Jet Reconstruction with Julia

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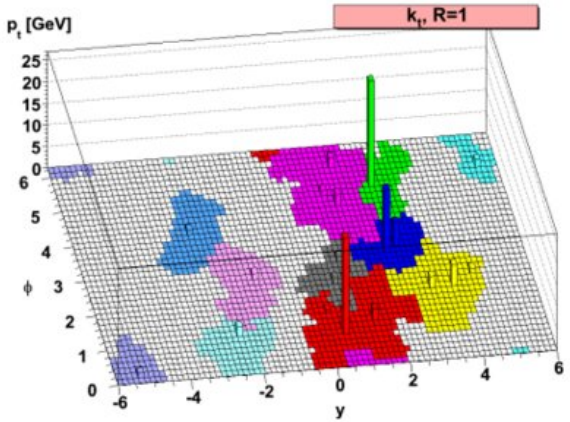
Jet Reconstruction

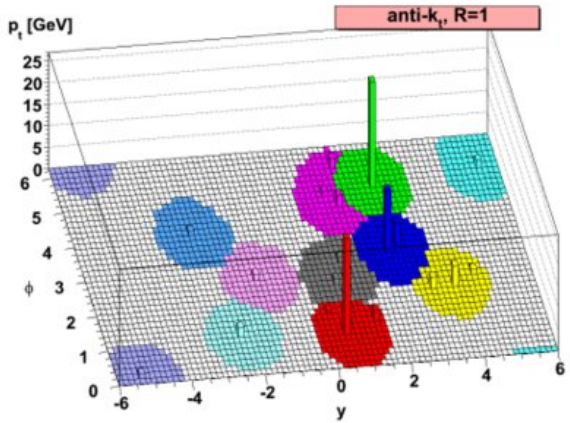
- Cluster together measurement points of the same origin
- Algorithm defines the jets
- Iterative process involving computing distances

$$d_{ij} = \min(k_{ti}^{2p}, k_{tj}^{2p}) \frac{\Delta_{ij}^2}{R^2} ,$$

$$d_{iB} = k_{ti}^{2p} ,$$

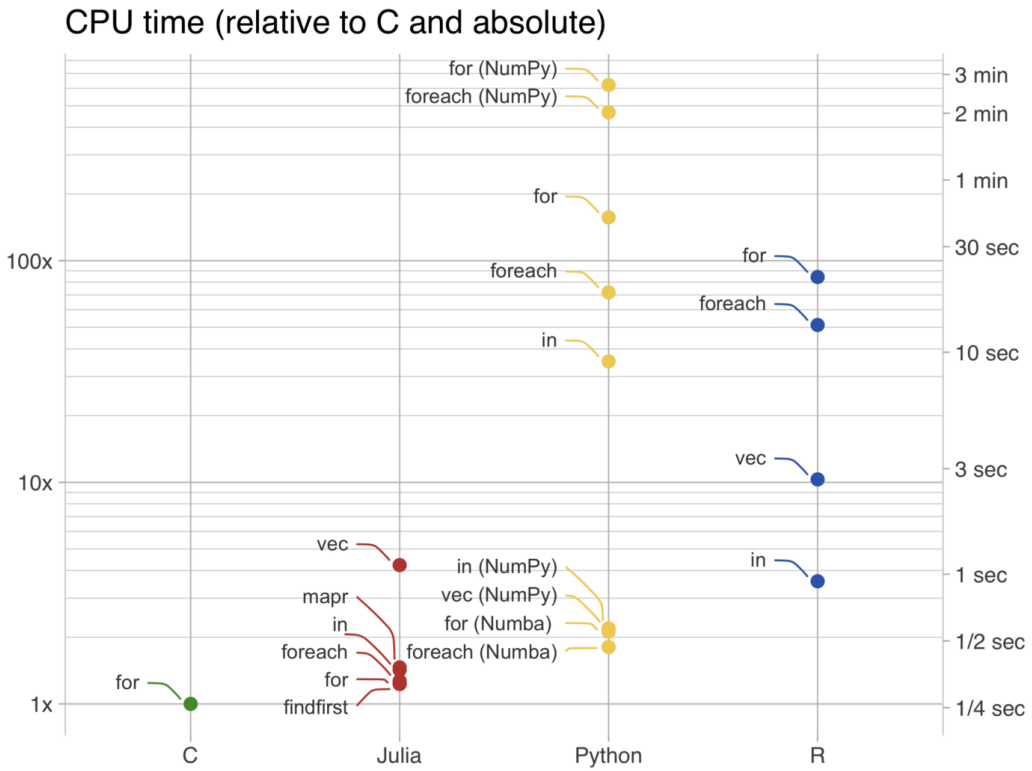
$$\Delta_{ij}^2 = (y_i - y_j)^2 + (\phi_i - \phi_j)^2$$





Why Julia (Speed)

- Python & C++ → Julia?
- Simple and efficient, way faster than Python
- Fast by design, not because of packages
- JIT-compiled
- Can interact with C, FORTRAN & Python



(towardsdatascience.com/r-vs-python-vs-julia-90456a2bcbab)

Why Julia (Convenience)

```julia
using Plots

# JIT-compiled for c::ComplexF64
function mandelbrot(c; maxiter=100)
    z = c
    for n in 1:maxiter
        if abs(z) > 2
            return n-1
        end
        z = z^2 + c
    end
    maxiter
end

C = hcat([[x+y*im for x in -2:0.01:2]
    for y in 2:-0.01:-2]...)' # complex matrix

# broadcasting over C, we get a matrix of integer type
M = -mandelbrot.(C)

heatmap(M) # plot
```

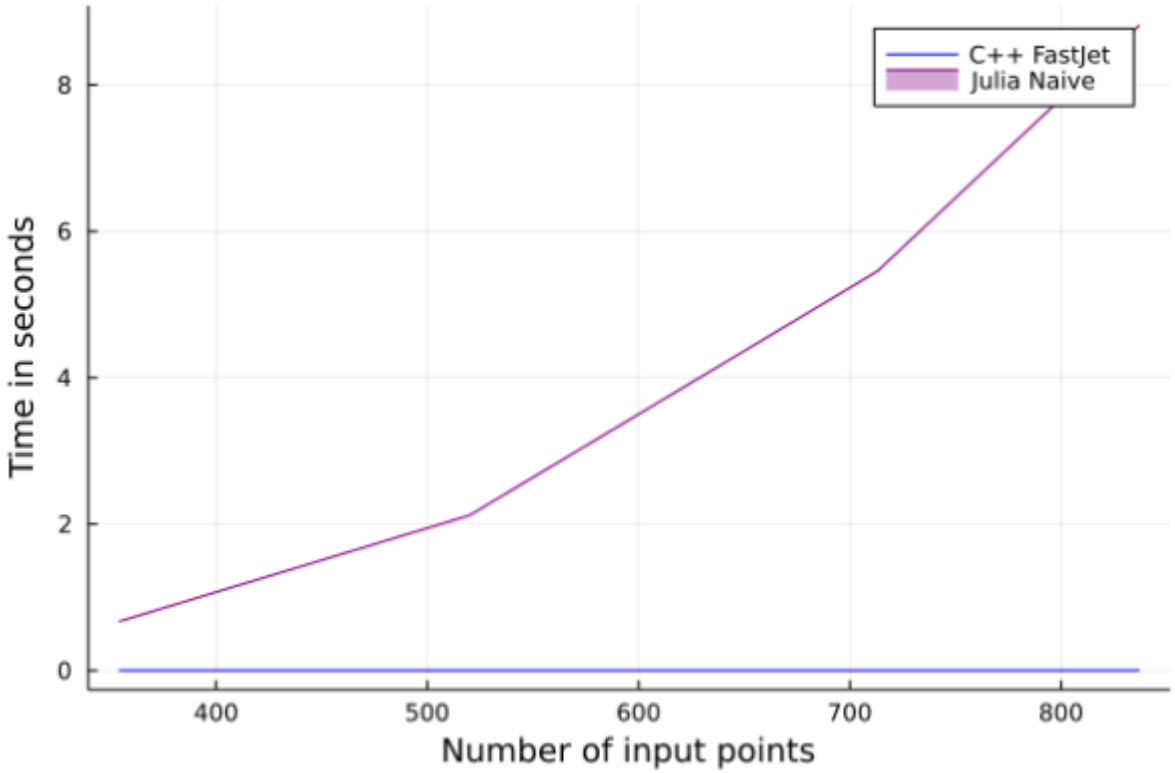
```python
import numpy as np
import matplotlib as mpl
import matplotlib.pyplot as plt

def _mandelbrot(c, maxiter=100):
    z = c
    for n in range(maxiter):
        if abs(z) > 2:
            return n-1
        z = z**2 + c
    return maxiter

C = np.array([[complex(x,y) for x in np.arange(-2, 2, 0.01)]
    for y in np.arange(2, -2, -0.01)])

mandelbrot = np.vectorize(_mandelbrot)
M = -mandelbrot(C)

fig, ax = plt.subplots()
im = ax.imshow(M)
plt.show()
```

Naive Method

- Naive implementation takes ~42 lines of code
- Not a very sophisticated approach

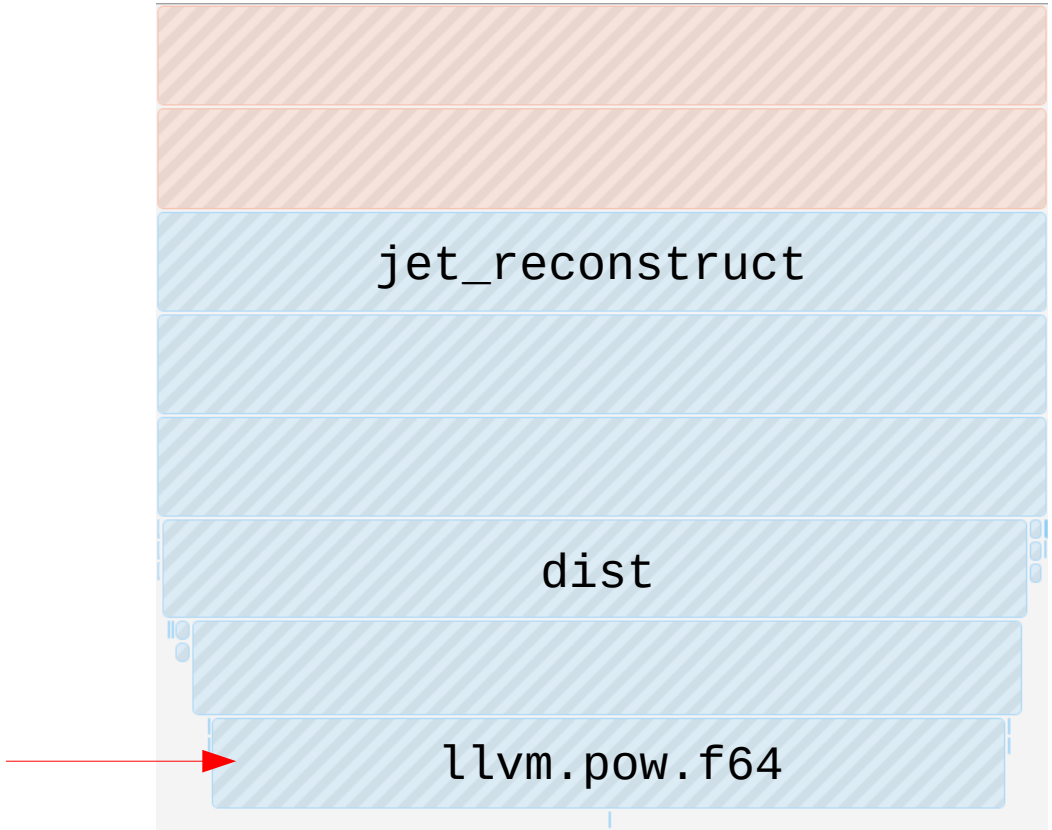
```julia
function sequential_jet_reconstruct_alt(_objects::AbstractArray{T}; p=-1, R=1, recombine=((i,j)->i+j)) where T
    #global pt, eta, phi
    objects = copy(_objects)

    jets = T[] # result
    cyl = [[JetReconstruction.pt(obj), JetReconstruction.eta(obj), JetReconstruction.phi(obj)] for obj in objects] # cylindric
     CALCULATE THEM HERE OR LATER? Maybe switch to StaticVector

    # d_{ij}
    function dist(i, j)
        Δ = (cyl[i][2] - cyl[j][2])^2 + (cyl[i][3] - cyl[j][3])^2
        min(cyl[i][1]^(2p), cyl[i][1]^(2p))*Δ/(R^2)
    end

    # d_{iB}
    function dist(i)
        cyl[i][1]^(2p)
    end

    while !isempty(objects)
        mindist_idx::Vector{Int64} = Int64[1] # either [j, i] or [i] depending on the type of the minimal found distance
        mindist = Inf
        for i in 1:length(objects)
            d = dist(i)
            if d < mindist
                mindist = d
                mindist_idx = Int64[i]
            end
            for j in 1:(i-1)
                d = dist(i, j)
                if d < mindist
                    mindist = d
                    mindist_idx = Int64[j, i]
                end
            end
        end

        if length(mindist_idx) == 1 #if min is d_{iB}
            push!(jets, objects[mindist_idx[1]])
        else #if min is d_{ij}
            pseudojet = recombine(objects[mindist_idx[1]], objects[mindist_idx[2]])
            push!(objects, pseudojet)
            push!(cyl, [JetReconstruction.pt(pseudojet), JetReconstruction.eta(pseudojet), JetReconstruction.phi(pseudojet)])
        end
        deleteat!(objects, mindist_idx)
        deleteat!(cyl, mindist_idx)
    end

    jets#, tree
end
```

Naive Method



FastJet is a package written in C++ that is considered a standard

Profiling



Julia is extremely easy to profile and optimise because of such native tools

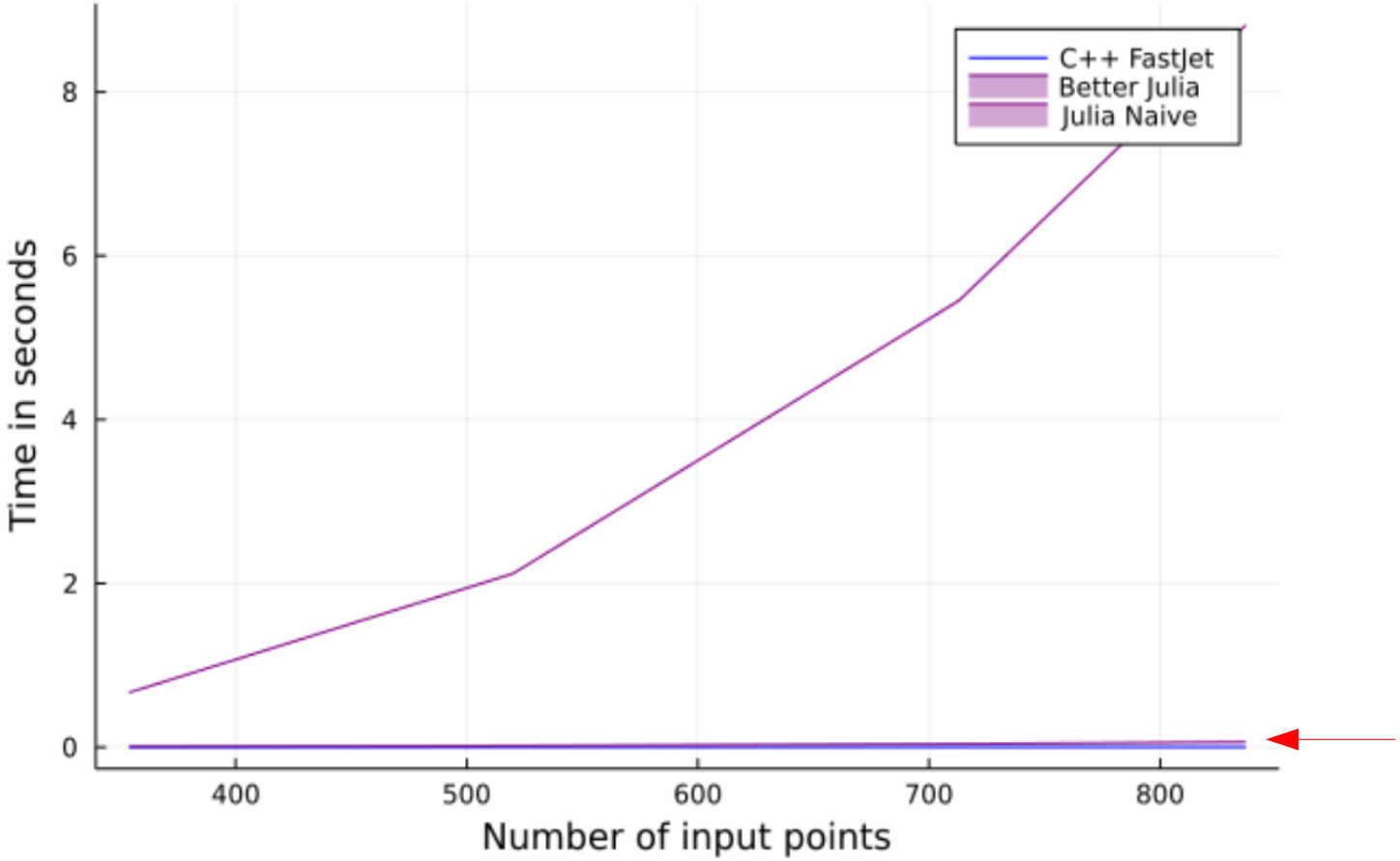
Changes

- Cache the distances
- Optimise the distance function to avoid floating point powers
- Clean the code up

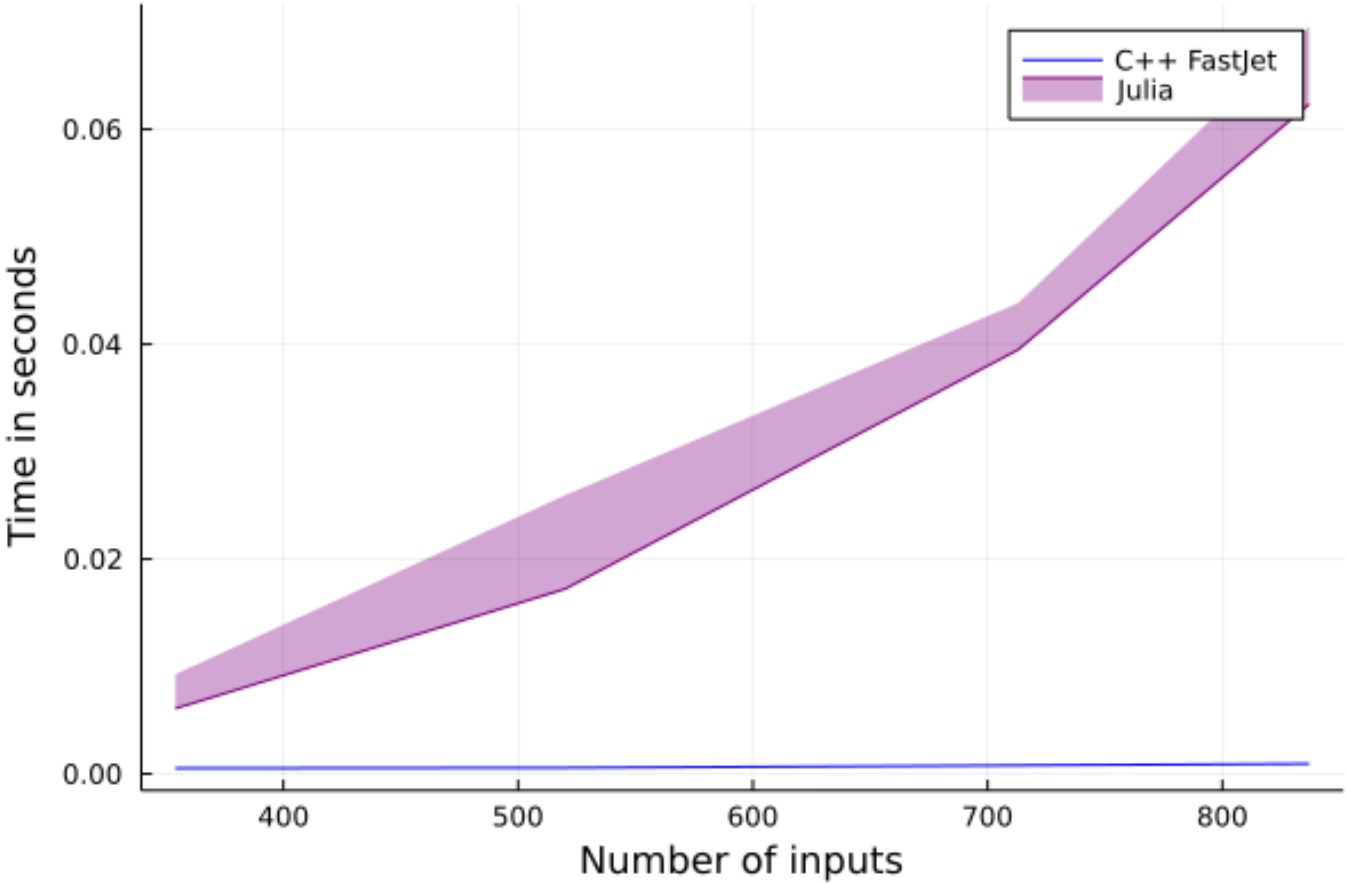
```julia
# d_{ij}
function dist(i, j)
    Δ = (cyl[i][2] - cyl[j][2])^2 + (cyl[i][3] - cyl[j][3])^2
    min(cyl[i][1]^(2p), cyl[i][1]^(2p))*Δ/(R^2)
end
```

```julia
# d_{ij} distance times R^2
function dist(i, j)
    deta = abs(_eta[i] - _eta[j])
    dphi = abs(_phi[i] - _phi[j])
    if dphi > 1π
        dphi = 2π - dphi
    end
    if deta > _R2 || dphi > _R2
        return Inf
    end
    Δ2 = muladd(deta, deta, dphi*dphi)
    if p < 0
        return @fastmath Δ2/max(_kt2[i]^ap, _kt2[j]^ap)
    end
    @fastmath Δ2*min(_kt2[i]^ap, _kt2[j]^ap)
end
```

Better Method

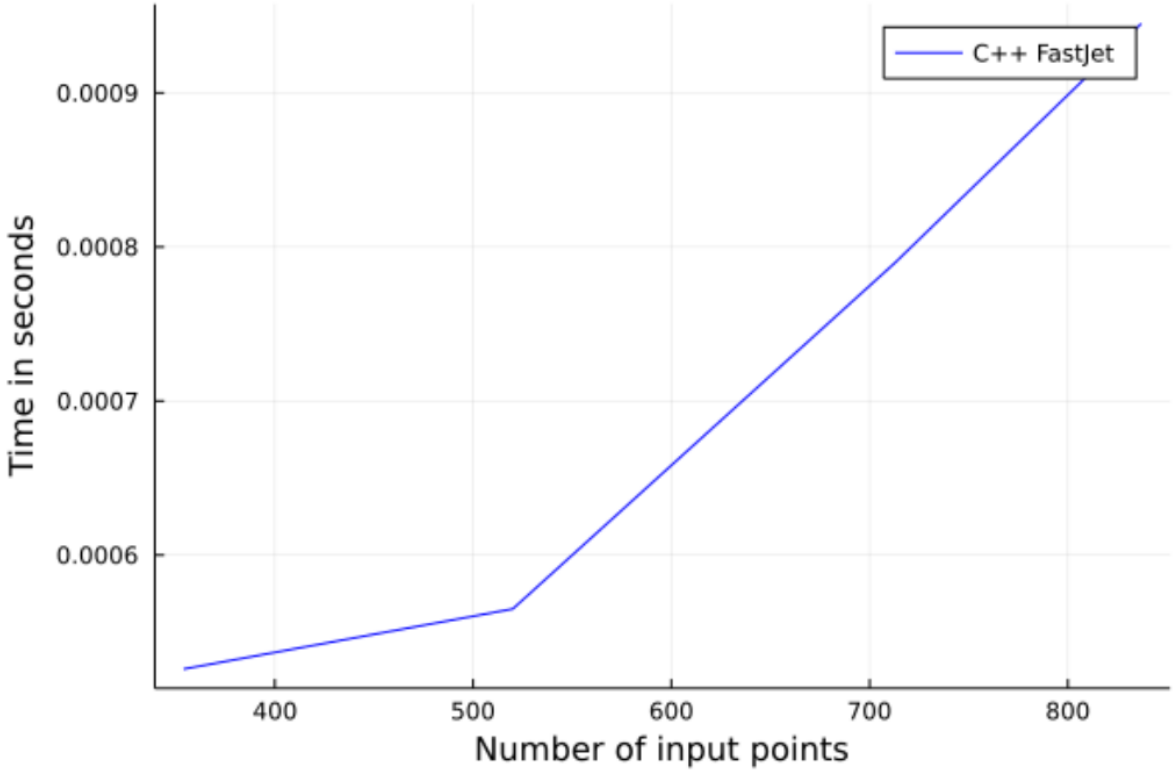


Better Method

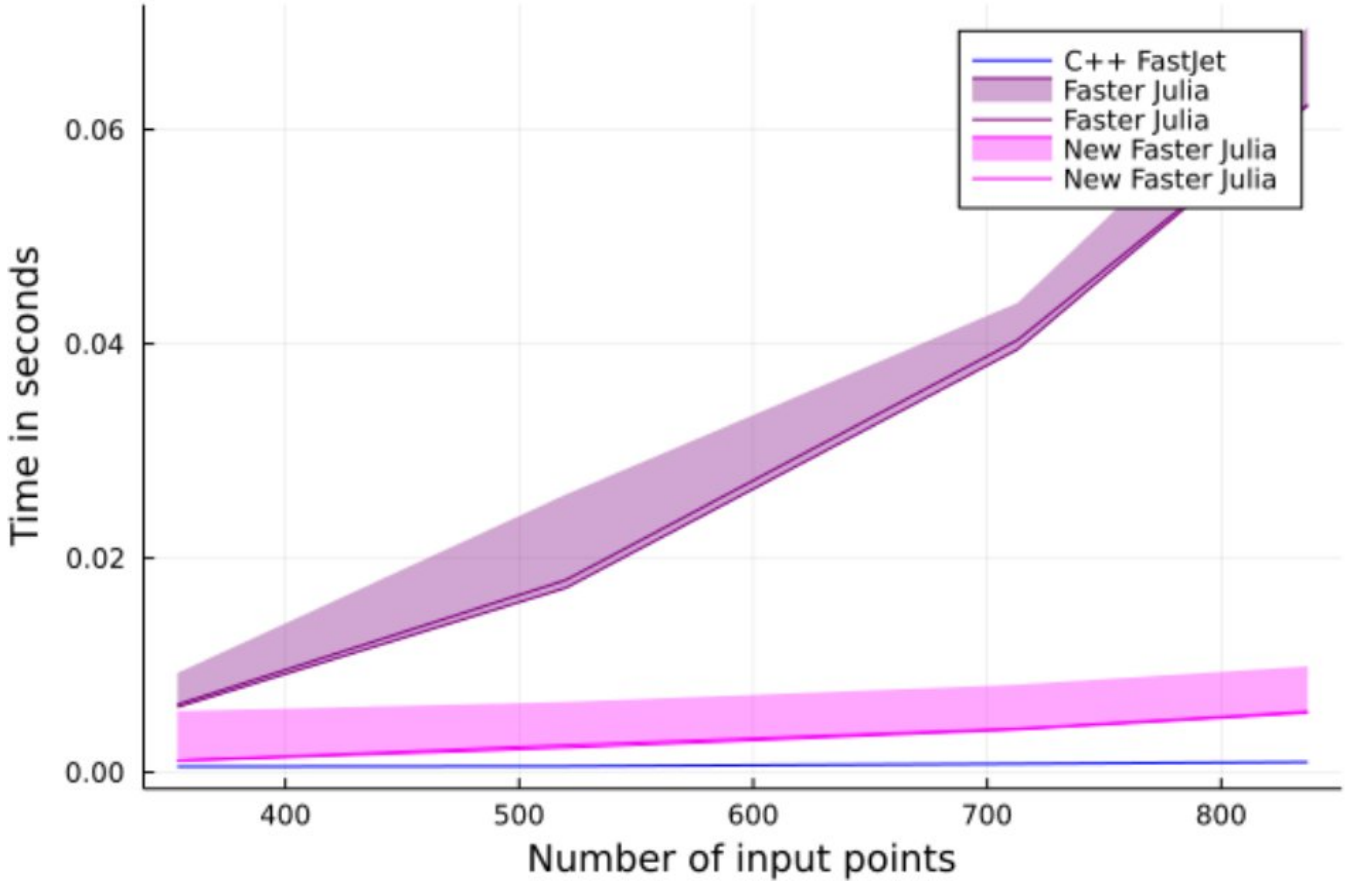


Next Steps

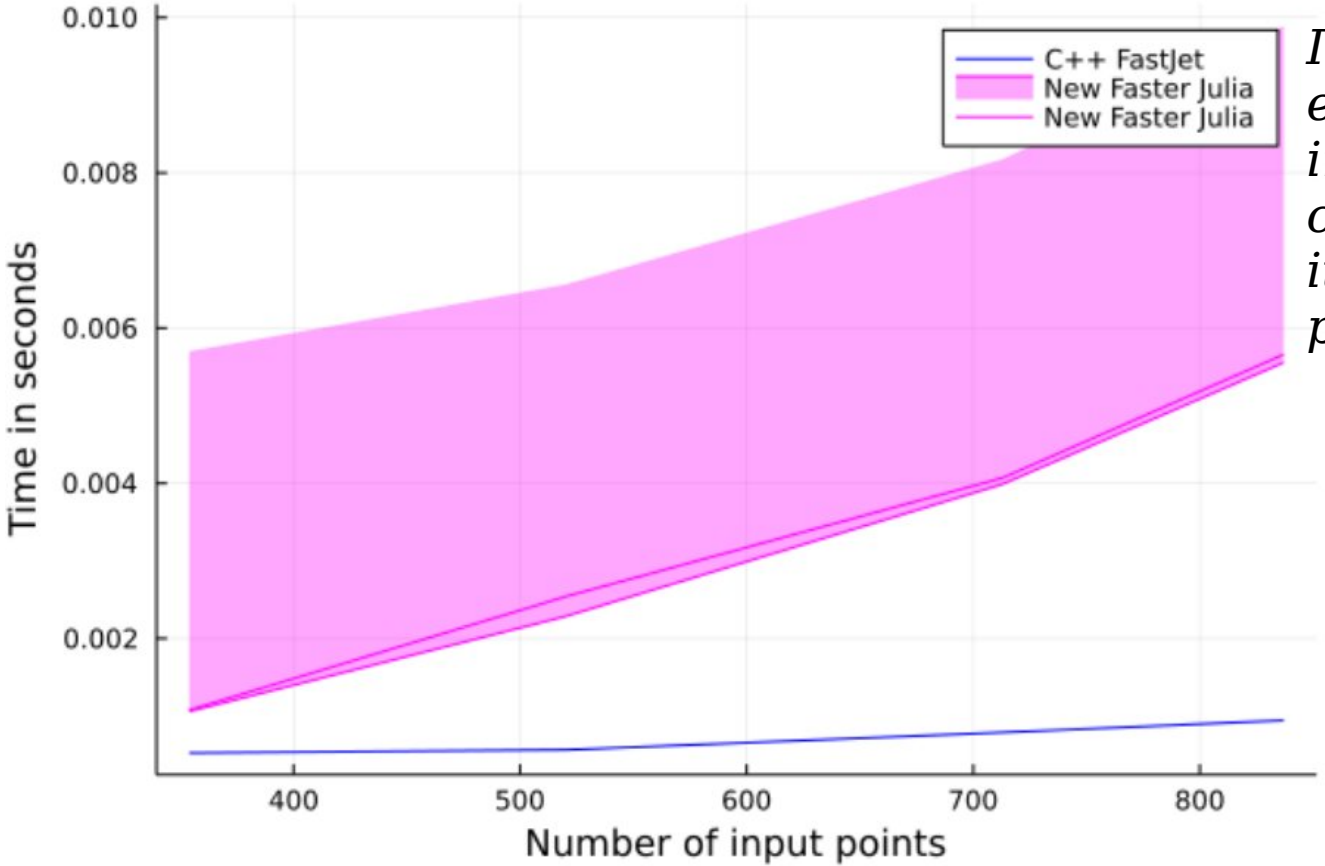
- Implement an exact copy of FastJet's optimised version of the algorithm and test if this sophisticated approach is better
- O(N log N) instead of O(N^3)



FastJet's Tricks

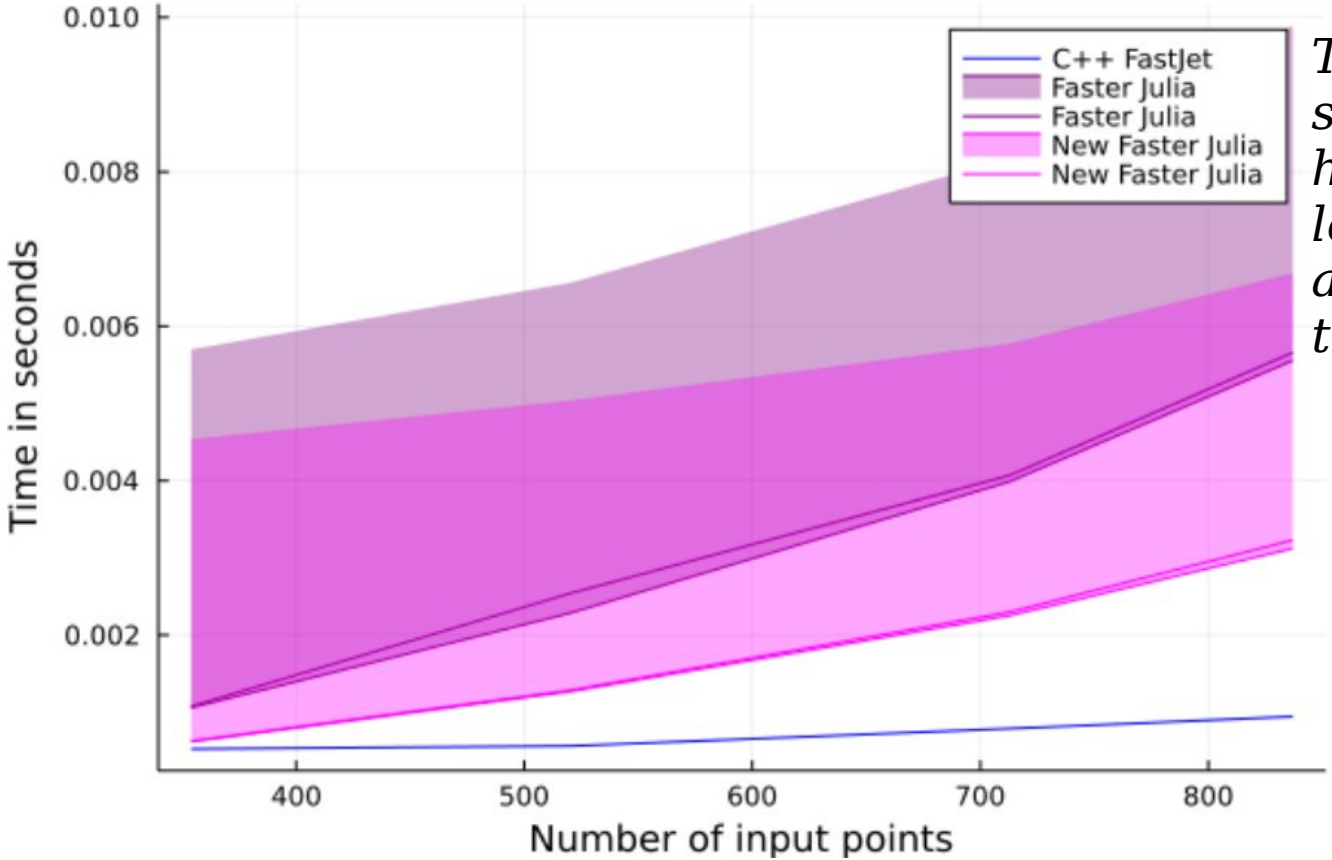


FastJet's Tricks



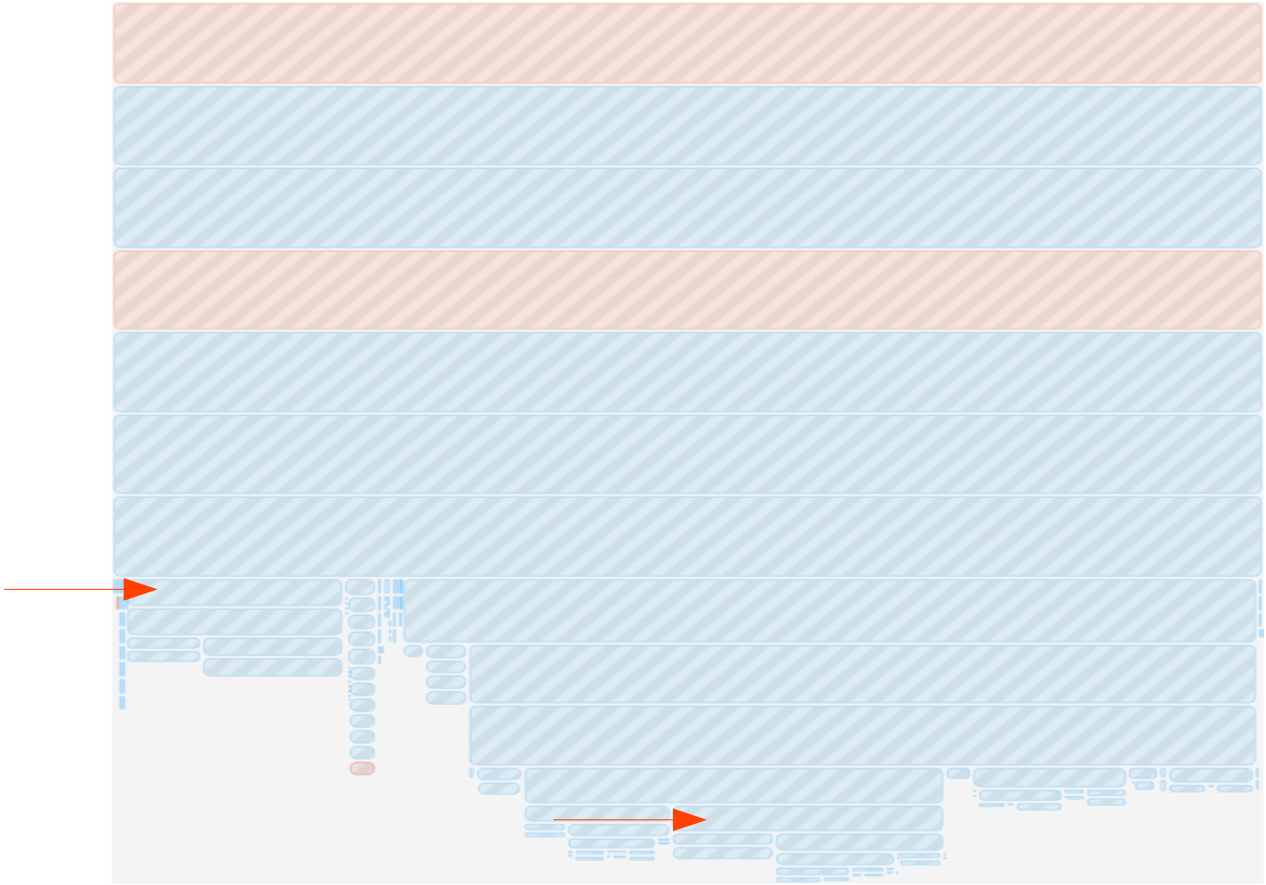
It took a lot of effort to dive into the FastJet code and make it work properly

FastJet's Tricks



This is another step that was hard to make (a lot of profiling and low level thinking)

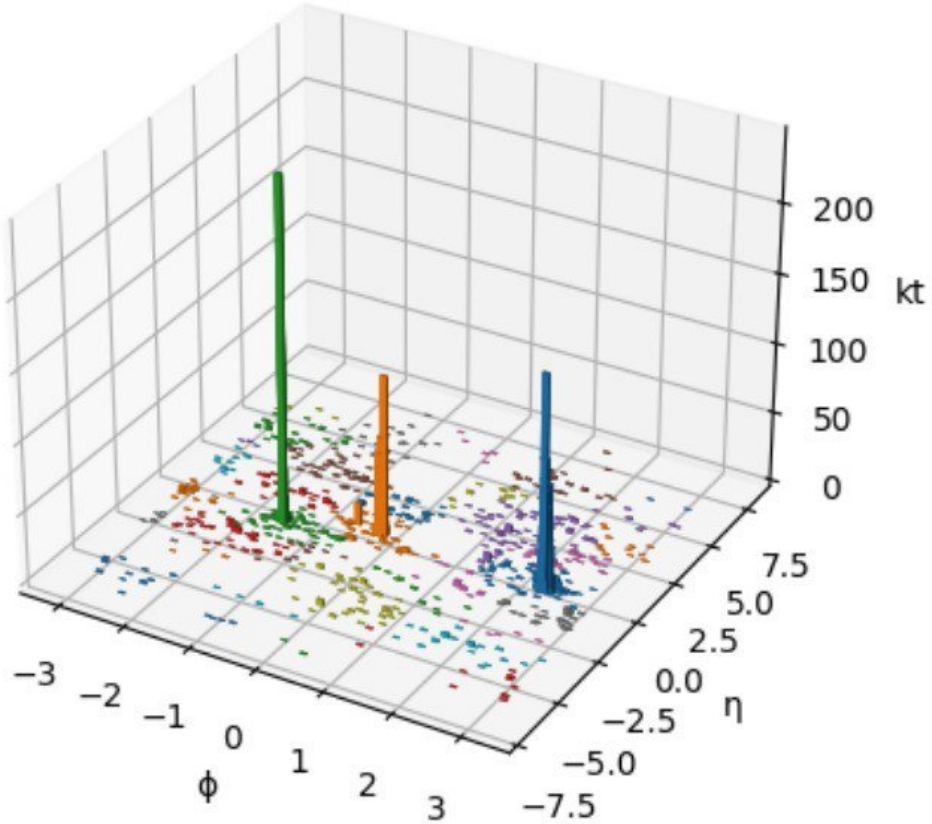
More Profiling



The longest bars are simply "for" loops that we cannot optimise.

Additional Features

- Possibility for other sequential recombination algorithms in Julia
- Plotting the results
- Comparison with FastJet (the C++ golden standard)
- Support for user-defined data types and extensions & GPU (because of multiple dispatch)



What Have I Learned?

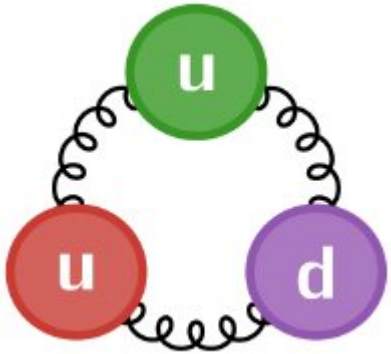
- A lot about high energy physics (tasks, software, algorithms)
- How to work with HEP data
- Automate tests for Julia repositories
- Use Julia's profiling tools

Summary

- Julia can be fast if you know what to do
- Julia can be a good alternative to Python
- Still a lot to explore in the usage of Julia in HEP yet
- Conclusion is yet to be made

JetReconstruction.jl

github.com/gojakuch/JetReconstruction.jl



github.com/JuliaHEP