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GÖTTINGEN

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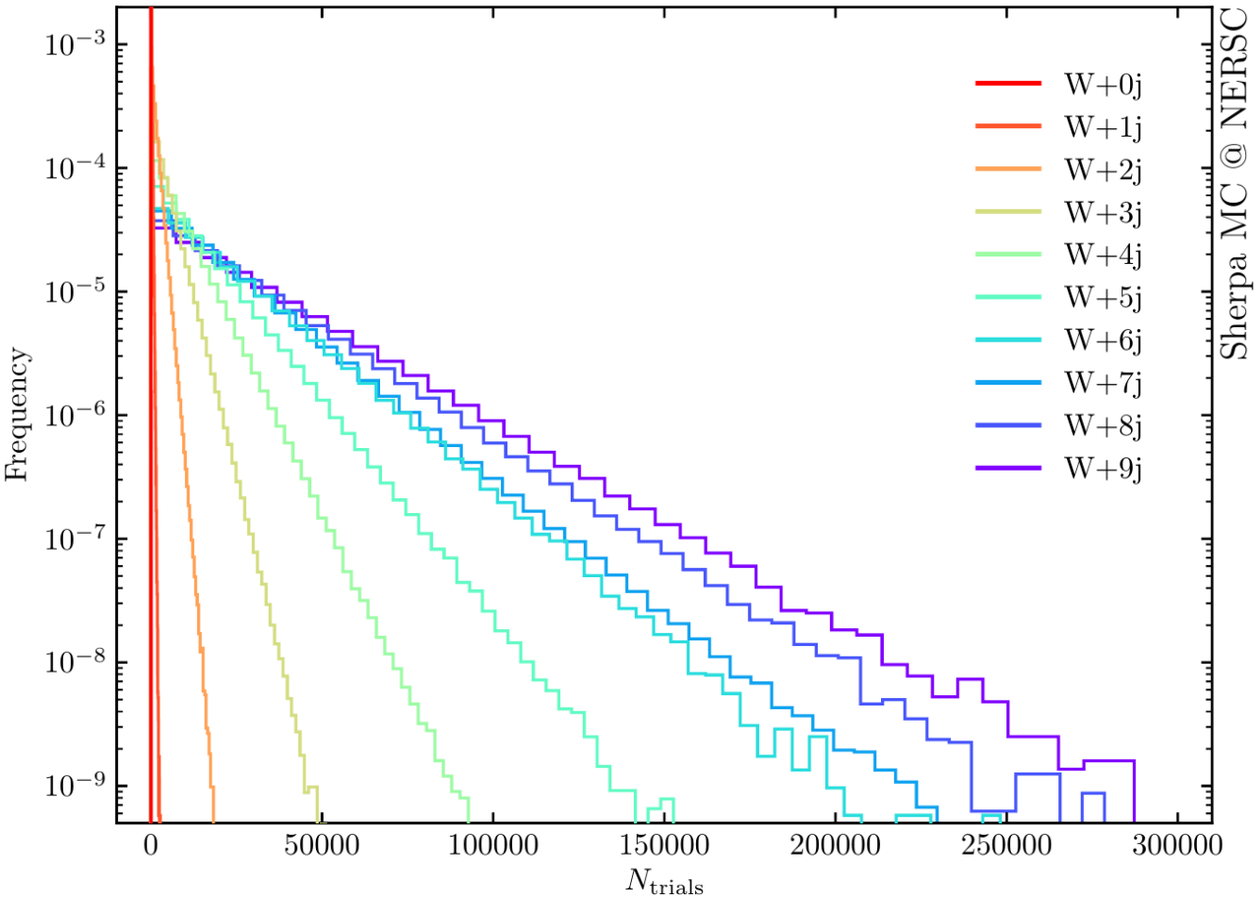
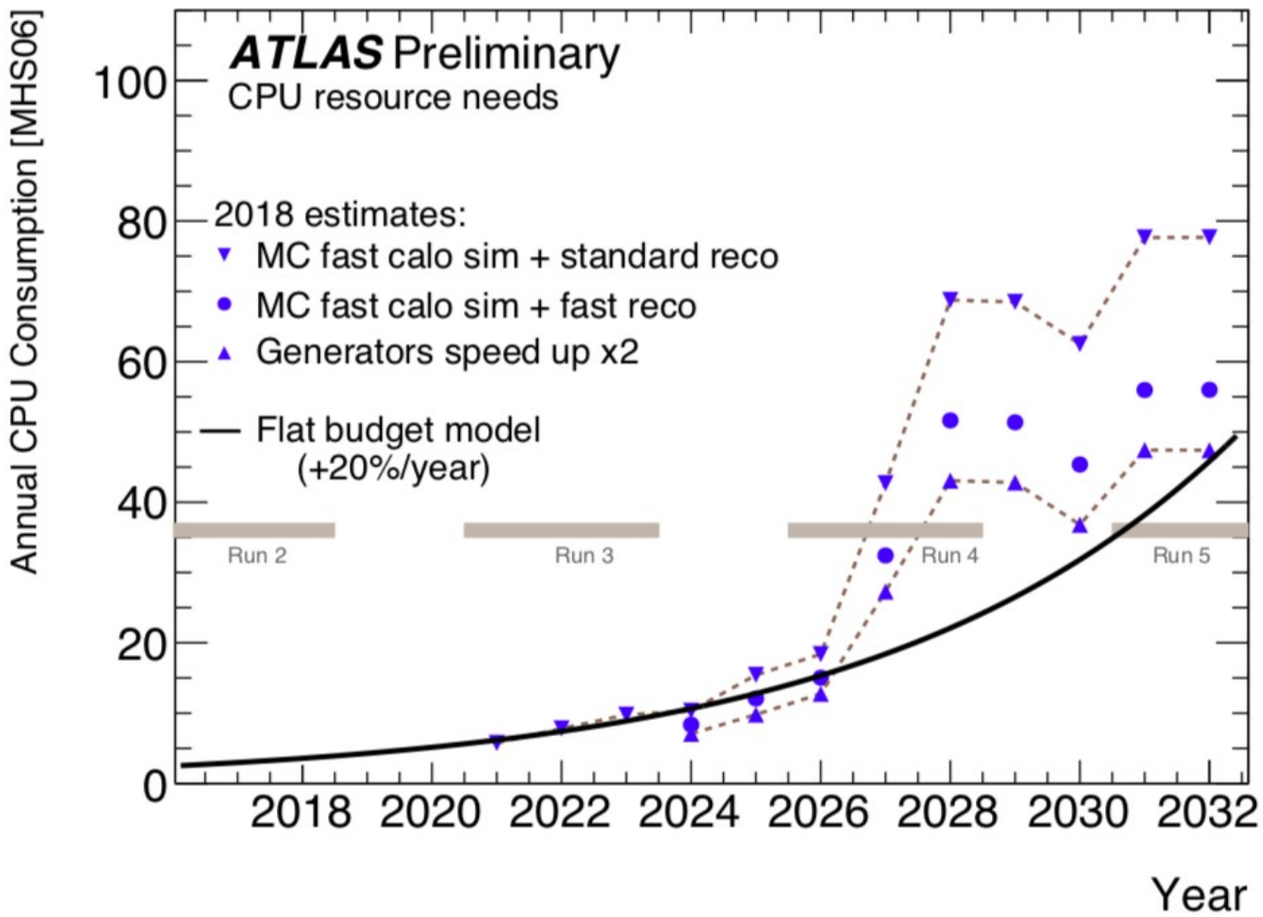
Exploring phase space with Neural Importance Sampling

Why?





arXiv:1905.05120 [hep-ph] S. Höche, S. Prestel, H. Schulz (2019)

Requirements

- Full phase space coverage
- Convergence to target distribution
- General method, lending itself to automation
- Produce uncorrelated events

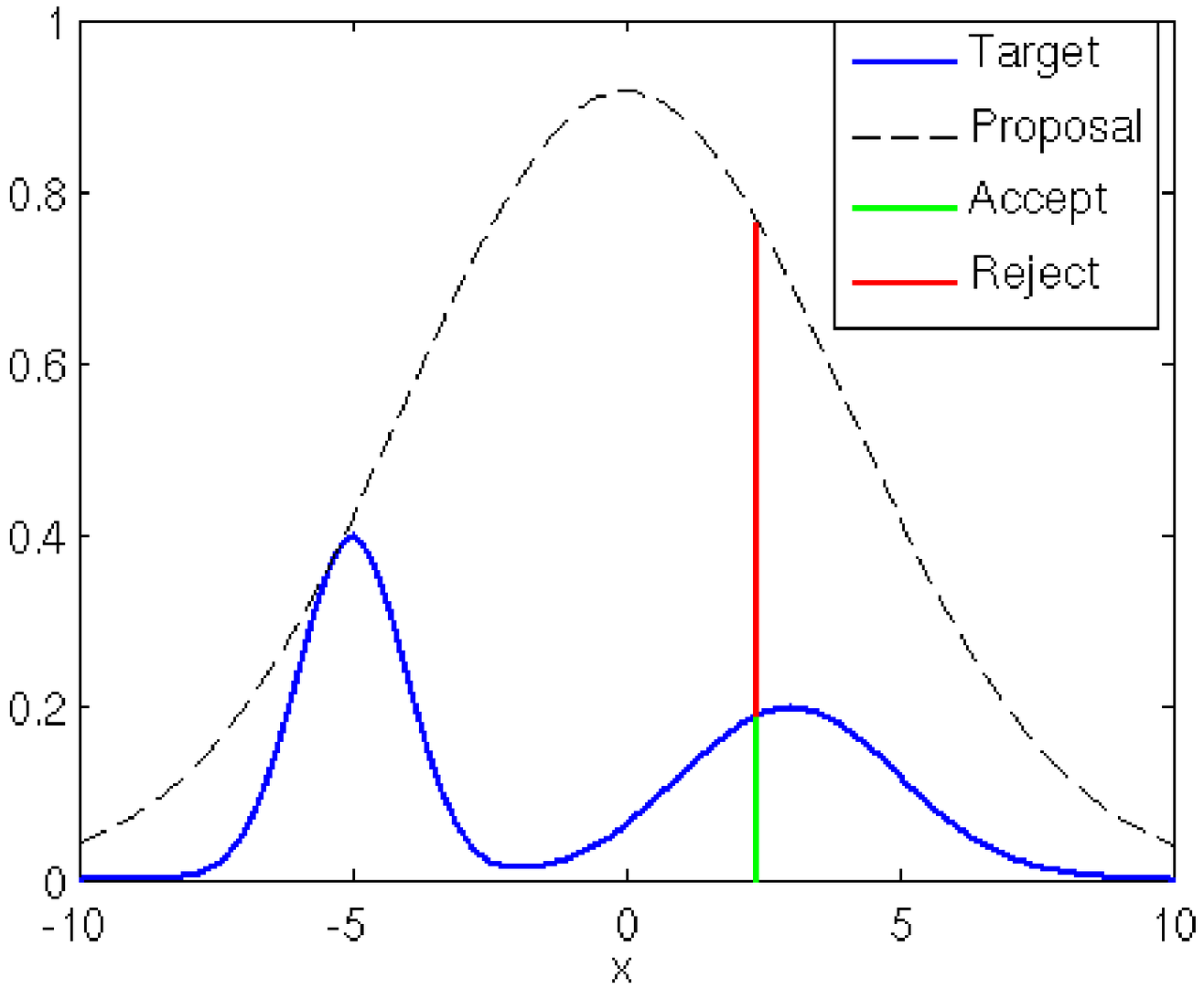
Reminder: Importance Sampling

$$\int_\Omega f(x)\mathrm{d}x = \int_\Omega \frac{f(x)}{g(x)} g(x)\mathrm{d}x \approx V \frac{1}{N} \sum_{i=1}^{N} \frac{f(x_i)}{g(x_i)}$$

- Choose g(x) similar to f(x)
- g(x) needs to be invertible

- Multi-channel: $g(x) = \sum_i \alpha_i g_i(x)$
- Channel weights can be adapted automatically (Kleiss, Pittau (1994))

Unweighting: Hit or Miss Algorithm



$$\text{Efficiency} \approx \frac{< w >}{\max(w)}$$

VEGAS Algorithm

Lepage (1978)

- Adaptive importance sampling
- Uses a piecewise constant function
- Partition every dimension into n_d bins
- The bin widths are adapted automatically in order to minimize the overall variance

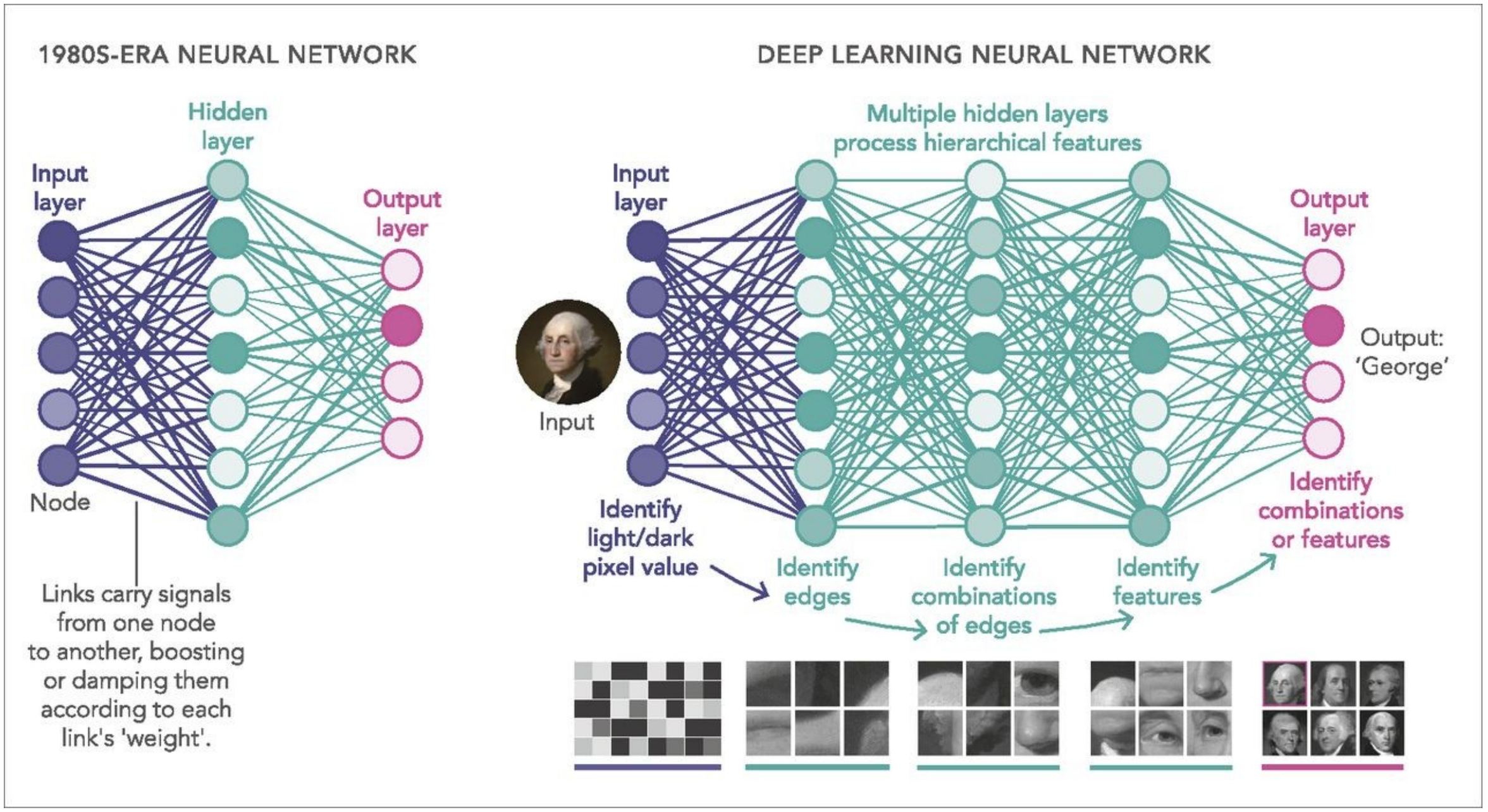
  → use many thin bins where integrand has peaks and few wide bins where it is flat
- Use factorised distribution to avoid curse of dimensionality:

$$g(x_1, x_2, \ldots) = g(x_1)g(x_2)\cdots$$

Phase Space Sampling in HEP – State of the Art

- Automatically generate process-specific channels based on Feynman diagrams / recursion relations
- Automatically optimize channel weights
- Use VEGAS to remap individual channels

Deep Learning



Neural Importance Sampling

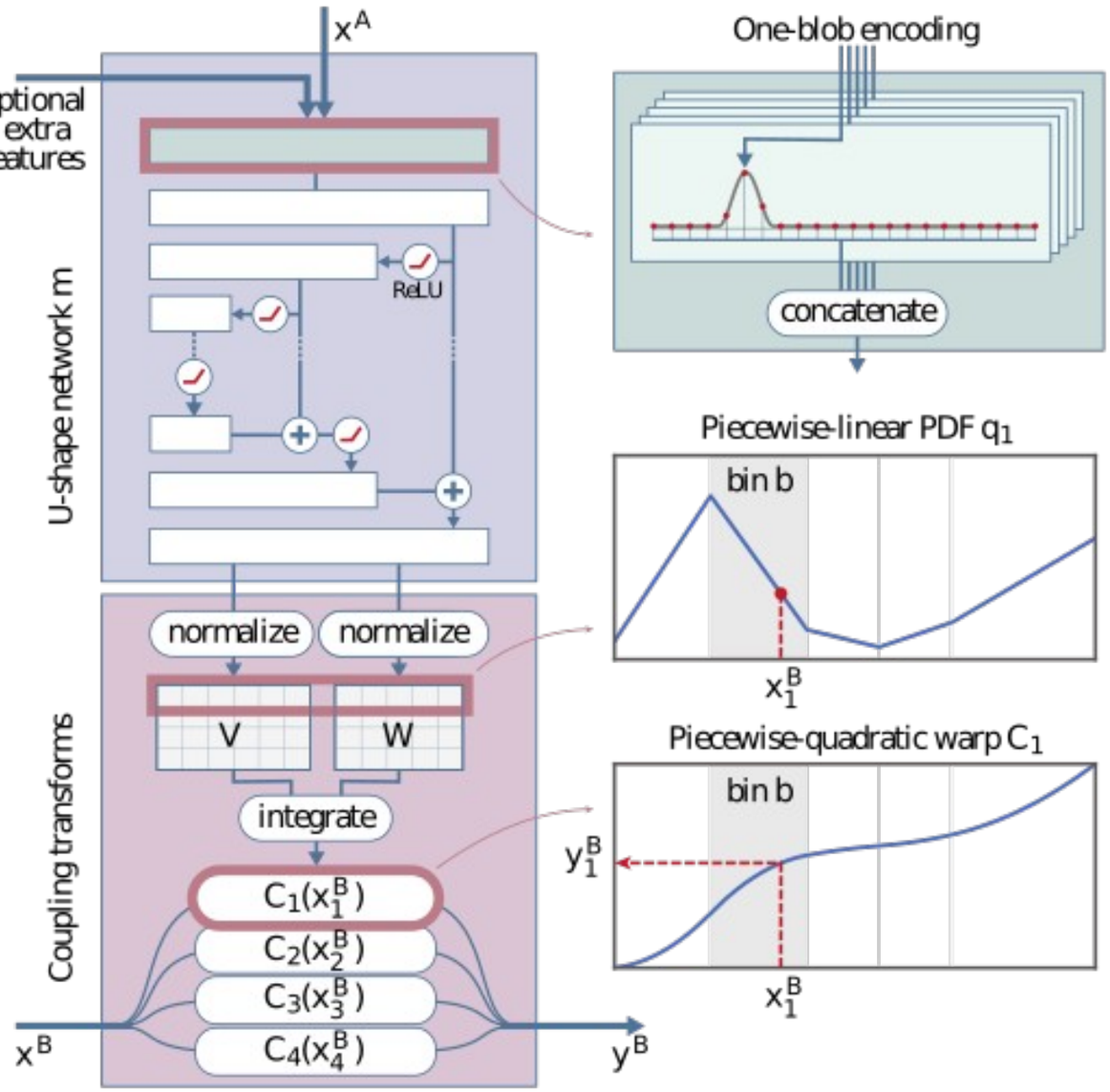
Müller et al. (2018)

- Developed for light transport simulation (image rendering)
- Based on an invertible DL model (normalizing flows)
- Provides a mapping $[0,1]^d \to [0,1]^d$

  → can replace VEGAS in our setup

Neural Importance Sampling

Müller et al. (2018)



Setup

- Standalone Python implementation using Tensorflow
- Use Sherpa‘s Python API to get matrix elements from AMEGIC

Two test cases:

$e^+e^- \to t[be^+\nu]\bar{t}[\bar{b}e^-\bar{\nu}]$

- Single channel
- No cuts
- Importance sampler based on Breit-Wigner

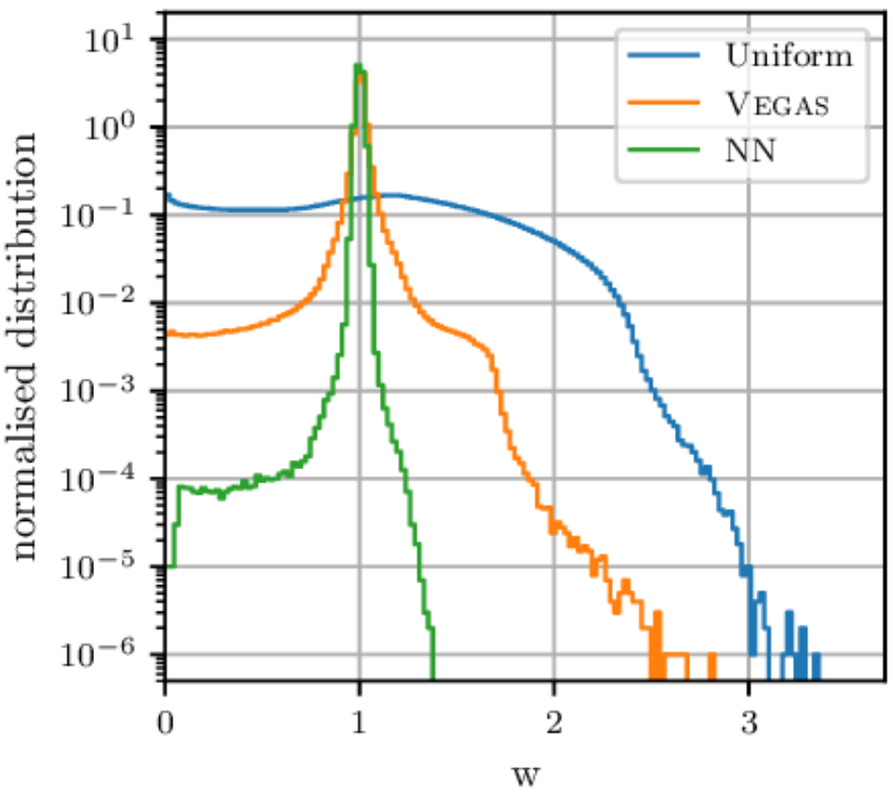
$gg \to ng$

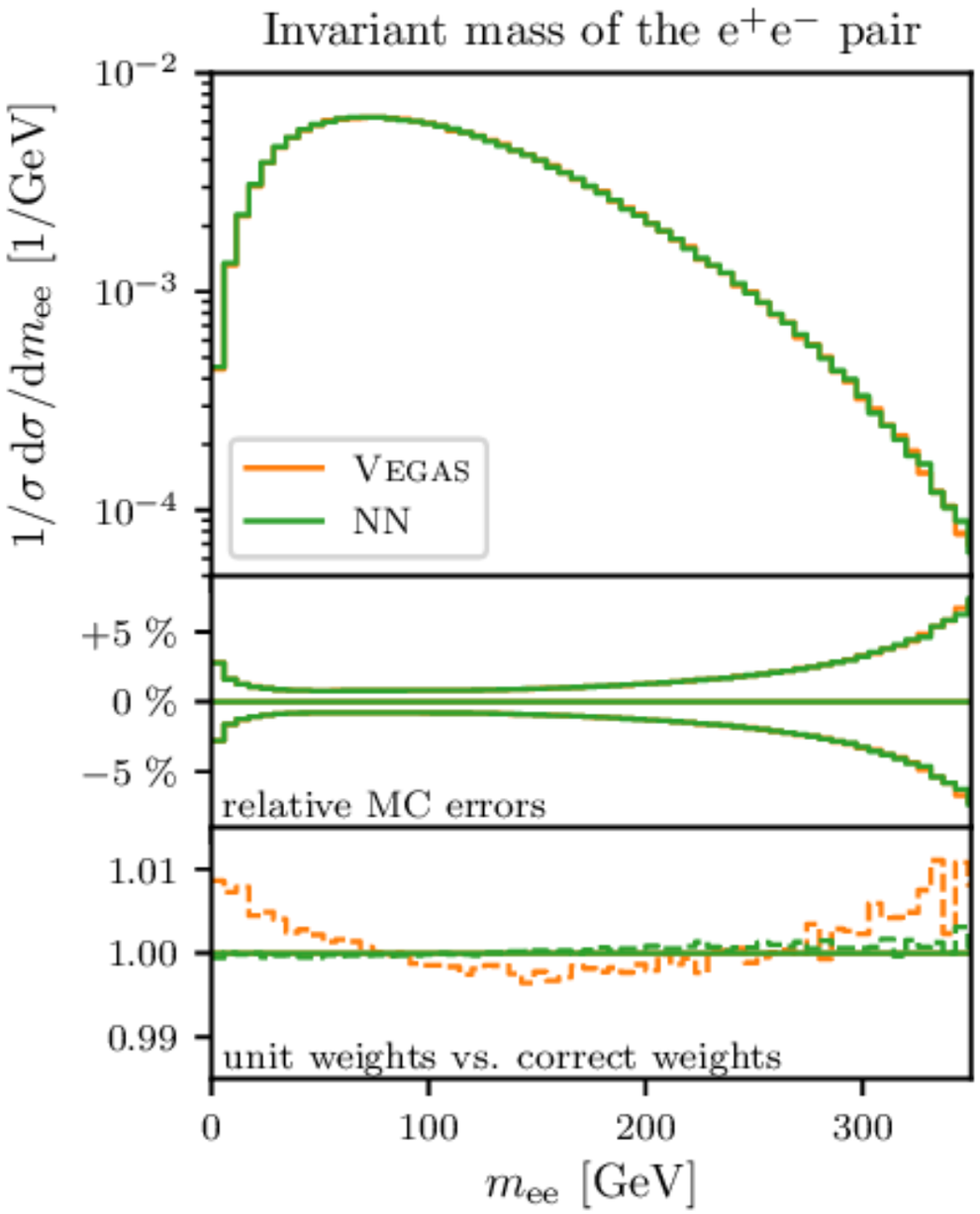
- Multi-channel
- Phase space cuts necessary
  → holes in phase space
- HAAG as importance sampler

Results

$e^+ e^- \to t[b\, e^+ \nu]\, \bar{t}[\bar{b}\, e^- \bar{\nu} b]$

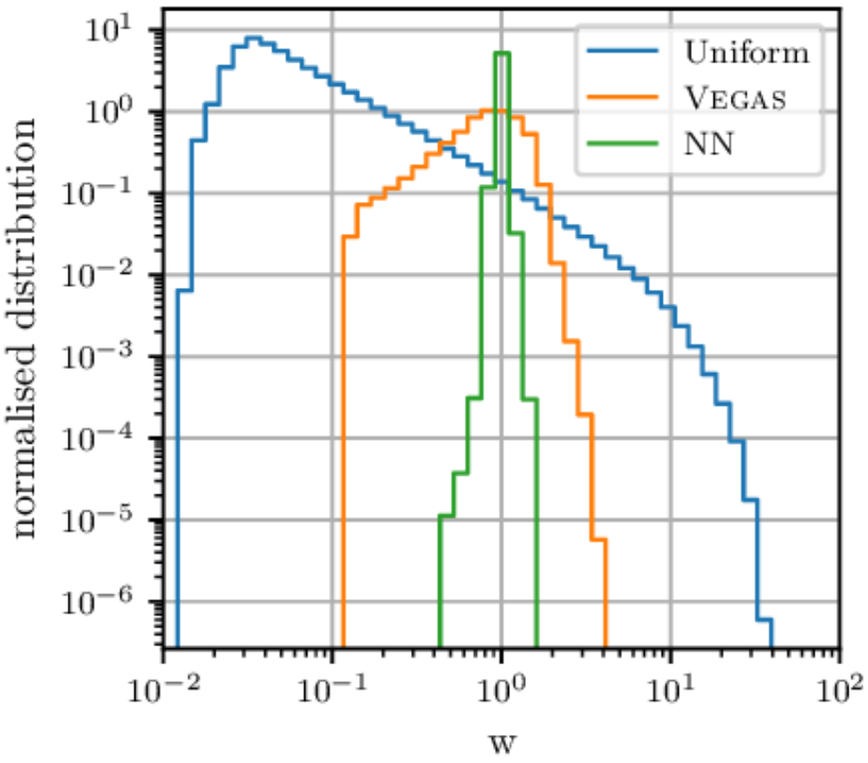
Sample	Unweighting Efficiency	σ [fb]
Uniform	35 %	1.5254(8)
VEGAS	40 %	1.5251(1)
NN	78 %	1.52531(2)

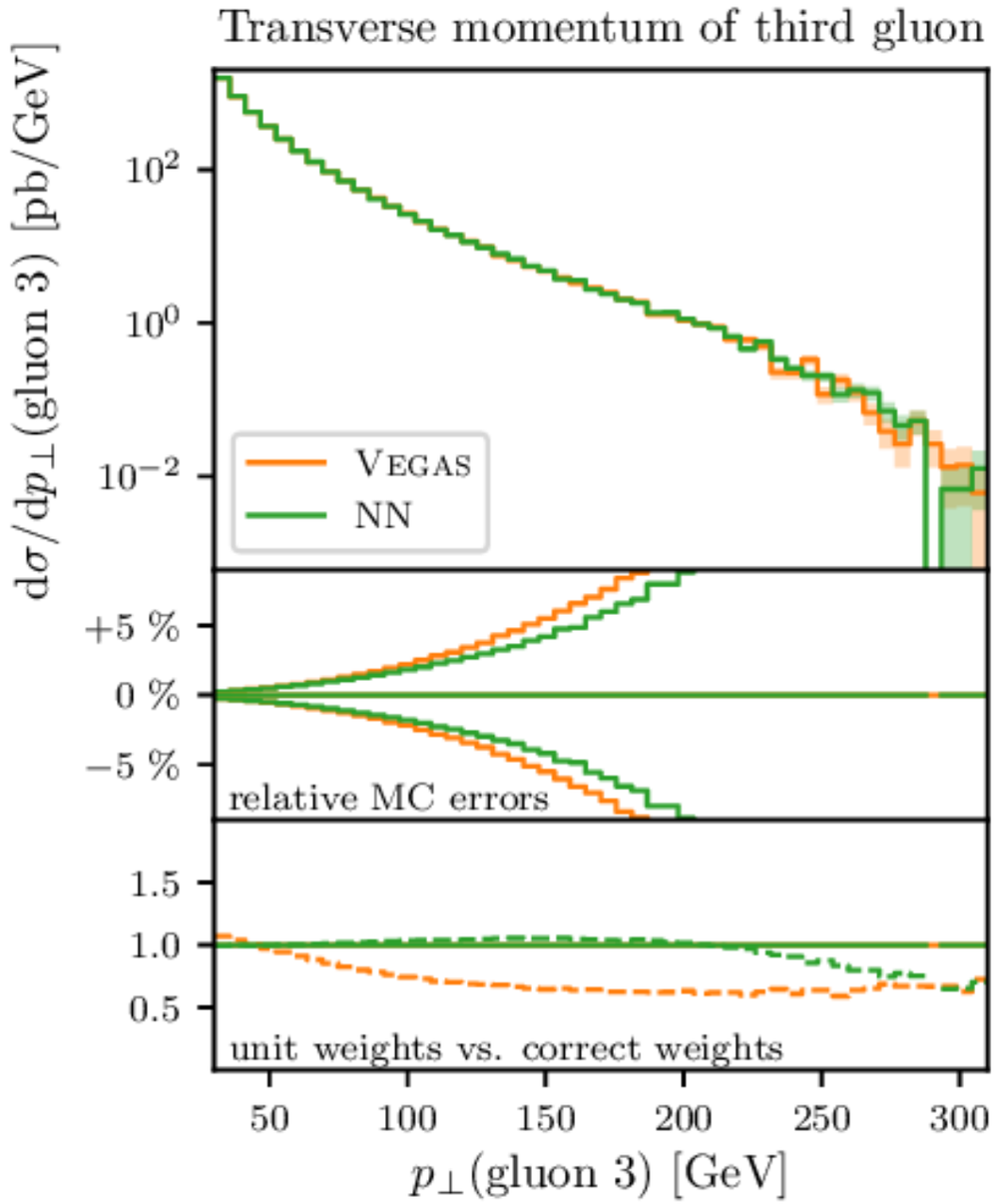




g g → 3 g

Sample	Unweighting Efficiency	σ [pb]
Uniform	3.0 %	24806(55)
VEGAS	27.7 %	24813(23)
NN	64.3 %	24847(21)





Conclusions

- Proof of concept for this technique
- Impressive results for simple processes
- For higher multiplicities not much gain over VEGAS
- Training cost is still rather high

Outlook

- There are many other DL models that could be used
- Handle cuts better
- Deal with multi-channel differently
- Implement interface to Sherpa‘s sampler to have access to arbitrary processes

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THANK YOU