Design Studies for an Electron-Ion Collider Detector Based on the sPHENIX Solenoid

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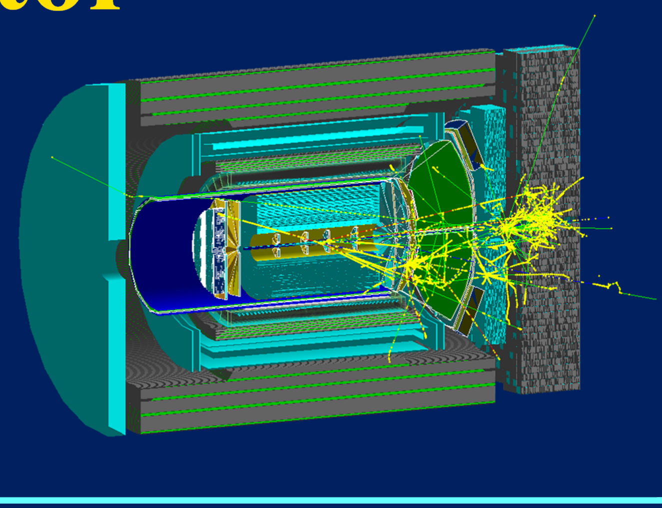
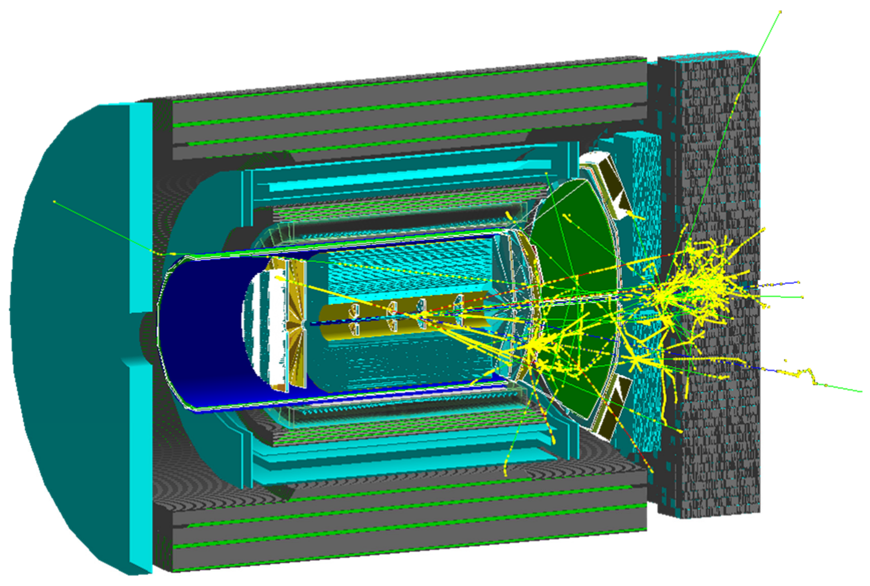


Introduction

In 2018, an Electron-Ion Collider (EIC) Detector Design Study Group was formed to start considering in detail how an EIC detector could be built around the sPHENIX solenoid, formerly used by the BaBar experiment. A series of studies examining the design and physics performance for select options of calorimetry, tracking, and particle identification covering -4 to +4 in pseudorapidity has already been performed, and further studies are ongoing.

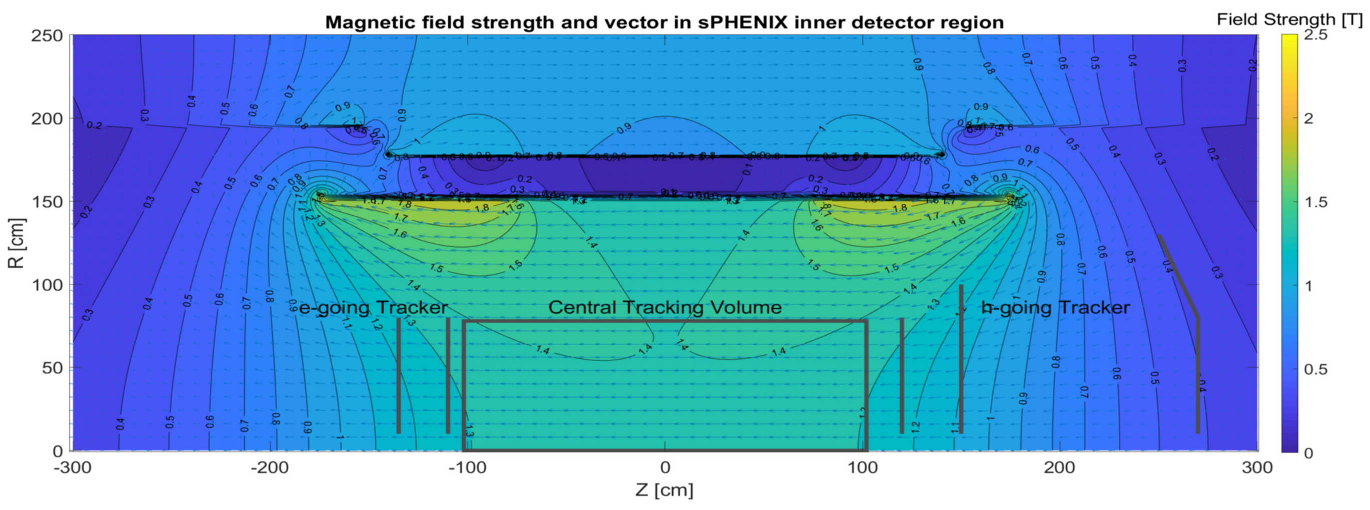


Event display for an 18 GeV electron colliding with a 275 GeV proton $Q^2 \sim 100$ GeV^2

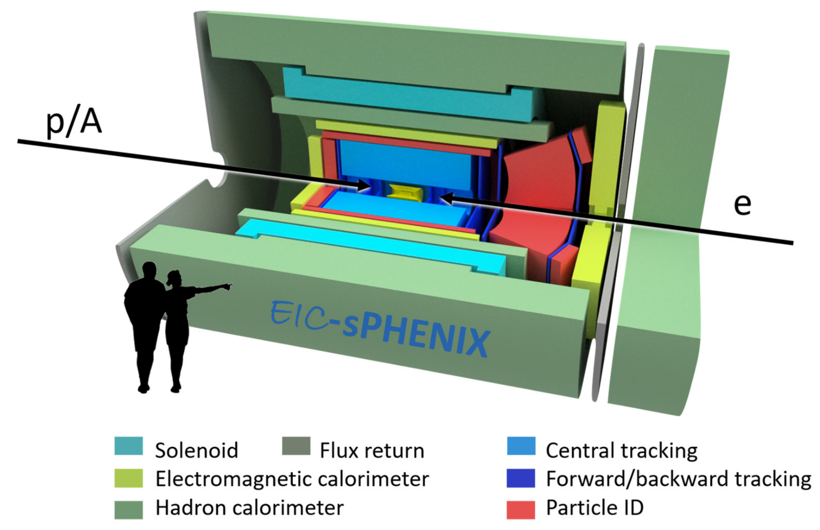
The sPHENIX Solenoid

The sPHENIX superconducting solenoid was originally designed and built for the BaBar experiment. With an inner cryostat radius of 150 cm, a length of 345 cm, and a central field strength of ~1.4 T, it is well suited for an EIC detector. For sPHENIX, the magnet flux return will be instrumented as an outer hadronic calorimeter (HCal), allowing reuse of the flux return/outer HCal for an EIC detector as well.

sPHENIX magnet testing at BNL



Basic Configuration of an EIC Detector Based on the sPHENIX Solenoid

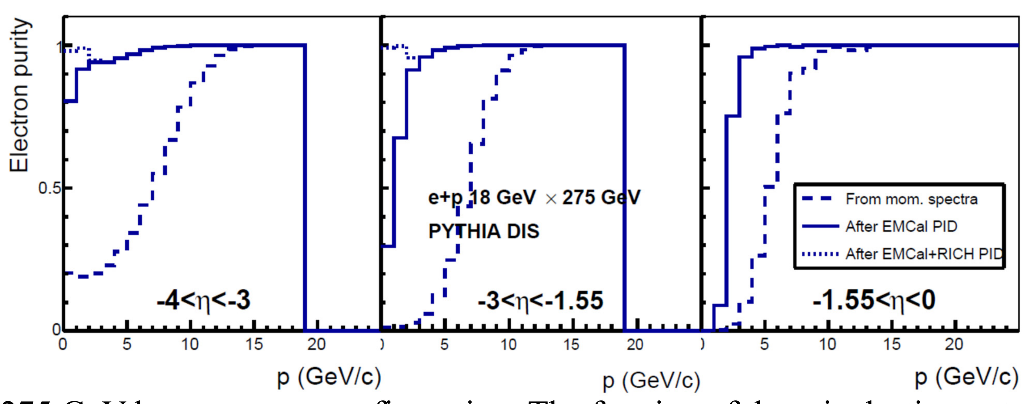


Detector	pseudorapidity	Type
TPC + MAPS + GEM	(-4, 4)	Tracking
barrel EMCAL	(-1.55, 1.24)	Calorimetry
barrel inner HCAL	(-1.1, 1.1)	Calorimetry
barrel outer HCAL	(-1.1, 1.1)	Calorimetry
e-side EMCAL	(-4, -1.55)	Calorimetry
h-side EMCAL	(1.24, 4)	Calorimetry
h-side HCAL	(1.24, 4)	Calorimetry
DIRC	(-1.4, 1.24)	PID
gas RICH	(1.24, 3.95)	PID
h-side mRICH	(1.10, 1.85)	PID
e-side mRICH	(-3.9, -1.4)	PID

Example Detector Performance Studies

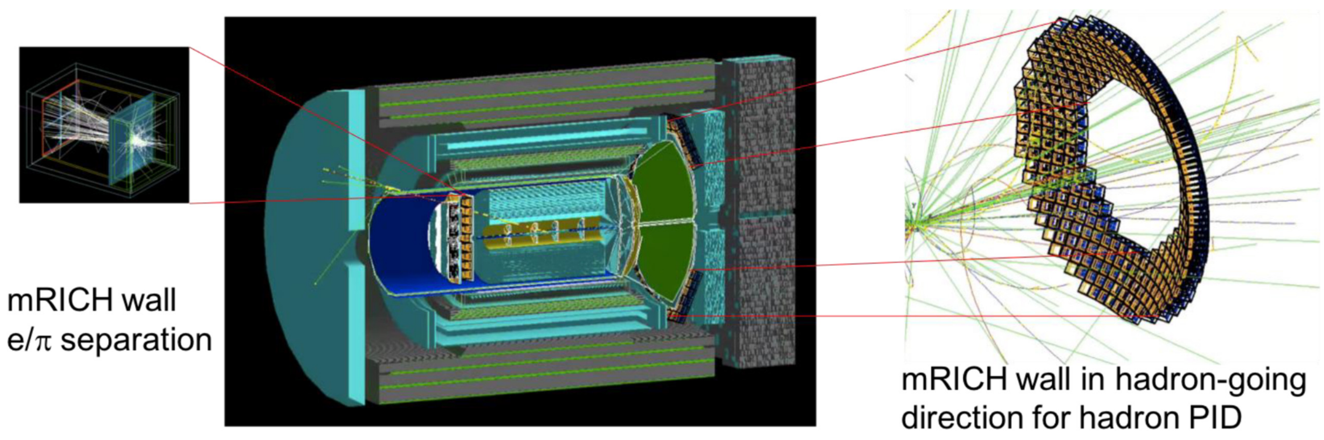
	σ_R (mm)	$\sigma_{R\varphi}$ (μm)	σ_Z (μm)
MAPS	–	5	5
TPC	–	150	500
EGEM0	10	50	–
EGEM1	10	50	–
EGEM2 Inner	10	50	–
EGEM2 Outer	10	100	–
EGEM3 Inner	10	50	–
EGEM3 Outer	10	100	–
FGEM0	10	50	–
FGEM1	10	50	–
FGEM2 Inner	10	50	–
FGEM2 Outer	10	100	–
FGEM3 Inner	10	50	–
FGEM3 Outer	10	100	–
FGEM4 Inner	10	50	–
FGEM4 Outer	10	100	–

Tracking detector properties used in the studies shown.



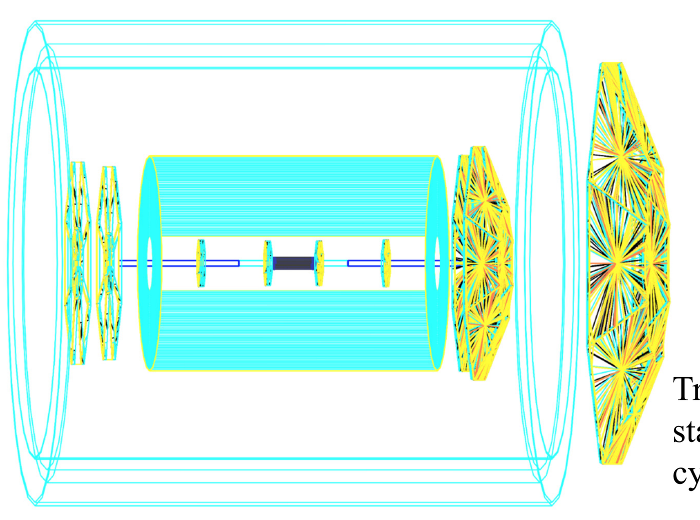
For 18 GeV x 275 GeV beam energy configuration: The fraction of deep-inelastic scattering electrons in the reconstructed charged particle sample before electron identification (dashed), after identification with the EMCal + tracking (solid), and after identification with the EMCal + tracking + RICH (dotted); the latter is estimated only for $-4 < \eta < -1.55$.

Detector	pseudorapidity	K/π 3σ separation (GeV/c)	e/π 3σ separation (GeV/c)
DIRC	(-1.4, 1.24)	$\lesssim$6	
gas RICH	(1.24, 3.95)	(15,50)	(5, 15)
h-side mRICH	(1.10, 1.85)	(3,9)	$\lesssim$2
e-side mRICH	(-3.9, -1.4)	(3,9)	$\lesssim$2



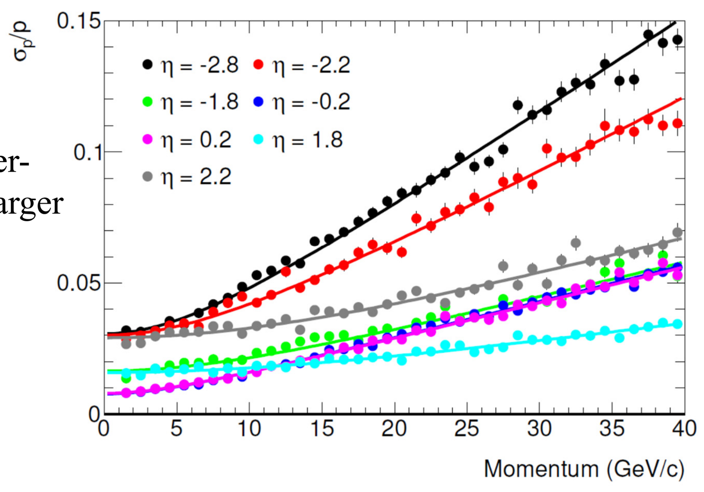
mRICH wall e/π separation

mRICH wall in hadron-going direction for hadron PID

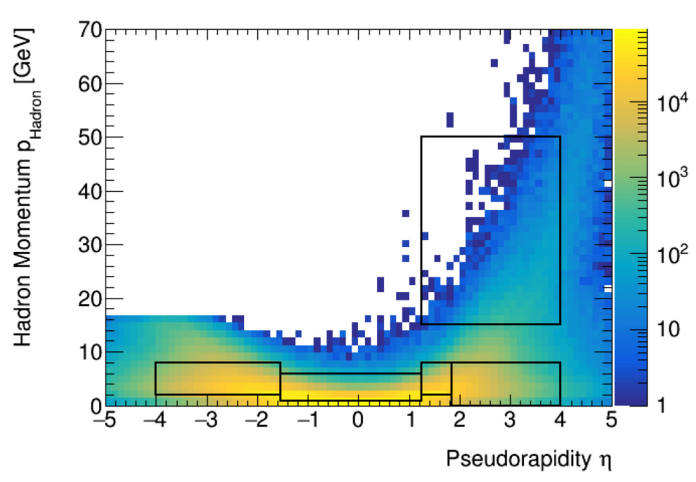


Tracking detectors as implemented in GEANT4: GEM stations in yellow, TPC in light blue, and the black cylinder near the interaction point is the MAPS detector.

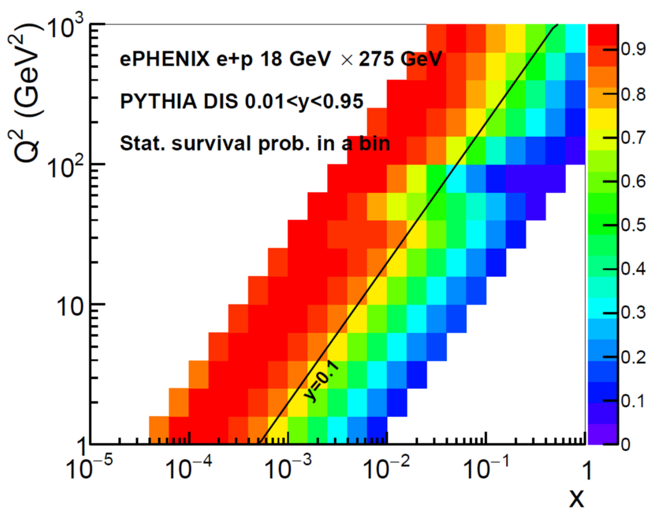
Momentum resolution from GEANT4 as a function of momentum for different pseudorapidities. A Kalman-filter-based track fit algorithm in the larger rapidity region at $|\eta|>2.5$, which involves also collision vertex position, is under development.



Momentum and pseudorapidity distribution for produced hadrons in 20 x 250 GeV collisions, for hadrons with $z > 0.2$. The boxed regions illustrate the ranges for kaon identification.

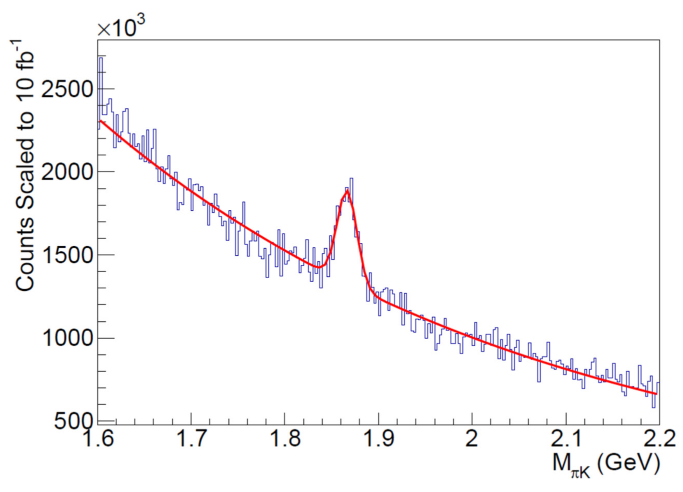


Example Detector Performance Studies



Fraction of events reconstructed in the correct x-Q^2 bin, for 18 GeV x 275 GeV beam energy configuration

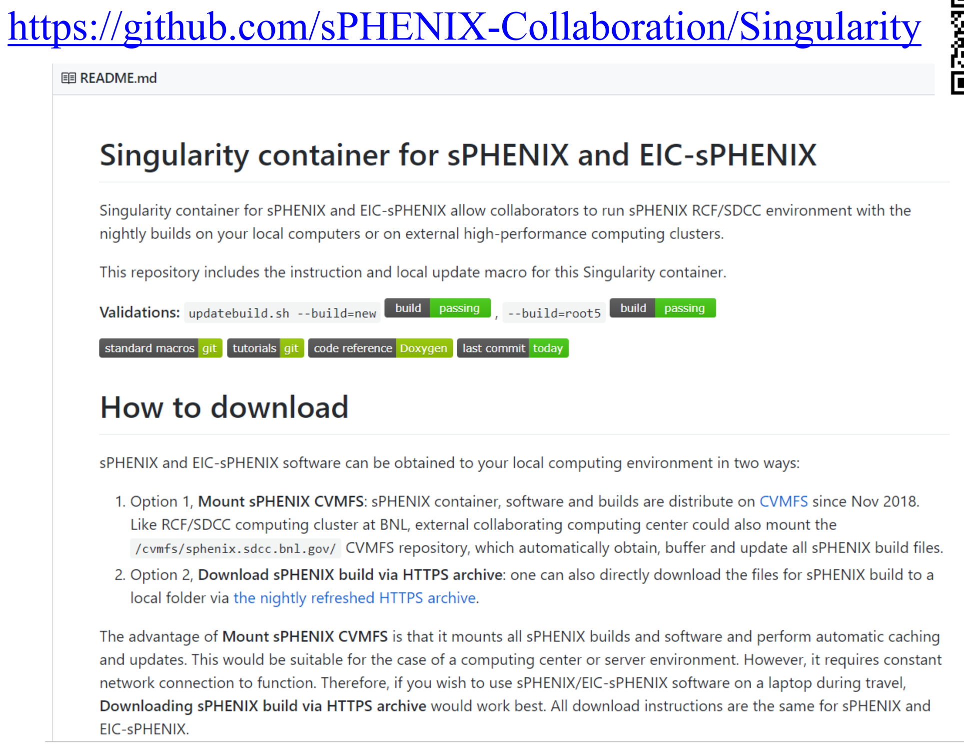
Open charm measurement: A fit to the D^0 mass peak from reconstruction of the exclusive decay $D^0 \rightarrow K^-\pi^+$ using smeared PYTHIA6 events



Adaptable for your own EIC detector simulation studies!

The entire simulation framework can be downloaded directly from a browser and run standalone on a local machine or cluster. Modifications can be made locally and/or uploaded for others in the community to use. The package includes a default GEANT implementation, full reconstruction for calorimeters (digitizer + clustering + jet finding), full reconstruction for tracking (fast pattern recognition + full Kalman filter + vertex reconstruction), and a detector resolution macro for fast simulation studies.

https://github.com/sPHENIX-Collaboration/Singularity


README.md

Singularity container for sPHENIX and EIC-sPHENIX

Singularity container for sPHENIX and EIC-sPHENIX allow collaborators to run sPHENIX RCF/SDCC environment with the nightly builds on your local computers or on external high-performance computing clusters.

This repository includes the instruction and local update macro for this Singularity container.

How to download

sPHENIX and EIC-sPHENIX software can be obtained to your local computing environment in two ways:

1. Option 1, Mount sPHENIX CVMFS: sPHENIX container, software and builds are distribute on CVMFS since Nov 2018. Like RCF/SDCC computing cluster at BNL, external collaborating computing center could also mount the /cvmfs/sphenix.sdcc.bnl.gov/ CVMFS repository, which automatically obtain, buffer and update all sPHENIX build files.
2. Option 2, Download sPHENIX build via HTTPS archive: one can also directly download the files for sPHENIX build to a local folder via the nightly refreshed HTTPS archive.

The advantage of Mount sPHENIX CVMFS is that it mounts all sPHENIX builds and software and perform automatic caching and updates. This would be suitable for the case of a computing center or server environment. However, it requires constant network connection to function. Therefore, if you wish to use sPHENIX/EIC-sPHENIX software on a laptop during travel, Downloading sPHENIX build via HTTPS archive would work best. All download instructions are the same for sPHENIX and EIC-sPHENIX.

Summary

The magnetic field and dimensions of the sPHENIX solenoid are well matched to the needs of an EIC detector, and the solenoid is already in the hands of the QCD community. It thus offers realistic constraints for working on concrete design of EIC subdetectors and ways to integrate them into a full, general purpose detector. One possible set of integrated subdetectors has been implemented in GEANT4, along with full reconstruction for calorimetry and tracking so far, and a corresponding detector resolution macro is available for fast simulations. A number of detector performance studies have already been done with the current GEANT implementation, and others are ongoing. The full software framework is available to download as a standalone package for use and modification by the entire EICUG community.

Acknowledgments

Thanks to all the other contributors to the 2018 Detector Design Study, available at https://indico.bnl.gov/event/5283/:

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