Small angle (Low Q^2) GDH sum rule experiments

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Outline:

- Sum rules, GDH, Bjorken, spin polarizability sum rules;
- Usefulness and context;
- Measurements (published, being analyzed, to come);
- What we learn practically;
- Perspectives.

The Gerasimov-Drell-Hearn Sum Rule

A **sum rule** is a *rule* (e.g. "=") that relates a *sum* (e.g. moment of structure functions) to a quantity characterizing the target.

GDH sum rule:

$$\frac{16\alpha\pi^2}{Q^2}\int_0^{1^-} g_1\, dx = \frac{-2\alpha\pi^2\,\kappa^2}{M^2}$$

First spin structure function

Bjorken scaling variable

anomalous magnetic moment

α: fine structure constant

Valid for any kind of target (nucleon, nuclei, ...).

The Gerasimov-Drell-Hearn Sum Rule

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$$\frac{16\alpha\pi^2}{Q^2}\int_0^{1^-} g_1\, dx = \frac{-2\alpha\pi^2\,\kappa^2}{M^2}$$

Originally derived for photo-absorption (Q^2=0) by Gerasimov, Drell, Hearn and others.

Generalized to Q^2>0 by Ji and Osborne: $\frac{16\alpha\pi^2}{Q^2}\int_0^{1^-} g_1\, dx = 2\alpha\pi^2 S_1$ ← spin-dep. DDVCS

Famous Bjorken sum rule is one aspect of generalized GDH sum rule:

At large Q^2: GDH(proton)-GDH(neutron) $\propto Q^2 \times$ Bjorken Sum Rule

$$\int g_1^{p} - g_1^{n} dx = \frac{1}{6} g_a\left(1 + \frac{\alpha_s(\ln(Q^2))}{\pi} + \ldots\right) + \ldots$$

Spin polarizabilities sum rules

A **sum rule** is a *rule* (e.g. "=") that relates a *sum* (e.g. moment(s) of structure function) to a quantity characterizing the target.

Sum rules with higher moments exist, e.g. spin polarizabilities sum rules:

Generalized forward spin polarizability:

$$\gamma_0 = \frac{4e^2M^2}{\pi Q^6} \int x^2\left(g_1 - \frac{4M^2}{Q^2}\, x^2 g_2\right)dx$$

Longitudinal-Transverse polarizability:

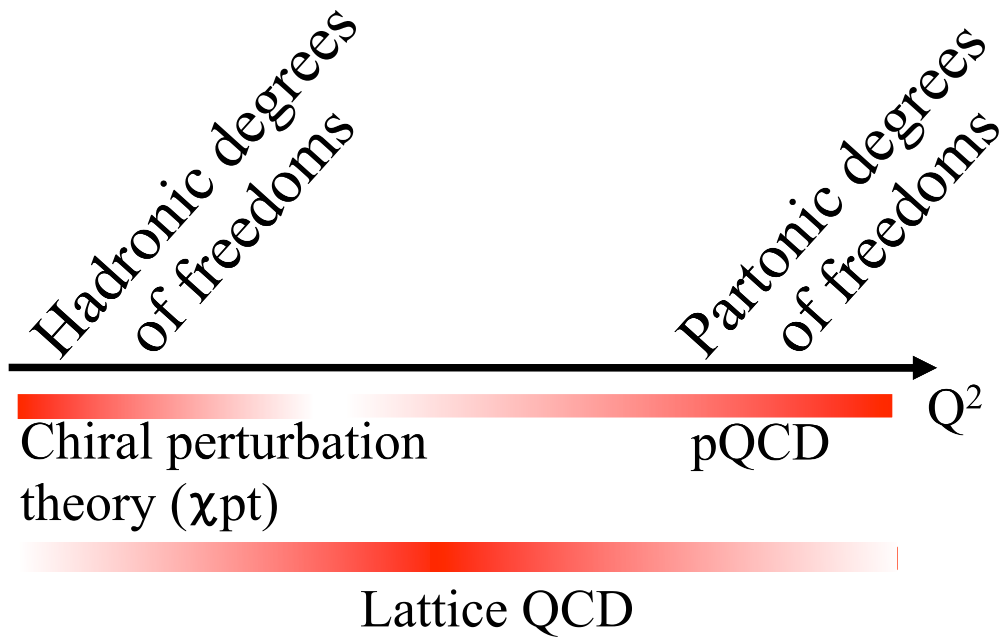
$$\delta_{LT} = \frac{4e^2M^2}{\pi Q^6} \int x^2(g_1+g_2)dx$$

x^2-weighting favors the large-x reactions (resonances, important at low Q^2).

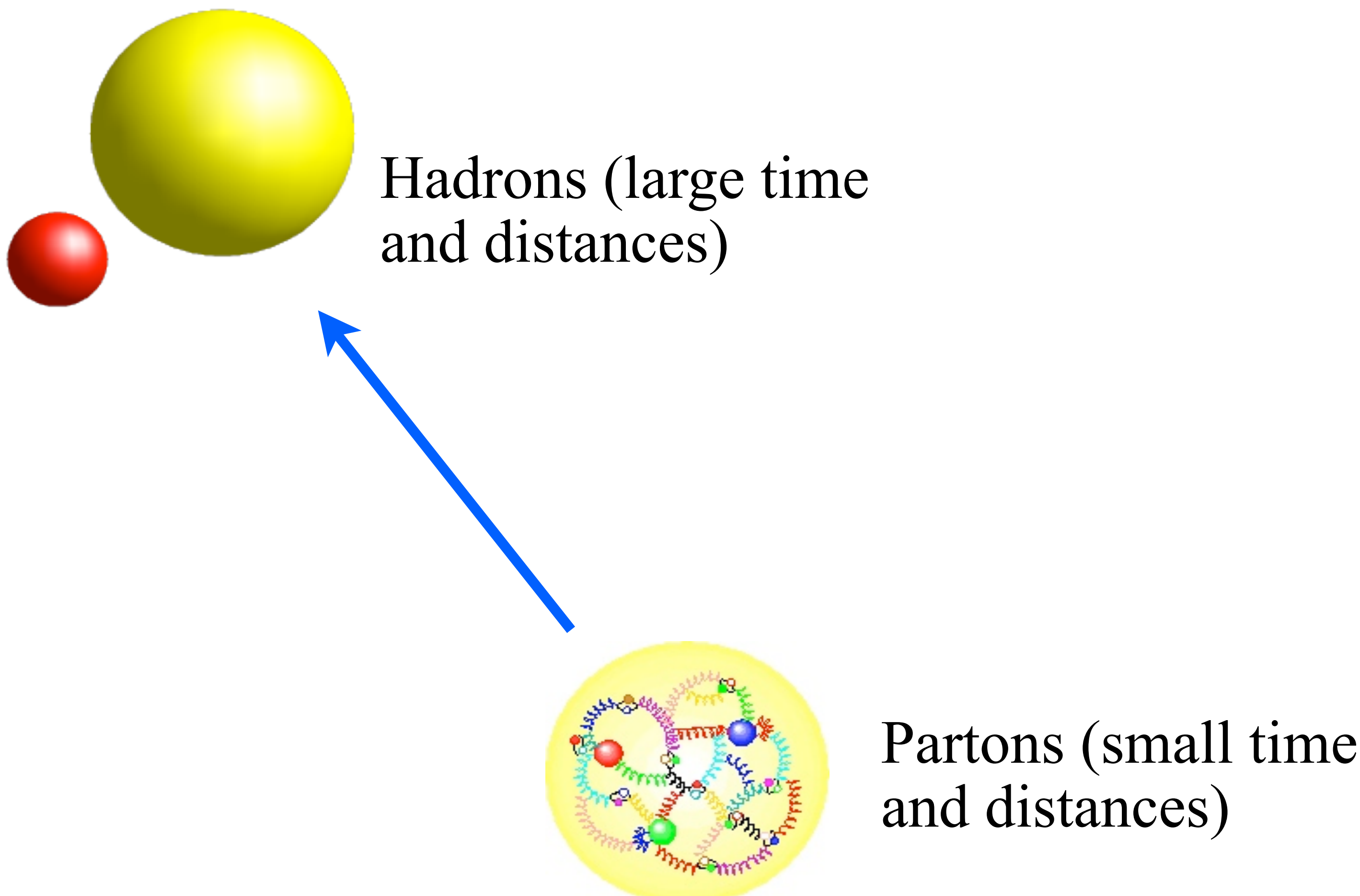
Interest of the generalized GDH sum rule

Sum rule valid at all Q^2:

We can measure $\int g_1 \, dx$ at different Q^2 and compute the right hand side of the sum rule using different technics:

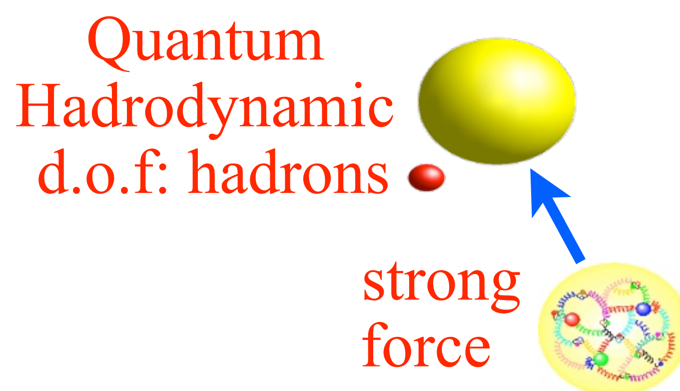


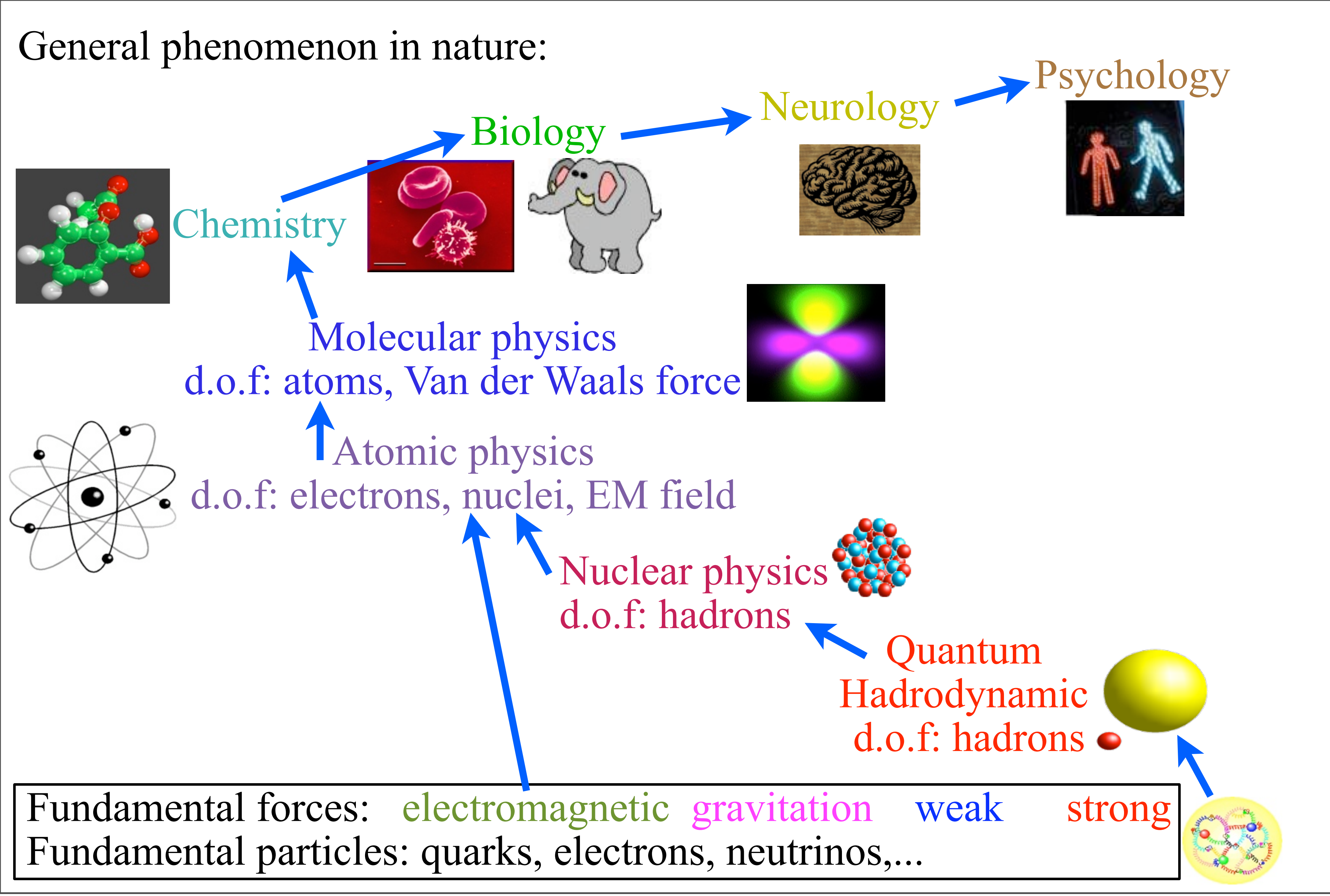
⇒Study transition from hadronic to partonic description of strong interaction i.e. study how effective degrees of freedom (hadrons) emerge from fundamental ones (partons).



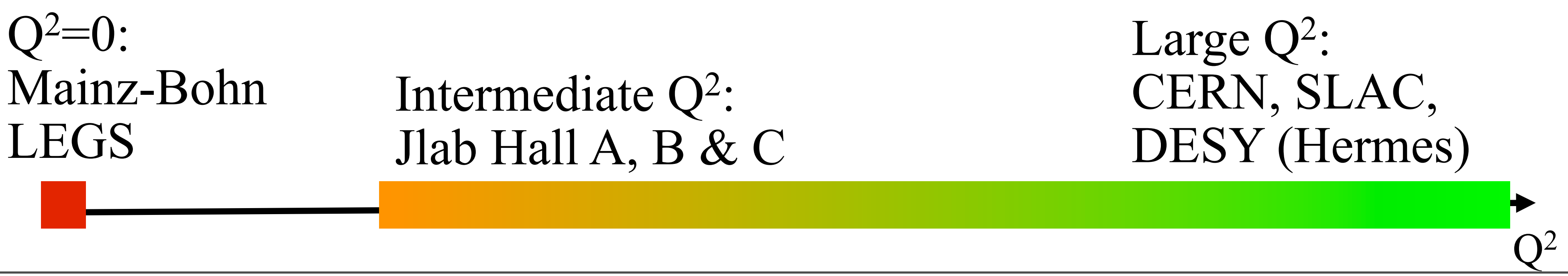
This is a general phenomenon in nature: When complexity makes the basic degrees of freedom to cumbersome to use, effective ones are used.

In addition to their practicality, effective descriptions provide a legitimate description of nature as long a the connection to the basic description is understood.




General phenomenon in nature:
Psychology
Neurology
Biology
Chemistry
Molecular physics
d.o.f: atoms, Van der Waals force
Atomic physics
d.o.f: electrons, nuclei, EM field
Nuclear physics
d.o.f: hadrons
Quantum
Hadrodynamic
d.o.f: hadrons
Fundamental forces: electromagnetic gravitation weak strong
Fundamental particles: quarks, electrons, neutrinos,...

Existing data



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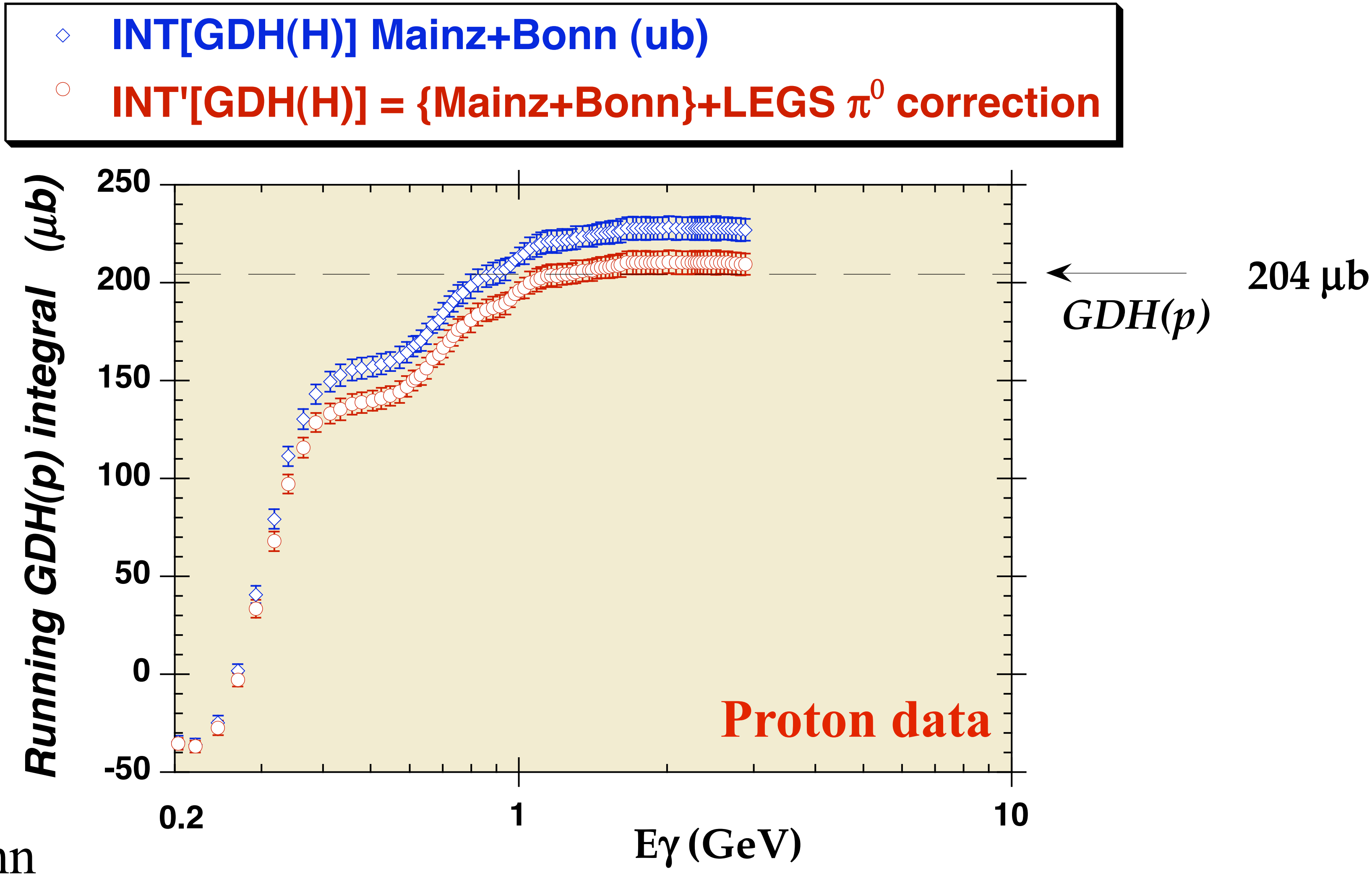


Q^2=0:
Mainz-Bohn
LEGS

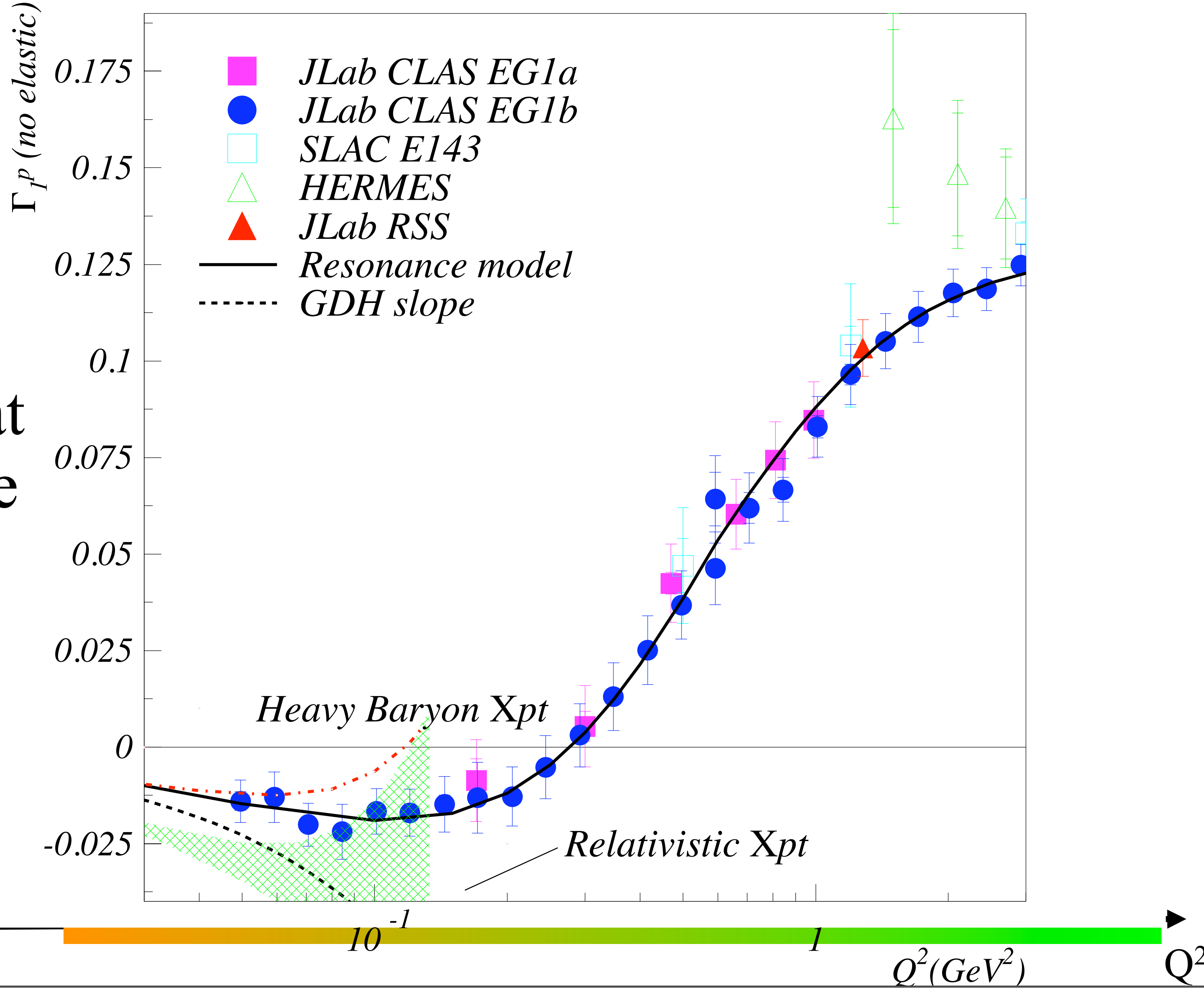
GDHp [combined Mainz+Bonn+LEGS]
= 208 ±6(stat) ± 14(sys) μb

PRL **102**, 172002(09)

Q^2

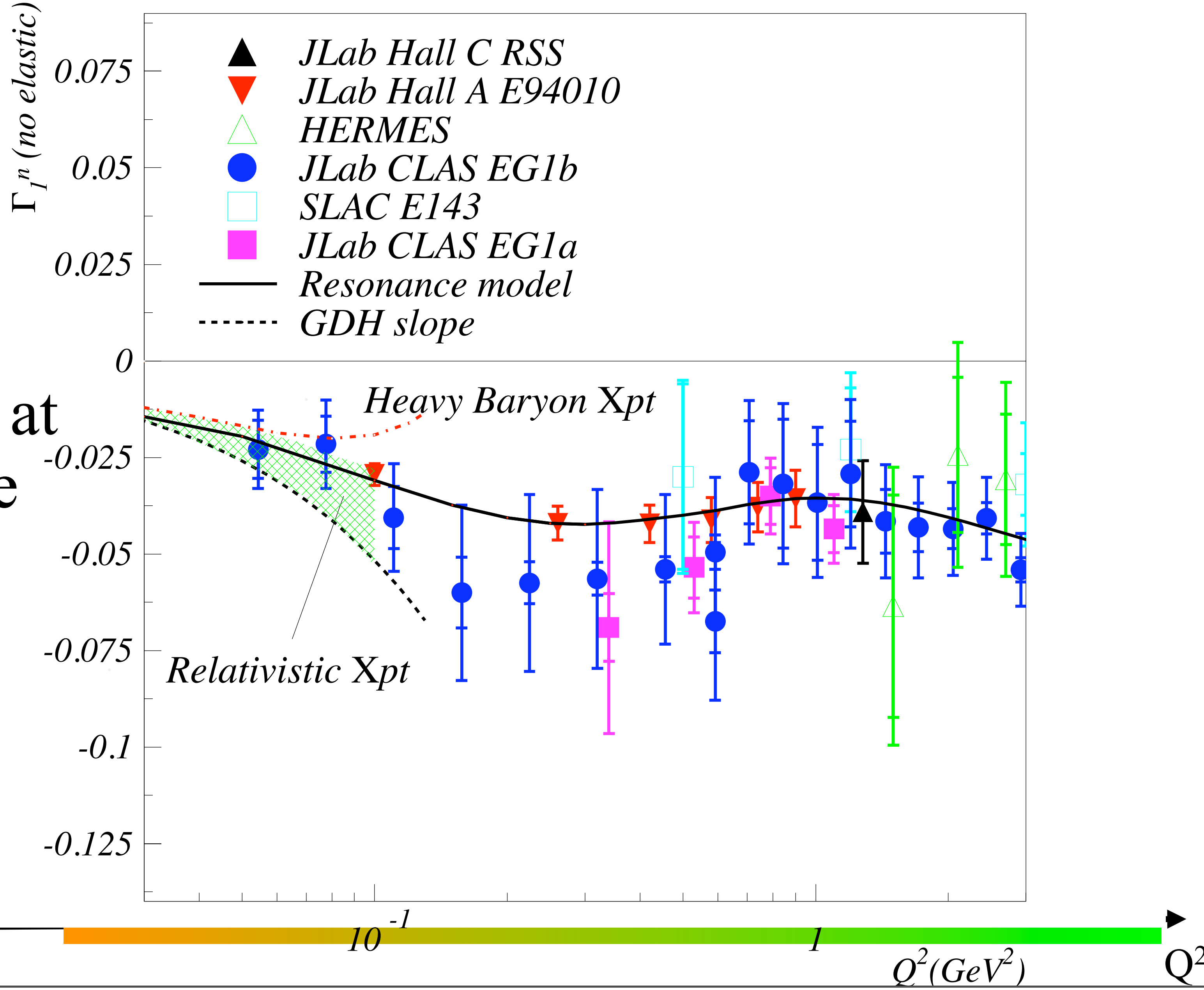
Existing data

$\int g_1 \, dx$ on **proton** at intermediate Q^2.



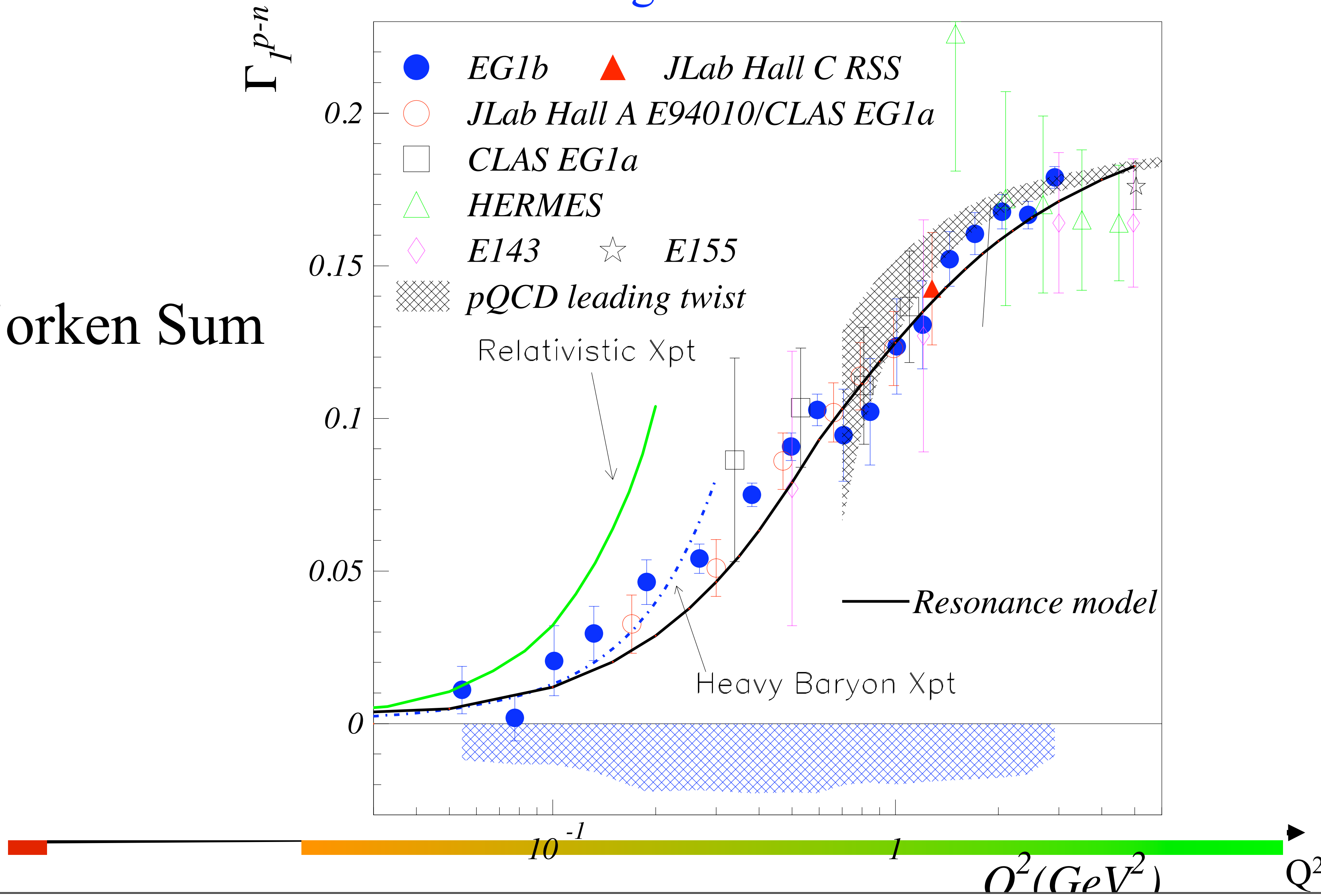
Existing data

$\int g_1\,dx$ on **neutron** at intermediate Q^2.



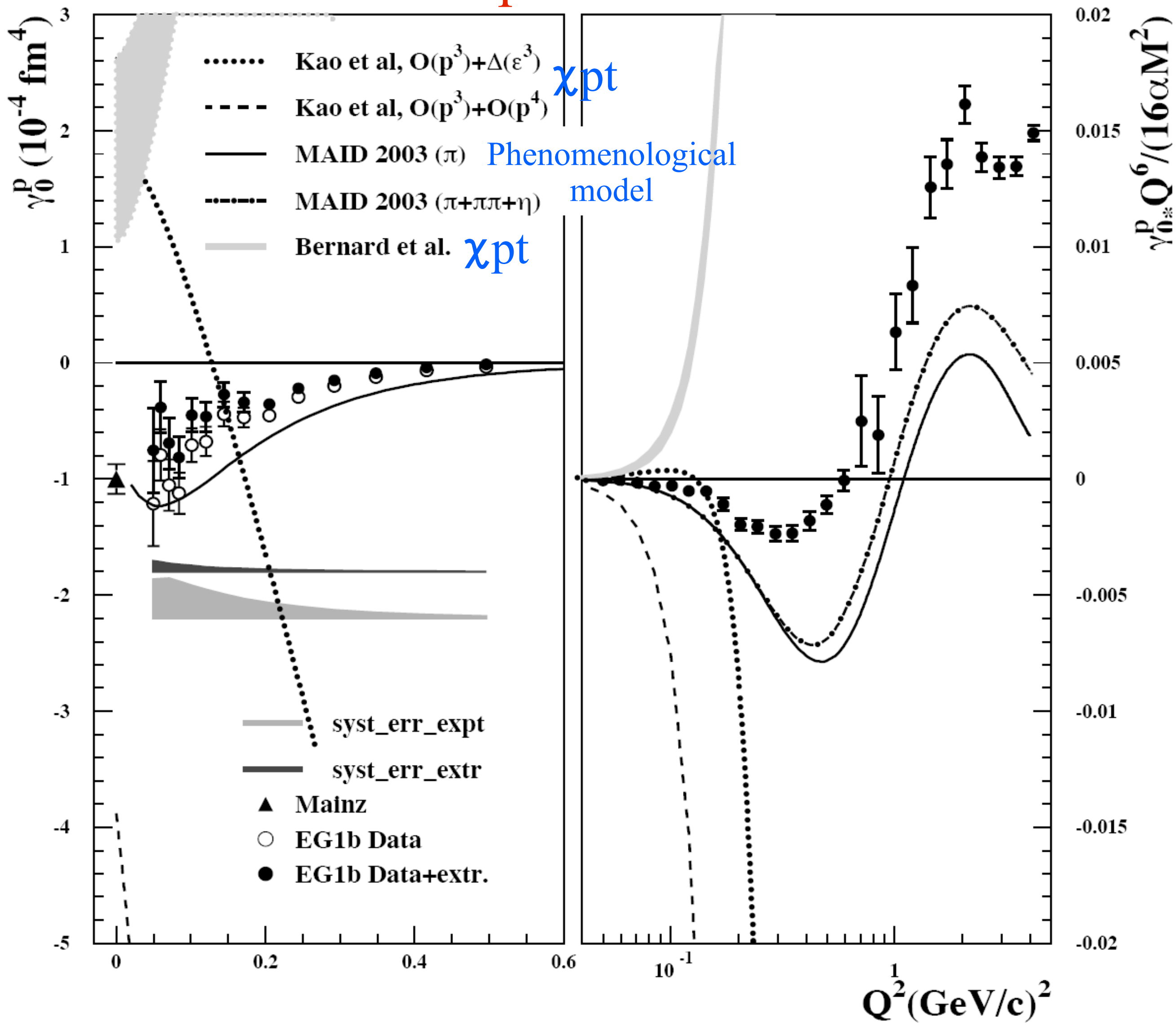
Existing data

Bjorken Sum



Existing data

Spin Polarizabilities

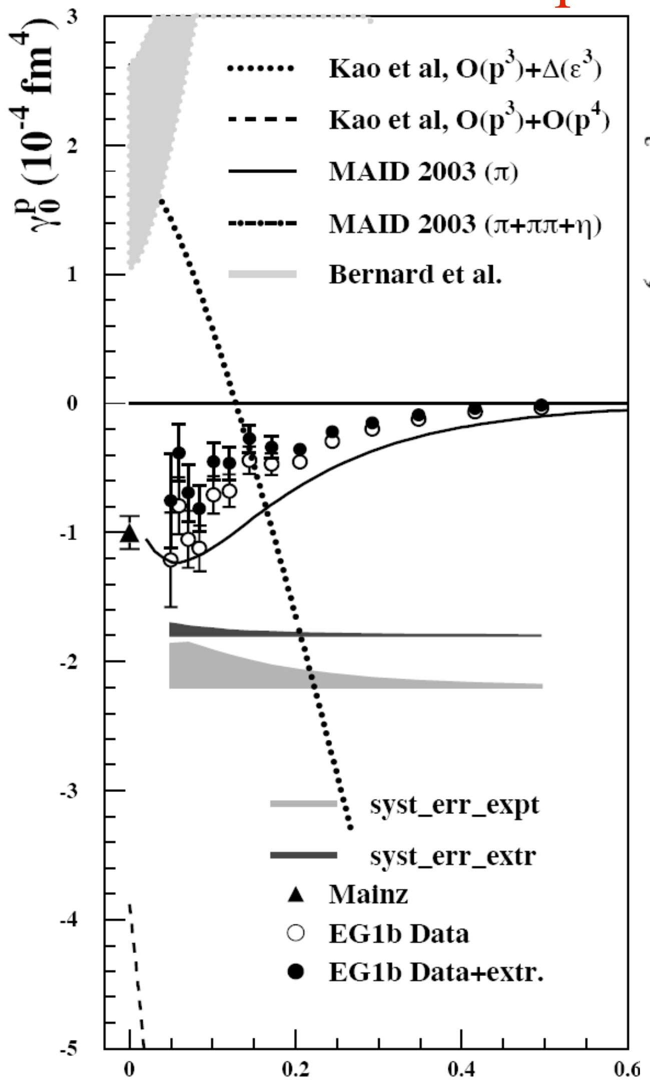


Large Q^2:
CERN, SLAC,
DESY (Hermes)

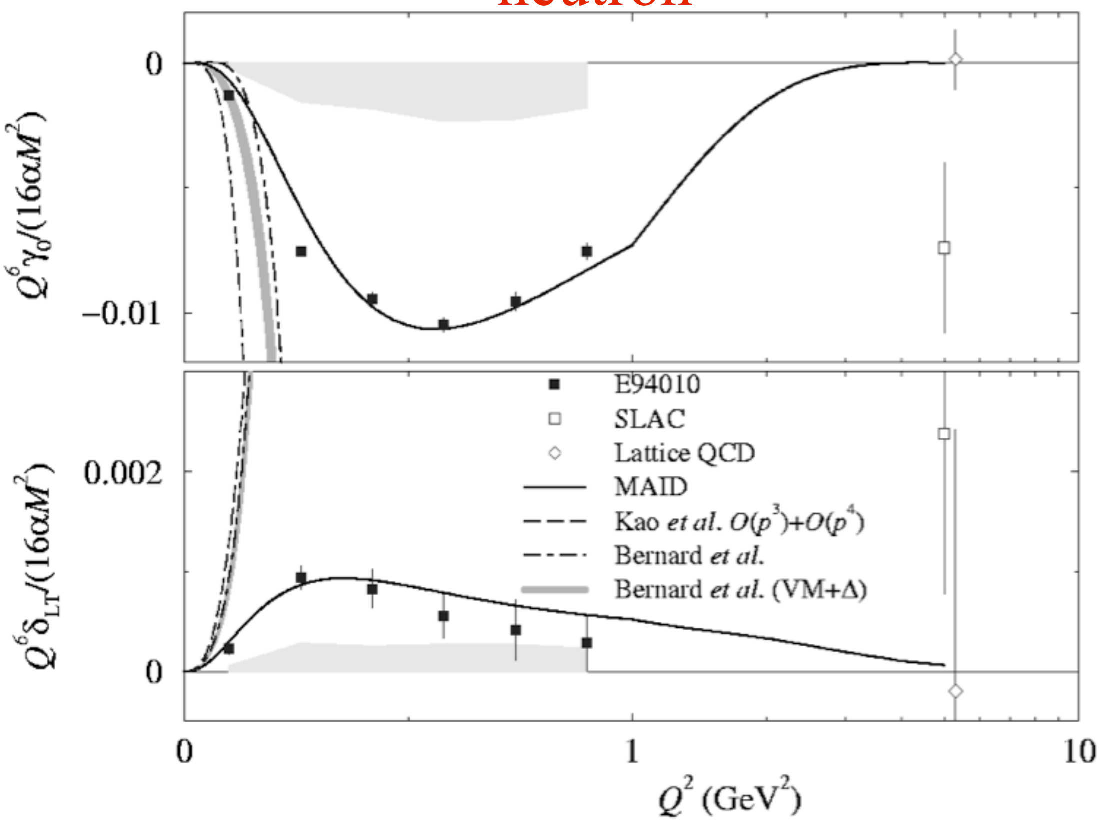
Existing data

Spin Polarizabilities

proton



neutron



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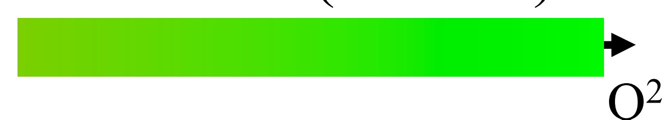
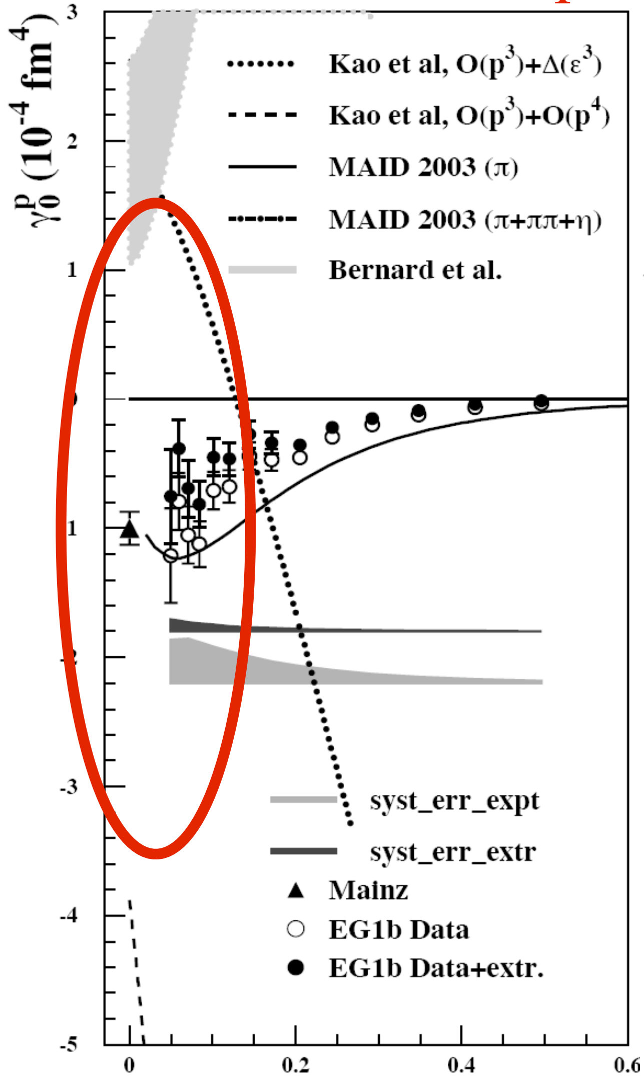


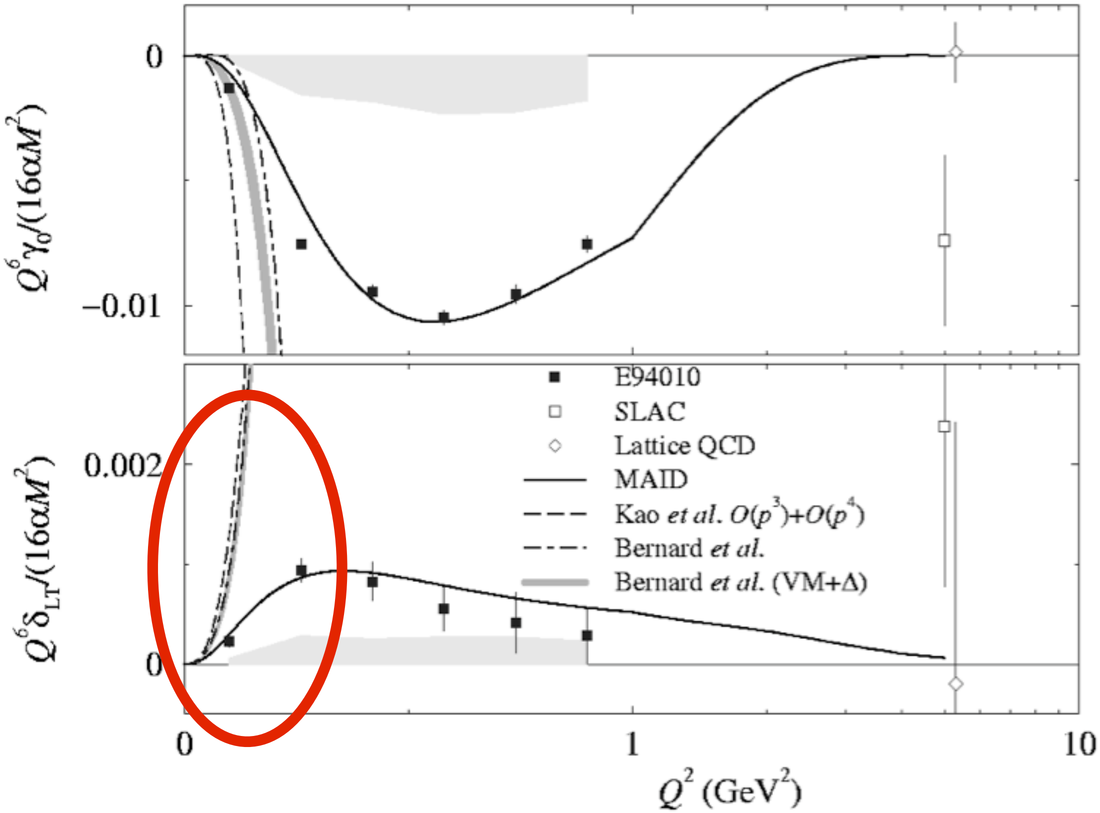
Existing data

Spin Polarizabilities

proton



neutron



Large Q^2:
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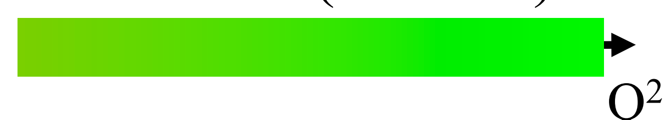
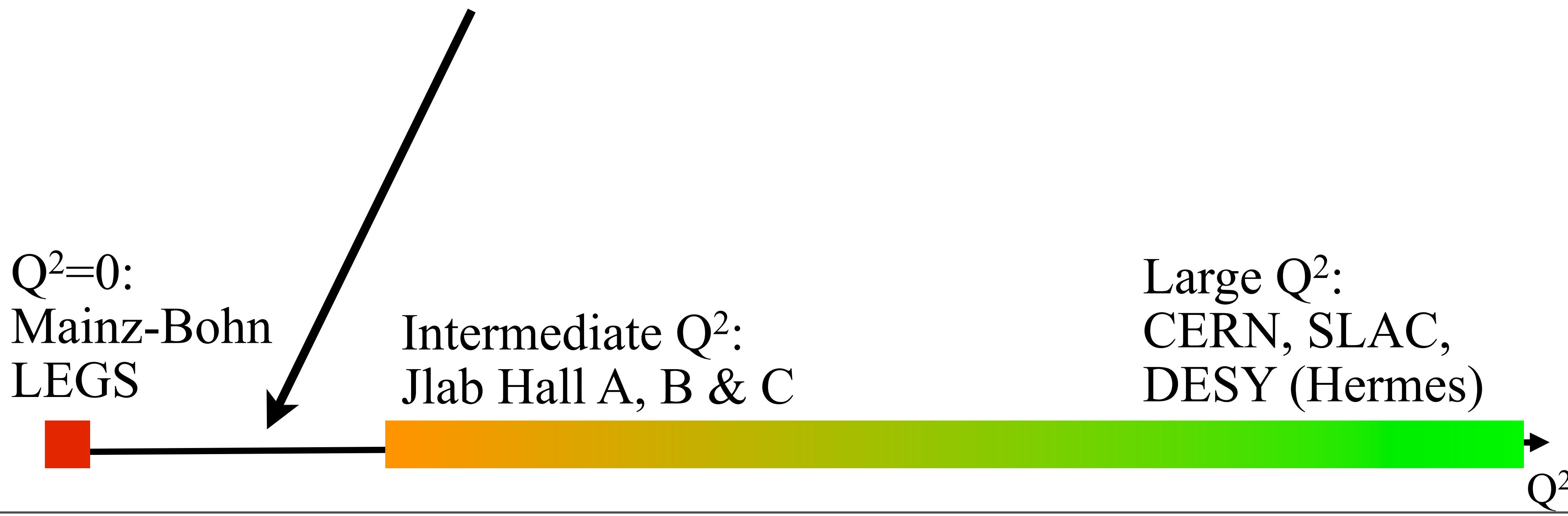


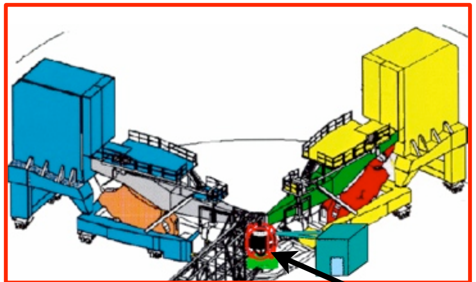
GDH at low Q^2 in:

- Hall A: E97110, neutron(^{3}He)
- Hall B: EG4, proton & neutron(D)

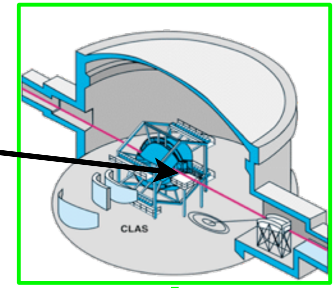
Upcoming results
bridge the gap:



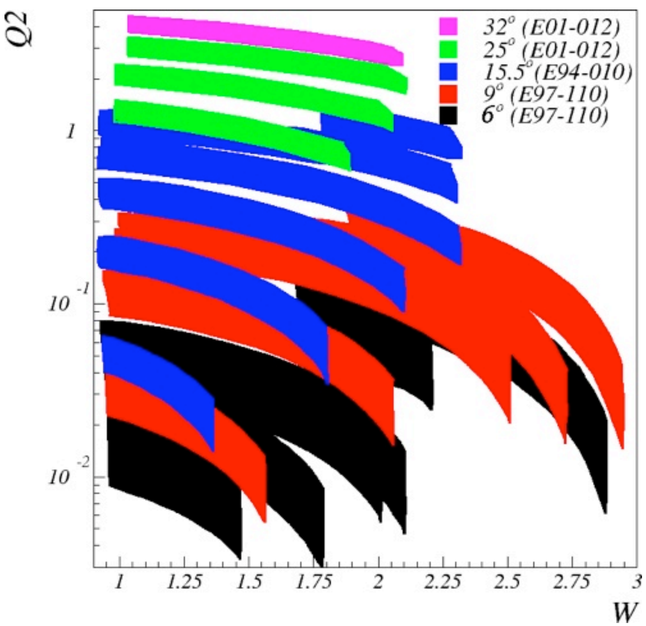
Kinematic coverage



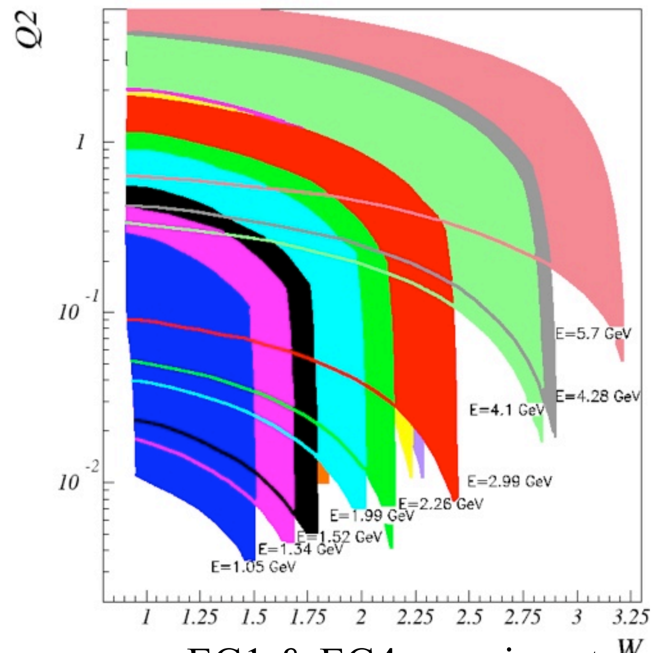
Polarized
^{3}He target



Polarized
NH_3 and
ND_3 targets

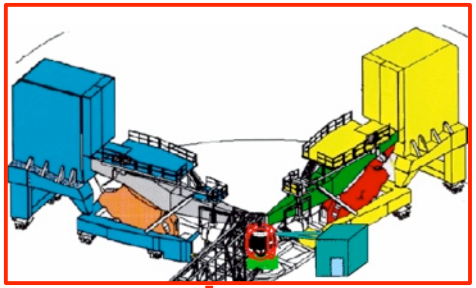


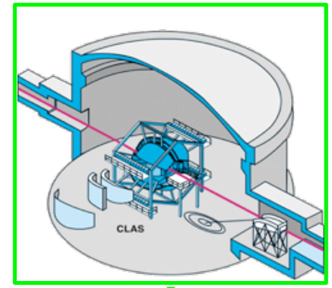
E94-010 E97-110 & E01012 experiments

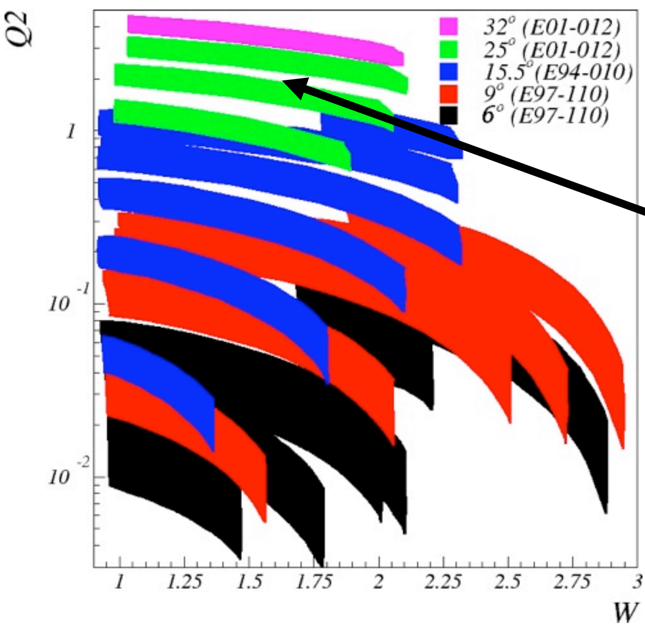


EG1 & EG4 experiments

Kinematic coverage

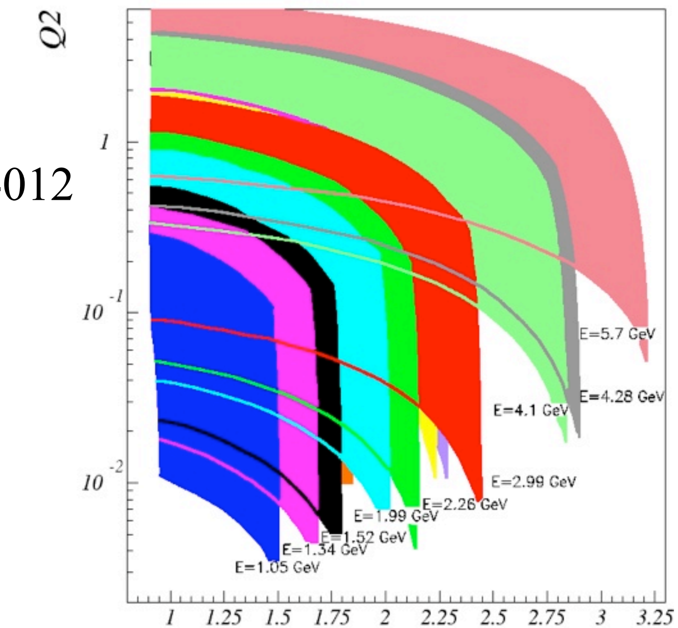






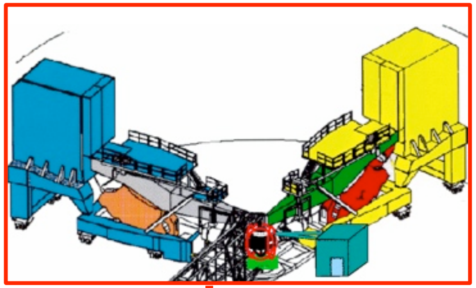
Experiment E01-012 (Spin-Duality)

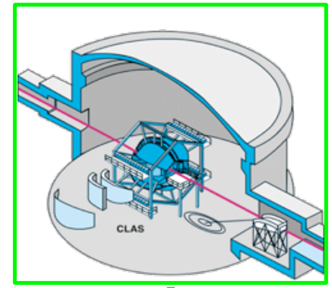
E94-010 E97-110 & E01012 experiments

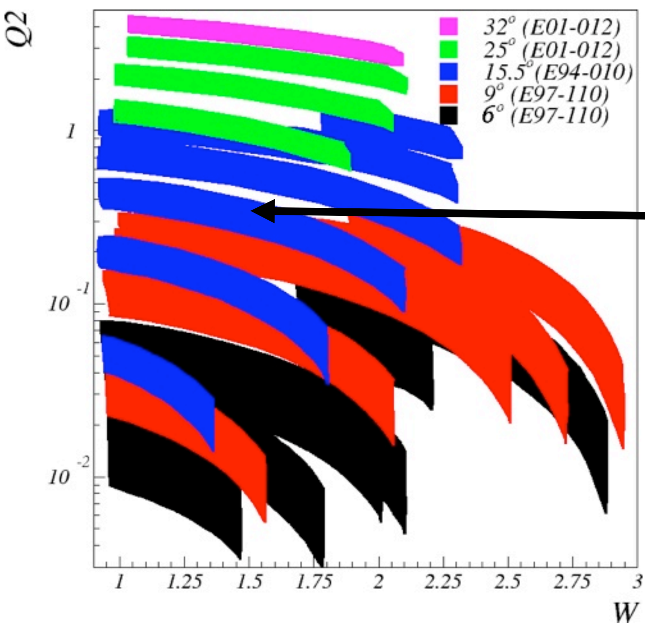


EG1 & EG4 experiments

Kinematic coverage

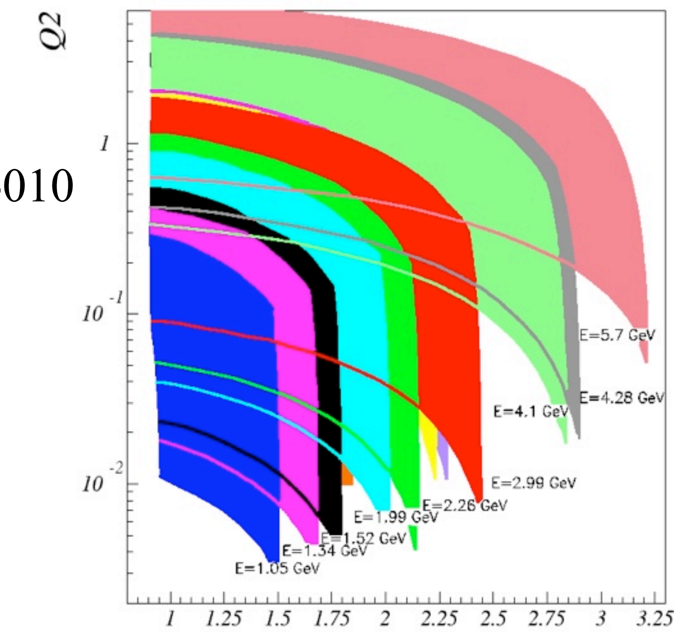






Experiment E94-010

E94-010 E97-110 & E01012 experiments



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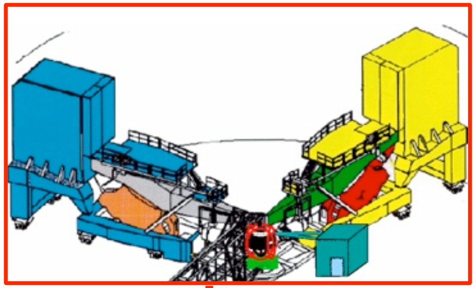
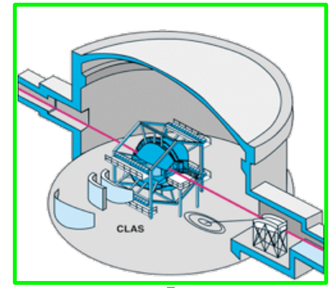
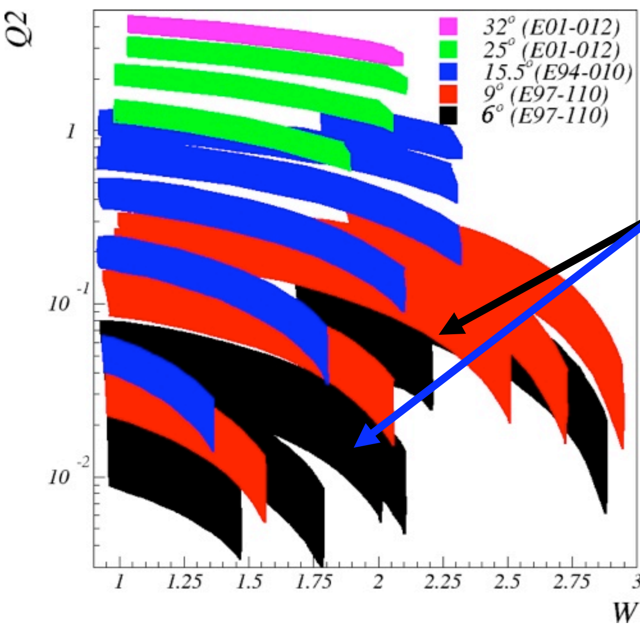
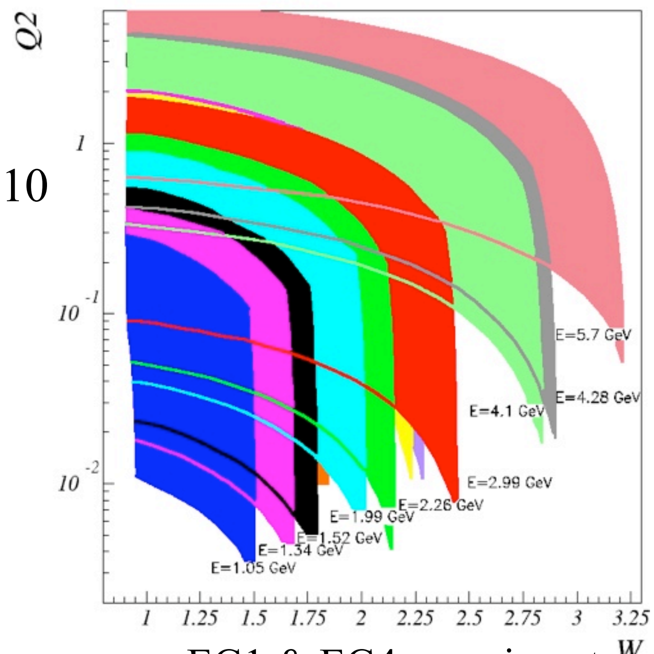






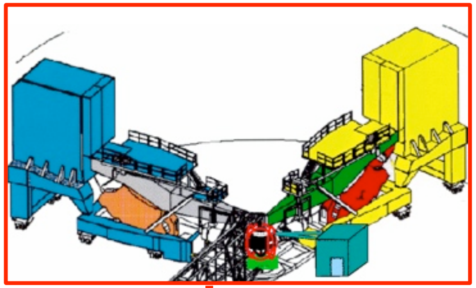
Experiment E97-110

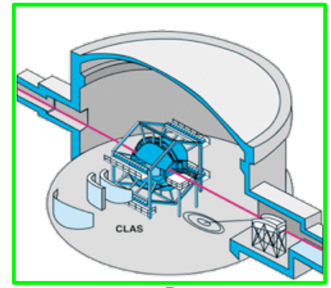
E94-010 E97-110 & E01012 experiments



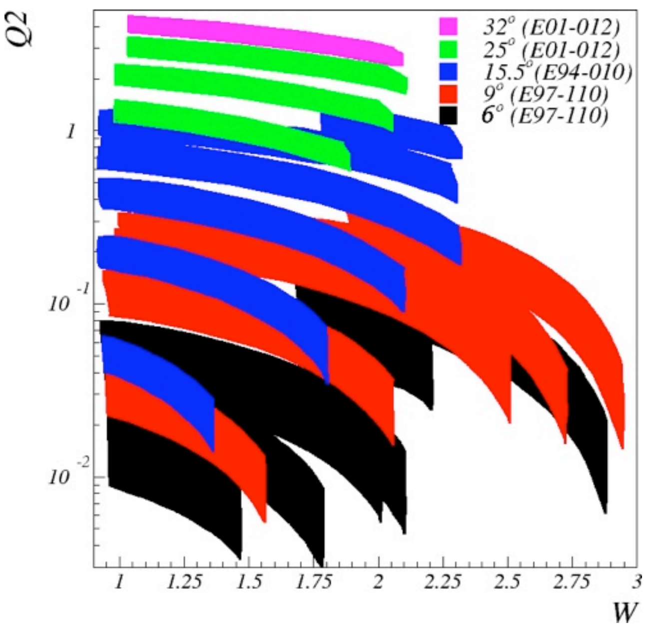
EG1 & EG4 experiments

Kinematic coverage





Experiment Group EG1:
NH_3 & ND_3



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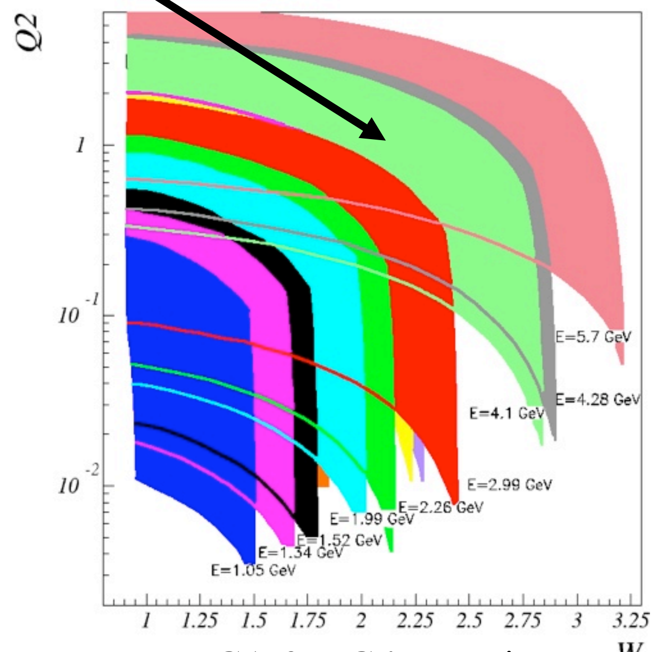
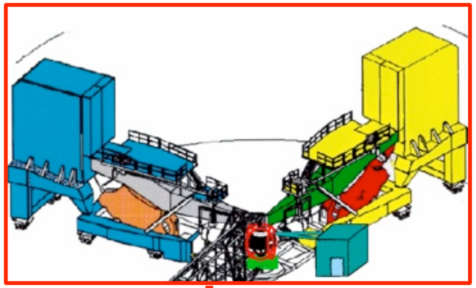
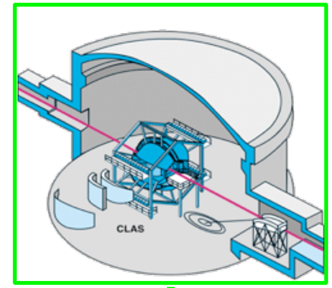


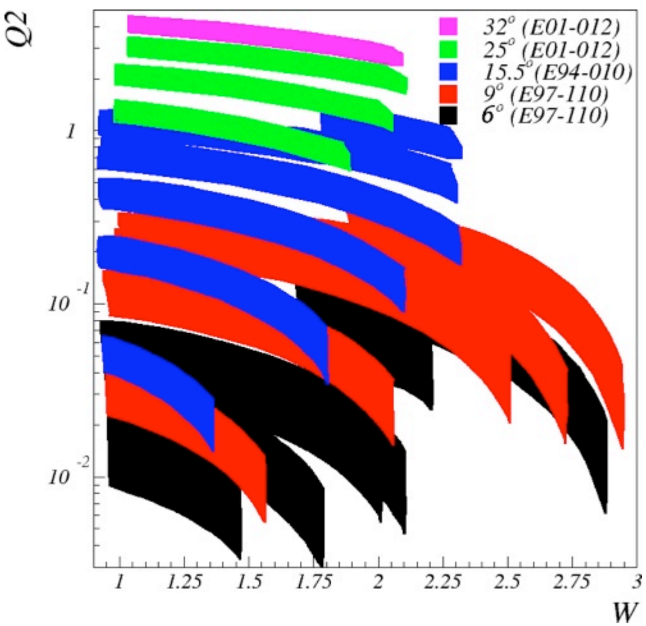
EG1 & EG4 experiments

Kinematic coverage

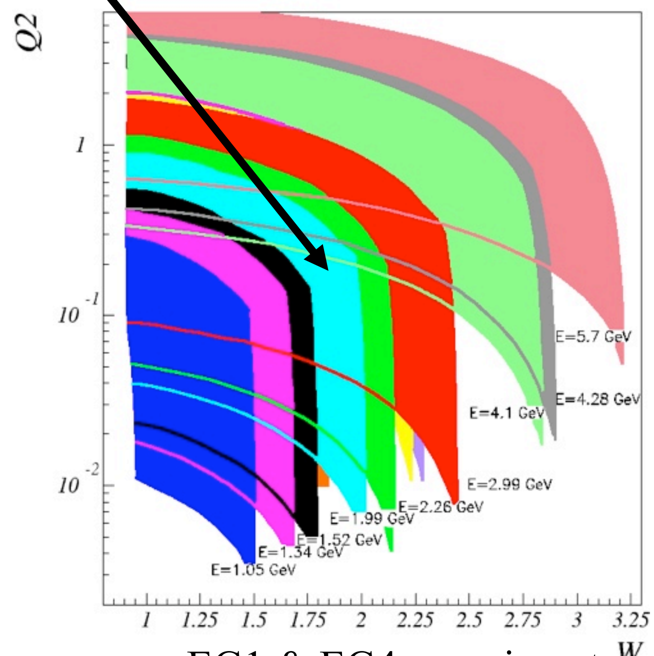


Experiment Group EG4:
NH_3 & ND_3





E94-010 E97-110 & E01012 experiments



EG1 & EG4 experiments

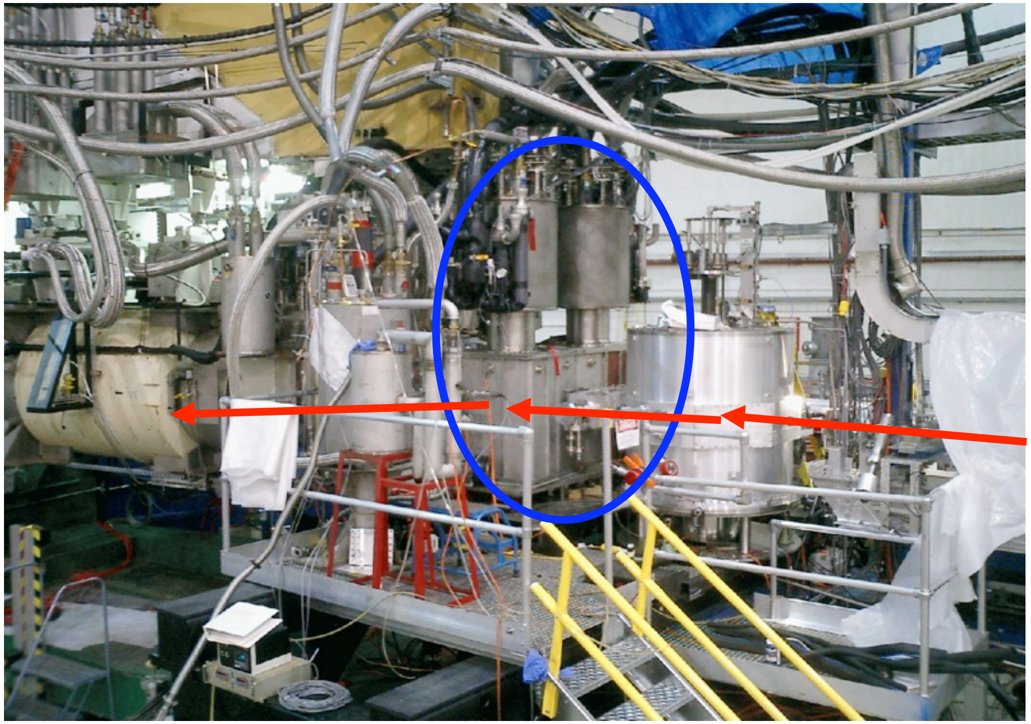
Going to low Q^2

Low Q^2 : $\begin{cases} \text{low beam energy} \\ \text{and/or} \\ \text{forward angle} \end{cases}$

Because we need integrals, our only choice is to work at forward angles.

In Hall A:

Septum magnets:



Going to low Q^2

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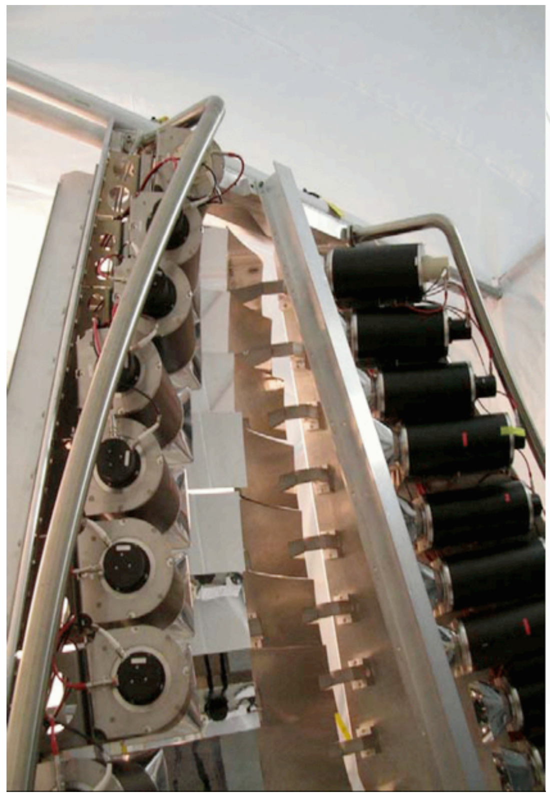
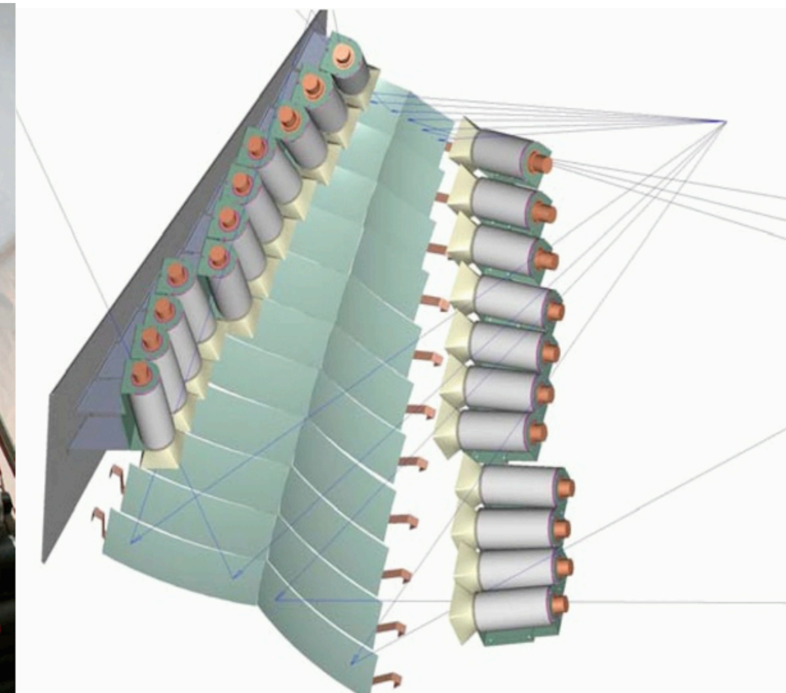
and/or
forward angle

Because we need integrals, our only choice is to work at forward angles.

In Hall B:

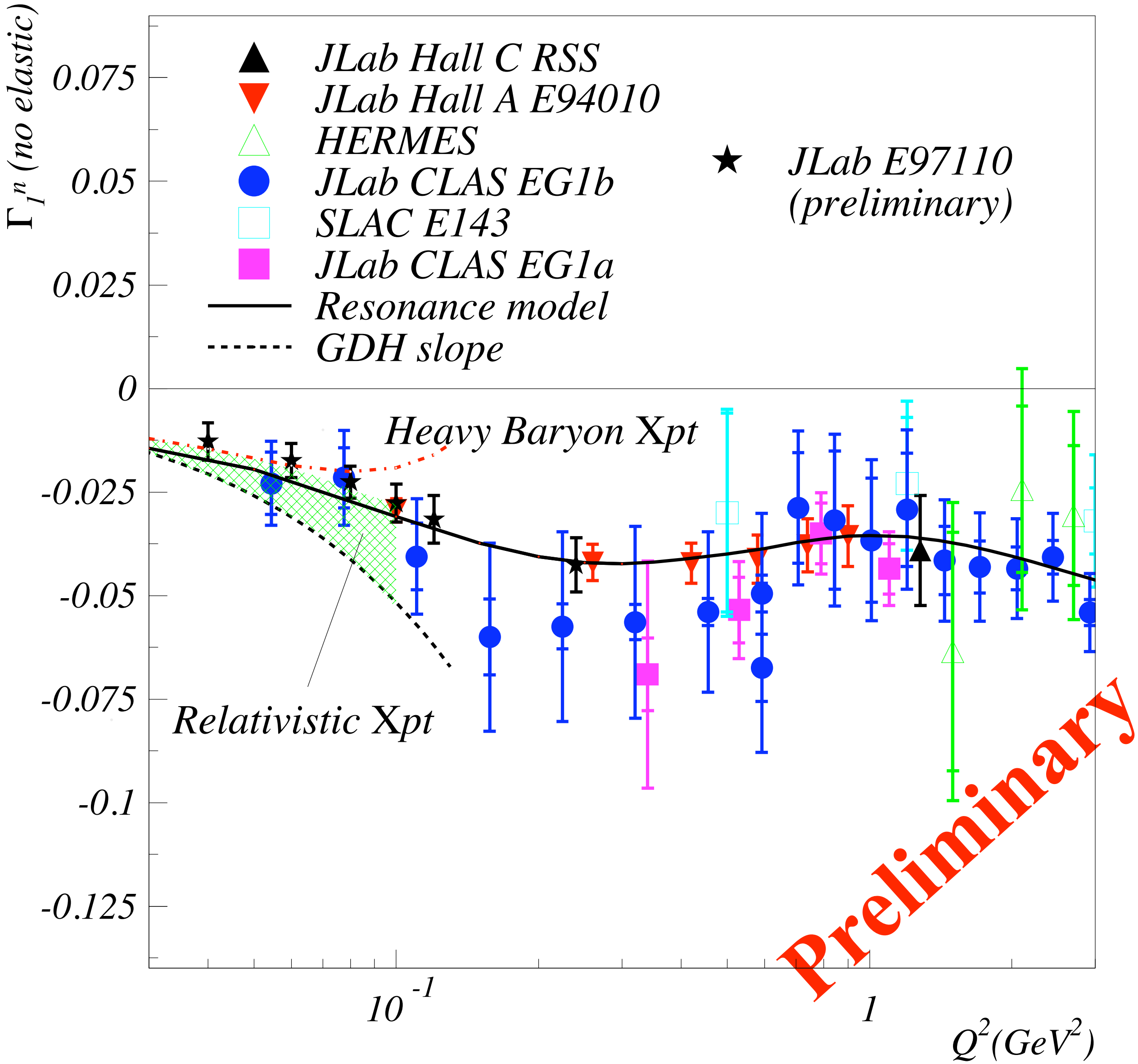
New Cerenkov detector:





Preliminary results on $\int g_1\,dx$

Hall A (neutron):

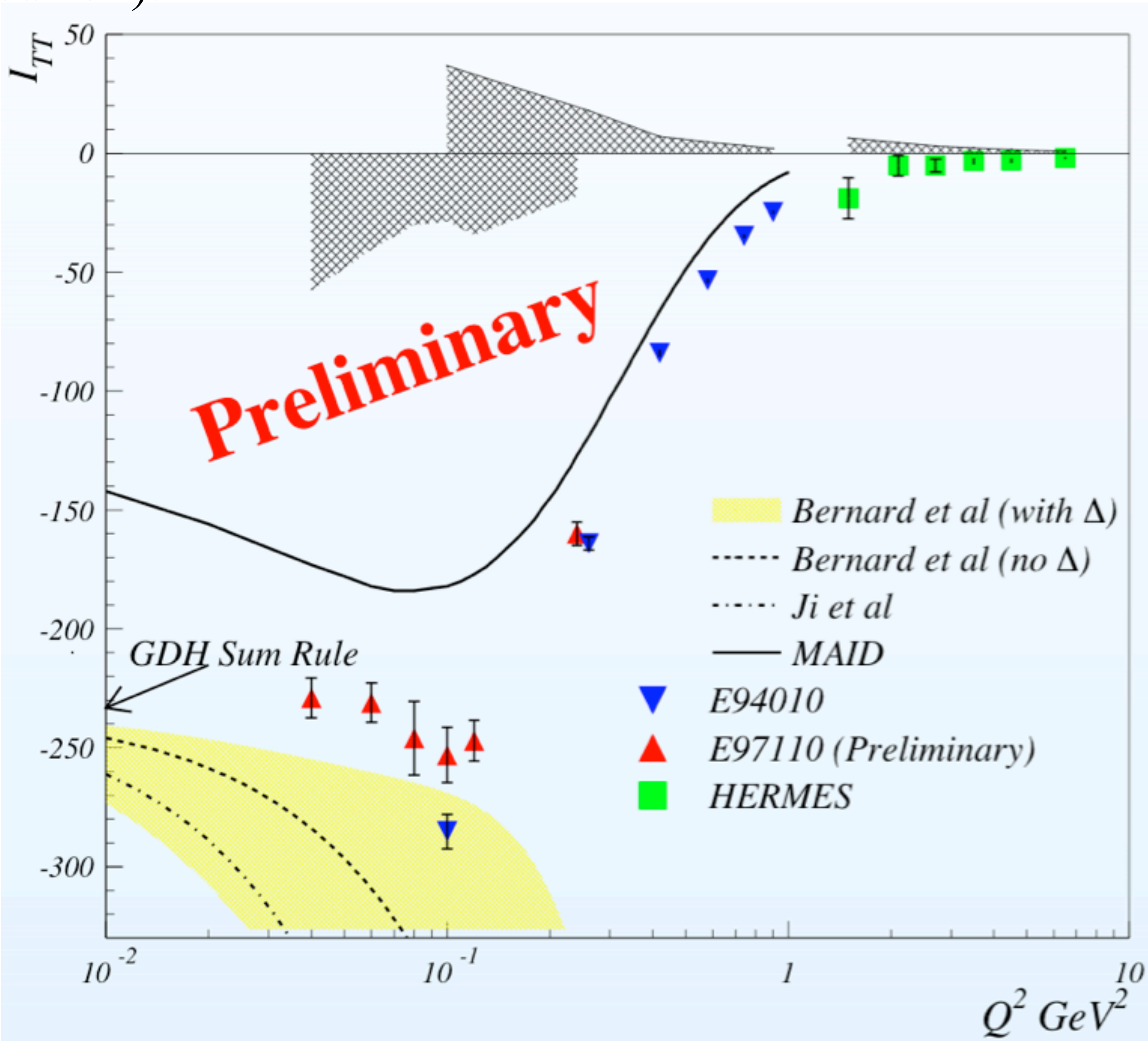


Remaining tasks:

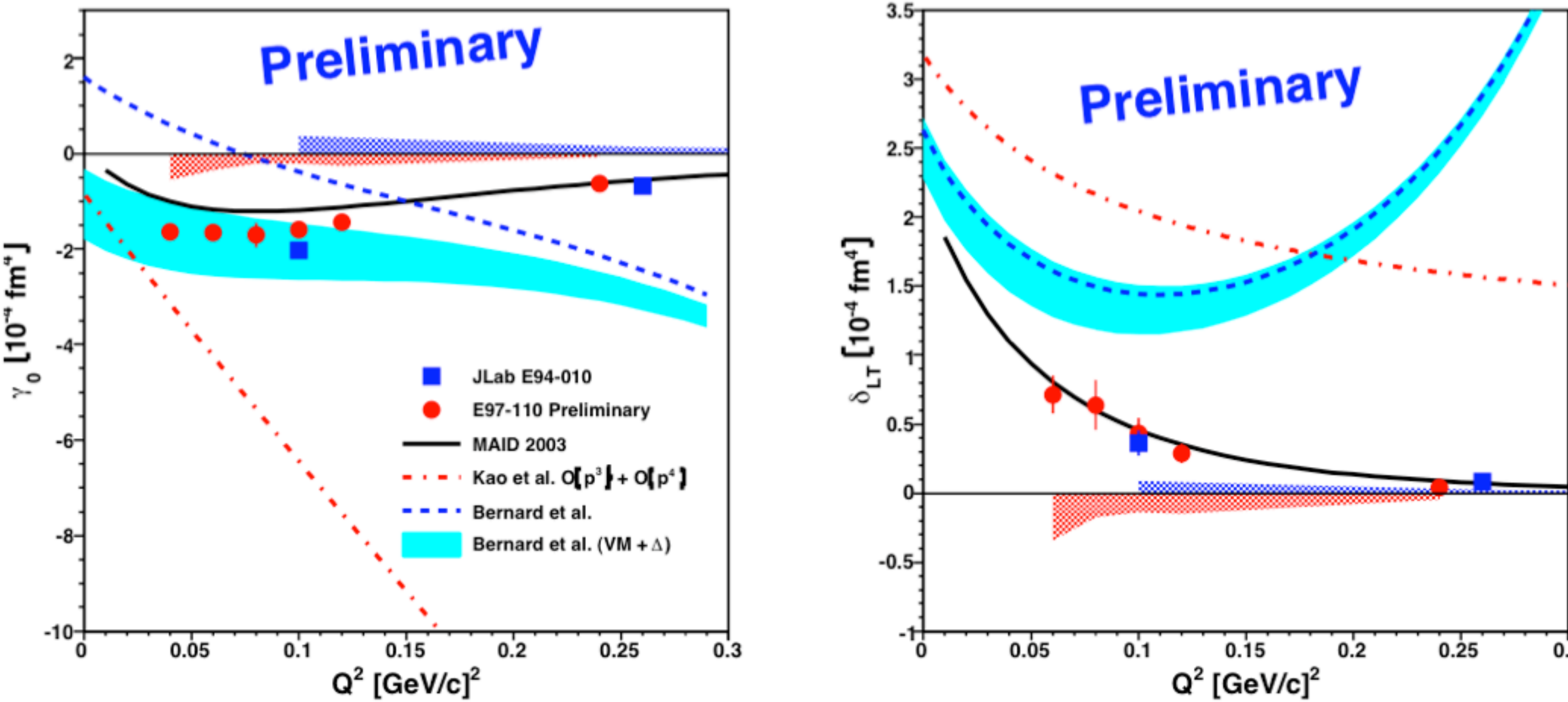
- Finalized:
  - Radiative corrections;
  - Target polarimetry;
  - Acceptance study.
- Analyze the lowest Q^2 points.

Preliminary results on GDH sum

Hall A (neutron):



Hall A (neutron): Preliminary results on neutron spin polarizabilities

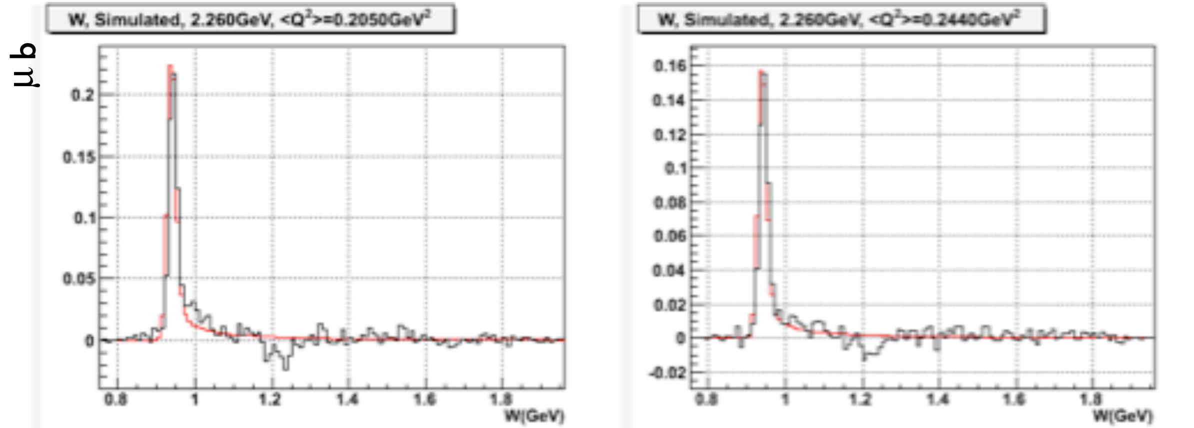


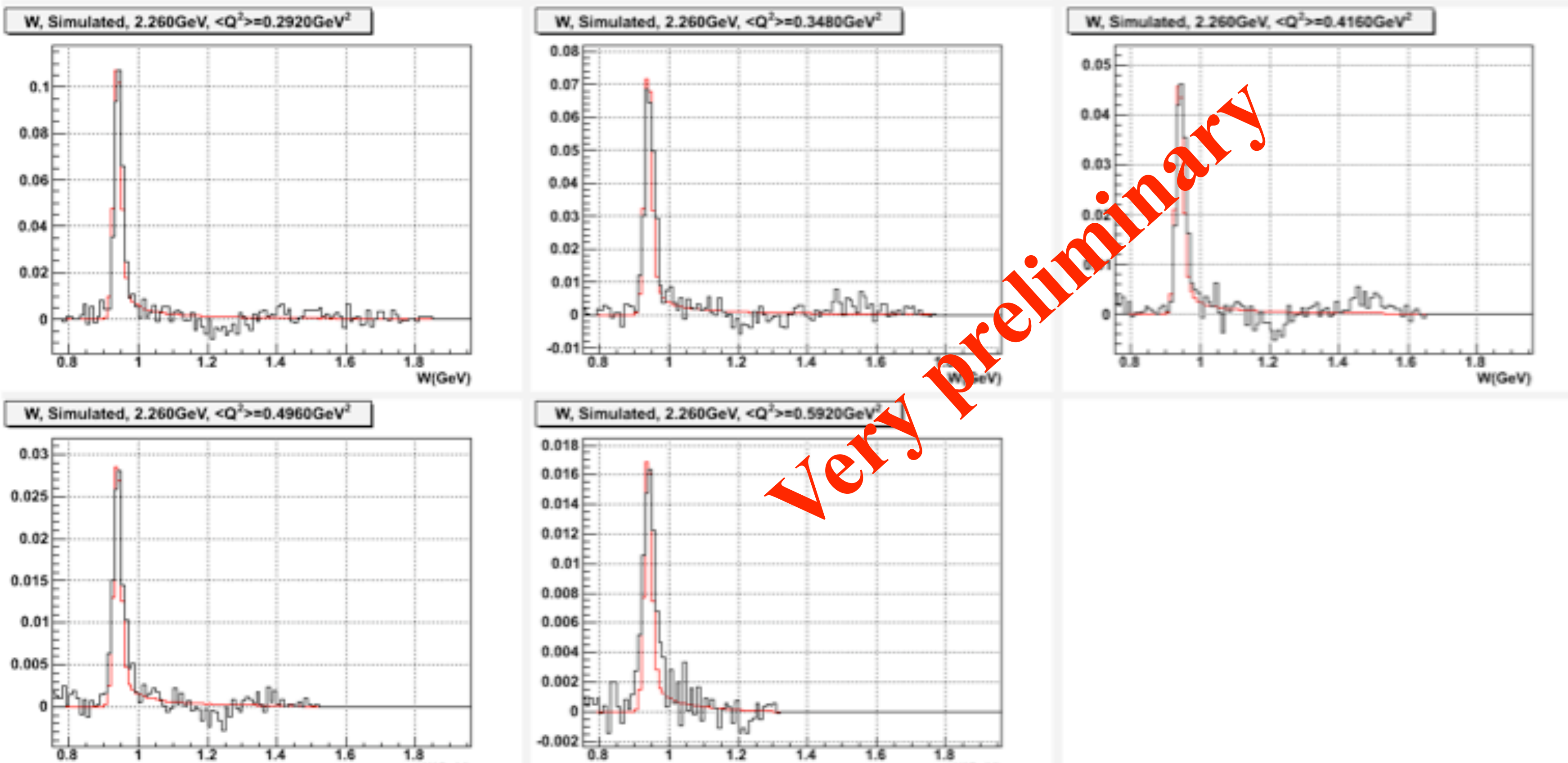
Hall B: Preliminary results on difference of polarized cross sections

One step away from g_1: $\sim g_1 \propto \sigma^{\uparrow\downarrow} - \sigma^{\uparrow\uparrow}$.

Proton, 2.3 GeV

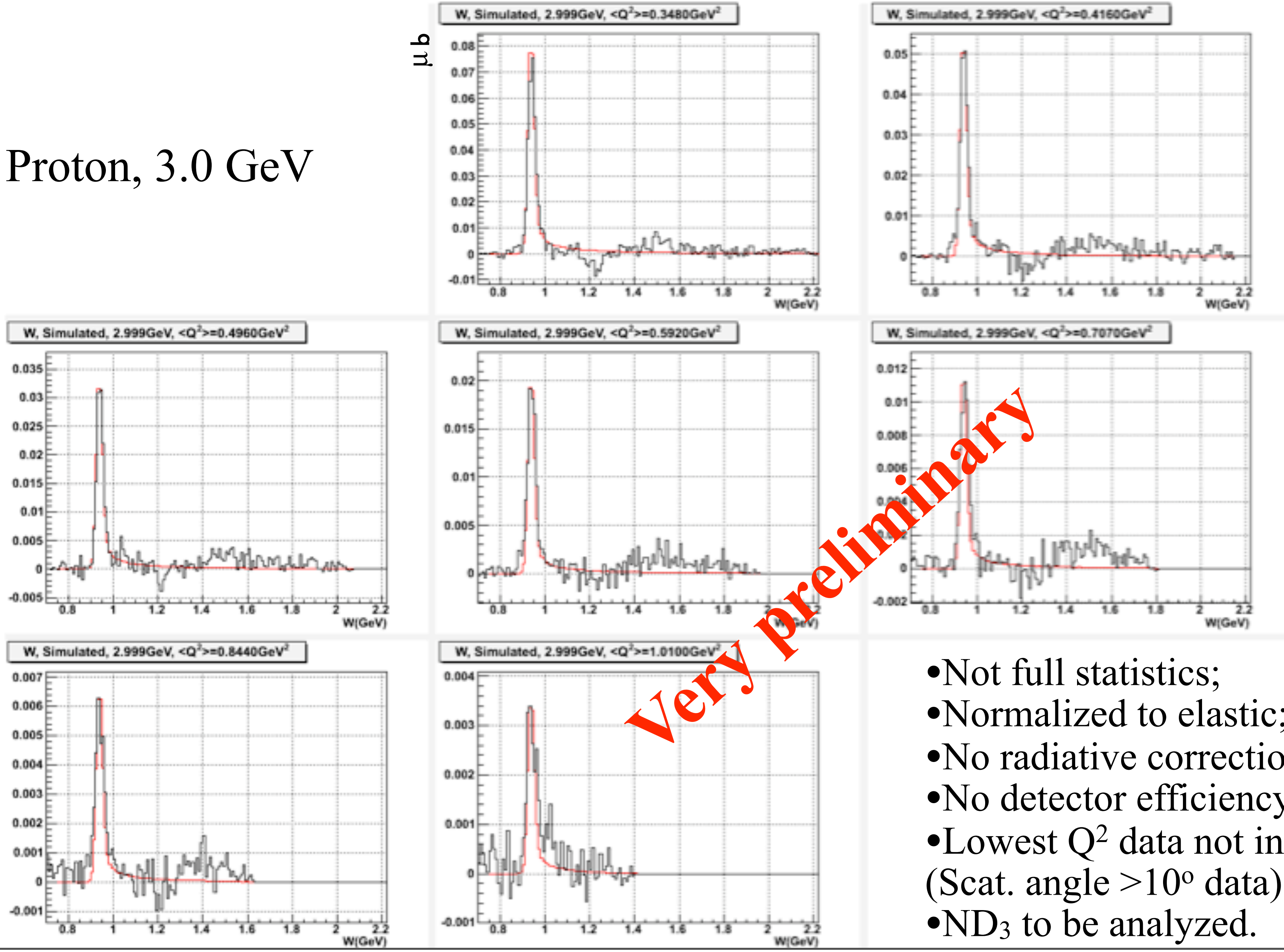
Data (black) normalized to elastic simulation (red)





Hall B: Preliminary results on difference of polarized cross sections

Proton, 3.0 GeV



- Not full statistics;
- Normalized to elastic;
- No radiative corrections;
- No detector efficiency;
- Lowest Q^2 data not included (Scat. angle >10^o data);
- ND_3 to be analyzed.

GDH: ”Study transition from hadronic to partonic description of strong force”

Examples of practical applications:

- Low Q^2: extraction of χpt series coefficients;

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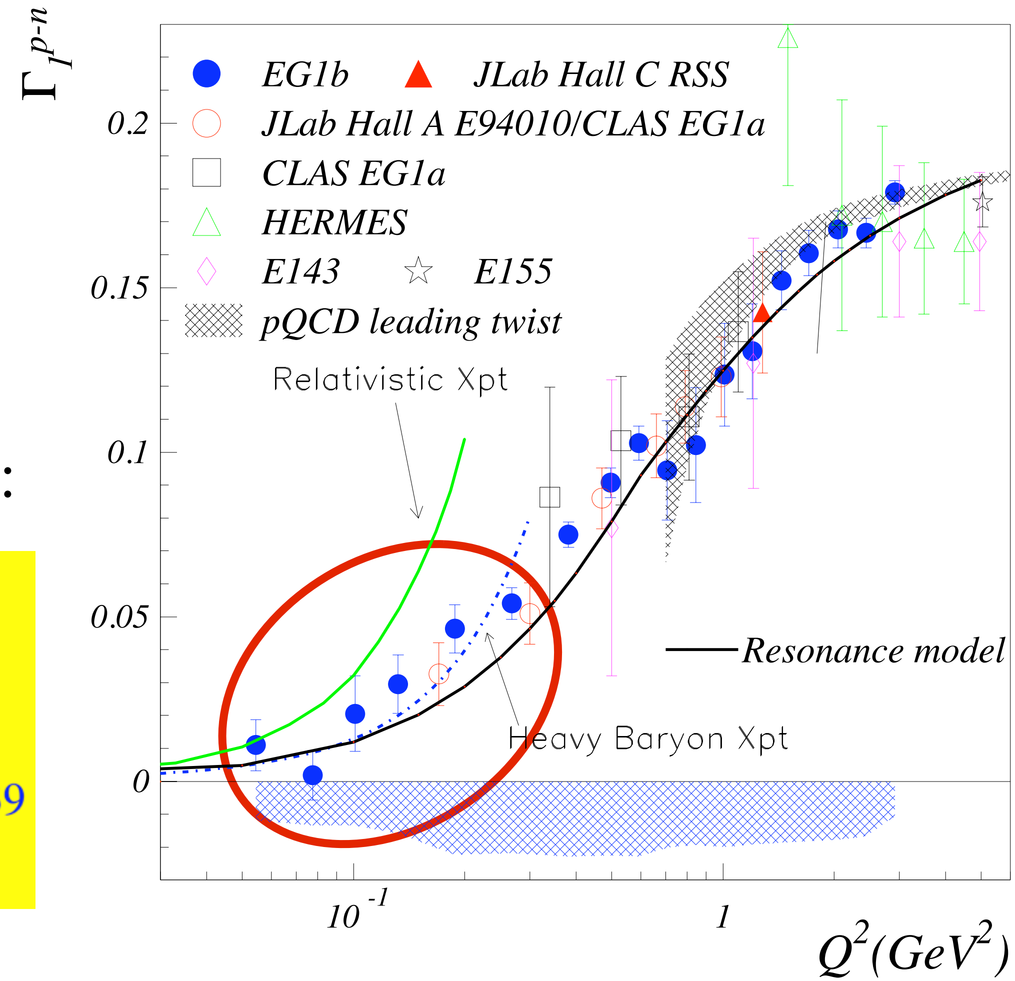
Ex. Bjorken sum:



Low Q^2 fit:

$$\Gamma_1^{p-n} = \frac{\kappa_n^2 - \kappa_p^2}{8M^2} Q^2 + aQ^4 + bQ^6$$

$a = 0.80 \pm 0.07 \pm 0.23$, $b = -1.13 \pm 0.16 \pm 0.39$

$a^{\chi pT,Ji} = 0.74$, $a^{\chi pT,B.} = 2.4$

Q^2 upper limit: 0.4 ± 0.1 GeV^2

GDH:

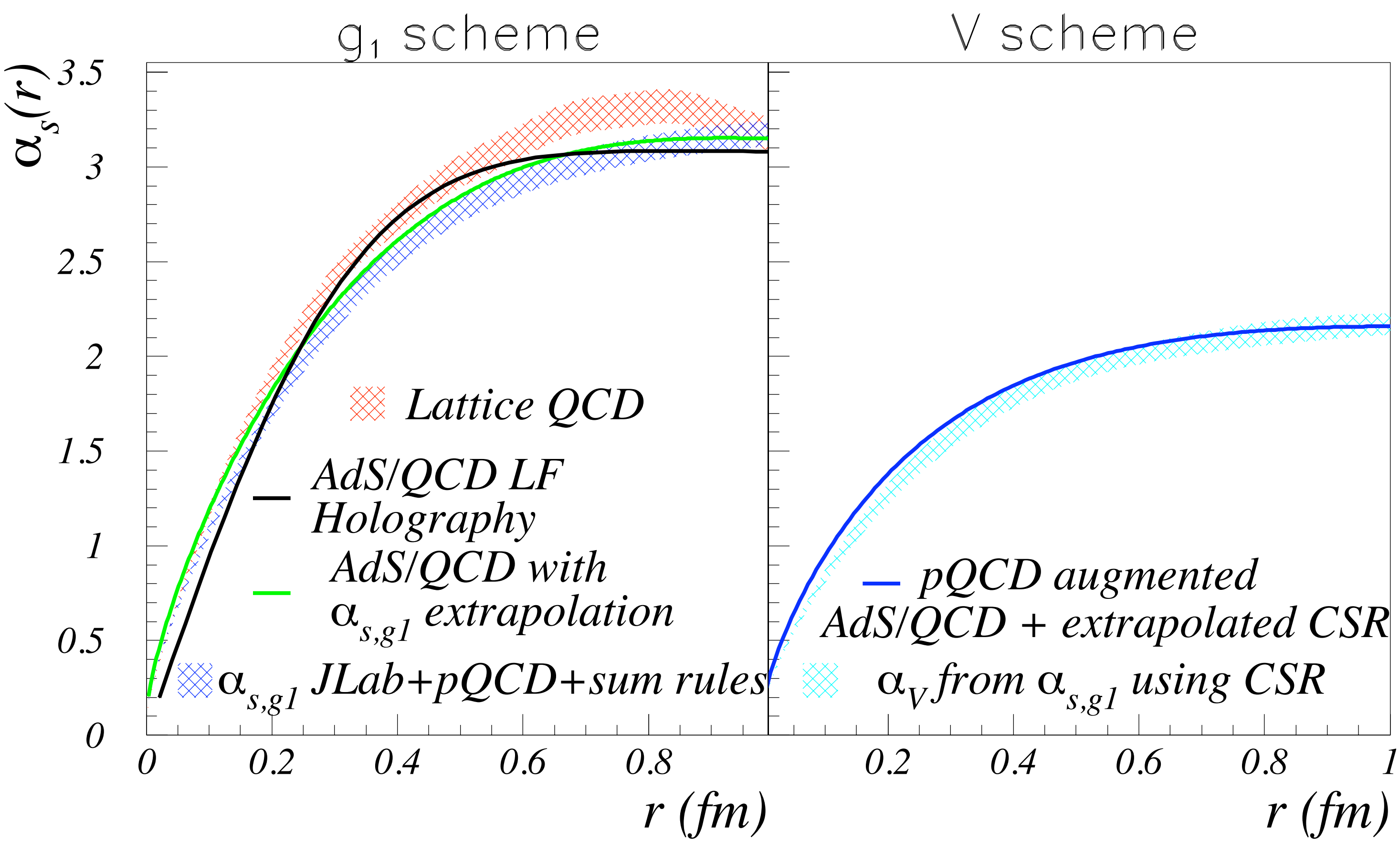
Examples of practical applications:

- Low Q^2: extraction of χpt series coefficients;
- High Q^2: extraction of pQCD series coefficients (higher twists);

GDH:

Examples of practical applications:

- Low Q^2: extraction of χpt series coefficients;
- High Q^2: extraction of pQCD series coefficients (higher twists);
- α_s, the strong coupling constant at large distances (>0.2 fm, i.e. low Q^2).



Summary/Perspective

Two experiments in Hall A & B fill the last gap (low Q^2).

Data are being analyzed:

- Hall A data ($0.05<Q^2<0.25$ GeV^2) will be available in upcoming months;
- Data at $0.02<Q^2<0.05$ GeV^2 requiring longer analysis;
- Hall B preliminary data on moments should be available this year.

One last missing piece: low Q^2 data on transversally polarized proton. Goal of the next Hall A experiment E08-027 (starts Nov. 2011.)

Low Q^2 data are of high precision. Higher precision data at intermediate *and large* Q^2 desirable.

- Hall B EG1b (intermediate Q^2) and EG1dvcs (higher Q^2);
- Hall C Sane;
- 12 GeV, important for the large Q^2 part of this program:
  - Convergence of sum rules;
  - minimize low-x issue;
  - increase Q^2 range;
  - higher precision extraction of higher twists.

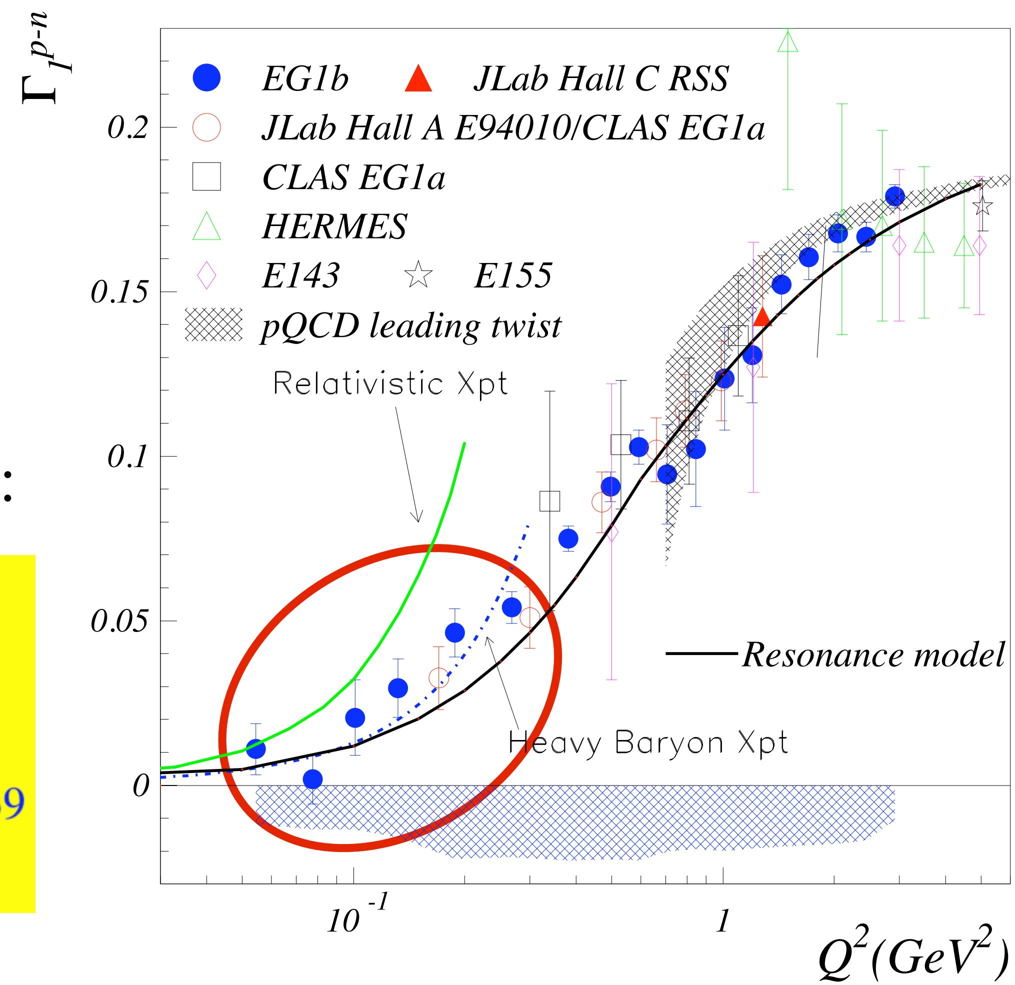
Polarized HD target in Hall B: precision check of GDH sum rule ($Q^2=0$) and may provide a transverse target for electroproduction ($Q^2>0$).

GDH: "Study transition from hadronic to partonic description of strong force"

Examples of practical applications:

- Low Q^2: extraction of χpt series coeficients;

Ex. Bjorken sum:



Low Q^2 fit:

$$\Gamma_1^{p-n} = \frac{\kappa_n^2 - \kappa_p^2}{8M^2} Q^2 + aQ^4 + bQ^6$$

a=0.80±0.07±0.23, b=-1.13±0.16±0.39

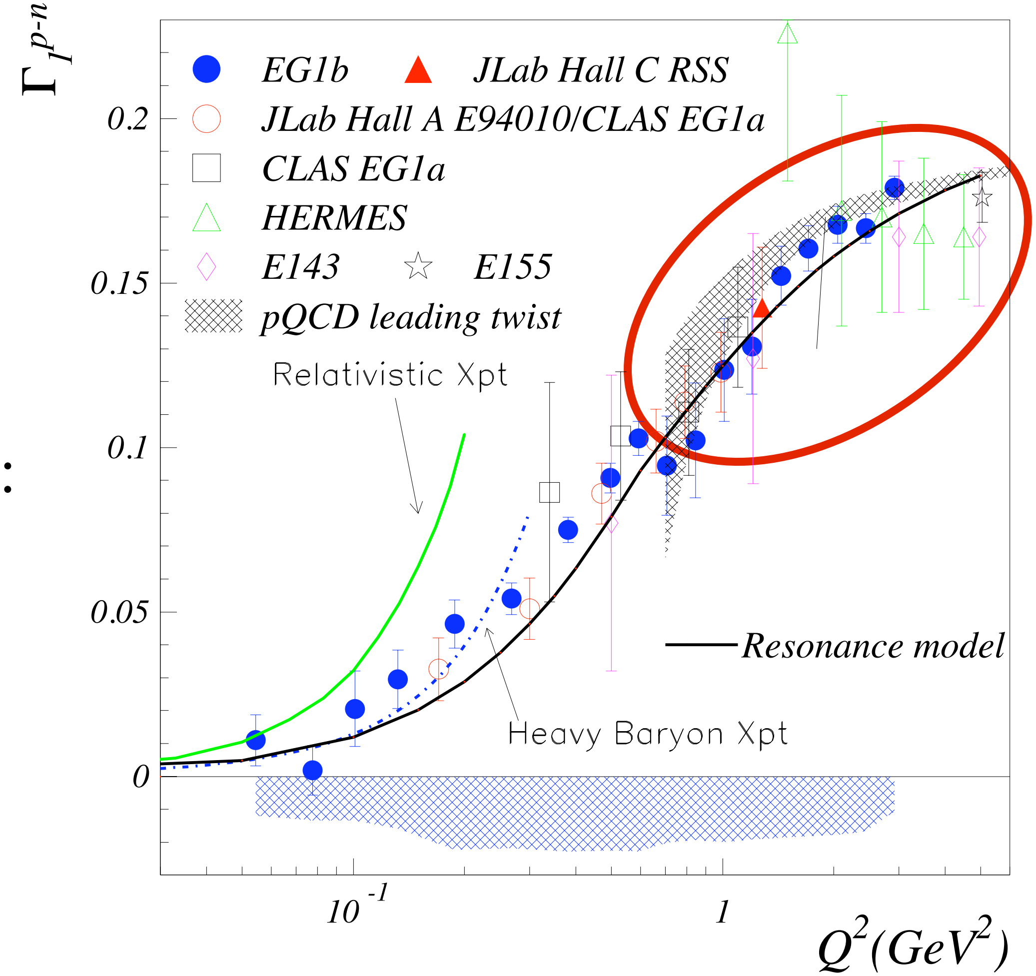
$a^{\chi pT,Ji}=0.74$, $a^{\chi pT,B.}=2.4$

GDH: "Study transition from hadronic to partonic description of strong force"

Examples of practical applications:

- Low Q^2: extraction of χpt series coeficients;
- High Q^2: extraction of pQCD series coeficients;

Ex. Bjorken sum:



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Examples of practical applications:

- Low Q^2: extraction of χpt series coeficients;
- High Q^2: extraction of pQCD series coeficients;

$$\int g_1 dx = \sum_{\substack{twist\\=2,4\ldots}} \frac{\mu_{twist}}{Q^{twist-2}}$$

Ex. Bjorken sum:

$$\int g_1^{p-n} dx = \underbrace{\frac{1}{6} g_a\left(1 + \frac{\alpha_s(\ln(Q^2))}{\pi} + \ldots\right)}_{\text{Leading twist (twist 2)}} + \underbrace{\frac{\mu_4}{Q^2} + \frac{\mu_6}{Q^4} + \ldots}_{\text{Higher twists}}$$

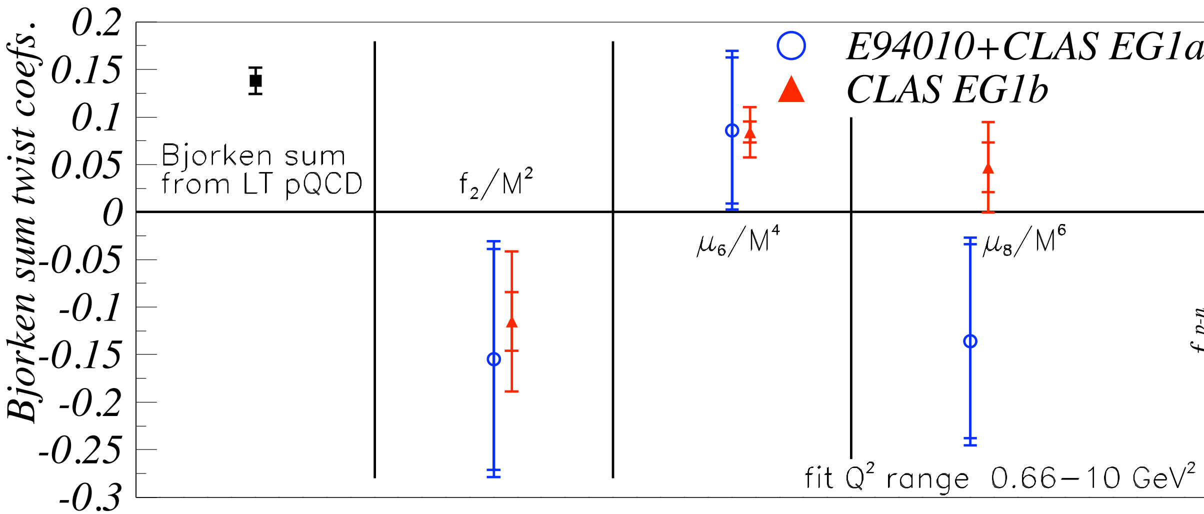
$$\frac{\mu_4}{Q^2} = \frac{M^2}{9}(a_2 + 4d_2 + 2f_2)$$

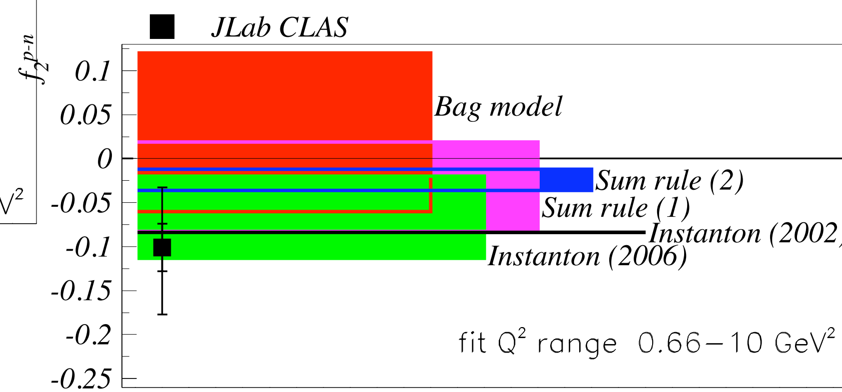
- a_2: Leading twist (known from high energy data)
- d_2: Twist 3 (known from high energy data)
- f_2: Twist 4

GDH: ”Study transition from hadronic to partonic description of strong force”

Examples of practical applications:

- Low Q^2: extraction of χpt series coeficients;
- High Q^2: extraction of pQCD series coeficients;





f_2 large (similar to leading twist at Q^2 =1 GeV^2) in accordance to intuition.

μ_6/M^4 similar size as f_2 but opposite sign.

Overall, higher twist contribution small at Q^2 =1 GeV^2.