The STAR Experiment: The second decade and beyond

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The STAR experiment at RHIC has been running successfully for over 10 years. Over this time, many upgrades have been made to the detector configuration, driven by the physics requirements. In this presentation, I will review the upgrades in the near term with respect to A+A and p+p physics and review what STAR can contribute to an eRHIC era.

1 Introduction

The STAR experiment started taking data at the Relativistic Heavy Ion Collider at BNL in 2001. From the outset, STAR was designed as a large volume (acceptance) detector with a large array of physics capabilities, focussed on charged particle identification in its Time Projection Chamber (TPC). The TPC has uniform acceptance over 2 units of pseudo rapidity, centred at mid-rapidity, and provides particle identification through specific ionisation with up to 45 samples per track. Also in the first year, a small-volume mid-rapidity RICH detector was in use, together with a small-volume TPC in the forward region and a number of trigger detectors. The whole of the mid-rapidity part of the detector was situated in a magnetic field of up to 0.5 T.

Over the past decade, STAR has evolved from this initial setup and is now a much more complex series of detectors, comprising electro-magnetic calorimetry in both the barrel and the forward regions, a Time of Flight detector at mid-rapidity and a 3-layer silicon vertex tracker has come and gone, along with 2 forward TPCs. A detailed description of all these detectors mentioned above can be found elsewhere [1].

The STAR detector has performed admirably over the last decade and has produced a great wealth of physics results, resulting from the polarised p+p programme to the heavy-ion programme, where it is believed a “perfect liquid’ of de-confined quark-gluon matter has been created. The page limit in these proceedings does not afford me room to discuss these further, so I refer the reader to the literature [2].

2 STAR upgrades in the near term

Despite the success of the STAR physics programme, STAR has not sat on its laurels but has been following an aggressive path of upgrades to its detector system, led by the questions arising from the RHIC data which so far remain unanswered. In the following section, I will describe three of the upgrades planned in the near-term, which are aimed specifically at the heavy-ion and spin physics programmes.

2.1 Forward GEM Tracker

In order to study the spin dependence of the sea-quarks, STAR plans to make measurements using parity violating W production in the $e^{-(+)}$ decay mode in p+p collisions at $\sqrt{s} = 500$ GeV. First measurements of this effect have been made using the calorimeter currently in place in STAR and these are shown in the left-hand-side of figure 1 [3]. This preliminary measurement was made with 12 pb^{-1} of data. The right-hand-side of figure 1 shows a prediction of this measurement for 300 pb^{-1}, a polarisation of 70% and with precise tracking information.

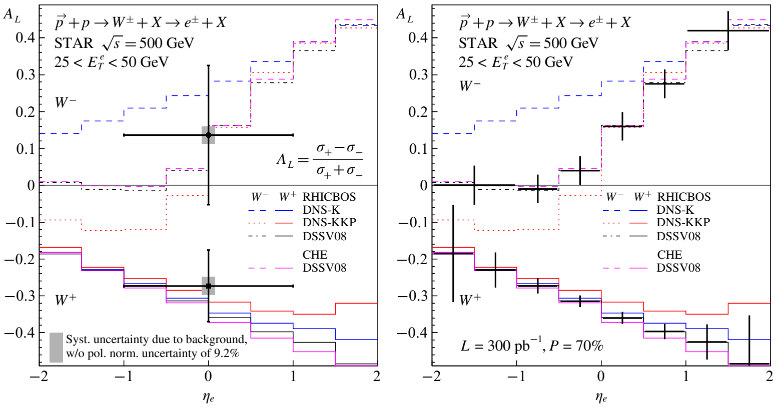

Figure 1: The current measurement (left) and future capabilities (right) for measuring A_L of W^+ and W^- in STAR.

This tracking information comes from a forward GEM tracker (FGT) which consists of six triple-GEM planar detectors currently under construction. The FGT sits around the beam pipe in the forward direction and covers the same pseudo-rapidity range ($1.1 < \eta < 2$) as the endcap calorimeter. The inner radius of the FGT is 10.5 cm and the outer radius is 39 cm. The GEM foils themselves have an inner hold radius of 50 µm, an outer radius of 70 µm and a 140 µm pitch. Each of the 6 rings are subdivided into 4 quadrants, 14 of which are installed in the current RHIC run and the rest will be completed in time for the 2013 run. The data from 2012 will allow for an evaluation of the detector performance.

2.2 Heavy-Flavour Tracker

One of the interesting questions to arise from the RHIC data is whether or not charm flows hydro-dynamically or not. Measurements of charm flow, via the flow of secondary non-photonic electrons have proved inconclusive. This is a very challenging measurement, partially due to the unknown contribution of bottom and charm to the electron spectra. To overcome this, it is desirable to measure the flow of D mesons themselves. In order to do this, STAR is building a Heavy-Flavour Tracker (HFT) - a very thin vertex detector which can measure the secondary decay vertex of the D meson. The HFT is a silicon detector consisting of 4 layers. The innermost layer is at a radius of 2.5 cm from the centre of the beam pipe and uses CMOS active pixel

Detector	Technology	Radius	Hit Resolution R-ϕ (μm)	Rad. Length
PIXEL	Active pixels	2.5, 8 cm	8.6-8.6	0.4 %
IST	Si strip pad sensors	14 cm	170 - 1700	1.2 %
SSD	Double-sided strips	23 cm	30 - 857	1.0 %

Table 1: Detector technologies used for the STAR Heavy-Flavour Tracker

sensors which are 50 μm thick. This radius is actually smaller than the radius of the current beam pipe so a new beam pipe, with radius 2 cm, will be installed along with the detector. The second layer of the detector also uses active pixel technology and sits at a radius of 8 cm. The next layer, at a radius of 14 cm utilises silicon strip pad sensors whilst the final layer, at a radius of 23 cm, uses double sided strips. Table 1 summarises the technology together with the corresponding radiation lengths and hit resolutions.

As well as charm flow, the HFT can be used to investigate the baryonic composition as a function of transverse momentum. In heavy-ion collisions, it was observed that at a few GeV/c, the ratio of p/π and Λ/K was significantly enhanced, leading to theories on quark coalescence of constituent quarks dominating over fragmentation at these momenta. If this is also true in the charm sector, it will lead to a re-interpretation of the non-photonic electron results as the branching ratios in the medium would be different to what was expected. The installation of the HFT will start ahead of the 2013 RHIC run.

2.3 Muon Telescope Detector

Due to the large mass of the charm and bottom quarks, heavy flavour measurements play an important role in heavy-ion collisions. Complementing the HFT, which will measure heavy-flavour particles by reconstructing their secondary decay vertex, it is also possible to measure those particles which decay through leptonic channels (e.g. J/ψ, Υ). It is desirable to measure these through the muon decay channels, rather than the electron, because this minimises the Dalitz decay background and importantly, the Bremsstrahlung radiation, allowing for the Υ 1S, 2S and 3S states to be distinguished.

To accomplish this goal, STAR is building a Muon Telescope Detector (MTD) which differs from conventional muon detector technology and instead uses the same Multi-Gap Resistive Plate Chamber (MRPC) technology that has been shown to work successfully in the STAR Time-of-Flight Detector. The MTD will consist of 118 modules and will sit outside the return iron bars of the STAR magnet system and will cover $\approx$ 45% in azimuth and $|\eta| < 0.5$. The MTD will be ready for operation in 2014.

3 eSTAR - can STAR be viably used in a future EIC?

Whilst the near-term upgrades in STAR, described above, are important in addressing the questions discussed, some of the remaining unknowns arising from the RHIC programme can only be addressed with the precision afforded by colliding lepton beams with ions. Therefore, a proposal to add an electron beam to the RHIC complex has been put forward (eRHIC) [4]. In order to fully address all the physics, it is clear that a new detector will need to be built [5].

However, as long as it remains feasible to run STAR in the eRHIC era, it is only natural to investigate the capabilities of an eSTAR detector.

It is envisaged that the building of eRHIC will be staged. Whilst there are no significant increases in ion-beam energy foreseen, the first stage of eRHIC will see a 5 GeV electron beam, increasing in later stages to 30 GeV. Figure 2 is a representation of the detector coverage in the $x-Q^2$ plane of the outgoing electron (left). The same plot is shown in the right-side of figure 2 for 30 GeV electrons. In the case of Deep-Inelastic Scattering (DIS), only the outgoing electron needs to be detected. As can be seen, for 5 GeV beams, the $x-Q^2$ coverage is good, with existing detectors covering everything above Q^2=10 GeV^2. However, this gets worse as the energy increases and as can be seen for 30 GeV, this coverage is very small and only for very high Q^s. Therefore, whilst STAR will be able to make strong contributions to the physics programme at eRHIC in stage-1, complementing a dedicated detector, it becomes more and more important that a dedicated detector is built, the higher the electron energy.

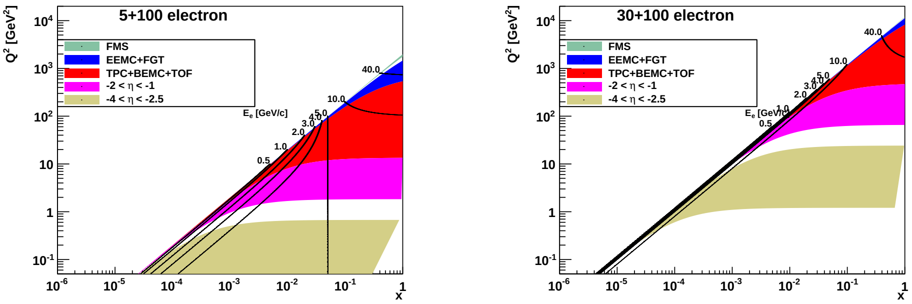

Figure 2: STAR detector coverage in $x-Q^2$ space and how it pertains to the outgoing electron in e+p(A) collisions for 5 GeV (left) and 30 GeV (right) electrons.

4 Summary and Conclusions

In summary, the STAR experiment has provided a rich set of results in heavy-ion and p+p collisions over the last decade and is well positioned to continue this in the near term with a strategy of detector upgrades. This process has already started with the partial construction of the Forward Gem Tracker in the current 2012 RHIC run. Looking to the long-term and the construction of an electron-ion collider (eRHIC), STAR is participating in the BNL-led R&D programme and investigating what is required to add to the current suite of detectors in order to be viable in this phase of RHIC's future.

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