UNIVERSITY OF BIRMINGHAM | SCHOOL OF PHYSICS AND ASTRONOMY
ePIC

Kinematic Fitting for NC-DIS at the EIC

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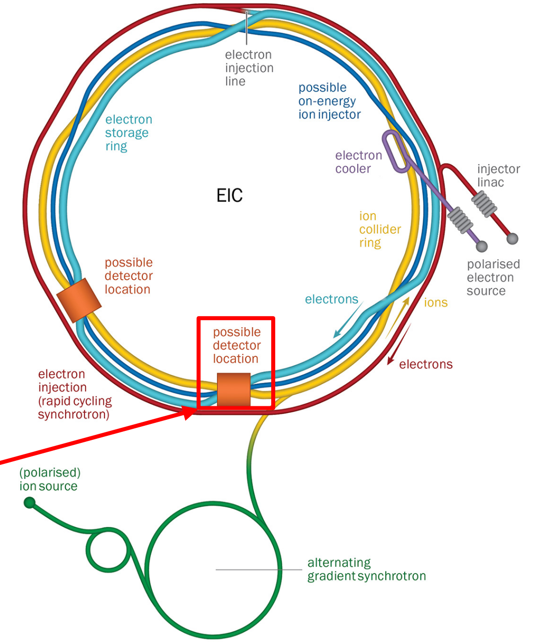
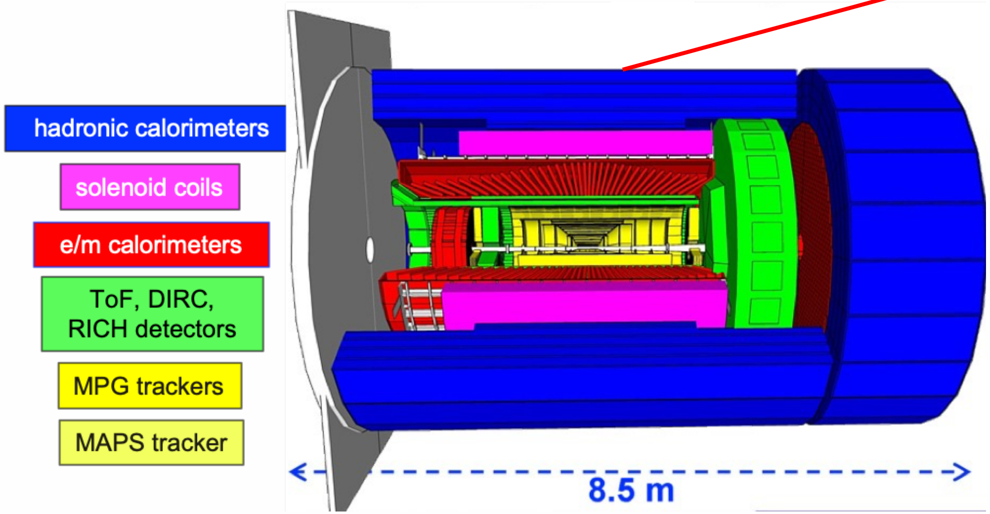
… and thanks to the ePIC collaboration

ePIC @ EIC

- The EIC is a future collider with:
  - High luminosity: $\mathscr{L}_{max}$ **= 10^{34} cm^{-2}s^{-1}**
  - Variable $\sqrt{s_{ep}}$: ranging from **28 to 140 GeV**
  - High polarisation: **~70%** for e, light nucleon
  - Ion beams: Proton to Uranium

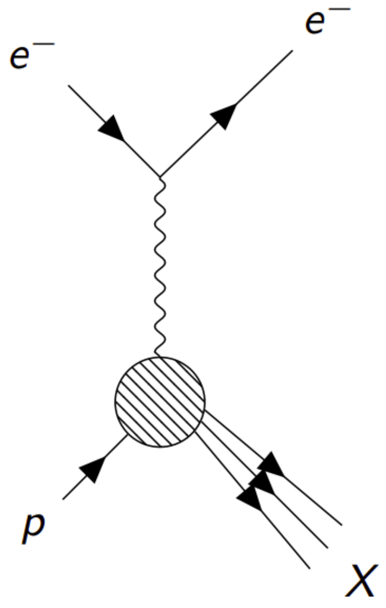




- ePIC is a general purpose EIC detector:
  - **Large η coverage:** |η|<4 in main detector, far forward detectors for higher |η|
  - **High precision + low material** tracking system
  - Excellent particle ID capabilities
  - High performance EM calorimetry

Inclusive NC DIS Kinematics

- DIS kinematics can be reconstructed from **two measured quantities**
  → $\vec{D} = \{E_e, \theta_e, \delta_h, p_{t,h}\}$
  - Where δ_h is $E - p_z$ sum of all particles in the Hadronic Final State: $\Sigma E_i(1 - \cos\theta_i)$
  - $P_{t,h}$ is the transverse momentum of the HFS
- Resolution of conventional reconstruction methods depend on:
  - Event x-Q^2
  - Detector acceptance and resolution effects
  - Size of radiative processes



Electron method

$$Q^2 = 2E_eE'_e(1+\cos\theta_e)$$

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

JB method

$$y = \frac{\delta_h}{2E_e}$$

$$Q^2 = \frac{p_{t,h}^2}{1-y}$$

e-Σ method

$$Q^2_{e\Sigma} = Q^2_e \quad y_\Sigma = \frac{\delta_h}{\delta_h + \delta_e}$$

$$x_{e\Sigma} = \frac{Q^2_\Sigma}{s y_\Sigma} \quad Q^2_\Sigma = \frac{p^2_{t,e}}{1-y_\Sigma}$$

Double Angle method

$$y_{DA} = \frac{\alpha_h}{\alpha_h + \alpha_e} \quad \alpha_{e/h} = \tan\frac{\theta_{e/h}}{2}$$

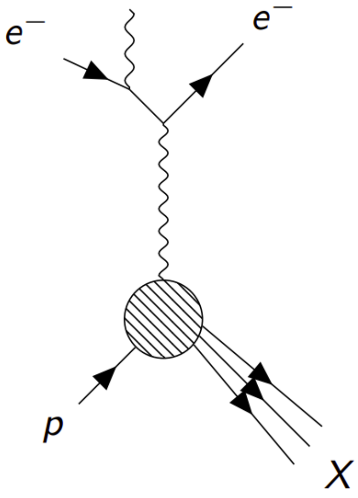
$$Q^2_{DA} = \frac{4E_e^2}{\alpha_e(\alpha_e + \alpha_h)}$$

Inclusive NC DIS Kinematics with QED radiation

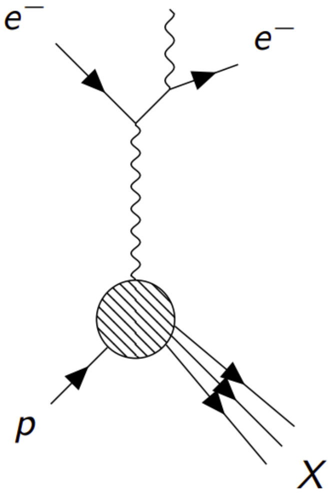
- Presence of **QED radiation changes event kinematics** → Errors in reconstruction when only using two measured quantities

- **FSR not too problematic**: typically collinear to scattered electron → measured together in ECAL

- **ISR more difficult to account for**: reduces electron beam energy, radiated photon typically disappears down beampipe



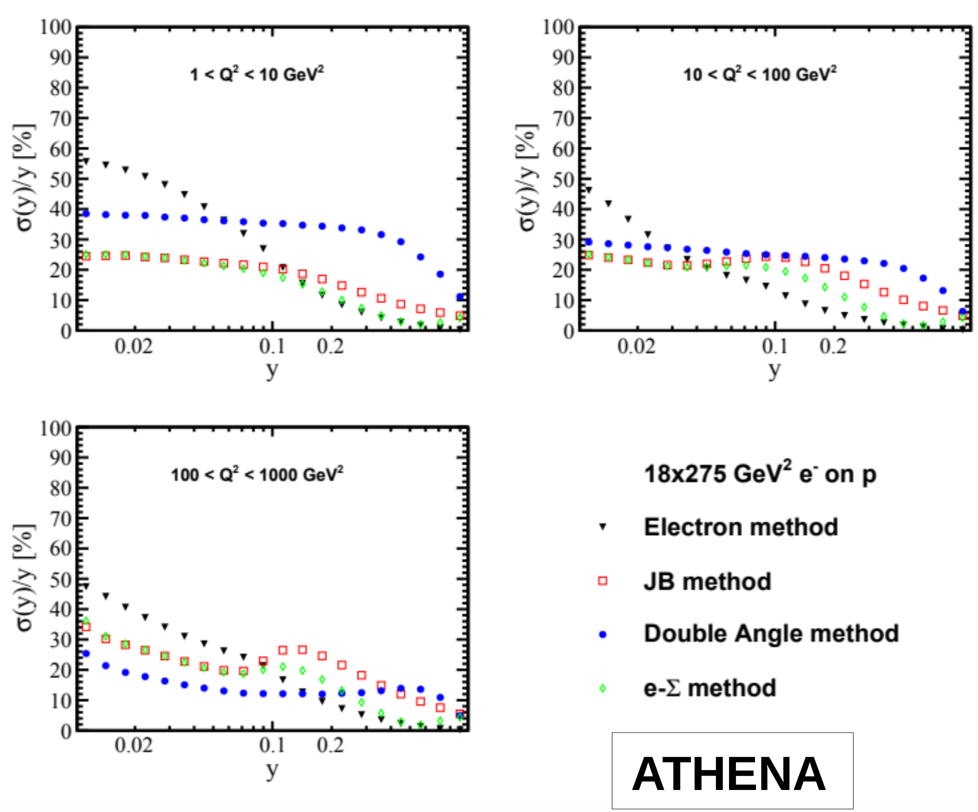
ISR

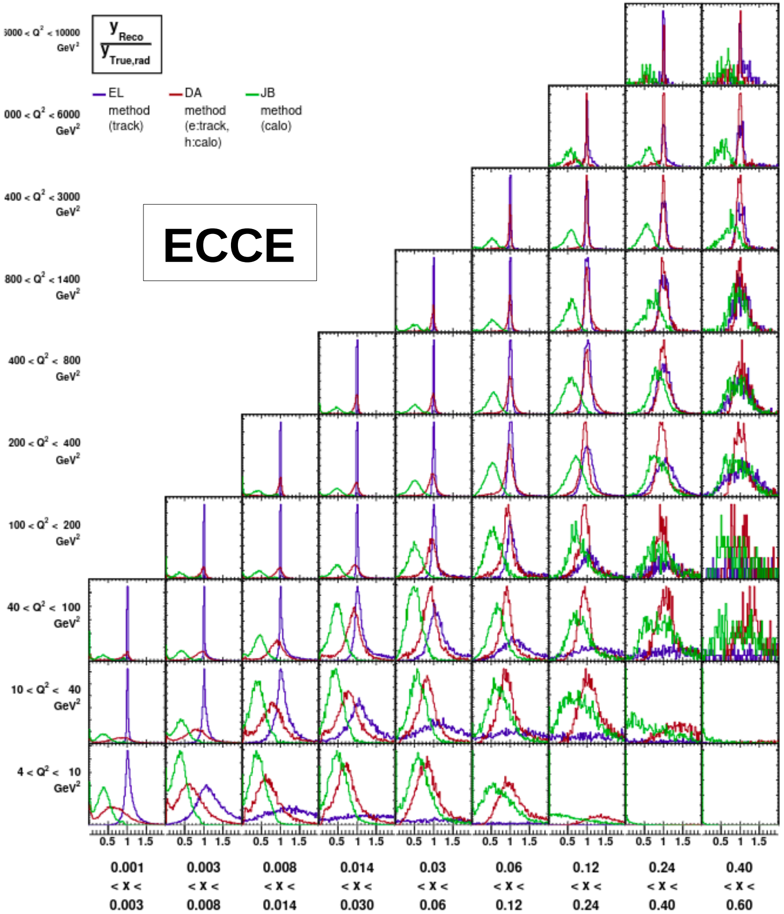


FSR

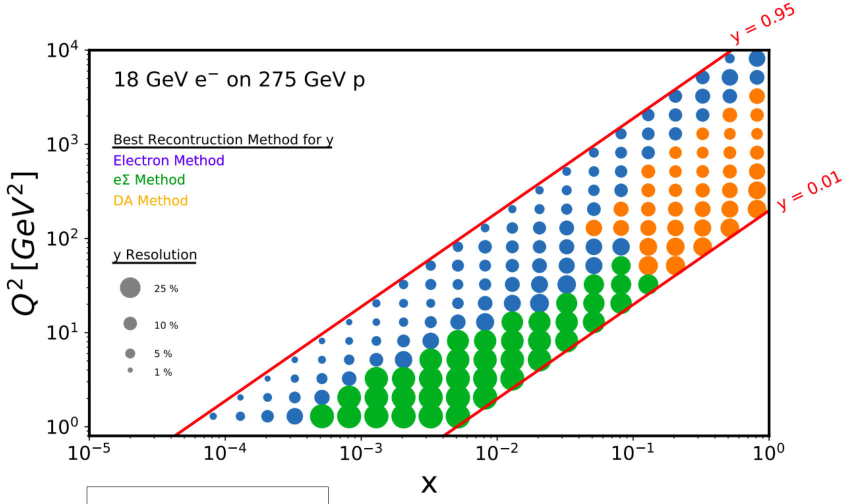
Kinematic Reconstruction for EIC – A Brief History

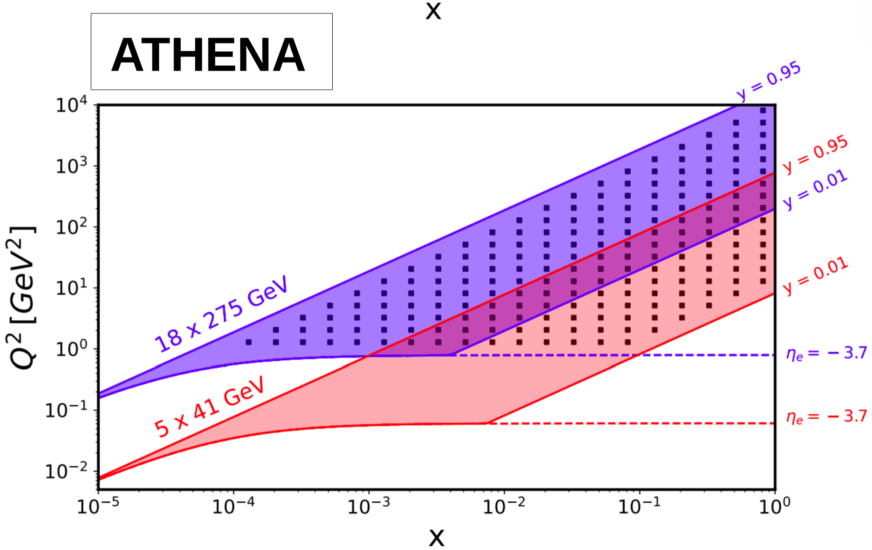
- Assessment of **relative performance of reconstruction methods** for measured phase space in ECCE and ATHENA proposals (1st approximation to particle flow algorithm)





Kinematic Reconstruction for EIC – A Brief History





- Detailed simulations performed, reconstruction methods chosen to optimise resolutions throughout phase space
  → Resolution throughout phase space allowing 5 (log) bins per decade in x and Q^2

- Coverage driven by acceptance:
  - $0.01 < y < 0.95$, $Q^2 > 1$ GeV^2

- Lower y accessible → however it's easier to rely on overlap between data at different √s

Credit where credit is due…

- Kinematic Fitting studies shown here follow on from those shown at DIS2022 by A. Caldwell exploring this method in the context of ZEUS
- **Aim is to extend this method to fully simulated events at ePIC**

KINEMATIC FITTING OF NEUTRAL CURRENT EVENTS IN DEEP INELASTIC ep COLLISIONS.

3 May 2022, 18:30
20m

Posters | WG6: Future Experi... | WG6: Future Experime...

Speaker

Prof. Allen Caldwell (MPP)

Description

We present a technique to reconstruct the scaling variables defining ep deep inelastic scattering based on a kinematic fit. Most techniques in use rely only on two of the four available quantities(energy and angle of the electron and struck quark), while the kinematic fit uses all available information simultaneously. Initial state radiation is included in the framework. The fitting is performed in a Bayesian framework [1] and informative priors are used for the relevant quantities fitted. The method has been tested on a simulated neutral current ep sample at a center of mass energy of 318 GeV with $Q^2 > 400\ GeV^2$, spanning the $x > 10^{-2}$ phase space. A significantly better resolution in the reconstruction of the scaling variables is achieved.

Submitted on behalf of a Collaborat... No

Kinematic fitting of neutral current events in deep inelastic *ep* collisions.

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ABSTRACT: In this paper we present a technique to reconstruct the scaling variables defining *ep* deep inelastic scattering by performing a kinematic fit. This reconstruction technique makes use of the full potential of the data collected. It is based on Bayes' Theorem and involves the use of informative priors. The kinematic fit method has been tested using a simulated sample of *ep* neutral current events at a center of mass energy of 318 GeV with $Q^2 > 400\,\mathrm{GeV}^2$. In addition to the scaling variables, this method is able to estimate the energy of possible initial state radiation (E_γ) which otherwise goes undetected. A better resolution than standard electron and double angle techniques in the reconstruction of scaling variables is achieved using a kinematic fit.

KEYWORDS: Analysis and statistical methods; Large detector systems for particle and astroparticle physics; Performance of High Energy Physics Detectors; Calorimeters

ARXIV EPRINT: 2206.04897

Kinematic Fitting for DIS

- Only **need** 2 quantities to obtain **x, y, Q^2**

- Using measured quantities $\vec{D} = \{E_e, \theta_e, \delta_h, p_{t,h}\}$ a kinematic fit can extract additional information: $\vec{\lambda} = \{x, y, E_\gamma\}$

E_γ is energy of an ISR photon

- For kinematic fit, can use a **likelihood** function based on knowledge of the detector resolutions:

Likelihood

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

- Note: above quantities taken to be uncorrelated → Correlations between E_e, θ_e and δ_h, $p_{t,h}$ will later need to be taken into account

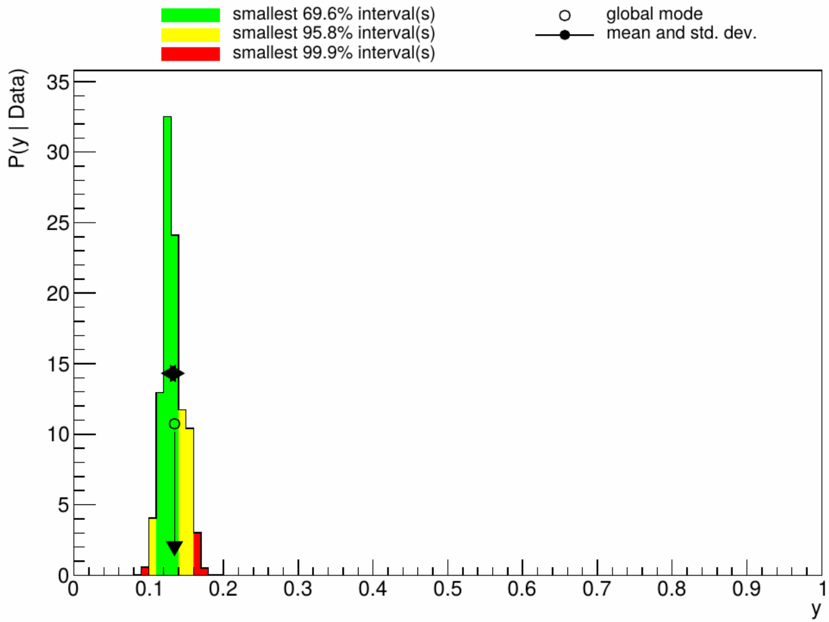
Kinematic Fitting for DIS – A Bayesian Approach

- A Bayesian method can be applied in which basic features of the DIS cross section are encoded as a **prior**:

Prior

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

- Use "Bayesian analysis toolkit" to calculate most probable values of set $\vec{\lambda}$ given measured quantities $\vec{D}$
  - Values for **x, y, E$_\gamma$** taken from global mode



Marginalised **y** distribution for a single DIS event

EIC Detector Parametrisations

- Test kinematic fitting approach using MC data smeared by known parameters
- Performance requirements for an EIC detector defined: see "Detector Matrix" in Yellow Report
  - Smearing parameters chosen based on requirement matrix

$\sigma(E_e)/E_e = 11\% \oplus 2\%$

$\sigma(\theta_e) = 1$ mrad

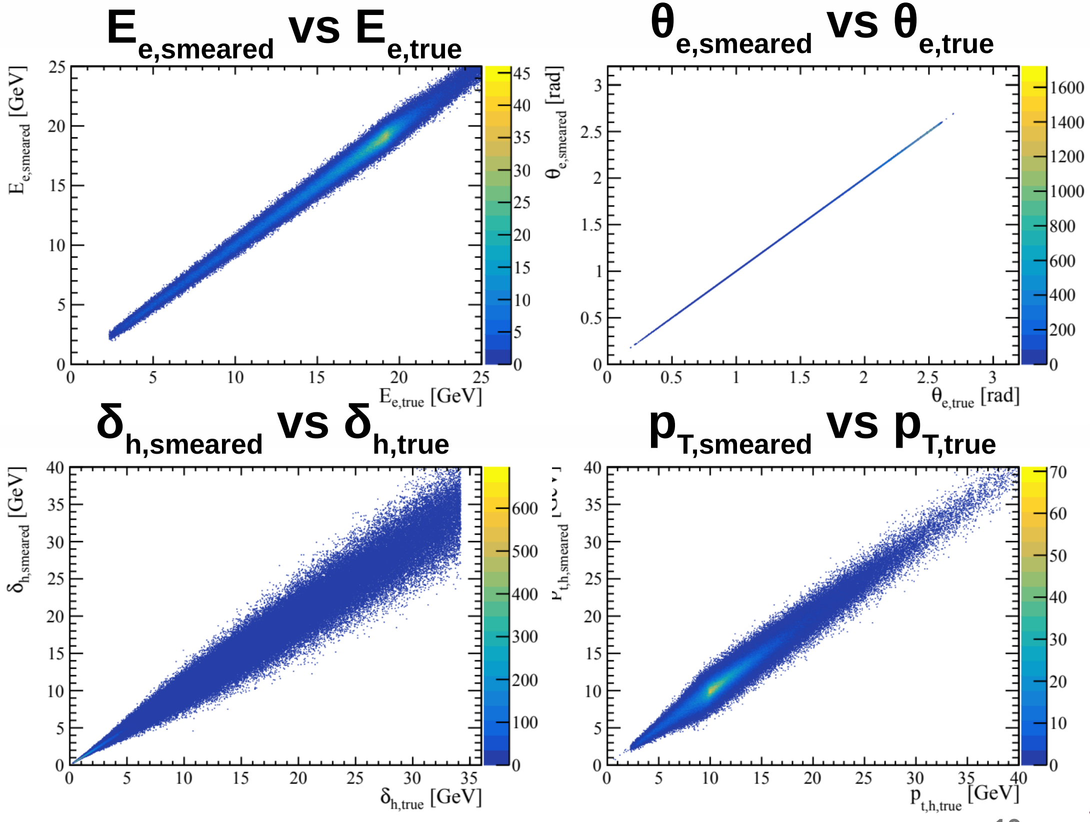
$\sigma(\delta_h) / \delta_h = 35\% / \sqrt{E_h}$

$\sigma(p_{t,h}) / p_{t,h} = 35\%\ p_{t,h} / \sqrt{E_h}$

Perfect knowledge of "resolutions" → use these as input for fit

- Generated e-p NC DIS events with Djangoh at 18x275 GeV^2
  - **ISR+FSR=ON**
  - **Q^2>100 GeV^2**
  - **W>2 GeV**

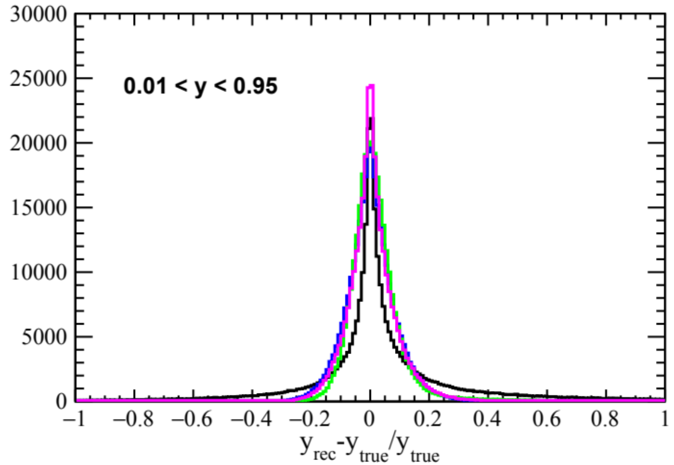
~53% Non Radiative
~28% ISR
~18% FSR



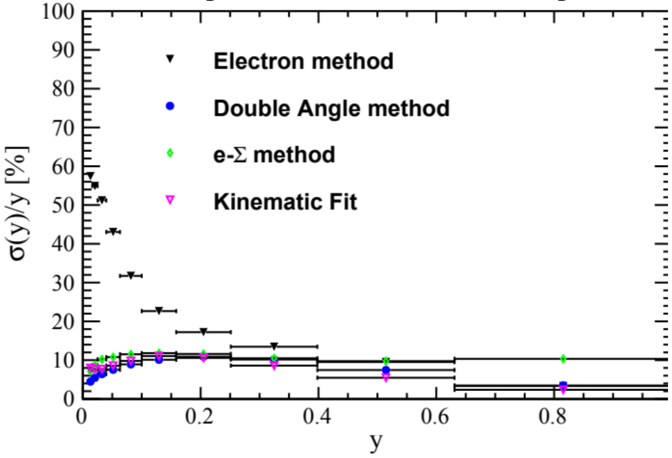
Kinematic Resolutions (smeared MC)

- Kinematic fit generally follows performance of best method for a given bin:
  - "Resolution" is RMS of (rec – true) / true histogram for a given bin
  - Note events are $Q^2 > 100$ GeV^2 → quite high for EIC energies (hence DA method does well)
  - Excellent Q^2 resolution!

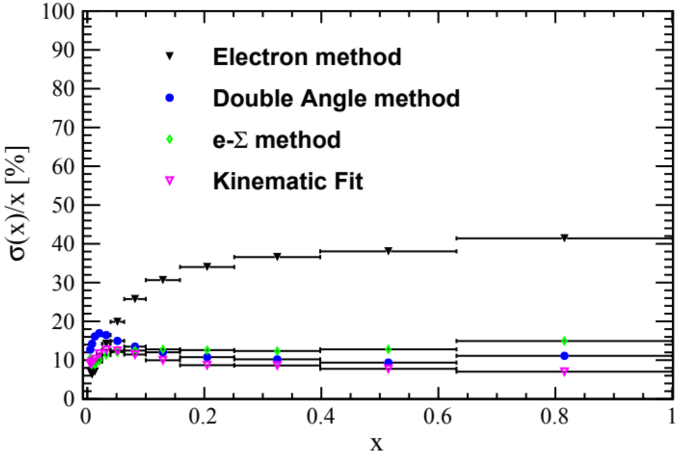
y_{rec}-y_{true}/y_{true} for 0.01 < y < 0.95



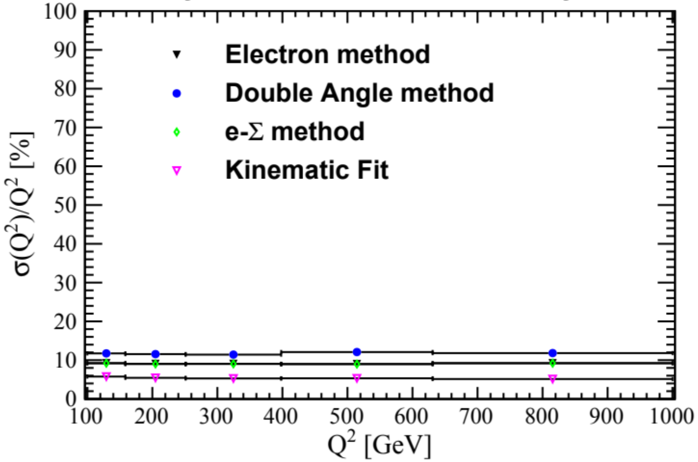
y resolution vs y



x resolution vs x

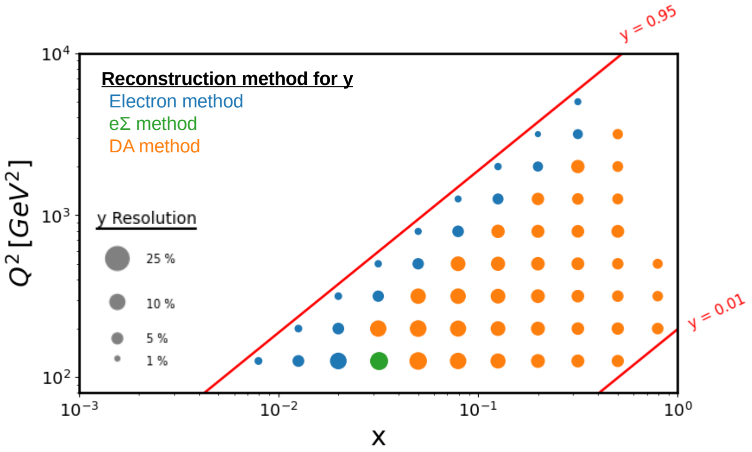


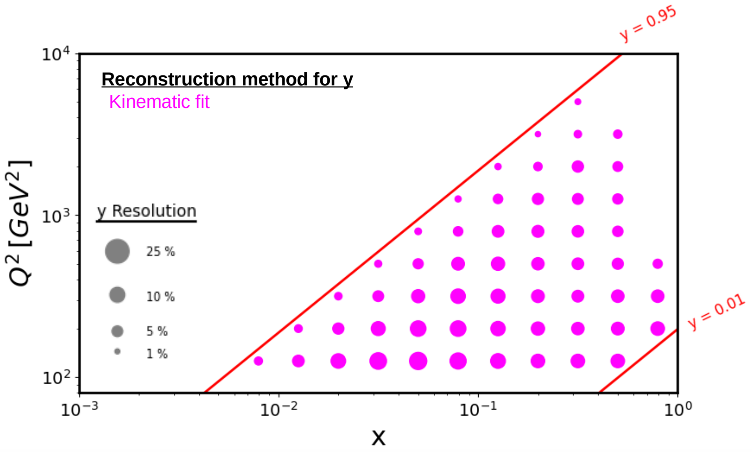
Q^2 resolution vs Q^2



Kinematic Resolutions (smeared MC)

- **Kinematic fit keeps up with best performing method in terms of y reconstruction!**

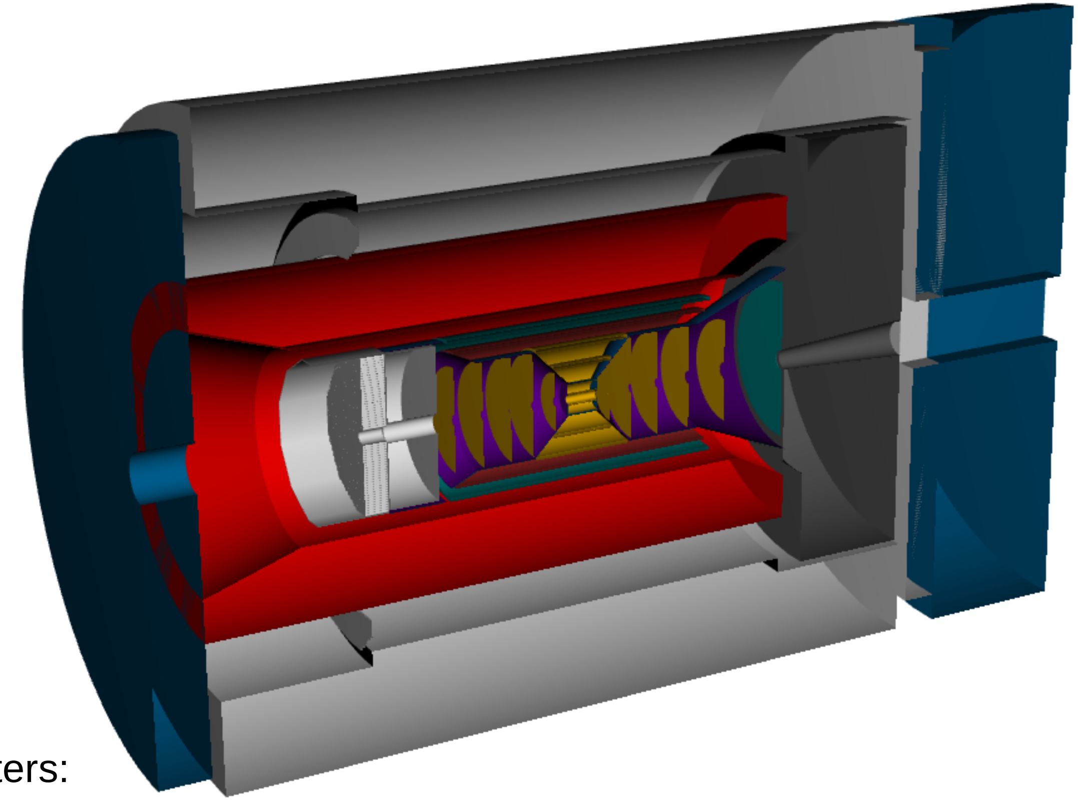




ePIC Full Simulations

- Full simulation of Neutral Current DIS events in ePIC main detector
  - Pythia8 event generation
    - No QED corrections
    - 18x275 GeV^2 e on p
    - $Q^2 > 100\ GeV^2$
    - Beam effects included

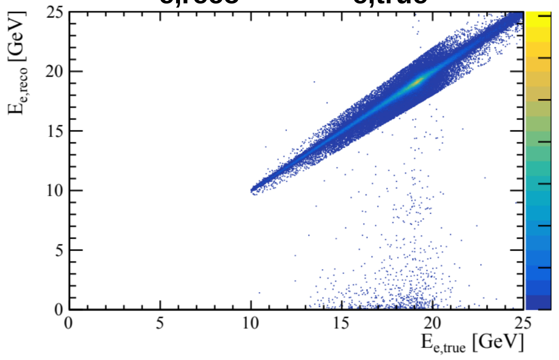
- Event reconstruction in Juggler (Gaudi-based reconstruction for EIC)
  - All charged particles taken from track measurements (ACTS)
  - Track projections matched to calorimeter clusters: → All clusters not associated with a track are added in as a neutral particle!



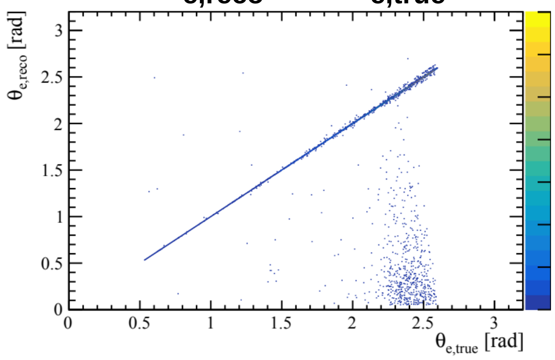
Kinematic Fitting of Full Simulation output

- Choose events to be processed:
  - Select events where scattered electron is found in barrel with $p_T > 10$ GeV (makes e^- finding easier)
  - Require $y_{true} > 0.01$: standard cut → also ensures HFS well measured in hadron endcap

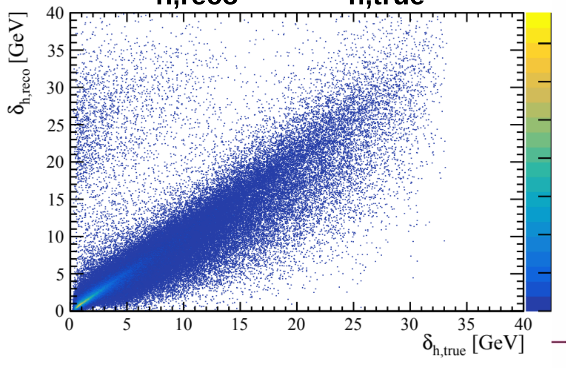
$E_{e,reco}$ vs $E_{e,true}$



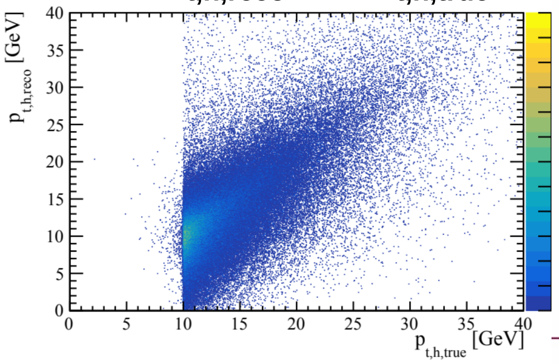
$\theta_{e,reco}$ vs $\theta_{e,true}$



$\delta_{h,reco}$ vs $\delta_{h,true}$



$p_{t,h,reco}$ vs $p_{t,h,true}$



<u>Parametrisation</u>

$\sigma(E_e)/E_e = 0.02E_e \oplus 1.1\%$

$\sigma(\theta_e) = 1.1/E_e \oplus 0.05$

$\sigma(\delta_h) / \delta_h = 25\%$

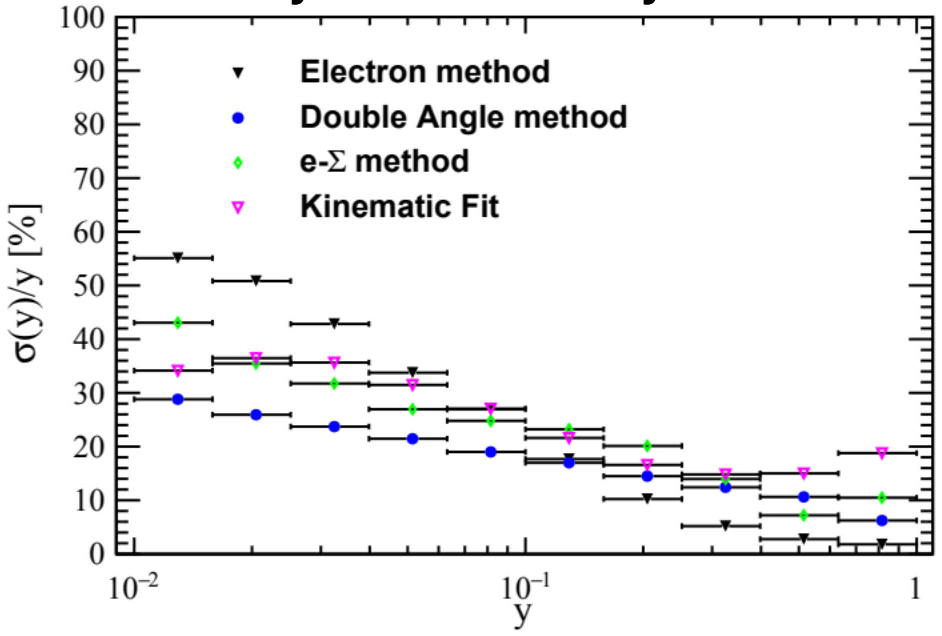
$\sigma(p_{t,h}) / p_{t,h} = 25\%$

Note: Distributions from full simulation are complicated
→ **Detailed studies needed**

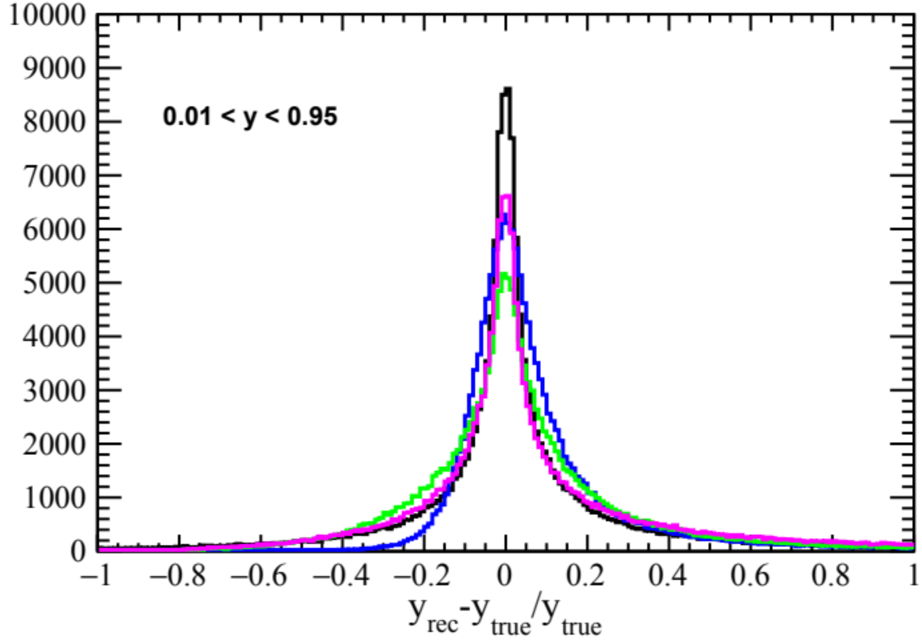
Full Simulations: Fit Results

- Kinematic Fit of fully simulated data gives performance consistent with conventional reconstruction methods
  - Potential for improved performance with better parametrisation of resolutions
    → detailed studies of $\vec{D}$ distributions

y resolution vs y



y_{rec}-y_{true}/y_{true} for 0.01 < y < 0.95



Full Simulations: Fit Results

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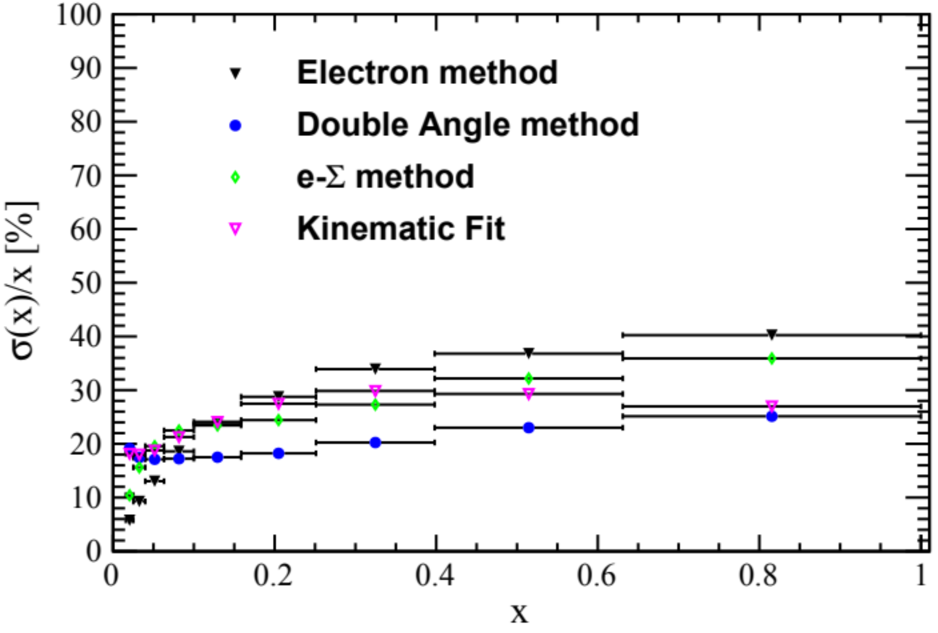
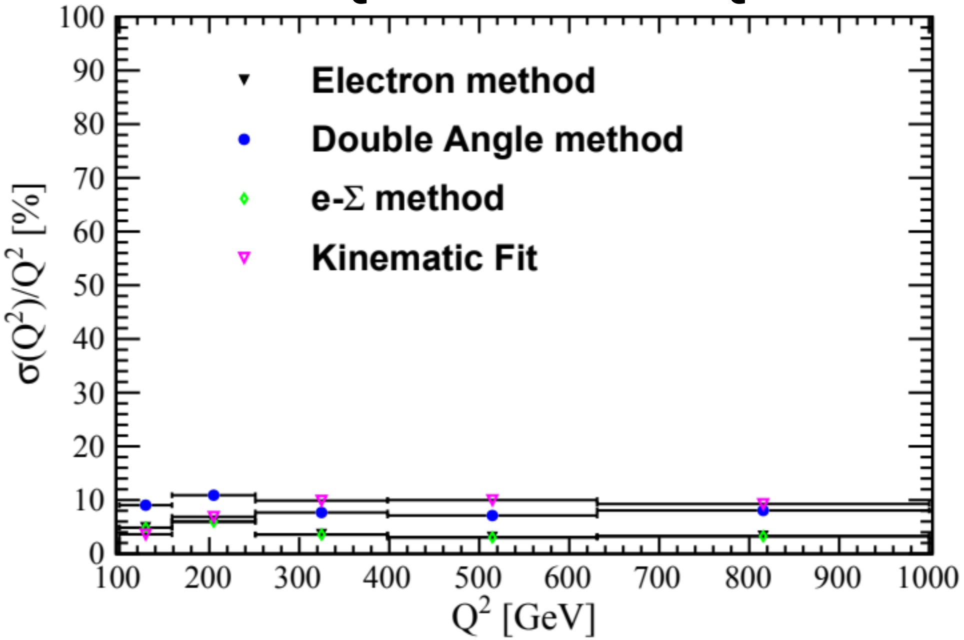
x resolution vs x



Q^2 resolution vs Q^2



Summary

- Neutral Current DIS measurements are the "bread and butter" of the EIC physics program → detailed studies of resolutions of inclusive variables x, y, Q^2 provide information on performance of detector for NCDIS measurements
- A reconstruction method based on a kinematic fit is explored with smeared and fully simulated data
  - Promising results with smeared data → performance is consistent with that of "best" reconstruction method for a given bin
  - Application to full simulation shows potential → rough parametrisation gives comparable performance to conventional methods, expect to leverage more performance through detailed studies of reconstructed electron and HFS

Next Steps

- Extend fitting studies to full kinematic range
- Study distributions of fully reconstructed data → improve parametrisation