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Beyond the Risk of Error: A philosophical approach to experimental uncertainties in particle physics

Institut de Physique des 2 Infinis (IP2I) Lyon
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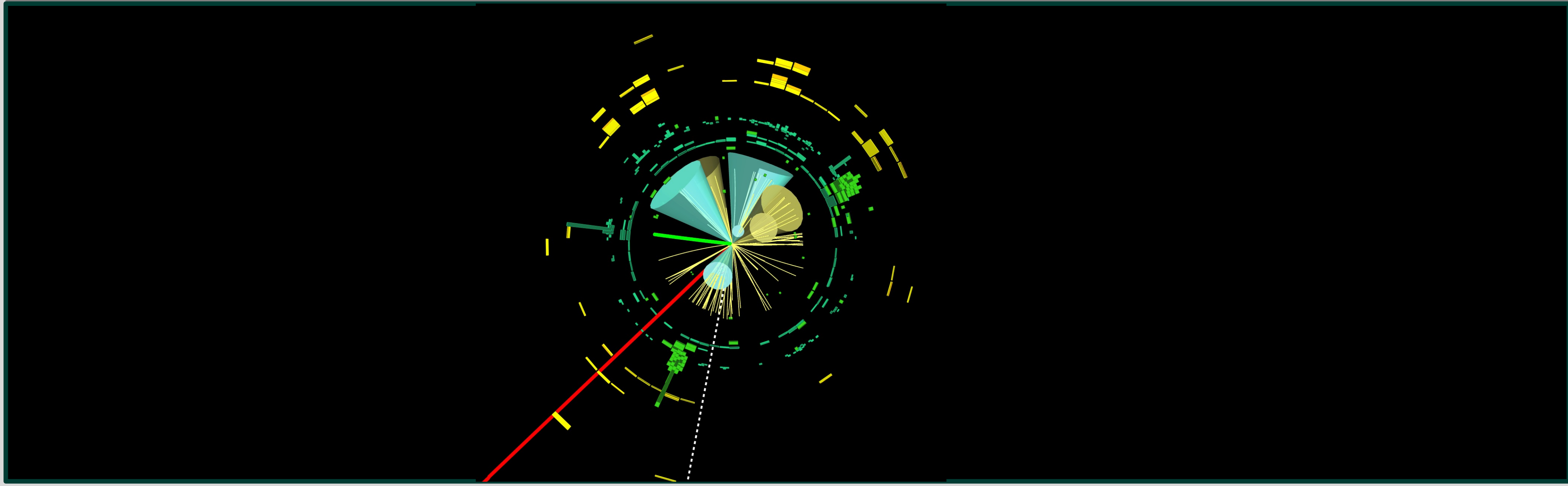

Outline

- **INTRODUCTION**

- **PART I: Philosophy for physicists and physics for philosophers**
- The LHC in a nutshell
- Terminological clarifications

- **PART II: Philosophical context and key notions**
- Philosophical problem
- An expanded epistemic risk framework
- Modelling and simulation practices at the LHC

- **PART III: A case study from ATLAS**
- Mapping risks in ATLAS search for four-top-quarks production in 2LLS/3L channel
- Signal and background modelling
- Event selection

- **CONCLUSION**

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INTRODUCTION

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Thesis dissertation: “Epistemic Risk(s) in particle physics“

Supervisor Prof. Dr. Dr. Rafaela Hillerbrand (KIT)

Interdisciplinary Research Unit the Epistemology of the Large Hadron Collider – DFG funded (2020-2024)

Project B1: The impact of computer simulation and machine learning on the epistemic status of LHC data

Research Group PhilETAS (KIT)
(Philosophy of Engineering,
Technology Assessment, and
Science) (2020-2025)

EPISTEMOLOGY LHC

INTRODUCTION

- Aim of the talk:

- Introduce you to the notions of **inductive risk** (i.e., the risk of error when reasoning from data to an empirical conclusion) and **epistemic risks (**i.e., the risks induced by the effects of uncertainty on the production of knowledge) (PART II)

- Connect an epistemic risk framework to **modeling and simulation practices** at the Large Hadron Collider (LHC) (PART III)

- Show how different **epistemic risks shape experimental outcomes** through a case study: ATLAS search for four-top-quark production, a rare process predicted by the Standard Model of particle physics (PART III)

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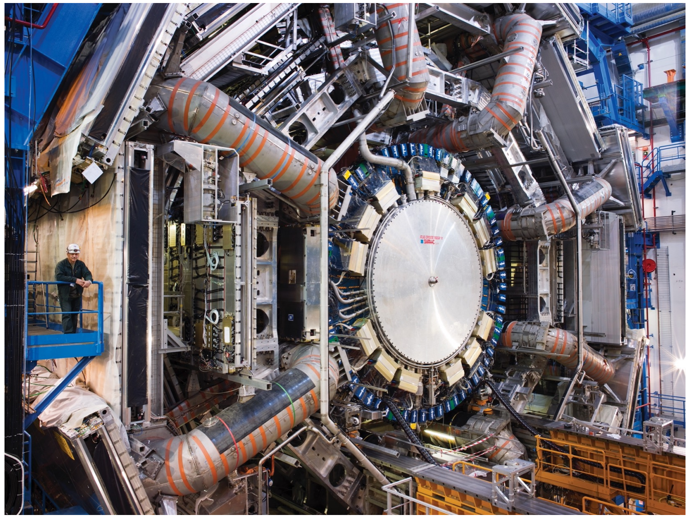
PART I – Philosophy for physicists and physics for philosophers



- The Large Hadron Collider in a nutshell:
- CERN and ”science for peace”
- The Standard Model and beyond
- Largest and highest-energy particle accelerator in the world

- From 17th century laboratory to contemporary particle physics:
- Radically large collaborations
- Simulation-aided experiments
- Resource intensive

> “simulation knowledge is what tells us where to look for a Higgs event, that a Higgs has occurred, and that we can trust the predictive capability of the collider itself” (Morrison, 2015, p. 10)

PART I – Philosophy for physicists and physics for philosophers

- Terminological clarifications

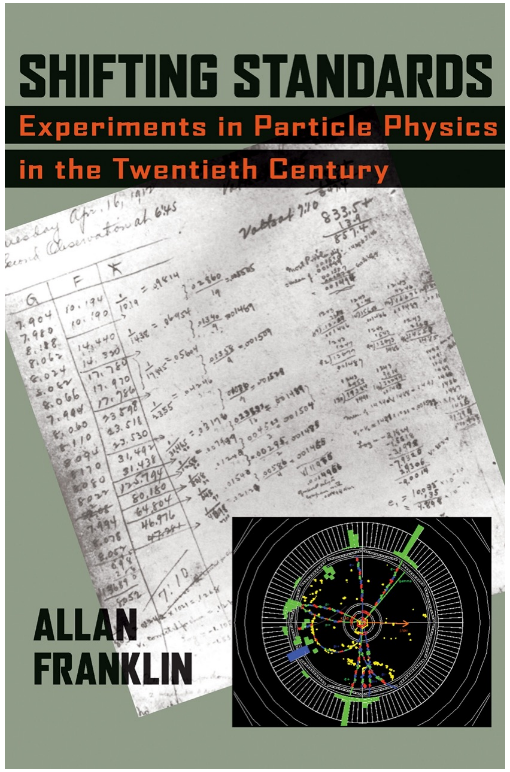
EVIDENCE and OBSERVATION

In Particle Physics

Succes terms: technical meaning and conventional thresholds

In Philosophy

Epistemological concepts: different theories about the nature of evidence and of observation, justification function



Example of LHC experiments: philosophers' ***evidence*** would refer to the physicists' ***candidate sample*** resulting from data acquisition and analysis

PART I – Philosophy for physicists and physics for philosophers

- Terminological clarifications

UNCERTAINTY

State of affair, either of our knowledge (in principle reducible) or of the world (irreducible)

In Particle Physics

Sources of uncertainty: *systematic* (modelling and instrumental > bias in measurement, unknown fluctuations, unstable values) and *statistical* (inherent fluctuations in measurement)

In Philosophy

Sources of uncertainty: *epistemic* (related to a state of knowledge) and *non-epistemic* (aleatory)

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PART II – Philosophical context and key notions

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Philosophical Problem

- The Problem of Induction

David Hume *A Treatise of Human Nature* (1739) and *An enquiry concerning human understanding* (1748)

Inductive inference *I* { All observed instances of *A* have been *B*.
The next instance of *A* will be *B*.

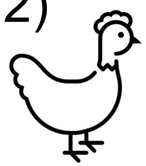
Inference *I* presupposes the Uniformity Principle (UP).

There is no demonstrative argument (non-contradiction) and no probable argument (circularity) for the UP.

Inference *I* is not justified.

- Inductive reasoning: The « glory of science » and the « scandal of philosophy » (C.D. Broad 1952, p.153)
- B. Russell's inductivist chicken

The Problems of Philosophy (1912)



"Just when the probability of being fed is higher than ever before, you're dead meat." (Gigerenzer 2014)

PART II – Philosophical context and key notions

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Philosophical Problem

How to deal with the inherent uncertainties of empirical reasoning?	•Problem of Induction > Inductive Risk •Problem of Underdetermination > Inferential gaps
The Value-Free Ideal of Science	•Non-epistemic values *should not* influence the appraisal of scientific hypotheses •Internal versus external stages of scientific inquiry
The Argument from Inductive Risk	•From descriptive to normative claims •If error induces direct socio-ethical consequences, then non-epistemic values are *allowed / should* influence scientific inquiry

« Values are needed to weigh the consequences of the possible errors one makes in accepting or rejecting a hypothesis, i.e., the consequences that follow from the inductive risk » (Douglas, 2000, p. 562)

Inductive risk: classic notion tied to statistical errors.
But **inferential gaps arise well before inductive inference,** e.g. in data acquisition (zoom-in on experimental tasks)

PART II – Philosophical context and key notions

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An expanded epistemic risk framework

- **What risk are we talking about?**

- Quantitative probabilistic notion of risk : “measurable uncertainty, or risk proper” = known probability distribution = known risk. In contrast, uncertainty = unmeasurable. (Fischhoff et al. 2011)

- In engineering, risk is defined as the effect of uncertainty on the achievement of goals (ISO, 2018)

- Philosophy of Technology: risk is always value-laden. Risk is understood as a value-judgement about a decision of action in a context of uncertainty. Risk = unwanted phenomena. (Hansson, 2005).

- Philosophy of Science: epistemic risk traditionnaly understood as risk of being wrong in accepting or rejecting hypothesis (inductive risk) induced by imprecise or incomplete knowledge (uncertainty). (Hempel, 1965)

PART II – Philosophical context and key notions

An expanded epistemic risk framework

- **From inductive risk to various epistemic risks:**

- Inductive risk as a special case of underdetermination (ChoGlueck, 2018)
- Inductive risk as a subset of epistemic risk (Biddle and Kukla, 2017)

➢ Epistemic risk understood in terms of risk of epistemic failure in relation to goals and interests, encompassing error, ignorance, and purpose-inadequacy.

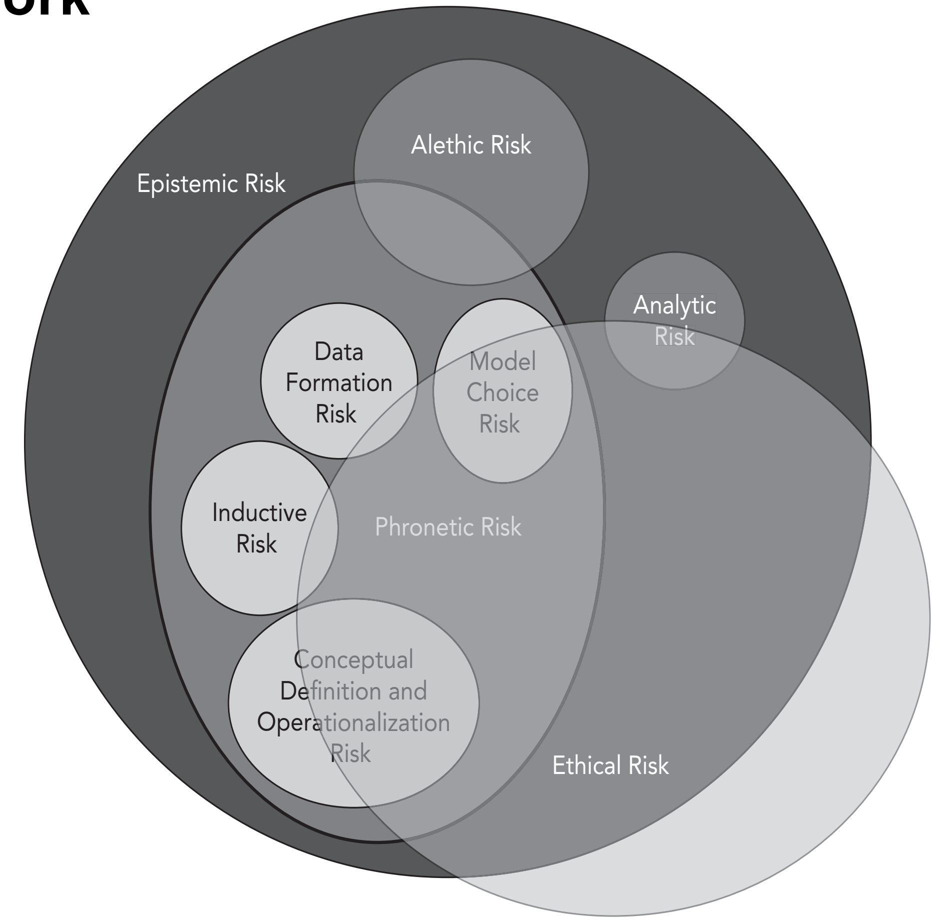


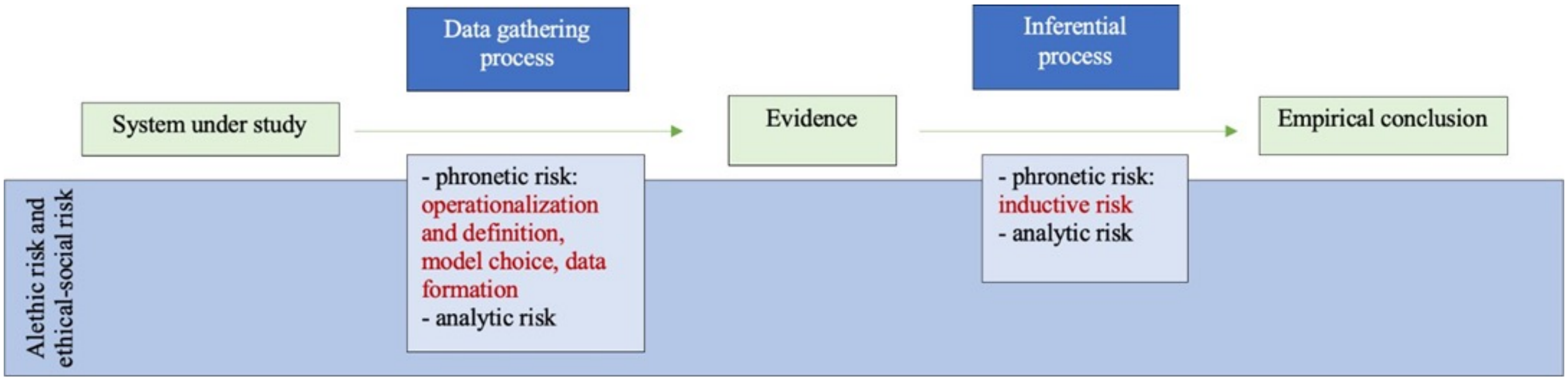
FIGURE 11.1 The geography of epistemic risk.

Biddle & Kukla (2017, p.222)

PART II – Philosophical context and key notions

An expanded epistemic risk framework

Locating epistemic risks in scientific experimentation



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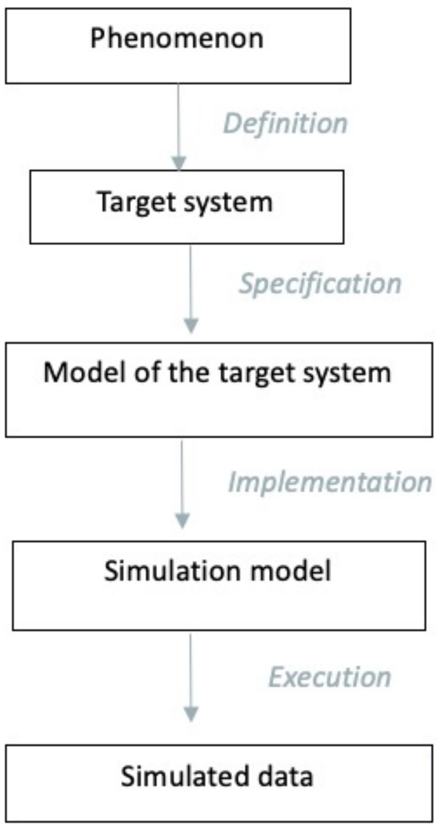
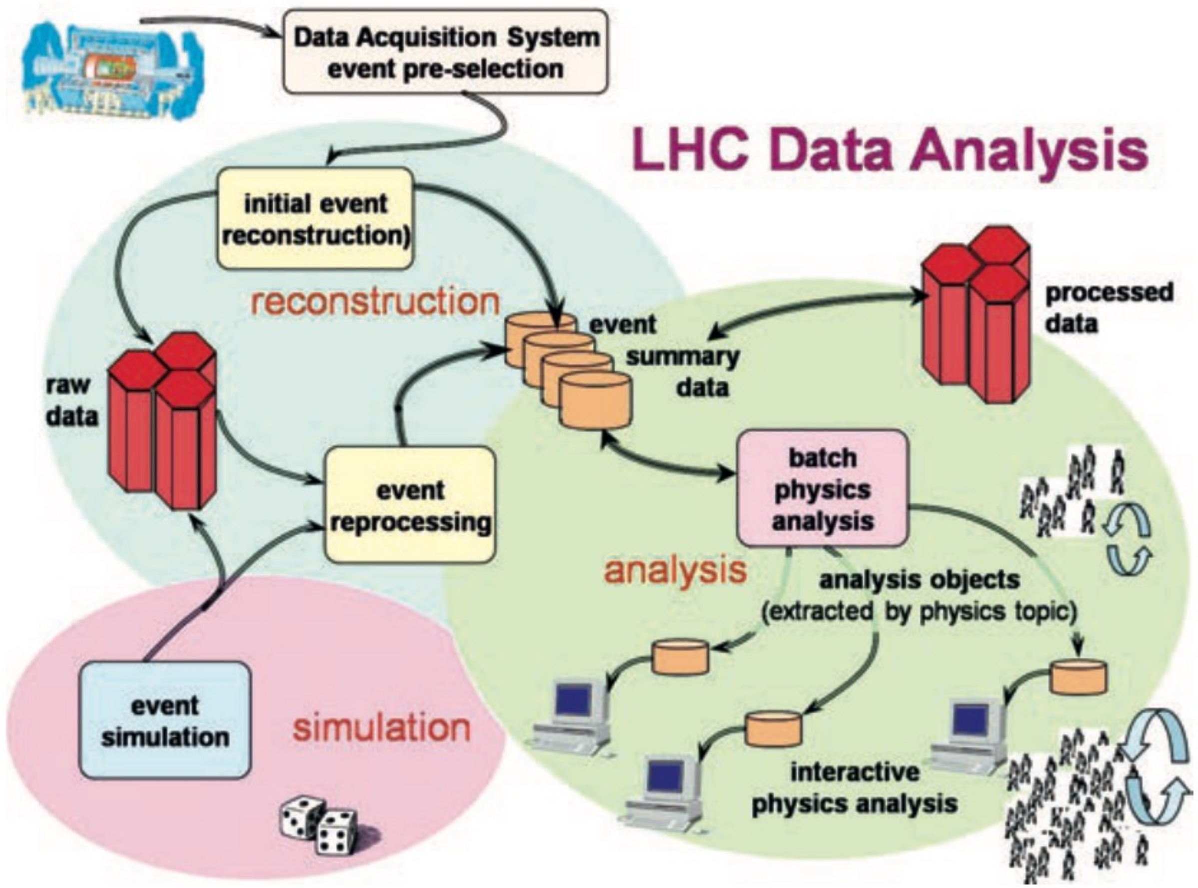
PART II – Philosophical context and key notions

Modelling and Simulation practices at the LHC

- Detector design and calibration
- Data generation and analysis





High level diagram of the data flow and major processing steps (fig.64, Evans 2009, p.244)

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PART III – A case study from ATLAS

Mapping Risks in ATLAS search for four-top-quarks production in 2LLS/3L channel

ATLAS Collaboration (2020)

Inductive risk: classic notion tied to **statistical errors.**

But **risks arise well before inductive inference** in data acquisition.

Therefore, we argue for a **broader taxonomy of epistemic risk.**

Case study from ATLAS search for four-top-quarks production.

Zoom-in on reported **systematic uncertainties and their associated experimental tasks**: modelling and simulation practices.

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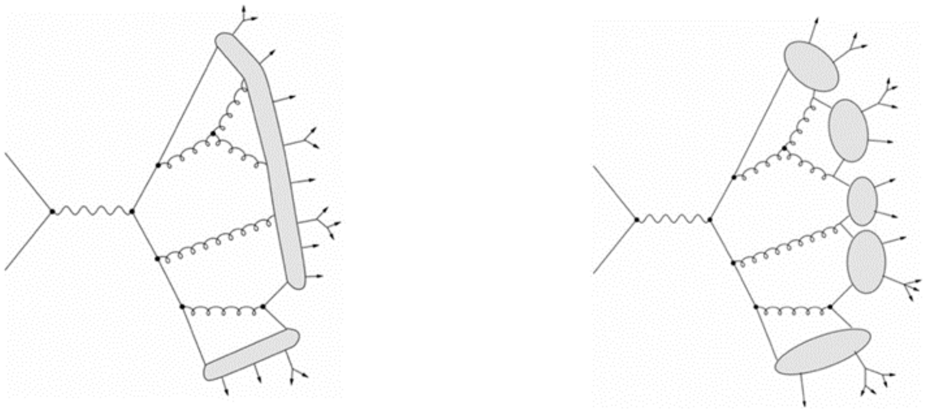
PART III – A case study from ATLAS

Signal and background modelling

- **Model choice risk:** Model-building assumptions, background theory (e.g., cluster *versus* Lund string model in QCD), methodological challenges (e.g., defining statistical procedures) and technical constraints (available software)
- **Data formation risk and analytic risk:** Reducible and irreducible backgrounds
- **Delayed risk:** Choice of the decay channel affects data formation risk in event selection (example of ATLAS *versus* CMS)



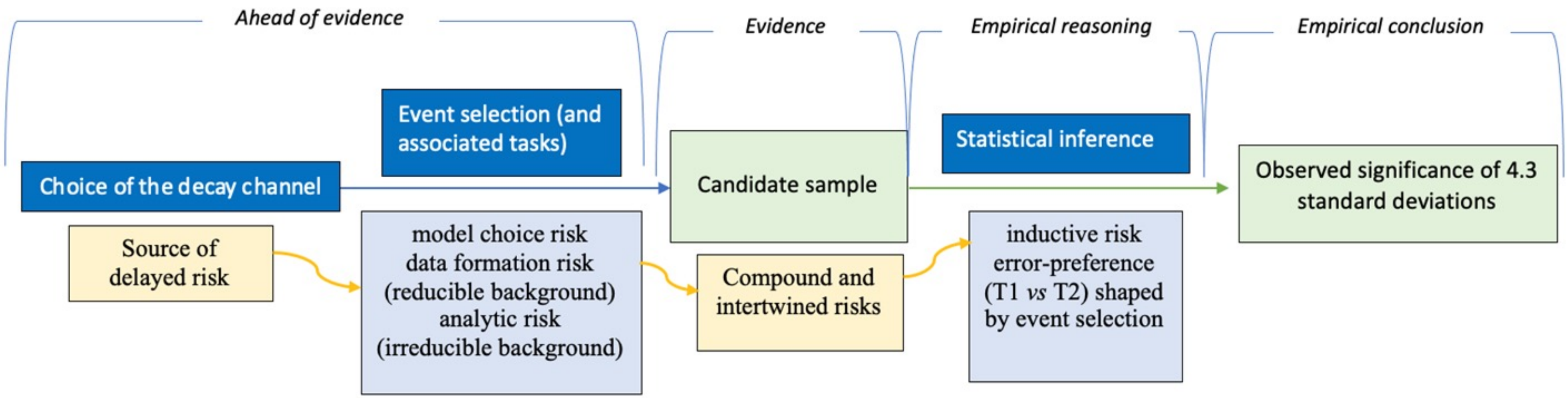
Feynman diagrams of hadronization

Event selection

- **Inductive risk:** Tradeoffs between background rejection and signal acceptance > error preference (T1 and T2) shaped by event selection
- **Cumulative data formation risks** arising from the data generative process

PART III – A case study from ATLAS

- Different modalities of risk: delayed, compound, intertwined
- Risk is dynamic throughout the experimental process



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CONCLUSION

- Inductive risk is just the tip of the iceberg

An expanded epistemic risk framework:

- appears fruitful to systematize the larger scale of experimental uncertainties and their (non) epistemic consequences
- helps to identify entry points for value-laden decisions upstream, especially in the context of simulation-intensive and radically collaborative empirical science.

- Epistemic-pragmatic entanglements reveal how knowledge is co-produced with values, constraints, and trade-offs.

- Take-home message:
  - For philosophers: New avenues for discussions on risk management and the role of values in fundamental research
  - For physicists: Increased awareness of risk pathways beyond statistical inference

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THANK YOU!

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EPISTEMOLOGY LHC

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