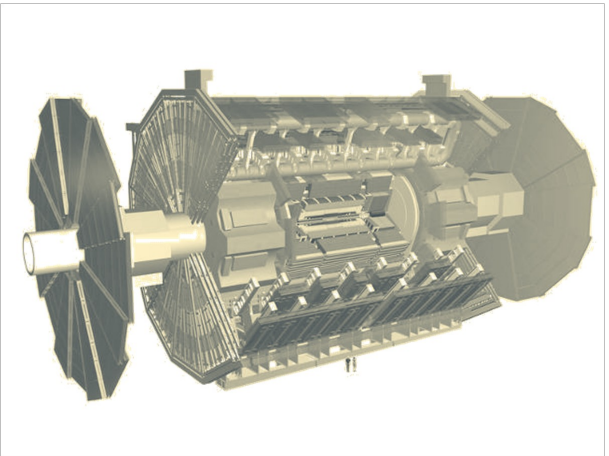
The EDRO board connected to the Associative Memory: a "Baby" FastTracKer processor for the ATLAS experiment

A. Annovi, M. Beretta, V. Bevacqua, F. Cervigni, **F. Crescioli**, L. Fabbri, P. Giannetti, F. Giorgi, D. Magalotti, A. Negri, M. Piendibene, C. Sbarra, C. Roda, M. Villa, R.A. Vitillo, G. Volpi



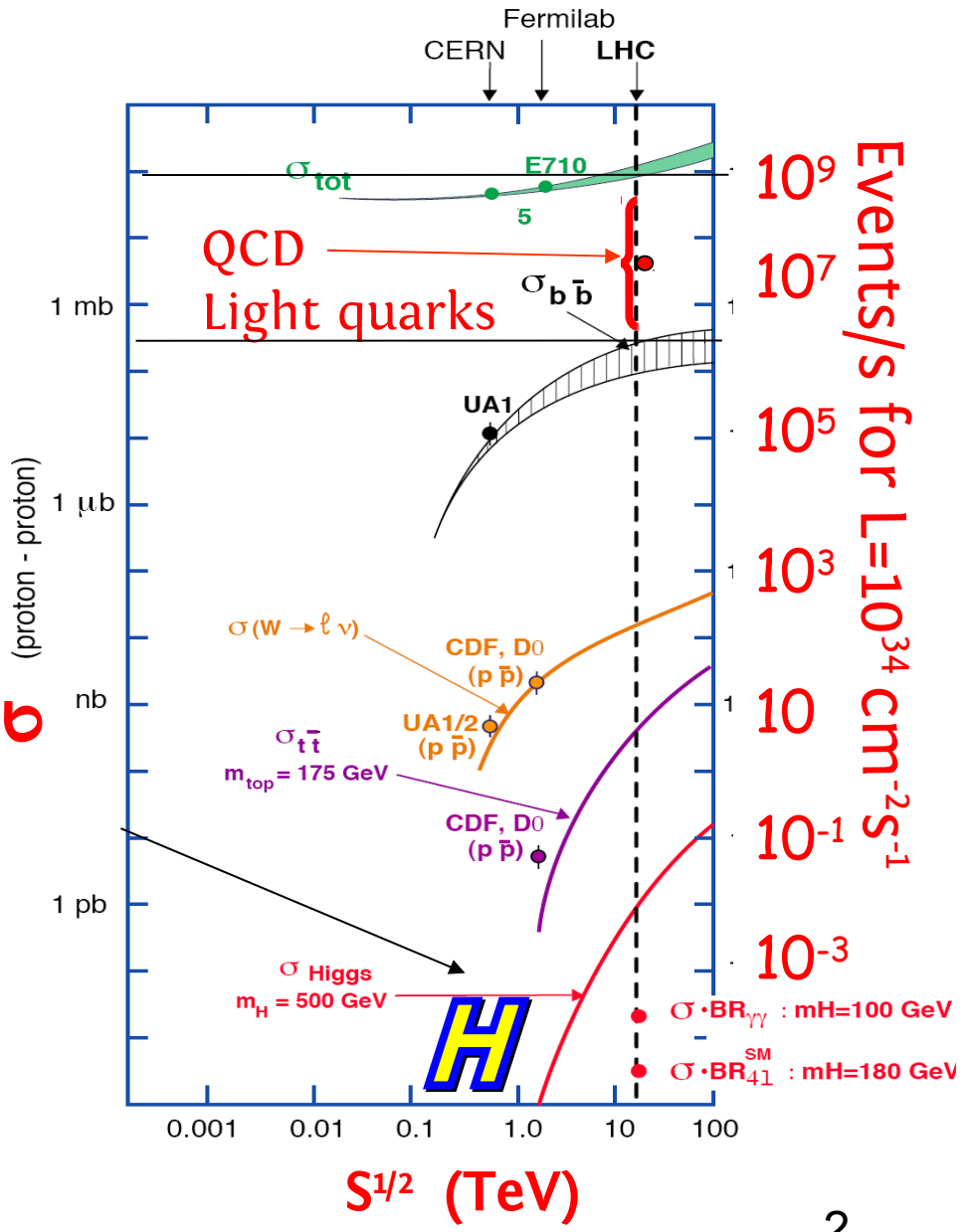
Data selection at hadron colliders

Search for rare SM or predicted BSM processes push the collider's intensity to new frontiers

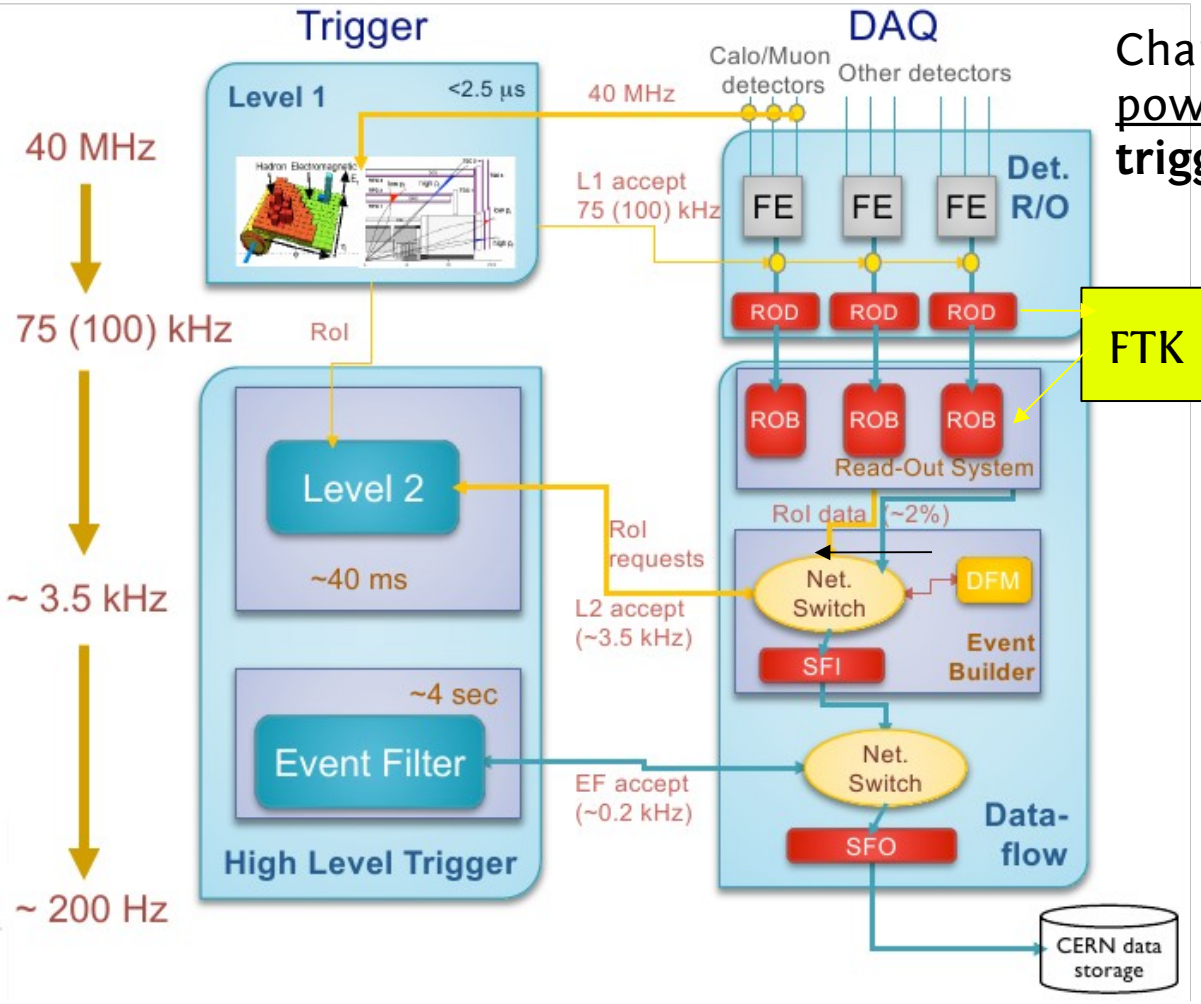
Rare processes are overwhelmed by well-known processes

- 8-9 orders of magnitude between Higgs and total cross-section
- Need to prioritize the physics output and leave flexibility for the unexpected

Need **sophisticated techniques** to maximize the bandwidth for interesting events



Online Tracking @ L2

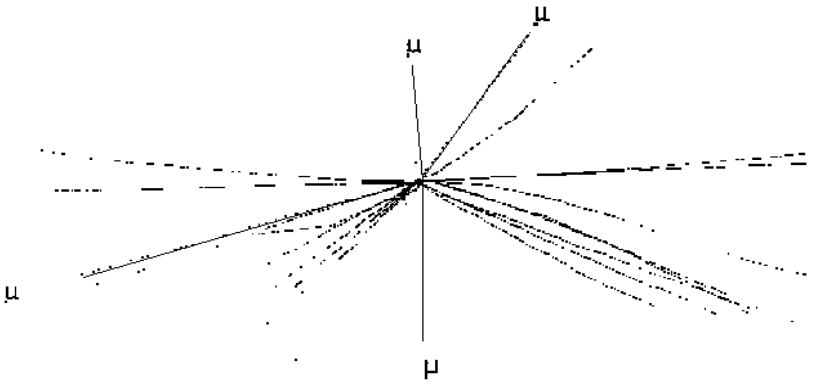


Charged particle trajectories provide very powerful information for **sophisticated trigger selection**.

SVT processor at L2 was a key element for many analyses in the CDF experiment.
FTK is the "*new generation*" SVT for ATLAS

30 minimum bias events + $H \to ZZ \to 4\mu$

all charged particles with $|\eta| < 2.5$

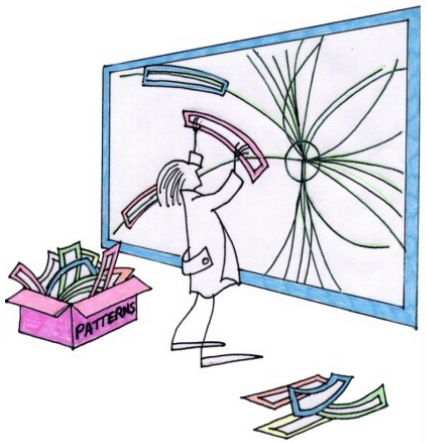


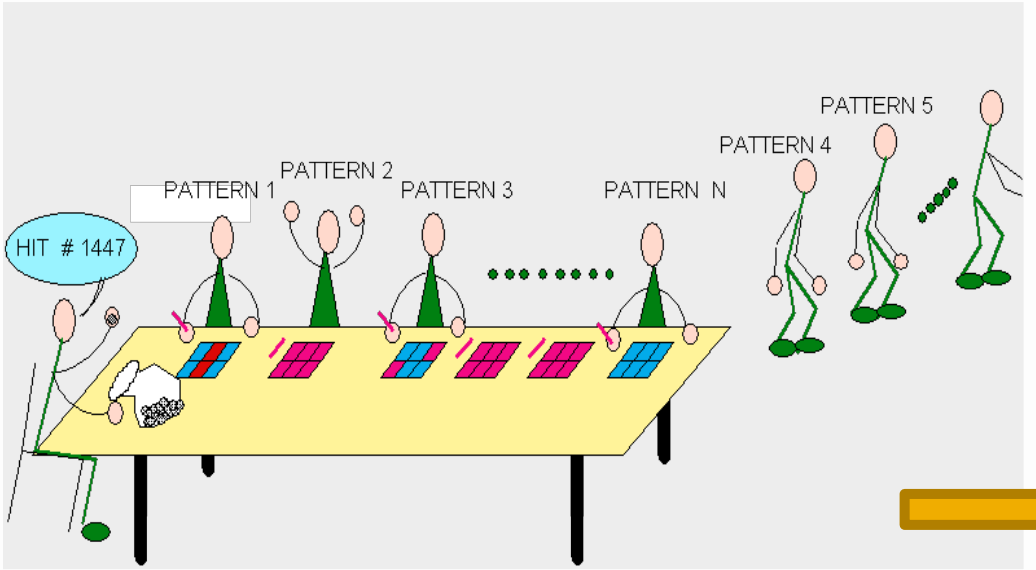
reconstructed tracks with $p_t > 2.0$ GeV

Track-based algorithms (b-tagging, lepton isolation, taus) have an **advantage** over calo-based algorithms in crowded events **with many pile-up interactions**.

LHC @10^{34} cm^{-2}s^{-1} → 25 pile-up events
LHC @3×10^{34} cm^{-2}s^{-1} → 75 pile-up events → **FTK target**

FTK Algorithm





An associative memory (AM) chip allows a full parallel search in the pattern bank.

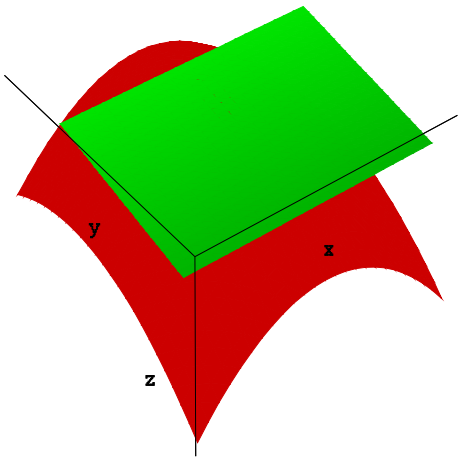
Similar to commercial CAMs + extended functionalities.

In FTK, tracking is divided into two separate steps

- The pattern matching uses a large bank of patterns and special hardware
  (associative memory - AM)
- The track's parameters are evaluated using a linear Principal Component Analysis algorithm
  (DSP MACC units in FPGA)

(j.nima.2003.11.078)

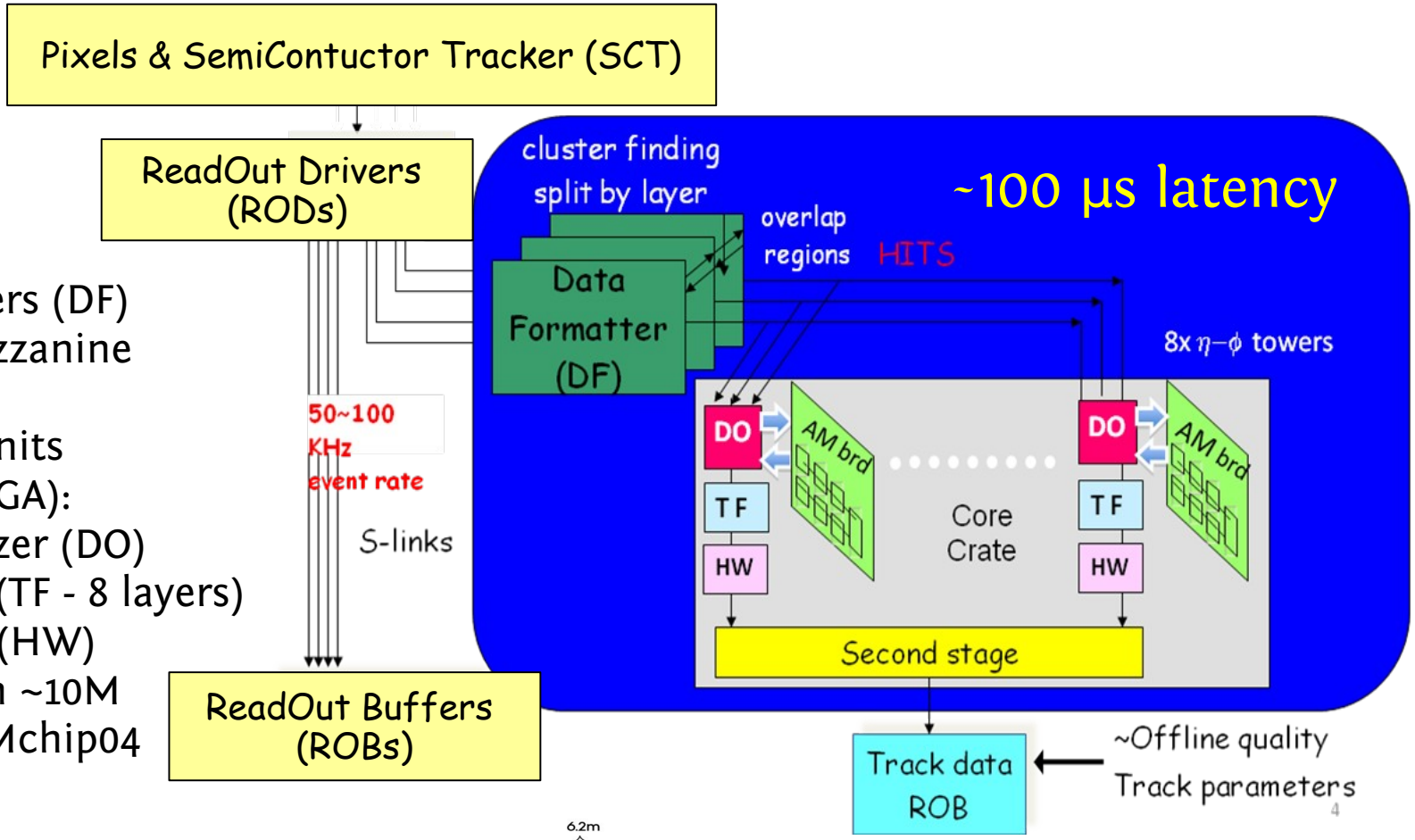
$$p_i = \sum C_{ij} \cdot x_j + q_i$$

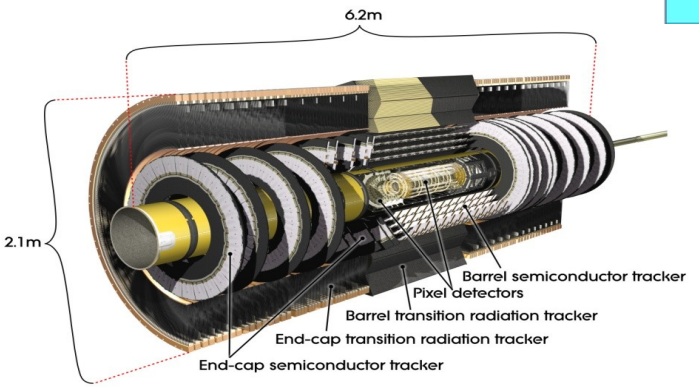


FTK Architecture

Complex system, many units:

- **48** Data Formatters (DF)
  - Clustering Mezzanine
- **128** Processing Units
  - AUX Board (FPGA):
    - Data Organizer (DO)
    - Track Fitter (TF - 8 layers)
    - Hit Warrior (HW)
  - AM Board with ~10M patterns on AMchip04 custom CAMs
- **32** Final Boards (FPGA)
  - Final Fit (11 layers)
  - Final Hit Warrior



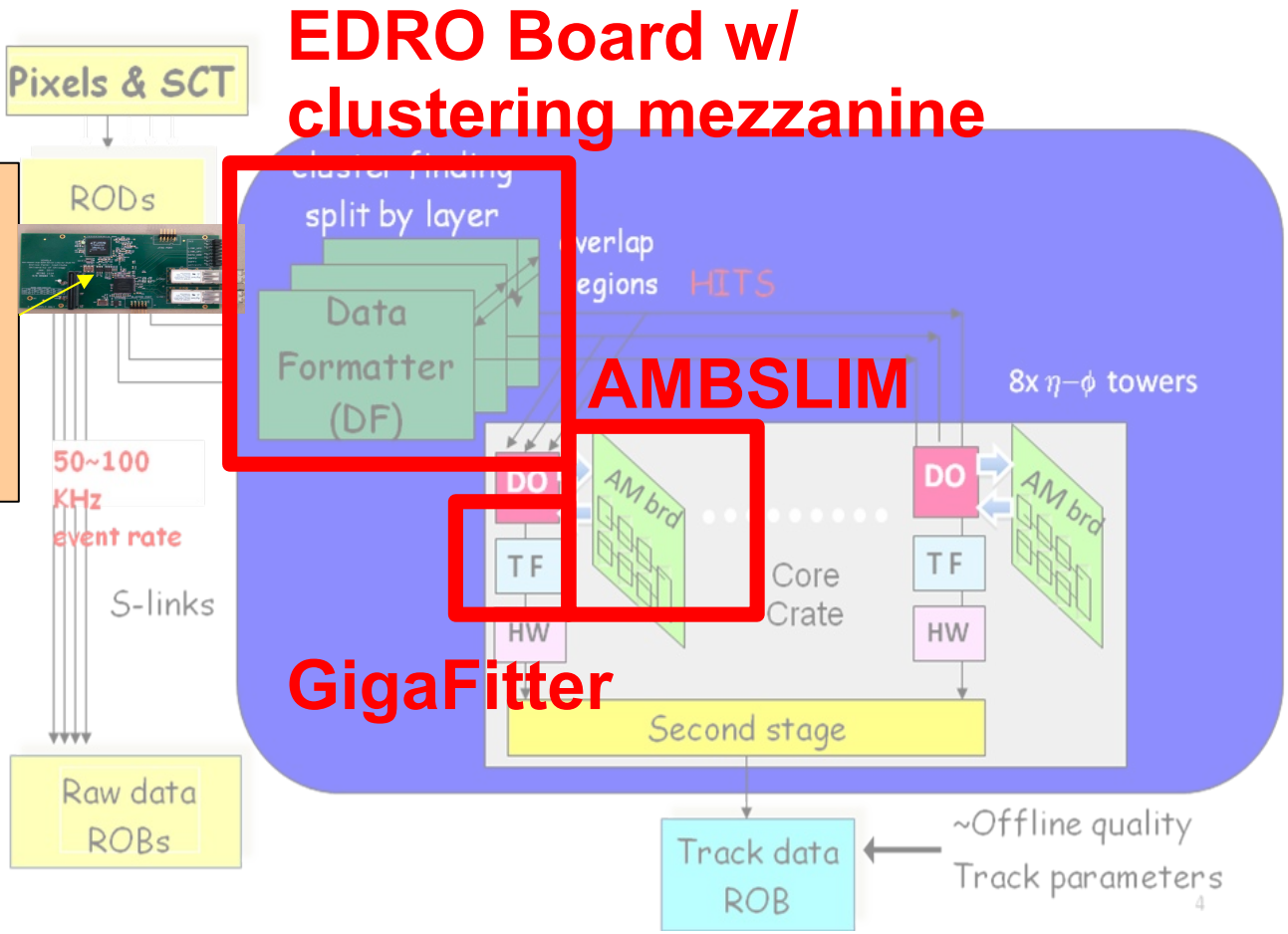


FTK will reconstruct tracks in all Inner Detector regions

EDRO+AM(+GF) "baby FTK"

Data from a small projective slice of silicon detector.

Dual Port HOLA (silicon detector front-end)
Flow Control (XON/XOFF) on second port disabled → parasitic with respect to the ATLAS data flow.

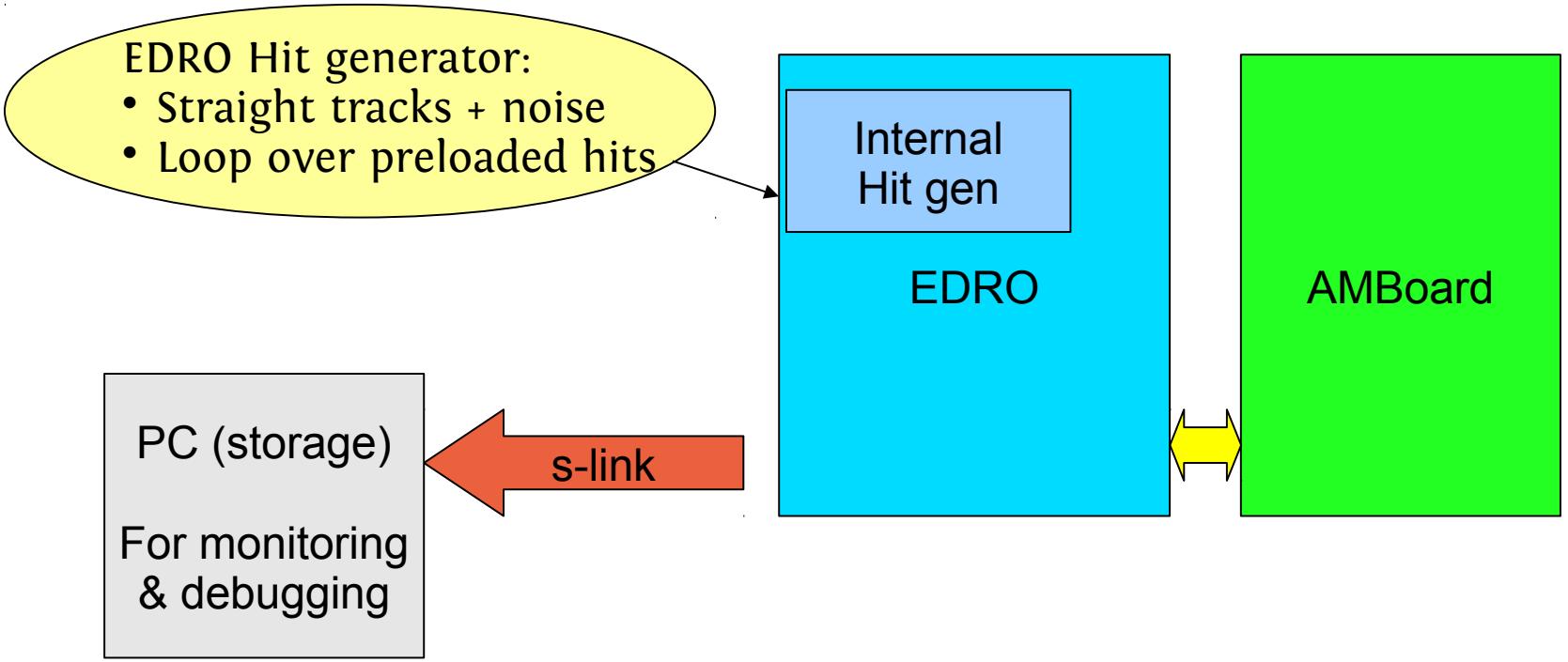


Start <u>early development</u> of **software** and **firmware** on existing boards and prototypes.

EDRO Board with **clustering mezzanine** + **AMBSLIM** (+ GigaFitter)

This setup is also the **environment for testing** future prototypes and production boards.

EDRO+AM basic setup

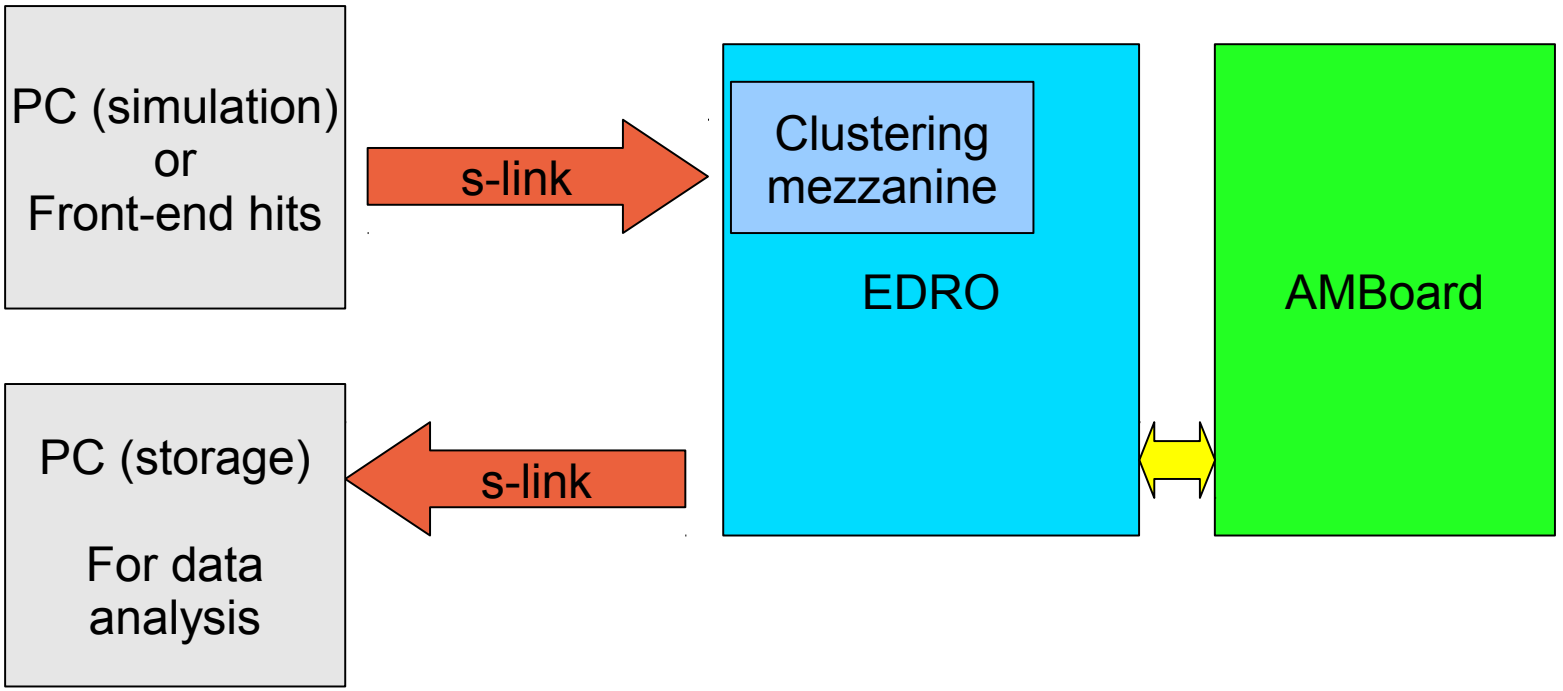


Simple Test Setup: the EDRO board internally generates simple events, the AMBoard finds known patterns and sends the information back to the EDRO board.

The EDRO board can trigger on hit multiplicity or AM roads:

- Test EDRO ↔ AM connection and stability
- Test AM vs AMsim over many events

EDRO+AM setup



FTK Stage 1 Setup: hits from PC simulation or real front-end are received by the Clustering mezzanine. Clustered hits are sent by the EDRO board to the AMBoard, the AMBoard finds patterns (roads) and sends them back to the EDRO.

- **Pattern bank efficiency** studies
- **Algorithm studies** → lepton isolation in a small projective tower

EDRO Board

General purpose DAQ board:

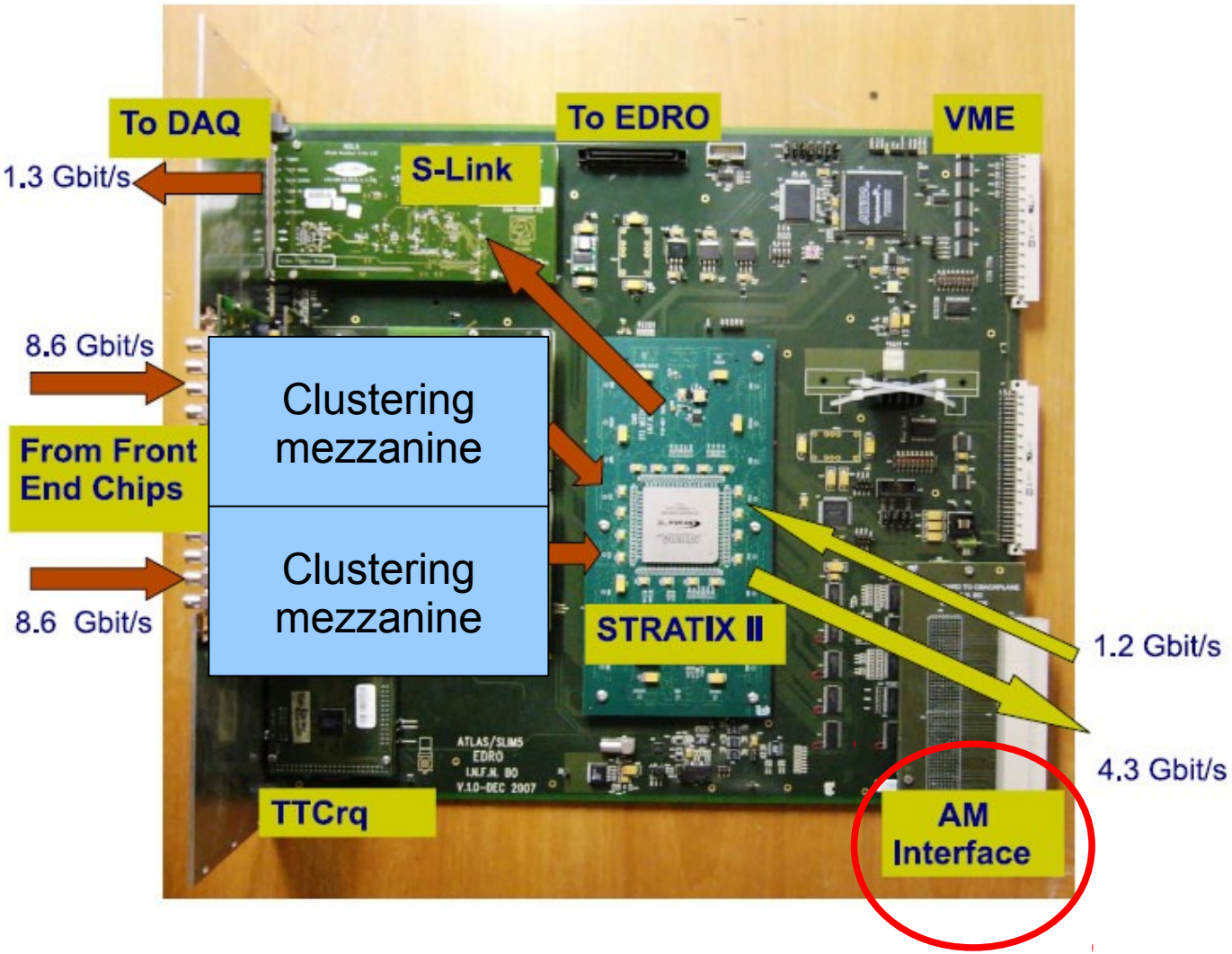
- **S-Link** connection to DAQ PCs

- **Two mezzanine slots** for inputs from front-end. *FTK clustering mezzanine* is compatible with this slot.

- **Large FPGA** (Stratix II) for local computation

- EDRO to EDRO connection to build complex DAQ systems (not used in this application)

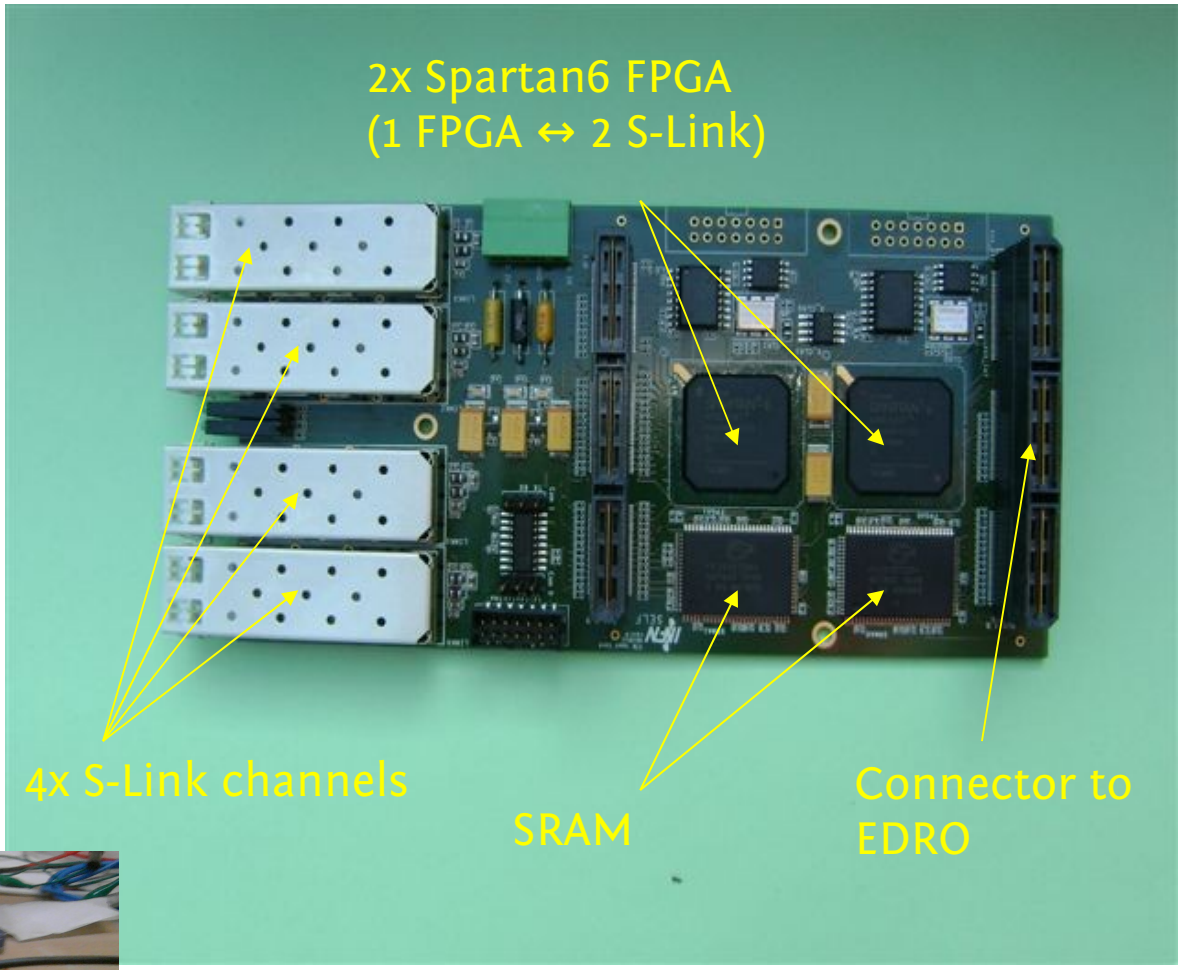
- **Backplane direct connection to AM Board**



Used for data acquisition in:
ATLAS Lucid
SLIM5 (silicon detectors r&d project)

Clustering Mezzanine

- Features
  - Receives up to 4 S-Link inputs
  - 2D clustering for pixels
    - Allows to correct with Time over Threshold information (TBC)
  - 1D association of contiguous SCT clusters from ABCD
  - Sustains input data rate of 40MHz S-Link words
  - Sends clusterized data out over 1 or more channels to mainboard (EDRO, DF)



First prototype just arrived (may 2011). Connection to EDRO tested.

Conceptual 2D pixel clustering firmware developed. Porting to mezzanine FPGAs ongoing.

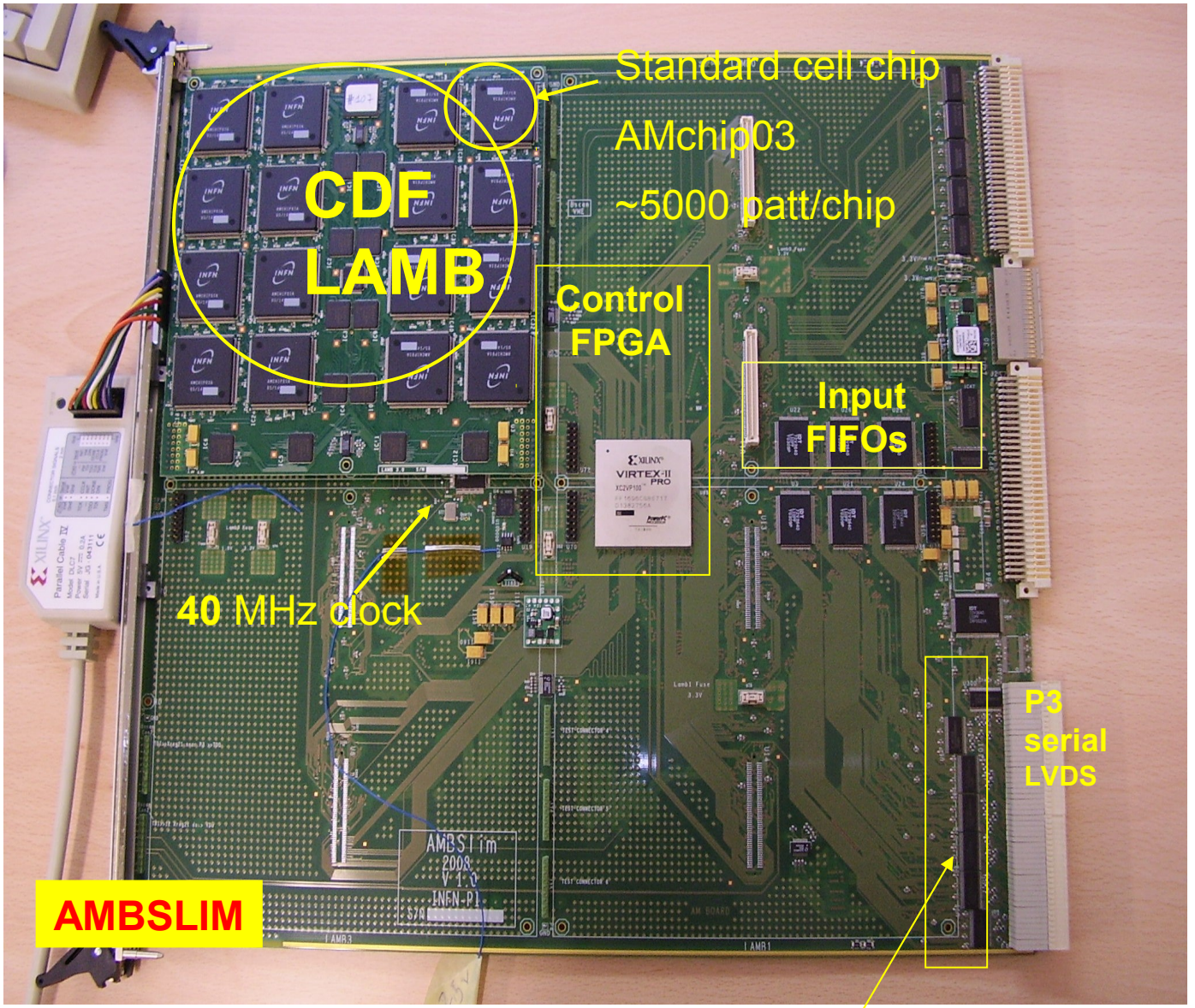
Associative memory board: AMBSLIM

New generation AM Board developed for SLIM5 and FTK:

- supports 4x CDF LAMB mezzanines (each up to 32 AMchip03) for a maximum capacity of 640k patterns (**320k** using CDF's single-sided LAMBs)

- **6 input buses**
- 1 output bus (roads)
- 6 output buses (hits, for pipelined AMBoards)

- Backplane connection to EDRO Board

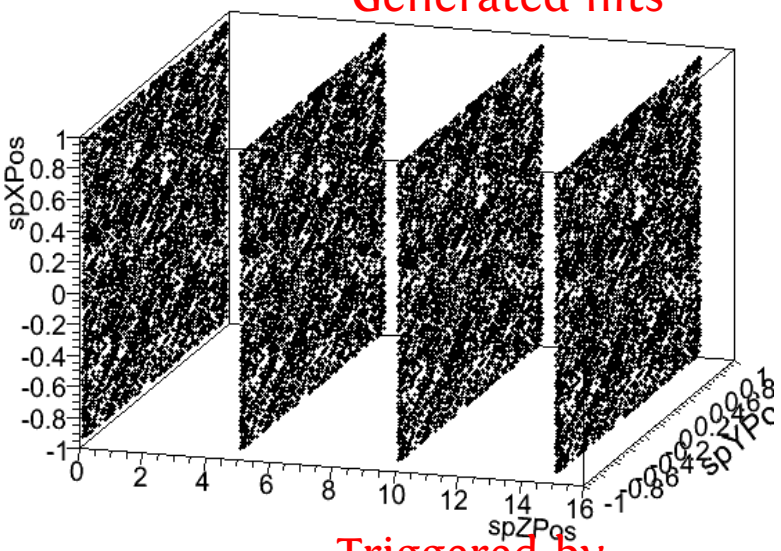


First tests in INFN Bologna

EDRO+AM Basic Setup
has been tested in INFN Bologna

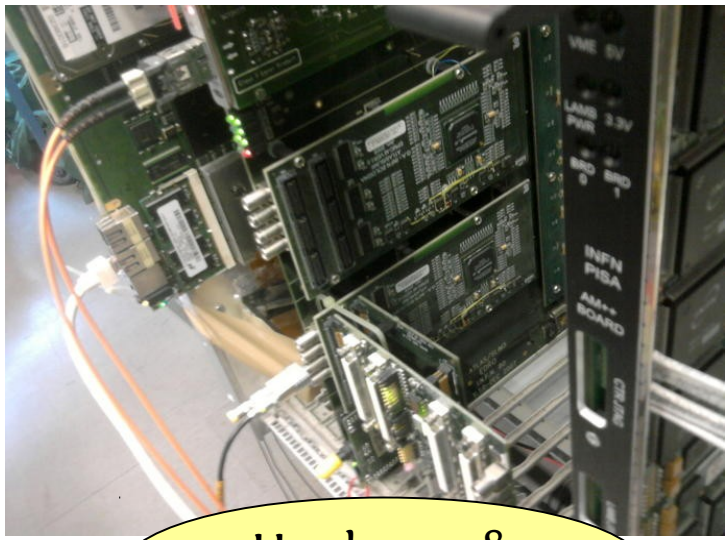
Events with 1-5 internally generated patterns+noise per event were sent @40MHz to the AMBoard to test board's connection, firmware and control software.

Generated hits

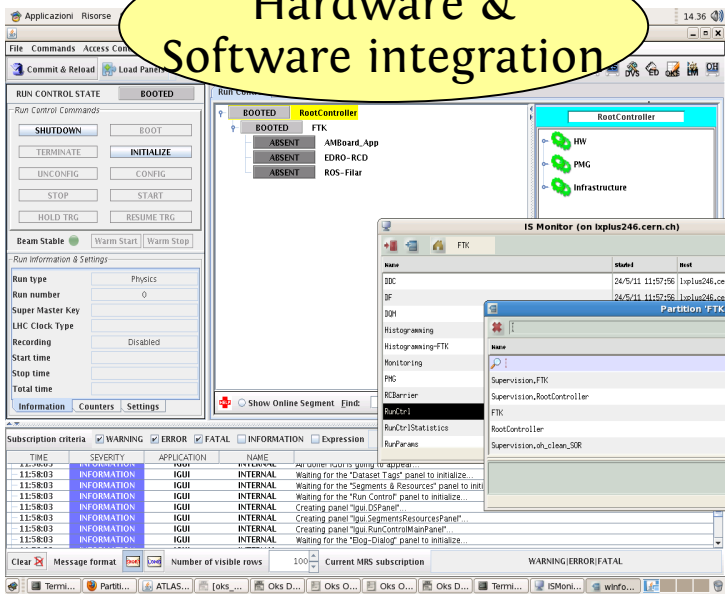


Straight tracks in a telescope-like configuration.

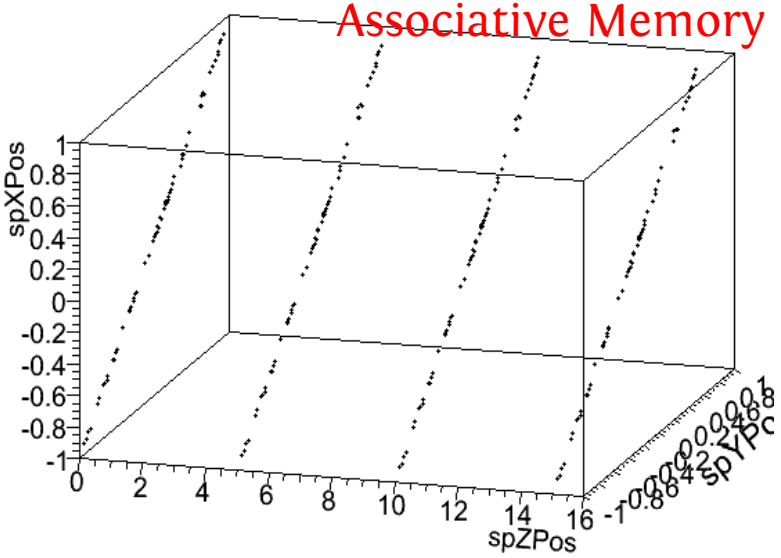
Plot hit position on 4 planes



Hardware & Software integration



Triggered by Associative Memory



Pattern bank was generated including only tracks on the diagonal.

AM trigger selects only those tracks

RoadMap to data taking in 2012

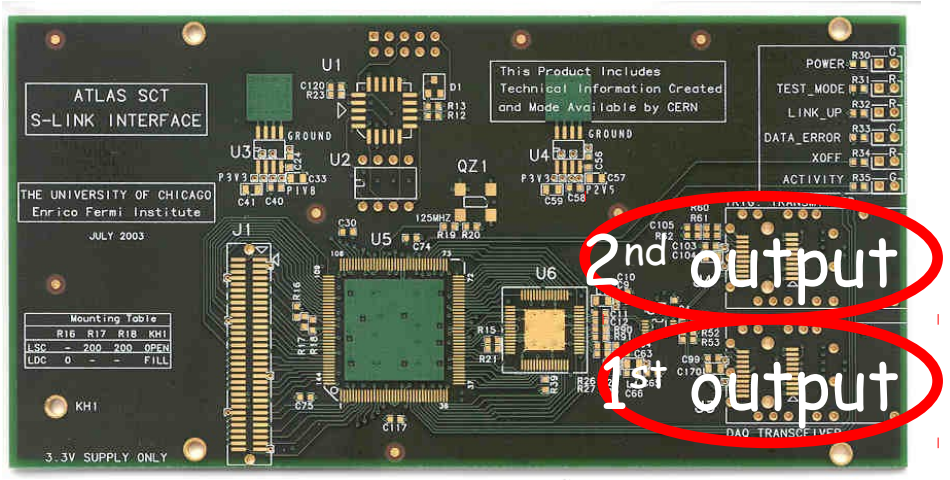
- Complete crate installation and debug (EDRO+Clustering mezzanine+AMBoard)
- Move EDRO+AM crate to a test stand at CERN by end of 2011
- Install dual port HOLAs in silicon detector RODs
- Start parasitic data taking and study in 2012
  - Add track fitting functionality using CDF GigaFitter board
  - When more prototypes are ready (ie. AMBoard with 8 input buses and AMchip04) add them to the test stand

Conclusions

- Tracking is an important tool for effective online data selection at hadron colliders
- FTK is a complex hardware processor to enable full track reconstruction with offline quality in the ATLAS Level 2 trigger
- EDRO+AM crate with all FTK functions for early testing of the algorithm and first prototypes in the ATLAS environment
  - It will reconstruct tracks in a small projective slice of the detector
  - It will use existing prototype boards from past experiments and R&D efforts
  - Our goal is to take real data (in parasitic mode) by 2012 and test with the acquired data the real efficiency of some of our track-based algorithms (lepton isolation)

Backup

Dual HOLA (UChicago)



Developed by University of Chicago

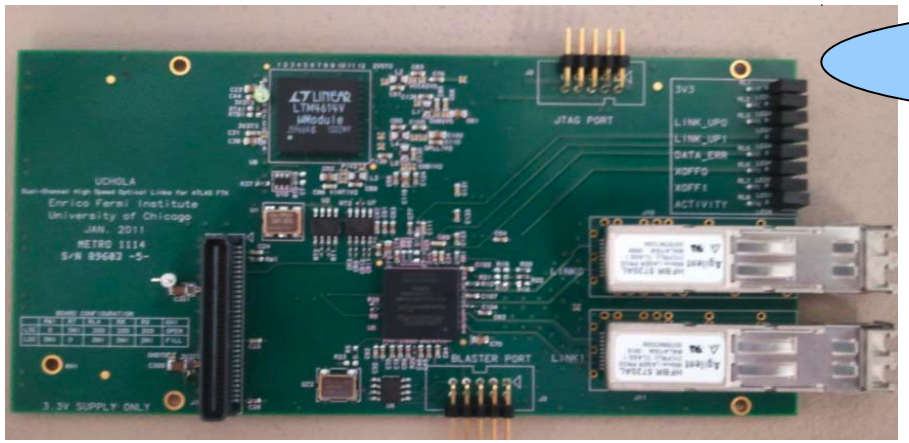
Backward compatible with old HOLA

Two outputs with flow control XON/XOFF

Possibility to disable flow control on each outputs

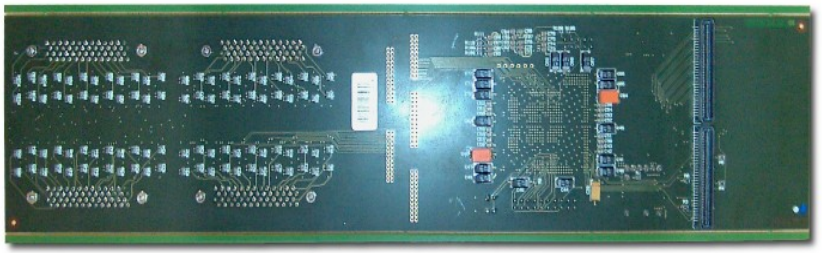
One output to normal silicon detectors RODs, no need to change anything in the rest of infrastructure.

One output to FTK. With flow control disabled we could be parasitic during installation/developing. After the system is fully installed and commissioned easy integration with ATLAS TDAQ just enabling flow control.

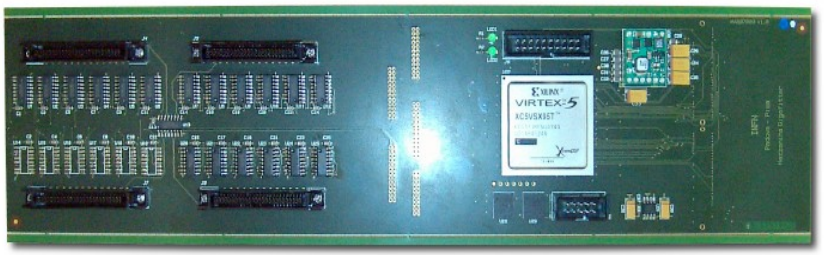


First prototype

GigaFitter



(a) Back view of the mezzanine

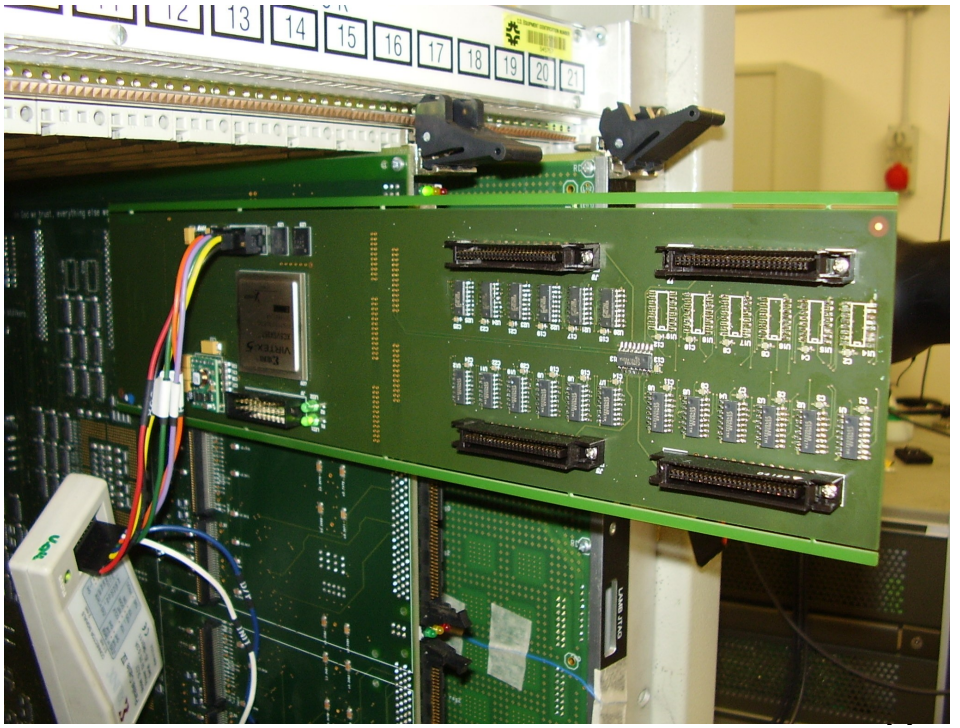


(b) Front view of the mezzanine

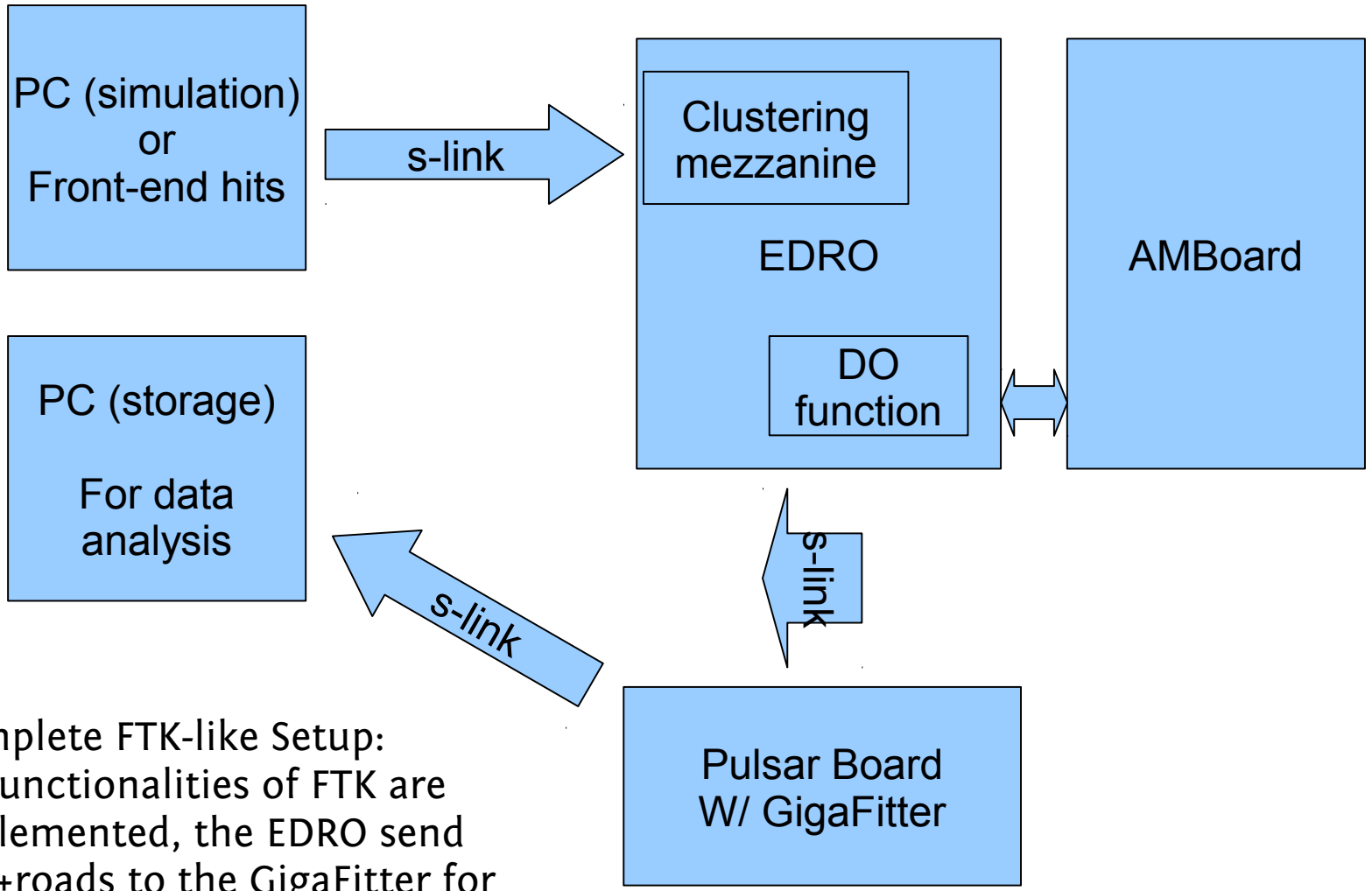
Mezzanine for Pulsar Board (CDF/Magic experiments) with a powerful Virtex-5 FPGA.

Used in SVT (CDF) for the linear fit of all 12 phi slices in parallel

The Pulsar Board has S-Link connection and can receive Hits+Roads from the EDRO Board and perform the second stage of the FTK algorithm: linear fit of the track parameters



EDRO+AM+GF setup



Complete FTK-like Setup:
All functionalities of FTK are implemented, the EDRO send hits+roads to the GigaFitter for the 2nd stage of the FTK algortihm.

Why L1-L2 early TRACKING is IMPORTANT?

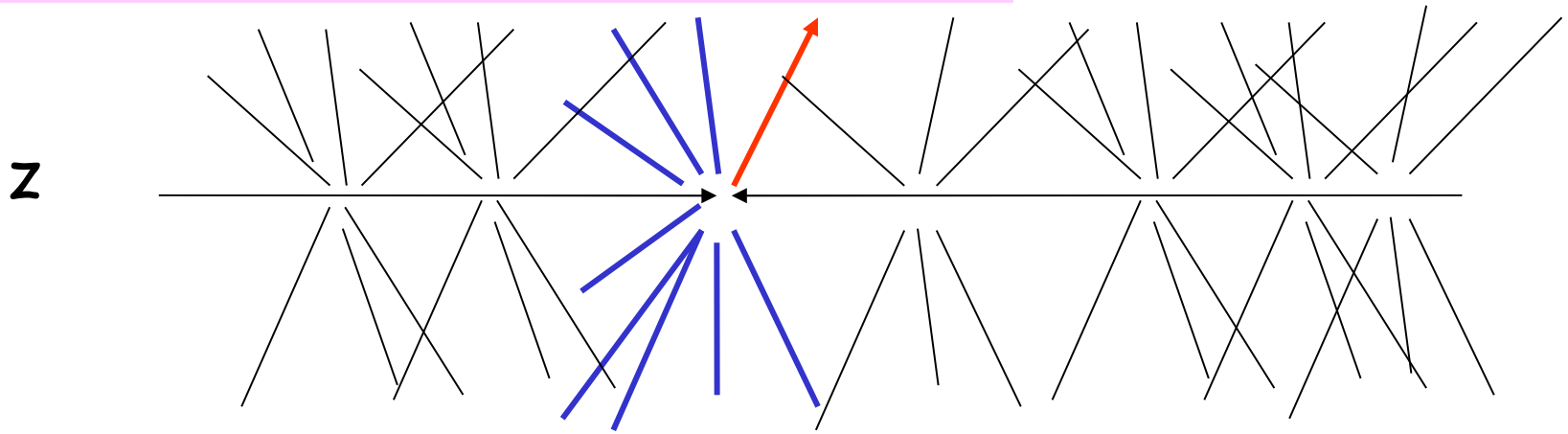
The most **STANDARD STIFF LEPTON TRIGGERS**
based on **ISOLATION** have problems at very high pile-up

The calorimeter tower integrates energy from **all the particles**,
also from **Pileup**!
We want **ISOLATION** from **HARD SCATTERING** not from **Pileup**!

Lepton identification: primary vertices fast identification
→ Isolation with tracks of Pt>Th and from right vertex

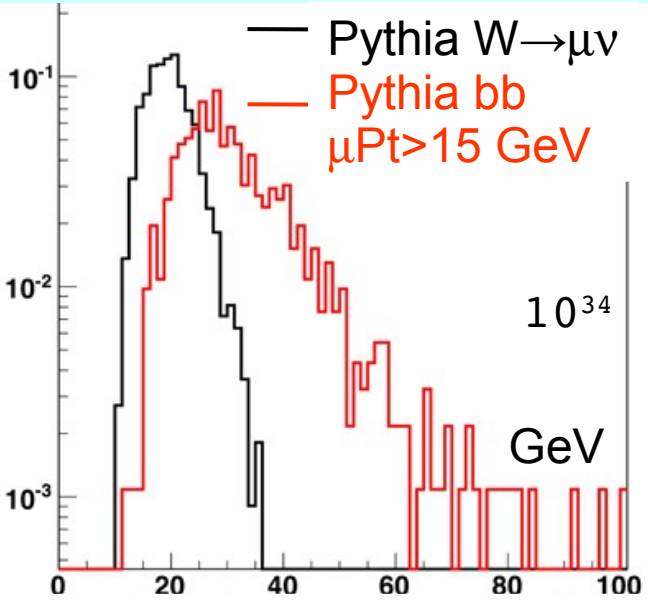
Only 7 vertices: imagine 100!

10 cm/100=1 mm

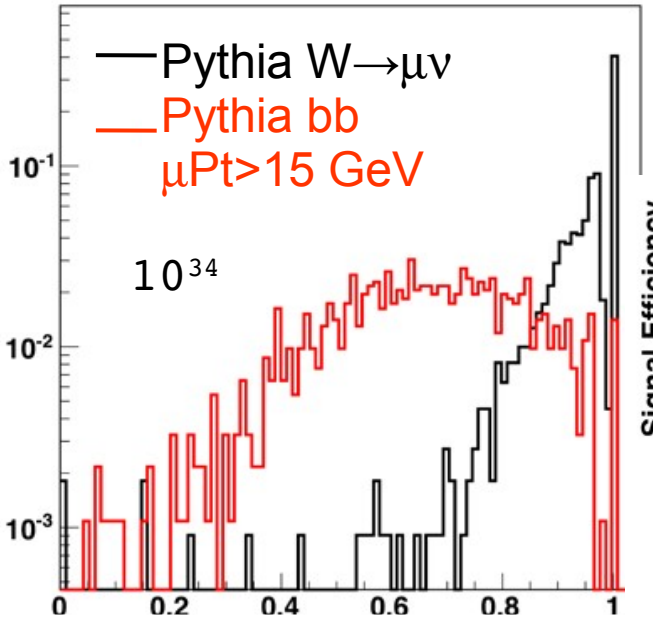


Tracking more stable than calorimetric isolation against pile-up!

Why FTK is IMPORTANT? Stiff Muon isolation

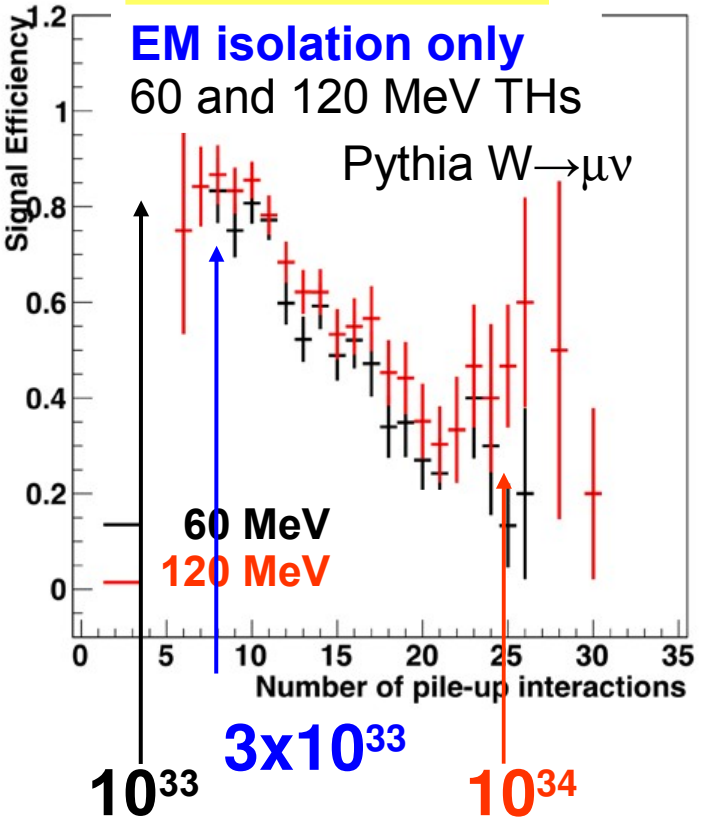


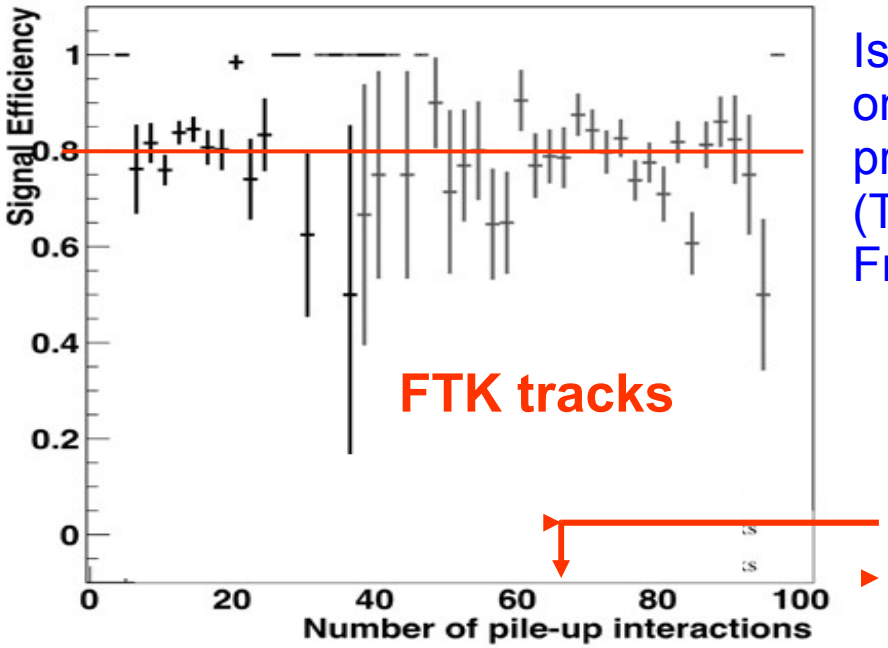
EM calorimeter isolation:
energy above 60 MeV in 0,07 <ΔR< 0.4



Tracking isolation:
μ *PT/(PT* sum tracks in ΔR<0.2)

cuts set so that rejection factor for *bb* events is **10**.

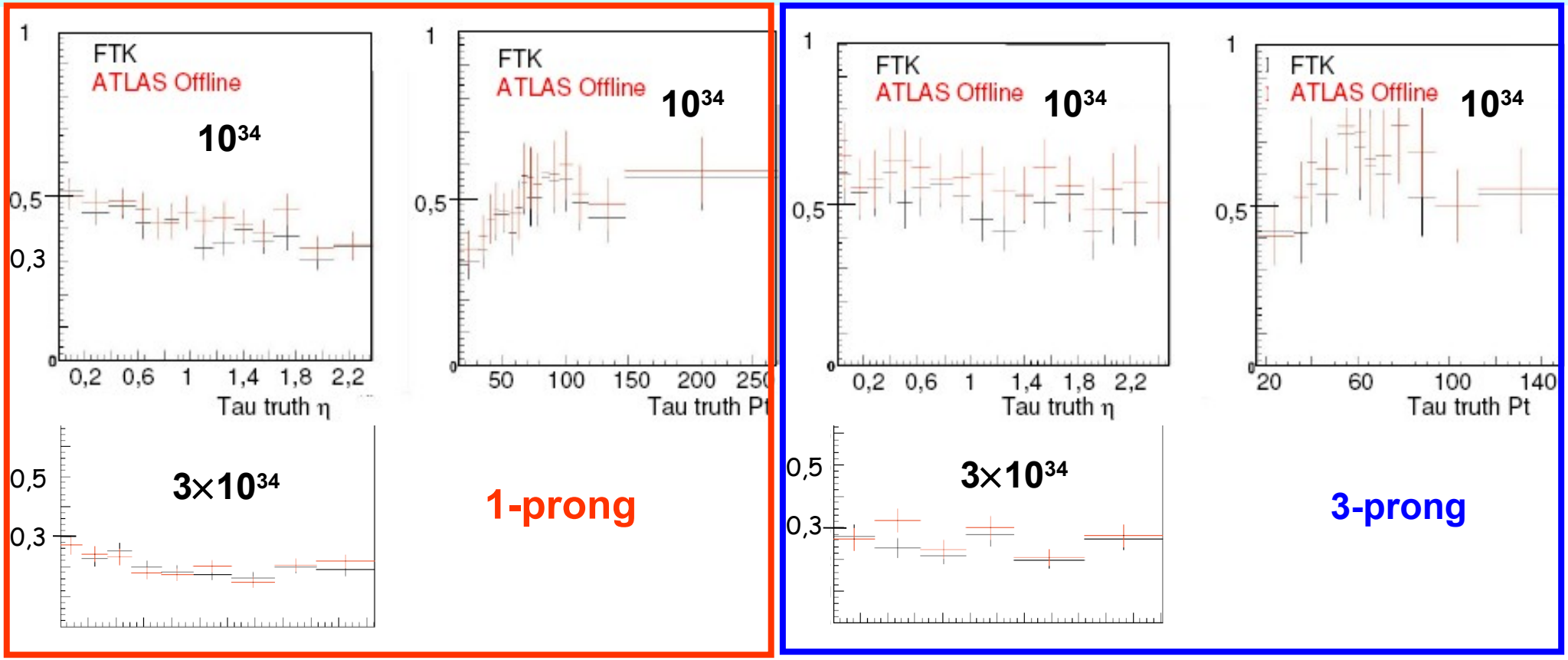


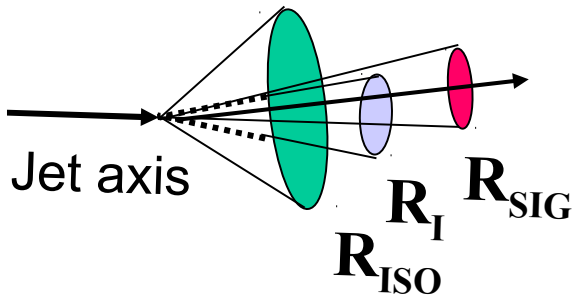


Isolation based on Tracks from primary vertex (Track_z<10 mm From μ_z)

EFFICIENCY from **20%** to **80%**
It is better than a factor 4 Luminosity increase!

Why Online Tracking is IMPORTANT? Hadronic Taus





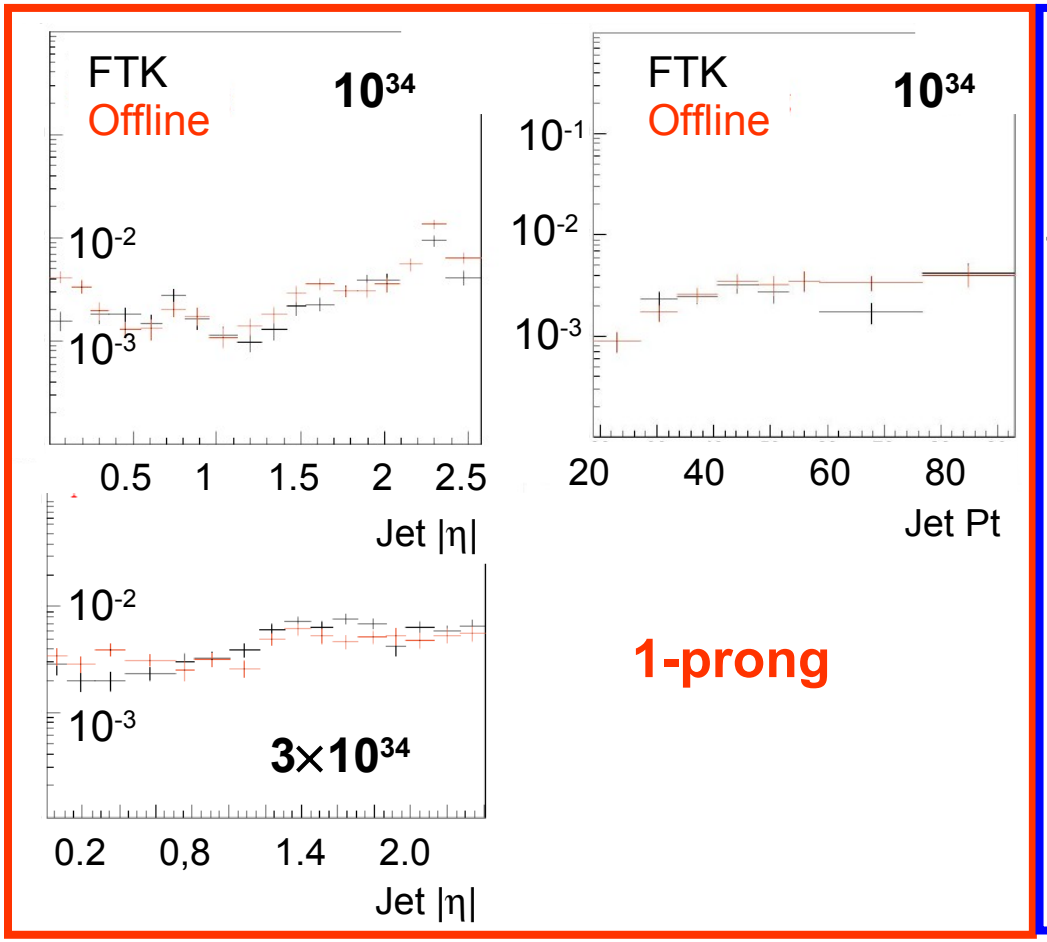
leading P_T track in Ri (Ri=0,35 around jet axis)

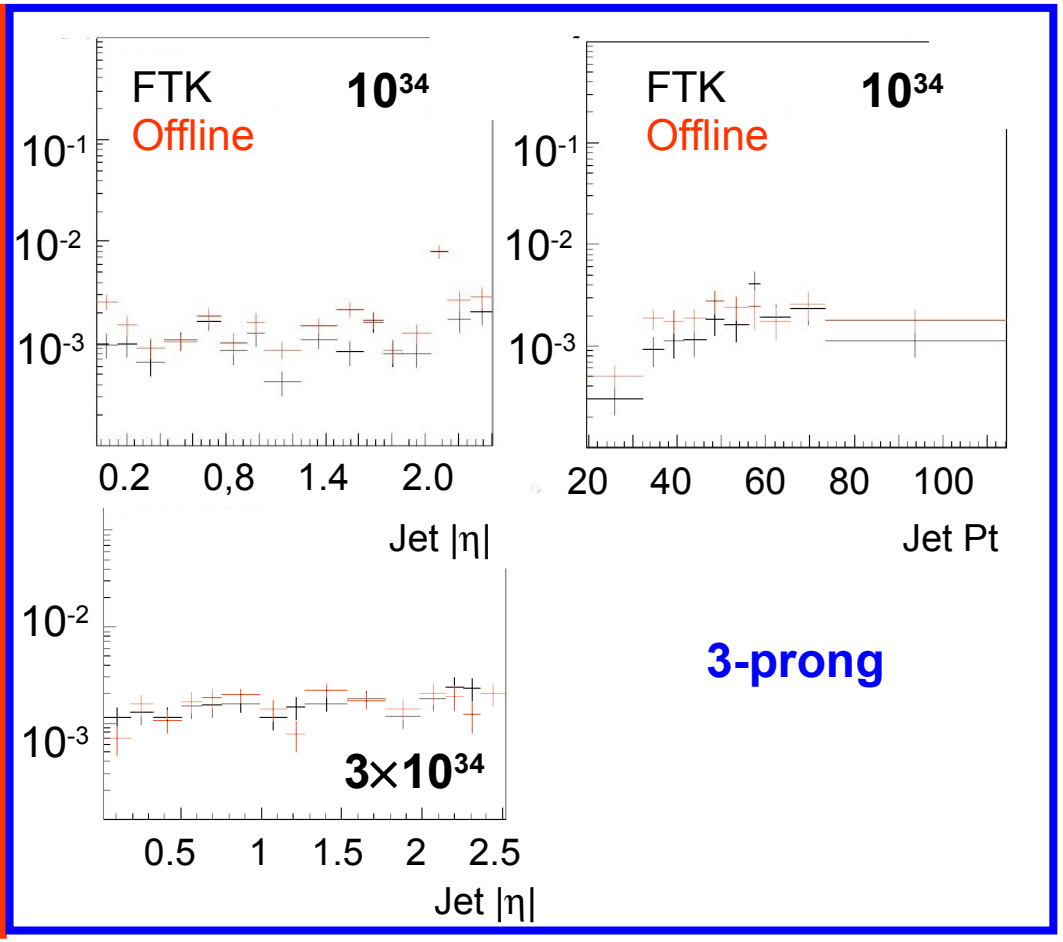
P_T> 6 GeV

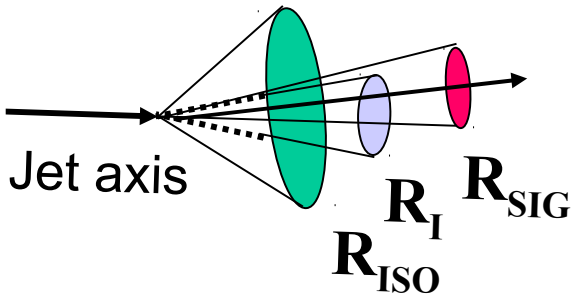
Rsig = 0,13 & Riso=0,26 around leading track;

1 (1-prong) or 2-3 (3-prong) tracks in Rsig;
no tracks with Pt above 1.5 GeV in Riso.

Efficiency on Jets: FAKES for Had Tau selection







leading P_T track