Online HLT tracking for BES-II

STAR High-Level Trigger & STAR Tracking Focus Group

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5. Shanghai Institute of Applied Physics

† Only currently active members are listed

Outline

- Tracking in STAR High Level Trigger
- Tracking in STAR offline software (BFC)
- Plan for BES-II

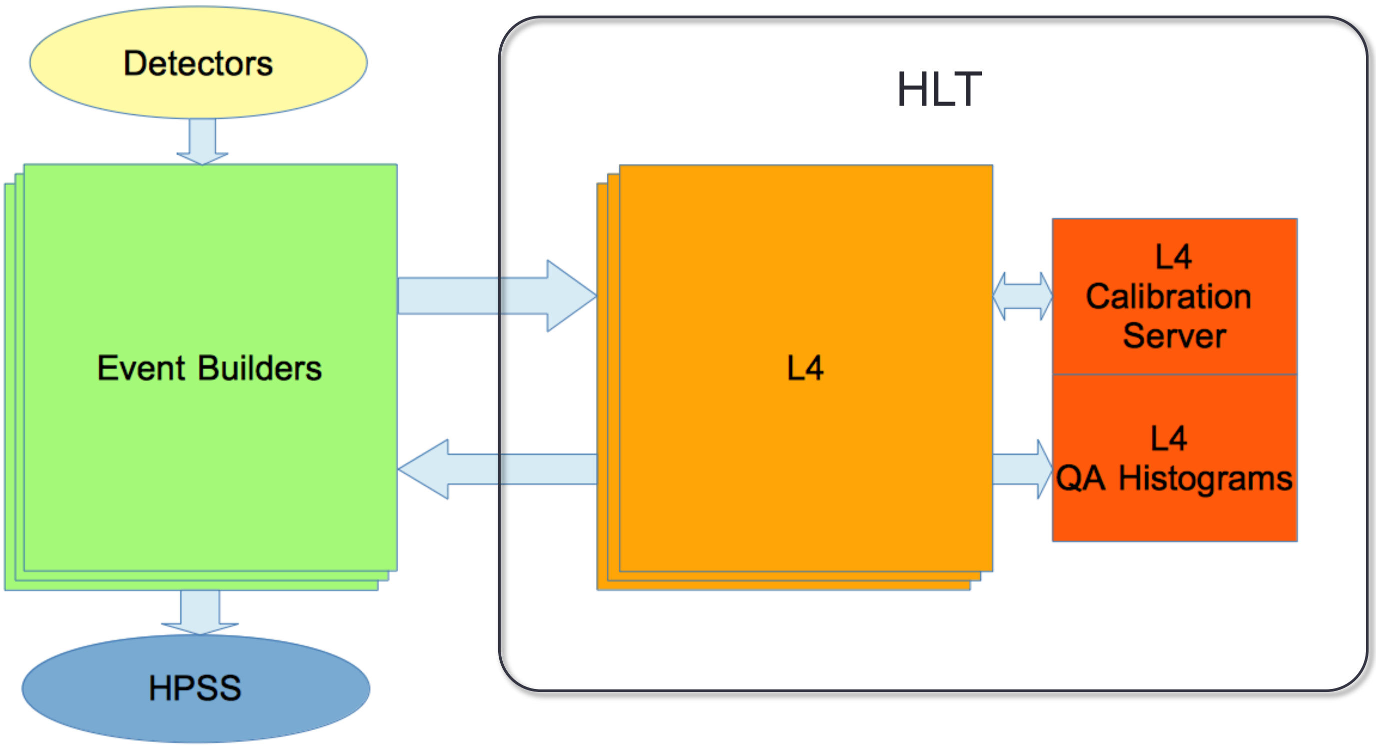
STAR HLT Development History

- STAR Level-3 trigger system of (Developed by Frankfurt group, conformal mapping based tracker, phased out ~2002)
- HLT 1.0 (2010 – 2012) – Borrowed CPU share from TPX machines. Fragmented event reconstruction. Not scalable.
- HLT 2.0 (2013 – 2016) – Integrate all tasks in one process. Use CA tracker to replace the L3 tracker, including experimental usage of KFParticle. Developed new DAQ infrastructure. Scale up effortlessly.

Year	# of Nodes	# of CPU
2012	4	96
2014	9	296
2016	27	1192 + 45 Xeon Phi

- HLT 3.0 (2017 –) – Balance the total throughput of ~1k CPU threads and ~10k Phi threads. Decompose the HLT task into independently schedulable sub-tasks and hide the details of Phi from DAQ side.

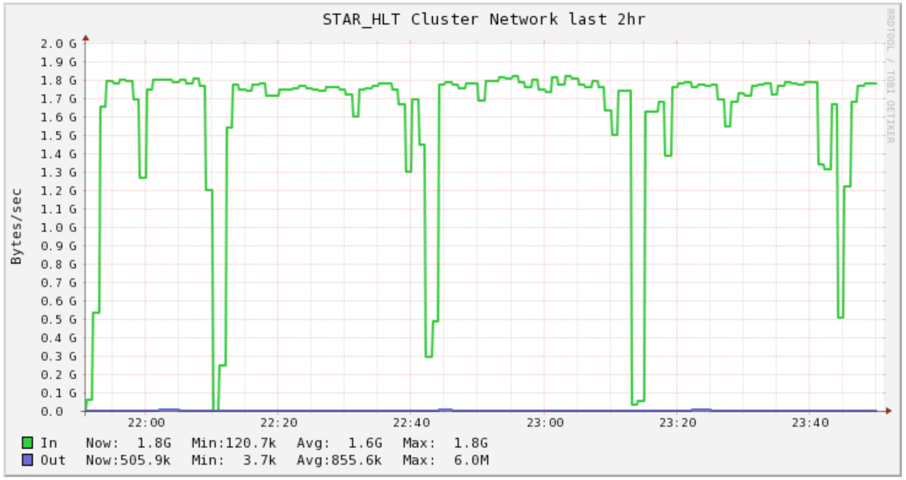
Integration with DAQ



- STAR HLT use high performance computers to do real time event reconstruction and analysis
- Provide additional event selection capability based on physics analysis on top of hardware trigger layers

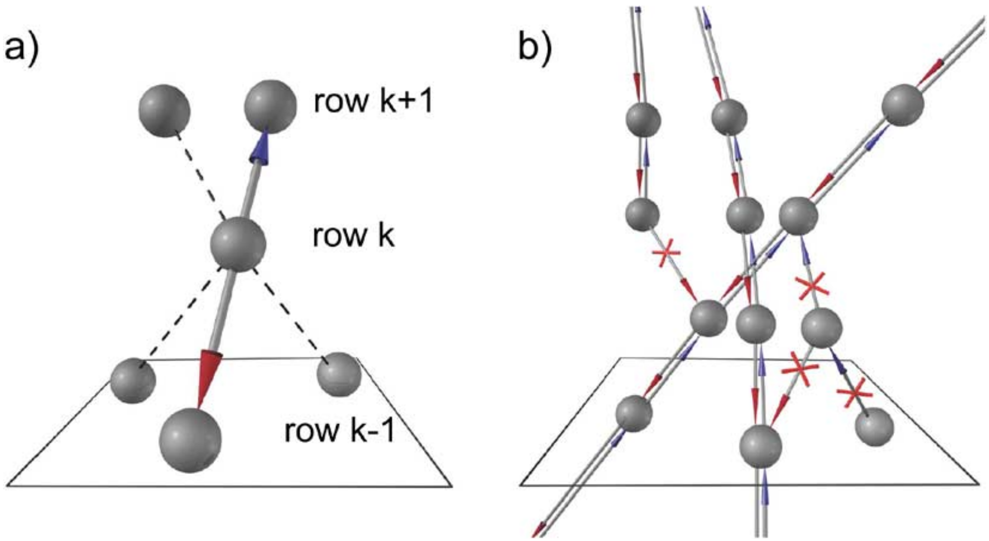
HLT Data Taking in Year 2016

- HLT process almost all of the data taking by DAQ at 1700+Hz, 1.7+GB/s input data
- ~1000Hz Mini-Bias
- ~700Hz MTD (tracking 6-8 sectors)
- < 40% CPU load



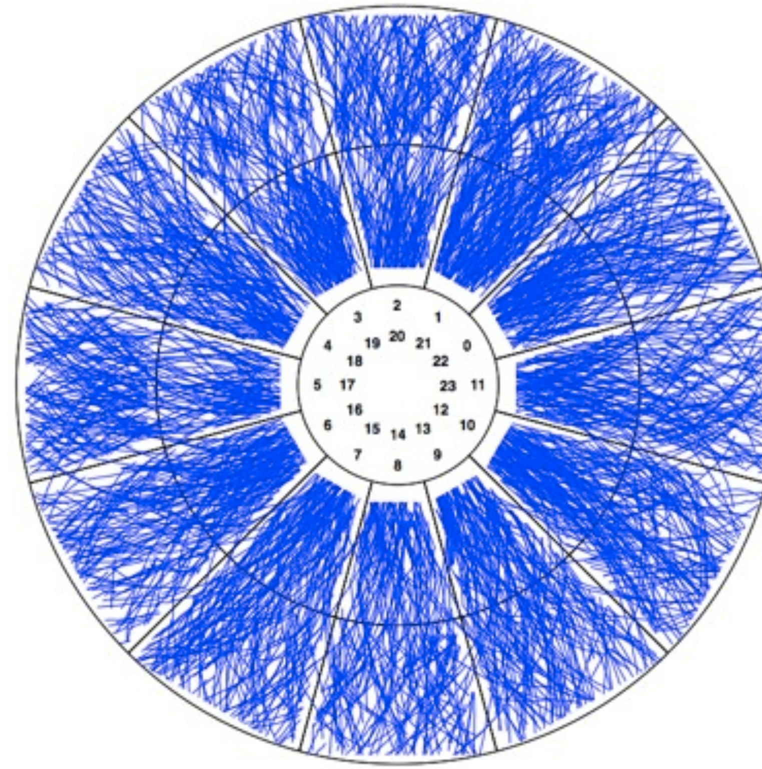
Det	State	Dead	CPU	Evts	Evts In	Hz	MB/s EVB	Err	MB/s RDO
TOF	RUNNING	10 %	15 %	459762	1	1777	21.6	1	21
BTOW	RUNNING	4 %	14 %	459634	0	1784	17.5	2	17
Trigger	RUNNING	0 %	-1 %	601598	-16787624	2277	16.9	0	0
ETOW	READY	0 %	0 %	171381	0	0	0.0	0	0
BSMD	RUNNING	5 %	18 %	33505	0	150	1.0	0	11
ESMD	READY	0 %	0 %	0	0	0	0.0	0	0
TPX	RUNNING	21 %	77 %	460336	22	1795	1346.5	5	15115
PXL	RUNNING	5 %	17 %	318562	0	1285	215.7	1	215
MTD	RUNNING	4 %	14 %	459288	0	1777	1.7	2	2
IST	RUNNING	6 %	77 %	318082	0	1245	25.9	0	930
SST	RUNNING	35 %	14 %	279764	0	1136	17.3	1	17
GMT	RUNNING	7 %	15 %	217682	0	851	20.6	1	20
L4	RUNNING	0 %	41 %	-1/418755	302	1685	1725.5	0	2067

Cellular Automaton Tracker



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

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

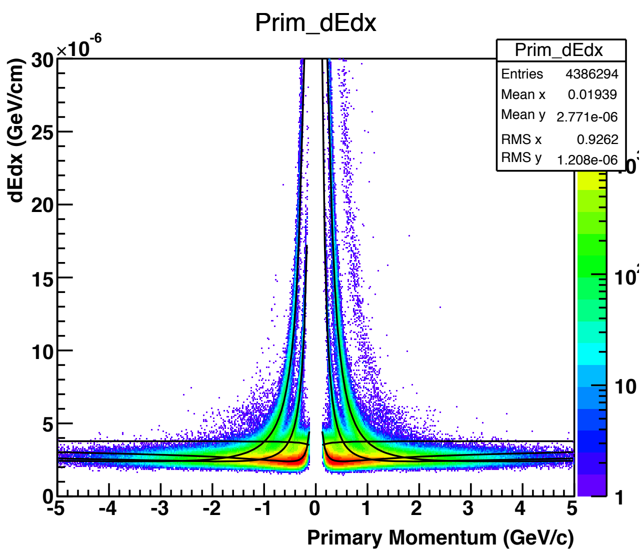


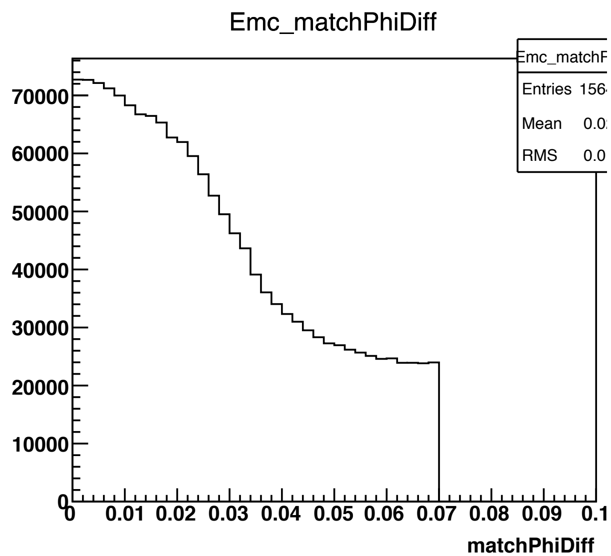
STAR AuAu 200GeV Run11

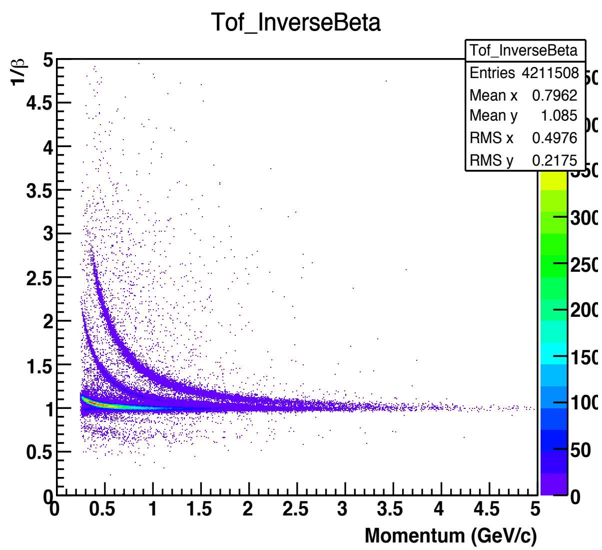
S. Gorbunov et al. Real Time Conference (RT), 2010

Particle Identification

- PID using TPC, BEMC and TOF
- online self-calibration of TPC dE/dx gain

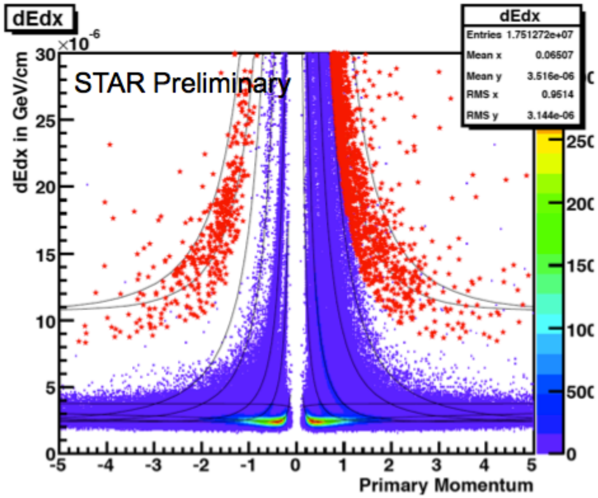


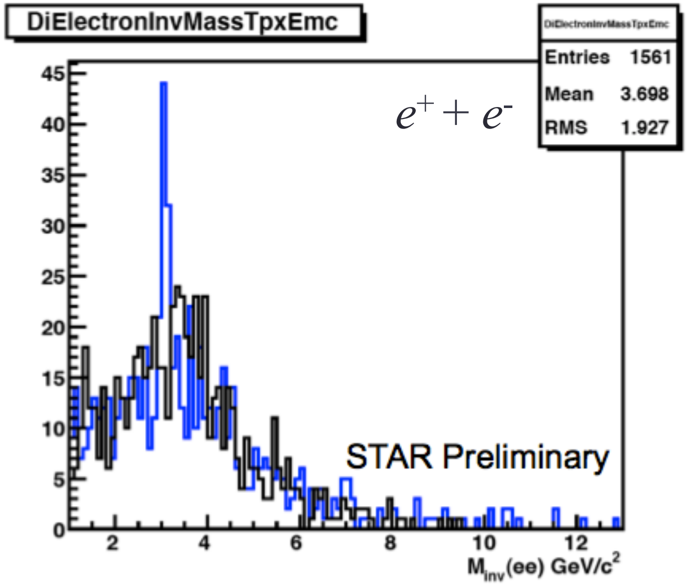




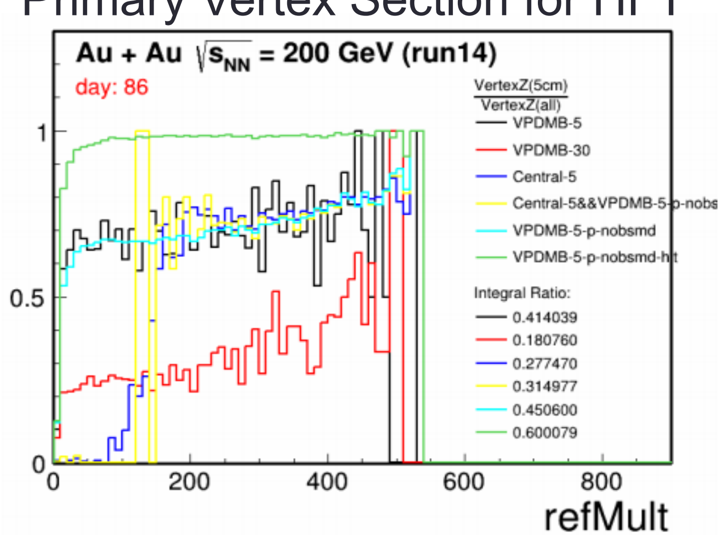
Selected HLT Trigger Algorithms

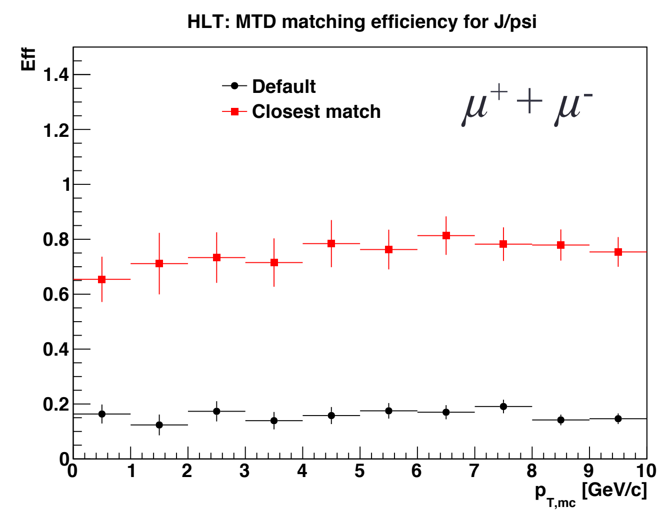
Heavy fragments, e.g. anti-^{4}He





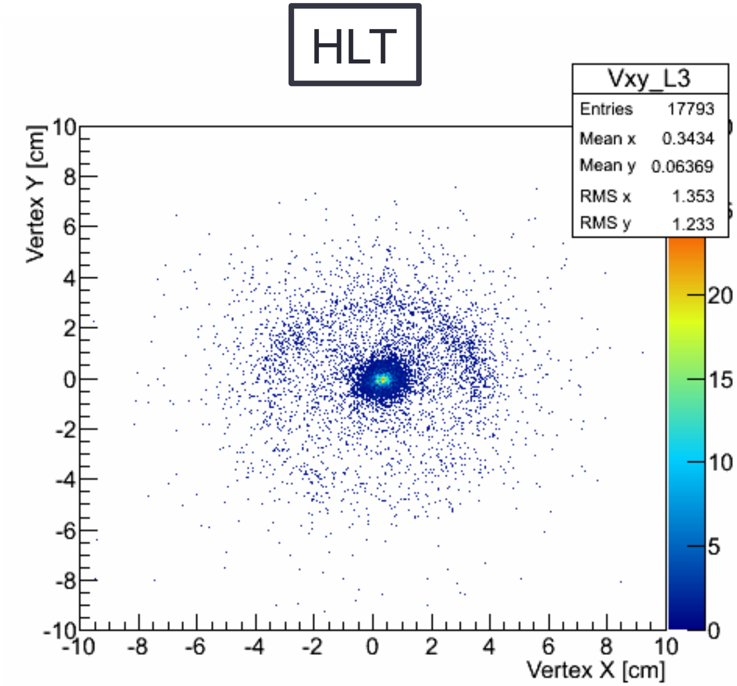
Primary Vertex Section for HFT

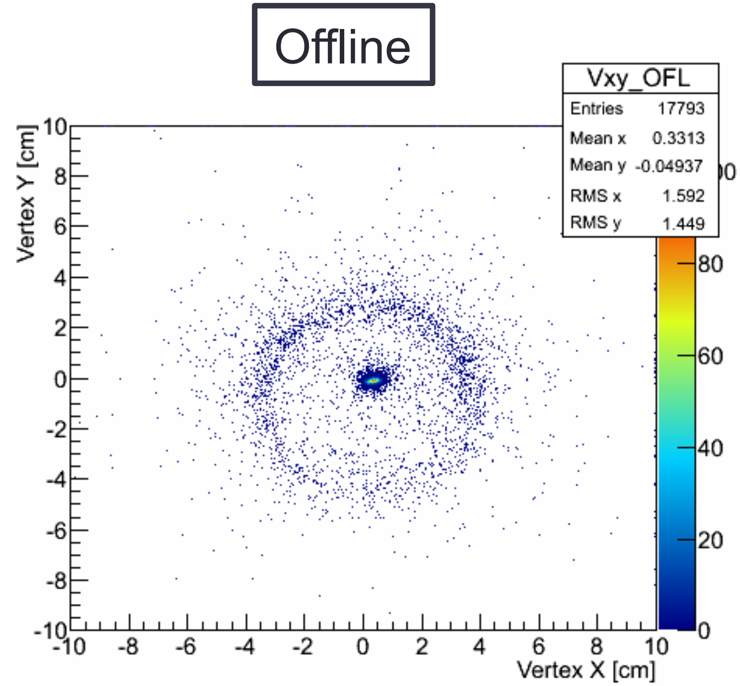




Beam Line Monitoring

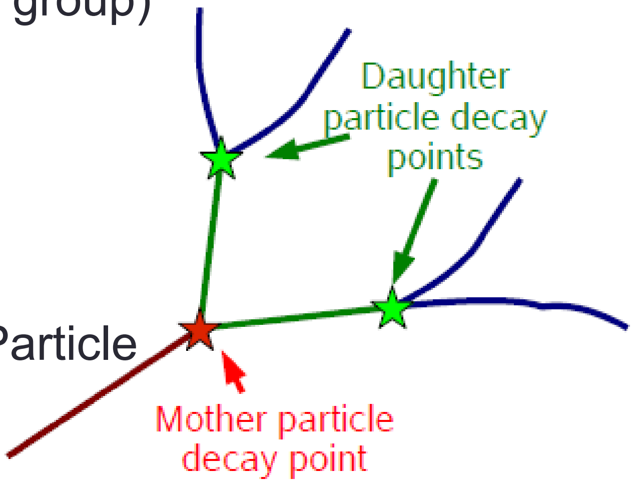
- Online 3D primary vertex reconstruction
- Real time beam position monitoring in RHIC low energy runs
- Reject background
- Live feedback to CA for accelerator monitoring and performance tuning
- Benefit all BES-I physics analyses
- Likely to be used again in BES-II

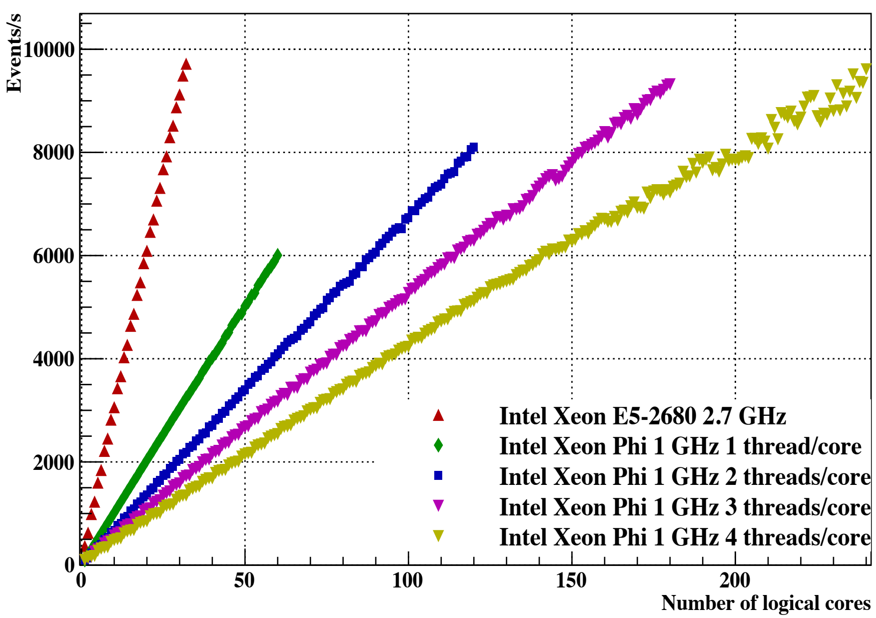




KFParticle and Xeon Phi Coprocessor

- KFParticle on Intel Xeon Phi (pioneered by FIAS group)
- Intel Xeon Phi 7120P
  - 61 core x 4 hardware threads per core
  - 512-bit vector register
  - 16G RAM
  - on board Linux
- Experience with Xeon Phi benefits more the KFParticle

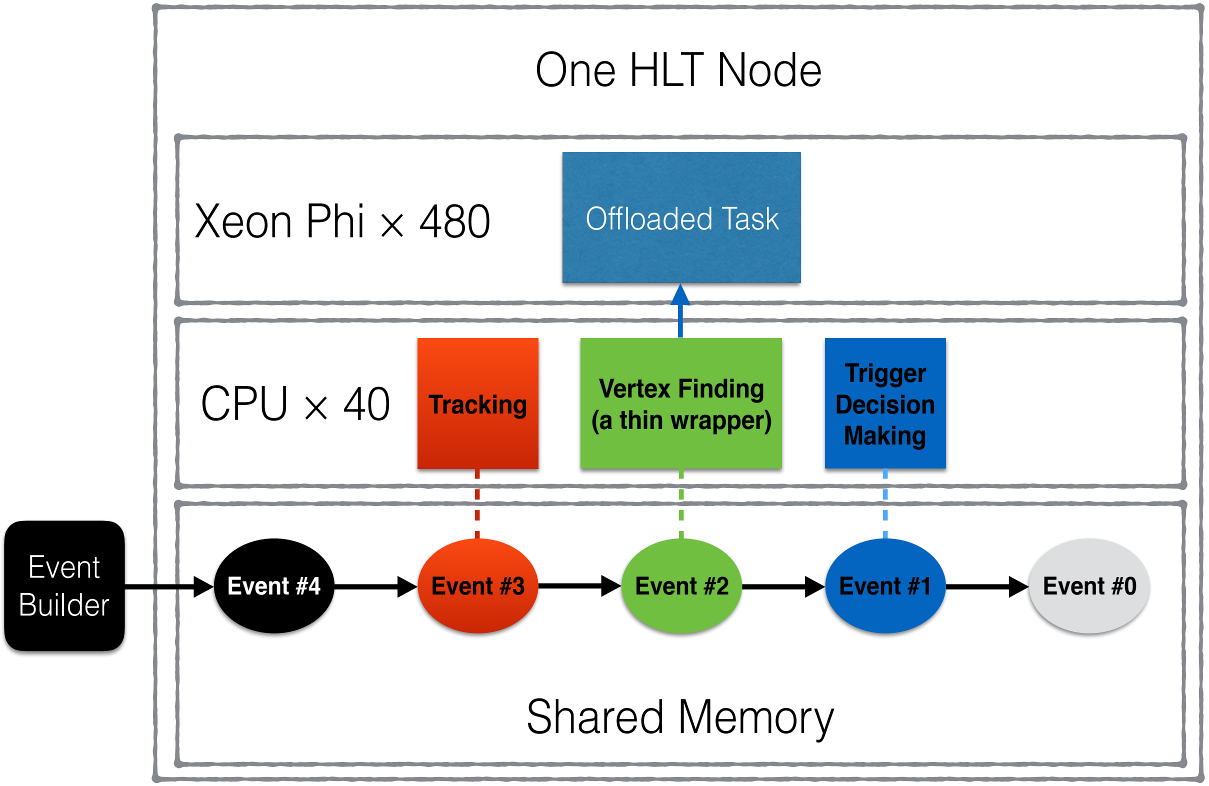




State vector — Position, direction and momentum

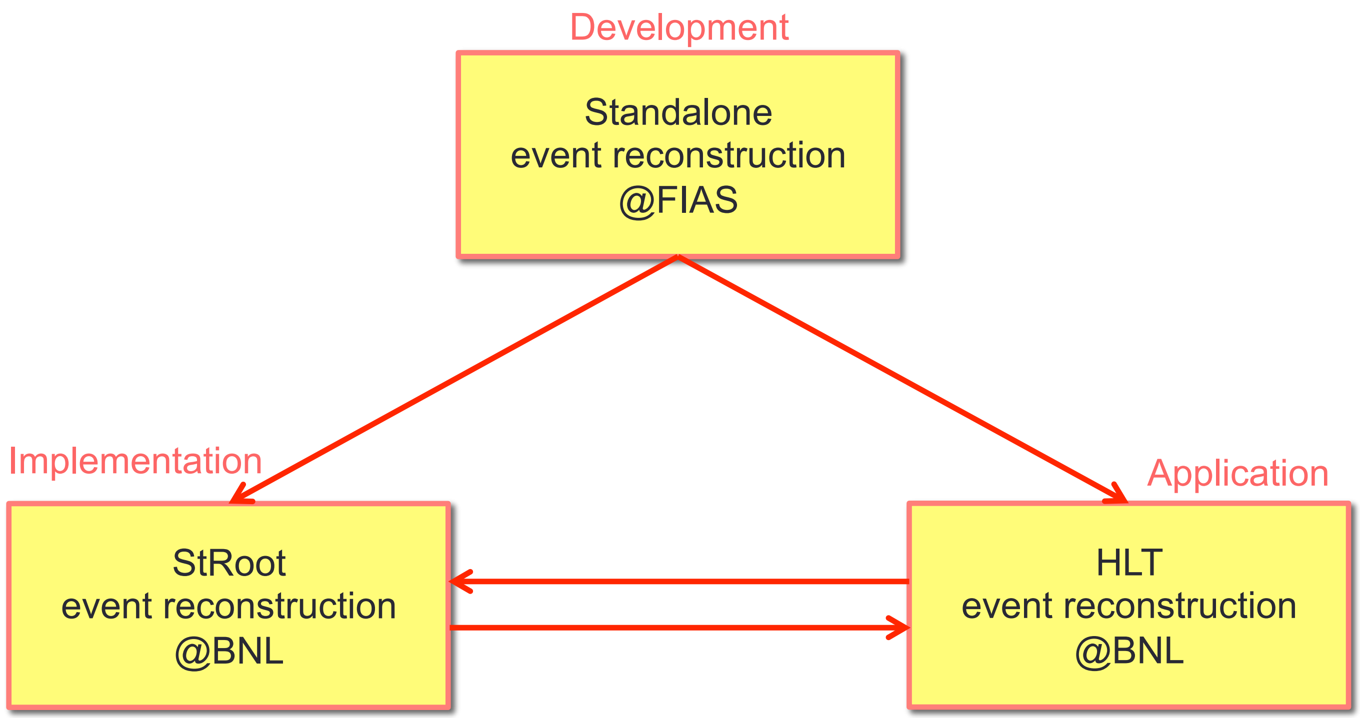
$\mathbf{r} = \{ x, y, z, p_x, p_y, p_z, E \}$

Software Conceptual Design 2017



- Fully synchronized system. All working threads are independently scheduled and workload balanced between different stages/ devices. DAQ infrastructure provided by J. Landgraf from BNL.
- Expose parallelism at difference levels, event level, within event

More Than HLT



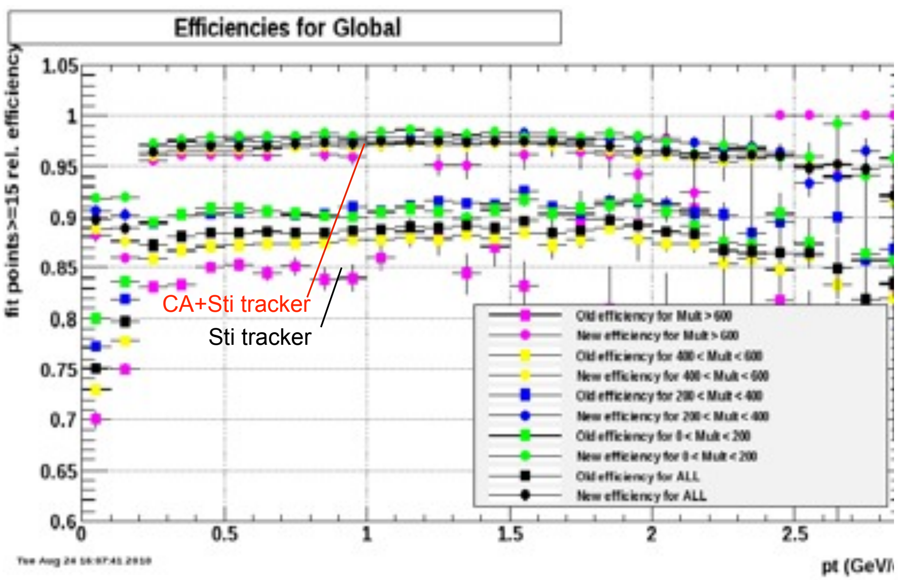
Ivan Kisel, STAR Collaboration Meeting, Berkeley, 18.10.2013

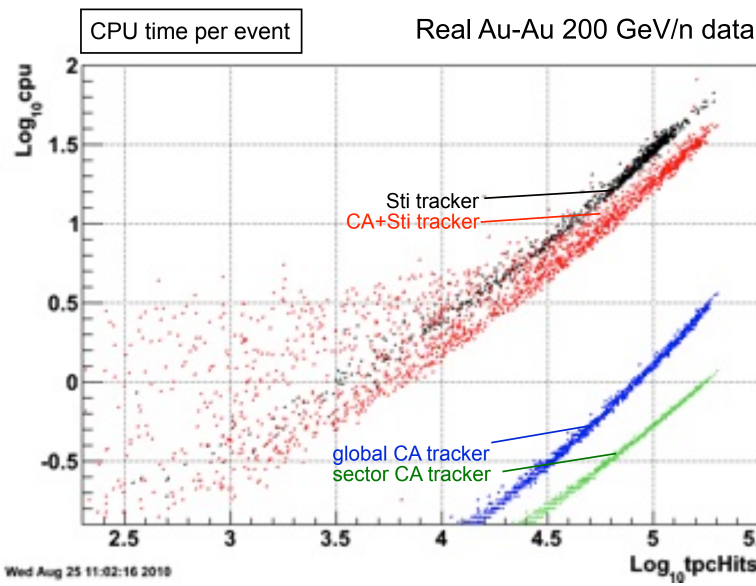
Cellular Automaton versus Track Following

The Track Following method is well suitable for simple event topologies, but suffers from large combinatorics in case of high track densities. In addition, the final efficiency of the TF method is limited by the seeding efficiency.

The Cellular Automaton method is based on local analysis of data. The CA algorithm has staged structure, therefore it accumulates continuously the tracking information while working with hits, neighbors, track segments, track candidates and tracks. In addition, CA can apply global competition at each stage of data analysis. Locality of the algorithm makes CA intrinsically parallel.

Improve the STAR tracking by integrating the CA track finder as a seed finder for Sti.





Efficiency for global tracks has been increased on 7-9%

CA+Sti is ~50% faster than Sti alone

Y. Fisyak, I. Kisel, I. Kulakov, J. Lauret, M. Zyzak, „Track Reconstruction in the STAR TPC with a Cellular Automaton Based Approach", CHEP-2010, Taipei, October 18-22, 2010

The CA track finder is more stable w.r.t. track multiplicity and is ~10 times faster than the TF based Sti track finder.

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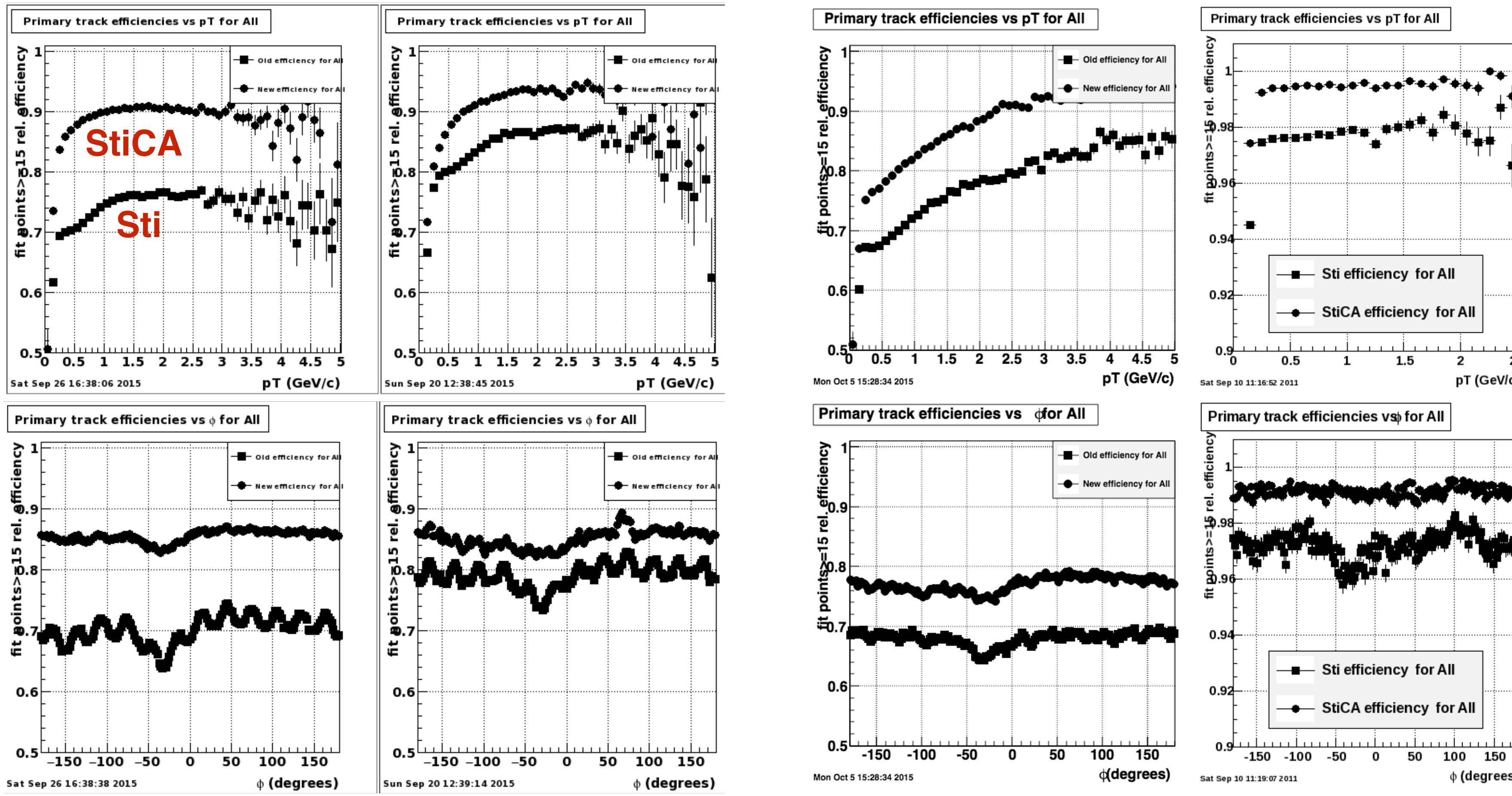
StiCA Evaluation 2015

- StiCA vs. Sti: Use CA as track finder and Sti do the track fitting as usual.

AuAu 200GeV | pp 510GeV

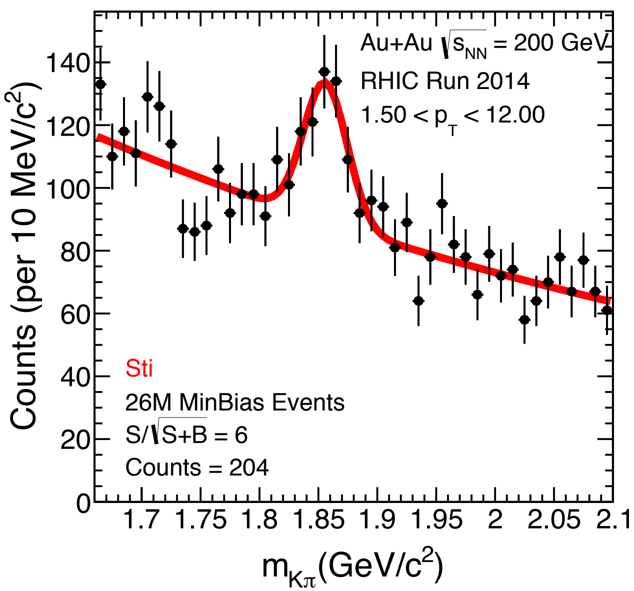
High $\mathcal{L}$ w/ HFT | Mid $\mathcal{L}$ w/o HFT | High $\mathcal{L}$ | Low $\mathcal{L}$

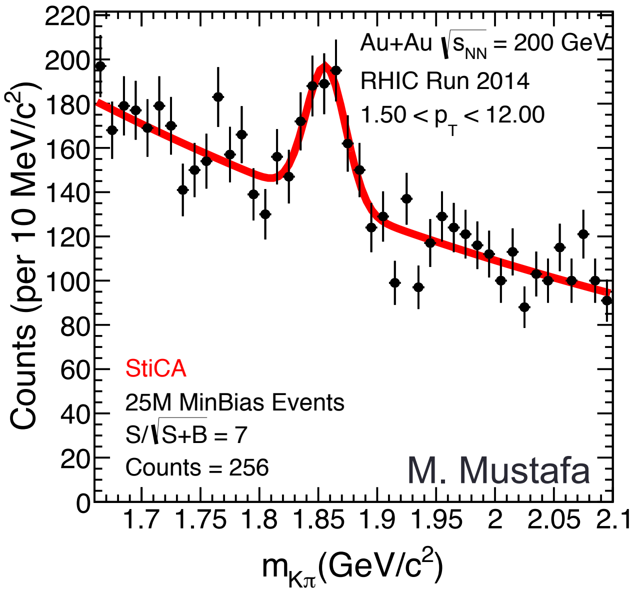


StiCA Evaluation 2015

- StiCA gives 6-12% higher tracking efficiency, depend on luminosity, than Sti in Au+Au 200GeV collisions
- StiCA gives ~8% higher tracking efficiency than Sti in p+p 510GeV collisions
- The p_T difference between Sti and StiCA is less than 3% for global tracks and no obvious difference for primary tracks
- StiCA is more stable when bad TPC sectors exist
- StiCA is the default tracker for Run16 offline data production

D^0 Production in Run14 Au+Au 200GeV

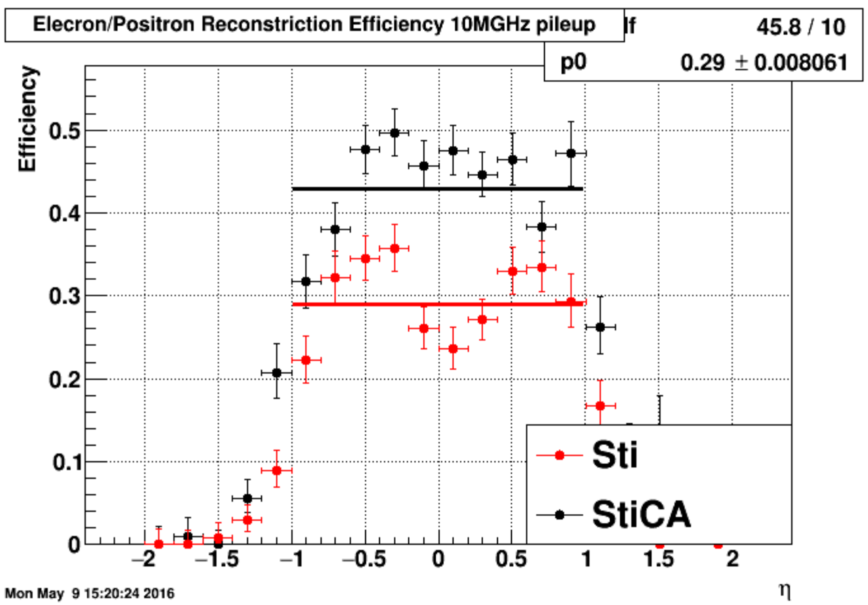


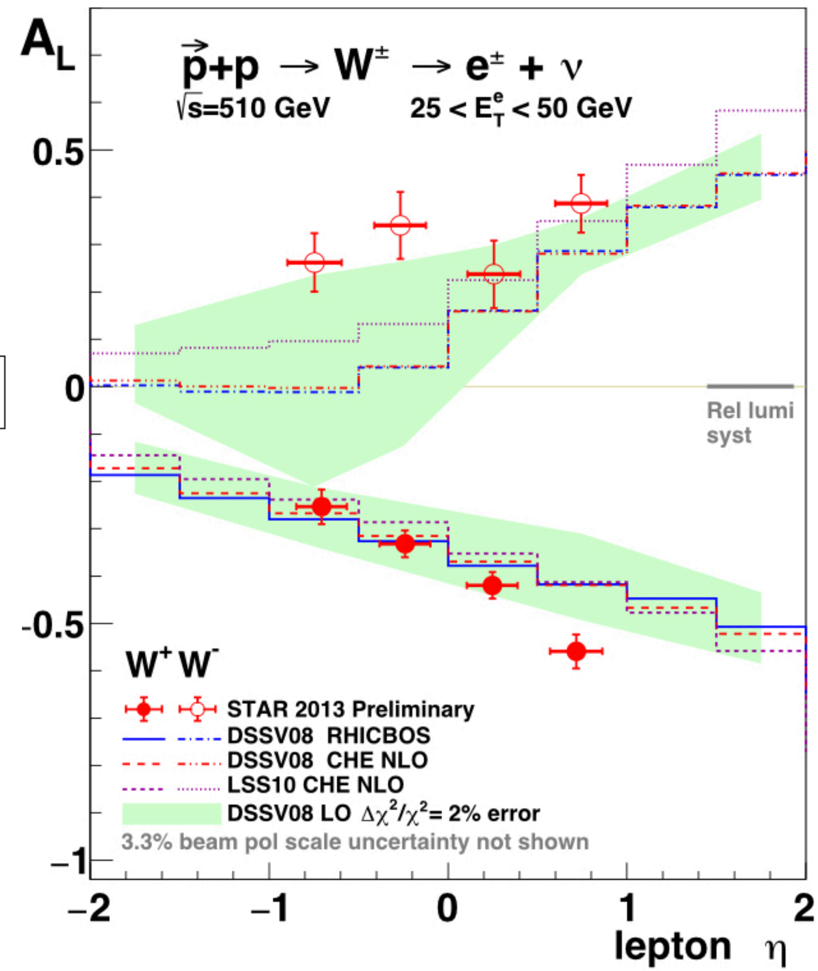


- Run14 Au+Au @ 200 GeV, 25M events production sample
- StiCA gives ~25% more D^0 count with better S/B ratio

Single-spin Asymmetries A_L for $W^{\pm}$

- Run13 longitudinally polarized p+p @ 510GeV
- StiCA provides 20+% W
- With StiCA the “eta-dip” at high luminosity is not observed





D. Gunarathne

RHIC Beam Use Request for Run17

- Transversely polarized *p+p* @ 510GeV
- Requested luminosity increase 10% in terms of ZDC rate

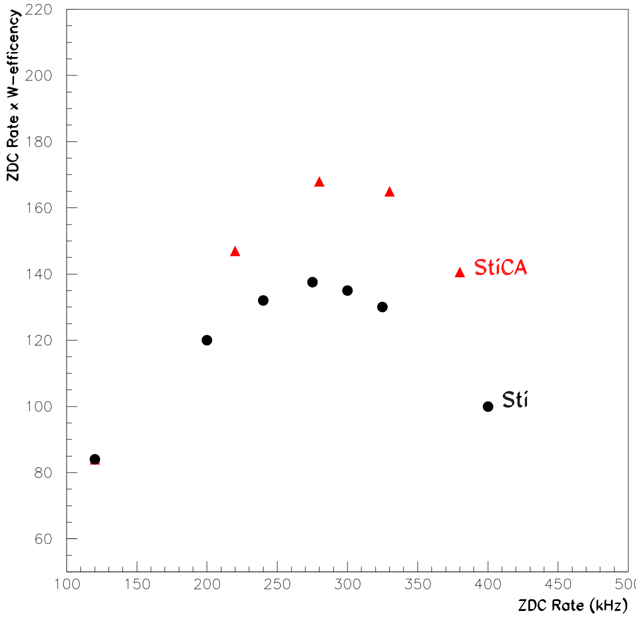
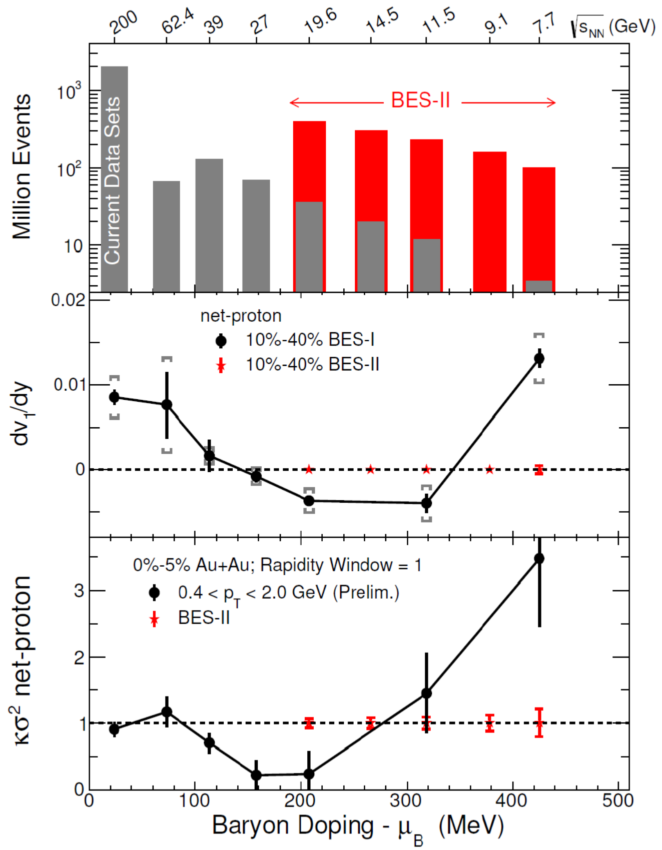


Figure 4–4: The FoM to reconstruct W-bosons in STAR as function of the ZDC raw rate. The W-boson reconstruction efficiency was obtained from the data measured in 2011 to 2013. The highest FoM is reached at a ZDC rate of 330 kHz corresponding to a luminosity of 1.5 x 10^{32} $cm^{-2}s^{-1}$.

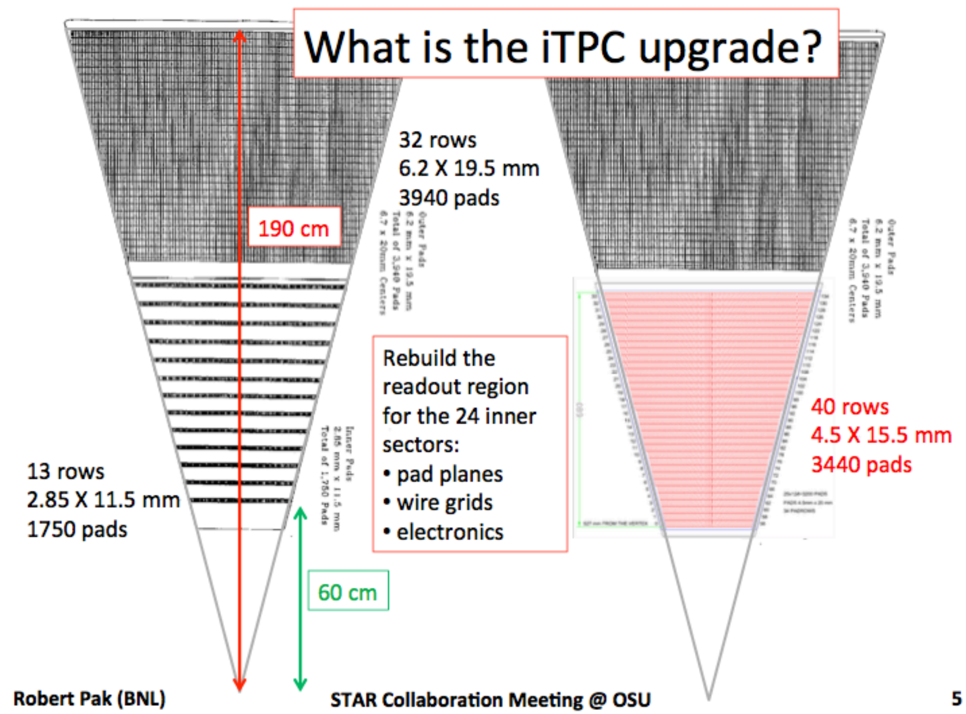
RHIC BES-II

Table 2. Event statistics (in millions) needed for Beam Energy Scan Phase-II for various observables.

Collision Energy (GeV)	7.7	9.1	11.5	14.5	19.6
μ_B (MeV) in 0-5% central collisions	420	370	315	260	205
Required Number of Events	**100**	**160**	**230**	**300**	**400**

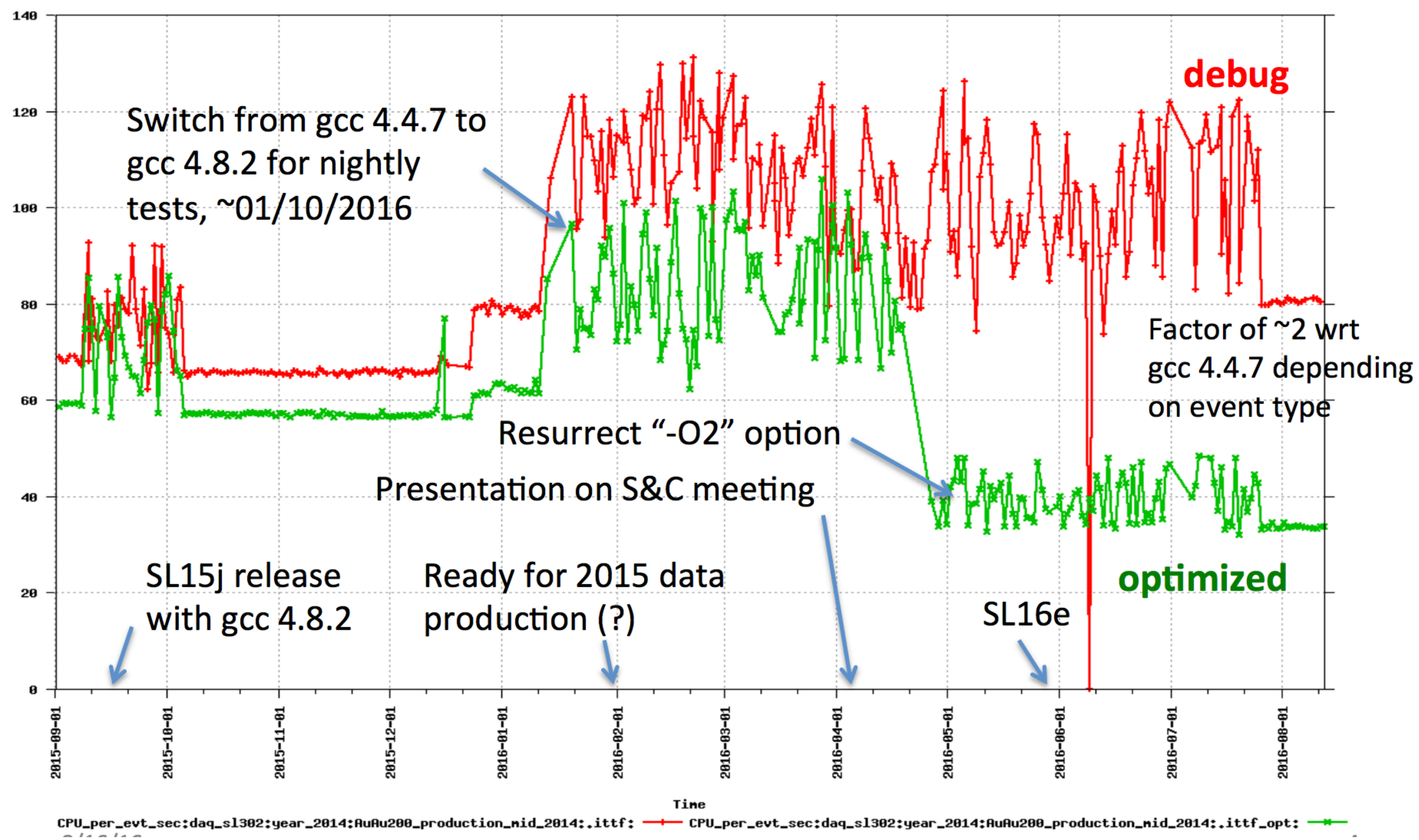


- iTPC extent eta coverage
- 45 pad rows to 72 pad rows



- The 2015 Long Range Plan for Nuclear Science
- Studying the Phase Diagram of QCD Matter at RHIC, BES-II Whitepaper

Current BFC Performance



- Au+Au @ 200GeV
- ~40s per event

- Au+Au @ 62GeV
- ~7s per event
- ~39GeV during BES-II ?

- 70+% time spend on tracking, CA tracking finding + Sti track fiting

Available HLT Resources

✧ **Total Computing Resources**

- **1192** CPU logical cores
- 45 Xeon Phi 7110P Coprocessors (2 per node, each has 240 hardware threads, 16GB RAM)
- Up to 48T disk storage for online calibration, QA and etc.

✧ During BES-II

- ~200 CPU cores for real time processing, e.g. PV monitoring
- ~1000 CPU cores + Xeon Phi for BFC chain
- Continuous running without sync. to DAQ
- need a large buffer
- need to develop a job management system, including job monitoring, submission, bookkeeping, error handling ant etc.
- Expect low luminosity, especially TPC space charge will not be a problem

Potential Speed Improvements

- (An ambitious) HLT goal for BES-II is to provide offline quality data practically online. STAR cannot afford ~5 years of data reconstruction and analysis before publishing the first BES-II results. For that we need speed up calibration and reconstruction.

- New compiler
- Pure 64bit code
- Use AVX instructions in CA
- CA sector-by-sector track finding on Xeon Phi
- Full CA tracking including track fitting
- Hopefully 3-5x speedup

- Need more realistic timing and profiling with iTPC
- Single event processing time budget depends on DAQ running time.

Summary

- Collaboration between STAR and CBM has been very fruitful within STAR High-Level Trigger and Tracking Focus Group. We expect it will be even more fruitful in BES-II era.

- It is demonstrated that we can deliver important physics fast with the STAR HLT

- Our working experiences with HLT and TFG benefit both online and offline computing

- Looking forward for the BES-II