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Requirements from EIC forward heavy flavor studies

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Outline

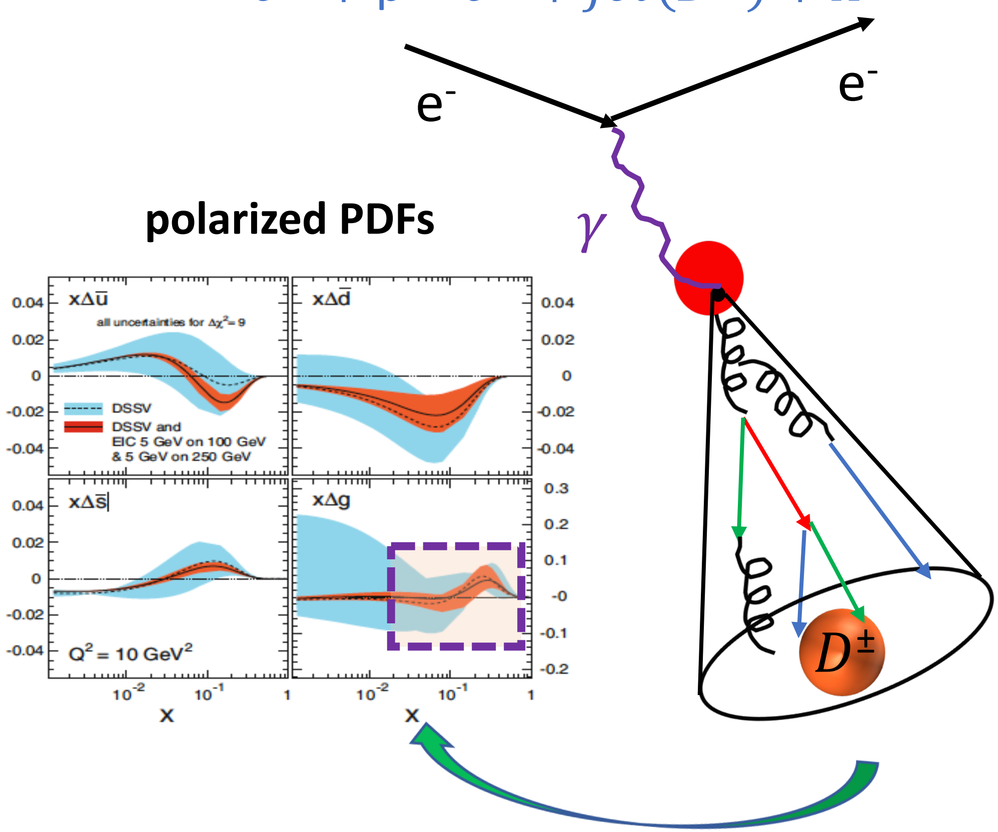
- Motivation
- EIC Heavy flavor studies in simulation
  - Implemented forward silicon tracker detector designs.
  - Heavy Flavor hadron reconstruction in different kinematic regions.
  - Projections on physics observables.
- Detector requirements.
- Summary and Outlook.

EIC golden channels: heavy flavor and jet probes (I)

- Through measuring heavy flavor hadrons, jets which can be treated as surrogates of initial quarks/gluons and their correlations in the hadron/nuclei going (forward) direction at the EIC.

arXiv:1610.08536 Phys. Rev. D 96, 114005 (2017)

$$e^- + \mathrm{p} \rightarrow e^- + jet(D^{\pm}) + X$$



- To precisely determine the initial quark/gluon distribution functions in the poorly constrained kinematic region (x_{BJ}>0.1).
- To precisely study the quark/gluon fragmentation and hadronization processes.
- To provide further information on the gluon Sivers function and other spin observables.

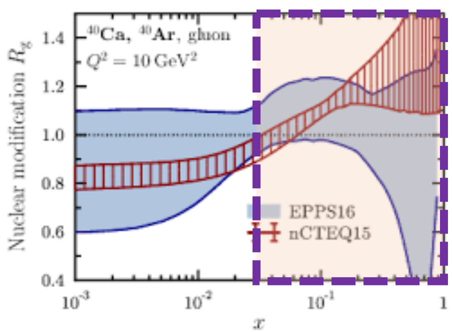
EIC golden channels: heavy flavor and jet probes (II)

- Measurement of heavy flavor hadrons, jets which can be treated as surrogates of initial quarks/gluons and their correlations in the hadron/nuclei going (forward) direction at the EIC.

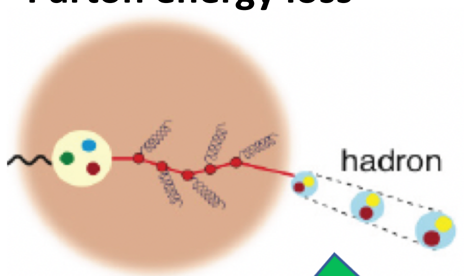
arXiv:1610.08536 Phys. Rev. D 96, 114005 (2017)

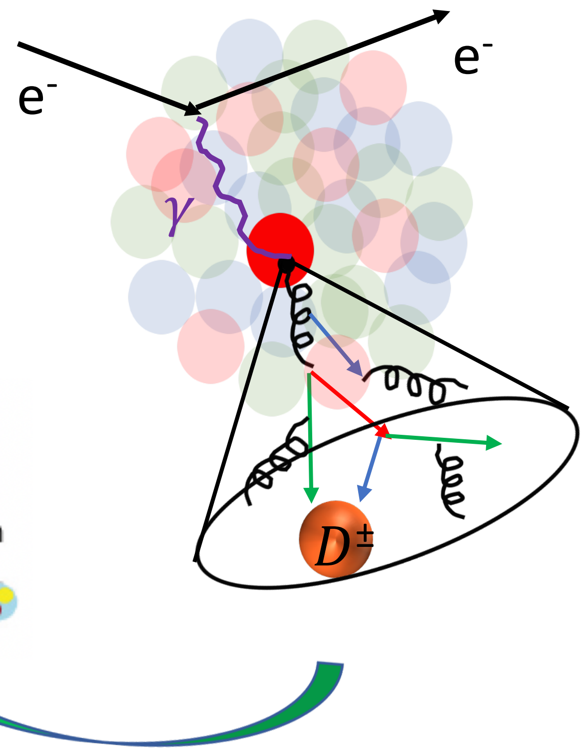
arXiv:2002.05880 $e^- + \mathrm{Au} \rightarrow e^- + jet(D^\pm) + X$

nPDF modification



Parton energy loss



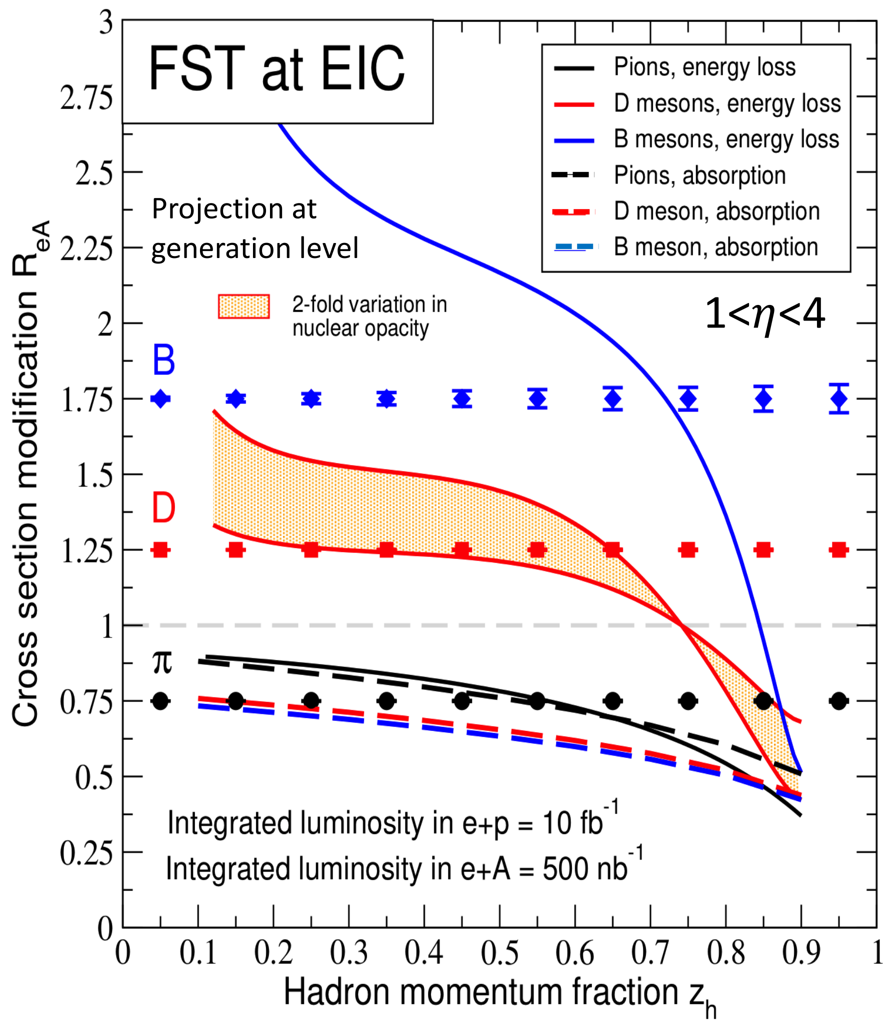


- To understand the nuclear medium effects on hadron production such as modification on nuclear PDFs, parton energy loss mechanisms and hadronization processes through the comparison of measured heavy flavor hadron/jet cross section between e+p and e+A collisions.

Key EIC physics observables are under study

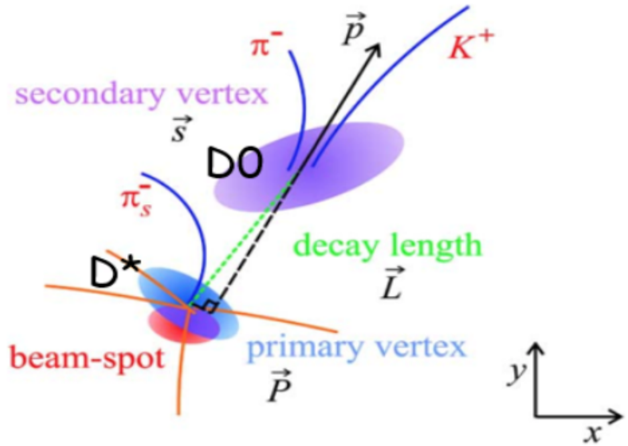
- Competing models of nuclear modification in DIS reactions with nuclei (e.g HERMES data). Differentiation not possible with light hadrons.
  - Hadronization inside nuclear matter (dashed lines).
  - Energy loss of partons, hadronization outside the medium (solid lines).
- Heavy mesons have very different fragmentation functions and formation times
  - Easy to discriminate between larger suppression for D/B mesons (in-medium hadronization) and strong/intermediate z enhancement (E-loss).
  - Enhanced sensitivity to the transport properties of nuclei.

EPJ Web of Conferences **235**, 04002 (2020)



Critical detector to realize heavy flavor measurements

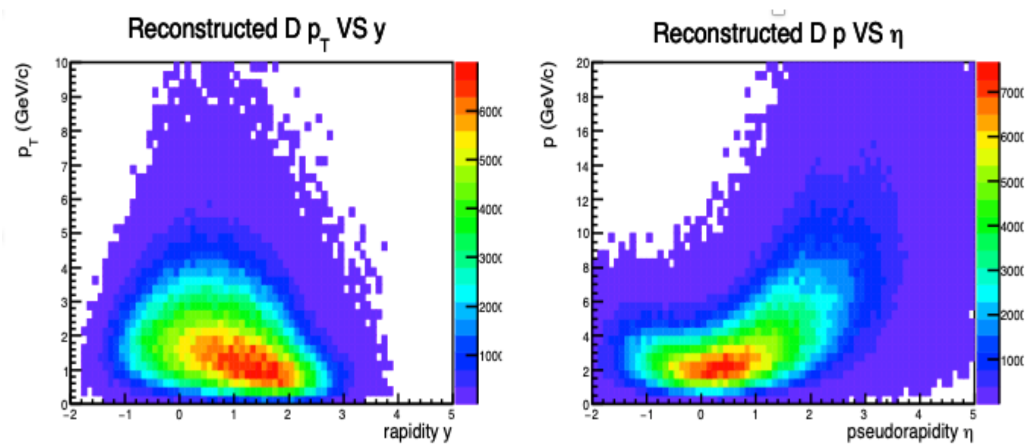
- Heavy flavor products can be measured by detectors based on their unique lifetime and masses.



Particle	Mass (GeV/c²)	$c\tau$ decay length
$D^{\pm}$	1.869	312 micron
D^0	1.864	123 micron
$B^{\pm}$	5.279	491 micron
B^0	5.280	456 micron

- Due to asymmetric collisions at the EIC, heavy flavor hadrons (e.g. D-meons) are produced more in the forward rapidity region compared to the backward region.

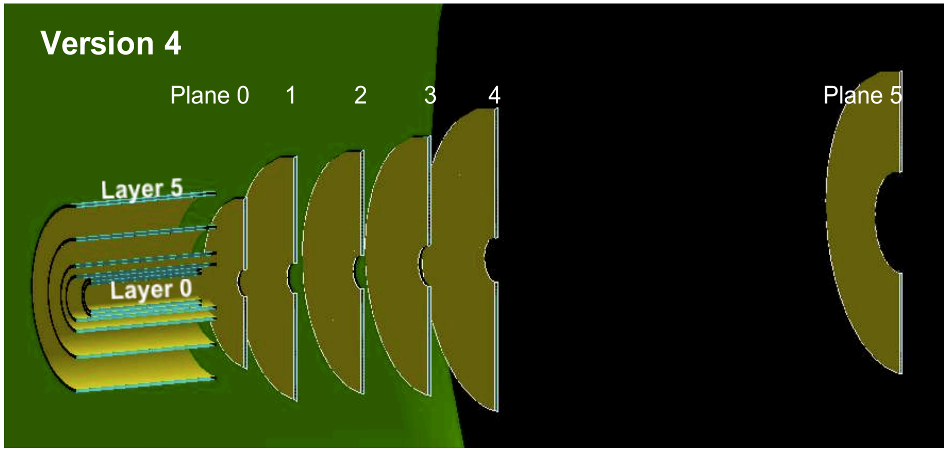
In 10 GeV electron and 100 GeV proton collisions



Silicon vertex/tracking detector is essential for EIC heavy flavor measurements

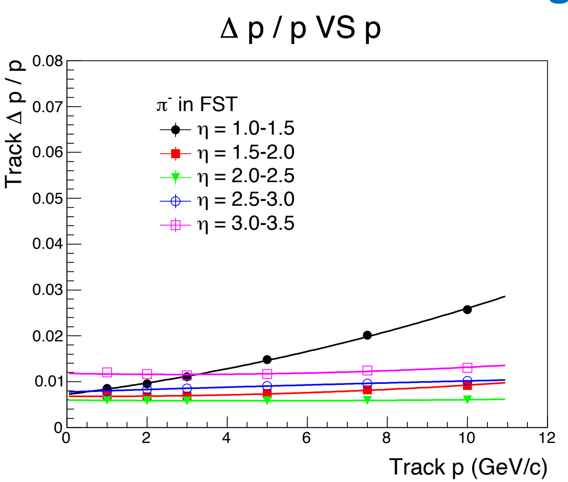
Talk by Astrid, more details in the LANL technical note.

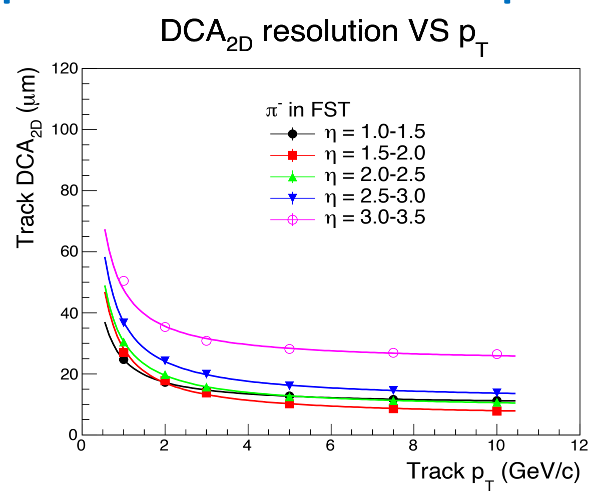
Forward Silicon Tracker design version 4

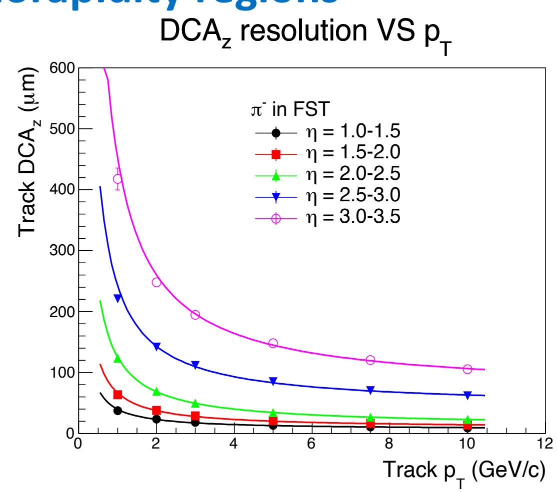


- One version of the Forward Silicon Tracker (FST) configuration:
  - Beast magnetic field peaked at 3T.
  - Barrel layer 0-5 silicon sensor thickness: 50 μm.
  - Forward plane 0-2 silicon sensor thickness: 50 μm, plane 3-5 silicon sensor thickness: 100 μm.
  - Barrel layer pixel pitch: 20 μm and forward plane pixel pitch: 20 μm.

Evaluated tracking performance in different pseudorapidity regions



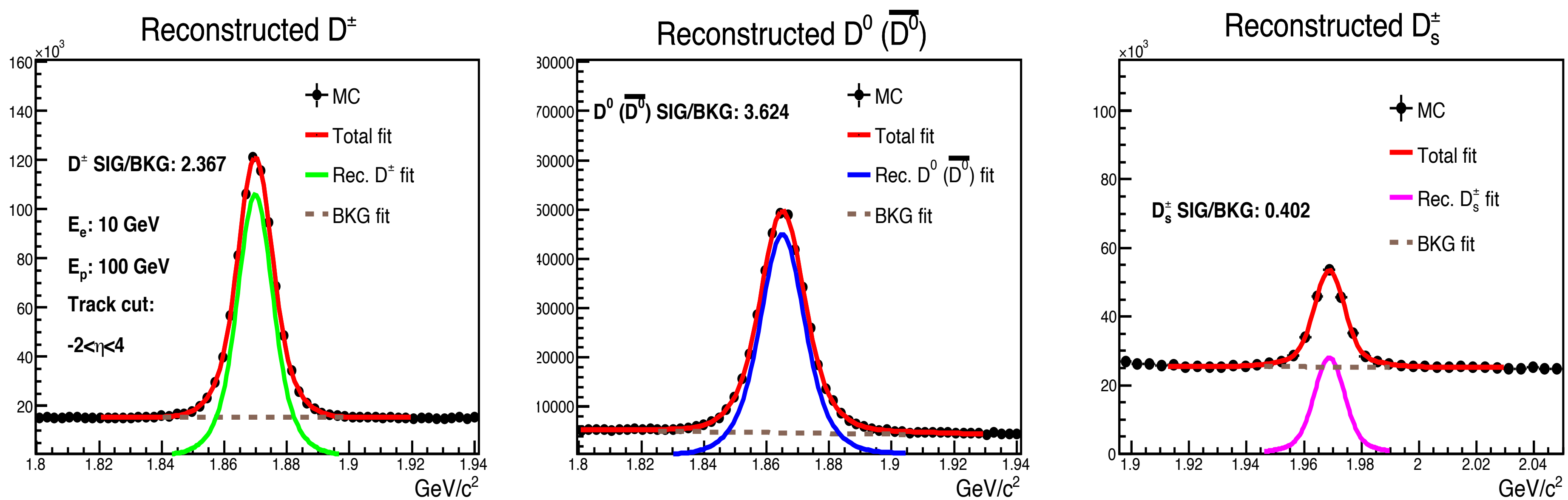




- These tracking performances are implemented in the heavy flavor reconstruction studies.

heavy flavor hadron reconstruction: D-mesons

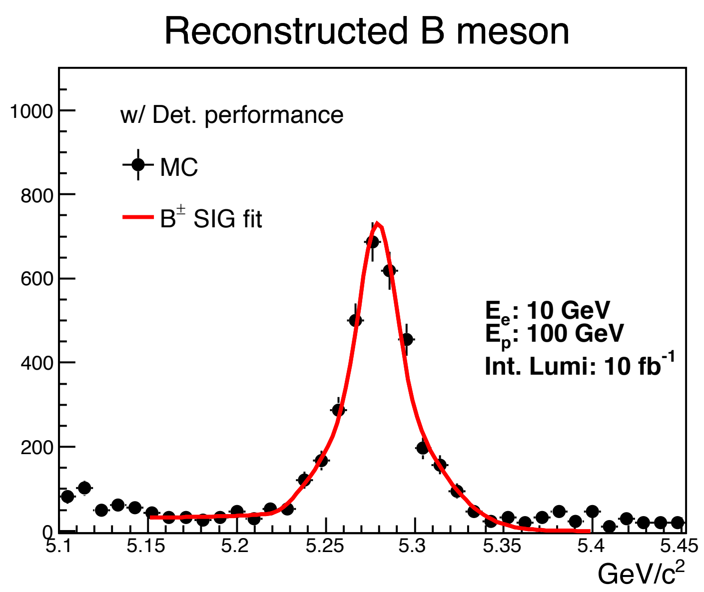
- In 10 GeV electron and 100 GeV proton collisions with 10 fb^{-1} integrated luminosity.
- Additional detector performance:
  - Primary vertex resolution: 20-35 (μm) depends on the track multiplicity.
  - 95% K/π/p separation over all the acceptance.
  - Charged track matching within a decay length (DCA) window (~100 μm).

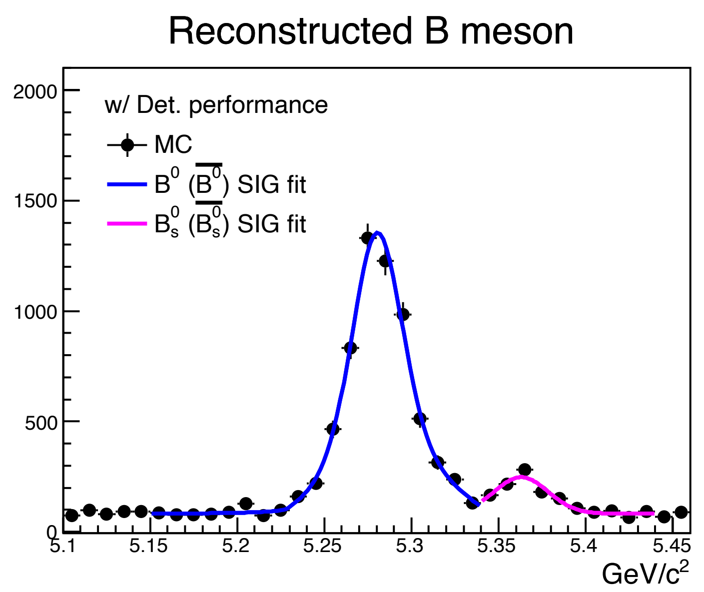


- Good signal over background ratios for reconstructed inclusive D-mesons in -2<η<4 region.

heavy flavor hadron reconstruction: B-mesons

- In 10 GeV electron and 100 GeV proton collisions with 10 fb^{-1} integrated luminosity.
- Additional detector performance:
  - Primary vertex resolution: 20-35 (μm) depends on the track multiplicity.
  - 95% K/π/p separation over all the acceptance.
  - Charged track matching within a decay length (DCA) window (~100 μm).

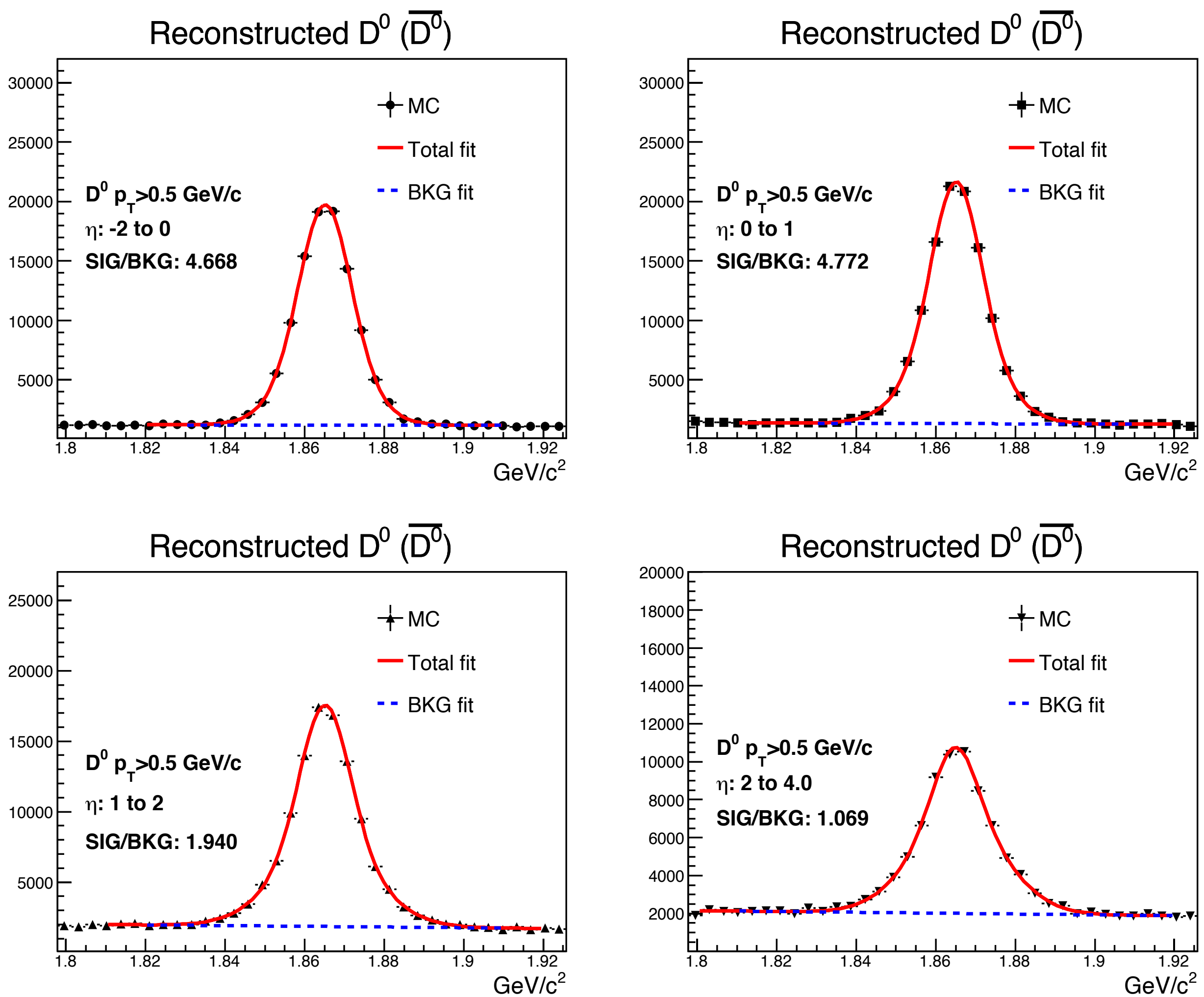




- Clear reconstructed B-meson signals have been found in -2<η<4 region.

Reconstructed D-mesons in different η regions

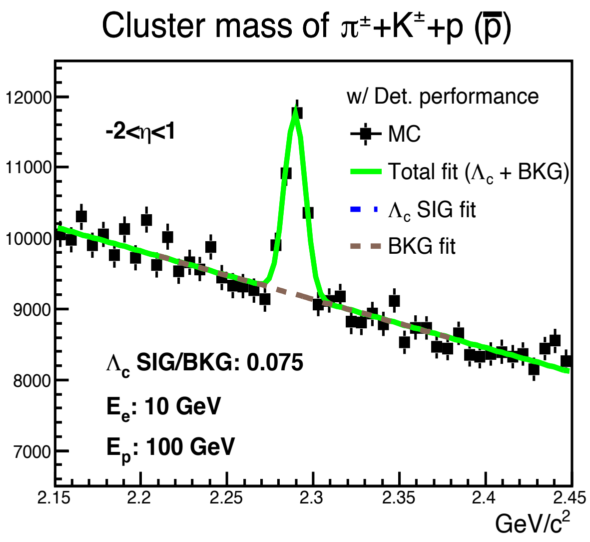
- Reconstructed D^0 within different pseudorapidity regions in 10 GeV electron and 100 GeV proton collisions with 10 fb^{-1} integrated luminosity.

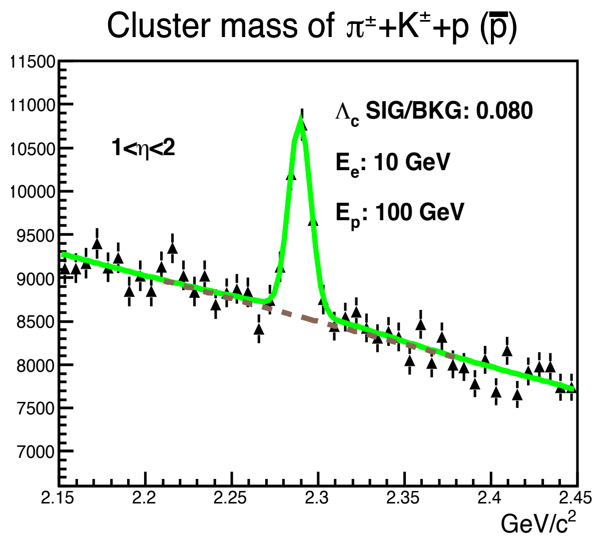


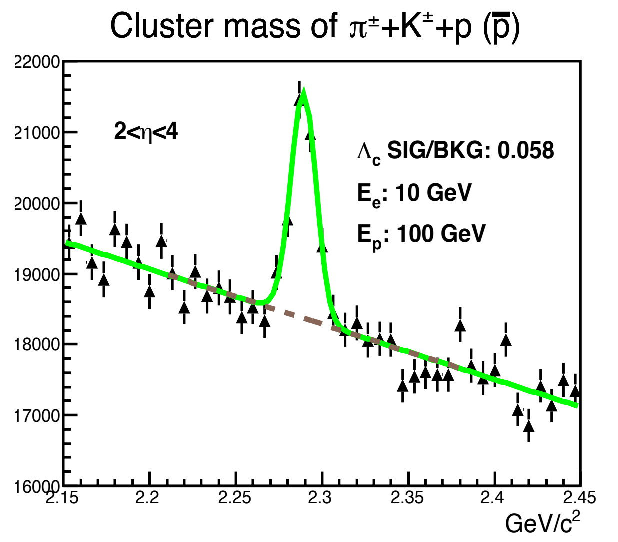
- Good signal over background ratio for all η region.
- Smaller signal over background ratio in the forward region is due to the rapidity dependent tracking performance.

heavy flavor hadron reconstruction: charm baryons

- Heavy flavor reconstruction has been expanded to charm baryons.
- Reconstructed Λ_c within different pseudorapidity regions in 10 GeV electron and 100 GeV proton collisions with 10 fb^{-1} integrated luminosity.



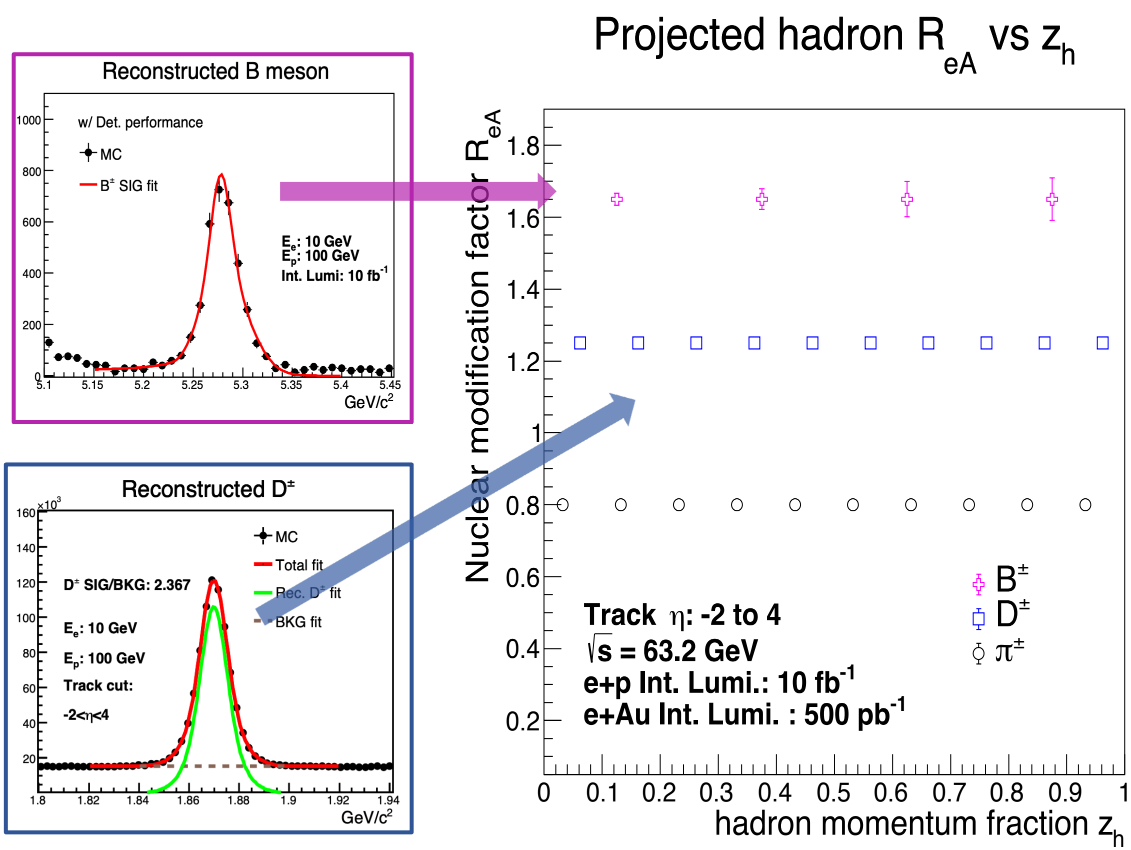




- Clear Λ_c signals have been found in all $\boldsymbol{\eta}$ regions with a smaller signal over background ratio in the forward region.

Physics observables to explore hadronization in medium: nuclear modification factor R_{eA}

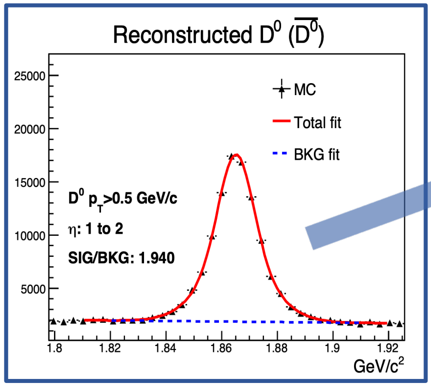
- Good statistical precision have been achieved for flavor dependent reconstructed hadron R_{eA} measurements at the EIC with the help of silicon vertex/tracking detector.

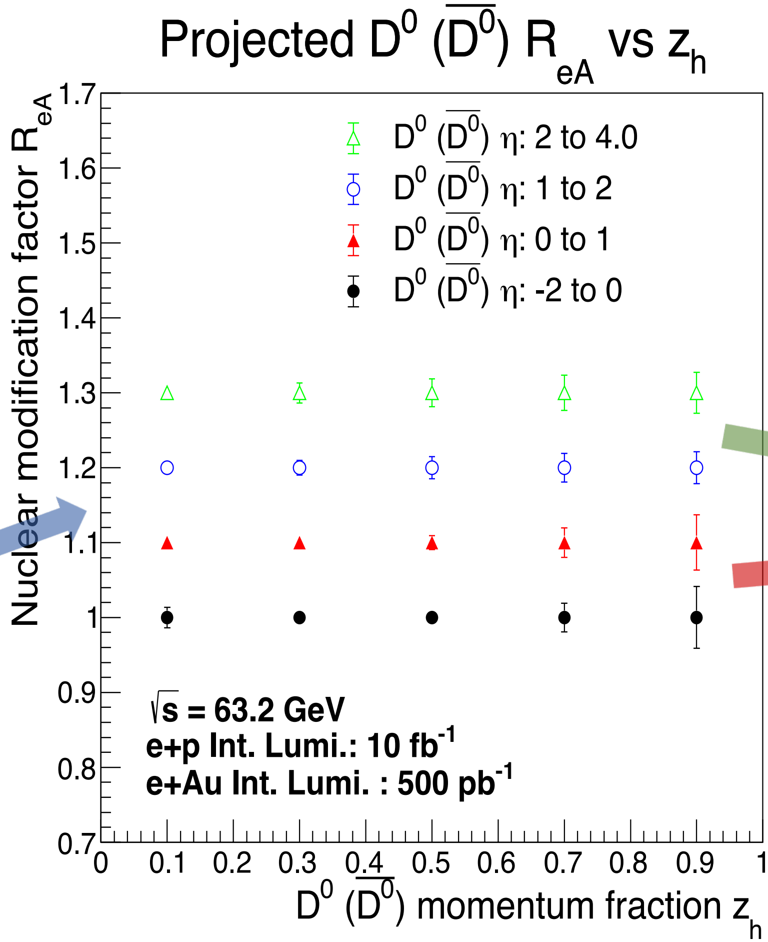


- EIC heavy flavor measurements will
  - explore the hadronization in medium with better precision.
  - provide strong discriminating power to separate different model calculations for nuclear transport coefficients.

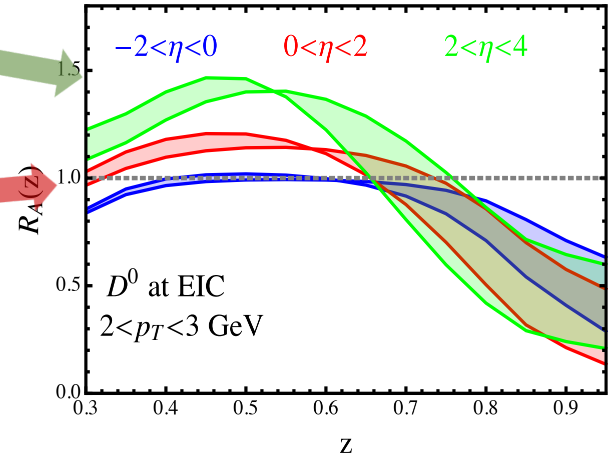
Projected open charm R_{eA} in different η regions

Reconstructed D^0
In $1<\eta<2$





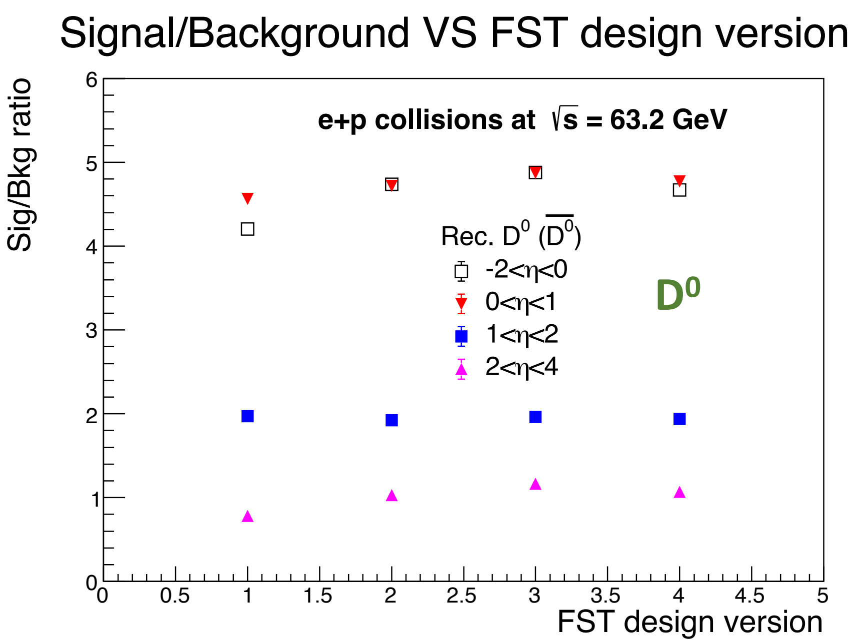
HF tomography in EIC
arXiv: 2007.10994
NLO calculation with the parton energy loss approach

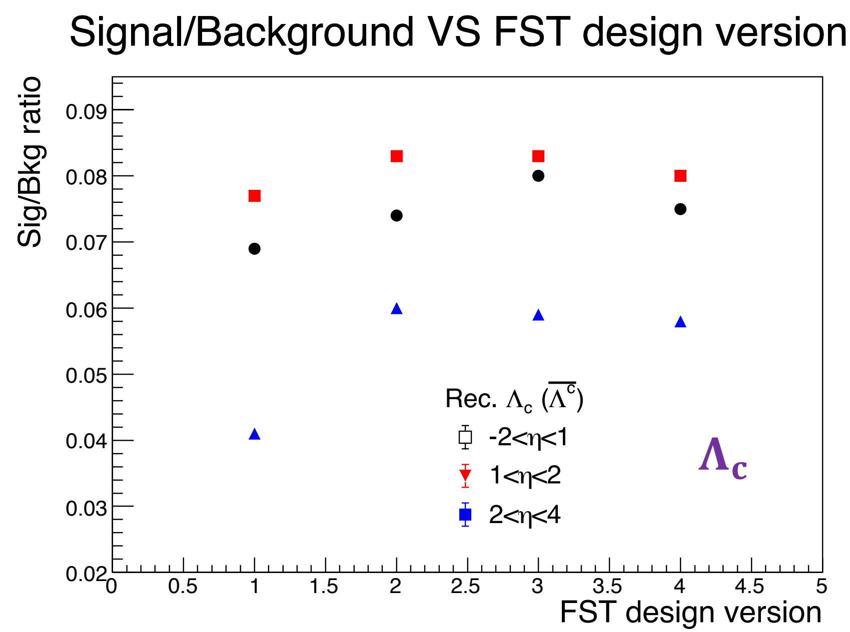


- Pseudorapidity dependent especially forward D-meson R_{eA} measurements can provide better constraints on theoretical calculations for hadronization within nuclear medium.

Dependence on detector performance for reconstructed heavy flavor hadrons

- Signal over background ratios for reconstructed heavy flavor hadrons in 10 fb^{-1} e+p collisions at $\sqrt{s}$ = 63 GeV with different silicon vertex/tracking detector designs and magnetic field maps (see details in the [LANL EIC technical note]()).





- Provide guidance for detector design optimization and silicon technology down selection.

Detector requirements for EIC heavy flavor studies

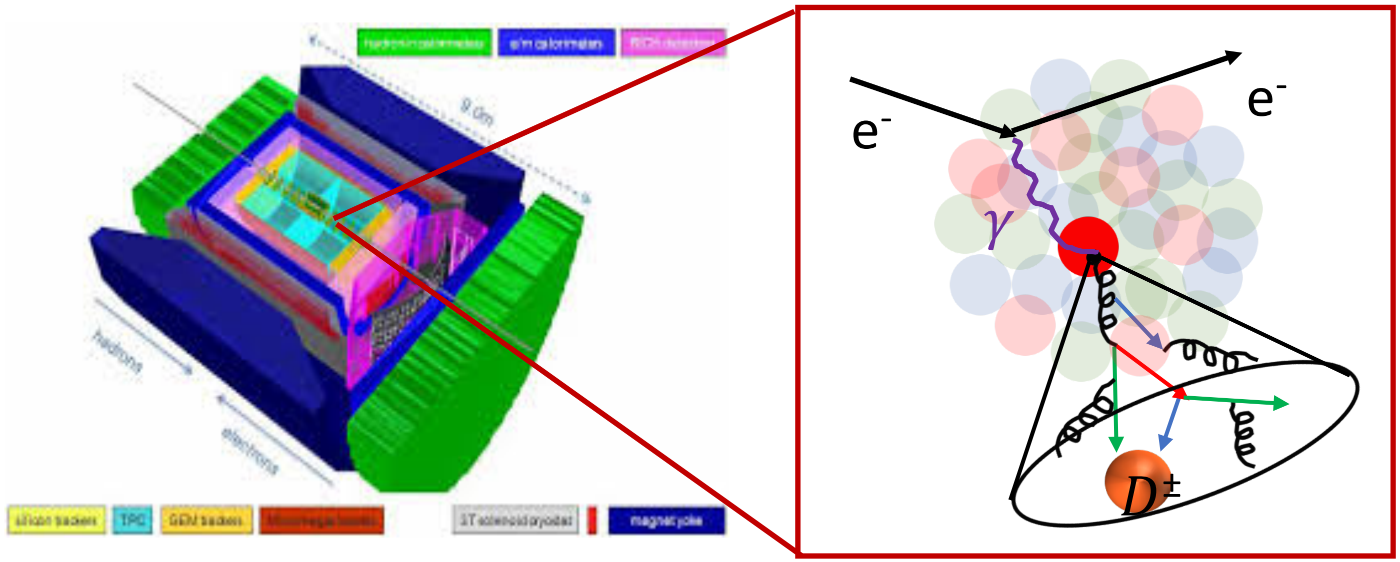
- Fully reconstructed heavy flavor hadrons rely on both the track momentum and primary/decay vertex (DCA) resolutions. Better tracking momentum resolution is related with the magnetic field – Beast magnet.
- Tracking can be improved by going to a lower proton/nuclei beam energy, which shifts the particle production towards mid-rapidity.
- Tracking requirement based on Beast magnet for the $DCA_{2D(xy)}$ resolution:
  - $-1<\eta<1$, 20 μm
  - $1<\eta<2$, $30/p_T$ + 20 μm or better
  - $2<\eta<3$, $30/p_T$ + 40 μm or better
  - $3<\eta<3.5$, $30/p_T$ + 60 μm or better
- The PID performance will impact on fully reconstructed heavy flavor hadron as well.

Summary and Outlook

- A series of studies have been carried out for heavy flavor reconstruction and associated physics studies (such as nuclear modification factor measurements).
- Silicon vertex/tracking detector is critical to realize the EIC heavy flavor measurements.
- The workflow has been established from detector R&D, detector/physics simulation to theoretical developments.
- We are open to collaboration to realize the silicon vertex/tracking detector sub-system for the EIC.

Workshop announcement

CFNS workshop: Opportunities with Heavy Flavor at the EIC, Nov 4-6, 2020. Online

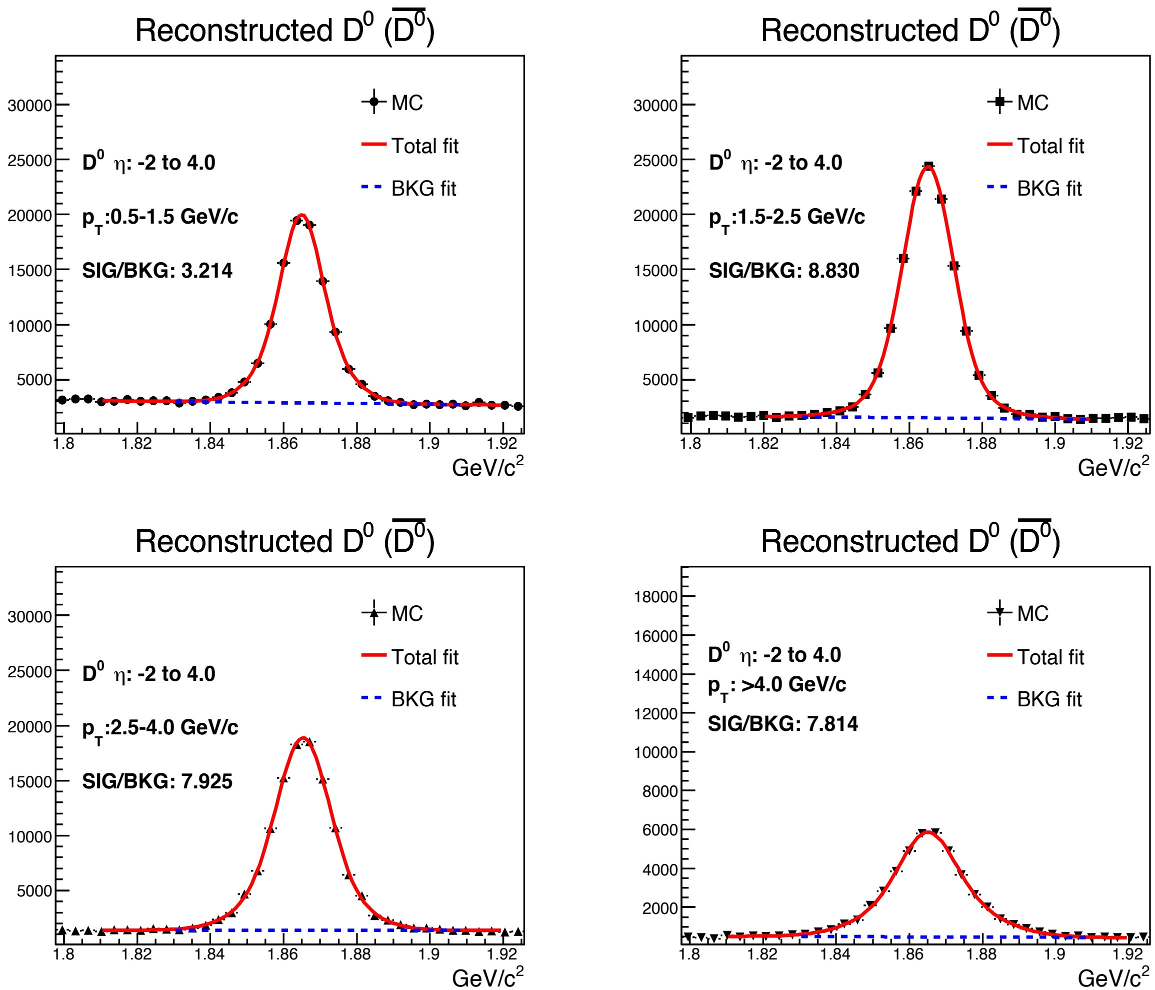


- Organizers: Ivan Vitev (LANL), Fred Olness (SMU), Christian Weiss (Jlab), Jin Huang (BNL), Xuan Li (LANL)
- Website is under setting up and phone bridge connection will be provided.
- We will send the official announcement shortly.

Backup

Reconstructed D-mesons in different p_T regions

- Reconstructed D^0 within different pseudorapidity regions in 10 GeV electron and 100 GeV proton collisions with 10 fb^{-1} integrated luminosity.



- Good signal over background ratio for all p_T region.
- Smaller signal over background ratio in the low p_T region is due to the p_T dependent tracking performance.