PLUMBIN'

— Developing solvents for unclogging the calculational bottleneck in high-energy physics

Are Raklev

The problem

How do you test your fancy new theoretical model?

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You compare it to the data

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What can you test in a physics model?

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best-fit parameters

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$\downarrow$

What *parameters* ϑ in
my model fit the data?

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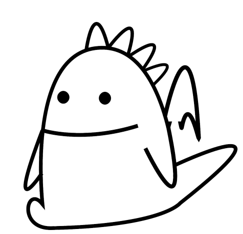
here be dragons!



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goodness-of-fit

best-fit parameters

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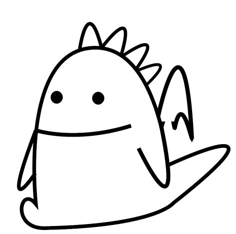

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goodness-of-fit

How probable is my model given the data?

(How probable is my model compared to another model?)

best-fit parameters

What $\boxed{\textit{parameters}\ \vartheta}$ in my model fit the data?

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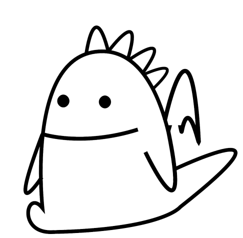

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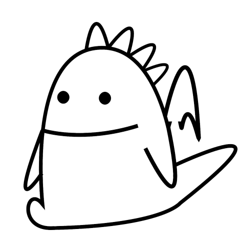


The focus here is always on *dis-proving* the model or the values of the parameters

The problem

How do you test your fancy new theoretical model?

You compare it to the data

How do you compare to data: the (global) likelihood

$$\mathscr{L} = \mathscr{L}_{\text{Collider}}\mathscr{L}_{\text{Higgs}}\mathscr{L}_{\text{Flavour}}\mathscr{L}_{\text{DM}}\mathscr{L}_{\text{Precision}}\cdots$$

What can you test in a physics model?

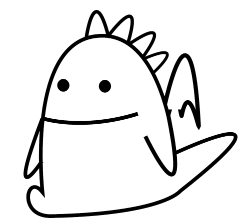
The focus here is always on *dis-proving* the model or the values of the parameters

goodness-of-fit → How probable is my model given the data?

(How probable is my model compared to another model?)

best-fit parameters → What $\boxed{\textit{parameters } \vartheta}$ in my model fit the data?

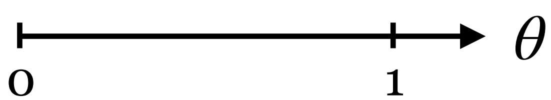
here be dragons!



G A M B I T $\mathcal{L}$

The problem with parameters

The problem with parameters



The problem with parameters

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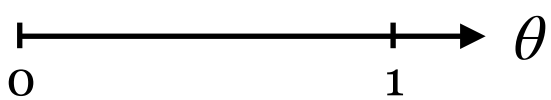

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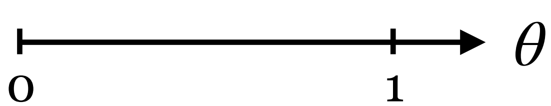

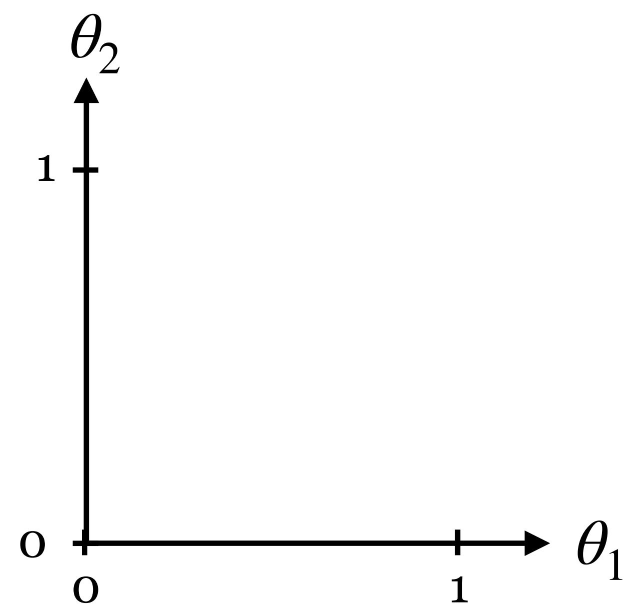

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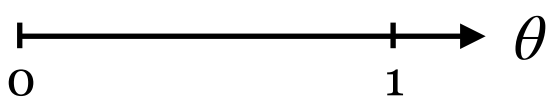

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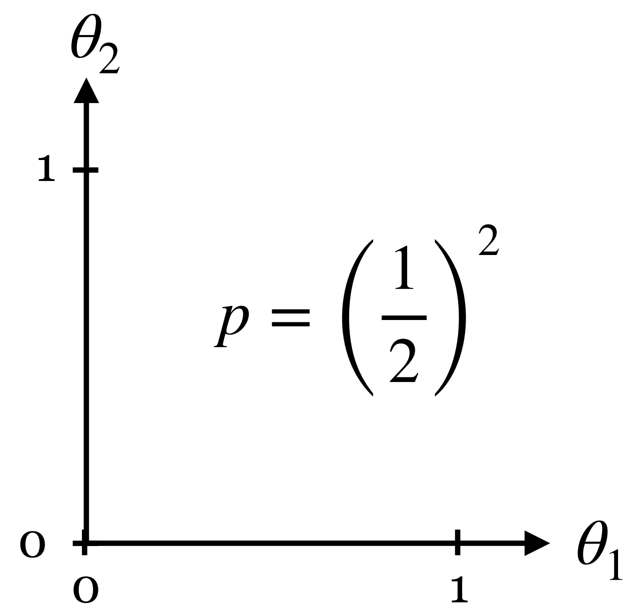

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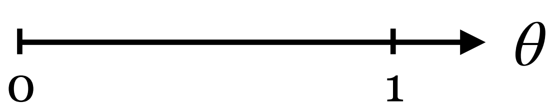

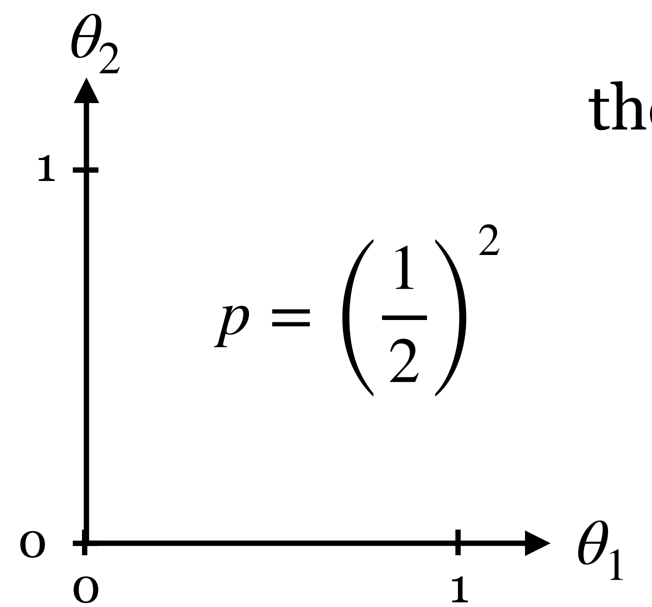

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the unit hypercube

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The problem with parameters

the unit hypercube

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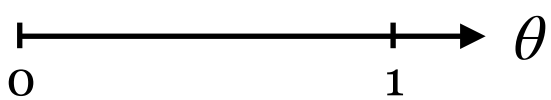

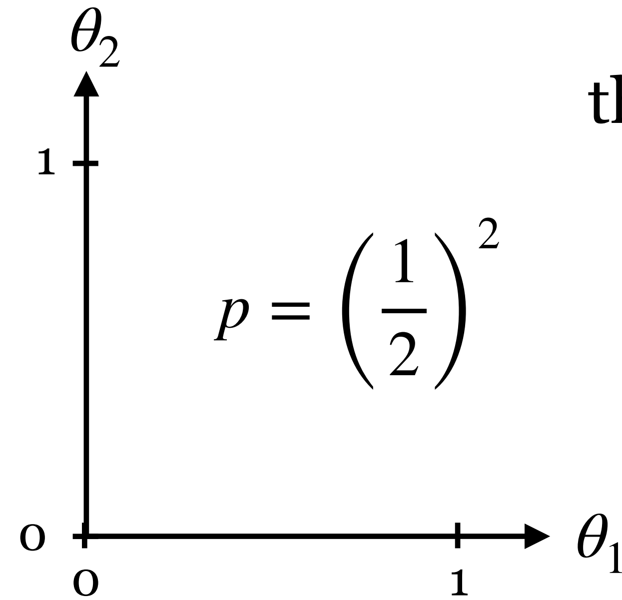

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$$p = \left(\frac{1}{2}\right)^n \xrightarrow{n\to\infty} 0$$

The problem with parameters

the unit hypercube

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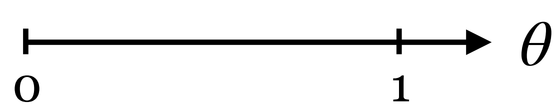

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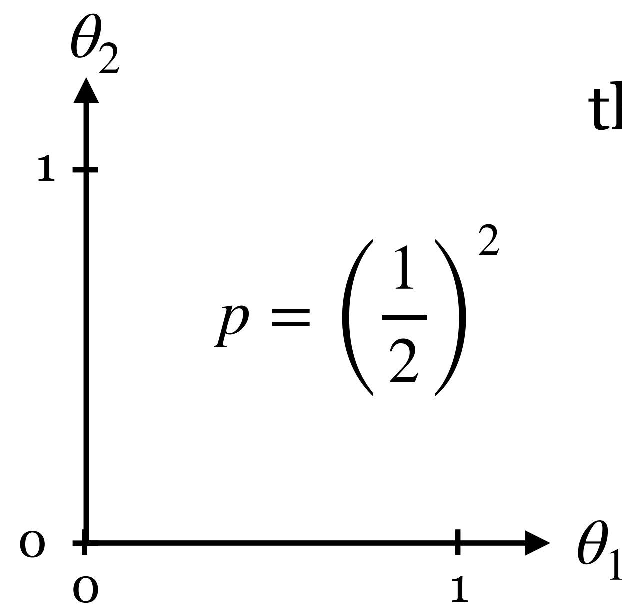

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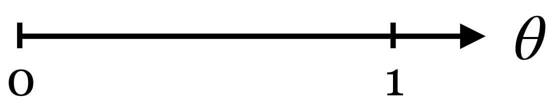

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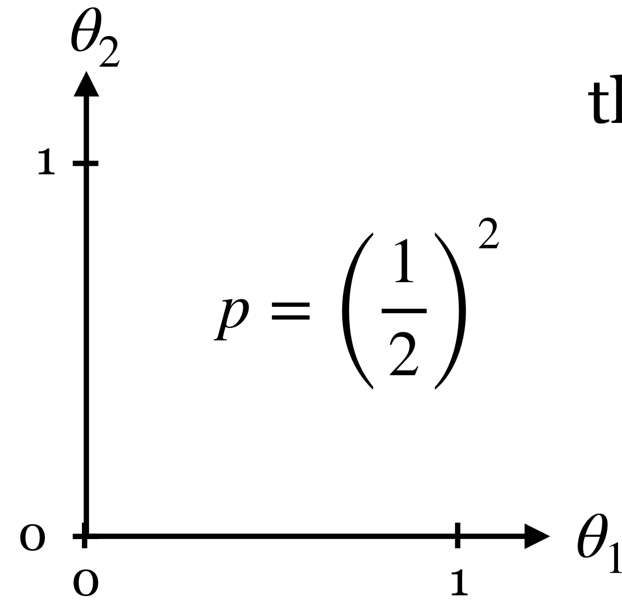

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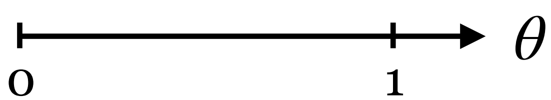

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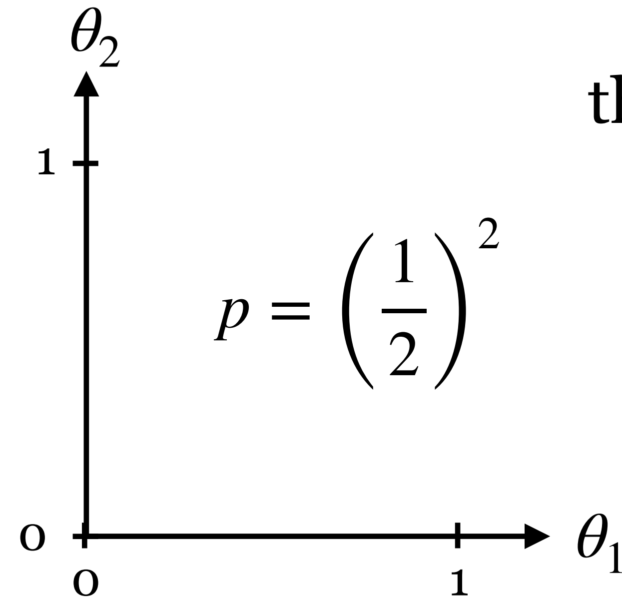

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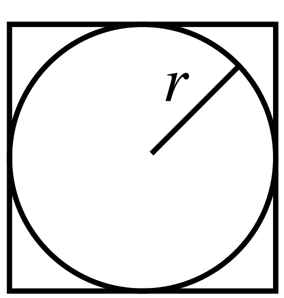

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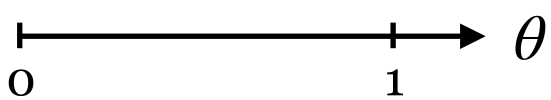

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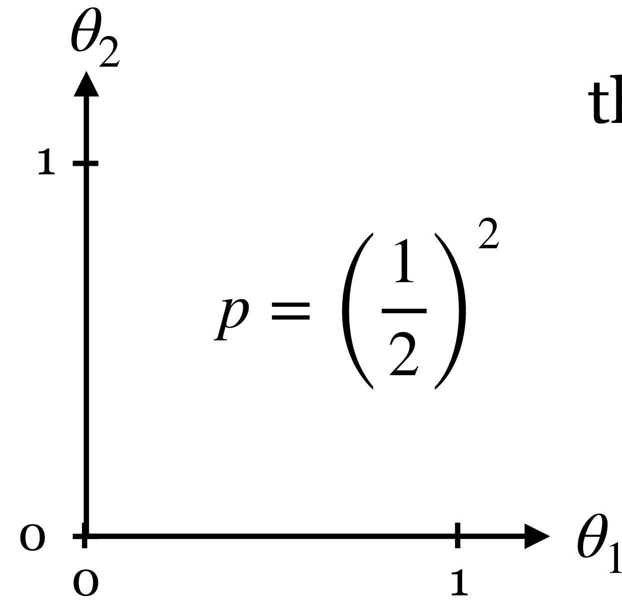

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the unit hypercube

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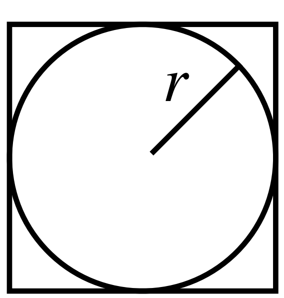

$$\frac{A_{\bigcirc}}{A_{\square}} = \frac{\pi r^2}{(2r)^2} = \frac{\pi}{4}$$

The problem with parameters

the unit hypercube

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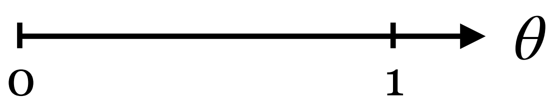

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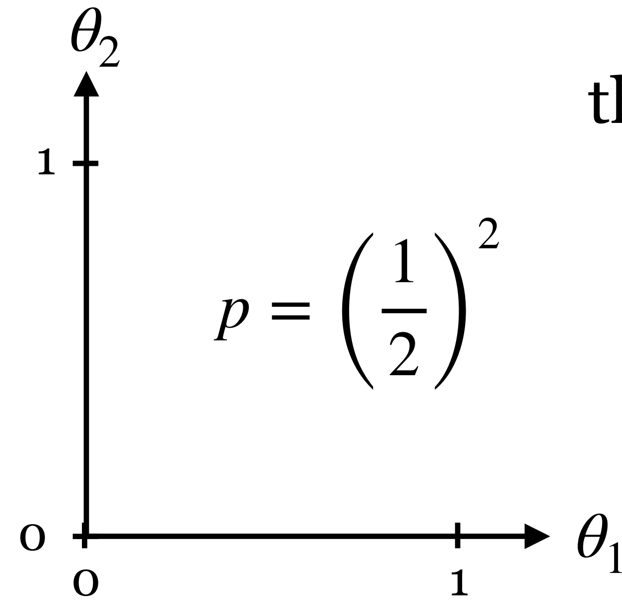

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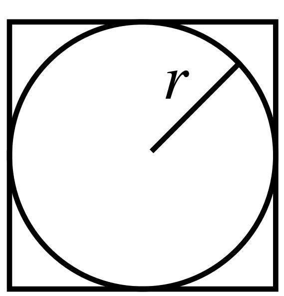

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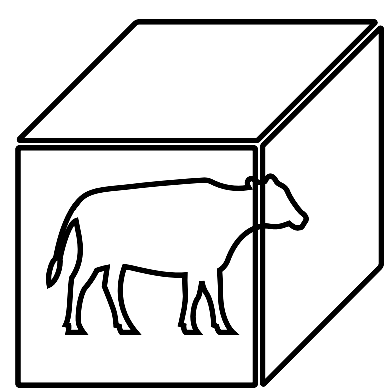

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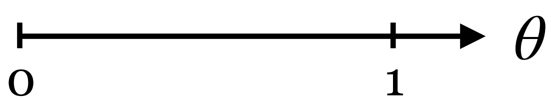

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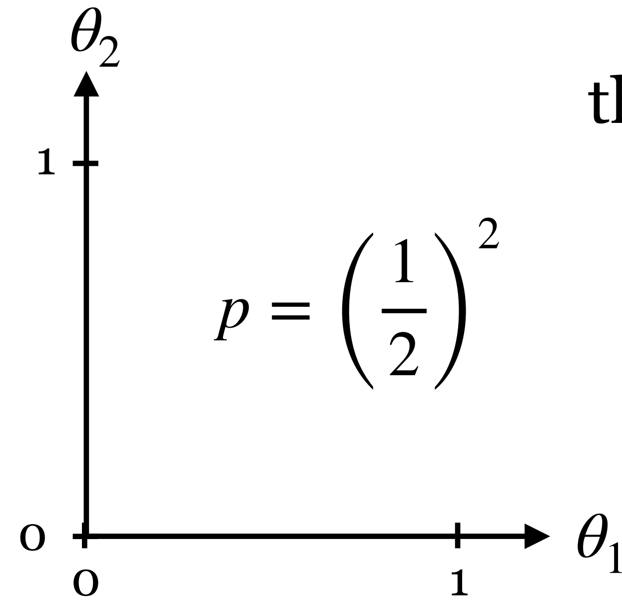

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$N = 10$

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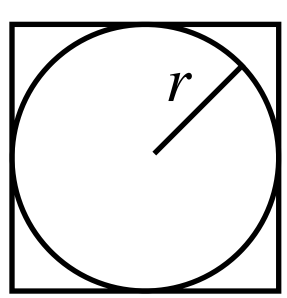

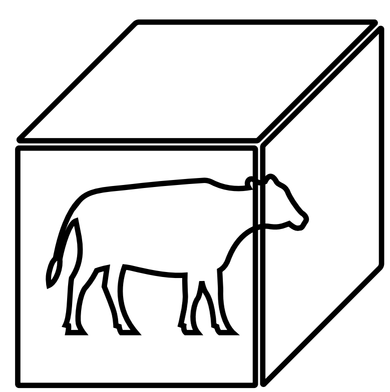

$$\frac{A_{\bigcirc}}{A_{\square}} = \frac{\pi r^2}{(2r)^2} = \frac{\pi}{4}$$

$$\frac{V_{\bigcirc}}{V_{\square}} = \frac{\frac{4}{3}\pi r^3}{(2r)^3} = \frac{\pi}{6}$$

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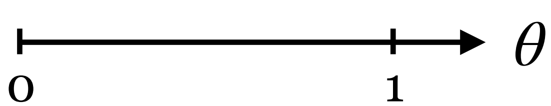

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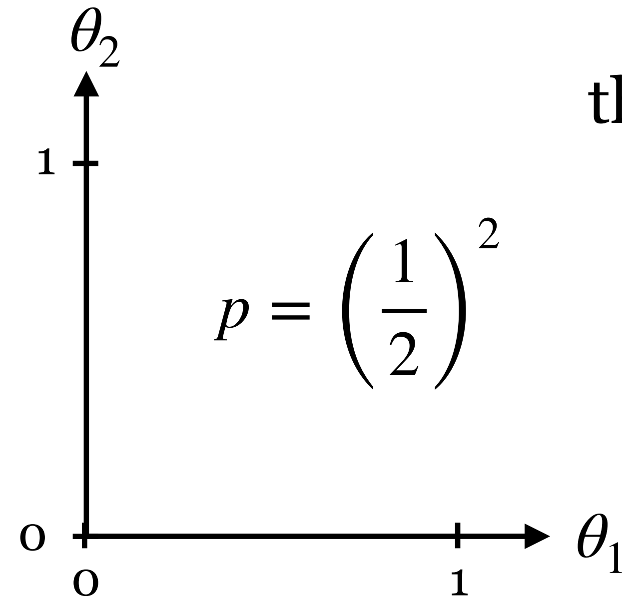

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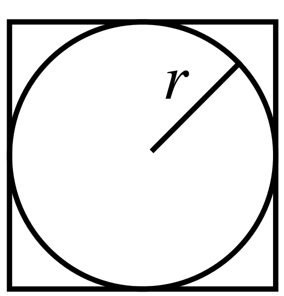

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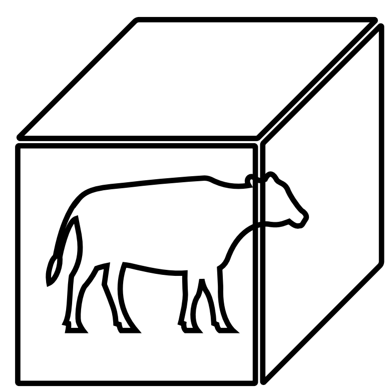

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$$\frac{V_{\bigcirc^n}}{V_{\square^n}} = \frac{\frac{\pi^{n/2} r^n}{\Gamma(n/2+1)}}{(2r)^n} \xrightarrow{n\to\infty} 0$$

The problem with parameters

The curse of dimensionality

the unit hypercube

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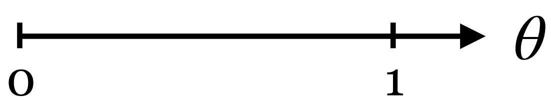

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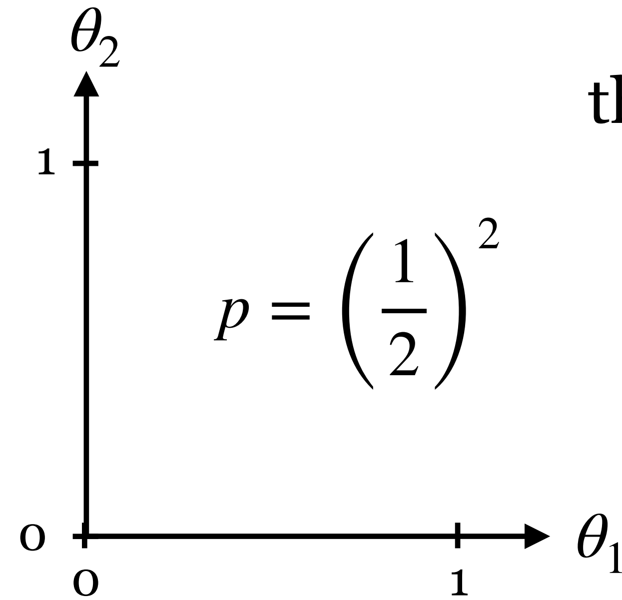

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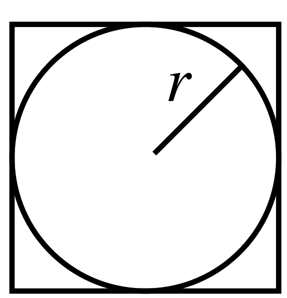

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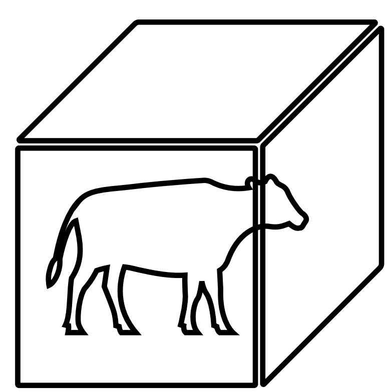

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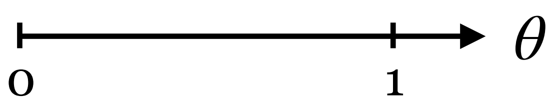

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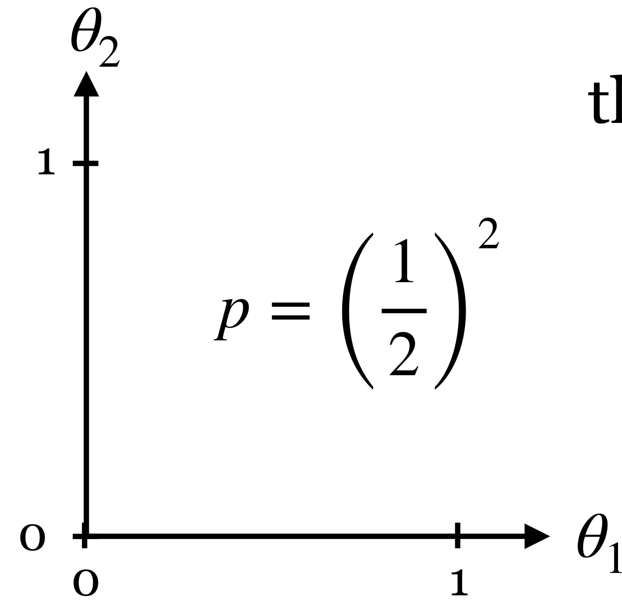

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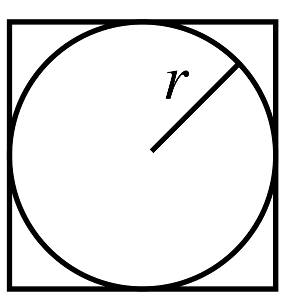

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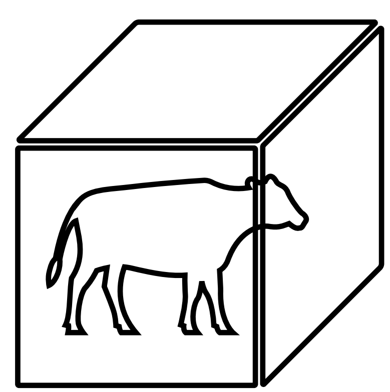

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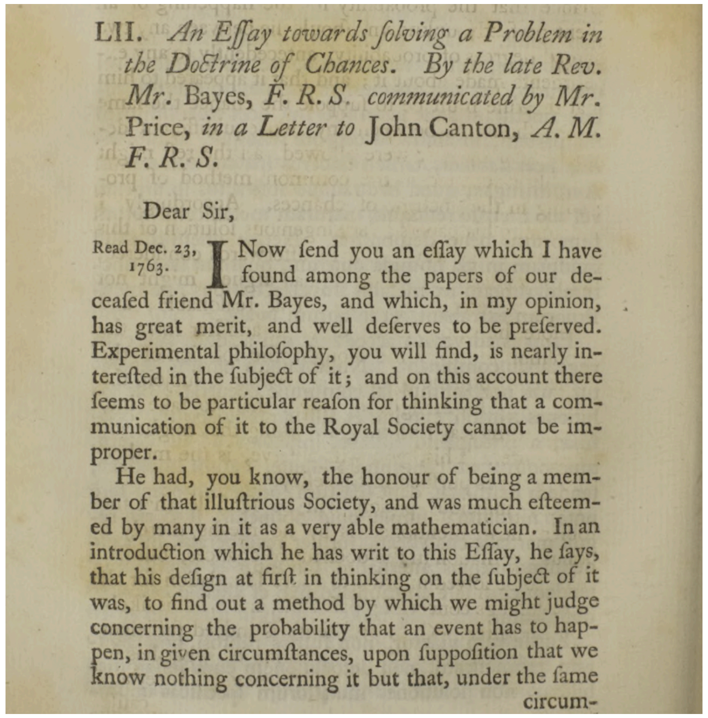
you can't find your socks
in 11-dimensions

Using likelihoods

Bayes' theorem

$$P(\theta \mid D) = \frac{P(D \mid \theta) P(\theta)}{P(D)}$$



LII. *An Eſſay towards ſolving a Problem in the Doctrine of Chances. By the late Rev. Mr.* Bayes, *F. R. S. communicated by Mr.* Price, *in a Letter to* John Canton, *A. M. F. R. S.*

Dear Sir,

Read Dec. 23, 1763. I Now ſend you an eſſay which I have found among the papers of our deceaſed friend Mr. Bayes, and which, in my opinion, has great merit, and well deſerves to be preſerved. Experimental philoſophy, you will find, is nearly intereſted in the ſubject of it; and on this account there ſeems to be particular reaſon for thinking that a communication of it to the Royal Society cannot be improper.

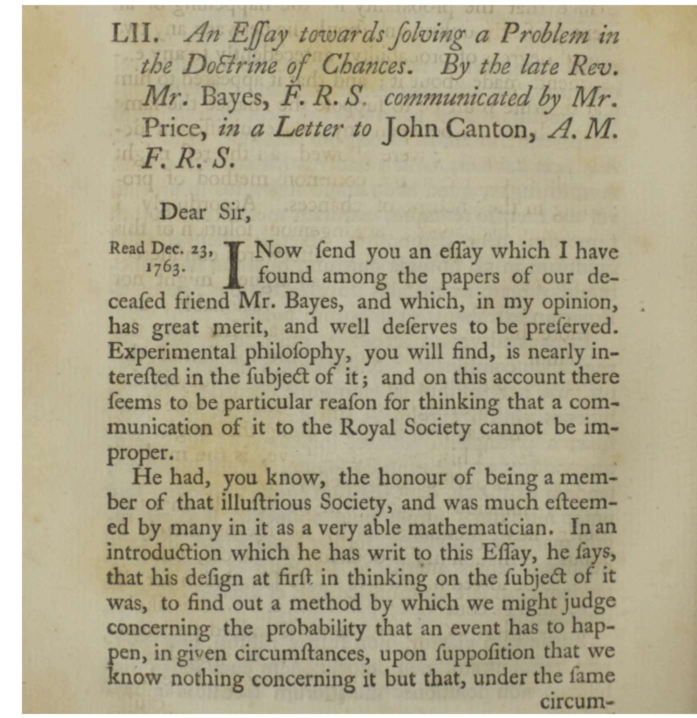
He had, you know, the honour of being a member of that illuſtrious Society, and was much eſteemed by many in it as a very able mathematician. In an introduction which he has writ to this Eſſay, he ſays, that his deſign at firſt in thinking on the ſubject of it was, to find out a method by which we might judge concerning the probability that an event has to happen, in given circumſtances, upon ſuppoſition that we know nothing concerning it but that, under the ſame circum-

T. Bayes, *An Essay towards solving a Problem in the Doctrine of Chances*, Philosophical Transactions of the Royal Society of London 53 (1763) 370–418

Using likelihoods

Bayes' theorem

$$P(\theta \mid D) = \frac{P(D \mid \theta) P(\theta)}{P(D)} \longleftarrow \begin{array}{c}\text{the } \textit{prior} \\ \pi(\theta) = P(\theta)\end{array}$$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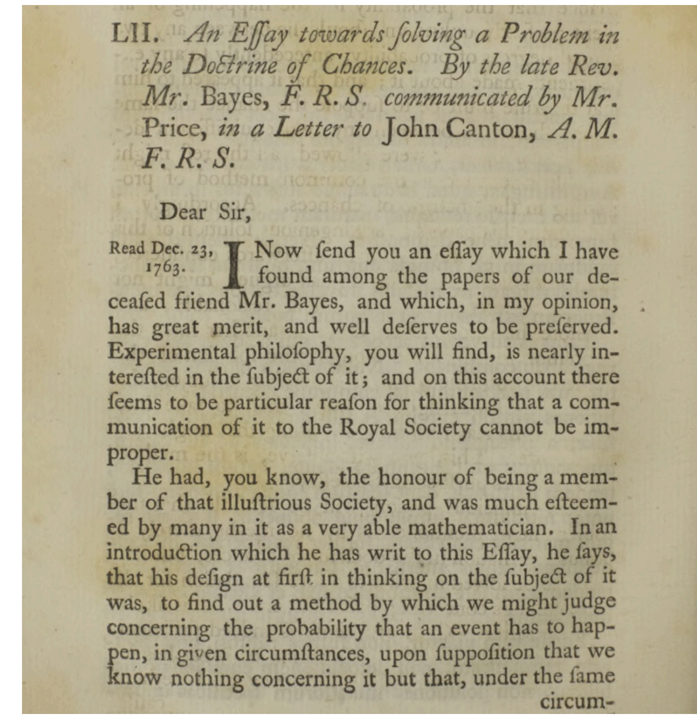

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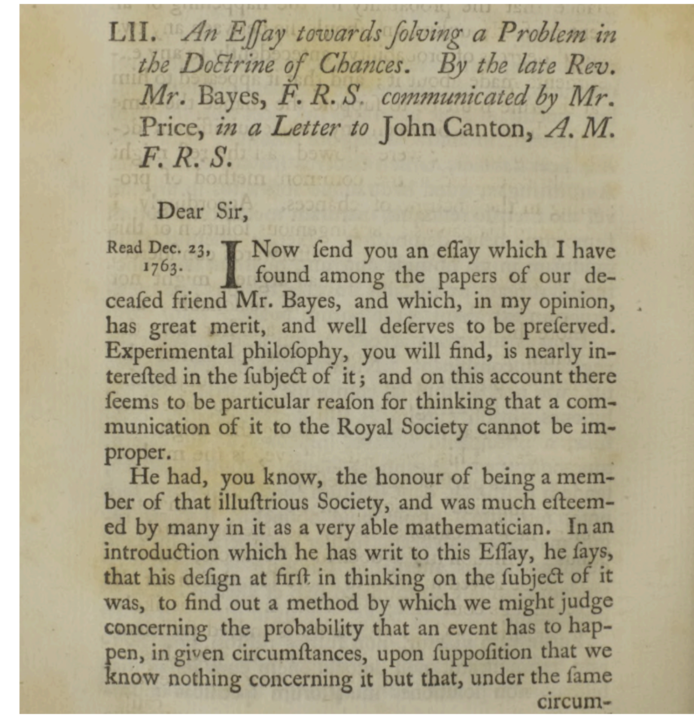

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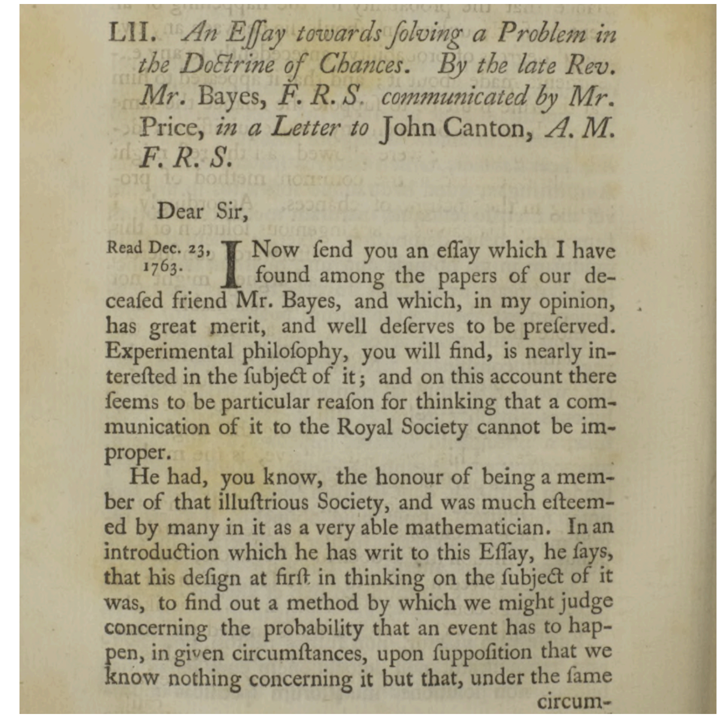

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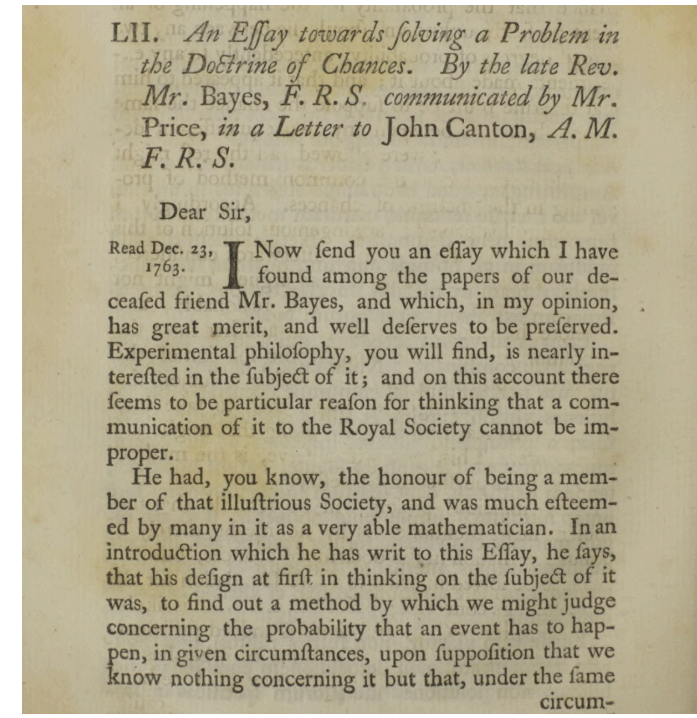

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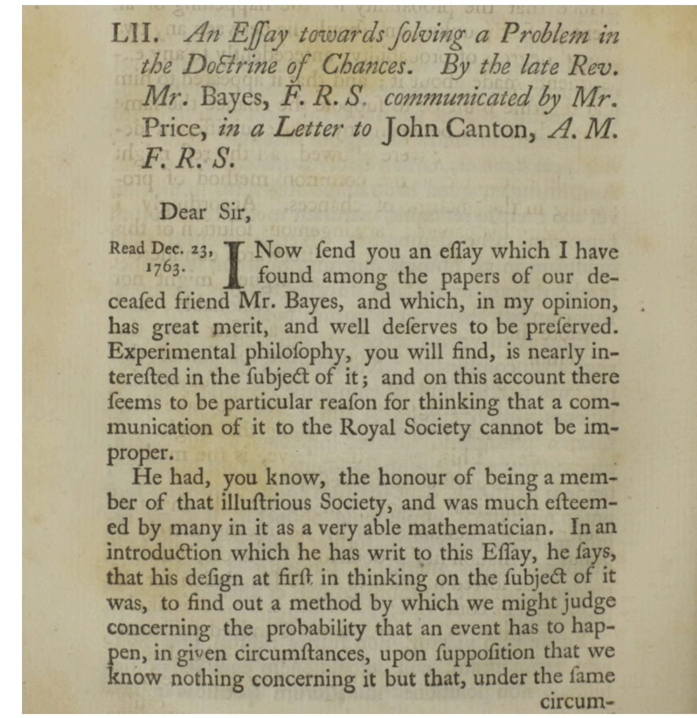

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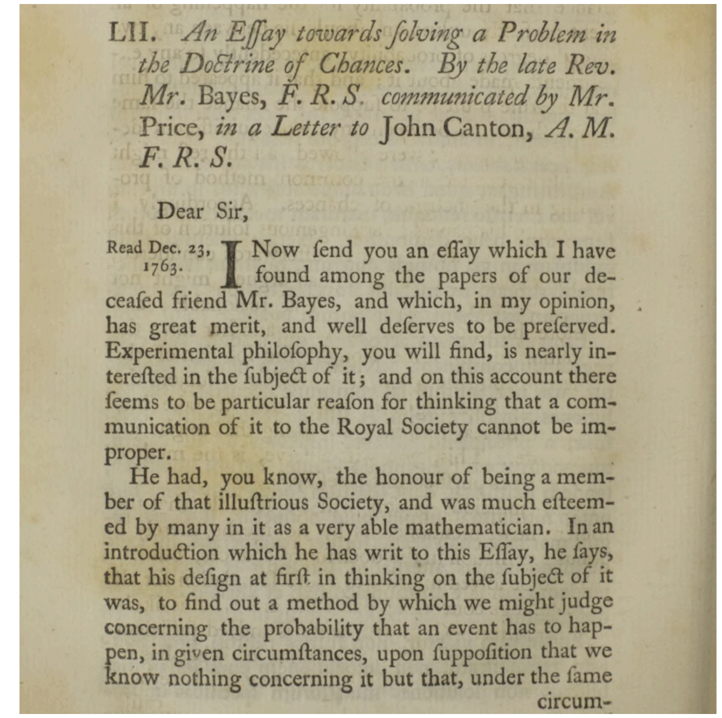

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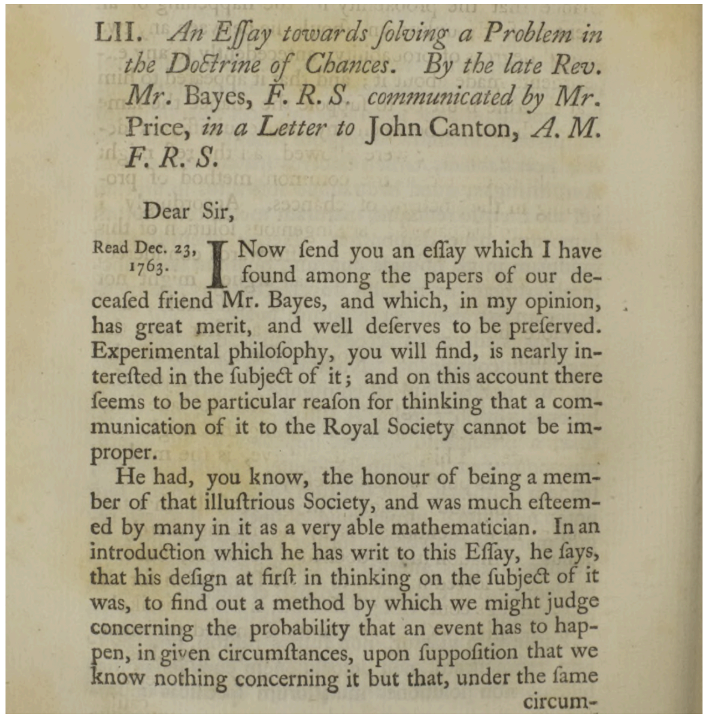

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Wilks' theorem: q is χ^2 distributed

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predicted number of
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number of measured events (data)

LHC likelihood including uncertainties

$$\mathscr{L}(n\,|\,s,b) = \int_0^\infty \frac{e^{-\xi(s+b)}[\xi(s+b)]^n}{n\,!} P(\xi)\,d\xi$$

$$P(\xi) = \frac{1}{2\pi\sigma_\xi}\frac{1}{\xi}\exp\left[-\frac{1}{2}\left(\frac{\ln\xi}{\sigma_\xi}\right)^2\right] \qquad \sigma_\xi = \frac{(\sigma_s^2+\sigma_b^2)}{(s+b)^2}$$

Cross sections

Cross sections

The parton level cross section in QFT

$$\hat{\sigma} = \alpha^2 \hat{\sigma}_{\mathrm{LO}} + \alpha^4 \hat{\sigma}_{\mathrm{NLO}} + \alpha^6 \hat{\sigma}_{\mathrm{NNLO}} + \ldots$$

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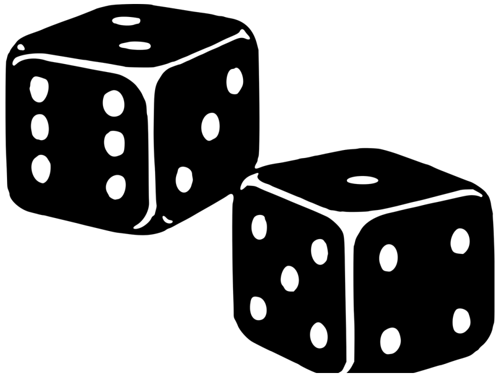
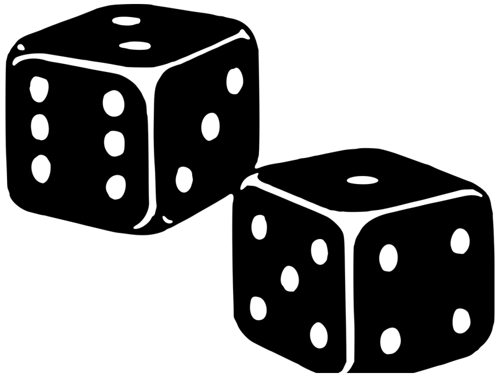
This depends on unknown scales μ_F and μ_R which can be taken to represent the uncertainty from higher order corrections.

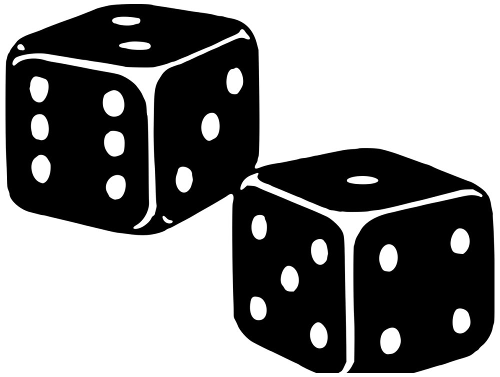


Event simulation



Event simulation

To find the efficiency ε you need to perform expensive repeated Monte Carlo simulations of collisions for each choice of parameters ϑ



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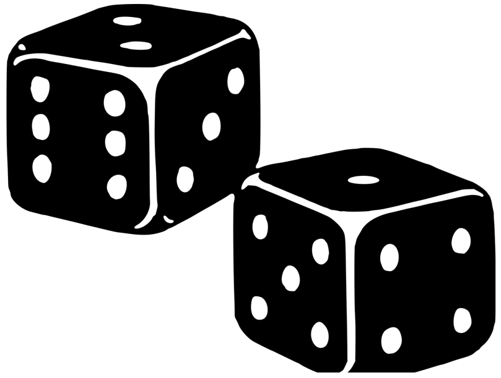
As a rule of thumb the error on your efficiency goes as $1/\sqrt{N}$, where N is the number of events generated



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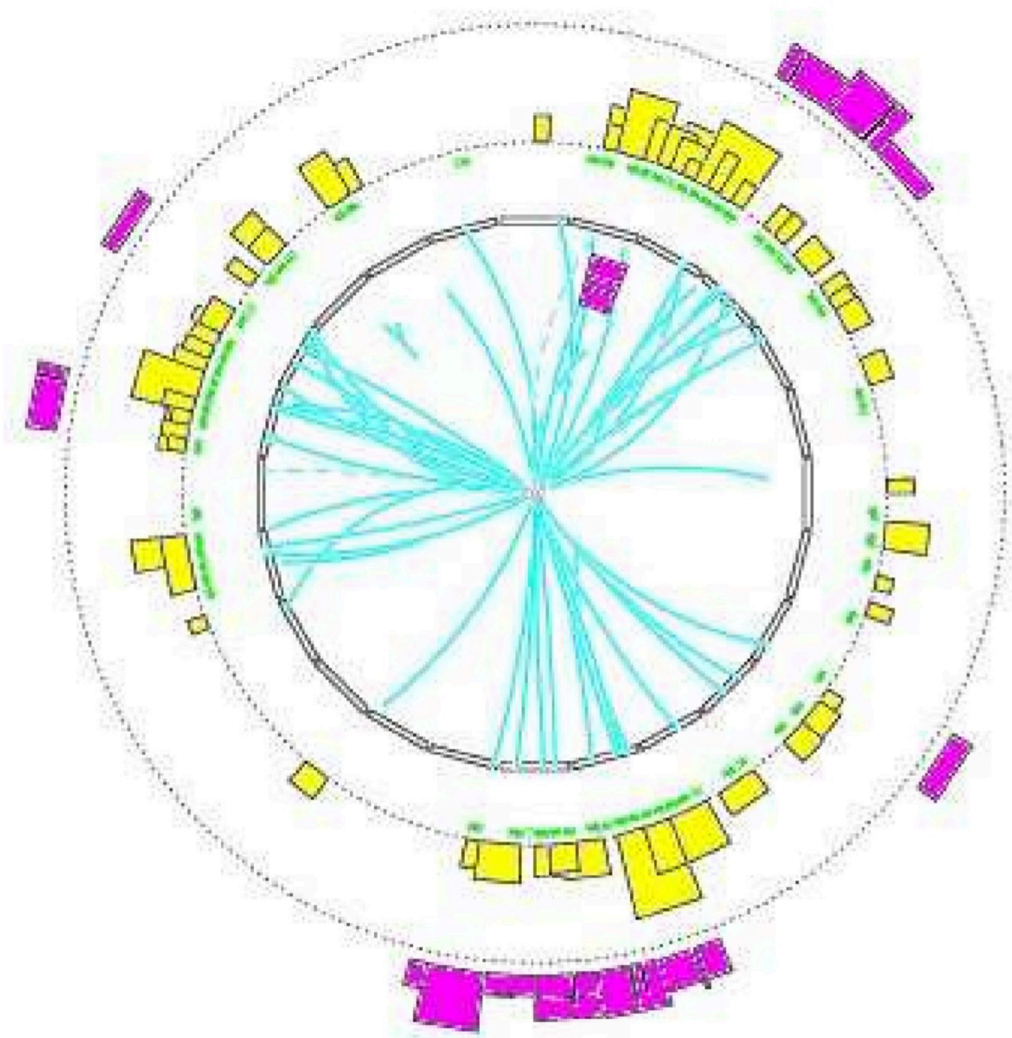

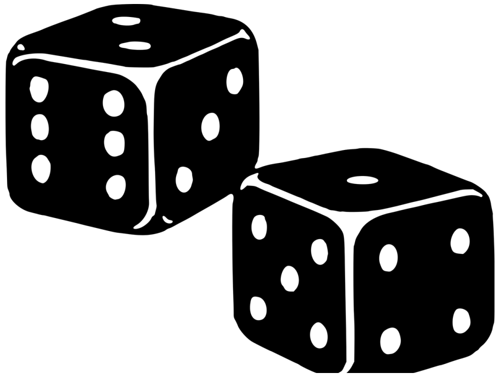

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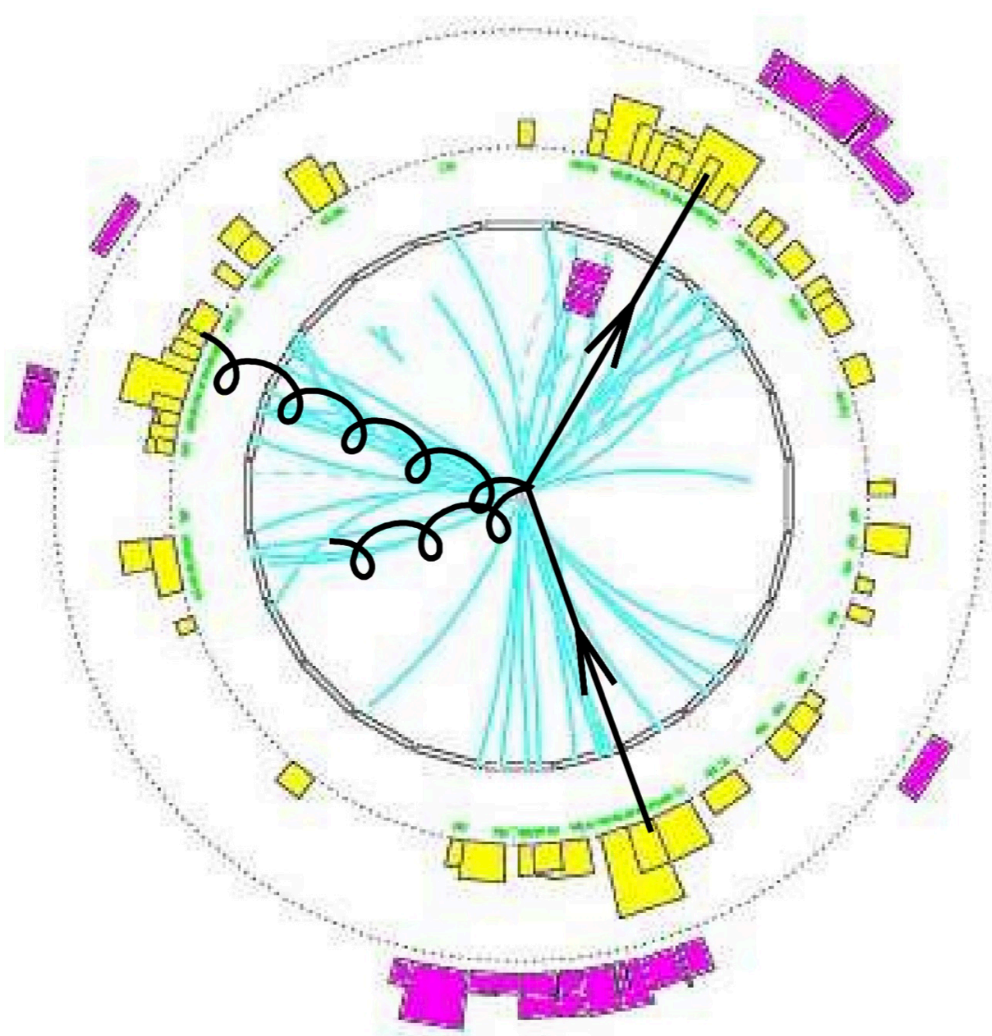

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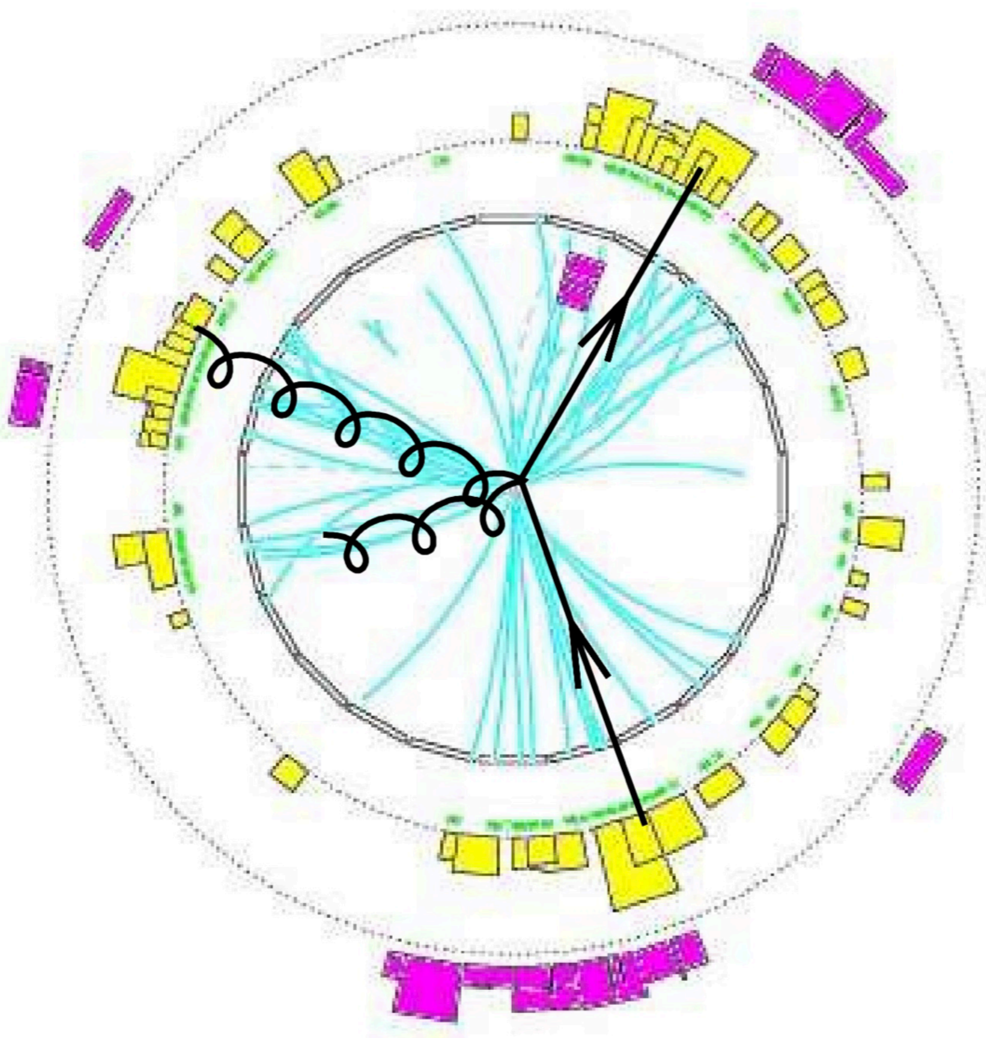
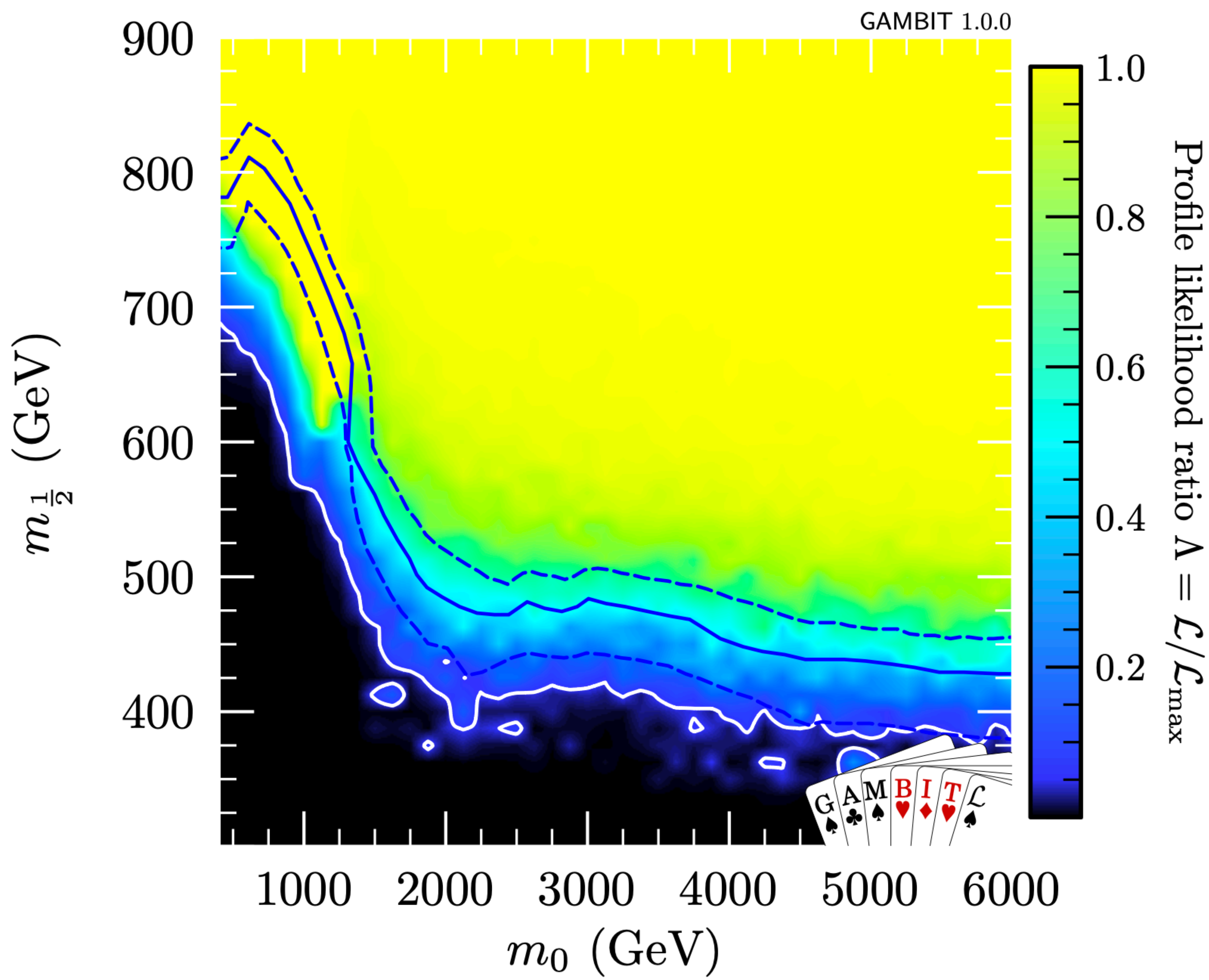


One of the most expensive parts is the reconstruction of hadronic jets, where the cost for n final state particles is $\mathcal{O}(n \ln n)$.

(however, in practise $\mathcal{O}(n^2)$ for $n < 10^4$)

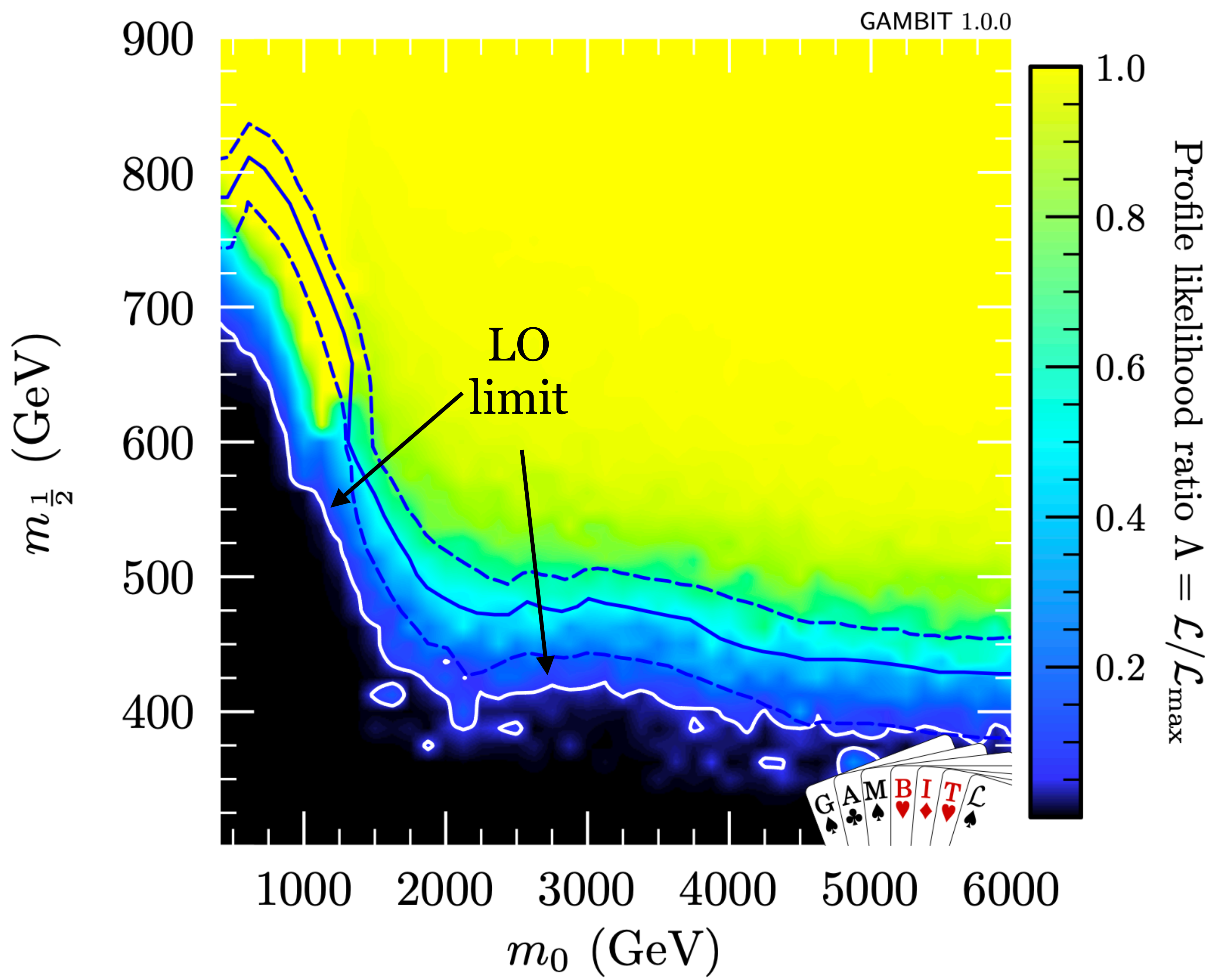
Putting it all together



An example of what happens in a simple supersymmetric model (mSUGRA/CMSSM) with four parameters: m_0, $m_{1/2}$, A_0, tan β.

The GAMBIT Collaboration (P. Athron *et al.*), *ColliderBit: a GAMBIT module for the calculation of high-energy collider observables and likelihoods*, Eur. Phys. J. **C77** (2017) 11, 795, e-Print: 1705.07919 [hep-ph]

Putting it all together



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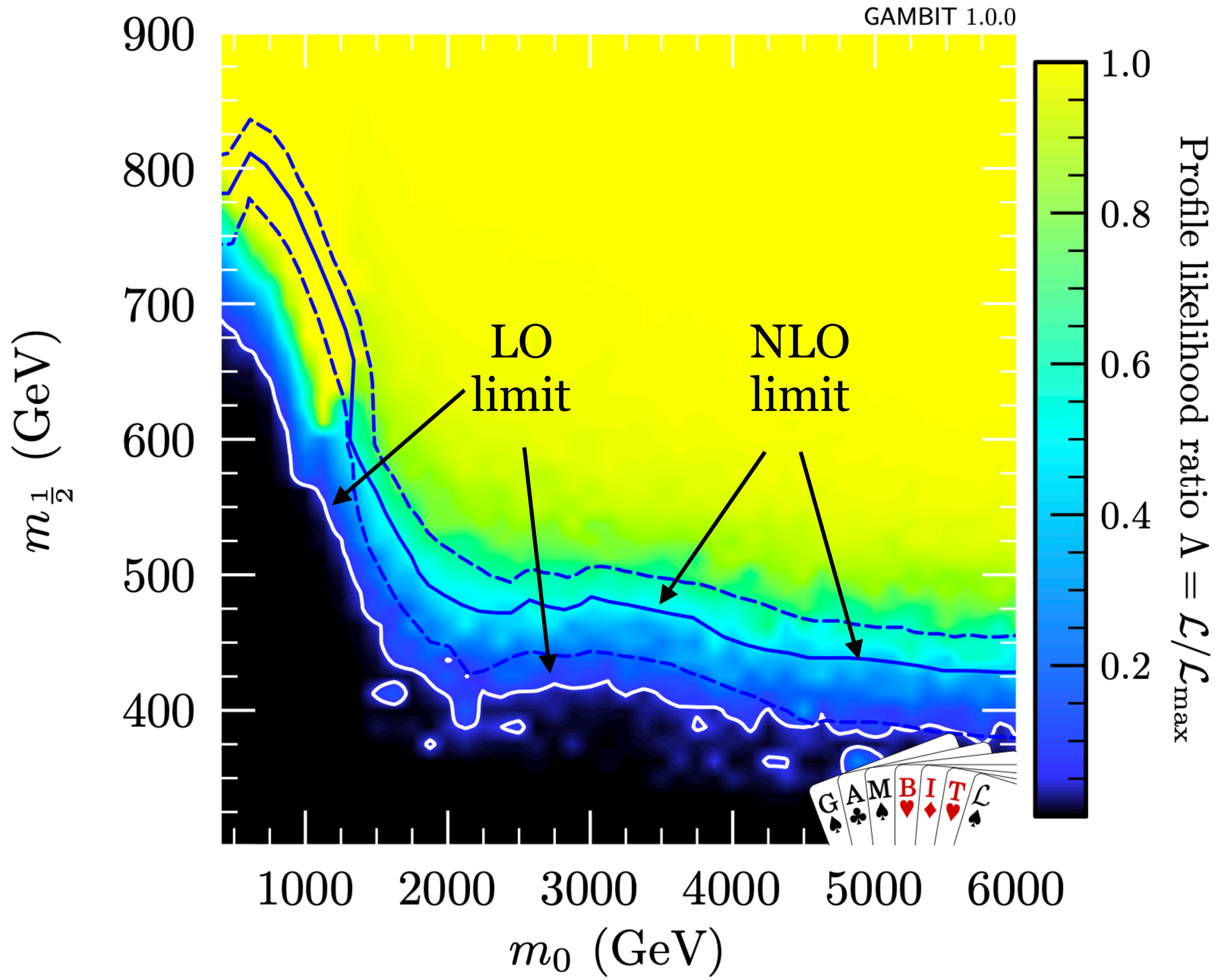

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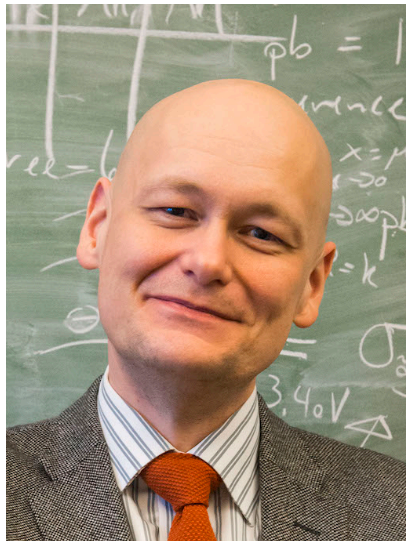
The PLUMBIN' Team



Are Raklev

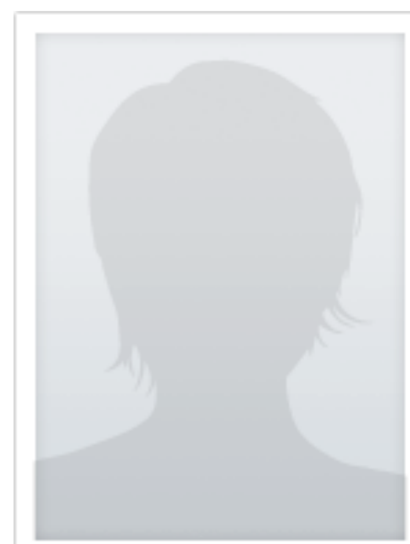
Riccardo De Bin

Anders Kvellestad

Co-PIs

Lasse Braseth

Timo Lohrmann



Tore Klungland

PhD-students

Andrea Jensen Marthinussen

Carl Martin Fevang

Erik Alexander Sandvik

Master-students

What’s in a name?

- We are PLUMBIN'?!?

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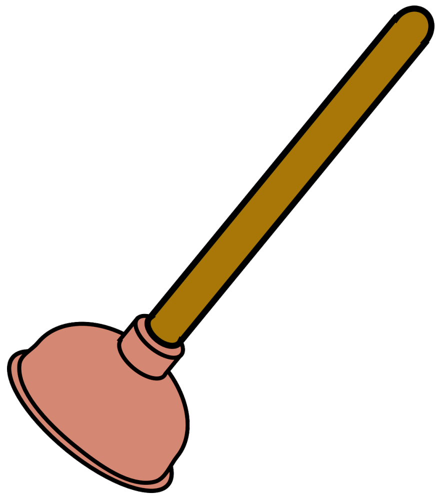

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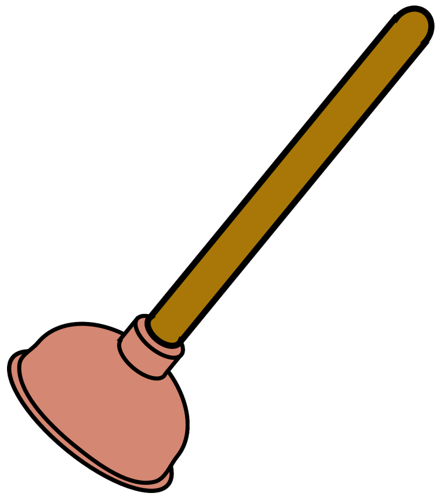
- Yes, because we are doing:
  - Physics Learning Using Machines and Bayesian INference

What's in a name?



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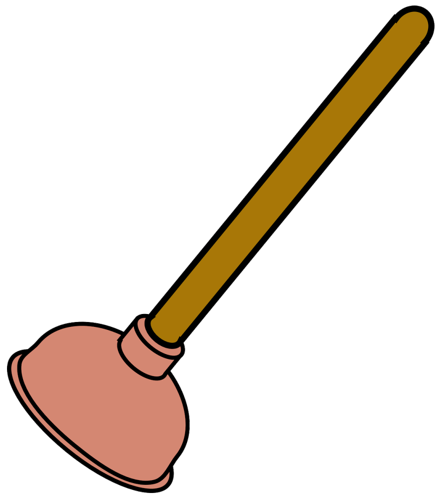

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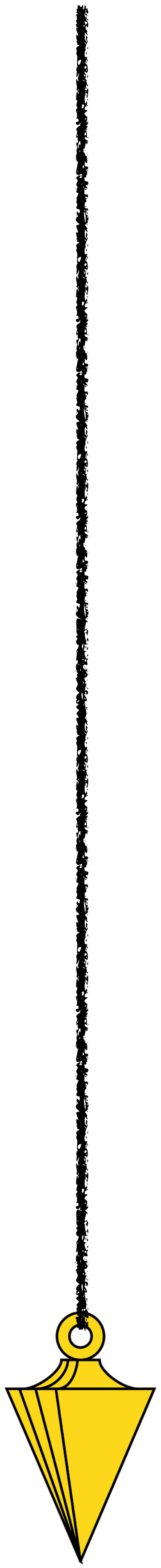

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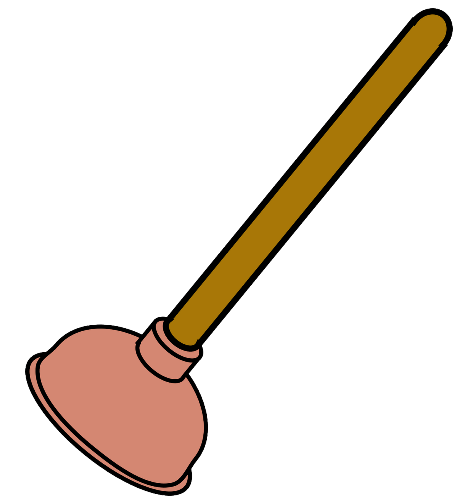

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Financing

Forskningsrådet

- **Funder:** Research Council of Norway (RCN) & UiO joint FRIPRO “Fellesløftet” funding 2021
- **Project duration:** 01.08.2022 to 31.07.2028
- **One five year researcher** position (Anders Kvellestad)
- **Three PhD-positions:**
  - 2022-2026: Tore Klungland (DP)
  - 2024-2027: NN (DM)
  - 2025-2028: NN (DP)
- **Two two-year postdoc positions**
  - 2023-2025: NN (DP)
  - 2024-2026: NN (DM)
- Money for **travel** and **HPC** computing (sigma2 resources)
- Relevant **master thesis projects.**

Our goals

- Create an open-source machine-learning based regression tool for fast numerical evaluation of quantum field theory calculations.
- Develop a framework and tool for reliable probabilistic modelling of uncertainties from higher-order quantum field theory contributions.
- Develop a continual learning framework to speed up global scans, *e.g.* by fast evaluation of the joint likelihood from past data.
- Develop a fast pseudo-likelihood approach for reliable extraction of *best-fit* confidence regions.
- Find corrections to existing test-statistics to make *goodness-of-fit* evaluation in global fits computationally feasible.
- Perform a number of global fits of new physics models utilising these developments.

Preliminary conclusions

- Lots of exciting physics/statistics/computational problems to solve!
- I'm not allowed to apply for more RCN projects ❤️ (until 2028)
- Potential master student projects with Anders, Lasse, Tore and myself as supervisors.
- Future PhD & postdoc positions here and at DM.