UNIVERSITY OF BIRMINGHAM | SCHOOL OF PHYSICS AND ASTRONOMY

# Reconstructing Inclusive variables in Radiative DIS

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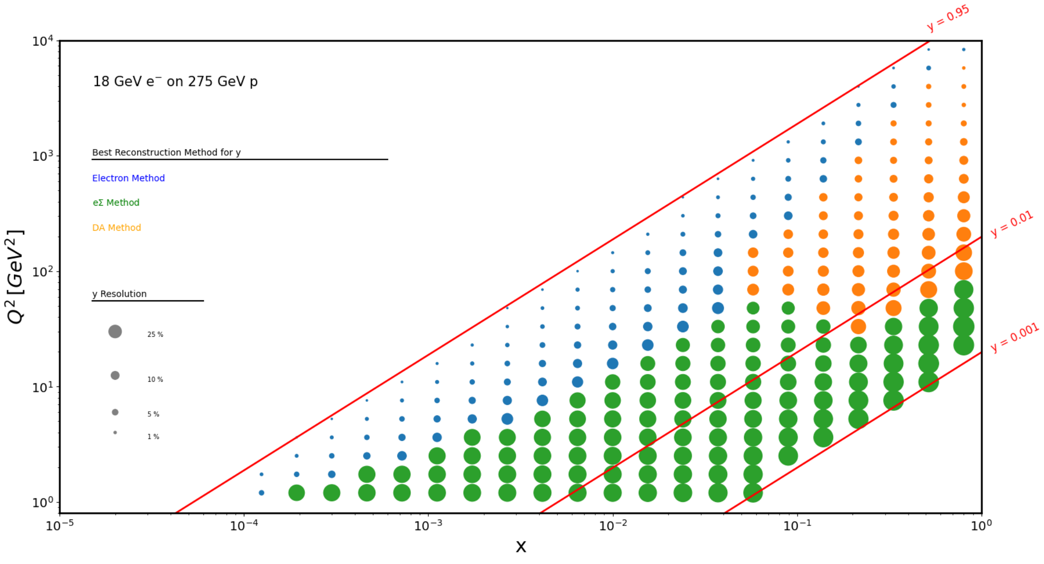
# Kinematic Reconstruction

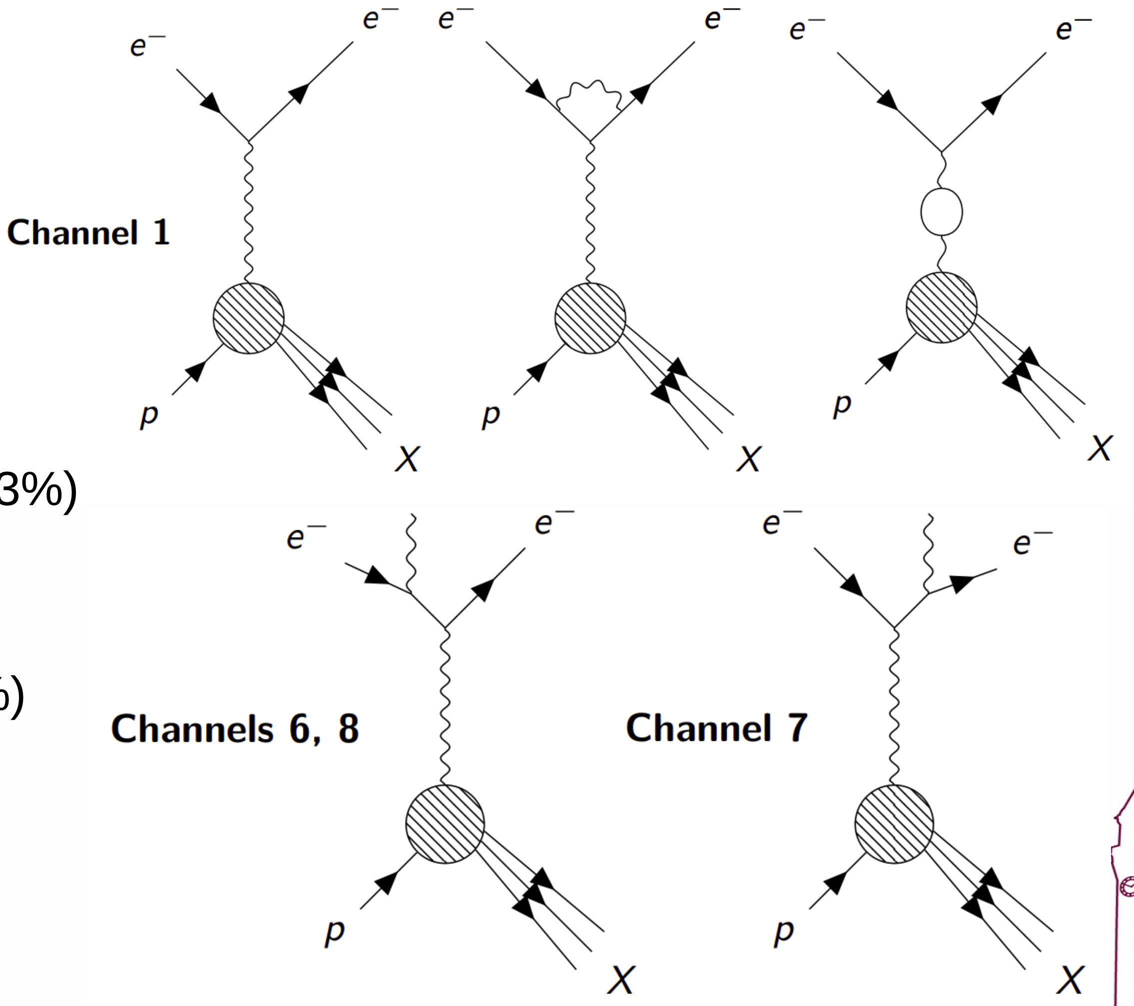
- The kinematics of DIS can be reconstructed from any two of the measured quantities $\vec{D} = \{E_e, \theta_e, \delta_h, p_{t,h}\}$
  - Where $\delta_h = \Sigma\, E_i(1 - \cos(\theta_i))$ . $E_i$ and $\theta_i$ are the energies and angles of deposits in the calorimeters which are not assigned to the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




- Electron and Double angle methods are best for much of the phase space for events without ISR
- Electron method deteriorates at low y and is sensitive to ISR
- DA method is sensitive to ISR
- → Other approaches possible that are less sensitive to ISR

# Event generation

- Djangoh 4.6.10 used to generate 18x275 $GeV^2$ e-p events
  - ISR/FSR=ON
  - $Q^2$>100$GeV^2$
  - W>2GeV
- Channel 1: Non Radiative NC (~53%)
- Channel 6: ISR (~28%)
- Channel 7: FSR (~18%)
- Channel 8: “Compton event” (~1%)

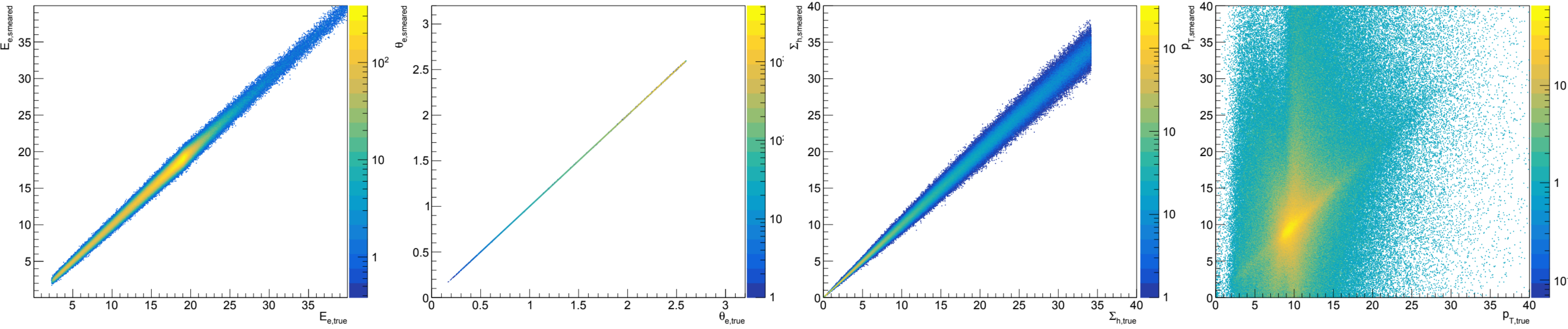


# Smearing

- “True” quantities smeared according to detector matrix:
- Use central/forward ECAL resolution (for $Q^2$>100GeV$^2$ most electrons scattered into barrel)
- Angular resolution requirement not present in detector matrix → 1mrad is conservative estimate

$\delta E/E = 11\%/\sqrt{(E)} \oplus 2\%$

$\delta\theta$ = 1mrad



# Kinematic Fitting in BAT (Bayesian Analysis Toolkit)

- Reconstruction is overconstrained: only need 2 quantities to obtain x, y, $Q^2$
- From the measured quantities $\vec{D} = \{E_e, \theta_e, \delta_h, p_{t,h}\}$ we can use a kinematic fit to reconstruct an additional piece of information: $\vec{\lambda} = \{x, y, E_\gamma\}$
- All we need is a prior and a likelihood function:

**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***

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

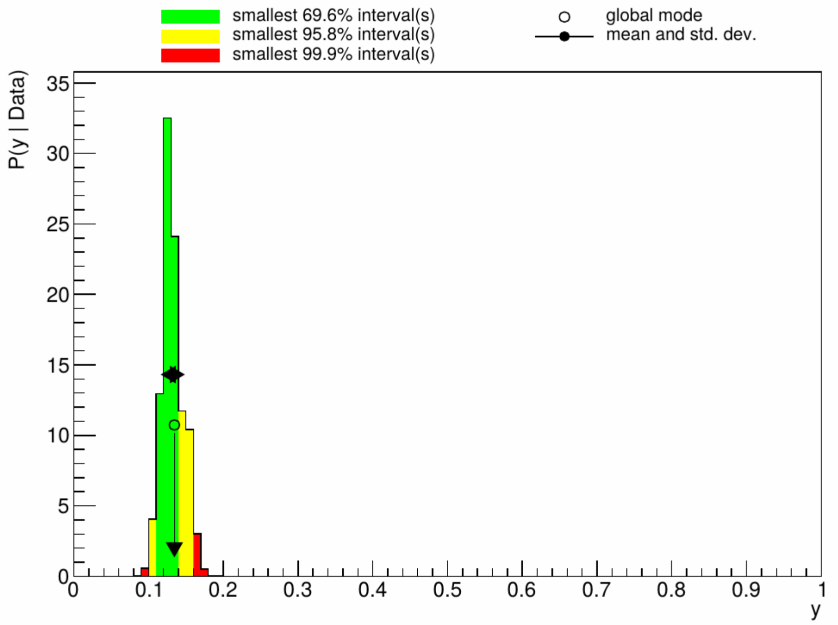
* Likelihood comes from parametrisation of resolution of measured values in $\vec{D}$ according to detector resolution → Required as input for model

# Reconstruction with Kinematic Fit

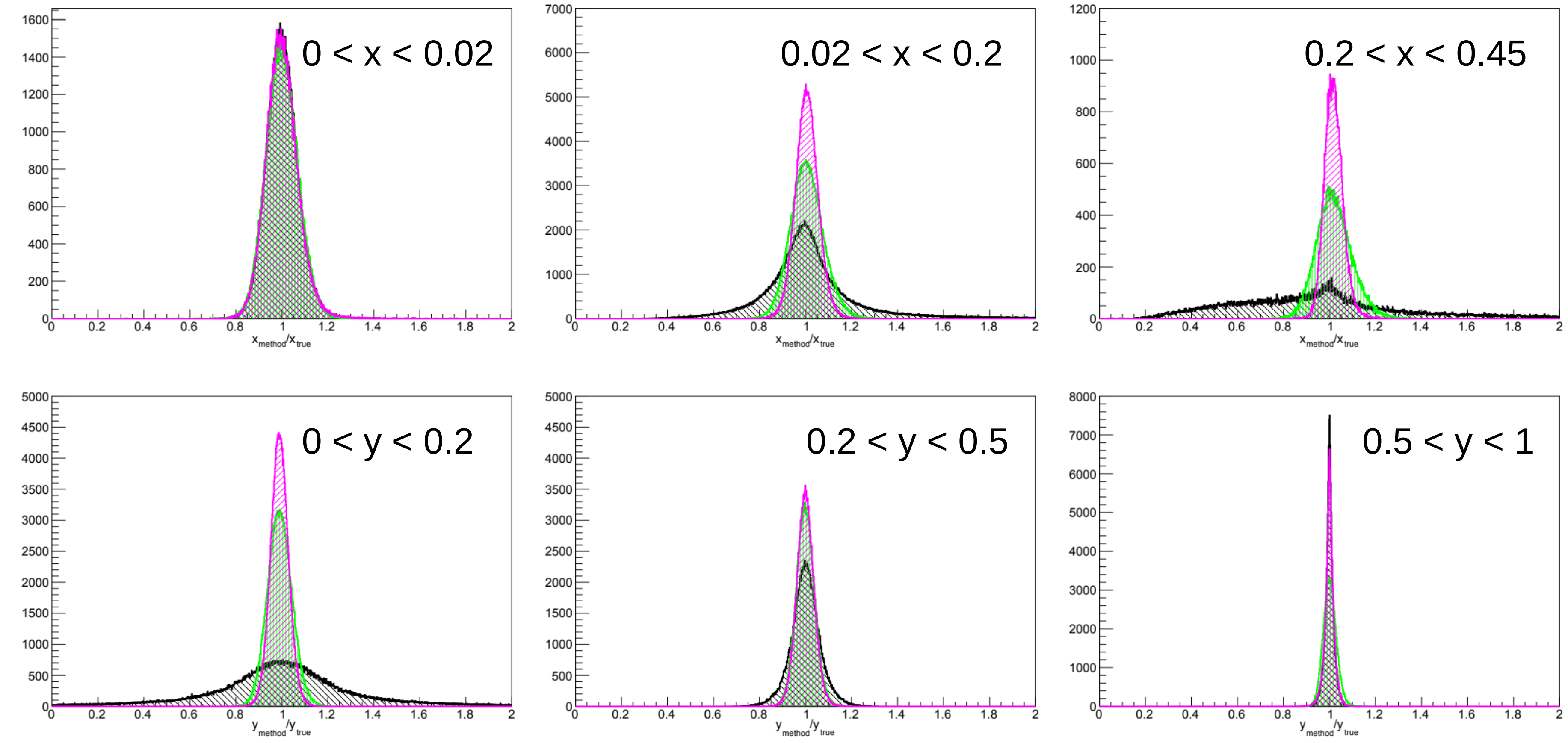
- Input smeared (or reconstructed) variables $\vec{D} = \{E_e, \theta_e, \delta_h, p_{t,h}\}$
- Define prior distribution and likelihood

$$P_o(\vec{\lambda}) = \frac{1+(1-y)^2}{x^3y^2}\frac{[1+(1-E_\gamma/A)^2]}{E_\gamma/A} \quad P(\vec{D}|\vec{\lambda}) \propto \frac{1}{\sqrt{2\pi}\sigma_E}e^{-\frac{(E_e-E_e^\lambda)^2}{2\sigma_E^2}}\frac{1}{\sqrt{2\pi}\sigma_\theta}e^{-\frac{(\theta_e-\theta_e^\lambda)^2}{2\sigma_\theta^2}}\frac{1}{\sqrt{2\pi}\sigma_{\delta_h}}e^{-\frac{(\delta_h-\delta_h^\lambda)^2}{2\sigma_{\delta_h}^2}}\frac{1}{\sqrt{2\pi}\sigma_{P_{T,h}}}e^{-\frac{(P_{T,h}-P_{T,h}^\lambda)^2}{2\sigma_{P_{T,h}}^2}}$$

- Uniformly distribute parameters x, y, $E_\gamma$ until initial parameters with valid probability are found
- Run Metropolis algorithm (MCMC):
  - Propose new values of parameters and use likelihood and prior information to decide whether to accept the change
  - Update posterior distribution and repeat for new values
- Output values of x, y, $E_\gamma$ at mode of posterior

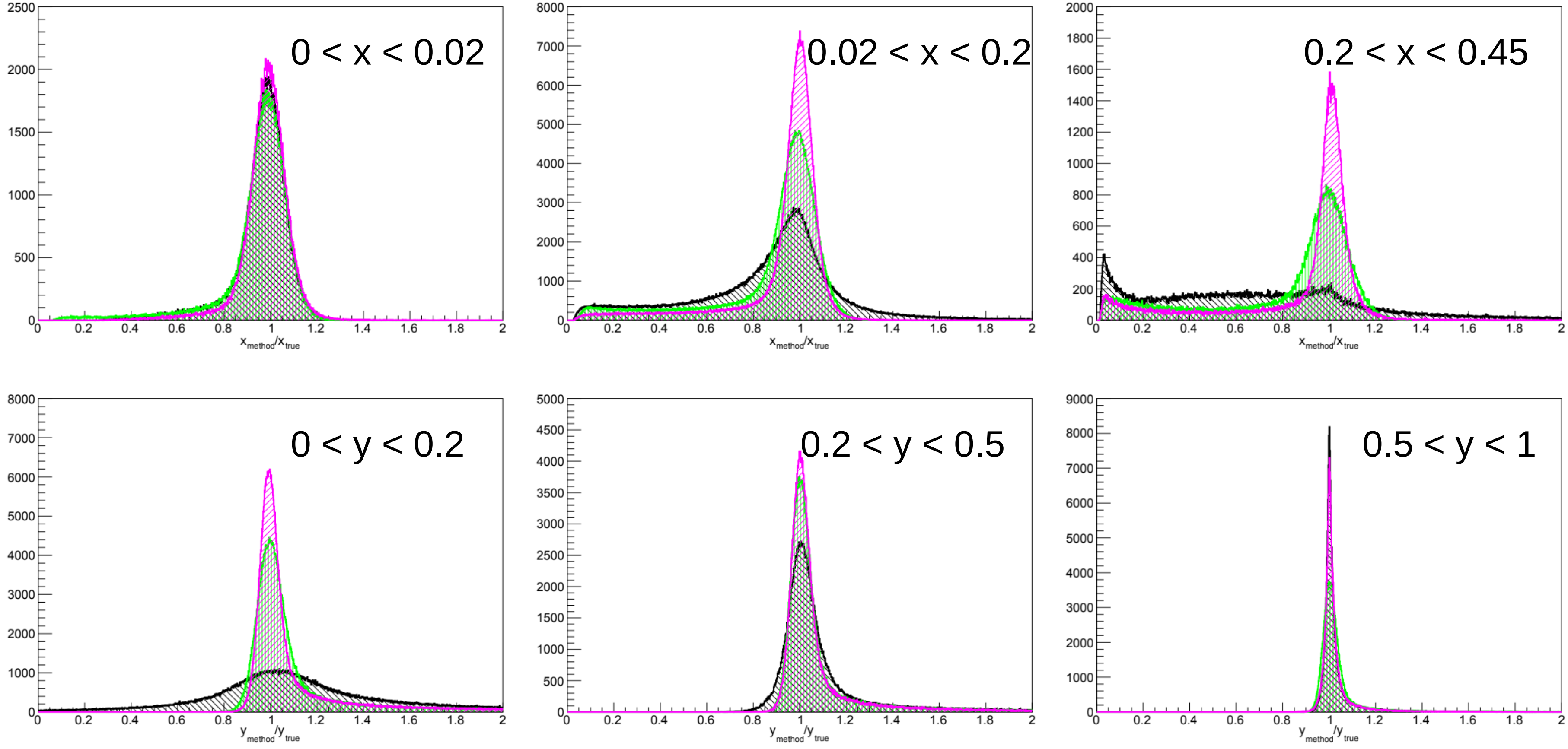


# Comparison to to conventional methods – Channel 1 only




Electron method    e-Σ method    Kinematic Fit

# Comparison to to conventional methods – All Channels

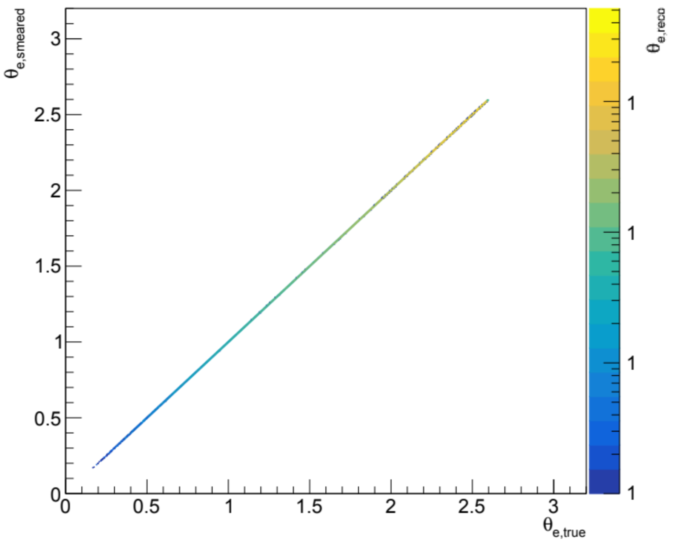



Electron method    e-Σ method    Kinematic Fit

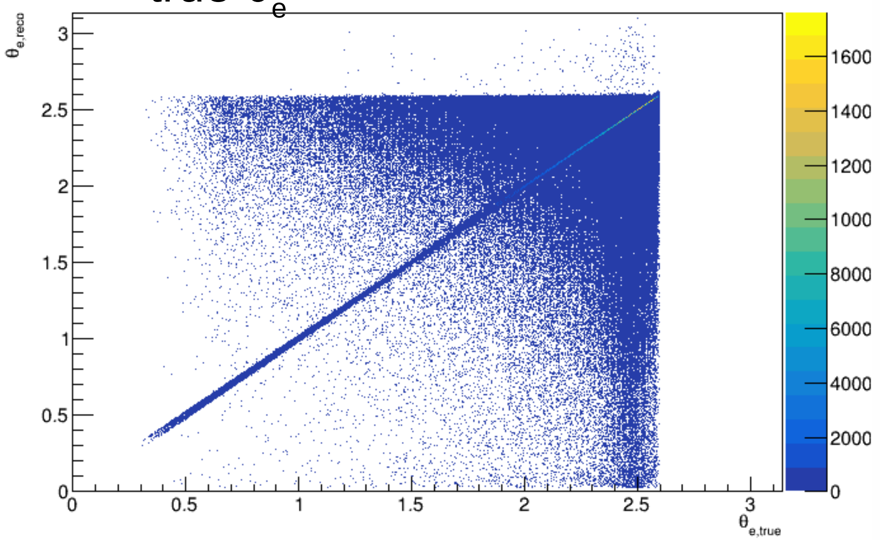
# Reconstructing a realistic detector output with kinematic fit

- The output of a “real” detector is not nearly as clean as gaussian smeared truth information

1mrad smeared $\theta_e$ vs true $\theta_e$




Reconstructed $\theta_e$ from Athena full simulations vs true $\theta_e$




*note that no ISR/FSR present for Athena full simulations

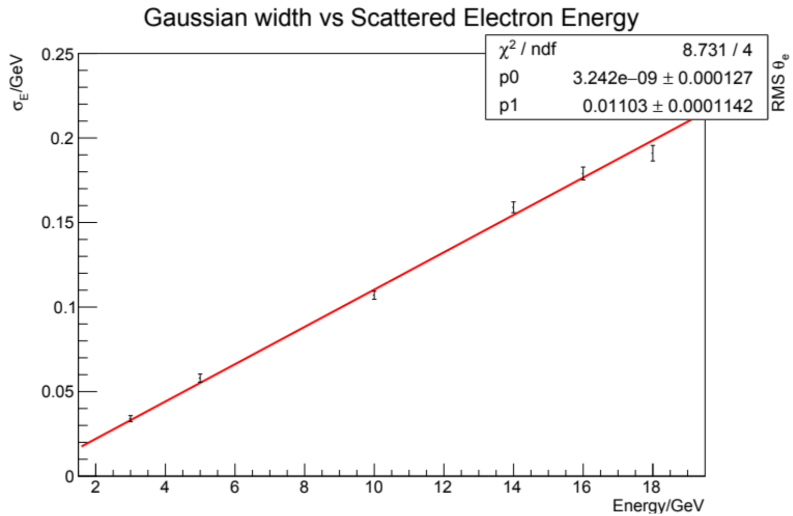
# Reconstructing a realistic detector output with kinematic fit

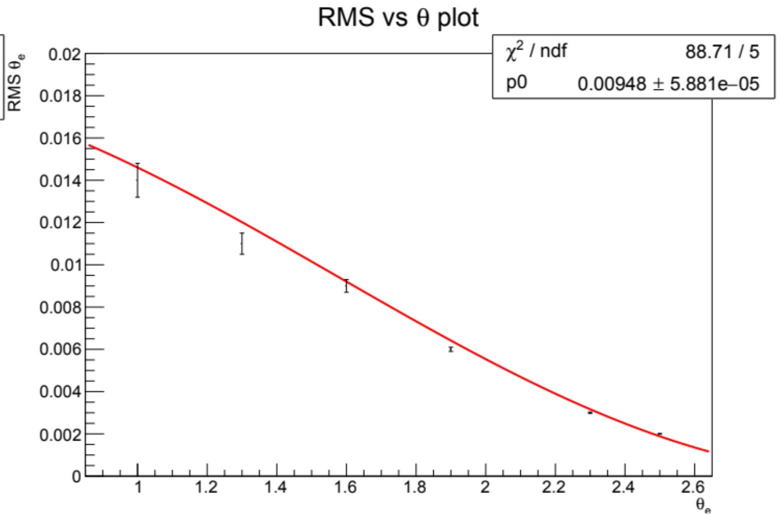
- For kinematic fit, just need a prior and a means of calculating the likelihood
  - One way to calculate the likelihood is to continue with the approximation that the reconstructed variables $\vec{D} = \{E_e, \theta_e, \delta_h, p_{t,h}\}$ are uncorrelated, and gaussian distributed according to a known width:

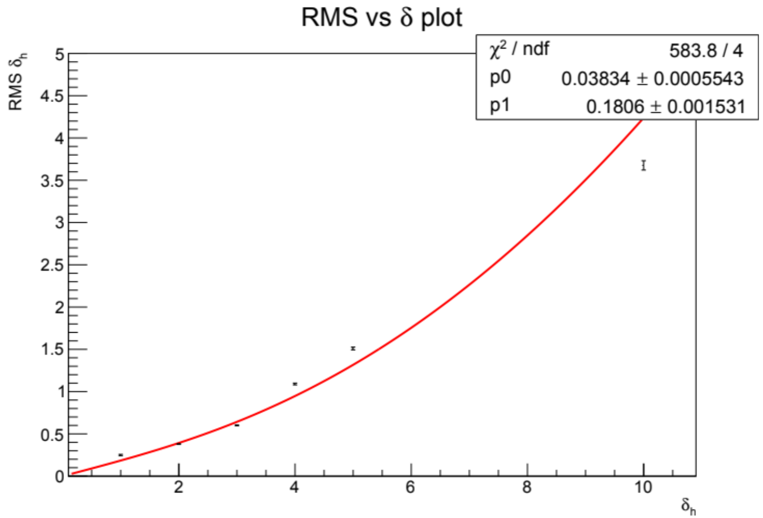
$$P(\overrightarrow{D}|\overrightarrow{\lambda}) \propto \frac{1}{\sqrt{2\pi}\sigma_E} e^{-\frac{(E_e - E_e^\lambda)^2}{2\sigma_E^2}} \frac{1}{\sqrt{2\pi}\sigma_\theta} e^{-\frac{(\theta_e - \theta_e^\lambda)^2}{2\sigma_\theta^2}} \frac{1}{\sqrt{2\pi}\sigma_{\delta_h}} e^{-\frac{(\delta_h - \delta_h^\lambda)^2}{2\sigma_{\delta_h}^2}}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

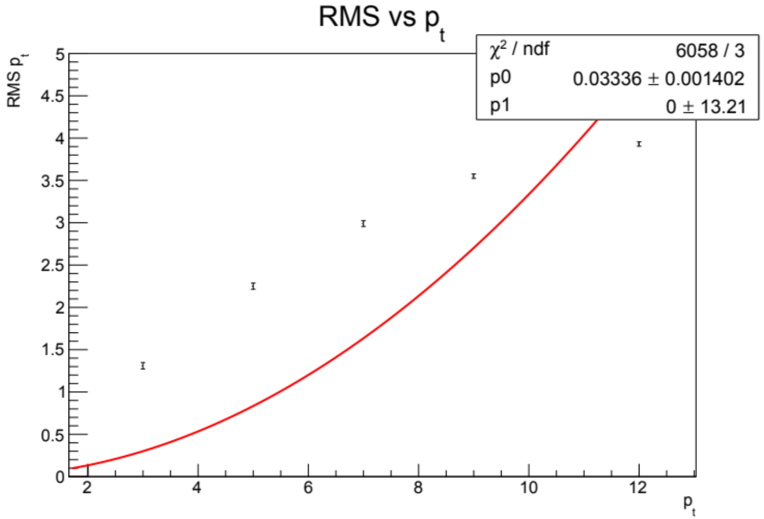
- Issues arise when attempting to obtain a resolution for this approximation:
  - Functional dependence of resolution on variables is not always obvious
  - Distribution of reconstructed variables w.r.t. true variables is often not Gaussian (for these reconstructed events)
  - → for these preliminary studies, where a gaussian fit is not possible the RMS value is used instead

# Reconstructing a realistic detector output with kinematic fit



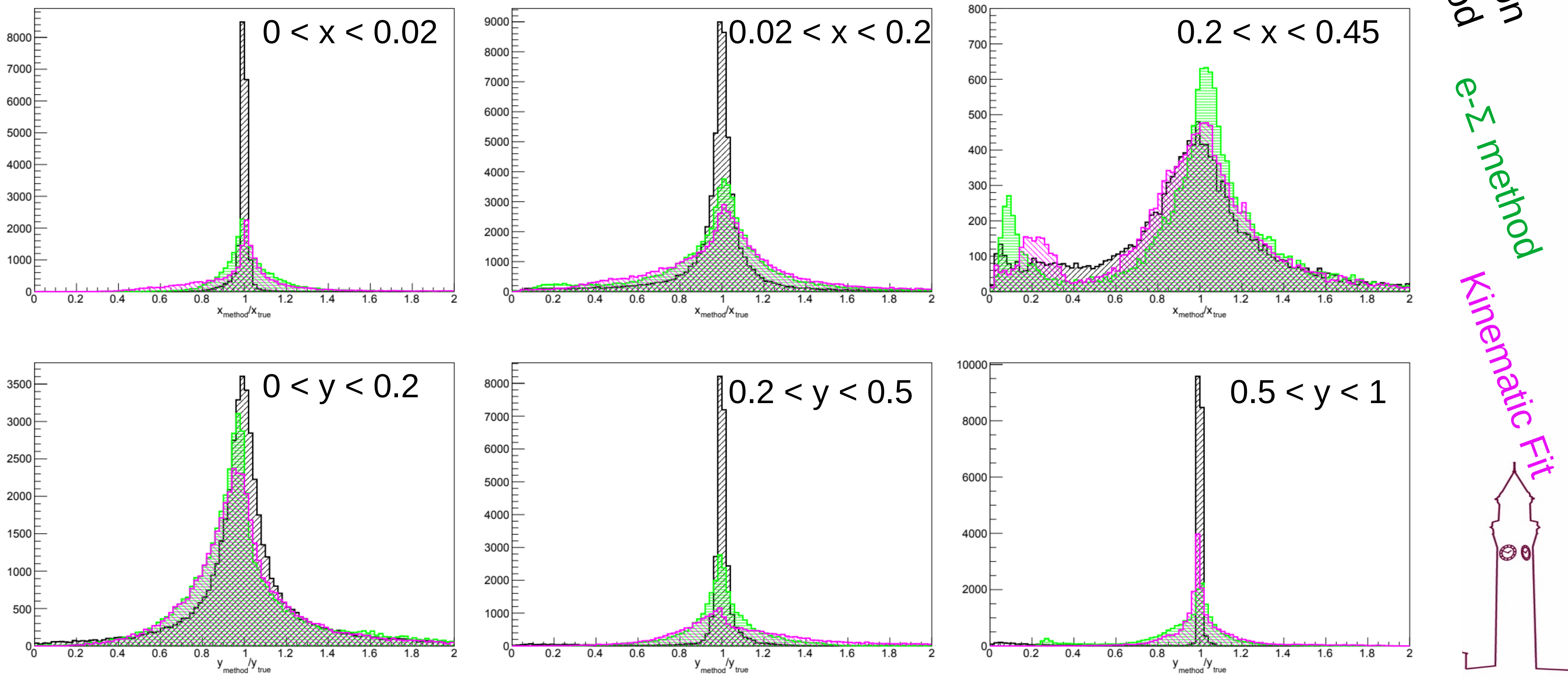




See here a **<u>very</u>** basic first effort at parametrising the Athena reconstructed variables

* Note that tracks are used for electron energy calculation in Athena reconstruction

# Reconstructing a realistic detector output with kinematic fit

- Input these parametrisations into kinematic fit → see that a poor parametrisation leads to a worse fit



# 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

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