Variable resolution Associative Memory optimization and simulation for the ATLAS FastTracker project

Carmela Luongo

INFN - Pisa

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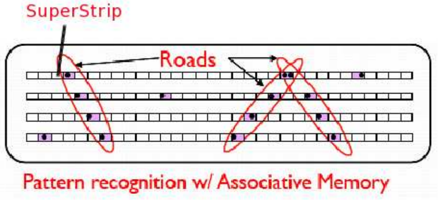
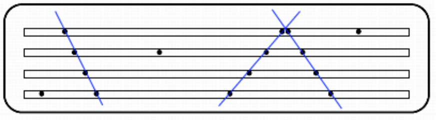
FTK algorithm

Two sequential steps:

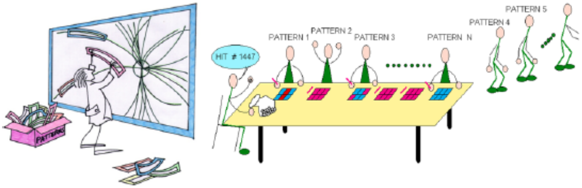
1. Pattern recognition, carried out by a dedicated device called Associative Memory (AM). Find coarse-resolution track candidates called "roads".
2. Track Fitter fits the full-resolution hits inside the road to determine the track parameters. Only the tracks passing the χ^2 cut are kept.





AM working principle

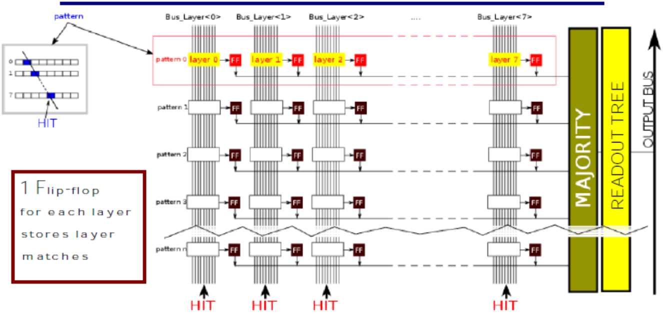
AM = BINGO GAME



- player=pattern
- card number=bin
- extraction number=hit
- winning players=pattern matching

- Each pattern has its private HW to compare itself with the event
- Bingo game goes on until completion of detector readout
- All the winning patterns get out from the door

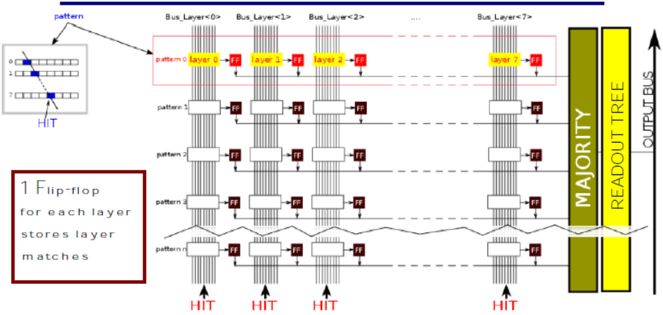
AM working principle



All patterns compared in parrallel with incoming data. Look for correlation of data received at different times (feature unique to AM chip)

- Fast pattern matching
- Flexible input

AM working principle



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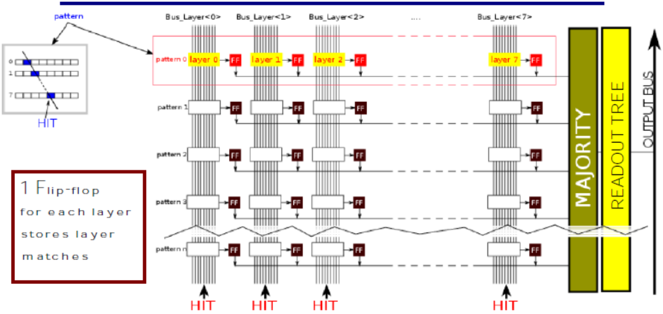


1 Flip-flop for each layer stores layer matches

All patterns compared in parrallel with incoming data. Look for correlation of data received at different times (feature unique to AM chip)

- Fast pattern matching
- Flexible input

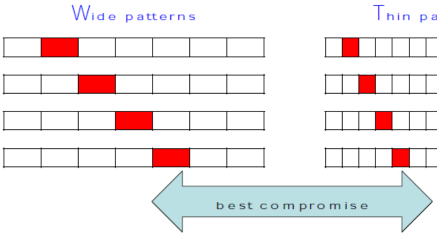
Parameters to define the pattern-bank performance

Pattern bank

Each track generates a hit pattern. The collection of all these patterns defines both the space of the tracks we are looking for and how they appear in the detector: this collection is the pattern bank

Trade-off

Number of roads vs number of fits ⇒ critical parameter: road width



- Too wide ⇒ more fake roads ⇒ excessive work for the Track Fitter
- Too narrow ⇒ more AM patterns ⇒ too large cost

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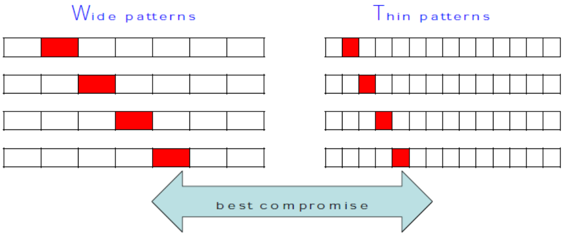

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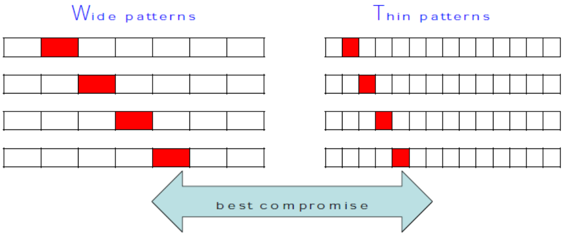

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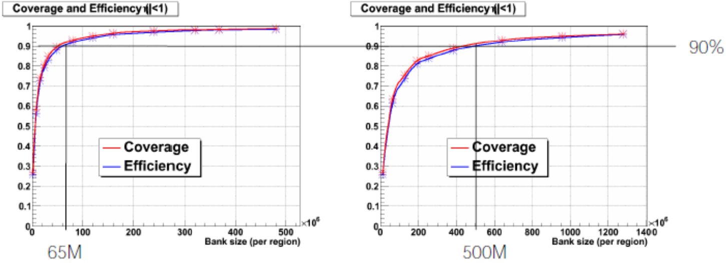
- Too narrow ⇒ more AM patterns ⇒ too large cost

Bank efficiency

Pattern size
r-ϕ: 24 pixels, 20 SCT strips
z: 36 pixels

Pattern size (half size)
r-ϕ: 12 pixels, 10 SCT strips
z: 36 pixels

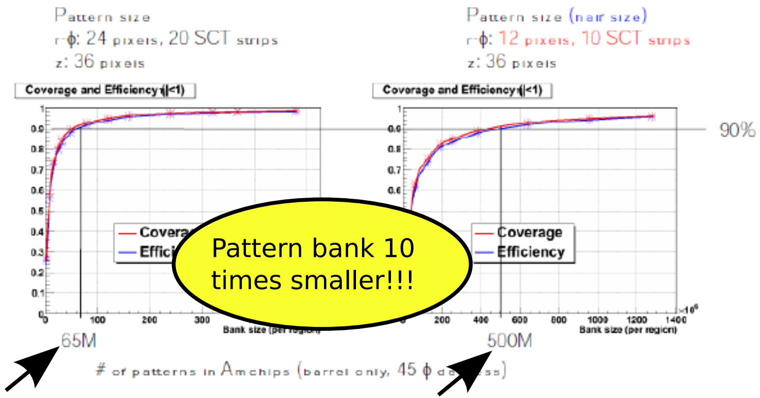


# of patterns in Amchips (barrel only, 45 ϕ degress)

<# matched patterns/event @ 3E34> = 342k

<# matched patterns/event @ 3E34> = 40k

Bank efficiency



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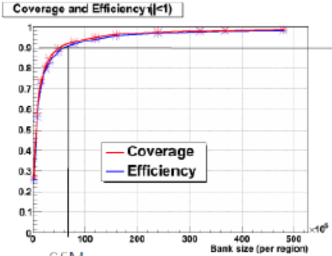
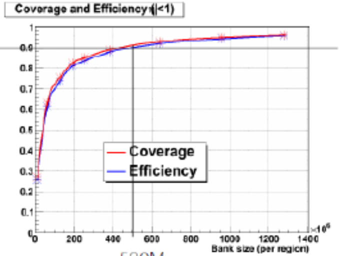


65M

Pattern size (half size)
r-ϕ: 12 pixels, 10 SCT strips
z: 36 pixels



90%

500M

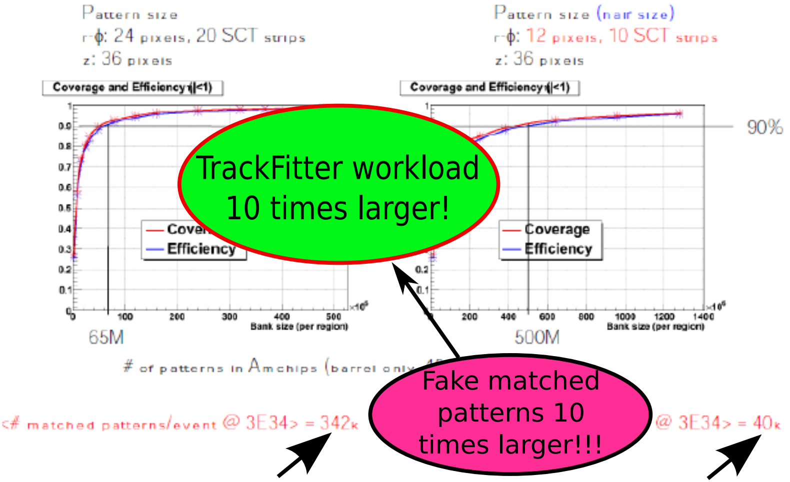
# of patterns in Amchips (barrel only

<# matched patterns/event @ 3E34> = 342k

Fake matched patterns 10 times larger!!!

@ 3E34> = 40k

Bank efficiency



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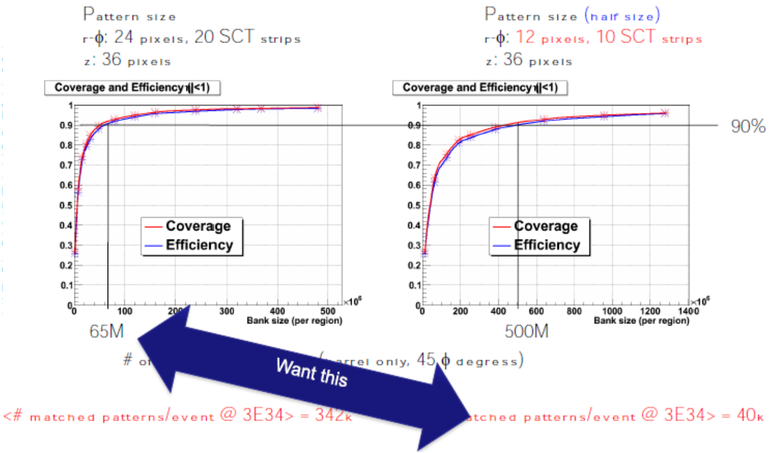
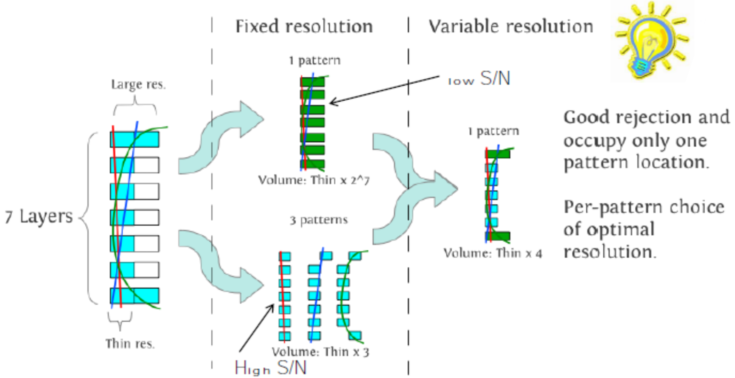


Variable resolution patterns

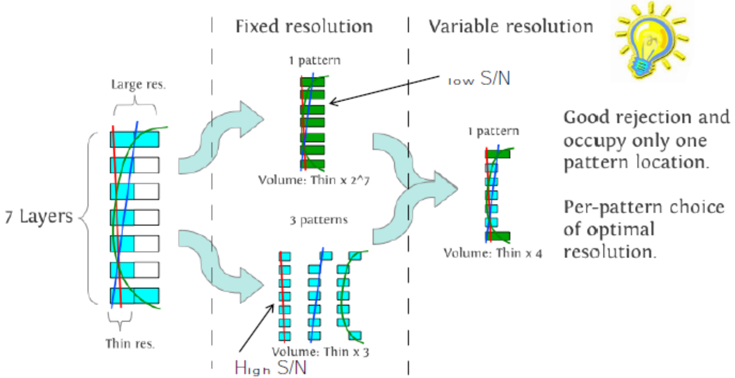


- Don't care (DC) on the least significant bit

⇒ Number of patterns within the HW limits

⇒ High rejection of fake roads

Variable resolution patterns



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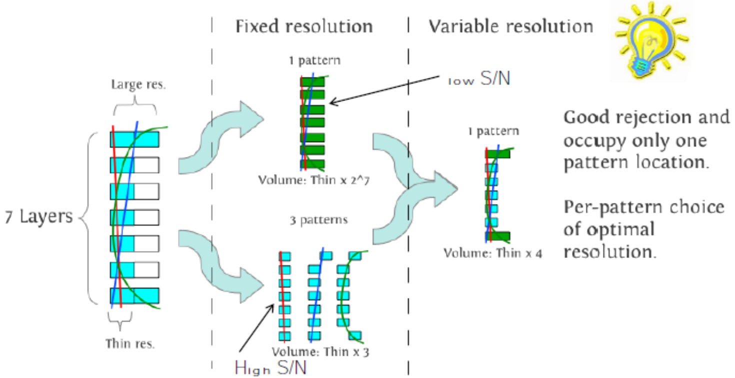

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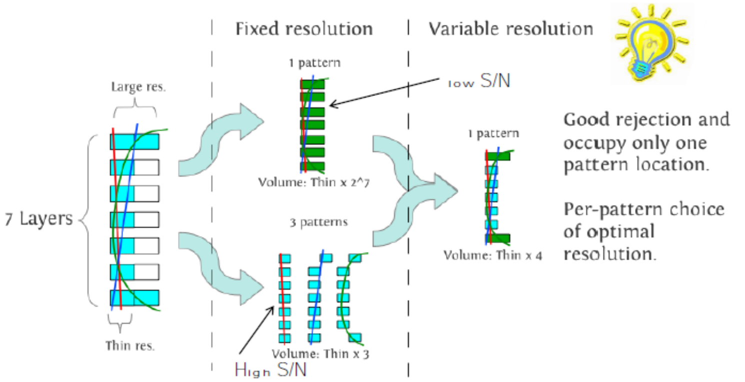

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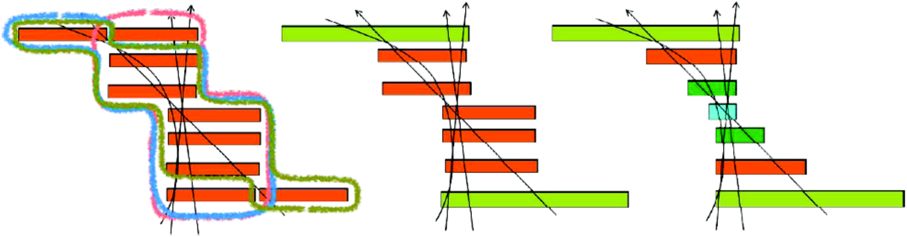
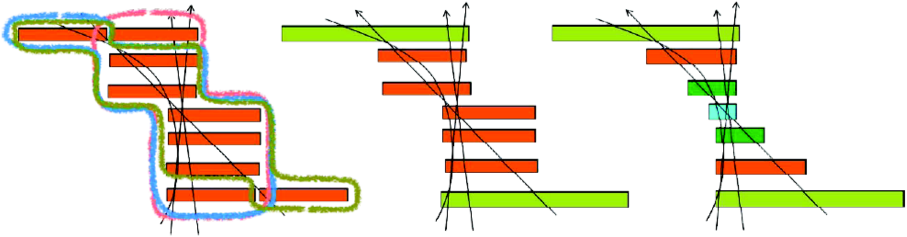
Many bits variable resolution



- No variable resolution $\Rightarrow$ 3 patterns needed to accept the tracks
- 1 bit variable resolution $\Rightarrow$ 1 pattern needed to accept the tracks
- 3 bits variable resolution $\Rightarrow$ 1 pattern needed but less volume

Many bits variable resolution



- 3 patterns
- 1 patterns
- 1 patterns

Any coincidence based trigger can exploit this technique!

Multiple DC bits study

Goals

- Keeping high efficiency with limited number of patterns
- Limiting workload for the Track Fitter

⇒ Optimizing use of variable resolution patterns

Main parameters

- Pattern bank size
-
- Roads size
- Number of fits

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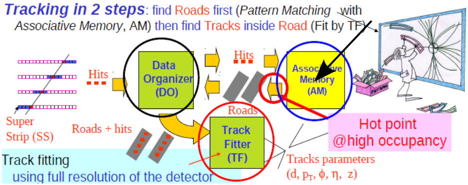

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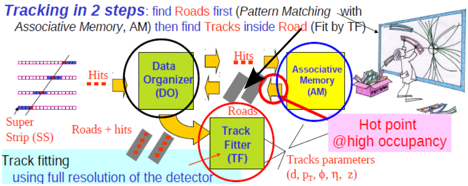

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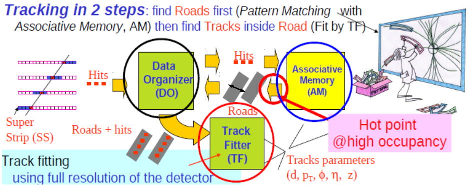

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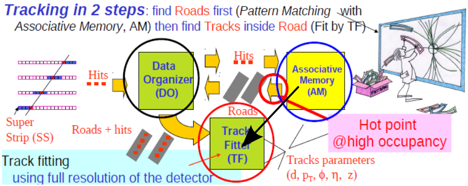

HW constraints per pile-up events

Maximum limits for each board:

- 8×10^6 patterns
- 8×10^3 roads
- 40×10^3 fits

Simulation results for 2015 (46 pile-up) and 2019 (69 pile-up):

1. 46 pile-up events: 16 boards working on 32 towers
   $\Rightarrow$ constraints for each tower:
   - $\#AMpatterns < 4 \times 10^6$
   - $\#Roads < 4 \times 10^3$
   - $\#Fits < 20 \times 10^3$
2. 69 pile-up events: 128 boards working on 64 towers
   $\Rightarrow$ constraints for each tower:
   - $\#AMpatterns < 16 \times 10^6$
   - $\#Roads < 16 \times 10^3$
   - $\#Fits < 80 \times 10^3$

Configurations

- High resolution road: 15x36x16
  - → 15x36 = number of pixels clustered in the same Super Strip
  - → 16 = number of strips clustered in the same Super Strip
- Dataset with 69 pile-up events
- Constraints:
  - $\#AM < 16M * 10^6$
  - $Roads < 16 * 10^3$
  - $Fits < 80 * 10^3$
- AM bank configurations:

1. $(30x36)_{pix}x32_{sct}$
2. $(30x72)_{pix}x32_{sct}$
3. $(30x144)_{pix}x32_{sct}$
4. $(30x72)_{pix}x64_{sct}$

⇒ Grouping with DC bit makes the SS granularity decrease

Endcap - 69 pile-up events ($\sim$ 2019)

DC bit	#AM $\cdot 10^6$	Efficiency(%) R=64	Roads/evt $\cdot 10^3$	Fits/evt $\cdot 10^3$	Tracks/evt
$(30x72)_{pix}x32_{sct}$	18	91.2	7.1	56	106
$(30x72)_{pix}x32_{sct}$	16.8	91.2	6.9	55	...
$(30x72)_{pix}x32_{sct}$	15	91	6.2	50	...
$(30x144)_{pix}x32_{sct}$	8	92	5	90	...
$(30x72)_{pix}x64_{sct}$	8	93	9	154	...

Table: Results in endcap towers. #AM patterns, #Roads, #Fits and #Tracks are reported for one tower.

- The #Roads provides a measure of the fake roads
- The efficiency is evaluated on a single muon dataset (no pile-up)

Endcap - 69 pile-up events ($\sim$ 2019)

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Table: Results in endcap towers. #AM patterns, #Roads, #Fits and #Tracks are reported for one tower.

- For a given DC configuration:
  - Reducing the number of patterns reduces the number of roads and fits
  - Efficiency minimally reduced
  - Number of fake roads proportional to the bank size

Endcap - 69 pile-up events ($\sim$ 2019)

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- The power of the variable resolution pattern
  - Increased efficiency and reduced roads number
  - Half size bank!

Barrel - 69 pile-up events ($\sim$ 2019)

DC bit	#AM $\cdot 10^6$	Efficiency(%) R=64	Roads/evt $\cdot 10^3$	Fits/evt $\cdot 10^3$	Tracks/evt
$(30x72)_{pix}x32_{sct}$	21	94.75	3.9	33	42
$(30x72)_{pix}x32_{sct}$	18	94.07	3.4	28	38
$(30x72)_{pix}x32_{sct}$	16.8	93.35	3.2	26	36
$(30x144)_{pix}x32_{sct}$	8	95	4	60	...
$(30x72)_{pix}x64_{sct}$	8	96	6	98	...

Table: Results in barrel towers. #AM patterns, #Roads, #Fits and #Tracks are reported for one tower.

Work in progress - 46 pile-up events ($\sim$ 2015)

- Exploring better initial road resolutions and larger number of DC bits
- High resolution road: 11x18x12
  - $\rightarrow$ 11x18 = number of pixels
  - $\rightarrow$ 12 = number of strips
- We are trying some DC-bits bank configurations:
  - $(22x72)_{pix}x24_{sct}$
  - $(44x72)_{pix}x48_{sct}$
  - $(44x144)_{pix}x48_{sct}$
- We will have the efficiency, roads, and tracks numbers soon

Conclusions

- We have simulated complex configurations of the powerful variable resolution pattern-matching
  - The patterns are able to change in shape and matching volume
  - The "don't care" bit improves the precision only where needed
  - High rejection of fake roads $\Rightarrow$ the number of roads out of the AM chip is reduced greatly by using the variable resolution patterns
  - High compression factor in case of similar patterns $\Rightarrow$ the number of patterns in the AM chip is significantly reduced

Thanks to the variable resolution implementation we are able to set the architecture parameters so that all HW constraints are satisfied.