Luminosity Considerations for STAR in the Years 2020+

# Update on the Info in Section 2 to 4

## Multiple interactions per bunch

After discussing more with Wolfram it turns out he used for his calculation the total p+p cross section from the PDG, this includes QCD 2->2, single and double diffractive as well as the elastic part, resulting in 50 mb at √s=200 GeV and 60 mb for 500 GeV. Looking to our own papers <http://arxiv.org/pdf/nucl-ex/0305015.pdf> and <http://arxiv.org/pdf/hep-ex/0608030> show that BBC coincidences see only 87% of the non-singly diffractive cross section 26.1 ± 2.0mb (NSD).

Assuming 100% NSD (30 mb) at 500 GeV, which is only 50 % of the total p+p cross section, leads to ~4 multiple interactions at 500 GeV and as the luminosity at 200 GeV is roughly half of the one at 500 GeV ~2 multiple interactions at 200 GeV.

For pA the cross section seen by the detector is 36 mb, which is NSD plus ½ of the single diffractive cross section contribution. This together with the pA luminosity gives ~0.5 interaction per bunch crossing, so no problem.

## Luminosity and Polarization guidance:

Even so the multiple interactions per bunch go down the problem with the pile-up in the TPC remains. Therefore and based on the discussion below and the follow up answers from Wolfram, the suggestion is that in 2020+ the dynamic \*–squeeze is successful and we can run with a constant 2013 luminosity, throughout the entire fill, this will give 120 pb-1/week at √s=500 GeV and at √s=200 GeV, the suggestion is to use the 20 pb-1/week, which is the mean of the projected luminosity in table 6 in <http://www.rhichome.bnl.gov/RHIC/Runs/RhicProjections.pdf> for 2018+. The average polarization is to be used is 0.6 for both beam energies.

## Suggested running by Carl:

Instead of running all physics programs in a running period in parallel Carl suggested to consider the following alternative.

“The pp500 NLO inclusive jet cross section into the FCS with pT>5 GeV/c is ~0.4% of the NSD cross section.  Thus, there will be a >=5 GeV/c jet in 2% of the active bunch crossings.  That's a rate of 160 kHz!!!  Jets are NOT "rare probes" in pp500 collisions (except at the highest pT's).  I would suggest that the right way to do jet physics using the FCS would be to turn the rate down to the point where we can saturate the available bandwidth at prescale 1, then record like crazy.”

## Answers by Wolfram to our questions in section 4.

* What is the impact on the predicted luminosity increase that there will be no p+p running between 2015 and 2020

That is a good point. Without running it is difficult to make progress. I think we will know of the generally principle with new OPPIS and the electron lenses can be demonstrated at 100 GeV. For this the next 2 runs will give good guidance, even if we do not run 255 GeV protons. I had assumed pp running in Run-15 and Run-16.  Having then no polarized protons in RHIC for 3 years does prevent demonstration of progress, and studies/progress need to rely on data to date, theory, and simulations.

* What is the increase in luminosity per fill if the luminosity is kept constant through a dynamic \* squeeze through the fill; lets assume we would like hold it constant on the 2013 luminosity level.

In Run-13 the average store luminosity was 64% of the peak luminosity. If one could go to 100%, one would gain 56%.

* Why is there no impact through beam-beam on the beam polarization? The beam-beam should be much higher with a decreased bunch length and more protons per bunch.

Beam-beam is only weakly dependent on bunch length, but the beam-beam parameter is proportional to the intensity. So far we have not seen any depolarization effects from beam-beam (Mei's student had revisited that topic last year). Beam-beam is a disturbance in the lattice, but not large enough that the snakes would not overcome it. The increase in the beam-beam parameter we are targeting is only about 50%.

Follow up on the last question.

* Is Mei's students study the one where he looked into the difference in polarization for bunches which collide once, twice and three times (as AnDY) was in collision? If yes, I'm surprised he could get enough statistical precision. But is not the polarization lifetime indirectly caused by beam-beam, or is the emittance growth not caused by beam-beam?

Yes, beam-beam does cause emittance growth, and the beam-beam tune spread can move particles onto an unfavorable tune. The idea of the electron lenses, however, is to store more intensity without an increase in the beam-beam parameter.

# Basis for the discussion

The main input to the discussion is the talk by Wolfram Fischer to be found here <https://www.phenix.bnl.gov/WWW/publish/elke/STAR/pp-pA-LoI/2014-0321%20p+p%20and%20p+Au%20in%202020+.pptx>

In this talk luminosities for p+p at 500 GeV as summarized in the table below have been presented, the luminosity increase in 2018 and later is driven by a higher bunch intensity and a shorter bunch length, based on

* New polarized source (first operated in 2013)
* Electron lenses (under commissioning)

**Multiple interactions per bunch at peak luminosity are going from 1.7 (2013) to 7.7 (2018)**

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For 200 GeV p+p the rule of thumb is that the luminosity is half of that at 500 GeV. The multiple interactions also scale by a factor of 2, so are in the order of 4 in the 2020+ years.

# Can STAR benefit from this luminosity increase

* The 2013 p+p 500 GeV run constituted the limit or very close to the limit acceptable by the TPC. The iTPC upgrade will not make any difference to this; actually on the contrary the iTPC could potentially make things worth as the pad size for the inner pads is increased this together with the increased luminosity might lead to the fact that the inner pads at 200 GeV are as difficult to use as at 500 GeV now. The impact of this potential change on the forward physics utilizing the iTPC and the EEMC needs to be investigated. Using a dynamic \* squeeze technique through the fill can mitigate some of the luminosity limit of the TPC.

## Summary on p+p / p+A physics planned in the years 2020+

In the following a quick summary of the p+p and p+A physics planned in 2020+ is given, special emphasis is given if the TPC is needed for this physics or not and the program can be done with the increase multiple interactions per bunch. The physics goals have been outlined in the following tables <https://www.phenix.bnl.gov/WWW/publish/elke/STAR/pp-pA-LoI/pp.pA.table.ppt> as well as many talks given in the pp-pA-LoI group meetings.

In the following it is assumed that for the rapidity range -1 to 2 the dominant tracking detector is the TPC. It is also assumed the iTPC upgrade is available in the years 2020+. For jet or any other charged particle id the TPC is combined with the EEMC in the rapidity range 1 to 2. In the rapidity range 2 to 4 the setup is the FCS (ECAL+HCal+Preshower) combined with a fast tracking detector, i.e. Silicon. Such in the rapidity range 2 to 4 there are no limitations from the detectors to take a factor four higher instantaneous luminosity.

### 500 GeV Longitudinal Polarized Physics

* + Di-jets to measure g(x,Q2) and to constrain the shape of g(x,Q2). This involves measuring di-jets with different rapidity combinations from barrel-barrel to forward-forward combinations. Especially the asymmetries for forward-forward jets are very small, which poses a special challenge to the relative luminosity measurement (< 10-4).
    - As for certain di-jet rapidity combinations the jets involve the TPC this program cannot benefit from the luminosity increase as long as the limitations due the TPC cannot be overcome.
    - With 8 interactions per bunch it will be extremely important to reach a goal of <10-4 for the relative luminosity to understand and resolve how many interactions occurred per bunch crossing and spin alignment. Even without this additional complication there is not yet a concept to measure relative luminosity to this precision
  + The same holds for any other correlation measurements like -jet, hadron-jet.
* **200/500 GeV Transverse Polarized Physics**
  + The main physics observables, Collins, IFF and Sivers, involve jets or di-hadrons in a rapidity range +1 to +4, this rapidity range combines the EEMC with the iTPC to reconstruct jets. Like in the case for 500 GeV jets as long as the limitations of the TPC are not overcome, STAR cannot benefit fully from this luminosity increase.
  + AN(DY) at 500 GeV, this is the only measurement, which is done only in the rapidity range 2 to 4. It does not require any correlation with another particle. The absolute critical requirement is to control the background from QCD 2🡪2 to equal or better 1:1, if not asymmetries of 2%-4% are not measurable. With multiple interactions per bunch, this will require a tracker in this rapidity range, which can resolve the different vertices The suppression factor needed for DY is 106, simulations need to be done, which show that a tracker in the rapidity range 2 to 4 with STAR magnetic field can do this.
* **200 GeV un(polarized) pA**

One global remark if any of the measurements needs to be made as function of centrality, the detector measuring centrality in pA needs to be able to resolve the multiple interactions per bunch. One question, which needs to be answered first, do all the interactions maybe have the same centrality? If not how can this be resolved, what does the LHC do?

* + All observables related to UPC have the final state in -1 to max 2 in rapidity such involve the TPC.
  + NLO DY measurements, this involves to detect in addition to the e+e- pair an other hadron. As this measurement is thought as one of the measurements to be sensitive to saturation it will be critical to go in and out of the saturation regime, this is realized by changing the rapidity range and//or the kinematic requirements on the DY-pair and hadron.

Only if all products fall in the rapidity range 2 to 4 it will be possible to take the full luminosity. If this happens there is still one more concern with multiple interactions per bunch the new Si-tracker needs to resolve the different interaction vertices, which might be a challenge and needs to be simulated and integrated into the design of the tracker.

To resolve the interaction vertices is crucial to suppress QCD 2🡪2 background. Note the NLO-DY c.s. is ~20% of the LO DY c.s.

Measuring saturation through hadron-hadron of hadron-jet, photon-jet correlations, is much less luminosity hungry compared to DY, for the rest the same arguments apply it is supposed to be measured as fct. of rapidity and collision centrality as well as pt cuts on the trigger and associated particles.

* + CNM matter effects (pt-broadening, J/Ψ suppression, ….) need to be measured as fct. of rapidity, centrality and so on. Maybe we can ignore this and just measure at the rapidity range 2 to 4, this would then not need any TPC as J/Ψ and other particles are detected through peaks it will be easier to see the signal even with multiple interactions per bunch and to suppress the background.
  + Direct photon measurements can be done only in the rapidity range 2 to 4, the question here is how do the multiple interactions influence the background suppression, which is like in DY one of the challenges for a good direct photon measurement.
  + For any type of ridge-type of correlation measurements the TPC is always involved and as such no benefit of the luminosity can be made as long as the limitations of the TPC are not removed.

In summary, if we want to make use of the increase in luminosity for measurements in the rapidity range 2 to 4, the following questions need to be resolved.

* Can a tracker in the forward direction resolve the different vertices per bunch, to suppress background for the measurements with rare cross sections, i.e. NLO-DY.
* Can a detector be built, which resolves the centrality for the different interactions per bunch?
* How can we measure relative luminosity to 10-4 with multiple interactions per bunch?
* Are there any limitations due to the trigger and DAQ throughput?

It would be much more beneficial for STAR to have a luminosity profile per fill like we have with the stochastic cooling in A+A running, this could be achieved if the dynamic \* squeeze through the fill works.

# Questions for Wolfram

Several open points, which need to be clarified by Wolfram, are listed in the following

* What is the impact on the predicted luminosity increase that there will be no p+p running between 2015 and 2020
* What is the increase in luminosity per fill if the luminosity is kept constant through a dynamic \* squeeze through the fill
* Why is there no impact through beam-beam on the beam polarization? The beam-beam should be much higher with a decreased bunch length and more protons per bunch.