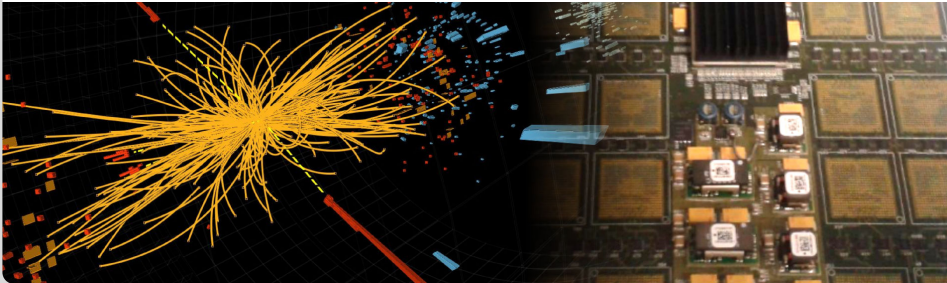


The CMS Track Trigger and the Processing of its Data

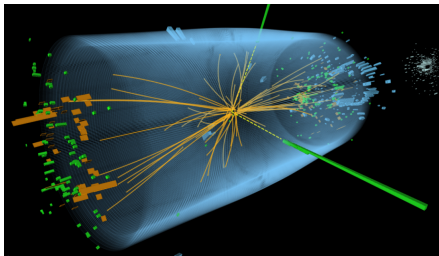
Christian Amstutz

Institute for Data Processing and Electronics (IPE)

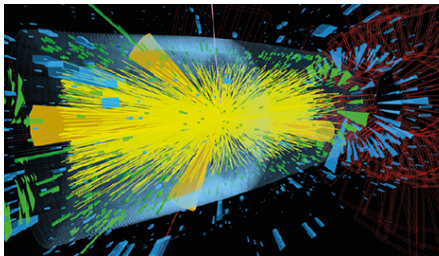


So many Particles!

Recorded Event (2012)

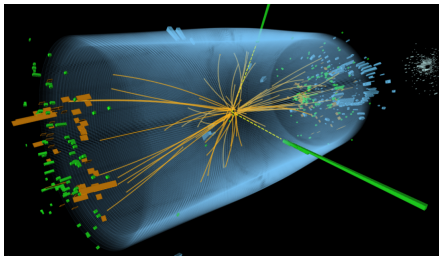


Simulation for HL-LHC (2025)

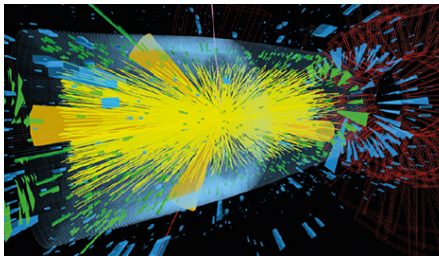


So many Particles!

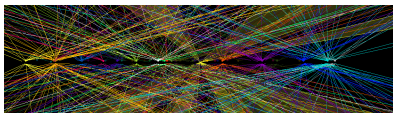
Recorded Event (2012)



Simulation for HL-LHC (2025)



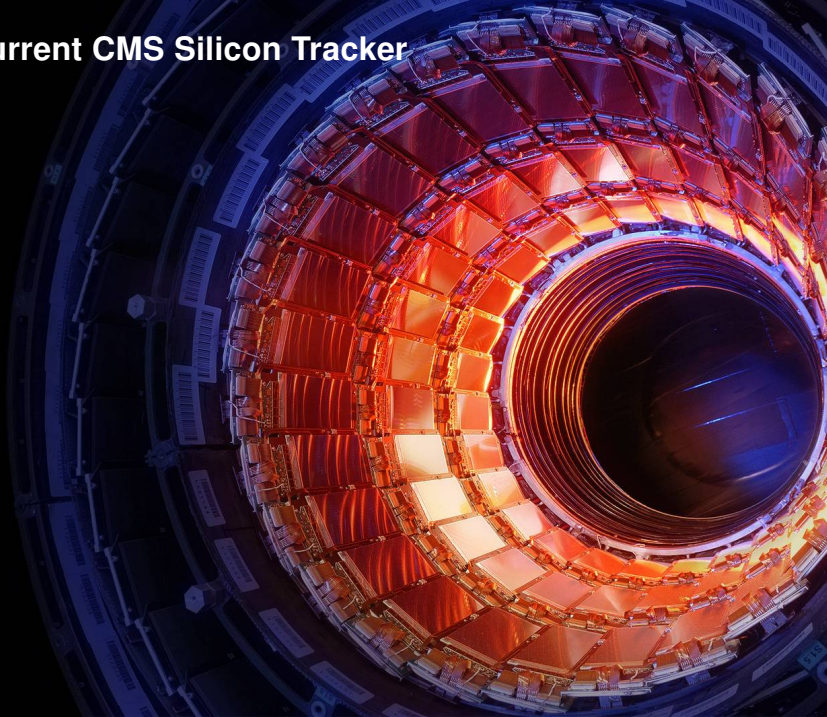
$\approx 10 \text{ cm}$



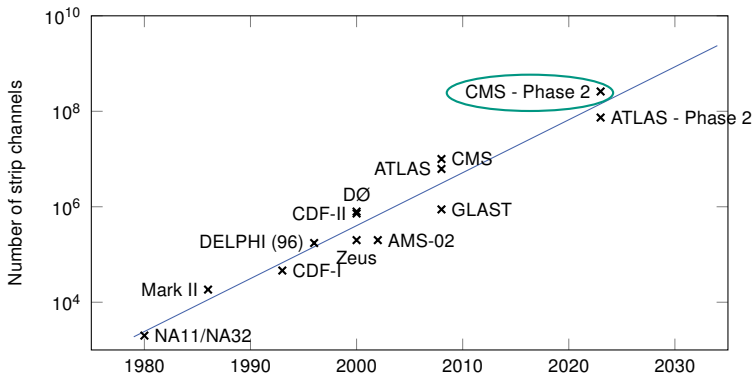
High-Luminosity LHC:

- Concurrent Collisions: up to 200
- Number Tracks: ≈ 10000

The Current CMS Silicon Tracker



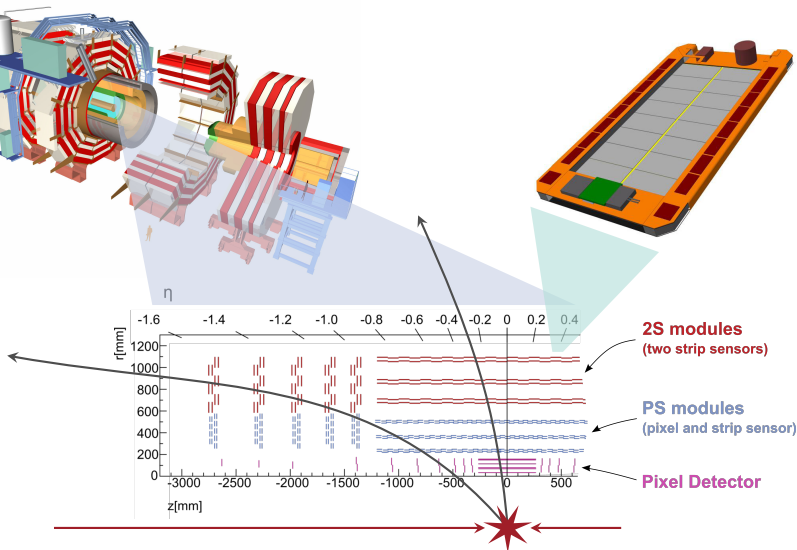
Evolution of Channels in Silicon Trackers



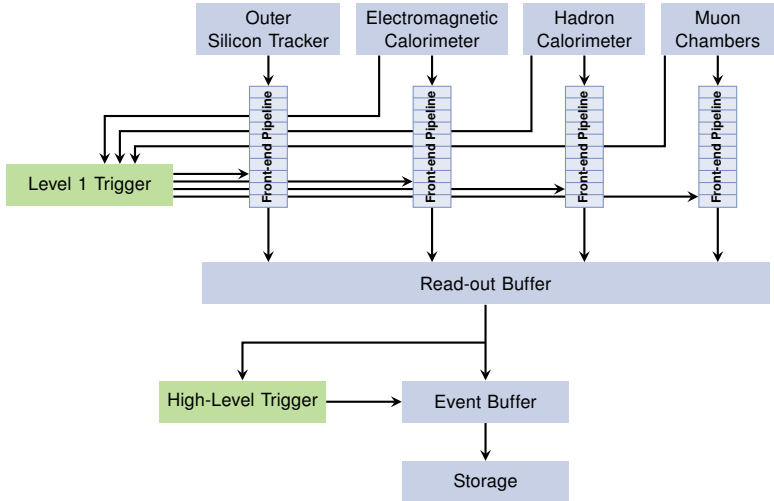
Silicon detectors: **1.7** times more channels every two years

Moore's law: **2** times more transistors every two years

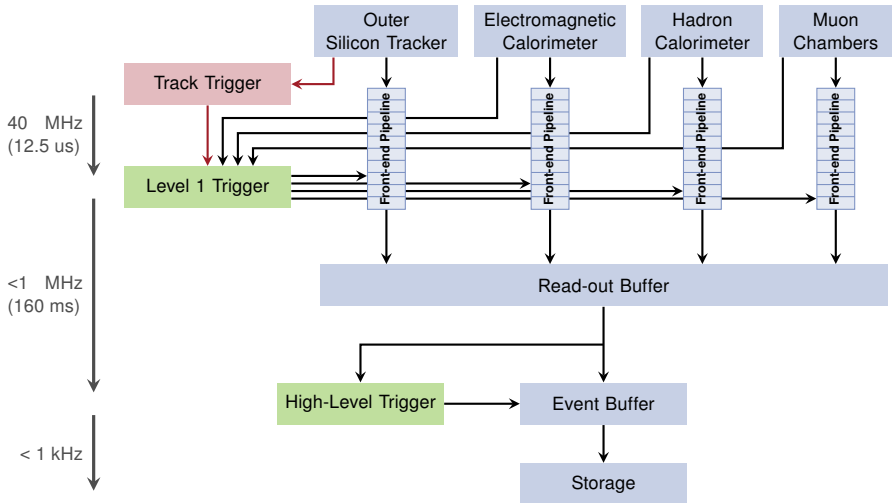
The CMS Silicon Tracker for HL-LHC



The Trigger System of CMS – *today*



The Trigger System of CMS – at the *HL-LHC*



Challenges of the CMS Track Trigger

Bunch collision rate:	40 MHz
Data rate produced by the detector:	11'200 Tbit/s
Data rate transmitted to Track Trigger:	50 Tbit/s
Optical Fibers:	15000
Latency (Sensor - L1 Trigger - Sensor):	< 12.5 us

Goal: Providing High-Energy Tracks to the Level-1 Trigger.

An Approach using Associative Memories (AM)

Working principle of Content Addressable Memories (CAM):

Christian Amstutz

An Approach using Associative Memories (AM)

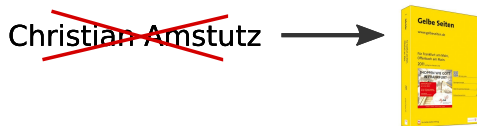
Working principle of Content Addressable Memories (CAM):

Christian Amstutz →



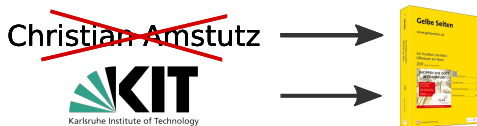
An Approach using Associative Memories (AM)

Working principle of Content Addressable Memories (CAM):



An Approach using Associative Memories (AM)

Working principle of Content Addressable Memories (CAM):



An Approach using Associative Memories (AM)

Working principle of Content Addressable Memories (CAM):



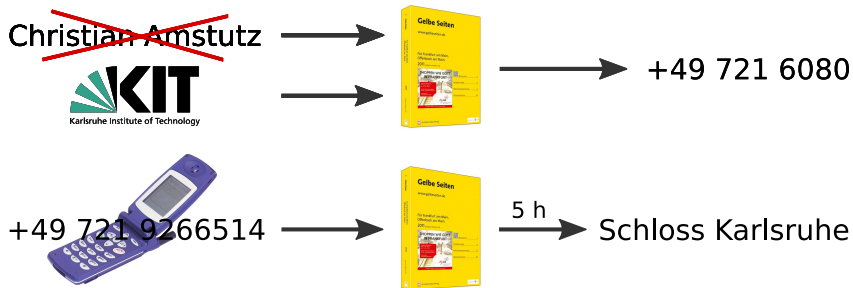
An Approach using Associative Memories (AM)

Working principle of Content Addressable Memories (CAM):



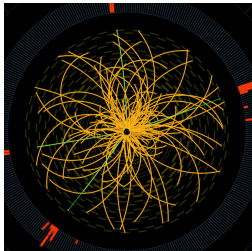
An Approach using Associative Memories (AM)

Working principle of Content Addressable Memories (CAM):

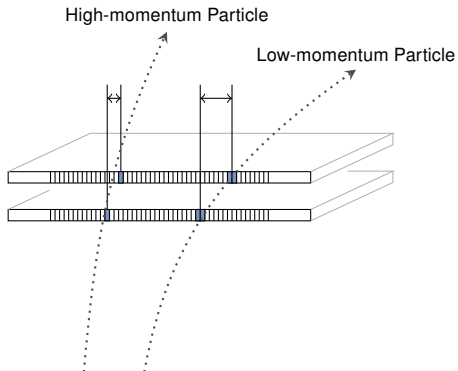
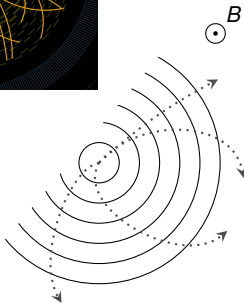


► Very fast lookup whether content is available

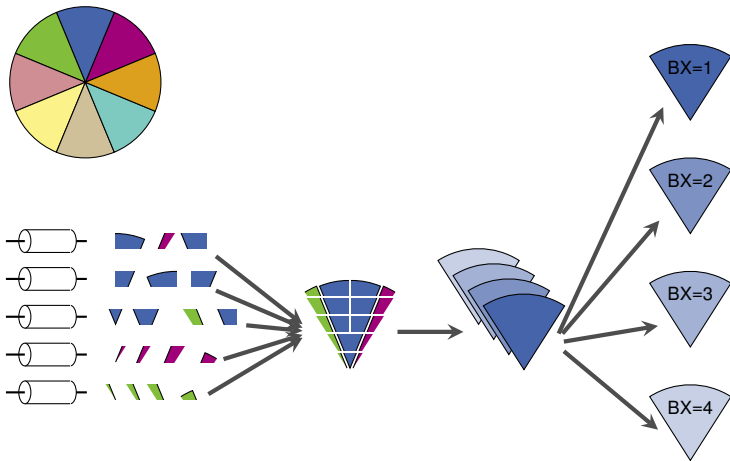
Stacked Modules and Stubs



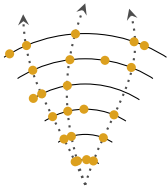
Accepted particles: $p_T > 3 \text{ GeV}$



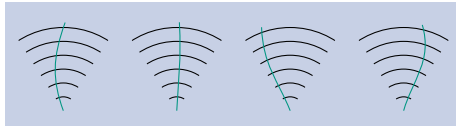
Arranging the Tracker Data



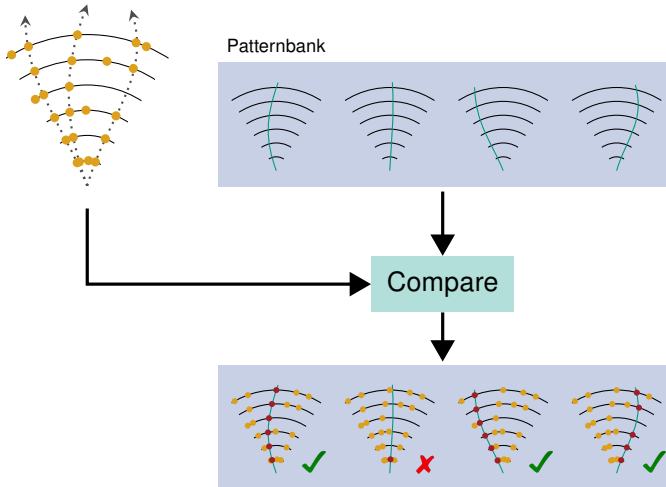
Track Finding by Associative Memory



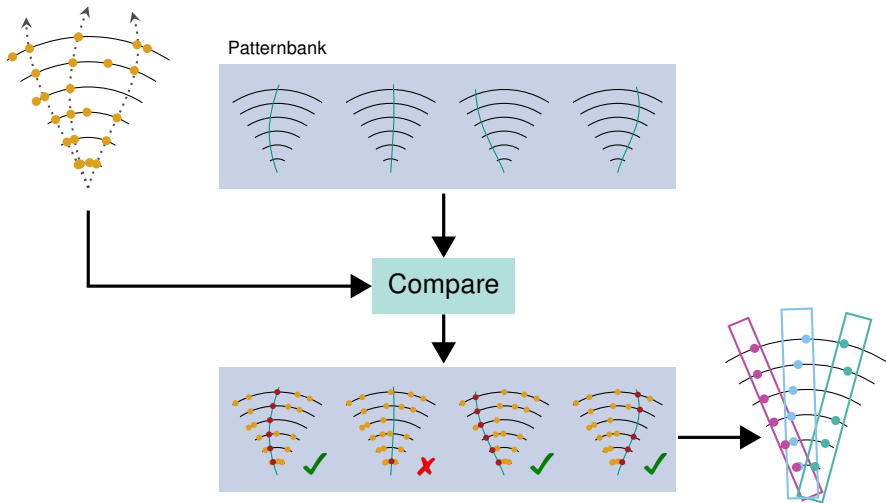
Patternbank

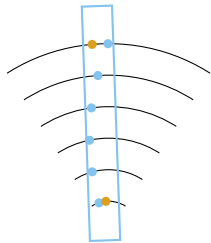


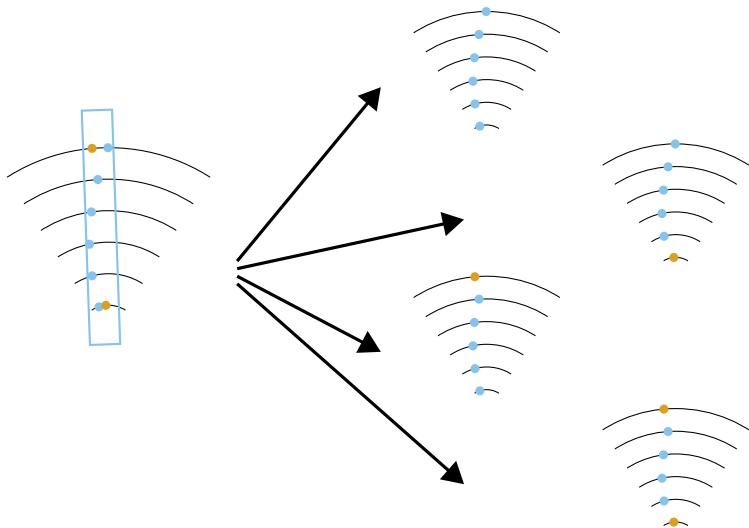
Track Finding by Associative Memory



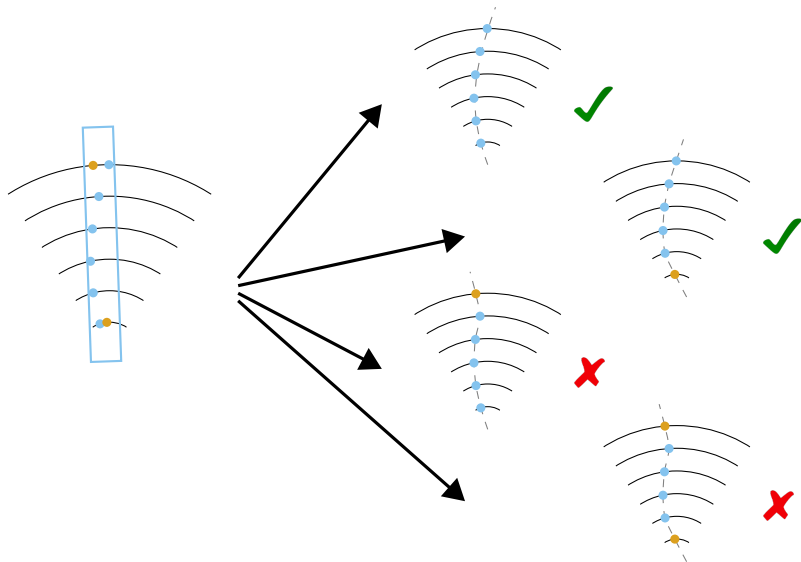
Track Finding by Associative Memory



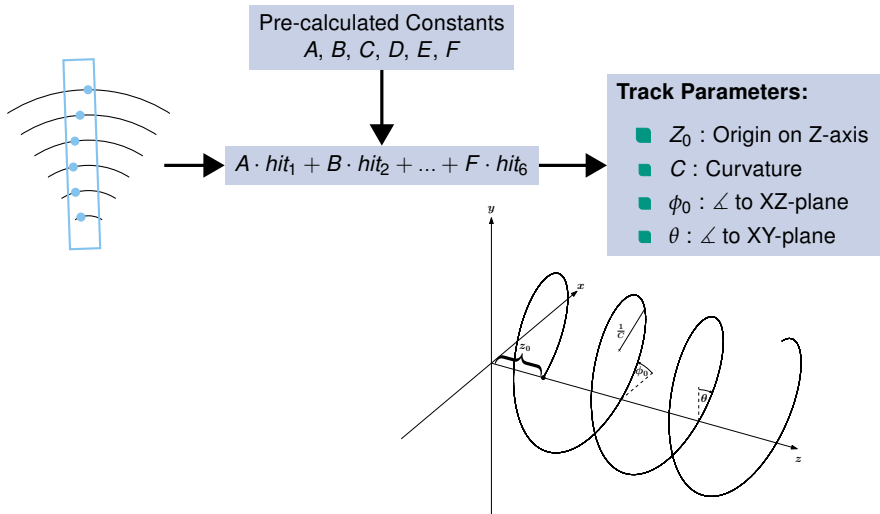


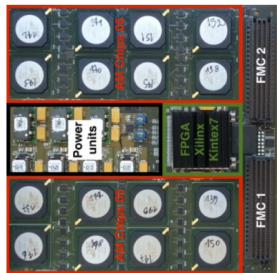
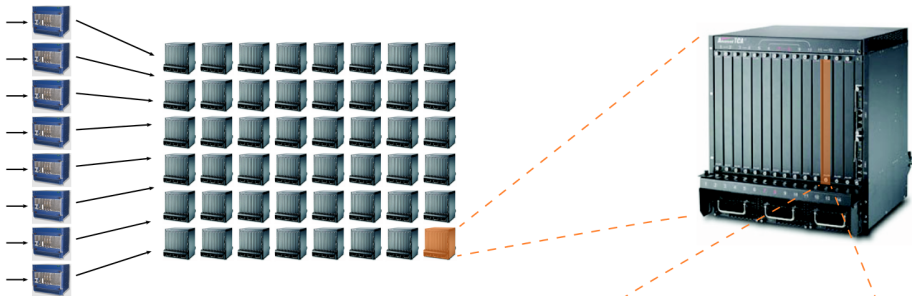


Event Building



Track Fitting by Linearized Fit





Idea: Model an essential part of the CMS Track Trigger electronics

Goals:

- Evaluation of system properties (latencies, link bandwidths, ...)
- Evaluation of system architectures
- Generation of test vectors for hardware debugging

Realization

- Realized in SystemC (a C++ library)
- All existing modules, but not all details
- Parameters of modules configurable



Idea: Model an essential part of the CMS Track Trigger electronics

Goals:

- Evaluation of system properties (latencies, link bandwidths, ...)
- Evaluation of system architectures
- Generation of test vectors for hardware debugging

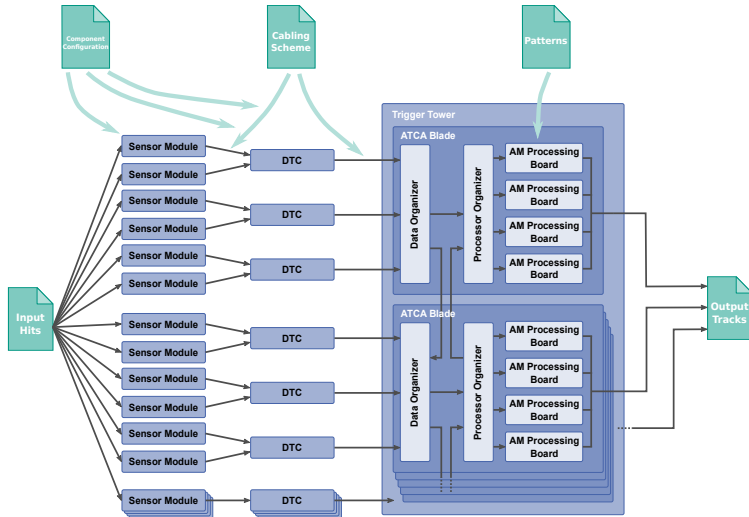
Realization

- Realized in SystemC (a C++ library)
- All existing modules, but not all details
- Parameters of modules configurable



One sector of the Track Trigger has been simulated

System Simulation II



FPGA — Programmable Digital Chips

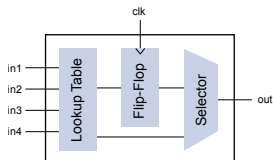
... a very very brief introduction

Field-Programmable Gate Array

FPGA — Programmable Digital Chips

... a very very brief introduction

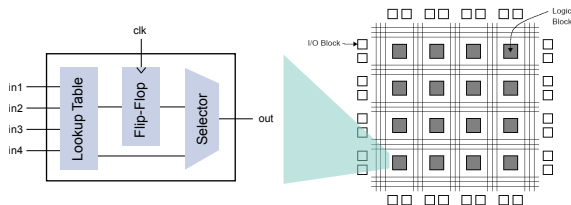
Field-Programmable Gate Array



FPGA — Programmable Digital Chips

... a very very brief introduction

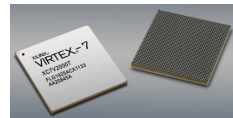
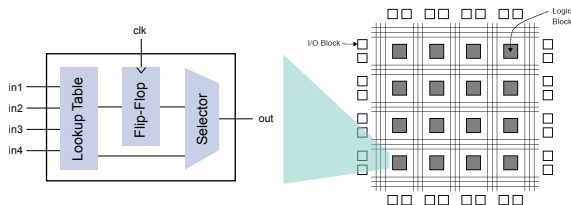
Field-Programmable Gate Array



FPGA — Programmable Digital Chips

... a very very brief introduction

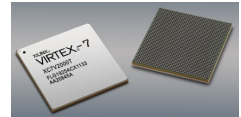
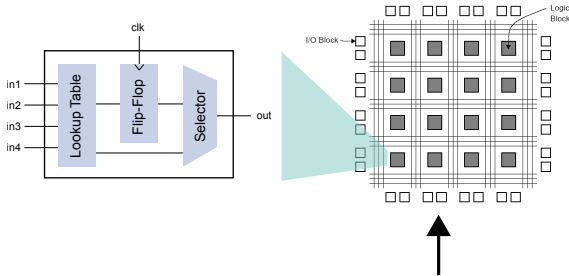
Field-Programmable Gate Array



FPGA — Programmable Digital Chips

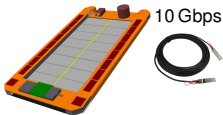
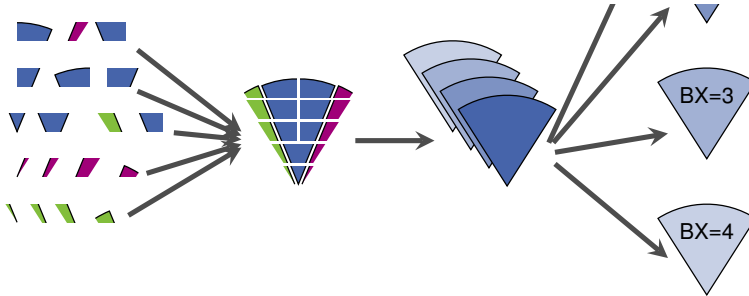
... a very very brief introduction

Field-Programmable Gate Array



```
multiply_vectors(a[1000], b[1000])  
  for i = 1 to 1000  
    c[i] = a[i] * b[i]  
  return c
```

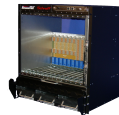
Electronic System behind the Data Processing



Sensor Module
15000



MTCA crate
72



ATCA crate
48

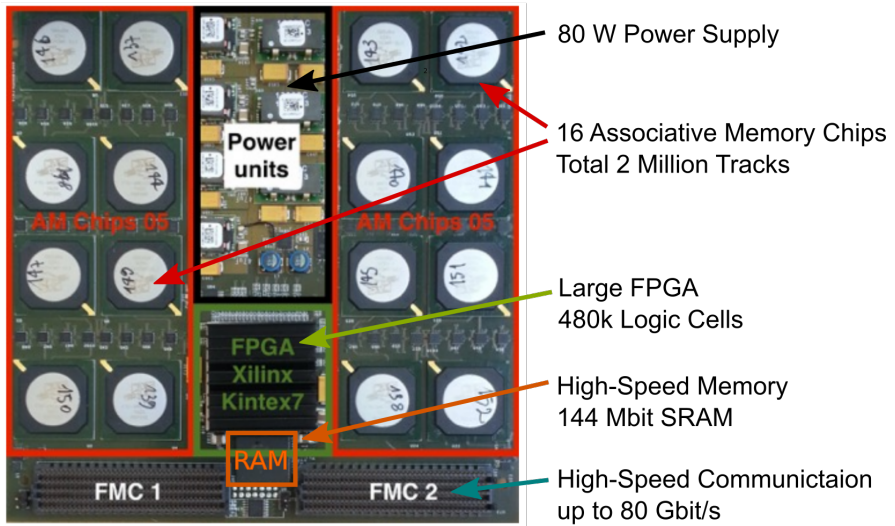


Pulsar-IIb Board
550



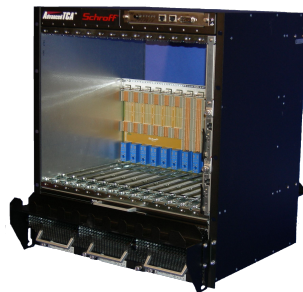
AM Board
2200

The Pattern Recognition Mezzanine



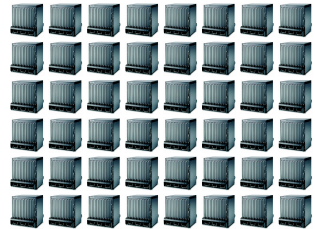
Cost Estimation for the Track Trigger

1	ATCA crate	8k €
	Cables and transceivers	24k €
12	<i>ATCA blades:</i>	
12	Printed Circuit Boards	36k €
12	FPGAs	64k €
12	AM Chip sets	64k €
		196k €



Cost Estimation for the Track Trigger

1	ATCA crate	8k €
	Cables and transceivers	24k €
12	<i>ATCA blades:</i>	
12	Printed Circuit Boards	36k €
12	FPGAs	64k €
12	AM Chip sets	64k €
		196k €

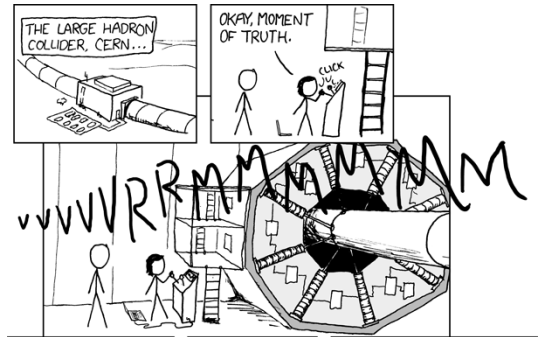


Total equipment cost: 48 crates * 196k € = **9.4M €**

- One of the most complex electronic systems ever built
- Contributions of many groups are necessary
- Very competitive spirit between different groups

 **The Track Trigger is essential for CMS HL-LHC**

Thank you for your attention



source: www.xkcd.com