Using Julia to Accelerate Monte Carlo Event Generation with Neural Importance Sampling

Tom Jungnickel

Erlangen, 09.11.2023

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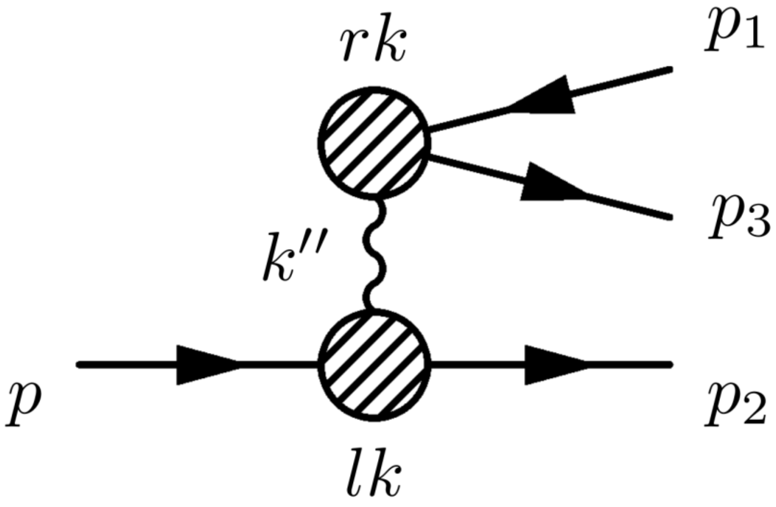
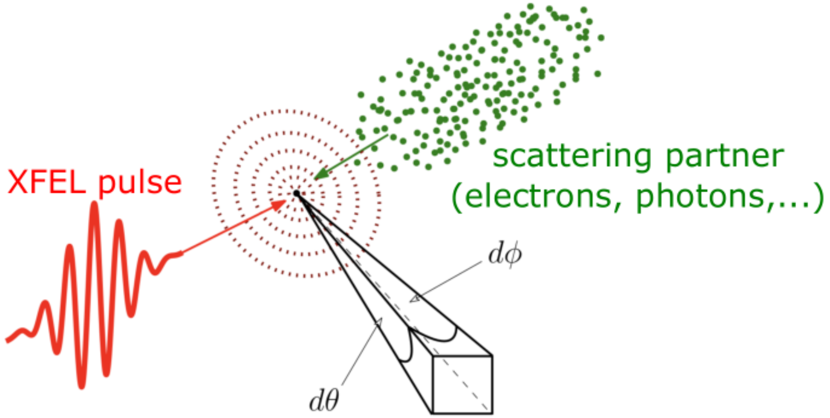
Recap: Physical background

Event generation for strong-field QED scattering processes

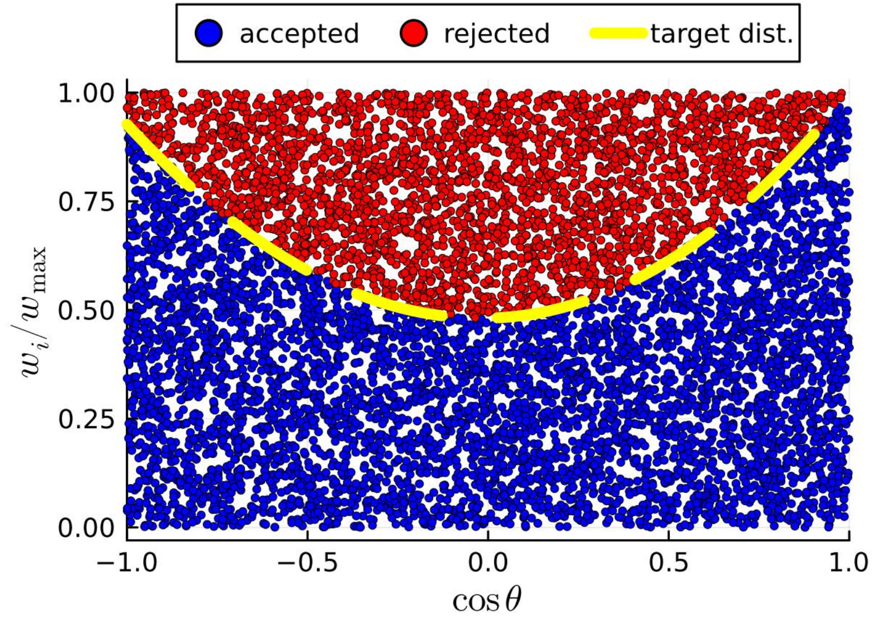




Feynman-diagrams → Differential cross sections

Monte Carlo Event Generation

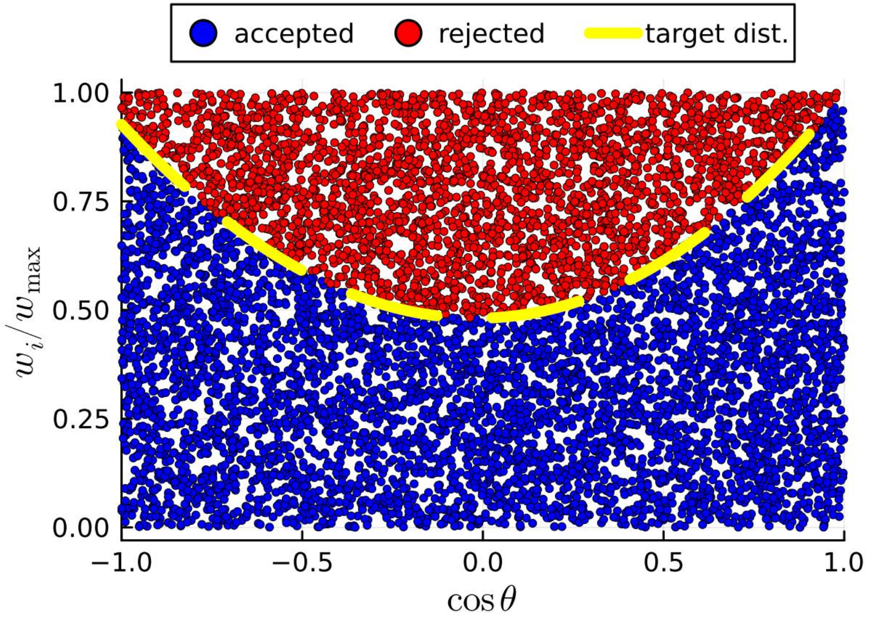
- Weight $w(x) := \frac{d\sigma}{dx}$



Monte Carlo Event Generation

- Weight $w(x) := \frac{d\sigma}{dx}$

- Unweighting
  1. $w_{i,\text{rel}} = \frac{w_i}{w_{\max}}$
  2. $u \sim U[0,1]$
  3. accept x if $u < w_{i,\text{rel}}$



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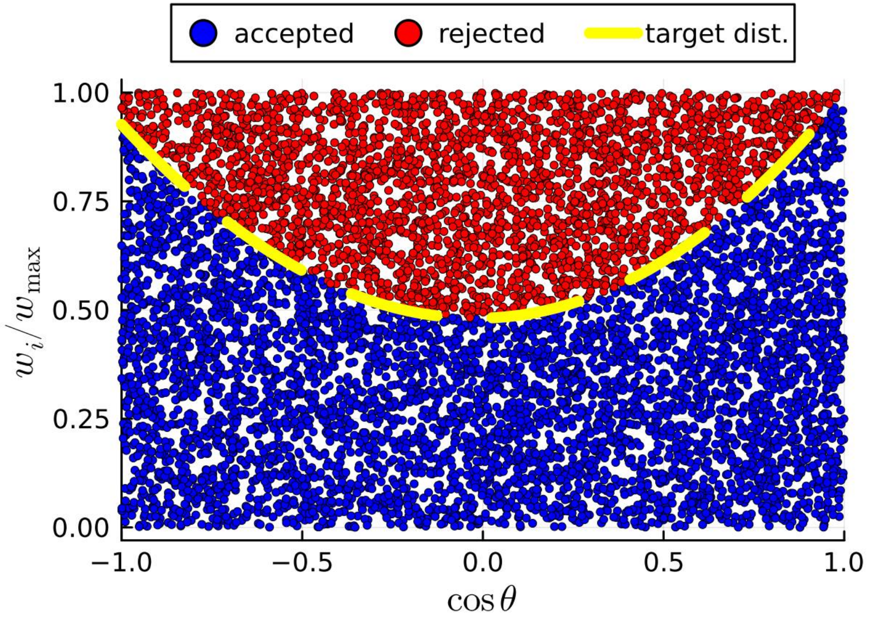
- Unweighting efficiency $\epsilon := \frac{\mathbb{E}[w_i]}{w_{\text{max}}} \leq 1$



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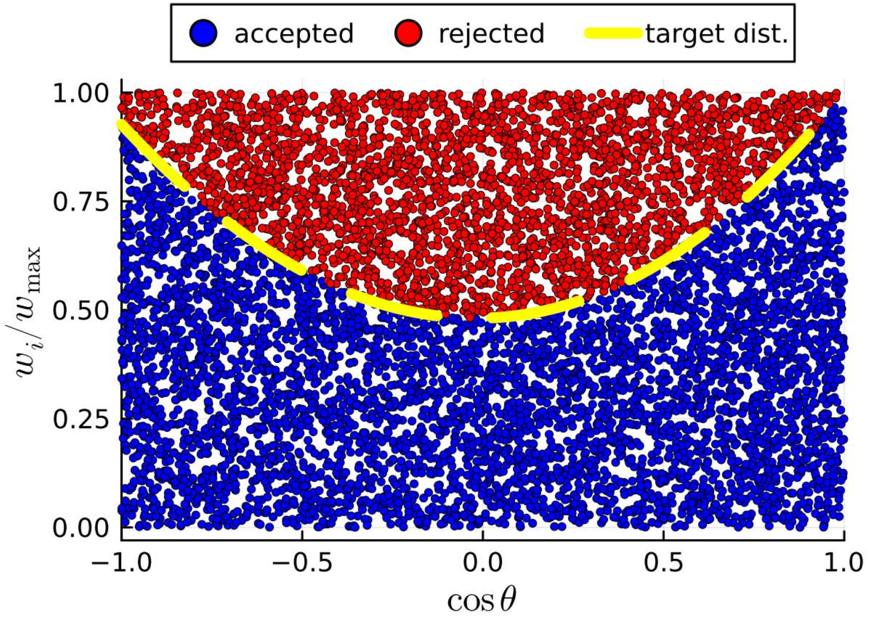
- Using a proposal $\tilde{w}_i = \frac{w_i}{g(x_i)}$

$$w(x) \approx c g(x)$$



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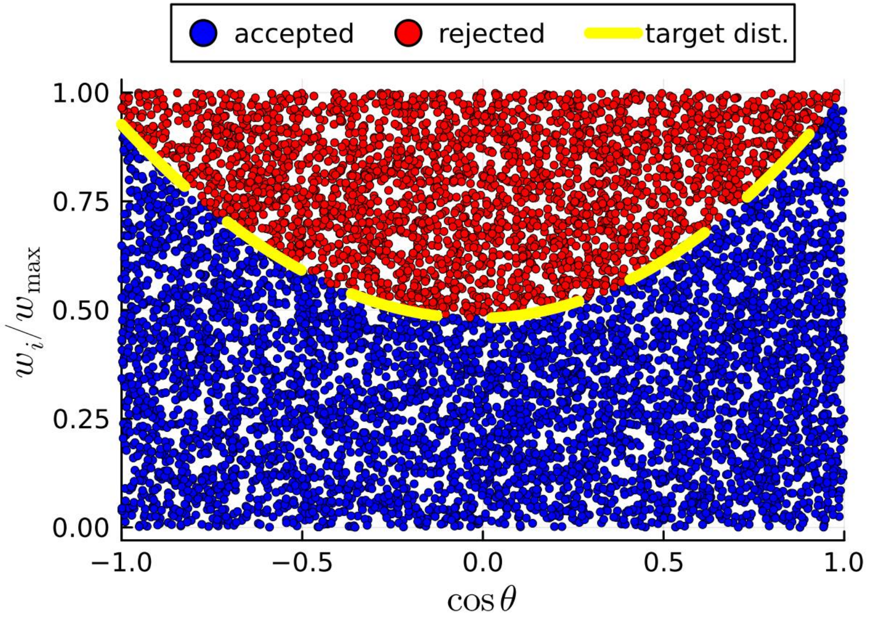
$$w(x) \approx c g(x) \Leftrightarrow \frac{w(x)}{g(x)} \approx c$$



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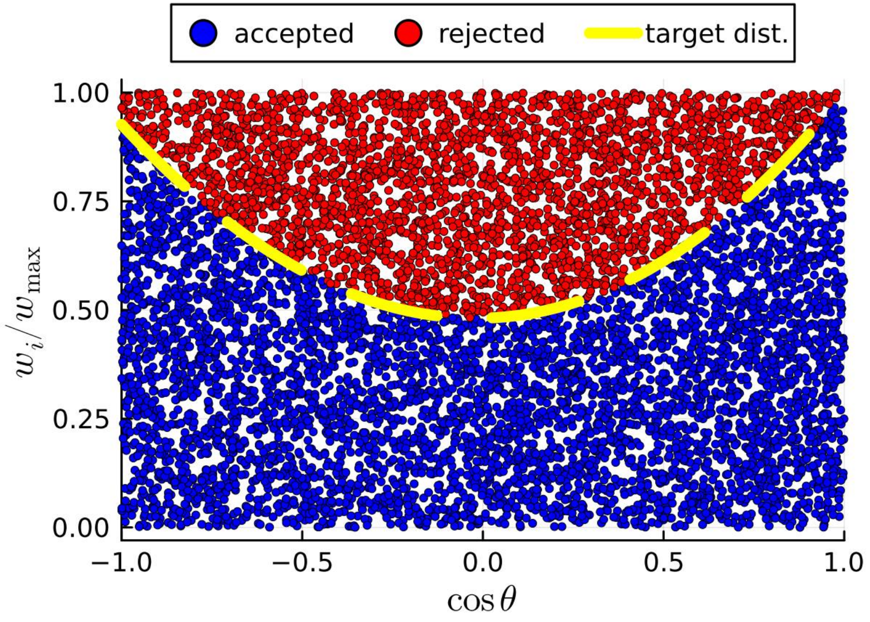
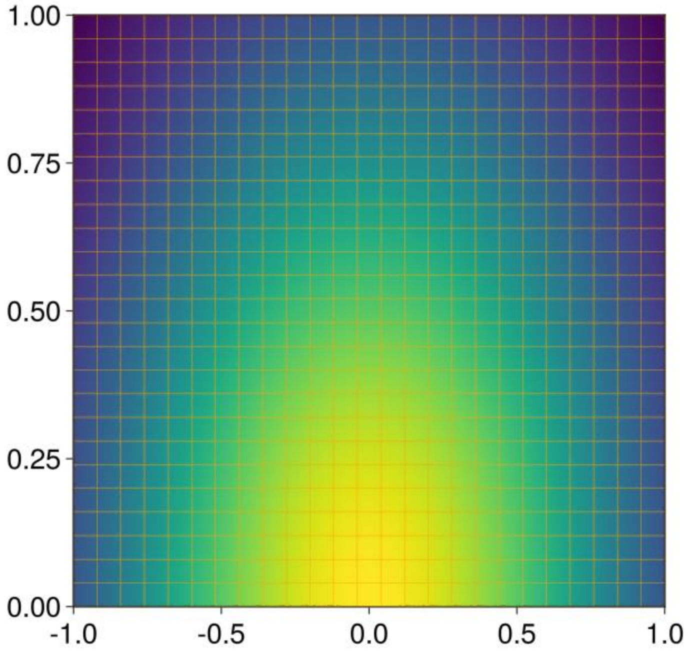
- Using a proposal $\tilde{w}_i = \frac{w_i}{g(x_i)}$

$$w(x) \approx cg(x) \Leftrightarrow \frac{w(x)}{g(x)} \approx c \Leftrightarrow \epsilon \approx 1$$



Importance Sampling

The classical approach - VEGAS



Adapting a grid by minimizing the variance in each bin

Importance Sampling

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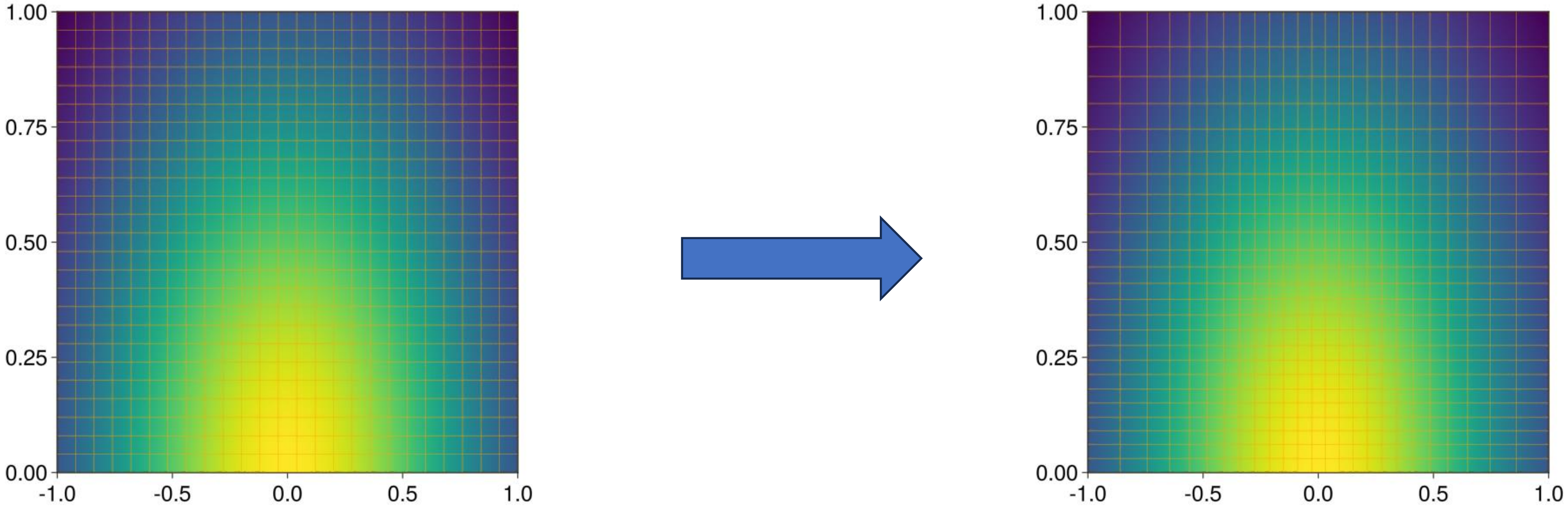
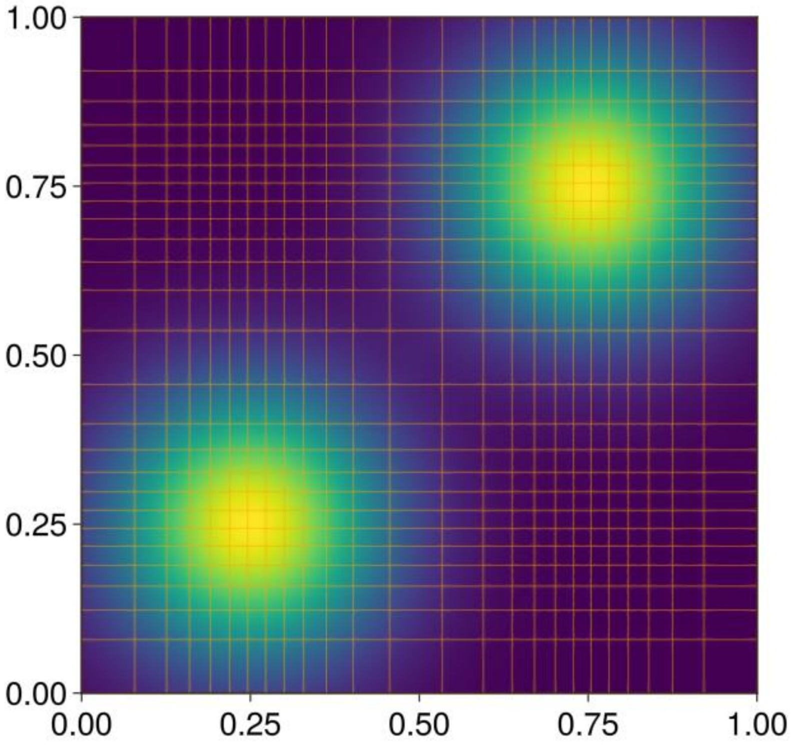


Adapting a grid by minimizing the variance in each bin

Importance Sampling

The problem with VEGAS

Adaption of ghost peaks for non coordinate aligned targets



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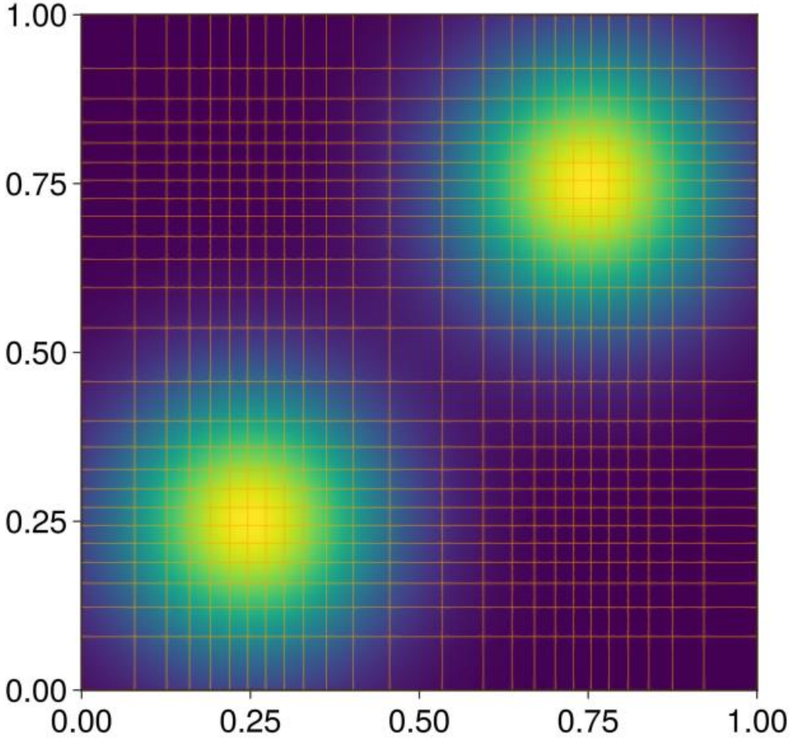
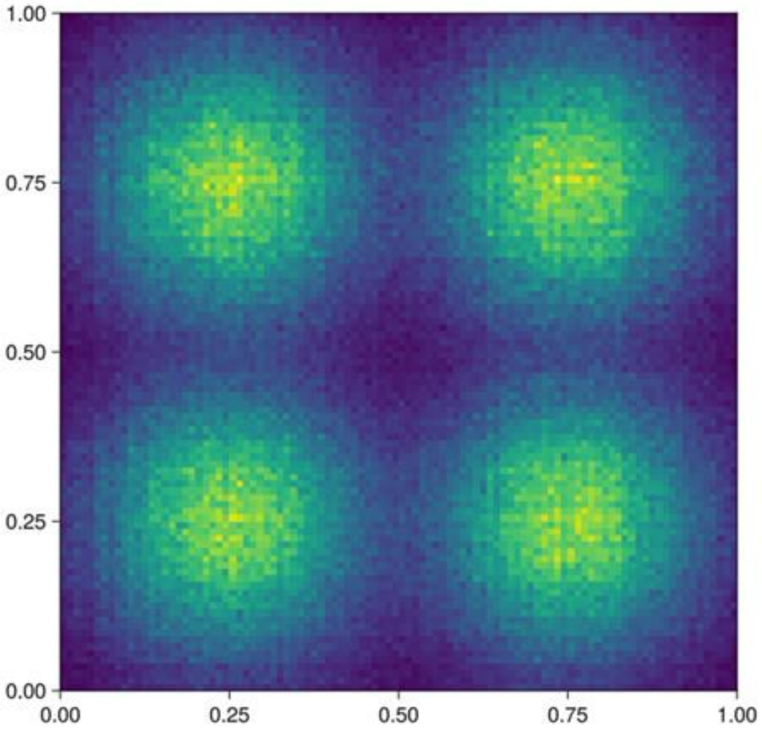
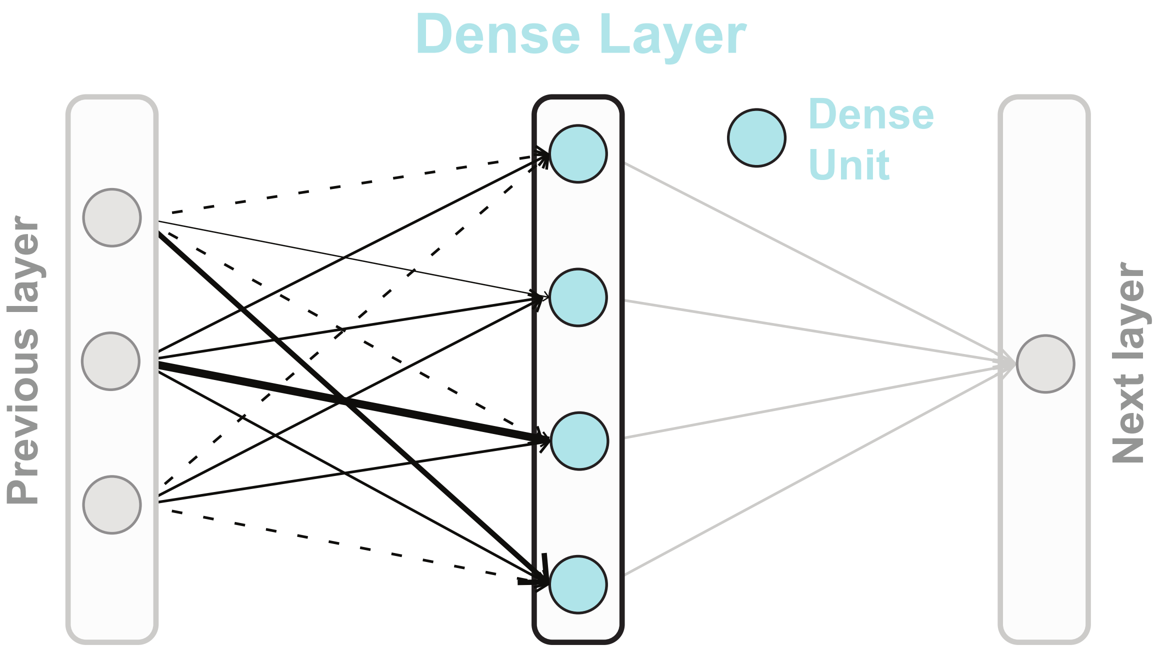




Recap: Neural Networks




```
y = σ.(W * x .+ bias)
```

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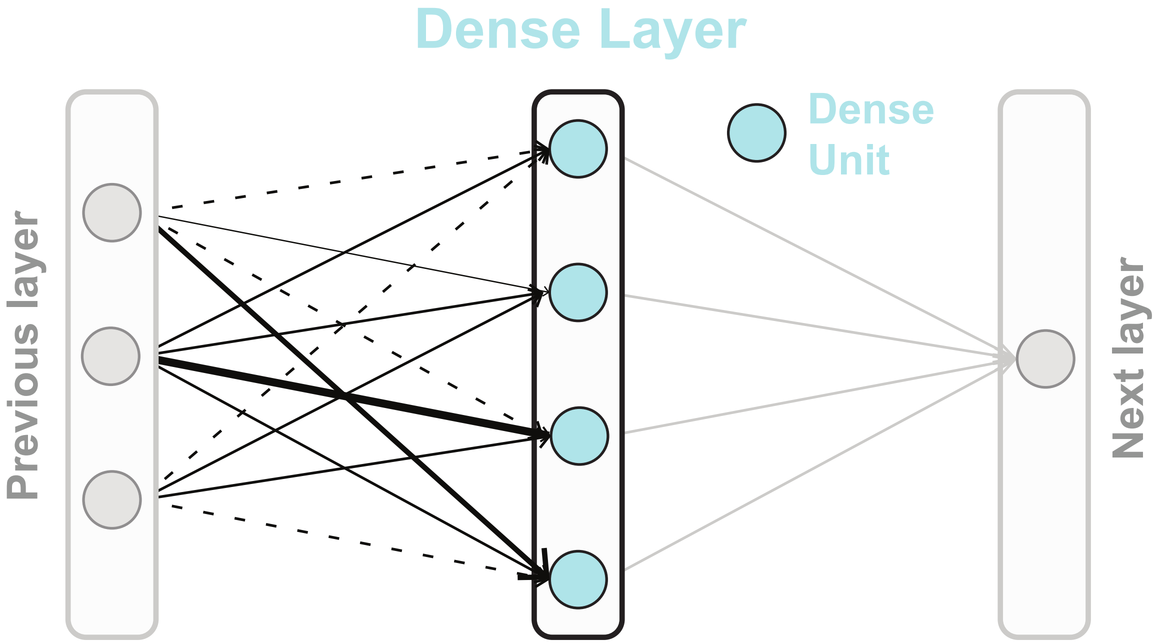


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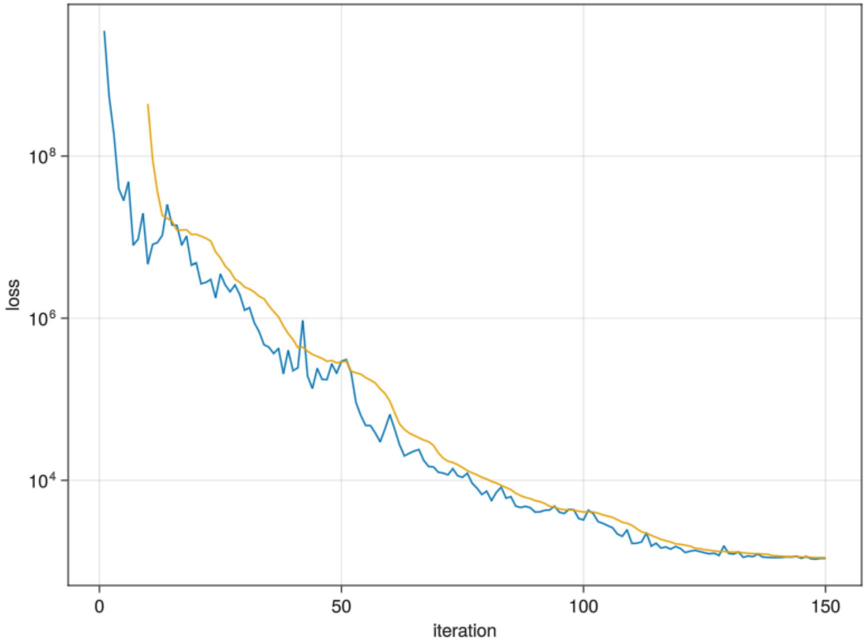
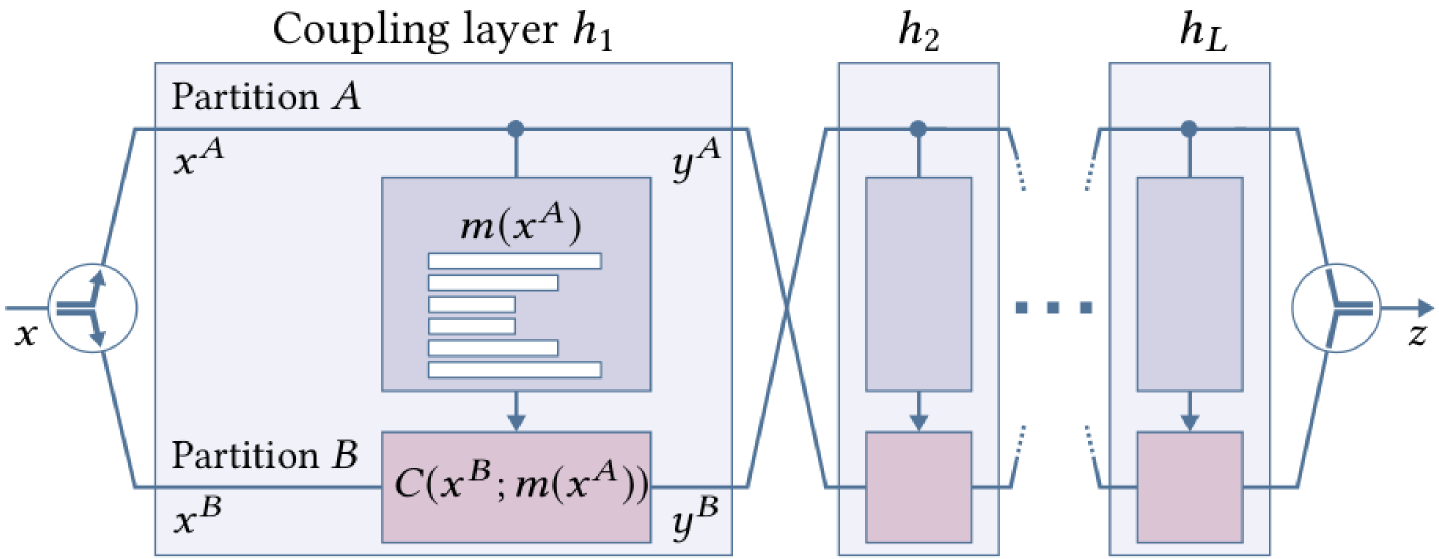


Change network parameters to reduce the loss

Importance sampling

Enhancing efficiency through neural networks

Neural Importance sampling



Transform a part of the input data in each layer

[T. Müller et al., ACM Transactions on Graphics (ToG) 38.5 (2019)]

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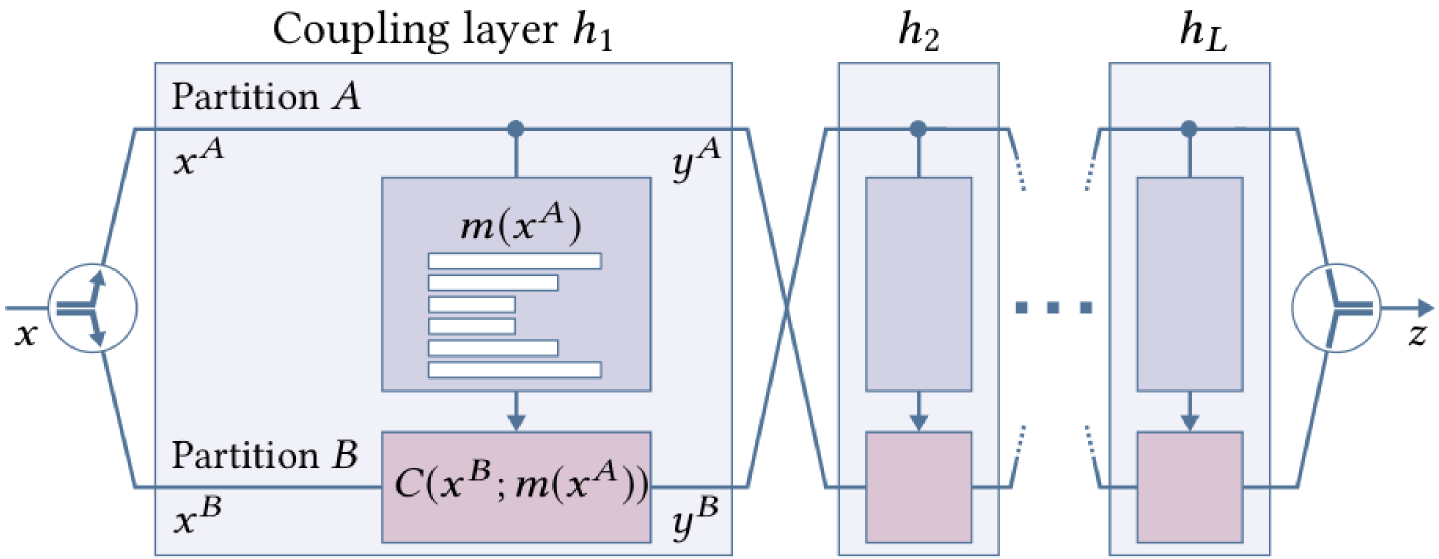

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SciPost | SciPost Phys. 8, 069 (2020)

Exploring phase space with Neural Importance Sampling

Enrico Bothmann, Timo Janßen, Max Knobbe, Tobias Schmale and Steffen Schumann

Flux.jl

Julia meets AI

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Just a few lines of code to train your first model

Flux.jl

Julia meets AI

Just a few lines of code to train your first model

```julia
dim = 2
bins = 10
cl1 = CouplingLayer(dim, 1, bins)
cl2 = CouplingLayer(dim, 1, bins)
ml = MaskLayer([false, true])
model = Flux.f32(Chain(cl1, ml, cl2) |> gpu)
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Julia meets AI

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```

```
opt_state = Flux.setup(Adam(0.001), model)
for epoch in 1:1000
    data = CUDA.rand(Float32, dim, 1024)
    val, grads = Flux.withgradient(m -> loss(m, f, data), model)
    Flux.update!(opt_state, model, grads[1])
end
```

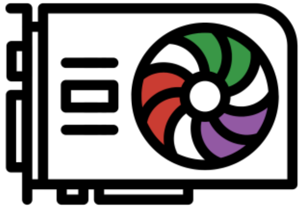
Parallelization

Getting started without writing kernels thanks to broadcasting

- Single calculation on CPU:

```
dσpT(k, p, p1, p2, p3)
```

QEDbase.SFourMomentum



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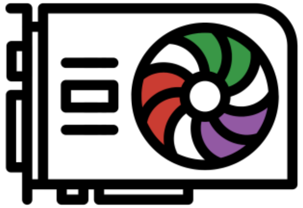

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gk, gp, gp1, gp2, gp3 = generat_momenta(10^5) .|> gpu
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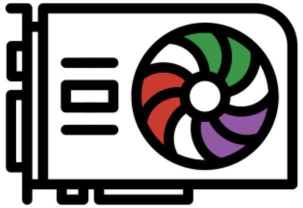

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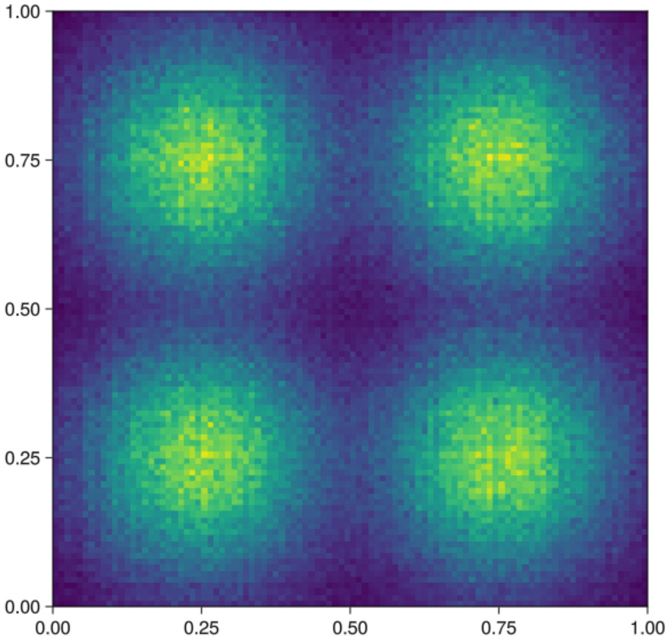
gk, gp, gp1, gp2, gp3 = generat_momenta(10^5) .|> gpu
```

```
dσpT.(gk, gp, gp1, gp2, gp3)
```

Results

Sampling two gaussians in 5d

Work in progress!



Proposal from VEGAS

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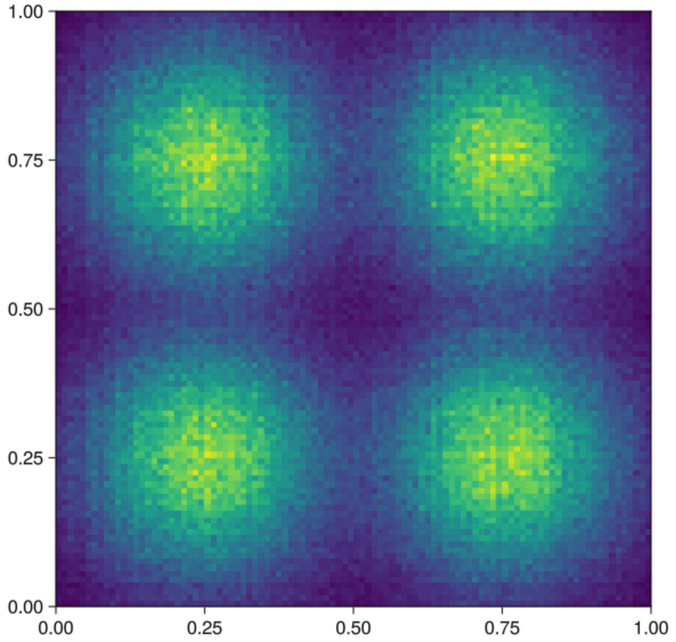

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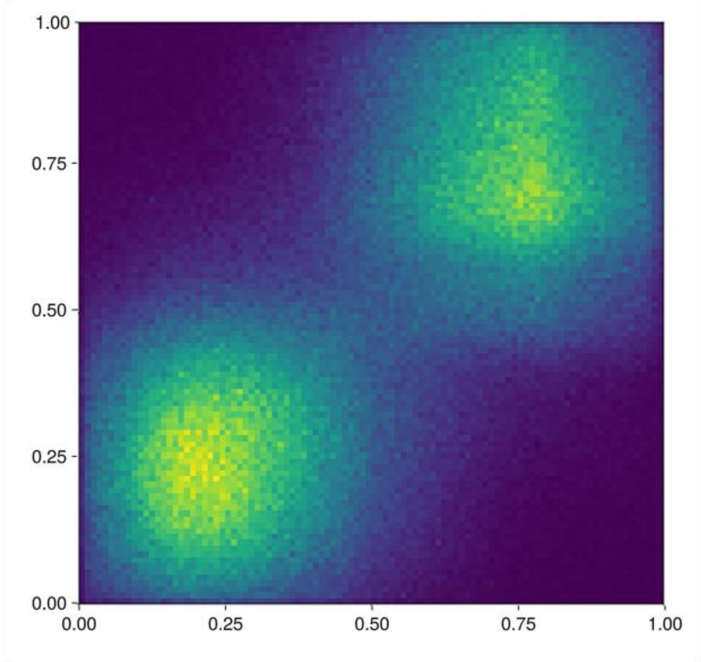
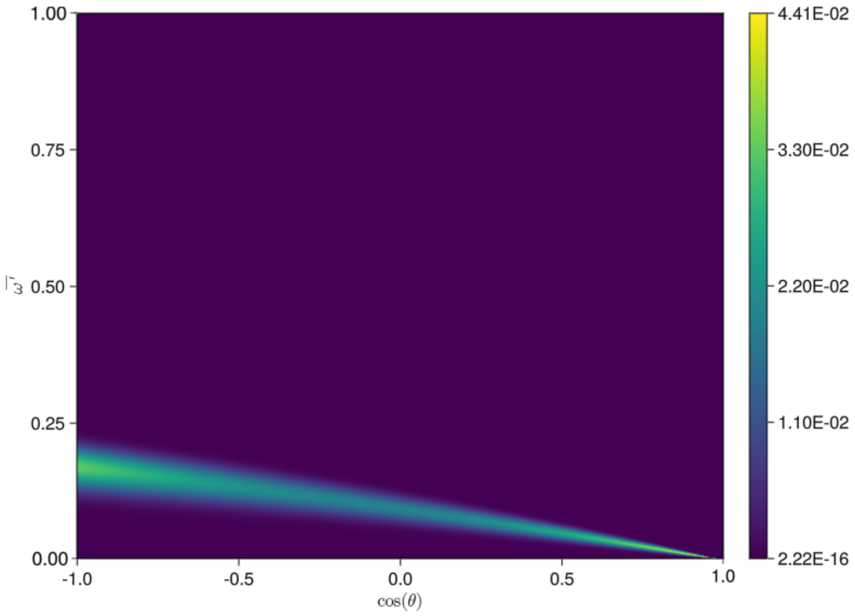


Proposal from NIS

Results

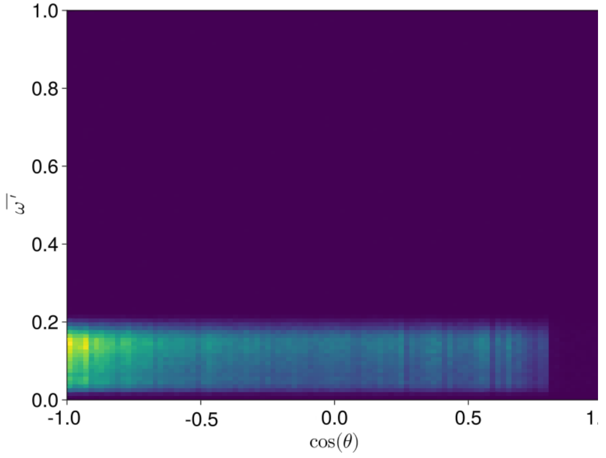
Sampling the strong-field Compton process

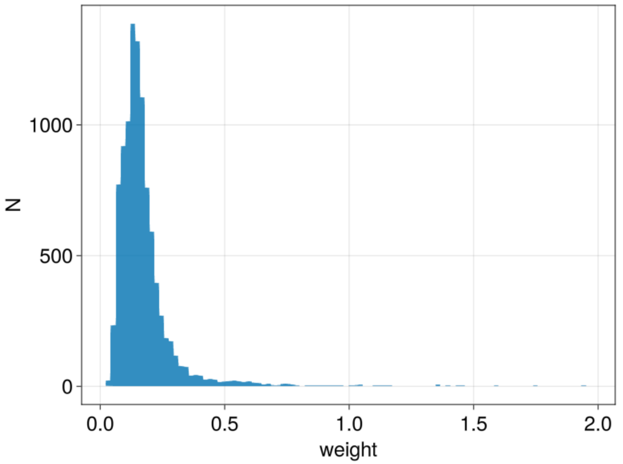
Work in progress!



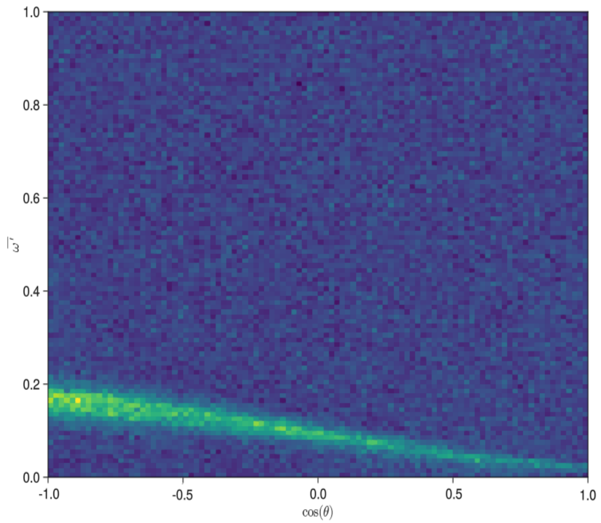
Ground truth

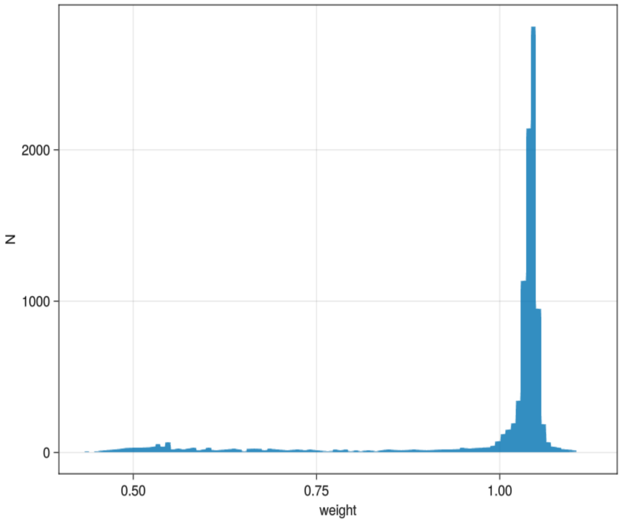
VEGAS:





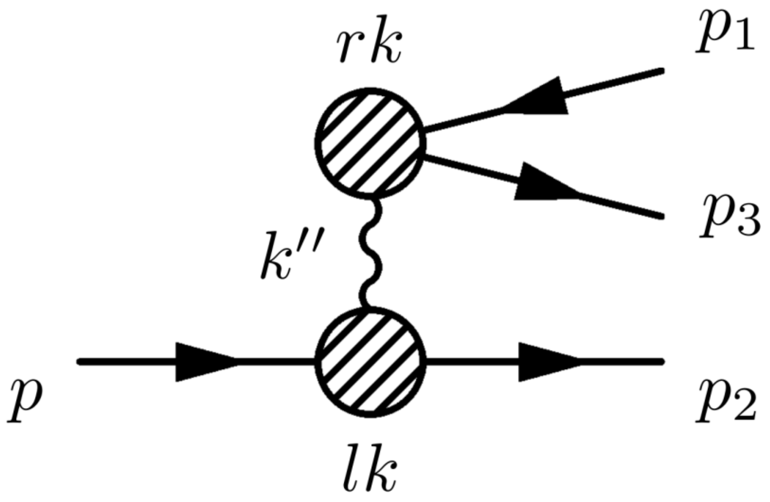
NIS:





Outlook

- network tuning
- application to the strong-field trident process (5d)



Acknowledgements

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- Simeon Ehrig
- Anton Reinhard

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