RTML – Design Status

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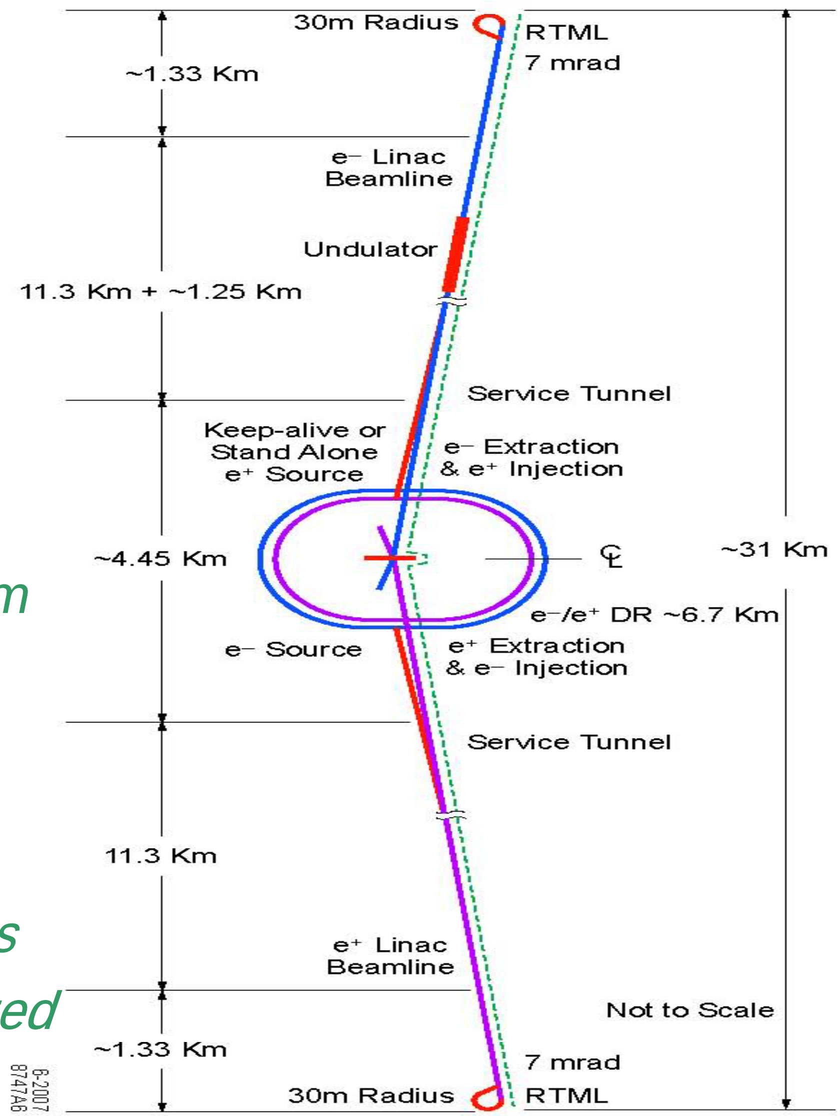
Outline

- RTML Optic Design
- Technical Systems
- Emittance control

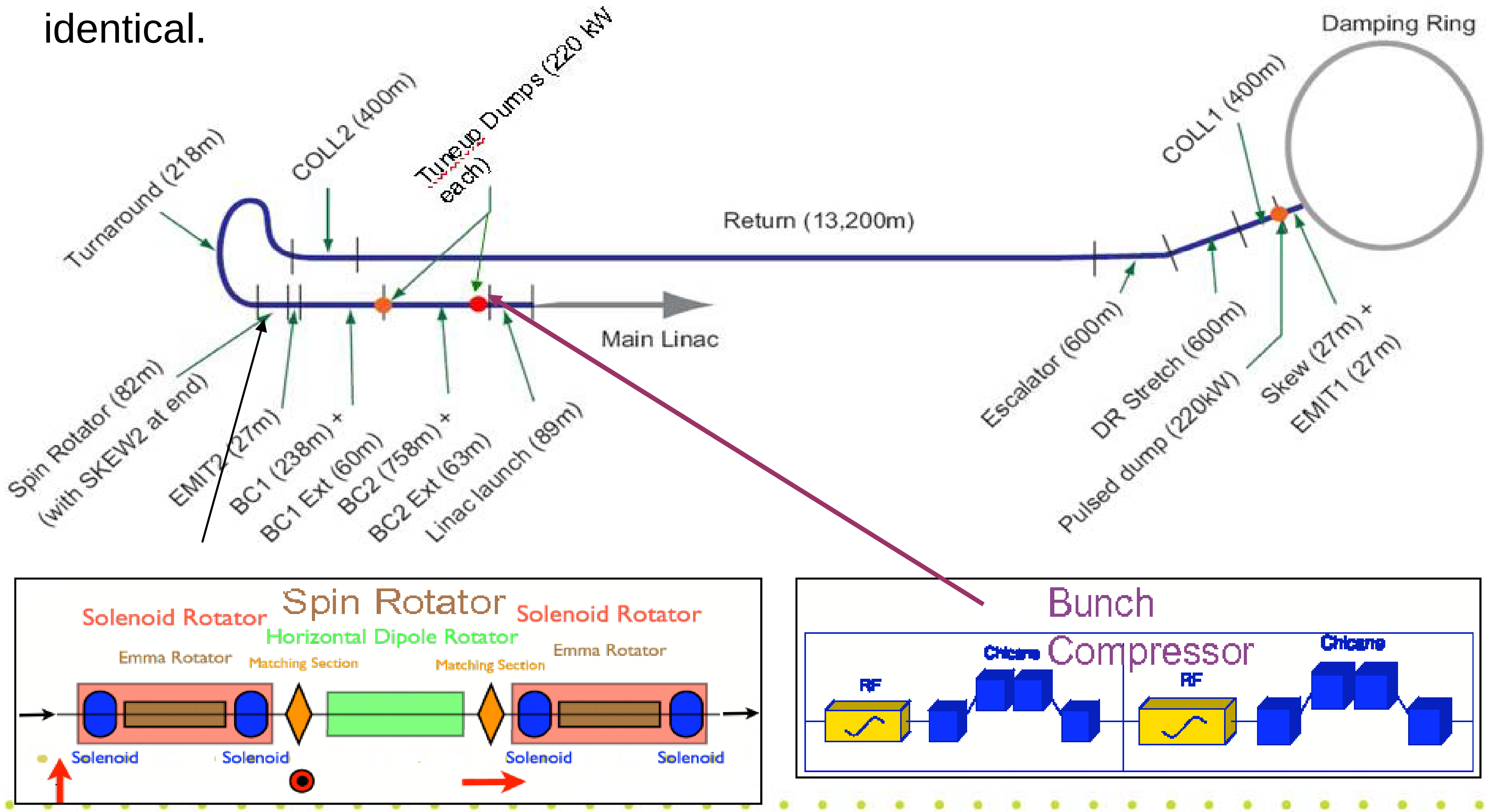
RTML Functions

- *Transport Beam* from DR to ML
  - *Match Geometry/Optics*
- *Collimate Halo*
- *Rotate Spin*
- *Compress Bunch (6mm→0.3mm)*
- *Preserve Emittance*
  - *Budget for Vert.norm. emittance < 4nm*
- *Protect Machine*
  - *3 Tune-up / MPS abort dumps*
- *Additional constraints:*
  - *Share the tunnel with e-/e+ injectors*
  - *Need to keep geometries synchronized*



RTML Schematic

Note: e- and e+ RTMLs have minor differences in Return line (undulator in e- linac side) and Escalator (DR's at different elevations); they are otherwise identical.



Optics Design (RDR)

- Horizontal Arc out of DR ~km straight
  - **In injector tunnel**
- “Escalator” ~0.6 km vertical dogleg down to linac tunnel
- Return line, weak FODO lattice
  - **In linac tunnel**
  - **Vertically curved**
- Vertical and horizontal doglegs
- Turnaround
- 8° arc in spin rotators
- BCs are net straight

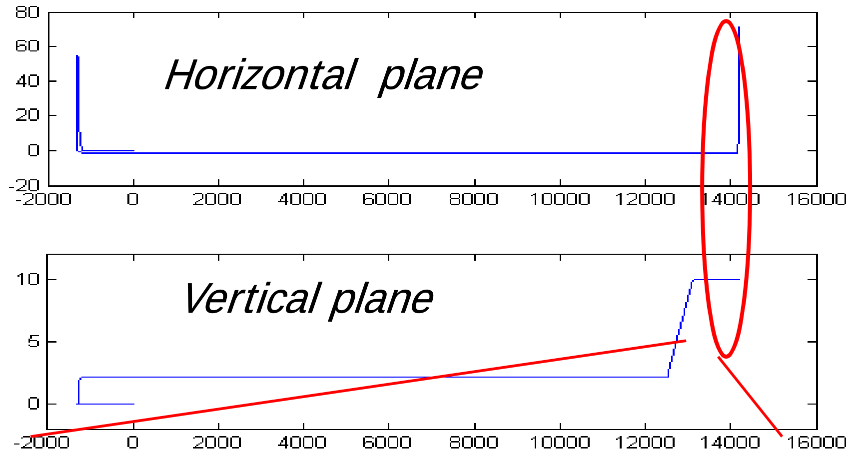
DR-RTML hand-off point defined

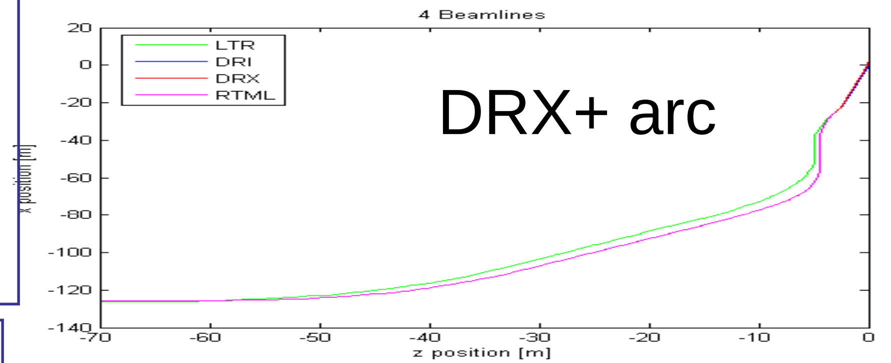
extraction point where η,η’ → 0

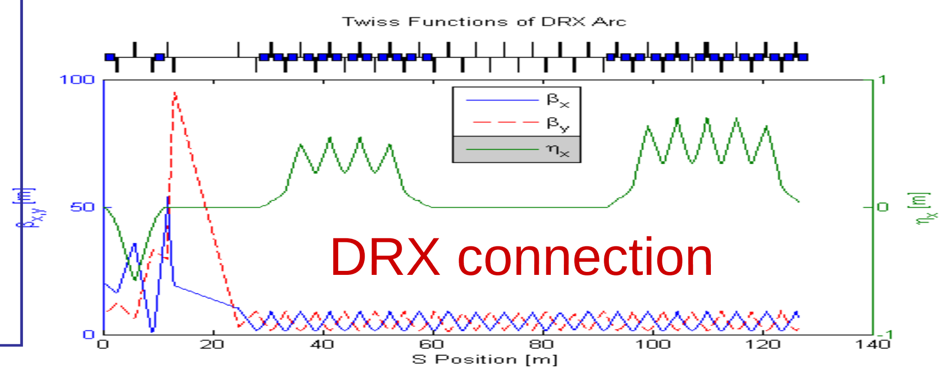
RTML mostly defined by need to follow LTR geometry

Stay in same tunnel

Design is OK at *conceptual* level



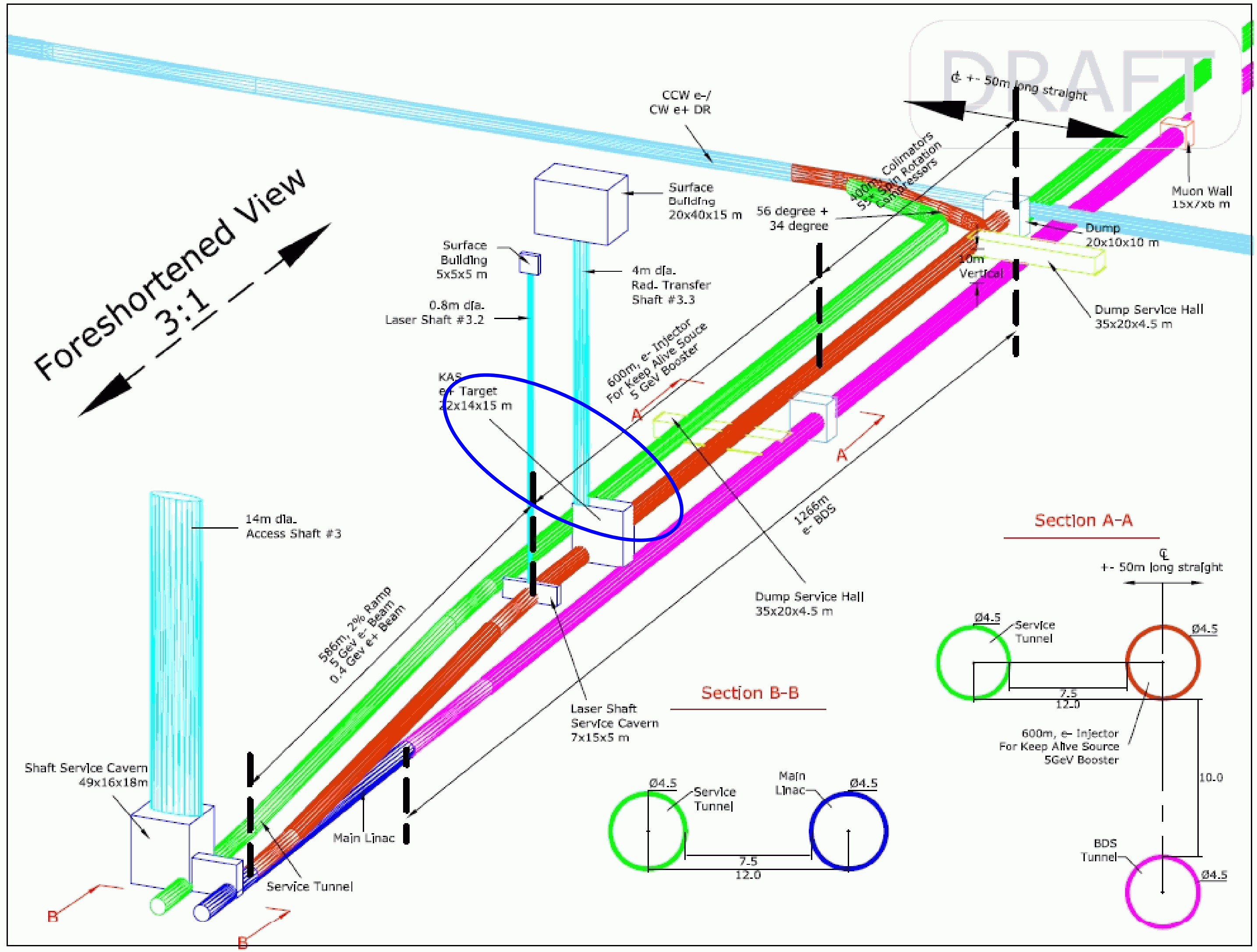




DR connection (RDR)

Post RDR modifications

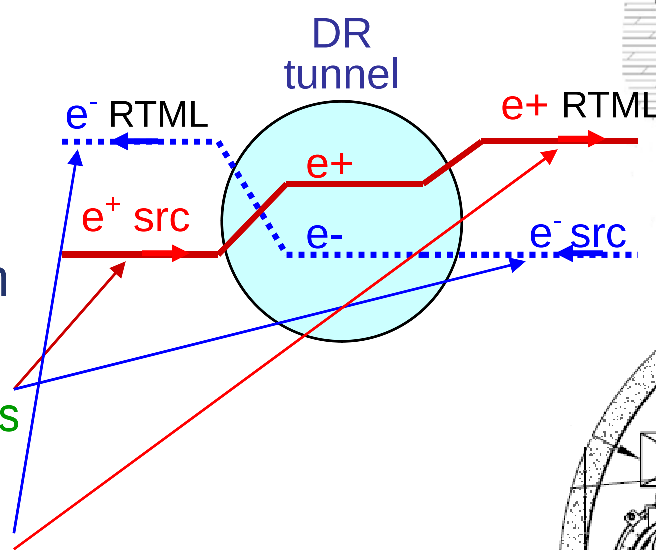
- No elevation for the service tunnel
- ML and RTML tunnels merge in horizontal plane
- Shorter ?

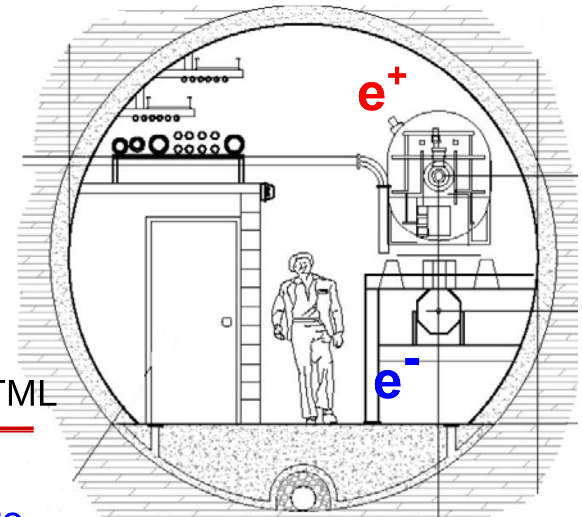


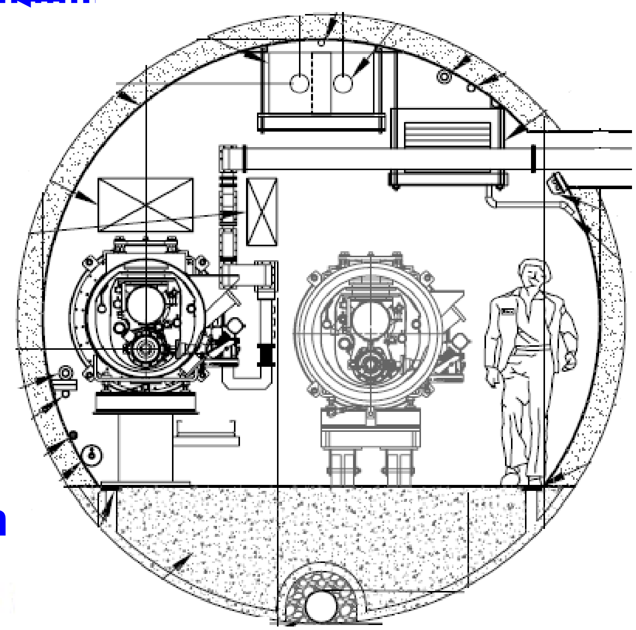
DRX Connection (2)

- Current design is entirely planar (horizontal plane)
- DRs are in different planes
- Sources need cryomodules and SC solenoids
  - **Big heavy objects which want to sit on the floor**
- Working agreement between sources, DR, RTML, CFS:
  - CMs and SC solenoids always sit on floor
  - RTML hangs from source tunnel ceiling at same location as in linac tunnel

DR Tunnel – 1.44 m
Vertical separation



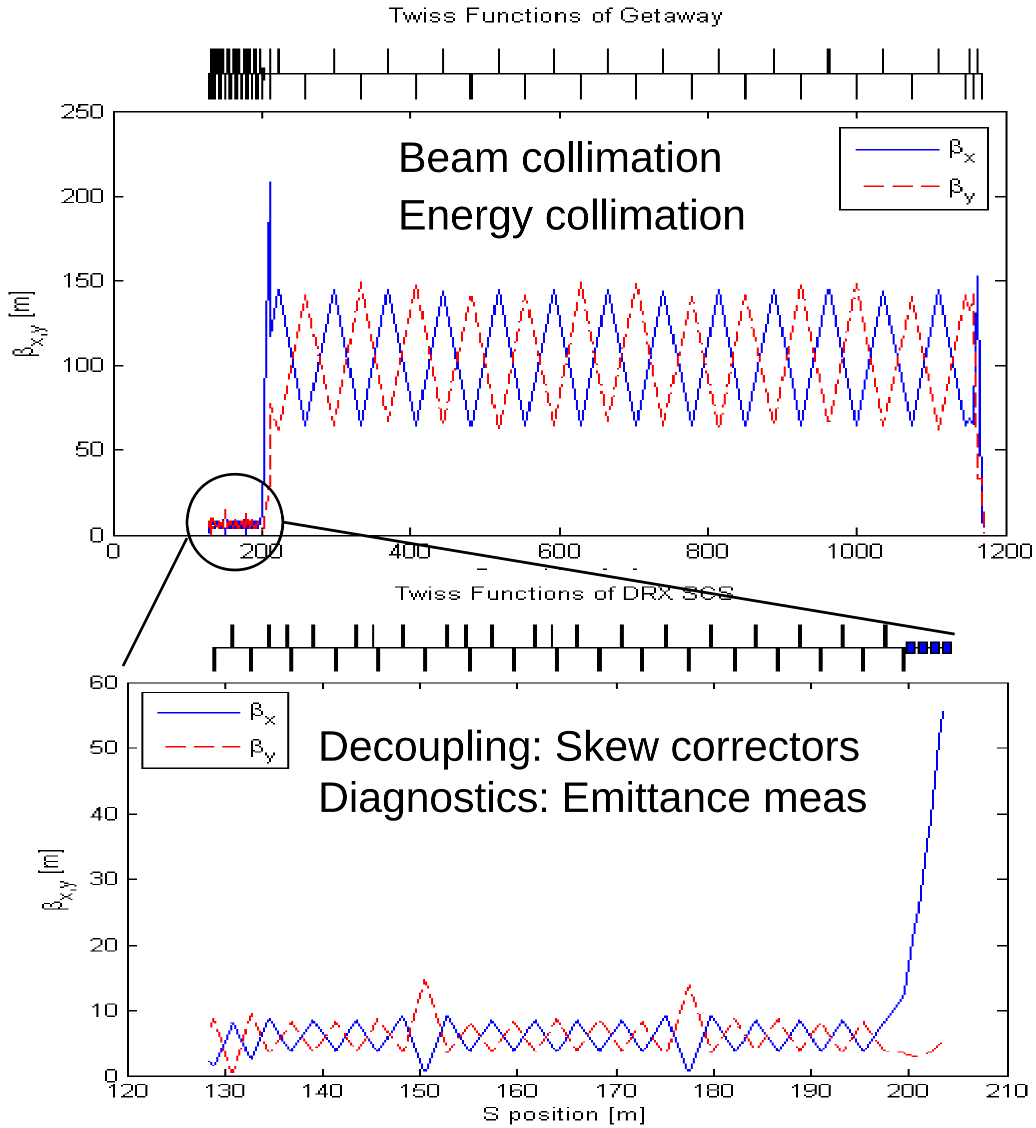




ML Tunnel - 2.14 m
Vert. beam separation

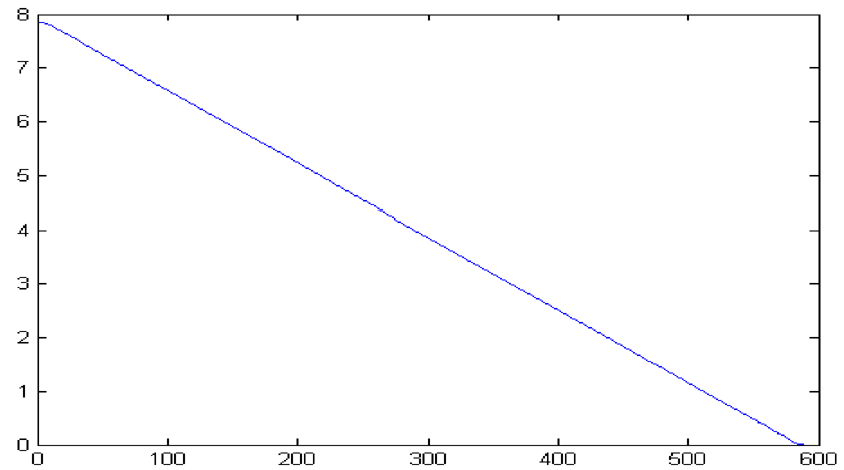
"Getaway" Straight (or "DR Stretch")

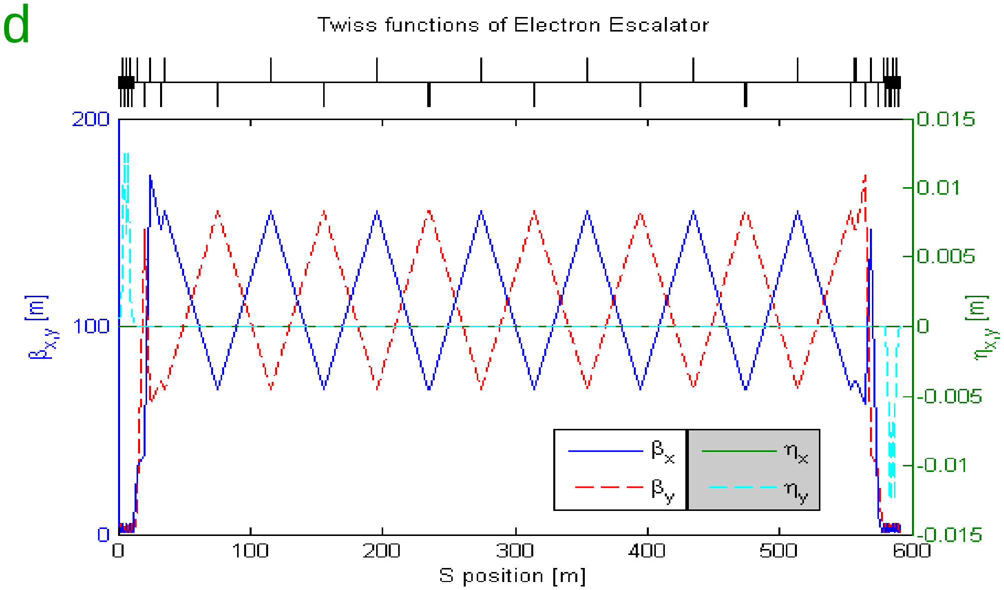
- About 1.1 km long
- Has two parts
  - **"Low-beta" region with decoupling and emittance measurement**
  - **"High-beta" region with collimation system**
- Includes PPS stoppers
  - **For segmentation**
- Good conceptual design
  - **Need to match exact required system lengths**
  - **Need to consider conflicts with source beamlines in this area**
  - **Beta match between low- and high-beta optics not great**



Escalator

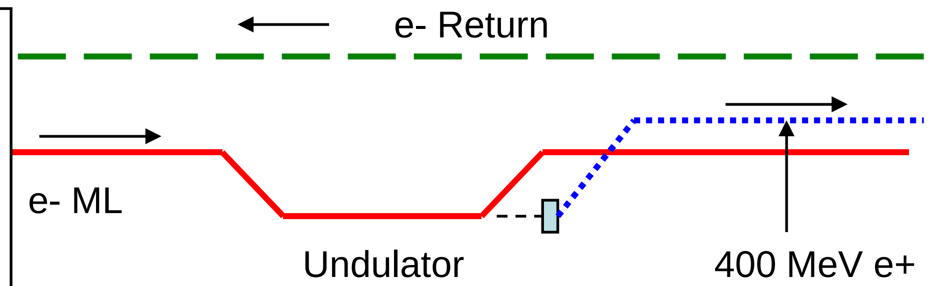
- Vertical dogleg
  - –Descends 7.85 meters over ~590 m
  - – Uses 2 vertical arcs separated by weak FODO lattice
- Good conceptual design
  - – Uses Keil-style eta matching
  - – Beta match between “strong” and “weak” lattices not great
- Escalator-linac tunnel connection does not match CFS design
  - – Need to make match according CFS design

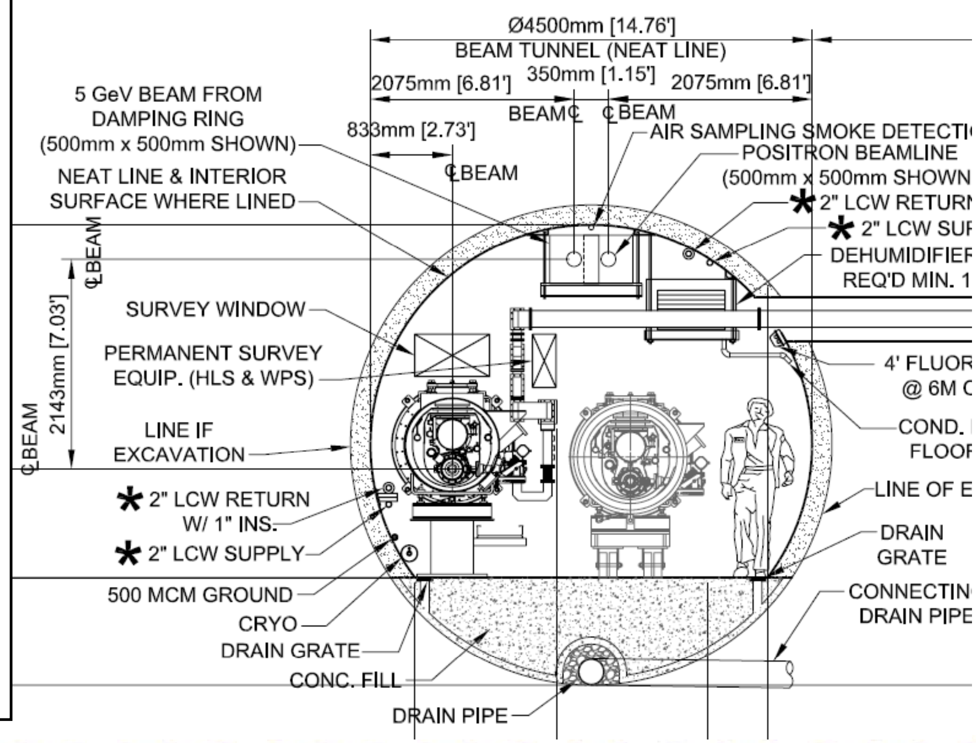




Return Line

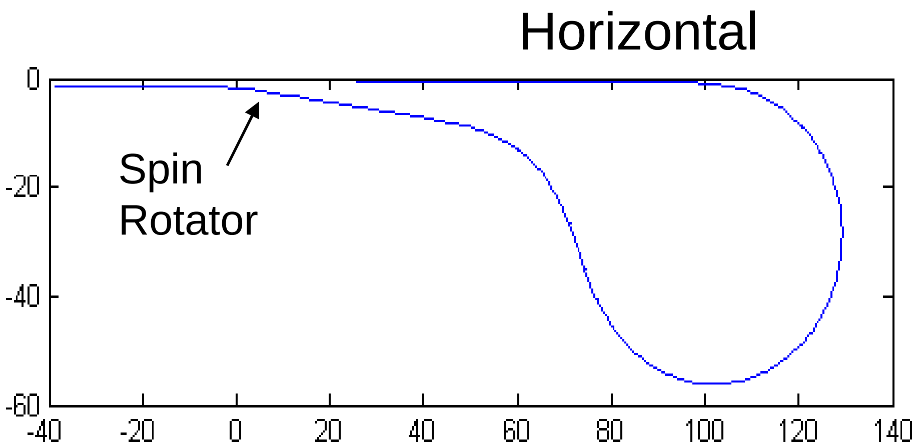
- Weak FODO lattice at ML ceiling elevation (1Q/~36m), XY_{corr}+BPM
- Vertically curved tunnel thru ML area
  - **Dispersion matching via dipole correctors**
- Laser-straight tunnel thru BC area
- Electron line ~1.2 km longer than positron
  - **Goes thru undulator area**
- Electron Return line and positron transfer line need to be exchanged

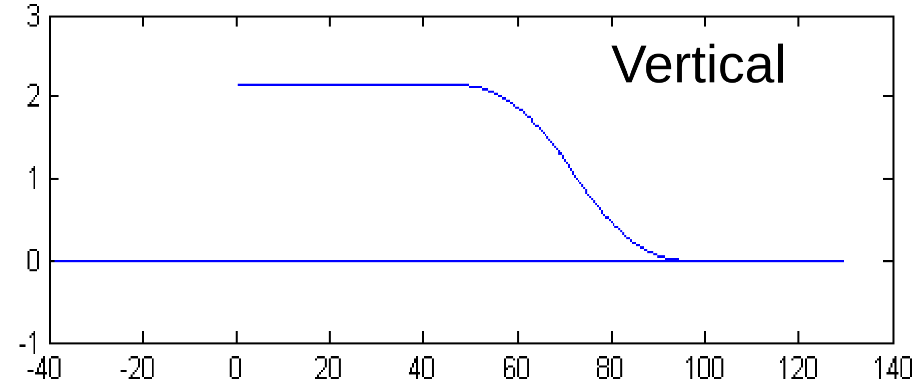




Turnaround

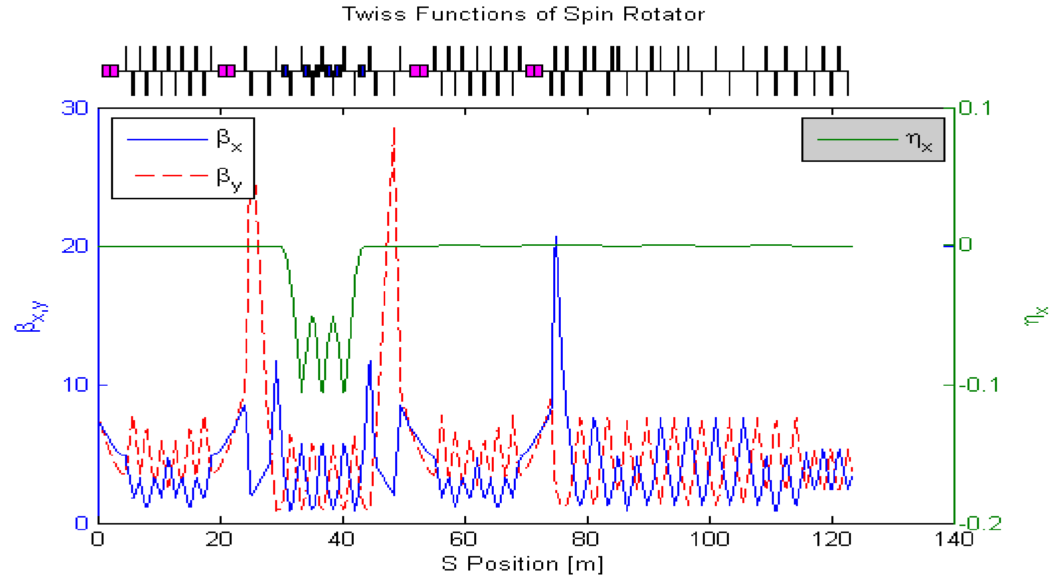
- Actually does 3 jobs
  - **Turns the beam around**
    - Note: need to bend *away* from service tunnel
  - **Brings beam down from ceiling to linac elevation (near floor)**
    - Vertical dogleg
  - **Adjusts x position to meet linac line**
    - Horizontal dogleg
- Order: H dogleg, V dogleg, turnaround
- High packing area ~90% magnets

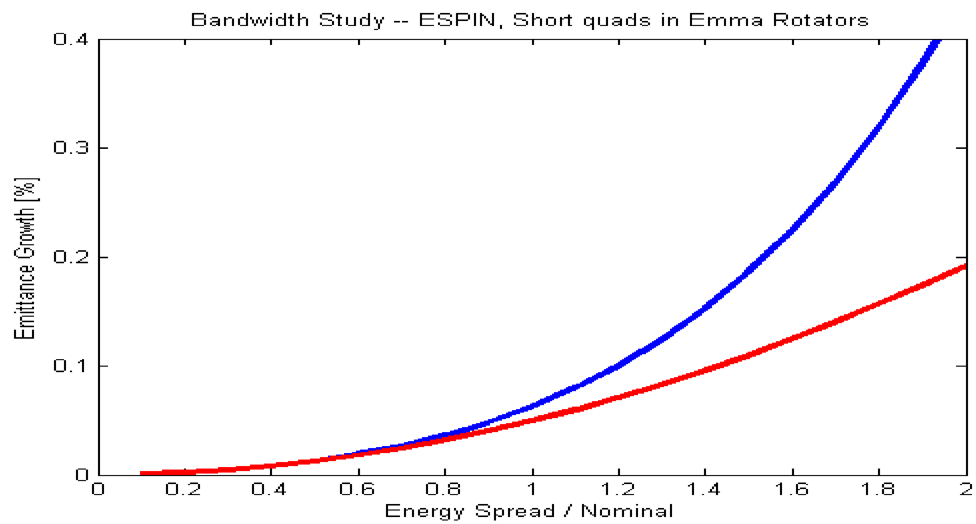




Spin Rotation

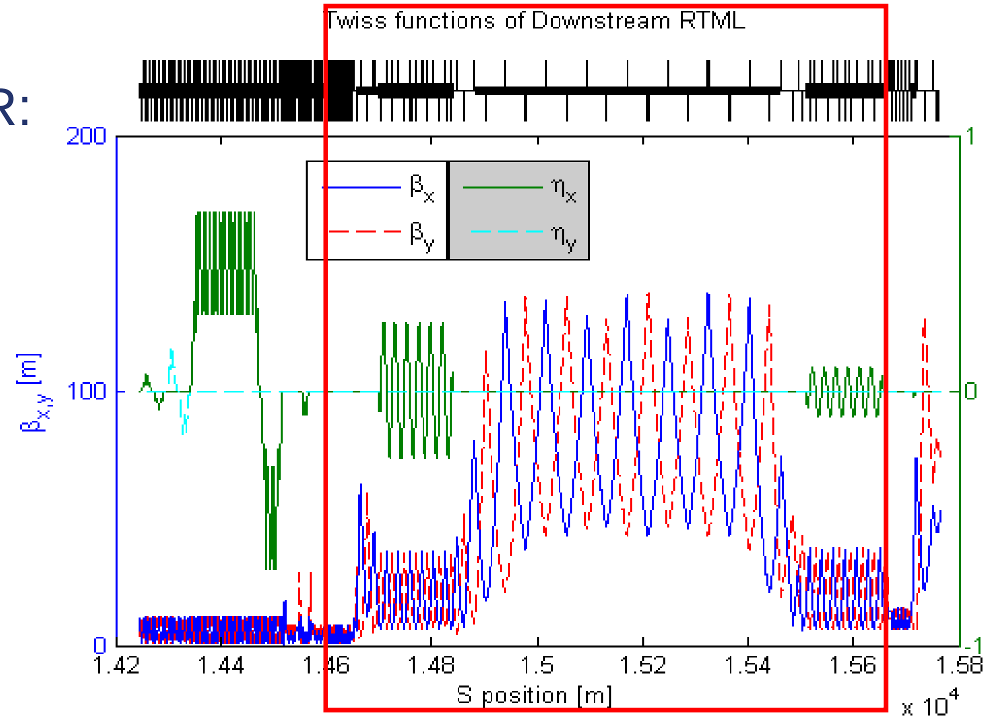
- Design based on Emma's from *NLC ZDR*
  - **2 solenoids with Emma rotator between them**
    - Rotate spin 90° in xy plane while cancelling coupling
  - **8° arc**
    - Rotate spin 90° in xz plane
  - **Another 2 solenoids + Emma rotator**
- Basic design seems sound
  - **Very small loss in polarization from vertical bending in linac tunnel**
- Important issue = bandwidth
  - **Off-energy particles don't get perfect cancellation of dispersion and coupling**





Bunch Compression

- Longitudinal emittance out of DR:
  - *6 mm (or 9mm) RMS length*
  - *0.15% RMS energy spread*
- Want to go down to 0.2-0.3 mm RMS at IP
  - *Need some adjustability*
- Use 2-stage BC to limit max energy spread
  - *Compress to 1 mm at 5 GeV*
  - *Accelerate to 15 GeV*
  - *Compress to final bunch length*
- Both stages use 6-cell lattice with quads and bends to achieve momentum compaction (wiggler)
  - *Magnet aperture ~40cm*

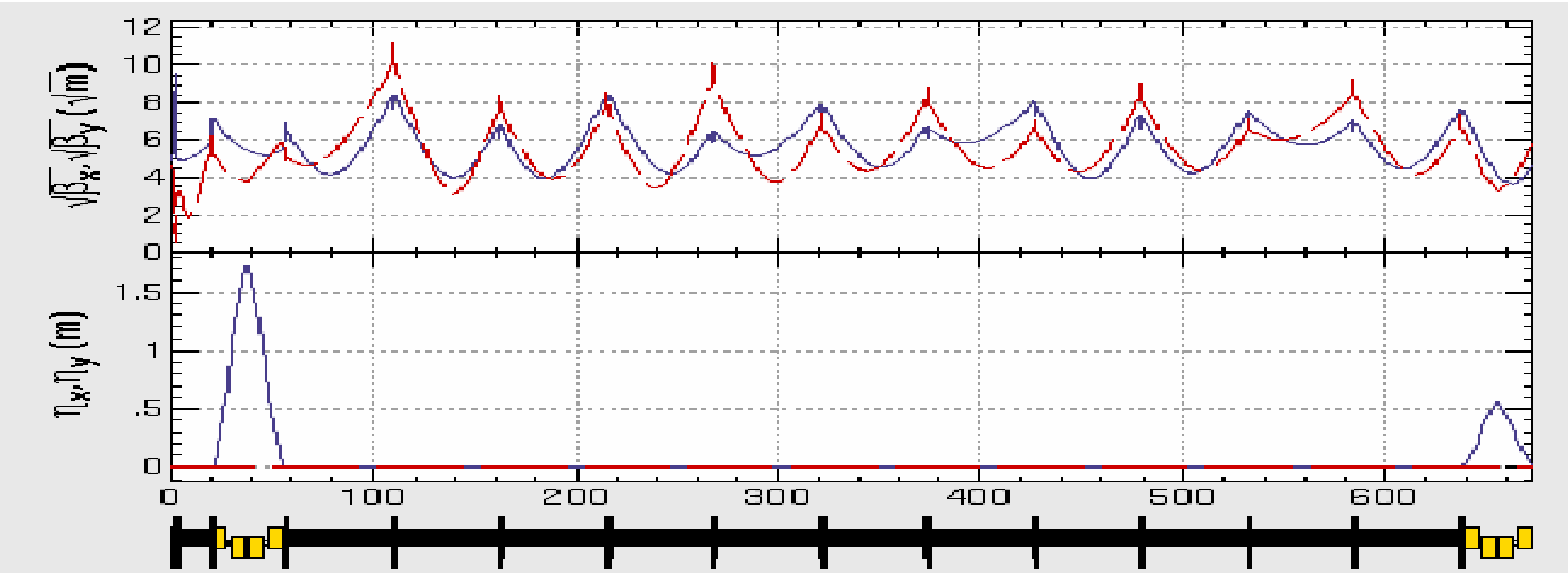


RF system

- BC1 has 3 CMs with quads (+spare kly)
- BC2 has 14 linac-style RF units (3CM's each) + 1 spare

Alternative Bunch Compressor

- An alternate bunch compressor design exists
  - ***6-cell wigglers (~150 m each, 102 bend magnets) replaced by chicanes (~40 m each, 4 bend magnets)***
  - ***Advantages:*** *Shorter, Simpler, Cheaper (?)*
  - **Disadvantages:**
    - *Big x offset from straight line (~1.8 m)*
    - *Doesn't have natural locations for dispersion tuning quads*

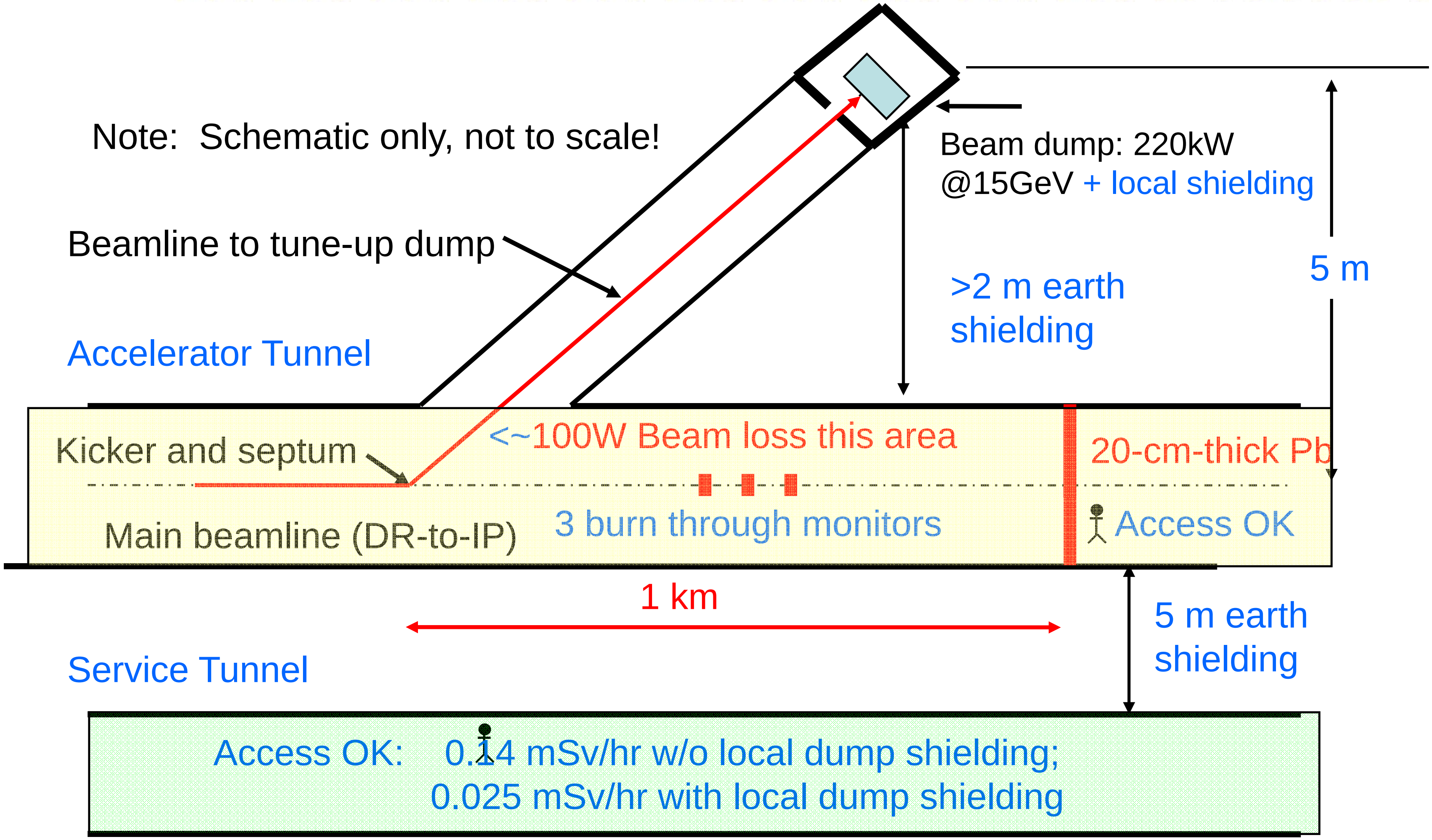


Halo and Energy Collimation

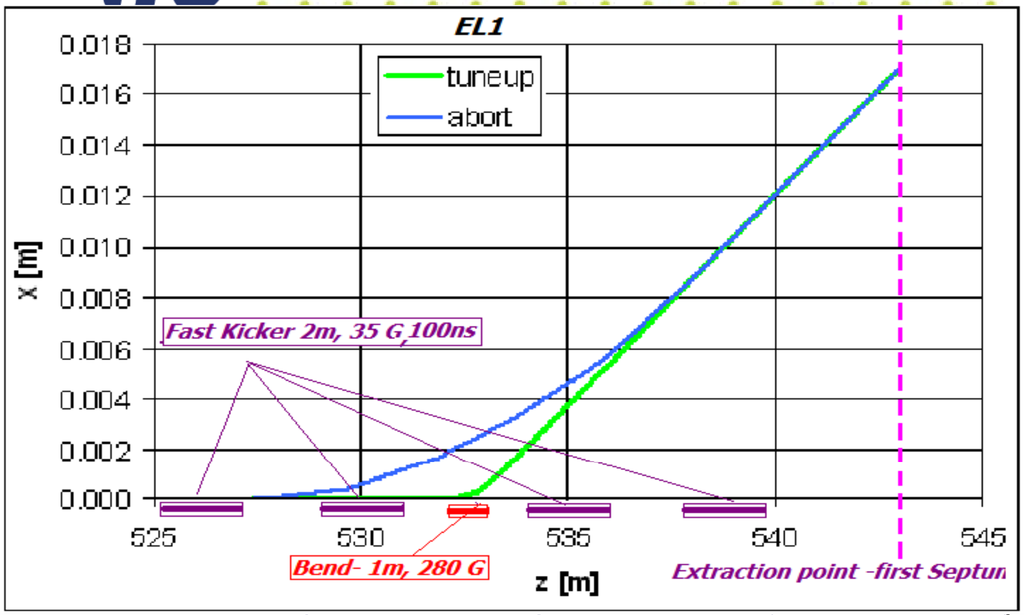
- ILC specification:
  - **Needs to limit halo at end linac to ~10^{-5} of total beam power**
- Halo Collimation after DR
  - **BDS specification as requirement**
    - Halo power ~ 220 W
    - Provide machine protection
      - Collimators stop out-of-control beam from DR
      - Need to keep out-of-control beam from frying collimators, too!
- Energy collimators after betatron collimation system
  - **Scattered particles**
  - **Off-momentum particles / bunches from DR**
- Additional energy collimators
  - **In BC1 wiggler**
  - **In BC2 wiggler**
- Collimators in Extraction Lines ELBC1 and ELBC2
- Need to understand machine protection issues for these collimators

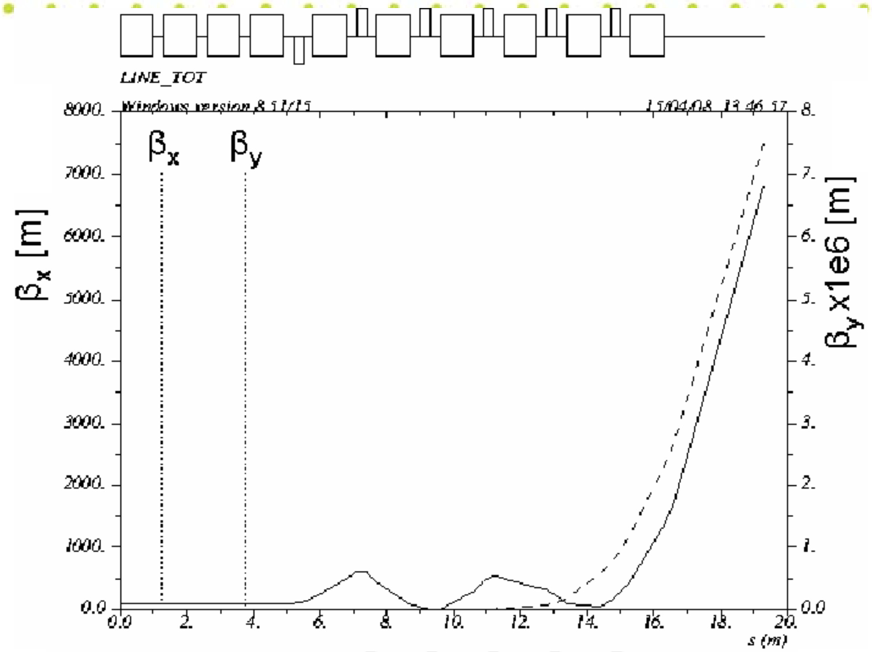
Pulsed Extraction Lines

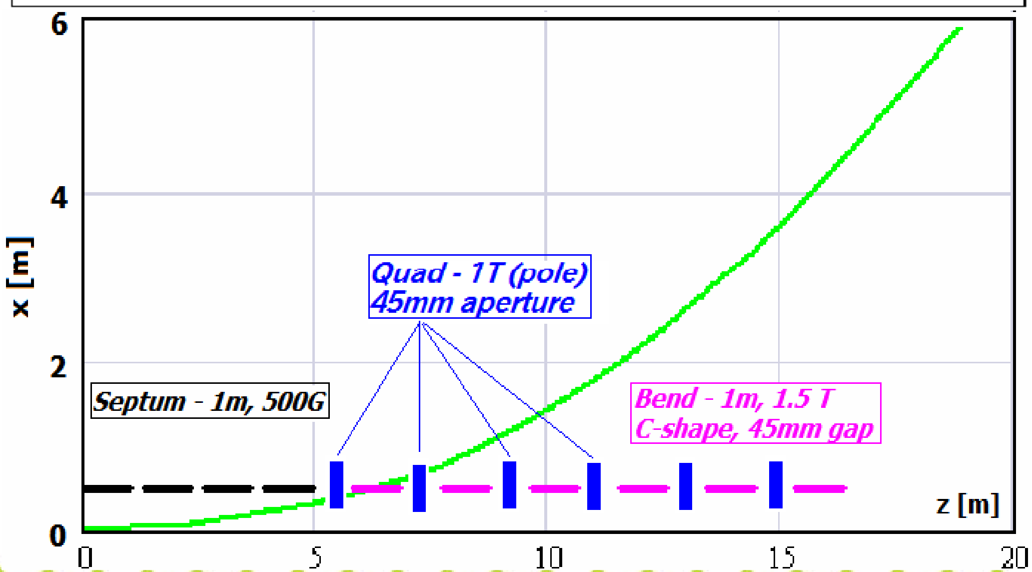
- 3 Extraction Lines in each RTML side for emergency beam abort (MPS) and tune-up
  - **EL1 - after DR exit, diagnostics, global correction**
  - **5 GeV, σ_E=0.15%**
    - Keep DRs running @ full power during access
    - Keep DRs and extraction tuned during access
    - MPS abort (~100ns)
  - **ELBC1 - after BC1**
  - **5 or 4.88 GeV, σ_E = 0.15% and 2.5%**
    - Tune up BC1 without beam in BC2
    - MPS abort
  - **ELBC2 - after BC2**
  - **15 GeV, σ_E = 0.15% and 1.8%**
    - Tune up BC2 without beam in linac
    - MPS abort
- All have 220 kW beam handling power
  - **Full power for DRX, BC1**
  - **1/3 power for BC2**

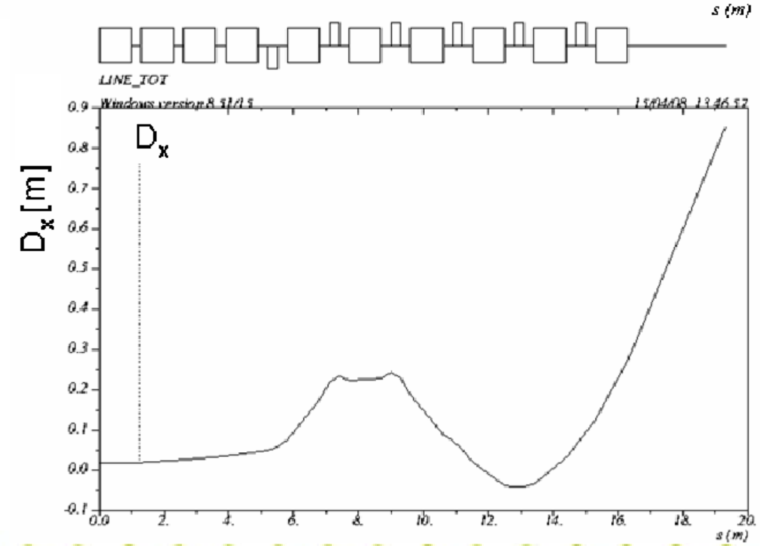

Note: Schematic only, not to scale!
Beamline to tune-up dump
Beam dump: 220kW
@15GeV + local shielding
5 m
>2 m earth
shielding
Accelerator Tunnel
Kicker and septum
<~100W Beam loss this area
20-cm-thick Pb
Main beamline (DR-to-IP)
3 burn through monitors
Access OK
1 km
5 m earth
shielding
Service Tunnel
Access OK: 0.14 mSv/hr w/o local dump shielding;
0.025 mSv/hr with local dump shielding

EL1 design


EL1
tuneup
abort
x [m]
Fast Kicker 2m, 35 G,100ns
Bend- 1m, 280 G
z [m]
Extraction point -first Septun

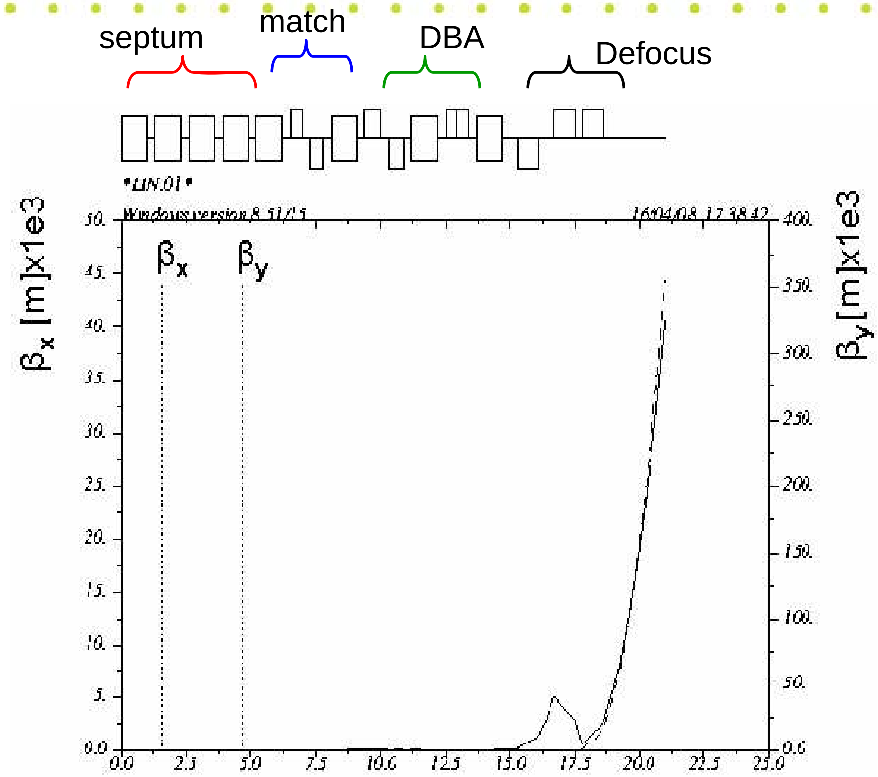

LINE_TOT
βx
βy
βx [m]
βy x1e6 [m]
s (m)

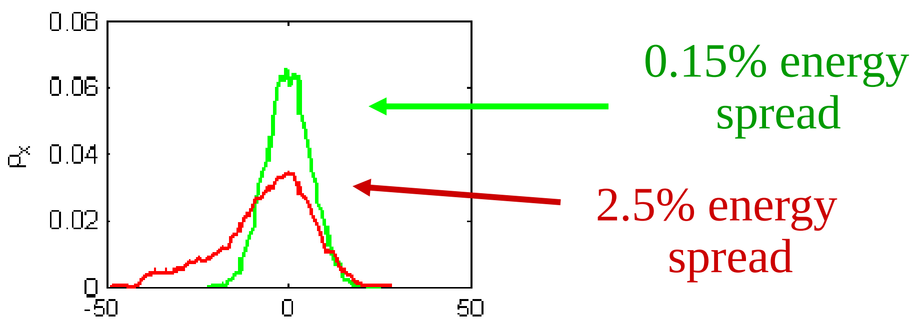

x [m]
Quad - 1T (pole)
45mm aperture
Septum - 1m, 500G
Bend - 1m, 1.5 T
C-shape, 45mm gap
z [m]

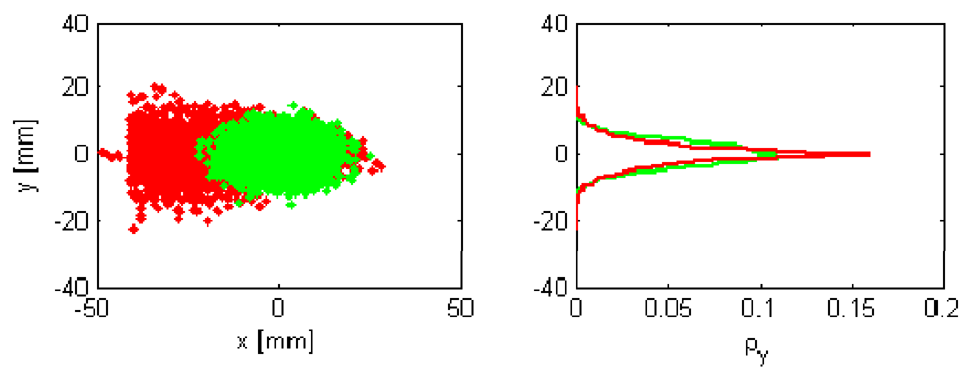

LINE_TOT
Dx
Dx [m]
s (m)

ELBC1 Line Design

- Separation of the two lines at CM location (14m down) - 2m;
- Separation of the dump and the ML ~5 m;
- DBA to decouple dispersion and beam size issues
- Beam size on the dump window ~15 mm^2
- Length = 20.7 m



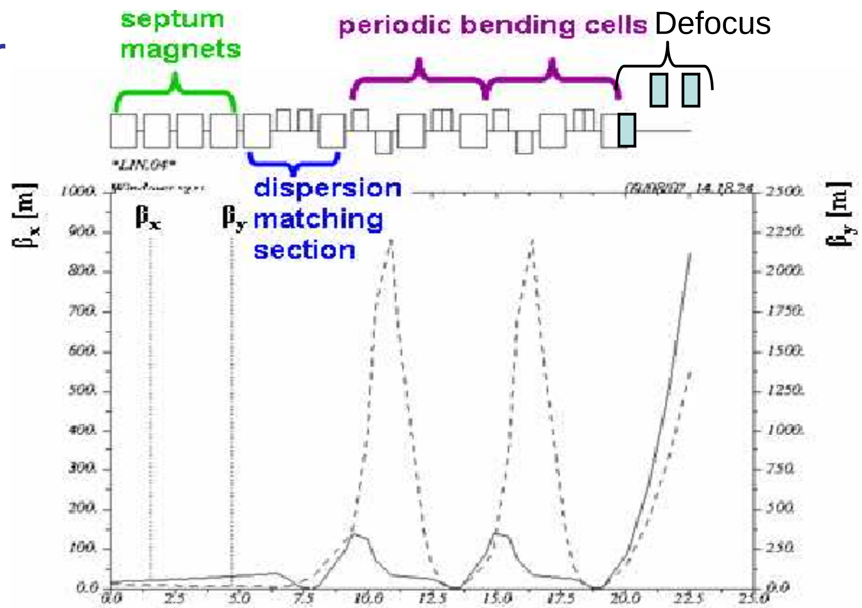


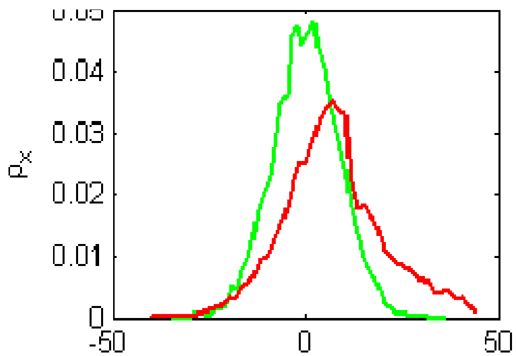


- Two collimators to protect downstream triplet
- intercepts 3.9 kW/train and 18.8 kW/train

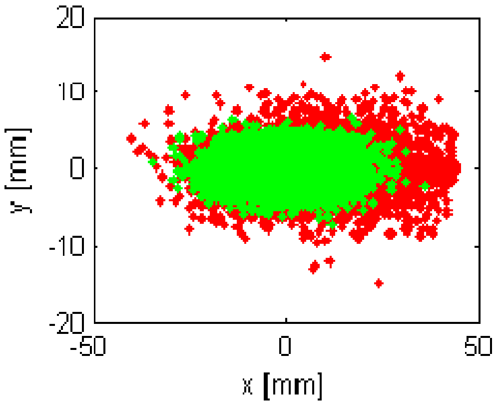
ELBC2 Design

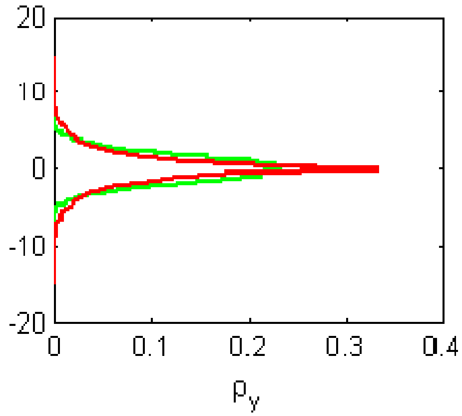
- ELBC2 similar to ELBC1, but ~ 5m longer (extra bending cell)
  - 6 septum+6 bends+12 quads,
  - two collimators: 5.2 kW (protect quads) and 14.1 kW (dump window)





0.15% (green)
and 1.8% (red)
energy spread

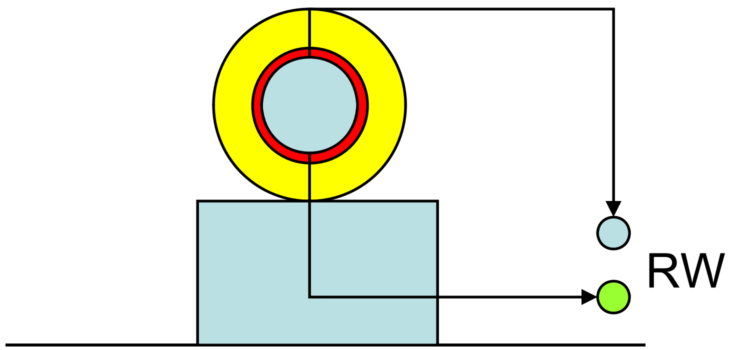




	2 coll	1 coll	No coll
Final quads	1T 45mm	1T 45mm	2T 80mm
Collimat	5.2 kW 14.1kW	5.2kW	No coll
Dump window	12.5 cm	30 cm	100 cm

Six ~220kW Aluminum Ball Dumps

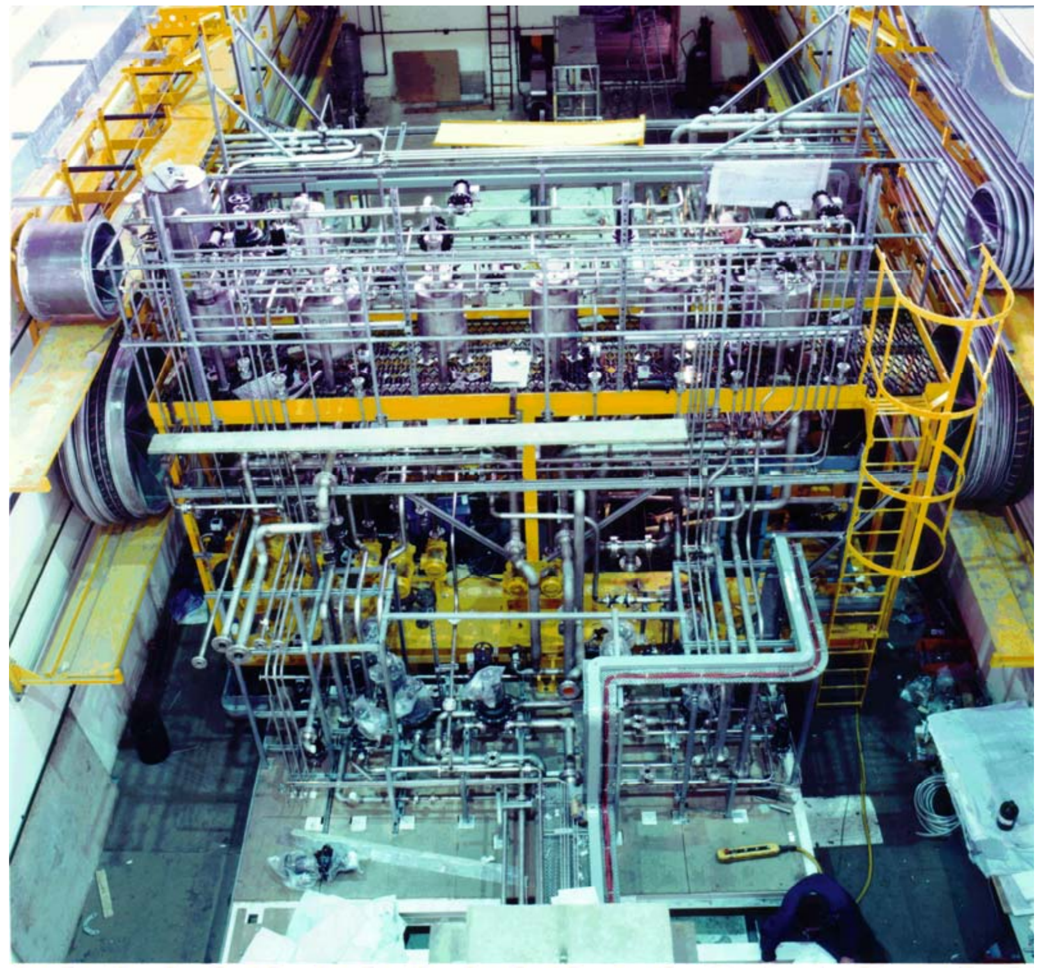
50cm Diameter x 2m long
Aluminum Ball Dump with Local
Shielding



Cost ($1M each) is dominated by:
- **3-loop radioactive water processing system**
- **The CFS infrastructure, shielding, etc.**

Similar dumps in use at SLAC

50kW 3-loop 2006 Rad Water Cooling for ISIS Neutron Spallation Targets



Technical Systems

- Magnets and power supplies (~4600 Magnets)
  - **SC quads/correctors/solenoids (36/54/8),**
  - **RT quad, correctors, septa**
  - **Pulsed magnets, kickers, bends, FB/FF correctors**
- Vacuum system
  - **Current baseline**
    - 2 cm OD stainless chambers
      - Exceptions: BC bends, extraction lines, CMs
    - 20 nTorr in long line from DR to turnaround
      - Passivated to reduce outgassing rate
    - 100 nTorr in balance of system (turnaround to linac)
    - Not *in situ* baked
    - No photon stops or water cooling in bend areas
- Dumps and Collimators
  - **3 dumps per side with 220 kW capacity**
  - **Betatron and energy spoilers / absorbers with ~200 W capacity**
  - **Few collimators with ~10 kW capacity**

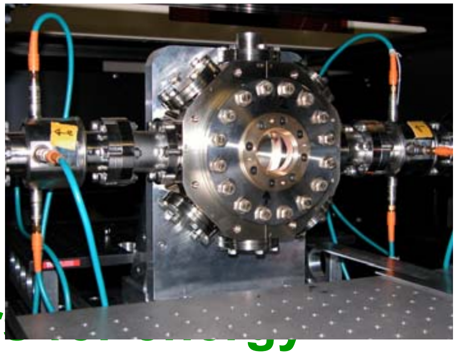
Collimators

Adjustable-aperture Collimators	DR stretch	Turnaround	BC1	BC2	RL	Water cooling	Power W	Half-gap size, mm	N
Adjustable two-jaws Rcoll, x	2x2	0	0	0	0.6	no	5	3.4 (x)	
Adjustable two-jaws Rcoll, y	2x2	0	0	0	0.6	no	5	1.0 (y)	
Adjustable two-jaws Rcoll, longit	0	2x2	0	0	0.6	no	5	0.98	
Adjustable two-jaws Rcoll, longit	0	0	2x2	0	0.6	no	5	18	
Adjustable two-jaws Rcoll, longit	0	0	0	2x2	0.6	no	5	4	
Total:	8	4	4	4					**20**

Fixed-aperture Collimators									
Fixed Ecoll	2x8	2x2	0	0	20	yes	200	6.5	
Fixed Ecoll	0	0	2x2	0	20	yes	200	30	
Fixed Ecoll	0	0	0	2x2	20	yes	200	5	
Total:	16	4	4	4					**28**

Technical Systems (2)

- Instrumentation
  - **BPM's at every quad, plus high dispersion points in wigglers**
    - Serve a number of functions: feedback, feed-forward, beam-based alignment and steering, energy diagnostic
    - room-temp C- or L-band (BC2 upstream) cavity BPM's
  - **3 suites of Laser Wires (LW) in each RTML**
    - 4 wires per suite, set up for 2D emittance measurement
  - **Bunch length measurement**
    - LOLA (3.9 GHz) + screens in each BC
    - Possibly EO monitors (not in RDR baseline)
  - **SLMO's (Synchrotron Light monitor) in BC wigglers for energy spread measurement (4)**
  - **3 dedicated phase monitors per side**
  - **Toroids, 4 ion chambers and 150 photomultipliers (MPS)**



Technical Systems (3)

- 1.3 GHz SC RF system plus supporting utilities
  - **48 CMs per side (1 RF source per 3 CMs, as in ML)**
    - 3 CM x “8Q” in BC1
    - 15 RFunits x “9-8Q-9” in BC2
    - BC1: 2^{nd} source with RF switch for redundancy
  - **LLRF issues**
    - Phase stability
    - Beam loading compensation
      - Beam loads RF at decelerating phase
      - Unlike ML, need to “jump” both amplitude and phase of RF source @ beam time
  - **Cryo system (~6.5% cost of ML Cryo system)**
    - Part of ML cryogenic system
      - Also supports SC solenoids in spin rotator
    - BC’s are laser-straight
      - Probably OK – only ~1 km long

WP4: R&D on Phase and amplitude stability

The required tolerances for amplitude and phase stability in BC are very tough:

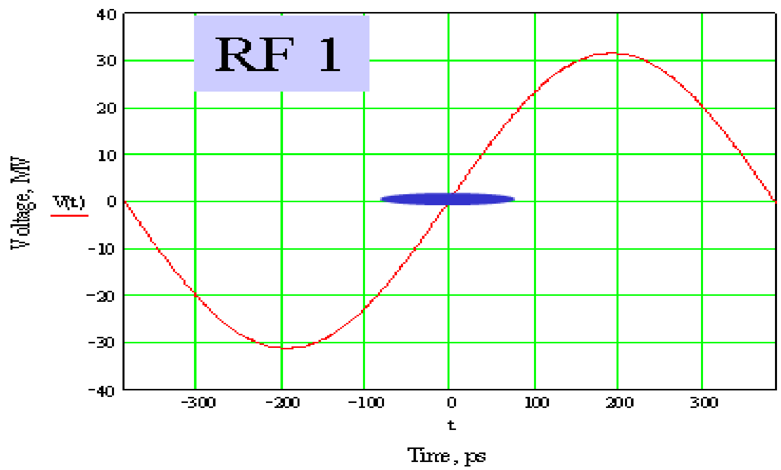
- Phase stability tolerance: 0.25°/0.16° – long/short bunch
- Amplitude stability tolerance: 0.5%/0.35% rms – long/short bunch

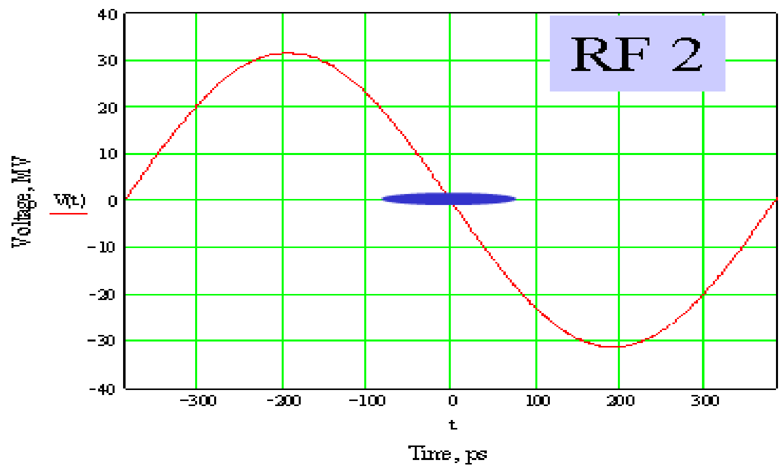
➢ Bunch compressor RF cavities operate close to zero-crossing:

- Phase 105° off-crest (BC1)
- Phase 27.6° off-crest (BC2)

➢ The gradient in the RF system ~30 MeV/m. Zero crossing regime – complication for LLRF system.

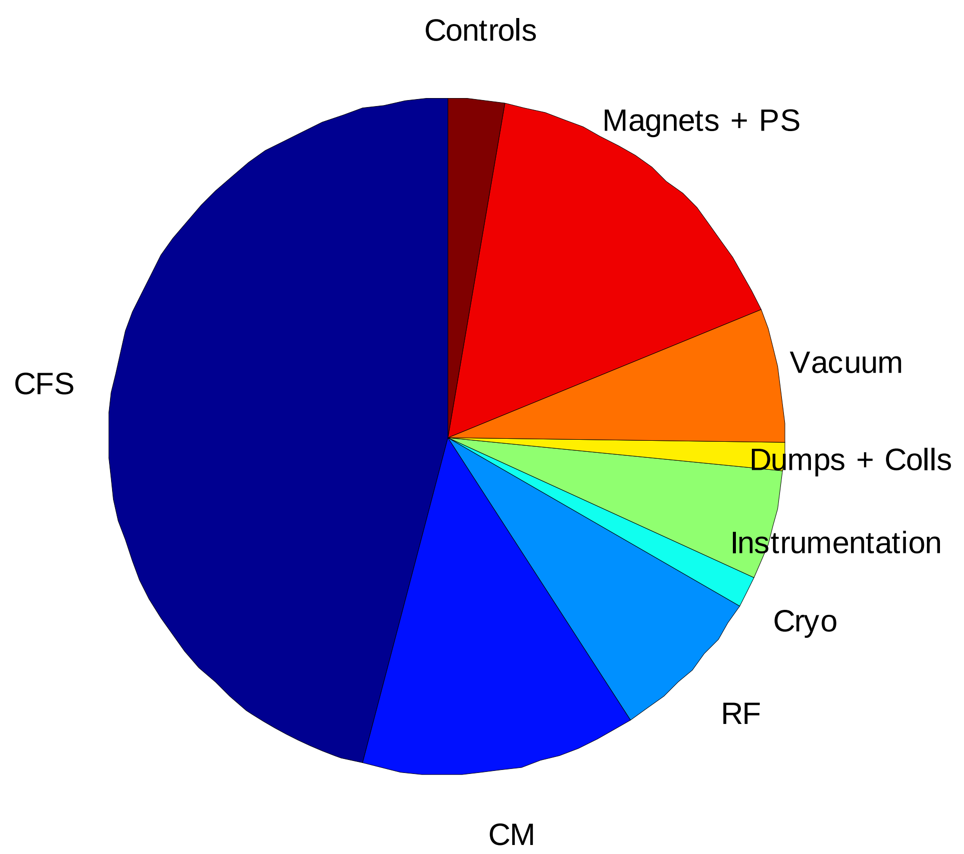
➢ Study of the phase and amplitude stability of the RF system @ FLASH (2009).





Cost and its Distribution

- CFS + BC RF system = 68% of costs
  - **Correlated – much of CFS cost is housing for BC cryomodules**
- Remainder dominated by RT beam transport
  - **Quads, correctors, BPMs, vacuum system**
- Small amount of “exotica”
  - **Non-BPM instrumentation, controls, dumps, collimators**



Sources of luminosity/emittance degradation

- **Synchrotron radiation**
  - From DRX arc, turnaround, BC wigglers
- **Beam-ion instabilities**
- **Beam jitter**
  - From DR
  - From stray fields
- **Dispersion**
  - DR extraction
  - Misaligned quads
  - Rolled bends
- **Coupling**
  - DR extraction septum
  - Rolled quads
  - Misaligned bends
  - Quad strength errors in spin rotator
- **Pitched RF cavities**
  - Produce time-varying vertical kick
- **RF phase jitter**
  - Varies IP arrival time of beams
- **Beam halo formation**
- **Collimator and cavity Wakefields**
- **Space charge**
- **Resistive wall wakes in vac. chamber**

LET BBA @ ILC RTML

Several BBA used:

- Ballistic Alignment (BA)
- Kick minimization (KM)
- Dispersion Free Steering
- Dispersion Bumps
- 4D Coupling Correction

- Adaptive alignment
- Wakefield Bumps

Feed-Back and
Feed Forward system

Luminosity

- Synchrotron Radiation
  - **Mainly managed by optics design**
  - **0.9 μm emittance growth in x (budget 2 μm)**
  - **Vertical bends in Escalator, Dogleg negligible**
  - **Analytic estimates indicate no CSR issues**
- Beam-ion instabilities
  - **Sets 20 nTorr pressure limit in Return line**
    - Limits jitter growth to 9% (ie, jitter out = 1.09 * jitter in)
- Beam Jitter
  - **Handled by feed-forward in turnaround**
  - **Sets limits on tolerable AC fields in Return line**
    - ~ 2 nTesla limit, comparable to measured value in ESB @ SLAC
  - **Can be improved by intra-train feedback as well**

Luminosity (2)

- Halo formation
  - Not a problem in Return line (vacuum 10nTorr from ion instability)
  - Sets 100 nTorr vacuum spec downstream of RL (10^{-6} halo formation**)**
- Dispersion
  - **Local correction via steering / orbit control**
    - BBA – quads have individual power supplies
    - BPM at each quad
    - Y corrector at each quad, X corrector at each F quad
  - **Global correction via normal / skew quads in locations with dispersion**
    - DRX arc, Escalator, Turnaround / vertical dogleg
    - BC1 / BC2 wigglers
      - Sets requirement for 6 cells with 90/90 phase advance

Luminosity (3)

- Collimator Wakefields
  - Y wakes seem marginal for “razor blade” collimators
  - Probably OK for tapered collimators
- Coupling
  - Global correction via orthonormal skew quads
    - Two decoupling systems
      - After DRX arc
      - After spin rotator
- Pitched RF cavity
  - Global correction via BC dispersion knobs
    - YZ coupling (pitch) + ZE coupling (off-crest running) = YE coupling (dispersion)

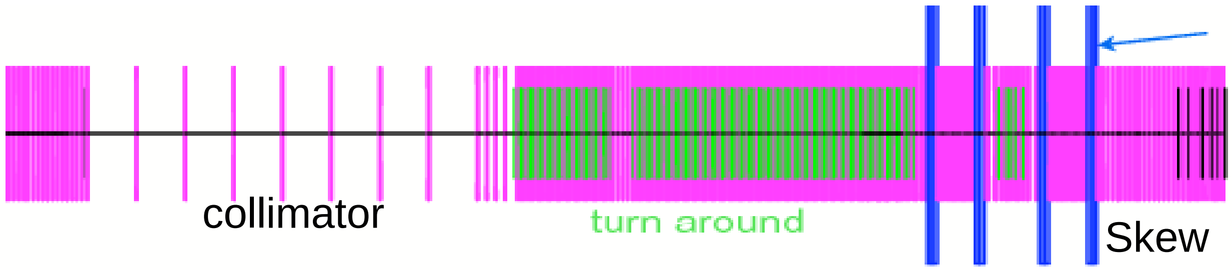
Survey Alignment

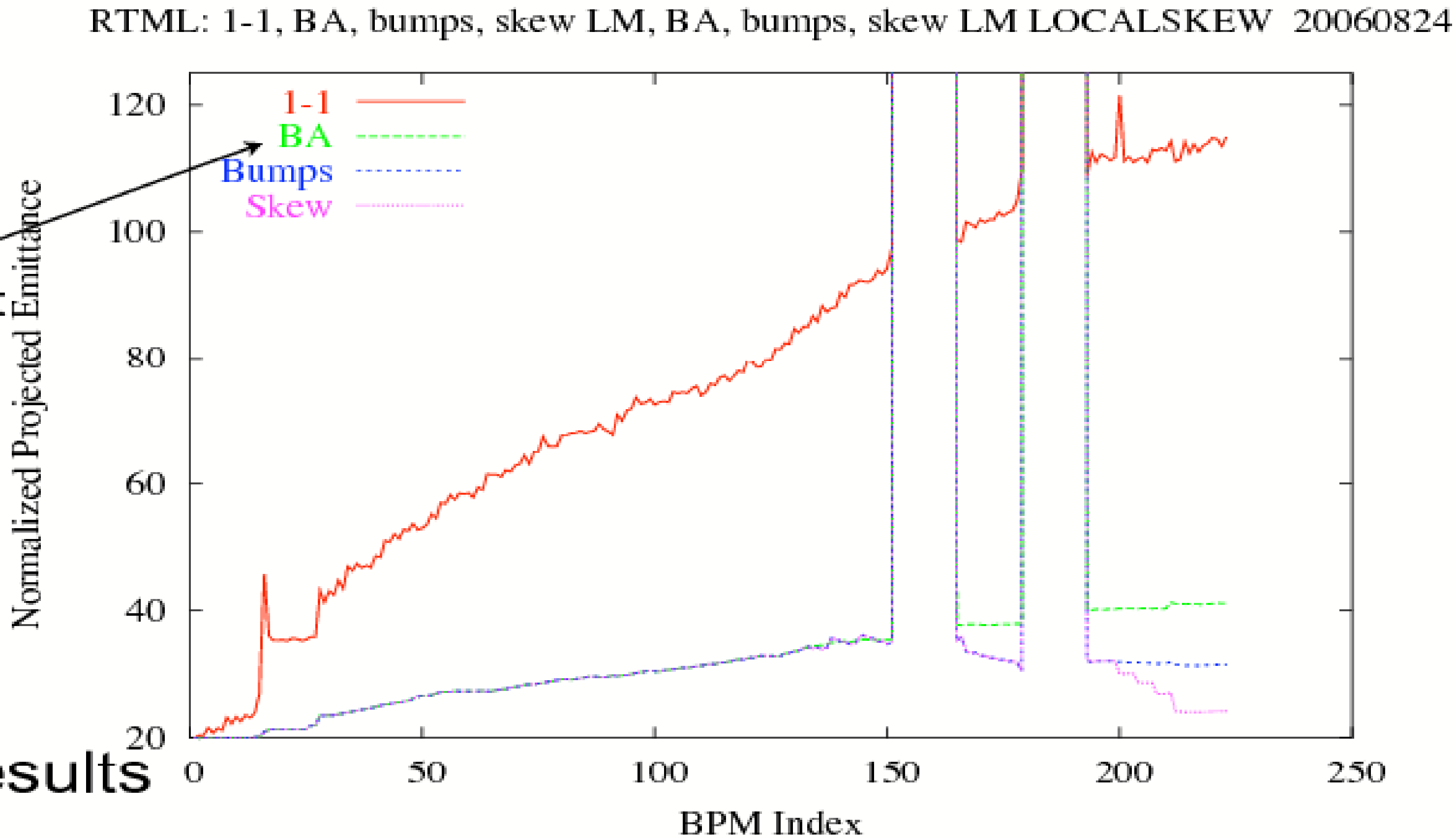
Our old canonical set, should consider more realistic misalignments…
Survey people would prefer we use cold specs for all components.

Error	Cold Sections	Warm Sections	With Respect To…
Quad Offset	300 µm	150 µm	Cryostat
Quad Tilt	300 µrad	300 µrad	Cryostat
Quad strength	0.25%	0.25%	Design Value
BPM Offset	300 µm	200 µm	Cryostat/Survey
BPM-Quad Shunting	20 µm?	7 µm	Quadrupole
BPM Resolution	1 µm	1 µm	True Orbit
Bend tilt	300 µm	300 µm	Survey Line
Bend Strength	0.5%	0.5%	
RF Cavity Offset	300 µm	n/a	Cryostat
RF Cavity Pitch	200 µrad	n/a	Cryostat
Cryostat Offset	200 µm	n/a	Survey Line
Cryostatic Pitch	20 µrad	n/a	Survey Line

Static tuning in part of RTML (upstream BC1)

COLL2
Turnaround
Spin rotator
SKEW
EMIT2





KM works ~about the same as BA, A little better

Jeff Smith results

Emittance budget

- Not there yet... Budget just 4 nm (factor ~2 larger)

Region	BBA method	Dispersive or Chromatic mean Emittance Growth	Coupling mean emittance Growth
Return Line	Kick Minimization and feed-forward to remove beam jitter	0.15 nm	2 nm (without correction)
Turnaround and spin rotator	Kick Minimization and Skew Coupling Correction	1.52 nm (mostly chromatic)	0.4 nm (after correction)
Bunch Compressor	KM or DFS and Dispersion bumps	greater than 4.9 nm (KM + bumps) 2.68 nm (DFS and bumps)	0.6 nm (without correction)
Total		~5 nm almost all from BC	3 nm (without complete correction)

Conclusion

- Lot's of work was done for RDR
- TDR stage will require much more work
  - Re-evaluate/match geometry and optics to accommodate DR changes and CFS req's
  - Static tuning
  - Dynamic tuning (ground motion)
  - Design/prototyping critical components
- Need resources, funding, wide collaboration

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