# Cost Comparison of Undulator and e-Driven Systems

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This is basically the same as my talk in the Cost Review Meeting with LCB and LCC on Sep.26 at KEK

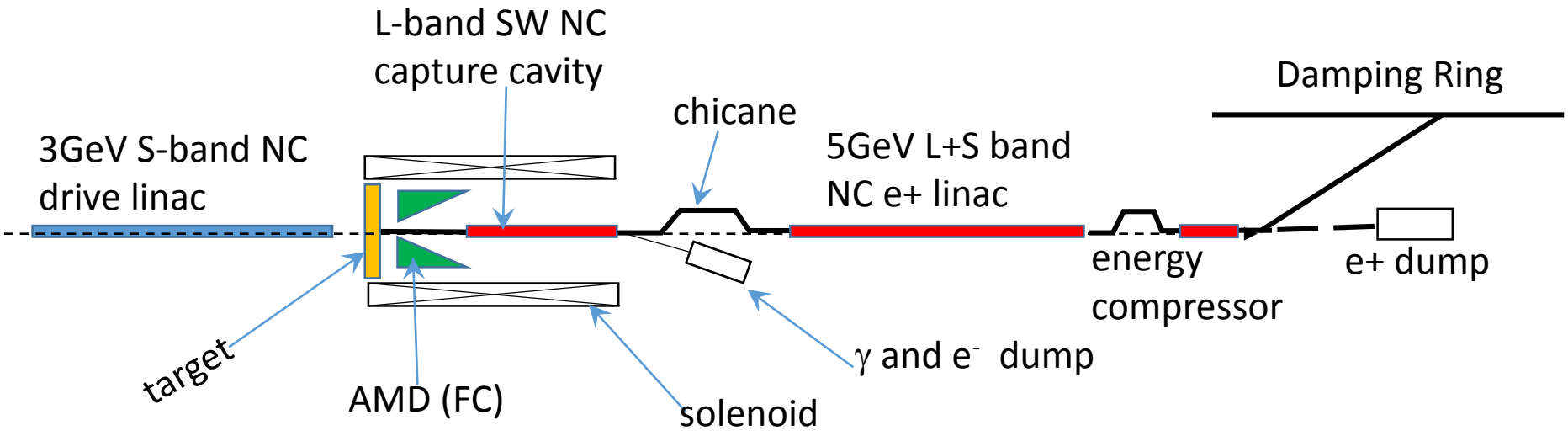
# Contents

- Cost of e-driven system
- Cost of undulator system: What's in TDR?
- Basic cost comparison
- First stage cost
- Luminosity upgrade

- No technology discussion

# Basic Assumptions for e-Driven Scheme

- Number of bunches per pulse 1312
- Number of positrons per bunch $3 \times 10^{10}$ (incl. margin)
- Beam pulse structure
  - Repetition 5Hz : 200ms interval
  - 20 times 0.48μs pulse in 63ms (300Hz)
  - Bunch distance 6.15ns
  - No pulse in the rest 137ms
  - Electron spot size on the target 2mm (RMS)



# Electron Drive Linac

- 3GeV sufficient owing to $n_b$ = 1312 (4.8GeV for $n_b$ = 2625)
- Bunch charge 2.4nC (peak current 0.39 Ampere)
- S-band photo-cathode RF gun
- 80MW klystron drives two 3m structures
- 60+4 (spare) 3m TW structure
- Total length 255m including RF gun and matching section

- Major cost drivers

| | unit cost | # in RF unit | # of RF units | cost sum |
|---|---|---|---|---|
| Electron gun | | | | 6.24 |
| Klystron | 0.285 | 2 | 16 | 9.12 |
| Modulator | 0.3972 | 2 | 16 | 12.71 |
| Circuit | 0.3487 | 1 | 16 | 5.58 |
| Acc. Structure | 0.1806 | 4 | 16 | 11.56 |
| Vacuum | 0.22 | 1 | 16 | 3.52 |
| Sum | | | | 48.76 |

- Include others (magnets, vacuum, construction, etc)
- Total cost 58.38 OkuYen

# Target System

- Electron spot size on target 2mm r.m.s.
  - Larger spot needed for for $n_b$ = 2625
- Rough cost estimation

| | note | cost (OkuYen) |
|---|---|---|
| Solenoid (incl. PS) | longer by 20% than undul. | 10.00 |
| Flux concentrator (incl. PS) | ~5.2OkuYen for undul. | 3.00 |
| Remote handling | ~1.2OkuYen for undul. | 2.00 |
| target | ~6.4OkuYen for undul. | 1.60 |
| Sum | | 16.50 |

# L-band Capture Linac

- L-band SW NC

| | unit cost | # of units | cost sum |
|---|---|---|---|
| Klystron | 0.285 | 18 | 5.13 |
| Modulator | 0.3276 | 18 | 5.90 |
| Circuit | 0.088 | 18 | 1.58 |
| Acc. Structure | 0.3224 | 2x16 | 11.61 |
| Vacuum | 0.15 | 18 | 2.70 |
| Sum | | | 26.82 |

- Including others (magnets, construction, etc)
- Sum is 32.80 OkuYen

# Booster

| | unit cost | # in RF unit | # of RF units | cost sum |
|---|---|---|---|---|
| L-band section | | | | |
| Klystron | 0.285 | 2 | 36 | 20.52 |
| Modulator | 0.3276 | 2 | 36 | 23.59 |
| Circuit | 0.3937 | 1 | 36 | 14.17 |
| Acc. Structure | 0.2621 | 4 | 36 | 37.75 |
| S-band section | | | | |
| Klystron | 0.285 | 1 | 23 | 6.56 |
| Modulator | 0.3972 | 1 | 23 | 9.14 |
| Circuit | 0.3424 | 1 | 23 | 7.88 |
| Acc. Structure | 0.1329 | 4 | 23 | 12.23 |
| Magnets incl. chicane) | | | | 7.02 |
| Vacuum | 0.185 | | 59 | 10.92 |
| Sum | | | | 149.66 |

- Including others, sum is 158.84 OkuYen

# Energy Compressor

| | | cost sum |
|---|---|---|
| Klystron | 3 units | 0.85 |
| Modulator | 3 units | 0.98 |
| Circuit | 18 | 0.67 |
| Acc. Structure | 2m structure x6 | 1.52 |
| Vacuum | | 0.48 |
| Magnets (incl.PS) | | 1.18 |
| Sum | | 5.68 |

- Including others, the sum is 6.27 OkuYen

# Sum of Accelerator System

| | |
|---|---|
| Electron drive linac (incl. electron gun) | 58.38 |
| Target system (excl. linac) | 16.50 |
| L-band capture linac | 32.80 |
| L+S band booster linac (incl. chicane) | 158.84 |
| Energy compressor | 5.68 |
| others | |
| Sum | 272.2 |

- Others should include (but level of a few OkuYen)
  - photon&electron dump after capture linac
  - positron tuning dump
  - Electron dump right after drive linac (perhaps needed)
  - Beamline from end of energy compressor to DR

# CFS Cost for e-Driven Source

- The required width of tunnel is quite complex. There is no definite design in the positron source region even for the undulator scheme.
- The RF source components for NC linac occupy the space in service tunnel more densely than SC components for undulator system, but detailed consideration including the transportation is necessary
- For upgrade to 2625 bunches some more space for the mudulators may be reserved due to the longer beam pulse (0.48μs → ~1μs)
- For simplicity here we assume a slightly increased cost per longitudinal length due to the larger power consumption and cooling water system.

# Cost Comparison Policy

- We estimated the cost of the accelerator components of e-driven system in JYen, as we saw.
- It is more convenient to convert the undulator scheme cost in ILCU in TDR into JYen than the other way
- We use the same policy which we used when we converted TDR cost in MILCU to JYen for MEXT
  1 MILCU = 1.09 OkuYen for tunnel civil engineering
  1 MILCU = 1 OkuYen for CFS others and components

# Cost of Undulator System

- TDR quotes 228MILCU as the value of accelerator components and 72MILCU for the CFS for the undulator positron source.
- However
  - There are several design changes since TDR
  - We could not reproduce 72 MILCU for CFS from other data. We will not use this number.
  - For the purpose of comparison with the e-driven system, numbers of items which are included in other area systems have to be modified

# Change of Undulator System Since TDR

- The undulator section must be lengthened 147m→231m for positron production at Ee=125GeV
  - TDR adopted 10Hz operation with 147m undulator
- The beam dump of spent electron after photon production is needed for 10Hz operation. This will not be built in the first stage.
- Auxiliary positron source will not be constructed, perhaps (majority of CRWG. It is not useful enough)

# Items that must be included as undulator system cost

- In TDR many items needed for undulator system are included in other area systems, because there was no concept of “comparison”
- The electron loses 3GeV in the undulator. This must be compensated for in the electron main linac (this is included in the value of ML in TDR). Also, RTML beam line cost should be added, though small.
- After the undulator the electron beam is separated from the photon beam by a dogleg. The cost of dogleg is included in BDS in TDR
  - The actual dogleg which has been re-designed is much shorter for Ee=125GeV because photon emission angle is larger

# CFS Cost for Undulator Scheme

- The tunnel length for the undulator scheme in TDR is 1678m.  40 OkuYen/km x 1678m = 67 OkuYen
  - The tunnel extention for the undulator length 147m → 231m is already included in the tunnel
- ML tunnel cost for the 3GeV compensation
- CFS cost for the dogleg is already included in positron source in TDR

# Basic Cost of Undulator Scheme (for comparison with e-driven)

- values were converted from MILCU to OkuYen

| | Accelerator | CFS |
|---|---|---|
| TDR | 227.5 | 67 |
| Longer undulator | 13.0 | 0 |
| 3GeV compensation | 27 | 7.3 |
| Dogleg | 21 | (1) |
| Beam dump for 10Hz | - 7.7 | 0 |
| Auxiliary positron source | -5.9 | 0 |
| SUM | 273.9 | 74.3 |

- (1) CFS cost for dogleg is already included in TDR

# Comparison of the Basic Cost

| | Undulator | e-Driven |
|---|---|---|
| Accelerator | 274 OkuYen | 272 OkuYen |
| CFS | 74 OkuYen | 44 OkuYen |
| Sum | 348 OkuYen | 316 OkuYen |

# Implementation in Staging

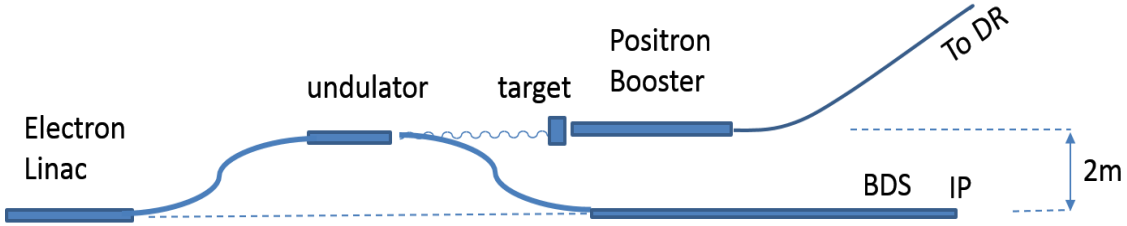
- Up to this point we naively estimated the cost difference, which is more or less independent of the scenario
- Now, there are several more points that must be considered when we take into account the staging scenario (higher lumi, higher energy).
- In particular, what must be estimated is the case when we start with the e-driven source.
  Depend on the order of upgrade
  undulator & higher lumi & higher energy

# Questions (1)

- The following items might be accounted for the cost comparison.
- The 250GeV stage that we are studying now (option C, Option D) includes some empty tunnel for global timing adjustment for undulator scheme, which is not necessary for e-driven case. Should we eliminate it from the beginning?
  - Rigorously speaking, the timing constraint is necessary in the positron wing only. The empty tunnel in the electron side is added for future extension to higher CM energy
  - The empty space is larger if we assume 35MV/m rather than 31.5MV/m. Can we cut this space? (less margin for 250GeV)

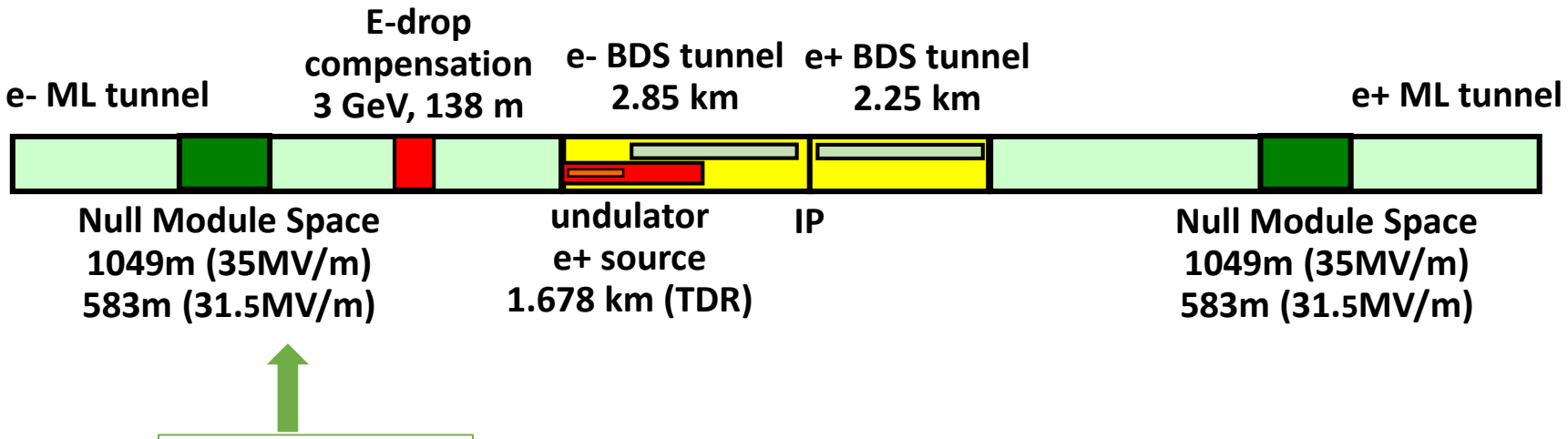
# Questions (2)

- Should the space of the undulator (and subsequent photon drift) be reserved for later upgrade?
  - The tunnel of this region is laser-straight in TDR. Presumably, we can manage from beam dynamics view point, even if it is bent. (BDS part must still be laser-straight)
  - Note: to reserve this space does not immediately mean that we can go to undulator scheme any time
- Should the dogleg of electron beam line after undulator be eliminated (different tunnel layout)? This brings about further cost reduction but a pair of doglegs (not a single dogleg) would be needed for later upgrade to undulator source if it is not implemented.



# 250GeV Stage for Undulator Scheme

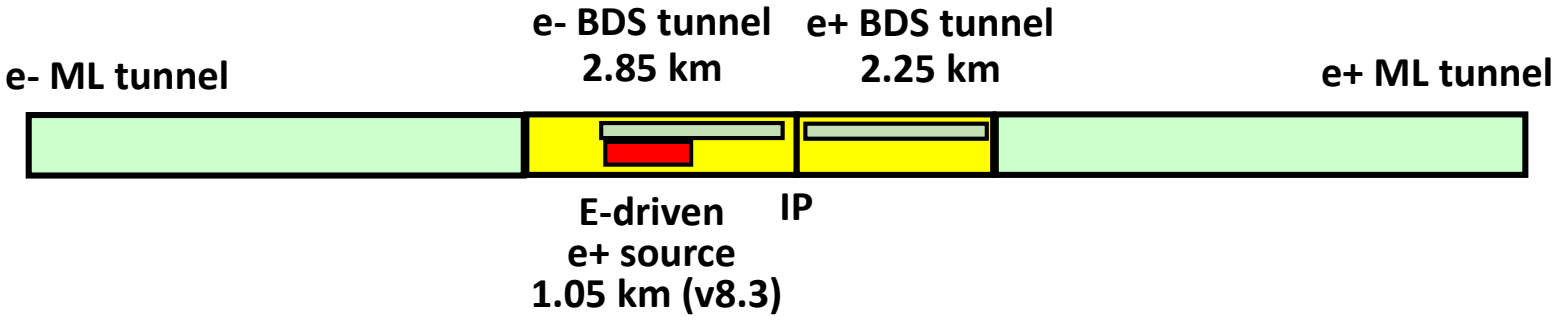
- Option C



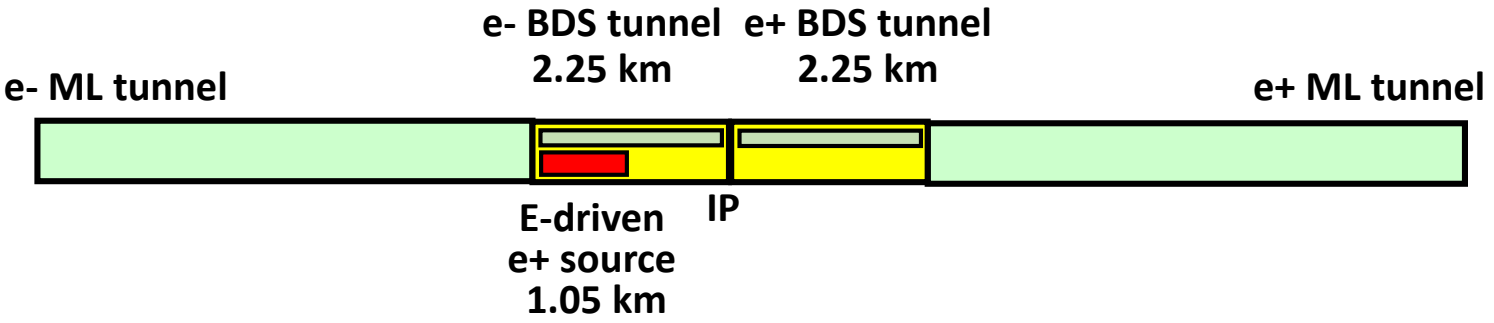

Not for timing.
Not included in
the comparison

# Tunnel for e-Driven Scheme

- With undulator/dogleg space




- Without undulator/dogleg space



# Final Cost Comparison

| | Undulator | e-Driven |
|---|---|---|
| Basic cost (1) | 348 | 316 (2) |
| | | |
| Empty space for timing (3) for 31.5 MV/m | 26 | |
| for 35 MV/m | 46 | |
| | | |
| Sum for 31.5 MV/m | 374 | 316 |
| 35 MV/m | 394 | 316 |

- (1) components+CFS, including 3GeV compensation, dogleg
- (2) Assume the space for undulater+photon drift is eliminated. If reserved, the cost increases by ~23 OkuYen
- (3) CFS + RTML beam line + main beam line. Only the positron wing

# Luminosity Upgrade (1)

- Here, we cannot avoid mentioning the technology
- Basic change for upgrade 1312→2625 bunches
  - Reinforce main linac RF system (common to und.&edriven)
  - Electron damping ring (common to und.&edriven)
    - More RF system
    - Faster injection/extraction kicker
  - Positron damping ring
    - Same as electron DR if the e-cloud instability allows doubled beam current.
      - The first stage has factor ~3 margin to the instability. So, high possibility to double the bunches
      - We will get sufficient info from superKEKB and 1st stage ILC
    - If not, add one more positron DR. The room reserved.

# Luminosity Upgrade (2)

- Required change for e-driven source
  - Add one more positron DR (independent on electron-cloud)
    - Beam-loading compensation difficult with 3ns bunch spacing
    - ~166 MILCU
    - Might be possible with one e+ DR if not doubling the bunches
  - Increase the energy of drive electron 3 → 4.8GeV
    - ~ 31 OkuYen (simple scaling)
    - Tunnel length extension unnecessary (determined by BDS length)
  - Re-inforce modulators of drive linac and booster
    - due to longer beam pulse
    - Assume tunnel width is large enough
- Required change for undulator source
  - Target technology not confirmed yet
    - Target wheel would be heavier
  - To add positron DR or not depends only on the electron-cloud issue
  - Re-inforce RF of booster linac