



LABORATÓRIO DE INSTRUMENTAÇÃO  
E FÍSICA EXPERIMENTAL DE PARTÍCULAS  
*partículas e tecnologia*



Fundação  
para a Ciência  
e a Tecnologia



**Universidade do Minho**  
Escola de Ciências

# Using Machine Learning to Scan Beyond Standard Model Parameter Spaces

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8th LIP/IDPASC PhD Student Workshop - October 2024

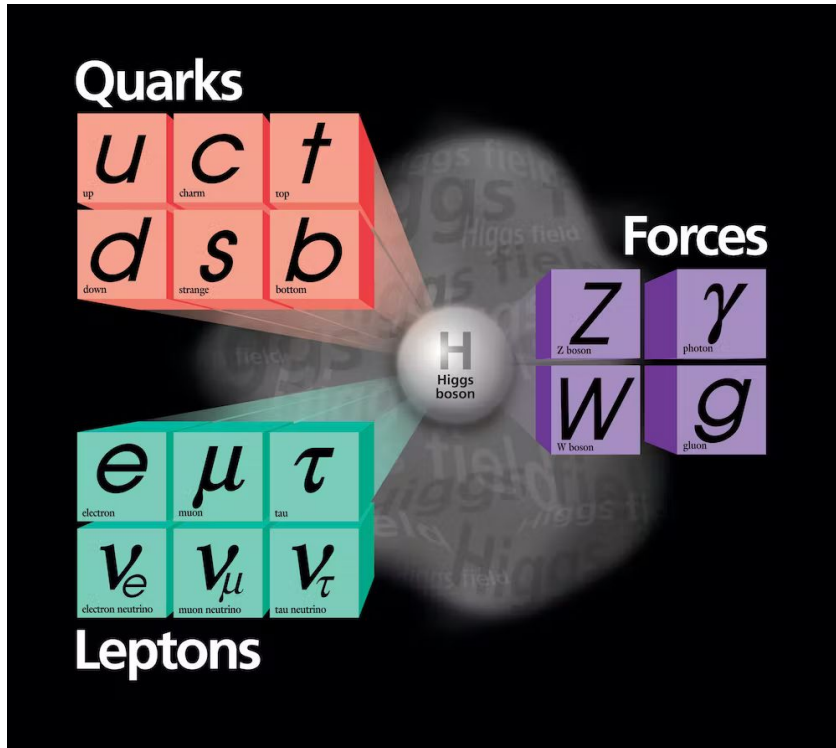
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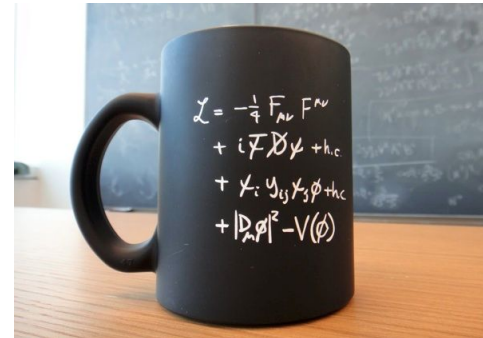
# Standard Model of Elementary Particles

# Standard Model

## Introduction



- One of the most successful theory in all of Physics
- Theoretical predictions with stupendous precision
- **Fermions** (quarks + leptons): matter
- **Bosons**: fundamental forces



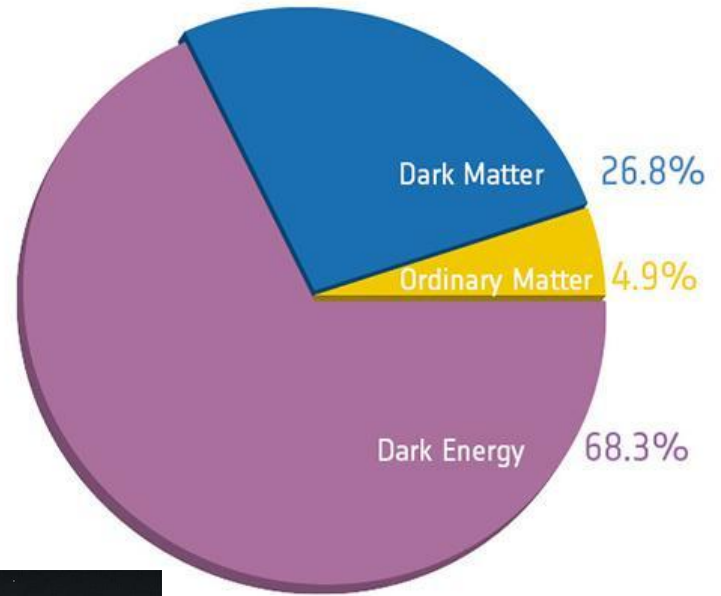
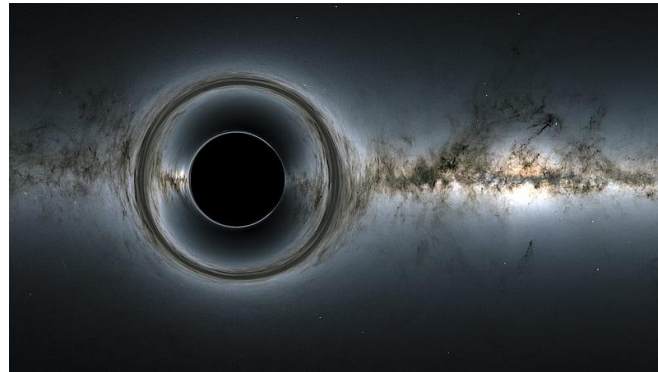
# Standard Model

## Is it the end?

What is dark matter made of?

What is Dark Energy?

What about gravity?

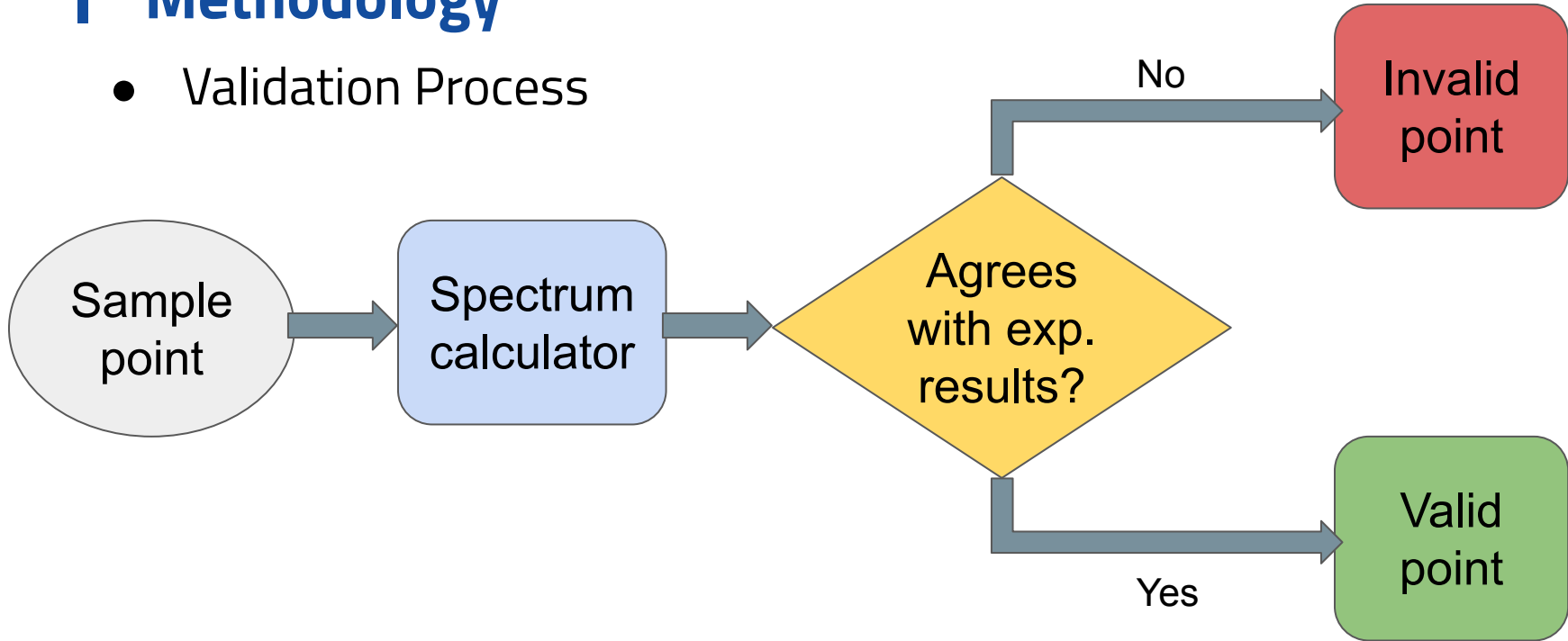


We need to go **Beyond** the Standard Model!

# Parameter Space Scans

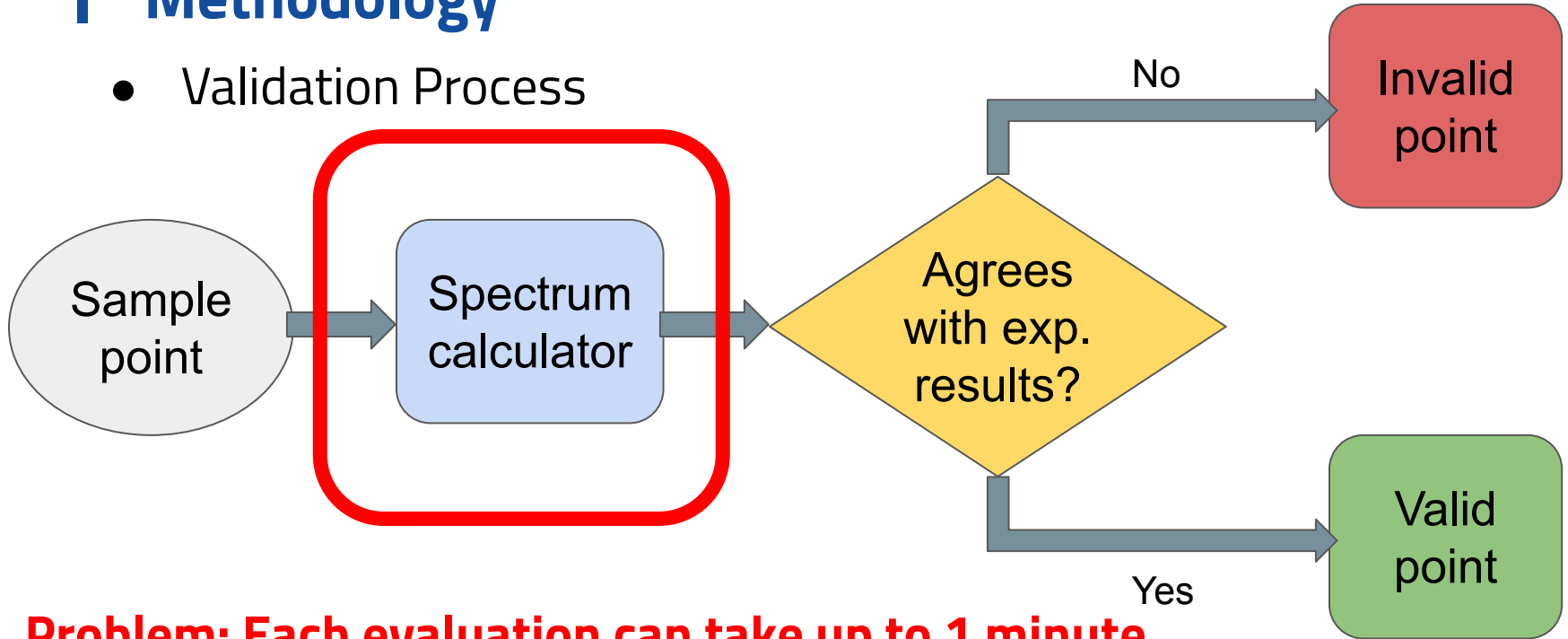
# Parameter Spaces Scan Methodology

- Validation Process



# Parameter Spaces Scan Methodology

- Validation Process

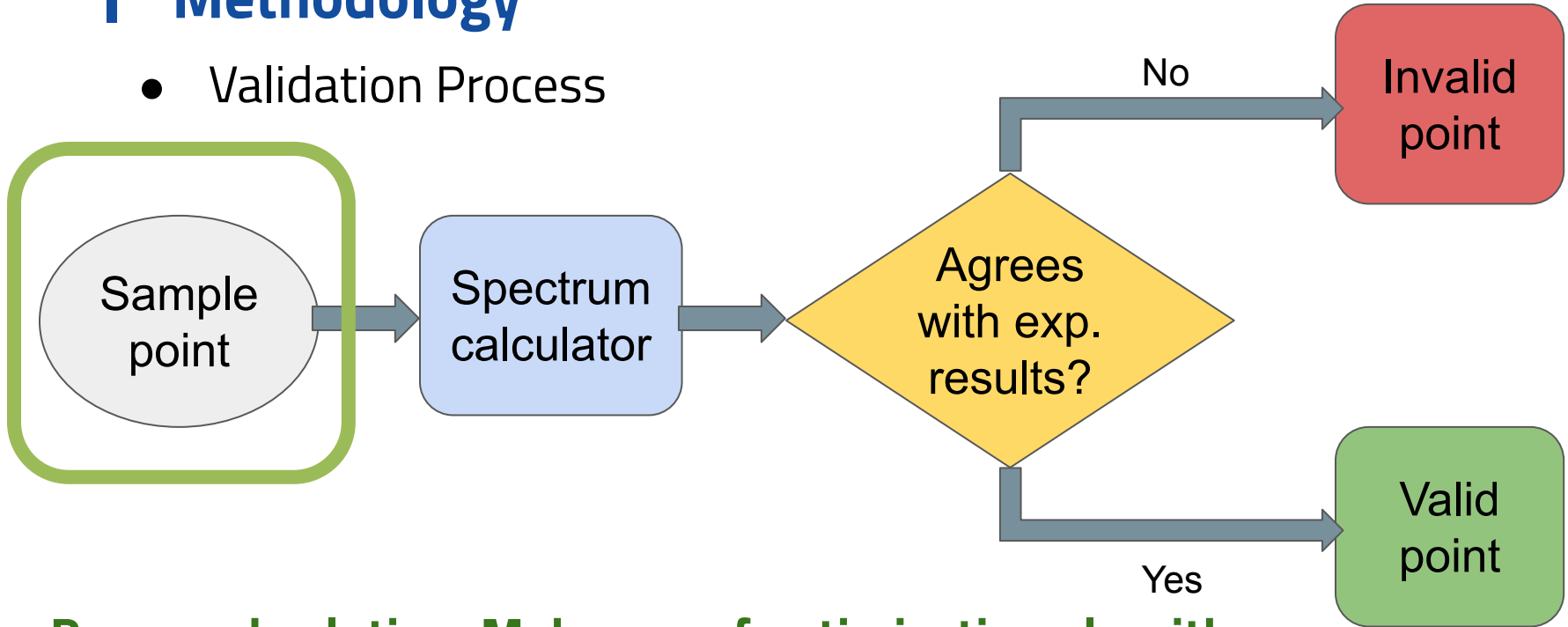


**Problem: Each evaluation can take up to 1 minute**

**→ 1:1,000,000 valid points**

# Parameter Spaces Scan Methodology

- Validation Process



**Proposed solution: Make use of optimization algorithms**



# Parameter Spaces Scans

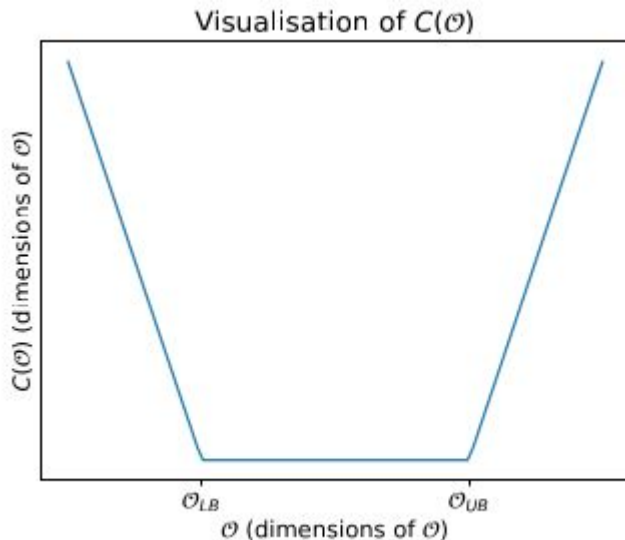
## Black Box Optimization

FAS, MCR, NFC, MN and WP  
Phys. Rev. D 107, 035004  
arXiv 2206.09223

- **How far** is the point from being valid
  - Cost function  $C(\mathcal{O})$
- To find valid points is to minimize  $C(\mathcal{O})$



**Optimization problem!**



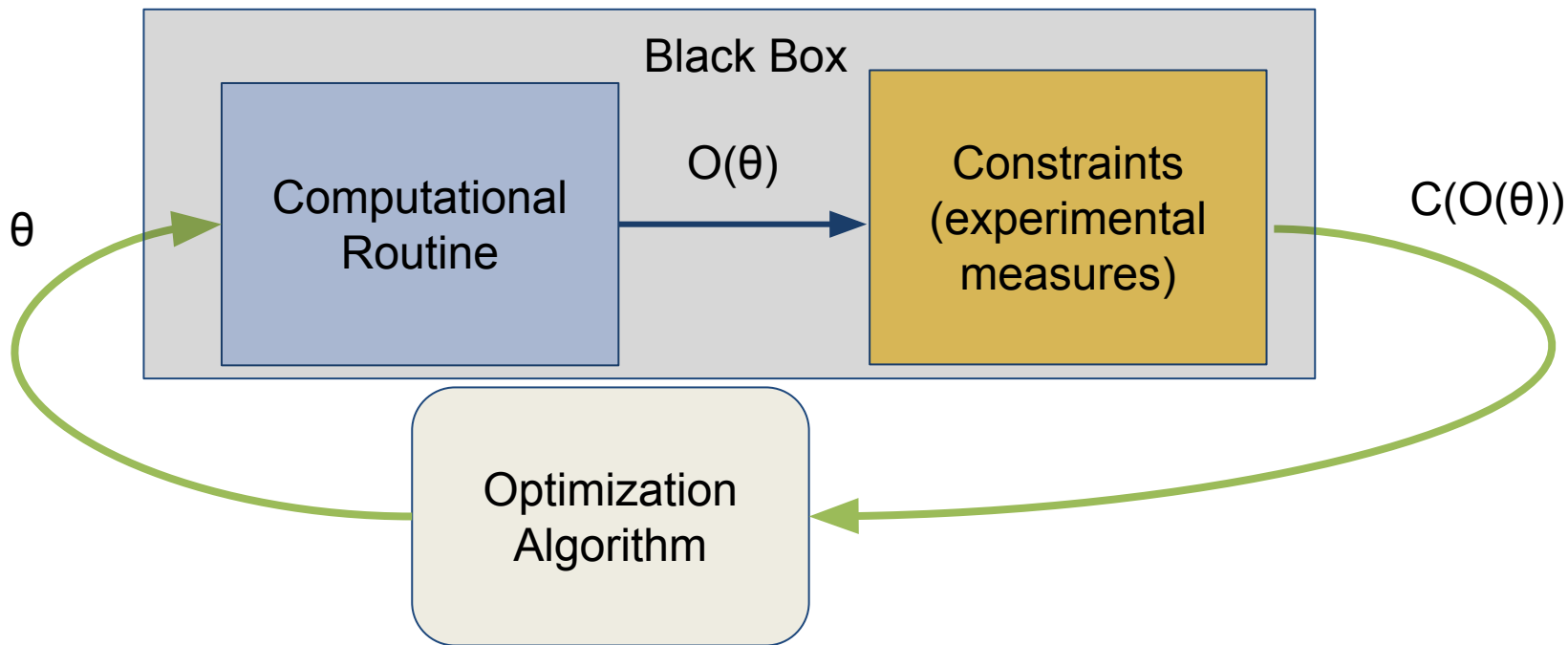
$$C(\mathcal{O}) = \max(0, -\mathcal{O} + \mathcal{O}_{LB}, \mathcal{O} - \mathcal{O}_{UB})$$

Point is valid when  **$C(\mathbf{O}) = 0$**

# Parameter Spaces Scans

## Black Box Optimization

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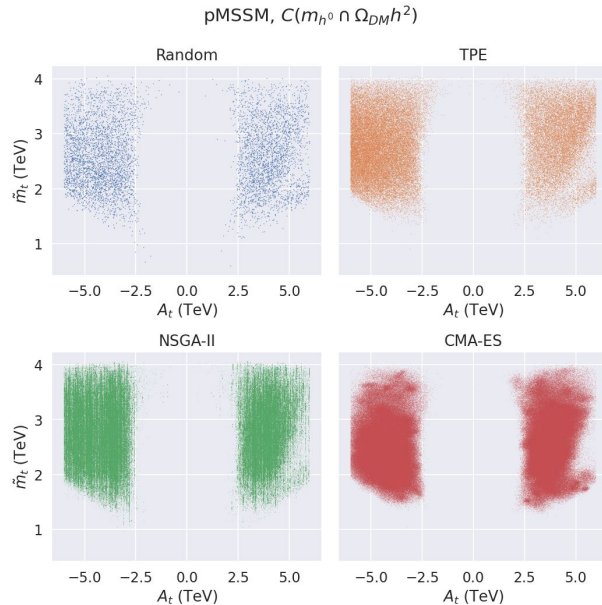




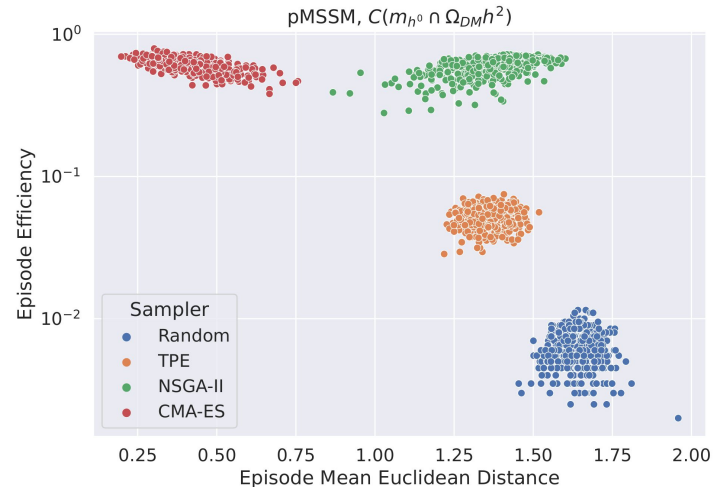
# Results

# Parameter Spaces Scan Results

- Physics cases: **Supersymmetry** constrained by **Higgs mass** and **Dark Matter Relic Density**
  - **cMSSM**: 4 free parameters
  - **pMSSM**: 19 free parameters



Optimisation Algorithms			
Bayesian:	TPE	➡	Best <b>coverage</b>
Evolutionary:	CMA-ES	➡	Best <b>efficiency</b>
Genetic:	NSGA-II	➡	In between



Gain of ~ 100x in efficiency!

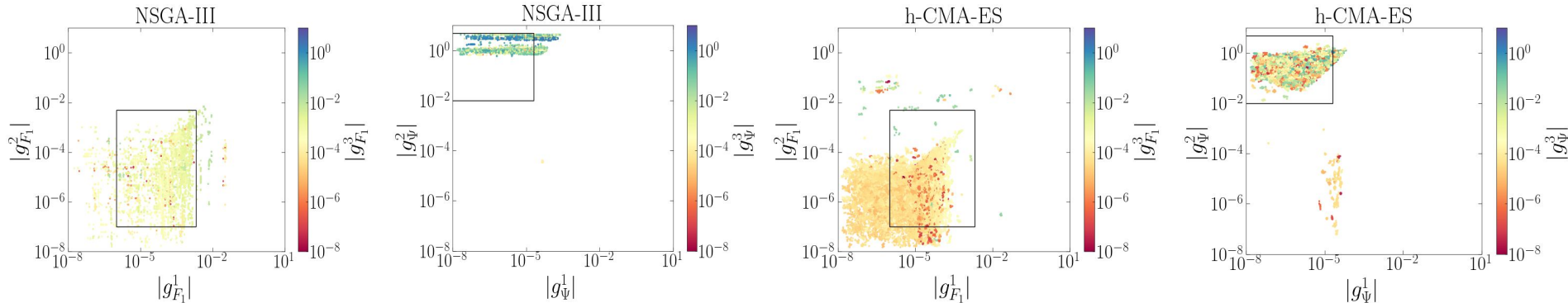
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# Parameter Spaces Scan

## Scotogenic model - ongoing work

- 46 free **parameters** with 31 experimental **constraints** (Higgs mass + Neutrino data + DM relic density + Lepton flavor violating bounds + Muon (g-2))
- New approach: **Multi-objective optimization (NSGA-III)**
- New approach: **Hierarchical CMA-ES** (Introduces **Hierarchy** in the objectives → **Muon (g-2)**)
- **Random scan**: No valid points after 10 Million evaluations



Rectangles show area of points obtained  
with a MCMC scan (2401.08485)

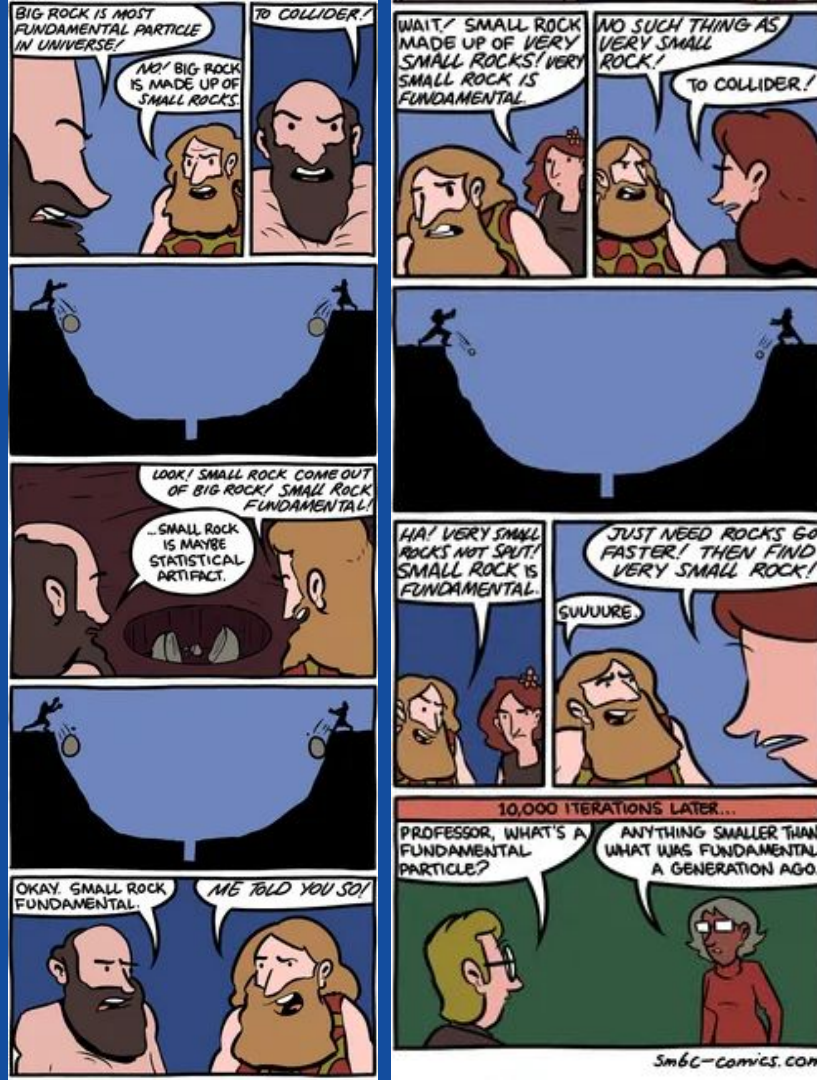
**Valid points after ~ 10k evaluations!**

**Found points missed by MCMC!**

# Conclusions

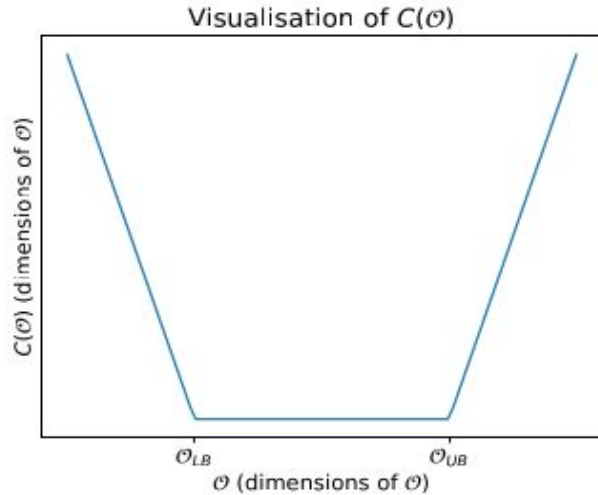
- New approach to parameter spaces exploration: **black-box optimization**
- Best results show a gain in **efficiency** in up to **2 orders of magnitude**
- Algorithms show an **exploration-exploitation trade-off**
- Use of **Multi-objective optimization** and the introduction of **hierarchy** in **single-objective optimization** show promising results
- Going forward:
  - Test the methodology in **EFT** framework
  - Mechanism to **improve coverage**
  - Develop open source package with **parameter space scan tools**

# Thank you! Questions?



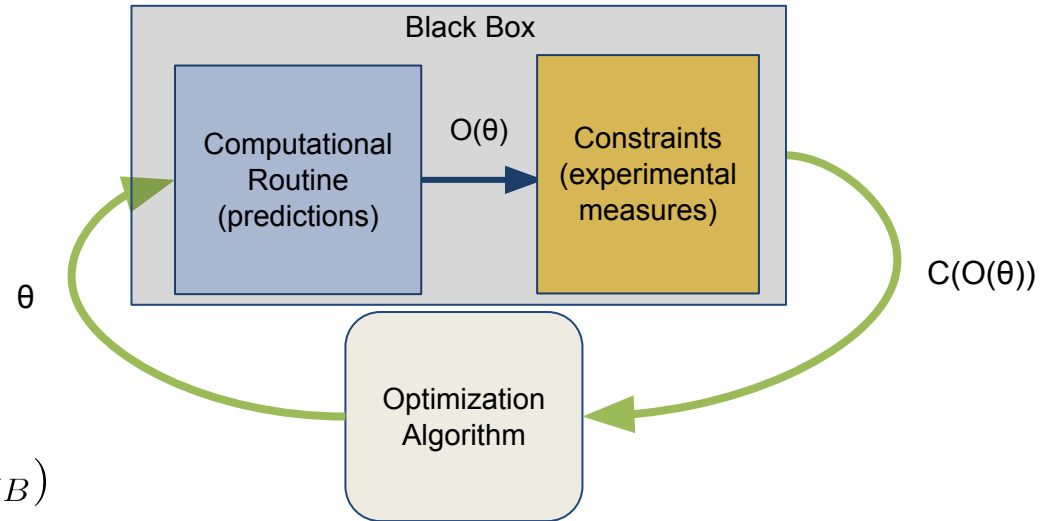
# Parameter Spaces Scans

## Black Box Optimization



$$C(\theta) = \max(0, -\theta + \theta_{LB}, \theta - \theta_{UB})$$

Point is valid when  $\mathbf{C}(\theta) = \mathbf{0}$



- $\theta$ : Sampled point in parameter space
- $O$ : Observable
- $C$ : Cost function