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Illuminating the dark side of statistics: Bayesian inference in particle physics

Wednesday 26 March 2025 10:00 (1 hour)

High energy physics (HEP) has historically favoured frequentist statistical methodologies, leading to the development of analysis workflows and tools optimized around this paradigm. Frequentist techniques, such as those embedded in the HistFactory statistical model, have become standard in particle physics, often utilizing asymptotic approximations for efficient parameter estimation and hypothesis testing. While these methods are highly effective, their assumptions may restrict flexibility in certain analyses, especially when asymptotic approximations break down or simply do not apply.

Bayesian approaches are starting to gain attention in HEP for their interpretative advantages, providing the full posterior distribution, which allows for flexible inference even when distributions deviate strongly from Gaussianity. Bayesian inference also handles cases with multiple parameters of interest more naturally and can incorporate prior information directly, without the need of auxiliary data. Additionally, Bayesian inference does not rely on asymptotic assumptions, making them well-suited for cases where such approximations may fail.

Lecture plan

More concretely, the **lecture** (1 hour) could be structured as follows:

What makes an analysis "frequentist" or "Bayesian"?
- The likelihood as a fundamental object
- Priors vs. constraints

Commonalities and differences in methodologies
- Simplicity and speed of frequentist inference
- Robustness and computational cost of Bayesian analyses
- Non-Gaussian parameter distributions
- Asymptotics and multiple parameters of interest
- Bayesian updating
- Confidence vs. credible intervals

MCMC sampling for posterior estimation
- Introduction to essential MCMC algorithms (e.g., Metropolis-Hastings, Hamiltonian Monte Carlo)
- (Practical considerations in Bayesian computation and convergence diagnostics)

Exercise plan

The **exercise session** (1 hour) could include:

Bayesian analysis of a mass parameter estimation

1. Select a simple frequentist analysis (e.g., mass scan yielding a non-Gaussian probability density function).
2. Construct the likelihood function for the mass parameter.
3. Implement or use an existing MCMC algorithm to sample from the posterior distribution.
4. Compute and visualize the posterior distribution of the mass parameter.
5. Derive the Bayesian credible interval and compare it to the frequentist confidence interval, discussing interpretational differences and implications.

Number of lecture hours

1

Number of exercise hours

1

Attended school

CSC 2024 (Hamburg)

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