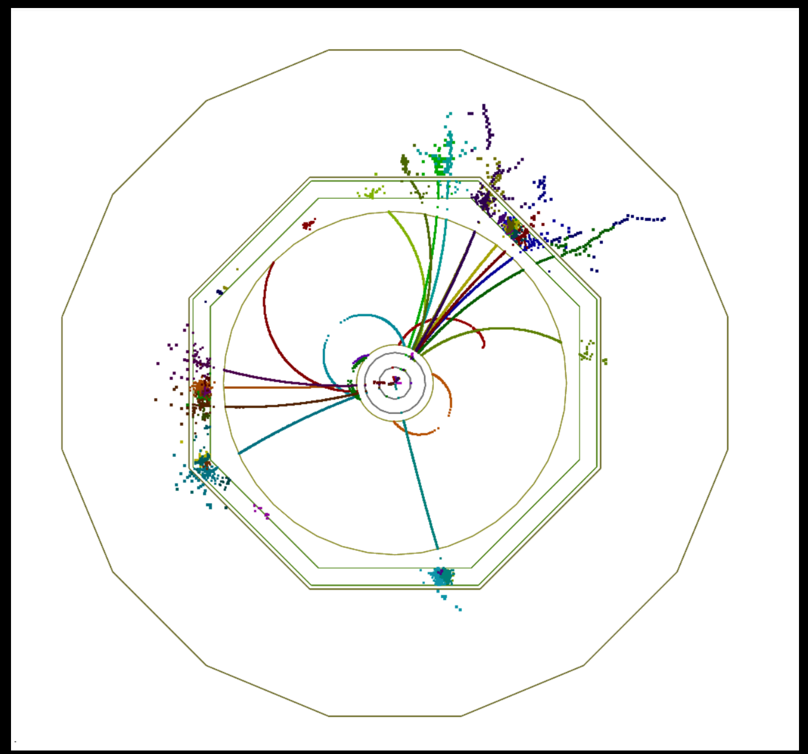
Monte Carlo simulations for the FCC-ee



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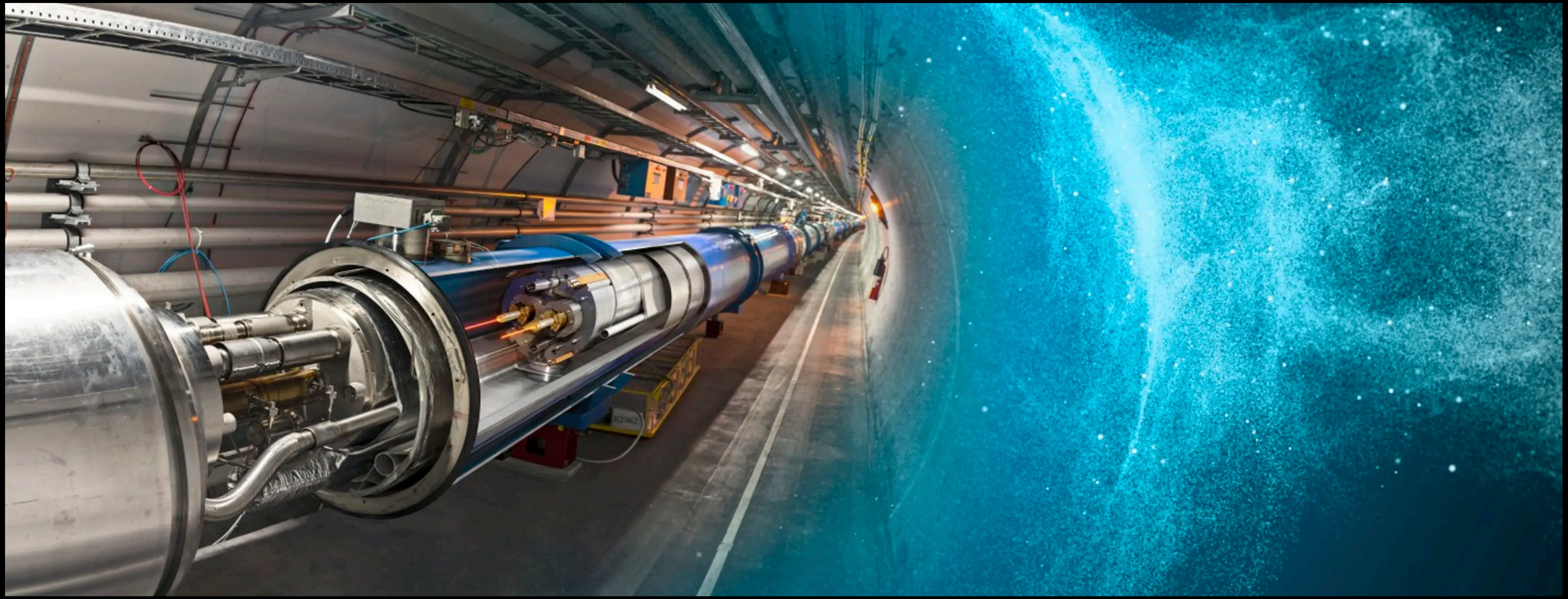
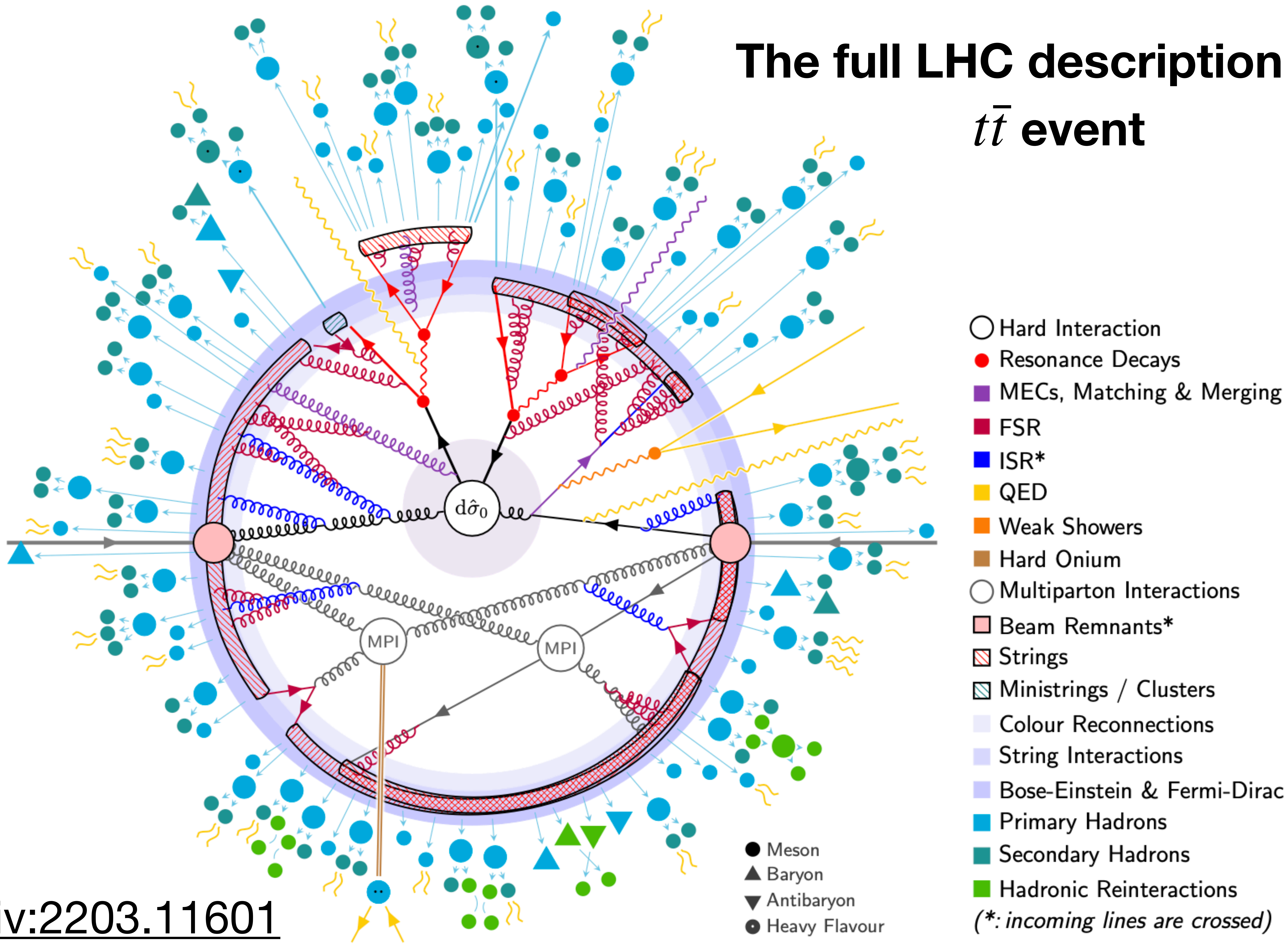
FCC-ee Workshop, Brookhaven National Laboratory

April 24-26, 2023

What have we learned from the LHC



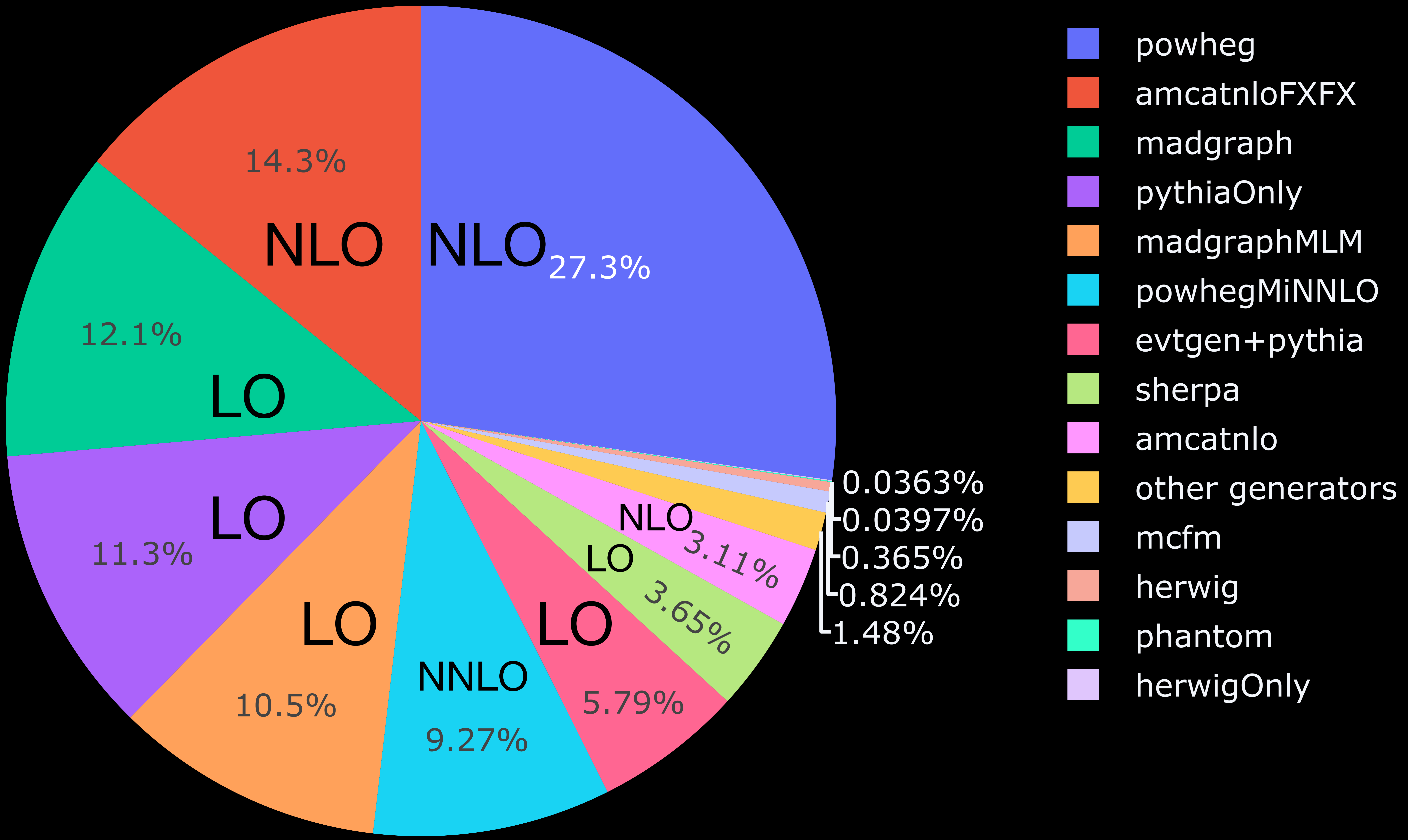
The full LHC description of a $t\bar{t}$ event



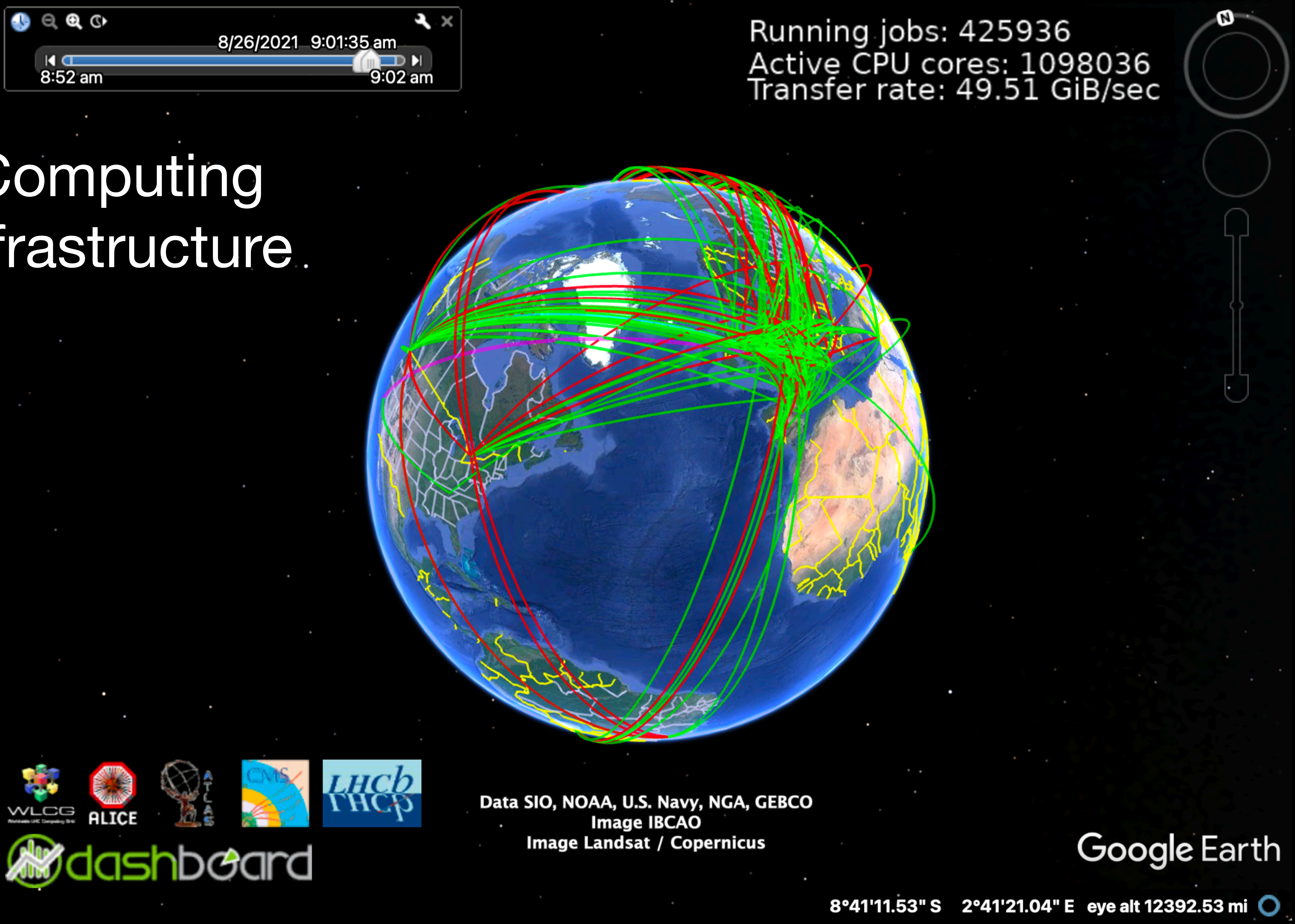
arXiv:2203.11601

Generator usage split by events in CMS

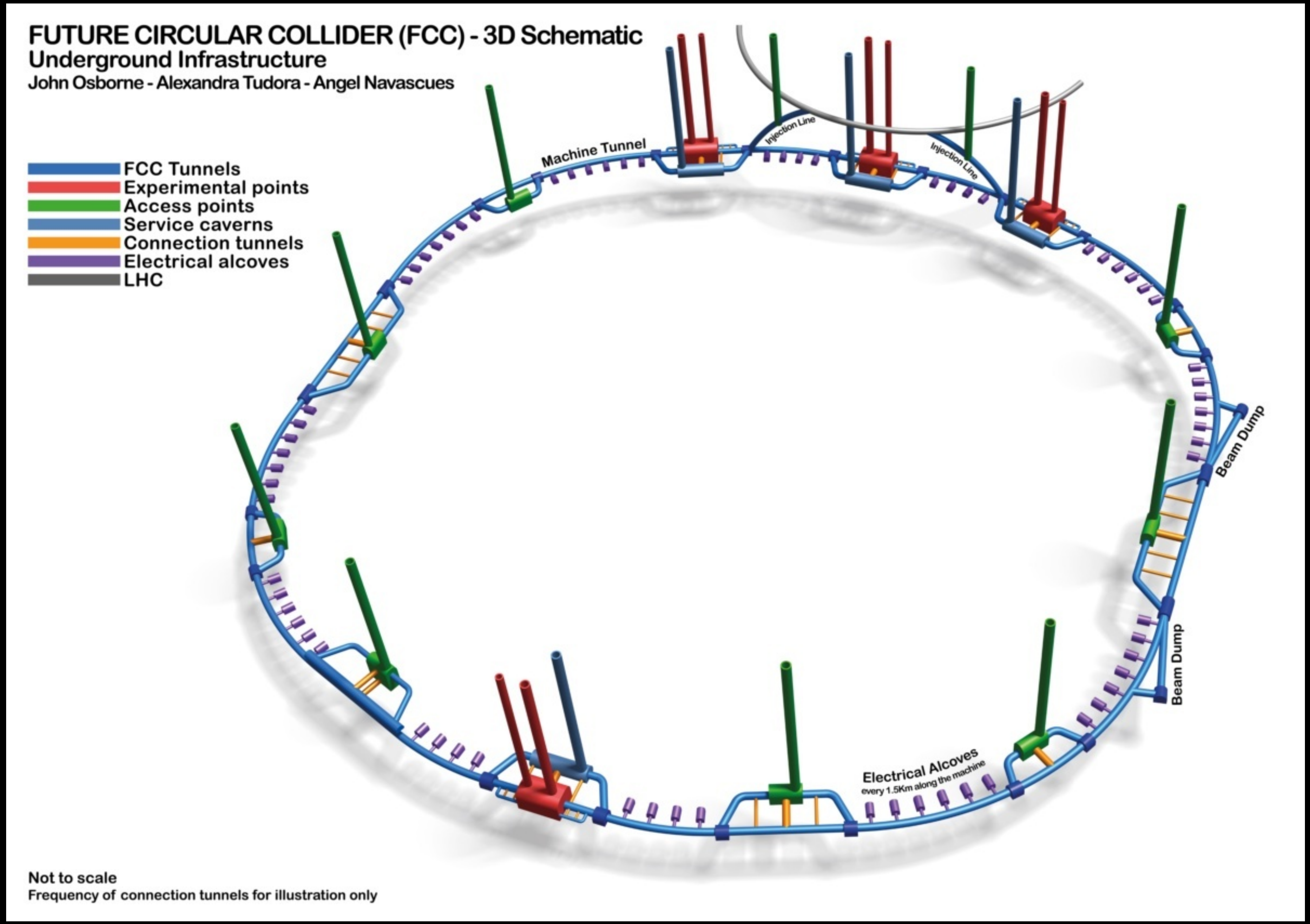
- NNLO: 9.27%
- NLO: 44.71%
- LO: 46.03%



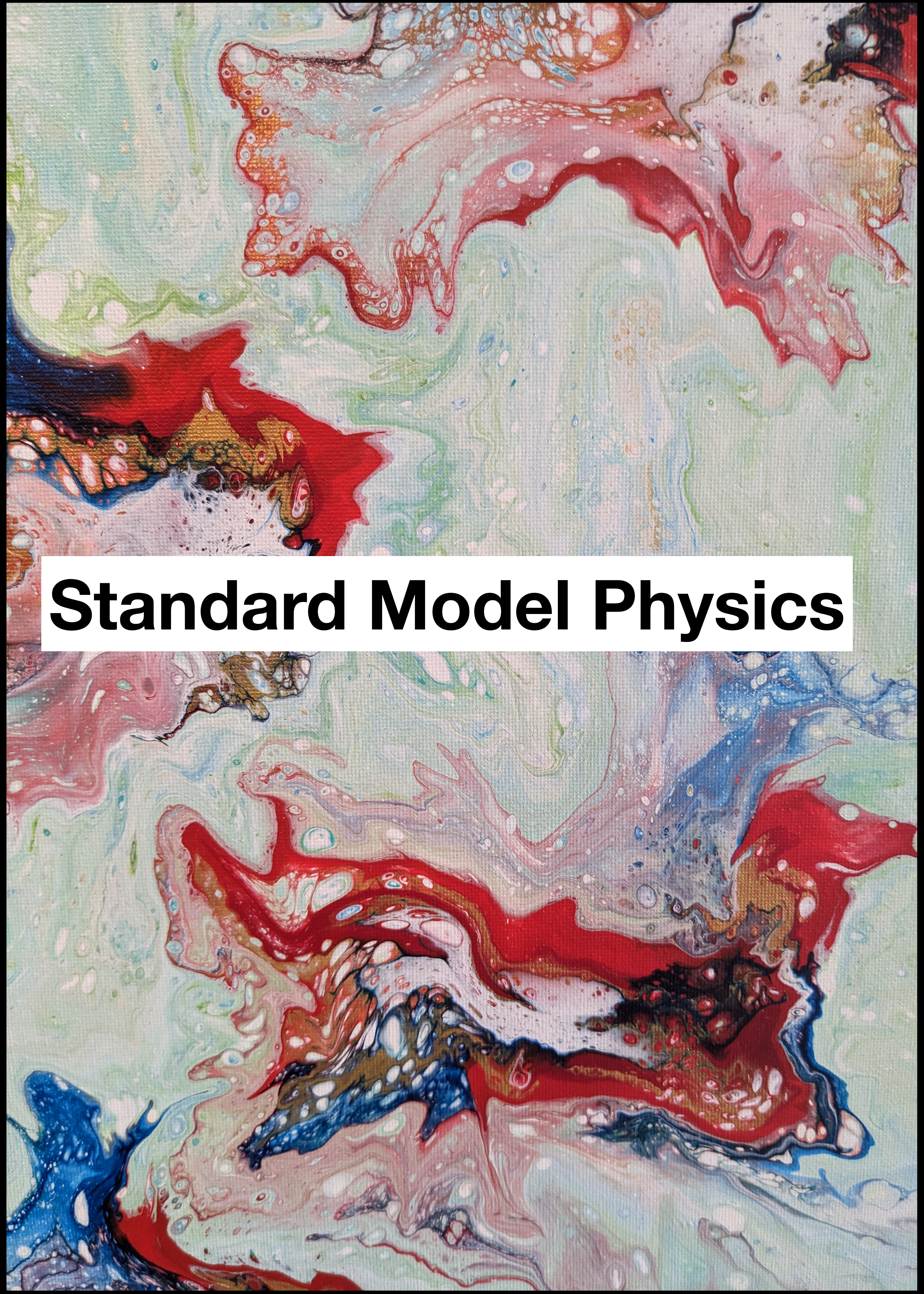
Computing infrastructure

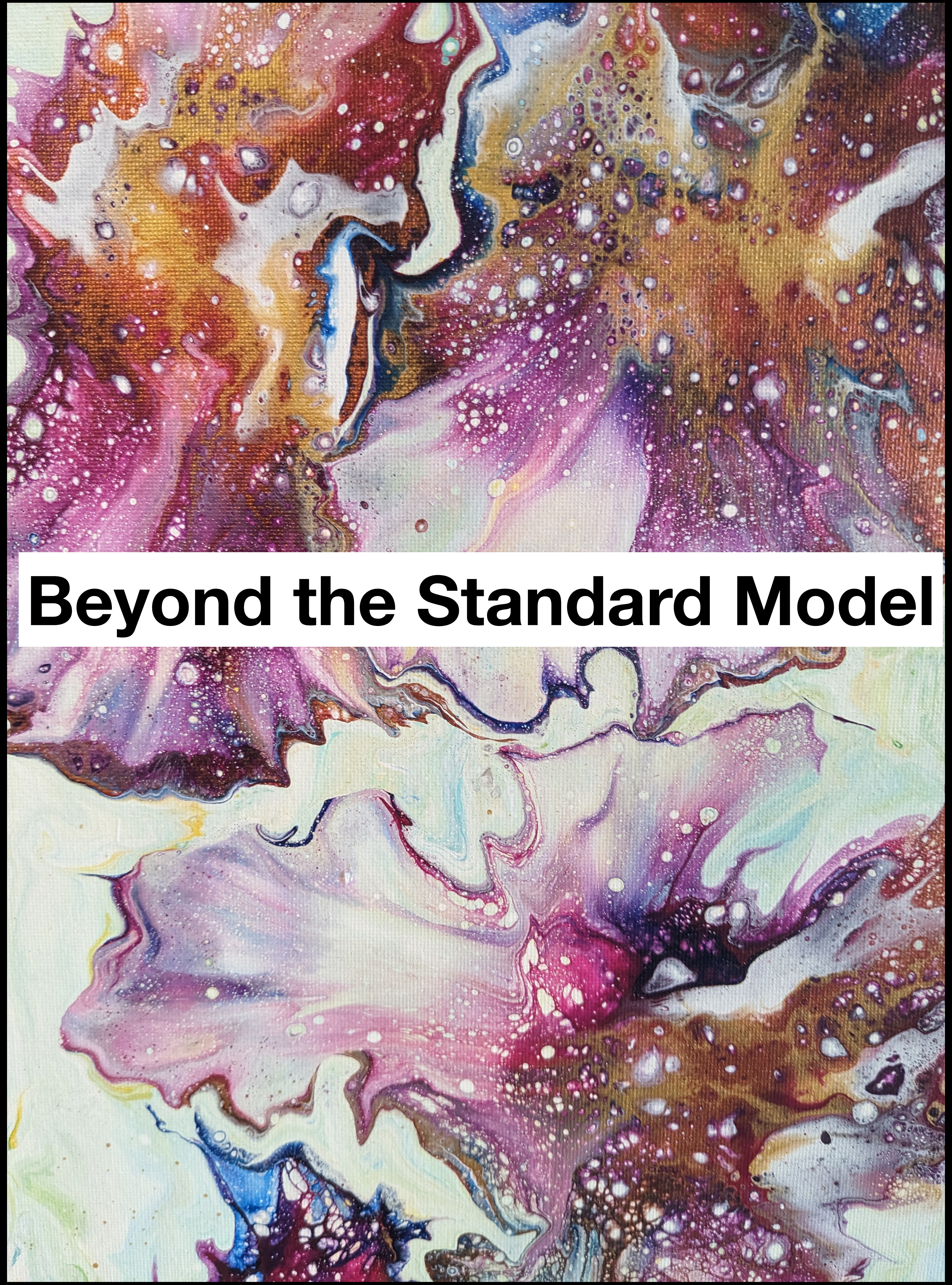


The potential of the FCC-ee



Physics Potential

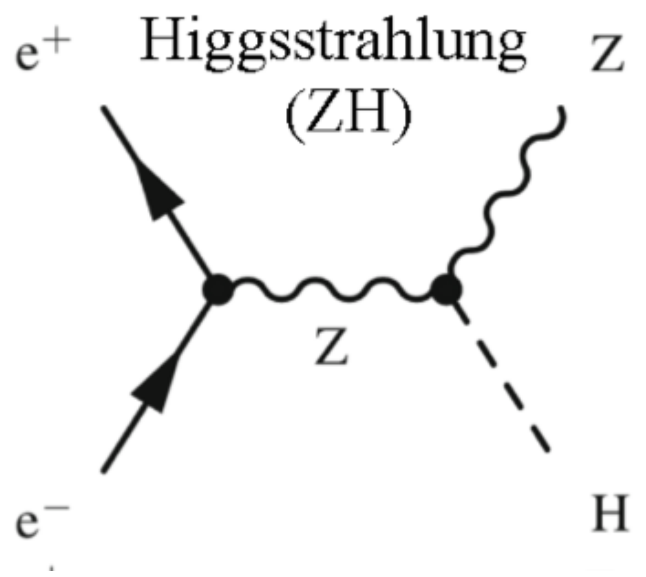




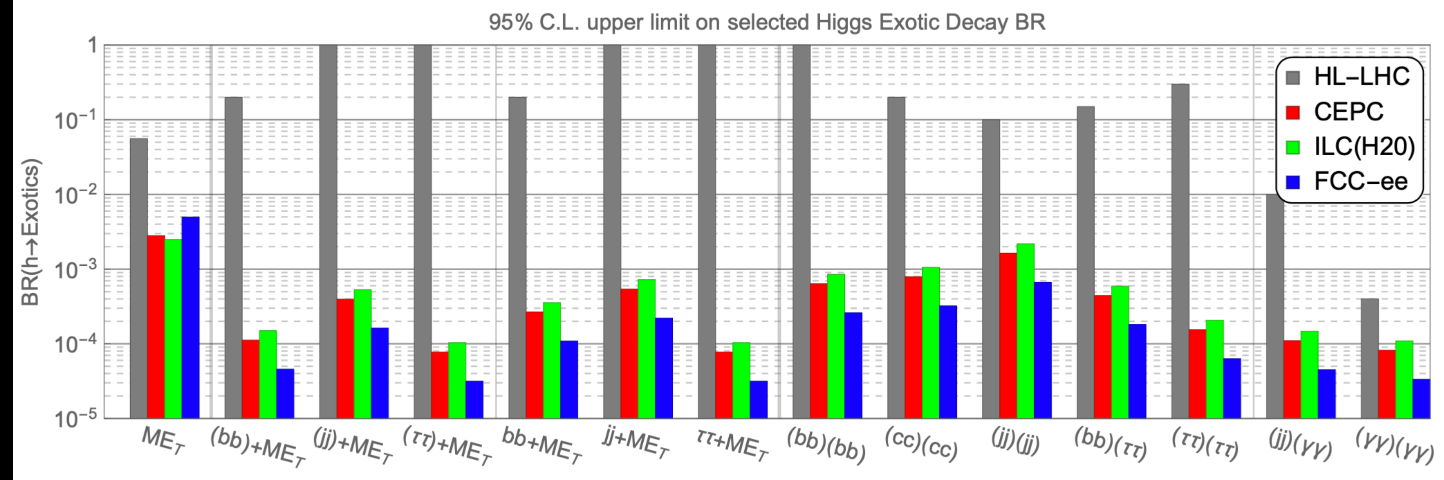
Scale of new physics

Physics Potential

https://arxiv.org/pdf/2203.06520.pdf

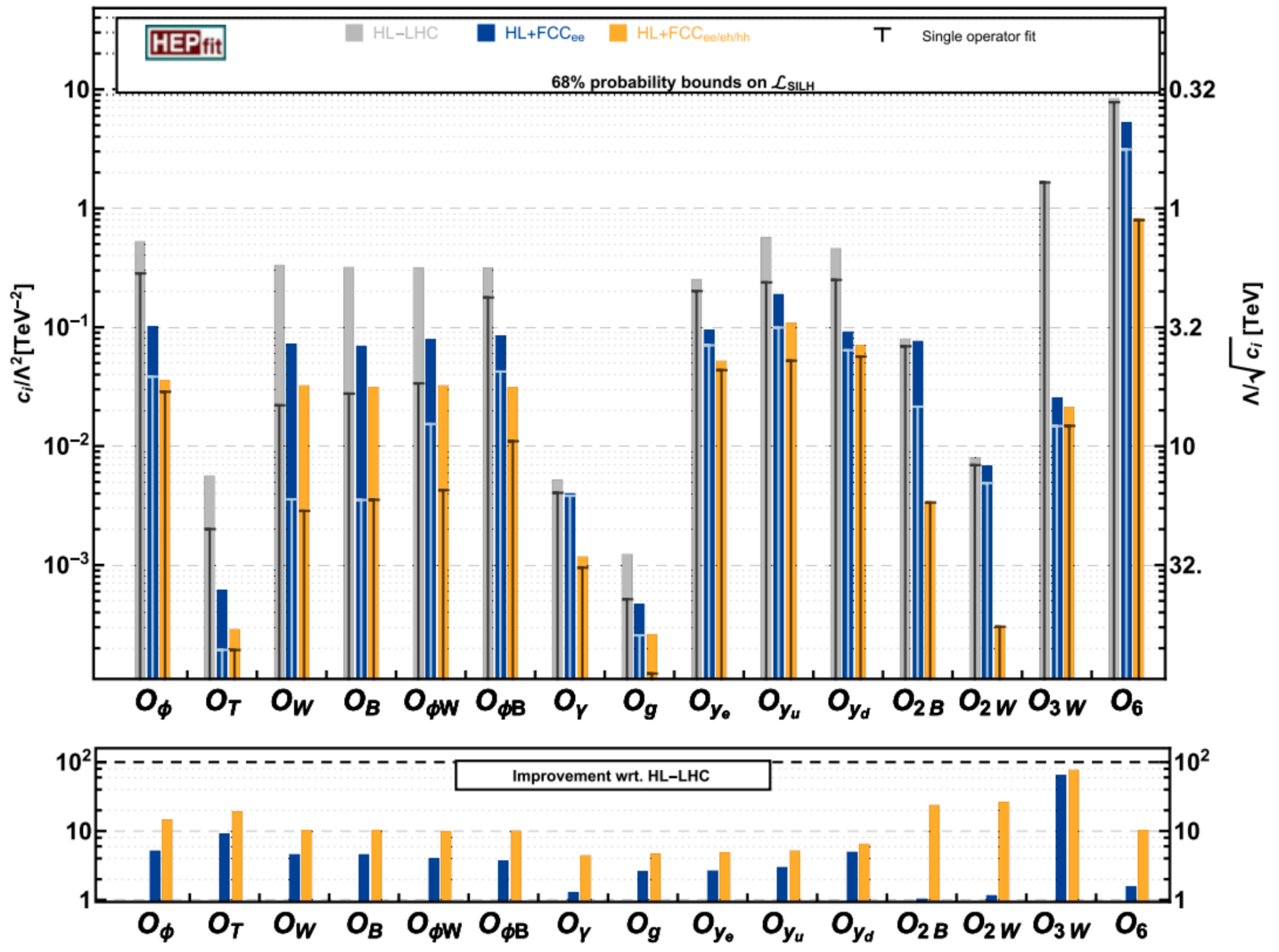


- Measure $gHZZ$ with 0.05% statistical precision
- Measure $gHcc$ with 1.3% statistical precision
- Unprecedented precision on top Yukawa
- Reduction of statistical uncertainties by ~500 (5×10^{12} Z's)
- WW threshold: 3 orders of magnitude more than LEP
- Flavor physics: allows for stringent tests of lepton flavor universality



- Opportunity for broad model independent search program
- Exotic decays of the Higgs
  - Sensitivity to Higgs branching fraction increases by several orders of magnitude with respect to the HL-LHC
- Long-lived particles
- Axion-like particles ($e^+e^- \to a\gamma \to (\gamma\gamma)\gamma$)
- Search for dark matter → heavy neutral neutrinos ($e^+e^- \to Z \to \nu N$, N is the long-lived particle)

$$\mathscr{L}_{\mathrm{SMEFT}} = \mathscr{L}_{\mathrm{SM}} + \sum_i \frac{C_i}{\Lambda^2}\mathcal{O}_i$$



The improvements on most Wilson Coefficients by factor of 4-10 with respect to HL-LHC

Thread of commonality

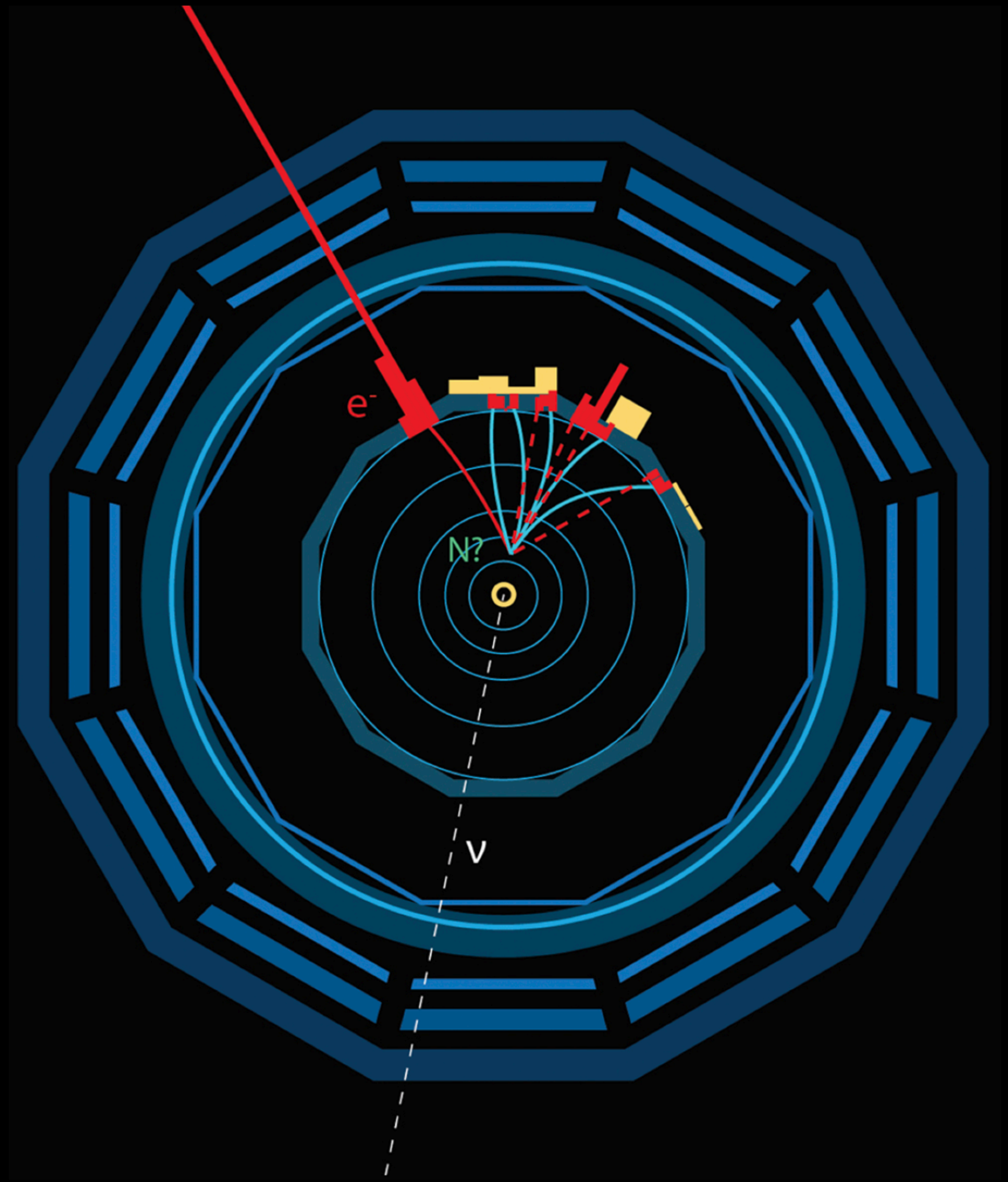
- What all of these scenarios have in common is that we need state-of-the-art simulations for FCC-ee
- Launch a concerted effort to make simulations available for physics feasibility studies
- Identify bottlenecks in workflows
- Leverage our knowledge and experience from the LHC
- Organizing the effort to produce large scale simulation samples is as important as discussions on detector designs → more than revisiting LEP era calculations

General considerations

David d'Enterria's Talk

https://arxiv.org/pdf/1911.12040.pdf

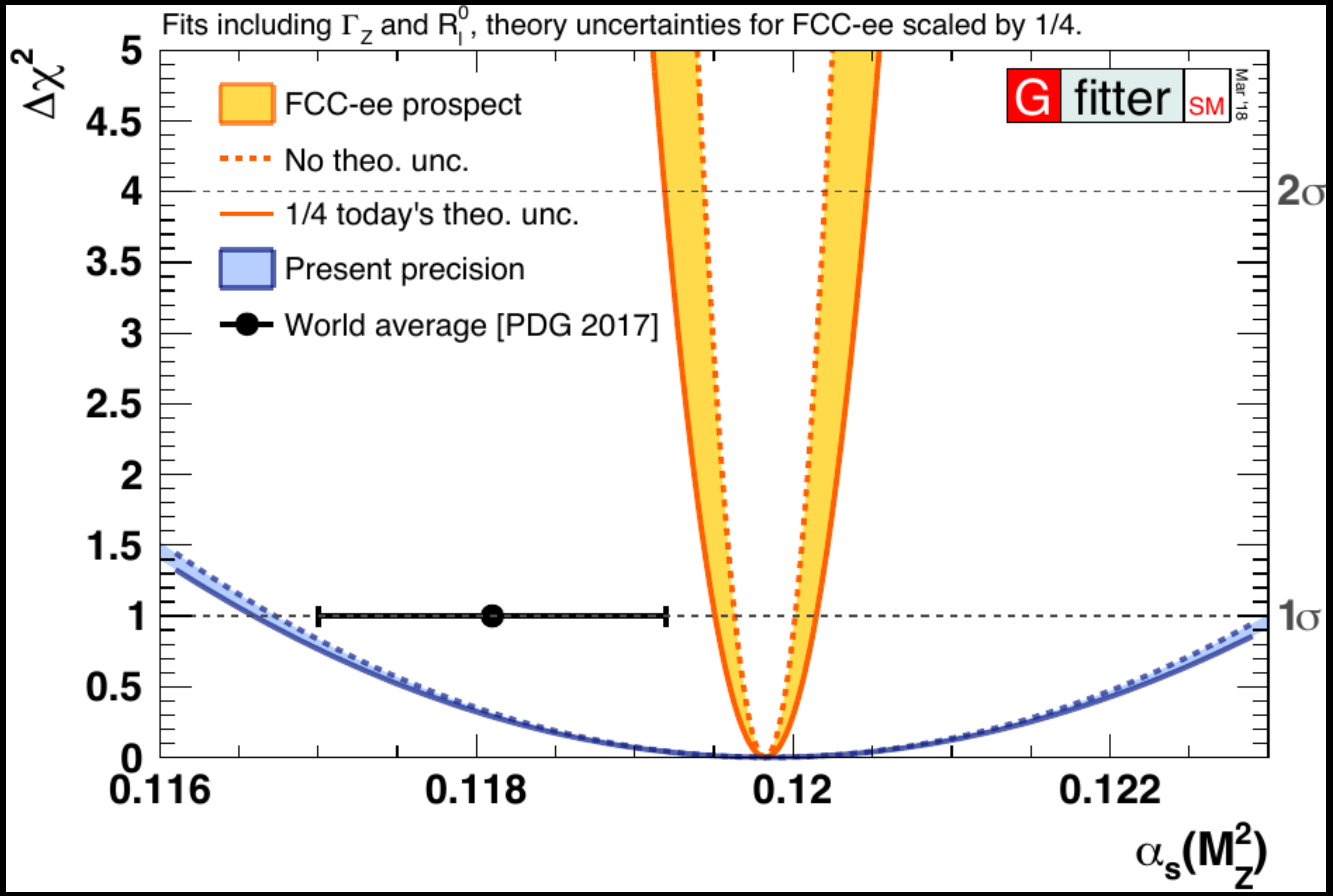
- Extremely clean events, for precise cross sections need:
  - Precise computation of α_s
  - N^nLO and N^nLL resummation
  - High-precision PDFs



Special Requirements

Marek Schönherr's Talk

- For electroweak precision observables
  - $m_Z, \Gamma_Z, \sin^2\theta_W^{\text{eff}}, \alpha(M_Z)$ and $\alpha_s(M_Z)$
- To take advantage of full potential of the FCC-ee, need:
  - At least NNLO EW needed for almost all computations
  - For Bhabha scattering: N3LO for luminosity measurements



LEP era computation

- Event generators from the LEP era cannot be scaled up to meet the needs of the FCC-ee
  - FORTRAN based → scaling up and GPU porting hard
  - Event Data Model (EDM), which is a compressed data format for LHC studies proven to be performant and efficient → non compliant

ELSEVIER

Computer Physics Communications 98 (1996) 206–214

Computer Physics Communications

NUNUGPV – A Monte Carlo event generator for $e^+e^- \to \nu\bar{\nu}\gamma(\gamma)$ events at LEP

Partnership with generator theory community

- Implement state-of-the-art event generator workflows with the most precise predictions available
- Design workflow for centralized Monte Carlo production
- Partnership with generator theory community is crucial
- Downstream steps include detector simulation
  - Use GEANT or Delphes for most physics studies?
  - Three different detector technologies proposed: full simulation to be run centrally or by individual groups and compare performance?

Martin Aleksa's talk

Bottlenecks?

- Total data to be collected: 150 ab^{-1} in the first two years at $\sqrt{s} = 240$ GeV
  - Assuming major background contributions from diboson processes (WW/ZZ) where $\sigma_{WW/ZZ}$ = 18 pb, which means 2.7 billion events
  - Need to generate 13 billion events to keep statistical uncertainties low
  - Even with the choice of storing events in compressed format (ROOT/ProMC) would require 40 TB
  - Required data storage with simulation and reconstruction steps could exceed several petabytes
  - Computation may be parallelizeable, storage *will be* a bottleneck

S. Chekanov

Organizing effort

The time is now

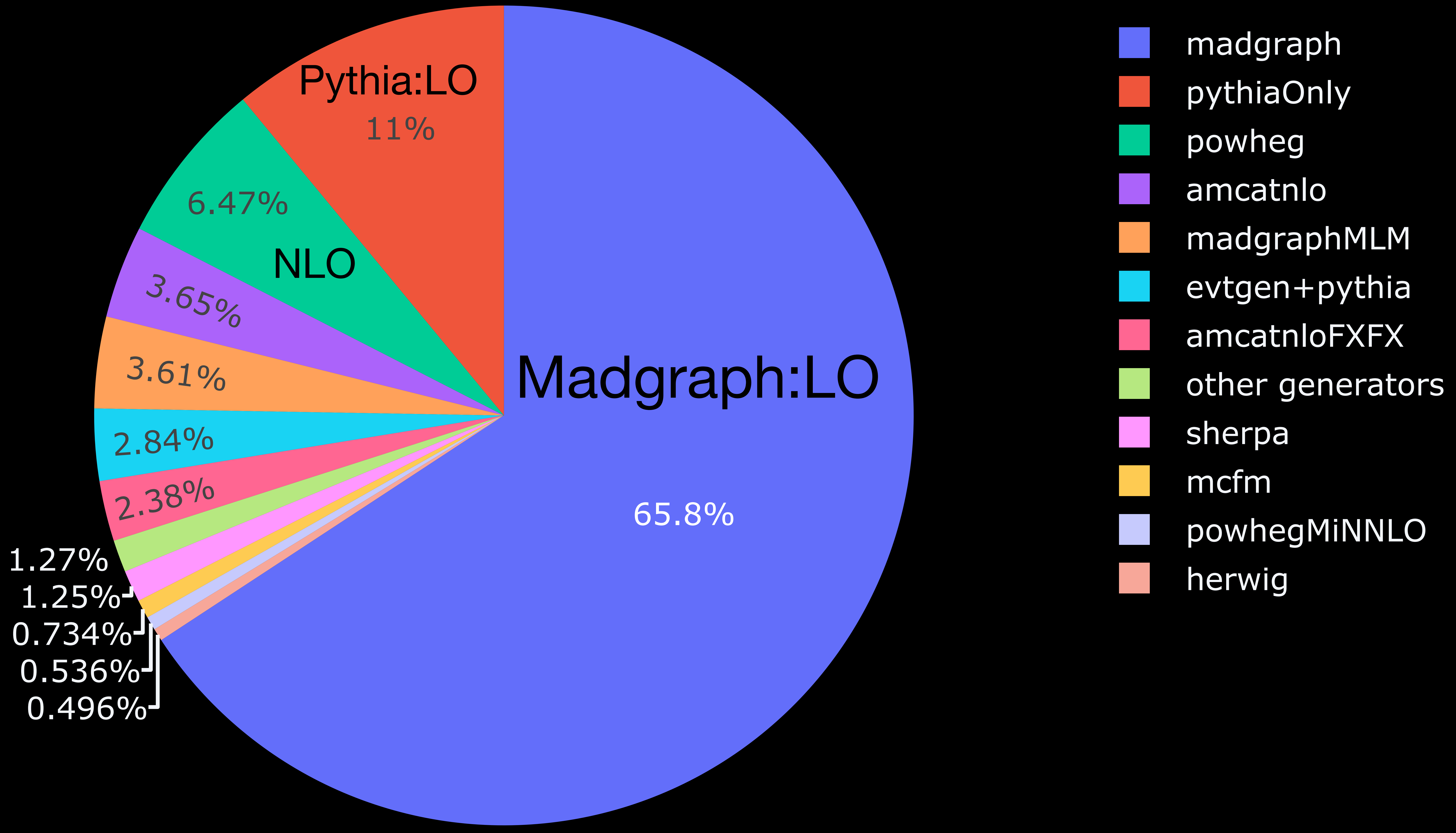
- This is the right time to start planning for generation of large scale Monte Carlo samples
- Imperative to pass *first step* in the long sequence of steps toward FCC-ee

2021-2025	2028	2030	2045-2048
Feasibility studies	Project approval by CERN council	Construction starts	Operation of FCC-ee

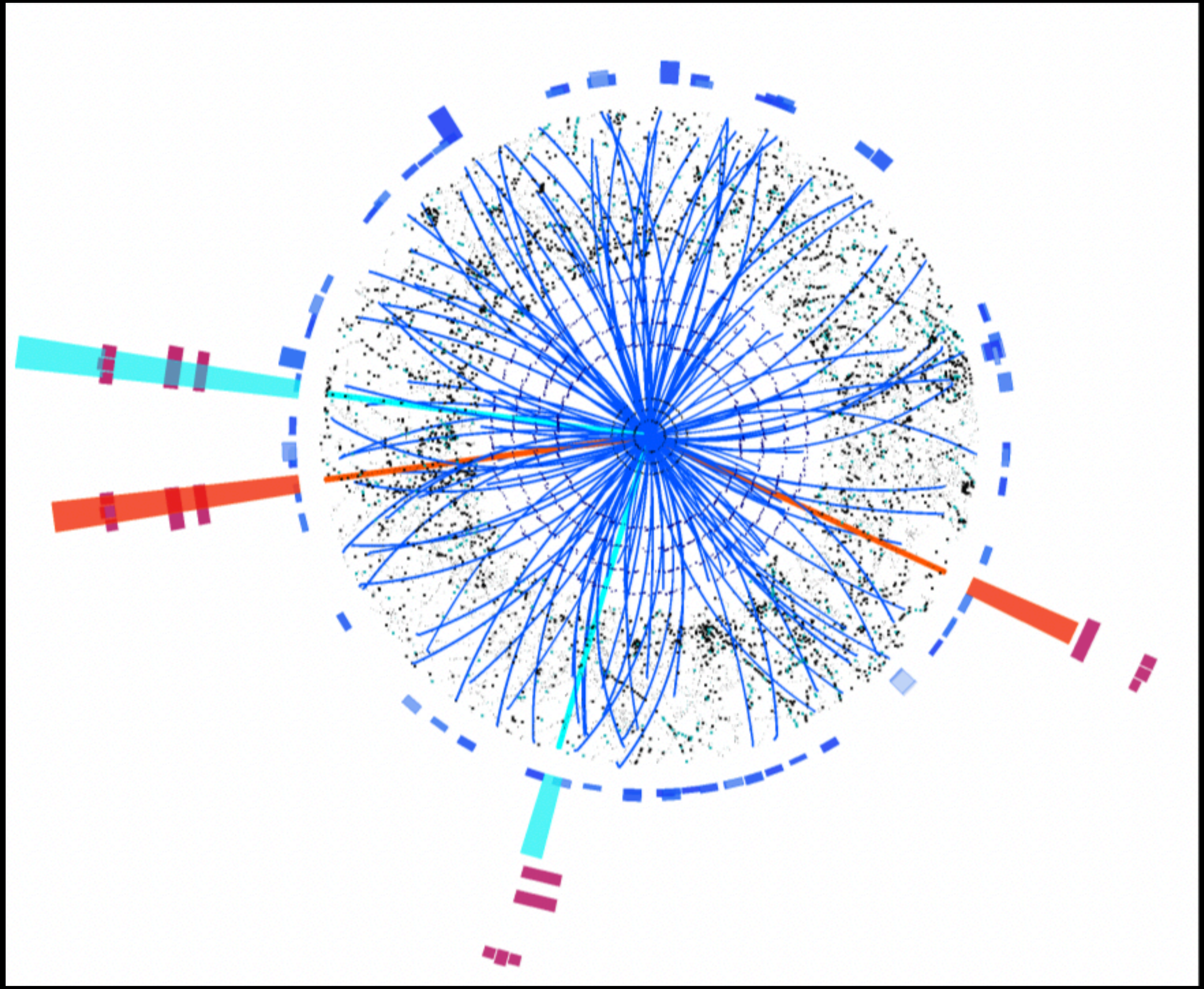
F. Gianotti

Additional Material

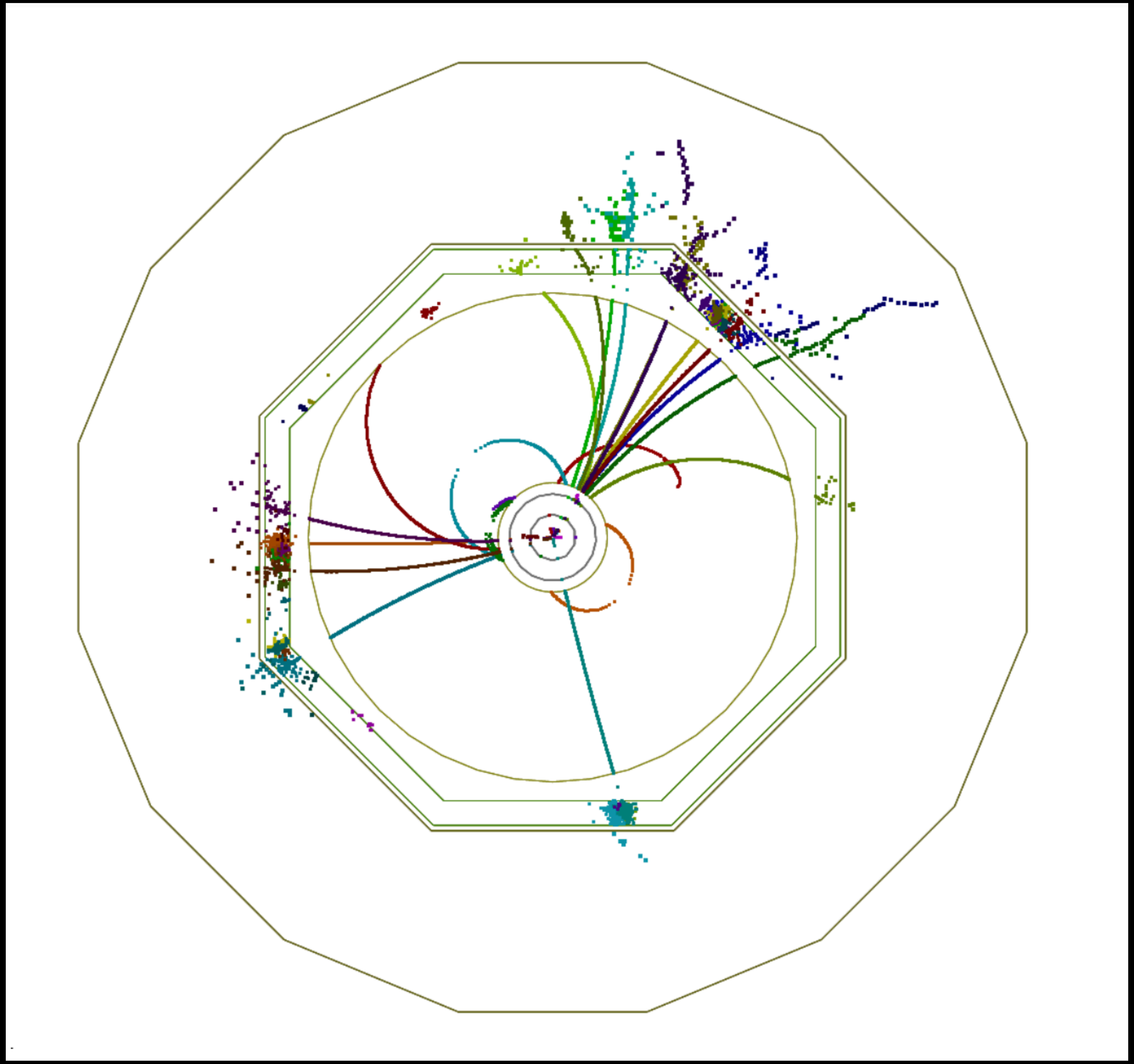
Generator usage split by samples (each MC request)



Event complexity



proton-proton collisions



e^+e^- collisions