Rapid Identification of Heavy Quarks and Leptons at the Large Hadron Collider
The FTK Project

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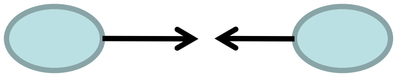
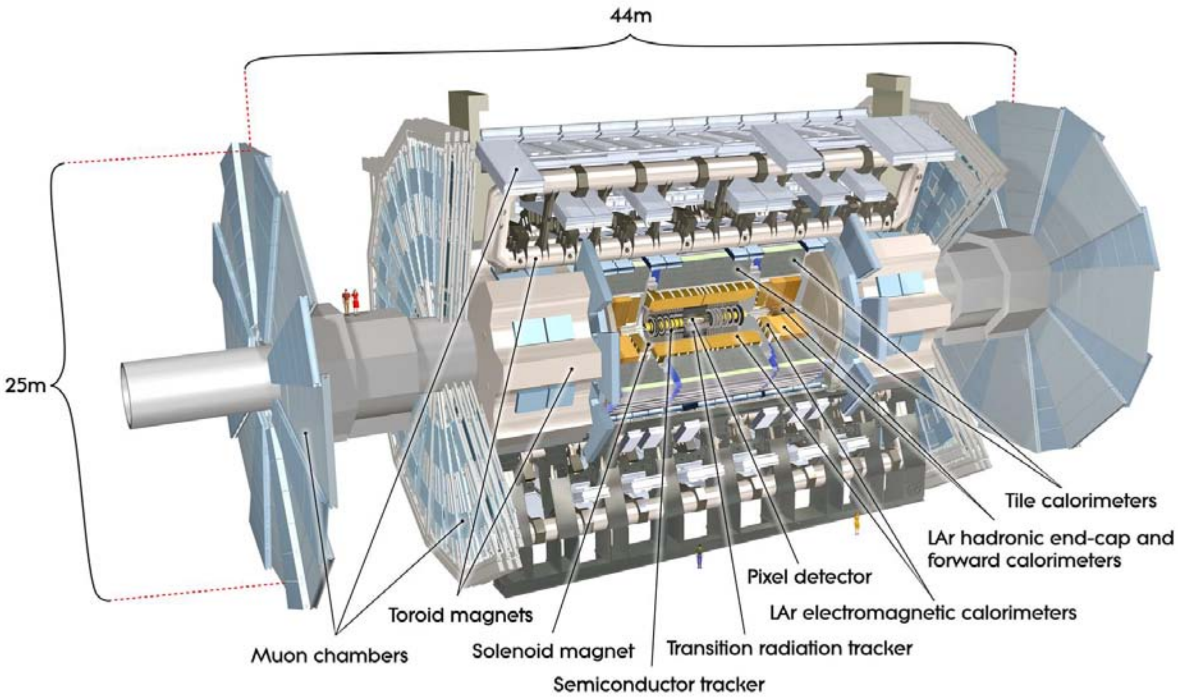
for the FTK team

The LHC Challenge



40 MHz accelerator bunch crossing rate

25-75 *pp* collisions per bunch crossing

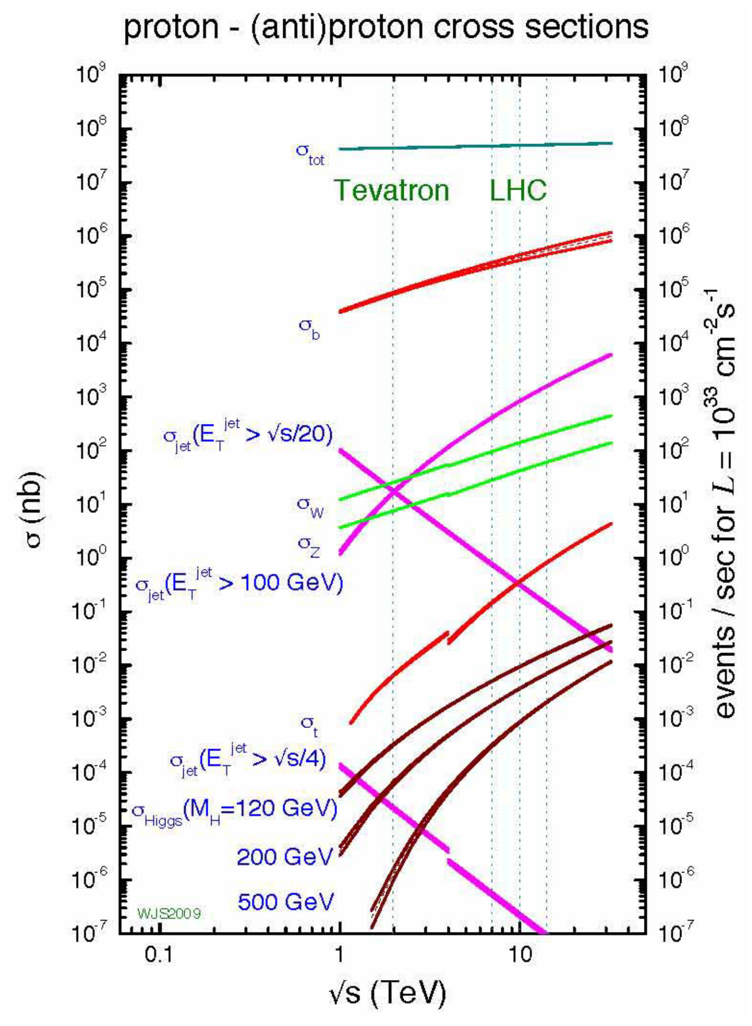


- **85M detector channels**
- **~ 1 MB of data/event**
- **⇒ can store 200 events/sec**

LHC ATLAS detector

Processes of interest are rare

- **@ Tevatron: reconstructed top quark events ~ 1/10^{12} collisions**
- **For the Higgs boson at the LHC, the ratio will be similar.**
- **⇒ real-time selection of the most important collisions (TRIGGER) is crucial.**



× few % acceptance

The importance of individual tracks

- **Many/most new physics scenarios produce final states containing heavy elementary particles (*b* quarks & τ leptons).**
  - **must be separated from an enormous background of light quarks and gluons produced through the strong nuclear force**
    - ***b*-jets: displaced vertices from *B* meson with picosecond lifetime**
    - **τ-jets: 1 or 3 tracks in a narrow cone with a surrounding isolation region due to the decay of a relatively low mass object.**
- **Even for the traditional workhorse trigger, an isolated high energy electron or muon, tracking is essential at very high accelerator intensity: The usual isolation (calorimeter) deteriorates badly in its efficiency because it integrates over the 25-75 *pp* collisions per beam crossing. Reconstructed tracks each point back to the beam. Isolation only using those close to the muon or electron at the beamline largely removes the effect of the "pile-up".**

The technical difficulties

- **# of hits in the tracking chamber per beam crossing: 200k**

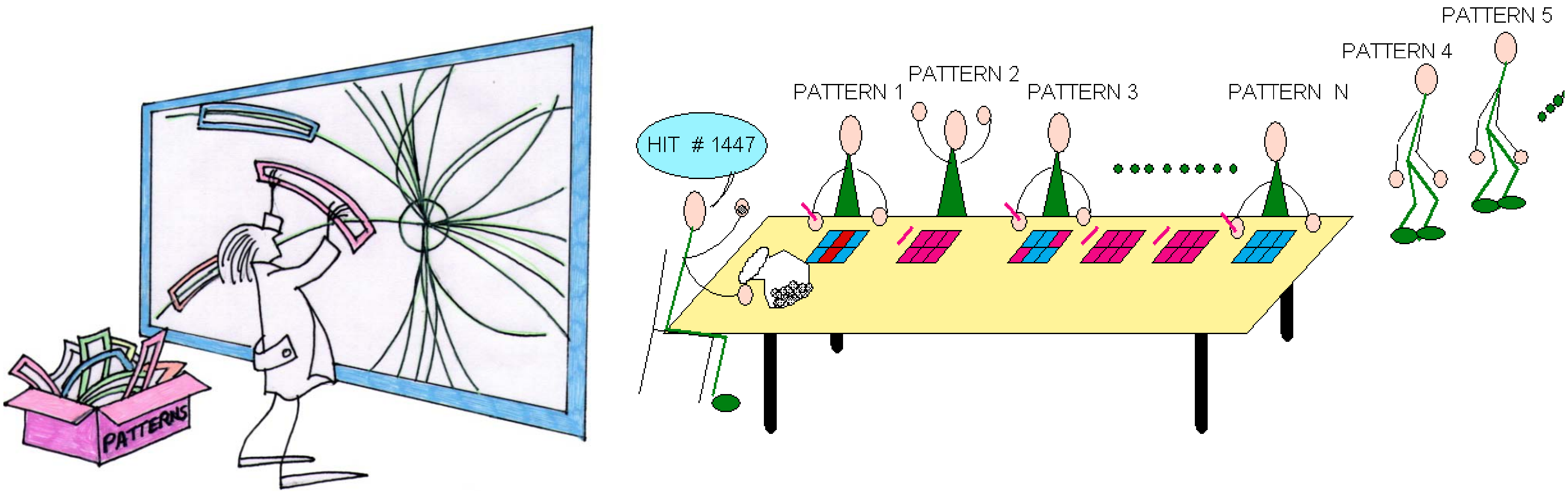
  Must transfer to FTK each 10 μs (100 kHz level-1 trigger rate)

  ⇒ ~ 20 gigawords per second transfer

- **This much data makes both stages in tracking very challenging: pattern recognition and track fitting in 3 dimensions**
- **There are several hundred good tracks per beam crossing.**
  - **10 μs / event ⇒ < 100 ns/track for pattern recognition plus track fitting**

Pattern Recognition

- **Massively parallel – a billion prestored patterns simultaneously see each of the detector hits as it leaves the detector at full speed.**



- **By the time all of the silicon hits are out of the detector, pattern recognition is finished.**
- **Made possible by HEP-specific content-addressable memory chip (Associative Memory or AM).**

Track Fitting

- **To complete the tracking in 10 μs, must do a fit at a rate of 1 per ns!**
- **It is not possible to do a fit of hits to a helical path in 1 ns.**
- **However if a small region of the detector is considered, a linear approximation gives near ideal precision within the required execution time.**

$$p_i = \sum_{j=1}^{14} a_{ij} x_j + b_i$$

  - **p_i's are the helix parameters and χ^2 components.**
  - **x_j's are the hit coordinates in the detector layers.**
  - **a_{ij} & b_i are prestored constants.**
  - **This is VERY fast in FPGAs (multiply & accumulate)**
  - **1 ns/fit is achievable (many DSPs within the FPGA)**

The collaboration

- **Italy, Japan, US**
  - **US: Argonne, Chicago, Fermilab, Illinois, Northern Illinois**
- **ANL, Chicago, and FNAL bring important expertise to the collaboration:**
  - **Fermilab: custom designed integrated circuits**
  - **Argonne: design and construction of ATLAS trigger electronics**
  - **Chicago: design of large trigger systems for the Tevatron**
- **We will design and build a system of 13 crates of custom designed electronics.**

Status

- **Technical Proposal written a year ago.**
- **Design Review held at CERN last week.**
- **Approval of FTK as an official ATLAS upgrade project expected in the next few weeks.**
- **MRI submission to the NSF in January.**