# Discussion session: $e^+e^-$ colliders

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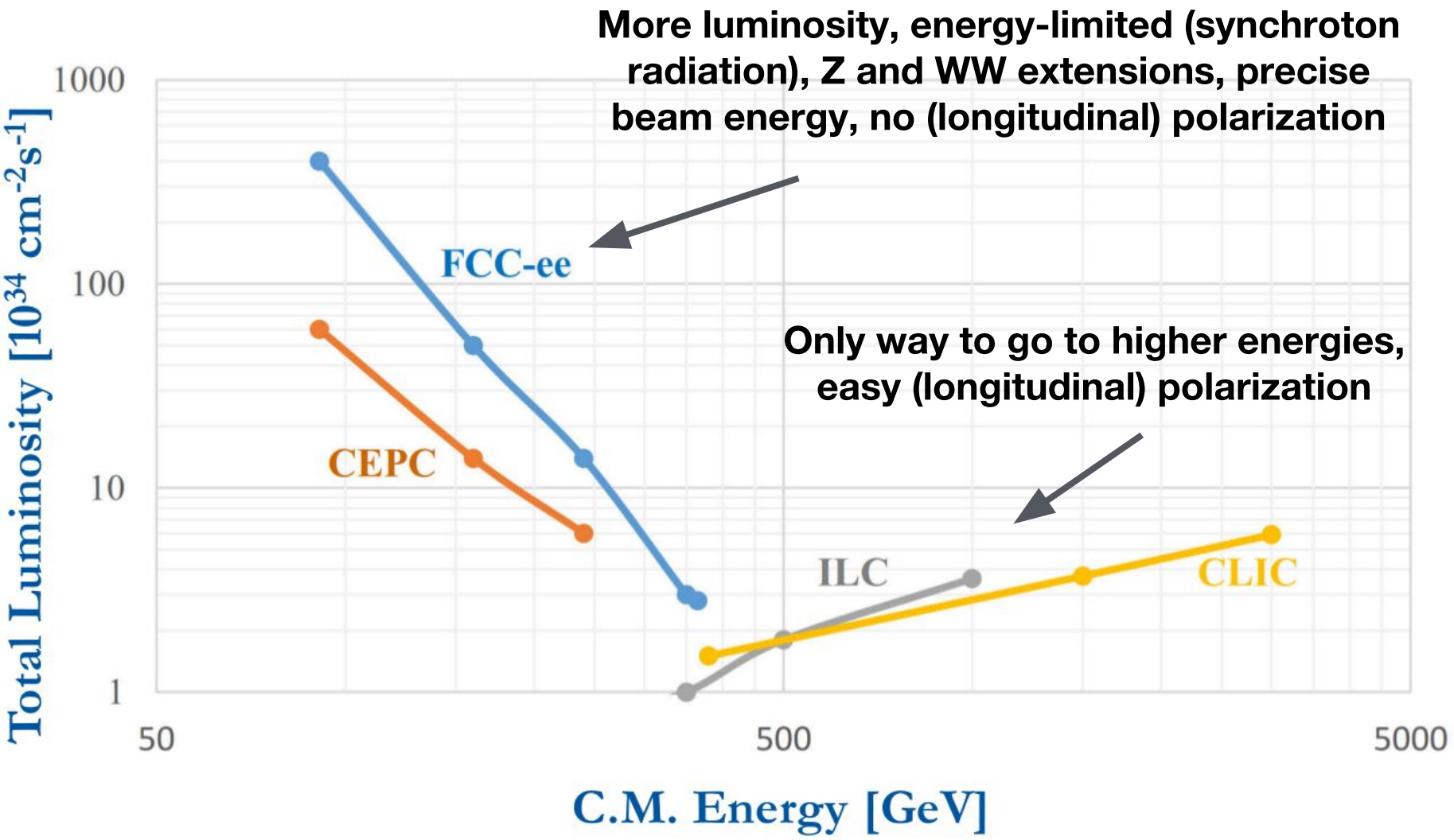
# $e^+e^-$ colliders

Next step in the understanding of the nature of the Higgs sector of the SM (and whether they are deviations pointing to New Physics):

- More precision (percent | sub-percent) almost everywhere
- Measurement of sigma*BR(ee->ZH) without looking at the Higgs side => measuring the Higgs width
- “Model independent” approach (EFT)
- Sensistive measurement of the Higgs-self coupling, particularly at high energies (CLIC) + search for deviations from SM at high energies

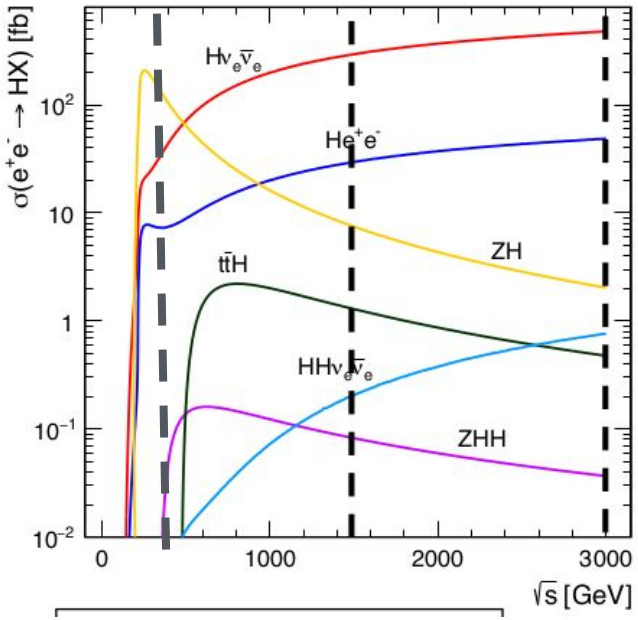
# Circular vs linear (i.e. FCC-ee/CEPC vs ILC/CLIC)



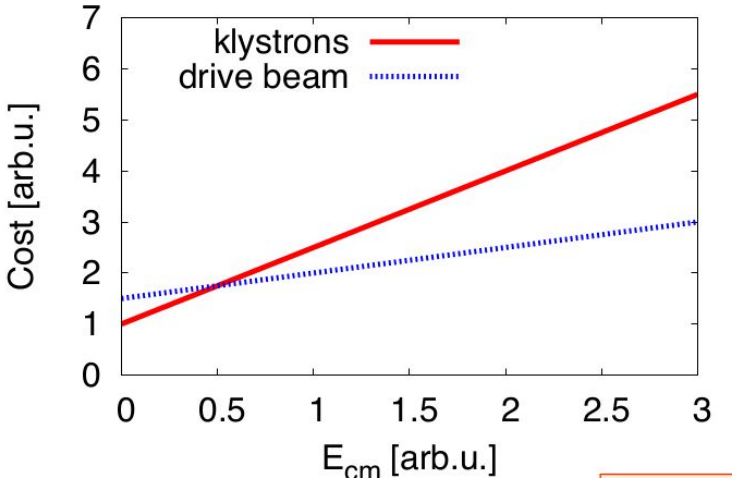
# CLIC

**Updated baseline**

| $\sqrt{s}$ [GeV] | $\mathcal{L}_{int}$ [fb$^{-1}$] |
|---|---|
| 380 | 500 |
| 1500 | 1500 |
| 3000 | 3000 |




**Mature technology. First step OK with klystrons**

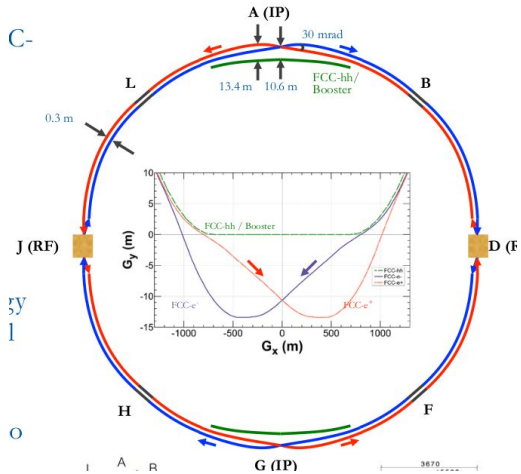



**Successful reduction of power (~200 MW) and cost (~6 GCHF)**

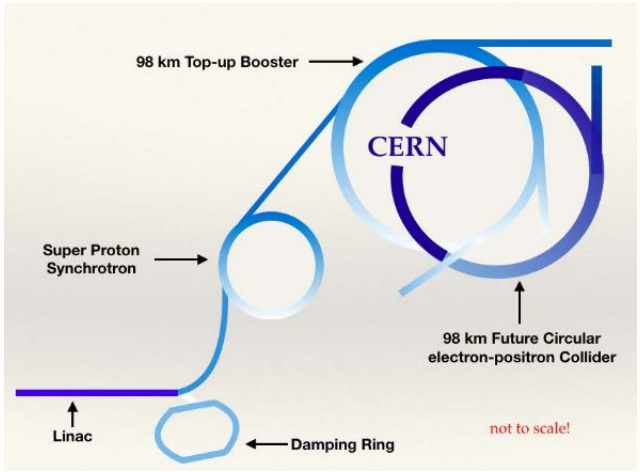
CLIC technology for CLIC and different applications

- EU co-funded FEL design study
- SPARC at INFN-LF
- …

# FCC-ee




**Double ring intersecting structure**




**Injection in main booster at 20 GeV**

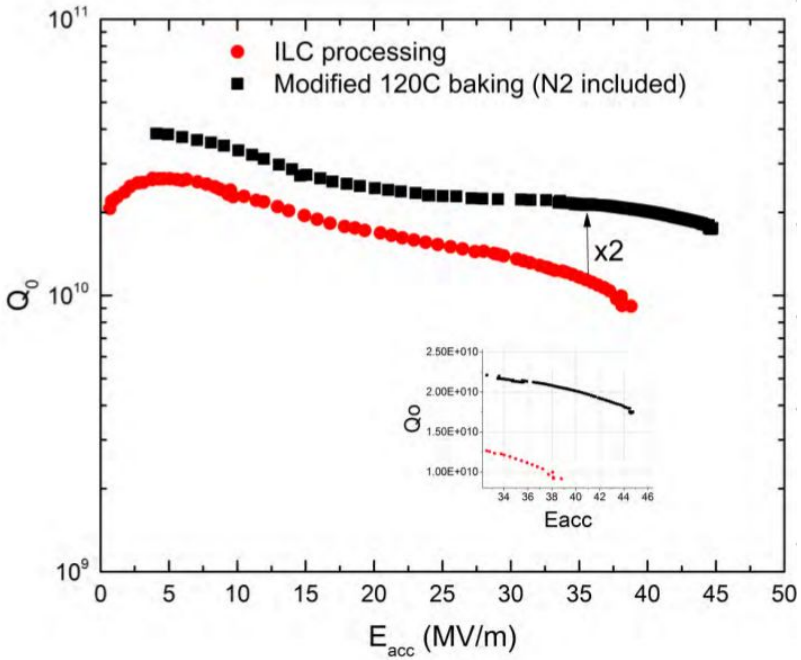
| Parameter | FCC-ee Baseline (10 yrs) |
|---|---|
| $\sigma(HZ)$ | 0.4% |
| $g_{ZZ}$ | 0.15% |
| $g_{WW}$ | 0.2% |
| $g_{bb}$ | 0.4% |
| $g_{cc}$ | 0.7% |
| $g_{\tau\tau}$ | 0.5% |
| $g_{t\bar{t}}$ | 13% |
| $g_{\mu\mu}$ | 6.2% |
| $g_{ee}$ | <100% |
| $g_{gg}$ | 0.8% |
| $g_{\gamma\gamma}$ | 1.5% |
| $g_{Z\gamma}$ | ( |
| $\Delta m_H$ | 11 MeV |
| $\Gamma_H$ | 1.0% |
| $\Gamma_{inv}$ | <0.45% |

**Community fully focused on the preparation of the CDR**

# ILC

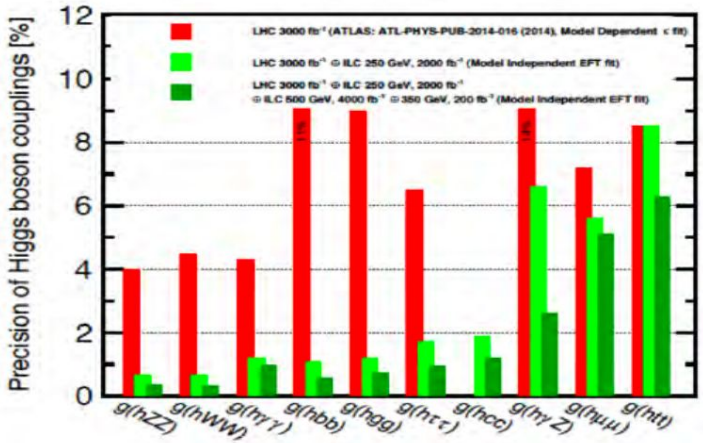
| | Collision E. [GeV] | Tunnel Space [GeV] | Value Total (MILCU) | Value Ratio |
|---|---|---|---|---|
| TDR | 250/250 | 500 | 7,980 | 1 |
| TDR update | 250/250 | 500 | 7,950 | 0.96 |
| Option A | 125/125 | 250 | 5,260 | 0.66 |
| Option A' (w/ R&D) | 125/125 | 250 | 4,780 w/ R&D success | 0.60 |

**250 GeV-only project (but extendable)**
**Large-scale existing facilities justify viability of project for >~30 MV/m**
**Additional cost reductions from advances in superconducting-RF R&D (N-doping, …)**

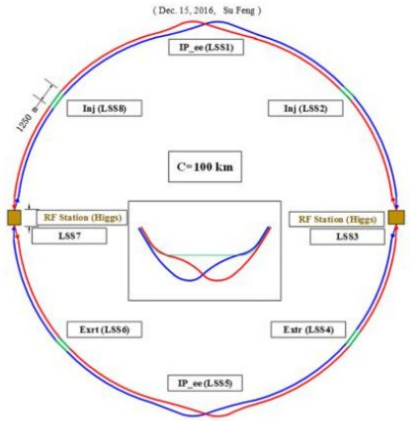



Effective Field Theory

With a new theoretical framework, expectations for the Higgs coupling measurements improved significantly.



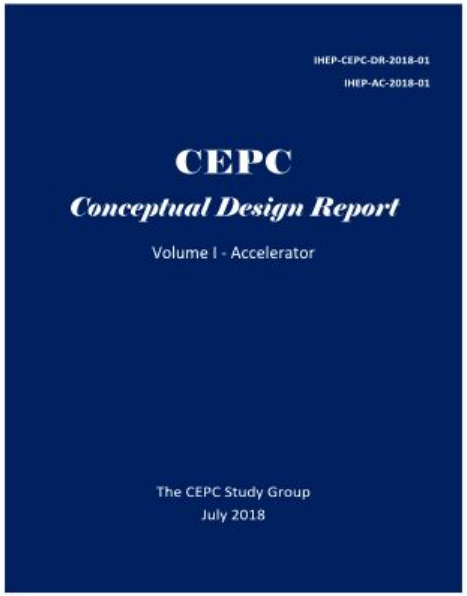
# CEPC




Since Nov 2016

**CEPC Baseline Design**

**Better performance for Higgs and Z compared with alternative scheme, without bottle neck problems, but with higher cost 30MW synchrotron radiation power/beam**




CDR Version for International Review June 2018

**Updated design end 2016, slightly different injection compared with FCC-ee**

- **CEPC hardware design and key technologies' R&D plan are ready for full TDR phase**
- **Developing of a coherent global plan towards completion of the project**

# Some theory comments (Tao's driven)

## SM EFT:

- Systematic, complete list of higher-dim operators, (in linear-realization, 2499 of them!)
- Correct power-counting, kinematic correlations
- Definite relations with the **κ** expressions

$$L = L_{SM} + \frac{1}{\Lambda^2}\sum_k \mathcal{O}_k + \cdots$$

$$\mathcal{O}_{HW} = -i\,g_2\,(D^\mu H)^\dagger \tau^I (D^\nu H)\, W^I_{\mu\nu},$$
$$\mathcal{O}_W = -\frac{i\,g_2}{2}\,(H^\dagger \overleftrightarrow{D}^I_\mu H)\,(D^\nu W^I_{\mu\nu}),$$
$$\mathcal{O}_T = (H^\dagger \overleftrightarrow{D}^\mu H)\,(H^\dagger \overleftrightarrow{D}^\mu H).$$

**Although consistent in theoretical calculations, perhaps only necessary for interpretations when a signal observation is made.**

- **How 'model independent' are we? Are not we imposing "artificial" dim-6 (many of them loop-driven) constraints in the game ?**

## Remarks for Discussion:

### e+e- Colliders:

- It is mainly on the experimental side for machine and detector performances.
- Higher order EW corrections may be needed for the Higgs production processes (e.g., Zh).

# Some fast physics/detector questions

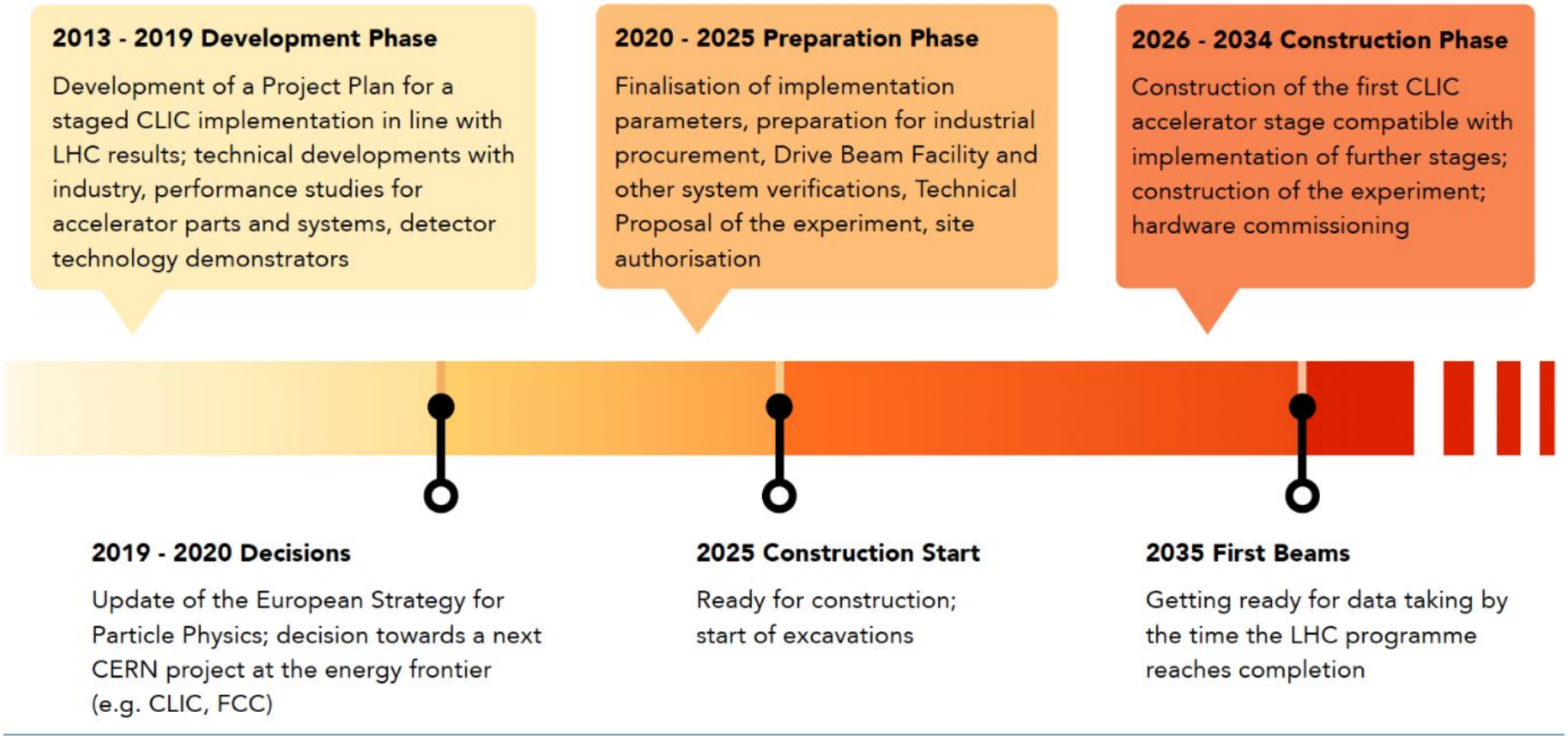
- $\sqrt{s} \cong 250$ GeV
  - Are all the possibilities well “covered”?
    - For instance, los-mass Higgses
  - Couplings to first generation and “Higgs scan”:
    - $e^+e^-H$ coupling search with “huge” luminosity ?
- Intermediate/high energies (ttbar threshold, 0.5-1 TeV, ..)
  - High-mass Higgses: holes left by HL-LHC?
    - $H \rightarrow ttbar$ ?
- Highest $\sqrt{s}$, up to 3 TeV (CLIC)
  - Potential for Higgs self-coupling studies: forward region, more advanced studies
- Polarization
  - More ideas?

# Backup

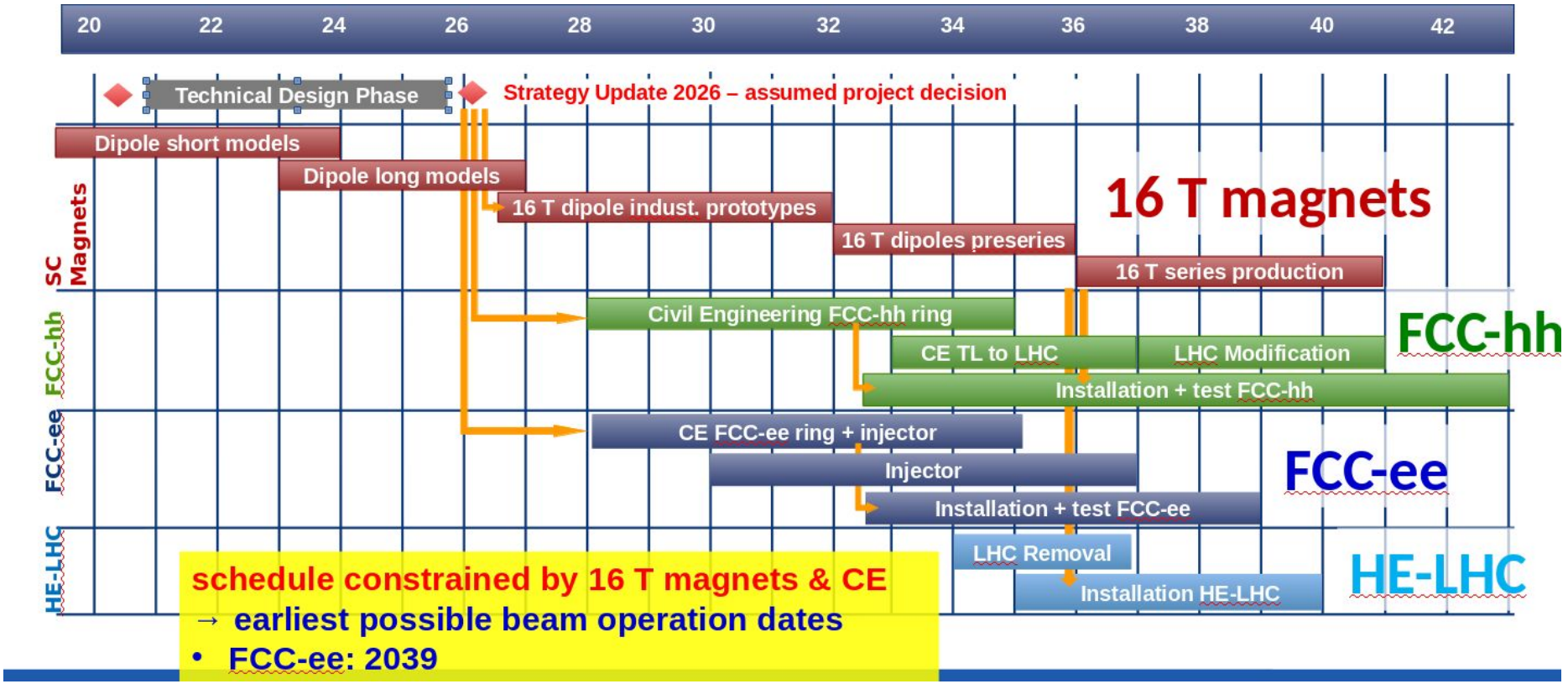
# Potentially rich program ahead:

- HL-LHC / HE-LHC lead the way:
  3 $ab^{-1}$ @ 14 TeV; 15 $ab^{-1}$ @ 27 TeV
  LHeC
  e(60 GeV) + p(7 TeV)@1 $ab^{-1}$; e(60 GeV) + p(14 TeV)@2 $ab^{-1}$
- ILC $e^+e^-$
  250 (500) GeV @ 2 (4) $ab^{-1}$, 80% / 30% polarization
- FCC(ee) / CEPC
  250 / 240 GeV @ 5 / 20 $ab^{-1}$; 350 GeV @ 1 $ab^{-1}$
- CLIC
  380 GeV@0.5 $ab^{-1}$, 80% / 0% pol; 1.5 TeV@1.5 $ab^{-1}$; 3 TeV@3 $ab^{-1}$
- FCC(hh)
  100 TeV @ 30 $ab^{-1}$
  FCC(eh) e(60 GeV) + p(50 TeV) @ 2 $ab^{-1}$
- Muon Collider
  mh @ 1 $fb^{-1}$ ; 20 TeV @ 5 $ab^{-1}$

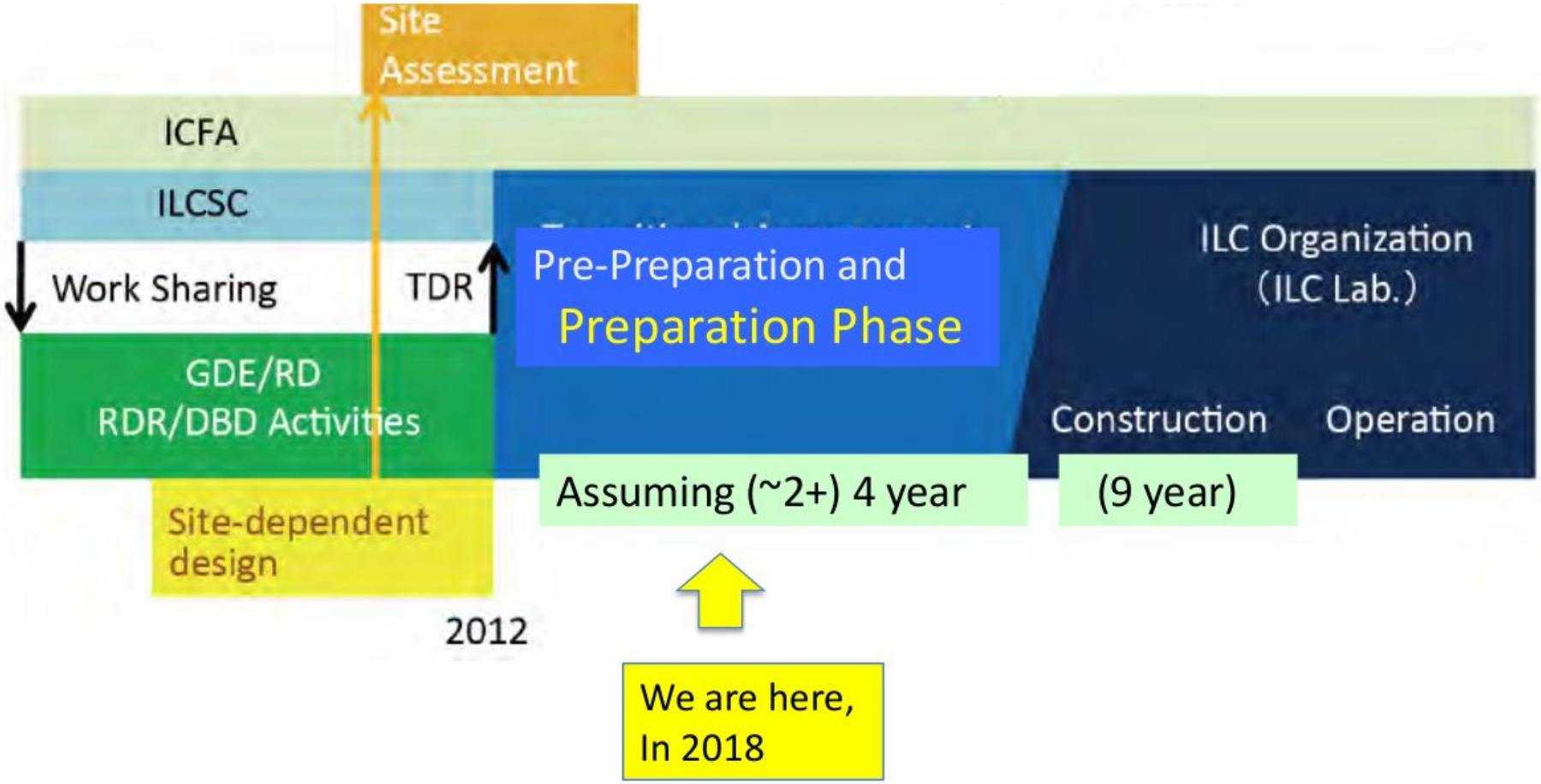
# Timelines: CLIC



# Timelines: FCC-ee



# Timelines: ILC



# Timelines: CEPC


**Figure 12.5:** A possible timeline.