TPC Data Rate Estimation FAQ
Jin Huang, Takao Sakaguchi (BNL)
September 5-6, 2019
BNL
What is discussed here?

• What is TPC data rate at given instantaneous luminosity?
• What is uncertainties in TPC data rate at given instantaneous luminosity?
• Recommendation Q1: Quantify the uncertainties in TPC data volume for possible commissioning and zero suppression scenarios. Present these scenarios at the next review.
First, on Rec. Q1

Q1: Quantify the uncertainties in TPC data volume for possible commissioning and zero suppression scenarios.

• Possible commissioning and zero suppression (ZS) scenarios:
  
  A. We will *not* use SAMPA Direct ADC serialization mode (non-ZS stream)
     • Due to the SAMPA E-Link limit
  
  B. Initial turn on: SAMPA triggered non-ZS mode
     • SAMPA in triggered mode, for each trigger collect 260 ADC samples, O(100Hz) trigger
     • Data = 30 MB / TPC event (13 us*20 MHz*160e3 ch*10bit/8e6 MB * 60% compression)
     • Expect O(1M) events per year in detector turn on check, negligible total data vol
  
  C. TPC Time-In Calibration: SAMPA ZS mode w/o DAM trigger throttling
     • SAMPA in ZS mode, but all data pass through DAM without trigger throttling
     • Only operate at low collision rate O(kHz) scenarios
     • Data rate ~ 8.8 Mb * AuAu collision rate * 60% compression, take 1 low-bunch RHIC fill.
  
  D. Production data: SAMPA ZS mode w/ DAM trigger throttling
     • Data rate as presented in the last review
What is the estimated TPC data rate?

- Data rate estimated as event size and **instantaneous** TPC data rate at a given **instantaneous** collisions rate
- Au+Au TPC data rate [Gbps] ~ 70 + 1 * Collision_kHz
- Au+Au TPC event size [MB] ~ 0.54 + 0.0085* Collision_kHz

<table>
<thead>
<tr>
<th></th>
<th>AuAu (Y-1)</th>
<th>AuAu (Y-3)</th>
<th>AuAu (Y-5)</th>
<th>pp</th>
<th>pA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average collision rate [kHz]</td>
<td>100</td>
<td>140</td>
<td>170</td>
<td>12900</td>
<td>2800</td>
</tr>
<tr>
<td>FFE → DAM data rate [Gbps]</td>
<td>1100</td>
<td>1476</td>
<td>1800</td>
<td>1700</td>
<td>1470</td>
</tr>
<tr>
<td>DAM → DAQ data rate [Gbps]</td>
<td>170</td>
<td>209</td>
<td>240</td>
<td>160</td>
<td>133</td>
</tr>
<tr>
<td>Per-event size @ DAQ [MB/evt]</td>
<td>1.4</td>
<td>1.7</td>
<td>2.0</td>
<td>1.3</td>
<td>1.1</td>
</tr>
</tbody>
</table>
How this data rate was estimated?

- FEE→DAM data: continuous-time DAQ simulation assuming cluster/layer = $<dNch/deta> \times 2$ (background), $3 \times 5$ 10b-ADC sample / cluster, $\times 1.4$ data header
- DAM→DAQ data: trigger throttling simulation and $\times 60\%$ lossless compression
Did you crosscheck with STAR/ALICE?

• This 1st principal estimation was initially developed by Takao after consulting/checking with STAR and ALICE experience

• STAR’s (Tonko) suggestion: “took into account the albedo particles, misidentification of hits (background and fakes) by doubling dN/dy of min-bias events” (to get number of clusters)

• ALICE comparison
  – ALICE Run3 TPC data rate = 8280 Gbps [ALICE TDR]
  – Takao use our method reproduced ALICE rate = 7520 Gbps [sPHENIX TDR]
  – Difference is 10% More details from Takao in the backup
How does that compare with Geant4?

- We estimated TPC data rate with full detector Geant4 simulation and pile up.
- Used stock QGSP_BERT_HP physics list. We DO need to further explore TPC simulation tunes to better reproduce TPC multiplicity.

  o Low pile up: We found in single Au+Au collision, the Geant4 data rate is **15% lower** than the previously quoted estimation
  o High pile up: in top Au+Au collision rate, the Geant4 data rate is **25% higher** than the previously quoted estimation
  o This is likely comes from pile up event contribute relatively more large clusters stretched in the z-direction due to the high eta tracks
  o More details in past talks in backup
What is the rate uncertainty at a given instantaneous luminosity?

• ALICE TDR data rate = 1.1 x our estimation method
• GEANT4 data rate = [0.85 – 1.25] x our estimation method
  – Further uncertainty as our TPC simulation is not fully tuned
  – There is also possibility of unforeseen detector noise, background and chan-to-chan cross talk that leads to higher data rate

• I suggest 30% systematic uncertainty on the current rate estimation at fixed instantaneous collision rate
  – This is NOT a conservative uncertainty, but encloses the current tests and it is handleable in DAQ
EXTRA INFORMATION
STAR estimate

• In the data format, they assign 8 bytes per measurement
  – No idea on the total data rate. STAR always says that the data rate varies and never provide us gut feeling.

• They took into account the albedo particles, misidentification of hits (background and fakes) by doubling dN/dy of minbias events
  – Tonko’s suggestion for estimate max rate.
  – In sPHENIX TPC rate estimate, we also took this into account (i.e., doubled dN/dy)

• No estimate of data rate fluctuation by changing zero-suppression, etc.
  – Probably it may be negligible compared to “doubled” dN/dy
  – No idea on event pile-up.
Past slides: Design parameters

- 154K readout channels from both ends
  - 40 measurements (clusters) in radial direction
- 15KHz is the baseline trigger rate
  - Limit of DAQ rate prior to livetime fall-off
  - We assume that beam interaction may happen as much as 100KHz for |z|<1m
- \( \frac{dN_{\text{ch}}}{dy} = 180 \) (minbias Au+Au @ 200GeV) \( \rightarrow \) 400 tracks in |\( \eta \)|<1.1
  - Background and fakes effectively doubles the number of tracks; 800 tracks in the TPC
- Raw rate: 940Gbits/s @ 100KHz
  - Caveat: Radially-averaged rate
  - \( \eta \) dependent acceptance change is taken into account
Past slides: Padplane layout

• New pad layout (30<r<78cm)
  – Three segments in radial direction, each divided into 16 (8 for 30<r<40cm)
  – 12 segments in phi direction, each divided into multiple of 16
  – Matching to number of input to a FEE
  – Each cell in the right figure corresponds to 16 pads in phi

• Variable pad size as a function of radial position

• Total 153,600 pads for both side
  – 600 FEE cards

• Data Rate (no header included)
  – 1.42Gbps/board for 30<r<40cm
  – 1.45Gbps/board for 40<r<60cm
  – 0.77Gbps/board for 60<r<80cm
  – \(28\)Gbps/(1/12 full azimuth)

5 FEEs for 30<r<40cm, 8 for 40<r<60cm, 12 for 60<r<78cm, for each 1/12 of full azimuth

Each cell = 16 pads in phi
Past slides: Data rate calculation

- Raw data (100% duty factor is assumed)
  - Sampling rate in z-direction: 10MHz (= 100nsec)
  - Pulse peaking time is 160nsec (fixed from SAMPA's specification), which leads to ~350nsec for whole pulse shape.
    - More than 4 samples in timing (z) direction is necessary. We decided on taking 5 samples including pre-signal
  - One cluster will be spread over 3 pads in r-\phi plane
    - Coming from the characteristics of the Ne2K (Ne - CF_4 - iC_4H_{10}: 95% - 3% - 2%) gas
  - We measure 40 clusters for one track
  - Each sample is 10 bits: 40 clusters * 15 * 10 bits = 6 Kbits/track
  - 800 tracks per event: 6Kbits/track * 800 = 4.8 Mbits/event
    - This number doesn’t take eta-dependent acceptance change of TPC into account
  - At 100 KHz: 4.8 Mbits/event * 100 KHz = 480 Gbits/s

- With header of SAMPA (40% increase at maximum): 670Gbits/s
  - With eta-dependent acceptance change: 940Gbits/s
ALICE estimate (cutout from their TDR)

- This data rate is based on their Run3 experience

<table>
<thead>
<tr>
<th></th>
<th>IROC 1</th>
<th>IROC 2</th>
<th>OROC 1</th>
<th>OROC 2</th>
<th>OROC 3</th>
<th>TPC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Avg. data rate / chan. (Mbit/s)</td>
<td>22</td>
<td>16</td>
<td>15</td>
<td>13</td>
<td>11</td>
<td></td>
</tr>
<tr>
<td>Req. bandwidth / chan.  (Mbit/s)</td>
<td>40</td>
<td>30</td>
<td>30</td>
<td>25</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>Front-end channels</td>
<td>2304</td>
<td>3200</td>
<td>2944</td>
<td>3712</td>
<td>3200</td>
<td>552,960</td>
</tr>
<tr>
<td>Total data rate       (Gbit/s)</td>
<td>50</td>
<td>50</td>
<td>45</td>
<td>50</td>
<td>35</td>
<td>8280</td>
</tr>
<tr>
<td>Total bandwidth       (Gbit/s)</td>
<td>100</td>
<td>100</td>
<td>90</td>
<td>100</td>
<td>70</td>
<td></td>
</tr>
<tr>
<td>FECs (5 SAMPAs each)</td>
<td>15</td>
<td>20</td>
<td>19</td>
<td>24</td>
<td>20</td>
<td>3528</td>
</tr>
<tr>
<td>SAMPAs</td>
<td>75</td>
<td>100</td>
<td>95</td>
<td>120</td>
<td>100</td>
<td>17,640</td>
</tr>
<tr>
<td>GBTx ASICs</td>
<td>30</td>
<td>40</td>
<td>38</td>
<td>48</td>
<td>20</td>
<td>6336</td>
</tr>
<tr>
<td>Versatile link twin transmitter (VTTx)</td>
<td>15</td>
<td>20</td>
<td>19</td>
<td>24</td>
<td>0</td>
<td>2808</td>
</tr>
<tr>
<td>Versatile link transceiver (VTRx)</td>
<td>8</td>
<td>10</td>
<td>10</td>
<td>12</td>
<td>20</td>
<td>2160</td>
</tr>
<tr>
<td>GBT uni-directional data links (3.2 Gbit/s)</td>
<td>30</td>
<td>40</td>
<td>38</td>
<td>48</td>
<td>20</td>
<td>6336</td>
</tr>
<tr>
<td>GBT uni-directional TTS links</td>
<td>8</td>
<td>10</td>
<td>10</td>
<td>12</td>
<td>10</td>
<td>1800</td>
</tr>
</tbody>
</table>

Table 6.1: Data rates and bandwidth requirement and partitioning of SAMPAs, FECs, optical components, readout and TTS fibers with 5 readout partitions per TPC sector. The acronyms are explained in the text. The numbers in the last column show the sum over the 2 x 18 TPC sectors. The uni-directional versatile links [4] for the data to be sent to the CRU and online farm are driven by bi-directional optical transceivers (VTRx) or uni-directional twin transmitters (VTTx). Since the bandwidth needs in the up- and downstream directions are asymmetric, less VTRx are needed to receive trigger and timing information via the ALICE TTS³ system. We aim at installing one TTS link on every
In this table, the ALICE’s number is shown based on our estimate.

It seems our number is consistent with their data rate estimate.
- Our number uses $2* \frac{dN}{dy}$
- No pile-up is taken into account in this calculation
- ALICE’s data rate in the previous slide is by experience

ALICE requested another a factor of 2 bandwidth for the TPC data
Data size for single MB collision

- Single MB collision, no pile up, emulated with 0-14.7 fm sHIJIGN collisions
- $<\text{dNch/deta}>x2$ estimation: 1.05 MB/event (before compression)
- Geant4 simulation: 0.9 MB/event (before compression)
- Consistent with in the uncertainty of the $<\text{dNch/deta}>x2$ arbitrary scale factor

$dNch/deta$ estimation:
Accepted ADC samples in bit size
After computing review, in July 2018, we improved the estimation in Geant4 based simulation: [https://indico.bnl.gov/event/4024/](https://indico.bnl.gov/event/4024/)

- Mean channel occupancy in inner rings ~25% for triggered event @ 170kHz collision, 30% @ 200kHz
- Average single MB event data rate consistent between $\frac{dN_{ch}}{d\eta}\times 2$ estimation and Geant4 simulation (15% smaller)
- Full pile up simulation suggest 25% higher data rate than $\frac{dN_{ch}}{d\eta}\times 2$ estimation (from longer ionization trail of off-time tracks?)