Concise biased takes on the Granada symposium
(to introduce the discussion)

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Outline

- Almost all talks used the Alhambra's picture from the Albayzin hill. We could tell where we were (to compensate for lack of tourism).

- 600+ participants.

- Eight tracks: in no particular order: Flavours, Dark Matter, Neutrinos and astroparticles, BSM, EW, QCD, accelerators, HEP Computing / instrumentation.

- In more details, I provide in the next slides the bottomline of the physics group summaries, when it comes to the next large collider. I disregard other items, e.g. astroparticles etc…

- The Thursday morning was satisfactory for the FCC proponents: each and every talk promoted the integrated project as a wishful future physics-wise. The final open discussion was not on the same line.

Summaries: neutrinos.

Understanding the neutrino mass

- The absolute mass is still unknown (challenging task m<~0.1 eV!). Laboratory (Katrin) and cosmology missions ongoing.
- Is the neutrino a Dirac or a Majorana fermion ? Neutrinoless double beta decay searches can provide an answer to this crucial question
- The neutrino mass might require new neutral fermions with masses between eV and GUT scale (!)
  - Clarify eV scale anomalies (SBL program at FNAL, reactor neutrino experiments)
  - CERN could have a leading rôle for the Search for new states at the GeV-EW scale (beam dump and colliders)

Summaries: flavours.

Dark sector summary

There seems to be a genuine window of opportunity left open by the current data

- **Short term:**
  - By products from current flavour experiments offer cost-effective and timely explorations to of the dark sector
  - existing experiments such as NA62, NA64, FASER at CERN, among others, are valuable training grounds towards ultimate beam dump explorations
- **Medium term:**
  - Future facilities like BDF/SHiP and eSPS/LDMX will allow for significant progress to dark sectors. The BDF could have an impact also on flavour (for instance tauFV@BDF)
  - Several experiments are proposed for full exploitation of LHC/HL-LCH (e.g. MATHUSLA, CODEX-b, FASER2)
- **Longer term:** Ordinary and Dark Flavour: FCC-ee can do a lot of both (5 10^{12} Z)

We owe a big thank to the PBC study:

- "Physics Beyond Colliders" (PBC) summary: arXiv:1902.00260
- PBC BSM WG: arXiv:1901.09966

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Provided that enough *Z* decays are on tape.

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

- 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

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A note about the Flavours session

- Most of the main contributors have a friendly view on the high-luminosity *Z*-factory.

- Consensus on the mid-term plans, consensus on the farer future. Not much room for controversy.

- As far as the symposium is concerned, it was a discrete community. For the bright future, it is a significant community on to build. The reference to b, c and tau Physics was repeatedly mentioned in several other sessions.

- Advertisement: series of three lectures by Gino Isidori
  https://indico.cern.ch/event/810849/

Summaries: QCD.

FCC-ee&
eh synergy
Highlighted

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.

Thank you for your attention

Summaries: Dark Matters !

Mostly asking that CERN gets associated to DM searches at large any time it is possible / meaningful

Only mention to FCC was here

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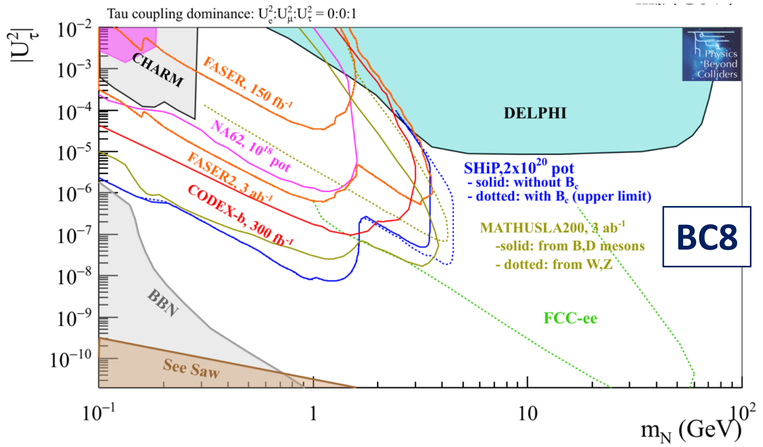
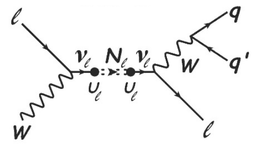
Heavy Neutral Leptons (HNL)

C. Vallee's Talk

Heavy Neutral Leptons could be connected to generation of neutrino masses, leptogenesis and appear in models of neutrino portals to the dark sector





Schematic diagram

See P. Sphicas' talk for details on Collider reach

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Summaries: EWK.

Conclusions I

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

Conclusions II

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 (also Γ_Z)
     - CLIC at high energy and FCC-hh excellent reach
   - **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

The message conveyed is that the most complete Higgs Physics program comes for the integrated FCC.

Summaries: BSM.

Extremely rich summary talk by Paris Sphicas reported here:

https://indico.cern.ch/event/808335/contributions/3365085/attachments/1845363/3027428/PPG-BSM-Summary-final.pdf

Benchmark models established for the Physics reach of the different machines:

Rather expectedly, highest mass scales reach for FCC-hh; closure of parameters space with CLIC3000.

Topics in BSM

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

Miscellanea

- S. Bethke attempted for an overview of national inputs to the ESPP.
- Italy, France and UK had to correct the interpretation.
- Judge by yourself:
https://indico.cern.ch/event/808335/contributions/3365090/attachments/1844919/3026522/Granada-nat-roadmaps.pdf
- The analysis can be redone in a more fair way but I have the feeling that the exercise is ill-defined since the statements are both outdated (since then, ILC non-decision and FCC CDR out) and resulted in some cases from a subtle synthesis of contradicting statements.

The final open discussion

- Expectedly focussed on the next large project. Let me fail to wrap it up correctly.

- Started by the noticeable statement from Michel Spiro in favour of the FCC integrated project. on behalf of ESPP#81.

- Several strong opinions against the FCC integrated program followed. There is no consensus (and a fierce competition b/w ILC, CLIC, FCC …)! The arguments heard:

  - HEP is a worldwide community. Bad to concentrate “everything” at the same place.
  - A lower-energy (Magnet ready ?TeV) FCC-pp was advocated.
  - The serial sequence ee/pp is a commitment that should not be taken (with support from LC and pp against highE pp and ee-factories, resp. and vice-versa … maximal entanglement)

- There was a hiatus (I felt it this way) b/w the Physics ordering attempt of the meeting (based on the project documented materials) and the not-much Physics oriented statements delivered.

- It is not following the path that is difficult, but it is difficulty that is the path (Kierkegaard).