Using Machine Learning to Improve Dynamic Aperture estimates

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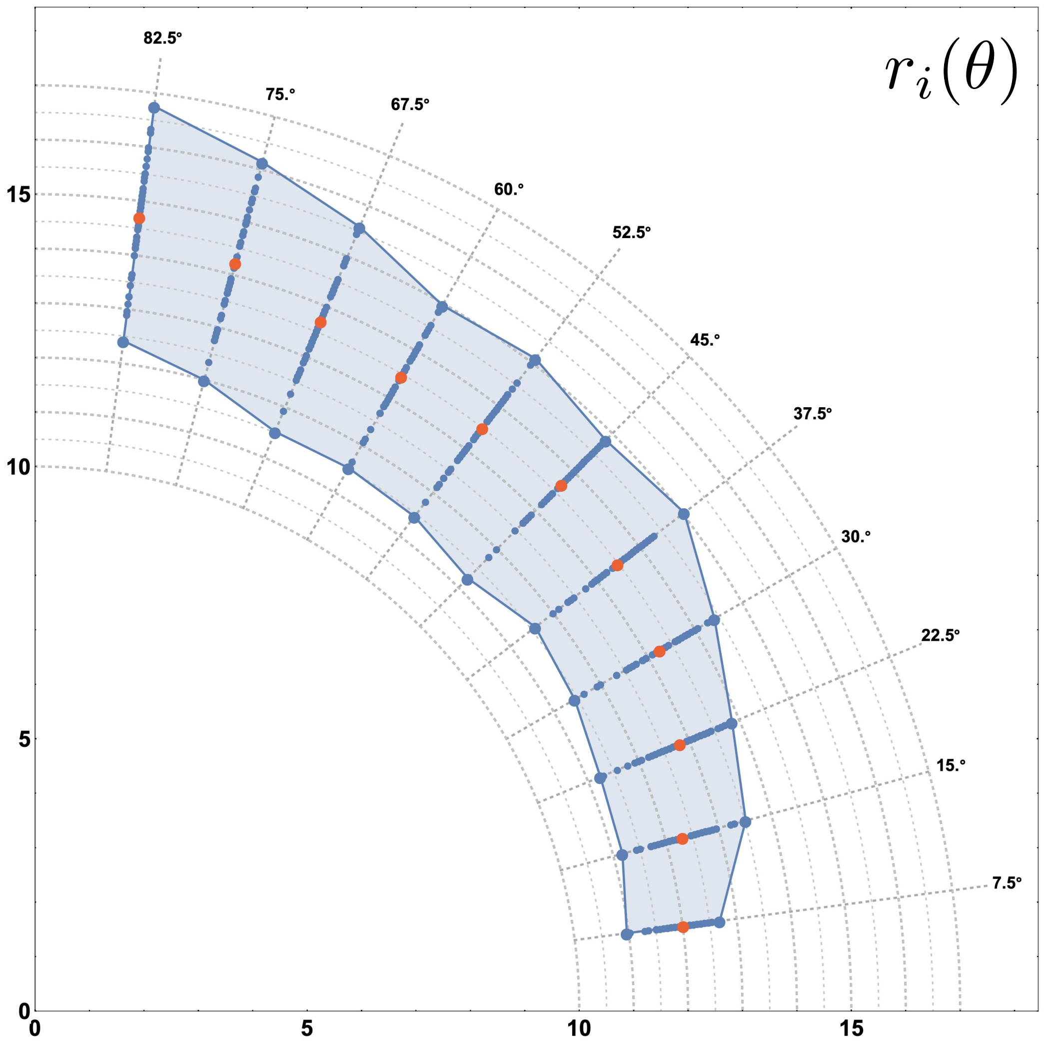
Dynamic Aperture

Definition

- Is the volume of the smallest connected region in phase space that is **stable** for a certain amount of time
- 60 random realisations (**seeds**) in LHC simulations
- Polar scan: for every seed i and angle θ, the maximum stable amplitude in phase space is $r_i(\theta)$
- Then the average and minimum DA are given by:

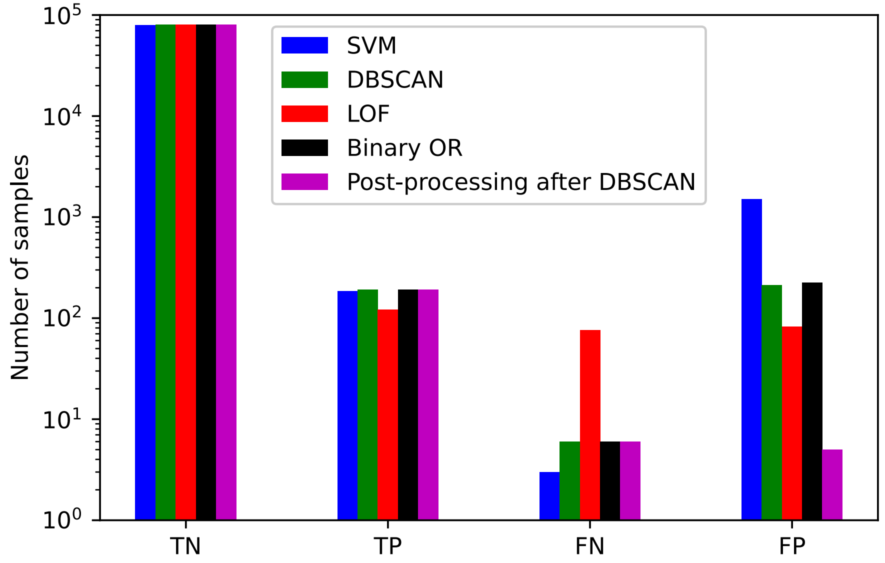
$$\mathrm{DA}_{\mathrm{av}} = \frac{1}{N_{\mathrm{seed}}} \sum_{i=1}^{N_{\mathrm{seed}}} \int d\theta \, r_i(\theta) \,,$$

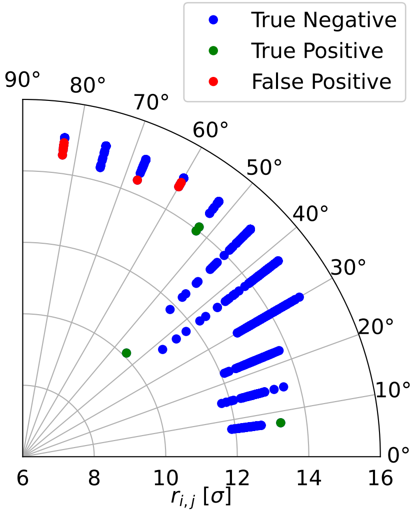
$$\mathrm{DA}_{\mathrm{min}} = \min_{i,j} r_i(\theta_j) \quad 1 \leq i \leq N_{\mathrm{seed}} \,,\, 1 \leq j \leq N_{\mathrm{angle}}$$



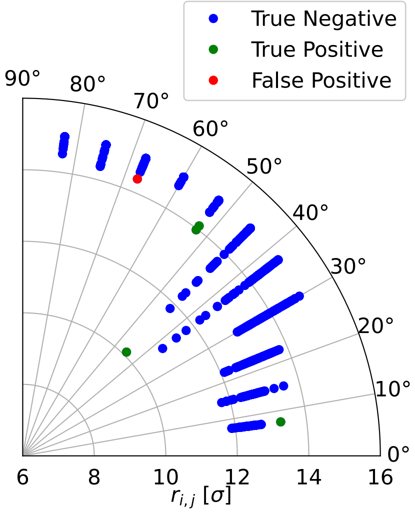
Anomaly Detection

- Sometimes one seed gives **very bad DA** for one angle
- Use ML to flag these outliers
- Compare several approaches: *SVM, LOF, DBSCAN, DBSCAN with post-processing*





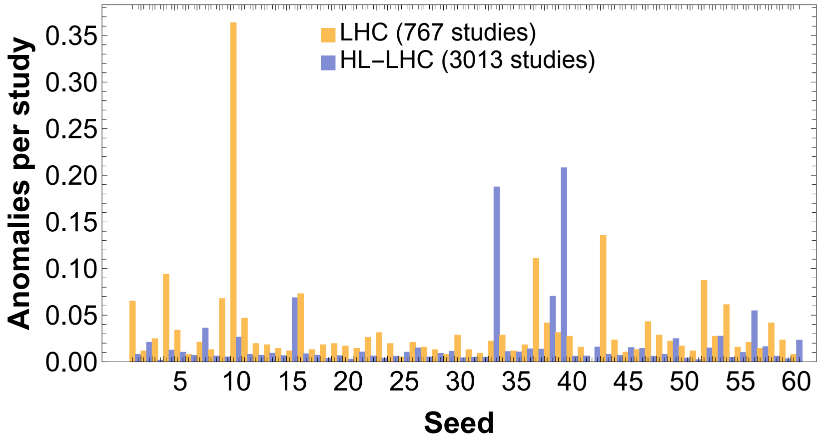
DBSCAN



DBSCAN with post-processing

Dependencies

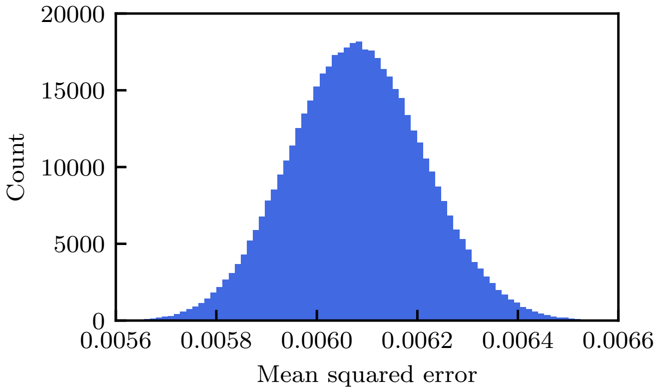
- Regular use of algorithm: detect outliers
- Alternative use: recognise strong dynamics (bad seed, …) by comparing anomaly distribution of specific sets of DA studies

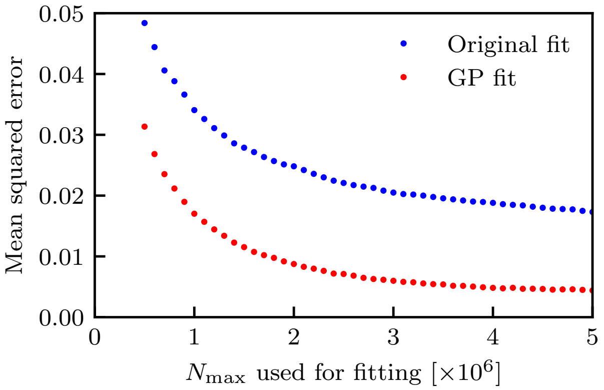


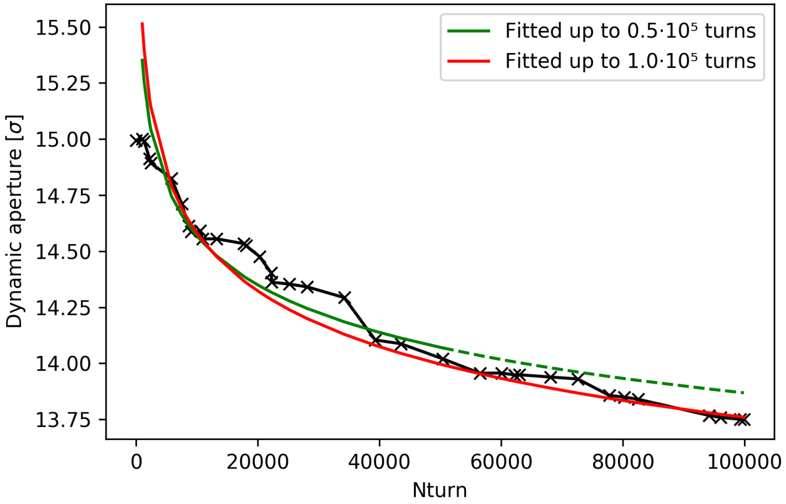
Time Evolution and Extrapolation

- DA simulations are very CPU-intensive, putting a limit on achievable simulated beam time
- Need to **extrapolate** to realistic time scales
- Analytic models exist, but adequate fitting is difficult, and extrapolation hence questionable

$$DA(N) = \rho \left[-\mathcal{W}_{-1}\Big(-(\mu N)^{-\frac{2}{\kappa}} \Big) \right]^{-\kappa}$$







- ML for extrapolation is known to be inadequate
- Use **Gaussian Processing** to improve quality of fit
- Estimate fit quality by Mean Squared Error
- 50 GP iterations improve MSE with 55% on average
- Reliable extrapolation up to a factor 5

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