# TeV Upgrade

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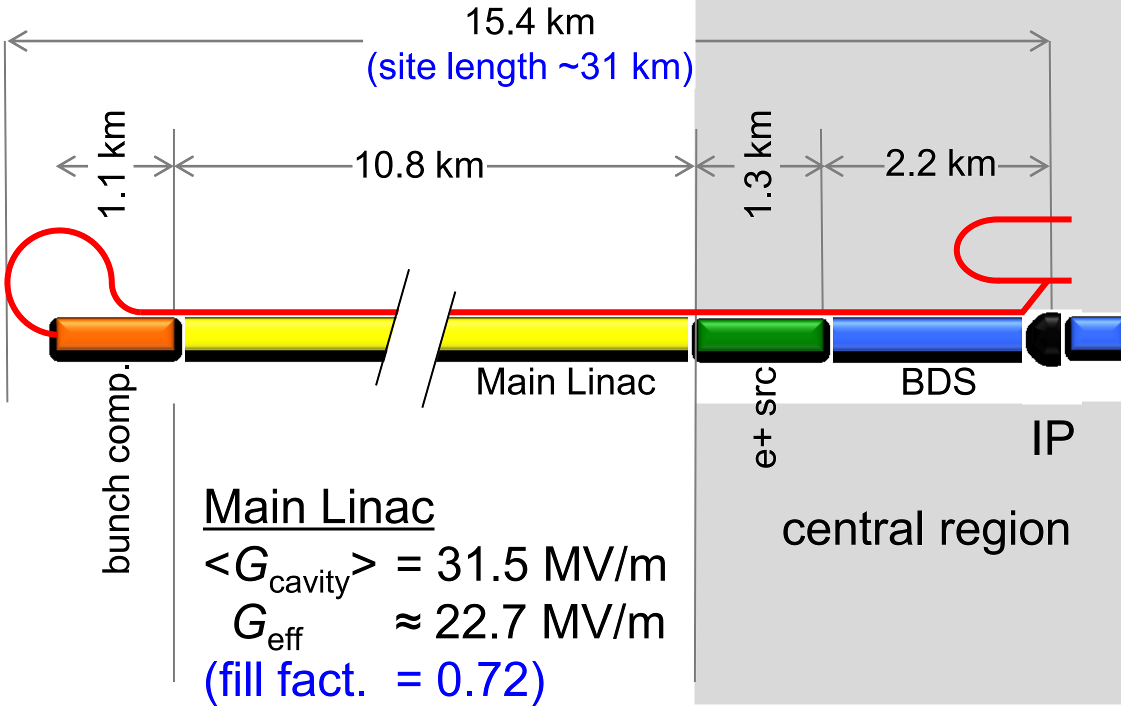
ALCPG, Univ. of Oregon, Eugene

21.03.2011

# Content

- From 500 to 1000 GeV – the Gradient Question
- Overall layout and impact on accelerator systems
- Parameters
- Cost & Schedule
- Proposal for White Paper as part of TDR

# From 500 to 1000 GeV



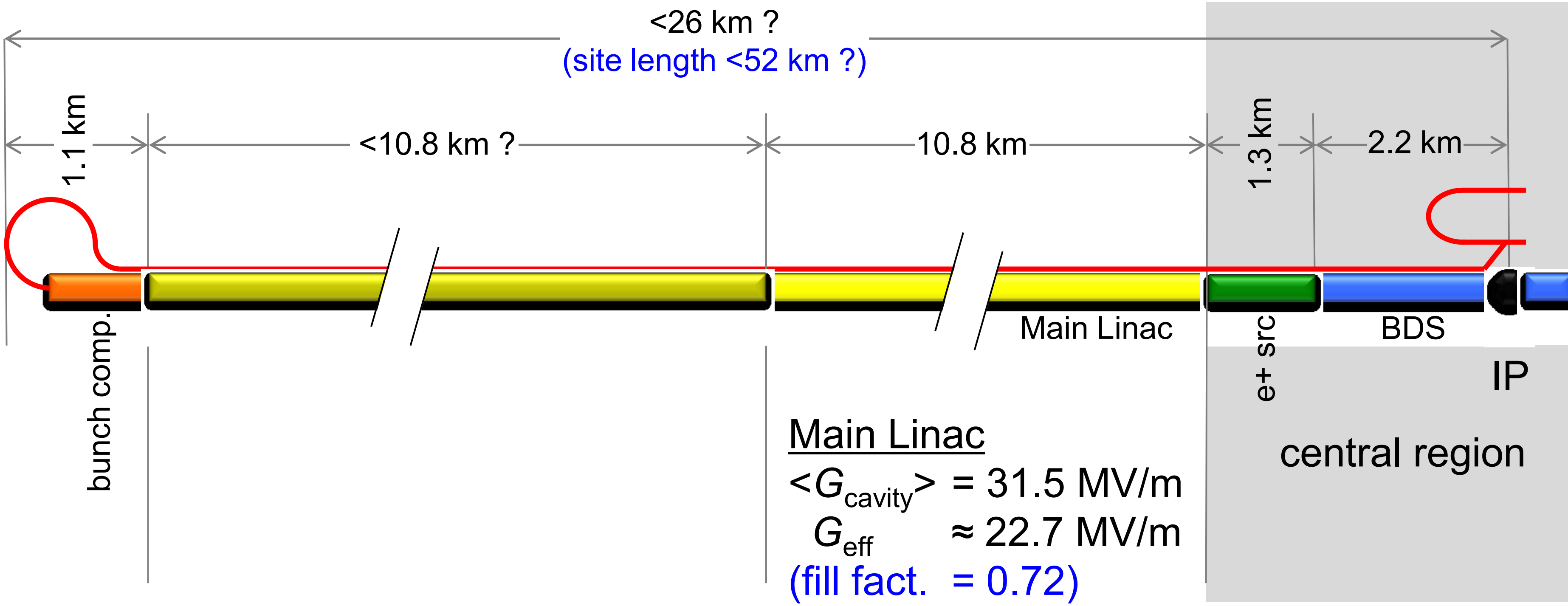
Main Linac

$\langle G_{cavity} \rangle = 31.5$ MV/m

$G_{eff} \approx 22.7$ MV/m

(fill fact. = 0.72)

# From 500 to 1000 GeV



Main Linac

$\langle G_{cavity} \rangle$ = 31.5 MV/m

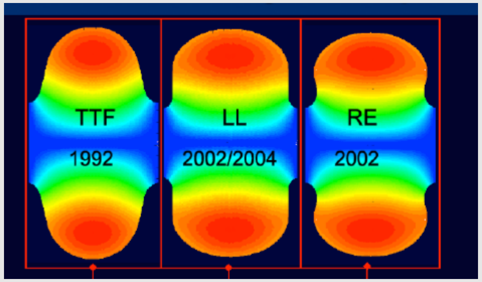
$G_{eff}$ ≈ 22.7 MV/m

(fill fact. = 0.72)

Snowmass 2005 baseline recommendation for TeV upgrade:

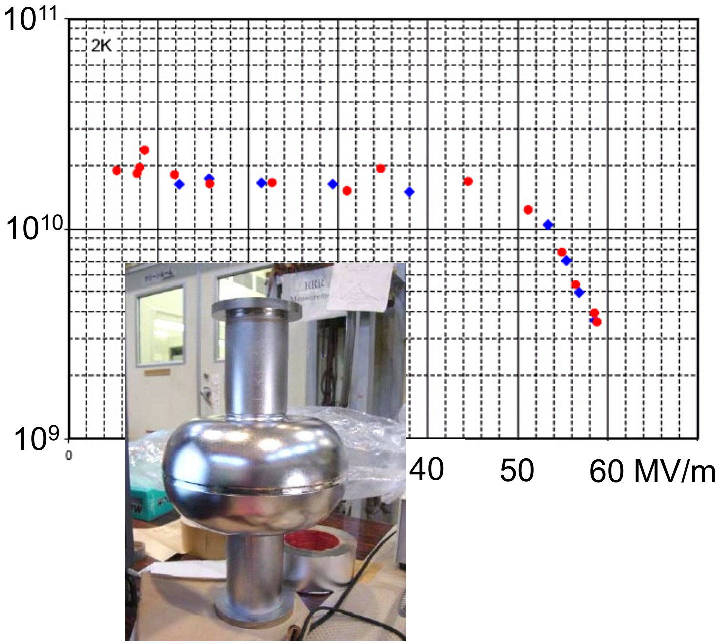
$G_{cavity}$ = 36 MV/m ⇒ 9.6 km

(VT ≥ 40 MV/m)



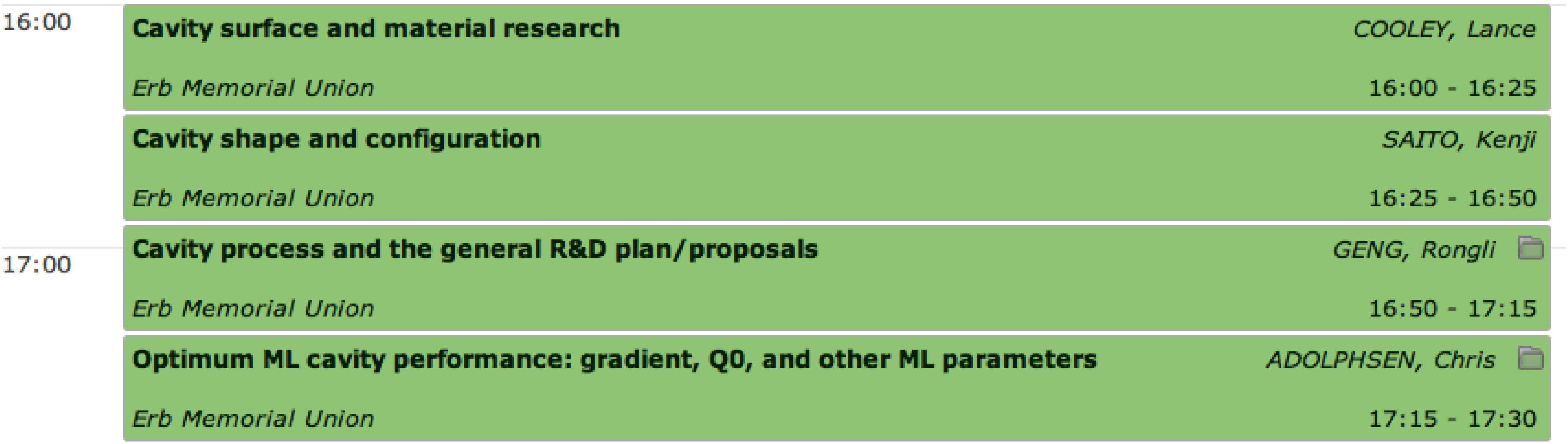
Based on use of low-loss or re-entrant cavity shapes

# Ultra-High Gradient Cavity R&D



- **Single-cell re-entrant cavity design achieved ~59 MV/m (cw)**
  - Cornell/KEK collaboration
- **In principle, multicells with 60 MV/m could be possible**
  - < 6 km additional linac (total site length ~ 43 km)
- **Overall cost-effective solution must be found**
  - $Q_0 \Rightarrow$ required cryogenic cooling
  - cost/cavity for increased performance
  - site constraints!

# Cavity R&D Prospects



16:00

**Cavity surface and material research** — *COOLEY, Lance*
*Erb Memorial Union* — 16:00 - 16:25

**Cavity shape and configuration** — *SAITO, Kenji*
*Erb Memorial Union* — 16:25 - 16:50

17:00

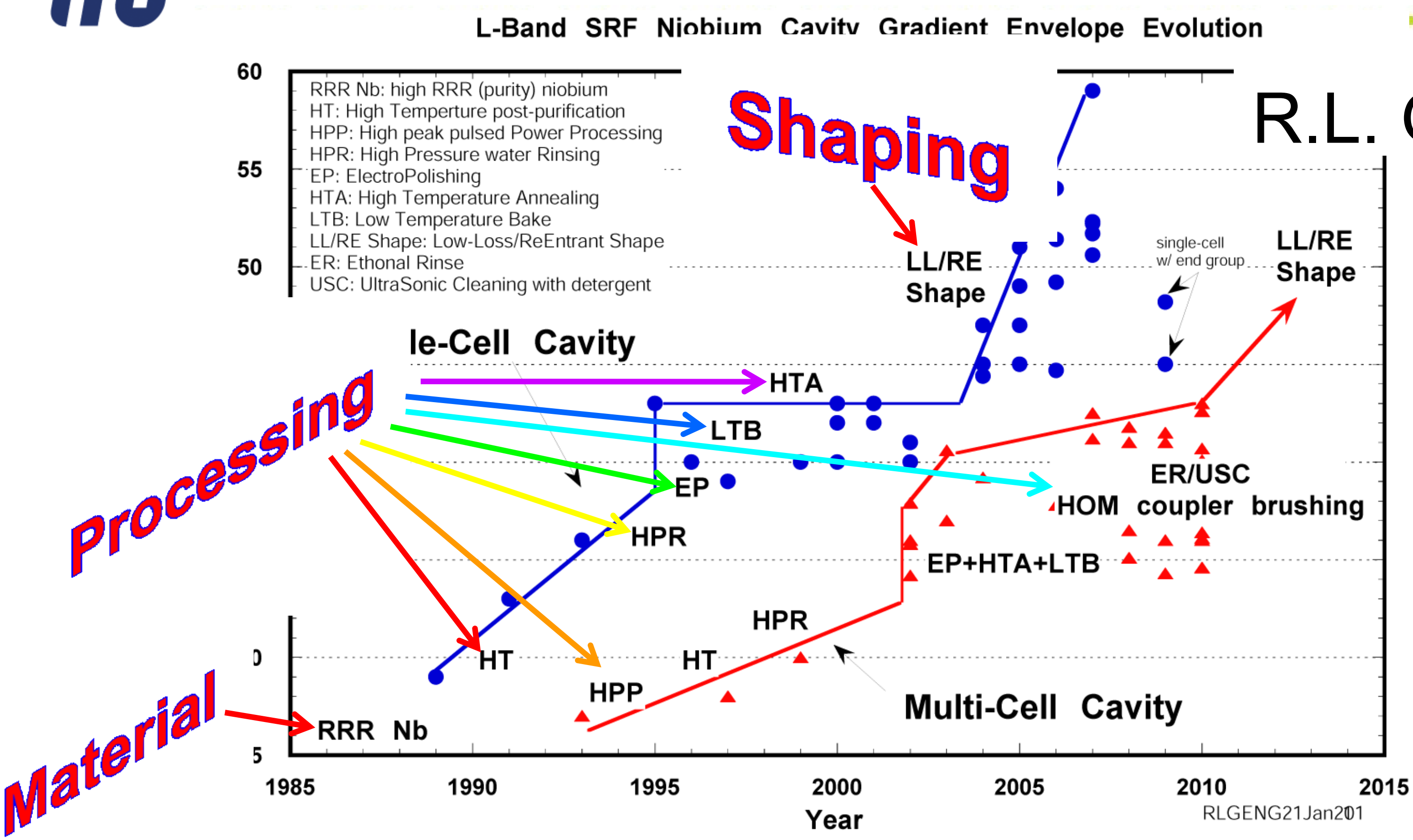
**Cavity process and the general R&D plan/proposals** — *GENG, Rongli*
*Erb Memorial Union* — 16:50 - 17:15

**Optimum ML cavity performance: gradient, Q0, and other ML parameters** — *ADOLPHSEN, Chris*
*Erb Memorial Union* — 17:15 - 17:30

- **Special GDE plenary yesterday to discuss prospects and future directions**

# SRF R&D Behind Gradient Progresses

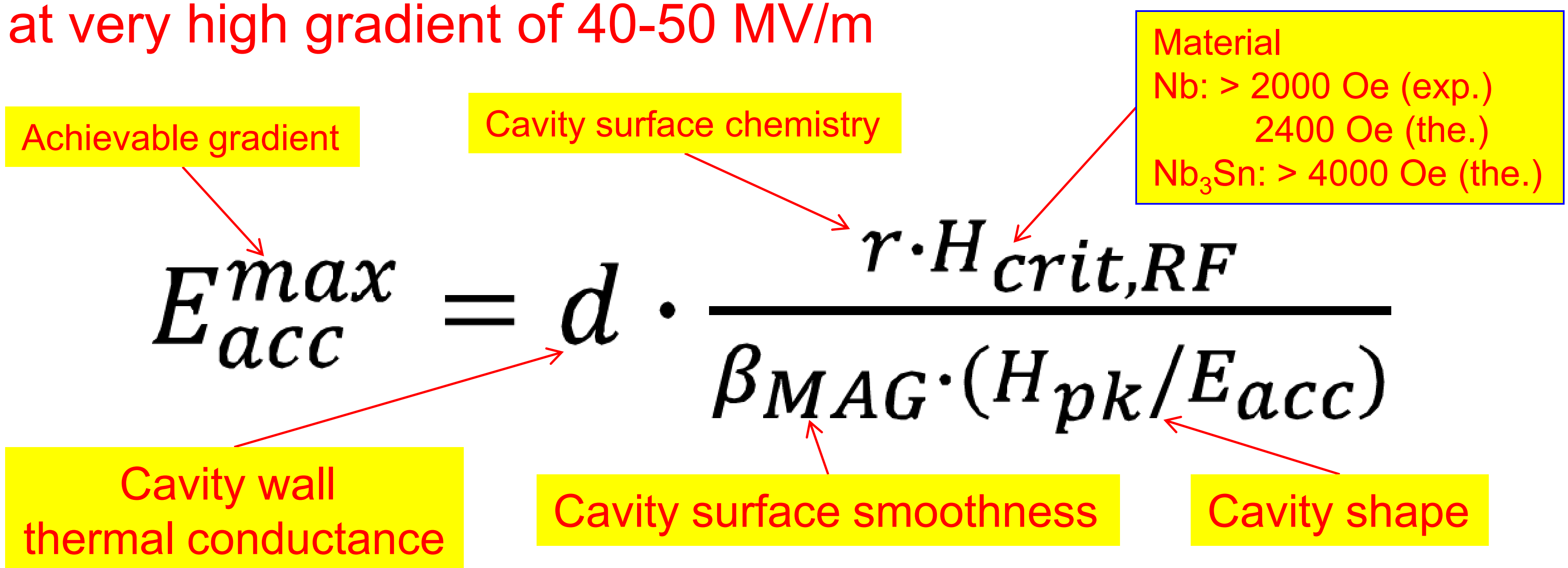
R.L. Geng



Understanding in gradient limits and inventing breakthrough solutions are responsible for gradient progresses. This has been a tradition in SRF community and rapid gradient progress continues. Up to 60 MV/m gradient has been demonstrated in 1-cell 1300 MHz Nb cavity. 45-50 MV/m gradient demonstration in 9-cell cavity is foreseen in next 5 years.

# Main Issues at Very High Gradient (3)

"Knobs" for improved reproducibility in overcoming local quench at very high gradient of 40-50 MV/m



Material
Nb: > 2000 Oe (exp.)
2400 Oe (the.)
$Nb_3Sn$: > 4000 Oe (the.)

Achievable gradient

Cavity surface chemistry

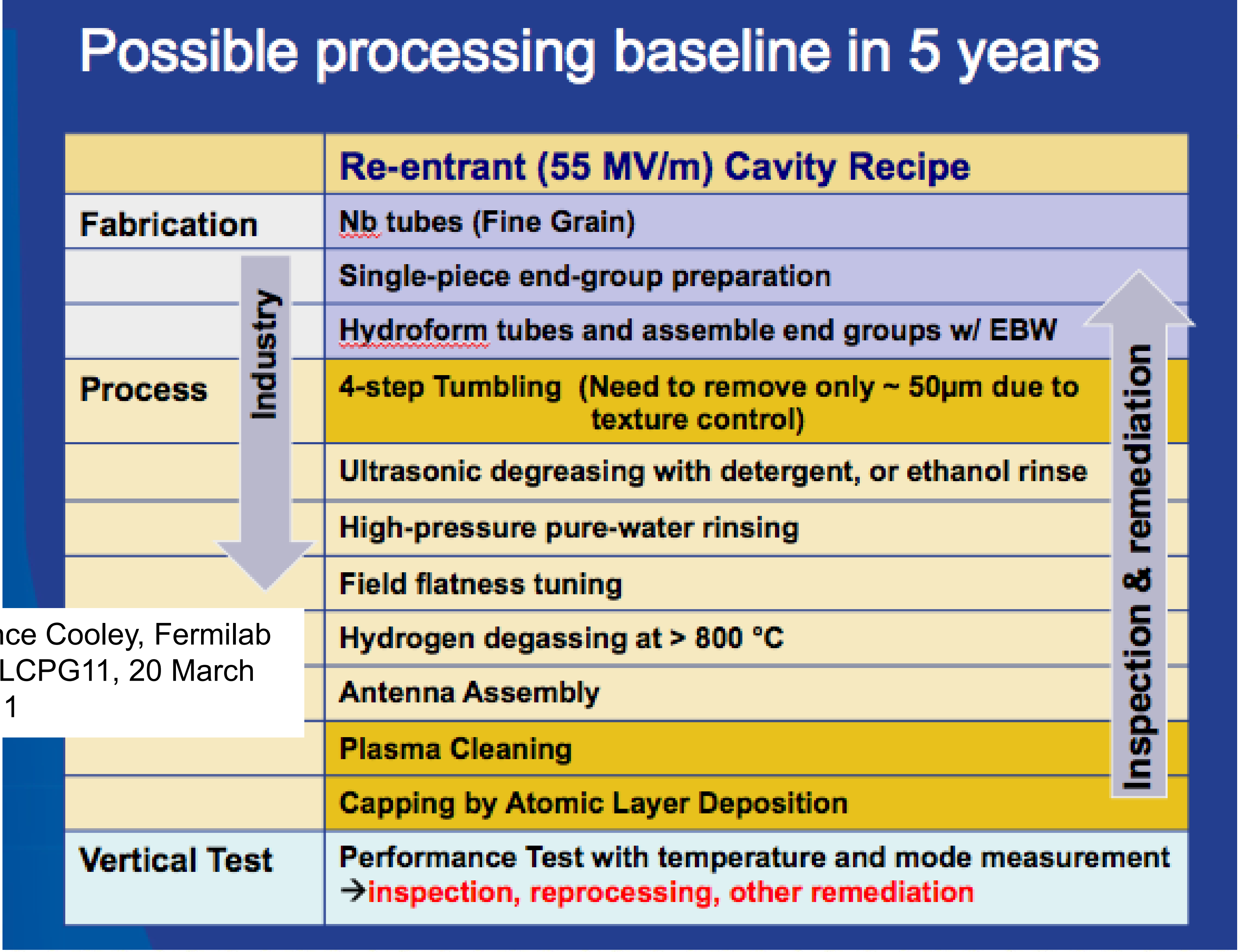
$$E_{acc}^{max} = d \cdot \frac{r \cdot H_{crit,RF}}{\beta_{MAG} \cdot (H_{pk}/E_{acc})}$$

Cavity wall thermal conductance

Cavity surface smoothness

Cavity shape

(1) Alternate cavity shape for reduced Hpk/Eacc ratio. In hand (LL, RE, LSF).
(2) Uniform cavity processing for reduced local "bad" spots. In hand (EP).
(3) Smooth surface for reduced local magnetic field enhancement. In hand(CBP & derivative + EP).
(4) Improved wall thermal conductance for increased local heating tolerance.
    - Cavity heat treatment optimization for "phonon peak engineering"
    - Use Nb/Cu composite material (such as explosion bonded material)
(5) The game-changing knob is a Nb replacement material (such as $Nb_3Sn$ or $Mg_2B$ w/ multi-layer).



# Possible processing baseline in 5 years

| | Re-entrant (55 MV/m) Cavity Recipe |
|---|---|
| Fabrication | Nb tubes (Fine Grain) |
| | Single-piece end-group preparation |
| | Hydroform tubes and assemble end groups w/ EBW |
| Process | 4-step Tumbling (Need to remove only ~ 50µm due to texture control) |
| | Ultrasonic degreasing with detergent, or ethanol rinse |
| | High-pressure pure-water rinsing |
| | Field flatness tuning |
| | Hydrogen degassing at > 800 °C |
| | Antenna Assembly |
| | Plasma Cleaning |
| | Capping by Atomic Layer Deposition |
| Vertical Test | Performance Test with temperature and mode measurement →inspection, reprocessing, other remediation |

Industry

Inspection & remediation

Lance Cooley, Fermilab – ALCPG11, 20 March 2011

# Upgrade Cost Estimate

- **For the TDR, an approximate cost for the upgrade is needed**
- **Zeroth-order estimate: current cost of main linacs ~ 3 BILCU**
  - roughly ½ RDR total project cost
  - Consider this an upper limit ?
- **Most difficult question will be cost of "upgraded" main linac technology**
  - cost of ultra-high gradient cavities?
  - Re-designed cryomodule?
  - Updated HLRF?
  - CFS solution
  - …

Forward looking R&D required for proof-of-principle

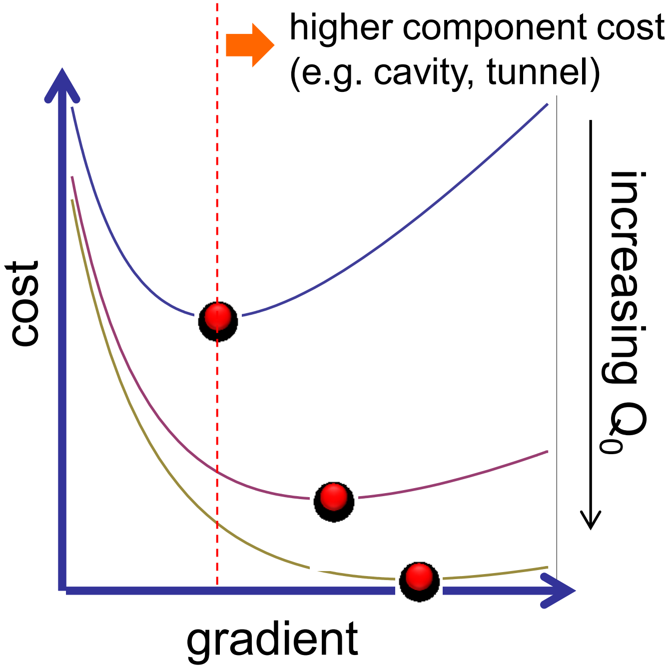
Cost effectiveness needs to be kept in mind

# Linac Cost Optimisation

For a fixed energy gain:

$$\$_{linac} \propto \frac{c_{linear}}{G} + c_{cryo}\frac{G}{Q_0}$$

simplistic – there are other terms!

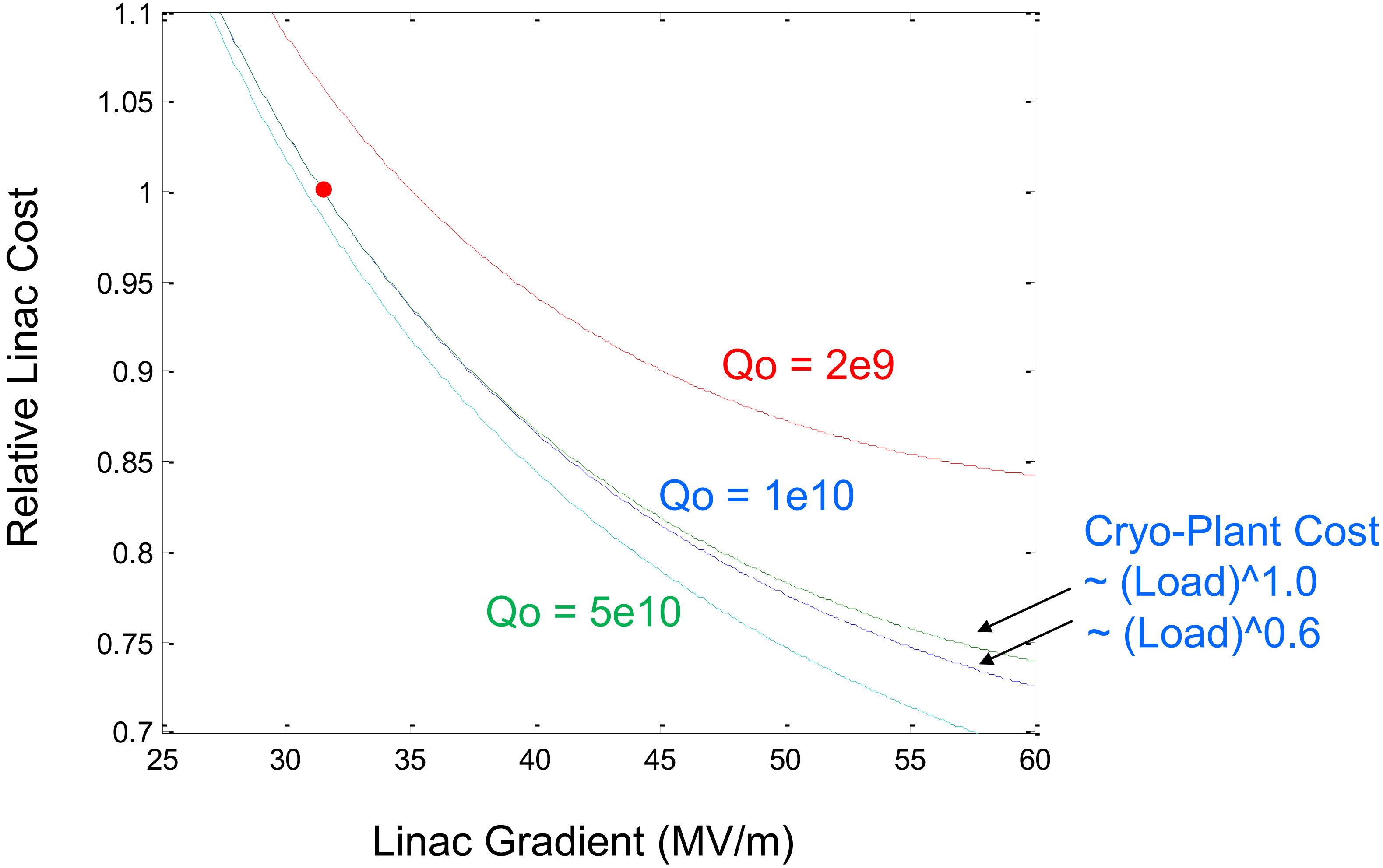


An overall cost-optimum should exist

Above model naïve since cavity/CM cost assumed independent of gradient

High-gradient R&D must also push $Q_0$ for optimum cost

# Cost Scaling



C. Adolphsen

http://ilcagenda.linearcollider.org/sessionDisplay.py?sessionId=2&confId=4572#20110320

# RDR Power Estimate

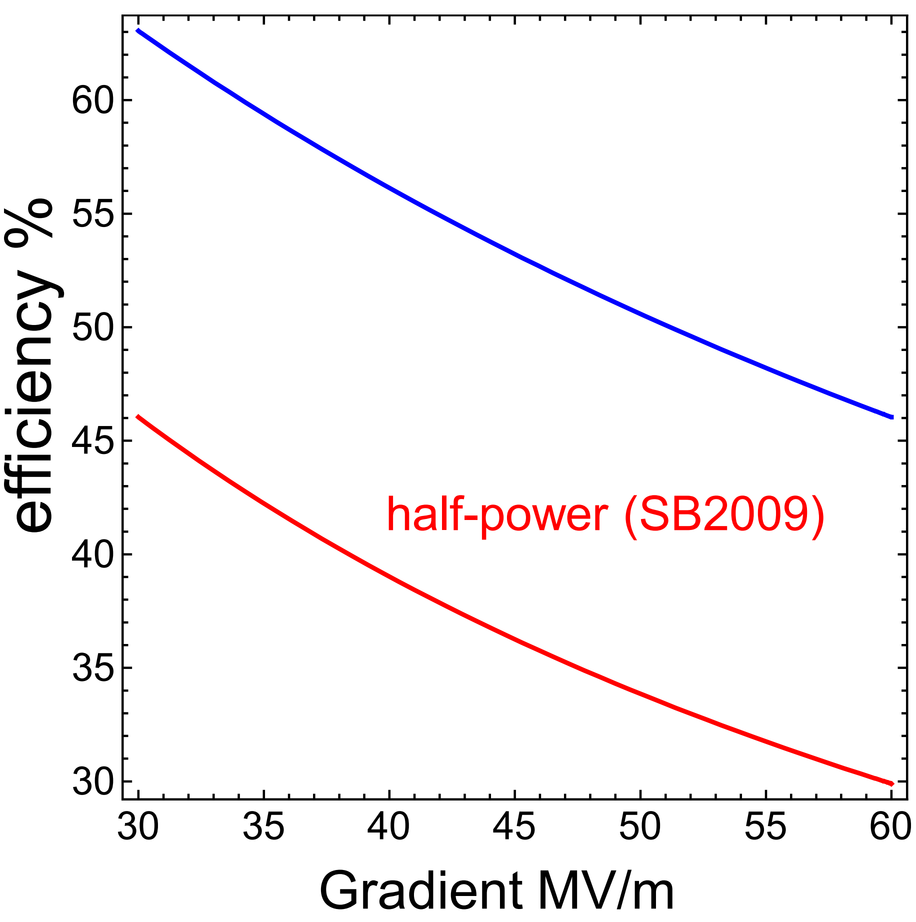
nb full 9mA

TABLE 4.3-1
Estimated nominal power loads (MW) for 500 GeV centre-of-mass operation.

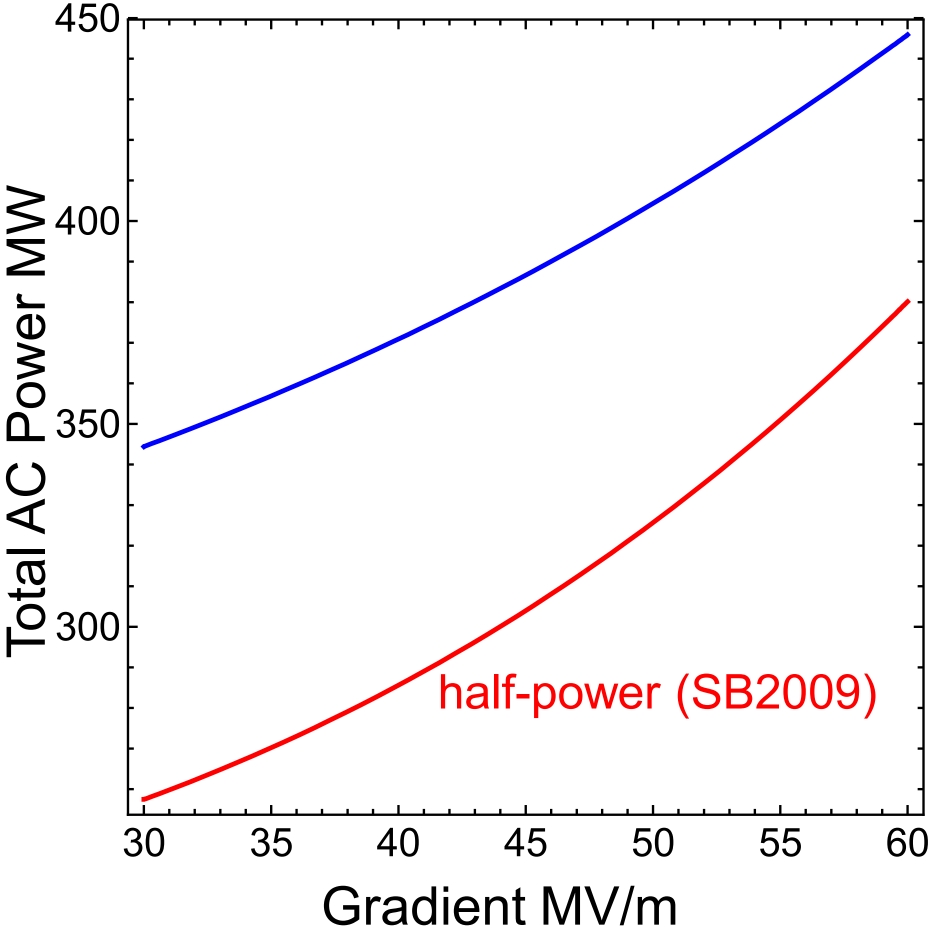
| Area System | RF Power | Conventional Power | | | | Emer Power | Total (by area) |
|---|---|---|---|---|---|---|---|
| | | Conv | NC Magnets | Water Systems | Cryo | | |
| Sources $e^-$ | 1.05 | 1.19 | 0.73 | 1.27 | 0.46 | 0.06 | 4.76 |
| Sources $e^+$ | 4.11 | 7.32 | 8.90 | 1.27 | 0.46 | 0.21 | 22.27 |
| DR | 14.0 | 1.71 | 7.92 | 0.66 | 1.76 | 0.23 | 26.29 |
| RTML | 7.14 | 3.78 | 4.74 | 1.34 | 0.0 | 0.15 | 17.14 |
| Main Linac | 75.72 | 13.54 | 0.78 | 9.86 | 33.0 | 0.4 | 134.21 |
| BDS | 0.0 | 1.11 | 2.57 | 3.51 | 0.33 | 0.20 | 7.72 |
| Dumps | 0.0 | 3.83 | 0.0 | 0.0 | 0.0 | 0.12 | 3.95 |
| Totals (by system) | 102.0 | 32.5 | 25.6 | 17.9 | 36.9 | 1.4 | 216.3 |

Doubling linac ⇒ 216 MW → 352 MW

# Efficiency and Power



nb 5 Hz rep. rate

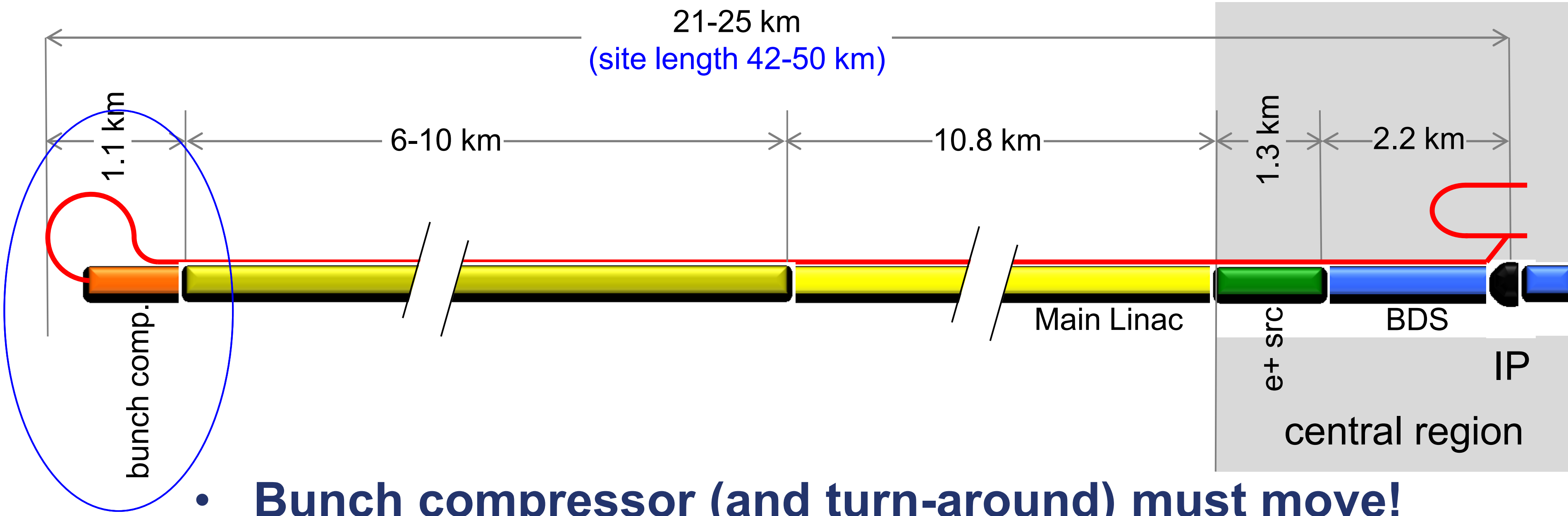


Simples scaling – needs more detailed analysis

# Other Accelerator System Impacts

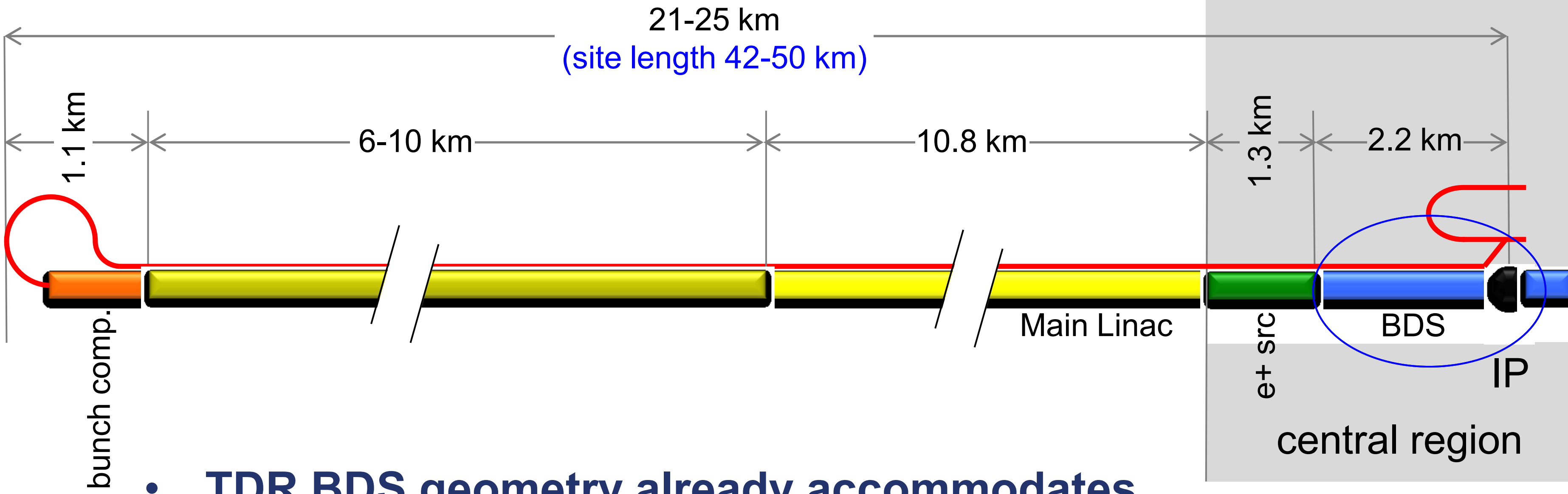
- **Damping Ring and electron source remain essentially unchanged**
  - Notwithstanding a chance in relevant parameters
  - not considered further in this report
- **Primary Main Linac concern is choice of technology, but**
  - Beam dynamics issues (higher wakefields in new cavity shapes)
  - Existing ML lattice now has to transport higher-energy beam
  - …
- **In the following, briefly consider impact to the following:**
  - RTML / Bunch Compressor
  - Beam Delivery System
  - Positron Source

# Bunch Compressor (RTML)



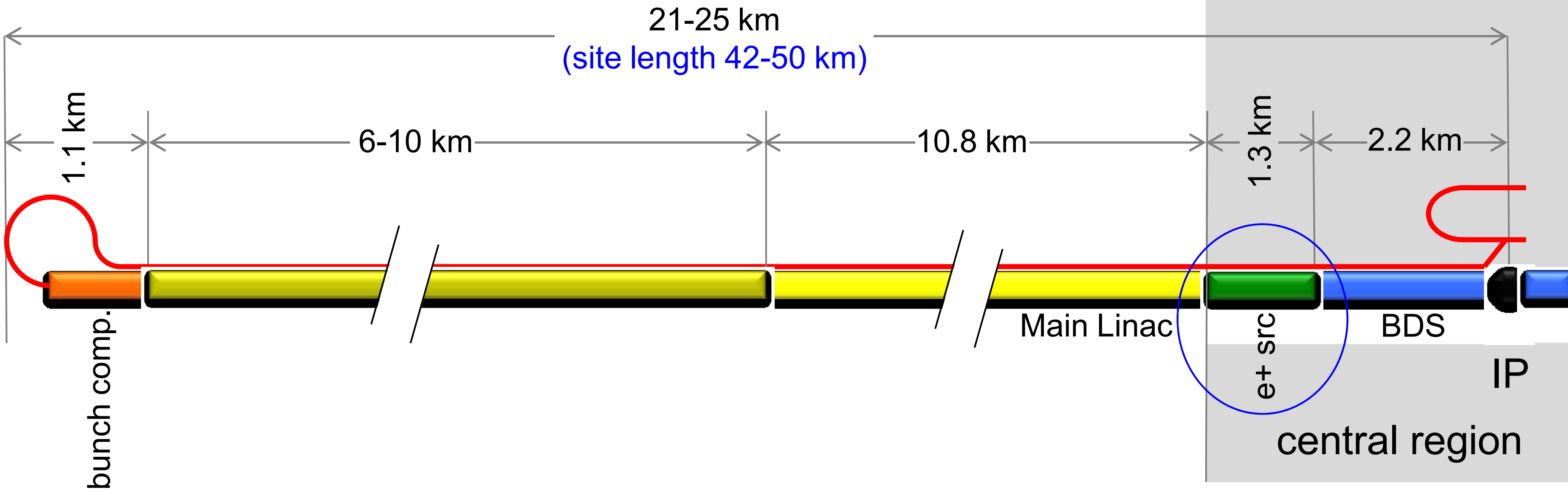
- **Bunch compressor (and turn-around) must move!**
- **During upgrade we can consider various design scenarios:**
  - stay with single-stage
  - Include two-stage compressor
  - (even) consider three-stage compressor
    - shorter $\sigma_z$
    - larger $\Delta p/p$
    - increased length, complexity (and cost)
- **Evaluate (physics) gain.**
- **Impact of energy spread etc.**

# Beam Delivery System



- **TDR BDS geometry already accommodates 1 TeV upgrade**
  - Upgrade requires additional dipole magnets
- **Primary beam dumps rated for 500 GeV 9mA beam @ 4 Hz**
  - 18 MW average beam power
  - Assumed not easy to ‘upgrade’

# Positron Source



- **Undulator-based positron source probably requires most attention**

# Positron Source (cont.)

- **Simplistic (first-order) approach: use existing location and drive with 500 GeV beam**
  - reduce undulator length to ~10-18 m (or reduced field by ÷4)
  - photon cone (spot size on target) reduced by ÷2
  - photon energy (1st harmonic) ~ 112 MeV
  - Impact on energy spread? Challenge for polarisation (photon collimator)?
- **What are the alternatives?**
  - construct new undulator source at *new* 250GeV point ??
  - construct completely new source (alternative, such as Compton)??
  - …
- **Physics requirements: Z running (or in general $E_{cm}$ <300 GeV) still required??**

# 1 TeV Parameters

| | | | |
|---|---|---|---|
| Collision rate | $f_{rep}$ | 4 | Hz |
| Number of bunches | $n_b$ | 2625 | |
| Bunch population | $N_-$ | 2 | $\times 10^{10}$ |
| Bunch seperation | $\Delta t_b$ | 356 | ns |
| Pulse current | $I_{beam}$ | 9.0 | mA |
| RMS bunch length | $\sigma_z$ | 0.3 | mm |
| RMS energy spread (e-, e+) | $\Delta p/p$ | 0.105, 0.038 | |
| Polarisation ($e^-$, $e^+$) | $P_-$ | 80, 22 | % |
| Emittance (linac exit) | $\gamma\varepsilon_{x,y}$ | 10, 0.035 | µm |
| IP beta function | $\beta_{x,y}^*$ | 30, 0.3 | mm |
| IP RMS beam size | $\sigma_{x,y}^*$ | 554, 3.3 | nm |
| Vertical disruption parameter | $D_y$ | 19.2 | |
| **Luminosity** | $\mathbf{L}$ | **2.70** | **$\times 10^{34}$ cm$^{-2}$s$^{-1}$** |
| Fraction of luminosity in top 1% | $L_{0.01}/L$ | 63.5 | % |
| Average energy loss | $\delta E_{\mathrm{BS}}$ | 4.9 | % |
| Number of pairs per bunch crossing | $N_{pairs}$ | 169 | |
| Total pair energy per bunch crossing | $E_{pairs}$ | 1084 | TeV |

Current “official” parameter set in EDMS*.

Should still be considered tentative, pending review and further study.

Understanding (and updating) these parameters is our job for the next ~6 months.

* EDMS Doc ID: D*925325
http://ilc-edmsdirect.desy.de/ilc-edmsdirect/file.jsp?edmsid=*925325&fileClass=ExcelShtX

# 1 TeV Parameters

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- **Working assumptions:**
  - 2625 bunches restored ← Site power! Careful consideration.
  - $2\times10^{10}$ particles per bunch (no change from 500GeV)
  - Reduced collision rate 5 → 4 Hz (AC/Cryo power)

- **Considerations**
  - $N \propto 1/n_b$ for fixed current
    - beam-beam → stronger focusing; source/injector issues
    - Requirements on bunch compressor
    - (cf alternative parameter proposal from J. Gao, SLAC BAW)
  - Reduced repetition rate?
    - 25% luminosity, but at a cost (increase AC/cryo power)

# 1 TeV Parameters

| | | |
|---|---|---|
| RMS bunch length | $\sigma_z$ | 0.3 mm |
| RMS energy spread (e-, e+) | $\Delta p/p$ | 0.105, 0.038 |
| Polarisation ($e^-$, $e^+$) | $P_-$ | 80, 22 % |

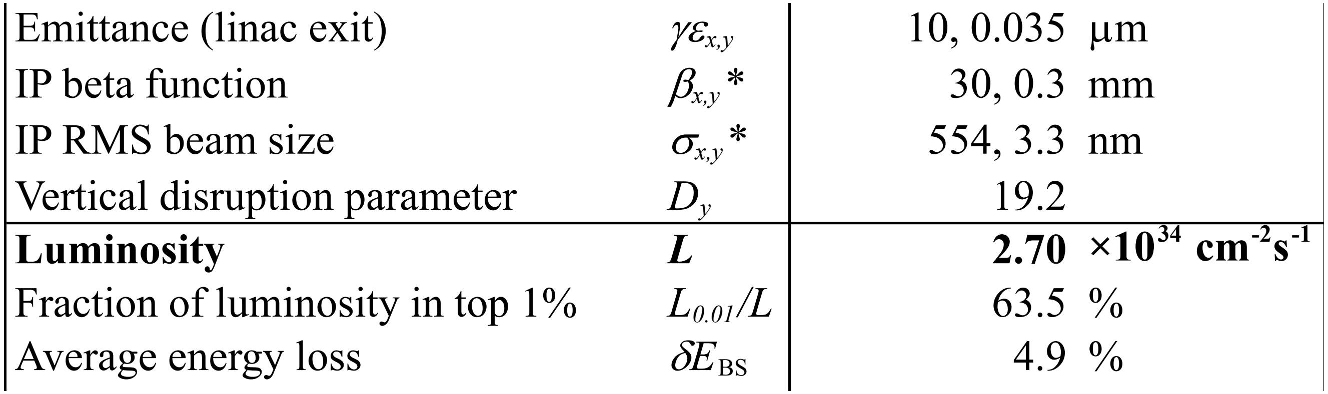
- **Working assumptions:**
  - bunch length unchanged
  - polarisation unchanged
  - energy spread scaled (simplistic)

- **Considerations**
  - bunch compressor options, possible shorter $\sigma_z$.
  - electron energy spread
  - positron polarisation

  } Strongly influenced by design choices for positron source

  - energy spread (general)
    - bunch compressor options
    - linac technology for upgrade (wakefield)

# 1 TeV Parameters



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|---|---|---|---|
| Emittance (linac exit) | $\gamma\varepsilon_{x,y}$ | 10, 0.035 | µm |
| IP beta function | $\beta_{x,y}*$ | 30, 0.3 | mm |
| IP RMS beam size | $\sigma_{x,y}*$ | 554, 3.3 | nm |
| Vertical disruption parameter | $D_y$ | 19.2 | |
| **Luminosity** | $\boldsymbol{L}$ | **2.70** | **$\times 10^{34}$ cm$^{-2}$s$^{-1}$** |
| Fraction of luminosity in top 1% | $L_{0.01}/L$ | 63.5 | % |
| Average energy loss | $\delta E_{\mathrm{BS}}$ | 4.9 | % |

- **Working assumptions:**
  - Horizontal β-function increased to limit beamstrahlung at ~5%
  - (Vertical reduced to increase partially compensate)
  - High disruption parameter regime (stability)
  - (Normalised) emittances assumed unchanged

- **Considerations**
  - $N \propto 1/n_b$ (see slide 20) beam-beam tradeoffs
    - This includes bunch length
  - Vertical emittance – beam dynamics studies required
    - influence of linac upgrade tech. choice and bunch compressor options

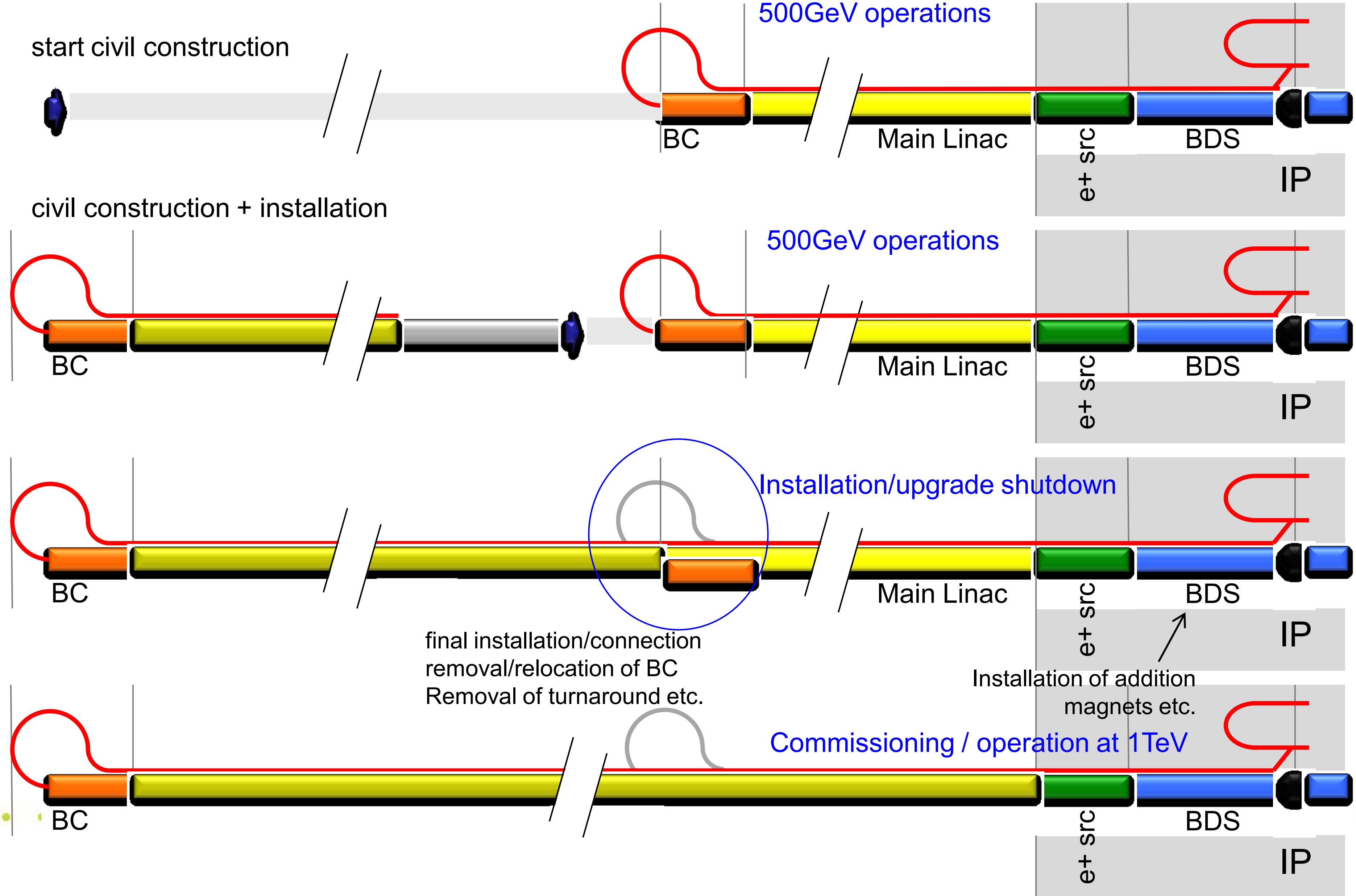
# 1 TeV Parameter with Travelling Focus

| | | | |
|---|---|---|---|
| IP vertical beta function (TF) | $\beta_y *$ | 0.2 | mm |
| IP RMS veritcal beam size (TF) | $\sigma_y *$ | 2.7 | nm |
| **Luminosity** | $\boldsymbol{L}$ | **3.39** | $\boldsymbol{\times 10^{34}\ \mathrm{cm^{-2}s^{-1}}}$ |
| Fraction of luminosity in top 1% | $L_{0.01}/L$ | 62.3% | |
| Average energy loss | $\delta E_{\mathrm{BS}}$ | 4.85% | |
| Number of pairs per bunch crossing | $N_{pairs}$ | 202.3 | |
| Total pair energy per bunch crossing | $E_{pairs}$ | 1327.8 | |

If Travelling Focus proves tractable, then it can equally be applied for the upgrade

Same caveats apply as for current ≤500 GeV parameter sets

# Construction Scenario(s)



start civil construction

500GeV operations

civil construction + installation

500GeV operations

Installation/upgrade shutdown

final installation/connection
removal/relocation of BC
Removal of turnaround etc.

Installation of addition
magnets etc.

Commissioning / operation at 1TeV

# The TDR Upgrade Study

- **Begins this workshop (next slide)**

- **Limited resources means only a <u>very</u> conceptual study**
  - design parameters
  - scaling of 500GeV designs
  - Working assumptions on ML technology

Note that 500GeV remains our primary focus for the TDR

- **SCRF Tech. will define forward looking R&D**
  - beyond 2012
  - upgrade scenarios can be ‘aggressively optimistic’ at this stage.

- **An AD&I activity – including physics & detector**

- **Proposal to produce a White Paper by early 2012**
  - Will eventually be part of TDR

- **Primary editors (tentative – needs discussion):**
  - 3 PMs
  - 1 Integration
  - 1 Parameters
  - 3 reps from physics and detectors (2 detectors + theory)
  - 1 cost & schedule

Expected to drive the study and write the White Paper

# Next Steps

- **Each TAG needs to produce a comprehensive list of issues/questions**
  - this workshop
- **Formation of the White Paper task force**
- **Early initial review of top-level parameter(s)**
  - working assumptions for remainder of studies
- **Identification of key studies and deadlines for reports**
  - integrated into monthly AD&I meetings
- **Outline of white paper and writing assignments**