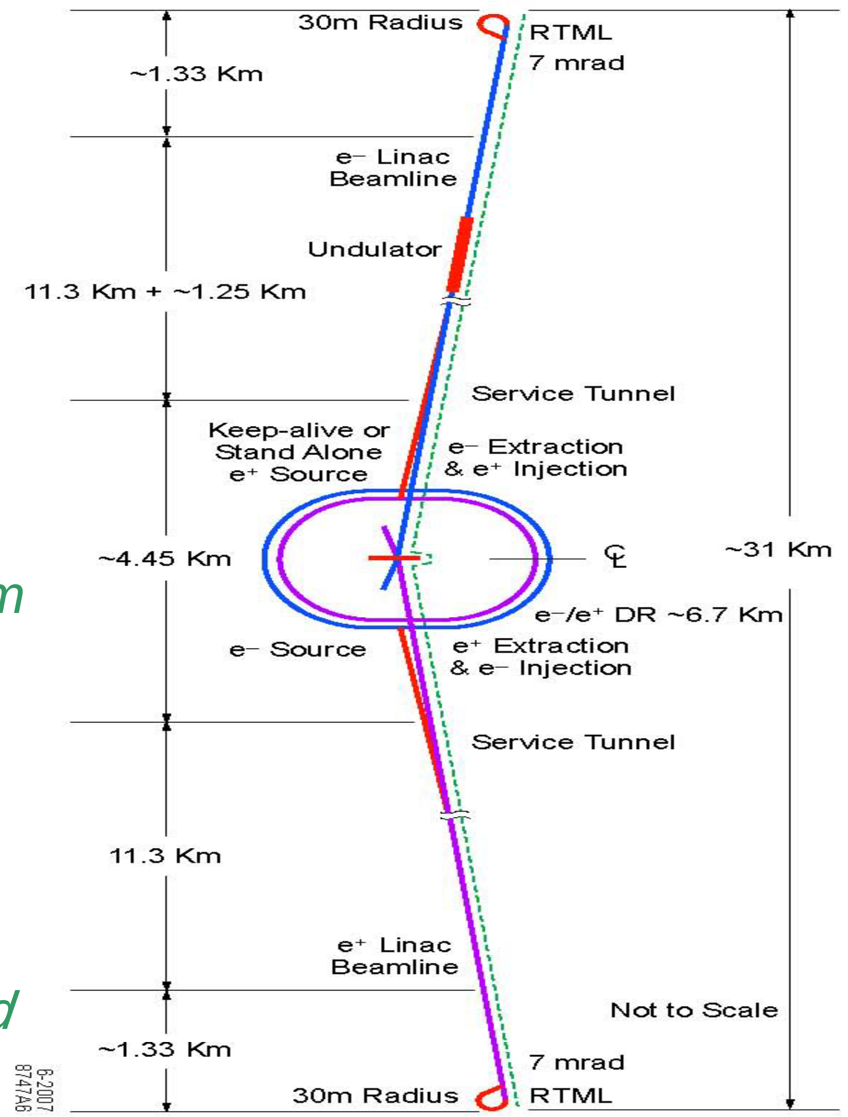
RTML
Design and Cost reduction

Nikolay Solyak
Fermilab

ILC GDE meeting, Dubna, June 4-6, 2008

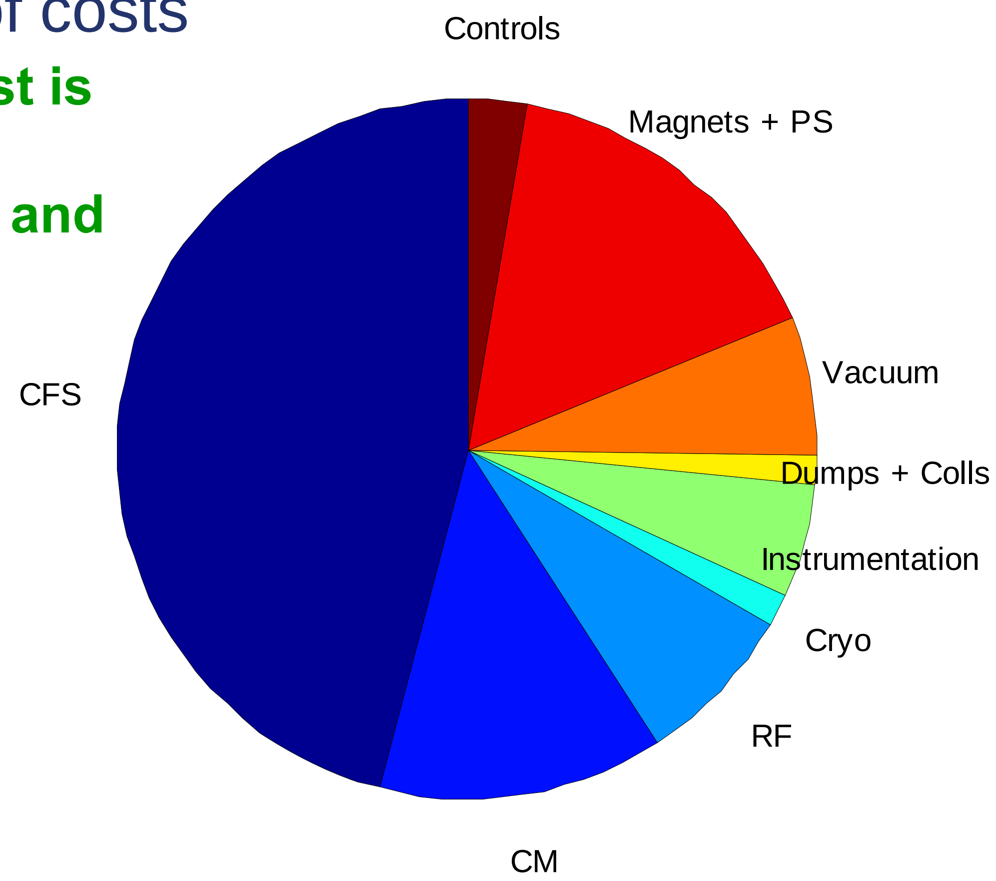
RTML Functions

- *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*



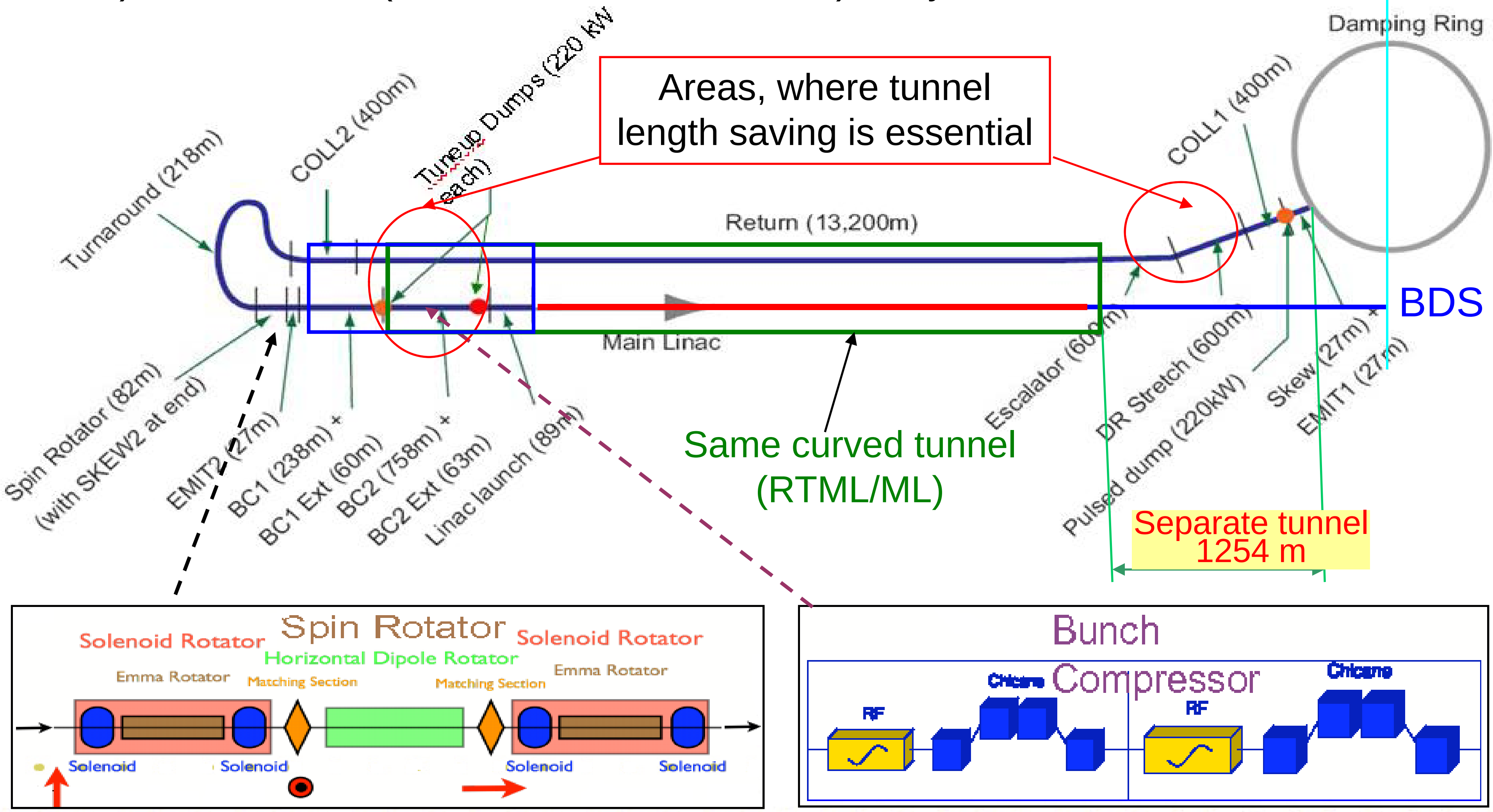
Cost Distribution (kick-off meeting, 2007)

- CFS+BC RF system = 68% of costs
  - **Correlated – much of CFS cost is housing for BC cryomodules**
  - **Specific tunnels: Turnaround and RTML/source tunnels. Expensive D & B technology**
- Remainder dominated by RT beam transport
  - **Quads, correctors, BPMs, vacuum system**
- Small amount of “exotica”
  - **Non-BPM instrumentation, controls, dumps, collimators**

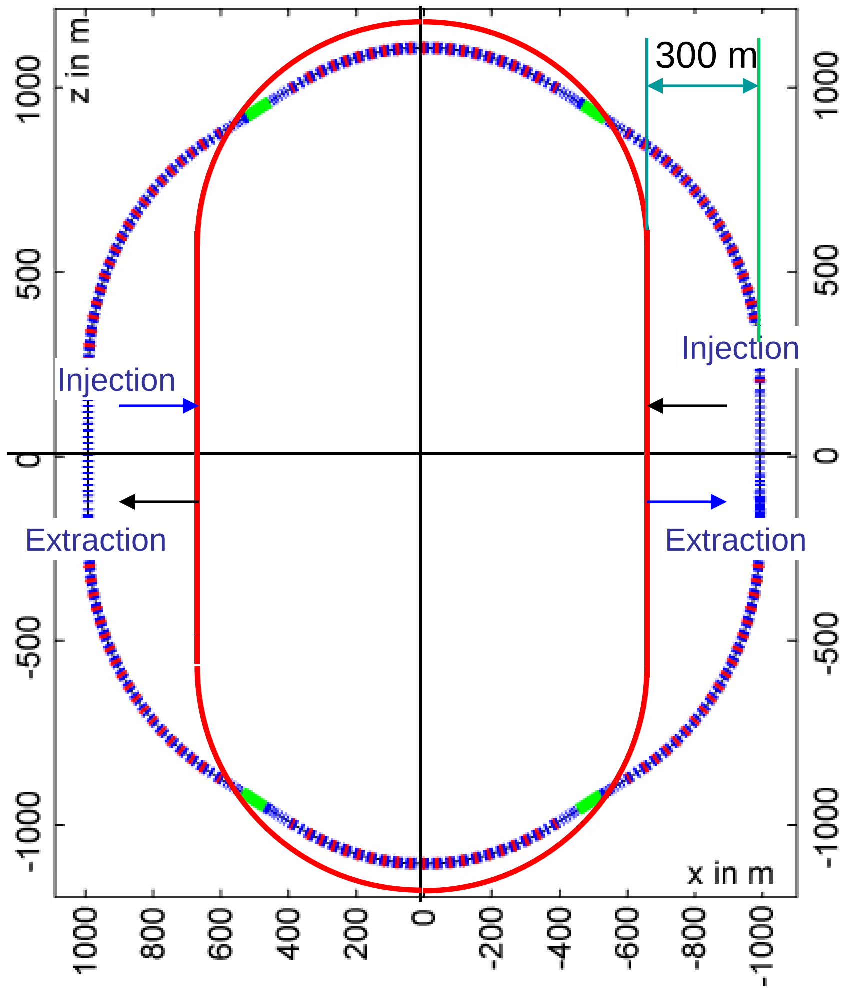


RTML Schematic (RDR)

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.



ILC Damping Ring



Layout of the ILC Damping Ring

blue - old RDR (2007); red - new DCO (Feb.2008)

- New ILC DR lattice is shorter.
- Bunch length = 6 mm
  In old RDR design:
  - 9 mm (easy)
  - 6 mm (more challenge)
- Energy spread = 0.15%
- New DR increases the length of the RTML linac in each side (e^+ and e^-) of ~300 m
- Need redesign/adjust DRX lattice to accommodate changes in DR

RTML Optics Design (RDR)

- Horizontal Arc out of DR ~1.1 km straight
  - **In injector tunnel**
- "Escalator" ~0.6 km vertical dogleg down to linac tunnel
- Return line (weak FODO lattice) ~13km
  - **In linac tunnel**
  - **Vertically curved**
- Vertical and horizontal doglegs
- Turnaround
- 8° arc in spin rotators
- BCs are net straight
- ML launch

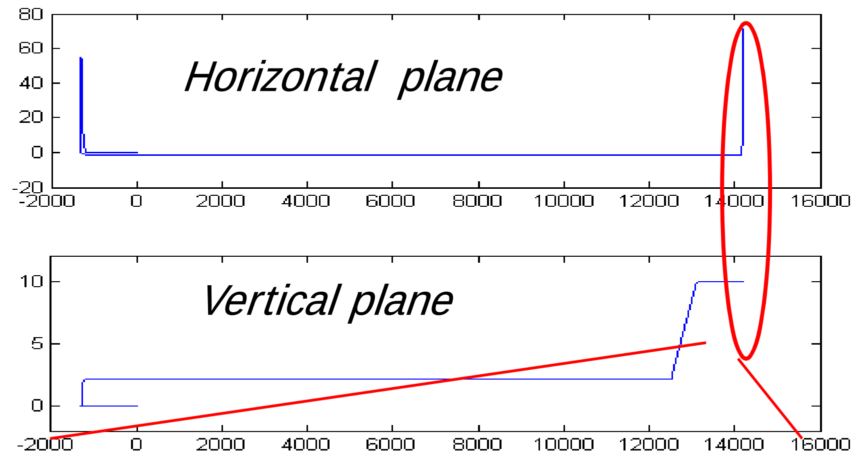
DR-RTML hand-off point defined

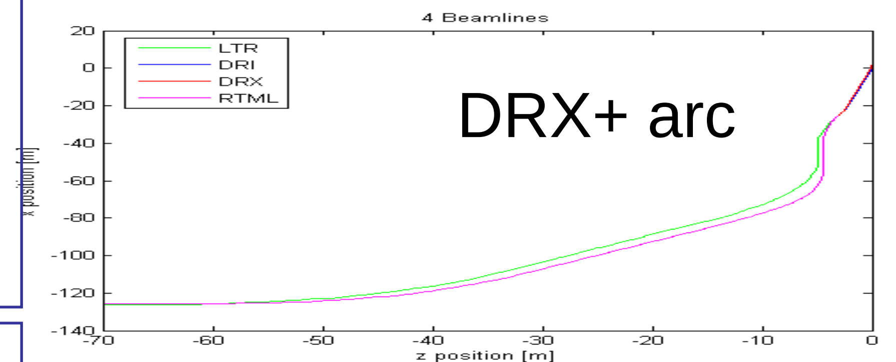
extraction point where η,η' → 0

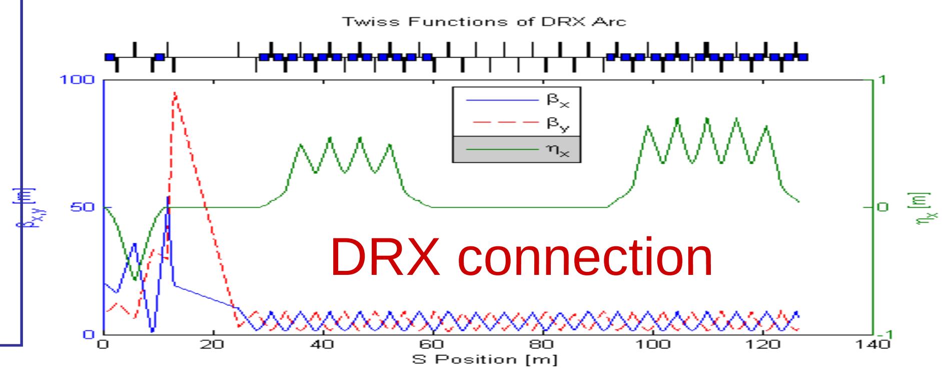
RTML mostly defined by need to follow LTR geometry

Stay in same tunnel

Design is OK at *conceptual* level

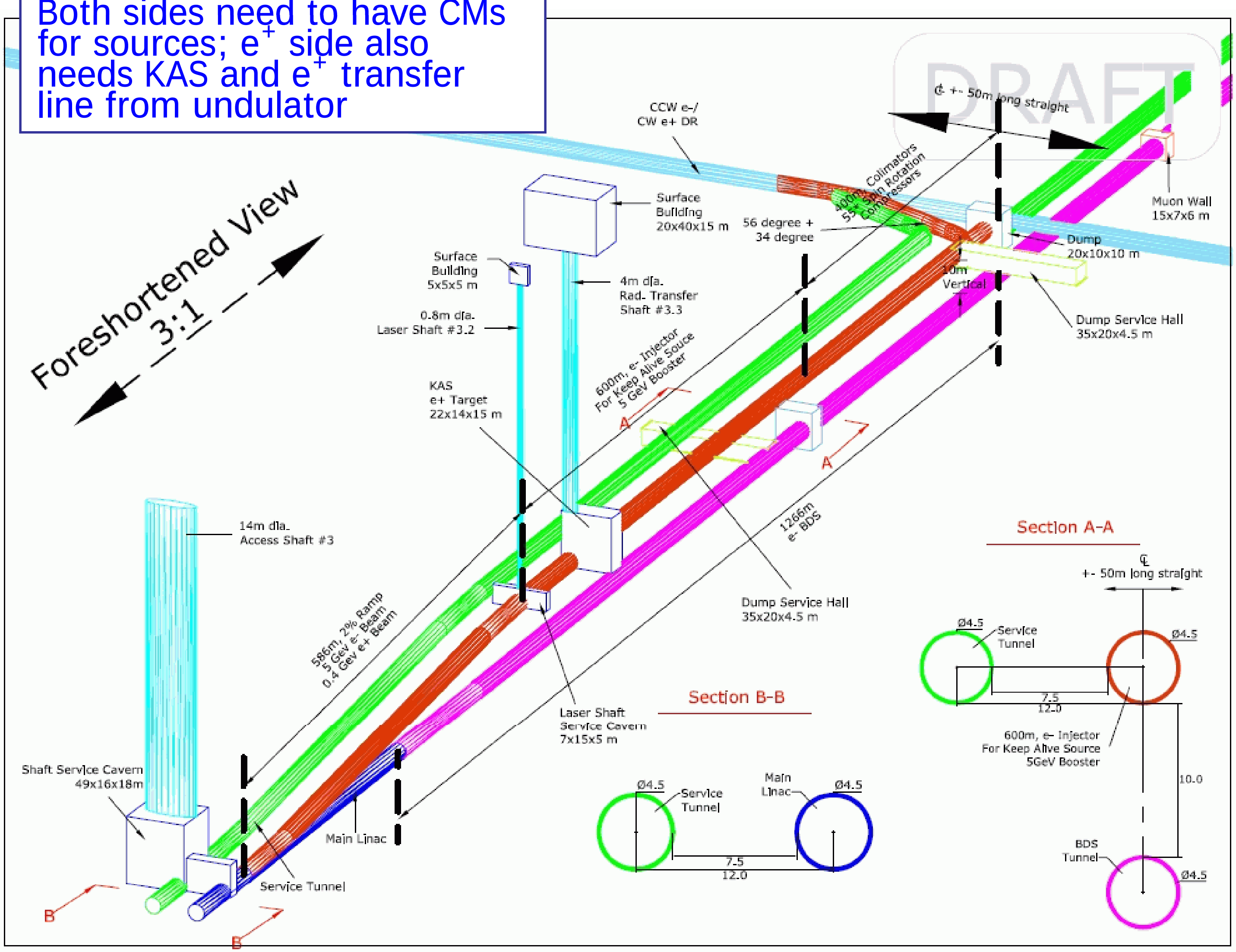






DR connection (RDR)

Both sides need to have CMs for sources; e^+ side also needs KAS and e^+ transfer line from undulator



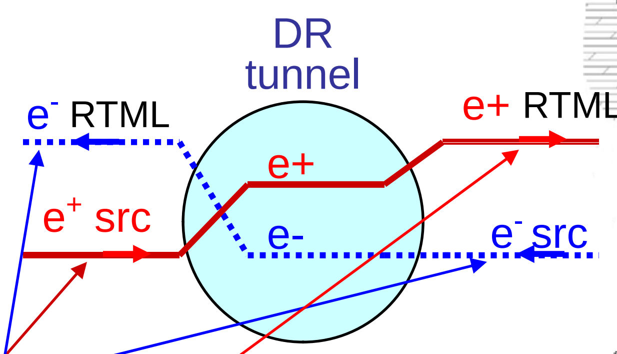
Post-RDR Modifications (ALCG'07 FNAL)

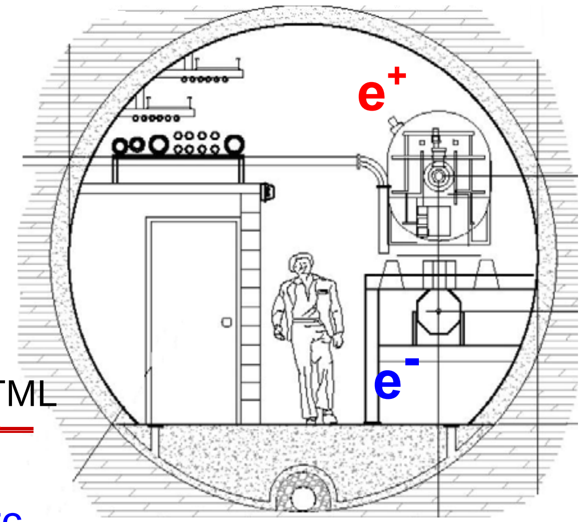
- No elevation for the service tunnel
- ML and LTR/RTML tunnels merge in horizontal plane
- Shorter ?

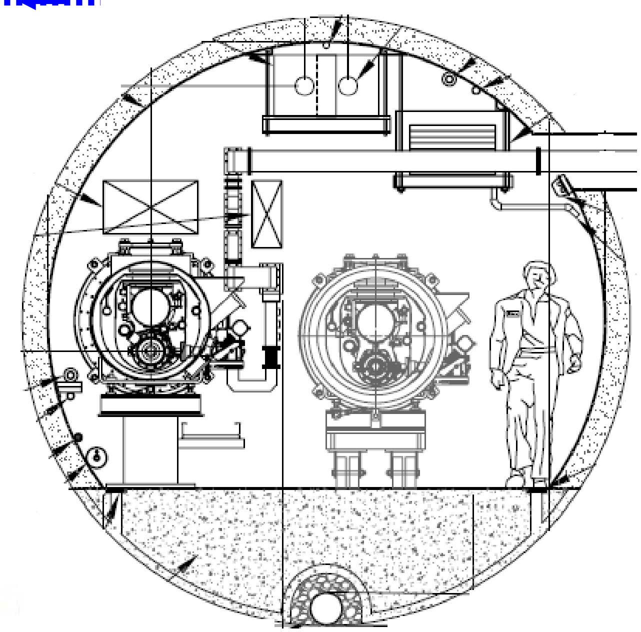
DRX Connection

- 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



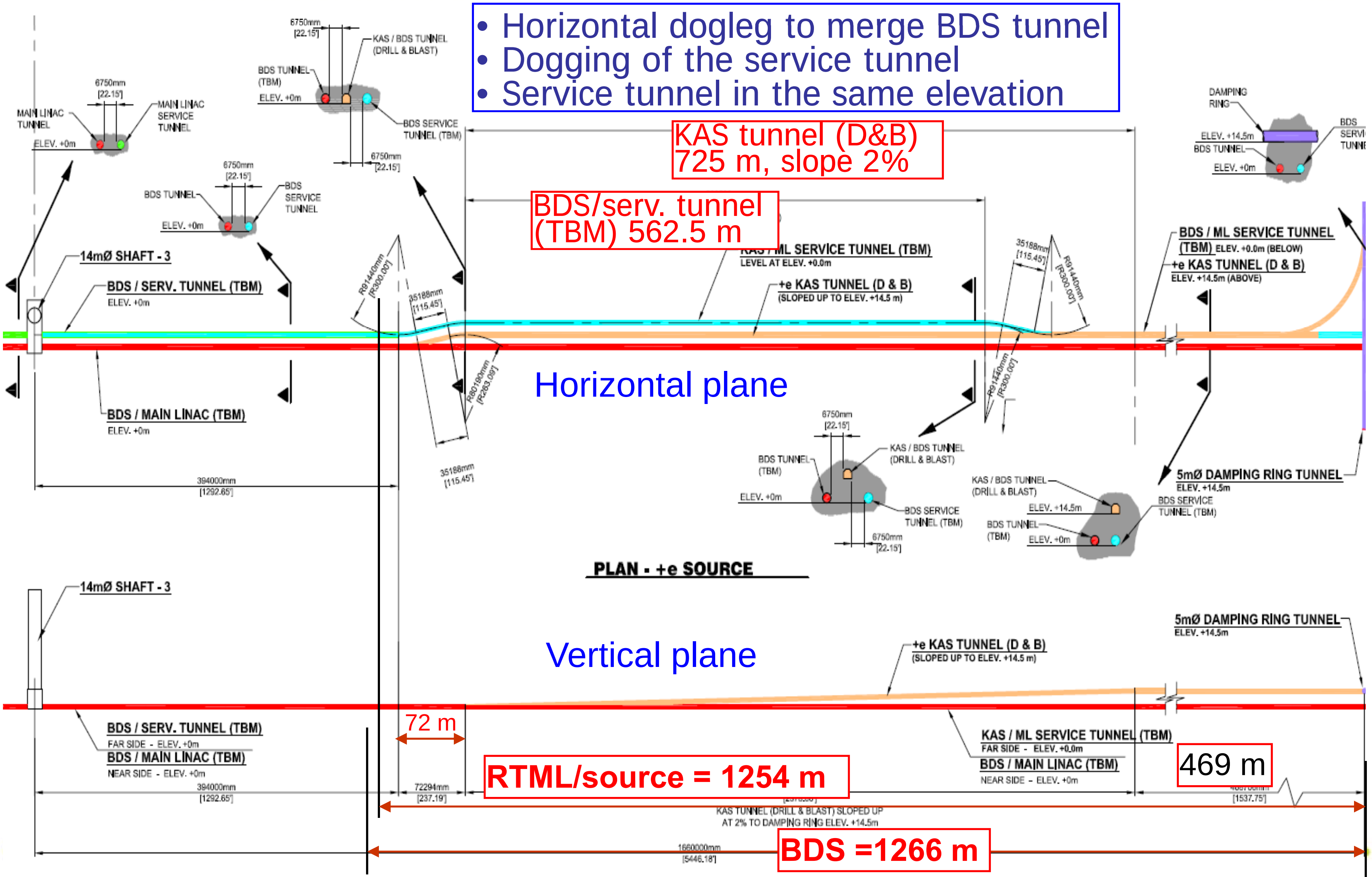




ML Tunnel - 2.14 m
Vertical beam separation

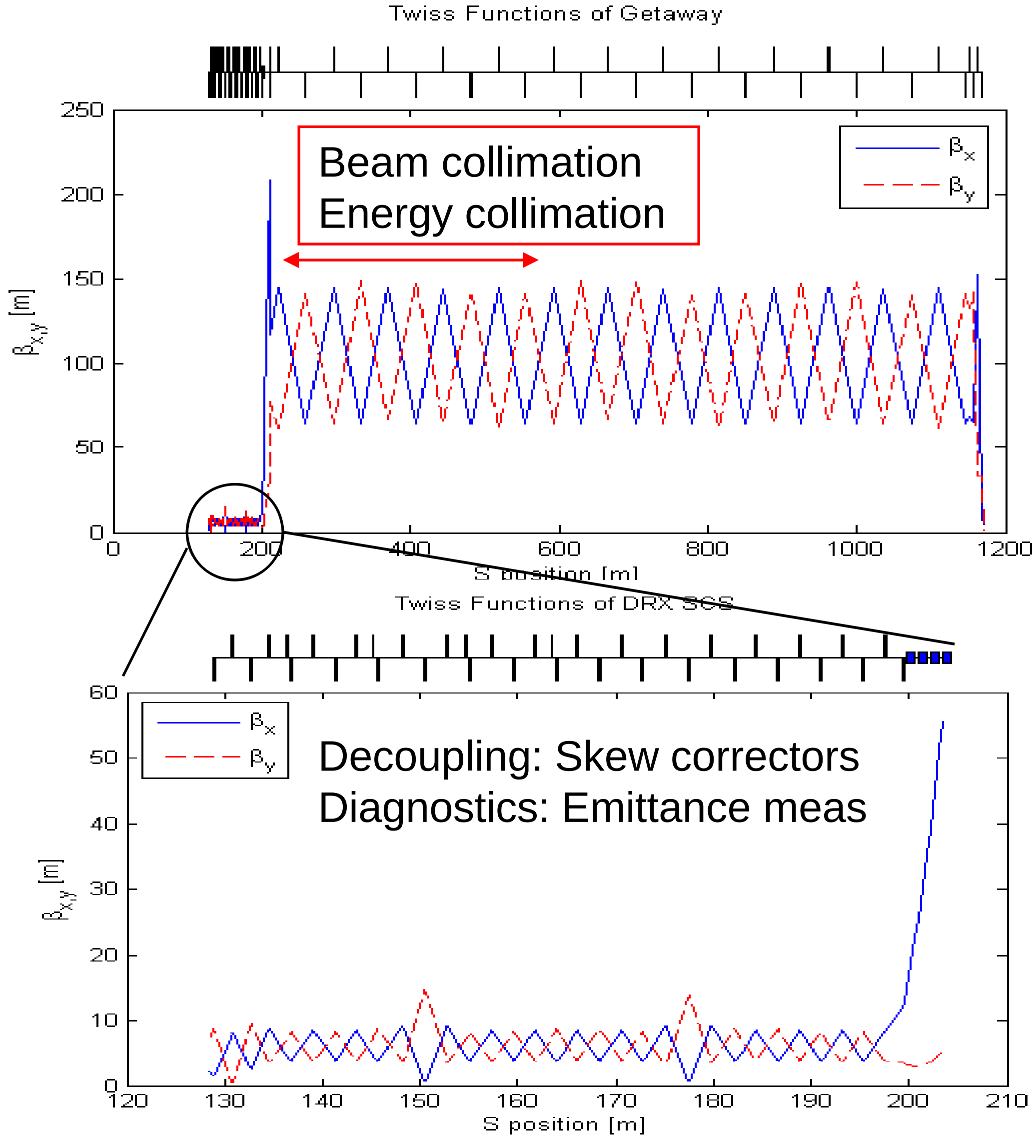
Configuration of the RTML/source tunnel (Nov.08)

- Horizontal dogleg to merge BDS tunnel
- Dogging of the service tunnel
- Service tunnel in the same elevation



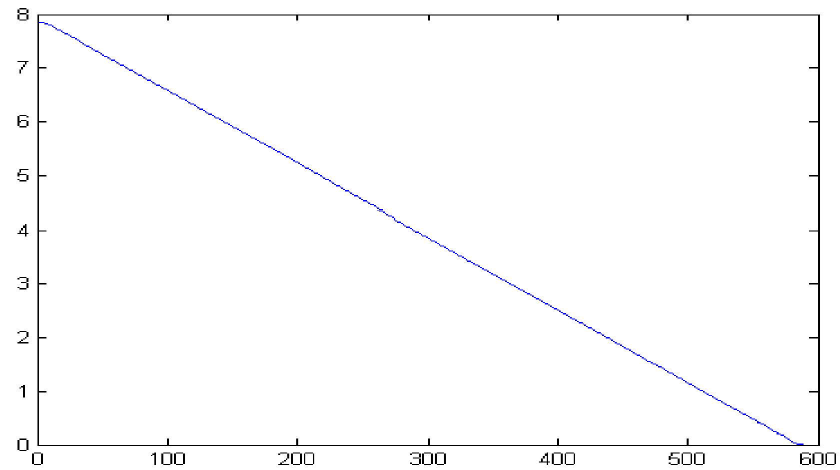
"Getaway" Straight (or "DR Stretch")

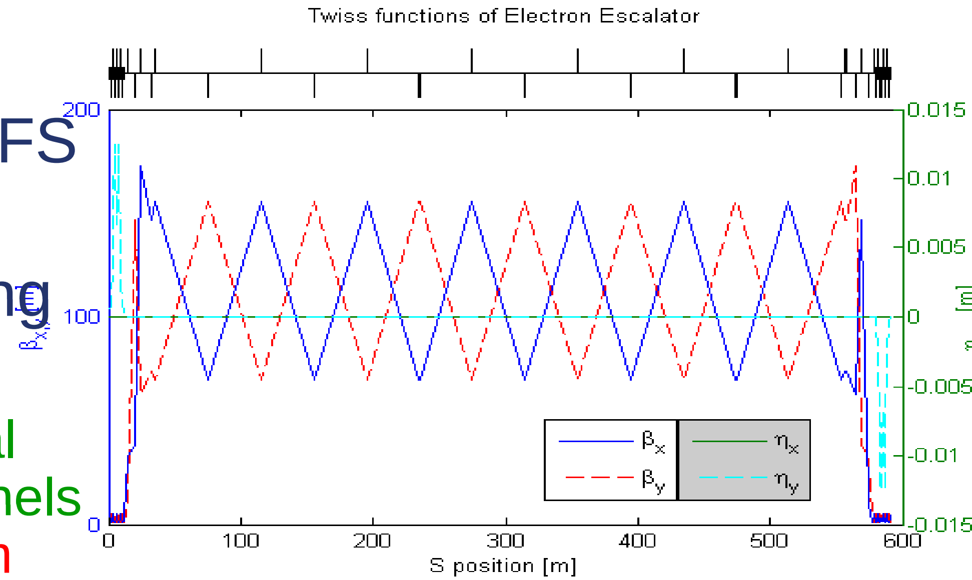
- About 1.1 km long
- Has two parts
  - **"Low-beta" region with decoupling and emittance measurement**
  - **"High-beta" region with collimation system**
- Includes PPS stoppers
  - **For segmentation**
- Good conceptual design
  - **Need to match exact required system lengths**
  - **Beta match between low- and high-beta optics not great**
- Length of "Getaway" can be minimized to ~ 500m



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
  - Shorter length for smaller vertical separation of the DR and ML tunnels and larger slope, min ~200-300 m





e⁻ source (RDR)

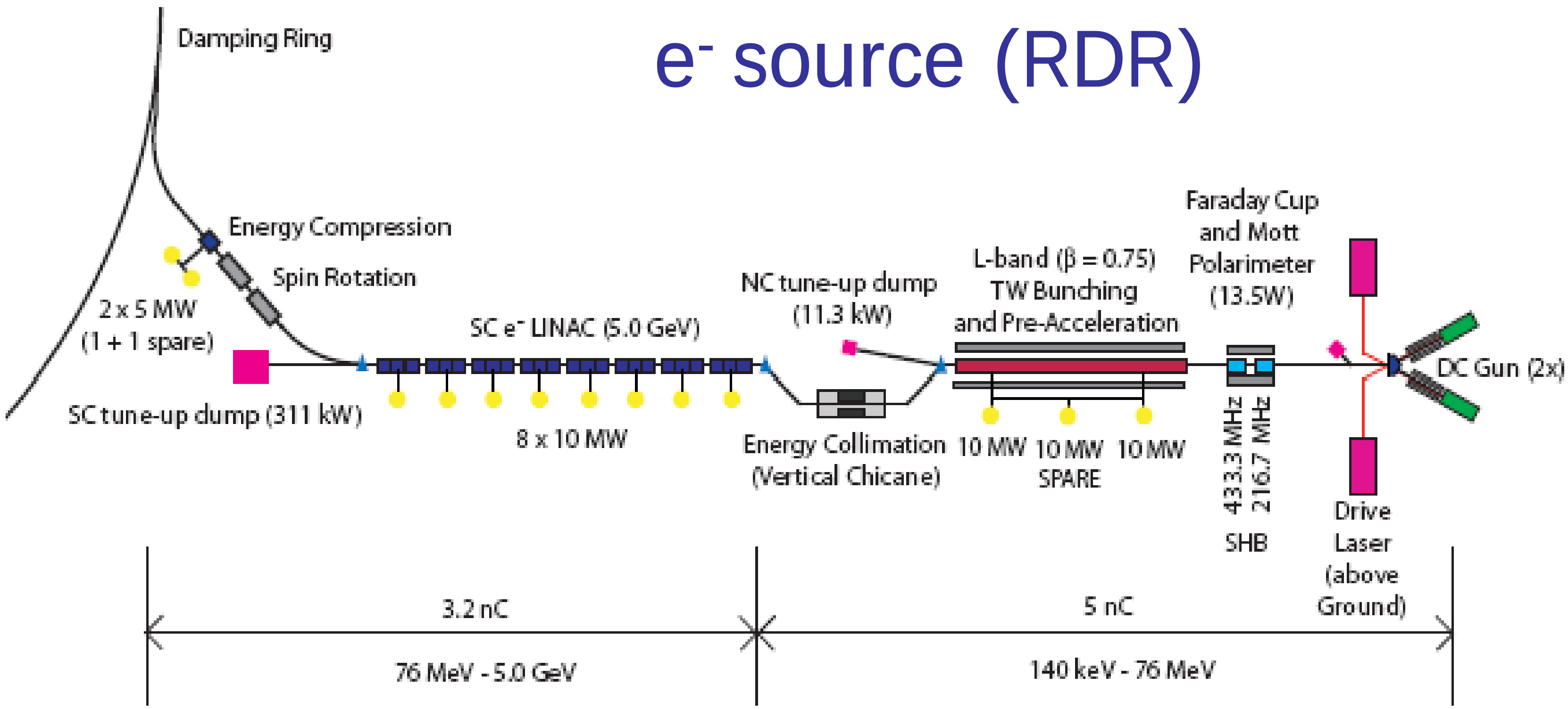


FIGURE 2.2-1. Schematic view of the polarized Electron Source.

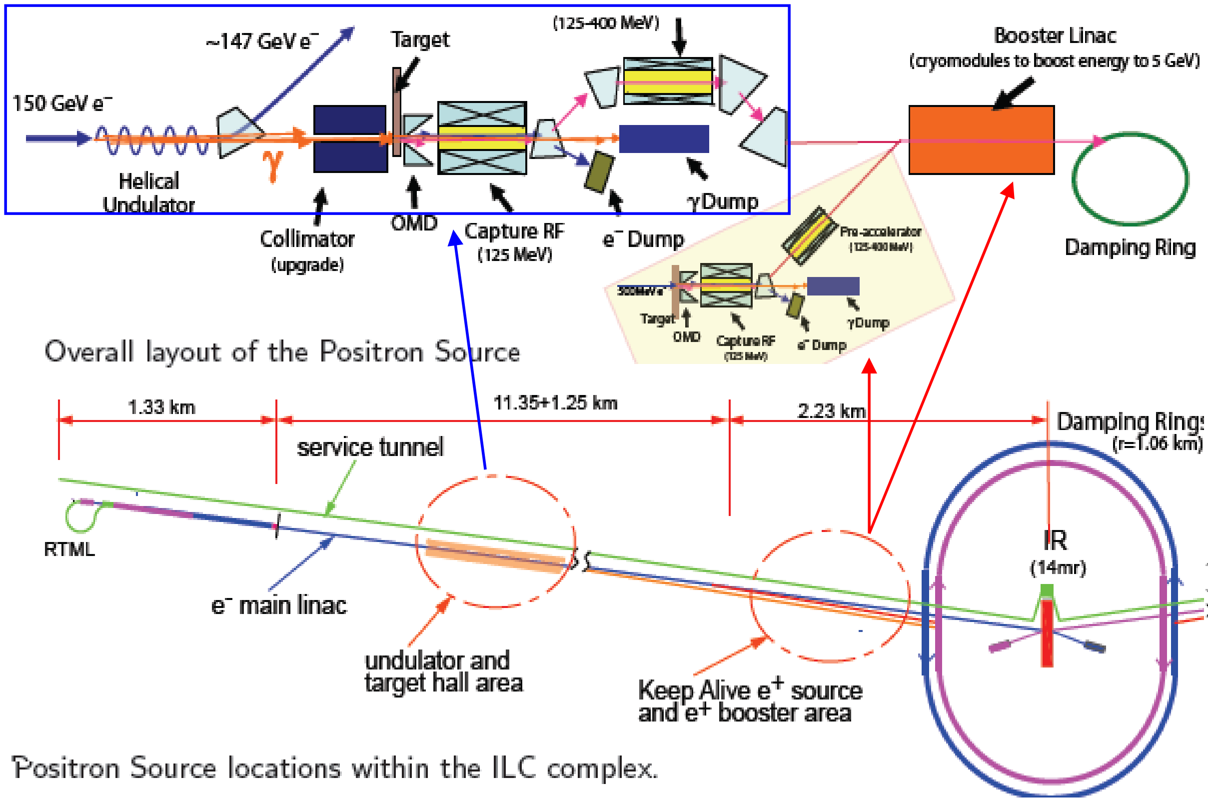
TABLE 2.2-4
System lengths for the e- source beamlines.

Beam Line Section	Length
Gun area	7 m
NC beam lines	14 m
Chicane + emittance station	54 m
SC beam lines	245 m
eLTR	157 m
Dumplines	12 m
Total beam line length	489 m
Total tunnel length	505 m

<u>Minimum RTML /e⁻ source Tunnel</u>

- DR elevation
- Total Length =505 m, straight tunnel =350 m
- SRF Linac = 245 m
- Needs Service Tunnel (with min separation)

e^+ source (RDR)

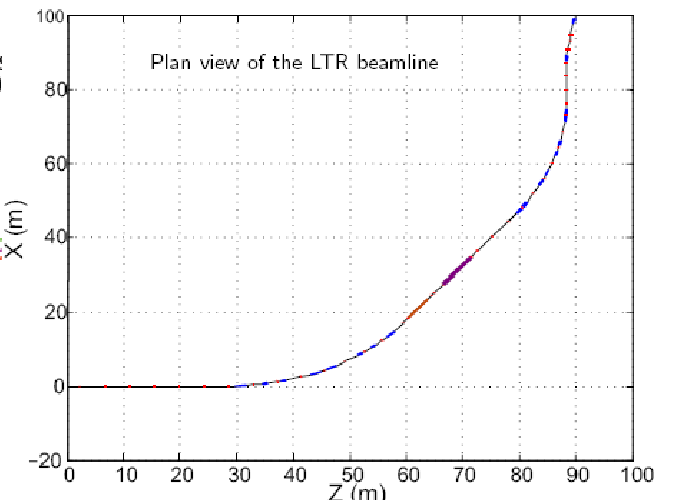


Overall layout of the Positron Source

Positron Source locations within the ILC complex.

Positron Source beamline lengths.

Area	Length (m)
Undulator chicane insert	1257
Undulator center to target	500
Undulator insert length	200
Target Hall length	150
400 MeV long transport line	5032
Total RF acceleration length	350
Damping Ring injection line	431



(matching happens from 1-25 meters and DR injection is at z=90meters)

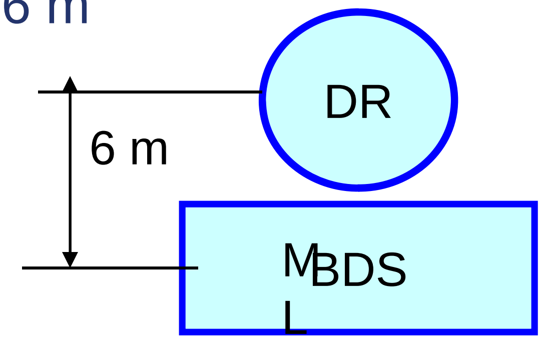
KAS and Booster area

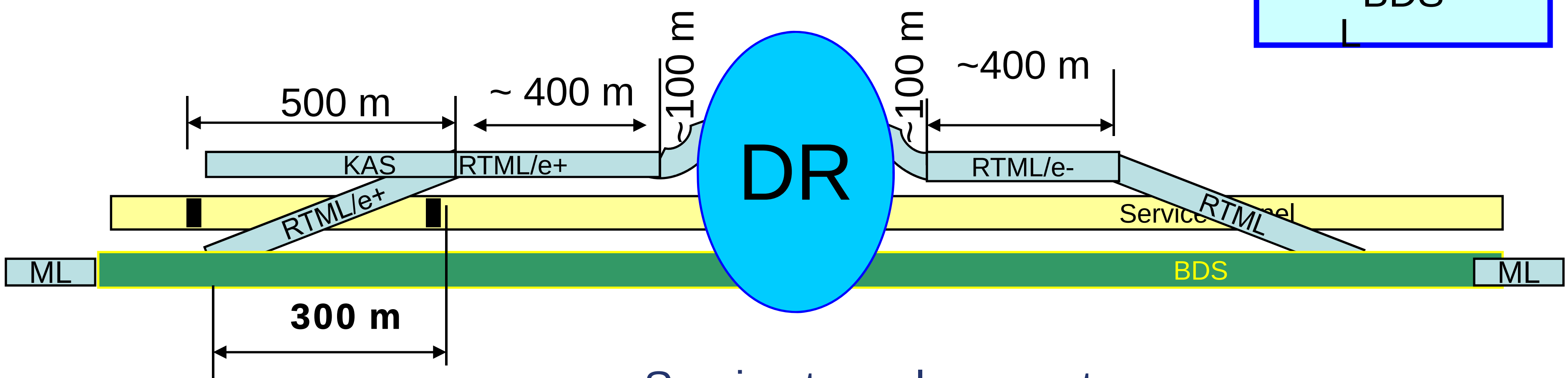
- Total 941 m of separate tunnel (KAS, Booster Linac and LTR)
  - KAS occupies ~ 500 m of tunnel just before SC 5-GeV Booster Linac
  - 5 GeV Booster SC Linac ~ 350 m
  - Linac to DR Beam Line (LTR) ~100m

Possible configuration of the RTML/source tunnels

Minimum length of separate RTML/source tunnel

- Smaller vertical separation DR/BDS tunnel: 10m → 6 m
- Length constrains:
  - Electron source side (straight) ~ 500 m
  - Positron source: 950m=500(KAS)+450m(SCL/TRL)
  - RTML tunnel length ~ 900 m (now ~1250 m)



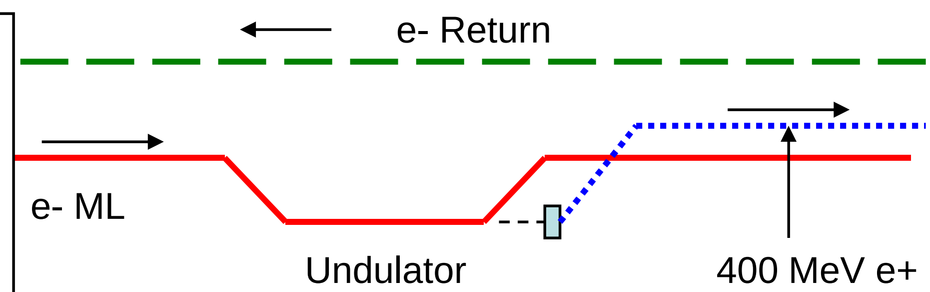


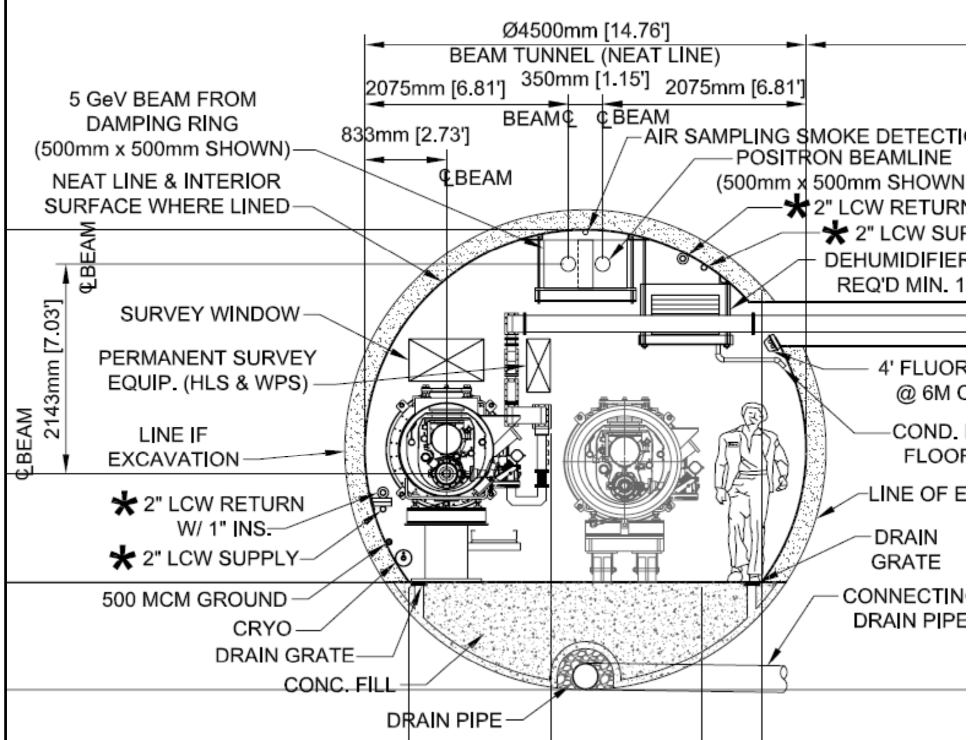
Service tunnel concept:

- Straight →good for TBM technology
- RTML tunnel crosses service tunnel
- Radiation issues ???

Return Line

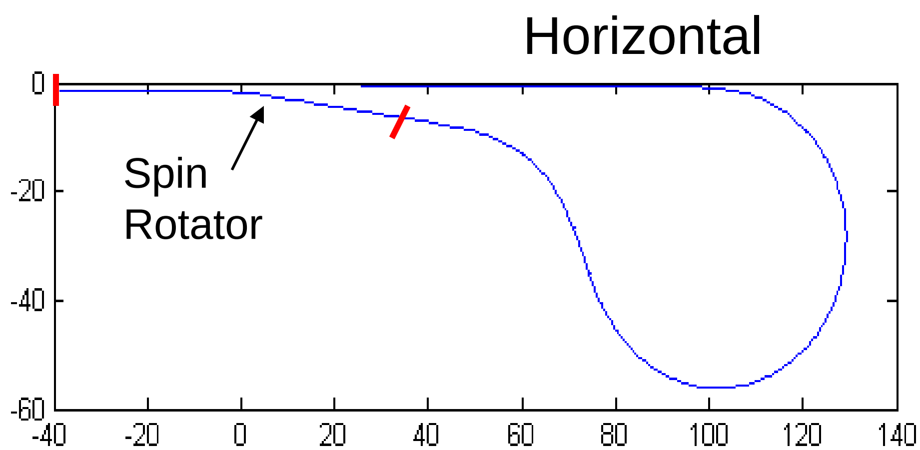
- Weak FODO lattice at ML ceiling elevation (1Q/~36m), XY_{corr}+BPM
- Vertically curved tunnel thru ML area
  - **Dispersion matching via dipole correctors**
- Laser-straight tunnel thru BC area
- Electron line ~1.2 km longer than positron
  - **Goes thru undulator area**
- Electron Return line and positron transfer line need to be exchanged
- Shorter e- Return line if no undulator (1.2km)

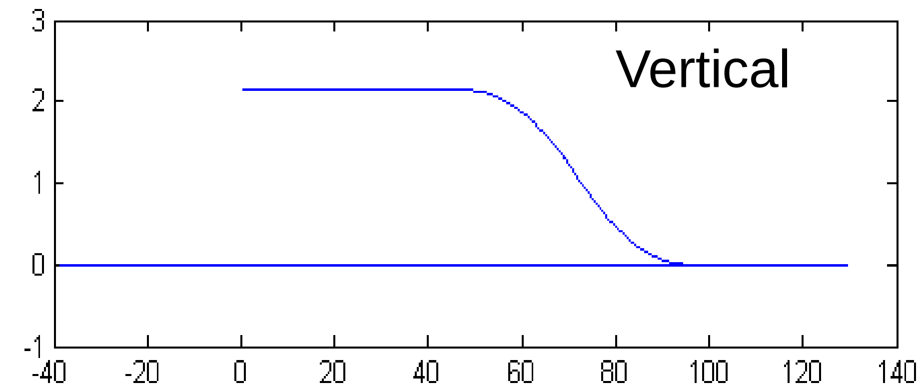




Turnaround (D & B)

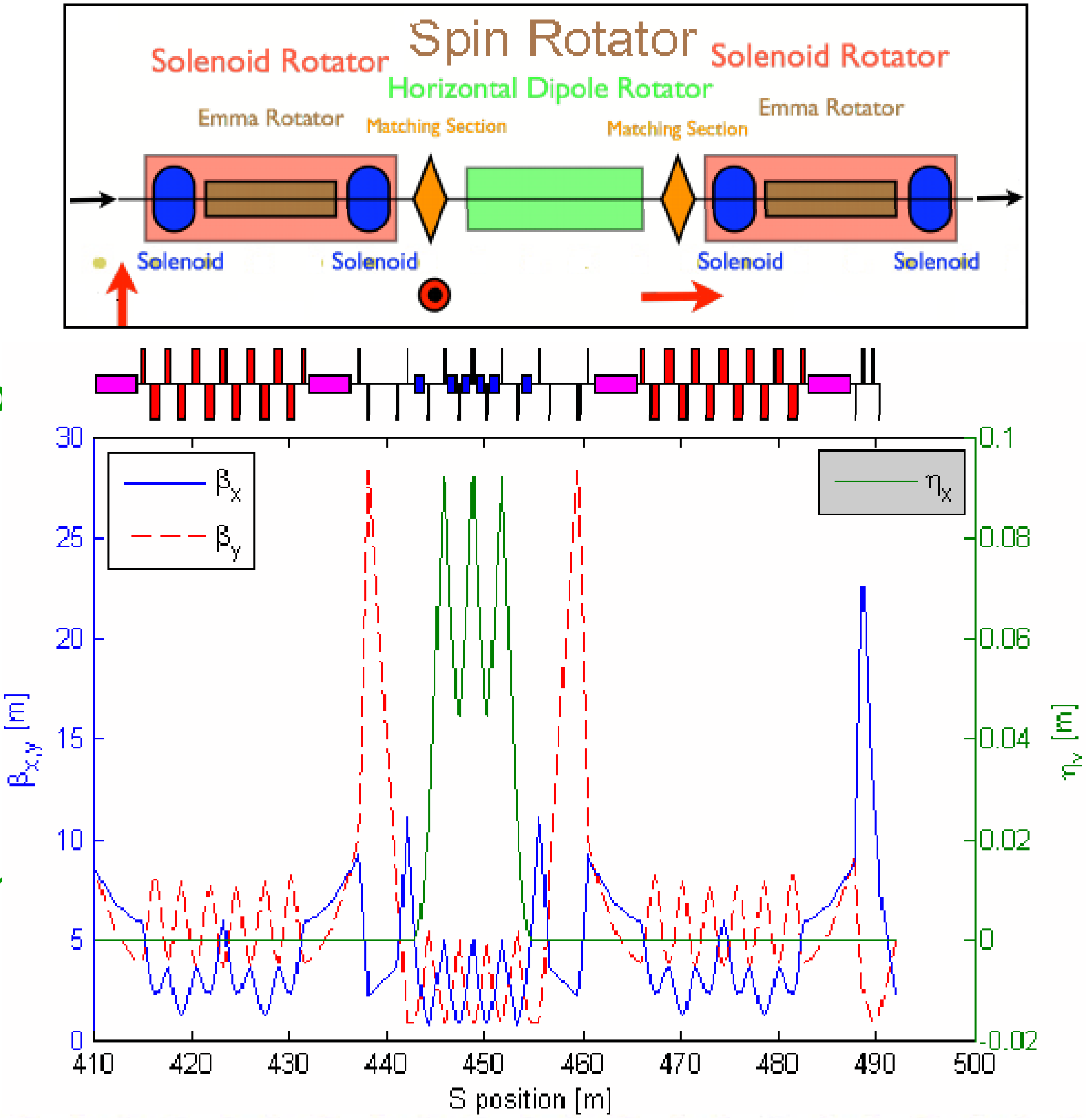
- Actually does 3 jobs
  - **Turns the beam around**
    - Note: need to bend *away* from service tunnel
  - **Brings beam down from ceiling to linac elevation (near floor)**
    - Vertical dogleg
  - **Adjusts x position to meet linac line**
    - Horizontal dogleg
- Order: H dogleg, V dogleg, turnaround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





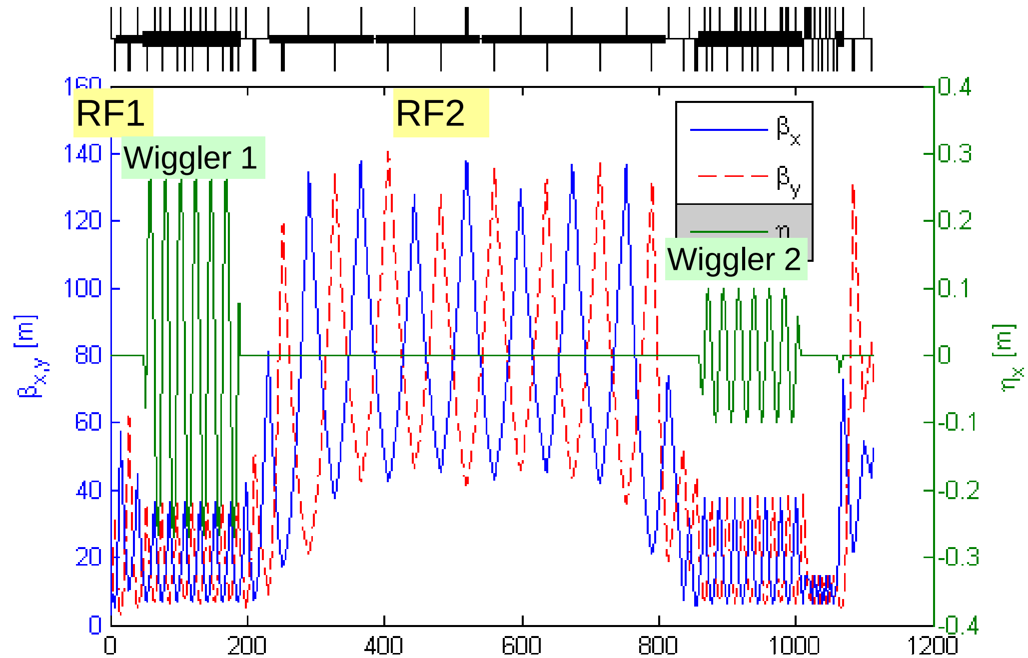
Spin Rotation

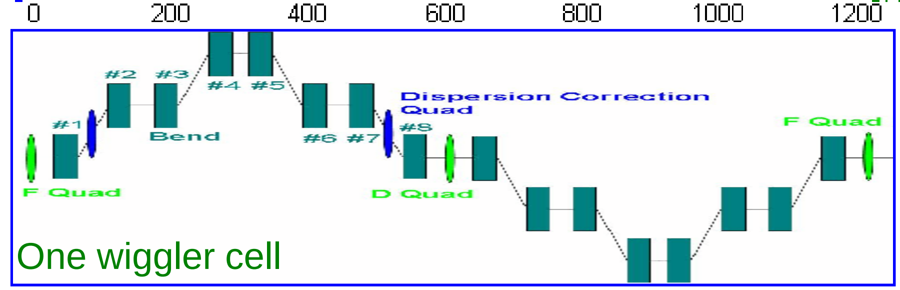
- Design based on Emma's from *NLC ZDR;*
- *Arbitrary spin orientation in IP*
- Paired solenoids separated by Emma rotator to cancel xy couping
  - **2 solenoids with Emma rotatc between them**
    - Rotate spin 90° in xy plane while cancelling coupling
  - **8° arc**
    - Rotate spin 90° in xz plane
  - **Another 2 solenoids + Emma rotator**
- Basic design seems sound
  - **Very small loss in polarizatior from vertical bending in linac tunnel**



ILC Baseline Bunch Compressor

- Longitudinal emittance out of DR:
  - ***6mm (or 9 mm) RMS length***
  - ***0.15% RMS energy spread***
- Want to go down to 0.2-0.3 mm
- *Need some adjustability*
- Use 2-stage BC to limit max energy spread
  - ***1st: Compress to 1 mm at 5 GeV***
  - ***2nd: Accelerate to 15 GeV and Compress to final bunch length***
- Both stages use 6-cell lattice with qua and bends to achieve momentum compaction (wiggler)
  - ***Magnet aperture ~ 40cm***
- Total Length ~1100 m (incl. matching and beam extraction lines)
- Minimum design is possible if assume compression 6→0.3 mm only
  - Shorter 2-stage BC
  - Or short single-stage BC
  - Cheaper magnets



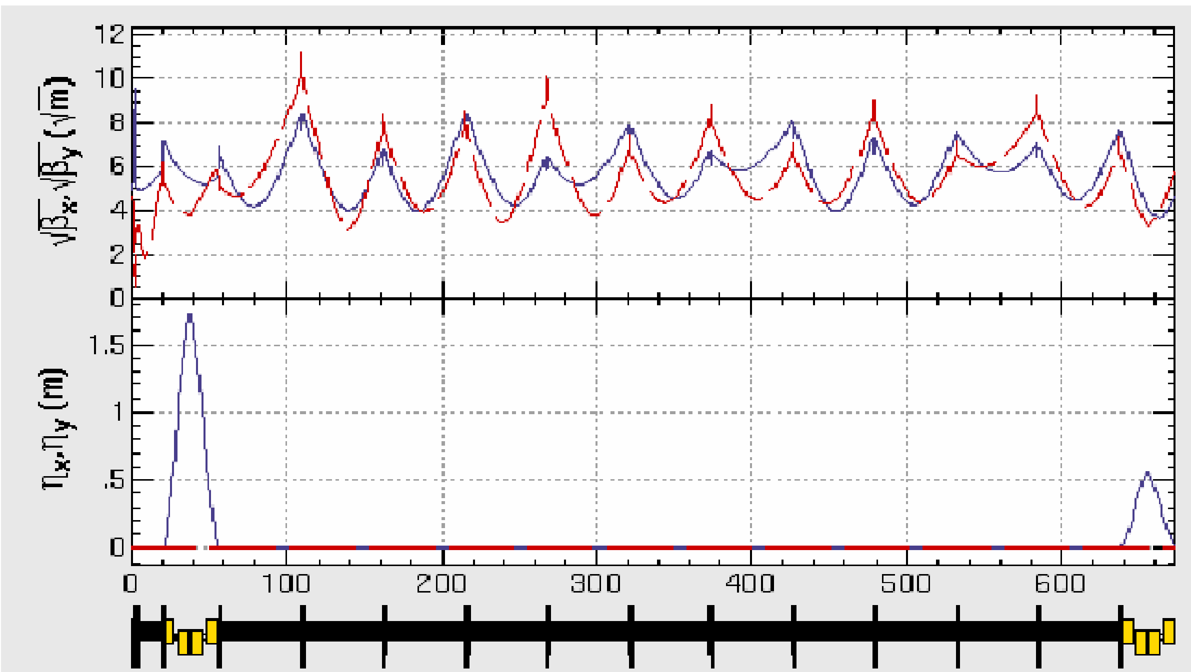


RF system

- BC1: 3 CMs with quads (+spare kly)
- BC2: 14 RFunits (3CM's each)+1spare
- Total 48 CM's per side

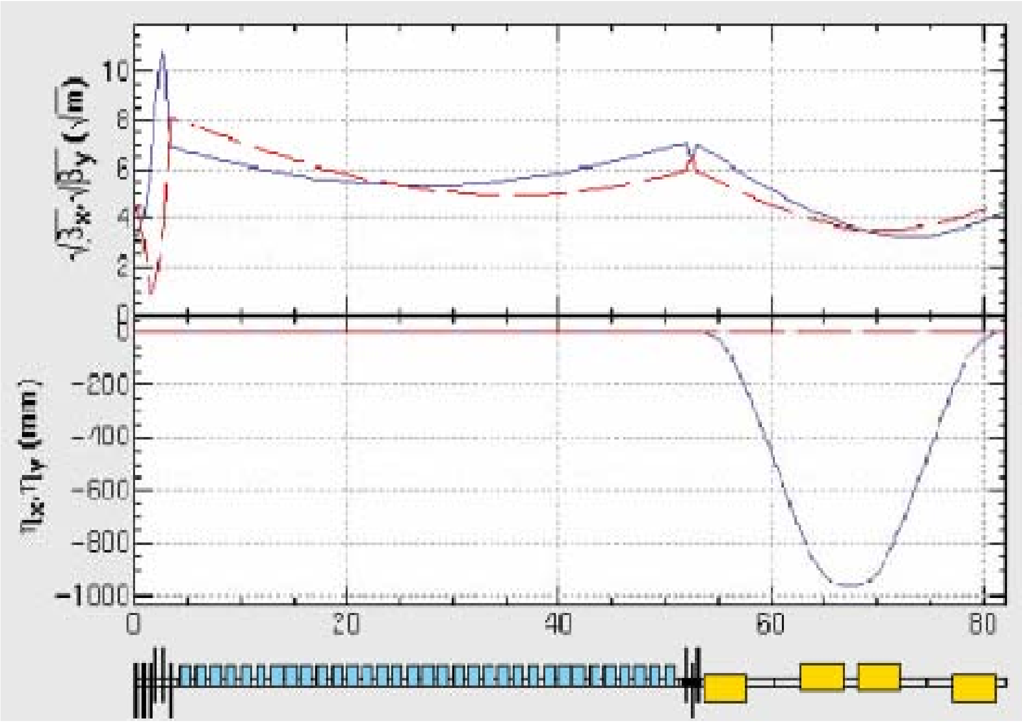
Alternative Bunch Compressor

- An alternate bunch compressor design exists (~700m)
  - ***6-cell wigglers (~150 m each, 102 bend magnets) replaced by chicanes (~40 m each, 4 bend magnets)***
  - ***Advantages:*** *Shorter, Simpler, Cheaper (less magnets)*
  - **Disadvantages:** *Big x offset from straight line (~1.8 m)*
    - » *Doesn't have natural locations for dispersion tuning quads*
  - ***Length Saving: ~ (200 ÷ 300 m)***



Initial Energy Spread [%]	0.15
Initial Bunch Length [mm]	6.0
Initial Emittance [μm]	8 / 0.02
BC1 Voltage [MV]	348
BC1 Phase [°]	-114
BC1 R_{56} [mm]	-474.2
End BC1 Bunch Length [mm]	1.1
End BC1 Energy [GeV]	4.86
End BC1 Energy Spread [%]	1.1
BC2 Voltage [MV]	11,800
BC2 Phase [°]	-45
BC2 R_{56} [mm]	-50.8
End BC2 Bunch Length [mm]	0.15
End BC2 Emittance [μm]	8.3 / 0.02
End BC2 Energy [GeV]	13.26
End BC2 Energy Spread [%]	2.2

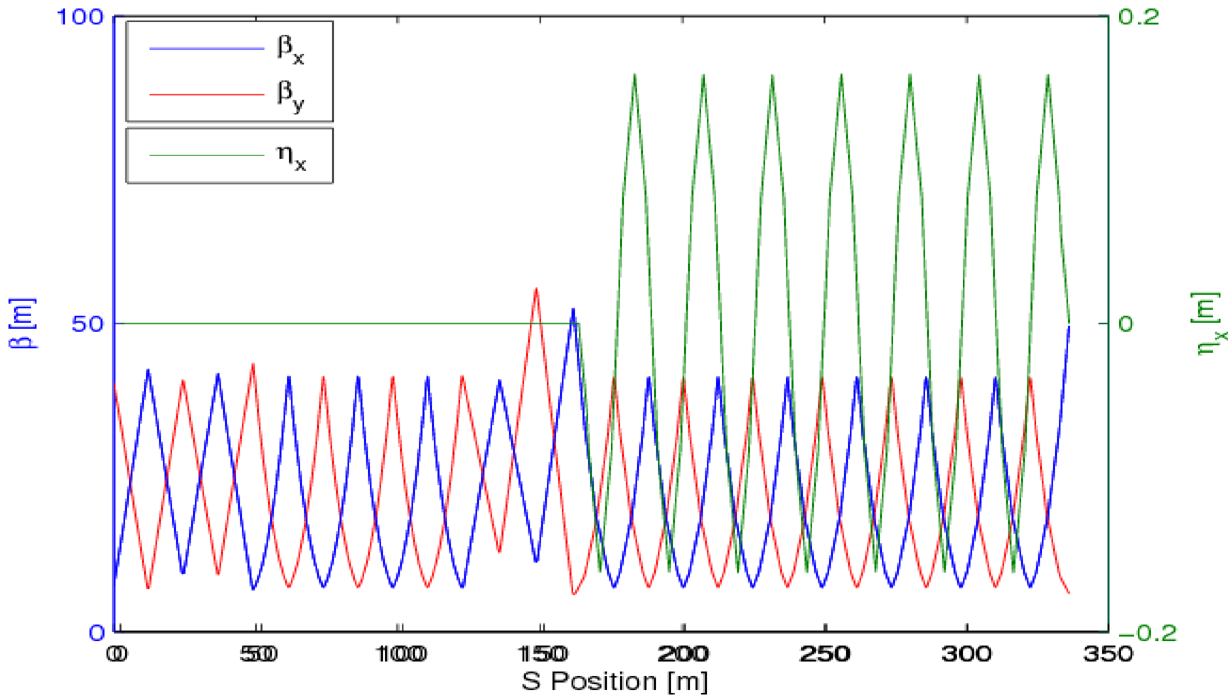
Short Single stage BC (Eun-San Kim)



Parameter	Units	Values
Legnth	m	80
Initial beam energy	GeV	5
Initial bunch charge	nC	3.2
Initial rms energy spread	%	0.15
Inital rms bunch length	mm	6
Initial emittance (H/V)	μm	8 / 0.02
RF phase	degree	-118
Chicane R_{56}	mm	-190
Bending angle	deg.	6
Length of a bend	m	4.16
End rms bunch length	mm	0.3
End energy	GeV	4.5
End bunch charge	nC	3.2
End emittance (H/V)	μm	8.3 / 0.02
End energy spread	%	3.5

- Compress 6mm →0.3mm only
- Acceleration 4.5→15 GeV will require 15 RFunits (incl. 1 spare) ~ 600 m
- Energy spread @ 15 GeV 3.5%*(4.5/15) ~ 1%
- BC length ~700m. Saving ~ 1100-700 = ~ 400m
- No ELBC2 extraction line
- Disadvantages: No flexibility, tunability, larger emittance growth ???

Single-stage BC (PT, TOR, AW) - 2005



Input beam parameters

- *Energy = 5 GeV*
- *Energy spread = 0.15%*
- *Bunch length = 9 mm*

(In new DR design bunch length = 6mm)

Single –stage BC:

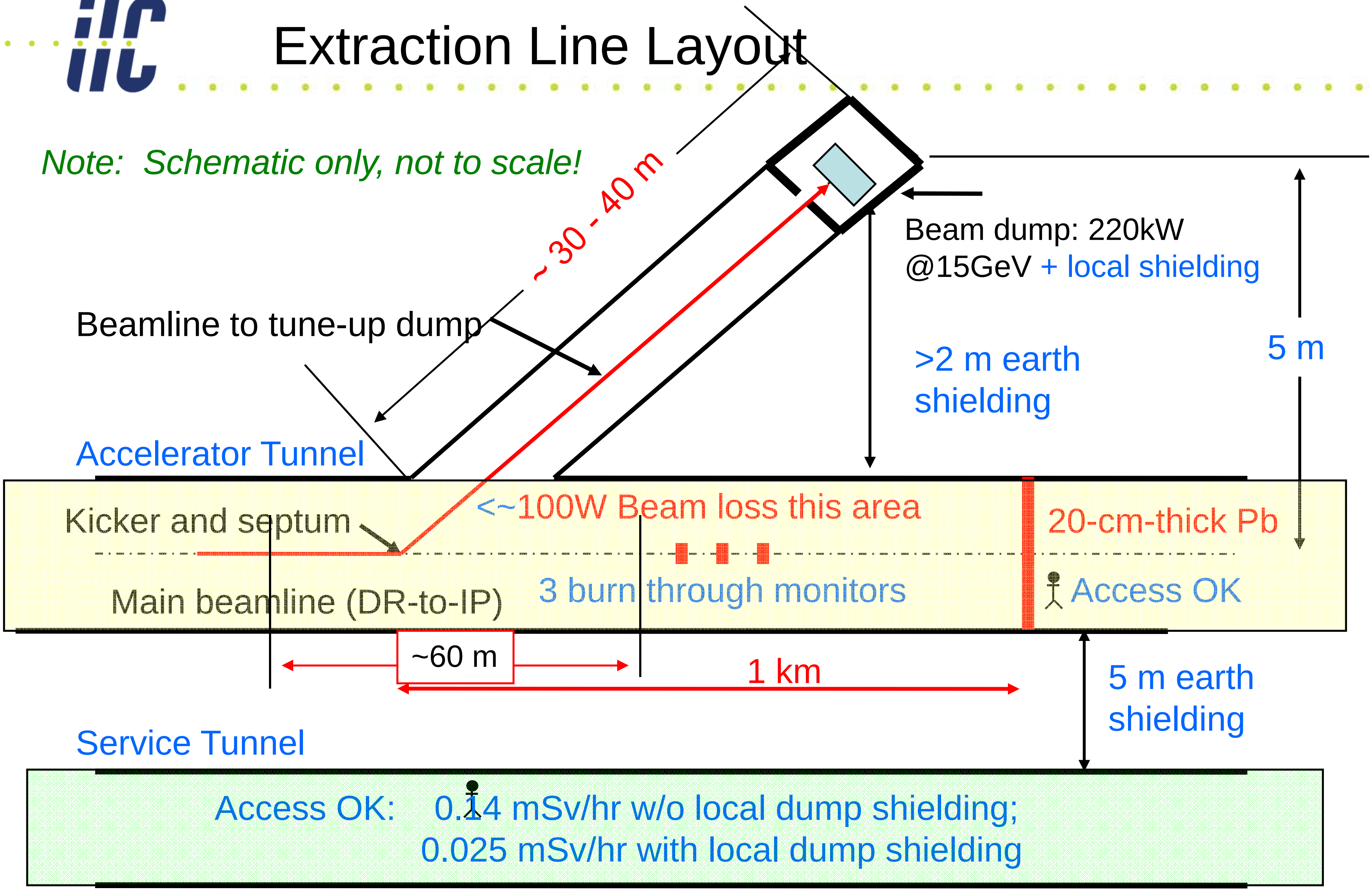
- Compression 9→0.3mm; energy spread = 4.5%
- Compression 9→0.2mm; energy spread = 6.75%
- In case 6→0.3mm energy spread will be ~ 3%
- Acceleration from 4.6→15 GeV will reduce energy spread by factor of ~3.2
- BC length ~340m, post-acceleration ~600m, Saving 1100-940 = ~ 160m
- Disadvantages (compare to 2-stage BC):
  - Low flexibility and tunability, emittance growth ???
  - No possibility for energy variation, needed for BBA alignment in ML

Pulsed Extraction Lines

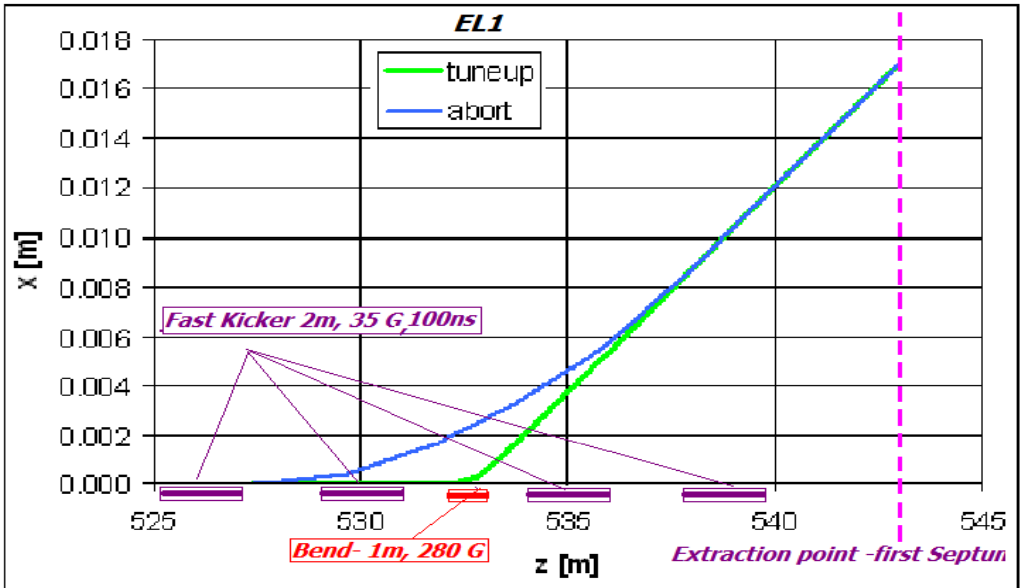
- 3 Extraction Lines in each RTML side for emergency beam abort (MPS) and tune-up
  - **EL1 - after DR exit, diagnostics, global correction**
  - **5 GeV, σ_E = 0.15%**
    - Keep DRs running @ full power during access
    - Keep DRs and extraction tuned during access
    - MPS abort (~100ns)
  - **ELBC1 - 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**

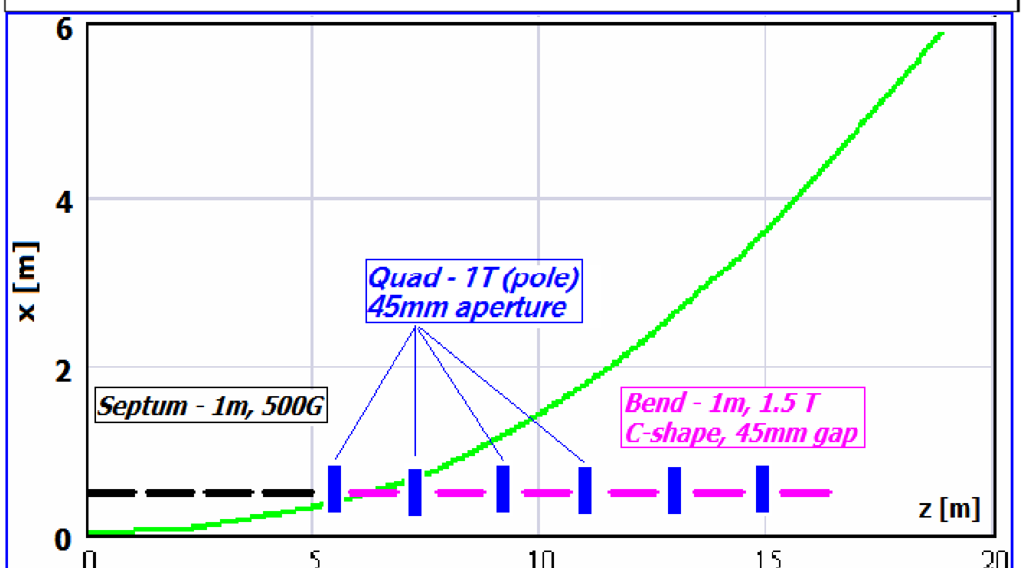
Extraction Line Layout

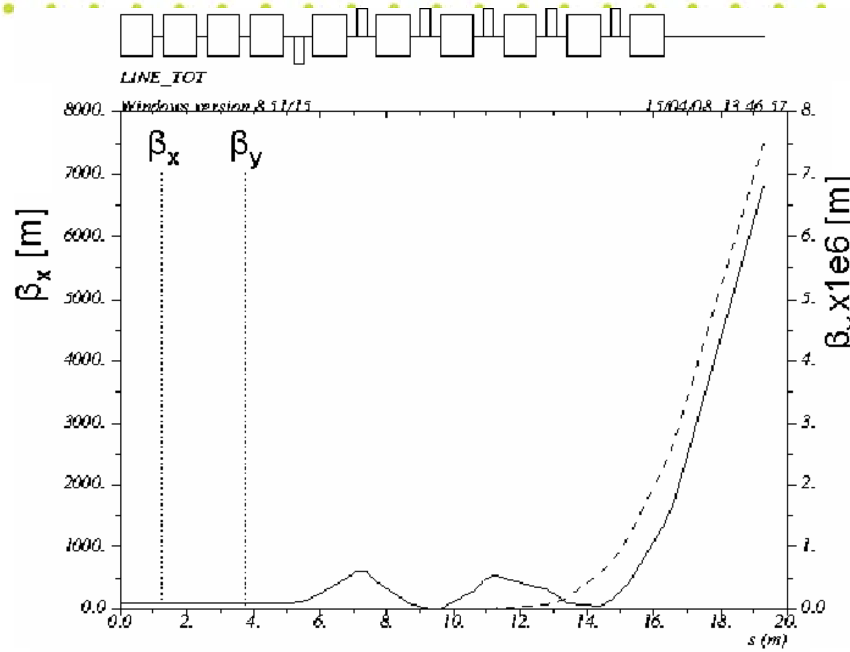
Note: Schematic only, not to scale!

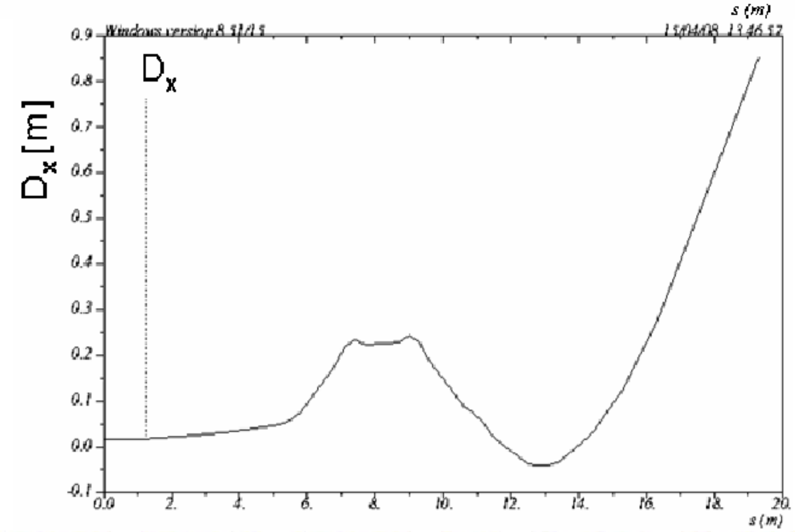


EL1 design


EL1
tuneup
abort
Fast Kicker 2m, 35 G,100ns
Bend- 1m, 280 G
Extraction point -first Septun
x [m]
z [m]
0.018
0.016
0.014
0.012
0.010
0.008
0.006
0.004
0.002
0.000
525
530
535
540
545

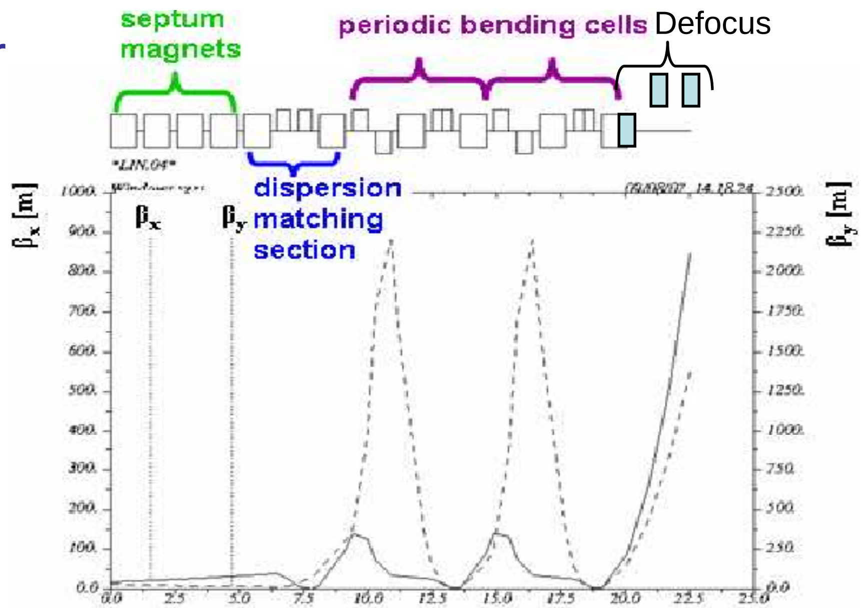

Septum - 1m, 500G
Quad - 1T (pole)
45mm aperture
Bend - 1m, 1.5 T
C-shape, 45mm gap
x [m]
z [m]
0
2
4
6
0
5
10
15
20

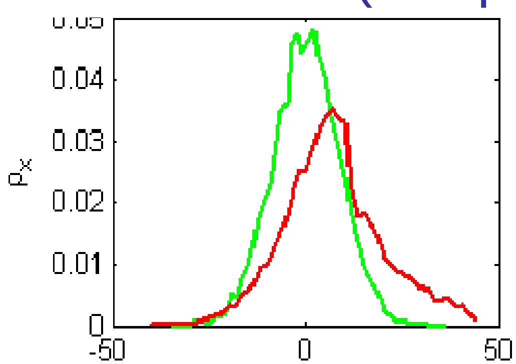

LINE_TOT
Windows version 8.51/15
15/04/08 13.46.57
β_x
β_y
β_x [m]
β_y x1e6 [m]
s (m)


Windows version 8.51/15
15/04/08 13.46.57
D_x
D_x [m]
s (m)

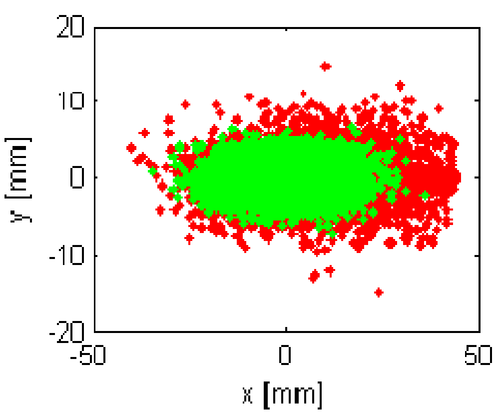
ELBC2 Design

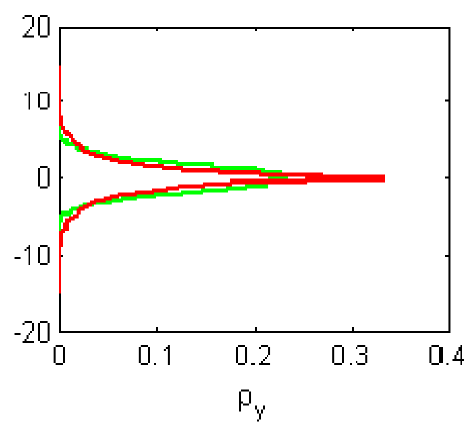
- ELBC2 similar to ELBC1, but ~ 5m longer (extra bending cell)
  - 6 septum+6 bends+12 quads,
  - two collimators: 5.2 kW (protect quads) and 14.1 kW (dump window)





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

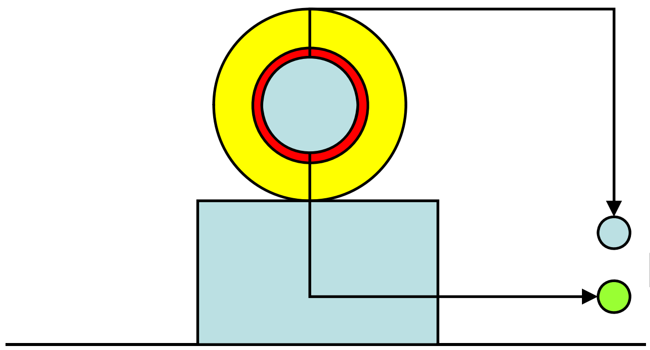




	2 coll	1 coll	No coll
Final quads	1T 45mm	1T 45mm	2T 80mm
Collimat	5.2 kW 14.1kW	5.2kW	No coll
Dump window	12.5 cm	30 cm	100 cm

Six ~220kW Aluminum Ball Dumps

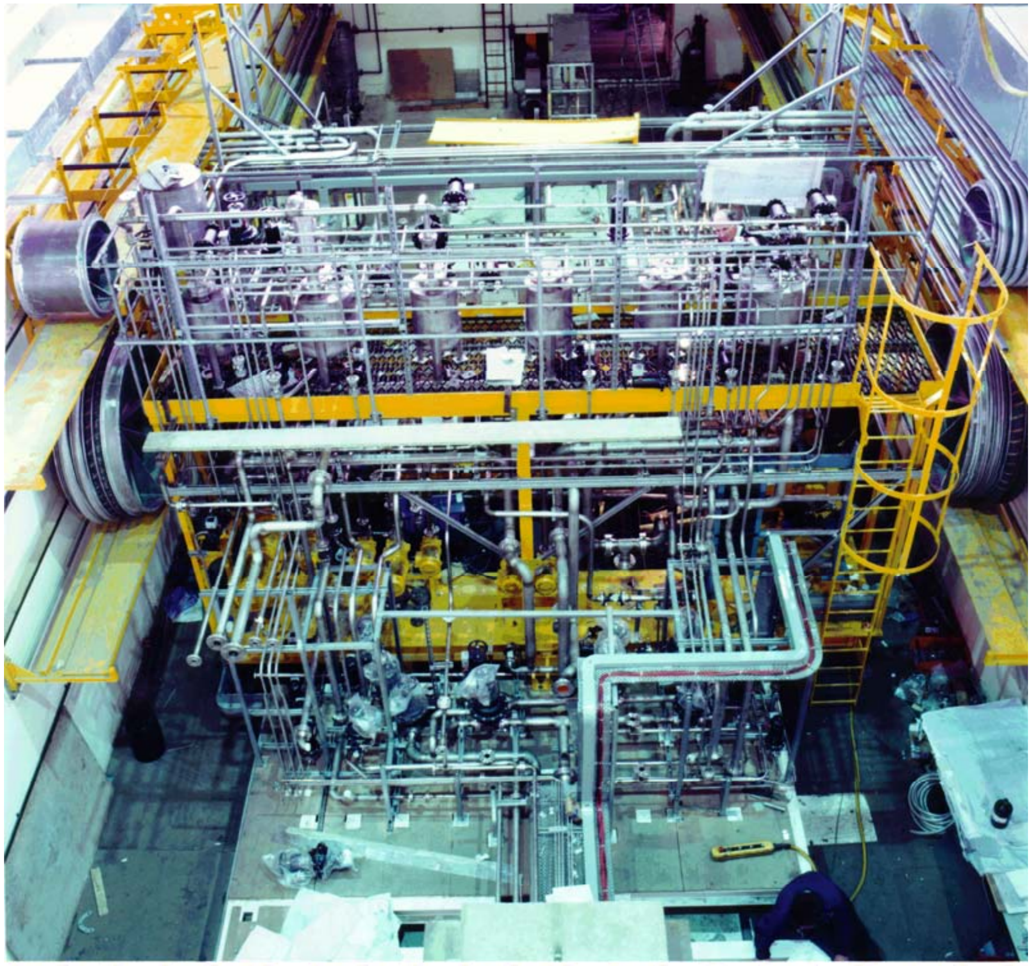
50cm Diameter x 2m long Aluminum Ball Dump with Local Shielding



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



Conclusion

- New DR increases length of RTML system by ~300 m from each side, with minor cost increasing (cost of the tunnels still the same)
- Possible Cost saving options:
  - Minimize length of RTML/source tunnel (D & B) from 1254 m to ~ 900 m per each side
  - Alternative 2-stage or 1-stage bunch compressor
  - Reduce pulsed extraction Lines from 3 per side to 2 per side
- Need discussion with CFS, e+/e- source groups
- Lattice design