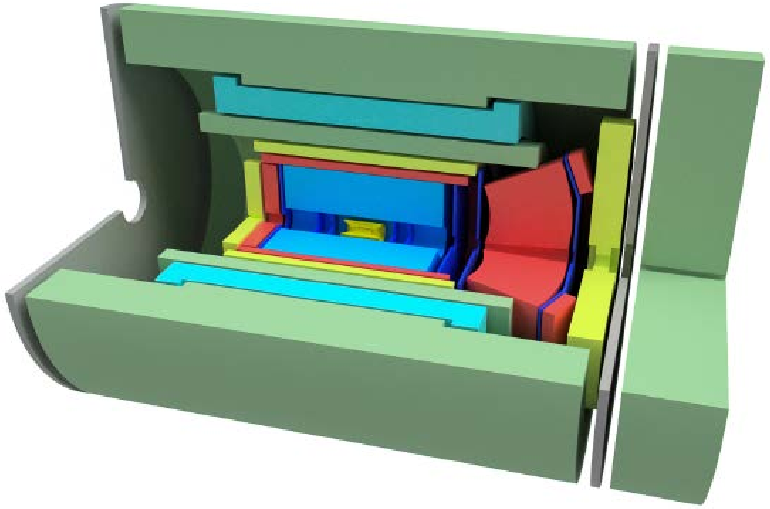
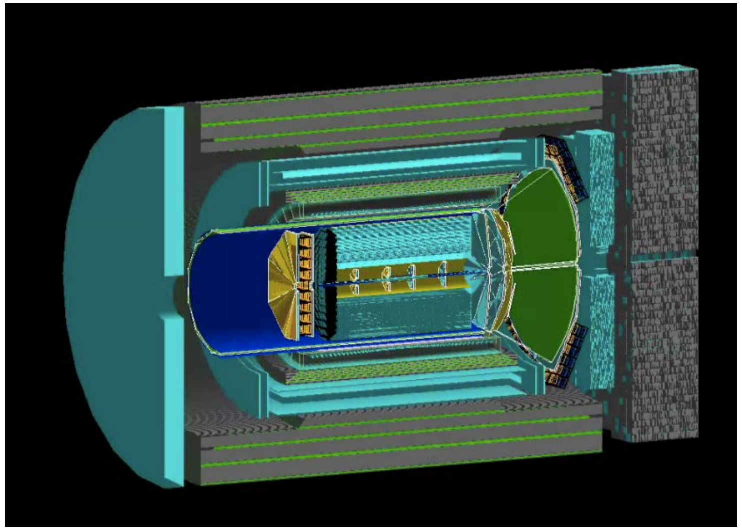




Science Program Enabled by an EIC Detector Based on sPHENIX

Christine Aidala
University of Michigan
For the EIC Detector Study Group and the sPHENIX Collaboration

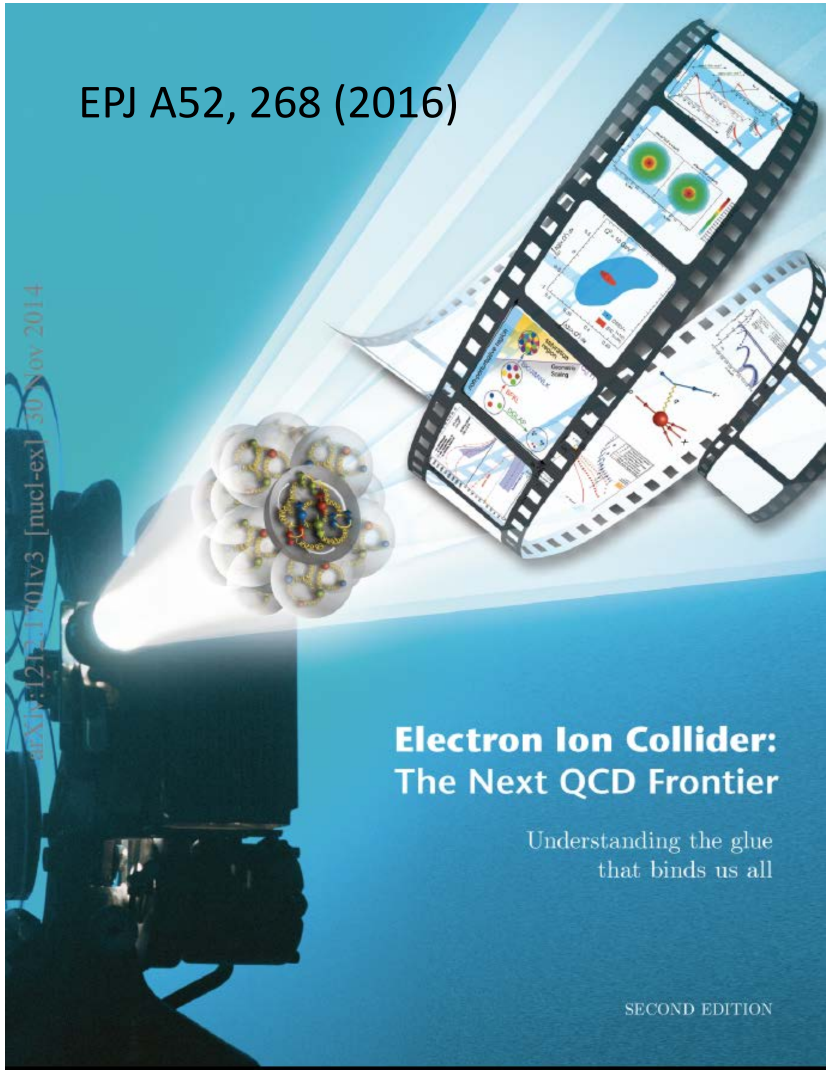
RHIC PAC Meeting
June 7, 2018

Physics case for an Electron-Ion Collider

- How are the quarks and gluons, and their spins, distributed in space and momentum inside the nucleon? How do the nucleon properties emerge from them and their interactions?

- How do color-charged quarks and gluons, and colorless jets, interact with a nuclear medium? How do the confined hadronic states emerge from these quarks and gluons? How do the quark-gluon interactions create nuclear binding?

- How does a dense nuclear environment affect the quarks and gluons, their correlations and their interactions? What happens to the gluon density in nuclei? Does it saturate at high energy, giving rise to a gluonic matter with universal properties, in all nuclei, even the proton?



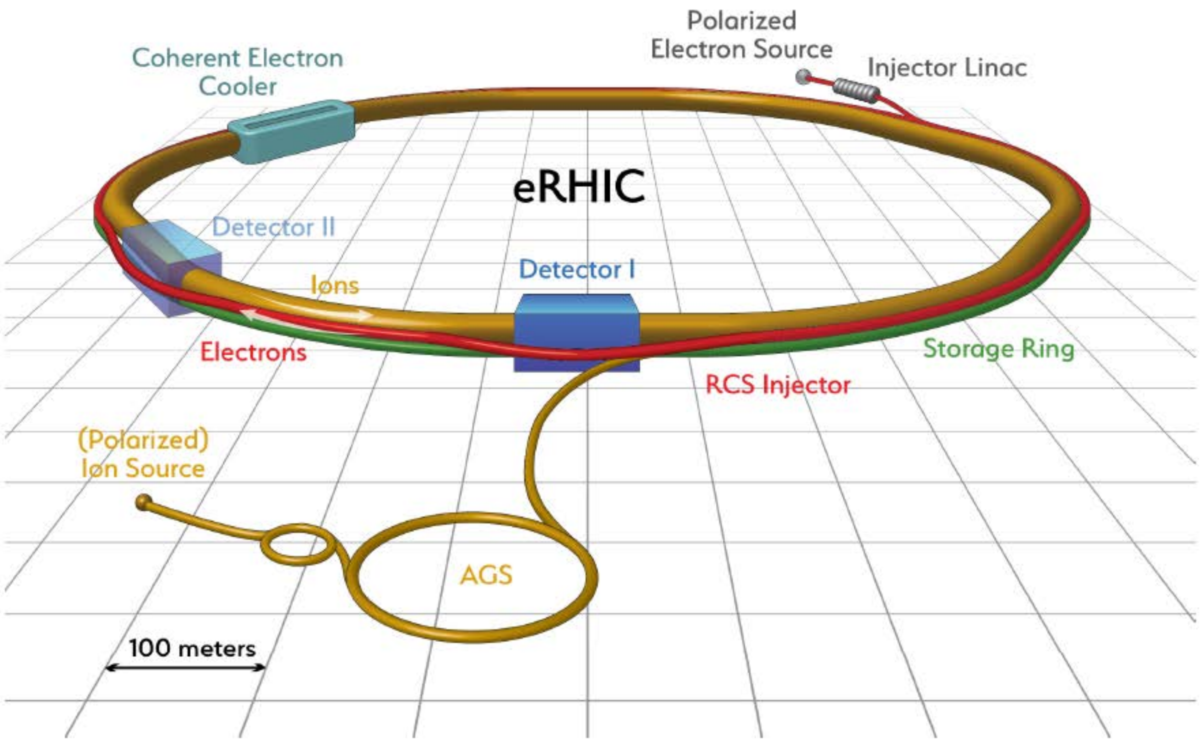
The eRHIC facility

Electrons
Protons
Deuterium, ^{3}He
Nuclei up to Uranium

Spin Polarized!

E_e 5-18 GeV
E_p up to 275 GeV
E_A up to 110 GeV/n
$\sqrt{s}$ = 29 -140 GeV

$L_{ep} = 10^{33} - 10^{34}\ cm^{-2}s^{-1}$



Charge from ALD

April 5, 2018

Dear Dave and Gunther

As you know, the eRHIC design team is close to completing the pre-conceptual design report, the NAS Study Panel is expected to publish its assessment of the value of a US based EIC in the May time frame, and DOE may declare CD-0 for an EIC sometime in the second half of 2018. In this context it will be important that we have a clear and up-to-date understanding of the value of sPHENIX as the basis of a Day-1 eRHIC detector. **The ePHENIX Letter of Intent now is four years old and urgently requires an update** that takes into account the developments in detector technology and interaction region design.

I am therefore asking you to **establish a detector study group consisting of members of the sPHENIX Collaboration and other individuals interested in EIC science from outside the sPHENIX Collaboration to update the Letter of Intent for an EIC detector built around the BaBar solenoid** in the context of the eRHIC pre-CDR. The Letter of Intent should contain an outline of the expected physics program for the detector in the first five years of running, using estimates of the luminosity development anticipated for initial EIC operation.

In parallel, I am asking you to perform a cost estimate of the construction costs in FY2018 dollars. This estimate should be performed with the methodology that the NPP Director for Project Planning and Oversight of Accelerator Projects, Diane Hatton, has developed for the EIC and that Elke Aschenauer and her group are using to develop a cost estimate for a generic EIC detector in conjunction with the ongoing pre-CDR cost estimation process. Please, do not include the cost estimate in the updated Letter of Intent, but transmit it as a separate document.

A brief presentation on the physics capabilities of the detector should be prepared for the PAC meeting in June 2018. After receiving comments from the PAC, I expect to be able to provide feedback and further guidance with respect to the process and goals of developing the updated LoI. The final versions of the revised LoI and the associated cost estimate should be submitted to me by September 30, 2018. The NPP Director for Project Planning and Oversight of Detector Projects, Maria Chamizo Llatas, will then convene a review with external experts, as appropriate.

These are exciting times for all those interested in the physics of an EIC. The facility is finally at the doorstep from concept onto the path toward realization. I hope that this request will build on and further strengthen the excitement of all those within the sPHENIX collaboration who are looking forward to participation in a future EIC physics program.

Best regards

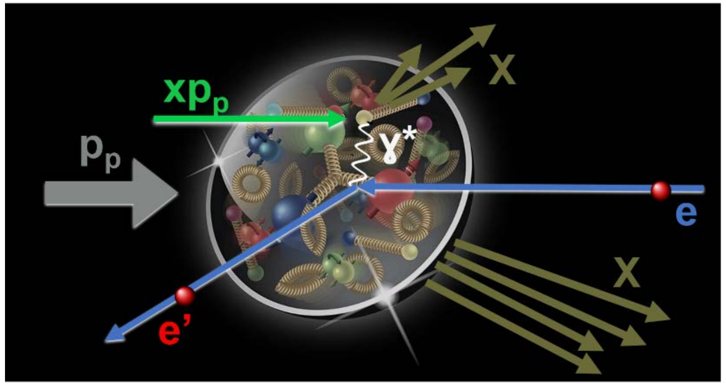
Berndt

sPHENIX configuration based on MIE reference design + MVTX

Charge has been useful in ramping up efforts

- Have created such an EIC Detector Study Group, co-convened by myself and Nils Feege of Stony Brook. Biweekly meetings in conjunction with the sPHENIX Cold QCD Topical Group.
  - eic-dsg-l@lists.bnl.gov
- *Charge has been useful in ramping up efforts to examine in realistic detail how sPHENIX could be transformed into an EIC detector.*
  - Integration with sPHENIX including envelopes necessary for readout, services, and mechanical support.
    - EIC detector design actively being discussed within sPHENIX Office of System Integration.
  - Time of engineers and some relevant experts tied up in DOE CD-1/3a review for sPHENIX until late May; more availability now.

Classes of EIC events

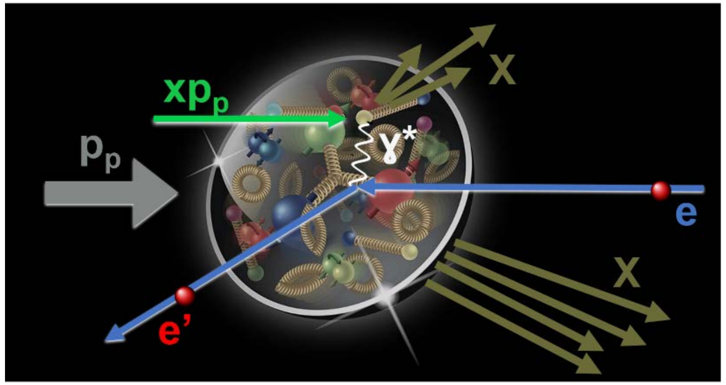


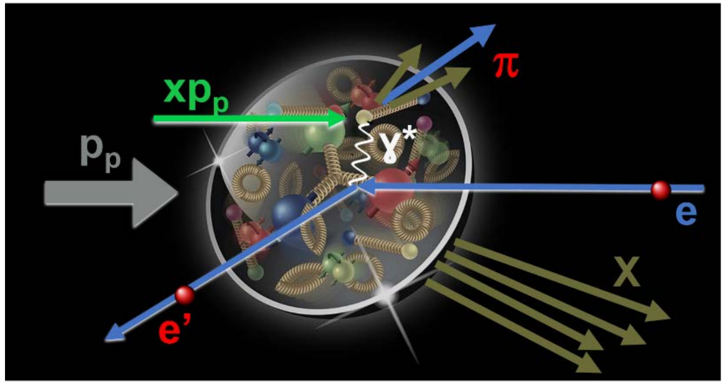
- Inclusive deep-inelastic scattering (DIS)
  - Measure only the scattered electron

- Semi-inclusive deep-inelastic scattering (SIDIS)
  - Measure the scattered electron and at least one other final-state particle

- Exclusive processes
  - Measure all final-state particles—typically diffractive events

Classes of EIC events





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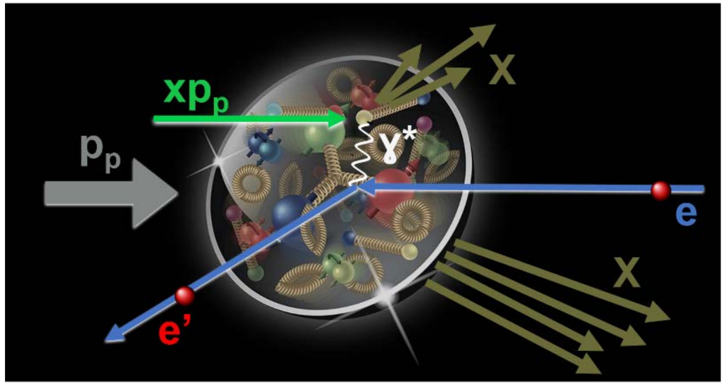
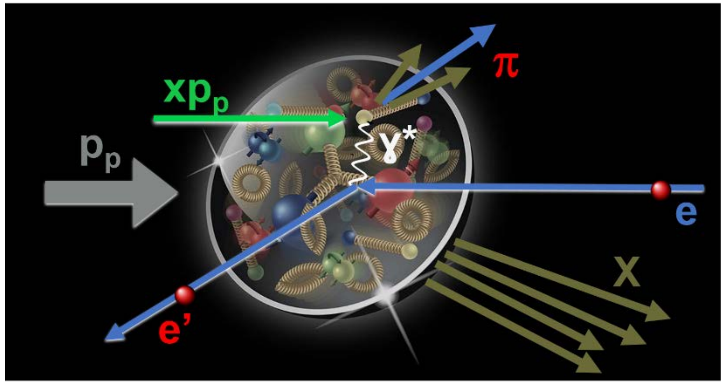
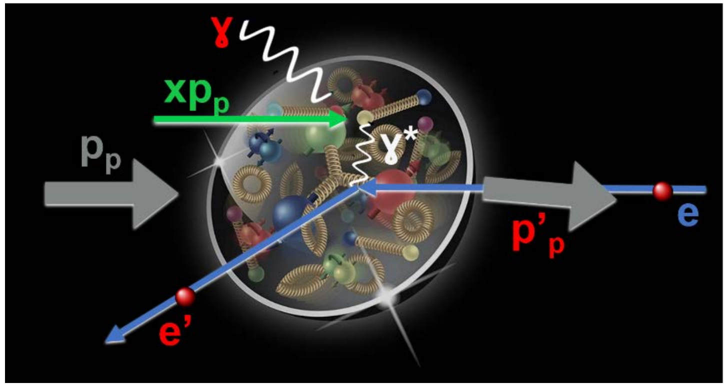
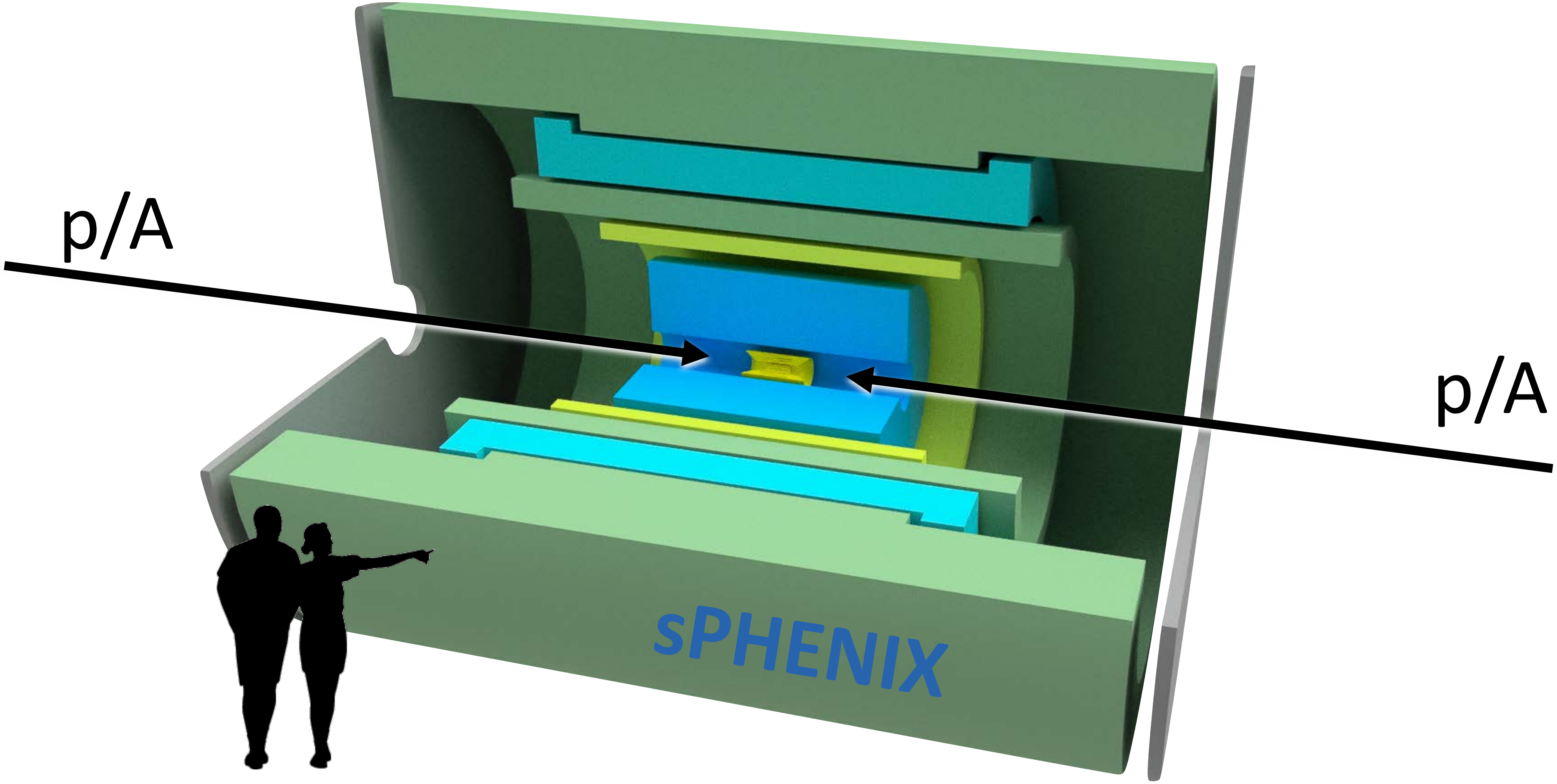
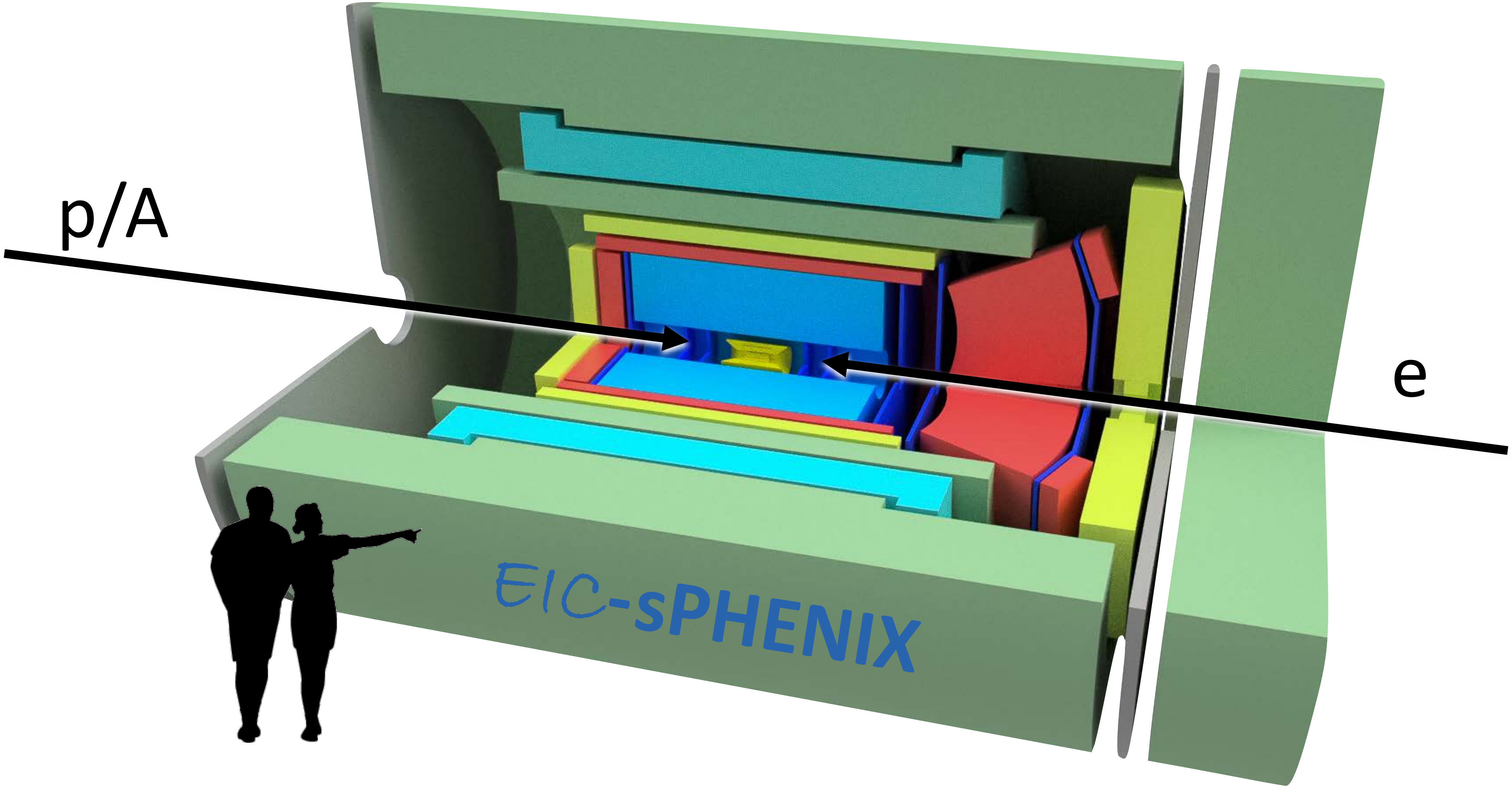








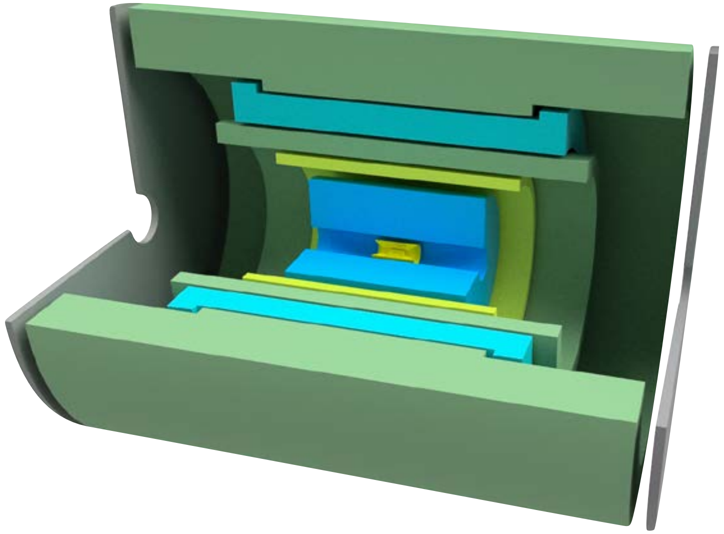
Solenoid Flux return Central tracking
Electromagnetic calorimeter
Hadron calorimeter



Solenoid
Flux return
Central tracking
Electromagnetic calorimeter
Forward/backward tracking
Hadron calorimeter
Particle ID

Detector components, sPHENIX and EIC detector

- sPHENIX
  - HCal/Flux return
  - Solenoid
  - Central EMCal
  - Silicon strip tracking
  - TPC
  - MAPS



Detector components, sPHENIX and EIC detector

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  - Solenoid
  - Central EMCal
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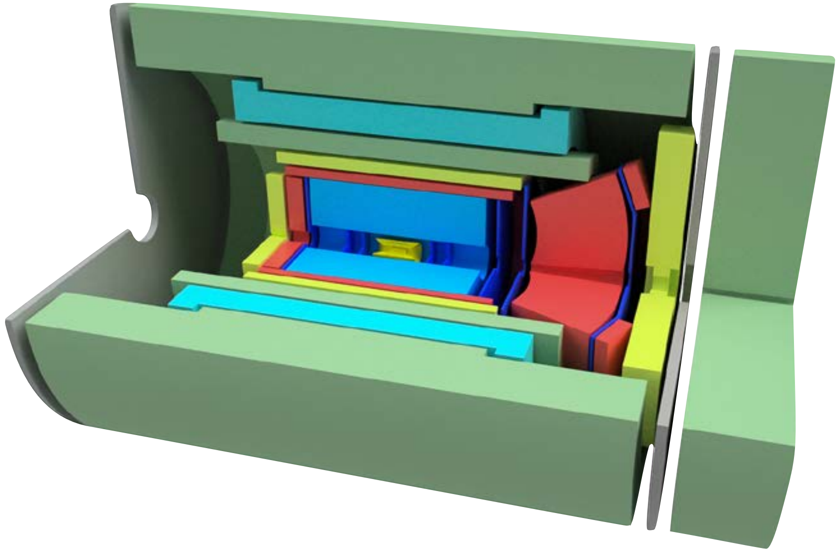
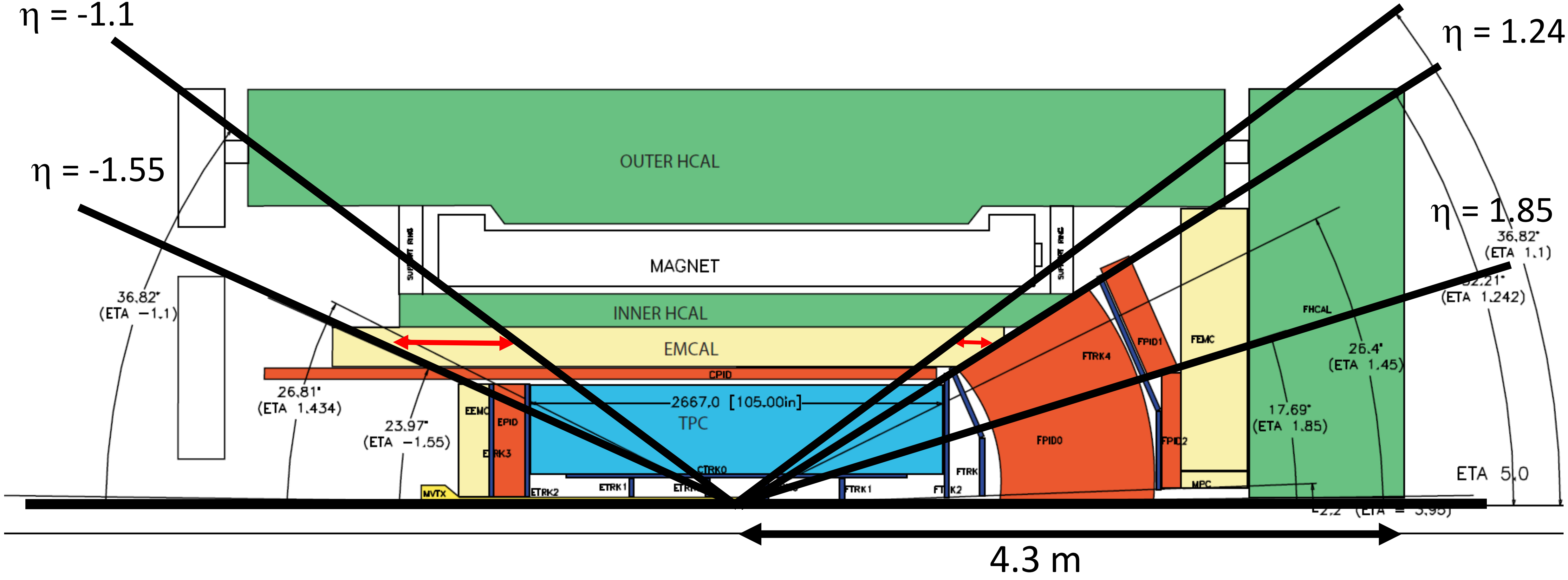
  - MAPS



- EIC detector
  - HCal/Flux return
  - Solenoid
  - Extended Central EMCal
  - Central hadron PID
  - TPC
  - MAPS
  - Forward and backward tracking
  - Forward and backward hadron PID
  - Backward crystal EMCal
  - Forward EMCal
  - Forward HCal

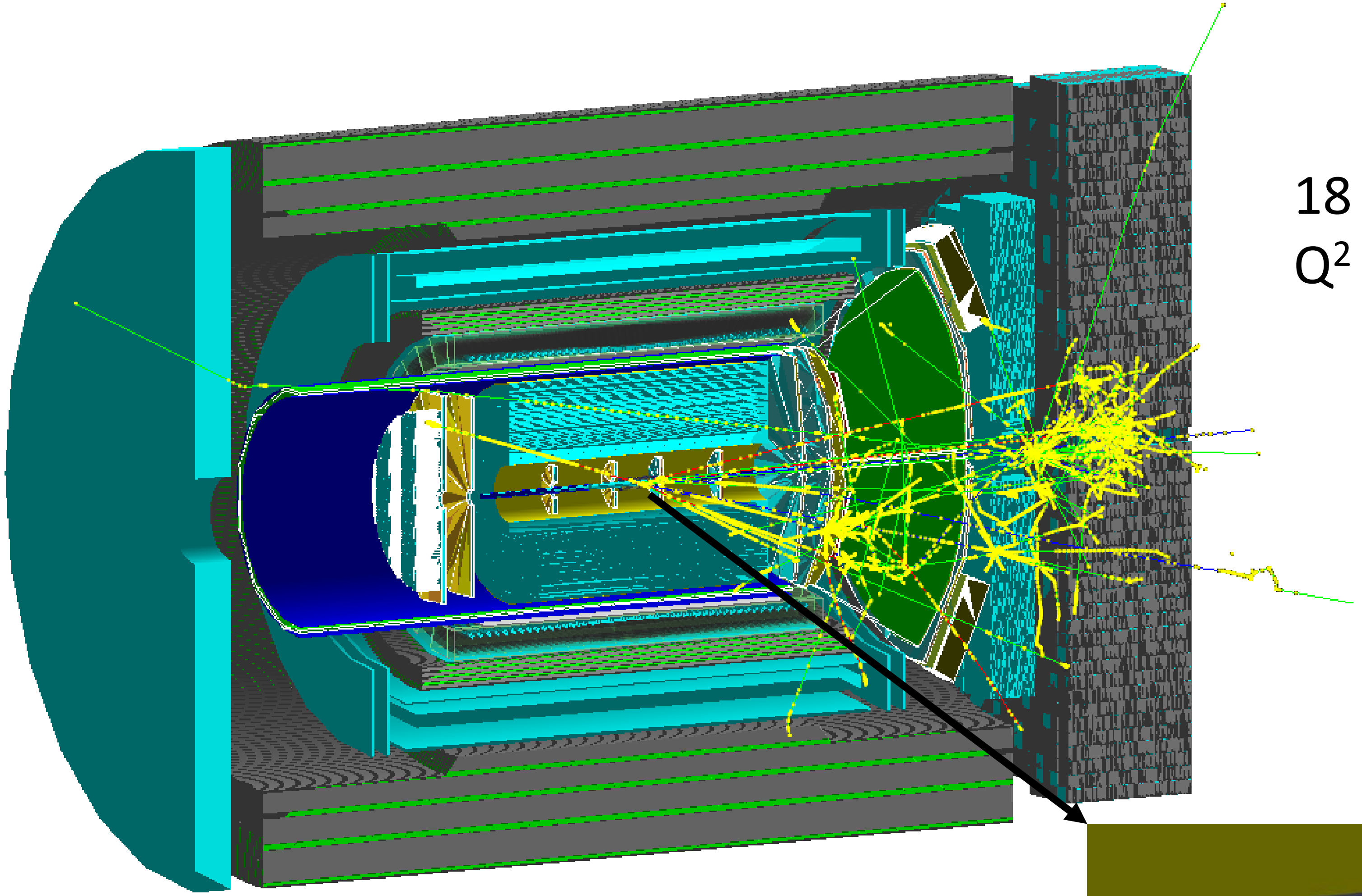
Continuous tracking, electromagnetic calorimeter, and particle ID coverage from $-4 < \eta < 4$



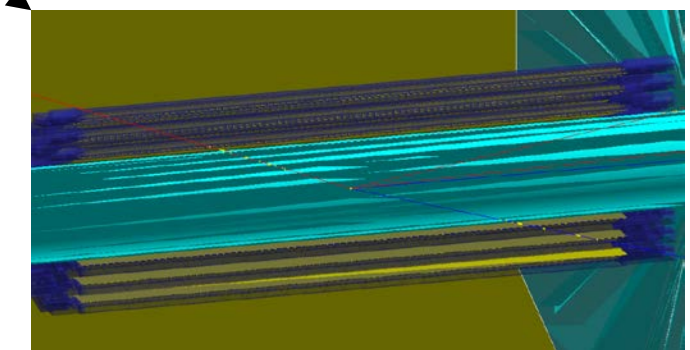
Measurement of scattered electron critical for nearly all of EIC physics program.

Red arrows indicate extension of Central EMCal active area to achieve EMCal coverage without gaps.

Detailed GEANT4 simulation available for users



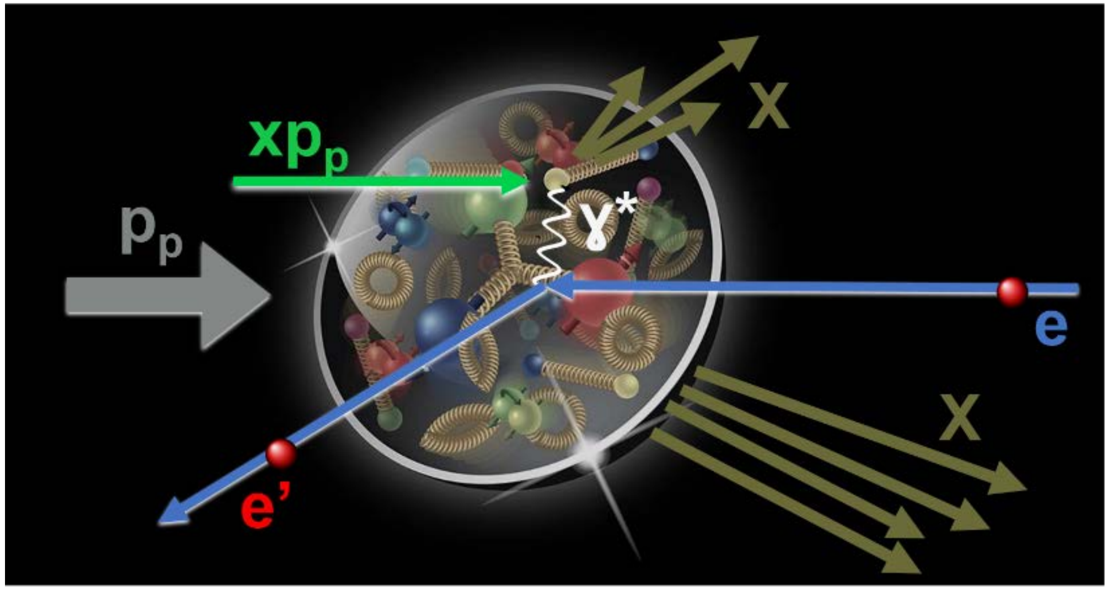
18 x 275 GeV DIS collision
$Q^2 \sim 100\ GeV^2$



Inclusive deep-inelastic scattering

- Measure only scattered electron, which allows reconstruction of x and Q^2 of partonic interaction

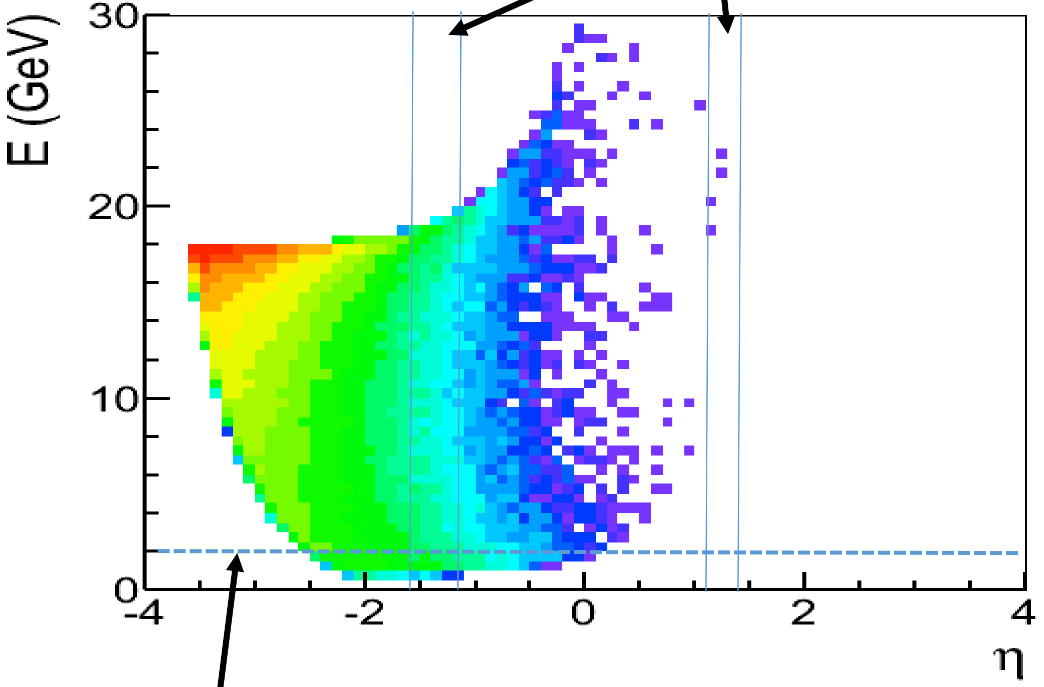
- Can measure, for example
  - Polarized and unpolarized parton distribution functions in protons and neutrons
  - Nuclear parton distribution functions



Inclusive DIS: Calorimeter coverage to η= -4 captures all scattered electrons

18×275 GeV

Regions covered by extended Central EMCal



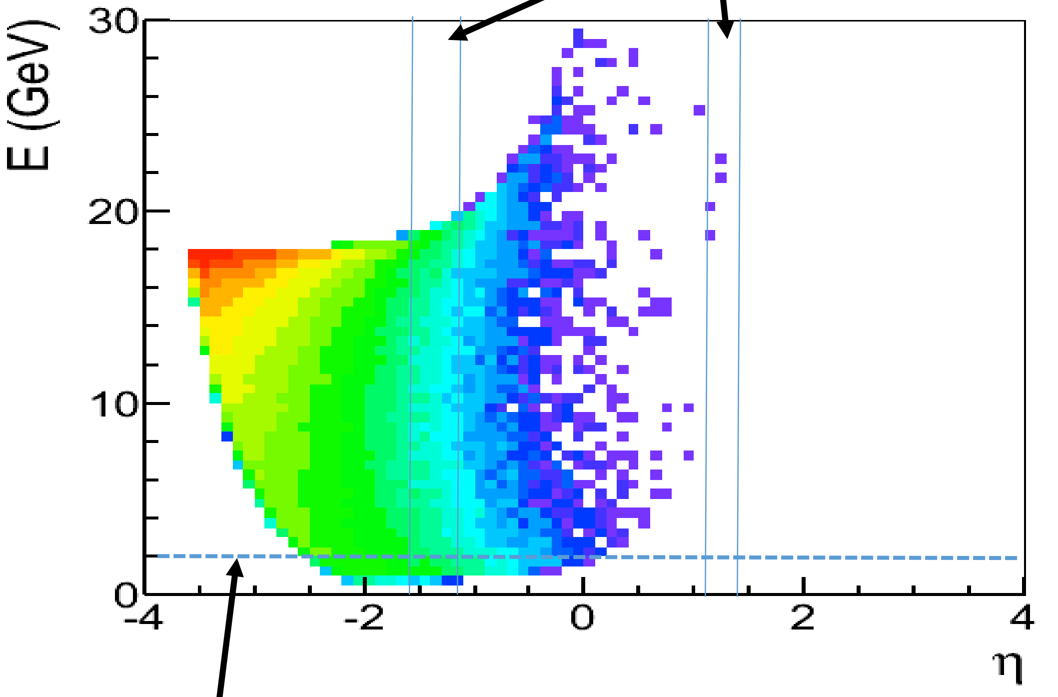
Very good electron purity above 2 GeV using electron ID via energy-momentum matching.

- Higher electron beam energy requires further backward coverage.
- Max E_e of 18 GeV and $Q^2 > 1$ GeV^2 → Need electron measurement and identification down to η ~ -4.

Inclusive DIS: Calorimeter coverage to η= -4 captures all scattered electrons

18×275 GeV

Regions covered by extended Central EMCal



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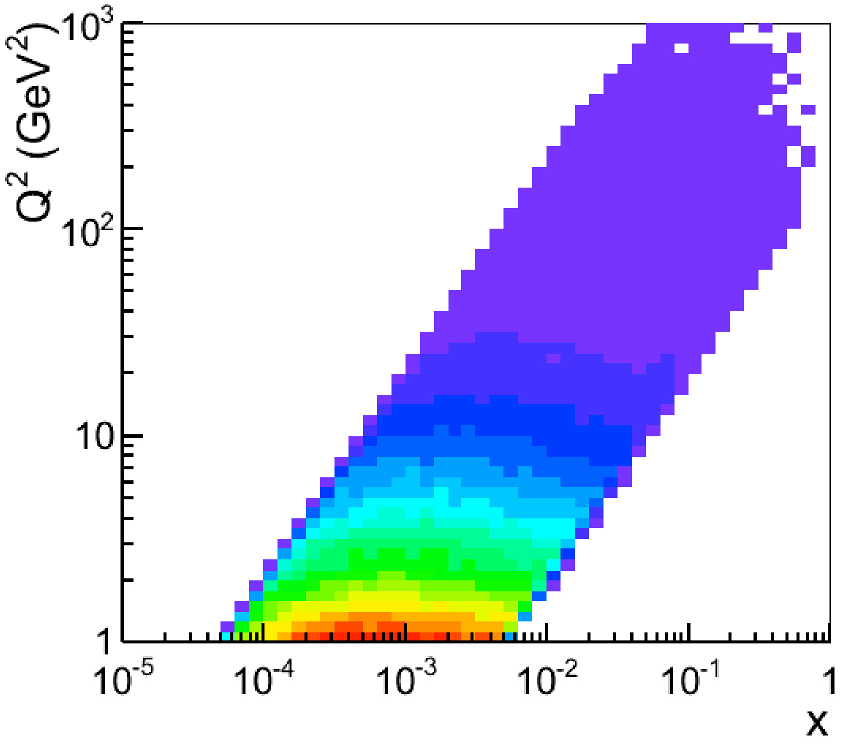
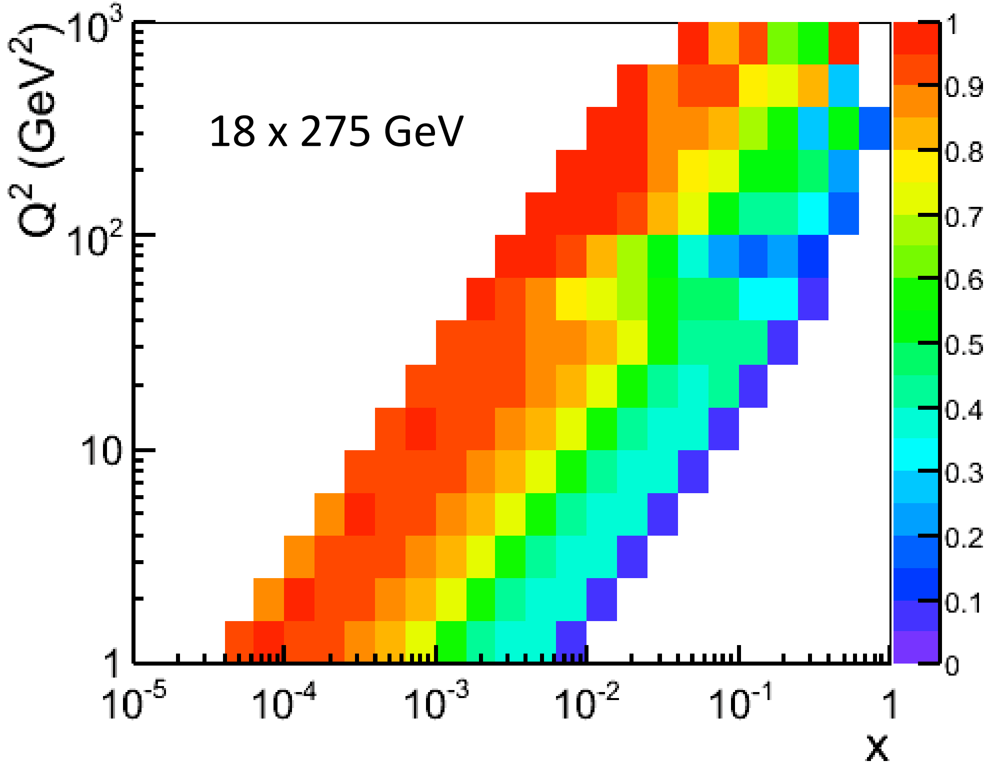


x-Q^2 distribution, 18 x 275 GeV

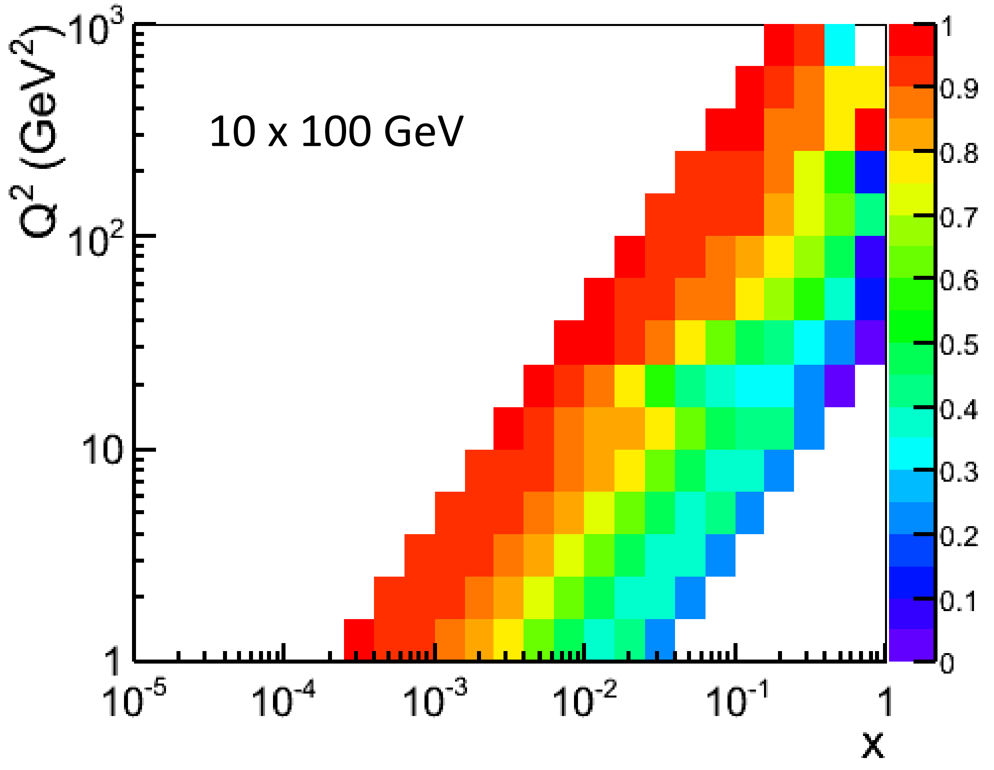
Inclusive DIS: x, Q^2 resolution based on scattered electron detection sufficient for EIC science program



Fraction of events reconstructed in correct x, Q^2 bin

Precise recovery of event kinematics from smearing effects possible using unfolding.

Inclusive DIS: x, Q^2 resolution based on scattered electron detection sufficient for EIC science program

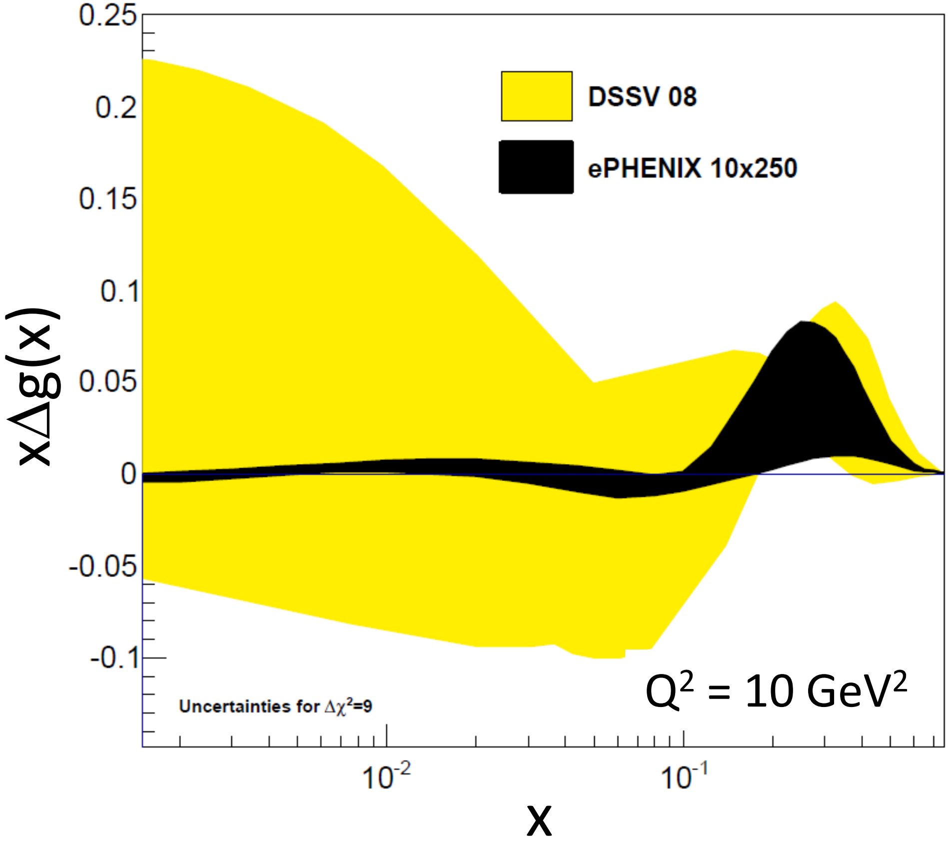


Fraction of events reconstructed in correct x, Q^2 bin

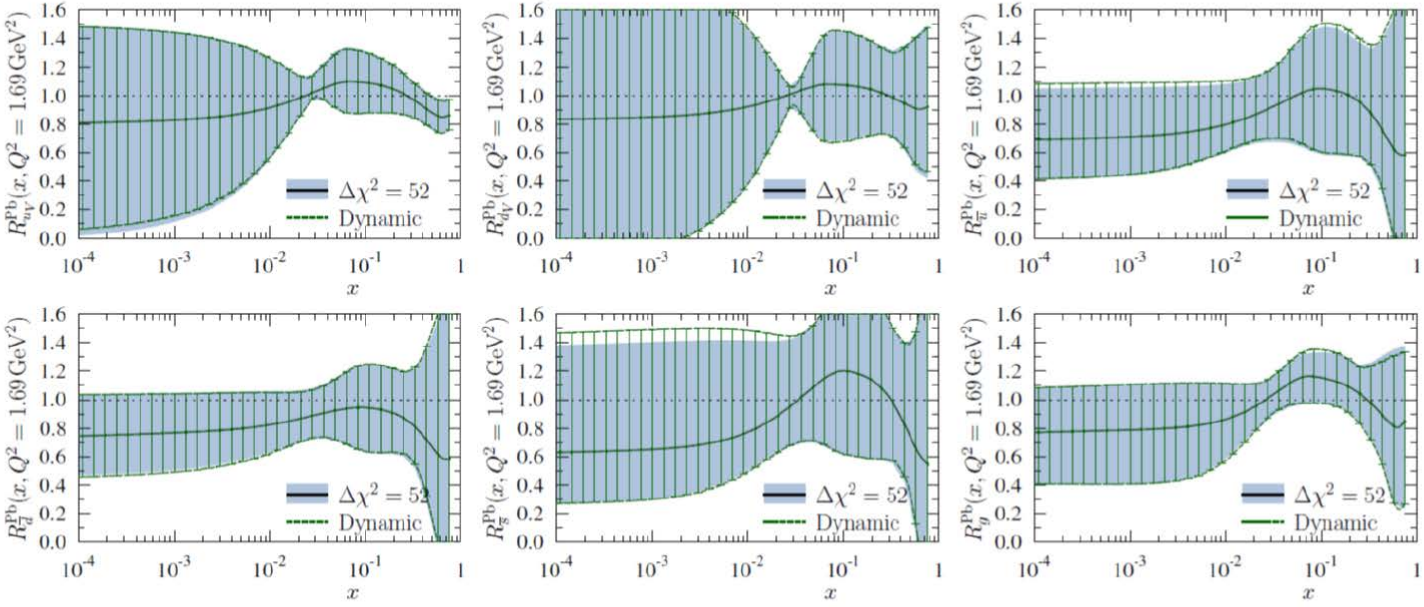
Precise recovery of event kinematics from smearing effects possible using unfolding.

Significant impact expected for inclusive DIS measurements

2014 LOI: arXiv:1402.1209



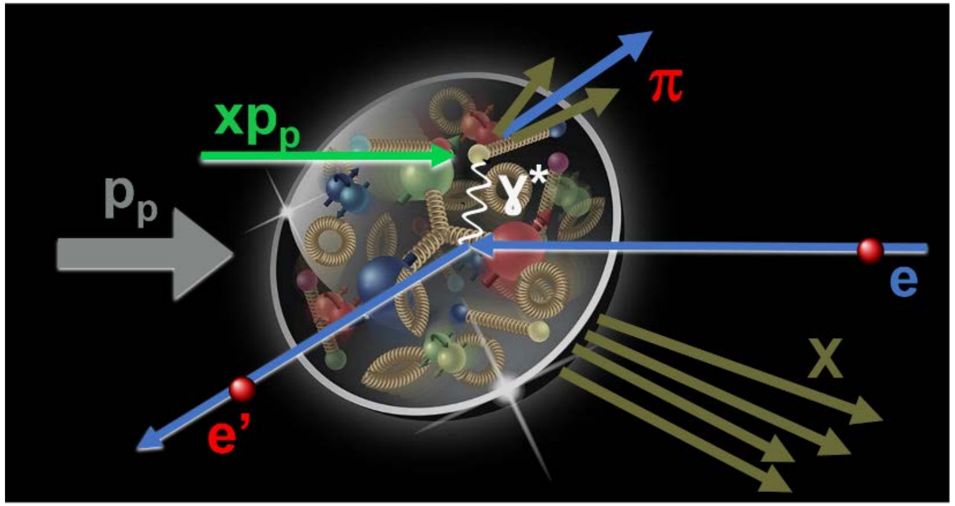
EPPS16 Nuclear PDFs: EPJ C77, 163 (2017)



Will update using pseudodata for EIC detector based on sPHENIX, taking into account expected detector performance based on GEANT studies

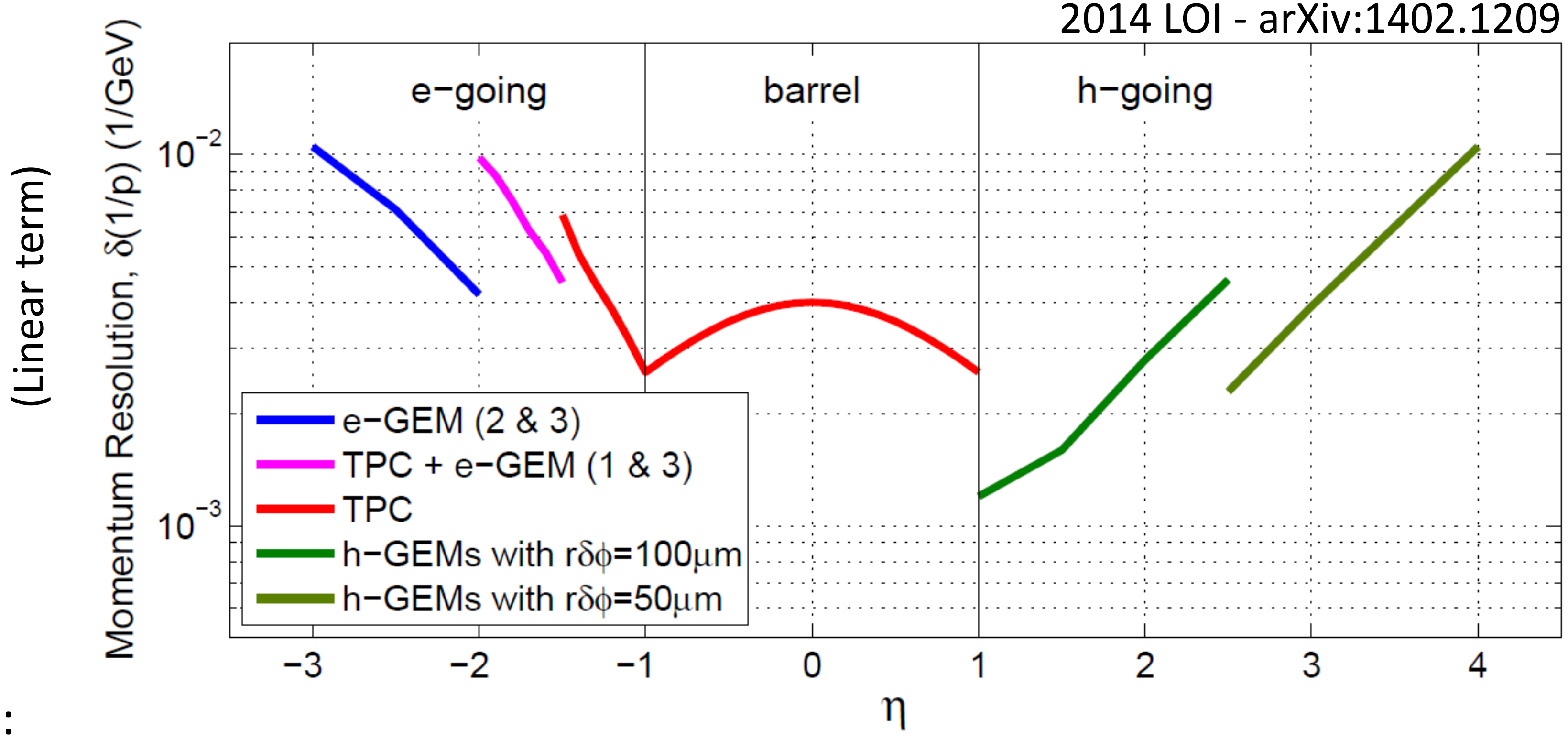
Semi-inclusive DIS

- Measure scattered electron + at least one final-state object
  - Requires tracking and PID
- Can measure, for example
  - Transverse-momentum-dependent parton distribution functions for momentum imaging
  - Nuclear modification of hadronization



Continuous tracking from -4 < η < 4

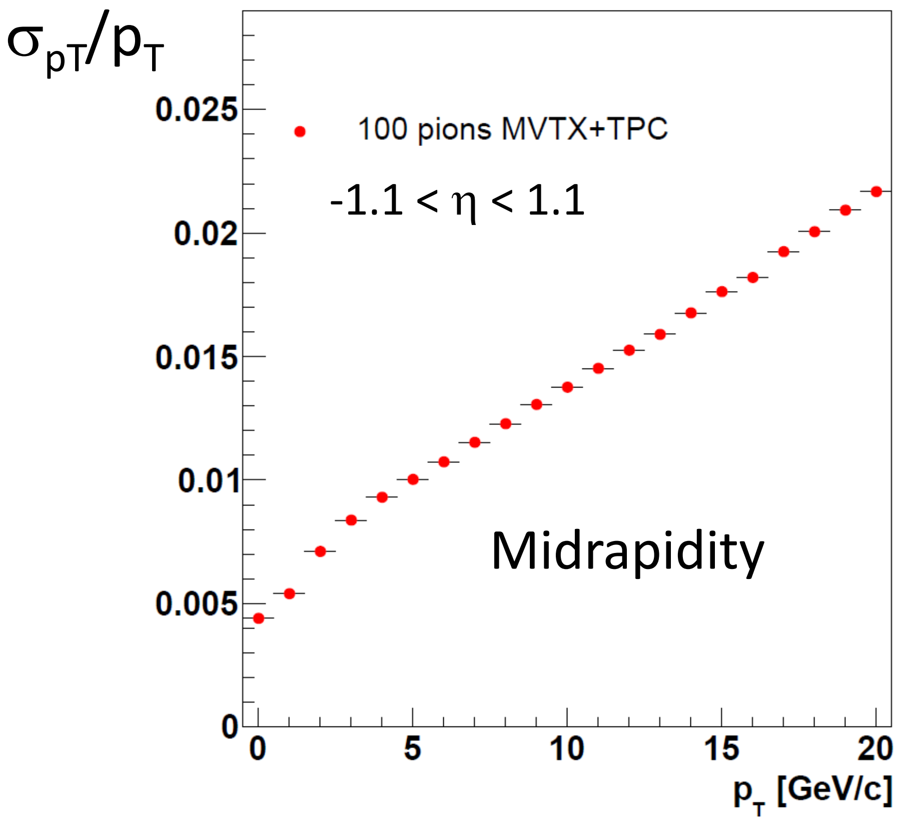
2014 LOI - arXiv:1402.1209

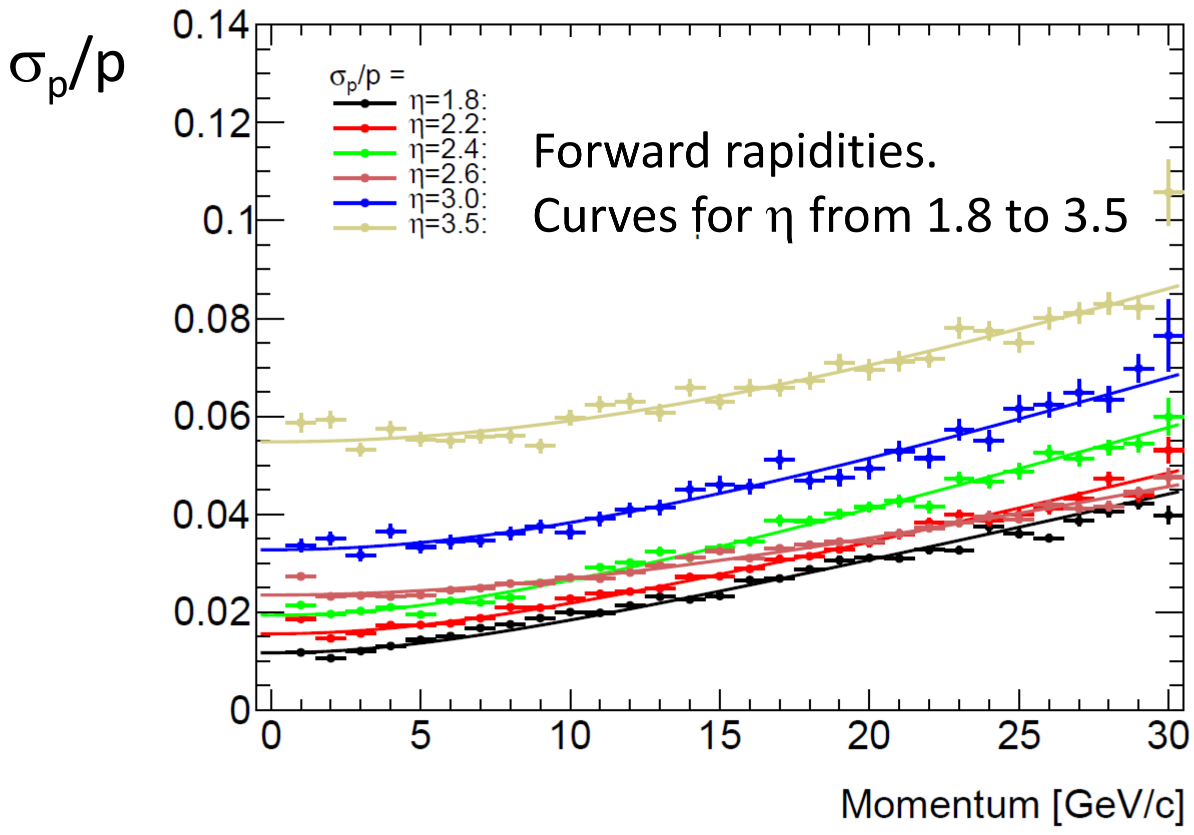


Since 2014 LOI:

- Full GEANT4 simulations now
  - Forward/backward pattern recognition from truth hits, then Kalman filter for fitting
- Extended backward tracking to η = -4
- Improved TPC resolution based on sPHENIX design
- MVTX added
- 5 forward GEM stations now rather than 3

Good momentum resolution demonstrated at mid- and forward rapidities via GEANT simulations

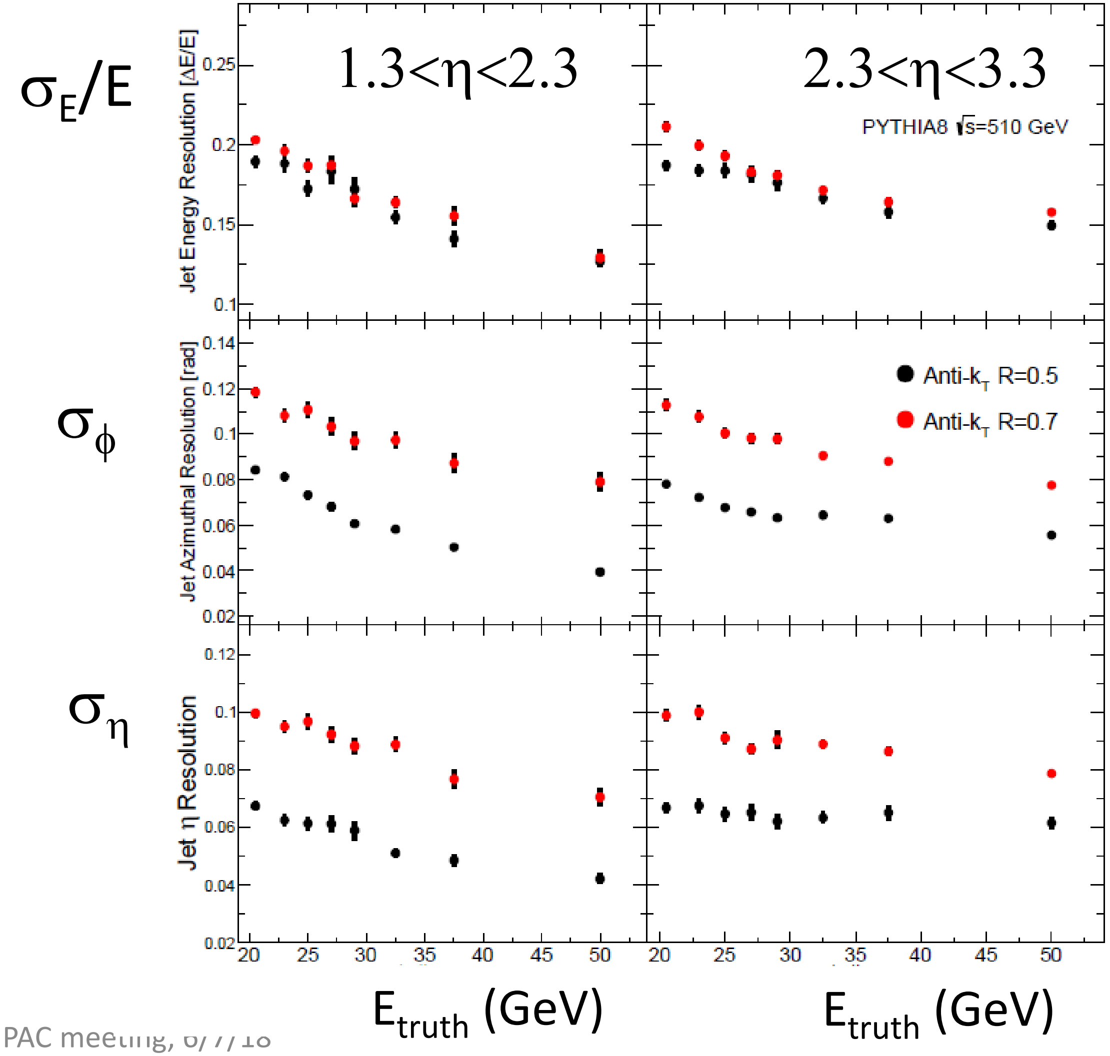




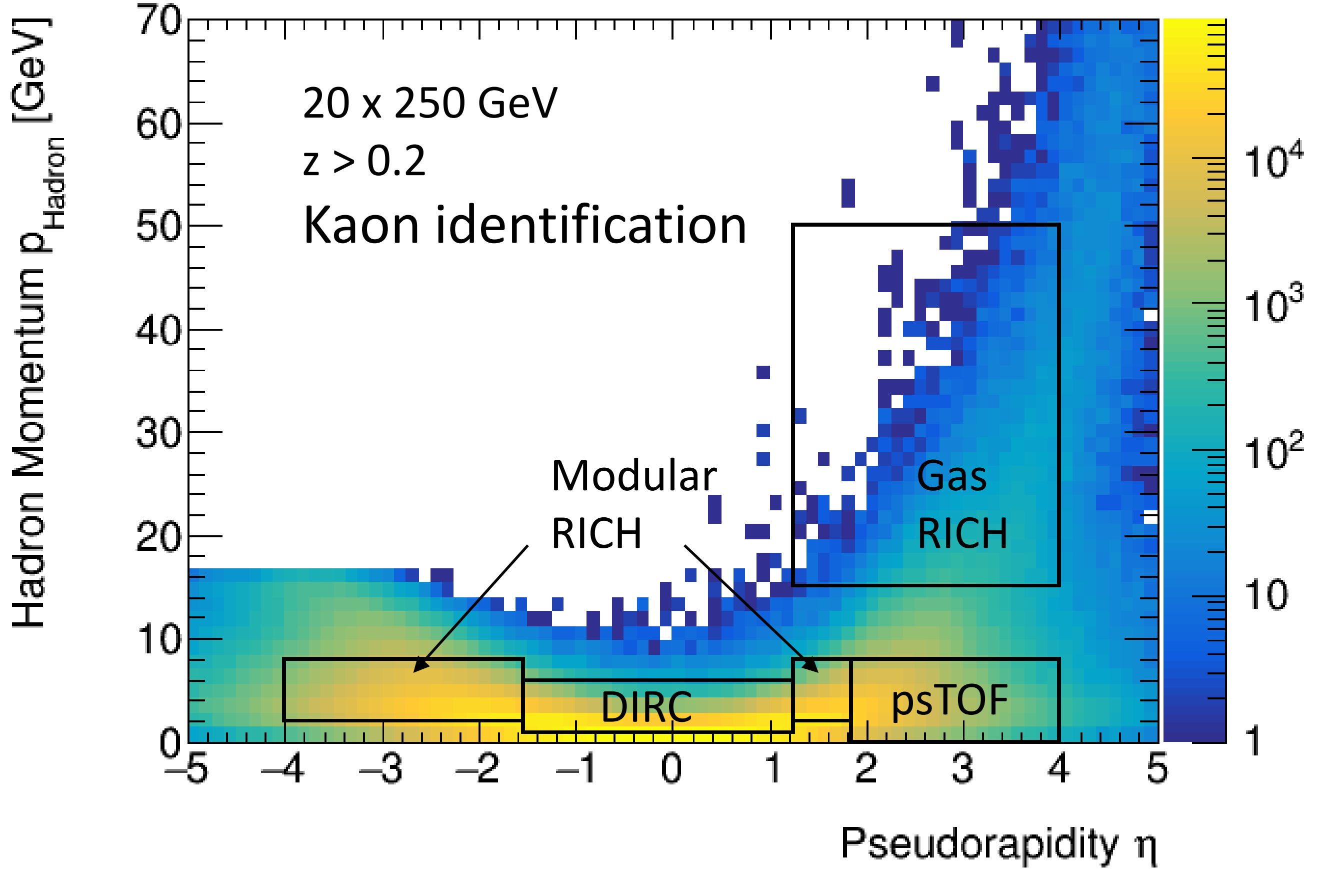
Studies at backward rapidities in progress.

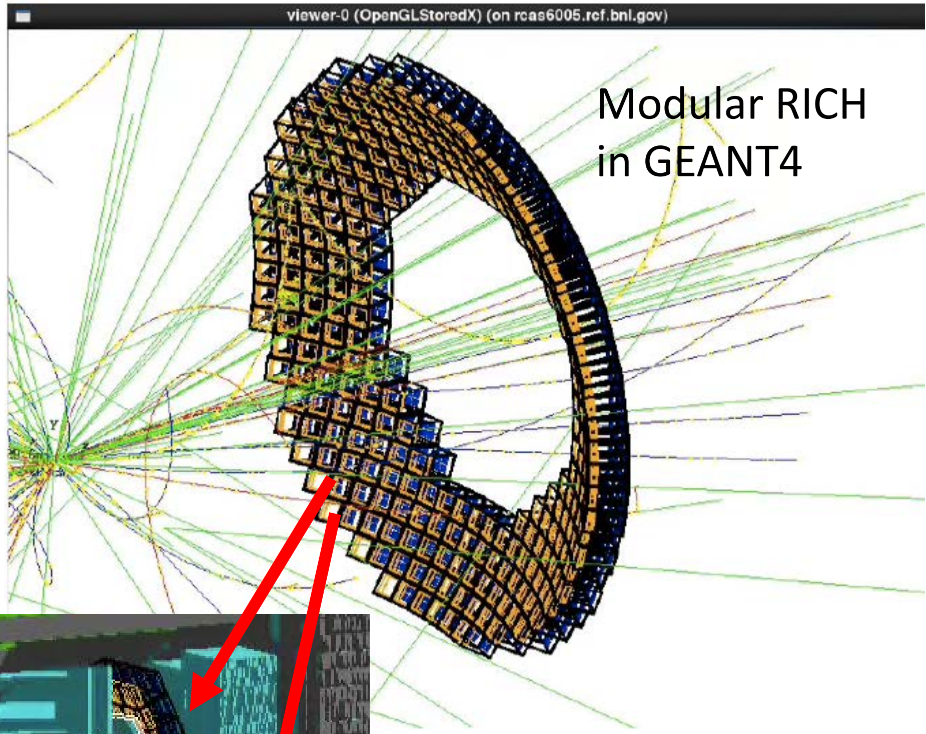
Good performance for mid- and forward rapidity jets

- sPHENIX designed as midrapidity jet detector
- Forward jets: GEANT study shown for forward jets in 510 GeV p+p with EIC sPHENIX forward tracking and calorimetry
- Currently updating for e+p with latest EIC detector configuration

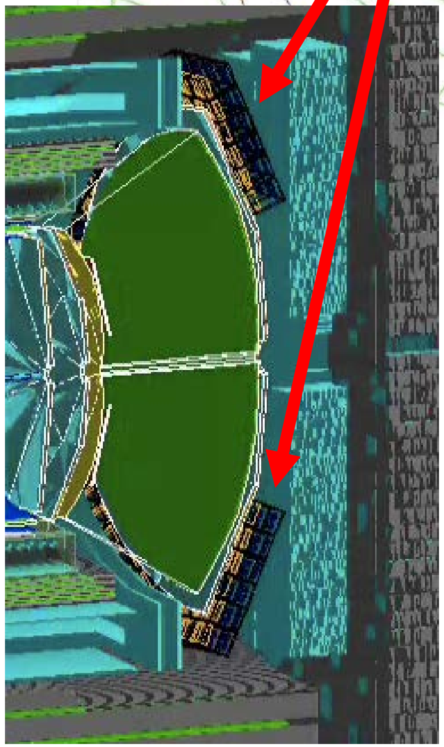


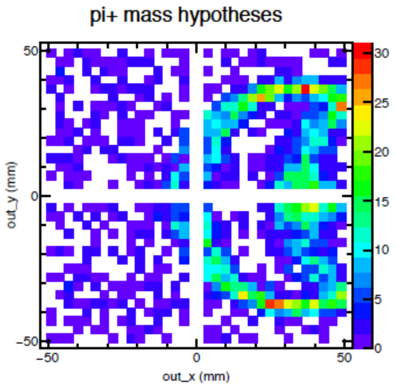
Hadron PID for $-4 < \eta < 4$





Modular RICH in GEANT4



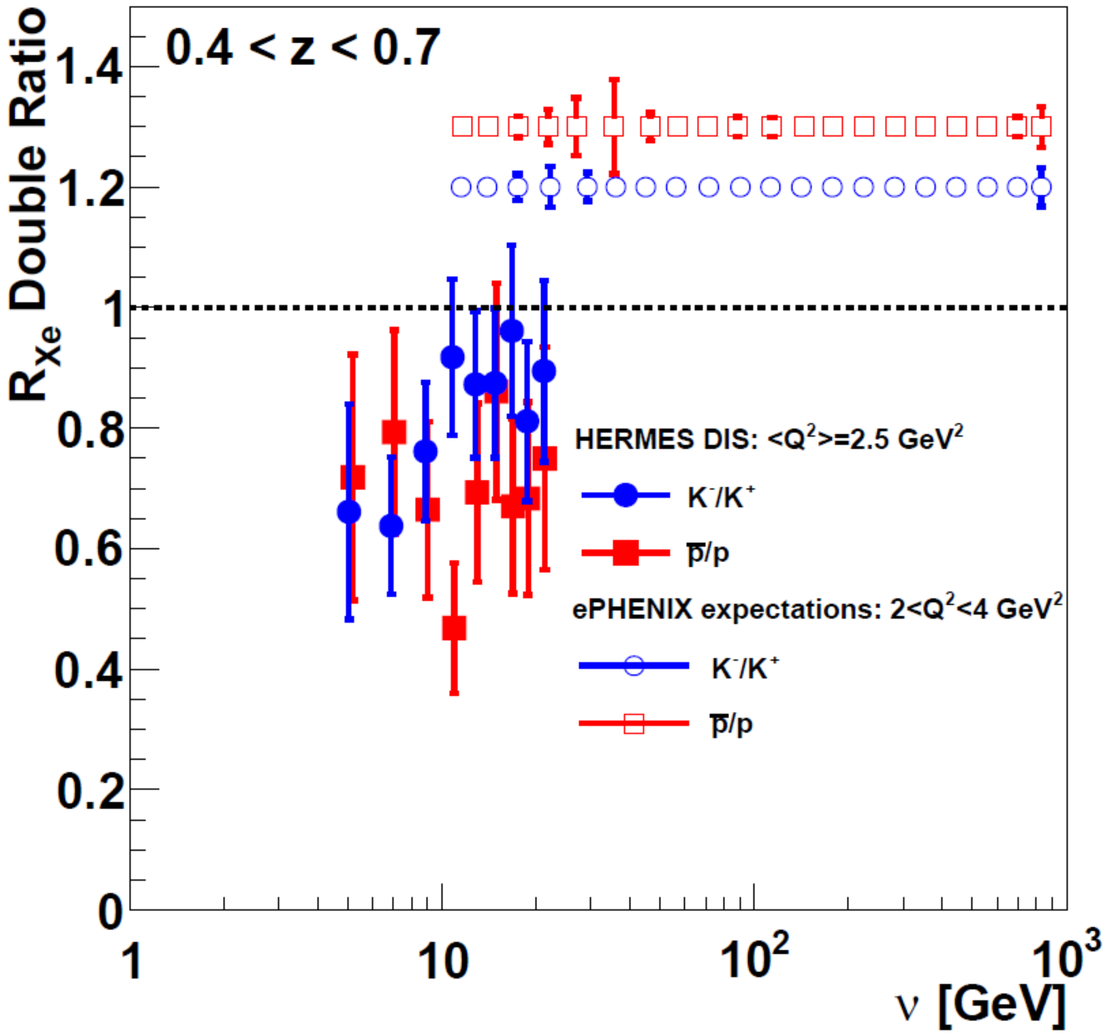


Ring reconstruction

Significant impact expected for semi-inclusive DIS measurements

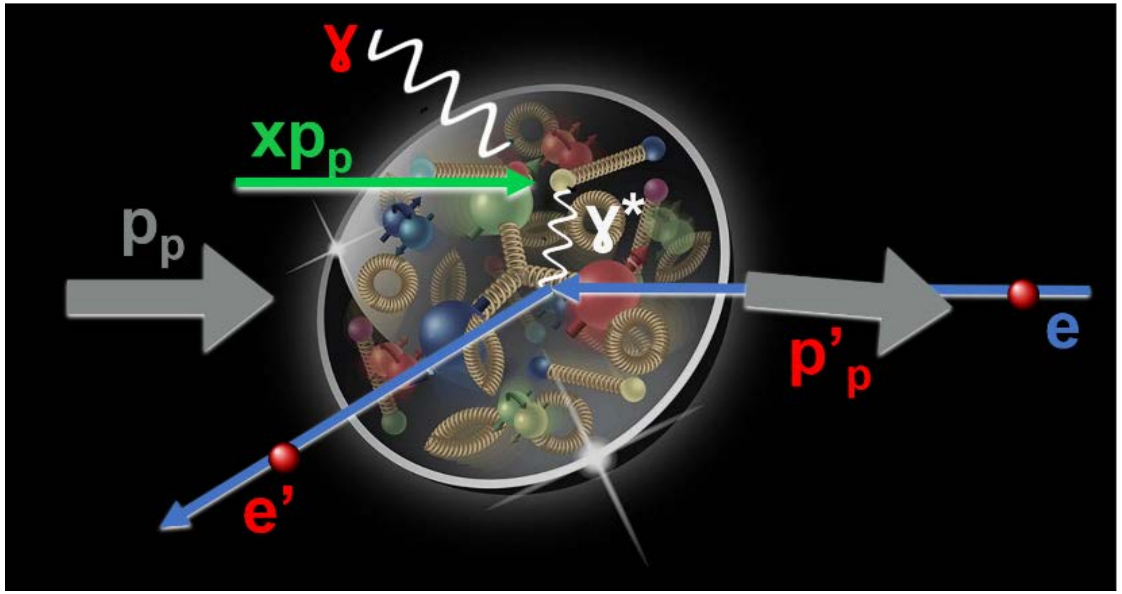
- Nuclear modification of hadronization
- Will update using pseudodata for EIC detector based on sPHENIX, taking into account expected detector performance based on GEANT studies

2014 LOI: arXiv:1402.1209



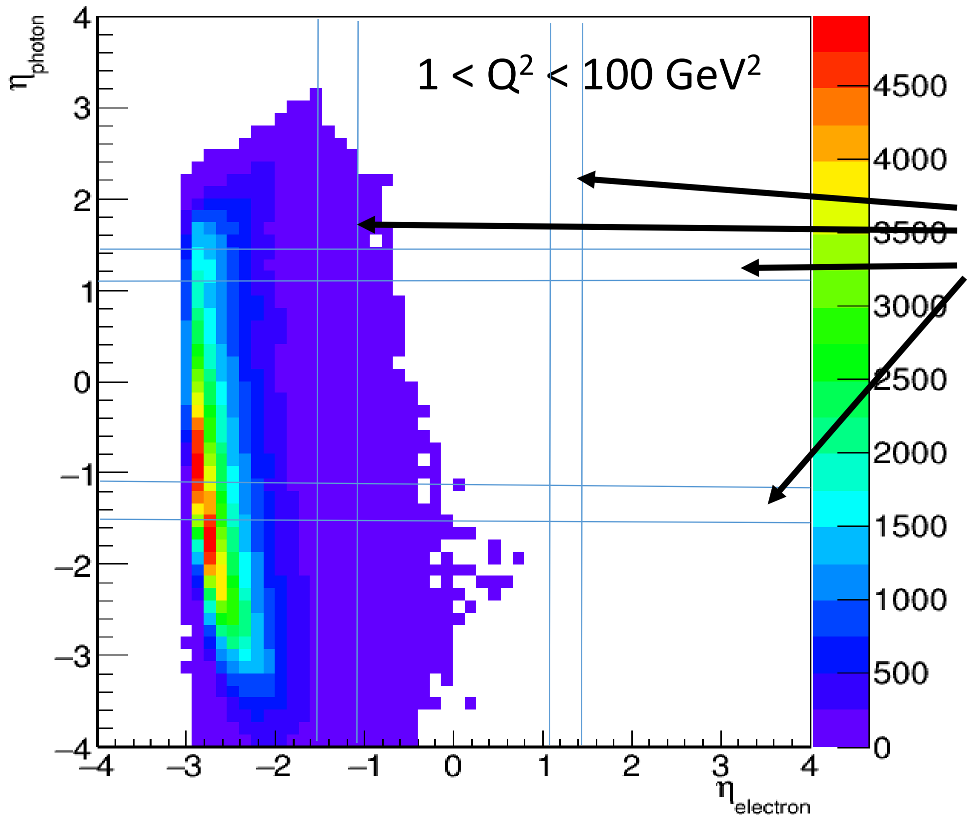
Exclusive processes

- Measure *all* final-state particles
- Can measure, for example
  - Deeply Virtual Compton Scattering (DVCS) for spatial imaging
  - Exclusive vector meson production to access gluon distribution



Calorimeter coverage to η= -4 captures all DVCS photons

10 x 100 GeV

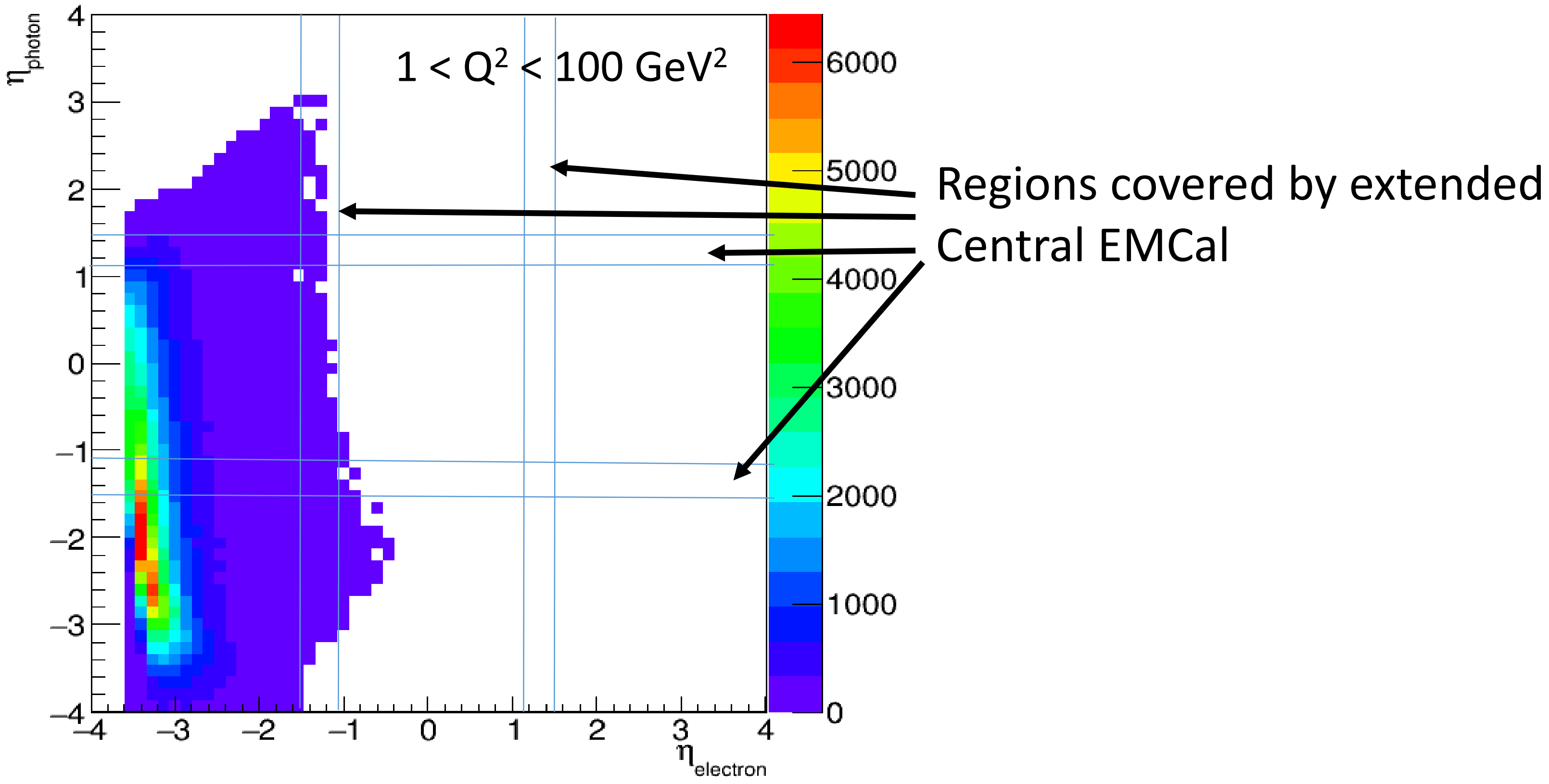


Regions covered by extended Central EMCal

Gap in EMCal coverage in electron-going direction would impact photon detection in particular

Calorimeter coverage to η= -4 captures all DVCS photons

18 x 275 GeV



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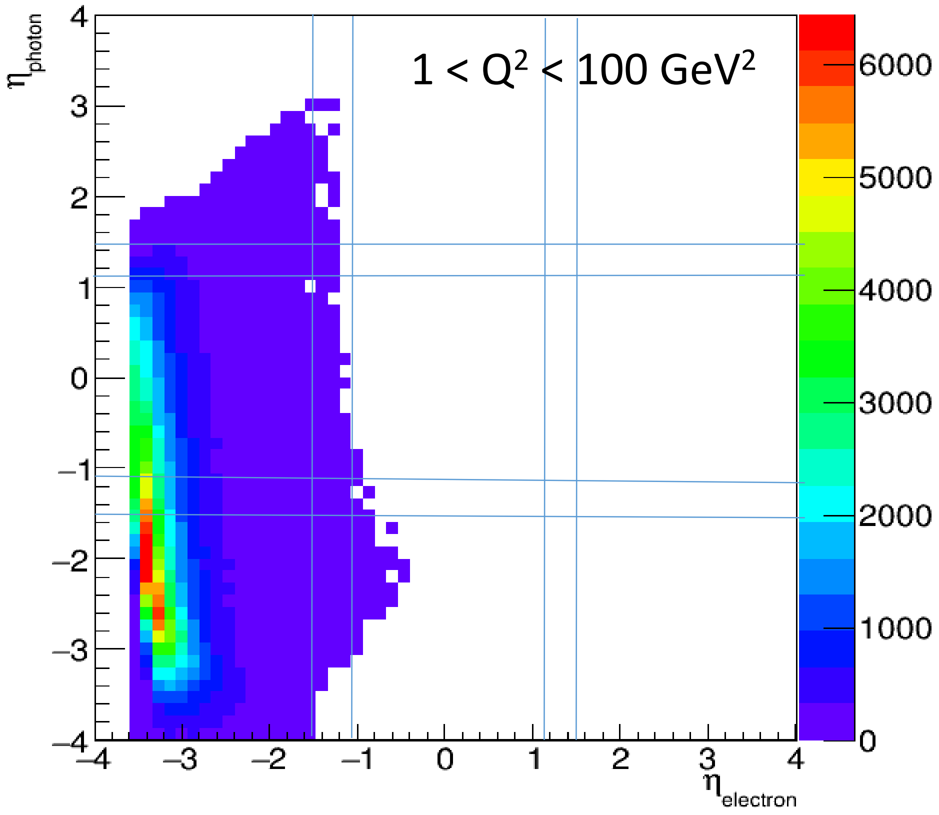

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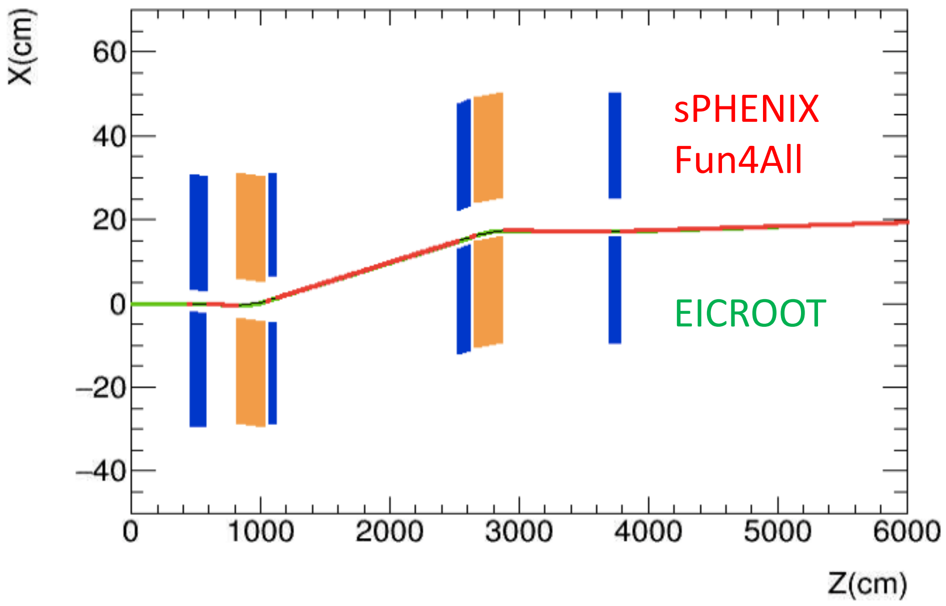
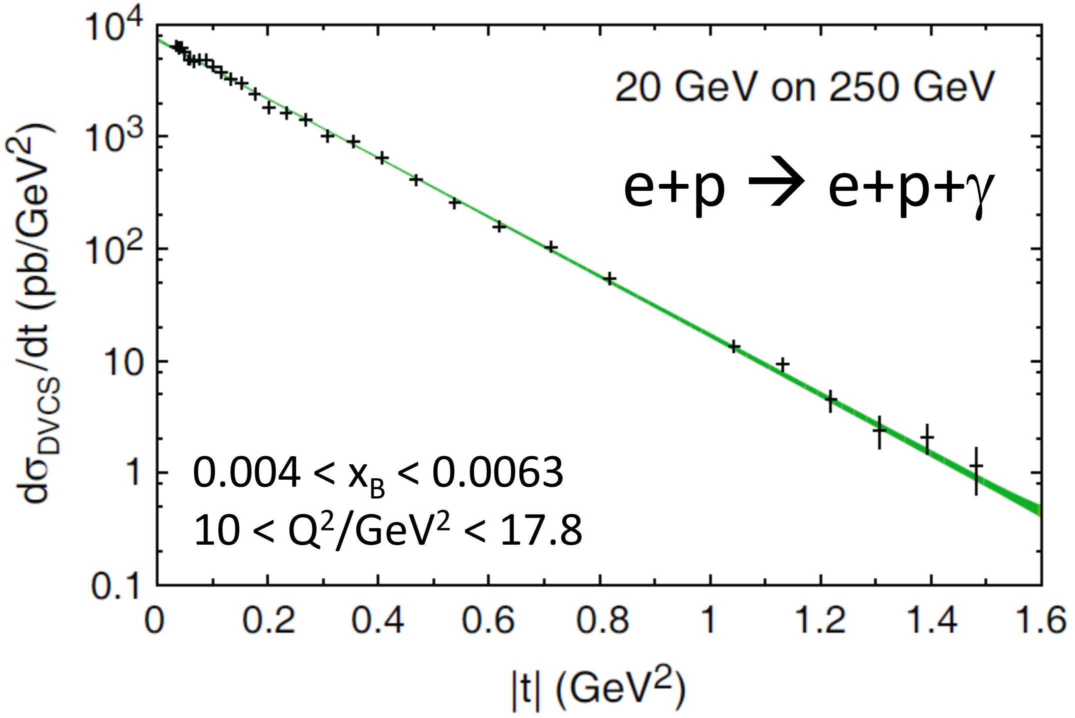


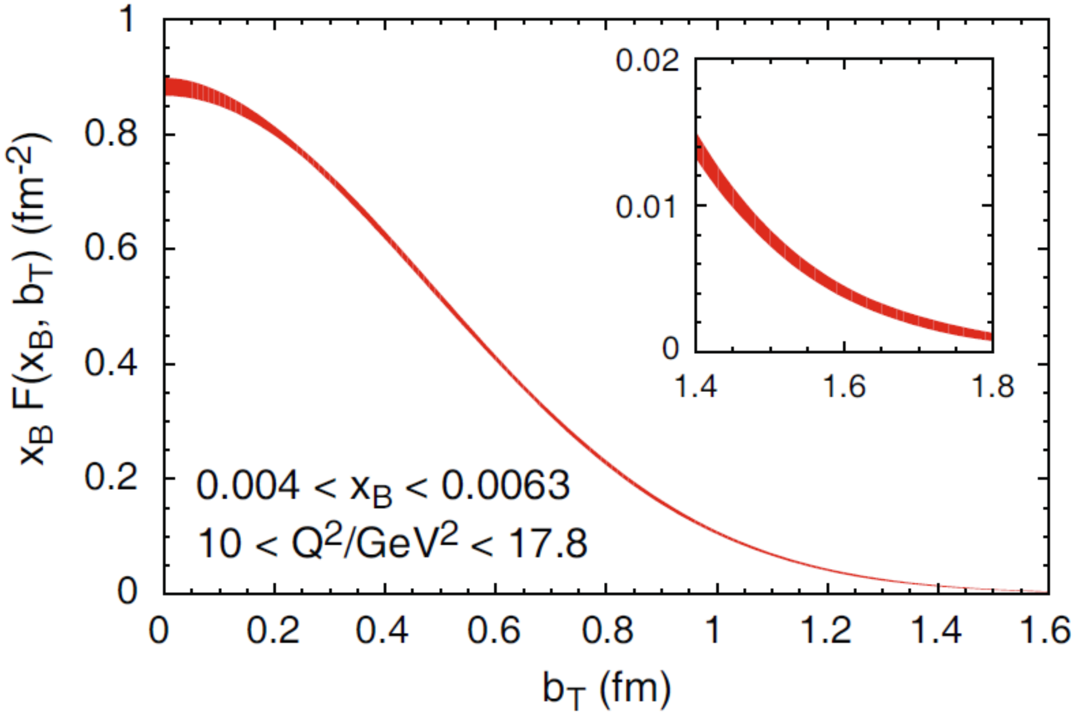
Detection of scattered (intact) proton

- Beam line dipoles and quadrupoles included in GEANT

Significant impact expected for exclusive process measurements

EPJ A52, 268 (2016)

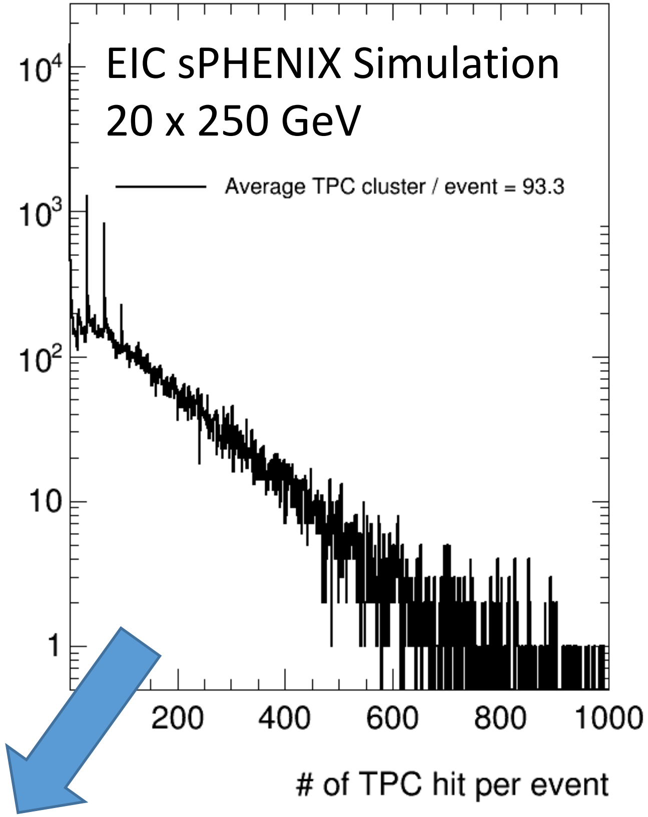




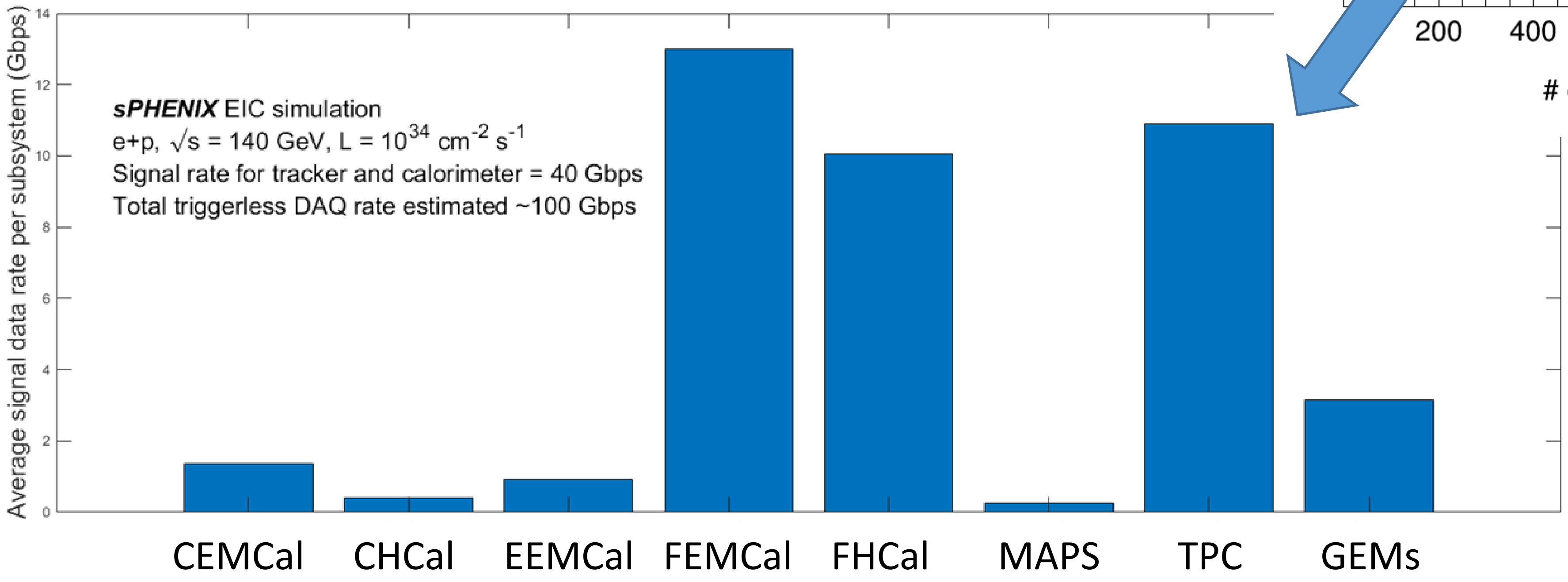
- Spatial imaging: Extract impact-parameter dependent distributions from DVCS cross section measurements

Reuse components of sPHENIX DAQ

- Versatility of EIC event topology calls for triggerless DAQ
  - 0.5 MHz interaction rate at top luminosity
- Using EIC-sPHENIX full detector simulation to estimate triggerless DAQ
  - Total data rate on order of 100 Gbps
  - Matches well with sPHENIX TPC/MVTX DAQ through-put rate
- sPHENIX TPC/MVTX DAQ may be expanded and reused for EIC detector
  - Similar architecture with ATLAS/LHCb/ALICE DAQ upgrade in 2020+



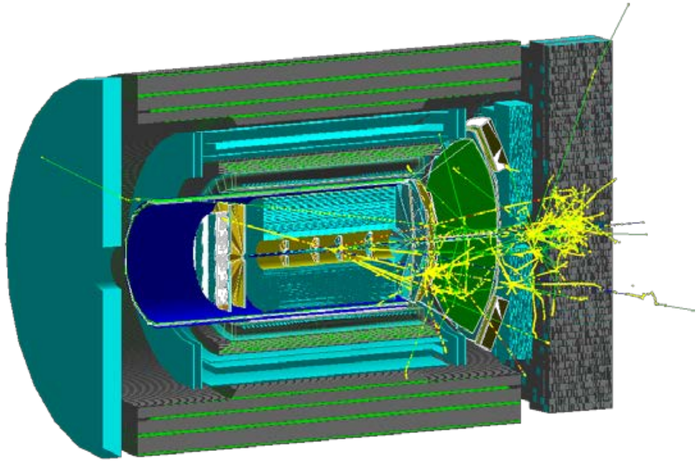
Avg signal data rate per subsystem (Gbps)



Additional studies are underway

- Fully integrated tracking with appropriate resolutions for combined TPC + forward/backward tracking stations
- Impact of projective geometry for electron-direction EMCal
- Reconstruction of kinematics based on hadronic activity
  - Complements kinematics reconstruction based on scattered electron
  - Necessary to measure charged-current DIS events (unmeasured outgoing neutrino)
- Charm tagging in low-multiplicity environment of EIC
- Exclusive J/Psi production
- Spectator tagging in collisions between electrons and light and heavy ions

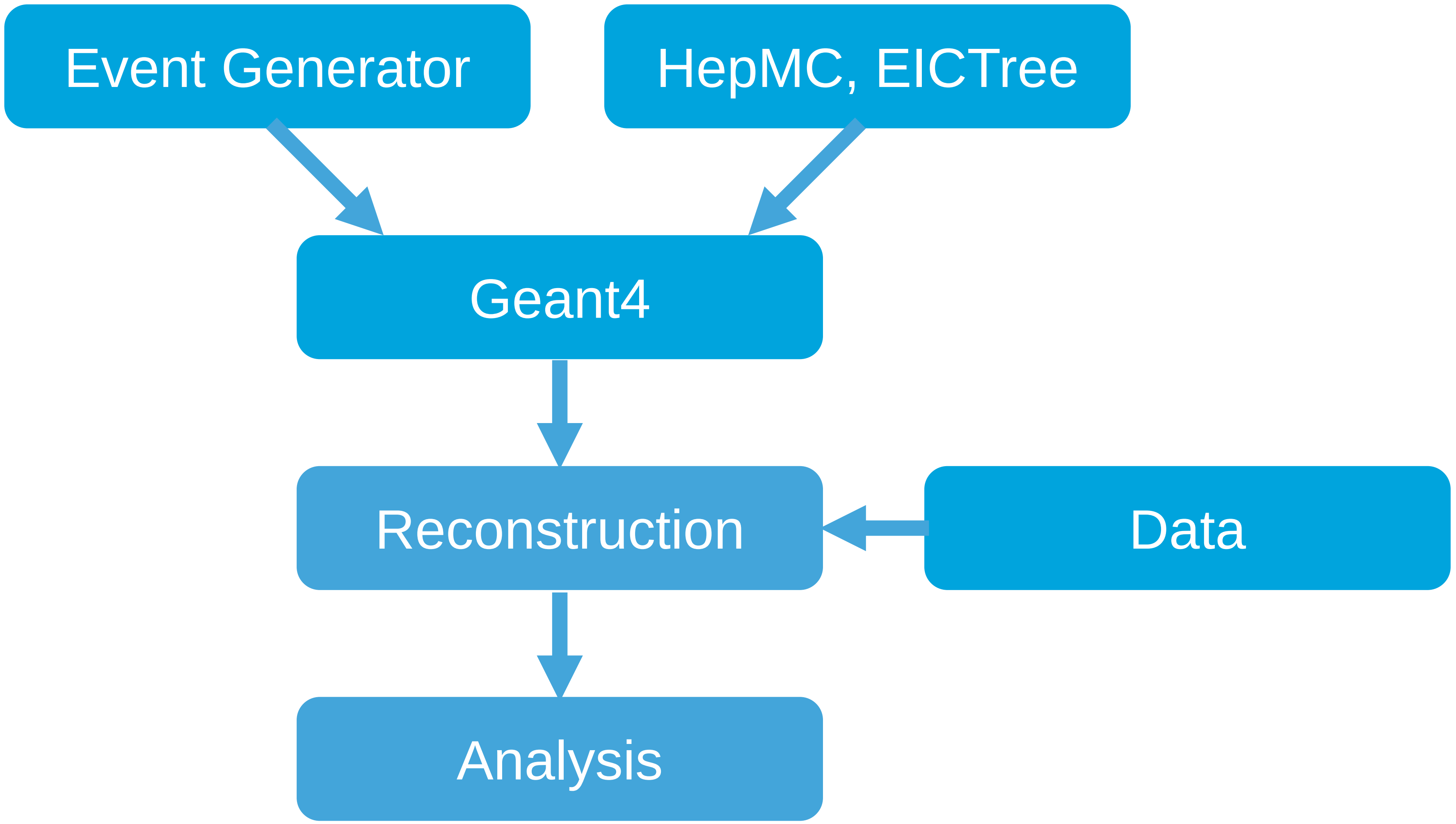
Conclusions and outlook



- An EIC detector based on sPHENIX can address the full physics program of the facility, spanning inclusive, semi-inclusive, and exclusive measurements.
- Efforts have ramped up investigating realistic possible implementations—lots of technical progress since 2014 LOI.
- Delivery of LOI in September will mark a milestone within ongoing work toward an EIC detector based on sPHENIX.

Backup

MODULAR FUN4ALL FRAMEWORK PROVIDES COMPLETE ANALYSIS CHAIN.

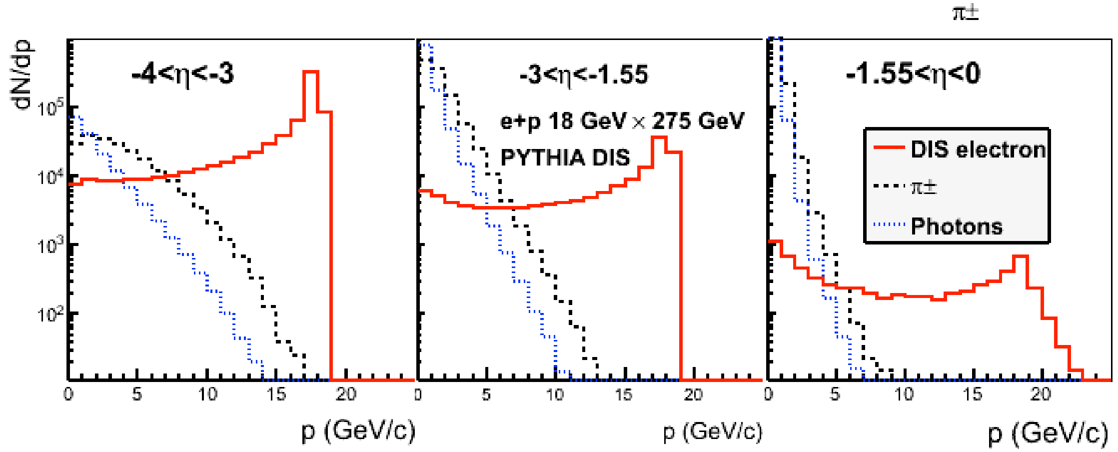


https://github.com/sPHENIX-Collaboration

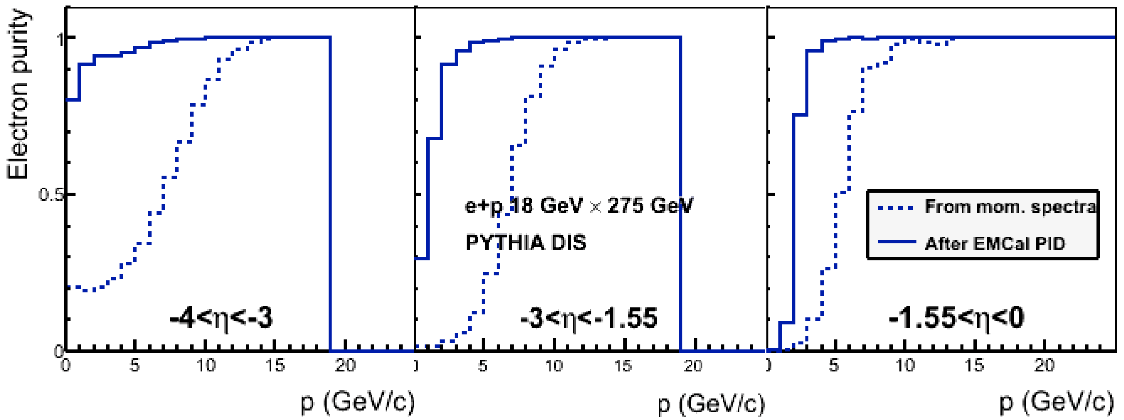
Calorimeter coverage -4 < η < 4

$-4 < \eta < -1.55$	$PbWO_4$	2 cm x 2 cm	$\frac{2.5\%}{\sqrt{E}} \oplus 1\%$
$-1.55 < \eta < 1.24$	W-SciFi	0.025 x 0.025	$\frac{16\%}{\sqrt{E}} \oplus 5\%$
$1.24 < \eta < 3.3$	PbScint	5.5 cm x 5.5 cm	$\frac{8\%}{\sqrt{E}} \oplus 2\%$
$3.3 < \eta < 4$	$PbWO_4$	2.2 cm x 2.2 cm	$\frac{12\%}{\sqrt{E}}$
$-1.1 < \eta < 1.1$	Fe Scint + Steel Scint	0.1 x 0.1	$\frac{81\%}{\sqrt{E}} \oplus 12\%$
$-1.24 < \eta < 5$	Fe Scint	10 cm x 10 cm	$\frac{70\%}{\sqrt{E}}$

Background from pions and electron purity



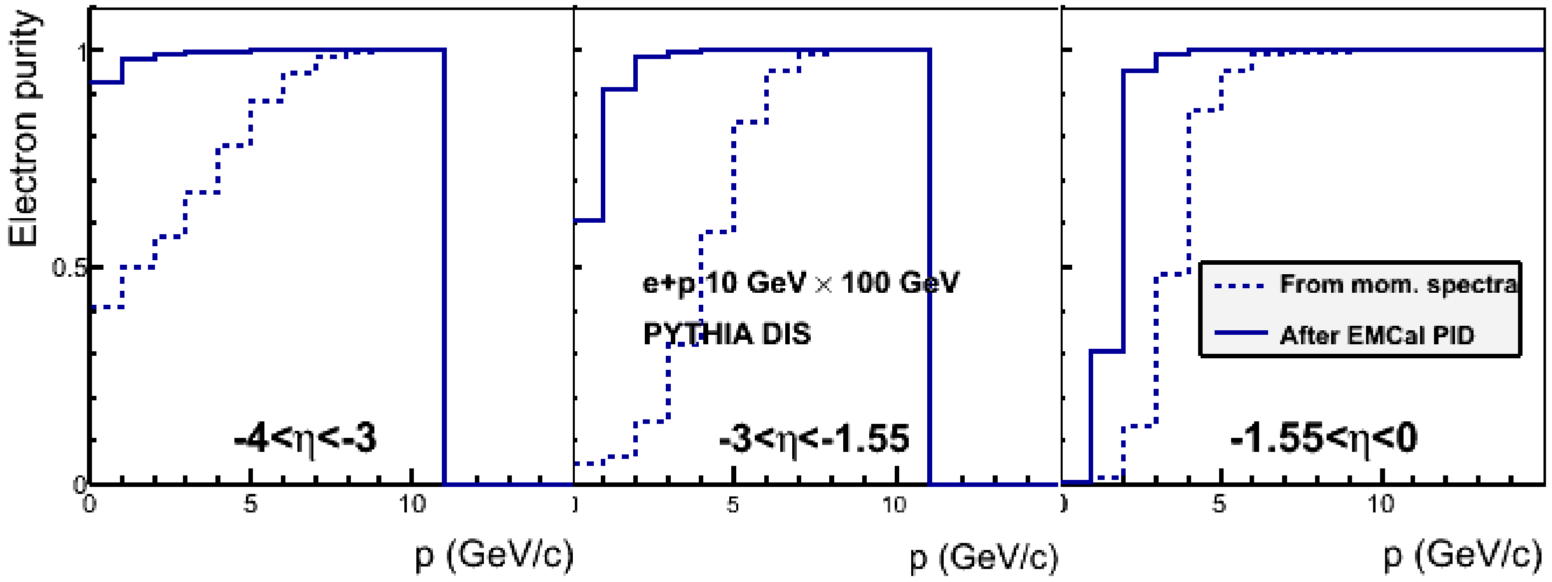
18×275 GeV



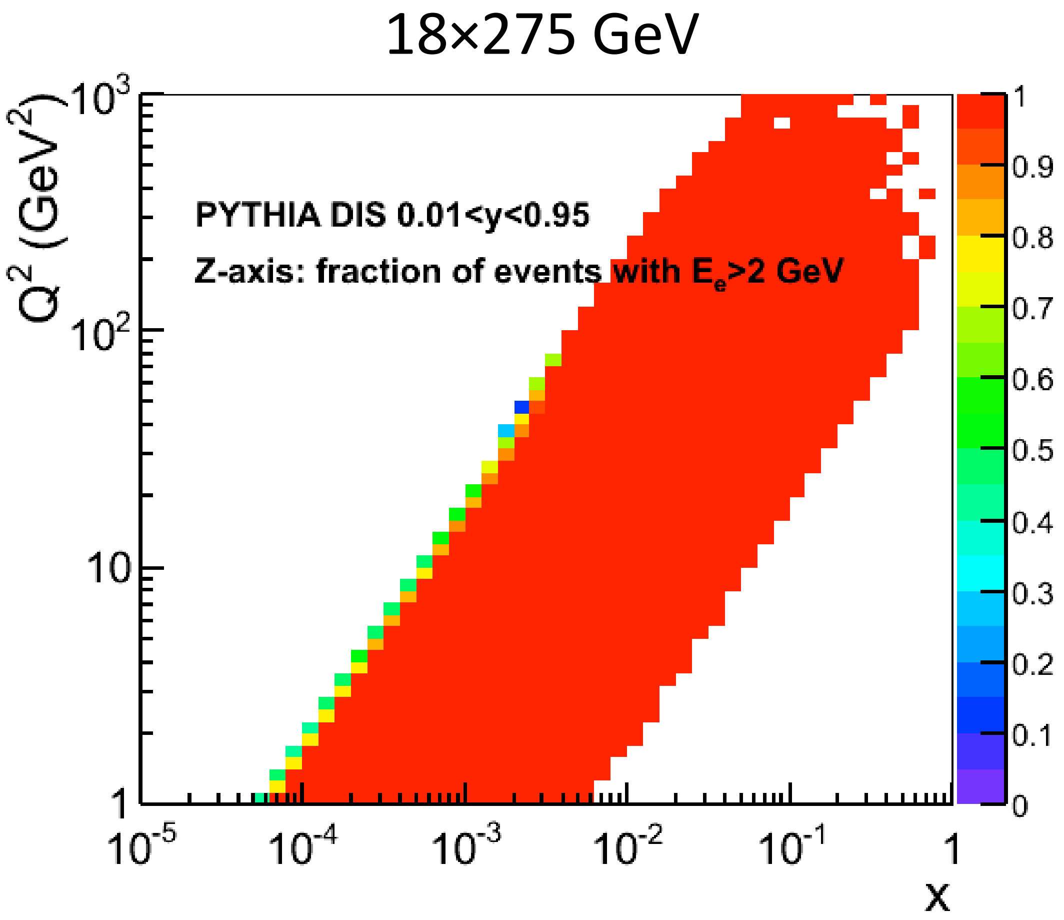
Electron ID based only on E-p matching so far. Shower profile information will improve further.

We can do well for E_e>2 GeV

Electron purity for 10 x 100 GeV

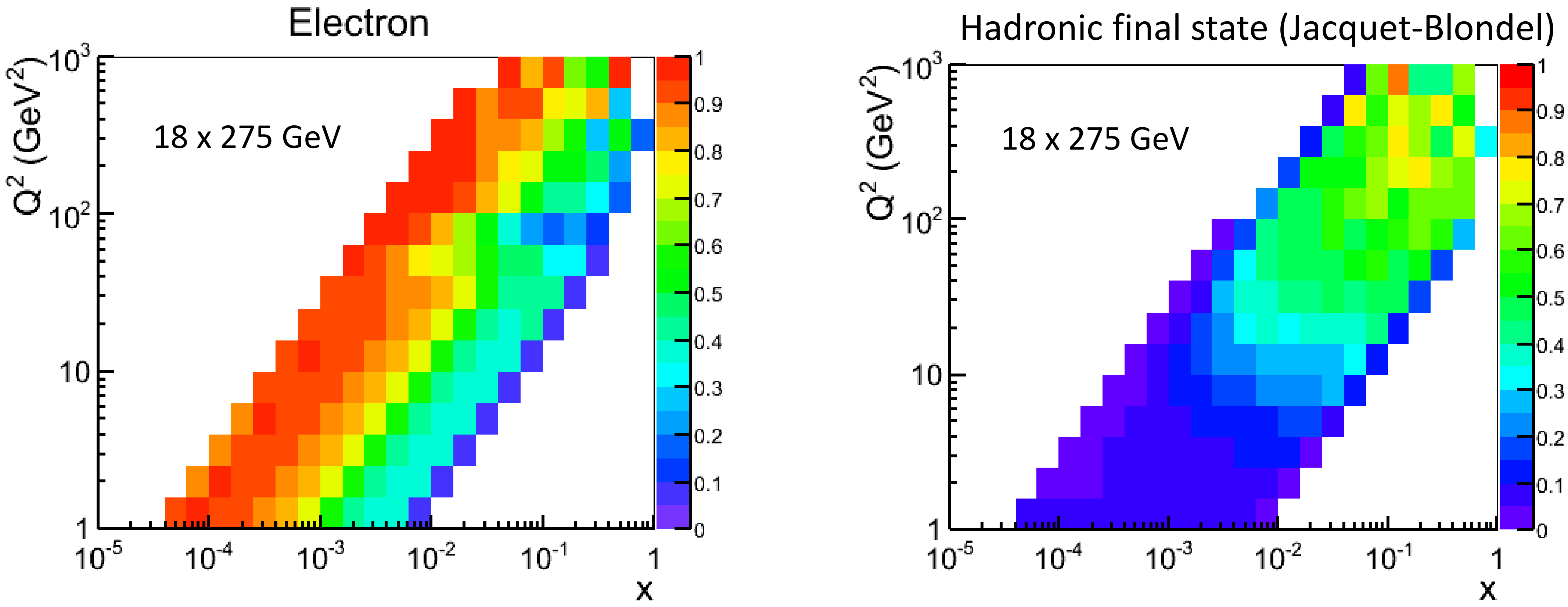


Very little x-Q^2 coverage reduction if poor electron ID at E_e<2 GeV



x, Q^2 resolution: Hadronic reconstruction method

Fraction of events reconstructed in correct x, Q^2 bin

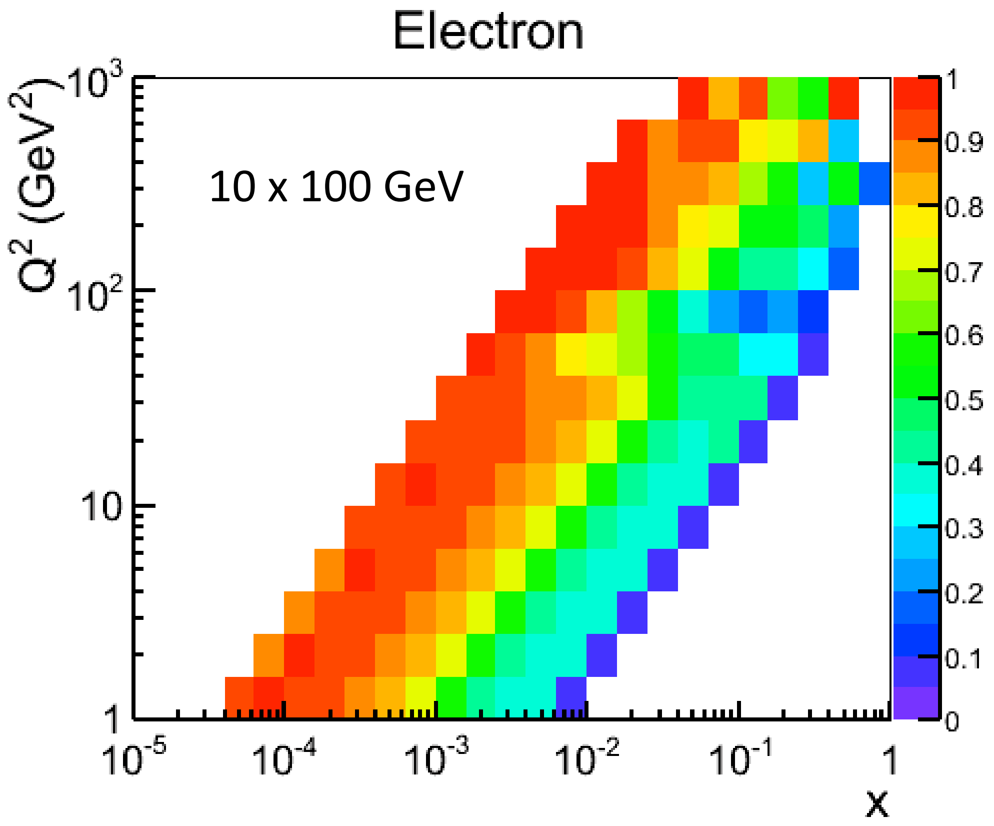


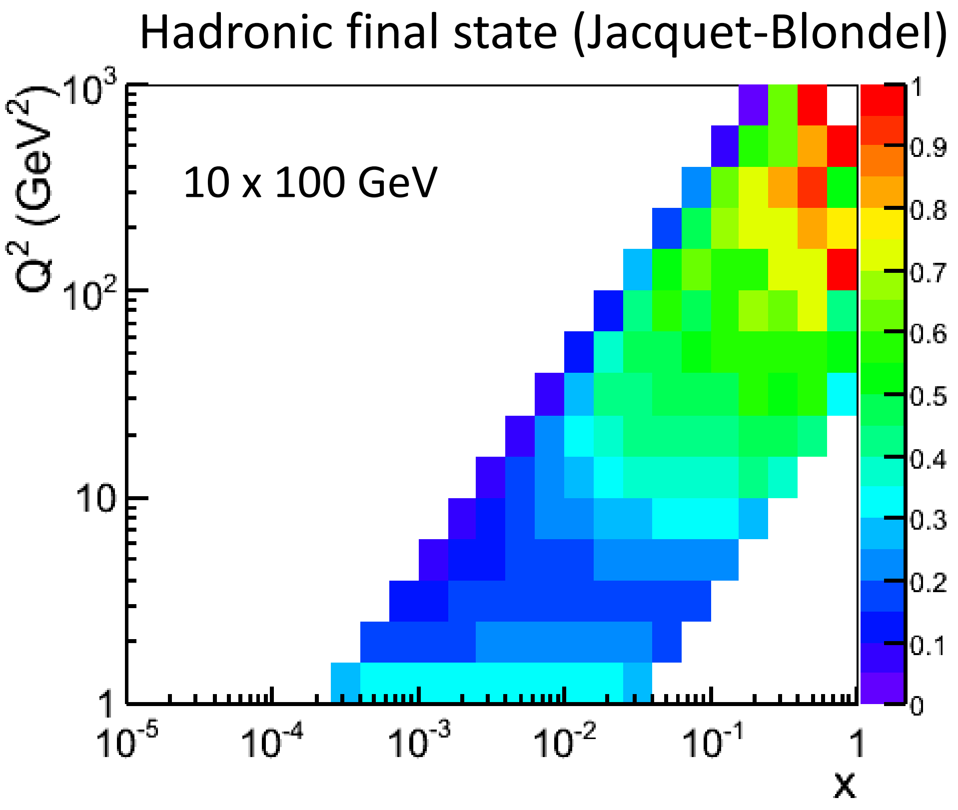
Jacquet-Blondel kinematics reconstruction from hadronic activity:

$$y_{JB} = \frac{\Sigma(E_i - p_{z,i})}{2E_e} \qquad Q^2_{JB} = \frac{\Sigma p^2_{T,i}}{1 - y_{JB}} \qquad x_{JB} = \frac{Q^2_{JB}}{y_{JB}s}$$

x, Q^2 resolution: Hadronic reconstruction method

Fraction of events reconstructed in correct x, Q^2 bin





Hadronic method provides complementarity at large Q^2—improves with Q^2 as more final-state particles are scattered into the detector.

Electron-photon cluster separation for DVCS