Tiny Triplet Finder

A Pattern Recognition Scheme for

Large Curvature Circular Tracks

and Its FPGA Implementation Using Hash Sorter

Jinyuan Wu

Fermilab

Sept. 2004

Tiny Triplet Finder

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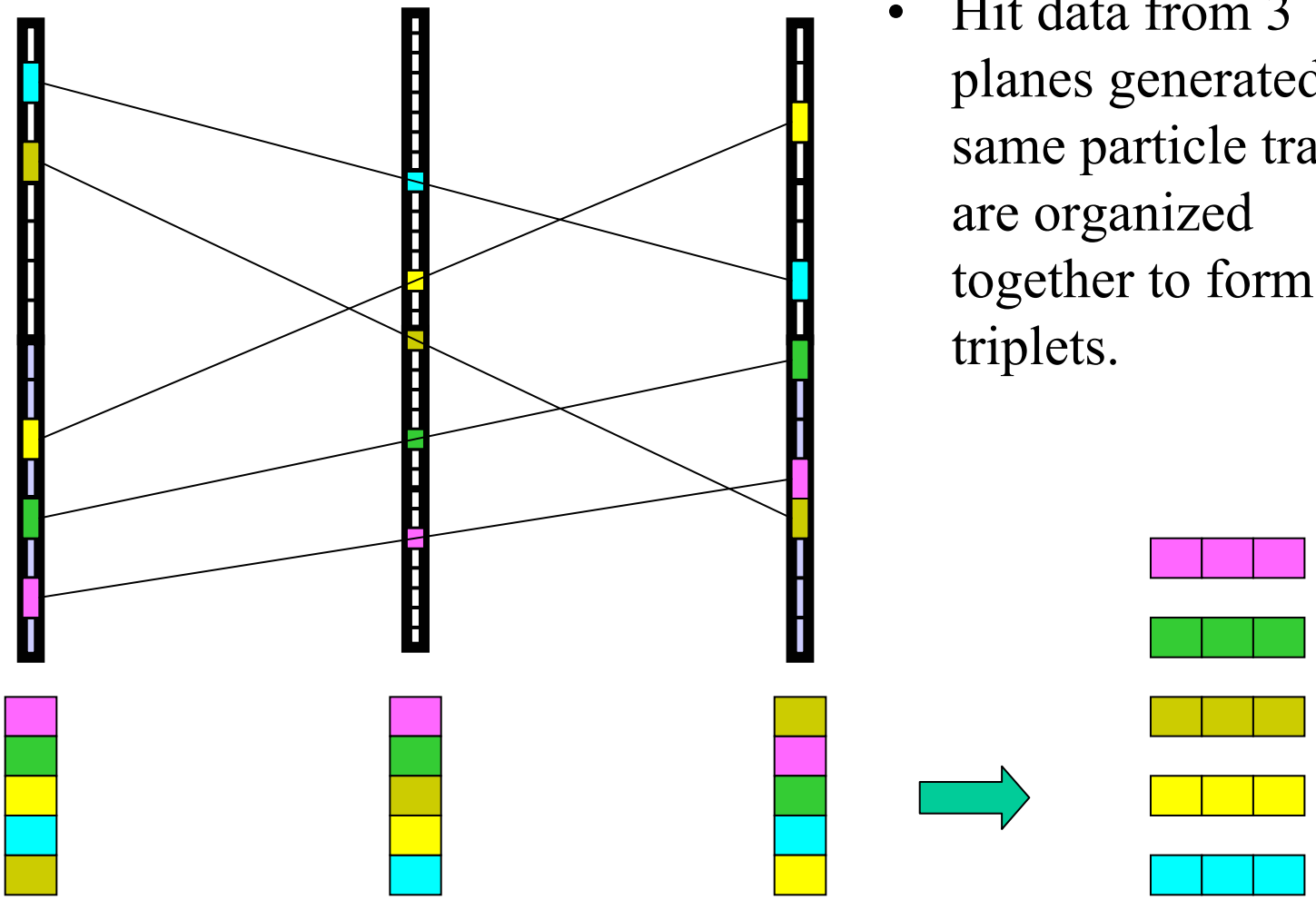
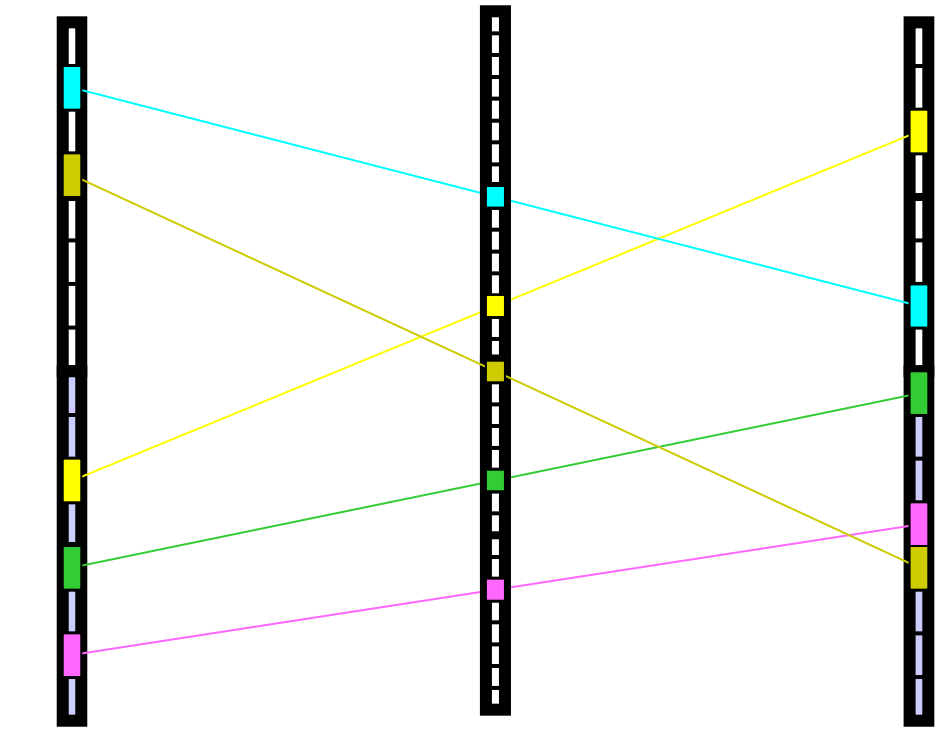
For BTeV Collaboration
Fermi National Accelerator Laboratory
Sept. 2004

Hits, Hit Data & Triplets (in BTeV)

- Hit data come out of the detector planes in random order.
- Hit data from 3 planes generated by same particle tracks are organized together to form triplets.

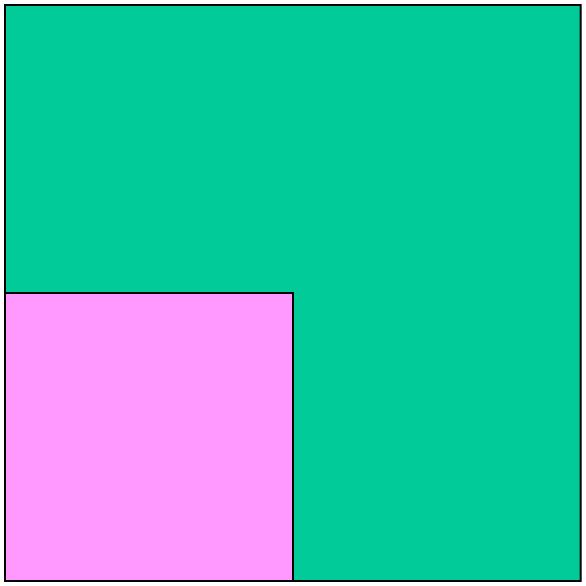


Triplet Finding



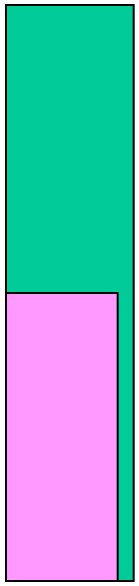
- Three data items must satisfy the condition: $x_A + x_C = 2\ x_B$.
- A total of n^3 combinations must be checked (e.g. 5x5x5=125).
- Three layers of loops if the process is implemented in software.
- Large silicon resource may be needed without careful planning: $O(N^2)$

Tiny? Yes, Tiny! – Logic Cell Usage:



CAM, Hough Transform

etc., $O(N^2)$

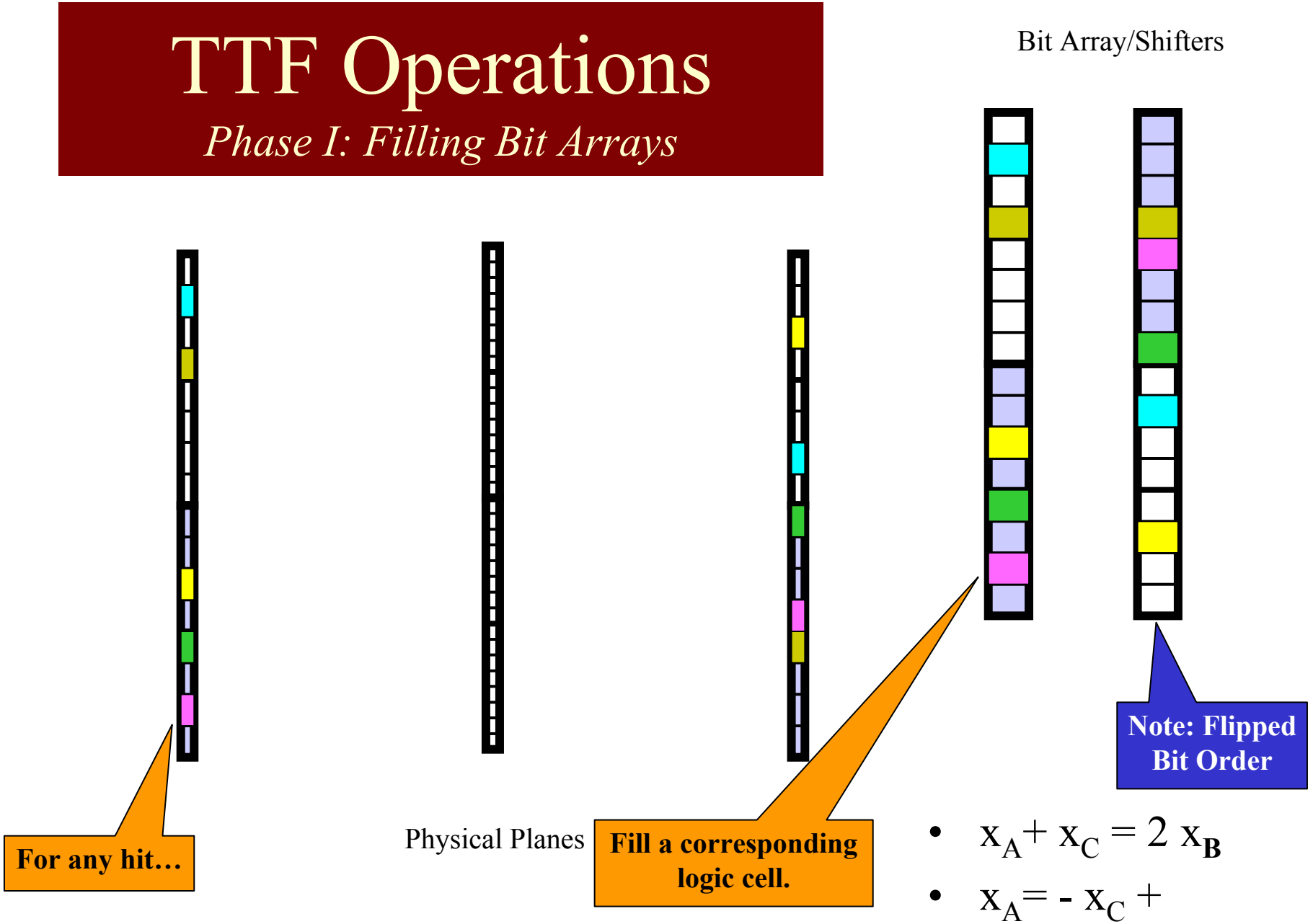


Tiny Triplet Finder

O(N*logN)

TTF Operations

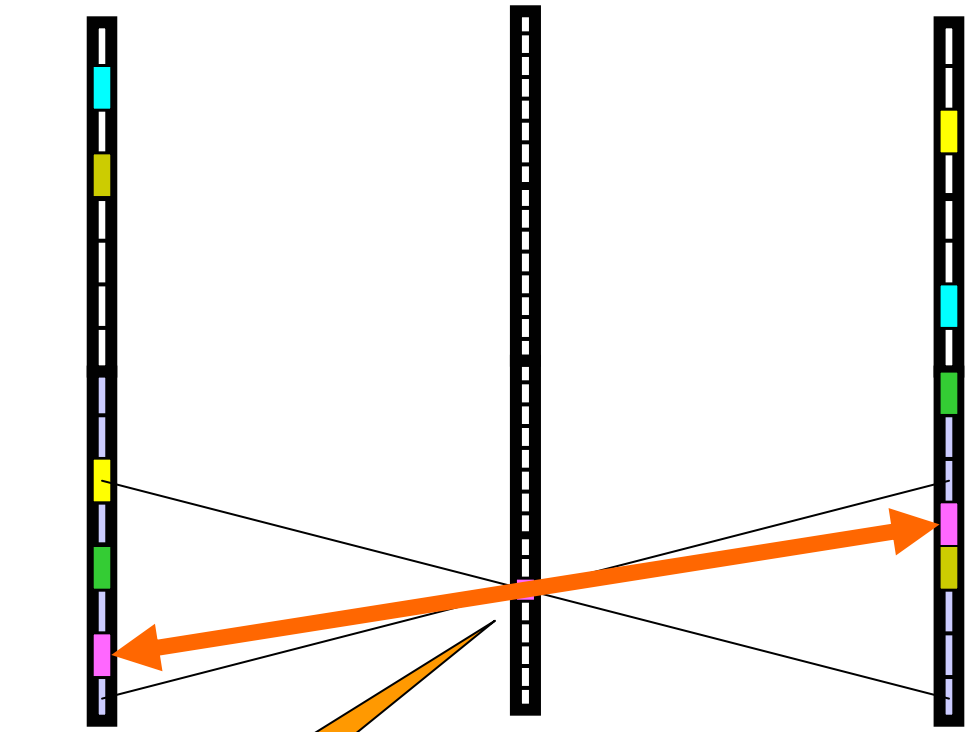
Phase I: Filling Bit Arrays



- $x_A + x_C = 2\ x_B$
- $x_A = -\ x_C +$ constant

TTF Operations

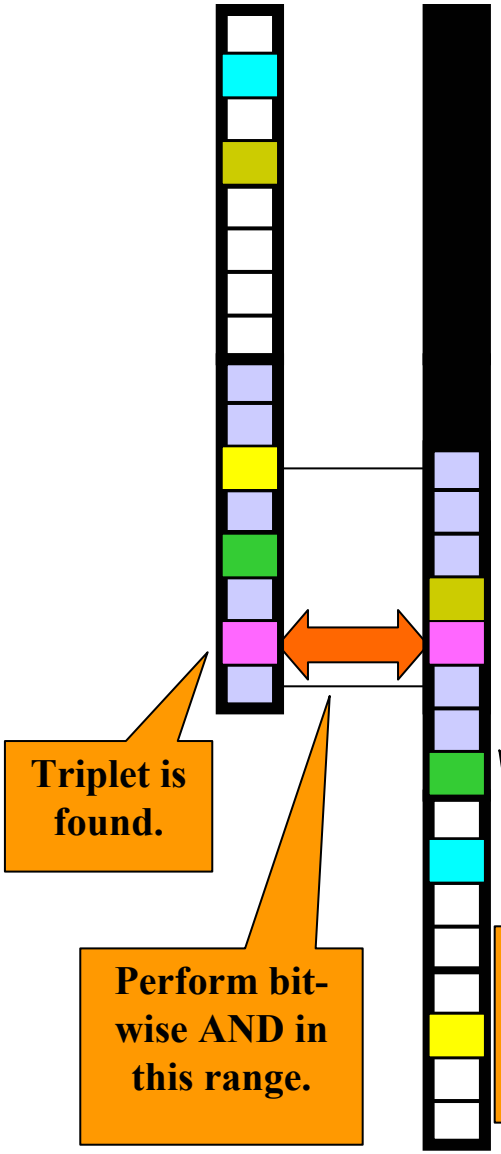
Phase II: Making Match



Physical Planes

For any center plane hit…

Bit Array/Shifters



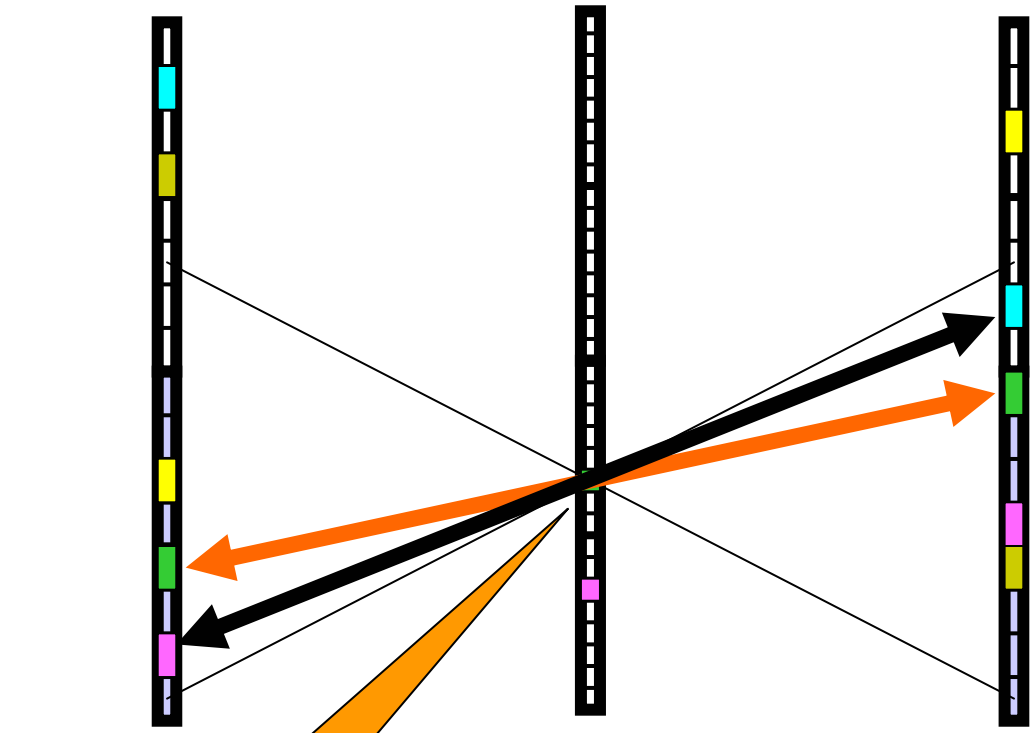
Triplet is found.

Perform bit-wise AND in this range.

Logically shift the bit array.

TTF Operations

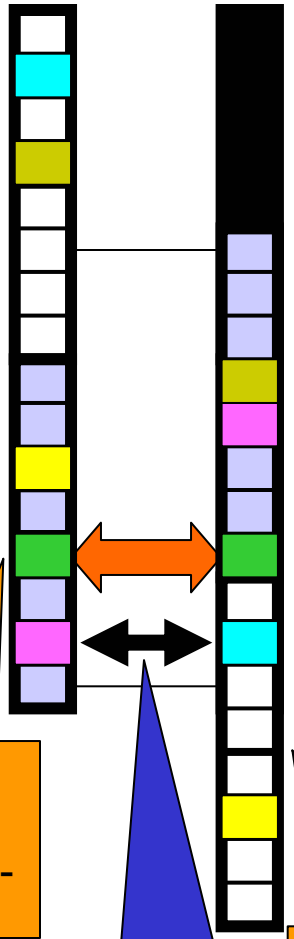
Phase II: Making Match (Next Hit)



Physical Planes

Loop to next center plane hit…

Bit Array/Shifters



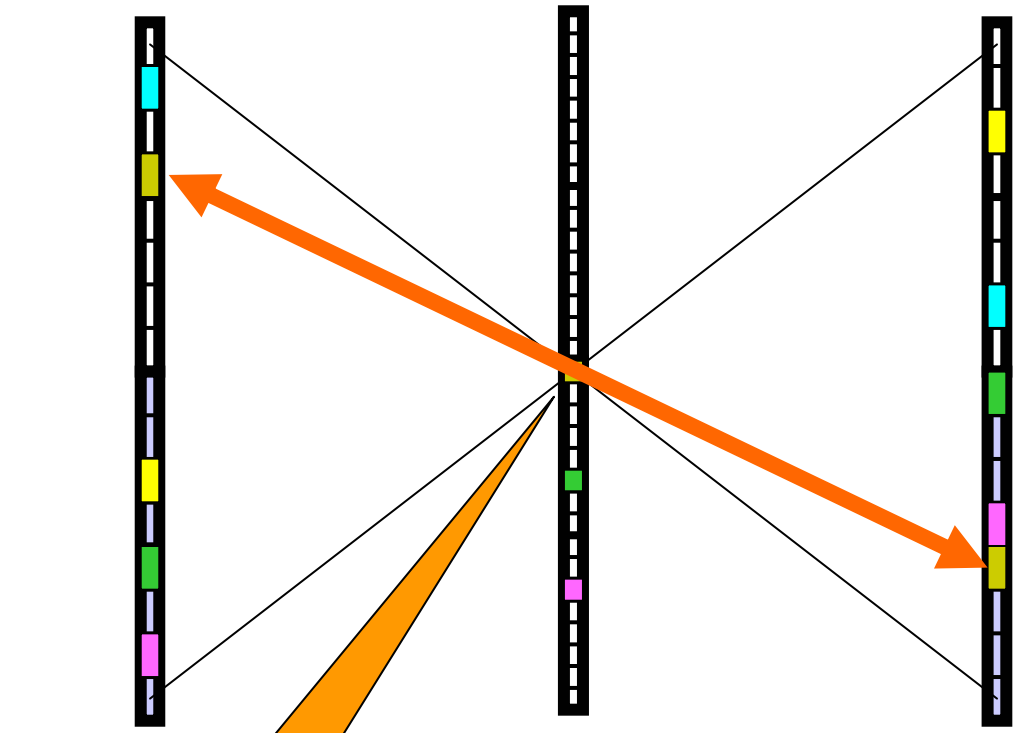
Triplet is found through bit-wise AND.

Fake triplet may exist. It will be cut out in the later stages.

Logically shift the bit array.

TTF Operations

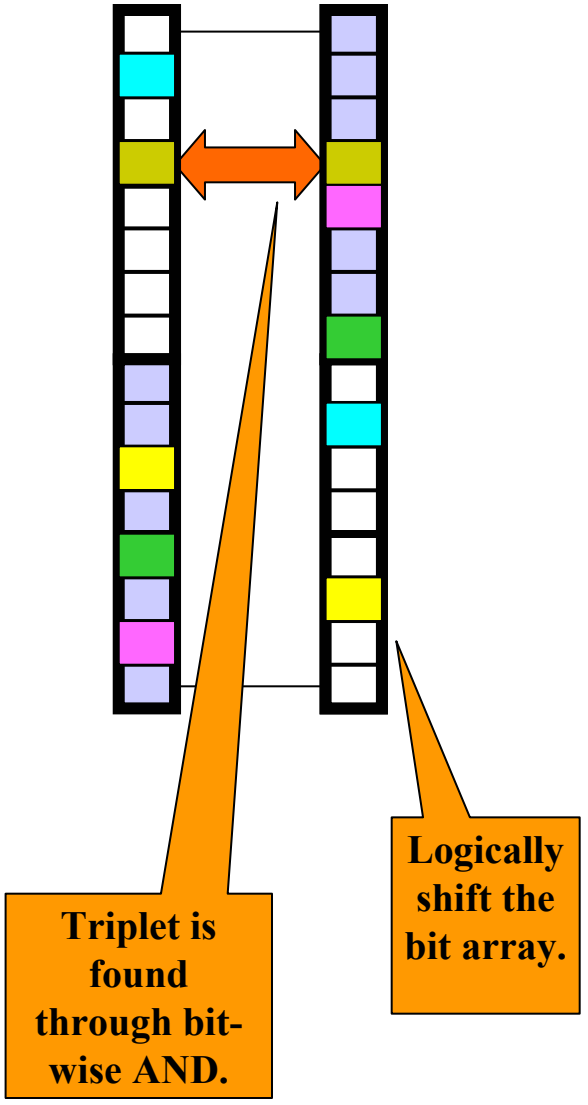
Phase II: Making Match (More…)



Physical Planes

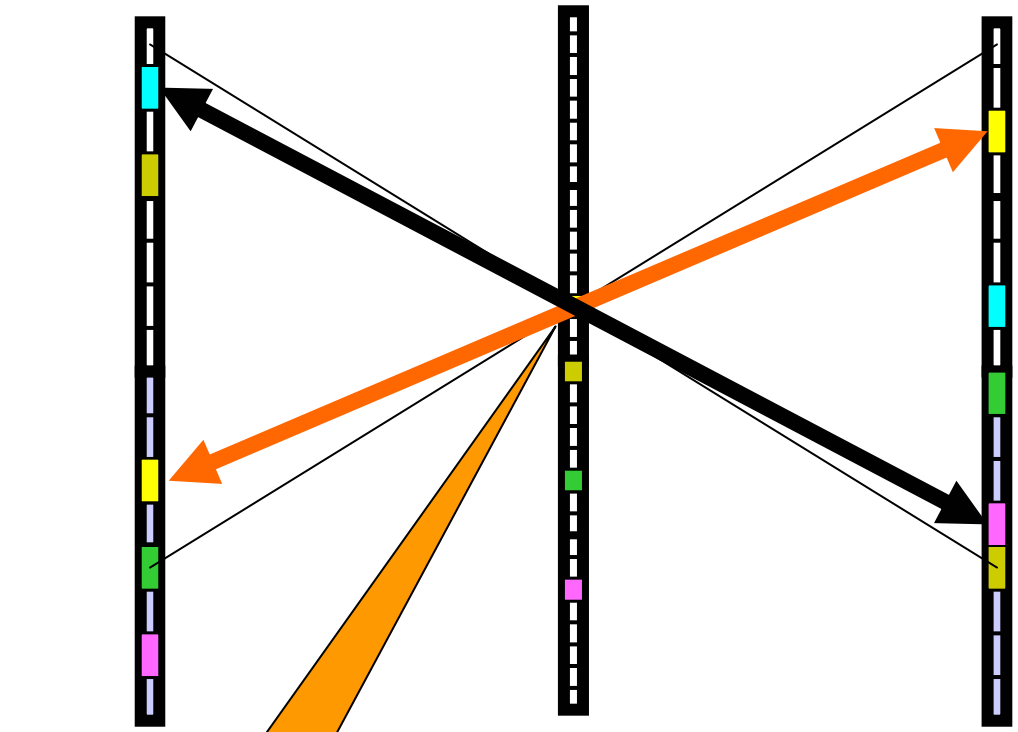
Loop to next center plane hit…

Bit Array/Shifters



TTF Operations

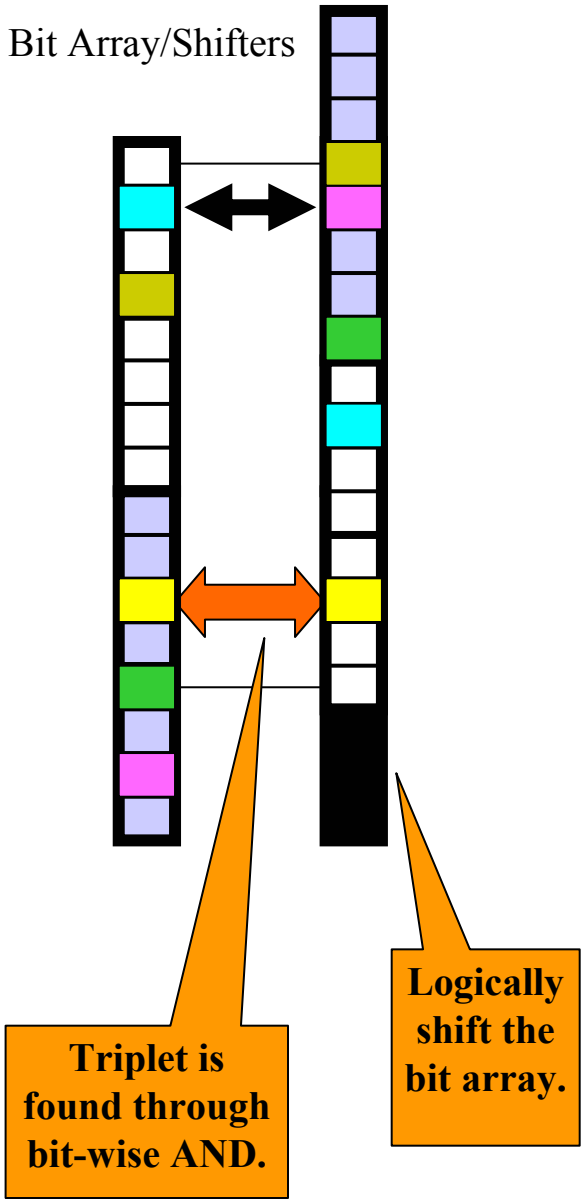
Phase II: Making Match (and More…)



Physical Planes

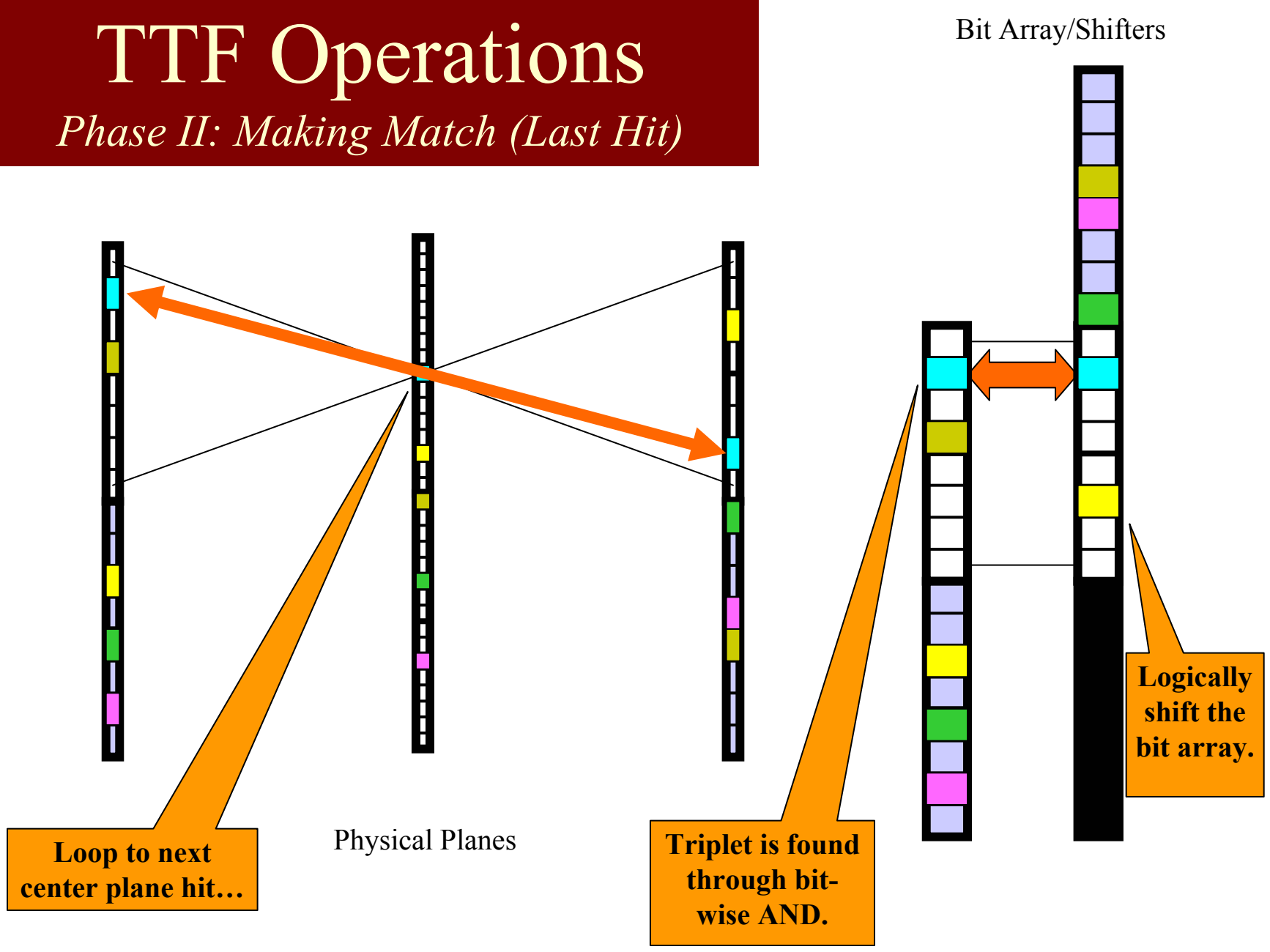
Loop to next center plane hit…

Bit Array/Shifters



TTF Operations

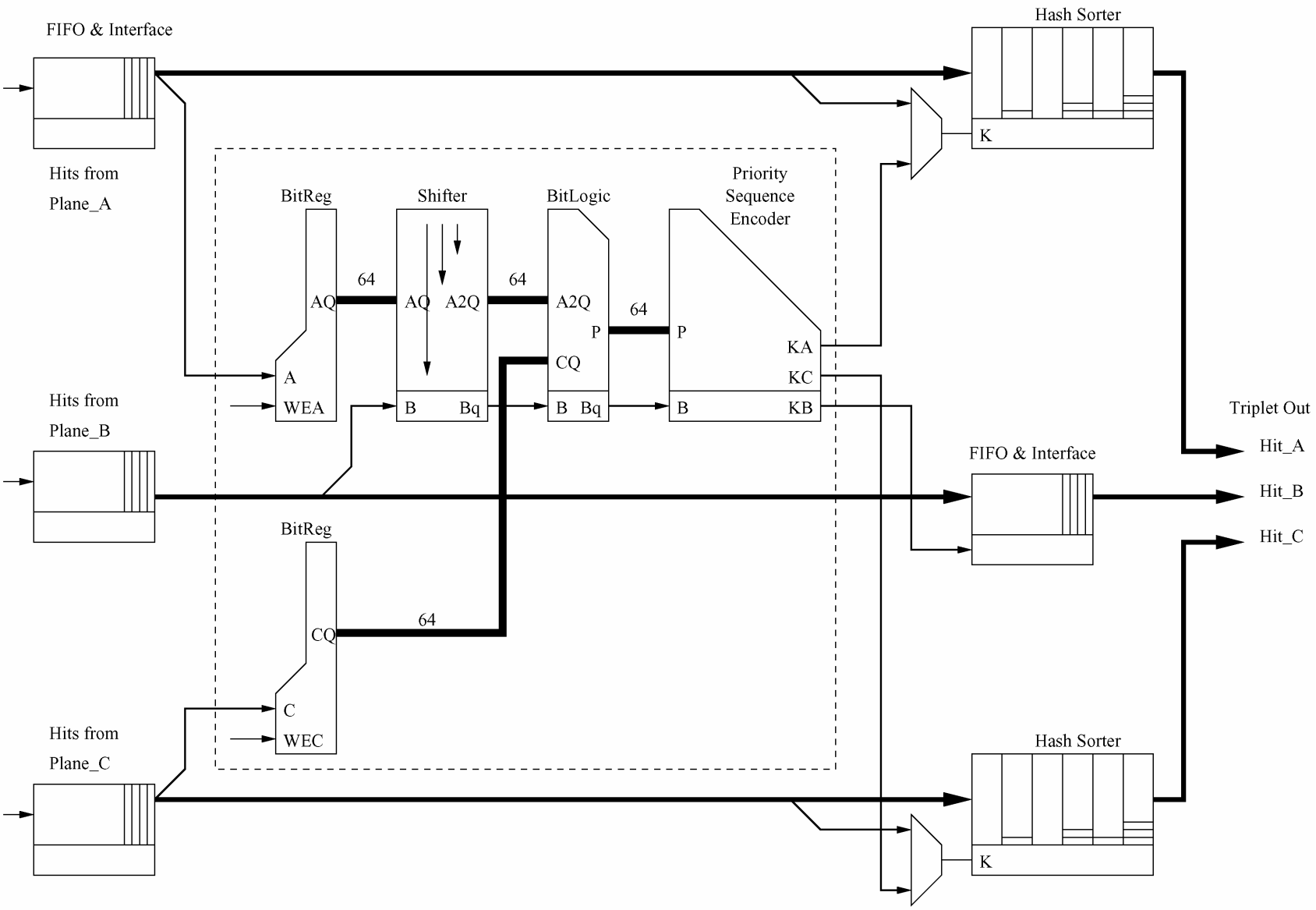
Phase II: Making Match (Last Hit)



Tiny Triplet Finder Operations

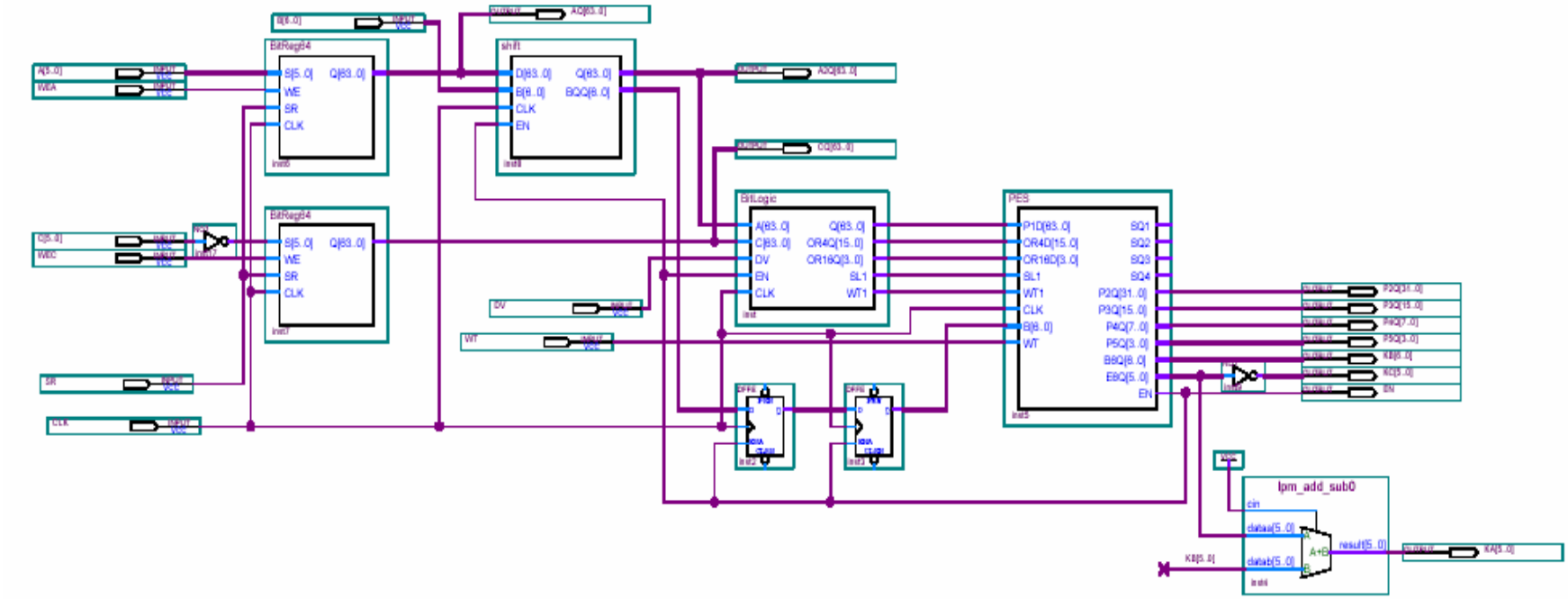
- Step 1:
  - Fill the bit arrays.
- Step 2:
  - Shift the bit array and check for bit-wise coincident.
- Step 3:
  - There is no step 3.

Block Diagram

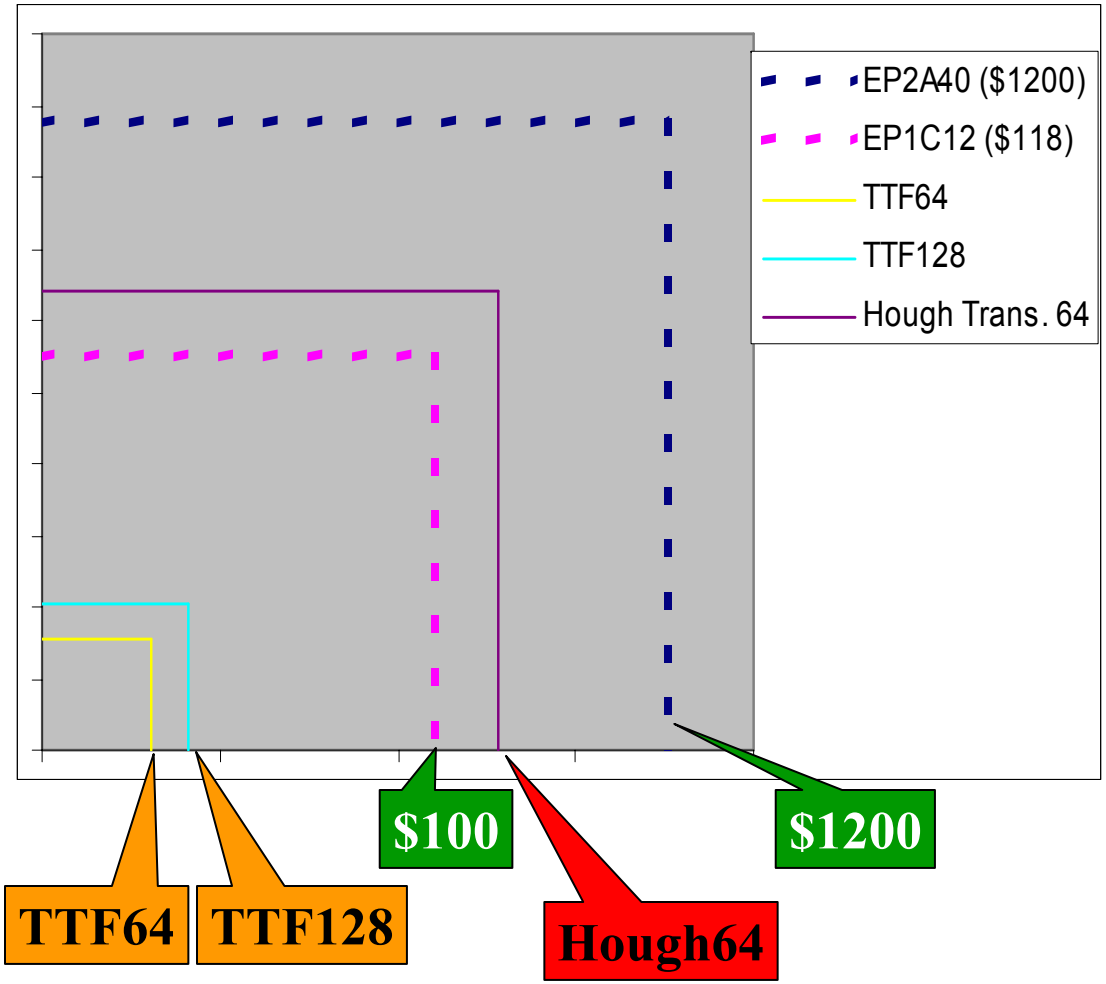


Schematics

Date: June 2, 2004 ttf.bdf Project: ttf

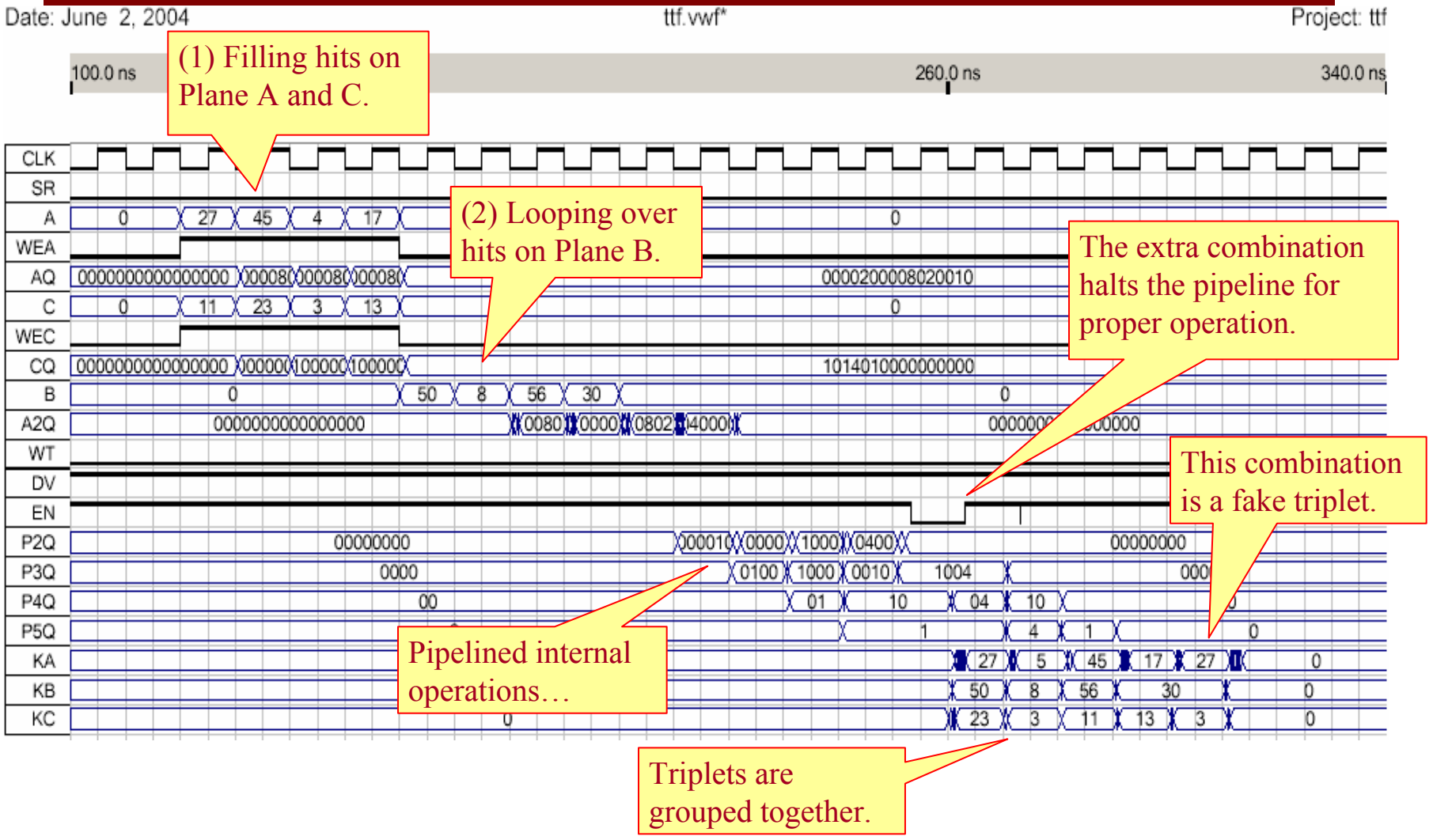


Logic Cell Usage



- Both 64- and 128-bit TTF designs fit $100 FPGA comfortably.
- A simple 64-bit Hough transform design is shown for scale.
- A $1200 FPGA is shown for scale.

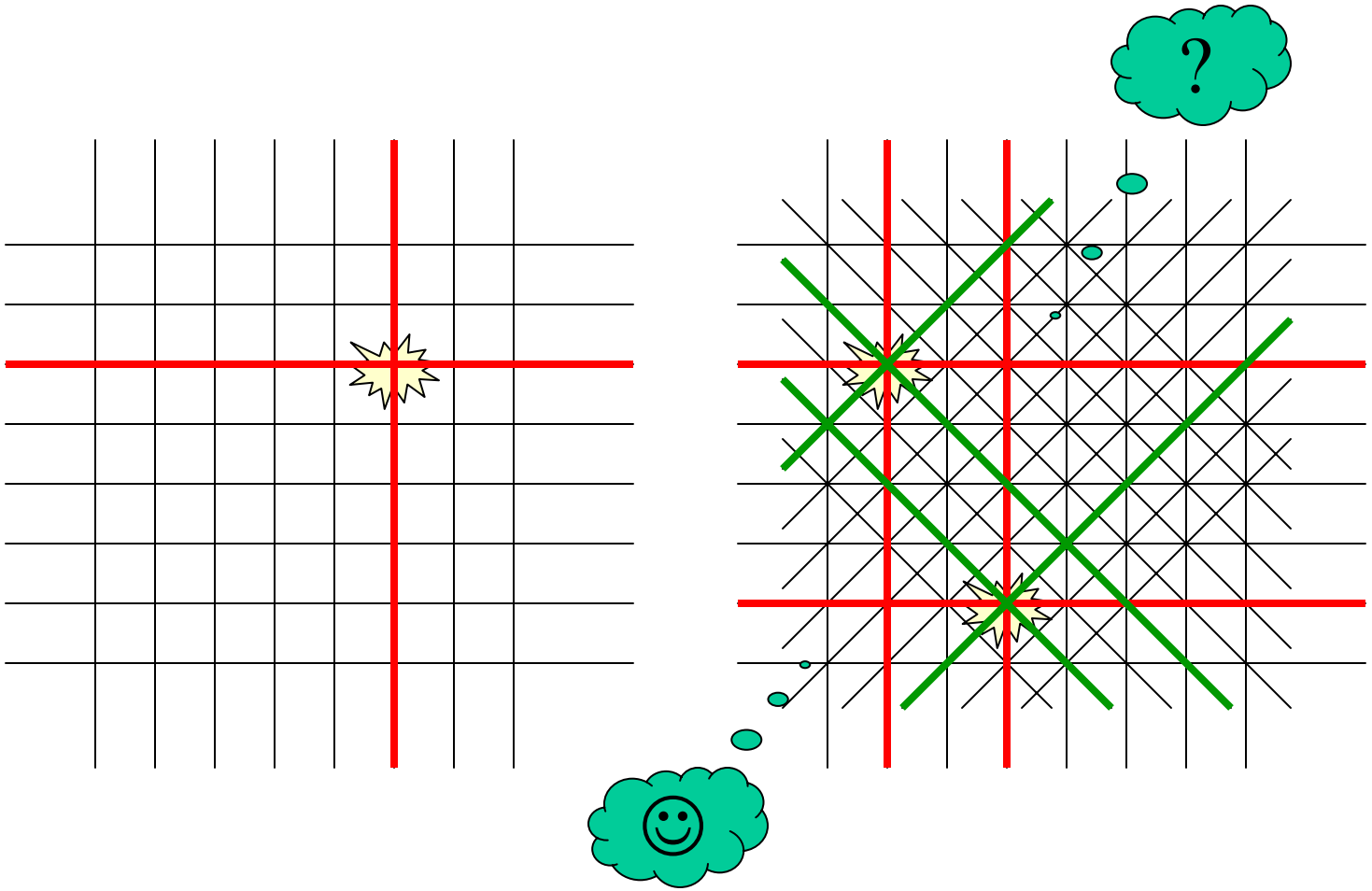
Simulation


Date: June 2, 2004
ttf.vwf*
Project: ttf
100.0 ns
260.0 ns
340.0 ns
(1) Filling hits on Plane A and C.
(2) Looping over hits on Plane B.
The extra combination halts the pipeline for proper operation.
This combination is a fake triplet.
Pipelined internal operations…
Triplets are grouped together.
CLK
SR
A
WEA
AQ
C
WEC
CQ
B
A2Q
WT
DV
EN
P2Q
P3Q
P4Q
P5Q
KA
KB
KC

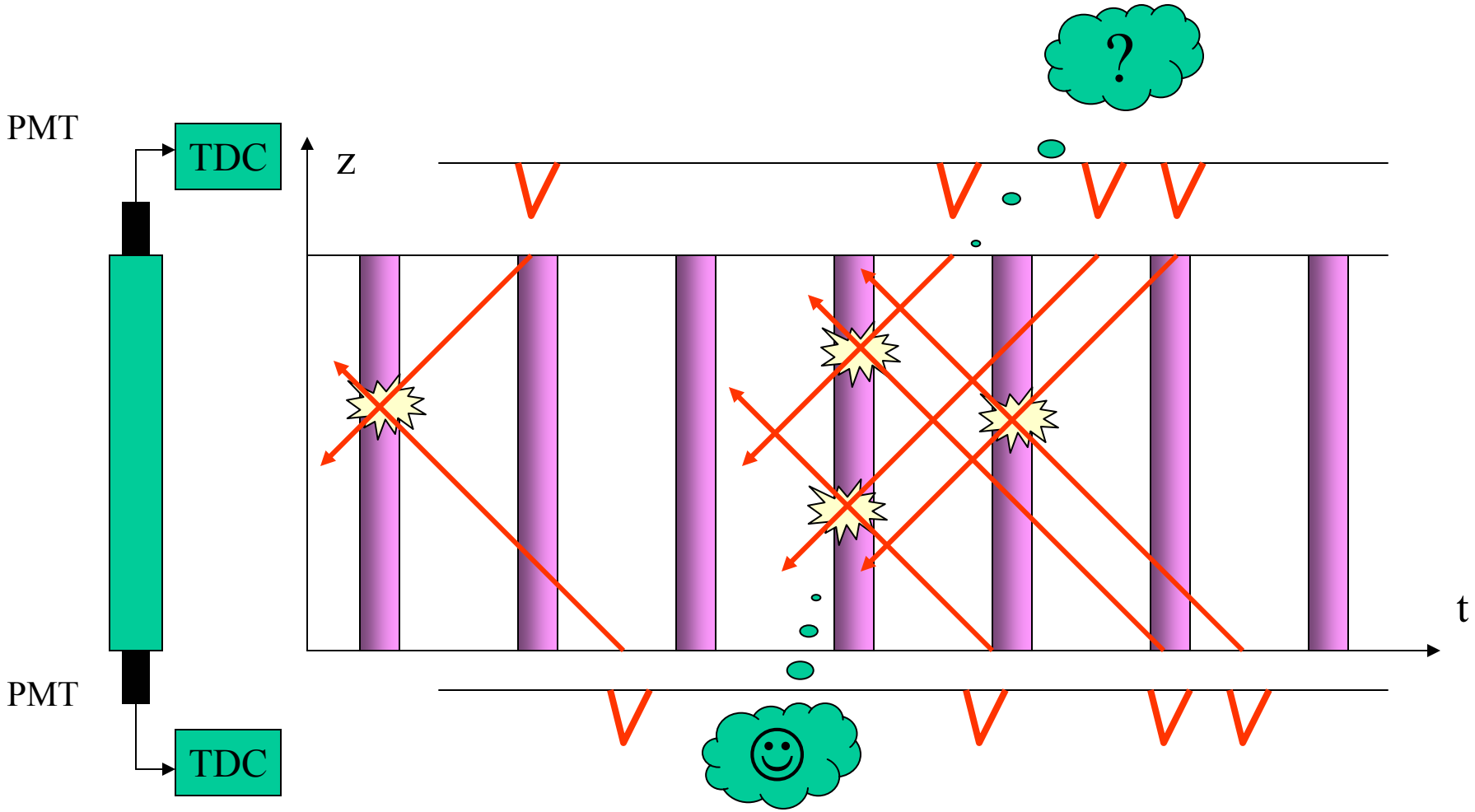
Other Applications of TTF

- There are other applications using same algorithm as TTF.
- Examples:
  - Wire chambers.
  - Time of flight counters.
  - GEM/MICROMEGAS

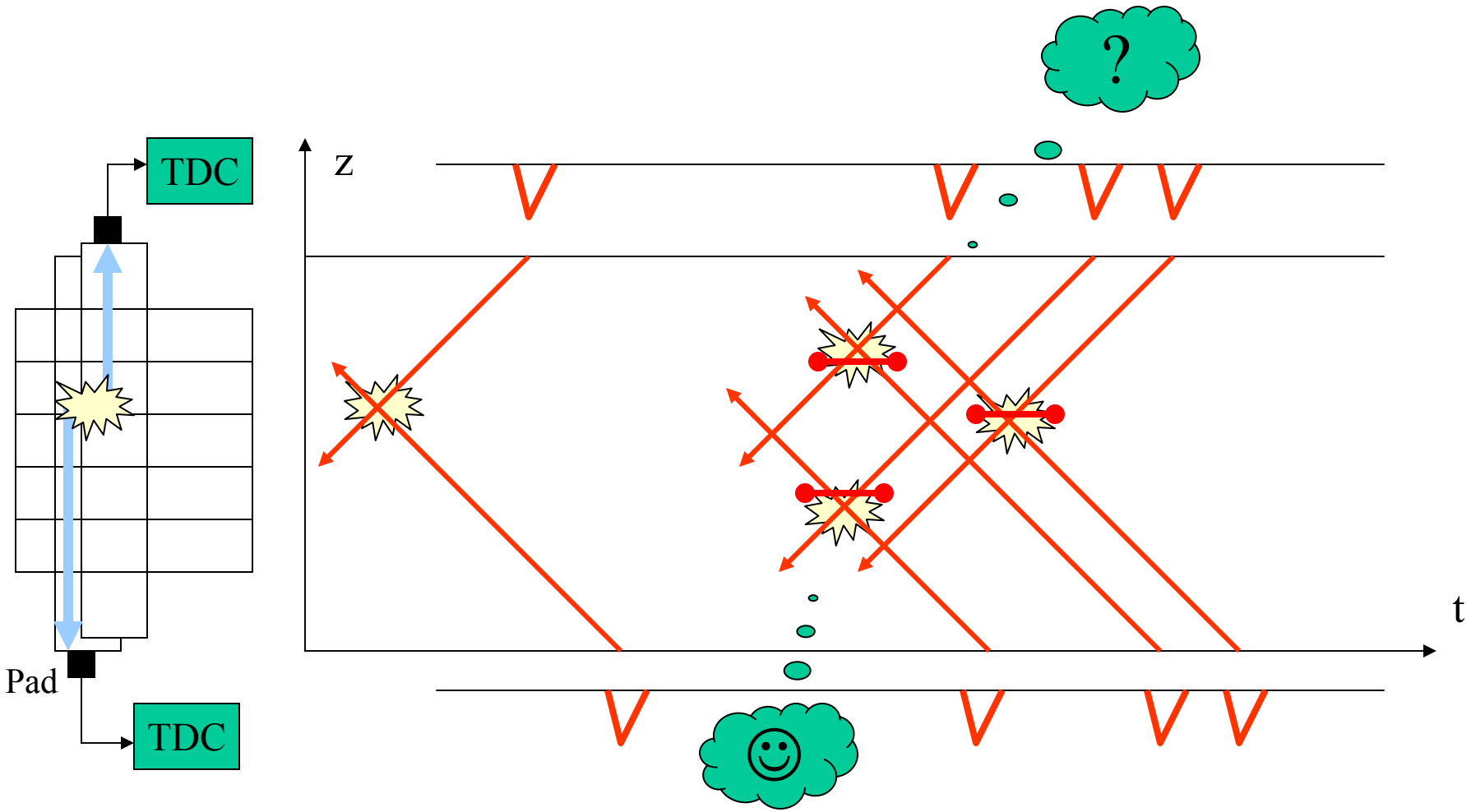
Other Applications: Wire Chambers



Other Applications: TOF



Other Applications: GEM/MICROMEGAS



Why Doing Something Tiny? Instead of Waiting for Moore's Law?

- Today, we hear Moore's law more often than Maxwell Equations.
- But in FPGA world, kilo- logic cells are still not so cheap – A quick argument.
- Consider FFT ($O(n^2)$->$O(n*\log n)$), 40 years ago:
  - If it were not developed, it would not be developed today.
  - Fortunately it was developed and we still use it today even though it is not necessary in many places.
  - We fully respect our grandparents for developing FFT.
- Now Tiny Triplet Finder ($O(N^2)$->$O(N*\log N)$):
  - If we do not developed it, it will not be developed in the future.
  - This piece of human knowledge will not ever exist.
  - Our grandchildren may say we are retarded – What's reputation of scientists of our generation?

A Pattern Recognition Scheme for Large Curvature Circular Tracks and Its FPGA Implementation Using Hash Sorter

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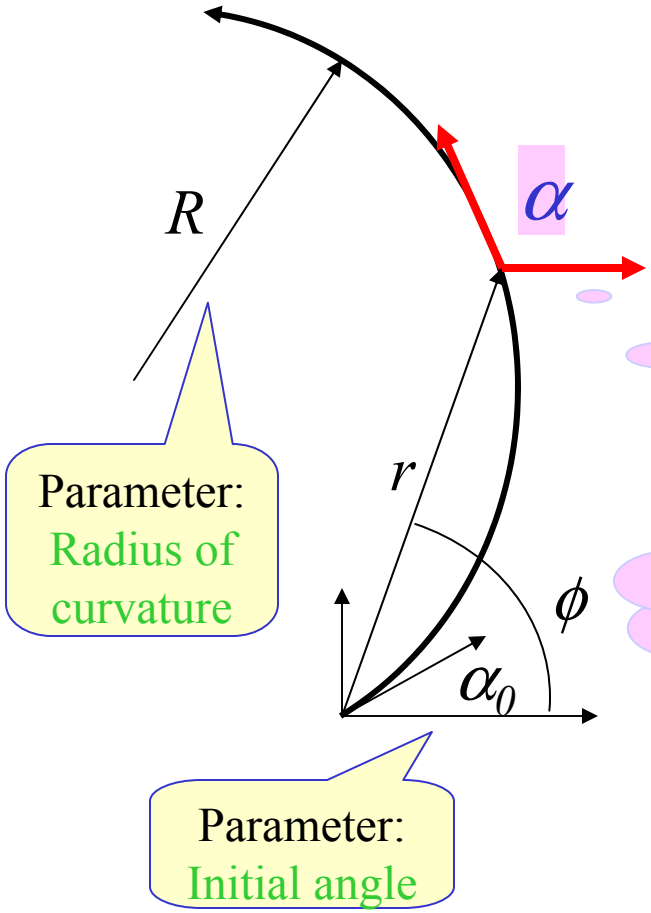
Batavia, IL 60510, USA

A Large Curvature Track

- A soft track hits large ϕ region.
  - A global algorithm is better suited.
- The "high-p_T" approximation is not valid globally.
  - Exact track equation is needed.



$$r = 2R\sin(\phi - \alpha_0)$$

Measure the tangent angle..

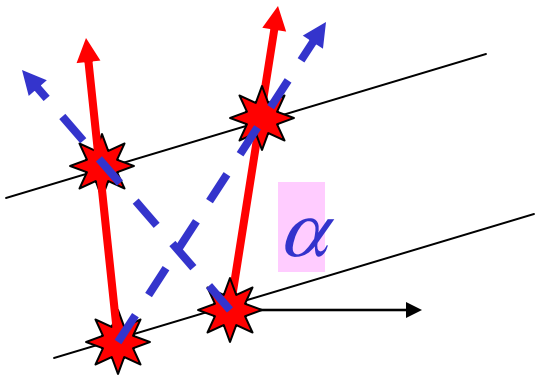
~~$r = 2R(\phi - \alpha_0)$~~

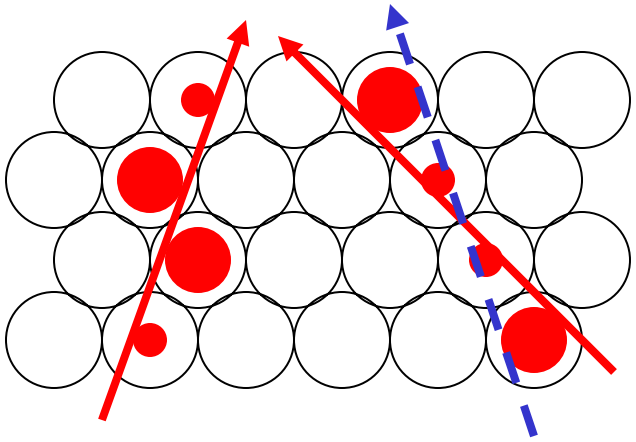
$$\alpha_0 = 2\phi - \alpha$$

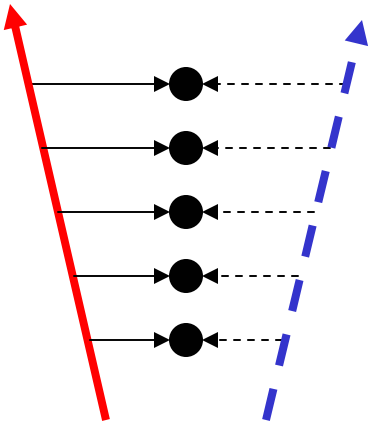
$$\frac{r}{2R} = \sin(\alpha - \phi)$$

Tangent Angle Measurements

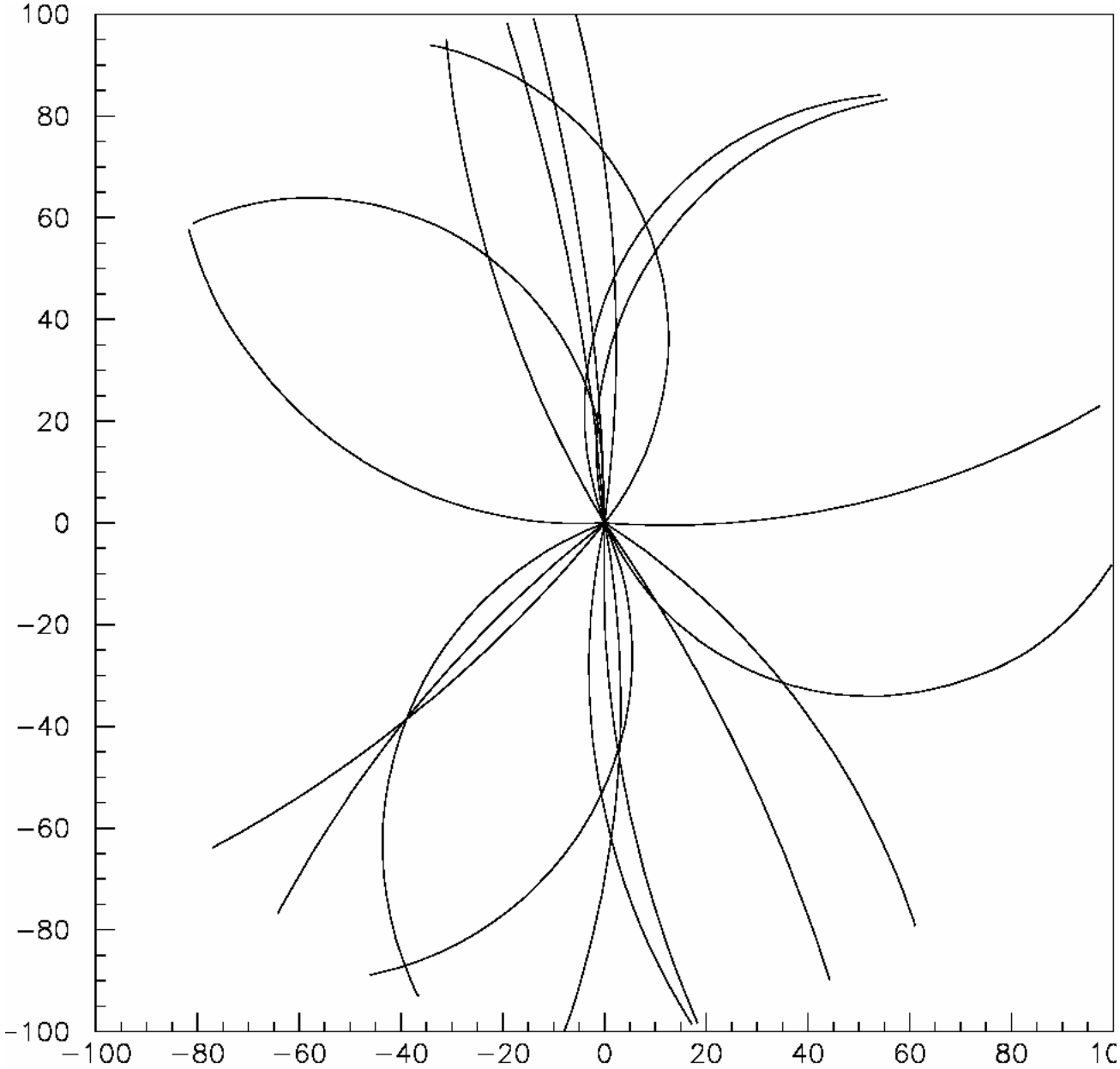
- There are various techniques to measure the tangent angle of the track segment (or “doublet”, or “cluster”).
- Sometimes extra “ghost” segments may exist.
- The ghost segments may be resolved in track recognition process later.





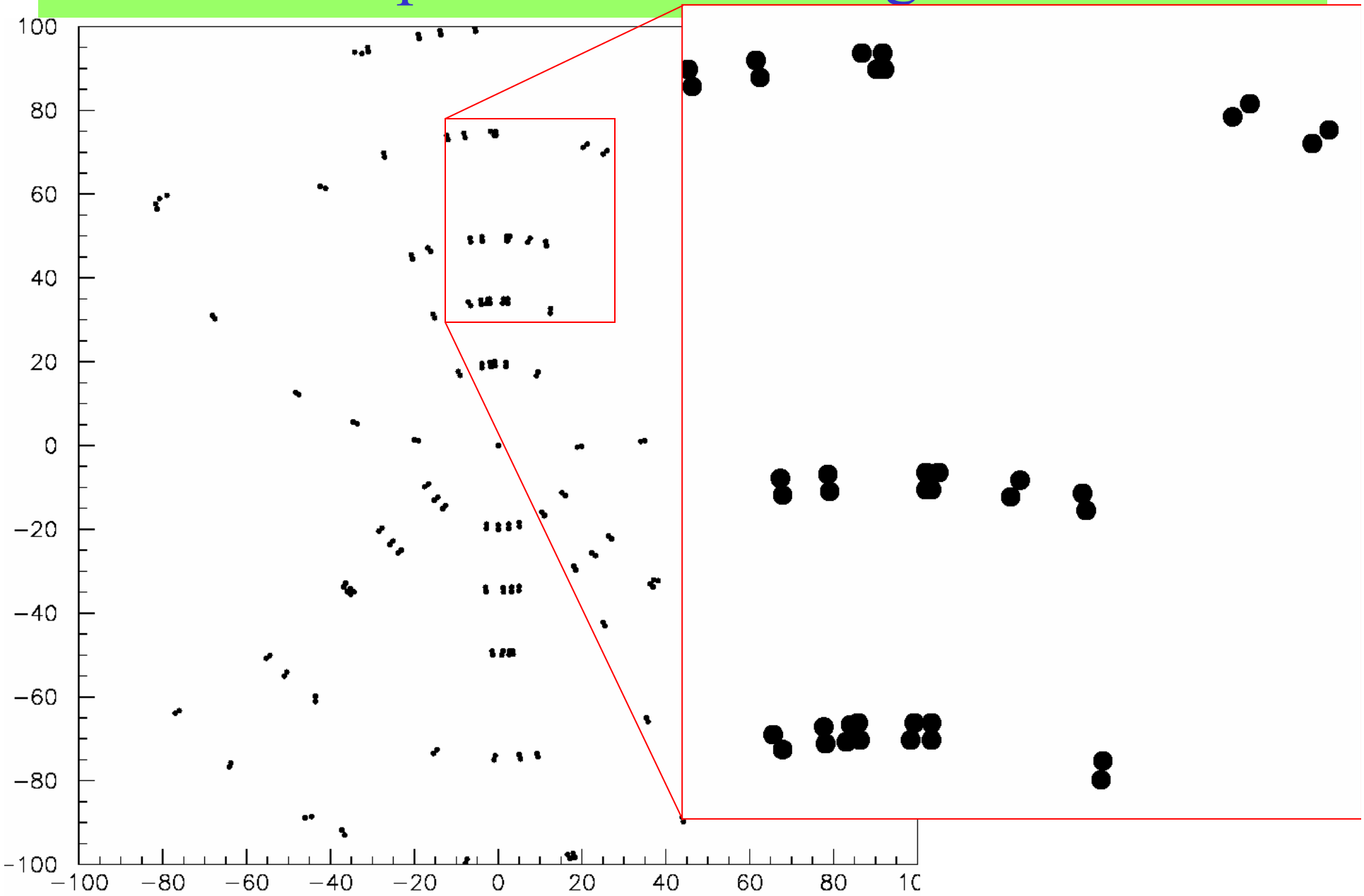


An Example of Track Recognition: *Event*

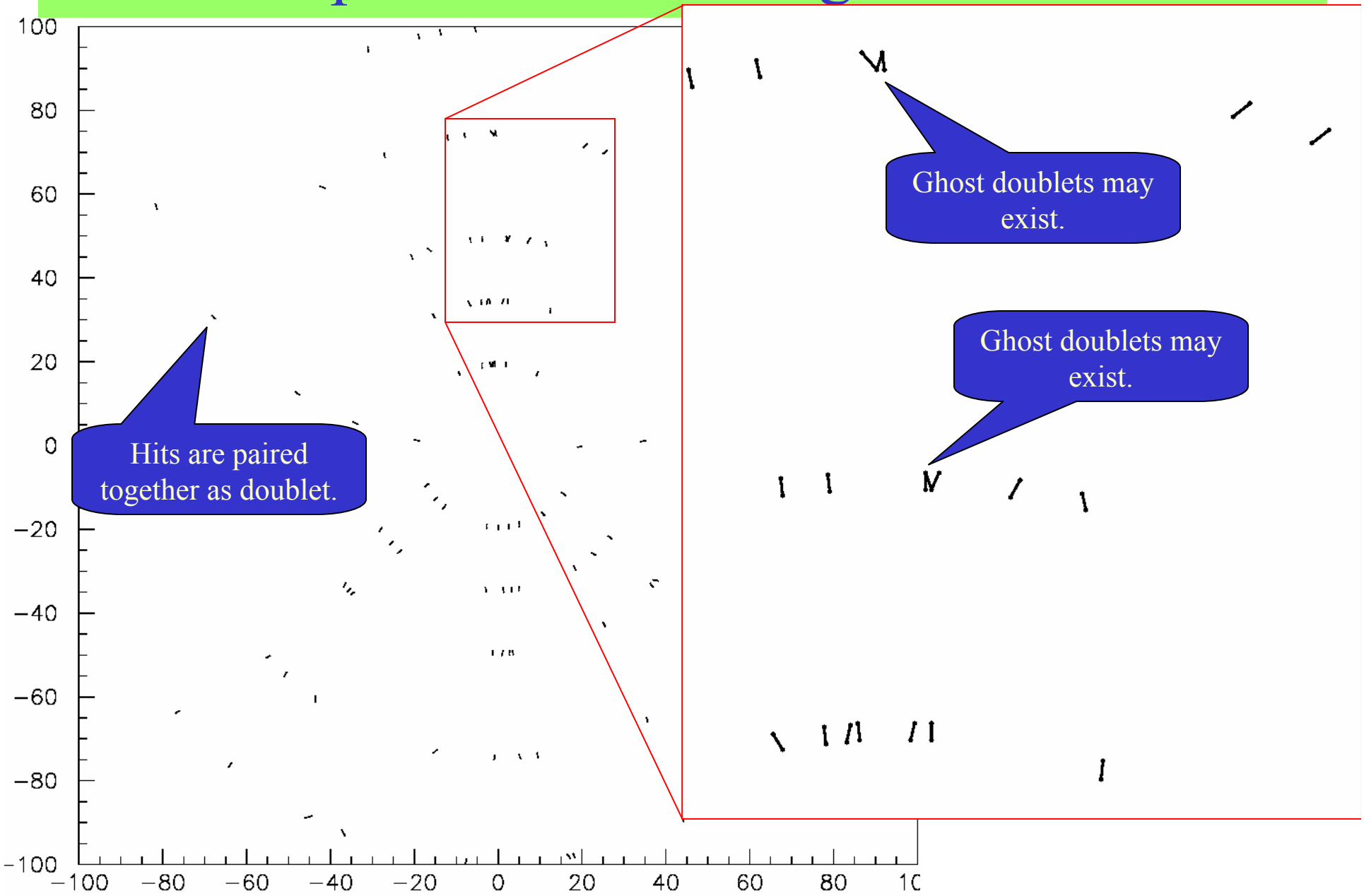


- We explain the track recognition process using this 20-track example.

An Example of Track Recognition: *Hits*



An Example of Track Recognition: *Doublets*



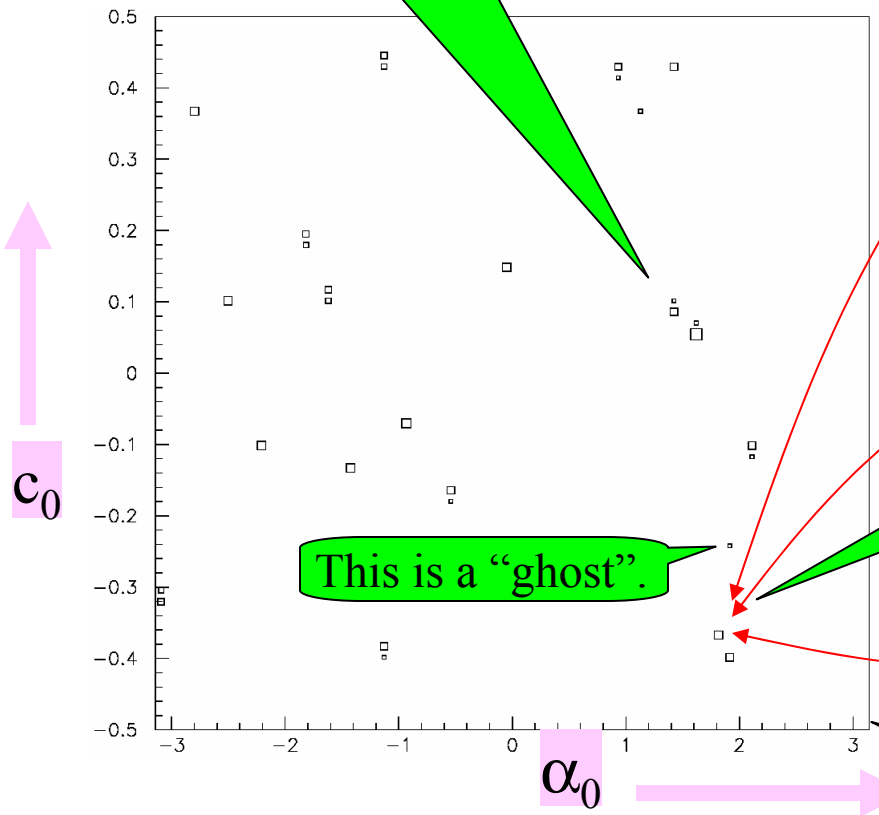
An Example of Track Recognition: *Histogram*

$$\alpha_0 = 2\phi - \alpha$$

$$c_0 = \frac{25cm}{R} = \frac{50cm}{r}\sin(\alpha - \phi)$$

Two track parameters can be calculated for each doublet.

Sometimes they are stored in clusters.



This is a "ghost".

Doublets from same track are entered into same bin, (since they have same track parameters).

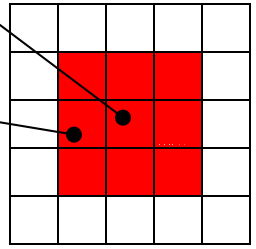
A 2-D histogram is booked.

An Example of Track Recognition: *Clustering*

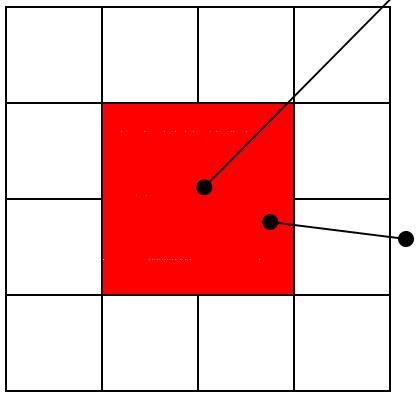
For doublets on the seeding super layer in this bin…

search for coincident in these 9 bins.

The 9-bin scheme



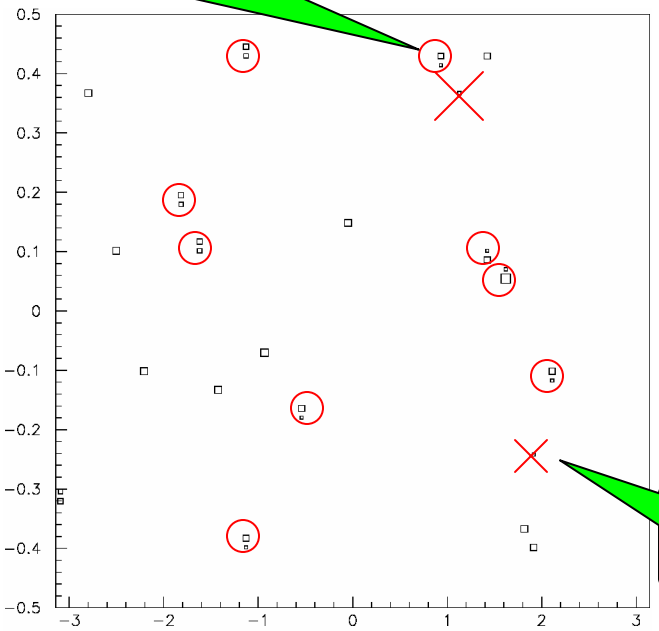
The 4-bin scheme



For doublets on the seeding super layer in this bin…

search for coincident in these 4 bins.

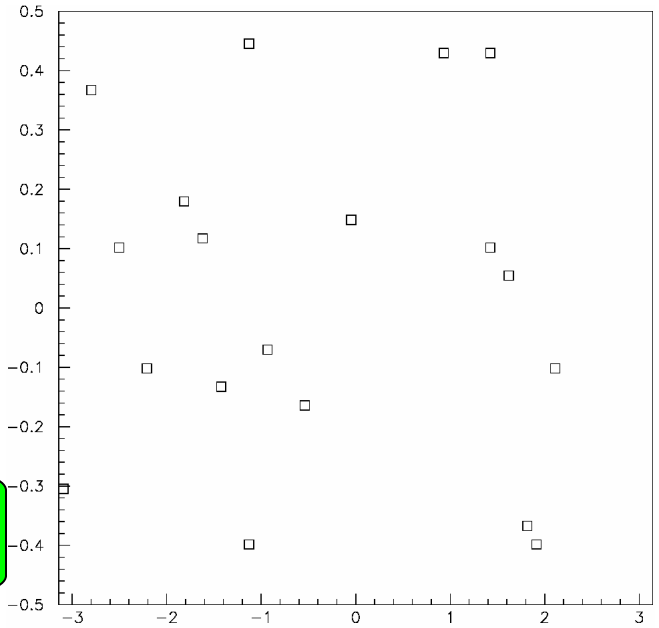
The doublets in clusters are grouped together.



c_0

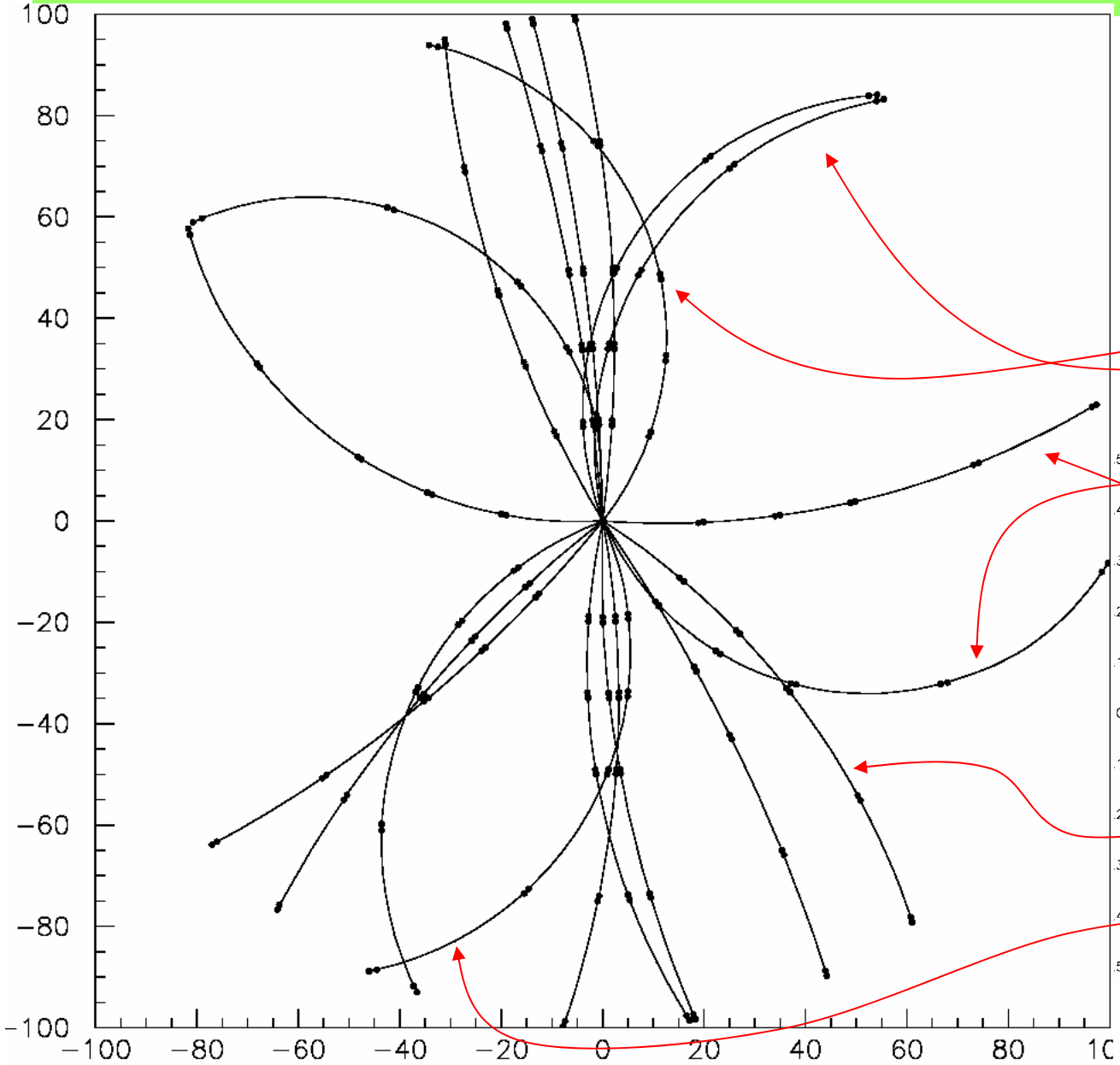
α_0

clustering

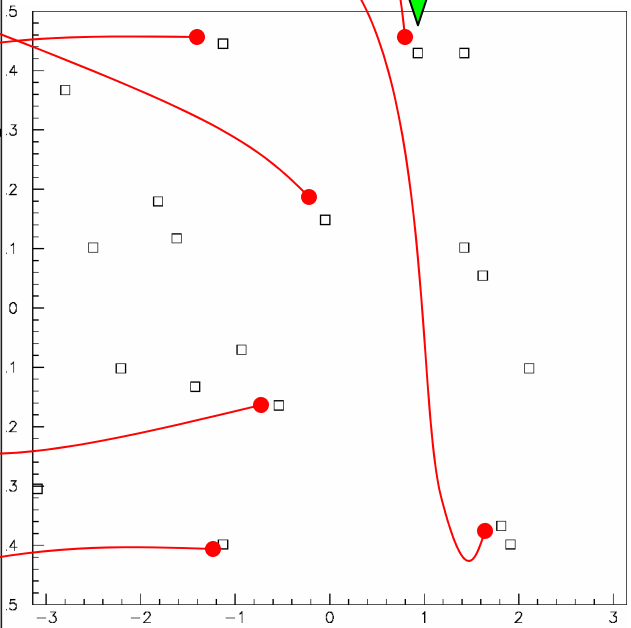


The "ghost" doublets are gone.

An Example of Track Recognition: *Tracks*



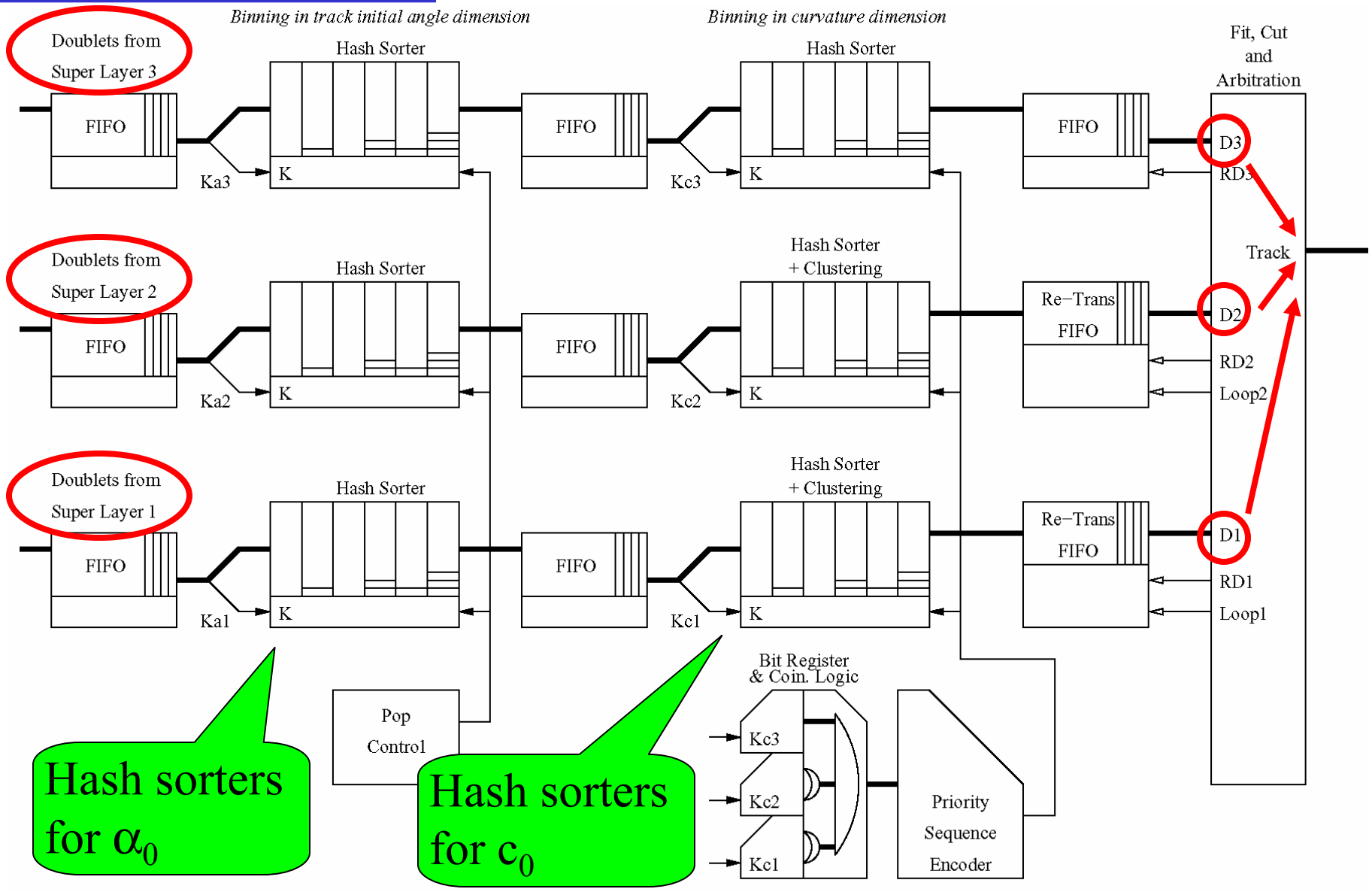
All doublets from a track are contained in a cluster.



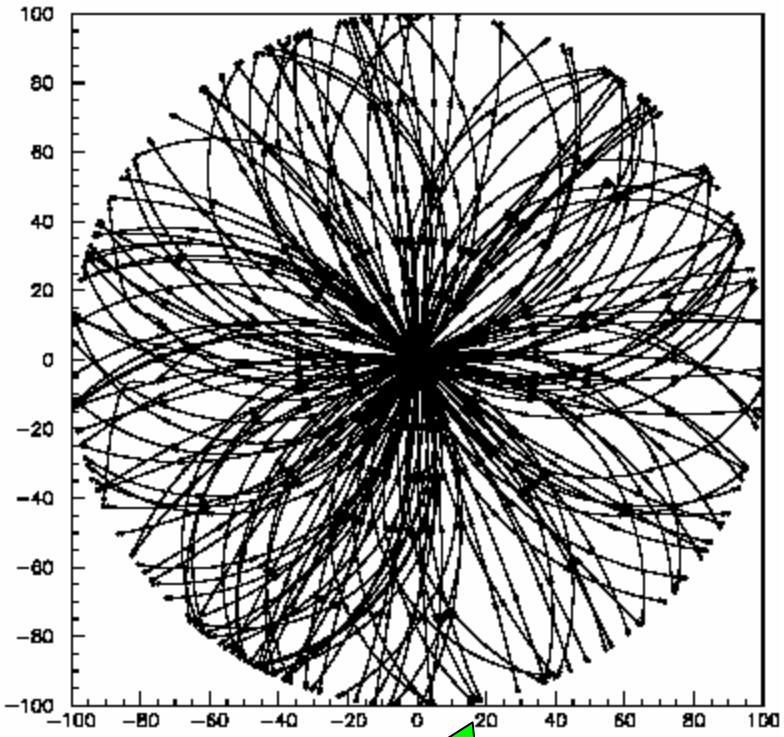
$$\alpha_0 = 2\phi - \alpha$$

$$c_0 = \frac{25cm}{R} = \frac{50cm}{r}\sin(\alpha - \phi)$$

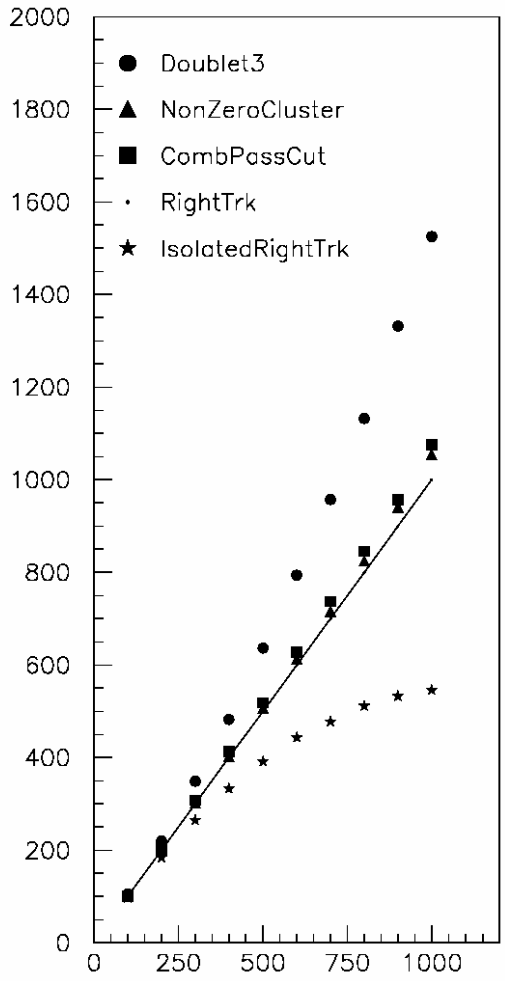
FPGA Block Diagram

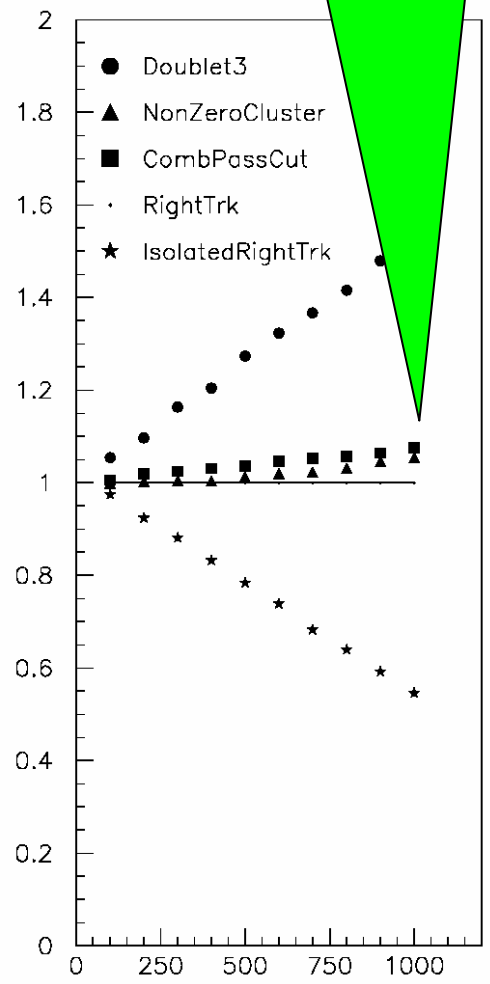


Simulation Results



An event with 200 tracks





It still works at 1000 tracks/event

Without Full Track Recognition

$$\alpha_0 = 2\phi - \alpha$$

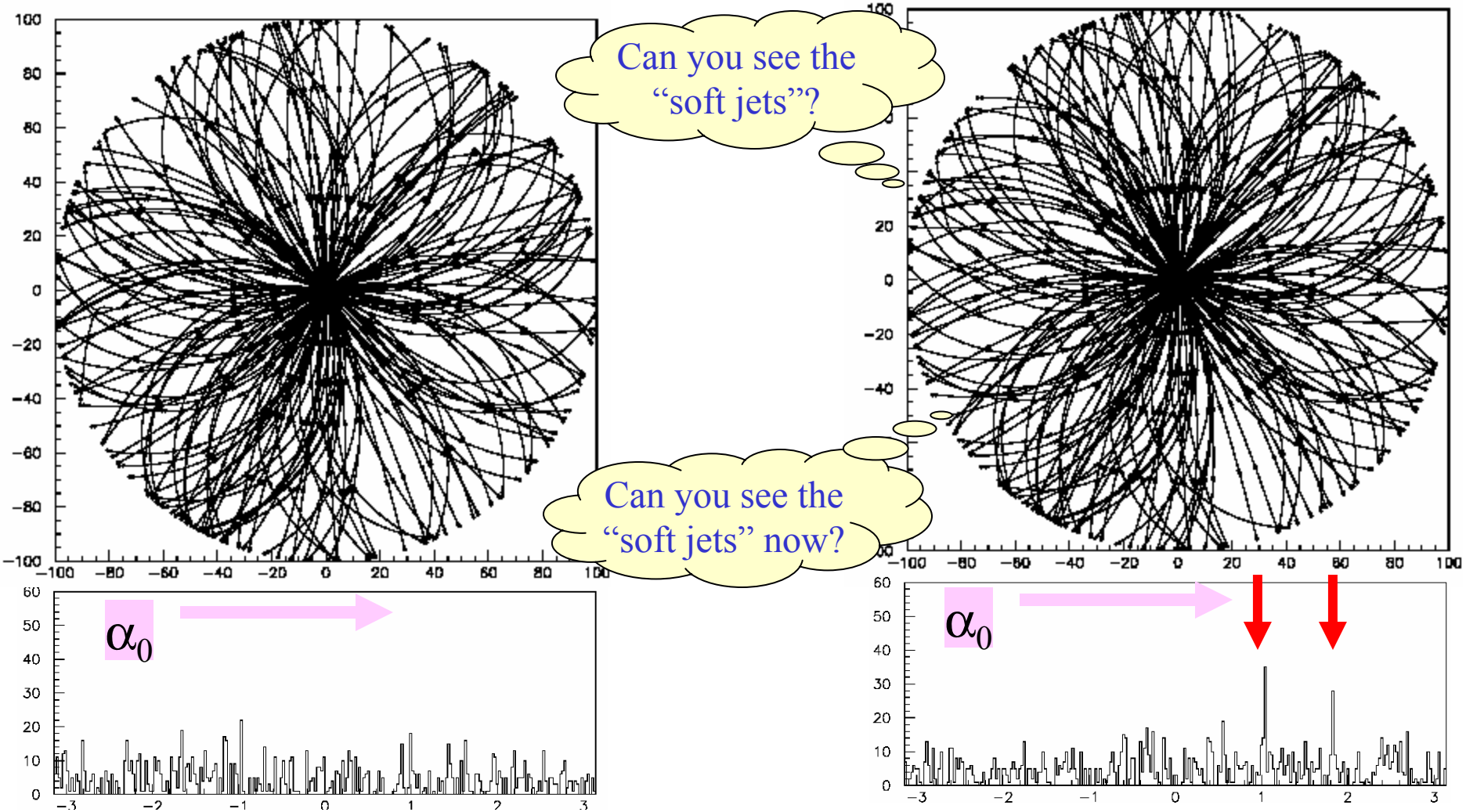
$$c_0 = \frac{25cm}{R} = \frac{50cm}{r}\sin(\alpha - \phi)$$

- Two track parameters can be calculated for each doublet.
- Useful trigger primitives can be found without full track recognition.
- For example…

Example: Finding "Soft Jets"

- A simulated event with 200 tracks.
- Flat distributions.
- Min. R = 55 cm

- 16 soft tracks are added.
- They are grouped in 2 small initial angle regions, i.e., 2 "soft jets".



Soft Tracks?

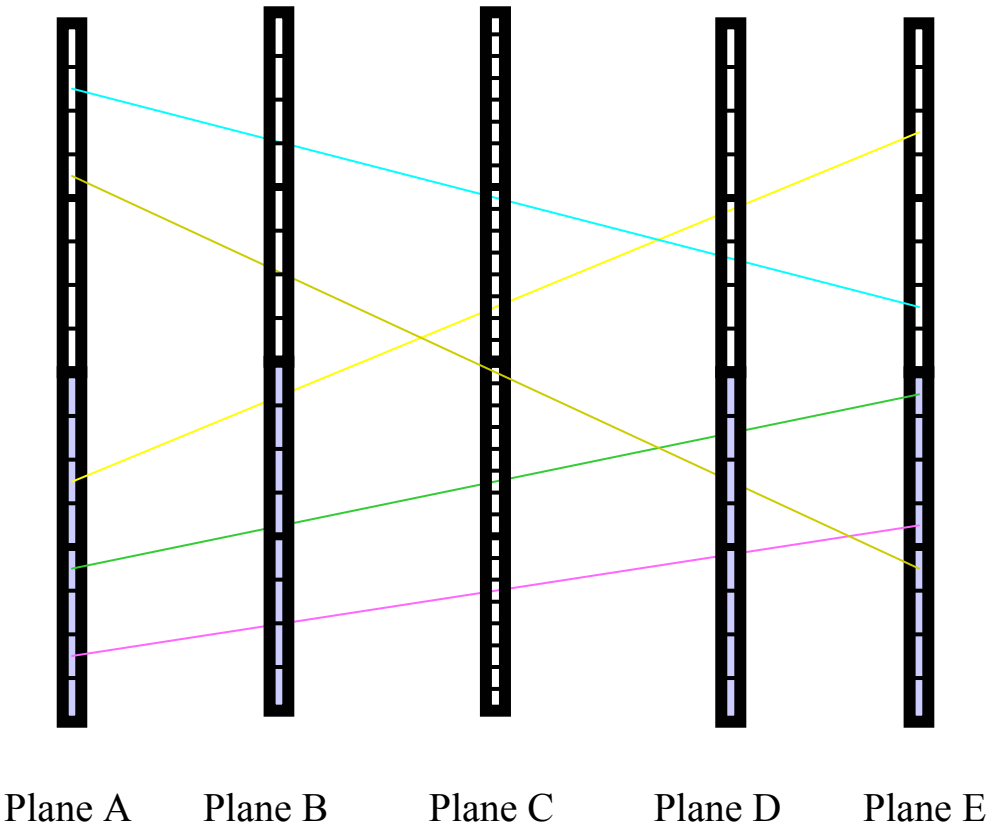
- Can we always anticipate high-p_T signatures?
  - Probably not.
- Do soft tracks carry useful information?
  - Maybe.
- In strong magnetic fields, (e.g. 4T in CMS), high-p_T tracks look soft.
- Isn't it too hard to use soft tracks in trigger stage?
  - It was, but now it is not too hard. ☺

The End

Thanks

Pentlet Finding

Beyond Just Bit-wise AND

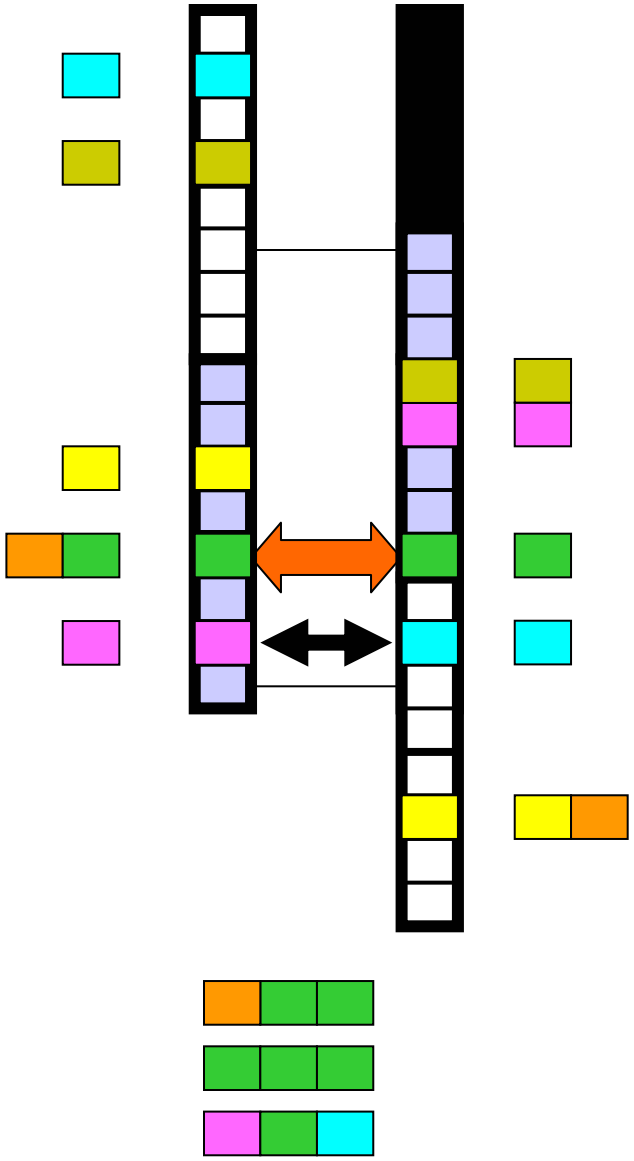


- Use 4 bit arrays.
- There are 3 constraints total.
- More constraints help to eliminating fake tracks.
- It is possible to use bit-wise majority logic (such as 3-out-of-4) to accommodate detector inefficiency issues.

Multiple Hits & Triplets

Keep Them All

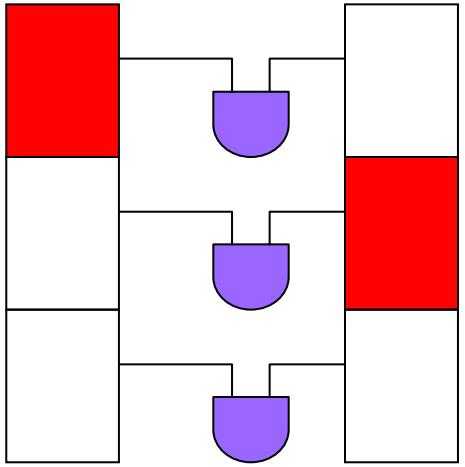
- Each bin may be filled with more than one hits.
- Hits data are kept in hash sorters – allowing multiple hits per bin.
- There are may be more than one match in each bit-wise AND operation.
- They are all sent out, one-by-one, to the later stages for fine cut and arbitration processes.

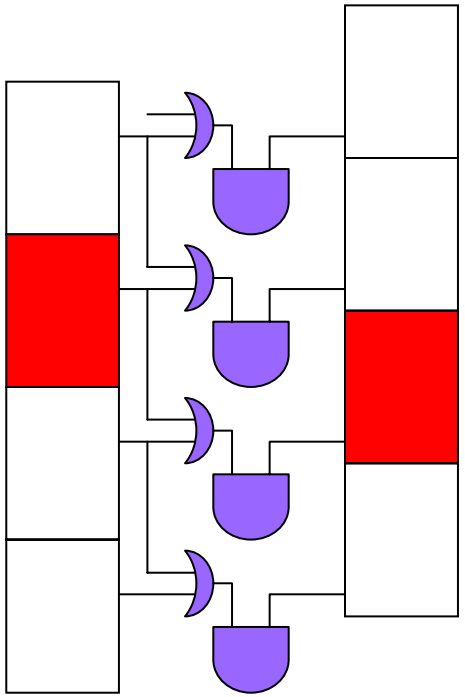


Boundary Issues

Beyond Just Bit-wise AND

- When the track hits near the boundary of a bin, simple bit-wise AND may miss the triplet.
- The bit-wise OR-AND logic will cover the boundary.
- The logic cells in most of today's FPGA's have 4 inputs. So the OR-AND bit-wise logic doesn't increase any resource usage.





Tiny Triplet Finder (Animation)