The sPHENIX Experiment

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Abstract. Our understanding of QCD under extreme conditions has advanced tremendously in the last 20 years with the discovery of the Quark Gluon Plasma and its characterisation in heavy ion collisions at RHIC and LHC. The sPHENIX detector planned at RHIC is designed to further study the microscopic nature of the QGP through precision measurements of jet, upsilon and open heavy flavor probes over a broad p_T range. The multi-year sPHENIX physics program will commence in early 2023, using state-of-the art detector technologies to fully exploit the highest RHIC luminosities.
The experiment incorporates the 1.4 T former BaBar solenoid magnet, and will feature high precision tracking and vertexing capabilities, provided by a compact TPC, Si-strip intermediate tracker and MAPS vertex detector. This is complemented by highly granular electromagnetic and hadronic calorimetry with full azimuthal coverage.
In this document I describe the sPHENIX detector design and physics program, with particular emphasis on the comprehensive open heavy flavour program enabled by the experiment's large coverage, high rate capability and precision vertexing.

1 Introduction

The ultimate exploration of the properties of the hot QCD matter formed in heavy ion collisions requires a complementary study of the observables produced at both RHIC and LHC energies. Since both accelerators collide ions at different center of mass energy, the initial temperature of the QGP will be different and so will the in-medium evolution of hard probes. The main observables for a full characterization of the QGP dynamics are: jet suppression, since the origin of jets is in the hard scattering and jets live the whole evolution of the system; sequential suppression of closed heavy flavor states, since they are sensitive to the temperature of the system; suppression of heavy flavor hadrons; among others.

The sPHENIX detector [2] is a major upgrade to the PHENIX experiment, which concluded its final data taking run in 2016. The detector system has been redesigned completely to cope with the challenging physics goals that will be pursued at RHIC during its high intensity era in the 2020s. In this proceedings, I will briefly described the main elements of the current detector design its performance and the running scenario for a potential five year plan.

2 The sPHENIX Experiment Timeline

Since its formation in 2015, the sPHENIX collaboration have been guiding the experiment realization through different stages. The conceptual detector design was approved in late 2016 and currently the

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Table 1. Running scenario in a five-years plan

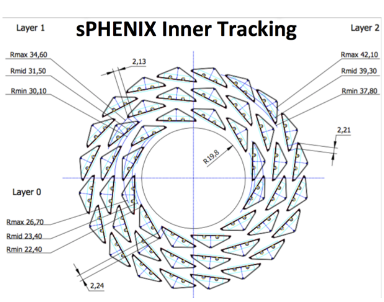
Year	System	Weeks	Samp. Lum (all Z)
1	Au+Au	16	34 nb^{-1}
2	p+p	11.5	267 pb^{-1}
2	p+Au	11.5	1.46 pb^{-1}
3	Au+Au	23.5	88 nb^{-1}
4	p+p	23.5	783 pb^{-1}
5	Au+Au	23.5	92 nb^{-1}

design for the proposed detector is being finalized. The detector construction is scheduled to begin in late 2018 and its installation in PHENIX interaction site will start in late 2020. Data taking is envisioned in the middle of 2023 which overlaps greatly with LHC Run 3 timeline and may continue passed the LHC Long Shutdown 3 (LS3).

sPHENIX will record data during the RHIC's highest intensity era for three different systems p+p, p+Au and Au+Au at RHIC's top Au+Au energy $\sqrt{s} = 200$ GeV . The proposal for a five-year running plan starts with six weeks of Au+Au the first year followed by 23 weeks of both p+p and p+Au in the next year. The next three years sPHENIX will be recording Au+Au and p+p events at even much higher rates. During the five year running plan, summarized in table 1, sPHENIX will record around 240 billion (1.5 trillion) minimum bias events for Au+Au with a collision vertex reconstructed in $|Z| < 10$ cm (all Z). Furthermore the usage of high level triggers in Au+Au collisions for b-tag or photon-tag events will increase the number of events by about a factor 2.

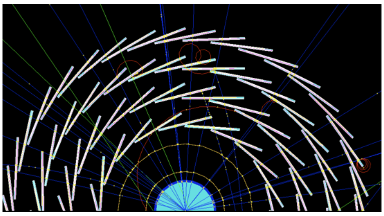
3 Detector Description

The detector features full azimuthal coverage and a wide pseudorapidity acceptance $|\eta| < 1.1$ and its final configuration is currently under intense R&D. The central detector consists of a charge particle tracking system provided by three subdetector with complementary technology and a calorimetry system with both electromagnetic and hadronic components. At the time of this conference the following technologies and specifications are part of the detector configuration.



	Layer 0	Layer 1	Layer 2
Min. Radius (mm)	22.4	30.1	37.8
Max. Radius (mm)	26.7	34.6	42.1
Sensitive Length (mm)	271	271	271
Active area (cm^2)	421	562	702
N. of pixel chips	108	144	180
N. of staves	12	16	20

Figure 1. The MVTX detector consists of three layers of silicon pixel detector (MAPS) located very close to the beam pipe and featuring fast response and accurate position measurents for tracking and vertexing.



	Radius (cm)	Number of Ladders	Strip Size ($\phi \times$ z, mm)
0	6	20	0.078×18 (18)
1	8	26	0.086×20 (20)
2	10	32	0.086×20 (20)
3	12	38	0.086×20 (20)

Figure 2. The INTT detector has four layers of silicon strip technology situated in between the MVTX and TPC detectors. It aids the patter recognition and momentum reconstruction for the central tracking system.

3.1 Charged Particle Tracking

The sPHENIX detector will feature the 1.4 T superconducting solenoid magnet used previously in the BaBar experiment. The magnet is 3.8 m long with an inner radius of 140 cm and a thickness of 33 cm. The charge particle tracking detectors will be housed Inside the magnet and consist of three different detector technologies: a silicon pixel detector, for accurate measurements of displaced vertices; a silicon strip detector, for complementary high momentum resolution, and a compact time projection chamber for high resolution up to very low transverse momentum ($\sim$ 2 GeV/c).

The MVTX detector consists of three layers of silicon pixel detector deployed radially as indicated in figure 1. The technology is based on that used by the ALICE ITS upgrade program: the MAPS sensors. It features a fine pitch of 28×28 μm^2 together with good time resolution of 5 μs. The detector has a DCA resolution better than 25 μm for charged particles with transverse momentum higher than 1 GeV/c.

The INTermediate Tracker INTT detector consists of four layers of silicon strip technology used previously in the FVTX detector at PHENIX. The INTT not only improves the momentum resolution for charged particles with the high transverse momentum, but also aids in the pattern recognition and event synchronization. The geometrical configuration of the detector can be seen in figure 2.

The compact Time Projection Chamber (TPC) detector is the main tracking element of the sPHENIX experiment. The TPC field cage spans a volume from 20 cm to 78 cm in radius and 211

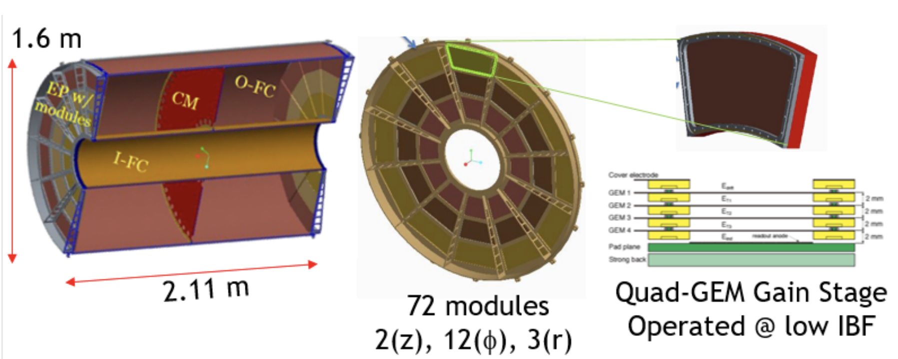


Figure 3. The compact TPC is a small Ne-based detector working in continuos readout using micropattern gas detectors. The high pad segmentation in the cathode plates provide optimal spatial resolution span in 40 radial layers of a mixed zigzag and rectangular pad configuration.

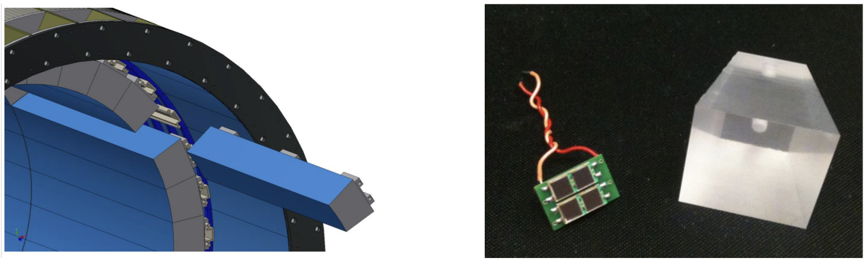


Figure 4. A drawing of part of the EMCal detector is shown on the left, where the block segmentation is also displayed. An individual tower and a SiPMT (resistent to hard magnetic field enviroment) is shown in the right.

cm in longitude. It will run on continuous readout mode using micro pattern gas detectors at the end plates. The readout will be segmented into 72 modules: $2 \times 12 \times 3$ ($\mathrm{Z} \times \phi \times \mathrm{R}$) using both rectangular and zigzag pad geometries. The TPC will use a Ne-based gas for high ion mobility and low transverse diffusion in order to fight against spatial distortions from space charge build-up without compromising the desired position resolution. Its geometrical configuration is detailed in figure 3.

3.2 Calorimetry Detectors

The ElectroMagnetic Calorimeter EMCal detector, figure 4, is the innermost calorimeter and consists of absorber blocks made from tungsten powder with embedded scintillating fibers. The design is similar to the SPACAL configuration used successfully in the past by various experiments. It features a sampling fraction of 2.3% and highly granular segmentation $\Delta\eta \times \Delta\phi = 0.024 \times 0.024$ (approx. 25k readout channels) while providing an energy resolution better than $15\%/\sqrt{E}$.

The Hadronic Calorimeter HCal detector, figure 5, consists of steel and scintillating tiles with wavelength shifter fibers. The HCal system is composed two subdetectors: one installed in between the EMCal and the magnet (inner HCal) and one installed outside of the magnet (outer HCal). The

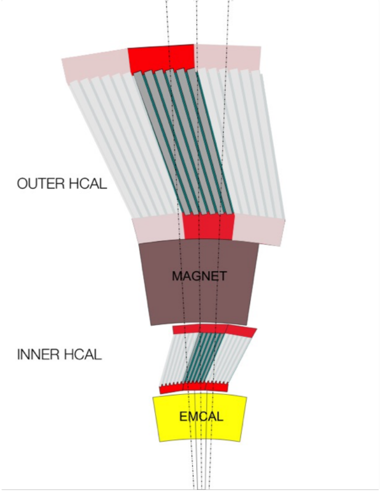


Figure 5. Traverse view of one sector of the hadronic calorimeter system (both inner and outer) together with the EMCal for scale comparison. The steel part of the HCal is also used as a return yoke for magnetic field containment. The geometrical orientation of the wavelength fibers is oposite between the inner and outter calorimeters.

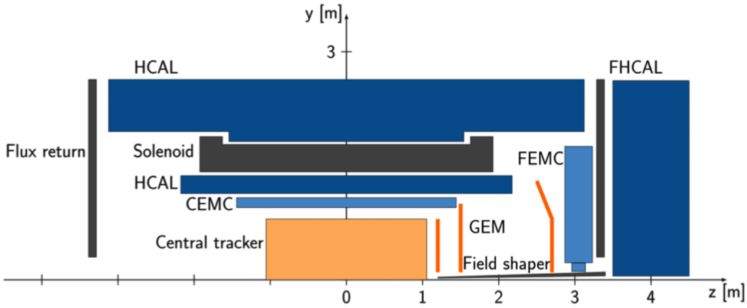


Figure 6. Sided-view drawing of the sPHENIX detector including the proposal for an upgrade in the forward p-going direction. The forward subsystem features a GEM tracker and both electromagnetic and hadronic calorimeters.

later will also be used also as a return yoke for the magnet. The inner (outer) HCal thickness amounts to 1.0 (3.5) λ_I. Both subdetectors feature a granular segmentation of $\Delta\eta \times \Delta\phi = 0.1 \times 0.1$.

Both calorimeter systems were designed to cover full azimuth and complement each other in the reconstruction of jets. The performance of the calorimeter prototype has recently been tested in the Fermilab's testbeam and the results of this study can be found in [3].

3.3 Detector Upgrade in the Forward Region

The sPHENIX collaboration has also prepared a comprehensive detector upgrade in the forward rapidity region [4]. The forward detector 6 consists of a forward tracker and calorimetry stations with a pseudorapidity coverage of $-1 < \eta < 4$. The forward upgrade allows for a broad physics program. It will not only allow for the study of nuclear structure and production at low X, but also complements the phase space of the sPHENIX central barrel in the pursue of photon-hadron correlations with a wide rapidity gap.

4 Simulation of Combined Performance

The sPHENIX collaboration has been working in putting together a comprehensive software framework with which to centralize the latest detector description and the different analyses being performed. There is many different topics studied within the different working groups in the collaboration. The following paragraphs are brief descriptions of a couple of selected topics.

4.1 Suppresion of b-jets

The analysis of b-jets is one of the main analysis in the sPHENIX program. Since b-quarks are mainly created in the hard scattering, due to its large mass, they feel the entire evolution of the medium and can be used to scan the properties of the QGP at different virtualities. In sPHENIX, b-jets (jets produced by a b quark shower) can be reconstructed all the way down to p_T = 15 GeV/c.

Figure 7 shows the accuracy expected in the nuclear modification factor of b-jets for 240 billion most central Au+Au collisions. In order to increase accuracy, specially at high p_T, the study of L1 trigger logics have been performed. One of them requires that tracks from the candidate jet do not originate from the main vertex but are rather displaced. Figure 7 shows the performance of such logic using the sPHENIX tracking system for a logic with one, two and three tracks. There is currently work in progress [5] to refine this selection as our tracking system is being finalized, however one can see in this plot the rough interplay of efficiency and purity depending on the severity of the cut used for triggering.

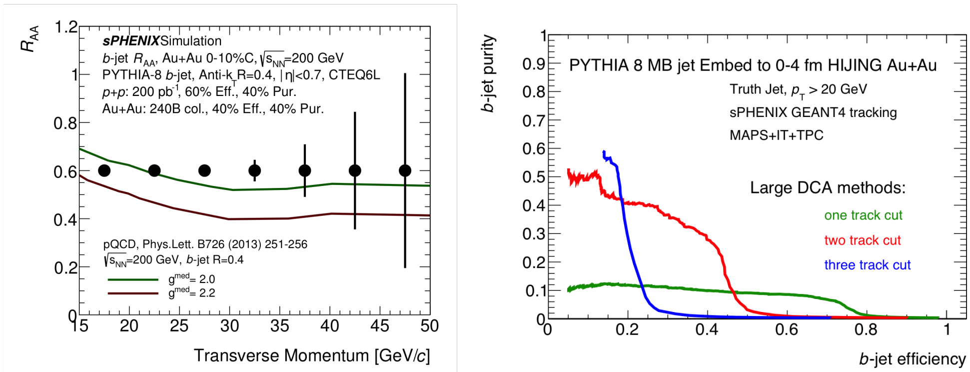


Figure 7. Left: b-jet R_{AA} as a function of transverse momentum for most central Au+Au collisions at $\sqrt{s}$ = 200 GeV. The data sample consists of 240billion events which would be the amount recorded based on the five-years run plan where no L1 trigger was used. Right: Efficiency vs purity of the L1 b-jet trigger performance for HIJING simulation of most central Au+Au collisions using one of the methods being studed in sPHENIX. Respective plots for other methods/conditions can be found in [5]

4.2 Fully reconstructed open heavy flavor

The dynamics of the parton energy loss in the QGP can be addressed via the study of suppression and angular correlations of fully reconstructed charm and bottom mesons. These measurements are possible due to the high spatial resolution of the MVTX for reconstruction of displaced vertices and the high momentum resolution for charged particles up to very low p_T provided by the TPC and INTT detectors. The decay channel explored is the decay of open charm (one decay vertex) and bottom (two decay vertexes) into hadrons (i.e. $D_0 \rightarrow K^- \pi^+$ and $B^{\pm} \rightarrow \bar{D}_0(K\pi)\pi^{\pm}$). Figure 8 shows the accuracy estimation for central to peripheral yield ratio in inclusive D-mesons and D^0 from B using 240 billion

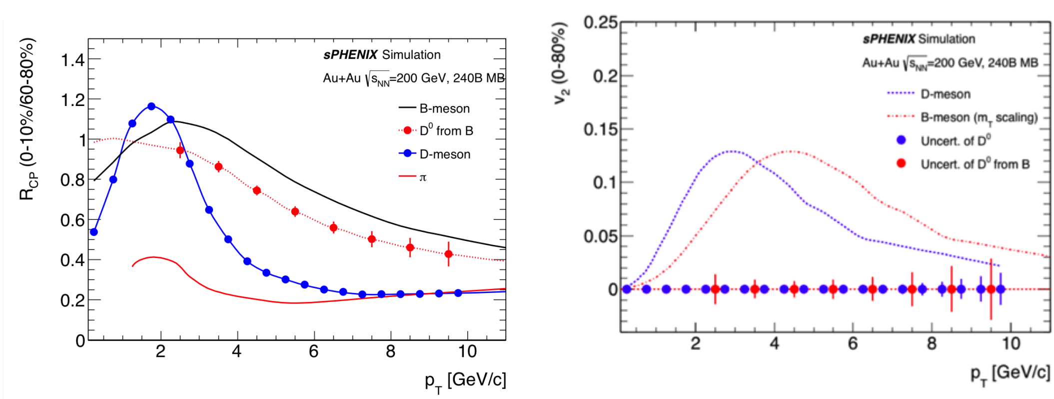


Figure 8. Simulation of the performance of D-meson R_{CP} and v_2 for MB Au+Au collisions at $\sqrt{s}$ = 200 GeV. The sample corresponds to 240 billion Hijing Events, which amounts to the expected statistics collected during the full experiment lifetime.

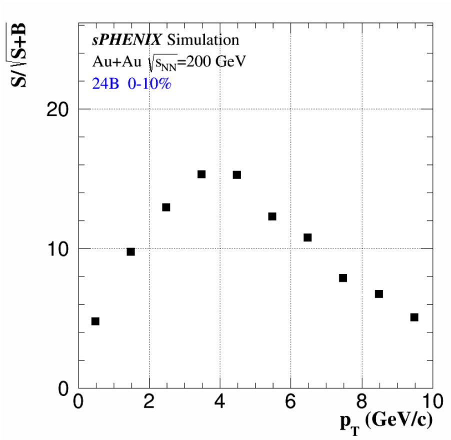


Figure 9. Significance of fully reconstructed B^+ mesons as a function of transverse momentum for 240 billion most central Au+Au collisions at $\sqrt{s}$ = 200 GeV. The peak at 4 GeV/c is due to the large combinatorial background present for low p_T candidates.

MB events. Figure 9 shows the significance of the B^+ meson fully reconstructed via double decay vertex for most central Au+Au collisions at $\sqrt{s}$ = 200 GeV. For both D- and B-mesons, the selection is done via topological multivariate cuts. A feature of sPHENIX is its low transverse momentum reach for heavy flavor measurements, which is important since low p_T hadrons are most sensitive to the medium as it expands and cools down, i.e. collective flow and heavy flavor transport.

5 Summary

In this proceedings, I have summarized the sPHENIX detector's current design. sPHENIX is currently going through R&D stage in order to finalize the detector layout by 2018. The detector array and technology have been chosen to provide a broad acceptance coverage, high momentum resolution down to 0.2 GeV/c for charged particles, highly granular electromagnetic and hadronic calorimetry, and quick readout time in order to cope with the high luminosity RHIC era. sPHENIX is suitable for the study of jets, fully reconstructed open heavy flavor, fully reconstructed upsilons and correlations, thus providing highly accurate measurements for a full characterization of the hot and dense QCD matter formed in heavy ion collisions.

References

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