ONLINE TRACKING IN PANDA

PANDA TRACKING WORKSHOP 2018

18.9.2018 | TOBIAS STOCKMANNS

Hough Transformation

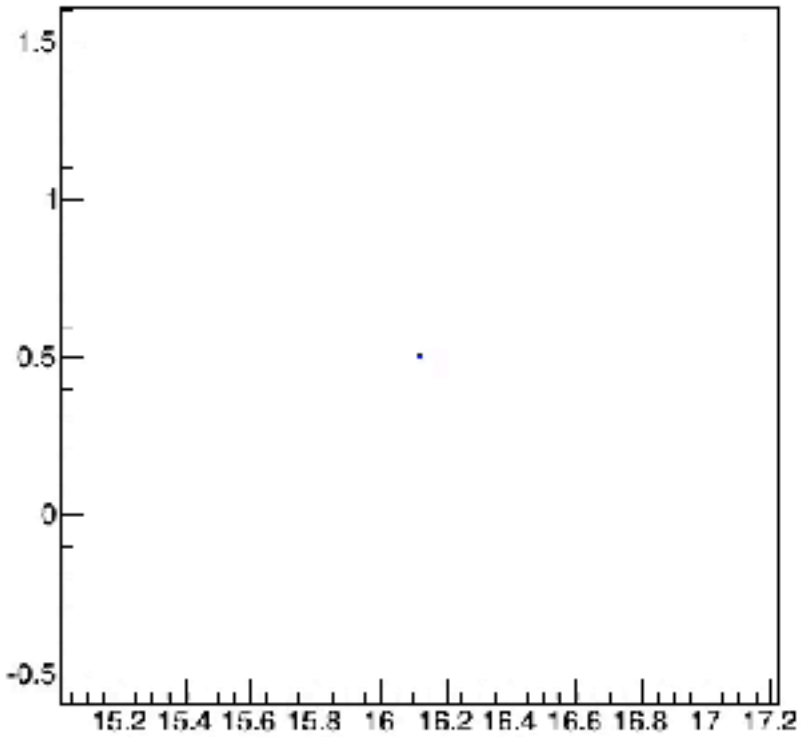
Hough Transform — Visualization Lines

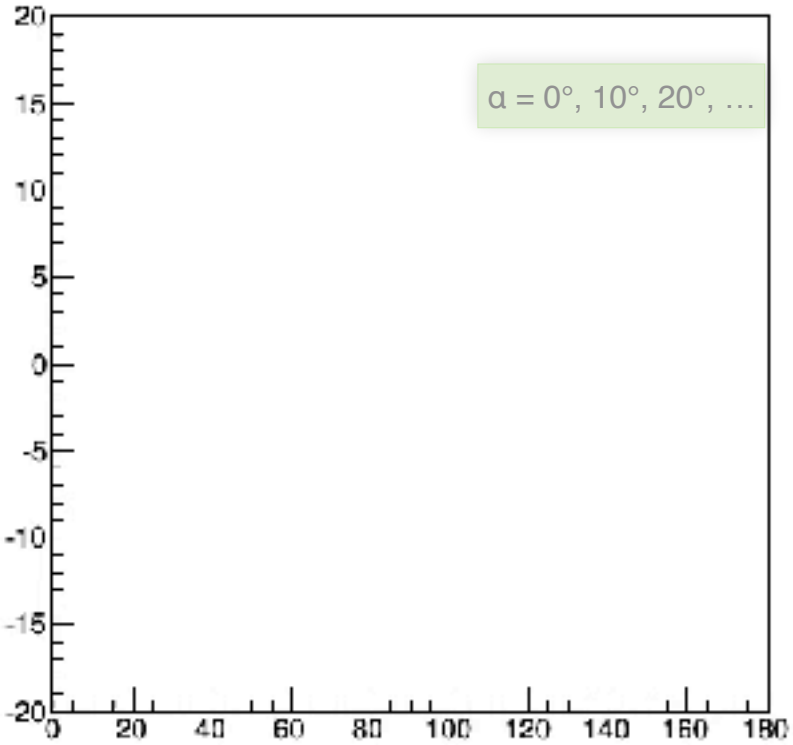
Create lines going through hit point (x,y)i

- **Line parameterized by rij = cos(αj) · xi + sin(αj) · yi**

Fill line parameters (α,r)ij into histogram

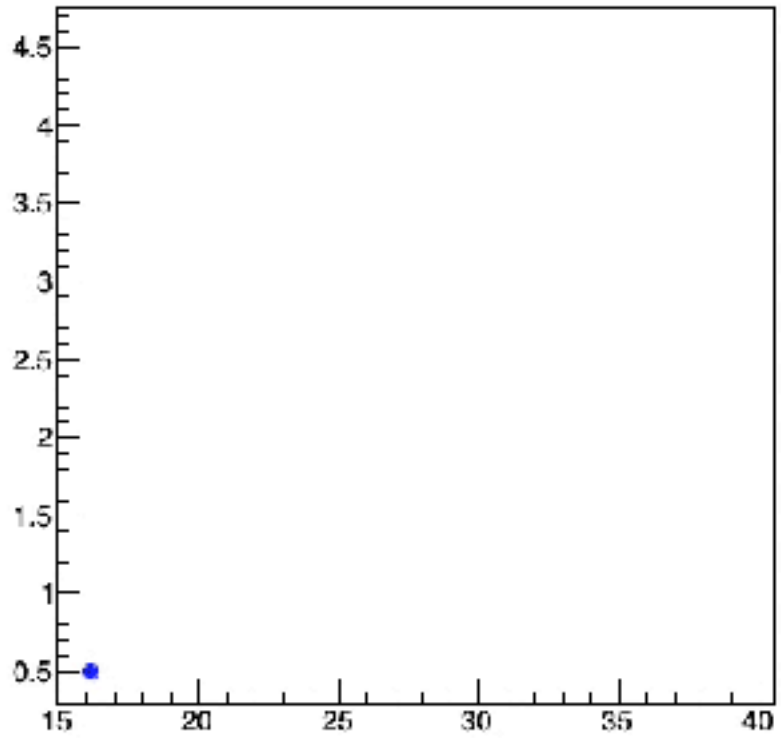
- **Rasterize for many αj ∈ [0°,180°)**

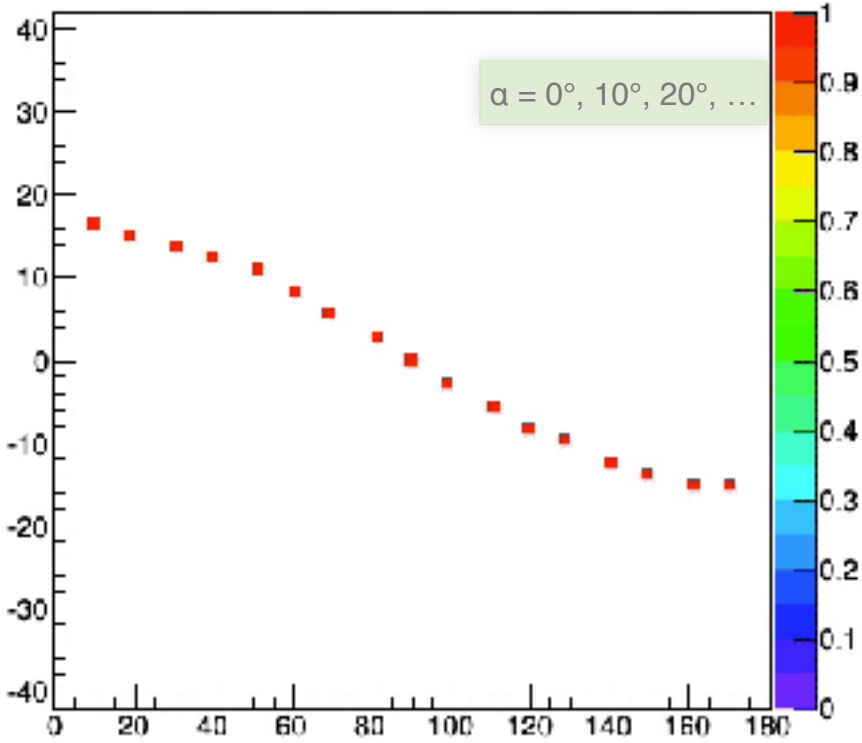




Hough Transform — Visualization Points

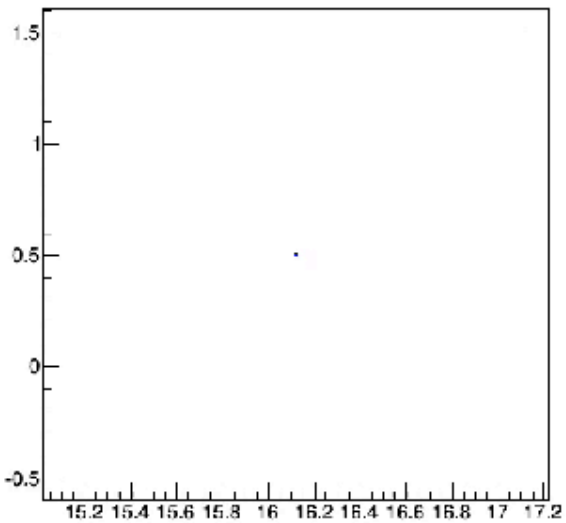
Create lines going through hit point $(x,y)_i$
Repeat for every hit point i

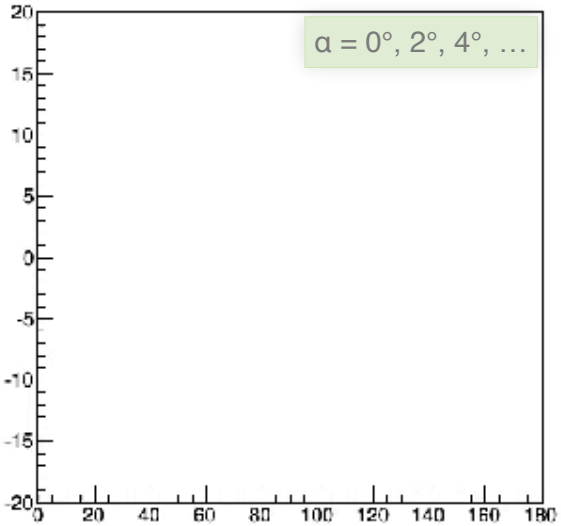




Hough Transform — Granularity

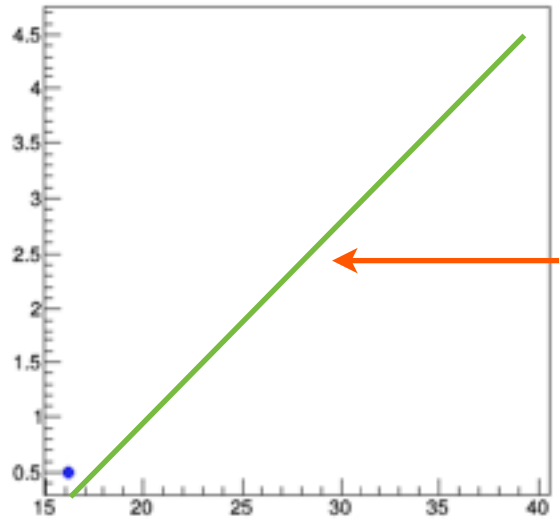
Choice of α granularity determines resolution

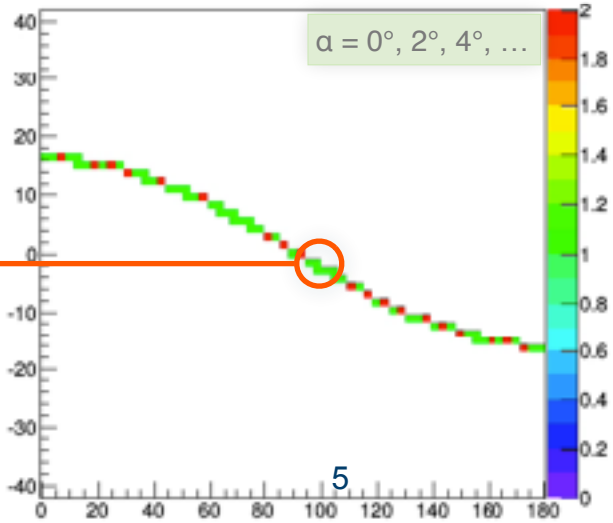




i: ~100 hits/event (STT)
j: every 0.2°

r_{ij}: 180 000





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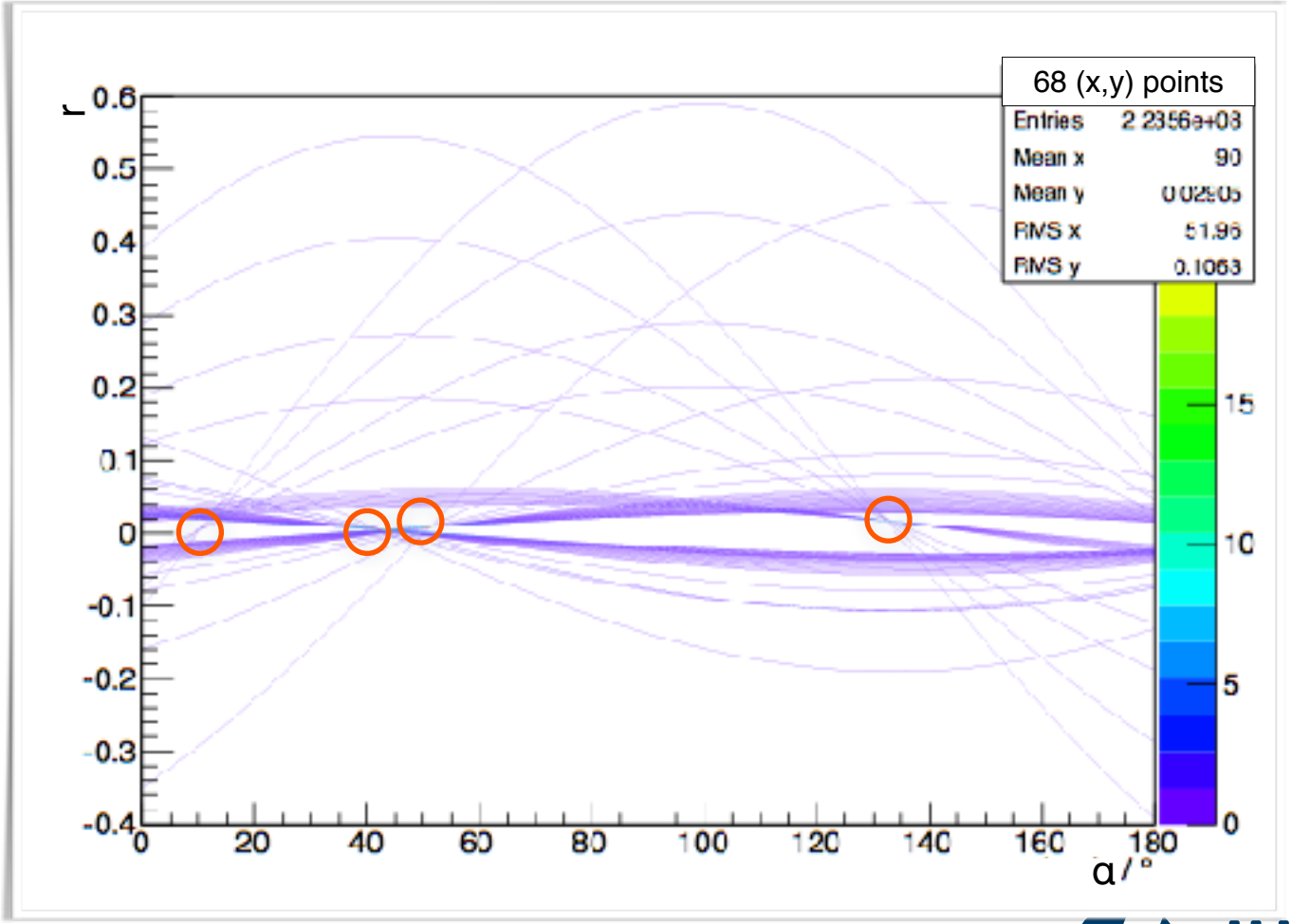
Algorithm: Hough Transform



Hough Transform — Remarks

Two Implementations

Thrust *(CUDA's STL)*

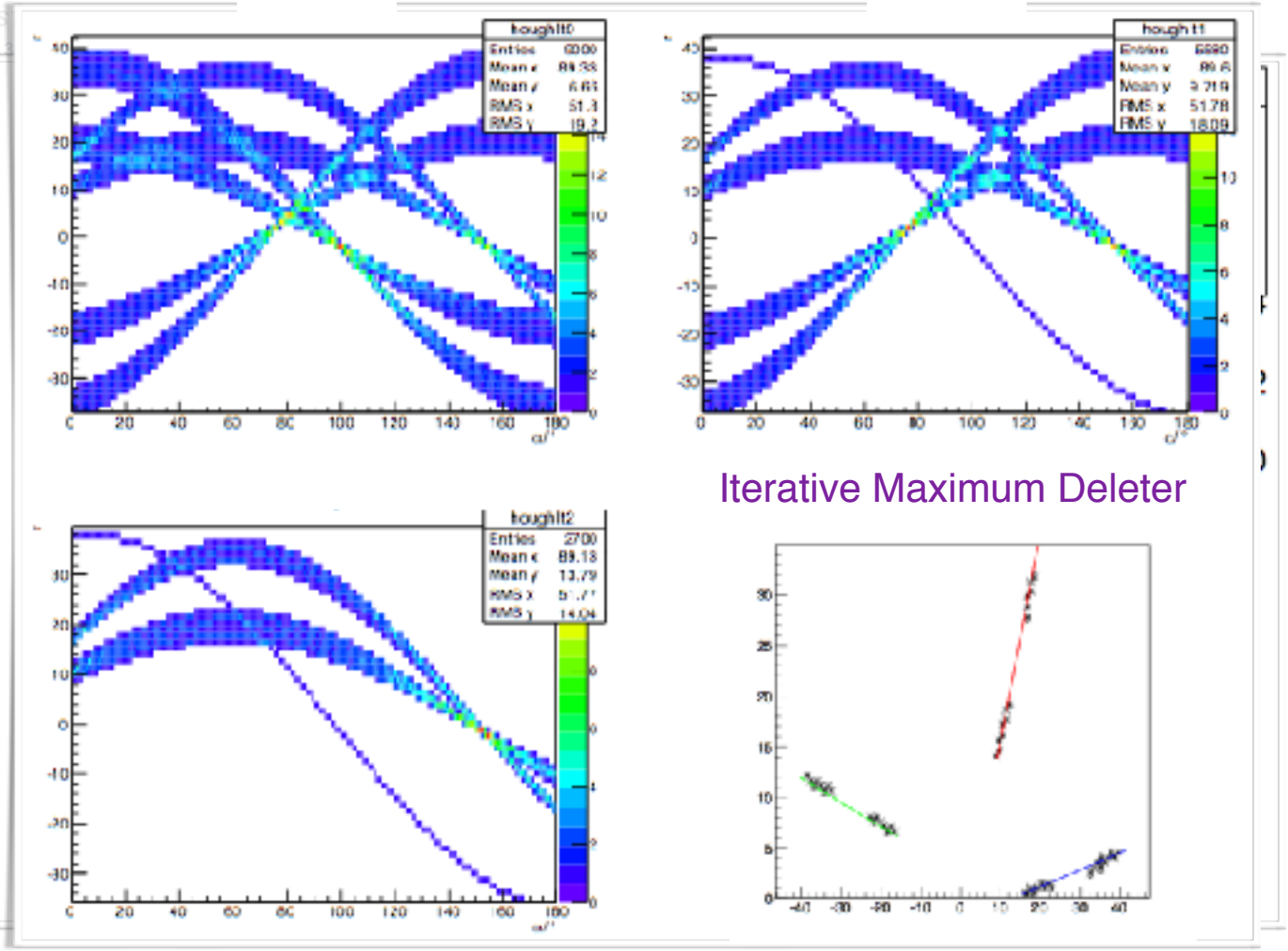
- Performance: 3 ms/evt
- Reduce to set of standard routines
  - Fast (uses Thrust's optimized algorithms)
  - Inflexible (hard to customize)
  - Not yet at performance maximum

Plain CUDA

- Performance: 0.5 ms/evt
- Build completely for this task
  - Fitting for PANDA; customizable
  - A bit more complicated at part

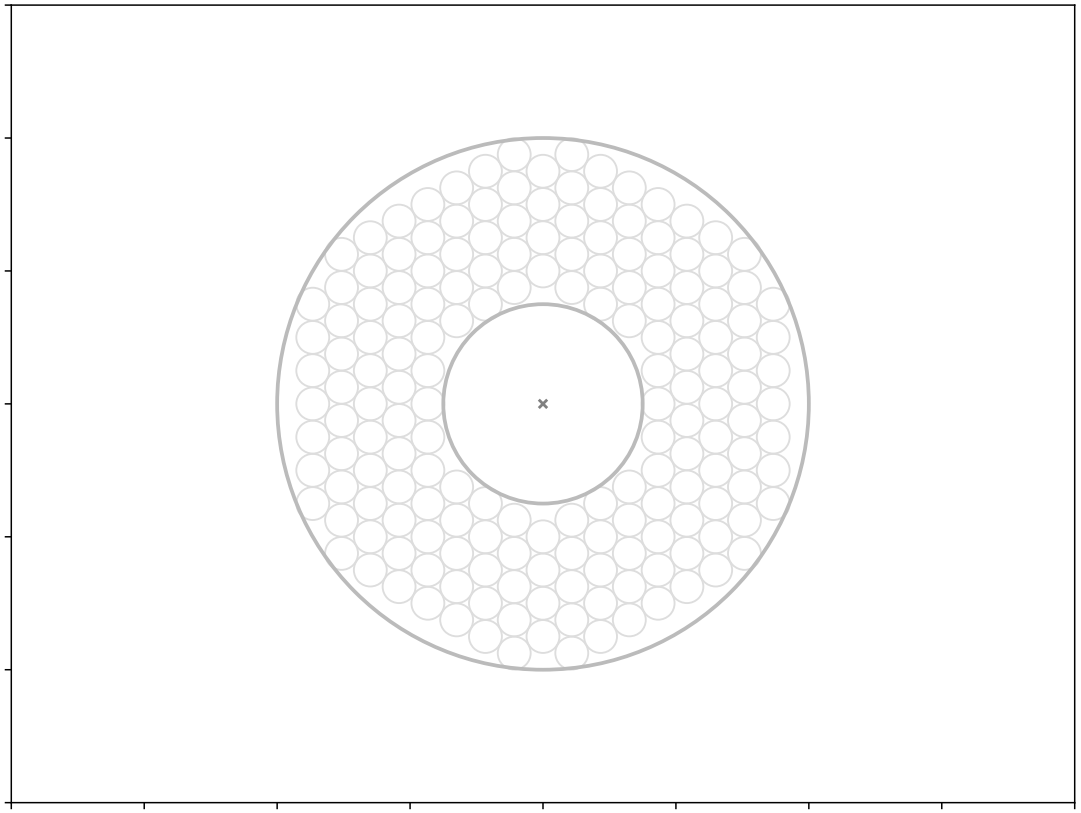
Peakfinding challenging

Hough Transform — Remarks



Peakfinding challenging

CIRCLE HOUGH



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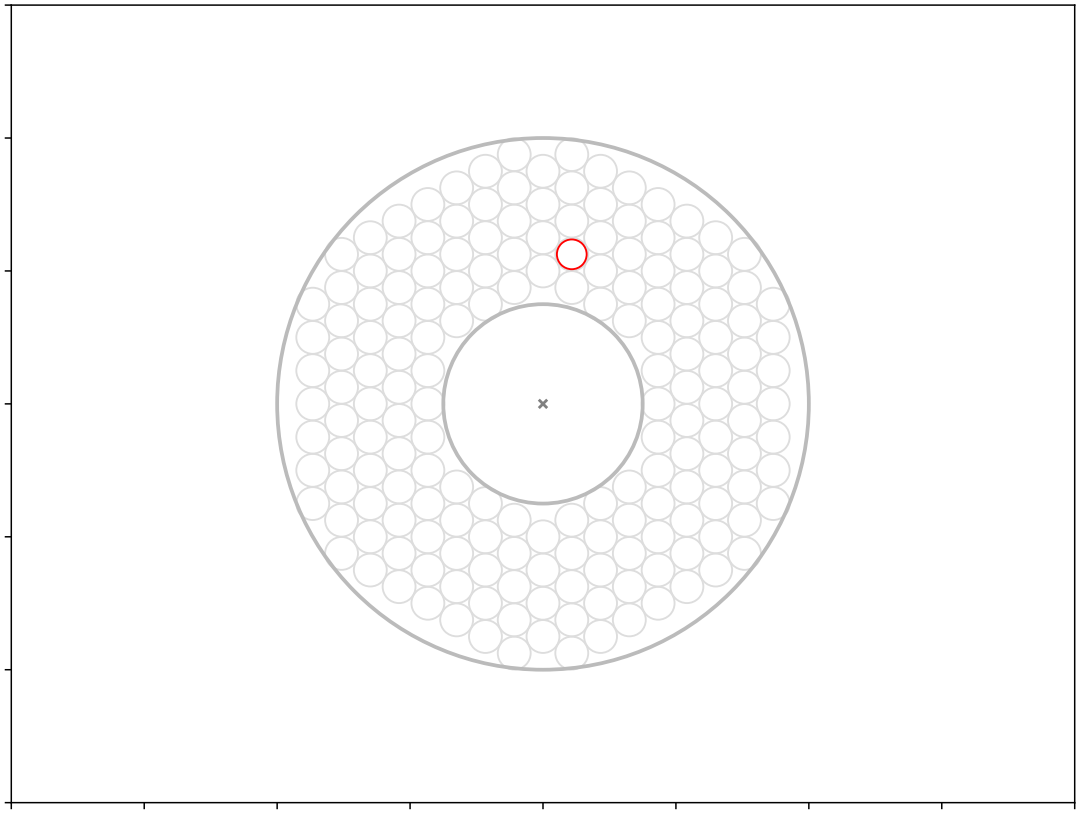

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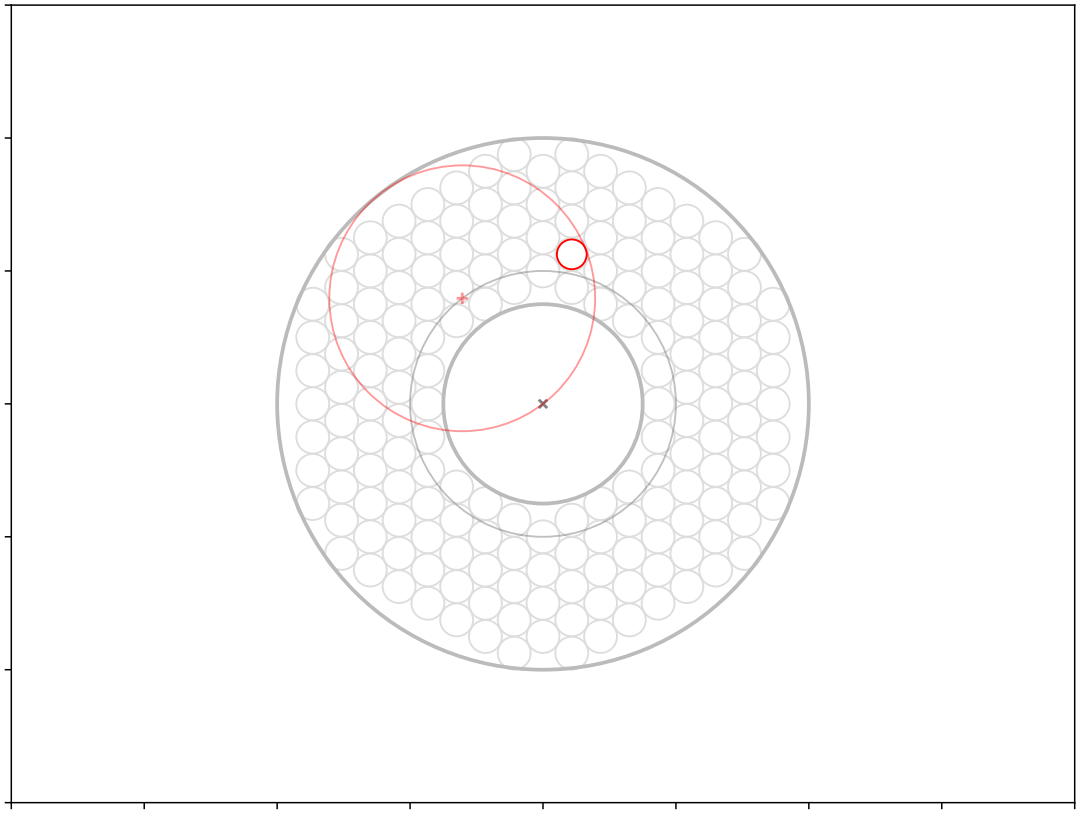

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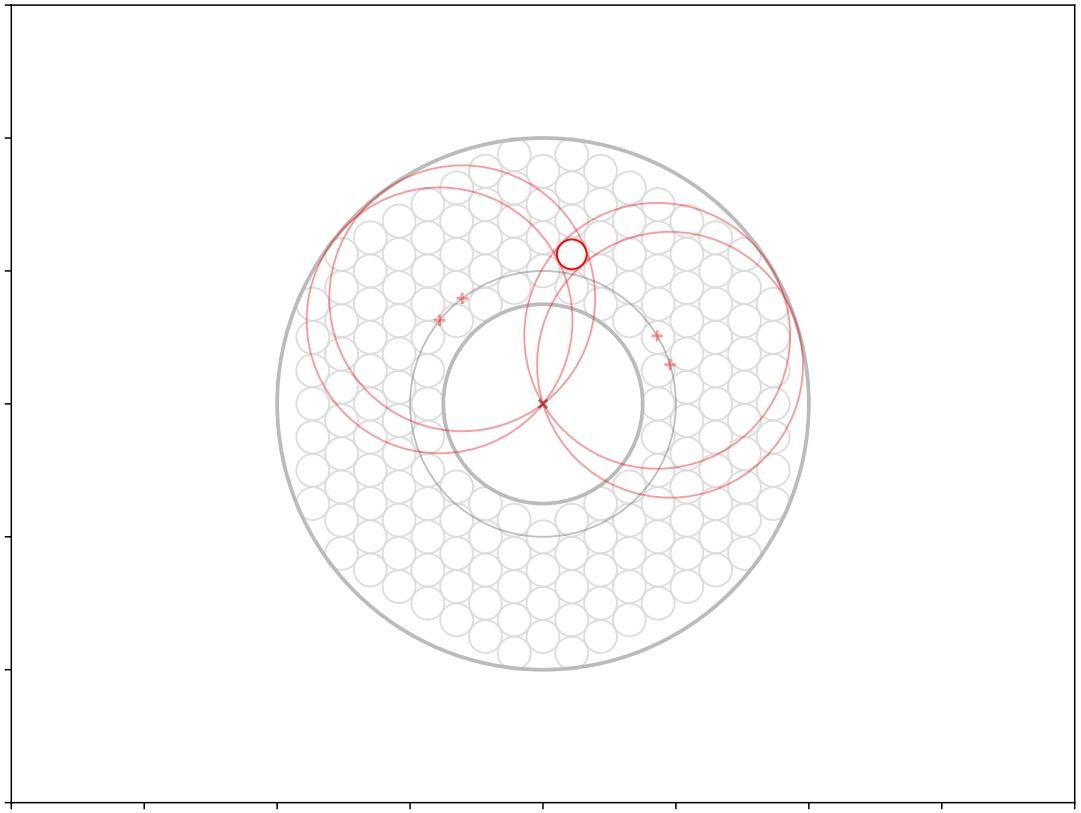

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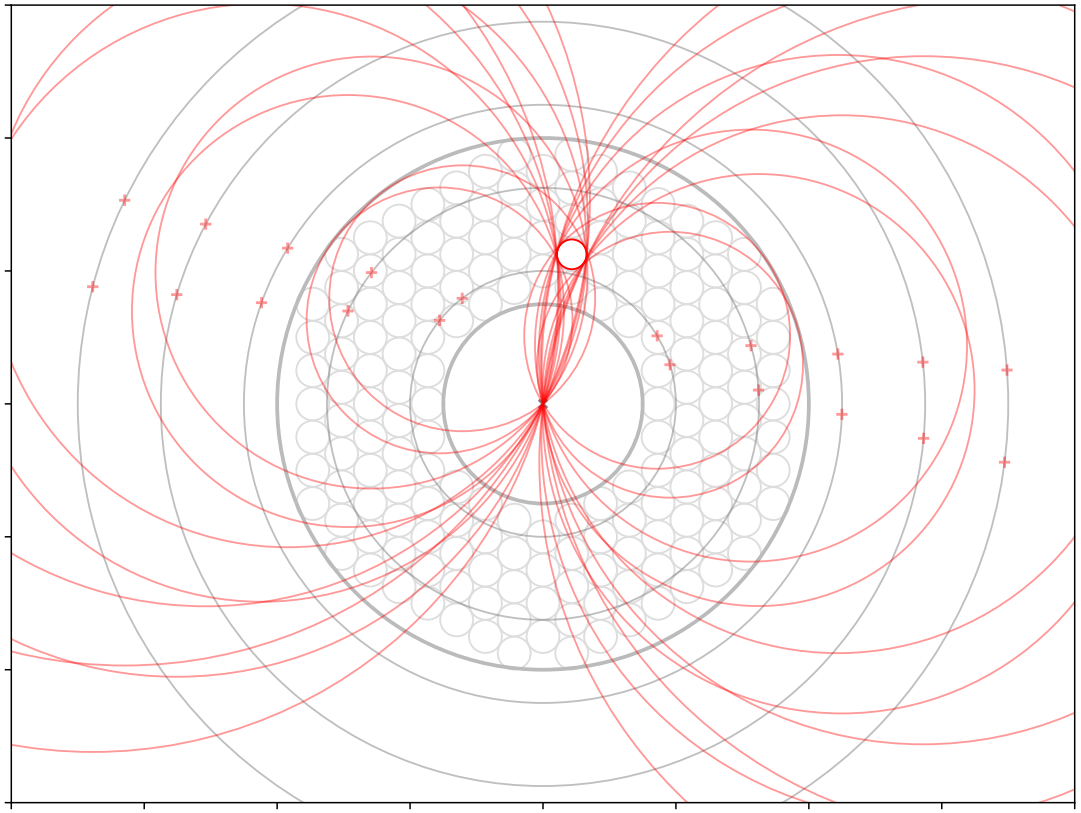

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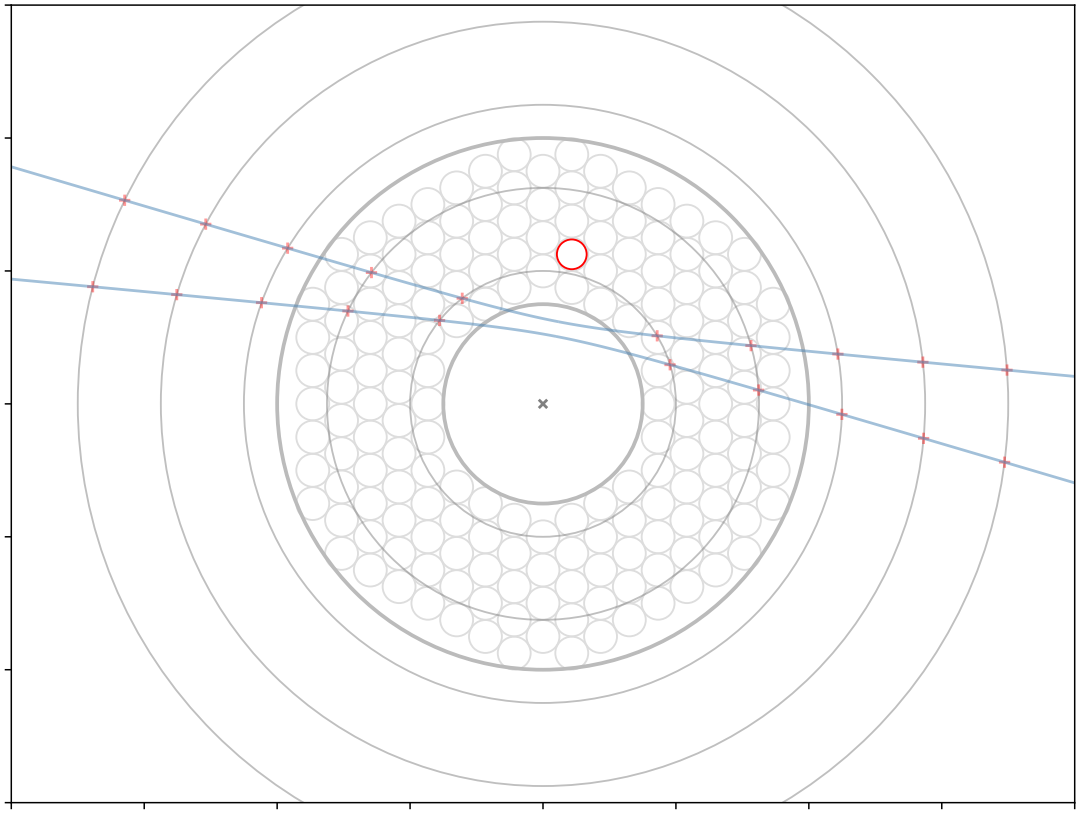

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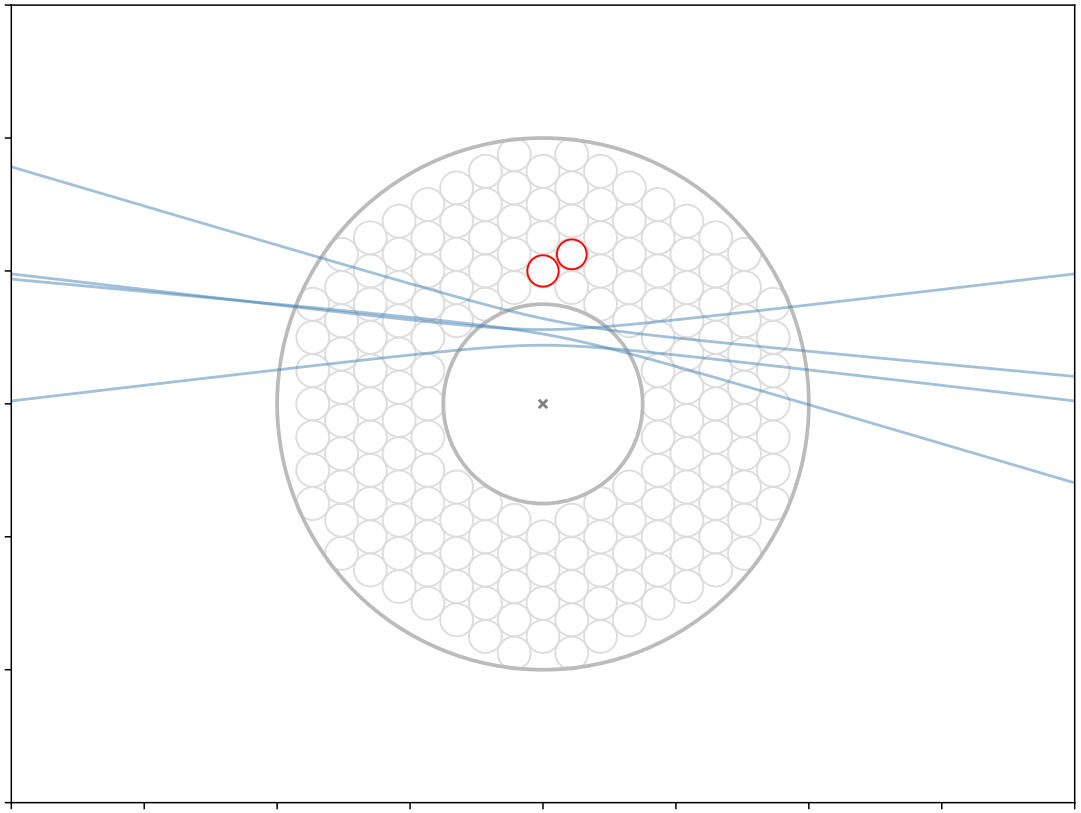

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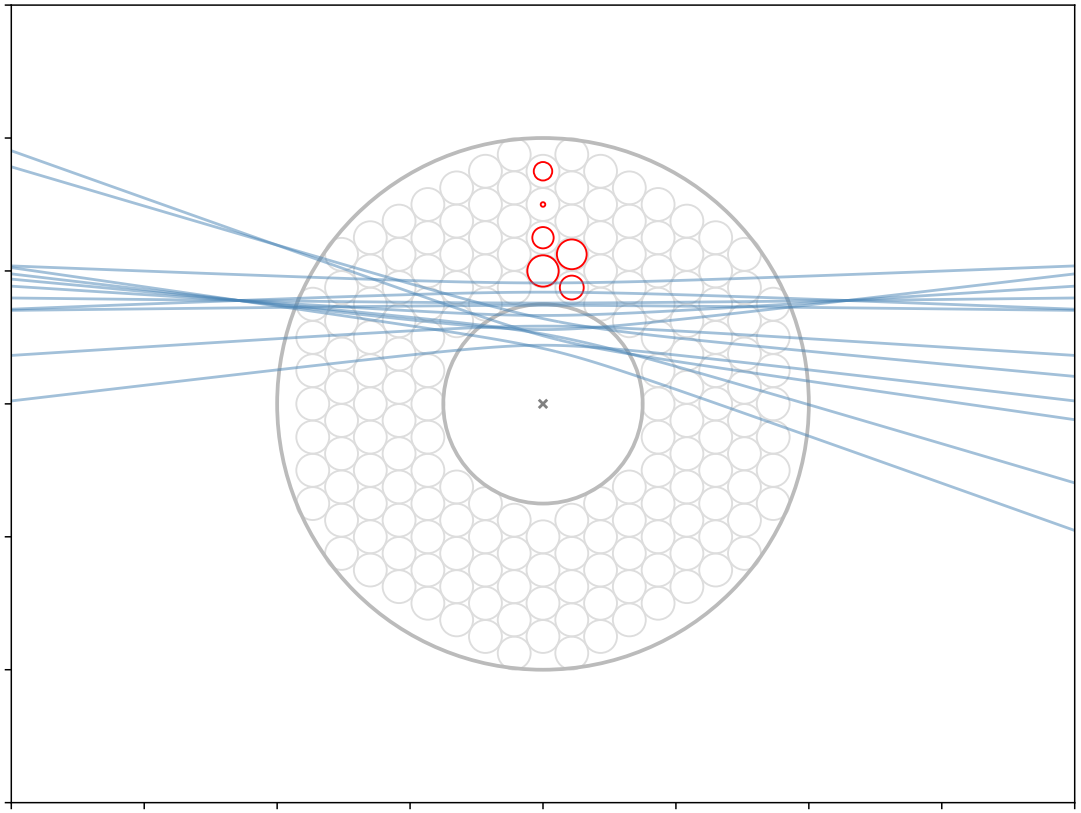

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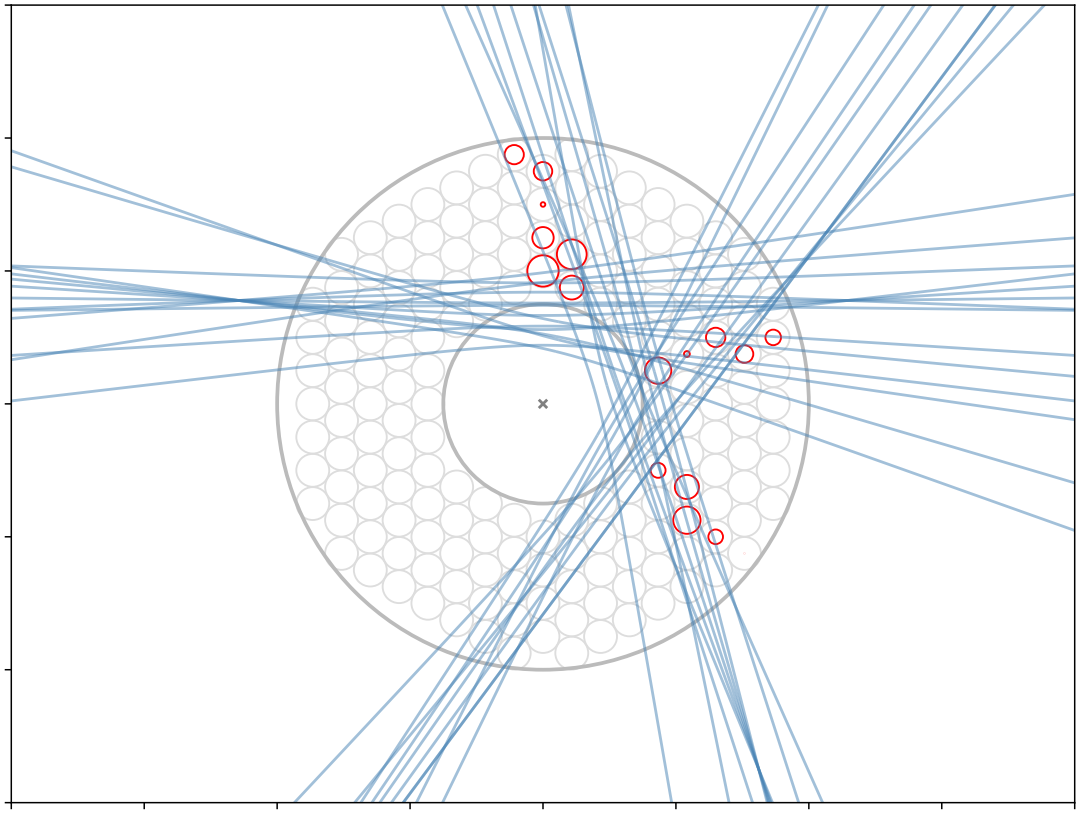

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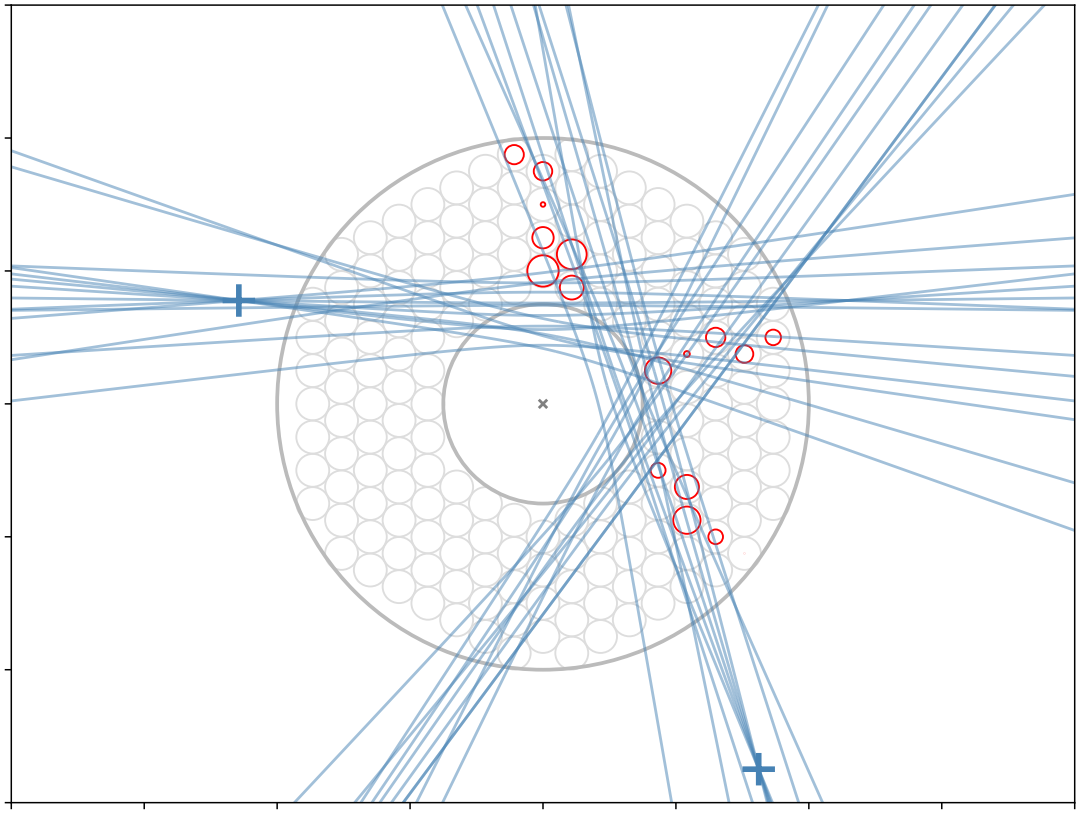

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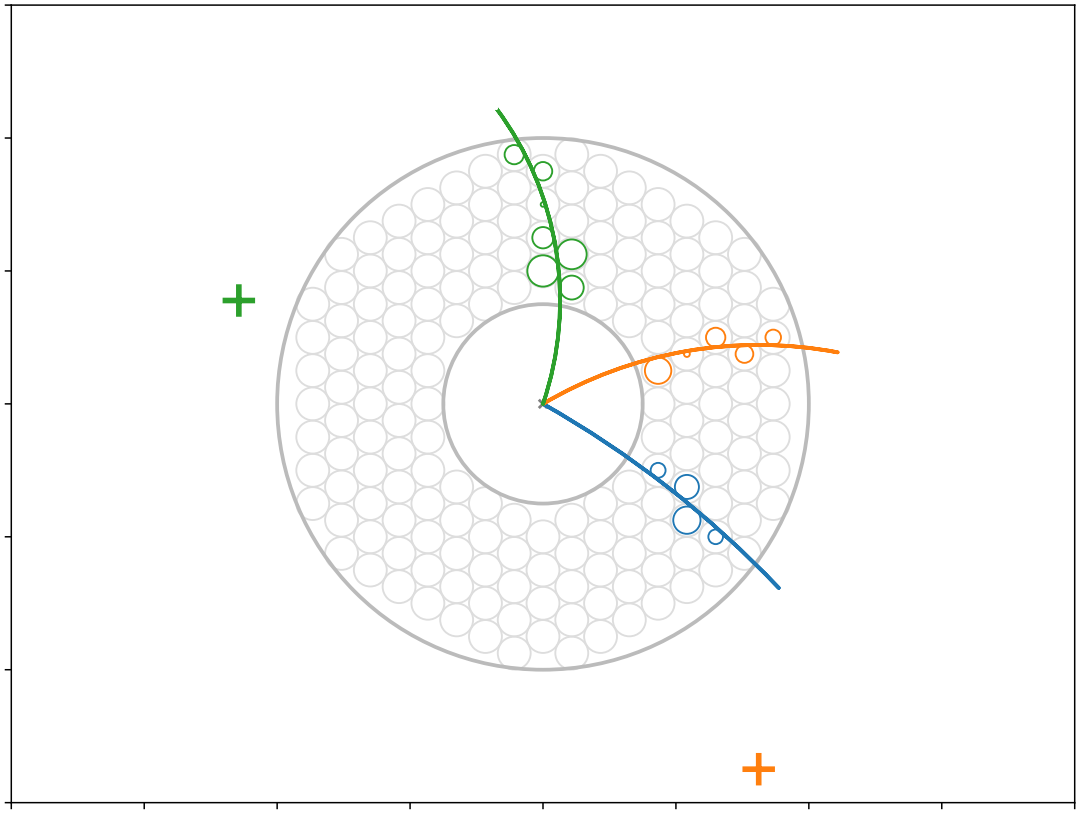

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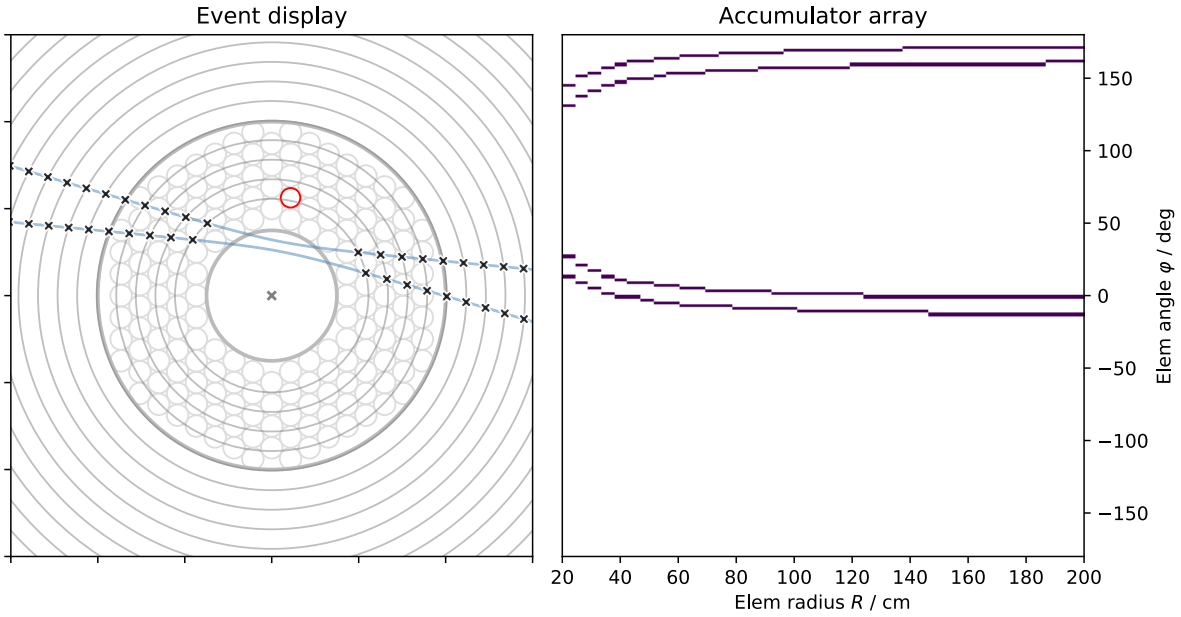

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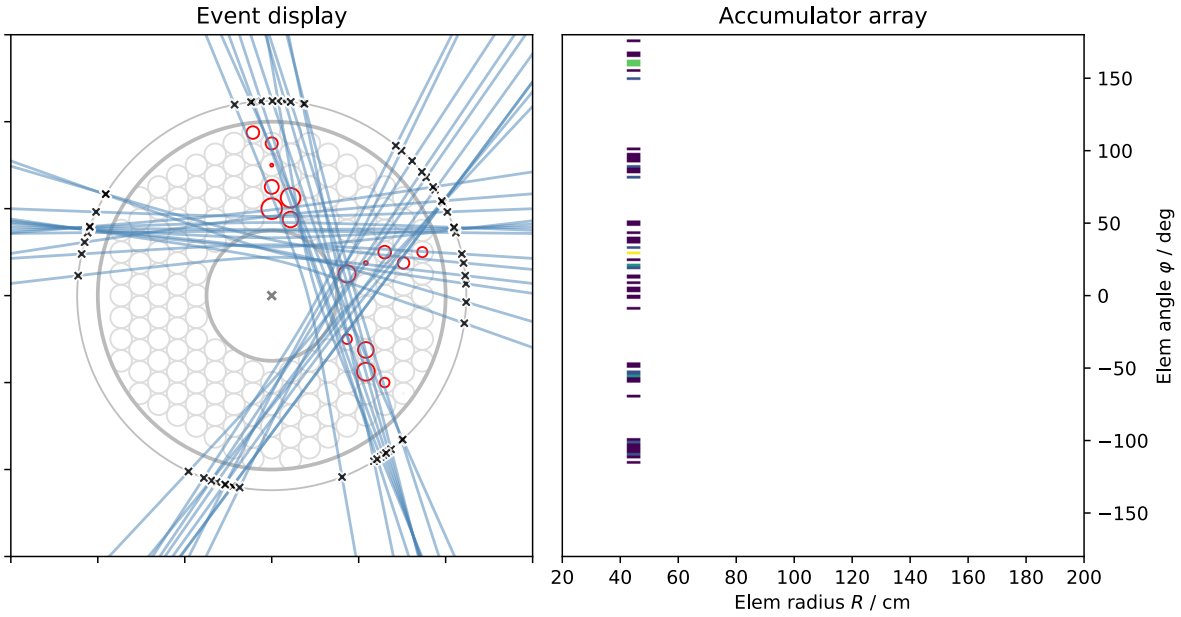

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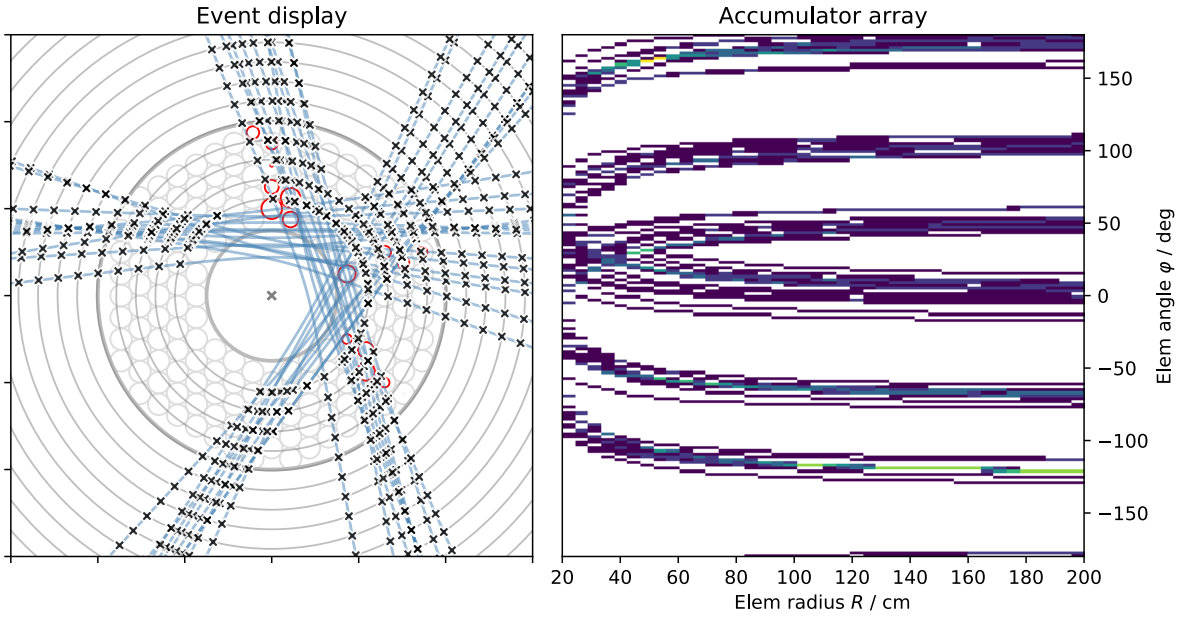
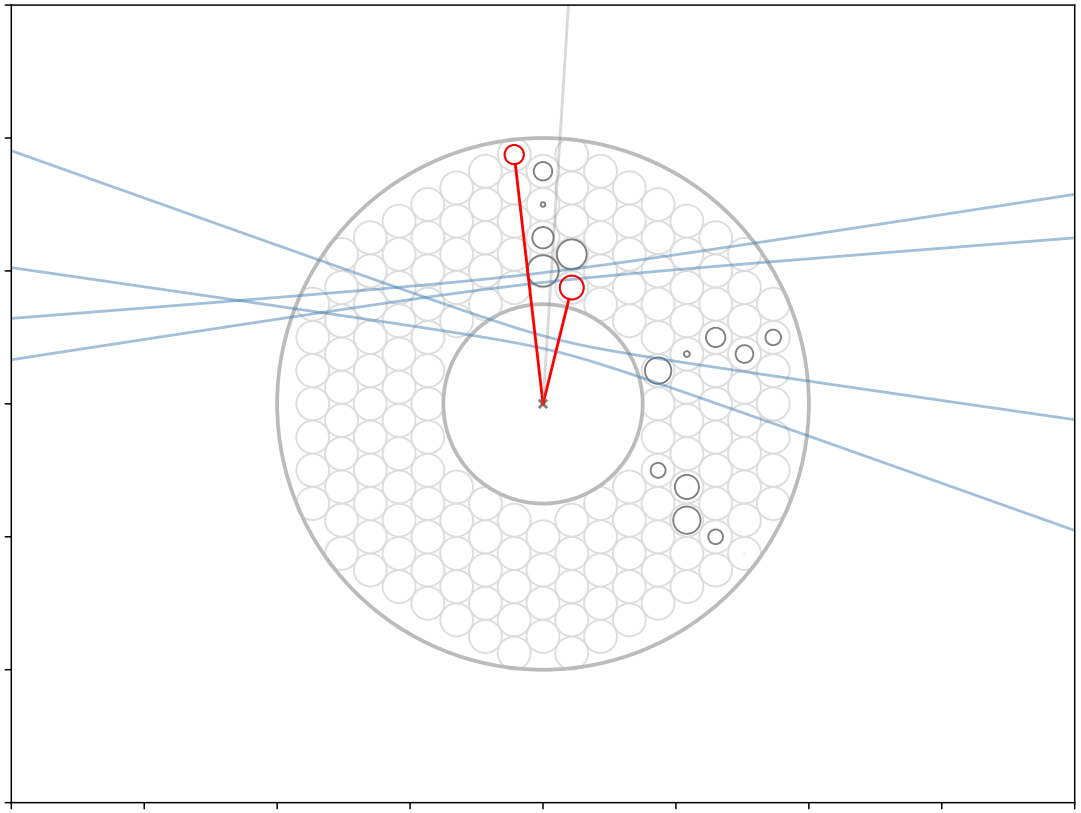


HIT PAIRS HOUGH



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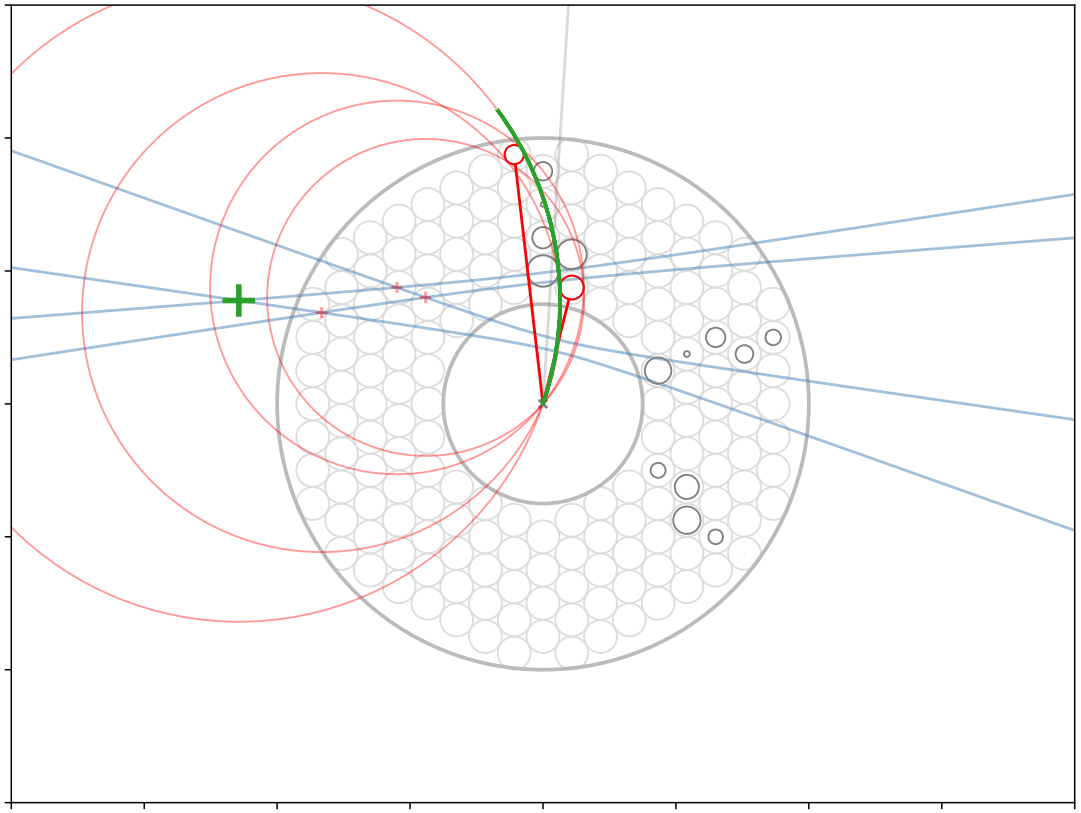
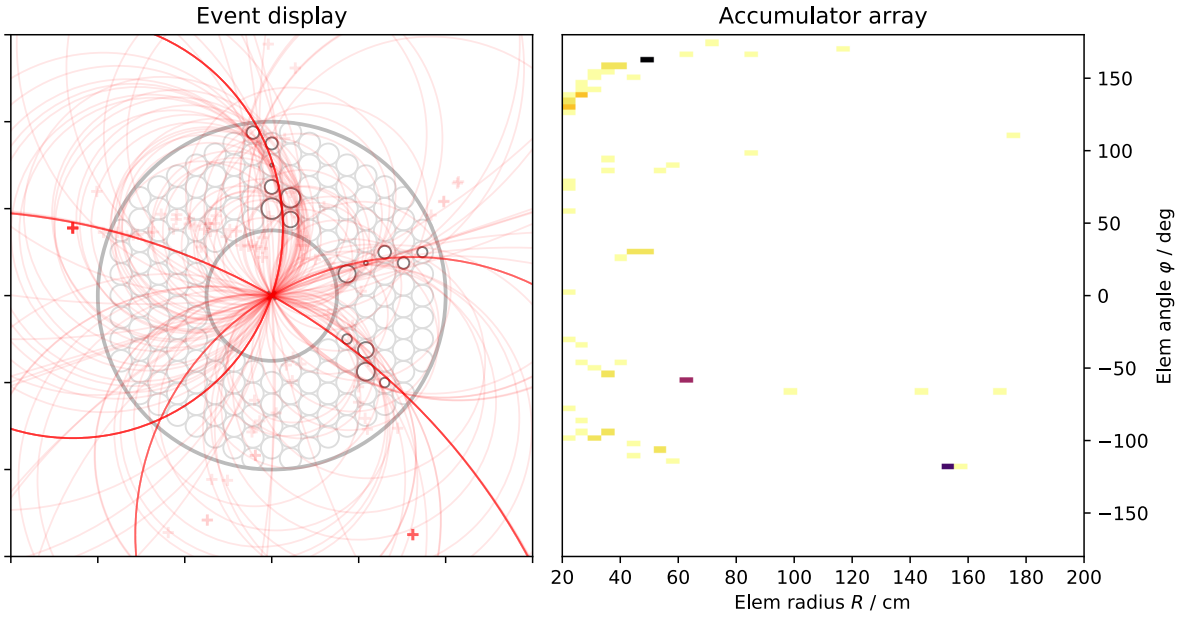


HIT PAIRS HOUGH



Riemann Track Finder

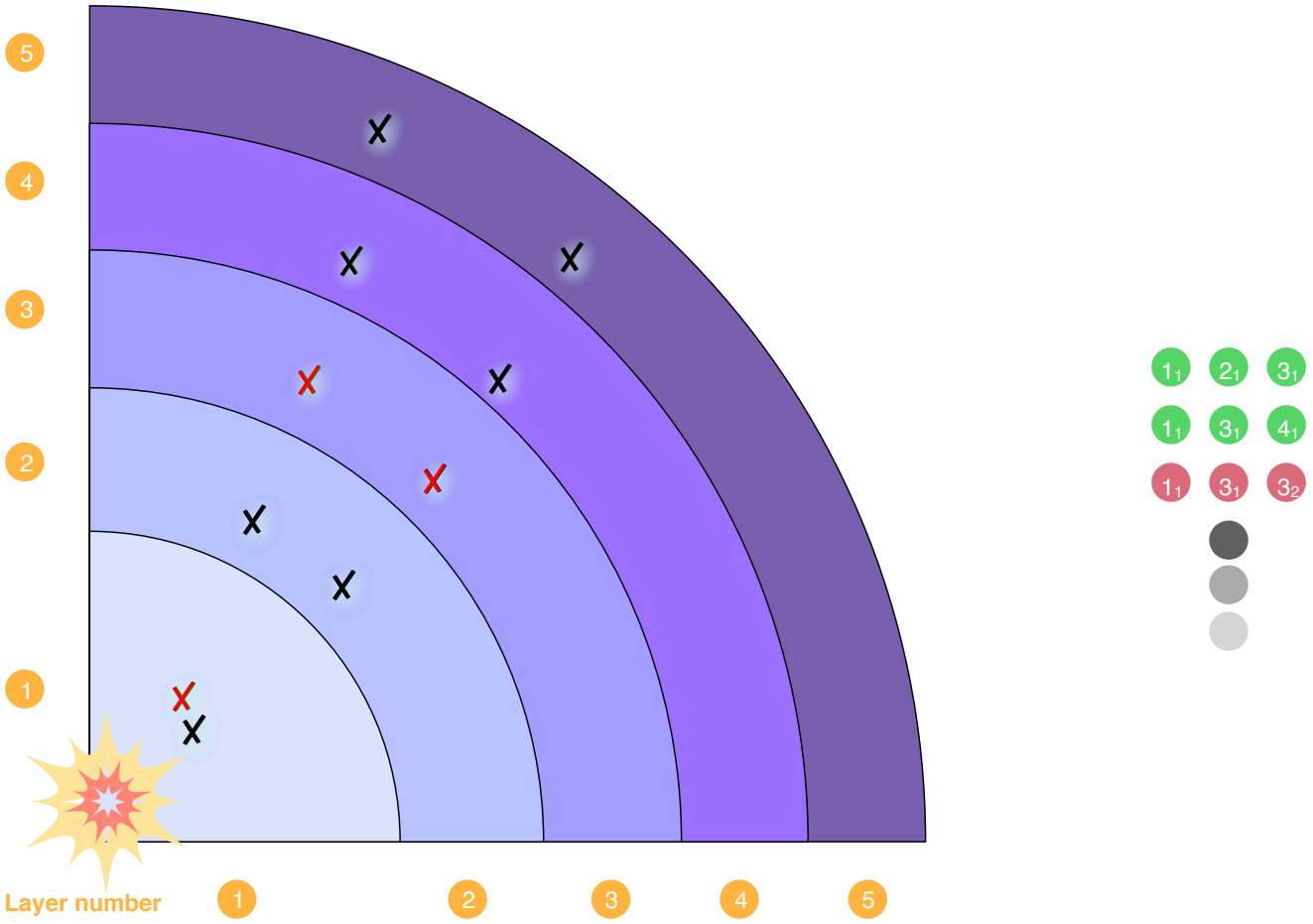
Riemann Algorithm — Procedure

Create triplet of hit points

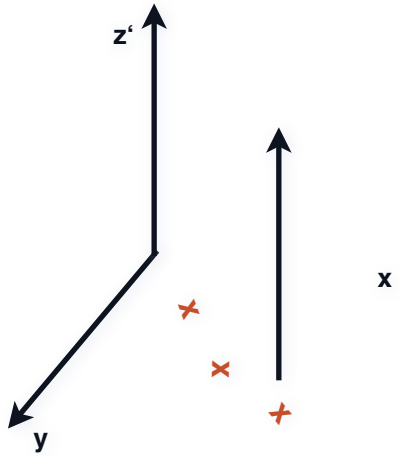
- **All possible three hit combinations need to become triplets**

Grow triplets to tracks:

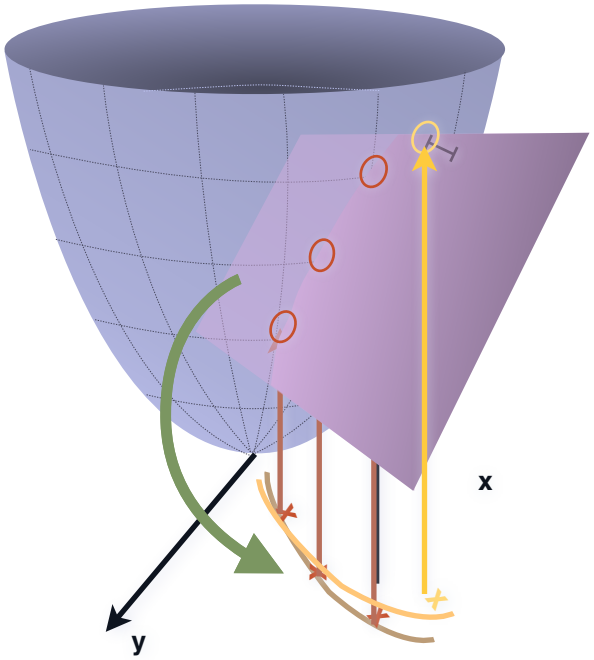
Riemann Track Finder — Seeds



Riemann Algorithm — Expansion

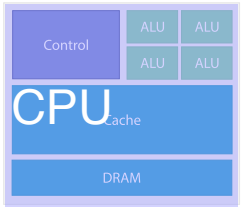


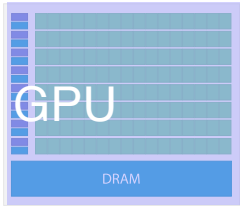
Expand to z‘



Riemann Surface
(paraboloid)

Riemann Track Finder — GPU Adaptations





1 **3 loops to generate seeds serially**

```
for (int i = 0; i < hitsInLayerOne.size(); i++) {
  for (int j = 0; j < hitsInLayerTwo.size(); j++) {
    for (int k = 0; k < hitsInLayerThree.size(); k++) {
      /* Triplet Generation */
    }
  }
}
```

Needed: Mapping of inherent GPU indexing variable to triplet index

```
int ijk = threadIdx.x + blockIdx.x * blockDim.x;
```

$$n_{Layer_x} = \frac{1}{2}\left(\sqrt{8x+1}-1\right)$$

$$pos(n_{Layer_x}) = \frac{\sqrt[3]{\sqrt{3}\sqrt{243x^2-1}+27x}}{3^{2/3}} + \frac{1}{\sqrt[3]{3}\sqrt[3]{\sqrt{3}\sqrt{243x^2-1}+27x}} - 1$$

2 Only *easy* computations; e.g. 3x3 matrices

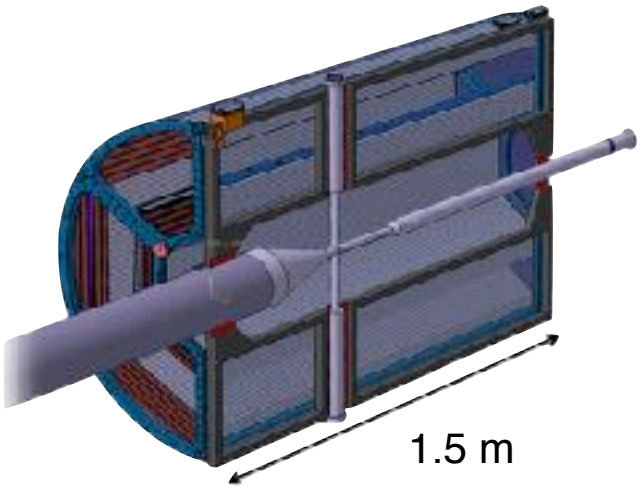
Port of CPU code; parallelism on seed base

→ 100 × faster than CPU version: ~0.6 ms/

Triplet Finder

Triplet Finder

Algorithm specifically designed for the PANDA Straw Tube Tracker (STT)



Original algorithm by
Marius Mertens *et al*

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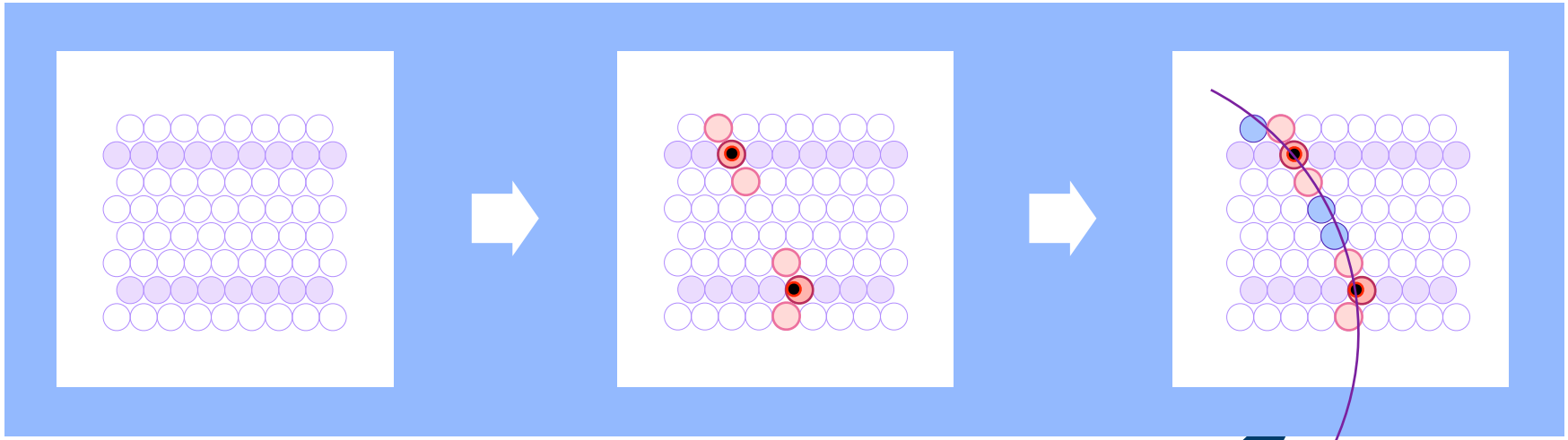
APPLICATION LAB
NVIDIA
http://www.fz-juelich.de/jas/jsc/

Triplet Finder

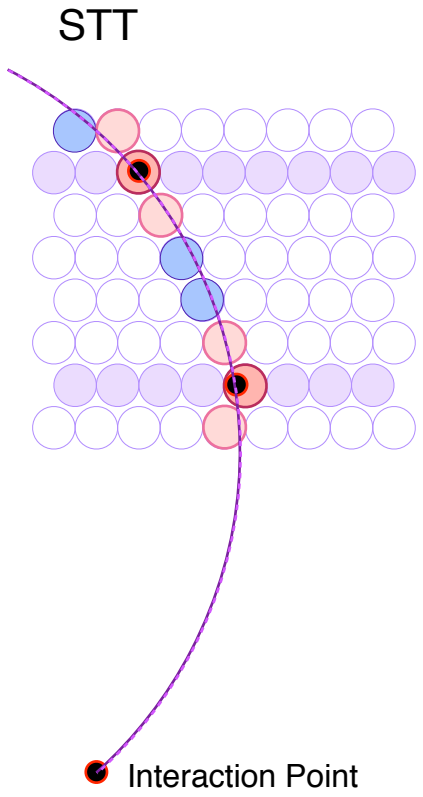
Idea: **Use only subset of detector as seed**

- **Don‘t use STT isochrones** ***(drift times)***
- **Calculate circle from 3 points (no fit)**

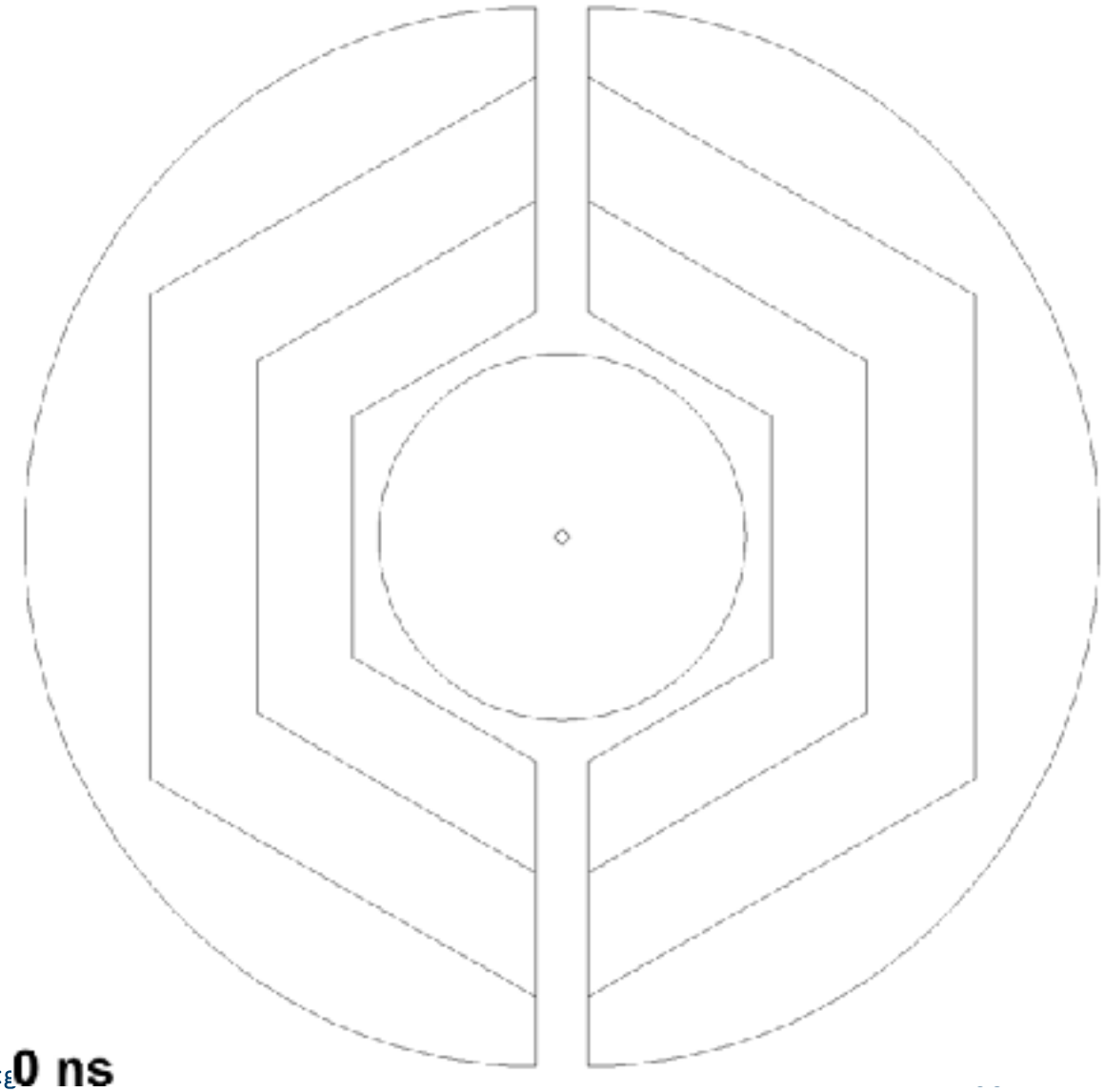


Triplet Finder — Method

STT hit in pivot straw
Find surrounding hits
→ Create virtual hit *(triplet)*



Triplet Finder — Animation



Isochrone *early*

Isochrone *early* & *skewed*

Isochrone *close*

Isochrone *late*

MVD hit

Triplet

Track *current*

Track *timed out*

Mitg 0 ns

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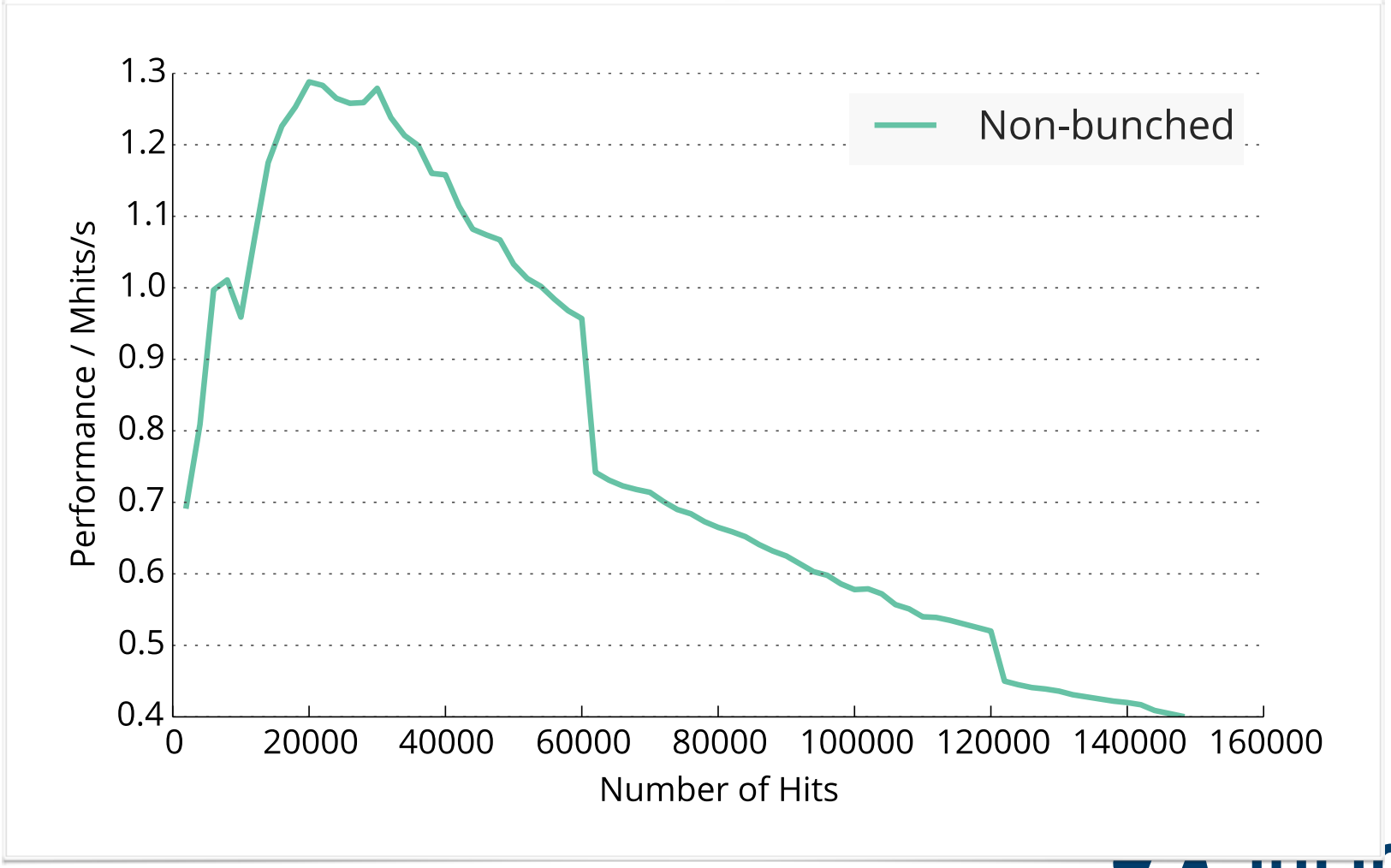
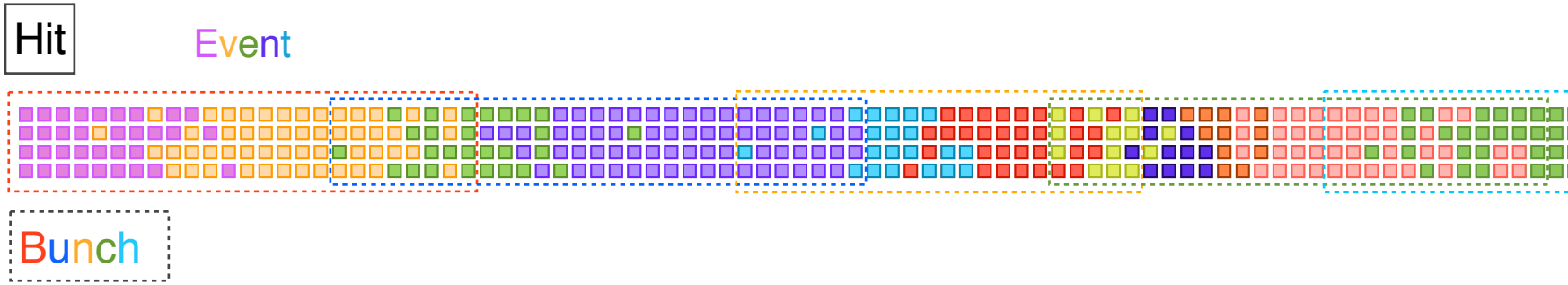
Triplet Finder — Times



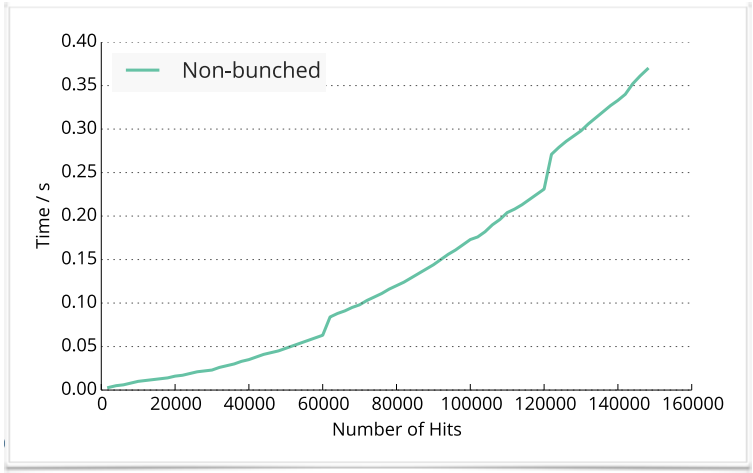
Triplet Finder — Optimizations

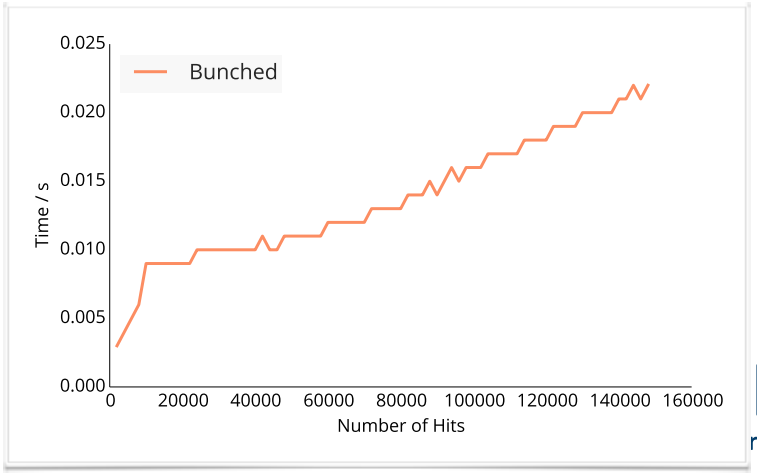
Bunching Wrapper

- **Hits from one event have similar timestamp**
- **Combine hits to sets (bunches) which occupy GPU best**



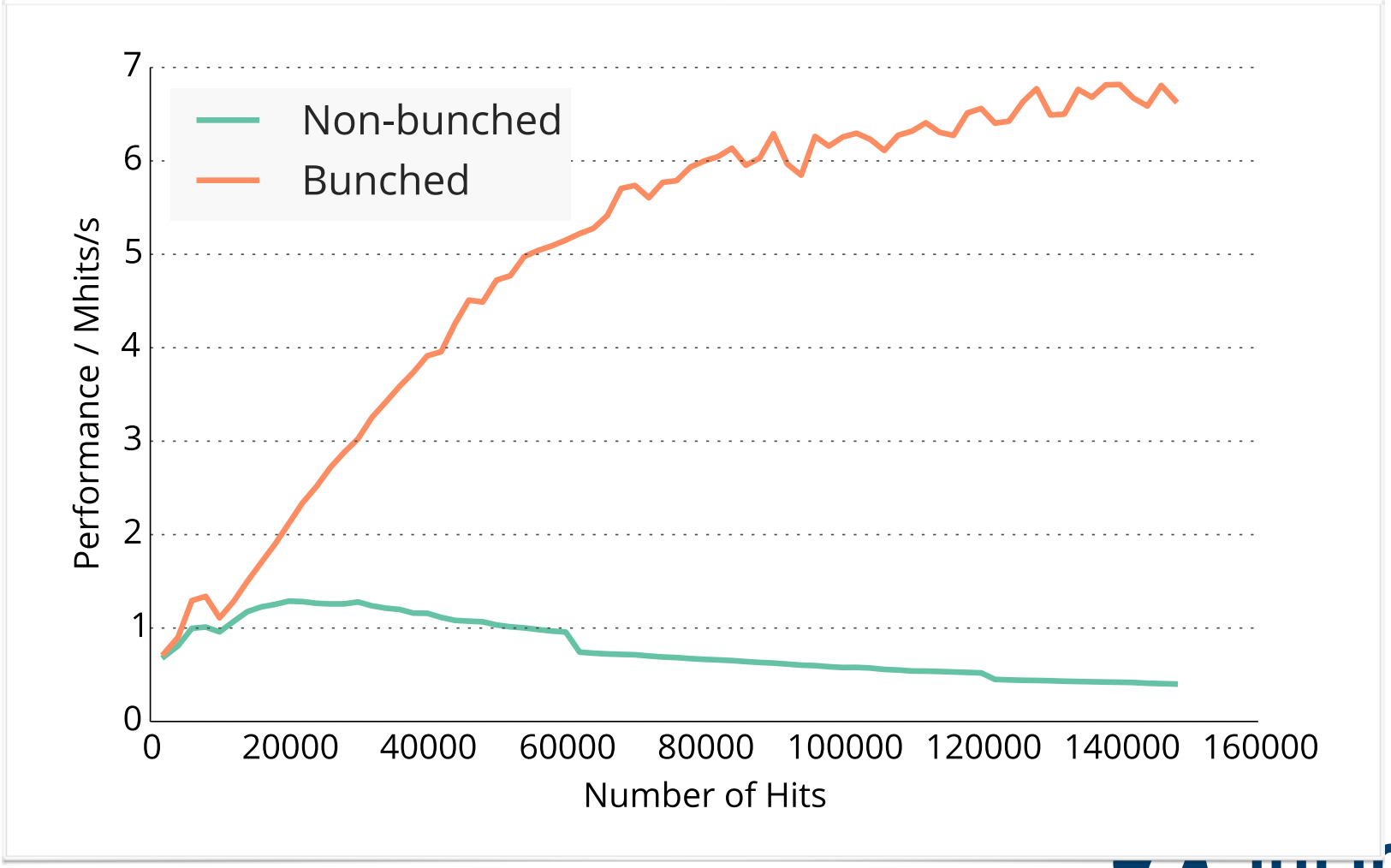
$$\mathcal{O}(N^2) \rightarrow \mathcal{O}(N)$$





Triplet Finder — Bunching

Performance

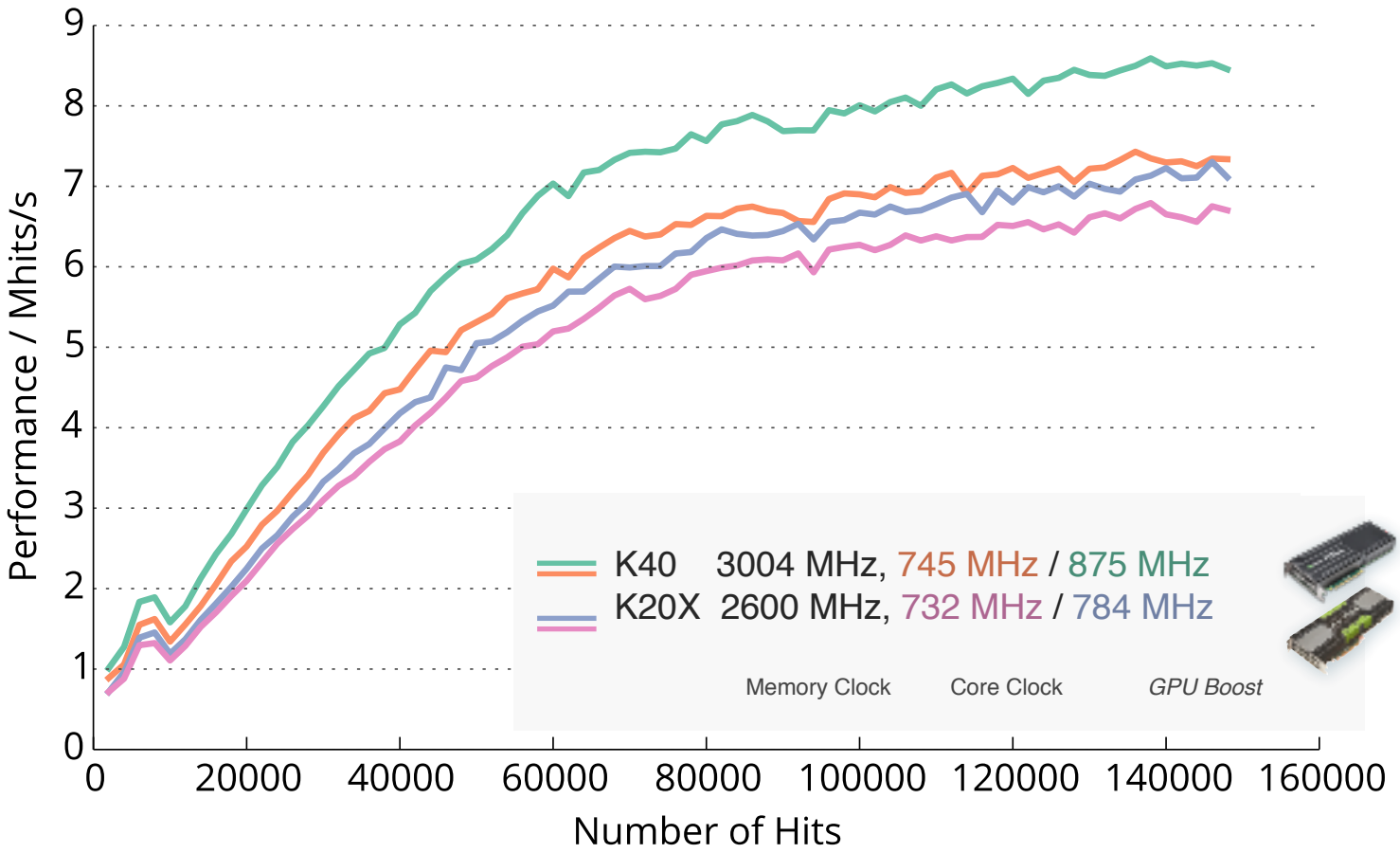


Triplet Finder — Clock Speed / GPU

Original algorithm by Marius C. Mertens *et al.*

Ported to GPU by Andrew A. Adinetz (NVIDIA Application Lab)

- **Thrust, CUDA, some dynamic parallelism**



Triplet Finder — Summary

Best performance: 20 *µs*/event

- **$20 \cdot 10^{-6}$ s/event * $2 \cdot 10^{7}$ event/s ⇒ 400 GPUs[2014]**
- **PANDA[2019]: Multi GPU system – $\mathcal{O}$(100) GPUs**

Optimizations possible & needed

- **ε needs to be improved**
- **Speed, €:**
  - ***More float less double*-cards a la K10**
  - **Consumer-grade cards a la GTX**

Summary

Many ideas how to do fast online tracking

But:

- **not a single version fully running in PandaRoot**
- **all have their strengths and weaknesses**

Still a lot of works!

List of Resources Used

#4: Earth icon by Francesco Paleari from The Noun Project

#4: Einstein icon by Roman Rusinov from The Noun Project

#6: FAIR vector logo from official FAIR website

#6: FAIR rendering from official website

#11: Flare Gun icon by Jop van der Kroef from The Noun Project

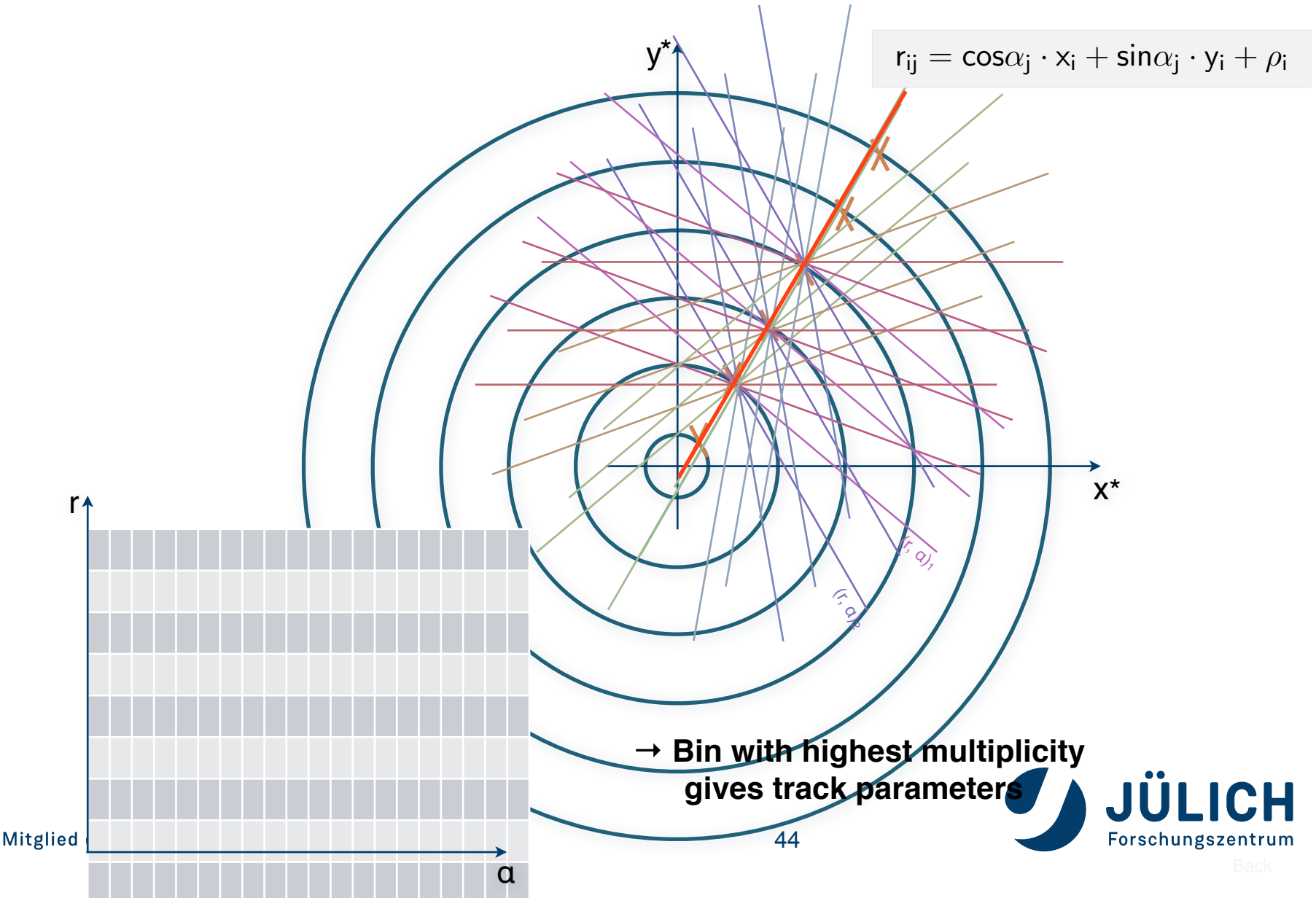
#27: STT event animation by Marius C. Mertens

#35: Graphics cards images by NVIDIA promotion

#35: GPU Specifications

- **Tesla K20X Specifications: http://www.nvidia.com/content/PDF/kepler/Tesla-K20X-BD-06397-001-v07.pdf**
- **Tesla K40 Specifications: http://www.nvidia.com/content/PDF/kepler/Tesla-K40-Active-Board-Spec-BD-06949-001_v03.pdf**
- **Tesla Familiy Overview: http://www.nvidia.com/content/tesla/pdf/NVIDIA-Tesla-Kepler-Family-Datasheet.pdf**

Hough Transform — Principle



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Back

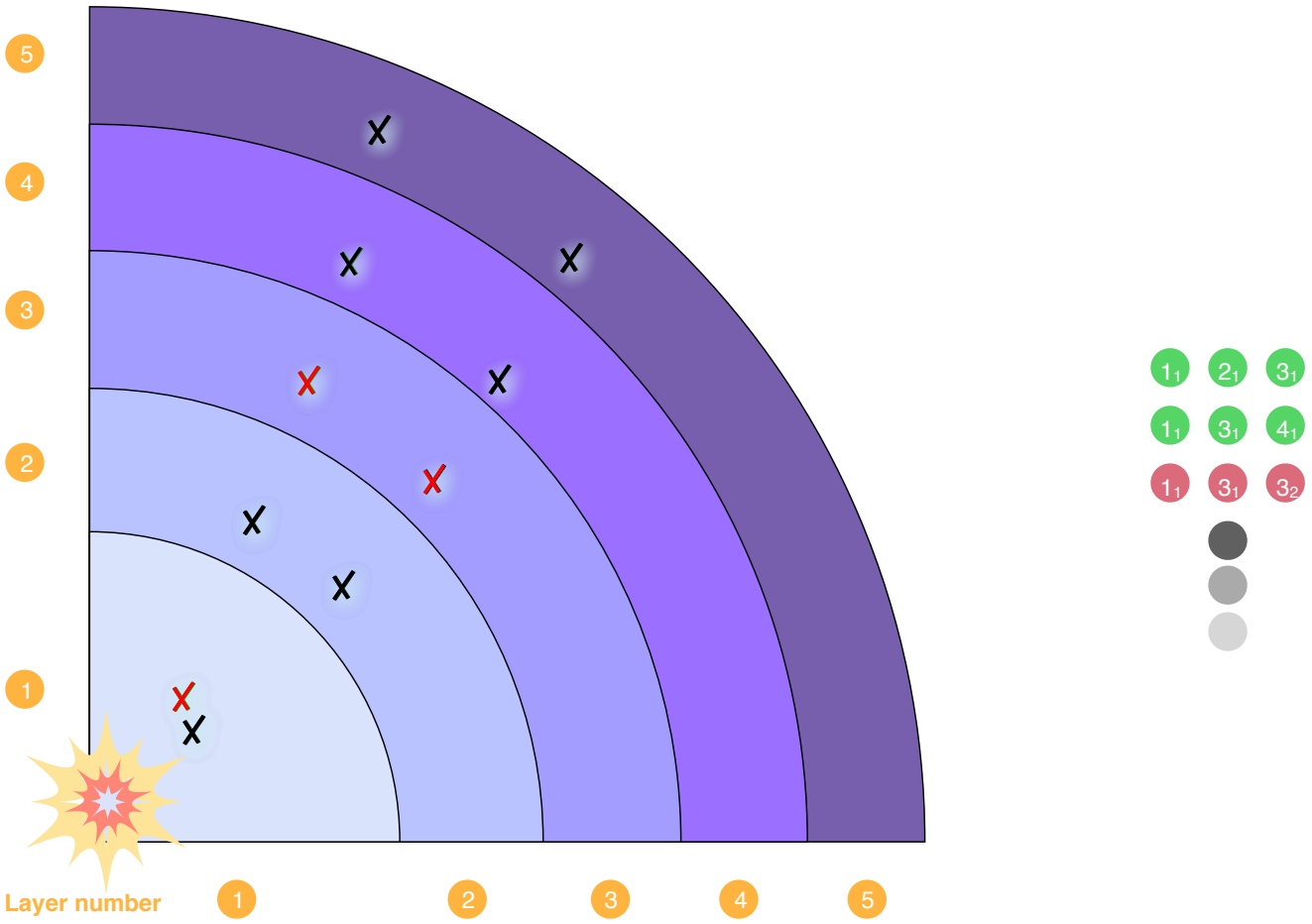
Riemann Algorithm — Procedure

1

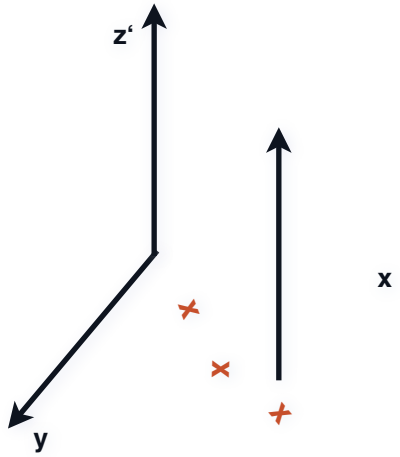
C triplet of hit points
l possible three hit combinations need to become triplets
G triplets to tracks:

2

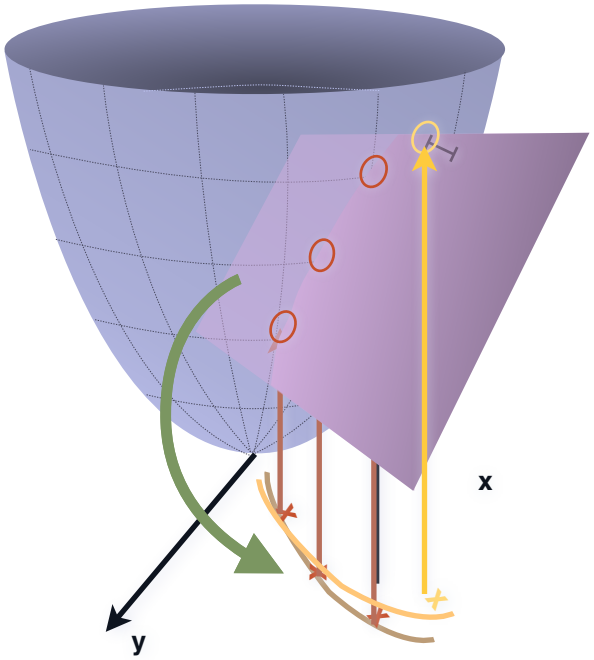
Riemann Track Finder — 1 Seeds



Riemann Algorithm — 2 Expansion



Expand to z‘



Riemann Surface
(paraboloid)

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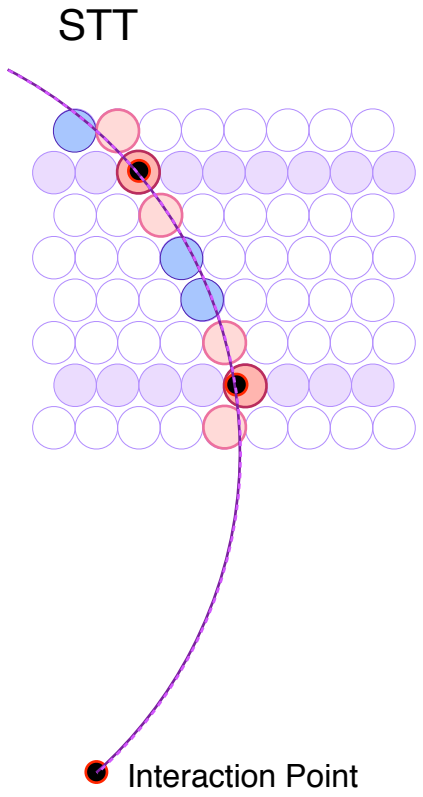
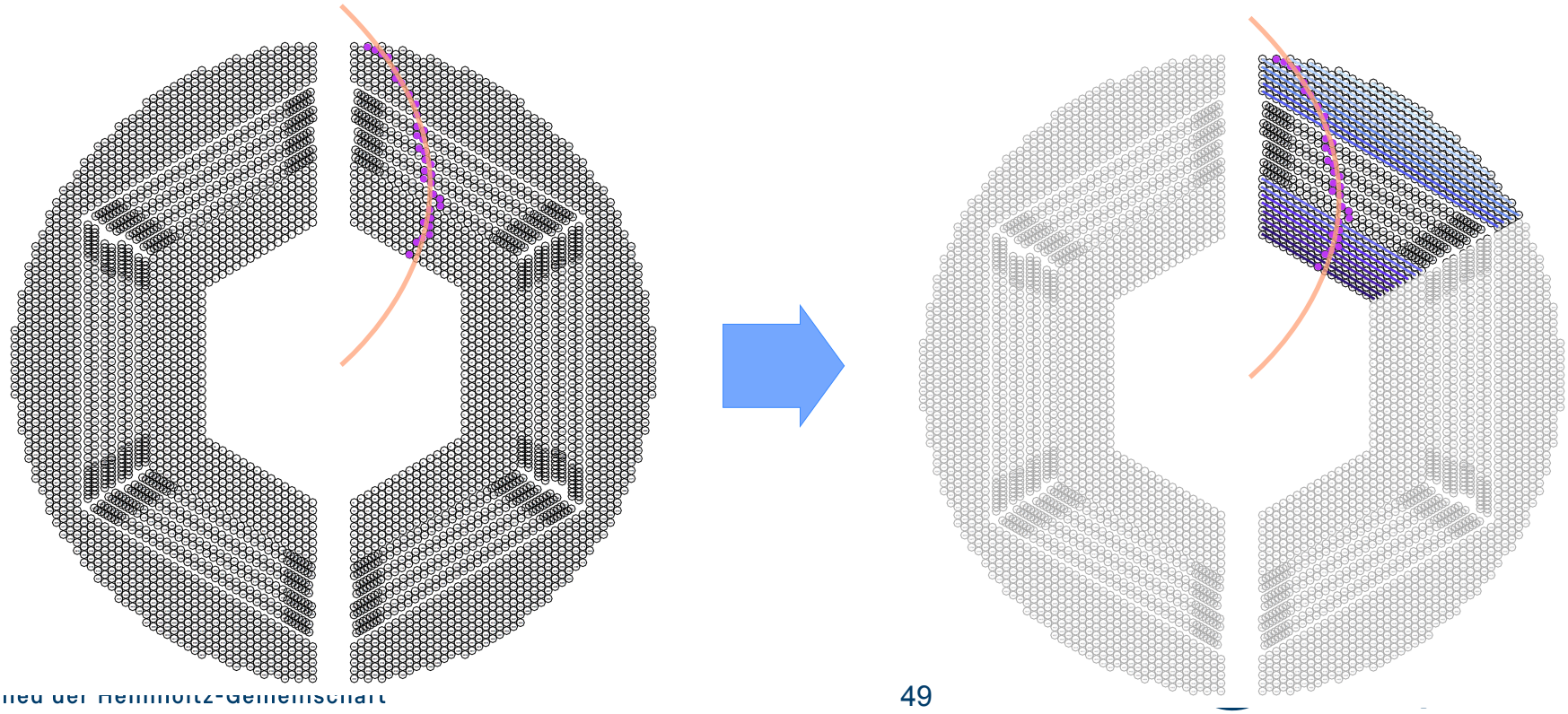


Triplet Finder — Optimizations

Sector Row testing

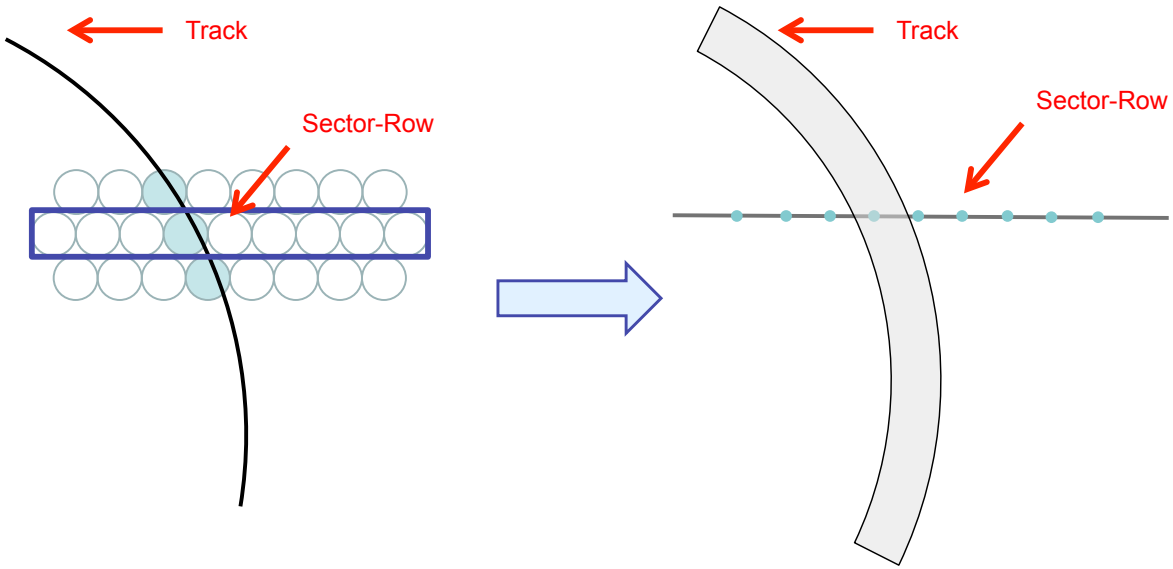
- **After found track:**
  Hit association not with *all* hits of current window,



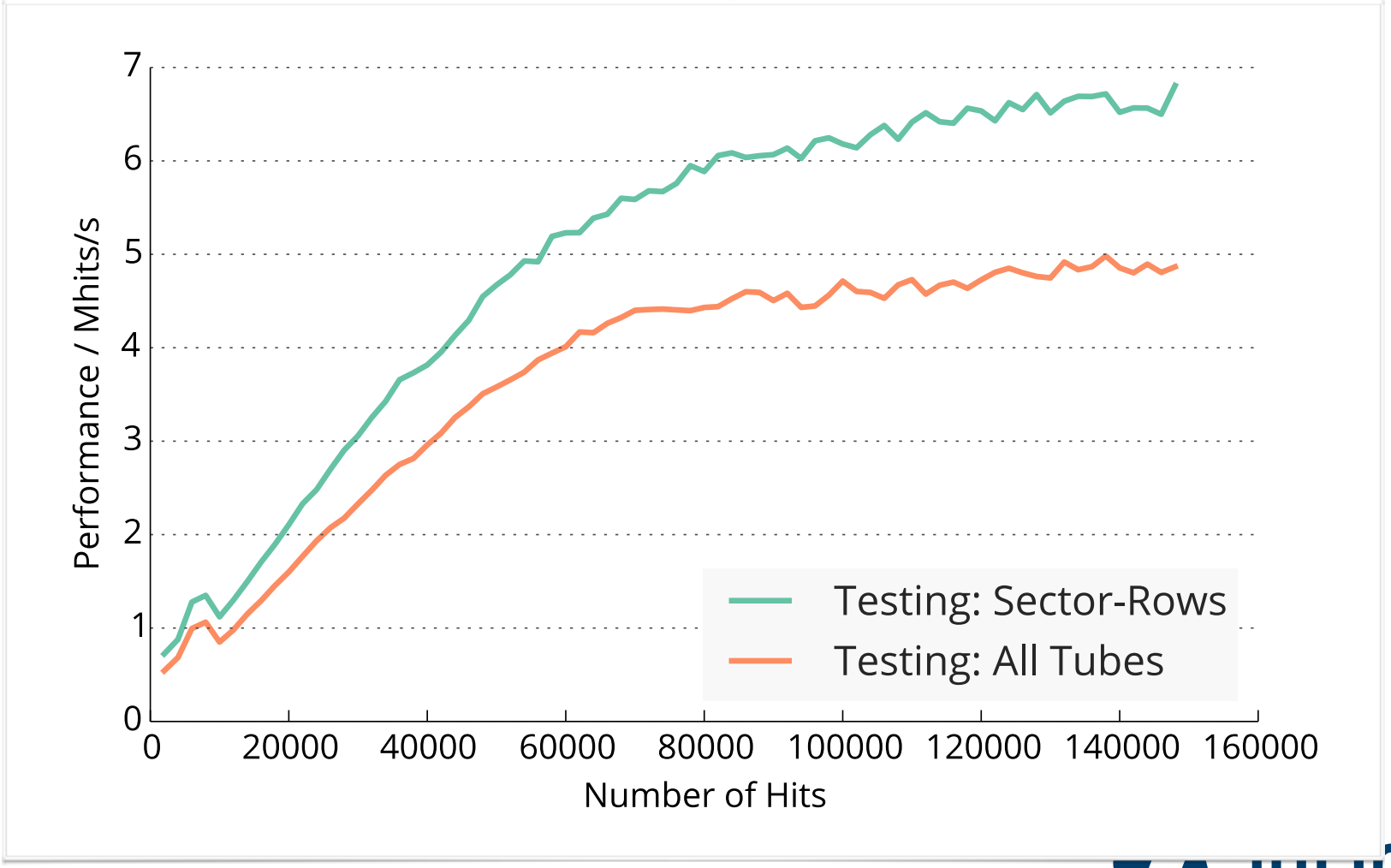
Triplet Finder — Optimizations

Sector Row testing

- **Thicken track; shrink sector row layer to line**
- **Find intersection**



Triplet Finder — Sector Rows



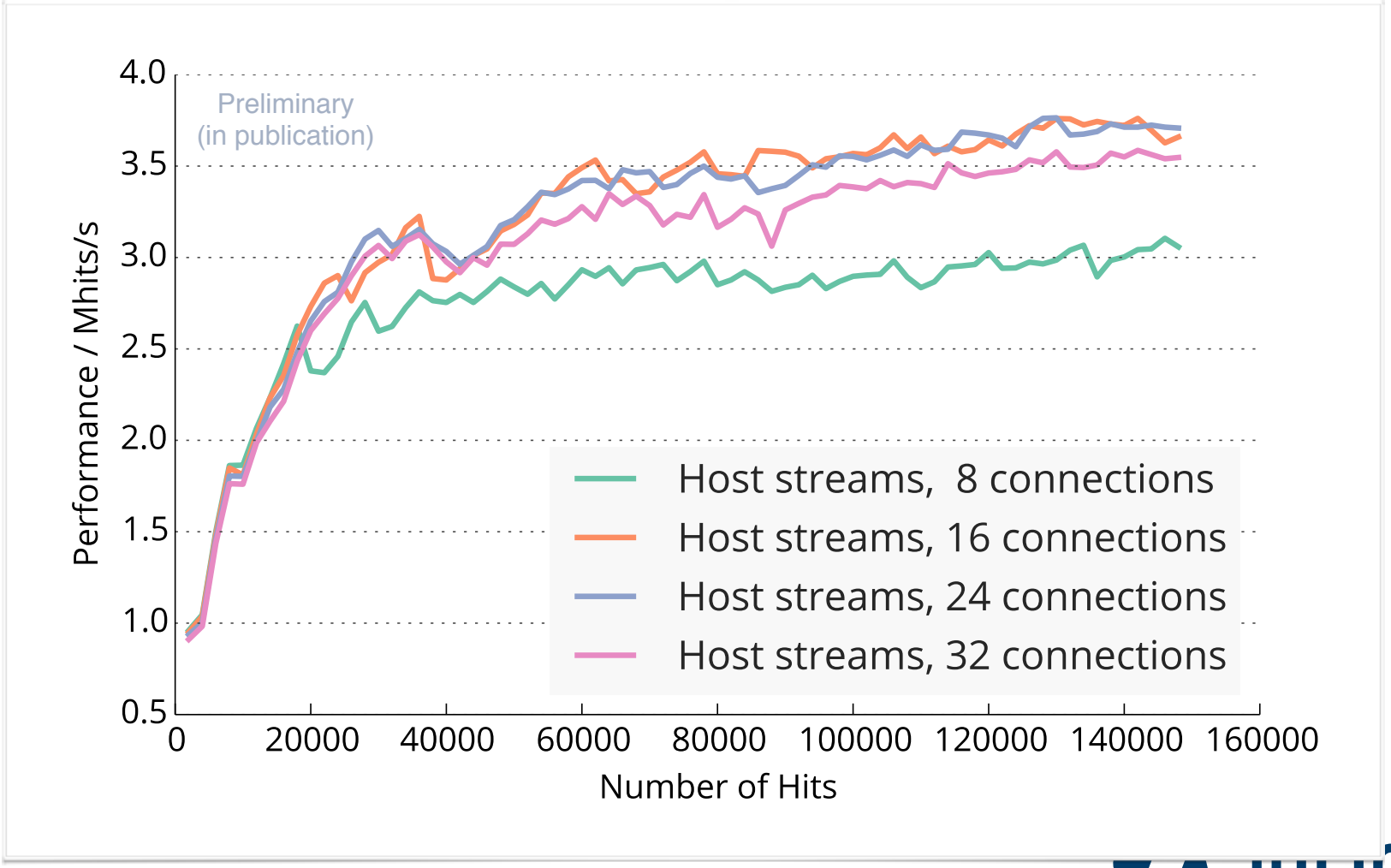
Triplet Finder — Kernel Launch Strategies

Joined Kernel *(JK)*: slowest

- **High # registers → low occupancy**

Dynamic Parallelism *(DP)* / Host Streams *(HS)*: comparable performance

Triplet Finder — Host Stream Connections



Triplet Finder — Bunch Sizes