Plans for inclusive systematics studies

Overview

- Systematic errors are expected to be dominant errors in inclusive NC cross section measurements for much of the EIC phase space

- It’s difficult to determine systematic uncertainties for a detector/accelerator that does not yet exist
  - Some guesswork is required based on experience of previous experiments (mostly HERA), and projections/experience of ePIC detector working groups

Possible systematic uncertainties

- There are many possible sources of systematic uncertainties → just look at H1/ZEUS papers

- Some notable ones are:
  - Electron/Hadronic Energy scale
  - Angular measurement
  - Track-cluster matching efficiency
  - Electron-finding efficiency
  - Background modelling
  - QED Radiative Corrections

- ...and of course, luminosity/polarisation measurements

https://arxiv.org/abs/1312.4821

Source	Region	Uncertainty
Electron energy scale	$z_{\mathrm{imp}} \leq -150\,\mathrm{cm}$	0.5% unc. $\oplus$ 0.3% corr.
	$-150 < z_{\mathrm{imp}} \leq -60\,\mathrm{cm}$	0.3% unc. $\oplus$ 0.3% corr.
	$-60 < z_{\mathrm{imp}} \leq +20\,\mathrm{cm}$	0.5% unc. $\oplus$ 0.3% corr.
	$+20 < z_{\mathrm{imp}} \leq +110\,\mathrm{cm}$	0.5% unc. $\oplus$ 0.3% corr.
	$z_{\mathrm{imp}} > +110\,\mathrm{cm}$	1.0% unc. $\oplus$ 0.3% corr.
Electron scale linearity	$E'_e < 11\,\mathrm{GeV}$	0.5%
Hadronic energy scale	LAr & Tracks	1.0% unc. $\oplus$ 0.3% corr.
	SpaCal	5.0% unc. $\oplus$ 0.3% corr.
Polar angle	θ_e	1 mrad corr.
Noise	$y < 0.19$	5% energy not in jets , corr.
	$y > 0.19$	20% corr.
Trigger efficiency	*high y*	$0.3 - 2\%$
	nominal	0.3%
Electron track and vertex efficiency	*high y*	1%
	nominal	$0.2 - 1\%$
Electron charge ID efficiency	*high y*	0.5%
Electron ID efficiency	*high y* $z_{\mathrm{imp}} < 20$ (> 20) cm	0.5% (1%)
	nominal $z_{\mathrm{imp}} < 20$ (> 20) cm	0.2% (1%)
Extra background suppression	$E'_e < 10\,\mathrm{GeV}$	$D_{ele} > 0.80 \pm 0.04$ corr.
High y background subtraction	*high y*	1.03 ± 0.08 corr.
QED radiative corrections	$x < 0.1$, $0.1 \leq x < 0.3$, $x \geq 0.3$	0.3% , 1.0%, 2.0%
	high y: $y < 0.8$ $(y > 0.8)$	1% (1.5%)
Acceptance corrections	*high y*	0.5%
	nominal	0.2%
Luminosity		4% corr.

Studying systematic uncertainties

- The procedure for evaluating systematic uncertainties requires first studying/estimating the values of the individual contributions (as in previous slide)

- The full analysis is repeated for each positive and negative fluctuation of the systematic
  - e.g. for 1% electron energy scale, we multiply the energy of each electron by 0.99 (-ve) or 1.01 (+ve) before reconstructing kinematics
    - If it’s 1% at 5GeV and 0.5% at 18GeV, could apply to electrons event by event, linearly interpolating
  - Note that the systematic may instead be estimated by the tightening or loosening of a cut, or repetition using a different model (event generator)

Studying systematic uncertainties

- After repeating the analysis with each systematic, you end up with a table like this:

x	Q^2 (GeV^2)	0: F_2 standard	1: Finding efficiency +	2: Finding efficiency -	3: BOX X 28cm	4: BOX Y 28cm	5: Wide gap	6: Narrow gap	7: R+0.2cm	8: R-0.2cm	9: Vertex efficiency -1%	10: Vertex efficiency low γ_H +3%	11: Vertex cut (-28,40)	12: Positron Energy scale +	13: Positron Energy scale -	14: Hadron scale -3%	15: Hadron scale +3%	16: Hadron scale F/B/RCAL +3/0/-3 %	17: Hadron scale F/B/RCAL -3/0/+3 %	18: Hadron scale F/B/RCAL 0/+3/0 %	19: Hadron scale F/B/RCAL 0/-3/0 %	20: Noise +	21: Noise -	22: MEPS	23: Diffractive [37] (take maximum 23,24)	24: Diffractive x 2	25: Relax p_{Th}/p_{Te} cut	26: 1 p_{Th} bin	27: More γ bins	28: PHP background x 1.5	29: PHP background x 0.5
6.3×10^{-5}	3.5	0.875	0.917	0.862	0.866	0.875	0.884	0.861	0.875	0.875	0.870	0.875	0.871	0.882	0.861	0.923	0.805	0.917	0.817	0.856	0.883	0.864	0.887	0.870	0.896	0.887	0.876	0.880	0.864	0.854	0.896
1.0×10^{-4}	3.5	0.939	0.949	0.937	0.980	0.889	0.954	0.929	0.939	0.939	0.946	0.939	0.939	0.952	0.928	0.973	0.905	0.954	0.910	0.935	0.947	0.923	0.943	0.936	0.946	0.946	0.938	0.935	0.945	0.926	0.952
1.0×10^{-4}	4.5	1.030	1.046	1.023	1.032	1.034	1.036	1.019	1.030	1.030	1.027	1.030	1.031	1.055	1.011	1.069	0.998	1.056	1.006	1.019	1.030	1.024	1.038	1.028	1.036	1.034	1.028	1.016	1.031	1.010	1.050
1.6×10^{-4}	4.5	1.038	1.042	1.037	1.056	1.015	1.046	1.024	1.038	1.038	1.041	1.038	1.060	1.044	1.037	1.034	1.034	1.028	1.046	1.032	1.047	1.029	1.049	1.036	1.029	1.041	1.036	1.034	1.031	1.028	1.047
2.5×10^{-4}	4.5	0.932	0.933	0.932	0.930	0.918	0.952	0.928	0.932	0.932	0.935	0.932	0.951	0.935	0.934	0.929	0.924	0.914	0.937	0.922	0.933	0.924	0.931	0.940	0.939	0.935	0.930	0.943	0.918	0.931	0.934
1.0×10^{-4}	6.5	1.221	1.257	1.204	1.220	1.227	1.235	1.208	1.221	1.222	1.221	1.221	1.246	1.254	1.201	1.282	1.173	1.266	1.179	1.213	1.237	1.214	1.226	1.215	1.212	1.229	1.223	1.222	1.216	1.199	1.243
1.6×10^{-4}	6.5	1.138	1.151	1.135	1.135	1.133	1.158	1.125	1.138	1.138	1.139	1.138	1.157	1.148	1.137	1.164	1.114	1.158	1.125	1.130	1.145	1.133	1.147	1.138	1.135	1.136	1.138	1.149	1.142	1.128	1.147
2.5×10^{-4}	6.5	1.038	1.042	1.038	1.031	1.042	1.046	1.022	1.038	1.038	1.035	1.038	1.044	1.030	1.032	1.045	1.037	1.032	1.043	1.030	1.046	1.028	1.045	1.046	1.033	1.035	1.039	1.037	1.037	1.032	1.044
4.0×10^{-4}	6.5	0.951	0.951	0.951	0.954	0.963	0.962	0.939	0.951	0.951	0.953	0.951	0.962	0.941	0.951	0.961	0.948	0.946	0.960	0.941	0.964	0.941	0.959	0.953	0.957	0.958	0.951	0.959	0.933	0.951	0.951
6.3×10^{-4}	6.5	0.841	0.841	0.841	0.837	0.847	0.857	0.834	0.841	0.841	0.841	0.841	0.851	0.835	0.843	0.842	0.839	0.832	0.848	0.838	0.845	0.837	0.843	0.844	0.852	0.848	0.842	0.830	0.848	0.841	0.841
1.0×10^{-3}	6.5	0.776	0.776	0.776	0.779	0.786	0.786	0.770	0.776	0.776	0.779	0.776	0.787	0.783	0.776	0.777	0.777	0.766	0.782	0.779	0.772	0.752	0.793	0.797	0.783	0.782	0.782	0.766	0.780	0.776	0.776
1.6×10^{-3}	6.5	0.753	0.753	0.753	0.745	0.755	0.760	0.740	0.753	0.753	0.755	0.753	0.762	0.750	0.752	0.747	0.752	0.752	0.757	0.755	0.746	0.729	0.764	0.767	0.755	0.760	0.756	0.750	0.747	0.753	0.753
2.5×10^{-3}	6.5	0.645	0.645	0.645	0.634	0.652	0.652	0.636	0.645	0.645	0.645	0.645	0.651	0.644	0.645	0.643	0.650	0.643	0.651	0.650	0.642	0.627	0.655	0.655	0.653	0.660	0.650	0.640	0.662	0.645	0.645
4.0×10^{-3}	6.5	0.629	0.629	0.629	0.626	0.631	0.637	0.619	0.629	0.629	0.629	0.628	0.633	0.625	0.630	0.630	0.629	0.627	0.631	0.631	0.628	0.605	0.643	0.619	0.629	0.624	0.634	0.629	0.627	0.629	0.629
1.6×10^{-2}	6.5	0.495	0.495	0.495	0.505	0.498	0.501	0.488	0.495	0.495	0.494	0.495	0.494	0.490	0.499	0.489	0.496	0.491	0.495	0.498	0.489	0.526	0.477	0.489	0.494	0.490	0.506	0.495	0.503	0.495	0.495
4.0×10^{-2}	6.5	0.403	0.403	0.403	0.431	0.407	0.409	0.401	0.403	0.403	0.403	0.405	0.404	0.376	0.424	0.393	0.416	0.414	0.394	0.405	0.400	0.522	0.344	0.375	0.405	0.392	0.484	0.407	0.402	0.403	0.403
1.6×10^{-4}	8.5	1.337	1.368	1.323	1.336	1.336	1.347	1.327	1.337	1.334	1.339	1.337	1.352	1.340	1.333	1.370	1.280	1.363	1.293	1.325	1.343	1.314	1.337	1.327	1.343	1.342	1.337	1.329	1.338	1.316	1.357
2.5×10^{-4}	8.5	1.151	1.161	1.150	1.151	1.152	1.168	1.135	1.150	1.151	1.151	1.151	1.166	1.145	1.148	1.171	1.148	1.159	1.157	1.145	1.155	1.143	1.159	1.152	1.147	1.146	1.149	1.150	1.160	1.143	1.159
4.0×10^{-4}	8.5	0.993	0.996	0.993	0.995	0.989	1.009	0.981	0.993	0.993	0.990	0.993	0.995	0.991	1.001	0.996	0.991	0.987	0.997	0.991	1.006	0.990	1.001	1.002	1.000	0.994	0.995	0.996	0.981	0.991	0.994
6.3×10^{-4}	8.5	0.920	0.921	0.920	0.914	0.927	0.930	0.916	0.920	0.920	0.922	0.920	0.922	0.915	0.912	0.919	0.918	0.907	0.924	0.910	0.924	0.907	0.922	0.920	0.921	0.921	0.919	0.919	0.916	0.920	0.920
1.0×10^{-3}	8.5	0.831	0.832	0.831	0.837	0.830	0.842	0.818	0.831	0.831	0.832	0.831	0.833	0.829	0.840	0.835	0.828	0.823	0.842	0.830	0.839	0.812	0.847	0.844	0.841	0.842	0.833	0.834	0.833	0.831	0.831
1.6×10^{-3}	8.5	0.704	0.705	0.704	0.708	0.703	0.713	0.694	0.704	0.704	0.705	0.704	0.716	0.700	0.703	0.706	0.702	0.700	0.707	0.708	0.701	0.698	0.713	0.714	0.708	0.713	0.707	0.699	0.711	0.704	0.704
1.6×10^{-4}	10.0	1.359	1.432	1.336	1.359	1.359	1.379	1.366	1.353	1.398	1.364	1.359	1.371	1.371	1.349	1.412	1.307	1.381	1.337	1.353	1.375	1.355	1.362	1.343	1.375	1.349	1.356	1.395	1.323	1.339	1.380
2.5×10^{-4}	10.0	1.231	1.246	1.227	1.230	1.231	1.238	1.218	1.231	1.228	1.229	1.231	1.254	1.240	1.219	1.247	1.203	1.247	1.209	1.226	1.239	1.221	1.238	1.238	1.230	1.226	1.232	1.230	1.233	1.218	1.243
4.0×10^{-4}	10.0	1.136	1.138	1.136	1.136	1.142	1.135	1.135	1.135	1.137	1.137	1.136	1.153	1.137	1.129	1.155	1.132	1.140	1.139	1.126	1.146	1.127	1.142	1.139	1.145	1.139	1.136	1.137	1.123	1.133	1.140
6.3×10^{-4}	10.0	0.968	0.969	0.968	0.967	0.967	0.981	0.951	0.968	0.969	0.967	0.968	0.980	0.964	0.976	0.972	0.971	0.964	0.981	0.960	0.978	0.962	0.980	0.974	0.979	0.976	0.966	0.969	0.968	0.967	0.969
1.0×10^{-3}	10.0	0.857	0.857	0.857	0.861	0.867	0.870	0.847	0.857	0.857	0.854	0.857	0.861	0.849	0.859	0.853	0.852	0.845	0.864	0.852	0.855	0.849	0.856	0.866	0.866	0.862	0.860	0.848	0.852	0.856	0.857
1.6×10^{-3}	10.0	0.792	0.793	0.792	0.797	0.795	0.799	0.785	0.792	0.792	0.790	0.792	0.796	0.789	0.792	0.797	0.790	0.790	0.800	0.792	0.791	0.773	0.801	0.801	0.798	0.803	0.794	0.793	0.785	0.792	0.792
2.5×10^{-3}	10.0	0.715	0.715	0.715	0.716	0.721	0.728	0.698	0.715	0.715	0.714	0.714	0.714	0.708	0.710	0.717	0.715	0.711	0.722	0.718	0.715	0.693	0.728	0.738	0.722	0.724	0.719	0.716	0.721	0.715	0.715
6.3×10^{-3}	10.0	0.593	0.593	0.593	0.596	0.597	0.601	0.587	0.592	0.593	0.592	0.593	0.597	0.592	0.594	0.591	0.593	0.589	0.594	0.597	0.589	0.574	0.602	0.586	0.596	0.597	0.595	0.593	0.607	0.593	0.593
1.6×10^{-2}	10.0	0.517	0.518	0.517	0.518	0.520	0.524	0.511	0.517	0.517	0.517	0.517	0.518	0.516	0.519	0.519	0.520	0.515	0.523	0.520	0.514	0.522	0.515	0.517	0.518	0.515	0.517	0.525	0.517	0.517	0.517
8.1×10^{-2}	10.0	0.395	0.395	0.395	0.397	0.395	0.401	0.389	0.395	0.395	0.395	0.396	0.396	0.371	0.409	0.387	0.398	0.395	0.389	0.397	0.394	0.490	0.354	0.363	0.394	0.384	0.410	0.392	0.392	0.395	0.395
2.5×10^{-4}	12.0	1.300	1.322	1.290	1.300	1.301	1.305	1.294	1.295	1.307	1.299	1.300	1.310	1.320	1.317	1.334	1.261	1.316	1.277	1.292	1.307	1.297	1.303	1.305	1.306	1.309	1.298	1.305	1.283	1.276	1.325
4.0×10^{-4}	12.0	1.128	1.140	1.128	1.127	1.130	1.150	1.117	1.130	1.130	1.129	1.128	1.138	1.127	1.121	1.143	1.114	1.128	1.132	1.125	1.137	1.119	1.134	1.134	1.134	1.139	1.127	1.130	1.129	1.119	1.138
6.3×10^{-4}	12.0	1.102	1.104	1.102	1.100	1.102	1.113	1.088	1.101	1.102	1.099	1.102	1.107	1.096	1.110	1.101	1.089	1.086	1.108	1.080	1.107	1.091	1.104	1.104	1.113	1.103	1.102	1.100	1.099	1.102	1.102
1.0×10^{-3}	12.0	0.903	0.903	0.903	0.904	0.904	0.912	0.892	0.902	0.903	0.905	0.903	0.915	0.889	0.908	0.900	0.908	0.893	0.909	0.906	0.903	0.892	0.910	0.923	0.913	0.905	0.885	0.905	0.910	0.903	0.903
1.6×10^{-3}	12.0	0.789	0.789	0.789	0.793	0.793	0.808	0.780	0.788	0.789	0.788	0.789	0.800	0.791	0.792	0.794	0.791	0.783	0.794	0.788	0.795	0.772	0.792	0.796	0.798	0.795	0.792	0.786	0.798	0.789	0.789
2.5×10^{-3}	12.0	0.746	0.746	0.746	0.747	0.753	0.755	0.731	0.746	0.746	0.745	0.746	0.756	0.735	0.747	0.745	0.743	0.743	0.755	0.750	0.744	0.732	0.758	0.756	0.757	0.764	0.745	0.746	0.739	0.746	0.746
2.5×10^{-4}	15.0	1.559	1.597	1.541	1.559	1.559	1.556	1.550	1.526	1.574	1.562	1.559	1.578	1.567	1.523	1.612	1.507	1.594	1.510	1.547	1.567	1.535	1.575	1.556	1.564	1.544	1.554	1.564	1.559	1.512	1.606
4.0×10^{-4}	15.0	1.338	1.352	1.337	1.337	1.338	1.349	1.329	1.331	1.345	1.339	1.338	1.351	1.341	1.336	1.366	1.320	1.360	1.333	1.333	1.356	1.329	1.358	1.333	1.347	1.334	1.341	1.340	1.329	1.329	1.347
6.3×10^{-4}	15.0	1.092	1.093	1.092	1.092	1.092	1.099	1.083	1.092	1.091	1.090	1.092	1.108	1.081	1.093	1.094	1.084	1.084	1.096	1.079	1.101	1.078	1.098	1.104	1.108	1.100	1.092	1.081	1.095	1.087	1.098
1.0×10^{-3}	15.0	0.992	0.993	0.992	0.993	0.992	1.002	0.986	0.990	0.992	0.992	0.992	1.013	0.996	0.999	0.995	0.976	0.981	0.998	0.976	1.002	0.978	1.001	1.012	1.001	0.998	0.994	0.995	0.976	0.992	0.992
1.6×10^{-3}	15.0	0.908	0.908	0.908	0.906	0.911	0.914	0.903	0.908	0.909	0.905	0.908	0.920	0.907	0.902	0.911	0.910	0.902	0.914	0.907	0.907	0.892	0.914	0.918	0.913	0.910	0.913	0.909	0.892	0.908	0.908
2.5×10^{-3}	15.0	0.793	0.793	0.793	0.794	0.795	0.802	0.790	0.792	0.794	0.791	0.793	0.806	0.790	0.791	0.791	0.803	0.790	0.798	0.807	0.790	0.786	0.801	0.811	0.802	0.801	0.796	0.787	0.812	0.793	0.793
6.3×10^{-3}	15.0	0.662	0.662	0.662	0.663	0.662	0.671	0.652	0.661	0.662	0.663	0.662	0.675	0.660	0.667	0.662	0.661	0.659	0.664	0.665	0.658	0.640	0.670	0.657	0.664	0.666	0.662	0.664	0.658	0.662	0.662
1.6×10^{-2}	15.0	0.553	0.553	0.553	0.553	0.553	0.558	0.548	0.552	0.553	0.552	0.552	0.562	0.552	0.553	0.552	0.552	0.548	0.557	0.555	0.549	0.543	0.559	0.551	0.559	0.550	0.548	0.552	0.551	0.553	0.553
8.1×10^{-2}	15.0	0.370	0.370	0.370	0.371	0.370	0.375	0.366	0.370	0.370	0.370	0.371	0.370	0.357	0.379	0.365	0.378	0.376	0.367	0.373	0.368	0.429	0.341	0.349	0.368	0.368	0.376	0.373	0.372	0.370	0.370
4.0×10^{-4}	18.0	1.438	1.465	1.432	1.438	1.438	1.447	1.436	1.429	1.445	1.433	1.438	1.460	1.440	1.421	1.469	1.425	1.451	1.428	1.430	1.449	1.435	1.449	1.448	1.440	1.438	1.430	1.437	1.456	1.417	1.459
6.3×10^{-4}	18.0	1.166	1.170	1.166	1.167	1.167	1.161	1.152	1.159	1.174	1.165	1.166	1.191	1.168	1.160	1.181	1.154	1.170	1.170	1.153	1.179	1.159	1.171	1.178	1.170	1.168	1.169	1.167	1.145	1.153	1.180
1.0×10^{-3}	18.0	1.015	1.016	1.015	1.015	1.015	1.036	1.009	1.017	1.014	1.014	1.015	1.012	1.002	1.028	1.017	1.025	1.005	1.034	1.009	1.022	1.004	1.018	1.020	1.022	1.017	1.001	1.022	1.014	1.013	1.016
1.6×10^{-3}	18.0	0.932	0.932	0.932	0.932	0.932	0.941	0.914	0.933	0.932	0.936	0.932	0.941	0.929	0.933	0.935	0.929	0.920	0.936	0.928	0.940	0.925	0.937	0.933	0.938	0.936	0.926	0.920	0.936	0.931	0.934
2.5×10^{-3}	18.0	0.879	0.880	0.879	0.880	0.879	0.884	0.872	0.875	0.880	0.876	0.879	0.883	0.873	0.878	0.881	0.889	0.872	0.882	0.888	0.874	0.870	0.888	0.895	0.886	0.889	0.881	0.881	0.874	0.879	0.879
6.3×10^{-3}	18.0	0.629	0.629	0.629	0.630	0.630	0.633	0.621	0.631	0.629	0.628	0.629	0.635	0.623	0.630	0.629	0.626	0.627	0.634	0.631	0.627	0.613	0.641	0.626	0.633	0.634	0.630	0.628	0.640	0.629	0.629

- Example systematics table from an F_2 analysis at ZEUS https://arxiv.org/abs/hep-ex/9607002

What systematics should we consider for ePIC? (...and how should we get them?)

- The systematics that I foresee as being important initially are:
  - Electron finding efficiency
  - Electron Polar Angle
  - Electron Energy Scale
  - Hadronic Energy Scale
  - QED Radiative Corrections
  - (Photoproduction) Background Subtraction

Just my thoughts for a starting point - other thoughts are welcome!

What systematics should we consider for ePIC? (...and how should we get them?)

- Some of these systematics are hard to evaluate before having real data to compare to – some guesswork may be required
  - Note that suggestions here as to how to estimate the systematics are just ideas for initial studies, not how we will probably end up doing it when the detector comes online

Electron finder efficiency

- First, we need proper benchmarks for the efficiency → **any volunteers?**
- May be hard to evaluate – can start by seeing impact of tightening/loosening cuts used in finding?

Electron Polar Angle

- Calibration and alignment procedures used to align tracker modules relative to each other and beam axis
  - Has this been discussed within ePIC? → confirm with tracking
- Could use 0.5mrad as conservative guess for now?

Electron Energy Scale

- Electrons lose energy in passive material
- Currently recon defaults to tracks for electrons → If using calorimeter energy then may need a correction
  - → kinematic peak calibration, QED Compton (no events currently)

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Hadronic Energy Scale

- Study mean of $p_{t,h}/p_{t,e}$ distribution (as a function of y_h) → Compare MC and data
  - We have no data, so may need to guess → 1%?

QED Radiative Corrections

- Compare size of radiative corrections with different event generators e.g. Djangoh/RAPGAP, Pythia if possible
  - Likely <1% for most of phase space, increases at high y

Background subtraction

- **First** we need generated photoproduction events (task for someone)
- Compare models – Pythia and ??? (Herwig maybe?)
- Expect ~1% contribution to cross section uncertainty, increasing to 2-3% at high y

Normalisation

- Two sources of normalisation uncertainty for inclusive analyses
  - Luminosity – global normalisation for **any** cross section
  - Polarisation – global normalisation for **spin dependent** observables

- Luminosity is easy to include, take e.g. 1% for all bins (correlated within run, uncorrelated across different runs)
  - Should communicate with relevant detector group to confirm exact number for immediate studies

- Polarisation – electron and proton/^{3}He each assigned uncertainty
  - As before, repeat analysis with each fluctuation separately
  - Communicate with relevant group to confirm numbers to use

Summary

- We need a plan moving forward for the inclusion of systematic uncertainties

- I've listed a few contributing uncertainties for an inclusive cross section measurement
  - Some of these can be estimated from MC studies now or in the near future
  - Others may be challenging to get meaningful estimates for before we have data

- Those who have relatively complete analyses should begin these studies ASAP