QWG 2019 - The 13th International Workshop on Heavy Quarkonium

European Strategy for Particle Physics

news from the Granada Open Symposium

a personal view

Nadia Pastrone INFN TORINO

Torino – May 17th, 2019

Now drafting the Briefing Book….

European Strategy Update

European Particle Physics Strategy Update 2020

EPPSU 2020

Timeline

160 input documents

2017 | 2018 | 2019 | 2020

organisation & input preparation by community

Jan.2018 ✓
Call for proposals for venues for Open Symposium and Strategy Drafting Session

Febr.2018 ✓
Call for scientific input

March.2018 ✓
Call for nominations of PPG & ESG members

June 14,2018 ✓
Council decision on venues and dates

Sept 27,2018 ✓
Council launches the Strategy Update process & establish the PPG and ESG

consultation & consensus building

Dec 18.2018 ✓
Closing submission community input

May 13-16,2019 ✓
Open Symposium
Granada, ES

Sept.2019
Physics Briefing Book available

Physics results appearing after May 2019 will be taken into account in the process

Jan 20-24,2020
Strategy Update Drafting Session
Bad Honnef, DE

March.2020
Strategy Update submitted to Council

May.2020
Council to approve Strategy Update

Open Symposium agenda-plenary

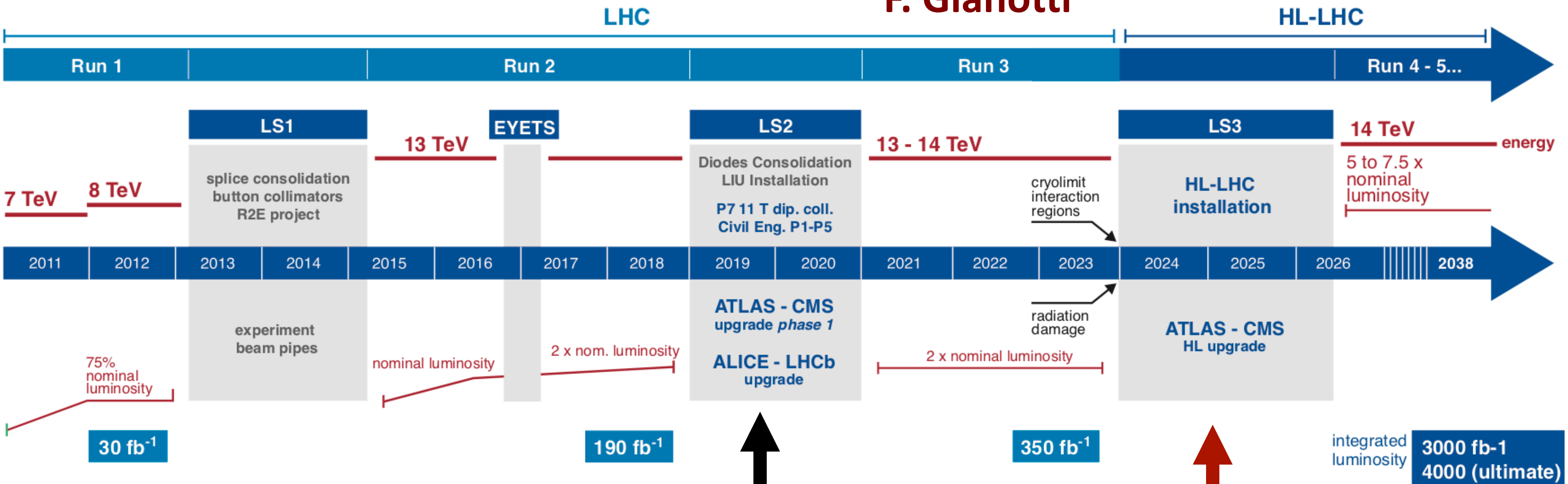
https://indico.cern.ch/event/808335

- Implementation of the 2013 European Strategy Update
- Outstanding Questions in Particle Physics
- State of the art and challenges in accelerator technology
  Past and present
- Future – Path to very high energies
- Technological challenges of particle physics experiments
- Computing challenges of the future

- Perspective on the European Strategy from the Americas
- Perspective on the European Strategy from Asia
- ApPEC Roadmap
- NuPPEC long term plan
- Programs of Large European and National Labs
- Overview of National Inputs to the Strategy Update
- Education, Communication and Outreach

HL-LHC parameters and timeline

F. Gianotti



LS2 (2019-2020):

- ❑ LHC Injectors Upgrade (**LIU**)
- ❑ Civil engineering for HL-LHC equipment P1, P5
- ❑ Installation of (part of) 11T Nb_3Sn dipoles for HL-LHC
- ❑ Phase-1 upgrade of LHC experiments

LS3 (2024-2026):

- ❑ HL-LHC installation
- ❑ Phase-2 upgrade of ATLAS and CMS

LIU will provide beams of intensity and brightness needed by HL-LHC (2.3×10^{11} p/bunch, ε~ 2.1 μm)

Linac 4: 160 MeV H^-

PSB: 1.4→ 2 GeV

PS: new injection and feedback systems

SPS: new 200 MHz RF system

High-priority large-scale scientific projects

F. Gianotti

d) CERN should undertake design studies for accelerator projects in a global context, with emphasis on proton-proton and electron-positron high-energy frontier machines. These design studies should be coupled to a vigorous accelerator R&D programme, including high-field magnets and high-gradient accelerating structures, in collaboration with national institutes, laboratories and universities worldwide.

CLIC continued R&D; project implementation plan submitted to this ESPP
FCC started in 2014 → CDR submitted to this ESPP
In both cases:
-- Compelling physics case developed, excellent potential (Higgs, direct/indirect discoveries, etc.)
-- Detailed studies of machine layout and technical and civil infrastructure
-- Many technical challenges addressed by dedicated R&D; mature understanding of remaining challenges and the path toward solution
-- Detector concepts developed
-- Global context: participating institutes from > 30 countries

Significant progress on superconducting magnets R&D and design, mainly within HL-LHC and FCC.
Efforts on SCRF intensified at CERN (HIE-ISOLDE cryomodules, HL-LHC crab cavities, etc.);
work on X-band warm accelerating structures within CLIC.

New acceleration concepts: AWAKE completed its first run

Strong collaborations and synergies in all these activities with labs and institutes in Europe and beyond.

High-priority large-scale scientific projects

e) There is a strong scientific case for an electron-positron collider, …
The initiative from the Japanese particle physics community to host the ILC in Japan is most welcome … *Europe looks forward to a proposal from Japan to discuss a possible participation.*

Since the last ESPP, in Europe and at CERN:

- ❑ ILC-related activities continued, in particular building upon synergies with CLIC:
  - -- accelerators (beam dynamics, damping rings, beam delivery system, etc.)
  - -- detector design and R&D (e.g. Linear Collider Detector group at CERN and many efforts in European countries).
- ❑ CERN-KEK cooperation agreements (e.g. accelerator studies at ATF KEK)
- ❑ CERN's help for civil engineering and geological studies of tunnel layout in Japan
- ❑ "Preparation plan for European participation in the ILC", describing possible scientific and industrial contributions of Europe to the ILC over a four-year preparatory phase, prepared by E-JADE (Europe-Japan Accelerator Development Exchange Programme, H2020)
  https://ilchome.web.cern.ch/sites/ilchome.web.cern.ch/files/ILC-EIPP.E-JADE.v2.12.20180703.pdf

Latest news on ILC in Japan

Statement by MEXT (Japanese Ministry of Education, Culture, Sports, Science and Technology) at ICFA and LCB meetings on 7 March 2019 in Tokyo https://www.kek.jp/en/newsroom/2019/03/13/2100/

MEXT's view in regard to ILC project, Executive Summary, March 7 2019

- *Following the opinion of the SCJ, MEXT has not yet reached declaration for hosting the ILC in Japan at this moment. The ILC project requires further discussion in formal academic decision-making processes such as the SCJ Master Plan, where it has to be clarified whether the ILC project can gain understanding and support from domestic academic community.*
- *MEXT will pay close attention to progress and discussions of the European Strategy for Particle Physics update.*
- *The ILC project has a certain significance in particle physics particularly in the precision measurements of the Higgs boson, and has possibility in the technological advancement and its effect on the local community, although the SCJ pointed out some concerns with ILC project. Therefore, considering the above points, MEXT will continue to discuss the ILC project with other governments while having an interest in the ILC project.*

Master Plan of SCJ (Scientific Council of Japan) to be officially released May 2020

High-priority large-scale scientific projects

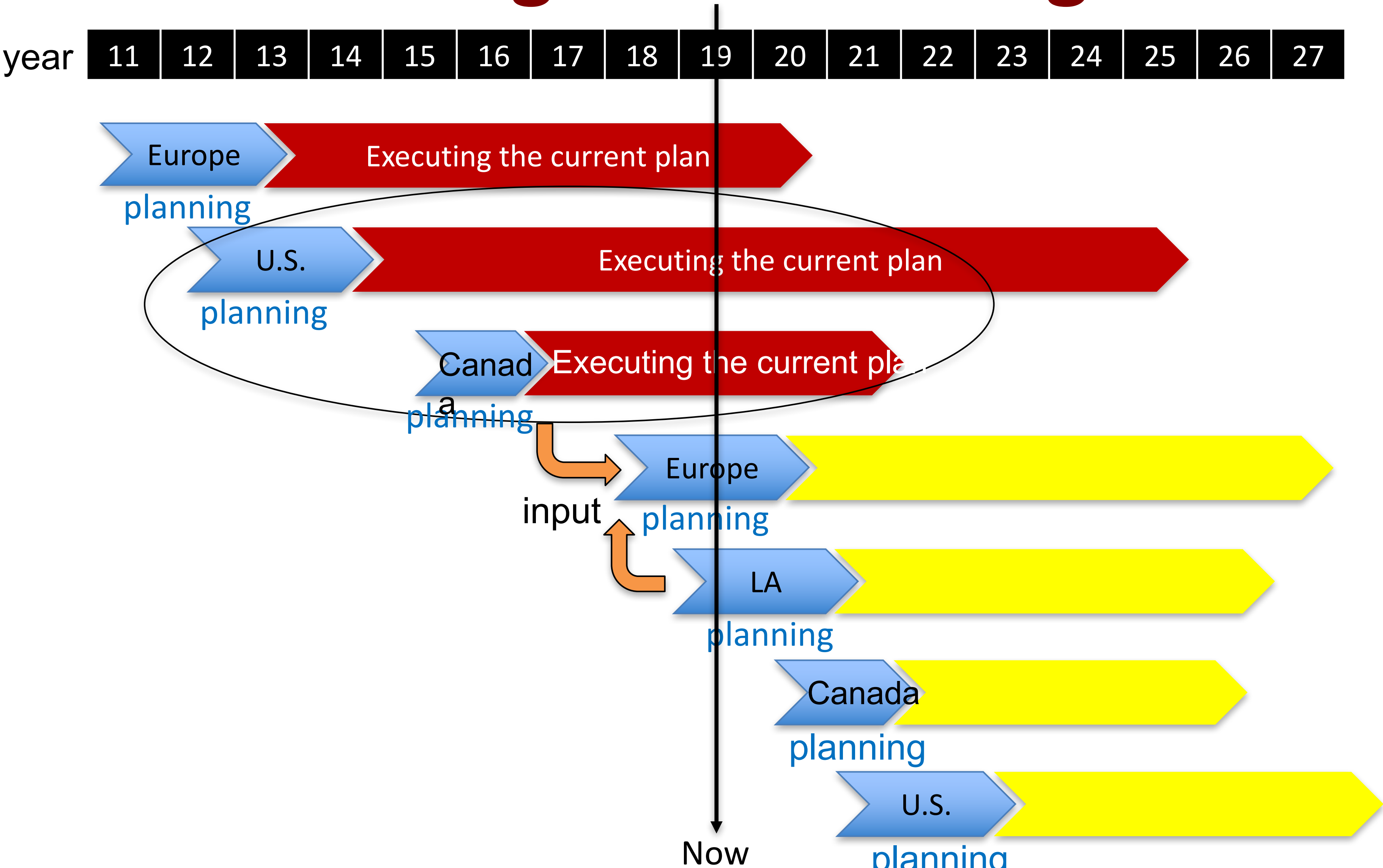
f) CERN should develop a neutrino programme to pave the way for a substantial European role in future long-baseline experiments. Europe should explore the possibility of major participation in leading long-baseline neutrino projects in the US and Japan.

CERN Neutrino Platform established in 2014 → became a project in 2016.
Today: ~ 90 European Institutions involved.

Main goals and activities:

- ❑ North Area extended to provide test beams and space for (big) detector prototypes
- ❑ Support to and participation in detector R&D and construction for projects with European interest and expertise (e.g. prototypes for DUNE at LBNF in US; ND280 for T2K in Japan)
- ❑ CERN is building first of four cryostats for DUNE detector based on new (for HEP) technology
- ❑ Neutrino group set up in CERN EP Department in 2016 to carry out software and physics activities in synergy with TH Department, and help enhance coherence of efforts in the European community (e.g. providing forum for Near Detectors discussions and studies)

Planning and Executing



From ASIA

CepC Path to Funding

- "Chinese Initiated International Large Scientific Plan and Large Scientific Project" :
  - *3-5 Projects will be selected for further development*
  - *By 2020 select 1~2 projects for construction*
  - *Should be complementary to other large national or multinational scientific projects.*
  - *Be seen to be important to international scientific organizations' and laboratory scientific projects and activities.*
  - *Process has commenced*

Yifang Wang, Jie Gao

CoEPP ARC Centre of Excellence for Particle Physics at the Terascale

Geoffrey Taylor "Perspective on the European Strategy from Asia", EPPSU2019, Granada 35

European Strategy Update

Accelerator Science and Technology

Caterina Biscari and ***Lenny Rivkin***

BIG QUESTIONS for the Accelerator Science and Technology

- **What is the best implementation for a Higgs factory?**
  Choice and challenges for accelerator technology: linear vs. circular?

- **Path towards the highest energies: how to achieve the ultimate performance (including new acceleration techniques)?**

- **How to achieve proper complementarity for the high intensity frontier vs. the high-energy frontier?**

- **Energy management in the age of high-power accelerators?**

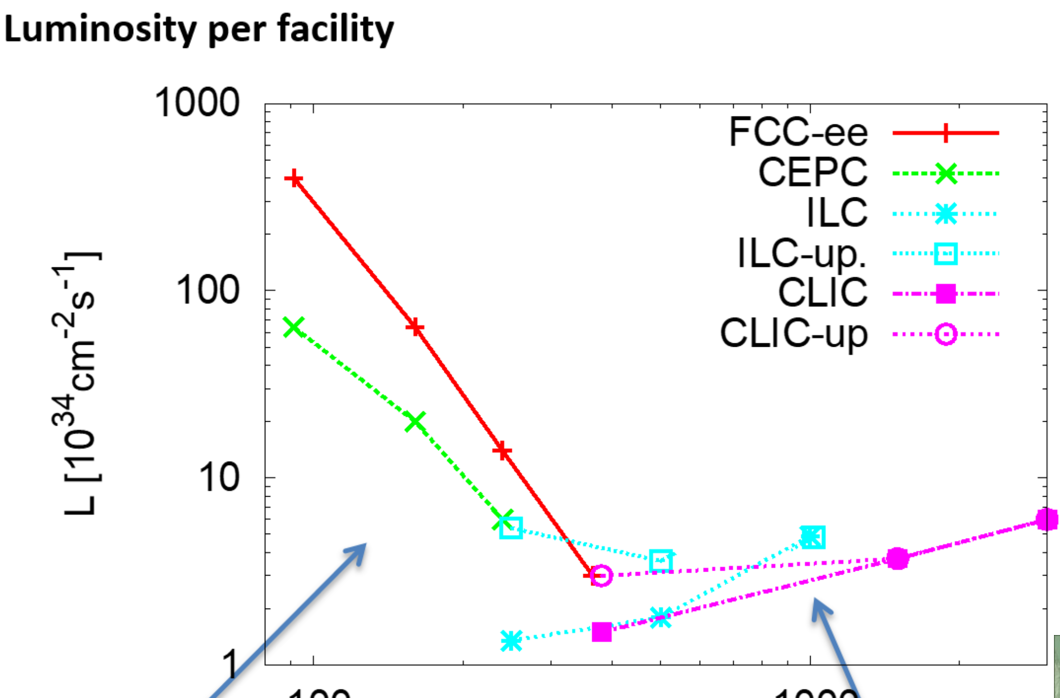
The future is in accelerating muons in plasma!
Vladimir Shiltsev

Energy Efficiency

Q4: Energy management in the age of high-power accelerators?

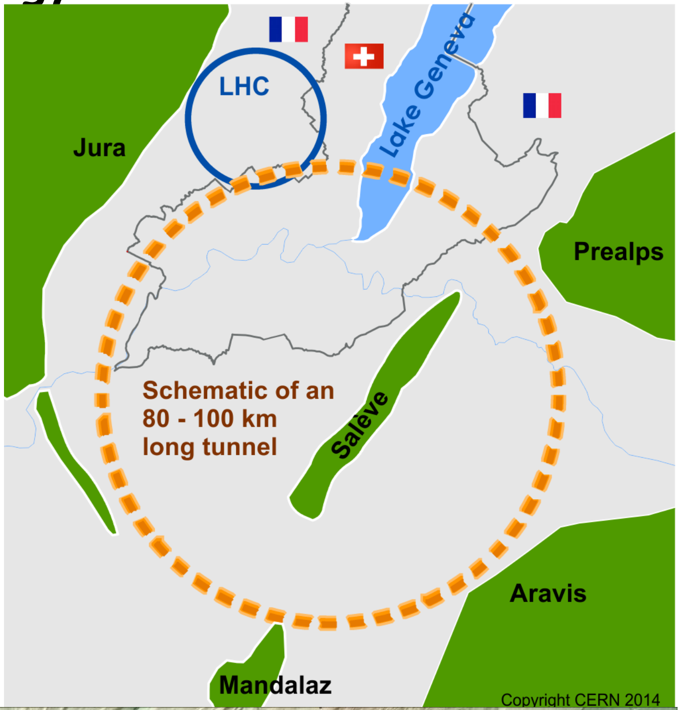
- Energy efficiency is not an option, it is a must!
- Proposed HEP projects are using $\mathcal{O}(\mathrm{TWh/y})$, where energy efficiency and energy management must be addressed.
- Investing in dedicated R&D to improve energy efficiency pays off since savings can be significant.
- This R&D leads to technologies which serve the society at large.
- District heating, energy storage, magnet design, RF power generation, cryogenics, SRF cavity technology, beam energy recovery are areas where energy efficiency can be significantly be improved.

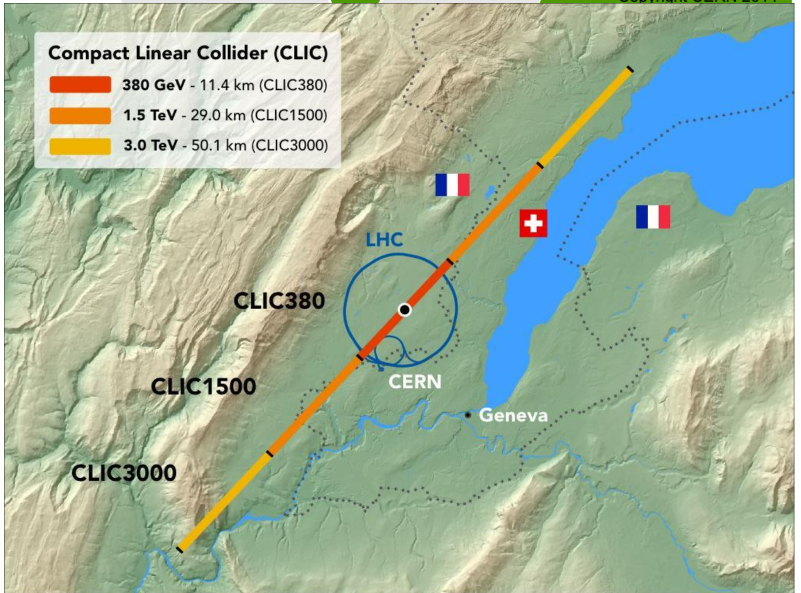
Q1: What is the best implementation for a Higgs factory? Choice and challenges for accelerator technology: linear vs. circular?



$$L \propto P_{synrad} E_{cm}^{-3.5}$$

$$L \propto P_{RF} E_{cm}$$





Ours is a very dynamic field!
(Luminosity upgrades for ILC, CLIC)

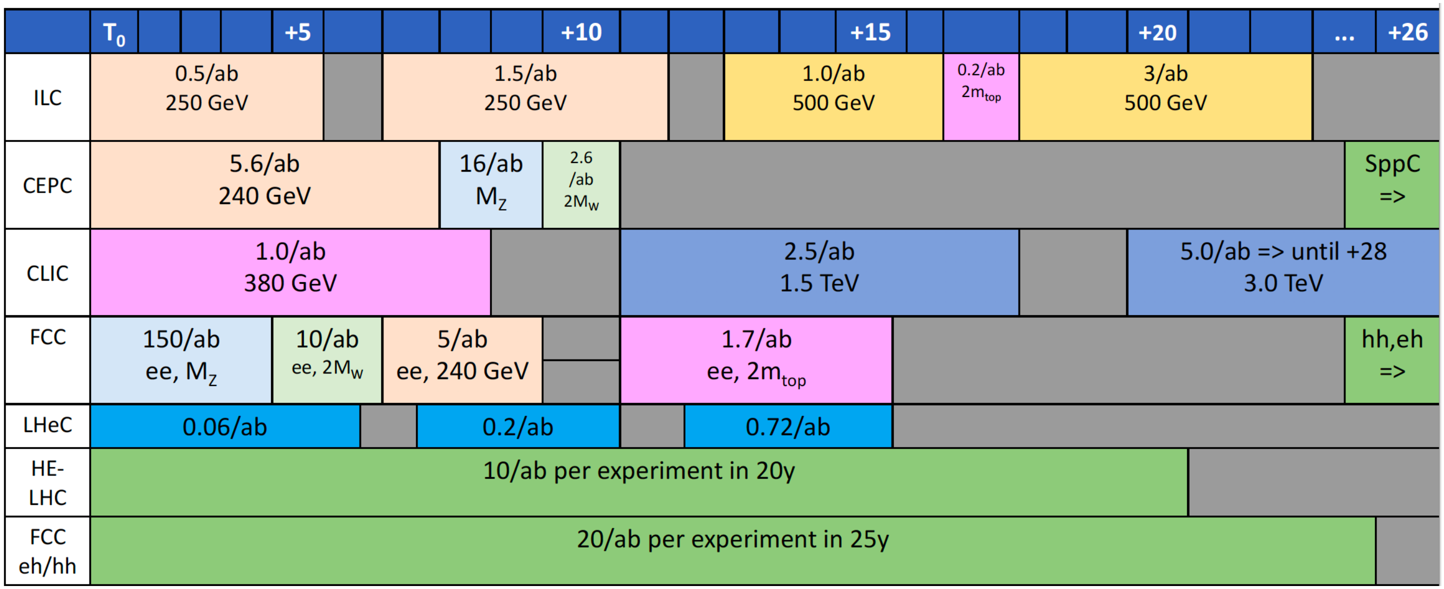
Higgs Factories Comparisons

D. Schulte

Project	Type	Energy [TeV]	Int. Lumi. [a^{-1}]	Oper. Time [y]	Power [MW]	Cost
ILC	ee	0.25	2	11	129 (upgr. 150-200)	4.8-5.3 GILCU + upgrade
		0.5	4	10	163 (204)	7.98 GILCU
		1.0			300	?
CLIC	ee	0.38	1	8	168	5.9 GCHF
		1.5	2.5	7	(370)	+5.1 GCHF
		3	5	8	(590)	+7.3 GCHF
CEPC	ee	0.091+0.16	16+2.6		149	5 G$
		0.24	5.6	7	266	
FCC-ee	ee	0.091+0.16	150+10	4+1	259	10.5 GCHF
		0.24	5	3	282	
		0.365 (+0.35)	1.5 (+0.2)	4 (+1)	340	+1.1 GCHF
LHeC	ep	60 / 7000	1	12	(+100)	1.75 GCHF
FCC-hh	pp	100	30	25	580 (550)	17 GCHF (+7 GCHF)
HE-LHC	pp	27	20	20		7.2 GCHF

Proposed Schedules and Evolution

D. Schulte

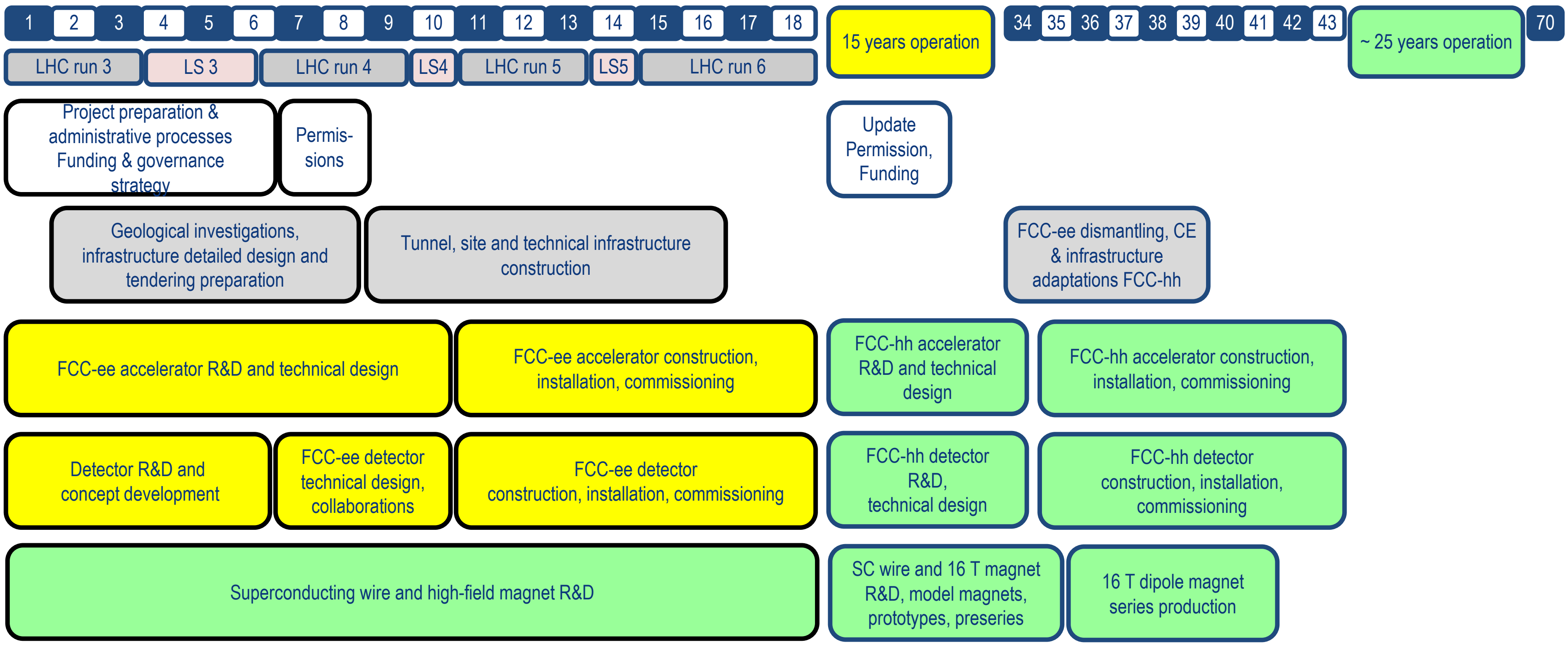


Project	Start construction	Start Physics (higgs)
CEPC	2022	2030
ILC	2024	2033
CLIC	2026	2035
FCC-ee	2029	2039 (2044)
LHeC	2023	2031

Proposed dates from projects

Would expect that technically required time to start construction is O(5-10 years) for prototyping etc.

FCC integrated project technical schedule



FCC integrated project is fully aligned with HL-LHC exploitation and provides for seamless continuation of HEP in Europe with highest performance EW factory followed by highest energy hadron collider.

Consideration on timeline:

LHC possible because SSC developed the superconductor…

L. Rossi

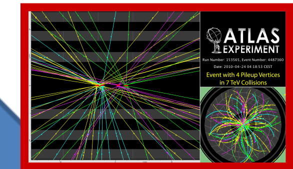
9 T - 1 m single bore

10 T-1m Nb3Sn dipole

9 T -10 m long protoype

9 T-15 m final protoype

Last LHC dipole



1985 1987 1990 1994 2000 2006 2010

Only 2 y to make a short magnet «near to final». Conductor available(SSC)

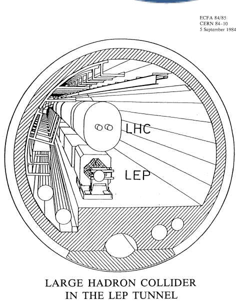
7 years from start R&D to 1st Industry proto

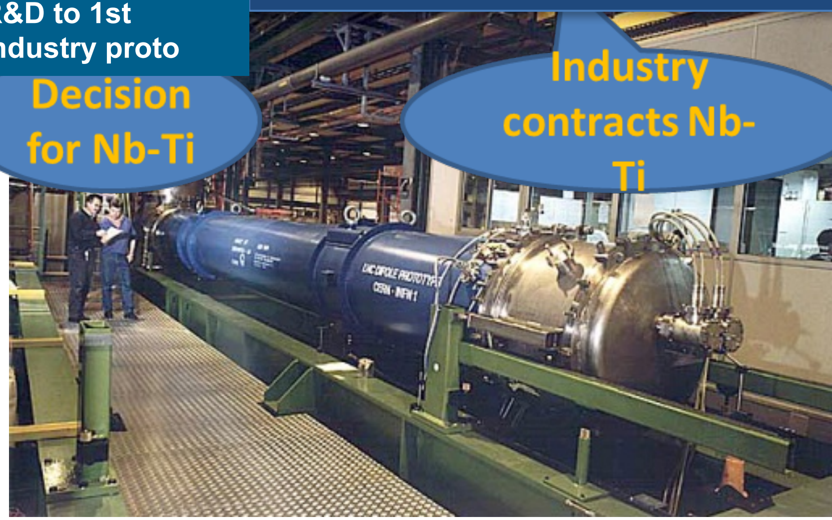
12 y from first working prototype to last magnet

Decision for Nb-Ti

Industry contracts Nb-Ti

LHC start-up

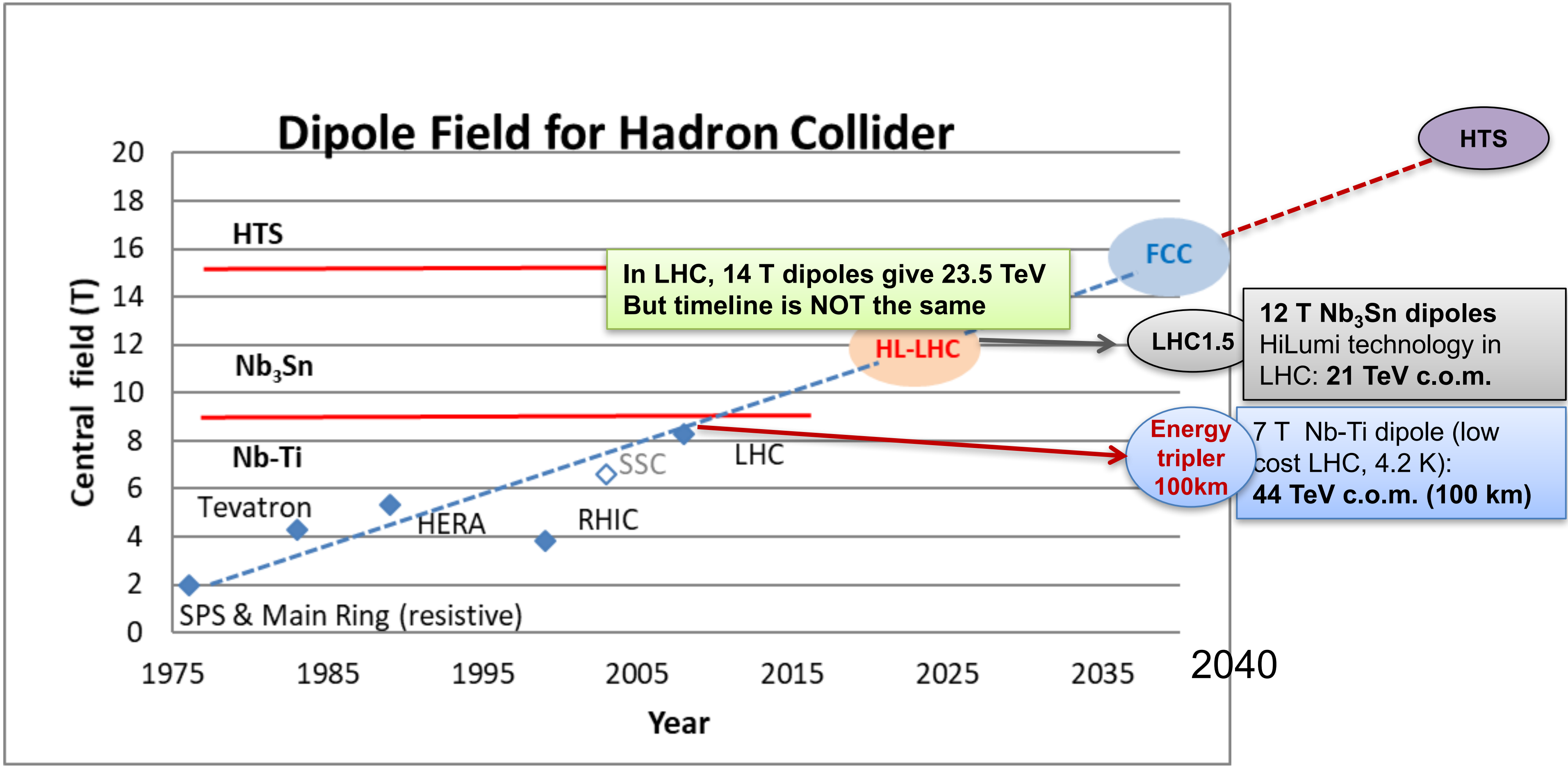




Q2: Path towards the highest energies: how to achieve the ultimate performance **(including new acceleration techniques)?**

High field magnet development

L. Rossi



The set up of a SC Open Lab for fostering development of superconductors (F. Bordry and L. Bottura proposal) is critical for HEP HC progress

Personal (A. Yamamoto) View on Relative Timelines

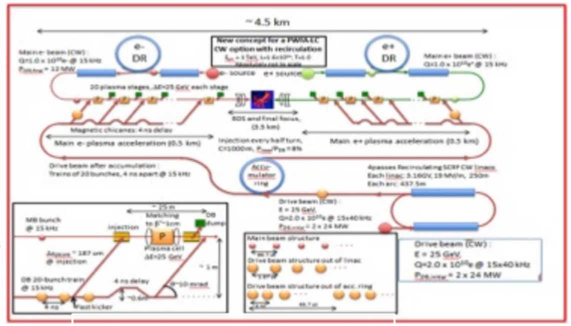
Timeline	~ 5	~ 10	~ 15	~ 20	~ 25	~ 30	~ 35
Lepton Colliders							
SRF-LC/CC	Proto/pre-series	Construction		Operation		Upgrade	
NRF—LC	Proto/pre-series	Construction		Operation		Upgrade	
Hadron Collider (CC)							
8~(11)T NbTi /(Nb3Sn)	Proto/pre-series	Construction		Operation			Upgrade
12~14T Nb_3Sn	Short-model R&D	Proto/Pre-series		Construction		Operation	
14~16T Nb_3Sn	Short-model R&D		Prototype/Pre-series			Construction	

Note: **LHC experience**: **NbTi (10 T)** R&D started in 1980's --> (**8.3 T**) Production started in late 1990's, in **~ 15 years**

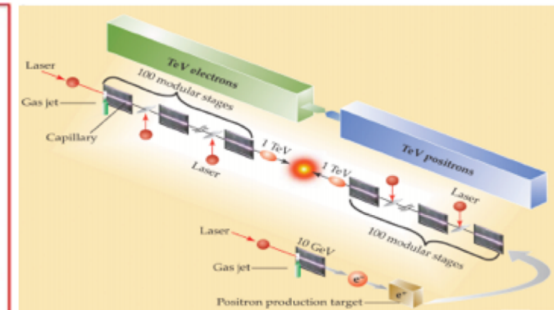
Plasma acceleration based colliders

Drive beams
Lasers: ~40 J/pulse
Electrons: 30 J/bunch
Protons: SPS 19kJ/pulse, LHC 300kJ/bunch

Witness beams
Electrons: 1010 particles @ 1 TeV ~few kJ



E. Adli et. al.,arXiv:1308.1145



Leemans & Esarey, Phys. Today 63 #3 (2009)

Key achievements in last 15 years in plasma based acceleration using lasers, electron and proton drivers

- Focus is now **on high brightness beams, tunability, reproducibility, reliability, and high average power**

The road to colliders passes through **applications** that need compact accelerators (Early HEP applications, FELs, Thomson scattering sources, medical applications, injection into next generation storage rings …)

Many key challenges remain as detailed in community developed, consensus based roadmaps (ALEGRO, AWAKE, Eupraxia, US roadmap,…)

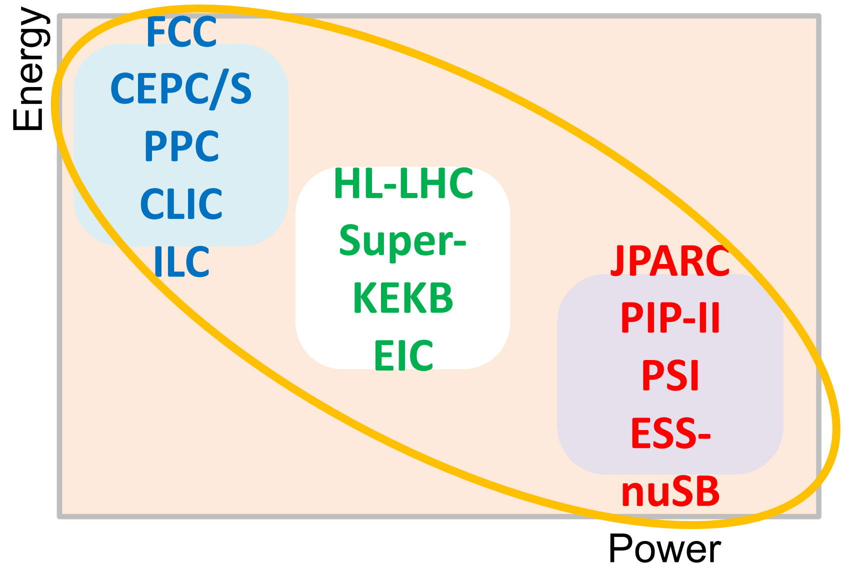
Strategic investments are needed:

- **Personnel** – advanced accelerators attract large numbers of students and postdocs
- Existing **facilities** (with upgrades) and a few new ones (High average power, high repetition rate operation studies; fully dedicated to addressing the challenges towards a TDR for a plasma based collider)
- **High performance computing** methods and tools

Q3: How to achieve proper complementarity for the high intensity frontier vs. the high-energy frontier?

Intensity – Acc.	Energy [GeV]	Power [MW]	Acc. Tech. Feature	SC Tech.
SPS*	450		Synchrotron	
Fnal M. Injector	120	0.7	Synchrotron	
J-PARC*	3 30	1 0,49 ~ 1.3	Linac/Synchr Ext. Beam	SCM
PIP-II	60 -120	.2	Linac (SRF) Synchrotron	SRF
PSI-HIPA*	0.59	1.4	Cycrotron	
FAIR (SIS100)	29	0.2	Synchrotron	SCM
(ESS) ESSnuSB *	2 2	2 ~ 5 (+5) 2 x 5	Linac	SRF
CEBAF	12	1	LINAC+Ring	SRF
Super-KEKB		---	Collider	
HL-LHC	2 x 7,000	---	Collider	SCM. SRF
EIC*		---	Collider	SCM, SRF

Common Issues:
- SC Mag. & SRF technology
- Target, Collimator, Beam Dump
- Radiation
- Energy Management



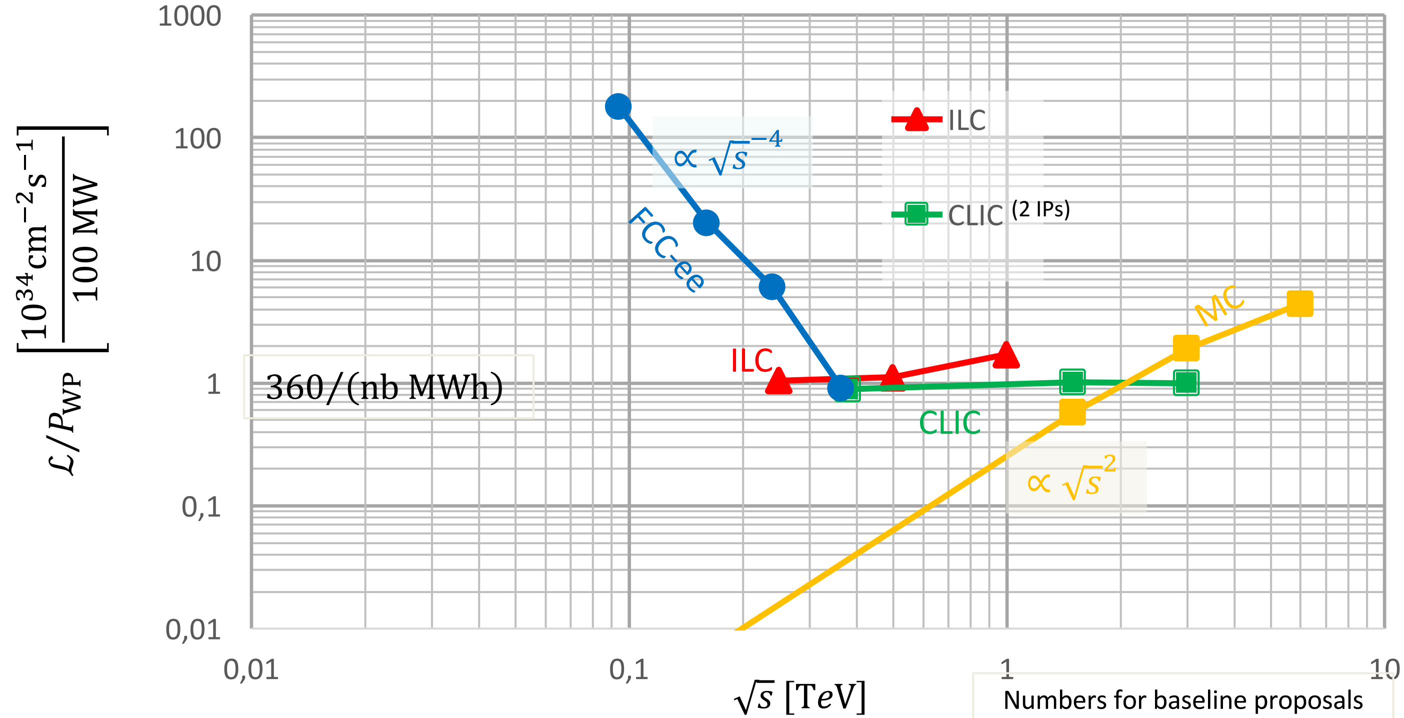
- Science is complementary, and
- Technology is based on common technology,
- Let us work together and maximize synergy !!

A. Yamamoto, 190512b

Figure of merit for proposed lepton colliders

Disclaimers:

1. This is not the only possible figure of merit
2. The presented numbers have different levels of confidence/optimism; they are still subject to optimisations



Numbers for baseline proposals

Neutrino Physics (accelerator and non-accelerator)

*Stan Bentvelsen and **Marco Zito***

Big questions

What is the origin of the neutrino masses ? And of the leptonic mixing ?

What is the optimal strategy towards a complete set of measurements of neutrino oscillation parameters and towards a precision global fit of the PMNS matrix ?

Is the existing experimental program (reactor, SBL) sufficient to confirm or exclude the existence of sterile neutrino states with masses in the eV/c^2 range ?

How to search for heavy neutral leptons with present and future facilities ?

Is gravity described by the Einstein theory of general relativity?

How do gravitational waves help to understand Dark Sector of the universe?

What is the proton-proton cross section at ultra-high energies?

How can cosmic neutrino's help to pin-down their properties - oscillations and mass hierarchy?

Neutrino Physics

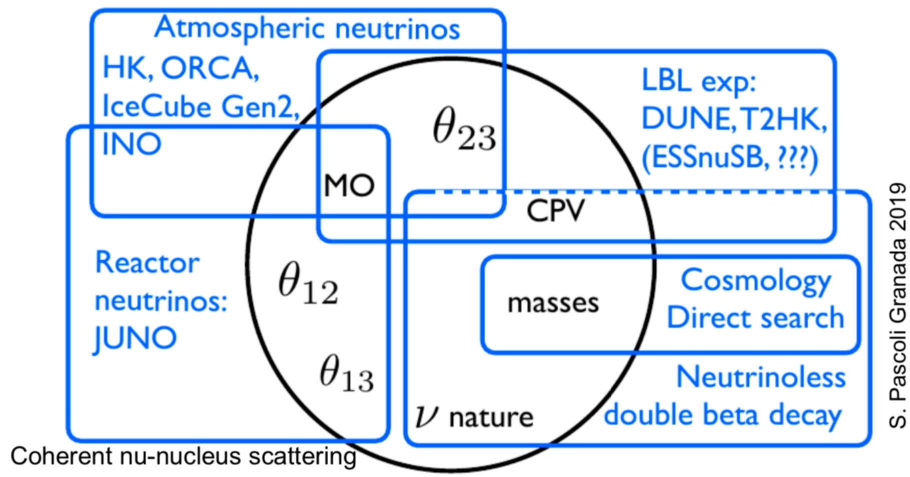
2013 Strategy

f) Rapid progress in neutrino oscillation physics, with significant European involvement, has established a strong scientific case for a long-baseline neutrino programme exploring CP violation and the mass hierarchy in the neutrino sector. CERN should develop a neutrino programme to pave the way for a substantial European role in future long-baseline experiments. Europe should explore the possibility of major participation in leading long-baseline neutrino projects in the US and Japan.

j) A range of important non-accelerator experiments take place at the overlap of particle and astroparticle physics, such as searches for proton decay, neutrinoless double beta decay and dark matter, and the study of high-energy cosmic-rays. These experiments address fundamental questions beyond the Standard Model of particle physics. The exchange of information between CERN and ApPEC has progressed since 2006. In the coming years, CERN should seek a closer collaboration with ApPEC on detector R&D with a view to maintaining the community's capability for unique projects in this field.

Neutrino Physics

A very diverse experimental approach



Motivation : necessary to get a complete picture, make the most out of every neutrino source, test at different L/E, possible existence of new neutrino states, of Non-Standard-Interactions

Astroparticle physics

- Gravitational waves and multimessenger physics open up a new window on the Universe. Very strong physics case.
- There is a very high impact on the field of particle physics (and fundamental interactions) (eg dark matter, neutrinos, general relativity, ...)
- There is clearly an opportunity for the particle physics community and laboratories to expand their involvement in this program

Flavour Physics and CP violation (quarks, charged leptons and rare processes)

*Belen Gavela and **Antonio Zoccoli***

Conclusions

Flavor physics crucial for BSM search:

- Outstanding BSM scale reach → $\Lambda > 10^2 - 10^5$ TeV
- Complementarity of low-energy, HE frontier and feebly interacting searches

Flavour is a major legacy of LHC:

- Main results from LHCb. ATLAS and CMS also contributing and enlarging their flavor physics scope

→ Charged hadron PID is mandatory for a full physics program.

→ Essential that HE future experiments follow this same path

- Important to have experiments in very different environments (pp and e+e-), and with PID

In the longer term:

- Z_0-factory is a fantastic tool for Flavor Physics

16/5/19 58

Dark matter and Dark Sector

(accelerator and non-accelerator dark matter, dark photons, hidden sector, axions)

Shoji Asai and ***Marcela Carena***

European Strategy Update

Big Questions

1) How do we search for DM, depending on its properties?
   What are the main differences between light Hidden Sector DM and WIMPs?
   How broad is the parameter space for the QCD axion?

2) What are the most promising experimental programs, approved or proposed, to probe the different DM possibilities in a compelling manner?

3) How to compare results of different experiments in a more model-independent way?

4) How will direct and indirect DM Detection experiments inform/guide accelerator searches and vice-versa?

We have started to address the big questions by

- looking at the experimental probes of the DM realm,
- evaluating the complementarity of different approaches
- attempting to compare their correlated impacts

This summary emphasizes the well defined targets of QCD axion DM & MeV-GeV thermal DM

Dark matter and Dark Sector

Comments from the Discussion Sessions

Need for better coordination

- Consensus emerged on the need for more coordination between accelerator based, direct detection and indirect detection dark sector searches, for common interpretation of results.
- This will also be of fundamental importance to validate, through different channels, a possible dark matter discovery.
- To address this issue, it was recommended to make profitable use of the initiative of APPEC on the EuCAPT Astroparticle Theory Centre.
- This offers a strong opportunity to collaborate with working groups such as the LHC DM and Physics Beyond Colliders and the many recognized dark sector experiments using different approaches

See talk by T. Montaruli, EPPSU Granada

Comments from the Discussion Sessions

Need for technology support and exchange between communities

- Technology challenges are shared between and beyond the communities engaged in dark matter searches.
- CERN and other large European National labs has relevant expertise and infrastructure for most/many of the big challenges, including vacuum over large volume, cryogenics, photosensors, liquid argon detectors, design and operation of complex experiments, software and data processing.
- Expanded support for dark matter research at CERN would stimulate knowledge transfer, increase coordination and synergies between experiments, and add guidance and coherence to the overall program.

Beyond the Standard Model at colliders

*Gian Giudice and **Paris Sphicas***

1) Electroweak breaking dynamics and resonances (EWSB/NewR)
   Andrea Wulzer (CERN) & Juan Alcaraz (CIEMAT)
   Composite Higgs, top partners, particles associated with EW symmetry breaking, heavy Z' and W'
2) Supersymmetry (SUSY)
   Andreas Weiler (TUM) & Monica D'Onofrio (Liverpool)
   Collider searches, motivations for supersymmetry after the LHC, unexplored corners, new models
3) Extended Higgs sectors & High-energy flavor dynamics (Ext-H/FD)
   Veronica Sanz (Sussex) & Philipp Roloff (CERN)
   Two Higgs doublets, singlets, new particles accompanying the Higgs, leptoquarks, particles related to flavour dynamics at the EW scale, rare top decays
4) Dark matter (DM)
   Matthew McCullough (CERN) & Caterina Doglioni (Lund)
   Collider searches, simplified models, comparisons with direct/indirect searches
5) Feebly-interacting particles (FIPs)
   Gilad Perez (Weizmann) & Gaia Lanfranchi (INFN, Frascati)
   Long-lived particles, right-handed neutrinos at the EW scale, dark photons at colliders, dark scalar/relaxion, ALPs at colliders

he Big Questions (BQs)

questions for BSM (@colliders):

- To what extent can we tell whether the Higgs is fundamental or composite?
  - EWSB/NewReson, SUSY
- Are there new interactions or new particles around or above the electroweak scale?
  - EWSB/NewReson, SUSY, Ext-H/FlavorDyn, DM, FIPs
- What cases of thermal relic WIMPs are still unprobed and can be fully covered by future collider searches?
  - DM, FIPs, SUSY
- To what extent can current or future accelerators probe feebly interacting sectors?
  - FIPs, SUSY

Beyond the Standard Model at colliders

Summary/Outlook

We are trying to provide a meaningful comparison between the different machines and experiments

- And to see what we really learn in response to “big questions”

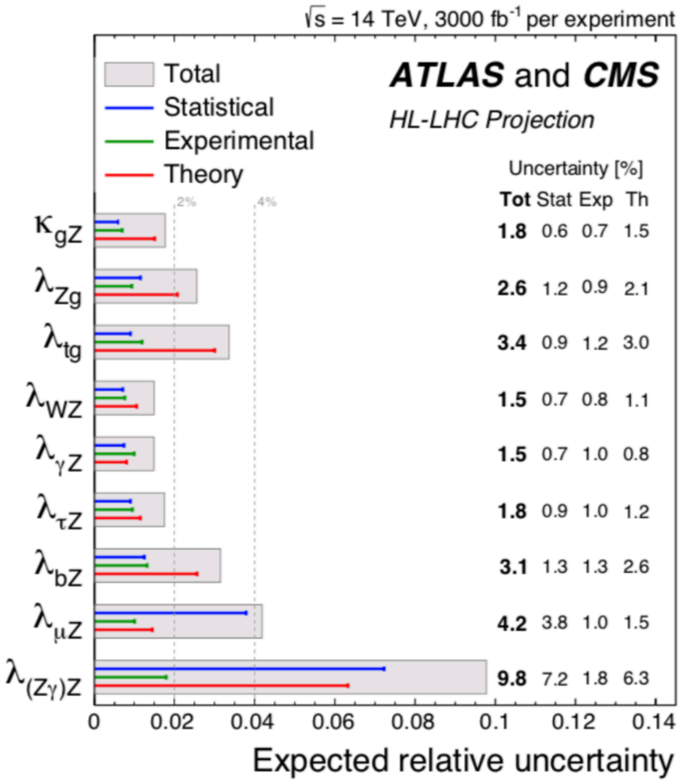
We do learn a lot

- But not everything we would like – answers, unfortunately, are not absolute. As expected, they are expressed in terms of reach in BSM energy/mass scale (and some extra parameters)

Next step: condense detailed reviews into a super-short summary

- And document the (much) longer story behind the Super Short Summary; suggestions welcome.

Electroweak Physics (physics of the W, Z, H bosons, of the top quark, and QED)



Keith Ellis and ***Beate Heinemann***

What else do we learn from Higgs?

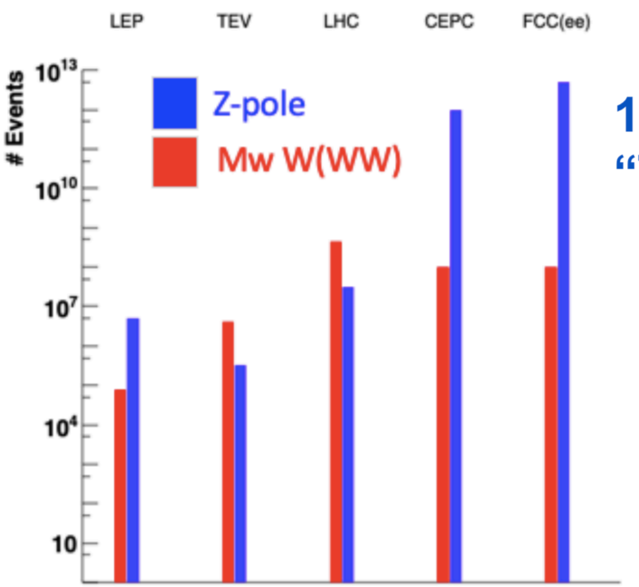
Question	κ_V	κ_3	κ_g	κ_γ	λ_{hhh}	σ_{hZ}	$\mathrm{BR}_{\mathrm{inv}}$	$\mathrm{BR}_{\mathrm{und}}$	κ_ℓ	μ_{4f}	$\mathrm{BR}_{\tau\mu}$	Γ_h
Is h Alone?	+	+			+	+				+		+
Is h elementary?	+	+	+	+		+						
Why $m_h^2 \ll m_{\mathrm{Pl}}^2$?	+	+					+	+		+		+
1st order EWPT?			+	+	+	+				+		
CPV?		+(CP)										
Light singlets?							+	+	+	+		+
Flavor puzzles?		+							+		+	

BH, Y. Nir, arXiv:1905.00382

Many problems of particle physics today relate to Higgs observables

Electroweak Physics

Electroweak Observables at Future Colliders



10^{12} Z's
"Tera-Z"

M. Lancaster

ILC:

- "Giga-Z" running not part of baseline but maybe later

Precision EWK Observables

Submission Inputs: 29, 145, 101, 132, 135

EWPO	Current	CEPC	FCC (ee)
M_Z [MeV]	2.1	0.5	0.1
Γ_Z [MeV]	2.1	0.5	0.1
N_ν [%]	1.7	0.05	0.03
M_W [MeV]	12	1	0.67
$A_{FB}^{0,b}$ [x10^4]	16	1	< 1
$\sin^2\theta_W^{\rm eff}$ [x10^5]	16	1	0.6
R_b^0 [x10^5]	66	4	2–6
R_μ^0 [x10^5]	2500	200	100

LHeC can measure $\sin^2\theta_W$ as f(E).

LHeC : Mw to 10 MeV but can measure PDFs allowing HL-LHC to half PDF uncertainty and achieve O(5 MeV) Mw.
ILC/CLIC : Mw to 5 MeV similar to HL-LHC/TeV average.

Electroweak Physics

Answers to Big Questions

1. **How well can the Higgs boson couplings to fermions, gauge bosons and to itself be probed at current and future colliders?**
   - Current colliders: ~1-3% for 3rd gen fermions and gauge bosons, 4% to μ, 50% to itself
   - Future colliders: factors of ~2-10 better (!) + $\kappa_c \sim 2\%$ + model-independent $\sigma(ZH)$
2. **How do precision electroweak observables inform us about the Higgs boson properties and/or BSM physics?**
   - Important to make sure precision H measurements (δg_Z) not limited by these
   - Themselves probe new physics in interesting and complementary way
3. **What progress is needed in theoretical developments in QCD and EWK to fully capitalize on the experimental data?**
   - A lot of progress needed! Plan exists but lots of work/people needed!!
   - In some cases, new ideas are needed => and unclear when/if new ideas come
4. **What is the best path towards measuring the Higgs potential?**
   - Di-Higgs and single Higgs production are sensitive to derivative $d^3V/d^3\phi$ near minimum
   - Seems conceivable to determine it with sufficient precision to test 1st order EWΦT

Conclusions I

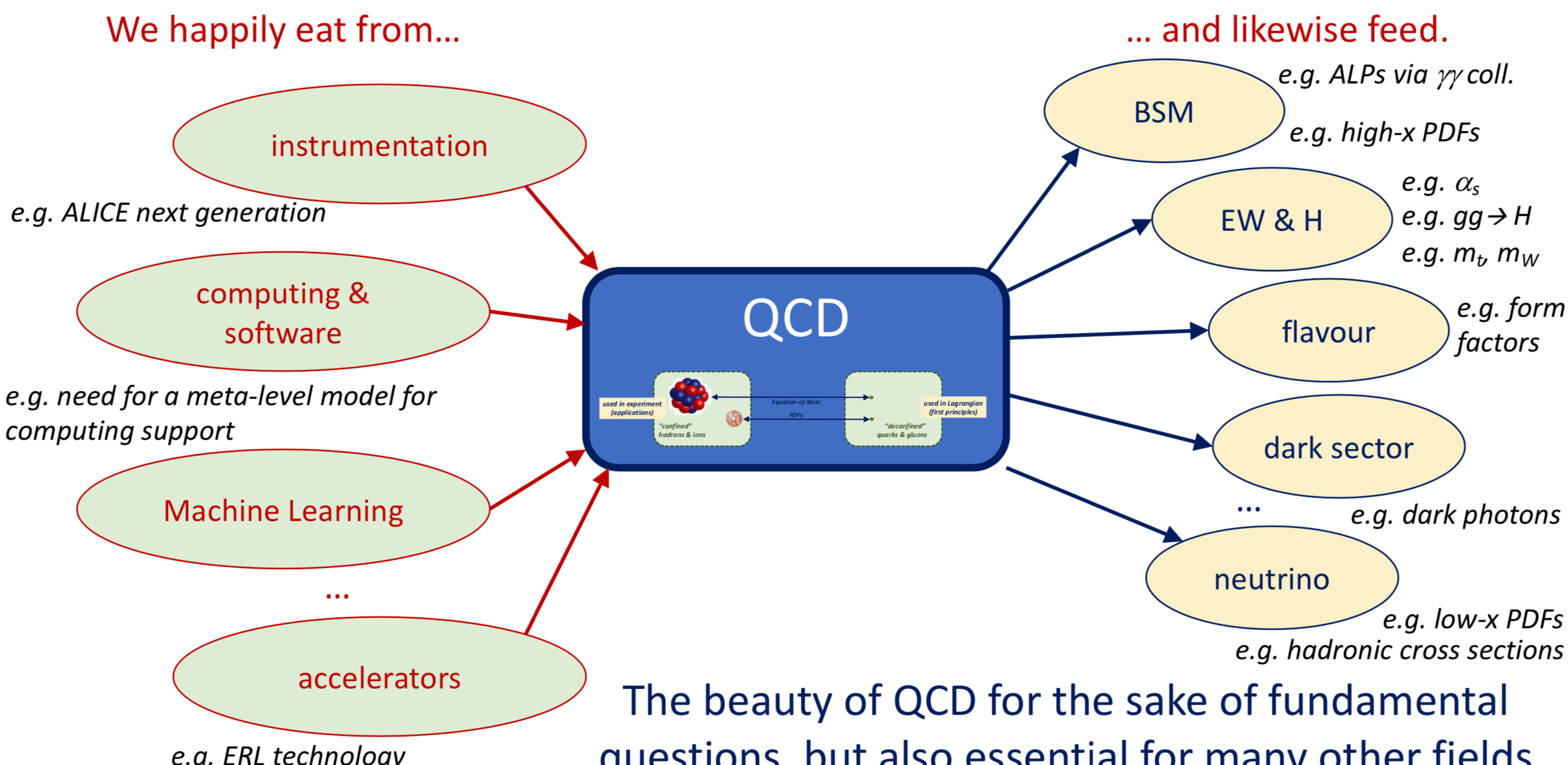
EW

1. **Measuring H coupling at the level of few% or better very interesting!!**
   - Naturalness vs simplicity tested: complementary to LHC direct searches
   - Many important questions are related to Higgs boson
2. **Significant advances in theory needed to exploit data from all (!) colliders**
3. **HL-LHC probes many H couplings to few % level**
   - Absolute values model dependent, ratios of couplings model-independent
4. **All ee colliders achieve major (and comparable) improvements in their first stage already in probing Higgs sector compared to HL-LHC:**
   - At least half of couplings get improved by factor 5 or more
   - W/Z effective couplings and $BR(H \rightarrow invisible)$ even probed to ~3x10^{-3}
   - Model-independent total cross section measurement => access to width, untagged BR
   - Clean environment to study H if/when anomalies are seen to understand underlying physics
5. **Higher energy stages of ee and hadron colliders important**
   - Excellent sensitivity to high-scale physics, e.g. CLIC3000 and FCC-hh
   - FCC-hh/eh improves rare Higgs couplings by large factor compared to FCC-ee
6. **Electroweak precision measurements important for Higgs programme and NP tests**
   - **Oblique parameters**
     - Circular colliders have naturally an extensive programme on EWPO at Z-pole => e.g. S and T, Γ_Z
     - CLIC at high energy and FCC-hh excellent reach on W and Y
   - **Precision top and W programme** important for EFT analysis and theor. Uncertainties
     - Top requires $\sqrt{s} \geq 350$ GeV
   - **Tera-Z programme** at FCC-ee (and potentially CEPC) impressive
     - Giga-Z programme at ILC (incl. polarisation) not part of baseline plan => needs follow-up
7. **Higgs self-coupling sensitivity interesting for electroweak phase transition:**
   - di-Higgs process probes κ_λ to 50% at HL-LHC => Improvements from HE-LHC (~15%), ILC$_{500}$ (~27%), CLIC$_{3000}$ (~9%), FCC-hh (~5%)
   - Single Higgs production also sensitive through loop effects
8. **A few other interesting submissions for non-collider/low-energy measurements:**
   - Not covered here but will include in briefing book

Strong Interactions

(perturbative and non-perturbative QCD, DIS, heavy ions)

***Jorgen D'Hondt** and Krzysztof Redlich*



The beauty of QCD for the sake of fundamental questions, but also essential for many other fields

Strong Interactions
(perturbative and non-perturbative QCD, DIS, heavy ions)

Principal Components for QCD

Hot & Dense QCD

A coherent and complementary "hot & dense QCD program" at the SPS brings valuable and unique contributions in the exploration of the QCD phase diagram.

An (HL-HE-)LHC/FCC based AA/pA/fixed-target program is unique and provides essential science at the frontline towards a profound understanding of particle physics.

Precision QCD

A globally concerted "precision QCD program" provides a unique avenue to find new physics that breaks the Standard Model.

A high-luminosity e^+e^- collider at the EW scale and a high-energy ep collider provide a unique environment for high-precision QCD, essential for most of our aspirations in particle physics.

Partonic Structure

A "hadronic structure program" exploring the complementarity of ep/pp/eA colliders provides vital ingredients for the high precision exploration in searches for new physics and as well steps into uniquely unknown territories of QCD.

Theory

It is vital to support coherently the QCD theory community to succeed in all these programs and to link QCD to the rest of the particle physics research program, especially for our HL-LHC exploration.

Organization

Strengthening the synergies in research and technology with adjacent fields will reinforce our efforts.

Global platforms, networks and institutes have the potential to enhance the research exchange among experts worldwide and to provide essential training opportunities.

Instrumentation and Computing

Xinchou Lou and ***Brigitte Vachon***

"Big questions"

European Strategy Update

Instrumentation:

(a) What **areas of instrumentation R&D** should be supported, and how, in order to meet the needs of future experimental programs?

(b) How to preserve knowledge, technical expertise and train the future generation of experts in detector R&D?

Computing:

(a) How should **HEP computing evolve** in order to support future scientific programs and their specific needs?

(b) What **R&D activities** must be supported, and how, in order to enable this computing evolution?

- **Training**
- **Career recognition & opportunities**
- **Industry**
- **R&D needs**

strong support

Instrumentation and Computing

General comments
common to both instrumentation and computing themes

European Strategy Update

- General opinion that R&D should not be centralized exclusively in large-scale facilities and/or in major labs.
- Current R&D collaborations (eg. RDx, AIDA2020, CALICE,etc.) seen to be effective models of collaboration.
  - Conduit to facilitate constructive exchange of information/expertise
  - Effective framework to share resources.
  - Coordinate work to limit duplication of efforts
  - Support wide dissemination and growth of knowledge
  - Excellent training environment
  - Provide door to industry relations
- Need support to strengthen R&D consortia - and establish new ones - while preserving expertise and working relationships
  - Essential to maintain/establish strong links between future project studies (FCC, LC) and ongoing or planned upgrades
  - Evolve common views on goals and feasibilities
  - **Importance of international and independent review processes**, in addition to experimental collaboration-internal procedures, for recognition by national funding agencies

Instrumentation and Computing

General comments

common to both instrumentation and computing themes

European Strategy Update

- Provide opportunities to build on, and benefit from, synergies with non-HEP and industry (e.g. through technology-centered R&D platforms across disciplines providing)
  - Pathway to tech transfer opportunities between fields (e.g. DarkSide use of ProtoDune cryostat, common computing/software tools)
  - Opportunity for developing industry partnership (non-trivial but necessary), and tech transfer (bringing fundamental research closer to the needs of the whole of society)
  - Multi-disciplinary approach could also address better exchange of the human capital and open up career opportunities.
  - Stimulating environment for new blue-sky ideas/development
  - Provide centralized source of information on ongoing activities to other fields and industry.

extras

A linear collider as part of an overall strategy?

2020 to ~2045	Goal	Status ~2035-45	Options open ~2040-50 →
2020 - 2038 LHC/HL-LHC	- on-going -	Programme completed	Could be extended
2020 - ~2035 construction 2035-2045 operation • CLIC or ILC	Fast access to a high quality e+e- data, at the lowest possible cost (at ~LHC scale). The scientific case is well established. Build in capabilities for higher energies and new technologies.	Physics guidance from HL, LC stage 1 and PBC (and others) Technical experience for LC stage 1	Possibilities: continue running at same or increased energy, use same/improved technology or introduce NAT
Develop hadron and muon machines towards construction readiness in 2030-2040 range	R&D for future machine with a timeline 10-20 years (mainly HF magnets and pp designs, and muon machine studies and designs)	Physics guidance from HL, LC stage 1 and PBC (and others) HF magnet R&D progress, hadron machine design options, muon TDR	Aim to put proton (FCC type or more modest) and/or muon machines into operation
Develop NAT technologies for LC colliders	R&D for much higher energy LCs (and linear accelerators in general), similar timeline	Possibly TDR for use in a LC facility	Around 2040-50: Introduce these technologies – if available – in LC facility (line above)
"Physics Beyond Collider" (PBC) projects	Cover (among others) light dark matter searches		Continue ?
Other projects – CEPC among them	…	Progress	…

Operational physics facilities

Blue: Ring based facility, Red: Linear facility

s.c. magnet technology

- Nb_3Sn superconducting magnet technology for hadron colliders, still requires **step-by-step** development to reach **14, 15, and 16 T**.
- It would require the following **time-line** (in my personal view):
  - **Nb_3Sn, 12~14 T:** 5~10 years for short-model R&D, and the following 5~10 years for prototype/pre-series with industry. It will result in **10 – 20 yrs** for the construction to start,
  - **Nb_3Sn, 14~16 T:** 10-15 years for short-model R&D, and the following 10 ~ 15 years for protype/pre-series with industry. It will result in **20 – 30 yrs** for the construction to start, (consistently to the FCC-integral time line).
  - **NbTi , 8~9 T:** proven by LHC and **Nb_3Sn, 10 ~ 11 T** being demonstrated. It may be feasible for the construction to begin in > ~ 5 years.
- **Continuing R&D effort** for high-field magnet, present to future, should be critically **important**, to realize highest energy frontier hadron accelerators in future.

A. Yamamoto, 190512b

Intensify HTS accelerator magnet development

Technical Challenges in Energy-Frontier Colliders proposed

		Ref.	E (CM) [TeV]	Luminosity [1E34]	AC-Power [MW]	Cost-estimate Value* [Billion]	B [T]	E: [MV/m] (GHz)	Major Challenges in Technology
CChh	FCC-hh	CDR	~ 100	< 30	580	24 or +17 (aft. ee) [BCHF]	~ 16		High-field SC magnet (SCM) - Nb3Sn: Jc and Mechanical stress Energy management
	SPPC	(to be filled)	75 – 120	TBD	TBD	TBD	12 - 24		High-field SCM - IBS: Jcc and mech. stress Energy management
CCee	FCC-ee	CDR	0.18 - 0.37	460 – 31	260 – 350	10.5 +1.1 [BCHF]		10 – 20 (0.4 - 0.8)	High-Q SRF cavity at < GHz, Nb Thin-film Coating Synchrotron Radiation constraint Energy efficiency (RF efficiency)
	CEPC	CDR	0.046 - 0.24 (0.37)	32~ 5	150 – 270	5 [B$]		20 – (40) (0.65)	High-Q SRF cavity at < GHz, LG Nb-bulk/Thin-film Synchrotron Radiation constraint High-precision Low-field magnet
LCee	ILC	TDR update	0.25 (-1)	1.35 (– 4.9)	129 (– 300)	4.8- 5.3 (for 0.25 TeV) [BILCU]		31.5 – (45) (1.3)	High-G and high-Q SRF cavity at GHz, Nb-bulk Higher-G for future upgrade Nano-beam stability, e+ source, beam dump
	CLIC	CDR	0.38 (- 3)	1.5 (- 6)	160 (- 580)	5.9 (for 0.38 TeV) [BCHF]		72 – 100 (12)	Large-scale production of Acc. Structure Two-beam acceleration in a prototype scale Precise alignment and stabilization. timing

A. Yamamoto, 190513b

*Cost estimates are commonly for "**Value**" (material) only.

Expect Shortage of Expert Accelerator Workforce

- *"Oide Principle"* :

  1 Accelerator Expert

  can spend intelligently

  (only) ~1 M$ a year
- + it takes significant time to get the team together (XFEL, ESS)
- Scale of the team: 10B$/10 years=1 B$/yr → need

  1000 experts ← world's total now ~4500

K.Oide (KEK)

Current initiatives of coordinated programs: EuPRAXIA, ALEGRO, AWAKE.

EuPRAXIA

Horizon 2020 EU design study funded in 2015.
Deliverable: Conceptual Design Report by Oct 2019

The EuPRAXIA Strategy for Accelerator Innovation:
The accelerator and application demonstration facility EuPRAXIA is the required intermediate step between proof of principle and production facility.

ALEGRO

Advanced LinEar collider study GROup, ALEGRO: formed at initiative of the ICFA ANA panel in 2017.

Mission of the ALEGRO community:

- **Foster and trigger Advanced Linear Collider related activities** for applications of high-energy physics.
- **Provide a framework** to amplify international coordination, broaden the community, involving accelerator labs/institutes
- **Identify topics requiring intensive R&D and facilities**.

Goal:

- Long-term design of a e^+/e^-/gamma collider with up to 30 TeV: the **Advanced Linear International Collider (ALIC)**
- **Construction of dedicated Advanced and Novel Accelerators (ANA) facilities** are needed over the next 5 to 10 years in order to reliably deliver high-quality, multi-GeV electron beams from a small number of stages.
  - Today: Existing facilities explore different advanced and novel accelerator concepts and are proof-of-principle experiments.

Fermilab and J-PARC: Proton Beam Power on ν Target