Measurement of the structure functions F_2^p and F_2^d at

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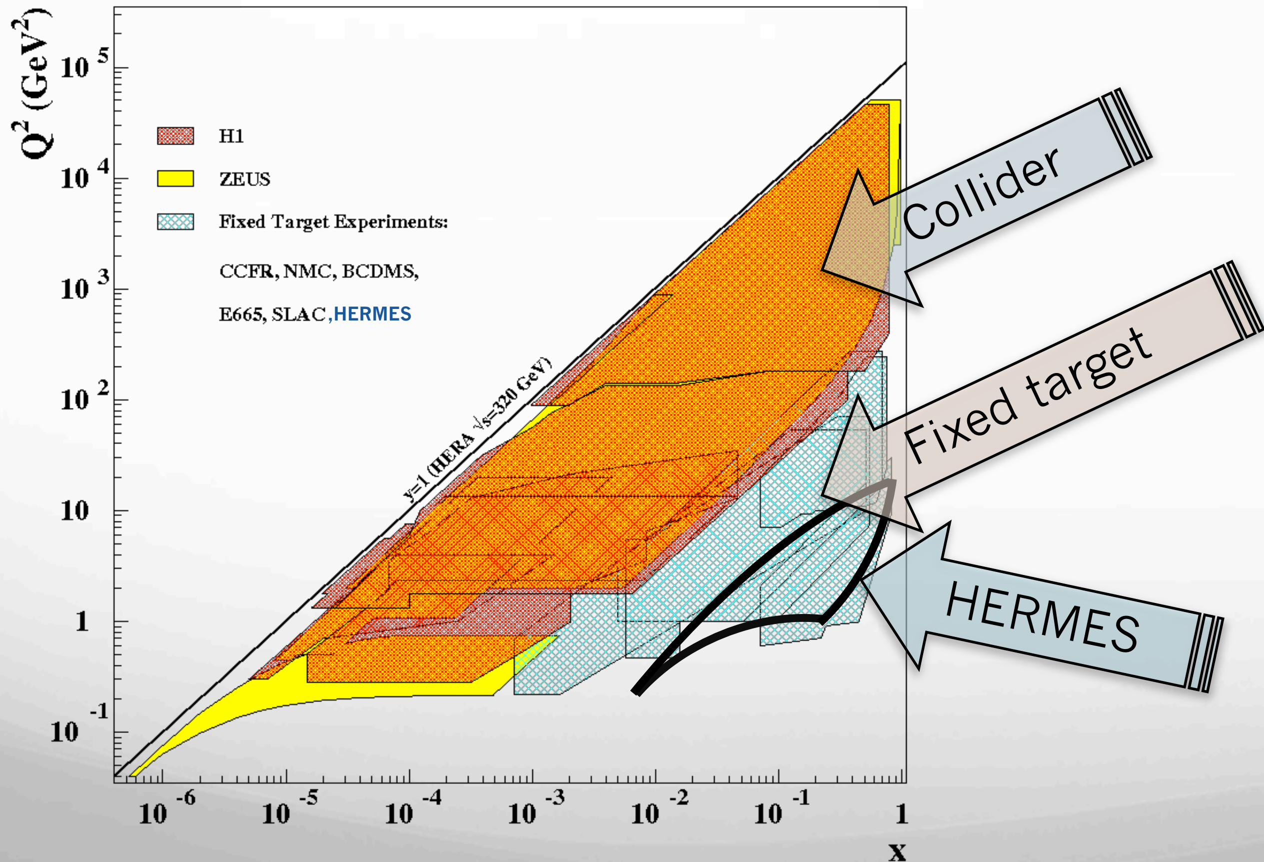
For the

HERMES COLLABORATION

DIS cross section and structure functions

$$\frac{d^2\sigma}{dx\,dQ^2} = \frac{4\pi\alpha_{em}^2}{Q^4}\frac{F_2(x,Q^2)}{x}\left[1-y-\frac{Q^2}{4E^2}+\frac{y^2+Q^2/E^2}{2\,(1+R(x,Q^2))}\right]$$



Why measuring inclusive DIS cross sections at HERMES?

HERMES (1996-2005)	30M proton ~450pb^{-1}	+	28M deuteron ~460pb^{-1}
eg. Compared to NMC	3M proton	+	6M 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

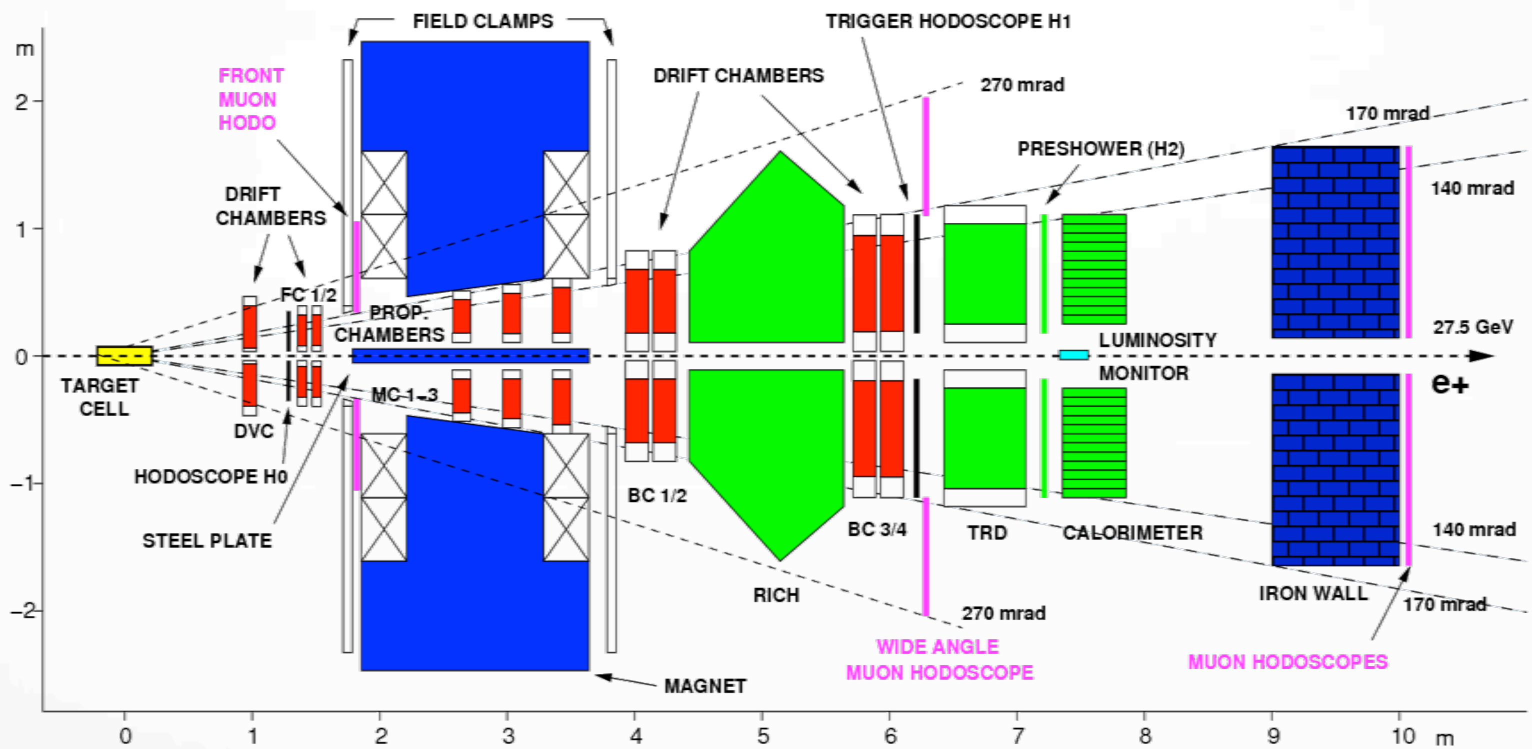
$\int \frac{dx}{x} \left(F_2^p - F_2^d\right)$

Gottfried Sum

d_v/u_v

Valence Quark Ratio

The HERMES Spectrometer

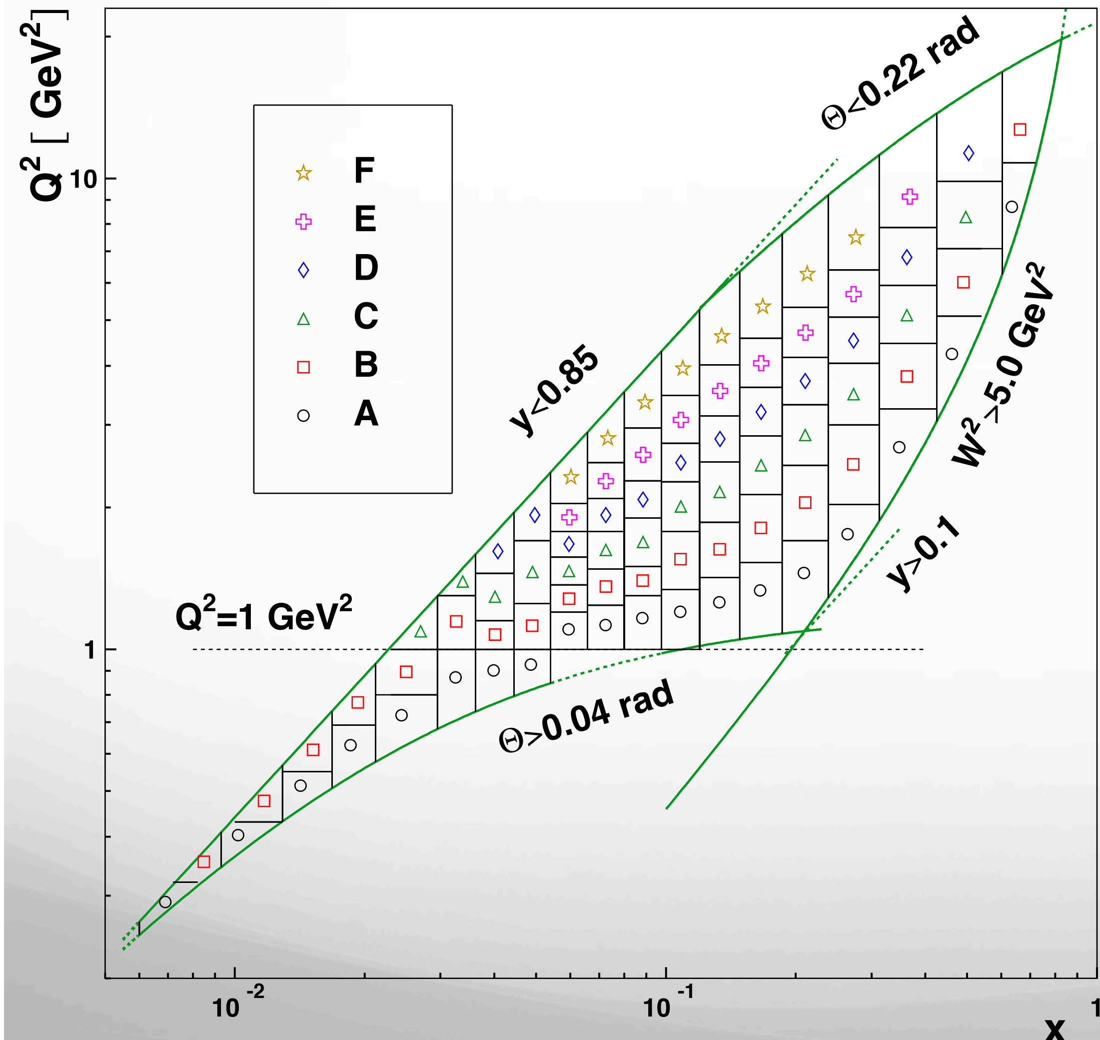


Reconstruction: $\delta p/p < 2\%$, $\delta\theta < 1$ mrad

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



$0.006 < x < 0.9$

$0.1 < y < 0.85$

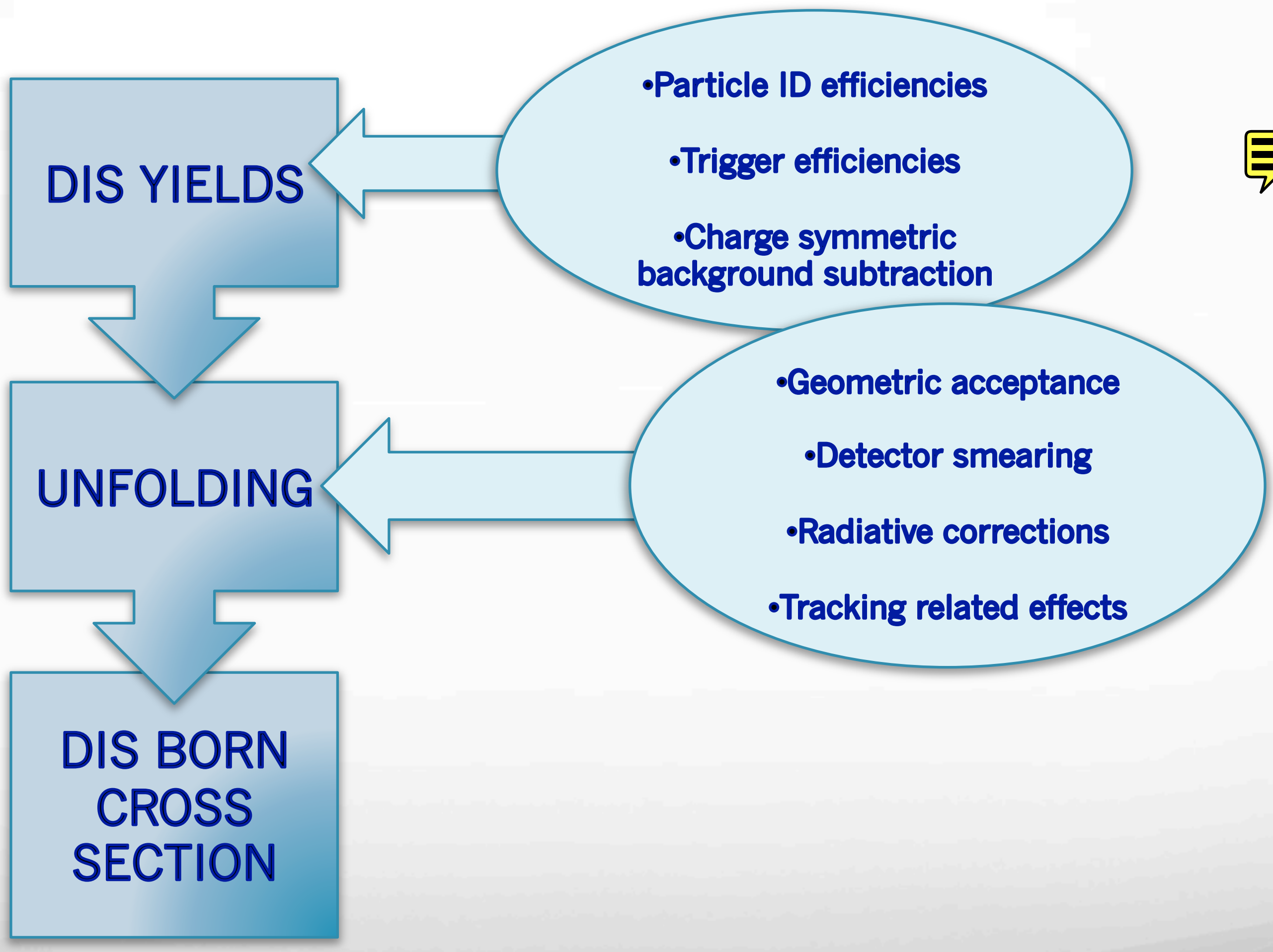
$0.2\ \mathrm{GeV}^2 < Q^2 < 20\ \mathrm{GeV}^2$

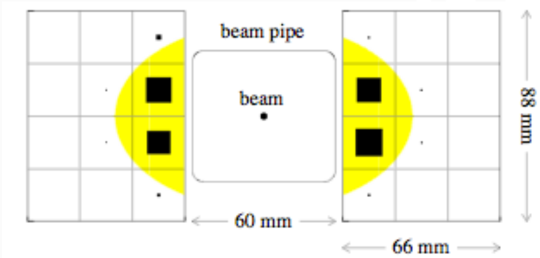
$W^2 > 5\ \mathrm{GeV}^2$

- 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 shell electrons

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

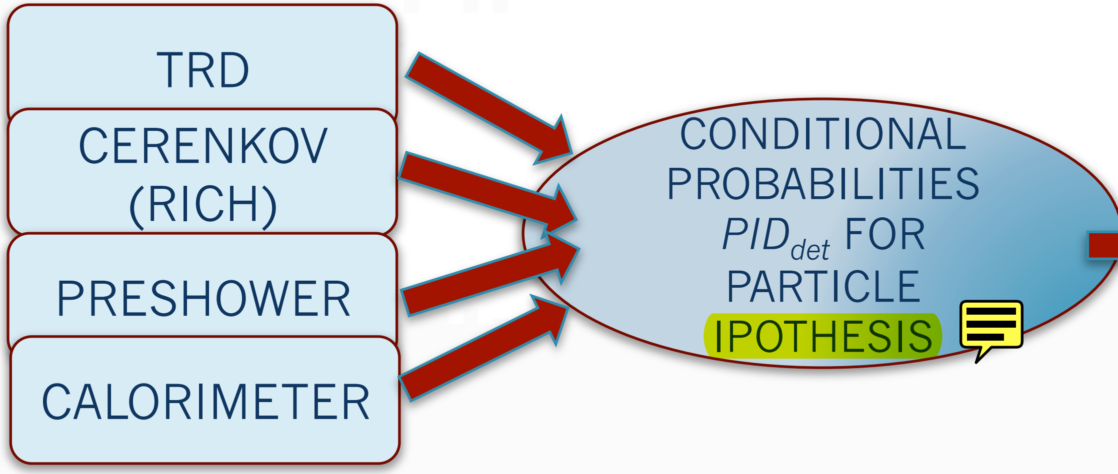
  annihilation $e^+ e^- \rightarrow 2\gamma$

$$L = \int \mathcal{L}\, dt = (R_{LR} - \Delta t \cdot R_L \cdot R_R) \cdot C_{Lumi} \cdot \frac{A}{Z} \cdot l \cdot \Delta t_{meas}$$

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

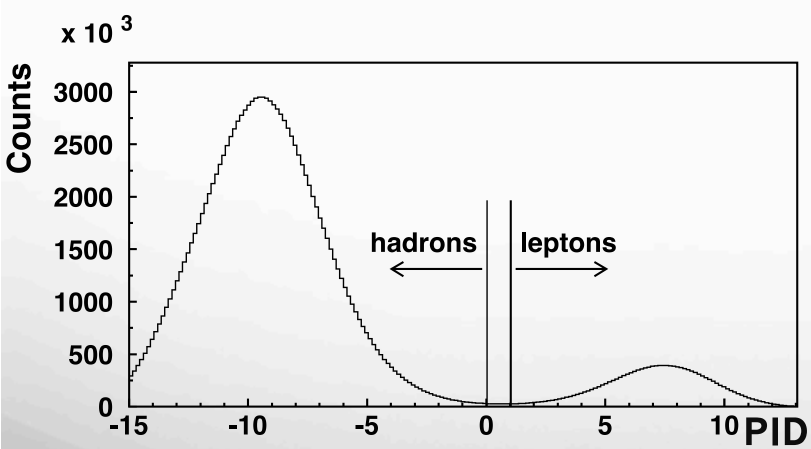
Normalization uncertainty 6.4% (proton) and 6.6%(deuteron)

Particle ID efficiencies



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

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



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

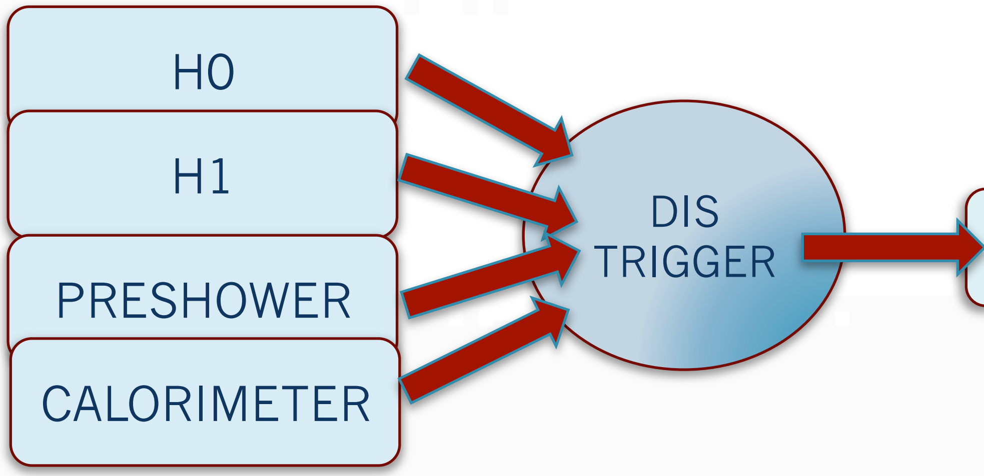
Hadron contamination:
fractional contribution of hadrons above PID_{cut}

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

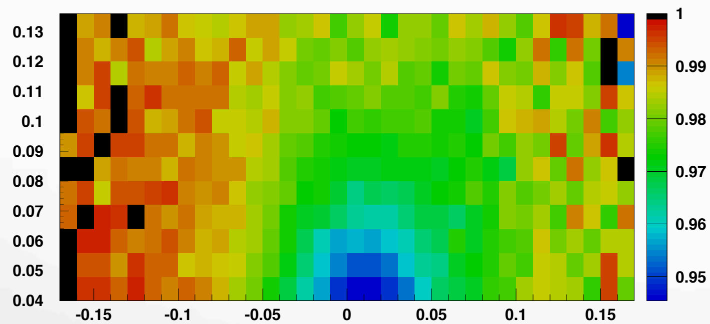
$$N_{corr} = N_{uncorr} \cdot \frac{1 - \mathcal{C}(PID_{cut})}{\mathcal{E}(PID_{cut})}$$

Correction ~1%

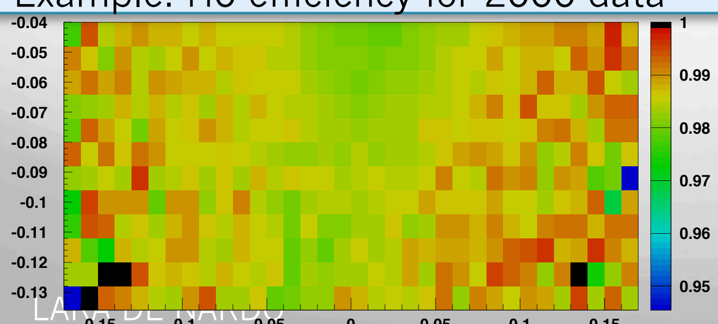
Trigger efficiencies



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



Example: H0 efficiency for 2000 data



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

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

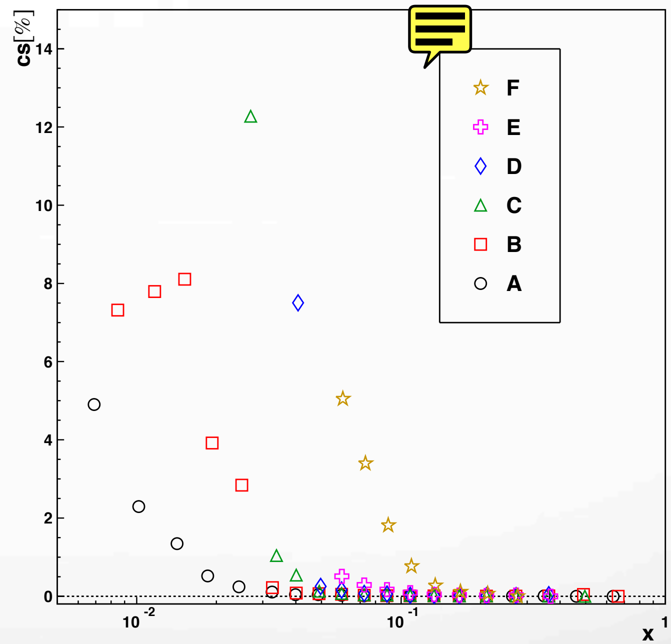
Charge symmetric backgorund

- 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

$$\sigma^{Exp}(j) = \frac{N_{corr}(j)}{\mathcal{L}}$$

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

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

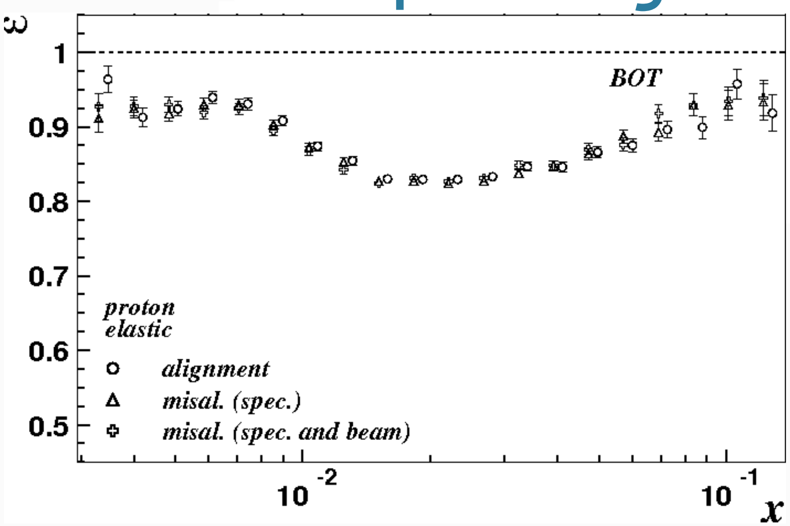
Smearing matrix

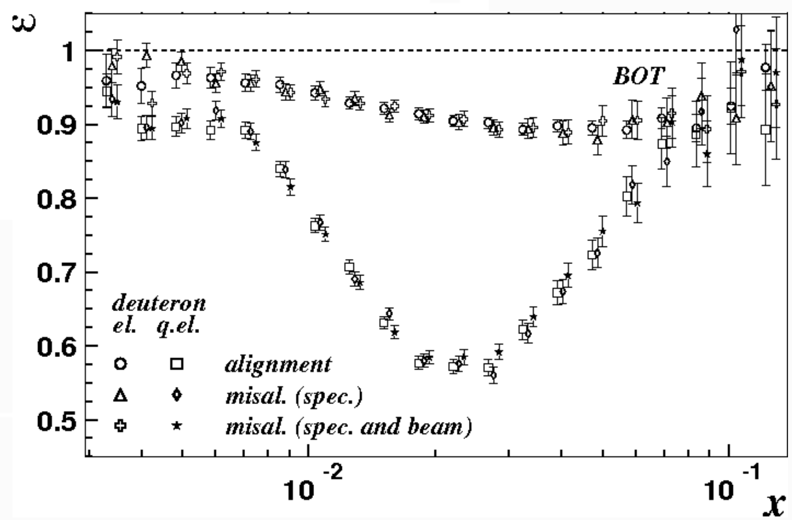
Events originating in bin j and measured in bin i

Events in bin j on Born level

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

Detection efficiencies for high multiplicity radiative events



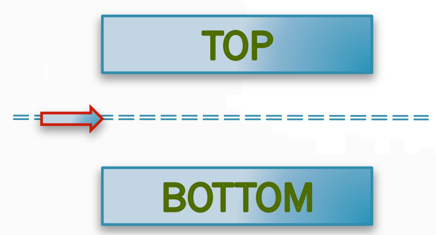


•The incoming *electron* can radiate a *high energy photon* and then scatter elastically with the nucleon.

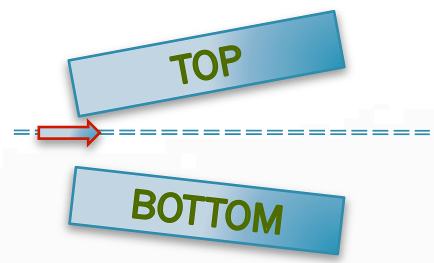
Photon:
- *Small scattering angle*
- *Large probability of hitting the beam pipe, causing a shower and saturating the wire chambers*

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

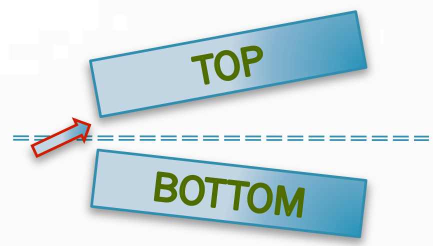
Main source of systematics: Misalignment



IDEAL



DETECTOR MISALIGNED



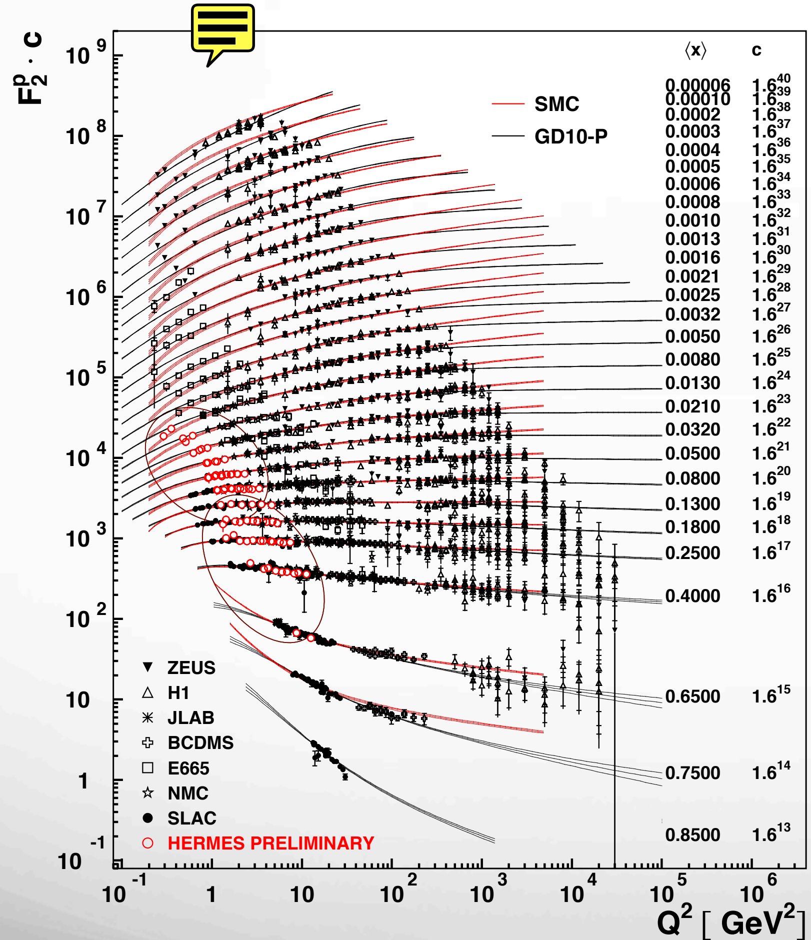
BEAM + DETECTOR MISALIGNED

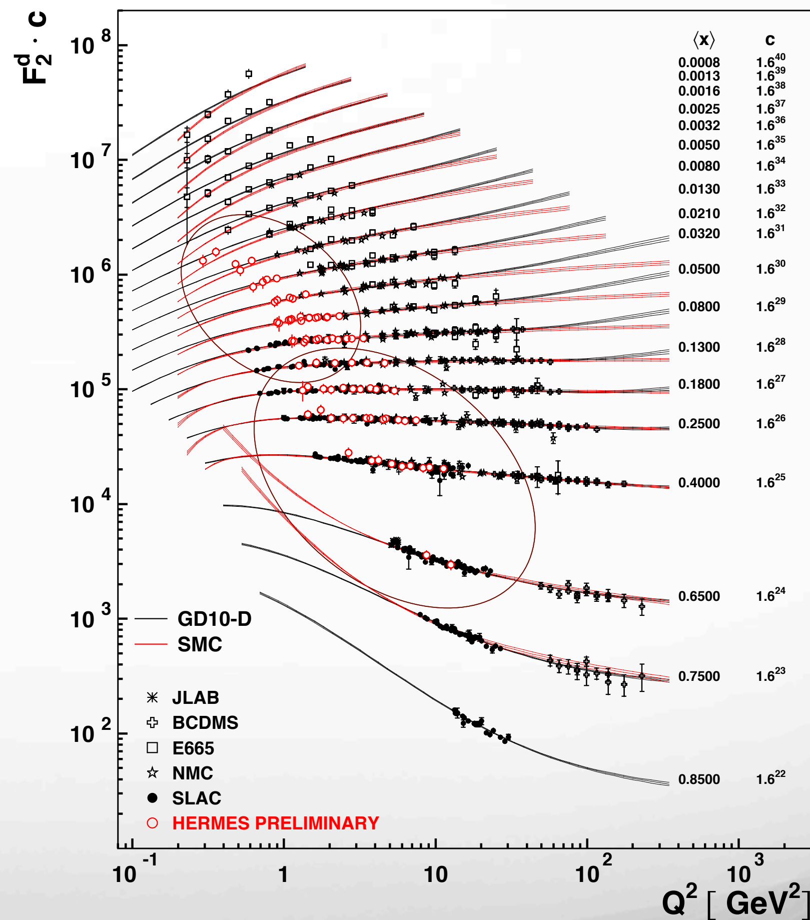
- IDEAL situation: Perfect alignment of beam and spectrometer
- In practice:
  - Top and bottom parts of the detector are displaced
  - Beam position differs from nominal position

- Simulation of misalignment done in MonteCarlo
- Difference between measured and simulated cross section used as systematic uncertainty (~7%)

$F_2^{p,d}$ results

- ✓Agreement in the region of overlap $0.03 < x < 0.7,\ 1.1\ GeV^2 < Q^2 < 13\ GeV^2$
- ✓Data in a so far unexplored region $0.007 < x < 0.05,\ 0.3\ GeV^2 < Q^2 < 0.9\ GeV^2$

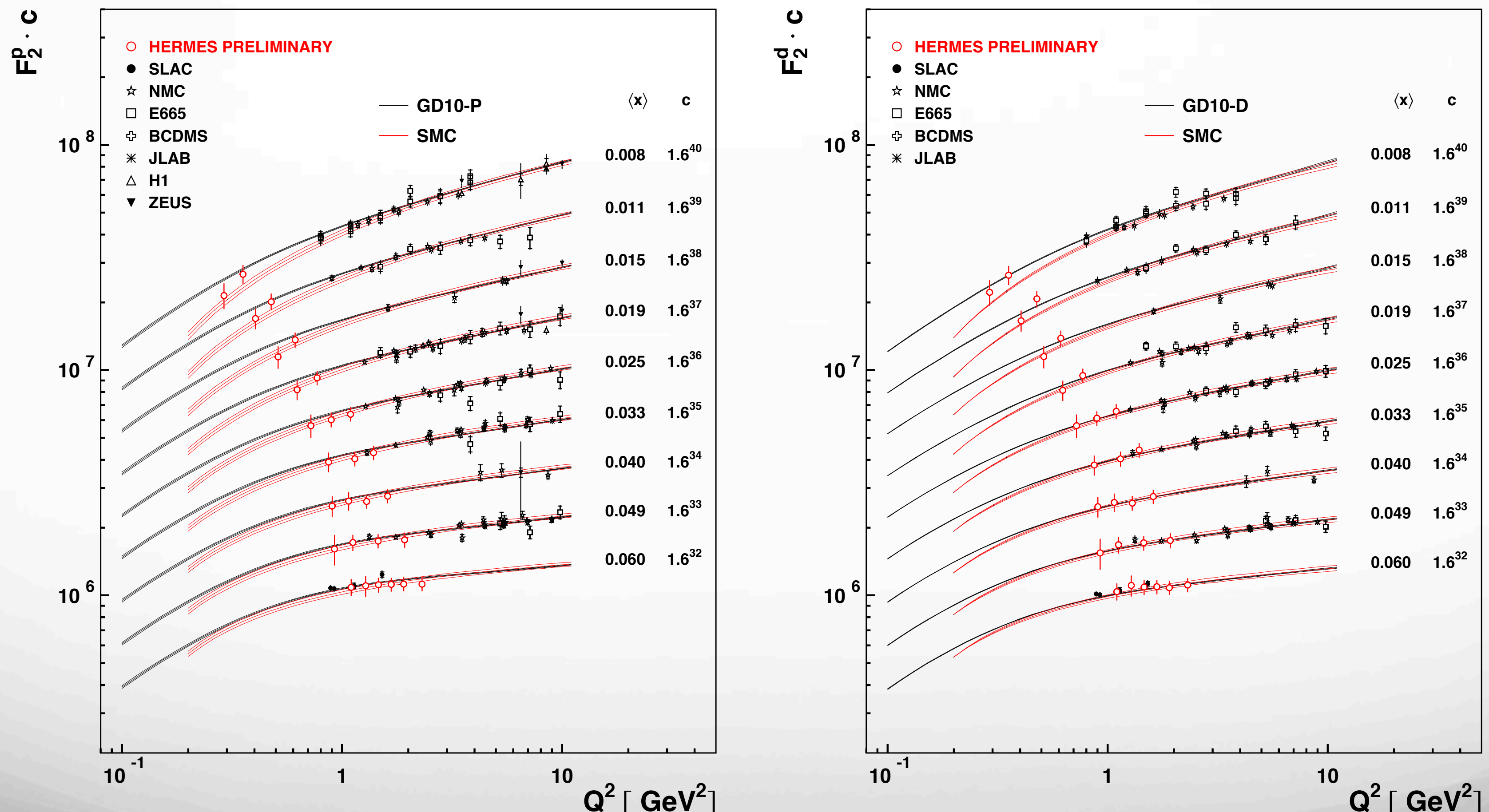




GD10: update of GD07 (*hep-ph/0708.3196*). Now including HERMES data
SMC fit: *Phys. Rev. D58 (1998)112001*

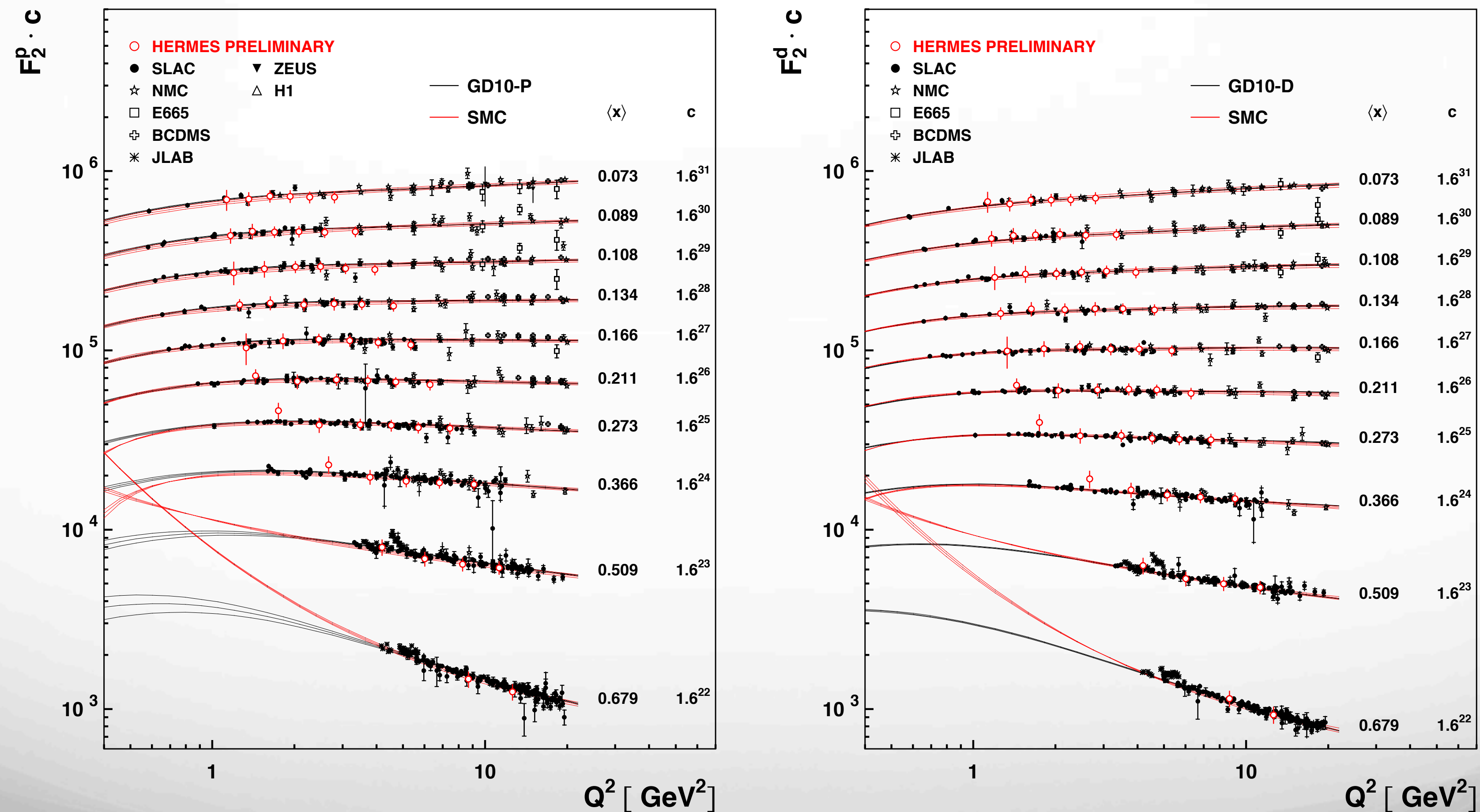
Normalization uncertainty: 6.4% (P), 6.6% (D)

Region with no previous data



- HERMES data agree with previous parameterization from SMC and are included in the fit GD10

Region with data overlap



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

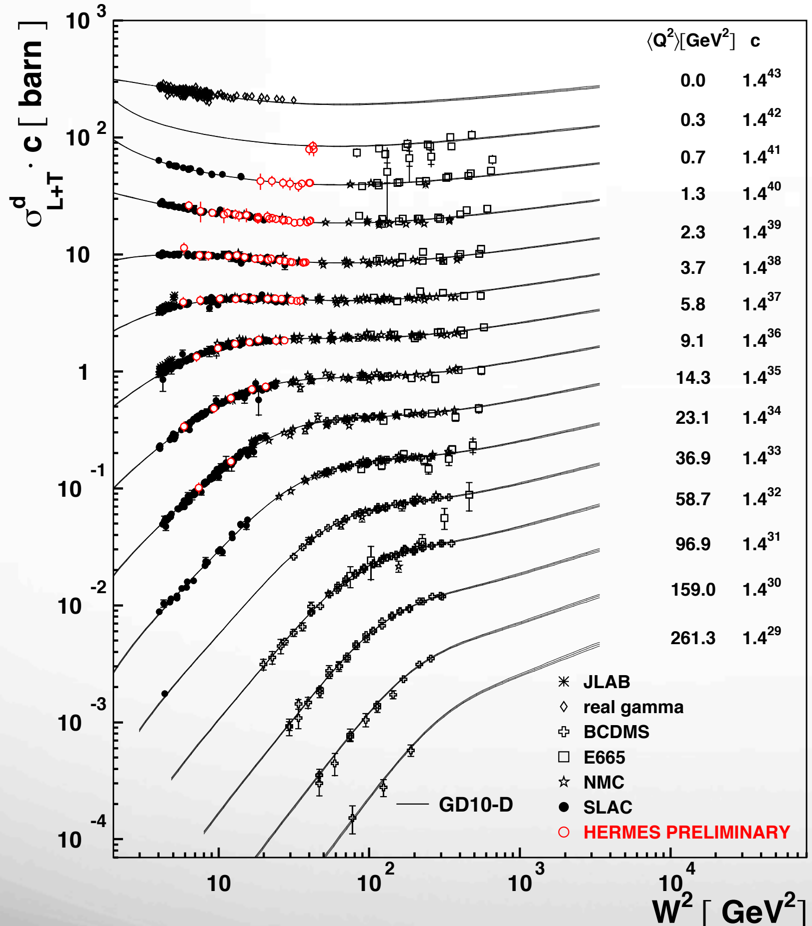
The Parameterization GD10-P,D

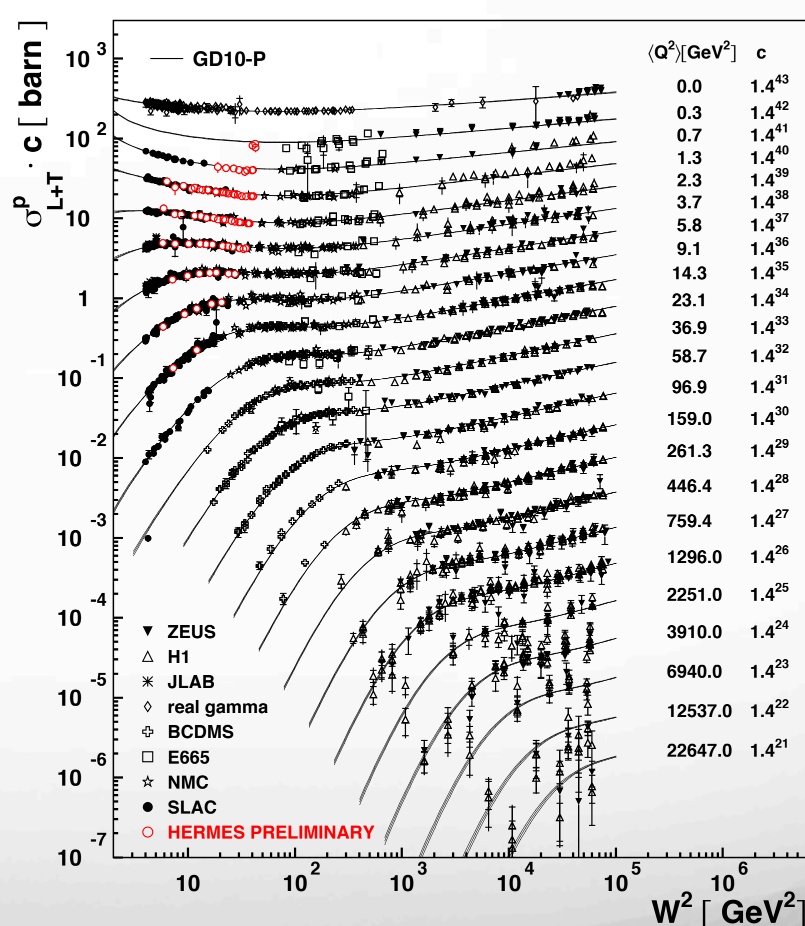
$$\sigma_{L+T}(\gamma^* p) = \frac{4\pi\alpha_{em}}{Q^2(1-x)} \frac{Q^2+4M^2x^2}{Q^2} \cdot F_2$$

•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 the inclusion of HERMES data:
•Parameter uncertainties decrease by up to 30% (proton) and 40% (deuteron)
•χ^2 changes from 0.90 to 0.92(proton) and 0.86 to 0.90 (deuteron)

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



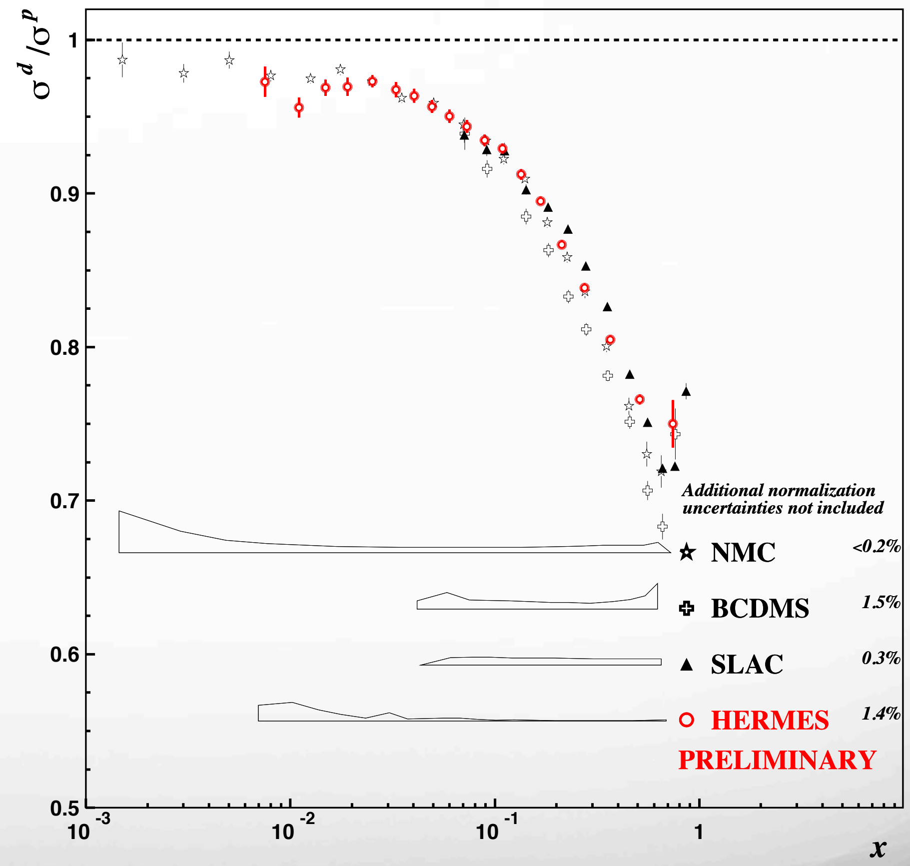


Cross section ratio σ^p/σ^d

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

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

HERMES data agree with data from SLAC (similar Q^2) and data at higher Q^2 from NMC.
BCDMS data are known to disagree with the other data sets.



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

⇨ clear improvement of parameter uncertainties

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

⇨ large cancellation of syst. uncertainties on the two targets

Extra slides

PID efficiencies and contaminations

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