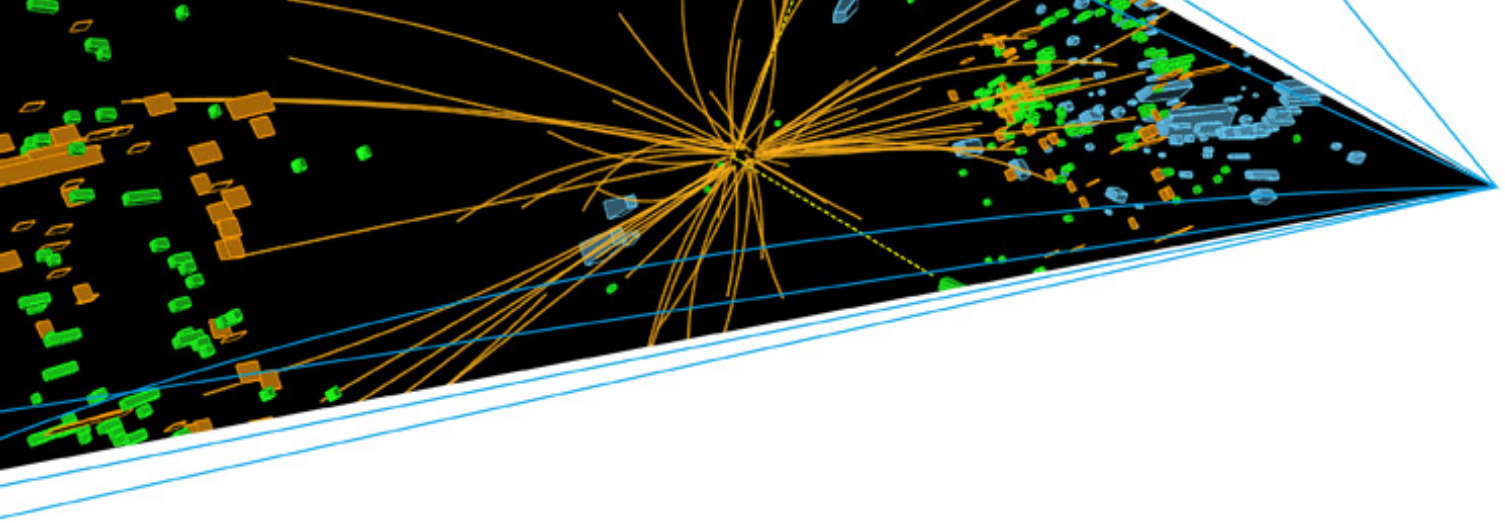


KET
Komitee für
Elementarteilchenphysik

KET e^+e^- Collider Workshop - Summary

Christian Zeitnitz

Bergische Universität Wuppertal

KET Recommendations 2012

Die Empfehlungen des KET

1. Das wissenschaftliche Potenzial des LHC bestmöglich nutzen.
2. Den LHC und seine Experimente für größere Energie und Kollisionsraten ausbauen.
3. Zur Realisierung eines internationalen Linearbeschleunigers als nächstes Großprojekt der Teilchenphysik aktiv beitragen.
4. Internationale Präzisionsexperimente mit B-Mesonen vorantreiben.
5. Beteiligung an weiteren internationalen Projekten der Teilchenphysik, insbesondere in der Neutrinophysik, ermöglichen.
6. Neue Beschleunigertechnologien und Detektorkonzepte entwickeln.
7. Ein starkes Theorie-Programm weiterführen, das die experimentellen Projekte begleitet.

Review of recommendations

- Determine the interests of the German HEP community through a series of workshops
  - Next generation e^+e^- Collider
  - Neutrino Projects
  - Big non-accelerator projects
  - Hadron Colliders
- Need conclusions from workshops
- Input to next European strategy 2018

Recommendation 3 from 2012

Actively contribute to the realization of a linear accelerator as the next big HEP project

This workshop should conclude with a statement about the currently proposed projects and which will allows to update the recommendation

→ afternoon discussion session

Summary of Workshop

- Physics case
- Machine requirements
- Linear and circular projects
- Timelines
- Additional Considerations
- Conclusion

Physics Case

- Is the found Higgs the SM Higgs?
- Precise measurements of Higgs, Top parameters and of electroweak observables
- Interpretation requires substantial effort by theory to match precision (see talk by Heinemeyer)
- Requires substantial improvements of measurements of parameters like M_W, α_s, α_{em} …
- BSM
  - Deviation from SM expectation
  - Direct search, e.g. DM

5. Conclusions

- Experimental precision must be matched with theory precision!
- EWPO can give valuable information about SM, BSM
  → only SM, MSSM "ready", more needed ⇒ TH input/effort needed!
  Most relevant: M_W, $\sin^2\theta_{\text{eff}}$, m_t, $\Delta\alpha_{\text{had}}$, ...
  Extraction from experiment? ⇒ TH input/effort needed!
- Current theory uncertainties of M_W, $\sin^2\theta_{\text{eff}}$ not sufficient
  Future theory uncertainties: not sufficient! ⇒ TH input/effort needed!
  $\Delta\alpha_{\text{had}}$: could be the limiting factor
- Top quark mass: mainly theory driven, α_s crucial!
  ⇒ TH input/effort needed!
- Higgs couplings: XS and BR have to be under control
  Can sub-percent/permille level be reached?
  - XS: 1% possible, full 2-loop calculations needed?!
  - BR: intrinsic uncertainties could be brought down below 1%
    parametric uncertainties (m_b) have (to me) unclear perspective

  ⇒ TH input/effort needed!

Conclusions

- BSM is well motivated, too many open questions in the SM
  - ➢ lots of models on the market
  - ➢ but 'no clue' which model is most likely to be realized in nature
- Current results at LHC do not point to a specific scale for BSM
  - ➢ caution: not guaranteed that new scale is ever known!
  - ➢ but one should not wait any longer: physics case is well established ... !
- Any BSM has new features/structure
  - ➢ chiral structure, spin, coupling properties have to be experimentally analyzed and tested
  - ➢ direct and indirect test of BSM go hand-in-hand
  - ➢ e+e- machines offer variable tools and high flexibility
  - ➢ tuneable precise energy, polarized beams, '4π detector', bonus options (GigaZ, γγ, eγ)

- LC offers highest flexibility.....technical design should not preclude options
  - ➢ *well prepared for the 'Known' but also for the 'Unknown' !*

LHC + LC mandatory to resolve the BSM snooker !

Requirements

- Energy
  - optimally tunable from M_Z to (at least) 2 x M_{top}
  - Self-coupling needs high energy
- Substantial benefits from polarized beams
- High luminosity order $10^{34}cm^{-2}s^{-1}$
- Possibility of an energy upgrade in case of further LHC discoveries

- Starting of data taking around 2035

Circular Projects: CEPC

- Circular Electron Positron Collider (CEPC)
  - Default: 54km circumference
  - Center of mass energy tunable from M_Z up to 250 GeV
  - High lumi (up to 10^{36} $cm^{-2}s^{-1}$) for precision masurements at low energy
  - Pre-Conceptual Design Report published 2015
  - CDR to be published in 2016
- Status
  - Still conceptual problems and no working design yet
  - Open discussion of current problems
  - Ambitous timeline
- Question

Science

- **Electron-positron collider(90, 250 GeV)**
  - **Higgs Factory（10^6 Higgs）:**
    - **Precision study of Higgs(m_H, J^{PC}, couplings)，Similar & complementary to ILC**
    - **Looking for hints of new physics**
  - **Z & W factory（10^{10} Z^0）:**
    - **precision test of SM**
    - **Rare decays ?**
  - **Flavor factory: b, c, τ and QCD studies**
- **Proton-proton collider(~100 TeV)**
  - **Directly search for new physics beyond SM**
  - **Precision test of SM**
    - **e.g., h^3 & h^4 couplings**

CZ Comment:
Higgs Self-coupling requires SppC

Precision measurement + searches:
Complementary with each other !

Timeline (dream)

- **CPEC**
  - Pre-study, R&D and preparation work
    - Pre-study: 2013-15
      - **Pre-CDR for R&D funding request**
    - R&D: 2016-2020
    - Engineering Design: 2015-2020
  - Construction: 2021-2027
  - Data taking: 2028-2035
- **SppC**
  - Pre-study, R&D and preparation work
    - Pre-study: 2013-2020
    - R&D: 2020-2030
    - Engineering Design: 2030-2035
  - Construction: 2035-2042
  - Data taking: 2042 -

Circular Projects: FCC-ee

- Future Circular Collider (FCC)
  - Goal: 100 TeV pp machine
  - 100km circumference
  - First step could be e^+e^- Collider
    - Center of mass energy tunable up to tt-threshold (350 GeV)
    - Polarized beams for low energy
    - High lumi (up to 10^{36} $cm^{-2}s^{-1}$) for precision masurements at low energy (TeraZ)
  - Conceptual design report (CDR) by end 2018
  - Cost review 2018/19
- Status
  - F. Zimmermann: Design on paper is working
  - Very ambitious timeline. Might be pushed by CERN finances
  - Construction time estimated to 12 years
- Question
  - Financially possible for CERN to start construction in 2025?

FCC-ee discovery potential

of course discovery depends on the goodwill of nature;
a few things that FCC-ee could do and discover (if they exist):

EXPLORE 10 TeV energy scale (and beyond) with Precision Measurements

~20-50 fold improved precision on many EW quantities
(equivalent to factor 5-7 in mass)

m_Z, m_W, m_{top}, $\sin^2\theta_w^{eff}$, R_b, $\alpha_{QED}(m_z)$, $\alpha_s(m_z)$, **Higgs and top couplings**

DISCOVER a violation of flavour conservation

- **ex FCNC** ($Z \rightarrow \mu\tau, e\tau$) **in 5** 10^{12} **Z decays.**
  + flavour physics (10^{12} **bb events!)**

also see
M. Bicer et al.,
"First Look at the Physics Case of TLEP,"
JHEP01 (2014) 164

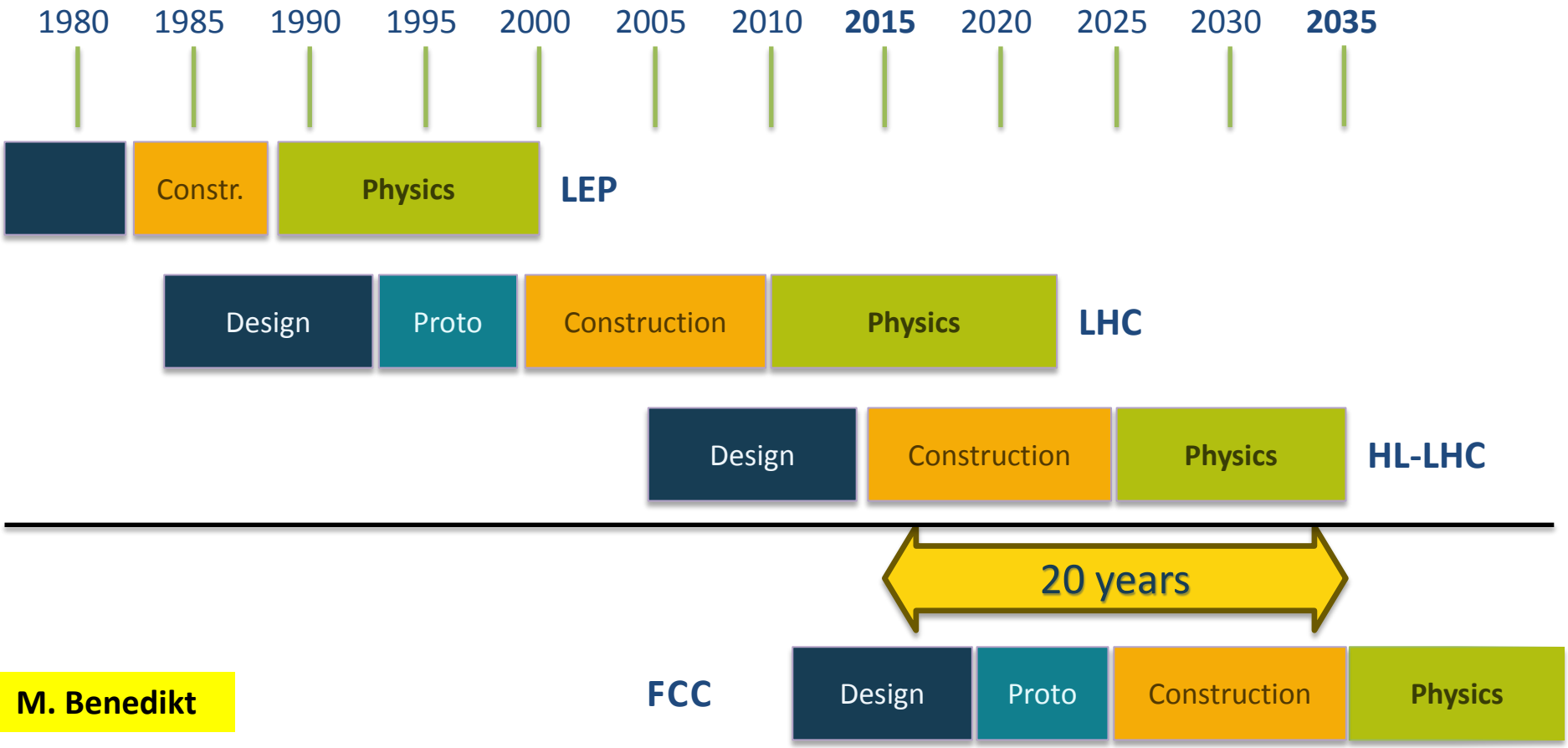
DISCOVER dark matter as «invisible decay» of H or Z

DISCOVER very weakly coupled particle in 5-100 GeV energy scale
such as: right-handed neutrinos, dark photons etc…

…..

A. Blondel

CERN Circular Colliders and FCC

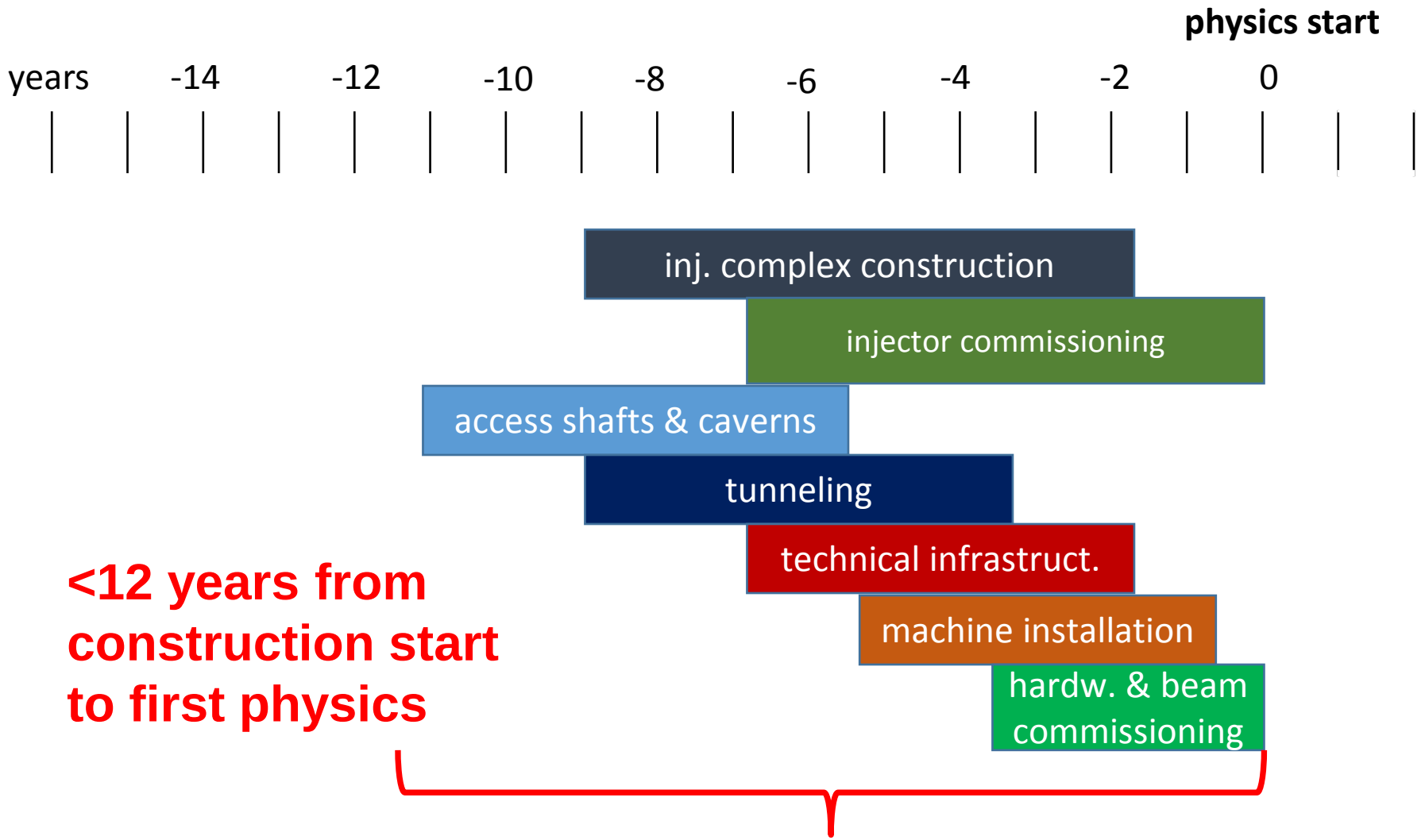


M. Benedikt

Now is the right time to plan for the period 2035 – 2040
Goal of phase 1: CDR by end 2018 for next update of European Strategy

F. Zimmermann - FCC-ee (this workshop)

tentative preliminary time line for FCC-ee construction



Linear Projects: ILC

- International Linear Collider (ILC)
  - Length 34km (500GeV)
  - Center of mass energy tunable up to 500 GeV
    - Might start with lower energy (350 GeV ?)
  - Extension to 1TeV possible
  - Polarized beams
  - Substantially lower luminosity at low energy
  - GigaZ Option (luminosity ~10^{33})
  - Technical design report (TDR) published in 2013
- Status
  - Engineering design complete
  - Cost review exists
  - Only project, which is ready to go
  - Interest of Japan to build the ILC
  - Two detector collaborations (SiD and ILD) exist
  - Discussions in Japan to build ILC

Summary on ILC Analysis Highlights

The ILC energy range matches the guaranteed physics:

- Higgs couplings to ≲ 1% level
- top couplings => indirect reach to ~ 20 TeV NP
- Higgs self-coupling 27% … 10%
- top-Yukawa ≲ 6%
- … and many more!

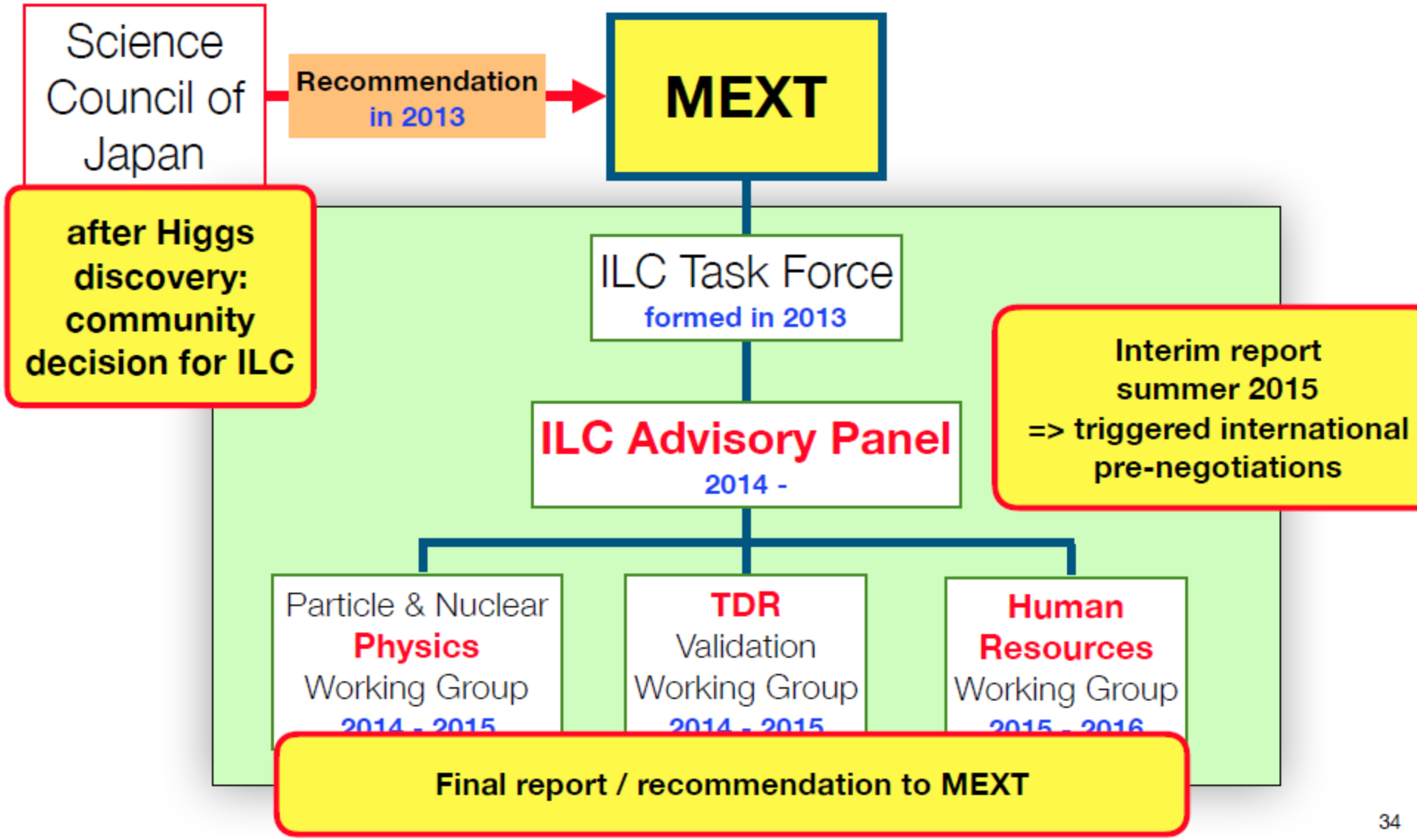
In addition offers unique opportunities for direct discoveries, e.g.:

- Dark Matter
- natural SUSY

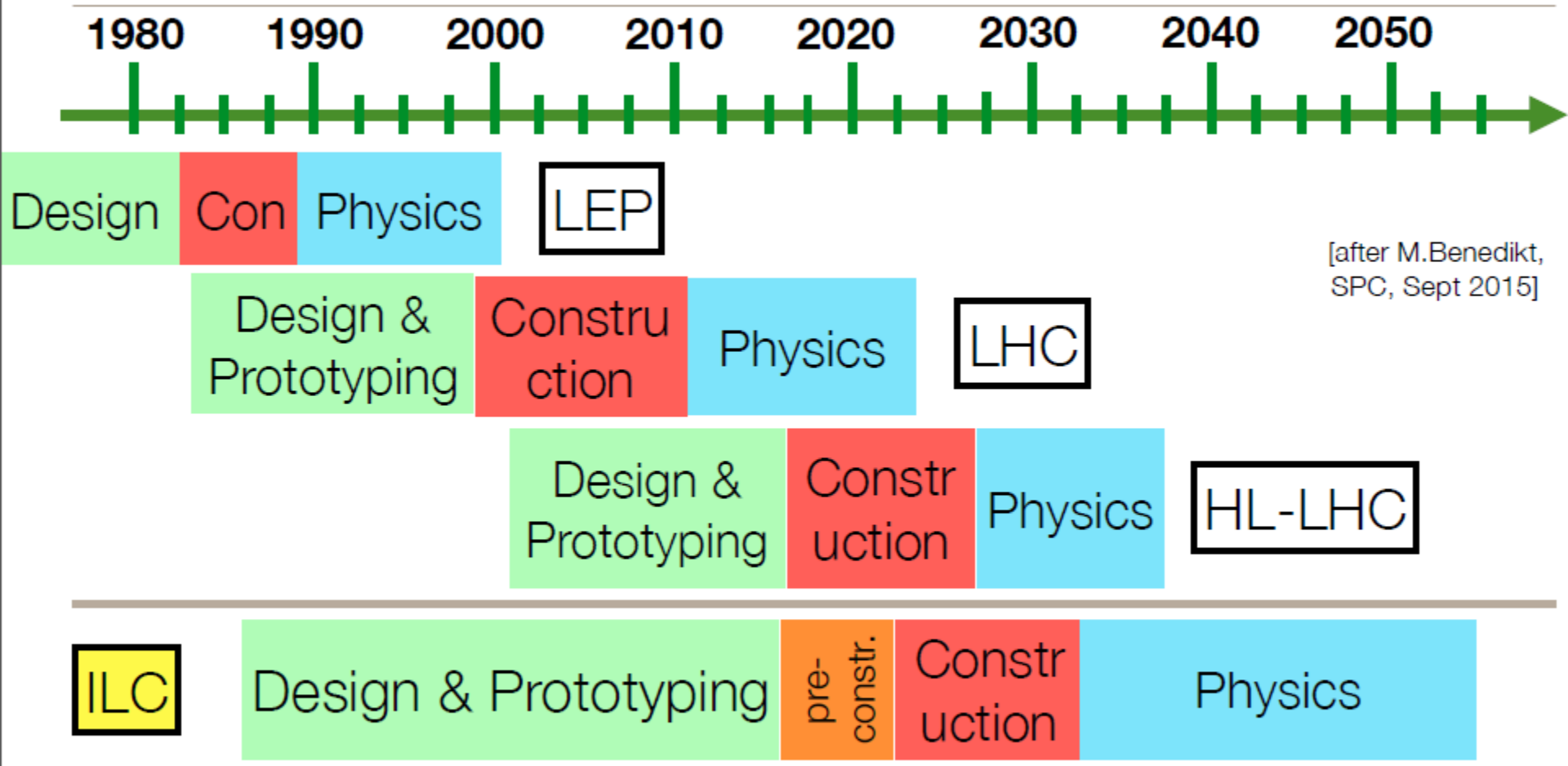
The ILC programme

- is extendable in energy and adjustable if physics requires
- is fully complementary to HL-LHC capabilities
- provides guidance for higher energy colliders
- rests on 500 GeV and polarised beams as key ingredients

Review by Japanese Science Ministry (MEXT)



Timelines: Past, Plans & Possibilities



Linear Projects: CLIC

- Compact LInear Collider (CLIC)
  - 50km long at 3 TeV
  - Start with 380GeV (Higgs and Top physics) – 11km
  - Step to 1.5 TeV
  - Ultimate energy 3 TeV
  - Polarized electrons, not the positrons
  - Physics comparable with ILC
  - Energy upgrade increases BSM reach in direct searches
- Status
  - Conceptual design report published 2012
  - Detector and physics collaborations (CLICdp)
  - R&D ongoing
    - High gradient structures
    - Test of drive beam moduls
  - CDR: 500GeV options – costing exists

Linear Projects: CLIC (2)

- Timescale (optimistic?)
  - Assume decision 2019 (in competition with FCC)
  - Start construction 2024
  - Start data taking around 2035

Additional Considerations

- Start of data taking within few years after end of HL-LHC
  - Avoid loss of know how and drain of man power
- Consider project with highest chance to be realized within next 15-20 years
  - Might not be the optimum for physics due to limited resources

Conclusions

- Pin down, if the LHC-Higgs is the SM Higgs
  - Covered by all projects
- Higgs self-coupling
  - Limited improvement wrt LHC at CEPC
  - Advantage for ILC and CLIC
- Top physics
  - Threshold reached by ILC, FCC-ee and CLIC
- Precision electroweak measurements at M_W and M_Z
  - TeraZ at FCC-ee and CEPC
  - GigaZ option at ILC
  - CLIC ?
- BSM
  - Indirect discovery through precision measurements covered by all projects
  - CLIC, (ILC) have advantage for direct measurements of heavy mass particles at TeV scale

Conclusion (2)

- Timeline
  - CEPC, FCC-ee and ILC have roughly the same timeline: start data taking around 2035 (coincidence?) (makes no sense to draw the timelines side by side)
  - CEPC, CLIC and FCC-ee planning look very optimistic and might only be able to start end of 2030s
- ILC is currently the only mature project
  - Covers the requirements well (with GigaZ option)
  - Allows for (some) extension in case of further discoveries in the high mass regime at LHC

My Pros and Cons Matrix

Topic	CEPC	FCC-ee	ILC	CLIC
Higgs Mass, couplings	+	+	+	+
Higgs self-coupling	-	+-	+	+
Top physics	-	+	+	+
ew- precision parameters	+	+	+-?	?
BSM	-	+-	+-	+
Flexibility to new high mass signal	-	-	+-	+
Maturity of project (not age!)	-	-	+	-
Detectors	-	-	+	+
Start 2035	-	-	+	-