UNIVERSITY OF BIRMINGHAM | SCHOOL OF PHYSICS AND ASTRONOMY

Reconstructing Inclusive variables with a Kinematic Fit

L. Gonella, P. G. Jones, S. Maple, P. R. Newman

Recap of reconstruction methods

- The kinematics of DIS can be reconstructed from any <u>two of the measured quantities</u> $\vec{D} = \{E_e, \theta_e, \delta_h, p_{t,h}\}$
  - Where $\delta_h = \Sigma E_i(1 - \cos(\theta_i))$. E_i and θ_i are the energies and angles of deposits in the calorimeters which are not assigned to the scattered electron.
  - $P_{t,h}$ is the transverse momentum of the hadronic final state

Electron method

$$Q^2 = 2E_eE'_e(1+\cos\theta_e)$$
$$y = 1 - \frac{E'_e}{2E_e}(1-\cos\theta_e)$$

JB method

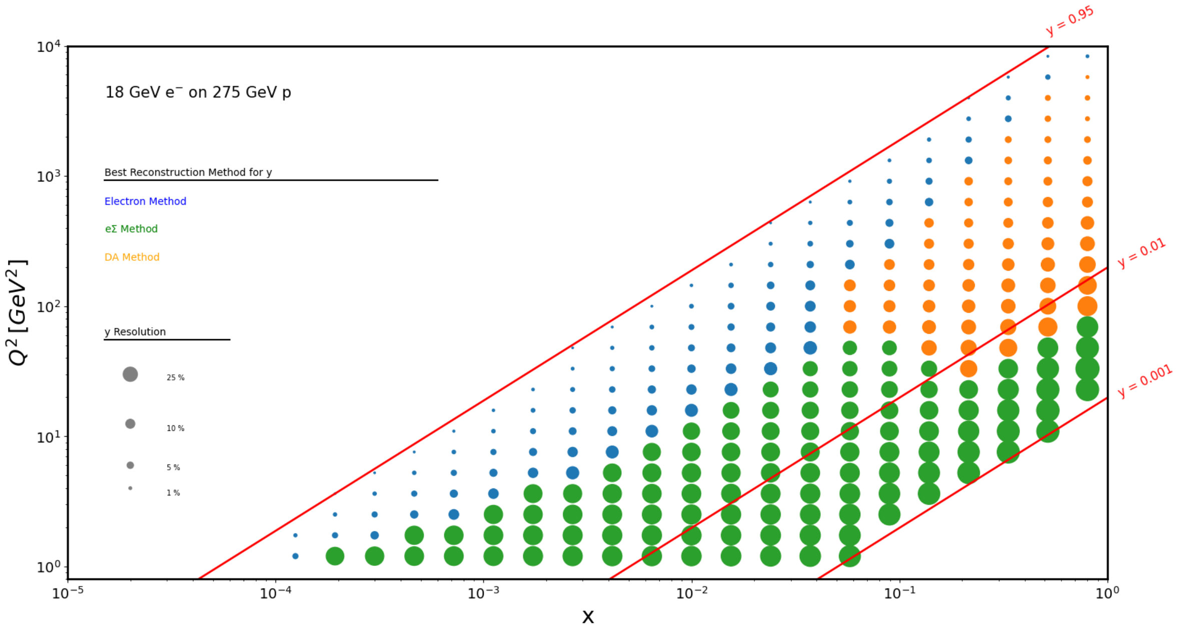
$$y = \frac{\delta_{had}}{2E_e}$$
$$Q^2 = \frac{p^2_{t\,had}}{1-y}$$

Double Angle method

$$Q^2 = 4E_e^2\frac{\sin\gamma(1+\cos\theta_e)}{\sin\gamma+\sin\theta_e-\sin(\theta_e+\gamma)}$$
$$x = \frac{E_e}{E_p}\frac{\sin\gamma+\sin\theta_e+\sin(\theta_e+\gamma)}{\sin\gamma+\sin\theta_e-\sin(\theta_e+\gamma)}$$

Recap of reconstruction methods

- These methods each come with advantages and drawbacks that depend on:
  - The x and Q^2 of the event
  - The presence of ISR/FSR



- Electron method deteriorates at low y and is sensitive to ISR
- Double Angle method is sensitive to ISR
- Can we do better?

e-Σ method

$$Q^2_{e\Sigma} = Q^2_e$$

$$x_{e\Sigma} = \frac{Q^2_\Sigma}{s y_\Sigma}$$

Kinematic Fitting in BAT (Bayesian Analysis Toolkit)

- From the measured quantities $\vec{D} = \{E_e, \theta_e, \delta_h, p_{t,h}\}$ we can reconstruct 3 pieces of information: $\vec{\lambda} = \{x, y, E_\gamma\}$
- All we need is a prior and a likelihood function:

This approach allows one to calculate the energy of a potential ISR photon!

Prior

$$P_o(\vec{\lambda}) = \frac{1 + (1-y)^2}{x^3 y^2} \frac{[1 + (1 - E_\gamma/A)^2]}{E_\gamma/A}$$

Likelihood*

$$P(\vec{D}|\vec{\lambda}) \propto \frac{1}{\sqrt{2\pi}\sigma_E} e^{-\frac{(E_e - E_e^\lambda)^2}{2\sigma_E^2}} \frac{1}{\sqrt{2\pi}\sigma_\theta} e^{-\frac{(\theta_e - \theta_e^\lambda)^2}{2\sigma_\theta^2}} \frac{1}{\sqrt{2\pi}\sigma_{\delta_h}} e^{-\frac{(\delta_h - \delta_h^\lambda)^2}{2\sigma_{\delta_h}^2}} \frac{1}{\sqrt{2\pi}\sigma_{P_{T,h}}} e^{-\frac{(P_{T,h} - P_{T,h}^\lambda)^2}{2\sigma_{P_{T,h}}^2}}$$

* Here we assume the measured parameters in $\vec{D}$ are gaussian distributed according to the detector resolution: this does not have to be the case!

Event generation

- Pythia8 used to generate 18x275 GeV^2 e-p events (no ISR/FSR, Q^2>100GeV^2)
- “True” quantities smeared according to paramaterisations of the ZEUS detector*

Smearing taken for hadronic variables as

$$\sigma_{P_T^{\mathrm{had}}} = 0.35\sqrt{P_T^{\mathrm{had}}}$$

$$\sigma_{\delta_{\mathrm{had}}} = 0.35\sqrt{\delta_{\mathrm{had}}}$$

$$\sigma_E = 0.2\sqrt{E} \oplus 0.008$$ (ZEUS values, R. Aggarwal, PhD thesis)

$$\sigma_\theta = 0.0025\sqrt{\theta}$$ (ZEUS values, R. Aggarwal, PhD thesis)

See A. Caldwell talk at DIS2022
https://indico.cern.ch/event/1072533/contributions/4806091/attachments/2435573/4171130/KF-DIS.pdf

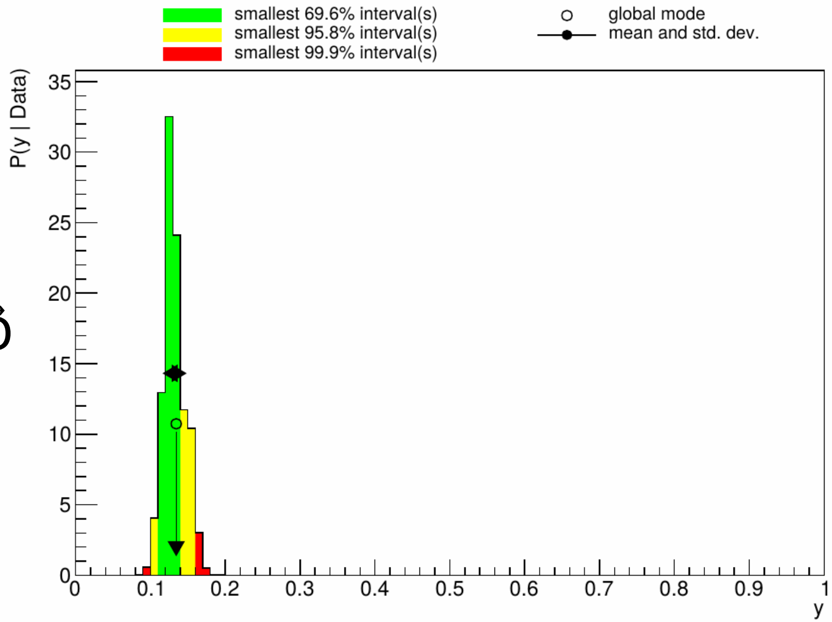
* Can think of this as being like running 18x275GeV^2 events at ZEUS → this does not correspond to any “real” experiment, it is only being used as a proof of concept → to be repeated with Detector 1 parameterisations

Reconstruction

- Input smeared (or reconstructed) variables $\vec{D} = \{E_e, \theta_e, \delta_h, p_{t,h}\}$
- Start off with prior distribution

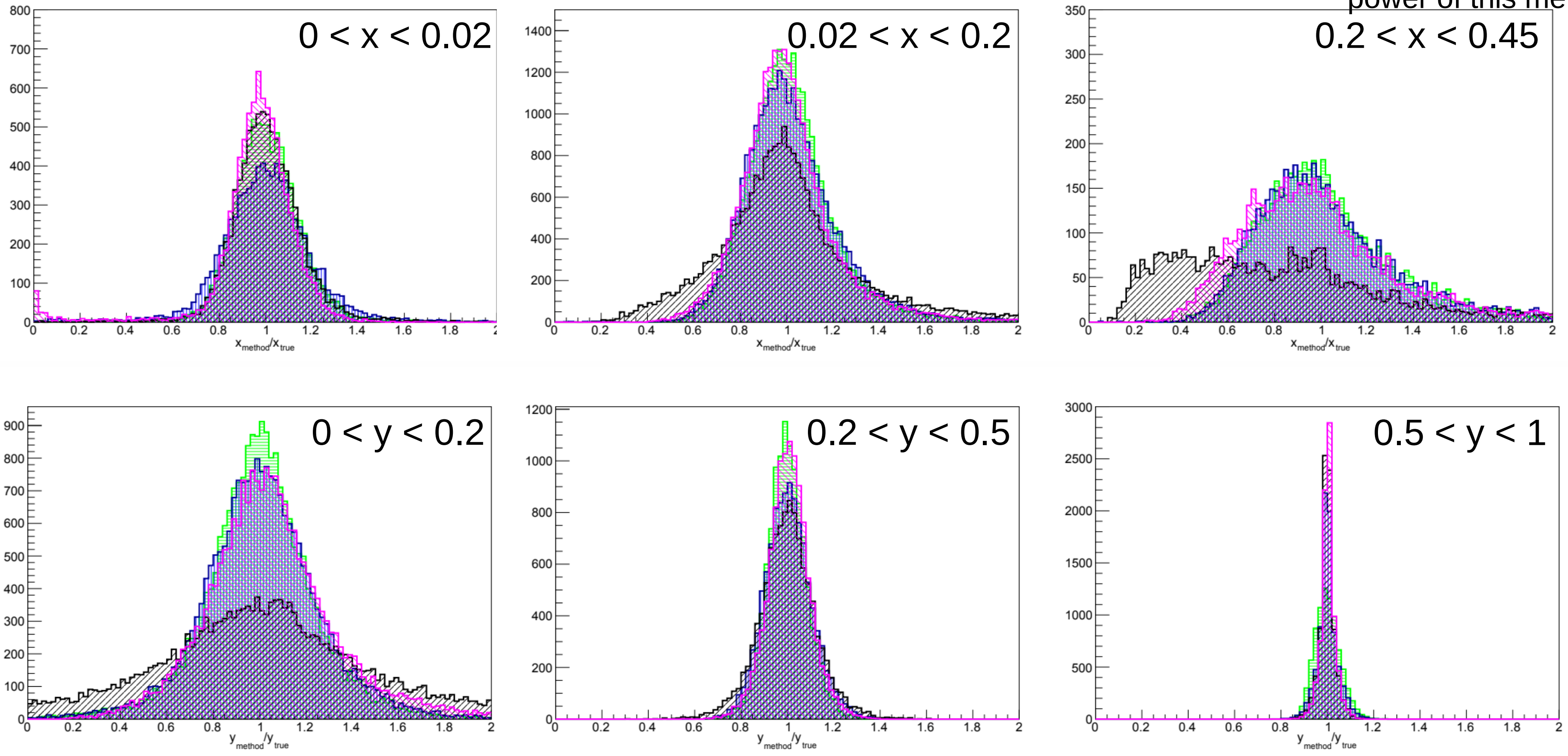
$$P_o(\vec{X}) = \frac{1+(1-y)^2}{x^3y^2}\frac{[1+(1-E_\gamma/A)^2]}{E_\gamma/A}$$

- This gives our initial model parameters x, y, E_γ
- Calculate what values $\vec{D}$ would have if these were our parameters ($\vec{D}_{model}$)
- Determine the likelihood of getting our measured $\vec{D}$ values given the expected distribution of the $\vec{D}_{model}$ variables
- Run Metropolis algorithm (Markov Chain Monte Carlo algorithm) for 100k iterations to find the marginalised posterior
- Output is values of x, y, E_γ at mode of posterior



- * Note that no ISR/FSR is present in the sample
  - → not leveraging full power of this method

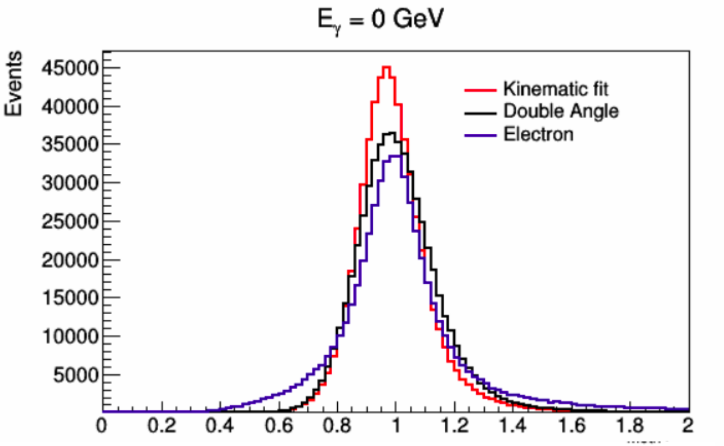
Comparison to conventional reconstruction methods

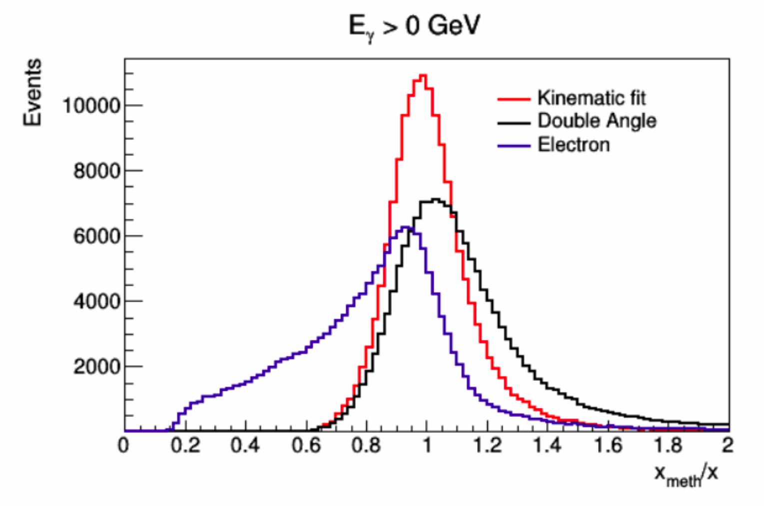


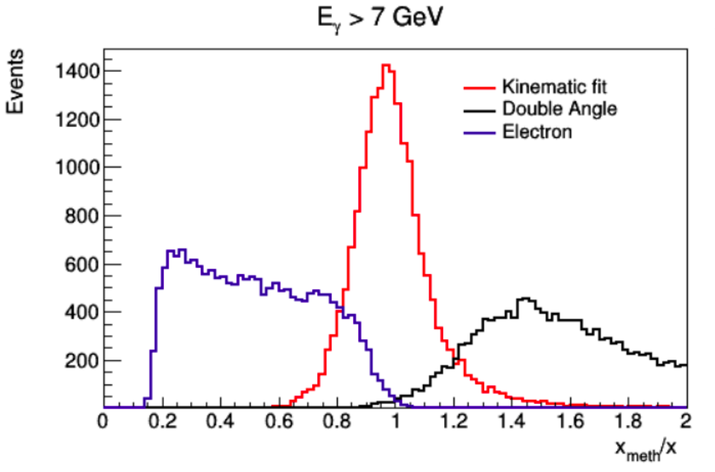
Electron method Double-Angle method e-Σ method Kinematic Fit

If ISR/FSR is present?

- Expect to see large gains compared to traditional reconstruction methods when ISR/FSR is strong





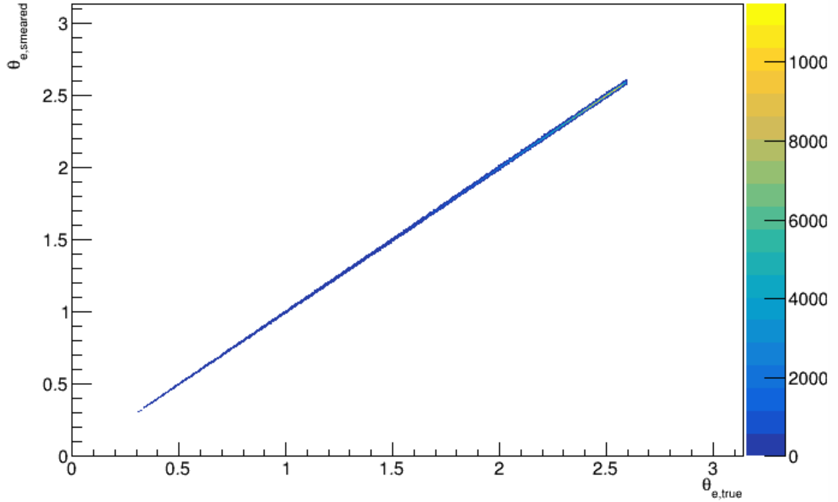


Plots from https://arxiv.org/abs/2206.04897

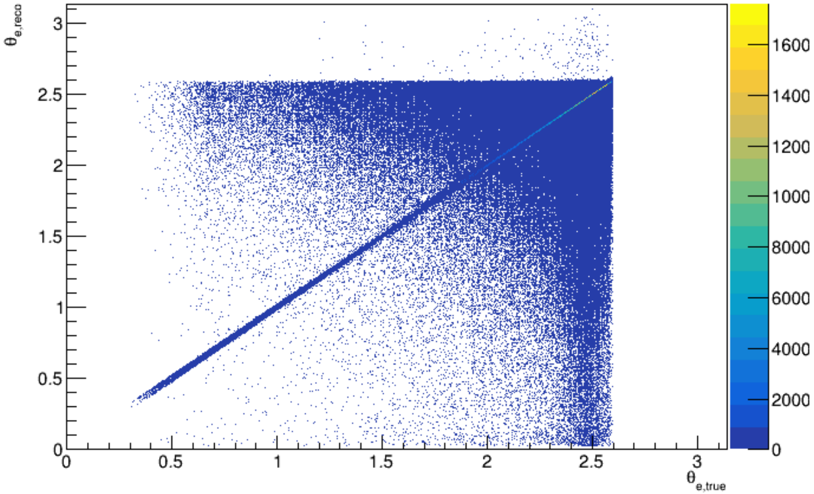
Application to a “real” detector

- Output from full detector simulations (Right) does not match the perfect gaussian distribution we get by smearing
  - We can either parameterise the reconstructed distributions (e.g. using our detector resolutions), or use the distributions to obtain a likelihood function

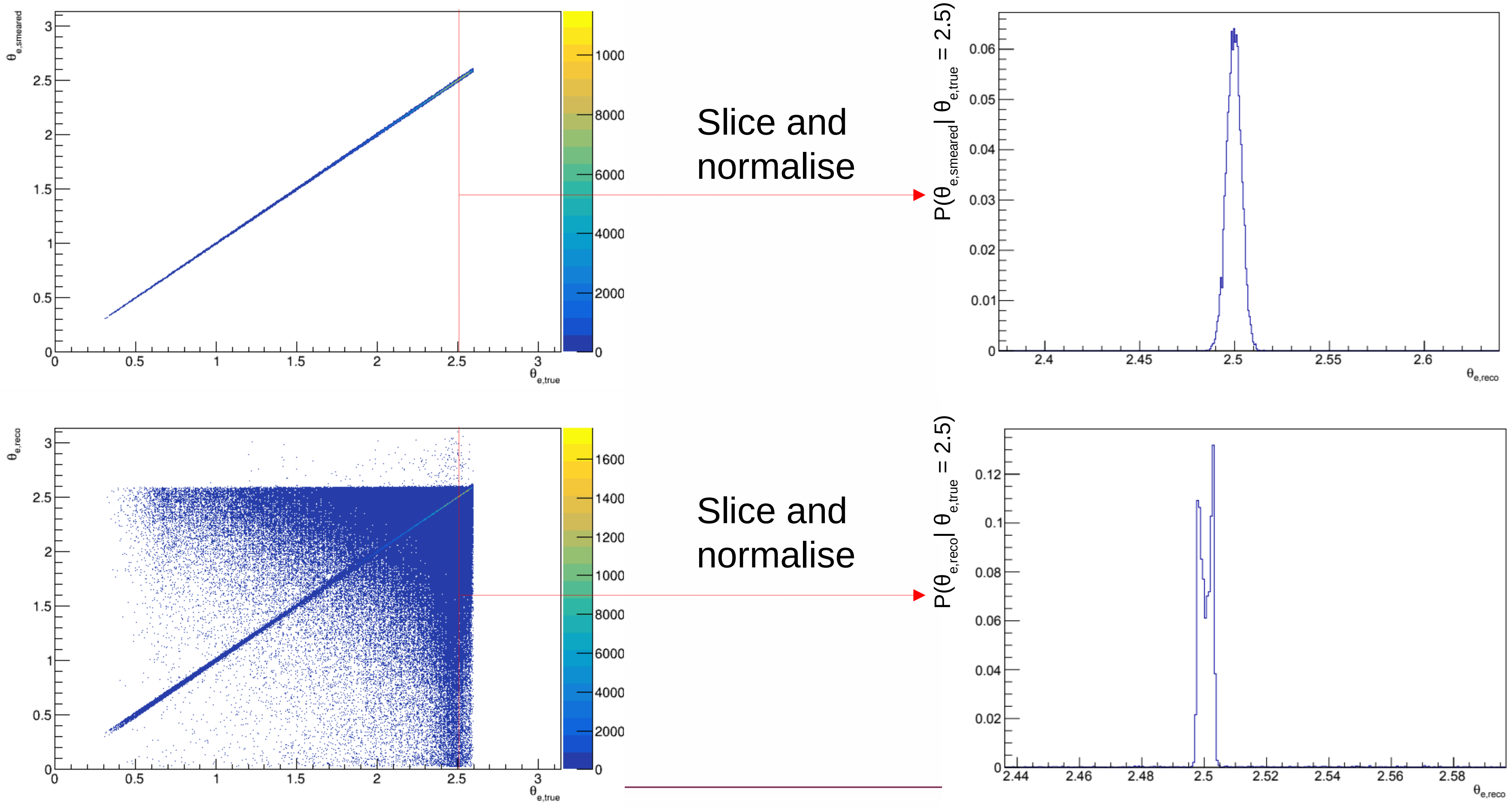
“ZEUS” smeared θ_e



Reconstructed θ_e (from ATHENA full sim)



Probability Distribution from histograms



Summary

- Traditional reconstruction methods do not leverage all of the information available to us:
  - → Using a kinematic fit can obtain a high quality reconstruction and the energy of a possible ISR photon

Next Steps

- Parameterising the quantities in $\vec{D}$ may not lead to the best possible reconstruction
  - → Produce likelihood distribution from MC information → compare against results from parameterisation