Physics motivation and simulations for the calorimeter insert

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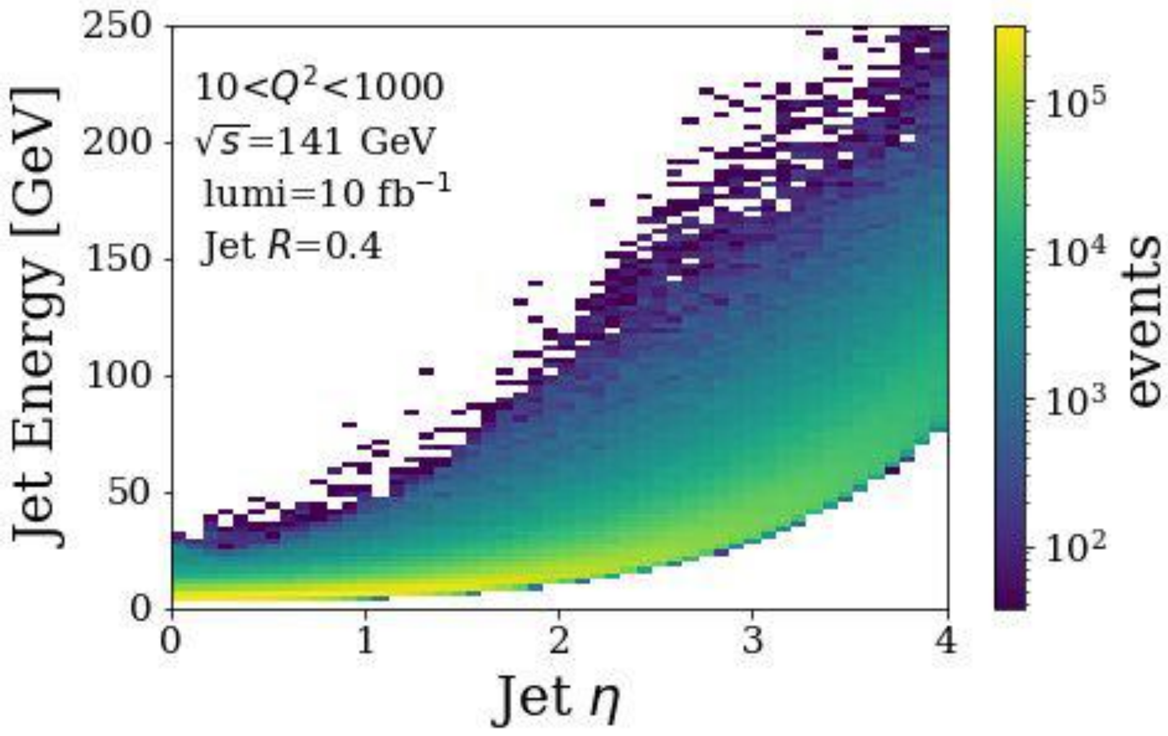
Outline

- ❑Overview of physics motivation
- ❑Angular acceptance in forward endcap
- ❑DIS simulations on the impact of calorimeter insert

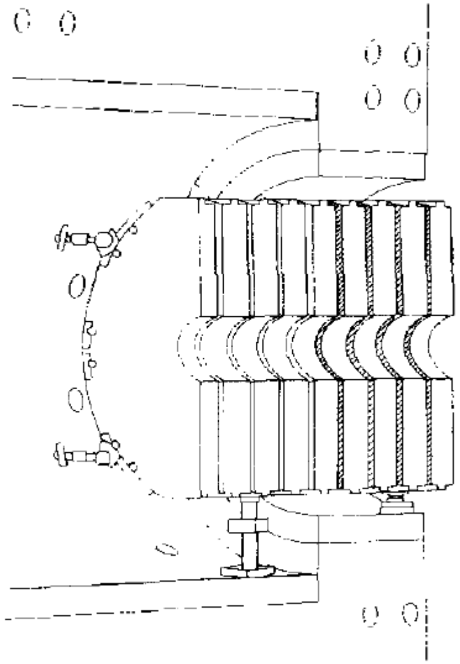
Motivation

- EIC detectors should have "as large coverage as technically possible", up to η=4.0.
- Tracking degrades rapidly at forward rapidity, so calorimeters at 3<η<4 crucial to:
  1. Hadronic-final-state (HFS) transverse momentum to reconstruct high-x / low-y NC DIS and CC DIS
  2. Highest-energy jets (sensitive to both high-x and low-x)
  3. Tagging of beam-induced backgrounds



Motivation

H1 Plug calorimeter



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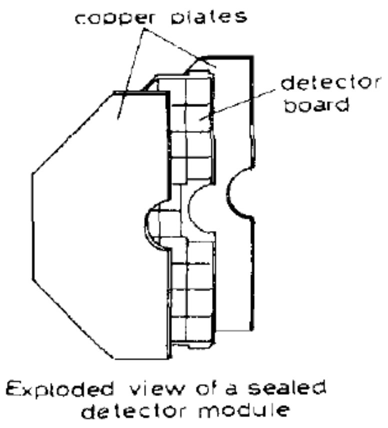


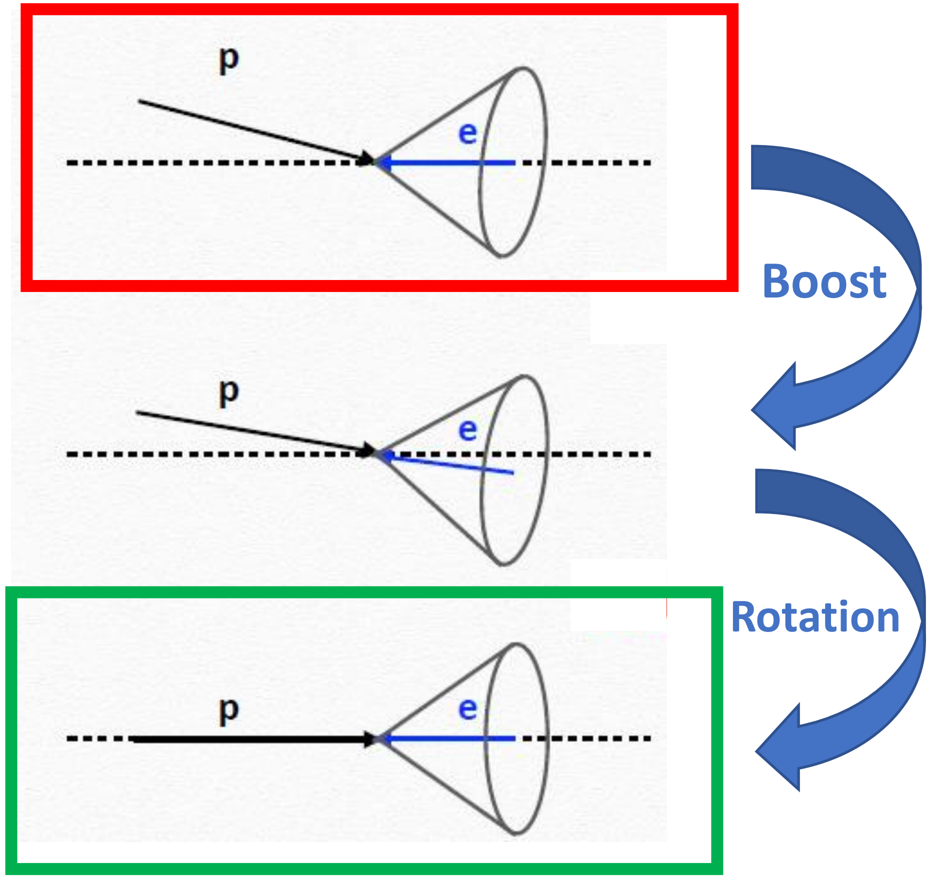
Our motivation for an insert (plug) calorimeter at the EIC is similar. The technology we will use is, of course, quite different.

"[The Plug's] main task is to minimise the missing part of the total transverse momentum due to hadrons emitted close to the beam pipe. In addition the energy, emitted into a narrow cone around the beam pipe can be used to separate the proton jet as well as to veto beam gas and beam wall background."

x, Q^2	$p_{T,tot}$		$\langle p_{T,hole} \rangle$	
			without plug	with plug
0.6, 3000	53.4	no gluons	1.22 (2.3%)	0.55 (1.0%)
		with gluons	1.62 (3.0%)	0.52 (1.0%)
0.3, 600	24.2	no gluons	1.41 (5.8%)	0.59 (2.4%)
		with gluons	2.80 (11.6%)	0.65 (2.7%)
0.2, 200	14.1	no gluons	1.83 (13.0%)	0.60 (4.3%)
		with gluons	4.27 (30.3%)	0.59 (4.2%)

Table 5.11 in H1 Detector TDR

Angular acceptance in the forward endcap



$$p_i = E_p(\sin\theta, 0, \cos\theta, 1)$$

$$e_i = E_e(0, 0, -1, 1)$$

There are two important frames to consider initially:

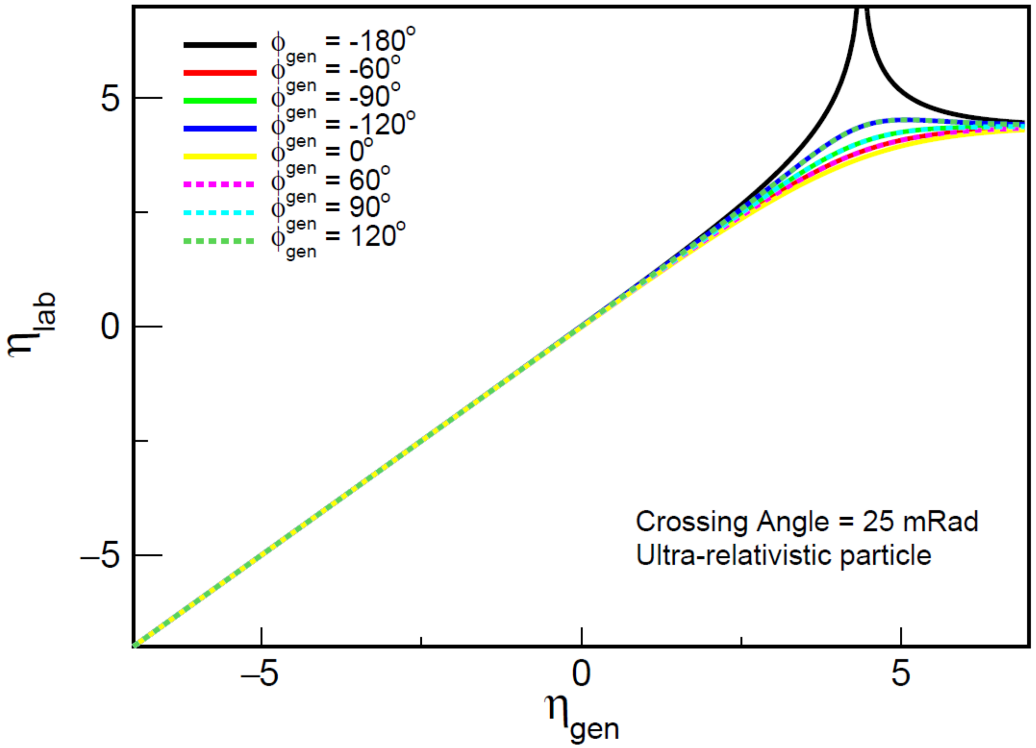
1. **The EIC detector frame (i.e. lab frame). This is where the beams have a non-zero crossing angle and where the detector acceptances are set.**
2. **The minimally-boosted colinear frame. This is a colinear frame where the beam energies are the closest to those in the lab frame. This is the 'physics' frame, where many observables are defined.**

Angular acceptance in the forward endcap

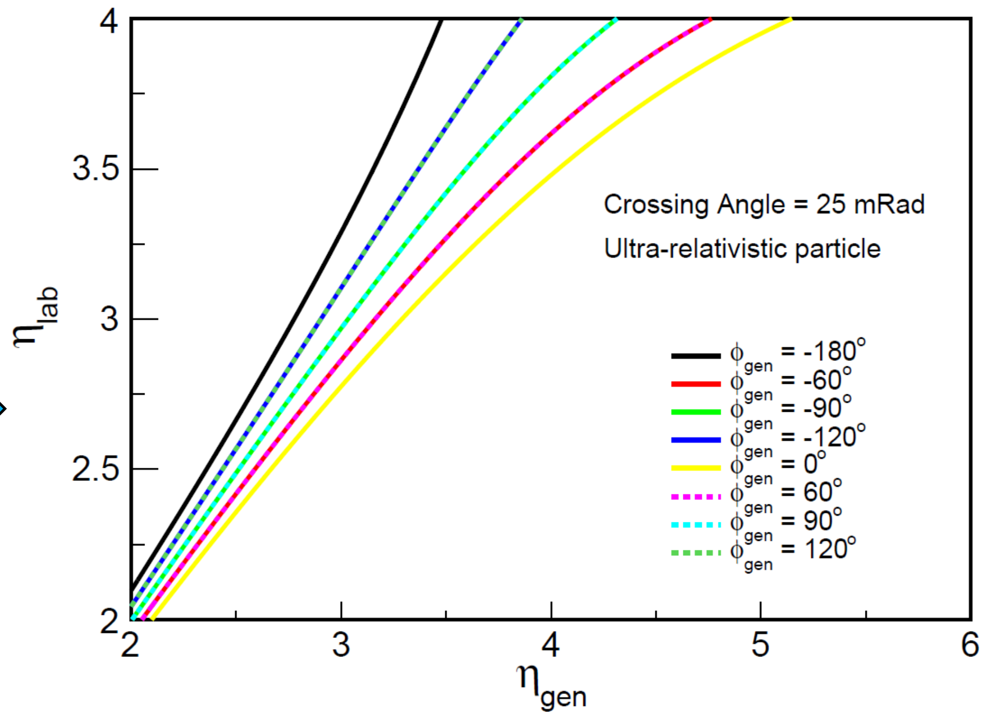
η_{lab} is calculated in the EIC detector (lab) frame with respect to the solenoid +z – (anti-parallel) to incoming electron beam.

η_{gen} is calculated with respect to the proton direction in the minimally-boosted colinear frame.

Acceptance cut of, for example, η_{lab} < +4.0 leads to a ϕ dependent acceptance in the colinear frame.



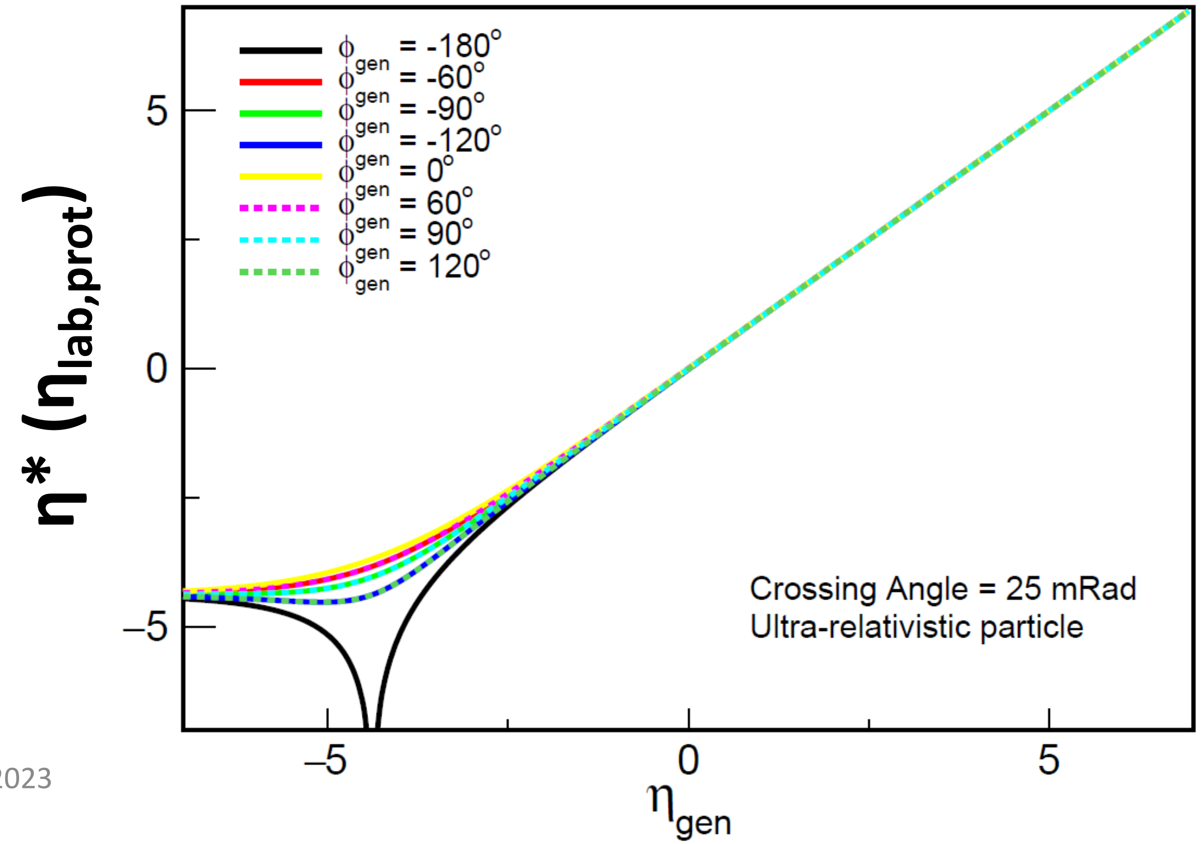
Zoomed in on positive endcap region



Angular acceptance in the forward endcap

η^* ($\eta_{lab,prot}$) is calculated in the EIC detector (lab) frame with respect to the proton beam direction at the interaction point.

η_{gen} is calculated with respect to the proton direction in the minimally-boosted colinear frame.

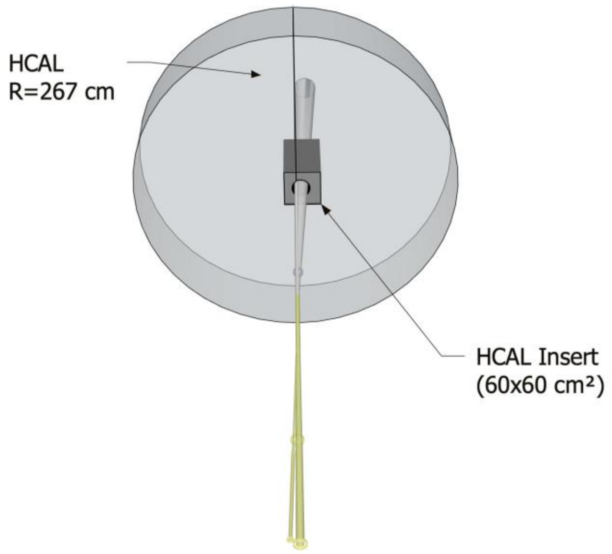


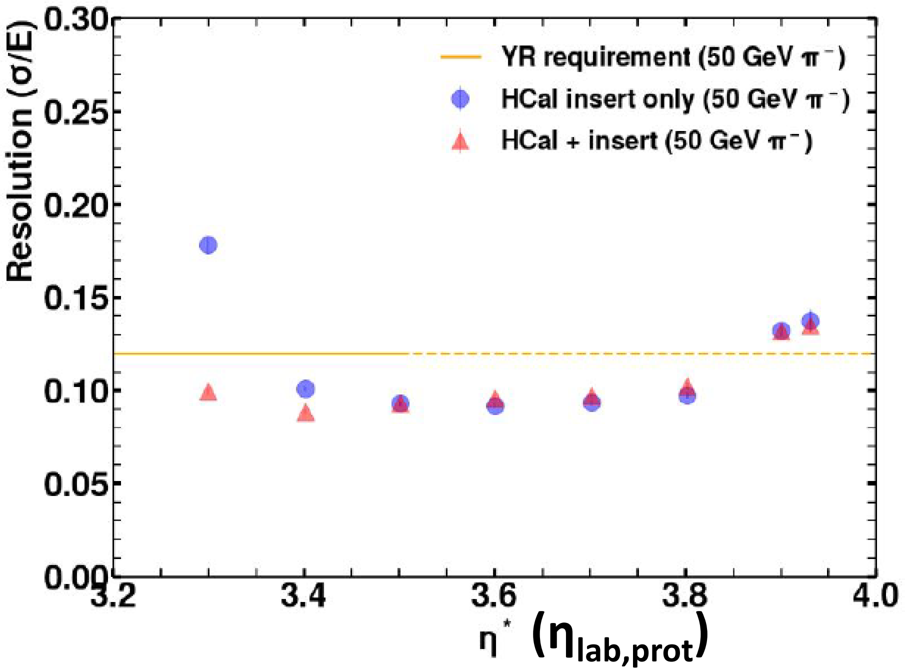
Acceptance cut of, for example, η^* ($\eta_{lab,prot}$) < +4.0 does not lead to a ϕ dependent acceptance in the colinear frame.

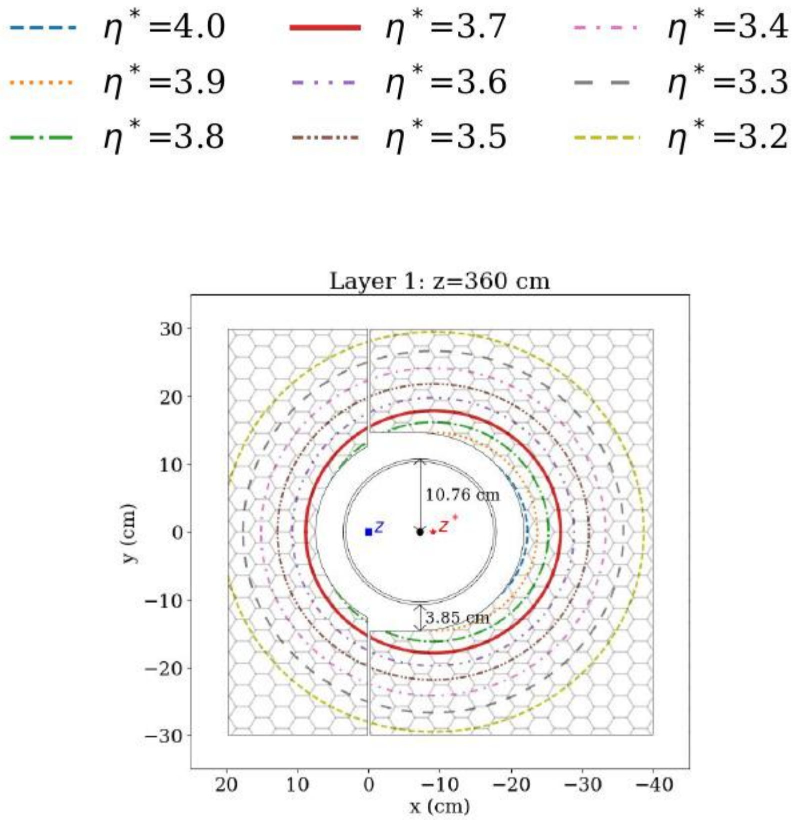
Angular acceptance in the forward endcap

The beampipe in the hadron endcap has a complex shape, but more closely follows the hadron beam direction at the IP.

The calorimeter insert both extends the acceptance to more positive values of pseudo-rapidity and provides a more uniform acceptance in the colinear frame.



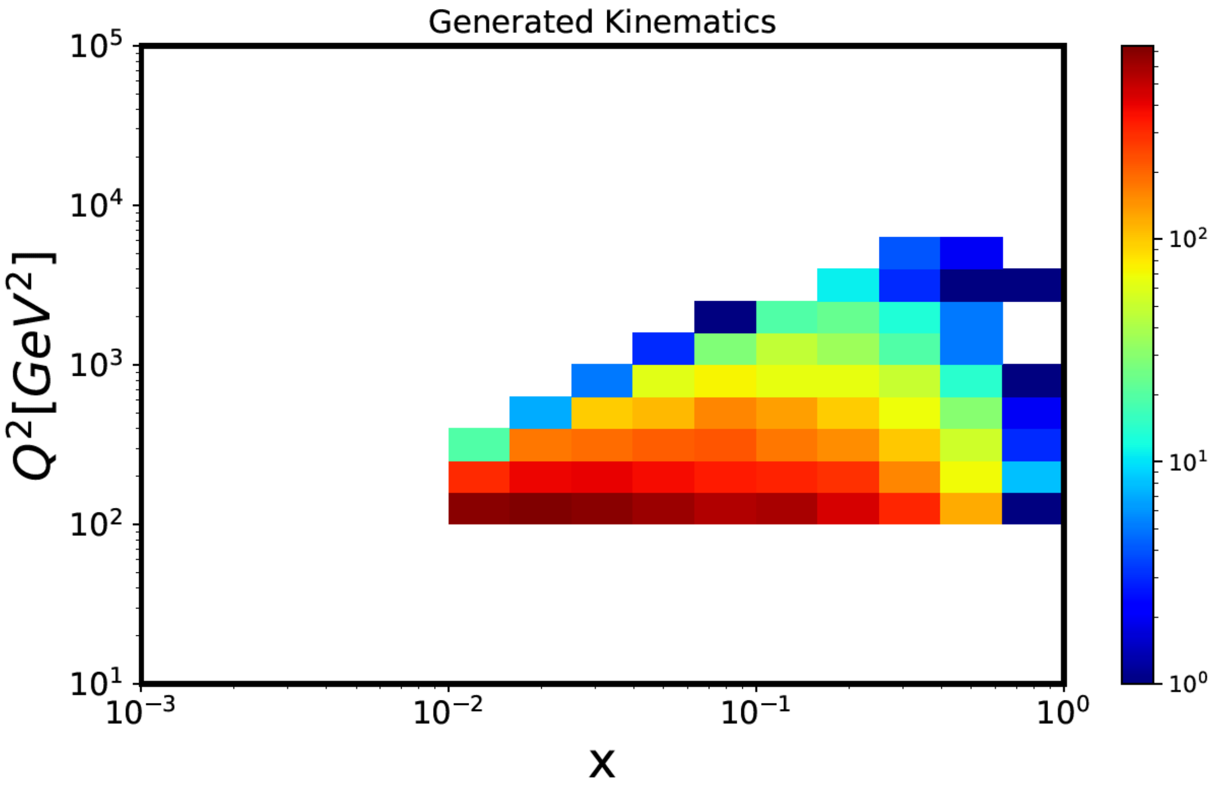


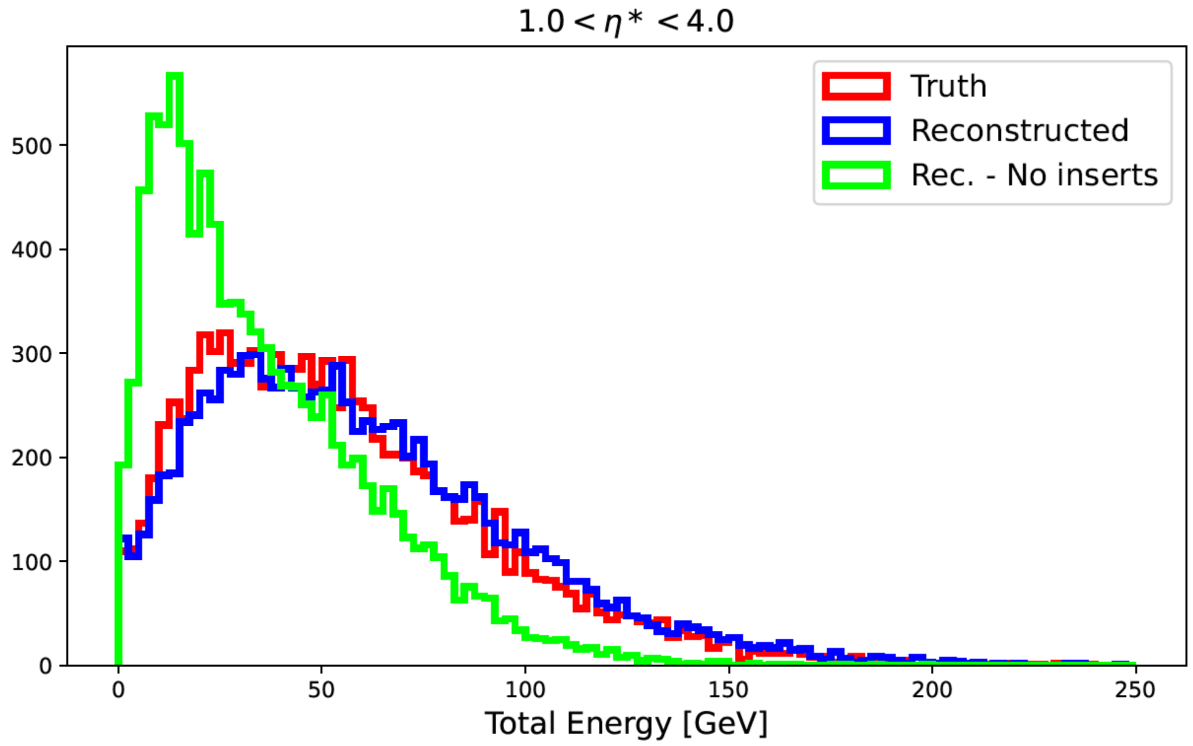


Simulation steps

1. We generate DIS events at 18x275 GeV and Q^2 > 100 GeV^2 with the *Djangoh* event generator (QED radiation OFF). We pass the events through the beam-effects afterburner. (N.B., We use *Djangoh* instead of *Pythia8* because we want to turn QED effects ON in future studies, but we currently have trouble running these QED events through the beam-effects afterburner.)
2. The generated DIS events are run through the *BryceCanyon* geometry + reconstruction. Only the 4 hadron-endcap calorimeters are included in the simulation (i.e. no tracking or PID detectors upstream, magnetic field turned off).
3. Using the reconstructed energy per tower (i.e. *MergedHits*), we calculate various kinematic quantities, either including the insert contributions or removing them. For example, to calculate the Hadronic Final State (HFS) E-p_z, we sum over $E \times [1-\cos(\theta)]$ for all calorimeter hits. No clustering is used in this analysis.

Energy reconstruction for the HFS

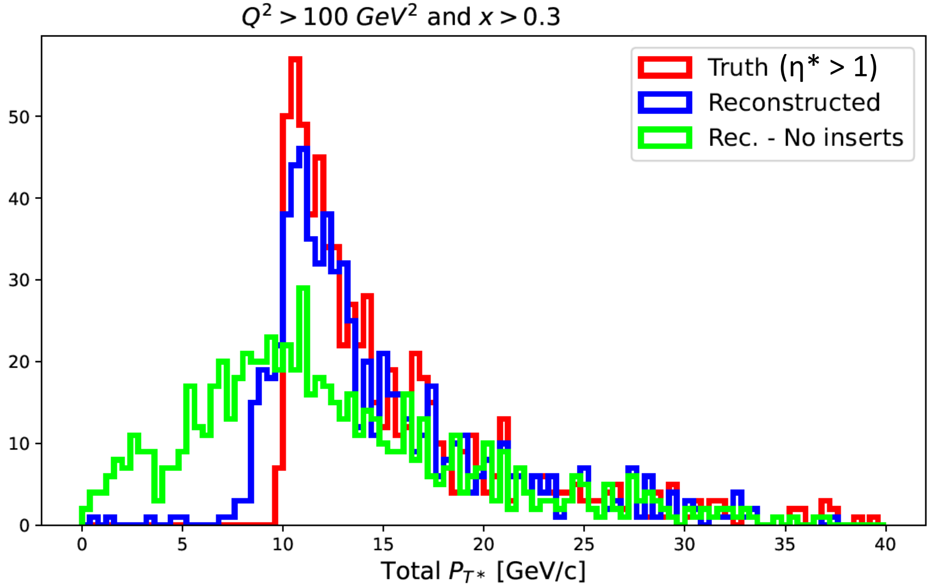


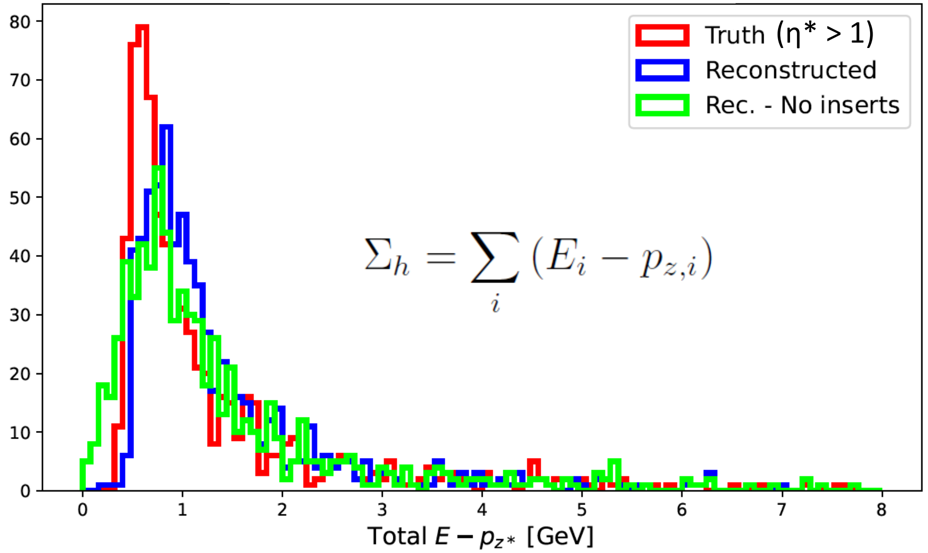


A large fraction of the HFS energy goes into the insert region, including part of the proton remnant when the struck quark scatters towards more central pseudo-rapidities.

For all events with $Q^2 > 100$ GeV^2, the red curve shows the true energy of the generated particles in the $1 < \eta^* < 4$ range.
The blue curve shows the reconstructed energy when the insert detector hits are included.
The green curve shows the reconstructed energy when the insert hits are not included.

Kinematic reconstruction at high x

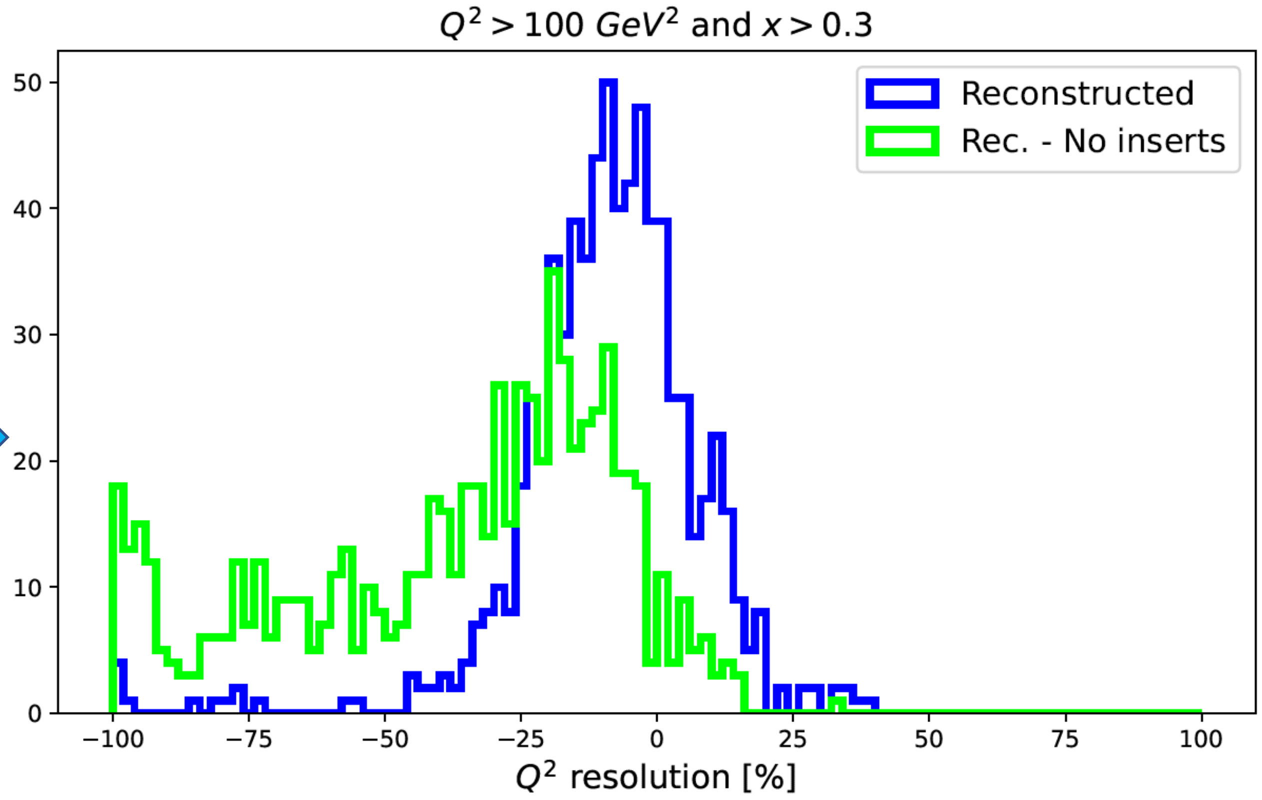




$$\Sigma_h = \sum_i (E_i - p_{z,i})$$

$$y_h = \frac{\Sigma_h}{2E_e}$$

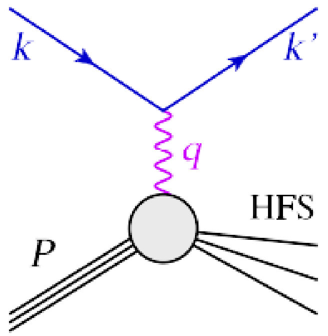
$$Q_h^2 = \frac{p_{t,h}^2}{1 - y_h}$$

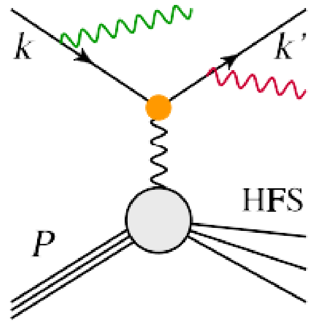


Simulation results come from a simple sum over the calorimeter hits. A more complex analysis should improve the above resolution further.

Importance of HFS reconstruction for inclusive kinematics

- For NC events, the ability to reconstruct the kinematics using only the scattered electron degrades towards high x (low y).
- In addition, the scattered electron kinematics are more sensitive to QED radiation than the HFS kinematics. The momentum balance between the electron and the HFS is therefore a useful event-by-event input to both AI and kinematic-fit methods for kinematic reconstruction.
- For CC events, the reconstruction of the kinematics relies entirely on the HFS.





$$p_T^{\mathrm{bal}} = 1 - \frac{p_{T,e}}{T} = 1 - \frac{\Sigma_e \tan\frac{\gamma}{2}}{\Sigma \tan\frac{\theta}{2}}$$

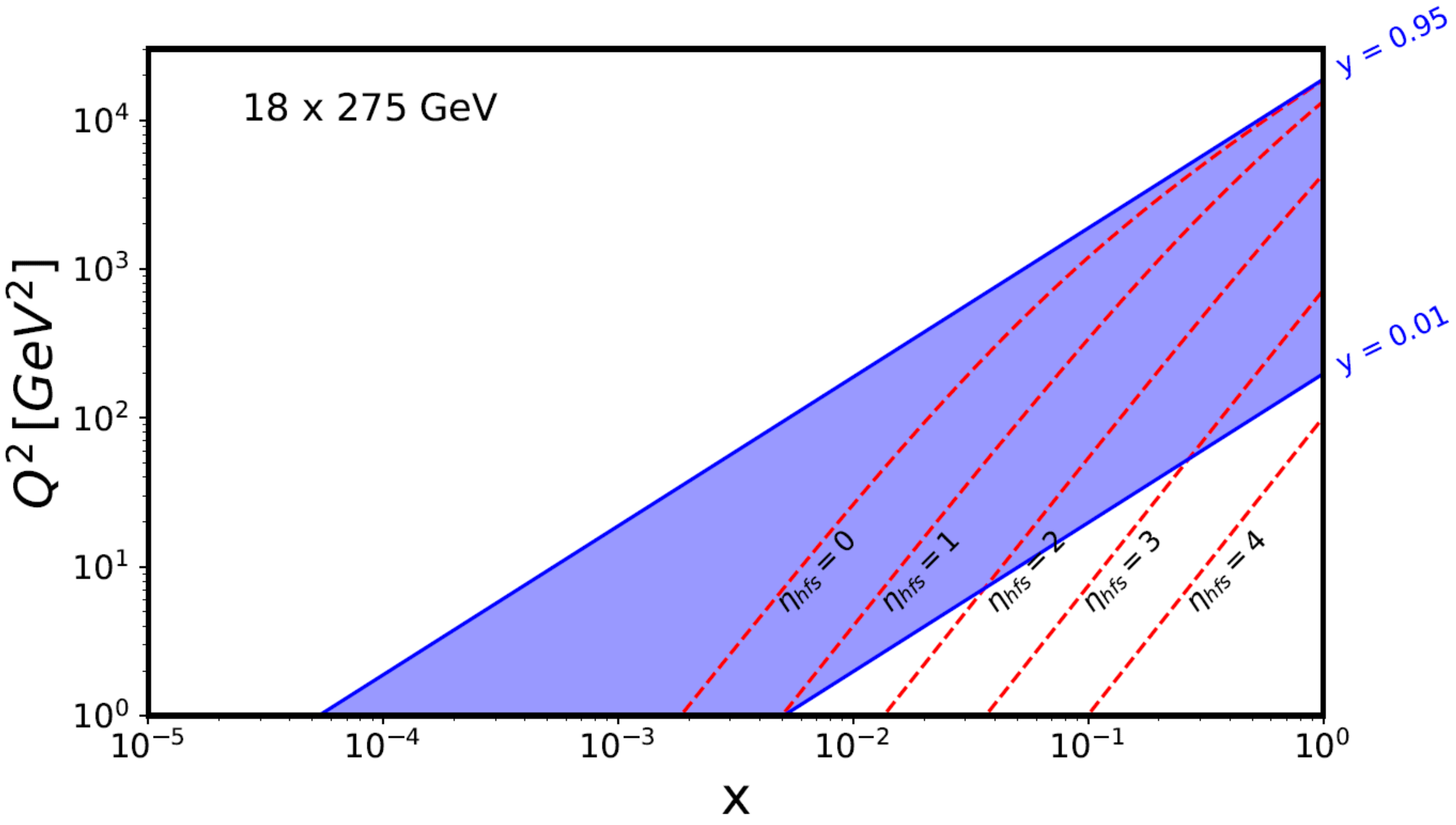
https://arxiv.org/abs/2110.05505

Summary

- The ability to detect particles in the calorimeter insert region is very important for the reconstruction of the transverse momentum of the HFS, as well as the inclusive kinematics at high x. Our simulation results agree with the expectation of the H1 motivation.
- The next steps will be to turn on the solenoid field and detectors upstream of the endcap calorimeters and see if there is any effect. As the sampling fraction and other necessary parameters have been updated for the insert in *EICRecon*, we will be able to use output from the next official simulation campaign for our future studies.
- Also, we want to include the *Djangoh* QED effects in the simulation, as this will allow us to test whether quantities such as the transverse momentum balance are sensitive to QED radiative effects. The Inclusive PWG is working to produce some of these *Djangoh* files for the next simulation campaign.
- Once backgrounds have been embedded into the simulation, we plan on checking the ability of the insert to tag beam-induced backgrounds.

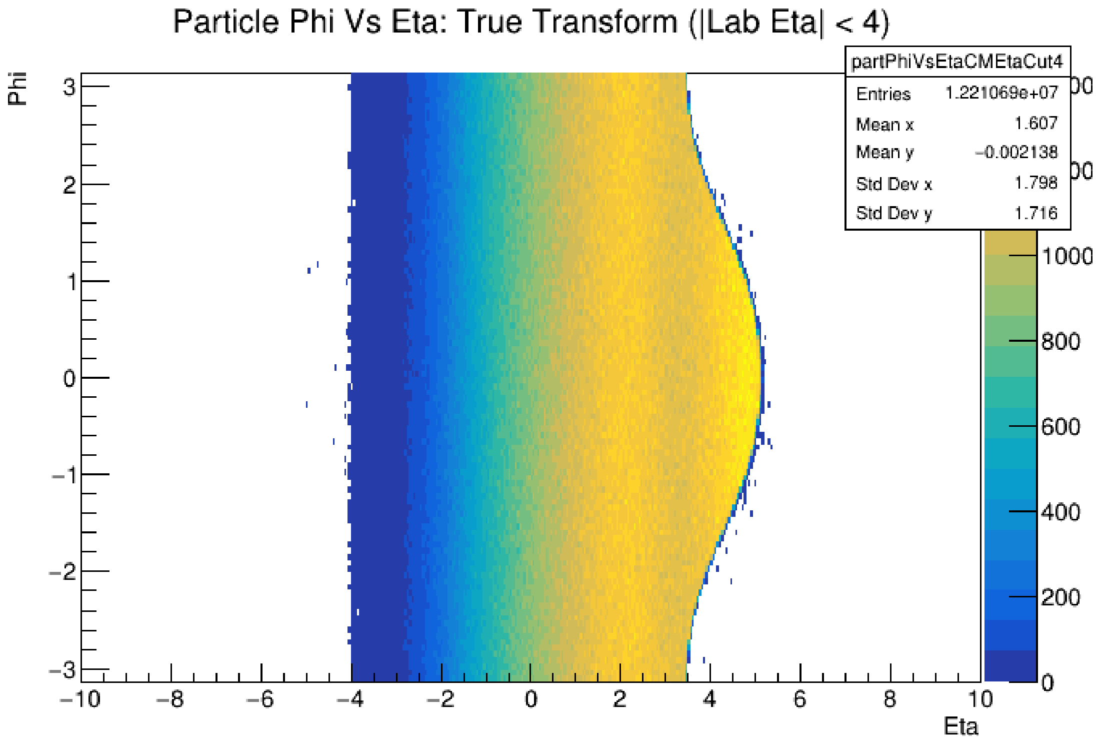
Backup

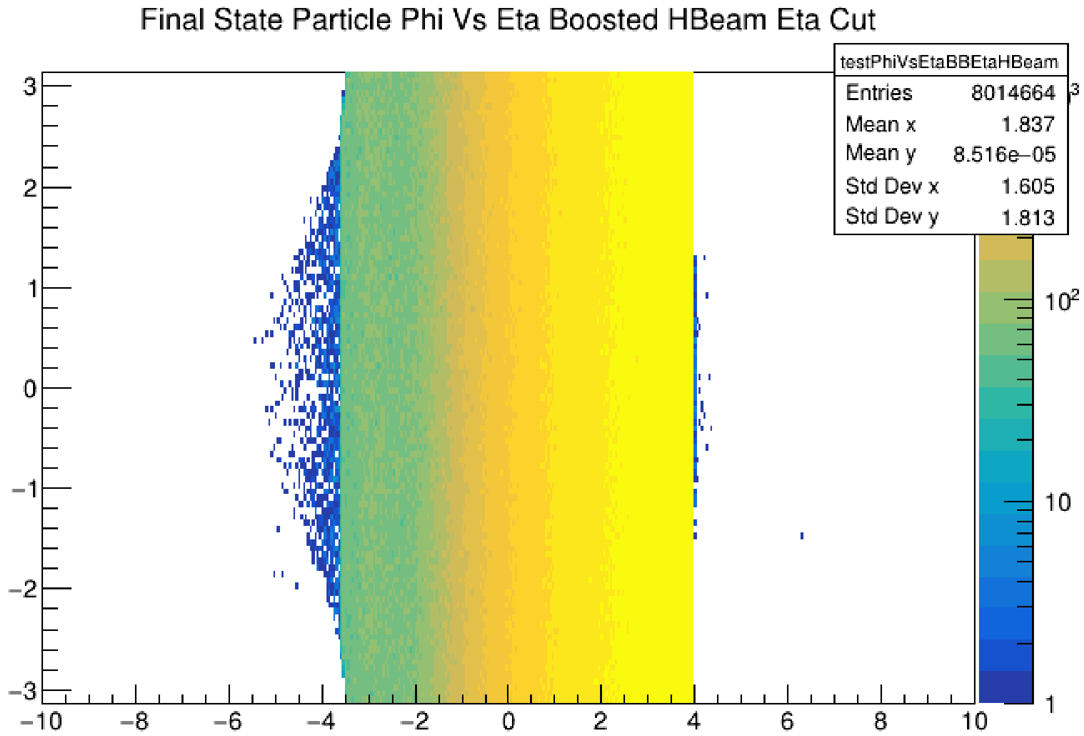
Kinematics of the struck quark



Acceptance effect in hadron endcap

Monte Carlo studies by Brian Page





Size of radiative corrections