HLT and CA Tracker

STAR High-Level Trigger & STAR Tracking Focus Group

Aihong Tang

Outline

- ❑ STAR High Level Trigger
  - History
  - CA tracker (online tracking & offline as seeding)
  - Infrastructure
- ❑ HLT Spring/Summer 2017 activities
- ❑ Plan for BES-II

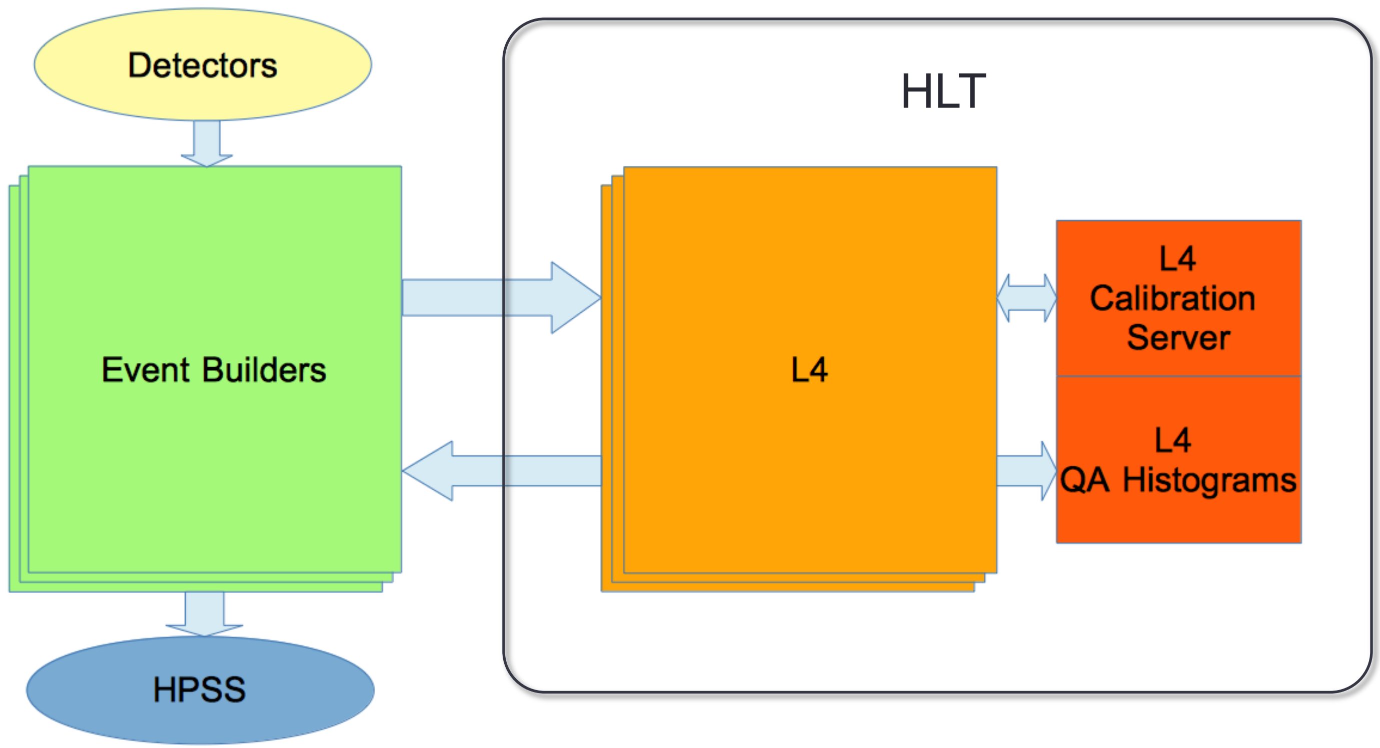
STAR HLT History

- STAR Level-3 trigger system (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) – Independent farm sponsored by NSFC. 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

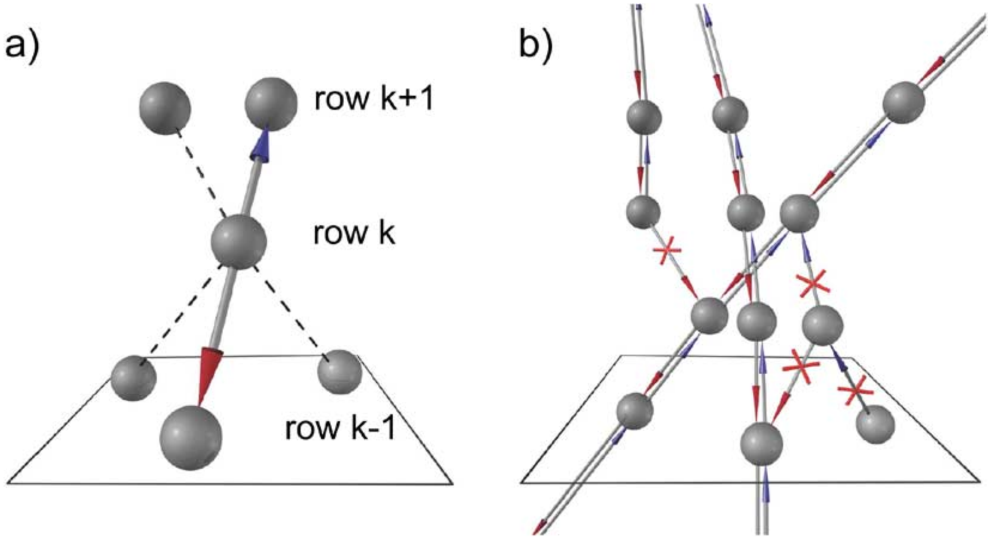
- HLT 3.0 (2017 –) – Balance the total throughput of ~1k CPU threads and ~10k Phi threads. Decompose the HLT task into independently schedulable sub-tasks and hide the details of Phi from DAQ side.

Integration with DAQ

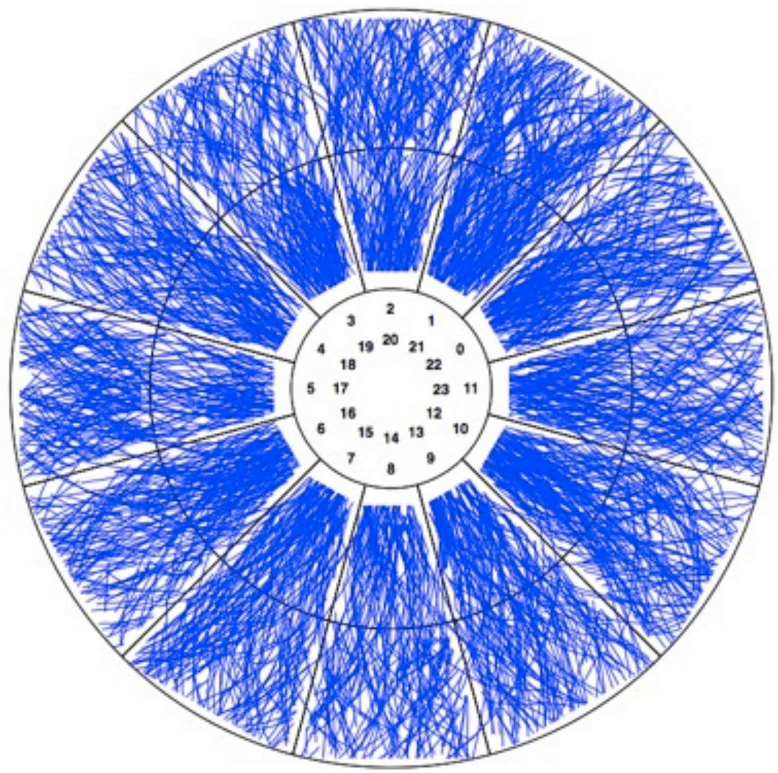


- STAR HLT use high performance computers to do real time event reconstruction and analysis
- Provide additional event selection capability based on physics analysis on top of hardware trigger layers

Cellular Automaton Tracker



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



STAR AuAu 200GeV Run11

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

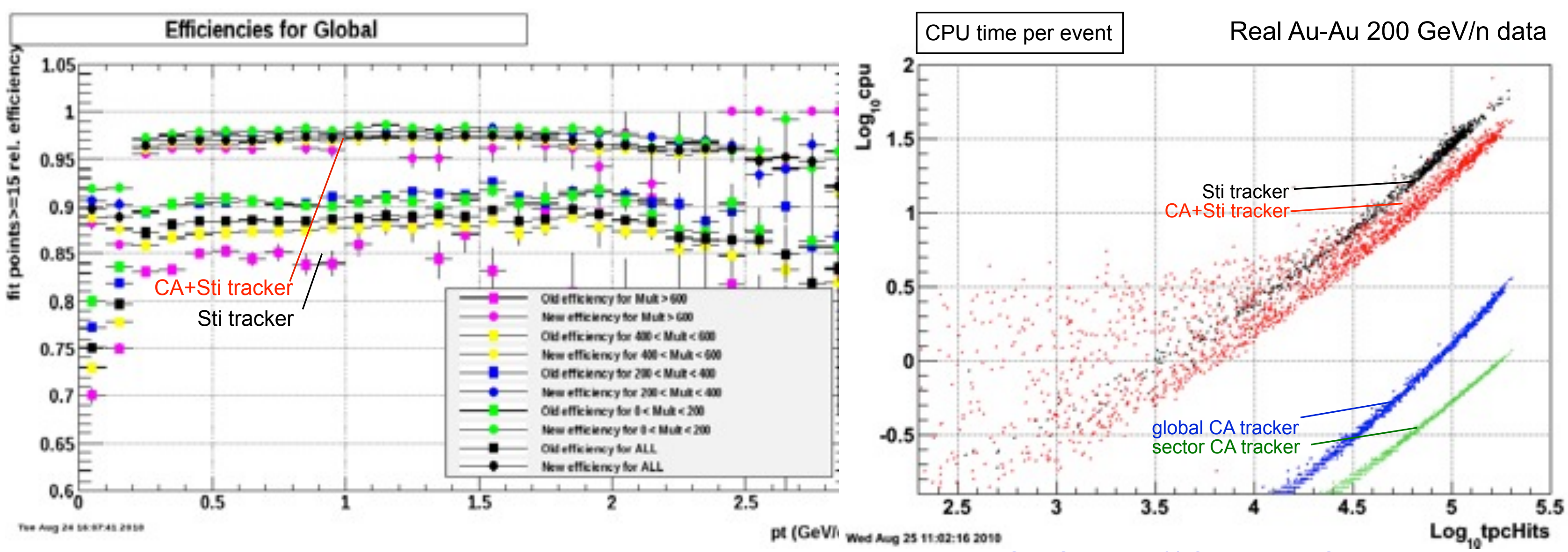
S. Gorbunov et al. Real Time Conference (RT), 2010

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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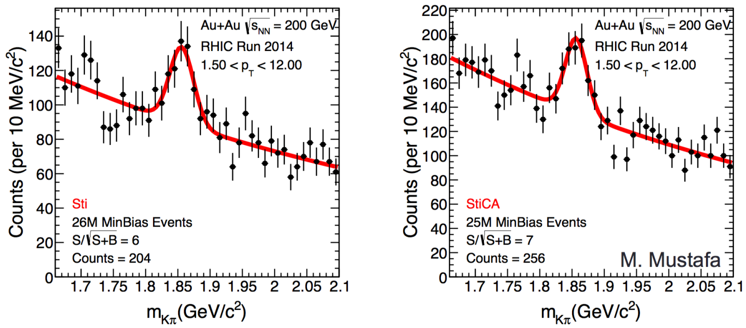
D^0 Production in Run14 Au+Au 200GeV



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

M.Mustafa & X. Chen

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

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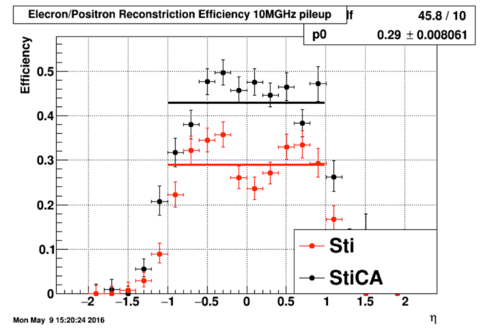
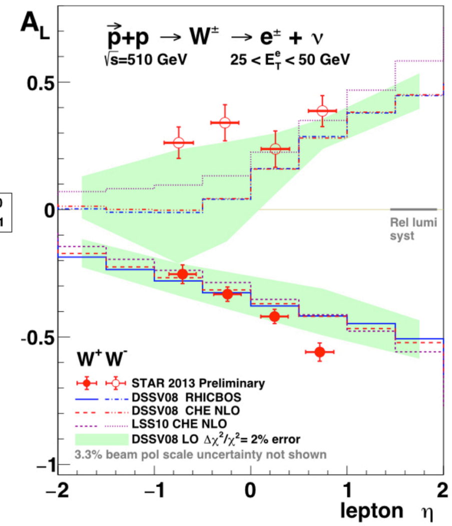
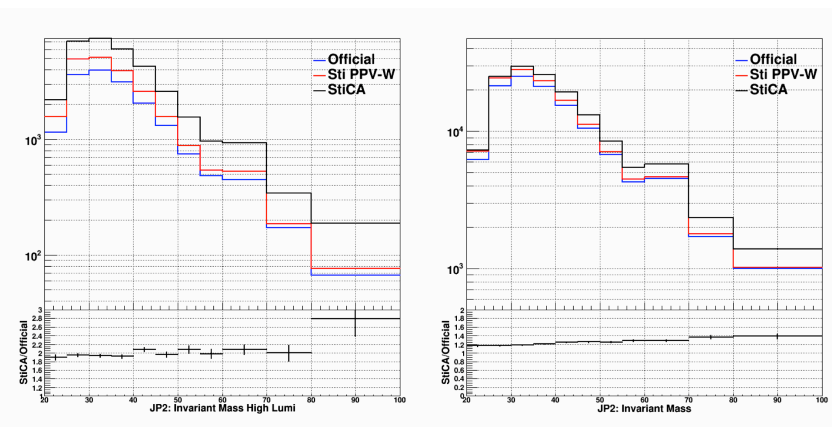




Devika Gunarathne

Di-jet observables

JP2 Mass Distribution



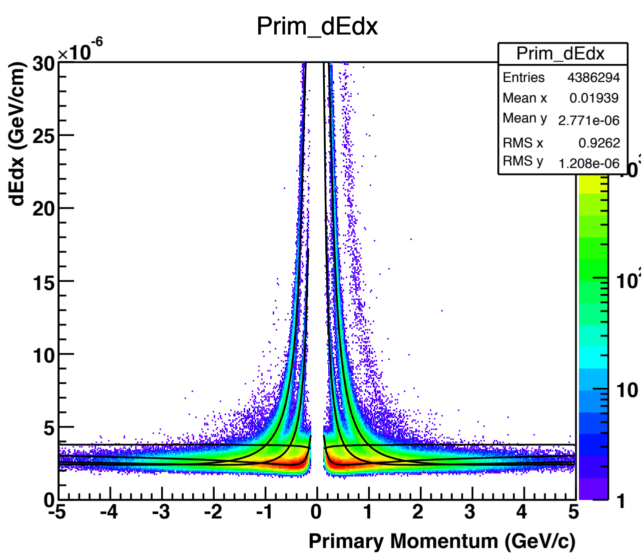
- Approx. twice the statistics at high luminosity
- Across the fill ~30% increase in statistics

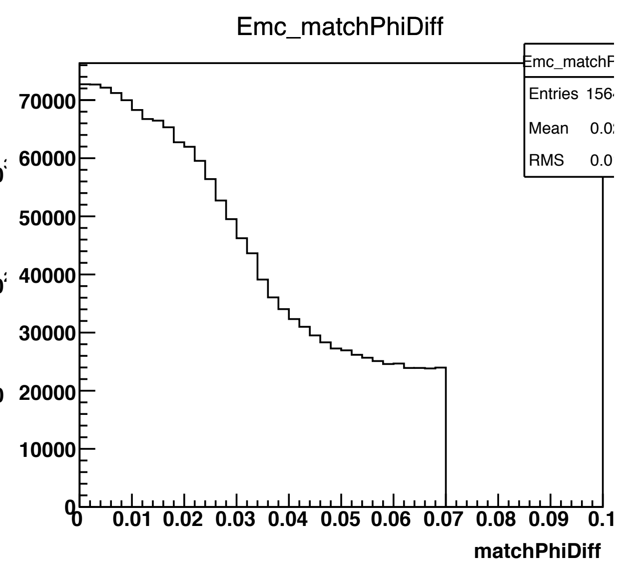
Daniel Olvitt

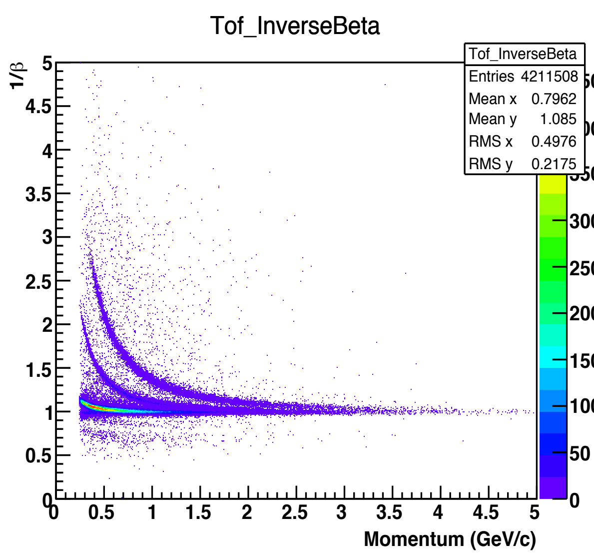
- StiCA gives 6-12% higher tracking efficiency, depend on luminosity, than Sti in Au+Au 200GeV collisions
- StiCA gives ~8% higher tracking efficiency than Sti in p+p 510GeV collisions
- The p_T difference between Sti and StiCA is less than 3% for global tracks and no obvious difference for primary tracks
- StiCA is more stable when bad TPC sectors exist
- StiCA is now the default tracker for Run16/17 offline data production

Particle Identification

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

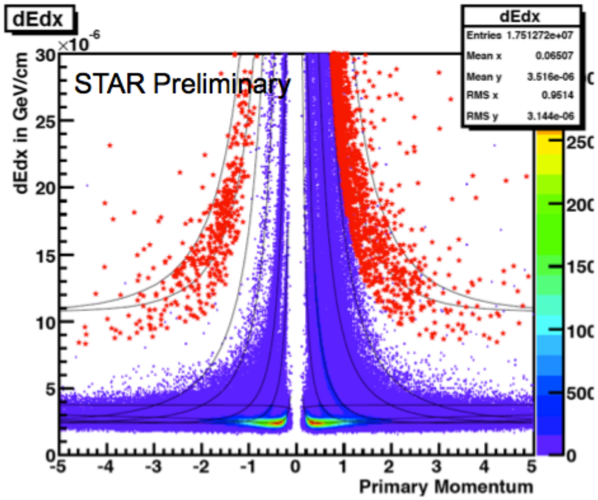


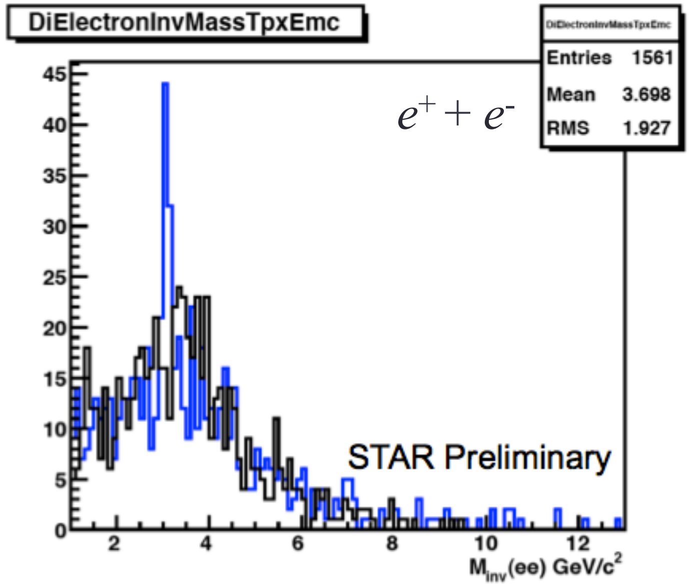




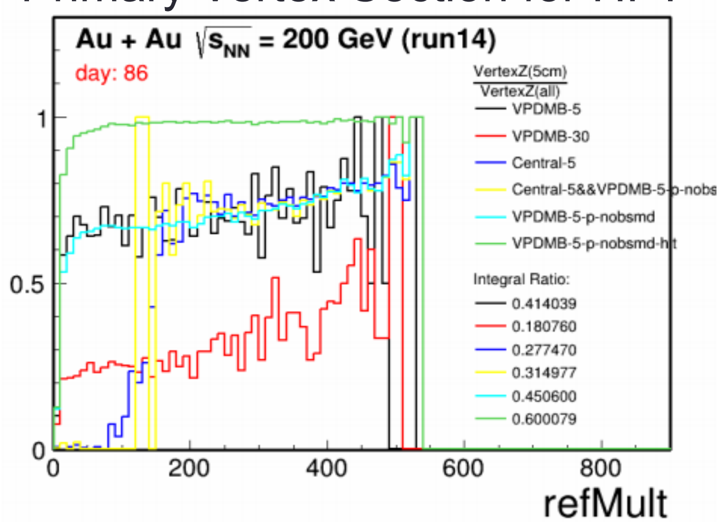
Selected HLT Trigger Algorithms

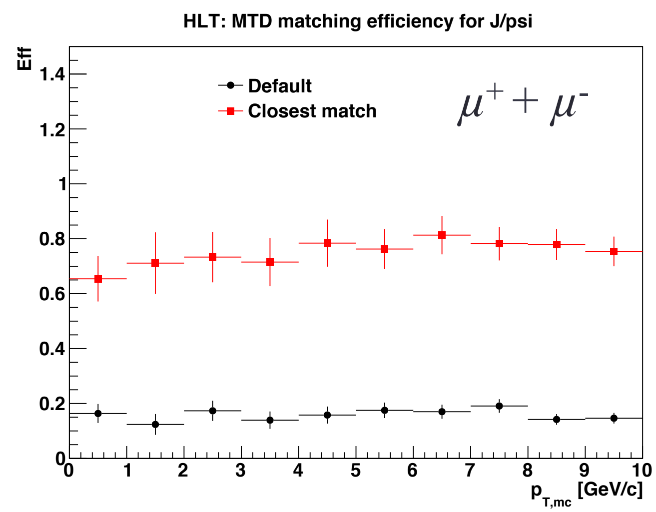
Heavy fragments, e.g. anti-^{4}He





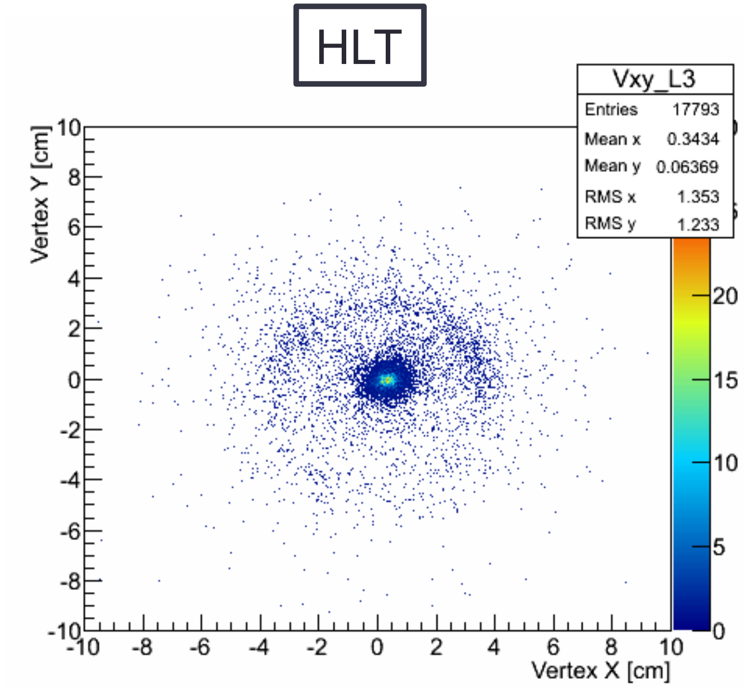
Primary Vertex Section for HFT

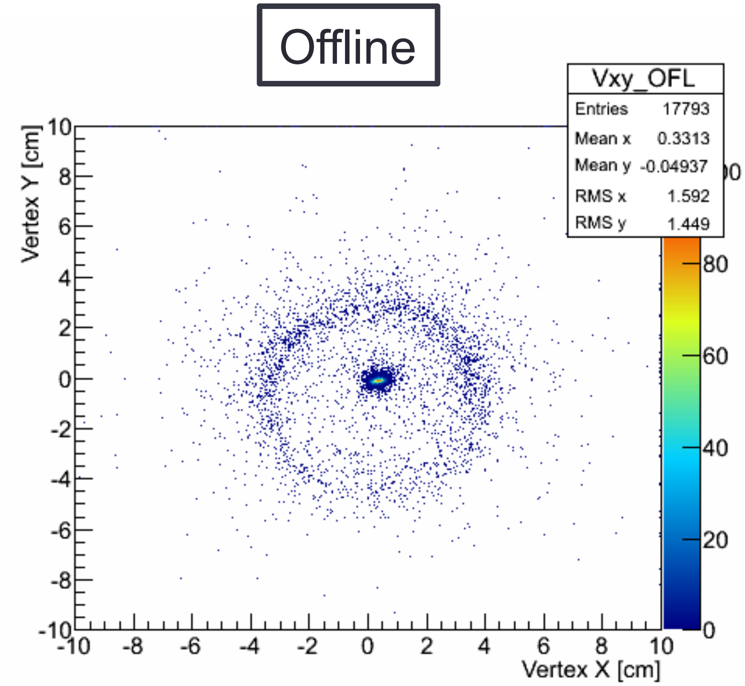




Beam Line Monitoring

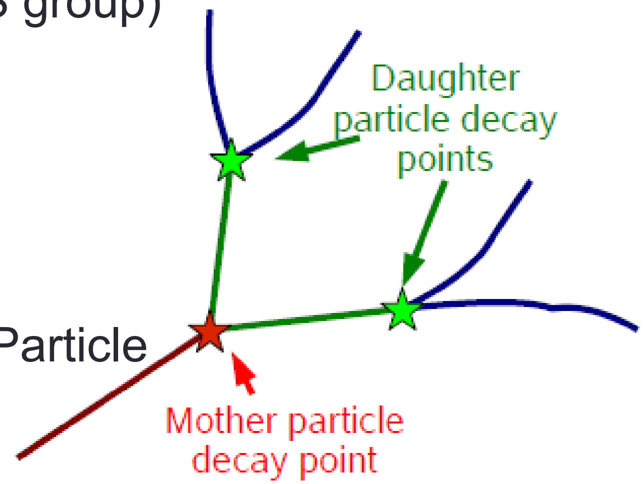
- Online 3D primary vertex reconstruction
- Real time beam position monitoring in RHIC low energy runs
- Reject background
- Live feedback to CA for accelerator monitoring and performance tuning
- Benefit all BES-I physics analyses
- Likely to be used again in BES-II

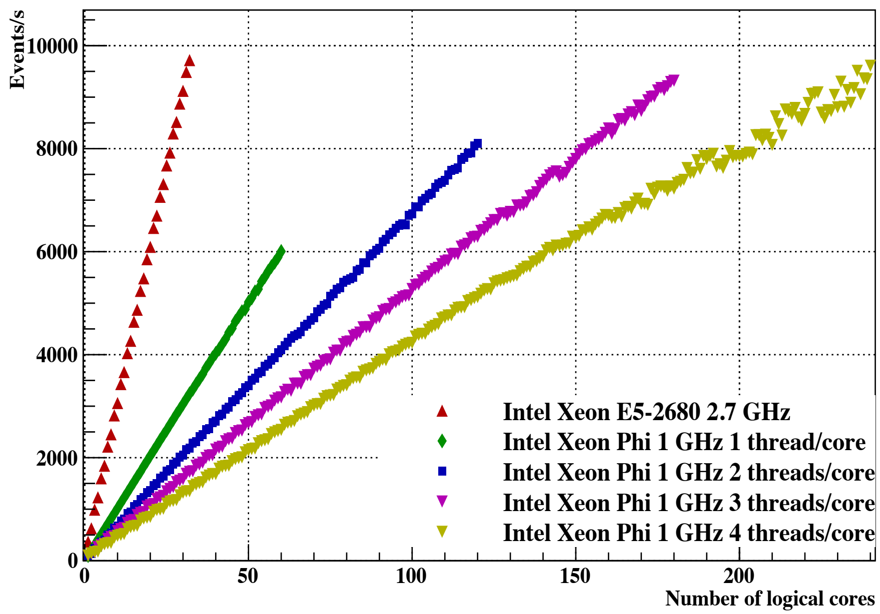




KFParticle and Xeon Phi Coprocessor

- 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





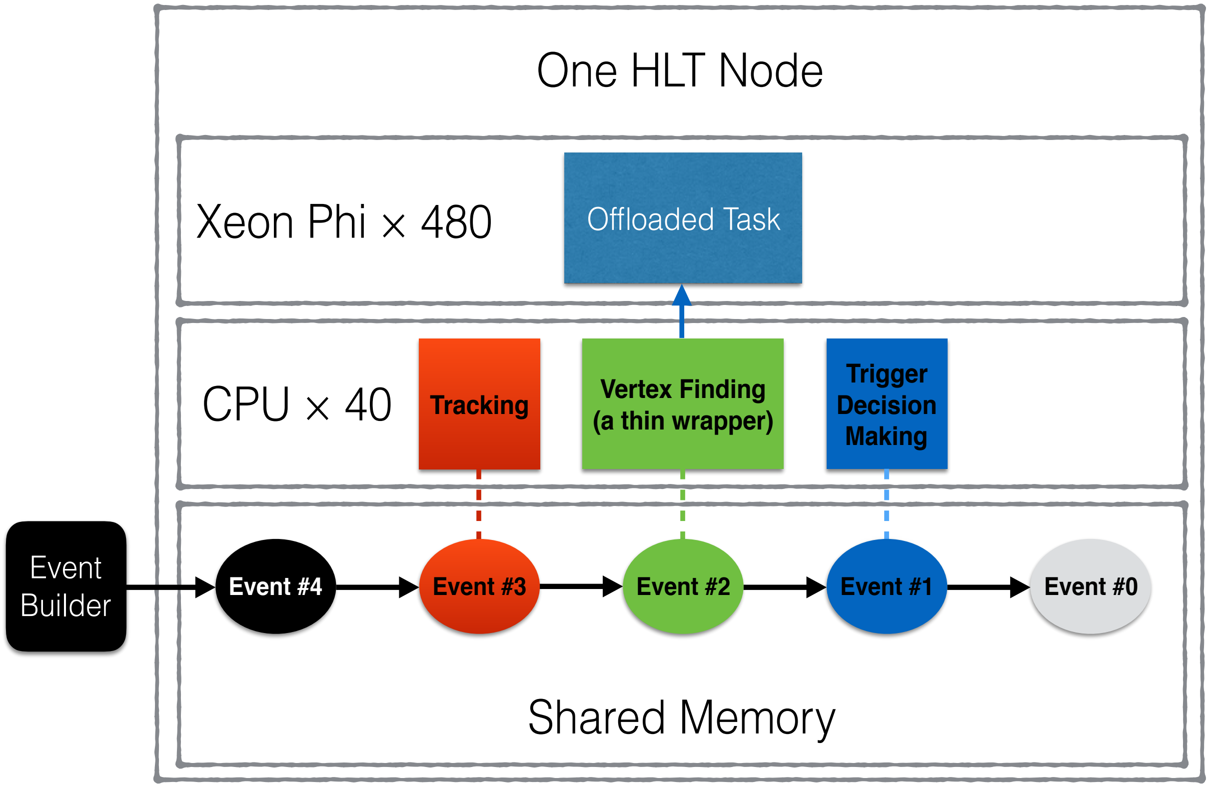
State vector

Position, direction and momentum

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

See M. Zyzak's talk

Infrastructure Reshape in 2017

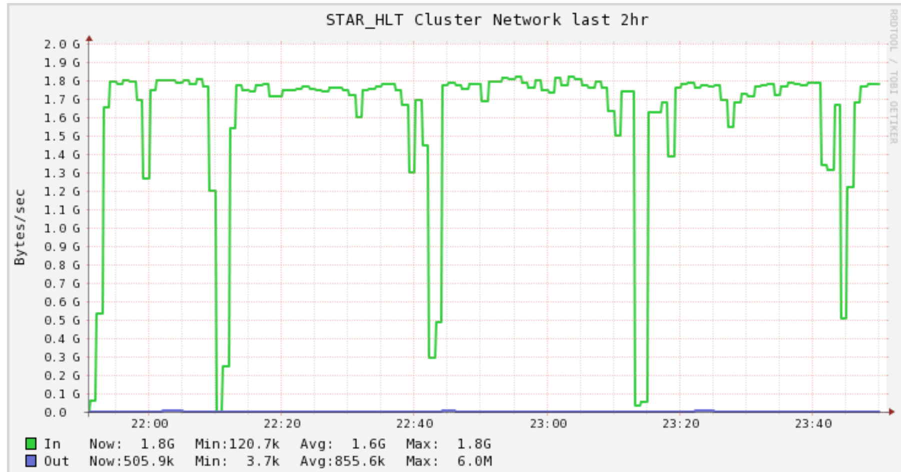


- Fully synchronized system. All working threads are independently scheduled and workload balanced between different stages/ devices. DAQ infrastructure provided by J. Landgraf from BNL.
- Expose parallelism at difference levels, event level, within event

J. Landgraf and H. Ke

HLT Data Taking in Year 2016

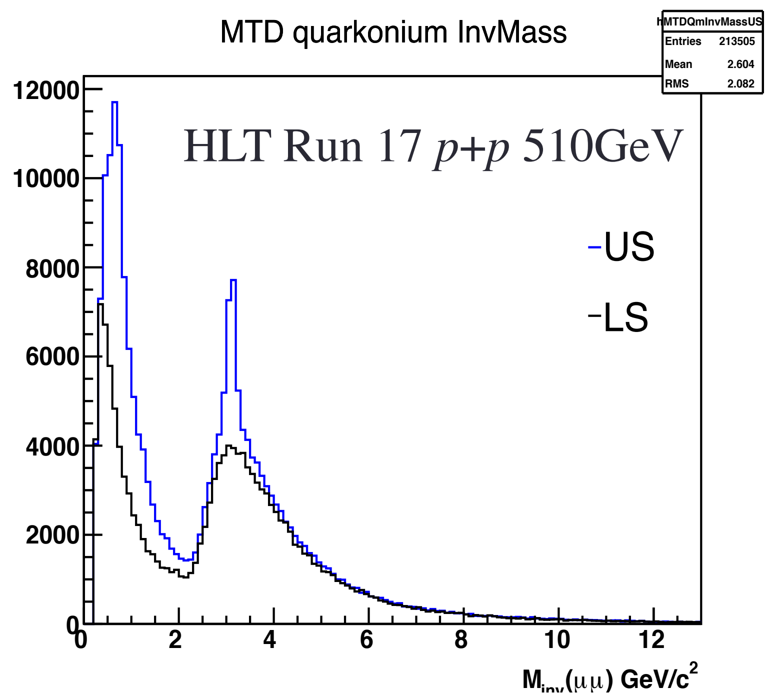
- HLT process almost all of the data taking by DAQ at 1700+Hz, 1.7+GB/s input data
- ~1000Hz Mini-Bias
- ~700Hz MTD (tracking 6-8 sectors)
- < 40% CPU load



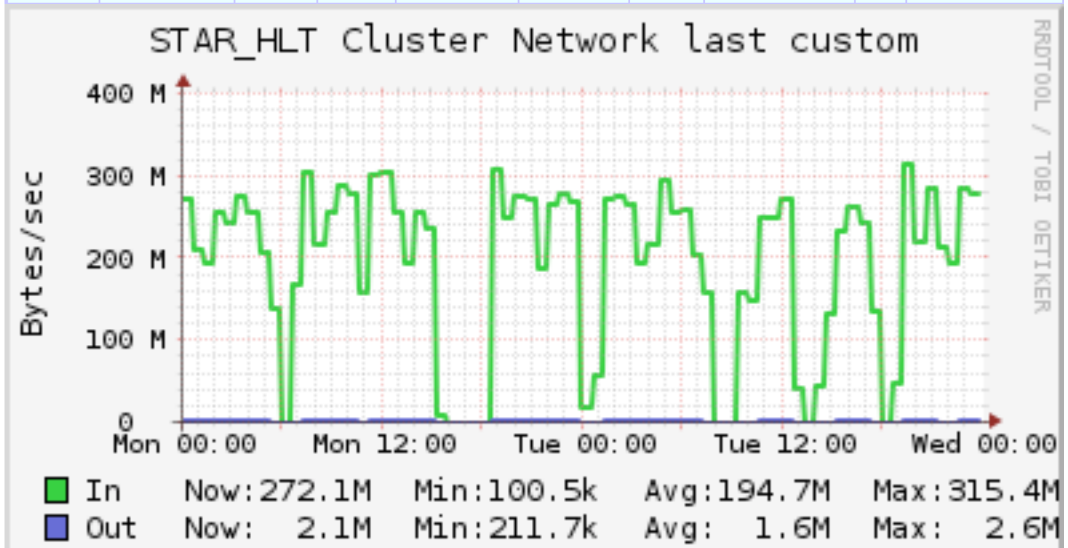
Det	State	Dead	CPU	Evts	Evts In	Hz	MB/s EVB	Err	MB/s RDO
TOF	RUNNING	10 %	15 %	459762	1	1777	21.6	1	21
BTOW	RUNNING	4 %	14 %	459634	0	1784	17.5	2	17
Trigger	RUNNING	0 %	-1 %	601598	-16787624	2277	16.9	0	0
ETOW	READY	0 %	0 %	171381	0	0	0.0	0	0
BSMD	RUNNING	5 %	18 %	33505	0	150	1.0	0	11
ESMD	READY	0 %	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

HLT Data Taking in Year 2017

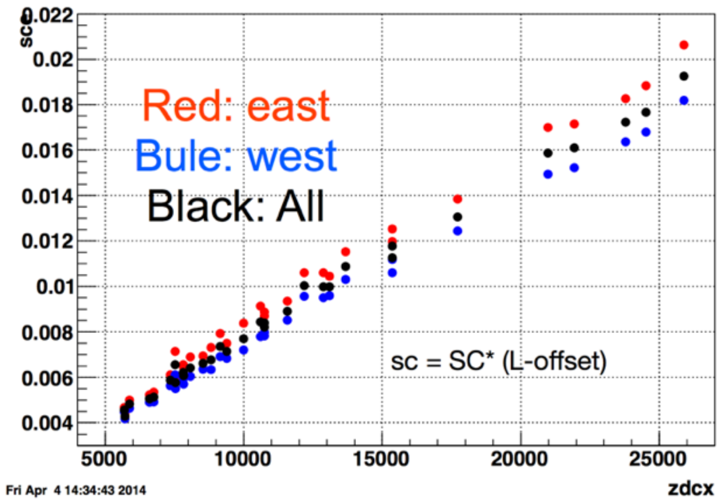
- MTD di-muon quarkonium selection
- Partial TPC tracking, < 300Hz
- TPC-MTD matching
- Selection rate ~1%

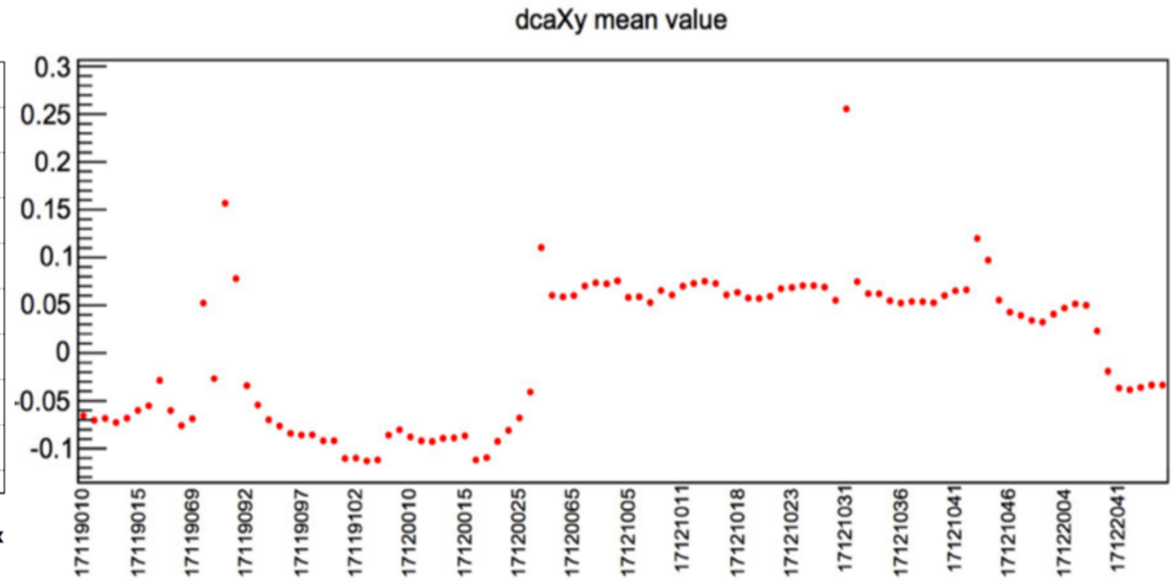


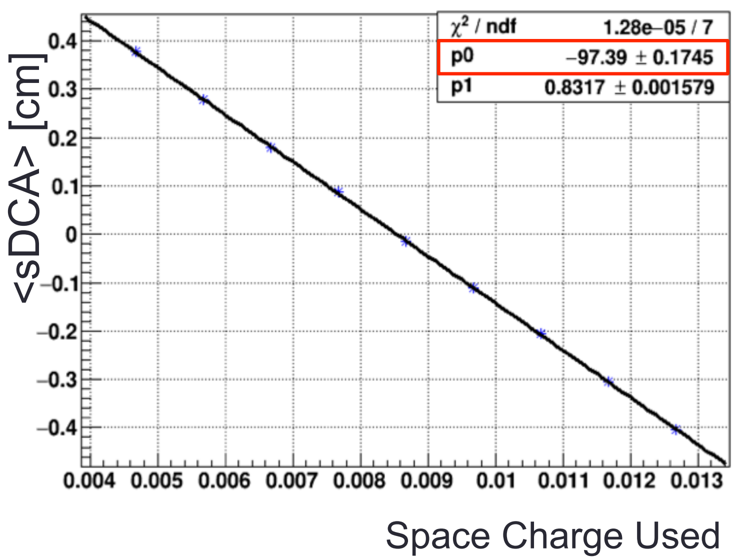
Det	State	Dead	CPU	Evts	Evts In	Hz	MB/s EVB	Err	MB/s RDO
TOF	RUNNING	7 %	15 %	110272	0	2219	9.1	0	9
BTOW	RUNNING	9 %	15 %	188009	0	3778	37.0	0	37
Trigger	RUNNING	0 %	-1 %	205248	1	4117	14.8	0	0
ETOW	RUNNING	9 %	14 %	187142	0	3766	7.9	0	8
PP2PP	RUNNING	16 %	54 %	66130	0	1308	3.2	0	2
BSMD	READY	0 %	0 %	0	0	0	0.0	0	0
ESMD	RUNNING	10 %	56 %	187929	0	3770	70.0	0	70
TPX	RUNNING	11 %	87 %	75168	19	1505	1573.0	5	15766
MTD	RUNNING	4 %	13 %	72830	0	1473	1.5	0	1
GMT	RUNNING	2 %	13 %	15362	0	312	7.5	0	7
L4	RUNNING	0 %	0 %	0/13414	20	280	300.5	0	301
FPS	RUNNING	0 %	56 %	155514	0	3112	4.5	0	4
RHICF	READY	0 %	0 %	404	0	0	0.0	0	0
ETOF	RUNNING	2 %	40 %	73696	0	1482	0.6	0	0
FCS	RUNNING	0 %	10 %	334	0	6	0.0	0	0
iTPC	RUNNING	0 %	6 %	2424	0	29	0.0	0	0



Spring/Summer activities :TPC Space Charge Calibration (AuAu)







- TPC SC calibration needs to be done once at the very begging of each run for HLT and fast off-line production
- It needs to be done multiple times during the run if things get bad
- <sDCA> as a function of SC offset has a almost universal relationship, which can be used for self-calibration.

Making the SCC automatic

$$\langle DCA_{xy} \rangle = a \cdot SC + b$$

$$SC_{k+1} = SC_k - \frac{\langle DCA_{xy} \rangle_k}{a}$$

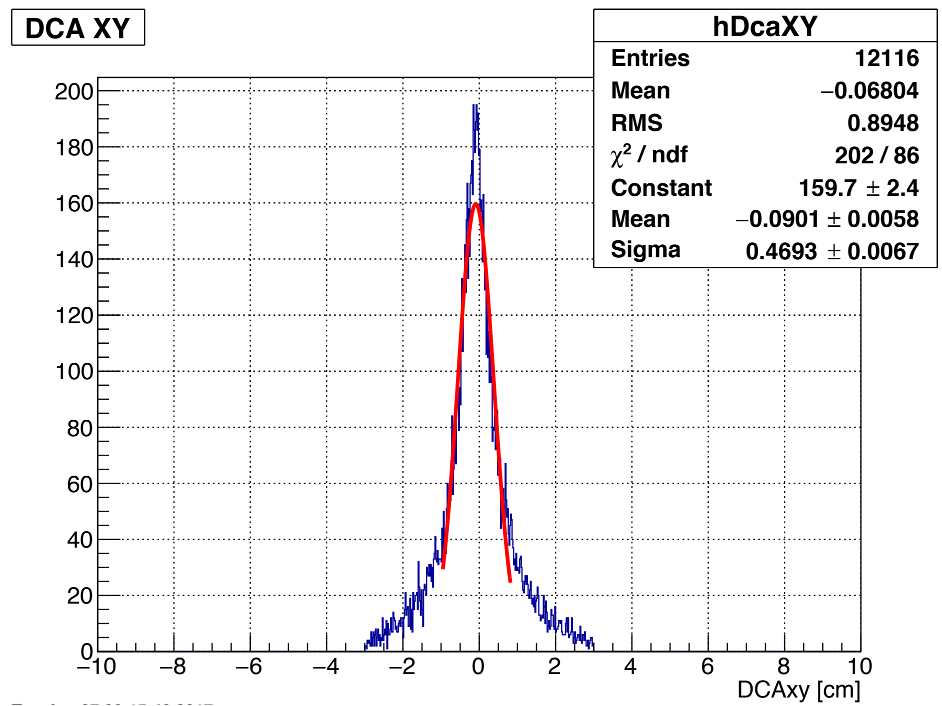
$$a \approx -100 \text{ for Au+Au 200 GeV}$$

Assumption:

- True SC stays the same at t_k and t_{k+1}

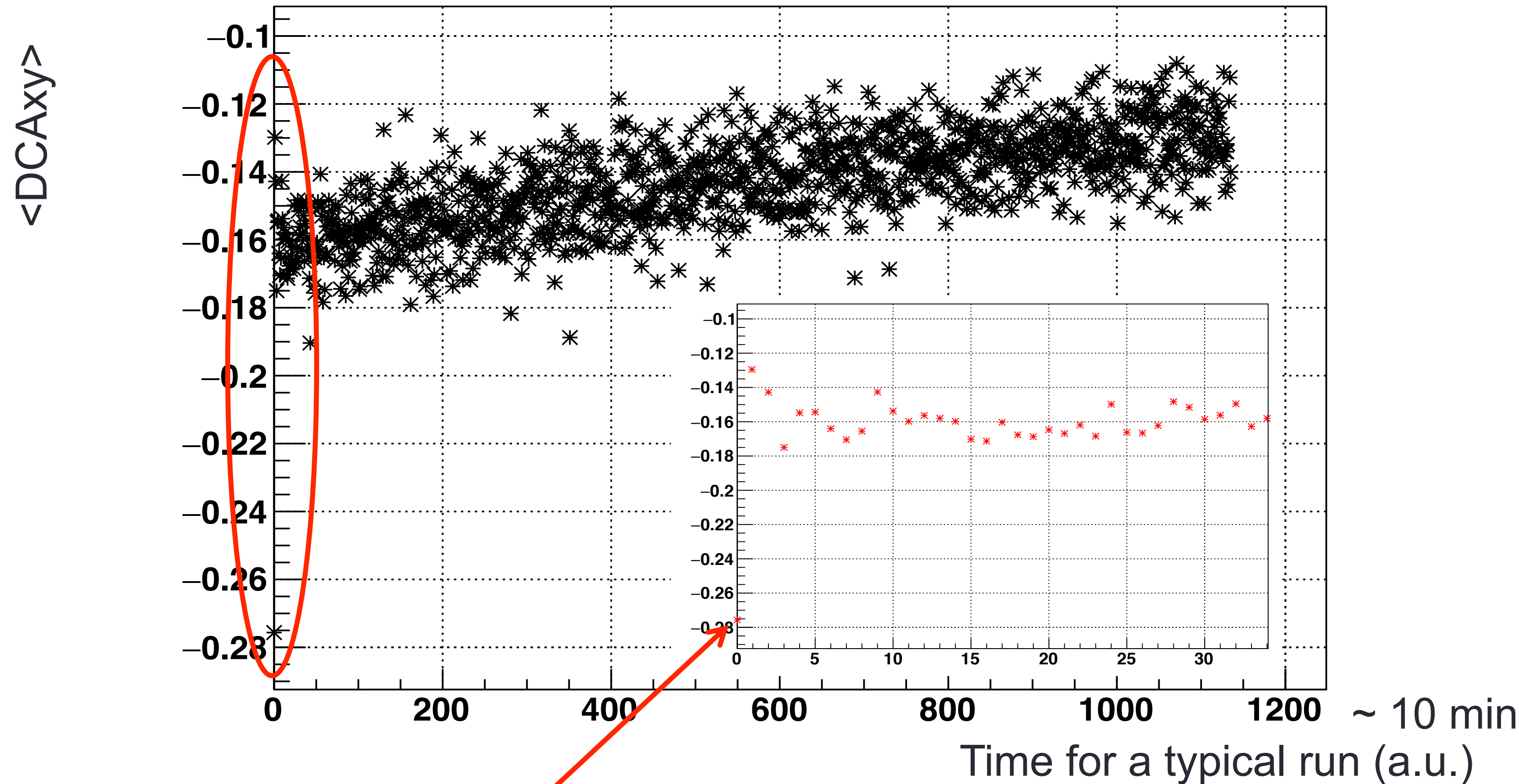
Reality:

- At Au+Au 54 GeV, ZDCx changes in a fraction of a second
- Need to fit multiple times in a second
- HLT run at ~1500 Hz
- Fit once every 2000, 500, and 200 events



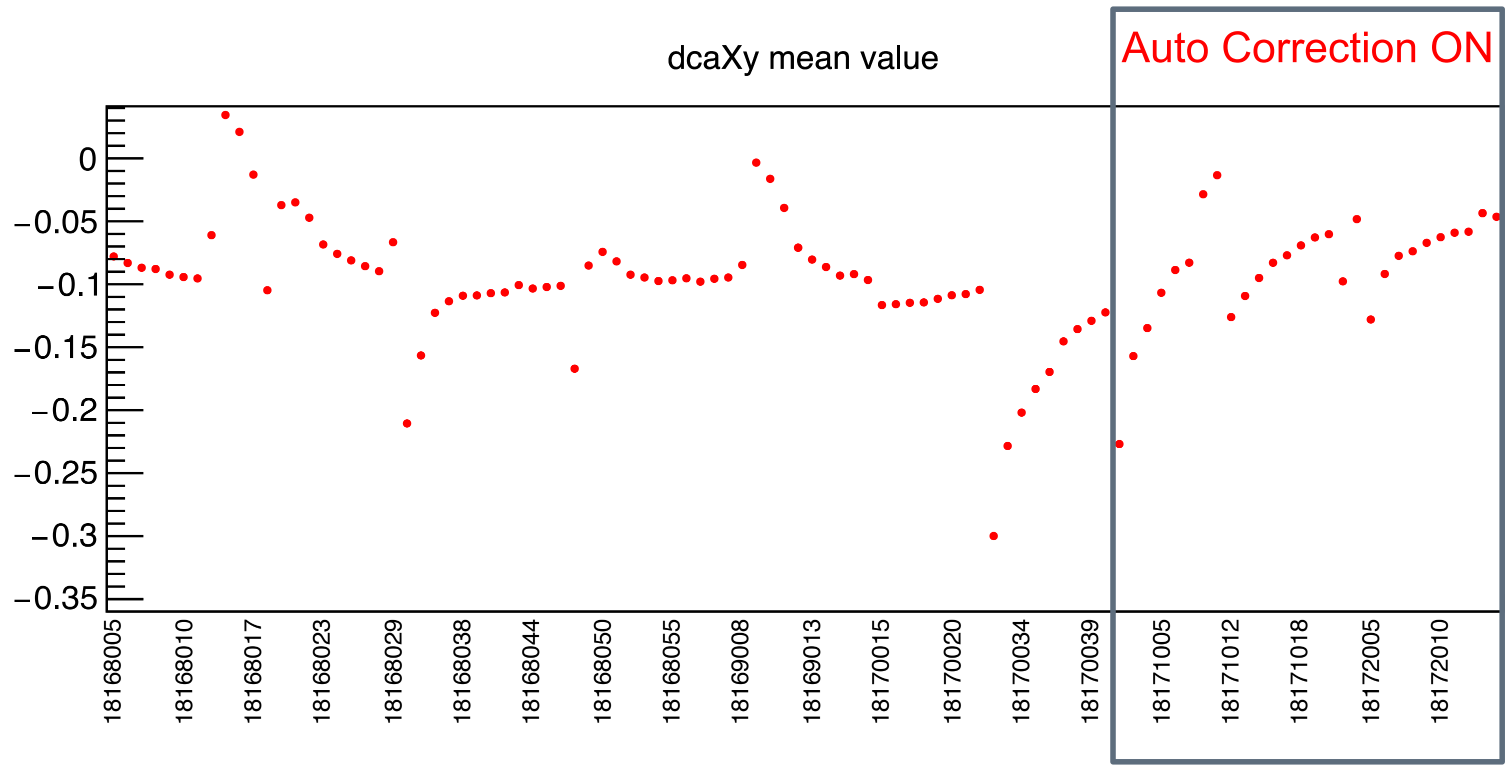
Y. Ye, H. Ke and G. Van Buren

Test for Auto-SCC in 2017



- Auto calibration has effect. Converge in no more than a few seconds.
- Long time, ~10 min, trend is dominated by the luminosity
- The yet deviating from zero and the luminosity dependence is due to the inaccuracy of the slope a in the previous page

Test for Auto-SCC in 2017

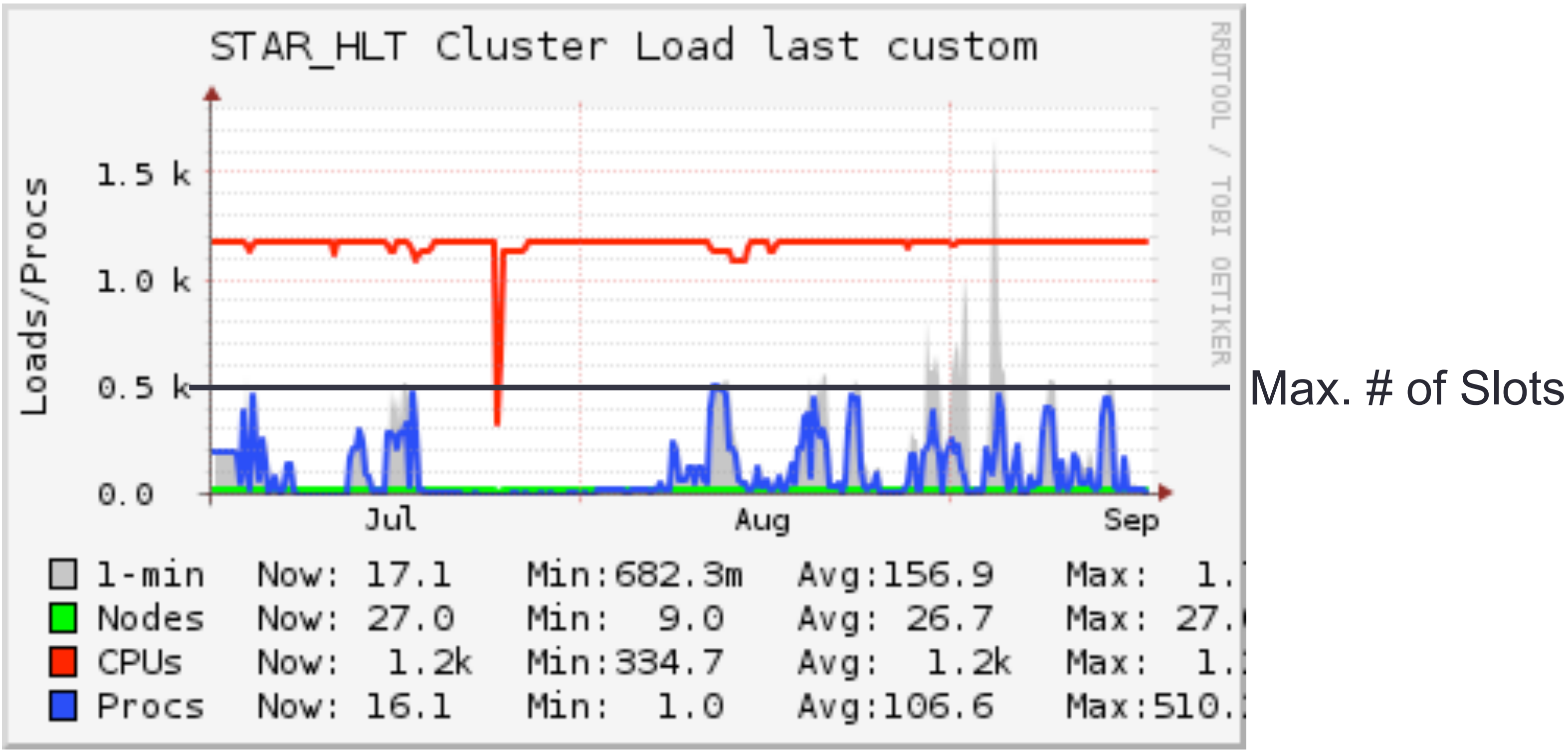


Spring/Summer activities : HLT Job Management/Sharing

- HLT Cluster Sharing Resources for Offline Production
  - ~500 job slots available for use during experiment downtime
  - Intend to share the resources with anyone
  - Wayne Betts is experimenting migrating production jobs submitted to STAR online pool to HLT cluster
    - Both two clusters are in DAQ room
    - HLT cluster has no AFS access, in general, has no network access (easy to solve, need additional cable and switch)
    - Two ways of doing this and both has been successful
      - Merge to online linux pool
      - Flock jobs, i.e. grid production
    - CephFS (massive storage) and Xeon Phi cards both require specific version of Linux kernel version. Potential conflict is under investigation.

W. Betts & H. Ke

HLT Cluster Summer Activities



- Users mainly from BNL, GSI and Czech for TFG
- ~67000 CPU hours in two weeks (as of 09/17/2017, only limited historical data available)

Plans for BES-II

- Produce picoDST online (express online production) for fast diagnostics with physics quantities, which is critical for decision making and fast turning around.

  Take advantage of otherwise mostly idling resource.
  Speed up BFC with new tracker and Xeon Phi cards.
  Gain experience for future online parallel computing.

- Prototype next year

BES-II

- Will run express online production for HLT-good events only.
- Total ~1200 slots. For HLT PV filtering : ~400 slots. For express production : 500 – 800 with all Xeon phi cards.
- Projected production CPU time per event is ~3s at 39GeV without additional optimization, i.e. 0.3Hz per slot[1]
- Total processing rate is 150-240Hz
- Targeting event rate is up to 450Hz for HLT-good events[2]
- Looking for a 3x speed-up

- 25-30TB buffer needed for buffering one days' data, assuming DAQ runs 16hr per day at 450Hz "HLT good events"

- Require a copy of all "HLT Good Event", which is additional pressure to the DAQ network and CPU power, especially the later is already stretching

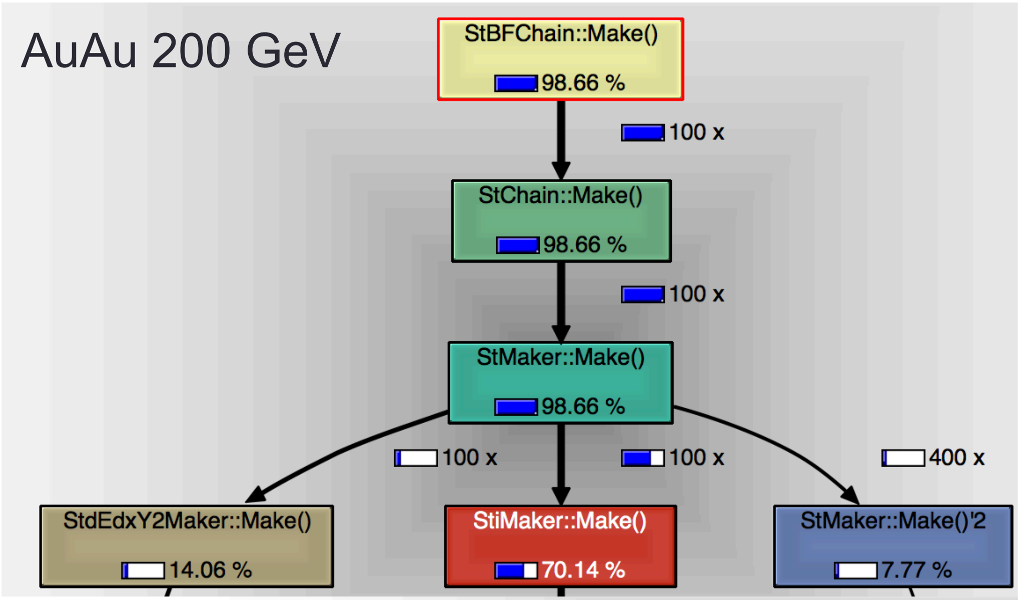
[1]Energies for BES-II are below 20 GeV, here we use 39 as baseline is to take into account the ~50% event size increase due to iTPC.
[2]From D. Cebra's estimation.

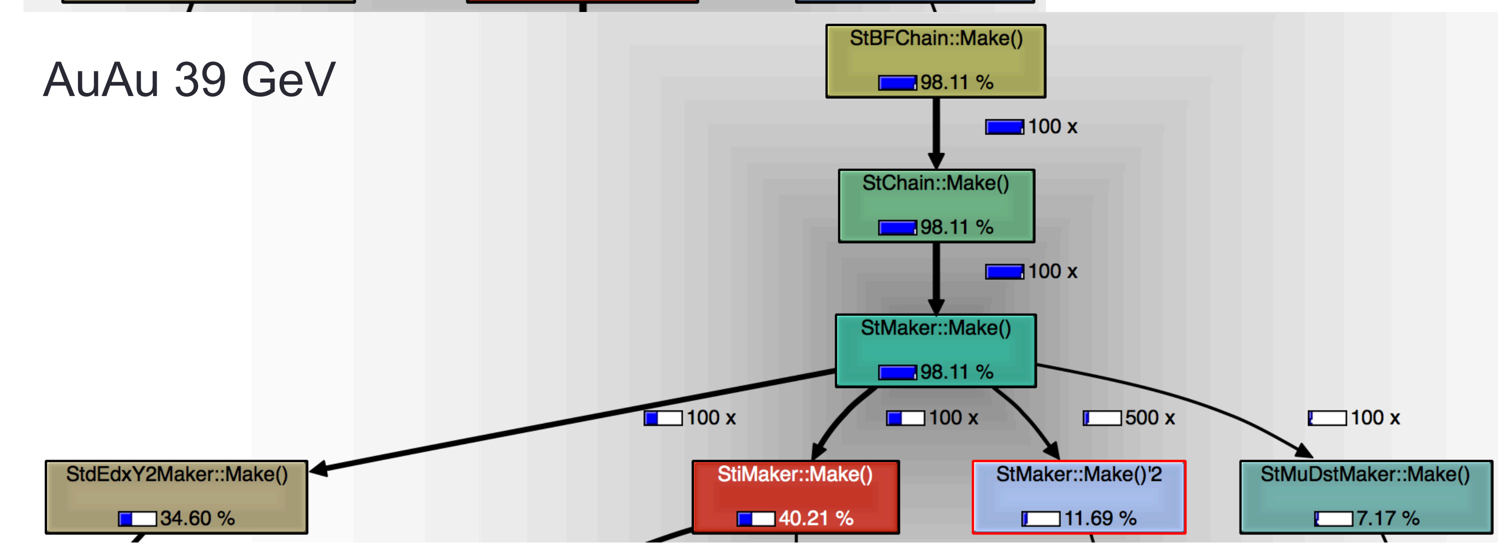
Potential Improvements aka. Action Items

- Full CA tracking including speeding up fitting (Yuri and Grigory)
- Use AVX instructions in CA (Grigory)
- Try to run dN/dx on Phi cards (Hongwei/Biao)
- Additional possible gain from trying out new compiler and 64 bit.

- Job management system, needed for resource sharing anyway. In place. (Wayne/Levente/Hongwei)
- Disk space requirement and data transfer IO bandwidth – needs to be tested and be sorted out (Hongwei/Jeff)

BFC timing profile





Sti and dN/dx take most of the time.

Inside Sti, track (re)fitting takes most of the time.

Solution :

1. Speed up fitting.
2. Run one or both on Xeon Phi cards.

HLT Job Management/Sharing for BES II express production

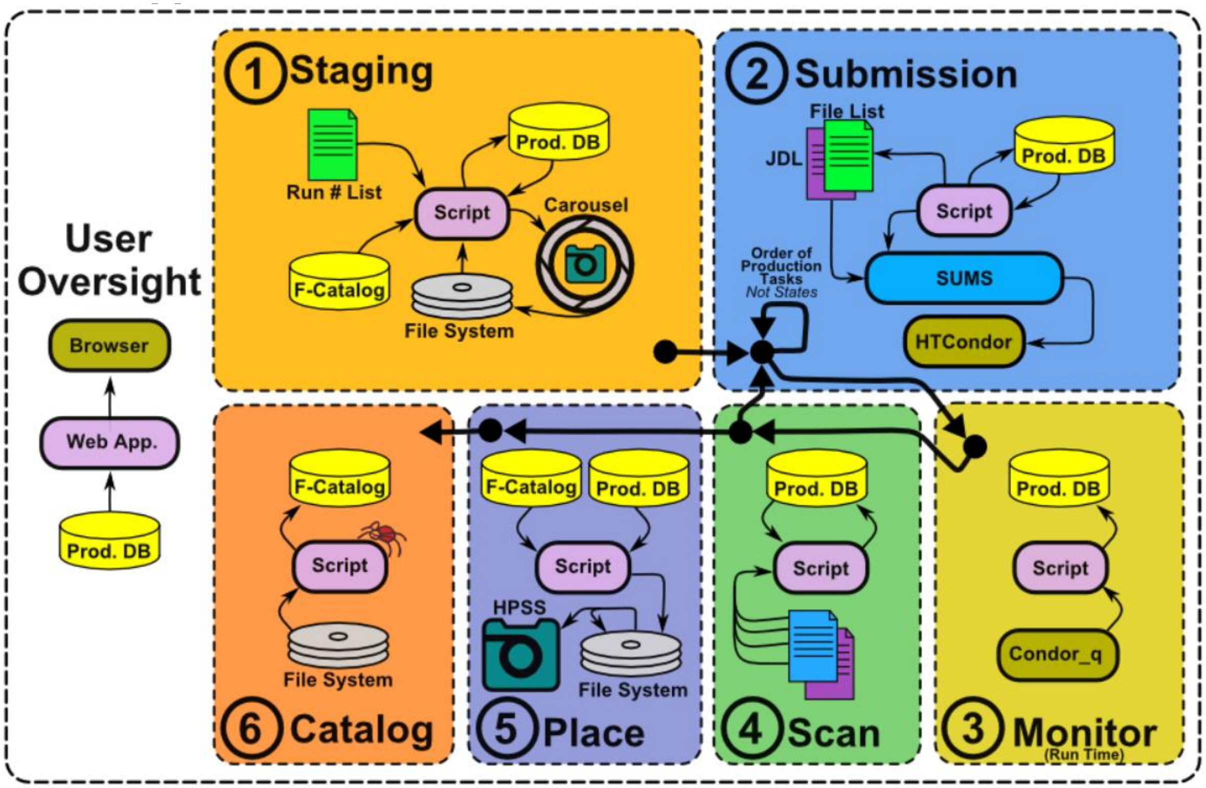


Figure 1. Stages of STAR's production system – each box and stages are explained in details as sub-sections of section 3.

L Hajdu *et al,* Automated Finite State Workflow for Distributed Data Production, Journal of Physics: Conference Series **762** (2016) 012006

Considered PANDA and Levente's scheme.
Decided to use the latter. In place already.

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. We continue to make improvements to the system, and expand its functionalities for multi-purpose usages.

Backup Slides

RHIC Beam Use Request for Run17

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

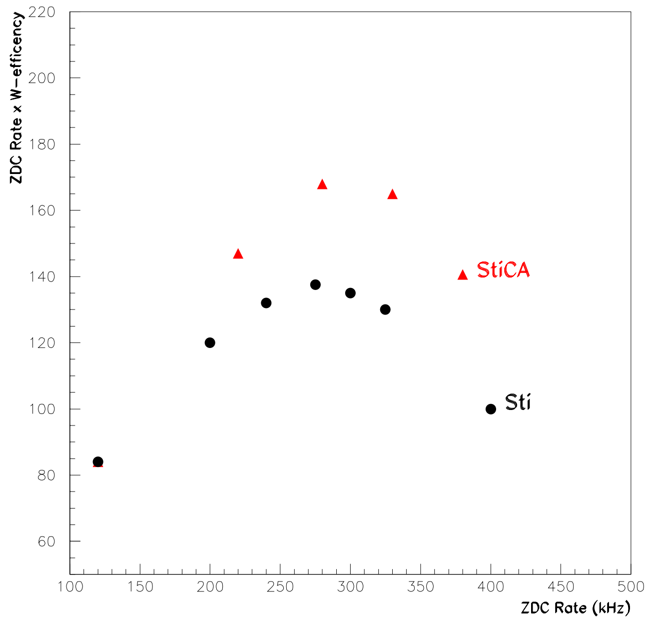


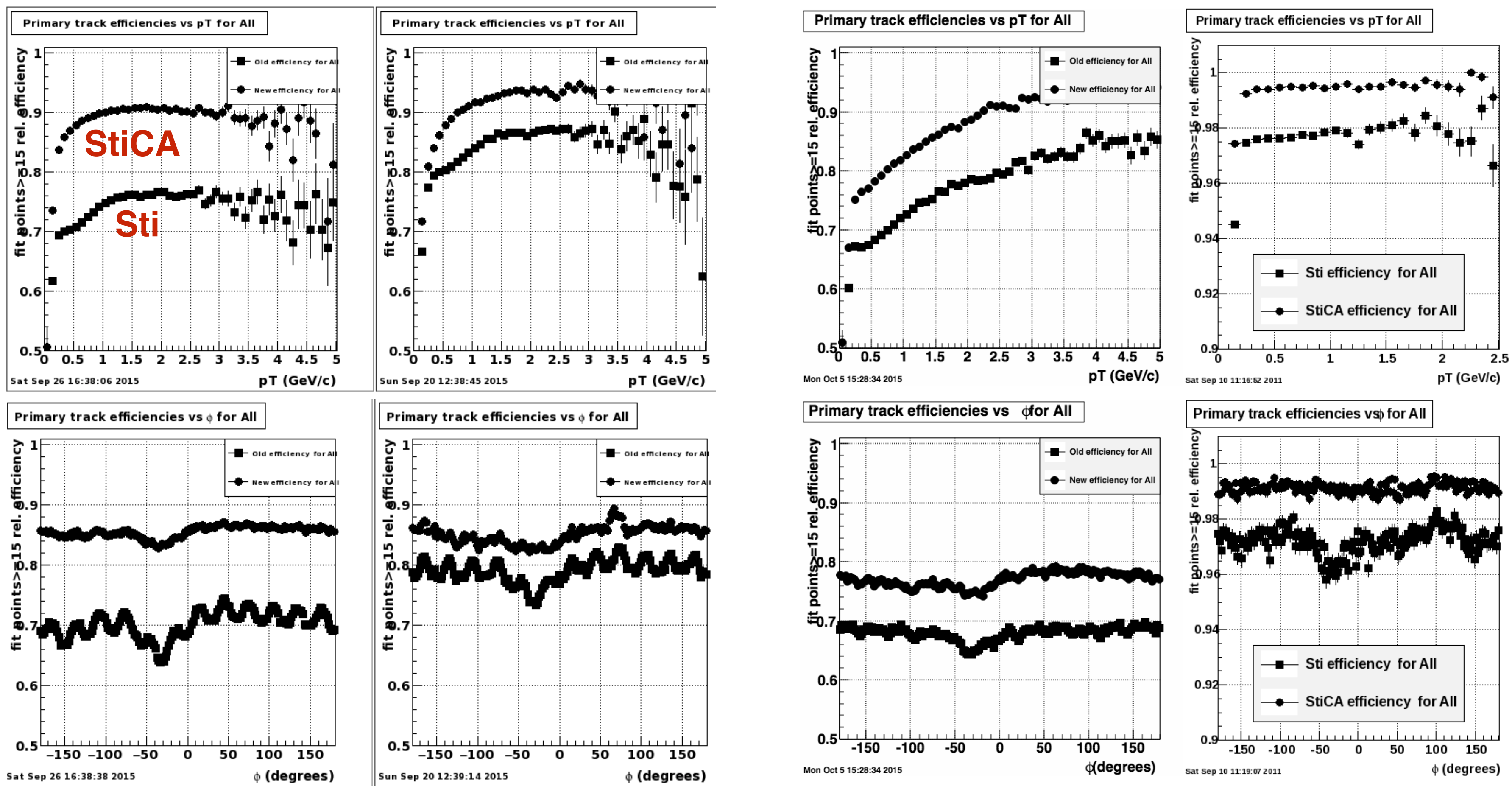
Figure 4–4: The FoM to reconstruct W-bosons in STAR as function of the ZDC raw rate. The W-boson reconstruction efficiency was obtained from the data measured in 2011 to 2013. The highest FoM is reached at a ZDC rate of 330 kHz corresponding to a luminosity of 1.5 x 10^{32} $cm^{-2}s^{-1}$.

StiCA Evaluation 2015

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

AuAu 200GeV | pp 510GeV

High L w/ HFT | Mid L w/o HFT | High L | Low L



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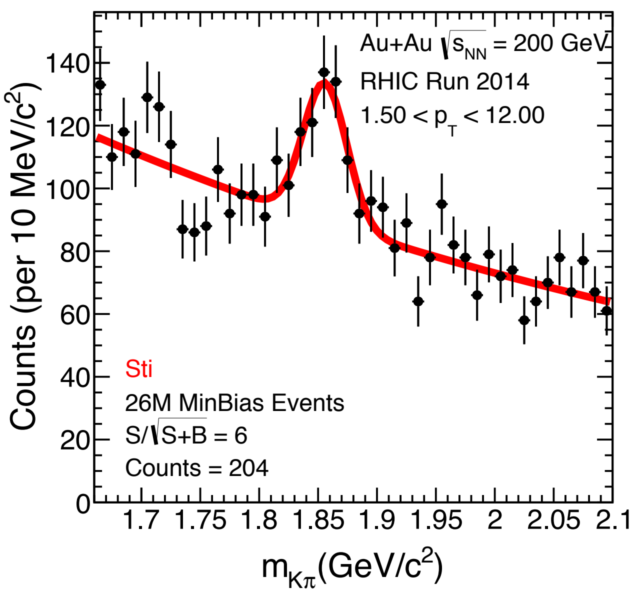

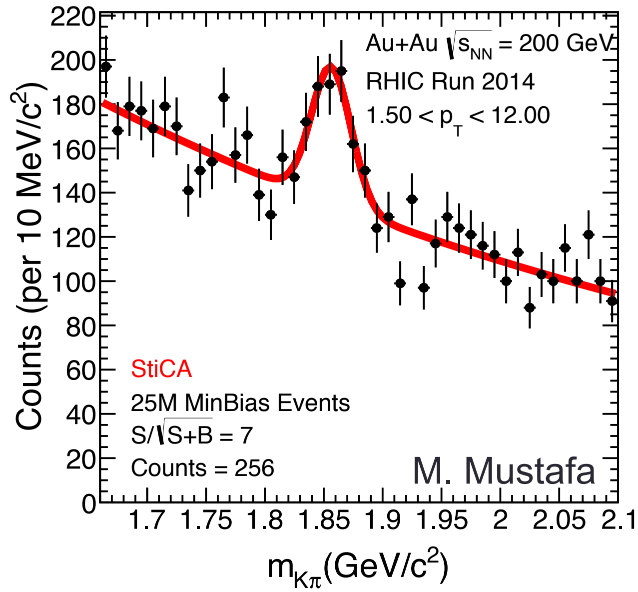

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Single-spin Asymmetries A_L for $W^{\pm}$

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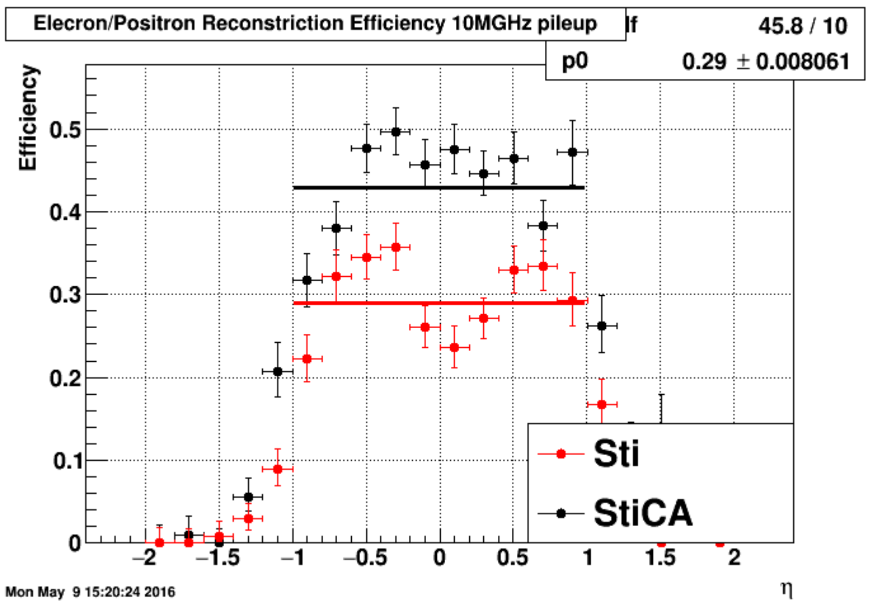
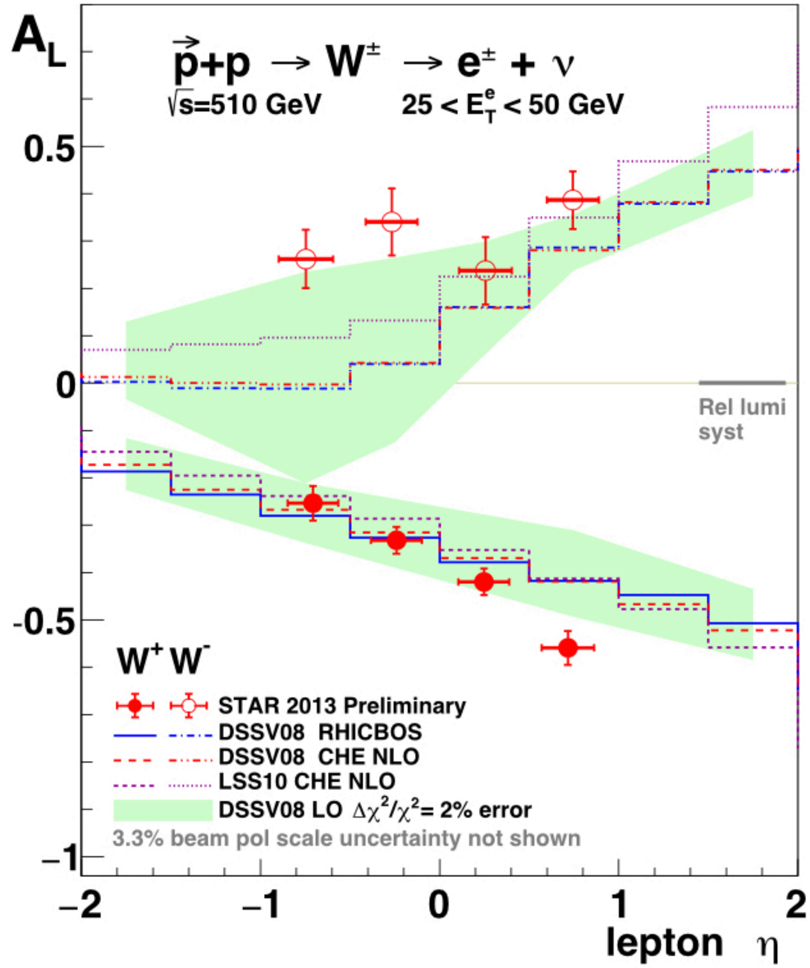
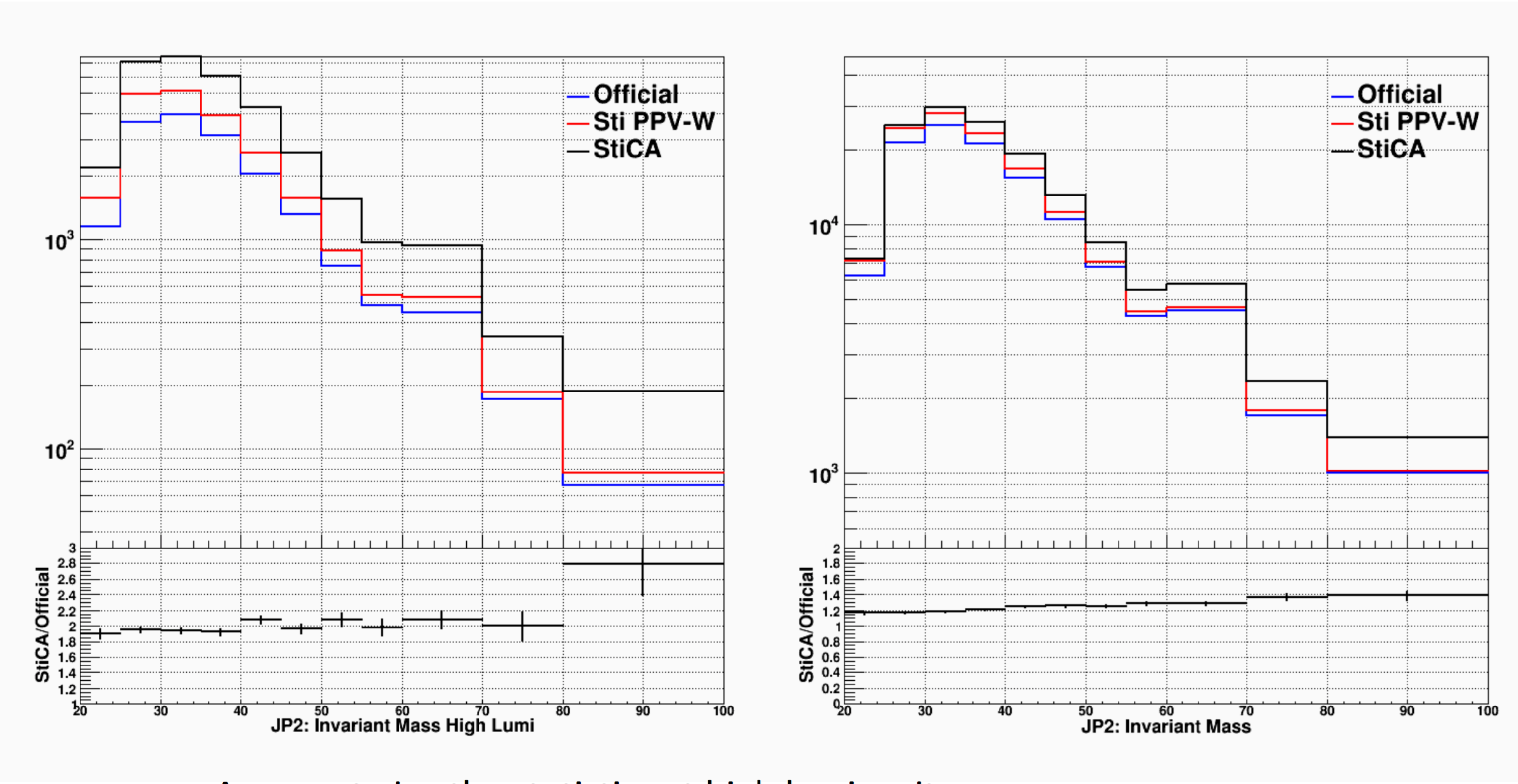




Devika Gunarathne

Di-jet observables

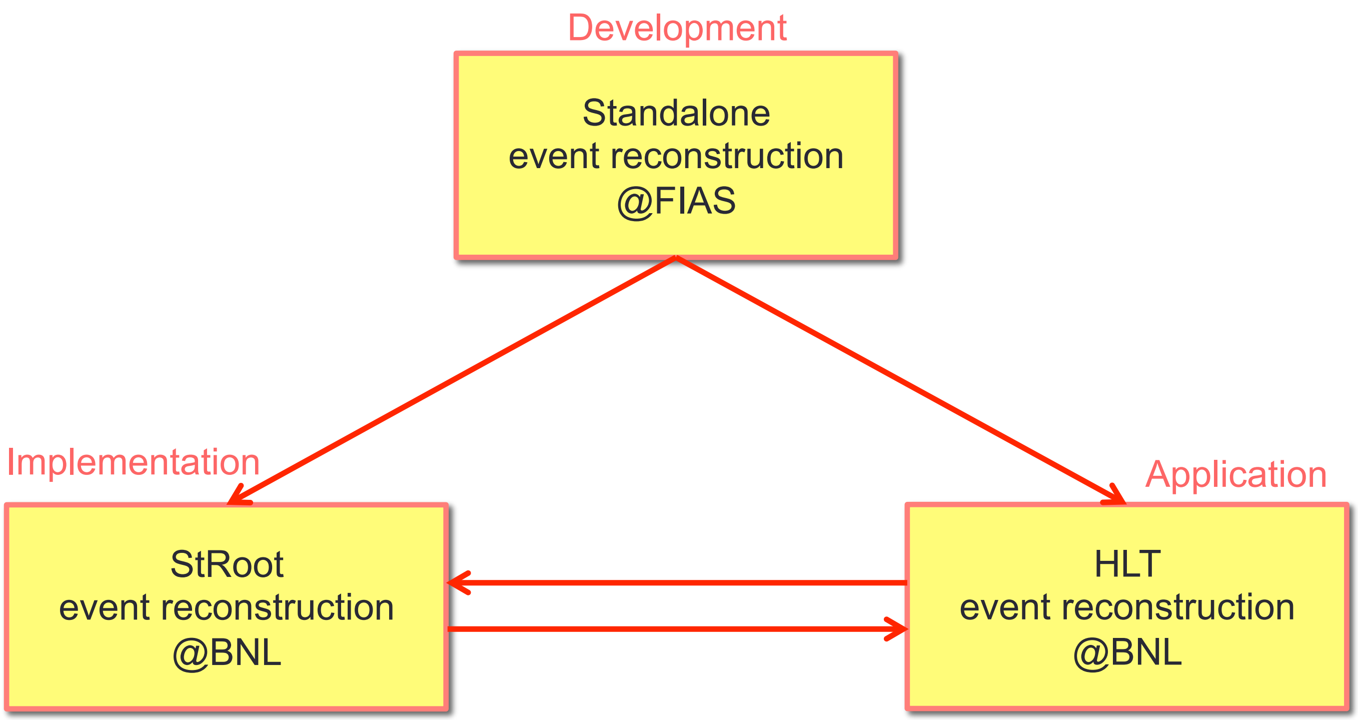
JP2 Mass Distribution



- Approx. twice the statistics at high luminosity
- Across the fill ~30% increase in statistics

Daniel Olvitt

More Than HLT

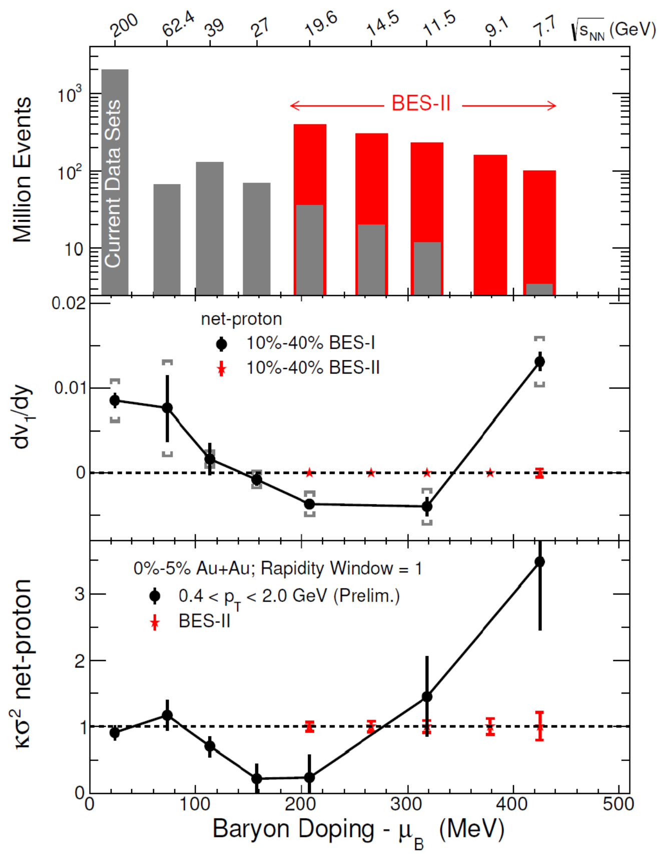


Ivan Kisel, STAR Collaboration Meeting, Berkeley, 18.10.2013

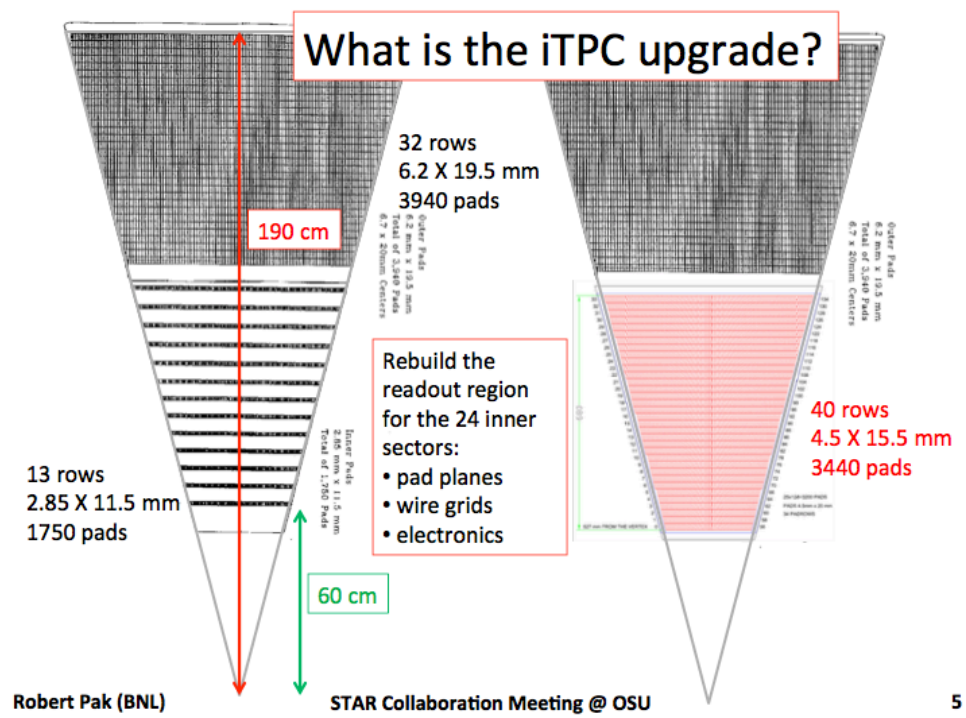
RHIC BES-II

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**

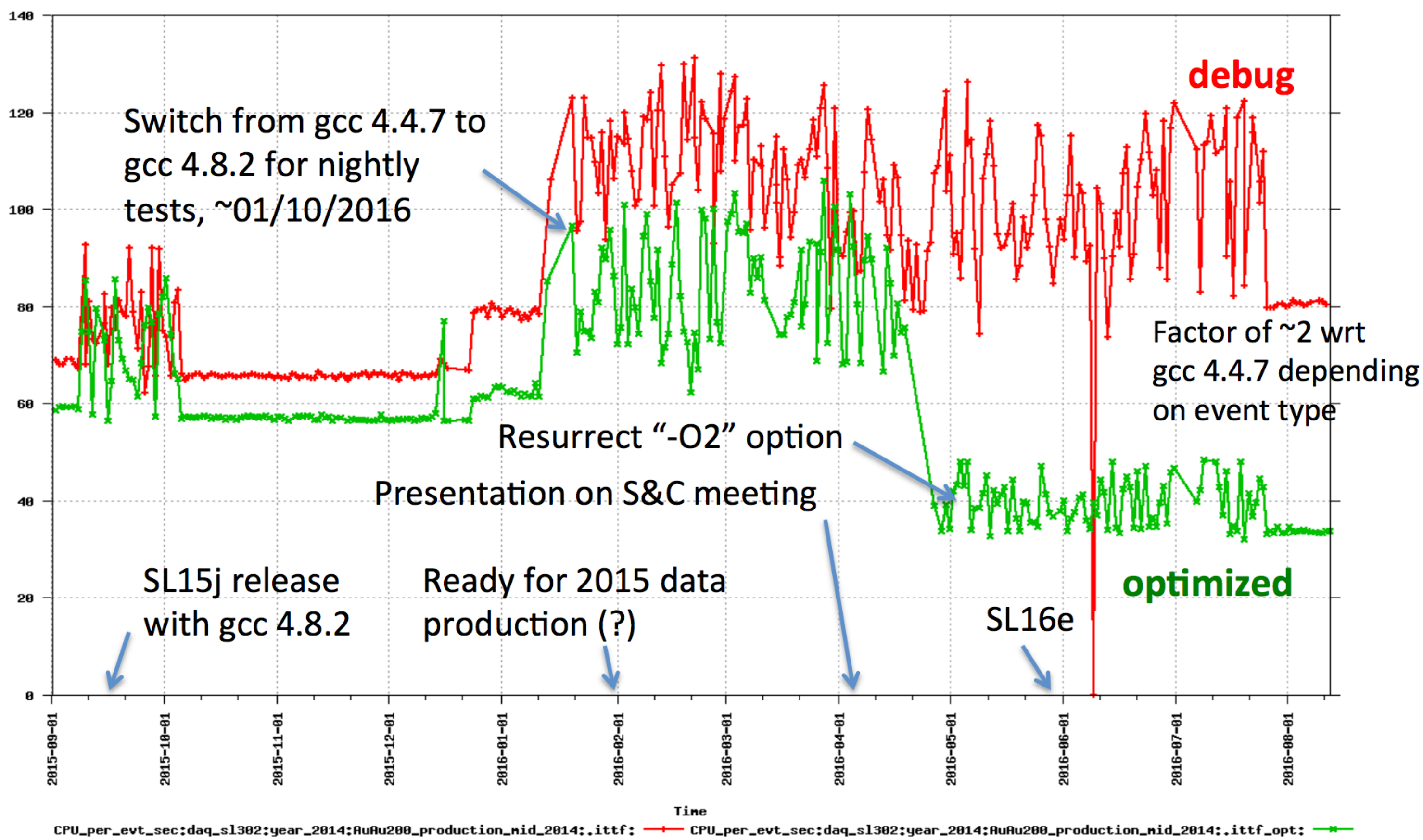


- iTPC extent eta coverage
- 45 pad rows to 72 pad rows



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

Current BFC Performance

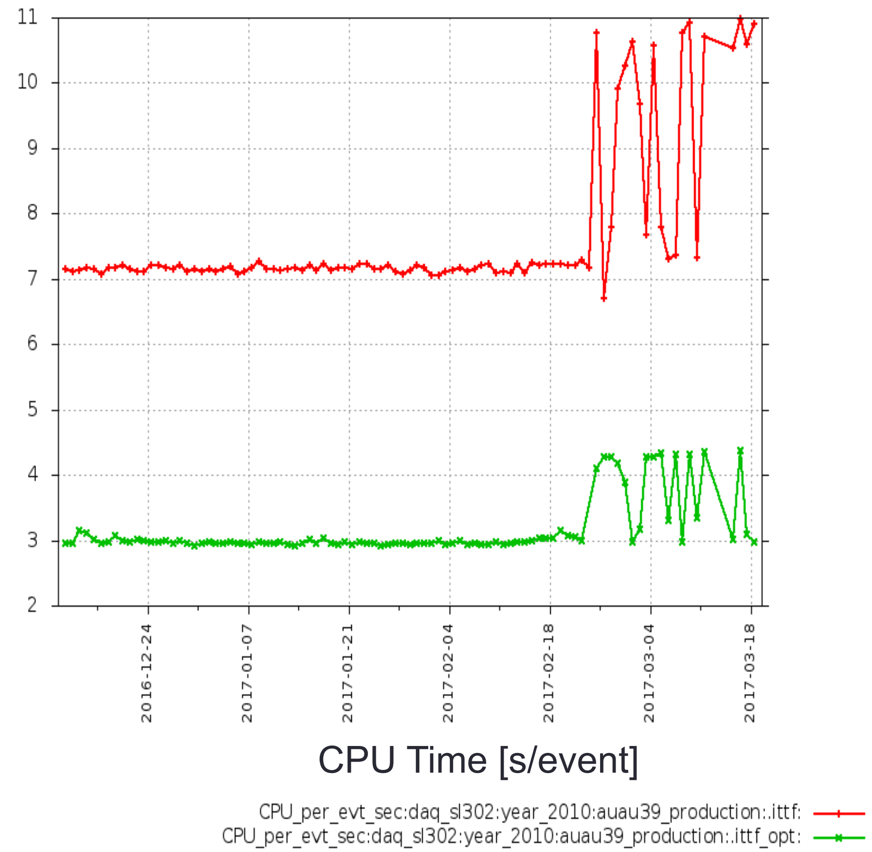


- Au+Au @ 200GeV
- ~40s per event

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

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

STAR BFC Performance @ 39GeV

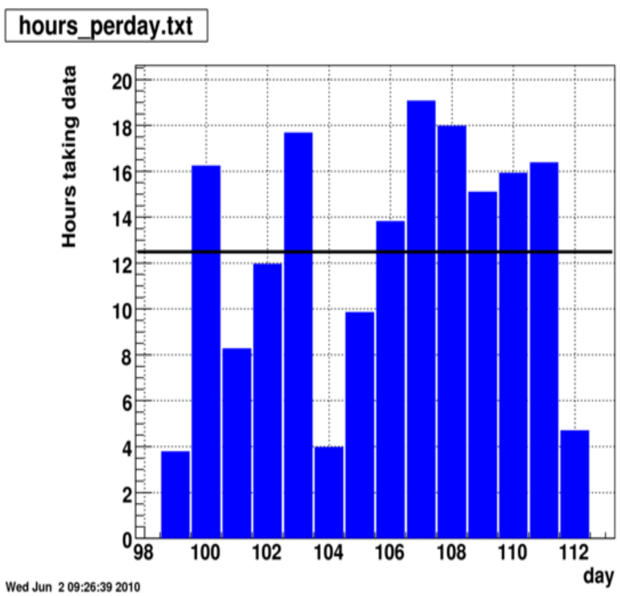


- Consider the iTPC will increase the TPC data volume by ~50%, use 39GeV as estimation baseline.

Expected Rates during BES-II

Collision Energy	Au+Au collision rate	Total Trigger Rate		Average Au+Au rate	Average total trigger rate
7.7	25	320		10	80
9.1	60	440		30	110
11.5	170	560		90	140
14.5	240	1200		130	300
19.6	450	1500		240	600

D. Cebra



- DAQ hours per day during Run10 39GeV
- ~70TB per day on average
- Need to be prepared for the worst case scenario

Available HLT Resources

✧ **Existing 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.

dN/dx Status and Plans

Status

- Year ago new dN/dx method to use ionization measurement from TPC has been proposed (https://drupal.star.bnl.gov/STAR/system/files/dNdx_rev3.pptx.pdf). The main goal is to improved particle identification (PiD) in iTPC era.
- The main idea on the dN/dx method is to use model for shape of energy deposited in a given TPC cluster versus number of primary clusters created during passage of charged particle in TPC. The shape has been calculated using Photo absorption Ionization (PAI) Model (http://www.annualreviews.org/doi/abs/10.1146/annurev.ns.30.120180.001345).
- dN/dx method has demonstrated improvement in PiD by ~15% using 2016 AuAu200 calibration sample.
- It was proposed to use dN/dx for whole 2016 AuAu200 sample and to check its performance.
- The production has been done and PWG have tested the dN/dx performance (https://drupal.star.bnl.gov/STAR/system/files/dNdxdEdx_Run16.pdf, https://drupal.star.bnl.gov/STAR/system/files/20170726_ComparisionStiSticaStihr.pdf)

PWG test results

- dN/dx PiD resolution is ~10% better than dE/dx one.
- dN/dx distribution has longer tails wrt dE/dx.
- dN/dx measured for kaons is significantly shifted wrt the model prediction.
- Usage dN/dx does NOT give any improvement in significance of D^0 signal wrt dE/dx.
- Signal of $\phi \rightarrow K^+K^-$ is ~5% narrower for dN/dx wrt dE/dx (?).

Conclusions and plans for dN/dx

NO obvious improvement with dN/dx wrt dE/dx is seen. The plan to improve it includes :

1. It is necessary to improve dN/dx fit for tracks in order to avoid long tails.
2. It is necessary to correct model predictions of dN/dx for kaons, protons, …
3. It is necessary to revist dN/dx model in order to understand the reason why do we need these corrected predictions.