UNIVERSITEIT GENT

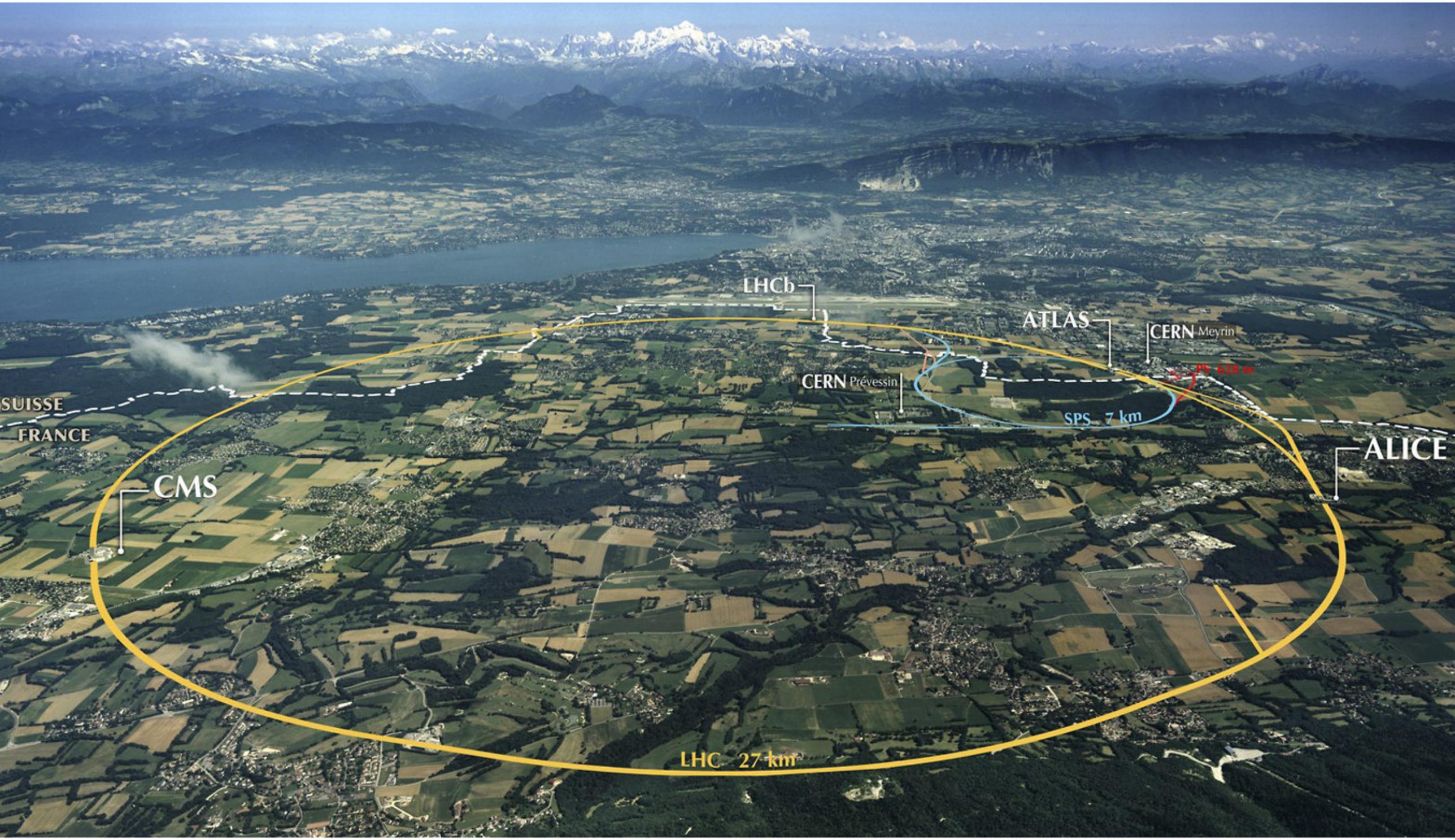
Future Collider Experiment

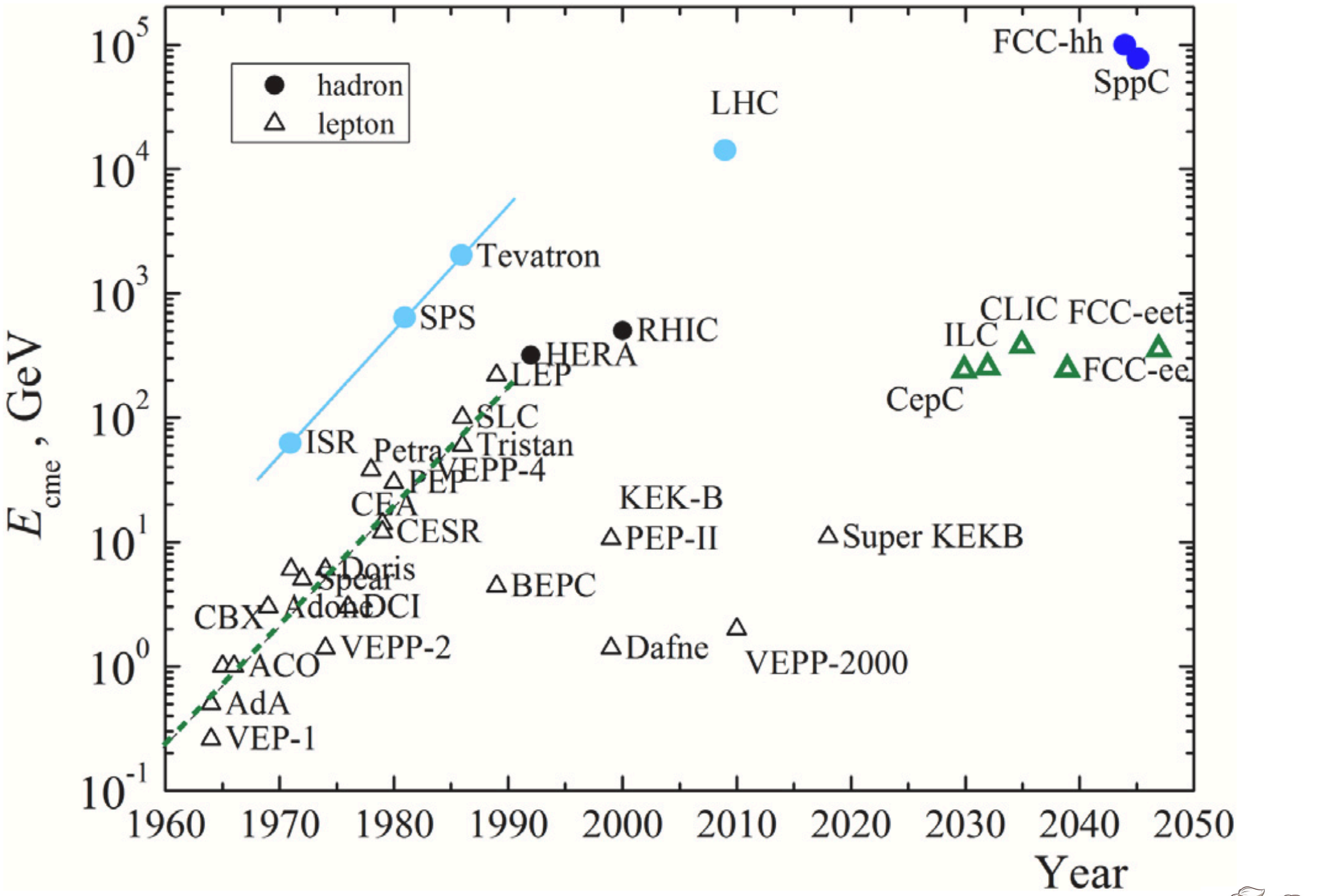
Kirill Skovpen (Ghent University)

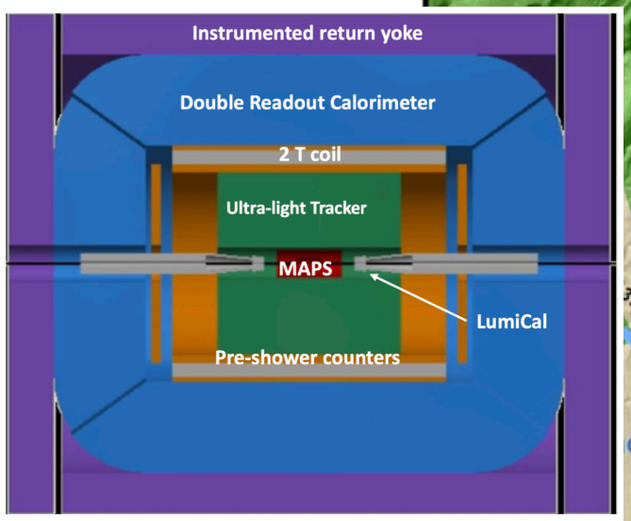
28th IPPOG meeting

CERN

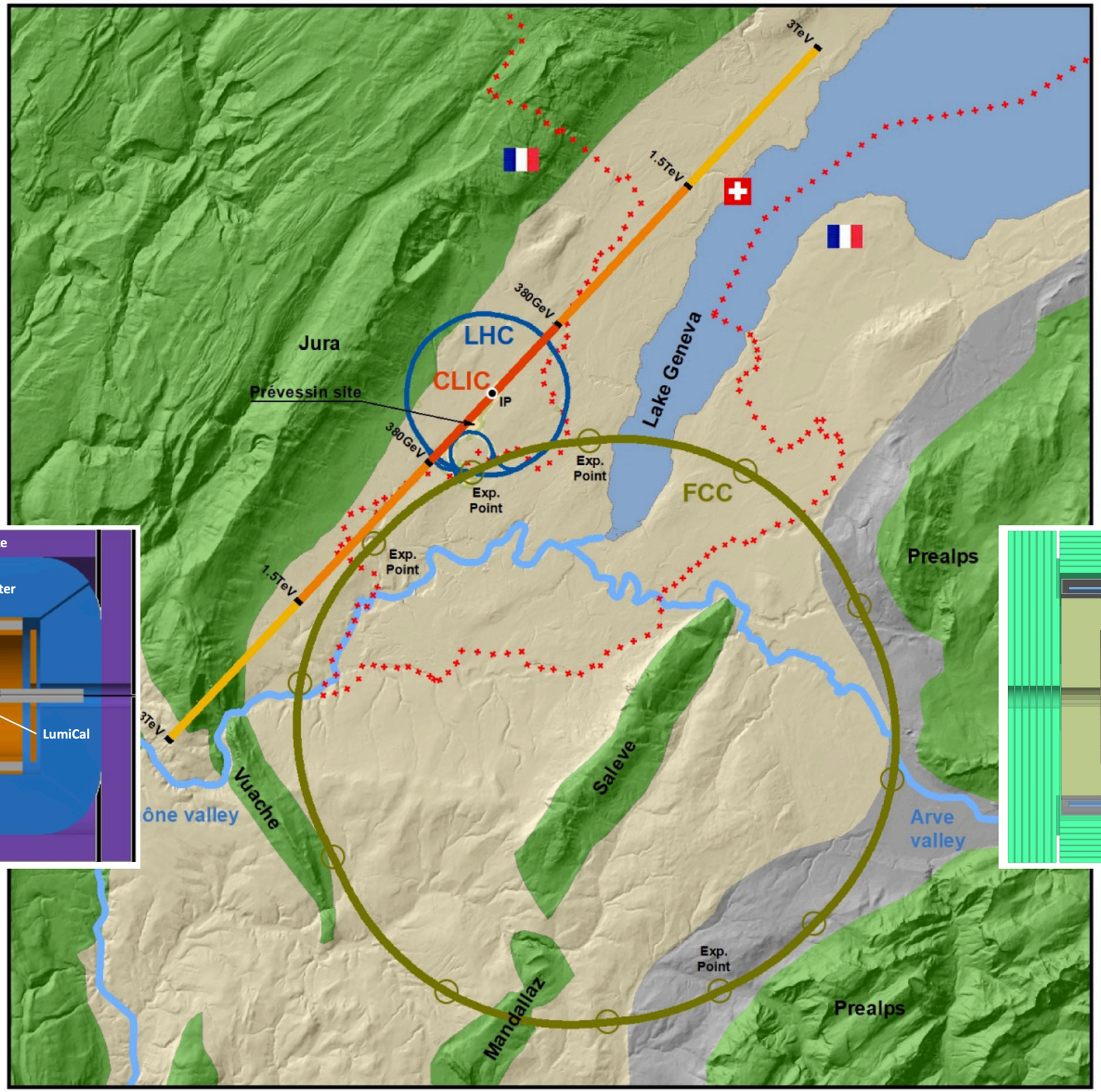
November 25-27, 2024

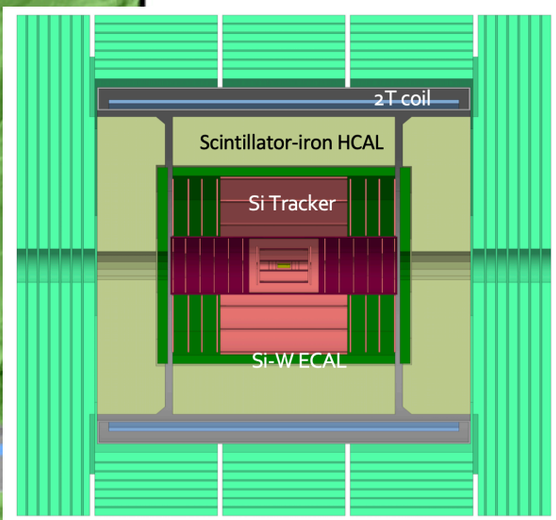

LHCb
ATLAS
CERN Meyrin
CERN Prévessin
PS 628 m
SPS 7 km
SUISSE
FRANCE
ALICE
CMS
LHC 27 km


hadron
lepton
FCC-hh
SppC
LHC
Tevatron
SPS
RHIC
HERA
LEP
SLC
Tristan
ISR
Petra
VEPP-4
PEP
CEA
CESR
KEK-B
PEP-II
Super KEKB
Doris
Spear
BEPC
CBX
Adone
DCI
VEPP-2
Dafne
VEPP-2000
ACO
AdA
VEP-1
CLIC
FCC-eet
ILC
FCC-ee
CepC
E_{cme}, GeV
Year
10^5
10^4
10^3
10^2
10^1
10^0
10^{-1}
1960
1970
1980
1990
2000
2010
2020
2030
2040
2050


Instrumented return yoke
Double Readout Calorimeter
2 T coil
Ultra-light Tracker
MAPS
LumiCal
Pre-shower counters

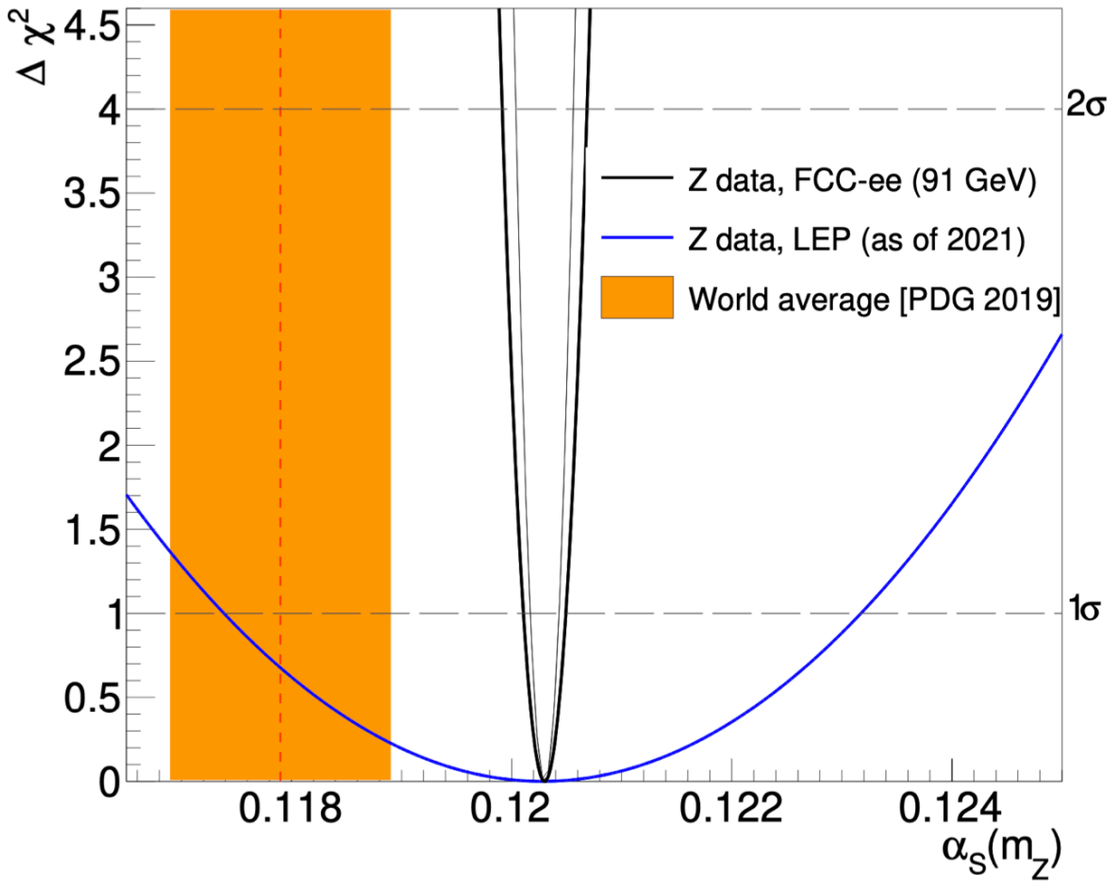
IDEA

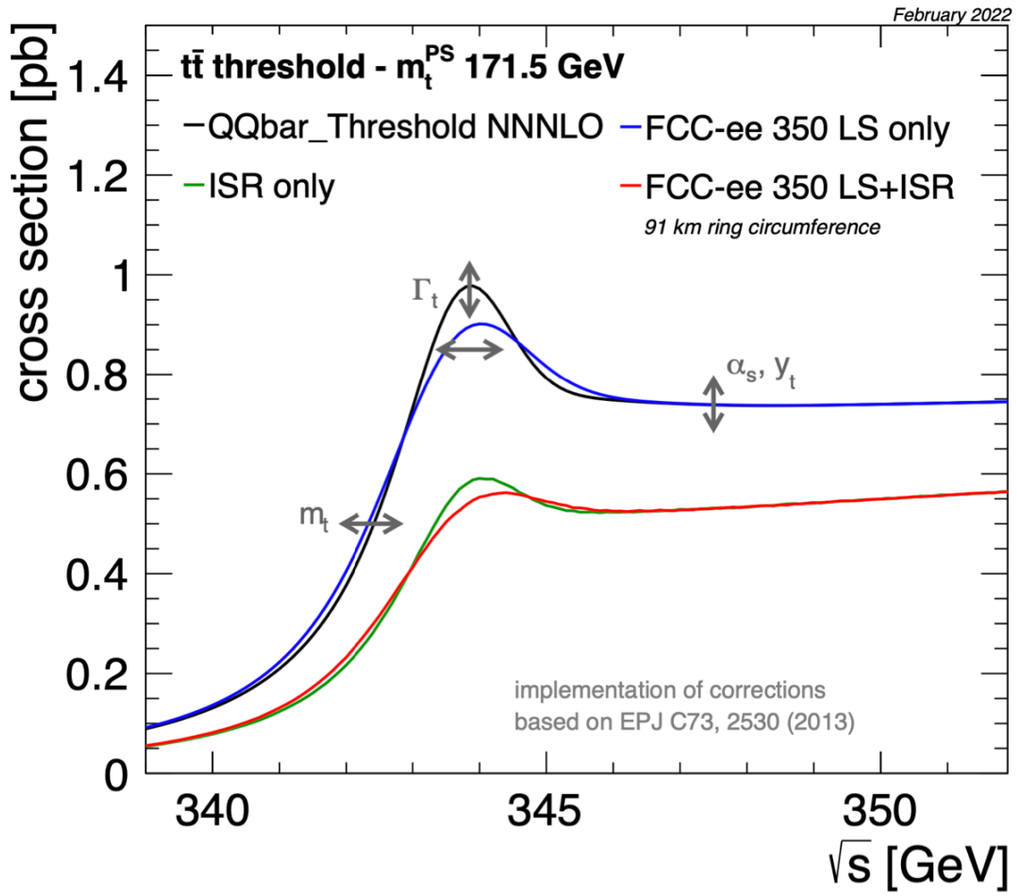

3TeV
1.5TeV
380GeV
LHC
CLIC
IP
Jura
Prévessin site
Lake Geneva
Exp. Point
FCC
Prealps
Vuache
Saleve
Arve valley
Mandallaz
LHC
CLIC
FCC
Limestone
Molasse
Molasse subalpine

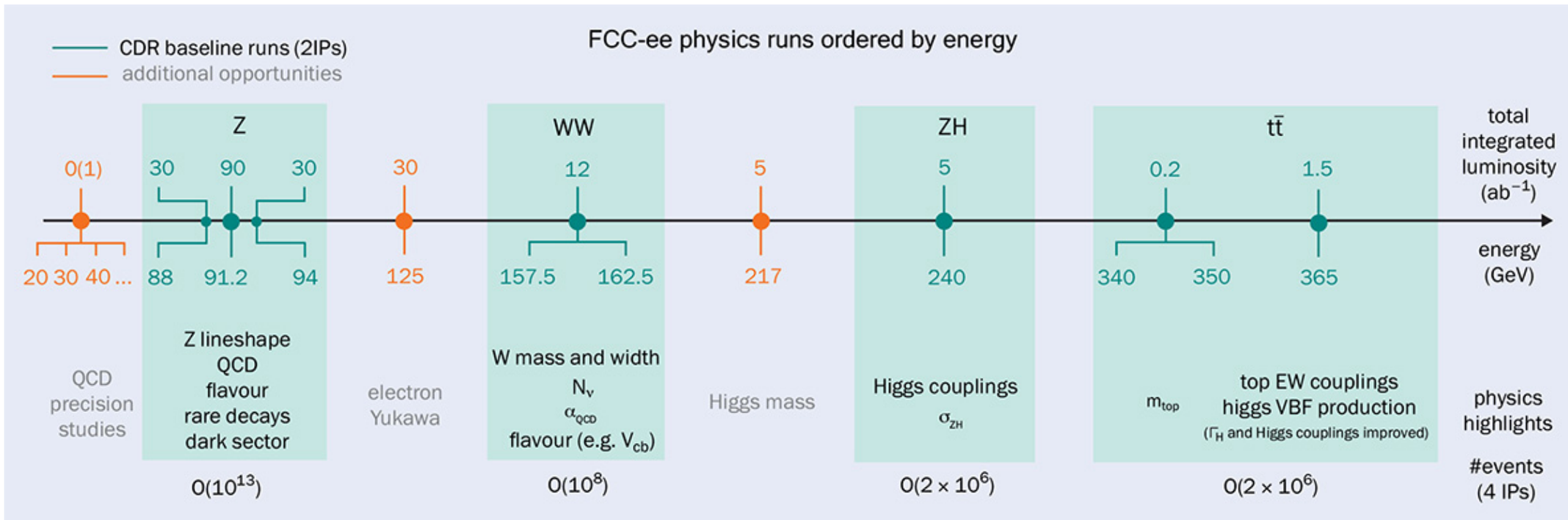

2T coil
Scintillator-iron HCAL
Si Tracker
Si-W ECAL

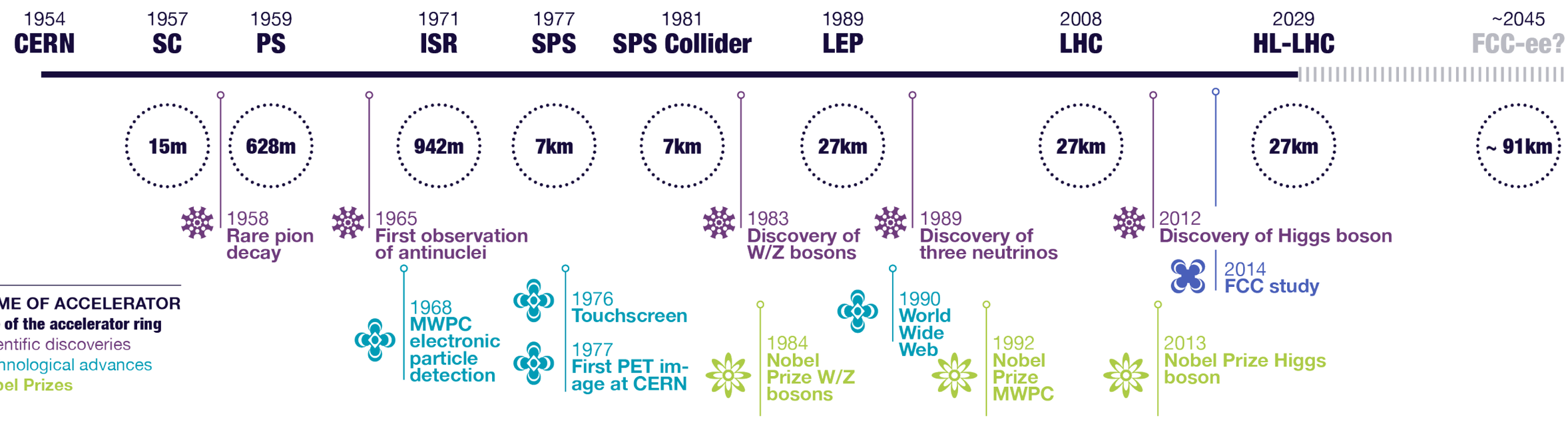
CLD

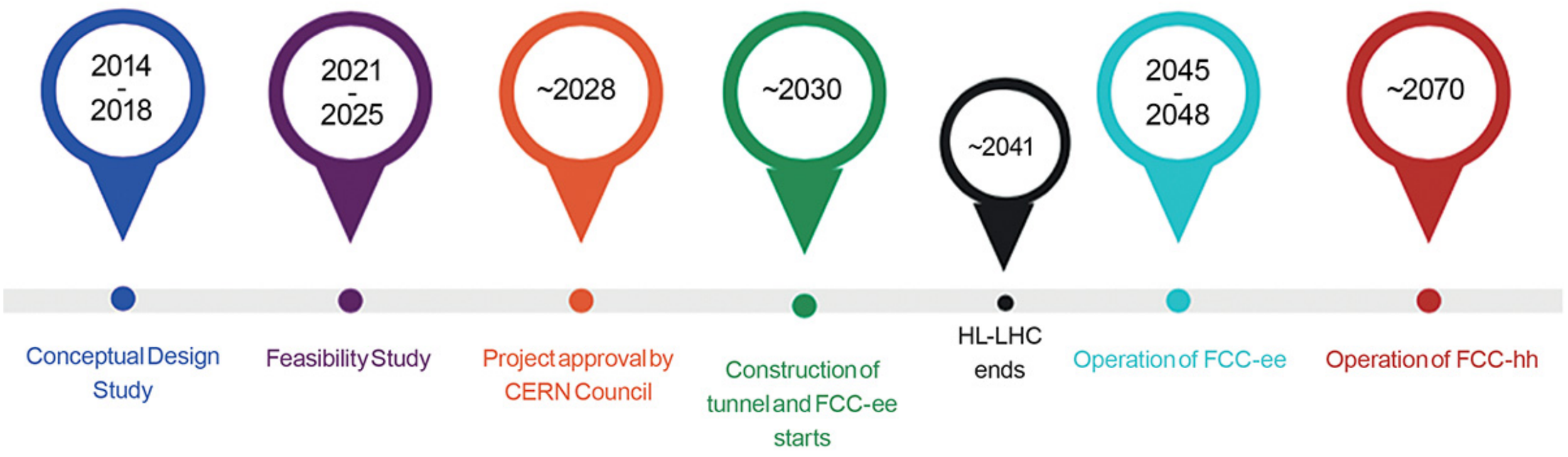
FCC-ee physics case








1954
CERN
1957
SC
1959
PS
1971
ISR
1977
SPS
1981
SPS Collider
1989
LEP
2008
LHC
2029
HL-LHC
~2045
FCC-ee?
15m
628m
942m
7km
7km
27km
27km
27km
~ 91km
1958
Rare pion decay
1965
First observation of antinuclei
1983
Discovery of W/Z bosons
1989
Discovery of three neutrinos
2012
Discovery of Higgs boson
2014
FCC study
1968
MWPC electronic particle detection
1976
Touchscreen
1977
First PET image at CERN
1984
Nobel Prize W/Z bosons
1990
World Wide Web
1992
Nobel Prize MWPC
2013
Nobel Prize Higgs boson
NAME OF ACCELERATOR
Size of the accelerator ring
Scientific discoveries
Technological advances
Nobel Prizes


2014 - 2018
Conceptual Design Study
2021 - 2025
Feasibility Study
~2028
Project approval by CERN Council
~2030
Construction of tunnel and FCC-ee starts
~2041
HL-LHC ends
2045 - 2048
Operation of FCC-ee
~2070
Operation of FCC-hh

Our today's students have a chance to witness the results of the next big collider project

How to keep them involved?

The project:
Future **C**ollider **E**xperiment

- **Time travel** a few decades into the future
- **Discover** how the physics analysis works with the data taken by the next-generation collider experiments
- **Measure** the already known processes
- **Hunt** for new particles and interactions

BND2024

- Schools organized every year for **Belgian-Dutch-German PhD students in HEP**
- This year BND was organized on the **Belgian coast** in Blankenberge: https://indico.ugent.be/event/32/
- **Two weeks** of lectures
- Students worked together in **small groups** on diverse research projects
- One of the project themes: **future colliders**

User interface

- Use the **fce** analysis tool (platform-agnostic)
- Get it via **pypi**: https://pypi.org/project/fce/

➡ pip install fce --user

Histogram creation

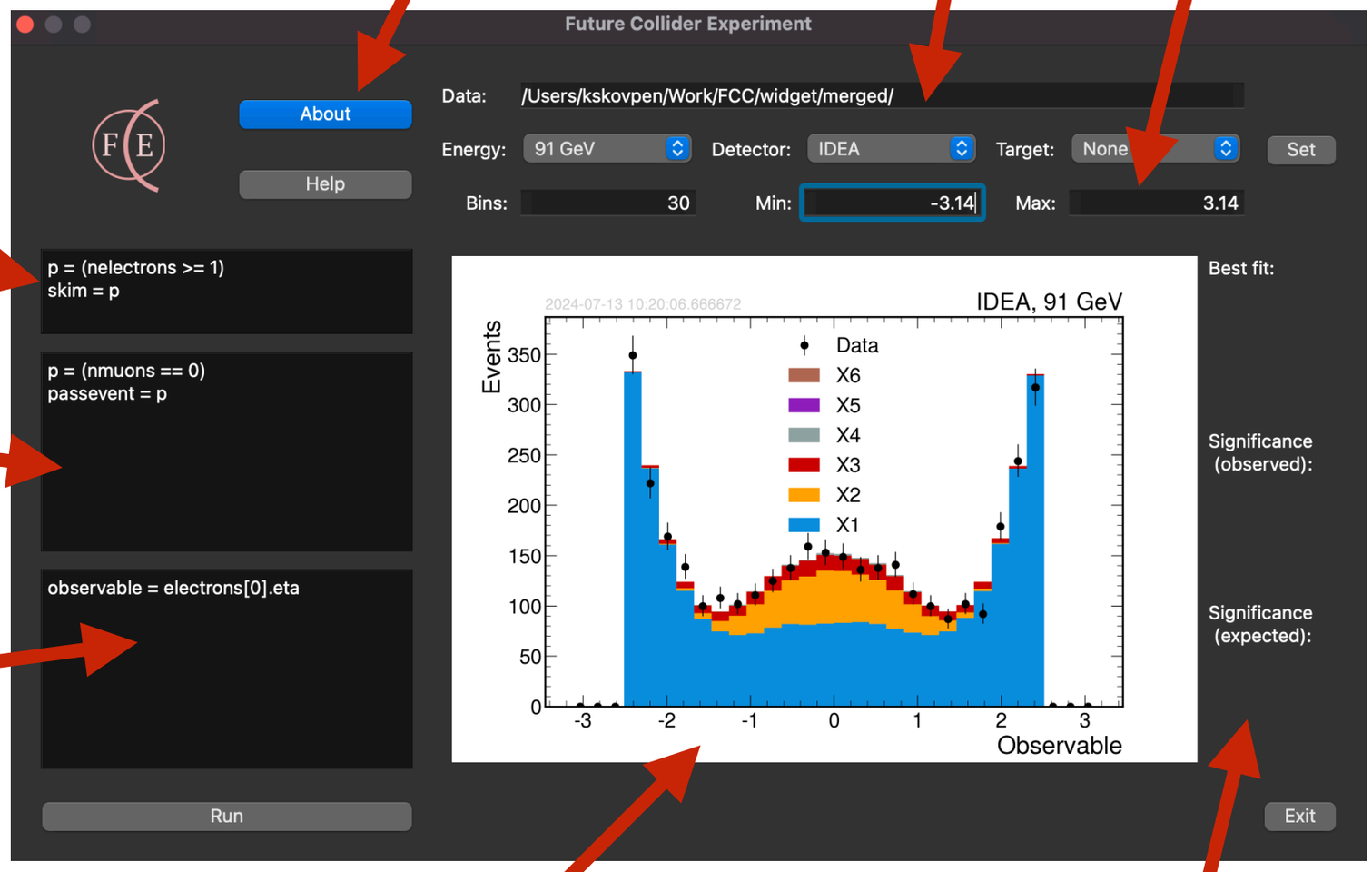
Dataset selection

List of predefined **variables**

Event **skim** selection

Event **selection** criteria

Define the main analysis **observable**



*N.B.: Code syntax is **python**!*

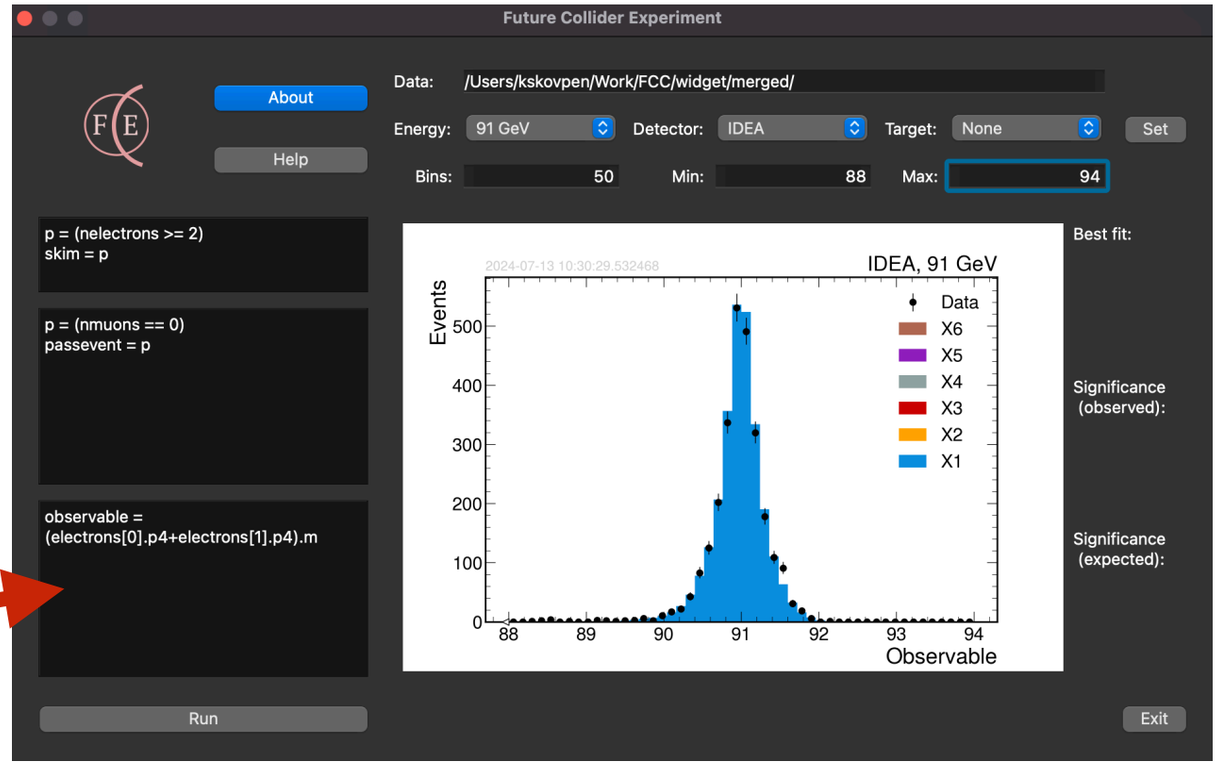
Analysis **result**

Statistical analysis

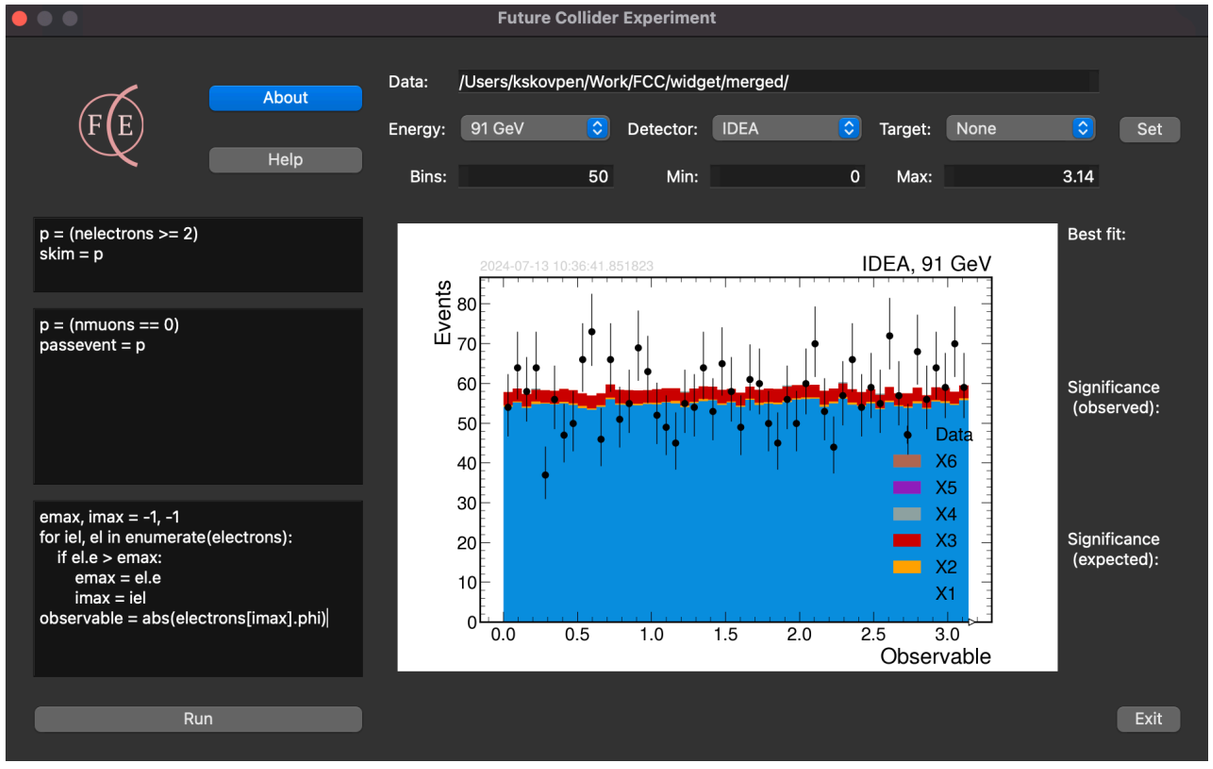
Analysis examples

Invariant mass of two electrons

Vector operations as defined by **vector** library



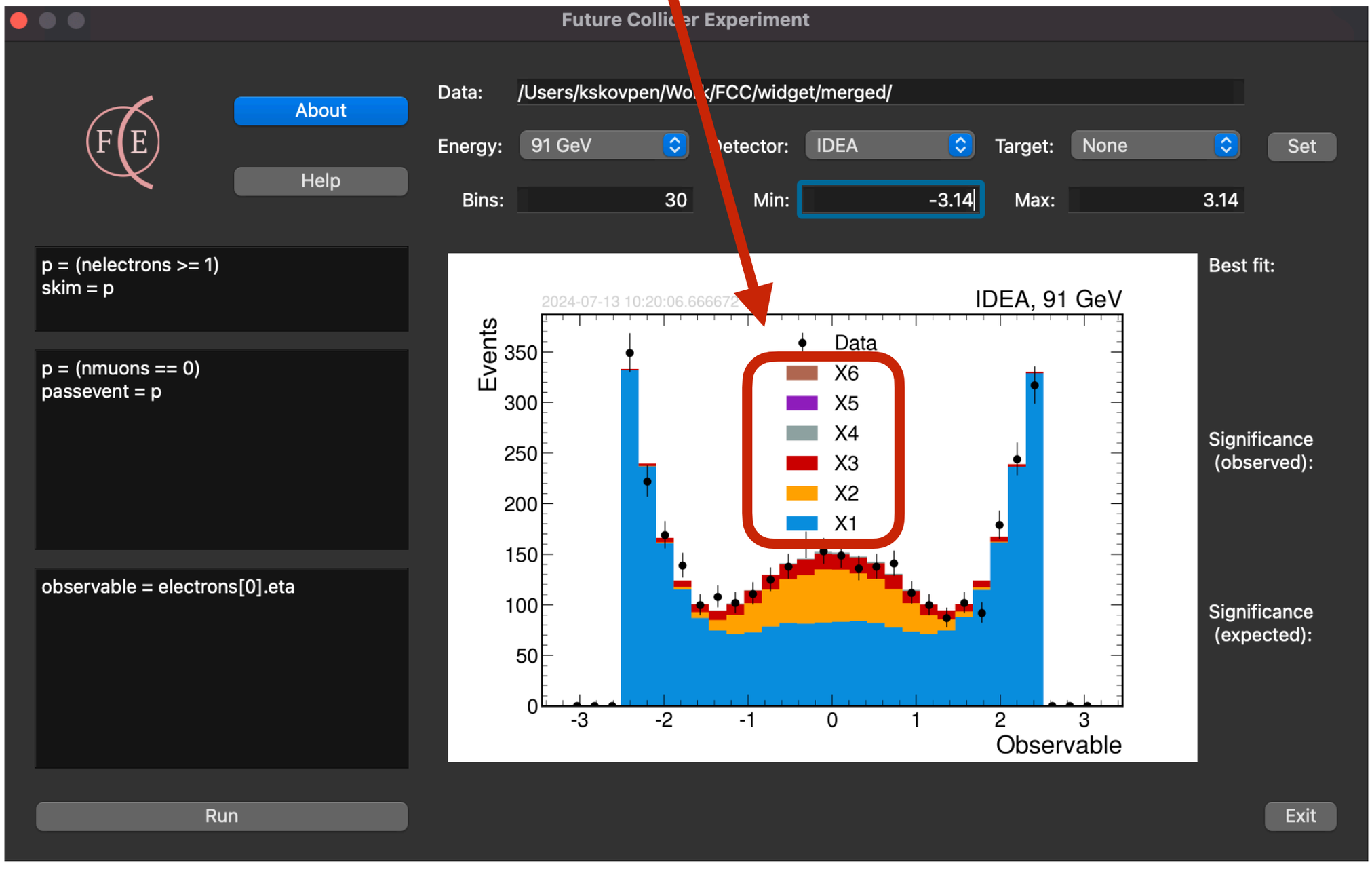
Beware of **tabulation** in python syntax



Azimuth angle of the **most energetic** electron in event

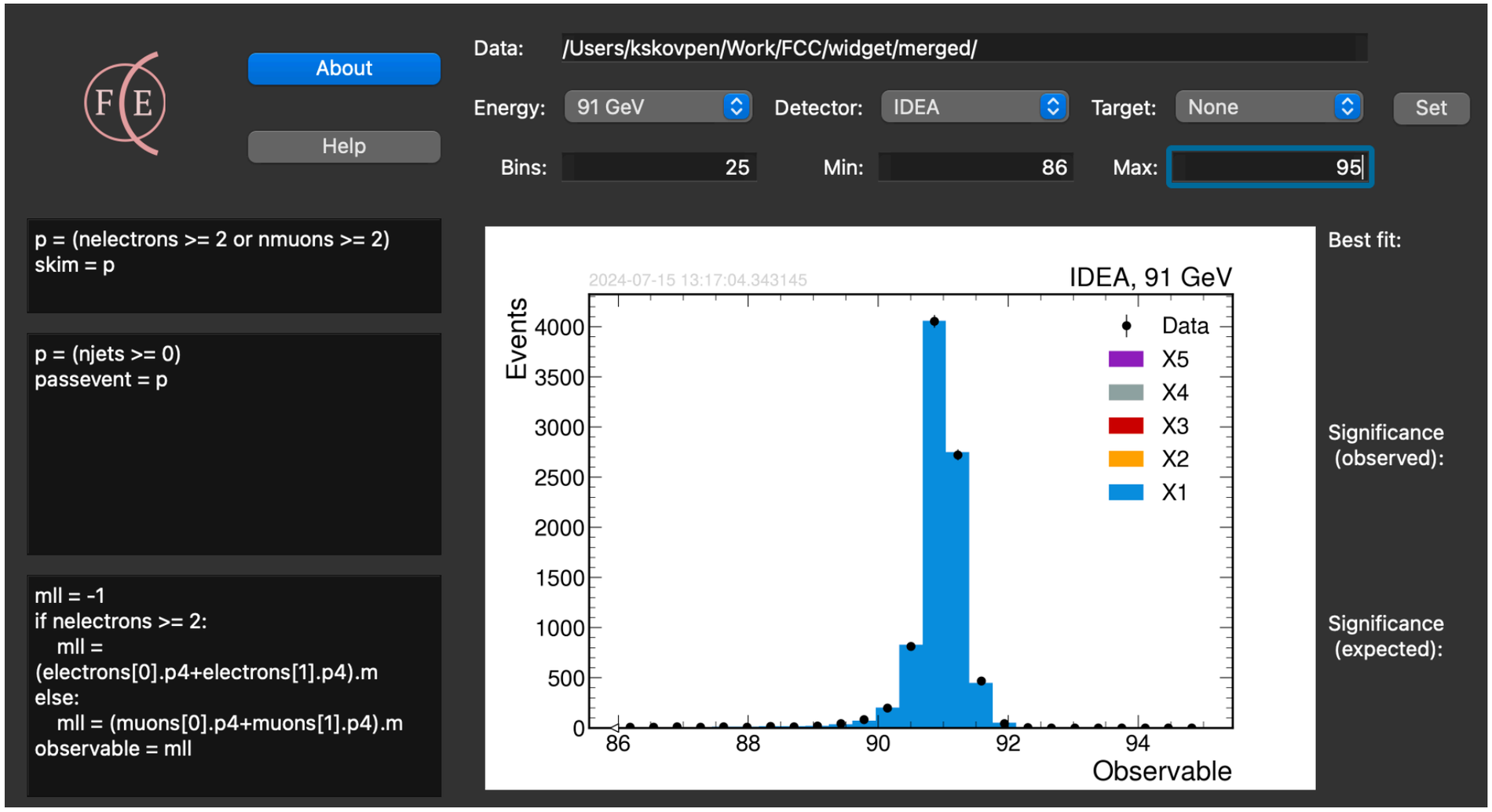
Task

What are these processes? Give the detailed definition and measure their production cross sections

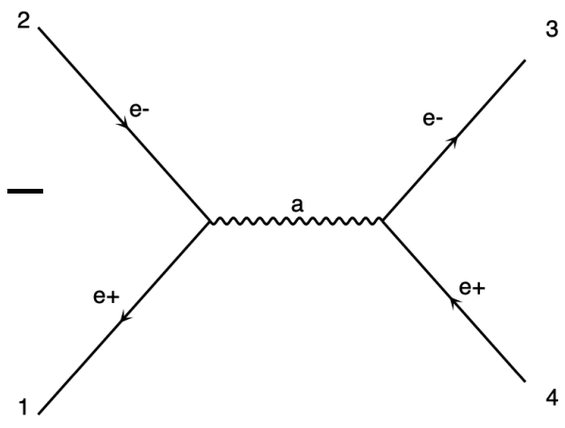


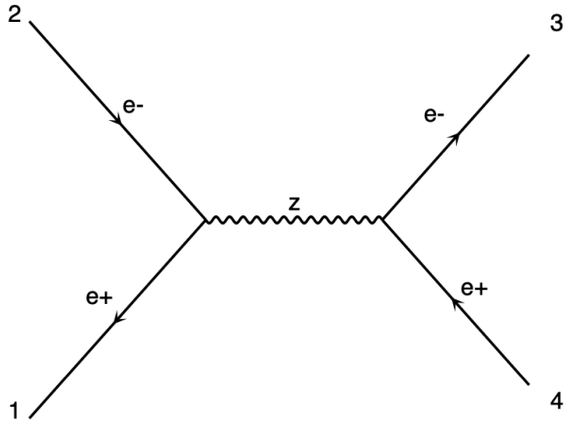
Example: Dileptons

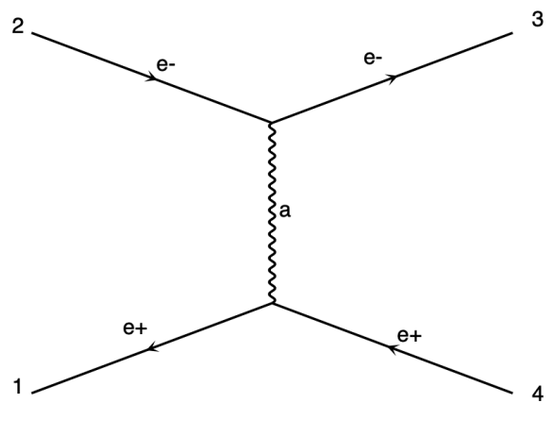
X1



$e^+e^- \to \ell^+\ell^-$

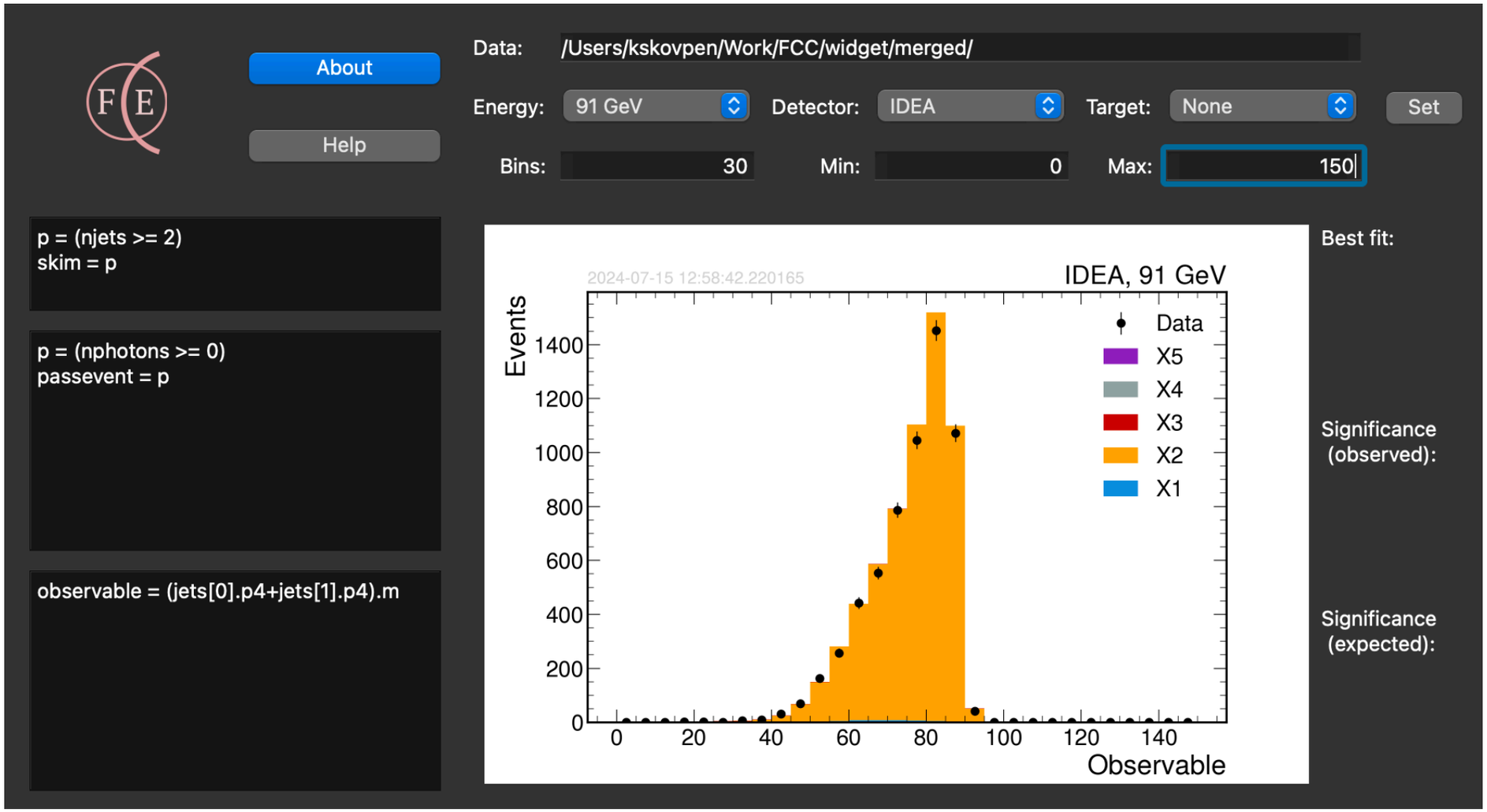




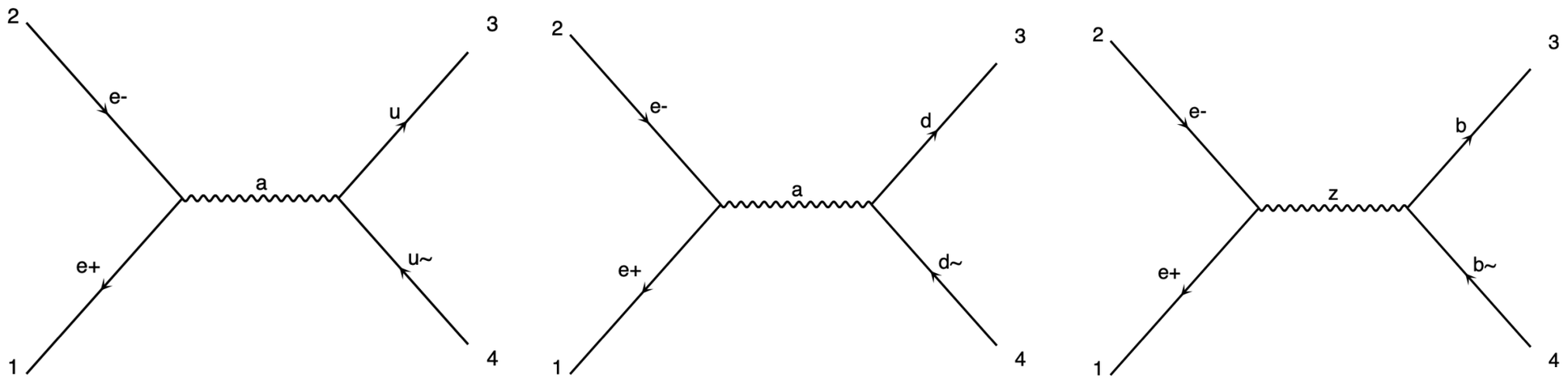


Example: Dijets

X2

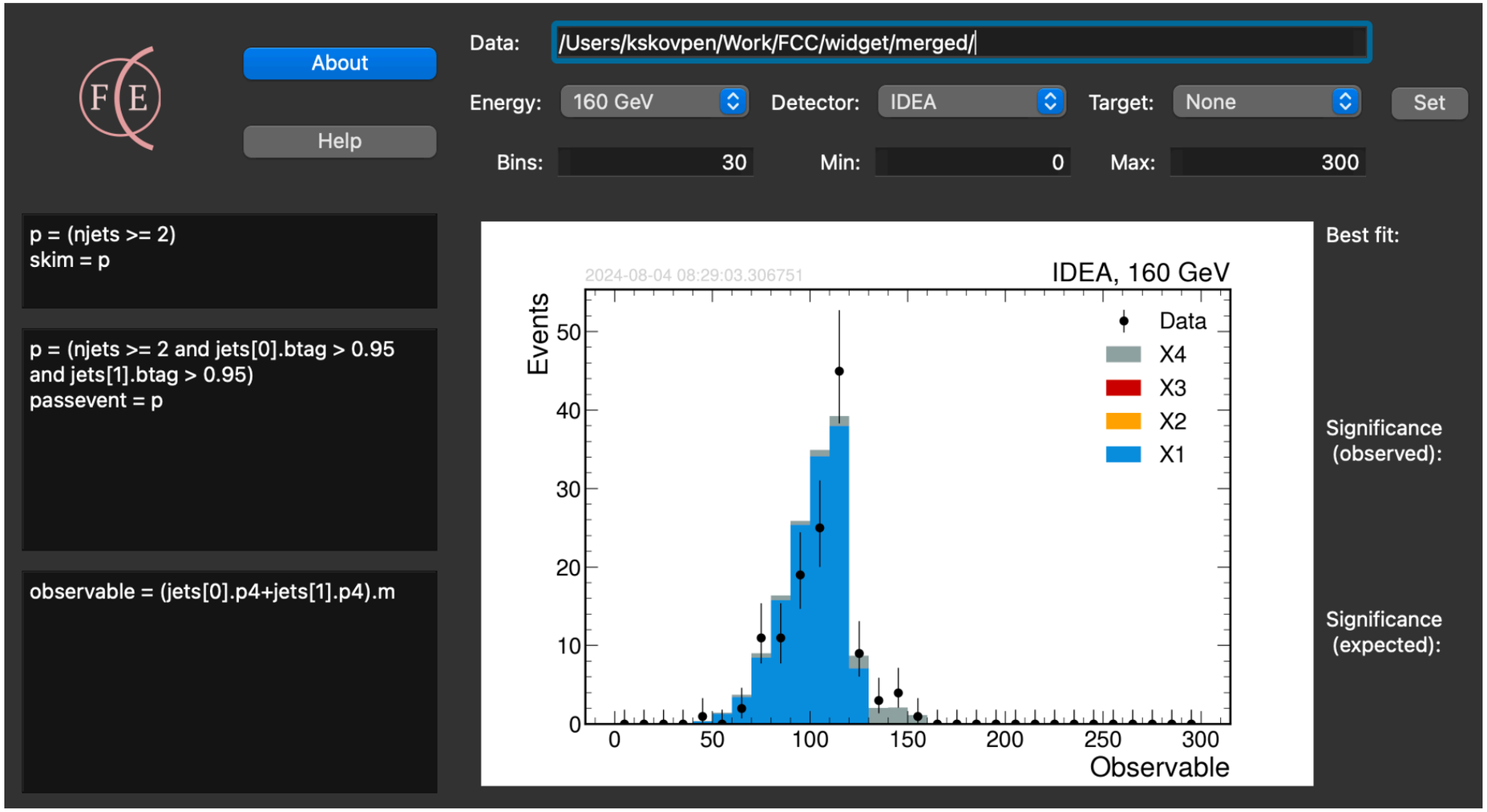


$e^+e^- \to q\bar{q}$



Example: Higgs production

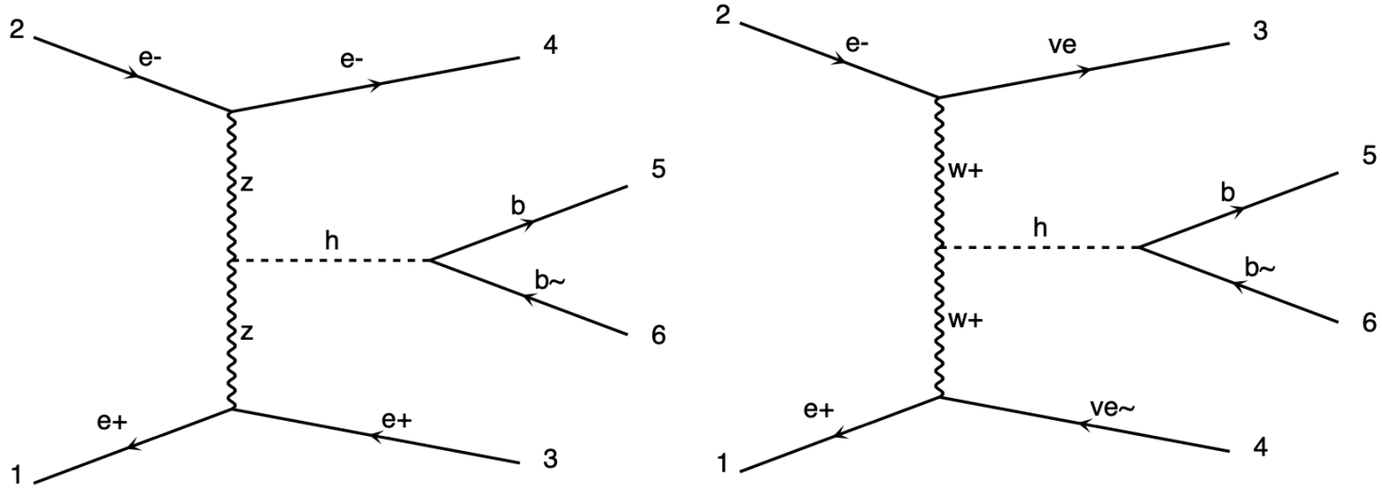
X1



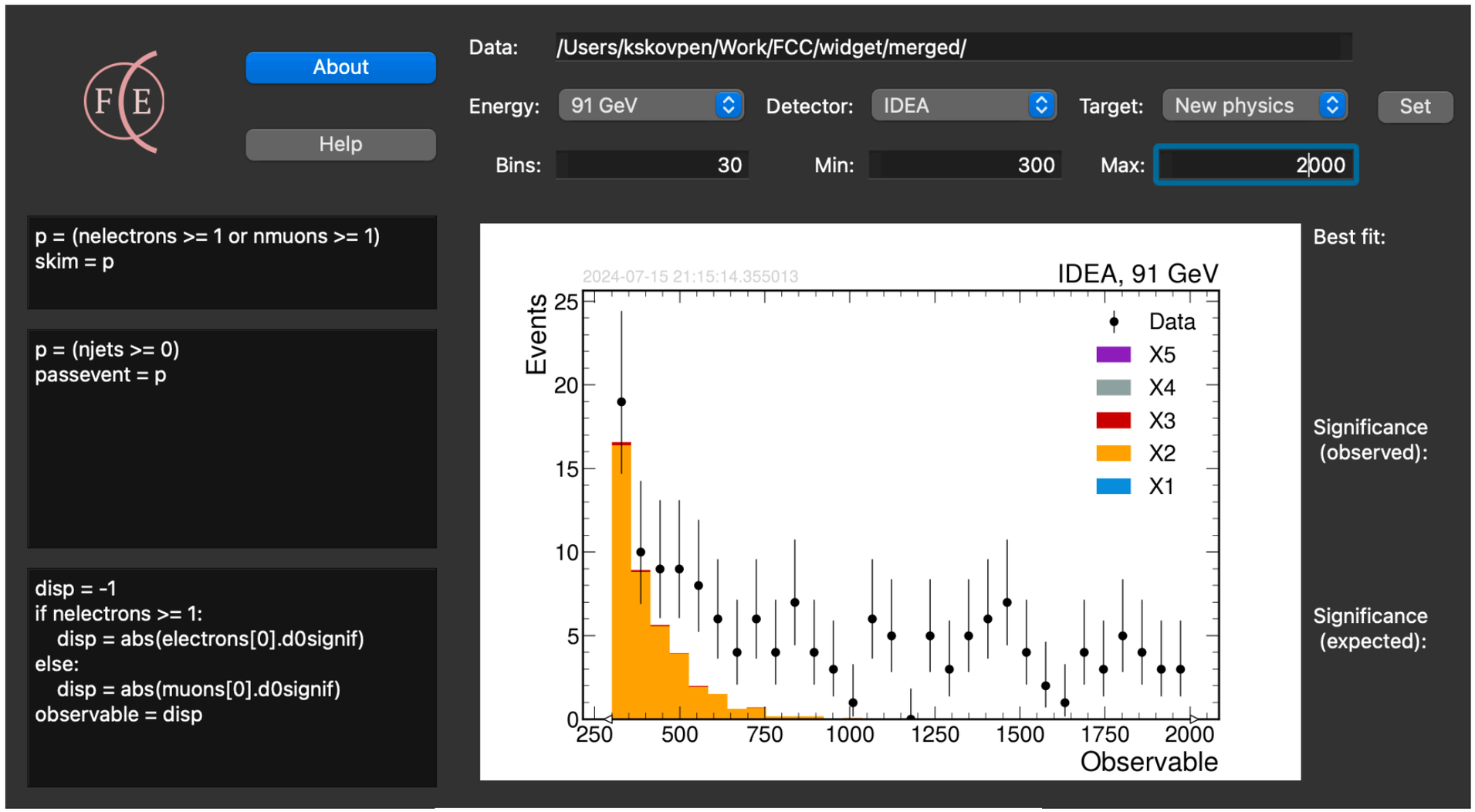
$e^+e^- \to e^+e^-h,\ h \to b\bar{b}$

$e^+e^- \to \nu\bar{\nu}h,\ h \to b\bar{b}$

VBF Higgs production
(ZZ and WW fusion)

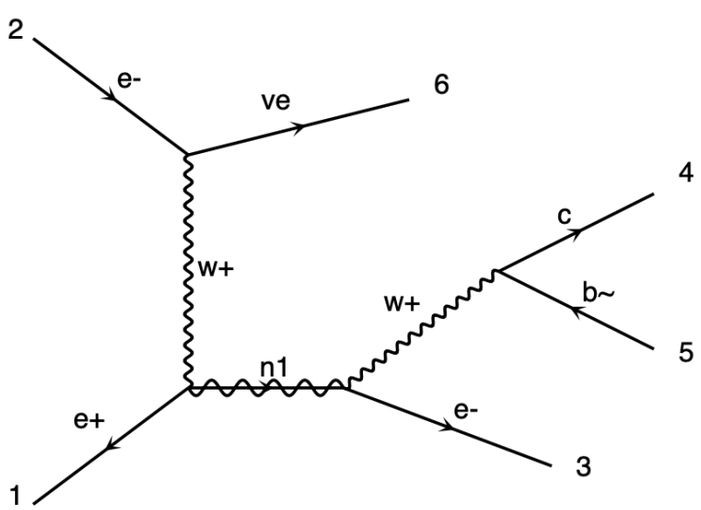


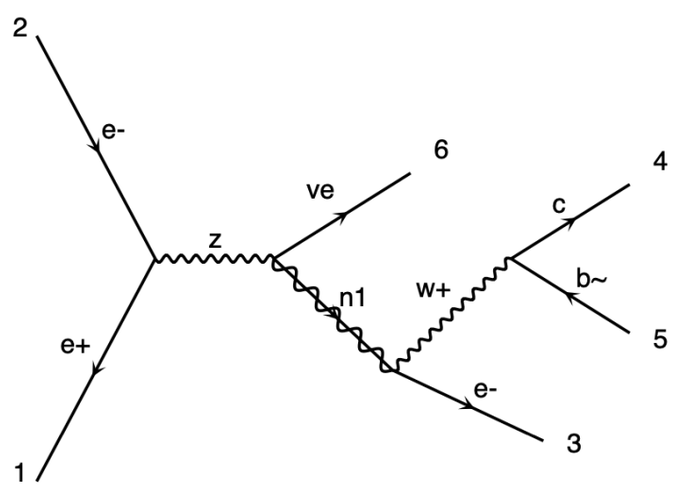
Example: New physics



$e^+e^- \to N\nu,\ N \to \ell q_i \bar{q}_j$

Displaced decays of long-lived heavy neutrino (70 GeV)



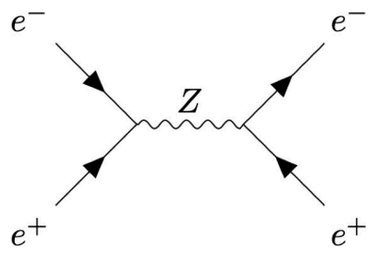


Student presentations

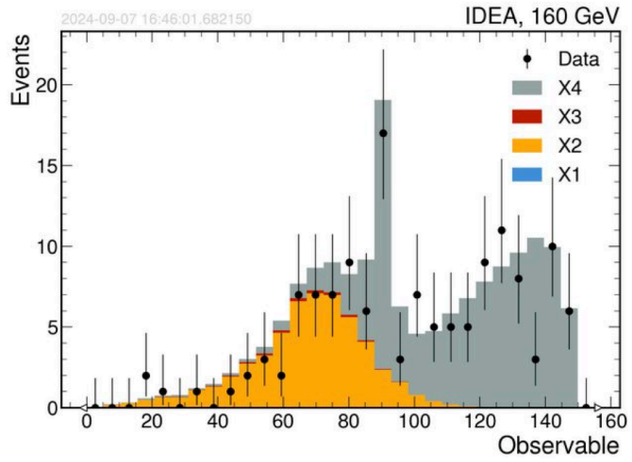
√s=91 GeV: Z production

Requirements for final state:

- 2 electrons
- $p_{T,e}$ > 25 GeV



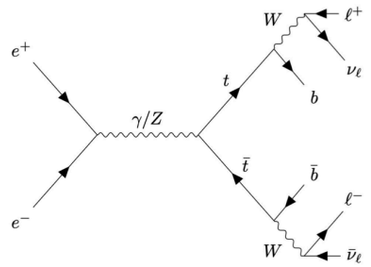
Observable: $m_{inv}(ee)$

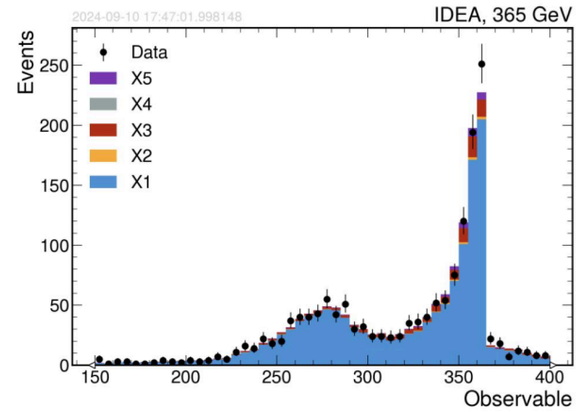


√s=365 GeV: ttbar production

Final state selection:

- Two b-tagged jets (>0.7)
- Two leptons



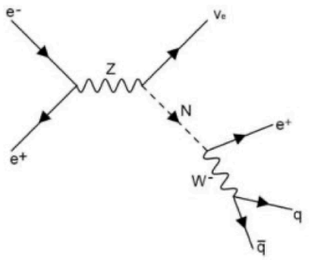


Mass top-quark pair → Invariant masses of the 2 jets, 2 leptons and of the missing transverse energy

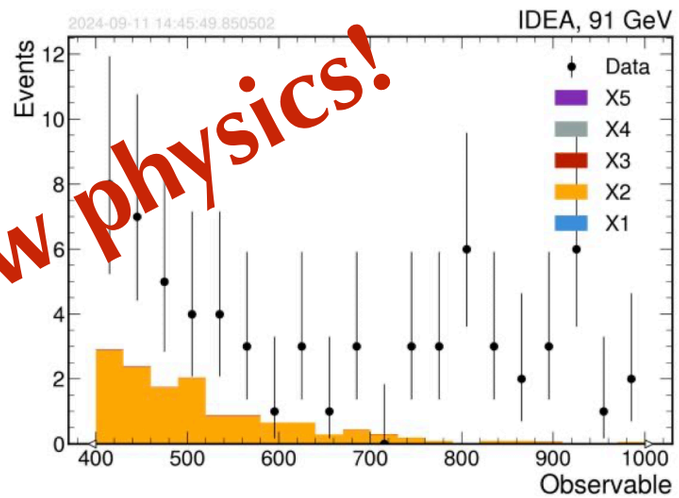
√s=91 GeV: long-lived Heavy Neutral Leptons

Restrictions for the final state

- 1 e or 1 μ

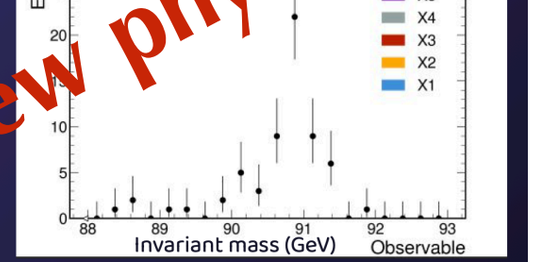


Observable: d_0 significance: $d_0(e, \mu)$



New Physics at 91 GeV?

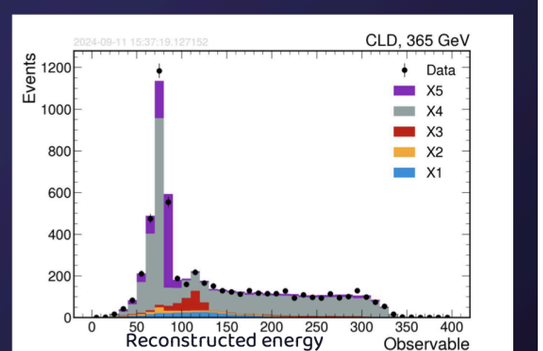
- Excess in invariant mass calculated from electron-muon pair
- Possible new particle Z' of mass ~ 91 GeV
- New particle would break flavour symmetry (may decay into neutrinos)



Nr of events as a function of the invariant mass for events with 1 e and 1 μ

X4 Standard Model at 365 GeV

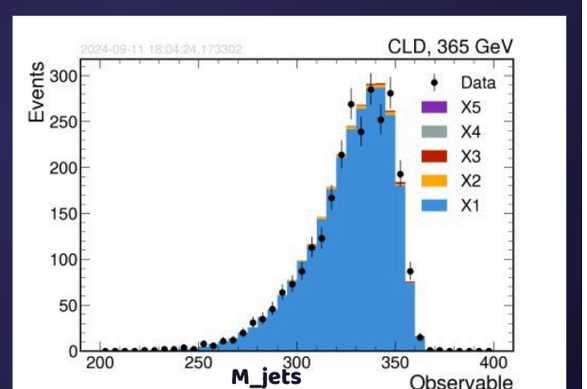
- Slight bump at 160 GeV, indicating W-W production
- Combing these results shows that
  - X4 is W-W production
  - X5 is Z-Z or Z-H production
- Note:
  - Higgs production is involved in X3
  - Slight bump in X2 around W-mass



Only 2 jets

X1 Standard Model at 365 GeV

- 6 jets chosen with at least one btag
- Reconstructed mass of all jets indicates a t-pair production.



Invariant mass of reconstructed jets

Summary

- The Future Collider Experiment (FCE) app can be used to **teach the physics data analysis** relevant to any (existing or future) particle physics collider experiment
- The target audience is of **advanced level**, e.g. graduate students
- Prior knowledge of **fundamentals of particle physics** is not required, though would greatly facilitate the exercise sessions

- **Other possible adaptations** of the FCE project:
  - **Hands-on sessions** during the master particle physics courses
  - **Reduce the complexity** by decreasing the number of processes and collision energy points
  - Rework the concept to be applicable for **standalone learning and mobile gaming**

Make it accessible for general public?