# Accelerator Design and Integration towards an updated ILC Baseline for TDP2

SB2009 Strawman Baseline Studies

Status Report Presented to the PAC, November 2009

Ewan Paterson (presented by Marc Ross)

# Rationale and Goals

- **Cost constraint in TDR**
  - **Updated cost estimate in 2012 ≤6.7 BILCU**
  - **Need margin against possible increased component costs**
- **Process forces critical review of RDR design**
  - **Errors and design issues identified**
  - **Iteration and refinement of design**
  - **More critical attention on difficult issues**
- **Balance for risk mitigating R&D**
  - **Majority of global resources focused in R&D**
  - **Important to prepare / re-focus project-orientated activities for TDP-2**
- **Need for design options and flexibility**
  - **Unknown site location**

We believe this will lead to a more

- <u>Robust</u>
- <u>Mature</u>
- <u>Defendable</u>

Design.

Basically a better design.

**Presented by NJW at ALCPG09 on 9/23/09**

# Siting 'Flexibility'

- Main Linac tunnel / surface building structure configuration depends strongly on High Level RF system
- We intend to develop *two different HLRF* systems to provide workable technical solutions for possible different site topography
  - Parallel HLRF R & D underway to support each option
  - Parallel design work – CFS etc.
- Important component of CFS strategy

# Two Important Documents

Ideas & Concepts

***ILC Minimum Machine Study Proposal***

January 2009

January 2009

Prepared by the Technical Design Phase Project Management

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Initial baseline Proposal (Working Assumptions)

***Summary report of the first meeting on Accelerator Design & Integration 28-29th May, DESY***

June 2009

5th June, 2009

Editors: Ewan Paterson (SLAC)
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ILC-EDMS ID: D*879845

Contains proposed parameter tables

# SB-2009 Proposals (PMs)

1. **A Main Linac length consistent with an optimal choice of average accelerating gradient**
   - **RDR: 31.5 MV/m, to be re-evaluated**

2. **Single-tunnel solution for the Main Linacs and RTML, with two possible variants for the HLRF**
   - **Klystron cluster scheme**
   - **DRFS scheme**

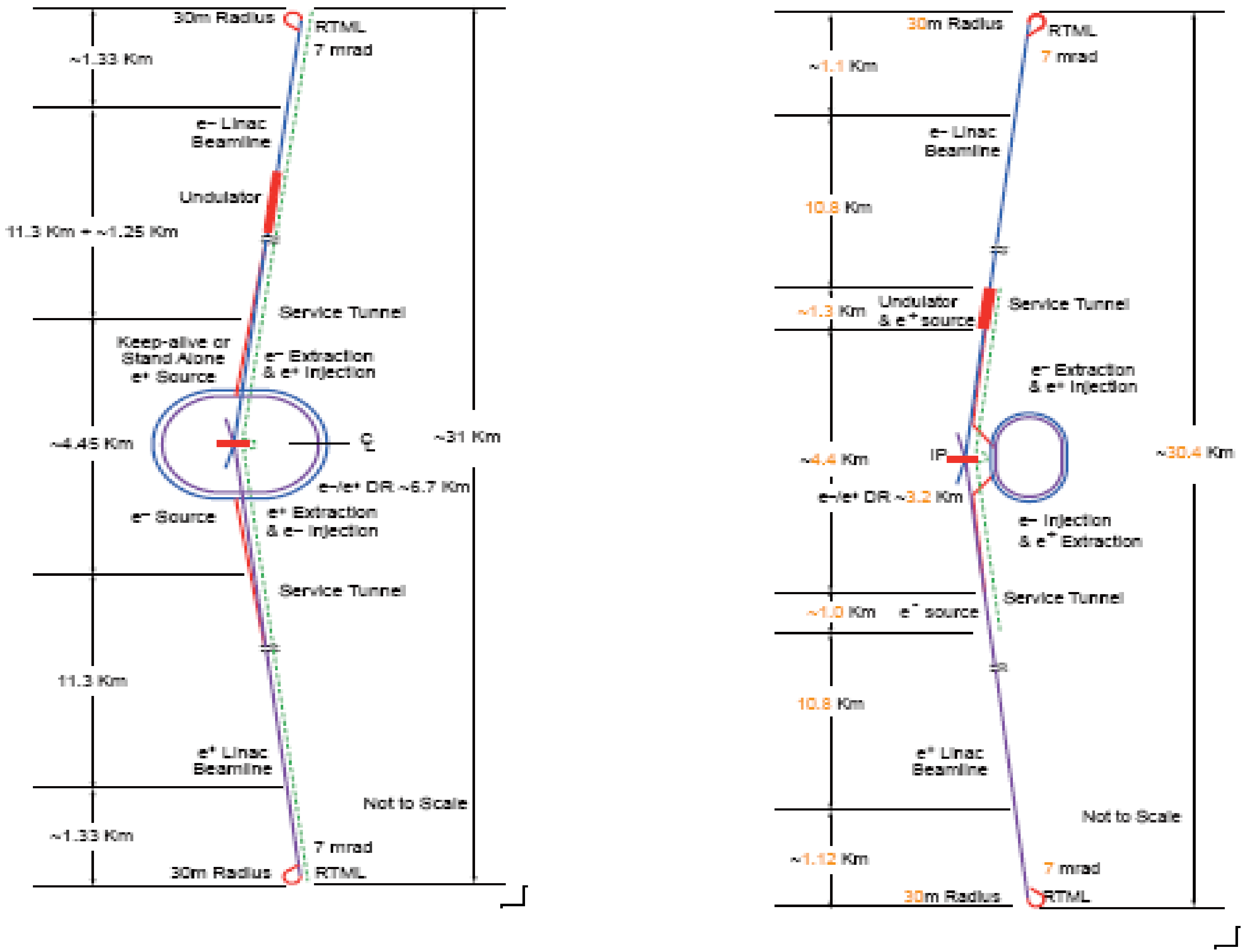
3. **Undulator-based e+ source located at the end of the electron Main Linac (250 GeV)**
   - **Capture device: Quarter-wave transformer, conservative with continued R&D on alternates**

# SB-2009 Proposals (PMs) cont

4. **Reduced parameter set (with respect to the RDR)**
   - $n_b$ = 1312 (so-called "Low Power")
5. **Approx. 3.2 km circumference damping rings at 5 GeV**
   - 6 mm bunch length for either 3 or 6 km rings
6. **Single-stage bunch compressor**
   - compression factor of 20
7. **Integration of the e+ and e- sources into a common "central region beam tunnel", together with the BDS.**

**(an 8th item: 'Estimation of incremental cost for TeV upgrade' was dropped in response to reviewer comments)**

# RDR & SB2009 Layouts



# CFS is a Primary Cost Driver

- **Assumed primary advantage of SB2009 options is in reduced CFS scope but also reduced technical systems**
  - **Underground tunnel / volume, shafts, caverns…**
  - **Reduced cooling requirements**
  - **Removed, added, modified SB2009 reduces underground tunnel length by ~27 km (40%)**
- **The ongoing AD&I studies are trying to answer the following questions.**
- **05.2009 – 09.2009: *Technically optimized solutions exist***
- **What is the impact on ILC system performance and/or overall Availability?**
- **What are the cost differentials compared to RDR?**

# Now a Review of the AD&I/SB2009 Topics

## 1) Accelerating Gradient and Linac Length

- Parameter with largest cost-leverage
  - Major focus of global R&D effort ('S0')
- For TDP-2 baseline, unlikely to change current Working Assumption (31.5 MV/m)
- Change of gradient at later stage only affects length of linacs assuming centralised sources.
  - At 10% level easily scalable
  - No other subsystems affected
- See Akira's presentation

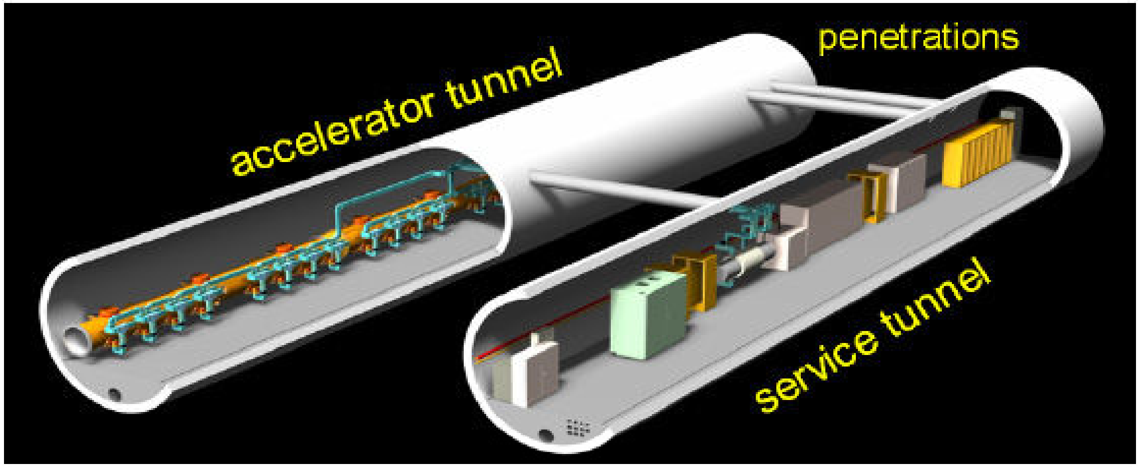
# 2) A Single Linac Tunnel

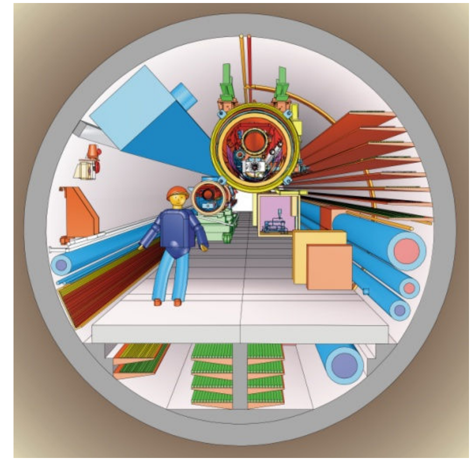
- **The RDR Twin Tunnel design was justified on the grounds that it was *necessary to have access* to equipment ( such as RF systems) during accelerator operation.**
- **The parallel support tunnel would be a part of the *safety egress* design.**
- **Both assumptions need to be addressed and there are multiple solutions.**

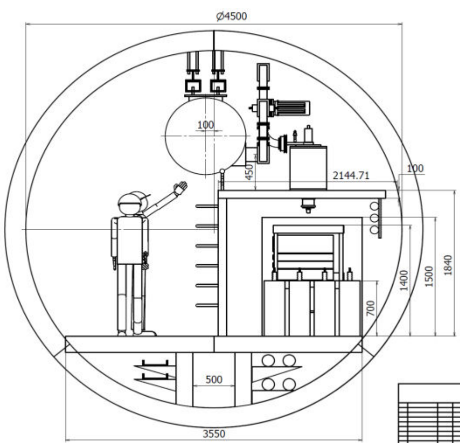
# Tunnel Variants

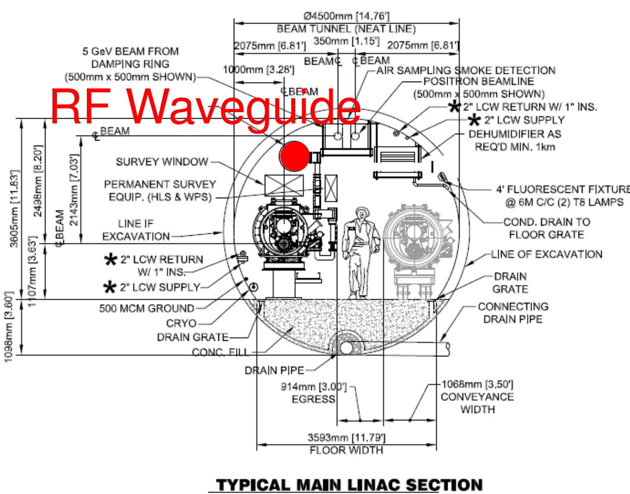
**RDR**

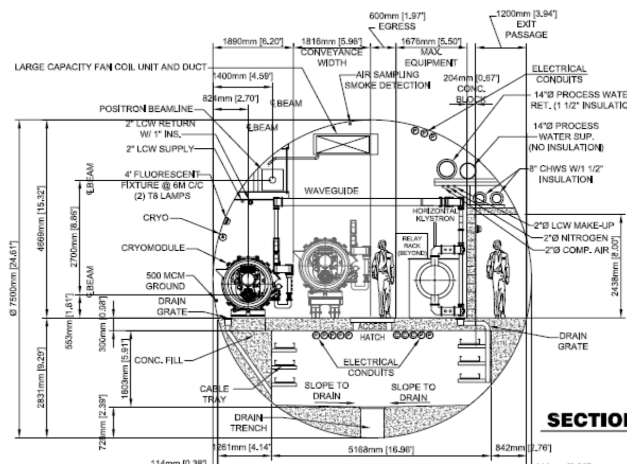
**XFEL**



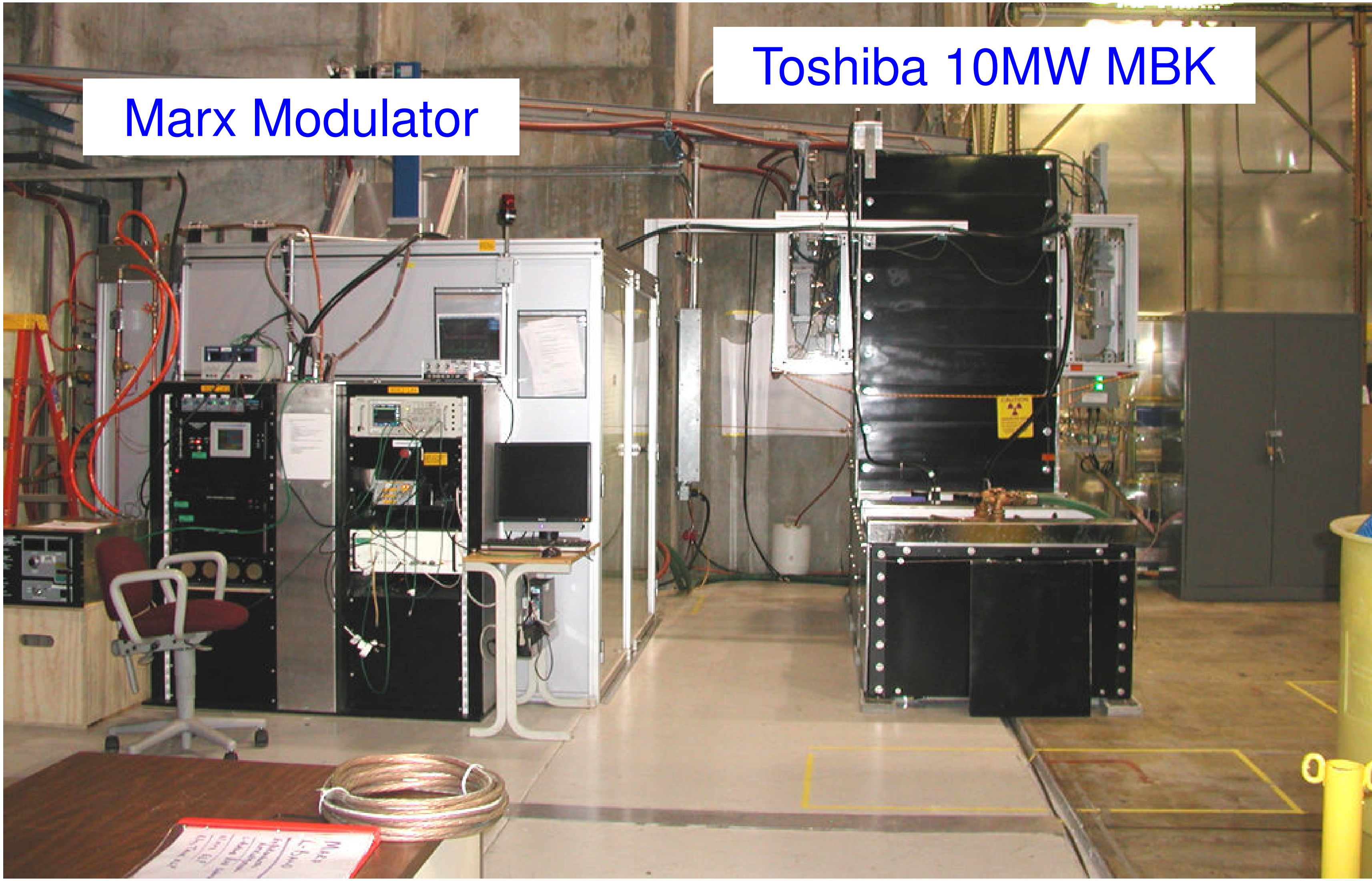





# ILC-ML Power System for 3 cryostats containing 26 cavities over 30 meters



# High-Level RF Solutions

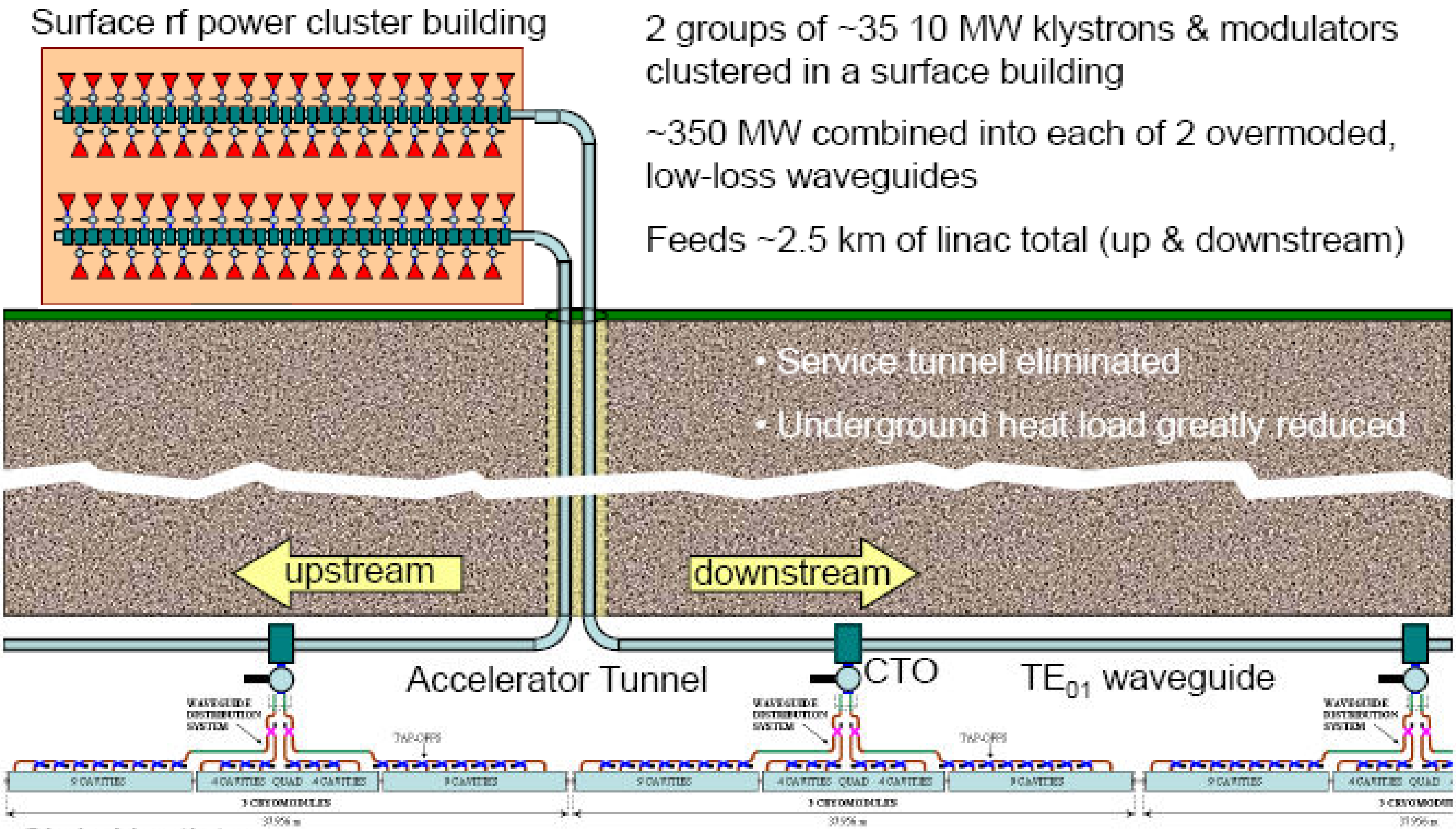
- **Seen as critical component for one-tunnel design.**
- ***Two solutions proposed and being studied*:**
  - **Klystron Cluster concept**
    - **RDR-like 10 MW Klystrons/modulators on surface**
    - **Surface building & shafts every ~2 km**
    - **Novel high-powered RF components (needs R&D)**
  - **Distributed RF Source**
    - **Smaller ~700kW klystrons+modulators in tunnel**
    - **One klystron per two cavities (four for LowP)**
    - **~13 X Number of klystrons per linac**
    - **Challenges are design for manufacture (cost reduction) and long MTTF to achieve good availability.**

# 2 HLRF Schemes: 1) Klystron Cluster Layout

2 groups of ~35 10 MW klystrons & modulators clustered in a surface building

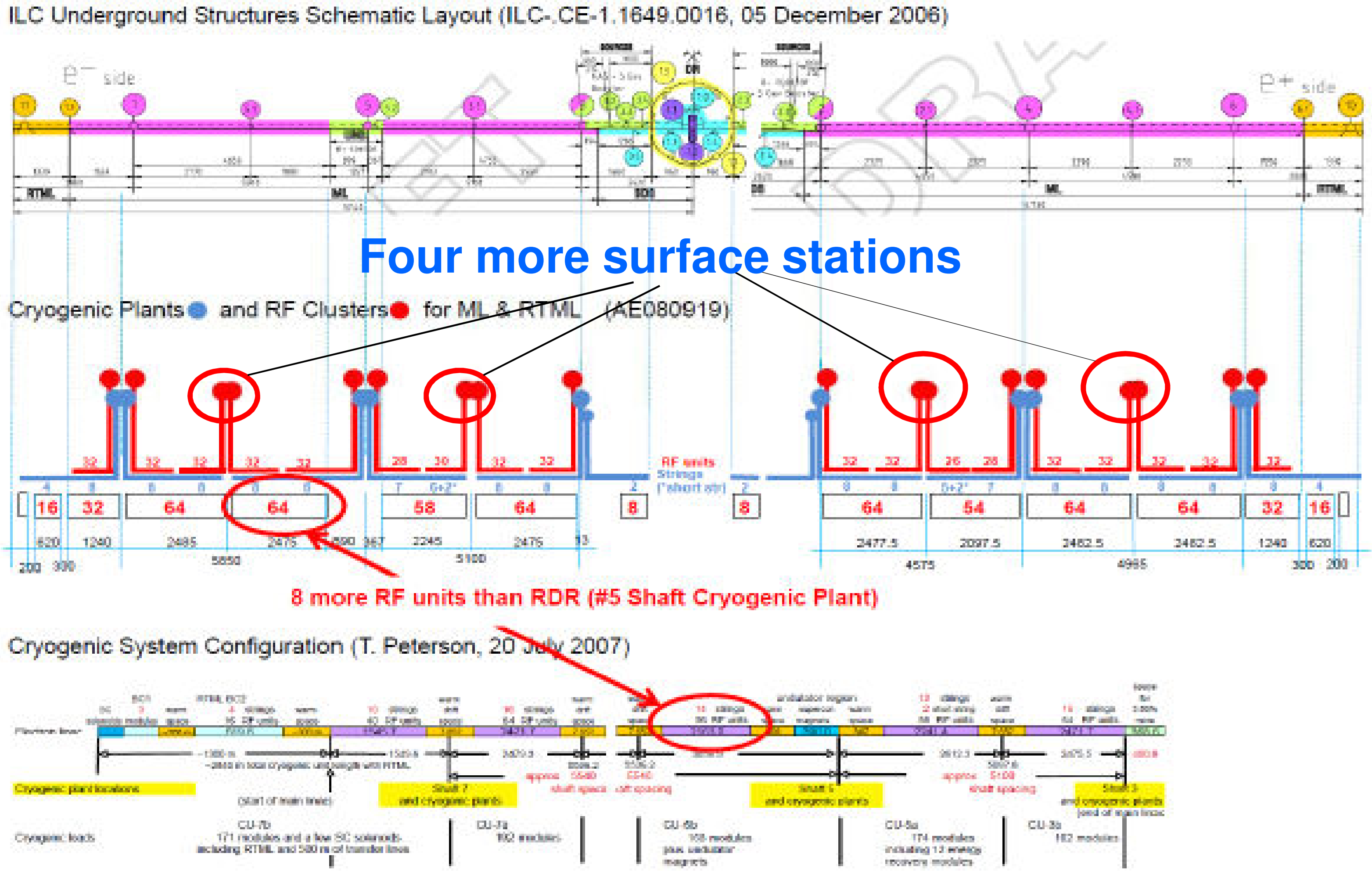
~350 MW combined into each of 2 overmoded, low-loss waveguides

Feeds ~2.5 km of linac total (up & downstream)



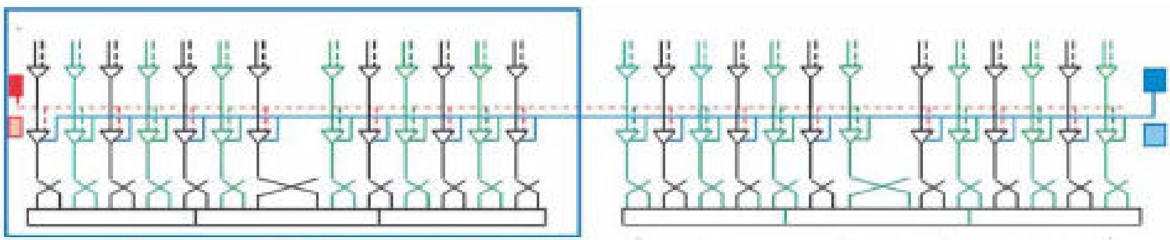

Chris Nantista

# Schematic layouts of conventional facilities and RF Klystron Cluster units



# 2) Distributed RF Scheme (DRFS)

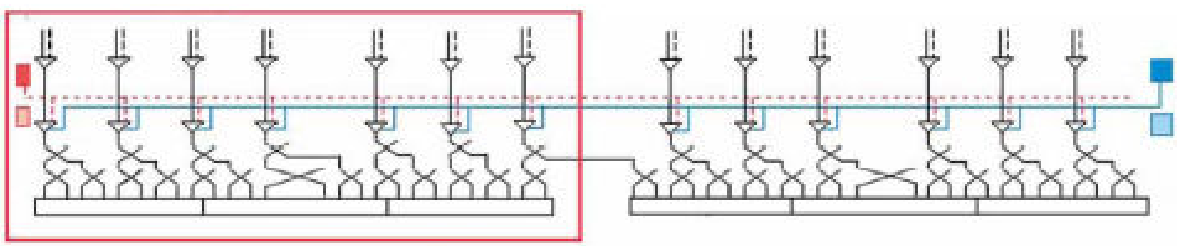
Standard Scheme: One DC PS/MA modulator drives 26 klystrons (6 cryomodules)



High availability with backup DC PS and MA modulator

Maximum efficient usage of SC cavity

Low Power Option

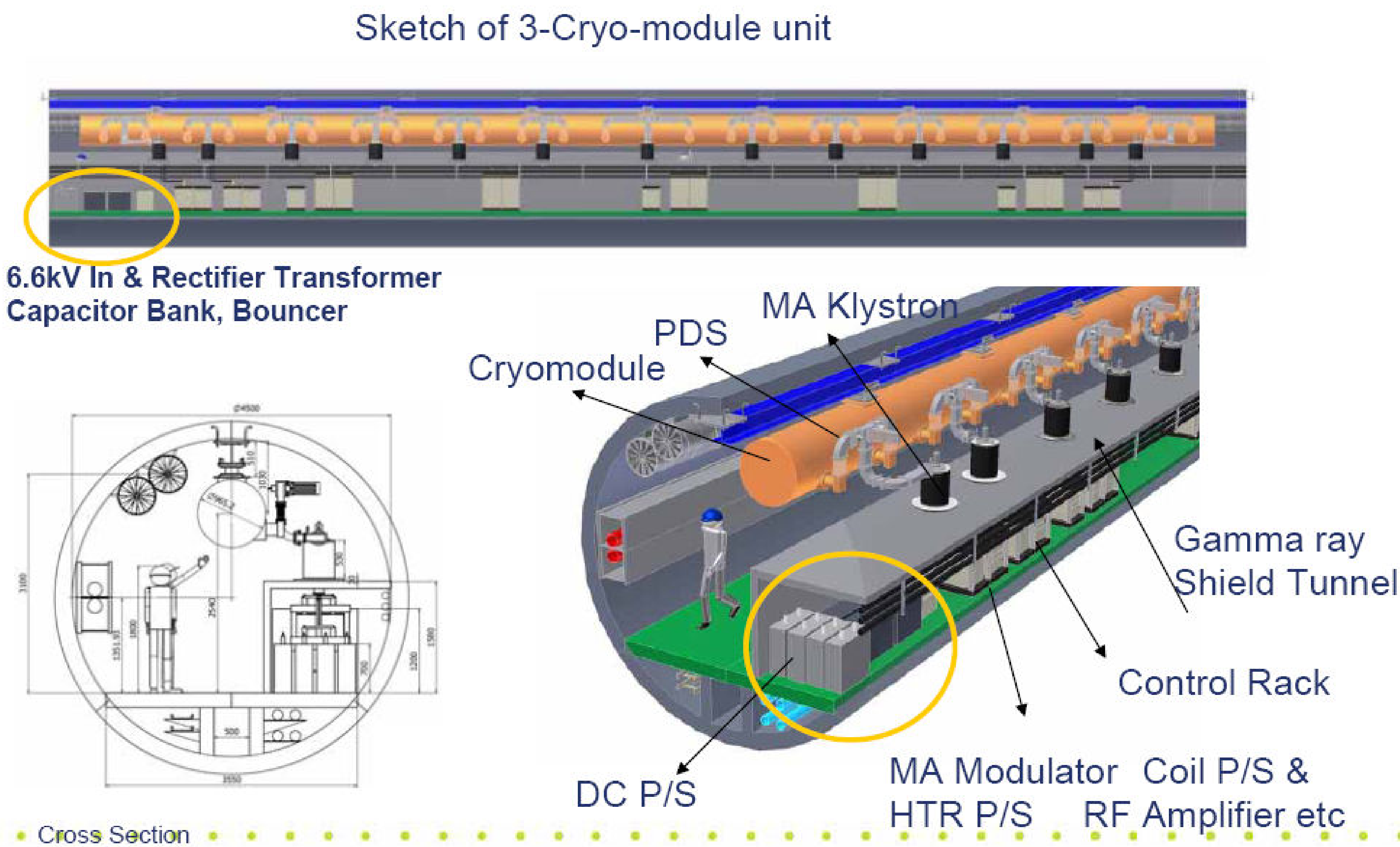


Low Power Option

Aiming for the easy upgradeability to standard scheme
Low cost
Partial sacrifice of DRFS operability

Shigeki Fukuda

# Distributed RF Source



# HLRF Issues needing R&D

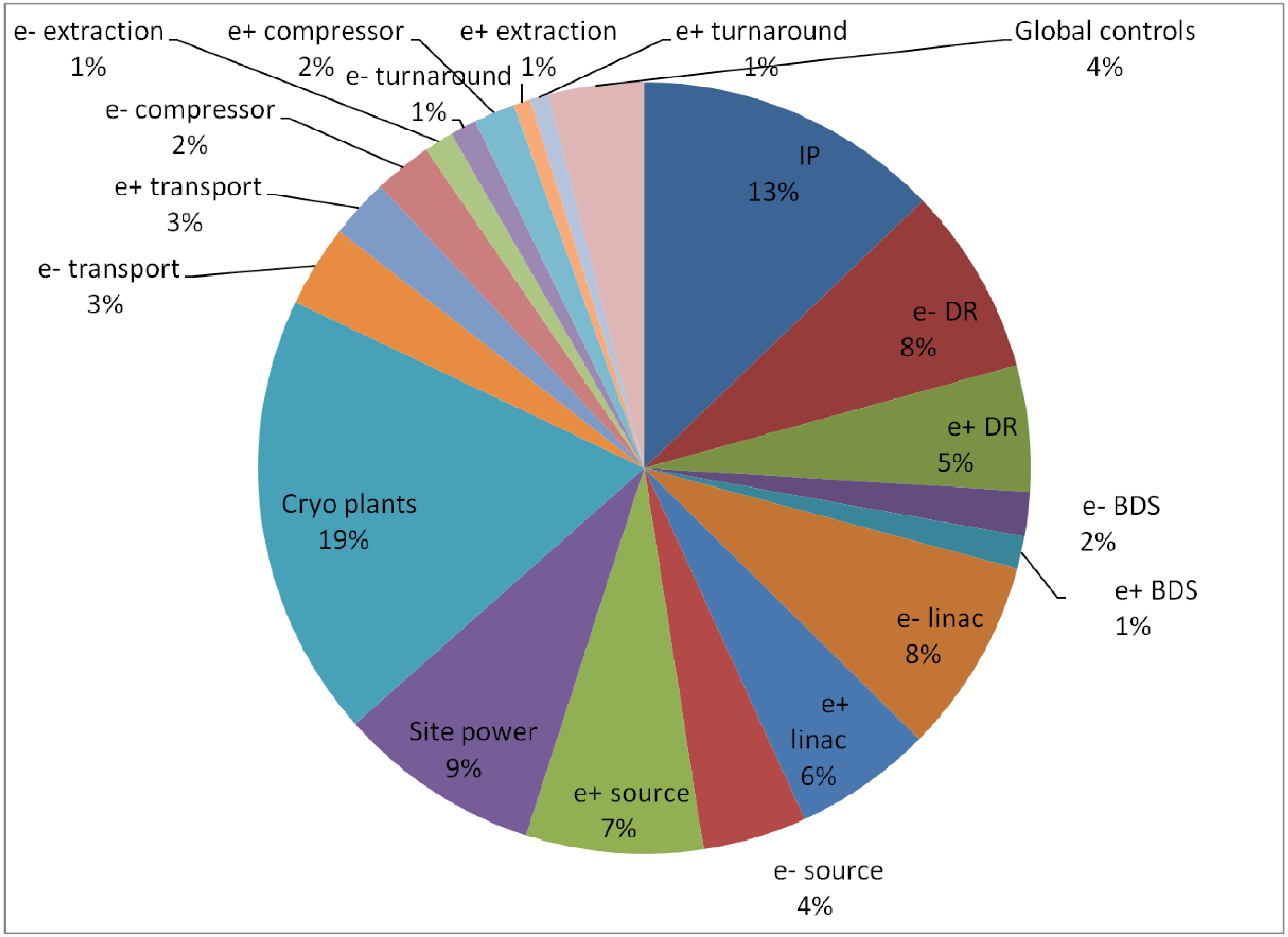
- **DRFS**
  - **Klystron lifetime**
  - **Modulator cost with redundancy**
  - **Layout (map RDR components into single tunnel) and issues of ceiling mounted CM**
- **Klystron Cluster**
  - **RF breakdown in transmission line or components**
  - **Transmission line --- vacuum -vs- pressurized operation**
  - **LLRF control**

# What is the Impact of a Single Tunnel on Availability

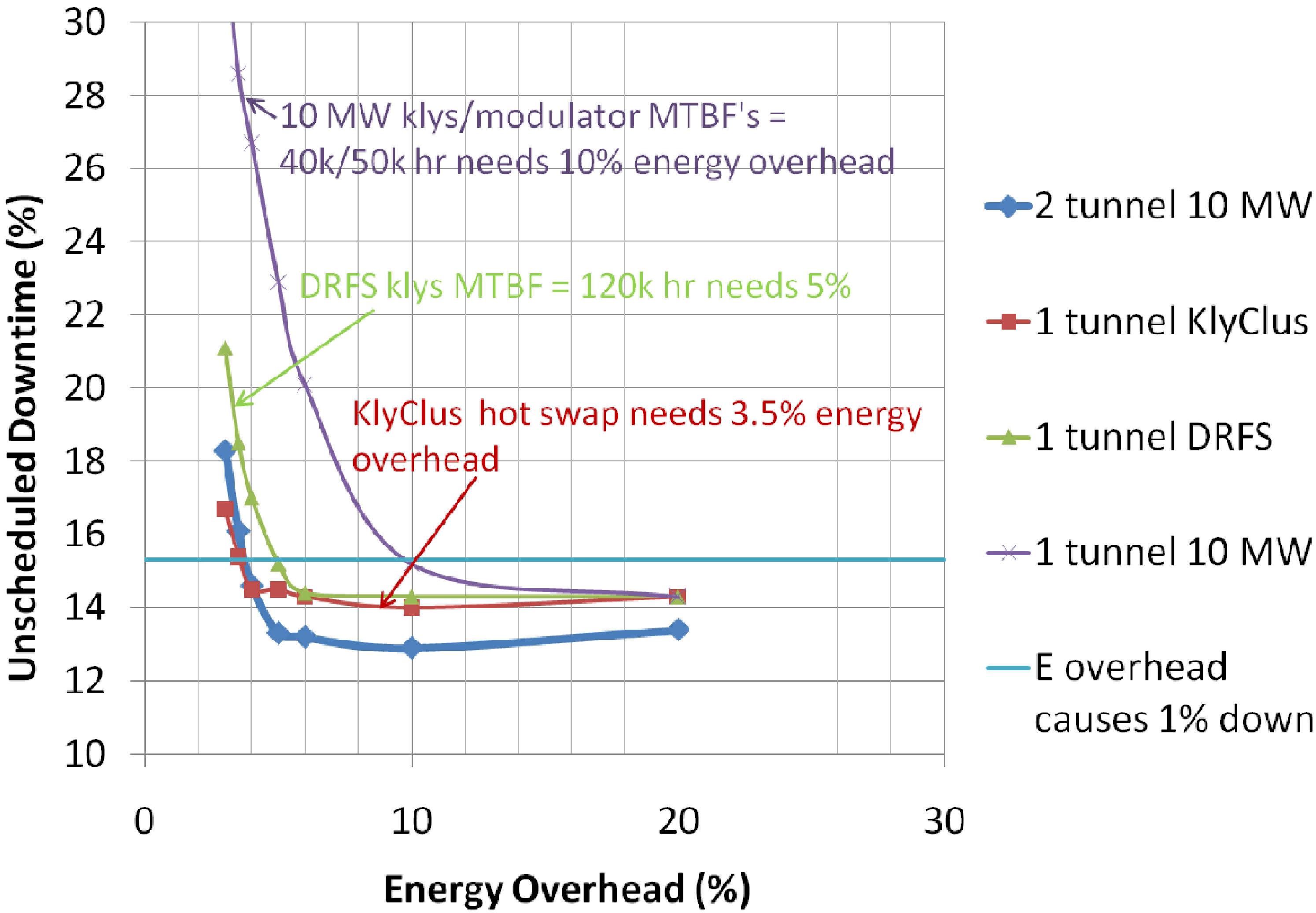
## Scheduled Running Time minus Unscheduled Downtime

- **Availsim--**A computer model of total ILC (or similar accelerator) in operation. Developed over many years by Tom Himel and others.
- **Inputs–** Physical layout with personnel access zones.
  MTTF of components, technical, civil etc. etc
  MTTR of above
  Model of operating and maintenance schedules
- **Outputs–** Total Unscheduled downtime.
  Downtime by type of technology, vacuum, controls etc.
  Downtime by major accelerator system, e- source,
  e- linac etc.
- **Uses–** Aid in directing R&D on critical component reliability.
  Aid in comparing alternate system designs and improving design for reliability.

# Example output from SB2009 study



# Comparison of HLRF Options



# Preliminary conclusions of impact of single ‘linac only’ tunnel on availability

- There are two alternate RF power system designs proposed for single tunnel linac operation. (The Klystron Cluster and the Distributed RF System). Either approach would give adequate availability with the present assumptions. The Distributed RF System requires about 1.5 percent more energy overhead than the Klystron Cluster Scheme to give the same availability for all other assumptions the same. This small effect may well be compensated by other non availability related issues.

- With the component failure rates and operating models assumed today, the unscheduled lost time integrating luminosity with a single main linac tunnel is only 1% more than the two tunnel RDR design given reasonable energy overheads. Note that all non-linac areas were modeled with support equipment accessible with beam on.

# 3) Undulator-based e+ source located at the end of the electron Main Linac

- **In the RDR:**
  - the e+ undulator source was positioned at the 150 GeV point in the linac
  - For operation at 300 Gev c.o.m. and above the first half of the e- linac would operate at maximum fixed gradient with the final E- energy adjustment being done in the second half.
  - For energies below 300, eg 200 to 300 GeV the e- beam must be decelerated. (A potential problem)
  - This puts some constraints on operation or early staged energy scenarios. (Less flexibility)

# Re-Consider E+ Source Layout

- ***Move the source to the end of the E- linac…..>***

**Share many systems :- Machine protection, Auxiliary E+ source etc  Avoid duplicate systems**

**While on access into the IR all systems operate and the main e- drive beam would go to the tune up dump, a shared dump.**

**We save  >450m, of the positron system length. But we also shorten the low energy e+ transport by several kilometers and integrated AUX source shares 5 GeV Booster accelerator**

**All systems except the linac are now within +/- 2.5 km of the IR.**

**A cost effective  Central Campus------ but what about operation at low energies, less than ~ 300 GeV c.o.m**

# Explore Parameters …

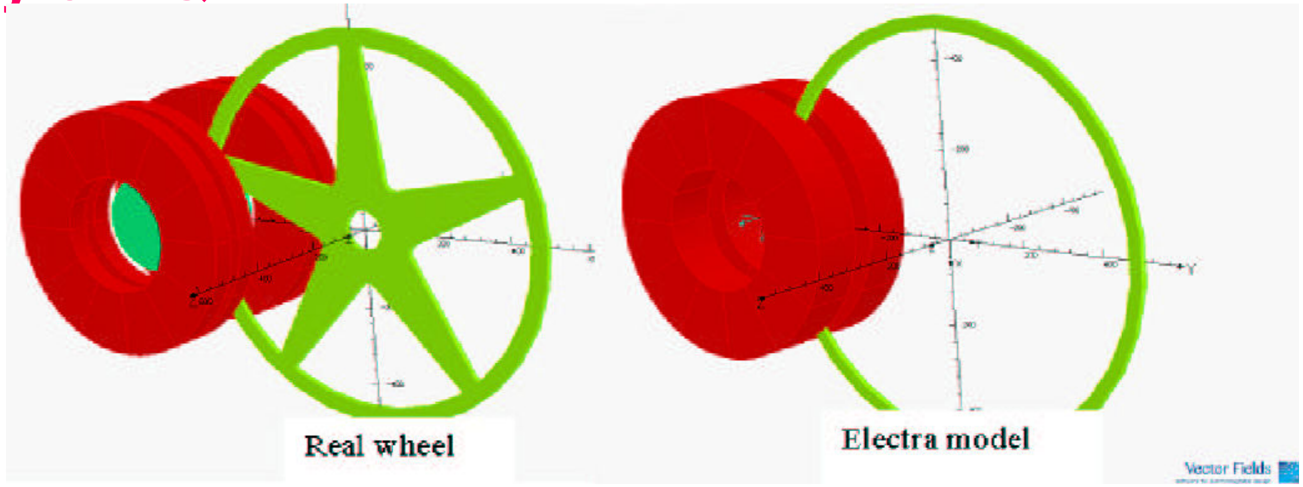
- **0.4 rad length Ti target & QWT non-immersed field**
- **Assume B = 1T (conservative) and QWT (conservative)**
- **For yield of 2.0 @ 250GeV need ~100m undulator**
- **For yield of 1.5 @ 150GeV need ~230m undulator**
- **For yield of 1.5 @ 125GeV? with~230m undulator will need less conservative OMD or target design or accept Luminosity reduction ~ 2 (Actual detail performance of 125 GeV is under study)**

**ALTERNATIVES**

- **Immersed Field R&D is ongoing; low eddy I power**
- **Li Lens**
- **½ Repetition Rate**

# Target Wheel Eddy Current Simulations/Expts

**Immersed target ⇒ up to a factor 2.5 increase in capture efficiency c.f. QWT**




- For 1T static field at ~2000rpm
  - RAL predicts ~6.6kW
  - ANL predicts ~9.5kW
    - S. Antipov PAC07 proceedings
  - LLNL predicts ~15kW

**2009 Experimental data is encouraging and indicates that simulations are conservative**

**→ 1.6 KW preliminary**

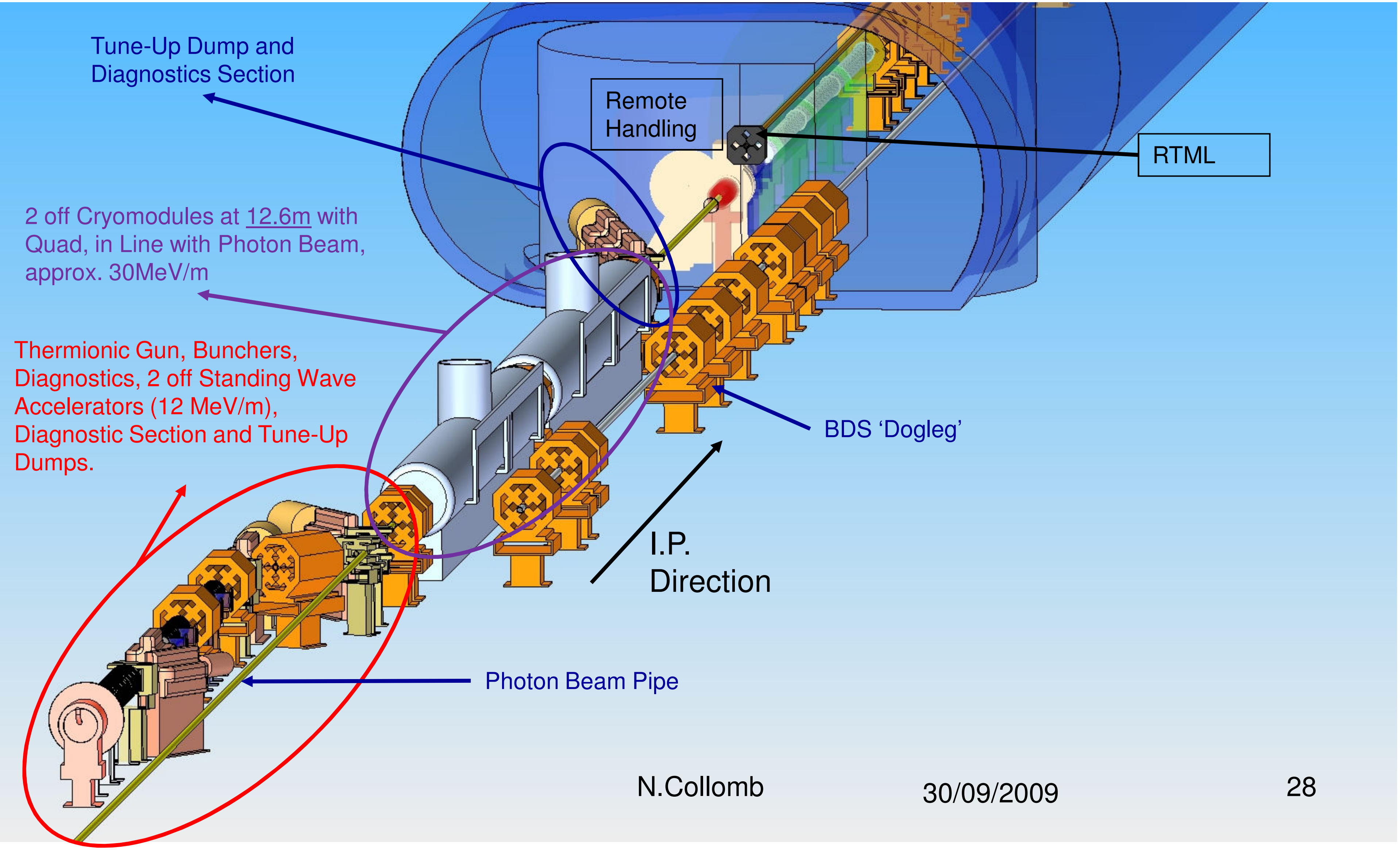
**⇒ Alternative capture optics, alternative materials, prototyping**

# Very Low Electron Energy Operation

- **For calibration purposes (Z-pole) the auxiliary source will be able to provide intensity at the few % level**
- **At some energy below 125 to150 GeV ? per beam  the ILC could operate in a pulse sharing mode @ ½ Lum**
  - **Positrons are generated at high energy but at half rep rate**
  - **Electrons are transported at the low energy to the IP at half rep rate**
  - **Initial studies reported this week (ALCPG09) suggest may be practical to transport low & high energy beams through linac but definitely needs work**

# Positron Source – AD&I

3 D Layout Positron Source 'AUX Source' region.

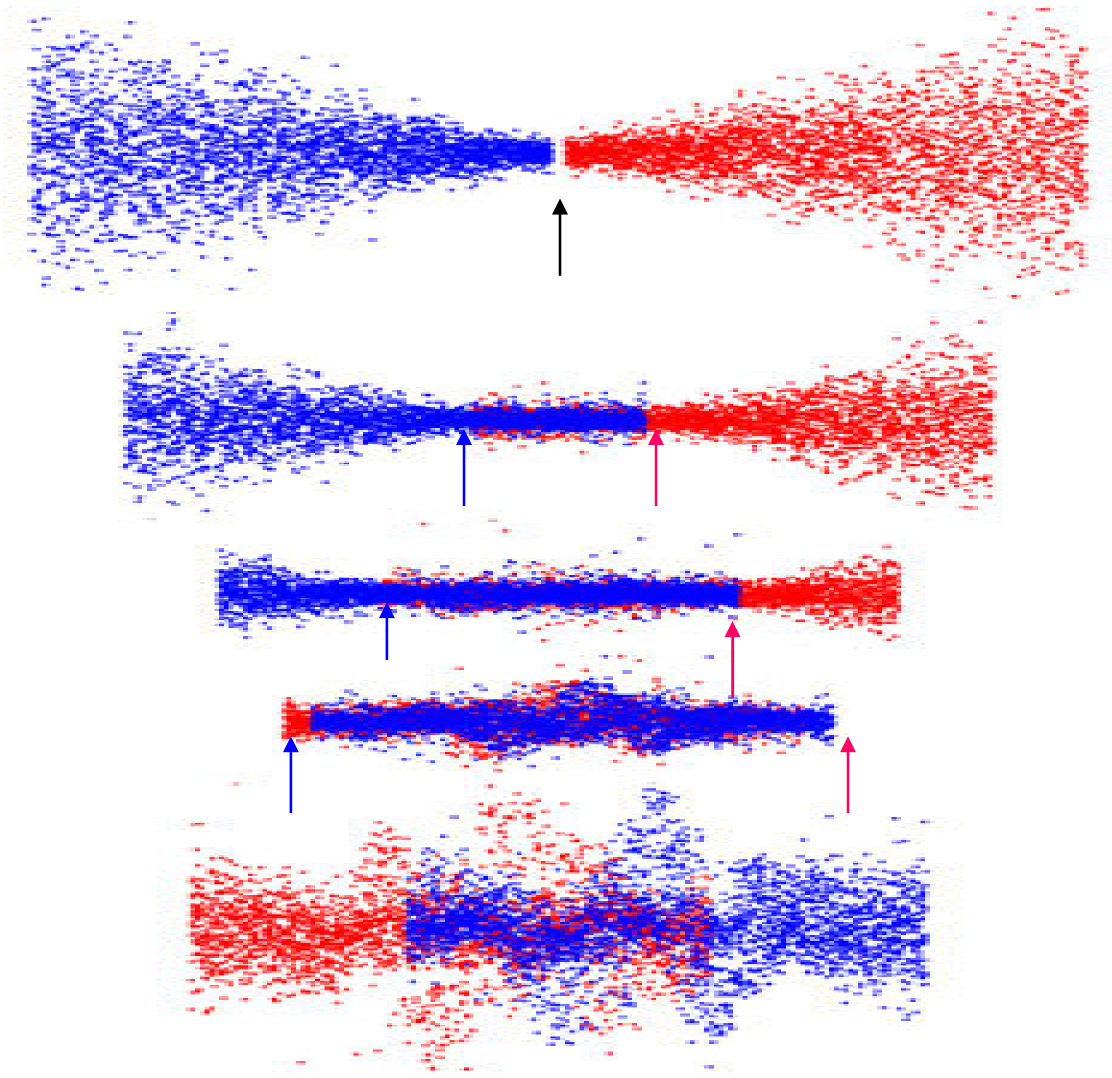


# 4) Reduced Parameter Set or Low P Option

- **Half the number of bunches in bunch train, 1312 v 2624**
- **Same charge per bunch**
- **Beam power reduced to 50%**
- **Luminosity reduced to 75% and increased ΔE/E**
- **Luminosity recovered with "Travelling Focus"**
- **Enables (not requires) 3.2 km Damping Rings**
- **SB2009 maintains power handling design parameters for sources, collimators, beam dumps etc, therefore allows for future upgrades.**

| Beam and RF Parameters | | | | |
|---|---|---|---|---|
| No. of bunches | | 2625 | 1312 | |
| Bunch spacing | ns | 370 | 740 | |
| beam current | mA | 9.0 | 4.5 | |
| Avg. beam power (250 GeV) | MW | 10.8 | 5.4 | |
| Accelerating gradient | MV/m | 31.5 | 31.5 | |
| $P_{fwd}$ / cavity (matched) | kW | 294 | 147 | |
| $Q_{ext}$ (matched) | | $3\times10^6$ | $6\times10^6$ | |
| $t_{fill}$ | ms | 0.62 | 1.13 | |
| RF pulse length | ms | 1.6 | 2.0 | |
| RF to beam efficiency | % | 61 | 44 | |
| | | | | |
| IP Parameters | | | | |
| Norm. horizontal emittance | mm.mr | 10 | 10 | |
| Norm. vertical emittance | mm.mr | 0.040 | 0.035 | |
| bunch length | mm | 0.3 | 0.3 | |
| horizontal b* | mm | 20 | 11 | |
| horizontal beam size | nm | 640 | 470 | |
| | | | no trav. focus | with trav. focus |
| vertical $\beta$* | mm | 0.40 | 0.48 | 0.2 |
| vertical beam size | nm | 5.7 | 5.8 | 3.8 |
| $D_y$ | | 19 | 25 | 21 |
| $dE_{BS}/E$ | % | 2 | 4 | 3.6 |
| Avg. $P_{BS}$ | kW | 260 | 200 | 194 |
| Luminosity | $cm^{-2}s^{-1}$ | $2\times10^{34}$ | $1.5\times10^{34}$ | $2\times10^{34}$ |

# Travelling Focus $\beta^* < \sigma_z$



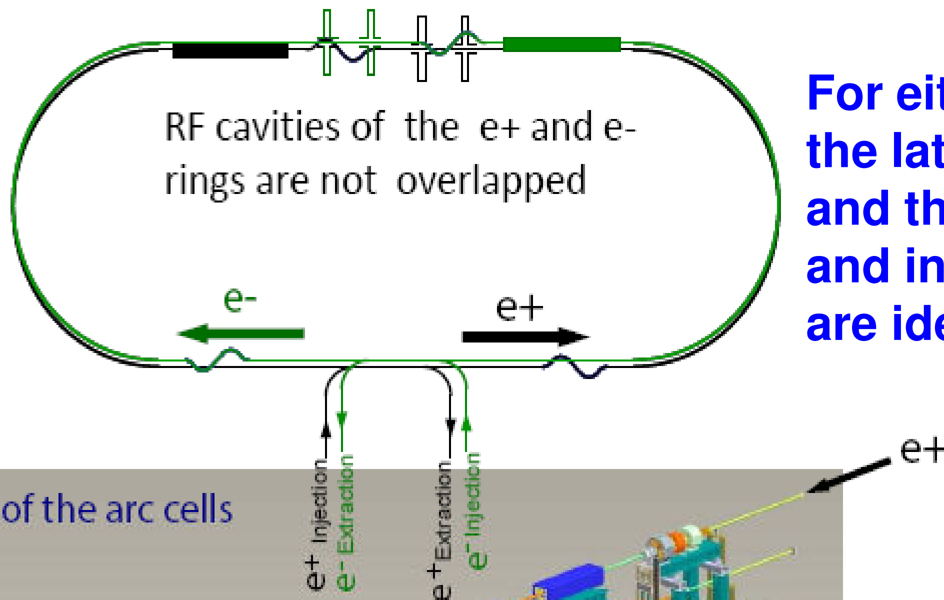
# Is a Travelling Focus worth considering for any design?

- **To create a travelling focus one can use a transverse deflecting cavity giving a z-x correlation in one of the FF sextupoles and thus a z-correlated focusing**
- **The cavity would be located about 100m upstream of the final doublet, at the $\pi/2$ betatron phase from the FD**
- **The needed strength of the travelling focus cavity can be compared to the strength of the normal crab cavity (which is located just upstream of the FD):**
  - $U_{trav.cav.}/U_{crab.cav.} = \eta_{FD} R_{12}^{cc}/ (L^*_{eff}\ \theta_c\ R_{12}^{trav})$.
  - **Here $\eta_{FD}$ is dispersion in the FD, $\theta_c$ full crossing angle, $R_{12}^{trav}$ and $R_{12}^{cc}$ are transfer matrix elements from travelling focus transverse cavity to FD, and from the crab cavity to IP correspondingly.**
- **For typical parameters $\eta_{FD}$ =0.15m, $\theta_c$ =14mrad. $R_{12}^{cc}$ =10m, $R_{12}^{trav}$ =100m, $L^*_{eff}$ =6m one can conclude that the needed strength of the travelling focus transverse cavity is about 20% of the nominal crab cavity.**

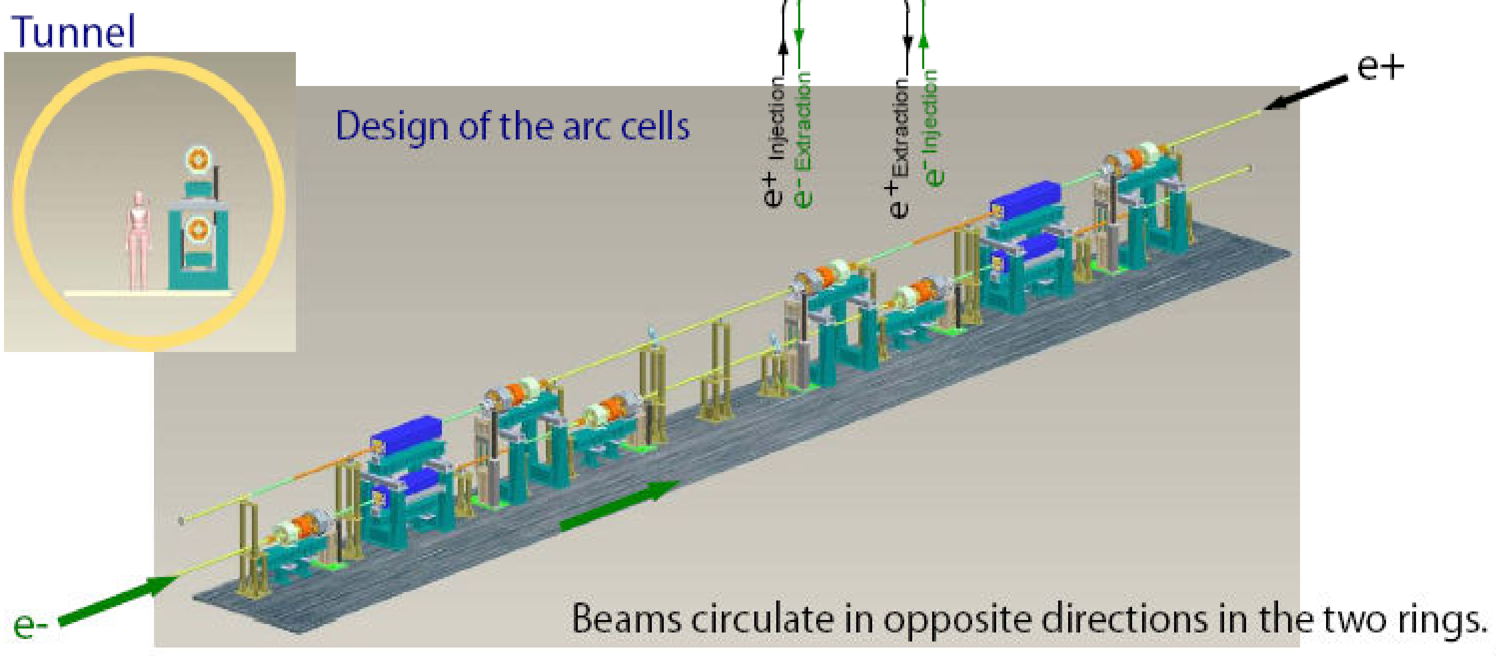
# 5) Damping Rings

e- Damping Ring
e+ Damping Ring

The lattice of e- DR is identical to the lattice of the e+ DR.




**For either 3 or 6 km ring, the lattices are the same and the straight sections and injection geometry are identical**




Beams circulate in opposite directions in the two rings.

# 3.2 and 6.4 km Rings

| | RDR | SB2009 |
|---|---|---|
| | DCO2 | DSB3 |
| Energy (GeV) | 5 | 5 |
| Circumference (m) | 6476 | 3238 |
| Bunch number | 2610 - 5265 | 2610 - 1305 |
| N particles/bunch | 2x10e10 | 2x10e10 |
| Damping time tx (ms) | 21 | 24 |
| Emittance ex (nm) | 0.48 | 0.53 |
| Emittance ey (pm) | 2 | 2 |
| Momentum compaction | 1.7x10-4 | 1.3x10-4 |
| Energy loss/turn (MeV) | 10.3 | 4.4 |
| Energy spread | 0,0013 | 0,0012 |
| Bunch length (mm) | 6 | 6 |
| RF Voltage (MV) | 21 | 7,5 |
| RF frequency (MHz) | 650 | 650 |
| B wiggler (T) | 1,6 | 1,6 |
| Lwig total | 216 | 78 |
| Number of wigglers | 88 | 32 |

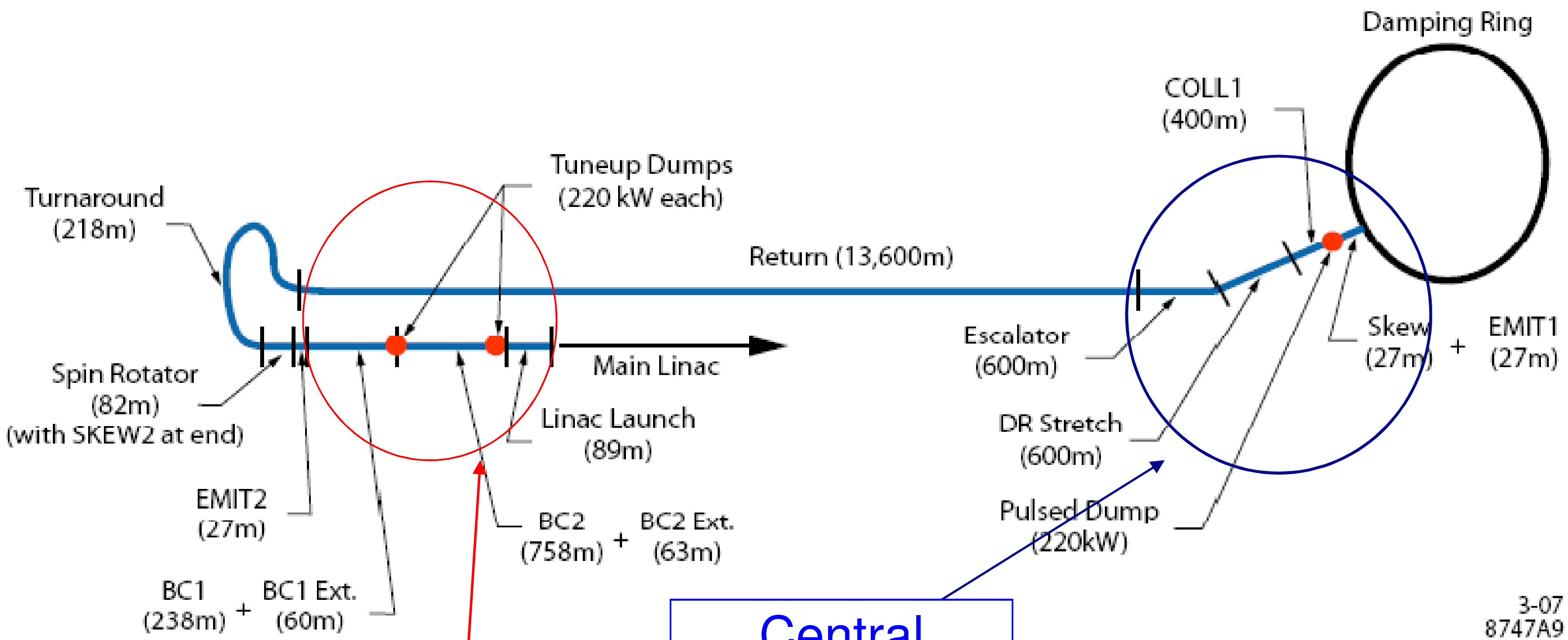
1/2 circumference

6mm bunch length Enables single stage bunch compression

<1/2 RF cavities

~1/3 wigglers

# 6) RTML in SB2009 vs. RDR




Single-stage BC

Central Integration Area

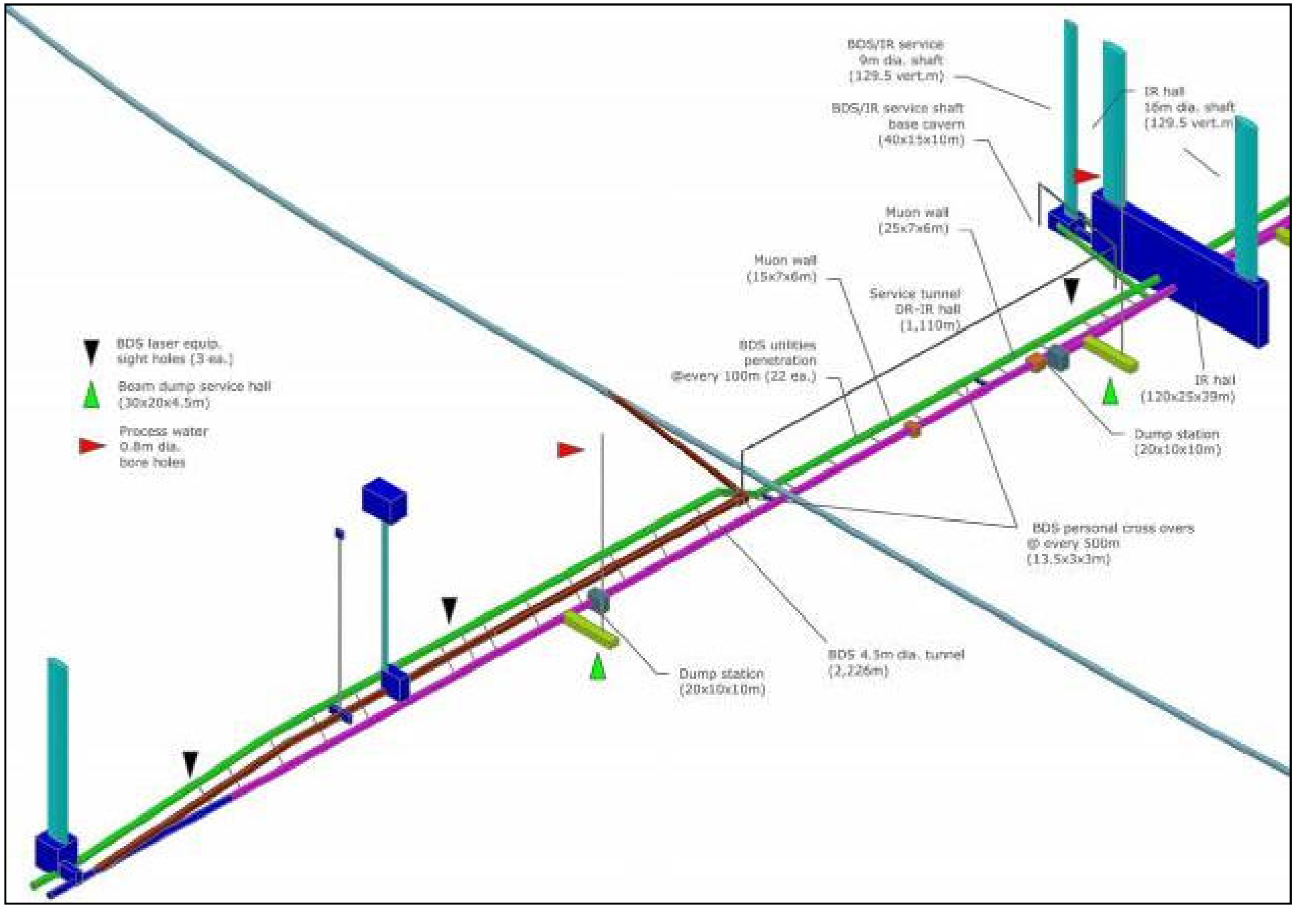
Redesign

**Bunch compression 20:1 vs 50:1**

# RTML Summary

- **Single stage Bunch Compressor is designed and studied. Design looks feasible:**
  - **Emittance growth in bunch compressor can be effectively controlled, by using movers to adjust tilt of the cryomodules.**
- **MPS /tune-up dump lines redesigned to accommodate bunch with a larger energy spread after BC.**
- **Proposal for changes of RTML lattice in central area. Next step – lattice design. Time scale – 2-3 months**
- **Cost estimation and CFS design in progress**

# 7) Central Region Integration or Consolidation




- **RDR solution complex (CFS)**

  :- Simplify?

- **Three tunnel concept**

  :- Two tunnel in one plane

- **Looked for consolidated solutions**

  :- Share shafts, dumps etc

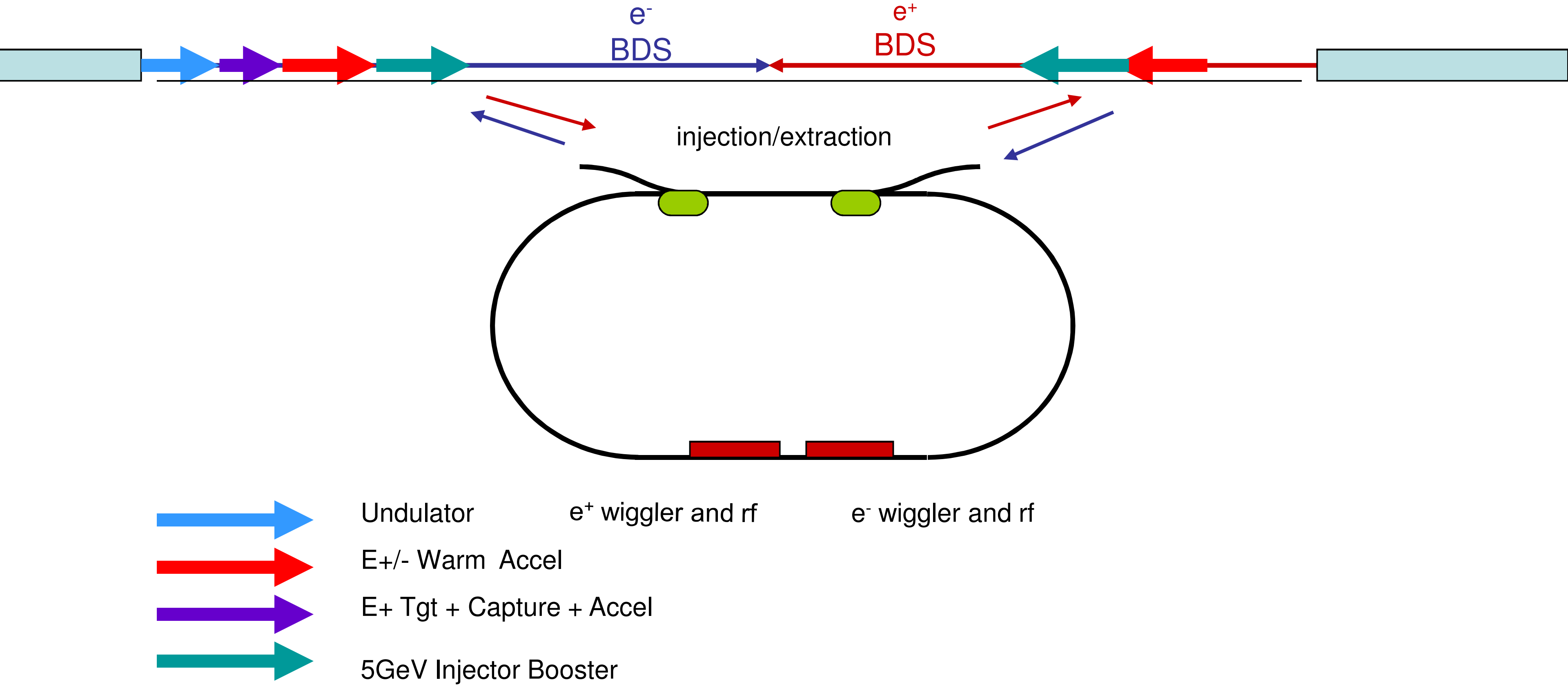
# Central Region Integration

**5 GeV Boosters share tunnel with BDS**

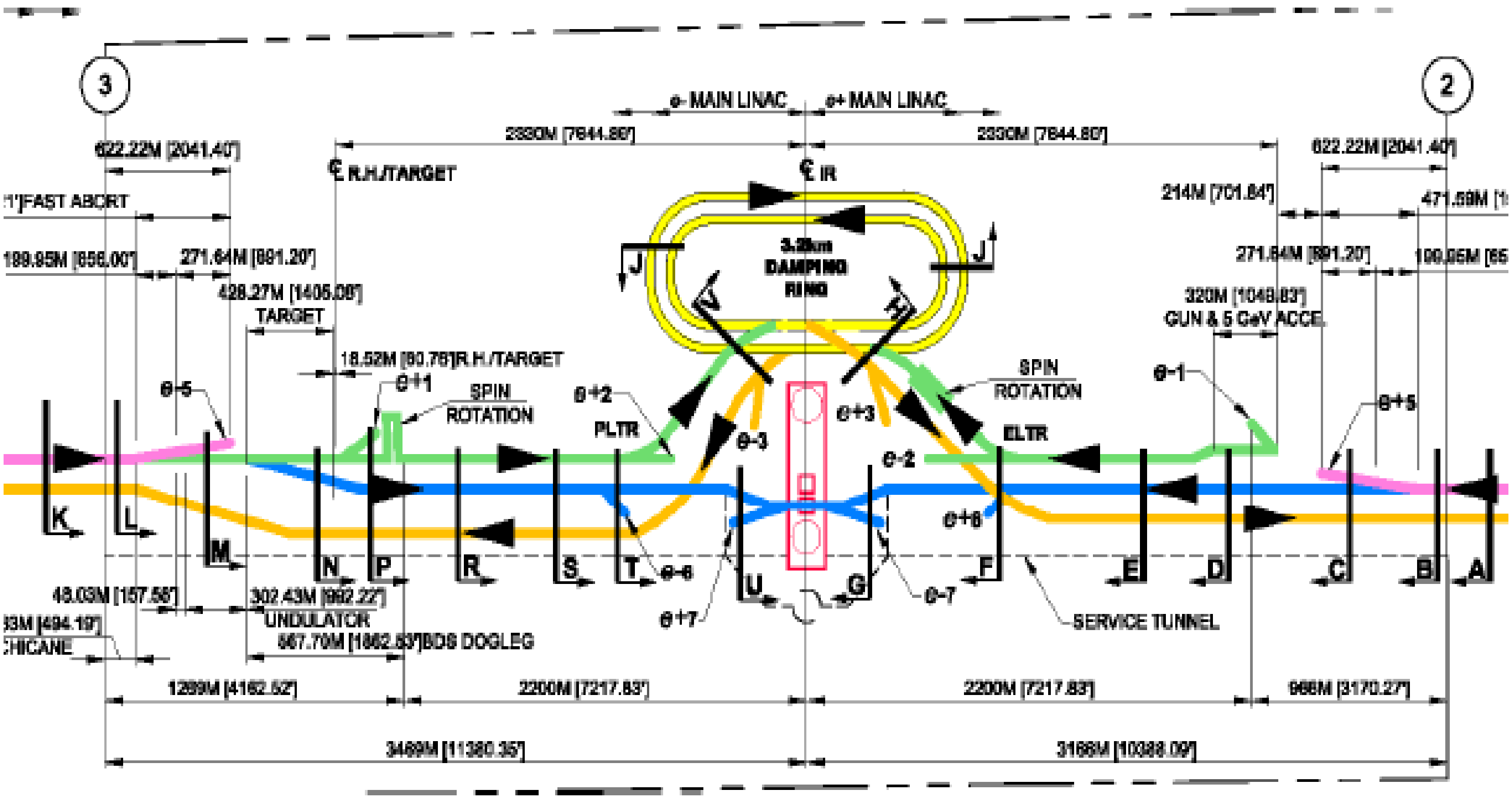
**E- Gun and injector share tunnel with BDS**

**Undulator + Aux Injector + E+ Tgt-Capture-Accel + Booster share tunnel with BDS**

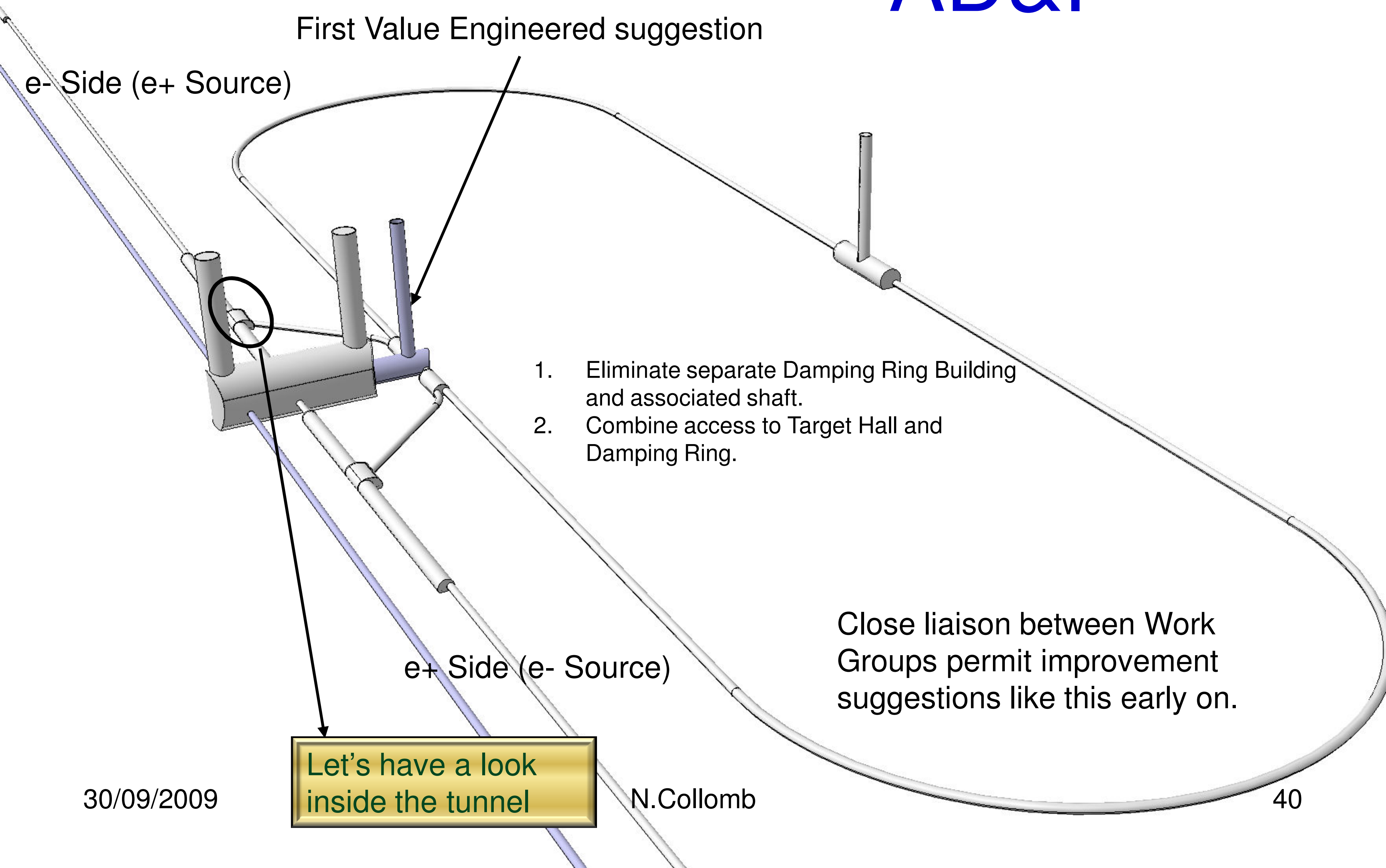
**No Independent Keep Alive source and only two tunnels, beam + support**



# Central Region Integration - CFS



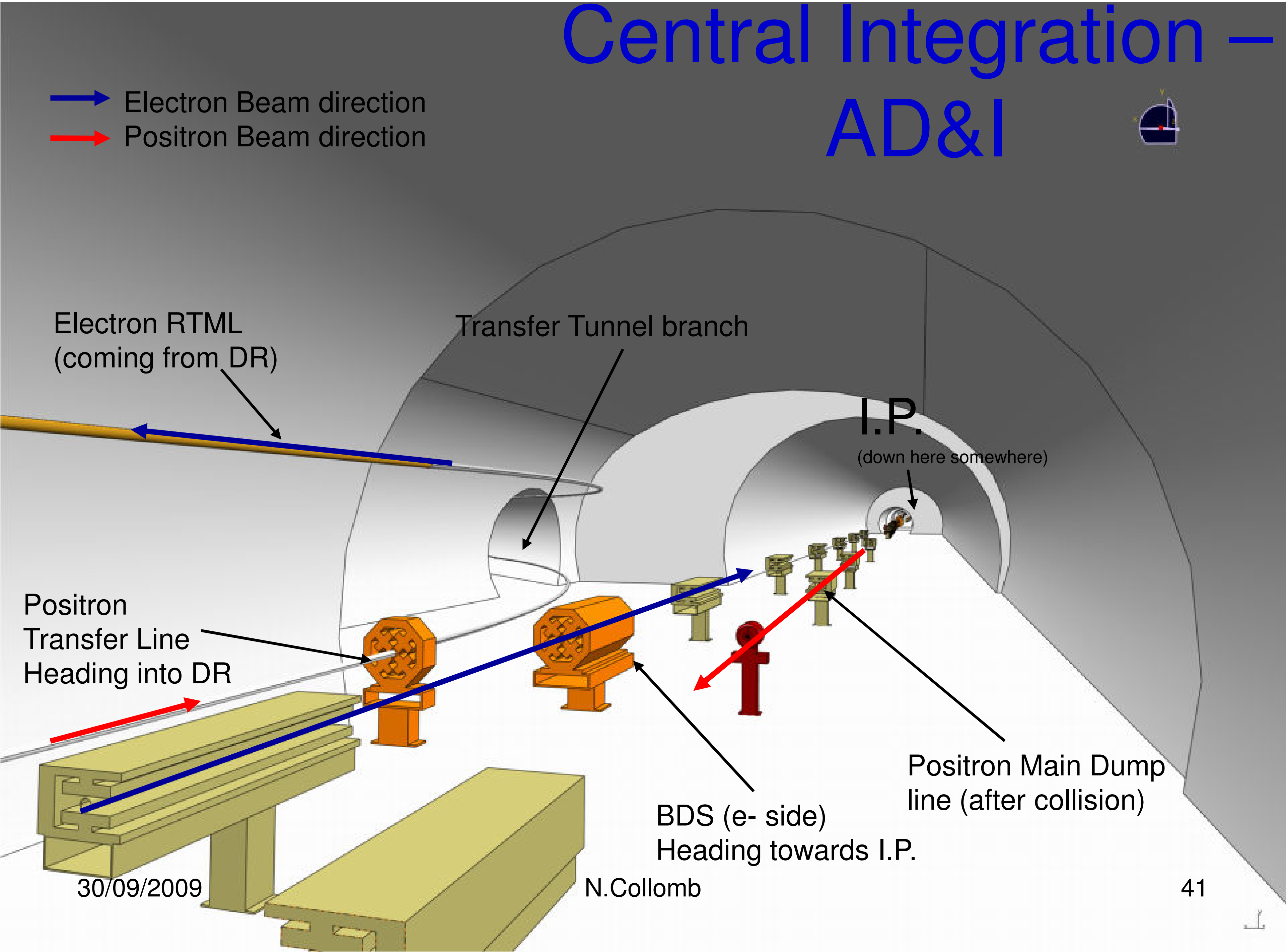
# Central Integration – AD&I




1. Eliminate separate Damping Ring Building and associated shaft.
2. Combine access to Target Hall and Damping Ring.

Close liaison between Work Groups permit improvement suggestions like this early on.

# Central Integration – AD&I



# 8) COST CHANGES

## (Rough Estimates from 10.2008)

- Main Linac (total) ~ 300 MILCU
- Low-Power option ~ 400 MILCU
- Central injector Integration ~ 100 MILCU
- Single-stage compressor ~ 100 MILCU




- VERY preliminary: better estimates will be made (end 2009)
  - But still based/scaled from RDR value estimate
- Elements *not* independent! Careful of potential double counting!
- **Cost vs Performance vs Risk**: important information for making

# Next Steps (2009)

- GDE focus at present time is to consolidate SB2009 Working Assumptions, Questions and Solutions
  - Review action items and outstanding issues from DESY and Albuquerque meetings including working with physics/detector groups to develop more detailed parameters associated with SB2009
  - Produce a first-guess estimate of cost changes
  - Begin to prepare Proposal Document

- AD&I meeting 2-3.12 (DESY)
  - 1st draft of Proposal Document
  - Resolve remaining issues

  Including designated representatives from Physics & Detector community & AAP members

- Proposal Document final draft made public 18.12.09
  - Formally to Director/EC
    - Forwarded to AAP for review
  - Entire community for comment/feedback

# AD&I and SB2009 Schedule