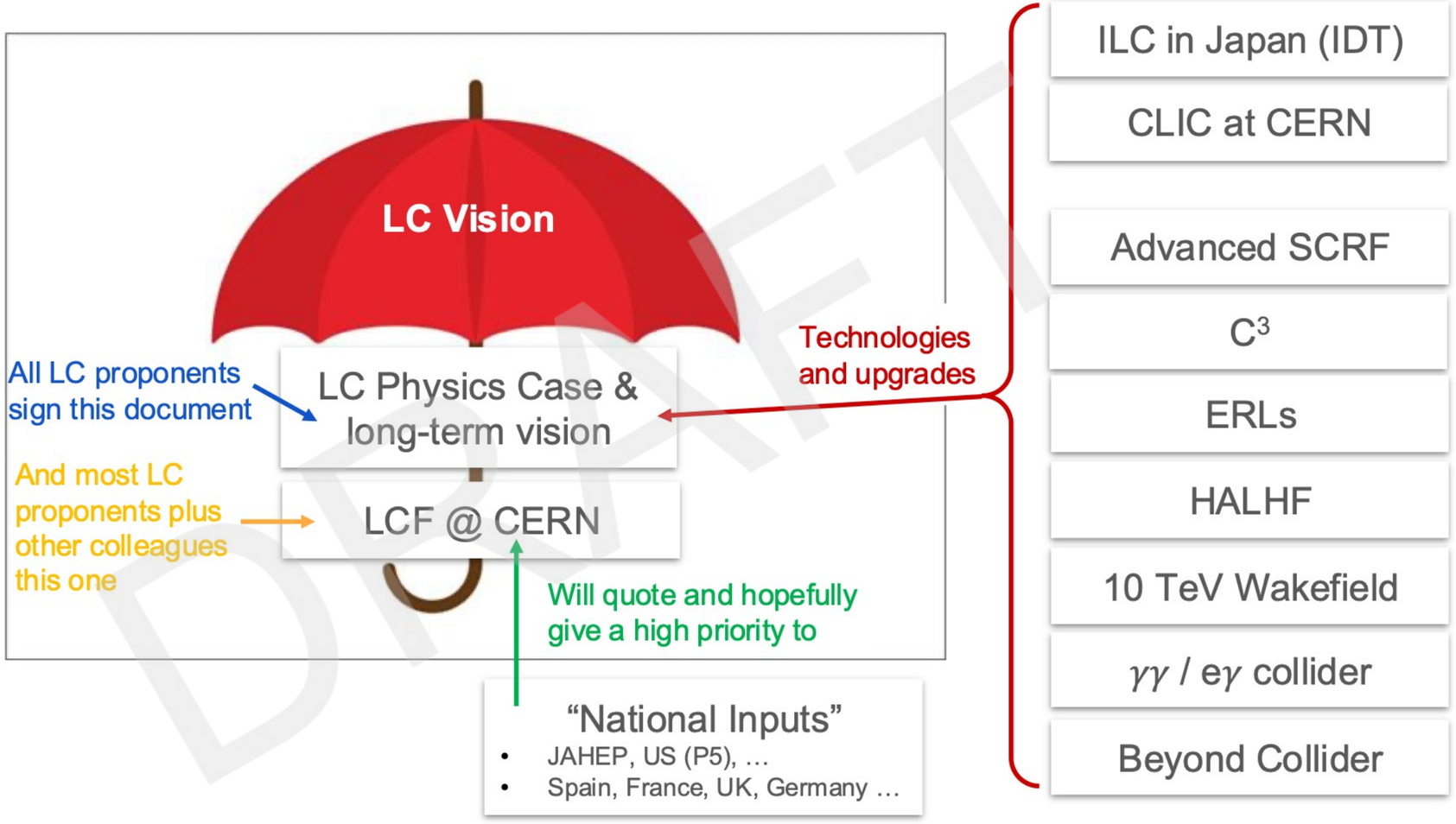
LC Vision – Idea and Goals

- the exploration of the fundamental laws of our universe requires, in addition to the HL-LHC and Belle II, a long-term e+e- program over a wide range of energies - not just a “gap-filler”
- this program should start “now” by unveiling the mysteries of the Higgs boson, with an affordable project based on technology at-hand - and then evolve from there
- the long-term program should not be statically defined “today” for decades into the future, but instead the initial facility must be sufficienctly versatible to allow choices to be taken as scientific knowledge and technologies advance - or even see revolutions
- this applies to the evolution of the e+e- facility itself as well as for the choice of the best avenue to eventually explore the 10-TeV parton-energy scale, for all of which sufficient resources for R&D and demonstrators must remain available

A few months ago, a spontaneous “think-tank” formed to reflect on these ideas
— and put them up for discussion at LCWS 2024!

- **LC Vision Documents and their relations to other EPPSU inputs** **idea: S. Gessner**



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LC Vision – Expert Team

Chairs: J. List, S. Stapnes

Coordination Group

Halina Abrahmovic, Erik Adli, Ties Behnke, Ivanka Bosovic, Phil Burrows, Marcel Demarteau, Yuanning Gao, Carsten Hensel, Mark Hogan, Masaya Ishino, Daniel Jeans, Imad Laktineh, Andy Lankford, Benno List, Kajari Mazumar, Shin Michizono, Emmanuela Musumeci, Tatsuya Nakada, Mihoko Nojiri, Dimitris Ntounis, Jens Osterhoff, Ritchie Patterson, Aidan Robson, Daniel Schulte, Taikan Suehara, Geoffrey Taylor, Caterina Vernieri, Marcel Vos, Georg Weiglein, Filip Zarnecki, Jinlong Zhang, Laura Monaco, Patrick Koppenburg, Hitoshi Murayama, Jochen Schieck

Expert Team 1
"Physics-driven run plan and EPPSU documents"
Roman Poeschl, Michael Peskin

Expert Team 3
"SCRF upgrades"
Sergey Belomestnykh, Hiroshi Sakai, Marc Wenskat

Expert Team 5
"ERL upgrades"
Walid Kaabi, Vladimir Litvinenko, Kaoru Yokoya

Expert Team 7
"Beyond Collider"
Yasuhito Sakaki, Ivo Schulthess

Expert Team 2
"LCF@CERN"
Steinar Stapnes, Thomas Schörner

Expert Team 4
"C3/CLIC upgrades"
Angeles Faus-Golfe, Enrico Nanni

Expert Team 6
"Plasma upgrades"
Brian Foster, Spencer Gessner

Expert Team 8
"Alternative Collider Modes"
Tim Barklow, Gudi Moortgat-Pick

LC Vision – Getting out of the starting blocks

- Important to define a baseline
  - **Two interaction points are considered as default**
  - Machine based on SCRF (=ILC) as starting point
  - Currently discussion turn around the question “What is a minimal scenario”?
    - 20km minimal as currently foreseen for ILC in Japan
    - A machine that can reach ttbar in its initial stage?
    - Already a 550 GeV machine from the start?
  - The latter two options imply (as of today) a longer initial tunnel (=> higher cost)

- Luminosity may/will become an issue
  - Can we increase the luminosity at least by a factor of two everywhere
    - … and maybe a factor of four at higher energies to e.g. target 5% on Higgs self-coupling
  - Note that HL-LHC gave recently promising prospects on measuring the self-coupling
  - Can energy recovery linacs help on a reasonable time scale?

LC Vision – Documents

The Linear Collider Project - A Vision for the Future of Particle Physics

Contents

- A generic site independent document
  - to outline/reiterate the physics case
- Options for start and upgrade and how this will fit together
- Length (100-150) pages

Linear Collider Strategy for the Study of the Higgs Boson

Contents

- A document tailored to a Linear Collider Facility at CERN
- Content will be short version of generic document
- Plus what LCF would add beyond FCCee / CEPC
  - with the necessary portion of caution
- Length 30 pages
- Shortened to 10 pages for European Strategy

Generic Document– Physics Part

- Higgs at 250 GeV (Team: Dirk Zerwas, Caterina Vernieri, Kei Yagyu)
- Z-Pole and 250 GeV (2-fermion processes and ee→WW) (Team: Graham Wilson, Adrian Irles, Taikan Suehara)
- Higgs at high(est) energies (Team: Shinya Kanemura, Johannes Braathen, Georg Weiglein, Margarethe Mühlleitner)
- ttH and WW Scattering (Team: Jürgen Reuter, Jan Strube, Koji Tsumura)
- Top physics programme: from threshold to highest energies (Team: Marcel Vos, XXX, XXX, XXX)
- Direct production of new particles (Team: Filip Zarnecki, Sabine Kraml, Sven Heinemeyer, Howie Baer, Natsumi Nagata)
- Global Interpretation (Team: Junping Tian, Jorge de Blas)
- Gamma Gamma Collisions (Team: Gudrid Moortgat-Pick, Ariel Schwartzman)
- Non collider physics (Team: Ivo Schultheiss, Yasuhito Sakaki, XXX)

- Thanks for being ready to join the effort (we know that everybody is superbusy)

- Guidelines:
  - 5 pages for each topic, Higgs at highest energies maybe 6-7 pages
  - Concentrate on new results since Snowmass or identify key plots results that should be repeated (that may even benefit from an update)

Physics Part – General Considerations

- A linear e+e- collider distinguishes itself from circular machines by tne reach of higher energies and the availability of beam polarisation
  - This might be pointed out wherever it is adequate
- Take into account that HL-LHC is still ahead of us
- Personally I would like to understand whether there is overlap with other fields of science
- Suppose that in the accelerator chapter of the LCVIsion document a plan/scheme will be outlined that allows for collision energies between the Z-pole and (at least) 1 TeV (by minimising civil construction beyond baseline)
  - Outlook beyond 1 TeV could be made as well (Don't be [too] shy)
- Suppose also that there will be too interaction regions (→ two detectors and/or complementary measurements, e.g. gammagamma)
  - Goal of the exercise is also to make optimal use of this
- This is a forum of experts
  - The topics have been settled essentially by R.P. and Michael with great help by Jenny, Masaya-san and Steinar
  - We may have overlooked something
  - Your input is needed
  - In the following slides we will go through the topics with a few (maybe wrong for sure insuffcient) key words as teasers
  - In this case all are R.P.'s faults
  - Please consult also Michael's slides shown at the C3-Meeting in October 2024

Physics Part – Short terms goals

- Teams should get organised now
  - If possible still one team meeting before Christmas
  - “Dump” your considerations as bulleted list directly into the overleaf file
  - The link should be editable for all of you (if not let us know)

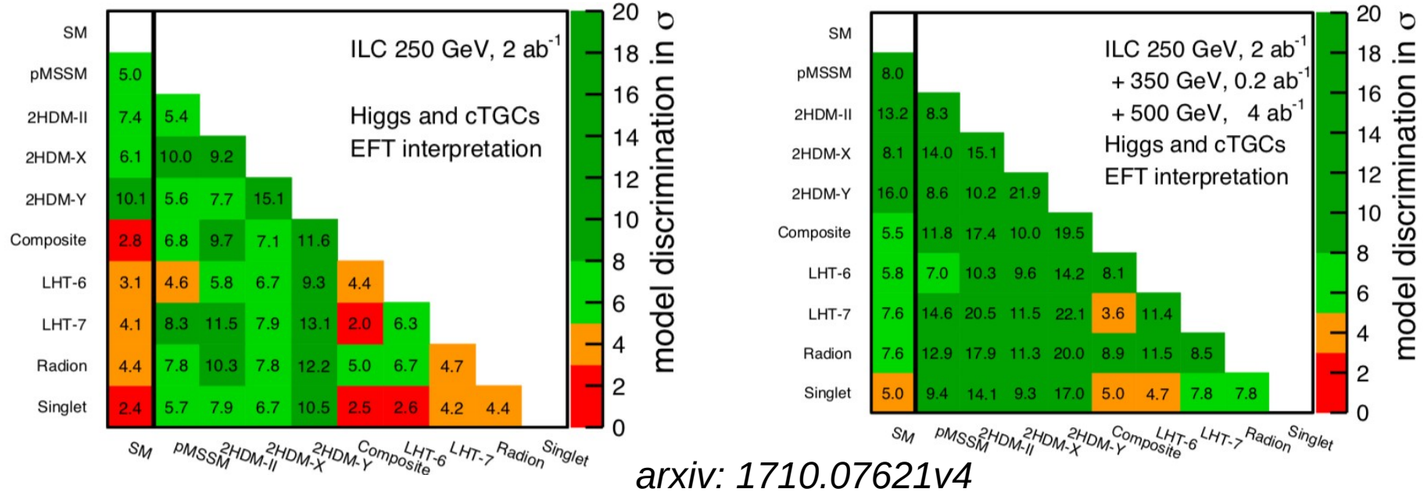
- First target is the LCVision meeting at the beginning of January
  - The bulleted list would be the foundation of the talks plus some iteration of the slides within the teams
  - Speakers to be recruited from the team and the conveners
  - After LCVision meeting the real editing phase should start

- Hope is to have complete text by the end of January (and I know that we are all overbooked)

Physics Part – Higgs@250 GeV

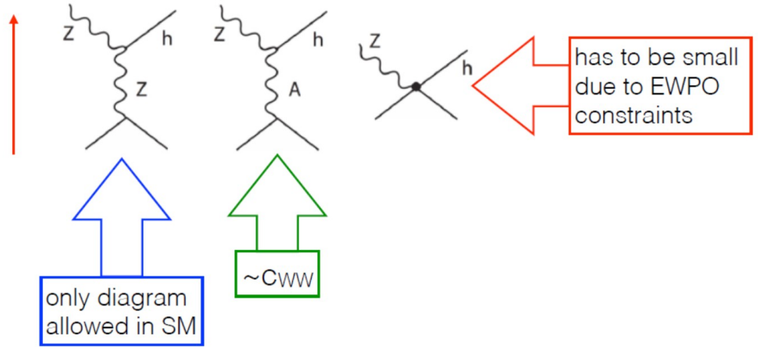
- The “backbone”
- Highest precision of Higgs couplings to light partcles
- Would precisions benefit from e.g. ECFA study (e.g. flavor tagging generators)

- Typical plots/arguments shown in recent years



arxiv: 1710.07621v4

- EFT adds additional spin structure to ZH production cross section (see backup)



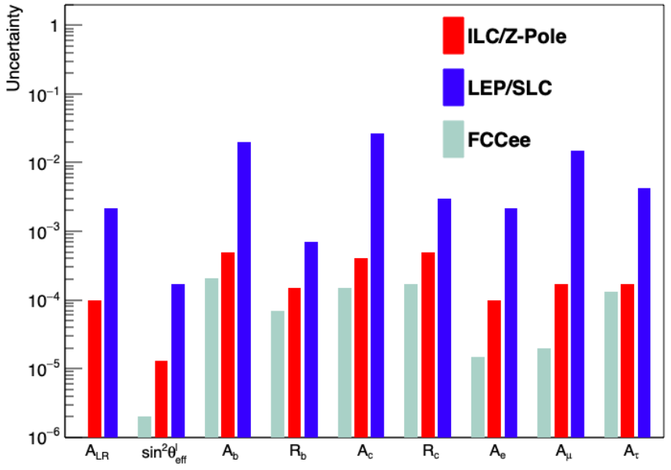
- **Precision for 2ab-1 polarised = 5ab-1 unpolarised**

- Plot and arguments may need revision/confirmation
- Aspects not yet covered
  - e.g. NLO EFT mixes “everyting”, top, self-coupling

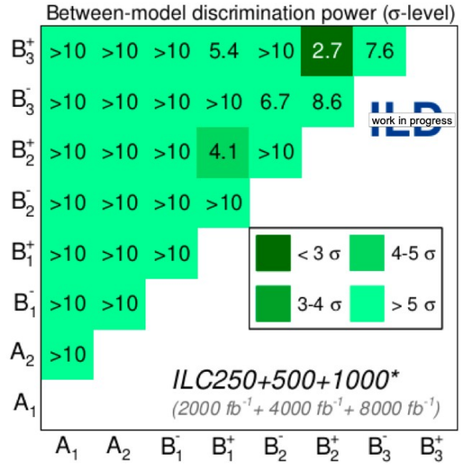
Physics Part – Z-pole and 250 GeV (2f and 4f)

- The second “backbone”
- EWPO to allow for correct interpretation of results at all energies
  - Important closure test
  - How many Z’s are “enough” (depends maybe on what you want to do)
- Physics potential of 2f (in particular above Z-pole, where polarisation is an asset)
- Typical recent plots

Z-pole precision



Separation power GHU models



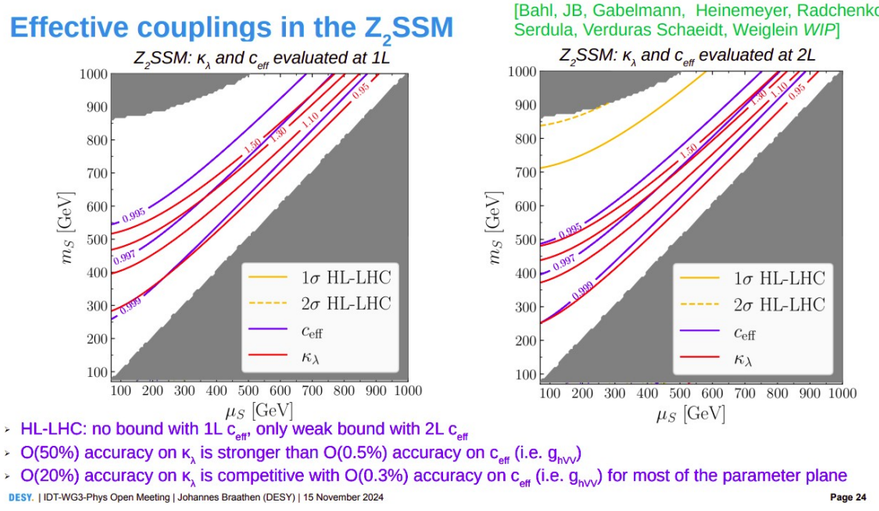
Placeholder for W-mass, Z-mass
Z-width (sorry, ddin’t have one on short notice)

- Any news?

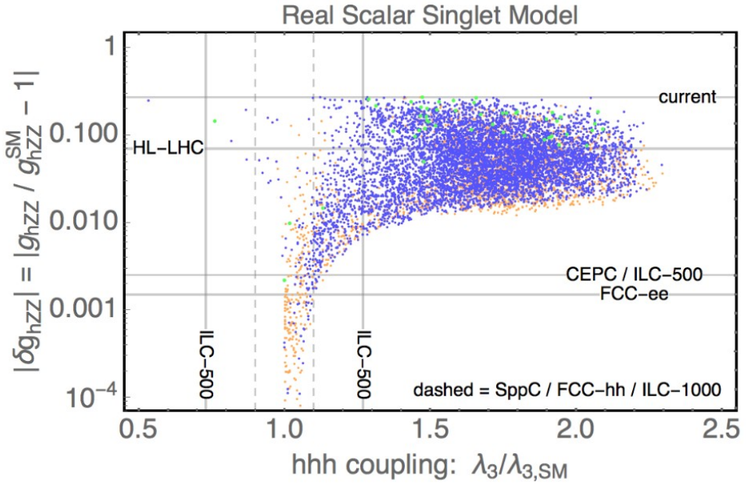
Physics Part – Higgs at highest energies

- Higgs self-coupling is a key argument for a linear e+e- machine

Recent work by Johannes, Georg et al.



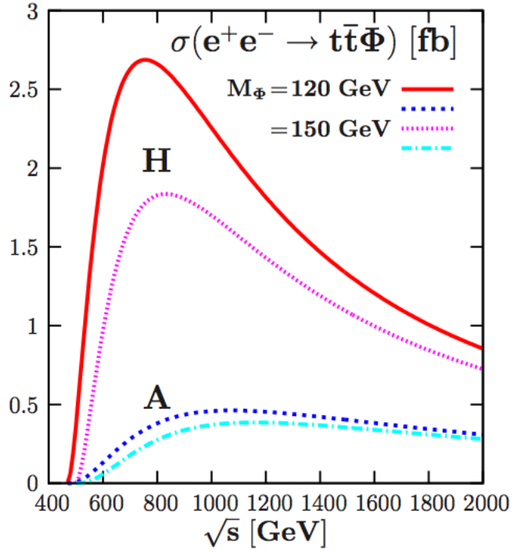
hhh coupling and GW/EWPT
as example for overlap with other fields



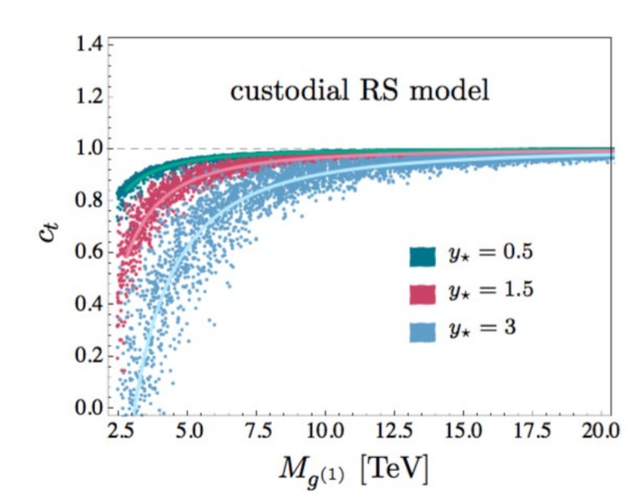
- Value of different centre-of-mass energies
  - This is unknown to the larger community
- Value of direct measurement of self-coupling
- Argumentation in view of HL-LHC Perspectives
- Quartic coupling?

- Personally I think this needs an overhaul (but I may have not read enough the literature)
- Typically we quote 1% precision on top-Yukawa and that's it
  - What does it bring us
- Plots that R.P. has shown in earlier talks

CP-Nature of Higgs



Top-Higgs couplings in "presence" of heavy particles

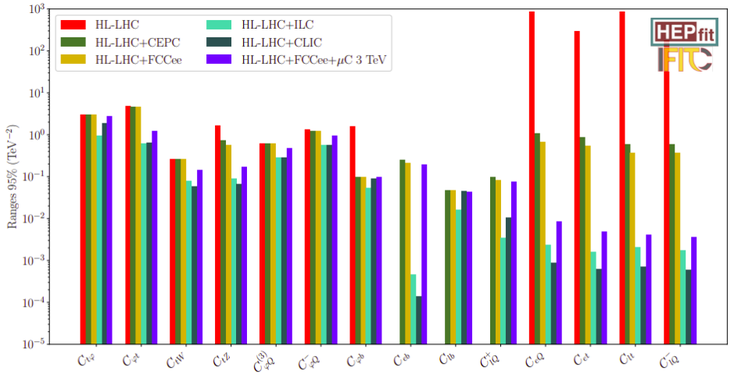


- Still relevant? New insights (also in view of LHC results)?
- WW scattering
  - Triple and quartic gauge couplings
  - WW->tt
  - What about WLWL scattering?
- For both HH production and ttH an eye on detector performance has to be kept
  - Flavor tagging but also acceptance, hermeticity might become decisive for a quality measurement

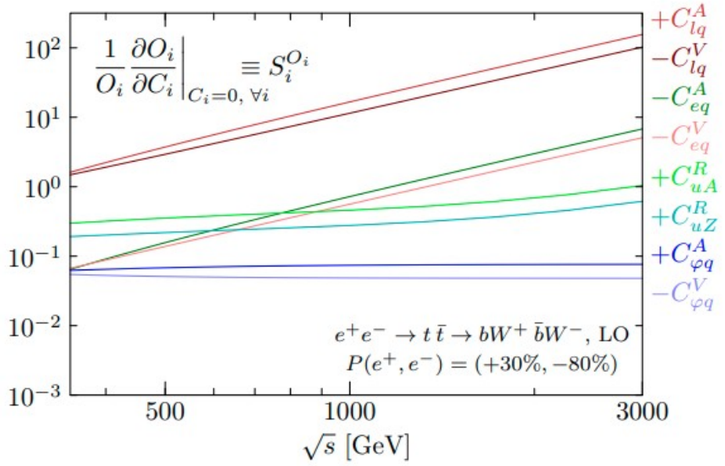
Physics Part – top – From threshold to highest energies

- Top mass is clear
- Top couplings
  - Typical plots shown recently

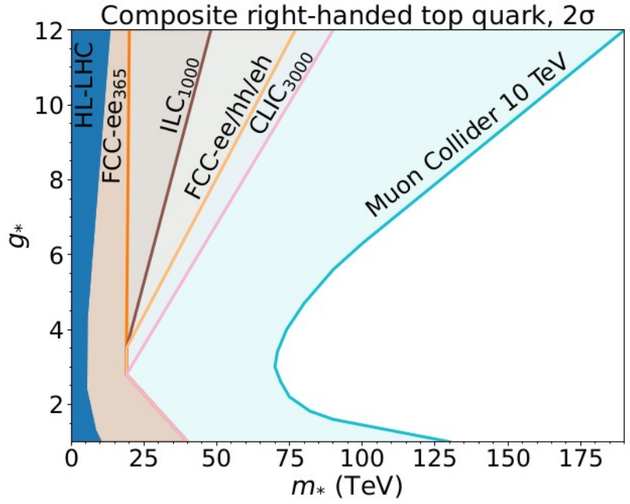
Operator precision and development



All e+e- colliders improve the bounds on the top sector dramatically
High-energy operation is important to provide the strongest global bounds



From Snowmass EF report

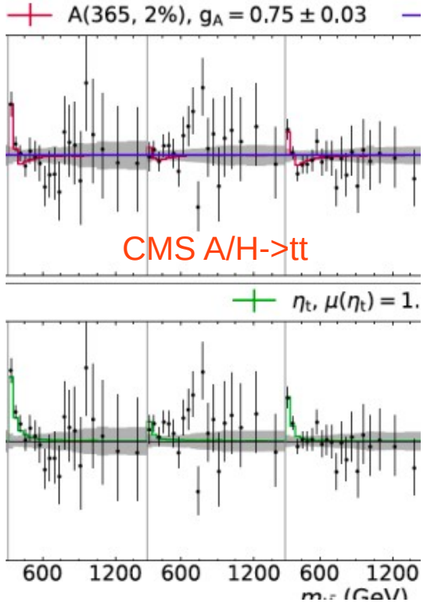


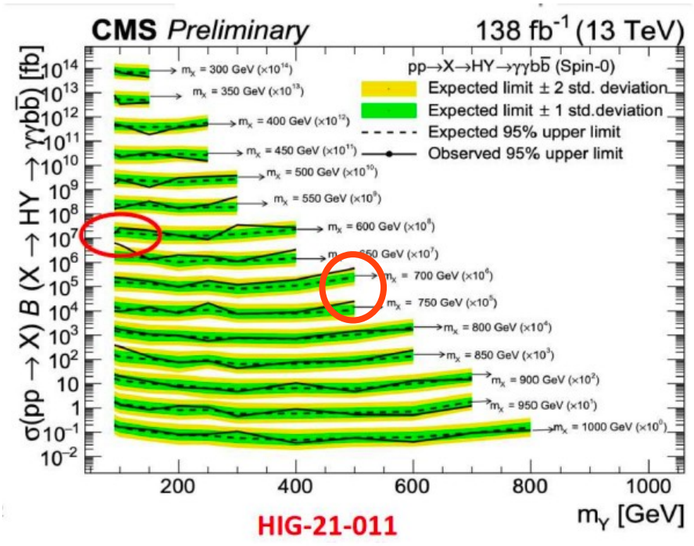
- How will the precision help to detect (and interpret) anomalies or exclude models (up to a which scale)?
- Beam polarisation vs. final state analysis
- Support of Higgs program (latest with NLO-EFT everything is entangled)?
- Compositeness
  - Could a LCF with 2 TeV centre-of-mass compete with FCC-hh?

Physics Part – Direct production of new particles

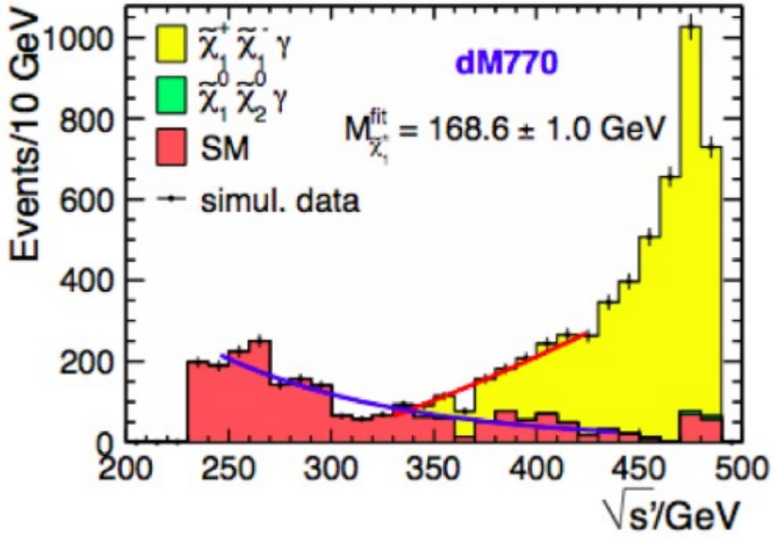
- Distinction of between intrinsic discovery potential, i.e. LHC Loopholes and reaction to/complementarity with observations at LHC
- It goes without saying that energy reach helps
- Polarisation to kill backgrounds?

Two plots from Sven's talk at Higgs Hunting





Higgsino Production

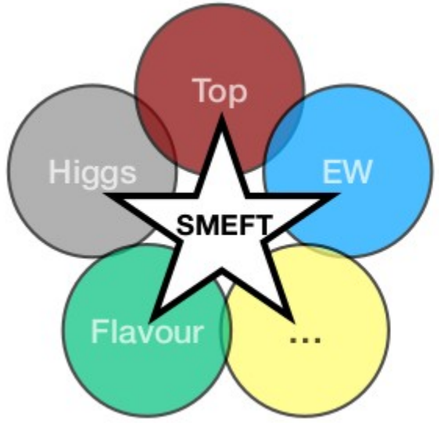


- Further examples are flavor changing neutral currents
- Others?
- Input from ECFA Study?

Physics Part – Global Interpretations

- Global interpretation is a wide field
- It looks as if SMEFT as basis is consensus (but there are also others Higgs basis …)
- NLO SMEFT seems to be the new kid on the block
- Where does a linear collider with a large energy reach and polarisation really help?

As teaser just a cartoon from Jorge's ICEPP seminar (Dec. 2023)



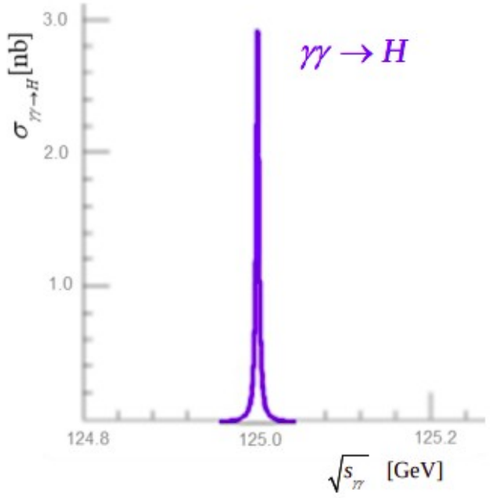
Study the different sectors globally
(i.e. including all operators)

⇒ Use Global fit (i.e. EW/Higgs/Top/Flavor)

to constraint all directions

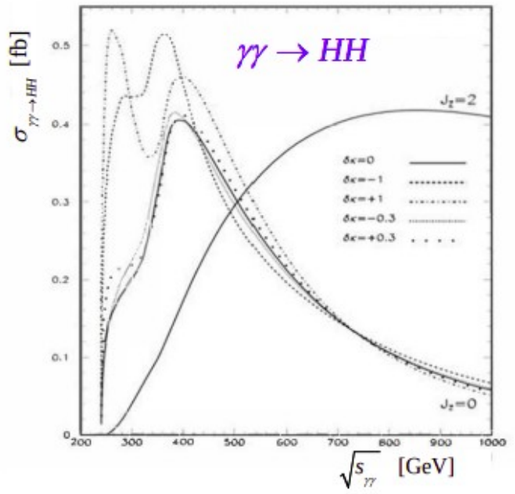
- Would the measurements described above deliver enough "input" to the global interpretations?
- What are the limits (too man parameters)?
- Interplay global interpretation, "individual" interpretation?
  - What if one really sees a pattern of deviations in Higgs, top or whatever?
- Personal remark, have to make sure that it doesn't appear too technical
  - Could one demonstrate the power of the fit at a concrete model?

- Example: Tim's slide shown at LCWS



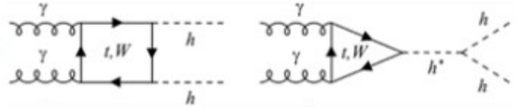
	$\sqrt{s}$ (GeV)	polarization	σ (fb)
$e^+e^- \to ZH$	250	$-80\%\ e^-\ +30\%\ e^+$	310
$\gamma\gamma \to H$	125	$+100\%\ \gamma\ +100\%\ \gamma$	3×10^6
$\mu^+\mu^- \to H$	125	$0\%\ \mu^-\ 0\%\ \mu^+$	7×10^4
$e^+e^- \to H$	125	$0\%\ e^-\ 0\%\ e^+$	1.64

† Can't take full advantage of $\sigma_{\gamma\gamma}$ =3 nb because $\gamma\gamma$ beam width < 4 MeV is impossible. But in general, narrower $\gamma\gamma$ beam width $\Rightarrow$ higher Higgs rate

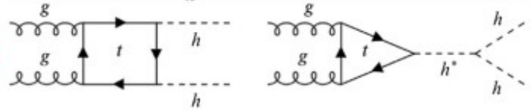


	$\sqrt{s}$ (GeV)	polarization	σ (fb)
$\gamma\gamma \to HH$	380	$+100\%\ \gamma\ +100\%\ \gamma$	0.40
$e^+e^- \to ZHH$	500 / 550	$-80\%\ e^-\ +30\%\ e^+$	0.20 / 0.22

XCC



LHC



- Narrow Higgs width is tantalising
- Complementarity in double Higgs production
- Others?

Physics Part – Non collider experiments

- Did run out of time to create a dedicated slide for tonight (Sorry)
- Keywords are:
  - QED in extreme fields
  - Dark matter searches
  - Material science?
  - What else?

LCVision Accelerator Part – Structure cont'd

- Community Event at CERN 8/1/25 – 10/1/25 https://indico.cern.ch/event/1471891/

Linear Collider Vision Community Event 2025

8–10 Jan 2025
CERN
Europe/Zurich timezone

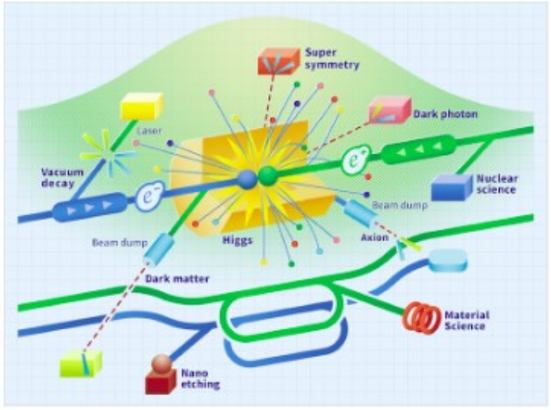
Enter your search term

Overview
Timetable
Registration
Privacy Information
Videoconference

Administrative Support
Alexia.augier@cern.ch

Born at LCWS2024, LC Vision brings together proponents and supporters of all kinds of Linear Collider projects, in order to discuss common topics, to develop a united perspective on the long-term evolution of a Linear Collider Facility, and to propose such a facility for CERN. At this meeting, the LC Vision plans for the EPPSU will presented to the interested community.

The meeting will be run in hybrid mode, the zoom link will be communicated to registered participants only. The registration is free of charge, but please register by December 15.
For participants at CERN, a number of hostel rooms has been blocked.... A visitor card for CERN can be requested during registration.



- LC Vision e-mail list (follow link)

Summary and outlook

- LC Vision aims to federate all ideas for LC technologies under one project
  - Choice of baseline such to be able to start the LC Project “now”
  - Show up ways for upgrades

- LCVision tries to convey the following messages
  - A LC is able to address the current questions in particle physics at affordable cost
    in particular it could provide a full Higgs programme
  - A LC provides a longterm vision of the field in general including CERN while not precluding or jeopardising other projects
  - A LC supports/fosters innovation and is therefore of strategic importance?

- Expert teams have been formed

- Basic structure of documents about to converge
  - Some details to be ironed out before distribution to expert team
  - Generic document will be complemented by a detector part (not discussed today)

- European strategy requires “preferred option” and alternative options for CERN
  - … but consider also projects outside of Europe

- Joining LCVision
  - Community meeting 8-10 January 2025 at CERN
  - LC Vision e-mail list (follow link)