Measurement Uncertainty Analysis for H1 Low Q^2 Data

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[with help of A.Glazov and T.Laštovička]

[$5 < Q^2 < 200$ GeV^2]

H1 2000 low Q^2 data

- Replacement of published 96/97 low Q^2 H1 data
- Analysis has started

- Goal: to reach very high precision, on 1% level
- Aim of this contribution
  1. Calculate full error tables [including correlated errors]
     - Realistic errors – as close as possible to the final ones
     - Use these in QCD fits – and estimate impact of the new data on PDFs and α_s
  2. Pursue paths how to
     - really reach such a high precision
     - and how to keep it under control

Why new data should be better than 96/97 data?

- Larger data statistics and smooth data taking
  - stat. errors approx. 1.5-2x better (e.g. 1.1% → 0.6%)
- H1 detector in 1999/2000 is well understood also due to other analyses, especially of minimum bias data.
- We can afford to use really large MC (e.g. 100 mil. events)
  - to minimize MC statistical error
  - to estimate more precisely correlated errors
  - to better understand uncorrelated errors

Systematic Uncertainties (published 96/97 low Q^2 data)

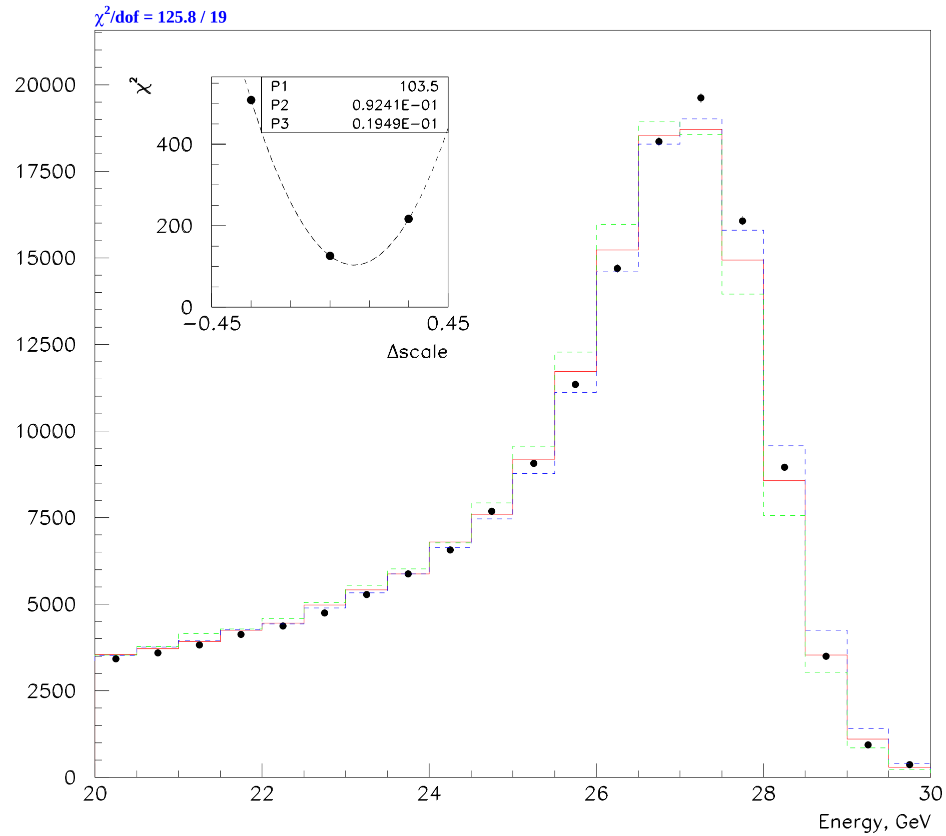
- Correlated systematic uncertainties
  - electron energy (0.3% at 27.6 GeV, 2% at 7 GeV)
  - electron angle (0.3[0.2] mrad, measured by BDC[BST])
  - hadronic calibration (2% LAr, 5% SpaCal and 3% tracks)
  - LAr noise contribution to $E-p_z$ and P_t (25%)
  - Photoproduction background (20% PHOJET normalisation)

- Uncorrelated systematic uncertainties
  - Monte Carlo statistics
  - trigger efficiency (0.5%)
  - BDC efficiency (1%)
  - radiative corrections, positron ID (0.5%, 1%)

- Total cross section uncertainty was 2-3% in the bulk region.

How can we control errors?

- <u>Example</u>: scattered electron energy calibration
  - data (points) vs. Monte Carlo (red line)
  - Calibration shifted up and down by 0.3% (blue and green lines)
  - χ^2 minimum at ~0.1%



- Includes a number of assumptions
  [correlation of error sources, MC cross section, …]

- How to estimate errors on more difficult quantities, like e.g. LAr calorimeter noise?

- <u>More sophisticated tools needed</u>

Impact of correlated error sources on σ

- Detailed study performed
- Effect of correlated systematic shifts on cross section calculated from variation/scan of particular error source
  - electron energy
  - electron polar angle
  - hadronic final state energy scale
  - noise in the LAr calorimeter

  - for both reconstruction methods [see next slide]
- Errors on correlated systematical errors estimated

Kinematics reconstruction

- Electron method – high y
  - scattered electron kinematics only
  - y-resolution deteriorates as 1/y

$$y_e = 1 - \frac{E'_e}{E_e}\sin^2\frac{\theta_e}{2} \qquad Q^2_e = 4E'_e E_e \cos^2\frac{\theta_e}{2} = \frac{E'^2_e \sin^2\theta_e}{1 - y_e}$$

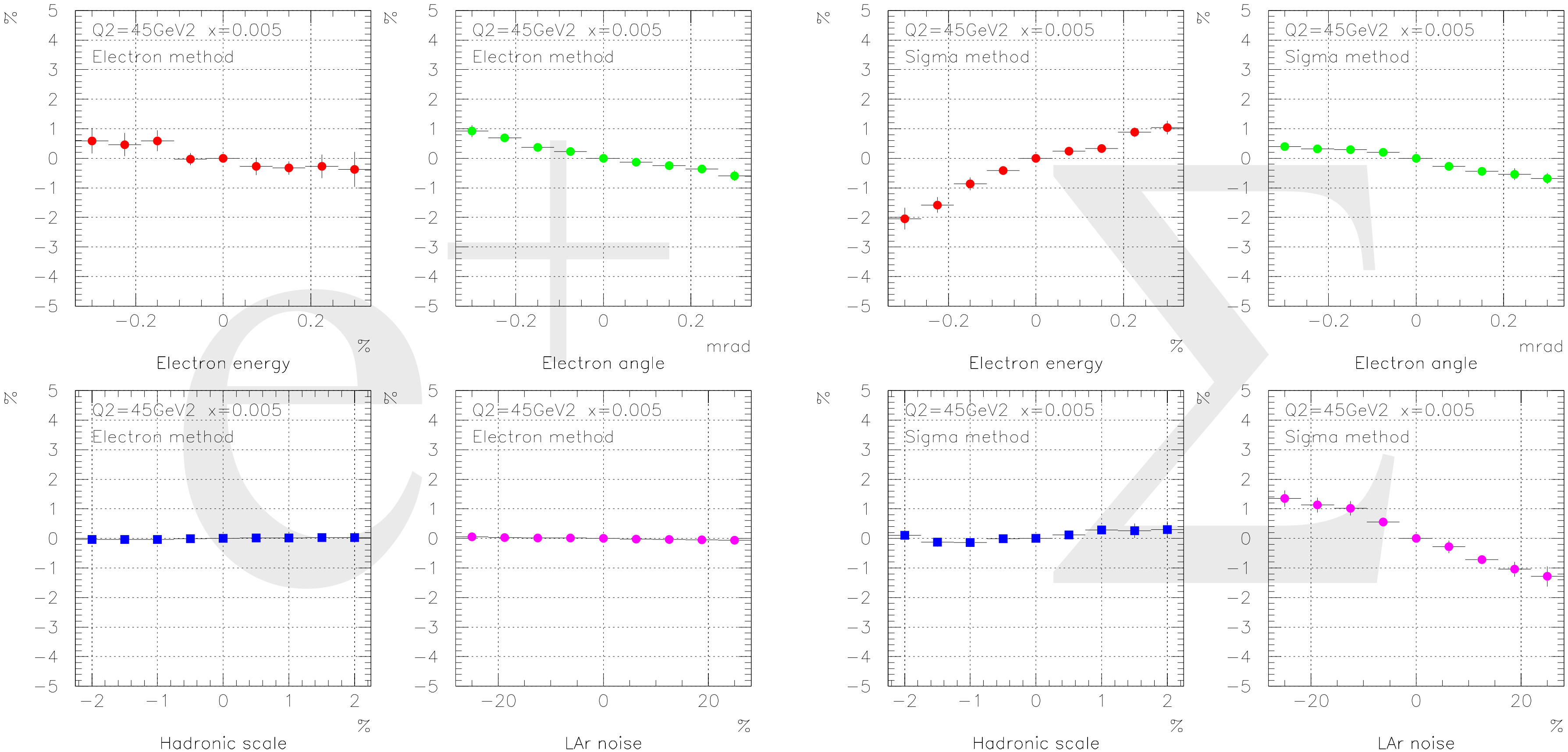
- Sigma method - low y
  - combines scattered electron and hadronic final state measurements
  - independent on the incoming electron energy → initial state radiation insensitive.

$$y_\Sigma = \frac{\Sigma}{\Sigma + E'_e(1 - \cos\theta_e)} \qquad Q^2_\Sigma = \frac{E'^2_e \sin^2\theta_e}{1 - y_\Sigma}$$

$$\Sigma = \sum_h E_h(1 - \cos\theta_h)$$

Scans of correlated error sources

- example bin Q^2=45GeV^2, x=0.005 (y=0.089)

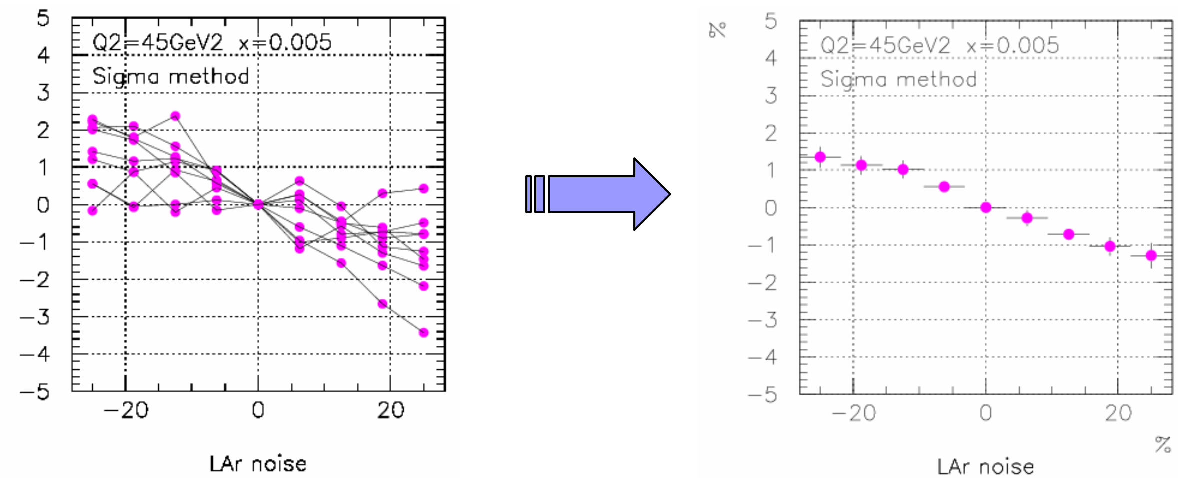


Estimation of errors on correlated error estimates

i. MC sample (12 mil ev) split into N subsamples (here N=9)
ii. On each of them correlated errors were obtained
iii. Mean calculated to estimate particular correlated error
iv. RMS calculated and <u>scaled</u> by factor 1/√N to estimate error corresponding to the full sample

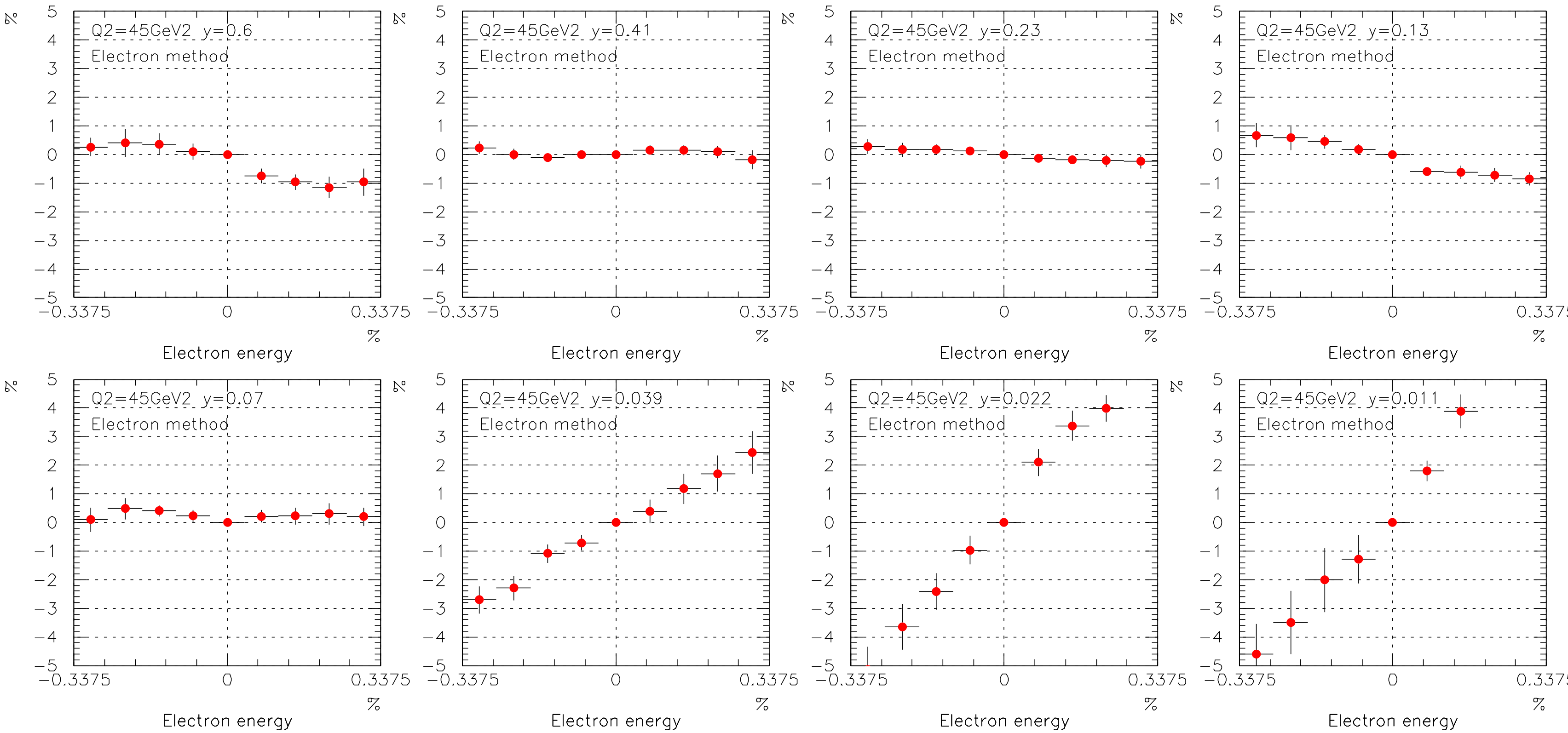
[so called <u>standard error of the mean</u>]

1 subsample
=
1.3 mil ev



Electron calibration – electron method

- worsens towards low y



Electron calibration – sigma method

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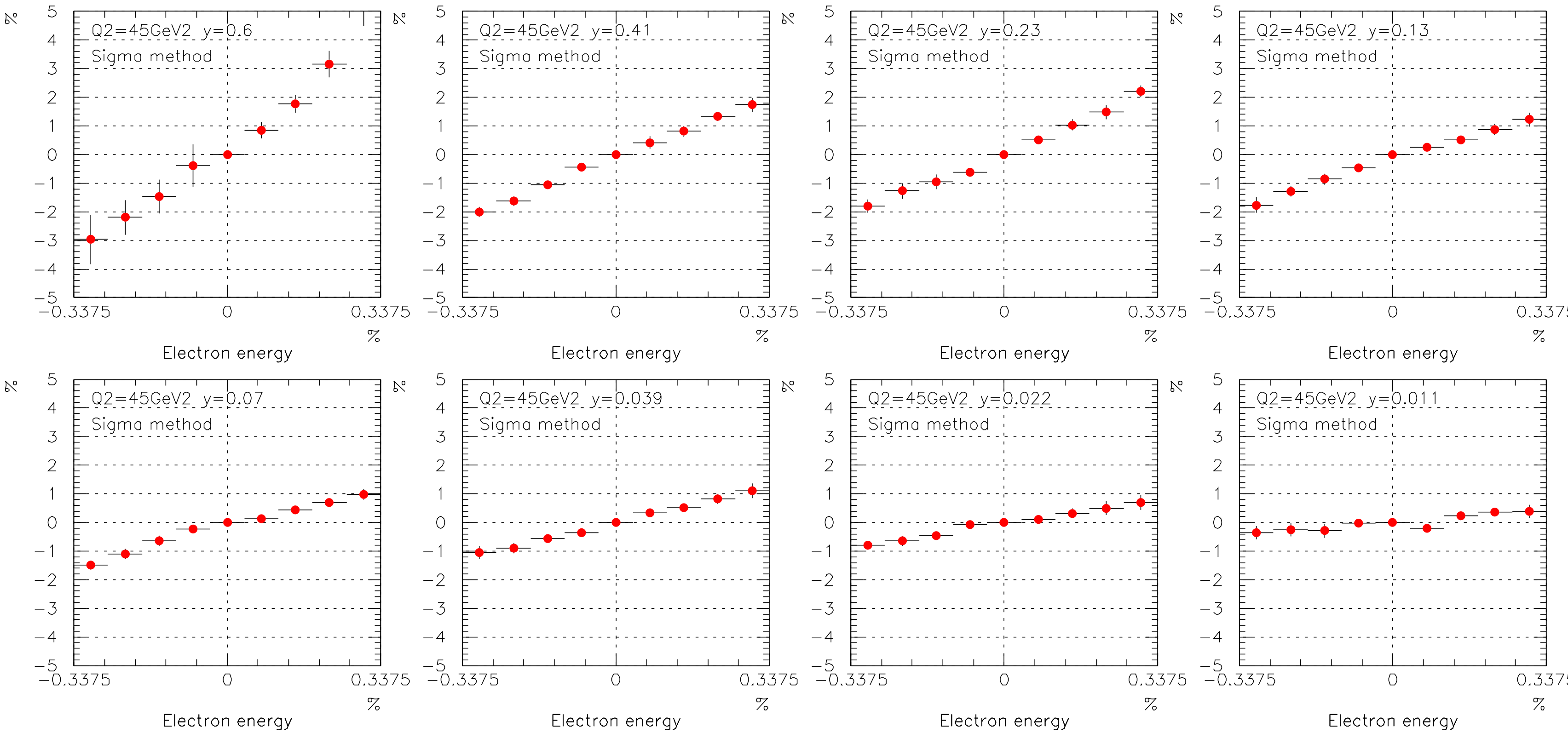
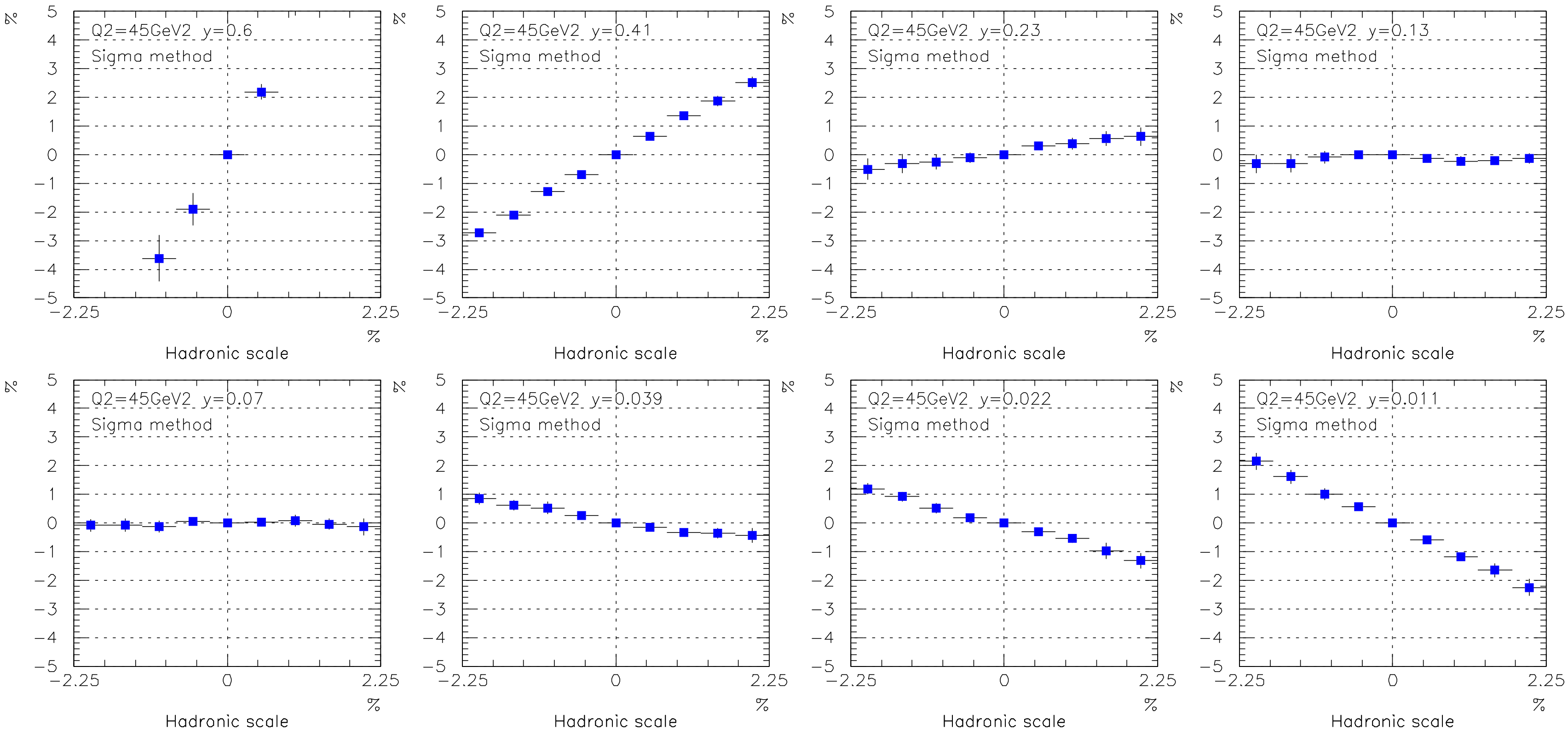


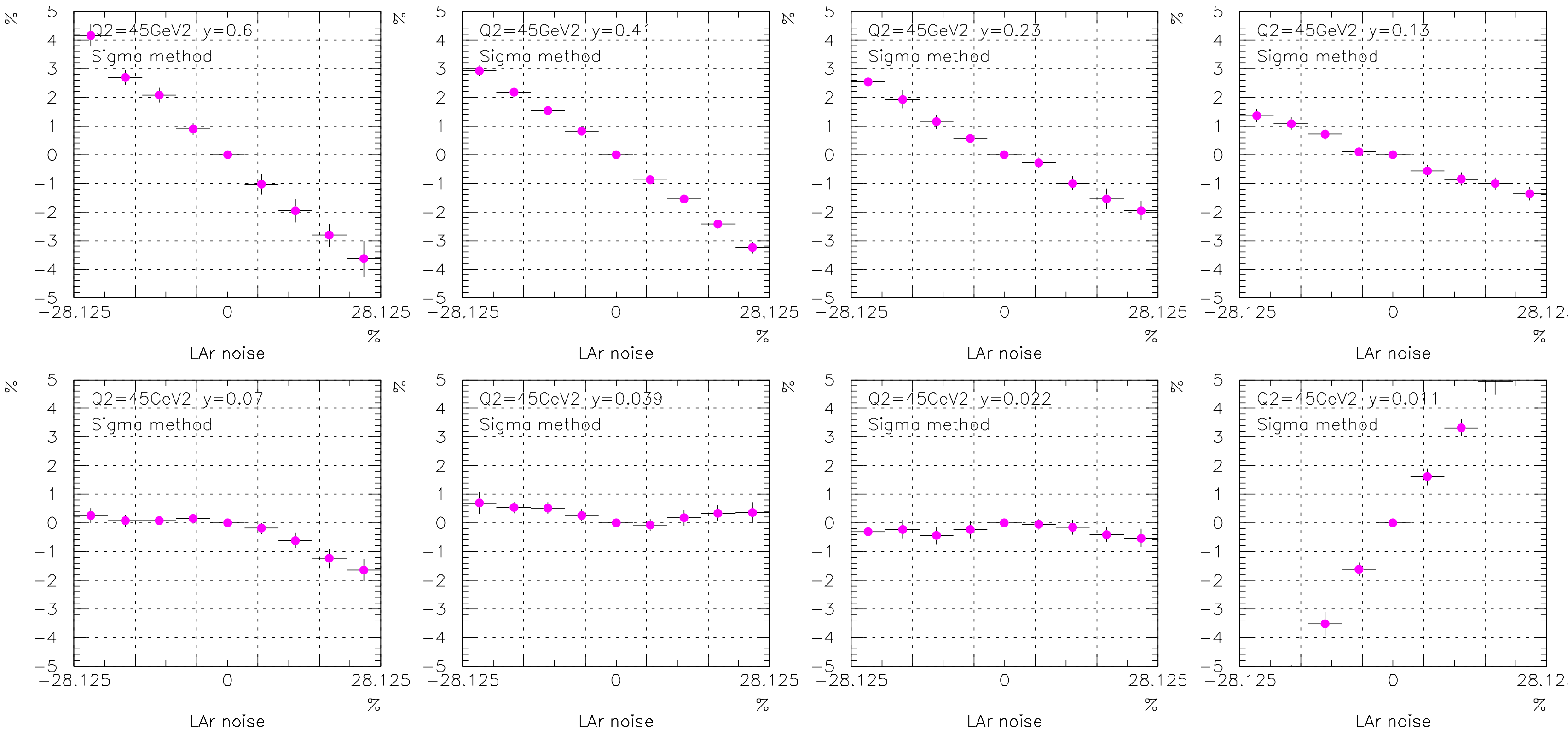
Hadronic final state calibration – sigma method

- potentially significant error source



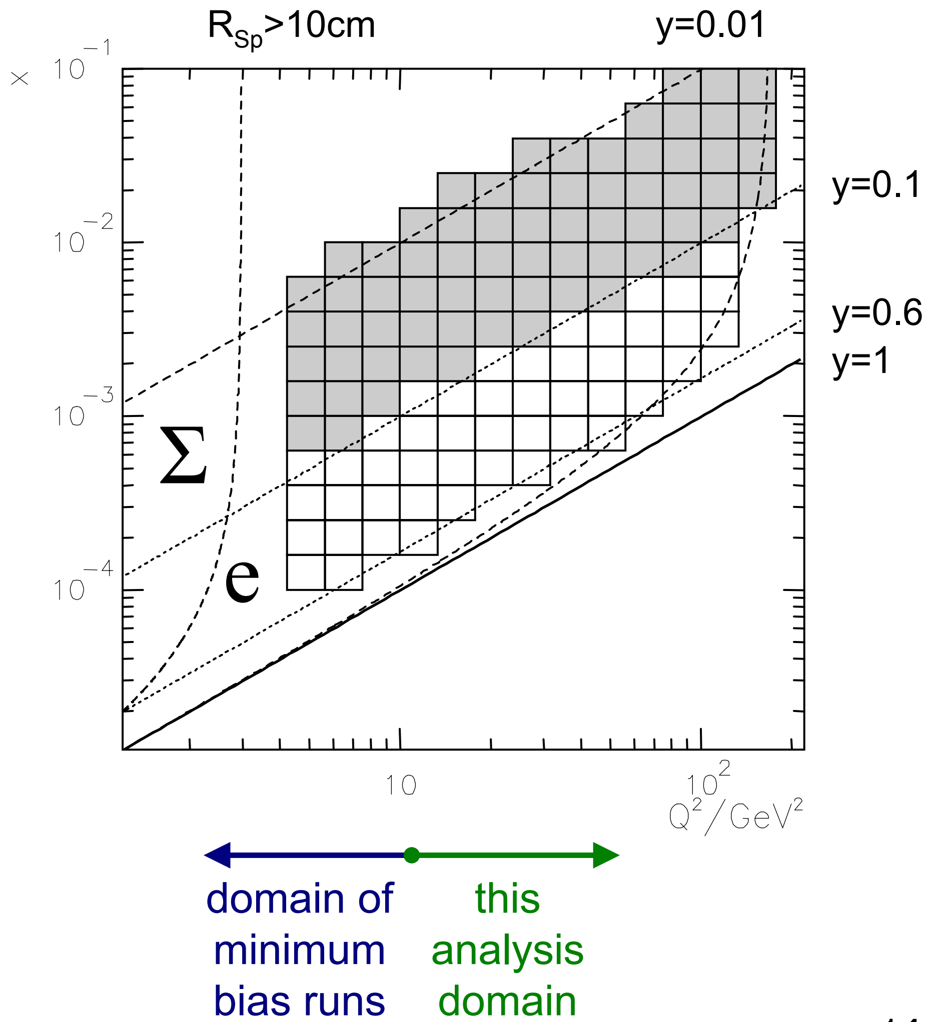
LAr noise – sigma method

- larger sensitivity at both large and very low y
- non-linearities



Full error table calculation

- Binning selection:
  - Q^2-x bins identical with 96/97 published data
  - Separation between methods at y=0.1
  - y>0.01 due to CT vertex usage
- Method selection:
  - Electron y>0.1
  - Sigma 0.01<y<0.1



Comparison to published data [Q^2=45GeV^2]

Q^2	x	y	σ_r	R	F_2	Tot.(%)	Sta.	Uncorr.	Corr.	E_e	θ	Ehad	Noise	γp
45	0.0008	0.555	1.491	0.241	1.569	1.64	0.75	1.28	0.7	0.52	0.4	0.18	0.09	0.1
45	0.0013	0.341	1.307	0.243	1.328	1.43	0.58	1.26	0.36	0.12	0.33	0.05	0.07	0.01
45	0.002	0.222	1.146	0.241	1.153	1.56	0.58	1.26	0.71	0.71	0.09	0.05	0.03	0
45	0.0032	0.139	1.023	0.225	1.025	1.46	0.6	1.26	0.44	0.32	0.3	0.02	0.02	0
45	0.005	0.089	0.857	0.227	0.857	2.3	0.67	1.27	1.8	1.53	0.36	0.17	0.85	0
45	0.008	0.055	0.765	0.205	0.765	1.83	0.69	1.27	1.12	1.01	0.16	0.36	0.28	0
45	0.013	0.034	0.625	0.201	0.625	2.21	0.76	1.28	1.63	1.18	0.38	1.04	0.21	0
45	0.02	0.022	0.557	0.176	0.557	1.97	0.86	1.29	1.22	0.88	0.39	0.68	0.33	0
45	0.032	0.014	0.526	0.133	0.526	2.3	1	1.31	1.61	0.26	0.07	1.55	0.34	0
45	0.0013	0.383	1.282	0.238	1.309	1.94	0.92	1.68	0.35	-0.24	-0.23	0.11	0.03	-0.05
45	0.002	0.249	1.107	0.234	1.115	1.75	0.88	1.38	0.6	-0.25	-0.54	0	0	0
45	0.0032	0.156	0.979	0.231	0.982	1.81	0.94	1.39	0.68	-0.17	-0.66	0	0	0
45	0.005	0.099	0.872	0.228	0.873	2.81	1.08	1.5	2.12	1.64	-0.53	0.26	1.08	0
45	0.008	0.062	0.743	0.224	0.743	2.5	1.15	1.53	1.61	1.24	-0.54	0.07	0.72	0
45	0.013	0.038	0.649	0.215	0.649	2.85	1.28	1.61	1.98	1.49	-0.81	-0.85	-0.51	0
45	0.0251	0.02	0.525	0.187	0.525	4.28	1.25	1.58	3.77	1.36	-0.54	-2.99	-1.7	0
45	0.08	0.006	0.396	0.091	0.396	7.6	2.06	3.48	6.44	1.27	-0.86	-2.98	-5.47	0

^published^

Comparison to published data [Q^2=25GeV^2]

Q^2	x	y	σ_r	R	F_2	Tot.(%)	Sta.	Uncorr.	Corr.	E_e	θ	Ehad	Noise	γp
25	0.0005	0.493	1.391	0.261	1.449	1.5	0.47	1.25	0.7	0.6	0.21	0.22	0.15	0.13
25	0.0008	0.308	1.251	0.261	1.268	1.43	0.43	1.24	0.56	0.41	0.37	0.02	0.04	0
25	0.0013	0.19	1.138	0.248	1.143	1.51	0.44	1.24	0.74	0.66	0.33	0.03	0.02	0
25	0.002	0.123	1.041	0.236	1.042	1.47	0.45	1.24	0.64	0.45	0.45	0.03	0.05	0
25	0.0032	0.077	0.842	0.254	0.843	2.16	0.5	1.25	1.69	1.43	0.36	0.17	0.8	0
25	0.005	0.049	0.745	0.245	0.745	1.79	0.52	1.25	1.17	1.01	0.42	0.25	0.33	0
25	0.008	0.031	0.667	0.225	0.667	1.99	0.56	1.25	1.43	1.22	0.35	0.66	0.09	0
25	0.013	0.019	0.586	0.214	0.586	2.44	0.65	1.26	1.99	1.08	0.57	1.43	0.65	0
25	0.02	0.012	0.569	0.159	0.569	6.08	0.86	1.29	5.88	1.8	0.52	3.51	4.33	0
25	0.032	0.008	0.553	0.065	0.553	10.83	1.34	1.39	10.66	1.96	0.64	3.86	9.72	0
25	0.0005	0.553	1.345	0.248	1.417	2.41	1.04	1.81	1.21	-1.04	-0.37	0.25	0.04	-0.41
25	0.0008	0.346	1.242	0.243	1.263	1.94	0.67	1.62	0.85	-0.6	-0.6	0.04	0.02	-0.07
25	0.0013	0.213	1.091	0.238	1.097	1.78	0.66	1.36	0.93	-0.64	-0.69	0	0	0
25	0.002	0.138	0.985	0.236	0.987	2.89	0.76	1.43	2.4	1.78	-0.7	0.17	1.34	0
25	0.0032	0.086	0.879	0.234	0.88	2.78	0.79	1.46	2.23	1.8	-0.77	-0.23	0.92	0
25	0.005	0.055	0.754	0.234	0.754	2.38	0.85	1.49	1.64	1.01	-0.58	0.16	1.03	0
25	0.008	0.034	0.663	0.234	0.663	2.52	0.92	1.54	1.78	1.11	-0.68	-0.72	0.84	0
25	0.0158	0.018	0.547	0.226	0.547	3.71	0.85	1.49	3.29	1.36	-0.88	-2.44	-1.42	0
25	0.05	0.005	0.447	0.148	0.447	7.54	1.28	3.35	6.64	0.99	-0.68	-3.28	-5.62	0

^published^

What to do to reach 1% precision ?

- Reaching 1.5% in the bulk part (medium y and Q^2, electron method) of the data is more or less straightforward, it basically requires large MC statistics

- For further improvements there is a bottleneck 1.23% in uncorrelated errors due to:
  i. BDC [tracking chamber] efficiency (1%)
  ii. radiative corrections (0.5%)
  iii. trigger efficiency (0.5%)

- Possible scenario (electron method):
  - SpaCal calibration improved to 0.15% at kin. peak and 1% at low energies
  - The bottleneck pushed down to ~0.5-0.6% level, e.g.:
    - BDC (0.3%), trigger (0.3%), radiative corrections (0.4%)
  - One should consider dependencies of some of these uncertainties to correctly estimate and minimize them (e.g. on y, Q^2, R_{Sp}, P_t, etc.)

Comparison to previous result [Q^2=45GeV^2]

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Comparison to previous result [Q^2=25GeV^2]

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25	0.02	0.012	0.569	0.159	0.569	5.77	0.86	1.29	5.56	1.8	0.52	2.94	4.33	0
25	0.032	0.008	0.553	0.065	0.553	10.75	1.34	1.39	10.58	1.96	0.64	3.63	9.72	0
25	0.0005	0.493	1.391	0.261	1.449	0.88	0.47	0.63	0.41	0.19	0.21	0.22	0.15	0.13
25	0.0008	0.308	1.251	0.261	1.268	0.91	0.43	0.62	0.51	0.34	0.37	0.02	0.04	0
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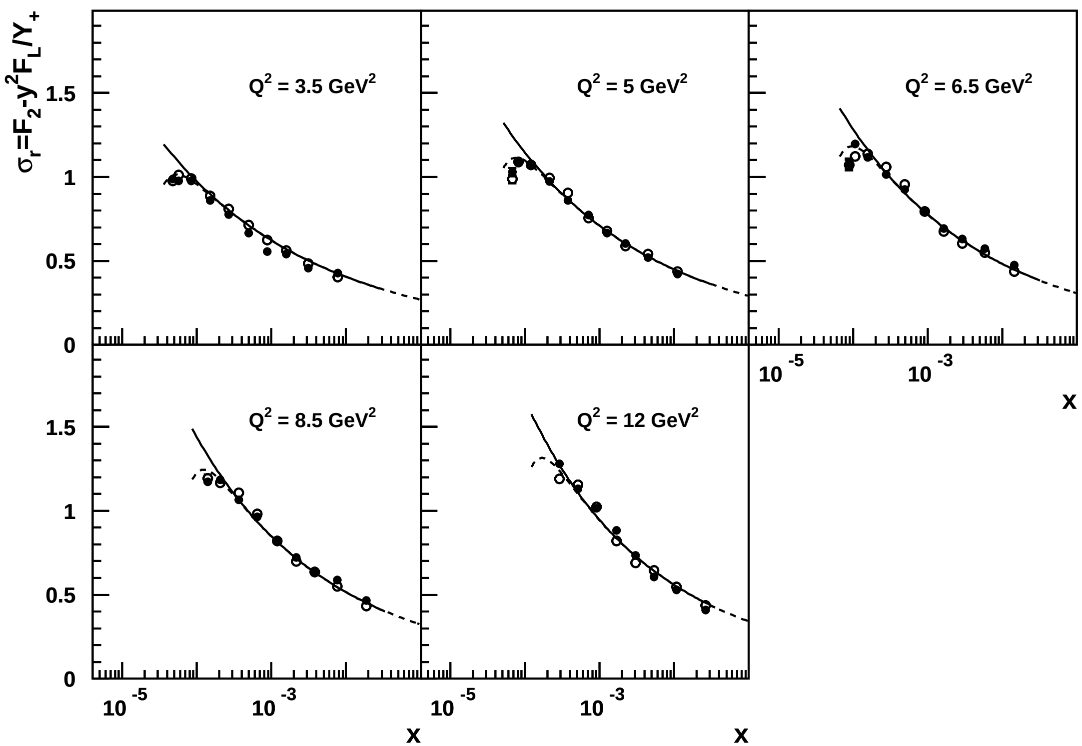
Electron/Sigma method σ_r comparison

- Used to cross check consistency of reconstruction methods
- Ratio $\sigma_r^{el}/\sigma_r^{sig}$: potentially powerful tool to monitor and estimate correlated errors

- if the true statistical error is small and correctly calculated

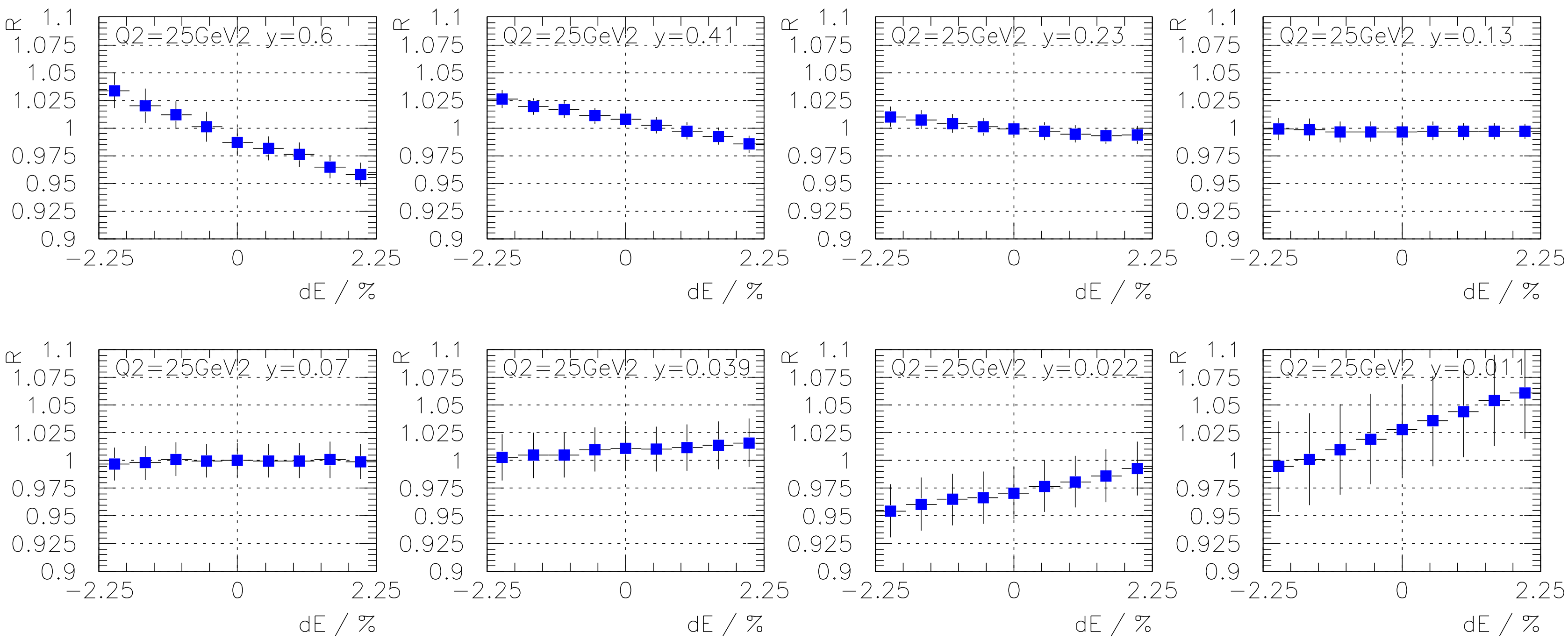
- data and MC samples are again split into N subsamples, mean and standard deviation of the mean calculated

  [in analogy to errors on correlated errors]



Electron/Sigma method σ_r comparison

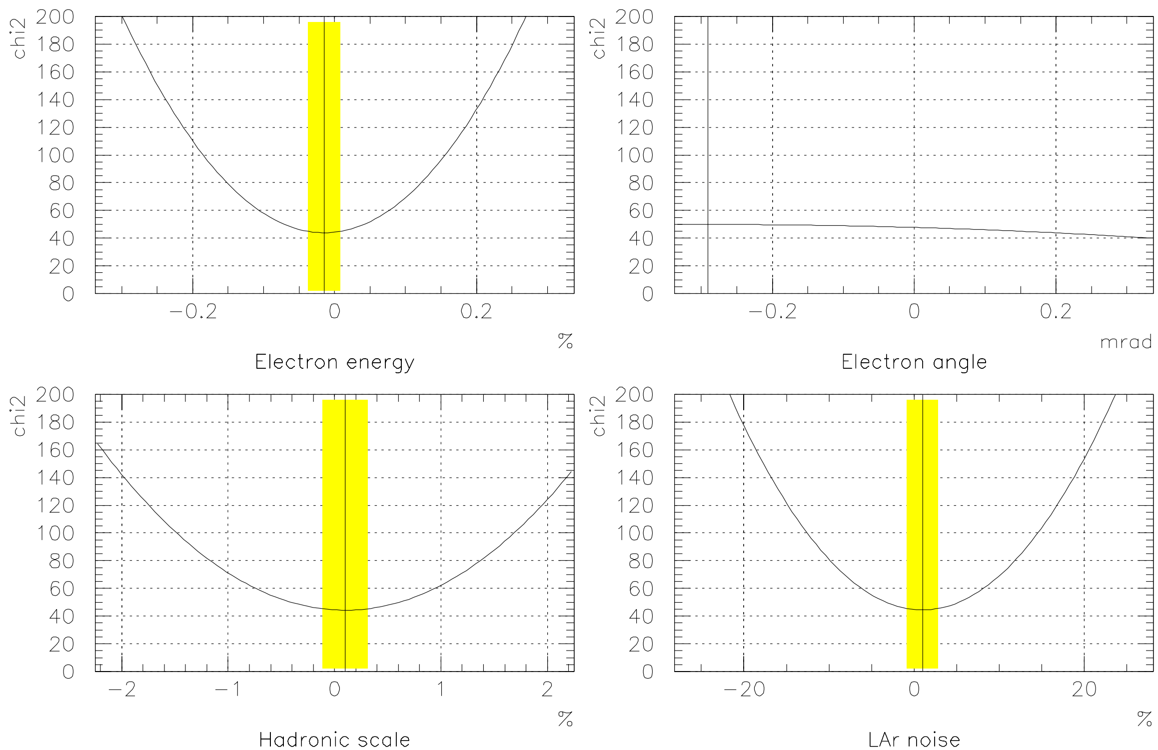
- Half of available Monte Carlo statistics [12 mil.ev.] used to simulate data.
- Number of subsamples N=12
- Example of ratio scan (hadronic final state calibration):



Electron/Sigma method σ_r comparison

- χ^2 calculated as a function of correlated error shifts
- Bin selection: $15 \leq Q^2 \leq 60$ GeV^2 $\wedge$ $0.6 \geq y \geq 0.011$
- χ^2/(number of bins) $\approx$ 1 → correctly estimated statistical errors

- consistent with 0 [ok!]
- potentially very good sensitivity to LAr noise, electron energy calibration, and hadronic scale <u>[not accounted for correlations yet]</u>
- no sensitivity to the electron polar angle



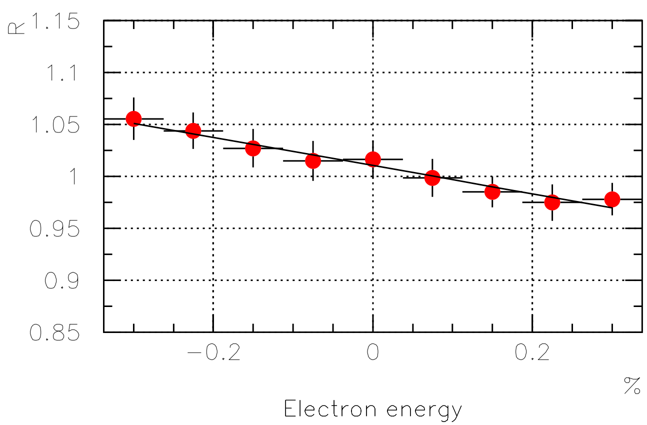
Electron/Sigma method σ_r comparison

- Unfolding of correlated error sources α_j can be linearized and directly solved by minimizing functional

$$\mathcal{L} = \sum_i \frac{1}{\sigma_i^2}(R_i + \sum_j \alpha_j R'_{ij} - 1)^2 \quad \text{where} \quad R_i = \frac{\sigma_r^{el.}}{\sigma_r^{\Sigma}}$$

for a measurement bin i and R'_{ij} is its derivative w.r.t particular correlated error source j.

- Derivative is obtained by approximating R_i dependece on correlated error source by line, e.g.

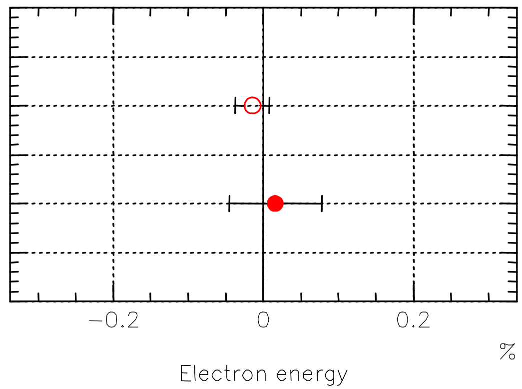


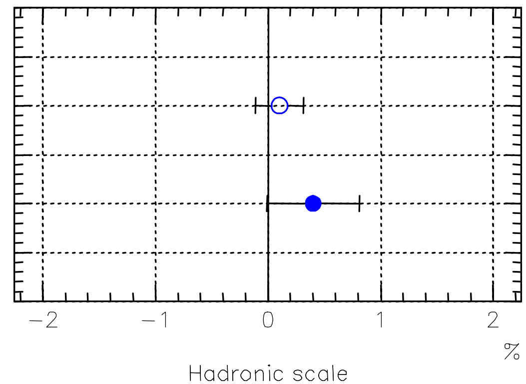
Q^2 = 35 GeV^2
y = 0.6

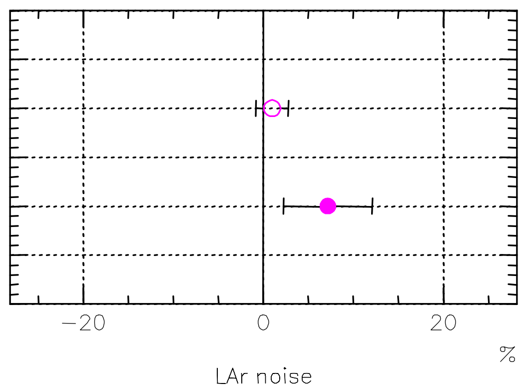
Electron/Sigma method σ_r comparison

- Unfolding correctly takes into account correlations of cross section [closed points]
- Comparison with one dimensional χ^2 scans shown previously [open points]
- Identical cross-section measurement bins

- consistent with 0 [ok!]
- about 3x larger errors
- no sensitivity to the electron polar angle [not shown]
- about 9x higher statistics forseen in the full analysis → 3x smaller errors
- <u>sufficient sensitivity to control correlated errors on required level</u>







A handle on LAr noise:

OK!

Summary

- Very high precision on 1% level is realistically achievable
  - Ways how to reach this goal studied
- Large Monte Carlo sample is essential to fully exploit the data
- Systematic errors studied in detail
  - Ratio $\sigma_r^{el}/\sigma_r^{sig}$ may be used to unfold correlated error sources

Outlook

- Estimate impact of new data using full error tables in QCD fits
- Apply developed tools in H1 analysis

Extras after here

Full error table calculation

- Test 1 – Standard approach (a la 96/97 and mb99)
  - electron energy: 0.3% at 27.6GeV, 2% at 7GeV
  - electron angle: 0.3mrad (BDC)
  - hadronic final state in LAr (SpaCal): 2% (5%)
  - LAr noise: 15%
  - PHOJET normalisation: 10%
  - MC statistics scaled to 100mil.

Comparison to published data

- Errors are generally smaller due to
  - Larger data statistics (bin dependent)
  - Presumed very large MC statistics (100 mil. events vs ?)
  - Better noise description (12% vs 25%)
  - Electron to sigma method transition is done one bin lower in y

- Sometimes slightly different corr. systematic errors
  - Is it within errors on systematic errors ?
  - Very large MC statistics is essential for reliable correlated systematic error estimates
  - At low y discrepancies can also be due to
    - different binning (in 96/97 x bins are joined)
    - different event selection (no CIP vertex)

Full error table calculation

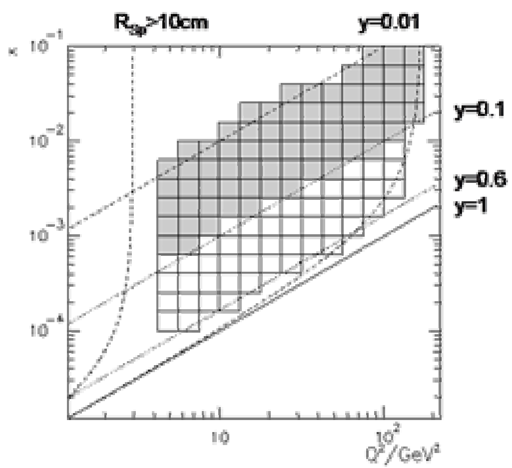
- Test 1 – Standard (a la 96/97 and mb99)
  - electron energy: 0.3% at 27.6GeV, 2% at 7GeV
  - electron angle: 0.3mrad (BDC)
  - hadronic final state in LAr (SpaCal): 2% (5%)
  - LAr noise: 15%
  - PHOJET normalisation: 10%
  - MC statistics scaled to 100mil.
- Test 2 - Best possible? As Test 1 plus:
  - electron energy: 0.15% at 27.6GeV, 1% at 7GeV
  - BDC efficiency (0.3%)
  - Radiative corrections (0.4%)
  - Trigger acceptance and efficiency (0.3%)
  - Hypothetical !

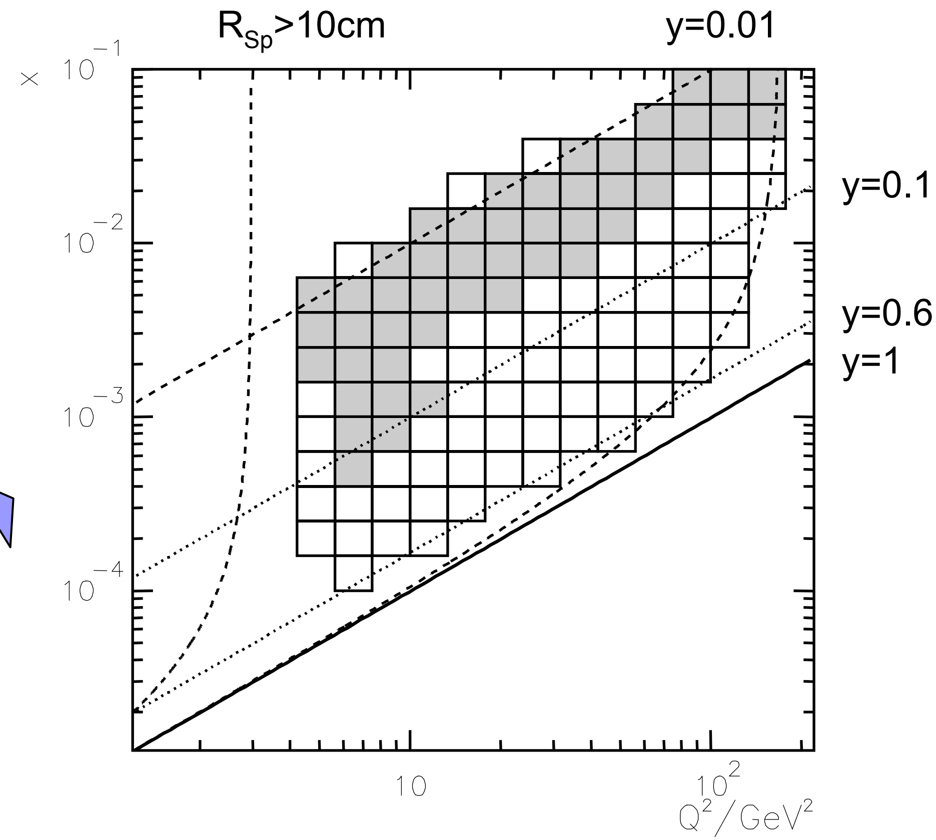
Outlook

- Finalize and cross-check code
- After agreement on amounts of ‘correlated shifts’:
  I. Full correlation error table production with asymmetric correlated errors
  II. QCD fit using this table to estimate errors of PDFs and α_s, which will be calculated in future with the new data

Automatic method decision (according to the total error)

- Electron method is preferred:
  - y<0.1: it gives better error but worse purity/stability
  - y~0.01: sigma has large error due to LAr noise, electron fine but purities/stabilities ~ 0





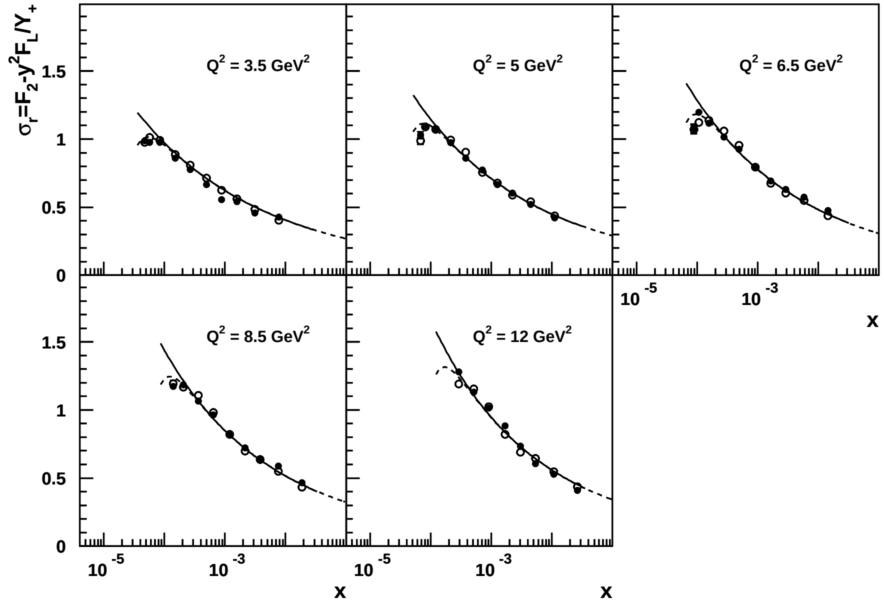
Systematic Errors for 2000 Data

- First look – November 2003, conclusions:
  - Very large MC sample is needed to fully exploit the data
  - Improvement of SpaCal/LAr calibration
  - Data have potential to replace 96/97 published data
  - Aiming for ultimate 1% (!) precision

- Analysis was redone
  - Larger MC sample (2mil → 12mil events)
  - New and flexible code
    - much faster and transparent
    - scans through correlated error dependencies
    - correlated error histograms are directly used in the final table calculation code (much simplified usage)
    - calculates electron and sigma method in parallel
      - decision which method is to be used may be based e.g. on the total error
    - final tables may be written both with asymmetric corr. errors and in the standard way (averaged)
    - errors on systematic errors

Electron/Sigma method σ_r comparison

- Used to cross check consistency of reconstruction methods



- Potentially powerful tool to monitor and estimate correlated errors
  - if the true statistical error is small and correctly calculated
  - data and MC samples are split into N subsamples, mean and standard deviation of the mean calculated
    [in analogy to errors on correlated errors]

Systematic Errors for 2000 Data

- Presented analysis of systematics is based on 96/97 approach, no additional errors are added.
- BDC and CT vertex used to reconstruct electron track
  - CIP validation
  - but no CIP vertex
  - no BST used
- Thus analysis covers the main region of data
  - 0.6 < y < 0.01
- MC statistics error scaled from 12mil. to 100mil. events
- Analysis chain (codes, kumacs, etc.) based on mb99 and svtx00 analyses