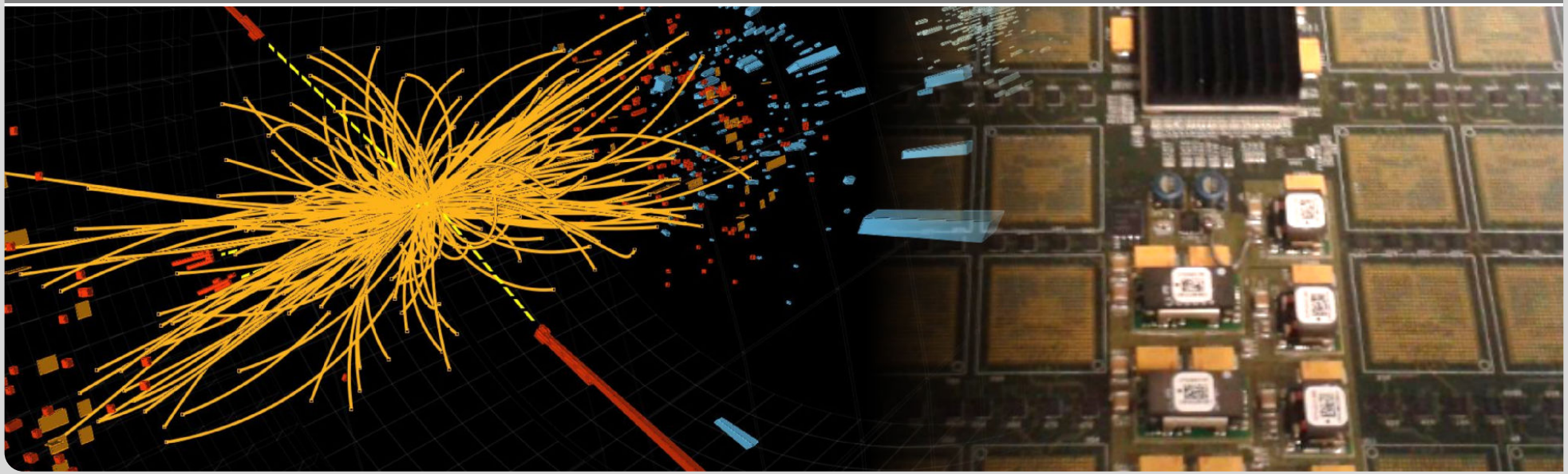
Karlsruhe Institute of Technology

The CMS Track Trigger and the Processing of its Data

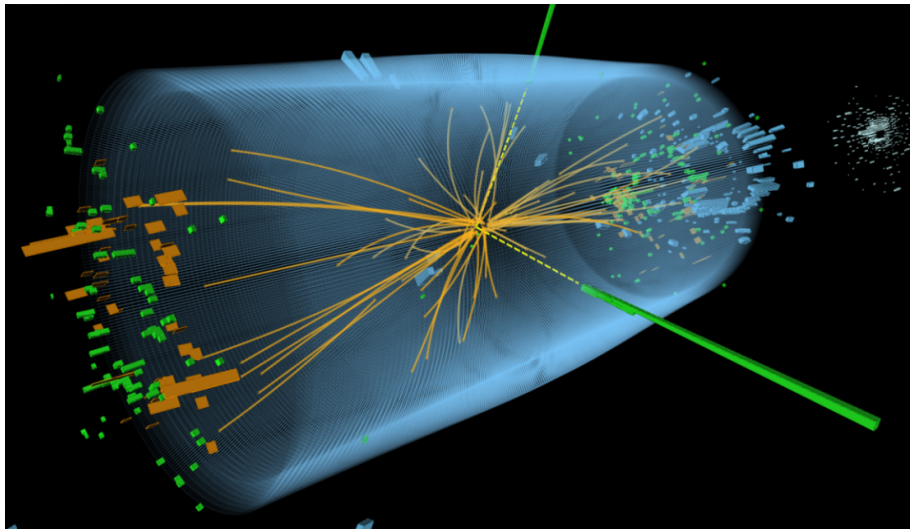
Christian Amstutz

Institute for Data Processing and Electronics (IPE)

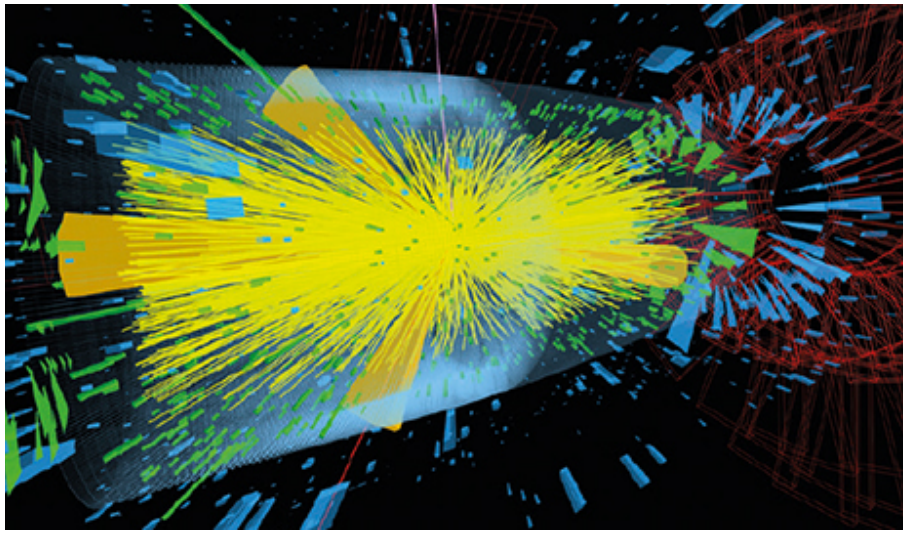


So many Particles!

Recorded Event (2012)



Simulation for HL-LHC (2025)



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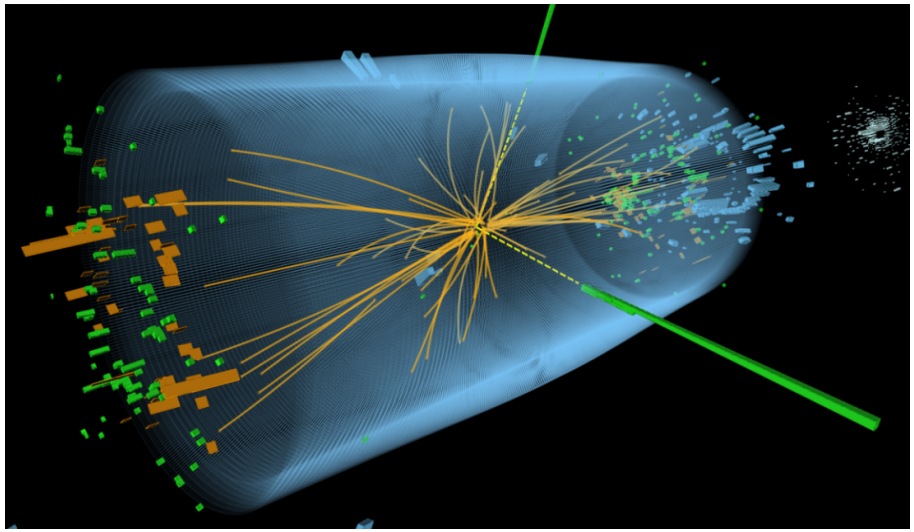

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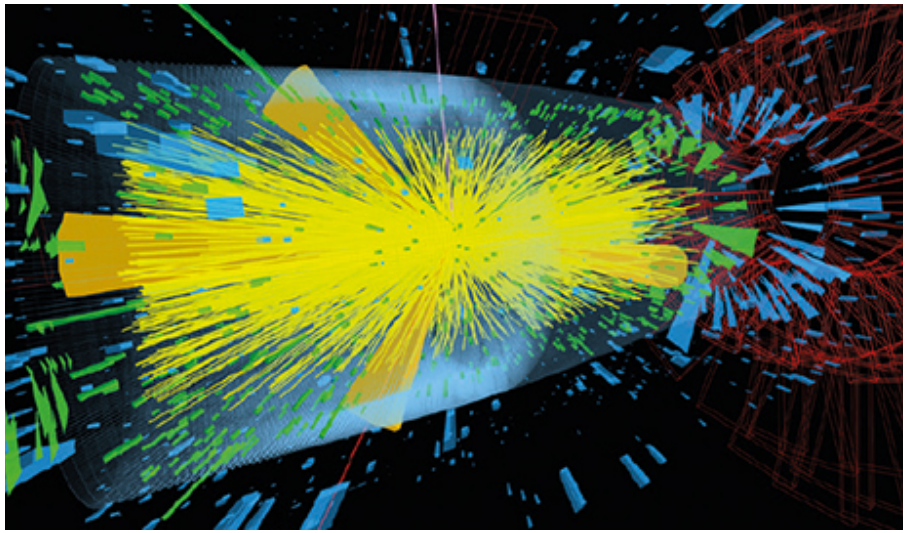
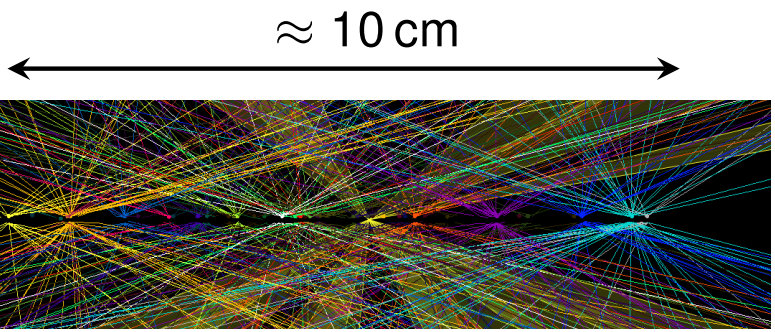
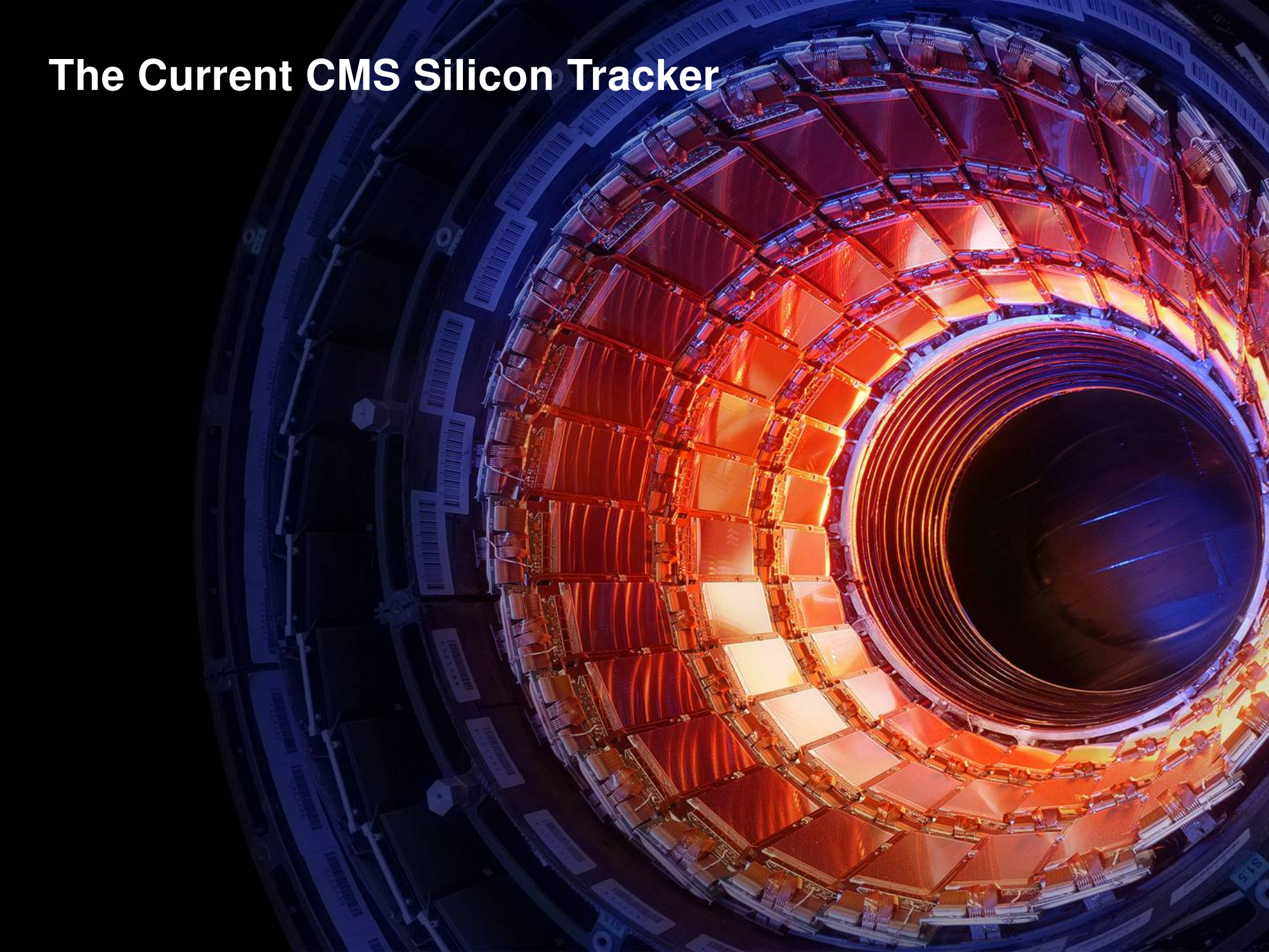




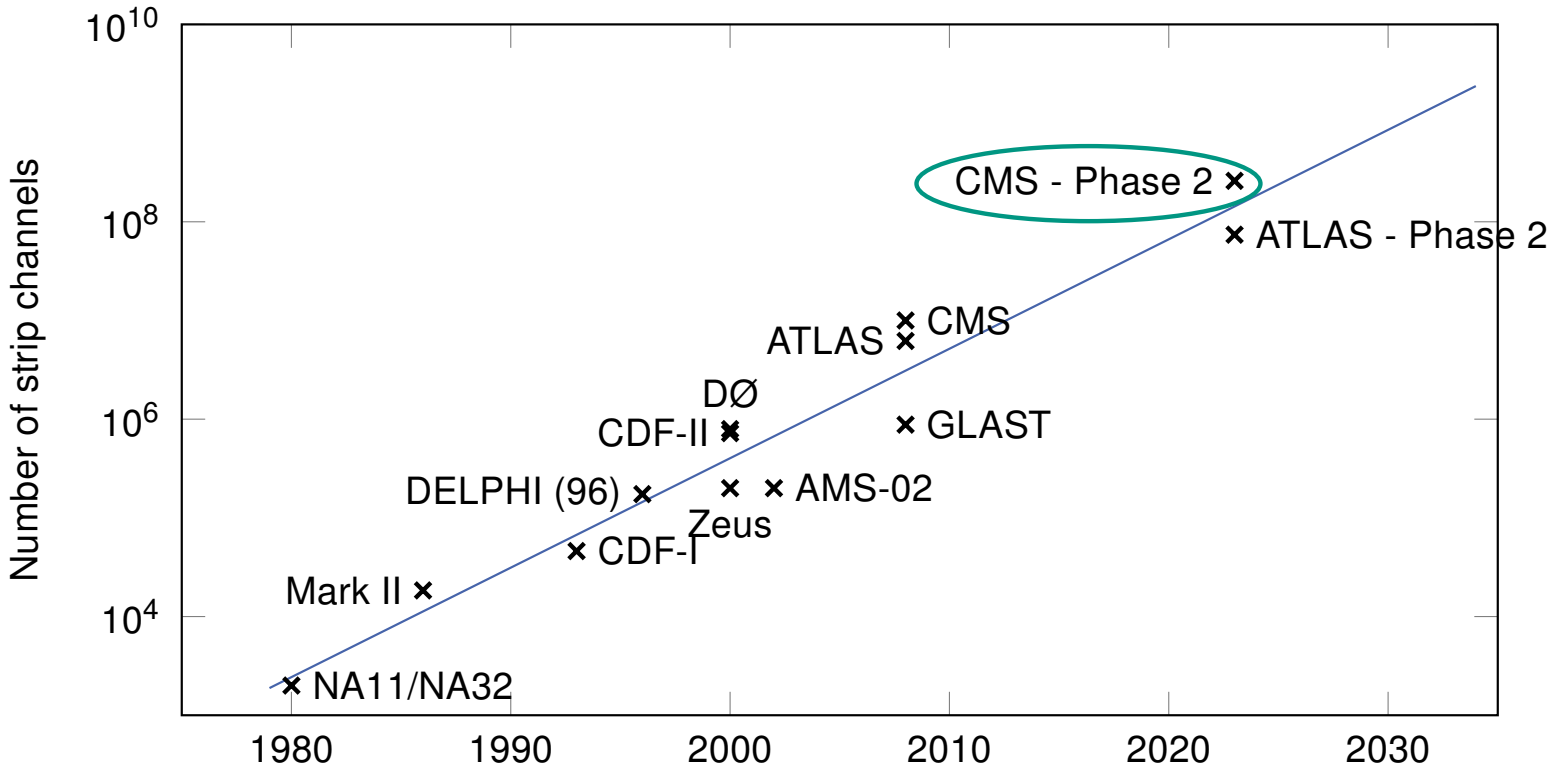
High-Luminosity LHC:

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

The Current CMS Silicon Tracker



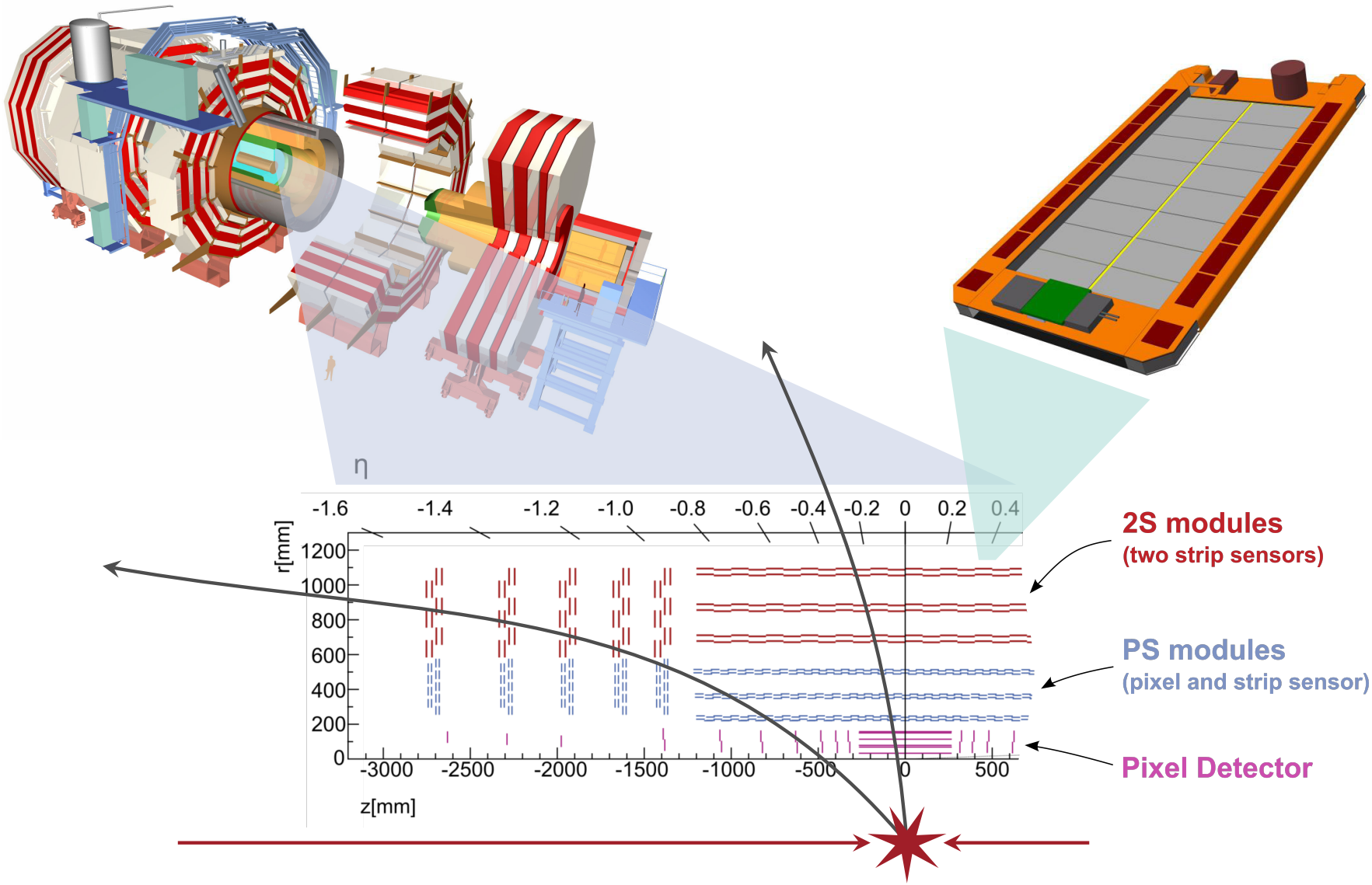
Evolution of Channels in Silicon Trackers



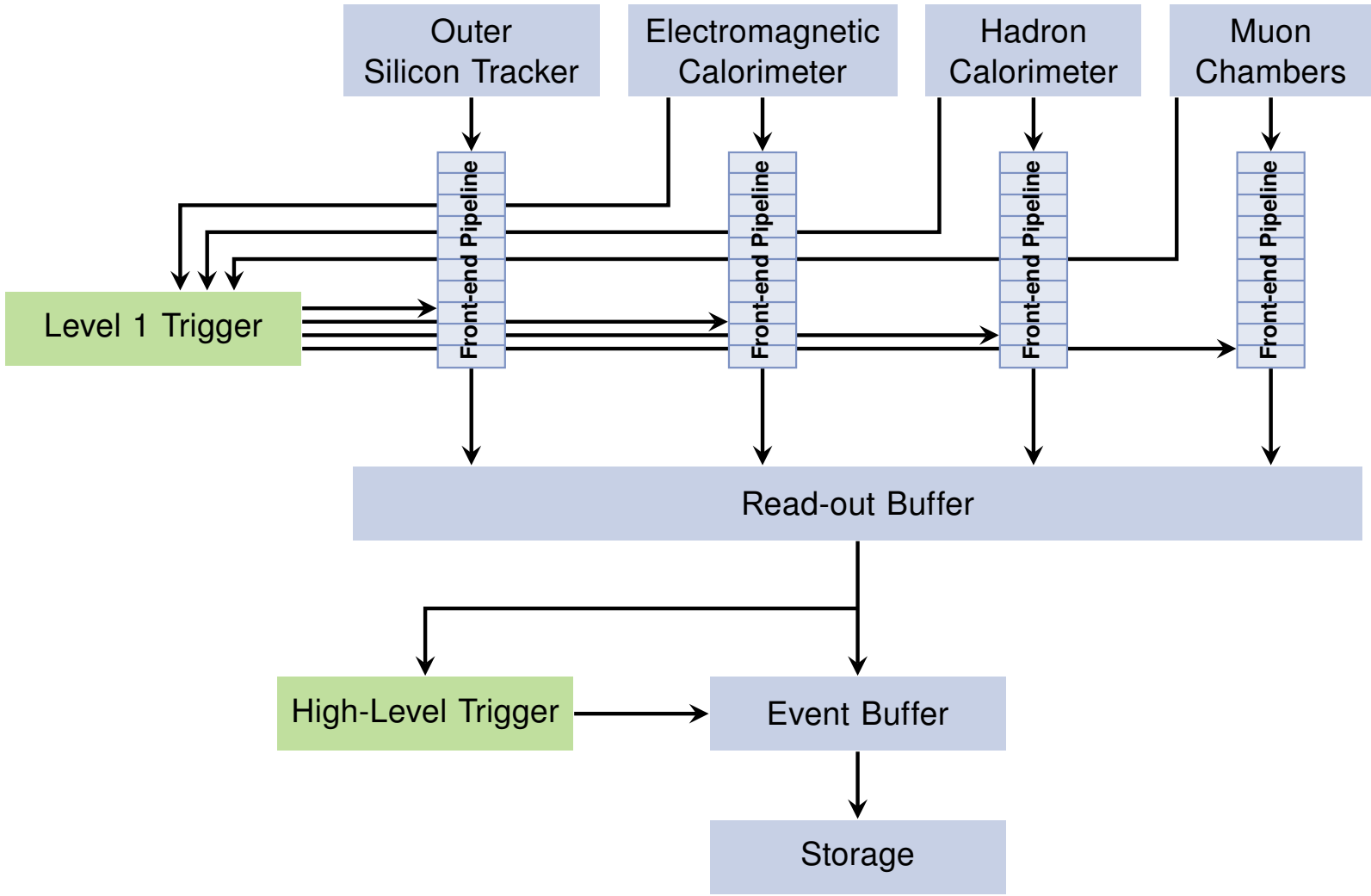
Silicon detectors: **1.7** times more channels every two years

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

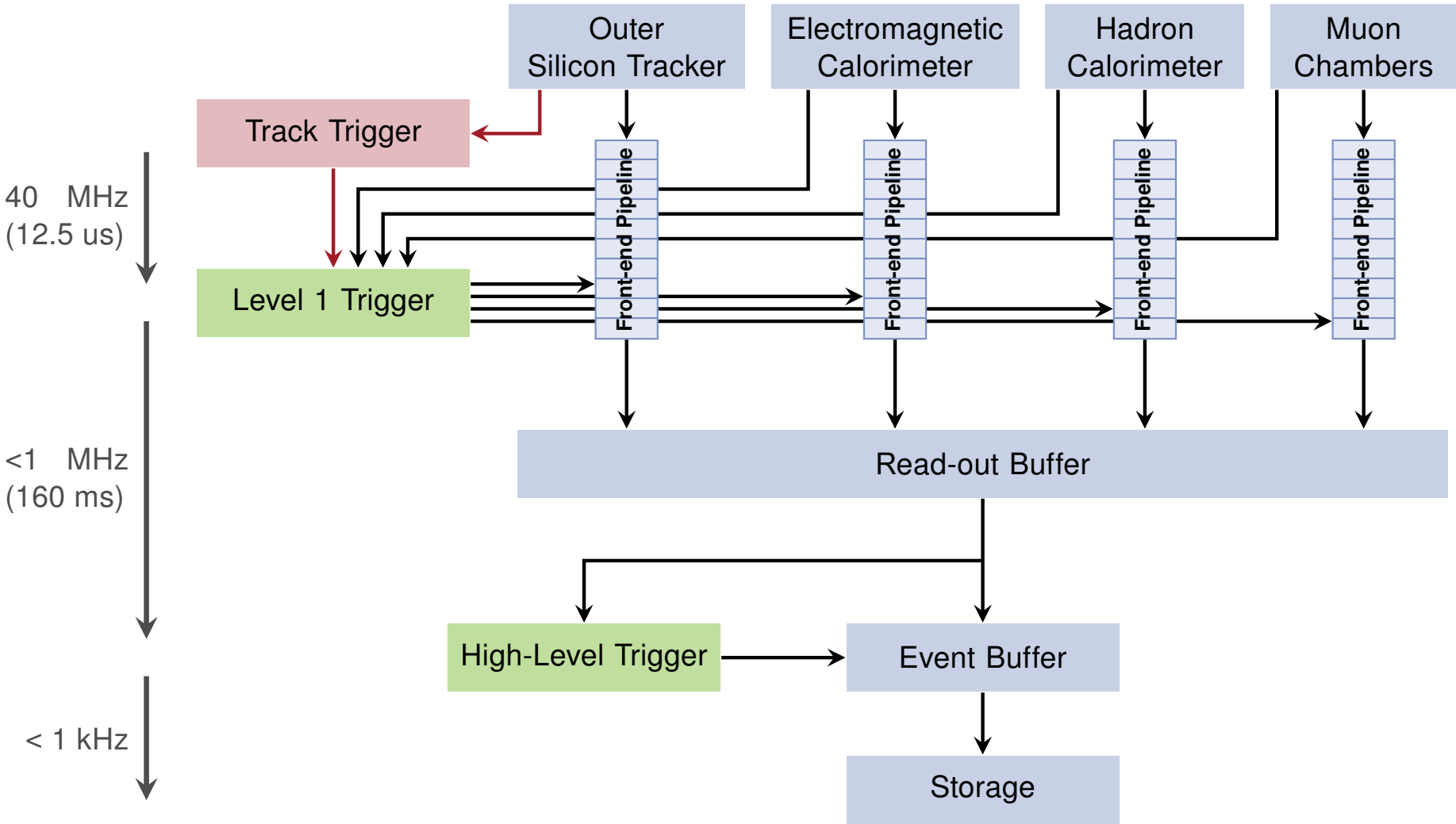
The CMS Silicon Tracker for HL-LHC



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)

Karlsruhe Institute of Technology

Working principle of Content Addressable Memories (CAM):

Christian Amstutz

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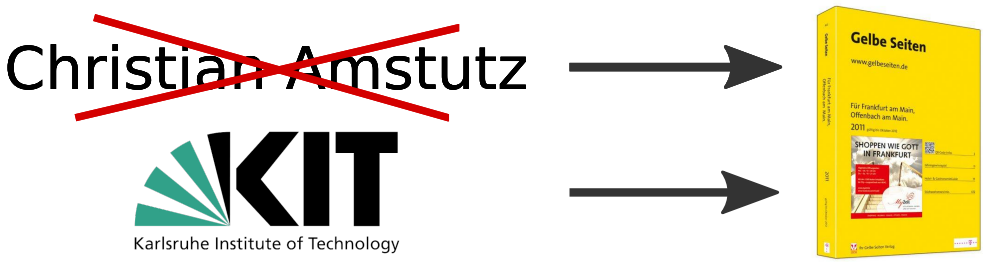

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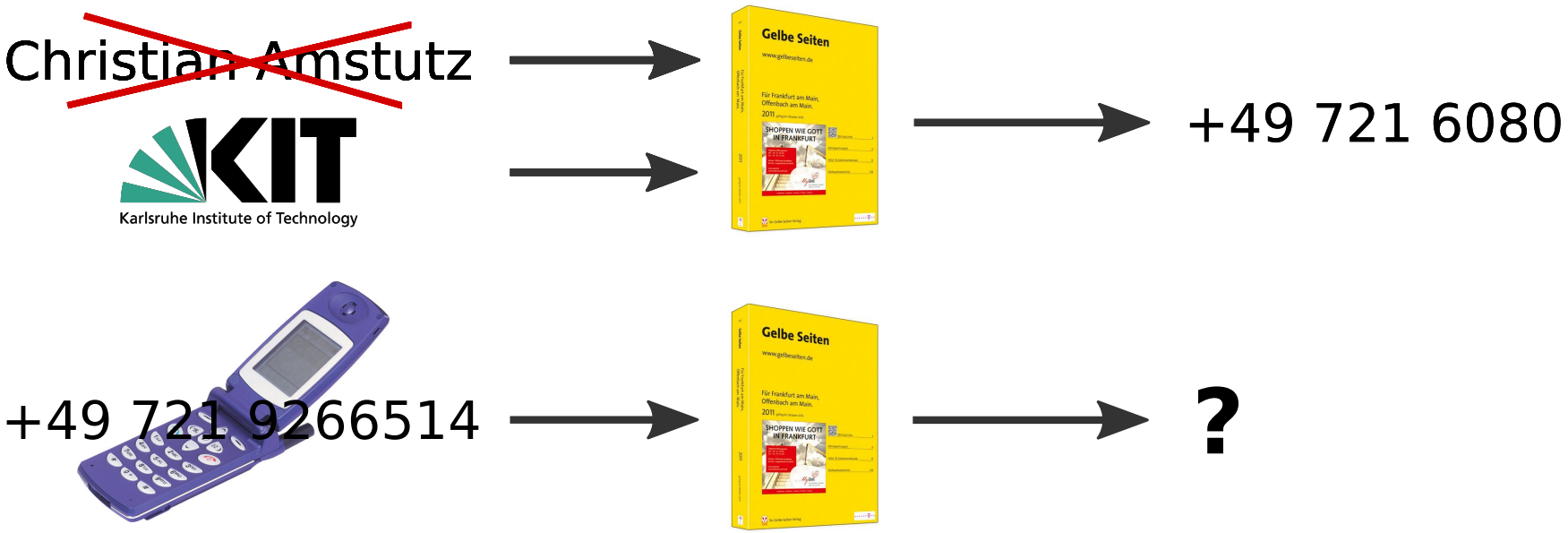

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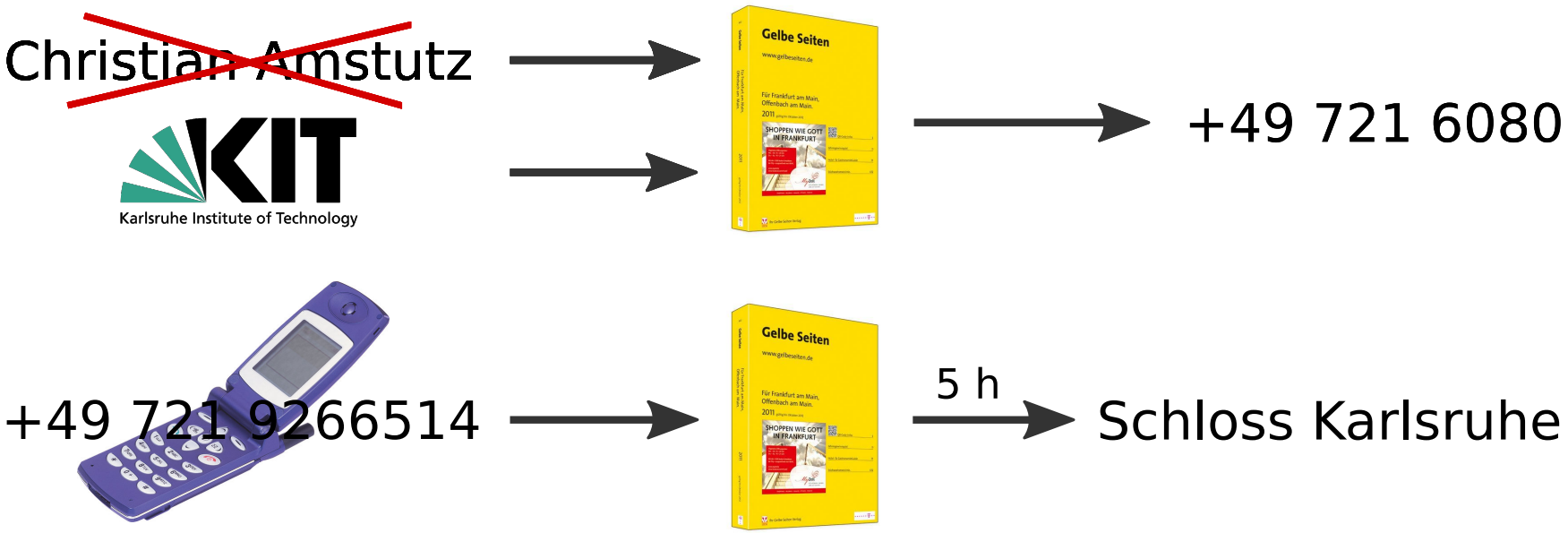
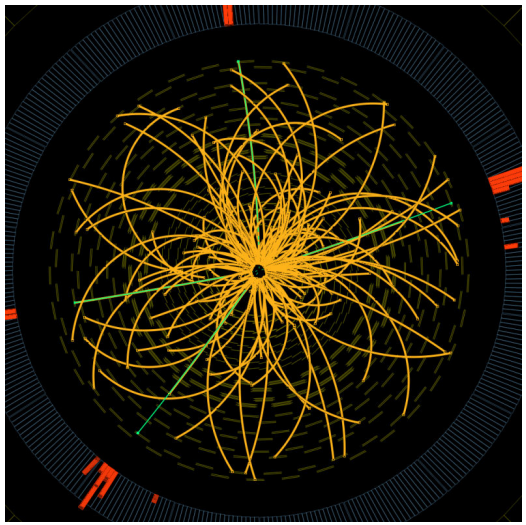
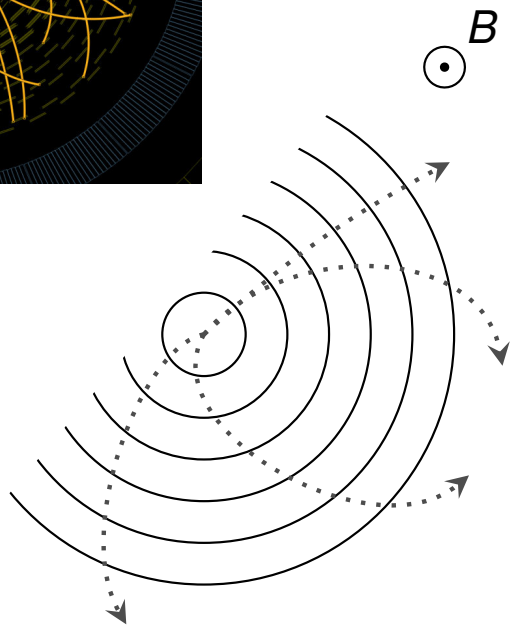


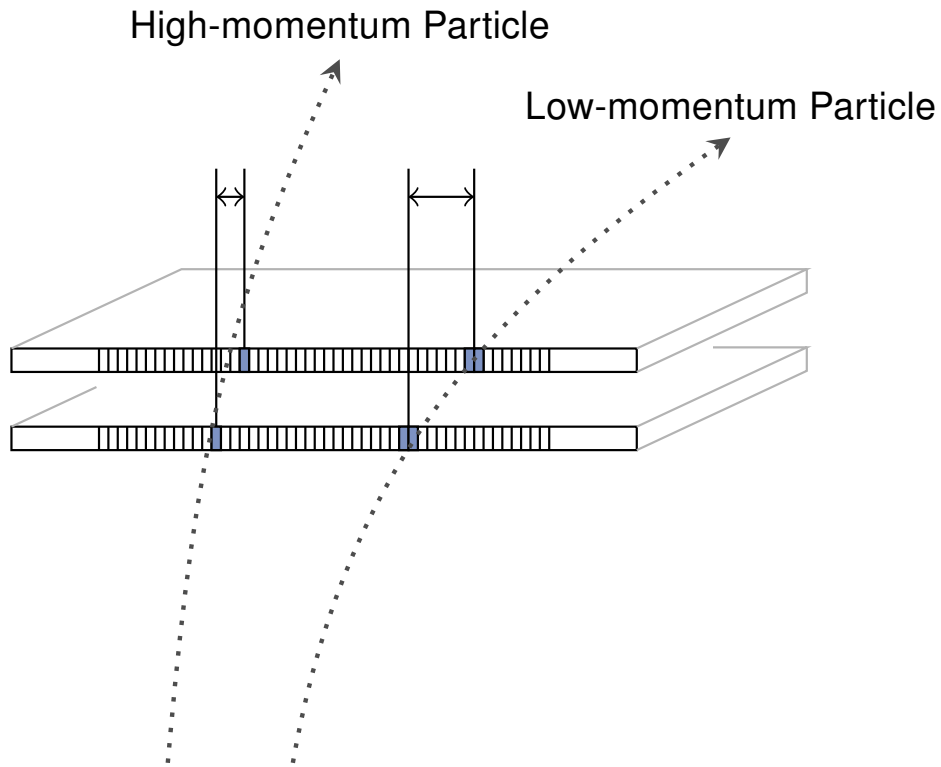
- Very fast lookup whether content is available

Stacked Modules and Stubs

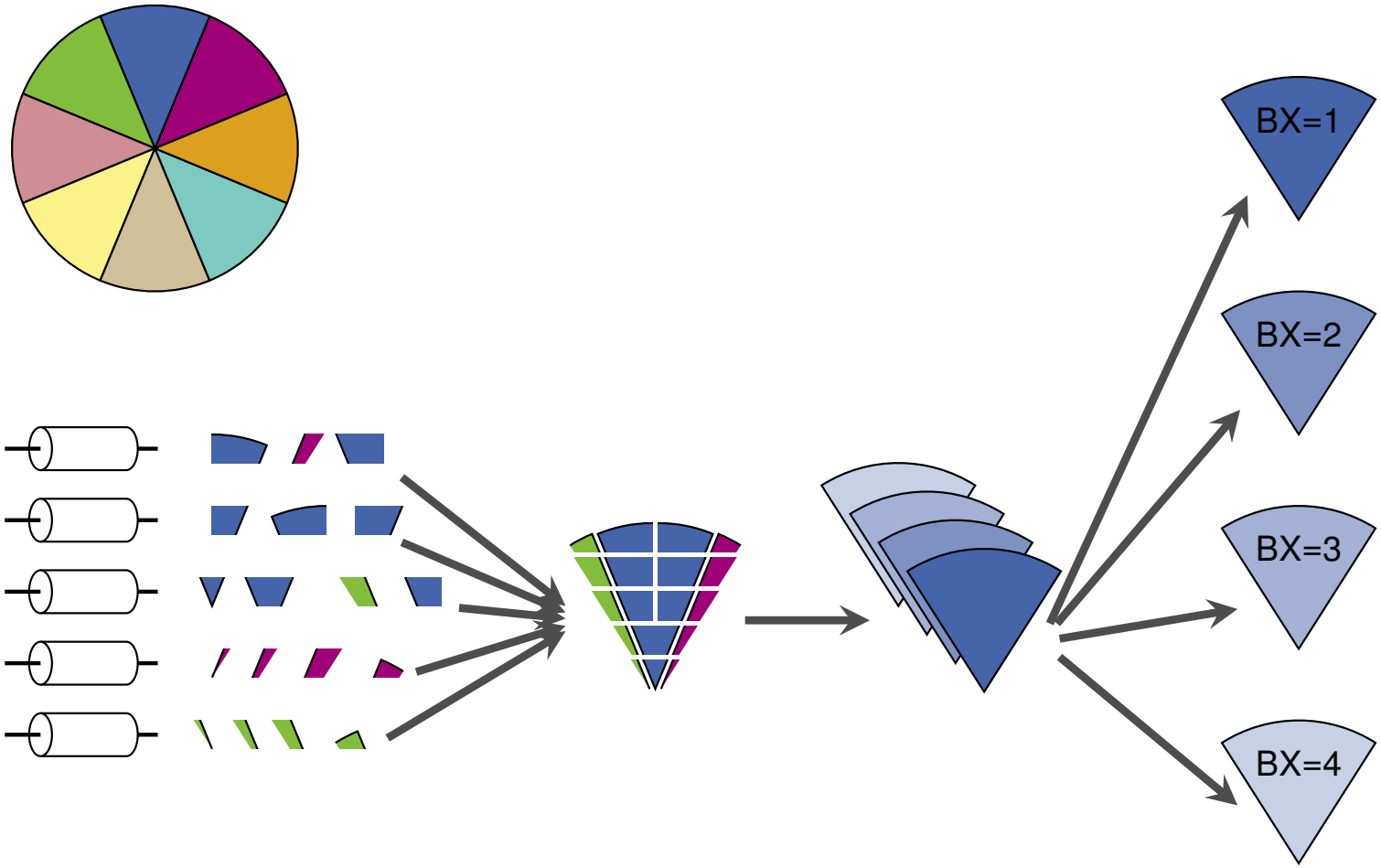


Accepted particles: $p_T > 3\,GeV$

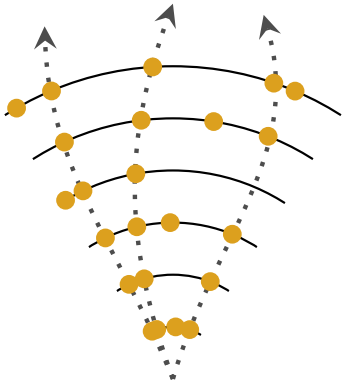




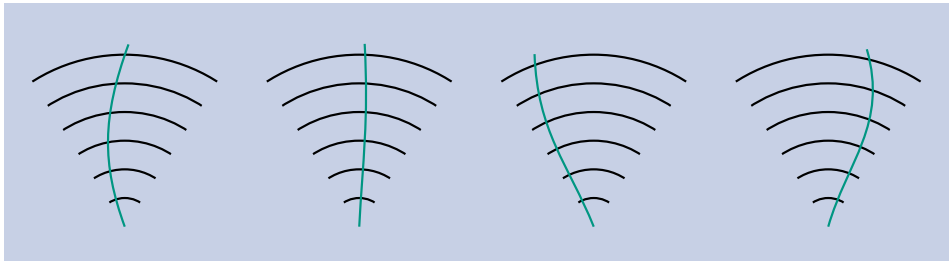
Arranging the Tracker Data



Track Finding by Associative Memory



Patternbank



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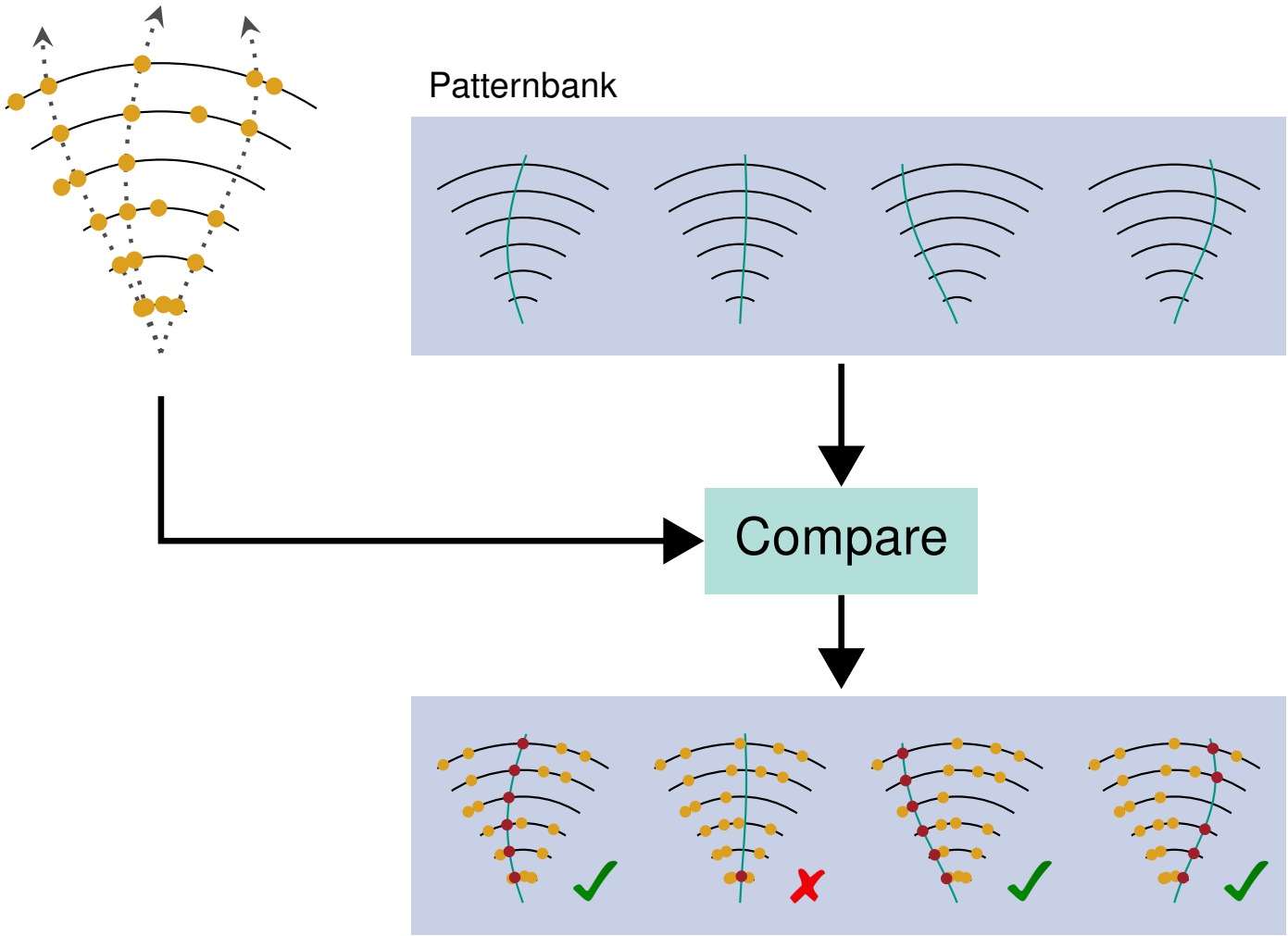
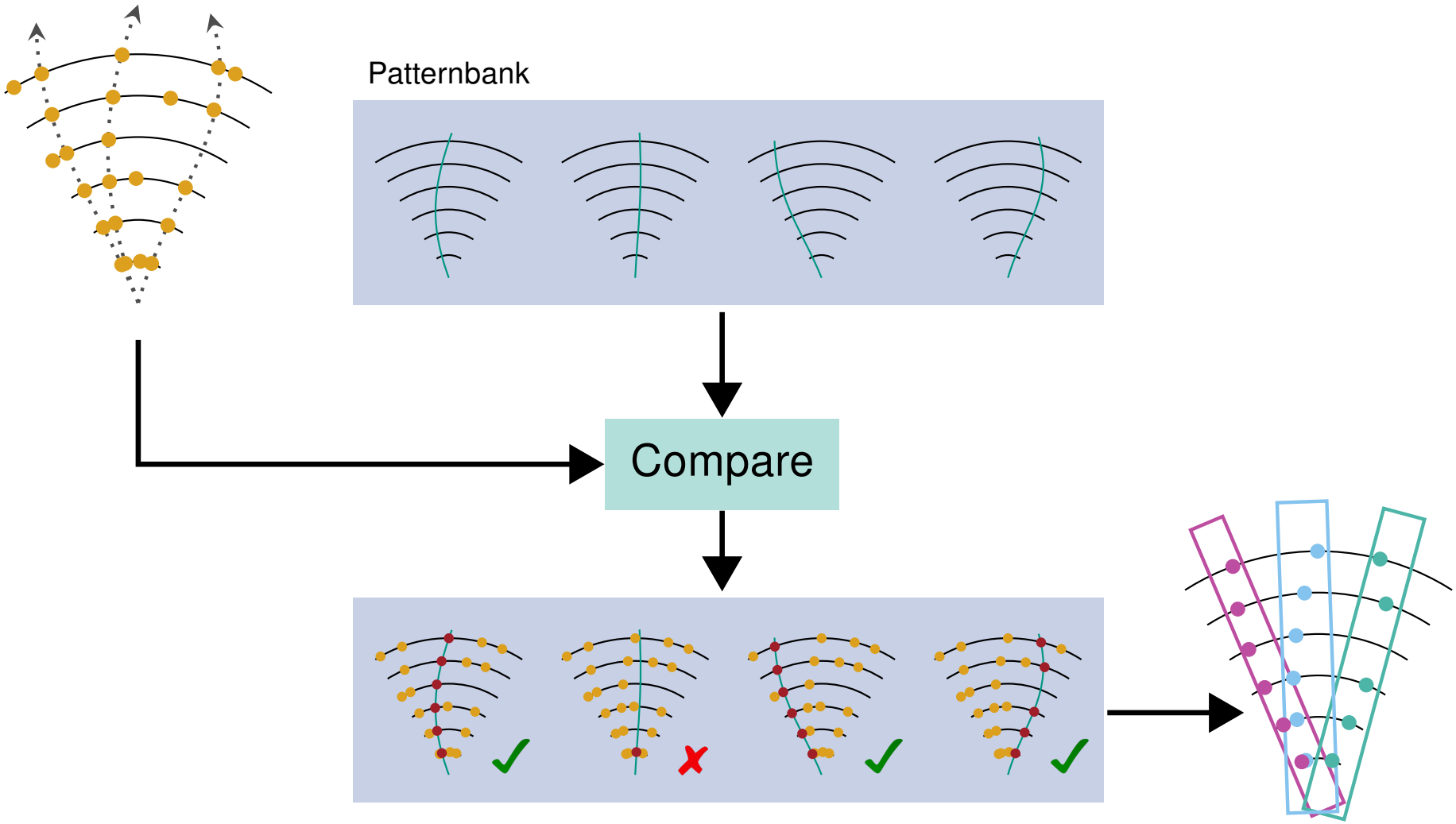
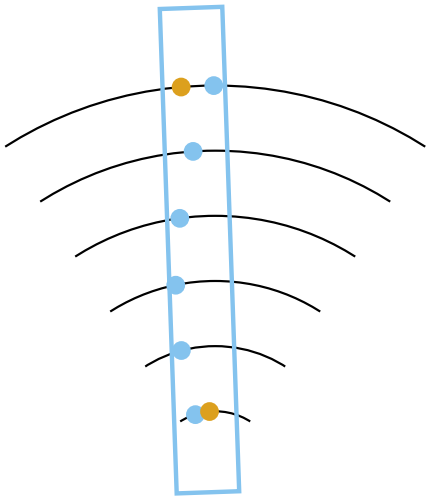


Track Finding by Associative Memory



Event Building



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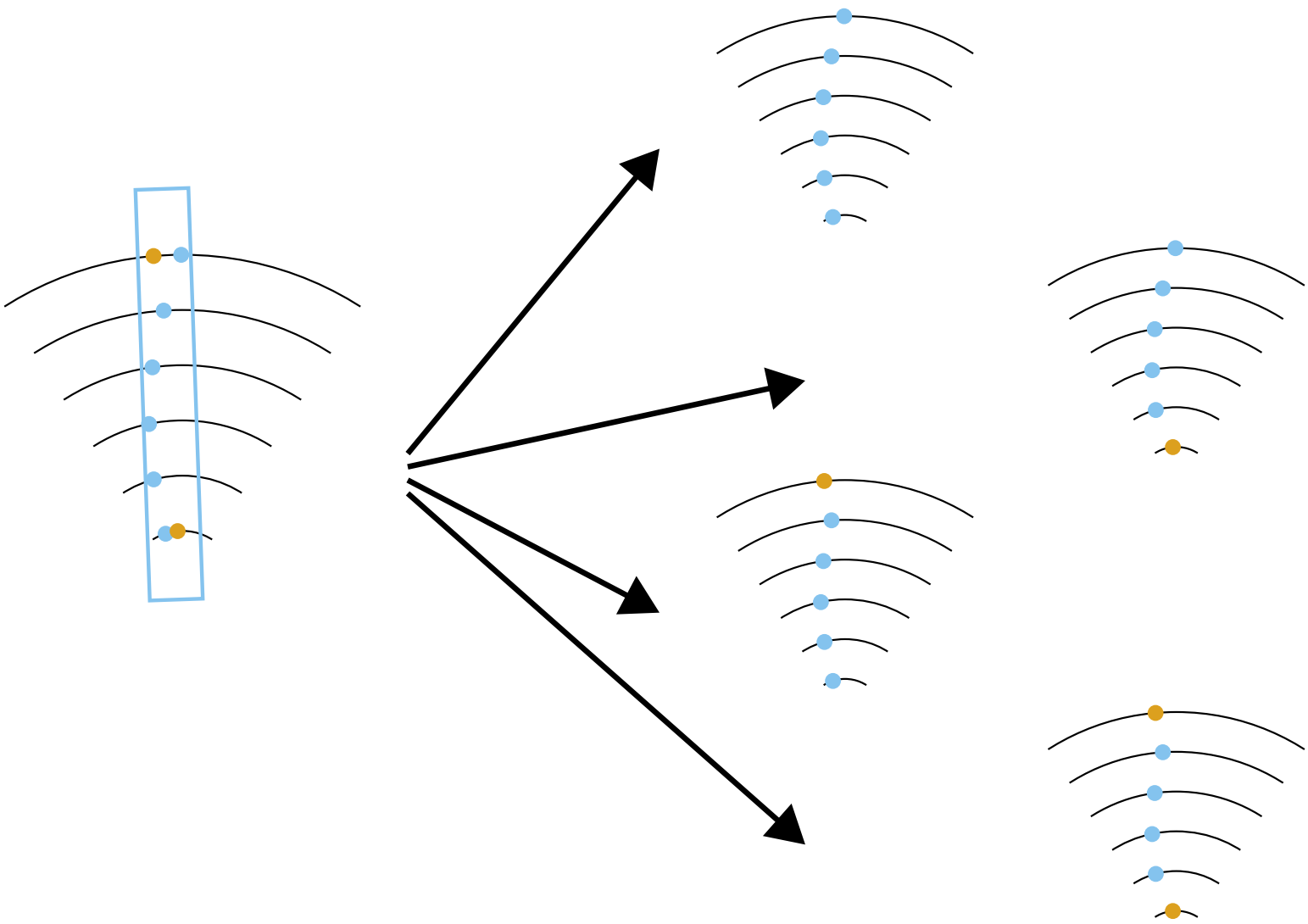

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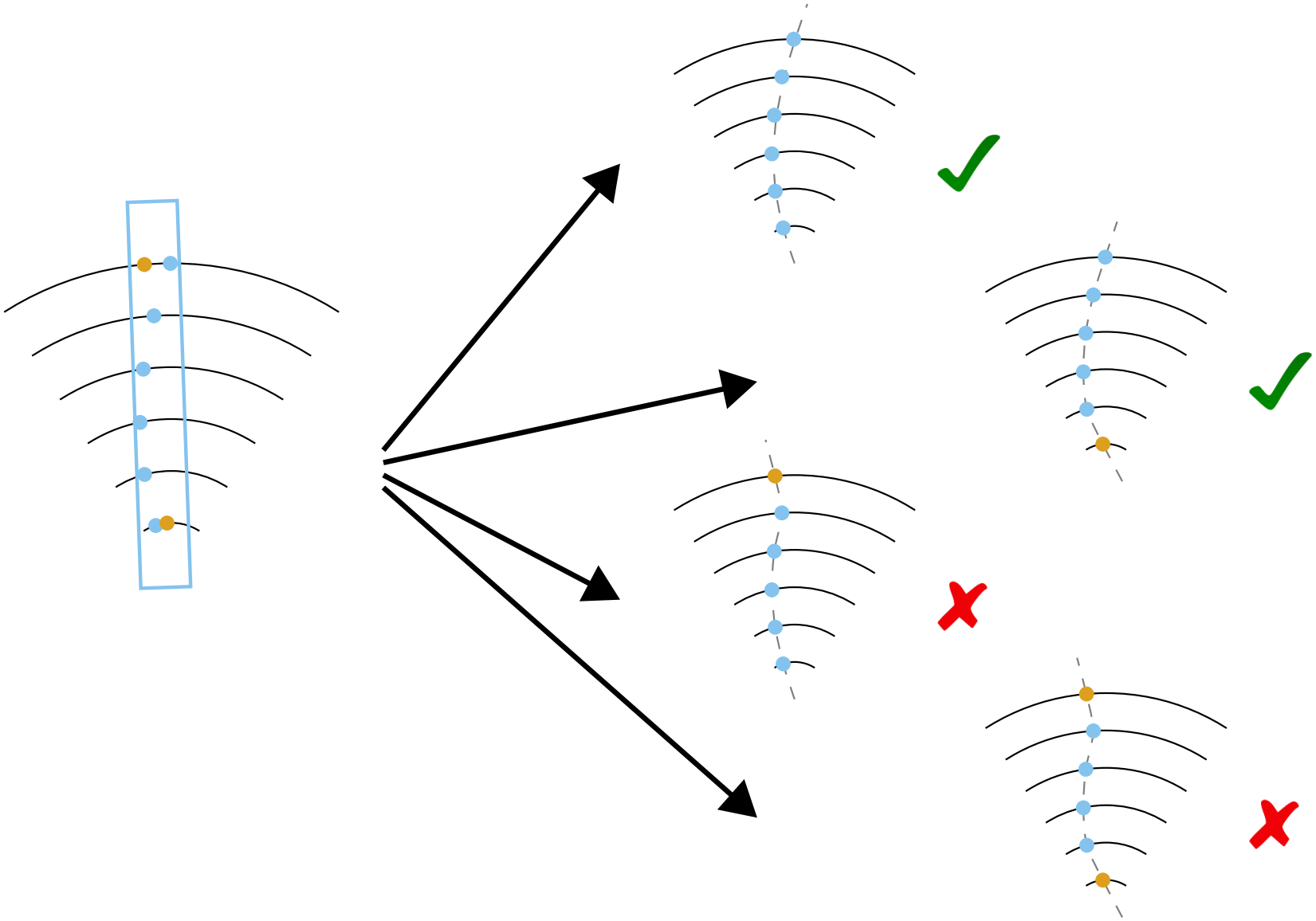
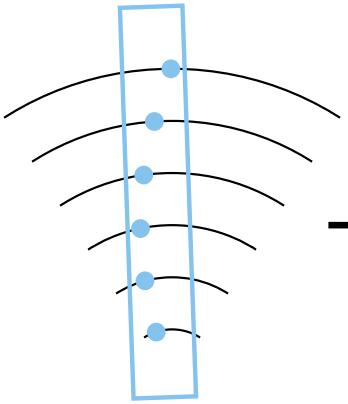


Track Fitting by Linearized Fit

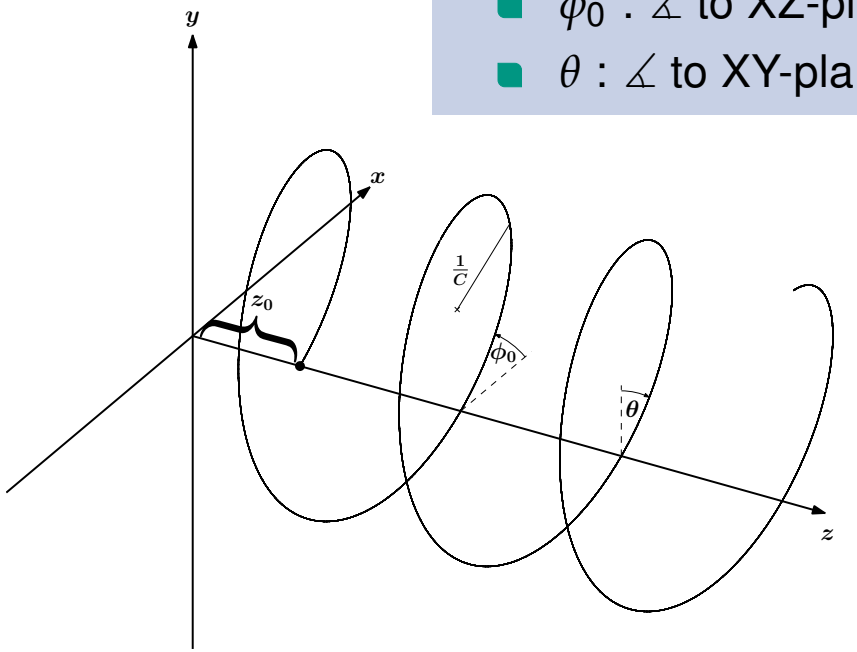


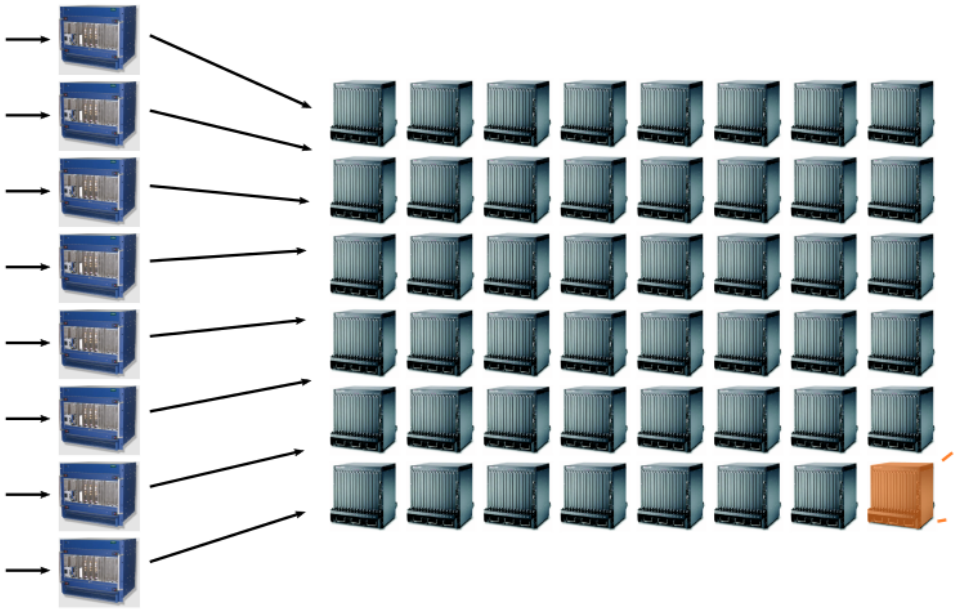
Pre-calculated Constants
A, B, C, D, E, F

$$A \cdot hit_1 + B \cdot hit_2 + ... + F \cdot hit_6$$

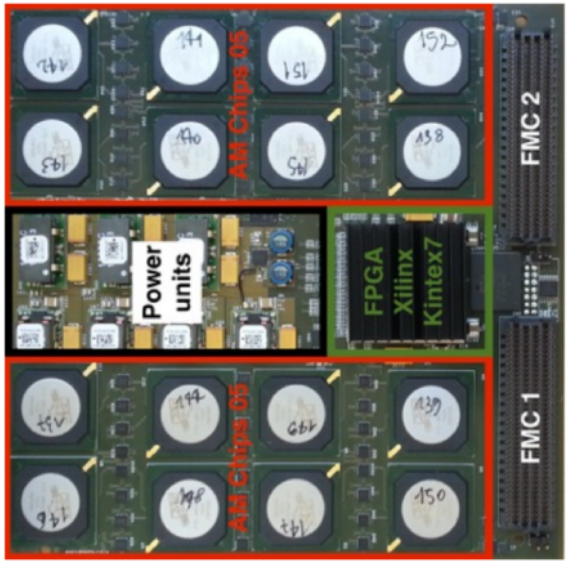
Track Parameters:

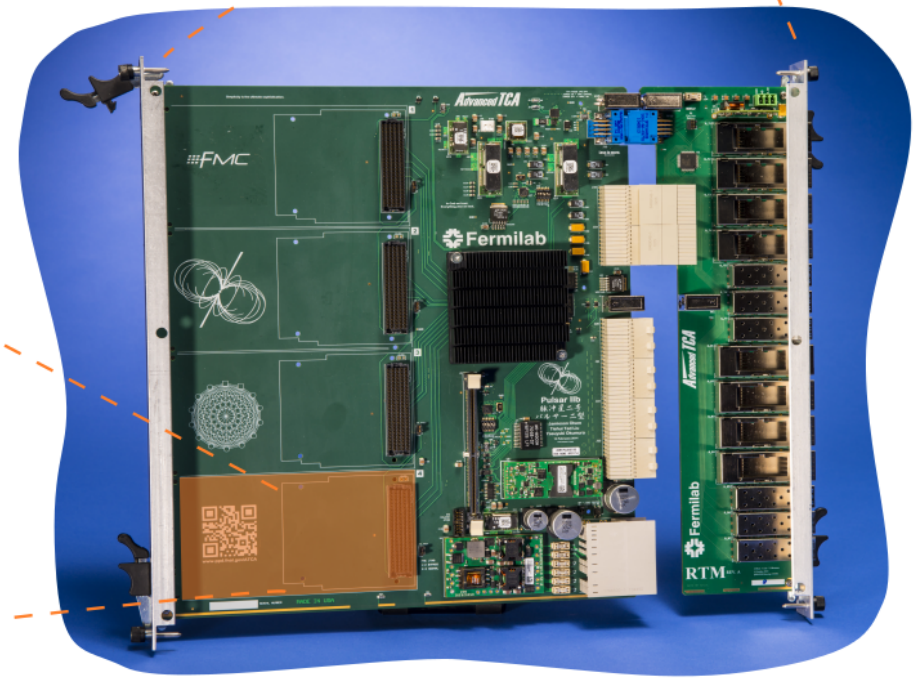
- Z_0 : Origin on Z-axis
- C : Curvature
- ϕ_0 : $\measuredangle$ to XZ-plane
- θ : $\measuredangle$ to XY-plane






AdvancedTCA


AM Chips 05
FMC 2
Power units
FPGA Xilinx Kintex7
FMC 1
AM Chips 05


FMC
AdvancedTCA
Fermilab
Fermilab
RTM

System Simulation I

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

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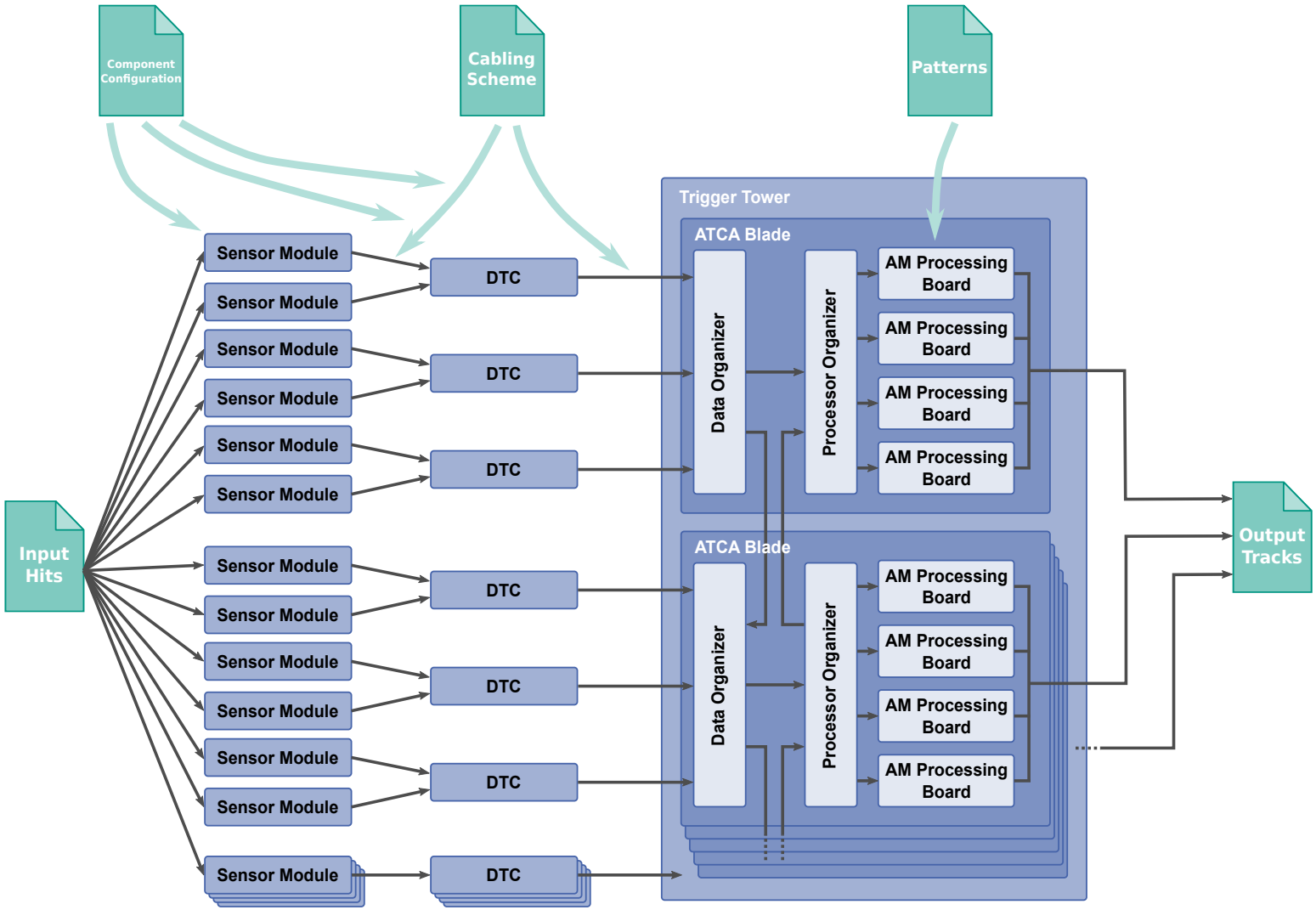
- All existing modules, but not all details
- Parameters of modules configurable

One sector of the Track Trigger has been simulated

System Simulation II



FPGA — Programmable Digital Chips

... a very very brief introduction

Karlsruhe Institute of Technology

Field-**P**rogrammable **G**ate **A**rray

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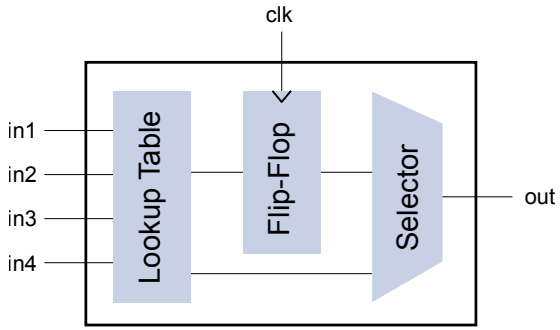

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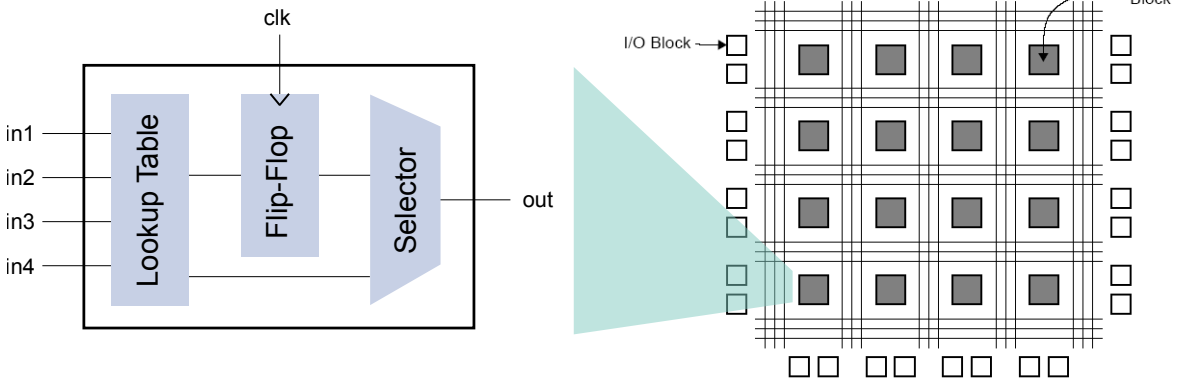
Field-Programmable Gate Array



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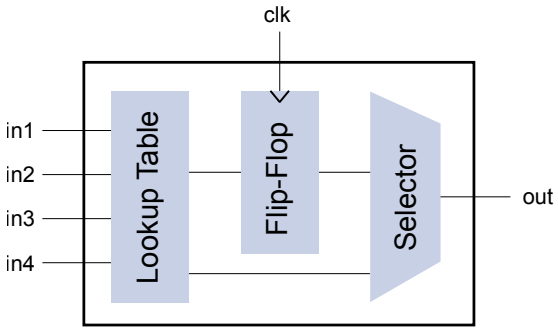

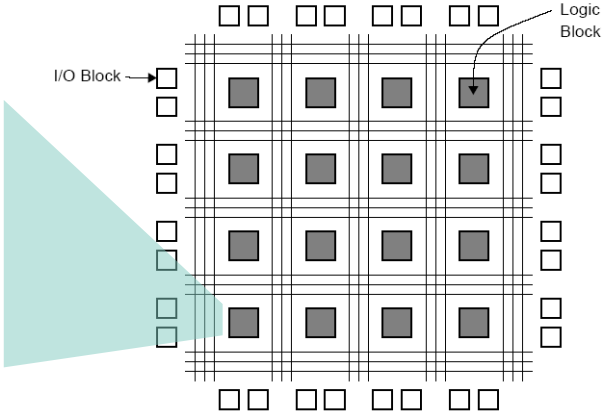

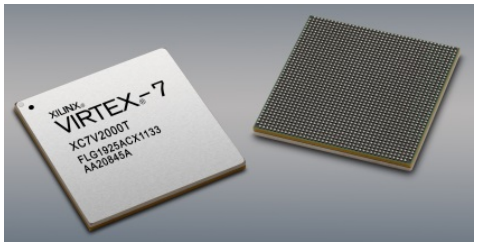

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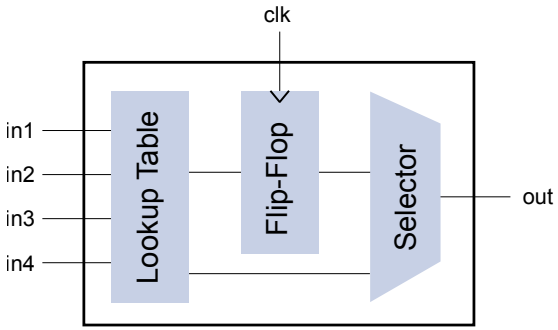
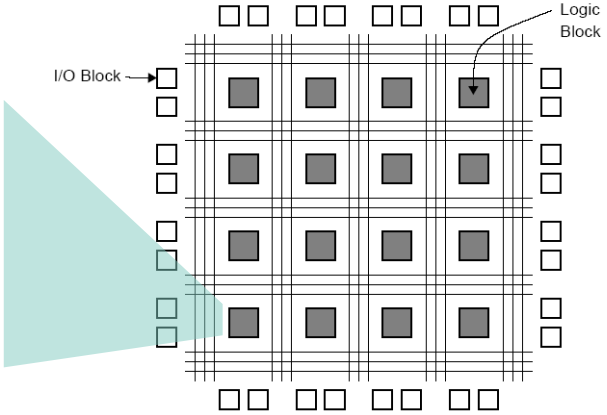
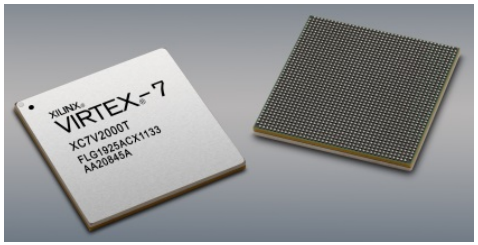
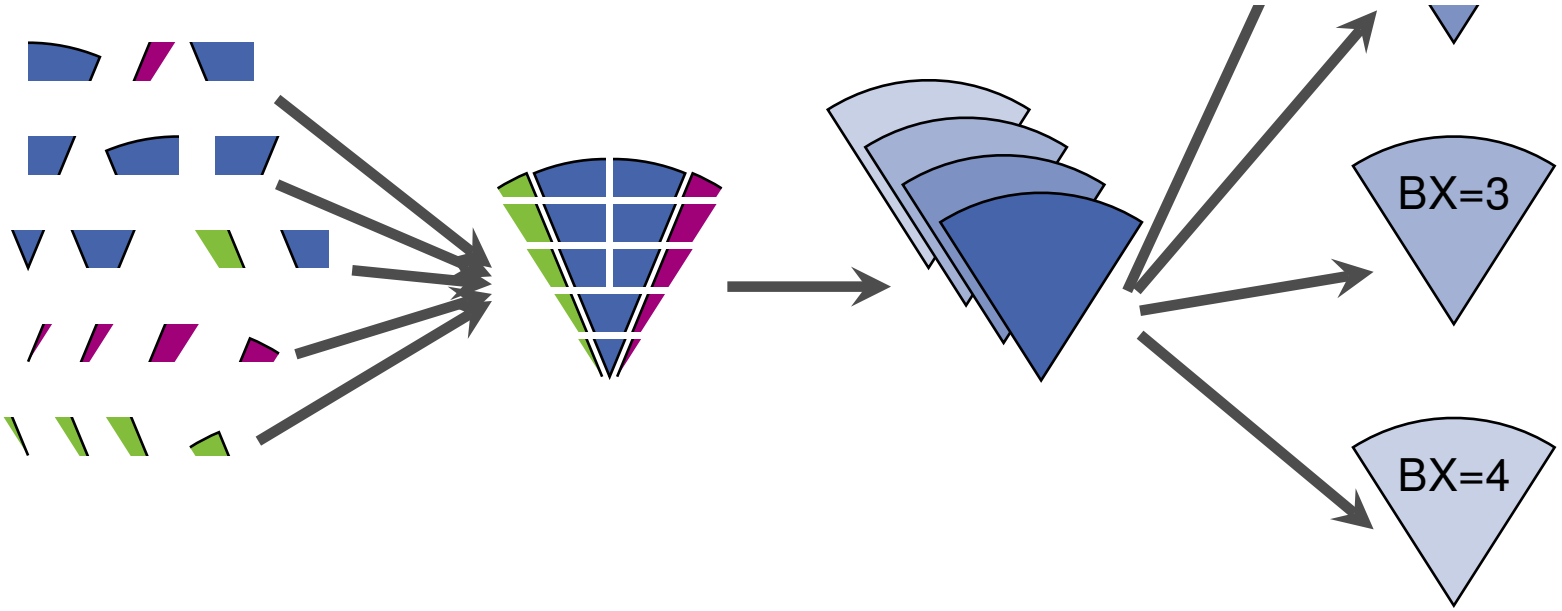


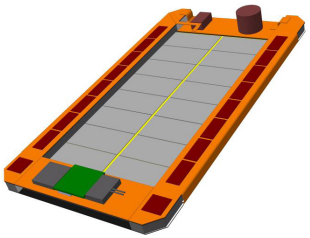





```
multiply_vectors(a[1000], b[1000])
   for i = 1 to 1000
      c[i] = a[i] * b[i]
   return c
```

Electronic System behind the Data Processing



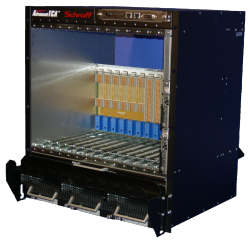


10 Gbps

Sensor Module
15000

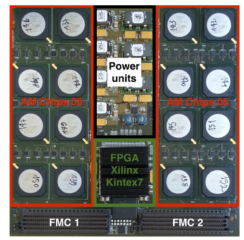
MTCA crate
72

100 Gbps



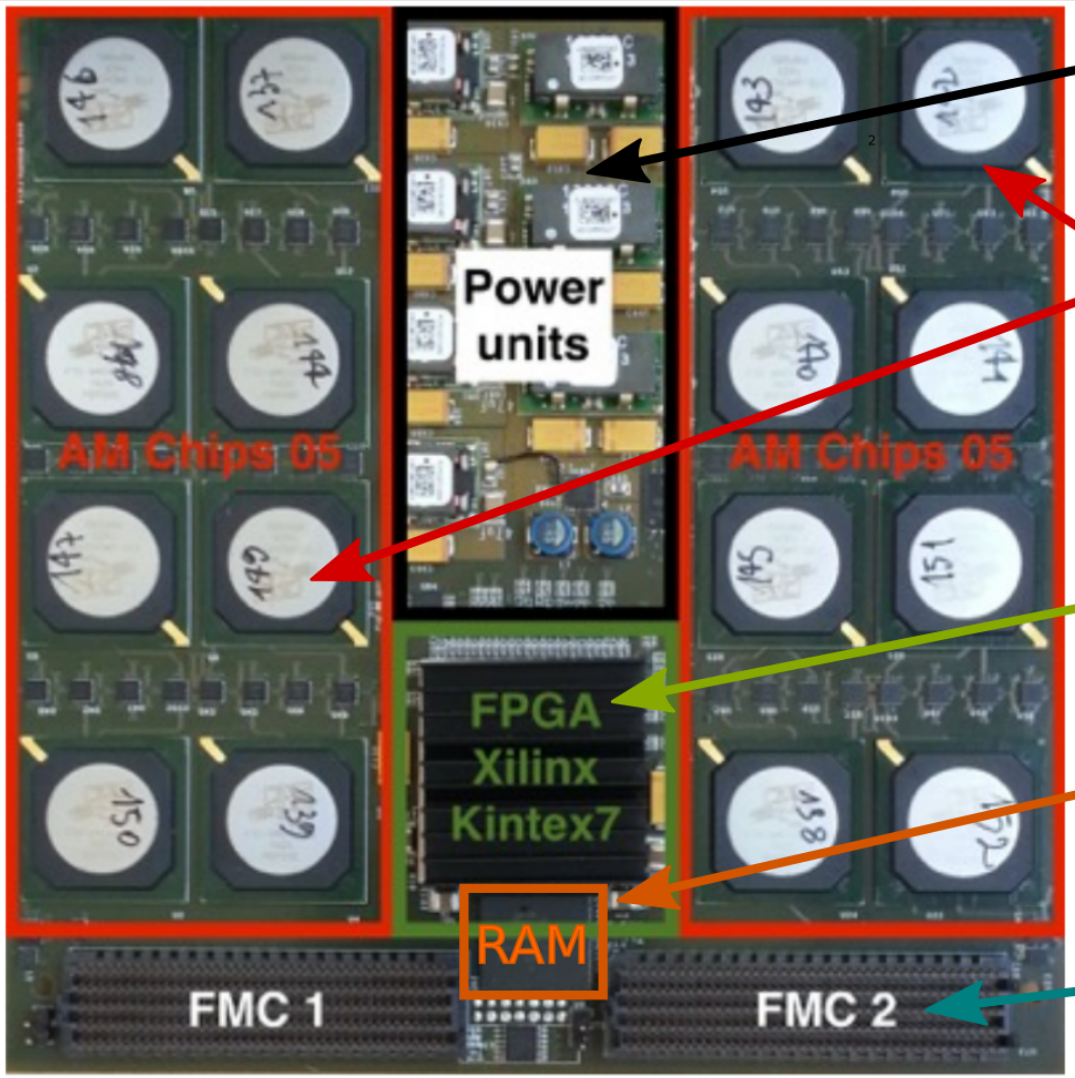
ATCA crate
48

Pulsar-IIb Board
550



AM Board
2200

The Pattern Recognition Mezzanine



80 W Power Supply

16 Associative Memory Chips
Total 2 Million Tracks

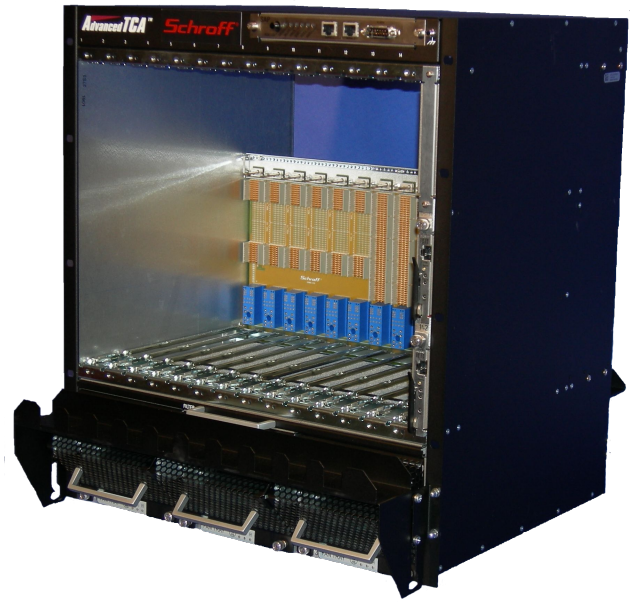
Large FPGA
480k Logic Cells

High-Speed Memory
144 Mbit SRAM

High-Speed Communictaion
up to 80 Gbit/s

Cost Estimation for the Track Trigger

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



Cost Estimation for the Track Trigger

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12	*ATCA blades:*	
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12	AM Chip sets	64k €
		196k €

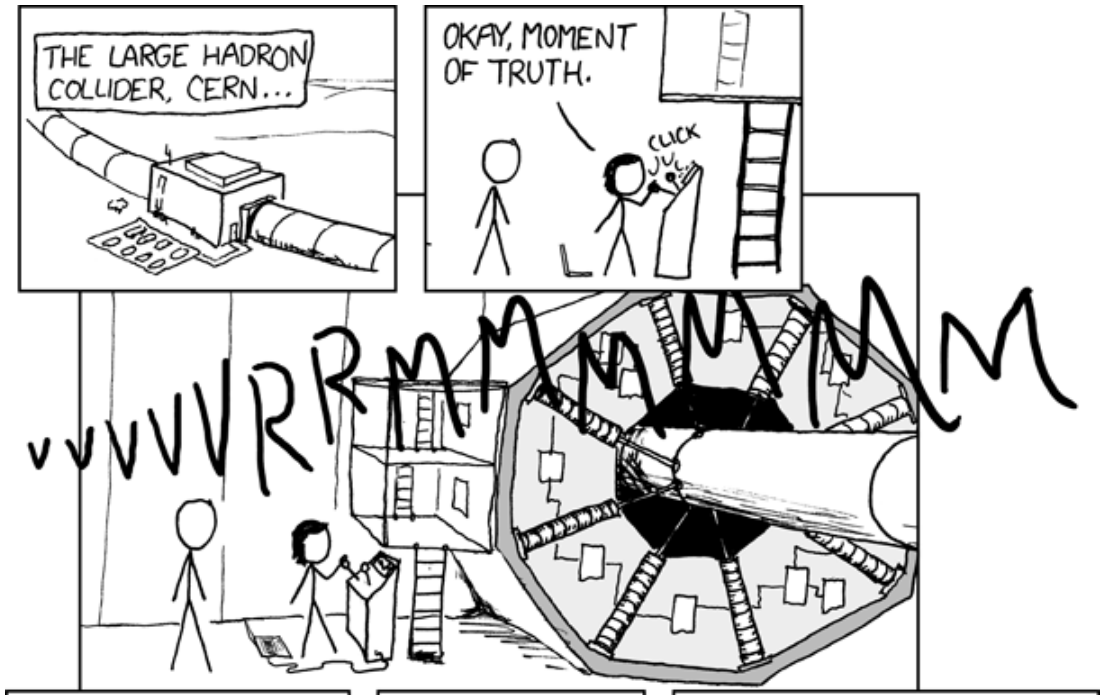
Total equipment cost: 48 crates * 196k € = **9.4M €**

Conclusion

- 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