# Tracking with Cellular Automaton at STAR

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With contributions from:
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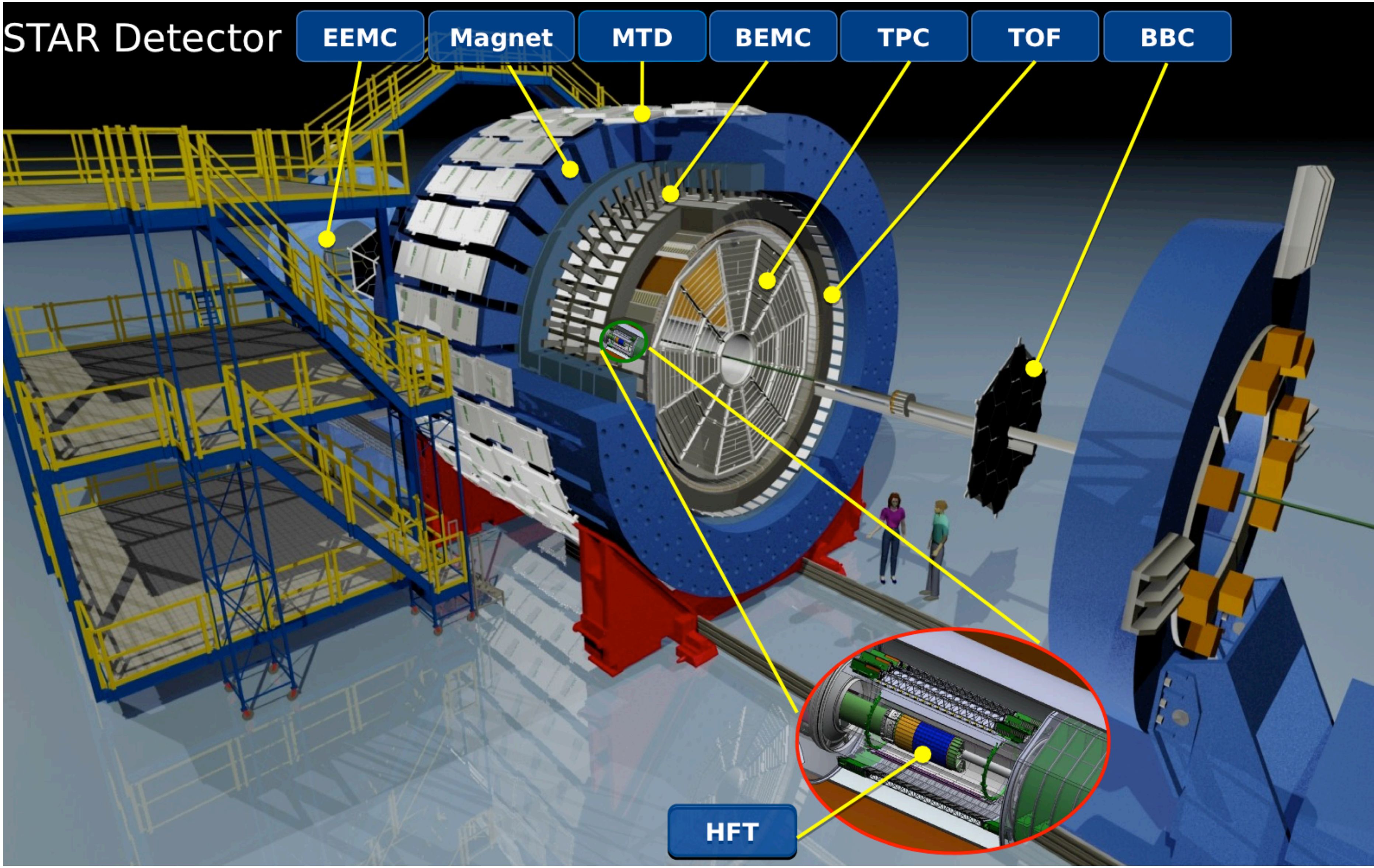
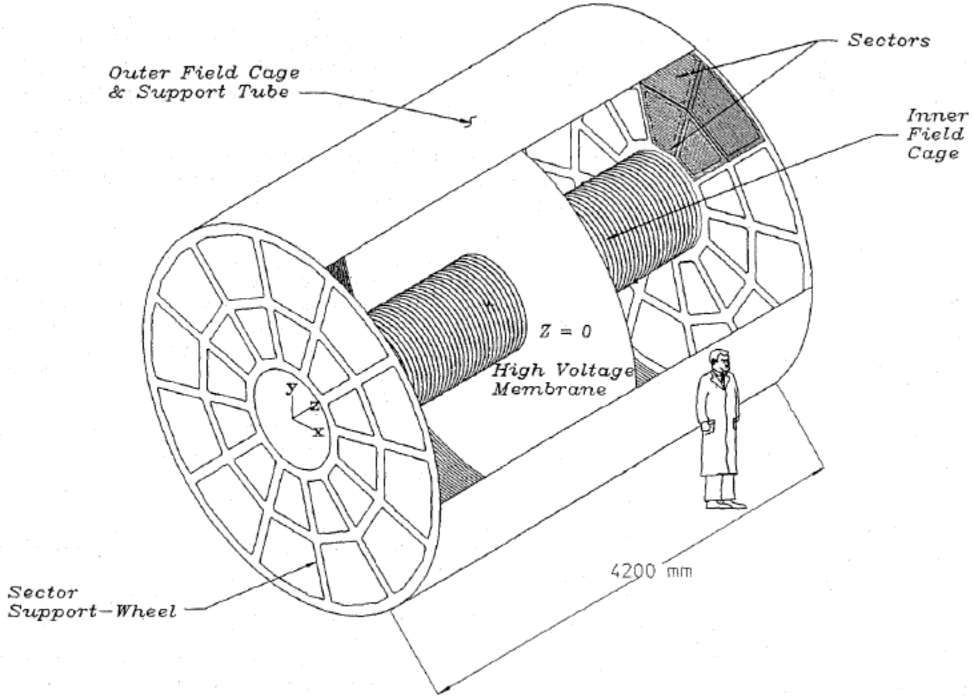
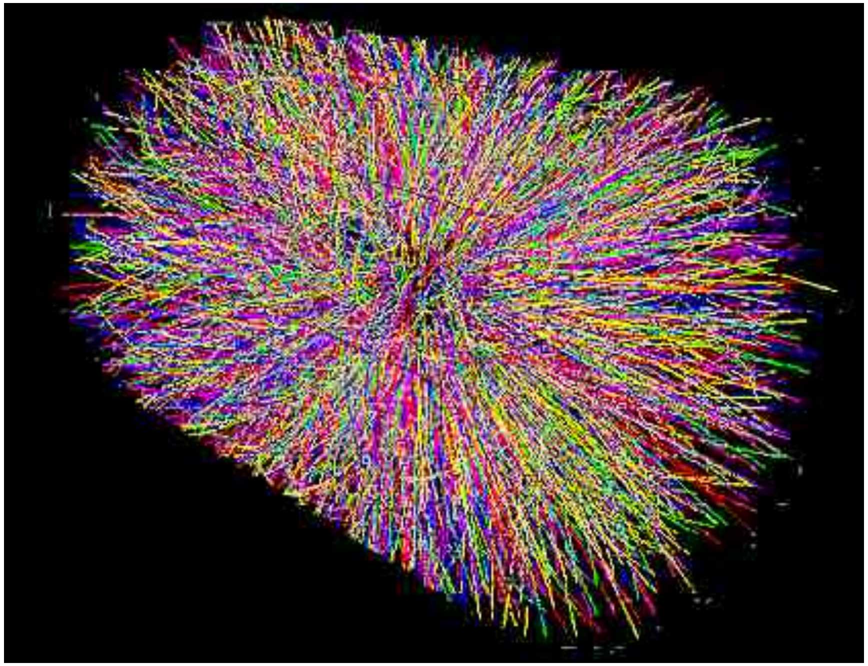
- Overview
- CA at STAR High-Level Trigger
- CA + Sti in STAR offline software
- CA + GenFit in express production

# STAR Detector



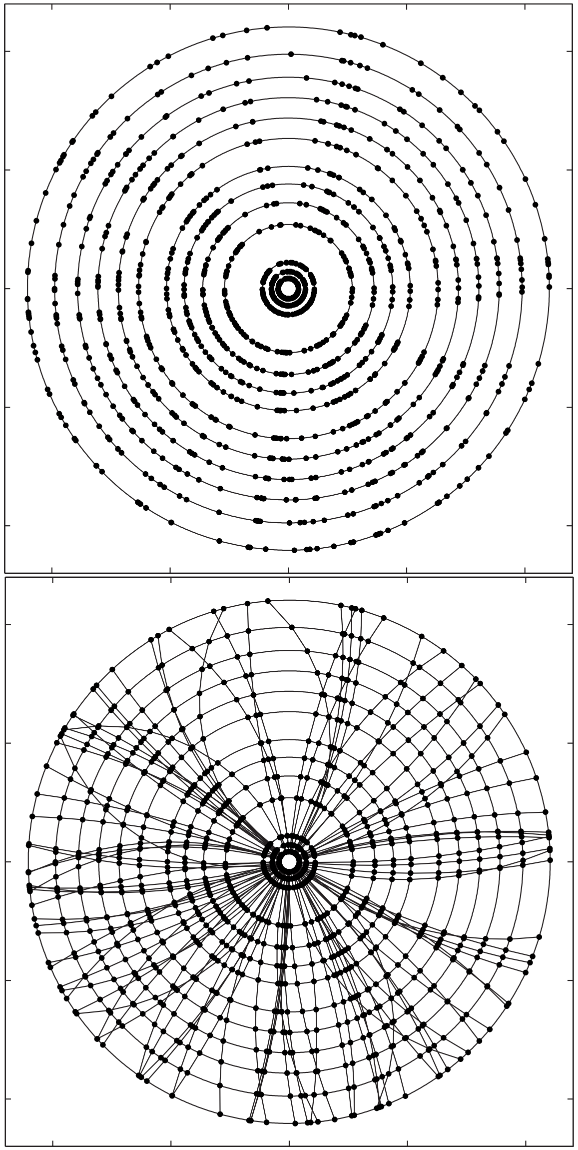
# STAR Time Projection Chamber

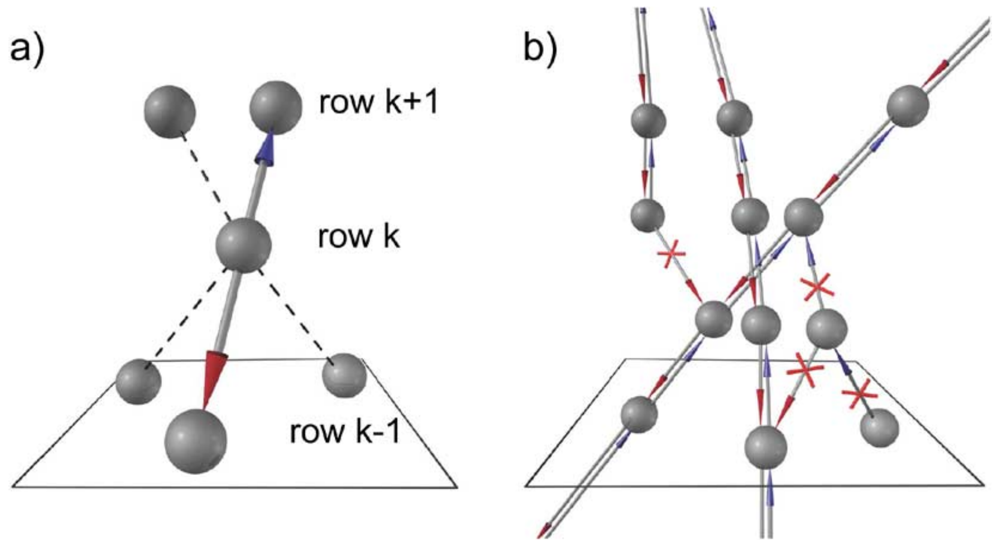


- TPC is the main tracking detector of STAR
- Each half has 12 sectors
- Each sector has 72 pad-rows
- Cover full azimuthal angle and $|\eta| < 1.5$
- Provide tracking and PID based on ionized energy lost

# Cellular Automaton Track Finding



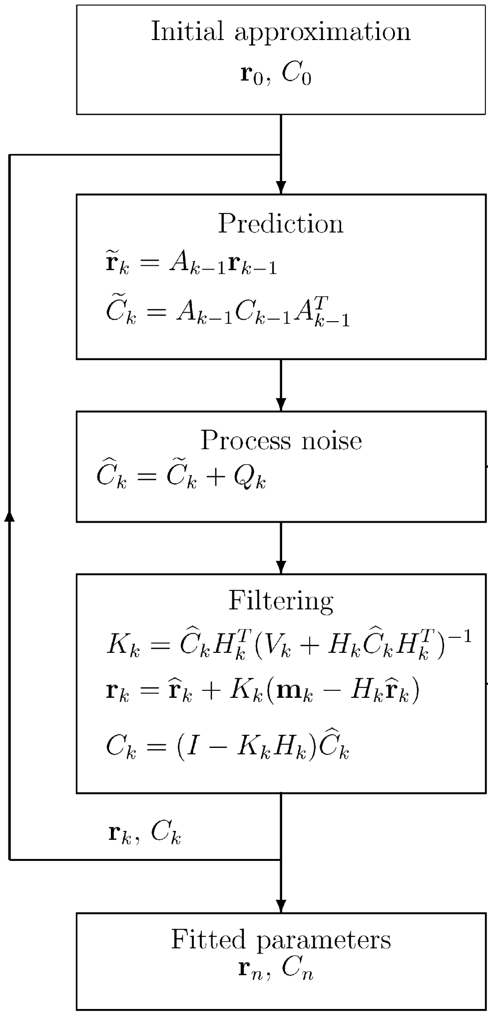


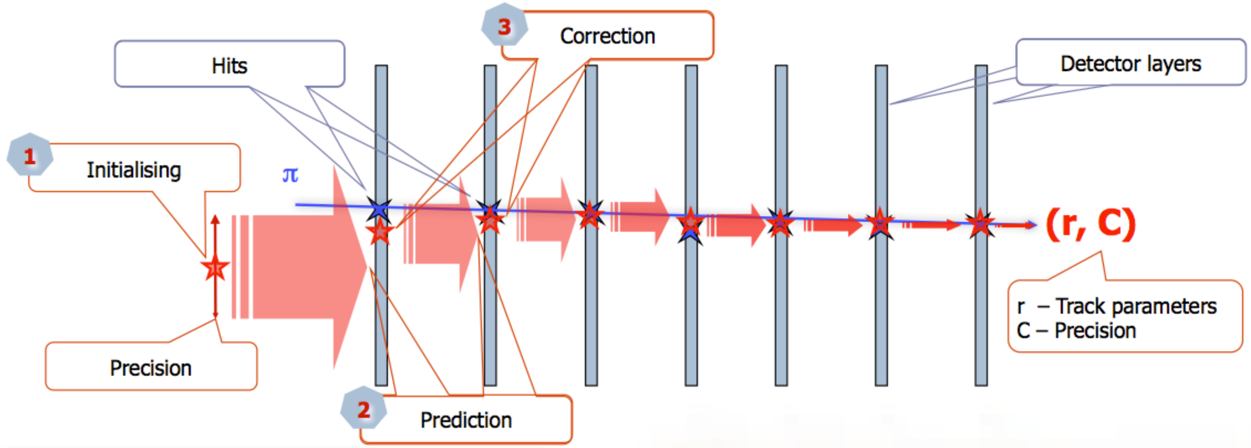

a) Neighbors finder. b) Evolution step of the Cellular Automaton.

- local data access
- intrinsically parallel
- extremely simple algorithms
- suitable for SIMD

S. Gorbunov et al. Real Time Conference (RT), 2010

# Kalman Filter Track Fitting



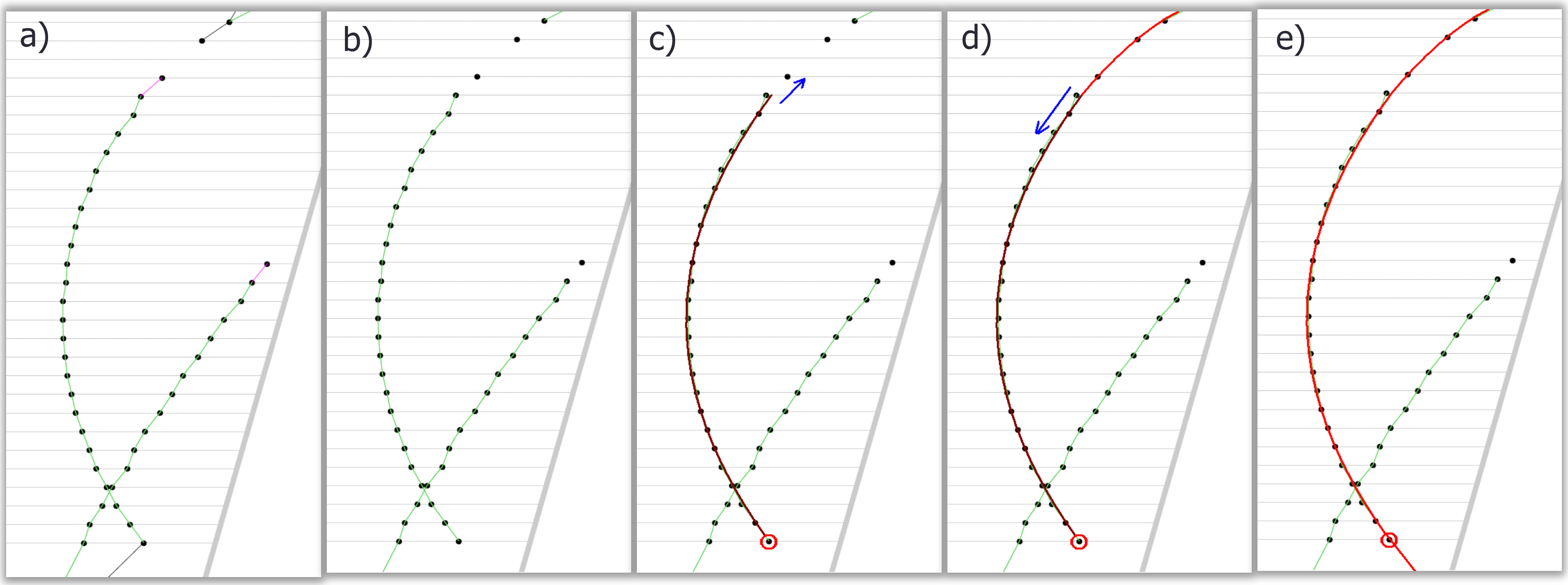




- Start with an arbitrary initialization
- Add measurement one by one
- Optimized parameters and covariance matrix are obtained after the last measurement added
- Independent to track model
- SIMD version available

S. Gorbunov et al., Computer Physics Communications **178** (2008) 374–383

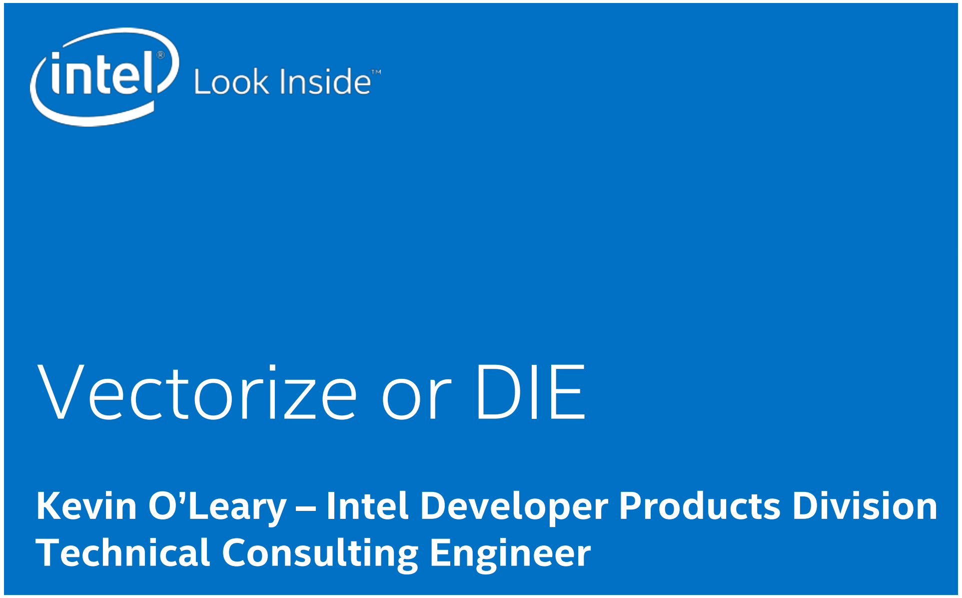
# CA Tracker

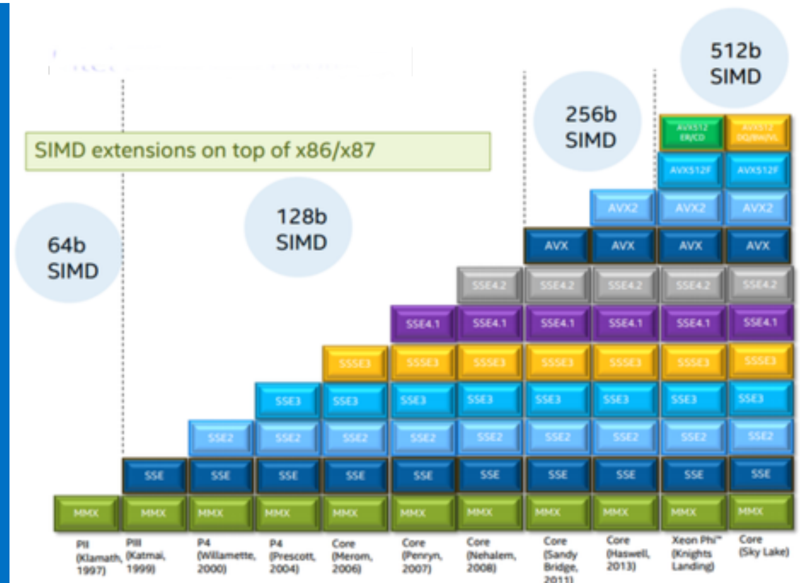
1. Reconstruction of track segments in each TPC sector:
   a) Find and link neighbors hits
   b) Clean links
   c) Create segments by fitting chains and adding outer hits
   d) Refit tracks and add inner hits
   e) Selection of tracks
2. Merge sector tracks into TPC global tracks.




- The version used by STAR is developed by Ivan Kisel's group and originally designed for Alice HLT

# Vectorization



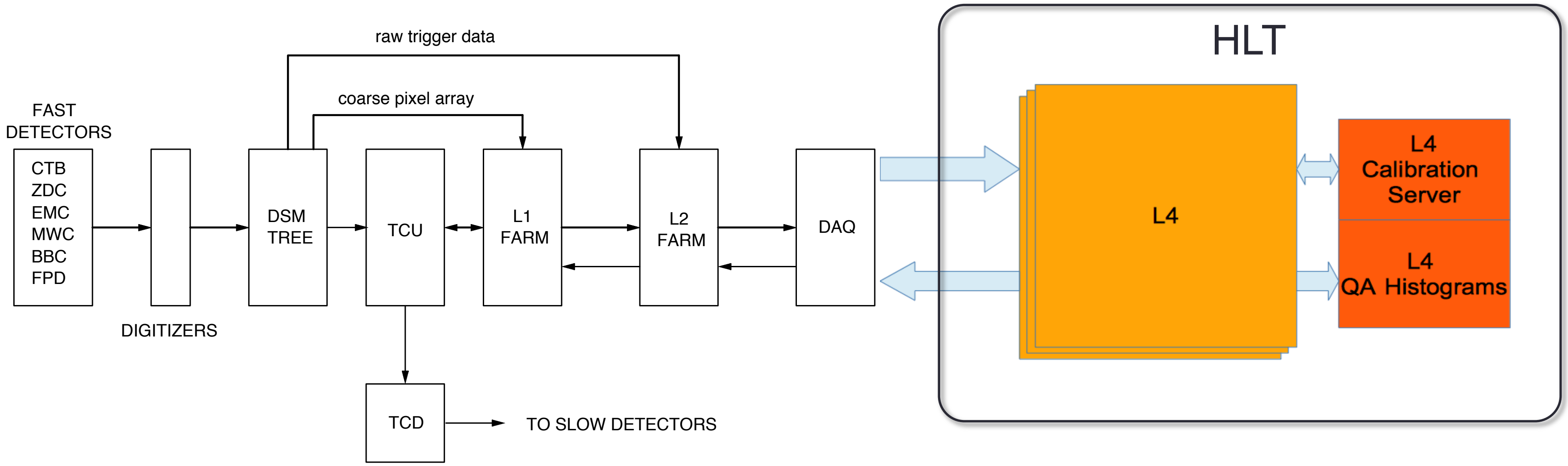




[Intel Develop Zone webinar]

- SIMD becomes important again given new instruction sets and wider registers
- 2 – 8x speed up for single-thread programs
- Both CA Track Finder and Kalman Filter Track Fitter are fully vectorized by using Vc library

Vc Project Homepage: https://github.com/VcDevel/Vc

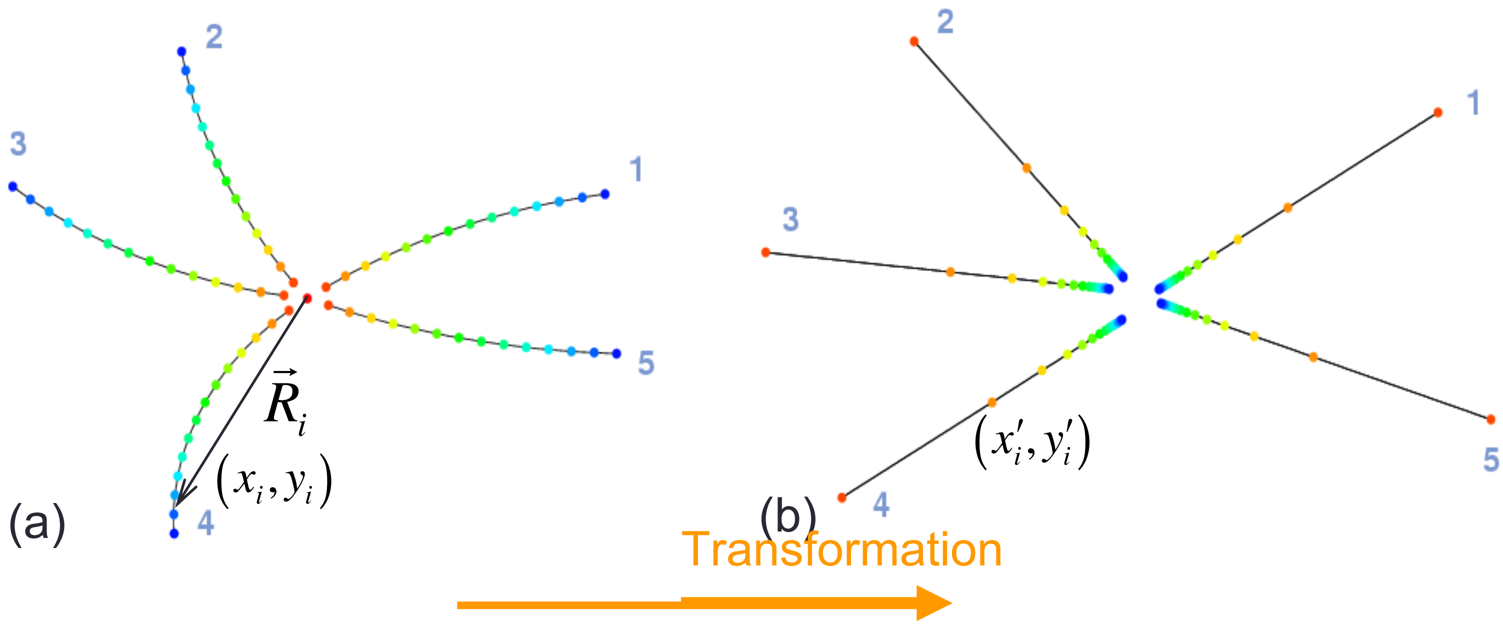
# STAR High-Level Trigger




- STAR HLT uses high performance computers to do real time event reconstruction and analysis
- Provide additional event selection capability based on physics analysis

# HLT Tracking

- Before 2013: Conformal mapping + Least squares fit

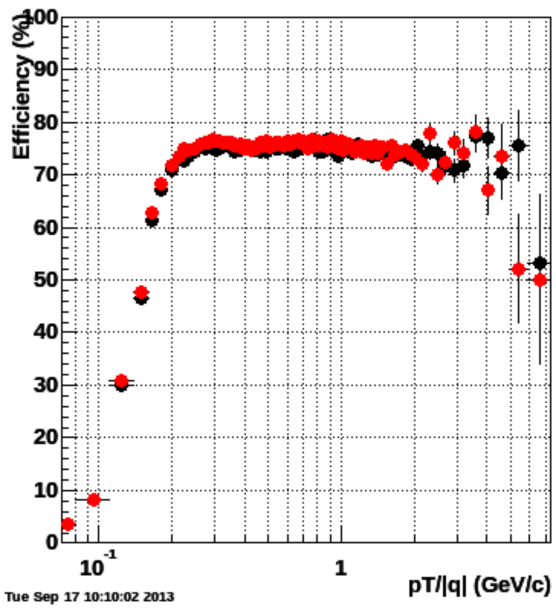


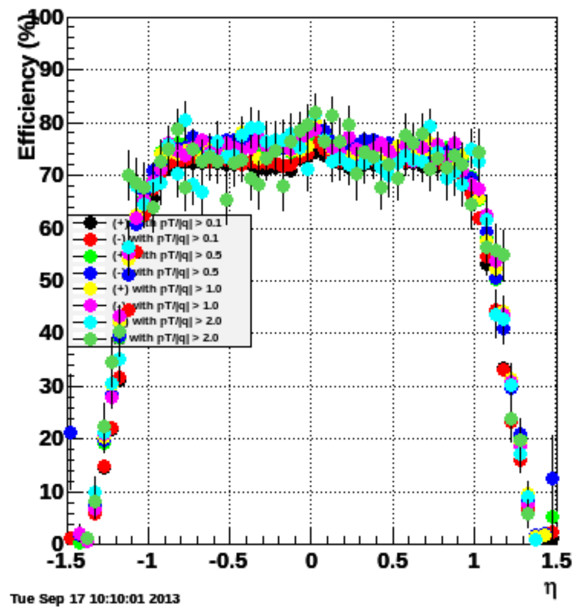

$$x'_i = \frac{x_i}{R_i^2}, y'_i = -\frac{y_i}{R_i^2}$$

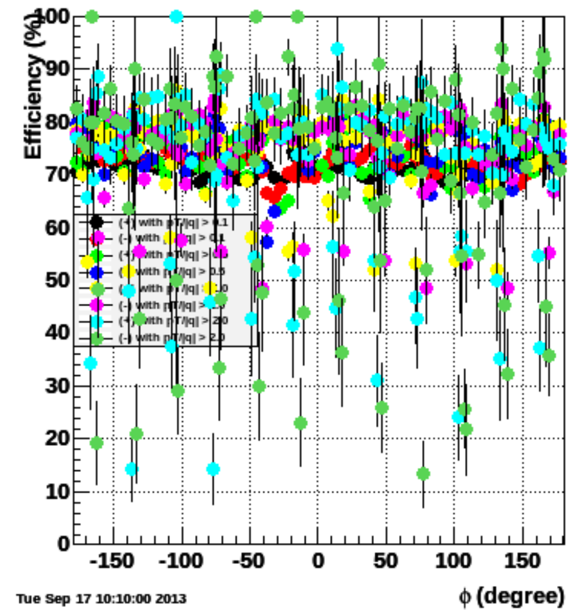
P. Yepes, A fast track pattern recognition, Nucl. Instrum. Meth. A server **380**, 582 (1996)

# HLT Tracking

- 2013+: CA + Kalman filter
- HLT use preliminary calibrations and simplified method to apply correction



# Sti-CA

- STAR integrated tracking (Sti): offline tracker
  - To integrate Silicon detector in reconstruction
  - To use Kalman filter in full scale

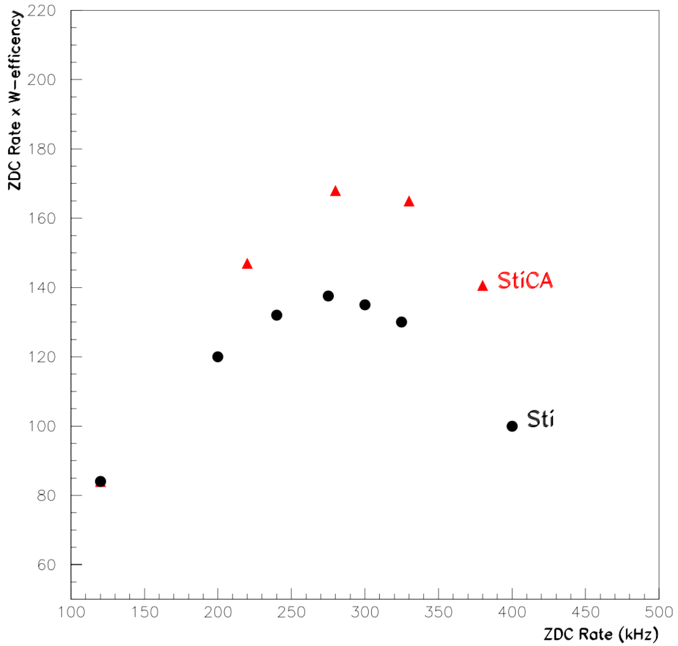
- Room to improve:
  - Speed
  - Tracking efficiency

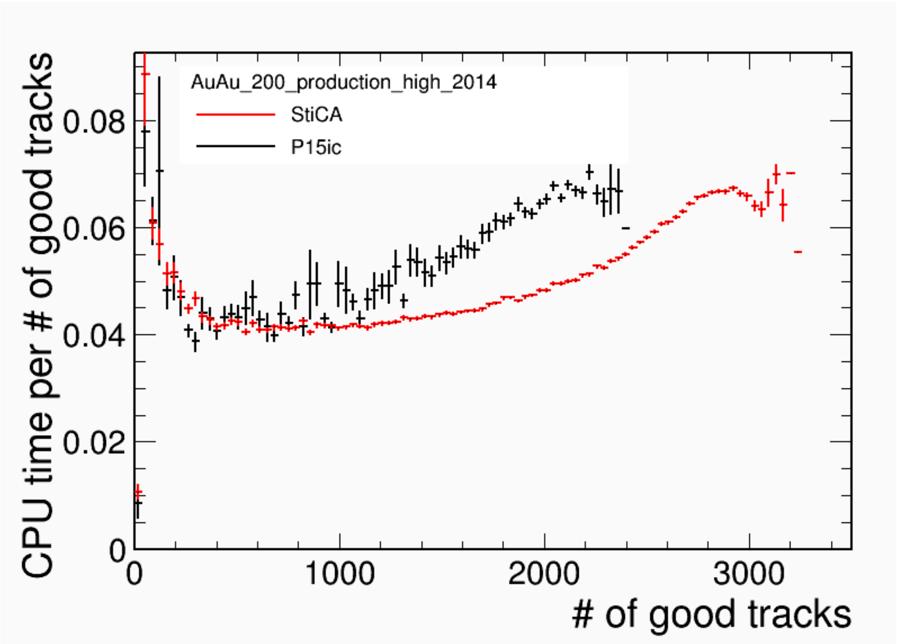
- Sti-CA: Use CA tracks as seeds and refit with Sti to ensure tracking consistency

| (fitted within 0.2–2.1 GeV) | Global tracks | | Primary tracks | |
|---|---|---|---|---|
| | Sti | CA+Sti | Sti | CA+Sti |
| Mult < 200 | 90.3% | 97.7% | 97.3% | 99.3% |
| 200 < Mult < 400 | 90.2% | 97.5% | 97.0% | 99.1% |
| 400 < Mult < 600 | 86.9% | 96.6% | 96.0% | 98.9% |
| Mult > 600 | 84.4% | 96.2% | 95.4% | 98.9% |
| All | 88.1% | 97.1% | 96.4% | 99.1% |

# Sti-CA

- Sti-CA gives 6-12% more tracking efficiency, which is curtail to the STAR HFT program and spin program. The efficiency study also determined the luminosity requirement of STAR to RHIC for the following p+p experiment
- Sti-CA runs about 8% slower per event; but about 13% faster per track because it finds more tracks
- ~70% of the event reconstruction time spend by Sti-CA on TPC tracking, while most of that time still used by Sti track fitting.

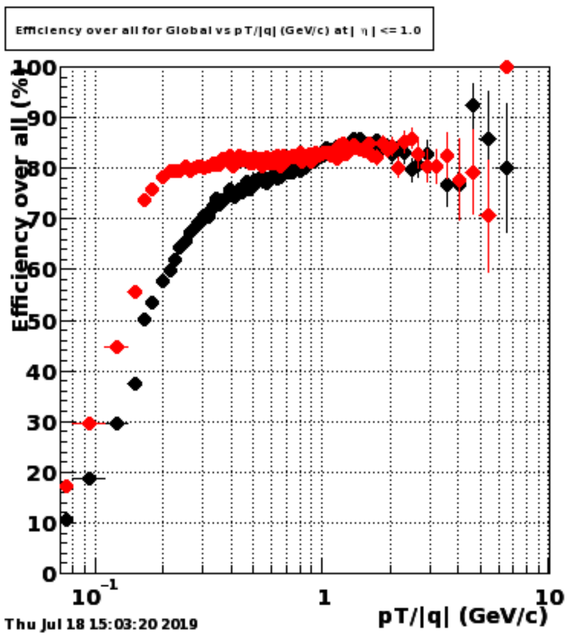


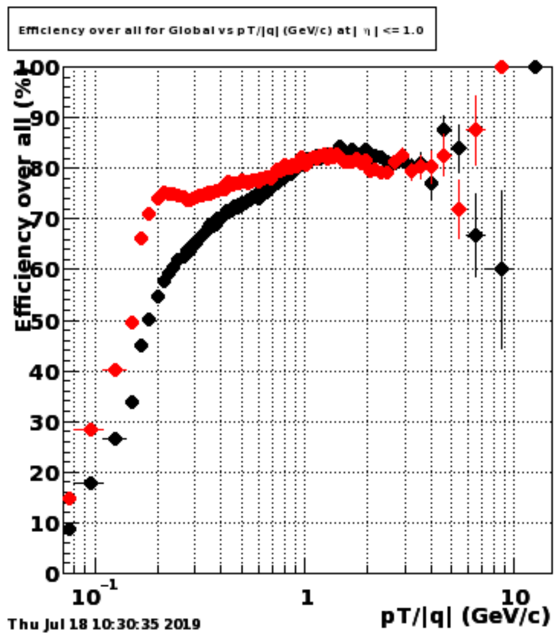
# CA + GenFit

- There is wasted information in StiCA: the track parameters fitted by CA. Use these values as initial values could speed up the fitting process.
- In the long term, we hope to with TPC tracks with other detectors, such as TOF and ETOF.
- We are looking for 2x overall speed up

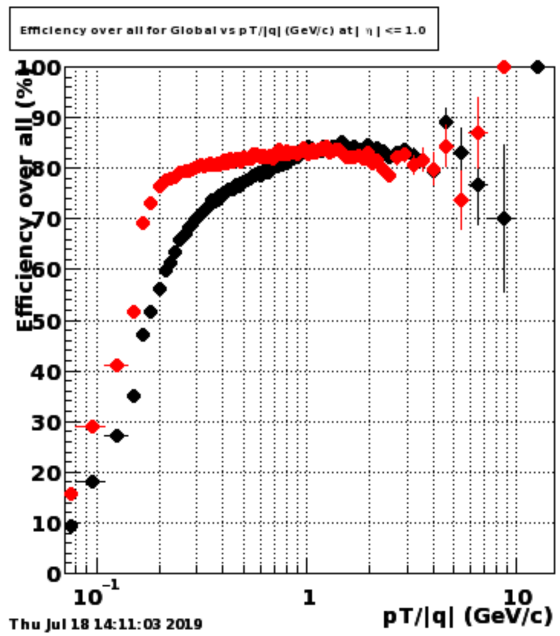
CA + Sti



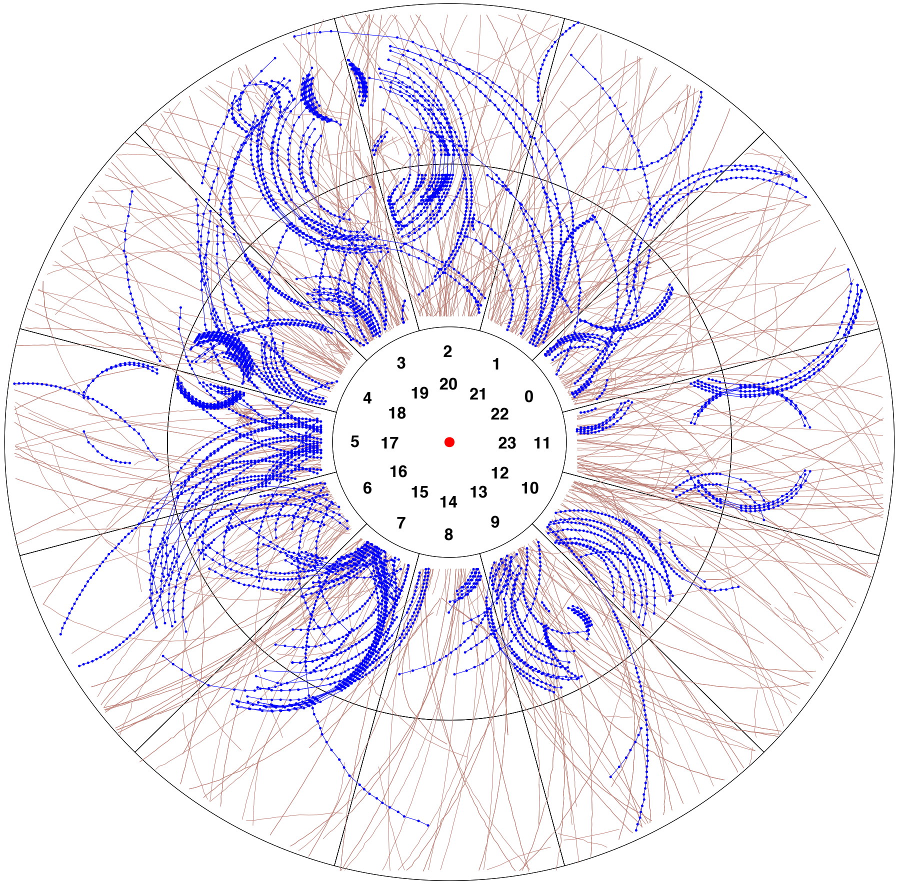

CA + GenFit

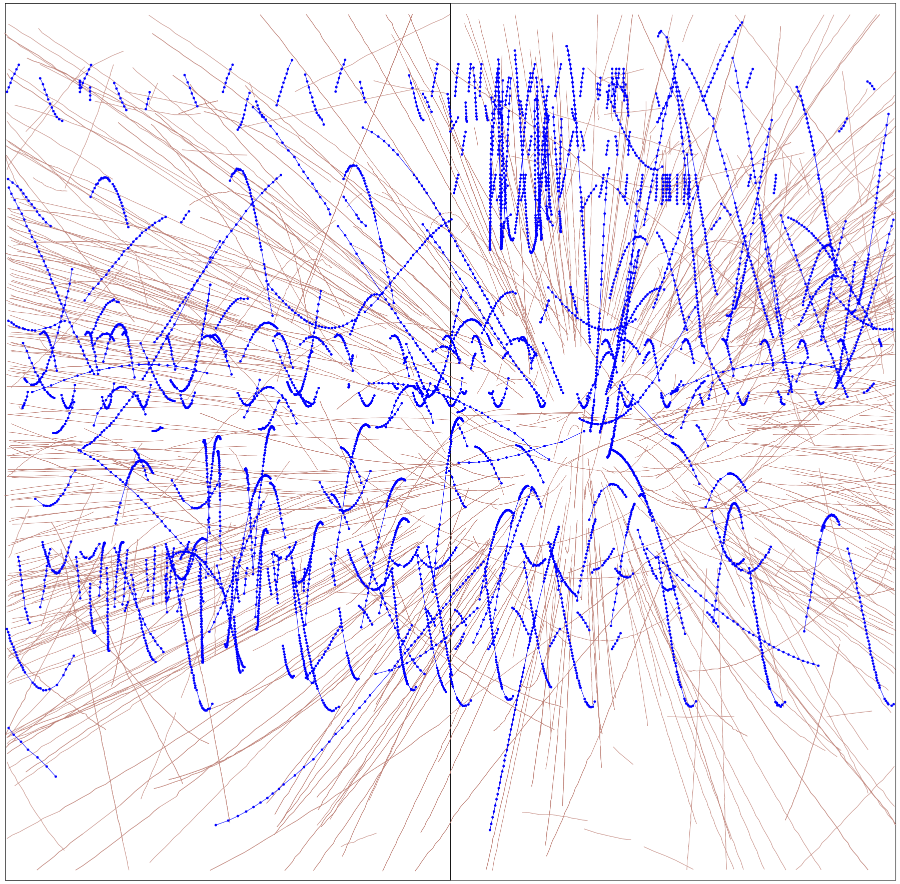



new CA + GenFit



# CA + GenFit

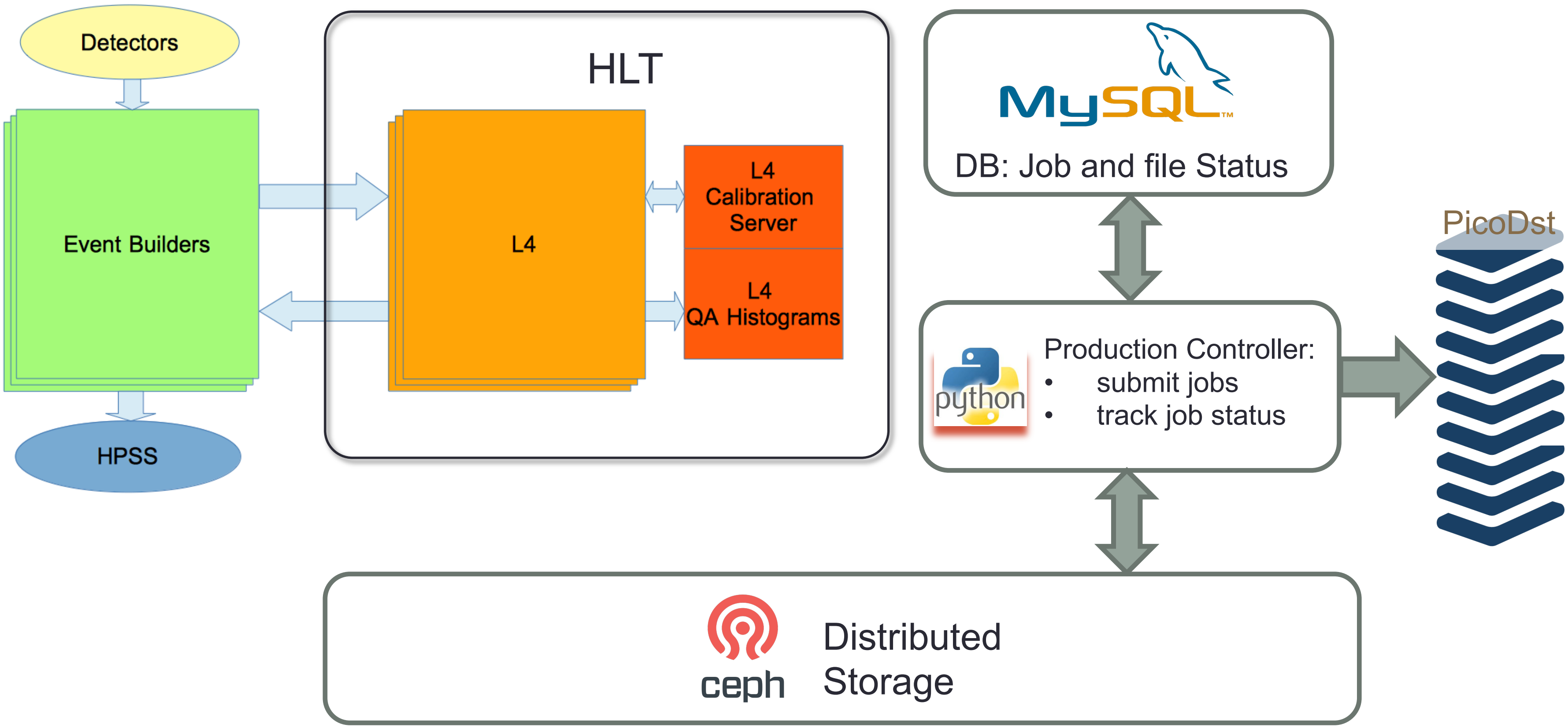


30 loopers / 346 tracks

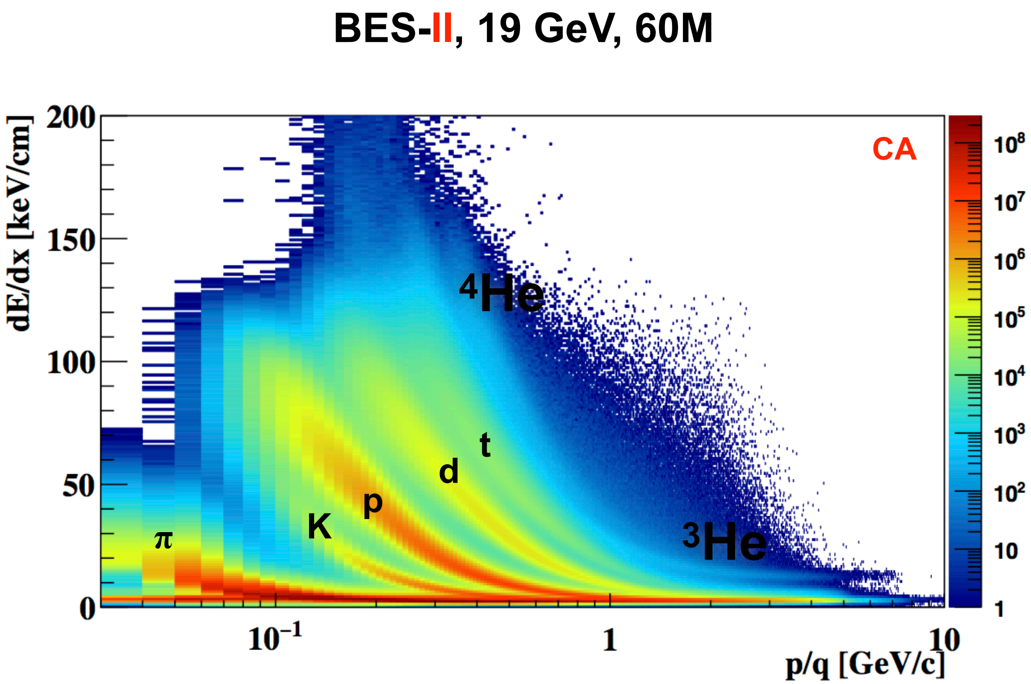
- The CA track finder has been extended to find loopers of low-momentum particles (+ GenFit).
- The resolution of loper problem allows us to increase pseudo rapidity acceptance for track with $p_T < 0.4$ GeV/c.

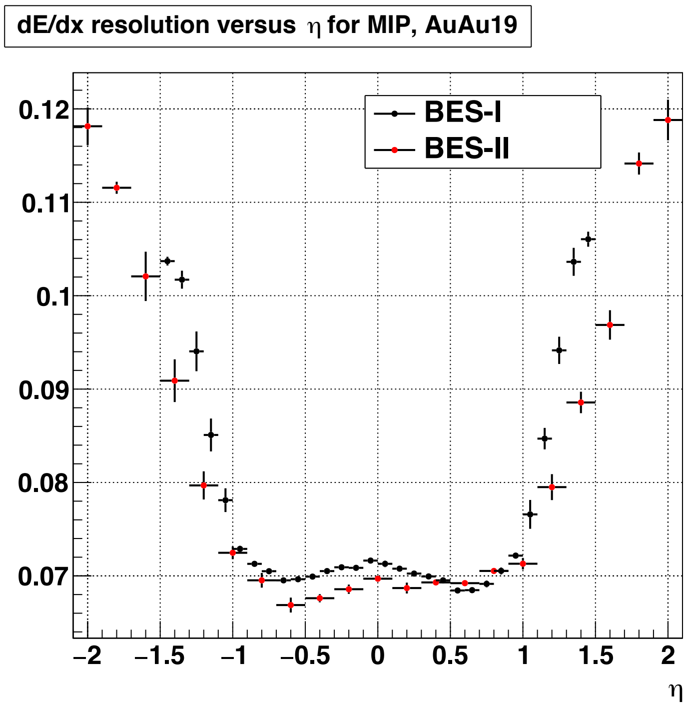
# HLT Express Production in BES-II




- Generate calibrations with a delay of hours
- Produce data with a delay of hours to days

# xCalibration, BES-II

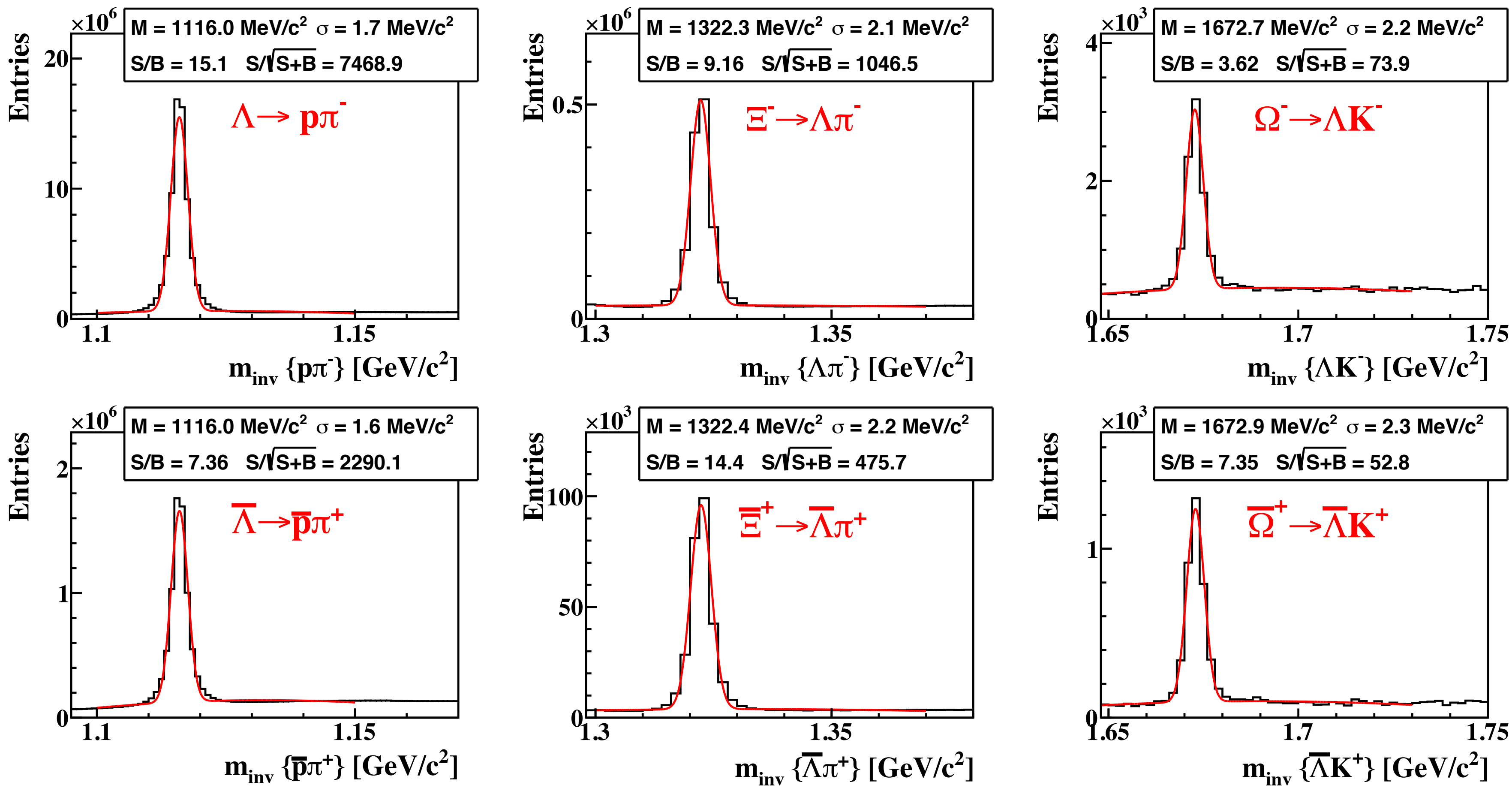



- The HLT expression calibration and production has been running since year 2019
- On average 70% of the data were produced with in 1-2 days after data taking
- Data quality is similar to BES-I

# BES-II: xPhysics

200M AuAu events at 14.5 GeV, 2019 BES-II express production




- Wthe express calibration and alignment we reconstruct hyperons with high significance and low level of background.
- Hyperons are clearly seen at all BES-II energies: 3, 3.2, 3.9, 7.7, 9.1, 14.5, 19.6, 27 GeV.
  High significance allows extraction of spectra.

# Summary

- STAR has been using CA tracker for about 10 years
- Successful application on both online and offline computing
- Fast, reliable and precise HTL is critical to STAR BES-II program and we provided that by applying CA and other technologies
- The express calibration and production mode has been demonstrated in year 2019 and running now. It provided us timely calibrations and early access to physics results.