Discussion on future electron-position collider project in the JAHEP Committee on Future Projects (CFP)

2023/9/4, ILC-Japan Physics WG meeting

Ken Sakashita (KEK/J-PARC) for CFP

Mandate to the CFP this term

- JAHEP committee asked to assess the following two items
  - Future collider projects ("Enhancement of the ILC" and "Consideration the future beyond ILC")
  - Advancement in Quantum Technology, AI, and Detector Technology
- There is no need to update the previous report of the future projects
  - A summary report for the above items will be prepared and submitted to the JAHEP committee
  - This report will be as an input for the next CFP

Rather than 'selecting' the future project or 'deciding' its direction, we should objectively assess the value and role of accelerator experiments from both a scientific and technological perspective, enhance and deepen them

Members

- 26 members from various experiments, accelerator experts and theorists
- We are also inviting experts from various fields and technologies as well as young researchers to participate in the discussions

2021.10~		
Kohei YORITA	Waseda University	Chairperson
Yasuyuki OKUMURA	The University of Tokyo・ICEPP	Secretary
Kazuyuki SAKAUE	The University of Tokyo	Secretary
Tsutomu MIBE	KEK・IPNS	Secretary
Yutaro IIYAMA	The University of Tokyo・ICEPP	
Akimasa ISHIKAWA	KEK・IPNS	
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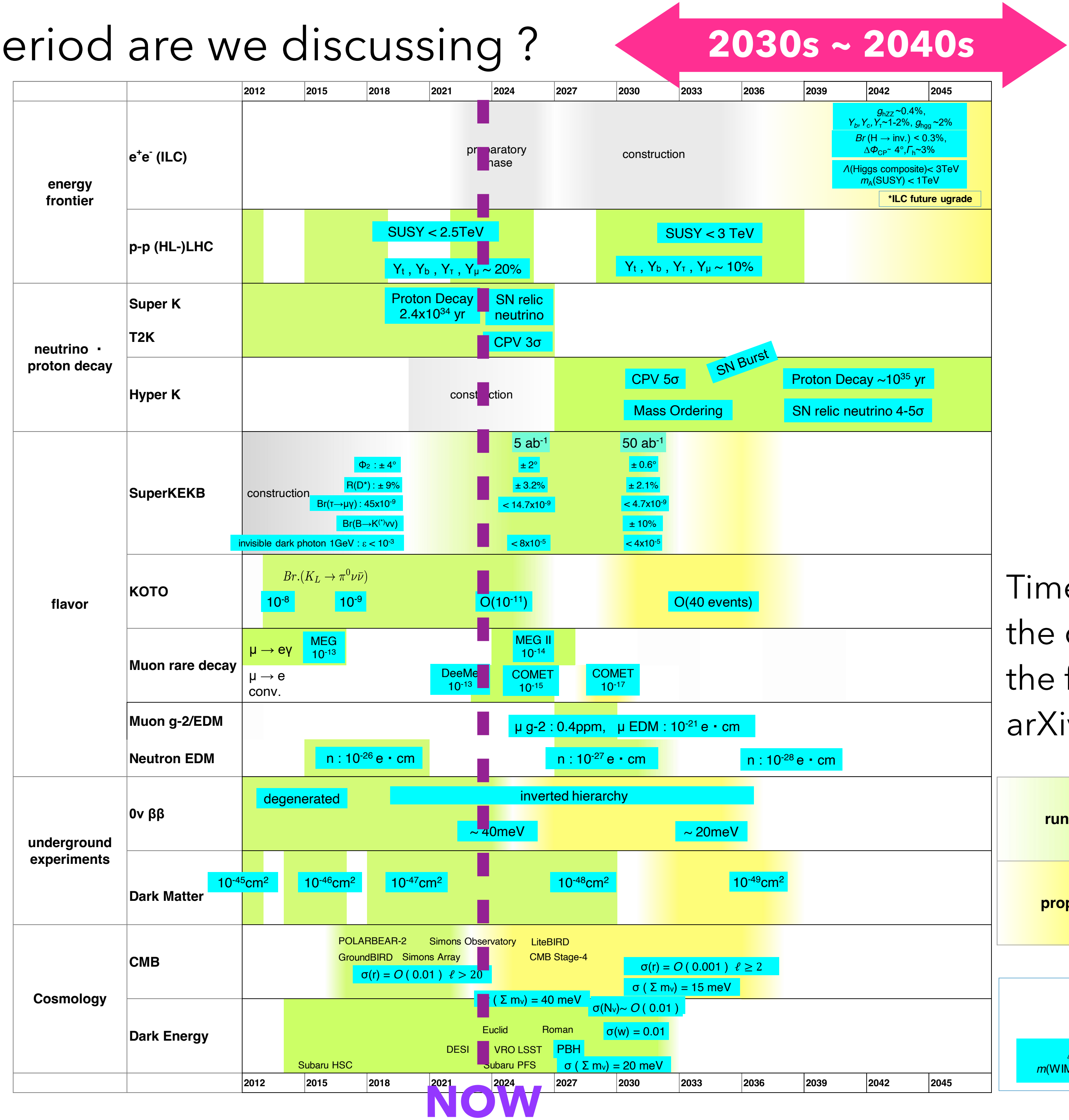
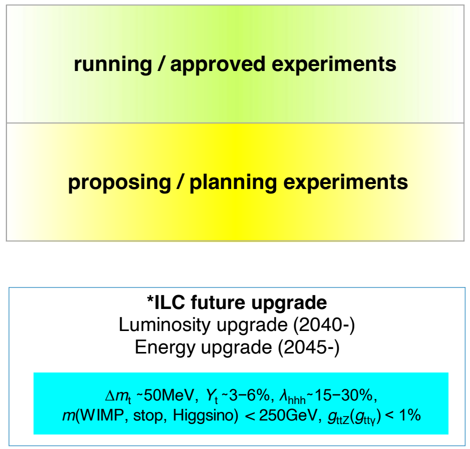
Masako IWASAKI	Osaka Metropolitan University, Osaka University・RCNP	
Kensei UMEMORI	KEK・ACCL	
Yoshinori ENOMOTO	KEK・ACCL	
Masashi OTANI	KEK・ACCL	
Shinsuke KAWASAKI	KEK・IPNS	
Ryuichiro KITANO	KEK・IPNS	
Teppei KITAHARA	Nagoya University・KMI	
Ken SAKASHITA	KEK・IPNS	
Masanori SATOH	KEK・ACCL	
Ryu SAWADA	The University of Tokyo・ICEPP	
Taikan SUEHARA	Kyushu University	
Heishun ZEN	Kyoto University	
Osamu TAJIMA	Kyoto University	
Nanae TANIGUCHI	KEK・IPNS	
Yu NAKAHAMA	KEK・IPNS	
Hajime NANJO	Osaka University	
Yasuhiro NISHIMURA	Keio University	
Kentaro MIUCHI	Kobe University	
Mitsuhiro YOSHIDA	KEK・ACCL	

What period are we discussing ?



Timeline table from the current report of the future projects arXiv:2203.13979



CFP activities up to now

- Discussion on physics and technology related to future collider projects and "Enhancement of the ILC" were conducted
  - 2022/Jun. Kick-off workshop https://kds.kek.jp/event/42229/
  - 2022/Jul.-Aug. 1st survey by questionnaire to community
  - 2022/Aug. YUGAWARA meeting https://kds.kek.jp/event/42257/
  - 2022/Sep. JPS symposium https://kds.kek.jp/event/43097/
- Discussion on "Consideration the future beyond ILC" and "Advancement in Quantum Technology, AI, and Detector Technology" are in progress
  - 2022/Dec. Roundtable discussion for future projects https://kds.kek.jp/event/44659/
  - 2023/Feb.-Mar. 2nd survey by questionnaire to community
  - 2023/Mar. Town hall meeting for future projects https://kds.kek.jp/event/45166/

Consideration the future beyond ILC

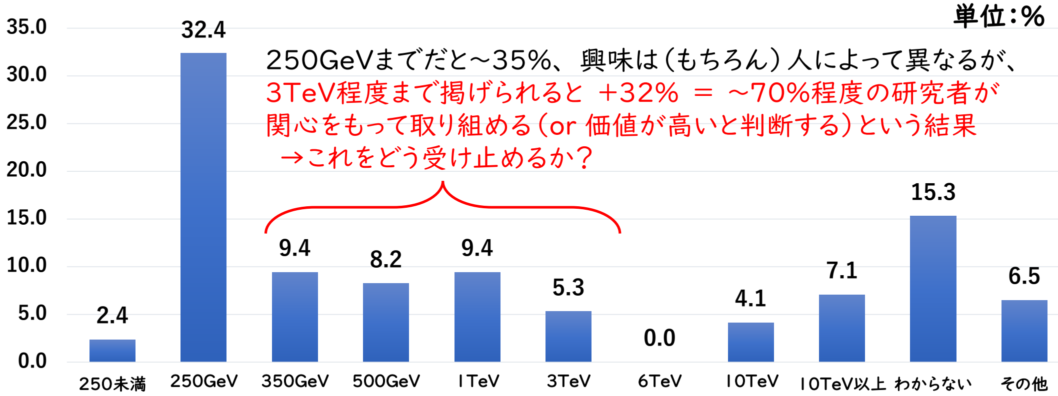
- Based on the results of the 1st survey, we are progressing with specific discussions for the following three aspects R), G), B)

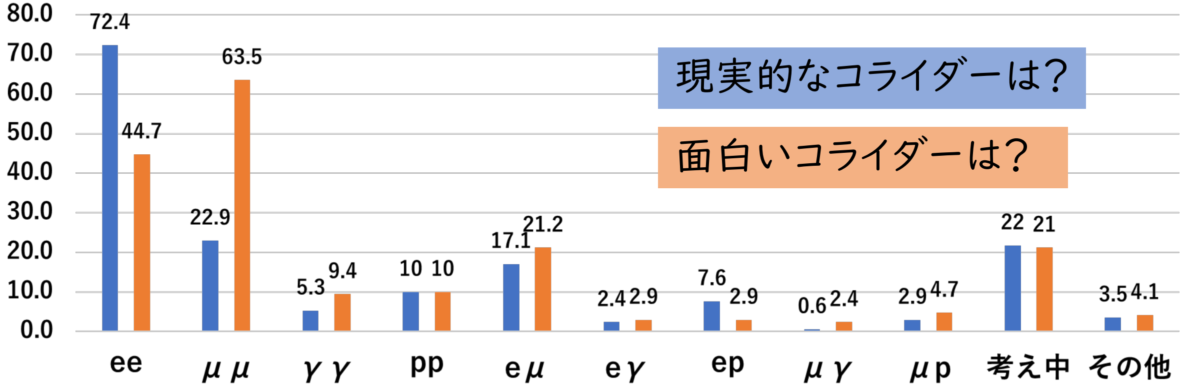
R) Electron positron collider ++

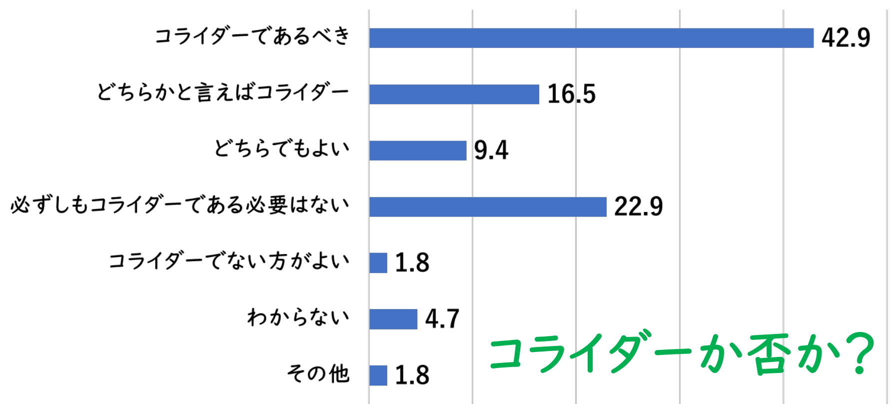
G) Flavor physics etc., non-collider exp.

B) Muon accelerator

Q2-3「物理」:どのエネルギーからご自身が関心をもって取り組めますか?
または、基幹プロジェクトとしての価値があると思いますか?







R) Electron positron collider ++

Member：Sakashita(chair,KEK), Okumura(UT/ICEPP), Ishikawa(KEK), Suehara(Kyushu), Taniguchi(KEK), Iwasaki(OMU), Iiyama(UT/ICEPP), M.Sato(KEK), Zen(Kyoto), Enomoto(KEK), Umemori(KEK), Yorita(Waseda), Oide(KEK), Y.Sato(Nigata), D.Sato(AIST)

- Exploring attractive possibilities of eebar collider experiments in the coming 20-30 years and beyond
  - These considerations encompass a wide range of scenarios, including those that have not been discussed in the current ILC baseline

Premises for discussions

- So far there is no clear signs of new physics at the LHC. Precise Higgs data from lepton energy frontier experiments are highly valuable to understand the energy scale of new physics
- Conclusion of the FCCee feasibility study by 2030
- Keep in mind that realization of the ILC is taking a long time
- Acknowledge the presence of ILC promotion activities (ILC-Japan, IDT)
  - In the CFP study, we are discussing a wide range of scenarios of eebar collider, including those that have not been discussed in the current ILC baseline

Boundary conditions for discussions

- Only “linear collider” with energy expandability
  - recognizing merits of the circular collider but not explore it this time
- Only “energy frontier” experiments
  - not explore flavor physics experiments (e.g. sequel to Belle2) this time
- Explore both SCRF and NCRF

Status of R group activities

- Gathering information on topics such as physics cases, accelerator technology, facility, power consumption, luminosity, international situation etc. before considering specific scenarios of eebar collider
- Considering five specific scenarios
- Currently, a summary report is under preparation

Physics cases (physics target at each E_{CM})

- < 250 GeV
  - (polarized) cross section of e+e- → qq
    - Precise QCD, muon g-2 theory calculation etc.
  - Electroweak oblique parameters (input to EFT etc.)
  - W mass (at WW threshold = 160 GeV), Weinberg angle

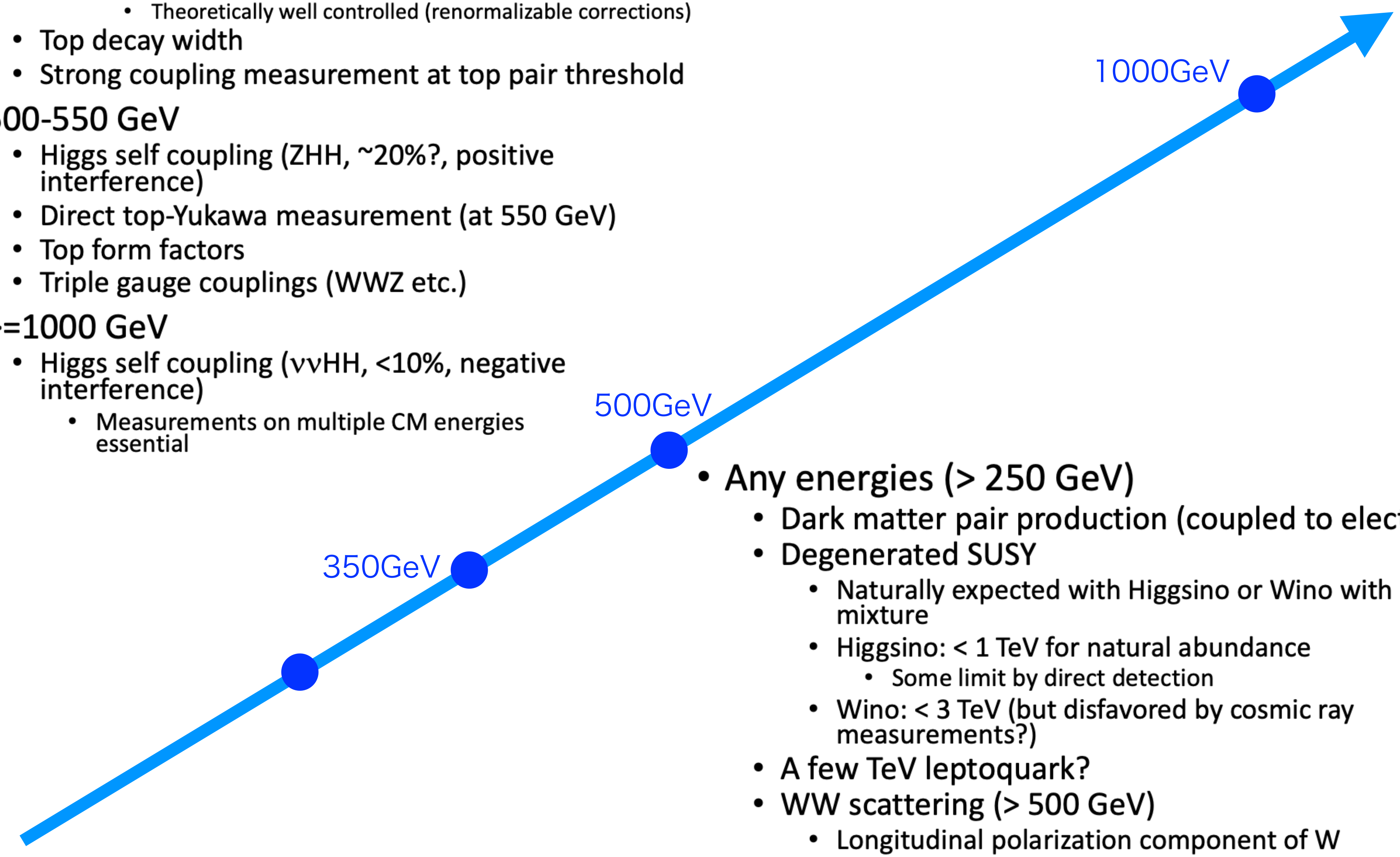
  Note: エネルギーが低いほどcircular colliderがluminosityで有利

- Fixed target
  - Light DM (eg. ALP) searches
  - Strong-field QED measurement

250GeV

- 250 GeV
  - Higgs physics
    - Absolute cross section (by recoil mass method, ~1%)
    - Higgs mass (by recoil mass method, ~20 MeV)
    - Higgs coupling to b, c, g, tau, Z, W
      - a few – 10 times better than HL-LHC
      - Absolute coupling measurement (cf. coupling ratio in hadron colliders)
    - Higgs total decay width (~10%)
    - Invisible decay (~0.1%)
    - Exotic decay (eg. 4b, 2b+2χ, 0.1 – 0.01%, depending on decay channel)
      - Probing light Higgs-portal DM

- 350 GeV
  - Top mass → vacuum stability (& Higgs inflation?)
    - Direct measurements of "Short-distance mass"
      - Theoretically well controlled (renormalizable corrections)
  - Top decay width
  - Strong coupling measurement at top pair threshold
- 500-550 GeV
  - Higgs self coupling (ZHH, ~20%?, positive interference)
  - Direct top-Yukawa measurement (at 550 GeV)
  - Top form factors
  - Triple gauge couplings (WWZ etc.)
- >=1000 GeV
  - Higgs self coupling ($\nu\nu$HH, <10%, negative interference)
    - Measurements on multiple CM energies essential



- Any energies (> 250 GeV)
  - Dark matter pair production (coupled to electrons)
  - Degenerated SUSY
    - Naturally expected with Higgsino or Wino with small mixture
    - Higgsino: < 1 TeV for natural abundance
      - Some limit by direct detection
    - Wino: < 3 TeV (but disfavored by cosmic ray measurements?)
  - A few TeV leptoquark?
  - WW scattering (> 500 GeV)
    - Longitudinal polarization component of W
    - Related to composite Higgs models
  - 2f final states
    - Z' search, indirect WIMP search
  - BSM parameter determination (if found)

(議論用) まとめ

Table shown at the 2022/Jun. Kick-off workshop
「現実的に2030-2040年代で狙う物理」(石川,末原,中浜)

色分け:Higgs/EW, BSM

衝突粒子	e^+e^-							
√s	91 GeV	160 GeV	250 GeV	350 GeV	500-700 GeV	1 TeV	multi TeV	10 TeV
Key physics 1	Precise EW physics (10^{12} Z, 10^8 W)		O(1)% H 結合 (H-c, H-gluon), CP in H-τ	m_{top}	O(30)% λ	O(10)% λ	3 TeV Wino DM	A few TeV LQ
Key physics 2	B anomaly (→K*ττ) tau LFU	m_W	Invisible/exo H (H portal) Rare H decays		H全崩壊幅 O(1) %	Direct BSM search		
Key physics 3	DM/mu g-2 inspired SUSY, ...					CP in H-t		
2030-40年代 実現性(目安)	円形 (CEPC, FCC-ee)				線形 (ILC, CLIC, C^3)			

衝突粒子	$\mu^+\mu^-$			pp	
√s	125 GeV	10 TeV	30 TeV	14 TeV	100 TeV
Key physics 1	H-μ結合, H全崩壊幅	4% λ	2% λ	O(50)% λ	O(5)% λ
Key physics 2	μ g-2 inspired SUSY	μ g-2 の相互作用の直接検証		O(2-5)% H 結合	O (1)% H-t 結合 Rare H decays
Key physics 3				BSM直接探索m_{g}~ 3 TeV, m_{t}~ 2 TeV	BSM直接探索, m_{g}~ 17 TeV, m_{q}~ 10 TeV, m_{t}~ 10 TeV
2030-40年代 実現性(目安)	Muon collider			HL-LHC 2029-38	FCC-hh

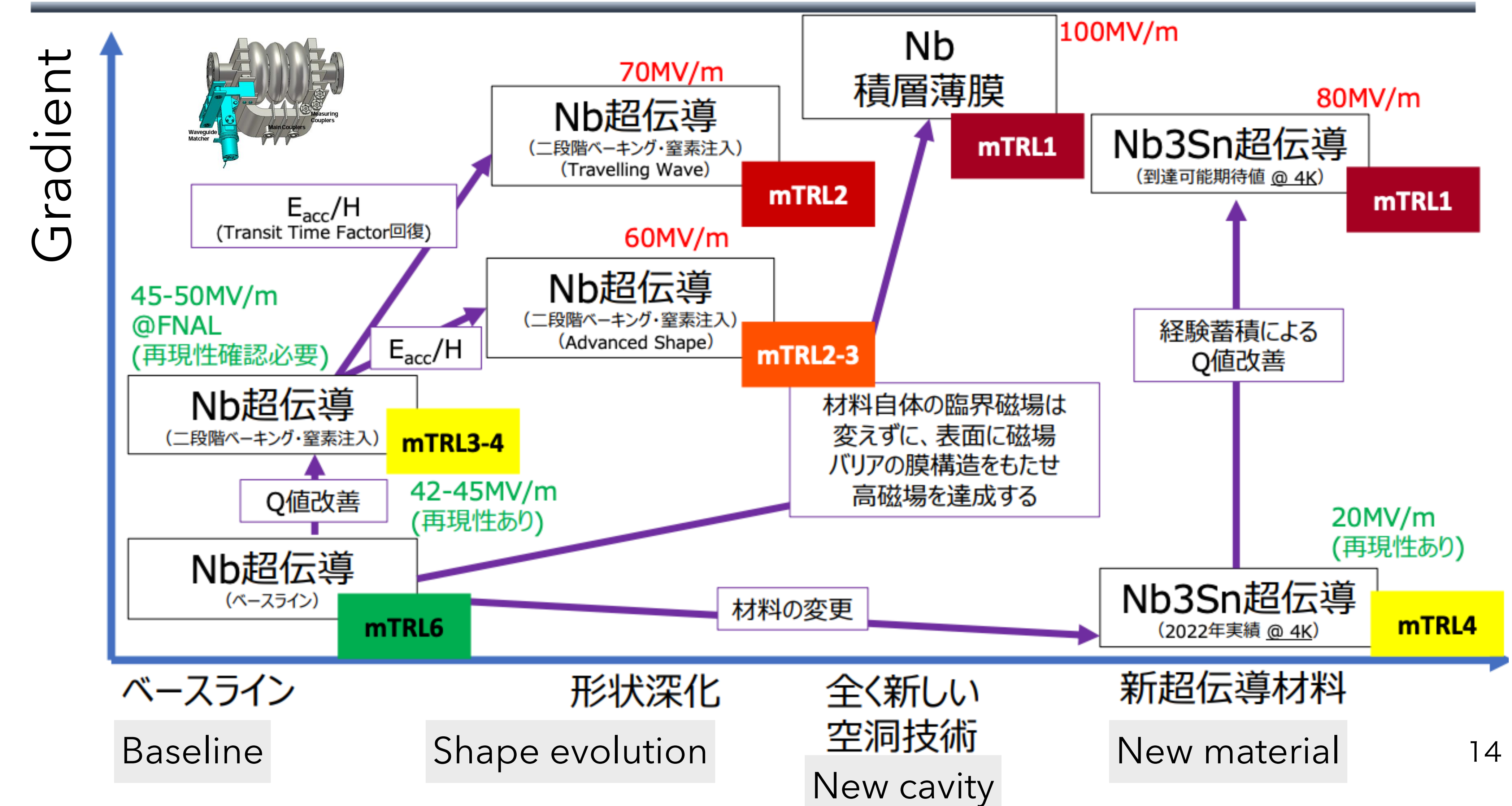
- Importance of ILC250 and HL-LHC running at a similar timing to complement each other
- Multi TeV eebar collider looks attractive

Accelerator technologies

Table shown at 2022/Sep. JPS symposium
「次世代コライダーへ向けた加速器技術」(坂上)

mTRL #	コライダー向け加速器開発用 Technology Readiness Level 定義
mTRL1	アイデアはあるが未検証。実現性も不透明
mTRL2	アイデアはあるが未検証。実現に向けた道筋は見えている
mTRL3	技術が実験室レベルで検証された
mTRL4	技術がシステムとして再現性を持って検証された
mTRL5	検証されたシステムがコライダーにおける要求を満たすことが確認された
mTRL6	検証されたシステムの量産技術が確立された

高加速勾配へのシナリオ（超伝導） Superconducting



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mTRL6	検証されたシステムの量産技術が確立された

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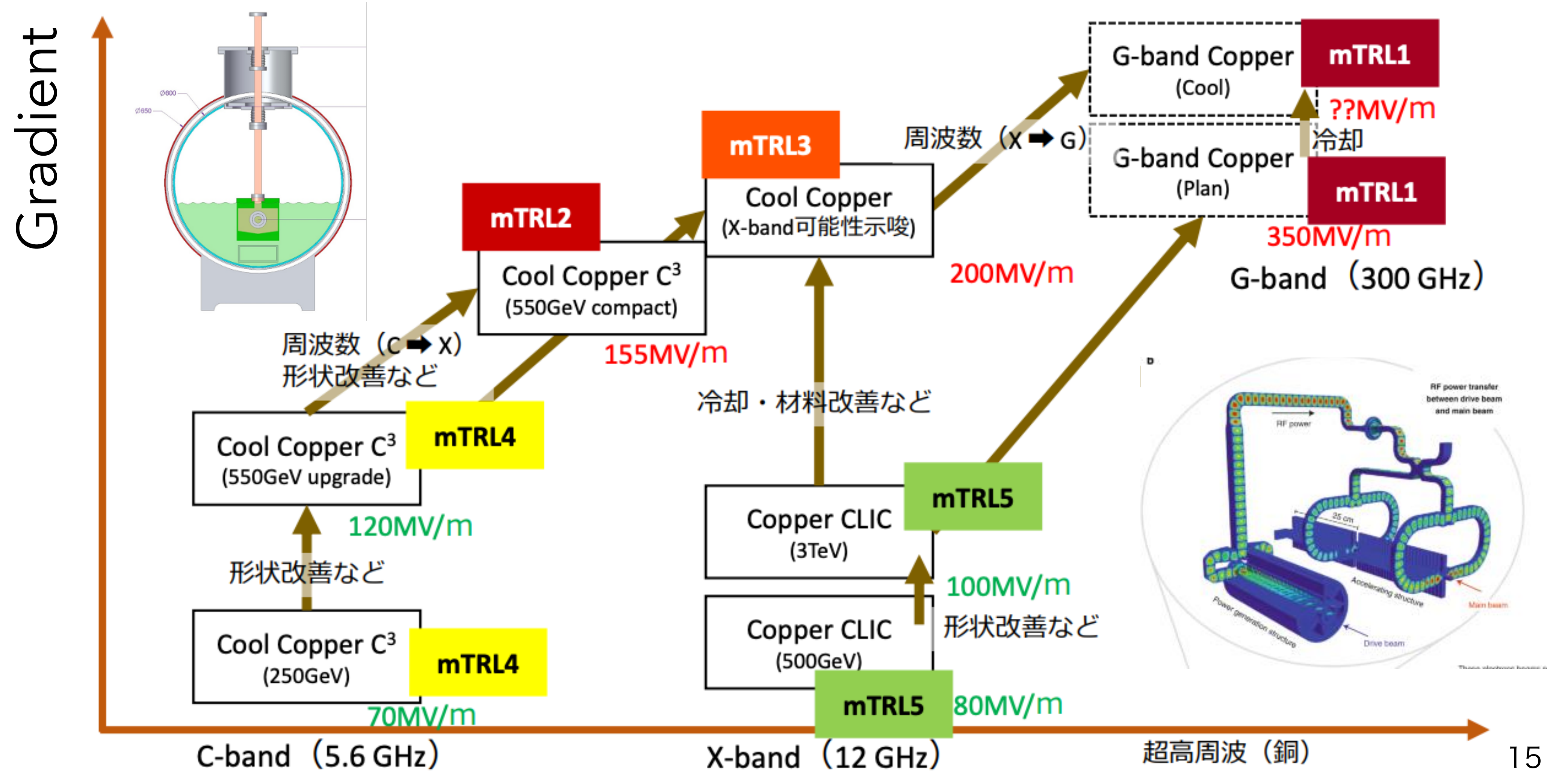
高加速勾配への技術達成度（常伝導）Normal conducting



Advanced and novel accelerator technology

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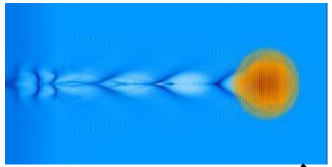
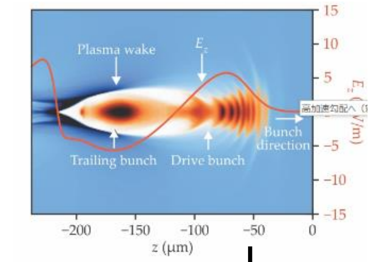
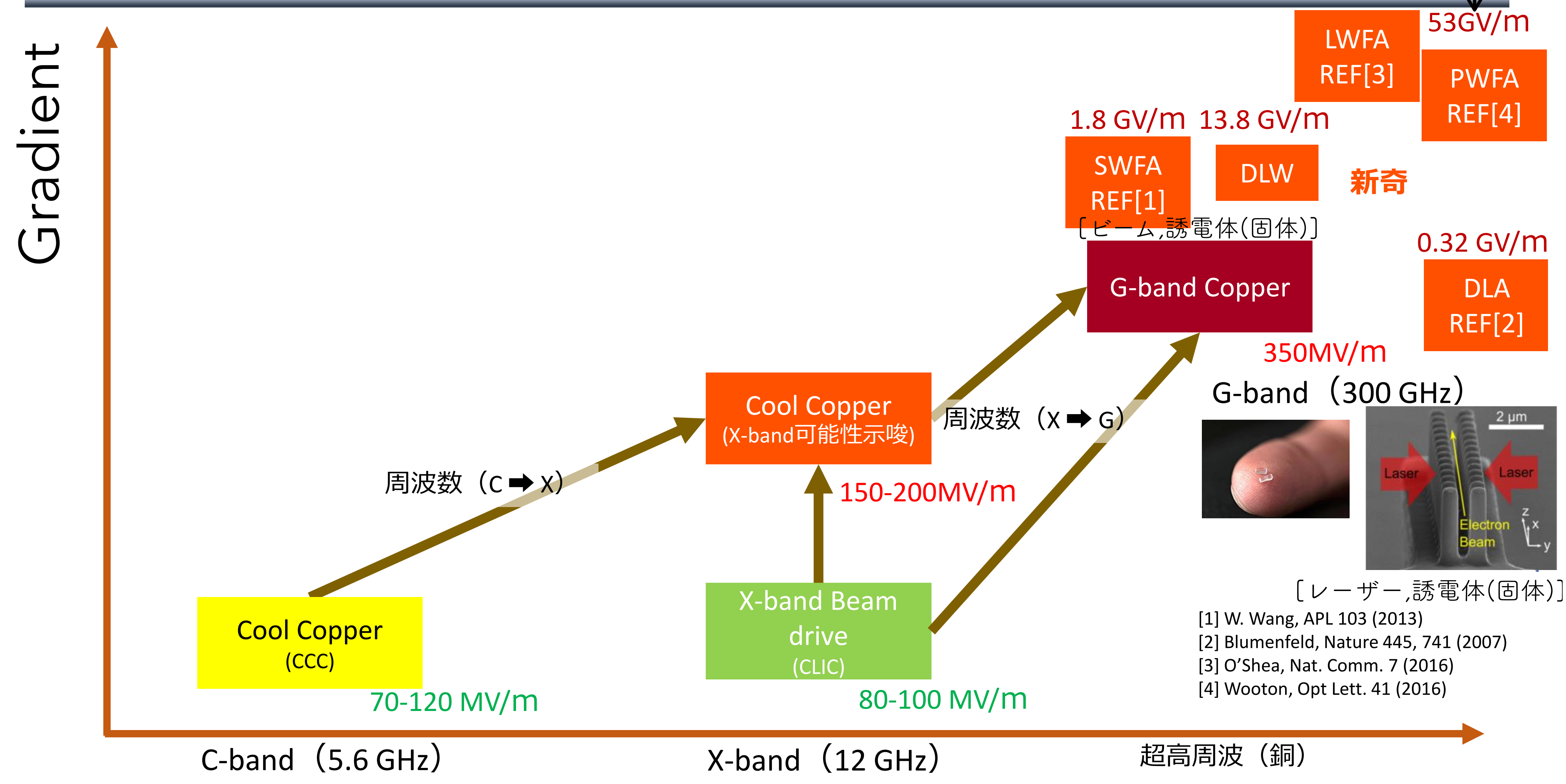
高加速勾配へ（新奇加速）







[1] W. Wang, APL 103 (2013)
[2] Blumenfeld, Nature 445, 741 (2007)
[3] O'Shea, Nat. Comm. 7 (2016)
[4] Wooton, Opt Lett. 41 (2016)

［ドライブ源,加速構造］

Note on accelerator tech.

- In case SCRF, operational gradient could be < 100MV/m
- In case NCRF, larger than 100MV/m could be possible by increasing the acceleration frequency
- Advanced/novel acceleration technologies utilizing intense laser and particle beam driven plasmas or structures can reach ultrahigh fields of 1-100 GV/m
- It is also necessary to consider that time required for the transition from "champion data at the lab level" phase to "establishment of mass production technology" phase

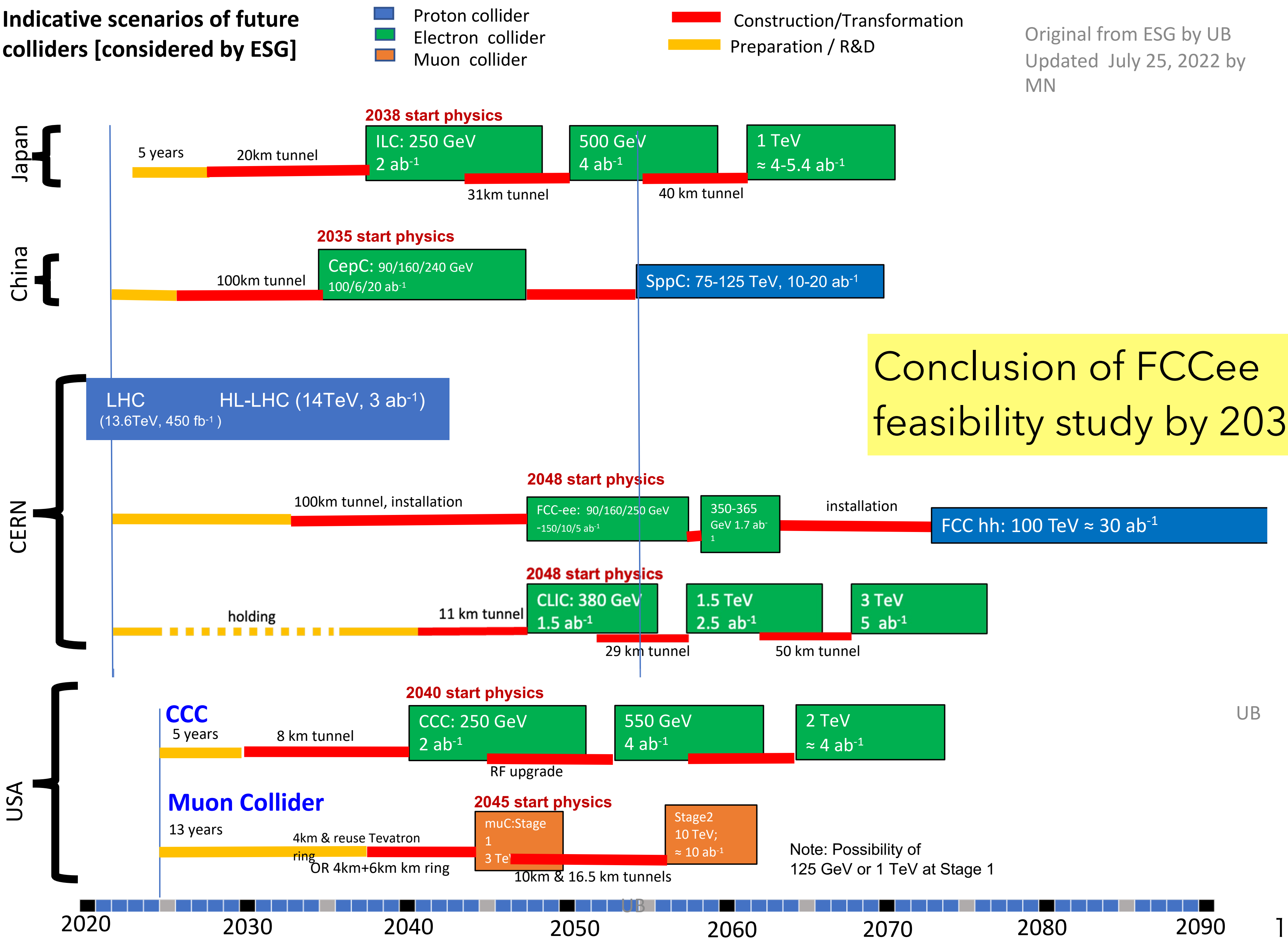
Comparison in terms of luminosity

$$L = f n_b \frac{N^2}{4\pi\sigma_x^*\sigma_y^*}$$

	ILC (SCRF)	CLIC (X-band,NCRF)	C3 (C-band, Cold NCRF)
L [/cm^2/s]	1.35E+34	1.5E+34	1.3E+34
Duty factor	8.3E-03	1.2E-05	1.9E-04
Bunch interval [ns]	554	0.5	5.26
Bunch crossing [kHz]	6.5	18	16
Bunch charge[nC]	3.2	0.83	1
Emittance [nm rad]	5000/35	900/20	900/20
β at IP	almost same size		

- In case NCRF, it is necessary to keep the bunch charge low and pursue designs that focus on emittance (but it seems challenging design)
- In case SCRF, high bunch charge (3.2nC) is possible with reasonable design parameters (e.g. power consumption etc)
- SCRF looks feasible when aiming for the early realization of a machine with sufficient luminosity

Other Higgs factory



Conclusion of FCCee feasibility study by 2030

Considering five specific scenarios

◉ 「Early realization of LC」

staging scenario to 250GeV including Test facility, E_{cm}=91GeV

◉ 「Early realization of 250GeV LC」

scenario of starting 250GeV as soon as possible

◉ 「Scalability」

scenario of having ~3TeV or more

◉ 「10km」

scenario with a tunnel length of 10km

◉ 「Multi-purpose accelerator laboratory」

scenario with a laboratory of accelerators for industrial applications, materials, biology, etc. and conduct an eebar collider experiment as a part of them

- Discussed these scenarios after '23 Mar. town hall meeting
- We're trying to summarize this discussion from **three perspectives**

(1) “Early realization”

◉ Reducing the facility size and considering cost reduction while maintaining the targeted physics

◉ Limiting initial luminosity to reduce cost

- for example, reducing the number of klystrons
- even if 1/10 of the initial luminosity, it is possible to conduct Higgs mass measurements

◉ Starting with an organization size that can be achieved immediately and get achievement

- for example, a facility larger than ATF, a facility like LCLS-II(4GeV) CW superconducting accelerator

Note: “scalability” is not exclusive, but there are cases where scalability can be limited and there are points to be aware when the initial facility is considered

(2) “Scalability”

- Important to aim for scenarios where exciting physics can be explored
  - e.g. “SUSY factory”, Elucidating the nature of DM, Higgs self-coupling <5% at 3TeV (similar to FCChh)
- Aim to ~3TeV with 50km facility
  - SCRF 45 MV/m is at mTRL3-4 (so, mass production could be in 10-20years)
  - SCRF TW 70MV/m is currently at mTRL2
    It has not been demonstrated yet
  - In case NCRF, it’s 70MV/m at mTRL4 for the cool C-band. It can reach 3TeV at 50km but achieving the required luminosity is challenging

ref.

250 GeV = 31.5MV x 8,000
1TeV = 31.5MV x 11,000 + 45MV x 16,000
===
beyond TDR (US)
2TeV(a) = 45MV x 11,000 + 55MV x 27,000
2TeV(b) = 45MV x 11,000 + 70MV x 21,000
3TeV(a) = 70MV x 43,000 (TW)
3TeV(b) = 80MV x 37,500 (Nb3Sn, 4.2K)
===
10TeV = 400MV/m x N

(3) “Enhancing the value of the accelerator”

◉ Building a multi-purpose accelerator laboratory and one of missions is eebar collider experiment

◉ Various cases of laboratory’s scheme

a) Expansion of KEK iCASA. Research in the role of fundamental technology development and demonstrate its applicability to various cases

b) A research institute with an industrial facility (e.g. SCRF application to EUV lithography)

c) Like AIST. Laboratory takes a board mission in accelerator technology so that it’s okay to work on anything related to accelerators

◉ Considering an “innovation commons”

- it’s also possible to consider having a power plant at own facility

Summary

- Discussions for future collider projects are underway in CFP
    - Three group discussions R), G), B) for the "Consideration the future beyond ILC"
- In R) group, we are exploring attractive possibilities of eebar collider experiments in the coming 20-30 years and beyond
- Current status and plan for the R) group's discussion are introduced

If you have any comments or suggestions to this discussion, please feel free to share them with us !