Projection study for A_1^n and g_1^n Measurement at ePIC in the Early Running of EIC

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ePIC Physics Forum
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Stony Brook University

Center for Frontiers in Nuclear Science

ePIC

Goal

Current Early Science Matrix

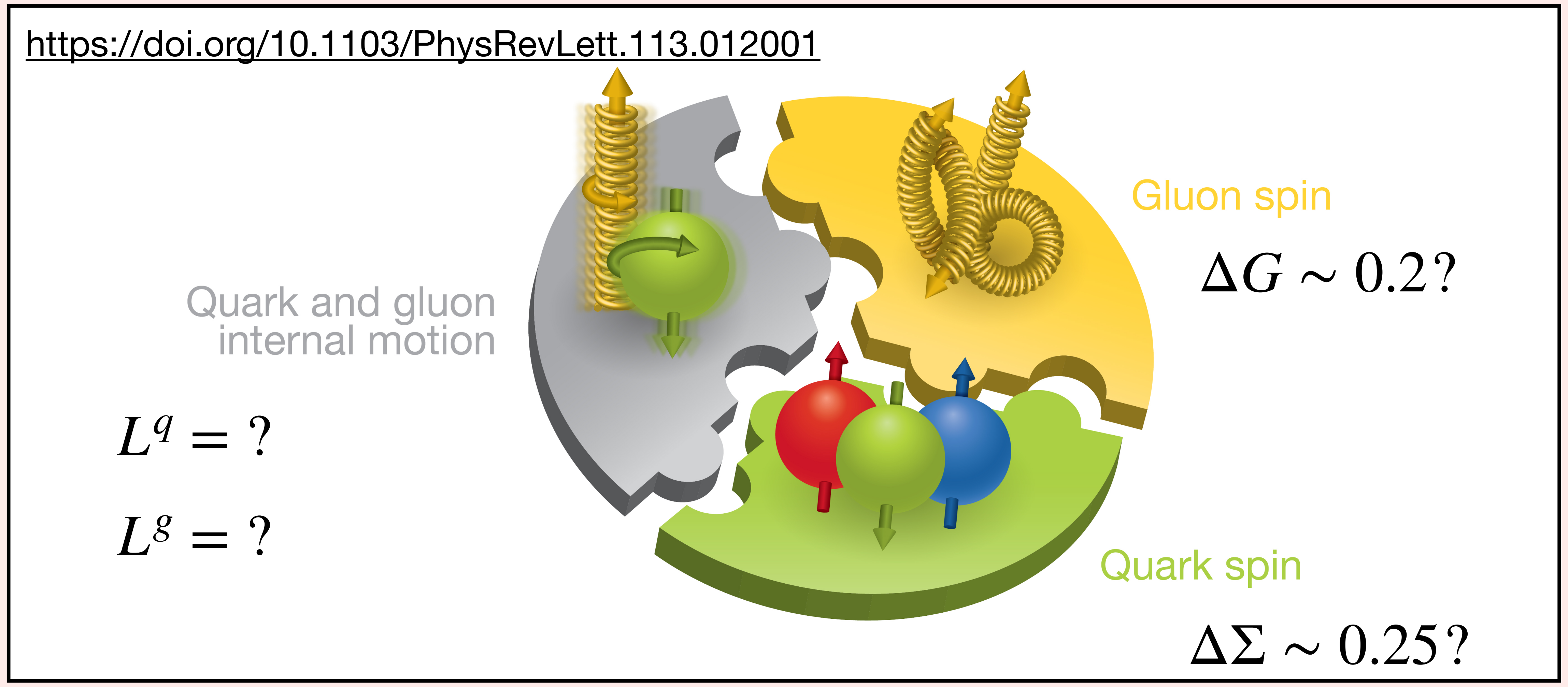
	Species	Energy (GeV)	Luminosity/year (fb-1)	Electron polarization	p/A polarization
YEAR 1	e+Ru or e+Cu	10 x 115	0.9	NO (Commissioning)	N/A
YEAR 2	e+D e+p	10 x 130	11.4 4.95 - 5.33	LONG	NO TRANS
YEAR 3	e+p	10 x 130	4.95 - 5.33	LONG	TRANS and/or LONG
YEAR 4	e+Au e+p	10 x 100 10 x 250	0.84 6.19 - 9.18	LONG	N/A TRANS and/or LONG
YEAR 5	e+Au e+3He	10 x 100 10 x 166	0.84 8.65	LONG	N/A TRANS and/or LONG

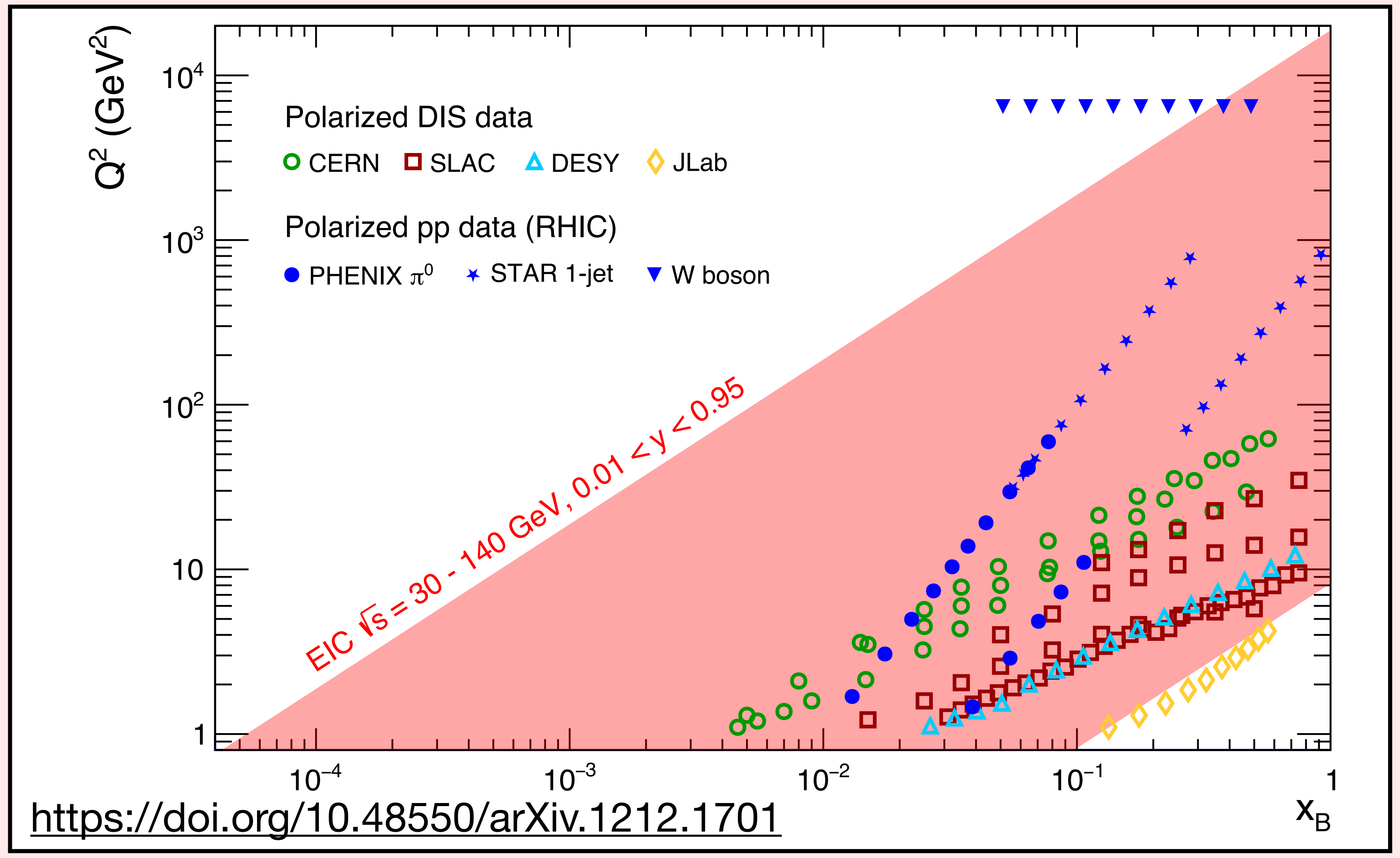
Note: the eA luminosity is per nucleon

A_1^n **Double spin asymmetry**

g_1^n **Spin structure function**

Motivation





Perturbative QCD:

$$g_1(x,t) = \frac{1}{2}\sum_{k=1}^{n_f}\frac{e_k^2}{n_f}\int_x^1\frac{dy}{y}\left[C_q^S\left(\frac{x}{y},\alpha_s(t)\right)\Delta\Sigma(y,t)\right.$$
$$+2n_f C_g\left(\frac{x}{y},\alpha_s(t)\right)\Delta G(y,t)$$
$$\left.+C_q^{\mathrm{NS}}\left(\frac{x}{y},\alpha_s(t)\right)\Delta q_{\mathrm{NS}}(y,t)\right]$$

Bjorken sum:

$$\Gamma_1^{\mathrm{p-n}}(\alpha_s) = \Gamma_1^{\mathrm{p-n}}(Q^2) = \int_0^{1^-}(g_1^p(Q^2) - g_1^n(Q^2))\,dx$$
$$= \sum_{n>0}\frac{\mu_{2n}^{p-n}(\alpha_s)}{Q^{2n-2}} = \frac{g_A}{6}\left[1 - \frac{\alpha_S(Q^2)}{\pi} - 3.58\left(\frac{\alpha_S(Q^2)}{\pi}\right)^2\right.$$
$$\left.-20.21\left(\frac{\alpha_S(Q^2)}{\pi}\right)^3 - 175.7\left(\frac{\alpha_S(Q^2)}{\pi}\right)^4 - \mathcal{O}((\alpha_S)^5)\right]$$

at finite Q^2

Double Spin Asymmetry

$$g_1 = \frac{F_2}{2x(1+R)}(A_1 + \gamma A_2)$$

$$A_1(x,Q^2) \equiv \frac{\sigma_{1/2} - \sigma_{3/2}}{\sigma_{1/2} + \sigma_{3/2}} = \frac{A_{\parallel}}{D(1+\eta\xi)} - \frac{\eta A_{\perp}}{d(1+\eta\xi)}$$

$\sigma_{1/2}$: p & γ^* spins anti-aligned

$\sigma_{3/2}$: p & γ^* spins aligned

$$A_{\parallel} = \frac{\sigma_{\downarrow\Uparrow} - \sigma_{\uparrow\Uparrow}}{\sigma_{\downarrow\Uparrow} + \sigma_{\uparrow\Uparrow}}$$

$\sigma_{\downarrow\Uparrow}$: p & e spins anti-aligned

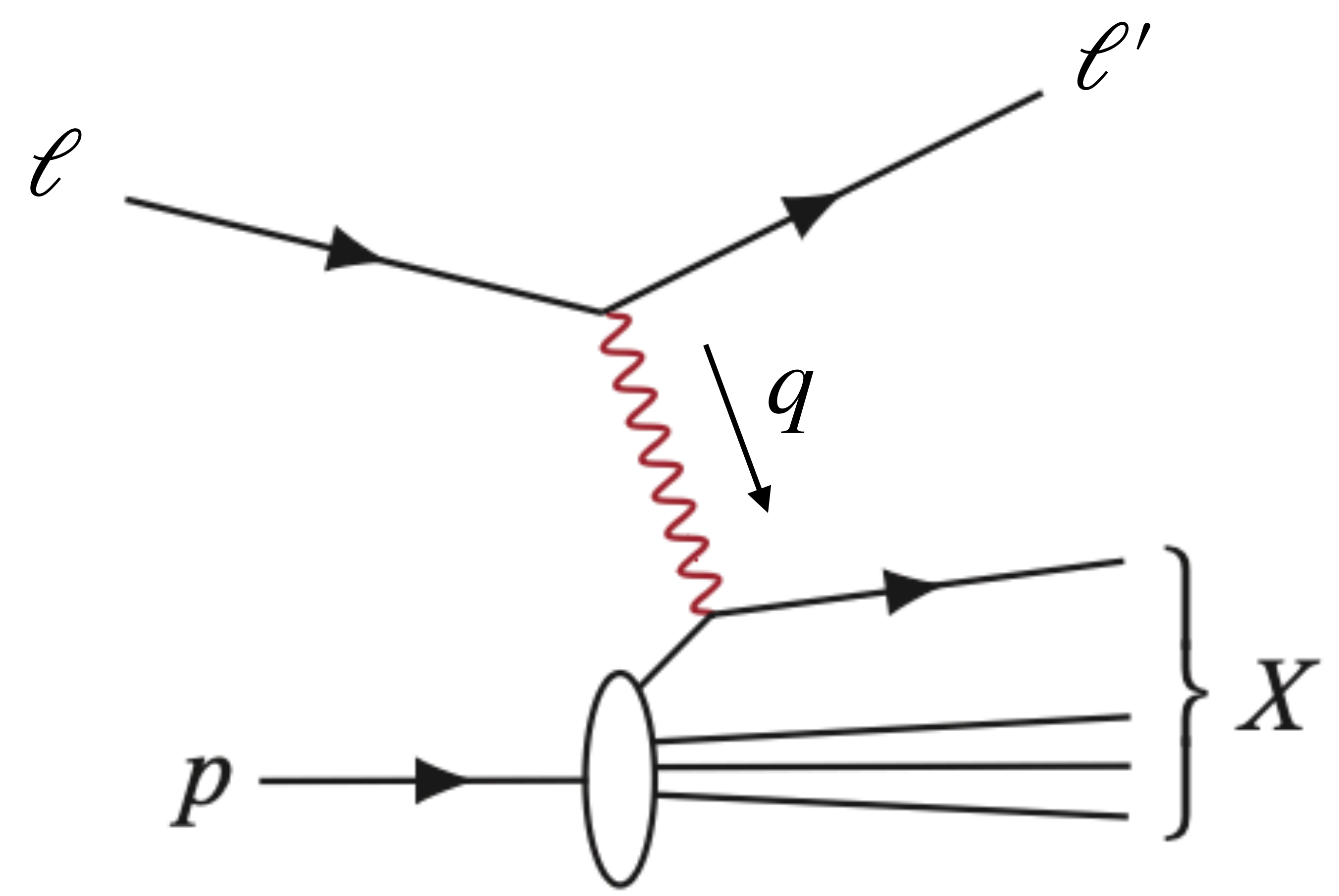
$\sigma_{\uparrow\Uparrow}$: p & e spins aligned

$$A_{\perp} = \frac{\sigma_{\downarrow\Rightarrow} - \sigma_{\uparrow\Rightarrow}}{\sigma_{\downarrow\Rightarrow} + \sigma_{\uparrow\Rightarrow}}$$

$\sigma_{\uparrow\Rightarrow}$: p & e spins perpendicular

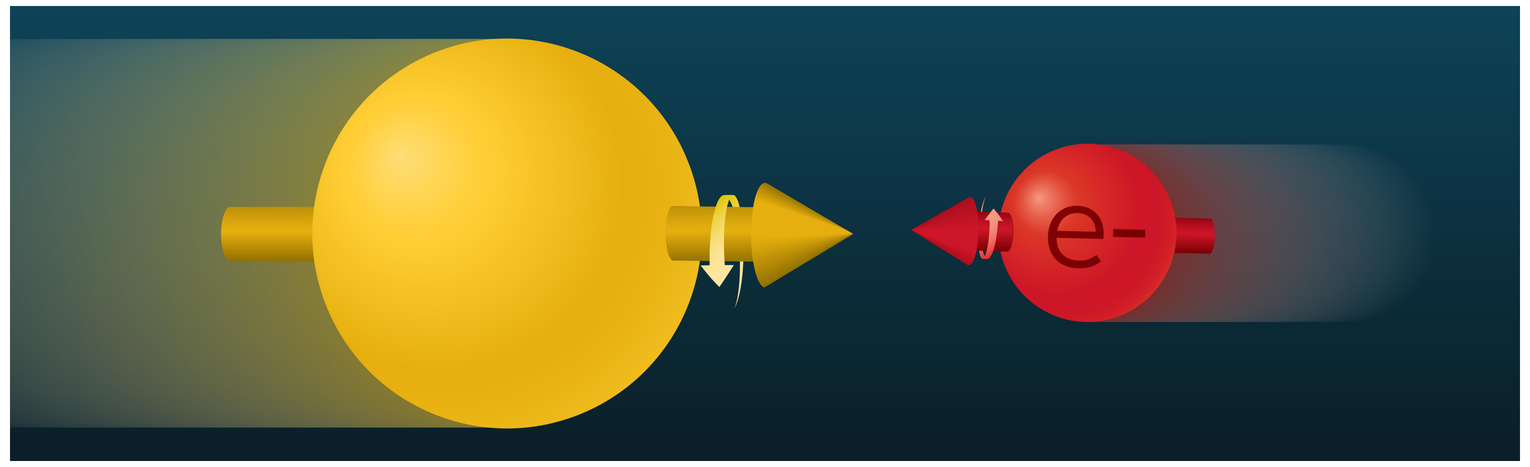
$$D = \frac{y(2-y)(2+\gamma^2 y)}{2(1+\gamma^2)y^2 + (4(1-y) - \gamma^2 y^2)(1+R)} \qquad d = \frac{D\sqrt{4(1-y) - \gamma^2 y^2}}{2-y}$$

$$R \equiv \frac{\sigma_L}{\sigma_T} = \frac{F_L}{F_2 - F_L} \qquad \gamma^2 = \frac{4M^2x^2}{Q^2} \qquad \eta = \frac{4(1-y) - \gamma^2 y^2}{(2-y)(2+\gamma^2 y)} \qquad \xi = \frac{\gamma(2-y)}{2+\gamma^2 y}$$



NC Inclusive DIS: $e + p \rightarrow e' + X$

https://arxiv.org/abs/2103.05419

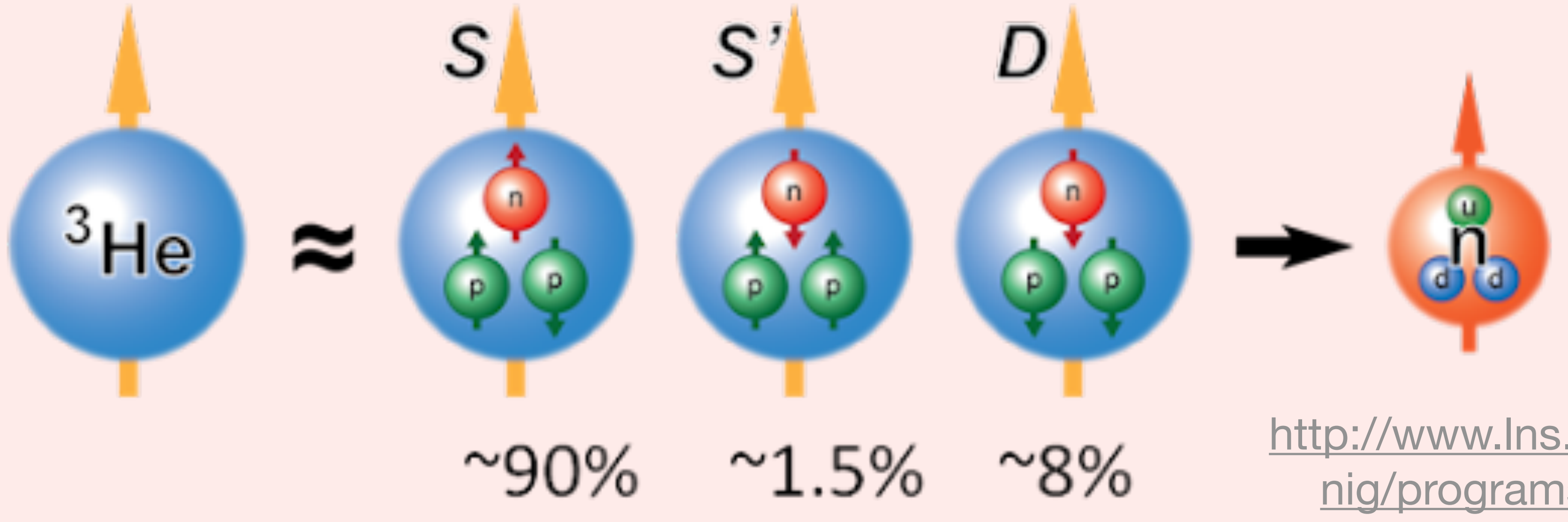


A_1^n from $e^3\mathrm{He}$ DIS:

- Can be extracted from $A_1^{^3\mathrm{He}} = P_n \frac{F_2^n}{F_2^{^3\mathrm{He}}} A_1^n + 2P_p \frac{F_2^p}{F_2^{^3\mathrm{He}}} A_1^p$

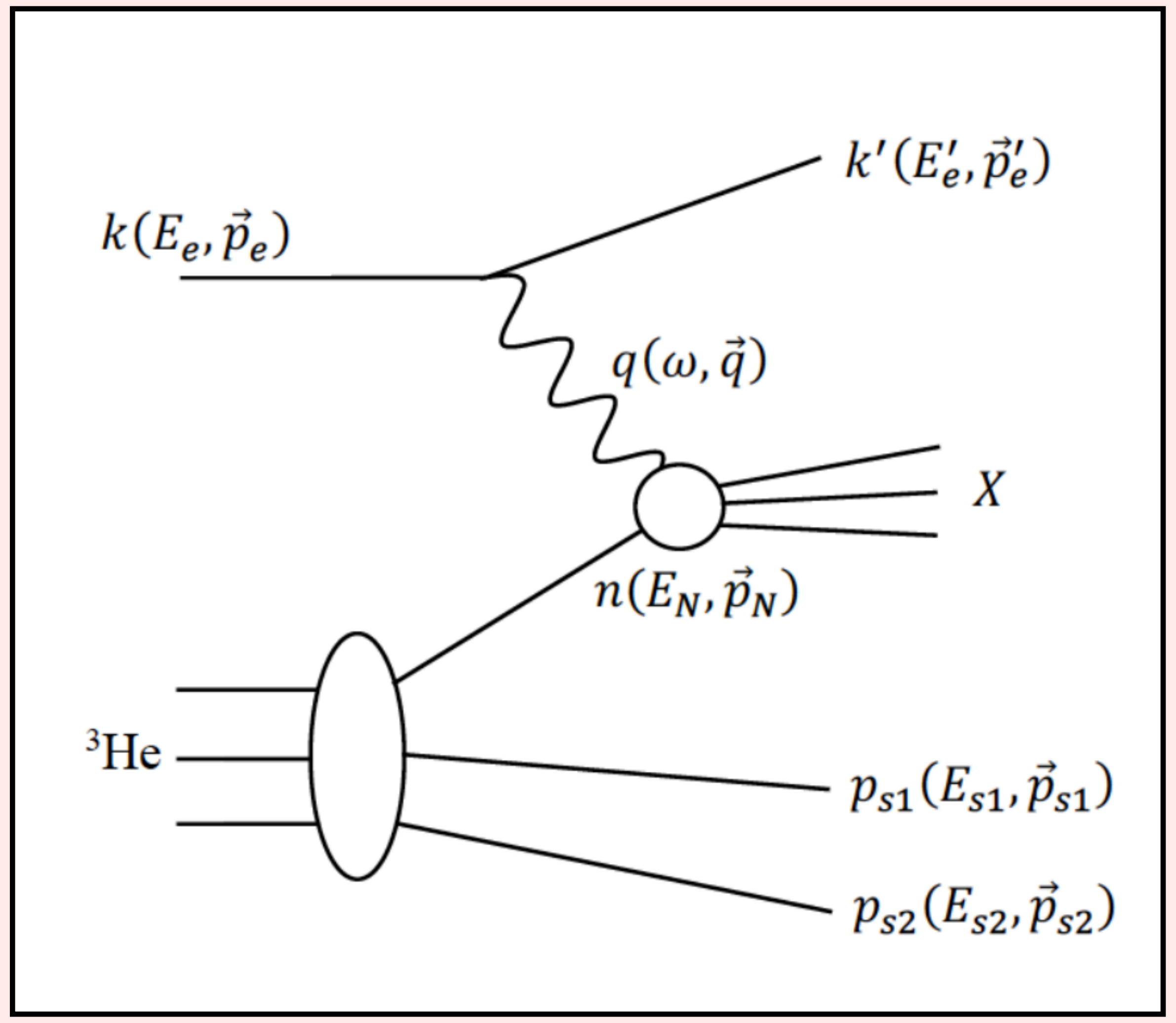
$$P_n = 0.86 \pm 0.02 \qquad P_p = -0.028 \pm 0.004$$

https://doi.org/10.1103/PhysRevC.64.024004



http://www.lns.mit.edu/nig/programs.html

Diagram of the DIS process



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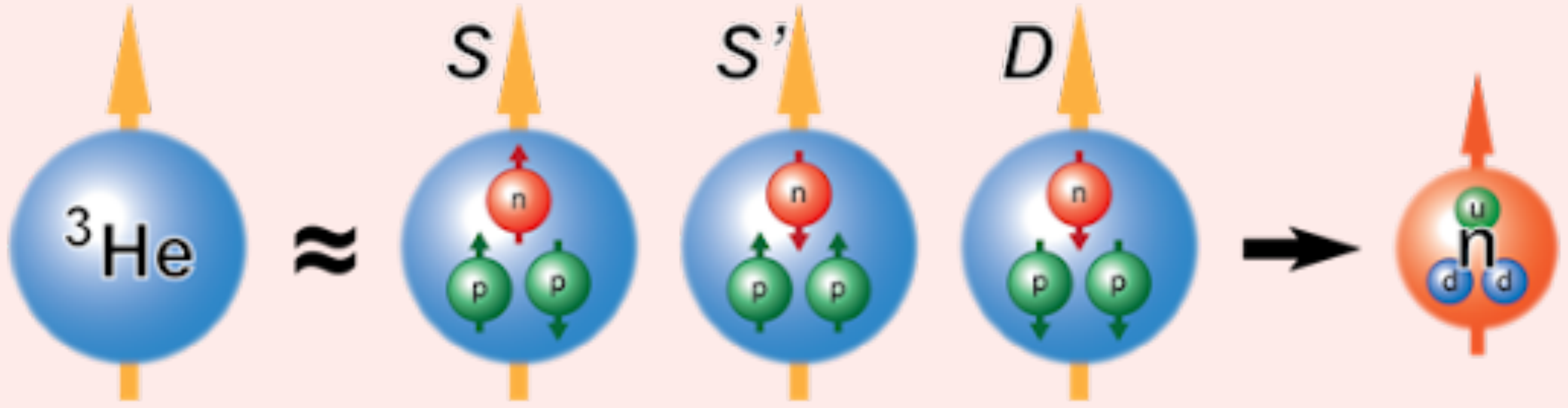
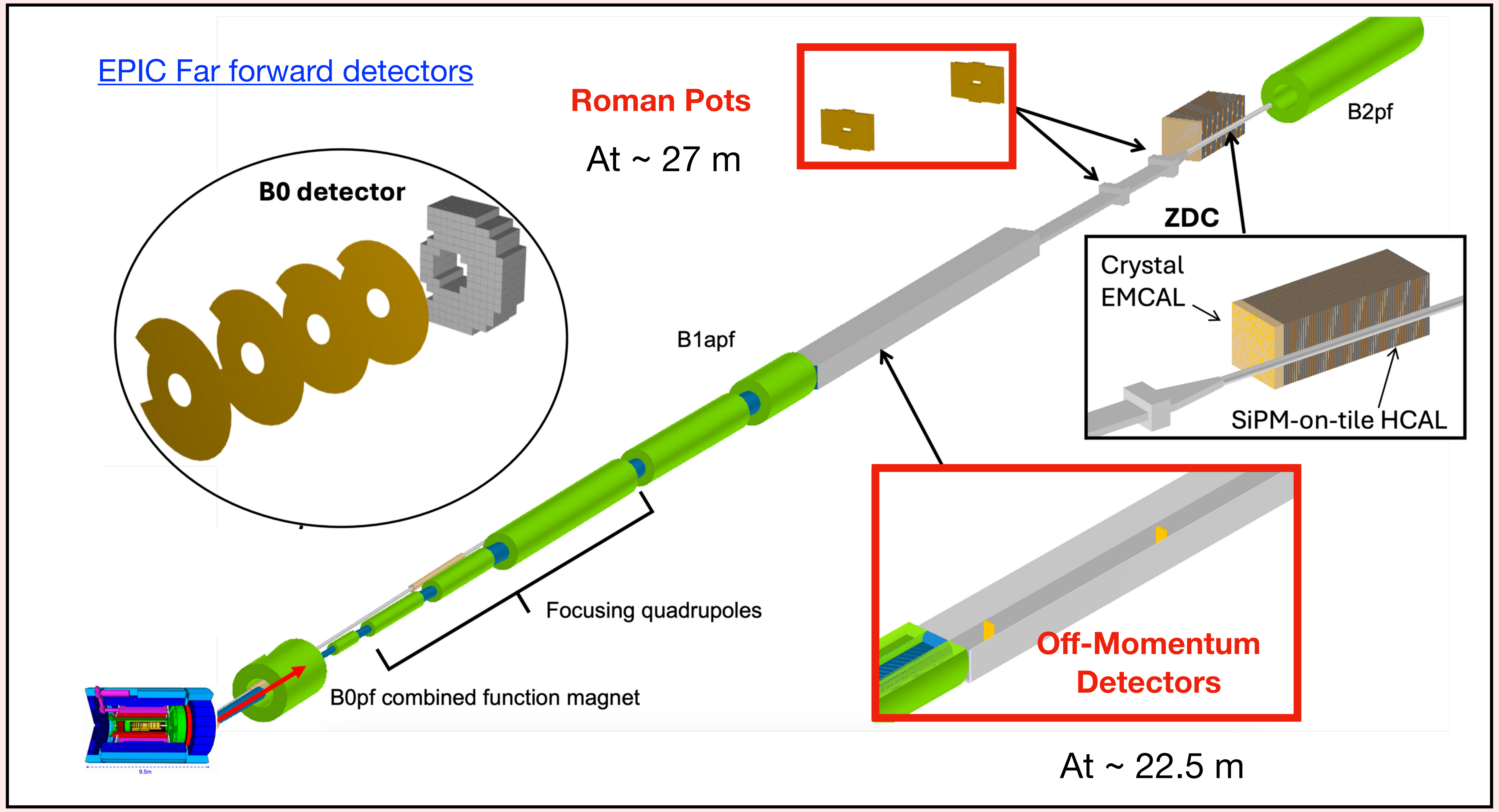


~90% ~1.5% ~8%

http://www.lns.mit.edu/nig/programs.html

- Or **directly** measured using double spectator tagging:



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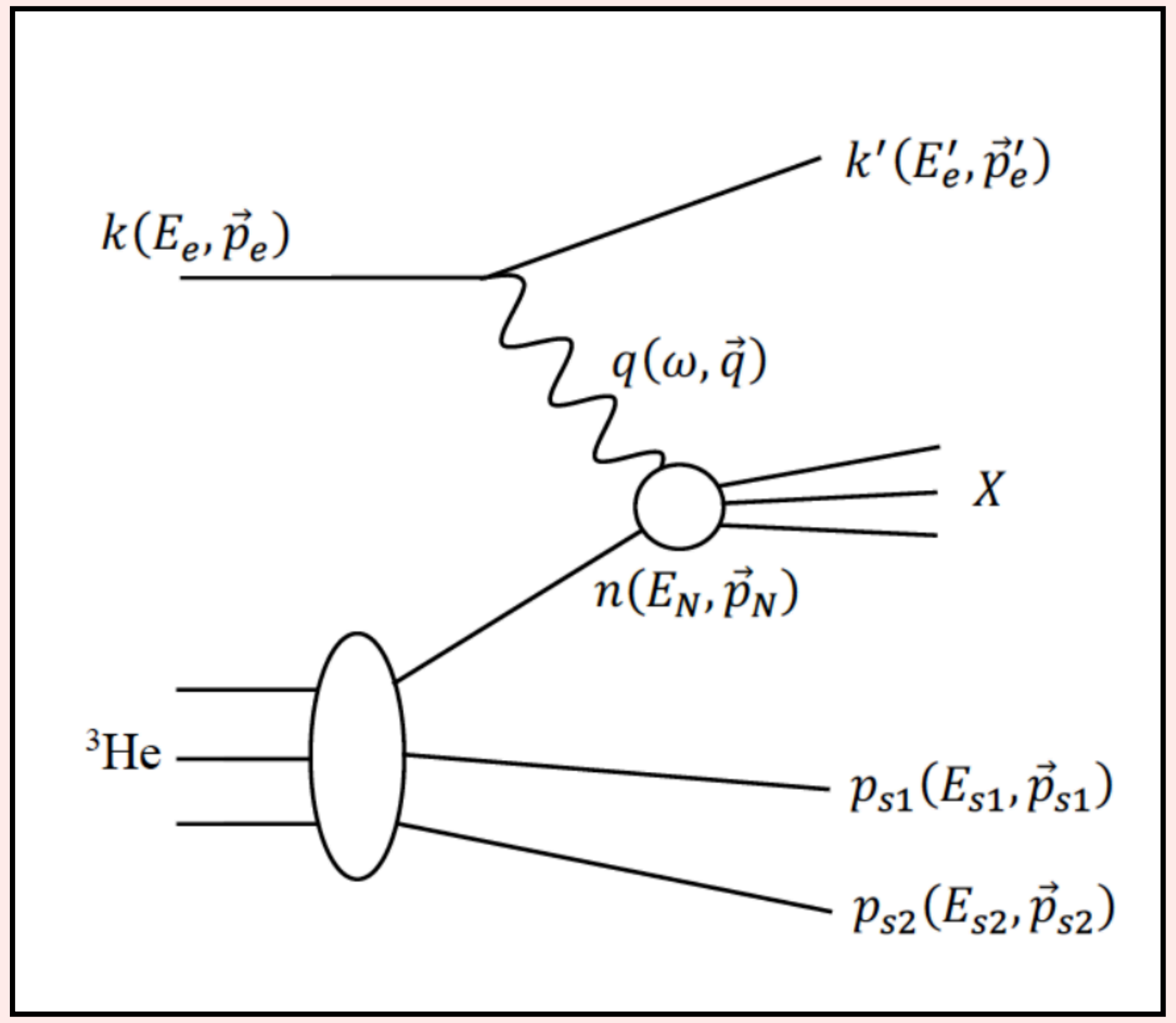
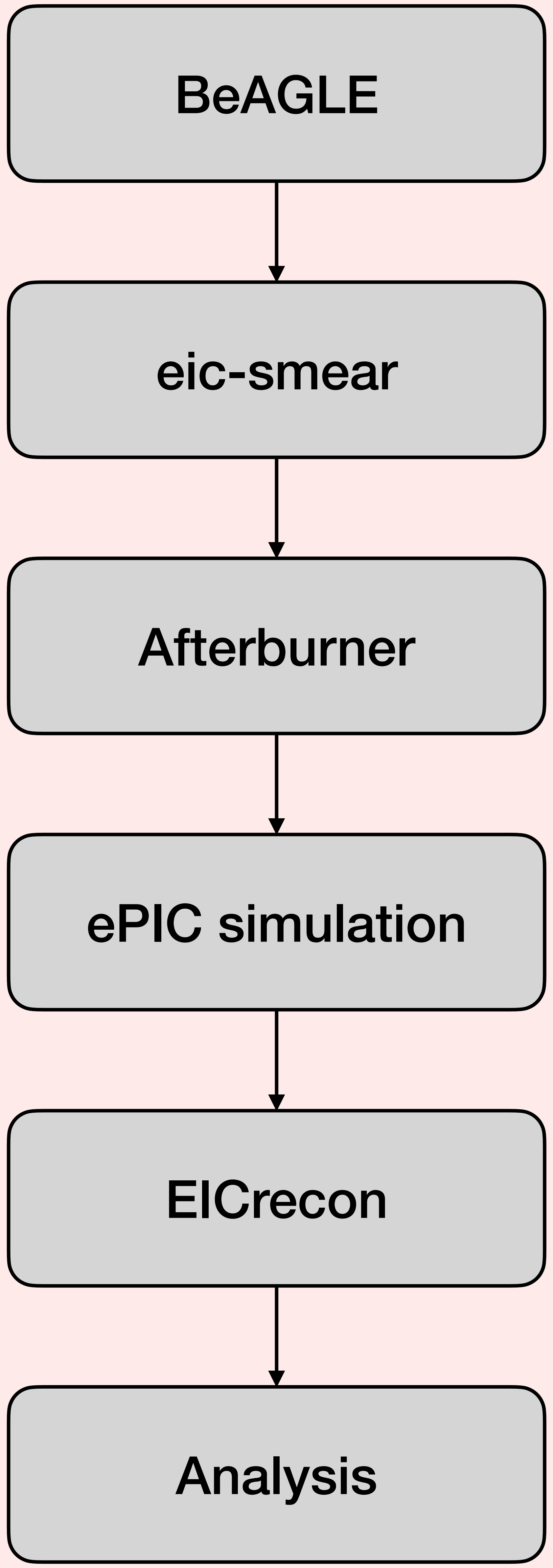
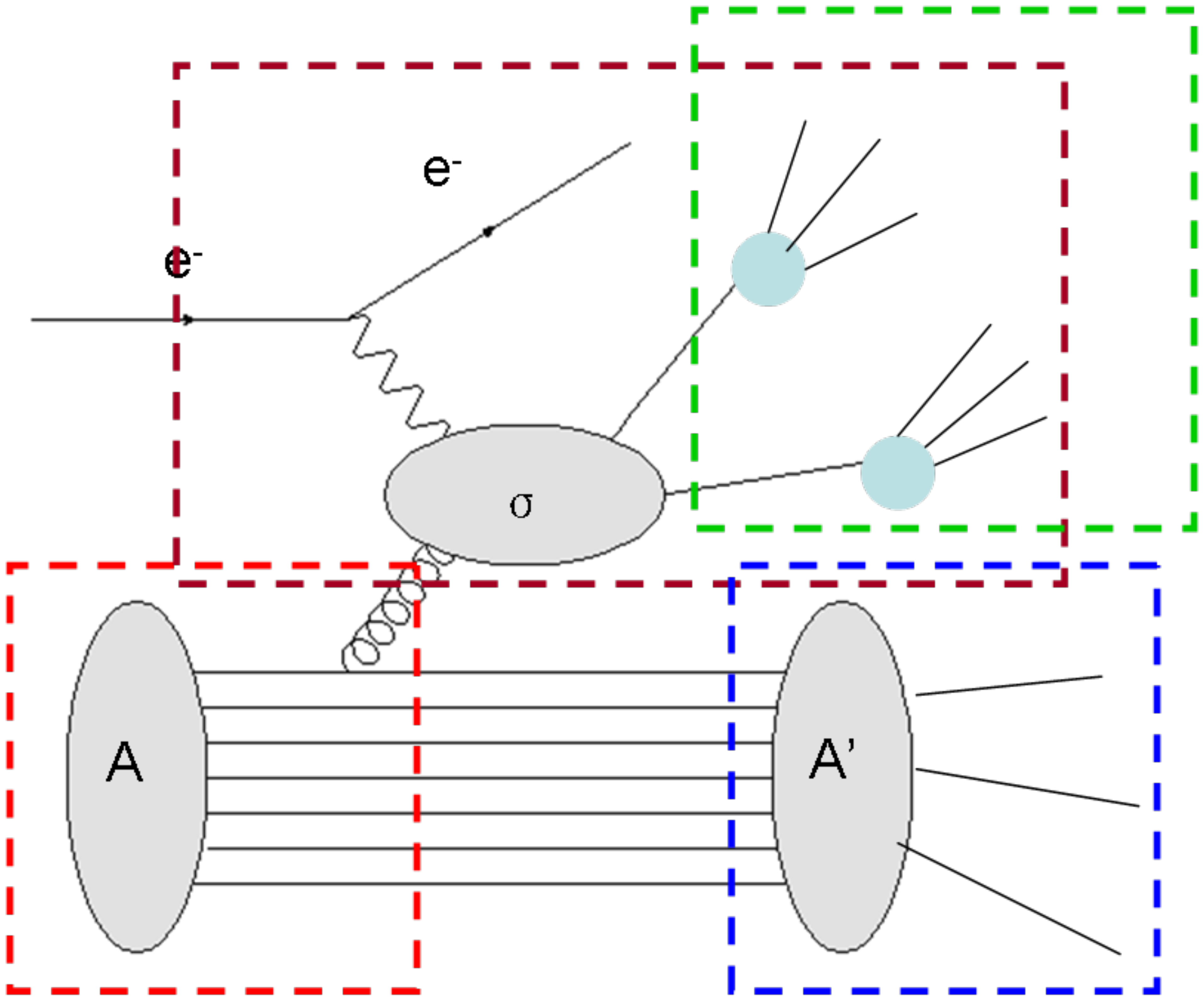


Simulation & Analysis flow



BeAGLE: eA event generator



A hybrid model consisting of DPMJet and PYTHIA with nPDF EPS09.

Nuclear geometry by DPMJet and nPDF provided by EPS09.

Parton level interaction and jet fragmentation completed in PYTHIA.

Nuclear evaporation (gamma dexcitation/nuclear fission/fermi break up) treated by DPMJet

Energy loss effect from routine by Salgado&Wiedemann to simulate the nuclear fragmentation effect in cold nuclear matter

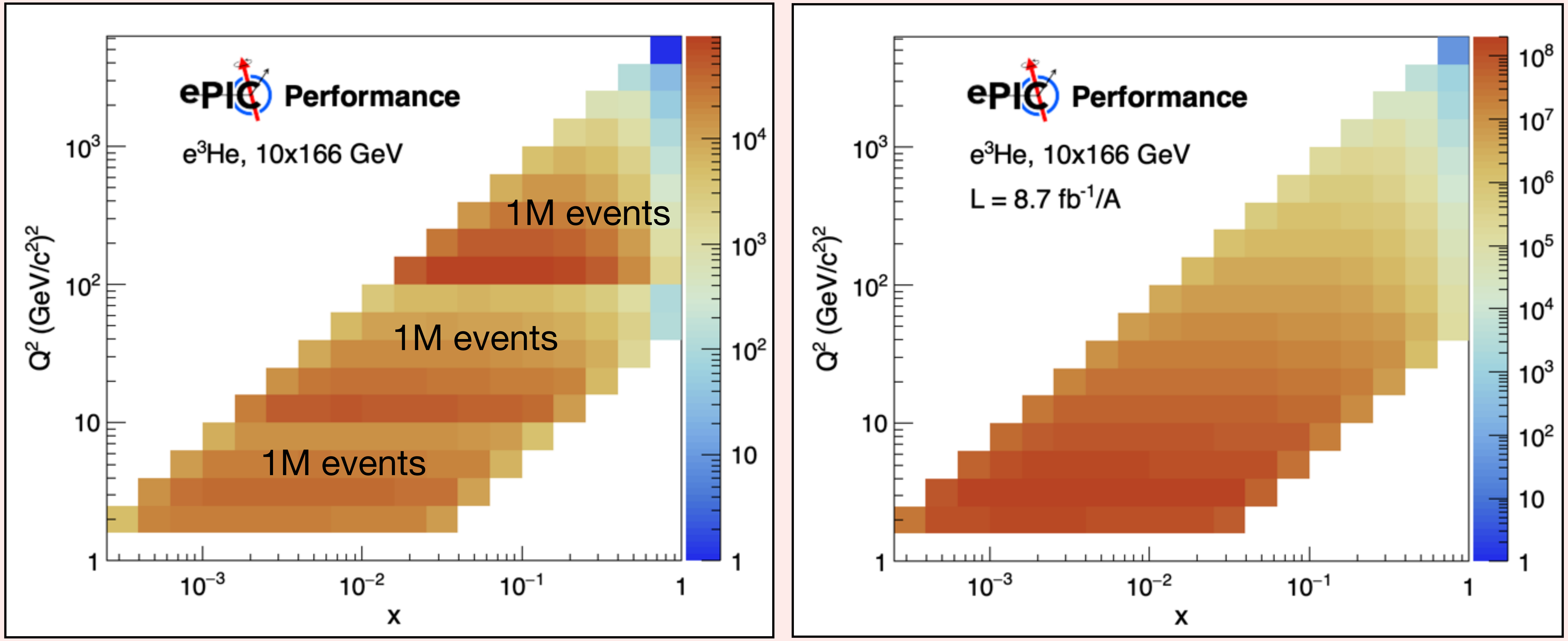
- ☑ Parton distribution functions
- ☑ Short-range correlations
- ☑ Fermi motion
- ☑ Partonic (or "dipole") MS
- ☑ Partonic gluon radiation
- ☑ Formation times
- ☑ Hadronic Cascade
- ☑ Nuclear evaporation, break up
- ☑ Photonic de-excitation of A*

Simulation & Analysis flow

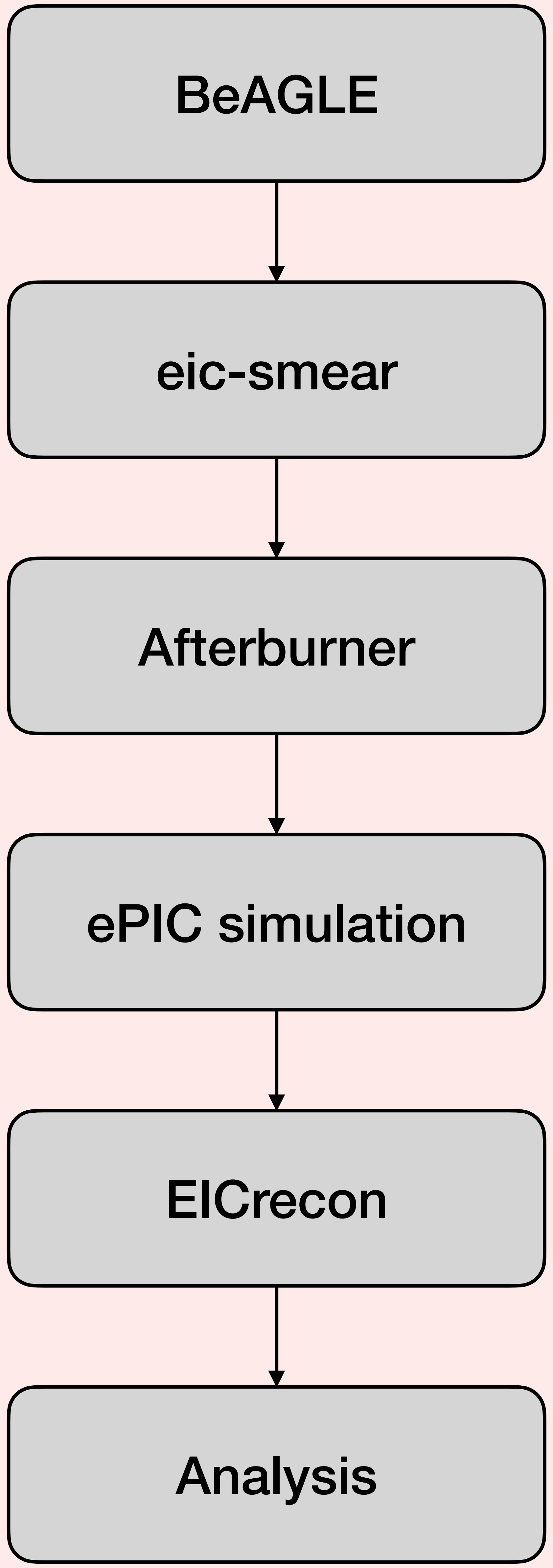
BeAGLE → eic-smear → Afterburner → ePIC simulation → EICrecon → Analysis

- Generated events are non-polarized, and have no QED radiative effect
- Use generated event to estimate statistical uncertainty: $\delta A_{\parallel,\perp} = \frac{1}{\sqrt{N P_e P_N}}$
- Use parameterization for central values of A_1^n

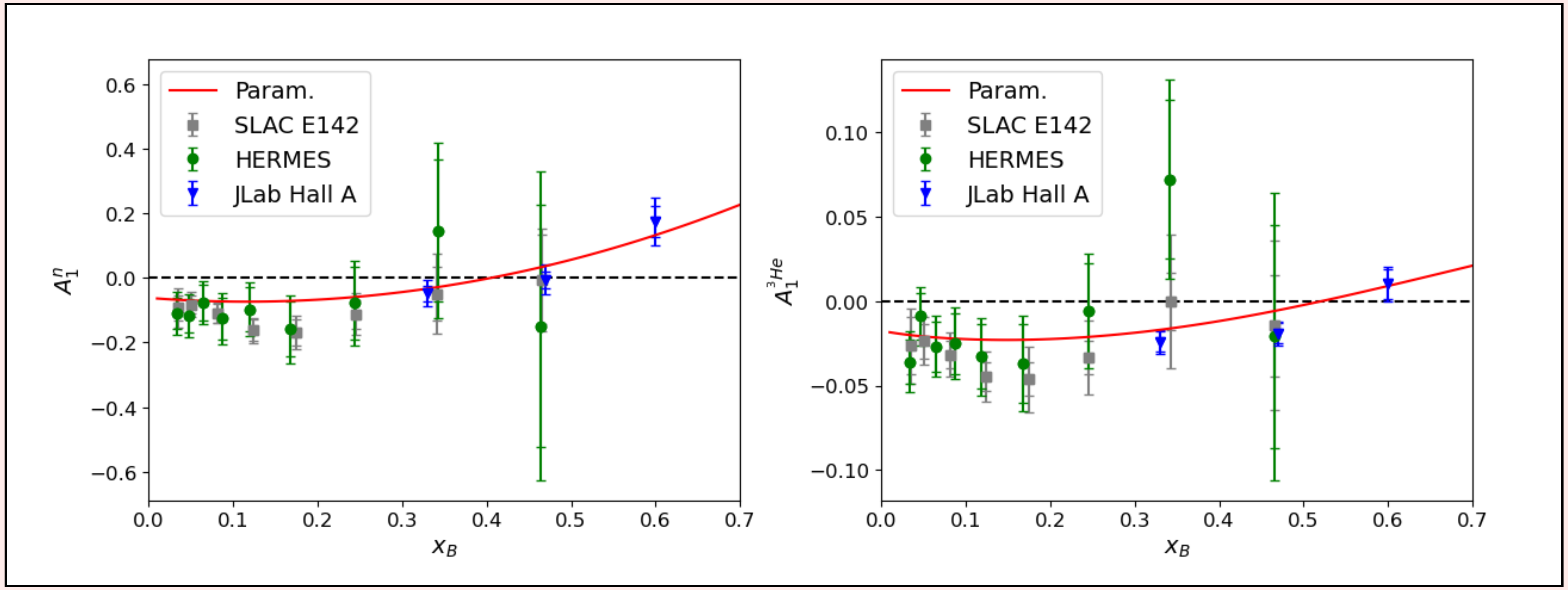
generated events → scaled to planned luminosity



Simulation & Analysis flow

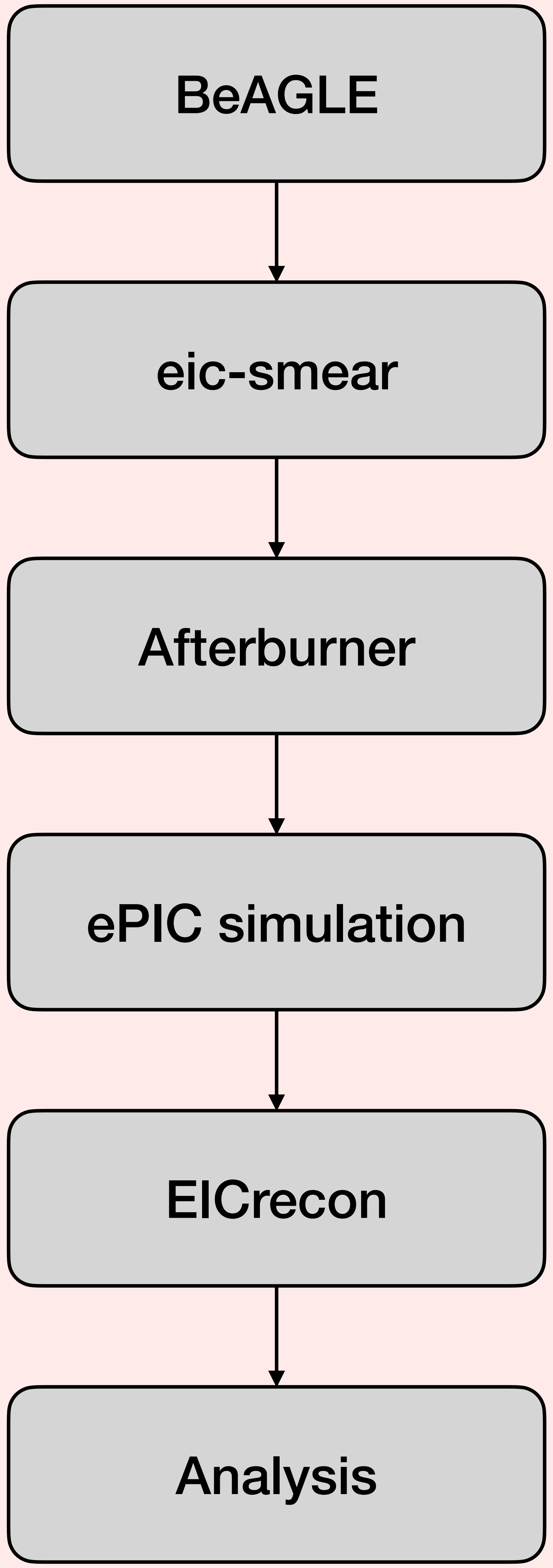


- A_1^n calculated from: Doi: 10.1103/PhysRevC.70.065207
- $A_1^{^3\mathrm{He}} = P_n \dfrac{F_2^n}{F_2^{^3\mathrm{He}}} A_1^n + 2P_p \dfrac{F_2^p}{F_2^{^3\mathrm{He}}} A_1^p$ $\quad P_p = -0.028 \pm 0.004 \quad P_n = 0.86 \pm 0.02$
- all F_2's are taken from JAM22

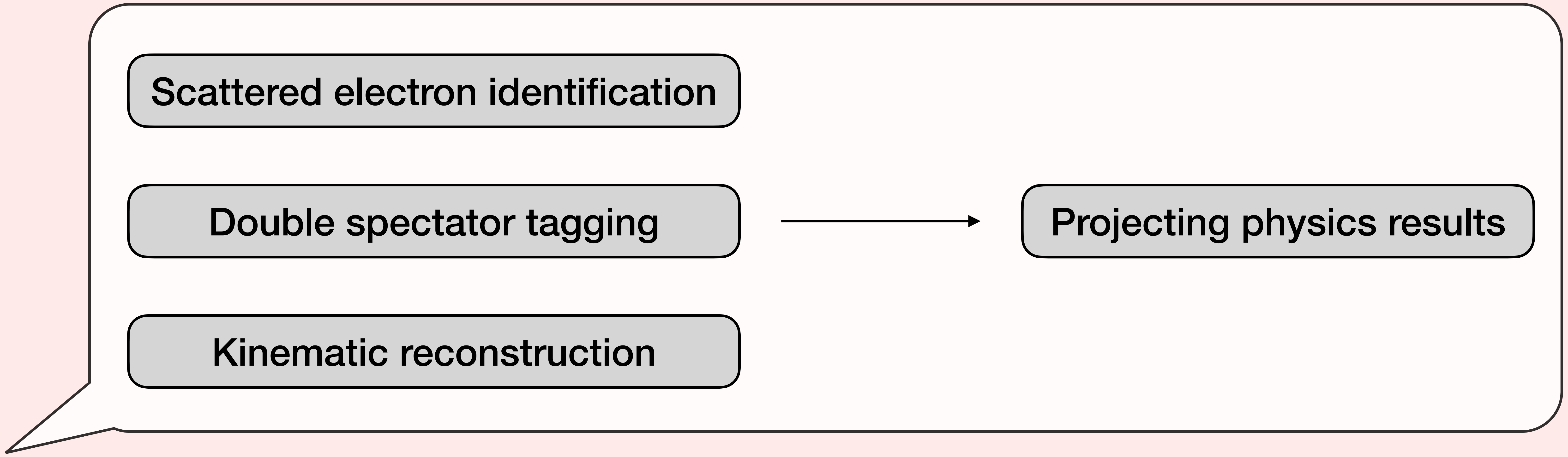


- Parameterization at $Q^2 = 2.88\ \mathrm{GeV}^2$
- Data points are at various Q^2 with majority $< 5\ \mathrm{GeV}^2$

Simulation & Analysis flow



- Event reconstruction is done in ROOT codes: GitHub link

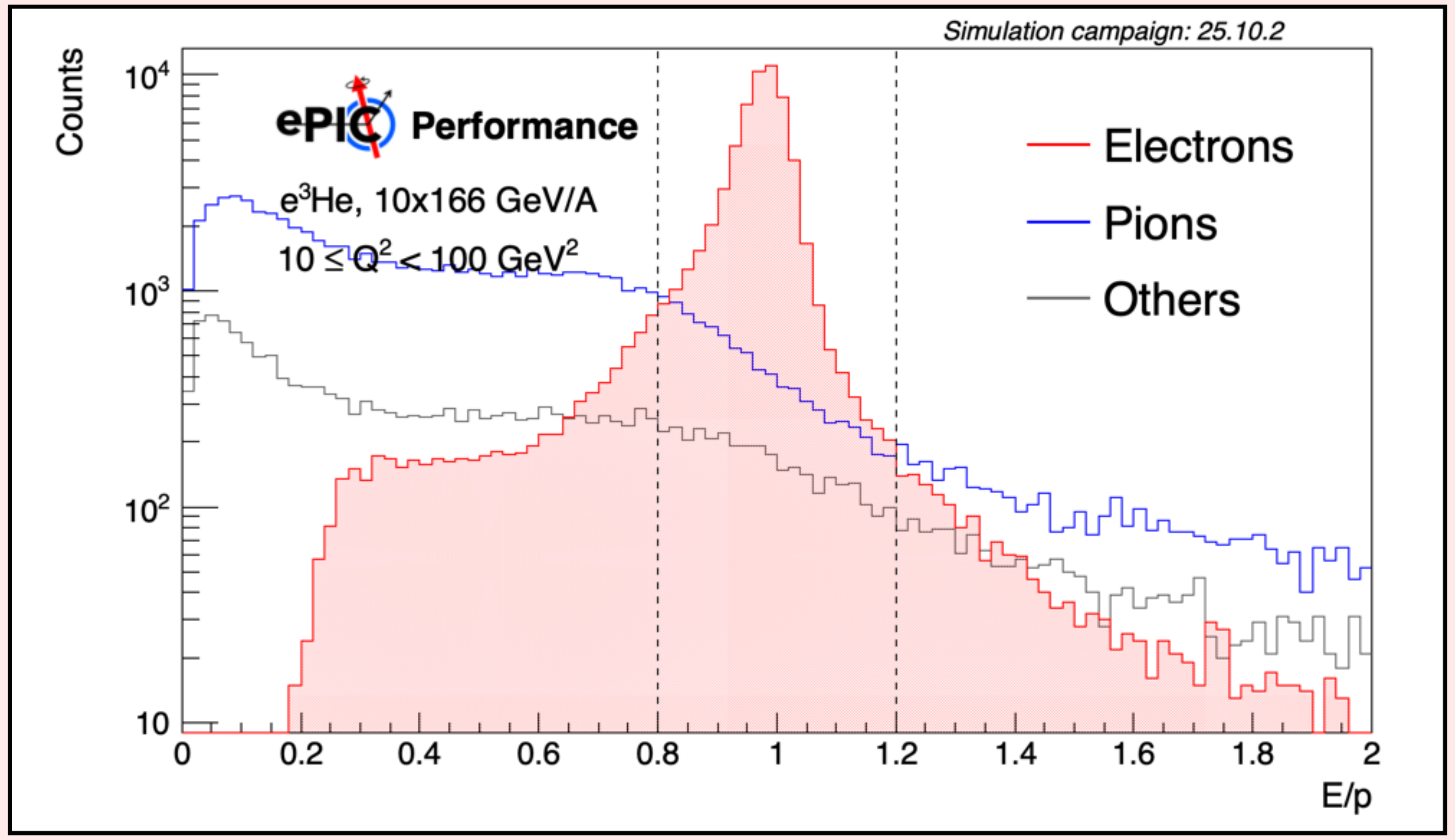


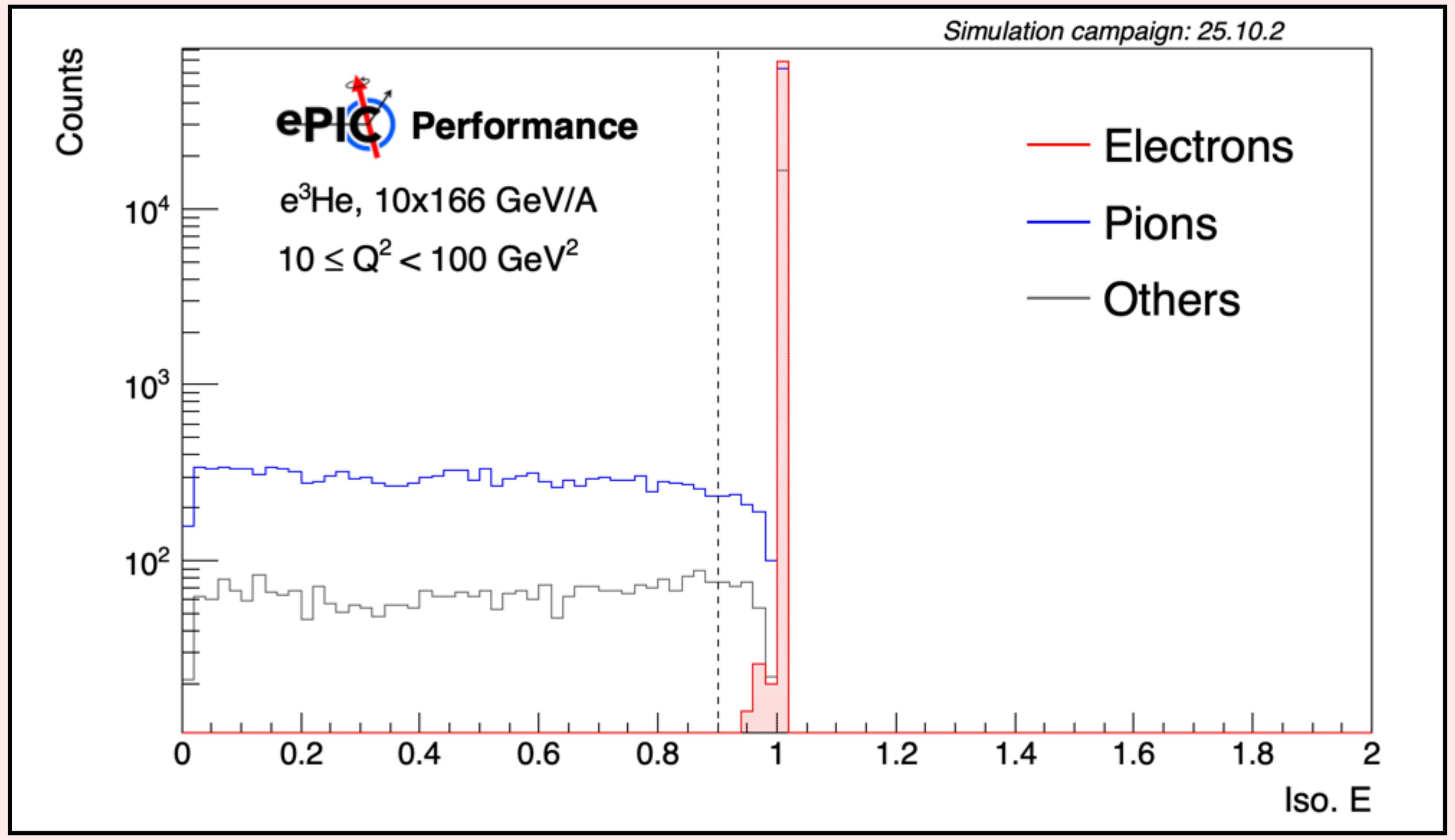
Scattered electron identification - selection criteria

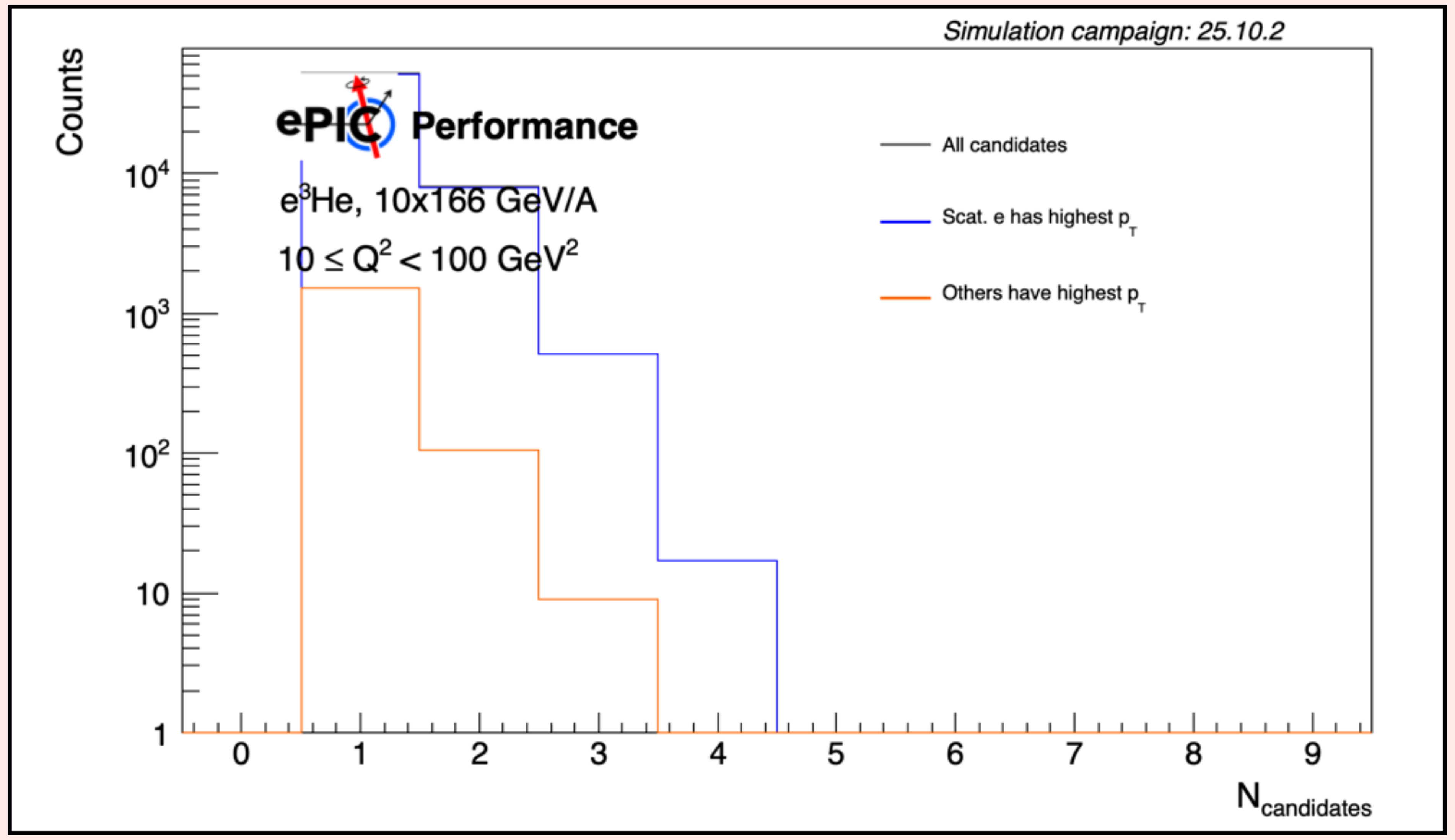
- Start from “ReconstructedParticleCollection” ⟵ Currently using MC to match clusters and tracks
- Require clusters and negative tracks
- $0.8 < E/p < 1.2$
- Isolated cluster:

$$E_0/\sum(E_{\Delta R<0.4}) > 0.9,\ \Delta R = \sqrt{\Delta\eta^2 - \Delta\phi^2}$$

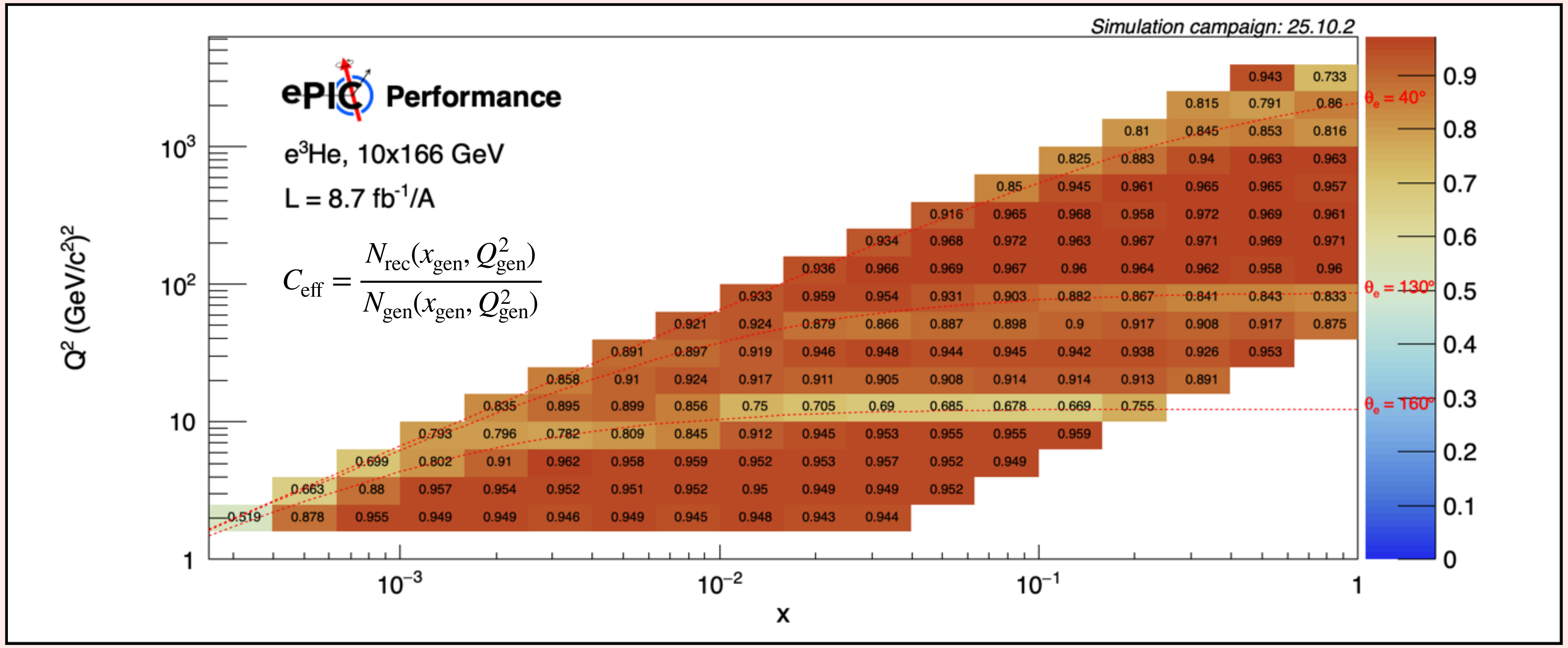
- Select the highest P_T particle

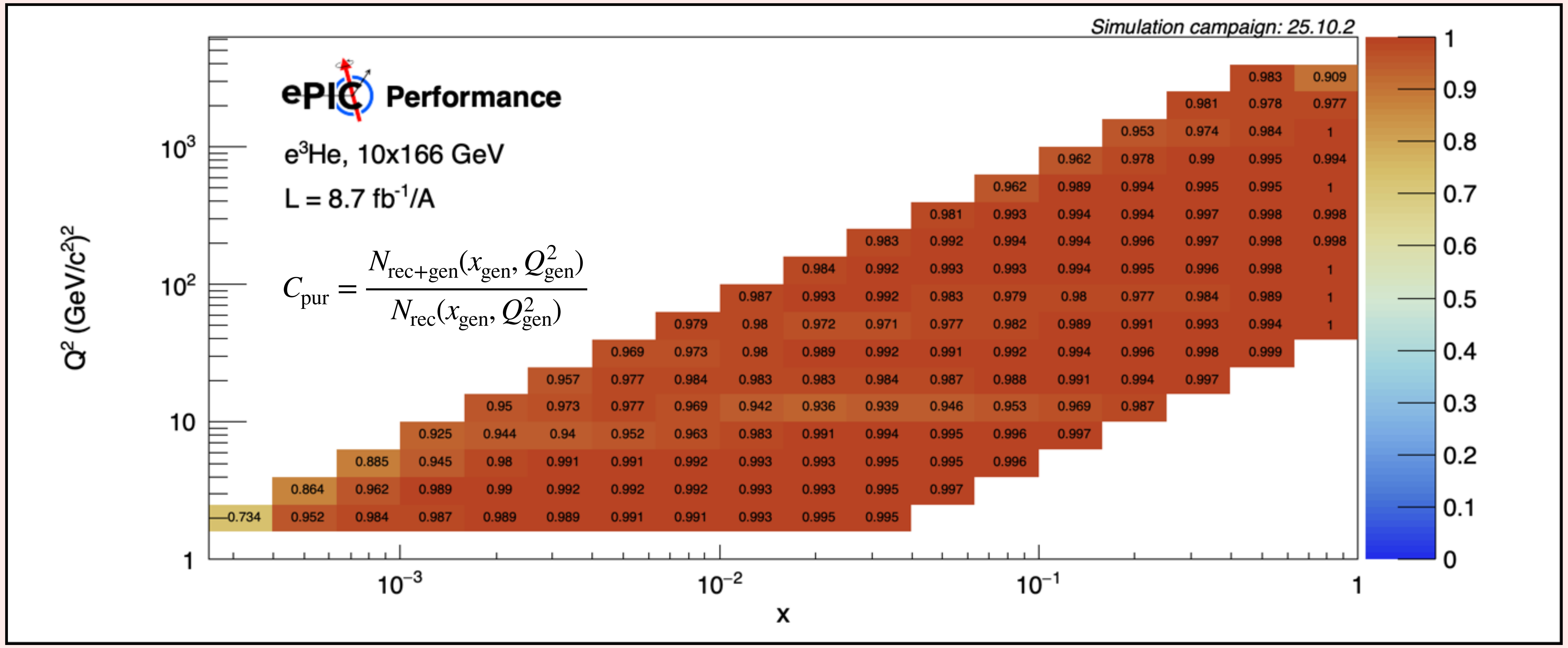


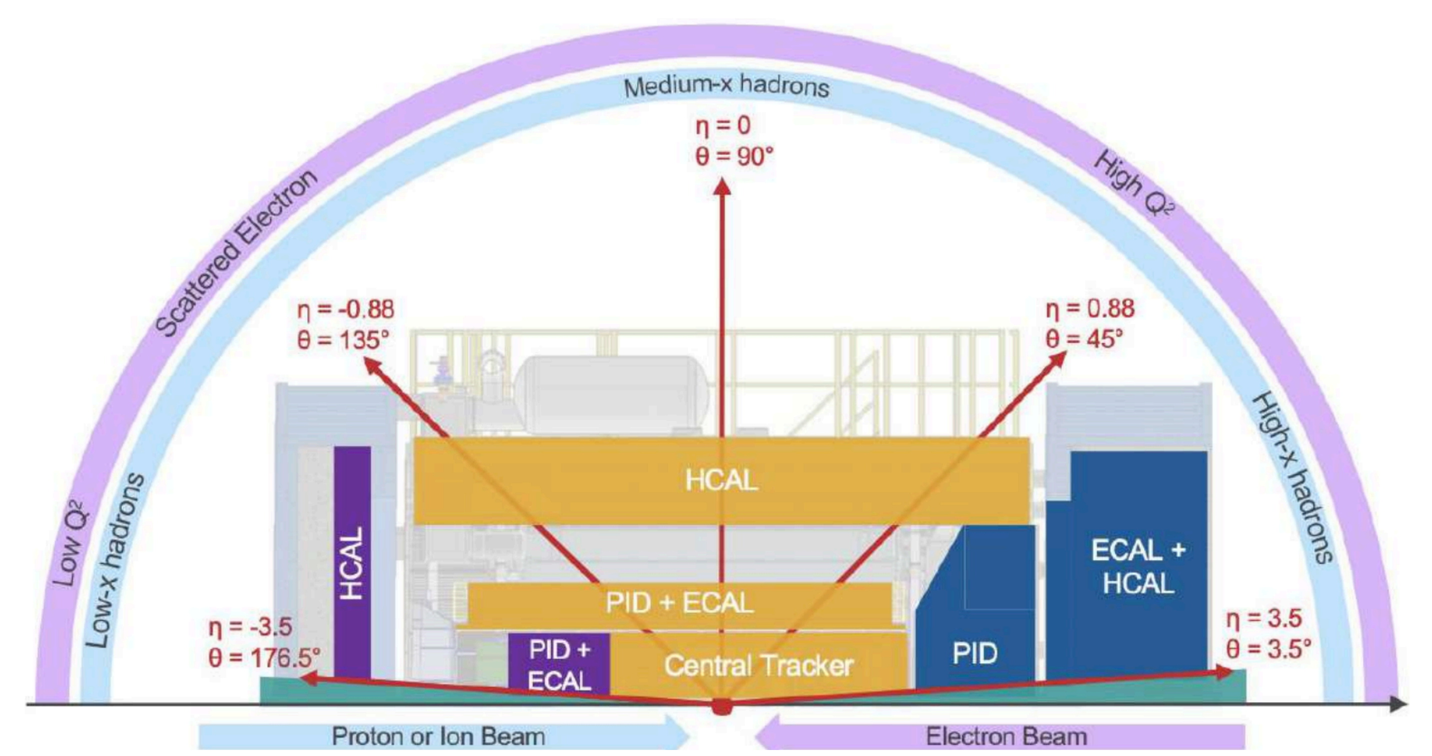


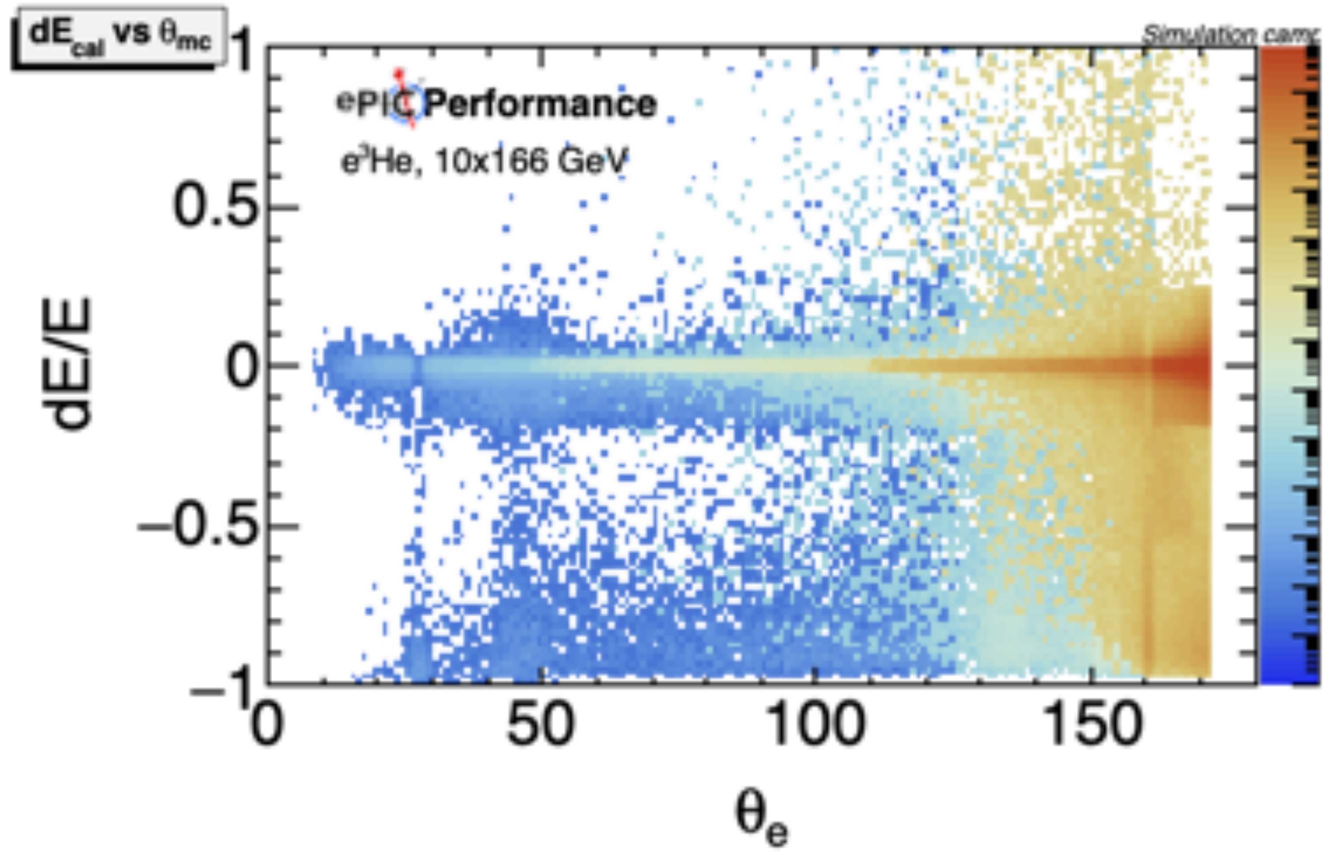


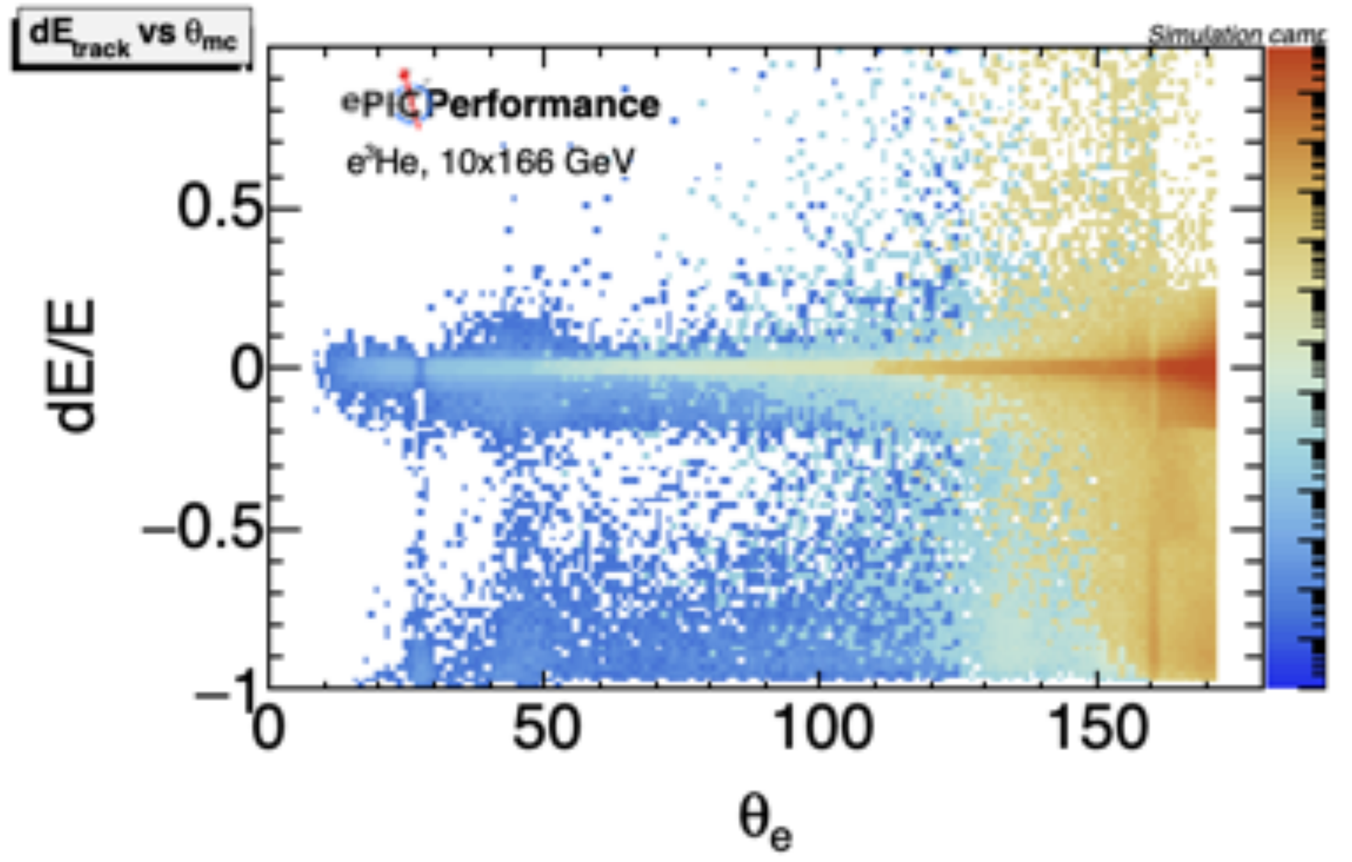
Scattered electron identification - efficiency & purity





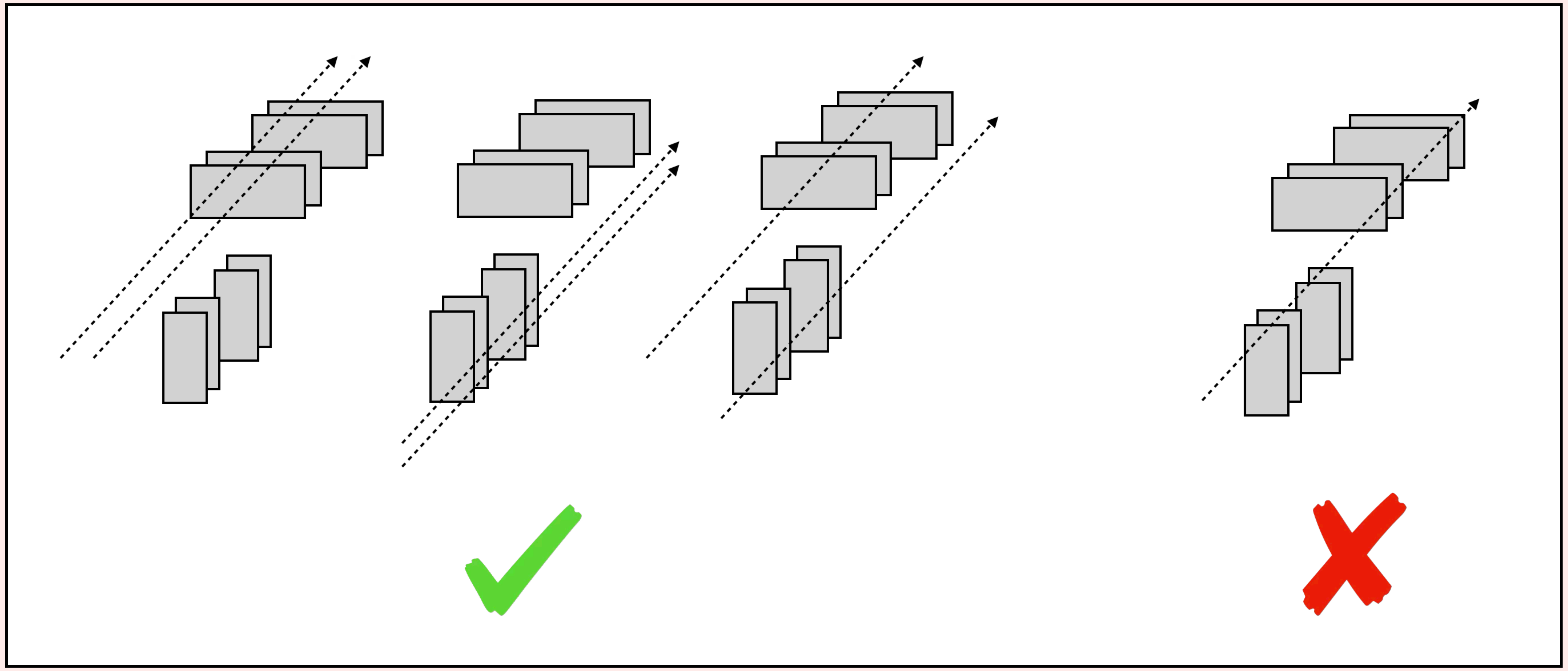


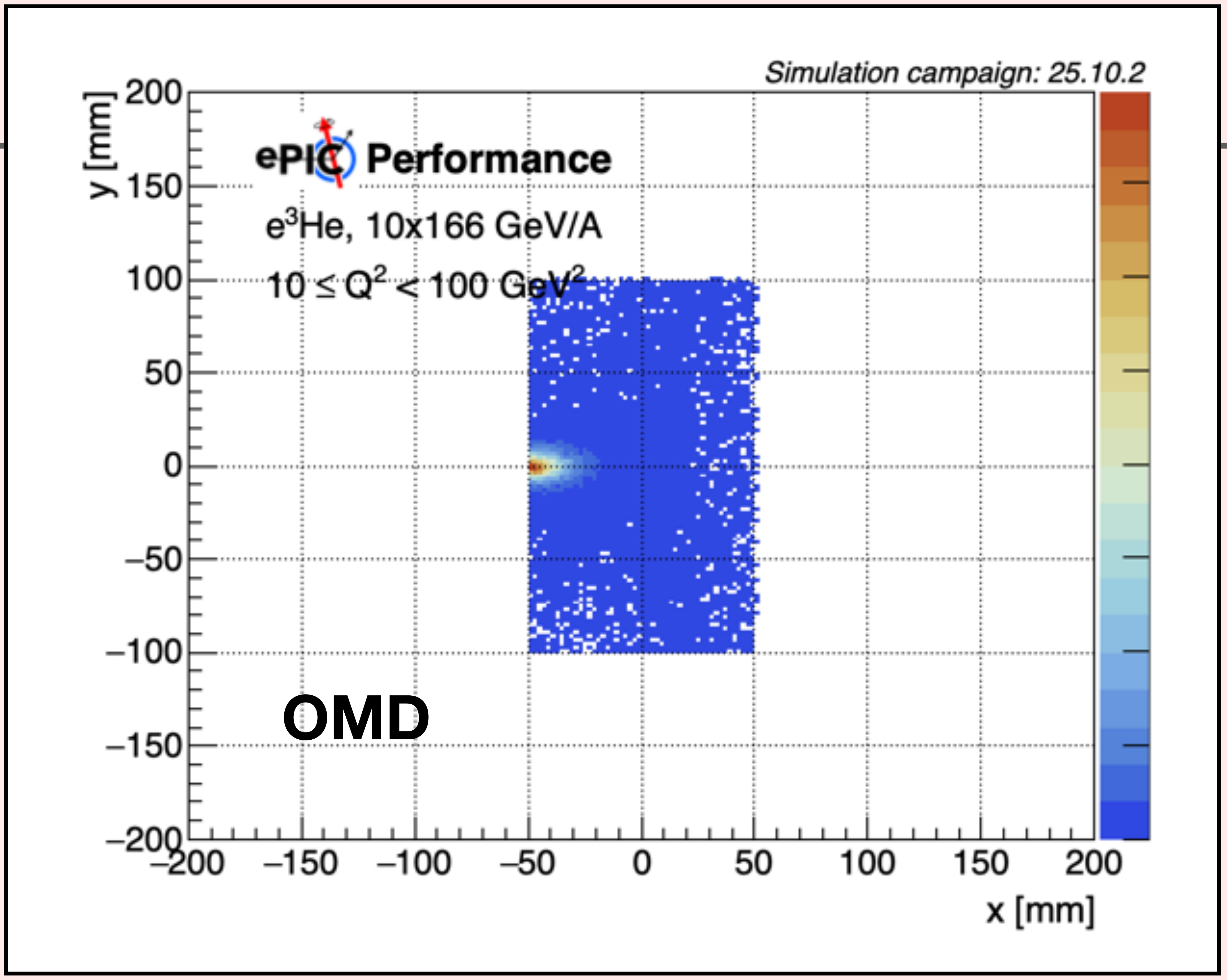


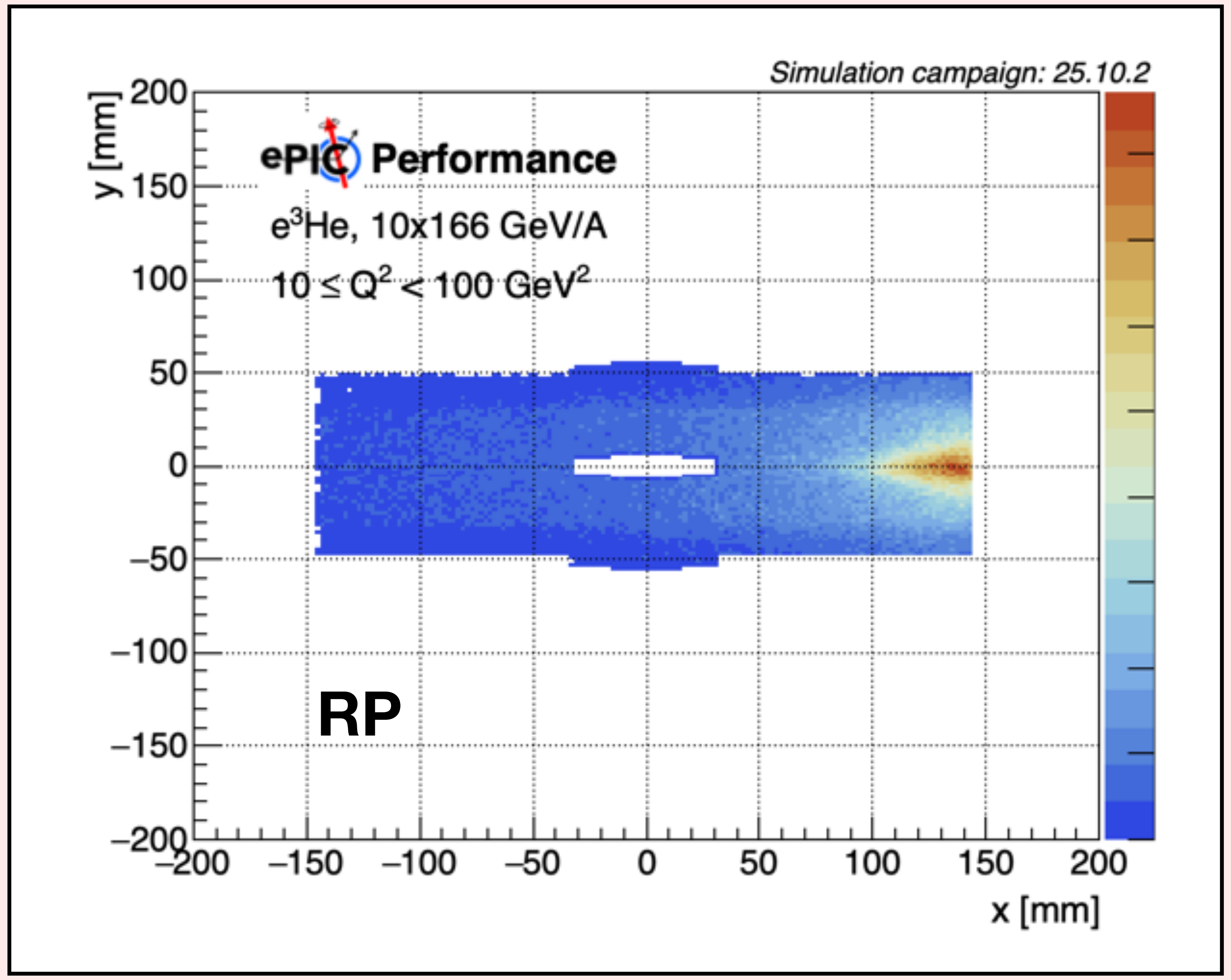


Double spectator tagging - method

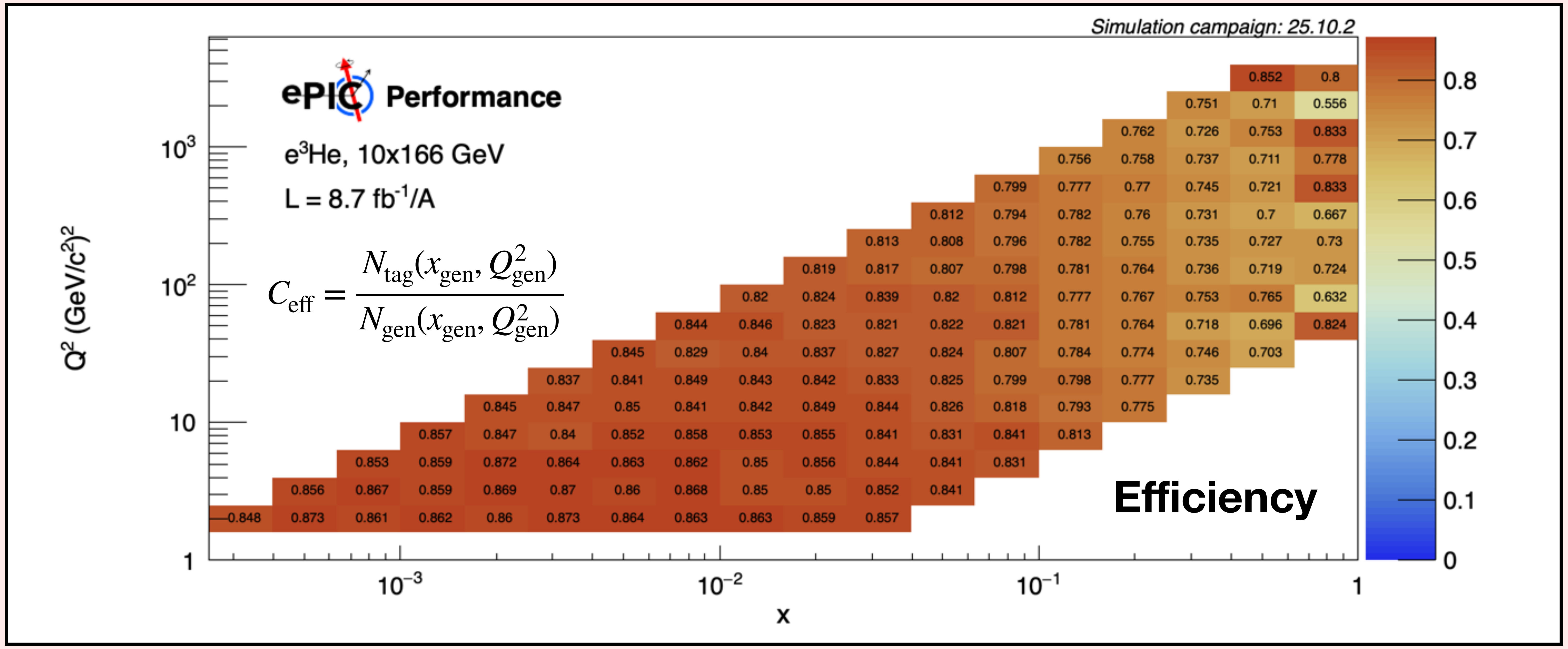
- Hit-based tagging algorithm
- Number of proton tracks = min number of hits per plane per detector
- If number of proton tracks > 2, then tag as double spectator

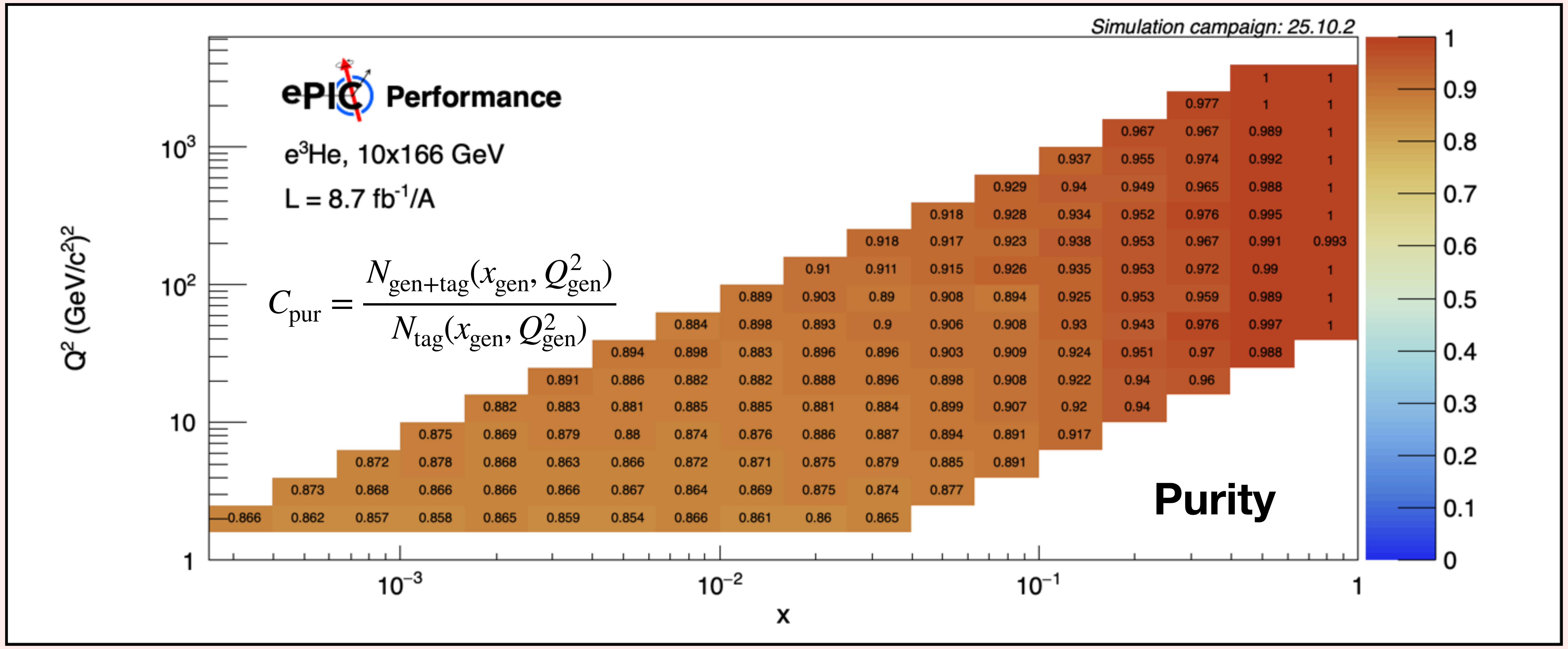




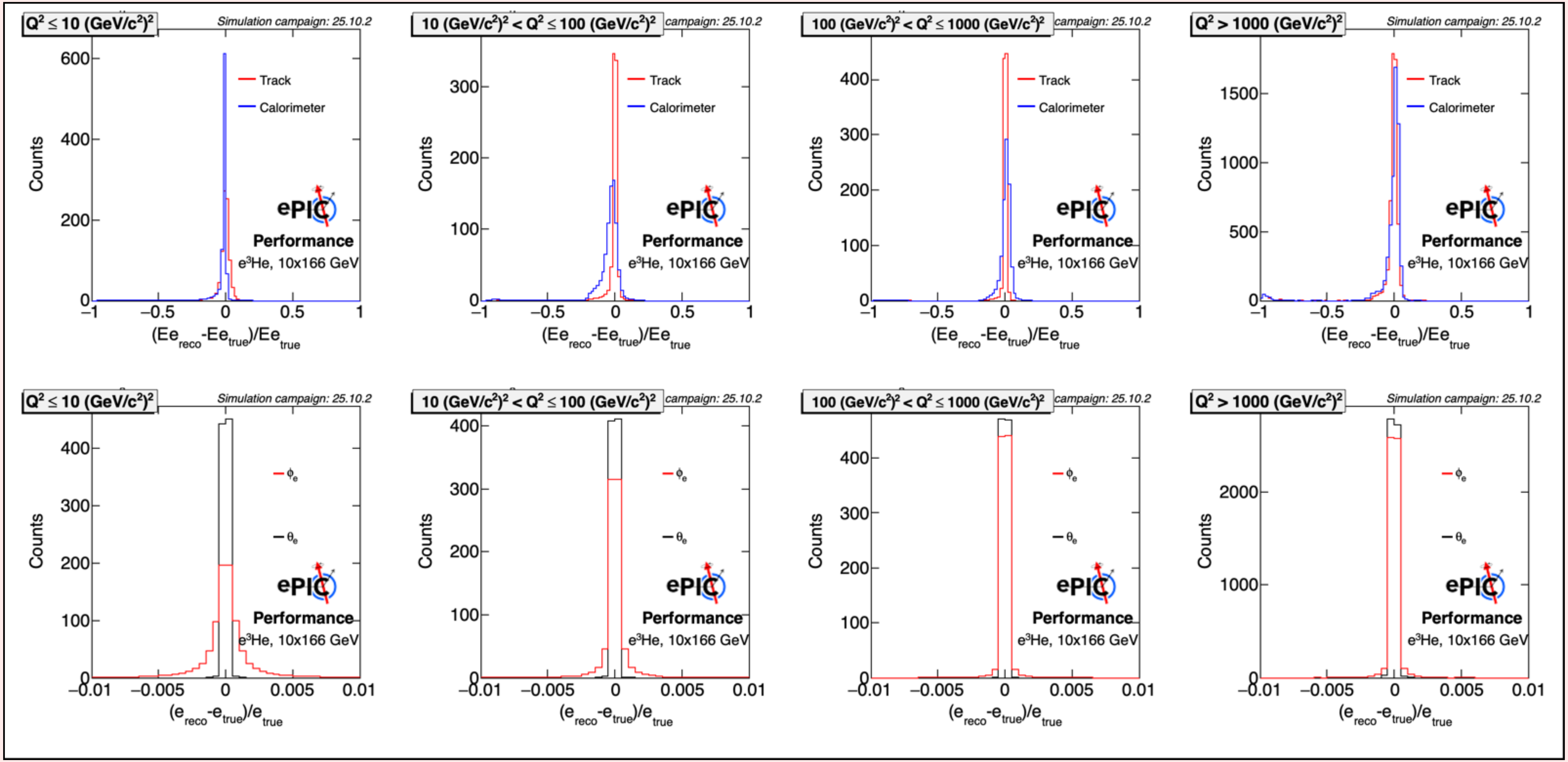


Double spectator tagging - efficiency & purity





Kinematic reconstruction - energy from track vs. cluster



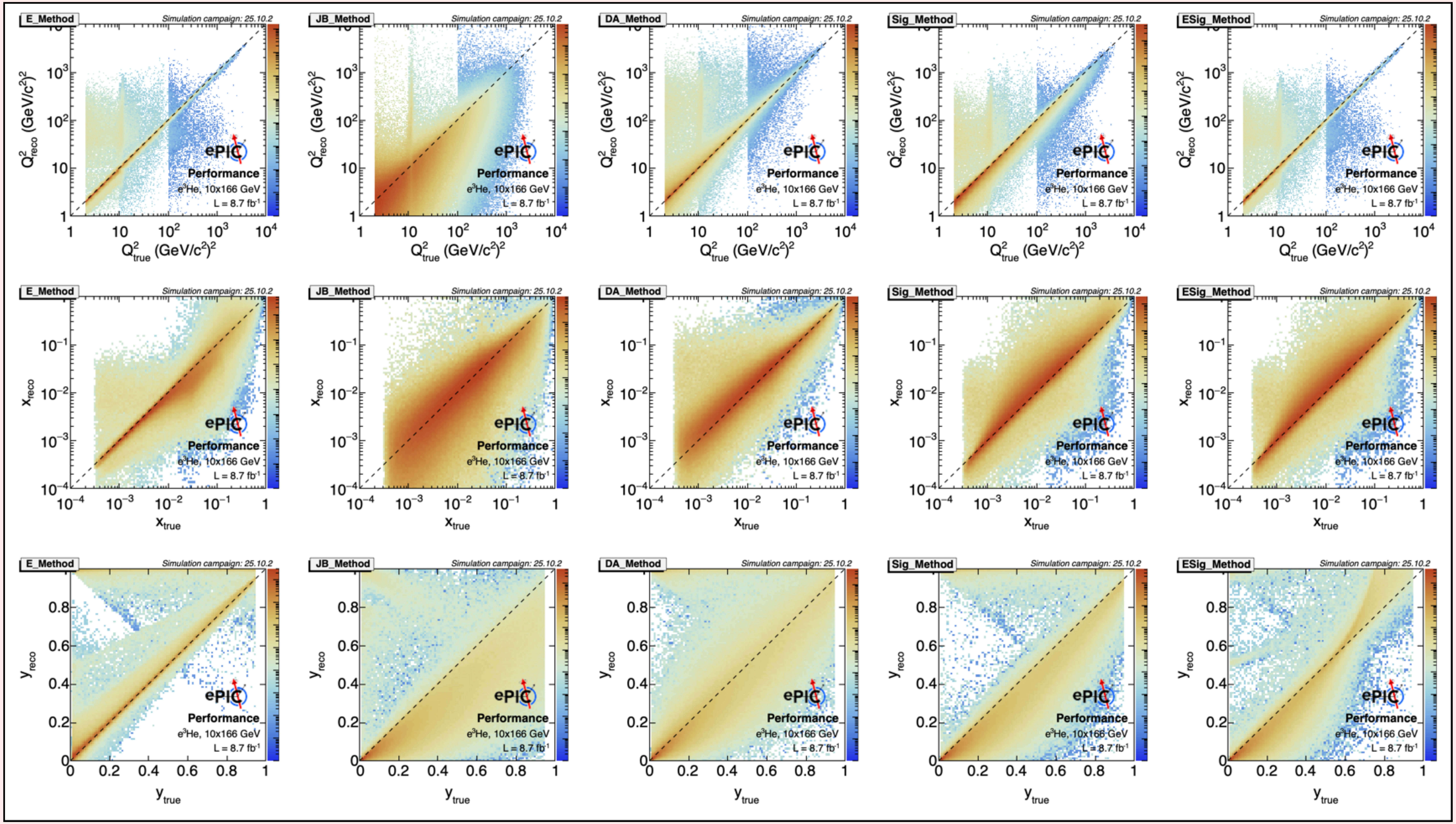
Kinematic reconstruction - algorithms

Current available reconstruction in EICRecon

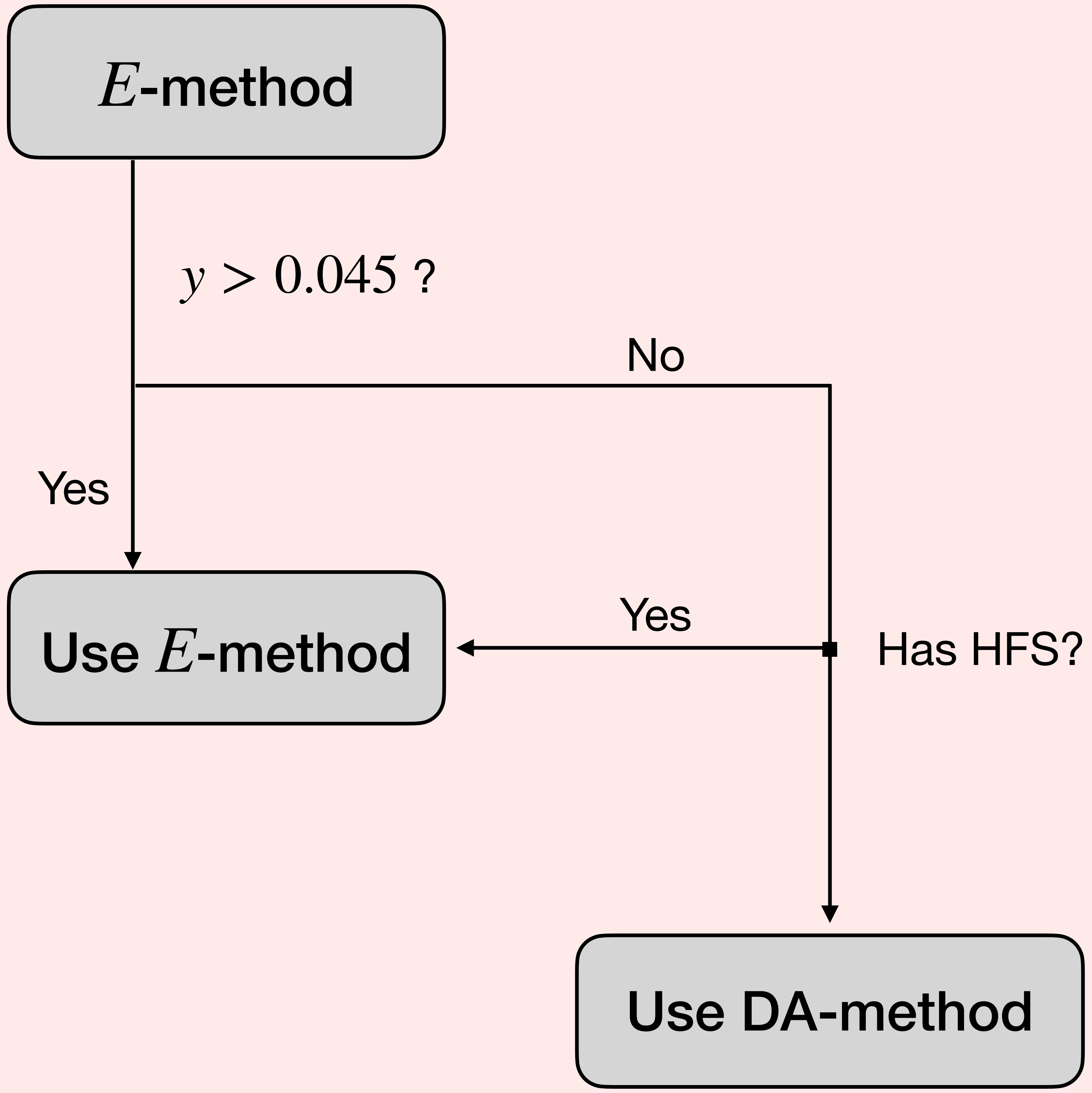
	Algorithm	Q^2	Inelasticity y	Bjorken x
Uses only scattered e^- info	Electron (E)	$2E_0E_e(1+\cos\theta_e)$	$1-\frac{E_e(1-\cos\theta_e)}{2E_0}$	$\frac{Q^2}{4E_0E_ey}$
Uses everything else	Jacquet-Blondel (JB)	$\frac{p_{t,h}^2}{1-y}$	$\frac{\delta_h}{2E_0}$	
No use of scattered E_e	Double-Angle (DA)	$\frac{4E_0^2}{\tan(\frac{\theta_e}{2})(\tan(\frac{\theta_e}{2})+\delta_h/p_{t,h})}$	$\frac{\delta_h/p_{t,h}}{\tan(\frac{\theta_e}{2})+\delta_h/p_{t,h}}$	
No use of scattered E_0	Sigma (Σ)	$\frac{E_e^2\sin^2\theta_e}{1-y}$	$\frac{\delta_h}{\delta_h+E_e(1-\cos\theta_e)}$	
Combine E and Σ method	E-Sigma ($e\Sigma$)	Q_E^2	$\frac{Q_E^2}{4E_0E_ex_\Sigma}$	x_Σ

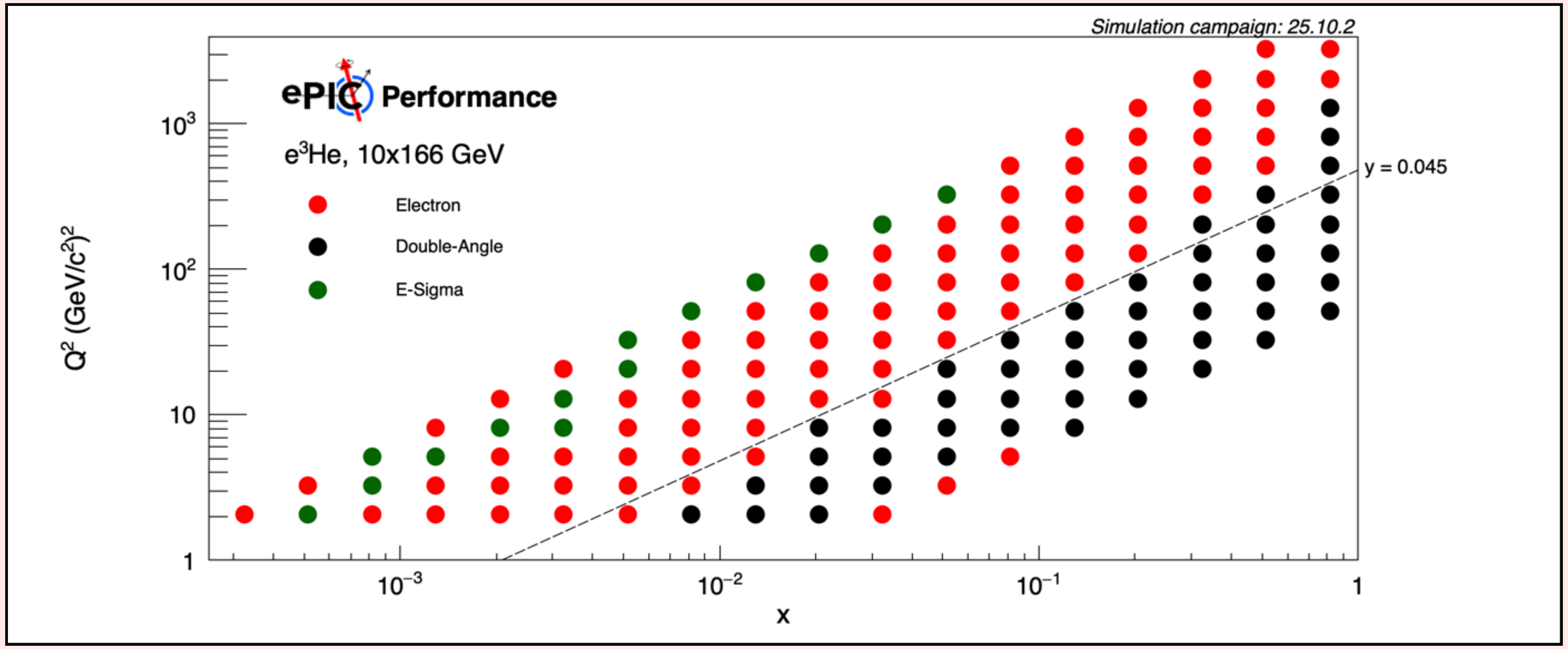
$$p_{t,h}^2 = (\sum_h p_{x,h})^2 + (\sum_h p_{y,h})^2 \qquad \delta_h = \sum_h E_h - p_{z,h}$$

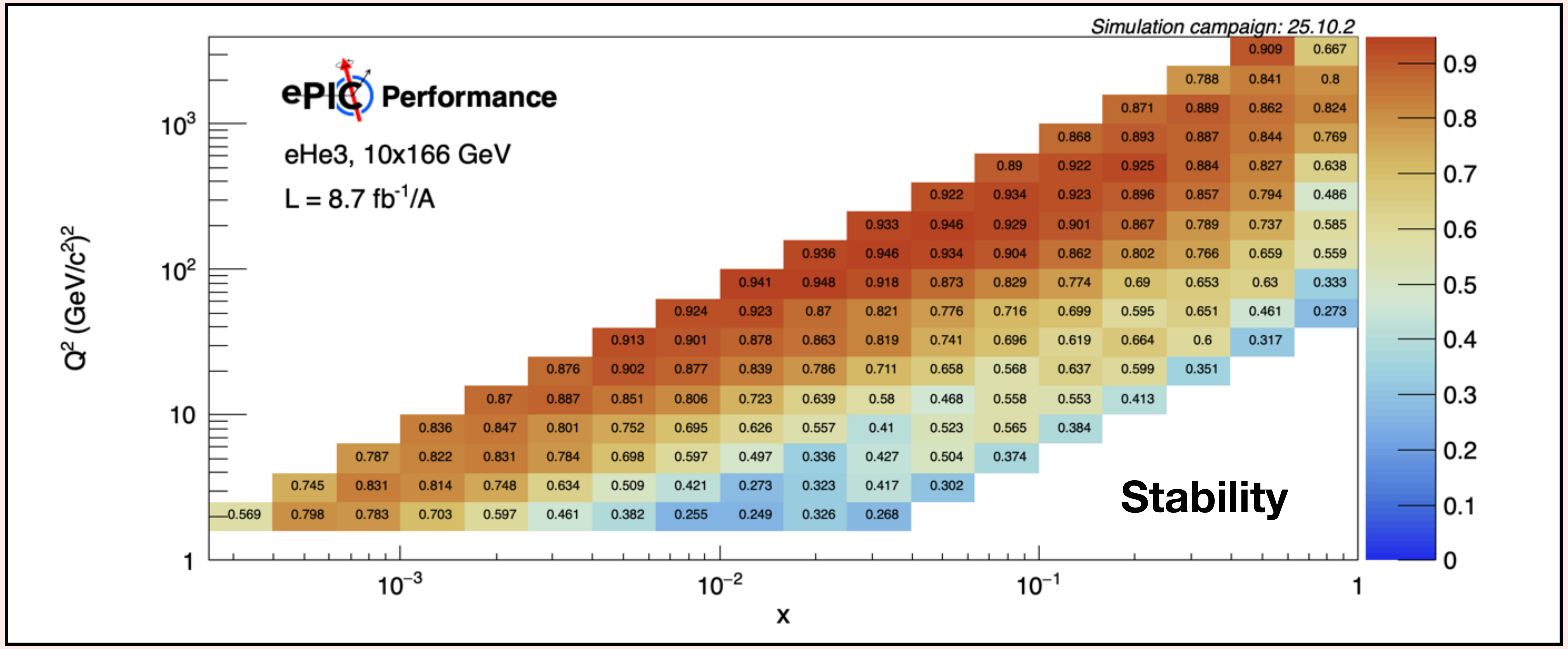
Kinematic reconstruction - qualities



Kinematic reconstruction - algorithms selection

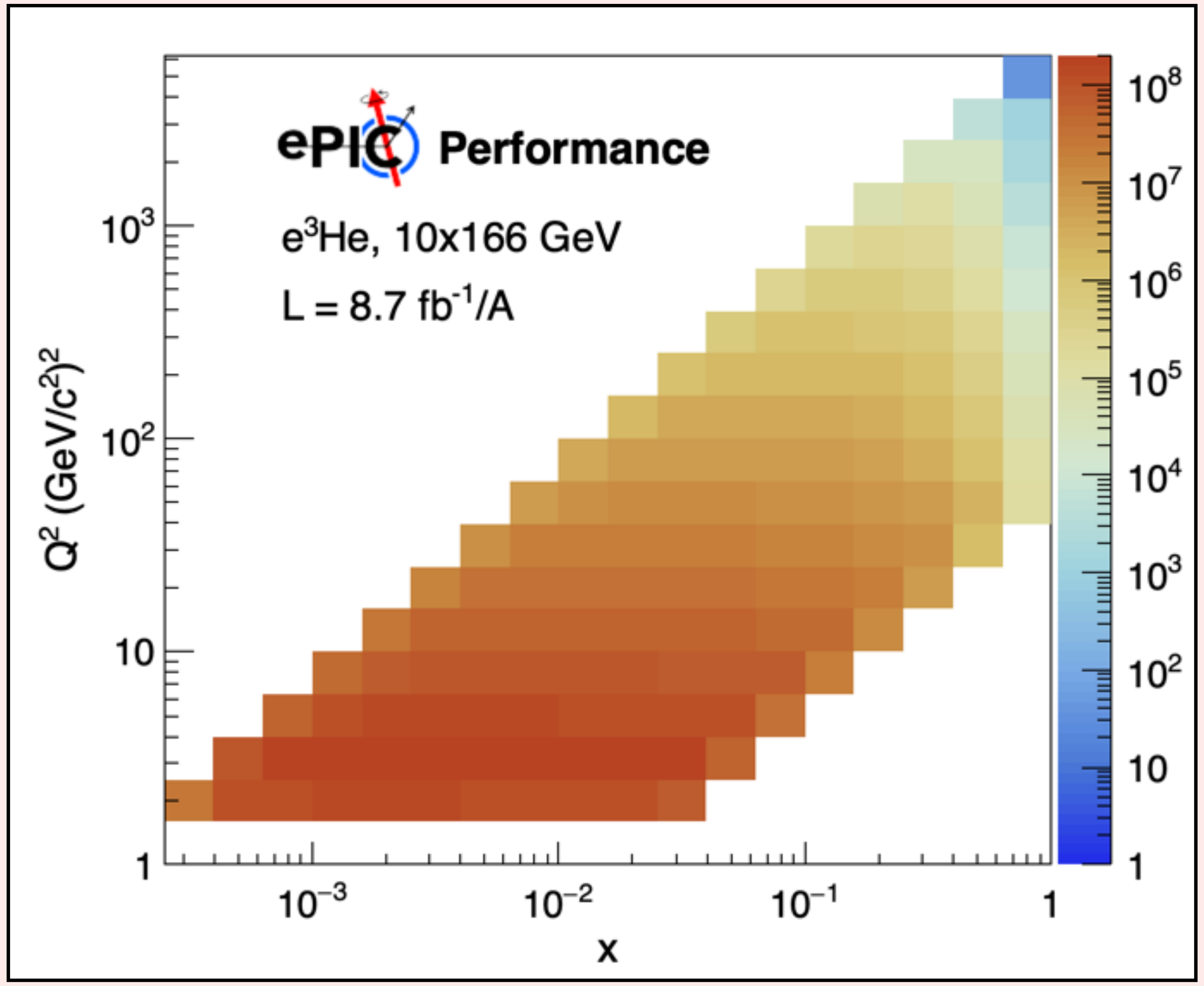




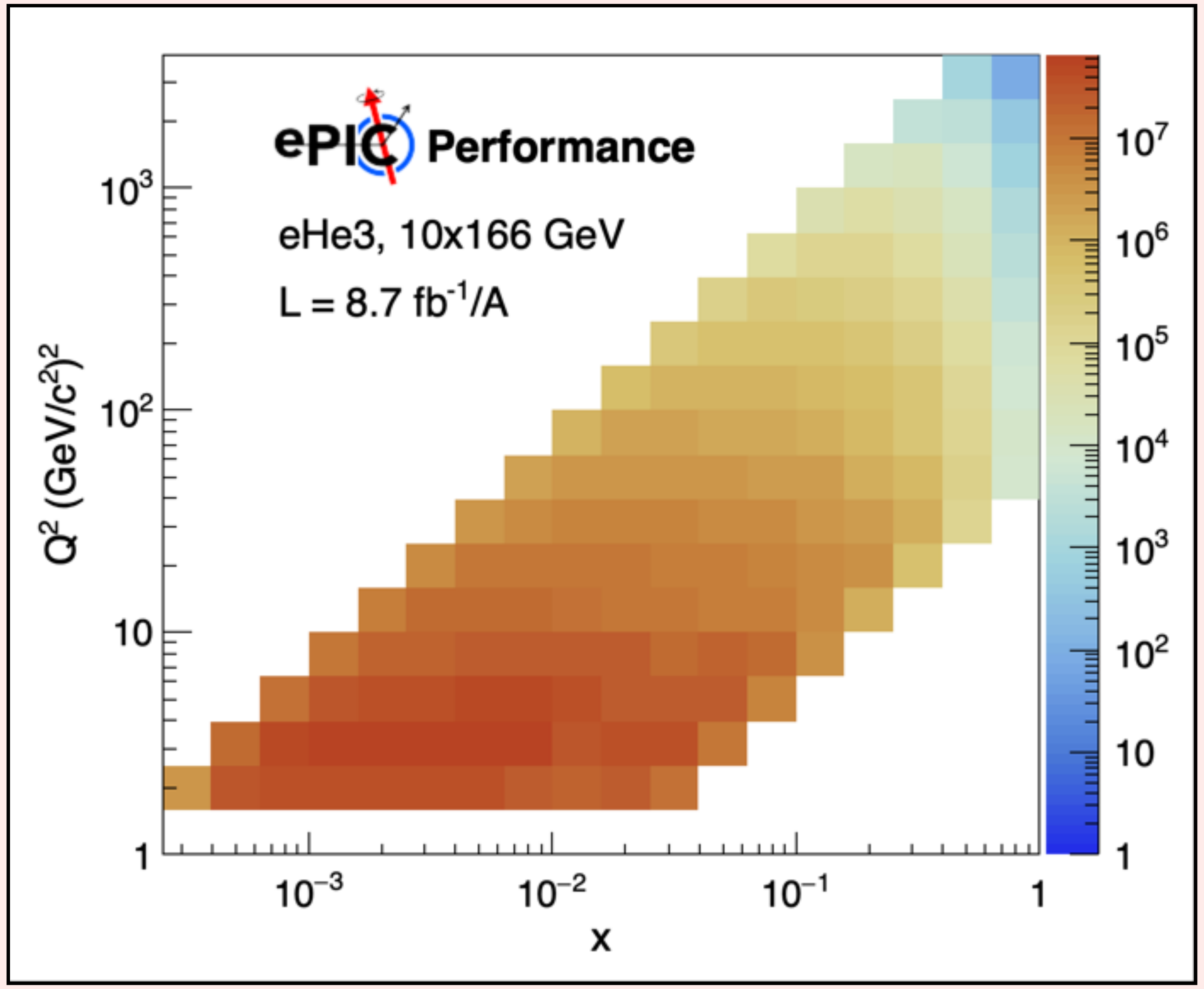


Asymmetry reconstruction

Scaled generated e^3He events



Scaled reconstructed en events



Scattered electron identification

Double spectator tagging

Kinematic reconstruction

Projecting physics results

Projected A_1^n from $e^3\mathrm{He}$ DIS:

- $A_1(x, Q^2) \equiv \dfrac{\sigma_{1/2} - \sigma_{3/2}}{\sigma_{1/2} + \sigma_{3/2}} = \dfrac{A_\parallel}{D(1+\eta\xi)} - \dfrac{\eta A_\perp}{d(1+\eta\xi)}$

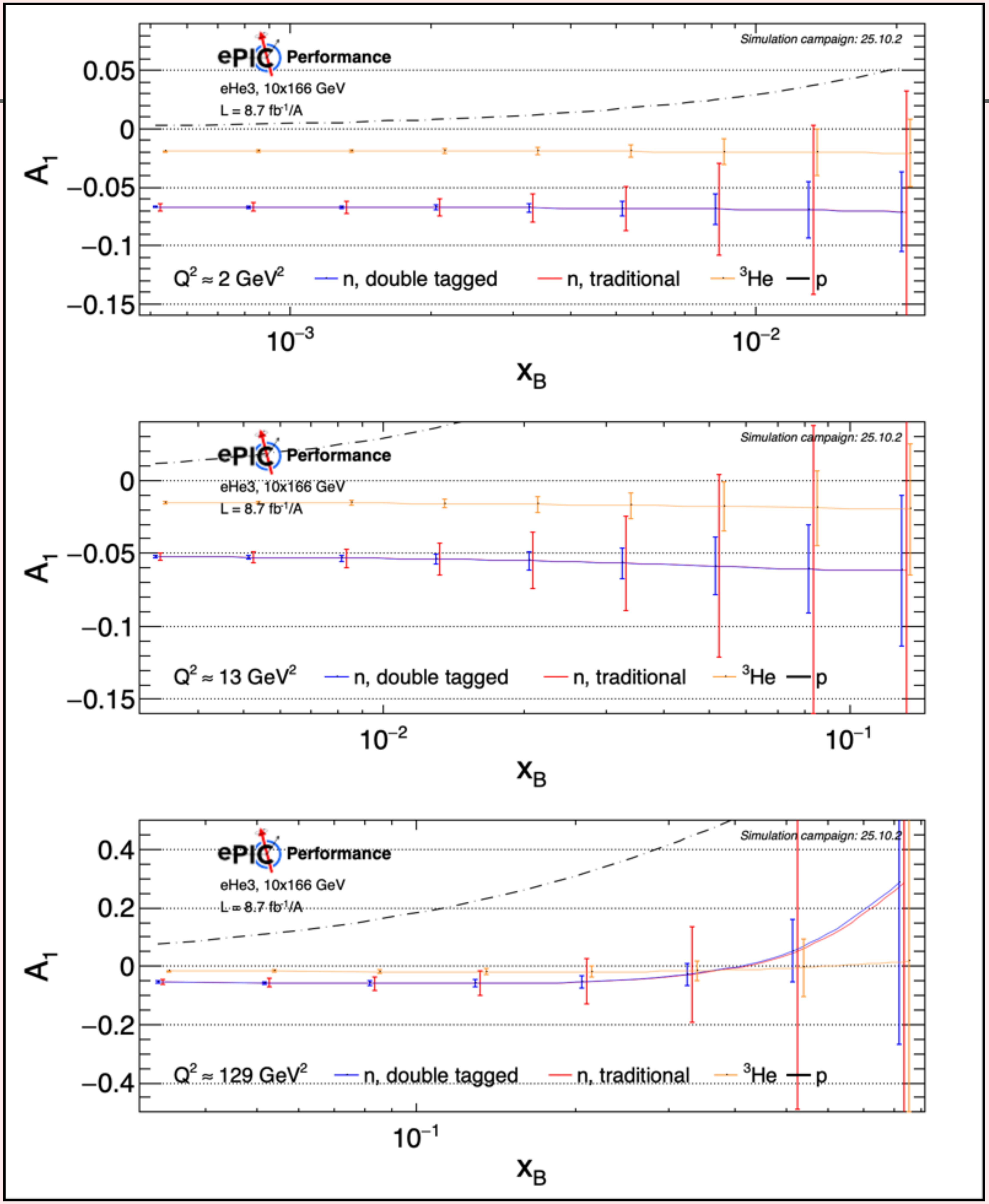
- $\delta A_{\parallel,\perp} = \dfrac{1}{\sqrt{N} P_e P_N}$

- $\mathscr{L} = 8.65\ \mathrm{fb}^{-1}$, $P_e = P_n = 70\,\%$

- $0.01 < y < 0.95$, $Q^2 \geq 2$, $W^2 > 4$

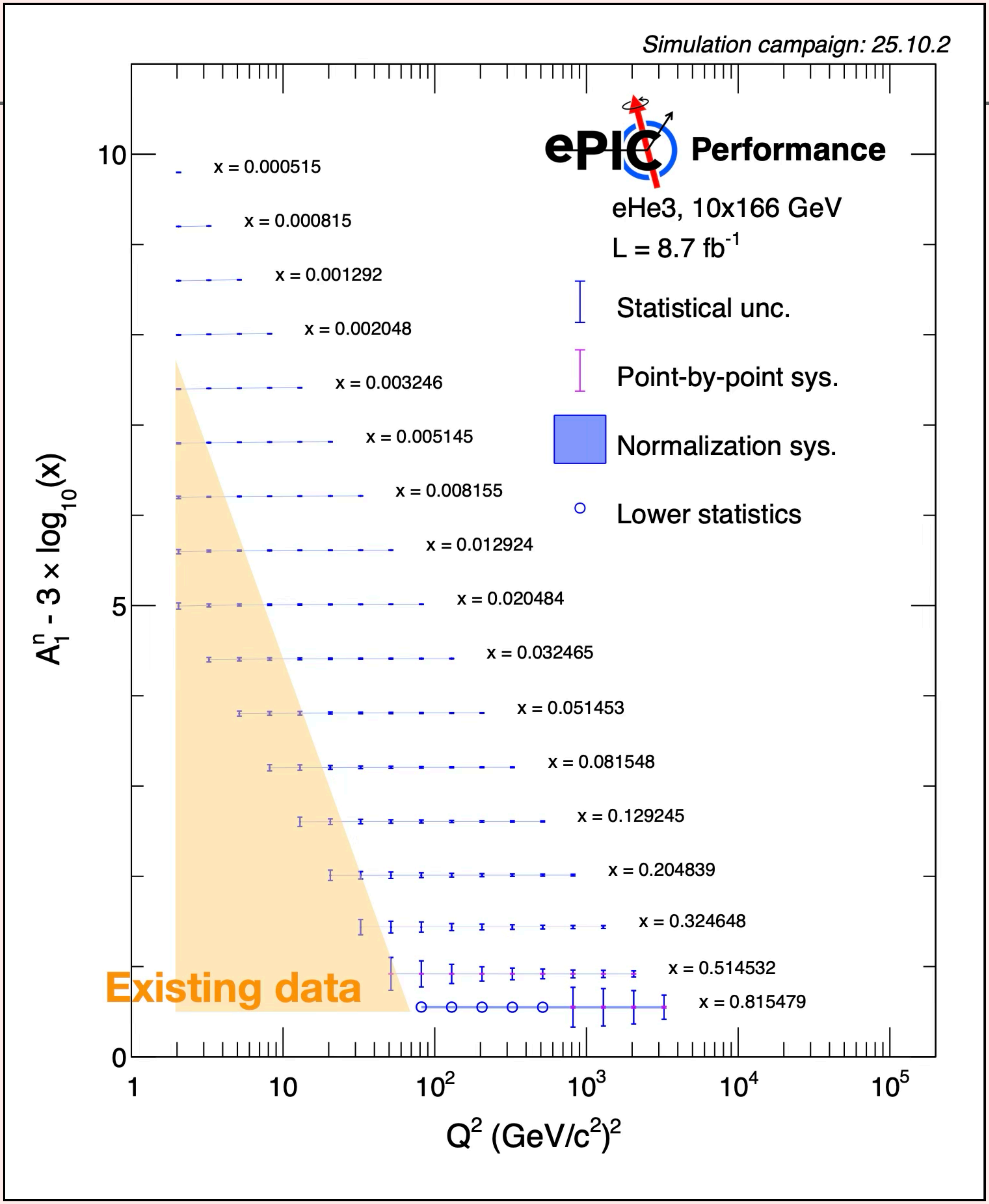
- R calculated from https://doi.org/10.1016/S0370-2693(99)00244-0

- Included statistical uncertainty and model uncertainties



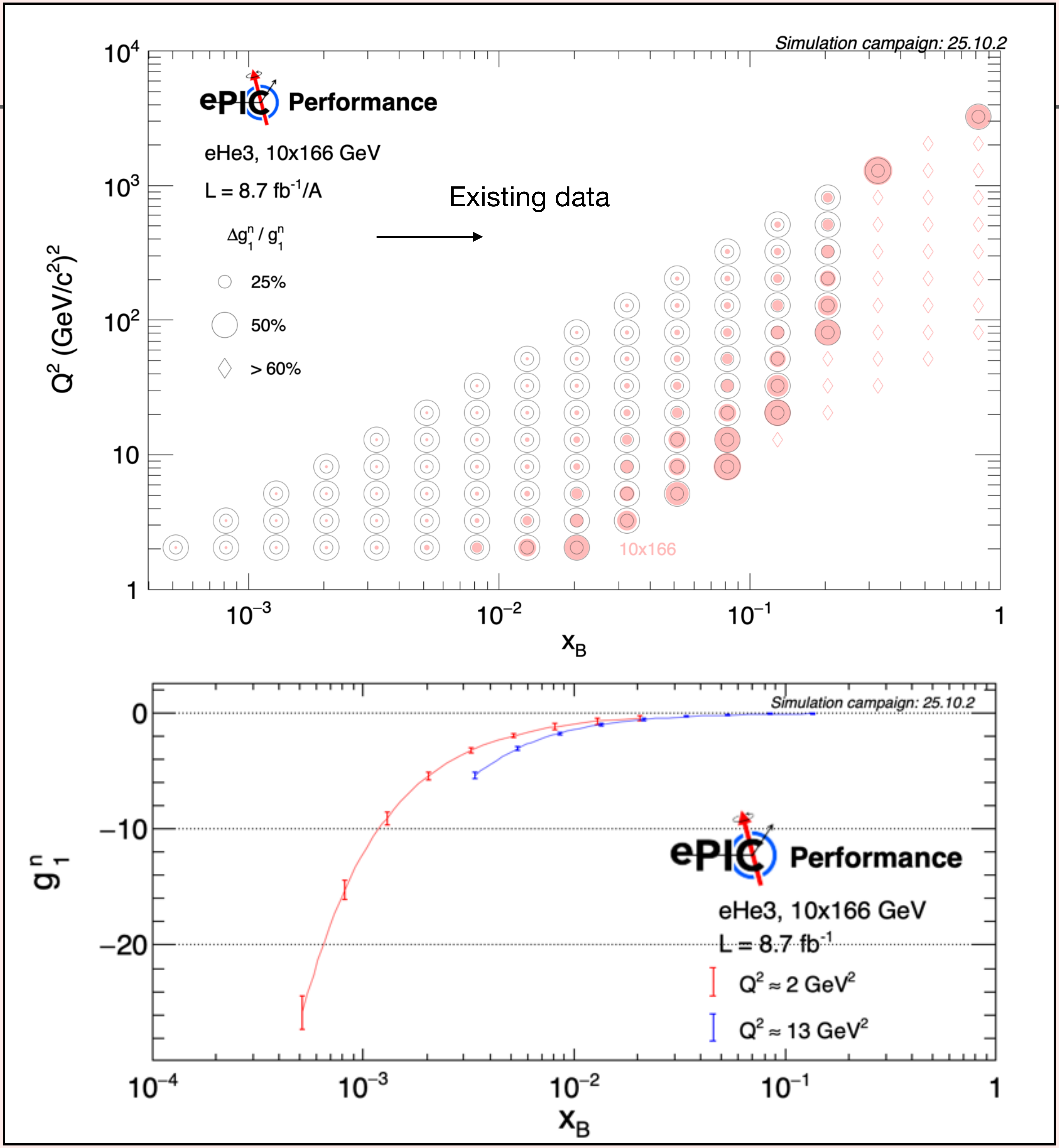
Projected A_1^n from e^3He DIS:

- Statistical: $\delta A_{\parallel,\perp} \approx \dfrac{1}{\sqrt{N} P_e P_N}$
- Systematics using estimate for ATHENA for $A_\parallel$
  - 1.5% point-by-point uncorrelated
  - 3% pion contamination
  - 4.7% normalization
    - 3% δP_e, 3% δP_N
    - 1-2% detector effects
- Estimated using $A_1 \approx \dfrac{A_\parallel}{D}$
- Systematics to be studied in more details



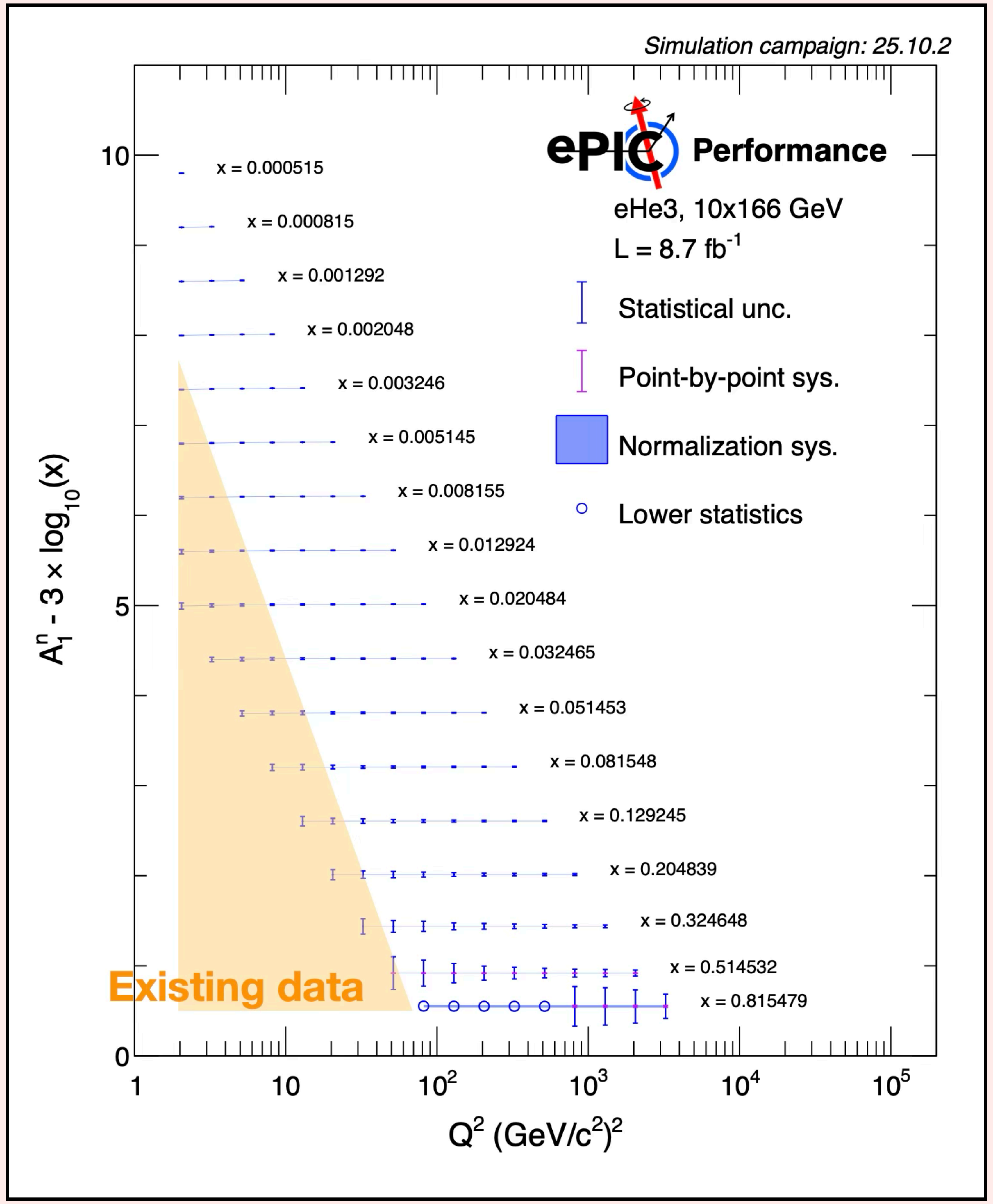
Projected g_1^n from $e\,^3\mathrm{He}$ DIS:

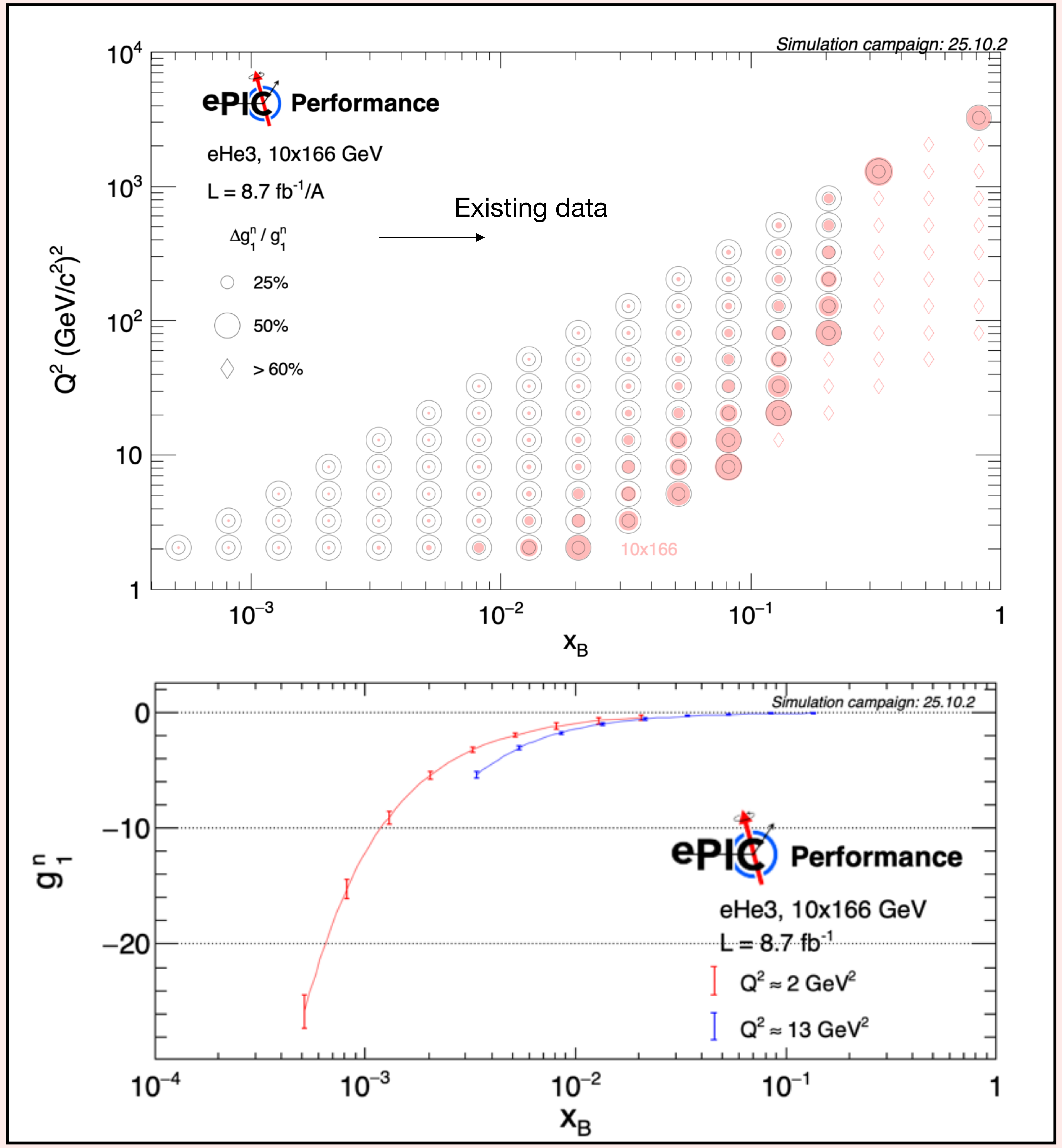
- $A_1 \approx g_1/F_1$ with F_1 calculated from JAM22
- $\mathscr{L} = 8.65\ \mathrm{fb}^{-1},\ P_e = P_n = 70\,\%$
- $0.01 < y < 0.95,\ Q^2 \geq 2,\ W^2 > 4$
- Top plot: Includes statistical uncertainty, systematic estimate
- Bottom plot: Includes statistical uncertainty, systematic estimate, and F_1 uncertainty



Conclusion

- High statistics, large & new kinematic coverage A_1^n and g_1^n starting in year 5 of early EIC running!





Thank you! Analysis note: Link