Inclusive Measurements of inelastic electron/positron scattering on unpolarized H and D targets at

hermes

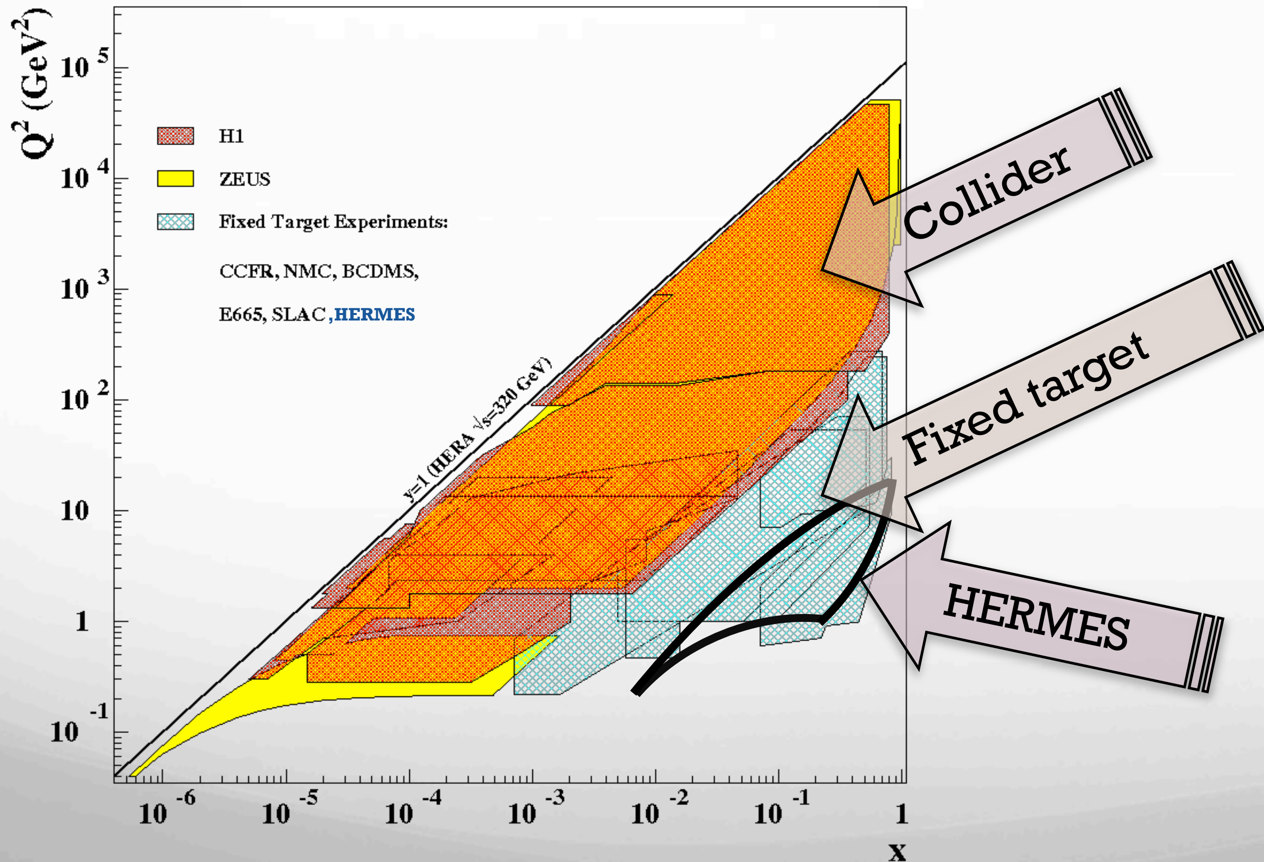
Lara De Nardo

for the

HERMES COLLABORATION

DIS cross section and structure functions

$$\frac{d^2\sigma}{dx\,dQ^2} = \frac{4\pi\alpha_{em}^2}{Q^4}\frac{\mathrm{F}_2(x,Q^2)}{x}\left[1 - y - \frac{Q^2}{4E^2} + \frac{y^2 + Q^2/E^2}{2\,(1+\mathrm{R}(x,Q^2))}\right]$$



Why measuring inclusive DIS cross sections at HERMES?

HERMES (1996-2000)	16.4 M proton + 18.5 M deuteron	
eg. Compared to NMC	3 M proton + 6 M deuteron	

$$F_2^p, \; F_2^d$$

$$\sigma^p, \; \sigma^d, \; \frac{\sigma^p}{\sigma^d}$$

Explore the transition between perturbative and non-perturbative QCD

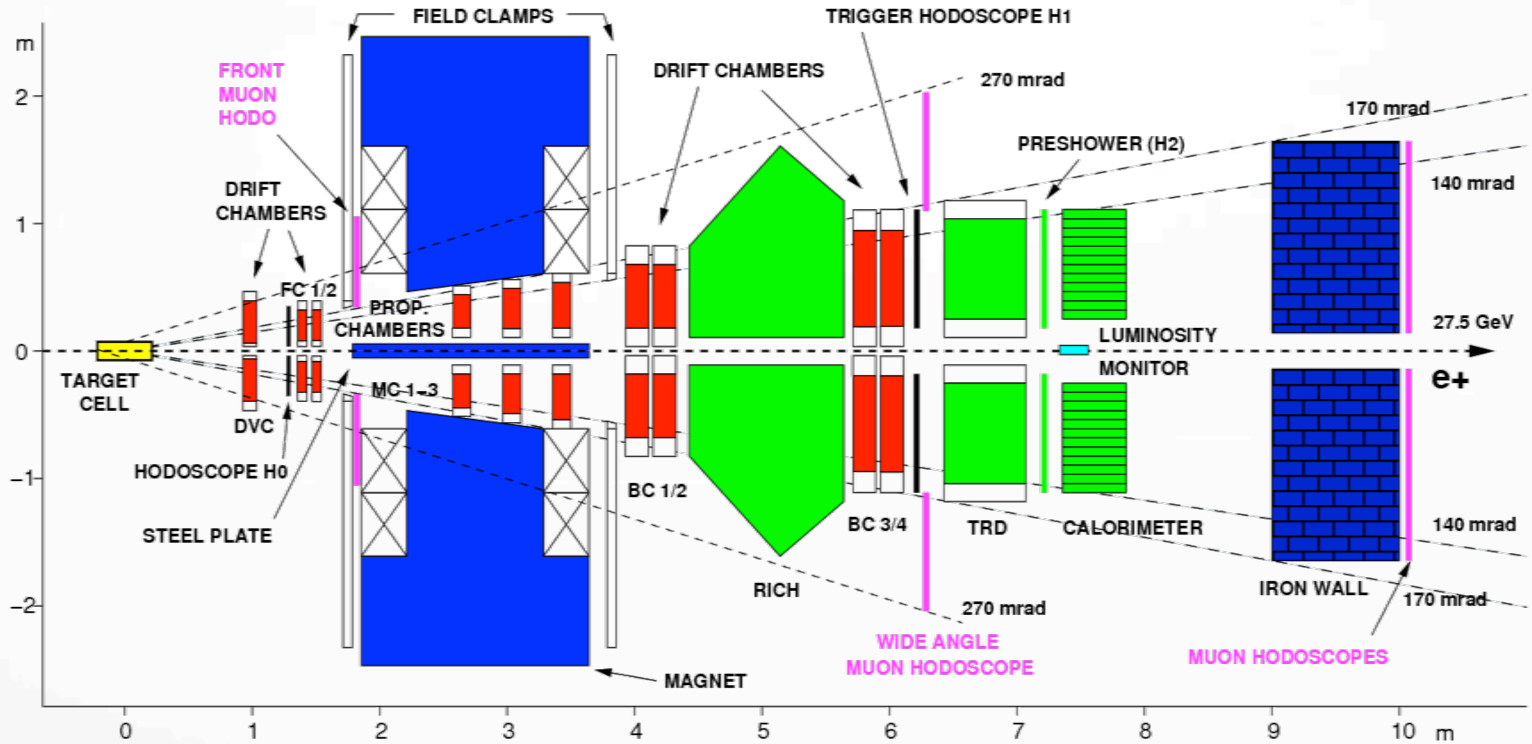
$$\int \frac{dx}{x} \left(F_2^p - F_2^n\right)$$

Gottfried Sum

$$d_v/u_v$$

Valence Quark Ratio

The HERMES Spectrometer

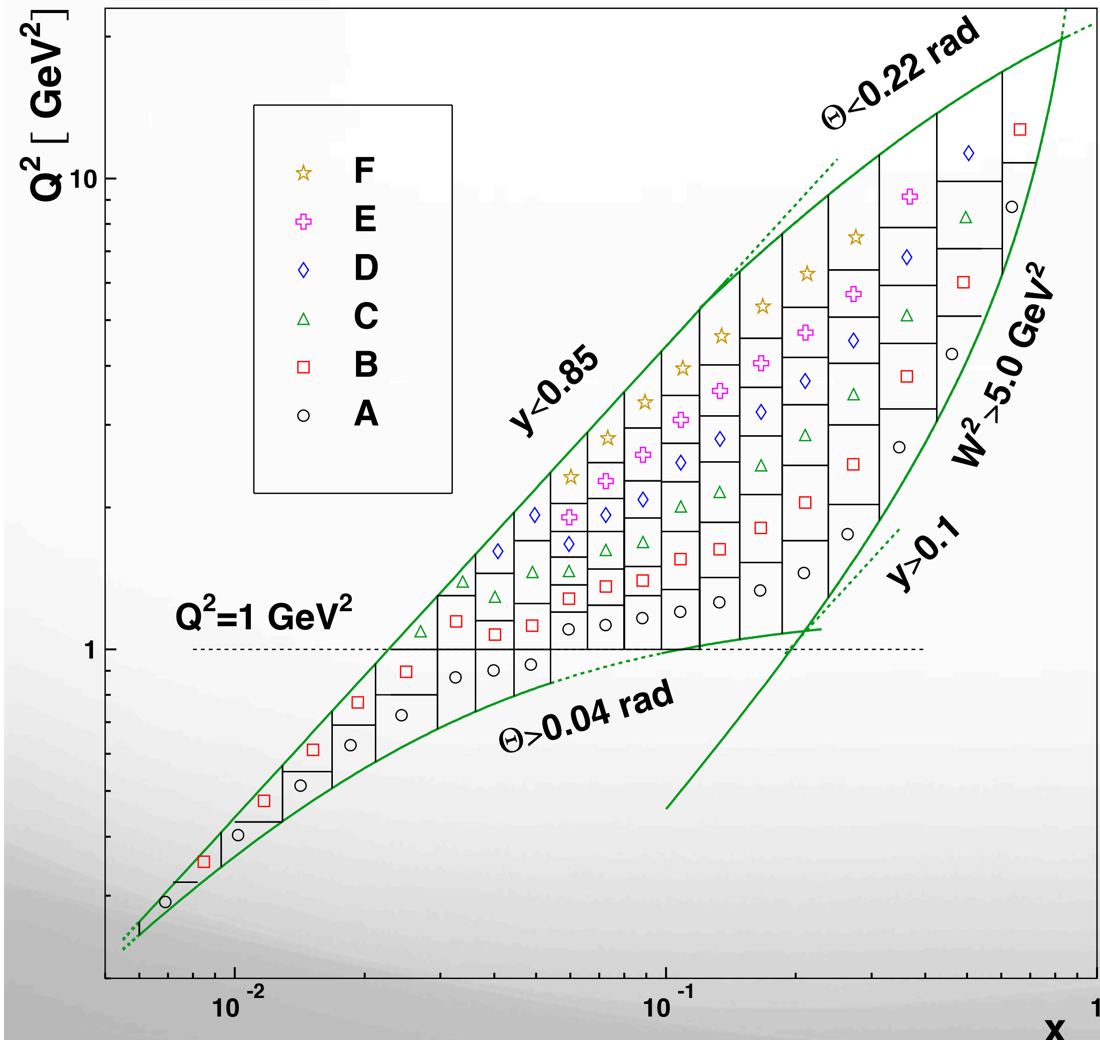


Reconstruction: $\delta p/p < 2\%$, $\delta\theta < 1$ mrad

Internal gas targets: unpol: H, D, He, N, Ne, Kr, Xe , $\vec{He}$, $\vec{H}$, $\vec{D}$, $H^{\uparrow}$

Particle ID: TRD, Preshower, Calorimeter, RICH

Kinematic plane



$0.006 < x < 0.9$

$0.1 < y < 0.85$

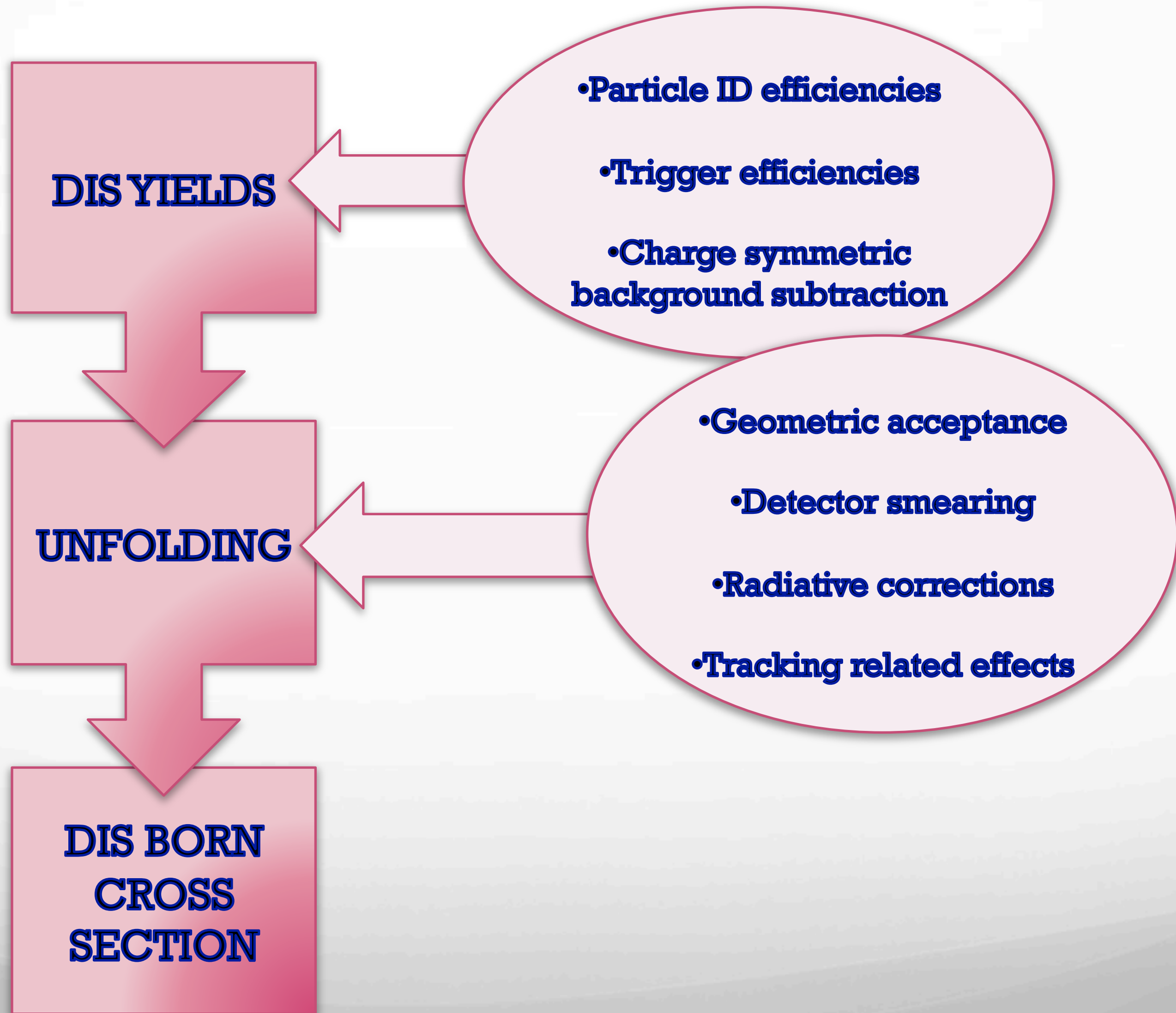
$0.2\ \mathrm{GeV}^2 < Q^2 < 20\ \mathrm{GeV}^2$

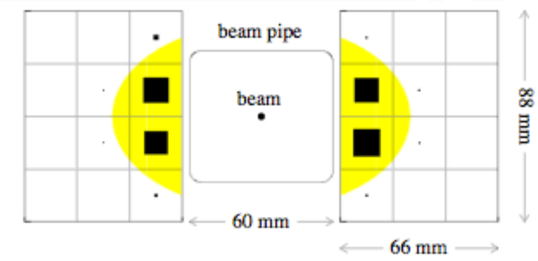
$W^2 > 5\ \mathrm{GeV}^2$

- 19 x bins
- Up to 6 Q^2 bins
- Total: 81 bins

- Traditional DIS region (Q^2>1GeV^2) can be easily separated

Extraction of cross sections





Luminosity

Elastic reference process: interaction of beam with target shell electrons

- Electron beam: Moller scattering $e^- e^- \rightarrow e^- e^-$
- Positron beam: Bhabha scattering $e^+ e^- \rightarrow e^+ e^-$

  annihilation $e^+ e^- \rightarrow 2\gamma$

$\mathcal{L} \simeq 10^{32}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$ (unpol H)

$$L = \int \mathcal{L}\, dt = (R_{LR} - 2\Delta t \cdot R_L \cdot R_R) \cdot c_{live} \cdot C_{Lumi} \cdot \Delta b \cdot \frac{A}{Z}$$

- R_{LR}: Coincidence rate
- $2\Delta t \cdot R_L \cdot R_R$: Correction for accidental coincidence
- c_{live}: Trigger livetime
- C_{Lumi}: Luminosity constant (time dependent)
- Δb: Time interval

Normalization uncertainty 7.5% (proton) and 7.6%(deuteron)

Particle ID efficiencies

TRD

CERENKOV (RICH)

PRESHOWER

CALORIMETER

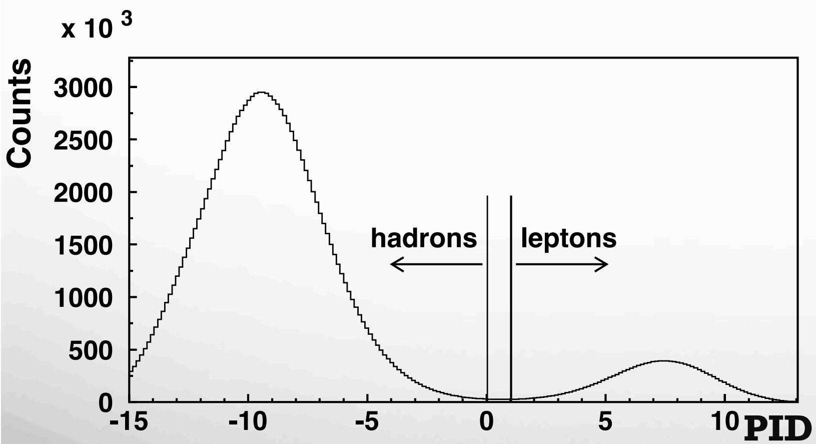
CONDITIONAL PROBABILITIES PID_{det} FOR PARTICLE HYPOTHESIS

$$PID = \log_{10} \frac{P(l|\mathcal{R}, p, \theta)}{P(h|\mathcal{R}, p, \theta)}$$

$$PID = \sum PID_{det} - \log_{10} \Phi$$

$$PID_{det} = \log_{10} \frac{P(\mathcal{R}|l, p)}{P(\mathcal{R}|h, p)}$$

$$\Phi = \frac{\Phi_{had}}{\Phi_{lep}} = \frac{P(h|p, \theta)}{P(l|p, \theta)}$$



Leptons identified by ***$PID > PID_{cut}$*** with $PID_{cut}=0$

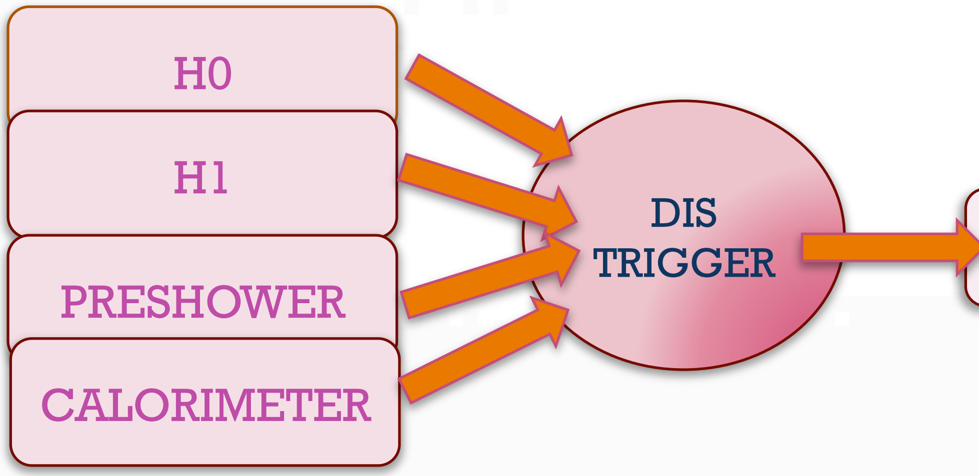
Hadron contamination:
fractional contribution of hadrons above PID_{cut}

Lepton identification efficiency:
fraction of leptons selected with $PID > PID_{cut}$

$$N_{corr} = N_{uncorr} \cdot \frac{1 - \mathcal{C}(PID_{cut})}{\mathcal{E}(PID_{cut})}$$

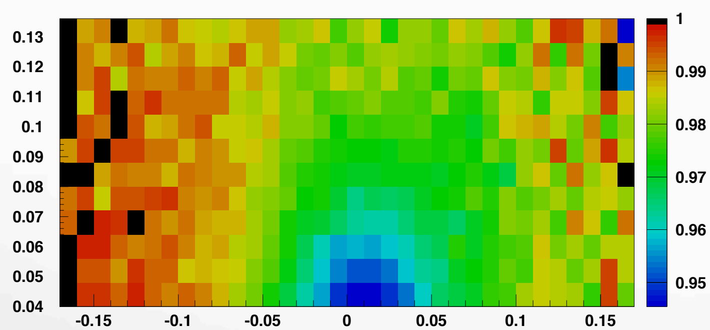
Correction ~1%

Trigger efficiencies

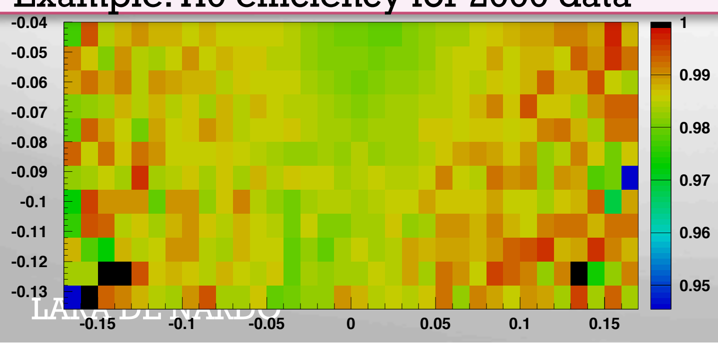


$$\mathcal{E}(TR) = \mathcal{E}(H0) \cdot \mathcal{E}(H1) \cdot \mathcal{E}(PRE) \cdot \mathcal{E}(CALO)$$

Dependence on time (voltage changes, radiation...), momentum , angle :
Efficiencies are calculated separately for Top and Bottom, data production, bin



Example: H0 efficiency for 2000 data



$$N_{corr} = N_{uncorr} \cdot \frac{1}{\mathcal{E}(TR)}$$

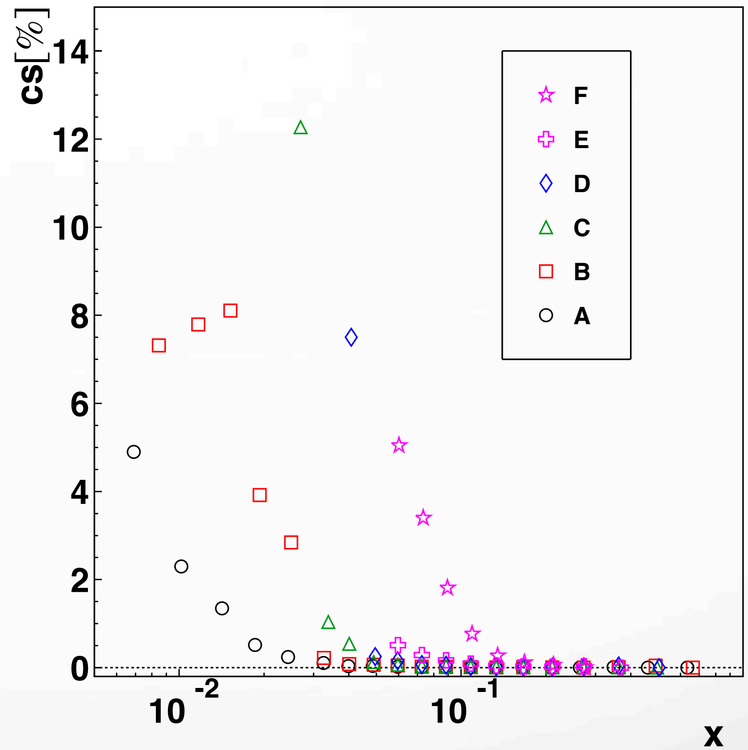
Charge symmetric background

- meson Dalitz decay $\pi^0 \rightarrow \gamma e^+ e^-$
- photon conversion $\gamma \rightarrow e^+ e^-$

These e^+ and e^- originate from secondary processes

➡ Lower momenta (high *y*) concentration

➡ Correction applied by counting the number of events with charge opposite of the beam



$$N^{+,-}_{corr} = N^{+,-}_{uncorr} - N^{-,+}_{cs}$$

Experimental cross section

Yields are corrected for

- Trigger efficiencies
- PID efficiencies
- Charge symmetric background

$$N_{events} = (N_{meas} - N_{cs}) \cdot \frac{1}{\mathcal{E}_{trigger}} \cdot \frac{1 - \mathcal{C}_{had}}{\mathcal{E}_{lep}} \, .$$

$$\frac{d^2\sigma_{Exp}}{dx \; dQ^2}(x, Q^2) = \frac{N_{events}(x, Q^2)}{\Delta x \; \Delta Q^2} \cdot \frac{1}{L}$$

Unfolding Kinematic bin Migration

4π BORN MC

- ✓Simulation of true cross section
- ✓No radiative effects
- ✓No tracking

(Same Luminosity)

FULL DETECTOR MC

- ✓Detector material (GEANT4)
- ✓Radiative effects
- ✓Tracking

$$S(i,j) = \frac{n(i,j)}{n^{Born}(j)}$$

Smearing matrix

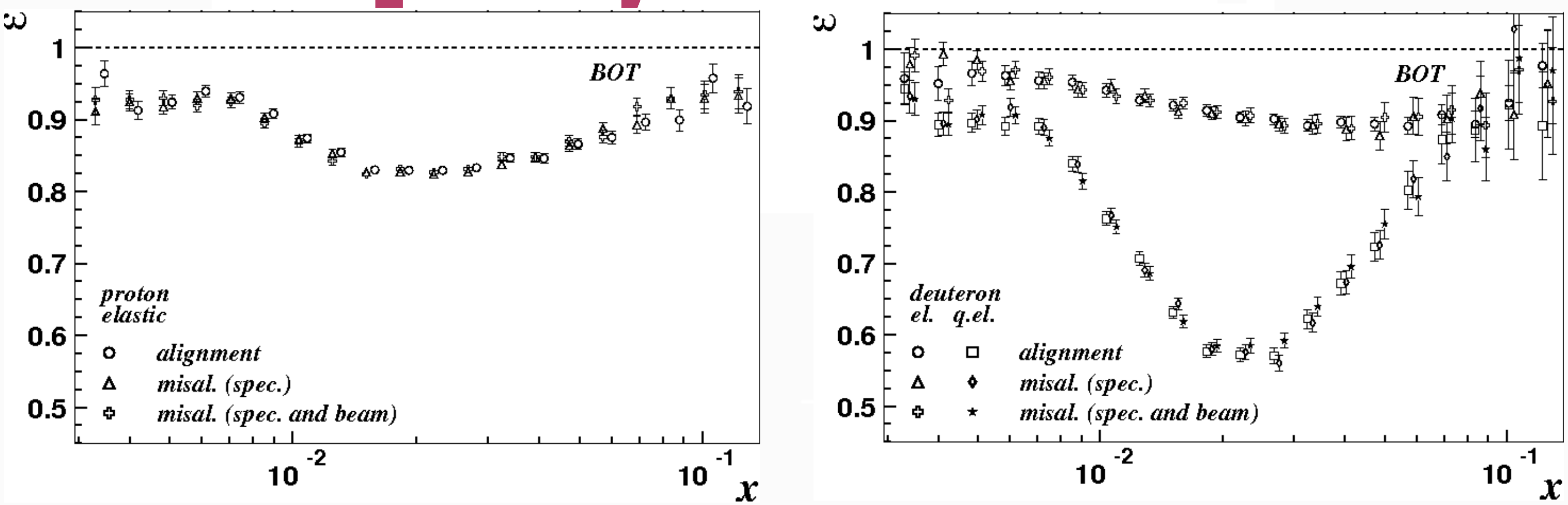
$n(i,j)$: Events originating in bin j and measured in bin i

$n^{Born}(j)$: Events in bin j on Born level

$$\sigma^{Born}(i) = S'^{-1}(i,j)\ \left[\sigma^{Exp}(j) - S(j,0)\ \sigma^{Born}(0)\right]$$

Background term: $S(j,0)\ \sigma^{Born}(0)$

Detection efficiencies for high multiplicity radiative events

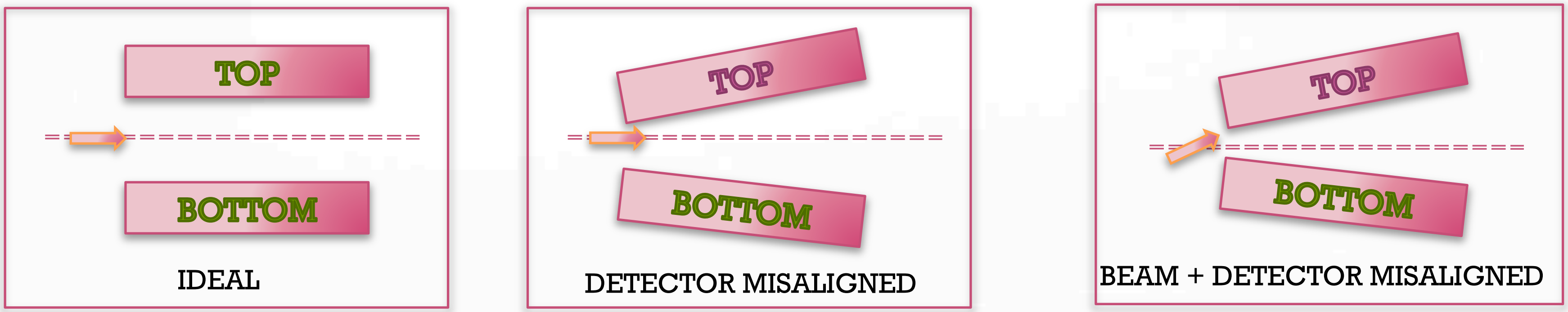


•The incoming *electron* can radiate a *high energy photon* and then scatter elastically with the nucleon.

Photon:
- *Small scattering angle*
- *Large probability of hitting the beam pipe, causing a shower and saturating the wire chambers*

•These unreconstructed events are included in the smearing matrix
•Efficiencies extracted from MC

Main source of systematics: Misalignment



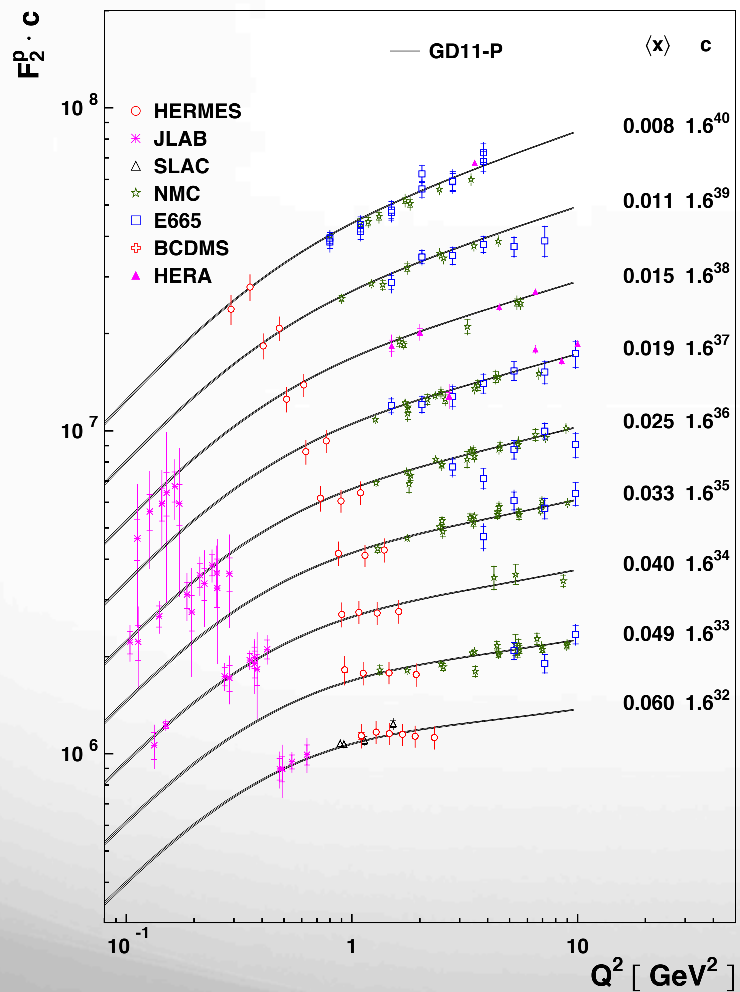
- IDEAL situation: Perfect alignment of beam and spectrometer
- In practice:
  - Top and bottom parts of the detector are displaced
  - Beam position differs from nominal position

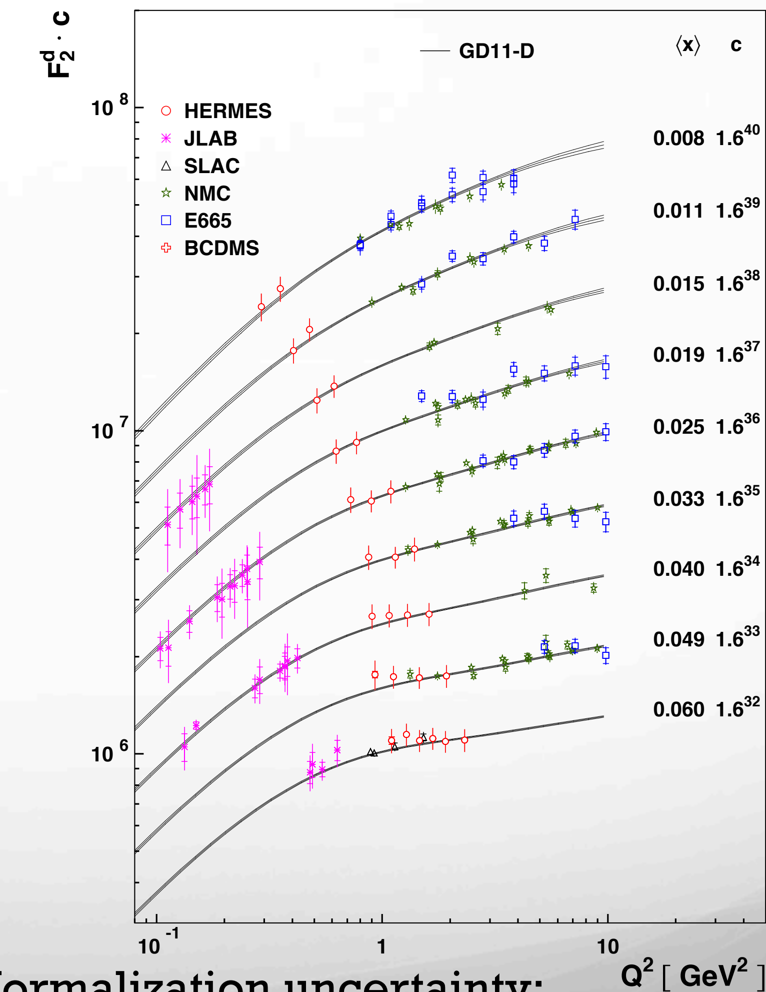
- Simulation of misalignment done in MonteCarlo
- Born cross-section rescaled by fractional changes in Born σ in MC with *aligned* and *misaligned* geometry
- Half the deviation in MC yields obtained with aligned and misaligned geometry are used as systematic uncertainty (< 7%, 2% on ave.)

Results: Region with no previous data

arXiv:1103.5704 (hep-ex) and DESY-11-048
Submitted to JHEP

$0.007 < x < 0.05,\ 0.3\ GeV^2 < Q^2 < 0.9\ GeV^2$





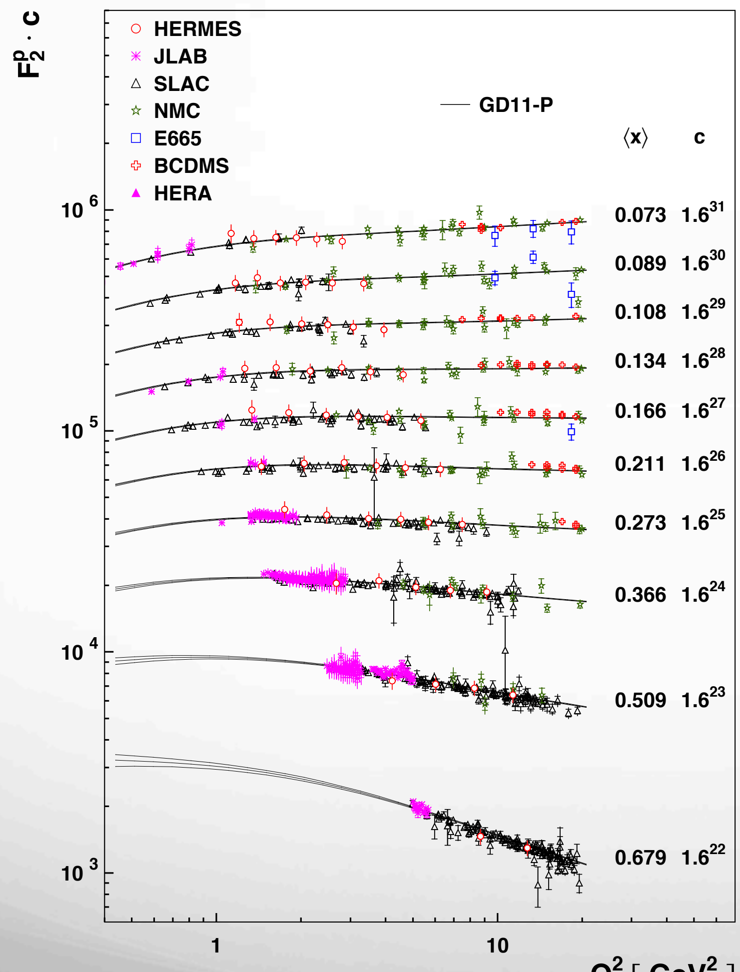
GD11: update of GD07 (*hep-ph/0708.3196*).

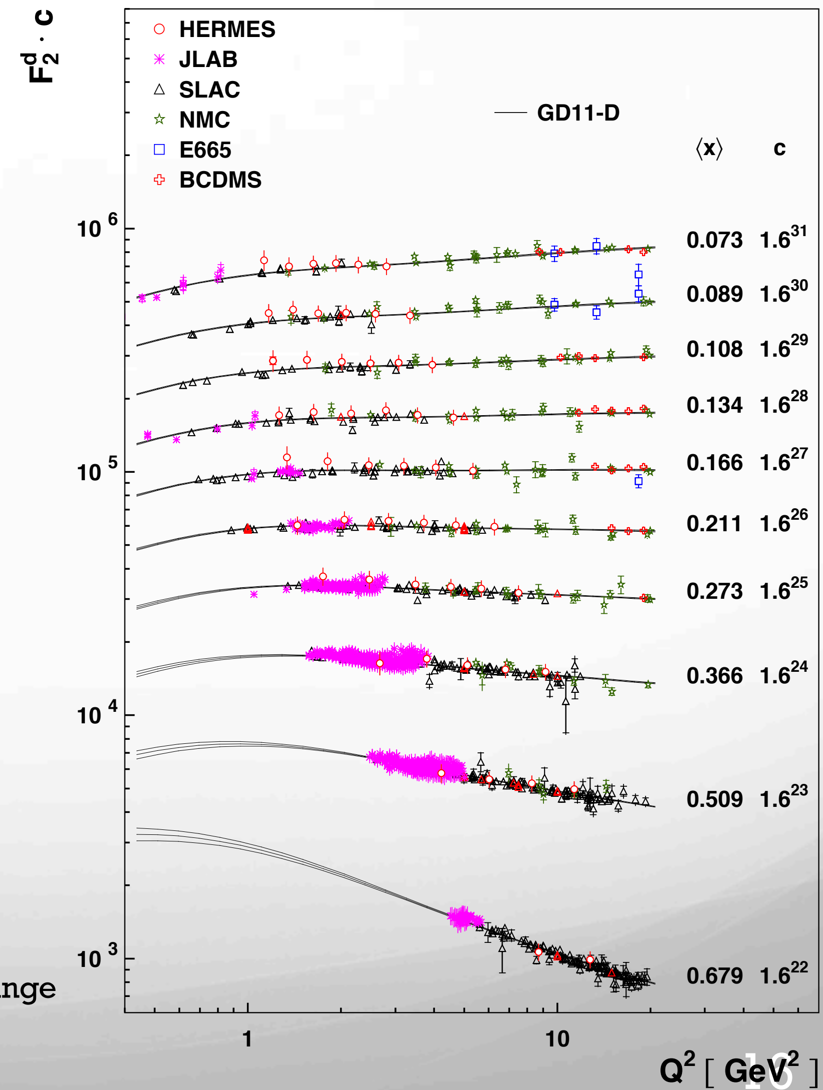
Normalization uncertainty:
7.5% (P), 7.6% (D)

Results: Region with data overlap

arXiv:1103.5704 (hep-ex) and DESY-11-048
Submitted to JHEP

$0.03 < x < 0.7,\ 1.1\ GeV^2 < Q^2 < 13\ GeV^2$





- HERMES data agree with previous data in the same kinematic range

The Parameterization GD11-P,D

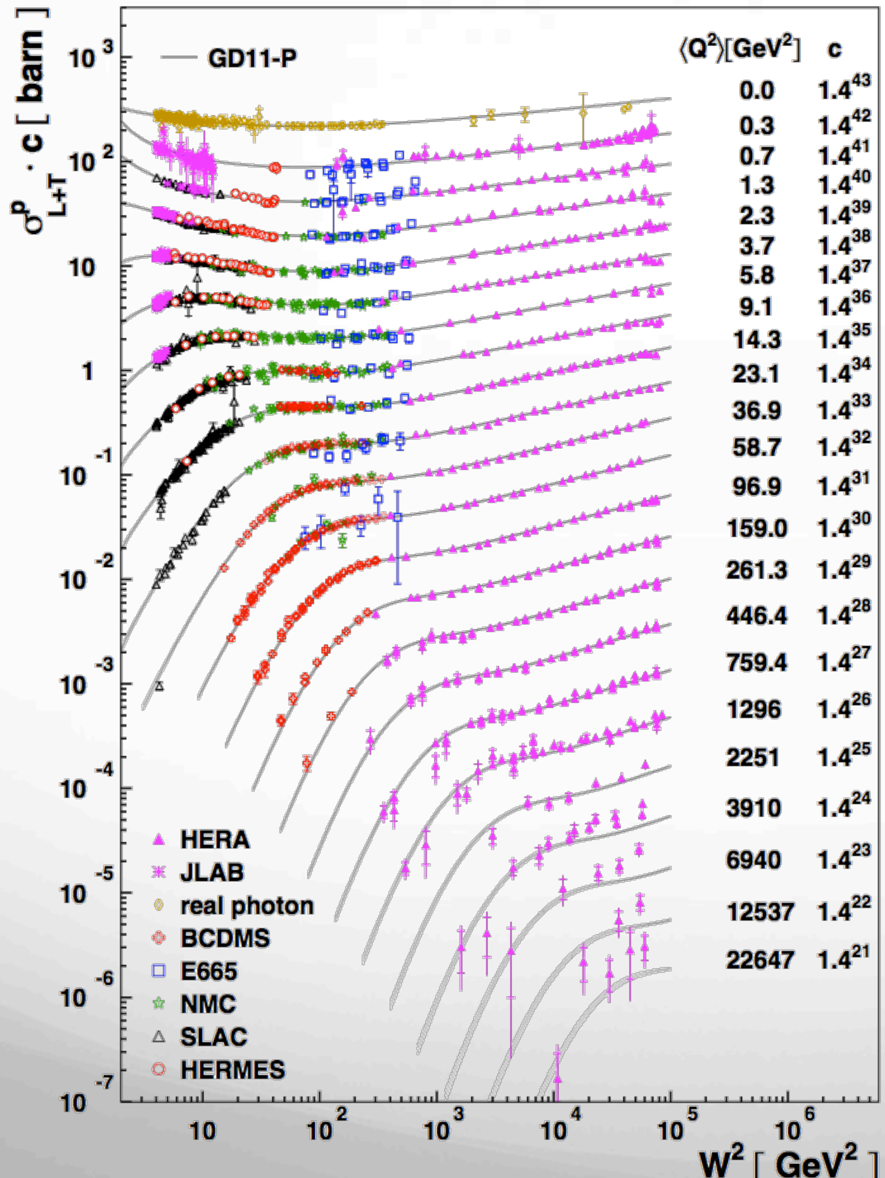
$$\sigma_{L+T}(\gamma^* p) = \frac{4\pi\alpha_{em}}{Q^2(1-x)} \frac{Q^2 + 4M^2x^2}{Q^2} \cdot F_2$$

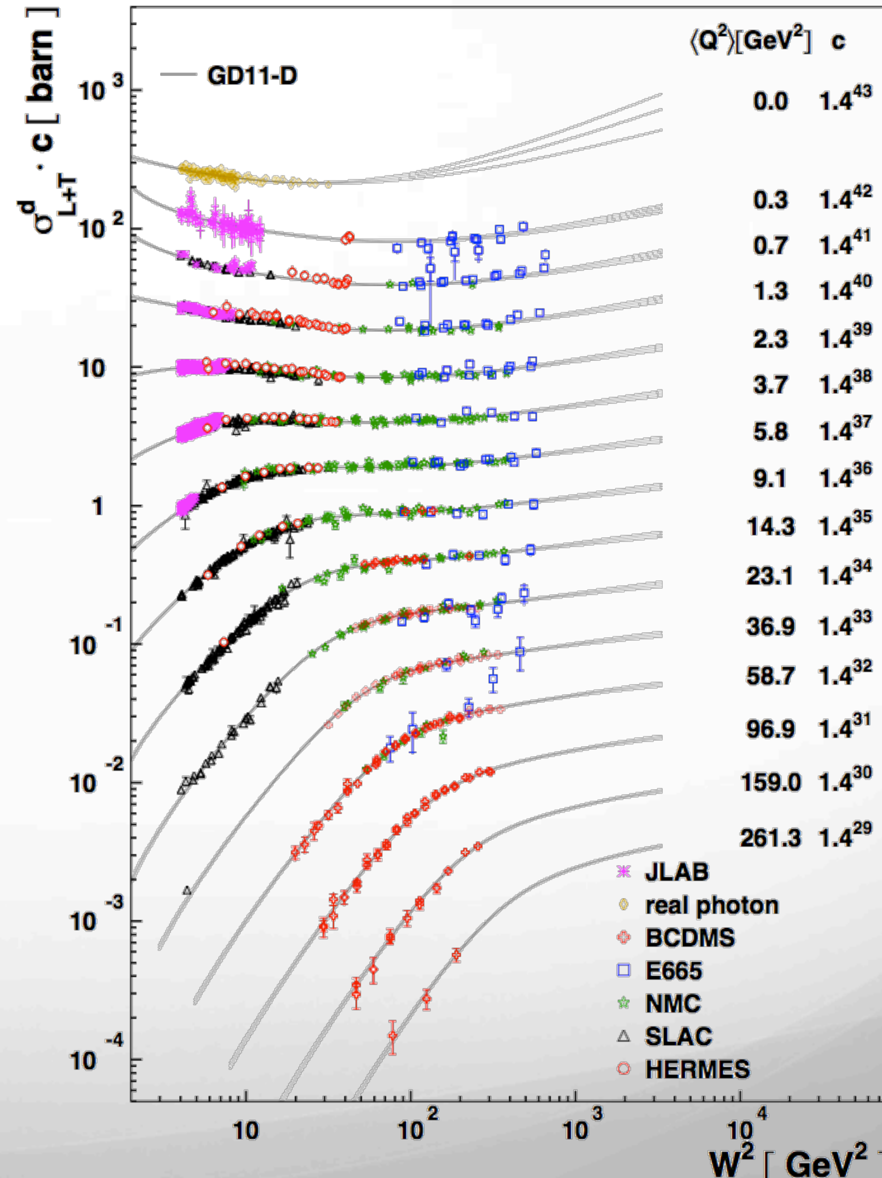
- 23 parameter fit using the Regge-motivated ALLM (*Phys. Lett.B269(1991)465*) functional form
- χ^2 includes point-by-point statistical and systematic uncertainties
- Consistency with respect to $R=\sigma_T/\sigma_L$
- Experimental normalizations are fitted
- Calculation of statistical error bands

With respect to GD07:

- Inclusion of
    - combined HERA e+ and e- data instead of ZEUS and H1 data sets
    - JLAB: E00-115 (50pts on p,d), CLAS (272 pts on p, 1018 pts on d), Tvaskis (5 Rosenbluth pts on p,d and model dependent 50 on p, 81 on d)
    - HERMES 81 pts on p,d

Cross section $\sigma^{p,d}_{L+T}$





Cross section ratio σ^d/σ^p

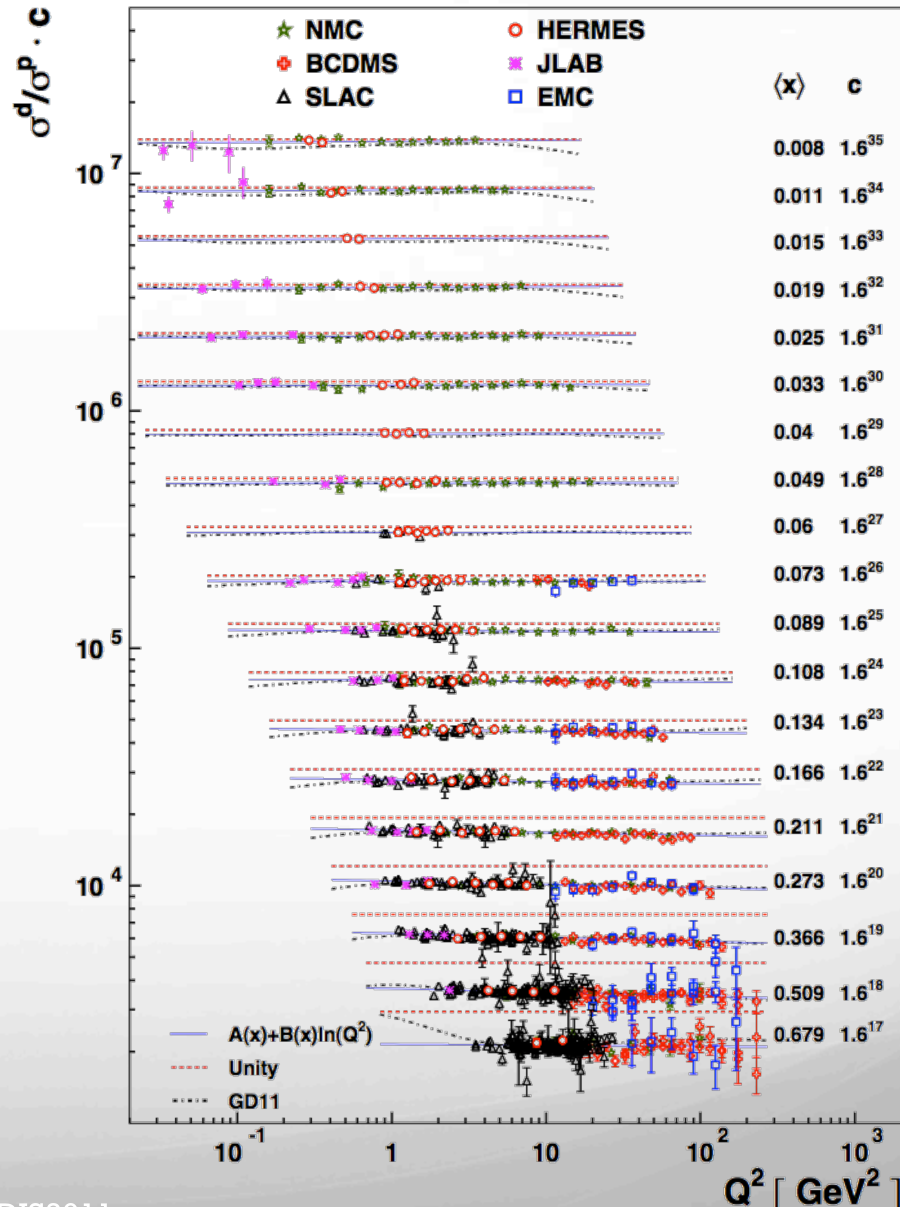
- Determined on a year-by-year basis and then averaged
- Reduction of
  - Normalization uncertainty
  - many systematic effects (misalignment, PID…) cancel

The remaining 1.4% normalization uncertainty comes from variations of beam conditions within each data set.

Data agree with simple fit of the form

$$\sigma^d/\sigma^p = A(x) + B(x)\ln(Q^2)$$

normalization	value
HERMES	0.996
NMC	0.999
BCDMS	1.010
SLAC	1.003
JLAB	1.000
EMC	0.995



Conclusions

HERMES has measured the structure functions F_2^p and F_2^d

Data points ⇨ agree with previous data in the data-overlap region

⇨ add new data in a previously unexplored region

Fits to $F_2^{p,d}$ world data are performed including all available world data

Proton and deuteron are combined to obtain σ^p/σ^d

⇨ large cancellation of syst. uncertainties on the two targets

⇨ cross-section ratio world data fitted to a $A(x)+B(x)\ln(Q^2)$ functional form

Results are submitted to JHEP and available at arXiv:1103.5704 (hep-ex) and DESY-11-048

Extra slides

F_2 FITS

The fits are based on the minimization of the value of χ^2 defined as:

$$\chi^2(\mathbf{p},\nu) = \sum_{i,k} \frac{[D_{i,k}(W^2,Q^2)\cdot(1+\delta_k\nu_k) - T(\mathbf{p},W^2,Q^2)]^2}{({\sigma^{stat}_{i,k}}^2 + {\sigma^{syst}_{i,k}}^2)\cdot(1+\delta_k\nu_k)^2} + \sum_k \nu_k^2$$

$$\approx \sum_{i,k} \frac{[D_{i,k}(W^2,Q^2) - T(\mathbf{p},W^2,Q^2)\cdot(1-\delta_k\nu_k)]^2}{{\sigma^{stat}_{i,k}}^2 + {\sigma^{syst}_{i,k}}^2} + \sum_k \nu_k^2 \ ,$$

where

$D_{i,k} \pm \sigma^{stat}_{i,k} \pm \sigma^{syst}_{i,k}$ are the values of σ_{L+T} for data point *i* within the data set *k*,
δ_k is the normalization uncertainty in data set *k* quoted by the experiment,
$T(\mathbf{p},W^2,Q^2)$ is the 23-parameter ALLM functional form,
$\mathbf{p}$ is the vector of functional parameters
ν is the vector of normalization parameters, analytically determined at each iteration:

$$\nu_k = \frac{\sum_i \delta_k T_{i,k}(T_{i,k} - D_{i,k})/\sigma^2_{i,k}}{\sum_i T^2_{i,k}\delta^2_k/\sigma^2_{i,k} + 1},$$

Normalizations from GD11

Data set	norm. unc. P [%]	GD11-P [%]	norm. unc. D [%]	GD11-D [%]
HERA (positron beam)	0.5	-0.65	-	-
HERA (electron beam)	0.5	-0.67	-	-
E665	1.8	2.0	1.8	-1.4
NMC-90 GeV	2.0	-0.020	2.0	-2.9
NMC-120 GeV	2.0	1.1	2.0	-0.96
NMC-200 GeV	2.0	0.93	2.0	0.36
NMC-280 GeV	2.0	0.35	2.0	0.23
BCDMS-100 GeV	3.0	-3.2	3.0	-
BCDMS-120 GeV	3.0	-2.8	3.0	-0.75
BCDMS-200 GeV	3.0	-2.7	3.0	-0.60
BCDMS-280 GeV	3.0	-2.3	3.0	-0.31
SLAC E49a	2.1	1.6	1.7	-0.13
SLAC E49b	2.1	2.2	1.7	0.62
SLAC E61	2.1	1.6	1.7	0.70
SLAC E87	2.1	1.6	1.7	0.45
SLAC E89a	2.1	3.6	1.7	0.87
SLAC E89b	2.1	1.8	1.7	0.081
SLAC E139	2.1	-	1.7	0.14
SLAC E140	2.1	-	1.7	0.25
JLAB E00-115	1.75	-1.2	1.75	-4.0
JLAB CLAS	1.0	-0.63	1.0	-0.12
JLAB (Rosenbluth)	1.0	0.14	1.0	0.88
JLAB (Model Dependent)	1.0	0.85	1.0	0.88
HERMES (T.A.)	7.5	1.5	7.6	-2.2

PID efficiencies and contaminations

Dependence on momentum (eff.'s decrease at higher p), production,bin
Eff> 94%, C<2%