Highlights from the Corfu Future Accelerators Workshop

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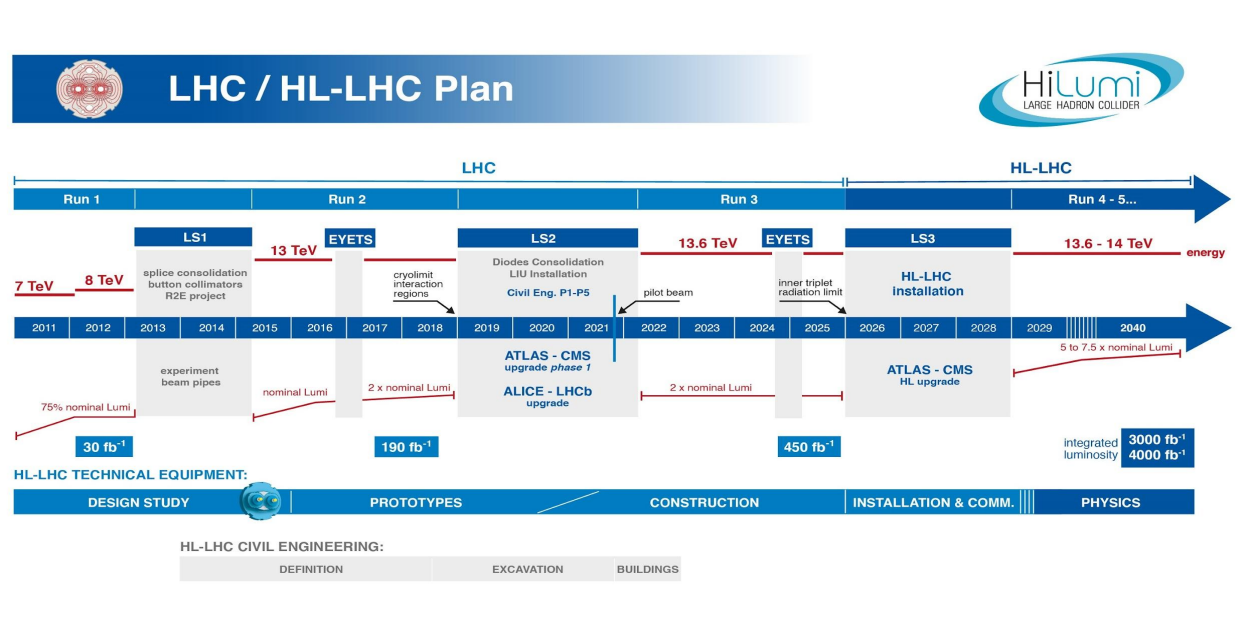
INFN - Sezione di Genova

1 September 2024

Corfu Workshop on the Standard Model and Beyond

Varkarola, Corfu – 7 August 2011

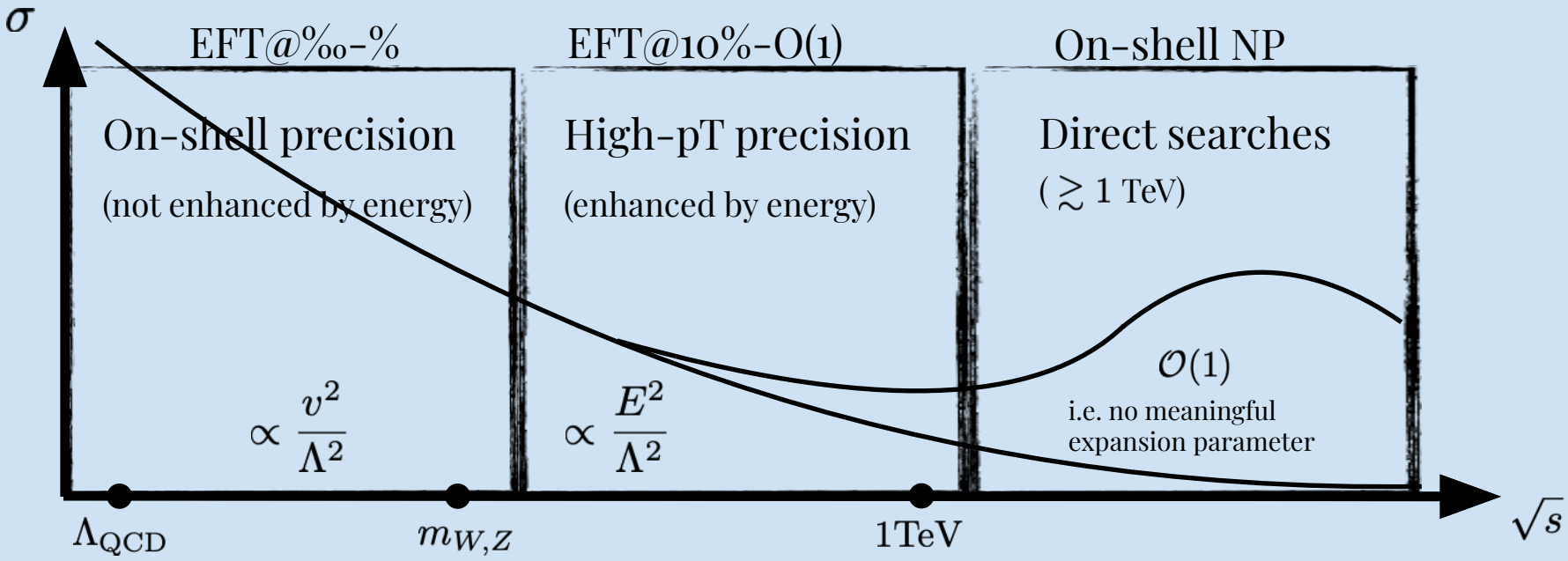
Where do (will) we start from?



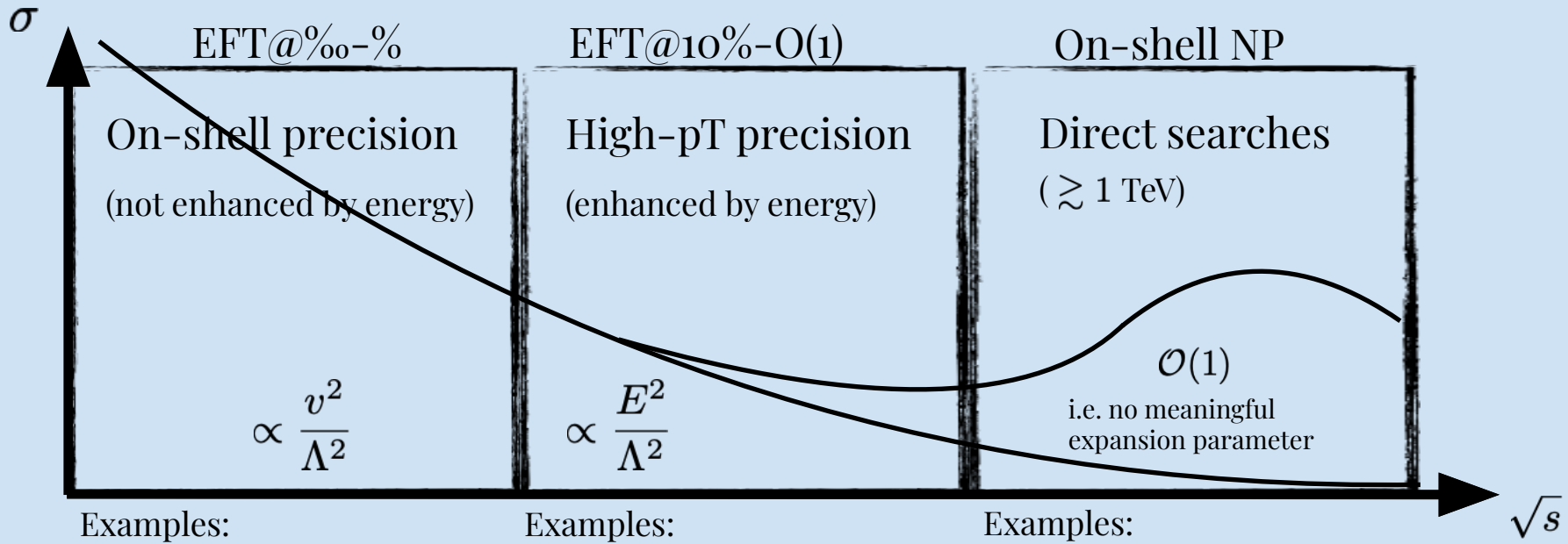
Main goal: find signs of new physics

- Directly: probing on-shell NP
- Indirectly: probing the effect of NP on precisely measured SM observables

Which NP?


σ
EFT@‰-%
EFT@10%-O(1)
On-shell NP
On-shell precision
(not enhanced by energy)
High-pT precision
(enhanced by energy)
Direct searches
($\gtrsim$ 1 TeV)
$\propto \frac{v^2}{\Lambda^2}$
$\propto \frac{E^2}{\Lambda^2}$
$\mathcal{O}(1)$
i.e. no meaningful
expansion parameter
$\Lambda_{\rm QCD}$
$m_{W,Z}$
1TeV
$\sqrt{s}$

Which NP?



Examples:

- SM parameters
- Pole observables
  e.g. S, T, etc.
- Higgs observables

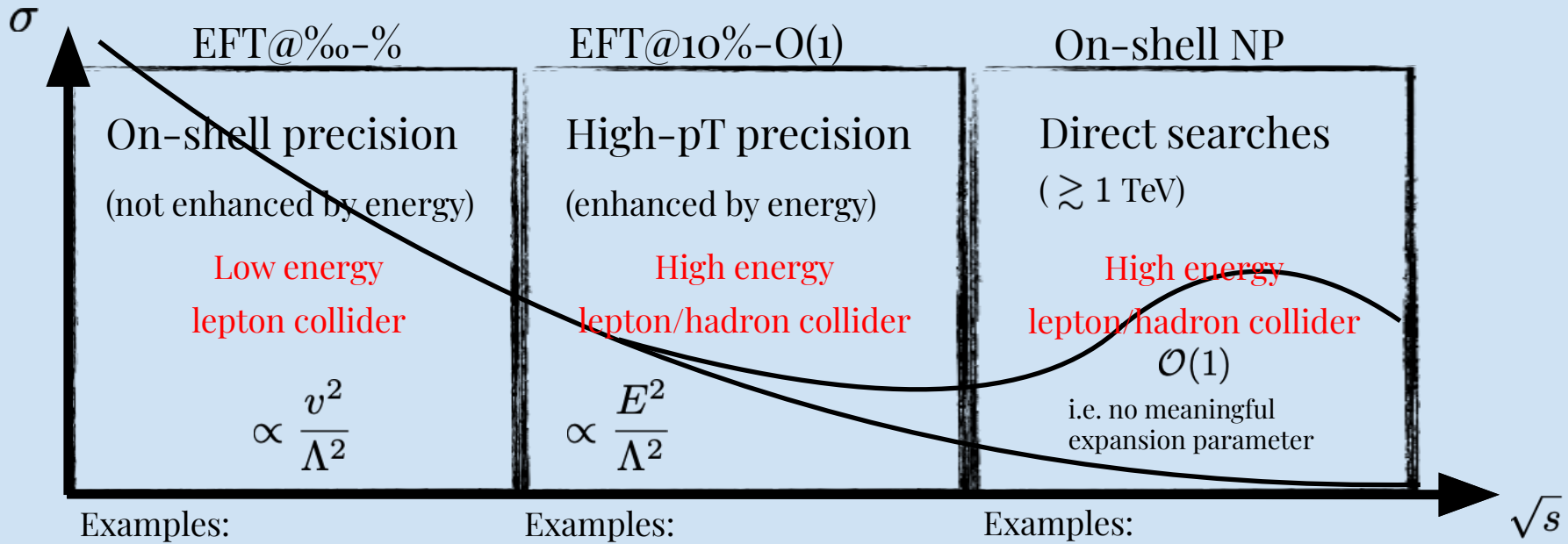
Examples:

- DY (e.g. W, Y, etc.)
- Di-bosons
- Di-jets
- Heavy quarks ($t\bar{t}$, etc.)

Examples:

- SUSY
- Top partners
- Resonances

Which NP?



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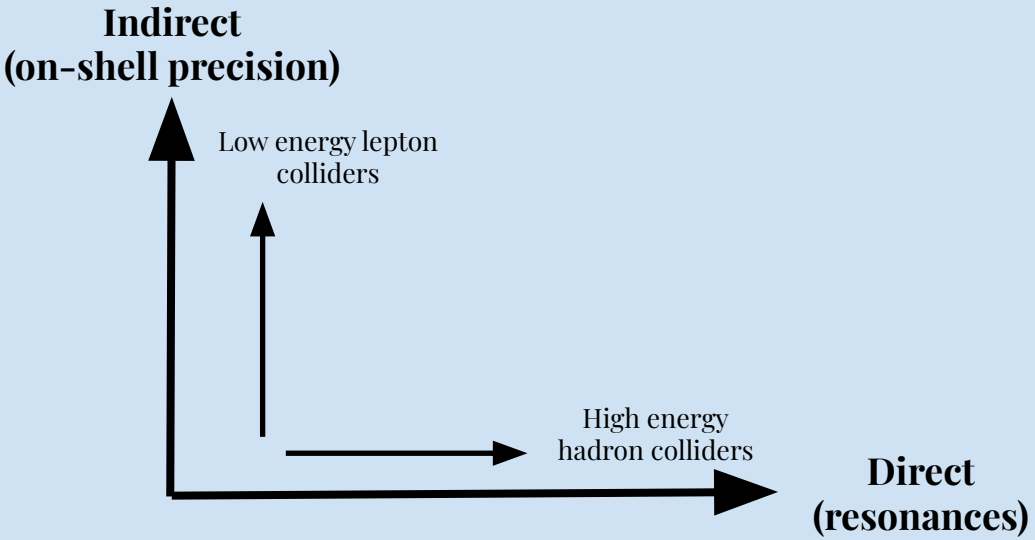
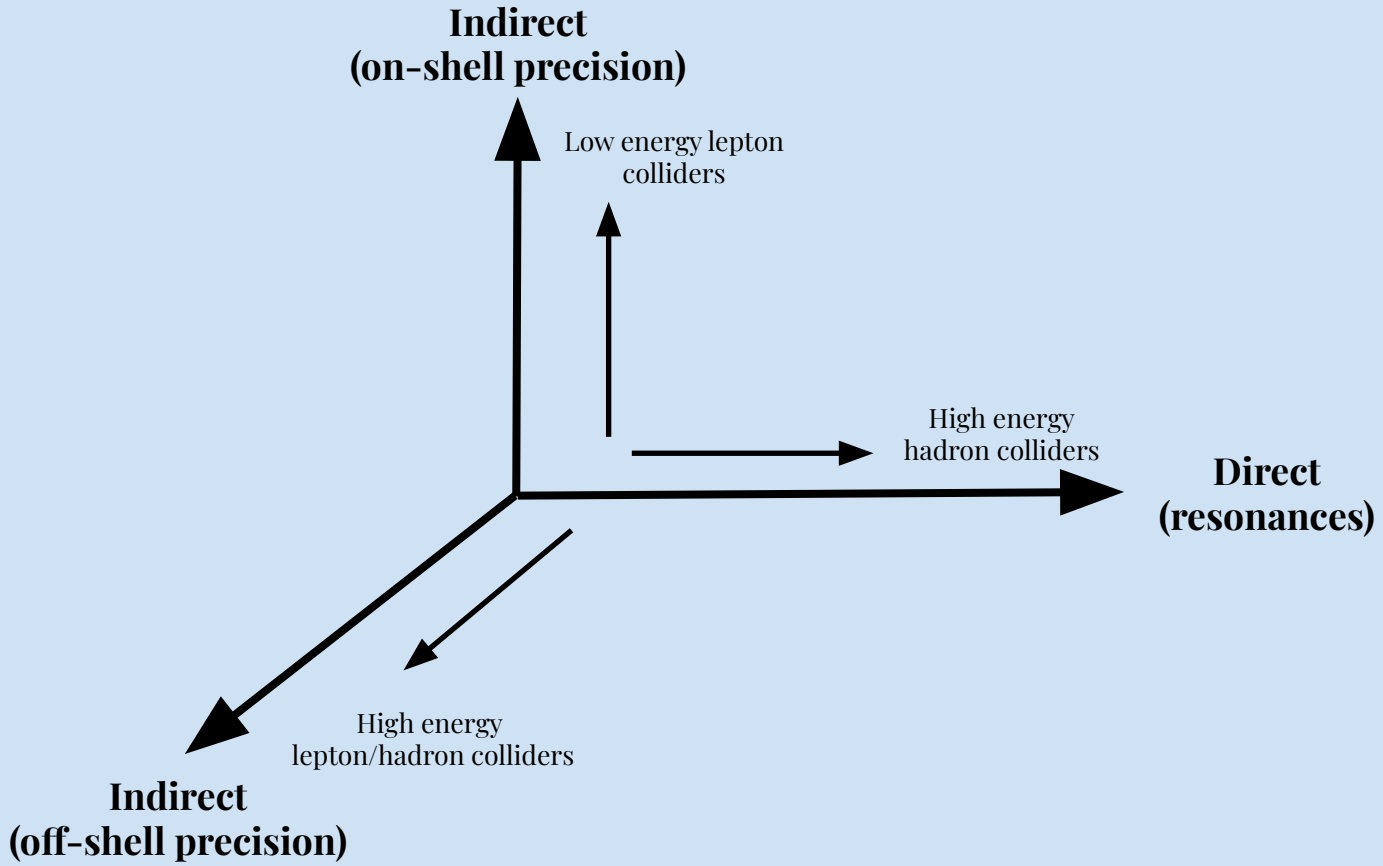
Future colliders in 3D



Future colliders in 3D



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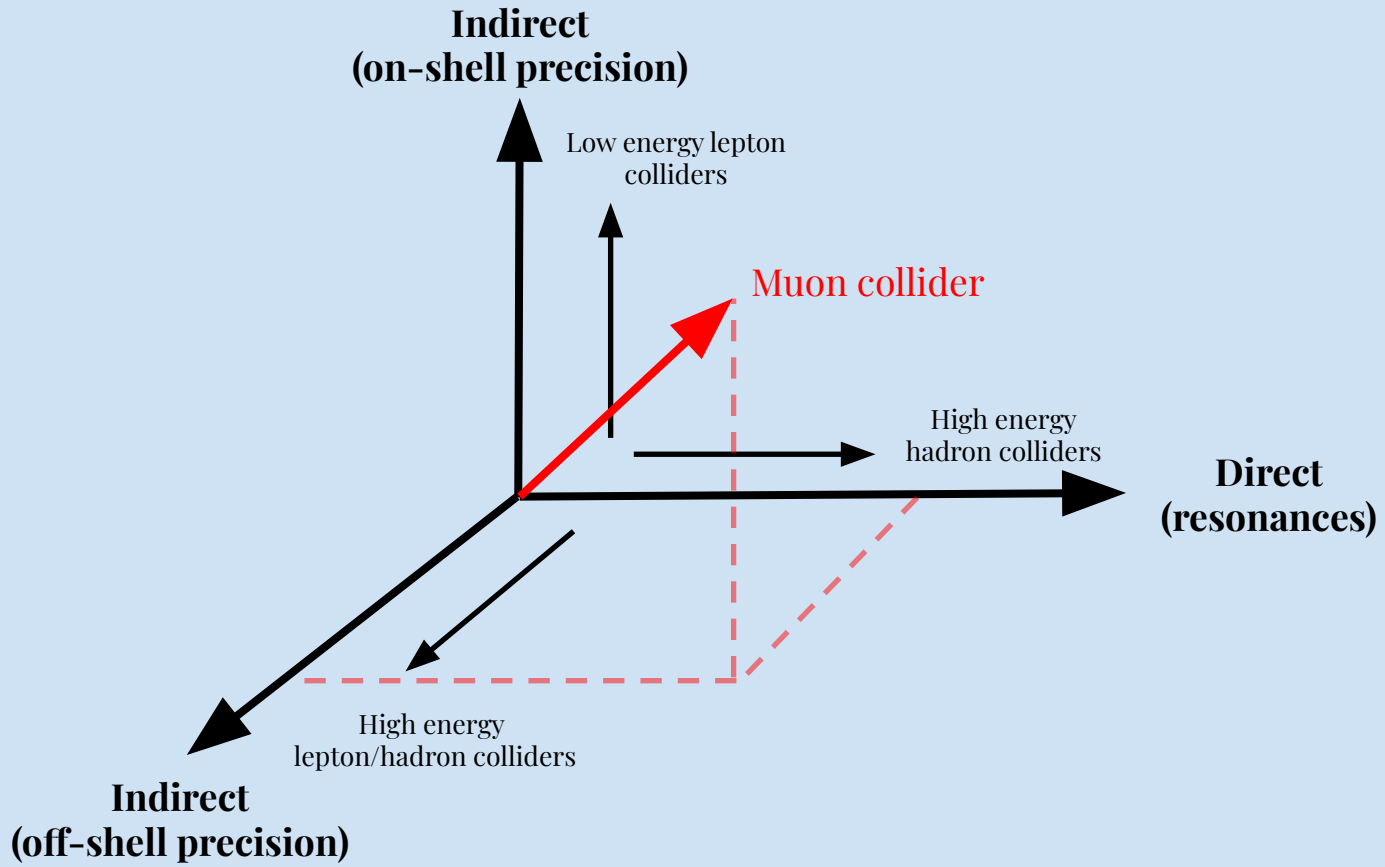

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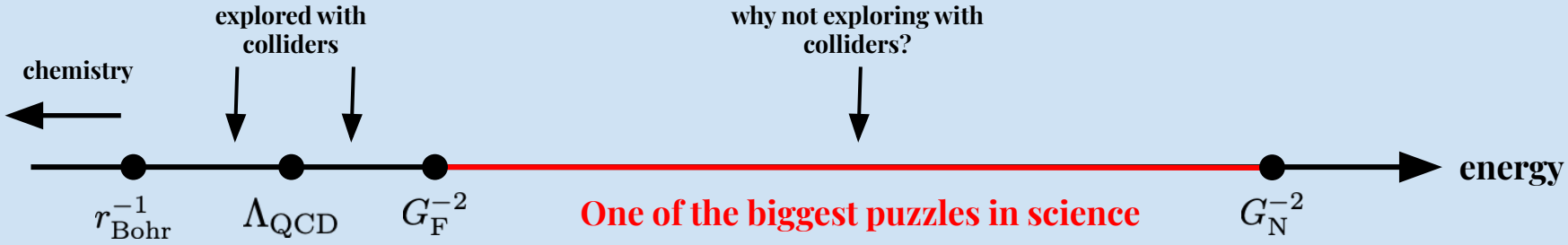

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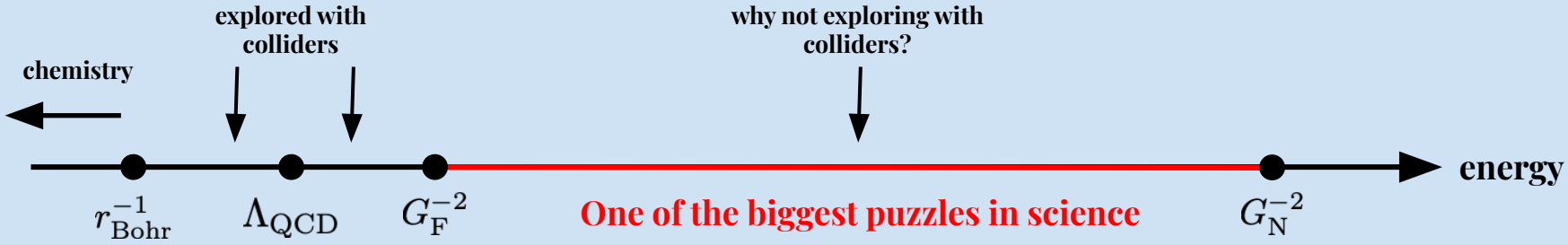

Advantages

- Only technique to probe higher energies model independently (agnostically)
- Experimenter defines experimental setup
- Repeatable (experimental ≠ observational)
- Measurement of SM in new energy regime and to unprecedented prevision
- Answer well posed questions about SM and BSM
- Tremendous impact on science and technology

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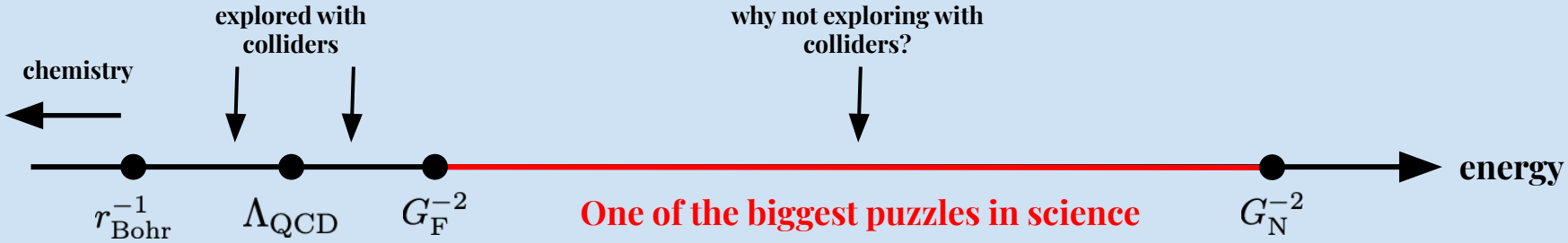

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Challenges

- Energy increases very slowly with time/money (driven by tech evolution, but not only)
- Need to convince funding agencies (the physics case is as simple as above, but it requires understanding of the scientific method and large funds)
- Long term planning is becoming harder due to the increasing speed of tech advance
- Keep the community engaged (or even alive)

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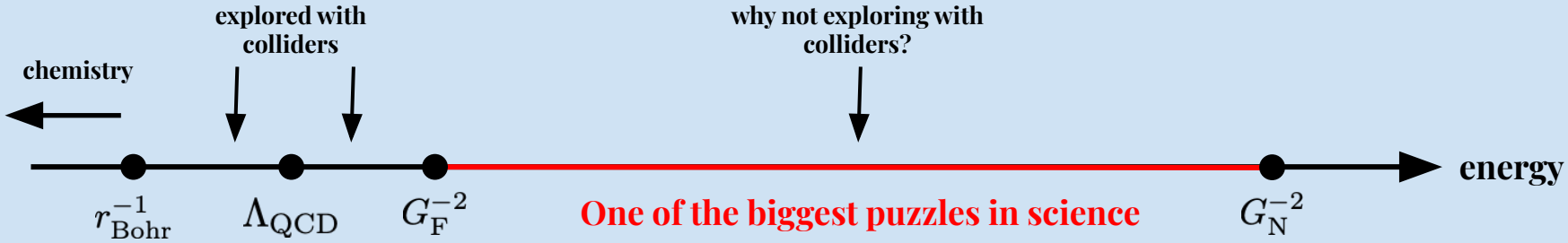

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We have no guarantee of any discovery, but
guarantees cannot be a criterion for fundamental research.
There is anyway the guarantee of a spectacular physics program!

Why colliders?

Collider physics is the only general-purpose experimental research field in fundamental science

- Only te… indepe…
- Experi…
- Repeat…
- Measu… unprece…
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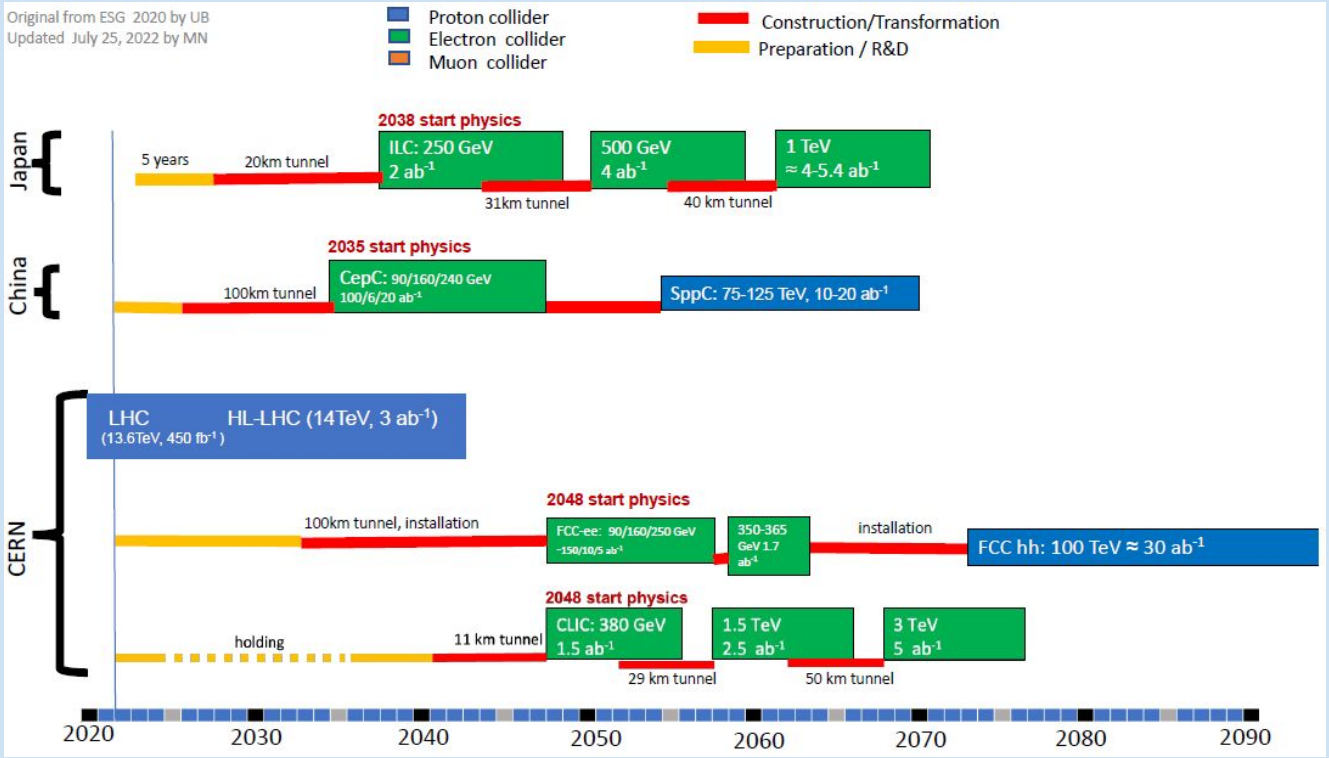
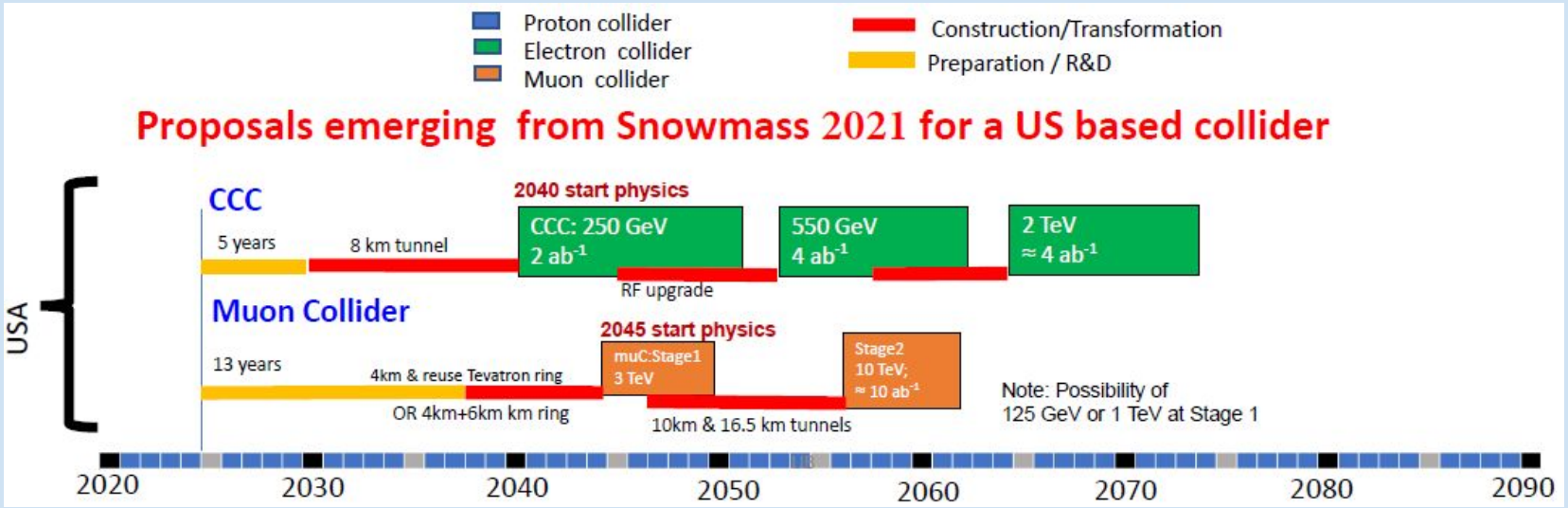


Snowmass Energy Frontier summary, 2211.11084

Which colliders?



Snowmass Energy Frontier summary, 2211.11084

The Corfu FA Workshop: a growing success!

- **23-29 April 2023**
  - First edition, 5 days
  - 39 talks + summary talk by Alain Blondel
- **19–26 May 2024**
  - Second edition, 6 days
  - 56 talks + summary talk by Michelangelo Mangano

The program is very timely given the forthcoming update of the European Strategy for Particle Physics (anticipated to 2025)

The European Strategy for Particle Physics

- In March 2024 the CERN Council launched the update of the ESPP (one year in advance)
- The process will be completed in June 2026
- During this time the case for future colliders should be made stronger and studies should be improved towards more realistic scenarios compared to the last strategy (i.e. improve over FCC CDR, etc.)
- A realistic path towards future colliders needs to be built around a large consensus and a better international coordination (CepC, ILC, etc.), that are both lacking at the moment

Is there consensus in the HEP community?

There is currently no consensus in the community about FC
HEP is (fortunately) also a matter of "taste"

The "negationist"

"Collider physics is "dead, we don't need a new collider!"

The "conservative"

"We obviously need a new lepton collider, such as FCC-ee!"

The "progressivist"

"China will do CepC, we should be ambitious and go for a FCC-hh!"

The "dreamer"

"We should immediately start a program towards a muon collider!"

- Physicists tend to have "strong" opinions
- Geo/political factors have a large impact

The negationist (no FC)

"Collider physics is dead, we don't need a new collider!"

Arguments

- LHC found nothing
- There are several other fields, e.g. related to astro-particle, who would take advantage from dropping the FC program
- Too hard to keep the community engaged for a long time during construction, especially if we go for "existing" technology and "modest" discovery reach (FCC-ee)
- S&T challenges are moving to fields other than HEP

Counter-arguments

- LHC delivered the most incredible experimental program to date, which is a great success!
- Other fields need to be followed "independently" of the decision of building a new collider: good research should go on in parallel, not compete
- Worries about community engagement are overestimated: people will always like to do research to answer fundamental questions
- New fields at the edge of S&T research will be new weapons for our research, not against our research

The conservative (FCC-ee/CepC)

"We obviously need a new lepton collider, such as FCC-ee!"

Arguments

- Any path towards continuation of a collider physics program will first require new precision measurements
- Unprecedented opportunity for precision measurements
- LHC could not have existed without LEP
- Technology already exists, so we will have simpler life convincing funding agencies that this would lead to a successful program
- Maybe a higher energy linear collider such as ILC/CLIC can be another option

Counter-arguments

- Building something that falls within "existing technology" will lower the level of new challenges compared to the past
- Harder to attract "the best people" to do something roughly within present technology
- While the opportunity for precision measurements is incredible, it cannot match the discovery potential of a hadron collider, so we should go directly for the latter, maybe with limited energy (~30/40TeV?)
- Linear colliders do not have neither the FCC-ee lumi, nor the FCC-hh energy, not worth investing on them

A personal remark

FCC-ee should NOT be thought of as the new LEP: with new physics knowledge, techniques, technology, tools, we could get much more than at LEP and doing physics at FCC-ee will be radically different than doing physics at LEP

The progressivist (HE-LHC/FCC-hh)

"China will do CepC, we should be ambitious and go for a FCC-hh!"

Arguments

- Two (FCC-ee/CepC) or even more (ILC/CLIC) lepton collider programs around the world are too much. China could focus on CepC while Europe should directly head towards FCC-hh
- FCC-hh is a discovery machine
- FCC-hh could also be a precision machine
- Since technology for ≳ 40 TeV will require very long time, one can envisage a preliminary "HE-LHC" phase
- The program is ambitious enough and with enough discovery potential that keeping community engaged will not be an issue

Counter-arguments

- Europe (CERN) cannot rely on the choices that China/Japan will make and anybody should go on independently
- FCC-hh "useless" without precise SM input measurements at a lepton collider
- Technology does not exist and will take a long time (first physics run > 2050)
- Going for an intermediate phase (HE-LHC) would make it "much more" expensive for a "modest" gain
- Harder to get funds compared to FCC-ee, while simpler after FCC-ee (tunnel already built)

The dreamer (muon collider)

Arguments

- This is the hardest challenge, so we should undoubtedly go for it
- Joins the high energy reach of FCC-hh and the high precision of FCC-ee
- A conceptually new direction in collider physics (nothing ever seen before)

Counter-arguments

- Technology does not exist and will not exist for a long time
- Too ambitious and with too little know-how to be allocated the huge funds it would need to make real progress
- Need to keep R&D alive, but not commit to it
- May become an inconclusive fund draining project that is not the standard in HEP

Some more lessons I learnt from the Corfu FA Workshop

- More reviews than new results
- Most studies assume design/running/analysis at FC will be performed with present tools and technology
- Conservative approach on S&T that is kind of new in the field of colliders: "we state that we are able to do only what we are already able to do today"
- Future planning requires a broader view, opened towards tools and technology developments also outside our field
- Two examples: AI & Quantum Computing

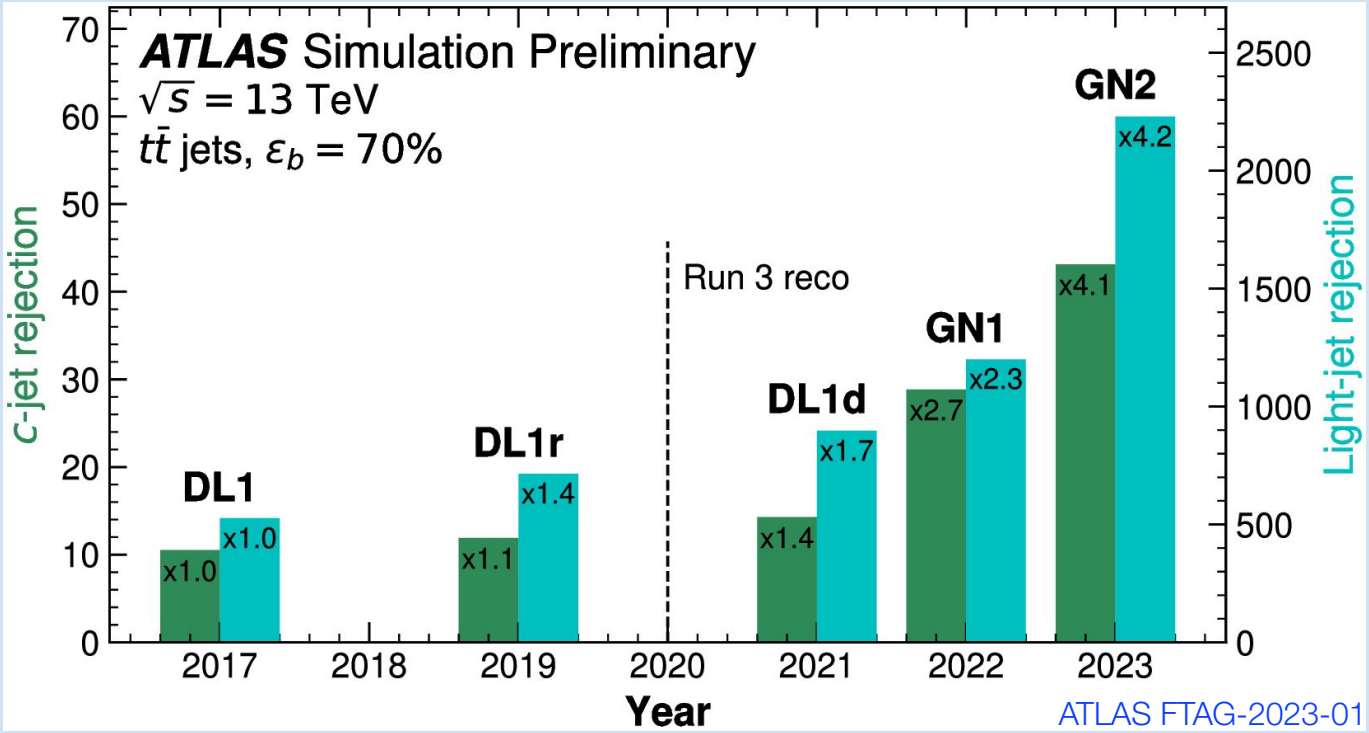
AI for FC

The impact of the current AI revolution may be O(1) on our FC planning

- Machine/detector R&D and design
- Data taking and monitoring (what if triggers will not be needed anymore?)
- Analysis techniques (also for projections and extrapolations)
- Object reconstruction
- Theory predictions (e.g. decrease theory errors by increasing efficiency/speed of numerical integration/sampling, etc.)
- Physics interpretations (meaningful fits with hundreds/thousands of parameters?)

See T. Golling talk at Corfu FA Workshop 2024

An example: c-flavor tagging



Factor of 4x in 4 years!

An example: c-flavor tagging

Factor of 4x in 4 years!

Future plans for the Corfu FA Workshop

- We aim at making the workshop a standard yearly appointment for Future Collider studies/planning
- Given the existence of tens of important meetings/workshops, we need to find a "unique" identity for our workshop
- Such identity can come from the interplay of progresses in AI&QC and FC
- This interdisciplinarity at the edge of knowledge also makes a good case for a COST action proposal/application

Proposal details

Proposal "PI": Riccardo Torre (INFN - Genova)

- Need to build a valid and "credible" network, including leading centers for Future Collider studies and leading centers for AI/Quantum Computing
- Future Accelerator Corfu Workshop worked well in the last two years and will act as prototype of the central proposed activity
- If you are interested in participating, please **reach us out**!
  - riccardo.torre@ge.infn.it
  - george.zoupanos@cern.ch
  - kostas.kordas@cern.ch
  - kalino@fuw.edu.pl
  - tevong.you@cern.ch
  - frank.simon@kit.edu
  - oliver.kortner@cern.ch

AI and Quantum Computing for Future Colliders

- Favour interactions among communities of theorists and experimentalists studying Future Colliders and physicists looking at new "computing technologies"
- Favour interactions between different generations of scientists supporting continuity of the field
- Corfu Future Accelerators workshop a central event for the action
- Corfu Summer Schools on Future Colliders physics and on new techniques also desirable

Thank you for your attention!