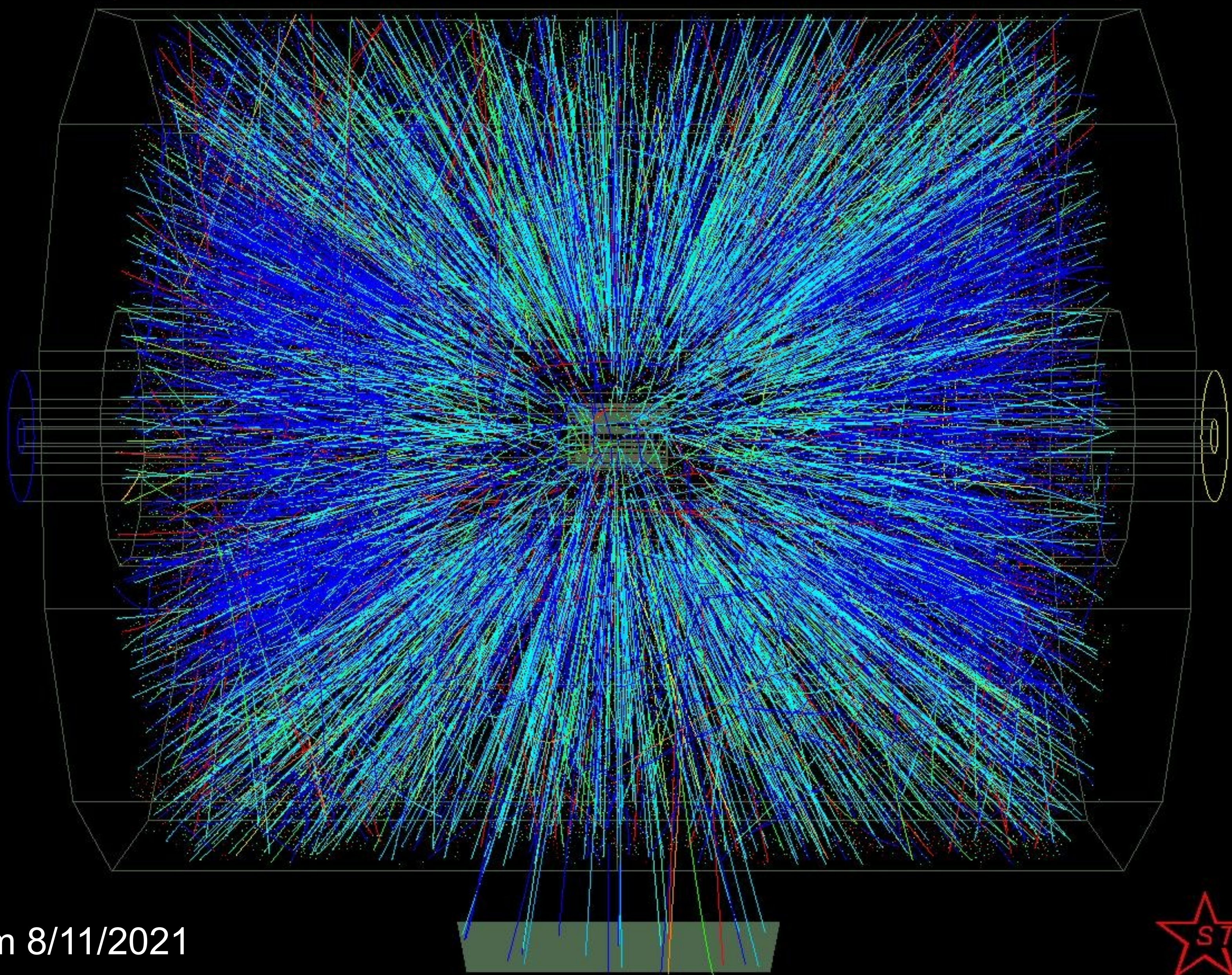
STAR Trigger / DAQ

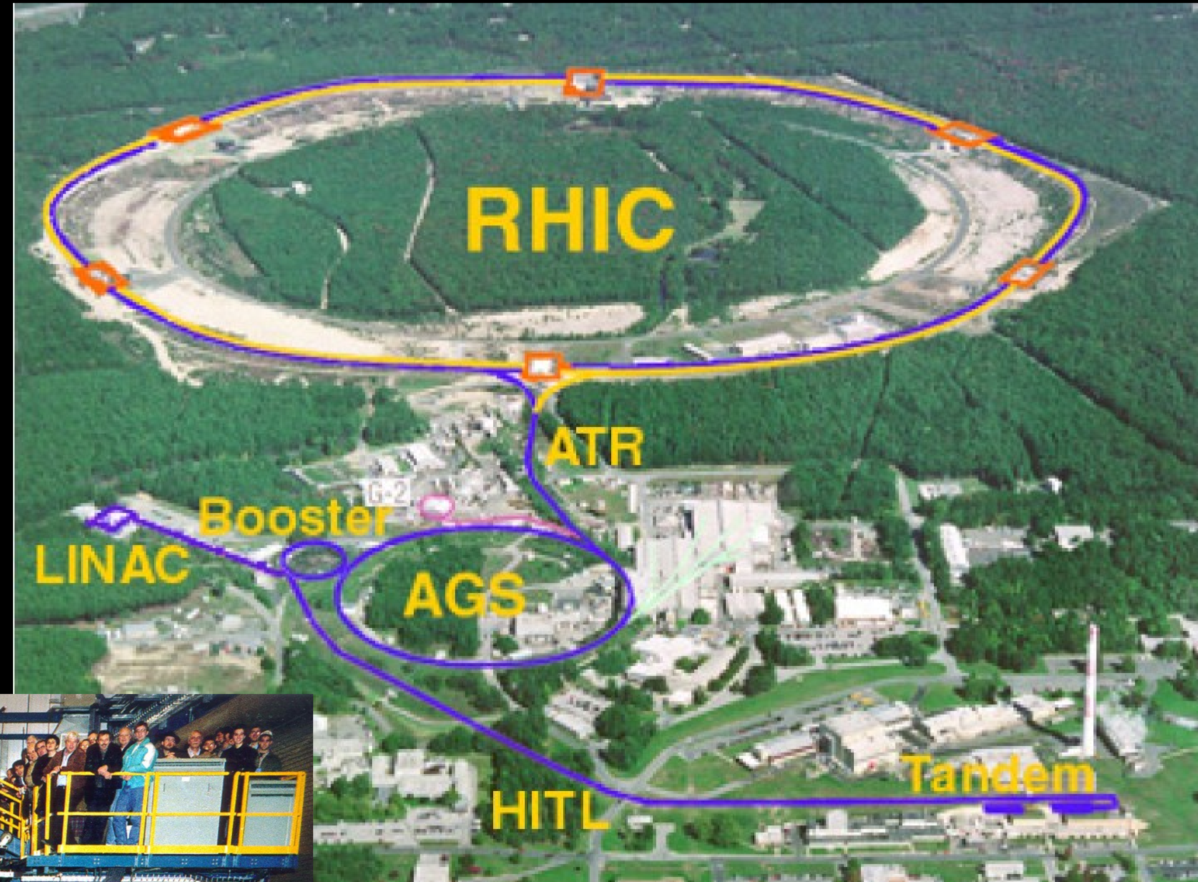
Jeff Landgraf

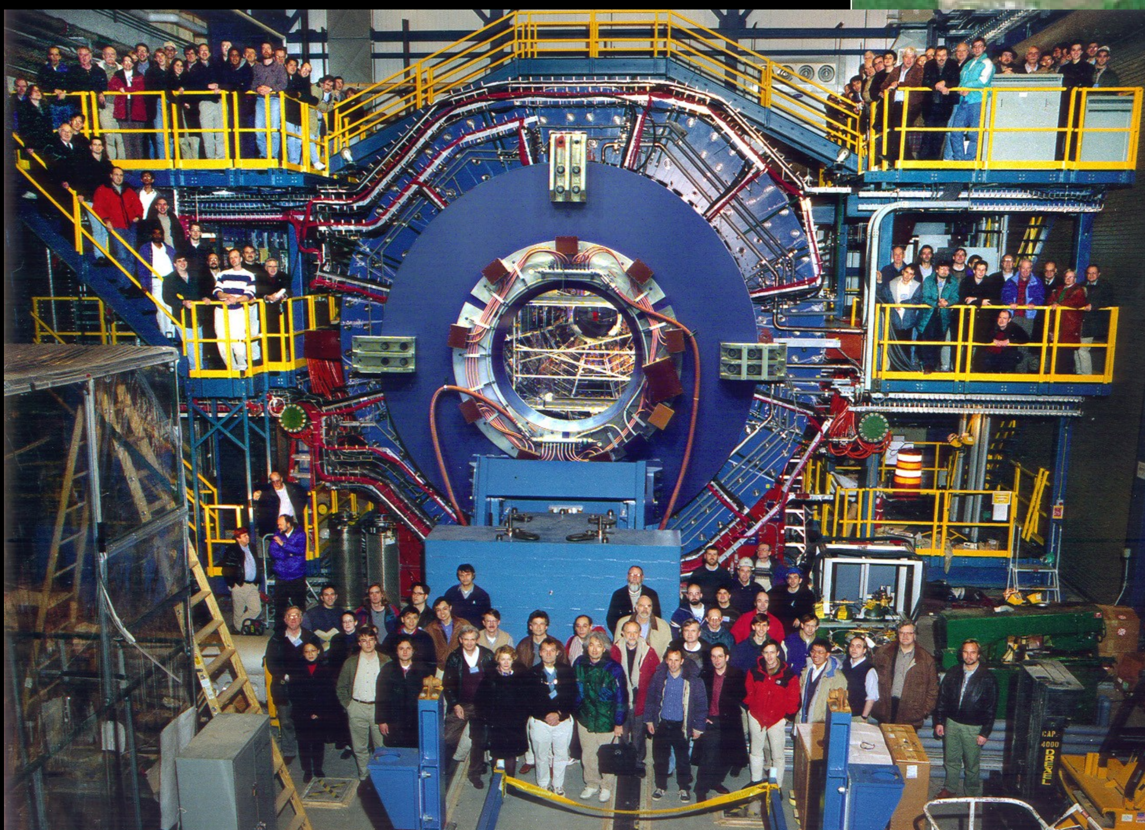


NuSteam 8/11/2021

The STAR Collaboration at RHIC

STAR is:
- 753 collaborators
- 70 institutions / 14 countries

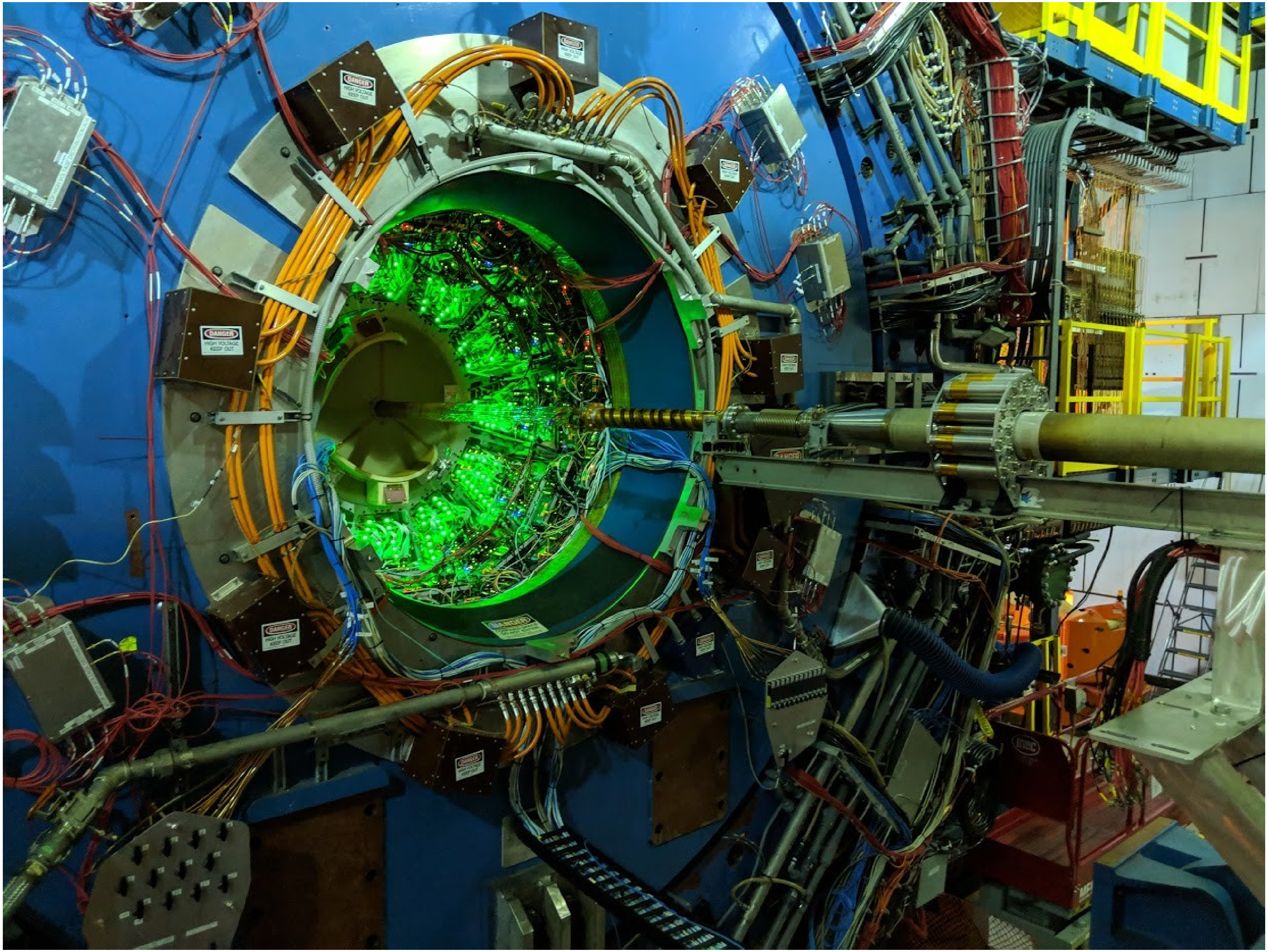




RHIC collides protons, gold and anything in between.

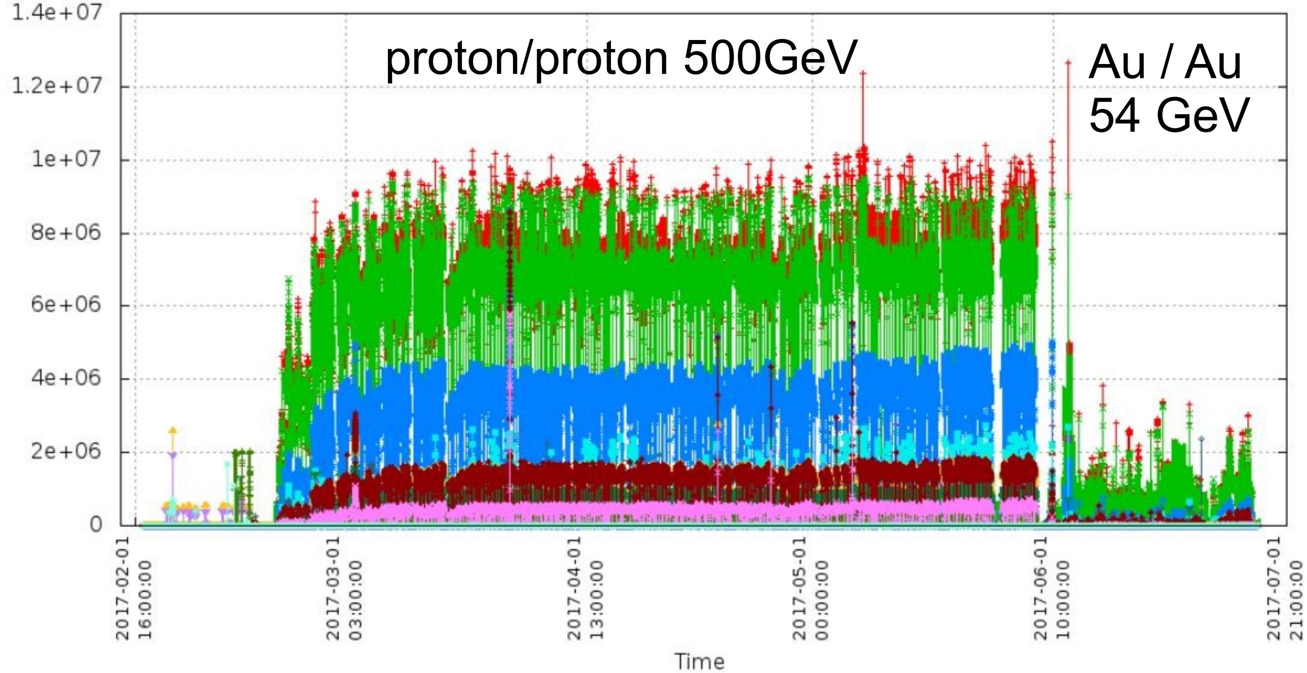
Maximum energy:
- 200 GeV / nucleon
- 500 GeV for protons

Heavy Ion & Polarized Proton Programs

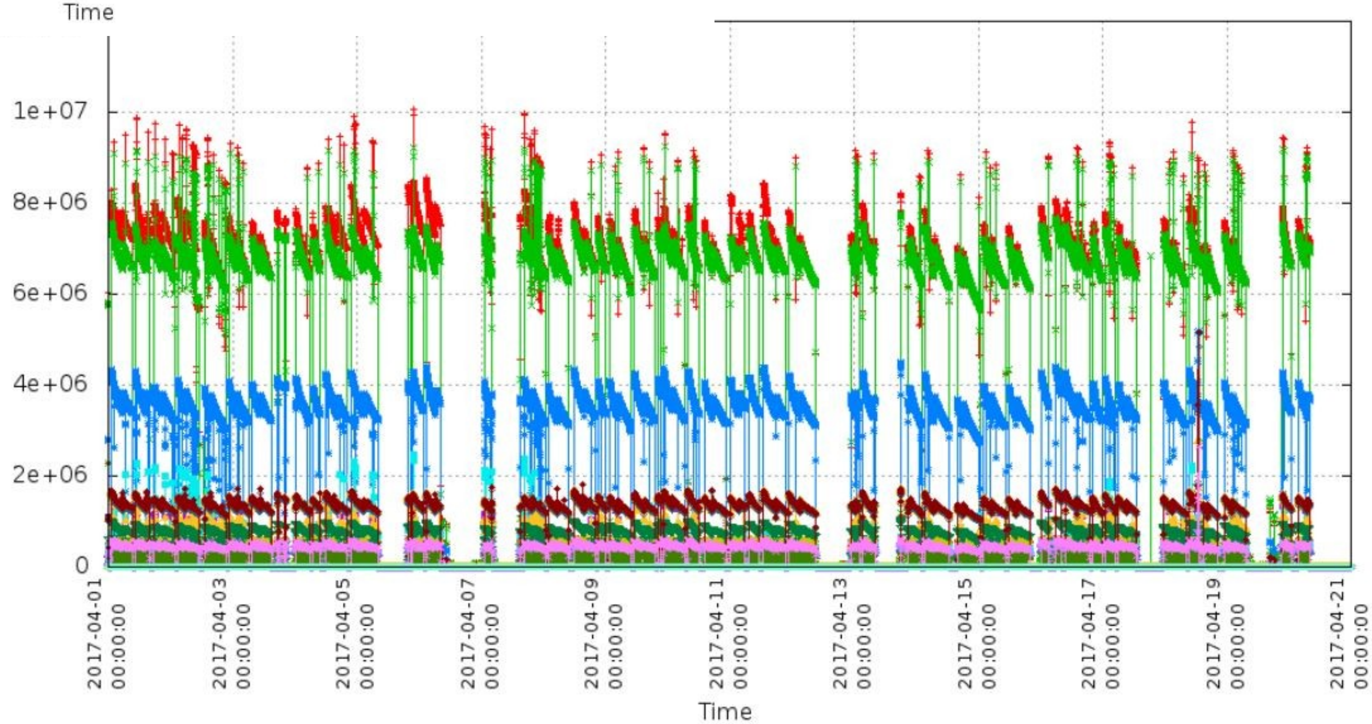


January 23, 2019

2017 RHIC run

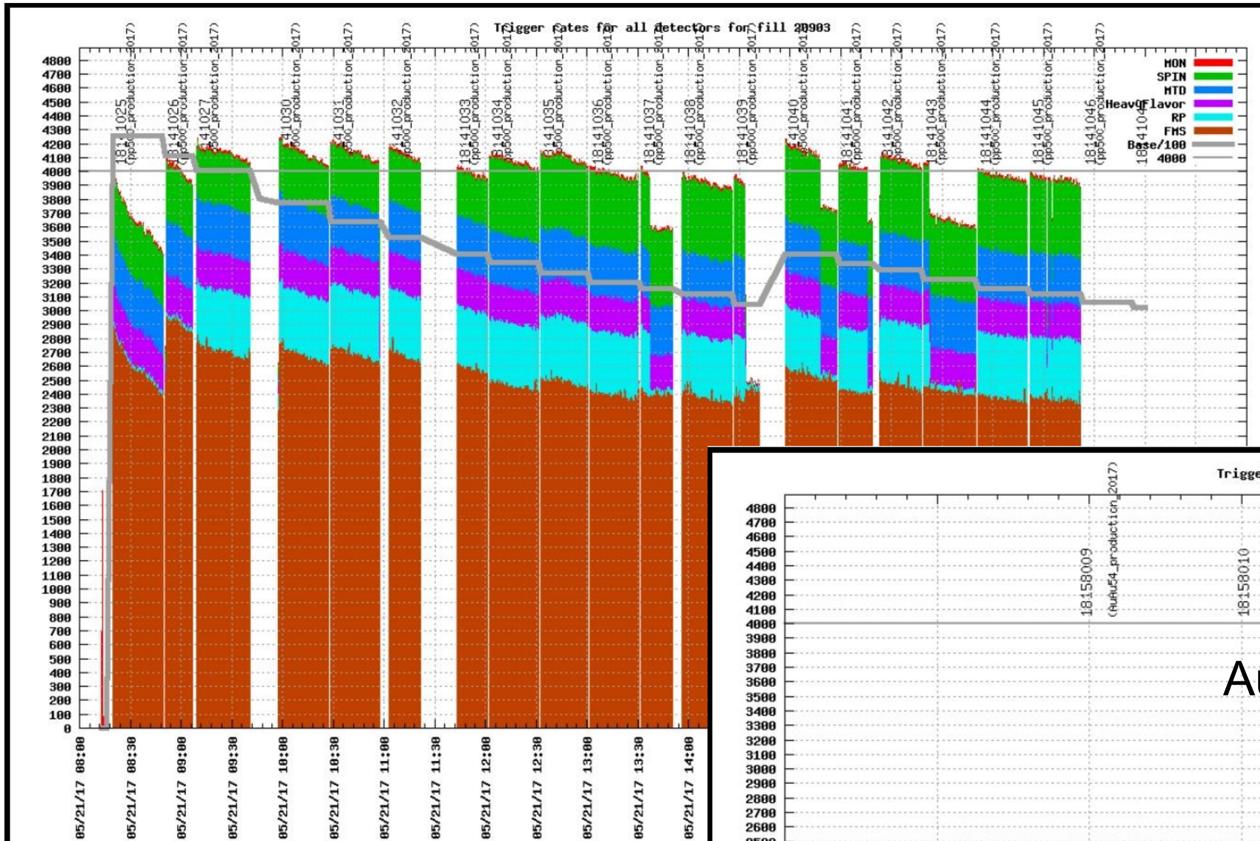


- RHIC Runs 5-6 Months / Year
- 2-3 Species / Year
- Running Conditions Vary by species!

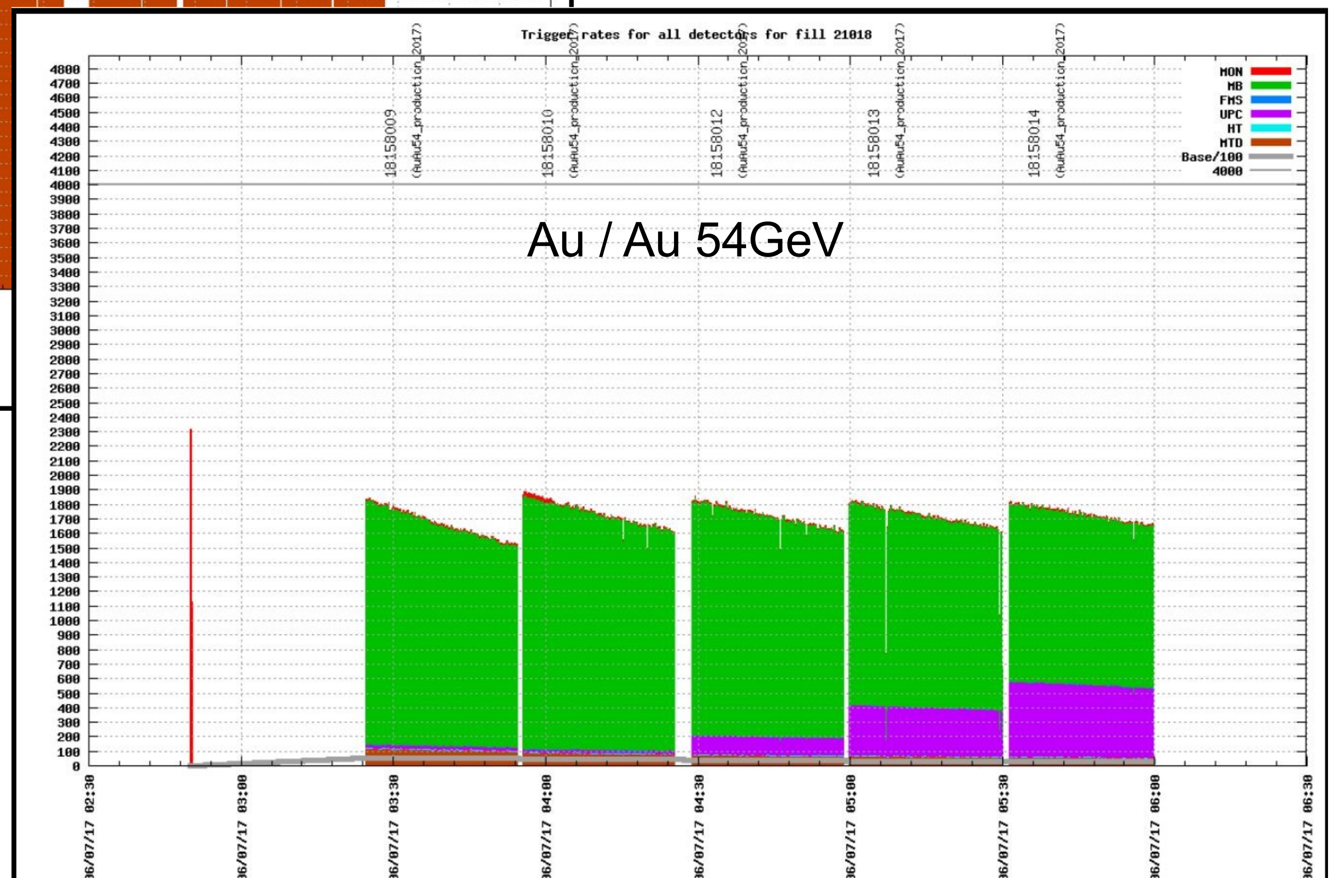


- Often exponential Decay during fill
- Maintenance Shift Every 2 weeks
- Machine Development
- Beam Experiments

Proton / Proton 500GeV



- Long Fills
- High Rates
- Complex Trigger
- Radiation Issues
  * Detector Failures
  * Detector Omission



Au / Au 54GeV

- Short Fills
- Lowish Rates
- Simple Trigger
- Few failures

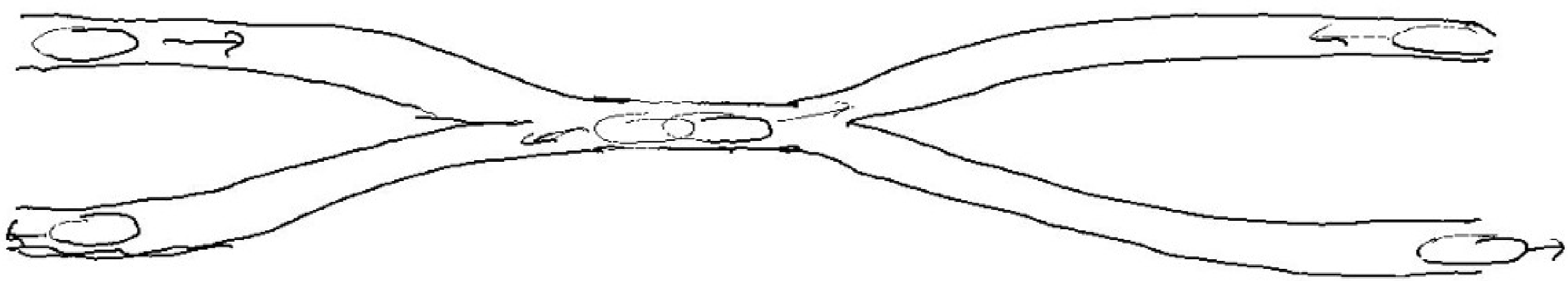
Bunches:

* The ions / protons travel in bunches   (~10^11 particles per bunch)
* The bunches arrive at STAR every 109ns (9.3MHz)
* The trigger and detector electronics are driven by this RHIC clock.

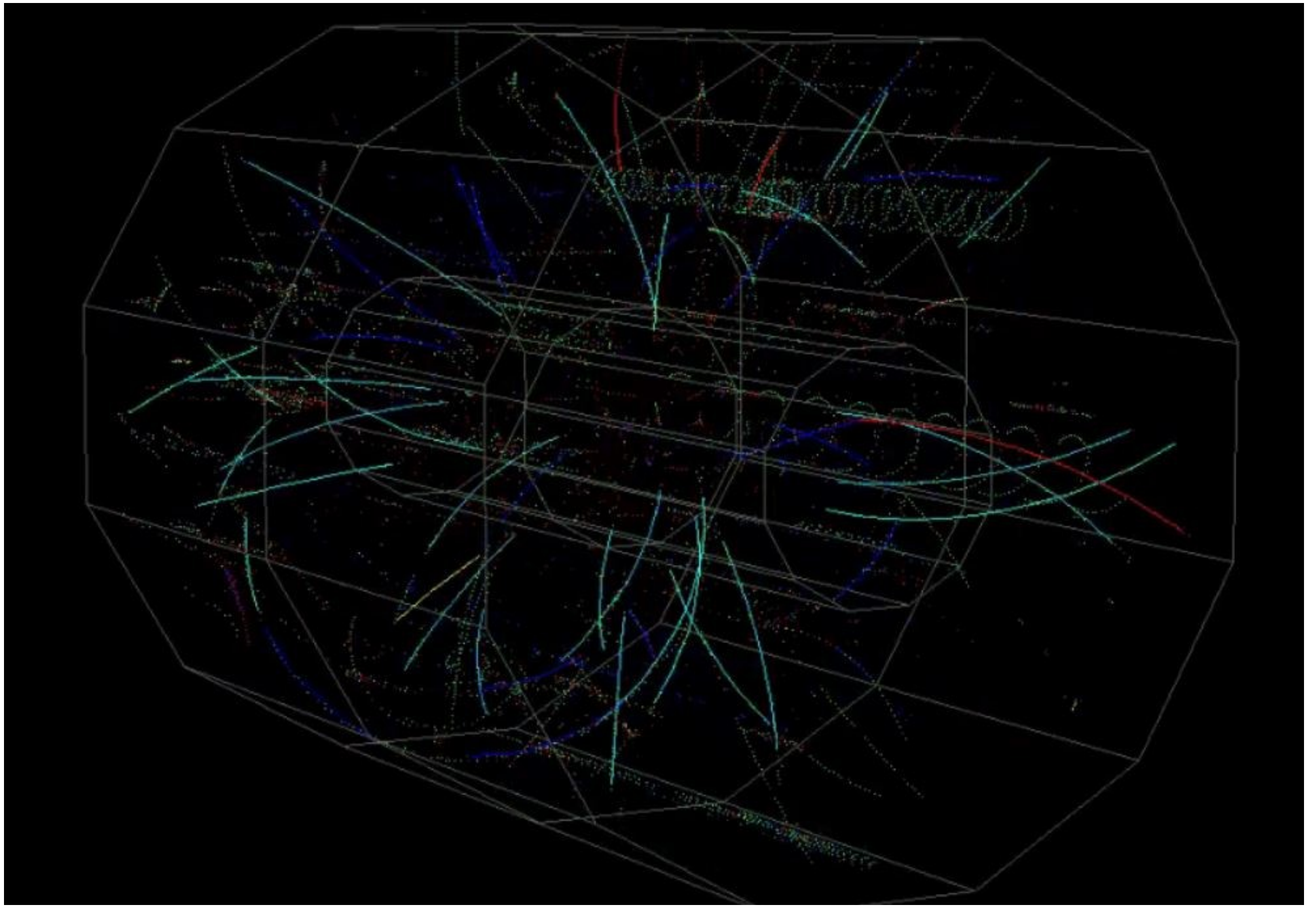
* The bunches tend to be fairly long.   The width of the vertex distribution can be from ~20cm to 1m depending on the running conditions.

* There is a gap of unfilled bunches in each ring.

* During polarized proton running the bunches have different polarization which means we must track the luminosity bunch by bunch.



Time Scales:



STAR Physics	<< 1ps
Time for particles to exit STAR	~ 10ns
Time between bunch crossings	~ 109ns
Average Time between collisions	~ (1us – 200us)
TPC Drift Time	~ 40us
Time to read out event (TPC)	~ 300us
Time to flush event out of system	~ 1s
Time to flush event out of event buffer	~ 1day

Original Conception Of STAR Trigger:

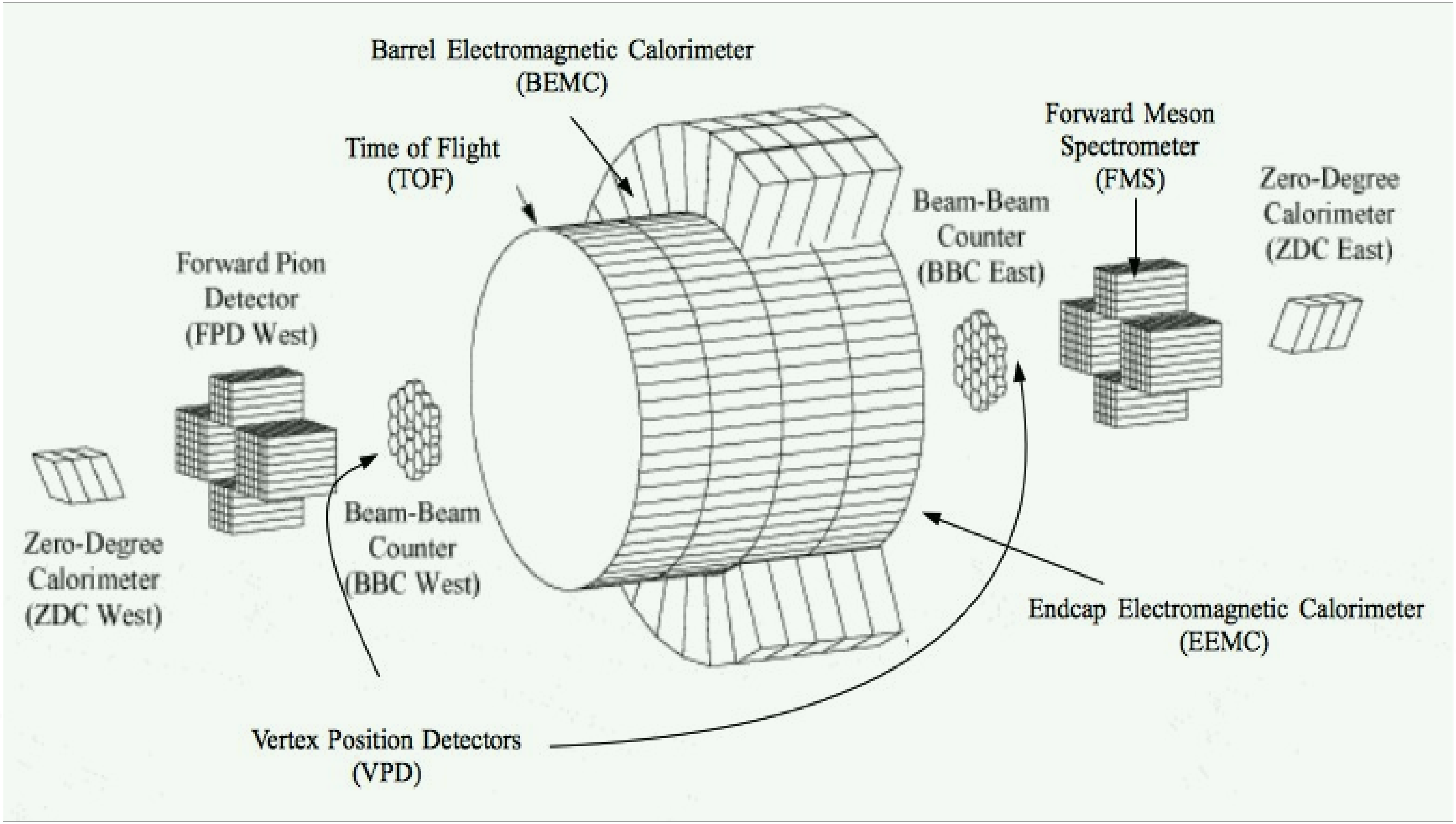
L0 decides within ~1.7us

L1 can abort during the drift of the TPC (40us)

L2 can abort during the Readout of the TPC (originally up 10ms)

L3 can abort before Building events (1Hz)

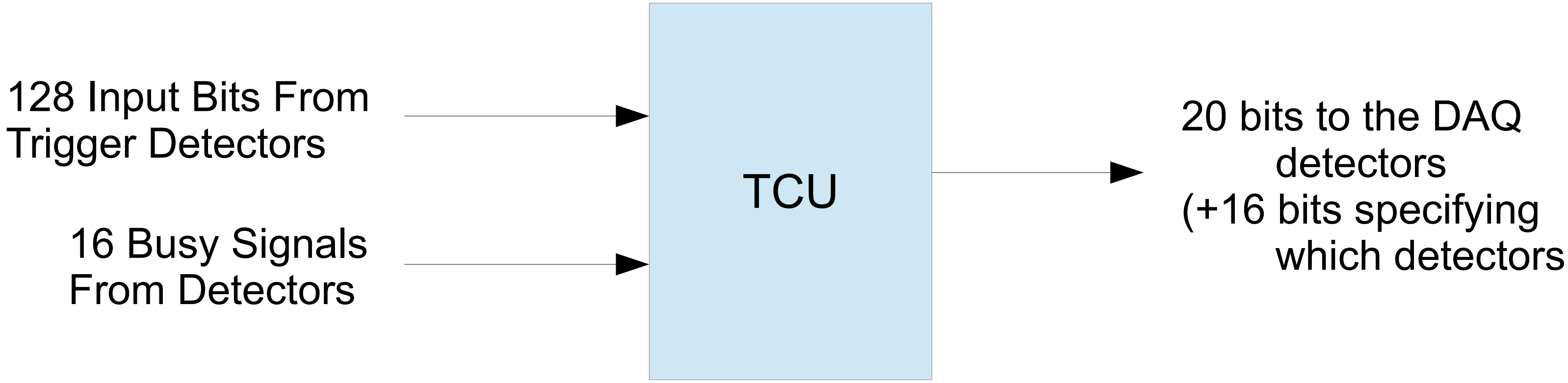
The Trigger Detectors:



Trigger detectors are capable of reading out every bunch crossing!

- Some read out all of their data each bunch crossing (ZDC, BBC, EPD, VPD…)
- Others read out a useful portion of their data each bunch crossing (EMC's, TOF)

The Brains of the L0 Trigger (Trigger Control Unit):



UPC-Jpsi-zdc condition 0 toggle enabled

MTD_th1	BBC-TAC		BEMC_HiTwr-th0	revtick-1	FMSsmall-BS3	- Laser-protection	
MTD_th2	- BBC-E		BEMC_HiTwr-th1	revtick-2	FMSsmall-BS2	Laser-fire	
RP_ET	- BBC-W		BEMC_HiTwr-th2	revtick-3	FMSsmall-BS1	Laser-lamp	
TOF-UPC	EPD-TAC		BEMC_HiTw4-th3	revtick-4	FMSlarge-BS3	Laser-diode	
TOFmult0	EPD-E		BEMC_HiTwr-th4	Yellow-filled	FMSlarge-BS2		
TOFmult1	EPD-W		Unused	QLINK4T-1	FMSlarge-BS1		
- TOFmult2	ZDC-TAC		Unused	Blue-filled	FMS-DiBS		
TOFmult3	+ ZDC-E		Unused	QLINK4T-3	FMS-JP2		
MTD1-T-Cosmic	ZDC-W		Unused	QLINK4T-4	FMS-JP1		
TOFsector0_3	ZDC-EW		+ EMC-UPCtopo	QLINK4T-5	FMS-JP0		
TOFsector1_4	Minimum-Bias		Unused	TTLIN-0	FMS-DiJet		
TOFsector2_5	Preceded		Unused	EPD-CR-Trigger	Unused		
RP_IT	VPD-TAC2		Unused	TTLIN-2	Unused		
RP_EOR	VPD-TAC		EEMC_HiTwr-th0	TTLIN-3	Unused		
RP_WOR	VPD-E		EEMC_HiTwr-th1	TTLIN-4	Unused	Zero-bias	
MTD-Cosmic	VPD-W		unused	TTLIN-5	Unused	Random	

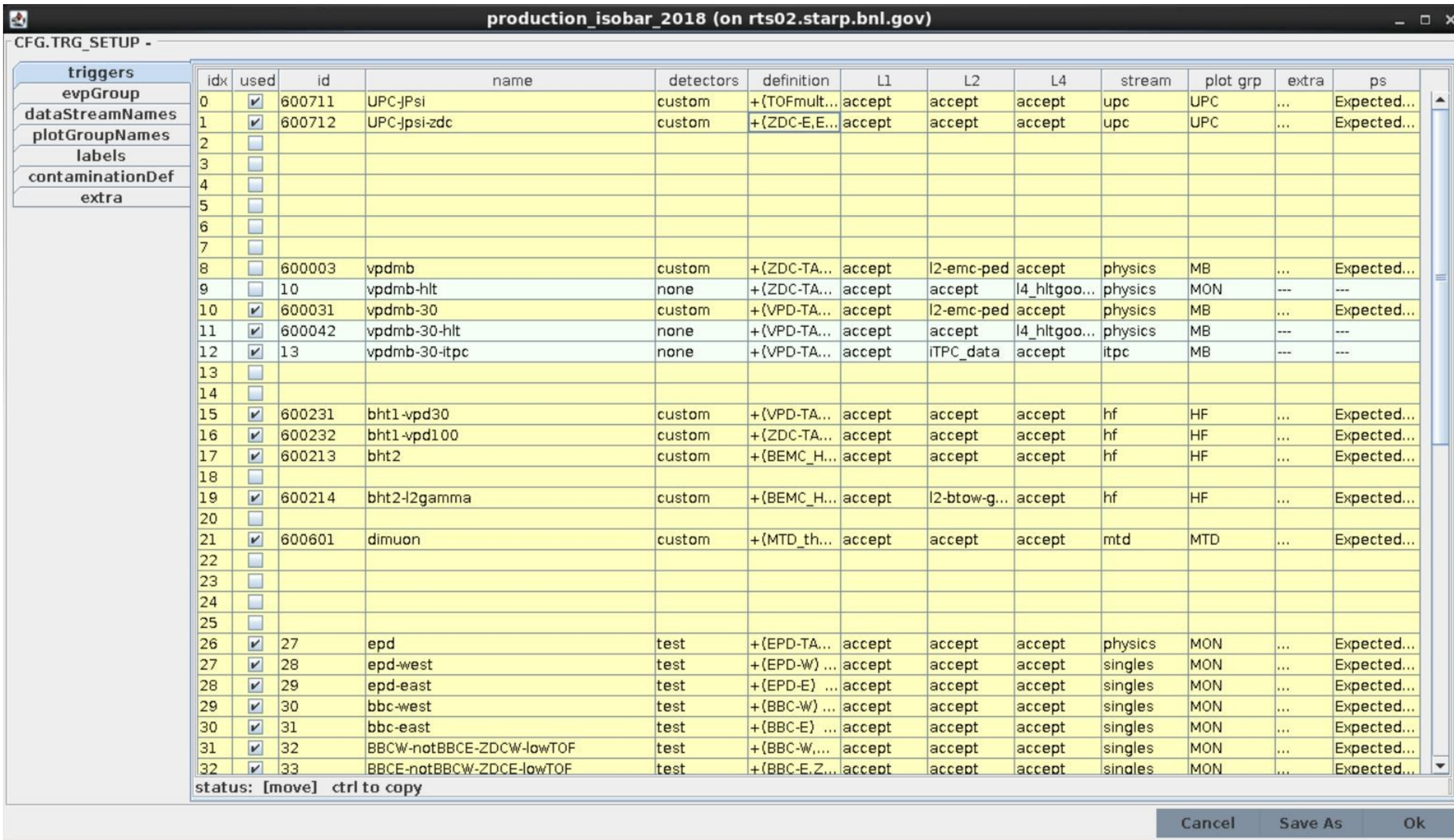
UPC-Jpsi-zdc condition 1 toggle enabled

MTD_th1	BBC-TAC		BEMC_HiTwr-th0	revtick-1	FMSsmall-BS3	- Laser-protection	
MTD_th2	- BBC-E		BEMC_HiTwr-th1	revtick-2	FMSsmall-BS2	Laser-fire	
RP_ET	- BBC-W		BEMC_HiTwr-th2	revtick-3	FMSsmall-BS1	Laser-lamp	
TOF-UPC	EPD-TAC		BEMC_HiTw4-th3	revtick-4	FMSlarge-BS3	Laser-diode	
TOFmult0	EPD-E		BEMC_HiTwr-th4	Yellow-filled	FMSlarge-BS2		
TOFmult1	EPD-W		Unused	QLINK4T-1	FMSlarge-BS1		
- TOFmult2	ZDC-TAC		Unused	Blue-filled	FMS-DiBS		
TOFmult3	ZDC-E		Unused	QLINK4T-3	FMS-JP2		
MTD1-T-Cosmic	+ ZDC-W		Unused	QLINK4T-4	FMS-JP1		
TOFsector0_3	ZDC-EW		+ EMC-UPCtopo	QLINK4T-5	FMS-JP0		
TOFsector1_4	Minimum-Bias		Unused	TTLIN-0	FMS-DiJet		

Cancel Ok

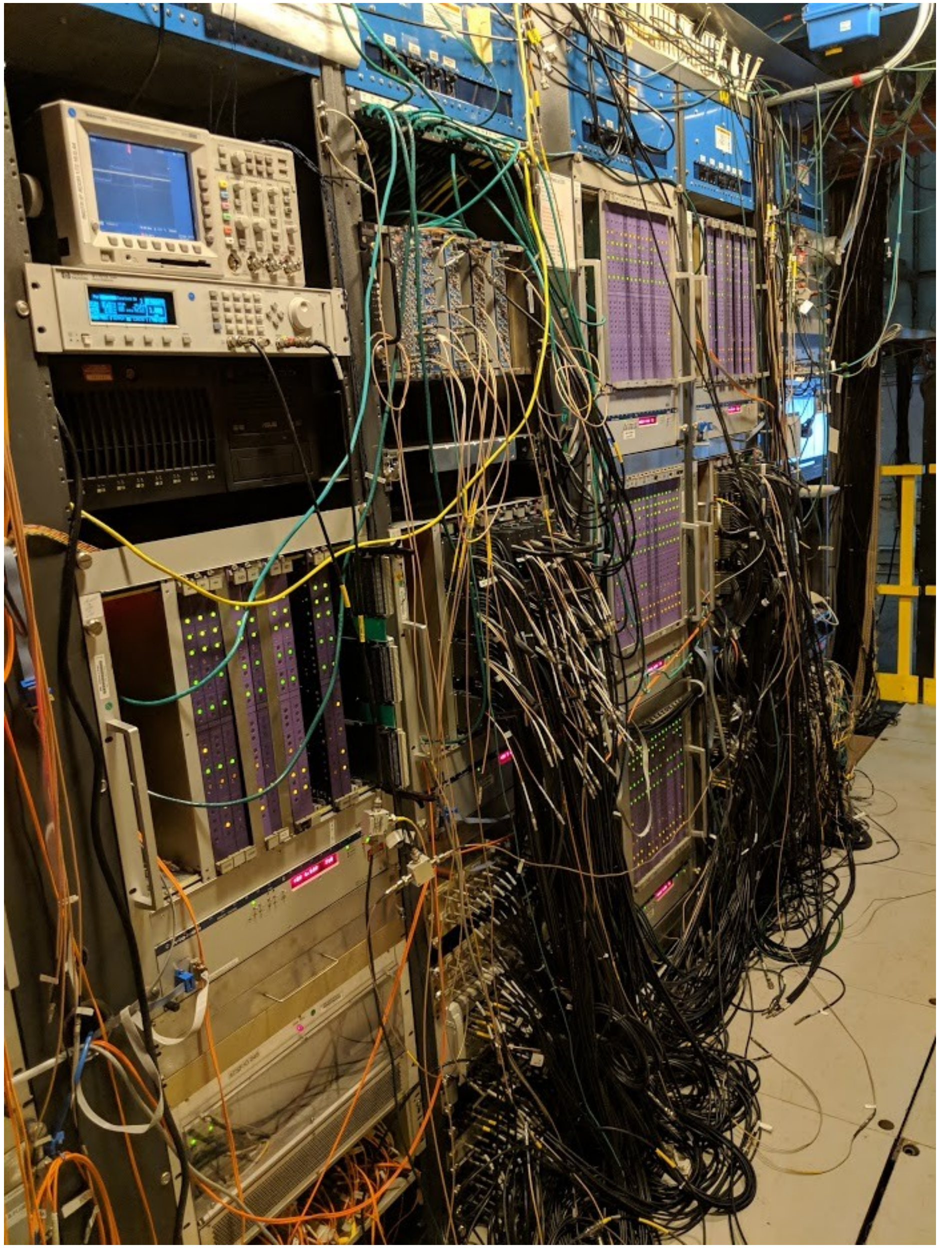
The Configuration File:

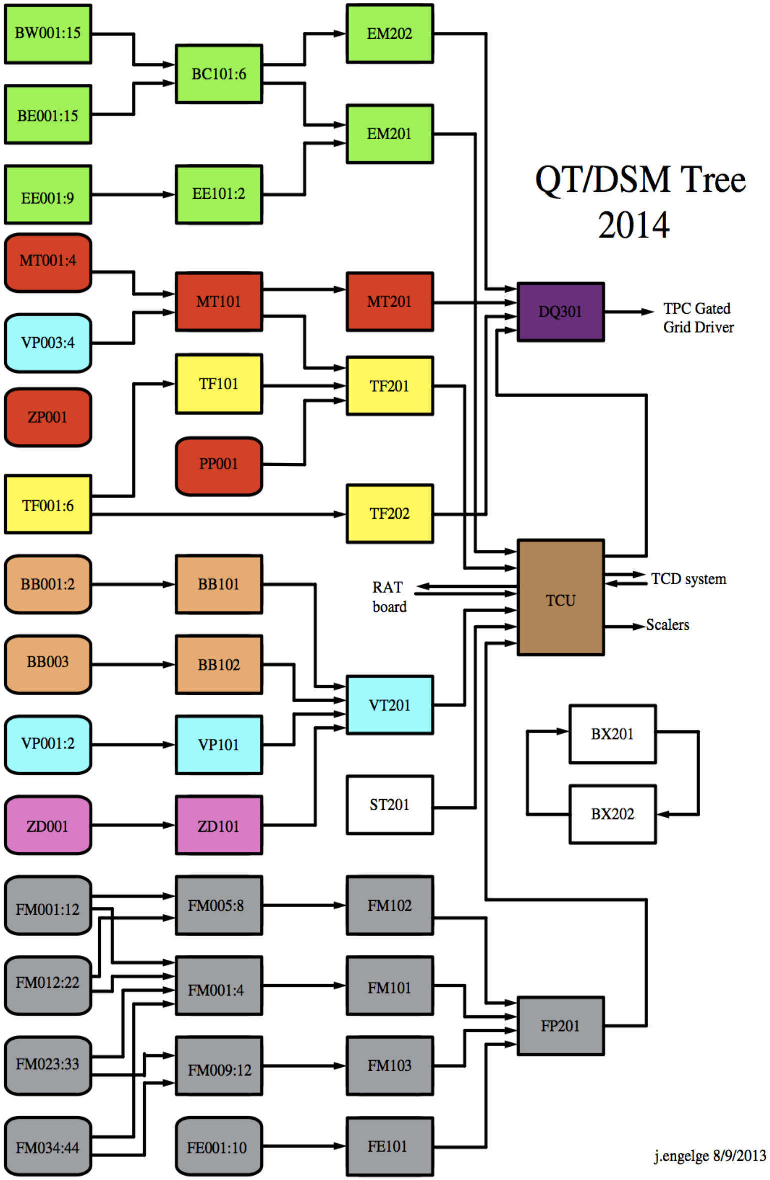
- The TCU supports up to 64 independent triggers running at the same time
- The concept of a trigger in STAR requires that ALL of the conditions L0 / L1 / L2 and HLT be fully specified.
- Rates are specified by a single prescale for every run, but that prescale can be specified by a program.



idx	used	id	name	detectors	definition	L1	L2	L4	stream	plot grp	extra	ps
0	☑	600711	UPC-JPsi	custom	+(TOFmult...	accept	accept	accept	upc	UPC	...	Expected...
1	☑	600712	UPC-Jpsi-zdc	custom	+(ZDC-E,E...	accept	accept	accept	upc	UPC	...	Expected...
2	☐											
3	☐											
4	☐											
5	☐											
6	☐											
7	☐											
8	☐	600003	vpdmb	custom	+(ZDC-TA...	accept	l2-emc-ped	accept	physics	MB	...	Expected...
9	☐	10	vpdmb-hlt	none	+(ZDC-TA...	accept	accept	l4_hltgoo...	physics	MON	---	---
10	☑	600031	vpdmb-30	custom	+(VPD-TA...	accept	l2-emc-ped	accept	physics	MB	...	Expected...
11	☑	600042	vpdmb-30-hlt	none	+(VPD-TA...	accept	accept	l4_hltgoo...	physics	MB	---	---
12	☑	13	vpdmb-30-itpc	none	+(VPD-TA...	accept	iTPC_data	accept	itpc	MB	---	---
13	☐											
14	☐											
15	☑	600231	bht1-vpd30	custom	+(VPD-TA...	accept	accept	accept	hf	HF	...	Expected...
16	☑	600232	bht1-vpd100	custom	+(ZDC-TA...	accept	accept	accept	hf	HF	...	Expected...
17	☑	600213	bht2	custom	+(BEMC_H...	accept	accept	accept	hf	HF	...	Expected...
18	☐											
19	☑	600214	bht2-l2gamma	custom	+(BEMC_H...	accept	l2-btow-g...	accept	hf	HF	...	Expected...
20	☐											
21	☑	600601	dimuon	custom	+(MTD_th...	accept	accept	accept	mtd	MTD	...	Expected...
22	☐											
23	☐											
24	☐											
25	☐											
26	☑	27	epd	test	+(EPD-TA...	accept	accept	accept	physics	MON	...	Expected...
27	☑	28	epd-west	test	+(EPD-W) ...	accept	accept	accept	singles	MON	...	Expected...
28	☑	29	epd-east	test	+(EPD-E) ...	accept	accept	accept	singles	MON	...	Expected...
29	☑	30	bbc-west	test	+(BBC-W) ...	accept	accept	accept	singles	MON	...	Expected...
30	☑	31	bbc-east	test	+(BBC-E) ...	accept	accept	accept	singles	MON	...	Expected...
31	☑	32	BBCW-notBBCE-ZDCW-lowTOF	test	+(BBC-W,...	accept	accept	accept	singles	MON	...	Expected...
32	☑	33	BBCE-notBBCW-ZDCE-lowTOF	test	+(BBC-E,Z...	accept	accept	accept	singles	MON	...	Expected...

Getting The 128 Bits
To the TCU (The DSM / QT Tree):





Getting The 128 Bits
To the TCU (The DSM / QT Tree):

- DSM are programmable FPGA based boards with 128 inputs bits and 32 bits outputs.

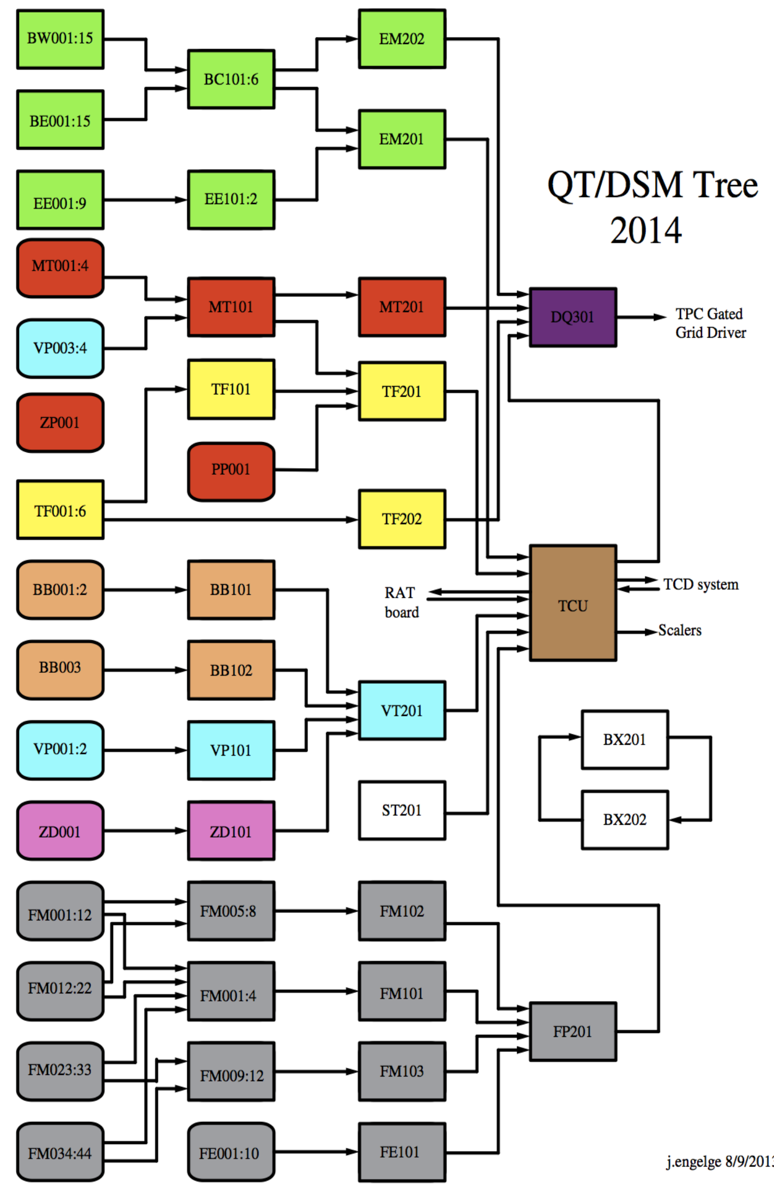
- The QT have a similar role, but can handle some analog input data.

- They receive the data directly from the electronics Of the various trigger detectors.

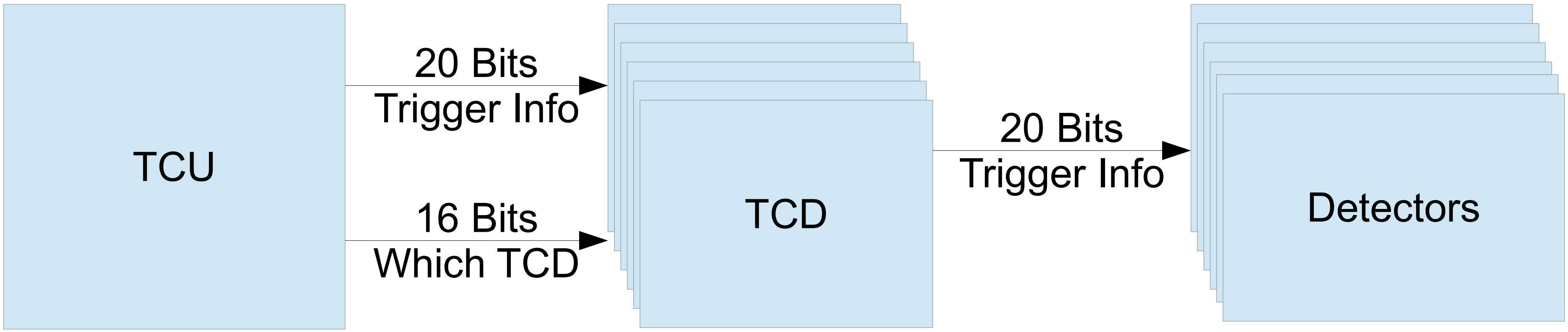
- They are arranged in 3 layers, and the boards within a layer have no information from the other boards in the same layer.

- They can have different code running each time A run is configured, so we have a protocol To group the firmware with along with appropriate Labels in the run control software.

- The DSM crates are connected to a computer called L2 using a custom network called STP. L2 gathers the data from all of the DMS/QT boards And ships it to DAQ.



After the TCU decides to trigger an event:



The Trigger Info is:

12 Bits Token. A unique identifier for the event until the all of it's components can be assembled.

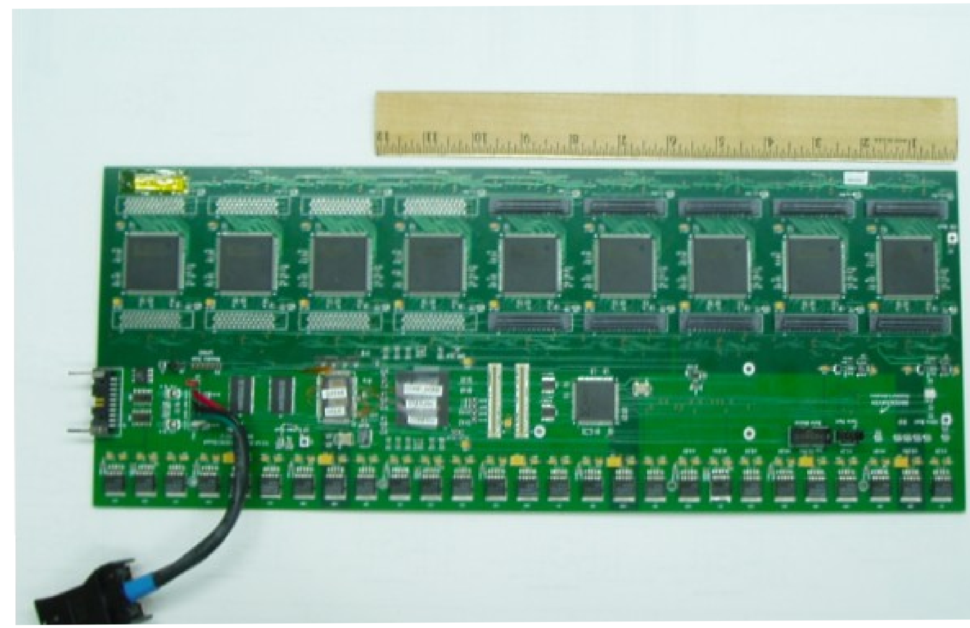
4 Bits Trigger command (laser / pulser / configuration evt/ physics)

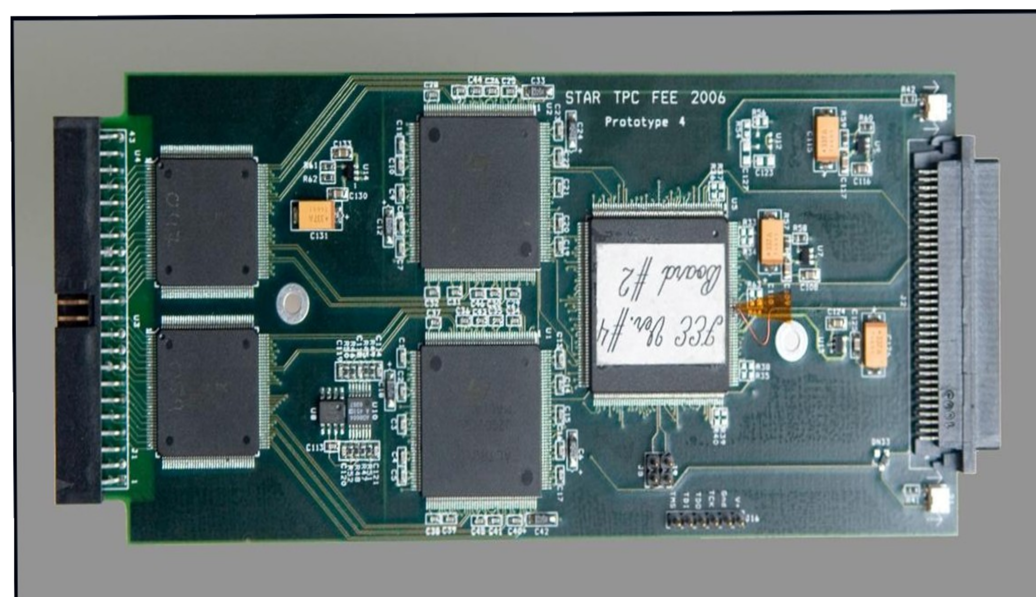
4 Bits DAQ command (read raw)

*** The detectors have no information as to what trigger fired!

Not So Random Detector Example (TPX – the outer part of the TPC):

- 96 RDO’s contain a fiber back to TPX DET computer.
- 18 FEE’s / RDO
- Black Event ~50MB
- The fee’s use ALICE’s ALTRO chip
  * digitization
  * pedestal subtraction
  * tail cancellation
  * zero suppression
- Electronics alone reduces event Size to about 2-12MB
- 36 TPX DET computers perform 2 dimensional cluster finding to Reduce data volume down to .25 – 2 MB/event.





The Event Building Network:

* The computers that receive the data from The detector fibers are called DETS. There Are roughly 75 DET computers.

* The event builders consists of 14 computers. Each containing 10-24 TB of buffer disk.

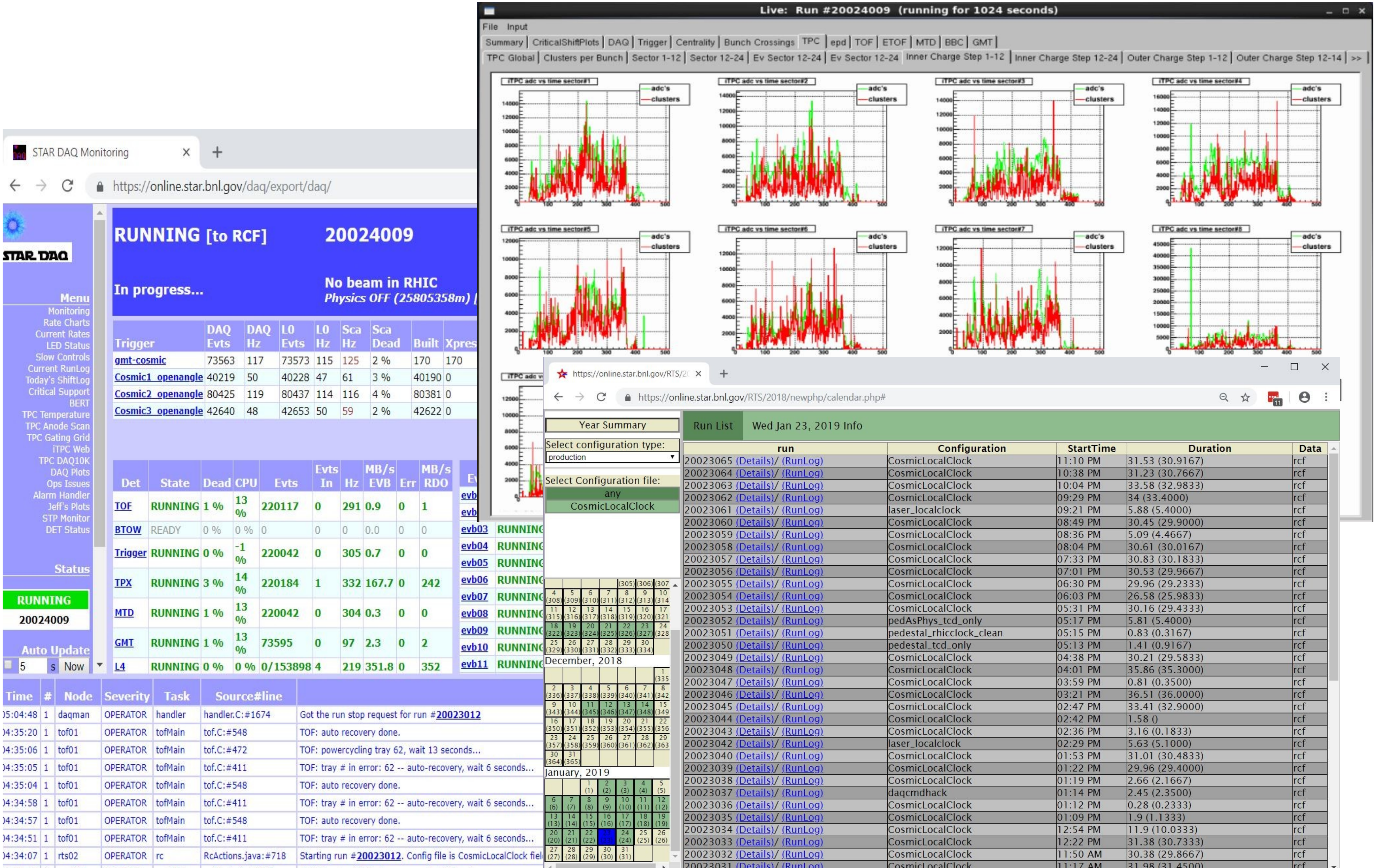
* The event building network is a hybrid of Gb and 10Gb ethernet.   The Event Builders and HLT computers are on 10Gb ports. The DETS use Gb ethernet, though the Switches have 10Gb uploads to the event Builders

* The HLT trigger (Hongwei's Talk!) is on A separate 10Gb network along with the Event Builders.   The EVBs send fully Assembled events to HLT, and receive An appropriate trigger decision.

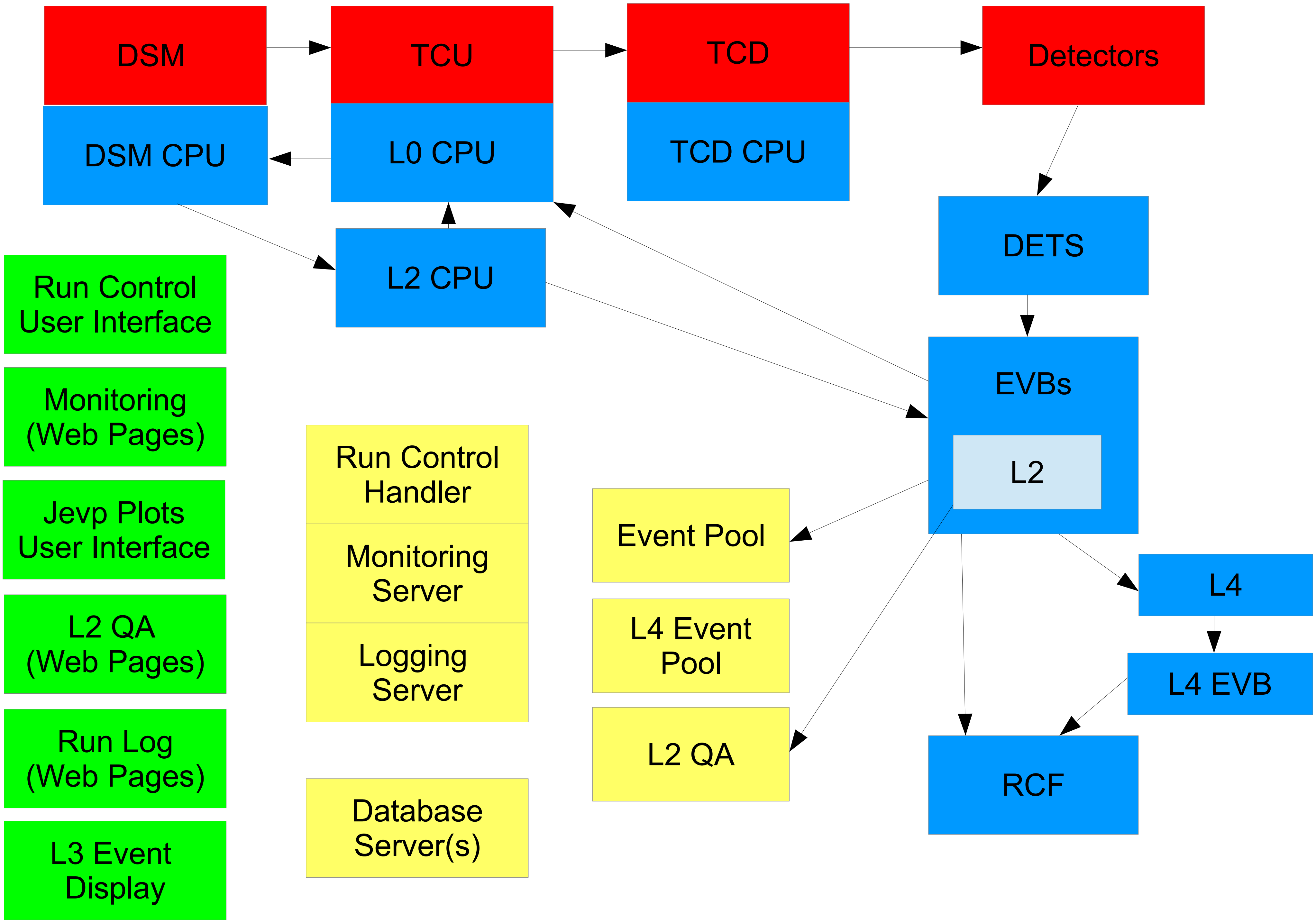
* The aggregate bandwidth of the system Is about 2000MB / second.

* Completed events are shipped to a tape robot system called HPSS.

Monitoring / QA / Databases:



Full Trigger DAQ Data Flow:



The future of DAQ at the Electron Ion Collider (2030):

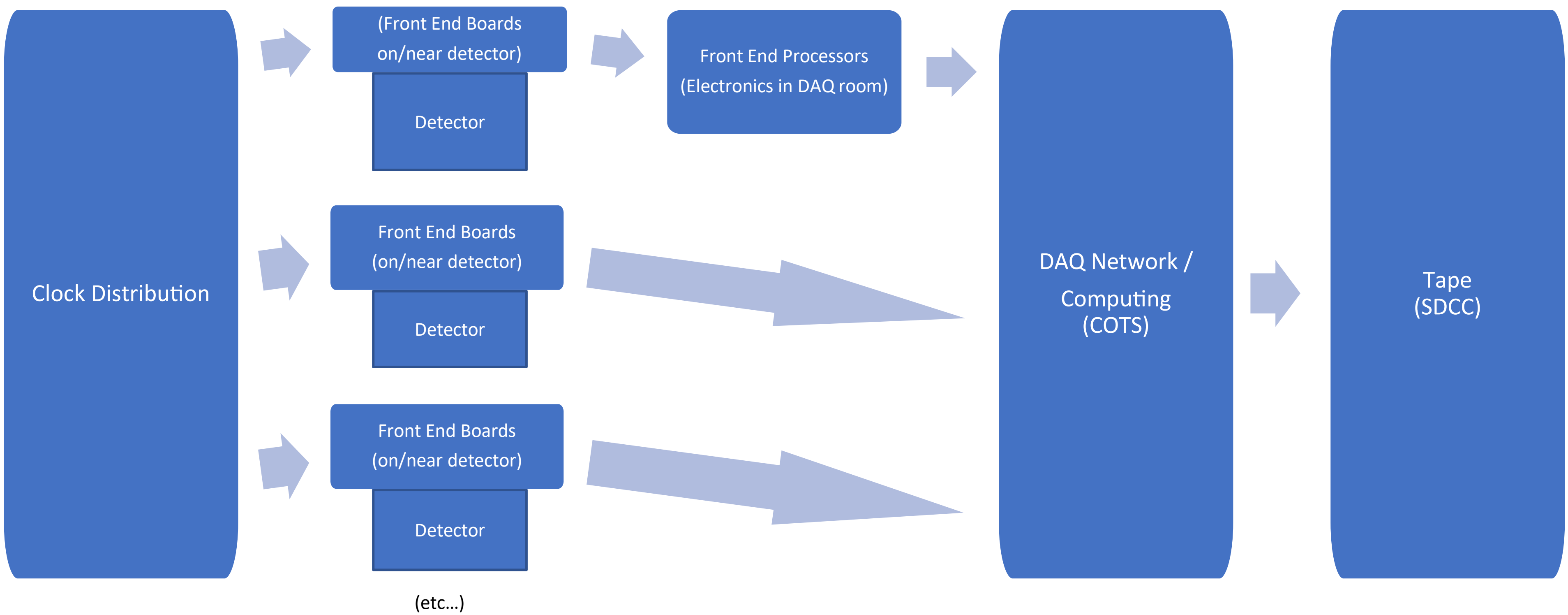
- The EIC will use one ion beam from RHIC and adds an electron beam in the same tunnel
- The physics is far different
  - 500 Khz event rates
  - Much smaller event size (~15KB / event)
  - Want to analyze all 500Khz of collision data
  - High resolution → Large numbers of channels

Detector	Readout Technology	Channel Count
Silicon Tracking	Si MAPS	37B
GEM/MMG Layer	GEM	217K
Cylindrical MPGD *	GEM	60M
HP-DIRC	MAP/MT	100-330k
ECAL	SiPM	1.7K
HCAL	SiPM	24K
HCAL imaging	Si MAPS	480M
dRICH	PMT/SiPM	350K
mRICH	PMT/SiPM	330K
B0	Si MAPS	32M + 320K
Off-Momentum	AC-LGAD (eRD24)	750K
Roman Pots	AC-LGAD (eRD24)	500K
ZDC	LGAD + ASIC eRD27	225+366
TOF	AC-LGAD	15M

The future of DAQ at the Electron Ion Collider (2030):

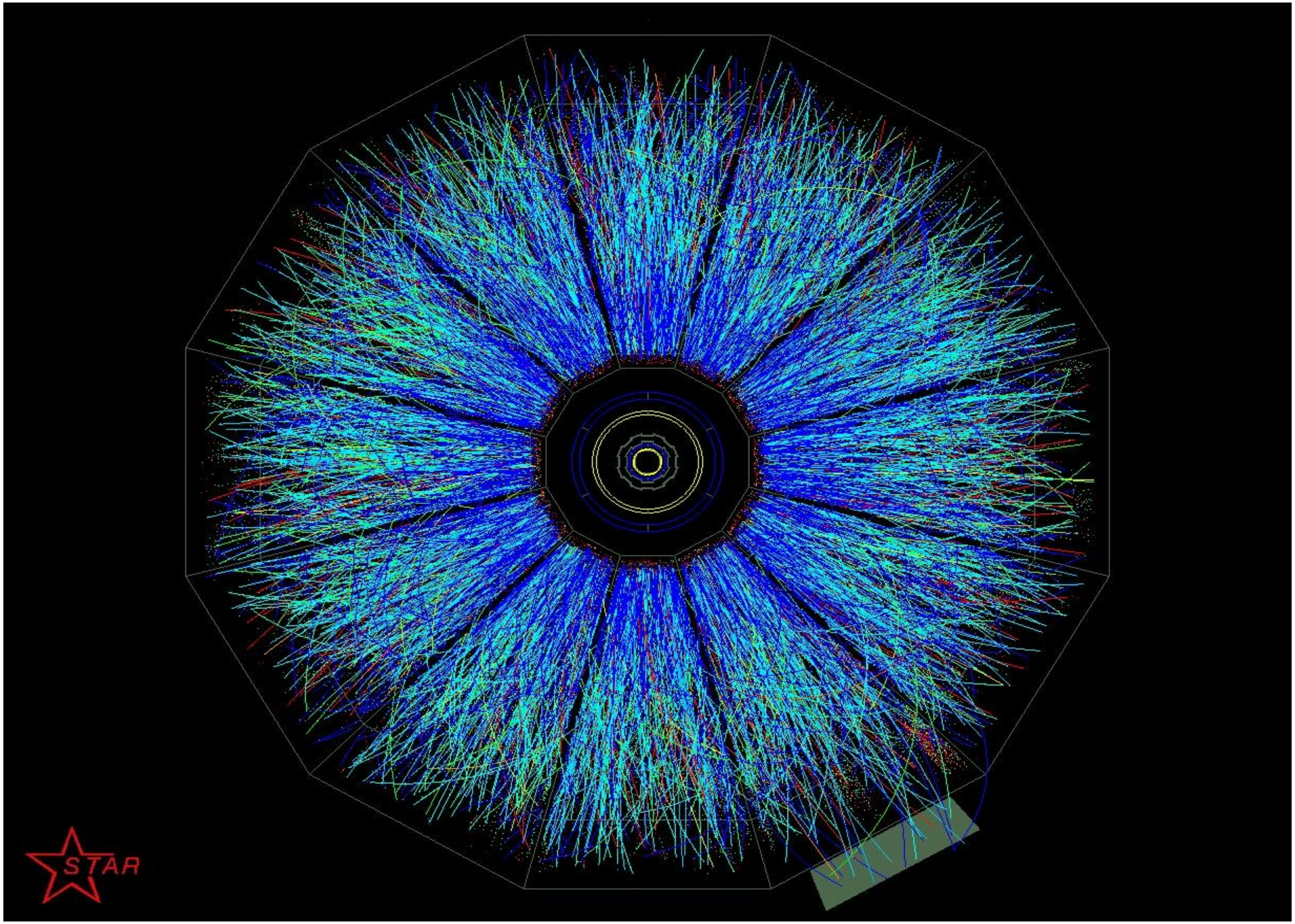
- The DAQ needs are different
- The Available technologies are different
  - ➢ Implies we need a different Architecture!
- 100MHz Clock → 500Khz rate means maximum trigger improvement is ~x200
- The noise/compression requirements are 50B → 15Kb (~x2,000,000)

- So concentrate on noise/compression and remove trigger system
  - ➢ Trigger-less Streaming DAQ



Summary:

My goal was to give you an understanding what the STAR trigger / DAQ systems are, how they work, and what they do.



Homework!

1. The time for an event to arrive can be modeled in a simulation by letting x be a random number between 0 and 1, and applying the formula:

$$t = -\frac{1}{r}\log(1-x)$$

Where r is the average rate. Convince yourself this is true!

Hints: a. assume a constant probability per bunch crossing

b. use

$$(1-x)^n = e^{-xn}$$

for small x, large xn, to get the probability distribution for the time between events

$$P(t)\,dt = r\,e^{-rt}\,dt$$

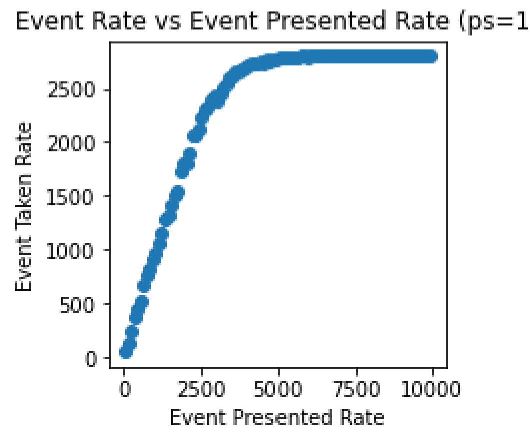
c. Think about the curve under the probability distribution as a set of boxes numbered from t=0. Integrating to time t gives the an index for that time

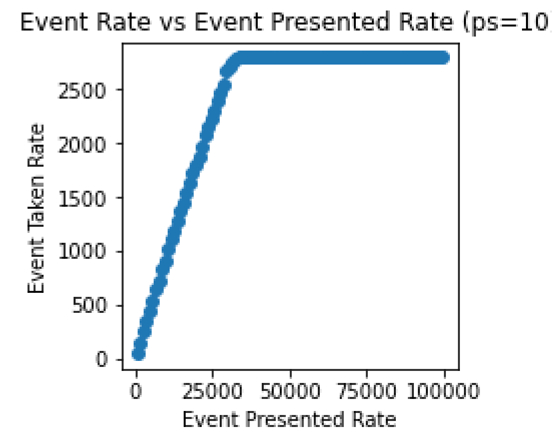
d. Solve for the time...

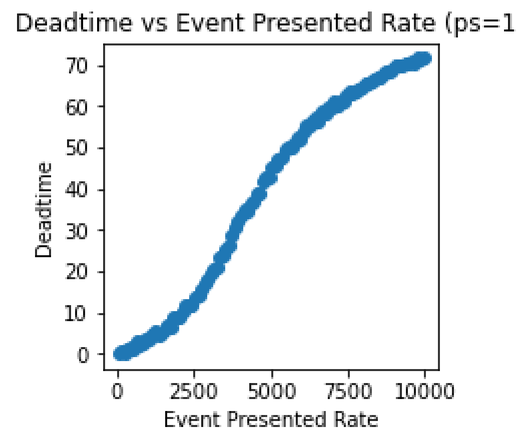
Small Event Simulation of STAR DAQ TPC DAQ

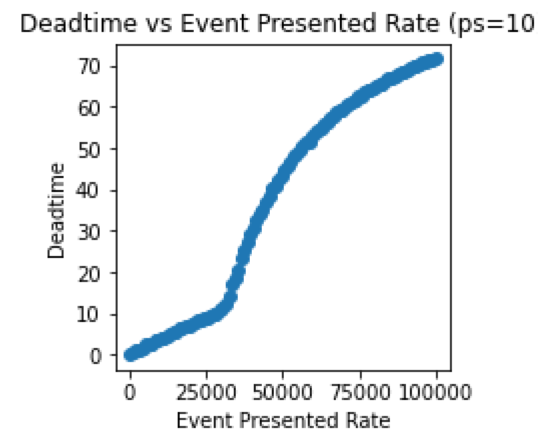
2. Using the small event simulation:

   a. What is the source of the linear deadtime below 1500hz?
   b. What is the source of the curved deadtime above 1500hz?
   c. Why are the curves for ps=10 sharper?
   d. What would the happen if the number of TPC buffers were increased or decreased?









3. Data transfers typically are modeled as taking time:

$$\text{TransferTime} = \text{Latency} + \text{ThroughputRate} * \text{sz}$$

Choose a parameter:

a. Disk write speed
b. Disk read speed
c. Ethernet transfer speed
d. Memcpy() speed

And plot transfer time vs transfer size!

It's very likely that this will NOT result in solid results. Why?