Determination of the GDH integral in the HERMES experiment

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LNF - INFN

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The GDH sum rule

The GDH sum rule, derived in the sixties by Gerasimov and independently by Drell and Hearn, relates the anomalous contribution κ to the magnetic moment of the nucleon ($\kappa_{\rm p}$=1.79, $\kappa_{\rm n}$=−1.91) with the total absorption cross sections for circularly polarised real photons on polarised nucleons:

$$\int_0^\infty \left[\sigma_{1/2}(\nu) - \sigma_{3/2}(\nu)\right] \frac{d\nu}{\nu} = -\frac{2\pi^2\alpha}{M^2}\kappa^2$$

general dispersion relation for forward Compton scattering
+ low-energy theorem of Low
+ additional assumption that the spin-flip part of the Compton scattering amplitude goes to zero at infinite energy without any poles.

Theoretical predictions:
-204 μb p
-233 μb n

Never been tested directly

The generalised GDH sum rule

The integral can be generalised to the absorption of virtual photons with energy ν and squared four-momentum $-Q^2$:

$$I(Q^2) \equiv \int_{Q^2/2M}^{\infty} \left[\sigma_{1/2}(\nu, Q^2) - \sigma_{3/2}(\nu, Q^2)\right] \frac{d\nu}{\nu}$$

$$= \frac{8\pi^2\alpha}{M} \int_0^1 \frac{g_1(x, Q^2) - \gamma^2 g_2(x, Q^2)}{K} \frac{dx}{x}$$

g_1, g_2 polarised structure functions of the nucleon
x Bjorken variable
$K = \nu\sqrt{1+\gamma^2}$ flux factor of the virtual photons
$\gamma^2 = Q^2/\nu^2$

$I(Q^2)$ connects the GDH expectation for real photon with the Ellis-Jaffe (or Bjorken in the case of p-n) in the asymptotic region

The Q^2 dependence of $I(Q^2)$ connects the static ground state properties of the nucleon with its helicity structure as measured in inelastic scattering in the resonance and deep inelastic regions

$$I(Q^2) \equiv \int_{Q^2/2M}^{\infty} \Delta\sigma(\nu, Q^2) \frac{d\nu}{\nu}$$

where :

$$\Delta\sigma(\nu, Q^2) = \sigma_{1/2}(\nu, Q^2) - \sigma_{3/2}(\nu, Q^2) = \frac{8\pi^2\alpha}{M} \frac{A_1 F_1}{K}$$

$F_1 = F_2 \frac{1+\gamma^2}{2x(1+R)}$

$F_2 \rightarrow$ NMC parameterization

$R \rightarrow$ SLAC parameterization
F_2^{res} modification of F_2 which account for nucleon resonances
$R^{res} = 0.18$ (the choice don't affect the result)

$A_1 = A_{\parallel}/D - \eta A_2$

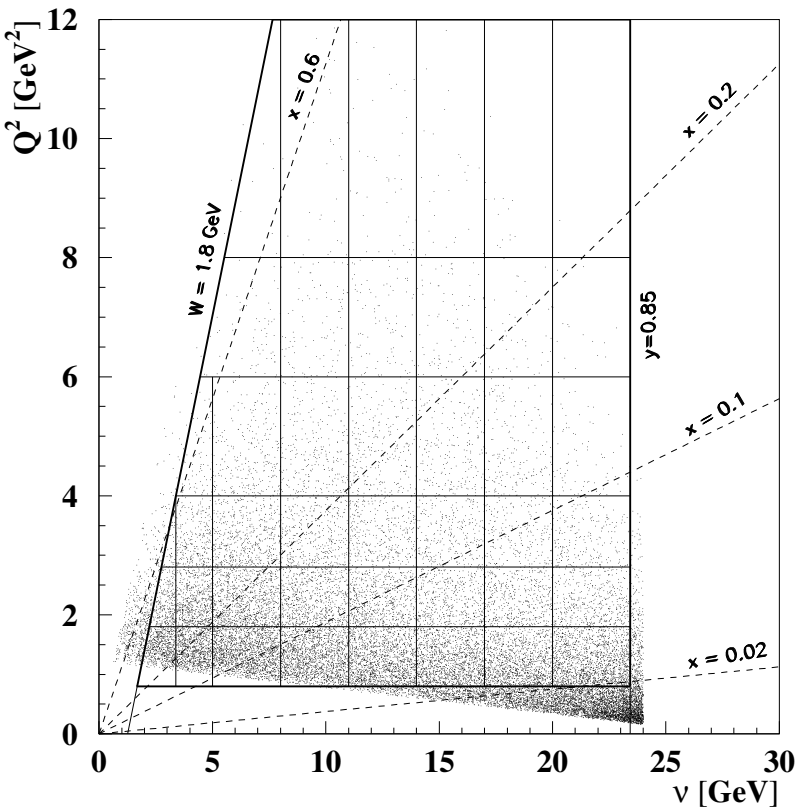
$A_2 \rightarrow$ SLAC measurement

$A_2^{res} = 0$ (almost unknown; effect of different values studied and included in systematic error)

$K = \nu\sqrt{1+\gamma^2}$ flux factor of the virtual photons

HERMES kinematic plane

$E_{\rm beam}$=27.5 GeV
W $>$ 1.8 GeV, $\nu < 23.5$ GeV (y<0.85)
$\theta_{\rm min} = 40$ mrad $\rightarrow Q^2 \geq 0.8$ GeV^2
$\theta_{\rm max} = 220$ mrad



$0.004 < x_{\rm Bj} < 0.8 \rightarrow g_1(x)$, Bjorken & E.J. sum rule;

$0.8 < Q^2 < 12$ GeV^2,
$2 < \nu < 23.5 \rightarrow \sigma_{1/2} - \sigma_{3/2}$, GDH sum rule

General cuts

$40 \leq \theta \leq 220$ mrad
y<0.85

DIS region

$W^2 > 3.24$ GeV^2
$0.8 \leq Q^2 \leq 12$ GeV^2

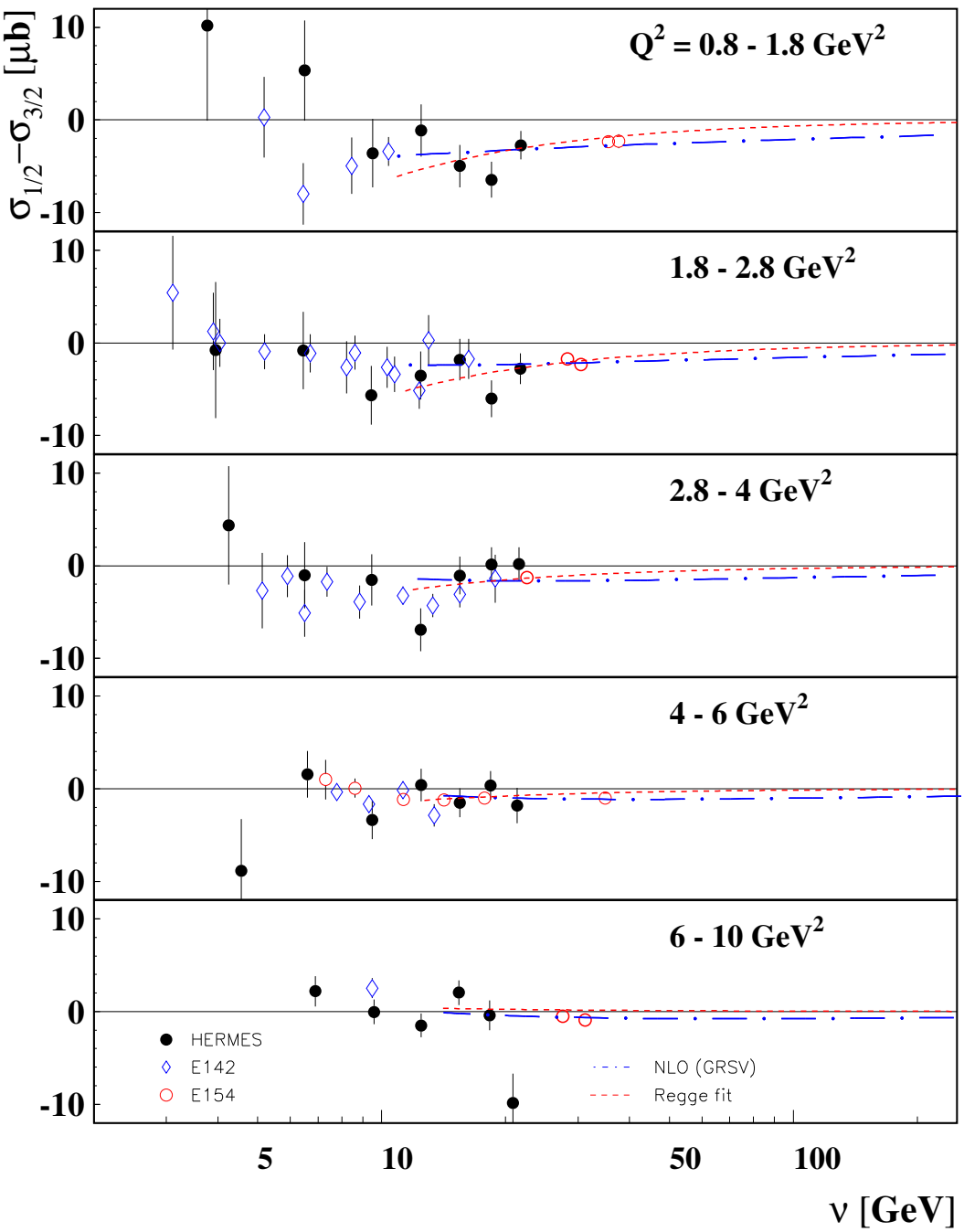
Resonance region

$1.0 \leq W^2 \leq 4.2$ GeV^2
$1.2 \leq Q^2 \leq 12$ GeV^2

Combined region

$1.0 \leq W^2 > 45$ GeV^2
$1.2 \leq Q^2 \leq 12$ GeV^2

Neutron cross section difference



$$\sigma_{1/2} - \sigma_{3/2} = \frac{8\pi^2\alpha}{M}\,\frac{A_1 F_1}{K}$$

A_1^n from $A_{\parallel}^n$ (1995 data on ^{3}He target)

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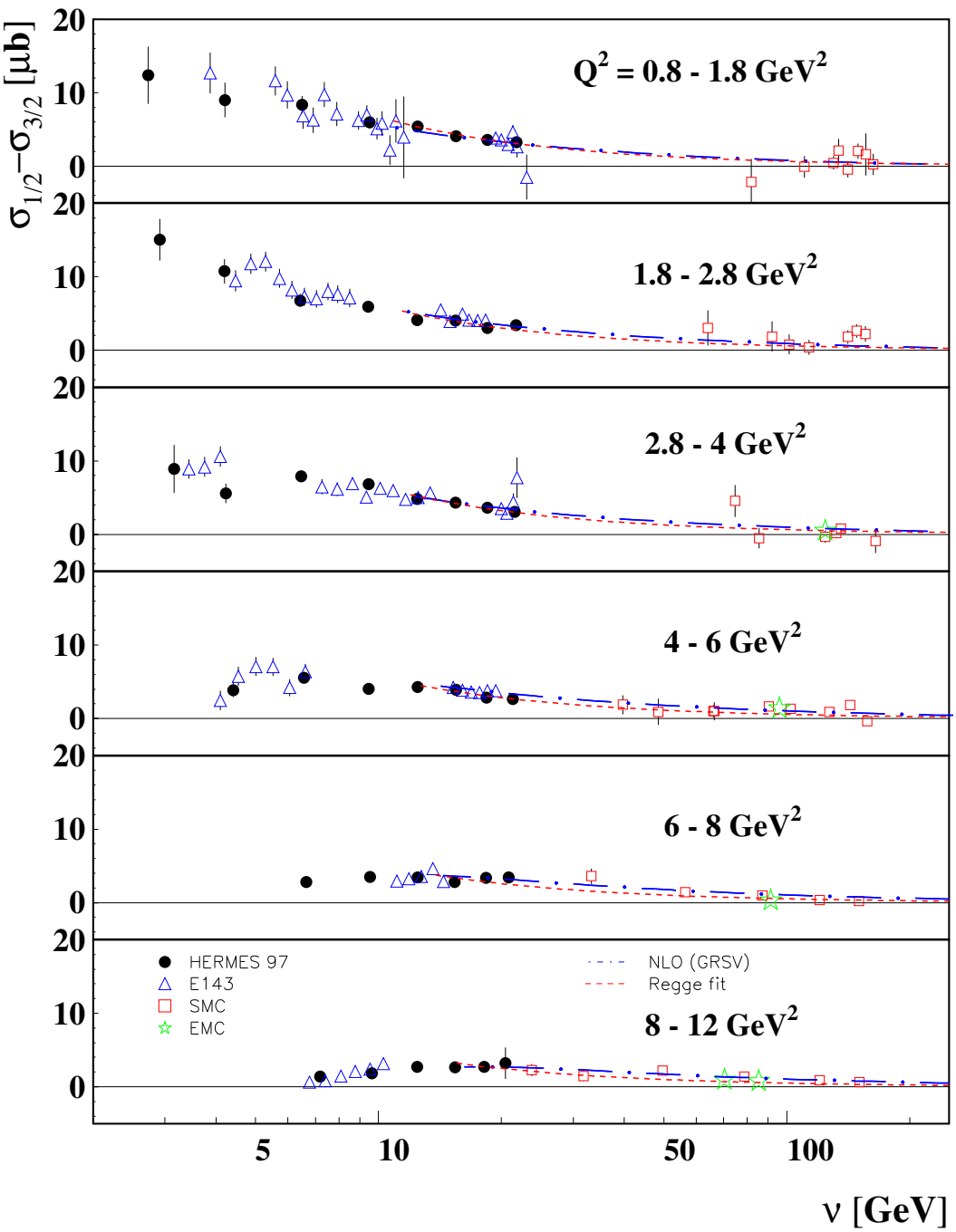
Proton cross section difference



$$\sigma_{1/2} - \sigma_{3/2} = \frac{8\pi^2\alpha}{M}\,\frac{A_1 F_1}{K}$$

A_1^p from $A_{\parallel}^p$ (1997 data on ^{1}H target)

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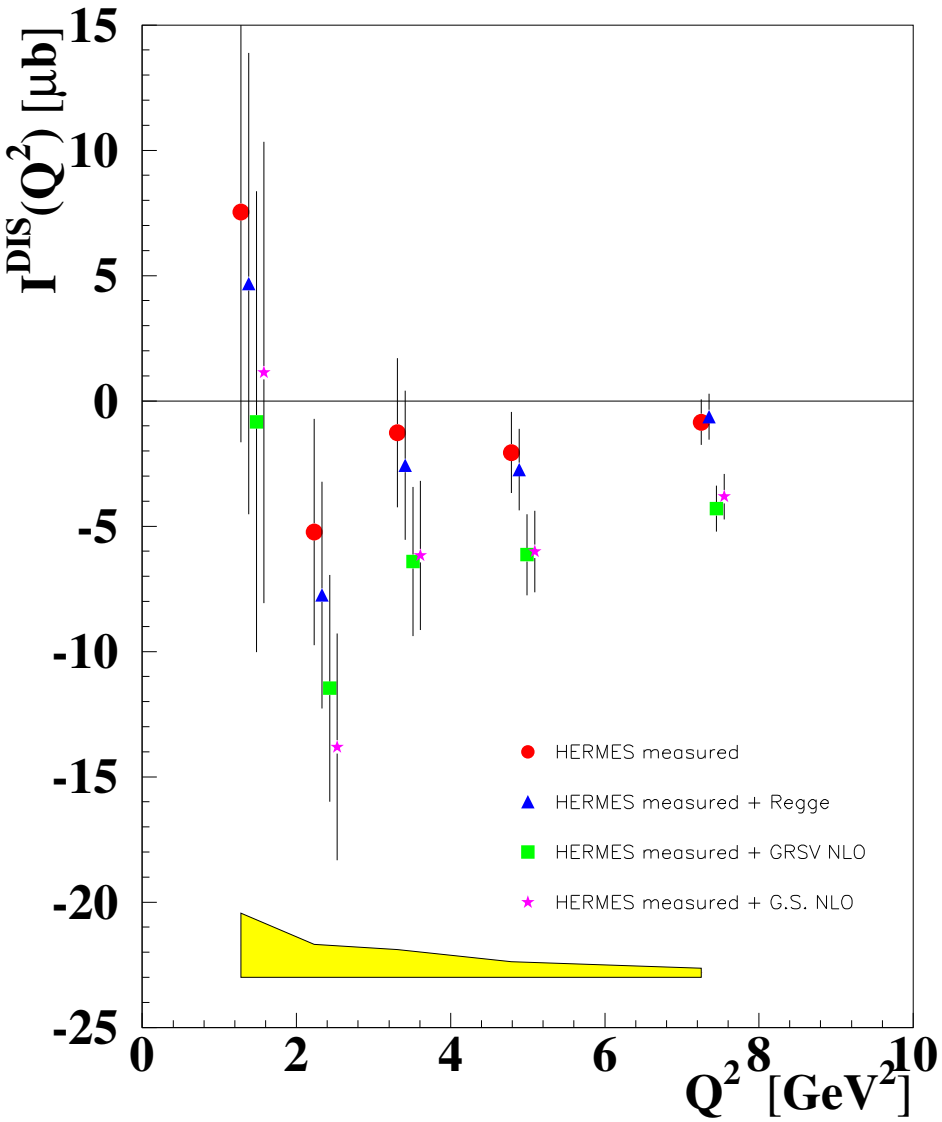
Generalised GDH integral for the neutron

Data + different high energies extrapolations :



$$I^{\rm DIS}_{\rm meas}(Q^2) = \int_{\nu_0}^{23.5} [\sigma_{1/2} - \sigma_{3/2}] \frac{d\nu}{\nu}$$

$$I^{\rm DIS}(Q^2) = \int_{\nu_0}^{\infty} [\sigma_{1/2} - \sigma_{3/2}] \frac{d\nu}{\nu}$$

$\nu_0 \rightarrow$ due to W=2 GeV cut

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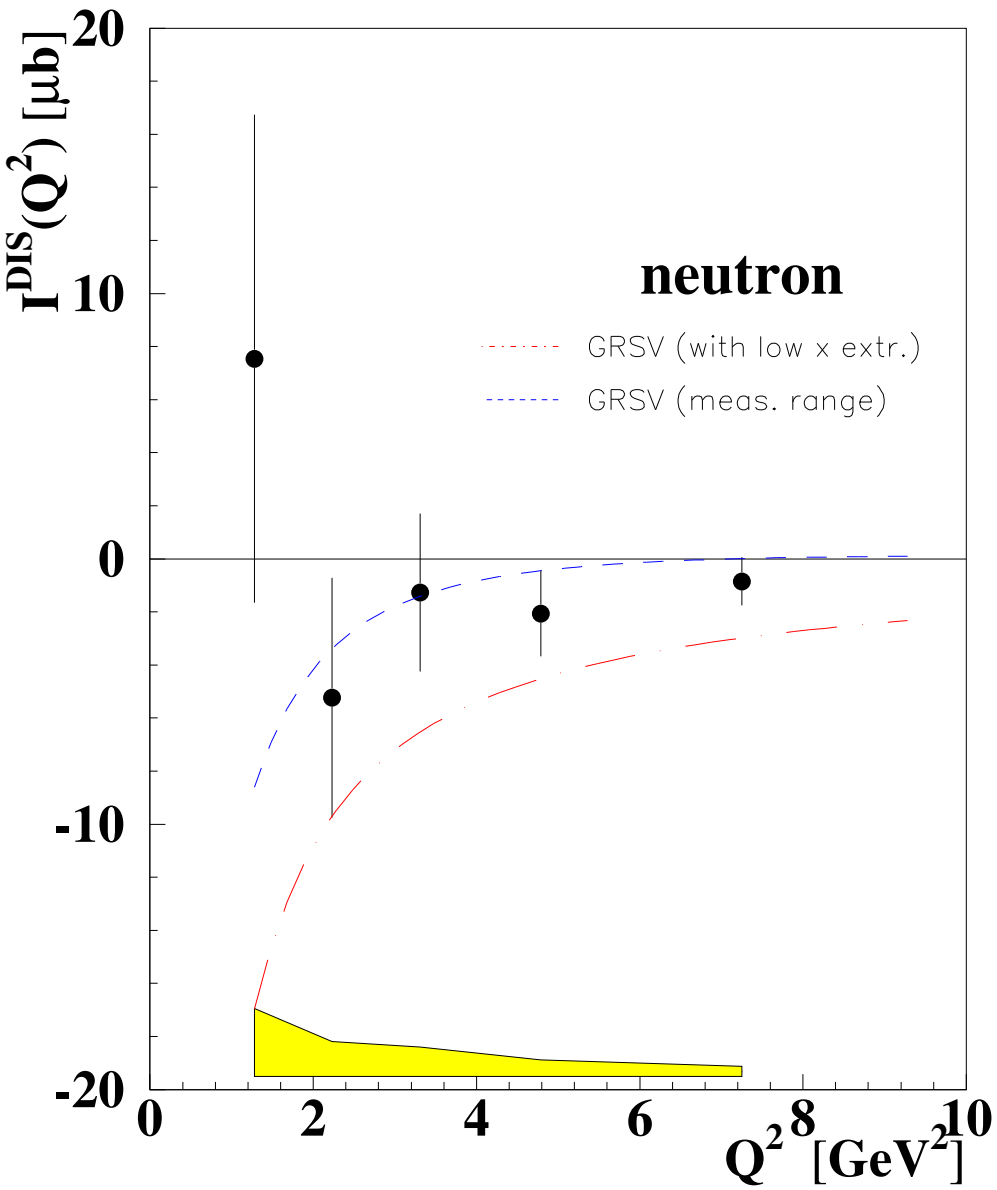
Generalised GDH integral for the neutron

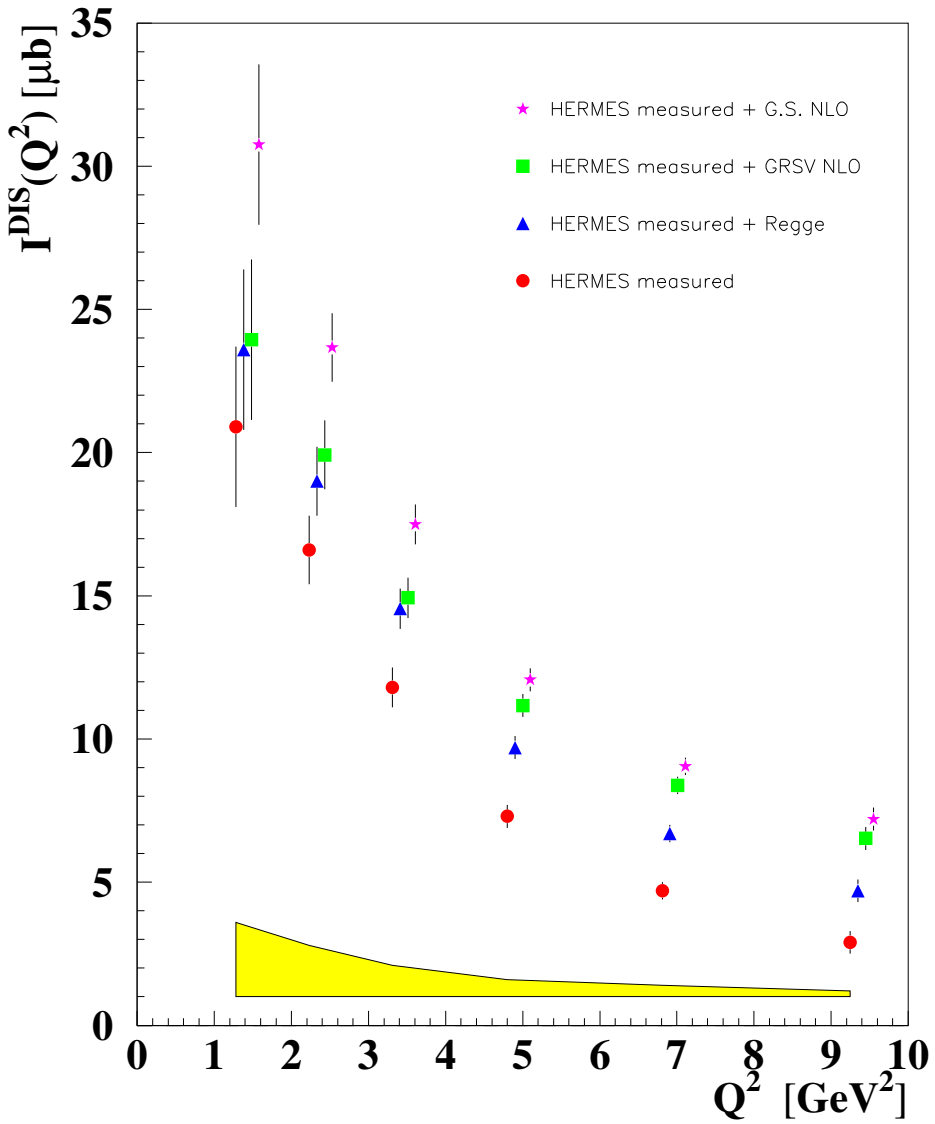
Comparison between data and NLO parameterisation :



The data are consistent with a QCD next-to-leading order fit based on previous deep-inelastic scattering data [M. Gluck *et al.*, *Phys. Rev.* **D 53 (1996) 6620**]

Generalised GDH integral for the proton

Data + different high energies extrapolations :



$$I^{\mathrm{DIS}}_{\mathrm{meas}}(Q^2) = \int_{\nu_0}^{23.5} [\sigma_{1/2} - \sigma_{3/2}] \frac{d\nu}{\nu}$$

$$I^{\mathrm{DIS}}(Q^2) = \int_{\nu_0}^{\infty} [\sigma_{1/2} - \sigma_{3/2}] \frac{d\nu}{\nu}$$

$\nu_0 \rightarrow$ due to W=1.8 GeV cut

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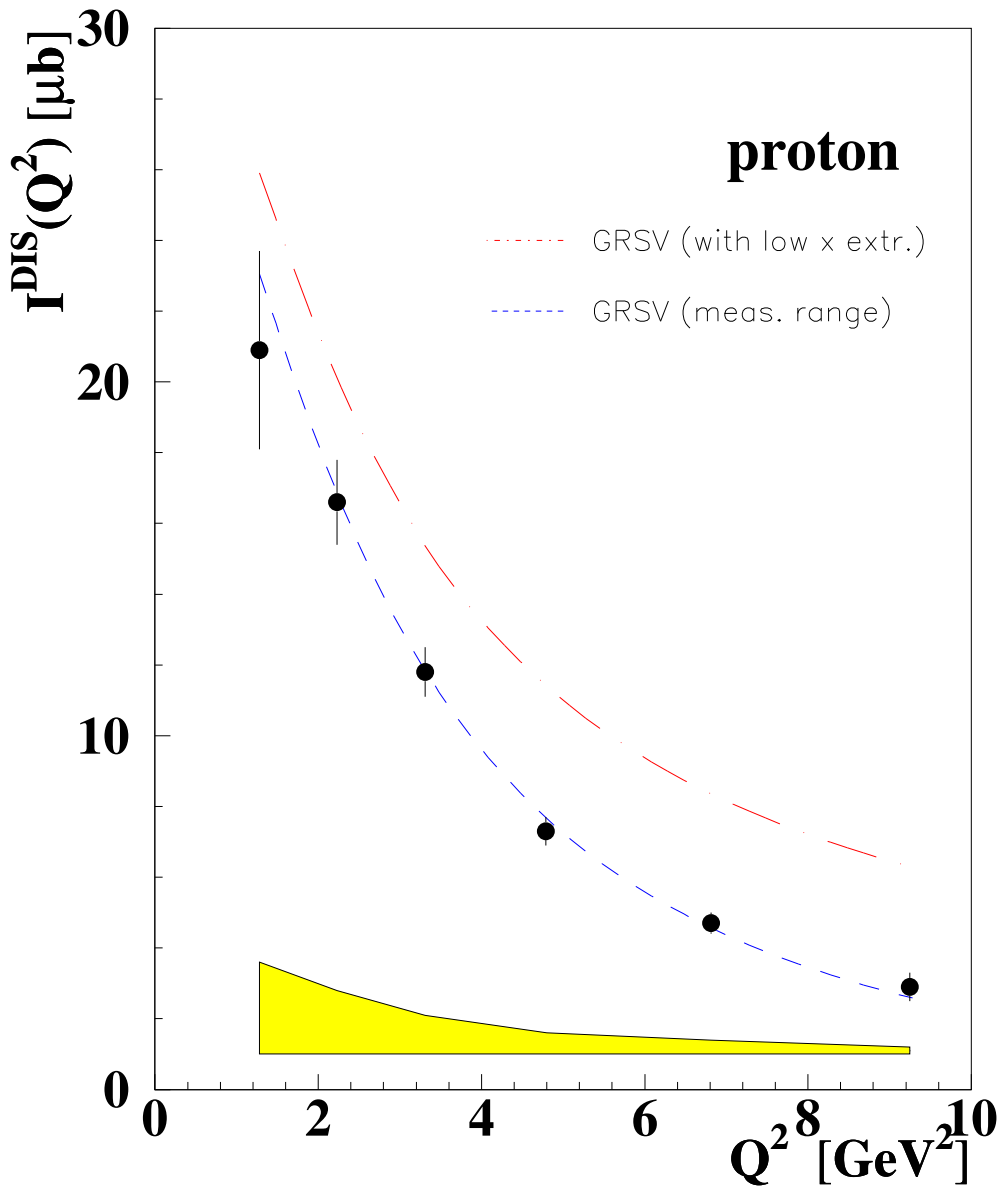
Generalised GDH integral for the proton

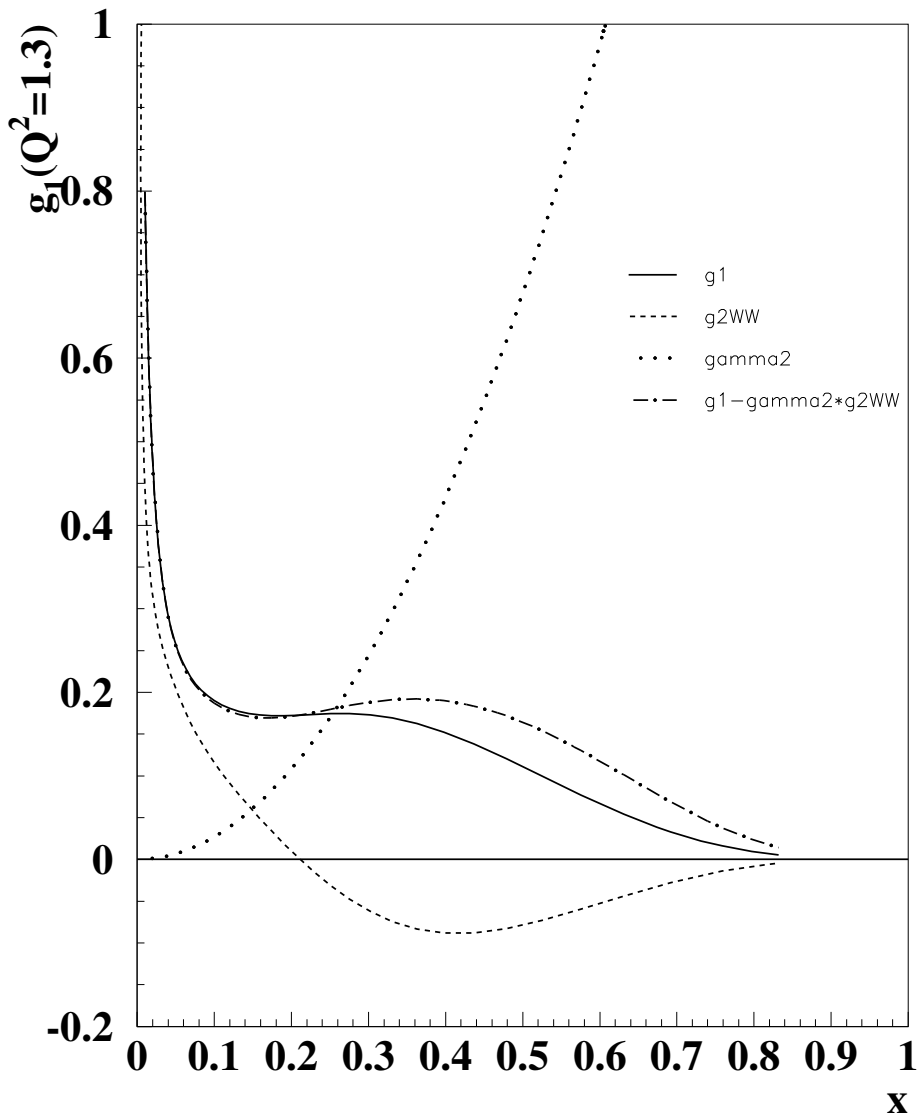
Comparison between data and NLO parameterisation :



The data are consistent with a QCD next-to-leading order fit based on previous deep-inelastic scattering data [M. Gluck *et al.*, Phys. Rev. **D 53** (1996) 6620]

Contribution of g_2 :

$$g_2^{\mathrm{WW}}(x,Q^2) = -g_1(x,Q^2) + \int_x^1 g_1(y,Q^2)\frac{dy}{y}$$

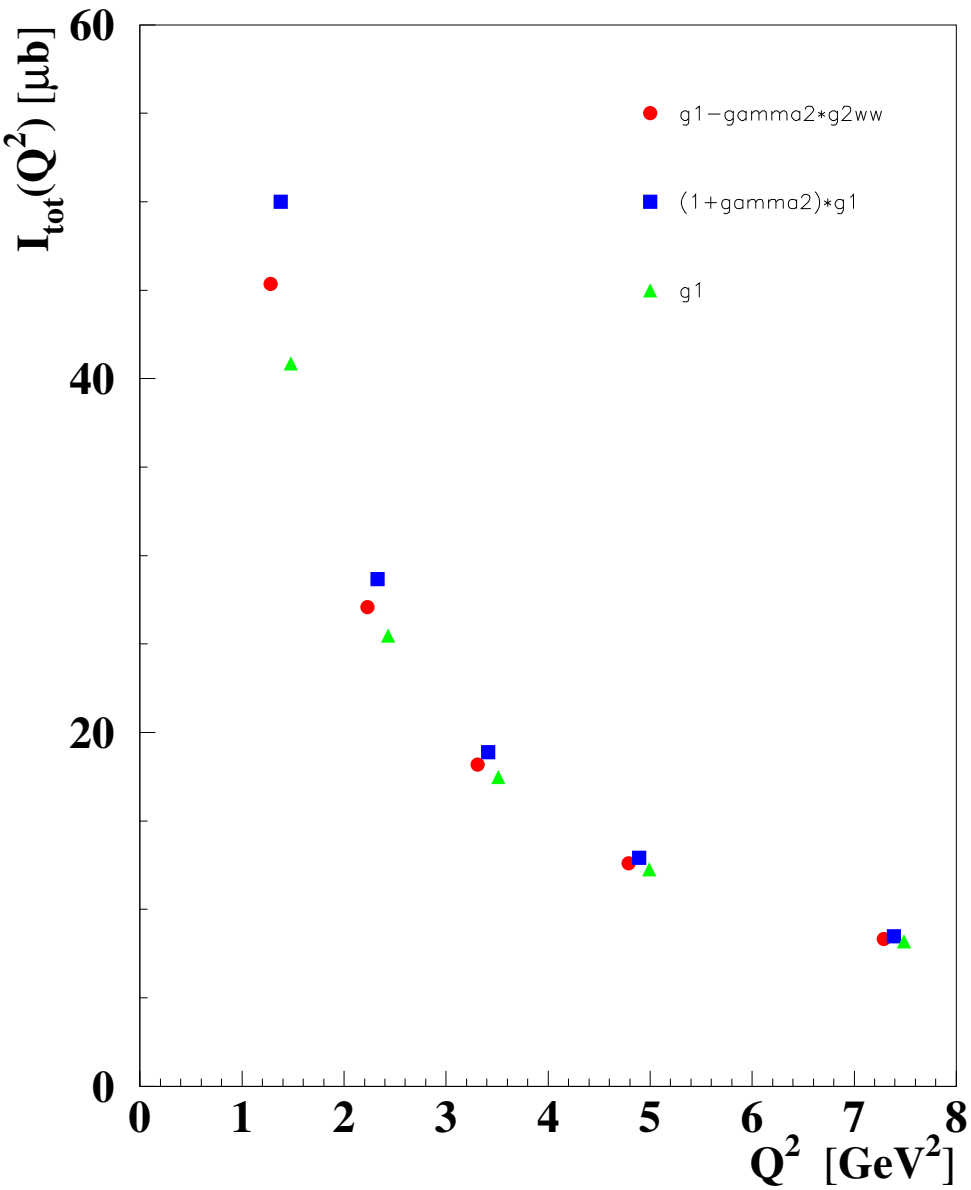


g_1^p from DGLAP NLO solution with G.S. parameterisation

[T. Gehrmann and W.J. Stirling, Phys. Rev. **D 53** (1996) 267, M. Hirai *et al.*, Comp. Phys. Comm. **108** (1998)]

$$I(Q^2) \equiv \int_{Q^2/2M}^{\infty} \left[\sigma_{1/2}(\nu, Q^2) - \sigma_{3/2}(\nu, Q^2)\right] \frac{d\nu}{\nu}$$

$$= \frac{8\pi^2\alpha}{M} \int_0^1 \frac{g_1(x, Q^2) - \gamma^2 g_2(x, Q^2)}{K} \frac{dx}{x}$$



The effect of g_2 is decreasing with Q^2 increasing:

20 % effect at $Q^2 = 1.3$ GeV^2

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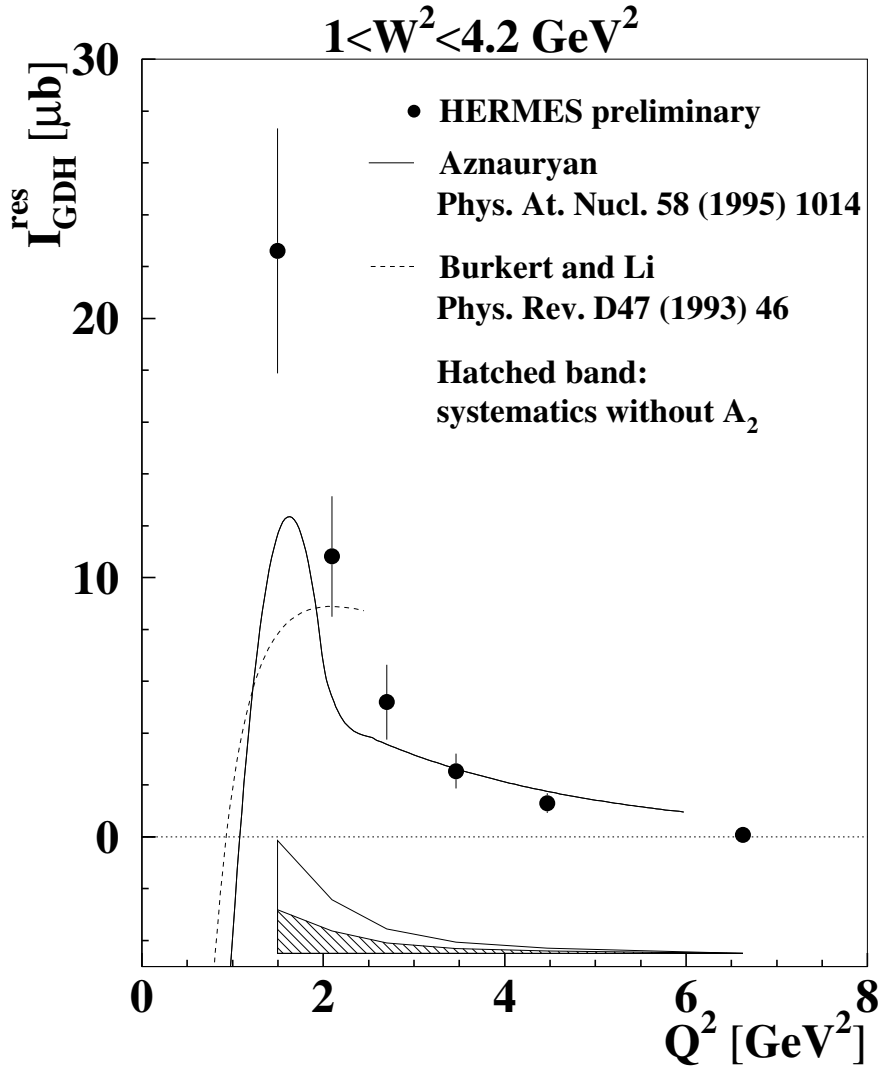
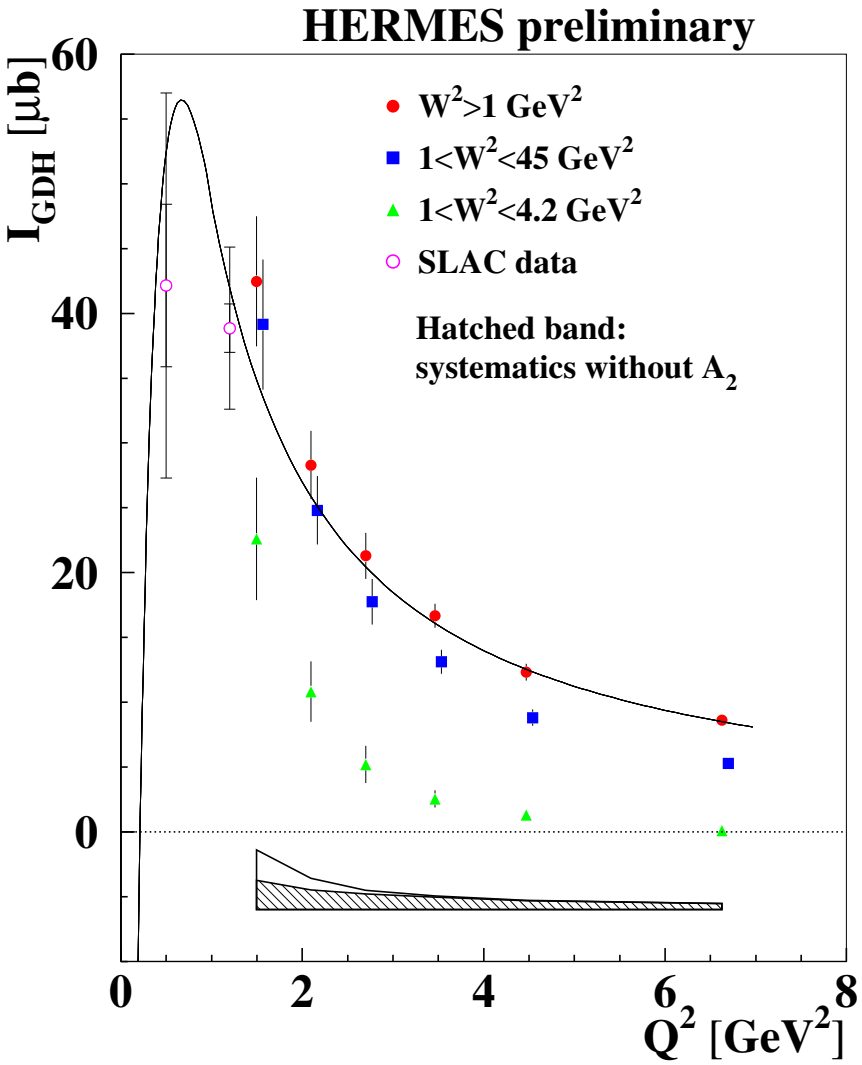
Resonance contribution to the GDH integral



- I^{res}_{GDH} strongly decrease with Q^2
  (strong reduction of the available x range for W^2 <4.2 GeV^2 as Q^2 increase)

- Comparison between models and data suggests that the resonance excitation models are not sufficient to well reproduce the experimental I^{res}_{GDH} for Q^2 >1.5 GeV^2

Combined results from Resonance and DIS re



- I_{GDH}^{res} small for Q^2 above 2 GeV^2
- SLAC result at Q^2=1.2 GeV^2 in agreement with the present data at lowest GeV^2
- Prediction in reasonable agreement with the experimental data
- I_{GDH} consistent with $1/Q^2$ law
- Q^2 behavior of I_{GDH} consistent with the pQCD evolution of the integral without considering any additional resonance or higher twist effect

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Conclusions

- High energy part is missing in ALL predictions and in ALL proposed experiments
- First direct determination of $I^{\rm DIS}(Q^2)$
- For Q^2 above 1 GeV^2 the results are at least of the same order of magnitude as expectations for the resonance part of $I(Q^2)$
- The data are consistent with a QCD next-to-leading order fit based on previous deep inelastic scattering data $\rightarrow$ higher twist effects are not significant even at the lowest measured Q^2
- I^{res}_{GDH} small for Q^2 above 2 GeV^2
- SLAC result at Q^2=1.2 GeV^2 in agreement with the present data at lowest GeV^2
- Prediction in reasonable agreement with the experimental data
- First determination of Q^2 dependence of GDH integral in both the resonance and DIS regions (Q^2 range 1.2$-$12 GeV^2)
- Total I_{GDH} shows a $1/Q^2$ behavior which supports the hypotesis of small modifications to the pQCD evolution of the integral due to resonance or higher twist effect in the whole Q^2 range
- The strong turn down of $I(Q^2)$ towards the real photon prediction of -204 μb should occur at Q^2 lower than 1.2 GeV^2