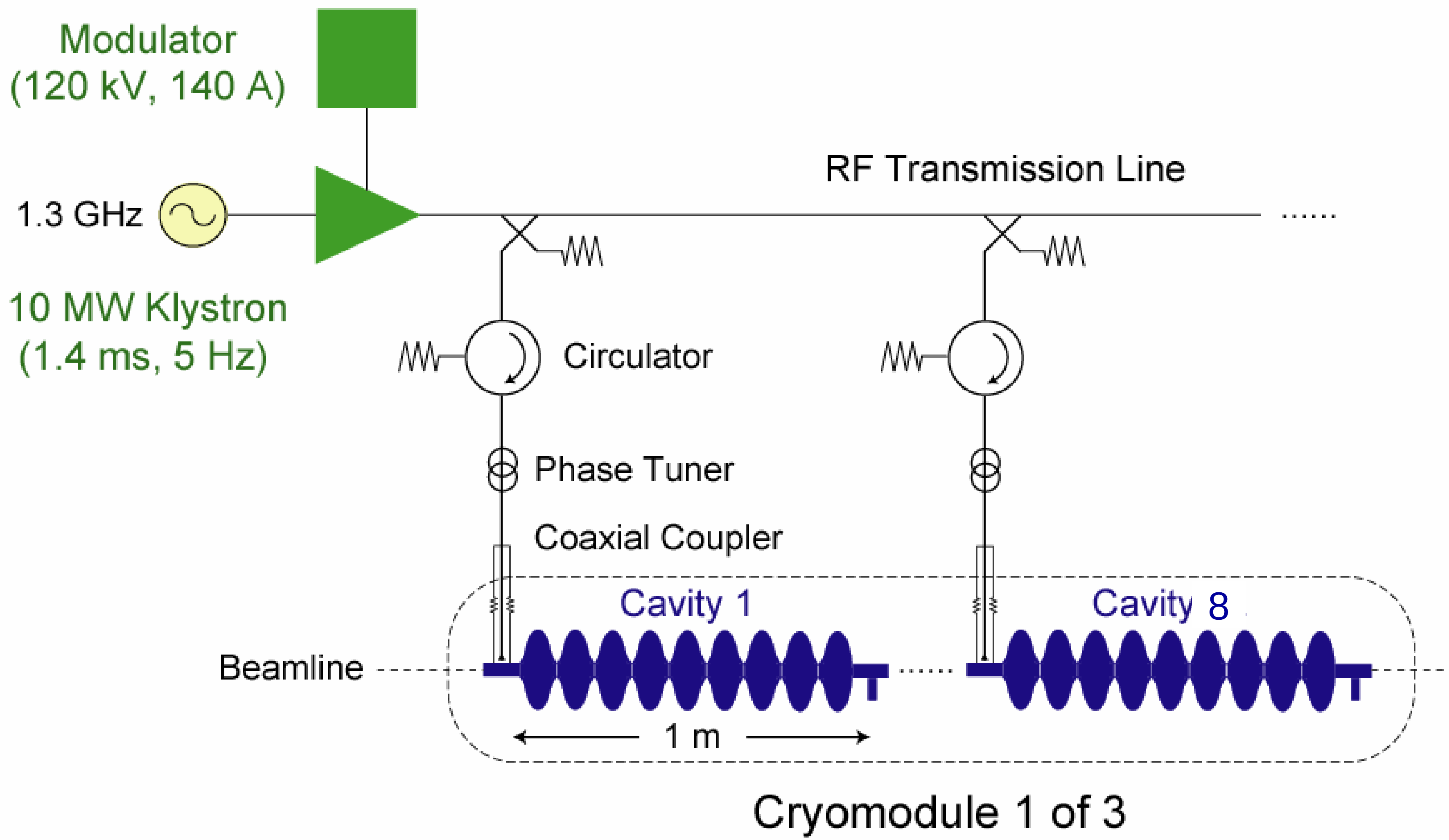
Availability Issues

- ILC is ~10x larger than previous accelerators
- Developed availability monte carlo AvailSim
  - **Working to compare against operating acc.**
- 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 of redundant sources (dual electron source & backup positron source) and dual linac tunnels**
    - Large impact on project and cost – needs further study

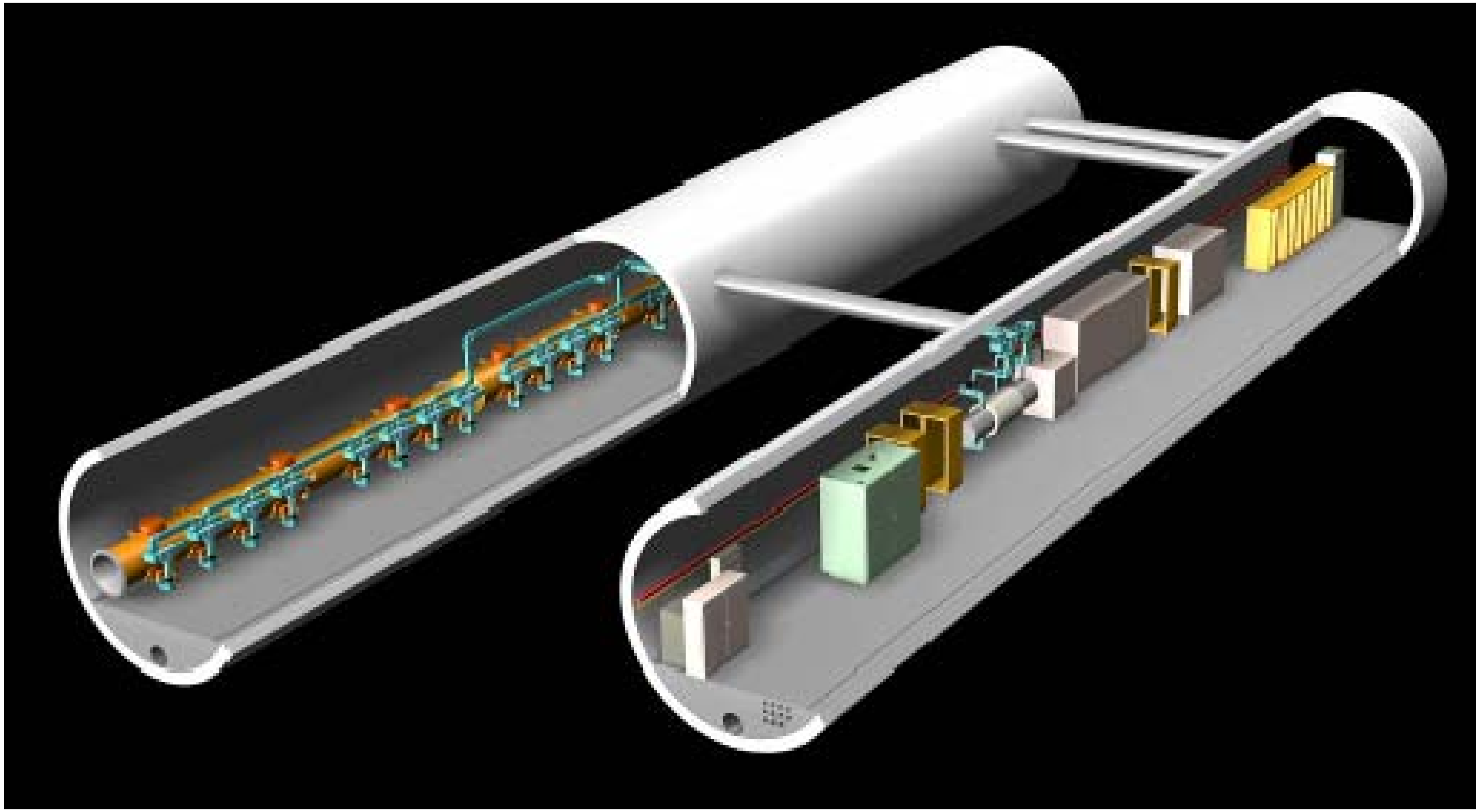
Main Linac

- Main features:
  - **Gradient of 31.5 MV/m**
    - Qualify cavities at 35 MV/m in vertical tests
    - ~5% overhead for variation in installed cryomodules
    - ~5% overhead for operations (1~2 MV/m below quench)
  - **Packing fraction ~70%**
    - Based on Type-IV cryomodule
      - Shorter cavity-cavity spacing (1.2λ vs $3\lambda/2$)
      - Quadrupole in center of cryomodule
    - Type-III cryomodules installing in TTF
  - **Rf power for 35 MV/m**
    - 9.5 mA average current
  - **3% additional rf units for repair & feedback**

Main Linac RF Unit



Conceptual View of Dual Tunnel

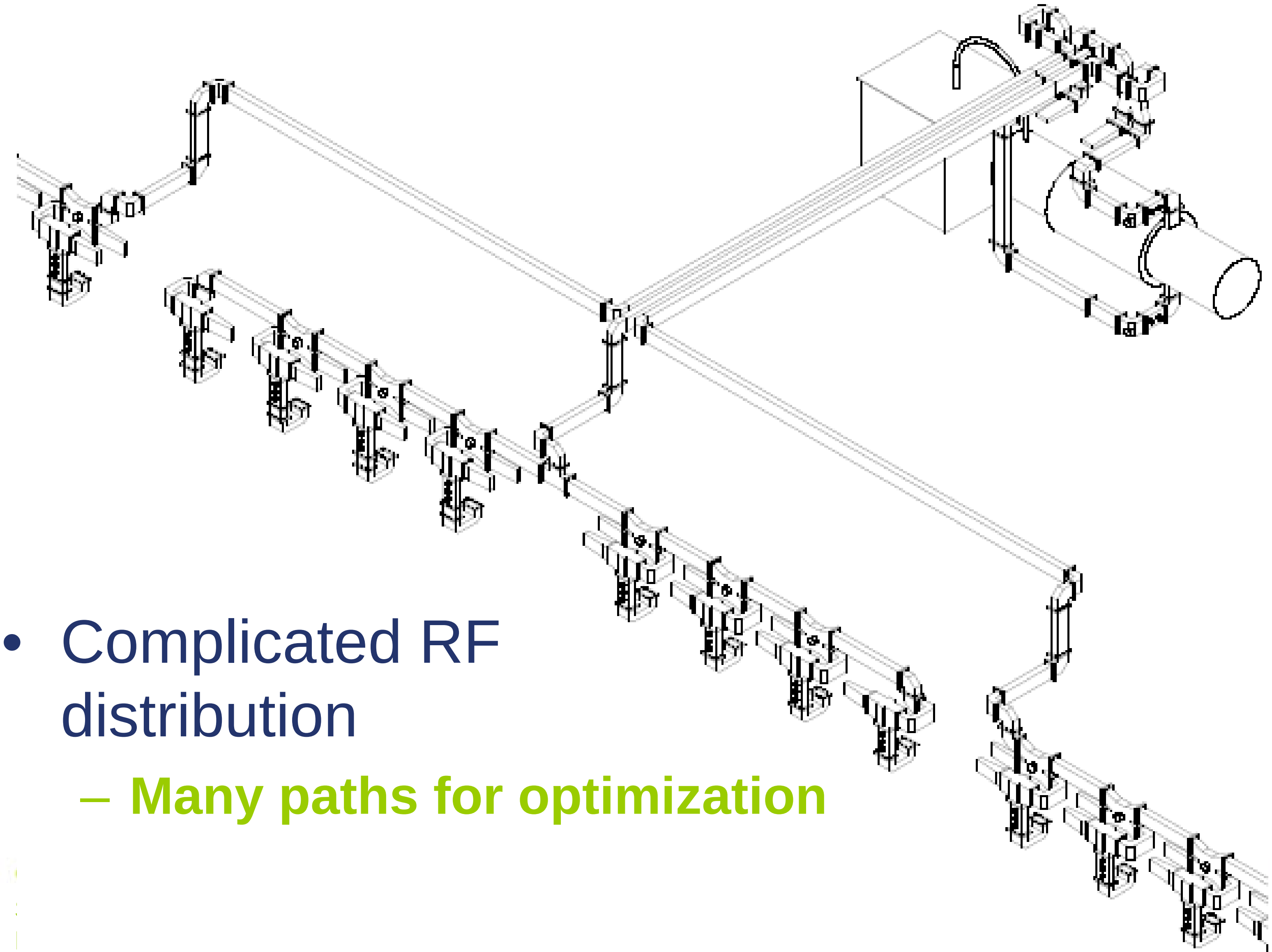


- Three RF/cable penetrations every rf unit (0.5 m)
- Safety crossovers every 500 m
- 34 kV power distribution

Modulators & Klystrons

- Baseline is the Fermilab/PPT bouncer modulator
  - **Extensive studies on alternate options inc. compact Marx Generator**
    - Better in terms of space, efficiency, cost, and availability
- Baseline klystron is 10 MW MBK
  - **Thales tubes appear to have lifetime problems when operating at full spec (4 tubes produced)**
  - **CPI tube tested to 10 MW but then operated at DESY at 8.3 MW and had vacuum failure**
  - **Toshiba tube has been running at full spec for ~1000 hours**

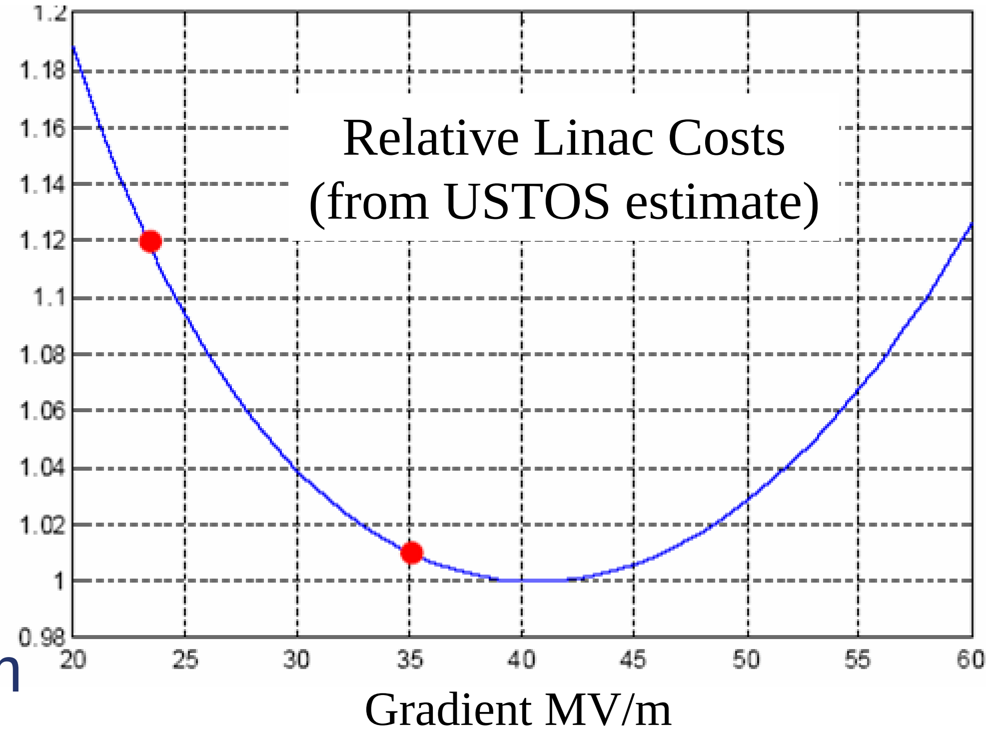
RF Distribution System



- Complicated RF distribution
  - **Many paths for optimization**

Cavity Gradient Choice

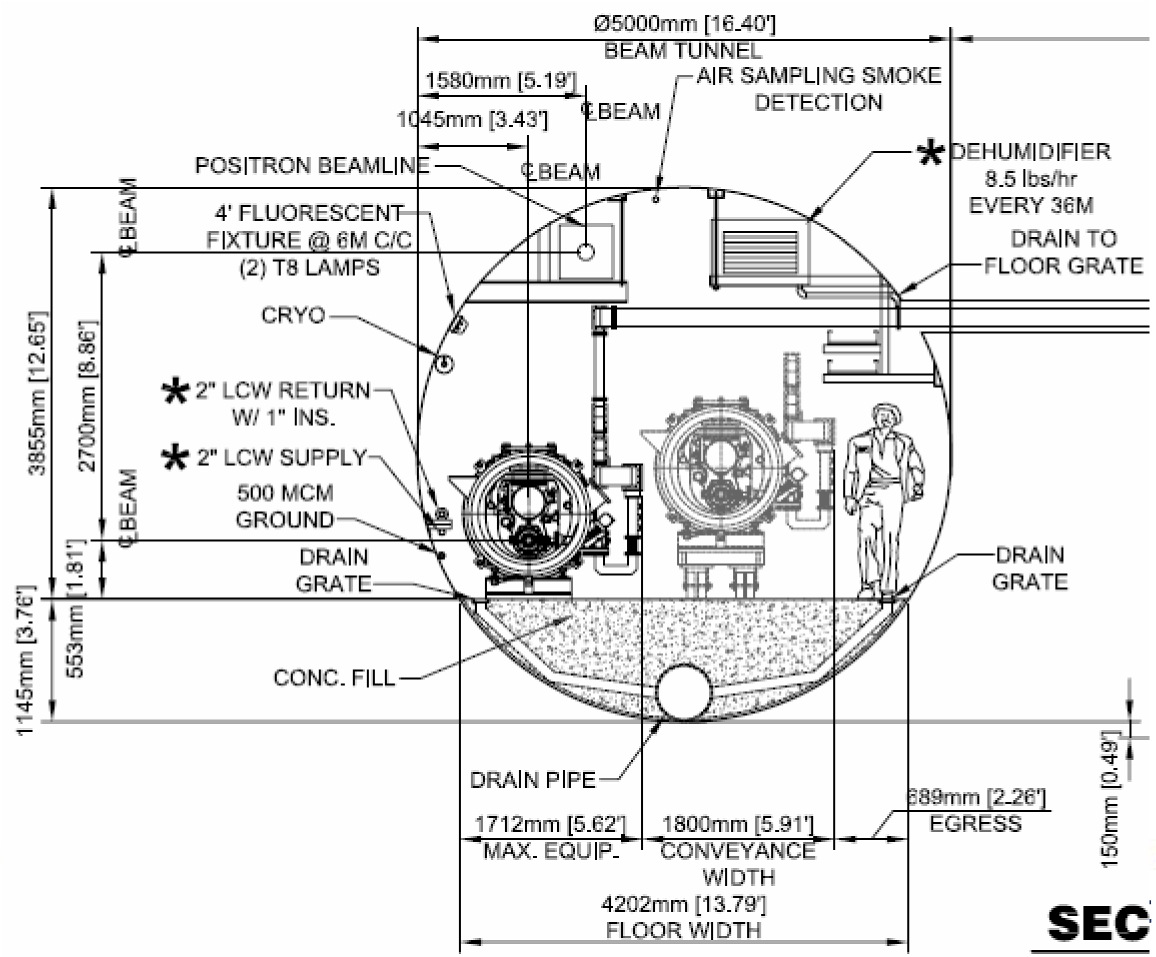
- Balance between cost per unit length of linac, the available technology, and the cryogenic costs
- Optimum is fairly flat and depends on details of technology
- Current cavities have optimum around 25 MV/m

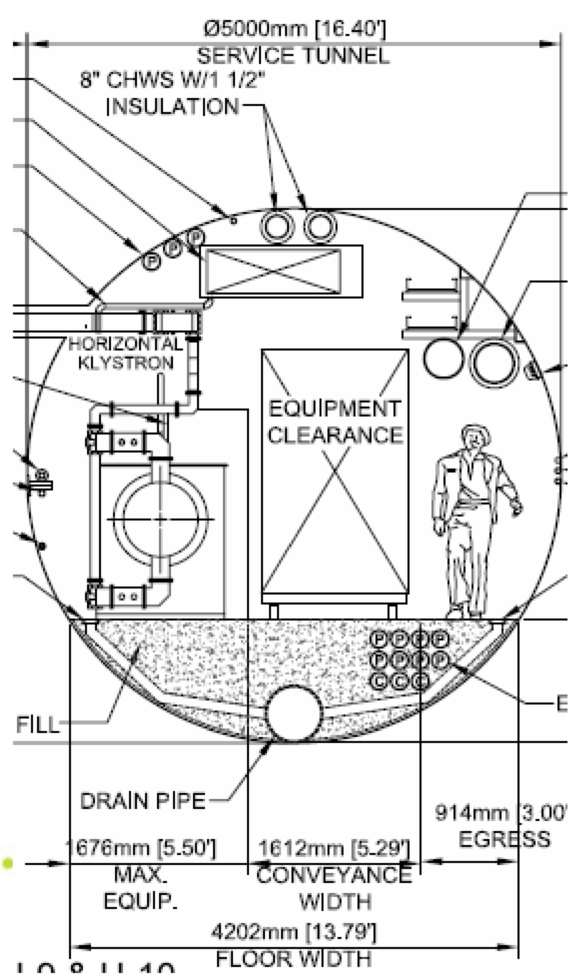


	Cavity type	Qualified gradient MV/m	Operational gradient MV/m	Length Km	Energy GeV
initial	TESLA	35	31.5	10.6	250
upgrade	LL	40	36.0	+9.3	500

Baseline Main Linac Tunnel

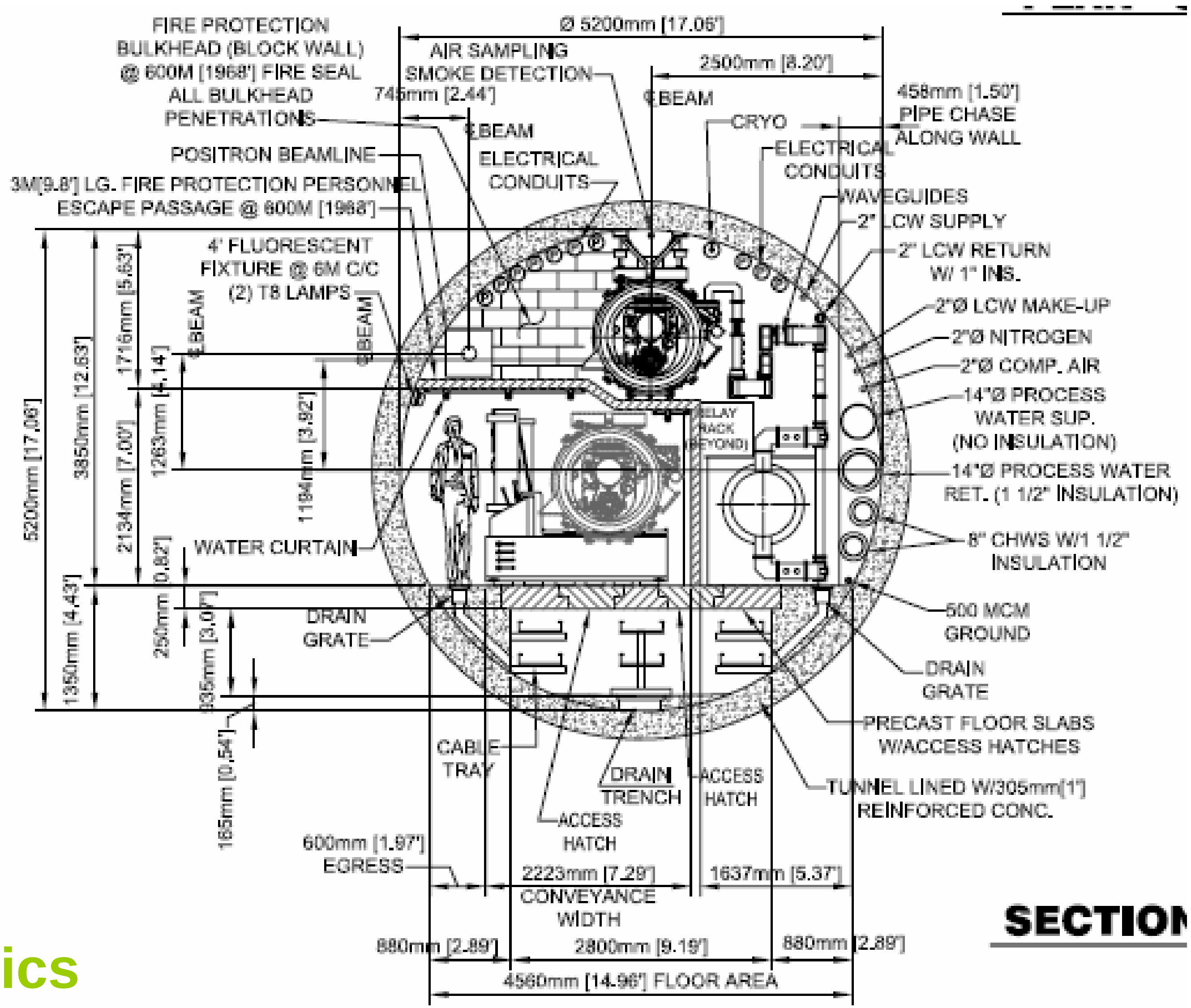
- Looking at smaller diameter tunnels to reduce costs





Single Tunnel Option

- Considered a single tunnel option
  - **Small net savings**
  - **Need to add linac to recover availability**
  - **Need additional shielding for electronics**



Main Linac Issues

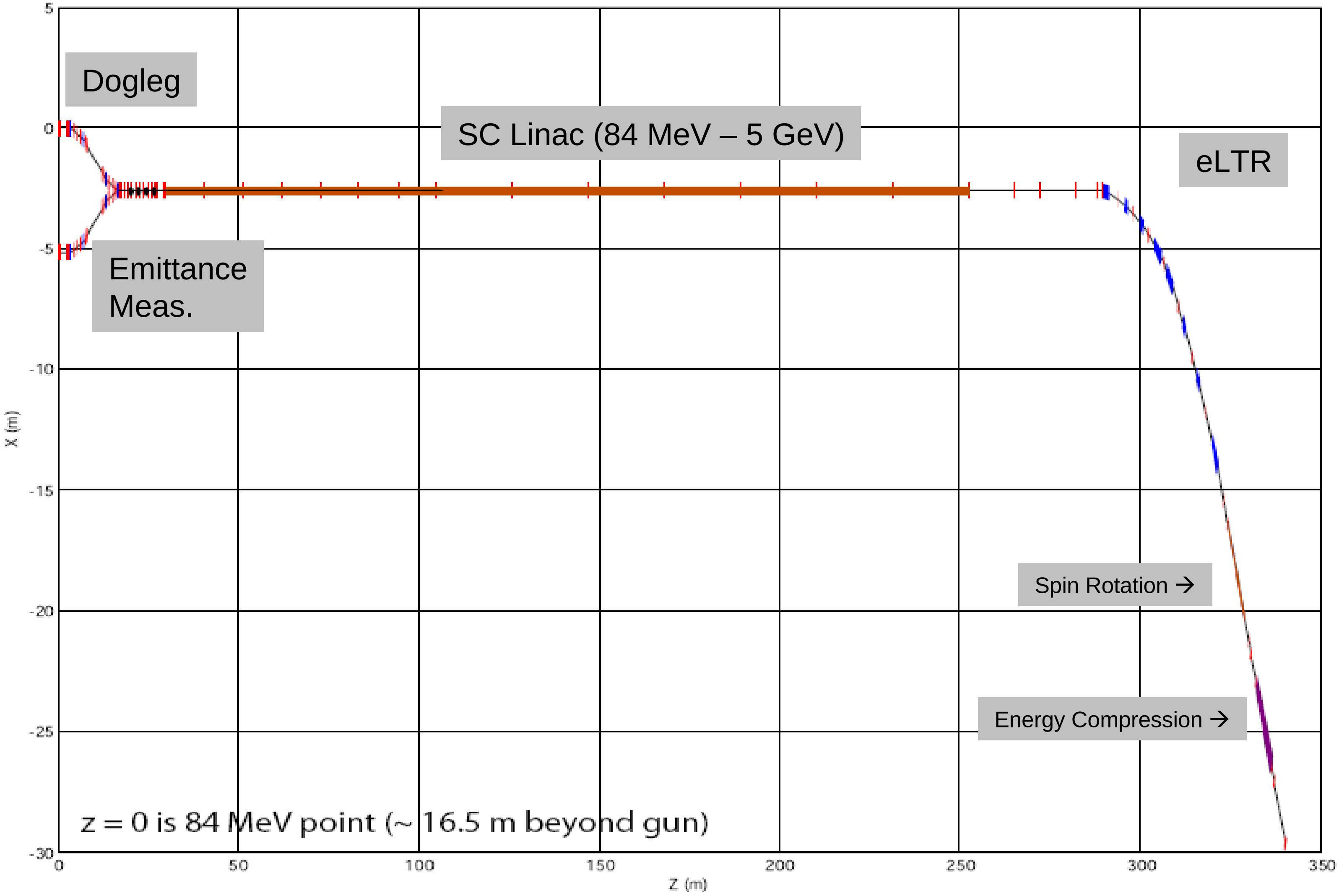
- Gradient choice
  - **35 MV/m demonstrated – work on fabrication process**
- RF klystron
  - **10 MW tubes demonstrated – work on improving lifetime**
- RF distribution
  - **Large system with many components – cost optimize**

- Cryosystem
  - **Segmentation at 2.5 km – some desire to reduce this**
- Machine protection system
  - **Not clearly defined**
- Diagnostic sections and instrumentation
  - **No diagnostics sections in linac**

Polarized Electron Source

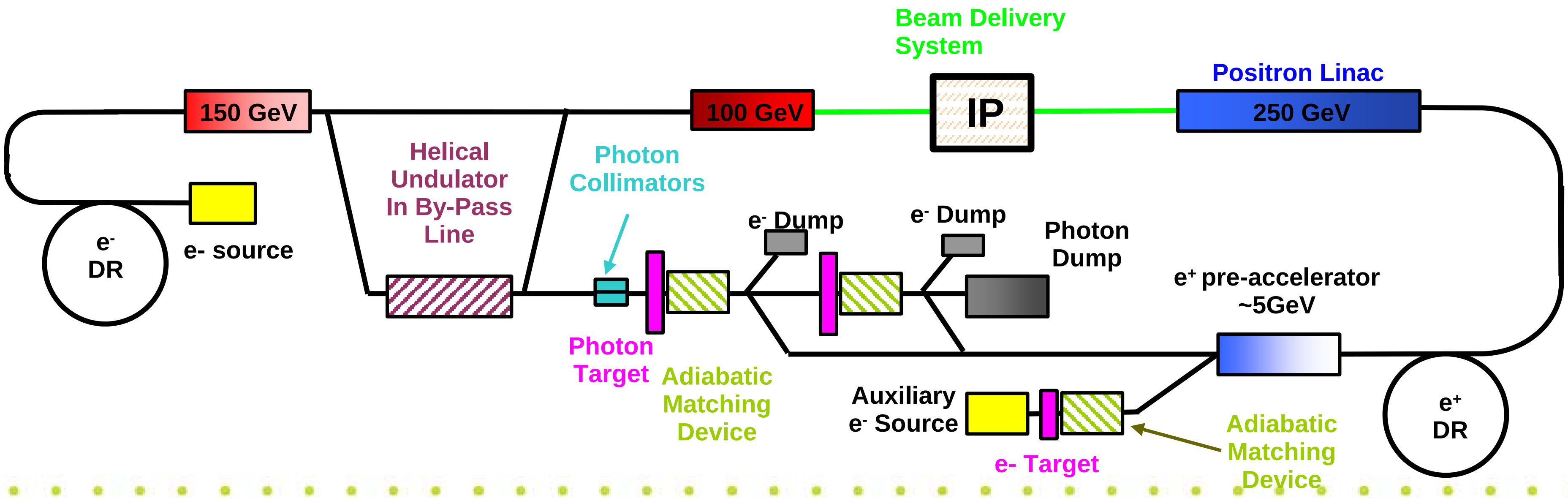
- Polarized electron source based on:
  - **Polarized DC gun at 120 kV**
  - **Sub-harmonic buncher system**
  - **70 MeV normal conducting linac**
  - **Energy and emittance diagnostics**
  - **5 GeV superconducting linac**
  - **Spin rotator**
  - **Energy compressor**
  - **Diagnostics and beam dump**
  - **System is well defined**
    - R&D needed to improve cathode lifetime and develop laser but relatively straight-forward

Electron Source



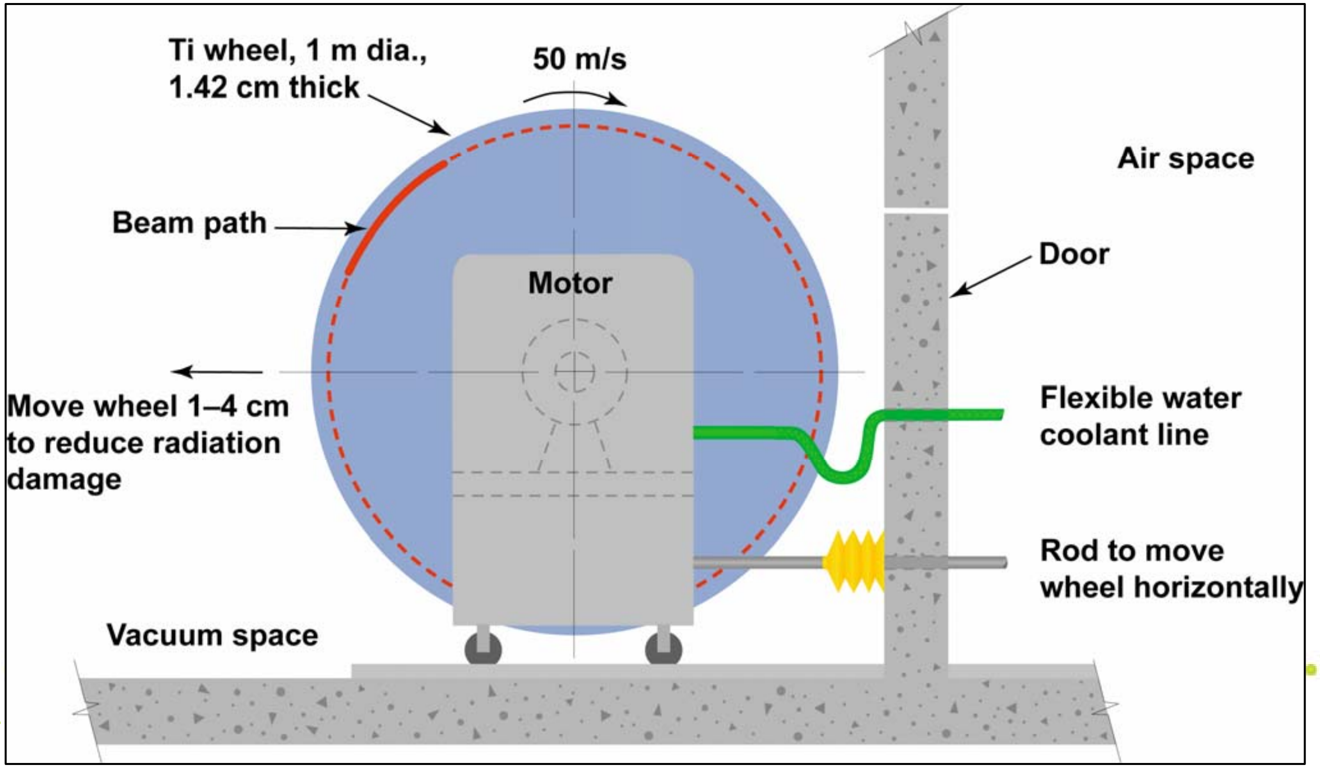
Undulator Positron Source

- Undulator-based positron source
  - **150 meter undulator with K=1; λ = 1cm; >6mm aperture**
- Two e+ production stations including 10% keep alive
  - **Provides beam for instrumentation and feedback systems**
- Keep alive auxiliary source is e+ side
  - **Better availability and possibly easier commissioning**



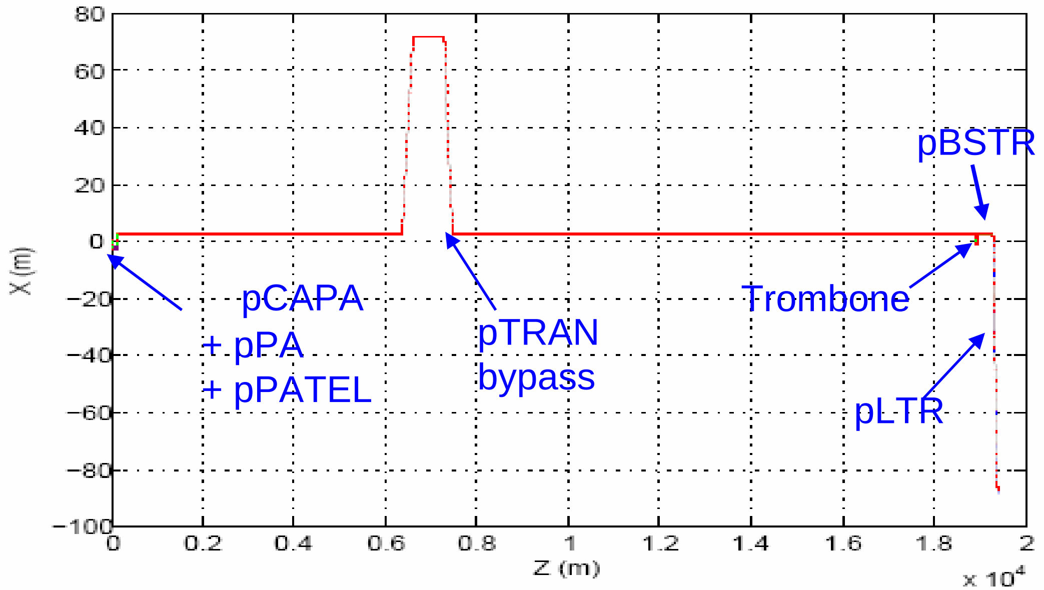
Positron Target

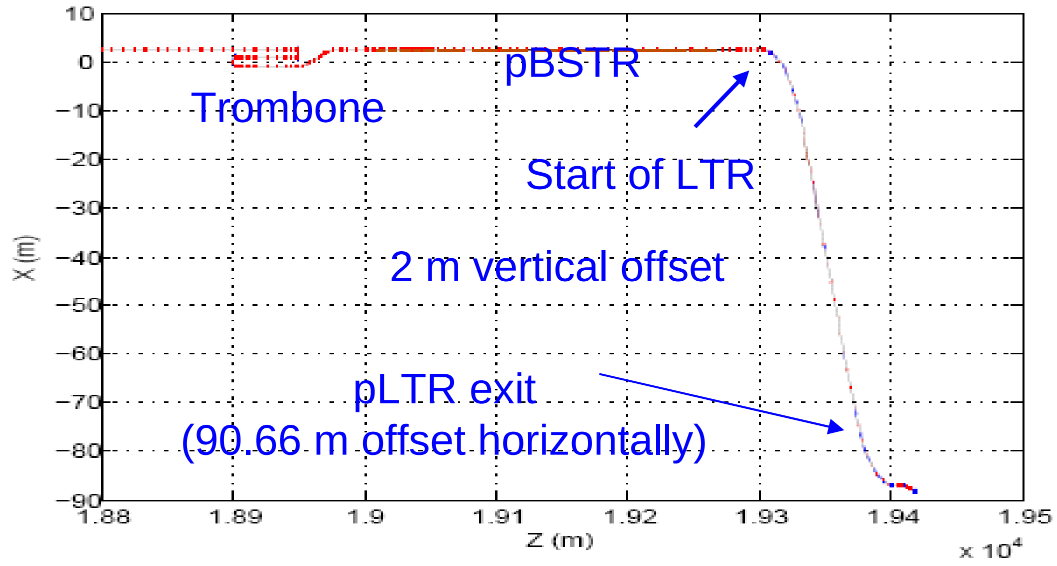
- Large positron flux required
  - **Large diameter Ti target wheel rotated at 500 rpm**
  - **Limited lifetime due to radiation damage**
    - Remote handling probably needed
  - **Immersion in 6~7T AMD field can improve yield by ~50%**
    - Requires R&D to understand target/AMD issues



Positron Source Optics

- ~20 km transport large aperture line
- Bypass around BDS
- ~1.2 km delay to adjust timing for DR injection
- Trombone to adjust timing for separated IPs and fine tuning





Positron Source Issues

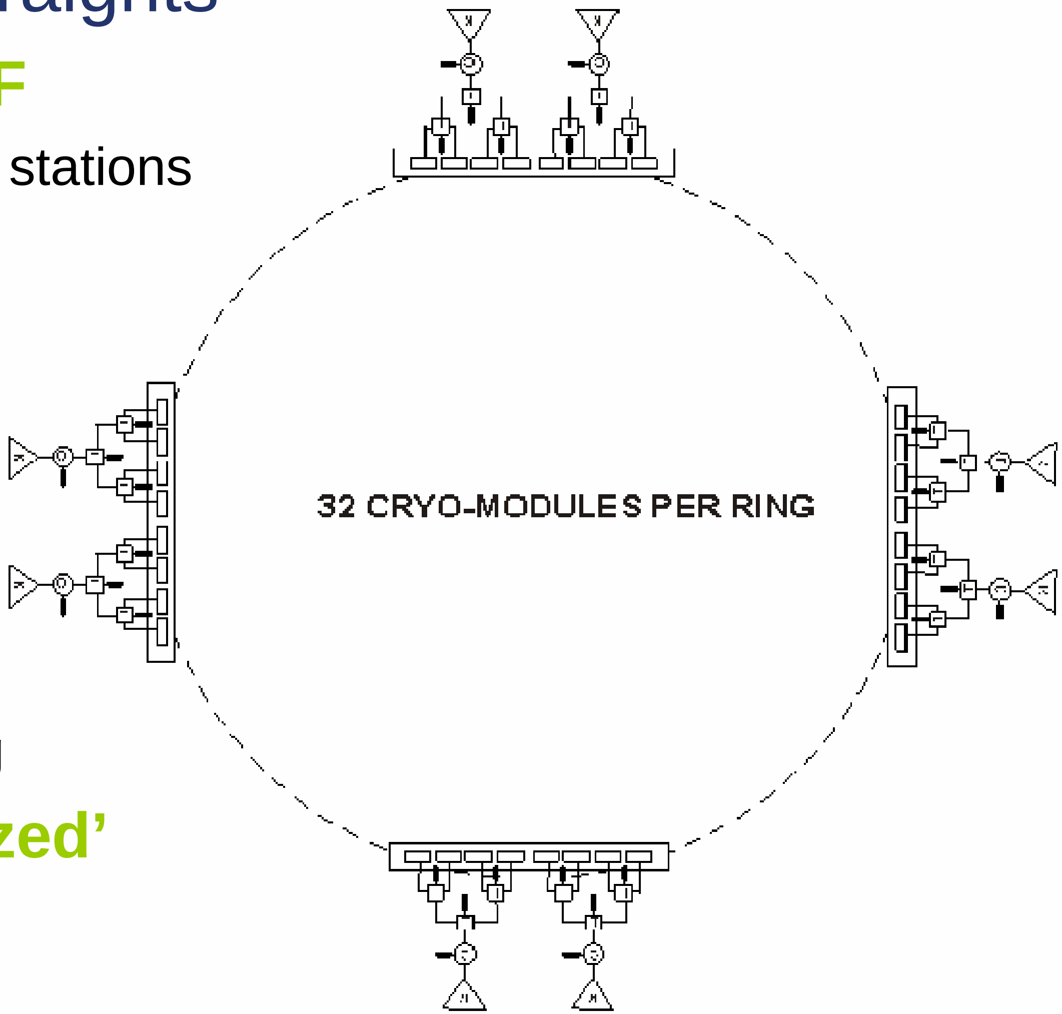
- Positron system design is coupled to linac and BDS design
  - **Present layout minimizes conflicts but costs $**
- Timing issues are a difficult constraint
  - **Either severely constrain path lengths or limit flexibility – discuss in damping ring section**
- E+ emittance requires very large apertures
  - **Long transport is expensive and may have problems with beam loss**
- Looking at centralized injector
  - **Significant potential cost savings**

Damping Ring Requirements

- Compress 1 ms linac bunch train in to a "reasonable size" ring
  - **Fast kicker (ns)**
- Damping of $\gamma\varepsilon_{x,y}= 10^{-2}$ m-rad positron beams to $(\gamma\varepsilon_x, \gamma\varepsilon_y)=(8 \times 10^{-6}, 2 \times 10^{-8})$ m-rad
  - **Low emittance, diagnostics**
- Cycle time 0.2 sec (5 Hz rep rate)→ τ = 25 ms
  - **Damping wiggler**
- 2820 bunches, 2×10^{10} electrons or positrons per bunch, bunch length= 6 mm
  - **Instabilities (classical, electron cloud, fast ion)**
- Beam power > 220 kW
  - **Injection efficiency, dynamic aperture**

Damping Ring Layout

- 6.7 km rings with 6 straights
  - **4 for wigglers and RF**
    - Can operate with 3 RF stations
  - **Injection/extraction is not fully designed**
  - **Arcs are ~20 TME cells in 4m tunnel**
  - **Baseline has 2 e+ rings to reduce ECI**
    - Pursuing single e+ ring
  - **Developing 'centralized' injector with e+ & e- in same tunnel**



Damping Ring Parameters (1)

Item	Baseline	Alternatives
Circumference	(e^+) 2×6.7 km (e^-) 6.7 km	1. (e^+) 6 km 2. (e^+) 17 km
Beam energy	5 GeV	
Injected emittance & energy spread	0.09 m-rad & 1% FW	0.045 m-rad & 2% FW
Train length (bunch charge)	2700 (2×10^{10}) - 4050 (1.3×10^{10})	
Extracted bunch length	6 mm - 9 mm	
Injection/extraction kicker technology	Fast pulser/stripline kicker	1. RF separators 2. Fourier pulse compressor

- Baseline had 2x6.7 km e+ rings to avoid the electron cloud instability → simulations with clearing electrodes suggests that a single e+ ring will be sufficient

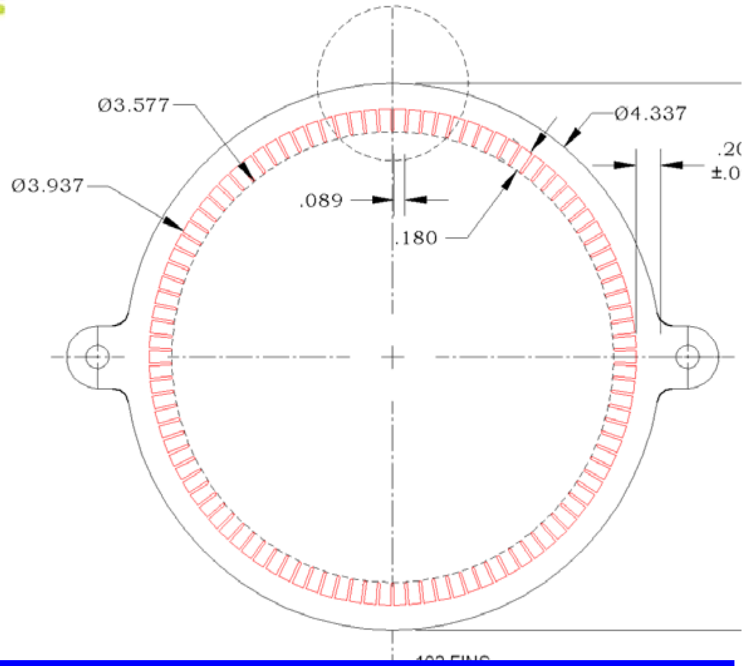
Damping Ring Parameters (2)

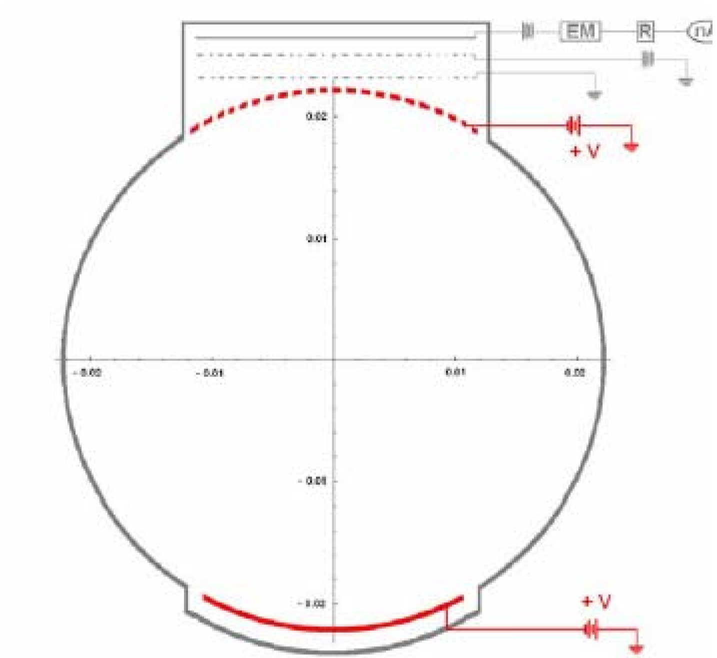
Item	Baseline	Alternatives
Wiggler technology	Superconducting	1. Normal-conducting 2. Hybrid
Main magnets	Electromagnetic	Permanent magnet
RF technology	Superconducting	Normal conducting
RF frequency	650 MHz	500 MHz
Vacuum chamber diameter, arcs/wiggler/straights	50 mm/46 mm/100 mm	

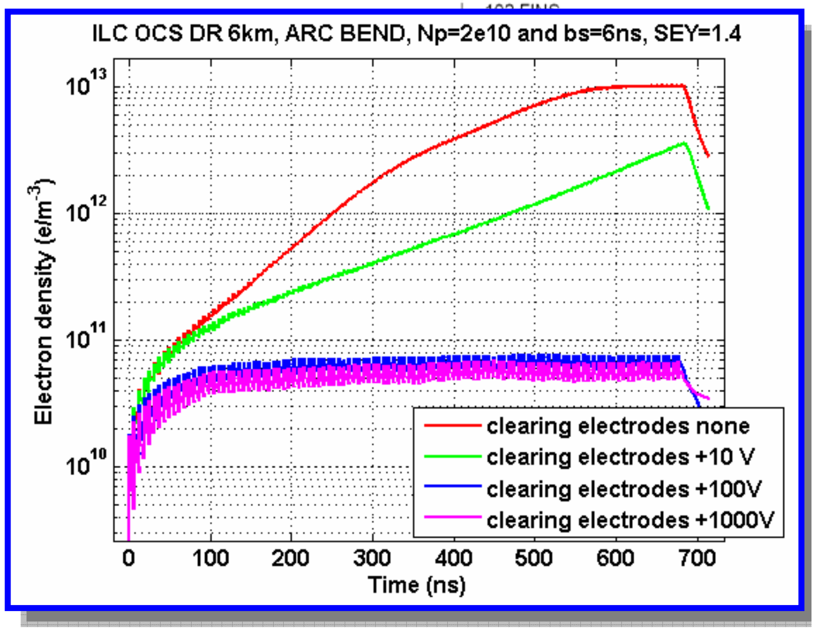
- 6.7 km rings with 650 MHz rf frequency will support all parameter options
- Superconducting wiggler parameters are similar to those demonstrated at CESR

Electron Cloud Instability

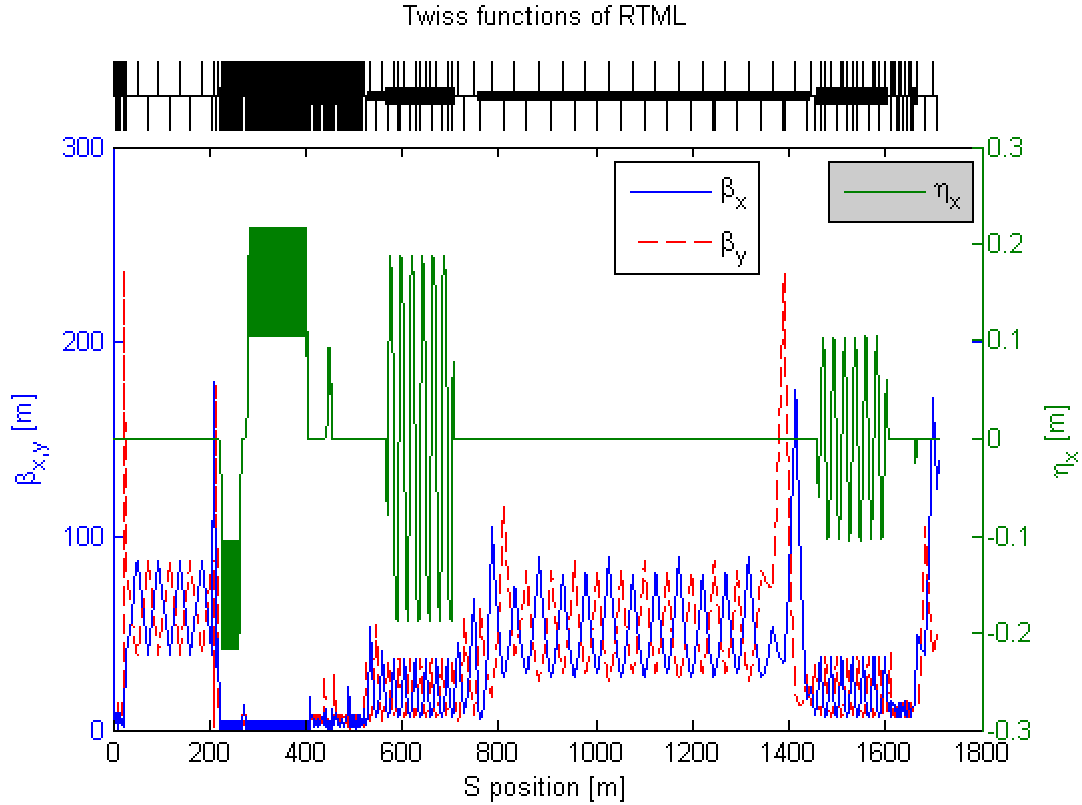
- Simulations indicate that problem is difficult in magnets – need SEY ~1.2
  - **Use solenoids in straights**
  - **Use electrodes/grooves in the magnets**



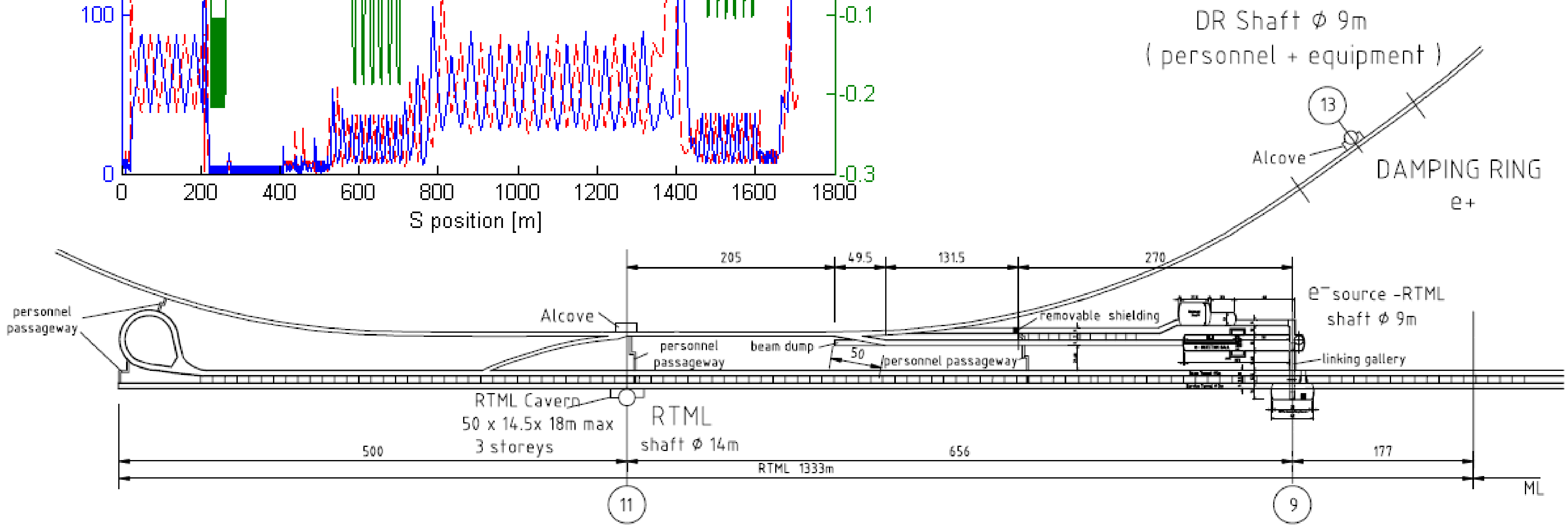




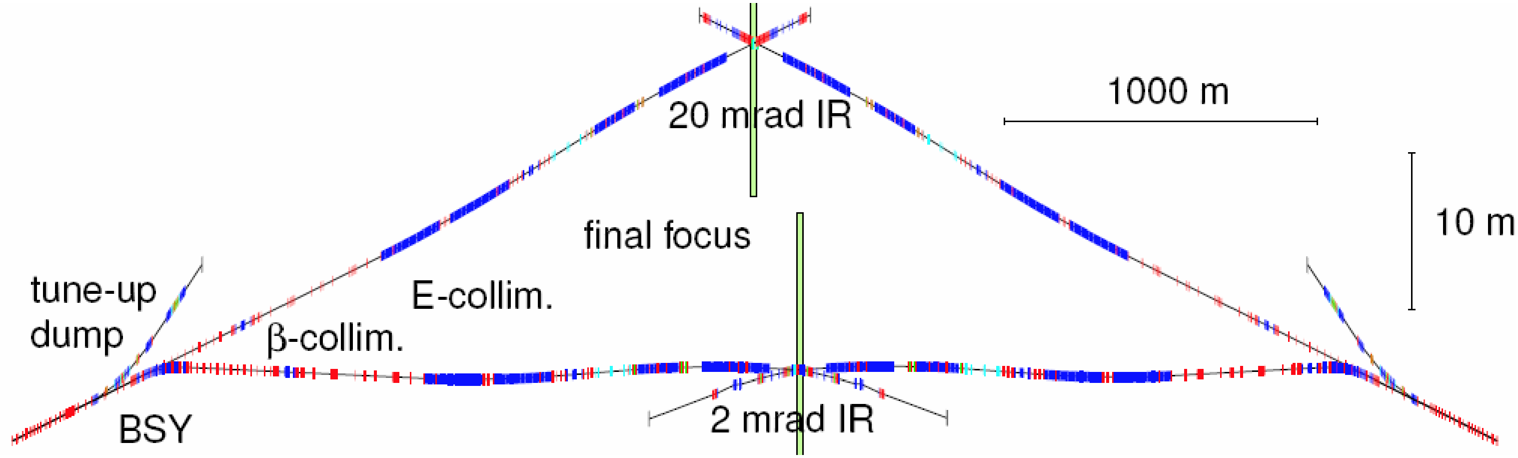
Ring To Main Linac



- Dual stage BC
- Pre-linac collimation
- 180° for feed-forward
- Diagnostics & tune-up dumps

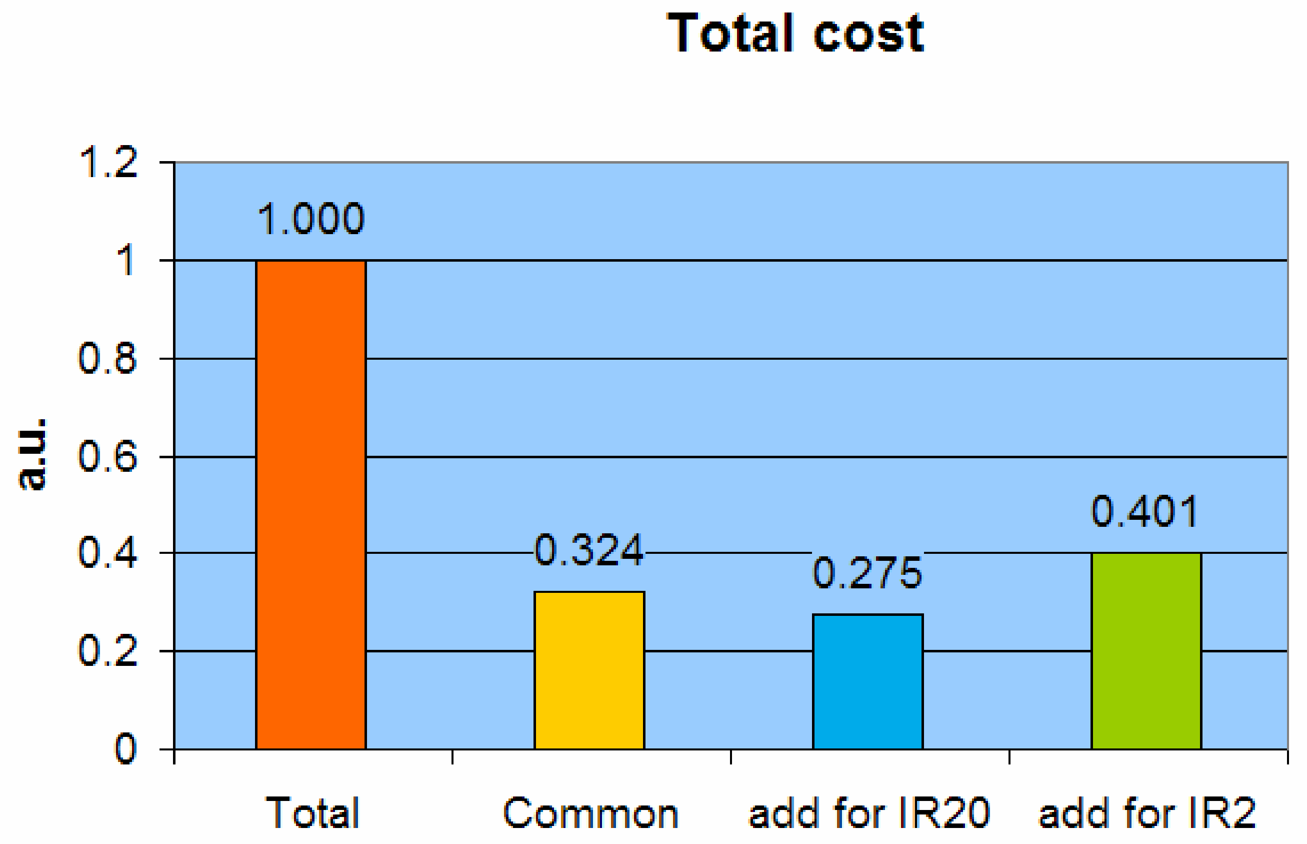


Vancouver Beam Delivery System



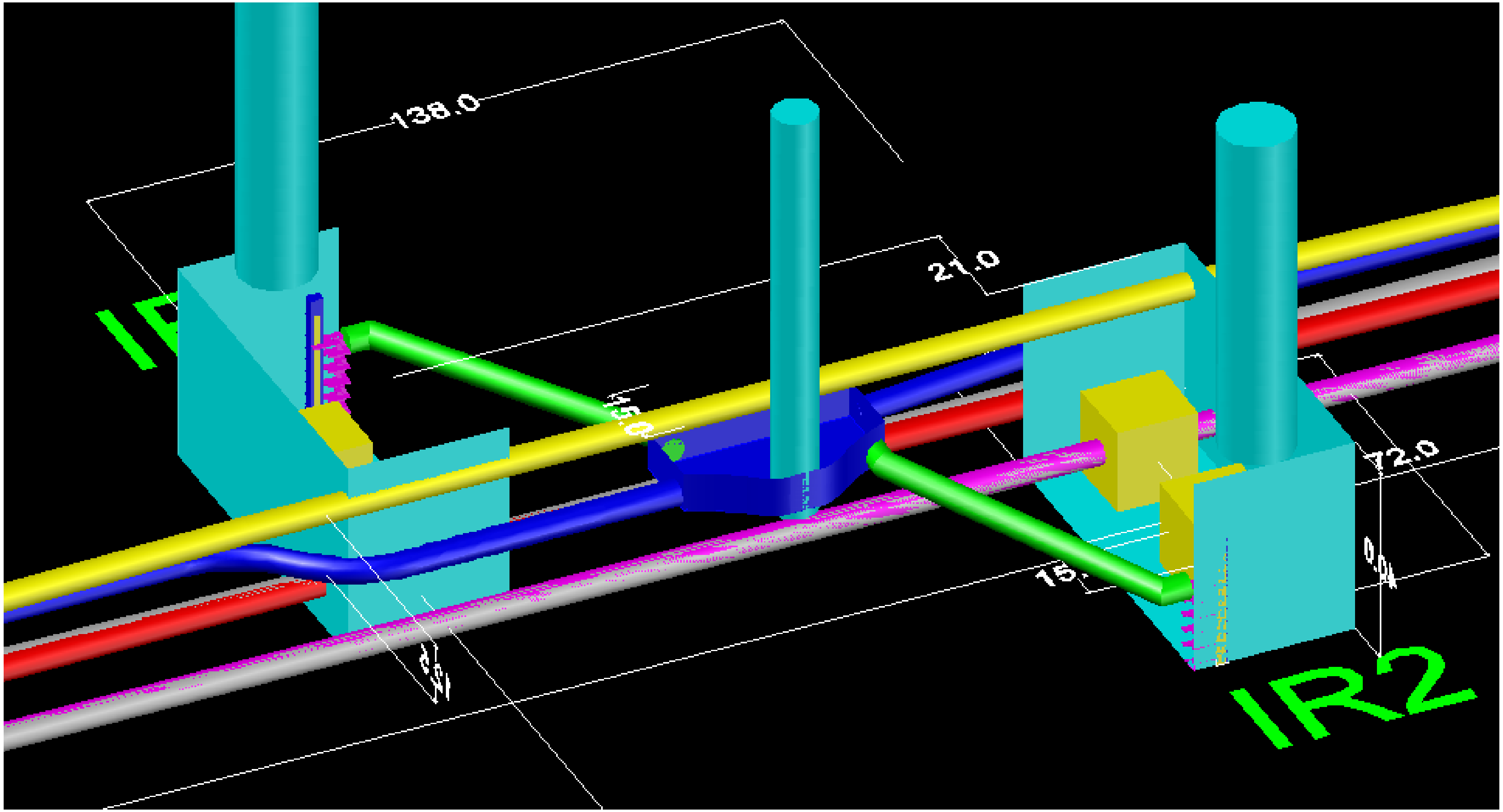
- Vancouver Baseline
  - **Two BDSs, 20/2 mrad, 2 detectors, 2 longitudinally separated IR halls**
- Present Baseline
  - **Two BDSs, 14/14 mrad, 2 detectors in single IR hall @ Z=0**
- Alternative #2
  - **Single IR/BDS, collider hall long enough for two push-pull detectors**

Vancouver BDS Cost Estimates



- Additional costs for 2 mrad BDS
  - **Extraction line significantly more difficult**

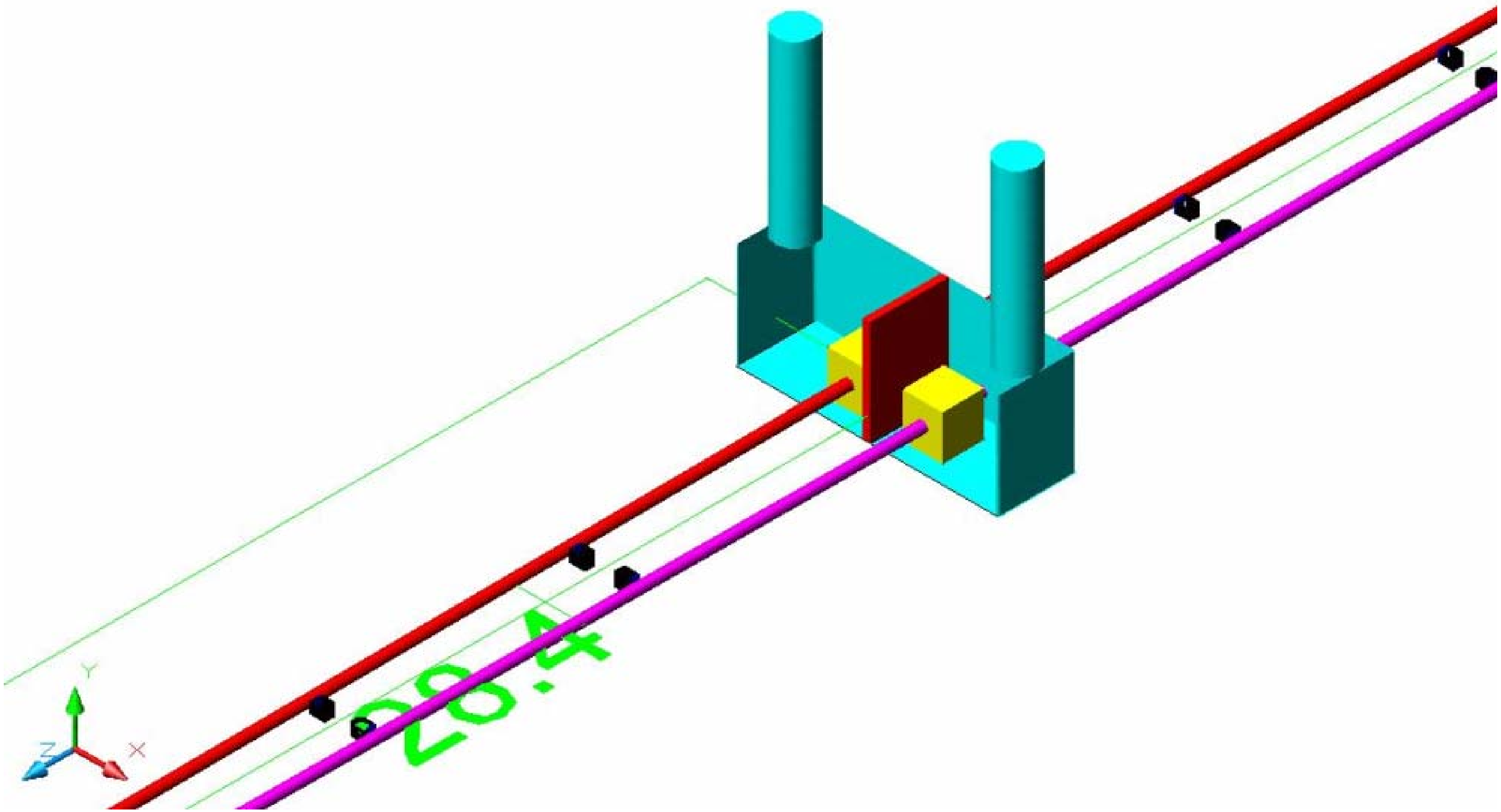
Detector Hall Layout 2/20 mrad



2 mrad and 20 mrad IRs

- Small separation of extraction and incoming beams in 2 mrad case
  - Complicated magnets
  - Backscattered radiation in IR
  - Long extraction with larger apertures
  - Higher cost and more technically difficult
- 20 mrad based on compact SC quadrupoles developed at Brookhaven
  - Technology works down to ~14 mrad crossing
  - Physics impact of 14 mrad vs 2 mrad is small
  - Design well studied and developed

Present 14/14 mrad Layout



Studies Since Vancouver

- Effort has been focused on cost
  1. **Understand the present cost estimates**
  2. **Review the Technical System costs**
  3. **Consider scope/layout for cost reduction**

- Major scope/layout considerations
  1. **Centralized injector complex**
  2. **Single stage BC and other RTML options**
  3. **Undulator vs conventional e+ source**
  4. **Lower current linac operation**
  5. **One vs Two linac tunnels**
  6. **Beam Delivery System options**

Summary

- Baseline configuration is well thought out
  - **Based on decades of R&D**
  - **Technology reasonable extrapolation of the R&D status**
  - **Inclusion of availability and operational considerations**
  - **Conservative choices (for the most part) to facilitate rapid cost evaluation**
- Made a 1st pass at the cost estimate for Vancouver
  - **Investigating a number of improvements post-Vancouver**
- Will need additional work on cost reduction
  - **Component optimization as well as the sub-systems**
  - **Working on procedures for this**