ATLAS Fast TracKer (FTK)
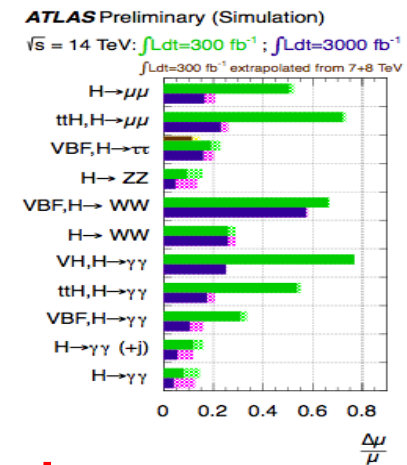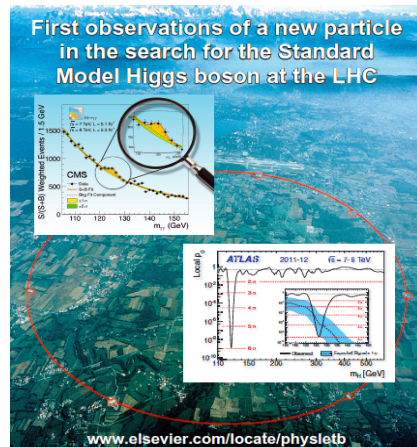
Rapid Identification of Heavy Quarks and Leptons at the Large Hadron Collider

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Physics Motivation

- **The Large Hadron Collider (LHC) discovered a Higgs boson, but to determine if it is the Standard Model Higgs boson**
  - Precision Higgs coupling measurements
- **The Standard Model can not be the whole story**
  - To solve the hierarchy problem (SUSY, compositeness, …)
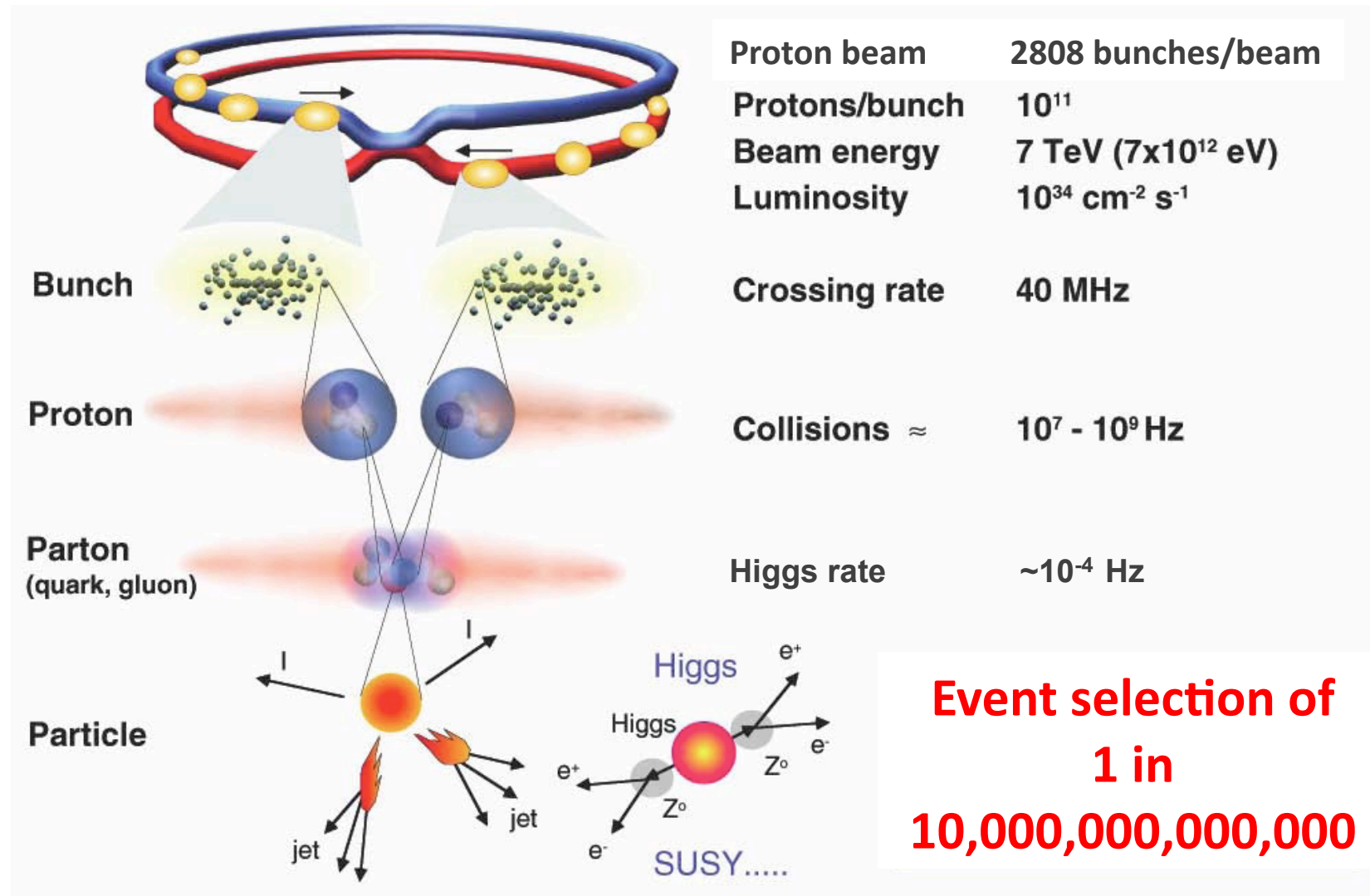 - To understand dark matter (data energy?)
  - … …

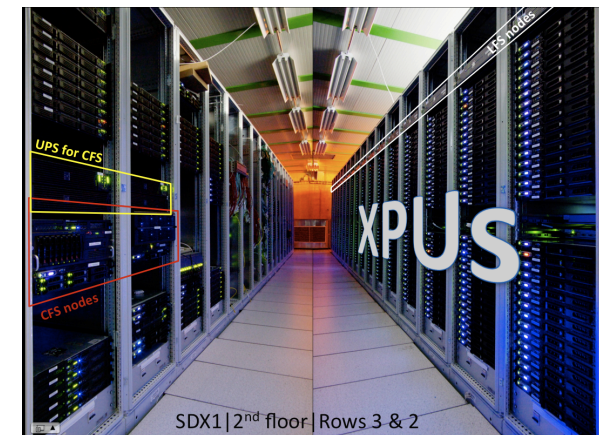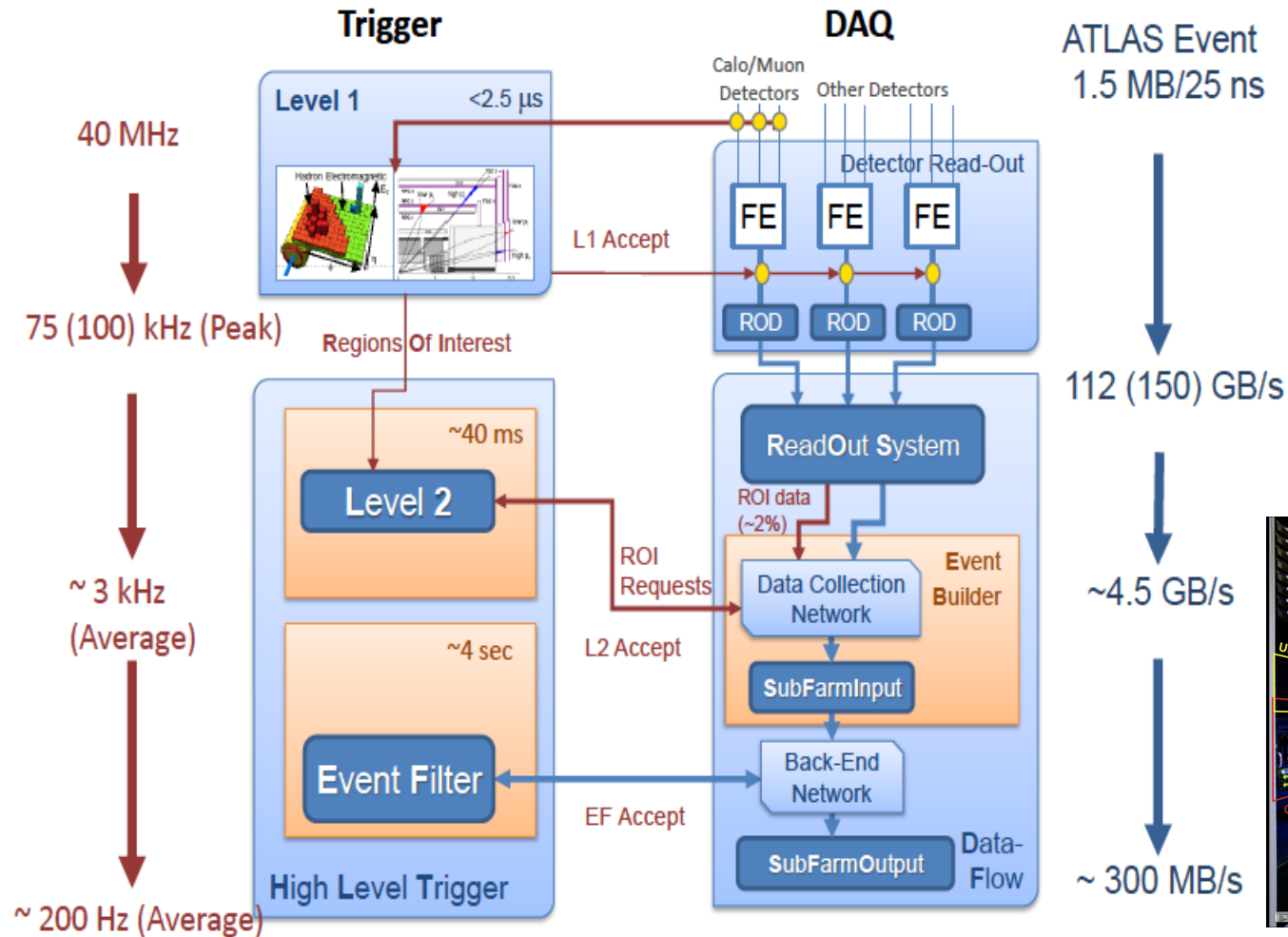**Large data samples are needed and coming**

Challenge @ LHC

Proton beam	2808 bunches/beam
Protons/bunch	10^{11}
Beam energy	7 TeV (7×10^{12} eV)
Luminosity	10^{34} cm^{-2} s^{-1}
Crossing rate	40 MHz
Collisions $\approx$	10^7 - 10^9 Hz
Higgs rate	$\sim 10^{-4}$ Hz

Bunch

Proton

Parton
(quark, gluon)

Particle

Higgs

e+

Higgs

e-

Z⁰

e+

Z⁰

e-

jet

jet

jet

SUSY.....

**Event selection of
1 in
10,000,000,000,000**

Multi Level Trigger Solution (ATLAS)

Tracking in Trigger

- **Capability to examine more event characteristics at the earlier trigger levels**
  - Tracking required for heavy flavor object (b-jets, τ-jets) identification and lepton isolation
  - Large tracking execution time due to hit density and time consuming trigger algorithms due to backgrounds

- **A hardware track finder (i.e., Fast TracKer FTK)**
  - Completing global tracking at the full L1A rate (100 KHz) and providing the full track list to the Level-2 trigger (LVL2) algorithms
  - Freeing up the LVL2 resource for sophisticated event selection algorithms
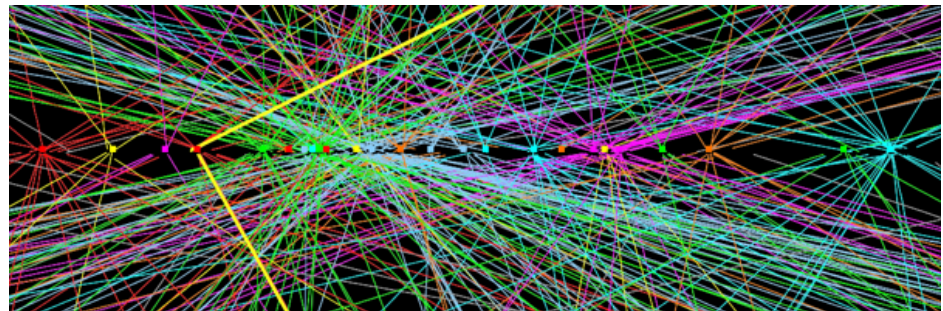
FTK Approach

Use hardware to perform the global tracking in two steps
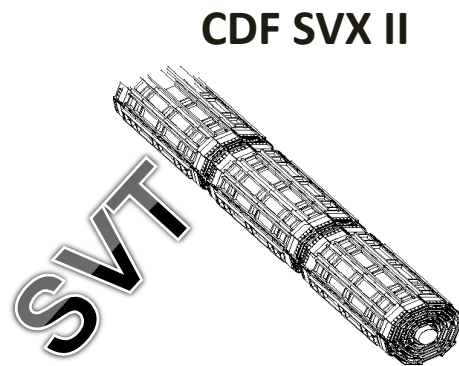**pattern recognition (in Associative Memory, AM) and track fit (in DSPs)**
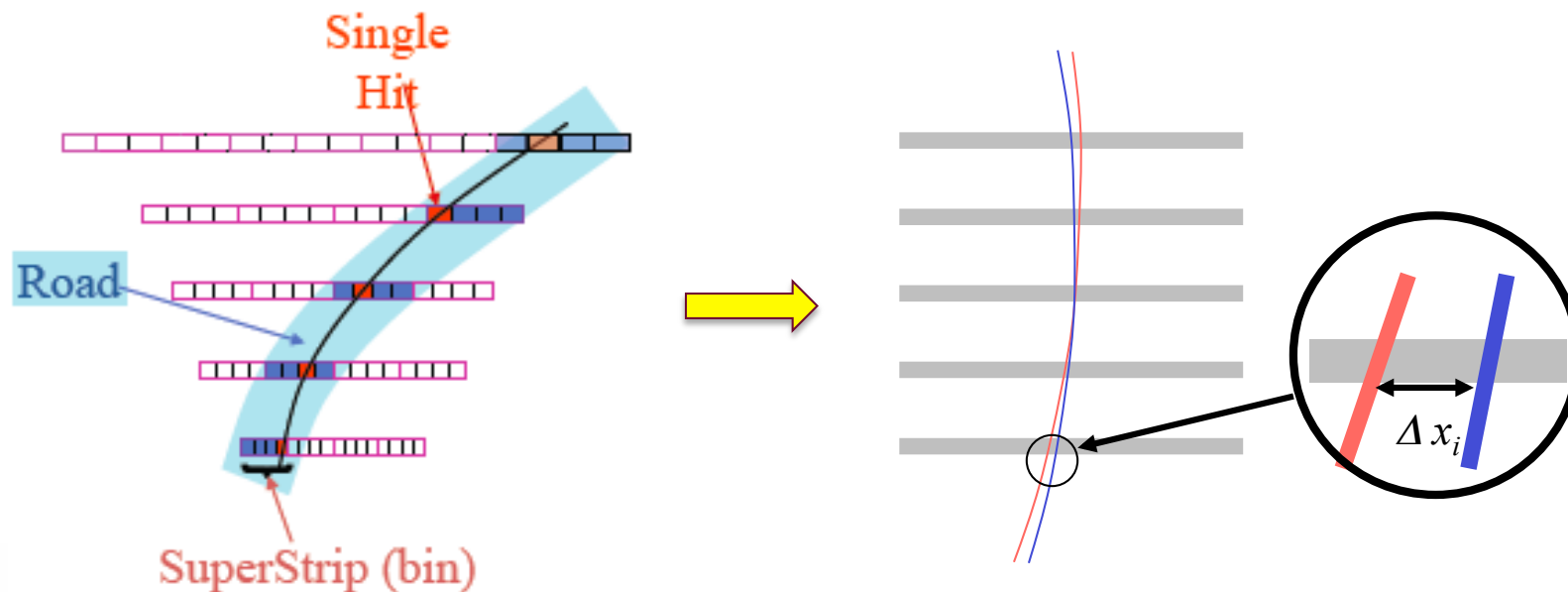
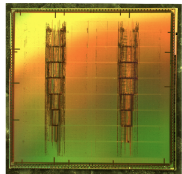| Pattern recognition in coarse resolution (superstrip➜road)	Track fit in full resolution (hits in a road) $F(x_1, x_2, x_3, ...) \sim a_0 + a_1\Delta x_1 + a_2\Delta x_2 + a_3\Delta x_3 + ... = 0$

Road size to balance the workload between two steps

From a Previous Success to a New Challenge

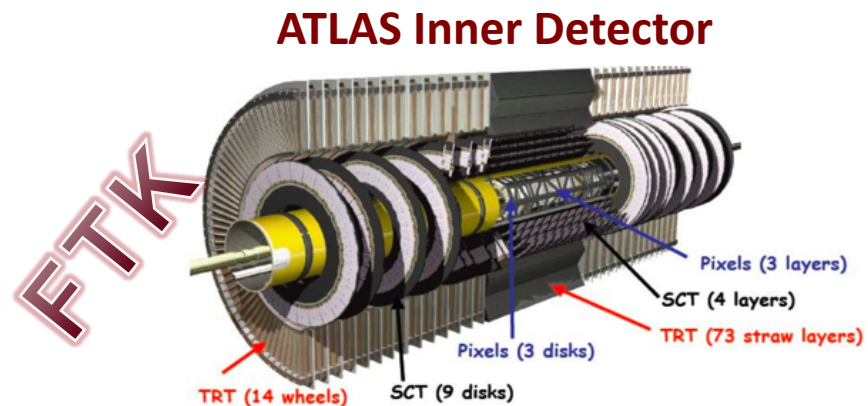## CDF SVX II

SVT

Channels used for SVT ~ 0.2 millions

Pattern stored ~400K

AMchip03
180 nm
3.7K pattern

Parallelism

- 64 $\eta-\phi$ towers
- Each tower with two processing units
- Overlaps to maintain high efficiency

ATLAS Inner Detector

FTK

Pixels (3 layers)
SCT (4 layers)
TRT (73 straw layers)
Pixels (3 disks)
TRT (14 wheels)
SCT (9 disks)

PIXEL 80 million channels
SCT 6 million channels
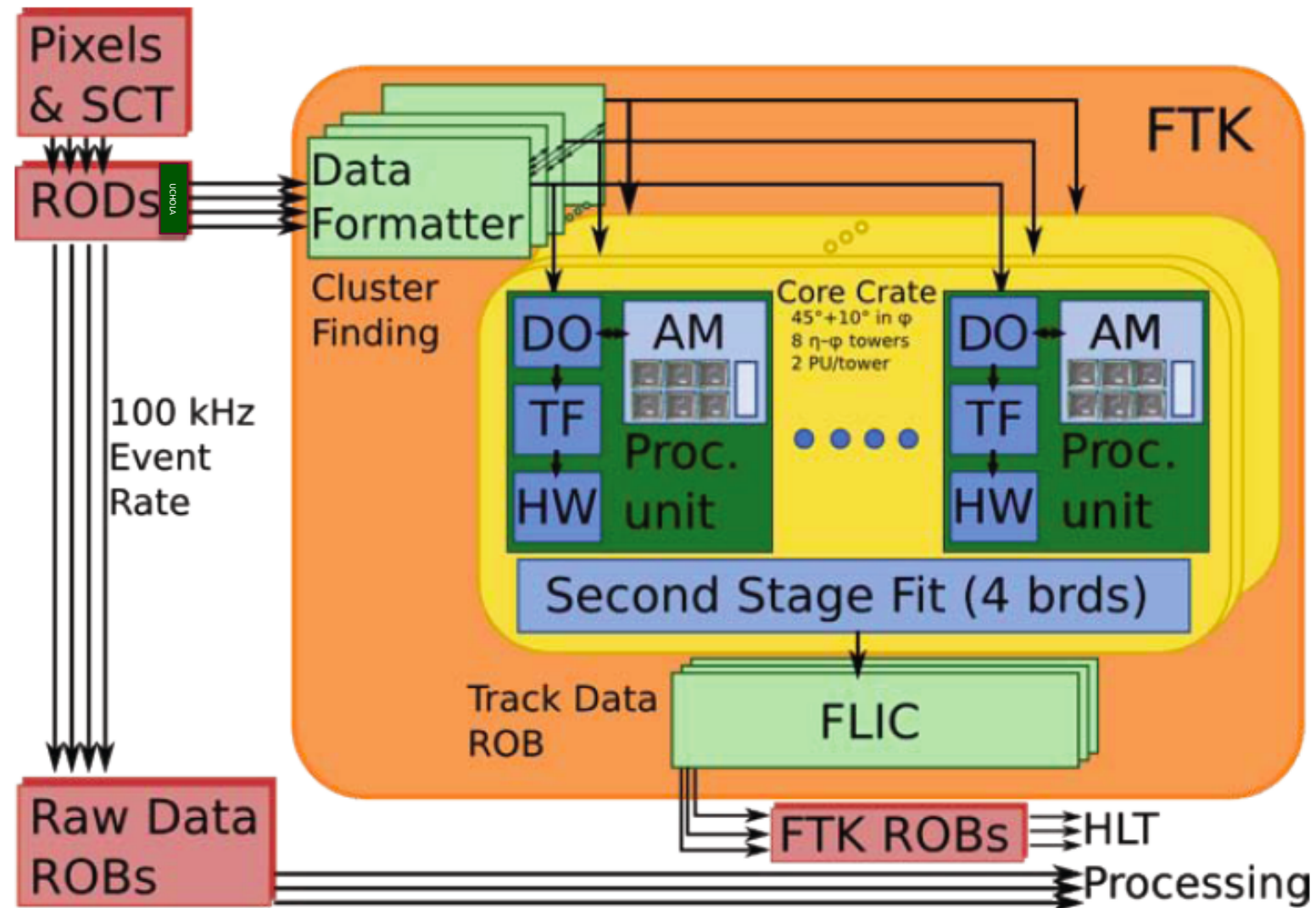
Pattern stored ~10^9
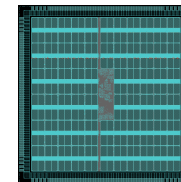
AMchip06
65 nm
128K pattern

Two stage architecture

- PIX 3 (B or IBL)+SCT 4 axial, 2nd stereo
- Other layer extrapolation & 12-layer fit

FTK System Overview

Duo-output HOLA Card

- **Duplicate the silicon detector output**

Data Formatter (DF)

- **Receive the silicon hits, perform cluster finding and send the cluster centroids**

Processing Unit Front Board (AM board)

- **Contain 4 mezzanine cards, with each holding 32 AM chips**

Processing Unit Rear Board (AUX card)

- **Store full resolution hits and send coarse ones by Data Organizer (DO), perform track fitting by Track Fitter (TF), and remove duplicates by Hit Warrior (HW)**

Second Stage Board (SSB)

- **Perform full 12-layer fit and duplicate track removal**

FTK Level-2 Interface Crate (FLIC)

- **Send formatted data to High Level Trigger and possibly perform advanced triggers**

FTK Team

- **Australia**
  - **Melbourne**
- **France**
  - **LPNHE**
- **Germany**
  - **Heidelberg**
- **Greece**
  - **AUTH**
- **Italy**
  - **Frascati, Milano, Pavia, Pisa**
- **Japan**
  - **Waseda**
- **Switzerland**
  - **Geneva**
- **US**
  - **Argonne, Chicago, Fermilab, Illinois, Northern Illinois**

FTK Funding

- **The bulk of the funds are coming from US and Italy, and some contributions from other countries**

- **Funding in US**
  - **Received a Chicago-Fermilab-Argonne seed grant**
  - **Received R&D support from DOE and NSF via USATLAS and other programs**
  - **Received a NSF Major Research Instrumentation (MRI) award of ~3M$**

Title: **Rapid identification of heavy quarks and leptons at the Large Hadron Collider**

- University of Chicago Investigator: Melvyn Shochet, Kersten Distinguished Service Professor of Physics, Enrico Fermi Institute
- Fermilab Investigator: Ted Liu, Scientist I
- Argonne Investigator: Jinlong Zhang, Assistant Physicist, High Energy Physics

The SCI program includes collaborative research projects, strategic joint appointments, and joint institutes among the University of Chicago, Fermilab and Argonne. The SCI program began in 2005 when the University renewed its contract with the U.S. Department of Energy to manage Argonne. The University extended the SCI program to Fermilab in 2006.
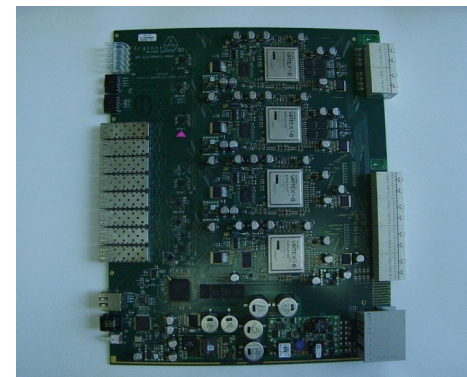
Argonne

- **Responsible for the FLIC to connect FTK and the rest of the ATLAS trigger system**

- **Using Advanced Telecommunications Computing Architecture (ATCA) technology for large data throughput and advanced functionalities**
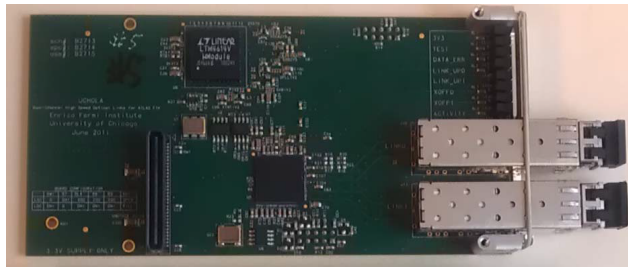

- ✓ **Prototyped board fabricated**
- ✓ **Testing undergoing**
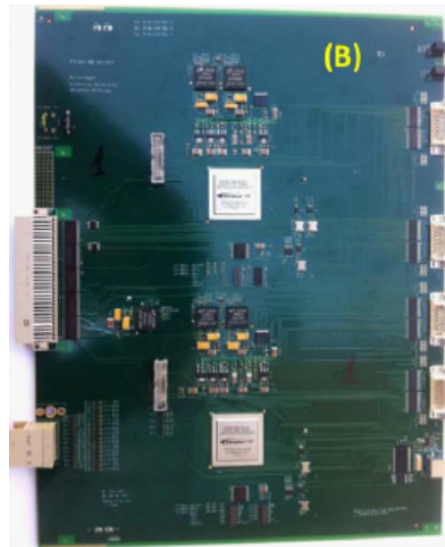- ✓ **Advanced algorithms being evaluated**

Chicago

- **Responsible for the design of duo-output HOLA cards**

- **Responsible for the design of the AUX card that carries out core FTK functions: smart database (DO), track fitting (TF), duplicate track removal (HW)**
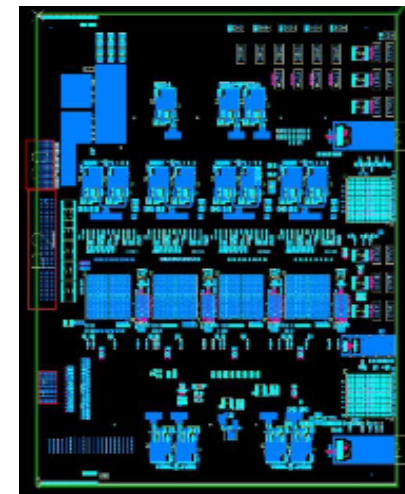

✓ **PCB being manufactured**

✓ **Tests planned in June 2013**

✓ **Firmware written for DO, TF and HW**

✓ **All cards produced and tested**

✓ **32 cards installed in 2012 for vertical slice testing**
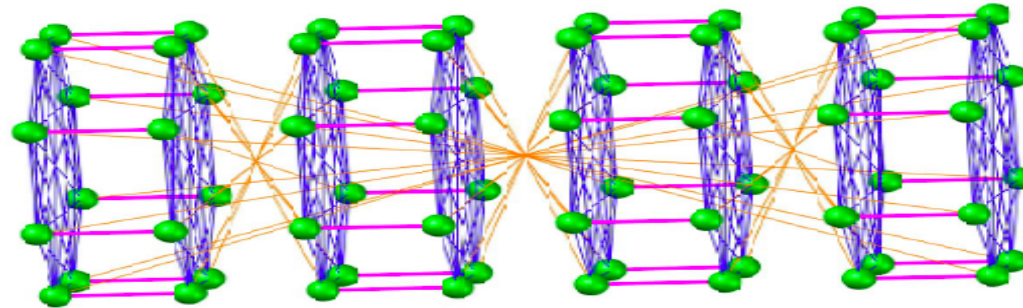
✓ **Next Installation planned in July 2013**

A dense VME RTM

Fermilab

- **Responsible for the DF to connect the ATLAS tracking detectors and FTK**

- **Using ATCA technology for DF to reorganize the enormous quantities of data**

✓ **2 prototypes assembled**

✓ **Tested in ATCA shelf**

✓ **Bandwidth performance meets design requirement**

Argonne Chicago Fermilab

- **Essential complementary expertise**
  - Detector, trigger and electronics
- Significant contributions in HEP experiments, close collaboration in some (CDF, ATLAS, ...)
- Experiences critical for the FTK project
  - Argonne: ATLAS TDAQ, ...
  - Chicago: CDF SVT, ...
  - Fermilab: CDF trigger, ...
- A great local team from the three
  - Duo-output HOLA card installation
  - Physics performance study for TDR
 - ... ...

Duo-output HOLA Card Installation

- **A thorough plan developed ahead**

- **An A-team from Chicago area**

- **A smooth execution**

32 installed cards were working properly during the data taking for Higgs discovery
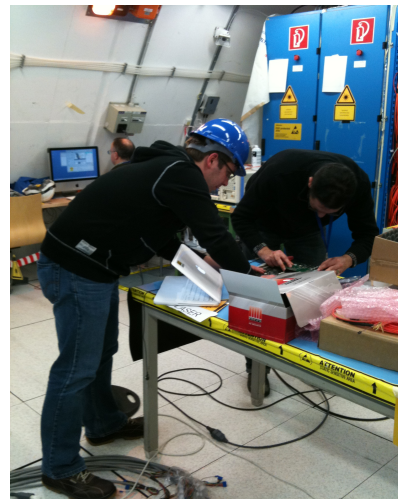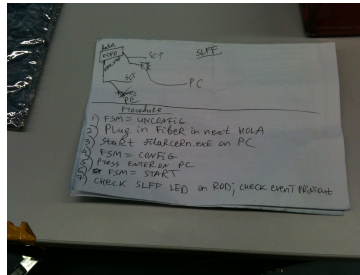
Physics Performance Study for TDR

- **Having a very tight schedule (now)**

- **Dealing with tremendous technical challenges (specific simulation, non-standard tools, different analysis framework, ambiguous reference, …)**

- **And Facing serious critics who think that all things can be accomplished with software alone**

- **But the team working together and managing to accomplish**
  - Performance comparison for lepton isolation, b-tagging and primary vertexing
  - **A conservative estimate that projects an increase of ~25% in the number of H➜ττ events collected**
  - **And more**
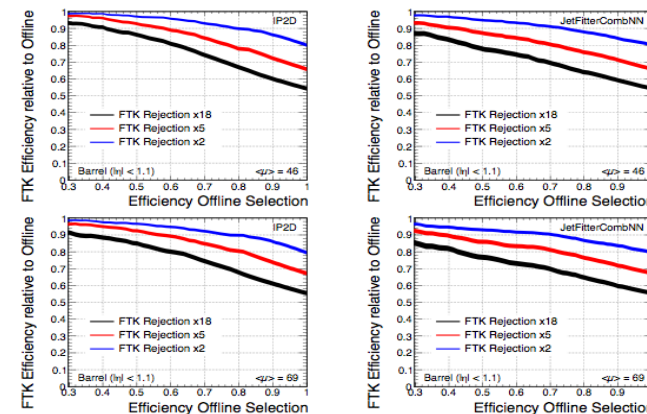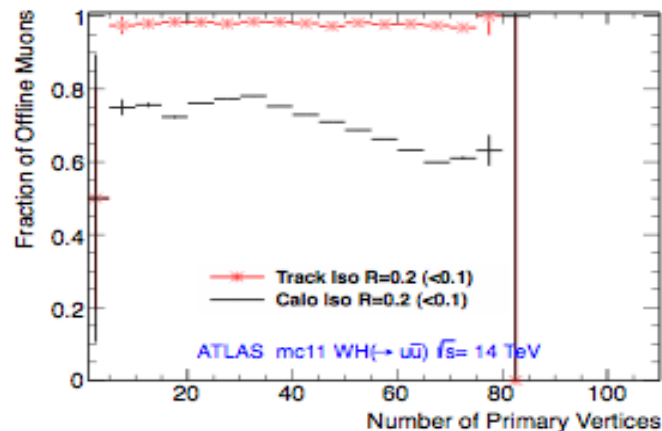
FTK Project Timeline

- **R&D proposal in 03/2008**
- **Technical Proposal (TP) in 01/2010**
- **Initial design review in 12/2010**
- **ATLAS Executive Board approval in 12/2010**
- **ATLAS Collaboration Board approval in 06/2011**
- **Technical Design Report (TDR) in 05/2013**
- **LHCC approval in 06/2013**
- **Installation in 2015 for barrel coverage**
- **Installation in 2016 for full detector coverage**

Summary

- **FTK is a powerful system that can have a big impact on the ATLAS physics program.**

- **Argonne, Chicago, and Fermilab are working together closely to make this project a great success.**