EPS HEP 2015, Vienna

Hardware-based tracking at trigger level for ATLAS:

The Fast TracKer (FTK) Project

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for the ATLAS Collaboration

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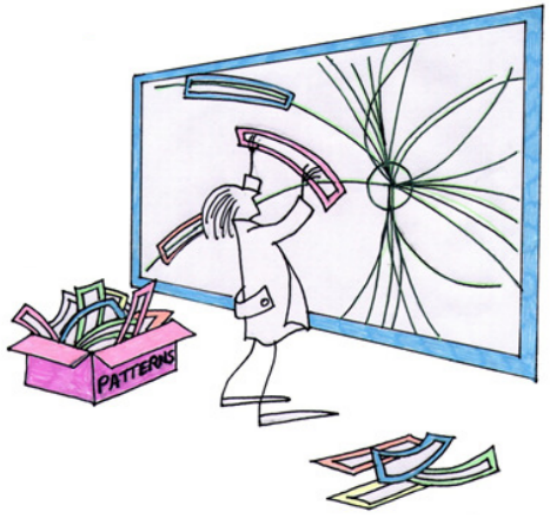
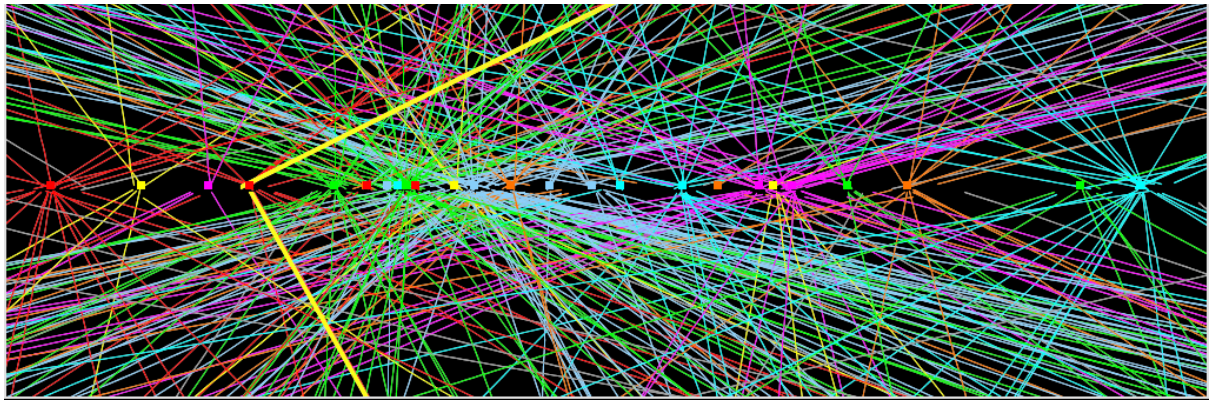
ATLAS-TDR-021



johanna.gramling@cern.ch

Why?

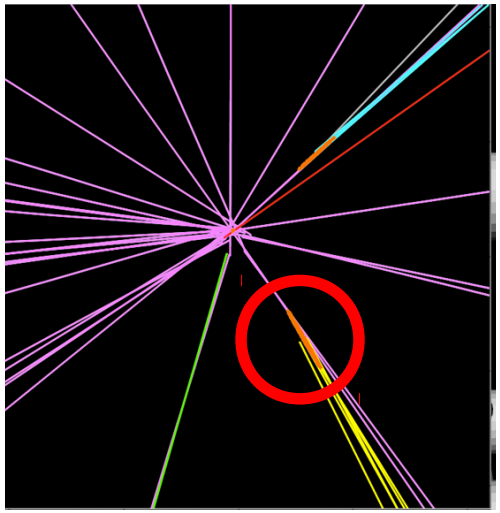
- Run II of LHC started - 13 TeV collisions!
  - With more than twice the luminosity compared to Run1, average of 40-50 collisions per bunch crossing expected
- Tracking at trigger level is essential to control rates while maintaining good efficiency for relevant physics processes – especially with high pile-up!
  - Measuring number and position of vertices improve robustness especially of jet and missing E_T triggers with changing pile-up conditions



8 TeV Z → μμ event with 25 reconstructed collision vertices (seen by the Inner Detector)

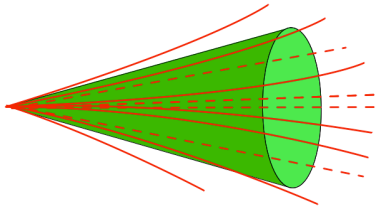
Why?

- Higgs found!
  - Fermionic-coupling measurements important to pin down (SM-like?) Higgs properties
  - Channels involving b and τ final states crucial, but:
    - Large QCD backgrounds
    - Low trigger efficiencies

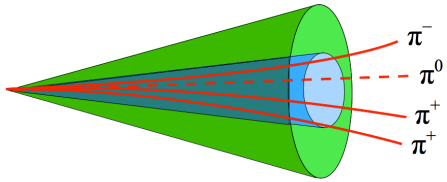


B-jets:
Displaced vertex

- SUSY could be hiding with light sbottom, stops, staus
  - Would lead to final states with moderate-momentum b's and τ's
    → difficult to trigger and select



"typical" jet



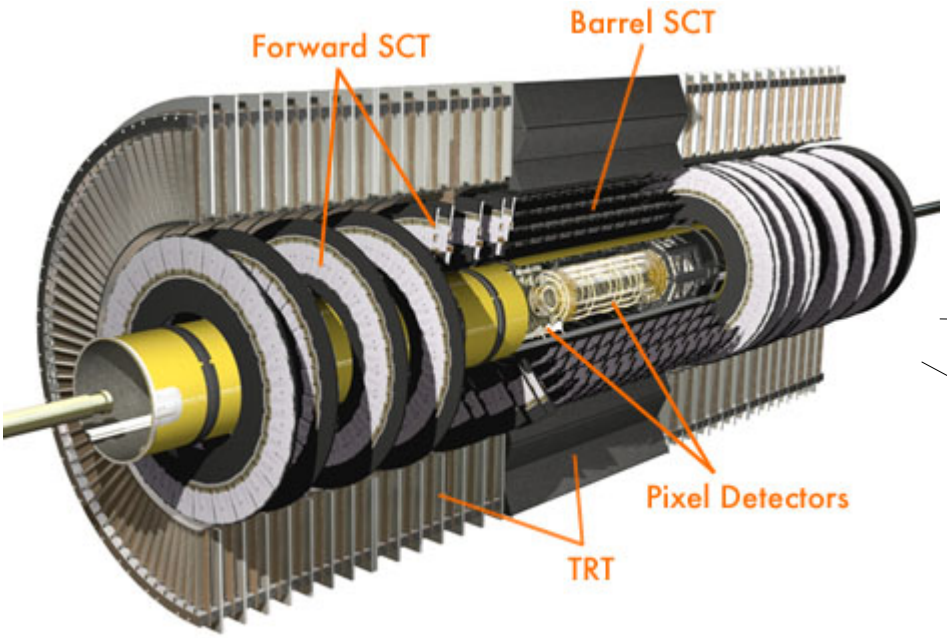
τ jet:
fewer tracks in smaller cone

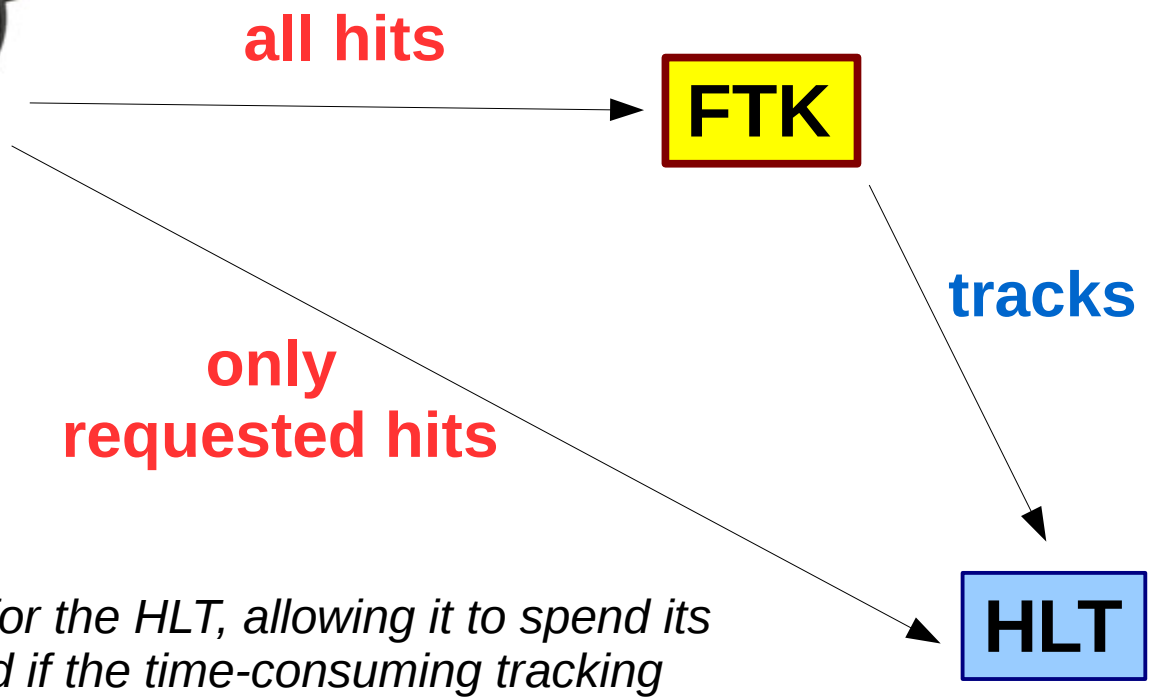
→ **Tracking and hence resolving topology of b- and τ jets at trigger level crucial for such analyses!**

Main Concepts of FTK

- Tracking at trigger level
  - For every event passing the Level-1 trigger, FTK receives data from the 98 million channels of the silicon detectors and provides tracking information to high level trigger (HLT)

More details on ATLAS trigger system:
see talk from Patrick CZODROWSKI

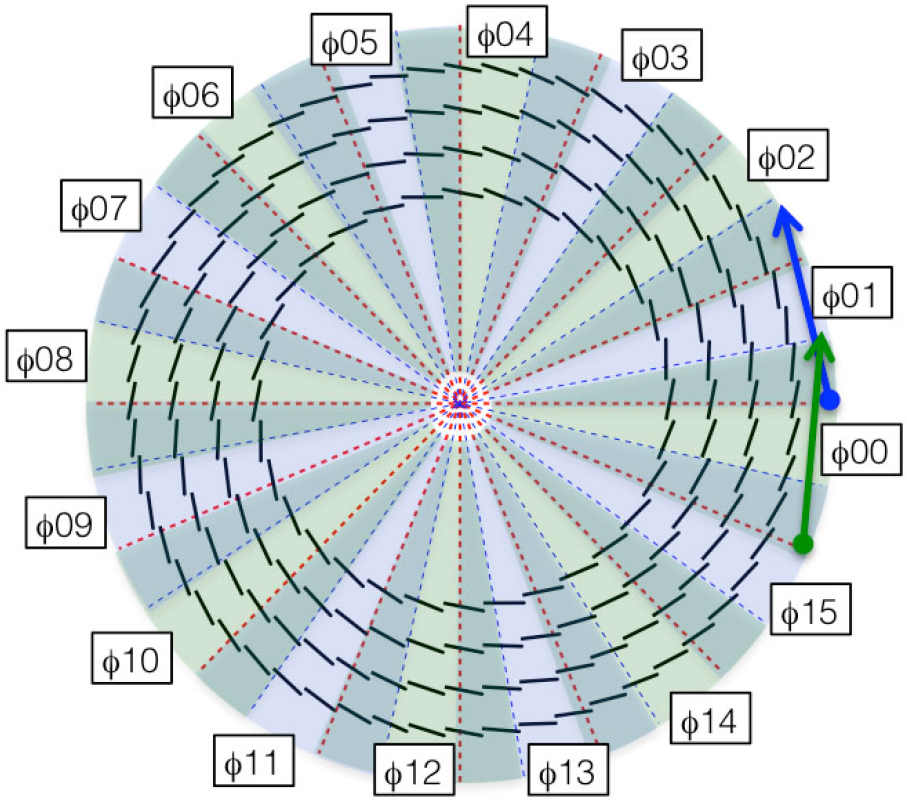


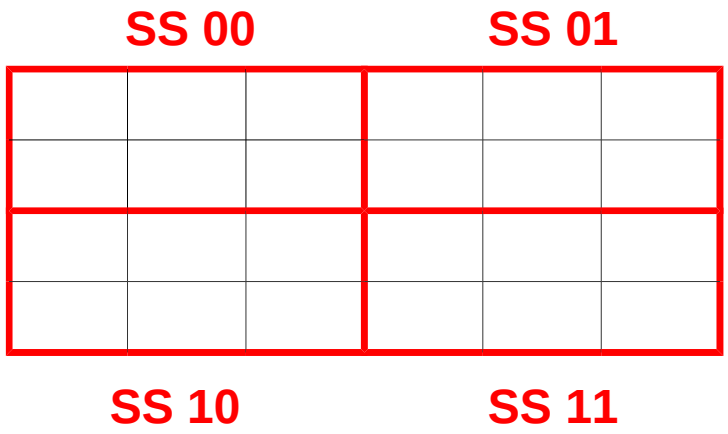


The FTK does the tracking for the HLT, allowing it to spend its time on algorithms instead if the time-consuming tracking

Main Concepts of FTK

- Tracking has to be very fast - maximum rate of 100 kHz
  - **Process in parallel:** decompose detector data into independent regions (64 ***Towers***)
  - **Data reduction:** each cluster of adjacent pixels/strips defines one "hit"
    - When appropriate, re-bin hit information to coarser resolution → ***SuperStrips***

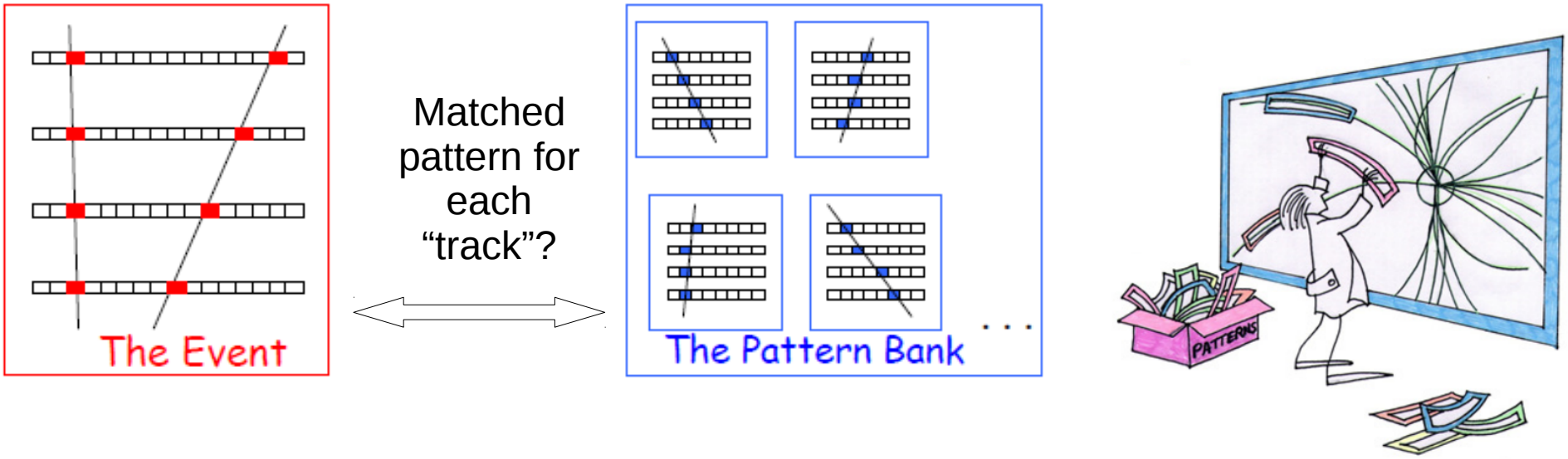




Several pixels are grouped together into one SuperStrip (SS)

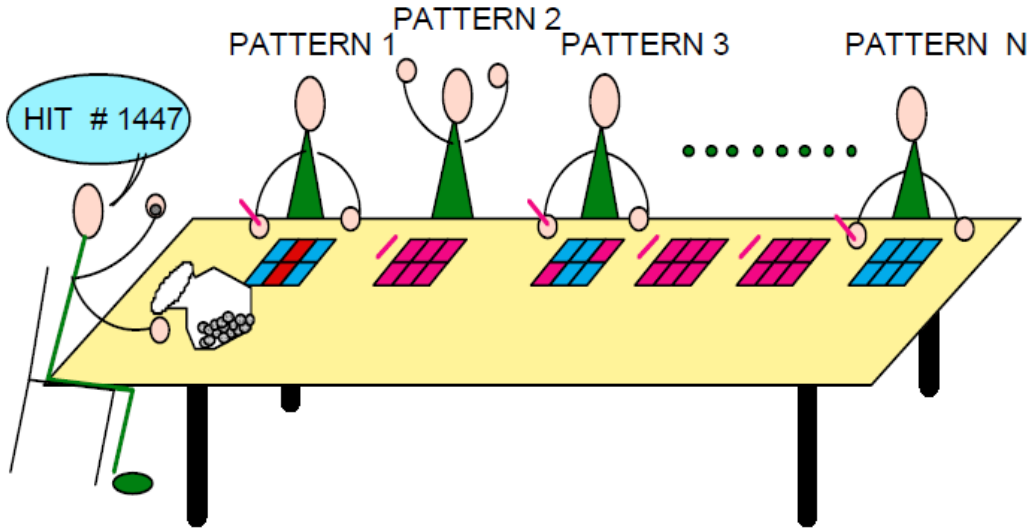
Main Concepts of FTK

- Tracking has to be very fast - maximum rate of 100 kHz
  - **Process in parallel:** Reorganize the received hits
  - **Data reduction:** each cluster of adjacent pixels/strips defines one "hit"
  - Perform **tracking in 2 steps**
    1. Find track candidates: ***Roads***
       - Compare fired SuperStrips to predefined track trajectories: ***Pattern matching***
       - Minimum number of matched layers programmable



Pattern Matching in detail

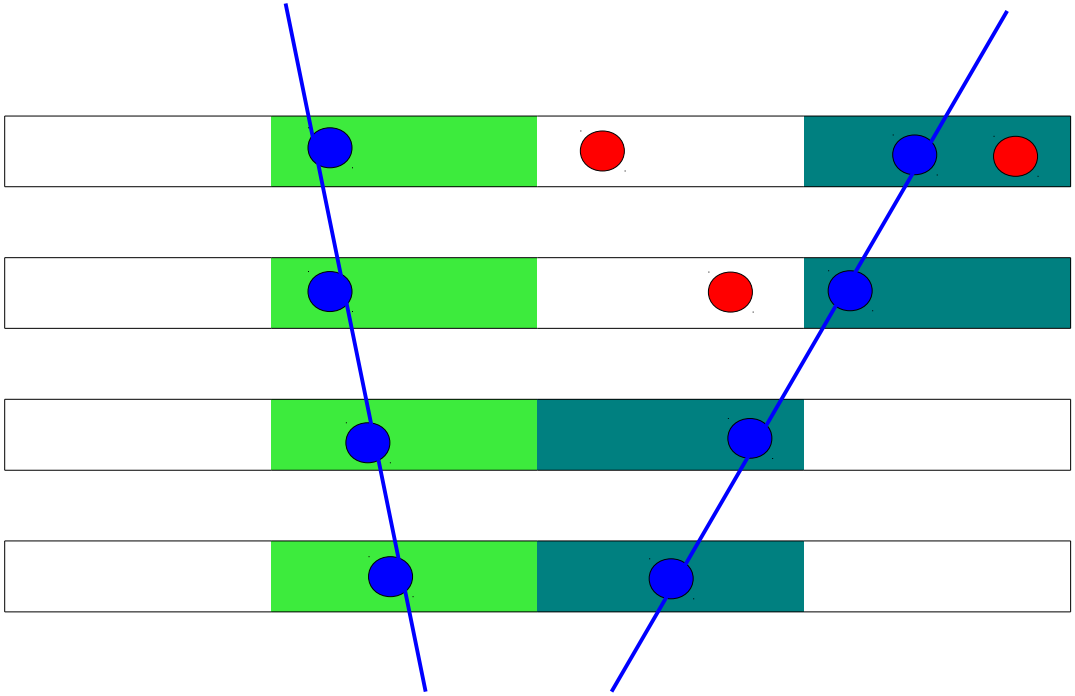
- Pattern matching is performed in customly-designed chip using Associative Memory (AM)
  - Like playing Bingo
  - Incoming data is **simultaneously** compared to **all** stored patterns
    → very fast matching!



More details on pattern matching:
see talk by *Francesco CRESCIOLI*

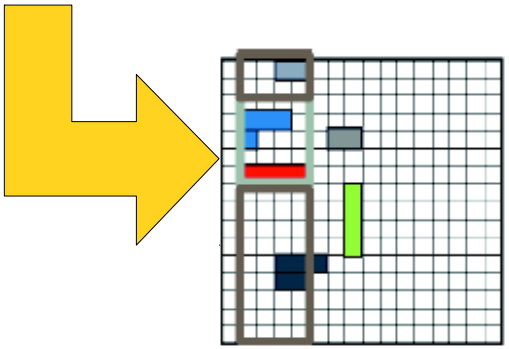
Main Concepts of FTK

- Tracking has to be very fast - maximum rate of 100 kHz
  - **Process in parallel:** Reorganize the received hits
  - **Data reduction:** each cluster of adjacent pixels/strips defines one "hit"
  - Perform **tracking in 2 steps**
    1. Find track candidates: ***Roads***
    2. Perform full-resolution ***track fitting*** INSIDE roads
       - Combinatorics reduced → faster!



Data Flow

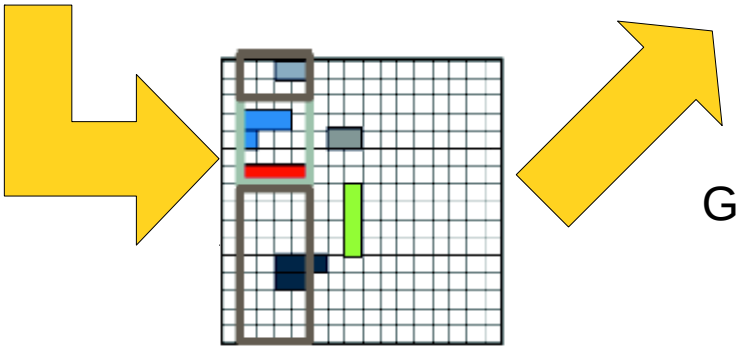
Tracking detectors



Custom pixel clustering algorithm on FPGAs

Data Flow

Tracking detectors



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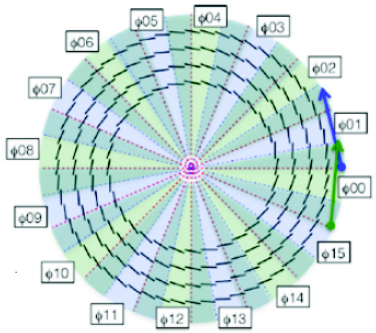
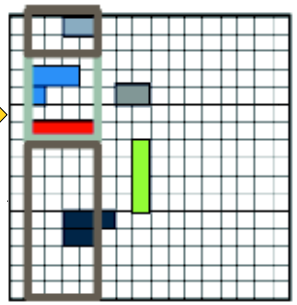


Geometrically grouped data distributed to processing units

Data Flow

Tracking detectors



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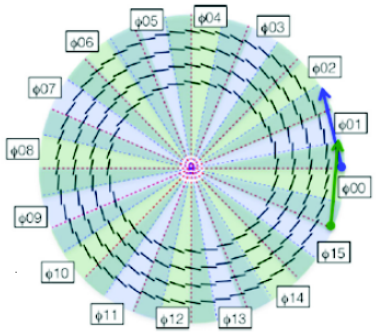

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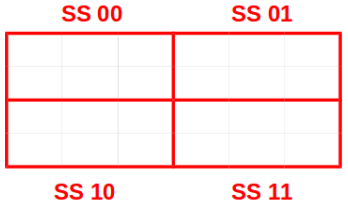
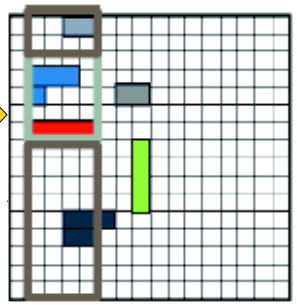


Transformation to coarse-resolution hits

Data Flow

Tracking detectors



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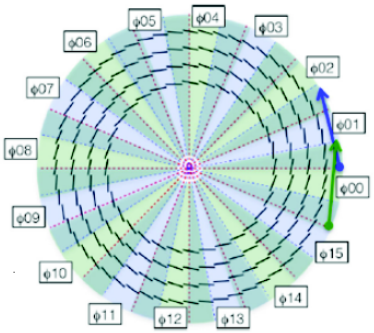

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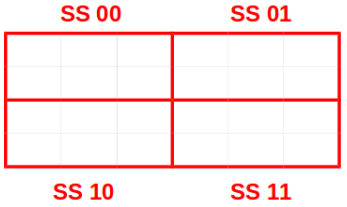

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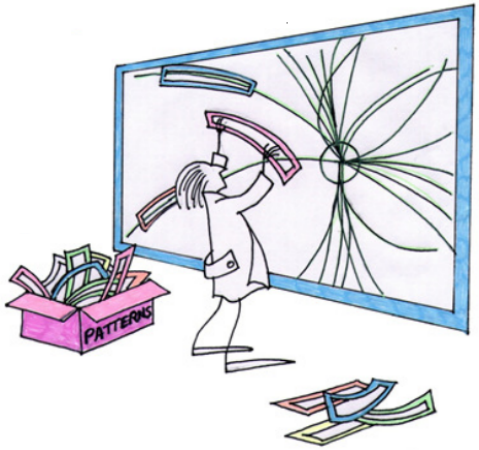
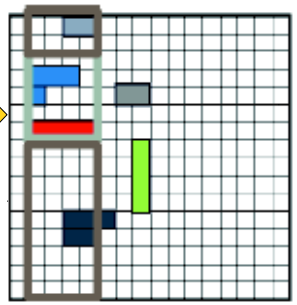


Comparison to reference track patterns at coarse resolution

Data Flow

Tracking detectors



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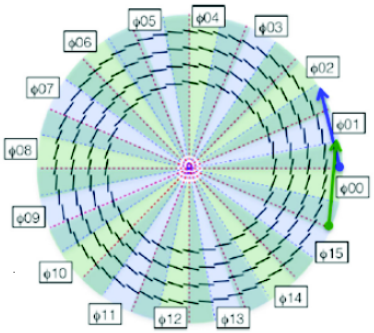

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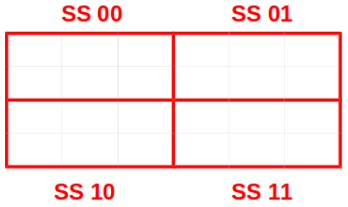

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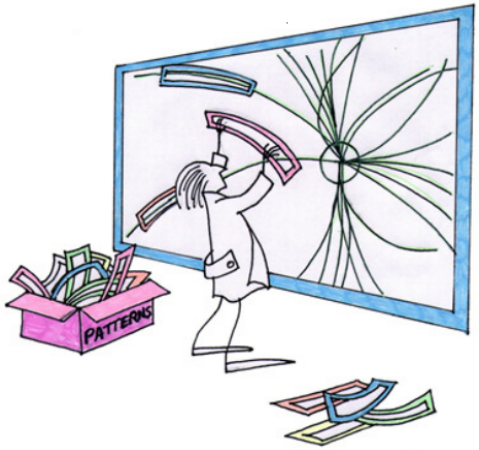

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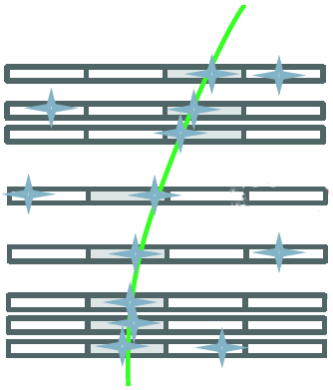

Track fit with full-resolution info for track candidates

Data Flow

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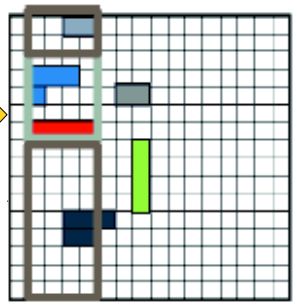

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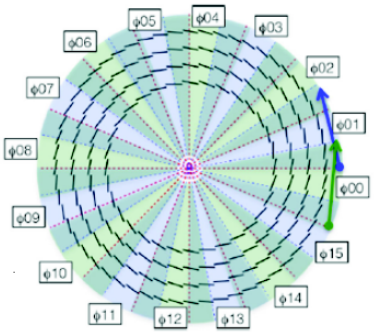

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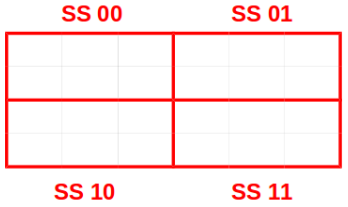

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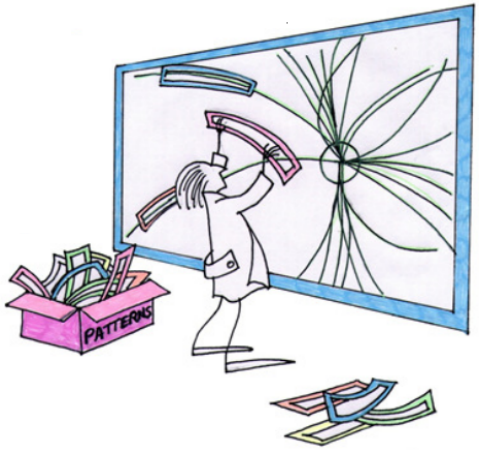

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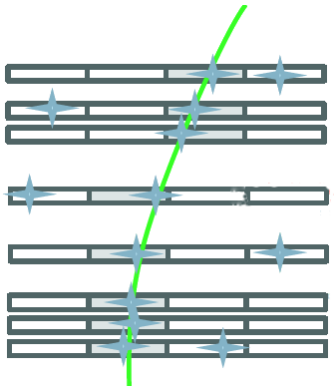

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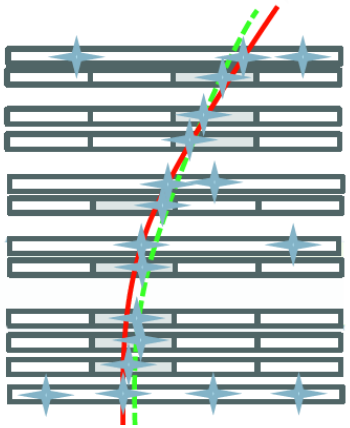
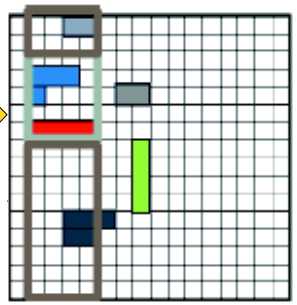


Precise fitting with good tracks being extrapolated to missing layers

Data Flow

Tracking detectors



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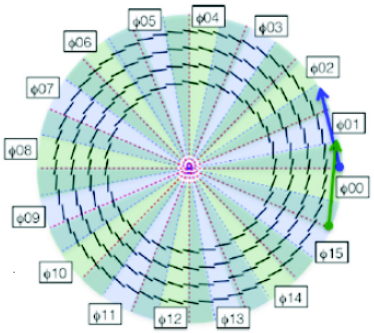

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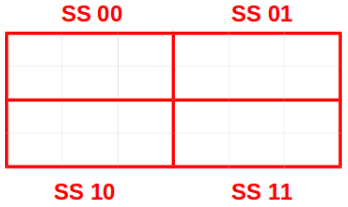

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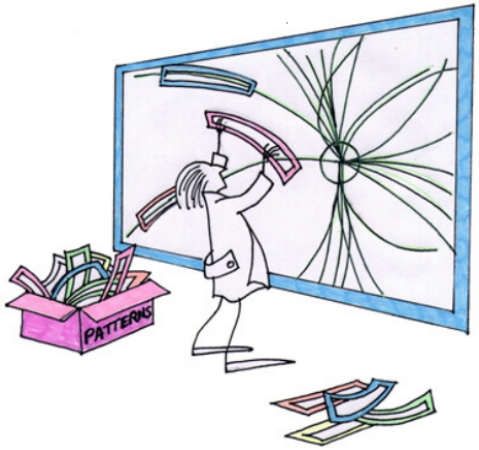

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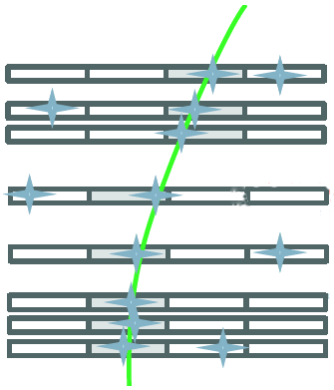

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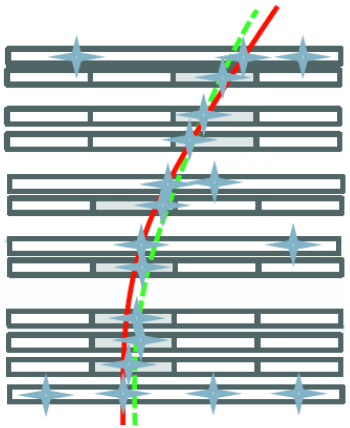


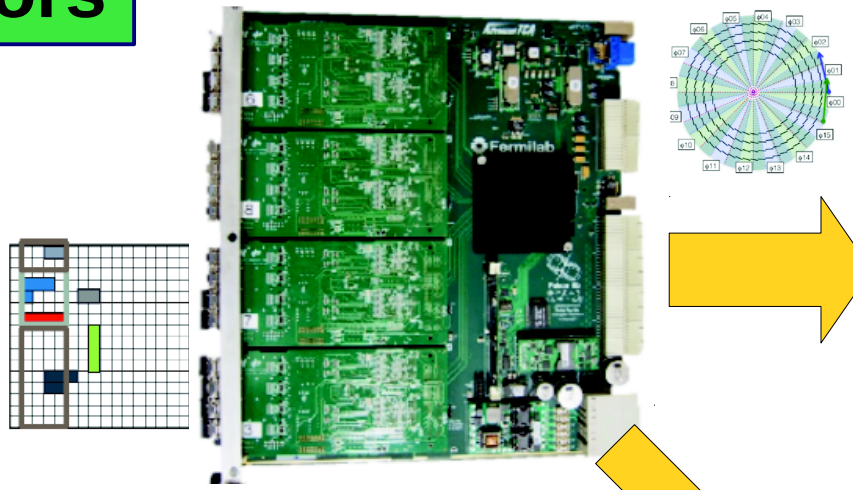
Precise fitting with good tracks being extrapolated to missing layers

HLT

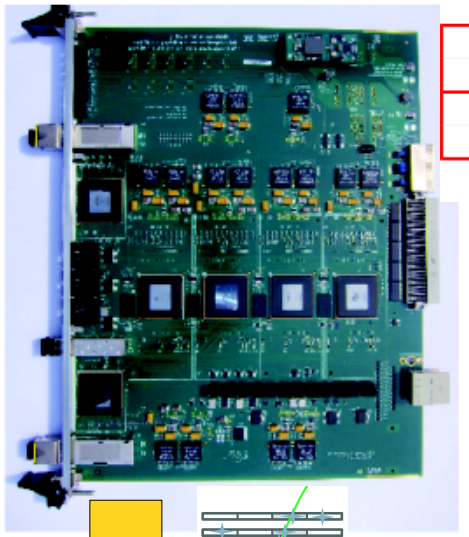
Data Flow – in hardware components

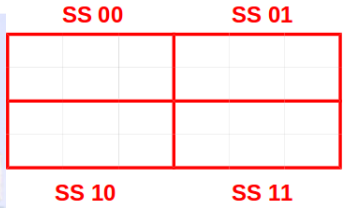
Tracking detectors

32x Input Mezzanine (IM) and Data Formatter (DF)

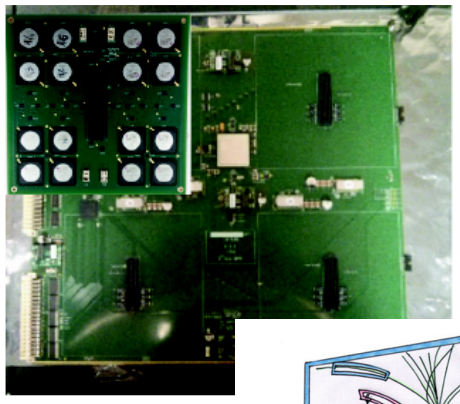


128x Auxiliary Boards (AUX)

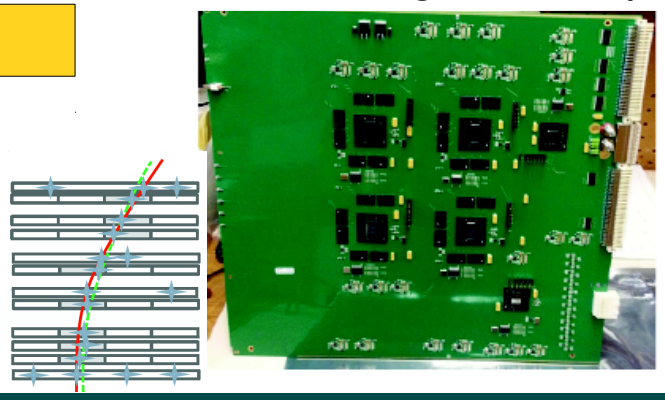




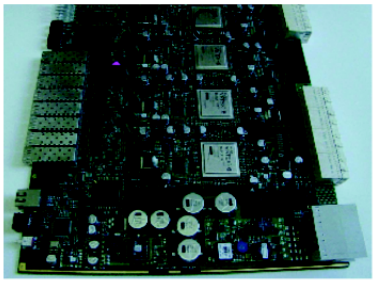
128x Associative Memory Boards (AMB)



32x Second Stage Board (SSB)



2x Level-2 Interface Crate (FLIC)



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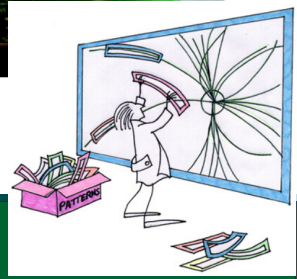
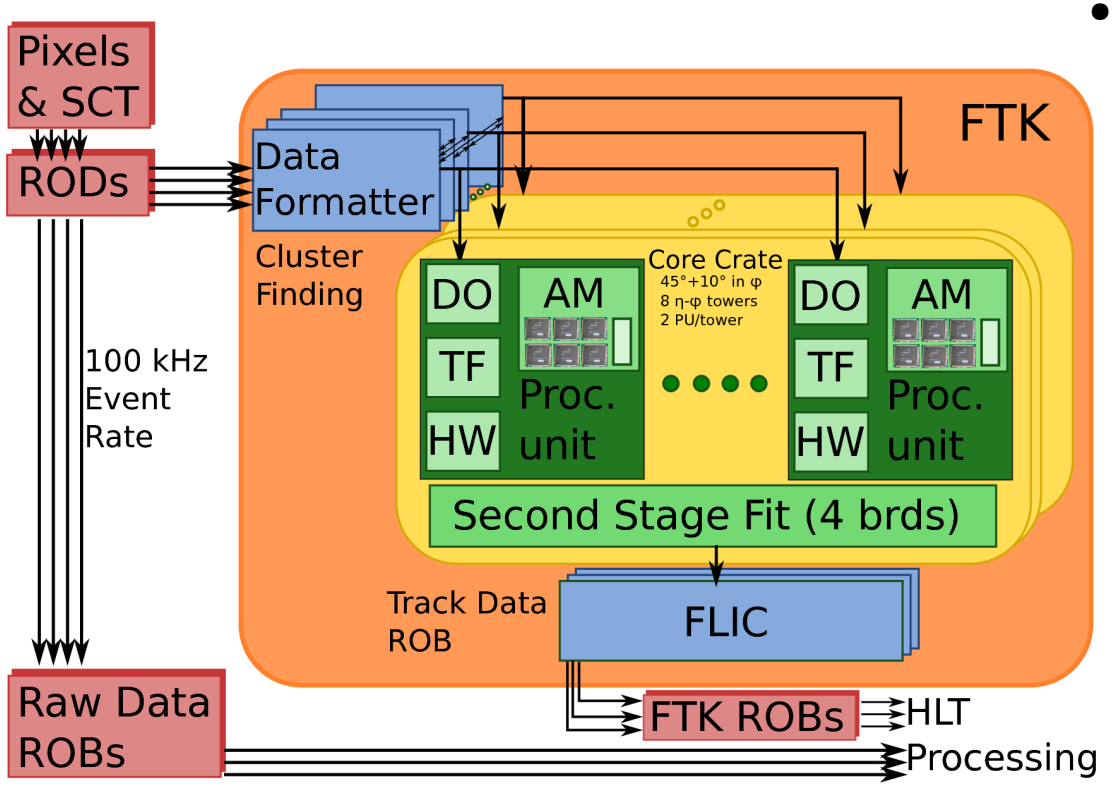


Data Flow

FTK = (very complex) custom parallel supercomputer

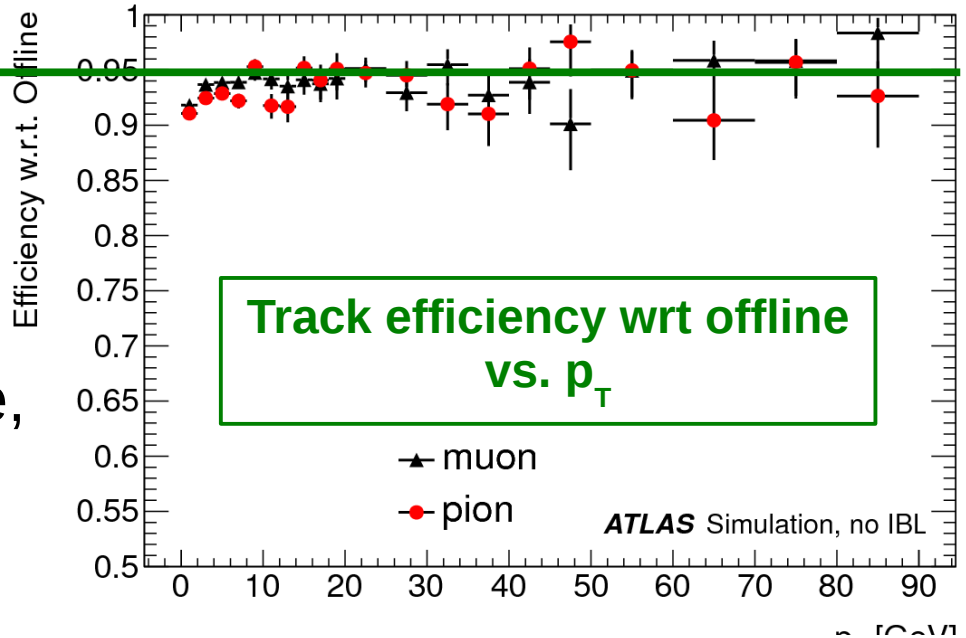


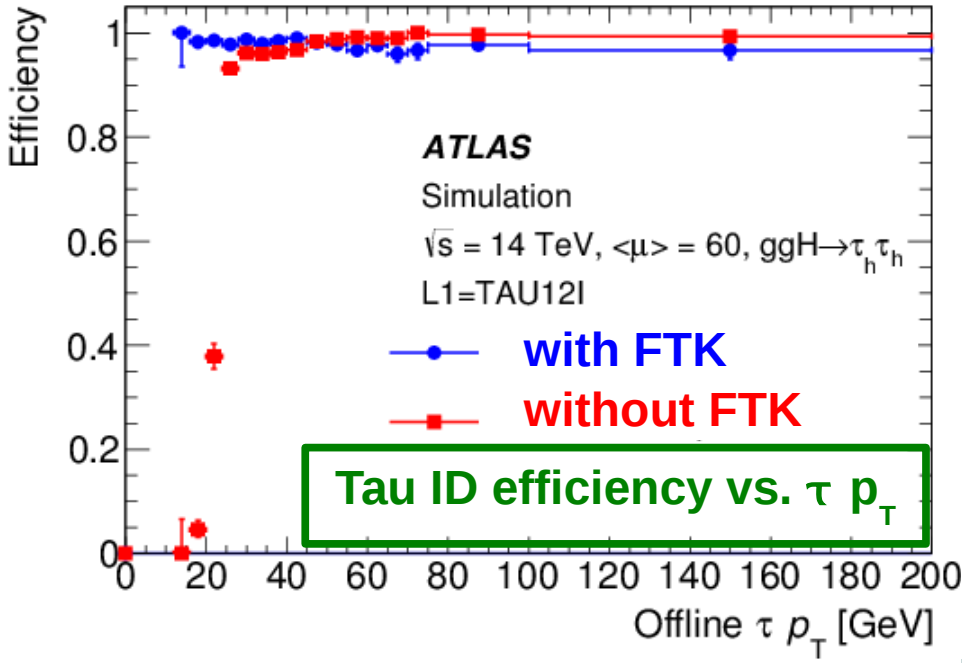
- FTK is a big system
  - 8 full 9U VME crates
  - 5 ATCA shelves
- Many different boards
  - 2 types of ATCA boards
    - Data Formatter (DF), FTK-to-Level-2 Interface Crate (FLIC)
    - mezzanine for clustering (input mezzanine)
  - 9U Auxiliary board (AUX)
    - data organizer, track fitting and fake reduction functions
  - 2 types of 9U VME boards
    - Associative Memory Board (AMB), Second Stage Board (SSB)
    - 9U/4 mezzanine for Associative Memory chip (AMchip06)

~2000 FPGAs and ~8000 custom AM chips

Expected Performance

- FTK online track quality comparable to offline **95%**
  - Slightly worse resolution
  - Small effect from pile-up
- b-tagging efficiency similar to offline, with high light-jet rejection when using FTK
- Linear correspondence between number of FTK and offline vertices
  - Independent of pile-up
- Trigger efficiency for 1-prong τ's in $H \rightarrow \tau\tau$ significantly improved when optimizing algorithms including FTK tracks





How to profit from FTK?

- **Jet Trigger**
  - Profit from precise pile-up information
    - energy corrections based on number of vertices found by FTK
    - Better jet quality cuts to reduce pile-up effects: especially important for multijets or b-jets (room for improvement for b-tagging!)
  - Use FTK tracks to recover efficiency for low-p_T or close-by jets
- **Muon/Electron Trigger**
  - Pile-up dependence of calorimeter-isolation and electron shower shapes
  - Track-based isolation for muons
  - Recover di-muon events via high-p_T FTK tracks
- **Missing E_T Trigger**
  - Improve MET resolution by track/pile-up info from FTK
- **Tau Trigger**
  - Refine algorithms by including FTK tracks
  - Improved calorimeter shower shapes due o precise pile-up inforation
  - Recover L1 inefficiencies via high-p_T FTK tracks

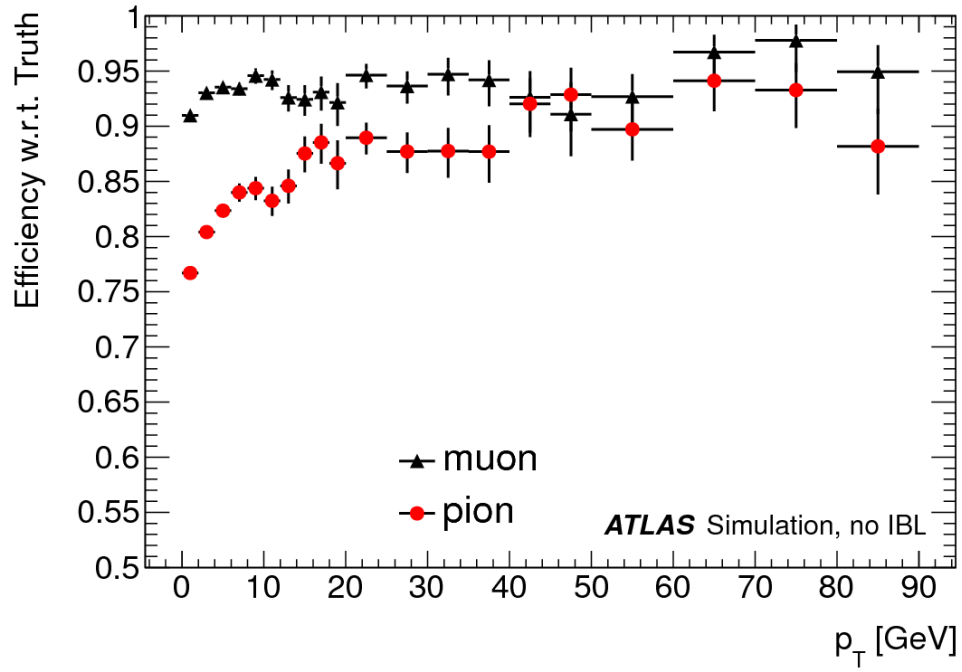
SUMMARY

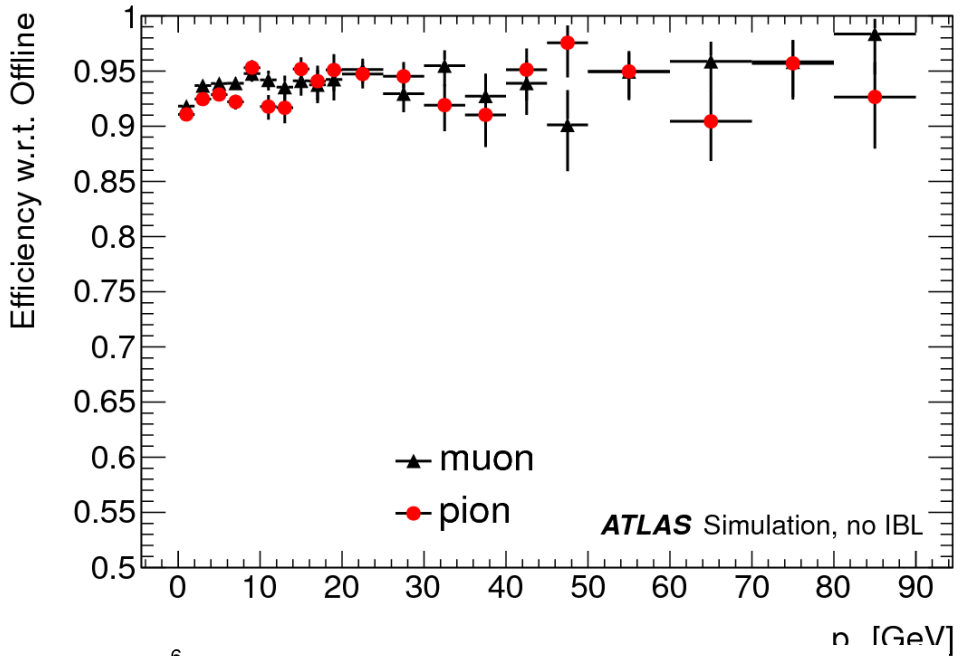
- **FTK aims at providing tracking information at trigger level**
  - Especially beneficial for signatures relying on medium-p_T b's or τ's
  - Constraints on pile-up improve many trigger selections
- **System optimized to achieve rates of 100 kHz**
  - Parallel processing of event data
  - 2-stage tracking: pattern matching to identify track candidates
- **Pattern matching done with custom AM chips**

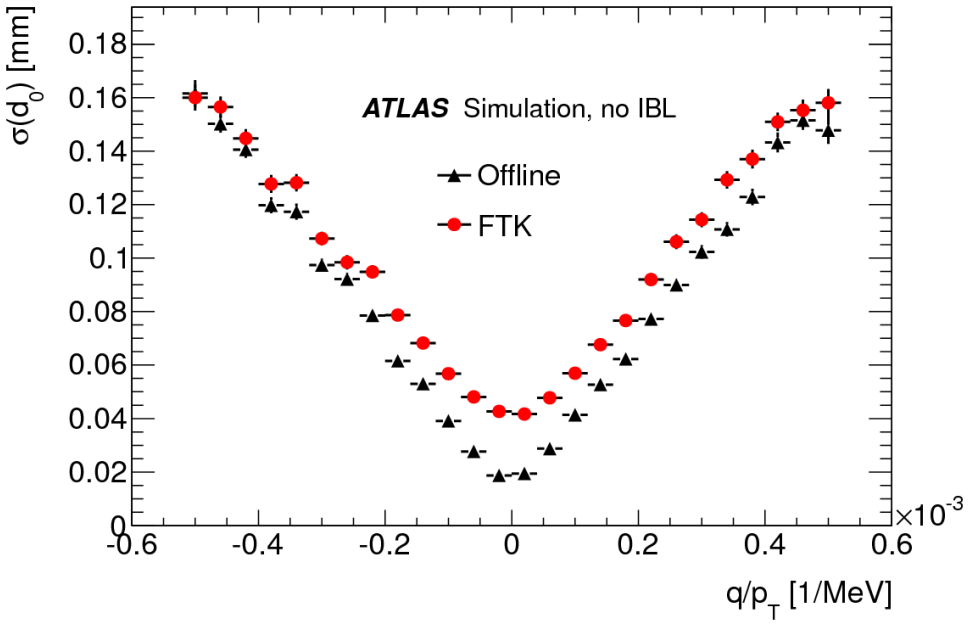
  → *Learn more in next talk by Francesco Crescioli*
- **FTK track quality and efficiency close to offline performance**
- **Integration of first boards ongoing**
  - Barrel-only FTK processing expected in spring 2016, then HLT integration and extension to full coverage will follow
- **HL-LHC: possibly extend and refine FTK concept to cope with high-luminosity conditions**
  - Tracking at Level-1 using an AM-based system with upgraded AM chip

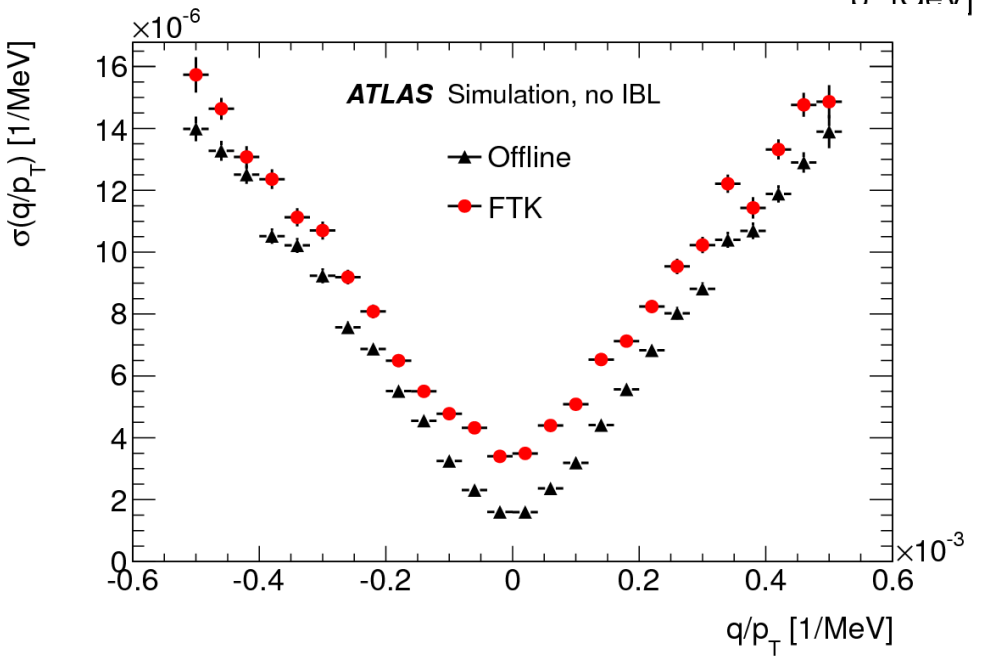
BACKUP

Expected Performance



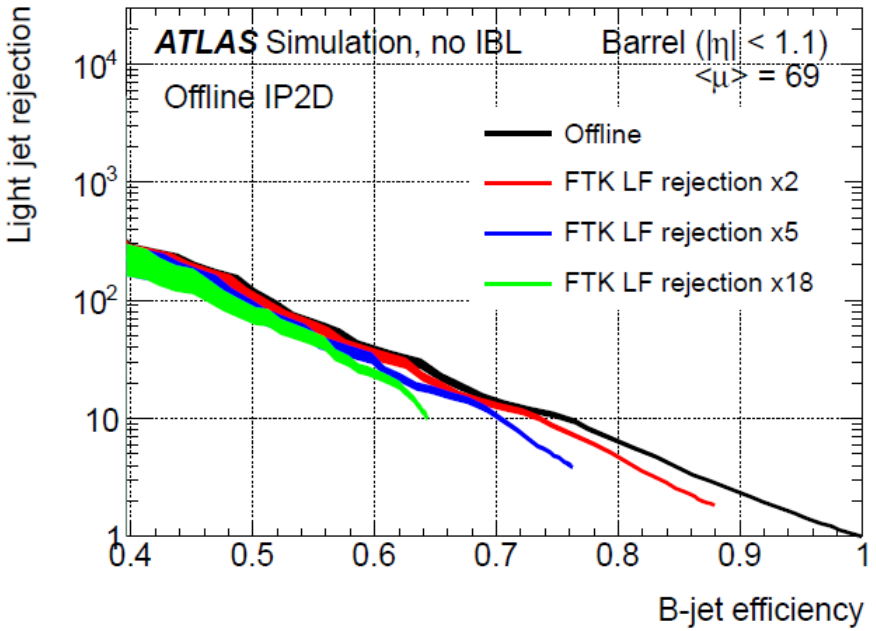


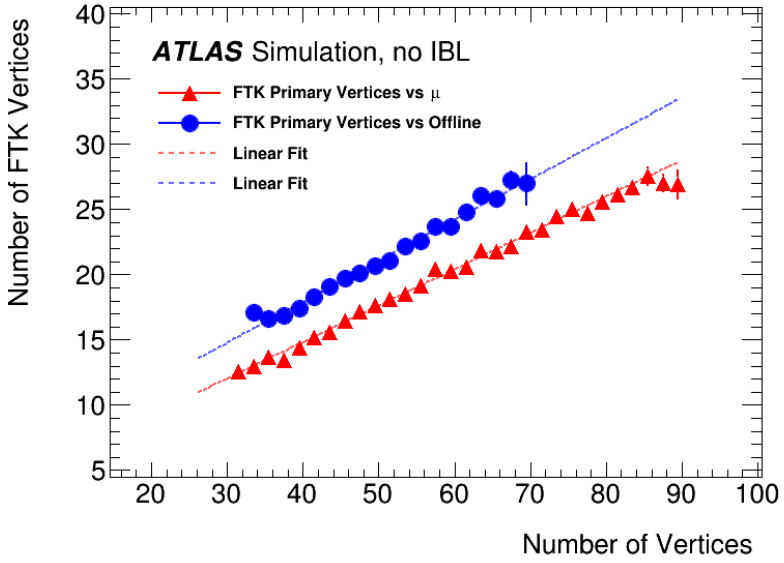


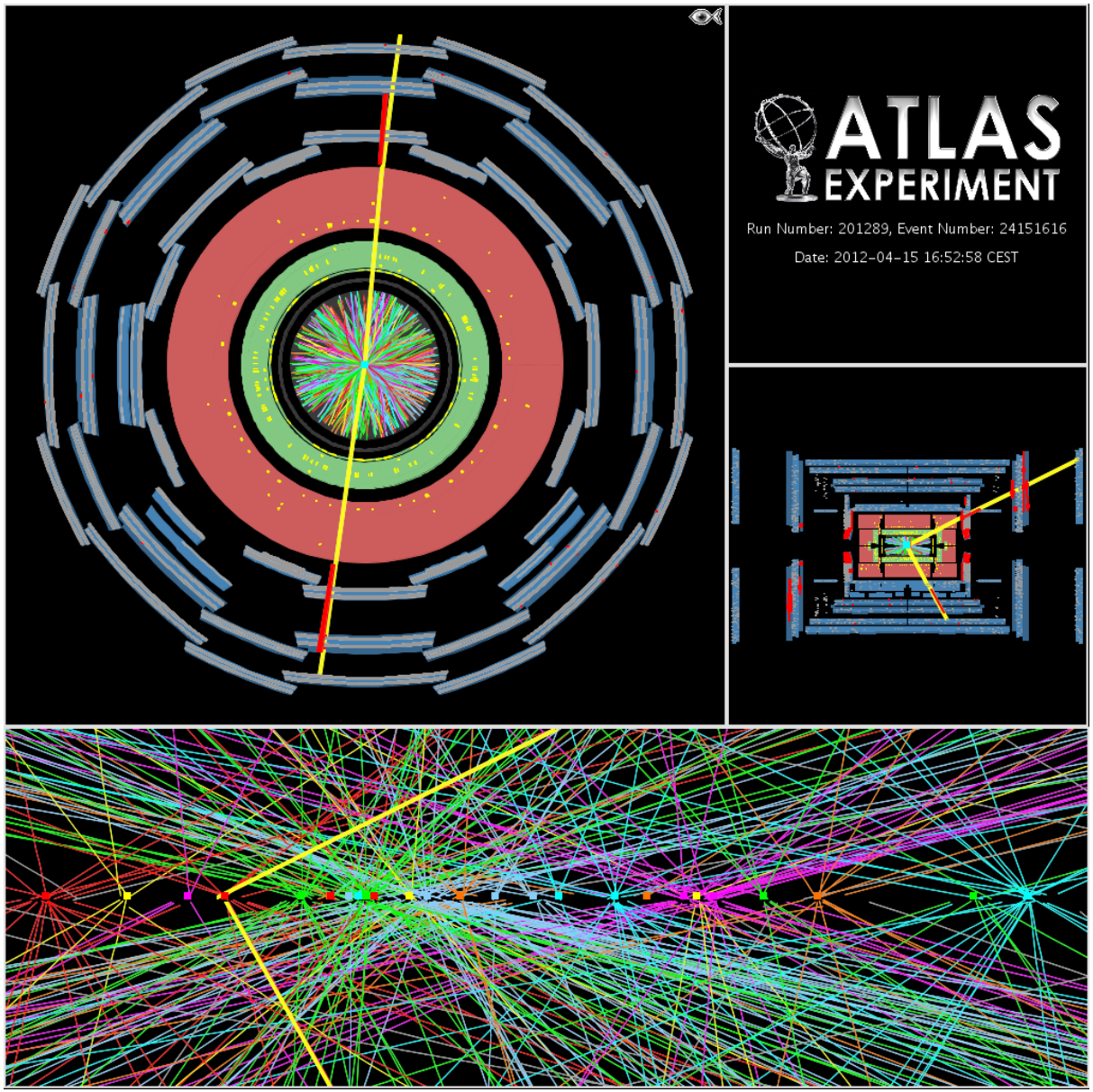


Vertexing, b-tagging

- Similar b-tagging efficiency with high online FTK light-jet rejection
- Linear correspondence between number of FTK and offline vertices
  - Independent of pile-up



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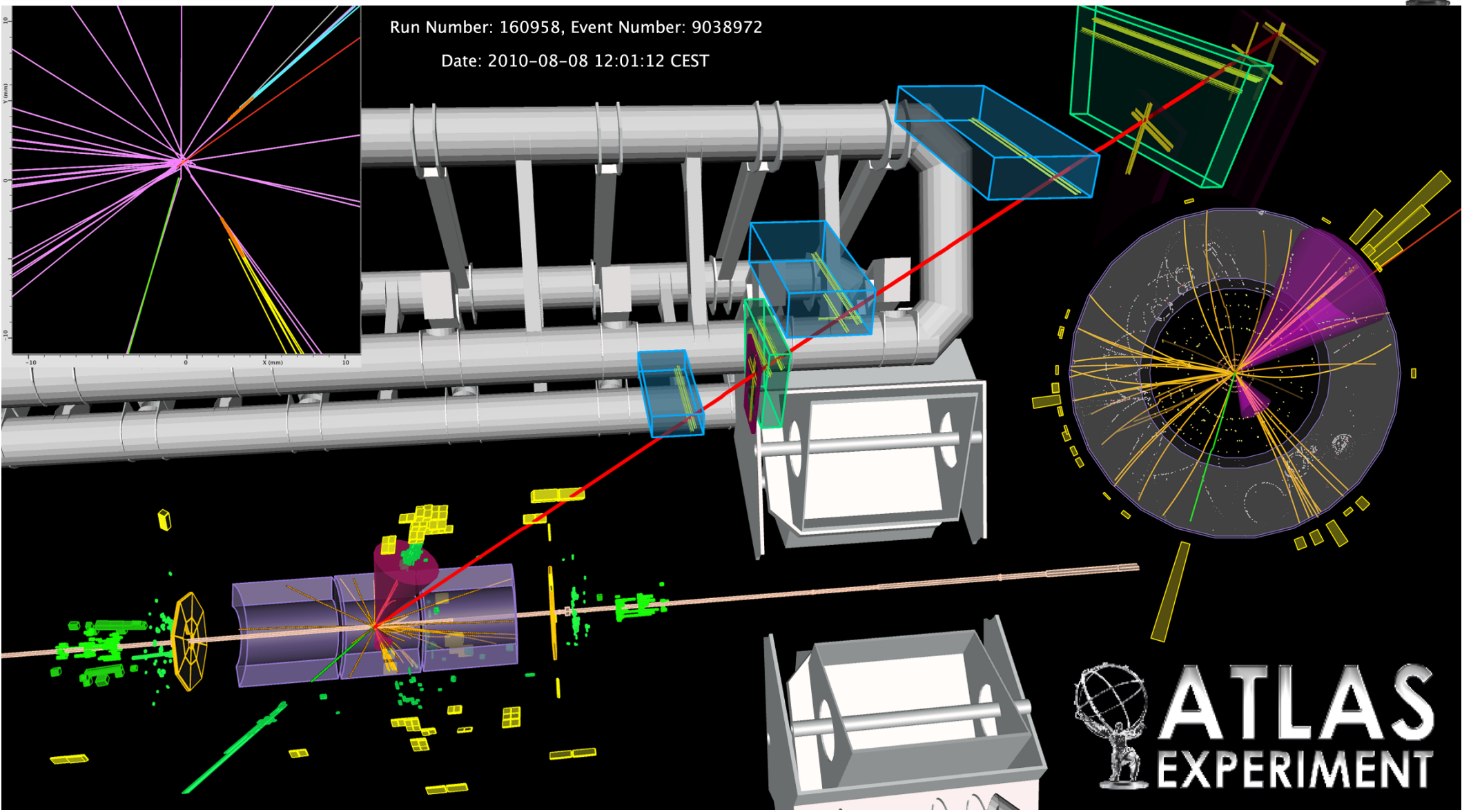
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