STAR High Level Tracking Trigger Upgrade and Physics Opportunities

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Outline

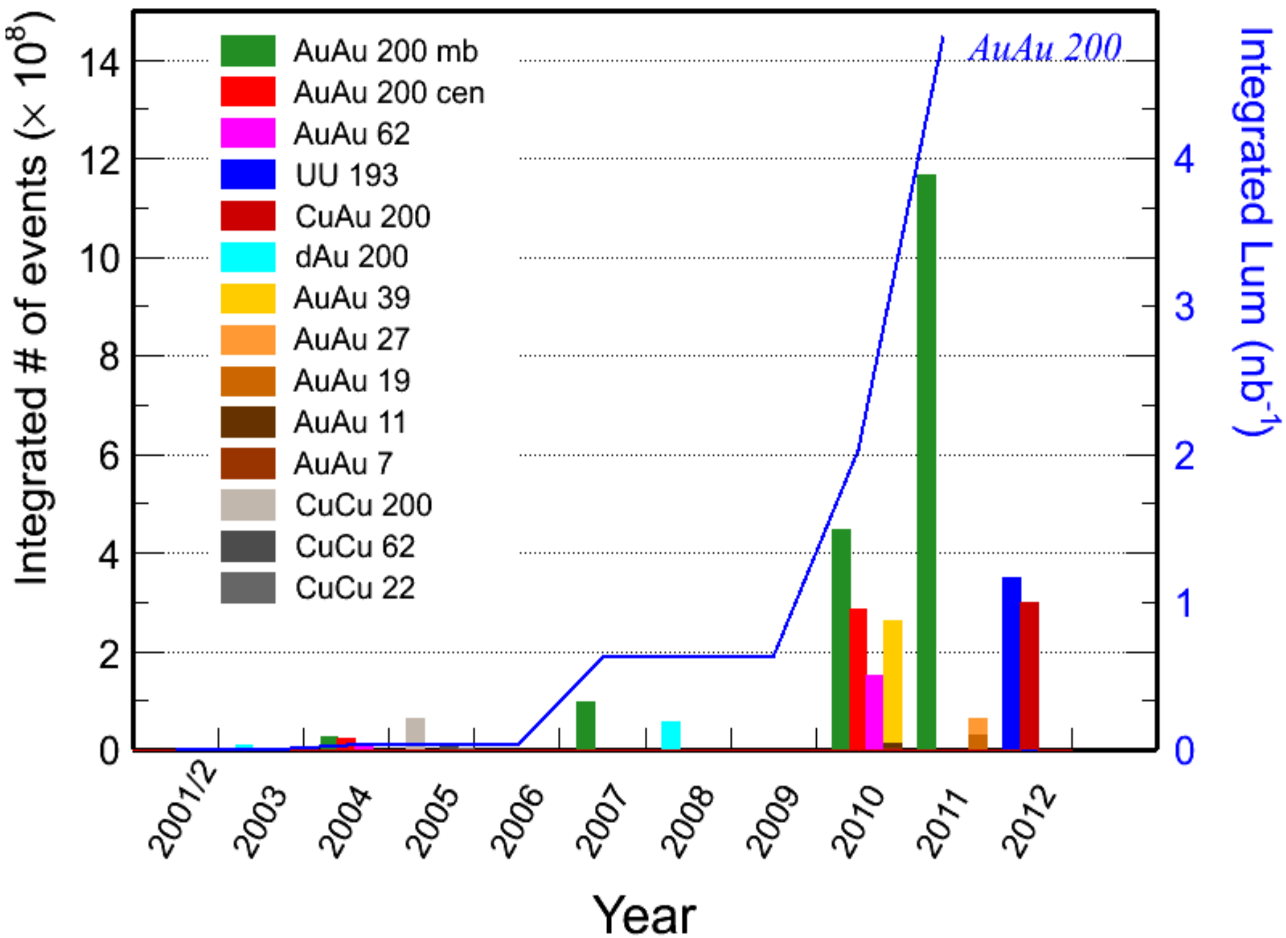
• Why we do it ? – HLT motivations.

• How we do it ? – HLT layout.

• What we have achieved ? – HLT performance and achievements.

• What is the plan for the future ? – HLT upgrade plan and new physics opportunities.

HLT motivations – the increasing date volume at STAR



HLT motivations – the increasing challenge on computing

How to digest timely ?

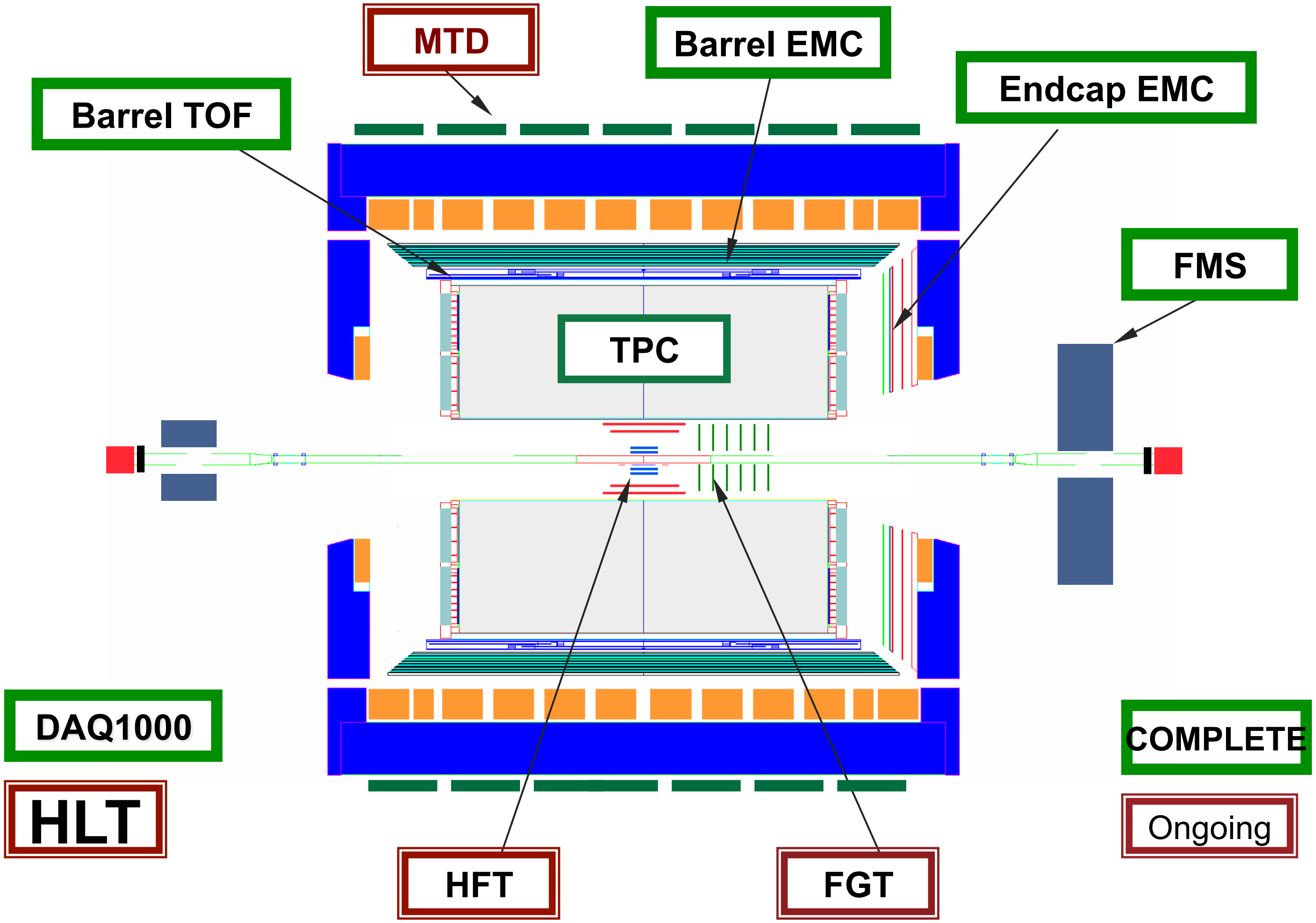
• The improved data taking capability imposes a challenge for STAR on:

1) computing resource in terms of CPU time and tape storage.

2) for analyzers, struggle with large data volume and bear with long analysis cycle.

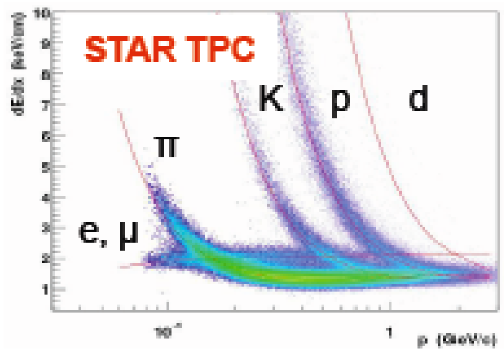
• By implementing a HLT it will be possibly to reduce the amount of data written to tape by selecting desired events while still maintaining a high sampling rate to fully utilize the high DAQ rate for a wide range of triggers.

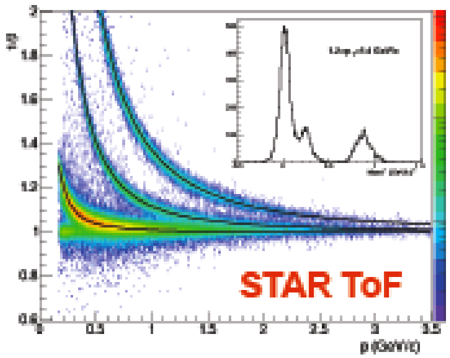
STAR Subsystems

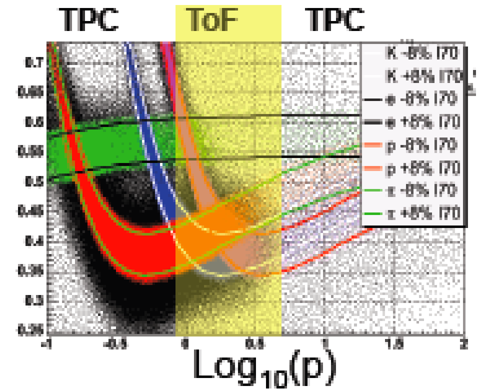


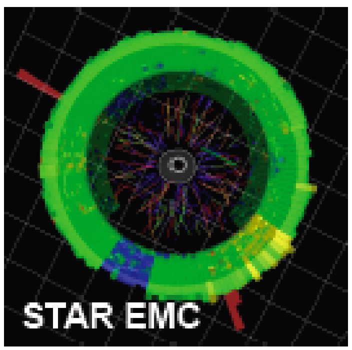
Large & uniform acceptance at mid-rapidity
Excellent particle identification
Fast data acquisition

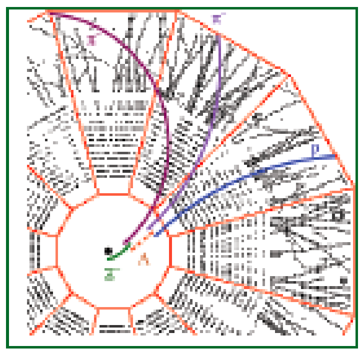
HLT motivations – optimize the potential of subsystems

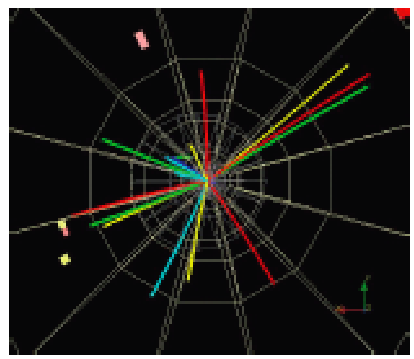


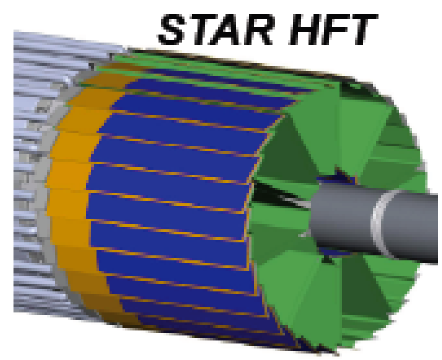












Neutral particles | **Strange hyperons** | **Jets** | **Heavy Quark Hadrons**

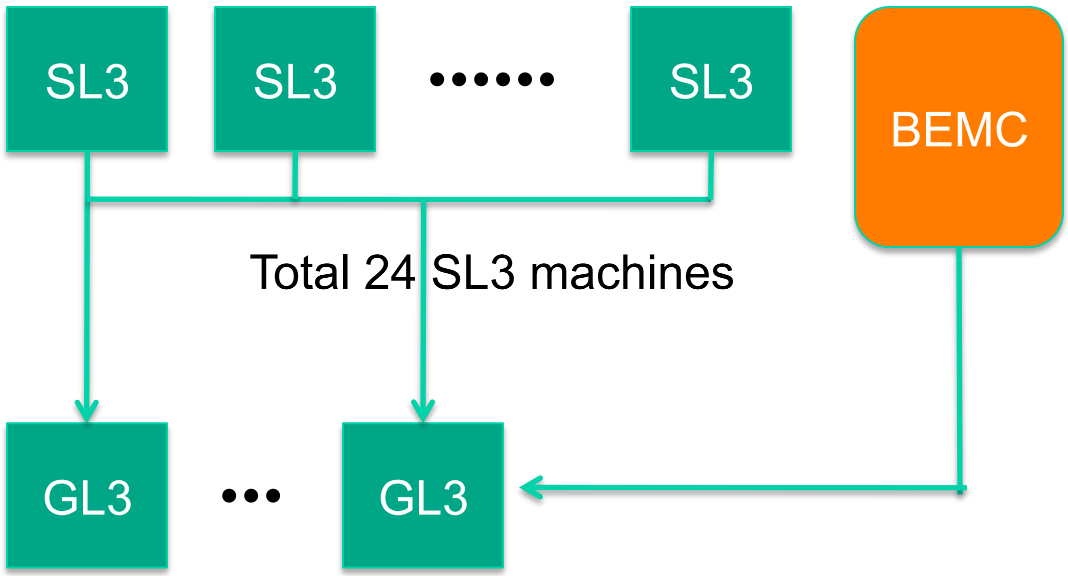
STAR has excellent PID and tracking capability,
can we take advantage of its full potential efficiently ?

HLT motivations – efficiently address interesting physics

- Heavy flavor measurement
- Electricmagnetic probe
- High pt probe
- Search for exotics

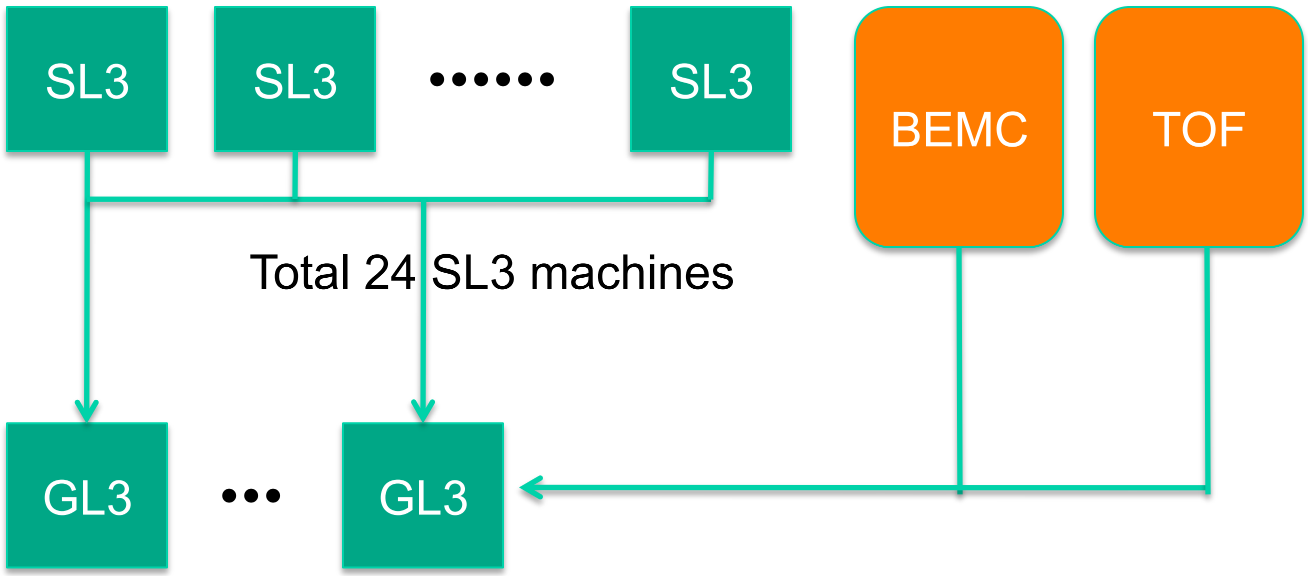
A platform for exploring interesting physics ideas.

HLT layout in 2009



•Sector level-3 tracking (SL3) in DAQ machines (24 in total, each for a TPC sector).
•Information from subsystems (SL3 and others) are sent to Global L3 machines (GL3) where an event is assembled and a trigger decision is made.

HLT layout in 2010-2012



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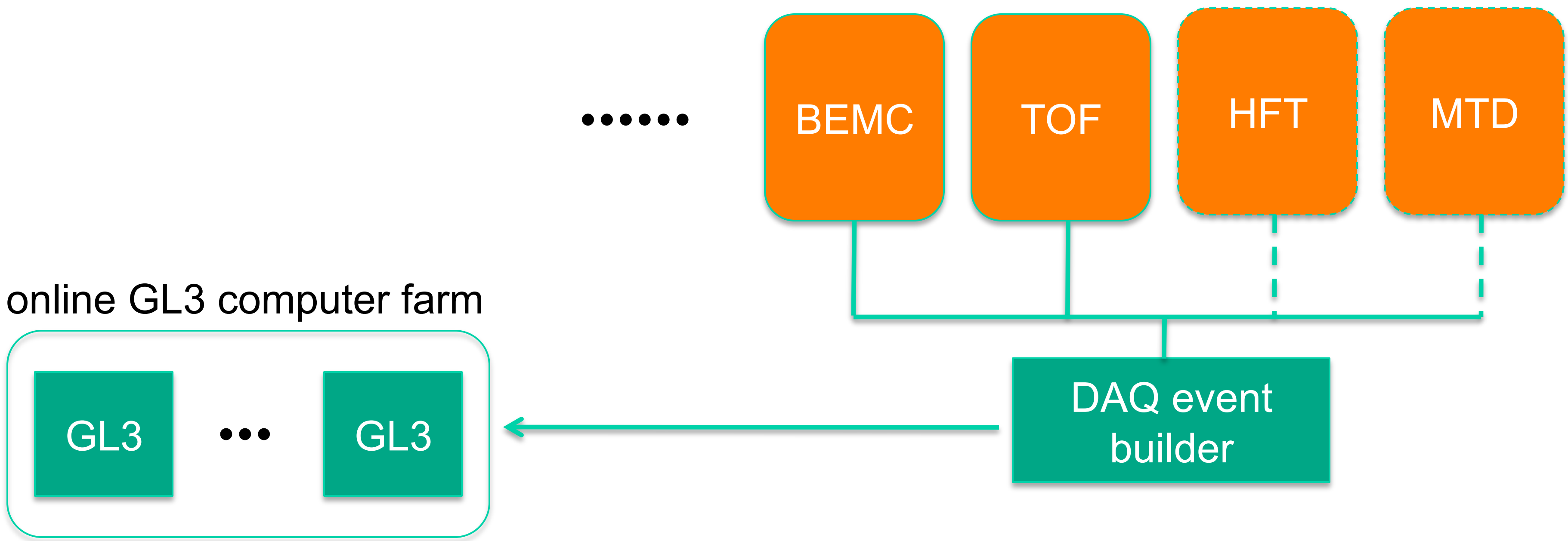
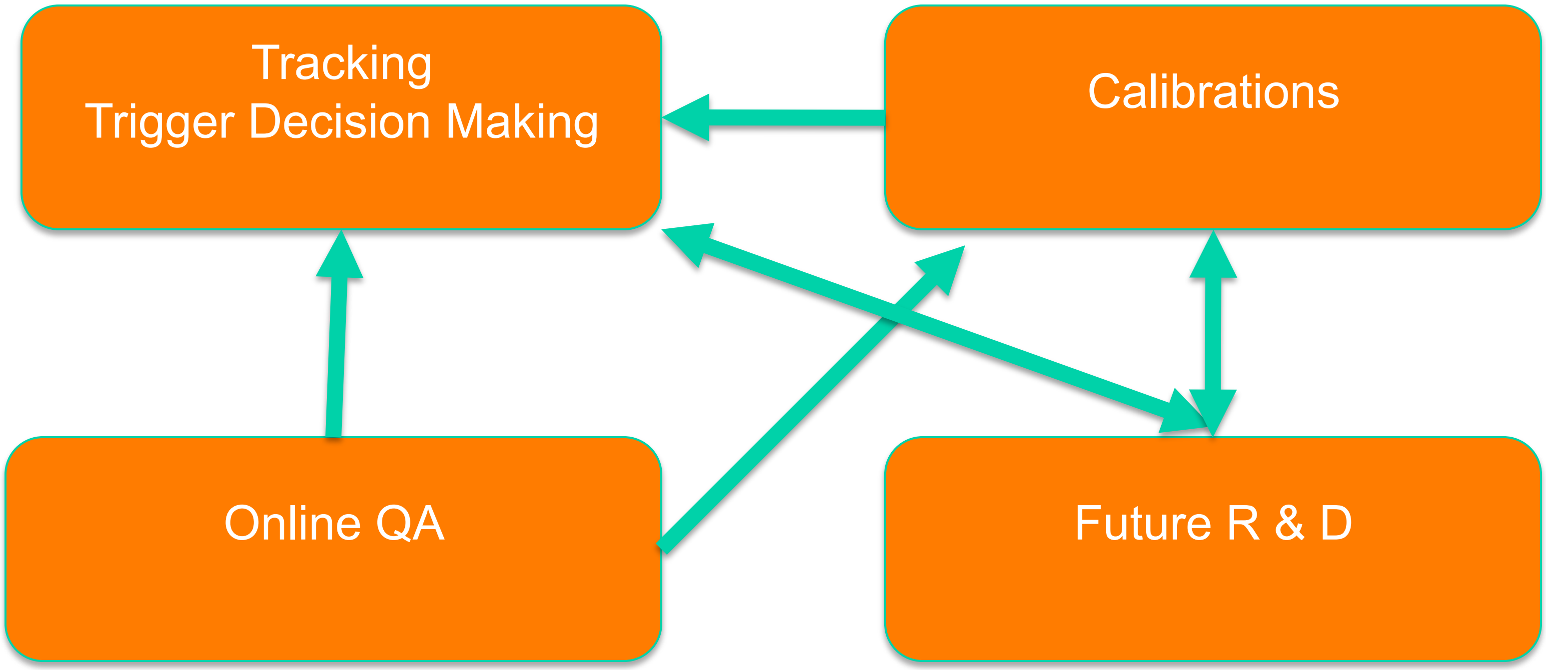
HLT layout in 2013 and beyond



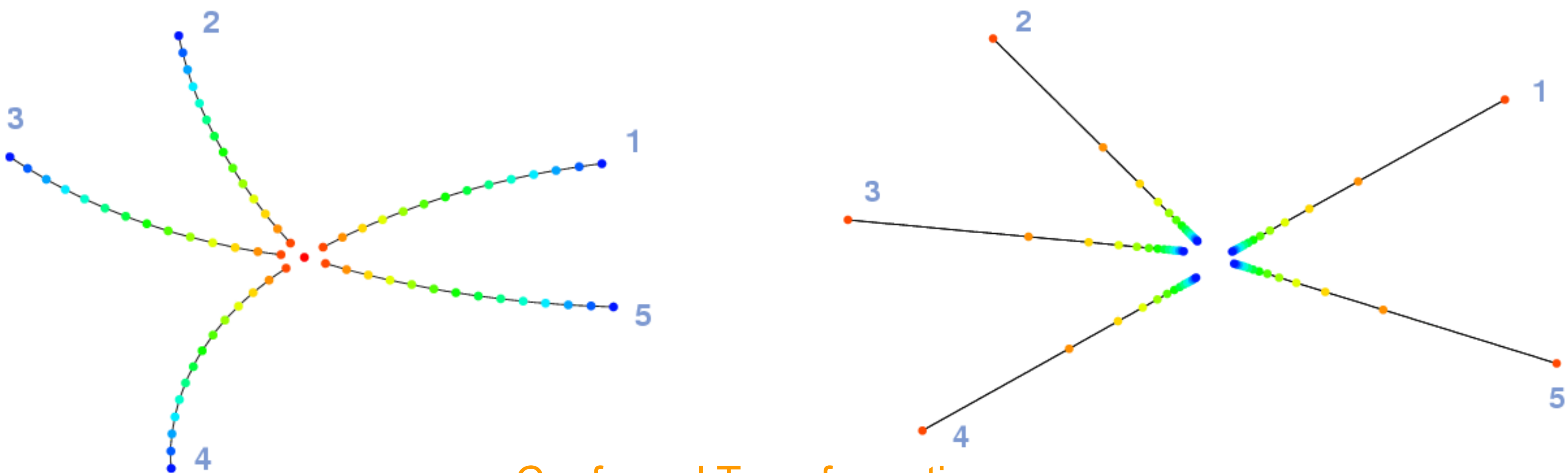
•Both tracking and trigger decision will be done by a online GL3 computer farm.

•The farm can be upgraded with Graphic Processing Unit (GPU) or Many Integrated Cores (MIC).

HLT Division by Tasks



Tracker



Conformal Transformation →

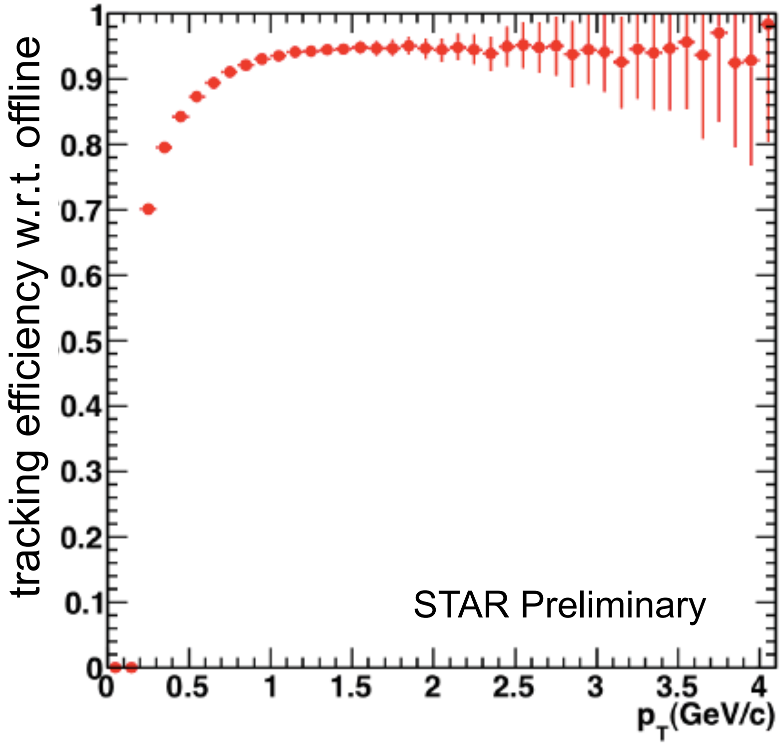
$$x_i' = \frac{x_i - x_0}{R_i^2}, y_i' = \frac{y_i - y_0}{R_i^2}$$

where $R_i = \sqrt{(x_i - x_0)^2 + (y_i - y_0)^2}$, and (x_0,y_0) is the primary vertex

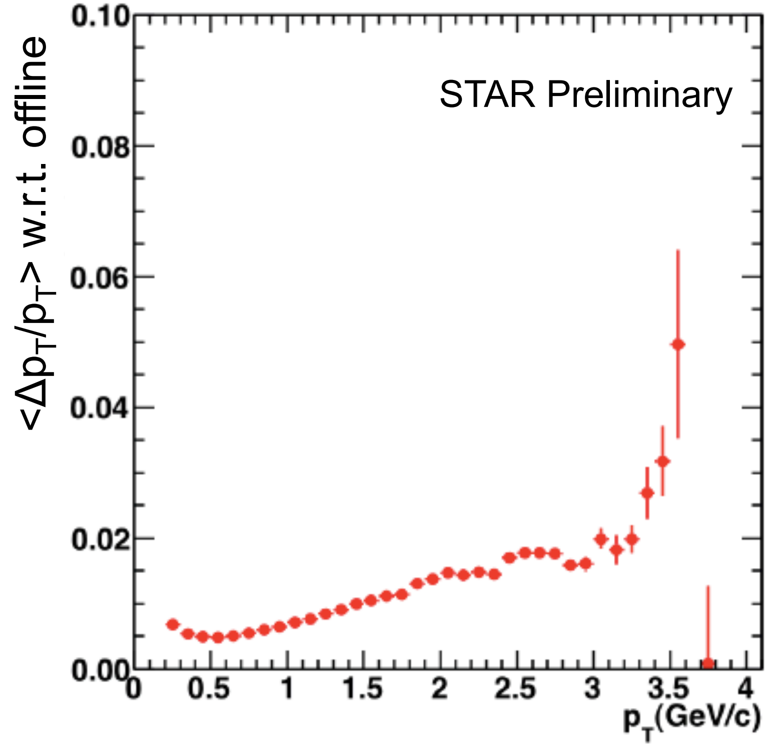
Fitting lines instead of fitting curves. Final fit with Helix model in real space.
Handle primary and global track non-uniformly.
Fast tracker with acceptable accuracy, but not an ideal tracker for parallel computing (will be replaced, see later slides).

Tracker Performance

Tracking efficiency w.r.t. offline

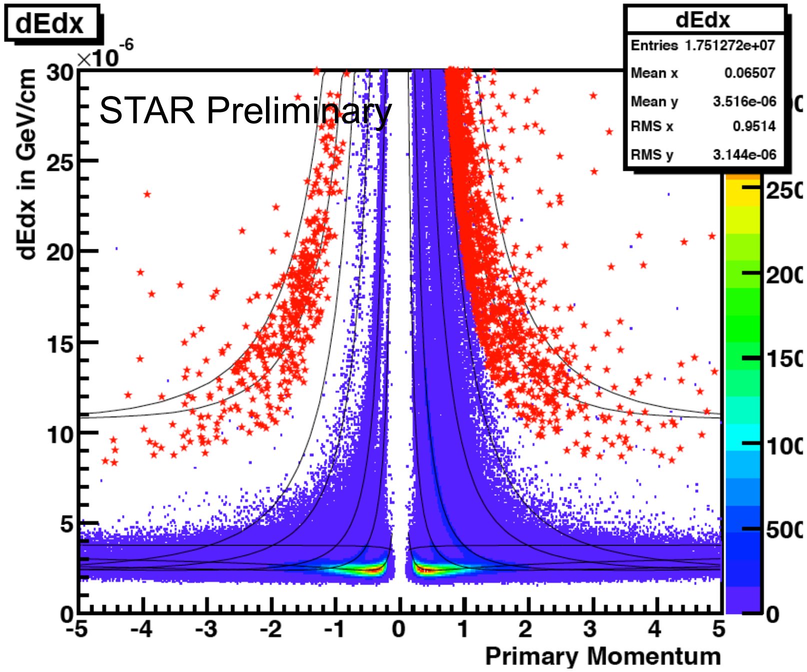


Relative p_T difference between HLT and offline



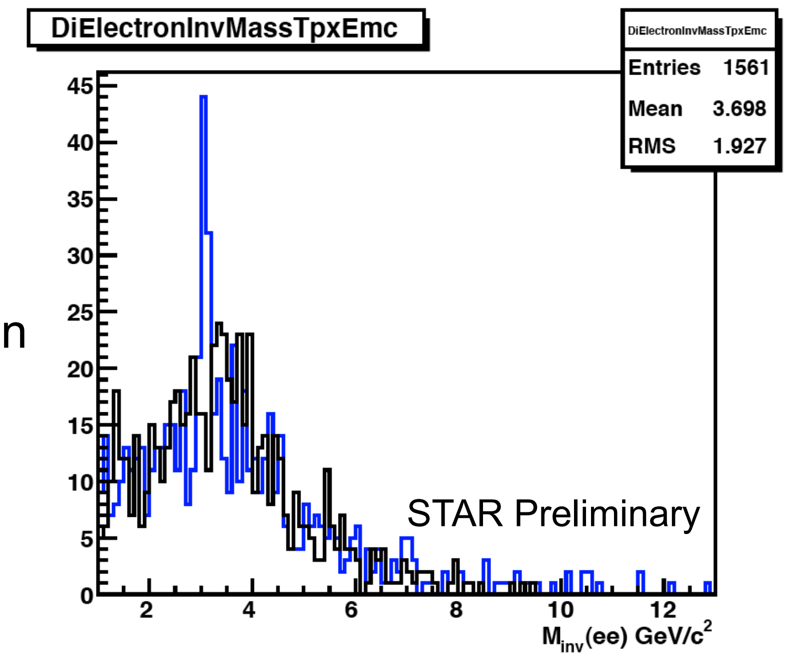
Performance evaluated based on online-offline association

Trigger Efficiency



> 90% for charge -2

~ 70% for di-electron



Estimated with AuAu 39 GeV data

Speed Performance (AuAu 200 GeV)

Year	2011	2013E	2014E	2015E	2016E	2017E
Peak L ($10^{26}cm^{-2}s^{-2}$)	50	41	46	55	60	60
#TPX hits (minbias, central)	36.7k, 70.7k	35.6k, 69.0k	36.2k, 70.0k	37.3k, 71.5k	37.9k, 72.3k	37.9k, 72.3k
Rate that HLT can handle (minbias, central)	2.0 kHz, 1.0 kHz	2.1 kHz, 1.1 kHz	2.0 kHz, 1.0 kHz	2.0 kHz, 1.0 kHz	1.9 kHz, 1.0 kHz	1.9 kHz, 1.0 kHz

✔

Assuming half CPU cores of DAQ machine can be used by HLT, we expect that HLT can handle ~1k Hz for Au+Au collisions in RHIC-II era, however we have to keep in mind HLT is sharing CPUs with DAQ cluster finding code.

Speed Performance (pp 200 GeV)

Year	2012	2013E	2014E	2015E	2016E	2017E
Peak L ($10^{30}cm^{-2}s^{-2}$)	46	60	89	107	107	118
#TPX hits (minbias)	11k	13.7k	20k	23.7k	23.7k	26.0k
Rate that HLT can handle	6.1 kHz	5.4 kHz	3.7 kHz	3.1 kHz	3.1 kHz	2.8 kHz

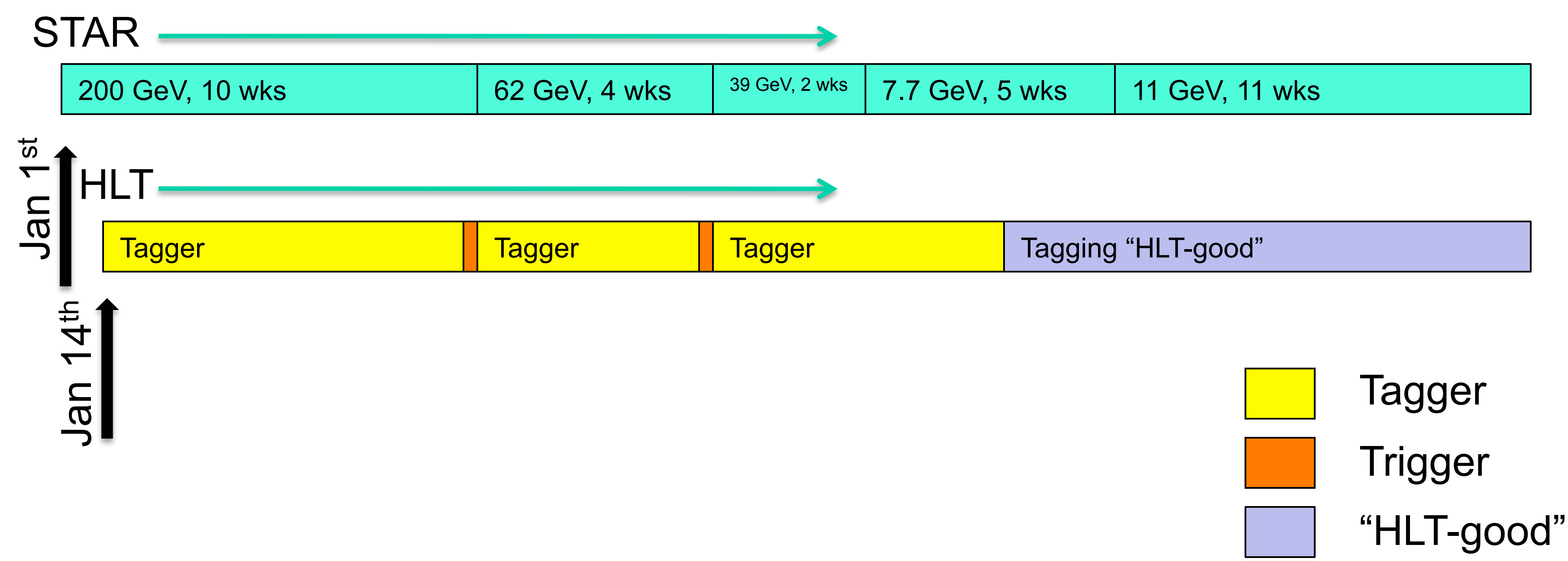
✔

Speed Performance (pp 500 GeV)

Year	2012	2013E	2014E	2015E	2016E	2017E
Peak L $(10^{30} cm^{-2} s^{-2})$	165	269	389	482	825	1010
#TPX hits (minbias)	89k	165k	252k	320k	570k	707k
Rate that HLT can handle	830 Hz	450 Hz	300 Hz	230 Hz	130 Hz	100 Hz

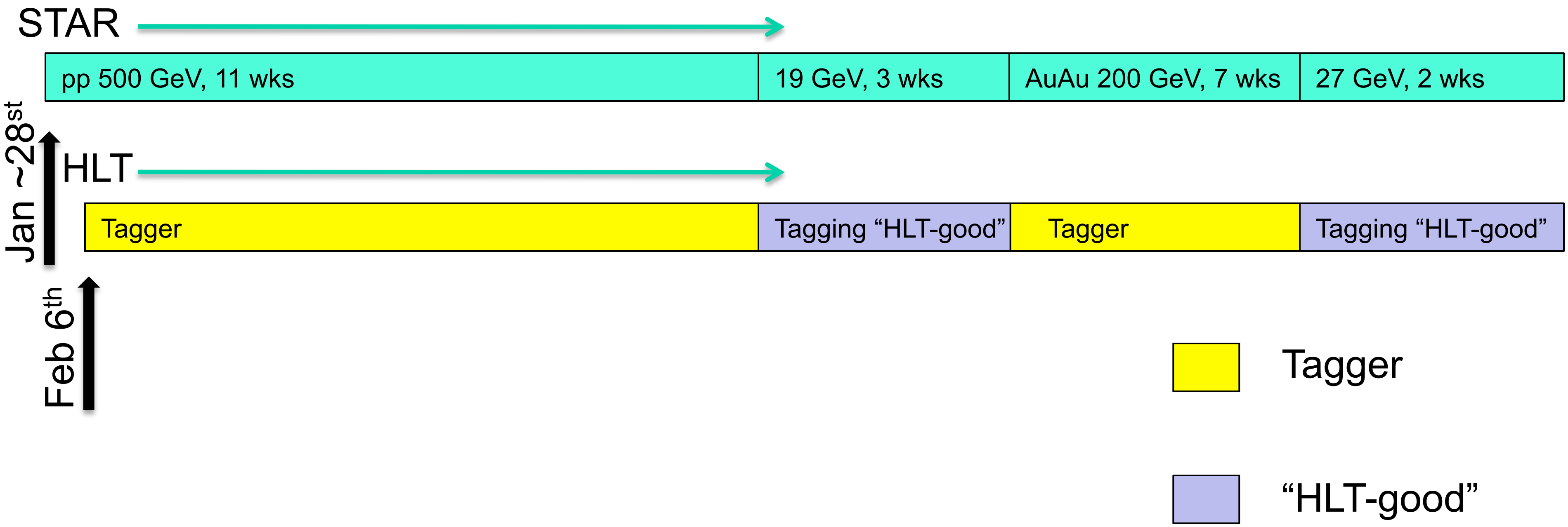
Problematic for handling pp 500 GeV collisions.

HLT-2010



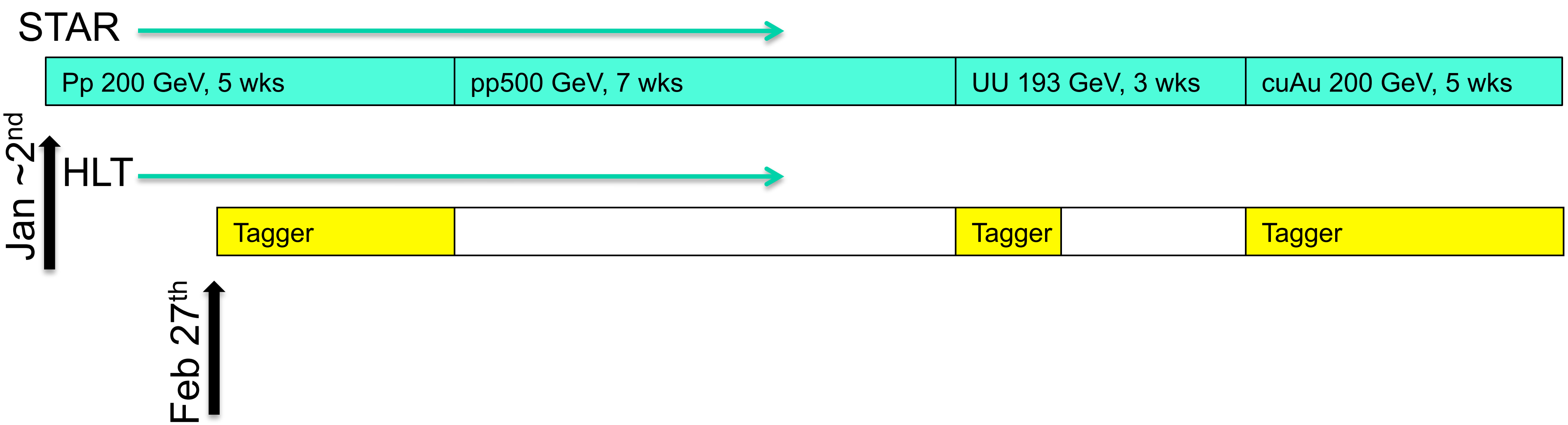
- Jan 9th. First TPX and TOF calibration ready.
- Jan 14th. HLT is up and running.
- Jan 15th. L2 crashed. HLT running with TPX and TOF only for some period.
- Feb. 05. HLT is decoupled from L2. Instead, HLT receives BTOWs from Tonko/Jeff.

HLT-2011



STAR
pp 500 GeV, 11 wks
19 GeV, 3 wks
AuAu 200 GeV, 7 wks
27 GeV, 2 wks
Jan ~28st
HLT
Tagger
Tagging "HLT-good"
Tagger
Tagging "HLT-good"
Feb 6th
Tagger
"HLT-good"

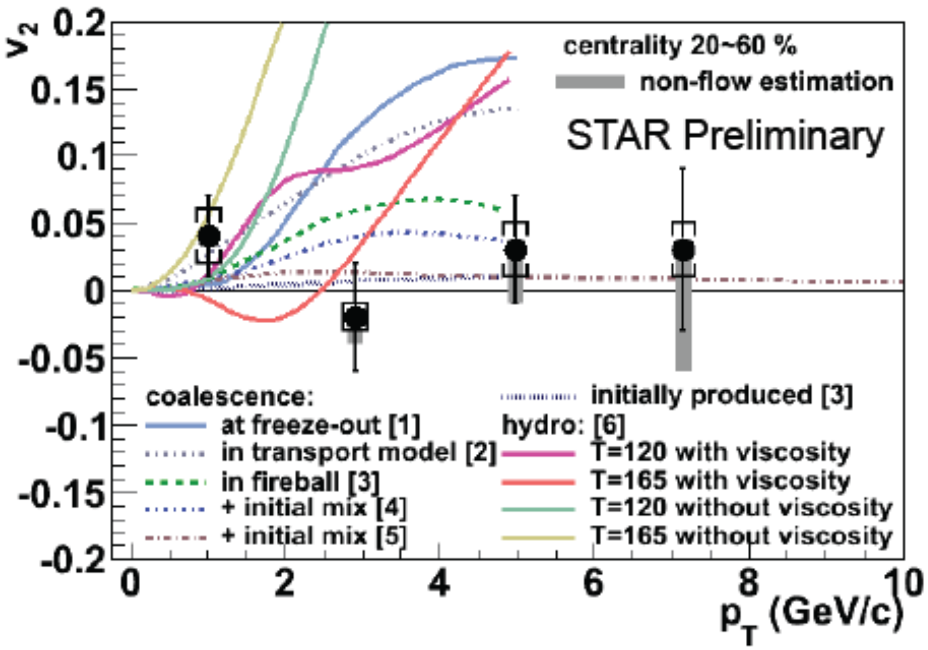
HLT-2012


STAR
Pp 200 GeV, 5 wks
pp500 GeV, 7 wks
UU 193 GeV, 3 wks
cuAu 200 GeV, 5 wks
Jan ~2nd
HLT
Tagger
Tagger
Tagger
Feb 27th

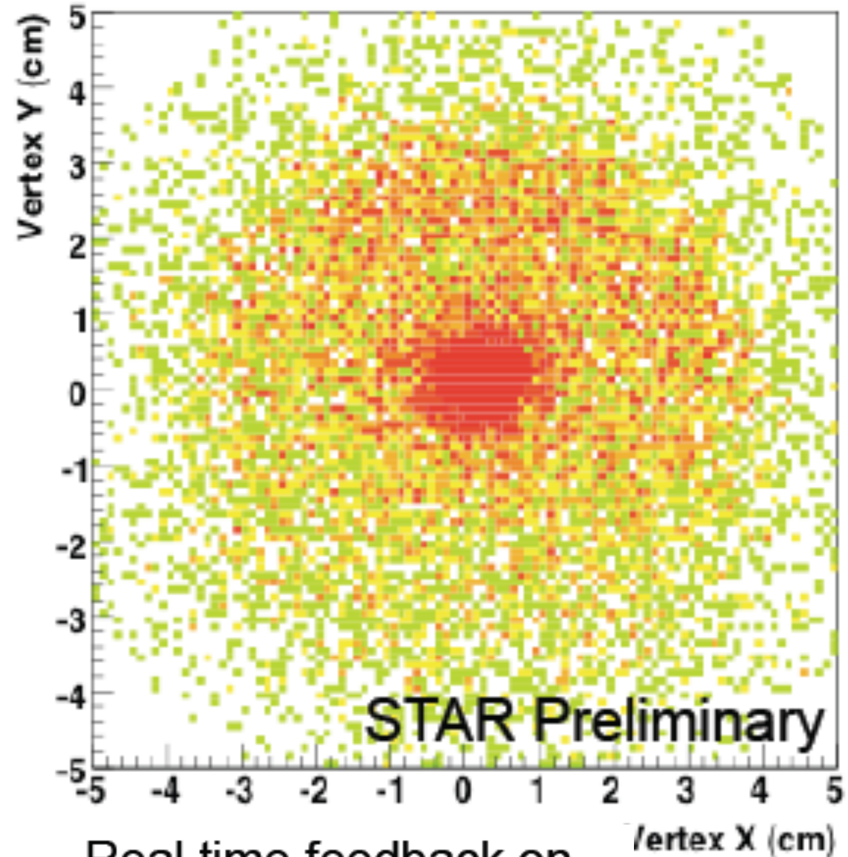
HLT Achievements

473, 353-356 (May 2011)

HLT Achievements



J/ψ v_2 highlighted at QM2011



Real time feedback on beam – beam pipe background during RHIC Beam Energy Scan program.

Future Upgrade Plan

- Adopt the Cellular Automaton (CA) tracker.
- Expand the GL3s to an online computer farm.
- Equip GL3 computers with GPU/MIC.

Physics Opportunities with HLT Upgrade

Push the boundary of Standard Model

- Dibaryon, Strangelets.

Look for new physics beyond Standard Model

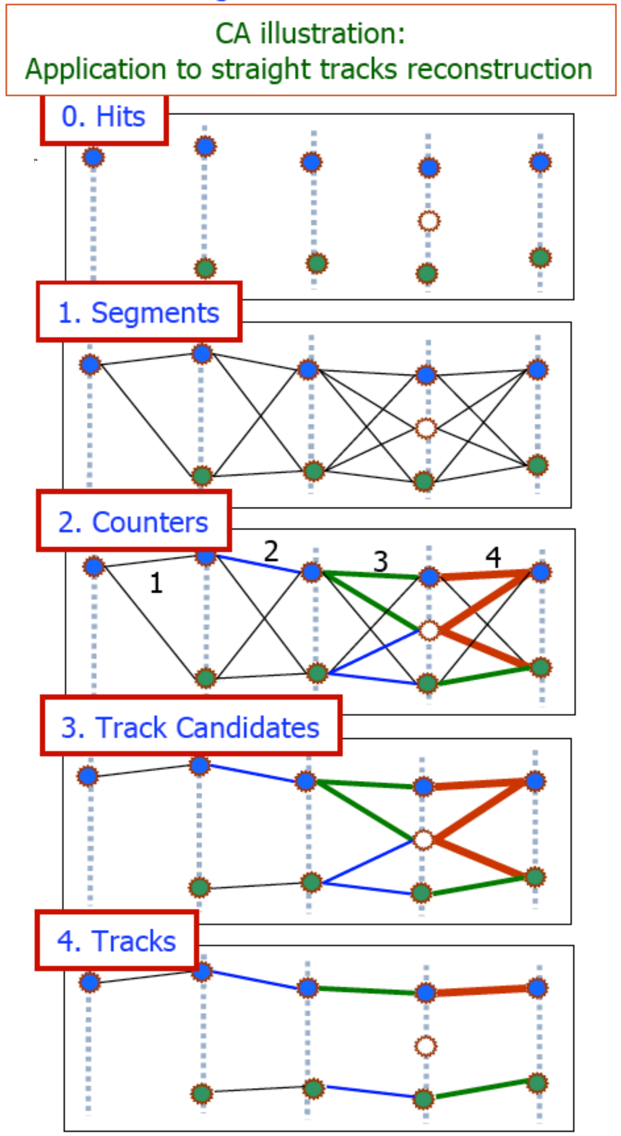
- Rare decay of hadrons, Antimatter.

Atom/parton chemistry test ground

- Multi-hyperon systems.

Adopting CA tracker

Track finding: Which hits in detector belong to the same track? – Cellular Automaton (CA)



I. Kisel *et al.*

Cellular Automaton:

1. Build short track segments.
2. Connect according to the track model, estimate a possible position on a track.
3. Tree structures appear, collect segments into track candidates.
4. Select the best track candidates.

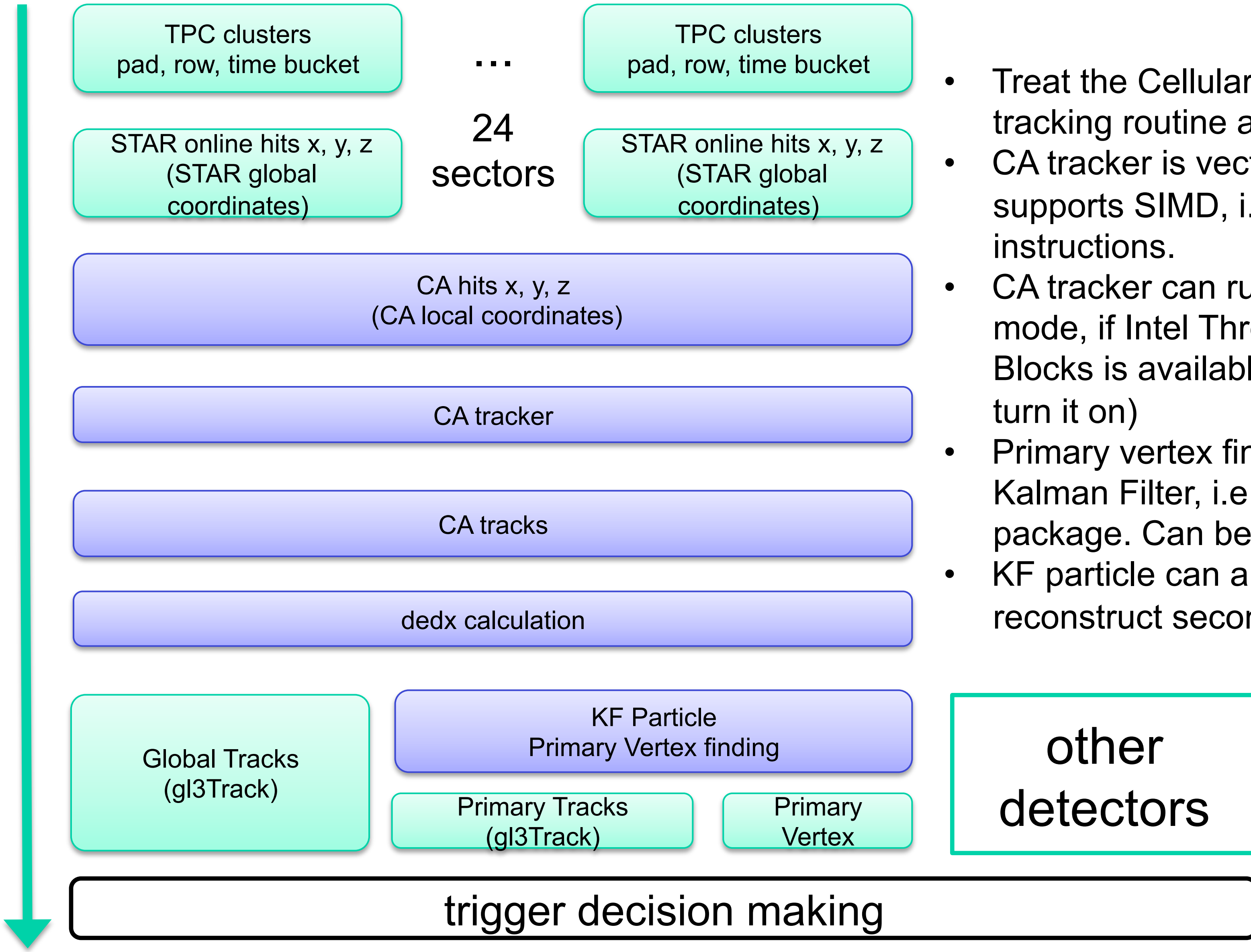
Cellular Automaton:

- local w.r.t. data
- intrinsically parallel
- extremely simple
- very fast

Perfect for many-core CPU/GPU !

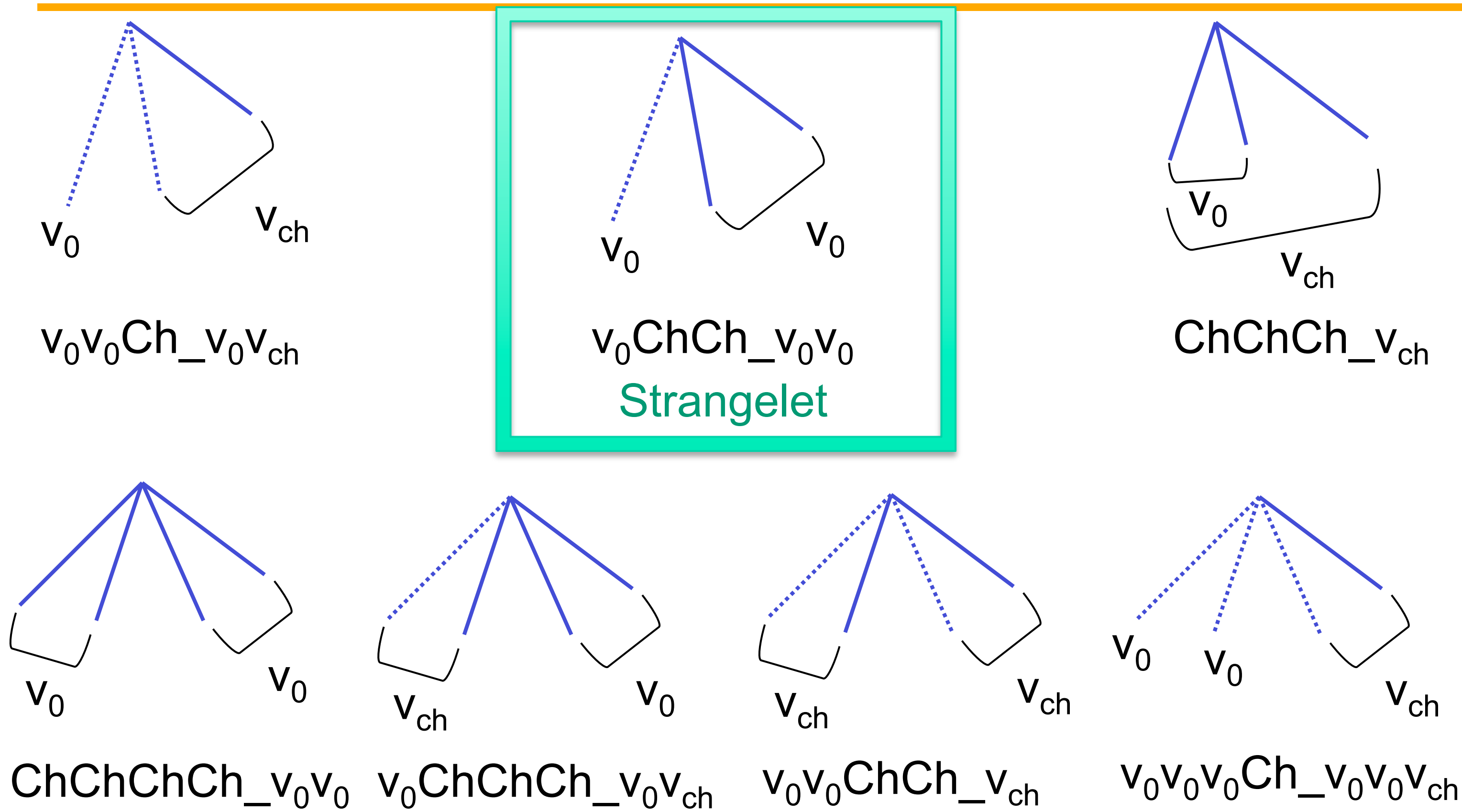
Compare to current STAR HLT tracker : same speed, better efficiency, easy for future parallelization.

Adopting CA tracker



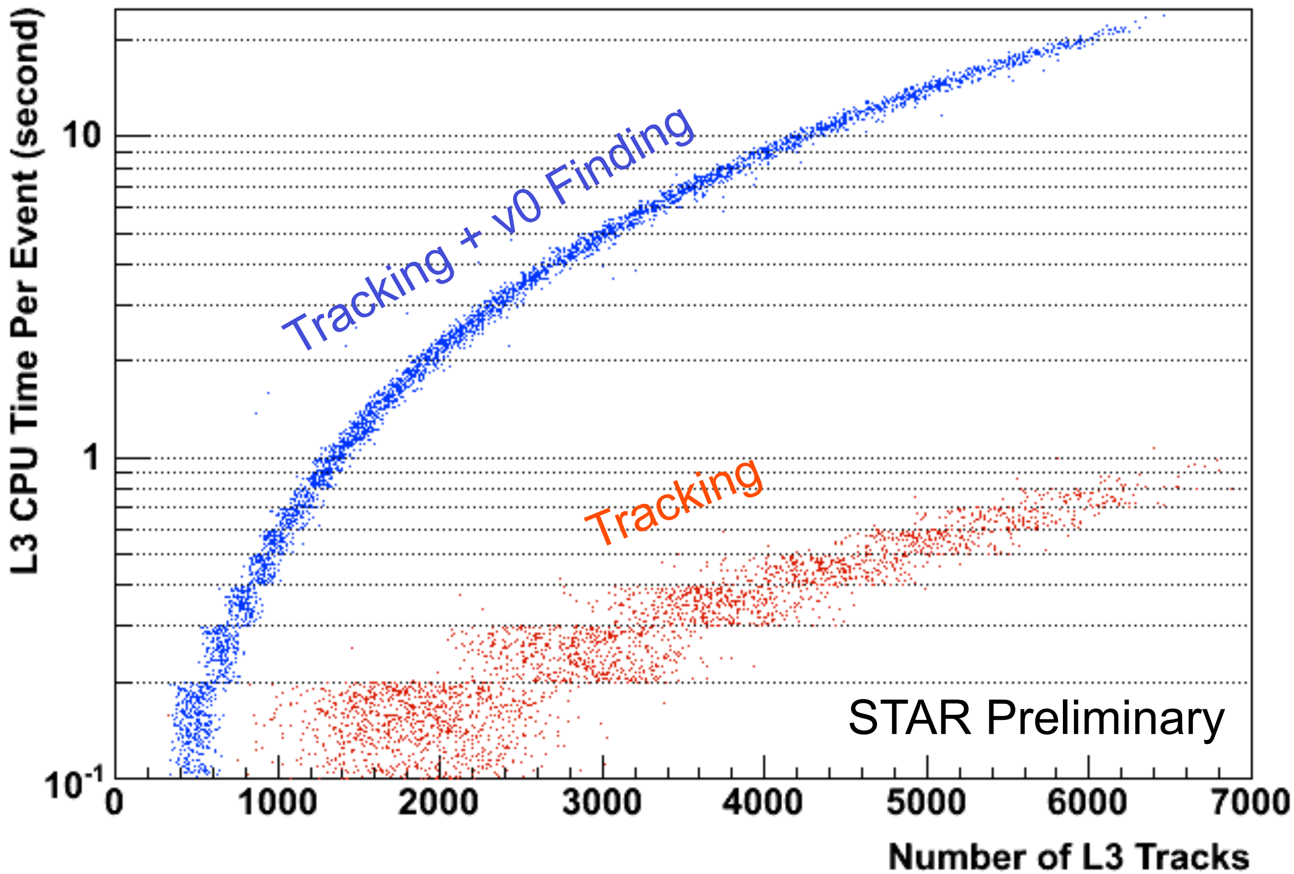
- Treat the Cellular Automata tracking routine as a black-box.
- CA tracker is vectorized, if CPU supports SIMD, i.e. SSE/AVX instructions.
- CA tracker can run in multi-thread mode, if Intel Thread Building Blocks is available. (we do not turn it on)
- Primary vertex finding based on Kalman Filter, i.e. KF Particle package. Can be vectorized.
- KF particle can also be used to reconstruct secondary vertices.

Trigger on Secondary vertices : Search for strangelets and other exotics



Good potential for new discoveries (Strangelets, di-Ω etc.) with GL3 upgrades

Secondary Vertex Finder



v_0 reconstruction is CPU intensive (~M^2).

Secondary Vertex Finder with GPU

Good task for GPU:	strategy	comformal mapping tracking	Kalman filter tracking	Secondary vertex finder
Input data amount	⬇	🔴	🔴	🟢
Communication between tasks	⬇	🔴	🔴	🟢
Frequency of accessing to input data	⬇	🔴	🔴	🟢
Complicacy of each task	⬆	🔴	🟢	🟢
Output data amount	⬇	🟢	🟢	🟢

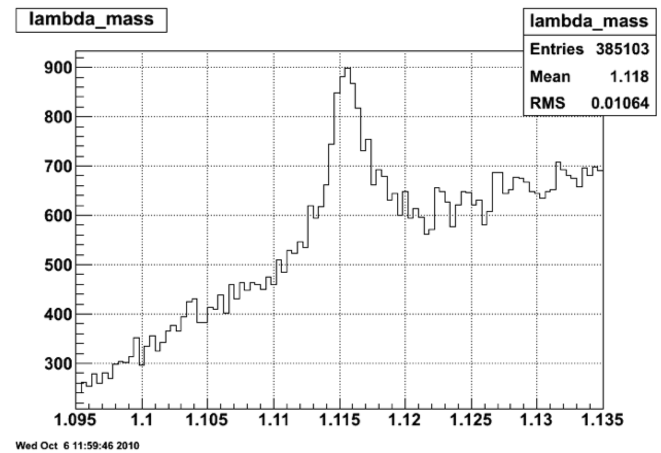
Secondary Vertex Finder is best candidate suited for GPU acceleration

Secondary Vertex Finder with GPU

Test result:

GTX280 VS 2.8CPU

	CPU	GPU (GeForce GTX 280)
clock	2.80GHz	1.3GHz
Time cost	93us/pair	1.3us/pair



Code running with GPU is 60 times faster than single CPU core considering data transmission.

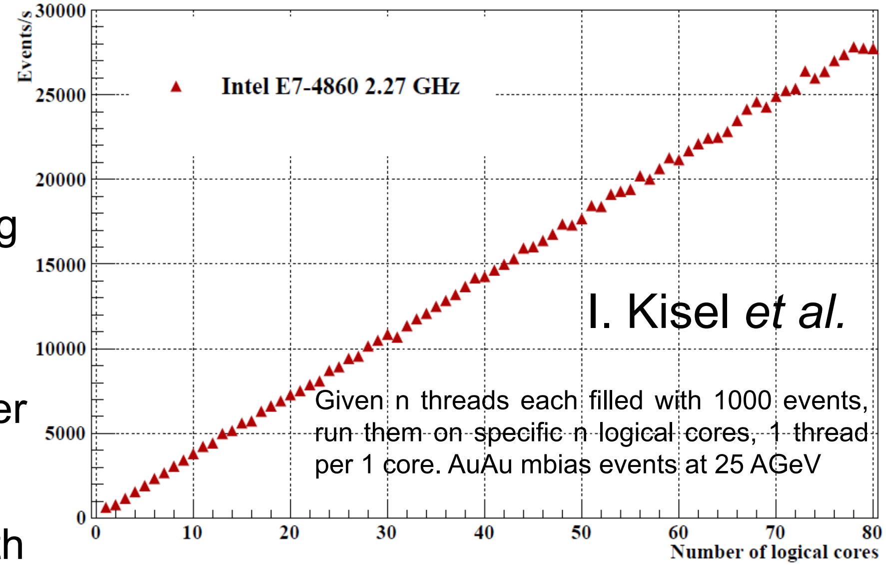
6x gain due to code optimization, 10x gain due to GPU.

Lambda reconstructed by GPU (real data, HLT tracks)

GPU significantly accelerates v_0 reconstruction.
The possible alternative approach ➔ see next slide.

The alternative approach : KF Particle with Many-core System

- KF Particle Finder + Many Integrated Core is an alternative approach to STAR-HLT's current v0 reconstruction plan with GPU
- The KF Particle Finder has been parallelized using Intel Thread Building Block.
- The KF Particle Finder shows linear scalability on many-core machines (the scalability on a computer with 80 cores is shown).
- STAR plans to test/adopt the KF particle along with the CA tracker.



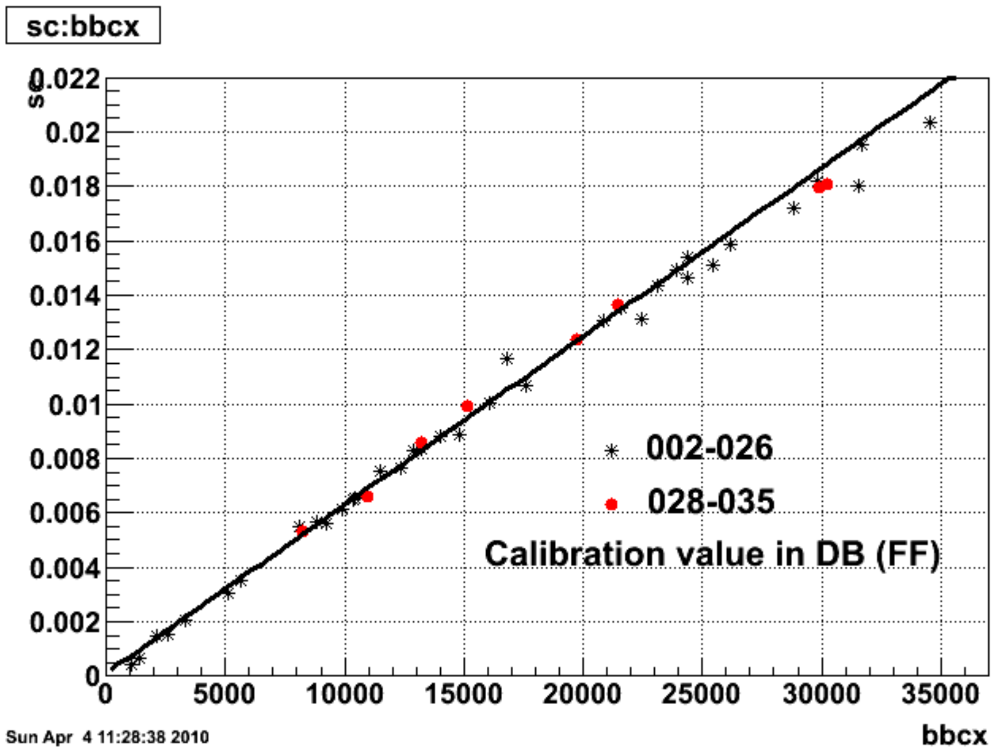
Looking forward to testing KF particle reconstruction with Many Integrated Core in STAR online environment.

Summary

- STAR's HLT has successfully selected events of interests in real time.
- It is demonstrated that STAR can deliver important physics fast with the HLT.
- Future upgrade plan is presented. With the upgrade, STAR will be in an excellent position for exploring a wide range of new physics opportunities.

Backup

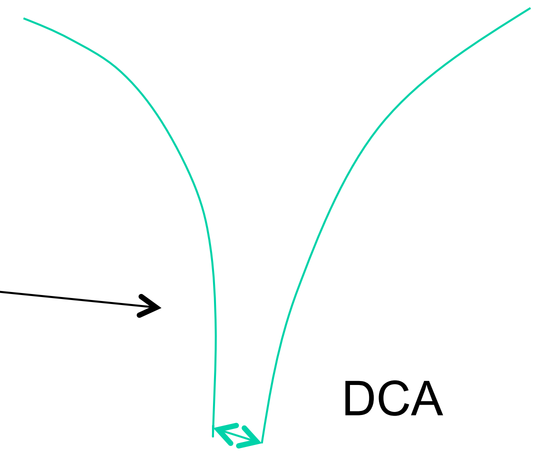
Online Calibration



HLT calibration and offline computing are mutual beneficial.

Identify issues early (for example, the TOF Time Over Threshold issue)

p_T (GeV/c)	< 0.8	0.8-3.6	> 3.6
π dca to primary vertex (cm)	> 2.5	> 2.0	> 1.0
p dca to primary vertex (cm)	> 1.0	> 0.75	> 0
dca between daughters (cm)	< 0.7	< 0.75	< 0.4
dca from primary vertex to V0	< 0.7	< 0.75	< 0.75
decay length (cm)	4-150	4-150	10-125



Cuts selection for Lambda (AntiLambda) at Au+Au 200GeV

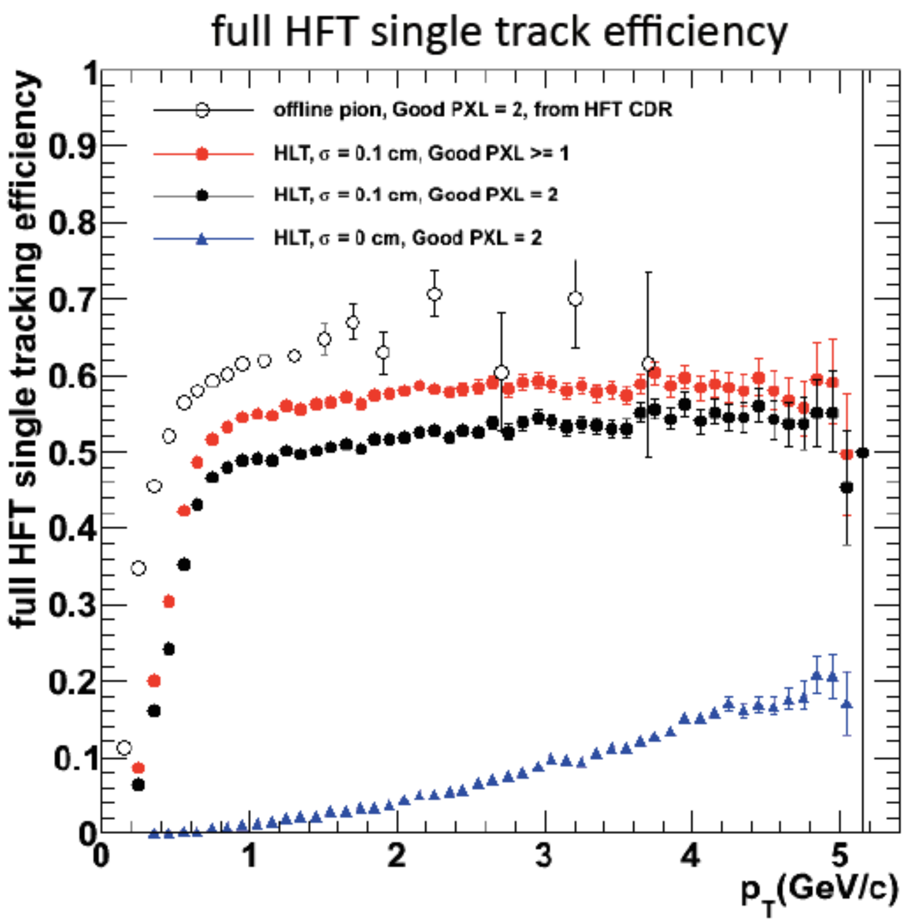
Dca between daughters is the most time consuming part.

1, Calculation of dca between daughters is more complicated than other parameters

2, The combination of candidates is much higher that other parameters.

HLT-HFT Precision Consideration

For a first time test, we just set a constant search range and tested two situations.



Data set	
Offline	pion embedding
HLT	$D_0 \rightarrow \pi^+ + K^-$ without the event background

✓ The single track efficiency is quite sensitive to the search range. We need a detailed description of multiple Coulomb scattering.

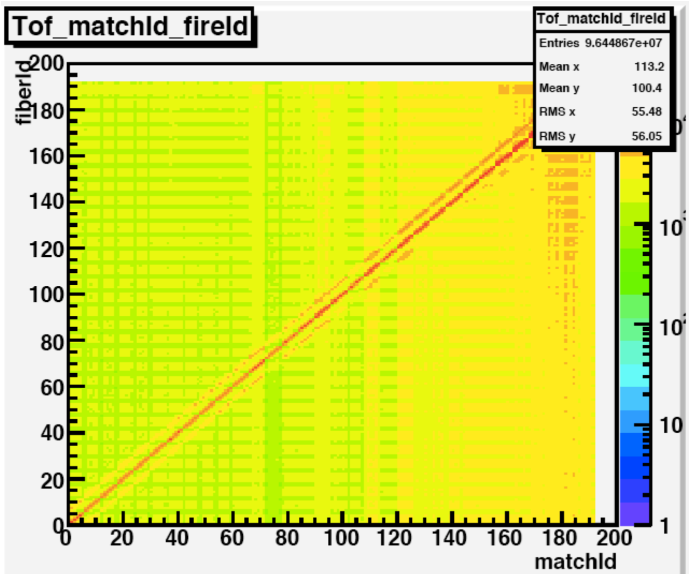
✓ We can increase the efficiency by extending the search range. This doable because the ghost will be controlled by TPC tracking.

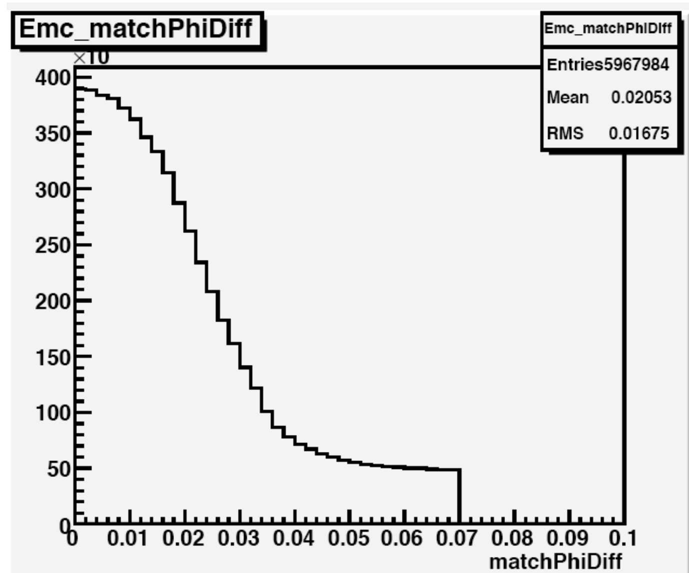
Good work-in-progress
Expect more collaborations with HFT experts

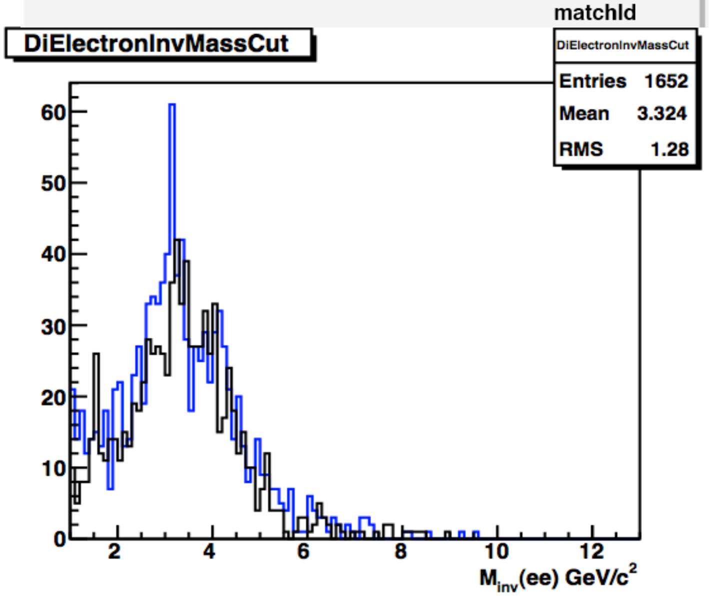
Related History

- STAR's old Level-3 system had been in limited function, phased out since then ~2002
- Propose of HLT at 2007 DAQ 1k workshop.
- Proof of principle in 2008.
- Prototype in 2009 with real data taking. DAQ 1k installed in 2009.
- In function in 2010.

Online Monitoring







Watch J/ψ peak grow online.

Early discovery for possible run condition changes