# The Baseline Configuration

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GDE
SLAC

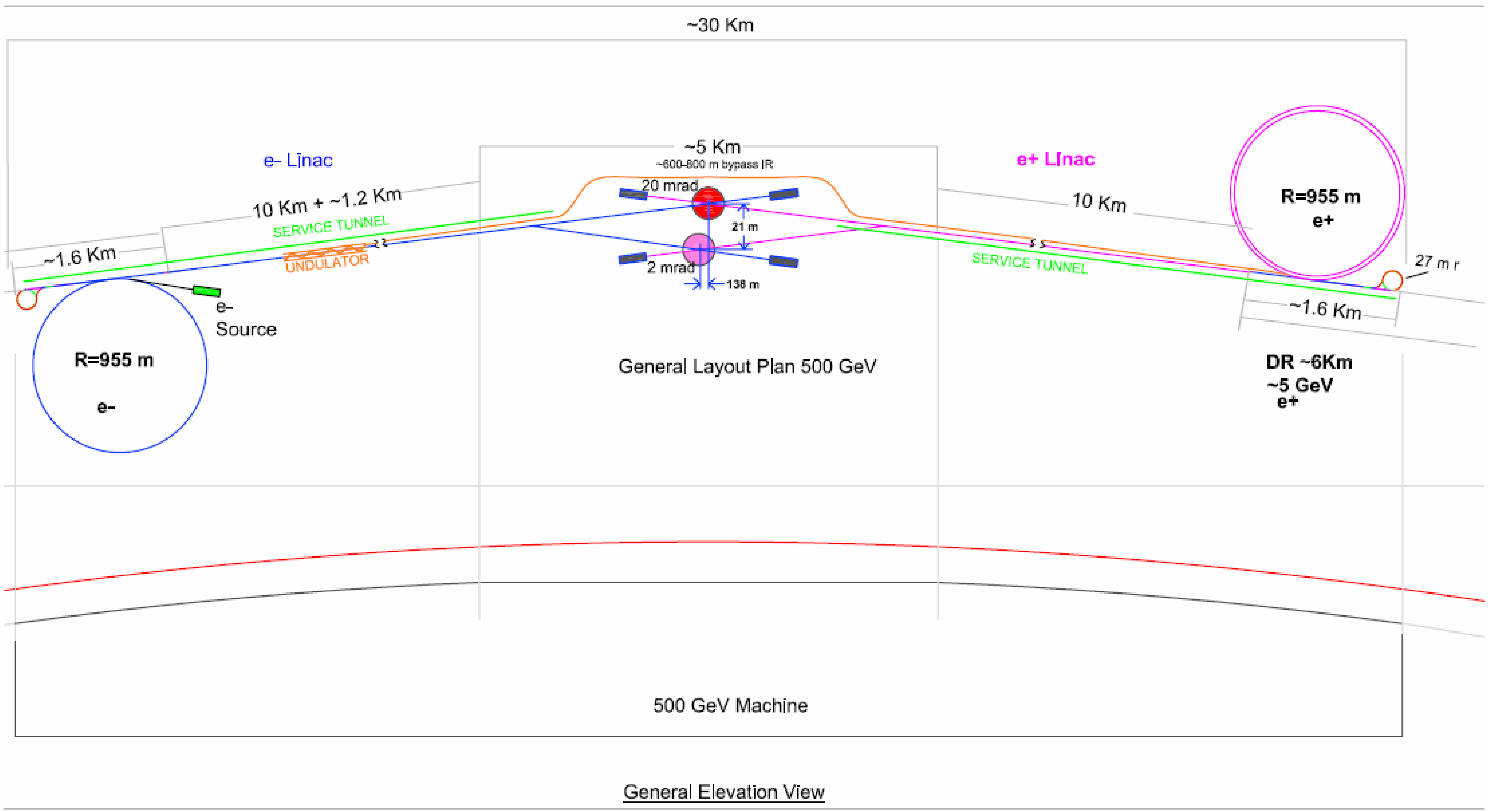
# The ILC Accelerator

- $2^{nd}$ 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 $\gamma$–$\gamma$ collisions**
  - **The machine must be upgradeable to 1 TeV**
- Three big challenges: energy, luminosity, and cost

# Baseline Configuration (BCD)

- BCD developed by ILC Working Groups established at KEK ILC Workshop (2004)
  - **Many working meetings during 2005**
  - **Discussed extensively at Snowmass ILC Workshop (2005)**
    - Working groups summarized Snowmass Workshop with bulk of the BCD
  - **White papers on contentious issues by GDE members in fall 2005**
    - Energy upgrade; Positron source; Number of tunnels; Interaction region configuration; Laser straight versus curved or terrain following tunnels
  - **Basic form ratified at Frascati GDE meeting**
- BCD has little consideration on cost minimization
  - **BCD will evolve as the cost estimates are developed**

# Schematic of the BCD



# 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**

# Parameters

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 |
| $\delta_{BS}$ | % | 2.2 | 1.8 | 2.4 | 5.7 | 7 |
| $\sigma_z$ | µm | 300 | 150 | 500 | 200 | 150 |
| $P_{beam}$ | MW | 11 | 11 | 11 | 5.3 | 11 |

# 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**

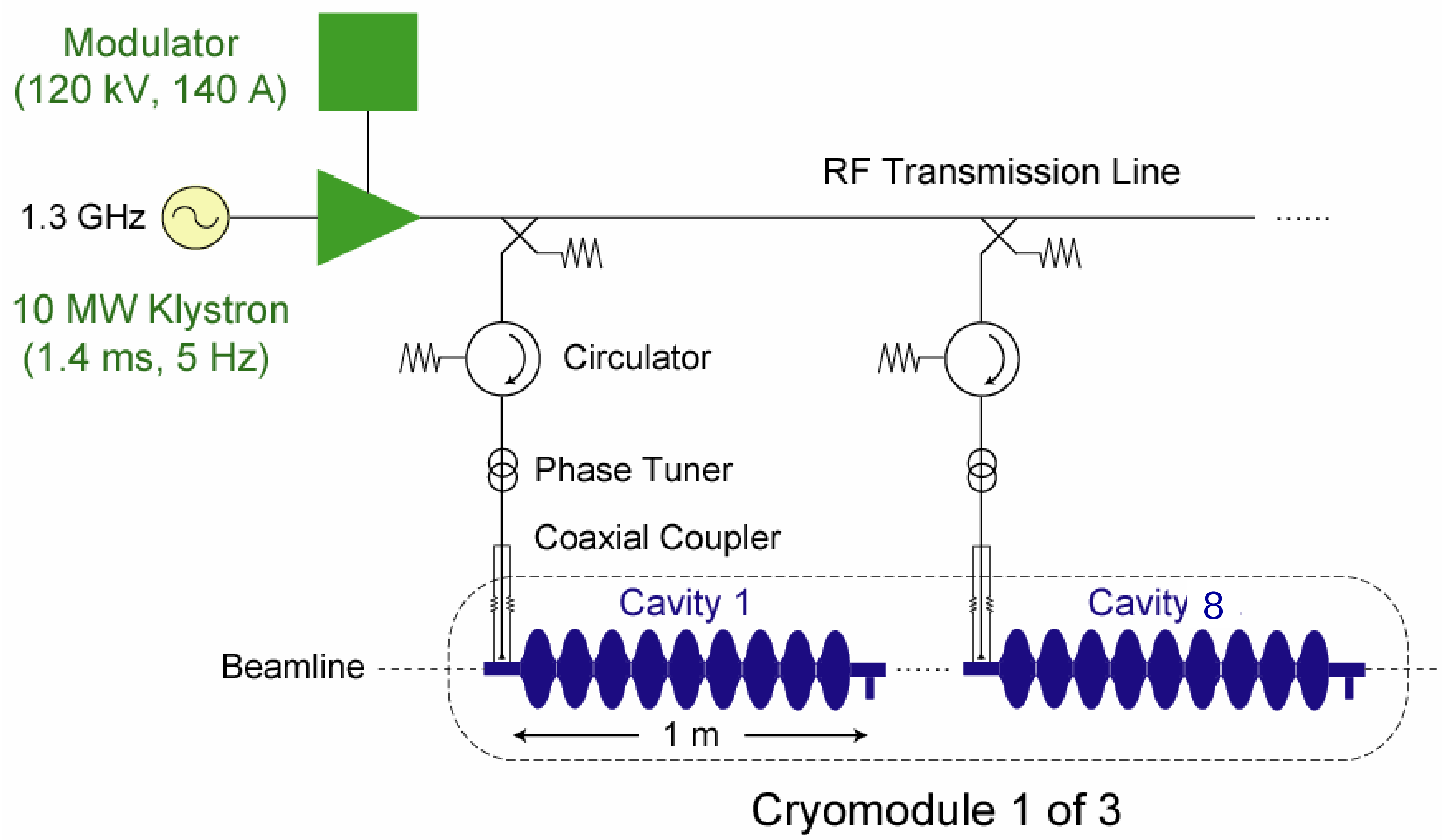
# Availability Issues

- 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

- Discussed in depth by Chris Adolphsen
- 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 ($1.2\lambda$ 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**

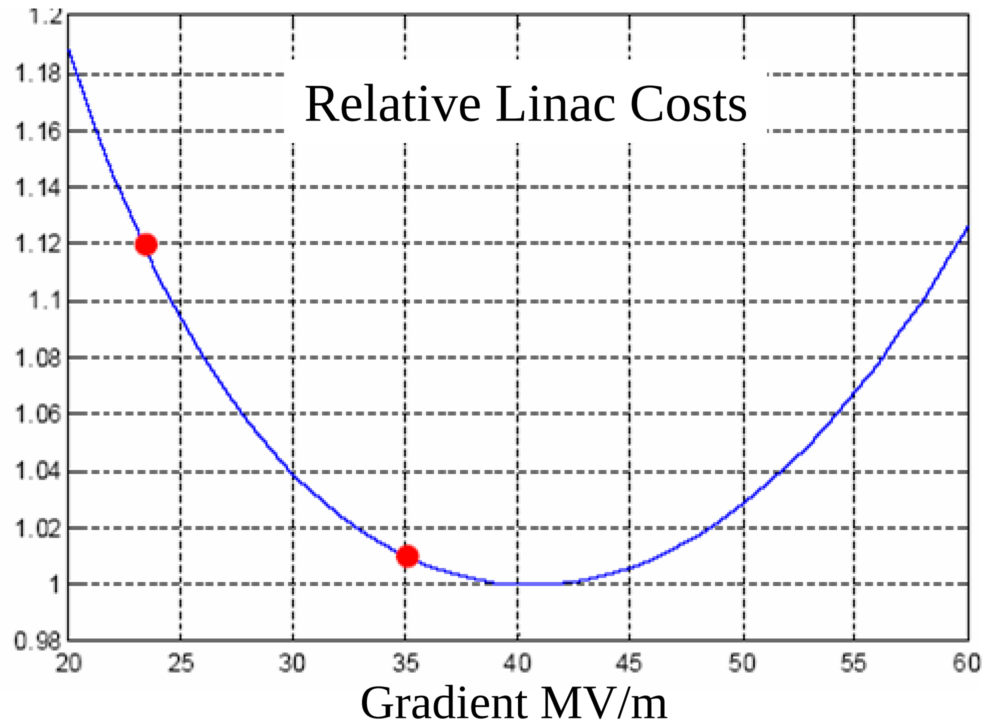
# Main Linac RF Unit



# Gradient Choice

- Balance between cost per unit length of linac, the available technology and the cryogenic costs

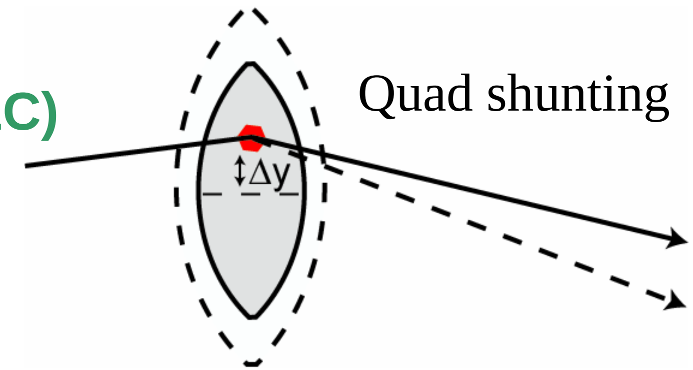
- Optimum is fairly flat and depends on details of technology




| | 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 |

# Main Linac Beam Dynamics

- Tolerances are comparable to those in SLC
  - **200~300 um on the structures and 25 um on the quadrupoles**
- Structure alignment has been measured at TTF
  - **Will get additional experience with new test facilities**
  - **Could be improved using beam-based diagnostics**
- Multiple quadrupole BBA alignment techniques
  - **Quad-shunting (used many places; FFTB demonstrated <7 mm)**
  - **Dispersion-Free Steering (tested on SLAC linac)**
  - **Ballistic alignment (tested in SLC)**
  - **Emittance bumps (used routinely in SLC)**




- Should not prove to be an important limitation
  - **Need stable magnetic centers**
  - **Present SC quadrupole probably will require stiffening**

# Main Linac Issues

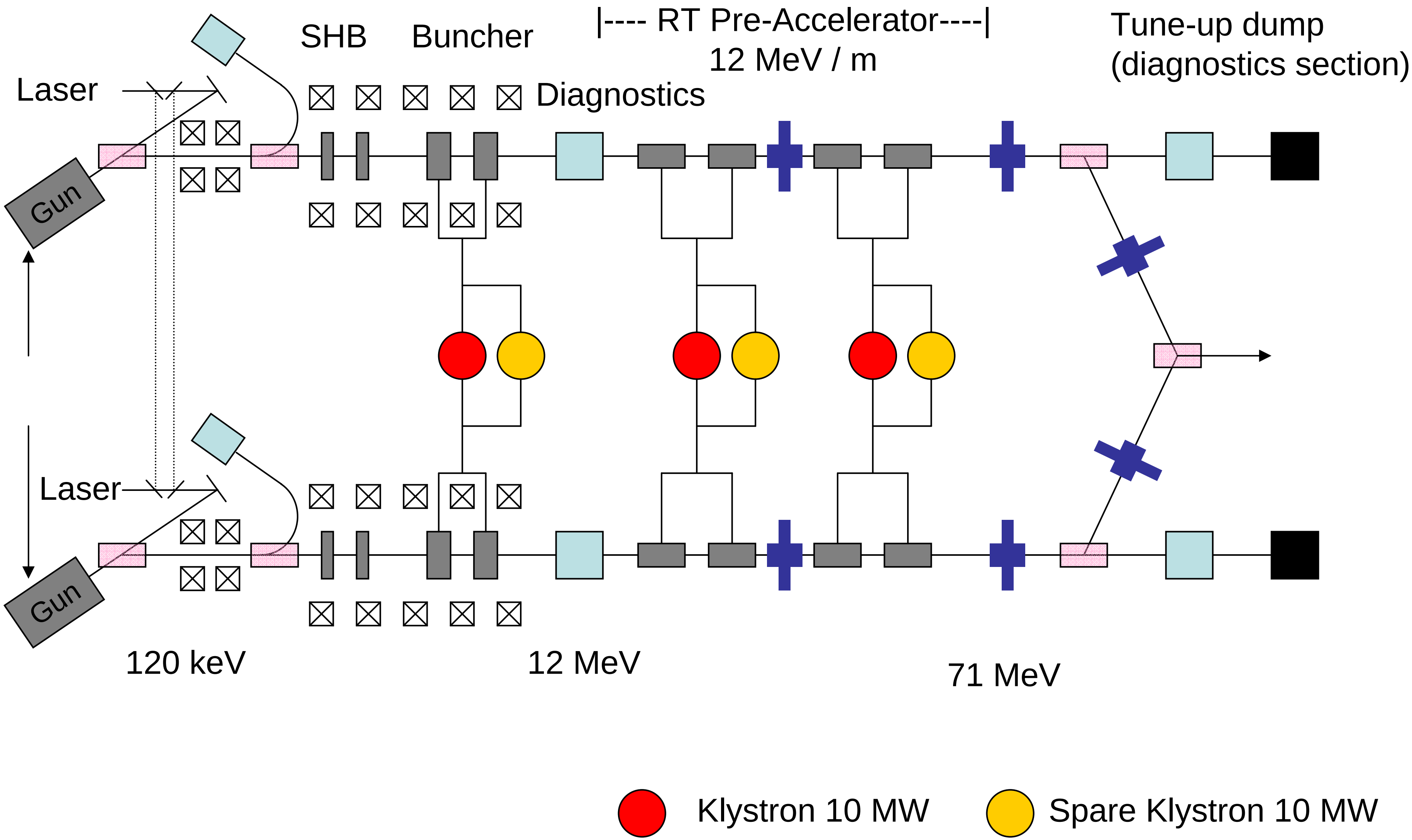
- Gradient choice
  - 35 MV/m demonstrated – work on fabrication process
- RF klystron
  - 10 MW tubes demonstrated – work on improving lifetime
- RF distribution
  - Large system with many components – cost optimize

- 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**
    - 8 main linac-type rf units (24 cavities per rf unit)
      - 7 rf units operating at 29 MV/m
      - One spare unit to maintain 5 GeV injection energy
  - **Spin rotator**
  - **Energy compressor**
  - **Diagnostics and beam dump**
  - **R&D on polarized rf gun**

# Capture Schematic

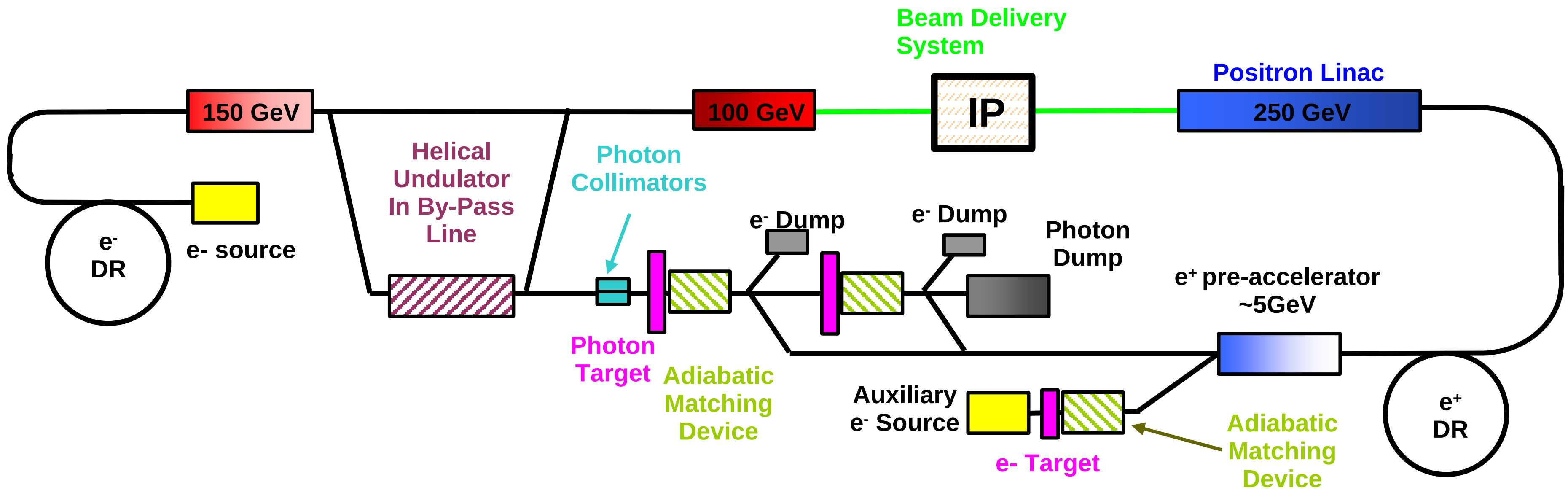


# Positron Source Choice

- Snowmass debate between conventional, undulator, and Compton sources
  - **Snowmass recommendation of undulator source with Compton source as ACD**
- Conventional source
  - **Reduces operational coupling**
- Undulator-based positron source
  - **Much lower radiation environment**
  - **Smaller e+ emittance for given yield**
  - **Similar target and capture system to conventional**
  - **Easy path to polarized positrons Photon production at 150 GeV electron energy**
- Compton source
  - **Requires large laser system and/or capture ring**

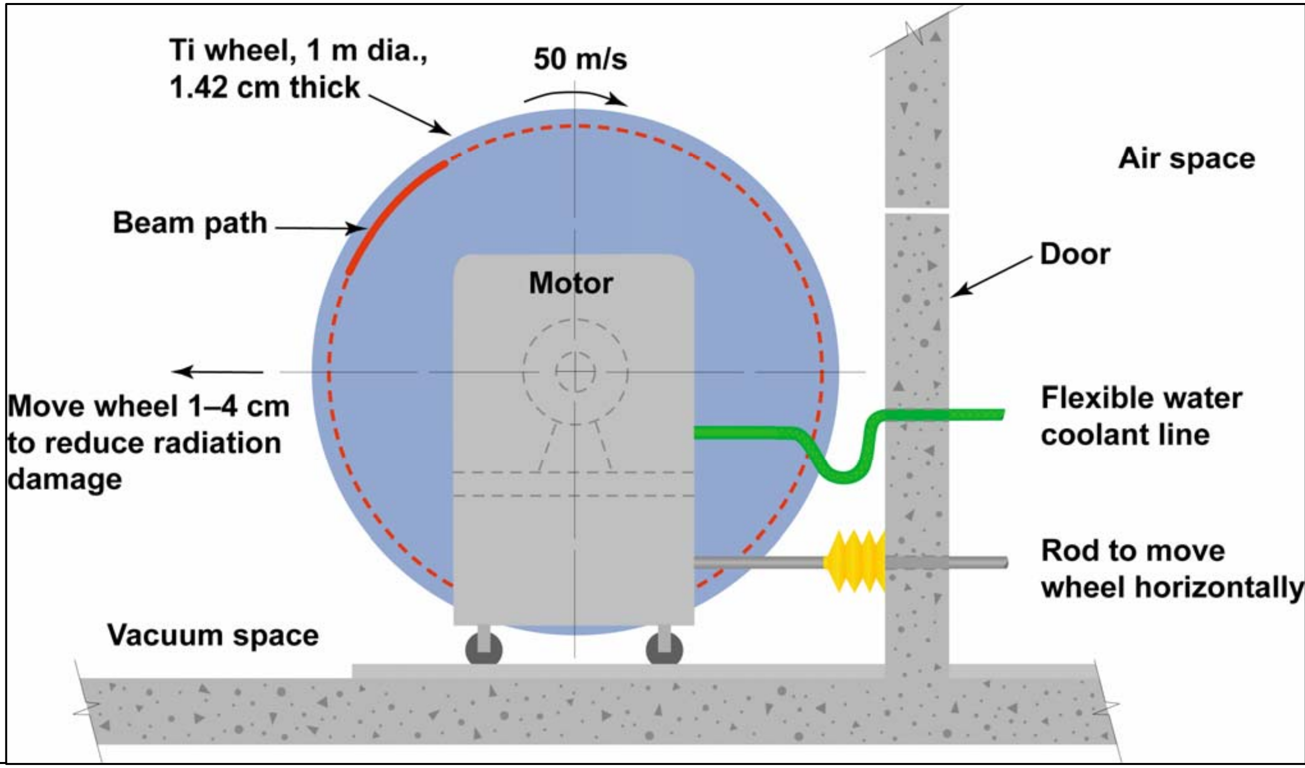
# Undulator Positron Source

- Undulator-based positron source
  - **150 meter undulator with K=1; $\lambda$ = 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%**



# Positron Source Linacs

- 0 → 400 MeV NC linac
  - **Normal conducting structures at ~14 MV/m**
- Transport line at 400 MeV
  - **Very large aperture quadrupoles in transport**
- 400 MeV → 5 GeV SC linac
  - **Large beam size requires strong focusing**
  - **1 rf unit with quadrupole after every SC cavity**
  - **2 rf units with quadrupoles every 4 SC cavities**
  - **3 main linac-style rf units**
  - **Overhead for rf failure not yet specified**
- Share SC linac with keep alive source (?)

# 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
  - **Damping ring designed to accept beam but will consider alternate approaches**
    - Longer undulator – smaller emittances for yield
    - Longitudinal emittance manipulation – higher yield
    - Location of keep alive source and acceleration

# Damping Ring Requirements

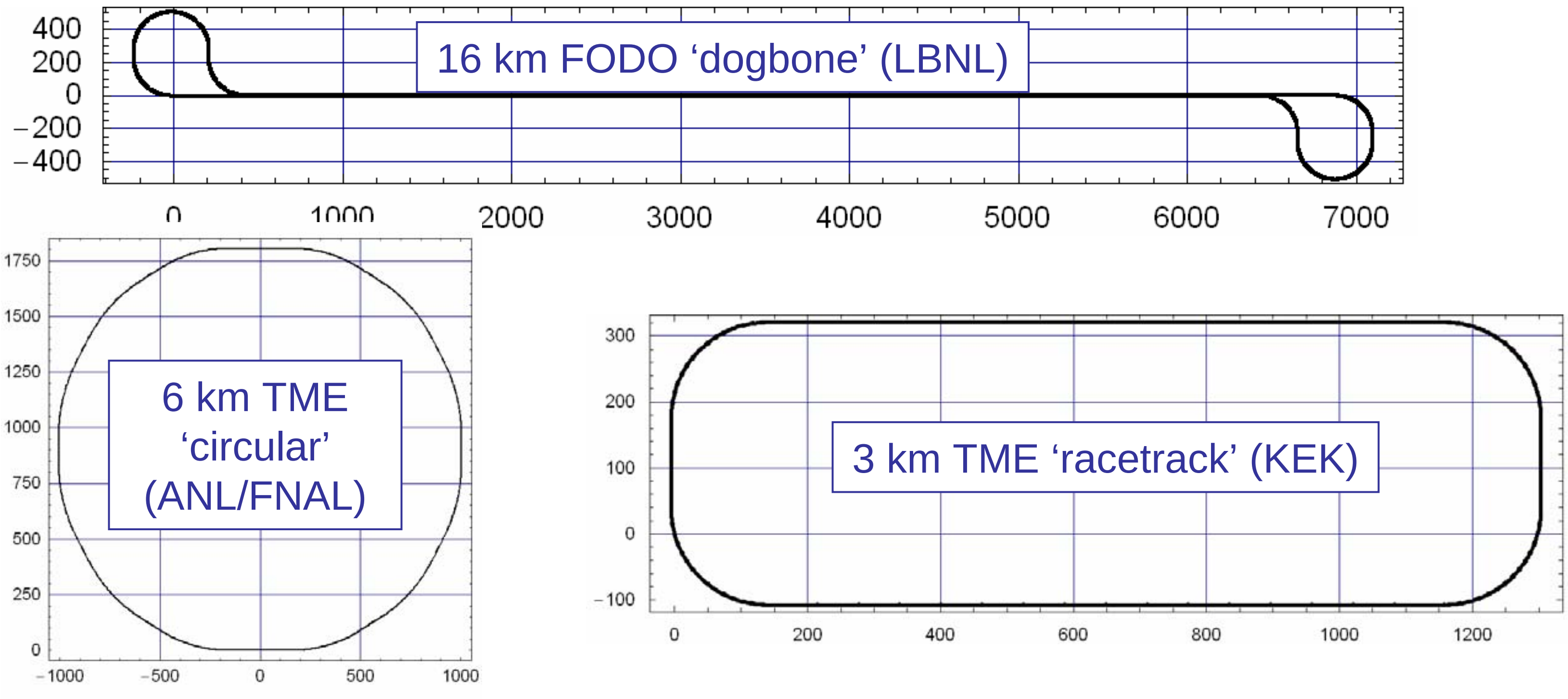
- Compress 1 ms linac bunch train in to a "reasonable size" ring
  - **Fast kicker (ns)**
- Damping of $\gamma\varepsilon_{x,y} = 10^{-2}$ m-rad positron beams to $(\gamma\varepsilon_x, \gamma\varepsilon_y) = (8 \times 10^{-6}, 2 \times 10^{-8})$ m-rad
  - **Low emittance, diagnostics**
- Cycle time 0.2 sec (5 Hz rep rate) → $\tau$ = 25 ms
  - **Damping wiggler**
- 2820 bunches, $2\times10^{10}$ 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 Issues

- Damping rings have most accelerator physics in ILC
- Required to:
  1. **Damp beam emittances and incoming transients**
  2. **Provide a stable platform for downstream systems**
  3. **Have excellent availability ~99% (best of 3$^{rd}$ generation SRS)**
- Mixed experience with SLC damping rings:
  - **Referred to as the "The source of all Evil"**
  - **Collective instabilities, dynamic aperture and stability were all hard**
- ILC damping rings have lower current than B-factories
  - **More difficult systems feedback because of very small extracted beam sizes in constant re-injection (operate with small S/N)**
  - **More sensitive to instabilities – effects amplified downstream**

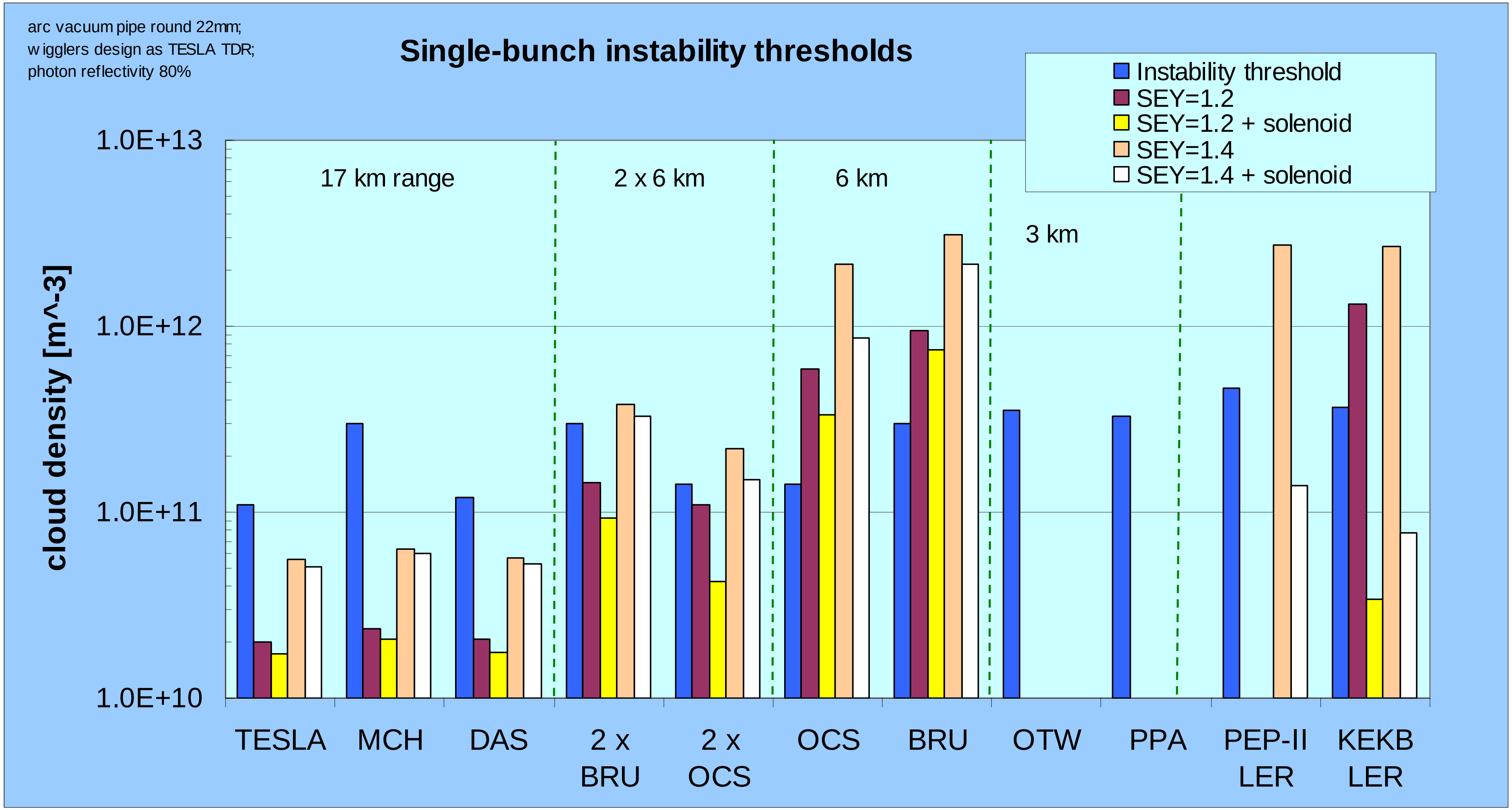
# Damping Rings – BCD Choice

- Compared multiple lattice styles
  - **Optics tuning and dynamic aperture**
  - **Collective instabilities (ECI, Ions, Space charge)**
  - **Cost**

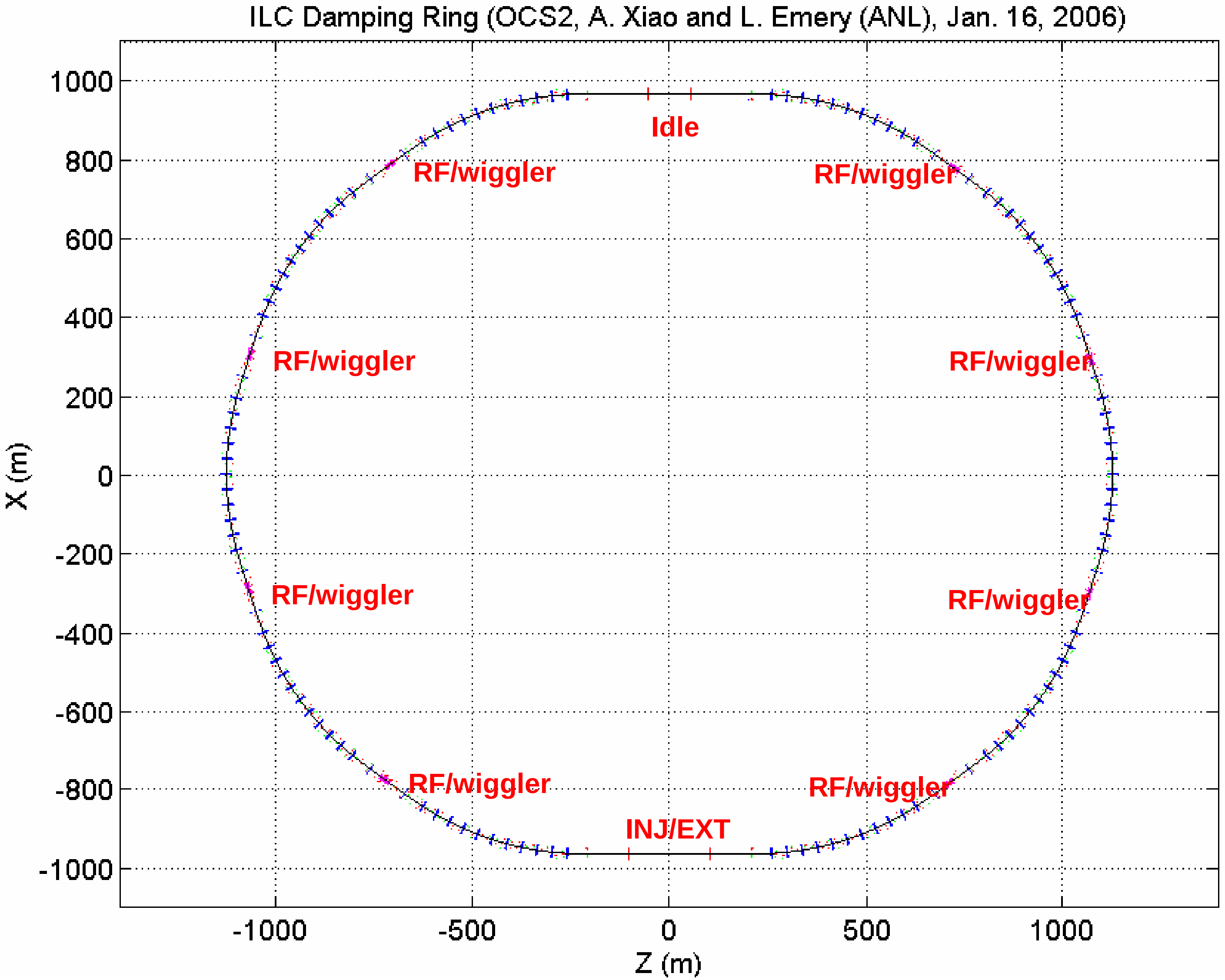


# Damping Rings – Example

- Comparison of ECI in different configurations



# Baseline DR Schematic



# Damping Ring Parameters (1)

| Item | Baseline | Alternatives |
|---|---|---|
| Circumference | ($e^+$) 2×6.6 km<br>($e^-$) 6.6 km | 1. ($e^+$) 6 km<br>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 ($2\times10^{10}$) - 4050 ($1.3\times10^{10}$) | |
| Extracted bunch length | 6 mm - 9 mm | |
| Injection/extraction kicker technology | Fast pulser/stripline kicker | 1. RF separators<br>2. Fourier pulse compressor |

- Two 6.6km rings on e+ are likely needed to avoid the electron cloud instability

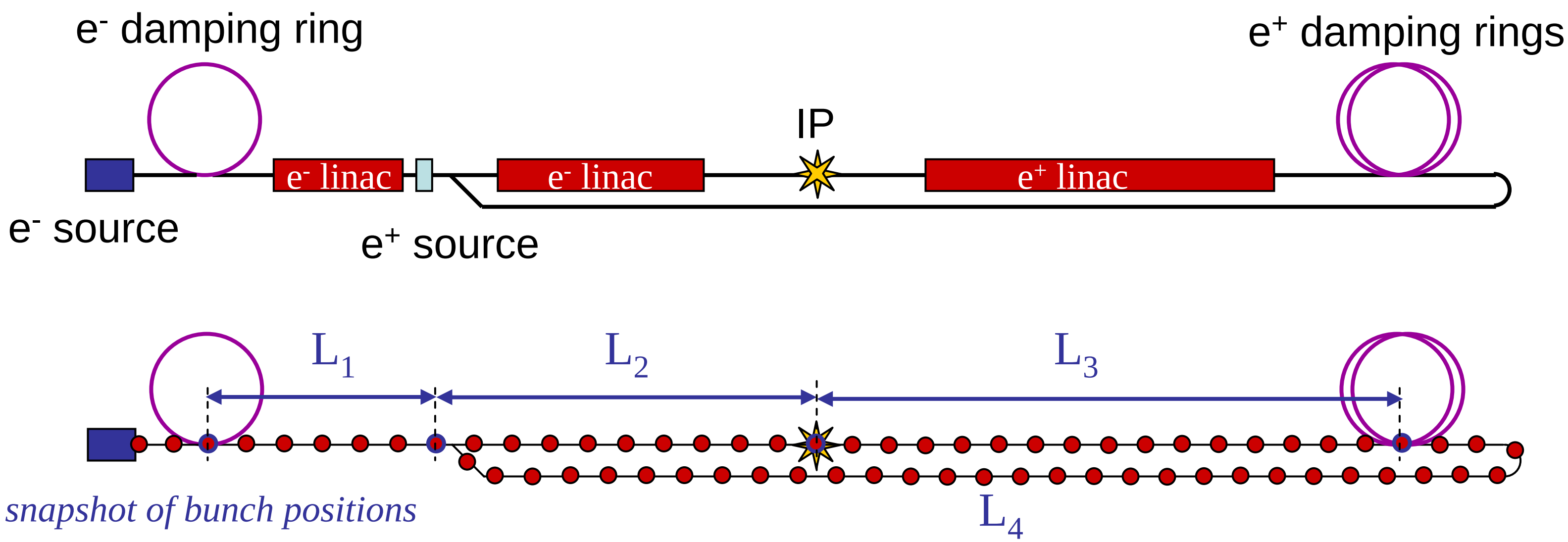
# Damping Ring Parameters (2)

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

- 6.6 km rings with 650 MHz rf frequency will probably support all parameter options
  - **Ion clearing gaps even with lowQ parameters**
- Superconducting wiggler parameters are similar to those demonstrated at CESR

# 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

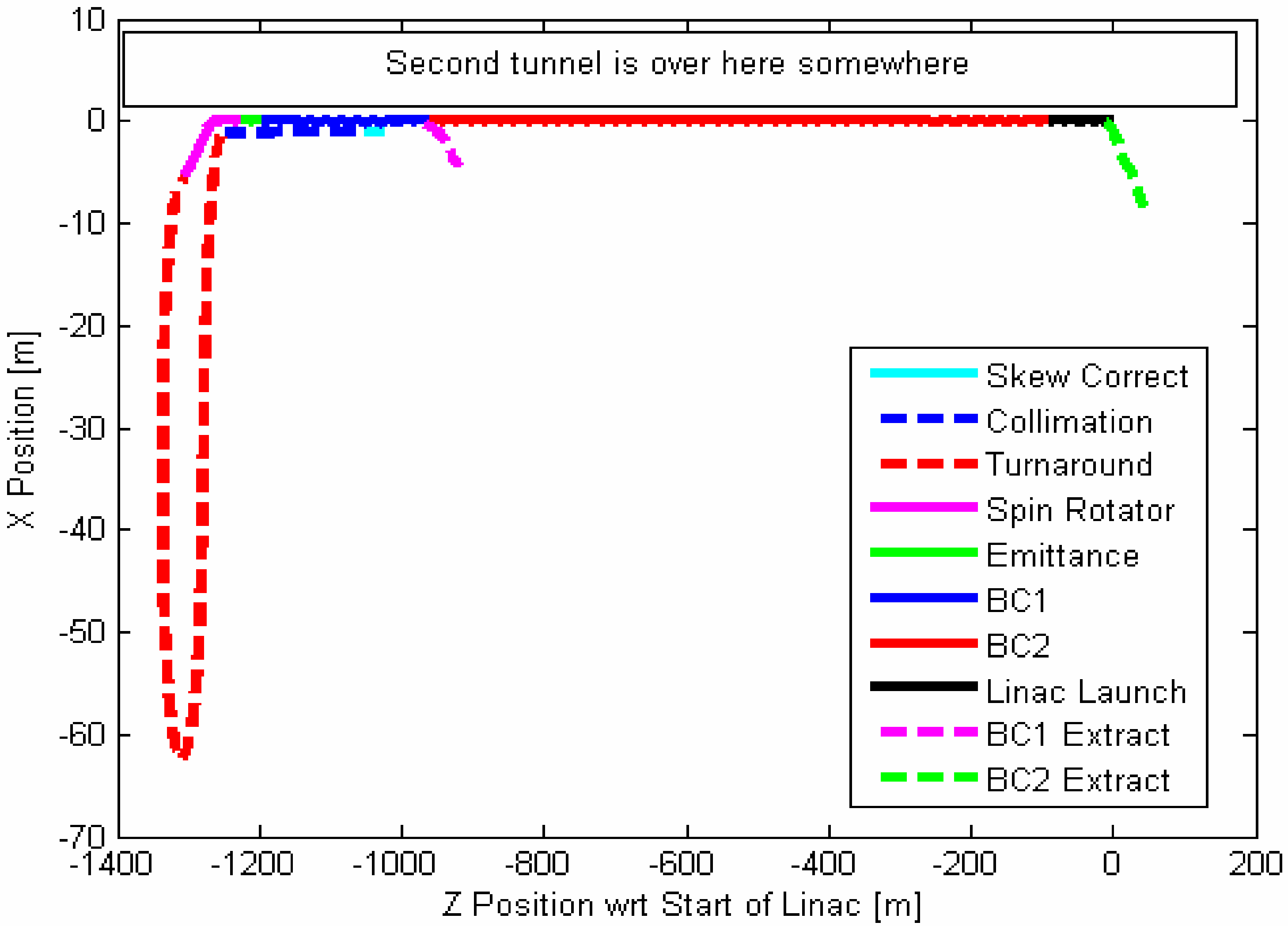


# RTML Requirements

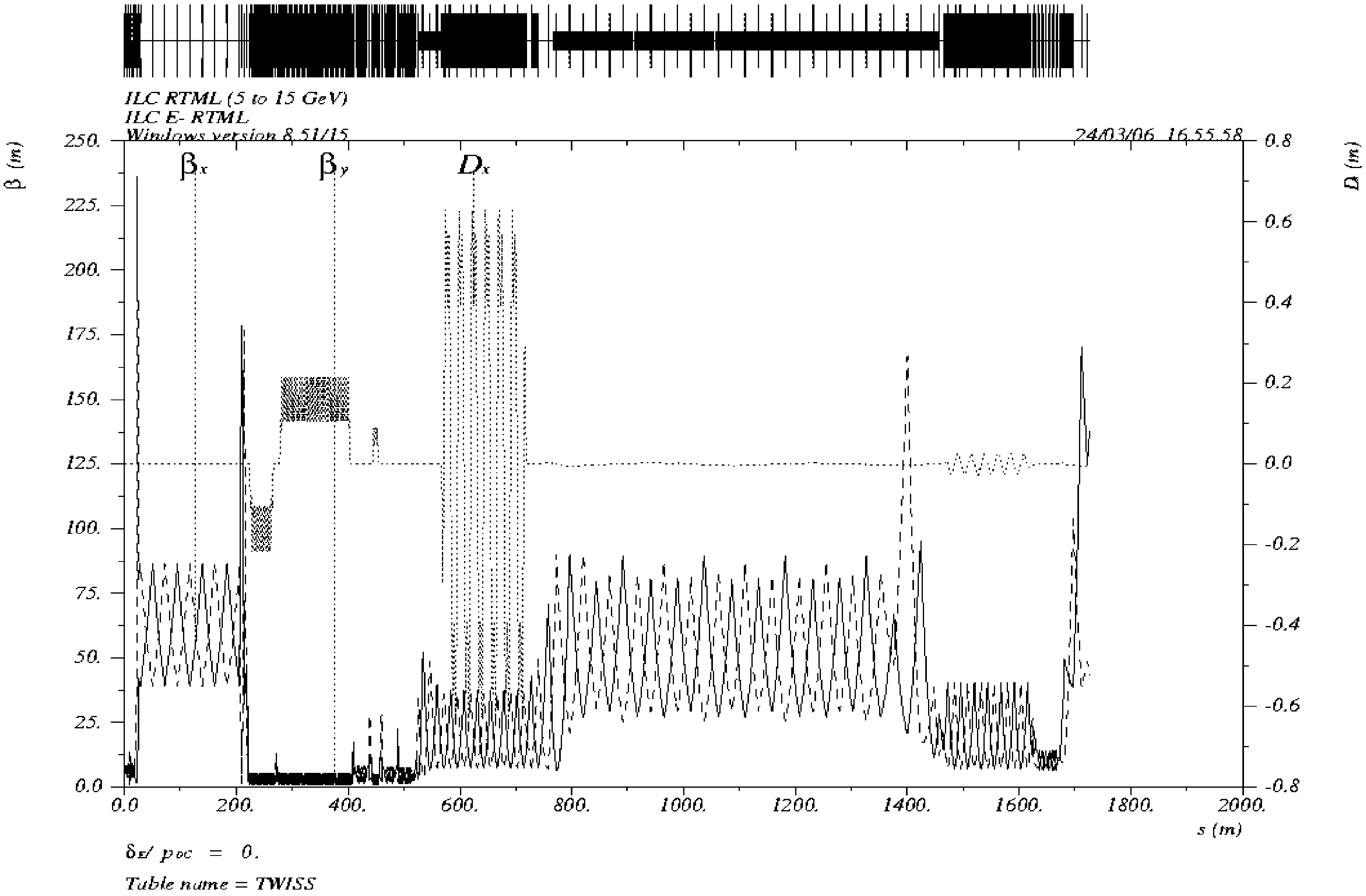
RTML = Ring-To-Main Linac

- Collimate DR halo in 6 DOF
- Correct DR extraction jitter via feed-forward
- Rotate polarization to arbitrary direction
- Compress bunch length to value required at IP
- Provide beam extraction points for tuneup or response to MPS fault
- Provide MPS and PPS Segmentation prior to linac
- ***Provide adequate diagnostic and correction capacity do perform all of these tasks to required specifications while limiting transverse emittance growth to tolerable levels***

# RTML Footprint

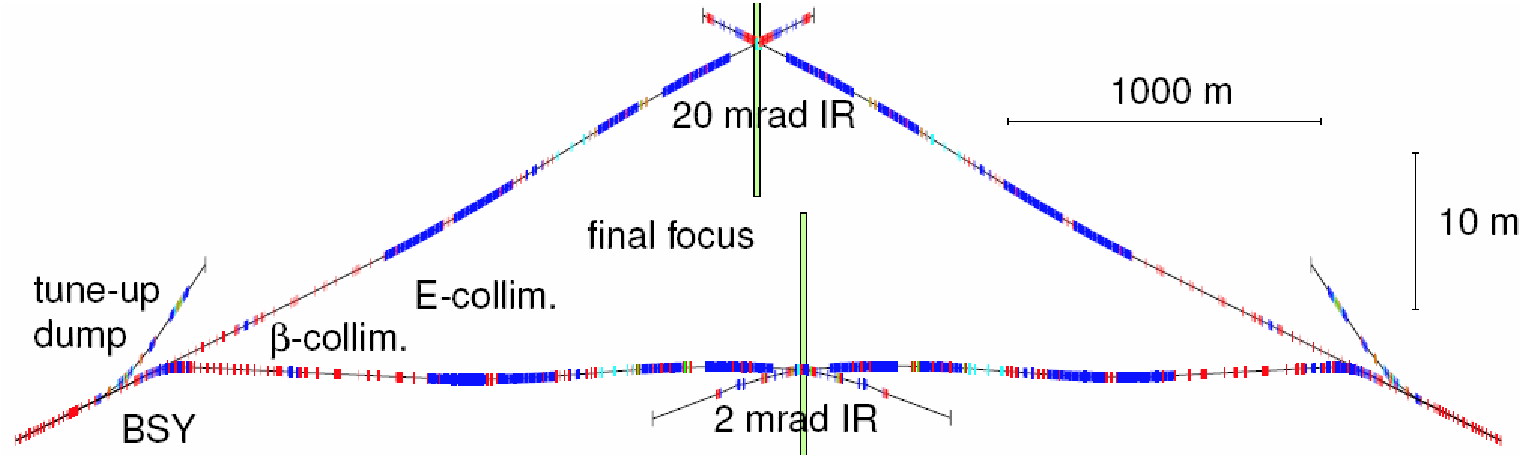


# RTML Optics



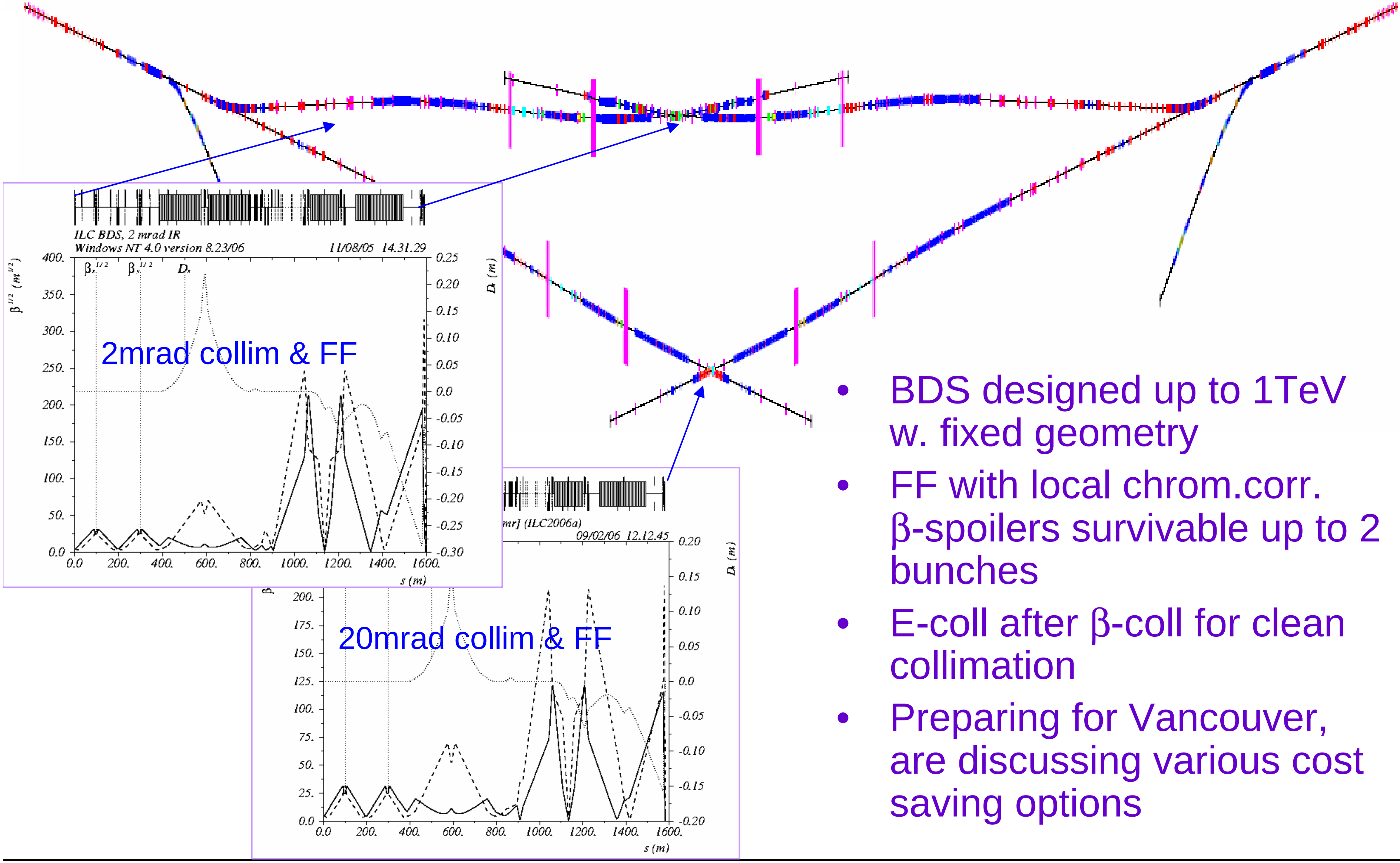
ILC RTML (5 to 15 GeV)
ILC E- RTML
Windows version 8.51/15
24/03/06 16.55.58
β (m)
D (m)
βx
βy
Dx
250.
225.
200.
175.
150.
125.
100.
75.
50.
25.
0.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
0.0
200.
400.
600.
800.
1000.
1200.
1400.
1600.
1800.
2000.
s (m)
δE/ p0c = 0.
Table name = TWISS

# Beam Delivery System



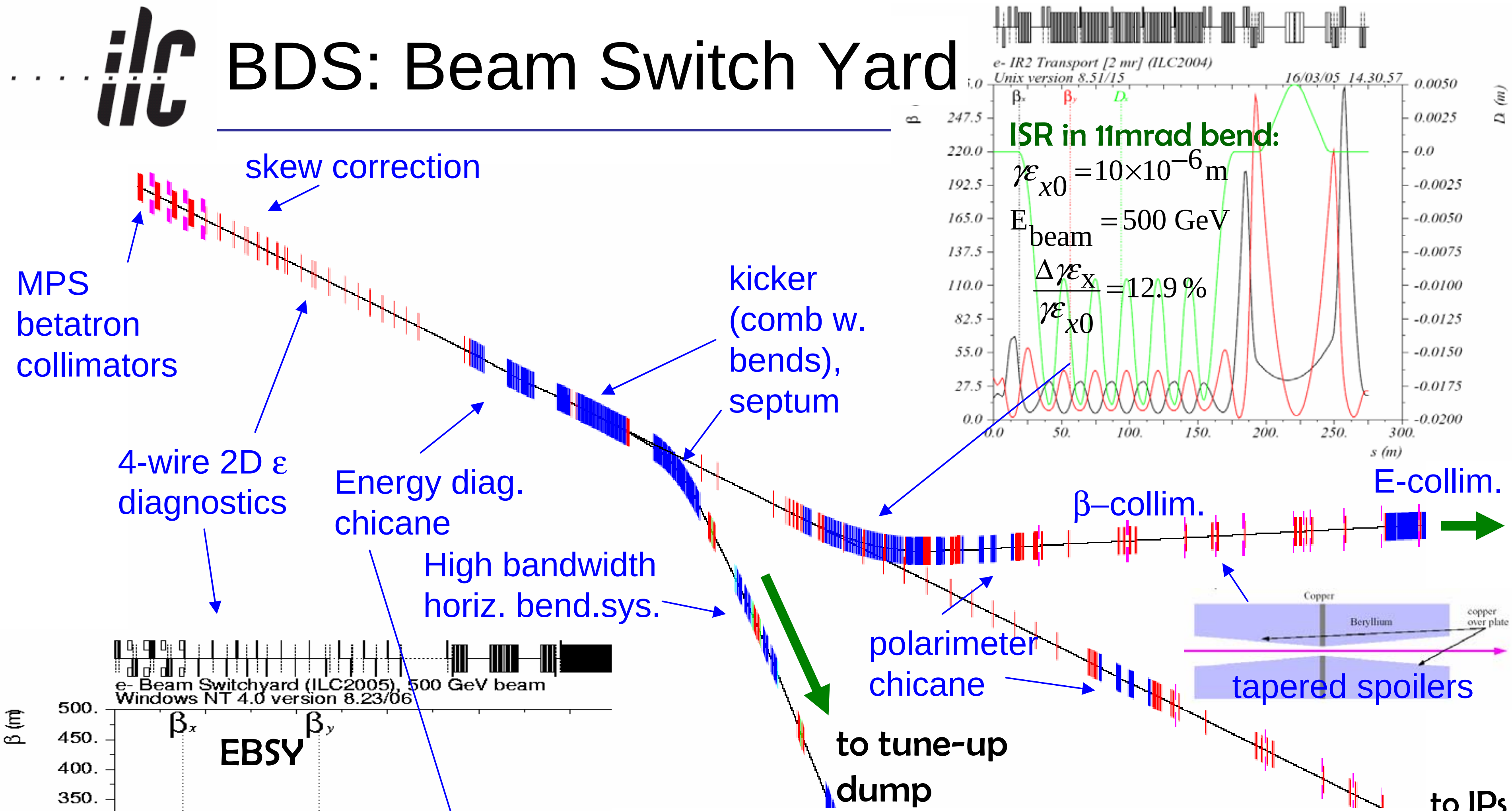

- Baseline
  - **Two BDSs, 20/2mrad, 2 detectors, 2 longitudinally separated IR halls**
- Alternative 1
  - **Two BDSs, 20/2mrad, 2 detectors in single IR hall @ Z=0**
- Alternative 2
  - **Single IR/BDS, collider hall long enough for two push-pull detectors**

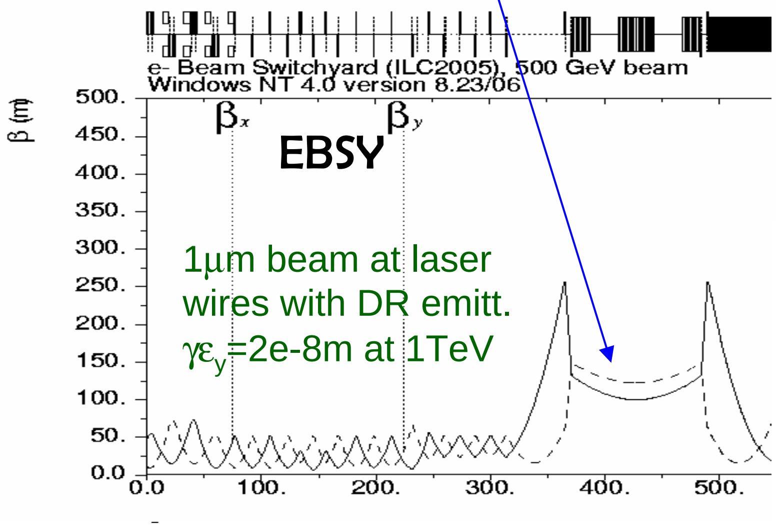
# BDS Design Criteria




- BDS designed up to 1TeV w. fixed geometry
- FF with local chrom.corr. β-spoilers survivable up to 2 bunches
- E-coll after β-coll for clean collimation
- Preparing for Vancouver, are discussing various cost saving options

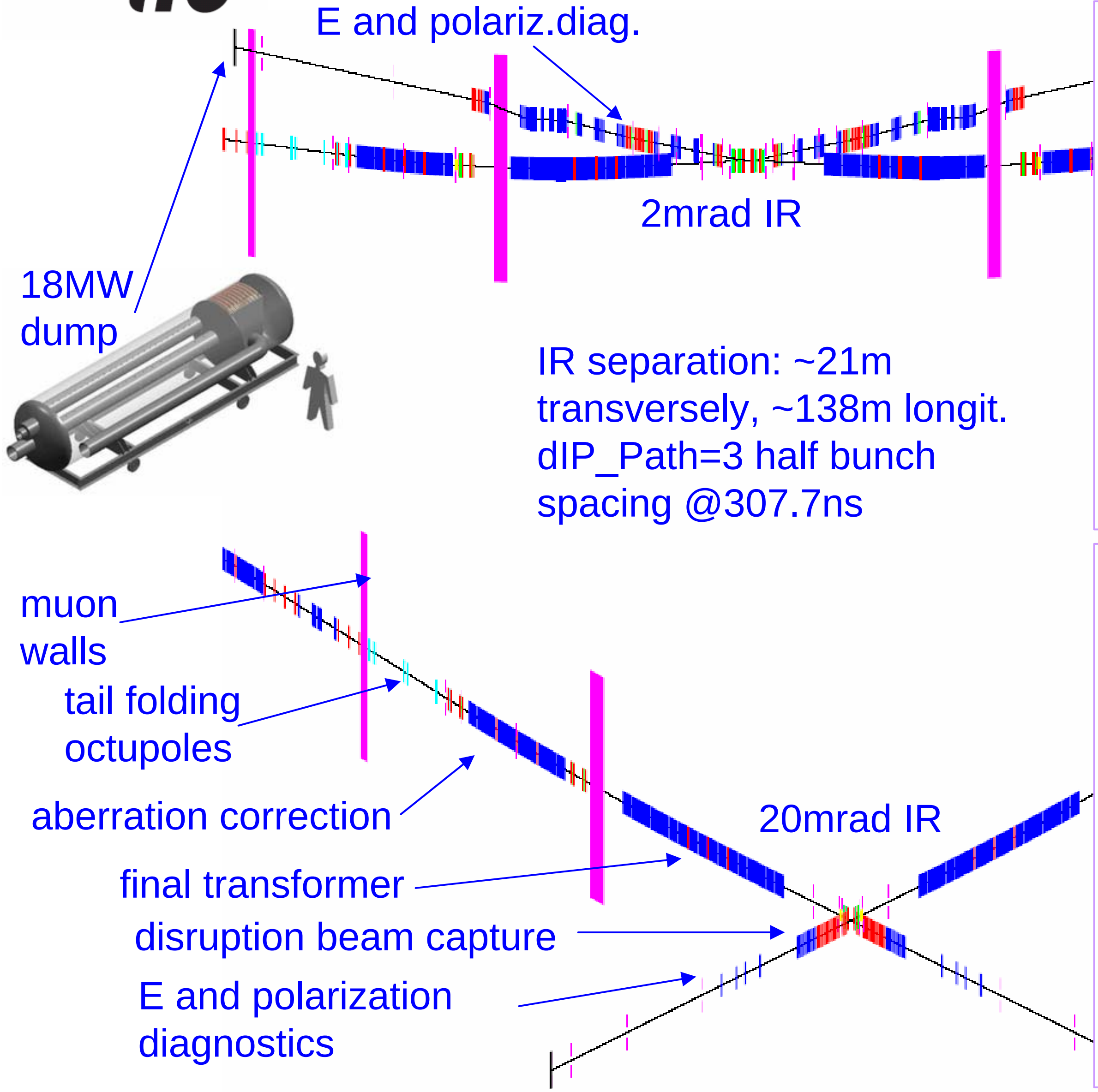
# BDS: Beam Switch Yard

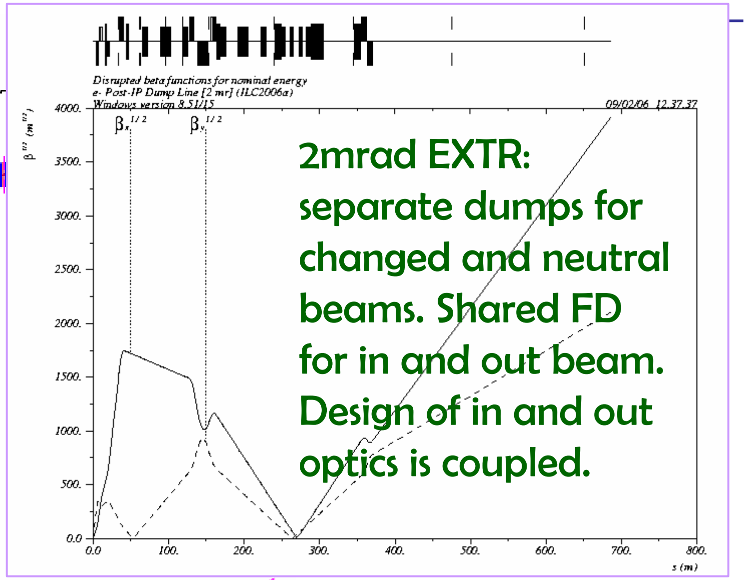


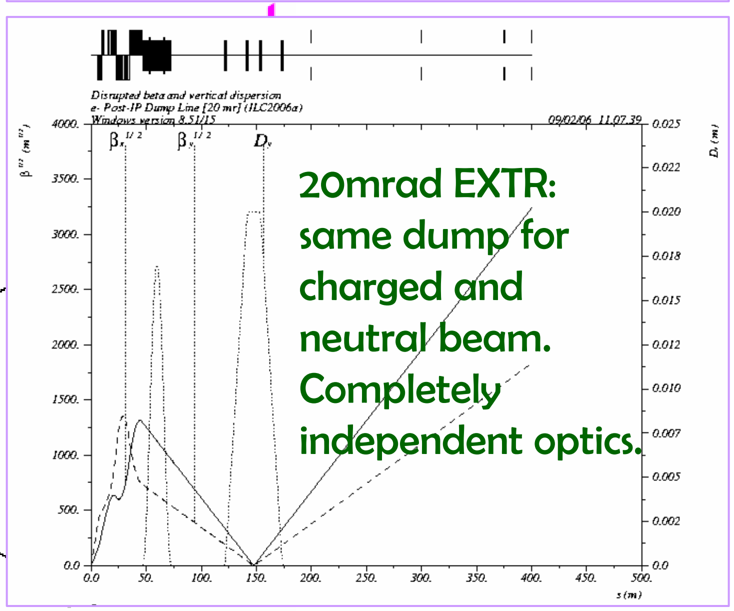




- Recent modifications:
  - **sacrificial MPS betatron collimation at entry**
  - **septum & tune-up line is being redesigned, to be released soon**

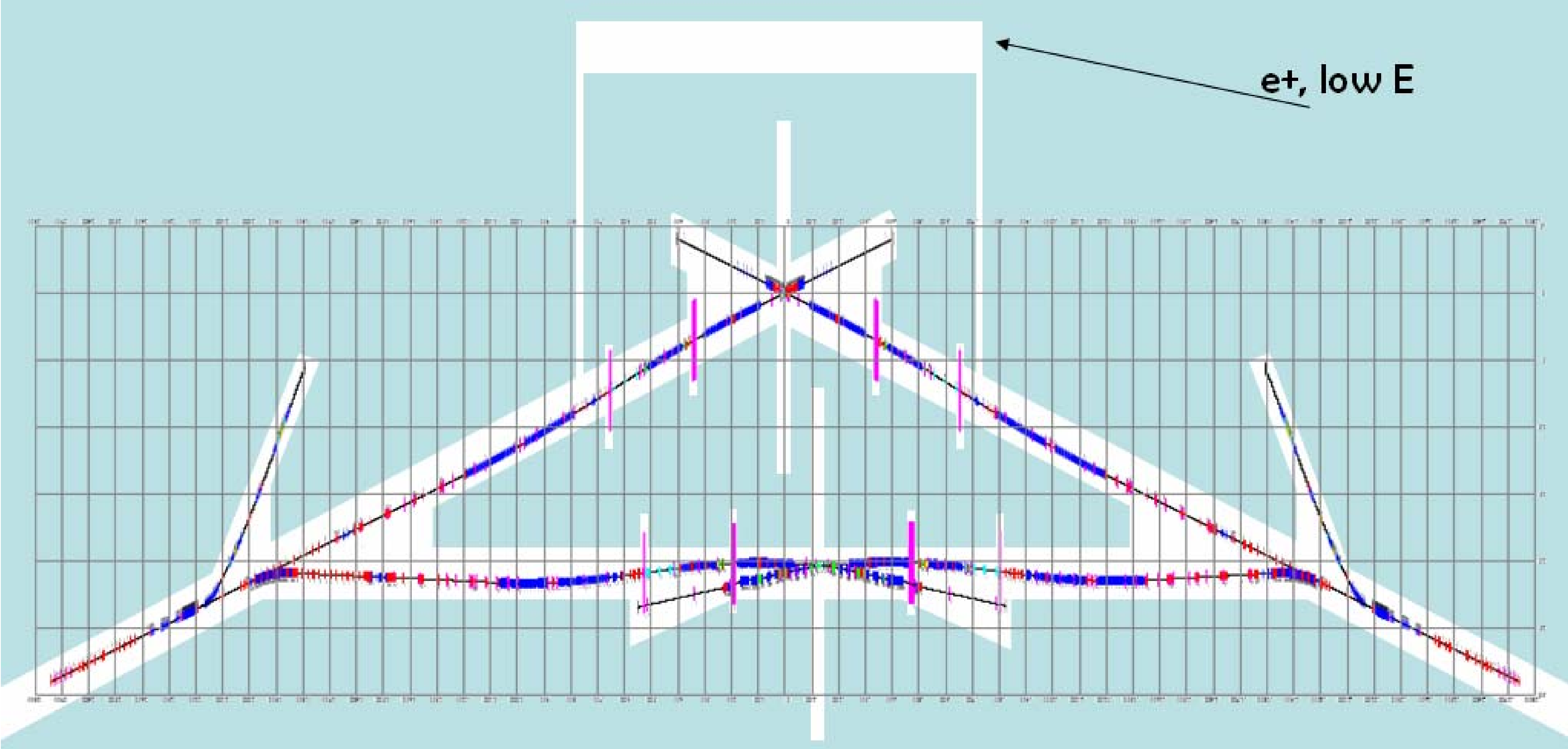
# BDS: FF, IR and extraction



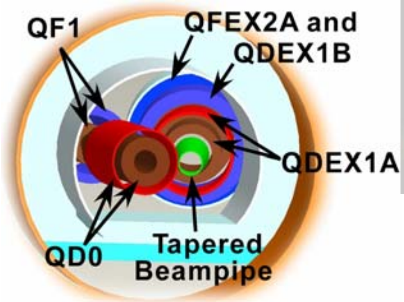
# BDS: Civil layout concept

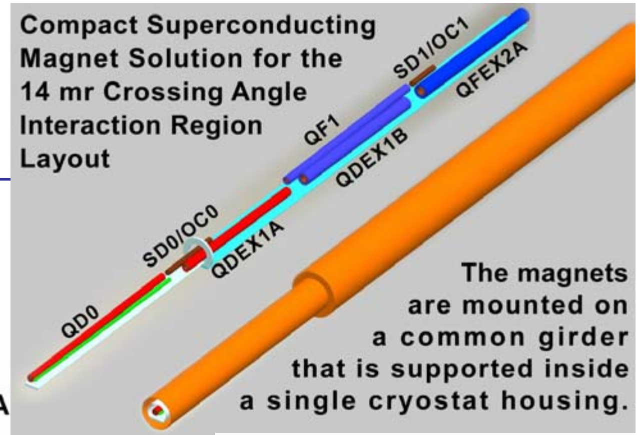



- Two longitudinally separated IPs, two independent collider halls for two experiments (grid size: 100m * 5m)
- Tunnel layout concept. Shafts & service tunnel not shown

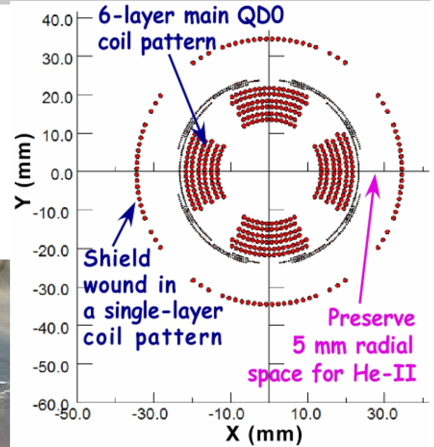
# BDS: IR design

- 20(14)mrad IR
  - **BNL self-shielded compact quads successfully tested**
  - **Focus on 14mrad alternative to push the technology**



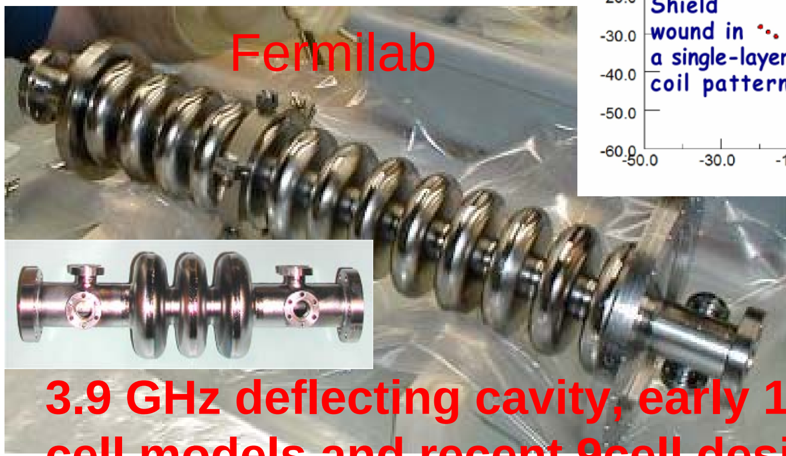




BNL




- ILC crab cavity:
  - **collaboration of Fermilab, UK (Daresbury, et al), SLAC**
  - **Based on 3.9GHz deflecting cavity designed at Fermilab**
  - **Design is being verified and preparing for fabrication**

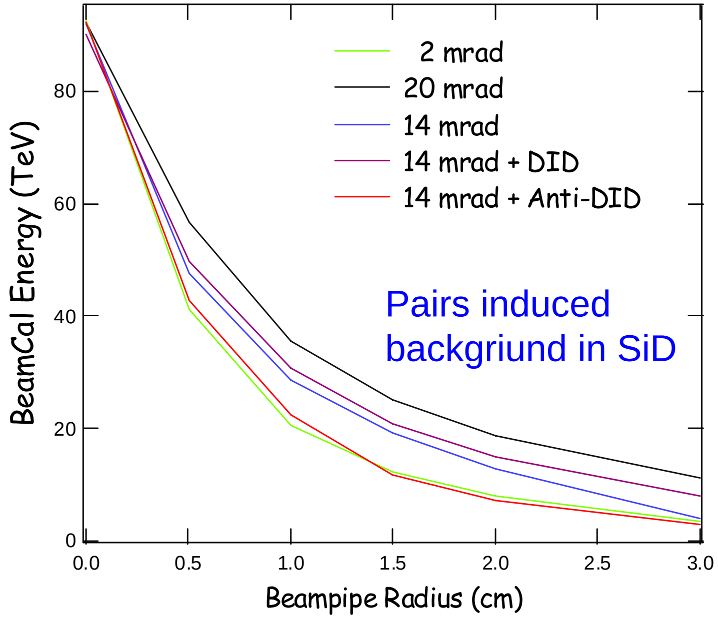
Fermilab

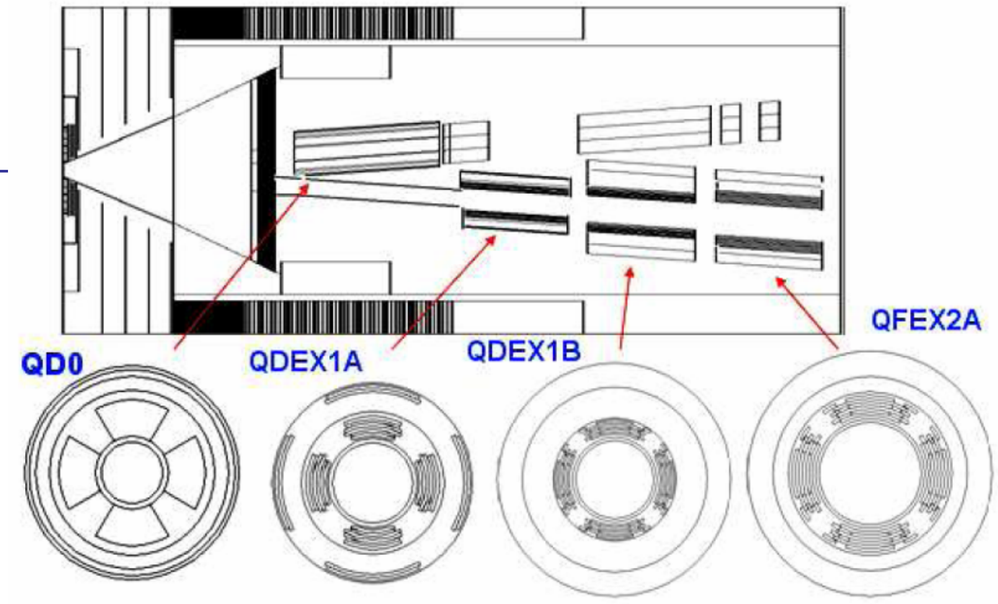


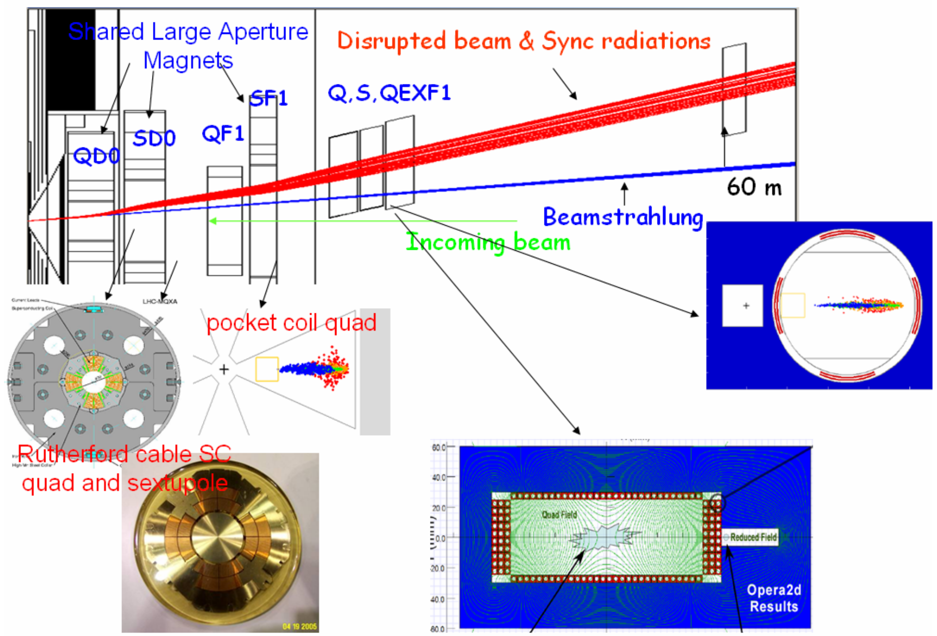
3.9 GHz deflecting cavity, early 13 & 3 cell models and recent 9cell design

# IR design

- Design of IR for both small and large crossing angles
- Pairs induced background similar in both cases
- Losses in extraction & background harder in 2mrad



# 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
- Working to develop designs with engineering and civil layout
  - Translation of design specifications in process
- Will likely need additional work on cost reduction
  - System and sub-system optimization as well as component level