LANL Forward Silicon Tracker for Jet and Heavy Flavor Measurements in EIC

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on Behalf of LANL EIC Team

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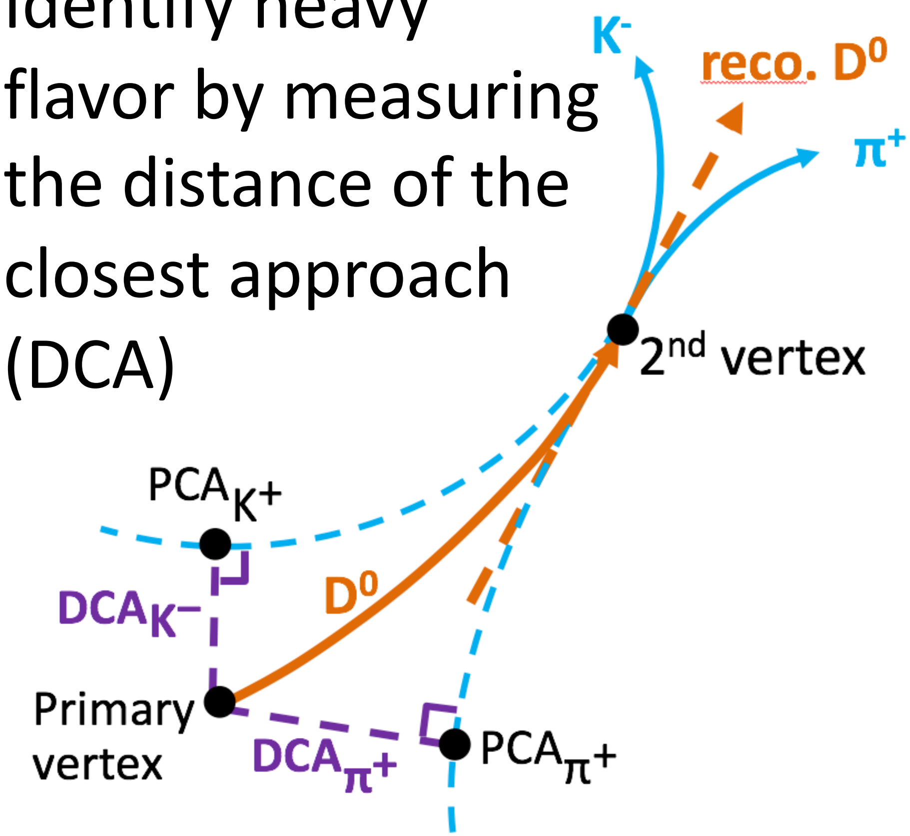
Outline

- Motivation:
  Propose a forward silicon tracker (FST) to measure heavy flavor and jet in EIC
- A forward silicon trackers:
  - Detector design and material budgets
  - Detector performance
- Overview of physics studies
- Summary and outlook

Heavy Flavor Identification

Identify heavy flavor by measuring the distance of the closest approach (DCA)

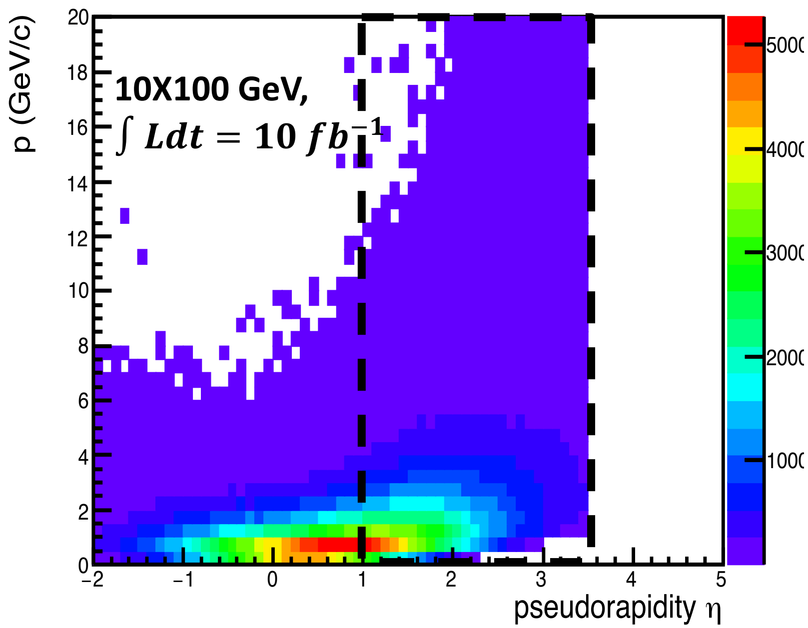


$$DCA_{2D} = (\overrightarrow{pca} - \overrightarrow{vtx}) \cdot (\overrightarrow{p_T} \times \hat{z})$$

Heavy flavor mass and decay length

Particle	Mass (GeV/c²)	cτ 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

Reconstructed D daughter p VS η

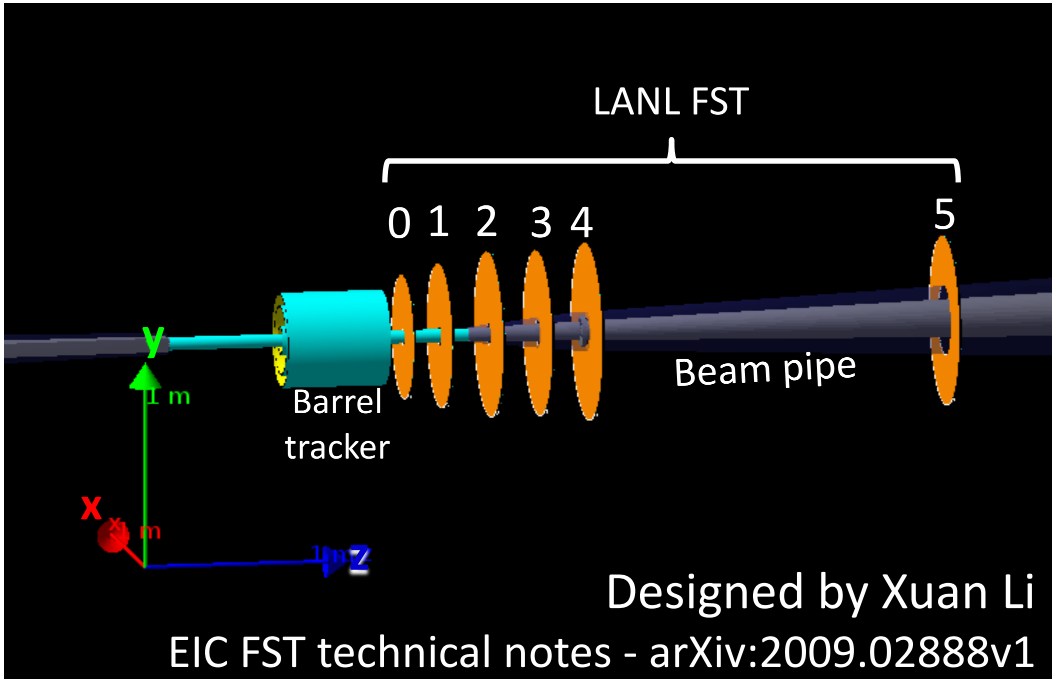


The LANL FST is proposed for the heavy flavor and jets studies in the $1 < \eta < 3.5$ region

Simulation Setup

- Fun4All Simulation: Geant based simulation package developed by PHENIX collaboration at BNL
- Both **BeAST** (max. 3T) and **Babar** (max. 1.4T) magnets are tested
- Event configuration:
  - **single (10) π-** per event for momentum (vertex) reconstruction
  - Vertex (0,0,0)
    - 20um smearing in x and y direction for track reconstruction
    - no smearing for vertex reconstruction
  - 7.5M events in each p (p_T) bin
- Track configuration:
  - p (p_T): **1-30 GeV**
  - Pseudorapidity correction for ion beam angle
  - Pseudorapdity: **1-3.5** w.r.t. to the beam pipe
  - Hit efficiency at 95%

EIC FST Setup in Fun4All



FST Setup

Plane	z (cm)	r_{in} (cm)	r_{out} (cm)	Pixel pitch (um)	Silicon thickness (um)
0	35	4	25	20	50
1	62.3	4.5	42	20	50
2	90	5.2	43	20	50
3	115	6	44	36.4	100
4	125	6.5	45	36.4	100
5	300	15	45	36.4	100

ITS-3 type (planes 0–2) MALTA (planes 3–5)

Barrel Tracker Setup

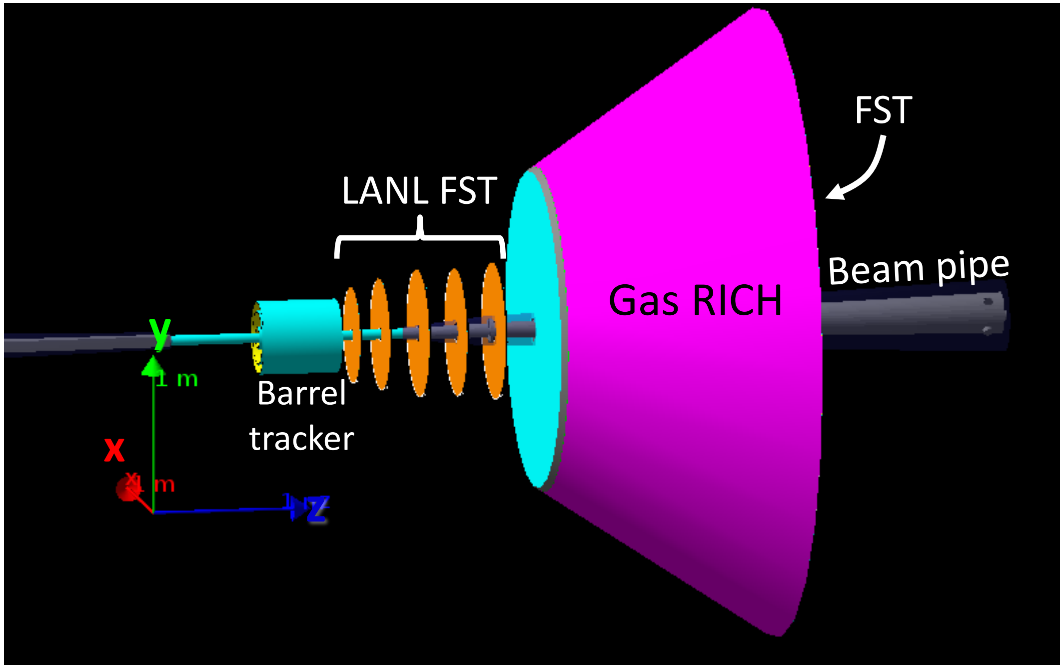
Layer	Half length (cm)	r (cm)	Pixel pitch (um)	Silicon thickness (um)
0	20	3.64	20	50
1	20	4.81	20	50
2	25	5.98	20	50
3	25	16	36.4	100
4	25	22	36.4	100

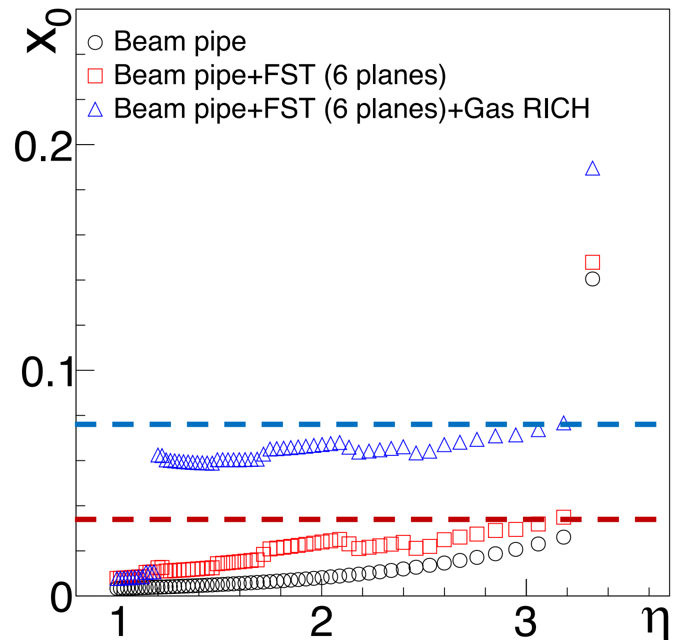
Silicon sensor options

	Pixel pitch	Silicon thickness	Integration time
LGAD/AC-LGAD	100µm	<300µm (<1% X_0)	300-500ps
MALTA	36.4µm	100µm (<0.5% X_0)	5ns
ITS-3 type	20µm	50µm	100ns ?

With the use of both sensor technologies, the FST can give good spatial and timing resolutions

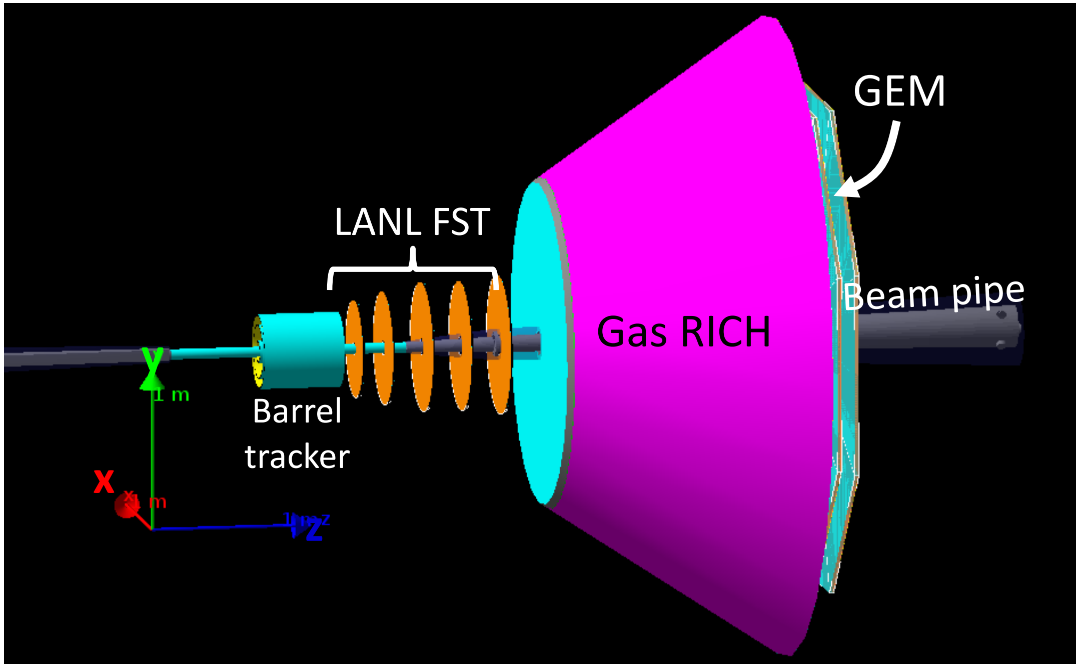
Material Budget: FST(6 planes)+RICH

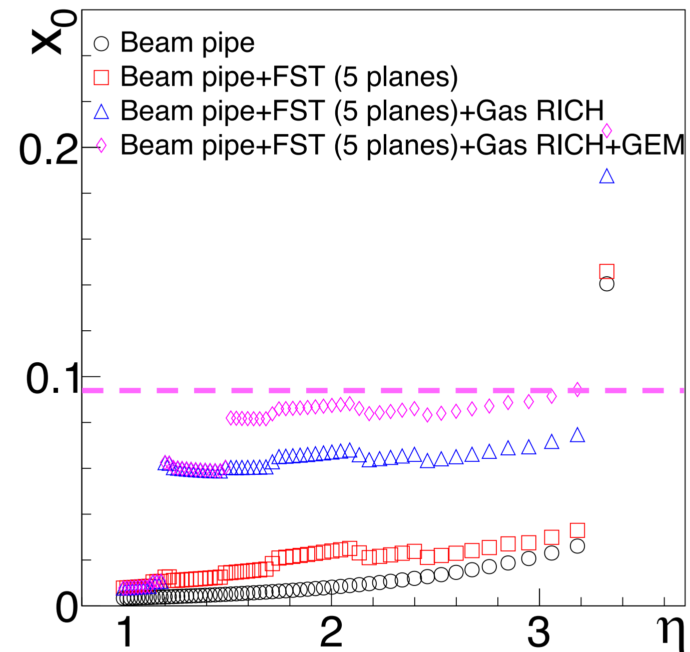




- Mockup Gas RICH by LBNL with dual radiators: aerogel and C_2F_6 gas
- Total material budget (blue) is <8% at $\eta < 3.3$

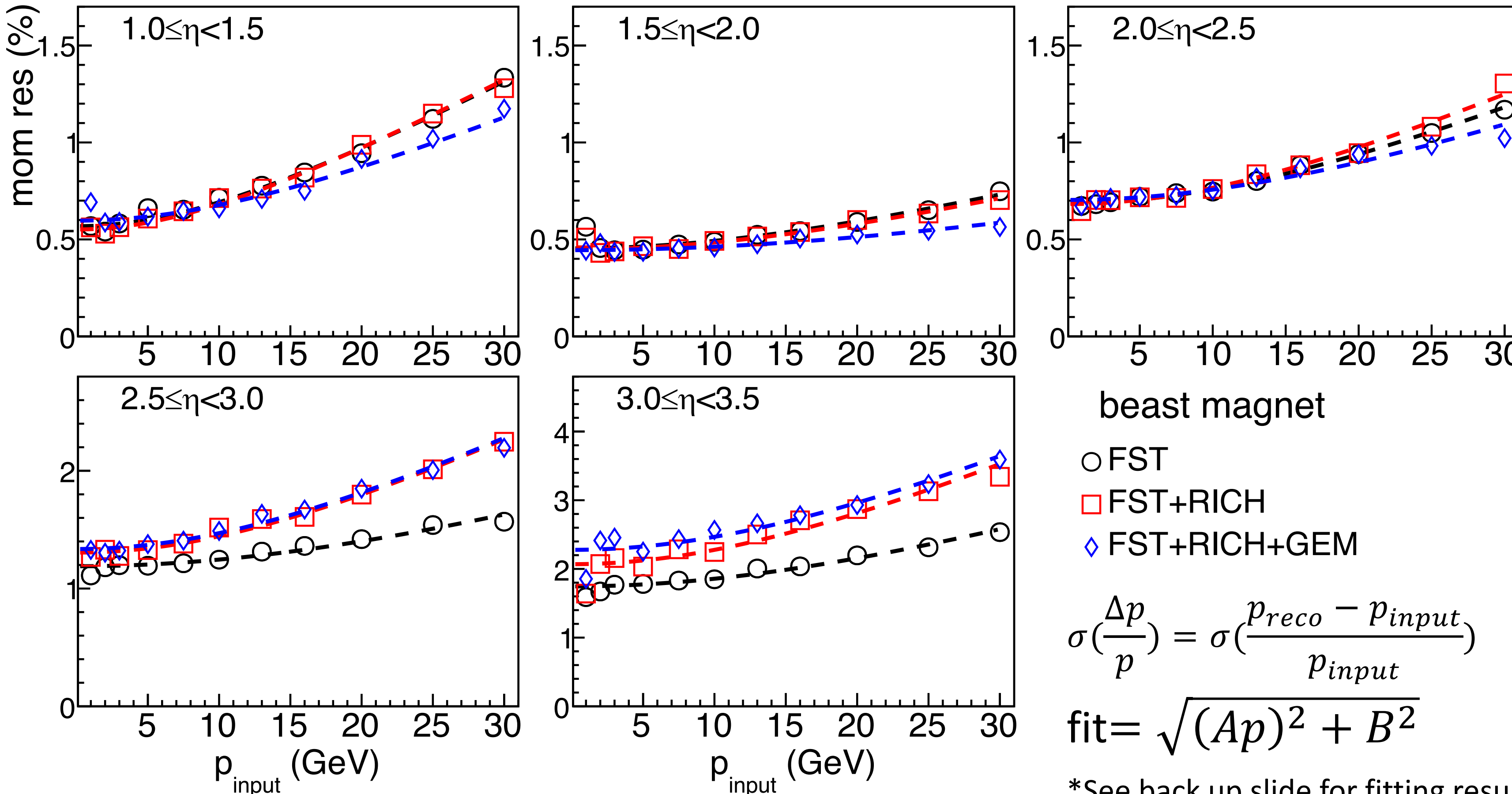
Material Budget: FST(5 planes)+RICH+GEM





- Replacing the last plane (z=300cm) of FST by a GEM tracker could be a cost-effective option
- Mockup GEM tracker: 3-plane / methane / $1.5 < \eta < 3.5$
- Total material budget (magenta) is ~10% at $\eta < 3.3$

Mom. Res. of EIC FST (BeAST Magnet)



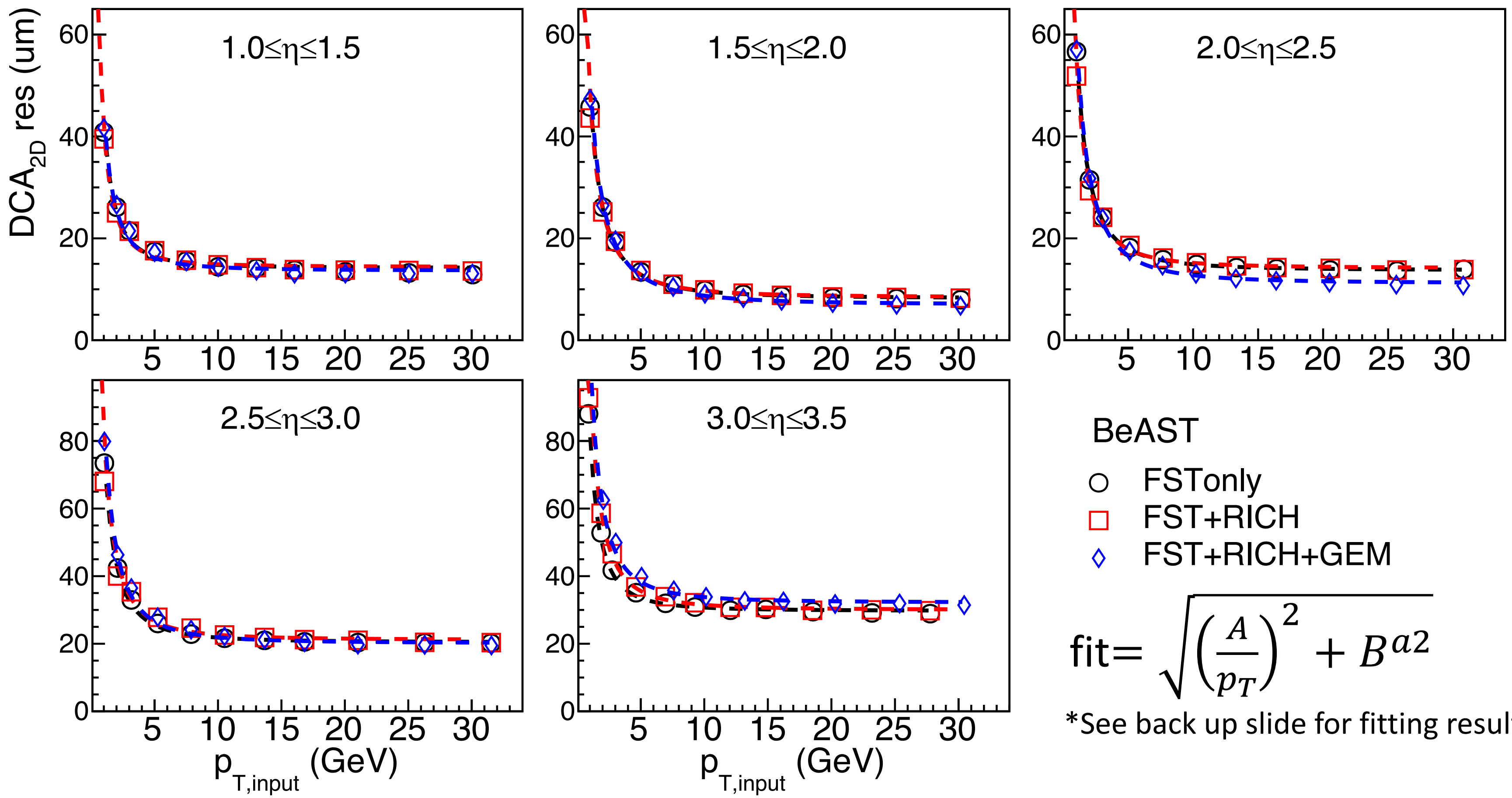
$$\sigma(\frac{\Delta p}{p}) = \sigma(\frac{p_{reco} - p_{input}}{p_{input}})$$

$$\text{fit} = \sqrt{(Ap)^2 + B^2}$$

*See back up slide for fitting results

- Momentum resolution <4%
- The Gas RICH worsen the mom res by ~1% at $\eta > 2.5$
- Changes in mom resolution is small when the last plane of FST is replaced with the GEM

DCA$_{2D}$ Res. of EIC FST with BeAST Magnet



$$\text{fit}= \sqrt{\left(\frac{A}{p_T}\right)^2 + B^{a2}}$$

*See back up slide for fitting results

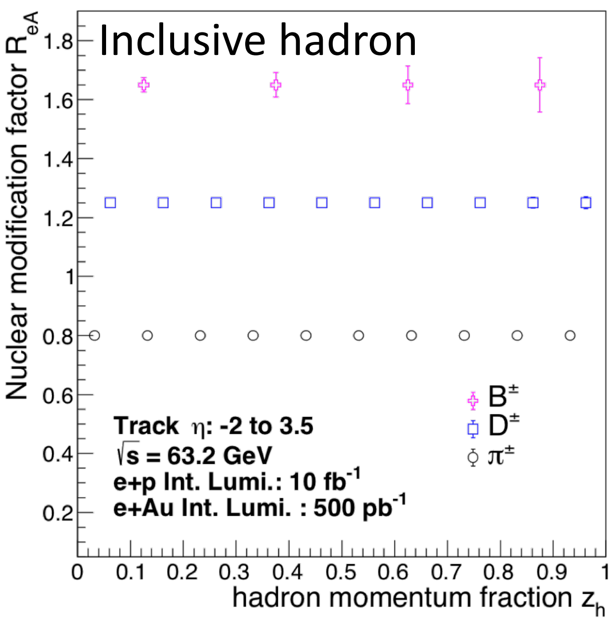
- $\eta < 2$: DCA$_{2D}$ res <50um / $\eta > 2$: DCA$_{2D}$ res <110um
- Similar results with the use of the Babar magnet

Overview of Physics Studies

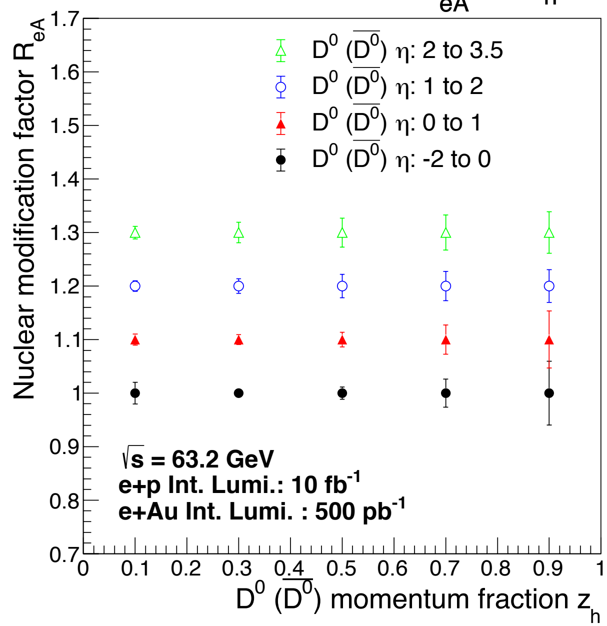
The full analysis framework includes the event generation (PYTHIA), detector response in GEANT4 simulation, beam remnant & QCD background, and hadron reconstruction algorithm

arXiv:2009.02888

Projected hadron R_{eA} vs z_h



Projected D^0 ($\overline{D^0}$) R_{eA} vs z_h



- Projection of R_{eA} including pseudorapidity dependence study can help constraint theoretical predictions

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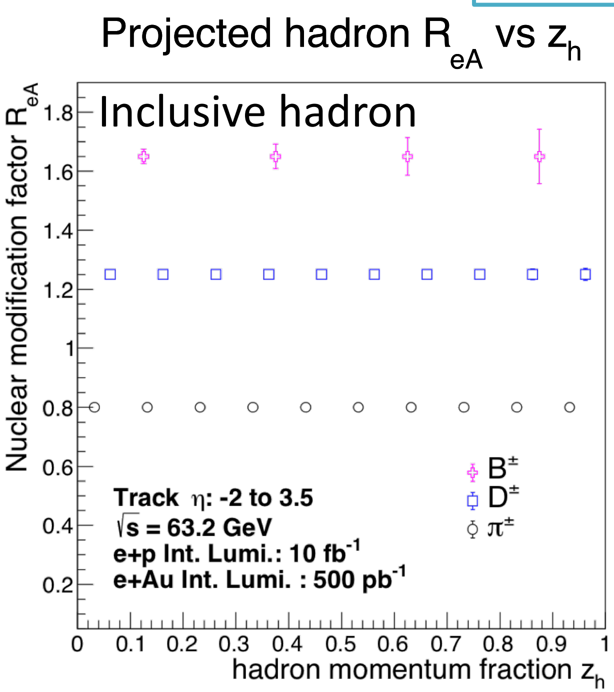
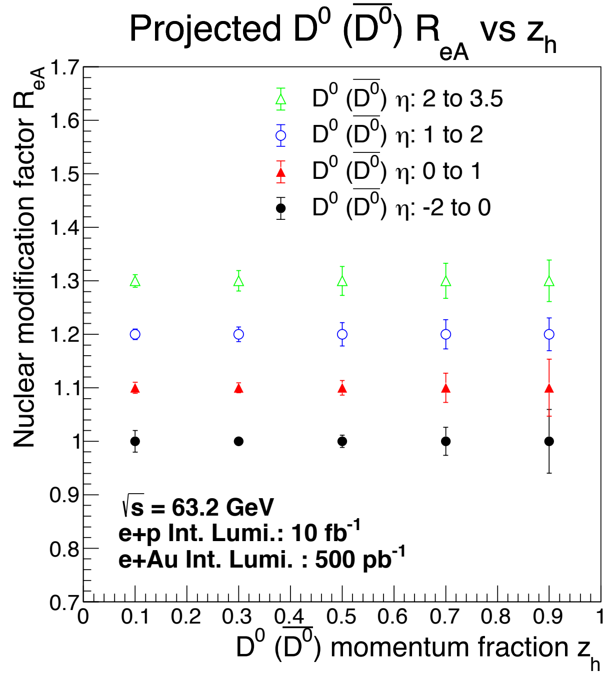
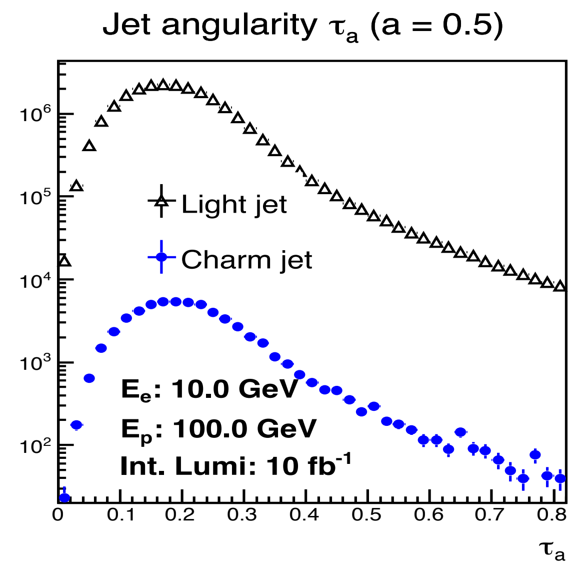
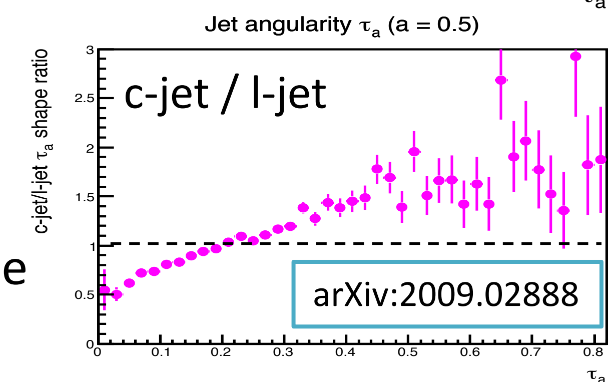








- Projection of R_{eA} including pseudorapidity dependence study can help constraint theoretical predictions
- Jet angularity: distinguish quark and gluons jet to explore the hadronization origin and process [JHEP 1804 (2018) 110]

$$\tau_a \equiv \tau_a^{pp} \equiv \frac{1}{p_T} \sum_{i \in J} p_T^i \left(\Delta \mathcal{R}_{iJ}\right)^{2-a}$$

Summary

- Integrated detector setup in Fun4All simulation with a 5/6-plane FST
  - Momentum resolution <4% with the used of BeAST magnet
  - DCA_{2D} resolution <50um for $\eta < 2$ and DCA_{2D} resolution <110um for $\eta > 2$
  - Replacing the last plane of FST with a GEM does not make a significant difference in detector performance
- Physics studies of heavy flavor R_{eA} and jet angularity
  - Help constraint theoretical predictions
  - Distinguish quark/gluon jets and nuclear medium effect in e+A collisions

EIC FST technical notes - arXiv:2009.02888v1

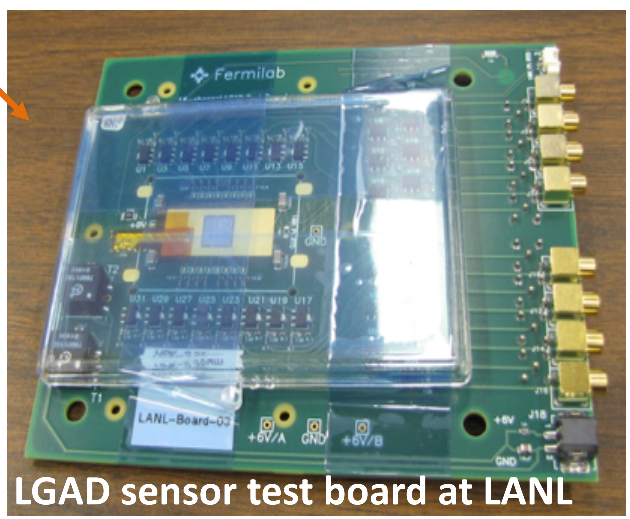
Outlook

Detector R&D work underway

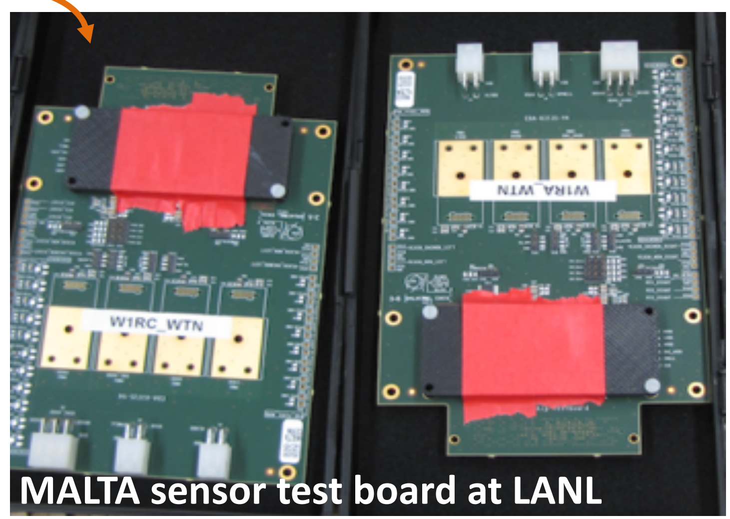
- Bench test for the LGAD & MALTA received
- FST prototype development and beam test

Silicon sensor options

	Pixel pitch	Silicon thickness	Integration time
LGAD/AC-LGAD	100µm	<300µm (<1% X_0)	300-500ps
MALTA	36.4µm	100µm (<0.5% X_0)	5ns
ITS-3 type	20µm	50µm	100ns ?



LGAD sensor test board at LANL

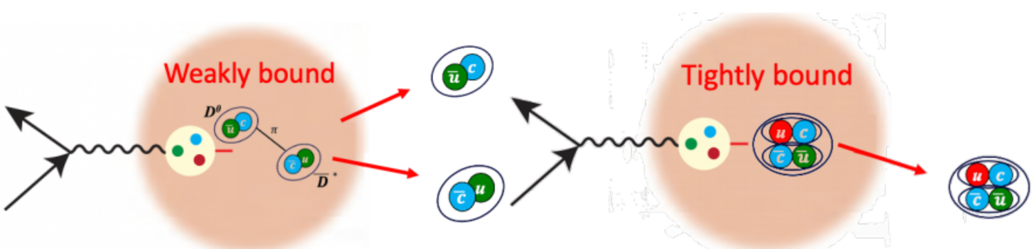


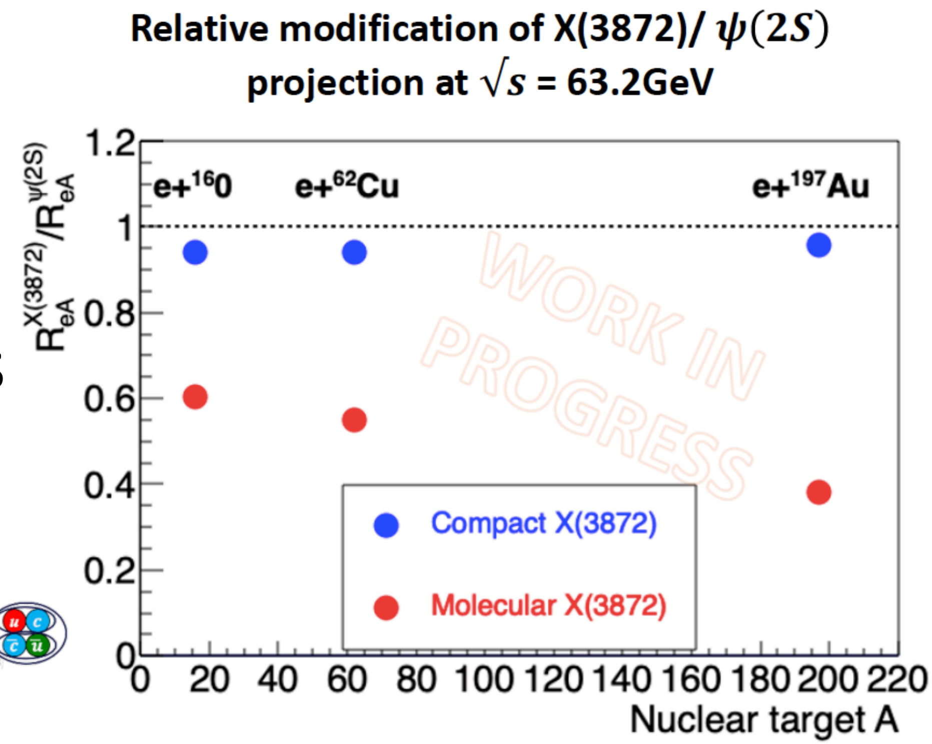
MALTA sensor test board at LANL

Outlook

Physics Study

- Continue heavy flavor and jet studies with updated detector response
- Exotic heavy flavor studies





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Back Up

Fitting Parameters of Momentum Resolution

$$\frac{\Delta p}{p}(p) = \sqrt{(Ap)^2 + B^2}$$

η	B field	FST (6 planes)		FST (6 planes) + RICH		FST (5 planes) + RICH + GEM	
		A (%/GeV)	B (%)	A (%/GeV)	B (%)	A (%/GeV)	B (%)
1.0–1.5	3 T	0.039	0.568	0.040	0.551	0.032	0.597
	1.5 T	0.076	1.039	0.077	1.120	0.070	1.088
1.5–2.0	3 T	0.019	0.454	0.018	0.448	0.013	0.445
	1.5 T	0.039	0.839	0.039	0.882	0.026	0.876
2.0–2.5	3 T	0.032	0.687	0.035	0.682	0.028	0.704
	1.5 T	0.068	1.346	0.070	1.374	0.051	1.402
2.5–3.0	3 T	0.037	1.190	0.062	1.306	0.062	1.336
	1.5 T	0.086	2.362	0.127	2.607	0.123	2.629
3.0–3.5	3 T	0.063	1.746	0.095	2.069	0.095	2.278
	1.5 T	0.124	3.378	0.189	4.305	0.189	4.868

- BeAST vs Babar: Fitting parameters with the use of Babar magnet are about double of the use of BeAST magnet
- $\boldsymbol{\eta < 2.5}$: Comparable values between different detector systems
- $\boldsymbol{\eta > 2.5}$: Fitting parameters increases with the more integrated detector systems

Fitting Parameters of DCA_{2D} Resolution

$$DCA(p_T) = \sqrt{\left(\frac{A}{p_T}\right)^2 + B^2}$$

η	FST (6 planes)		FST (6 planes) + RICH		FST (5 planes) + RICH + GEM	
	A (µm ·GeV)	B (µm)	A (µm ·GeV)	B (µm)	A (µm ·GeV)	B (µm)
1.0–1.5	41.54	14.19	39.47	14.39	40.73	14.06
1.5–2.0	49.57	8.24	48.49	8.43	51.56	7.36
2.0–2.5	57.87	13.73	54.79	14.16	59.58	11.48
2.5–3.0	76.78	20.42	81.63	21.13	83.90	20.35
3.0–3.5	77.79	29.71	95.90	30.01	104.95	31.55

- BeAST vs Babar: comparable fitting parameters
- $\eta < 2.5$: Comparable values between different detector systems
- $\eta > 2.5$: Fitting parameters increases with the more integrated detector systems