

Tracking with Cellular Automaton at STAR

Hongwei Ke

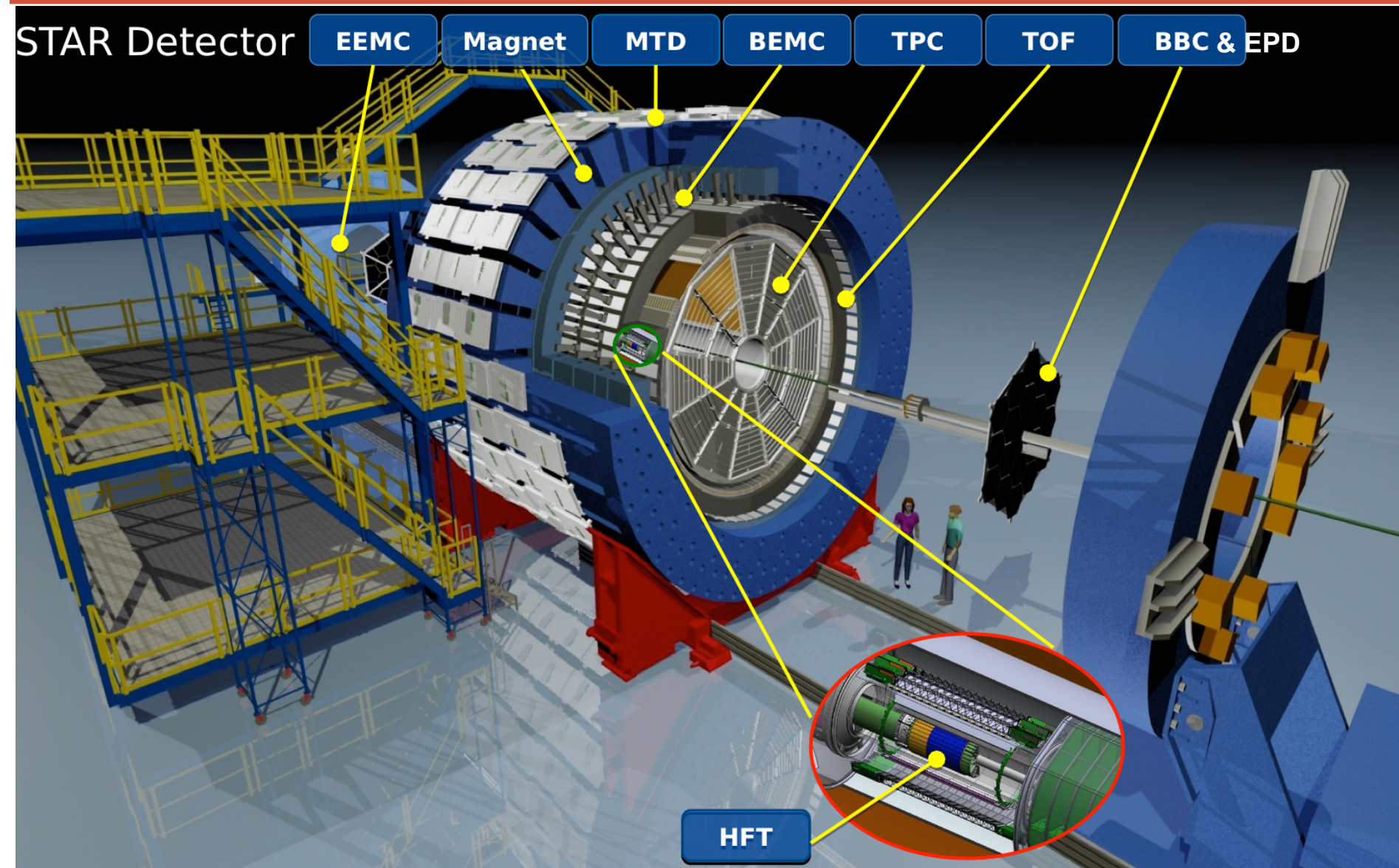
Brookhaven National Laboratory

With contributions from:

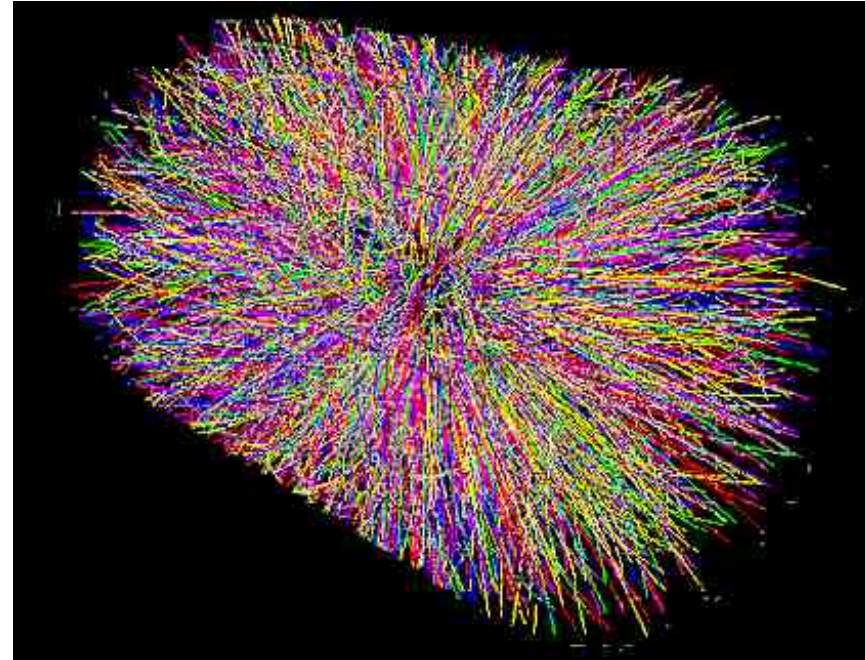
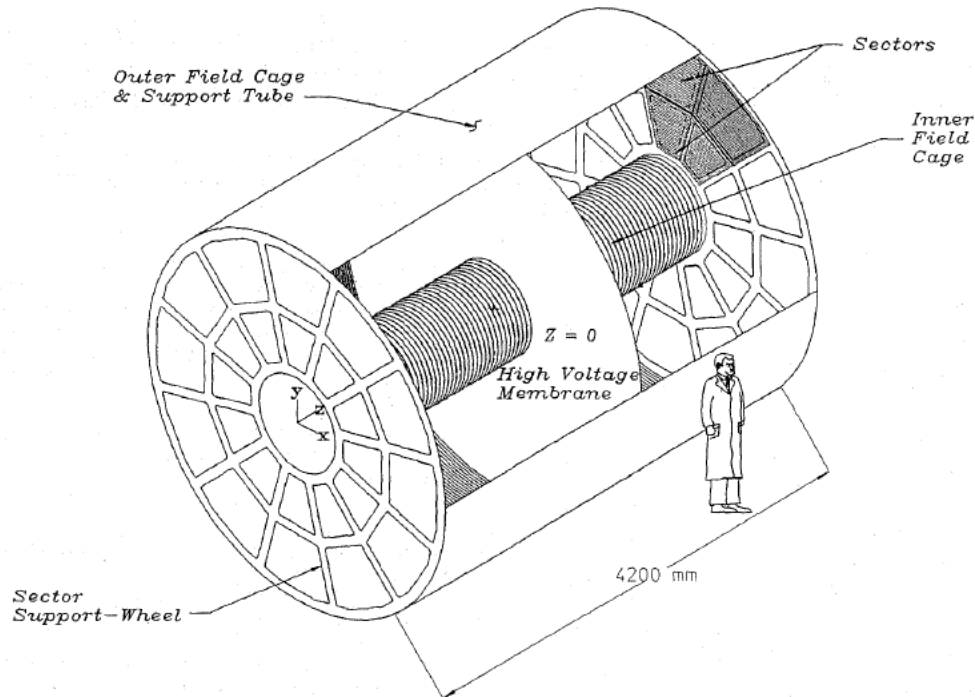
Maksym Zyzak, Ivan Kisel, Yuri Fisyak and Grigory Kozlov

- Overview
- CA at STAR High-Level Trigger
- CA + Sti in STAR offline software
- CA in express production

STAR Detector

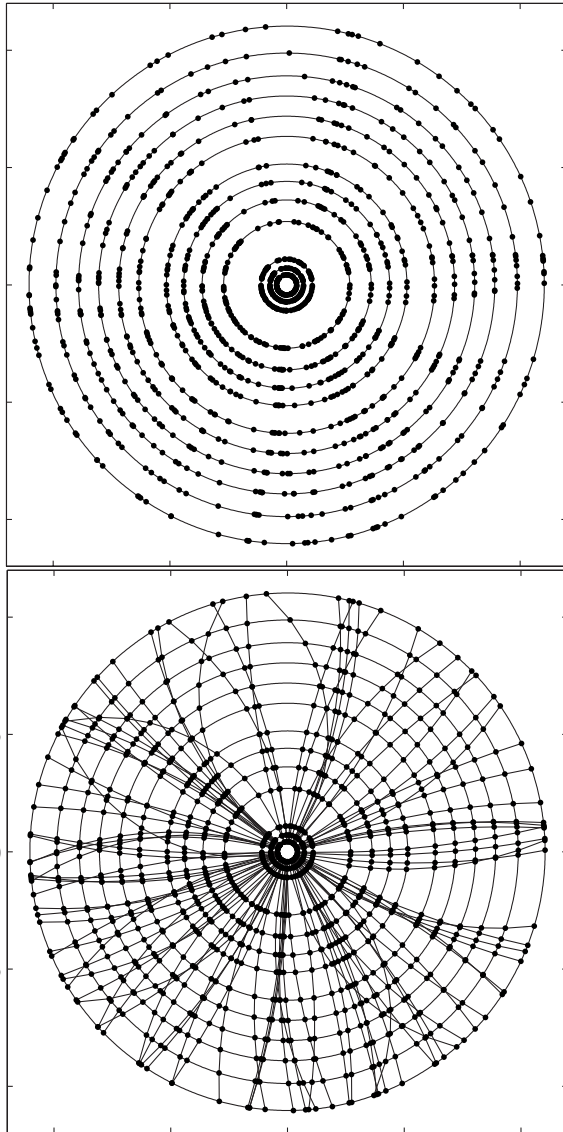


STAR Time Projection Chamber

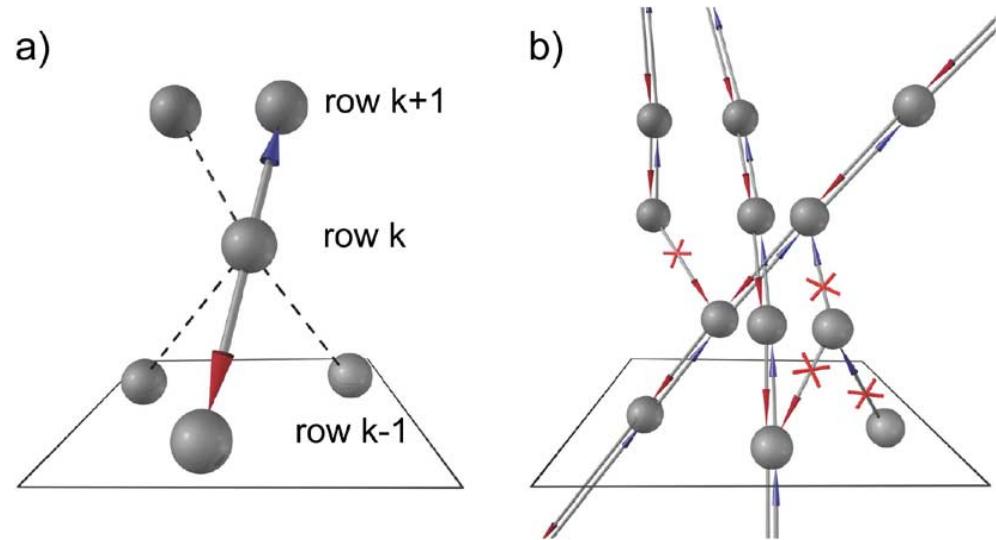


- TPC is the main tracking detector of STAR
- Each half has 12 sectors
- Each sector has 45 pad-rows, 72 pad-rows after inner TPC upgrade since 2019
- Cover full azimuthal angle and $|\eta| < 1.5$
- Provide tracking and PID based on ionized energy lost
- The whole detector is put in a homogeneous magnetic field, $\vec{B}_z = 0.5\text{T}$

Cellular Automaton Track Finding



RevModPhys.82.1419

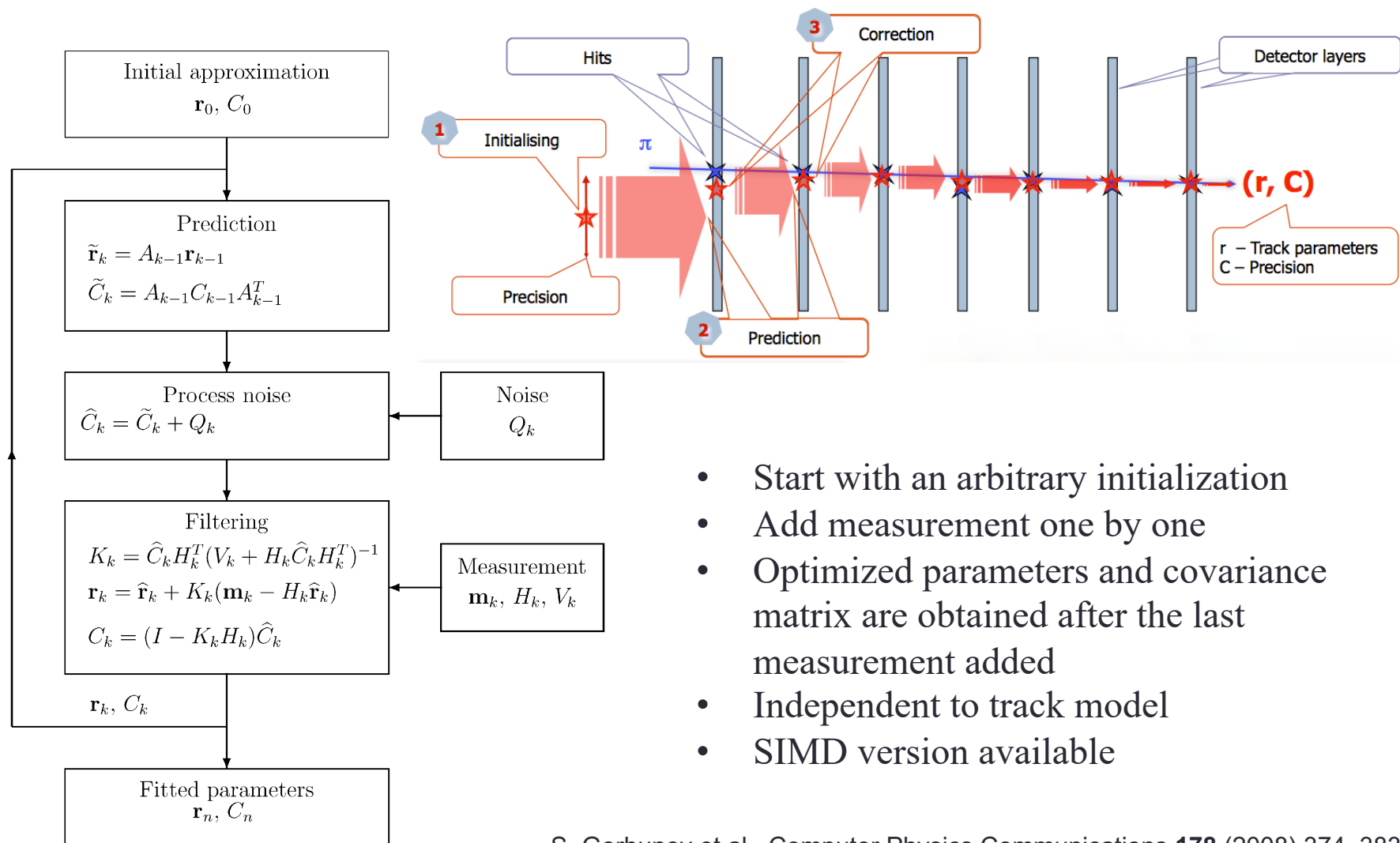


a) Neighbors finder. b) Evolution step of the Cellular Automaton.

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

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

Kalman Filter Track Fitting

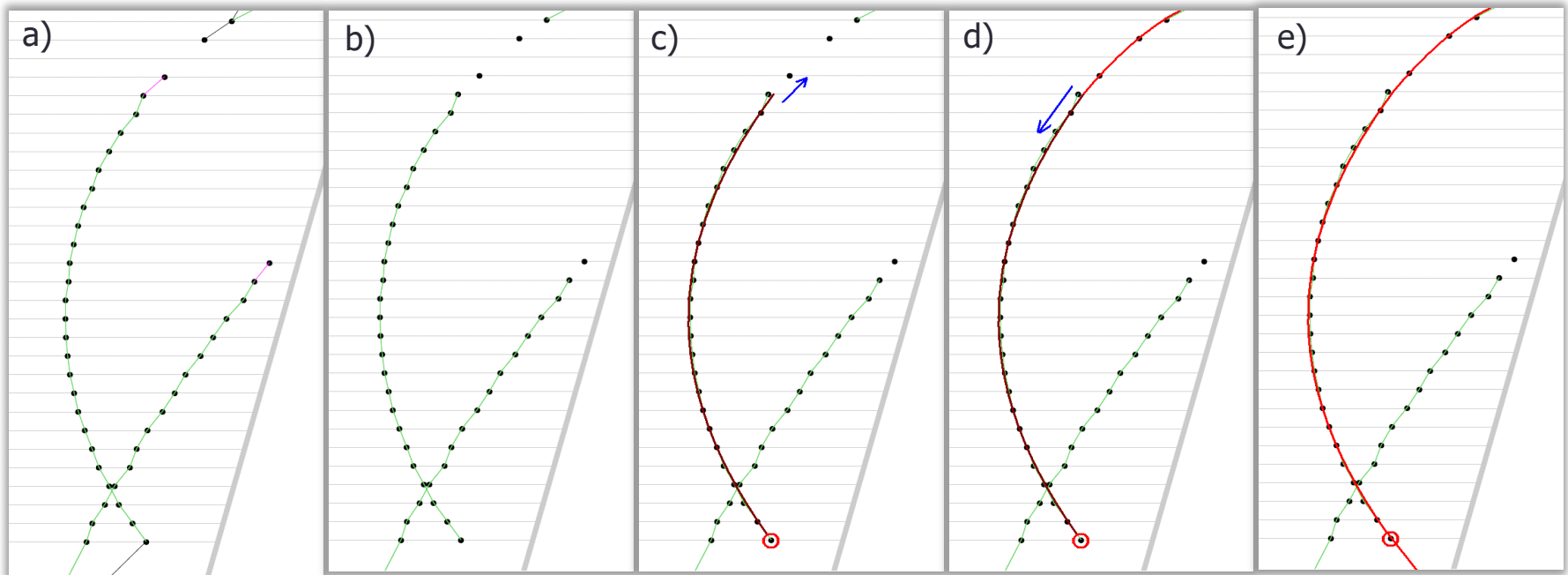


- Start with an arbitrary initialization
- Add measurement one by one
- Optimized parameters and covariance matrix are obtained after the last measurement added
- Independent to track model
- SIMD version available

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

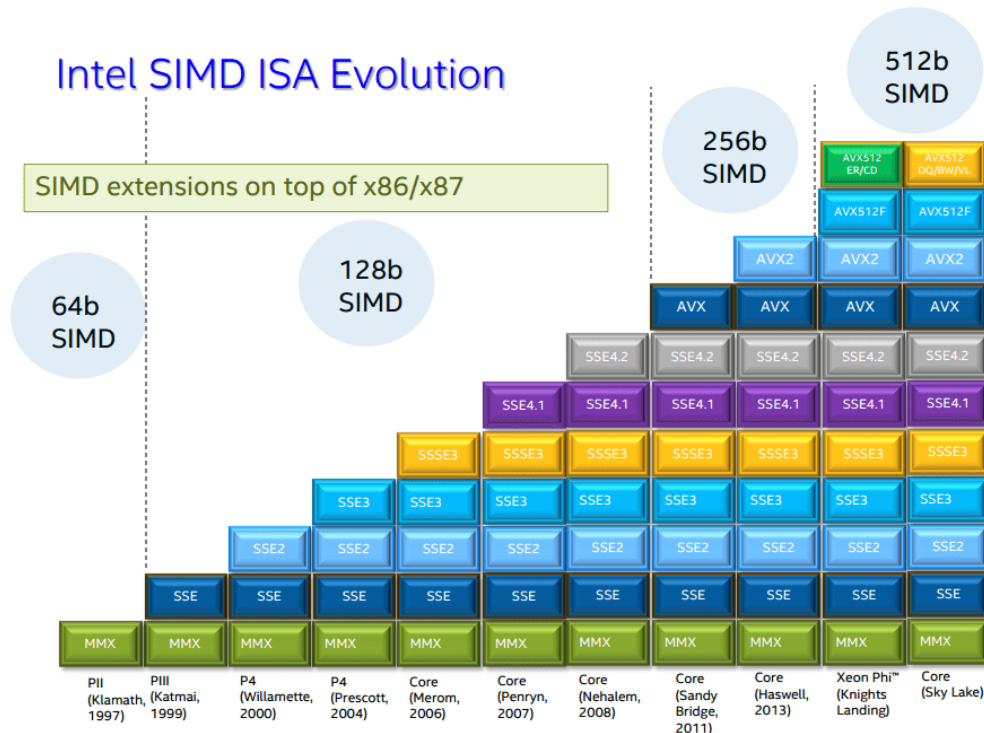
CA Tracker

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

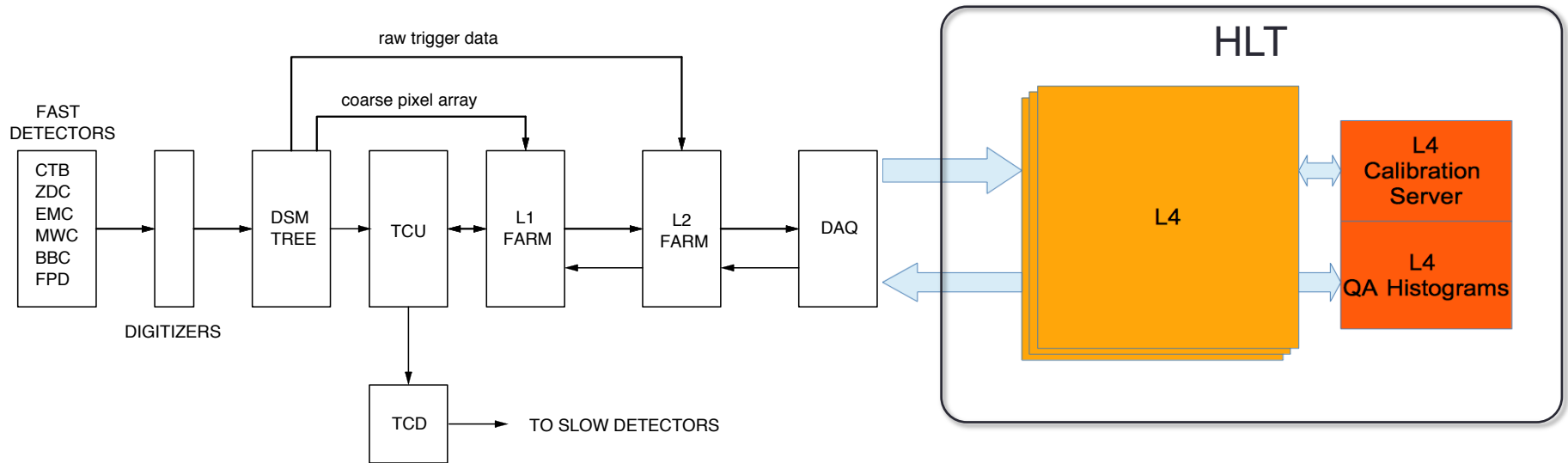
Vectorization



- 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: <https://github.com/VcDevel/Vc>

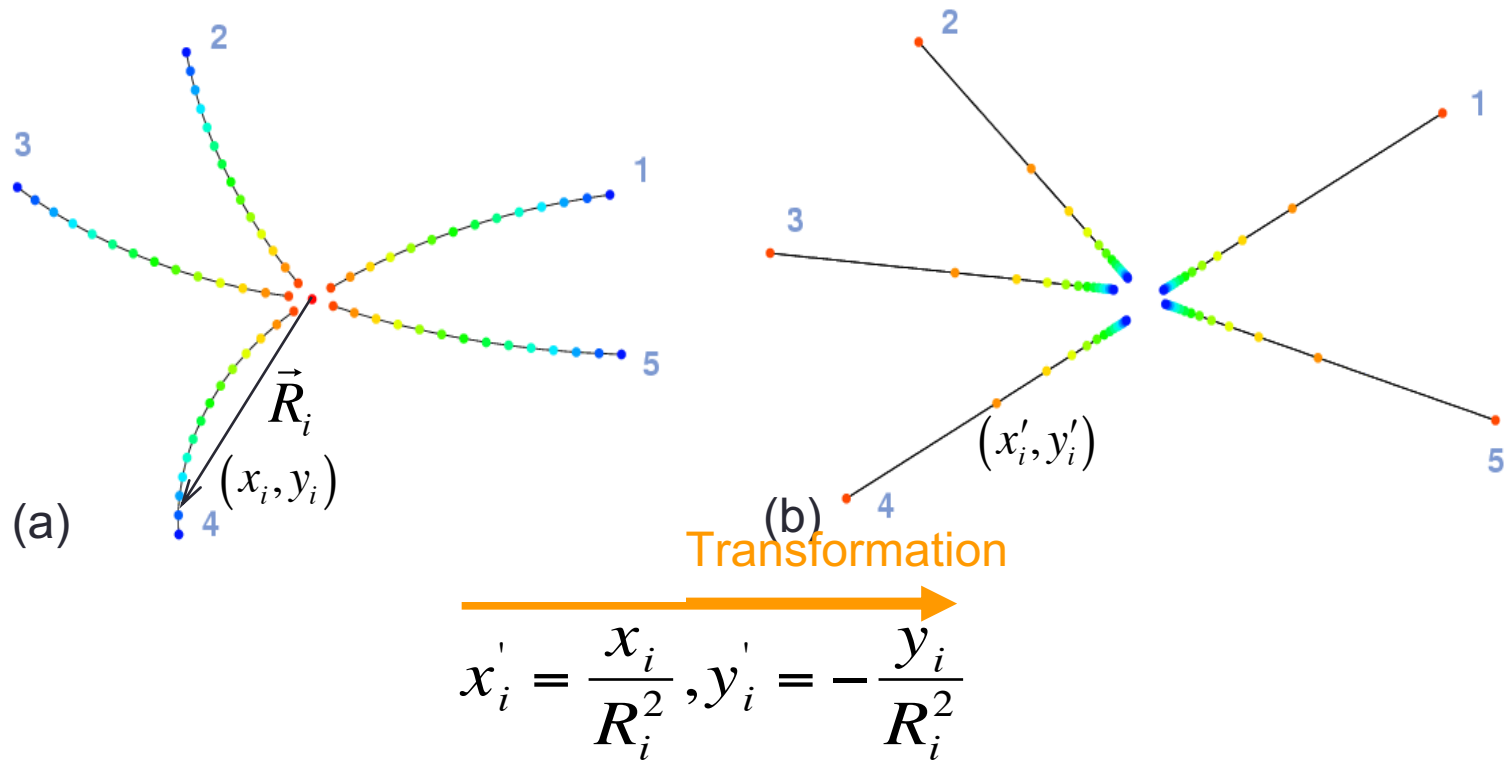
STAR High-Level Trigger



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

HLT Tracking

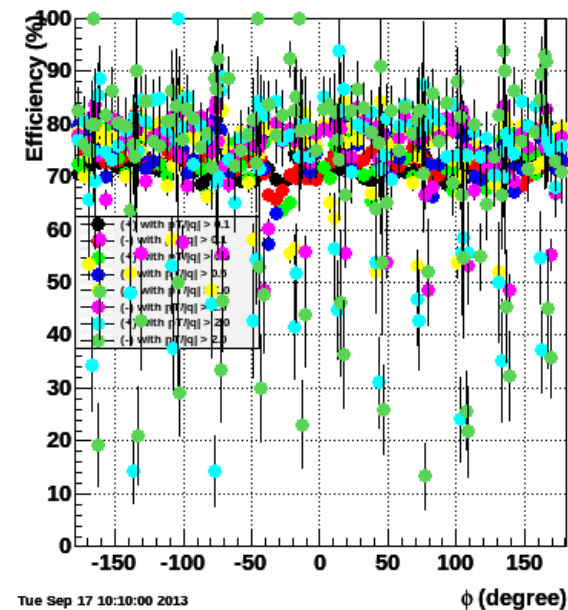
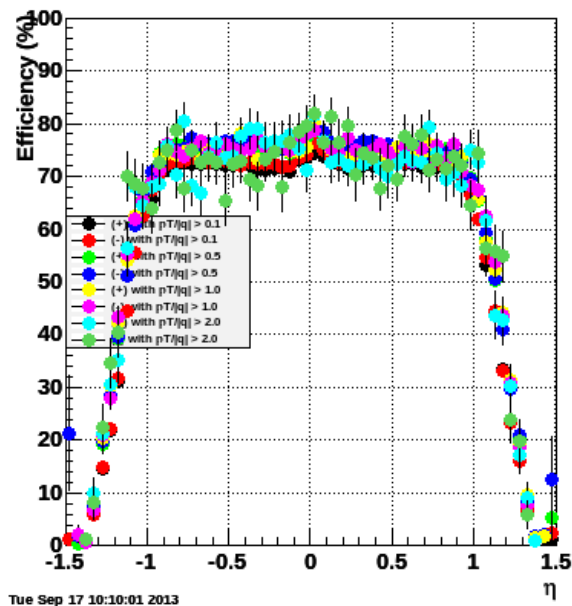
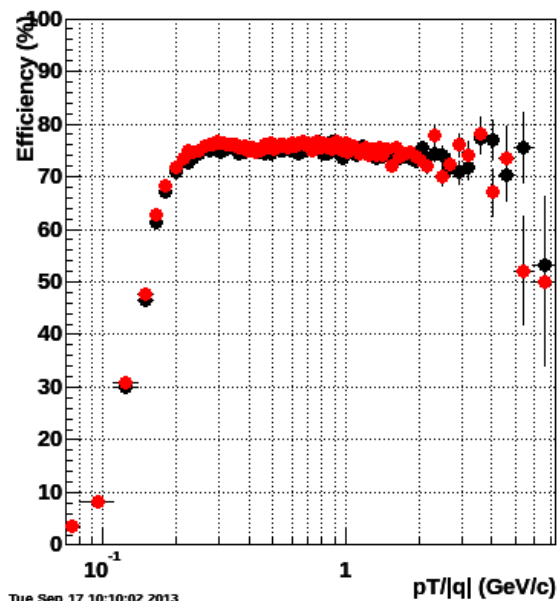
- Before 2013: Conformal mapping + Least squares fit



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



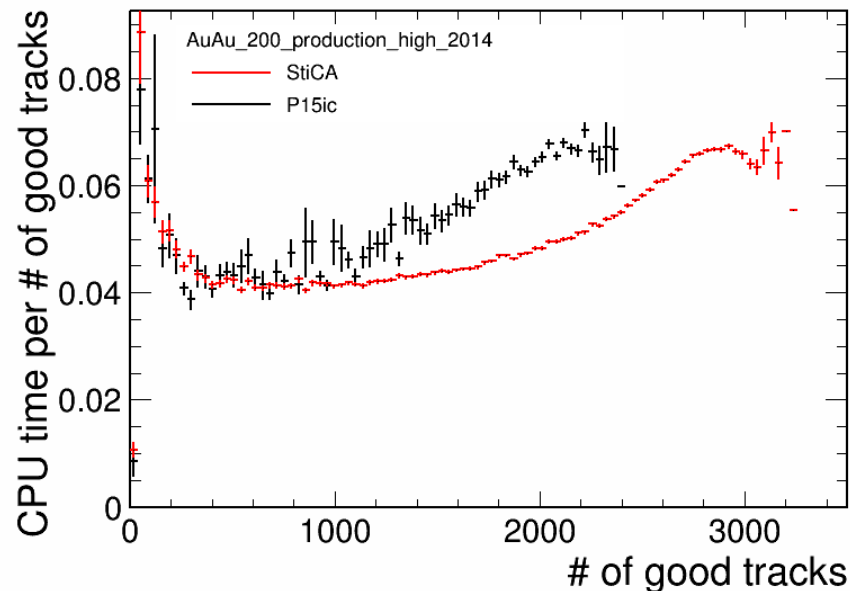
STAR Offline Tracking: Sti-CA

- STAR integrated tracking (Sti): track finding and fitting
 - 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%

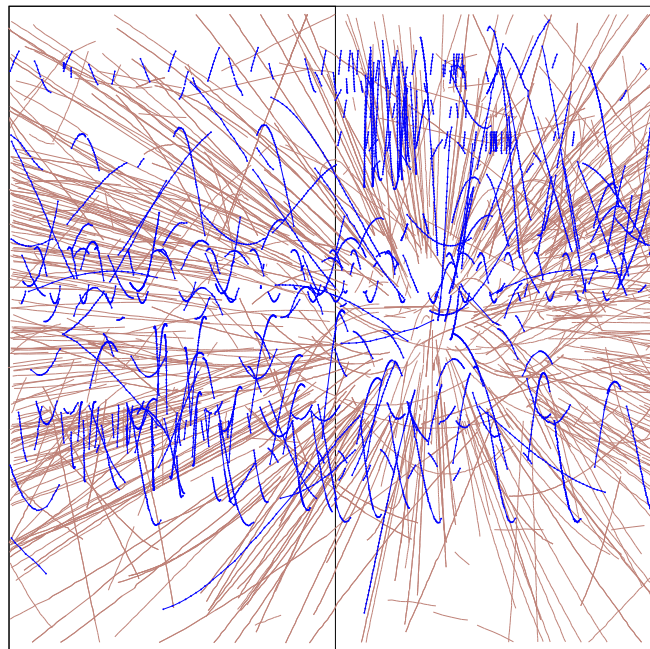
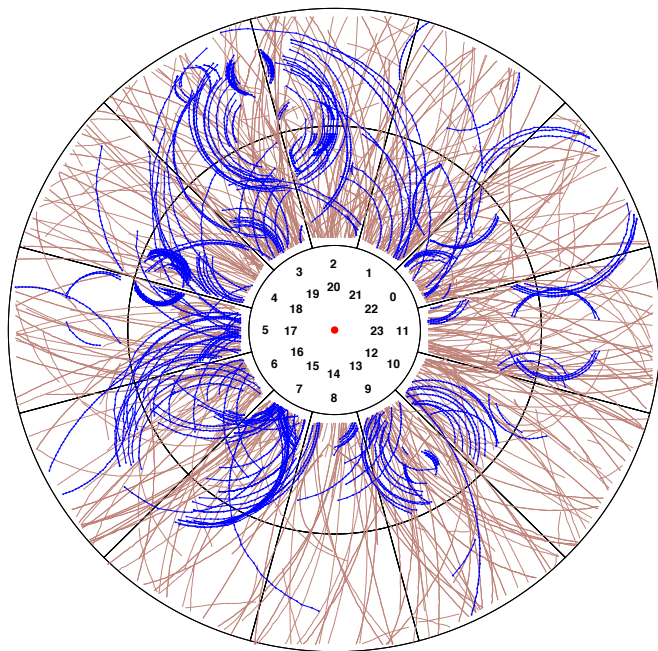
Sti-CA

- Sti-CA gives 6-12% more tracking efficiency, which is crucial to the STAR HFT program and spin program.
- 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.

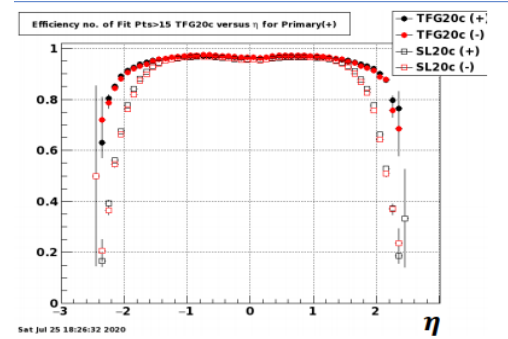
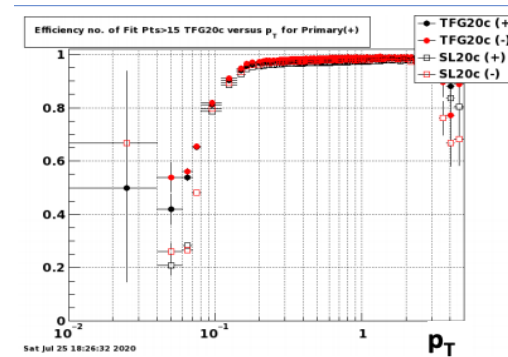


Extend CA to very low p_T

Most recent development:

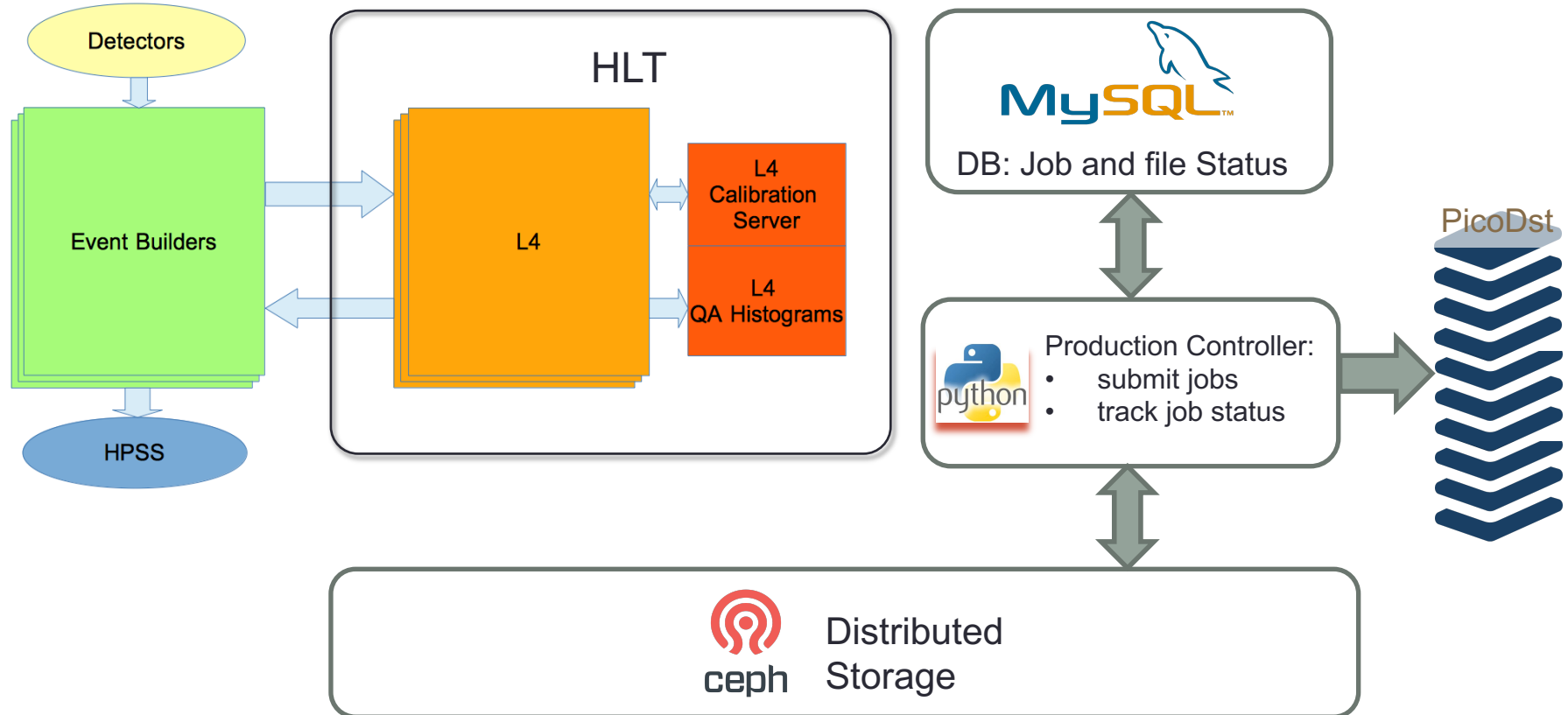


30 loopers / 346 tracks



- The CA tracker is recently to reconstruct loopers by merging very low p_T track fragments ($p < 200\text{MeV}$)
- The loopers reconstruction extend our acceptance at low p_T and high η
- This development is under evaluation before been put in production

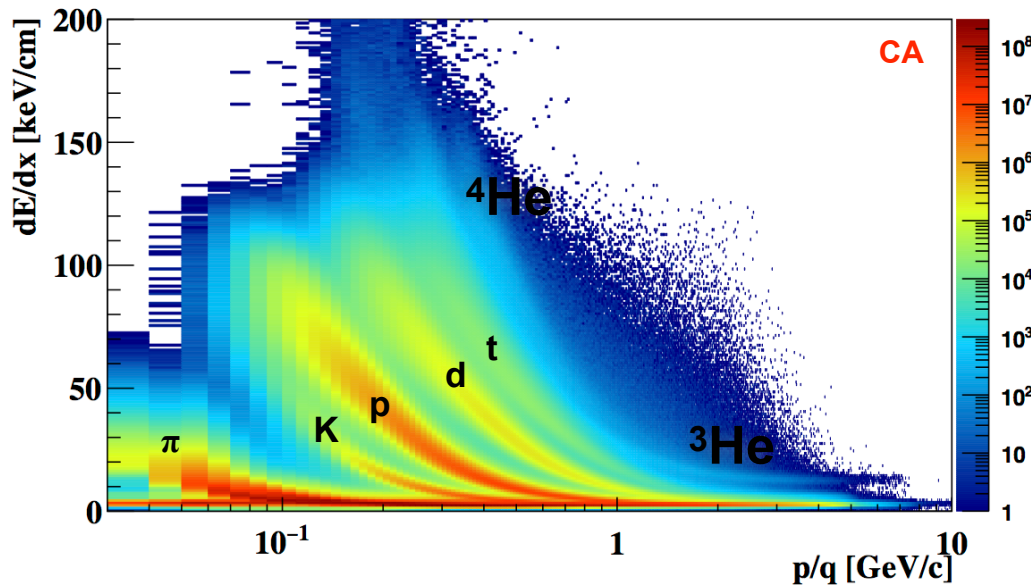
HLT Express Production in BES-II



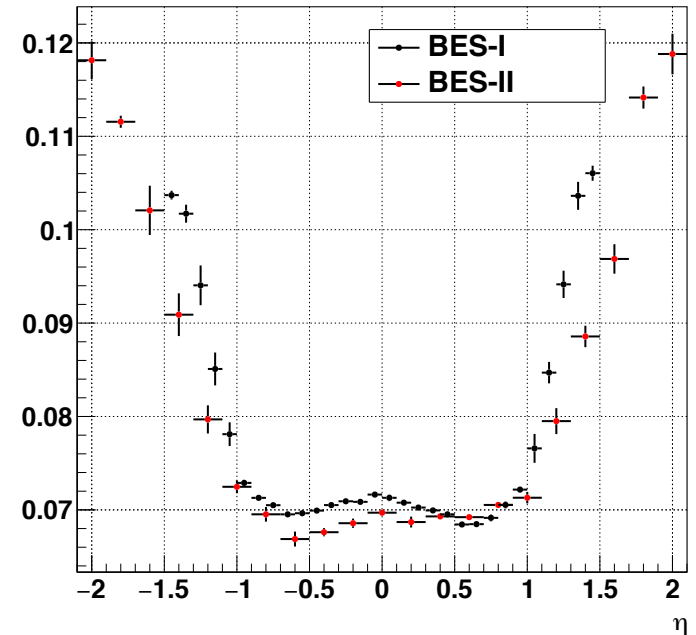
- Generate calibrations with a delay of hours
- Produce data with a delay of hours to days

xCalibration, BES-II

BES-II, 19 GeV, 60M



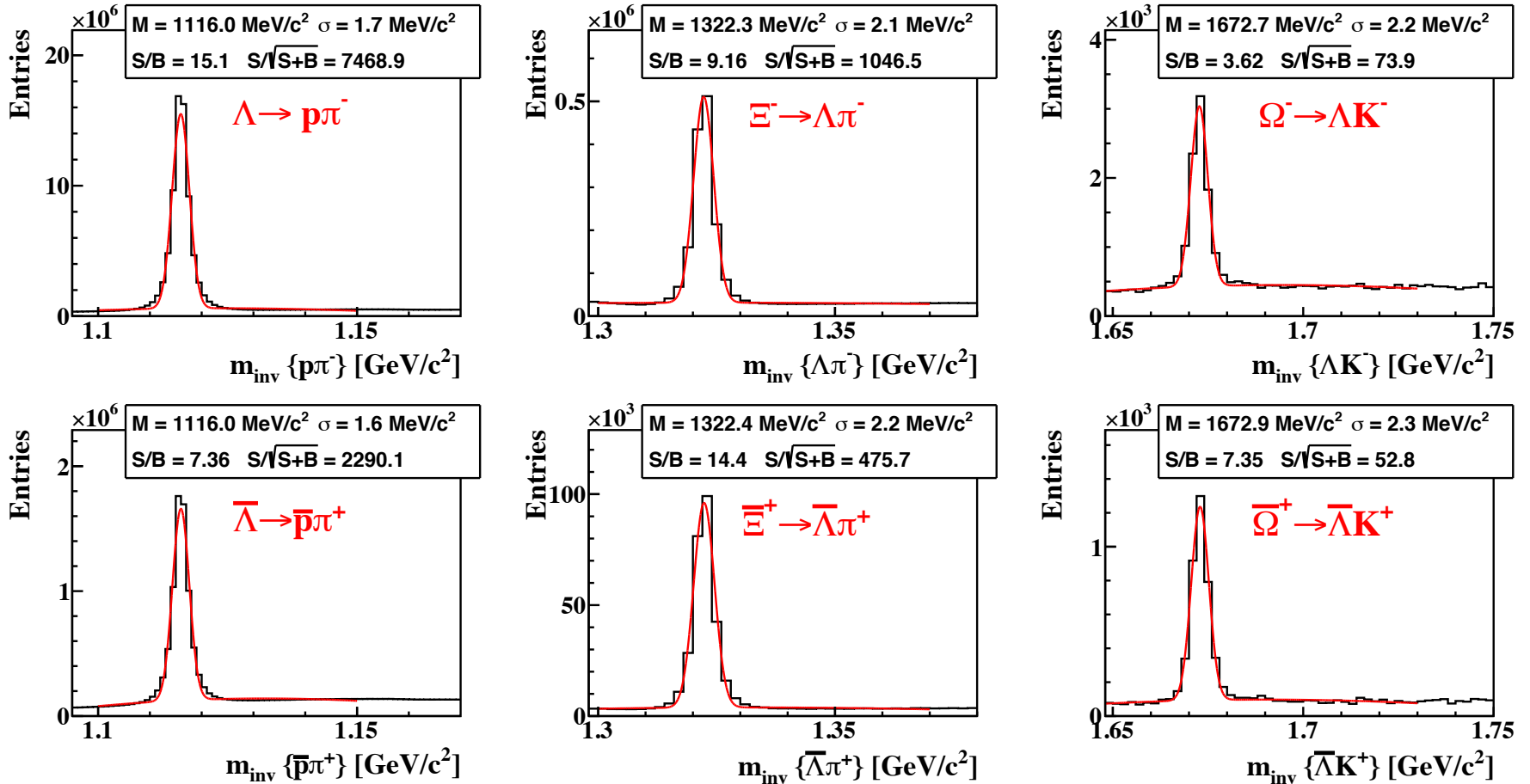
dE/dx resolution versus η for MIP, AuAu19



- 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

BES-II: xPhysics

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



- With express calibration we reconstruct **hyperons** with **high significance** and **low level of background**.
- Allow for data quality check and quick physics analysis.

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 2020. It provided us timely calibrations and preview of physics results.