Ephemeral Learning: Augmenting Triggers with online trained normalising flows

Anja Butter, **Sascha Diefenbacher**, Gregor Kasieczka, Benjamin Nachman, Tilman Plehn, David Shih, Ramon Winterhalder

sascha.daniel.diefenbacher@uni-hamburg.de

ErUM Data IDT Workshop 2022

14.02.2021

Universität Hamburg
DER FORSCHUNG | DER LEHRE | DER BILDUNG

CLUSTER OF EXCELLENCE
QUANTUM UNIVERSE

UNIVERSITÄT HEIDELBERG
ZUKUNFT SEIT 1386

Introduction

- LHC data rate is incredibly high
  - At 40 MHz ~40 Tb/s

Introduction

- LHC data rate is incredibly high
  - At 40 MHz ~40 Tb/s
  - Cargo container filled with hard drives (100 Pb)

Introduction

- LHC data rate is incredibly high
  - At 40 MHz ~40 Tb/s
  - Cargo container filled with hard drives (100 Pb) … every 41 minutes

Introduction

- LHC data rate is incredibly high
  - At 40 MHz ~40 Tb/s
  - Cargo container filled with hard drives (100 Pb) … every 41 minutes
  - 35 Containers per day

Introduction

- We can’t save everything
  - Reduce data rate: Triggers, save only the interesting events. storage ~ trigger-rate x luminosity

Introduction

- We can't save everything
  - Reduce data rate: Triggers, save only the interesting events. storage ~ trigger-rate x luminosity
  - Reduce per event size: Save only high level observables storage ~ (reduced size/full size) x luminosity

Introduction

- We can't save everything
  - Reduce data rate: Triggers, save only the interesting events.
    storage ~ trigger-rate x luminosity
  - Reduce per event size: Save only high level observables
    storage ~ (reduced size/full size) x luminosity
  - Save only histograms of observables
    storage ~ number of bins, lose not specified correlations

Introduction

- We can’t save everything
  - Reduce data rate: Triggers, save only the interesting events.
    storage ~ trigger-rate x luminosity
  - Reduce per event size: Save only high level observables
    storage ~ (reduced size/full size) x luminosity
  - Save only histograms of observables
    storage ~ number of bins, lose not specified correlations
  - Encode data in generative model
    storage ~ network weights

Introduction

LHC data

Trained model

Online Training

This is quite ambitious

Online Training

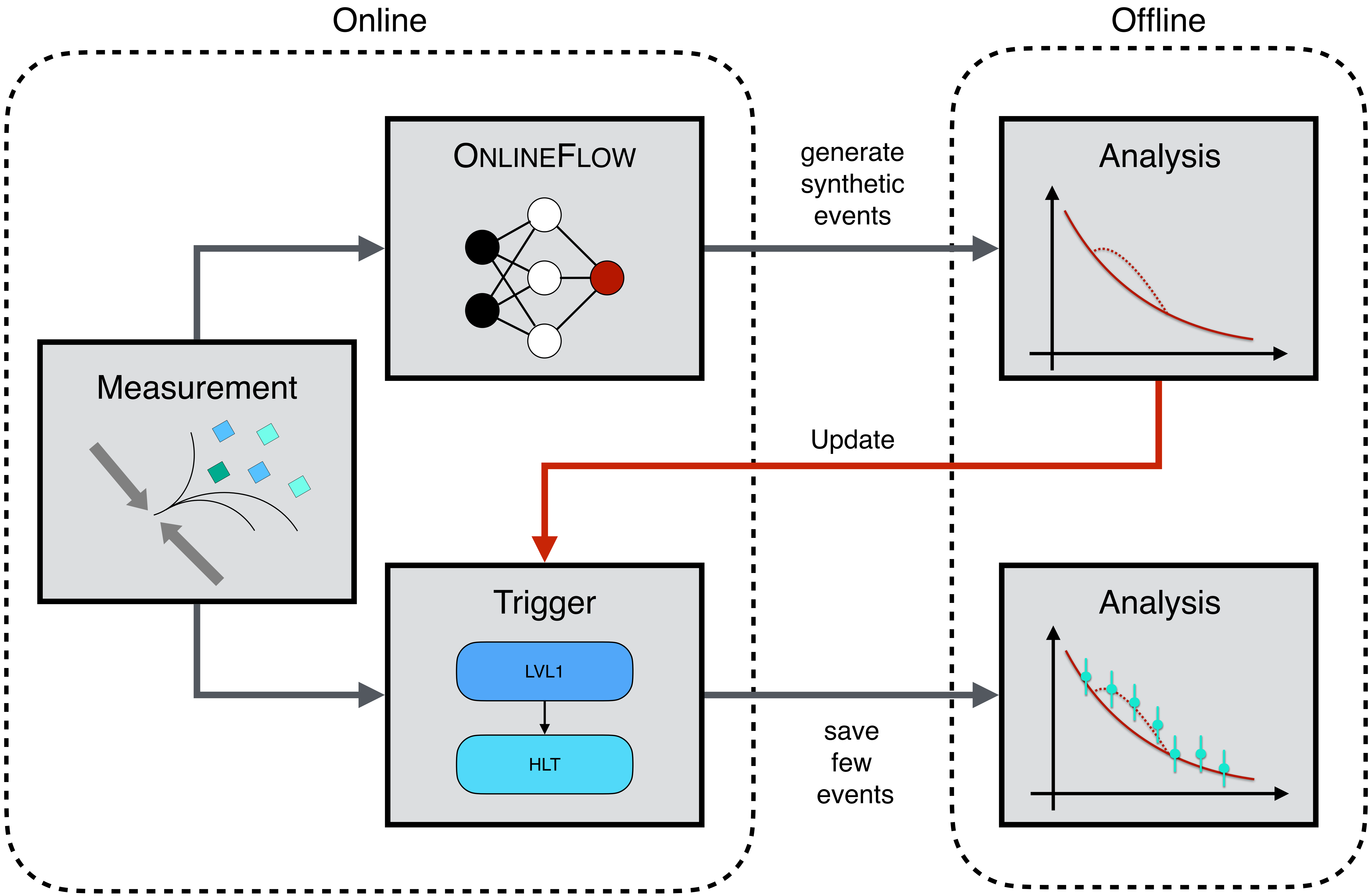
This is quite ambitious

- Lets start smaller

Online Training

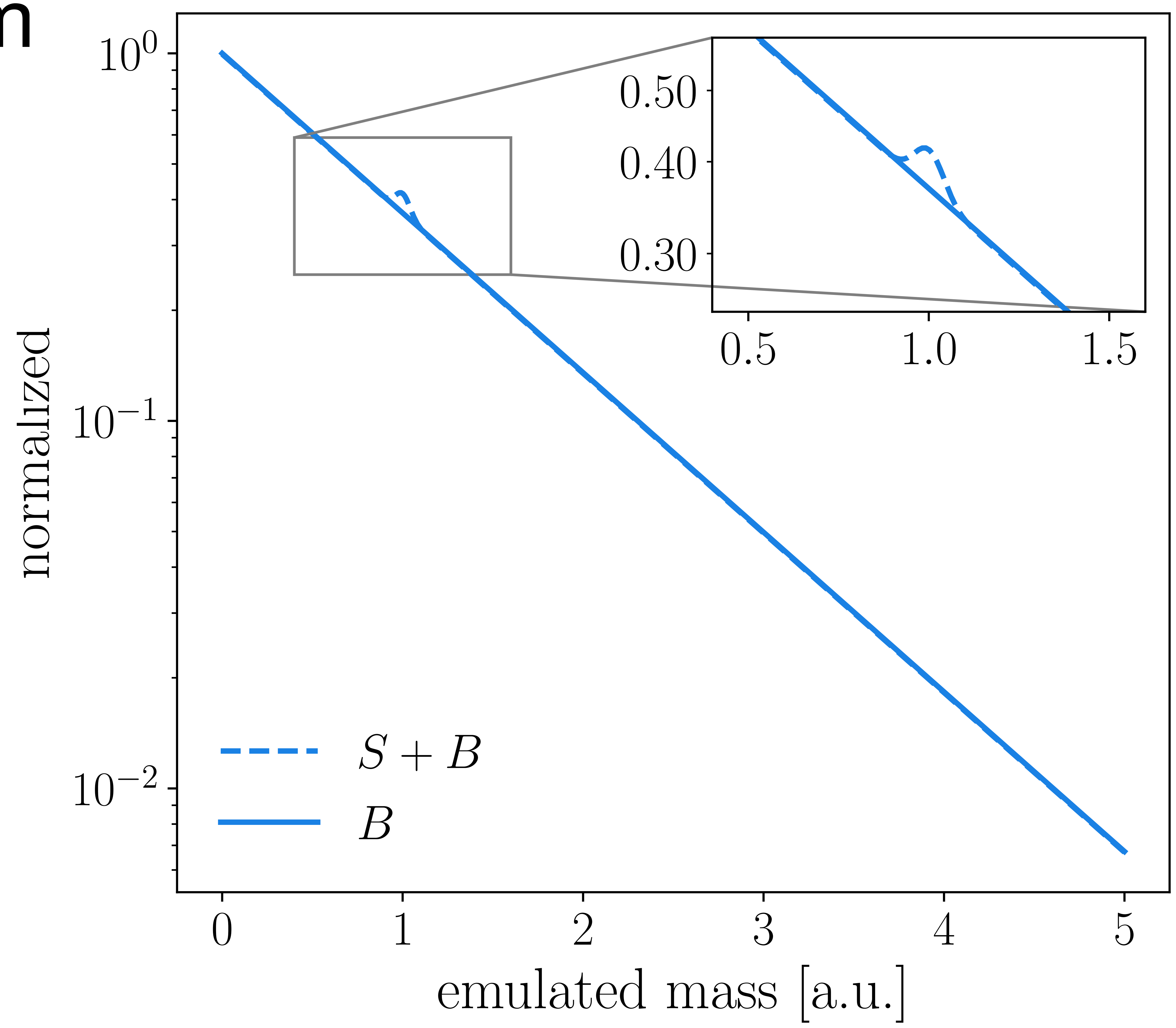
This is quite ambitious

- Lets start smaller
- Online model as additional scouting tool
- Investigate regions ignored by triggers



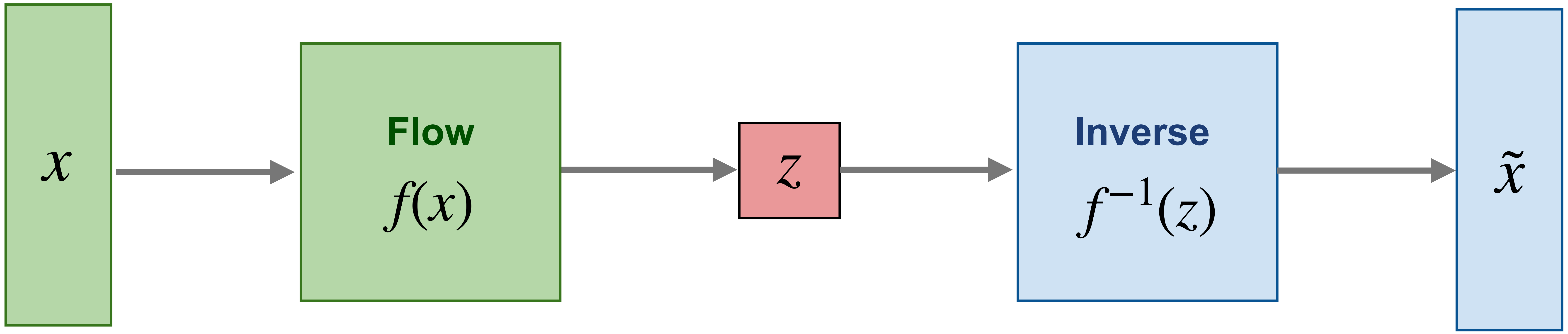
Proof of Concept

- 1 Dimension toy mass spectrum
- Exponential falling background
- Gaussian peak signal
- Train generative model



Generative Model

Normalising Flow

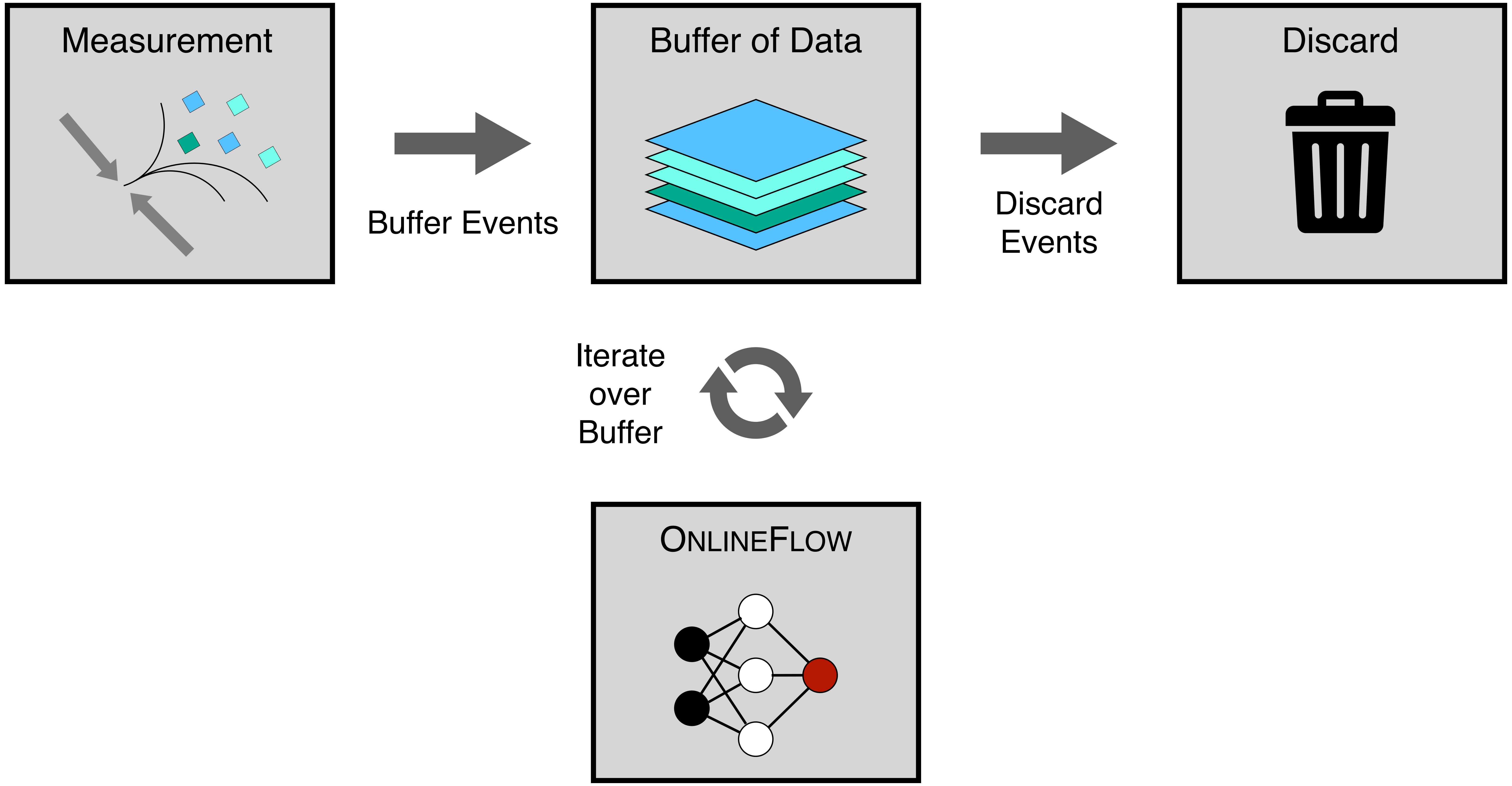


- Train invertible transform to map data to latent space
- Use inverse to generate new data form new latent samples

Online Training

Troubles with Online Training:

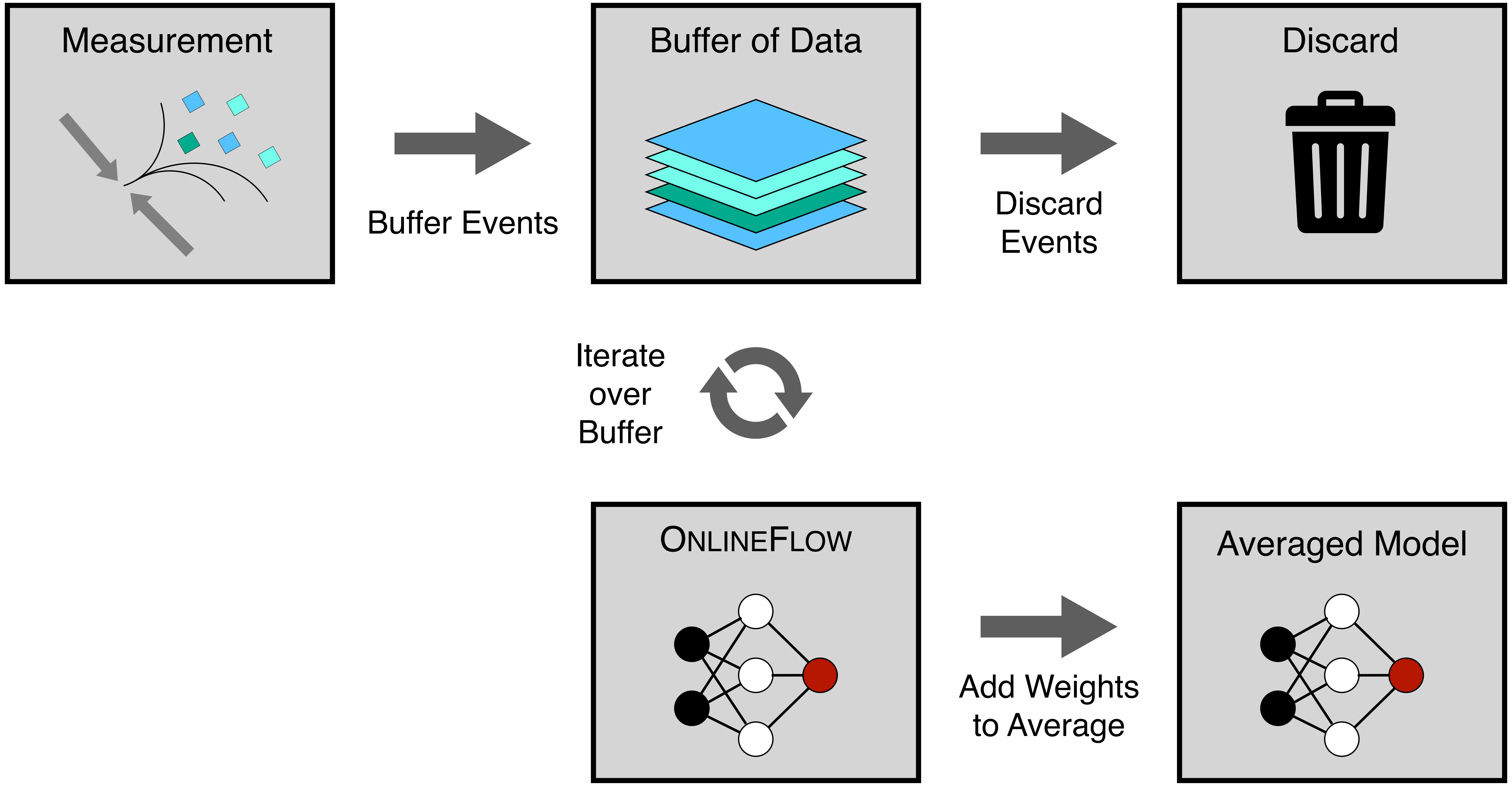
- Models designed for parallel training on batches
- Points should be seen more than once



Online Training

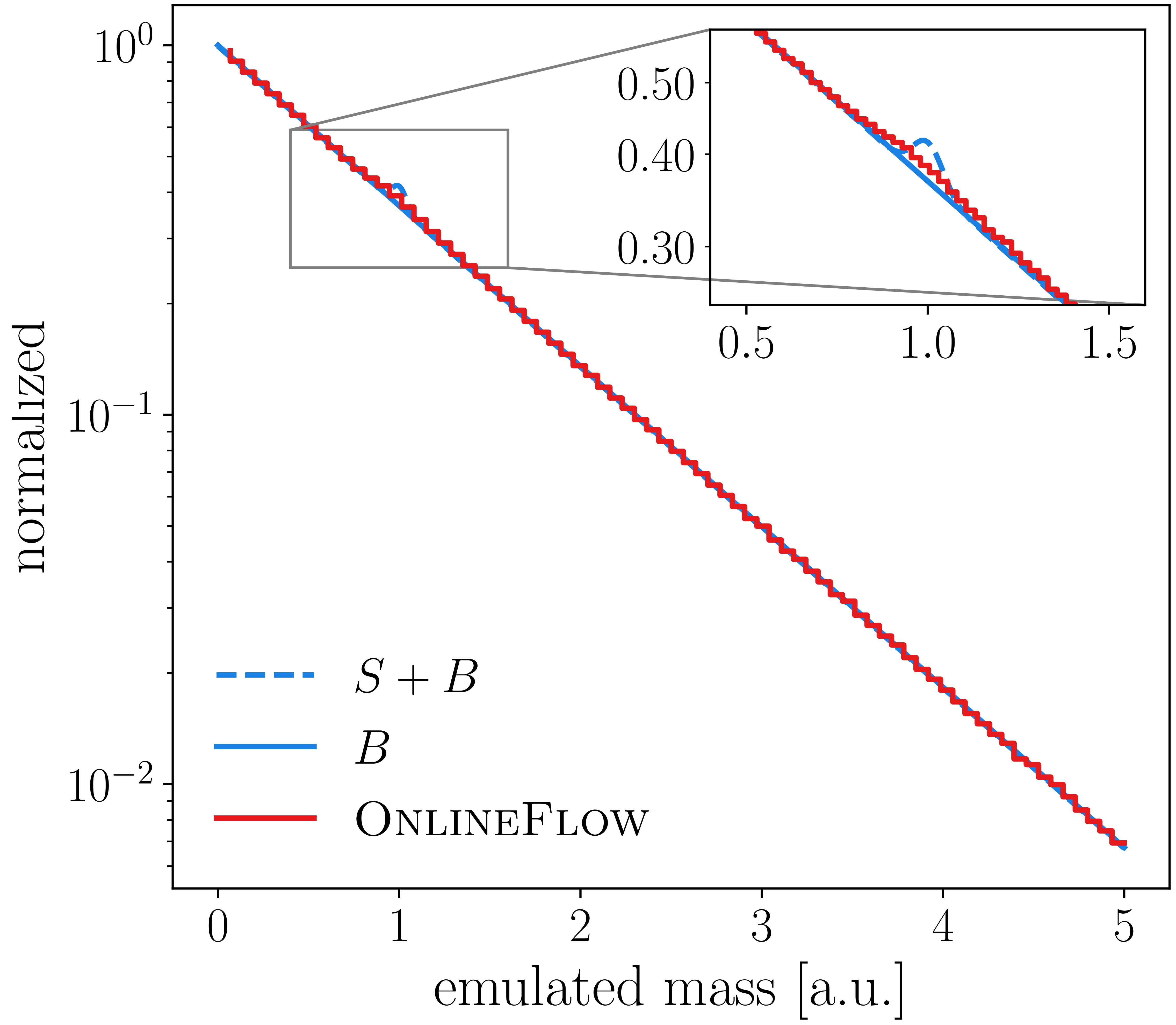
Model will be biased towards more recent buffers

- Stochastic Weight Averaging (SWA)
- Keep running average over model during training



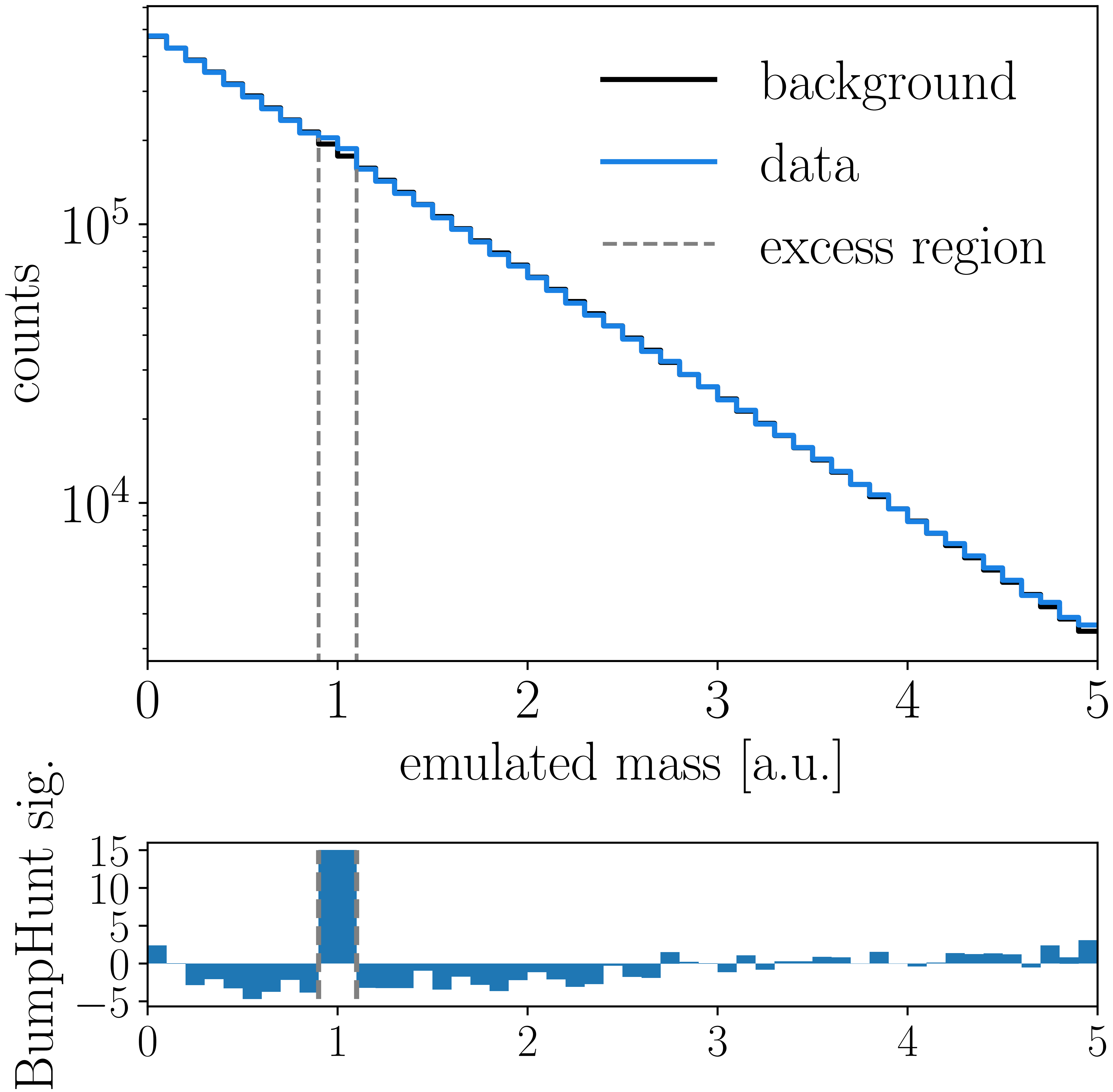
Proof of Concept

- 1 Dimension
- Exponential falling background
- Gaussian peak signal
- Train masked autoregressive Flow on S+B
- Check samples form Flow



Proof of Concept

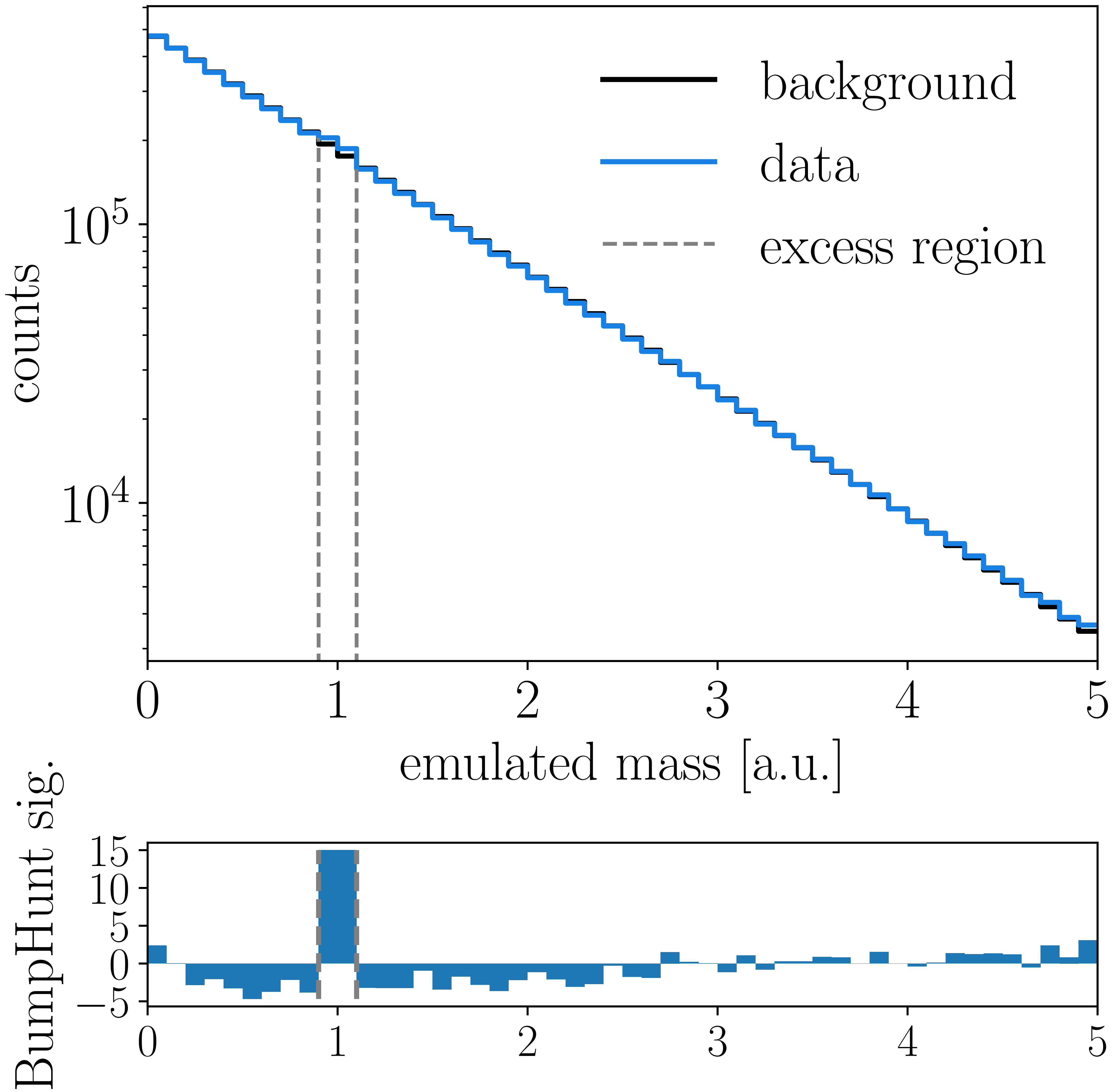
- Analyse data
- Fit exponential function to data to get background model
- Run pyPumpHunter (python implementation The BumpHunter)
- What is our significance?



Louis Vaslin, Julien Donini, **pyBumpHunter**

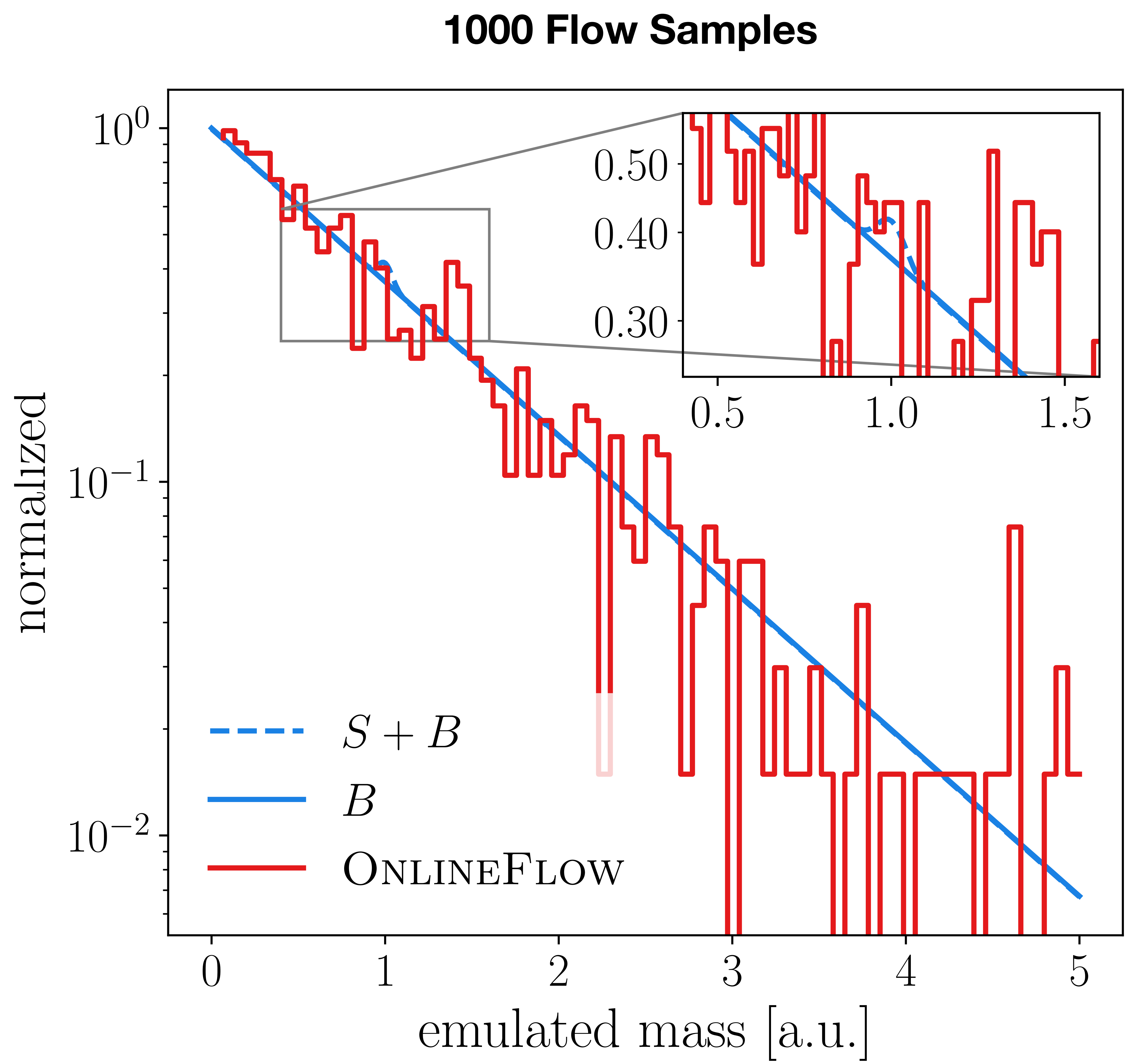
Proof of Concept

- What is our significance?
  - Classic assumption $\frac{S}{\sqrt{B}}$
  - Generative models break this



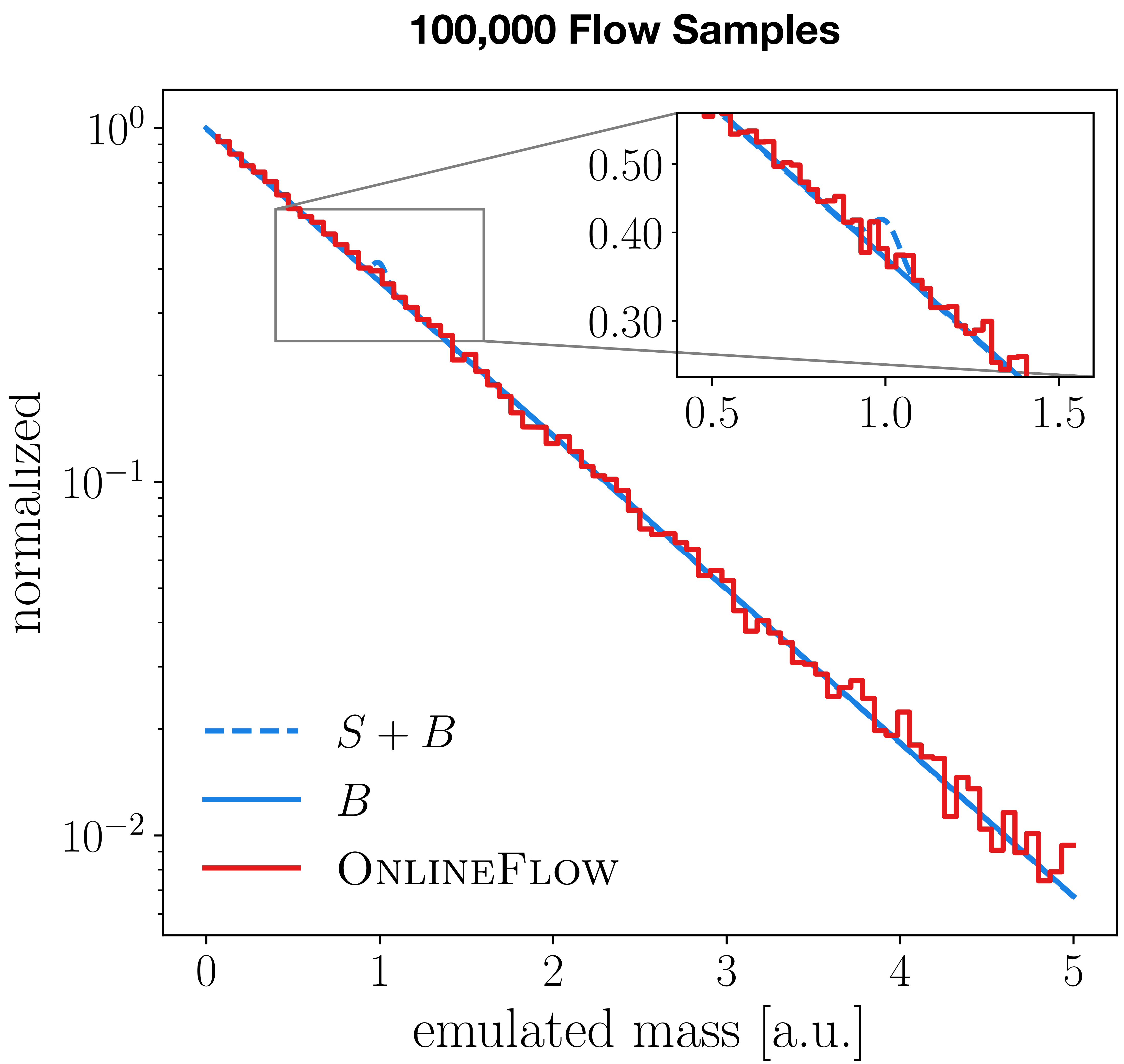
Proof of Concept

- What is our significance?
  - Classic assumption $\frac{S}{\sqrt{B}}$
  - Generative models break this
    - Fluctuations if few points



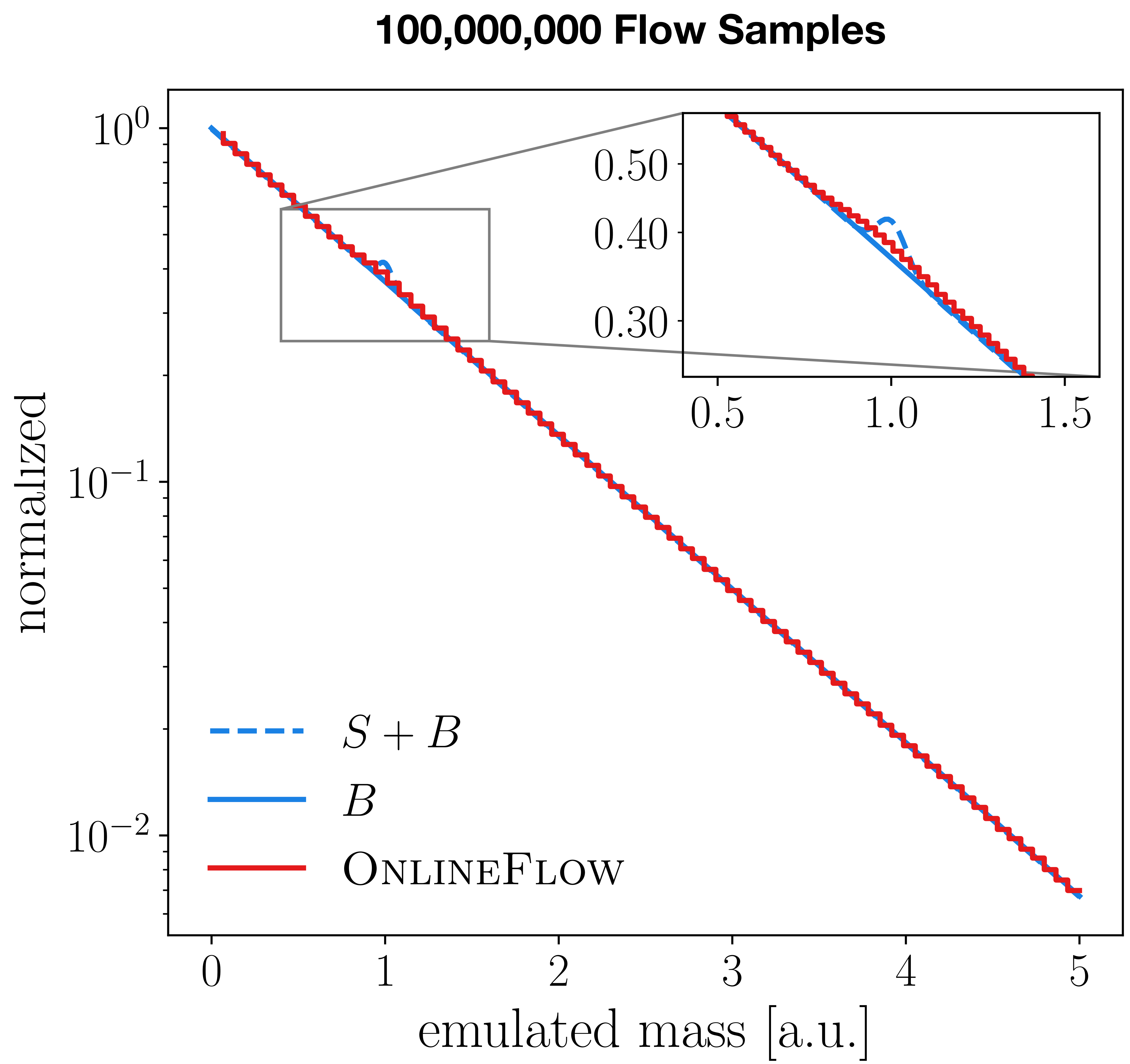
Proof of Concept

- What is our significance?
  - Classic assumption $\frac{S}{\sqrt{B}}$
  - Generative models break this
    - Fluctuations if few points
    - More points reduce this



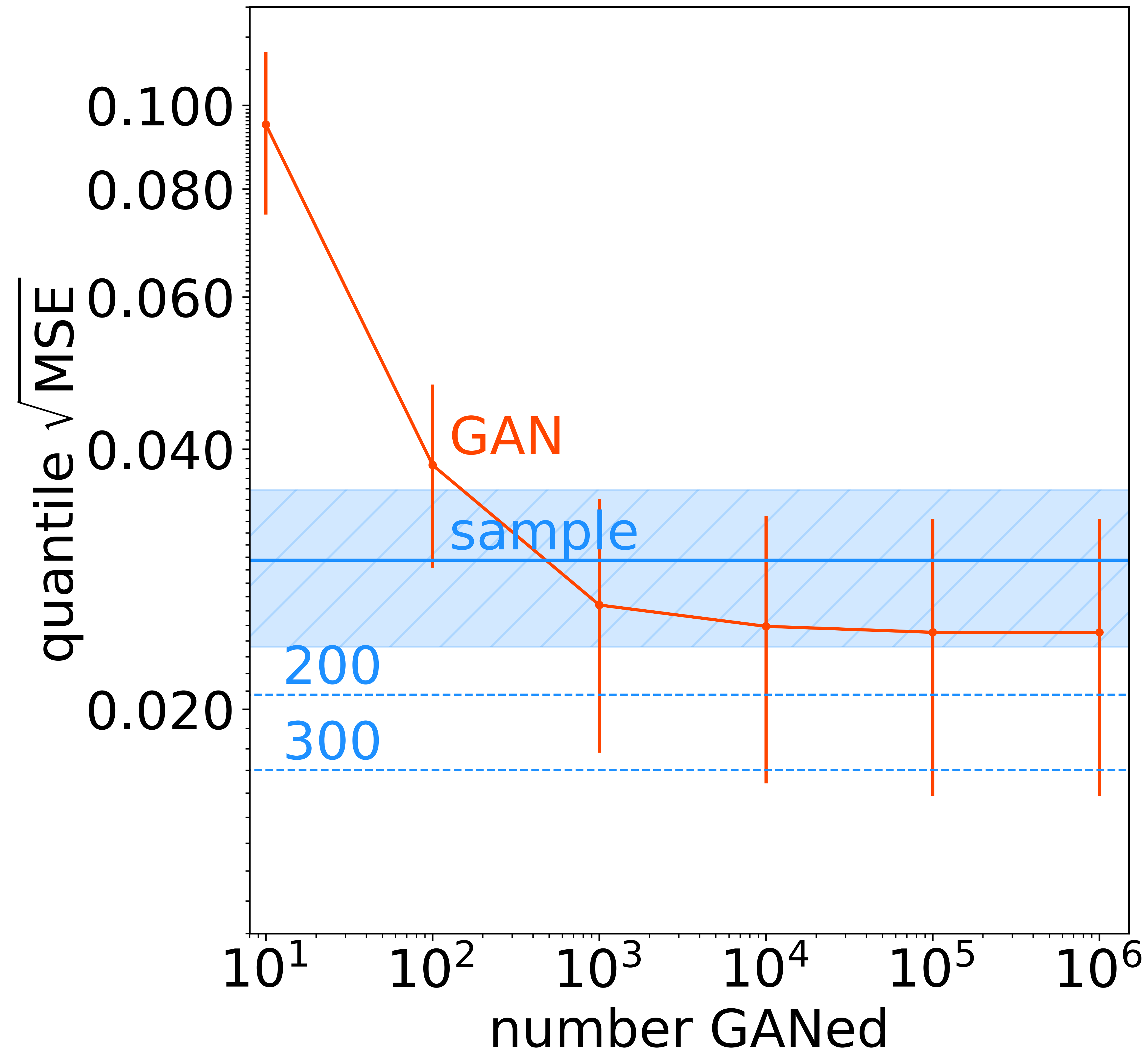
Proof of Concept

- What is our significance?
  - Classic assumption $\frac{S}{\sqrt{B}}$
  - Generative models break this
    - Fluctuations if few points
    - More points reduce this



Proof of Concept

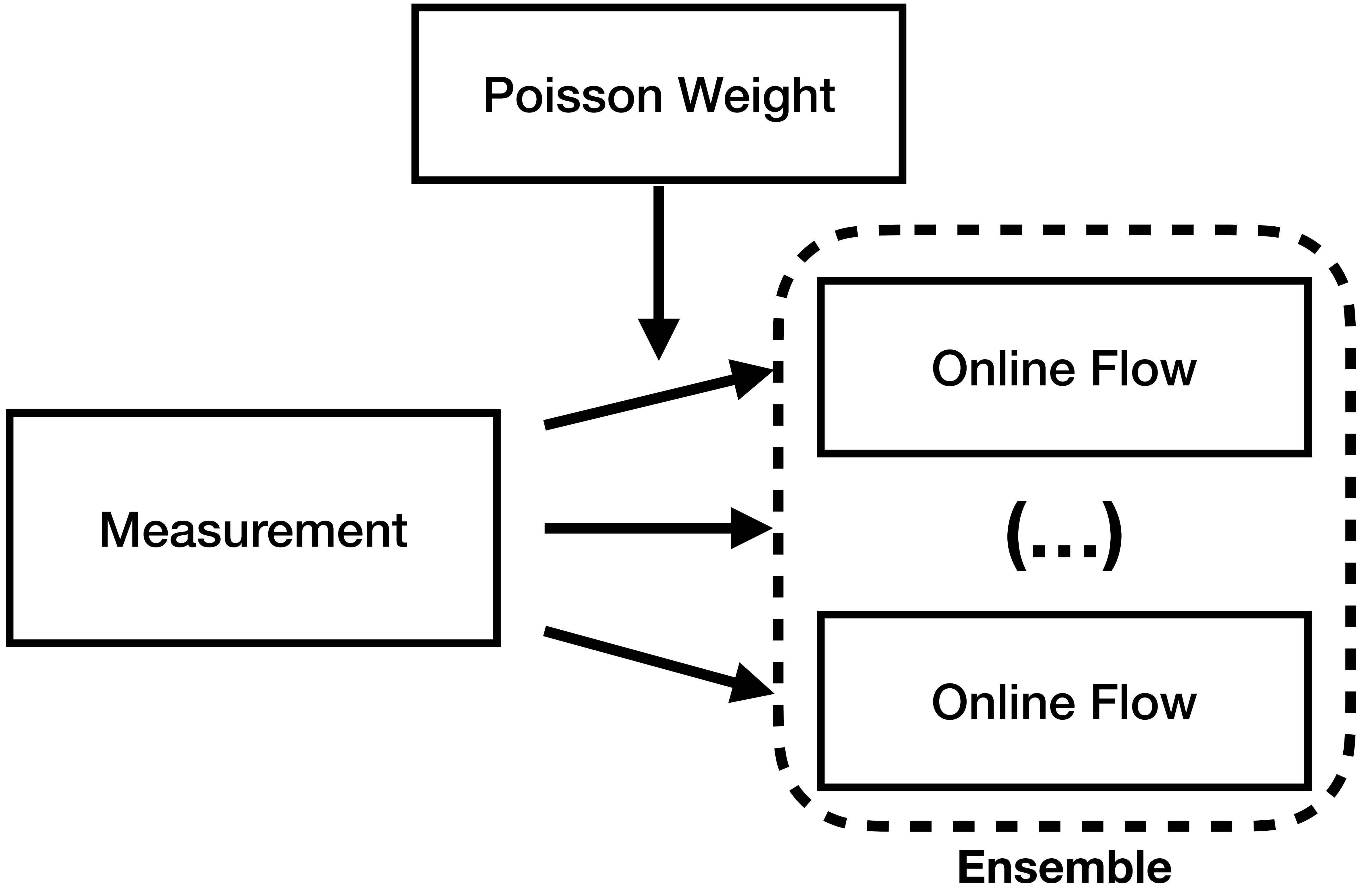
- What is our significance?
  - Classic assumption $\frac{S}{\sqrt{B}}$
  - Generative models break this
    - Fluctuations if few points
    - More points reduce this
    - More samples $\neq$smaller error
    - No Poisson error
    - Systematic errors dominant



Butter et al.: **Amplifying Statistics using Generative Models:** NeurIPS ML4PS 2020, 2008.06545

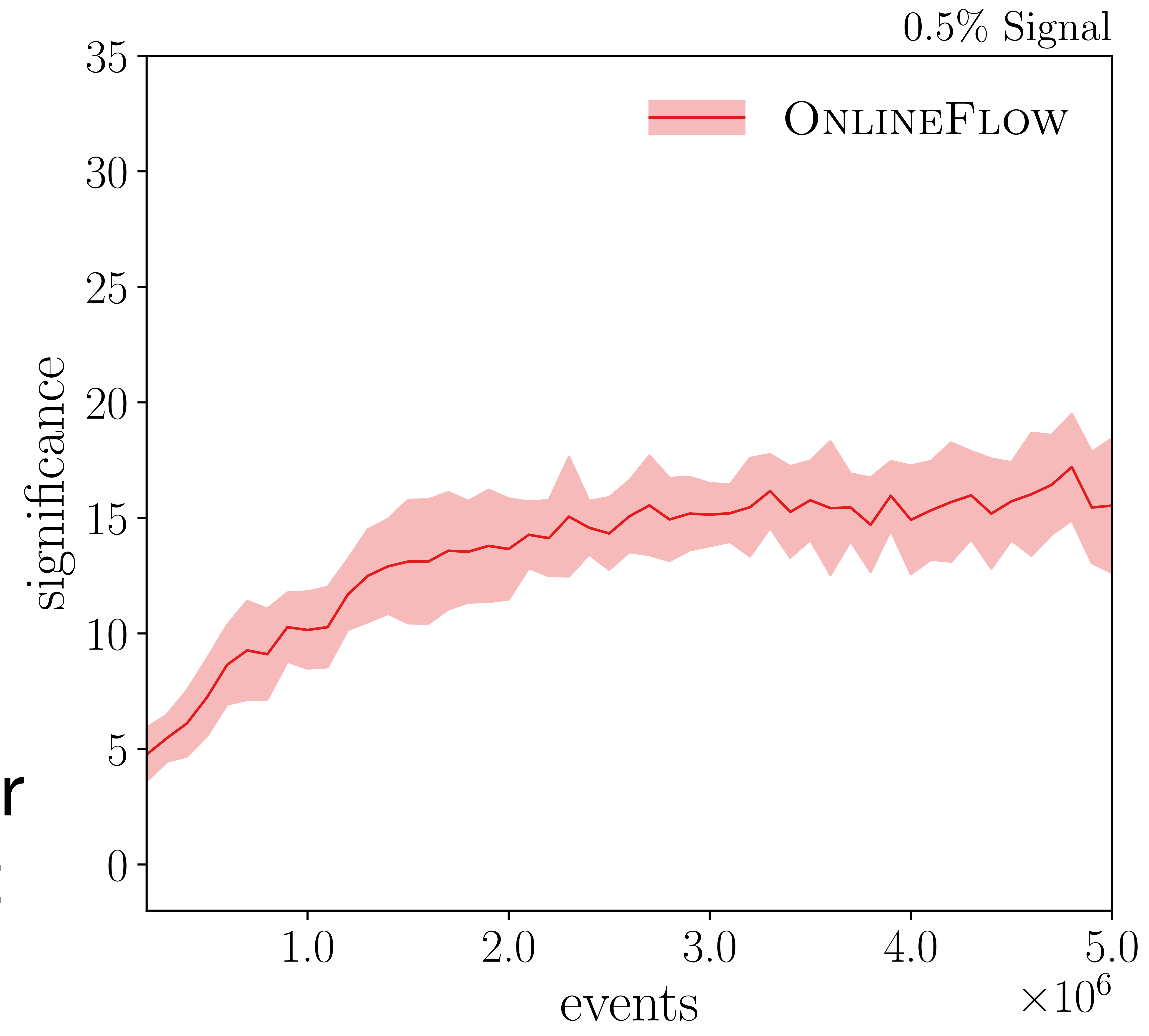
Proof of Concept

- Train **bootstrap ensemble of Flows**
  - Pass resampled version of dataset to each flow
  - Emulate online with Poisson weight for each event
- Compare flows within ensemble
  - Estimate uncertainty



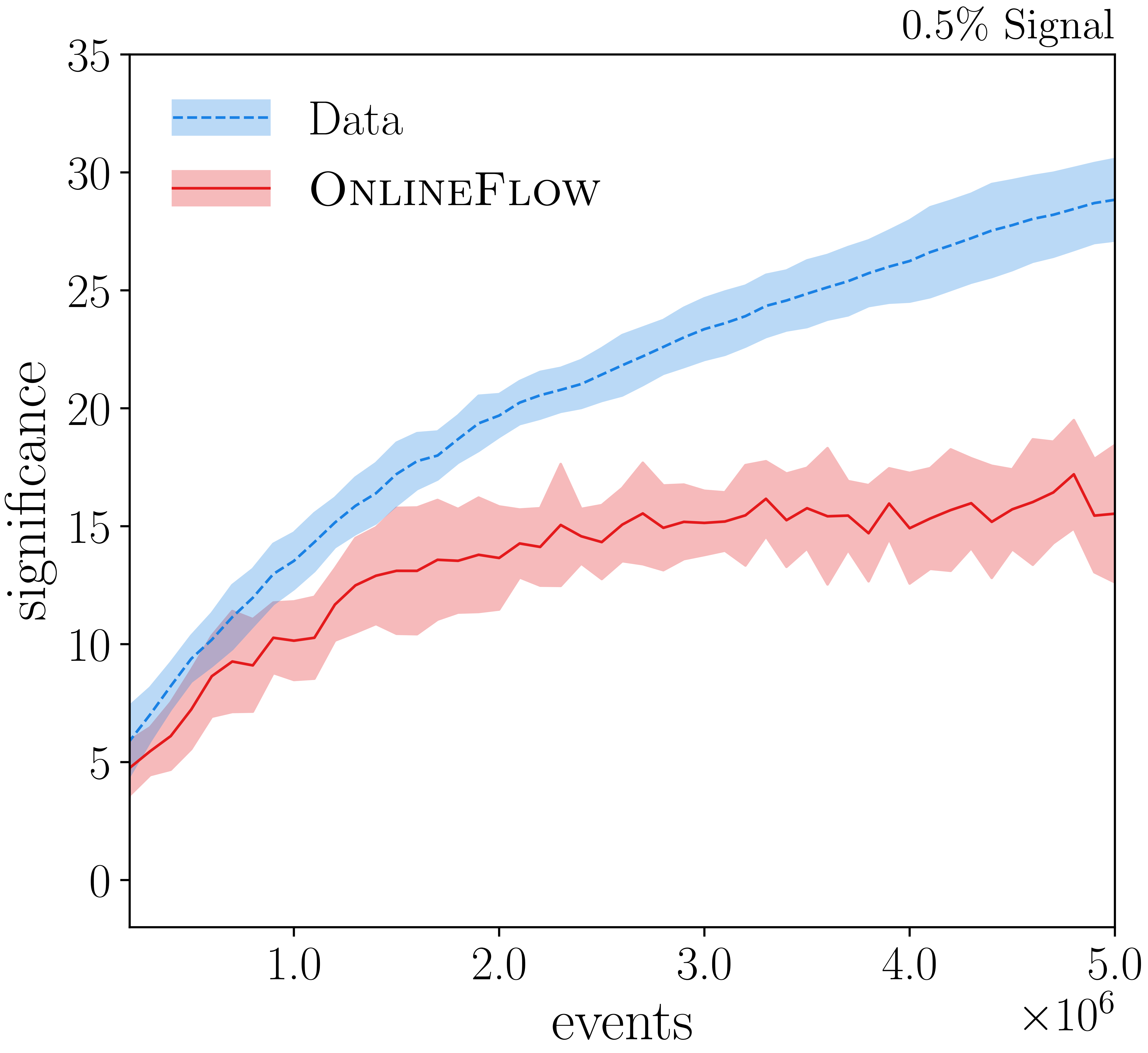
Proof of Concept

- Use half the ensemble to estimate bump position
- Use other half to determine signal rate
- Built in cross-check
- Estimate uncertainty form variance
- Plot as function of the number of events to see development



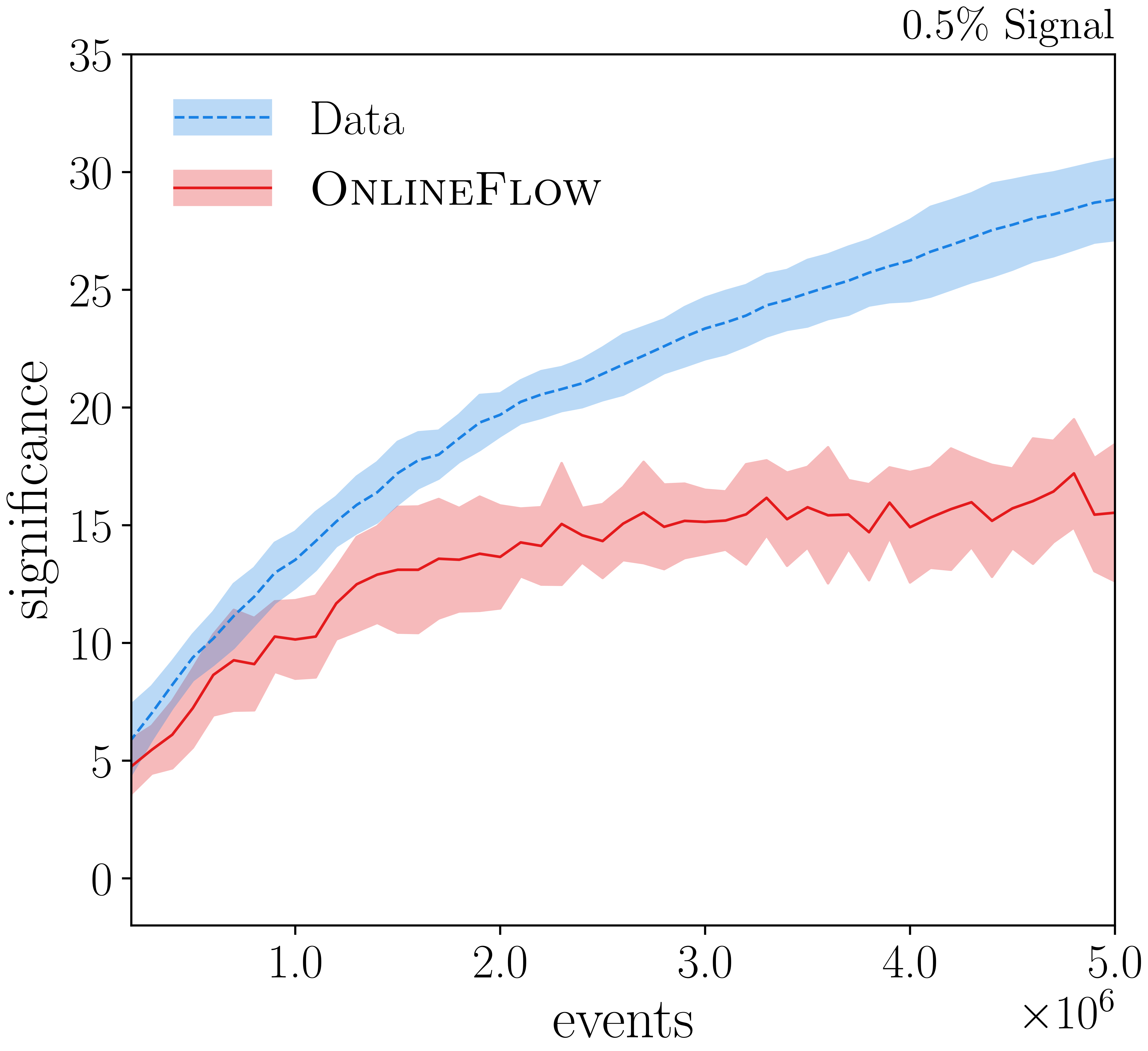
Proof of Concept

- Run same analysis in the training data itself
- Compare significance
- Flow similar shape as data
- Reaches high significance



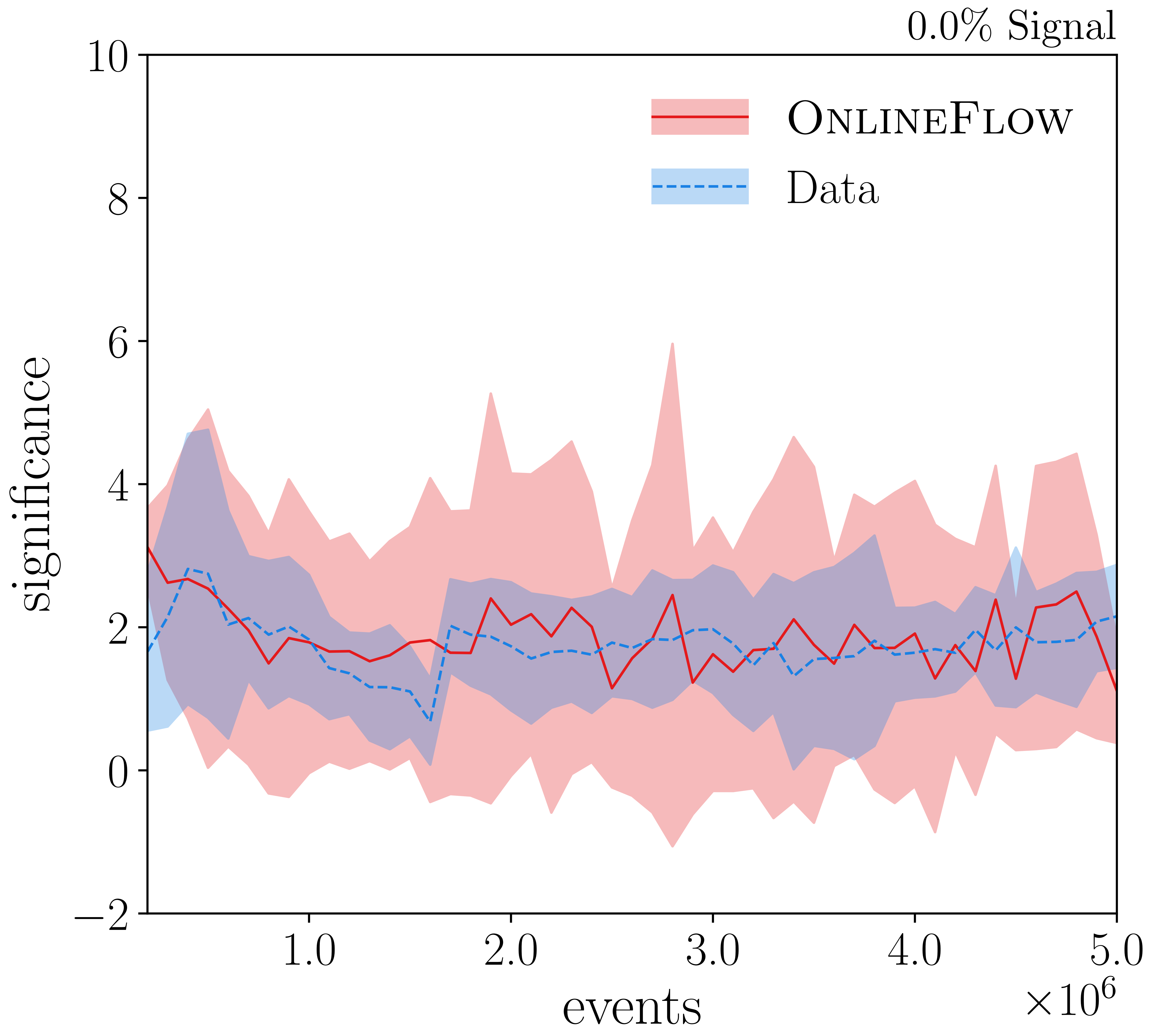
Proof of Concept

- False positives?



Proof of Concept

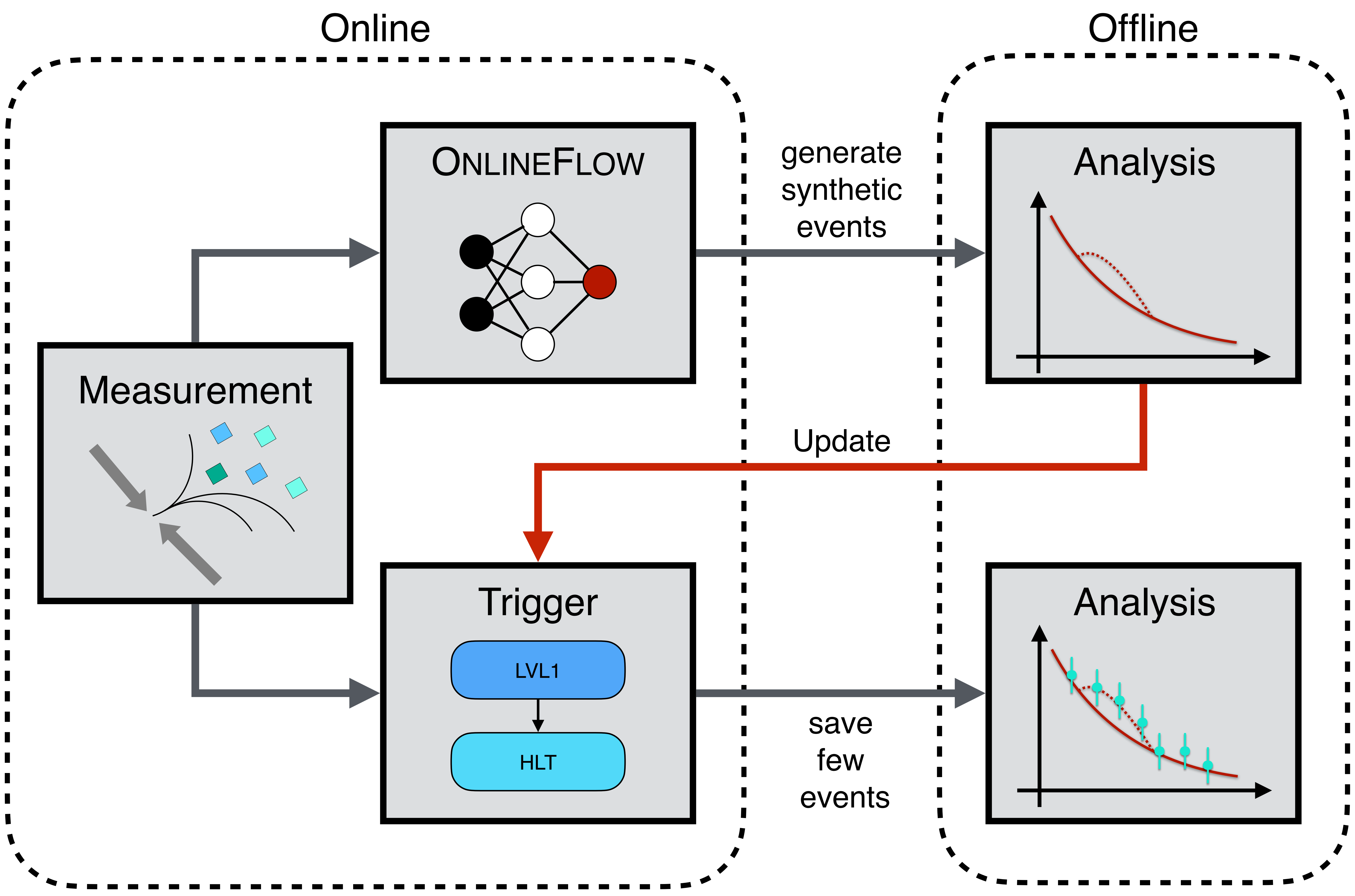
- False positives?
- Run same training on only background without signal
- Negligible significance in direct search
- Flow significance nearly identical



Prescale Case

Some event classes:

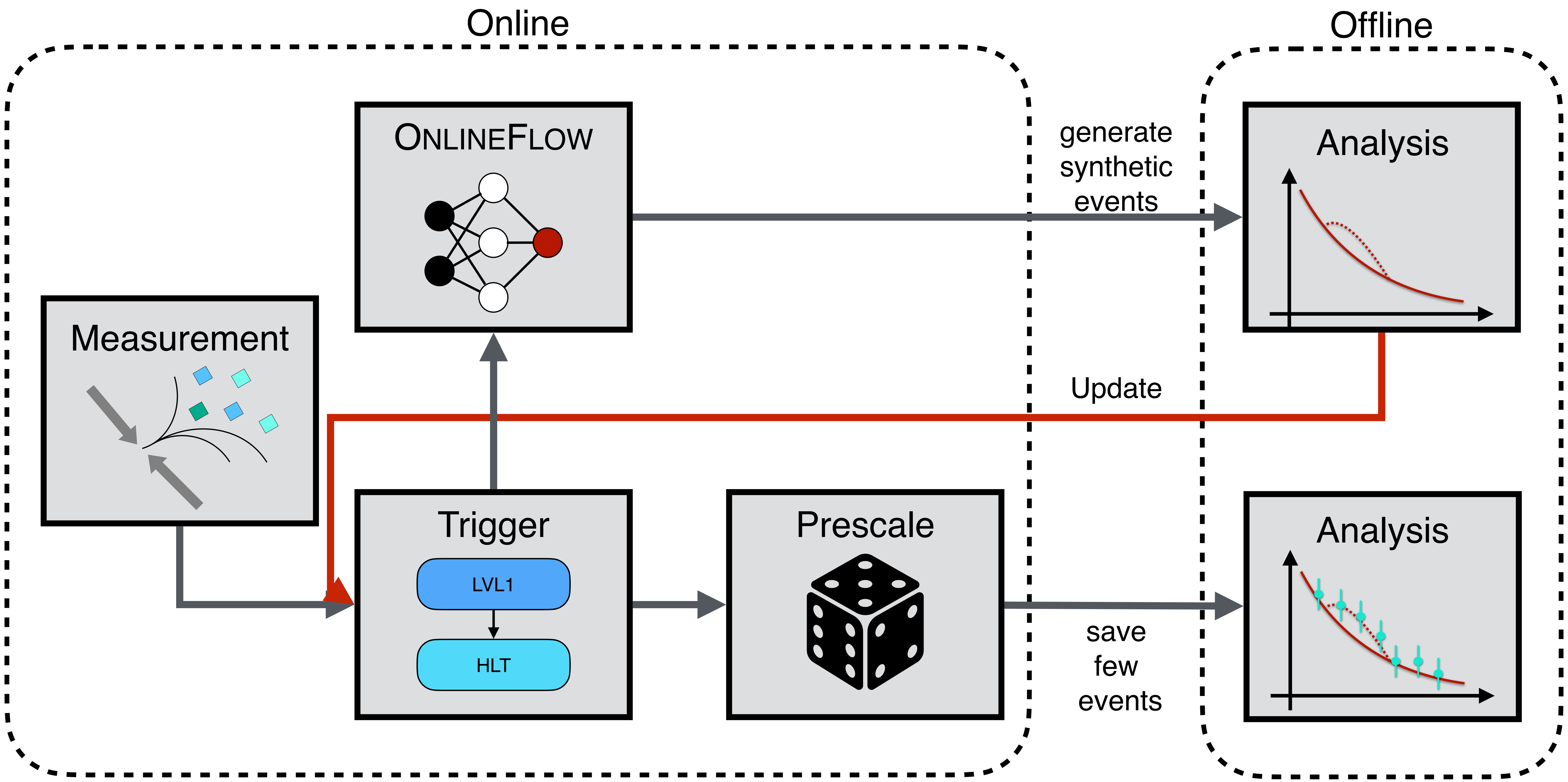
- Too high rates even after trigger



Prescale Case

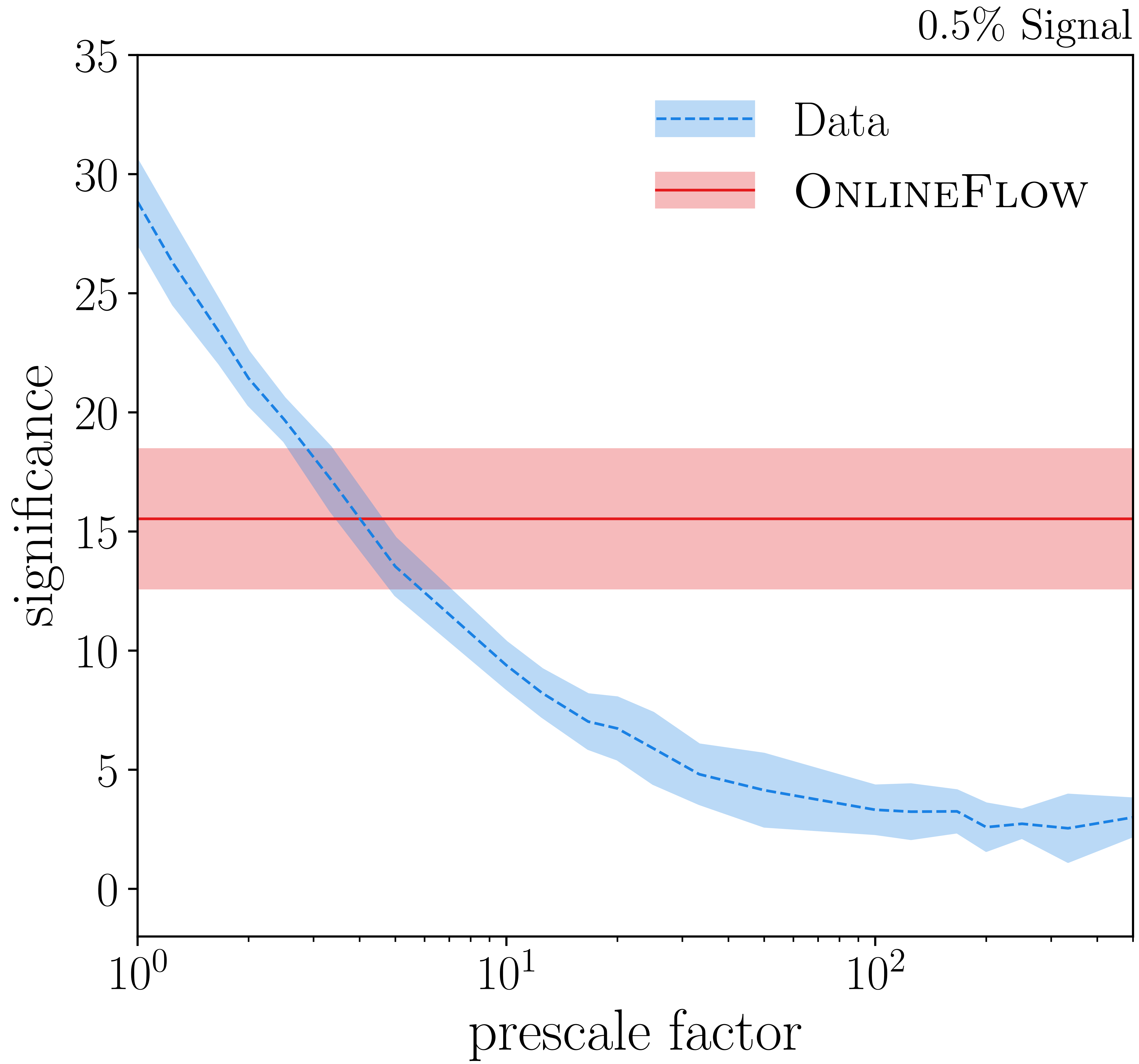
Some event classes:

- Too high rates even after trigger
- Apply percale
- Randomly select events to save
- 1/prescale chance to keep event

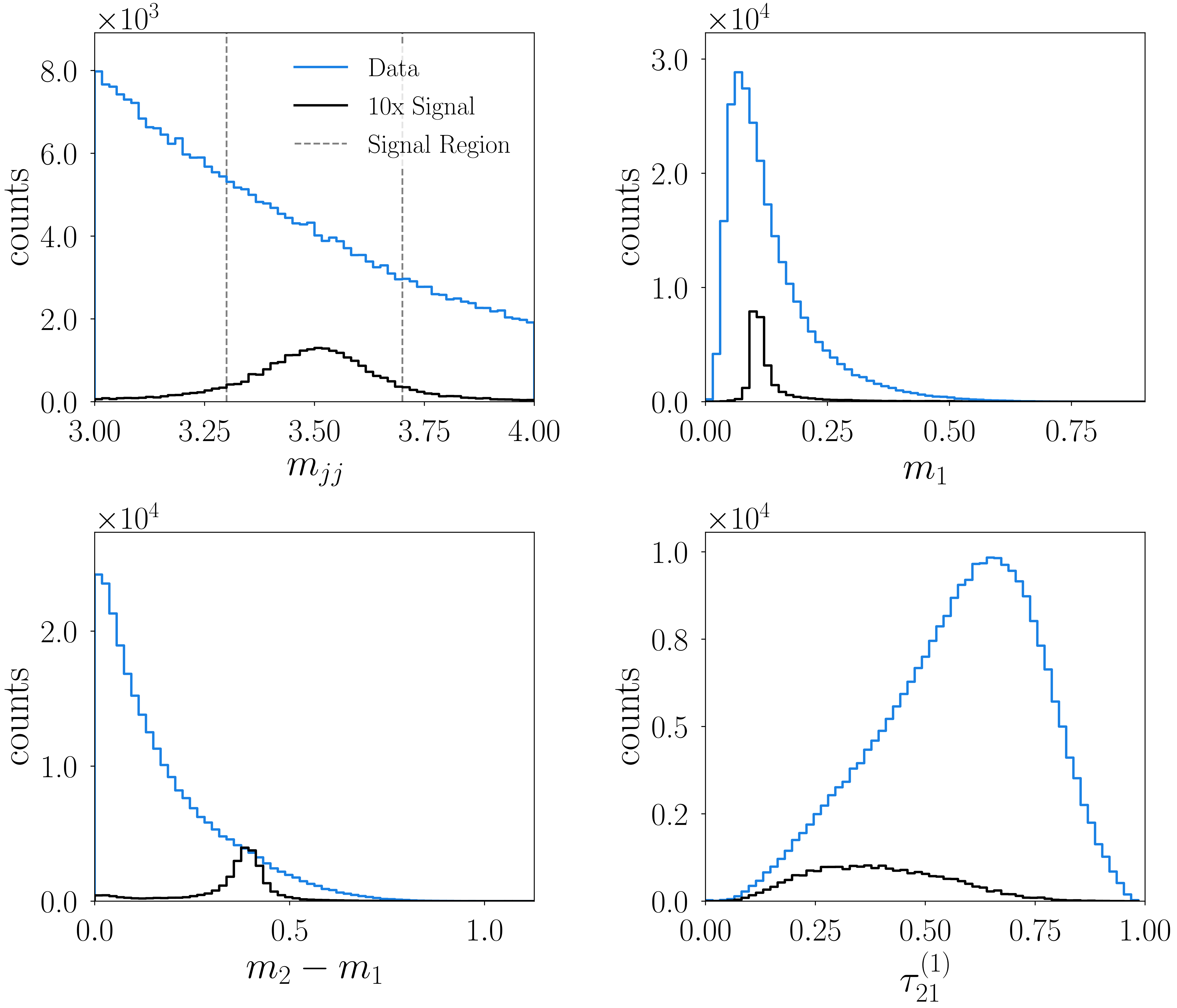


Prescale Case

- At what prescale factor do we benefit from the Flow?
- Quite early
- Factor of around 4
- Very promising in 1D



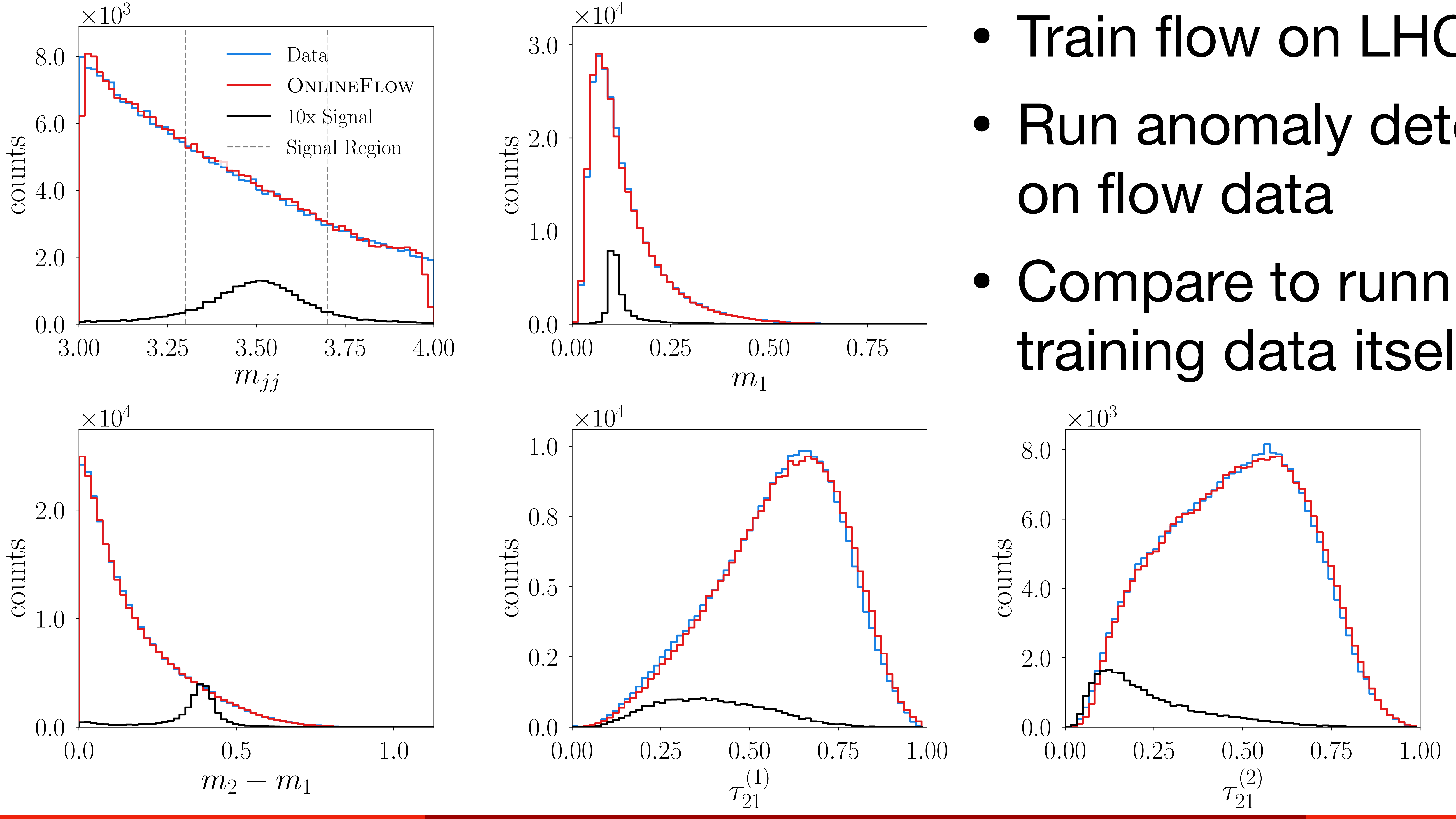
Higher Dimensional Case



- LHCO Challenge dataset
- Realistic physics case for anomaly detection
- Use state-of-the-art anomaly detection input format

Kasieczka et al.: **The LHC Olympics 2020: A Community Challenge for Anomaly Detection in High Energy Physics** kl 2101.08320

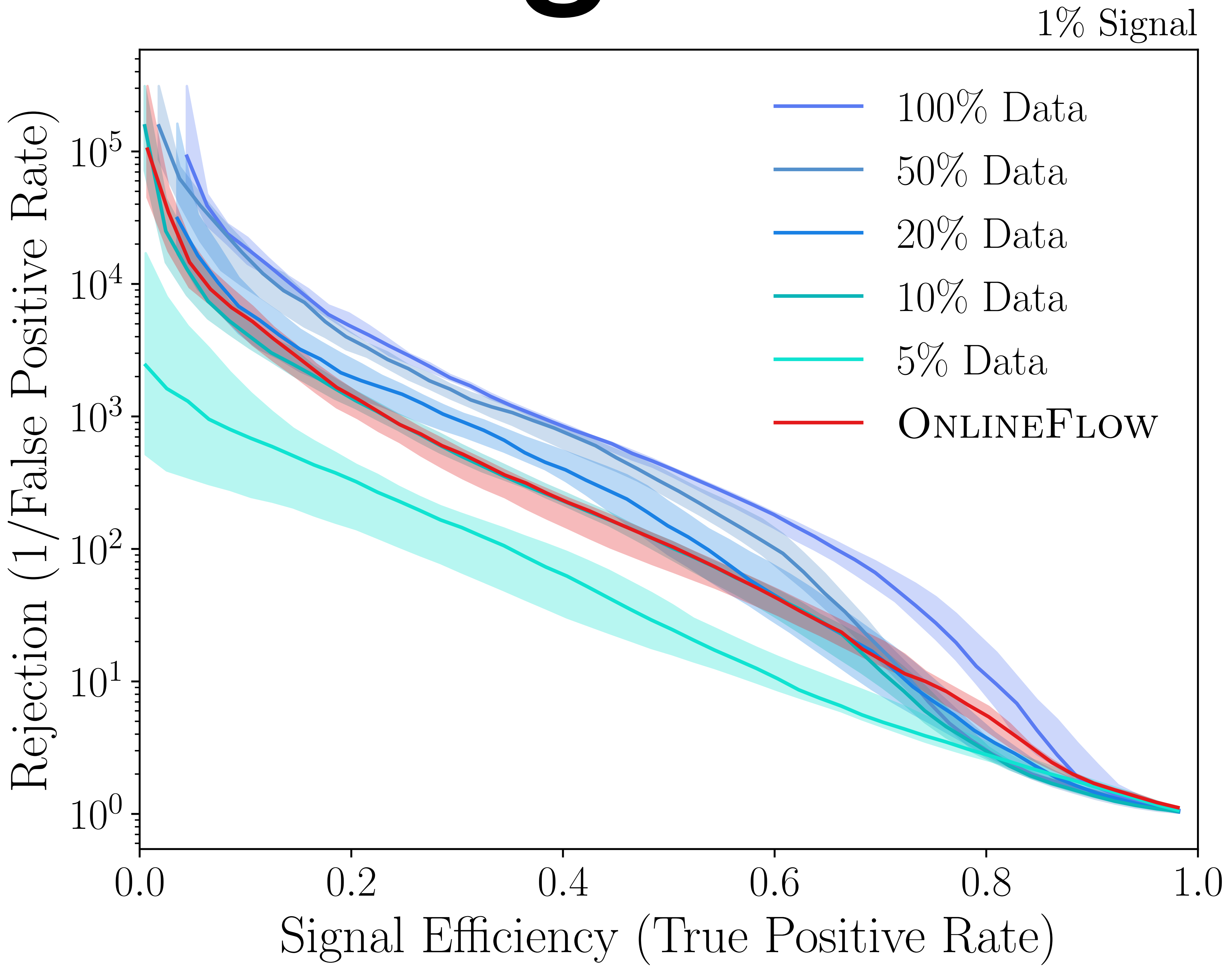
Higher Dimensional Case

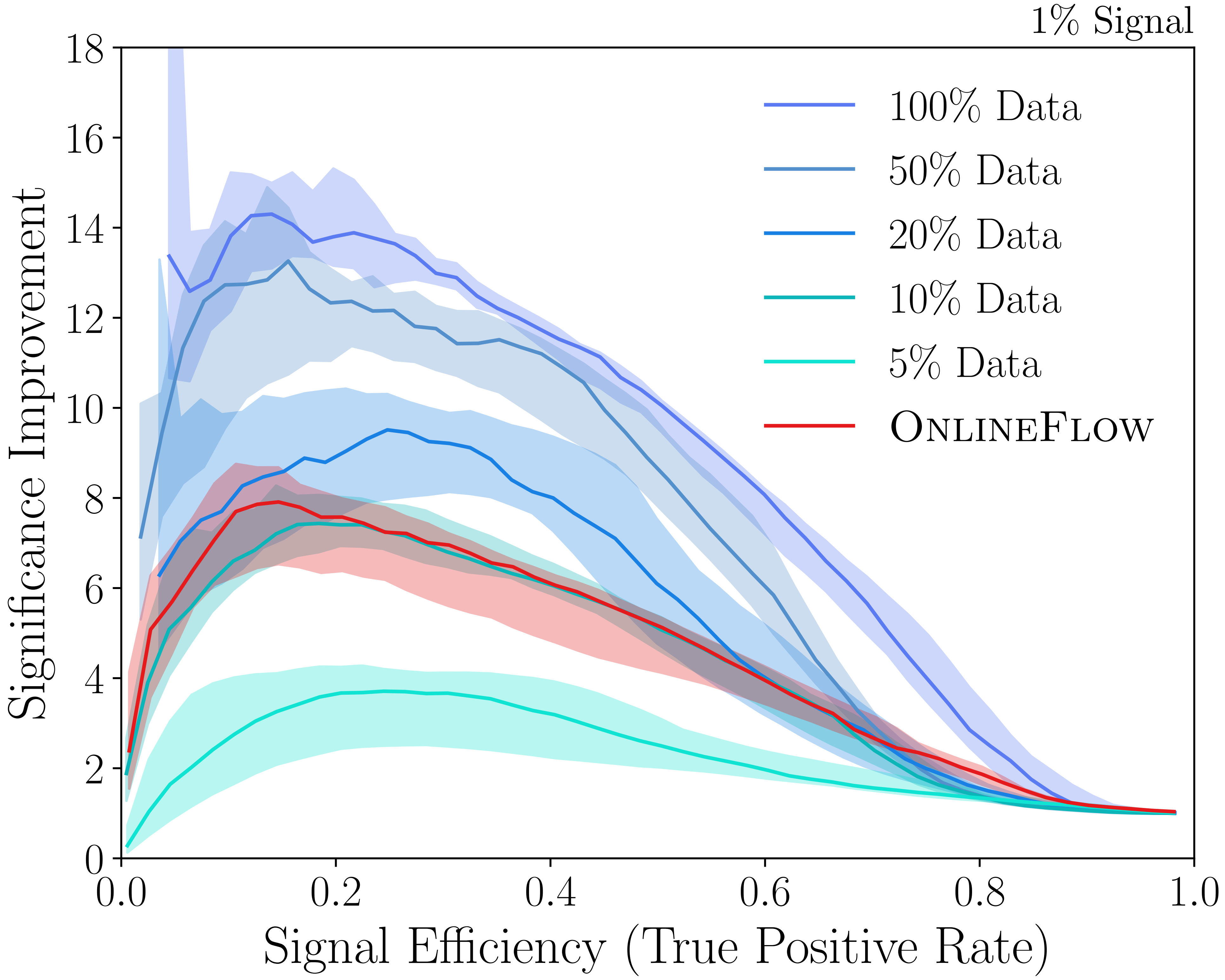


- Train flow on LHCO data
- Run anomaly detection setup on flow data
- Compare to running on training data itself

Kasieczka et al.: **The LHC Olympics 2020: A Community Challenge for Anomaly Detection in High Energy Physics** kl 2101.08320

Higher Dimensional Case

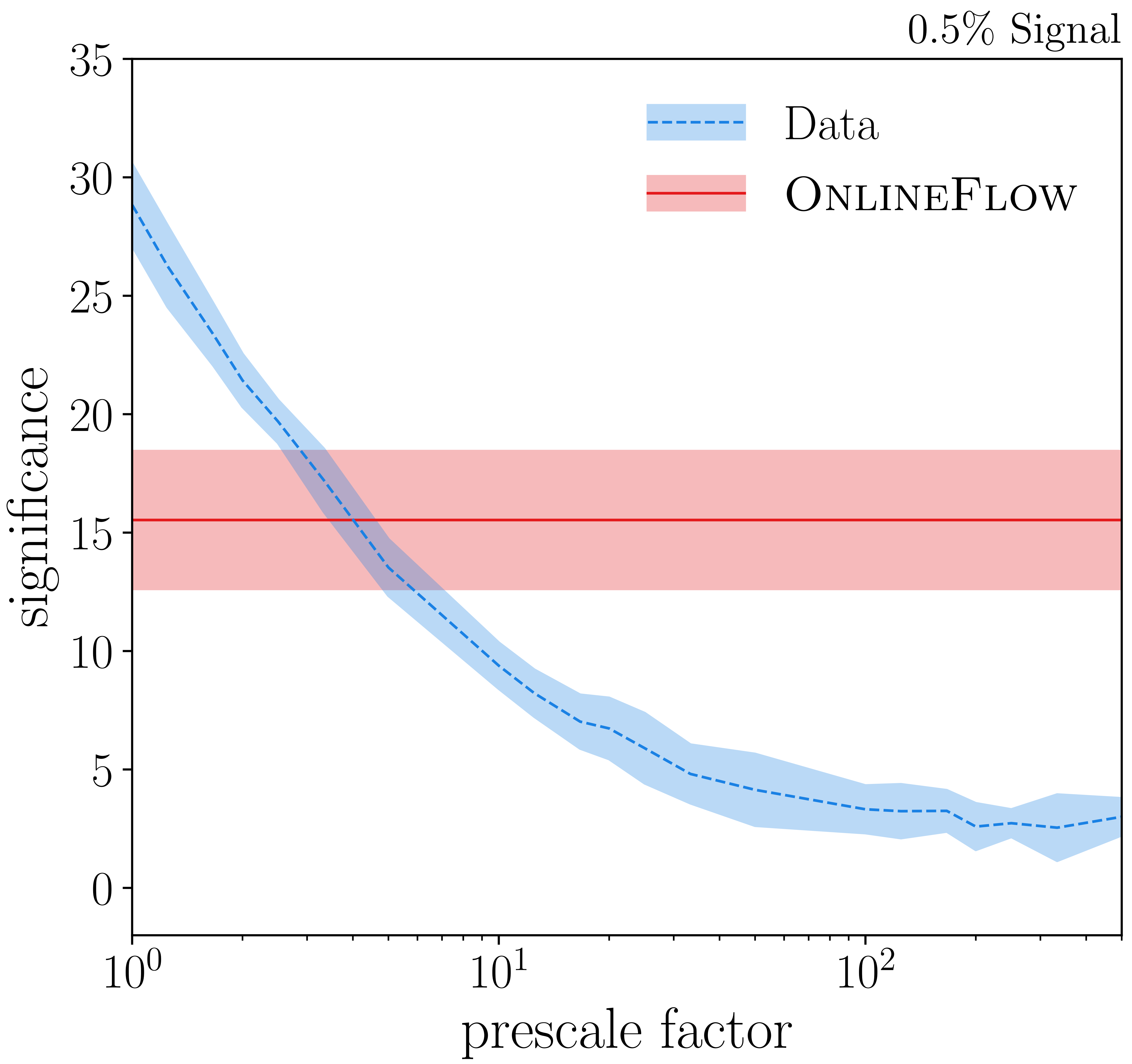




- ROC and SIC curves, larger Rejection/Improvement is better
- Flow data performs about as well as 10% of the training data
- Still gain benefit if perscale factor is 10 or larger

Conclusion

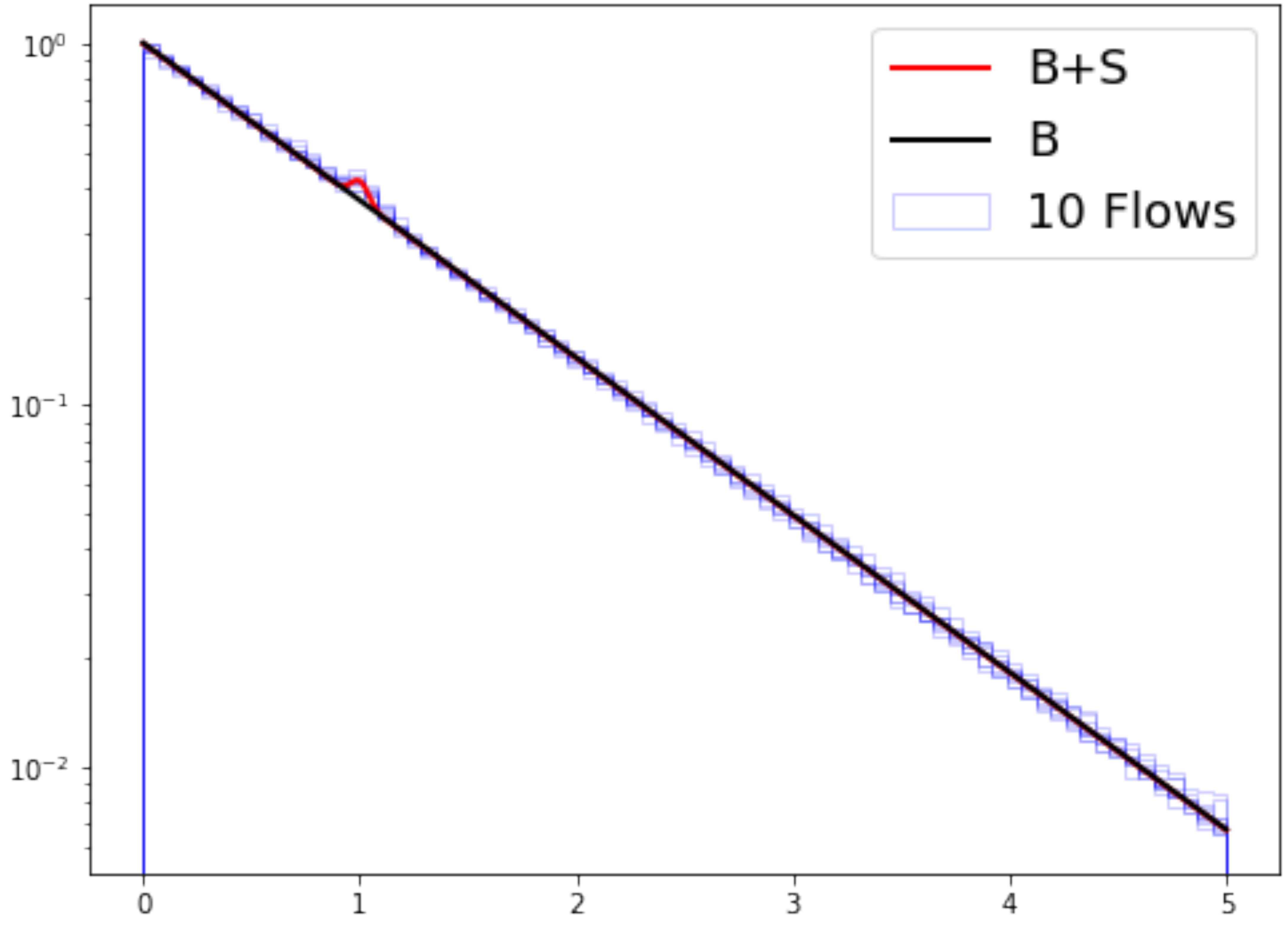
- Tested OnlineFlow approach on 1D proof-of-concept data
  - Promising Results
- Higher dimensional case:
  - Can extract signal features form LHCO challenge dataset
- Paper (hopefully) soon!



Thank You

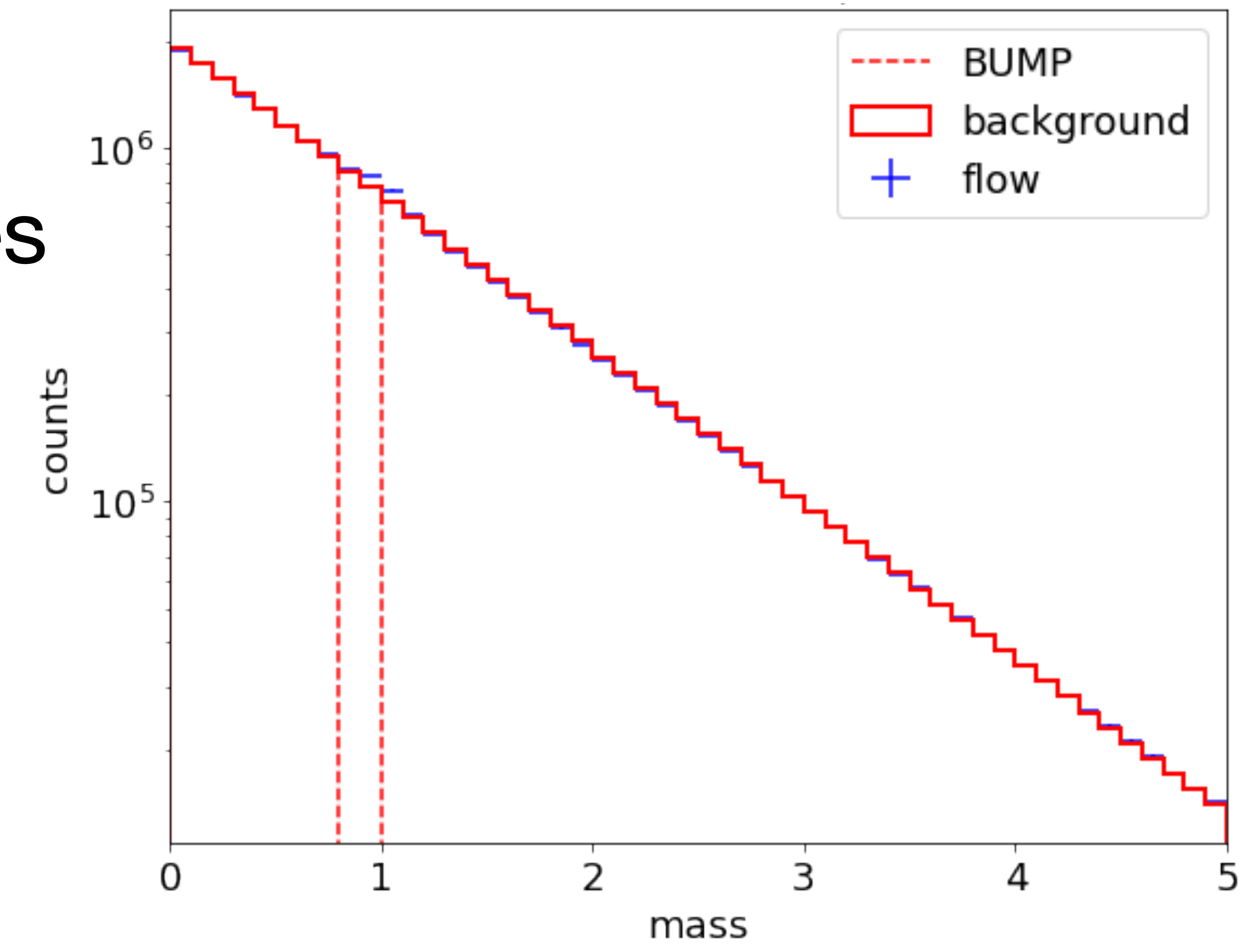
Backup

- Train **ensemble** of Flows
  - Same underlying distribution
  - Independant data points
- Lets us estimate systematic uncertainty
- Allows for easy parallelised training



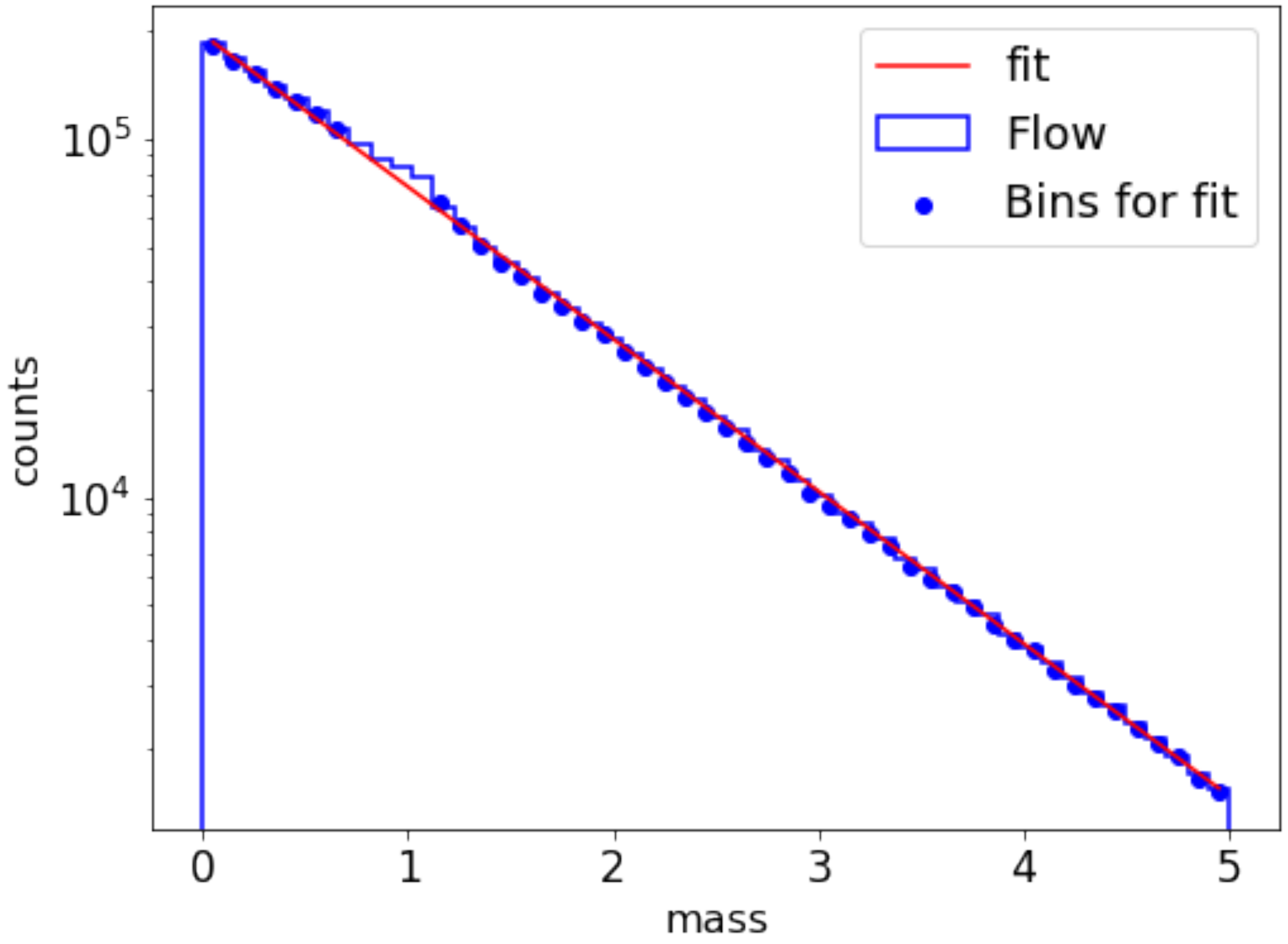
Backup

- Uncertainty estimate:
- Step 1:
  - Look at **combined** flow samples
  - Run bump-hunt
  - Get upper and lower bound for signal region



Backup

- Step 2:
  - Look at each **individual** flow F_i out of N flows in ensemble
  - Generate samples from F_i
  - Fit background model on samples excluding signal region from step 1
  - Get B_i and $(S+B)_i$ in signal region



Backup

- Step 3:
  - Calculate $B = \sum_i^N B_i$ and $\delta B = \mathrm{std}(B_i)\sqrt{N}$
  - Calculate $(S + B)$ and $\delta(S + B)$ equivalently
  - From this get S and δS
  - Significance: $\dfrac{S}{\sqrt{(\delta S)^2 + B}}$

Systematic error via ensemble

Statistical error