FTK

Ultrafast tracking electronics for the ATLAS trigger at the CERN Large Hadron Collider

Italy: **Bologna, Frascati, Milano, Pavia, Pisa**
Japan: **Waseda**
US: **Argonne, Chicago, Fermilab, Illinois, Northern Illinois**

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Physics Motivation

- **We do not know what the new phenomena to be discovered at the LHC will be.**
  - **Theorists have guesses, but they are only guesses. Nature may be even more clever than theorists!**
- **As experimentalists, we must be nimble in responding quickly to whatever is discovered.**
  - **We will want high efficiency for whatever the new phenomena are.**
    - **Discovery is great, but it is only the beginning of the story.**

The importance of statistics

- **Perhaps the greatest challenge at a hadron collider is determining what a new phenomenon is.**

Higgs, SUSY, KK excitations, Z′, ?

- **It took 15 years just to determine the top-quark's charge!**
- **Need high efficiency (and also good background rejection) to measure the object's properties.**

spin through angular distributions

helicities of decay products

multiple decay modes

couplings to other particles

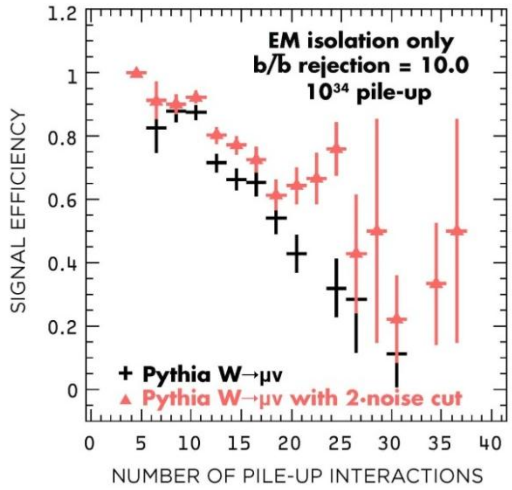
- **For each of these, large samples of events are needed. Depending on the new phenomenon, FTK could increase the number of events retained for detailed physics analysis by an order of magnitude, which could be crucial.**

Trigger

- **The Problem**
  - **There are $> 10^9$ *pp* collisions/sec. in 4×10^7 beam bunch crossings/sec.**
  - **Quantity of data/sec. $\Rightarrow$ can store ~200 /sec.**
  - **Rate of a typical new phenomenon of interest: 1/hour ($H \rightarrow \gamma\gamma$).**
  - **The needle in a haystack problem. The answer is not to pick up a handful of hay!**
- **The Solution**
  - **A multistage trigger**
  - **At each stage, use available information to reduce the collision rate to what can be handled at the next stage.**
  - **40 MHz $\rightarrow$ 100 kHz (level-1) $\rightarrow$ 2 kHz (L2) $\rightarrow$ 200 Hz (L3)**
  - **There is no information on individual particle tracks available to the level-1 trigger.**

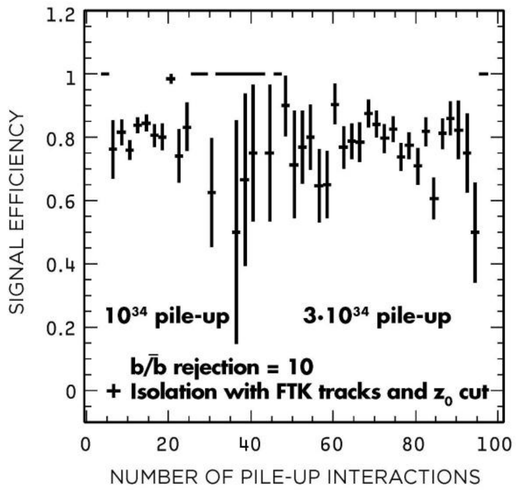
Tracking in the trigger

- **Many/most new physics scenarios: final state with heavy flavor**
  - **Select *b*-jets and τ-jets from enormous QCD background ⇒ tracking**
- **Selection of leptons using calorimeter isolation fails at high luminosity because of the pile-up. Solution is tracking isolation using tracks pointing to the lepton at the beamline.**

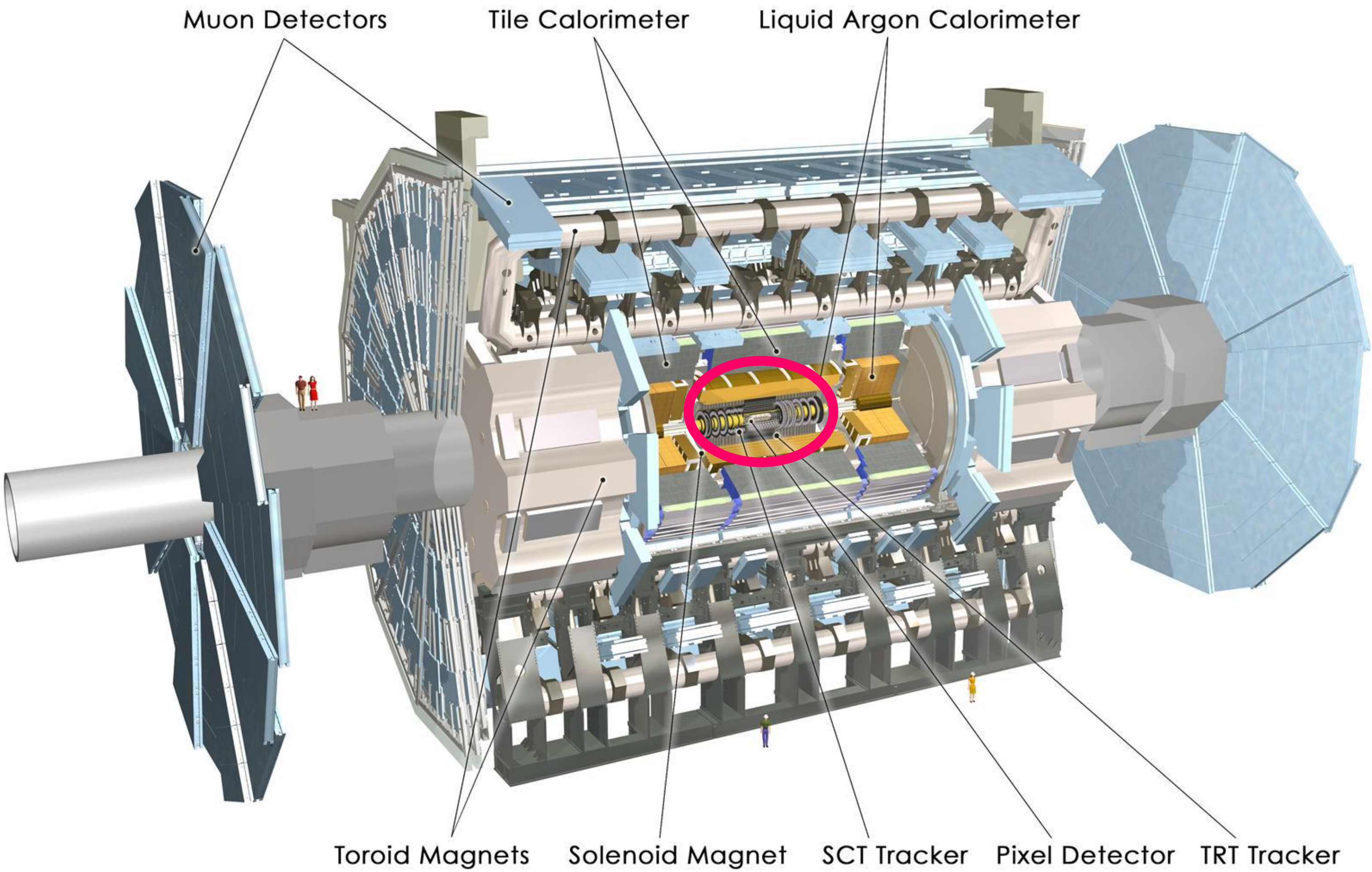


Calorimeter isolation

Tracking isolation

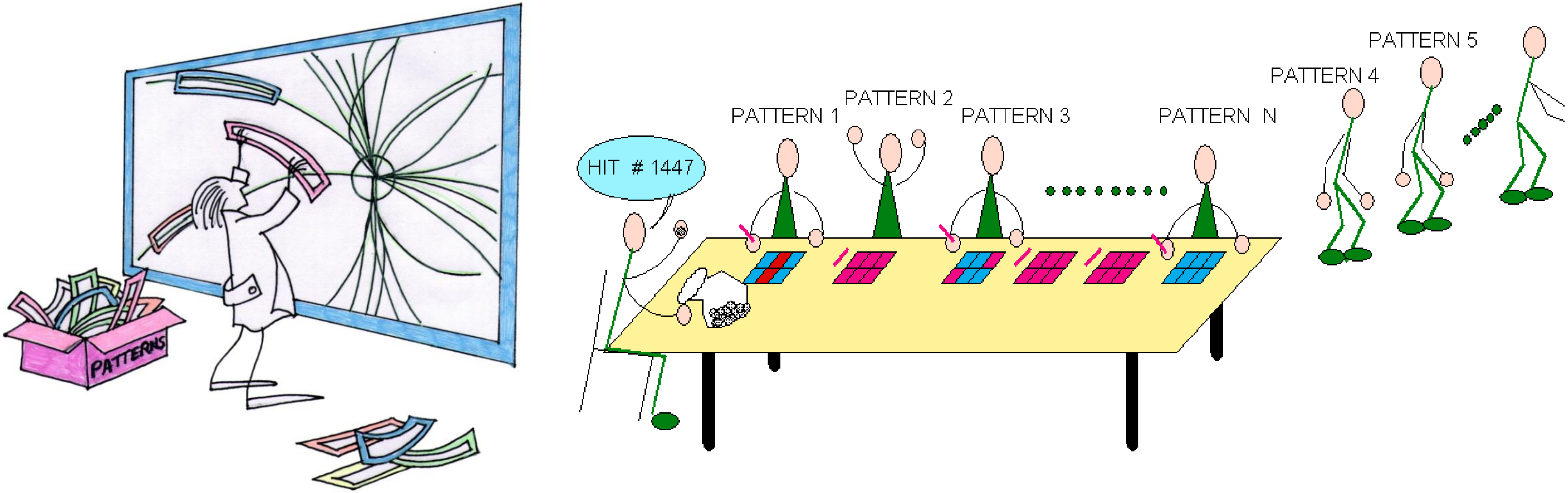


- **FTK: hardware processor that completes GLOBAL track reconstruction by the beginning of level-2 processing.**
  - **Rapid rejection of the background that dominates the level-1 trigger rate.**



Two time-consuming stages in tracking

- **Pattern recognition – find track candidates with enough Si hits**

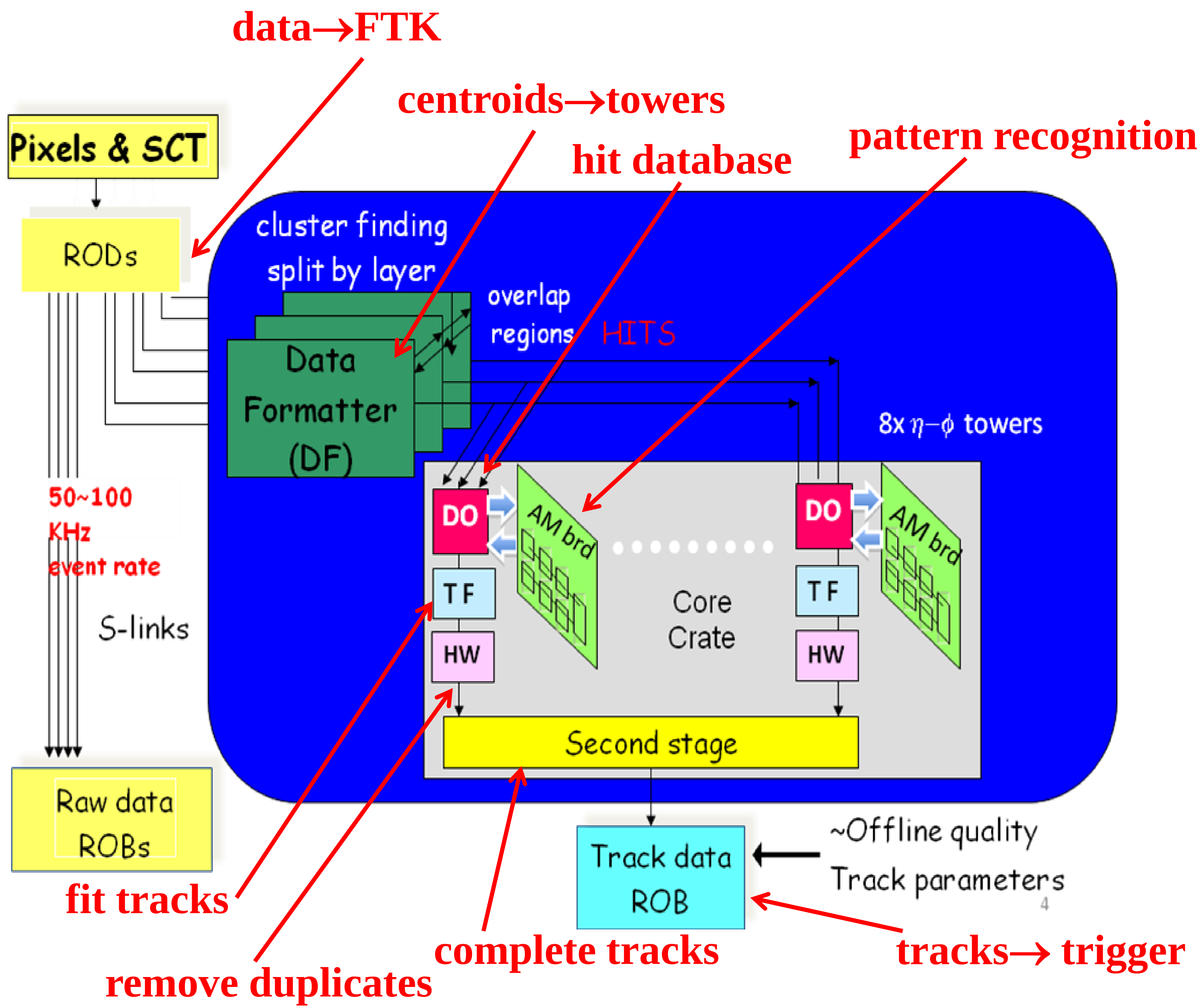


  - **10^9 prestored patterns simultaneously see each silicon hit leaving the detector at full speed.**
- **Track fitting – precise helix parameter & χ^2 determination**
  - **Equations linear in local hit coordinates give near offline resolution:**

$$p_i = \sum_{j=1}^{14} a_{ij} x_j + b_i$$ ***a* & *b* are prestored constants; VERY fast in FPGA**

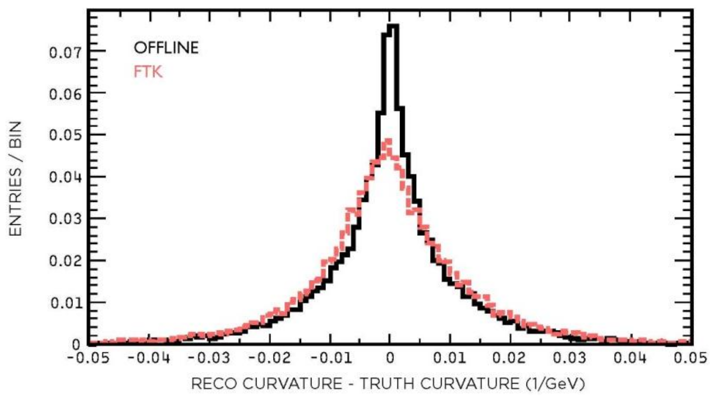
Technical Challenges

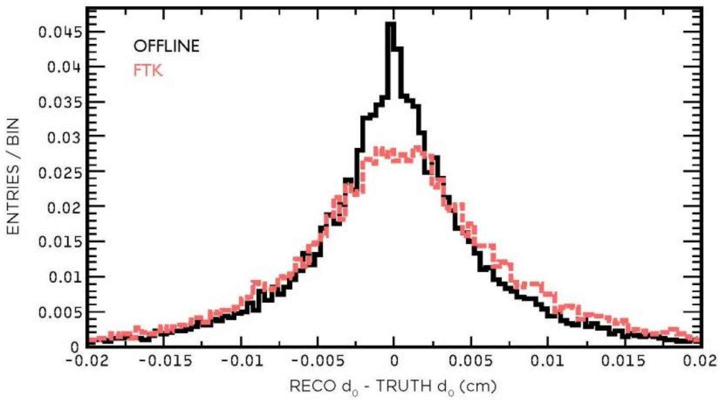
- **Data rate into FTK: 0.5 terabits/sec.**
- **Track fits: 0.3 terafits/sec.**


data→FTK
centroids→towers
hit database
pattern recognition
Pixels & SCT
RODs
cluster finding
split by layer
overlap
regions
HITS
Data
Formatter
(DF)
8x η–ϕ towers
50~100
KHz
event rate
S-links
DO
AM brd
TF
HW
Core
Crate
Second stage
Raw data
ROBs
Track data
ROB
~Offline quality
Track parameters
fit tracks
remove duplicates
complete tracks
tracks→ trigger

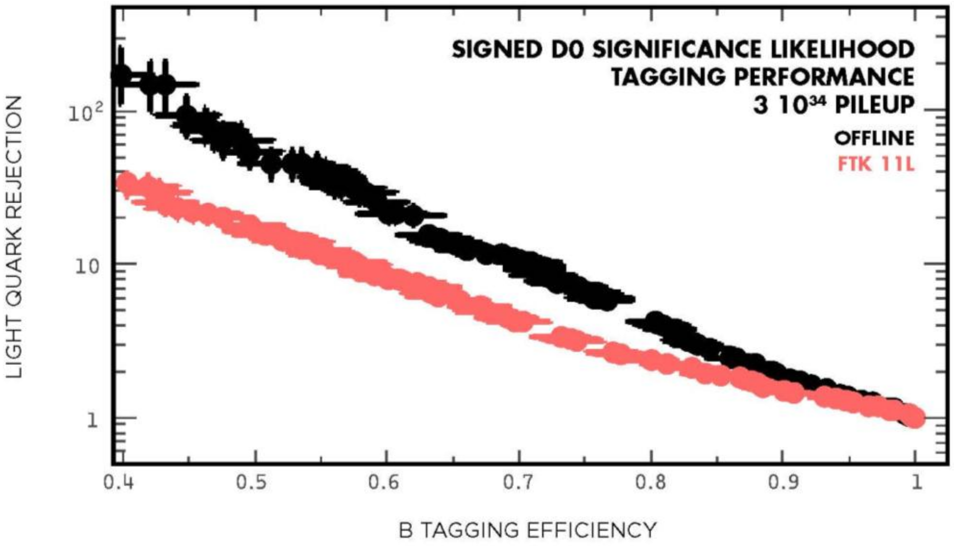
Performance: comparison to offline tracking

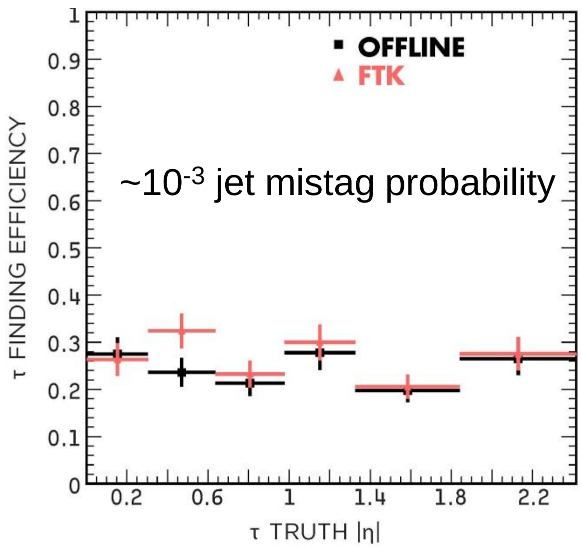
- **Track parameter resolution**





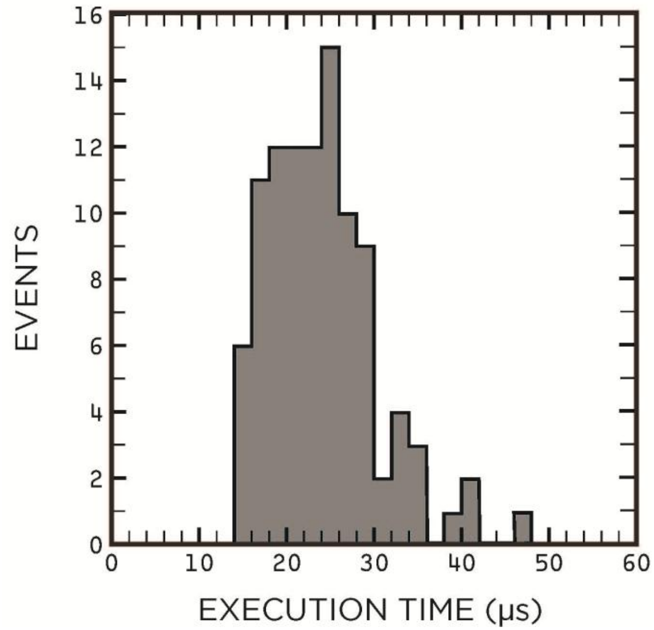
- ***b*-quark ID at 3×10^{34}** **hadronic τ decay at 3×10^{34}**

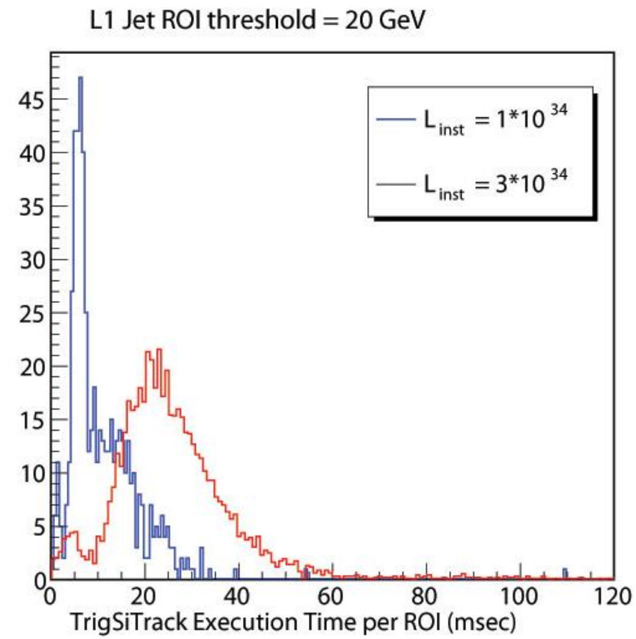




FTK timing vs. current ATLAS trigger

- **reconstructing tracks in quark jets at very high luminosity**





FTK global tracking | **current level-2 per jet**

- **FTK completes global tracking in 25 μsec at 3×10^{34}.**
- **Current trigger takes ~ 20 msec per jet at 3×10^{34}.**
  - **At high $\mathcal{L} \Rightarrow$ several hundred msec to track the jets & leptons in an event.**
- **FTK is 3-4 orders of magnitude faster!**

- **With the expected expansion of the existing trigger system to handle the large increase in accelerator luminosity, the level-2 computing farm could do global tracking for 5-10% of events.**
- **With FTK, all events would be fully tracked.**
- **If a new phenomenon require full tracking, ×10 increase in # of events for measuring its properties.**

Status of the project in ATLAS

- **We submitted a 100-page Technical Proposal to ATLAS in March, 2010, which was reviewed by a high-level committee.**
- **On December 2-3, 2010, ATLAS management held a technical design review of the project and a review of project management.**
- **Following its successful outcome, on December 9, 2010, the ATLAS Executive Board recommended that FTK proceed.**
- **The ATLAS Collaboration Board approved this recommendation on June 24, 2011.**

Funding FTK

- **The bulk of the funds will come from the US and Italy.**
- **The Italian funding agency has committed to 1.2M€ for construction.**
- **US**
  - **A Chicago-Fermilab-Argonne seed grant.**
  - **Recently we received a National Science Foundation MRI award: 3M$**

Plan

- **Run a small "vertical slice" system at CERN during the coming year starting with boards we already have.**
  - **future test bed for new prototypes**
- **HOLA & fiber installation this winter for the vertical slice so that we can run on real ATLAS data.**
- **Final board prototypes and Technical Design Report by the spring of 2013**

Argonne, Chicago, & Fermilab
essential complementary expertise

- **Argonne**
  - Responsible for the connection between FTK and the rest of the ATLAS trigger system
  - Alone among the FTK collaborating institutions, Argonne has built hardware used in the ATLAS trigger.
    - understands data flow, protocols, formats, limitations, error reporting
    - FTK is unique in ATLAS in sending all of its data to the level-2 trigger at the full 100 kHz level-1 trigger rate.
  - We may want to add new functionality in the future

    ex: rapidly finding all collision vertices (~ 70/event)
    - Use ATCA crates (new to HEP) to easily transfer all tracks to 1 board

- **Fermilab**
  - **Responsible for the connection between the ATLAS tracking detectors and FTK.**
  - **Enormous quantities of data have to be reorganized**

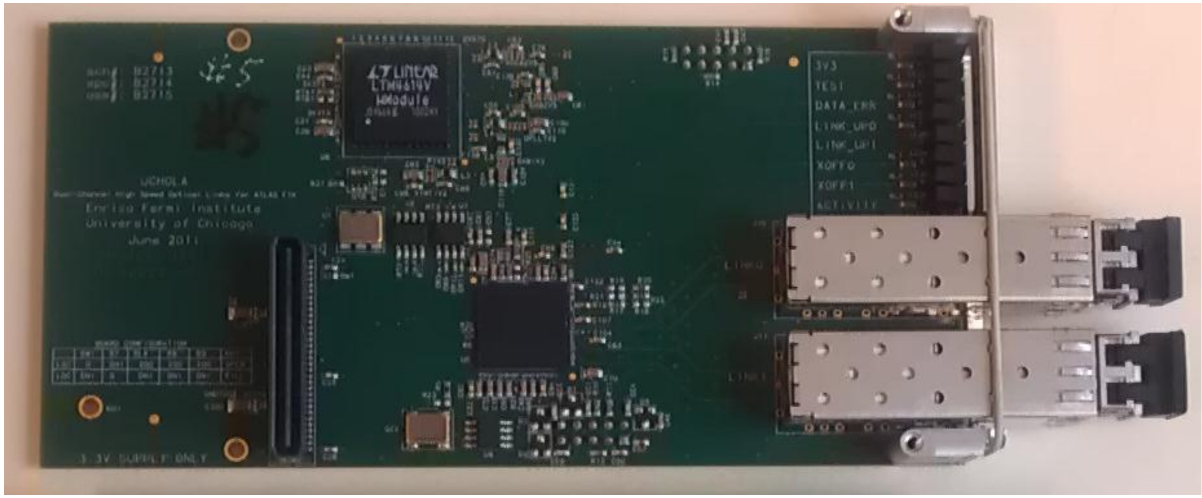
    300 optical fibers @ Gbs → 64 FTK regions

    - **Moving data between boards ⇒ ATCA full-mesh capability**
    - **synergy with Argonne**
  - **The Fermilab group designed and built a large system of electronics that very successfully processed and moved large data samples for the CDF trigger at the Tevatron.**
    - **Established a close relationship with the Chicago engineers**
    - **Some of the processing functions were designed by the Chicago group.**

- **Chicago**
  - **Responsible for a design that carries out several core FTK functions: smart database, track fitting, duplicate track removal**
  - **The Chicago group designed and built boards with similar functionality for the CDF SVT.**
  - **Close collaboration with Fermilab is needed since the output of the Fermilab boards provide the input to the Chicago boards.**
  - **Close collaboration with the Argonne team has already been important because we are testing FTK boards in the ATLAS trigger environment and the Argonne personnel are our experts.**

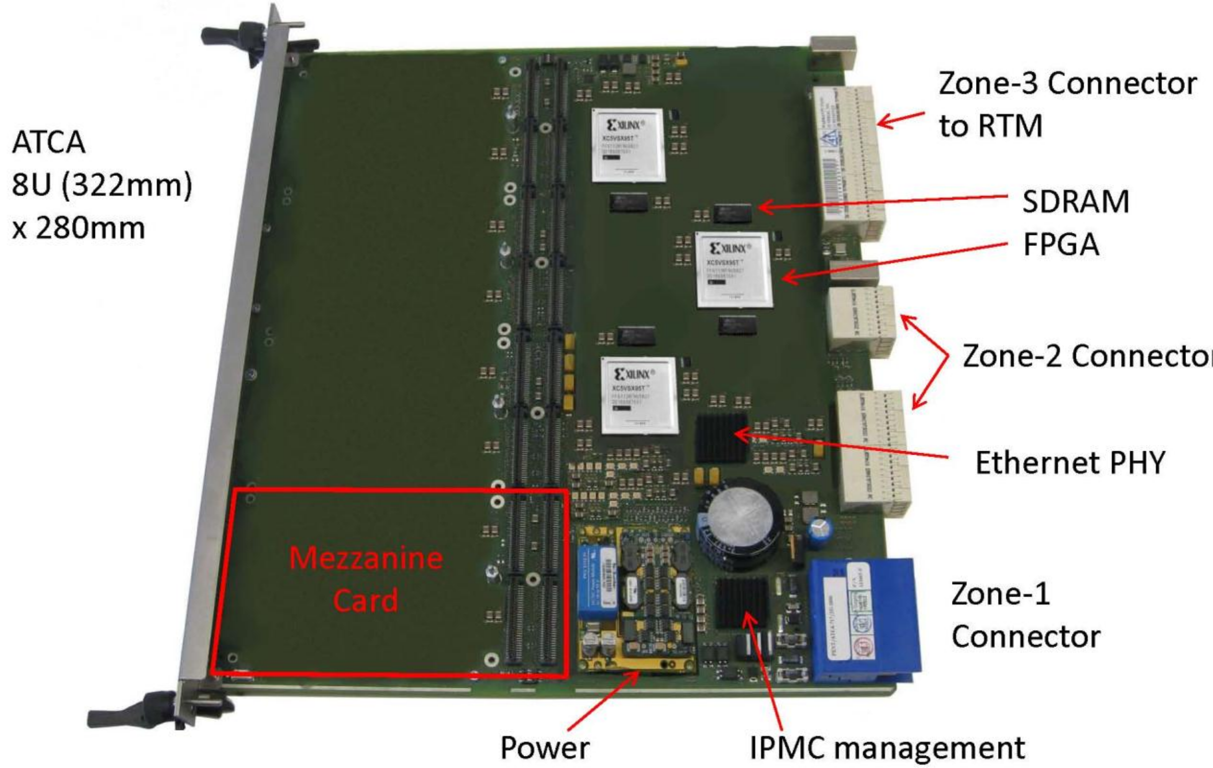
A quick tour of the local hardware development

- **Dual-output HOLA**
  - **Preproduction boards tested at Chicago and CERN**
  - **Full production is in progress, will be complete in early January**



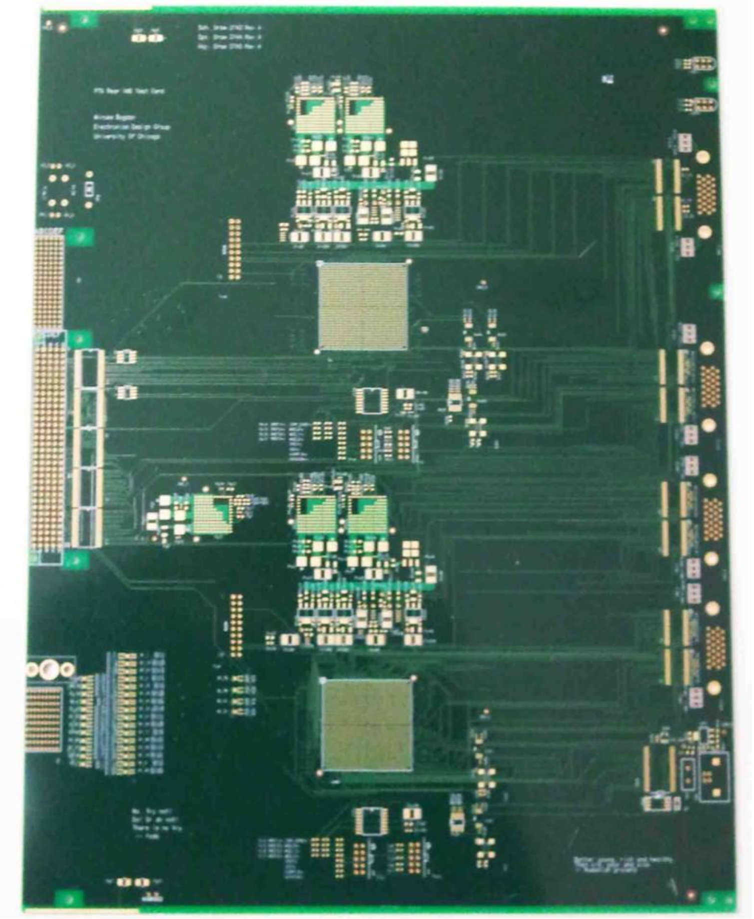
Univ. of Chicago

- **Data Formatter**
  - **draft design specifications written**
  - **mapping of silicon fibers to FTK towers ⇒ ATCA full mesh backplane**
  - **conceptual layout**



Fermilab

- **Associative Memory AUX card**
  - **firmware design has begun for final AUX functions**
  - **proto-AUX for testing high speed links being manufactured**



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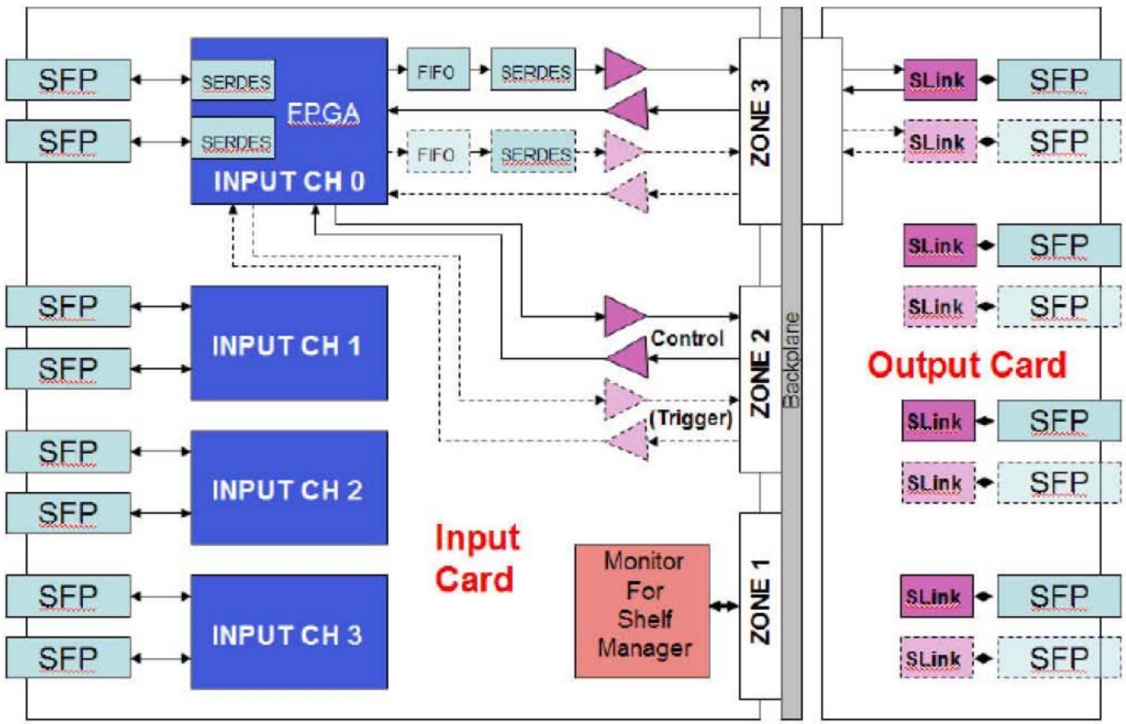
- **FTK→ L2**
  - **draft specification document exists for an ATCA implementation**
  - **full mesh allows for additional functions on a new board in the future (ex. primary vertex finding, beam spot determination)**



Argonne

Summary

- **FTK is a powerful system that can have a big impact on the future ATLAS physics program.**
- **Argonne, Chicago, and Fermilab are working together closely to make this project a great success.**