

Review of the bump-dip structure at small Q^2 .

Thomas Walcher

Institute for Nuclear Physics
Johannes-Gutenberg University Mainz



- Significance of form factors
- World data base up to ≈ 2006 and fits
- New results from Mainz using Rosenbluth formula
- Discussion
- Conclusions

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Significance of form factors

- form factors $\xleftrightarrow[\text{Breit frame}]{\text{Fourier transform}}$ charge distribution
 $\xleftrightarrow[\text{boost}]{\text{model}}$ wave functions of constituents
- comparison of proton and neutron
proton \longrightarrow bulk charge of valence quarks $\rho_{cq}(r)$
neutron \longrightarrow $\rho_{cq}(r) \equiv 0$ \curvearrowright small deviations from bulk charge
- dispersion relations
spectral functions of the nucleon \longrightarrow form factors

Prerequisite for conclusions

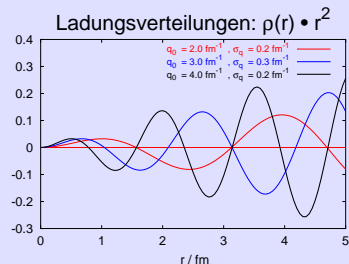
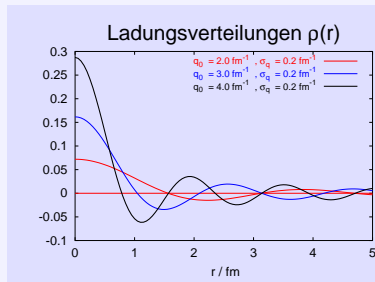
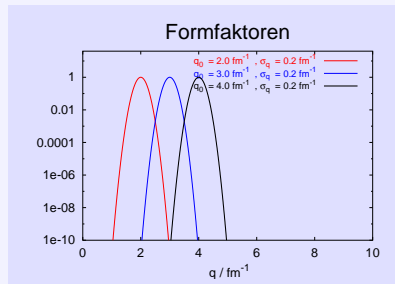
Significance depends on precise data at low and high Q^2 .

Significance of form factors

Fourier transform of bump

Variation of position of momentum transfer:

$$F(q) = e^{-\frac{1}{2}\left(\frac{q-q_0}{\sigma_q}\right)^2}$$

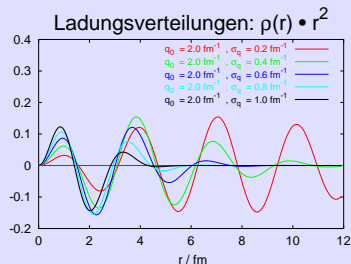
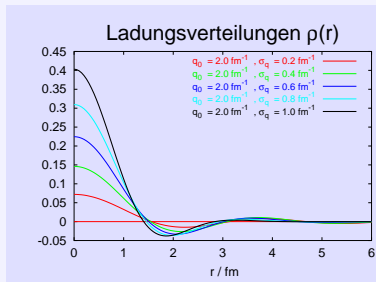
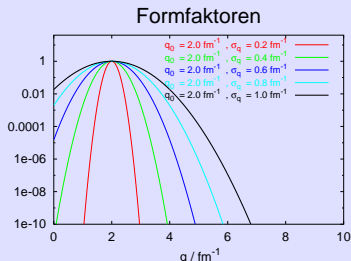


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Variation of width of momentum transfer:

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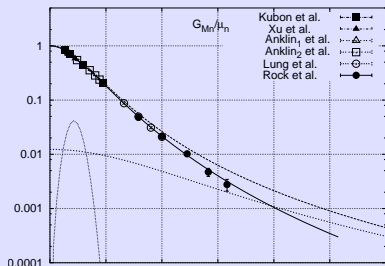
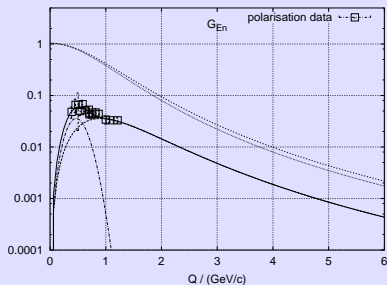
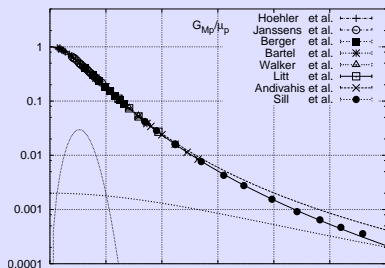
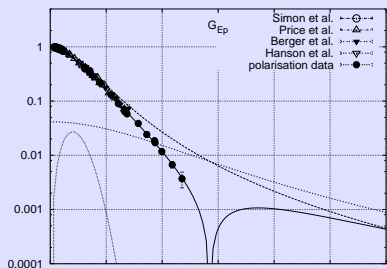
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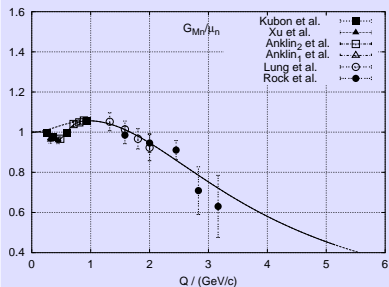
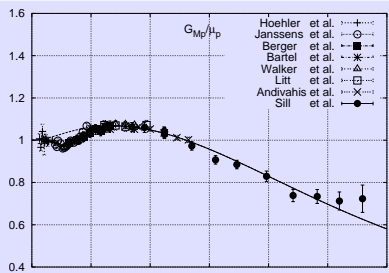
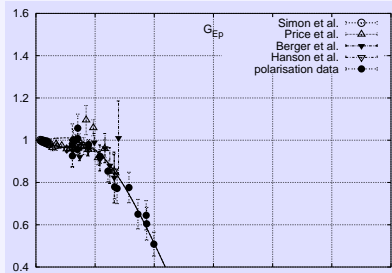
World data base up to $\lesssim 2006$ and fits

G_{Ep} , G_{Mp} , G_{En} , G_{Mn}

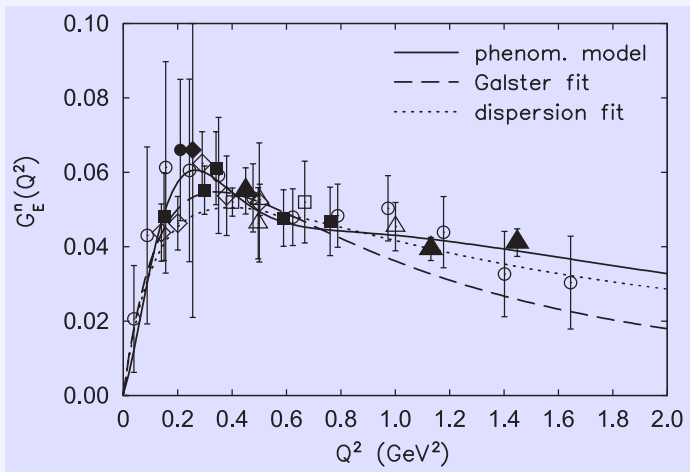


World data base up to $\lesssim 2006$ and fits

G_{Ep} , G_{Mp} , G_{Mn} , magnified

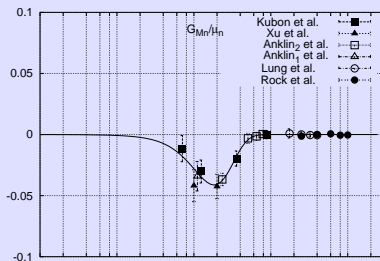
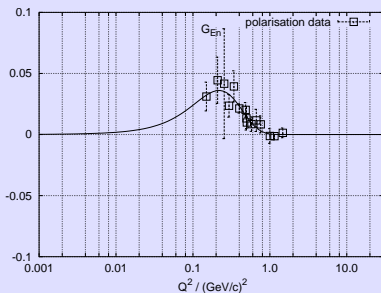
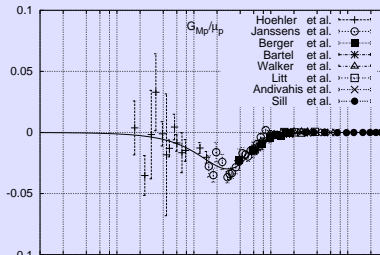
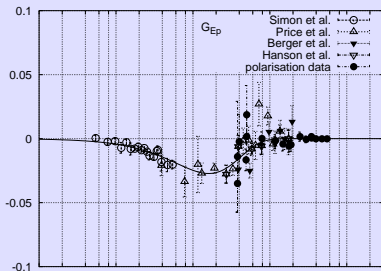


electric form factor of the neutron



World data base up to ≈ 2006 and fits

G_{Ep} , G_{Mp} , G_{En} , G_{Mn} after subtraction of an empirical background

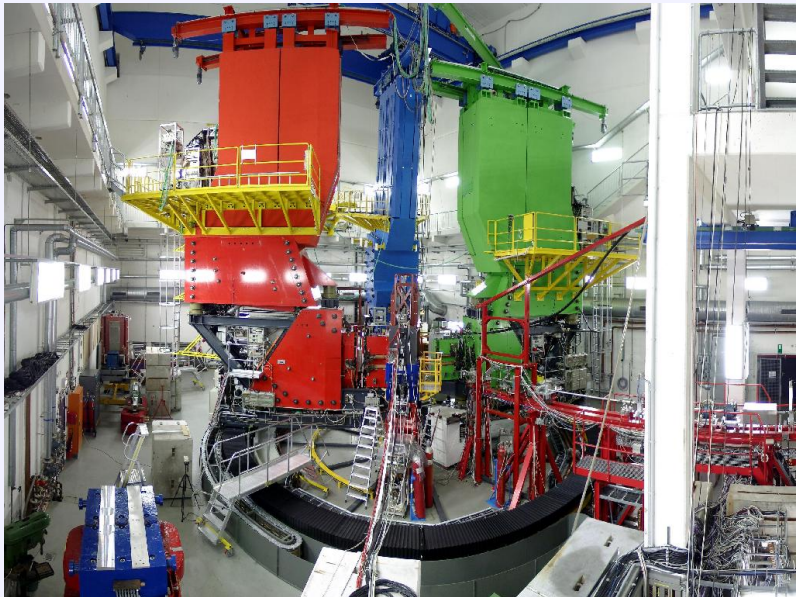


World data base up to $\lesssim 2006$ and fits

Summary

- Friedrich and Walcher (FW) representation is a fit, not a model cannot be better than the data
- Friedrich and Walcher (FW) have the naive idea (Ulf Meissner “popular fantasy”):
dressed nucleon \longleftrightarrow bare nucleon + pion
- bump/dip structure
 - G_{En} : bump significance of 2 standard deviations
 - G_{Ep} : dip coherent with bump in G_{En} according to “popular fantasy”
- needed better data at high and low Q^2
 - G_{Ep} and G_{En} at Bates and Jlab with polarized electrons
 - ↪ other talks at this workshop
 - G_{Ep} low Q^2 at MAMI using Rosenbluth formula
 - ↪ this talk

3 spectrometer set-up at MAMI



Rosenbluth formula

$$\frac{d\sigma}{d\Omega}\Big|_{lab} = \underbrace{\left(\frac{\alpha^2}{4E^2 \sin^4(\theta/2)}\right)}_{\sigma_{\text{Mott}}} \frac{E'}{E} \left\{ \left(F_1^2 - \frac{\kappa^2 q^2}{4M^2} F_2^2 \right) \cos^2(\theta/2) - \frac{q^2}{2M^2} (F_1 + \kappa F_2) \sin^2(\theta/2) \right\}$$

F_1 Dirac-form factor

F_2 Pauli-form factor

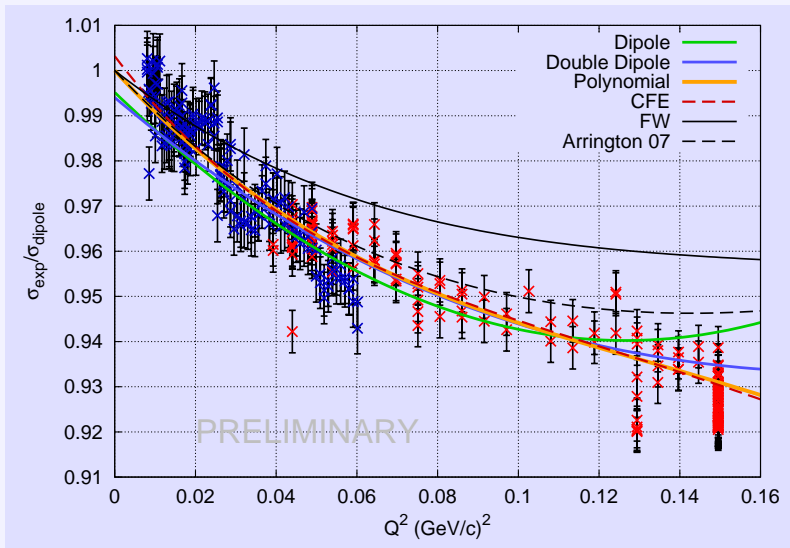
Sachs-form factors

$$G_E \equiv F_1 + \frac{\kappa q^2}{4M^2} F_2 \quad G_M \equiv F_1 + \kappa F_2 \quad \tau \equiv -\frac{q^2}{4M^2}$$

$$\left. \frac{d\sigma}{d\Omega} \right|_{lab} = \underbrace{\left(\frac{\alpha^2}{4E^2 \sin^4(\theta/2)} \right)}_{\sigma_{\text{Mott}}} \frac{E'}{E} \left\{ \frac{G_E^2 + \tau G_M^2}{1 + \tau} \cos^2(\theta/2) - \right. \\ \left. - 2\tau G_M^2 \sin^2(\theta/2) \right\}$$

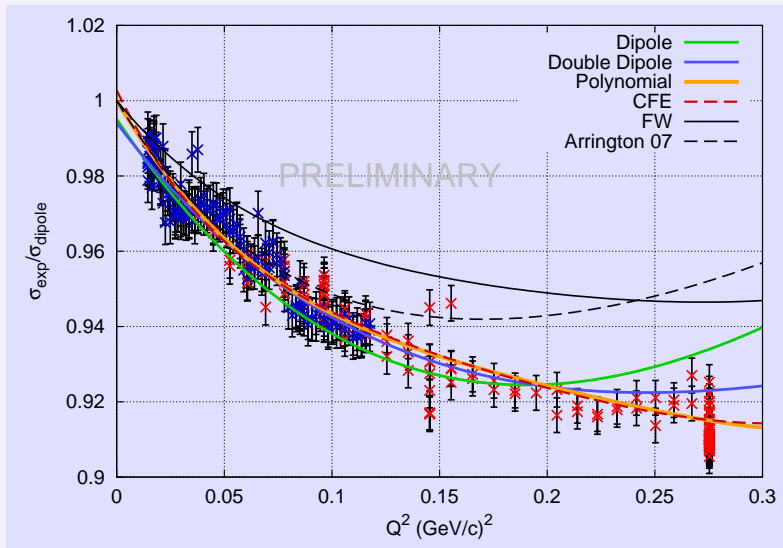
New results from Mainz MAMI 2008: Jan Bernauer et al.

$E_0 = 315 \text{ MeV}$



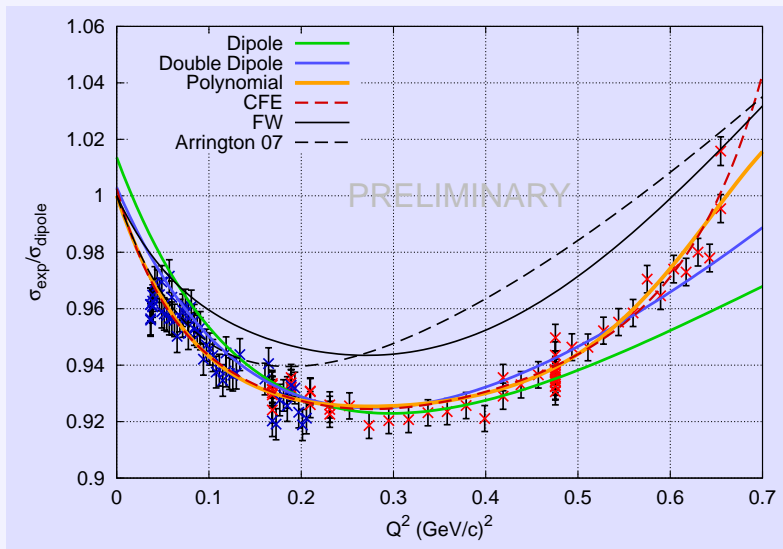
New results from Mainz MAMI 2008: Jan Bernauer et al.

$E_0 = 450 \text{ MeV}$



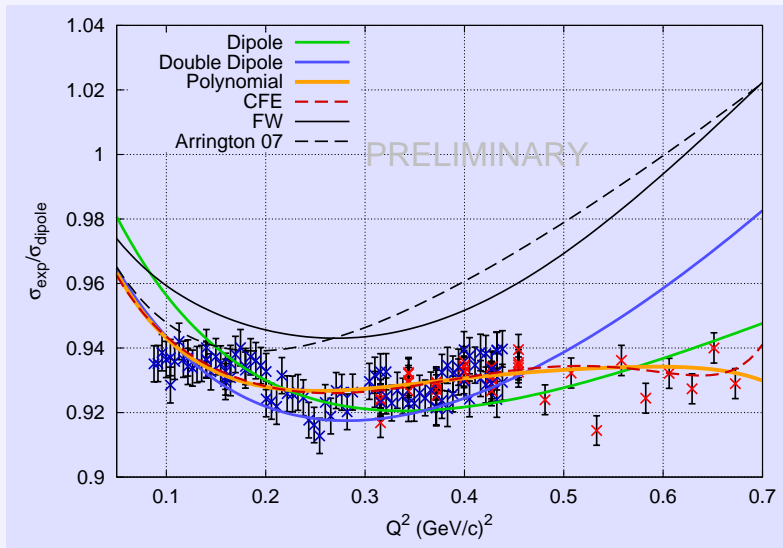
New results from Mainz MAMI 2008: Jan Bernauer et al.

$E_0 = 720 \text{ MeV}$



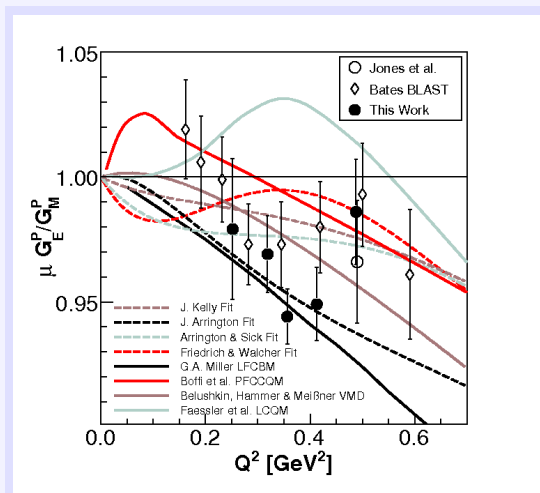
New results from Mainz MAMI 2008: Jan Bernauer et al.

$E_0 = 855 \text{ MeV}$



New results from BLAST and CEBAF

G_E/G_M for the proton from polarized electron scattering
Bates BLAST 2007: C.B. Crawford et al. ("Bates BLAST")
Jlab CEBAF 2007: G. Ron et al. ("this work")



New results from Mainz MAMI 2008: Jan Bernauer et al.

rms radii of proton: $R = \sqrt{\langle r^2 \rangle}$

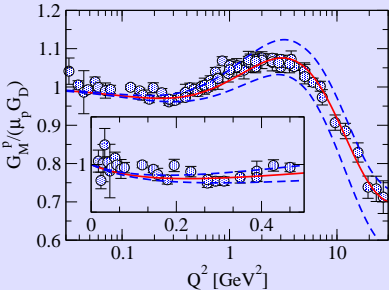
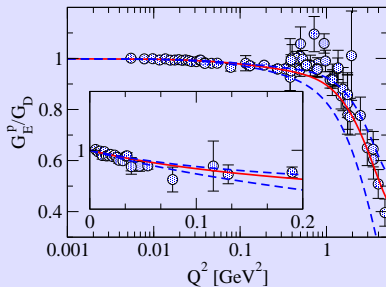
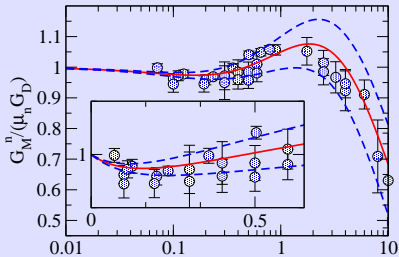
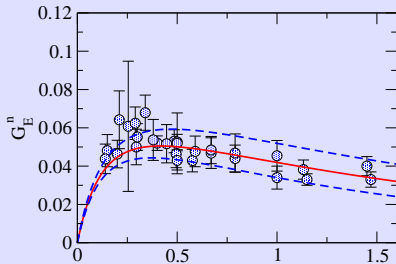
Model	R_E	R_M	χ^2	# fit param.
Dipole	0.8717 ± 0.0011	0.8140 ± 0.0005	1.831	2
Double Dipole	0.8648 ± 0.0015	0.845 ± 0.002	1.469	6
Polynomial	0.879 ± 0.003	0.841 ± 0.008	1.078	8
Cont. Fraction 1	0.892 ± 0.004	0.842 ± 0.018	1.0559	10
Cont. Fraction 2	0.891 ± 0.003	0.866 ± 0.018	1.0556	10

Electric rms radius of proton

authors	method	$R_E = \sqrt{\langle r_p^2 \rangle}$
Simon et al. 1980	no Coulomb correction	0.862 ± 0.012 fm
Rosenfelder 2000	with Coulomb corrections	0.876 ± 0.015 fm
Sick 2003	with Coulomb correction	0.895 ± 0.018 fm
Friedrich and Walcher 2003	no bump/dip structure	0.794 fm
Friedrich and Walcher 2003	with bump/dip structure, no Coulomb correction	0.858 fm
Friedrich and Walcher 2003	with Coulomb corrections	0.872 fm
Bernauer et al. (MAMI) 2008	no Coulomb corrections	0.885 ± 0.007 fm
Bernauer et al. (MAMI) 2008	with Coulomb corrections	0.895 ± 0.007 fm
	av. Coulomb corrected	0.885 ± 0.010 fm
Udem et al. 1997	atomic hydrogen transition	0.890 ± 0.014 fm
Hammer et al. 2006	dispersion relations	< 0.844 fm

Dispersion relation fit

Belushkin, Hammer, and Meissner, 2006



Discussion

Dispersion relation fit, Belushkin, Hammer, and Meissner, 2006

goodness of fits

probability $P(\chi^2/dof = 1.8, dof \approx 200) \lesssim 10^{-10}$

- ⤿ Monte-Carlo sampling of all χ^2/dof in interval $[\chi^2/dof, \chi^2/dof + 1]$ does not give the “1- σ band”
- ⤿ “1- σ bands” around “best χ^2 dispersion relation fits” are meaningless

consequences from mathematical statistics

- 1 data are wrong (Belushkin, Hammer, and Meissner, 2006 and 2007)
- 2 theory, i.e. this dispersion relation calculation, is incomplete
- 3 both: data are partially inconsistent or not precise enough?
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- The low Q^2 data for the form factor of the proton from different experiments begin to converge, though the overall picture is not yet clear.
- Data and models come closer, but the fundamental dispersion relation still have considerable problems.
- Bump/dip structure in G_{En} and G_{Ep} of FW
 - It appears to disappear.
 - However, one should still wait until all data are correctly analyzed.
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