European Strategy Update

European Particle Physics Strategy Update

Brigitte Vachon
McGill University

Lepton-Photon 2019
10th August 2019

What is the EPPSU?

- Every ~ 7 years, the European particle physics community reviews and updates the priorities and strategy of the field.
  - Bottom-up process involving the community.
  - Strategy driven by physics, taking into account technical and financial feasibility.

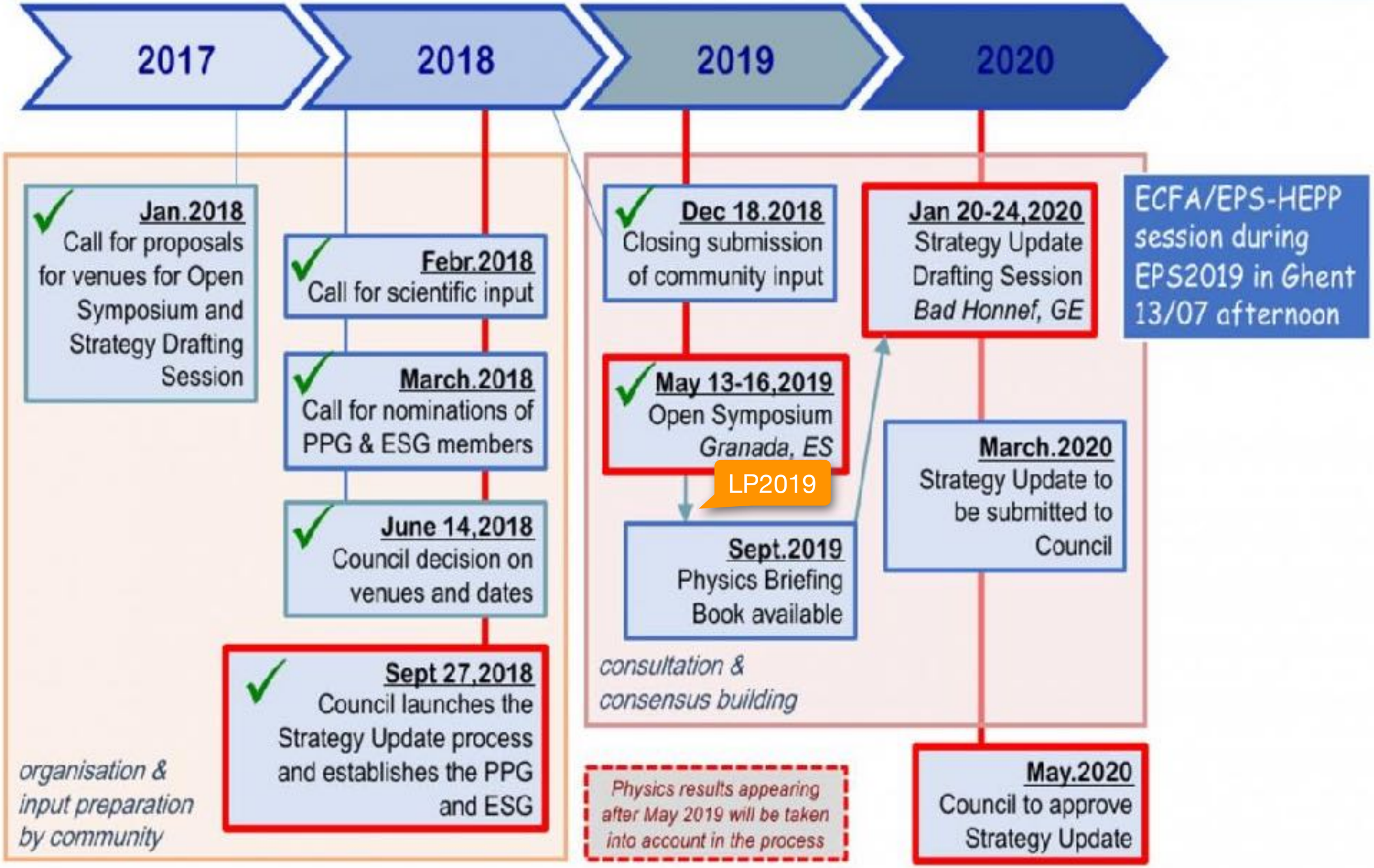
2006 First EPPS → 2013 First Update → 2020 Next Update

EPPSU organization

- Strategy Update adopted by **CERN Council**.
- Strategy Update document drafted by **European Strategy Group (ESG)**.
- Scientific input to the Strategy Update prepared by the **Physics Preparatory Group (PPG)**.
  - Processing of submitted community inputs
  - Open Symposium
  - Preparation of Briefing Book
- Strategy Update process coordinated by the **Strategy Update Secretariat (SUS)**.

The composition of each group can be found in the backup slides.

EPPSU 2020 Process



Scientific Input to EPPSU

- Call for community inputs issued in February 28, 2018 with deadline for submission set for December 18, 2018.
- 160 written submissions received (LINK).

Track ID	Granada sessions	# inputs	Description	Conveners	
1		40	Large experiments and projects	PPG	
2		42	National road maps	ESG	
11		22	Other (communication, outreach, strategy process, technology transfer, individual contributions,...)	ESG	
7	B1	21	Electroweak physics (physics of the W, Z, H bosons, of the top quark, and QED)	Keith Ellis	Beate Heinemann
8	B2	27	Flavour Physics and CP violation (quarks, charged leptons and rare processes)	Belen Gavela	Antonio Zoccoli
5	B3	25	Dark matter and dark sector (accelerator and non-accelerator dark matter, dark photons, hidden sector, axions)	Marcela Carena	Shoji Asai
3	B4	51	Accelerator Science and Technology	Caterina Biscari	Lenny Rivkin
4	B5	20	Beyond the Standard Model at colliders (present and future)	Gian Giudice	Paris Sphicas
10	B6	31	Strong interactions (perturbative and non-perturbative QCD, DIS, heavy ions)	Krzysztof Redlich	Jorgen D'Hondt
9	B7	27	Neutrino physics (accelerator and non-accelerator)	Stan Bentvelsen	Marco Zito
6	B8	35	Instrumentation and computing	Xinchou Lou	Brigitte Vachon

- Open Symposium organized based on written inputs.

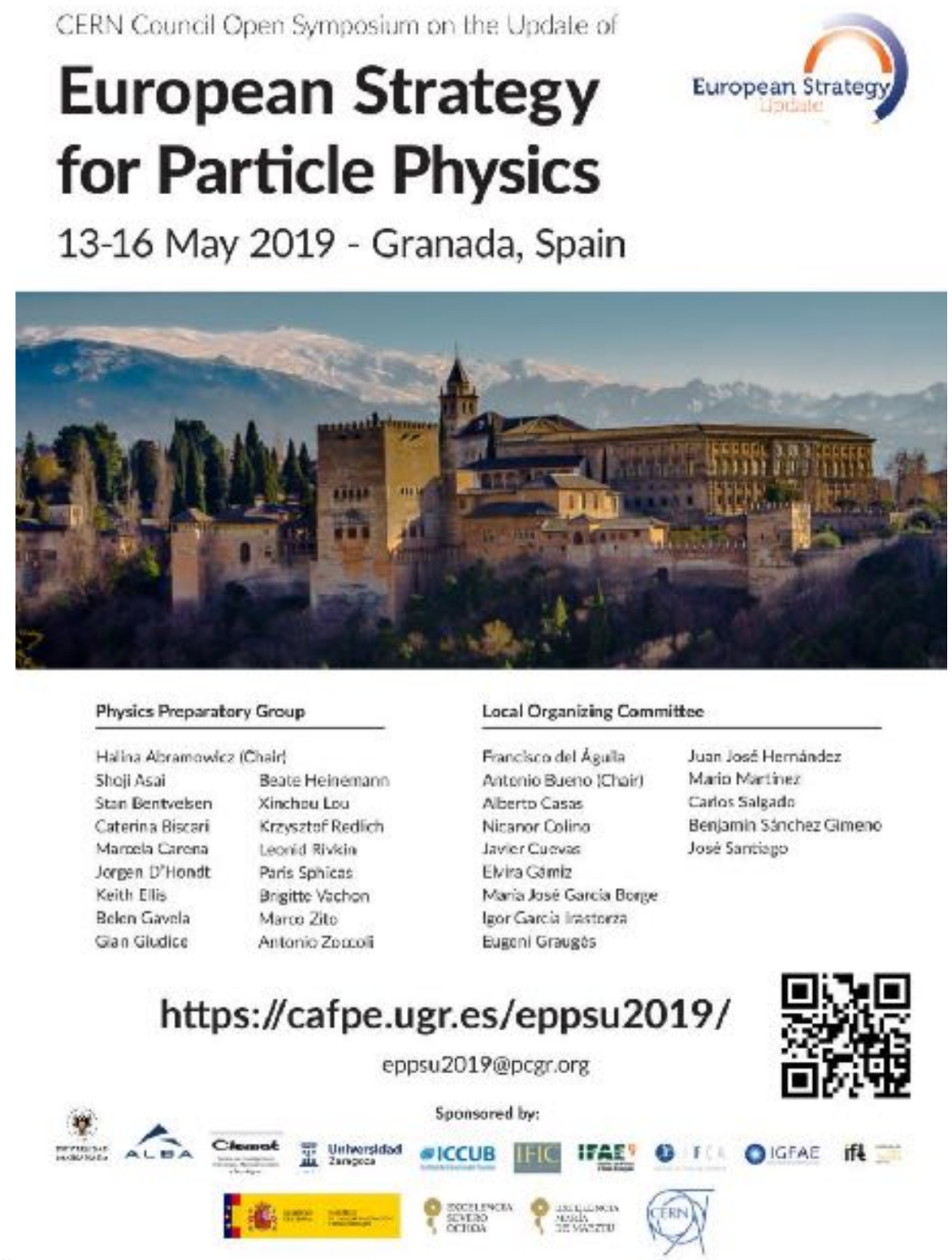
Open Symposium

- Symposium consisted in both parallel and plenary sessions, organized and convened by members of PPG.

- Parallel sessions were organized around 8 different themes:
  - Accelerator science and technology
  - Instrumentation and computing
  - Electroweak physics
  - Strong interactions
  - Neutrino physics
  - Beyond Standard Model at colliders
  - Dark matter and dark sector
  - Flavour physics and CP violation

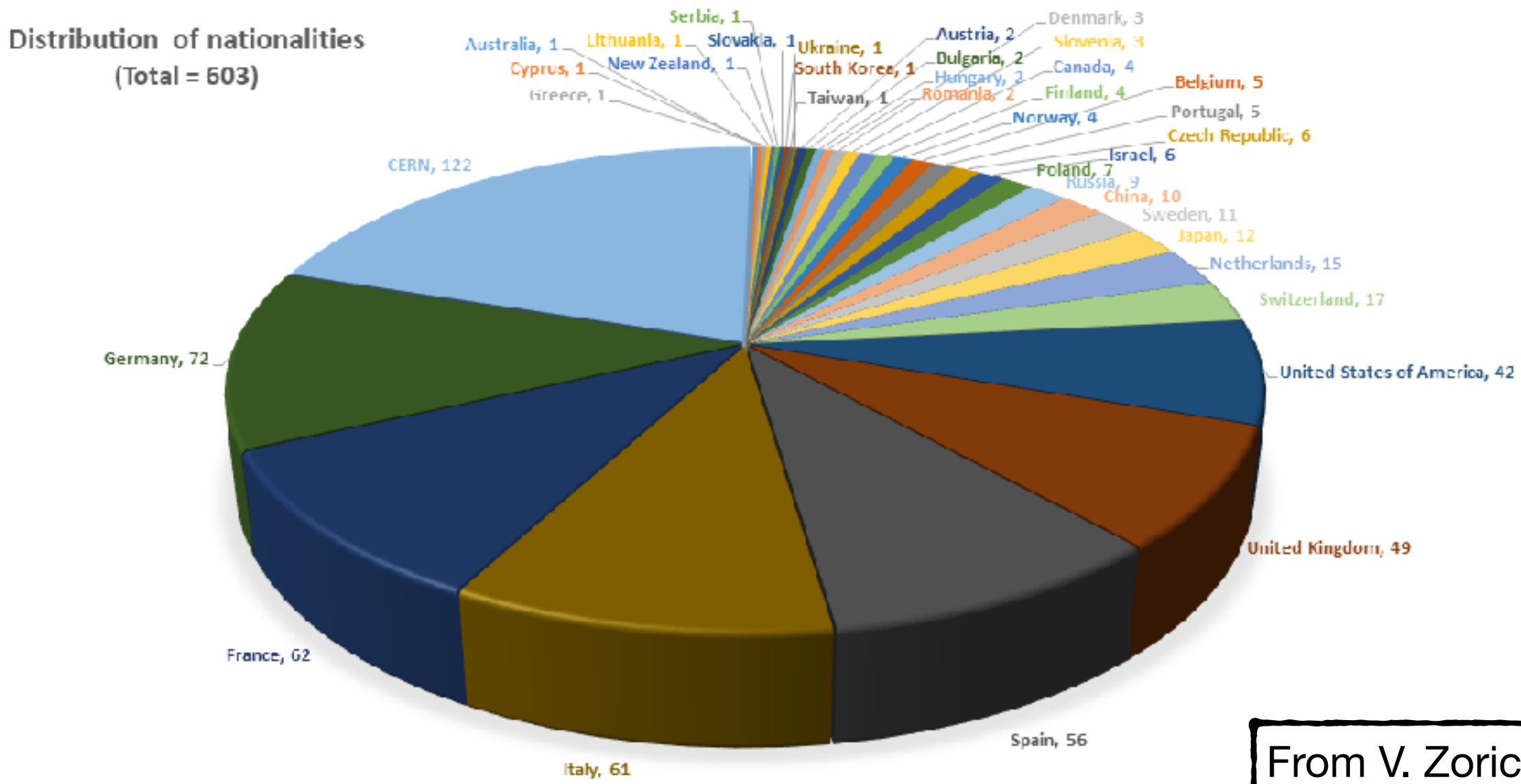
- Plenary sessions:
  - Current status of the field and where we stand.
  - Perspectives from different communities.
  - Summaries from parallel sessions.

- Symposium schedule designed to provide sufficient time for detailed discussion.



Open Symposium Participation

- Total of **603 participants**.
- **12%** of participants from outside Europe.
- Outstanding organization and presentations.
  - Thank you to all organizers, contributors and participants.



From V. Zorica

Open Symposium Highlights

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Implementation of the 2013 EPPSU (F. Gianotti)

- Run 2 completed successfully, with accelerators, detectors and computing performance exceeding expectations.
- HL-LHC approved by CERN Council June 2016.
- Design studies and accelerator R&D: CLIC, FCC, superconducting magnets R&D, AWAKE, etc.
- CERN Neutrino platform established in 2014.
- Physics Beyond Colliders Study group set up in 2016 to explore compelling projects complementary to high-energy colliders.
- New project for education of the general public started in 2018: Science Gateway.

F. Gianotti

2013 update of ESPP provided 17 "recommendations":

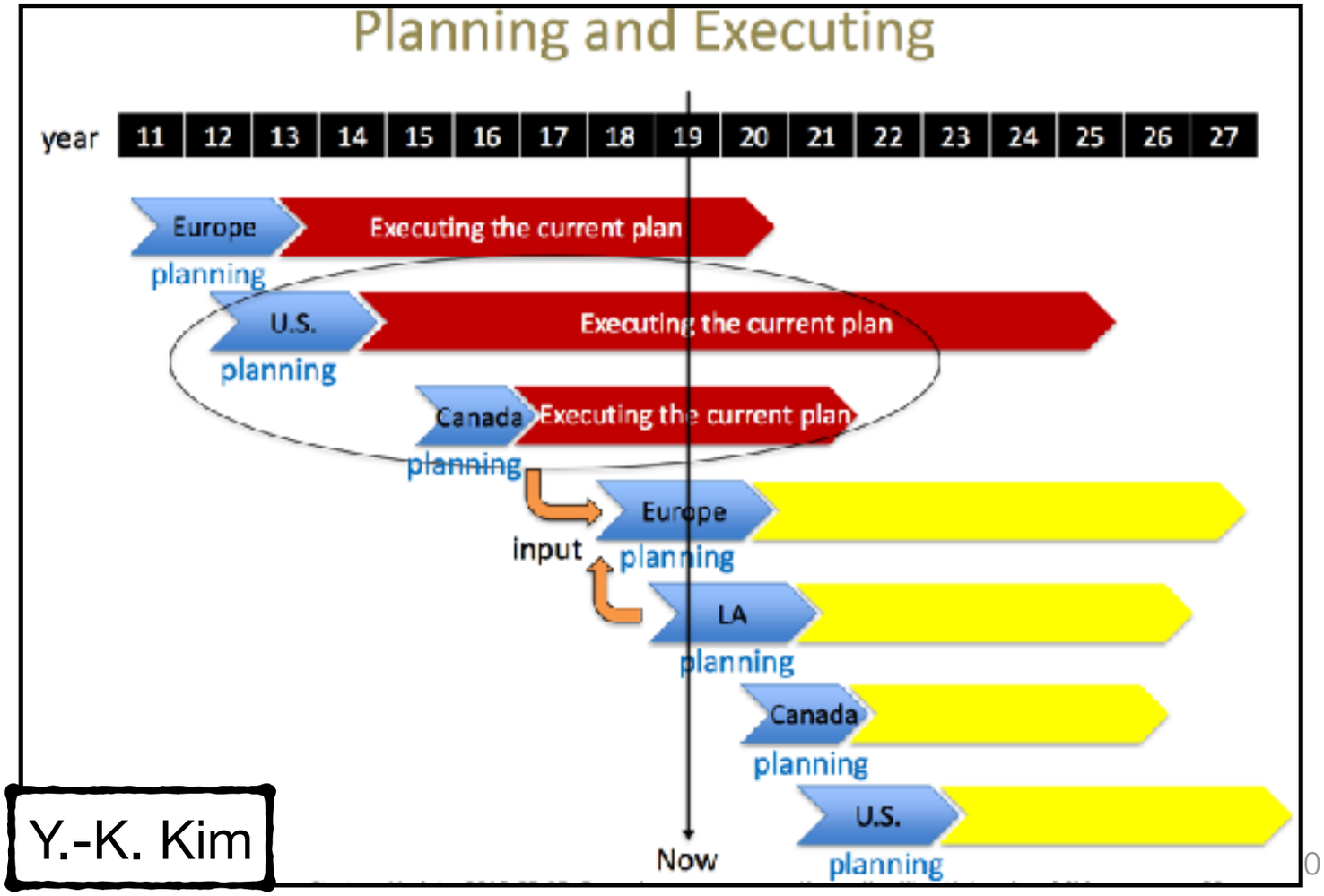
2 : General issues
4 : High-priority large-scale scientific projects
5 : Other essential scientific activities
3 : Organisational issues
3 : Wider impact on society

F. Gianotti

Open Symposium Highlights

Perspectives on the European Strategy Update from the Americas (Y.-K. Kim)

- Support from EPPSU plays an important role for success of facilities outside of Europe that serves the European / worldwide community.
- American community
  - will continue with its strong partnership with Europe.
  - would like to see steps taken toward a new collider.



Y.-K. Kim

"The worldwide particle physics community can together address the full breadth of the field's most urgent scientific questions with each major player hosting a unique world-class facility at home and partnering in high-priority facilities hosted elsewhere."

[Y.-K. Kim]

Open Symposium Highlights

European Strategy Update

Our physics landscape today:

- Higgs properties SM-like.
- Neutrinos have masses – not acquired in the SM.
- No (additional) signs of BSM physics.
- Compelling evidence for the existence of dark matter in the Universe with no candidate particle(s) in the SM.
- Prevalence of matter over anti-matter.

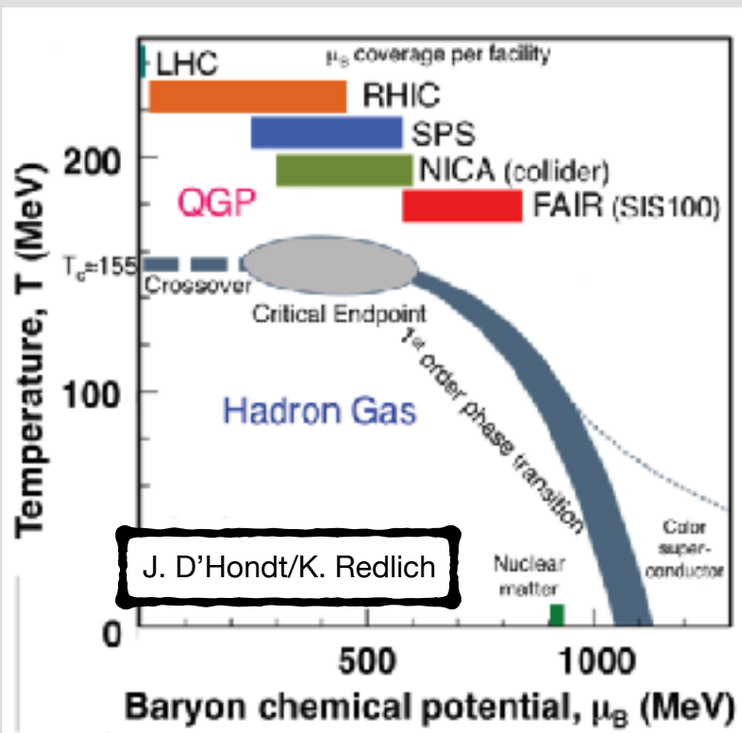
The particle physics community is engaged in a rich and diverse research program to address these puzzles.

Strong interactions

European Strategy Update

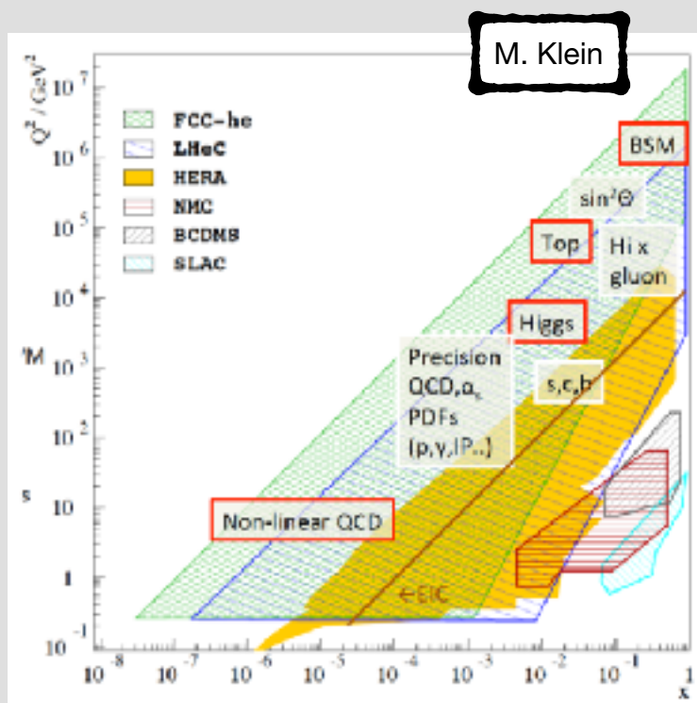
α_s (Q^2 low) ~ 1 → α_s (Q^2 high) ≪ 1

Hot and Dense QCD

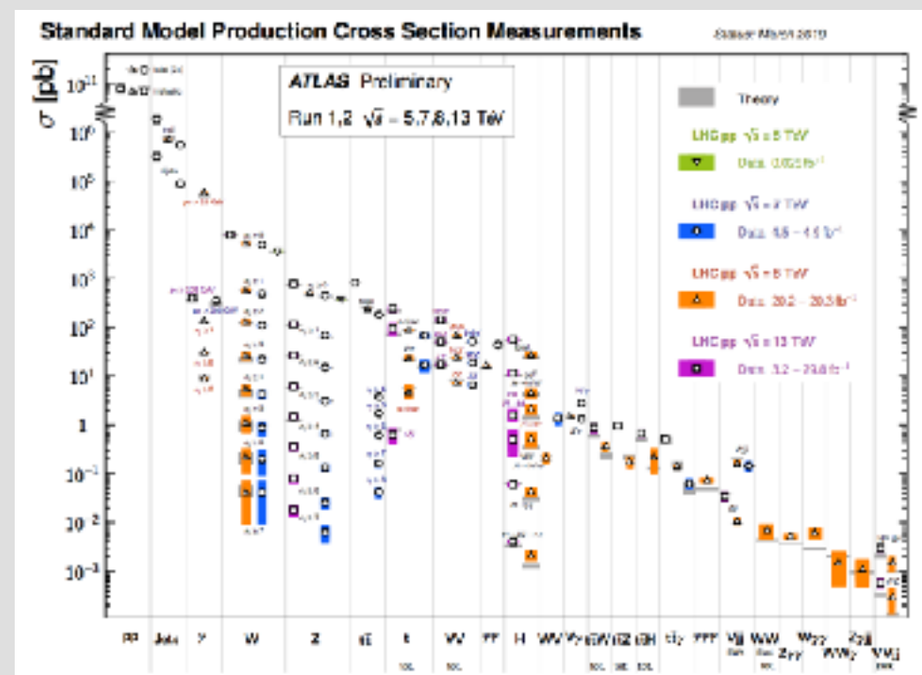


J. D'Hondt/K. Redlich

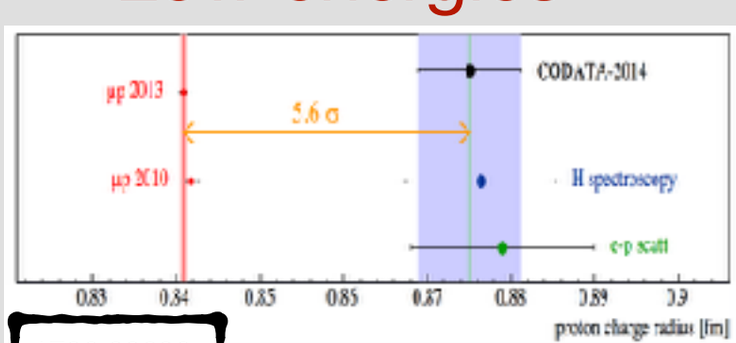
Partonic Structure



Precision QCD



Low energies



1706.00696

Neutrino

BSM

.....

EW & H

Dark sector

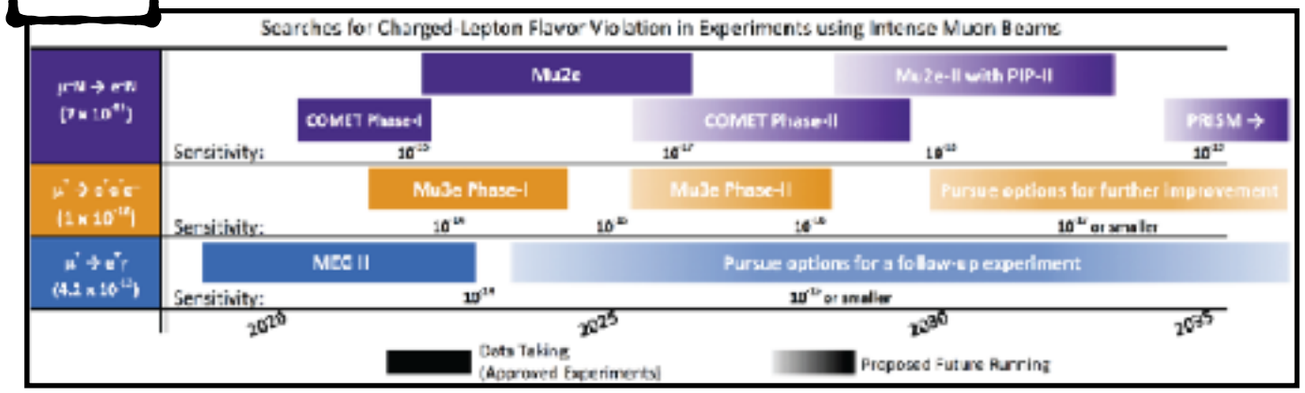
Flavour

Flavour and CP violation

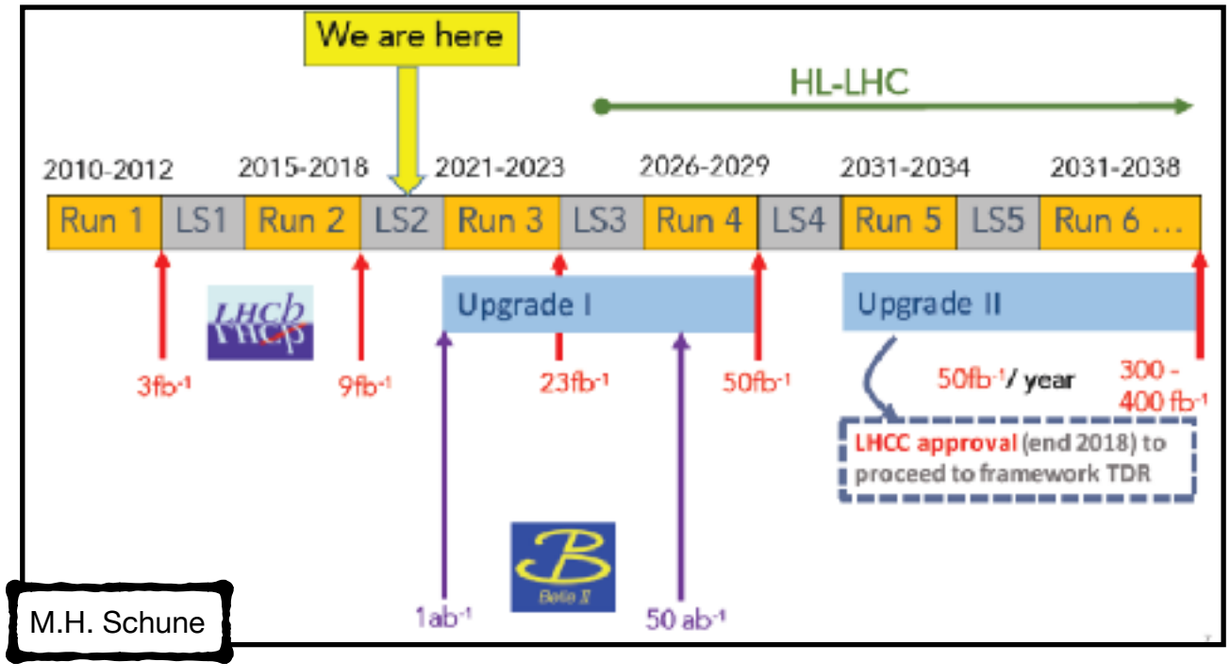
- Study of rare/forbidden reactions in SM.
  - Origin of weak CP and matter-antimatter asymmetry, flavour puzzle (quarks, charged leptons, neutrinos), strong CP problem.
- Outstanding BSM sensitivity: $\Lambda > 10^2$ - 10^5 TeV
- Synergy and complementarity between low-energy precision and high-energy frontier experiments.

Charged LFV expts.

Y. Kuno

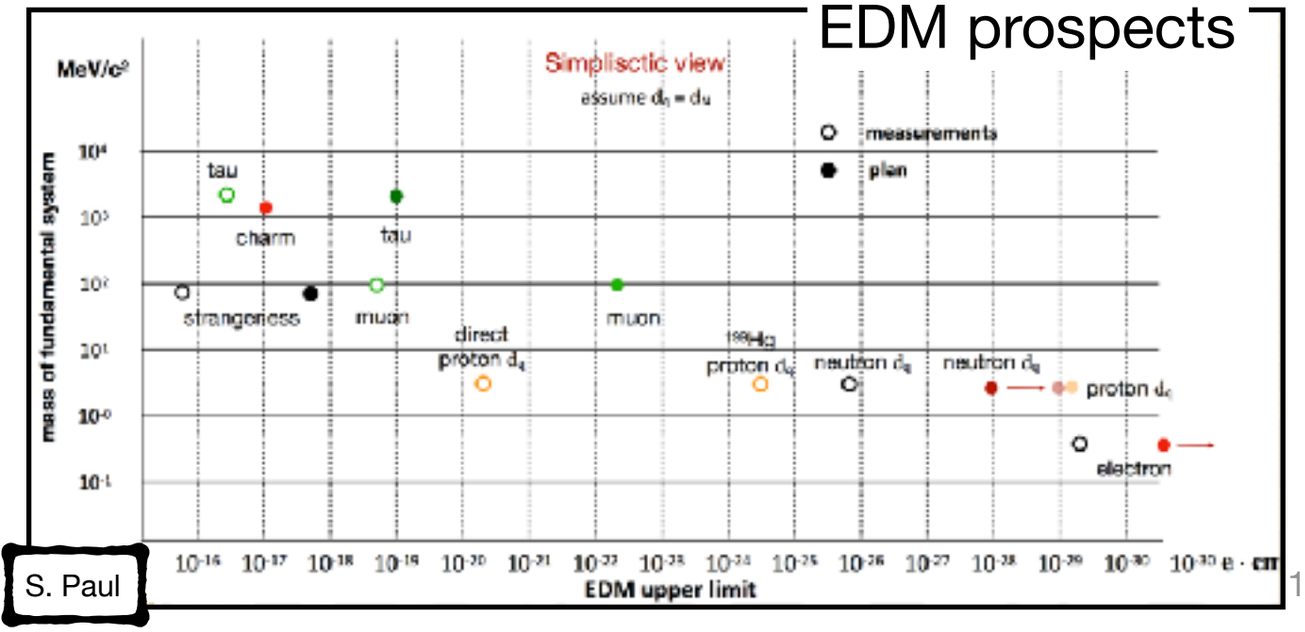


Exploring the b sector



M.H. Schune

EDM prospects

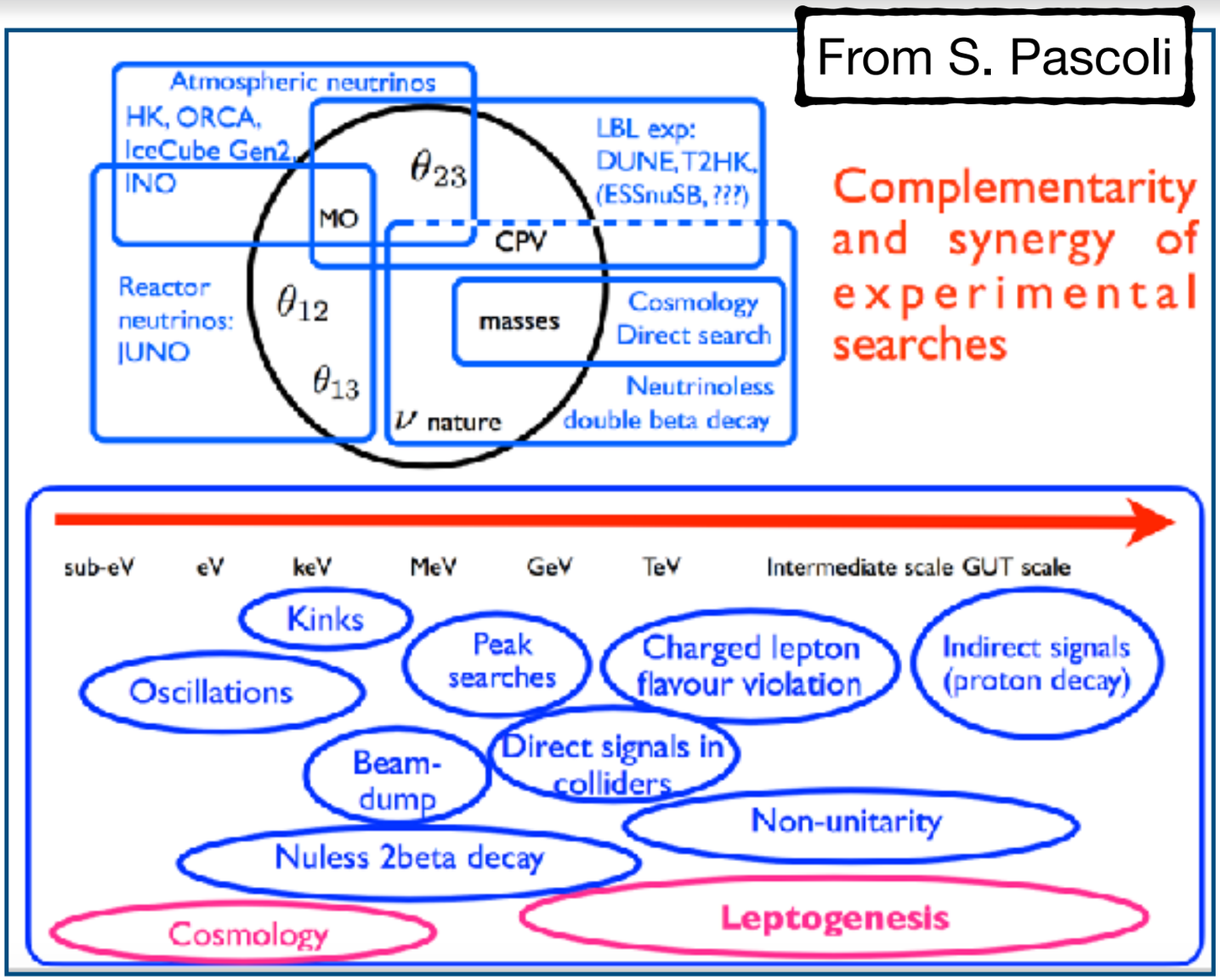


S. Paul

….kaons beams, LFV, CPV in charm, CPV in Higgs couplings, etc…

Neutrino and Astroparticle Physics

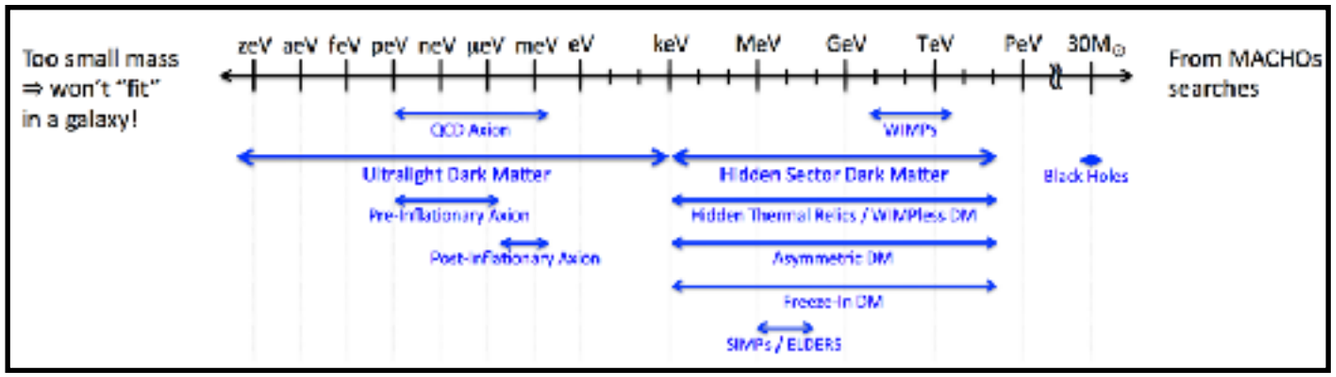
- Complementary window to search for BSM.
- Diverse experimental program.
- Very strong physics case for multimessenger physics, with a high impact on particle physics (e.g. DM, neutrino, GR, etc.)
  - Opportunity for particle physics community and labs to expand involvement.



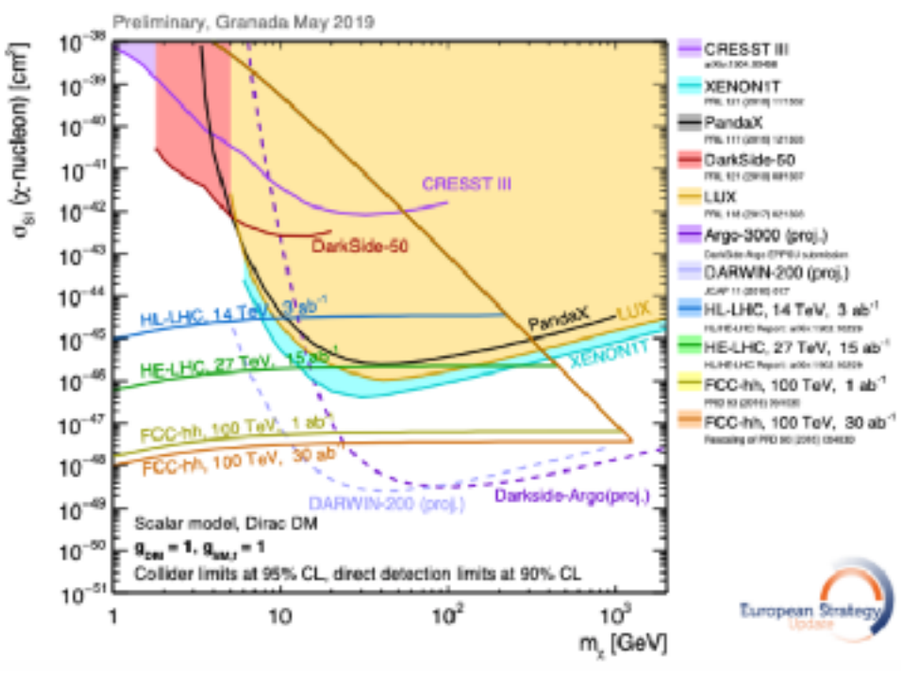
Dark Matter/Dark Sector

European Strategy Update

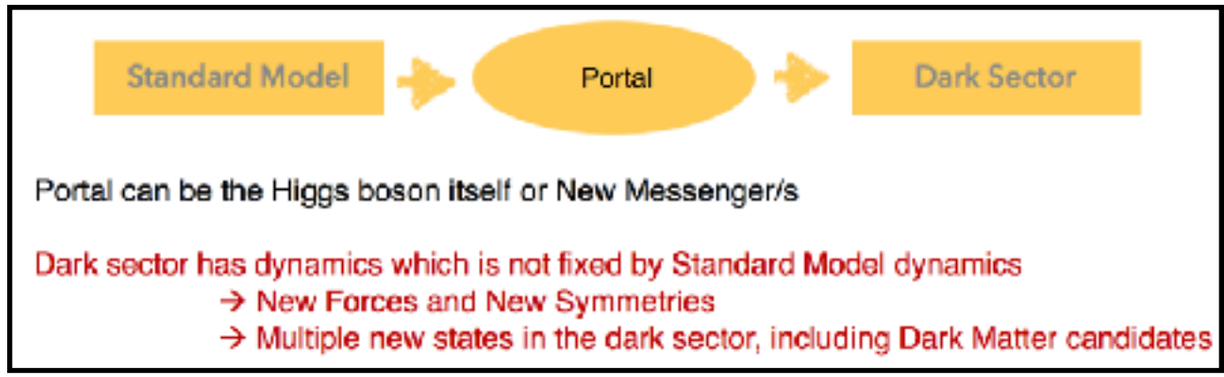
Dark Matter



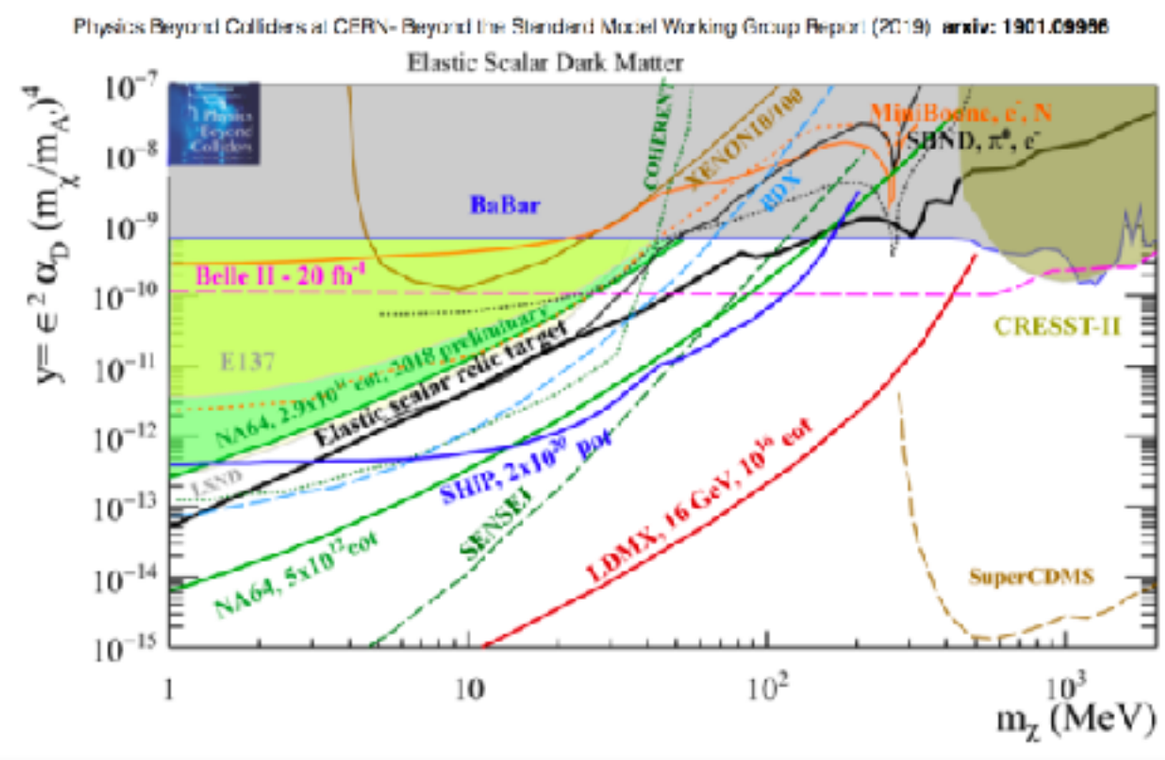
- Direct detection (underground expts, haloscopes, helioscopes)
- Direct production (colliders, fixed target, LSTW)
- Astrophysical probes (indirect searches, gravitational interactions, Galactic scale observables, etc.)



Dark Sector

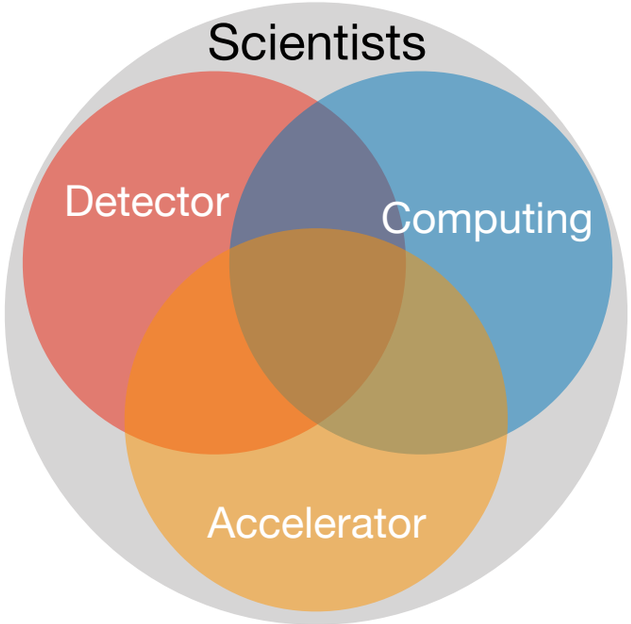


- Colliders
- Accelerator-based experiments (Beam dump, fixed targets)



$m_{A'} = 3m_\chi \quad \alpha_D = 0.1$

Open Symposium Highlights



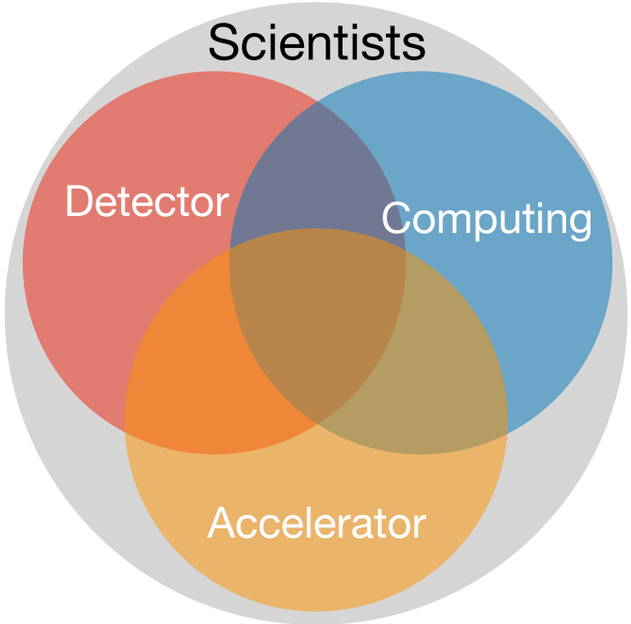
Open Symposium Highlights

European Strategy Update

Future experiments require **very challenging detector technologies**
Depending on the application:

- Much improved spatial resolutions (few μm per hit, low mass)
- Much improved time resolutions (down to ~10 ps per hit)
- High-performance photodetectors
- Very high tolerance to radiation
- Combined features in the same detector (5D imaging)
- Very large numbers of channels, very high readout speed
- Very large area coverage at low cost
- Accompanied with a large diversity of engineering challenges

From L. Linssen



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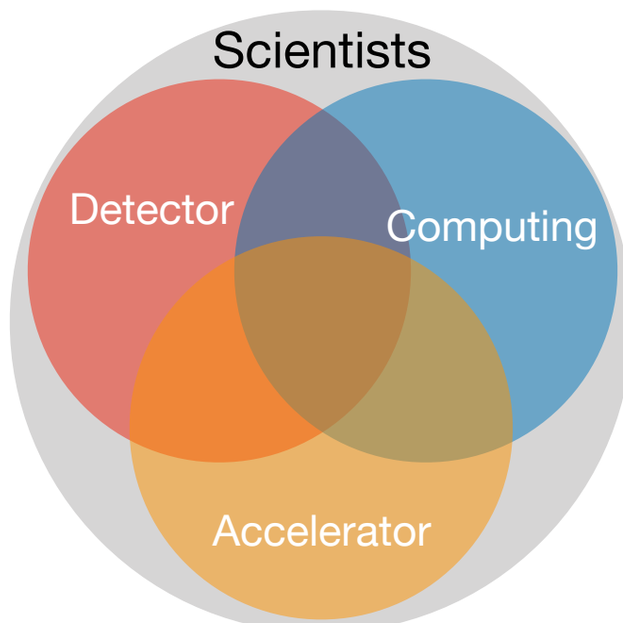

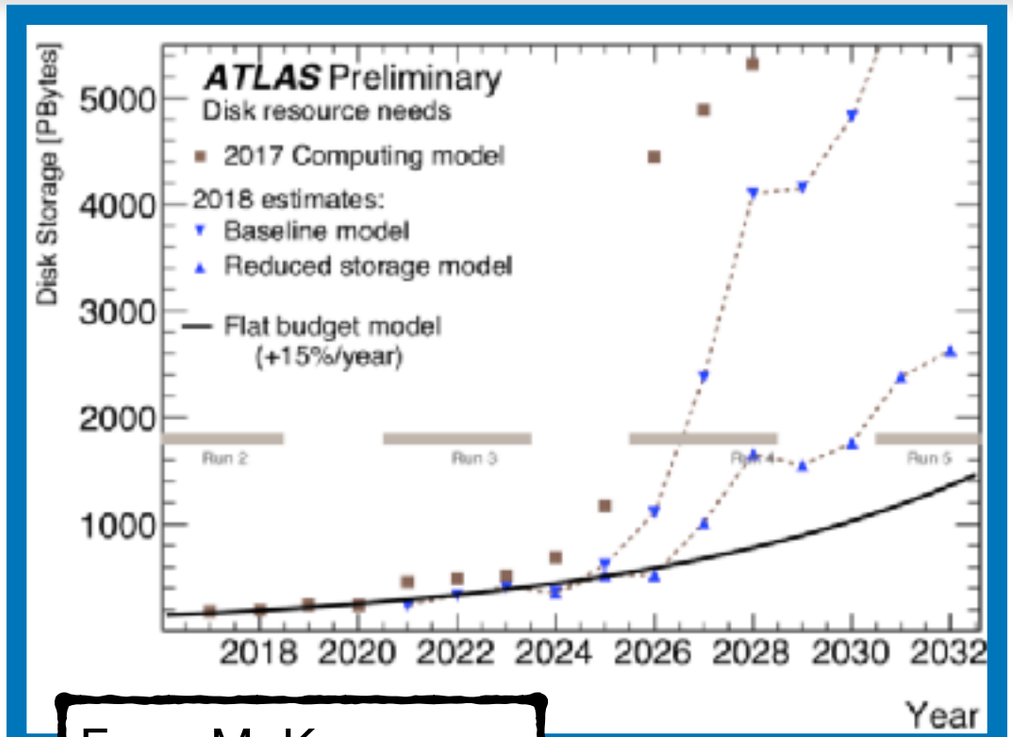

From M. Kasemann

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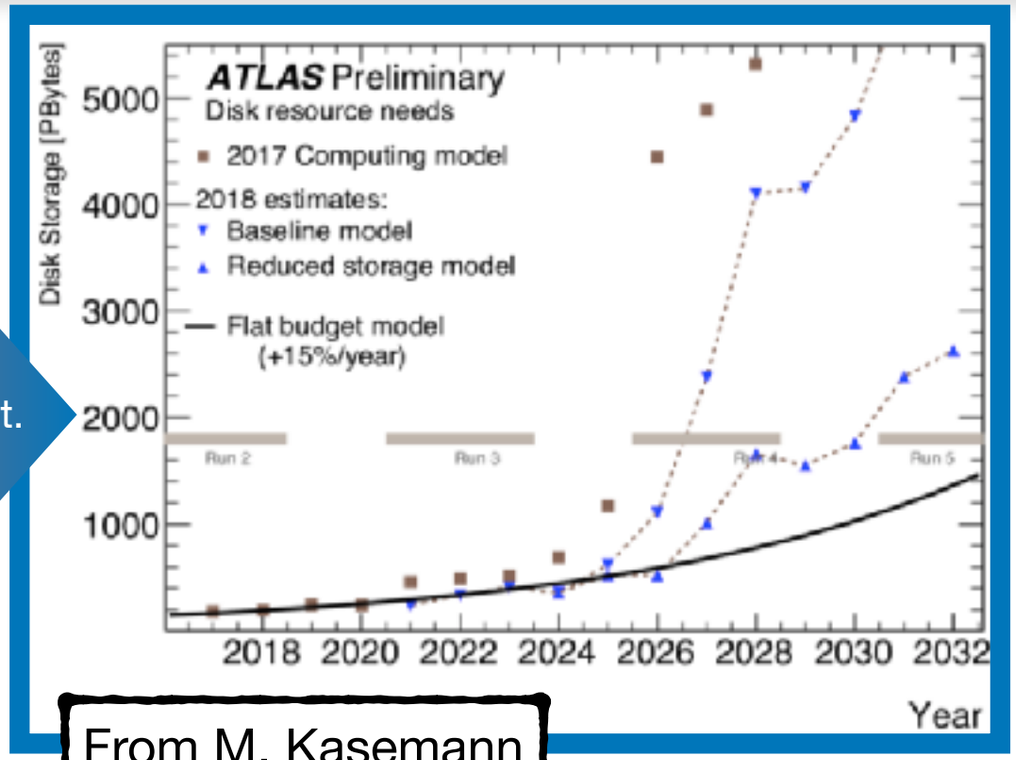
Need "holistic" approach to expt. design.



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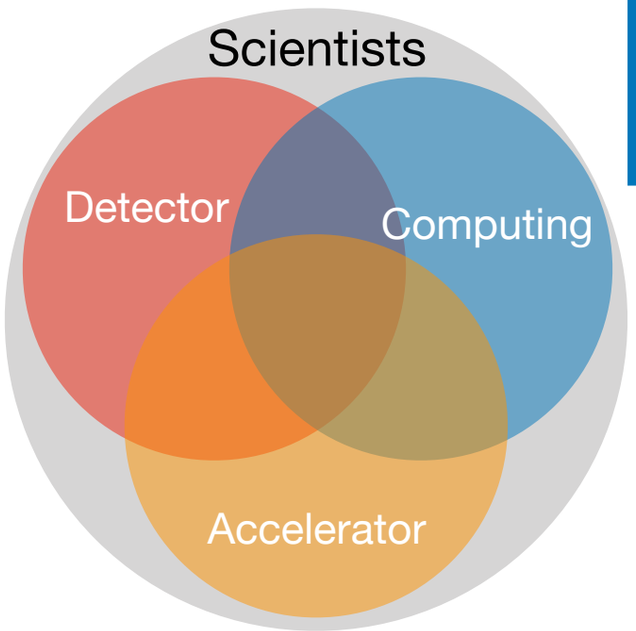

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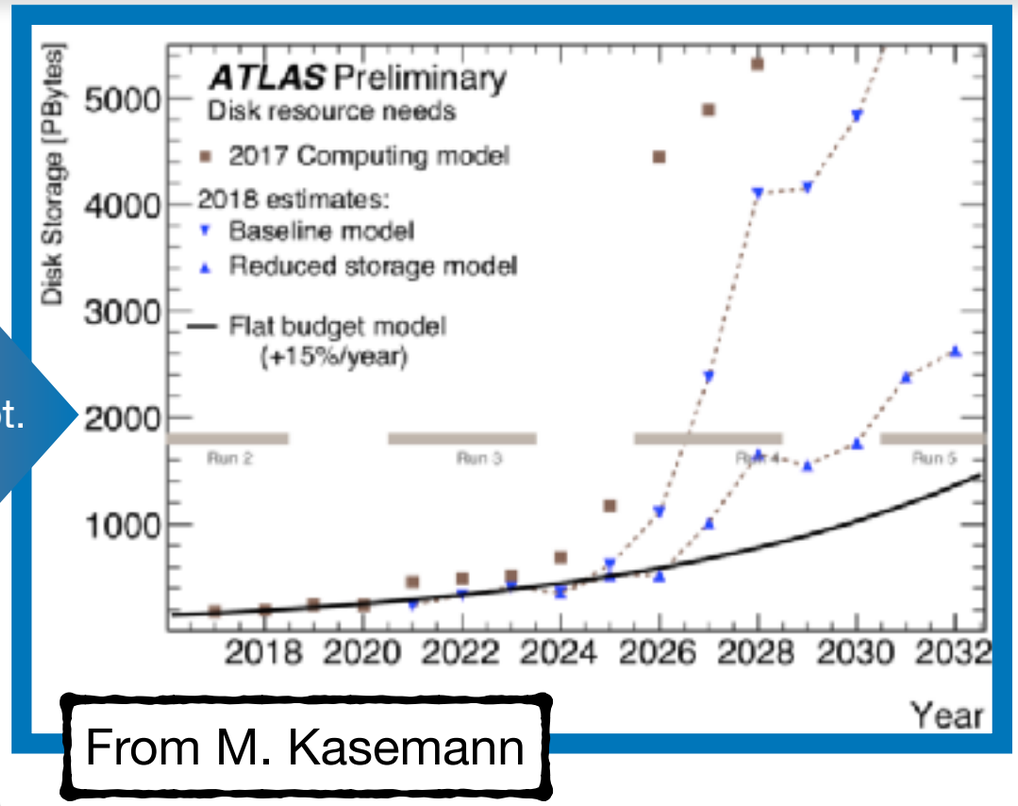

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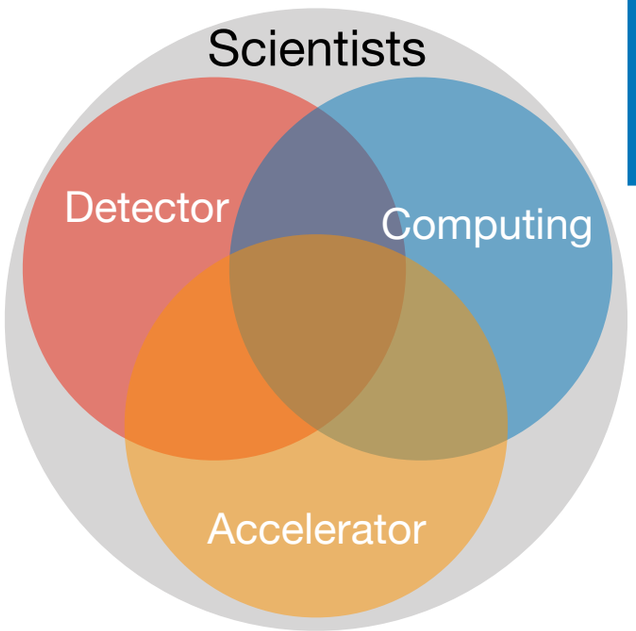

Crucial importance for the future of the field to address human factors:

- Recruitment of the most talented researchers (physicists and engineers).
- Training the next generation of experts.
- Career opportunities for detector/computing experts.

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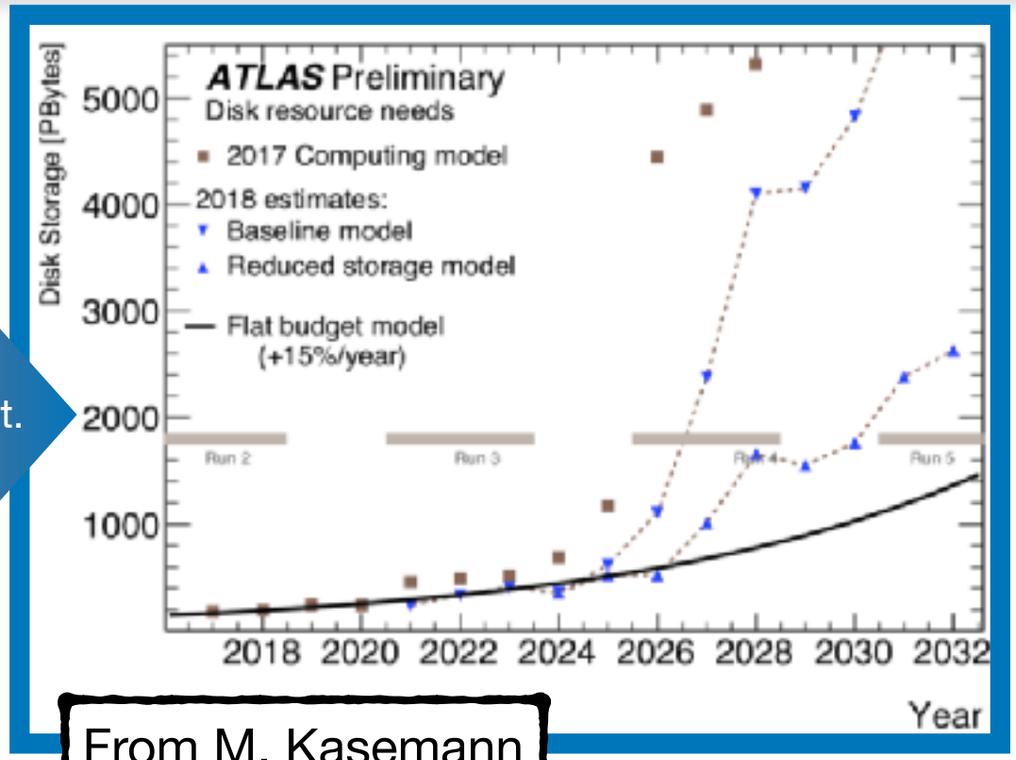

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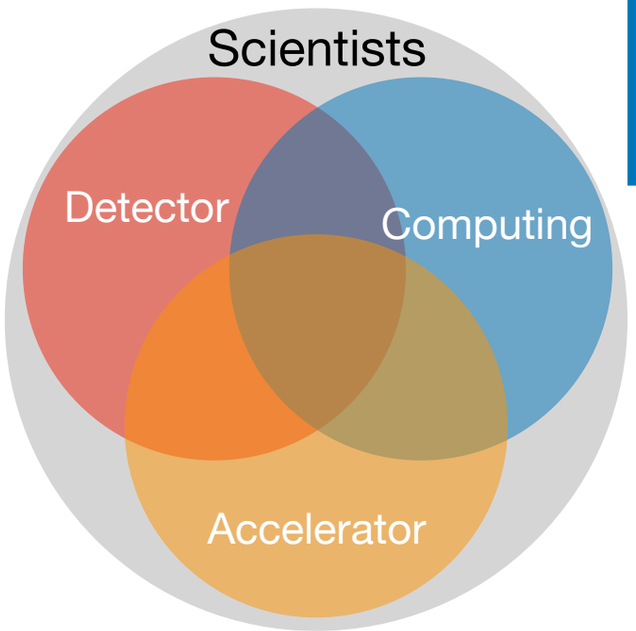

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Assessment of proposed future collider projects (physics reach, technological readiness, time scales, financial profile, operational costs, innovation, …).

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Proposed collider projects

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	15+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)
FCC-NbTi	*pp*	*37.5*	*10*	*20*	*240*	*14 GCHF (including tunnel)*
HE-LHC	pp	27	20	20		7.2 GCHF

Linear colliders

Circular colliders

From D. Schulte

New at request of ESG

Open Symposium Highlights

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Technical challenges of proposed colliders

		Ref.	E (CM) [TeV]	Luminosity [1E34]	AC-Power [MW]	Cost-estimate Value* [Billion]	B [T]	E: [MV/m] (GHz)	Major Challenges in Technology
	FCC-NbTi	(to be filled)	~ 100	< 30			~ 6		...Find the people who want to do it
C C hh	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
C C ee	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
L C ee	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

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

From A. Yamamoto

Possible scenarios of future colliders

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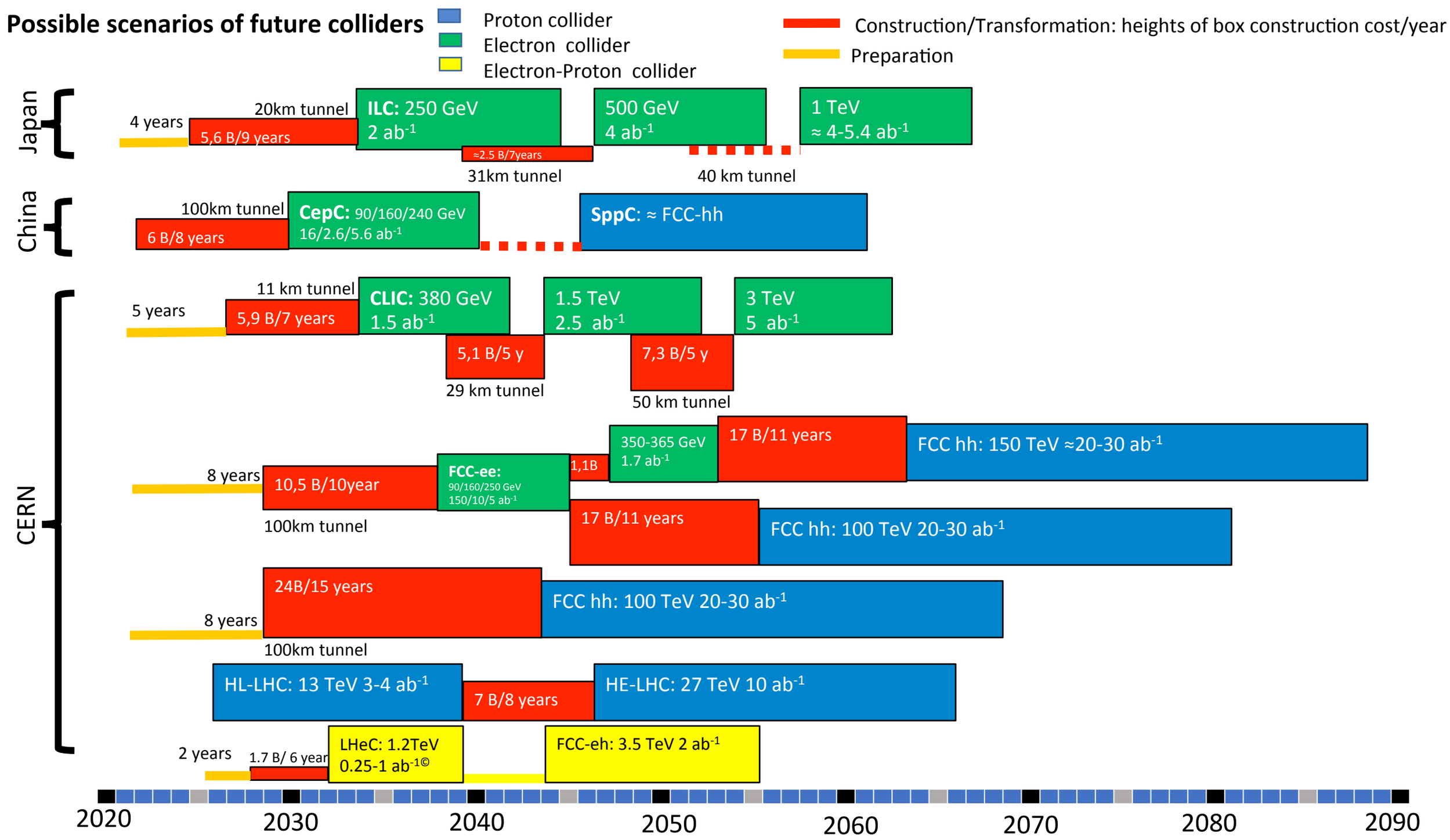


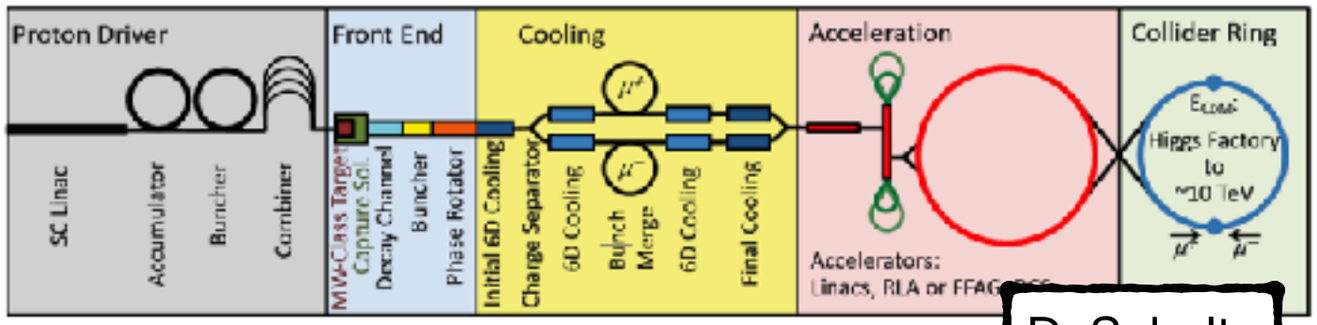
From U. Bassler

Future Accelerator Technologies

European Strategy Update

- Muon collider
  - From proton beams (c.f. MICE)
  - From positron beams (e.g. LEMMA)

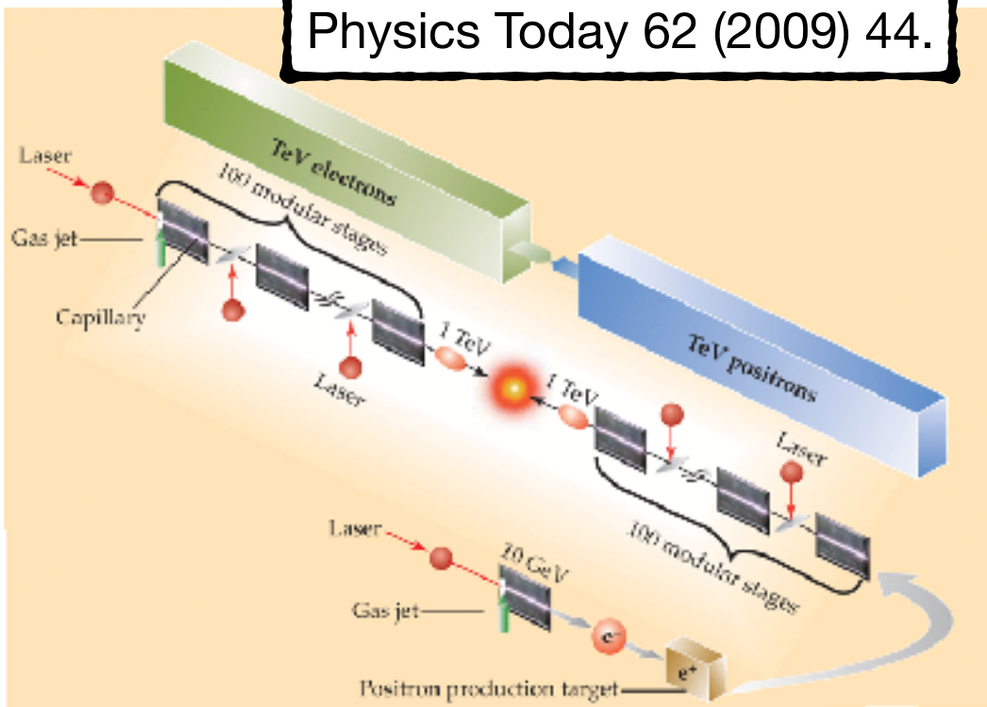
Muon-based technology represents a unique opportunity for the future of high energy physics research: the multi-TeV energy domain exploration.



D. Schulte

- Plasma wakefield acceleration
  - Can reach order 100 GV/m gradient.
  - Many key achievements in last 15 years in plasma based acceleration using **laser/electron/proton** drivers.

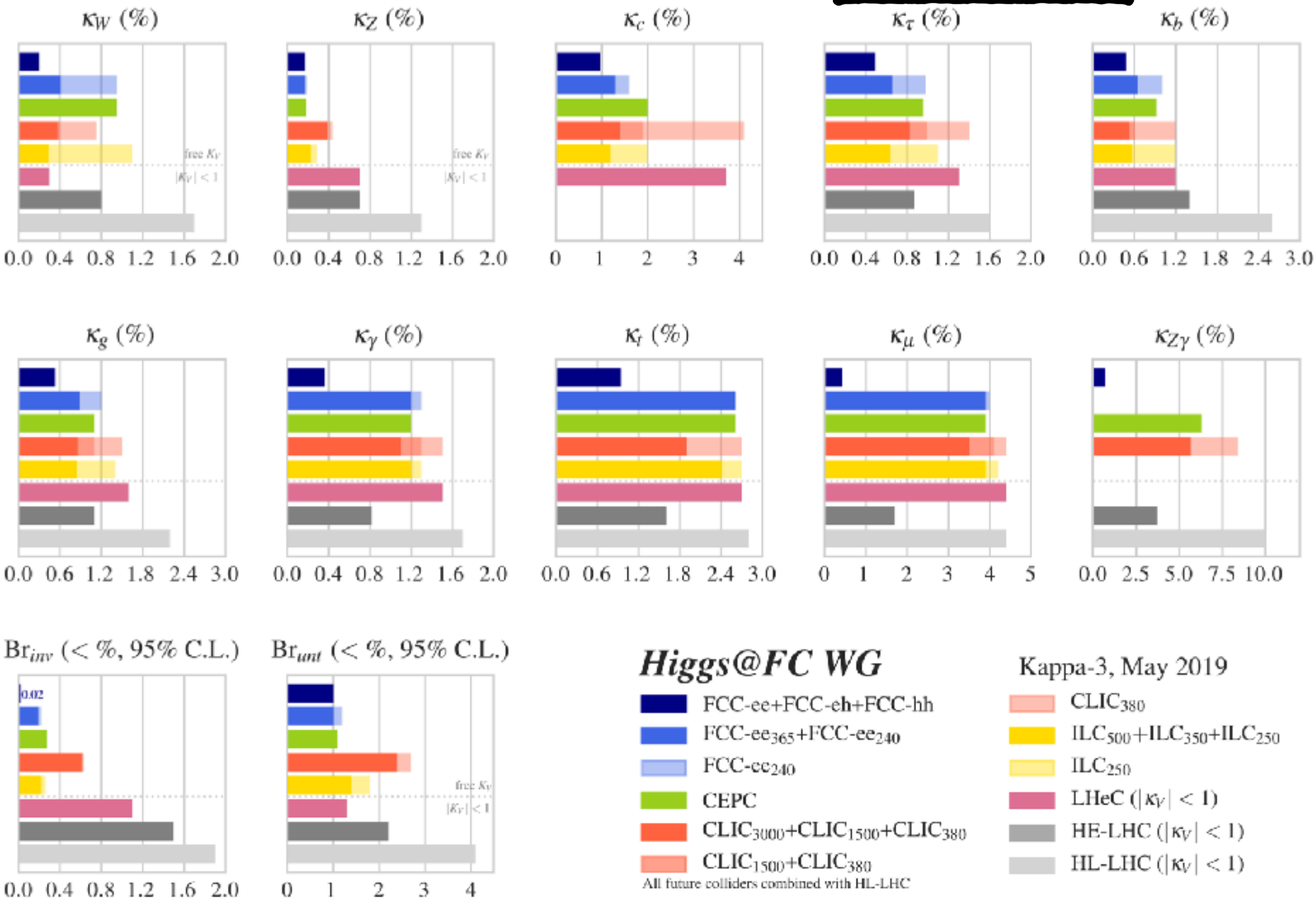
Physics Today 62 (2009) 44.



Need vigorous R&D in strongly coordinated global effort to address key challenges.

Higgs precision physics reach

arXiv:1905.03764



BSM reach at colliders

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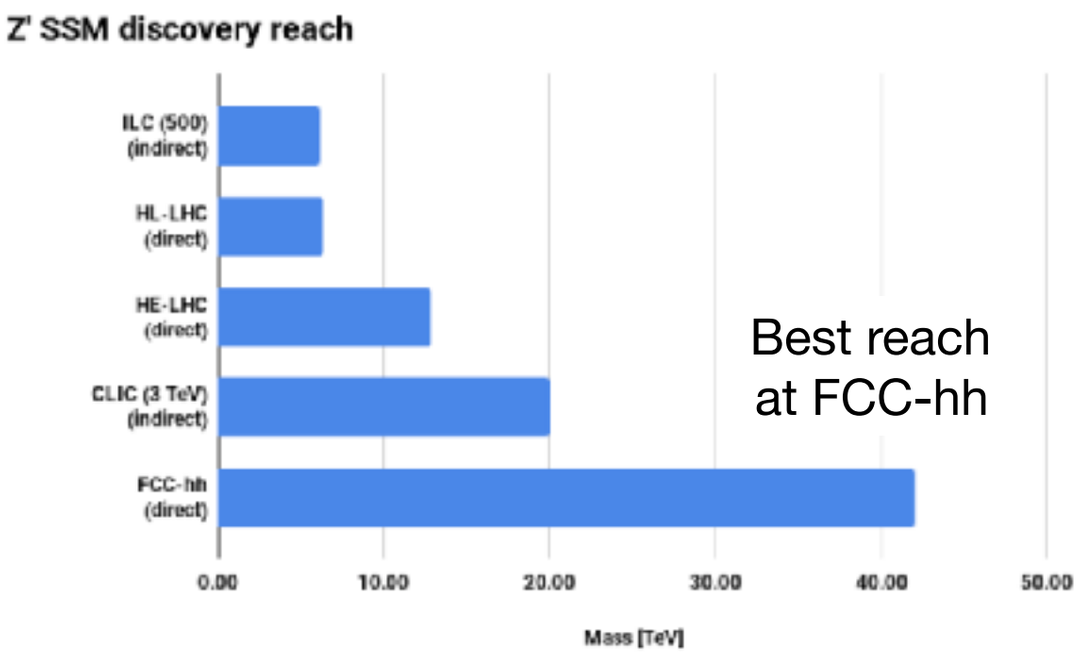
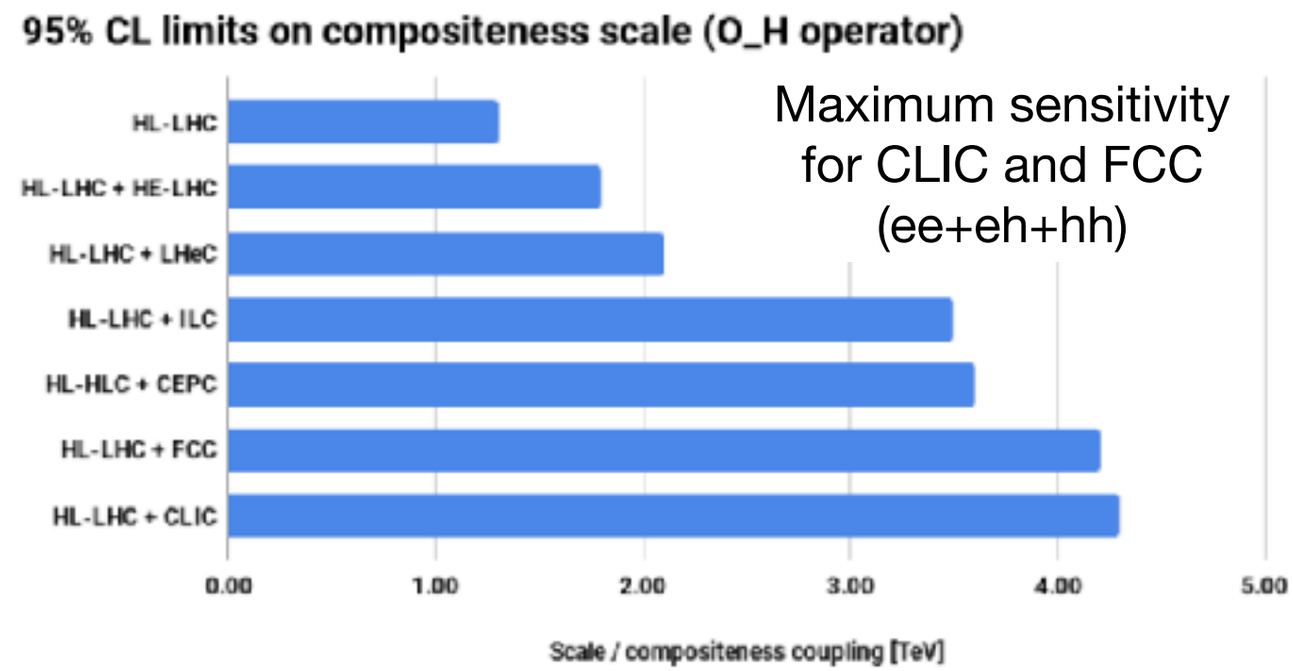
J.A. Maestre

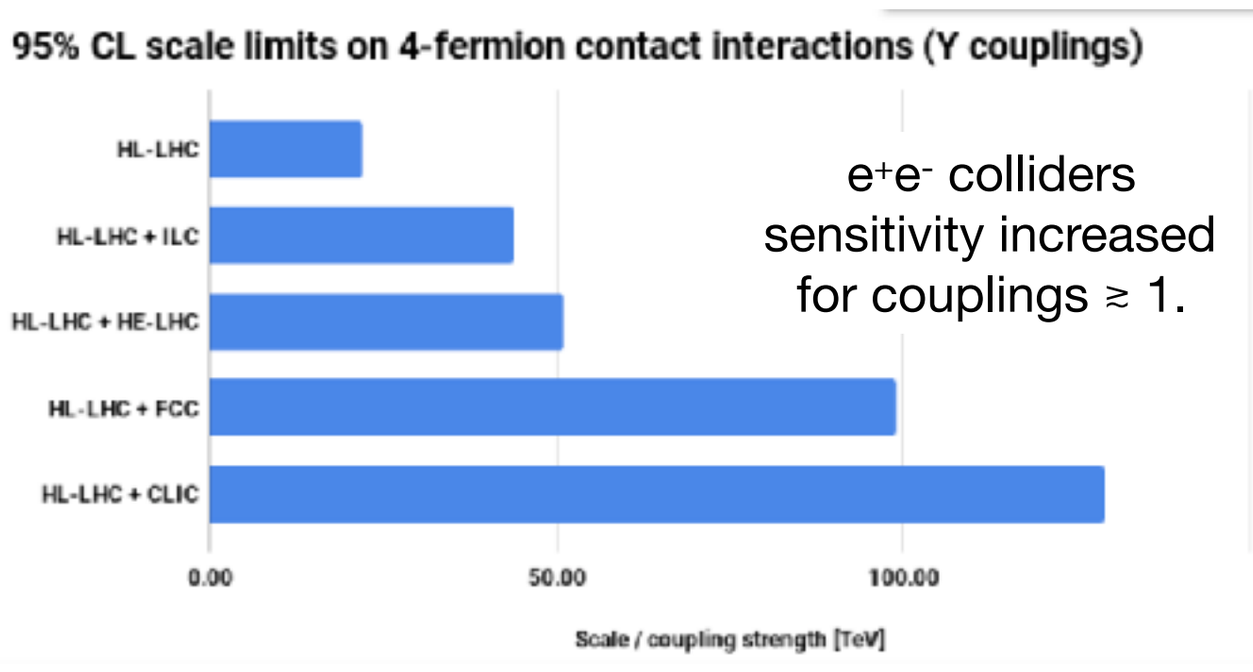
New high mass resonance



Higgs compositeness



4-fermions Contact interactions



Extended scalar sectors
FCNC
SUSY
etc…

Briefing Book Preparation

- Open Symposium outcomes and community inputs to be summarized in **Briefing Book**.
  - Prepared by members of the PPG, assisted by Scientific Secretaries (~ 100 pages).
  - Expected to be ready by September 2019.
    - Current status: Complete drafts of each chapter being reviewed.

- Briefing Book content:
  - Executive summary
  - Theoretical introduction
  - Summaries of 8 parallel sessions at Open Symposium
  - Synergies between various areas of research and different projects.
  - Addenda: list of submitted projects, timelines, cost estimates, etc.

Community feedback/considerations

European Strategy Update

- Emerging consensus for the importance of a "**Higgs factory**" to fully explore properties of the Higgs, EW sector, etc.
- Need to prepare a clear path towards **highest energy**.
- Future projects require **vigorous R&D** in accelerator technologies, detectors and computing.
- Ensure adequate level of dynamism for particle physics to remain attractive (long time scales)
  - Strong case for support of a **diverse research program** in particle physics.
  - Many interesting ideas to complement energy frontier with precision measurements (EDMs, rare decays, neutrinos, low energy searches for ALP / dark sector, etc.)
- Importance of further **exploiting synergies and complementarities** between fields (e.g. astroparticle physics, nuclear, material sciences, etc.)

Community feedback/considerations

European Strategy Update

- Ensure adequate support for **theory development and tools**.
  - E.g. career path: Difficult to convince academia - National labs/CERN may help
- Ensure **development and preservation of expertise** in detector, accelerator and computing sciences.
  - Training - University programs, PhD requirements
  - Recognition and career opportunities - difficult to convince academia - enhance the role of National Institutions.
- **Communicate** interest of science to other fields of research and to society.
  - Seek synergies with ApPEC, NuPPEC, light sources...
  - Help with ECO (Education/Communication/Outreach) with dedicated funding.
- Consider innovative ways to increase **funding**.

Summary

- EPPSU process ongoing and to conclude with approval of strategy, by the CERN Council, in May 2020.
- Open Symposium took place in Granada, Spain, 13-16 May 2019.
- Physics Preparatory Group (PPG) currently drafting the "Briefing Book" to be submitted to the European Strategy Group (ESG) [Sept. 2019]
- Plan to return to community with post-Granada scenarios.
- A very exciting (yet challenging ...) time for particle physics.

Additional Material

European Strategy Group (ESG)

http://europeanstrategyupdate.web.cern.ch/composition-esg

Members:

- the Strategy Secretary (acting as Chair),
- one representative appointed by each CERN Member State,
- one representative appointed by each of the Laboratories participating in the major European Laboratory Directors' meetings, including its Chair (CERN, CIEMAT (Madrid-Spain), DESY (Hamburg-Germany), Irfu (Saclay-France), LAL (Orsay-France), Nikhef (Amsterdam-Netherlands), LNF (Frascati-Italy), LNGS (Gran Sasso-Italy), PSI (Villigen-Switzerland), STFC-RAL (Didcot-UK)),
- the CERN Director-General,
- the SPC Chair,
- the ECFA Chair.

Invitees: [~ 29 people]

- the President of the CERN Council,
- one representative from each of the Associate Member States,
- one representative from each Observer State,
- one representative from the European Commission,
- the Chairs of ApPEC and NuPECC,
- the Chairs of FALC and ESFRI,
- the members of the Physics Preparatory Group.

Physics Preparatory Group (PPG)

http://europeanstrategyupdate.web.cern.ch/composition [17 members]

- Strategy Secretary
  - Halina Abramowicz (IL)
- SPC chair
  - Keith Ellis (UK)
- Delegates nominated by SPC
  - Caterina Biscari (ES), Belen Gavela (ES), Beate Heinemann (DE), Krzysztof Redlich (PL)
- ECFA chair
  - Jorgen D'Hondt
- Delegates nominated by ECFA
  - Stan Bentvelsen (NL), Paris Sphicas (GR), Marco Zito (FR), Antonio Zoccoli (IT)
- Chair of European Lab Director meeting
  - Lenny Rivkin (CH)
- Delegate nominated by CERN
  - Gian Giudice (CERN)
- Delegates nominated by ICFA
  - Americas: Marcela Carena (US) and Brigitte Vachon (Canada)
  - Asia: Shoji Asai (Japan) and Xinchou Lou (China)

Strategy Secretariat

http://europeanstrategyupdate.web.cern.ch/composition-0

STRATEGY SECRETARIAT

Scientific Secretary (Chair)	Prof. Halina Abramowicz (IL)
SPC Chair	Prof. Keith Ellis (UK)
ECFA Chair	Prof. Jorgen D'Hondt (BE)
Chair EU Lab. Directors' Mtg	Prof. Lenny Rivkin (CH)

Contact: EPPSU-Strategy-Secretariat@cern.ch

Future Colliders

European Strategy Update

Collider	Type	$\sqrt{s}$	$\mathscr{P}$ [%] [e^-/e^+]	N(Det.)	$\mathscr{L}_{inst}$ [10^{34}] cm^{-2}s^{-1}	$\mathscr{L}$ [ab^{-1}]	Time [years]	Refs.	Abbreviation
HL-LHC	pp	14 TeV	-	2	5	6.0	12	[10]	HL-LHC
HE-LHC	pp	27 TeV		2	16	15.0	20	[10]	HE-LHC
FCC-hh	pp	100 TeV		2	30	30.0	25	[1]	FCC-hh
FCC-ee	ee	M_Z	0/0	2	100/200	150	4	[1]	
		$2M_W$	0/0	2	25	10	1-2		
		240 GeV	0/0	2	7	5	3		FCC-ee$_{240}$
		$2m_{top}$	0/0	2	0.8/1.4	1.5	5		FCC-ee$_{365}$
							(+1)	(1y SD before $2m_{top}$ run)	
ILC	ee	250 GeV	±80/±30	1	1.35/2.7	2.0	11.5	[3, 11]	ILC$_{250}$
		350 GeV	±80/±30	1	1.6	0.2	1		ILC$_{350}$
		500 GeV	±80/±30	1	1.8/3.6	4.0	8.5		ILC$_{500}$
							(+1)	(1y SD after 250 GeV run)	
CEPC	ee	M_Z	0/0	2	17/32	16	2	[2]	CEPC
		$2M_W$	0/0	2	10	2.6	1		
		240 GeV	0/0	2	3	5.6	7		
CLIC	ee	380 GeV	±80/0	1	1.5	1.0	8	[12]	CLIC$_{380}$
		1.5 TeV	±80/0	1	3.7	2.5	7		CLIC$_{1500}$
		3.0 TeV	±80/0	1	6.0	5.0	8		CLIC$_{3000}$
							(+4)	(2y SDs between energy stages)	
LHeC	ep	1.3 TeV	-	1	0.8	1.0	15	[9]	LHeC
HE-LHeC	ep	1.8 TeV	-	1	1.5	2.0	20	[1]	HE-LHeC
FCC-eh	ep	3.5 TeV	-	1	1.5	2.0	25	[1]	FCC-eh

16T dipole magnets

100 km ring

20-40 km

100 km ring

11-50 km

pp

ee

ep

"Capability of future machines for precision Higgs physics", M. Cepeda

EPPSU organization

Composition of each group can be found in the backup slides.

- Strategy Secretariat:
  - Organize/coordinate EPPSU process.
  - 4 members.
- Physics Preparatory Group (PPG):
  - Prepares the scientific input to the strategy update based on community input, and submits the "Briefing Book" to the ESG.
  - 17 members.
    - Delegates from the Americas: Marcela Carena (US), **BV (Canada)**
    - Delegates from Asia: Shoji Asai (Japan), Xinchou Lou (China)
- European Strategy Group (ESG):
  - Drafts strategy update to be submitted to CERN council for approval.
  - ESG is assisted by the Physics Preparatory Group.
  - ~ 36 members (+ 29 invitees).

Based on input from Mike Roney (IPP director)

Canadian submission

European Strategy Update

Submission based on 2017-21 Canadian Subatomic Physics Long Range Plan (LRP)

- LRP Drafted by committee of 11 subatomic physicists appointed by NSERC (funding agency). Note that 1/3 of members were non-Canadian. There were also 7 observers from the IPP, CINP, TRIUMF, SNOLAB, CFI and NSERC.
- LRP Committee Mandate:

  Based on a broad consultation with the Canadian subatomic physics community:
  - *Identify subatomic physics scientific ventures and priorities that should be pursued by the Canadian community and that would ensure continuous Canadian global scientific leadership covering the period 2017-21 and look ahead to 2026.*
  - *Provide budgetary estimates, including funding ranges for prioritized endeavours.*
  - *Funding ranges should include funding levels that would allow for a restrained, yet efficient, contribution to the ventures, as well as levels that would enable a more extensive contribution.*
- Extensive and broad input: documents solicited from IPP and CINP (representing the particle and nuclear physics communities, respectively), surveys of all Canadian subatomic physicists who have held subatomic physics grants, two town hall meetings.

- **IPP, CINP, TRIUMF** and **SNOLAB** prepared the Canadian Roadmaps Submission to the European Particle Physics Strategy Update which summarized the 2017-21 Canadian Subatomic Physics LRP and included updates since that recent broad community consultations associated with the LRP. The **McDonald and Perimeter Institutes** reviewed and provided input to the submission.
  - Note that IPP Council, the elected representatives of the Canadian particle physics community, worked on the submission as did the CINP Board, which consists of the elected representatives of the Canadian nuclear physics community.

IPP: Institute of Particle Physics in Canada
CINP: Canadian Institute of Nuclear Physics
NSERC: National Sciences and Engineering Research Council of Canada
CFI: Canada Foundation for Innovation

US community submission

European Strategy Update

- Total ~ 8 submissions from US community.
- US community submission organized by APS Division of Particle and Fields (see next slide): "DPF Whitepaper"
- Other submissions received from US community include:
  - "Electron Ion Collider Accelerator Science and Technology - Designs, R&D and Synergies with European research in Accelerators"
  - "Synergies between a U.S.-based Electron-Ion Collider and the European research in Particle Physics"
  - "Deep Underground Neutrino Experiment (DUNE)"
  - "The Short-Baseline Neutrino Program at Fermilab"
  - "Status of Fermilab's Neutrino Facilities"
  - "MAGIS-1K: A 1000 m Atom Interferometer Device for Searches in Dark Matter and Gravity Waves"
  - "Charged Lepton Flavour Violation using Intense Muon Beams at Future Facilities"

Based on input from Priscilla Cushman (Chair) and Joe Incandela (past-Chair) of DPF

DPF Whitepaper

European Strategy Update

Process described in DPF Newsletter from August 2018.

Dates in 2018	Process
Until October 8th	Collect input from the US DPF community via email at dpfstrategy@fnal.gov
October 9th-November 11th	Draft white paper
November 12th-December 2nd	Post the draft for feedback from the DPF community
December 3rd-December 16th	Finalize the draft
December 17th	Submit paper to and post it on the DPF bulletin site

DPF submission available in 3 parts:

- Community Planning and Science Drivers
- Tools in Particle Physics
- Addendum of White Papers

"The focus of this document, […], is to describe research interests in the U.S. particle physics community beyond the P5 timescale. As the U.S. planning process described above has not yet commenced, we are unable to supply a comprehensive or prioritized summary of U.S. plans. For purposes of this document, editors representing the experimental and theoretical side of each science driver were identified [see Addendum] and asked to summarize the status of their sub-field. The DPF Executive Committee and the editors of this document sought and incorporated input from the community regarding future interests as well as feedback on preliminary drafts. This document does not claim to fully speak for the U.S. community, but the editors have attempted to produce an accurate summary of the current state of thinking in the U.S. particle physics community for consideration by the ESG based on input provided to us. An additional document submission describes other important activities within the U.S. and global particle physics communities: theory, accelerator development, computing, and detector R&D. For brevity we are omitting details and references about many of the initiatives mentioned in these white papers, given that independent white papers on specific initiatives are being submitted in parallel and information can easily be found online."