Future colliders WG

ECFA ECR Panel Meeting
10 November 2023

Armin Ilg, University of Zürich

Future colliders WG

Goal: Inform ECRs about future collider options and development, enabling them to shape their own vision on future colliders

Future colliders for early-career researchers

Short presentations on prospects, lots of time for discussions. Can serve as reference information for ECRs.

→ Almost one hundred in-person participants, > 100 on Zoom

Back to the future

Jorgen d'Hondt (experimental view): *The Future doesn't exist yet*

Federico Buccioni (theory view): T*omorrow is today!*

Let's instead write: *The future is ours!*
(Prof. Rabinovici)

So which future collider do we want?

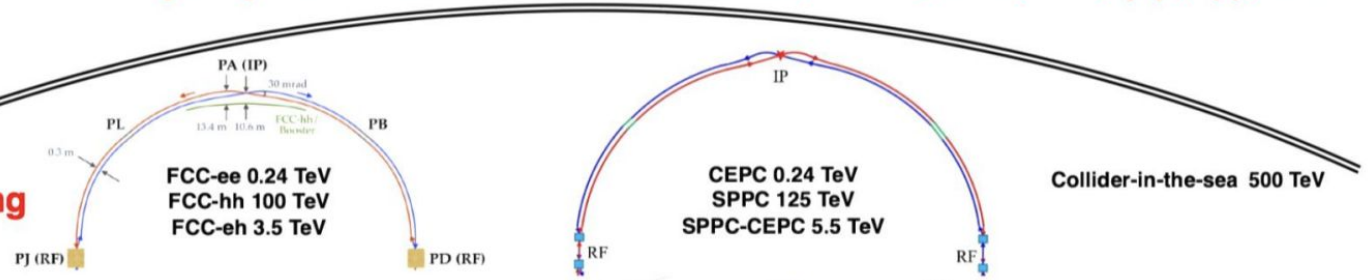
Requirements for the next HEP machine

- From pure physics
  - Capable of H and t physics complementary to/beyond LHC and HL-LHC
  - Capable of Z and W physics beyond currently known
    ⇒an e^+e^- collider covering a region of 90-350 GeV centre of mass energy (cme)
- Somewhat physics related issues
  - It is good to start data taking with some overlap with the HL-LHC operation since the results might influence each other's scientific programme.
    ⇒A machine which can be built within the next 10~15 years.
  - Can be upgraded to probe higher energy scales if physics result motivates.
  - Should not damage the diversity of particle physics activities.
    ⇒A machine with a reasonable cost
- HEP sociology
  - Continuity in the HEP programme to sustain the community
- Other issues have become increasingly important
  - Environmental impact, energy consumption, resource availability, attractivity in technology, impact on industries, spinoffs, …

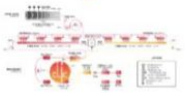
Tatsuya Nakada

Future collider proposals: 0.125 – 500 TeV; e+e-, hh, eh, μμ, γγ, …

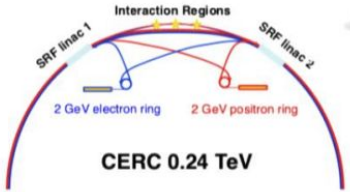
- **Storage ring colliders**
- **Linear colliders**
- **ERL colliders**
- **Muon collider**
- **Wakefield colliders**




ILC 0.25 TeV

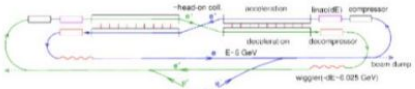

CLIC 0.24 TeV

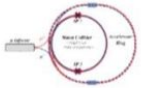

CCC 0.25 TeV



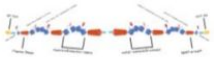
CERC 0.24 TeV


ReLiC 0.24 TeV


ERLC 0.24 TeV


MC 10 TeV

10 km

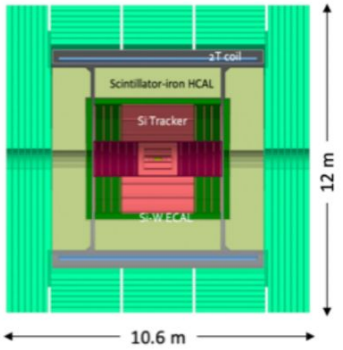

PWFA 15 TeV


LWFA 15 TeV


SWFA 3 TeV

CLD

https://arxiv.org/abs/1911.12230 and FCC CDS vol. 2



Well established design
- ILC -> CLIC detector -> CLD

Full Si vtx + tracker; CALICE-like calorimetry; large coil, muon system

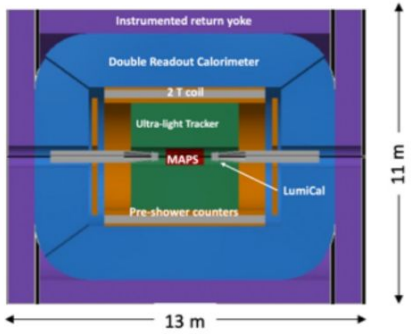
Engineering and R&D needed for
- reduction of tracker material budget
- operation with continous beam (no power pulsing: cooling of Si sensors for tracking + calorimetry)

Possible detector optimizations
- Improved σ_p/p, σ_E/E
- PID: timing and/or RICH?

CDR

IDEA

FCC CDR vol. 2



- Less established design
  - But still ~15y history: ILC 4th Concept
- Si vtx detector; ultra light drift chamber w powerfull PID; compact, light coil; monolitic dual readout fibre calorimeter; muon system
  - Possibly augmented by crystal ECAL
- Active community
  - Prototype designs, test beam campains, …

Allegro

M.Aleksa @ FCC Week, 2022

new

- A design in its infancy
- High granularity Noble Liquid ECAL is core
  - Pb+LAr (or denser W+LCr)
- Drift chamber; CALICE-like HCAL; muon system.
- Coil inside same cryostat as LAr, possibly outside ECAL
- Active Noble Liquid R&D team
  - Readout electrodes, feed-throughs, electronics, light cryostat, …
  - Software & performance studies

And even muon collider now!

Mogens Dam and Nadia Pastrone

Precision measurements at FCC-ee

Baseline FCC-ee operation model (+ potential resonant Higgs for electron Yukawa)

Working point	Z, years 1-2	Z, later	WW	HZ	tt		(s-channel H)
$\sqrt{s}$ (GeV)	88, 91, 94		157, 163	240	340-350	365	m_H
Lumi/IP ($10^{34}\,cm^{-2}s^{-1}$)	115	230	28	8.5	0.95	1.55	(30)
Lumi/year (ab^{-1}, 2 IP)	24	48	6	1.7	0.2	0.34	(7)
Physics Goal (ab^{-1})	150		10	5	0.2	1.5	(20)
Run time (year)	2	2	2	3	1	4	(3)
Number of events	5×10^{12} Z		10^8 WW	10^6 HZ + 25k WW → H	$10^6 t\bar{t}$ +200k HZ +50k WW → H		(6000)

Physics at the Z-pole, W^+W^-@threshold ~ m_W, Higgs factory, tt@threshold ~ m_t

great opportunities for precision QCD: a_s, jets, hadronization models...

The foreseen precision is staggering:

this poses astounding but also attractive challenges on theory predictions

- calculations within the SM of equivalent accuracy needed to exploit full discovery/exclusion power
- theory will serve as an input in many measurements, e.g. electroweak pseudo observables (EWPOs)

Federico Buccioni

[Blondel, Janot 2106.13885]

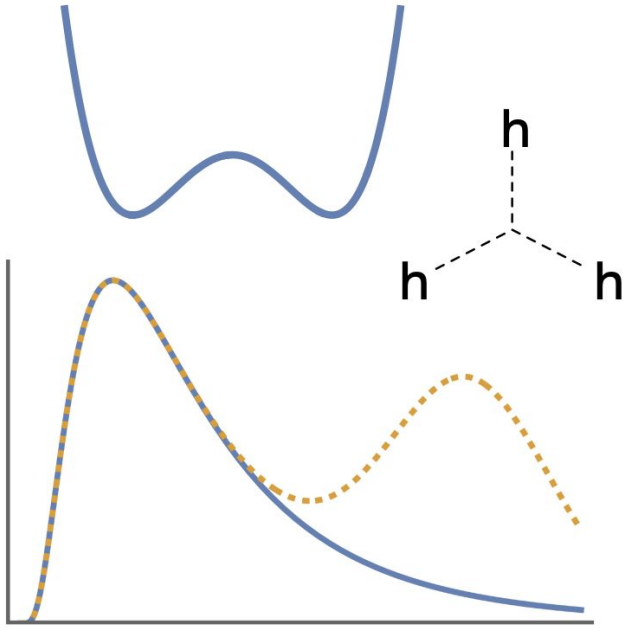
Observable	present value ± error	FCC-ee Stat.	FCC-ee Syst.	Comment and leading exp. error
m_Z (keV)	91186700 ± 2200	**4**	100	From Z line shape scan Beam energy calibration
Γ_Z (keV)	2495200 ± 2300	**4**	25	From Z line shape scan Beam energy calibration
$\sin^2\theta_W^{eff}(\times 10^6)$	231480 ± 160	**2**	2.4	from $A_{FB}^{\mu\mu}$ at Z peak Beam energy calibration
$1/\alpha_{QED}(m_Z^2)(\times 10^3)$	128952 ± 14	**3**	small	from $A_{FB}^{\mu\mu}$ off peak QED&EW errors dominate
R_ℓ^Z $(\times 10^3)$	20767 ± 25	**0.06**	0.2-1	ratio of hadrons to leptons **acceptance for leptons**
$\alpha_s(m_Z^2)$ $(\times 10^4)$	1196 ± 30	**0.1**	0.4-1.6	from R_ℓ^Z above
σ_{had}^0 $(\times 10^3)$ (nb)	41541 ± 37	**0.1**	4	peak hadronic cross section luminosity measurement
$N_\nu(\times 10^3)$	2996 ± 7	**0.005**	1	Z peak cross sections Luminosity measurement
R_b $(\times 10^6)$	216290 ± 660	**0.3**	< 60	ratio of $b\bar{b}$ to hadrons stat. extrapol. from SLD
$A_{FB}^{b,0}$ $(\times 10^4)$	992 ± 16	**0.02**	1-3	b-quark asymmetry at Z pole from jet charge
$A_{FB}^{pol,\tau}$ $(\times 10^4)$	1498 ± 49	**0.15**	<2	τ polarization asymmetry τ decay physics
τ lifetime (fs)	290.3 ± 0.5	**0.001**	0.04	radial alignment
τ mass (MeV)	1776.86 ± 0.12	**0.004**	0.04	momentum scale
τ leptonic ($\mu\nu_\mu\nu_\tau$) B.R. (%)	17.38 ± 0.04	**0.0001**	0.003	e/μ/hadron separation
m_W (MeV)	80350 ± 15	**0.25**	0.3	From WW threshold scan
Γ_W (MeV)	2085 ± 42	**1.2**	0.3	From WW threshold scan Beam energy calibration
$N_\nu(\times 10^3)$	2920 ± 50	**0.8**	small	ratio of invis. to leptonic in radiative Z returns
m_{top} (MeV/c^2)	172740 ± 500	**17**	small	From $t\bar{t}$ threshold scan QCD errors dominate
Γ_{top} (MeV/c^2)	1410 ± 190	**45**	small	From $t\bar{t}$ threshold scan QCD errors dominate
$\lambda_{top}/\lambda_{top}^{SM}$	1.2 ± 0.3	**0.10**	small	From $t\bar{t}$ threshold scan QCD errors dominate
ttZ couplings	± 30%	**0.5 − 1.5 %**	small	From $\sqrt{s} = 365$ GeV run

Summary

Exciting times ahead if a future collider is built!

- Guaranteed deliverables:
  - Precision measurements
  - Higgs self-coupling

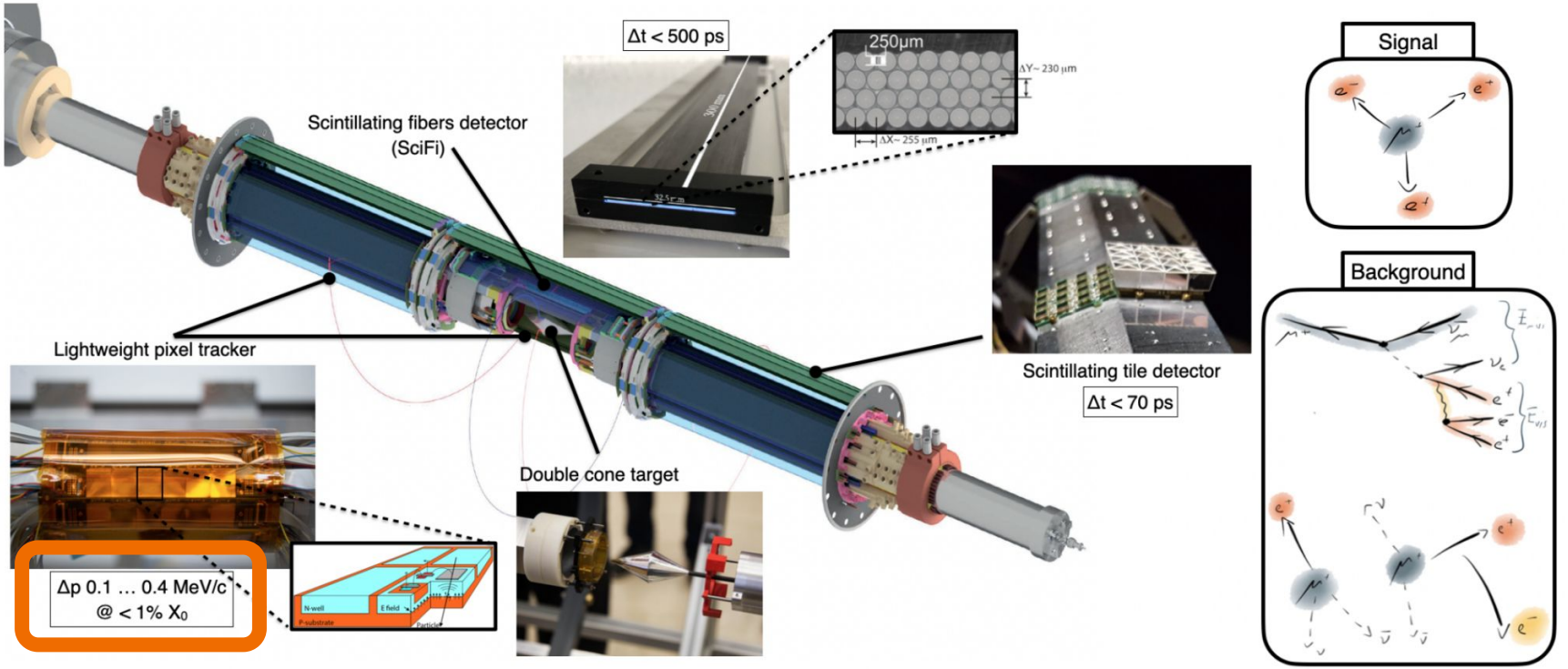
- Potential direct discoveries



Anke Biekoetter

Mu3e detector

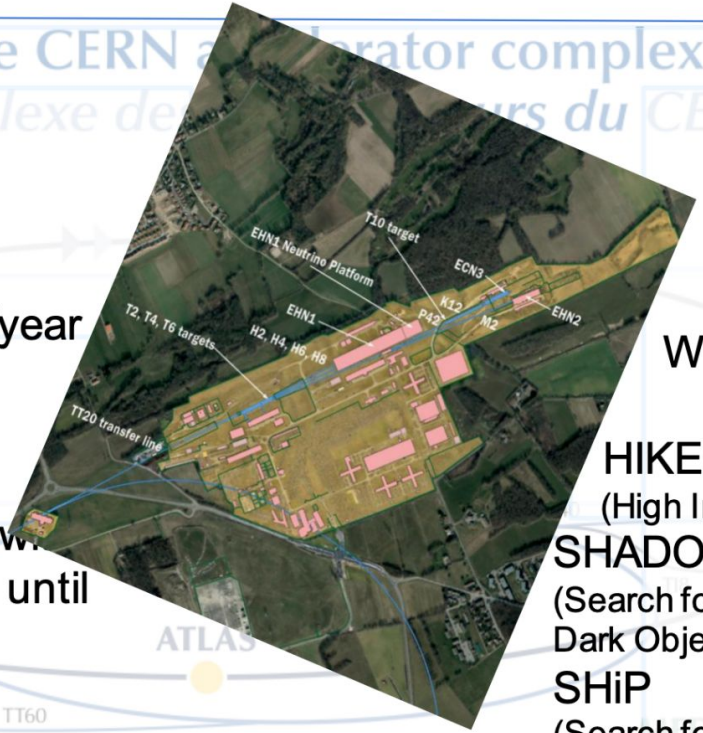
The aim is to improve the current limit of $\mathcal{B}(\mu \to eee) < 1.0 \times 10^{-12}$ (90 % C.L.) to S.E.S. $< 10^{-16}$[2].



- ECN3 - part of the SPS NA
- 400 GeV
- high intensity up to 10^{19} pot/year
- high duty cycle

Currently :

the NA62 experiment w
an approved program until
LS3.



What is after LS3?

HIKE
(High Intensity Kaon Experiment)
SHADOW
(Search for Hidden And
Dark Objects With the SPS)
SHiP
(Search for Hidden Particles)

Iaroslava Bezshyiko

What cool things can we do with ATLAS/CMS/LHCb/ALICE leftovers after HL-LHC?
Using waste particles: Beam dumps at future colliders?

Conclusions

(Ultra-relativistic) heavy-ion collisions: unique tool to study QCD matter under extreme conditions

Next decades will be crucial to shape the post-LHC future of heavy-ion field!

- Whole new opportunities for heavy-ion studies with colliders like FCC
- EIC will *complement* these future heavy-ion studies by exploring cold QCD
- New (and unconventional) ideas are welcome!

Future colliders need you 👊
Thank you for your attention!

Ivan Vorobyev

Reflections

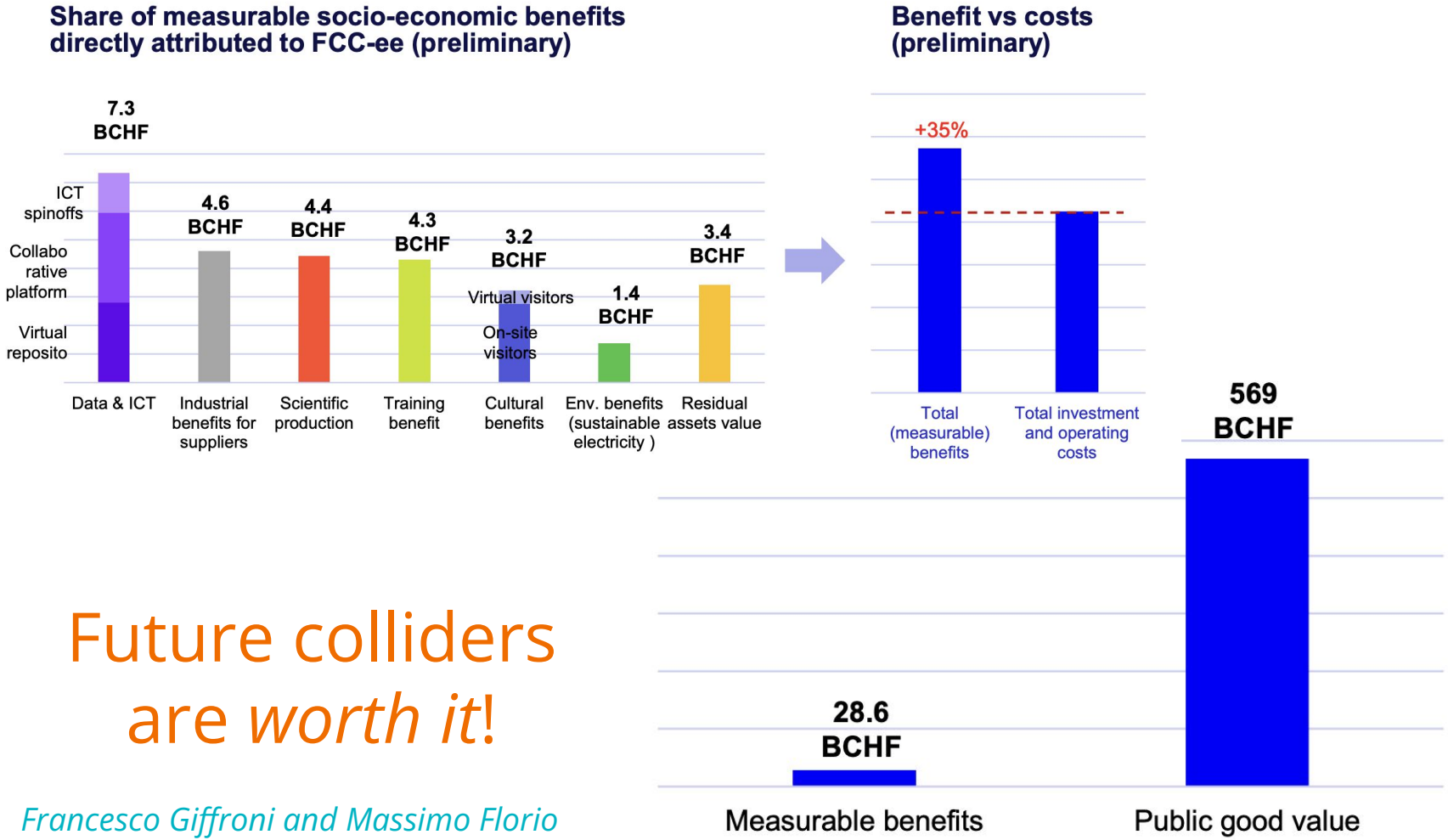
- ECRs need to be involved in future projects – it is **your** future
  - In the early stages, these projects are driven by experienced senior colleagues
    - They have the luxury/duty of preparing the future, but todays ECRs will benefit from this and actually carry out the science – get involved, you can make a difference ...
- Participating in running experiments gives invaluable experience
  - Real data is not simulation, but ATLAS SCT works a lot better than the testbeam
  - Experience the full chain from detector operations to paper acceptance
  - A different experience of collaboration, analysis WGs/hierarchies, getting results
    - Some colleagues worked only on LHC expts. from 1990 until now – I'm glad I did not
- Expertise is transferrable between experiments / projects
  - Figure out what you are interested in and good at – look for synergies
    - I have worked on tracking/b-tagging & precision measurements at OPAL and ATLAS
- Say yes to leadership opportunities even if it upsets your plans
  - Explore different areas, learn new skills, broaden your horizons
    - Less-attractive tasks are still vital, people appreciate that you take them on
- Be prepared for setbacks, surprises and successes – good luck !

Richard Hawkings

ECRs: This is YOUR TIME, YOUR FUTURE

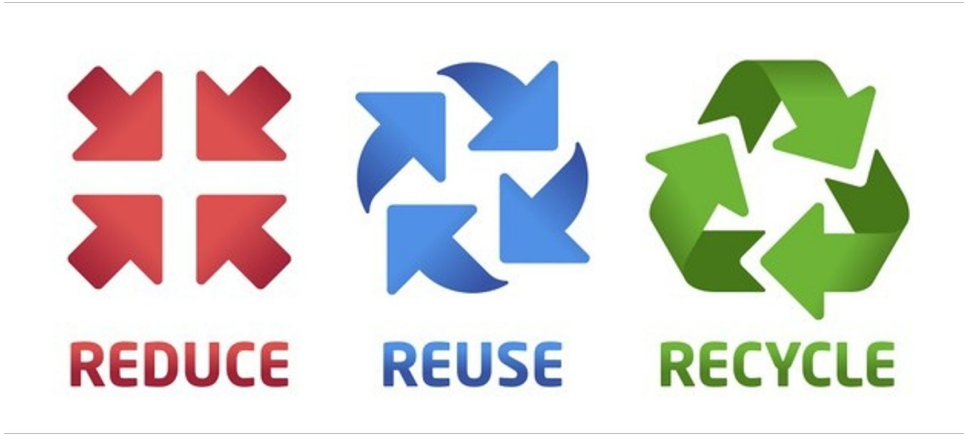
- BIRMINGHAM ONE FULL DAY, PARIS TWO HOURS, CAMBRIDGE, LONDON TWO HOURS, UK ECR+, GENEVA ONE FULL DAY.
- COUNCIL VIEW INFORMED ACTION
- ECR INFORMED ACTION

Eliezer Rabinovici

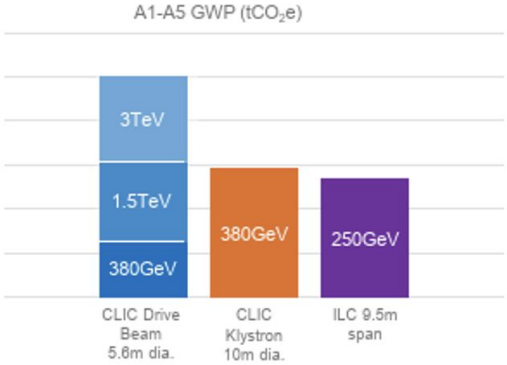


Future colliders are *worth it*!

Francesco Giffroni and Massimo Florio



LifeCycle Assessment: CLIC & ILC



UN Breakthrough Outcomes for 2030

For the built environment sector, the UN breakthrough outcomes for 2030 detail that 100% of projects due to be completed in 2030 or after are net zero carbon in operation, with at least 40% less embodied carbon compared to current practice. This has been set to make sure the sector is on track for 100% projects to be net zero carbon across the whole life cycle by 2050.

https://climatechampions.unfccc.int/system/breakthroughs/

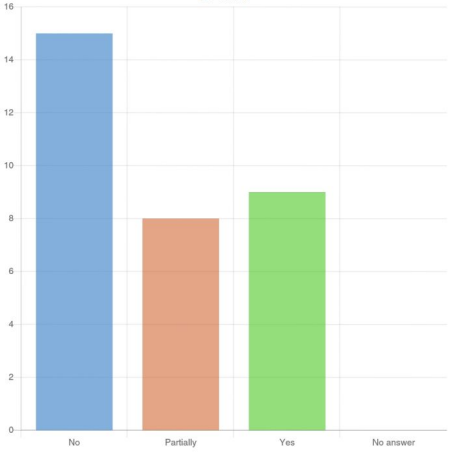
- **We need to consider how to get to net zero carbon operation and 40% less impacting construction for our future projects….**

Roberto Losito

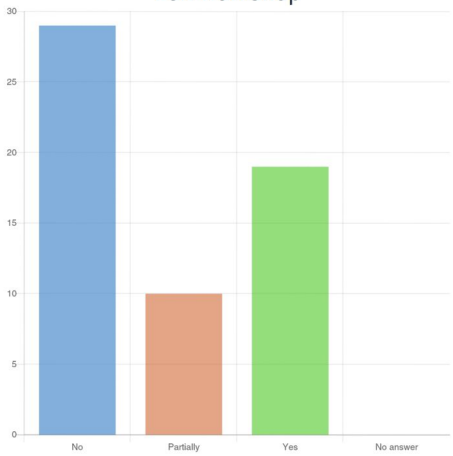
CERN and ECR Workshop survey (full presentation here)

- Are you currently working on projects connected to future colliders?

CERN



ECR workshop

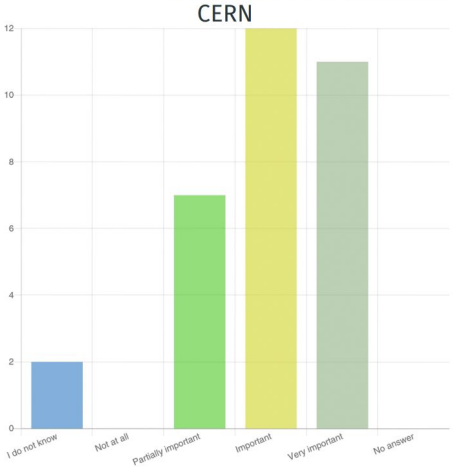


- Majority already working (partially or fully) on future collider projects

- Majority already working (partially or fully) on future collider projects

- How important is the future collider programme for your career?

CERN



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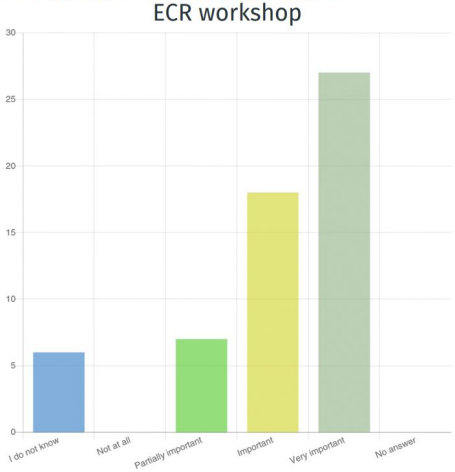


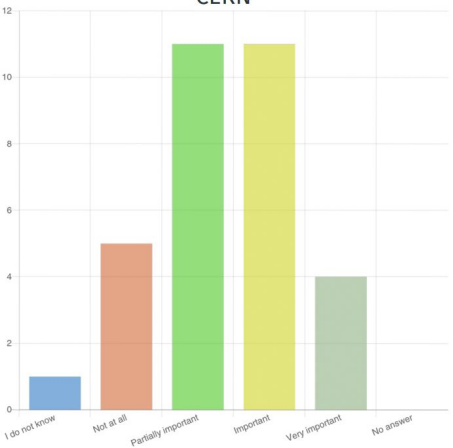
- A future collider program is considered important by (almostt) everyone

- A future collider program is considered important by (almost) everyone

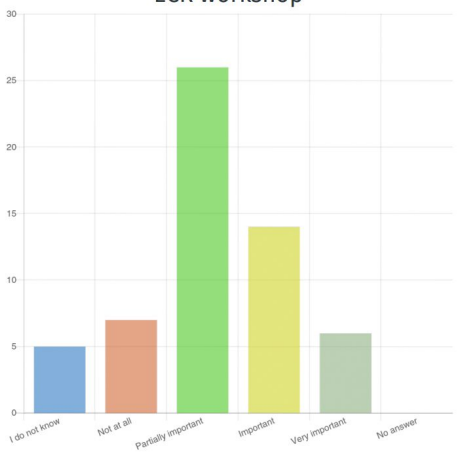
CERN and ECR Workshop survey (full presentation here)

- Is the choice of a specific future collider over another important for your career?

CERN



ECR workshop

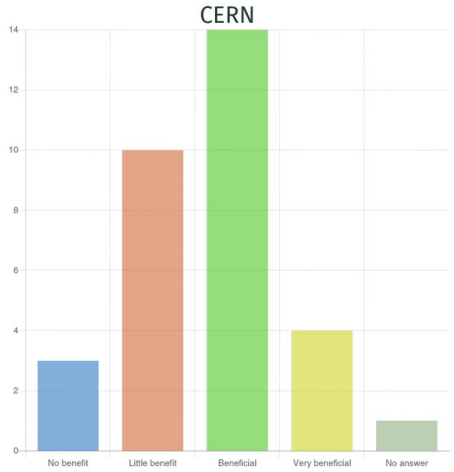


- The choice of the collider seems to matter, in part or completely

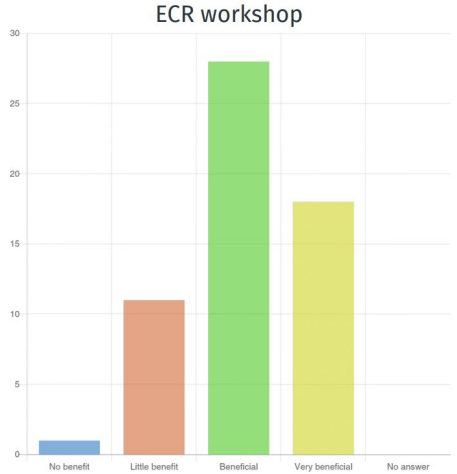
- The choice of the collider seems to matter, in part or completely

- Do you consider including future-collider related projects in your activities as beneficial to your career?

CERN



ECR workshop

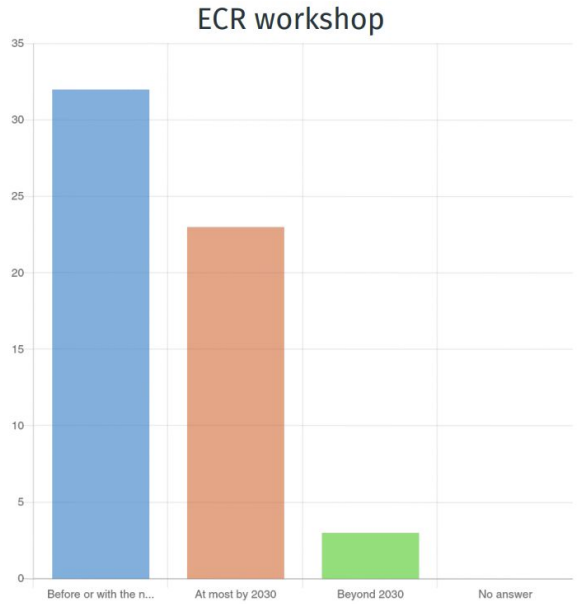


- Sizable 'little benefit' choice

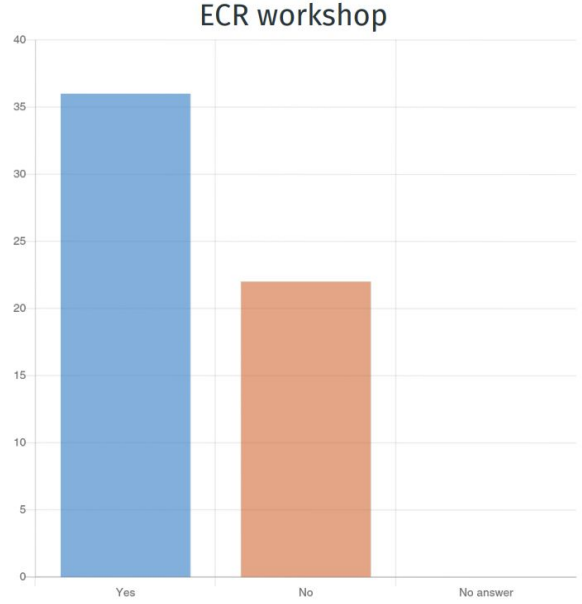
- More positive outlook

CERN and ECR Workshop survey (full presentation here)

In light of your career prospects, how long do you think it is acceptable to wait before the decision of which machine to build is made



Would you accept to work nearly full time on a project connected to a future collider, while the decision on the next machine is still pending? If yes, under which conditions



What are the considerations for choosing the next step

What do **WE** (the ECR community) find most important in the considerations for a next collider

We will not pick the next collider today, but we ask the questions that need answering

- What are the physics questions we want answered?
- How can we make sure that the probable physics is diverse enough?
  - Are several smaller colliders preferable over one large collider for the diversity of the achieved physics program?
- What are the upgrade possibilities of proposed projects?
- How precise can we get, taking realistic improvements in theory predictions into account?
- How can we make sure the collaboration with other energy range experiment is ensured?
- Is the future collider programme compatible with ECR careers considering possible large time gaps after HL-LHC runtime?
  - Would/could muon colliders make it in time to follow the HL-LHC?
- Can we bridge the gap between HL-LHC and a large future collider with enough attractive projects?
- How can we make a next collider is sustainable in terms of energy use?
- At what time-scale should the ECR community dedicate itself to one particular proposal?
- How can ECRs make the impact they desire on the decision making process?

Additional questions; please email them to; ecfa-ecr-future-colliders@cern.ch

What's next?

Spread the word

- A.I presented the workshop outcome at the CALICE ECR meeting
- Emanuele Bagnaschi presented the workshop outcome at the Second $e^{\pm}e^{-}$ Higgs/EW/top factory in Paestum, incl. ECR panel discussion

Write a short arXiv paper about the event (Marko Pesut has volunteered start this, thanks!)

From ECFA to the national communities

- Follow-up the ECFA-wide event with national, in-person events on future colliders, directing discussions into the ECFA countries as some issues are country dependent
  - Timeline? → To be discussed in WG
- A lot to be organised still! Let us know if you'd be willing to help!

Subscribe to ecfa-ecr-future-colliders e-group!

Thanks!