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Forward silicon tracking studies for the EIC Yellow Report preparation

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Outline

- Motivation.
- New EIC science portfolio with the heavy flavor and jet program.
- Simulation studies for a proposed forward silicon tracking detector.
- Silicon sensor candidates and relevant R&D.
- Conclusions and Outlook

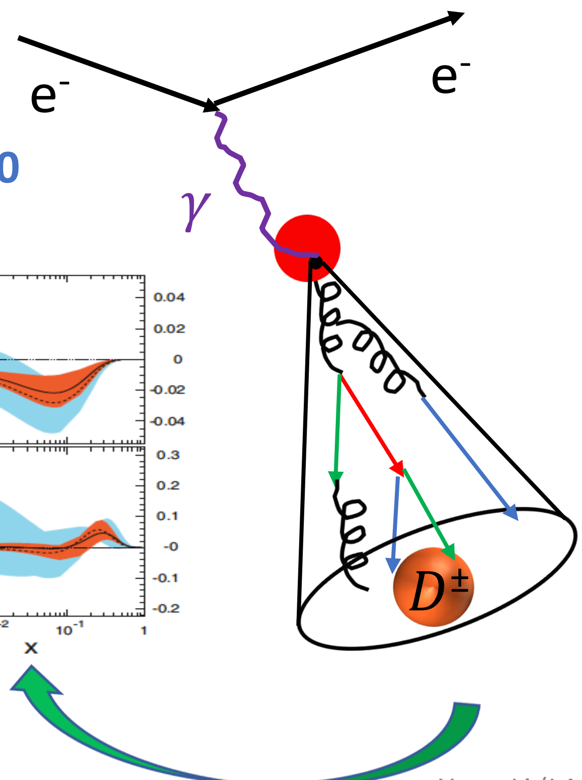
EIC heavy flavor and jet study goals by LANL (I)

- 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.

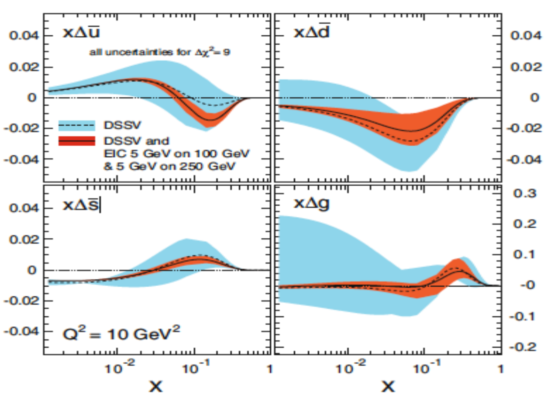
arXiv:1610.08536

Phys. Rev. D 96, 114005 (2017)

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



arXiv:2002.05880



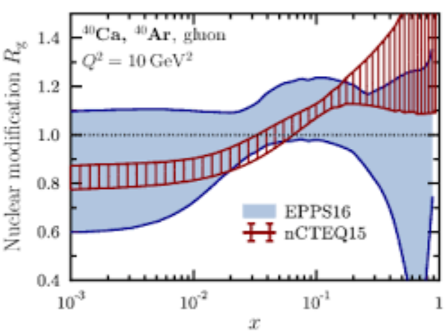
- To precisely determine the initial quark/gluon distribution functions in the poorly constrained kinematic region.
- To precisely study the quark/gluon fragmentation/hadronization processes.
- To provide further information on the gluon Sivers function and other spin observables.

EIC heavy flavor and jet study goals by LANL (II)

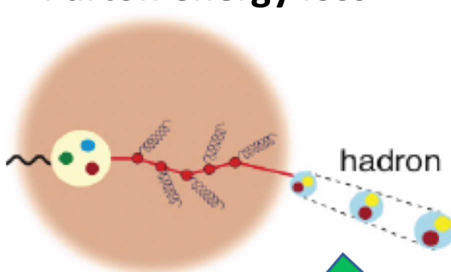
- Through measuring heavy flavor hadrons, jets which can be treated as surrogates of initial quarks/gluons and their correlations in the hadron/nuclei going (forward) direction at the EIC.

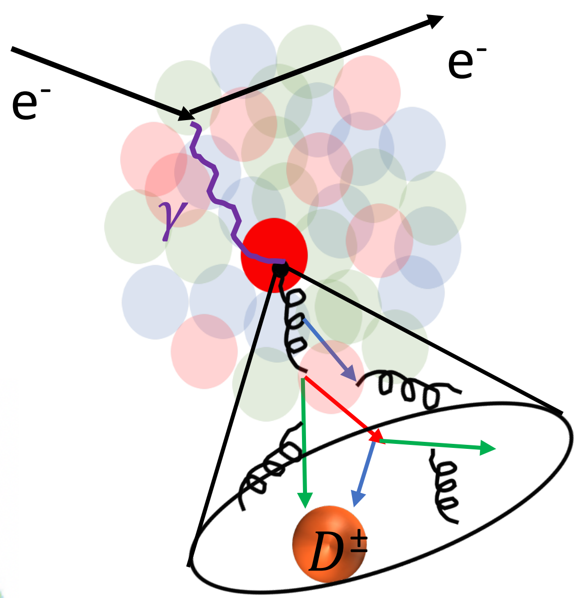
arXiv:2002.05880 $e^- + \mathrm{Au} \rightarrow e^- + jet(D^{\pm}) + X$

nPDF modification



Parton energy loss

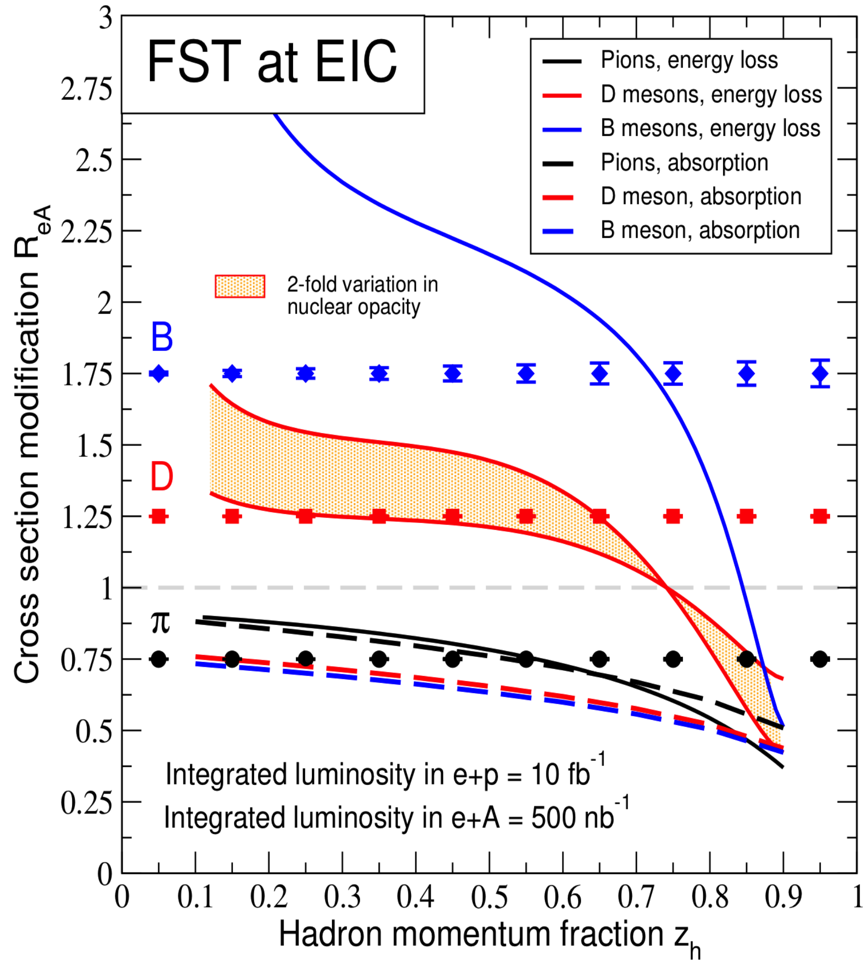




- To understand the nuclear medium effects on hadron production such as modification on nuclear PDFs, parton energy loss mechanisms and hadronization processes through the comparison of measured hadron/jet cross section between e+p and e+A collisions.

New EIC physics observables are under study

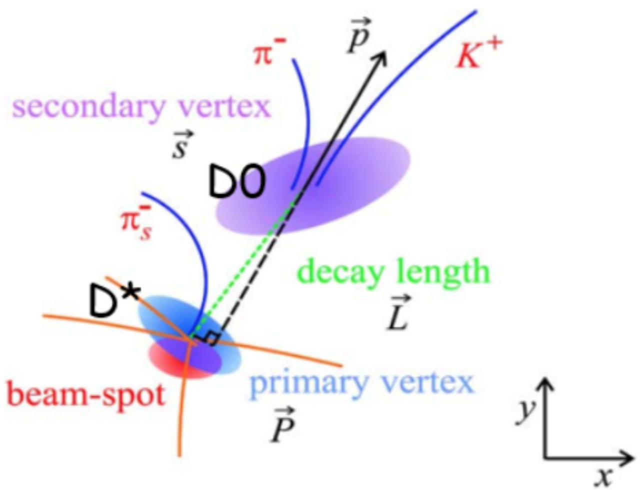
- Competing models of nuclear modification in DIS reactions with nuclei (e.g HERMES data). Differentiation not possible with light hadrons.
  - Hadronization inside nuclear matter (dashed lines).
  - Energy loss of partons, hadronization outside (solid lines).
- Heavy mesons have very different fragmentation 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.



arXiv:2002.05880

Proposed silicon tracking detector for EIC

- At EIC, hadrons or jets which contain heavy quarks can be measured by detectors based on their unique lifetime and masses.

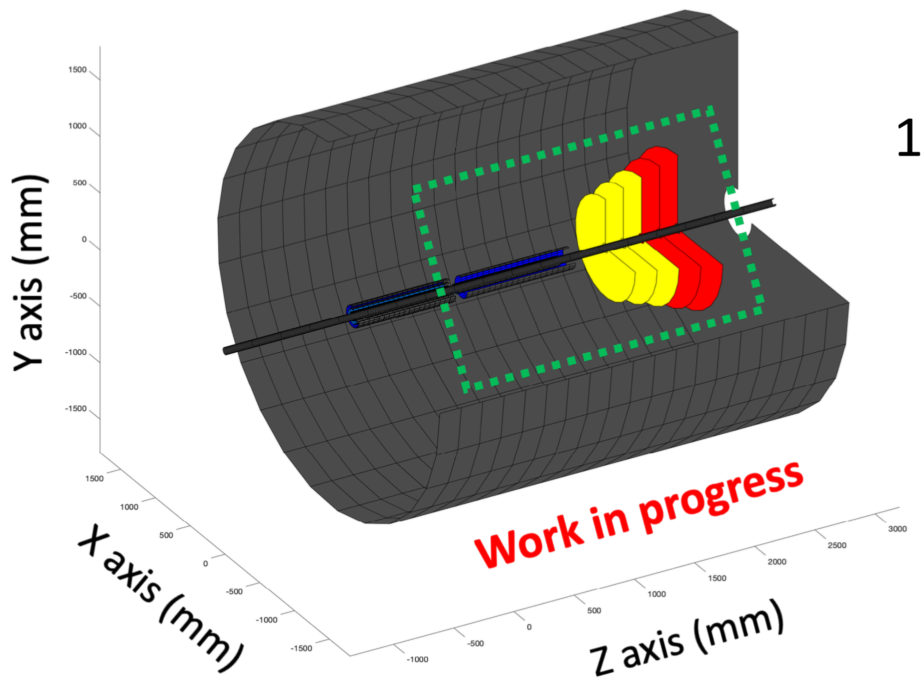


Particle	Mass (GeV/c²)	Average decay length
$D^{\pm}$	1.869	312 micron
D^0	1.864	123 micron
$B^{\pm}$	5.279	491 micron
B^0	5.280	456 micron

- To measure heavy flavor products, jets and their correlations in the hadron/nuclei going (forward) direction at the EIC, a Forward Silicon Tracking (FST) detector is needed.

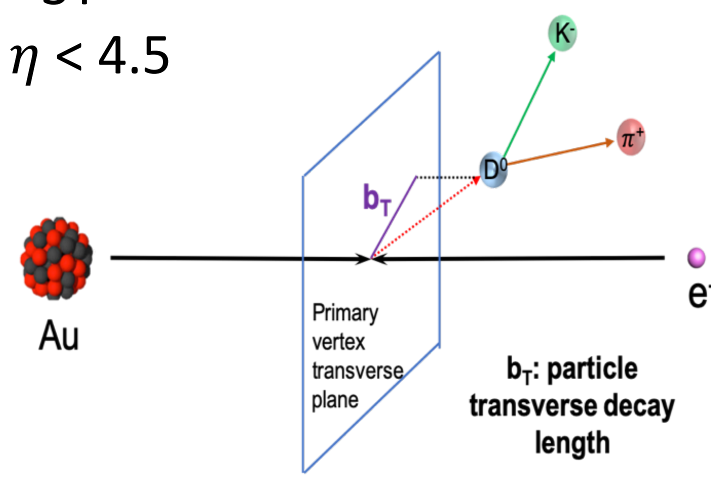
Initial FST design in fast simulation

- Initial detector design in fast simulation (LDT package):
  - Mid-rapidity silicon vertex detector: 3 barrel layers of Monolithic Active Pixel Sensor (MAPS) type detector.
  - Forward-rapidity silicon tracking detector (FST): 2 barrel layers of MAPS + other silicon detector and 5 forward planes of MAPS + other silicon detector.



B = 3T

$1.0 < \eta < 4.5$



arXiv:2002.05880

Initial FST tracking performance in fast simulation

- Initial tracking performance from the FST:

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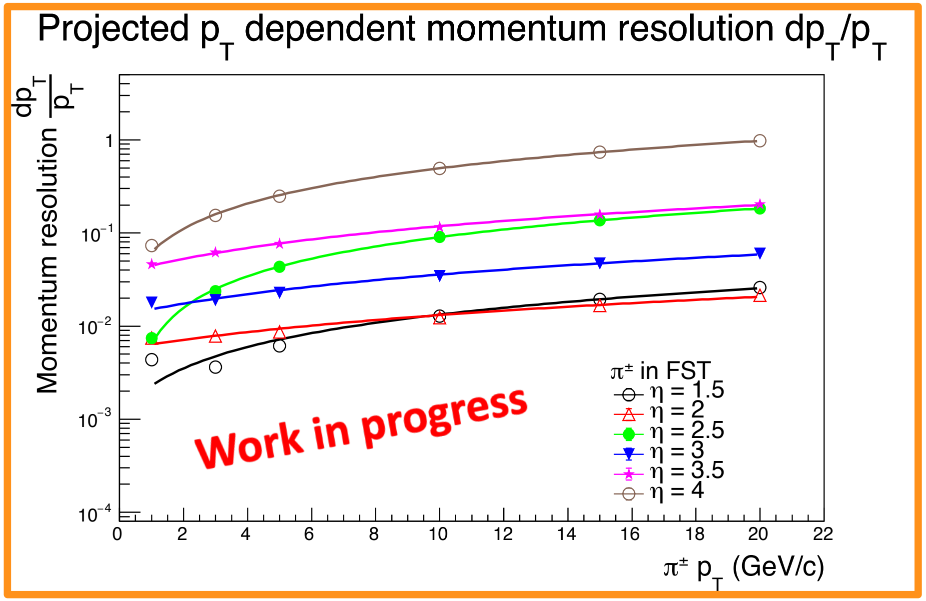
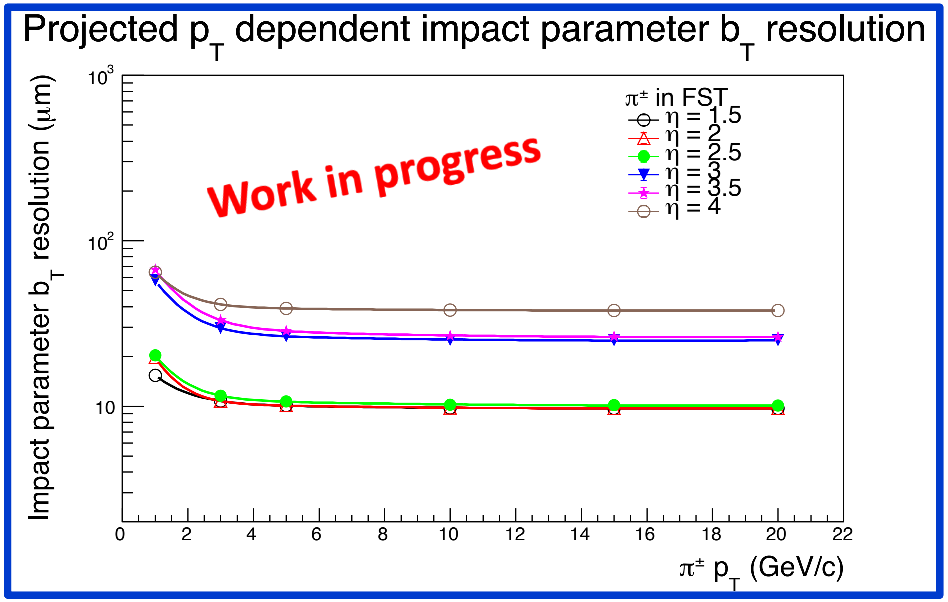


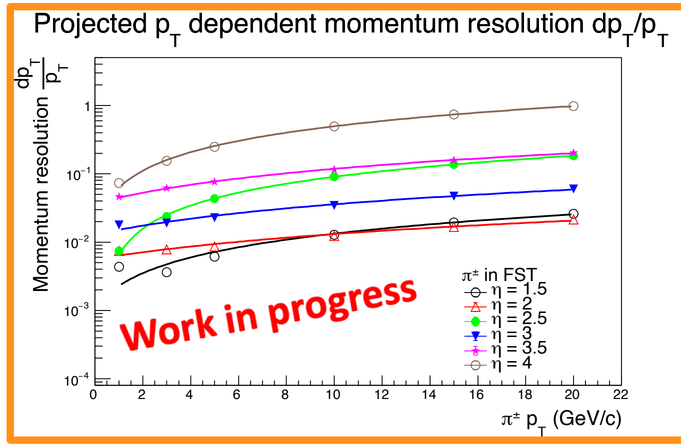


- Better than 70 μm resolution can be achieved by the initial FST design for the transverse decay length b_T measurements for tracks with p_T > 1 GeV/c over the 1.5<η<4.0 region.
- The momentum resolution dp_T/p_T are better than or consistent with the forward tracking requirements from the EIC detector handbook.

Simulation setup

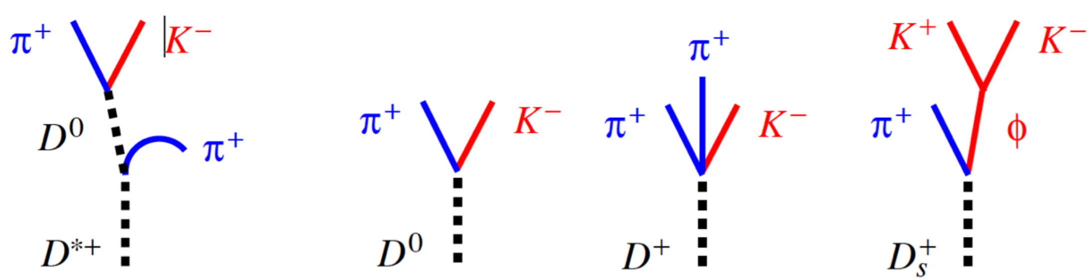
arXiv: 2002.05880

- Initial detector design in fast simulation to evaluate the tracking performance, which will be used for smearing in generated events.



- The full analysis framework which includes the event generation (PYTHIA8), detector response in fast simulation, beam remnant interaction background embedding, and hadron reconstruction have been setup.
- Start with heavy flavor hadron reconstruction:

D-meson decay channels

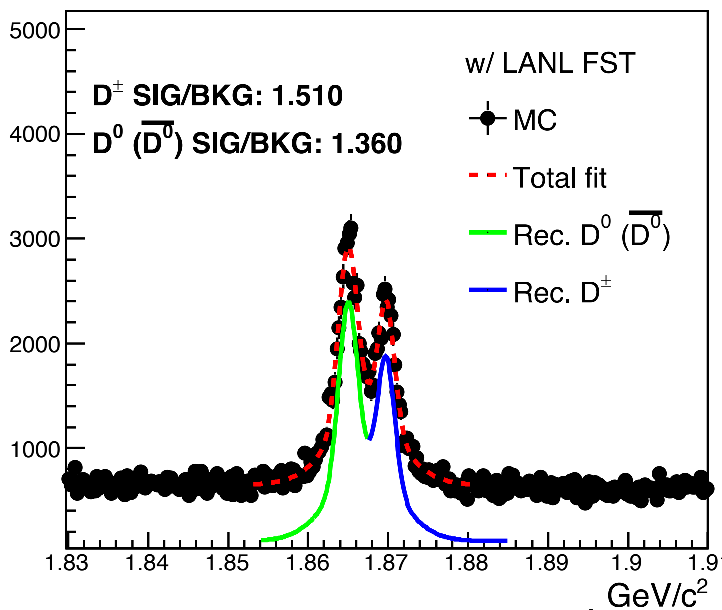


Reconstructed D mesons in PYTHIA8 simulation

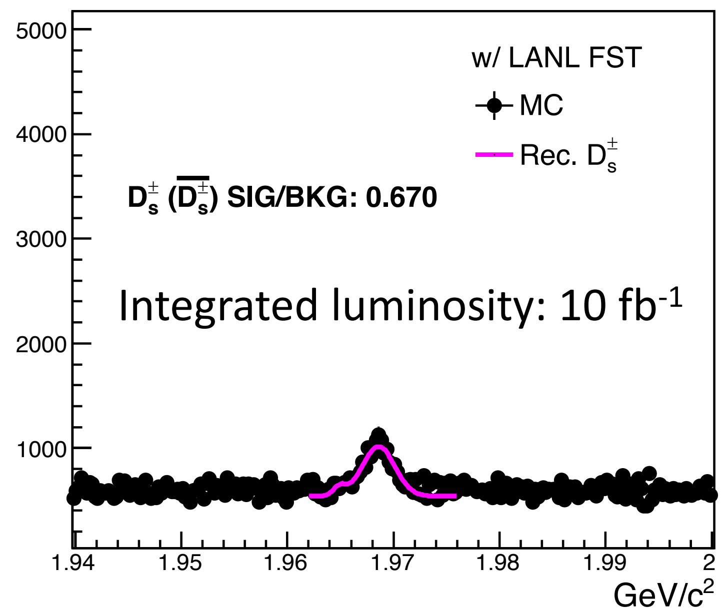
- Mass distributions of clusters with track transverse decay length matching between charged tracks. Clusters are required to have at least one $K^{\pm}$ tracks. The performances are based on K/π separation but no charge separation.
- Detector options: pixel pitch 30 μm, materials per detector layer: $0.4\%X_0$ and the readout rate is at 500 kHZ.

arXiv:2002.05880

Reconstructed cluster mass with $K^{\pm}$



Reconstructed cluster mass with $K^{\pm}$



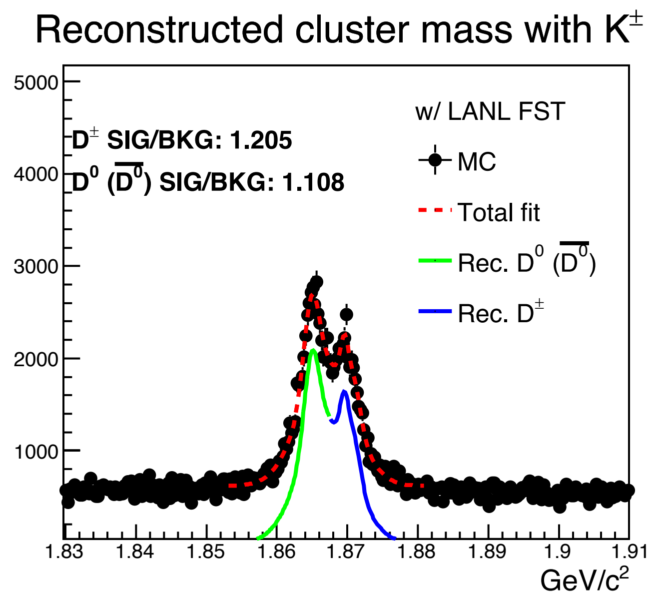
To extract the signal/background ratio for reconstructed D mesons.

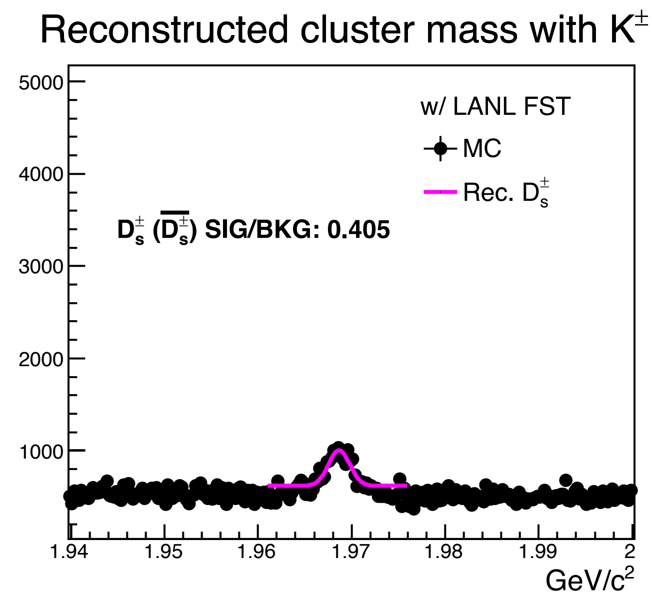
Reconstructed D mesons in PYTHIA8 simulation

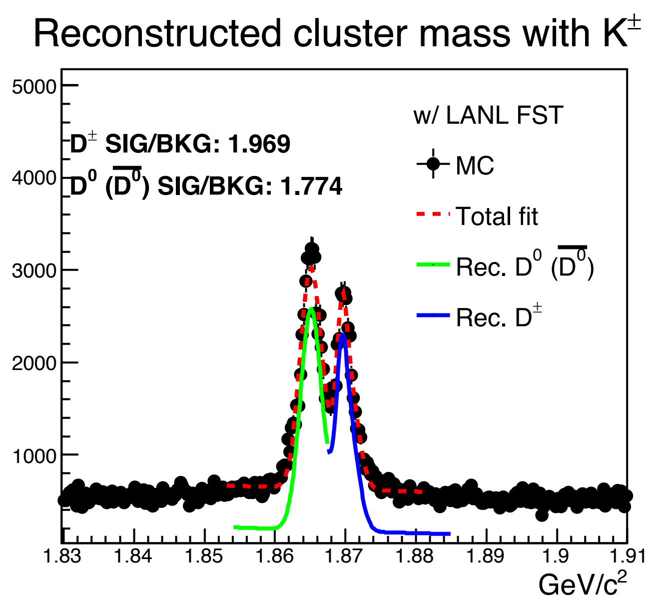
- Pixel size: $(100\ \mu m)^2$

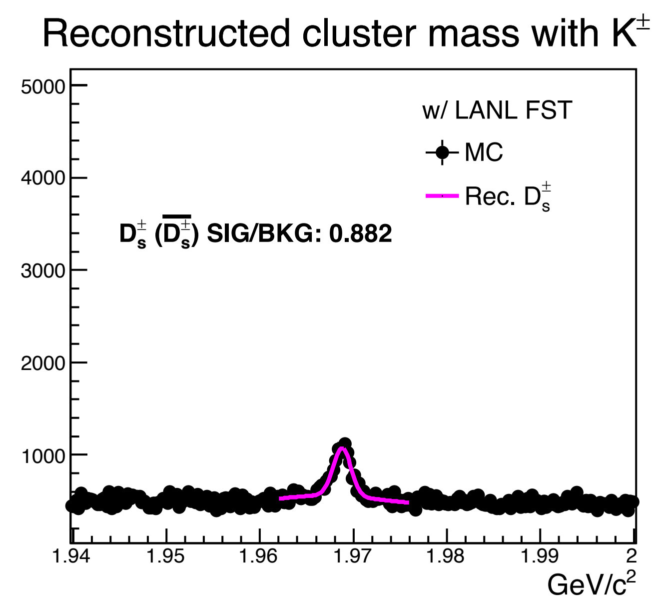
arXiv:2002.05880

- Material budget per layer: $0.3\%X_0$



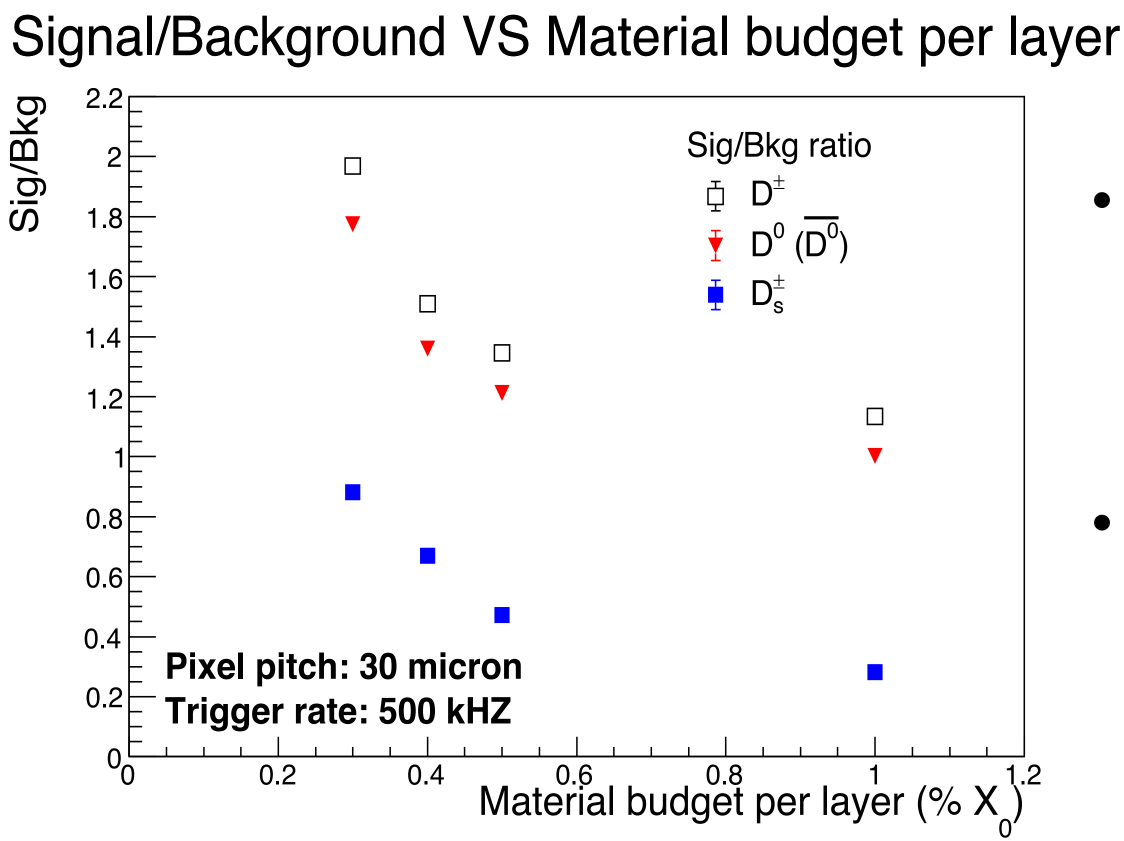






Physics dependence on detector options

- Check the signal/background ratio dependence on material budgets per layer.



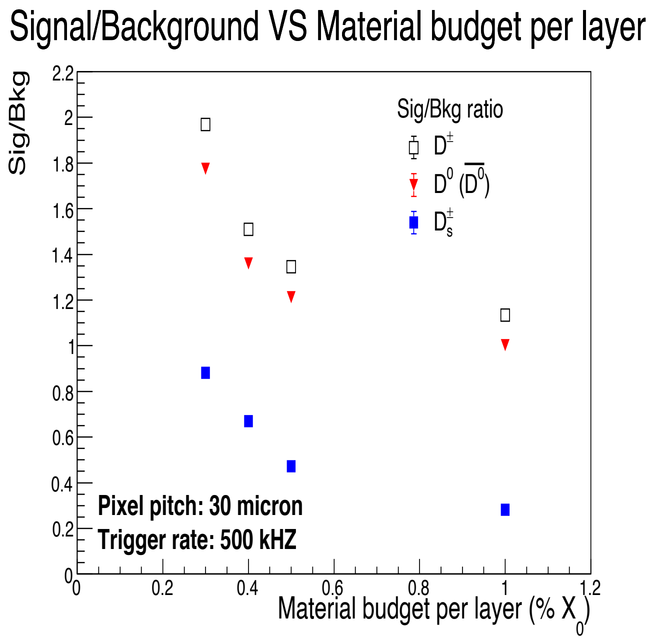
arXiv:2002.05880

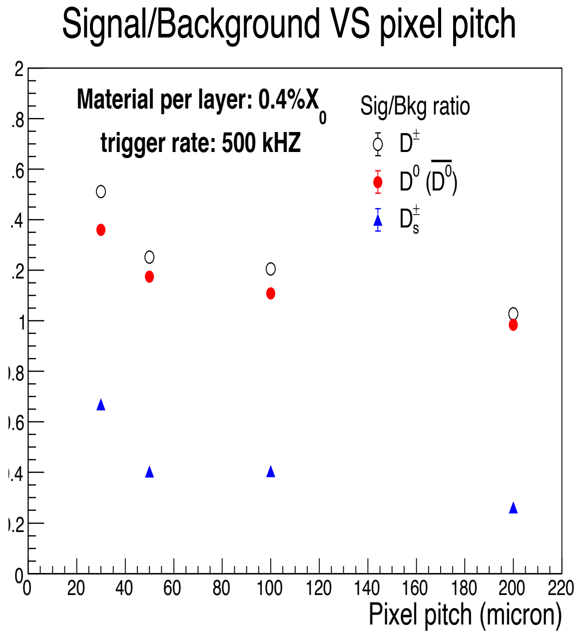
- Clear dependence on the detector material budgets for the D-meson reconstruction.
- Lower material budgets, higher signal over background ratio.

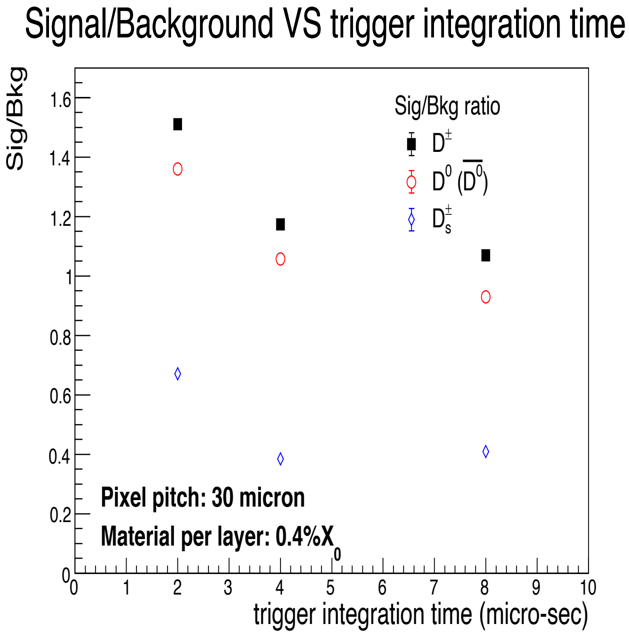
Physics dependence on detector options

- Check the signal/background ratio dependence on the material budgets per layer, pixel pitch and the trigger integration time for the single silicon technique.

arXiv:2002.05880



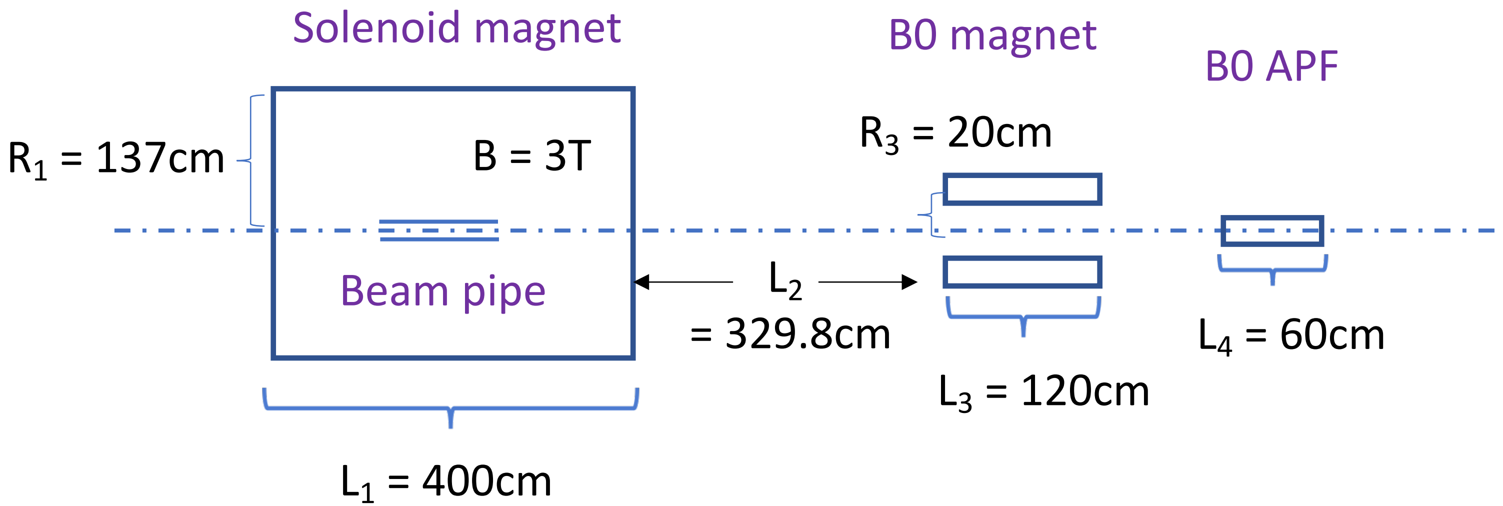




- Scan in a wider detector parameter phase space and work towards a full simulation setup are underway.

Integration requirements for EIC IR

- The EIC IR central+forward region side view:



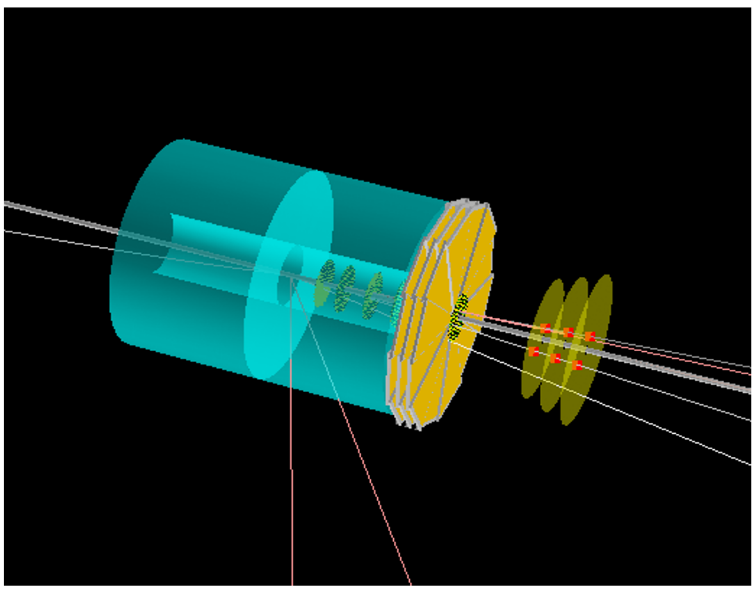
- Special thanks to Yulia Furletova, Alexander Jentsch, Alexander Kiselev, Elke Aschenauer and others for the help.
- We look forward to implement the proposed forward silicon tracking detector in GEANT with the updated IR.

Integration requirements for other sub-systems

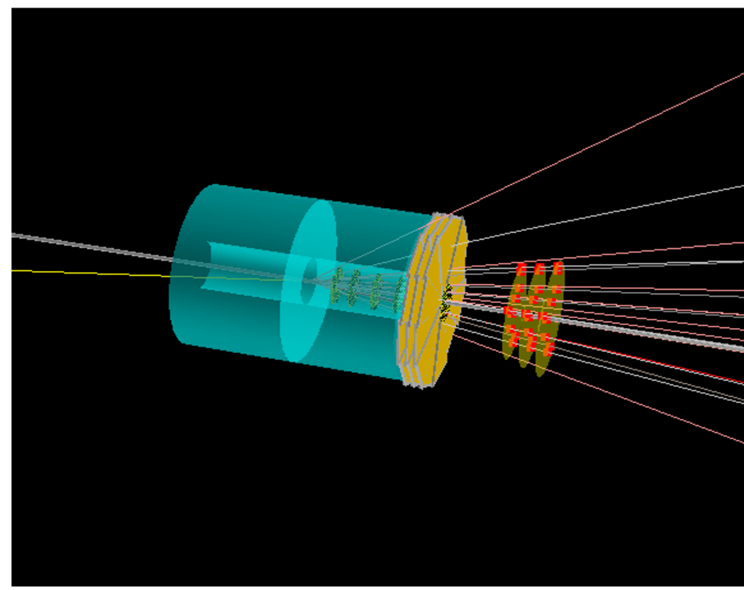
- To evaluate the performance of forward tracking detector in both e+p and e+A collisions, we need some estimated values from other sub-systems such as the PID detector.

Astrid Morreale (LANL)

Event display in e+p collisions (EICROOT)



Event display in e+Cu collisions (EICROOT)



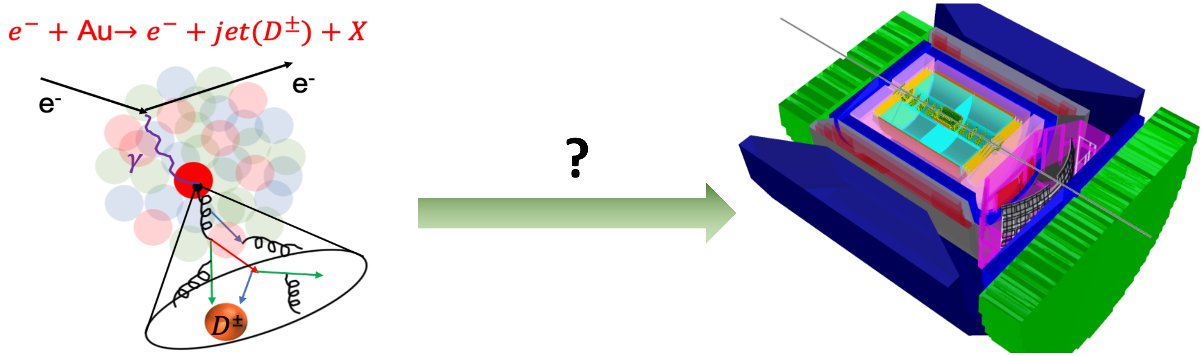
Will update this in the Fun4All or G4E

LANL EIC tracking simulation plan

- Work in progress:
  - Initial studies in fast simulation are completed.
  - Start to work on more realistic detector design and simulation with Geant4 in the Fun4All or G4E framework.
  - Provide the conceptual detector design for a forward silicon tracking detector at the EIC in collaboration with JLab, BNL and other colleagues.
  - Physics performance (such as heavy flavor hadron reconstruction) on detector options in fast simulation. See details in https://arxiv.org/abs/2002.05880.
  - Integration into the physics simulation such as the jet and heavy flavor topic.

Detector R&D status

- What detector techniques are needed to realize the proposed heavy flavor and jet measurements?

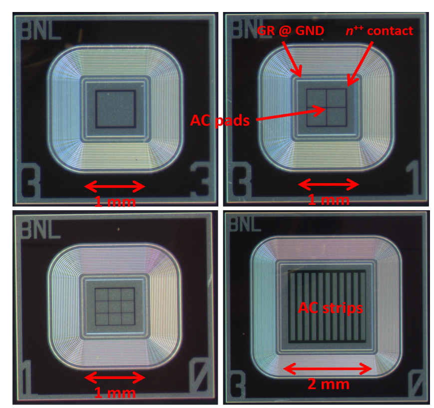


- Several advanced silicon sensor candidates are determined.

For example:

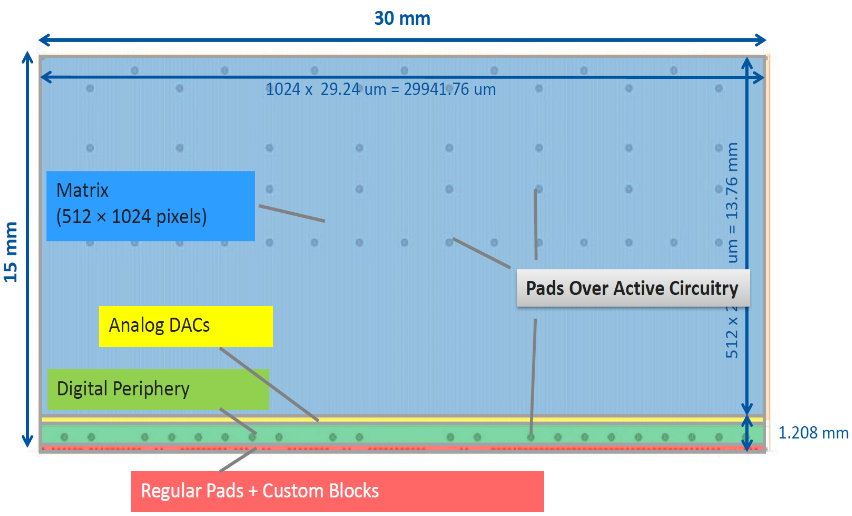
MAPS sensor

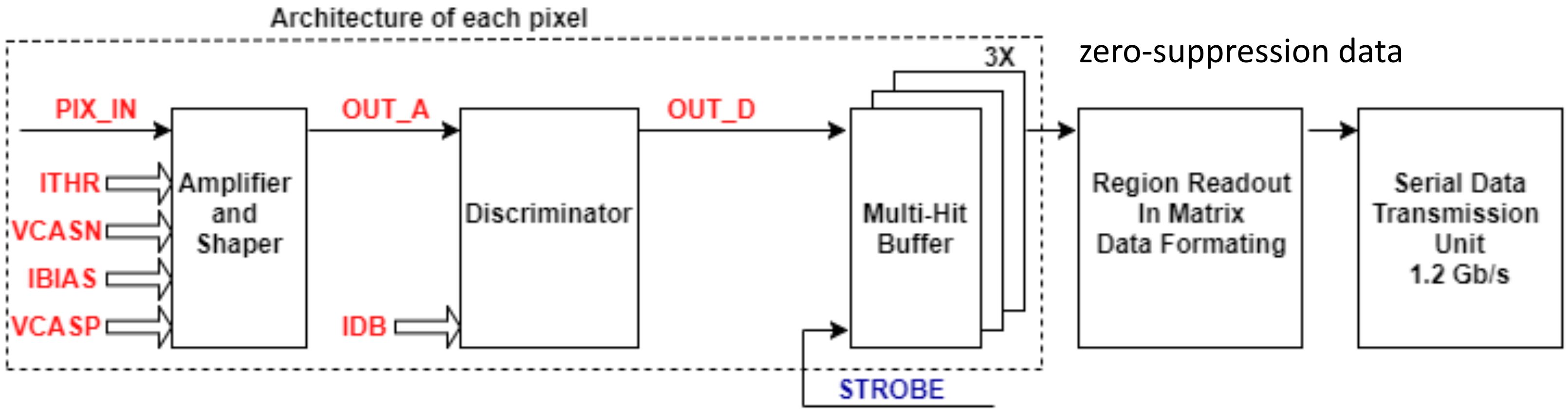
LGAD sensor



Monolithic Active Pixel Sensor (MAPS)

- The ALPIDE chip used for ALICE ITS upgrade and sPHENIX MVTX detector.
- 1024X512 pixels locate in the 3.0cmX1.5cm active region. Each pixel contains the charge sensitive amplifier, discriminator and 3 hit buffer.
- 11M channels in a 10X10 cm^2 active region.

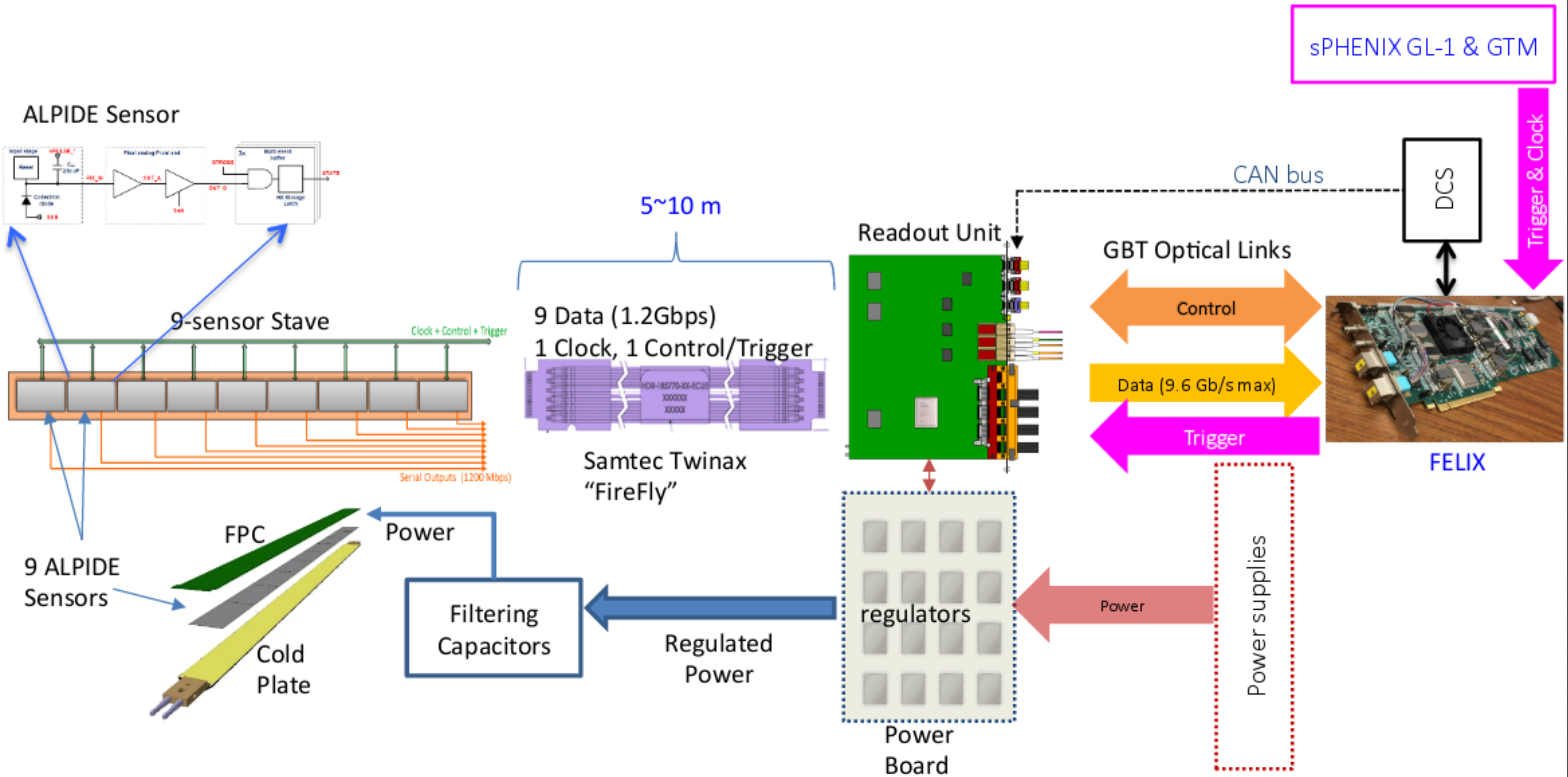




zero-suppression data

Readout chain of the MAPS

- Under R&D. Take the sPHENIX design for example:



- Although the spatial resolution can reach ~ 5 μm, but the typical integration time is ~5 μs.

Ongoing procurements for the LGAD sensors

- The ongoing R&D for the Low Gain Avalanche Detector (LGAD) can achieve <100 ps timing resolution and reduce the pixel size to 100 X 100 μm^2.
- We are collaborating with UC Santa Cruz colleagues to work on the R&D with the LGAD silicon sensor and relevant electronics.

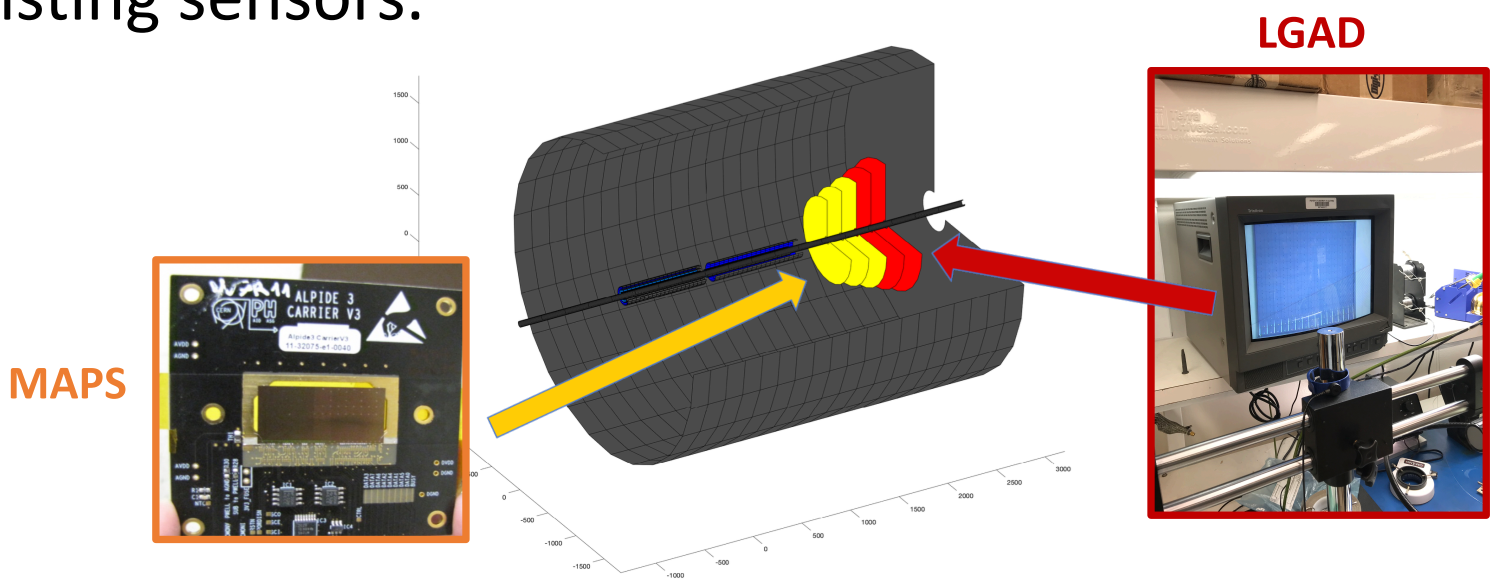
15X15 pixel LGAD sensor

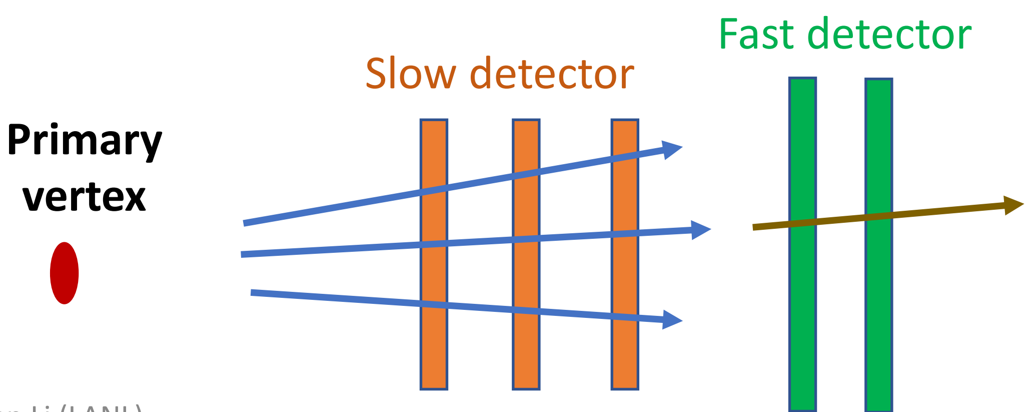
The LGAD font-end readout

Beta source test in refrigerator

Conceptual detector design underway

- In addition to utilize a single silicon sensor technique, we will investigate applying a hybrid design using existing sensors.



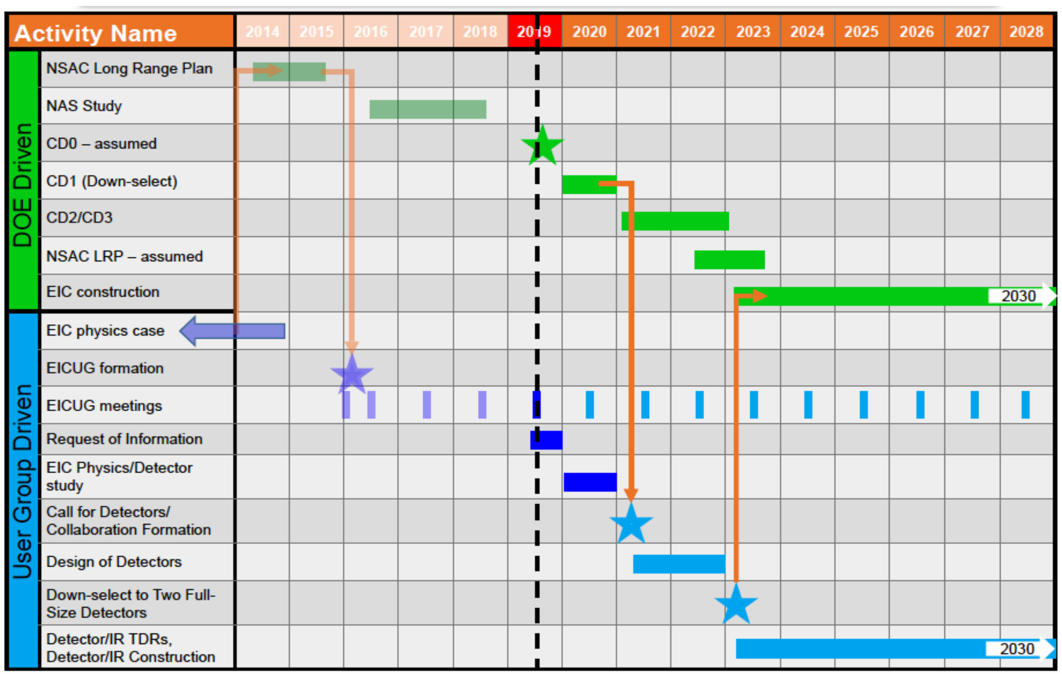


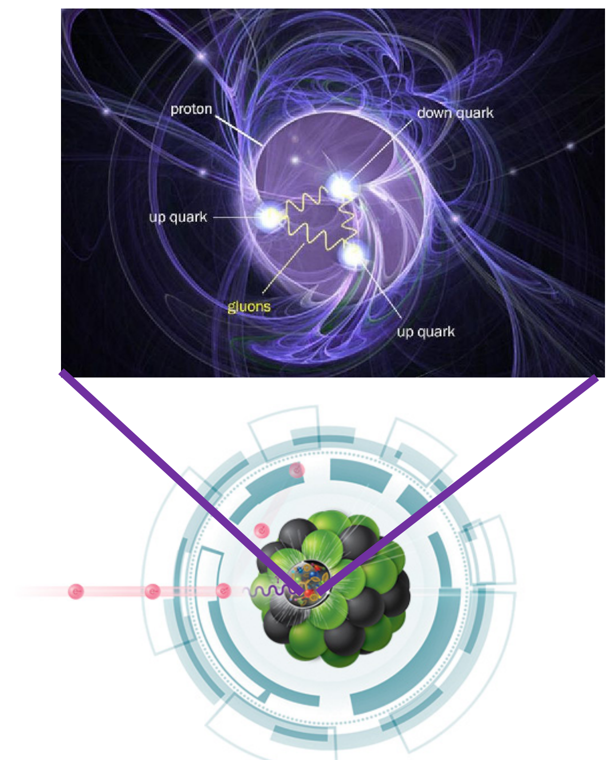
To reduce the pile up and background events.

Summary and Outlook

- A new EIC heavy flavor and jet project with dedicated R&D efforts for a forward silicon tracking detector has started at LANL.
- We look forward to work with more collaborators and contribute to the EIC realization.

Updated timeline from the EICUG





Backup

LANL EIC tracking simulation status – EICROOT setup

- ePythia:
  - Electron (20 GeV), proton (250 GeV).
  - Q^2>0.8 GeV/c^2 , no radiative corrections.
- DpmJetHybrid:
  - Electron (10 GeV), proton (100 GeV).
  - Q^2>1 GeV/c^2 , no radiative corrections.
- Detector setting in the EICROOT package:
  - 3 Silion pixel Disks with materials budget per layer at (0.3%) 1%X_0.
  - Inner radius at 5 cm.
  - Momenta smeared by 10% before giving hit collection over to Kalman filter fitter (vertex is also smeared).
  - Assume 100% hit association efficiency