BARYONS 2002: OUTLOOK

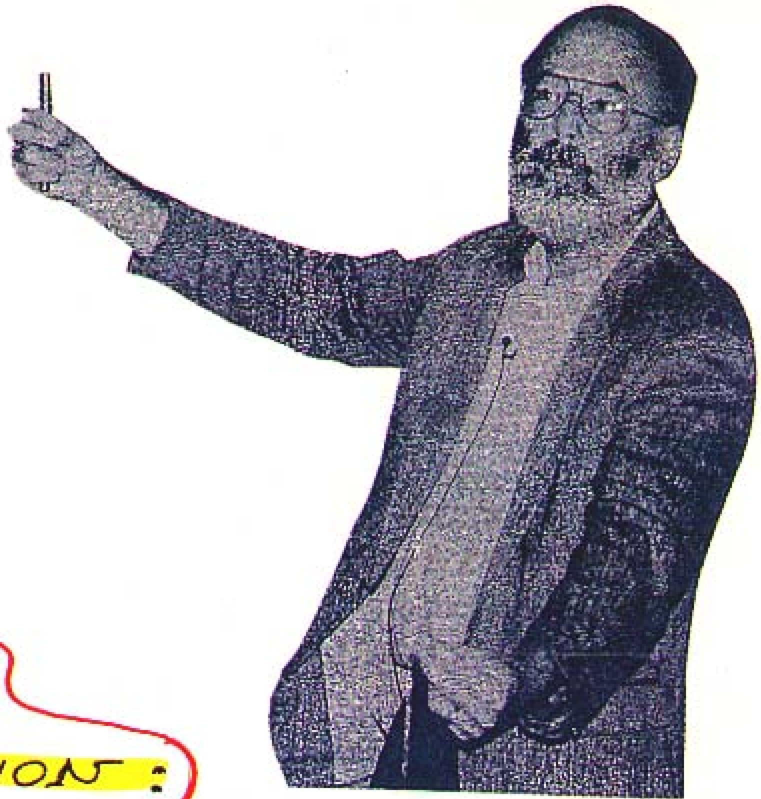
Wolfram Weise

(ECT Trento and TU Munich)*

- Status and Perspectives
- Open Questions and Burning Issues

BARYONS '98

the VISION:



Nathan Isgur

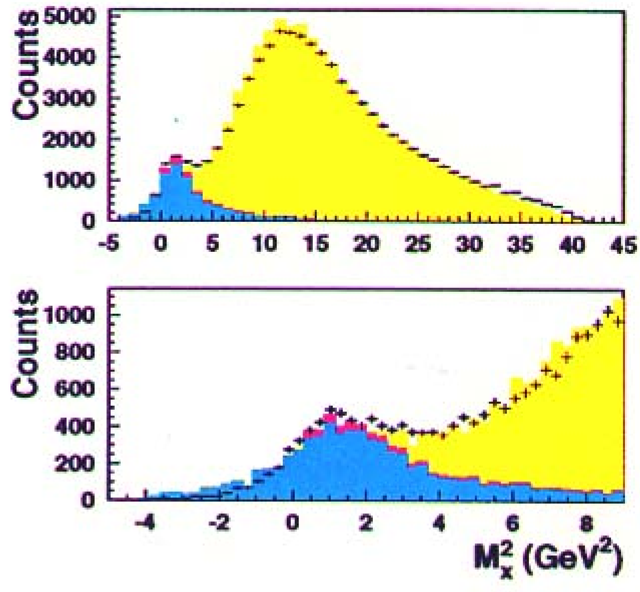
- zeroth order STRONG QCD: Relativistic CONSTITUENT QUARKS with FLUX TUBE GLUON DYNAMICS
- then add $q\bar{q}$ SEA and other $1/N_c$ effects as perturbations
- "... possible connection between

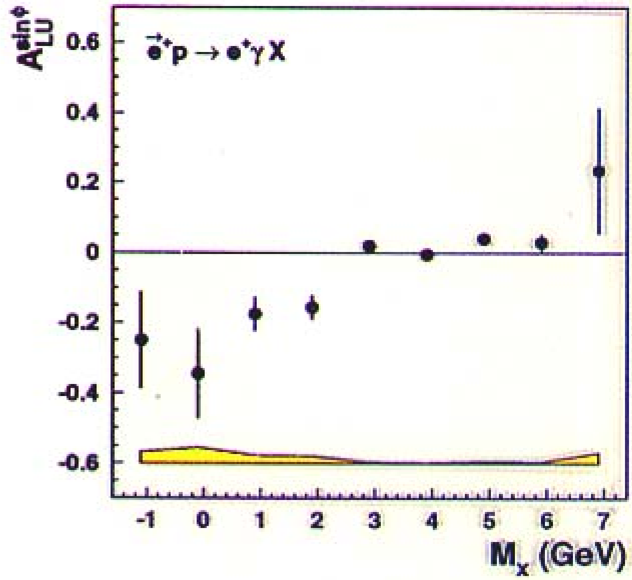
CURRENT QUARKS and GLUONS ⟷ VALENCE QUARKS and POTENTIALS

through $q\bar{q}$ VACUUM CONDENSATE" ...

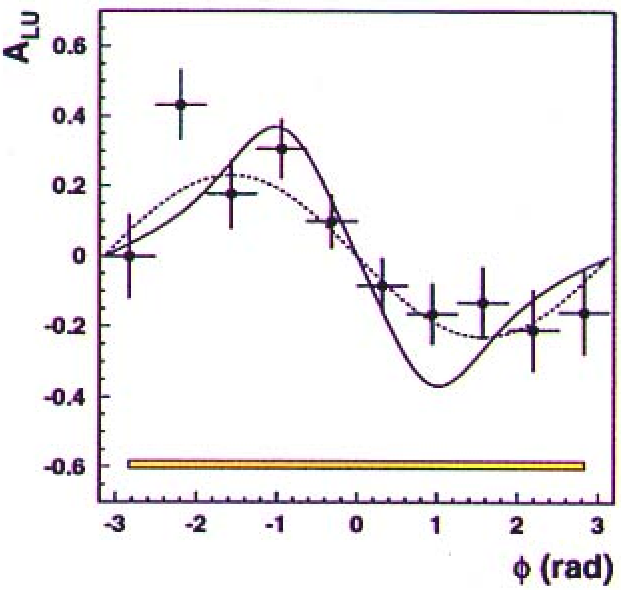
First observations of DVCS

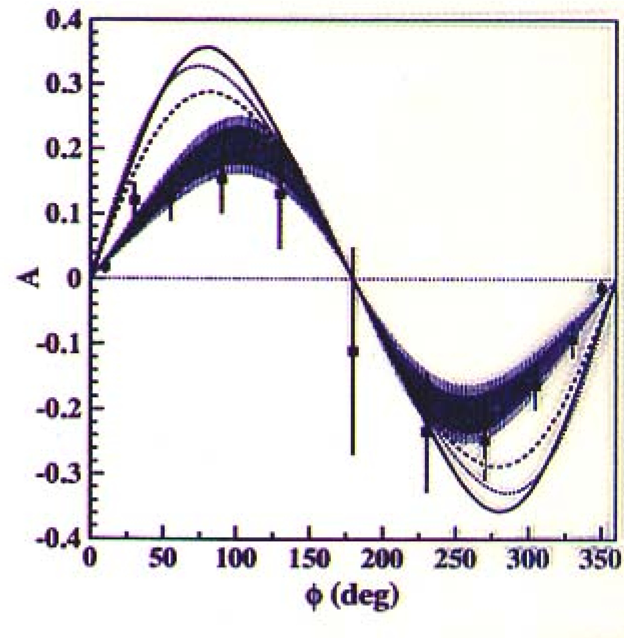
- Missing mass spectrum and $A_{LU}^{\sin\phi} = \frac{2}{N}\sum_{i=1}^{N} \frac{\sin\phi_i}{(P_l)_i}$:





- Azimuthal (ϕ) distributions from HERMES & JLab:

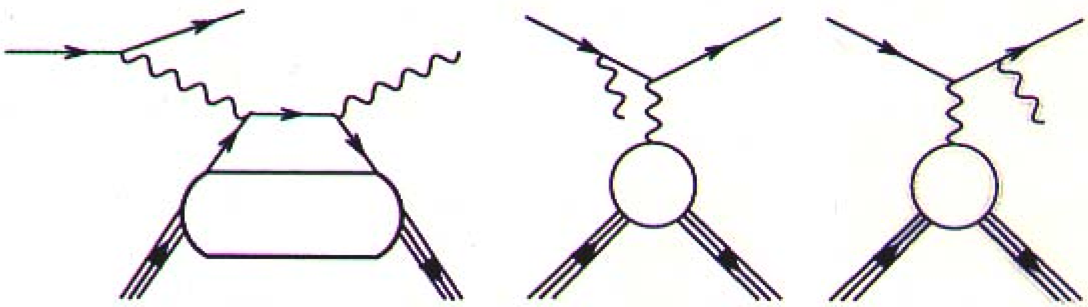




HERMES, PRL 87('01)182001 CLAS Collab., PRL 87('01)182002

Deep Virtual Compton Scattering

- Off-shell photon*-quark scattering:
  - Detect e' and γ, and require: $E_{miss} = 0$



- Ji's sumrule (Phys. Rev. Lett. 78 (1997) 610):

$$\int x dx [H(x, \Delta^2, \xi) + E(x, \Delta^2, \xi)] = A_q(\Delta^2) + B_q(\Delta^2)$$

with $\Delta^2 = -t$ and

$$\lim_{\Delta^2 \to 0} [A_q(\Delta^2) + B_q(\Delta^2)] = 2J_{quark} = \Sigma_q + 2L_q$$

⇒ DVCS: total quark angular momentum

- Experimental considerations:
  - Interference with Bethe-Heitler process:

    DVCS ⊗ BH makes DVCS measurable
  - Detect scattered photon, but suppress π^0's
  - Observe azim. asymmetry: $A_{LU}^{BetheHeitler} = 0$

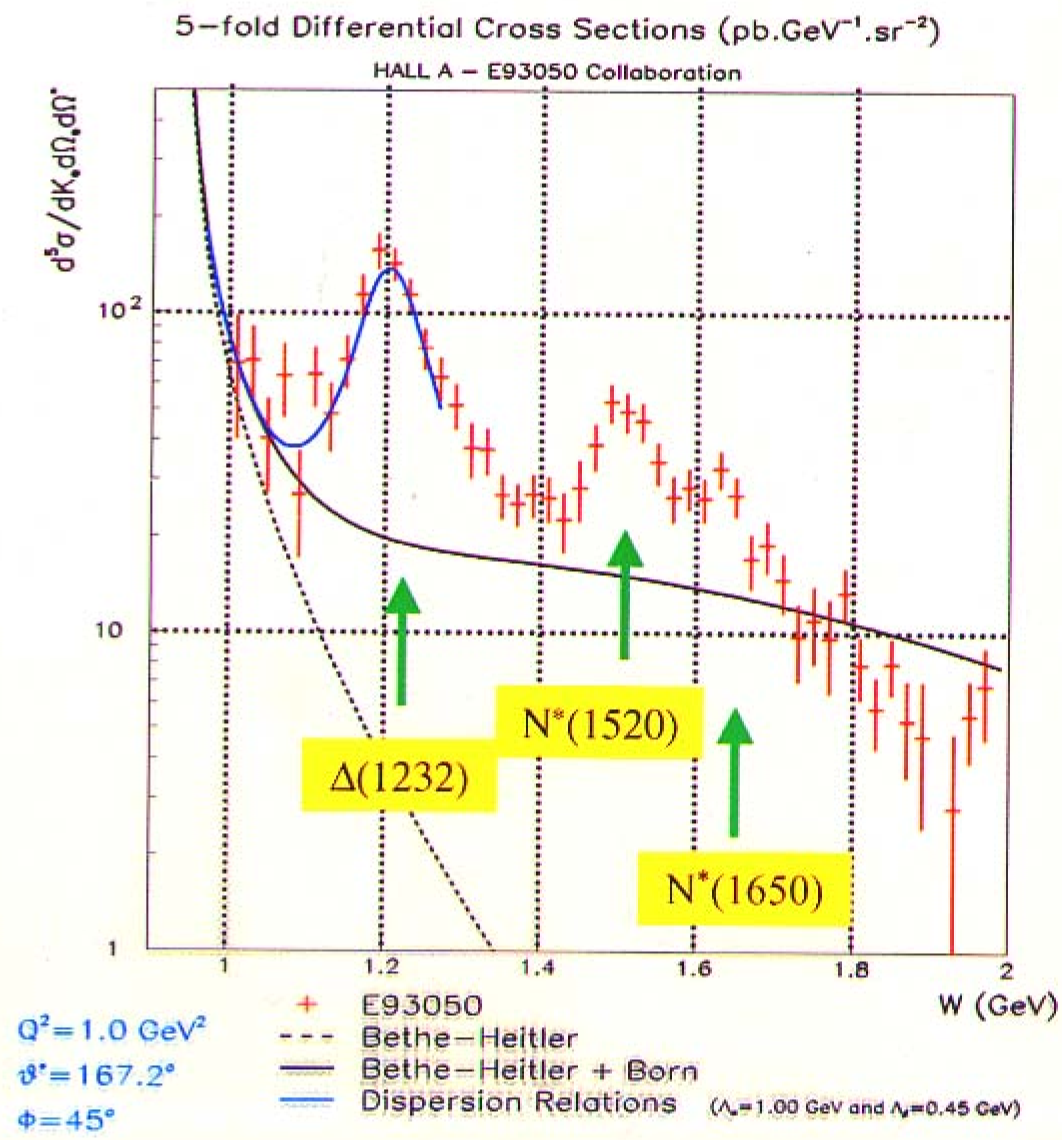
Resonances in Virtual Compton Scattering

Hall A - E93-50

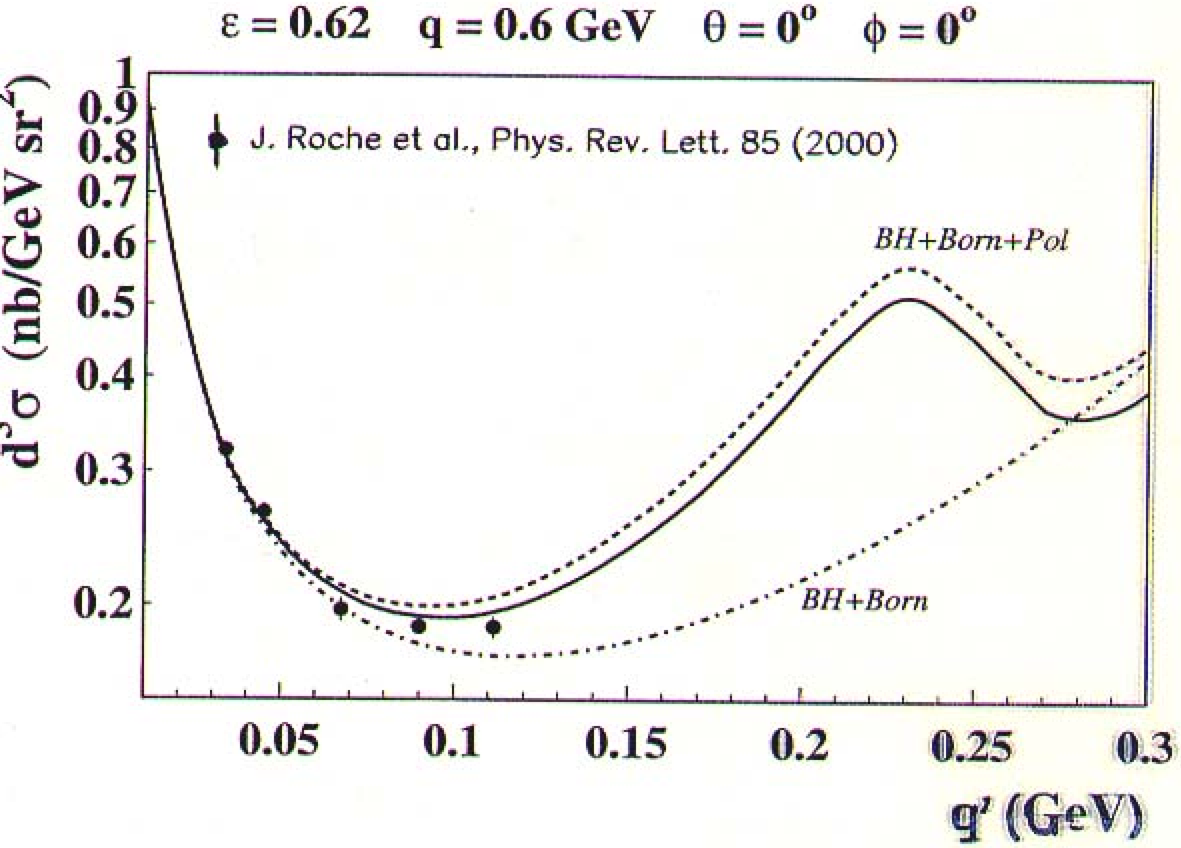
ep ⟶ epγ

- First measurement through entire resonance region
- advantage over mesons, the lack of final state interaction
- strong resonance excitations

⟶ ***Fonvieille***



DISPERSION RELATION ANALYSIS OF VCS



Pasquini, Gorchtein, Drechsel,
Metz, Vanderhaeghen;
Eur. Phys. J. A11 (2001)

Sensitivity to
ELECTROMAGNETIC
POLARIZABILITIES
of the NUCLEON

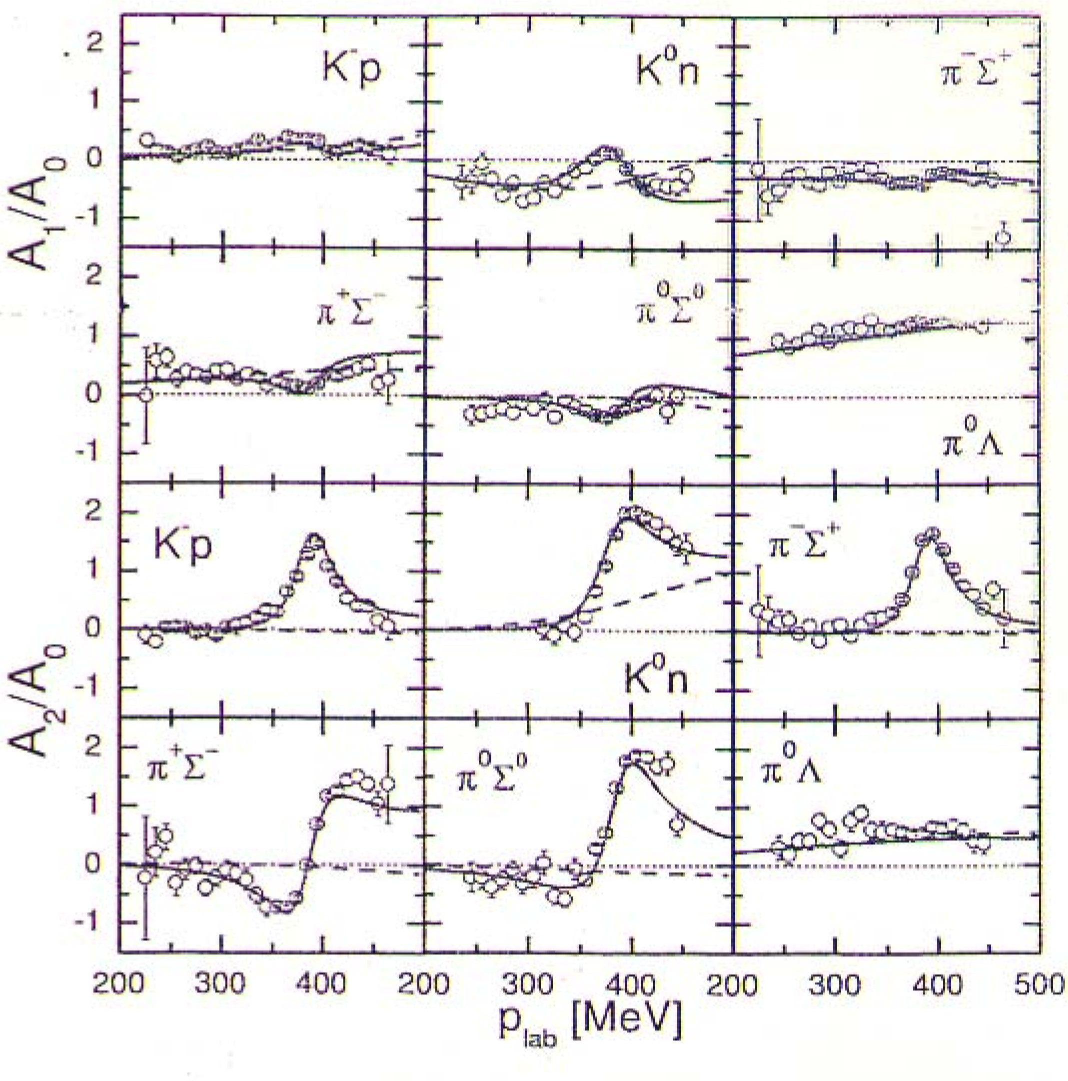
7. Virtual and Deeply-Virtual Compton Scattering

- Mainz
- JLAB
- Hermes

CHIRAL SU(3) MESON-BARYON DYNAMICS

- Coupled Channels
- Baryon Octet and Decuplet
- Large N_c book-keeping

example: $K^- p$ reactions ; $\frac{d\sigma}{d\Omega}$ Legendre coeff.



Lutz, Kolomeitsev NPA 700 (2002)

LIMITS of "CANONICAL" ChPT and WAYS BEYOND

Energy-dependence of the Magnetic Dipole Polarisability $\beta_{M1}(\omega)$

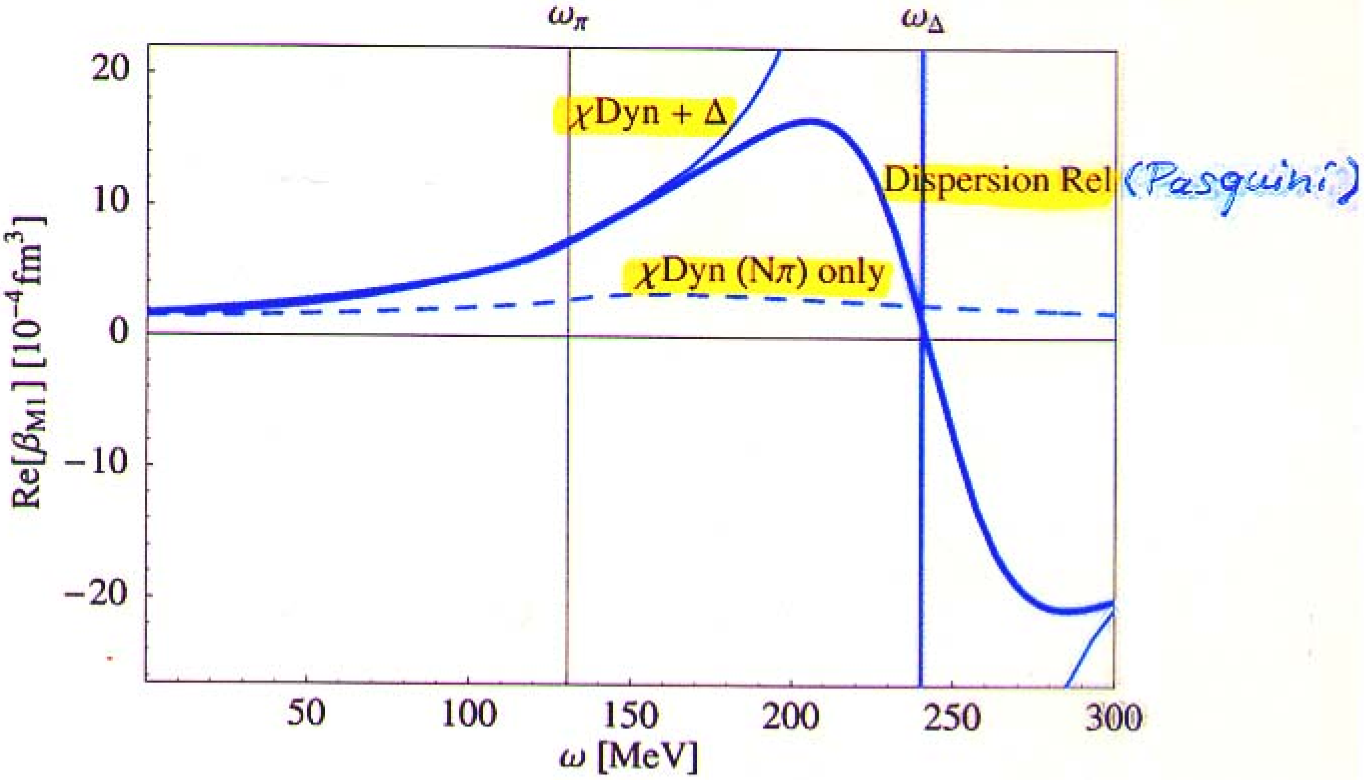
H. W. Grießhammer/T. R. Hemmert: nucl-th/0110006;

H. W. Grießhammer/T. R. Hemmert/R. Hildebrandt/B. Pasquini: in preparation.

Strong ω dependence from Δ: para-magnetic $M1 \to M1$.

Chiral dynamics part ($N\pi$ physics) small.

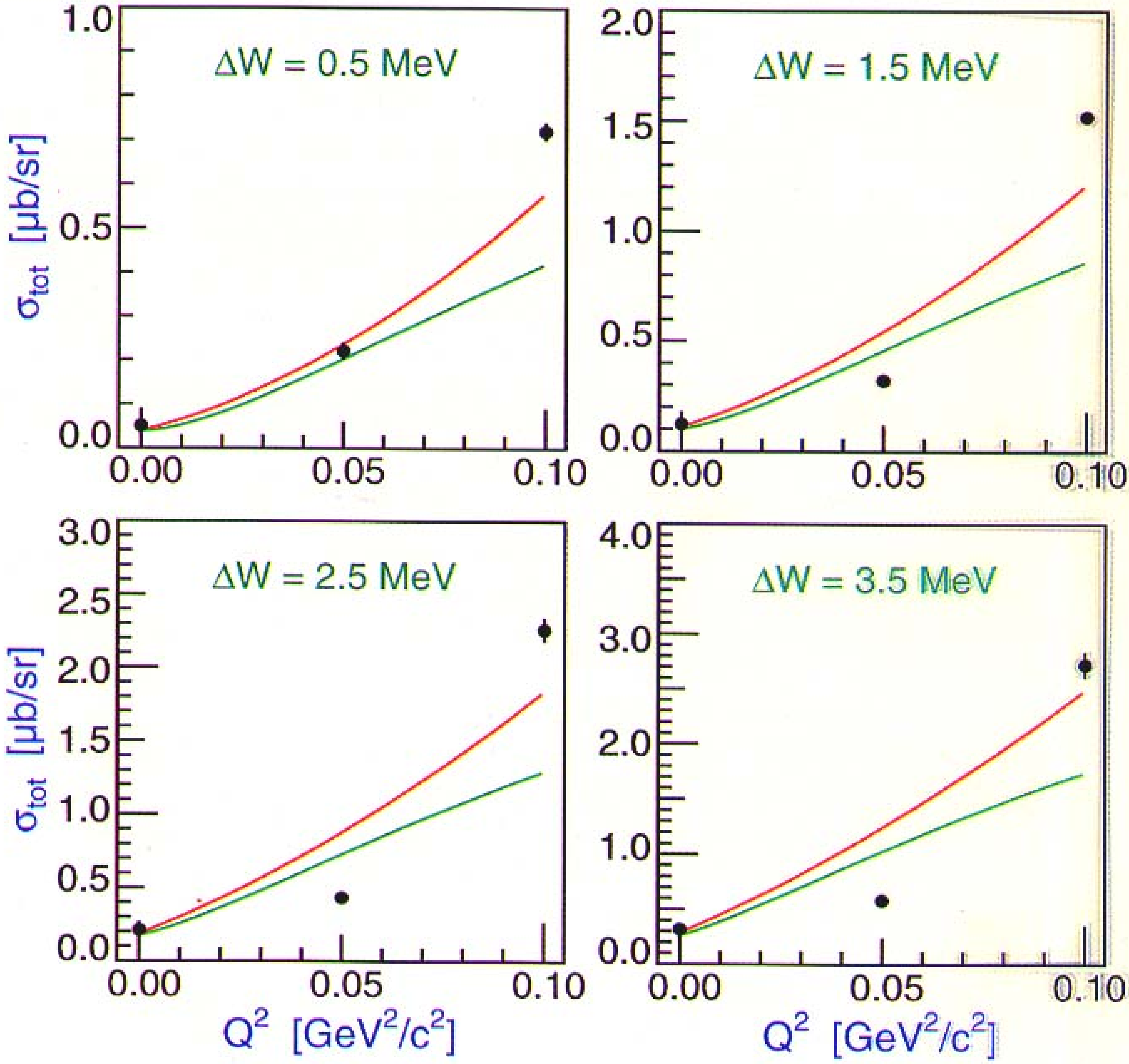
$\beta_{M1}(\Delta) \approx -\delta\beta_{M1}(\text{C.T.}) \approx 12 \times 10^{-4}\ \text{fm}^3$: [illegible] large !



→ **Promote $\Delta(1232)$ to leading order in COMBINED CHIRAL & LARGE N_c EXPANSION**

TEST of CHIRAL PERTURBATION THEORY

$\gamma^* + p \to p + \pi^0$ Total Cross Section vs. Q^2



— ChPT, V. Bernard *et al.*, Nucl. Phys. **A607** (1996) 379-401.

— MAID, D. Drechsel *et al.*, Nucl. Phys. **A645** (1999) 145-174.
and S. S. Kamalov *et al.*, Phys. Lett. **B 522** (2001) 27-36

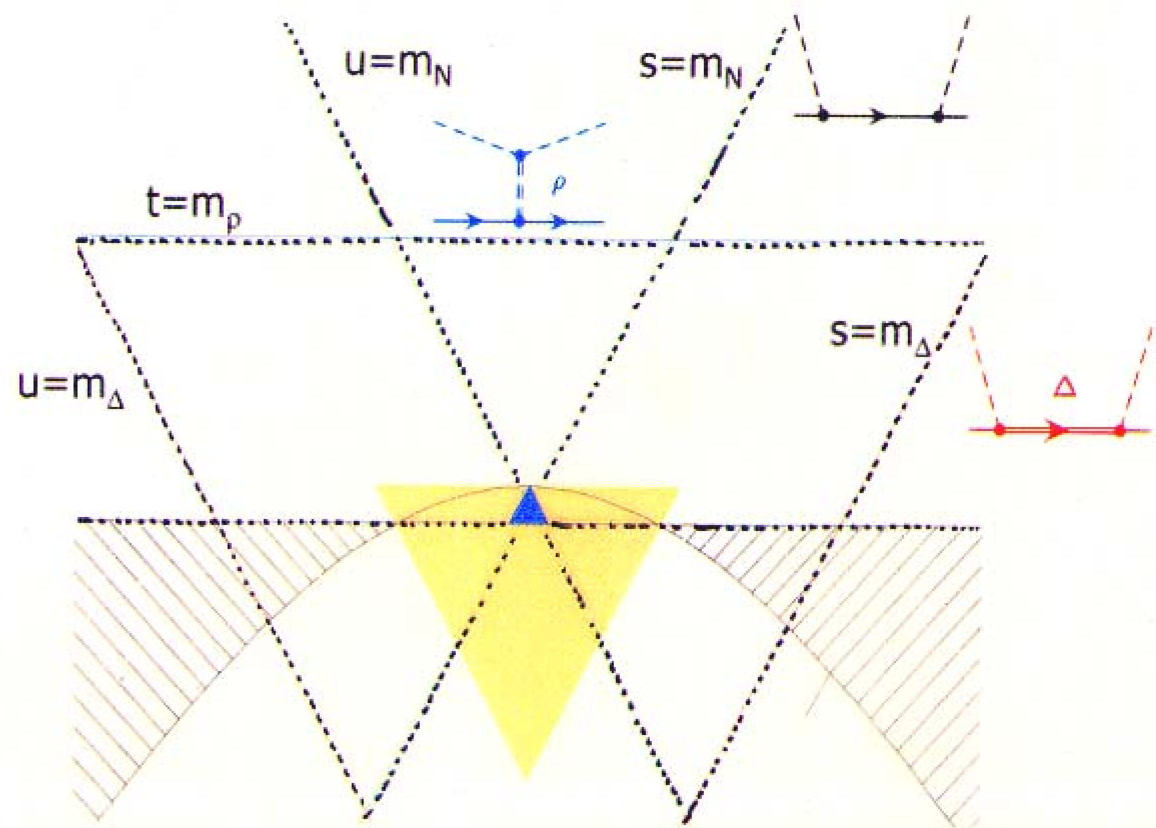
♦ $Q^2 = 0$ A. Schmidt *et al.*, Phys. Rev. Lett. **87**, 232501 (2001).
$Q^2 = 0.05\,\mathrm{GeV}^2/c^2$ H. Merkel *et al.*, Phys. Rev. Lett. **88**, 012301 (2002).
$Q^2 = 0.1\ \ \mathrm{GeV}^2/c^2$ M. O. Distler *et al.*, Phys. Rev. Lett. **80** 2294 (1998).

(Th. Becher)

πN Scattering

Low Energy Region

- Low energy expansion breaks down, once resonances are produced!



6. Chiral Symmetry and Chiral Dynamics

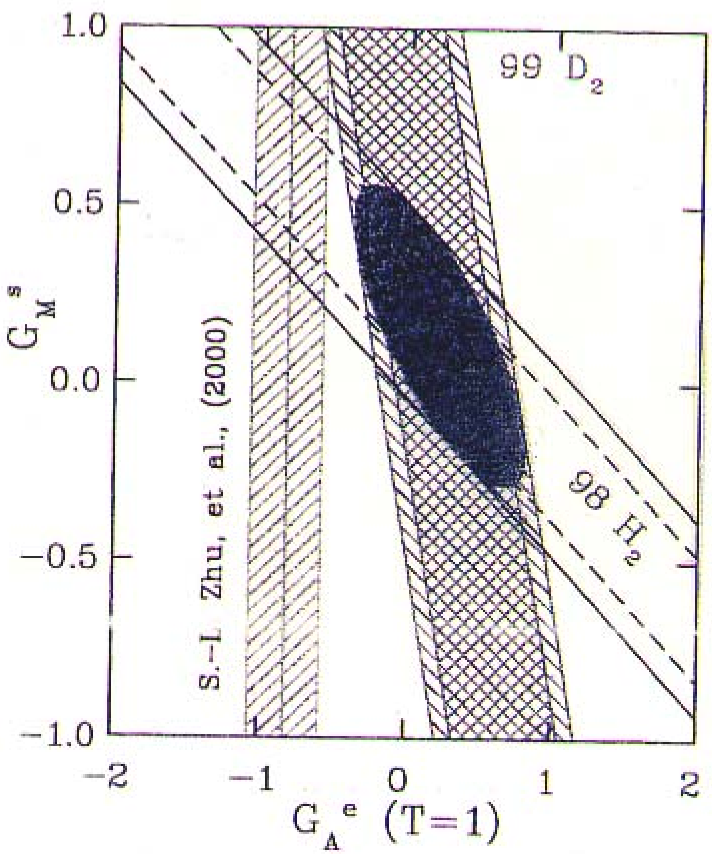
("QCD Lite")

- Chiral Perturbation Theory and beyond

5. STRANGENESS

in the NUCLEON

➡ VECTOR CURRENT $\langle p|\bar{s}\gamma_\mu s|p\rangle$ from parity-violating e-scattering (F. Maas)



SAMPLE

➡ HAPPEX @ JLAB :

$$G_E^s + 0.4\, G_M^s = 0.025 \pm 0.034 \quad (Q^2 \simeq 0.5\ \mathrm{GeV}^2)$$

➡ Progress from MAINZ :

limits on strange vector current in the proton

LOOKING FORWARD :

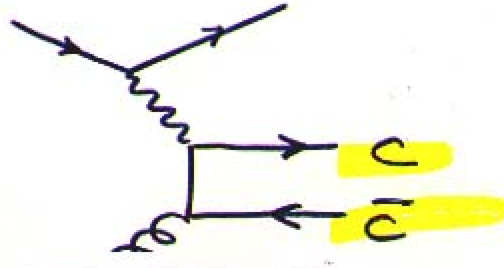
Key observables and experiments which will measure them

Quantity	Experiment	Dates
Δg	COMPASS	2003
	HERMES	2002 +
	RHIC	2002-05
	SLAC E-161	2005
Flavour separation	HERMES	2002
	RHIC	2002-04
Λ polarization	RHIC	2002+
Transversity, h_1	COMPASS	2004+
	HERMES	2002-03
	RHIC	2002+
Transversity from e^+e^-	BELLE	2002
DVCS plus meson production	COMPASS	2004+
	HERMES	2004-05
High energy GDH integrand	SLAC E-159	2006

(from: S. Bass, A. de Roeck, Trento proceedings 2001)

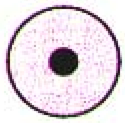
ΔG: high p_T pairs

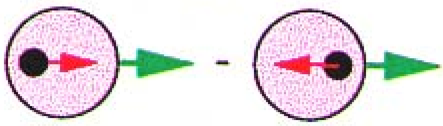
and

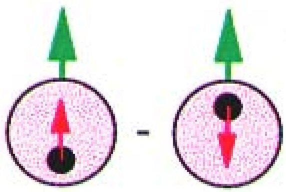


Transverse polarization

- Three leading order distribution functions:

f_1 =  momentum carried by quarks

g_1 =  longitudinal quark spin, $\Delta\Sigma$

h_1 =  transverse quark spin, $\delta\Sigma$

- Importance of $h_1(x)$ measurements:
  - HERMES data: $\Delta\Sigma = 0.30 \pm 0.04 \pm 0.09$
  - $\Delta\Sigma$ is so small because of axial anomaly:
    * Redistribution of angular momentum in nucleon:

$$\tfrac{1}{2}\Delta\Sigma \approx +0.15, \quad \Delta G \approx +1.0, \quad L_z \approx -0.65$$

    * Redistribution is less in transverse case:

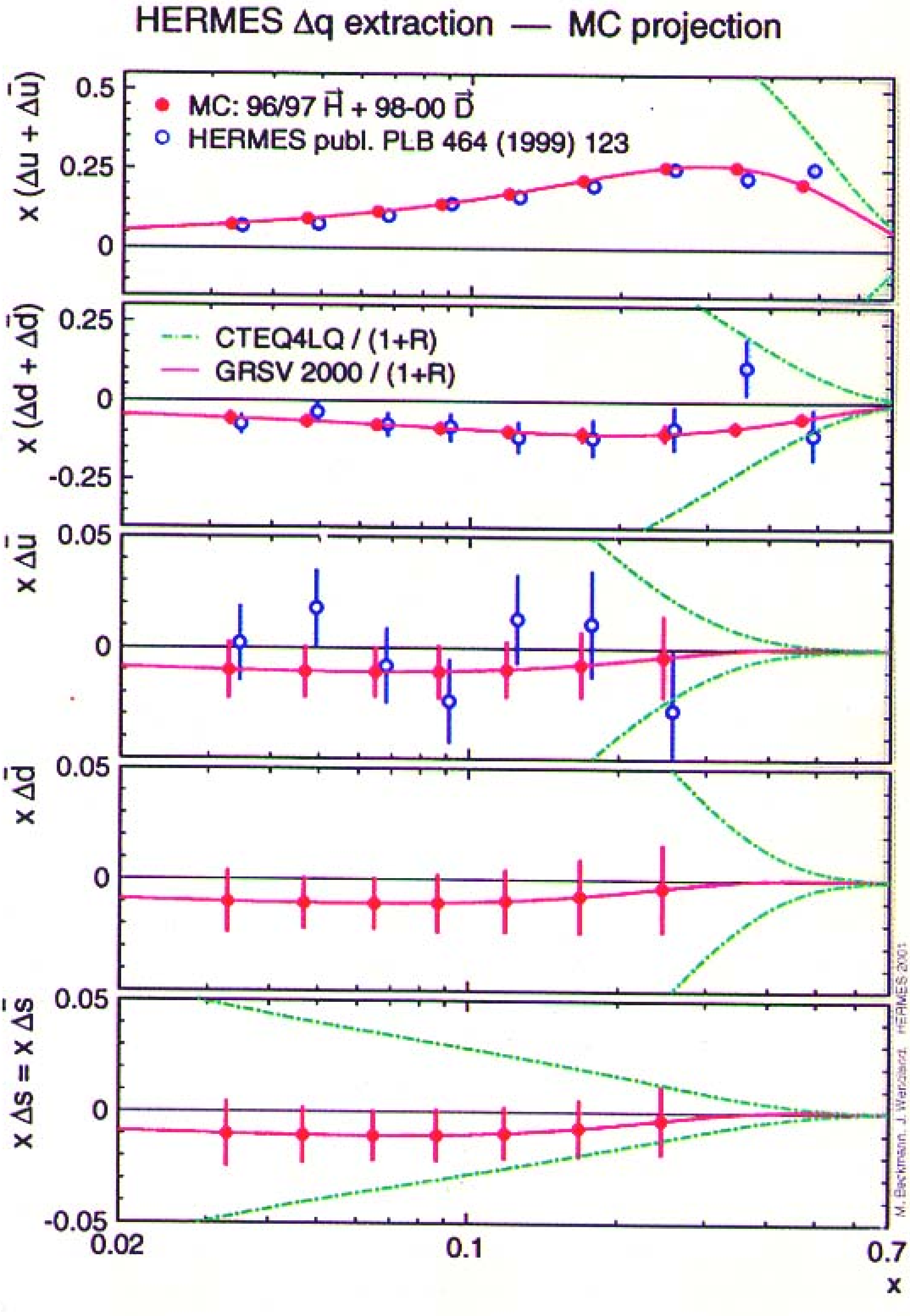
$$\Delta\Sigma \;<\; \delta\Sigma \;<\; 1 \quad \text{(Quark Parton Model)}$$

    * Lattice QCD calculation (Phys. Rev. D 56 (1997) 433):

$$\Delta\Sigma \;=\; 0.18(10) \quad \text{and} \quad \delta\Sigma \;=\; 0.56(9)$$

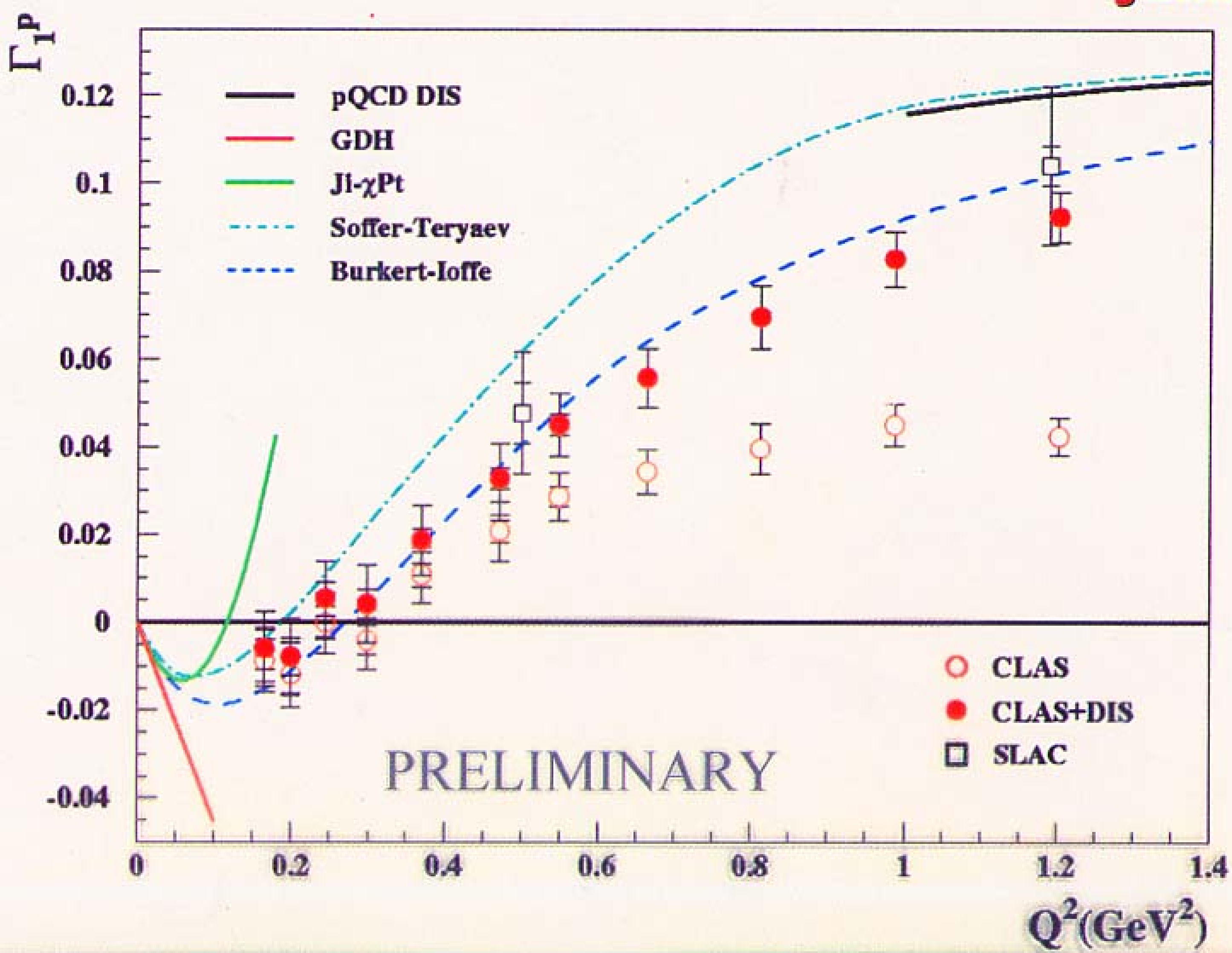
Polarized quark distributions - 2

- Expected data quality with '00 data included:

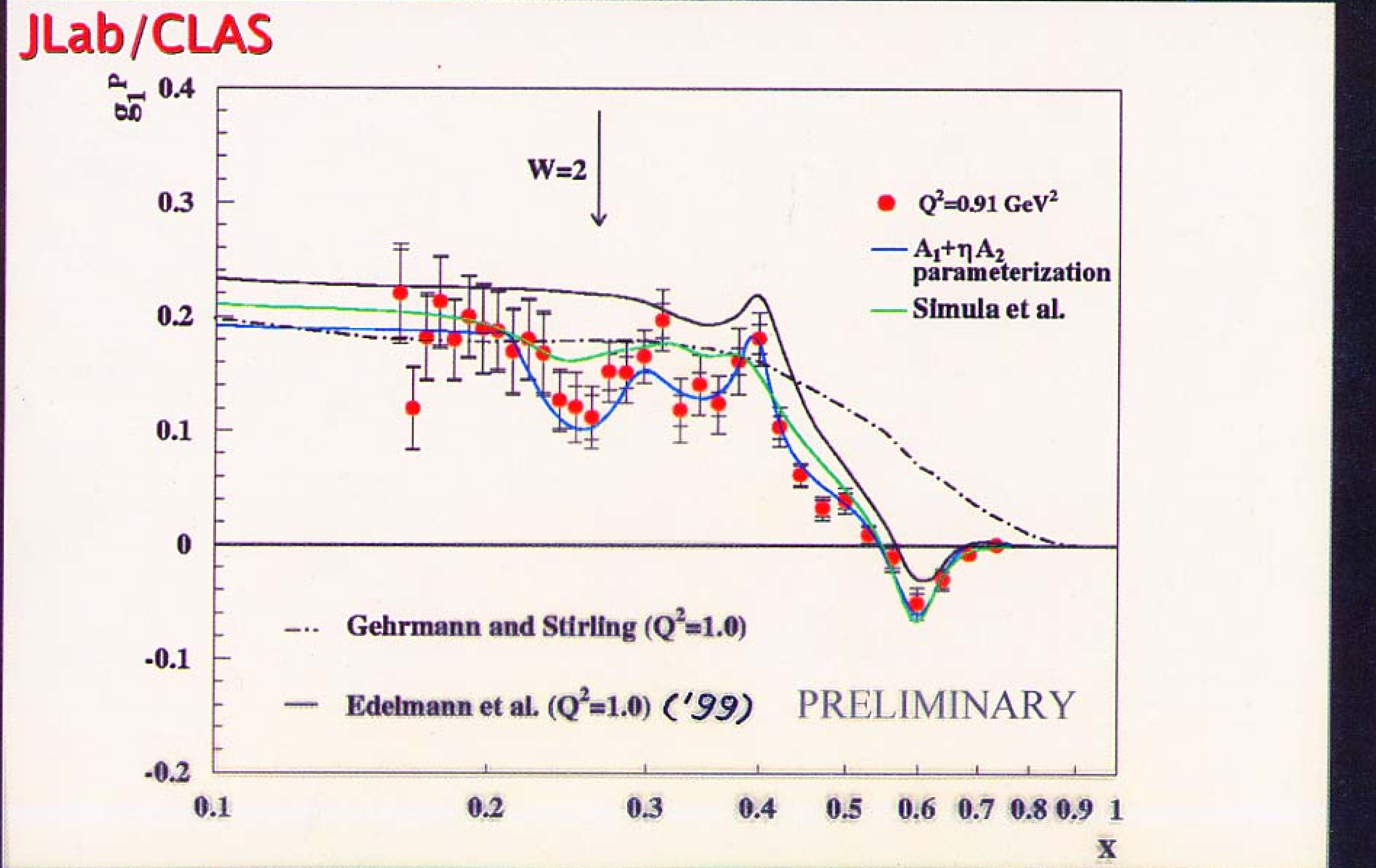


First moment of g_1 for the proton

JLab/CLAS

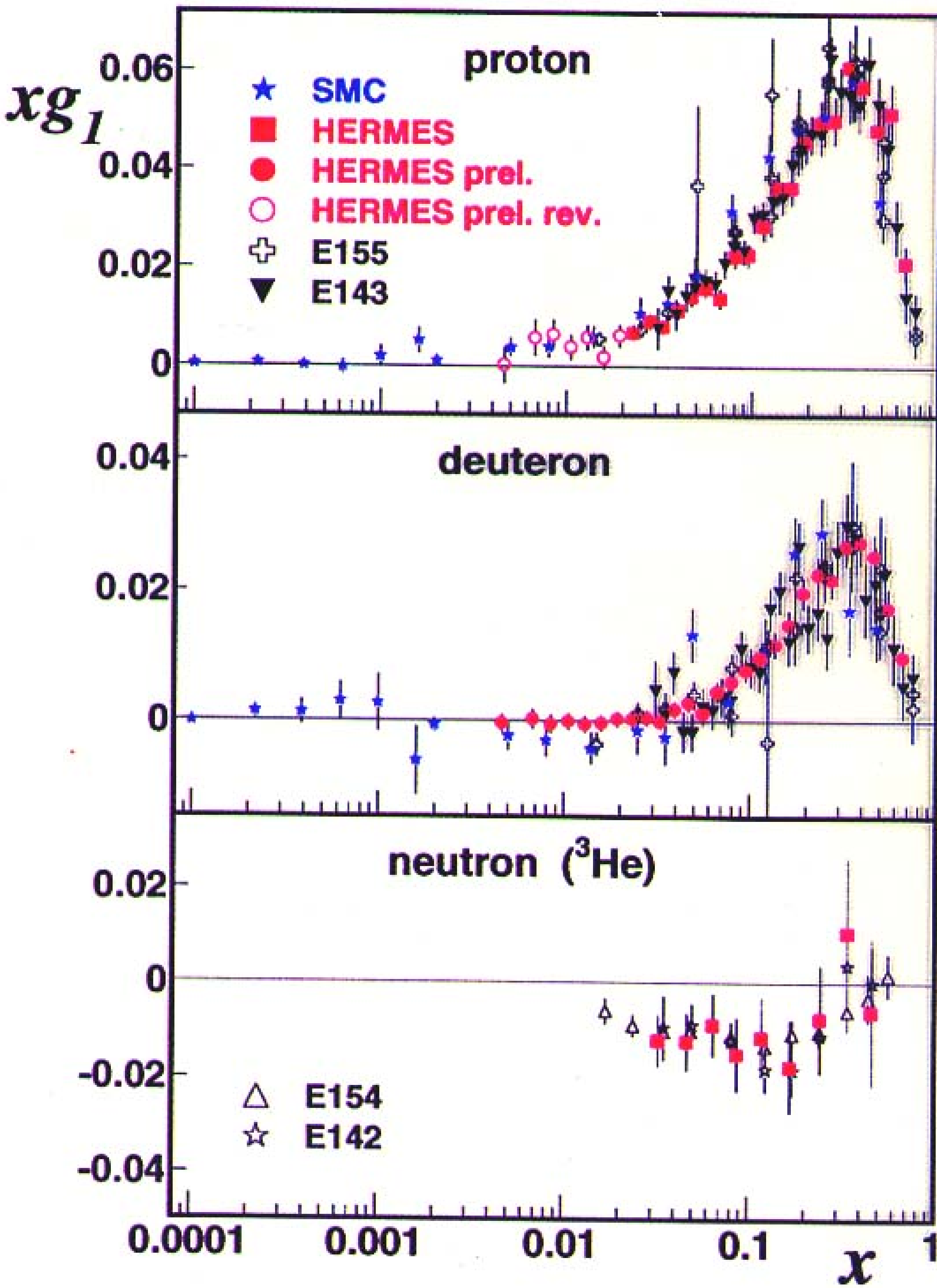


$g_1(x)$ for the proton



Polarized Structure Functions

- Overview of existing $xg_1(x)$ data:



4. Spin Structure

★ **Hermes** (G. van der Steenhoven)

$$\Delta\Sigma_q = \Delta u + \Delta d + \Delta s = 0.3 \pm 0.1$$
$$= 1 - 2(\Delta G + L_z)$$

➡ flavour decomposition

➡ Gluon contribution ΔG

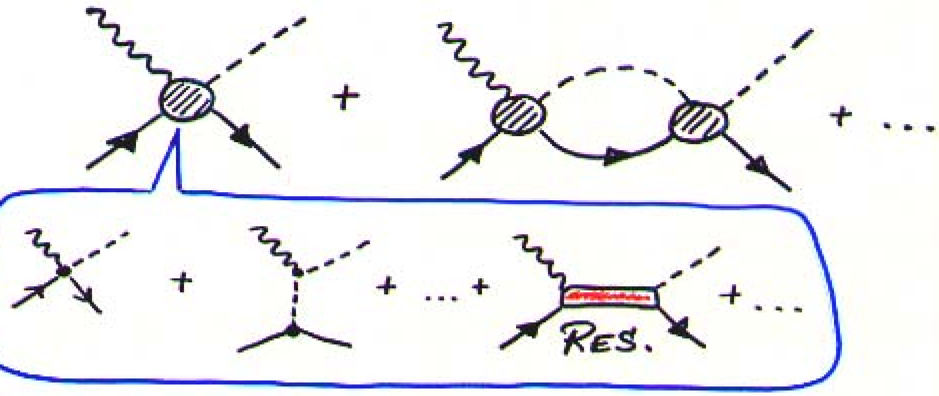
➡ transverse spin $\delta\Sigma_q$

★ **JLab** (R. De Vita)

➡ Spin structure and resonances

THEORY

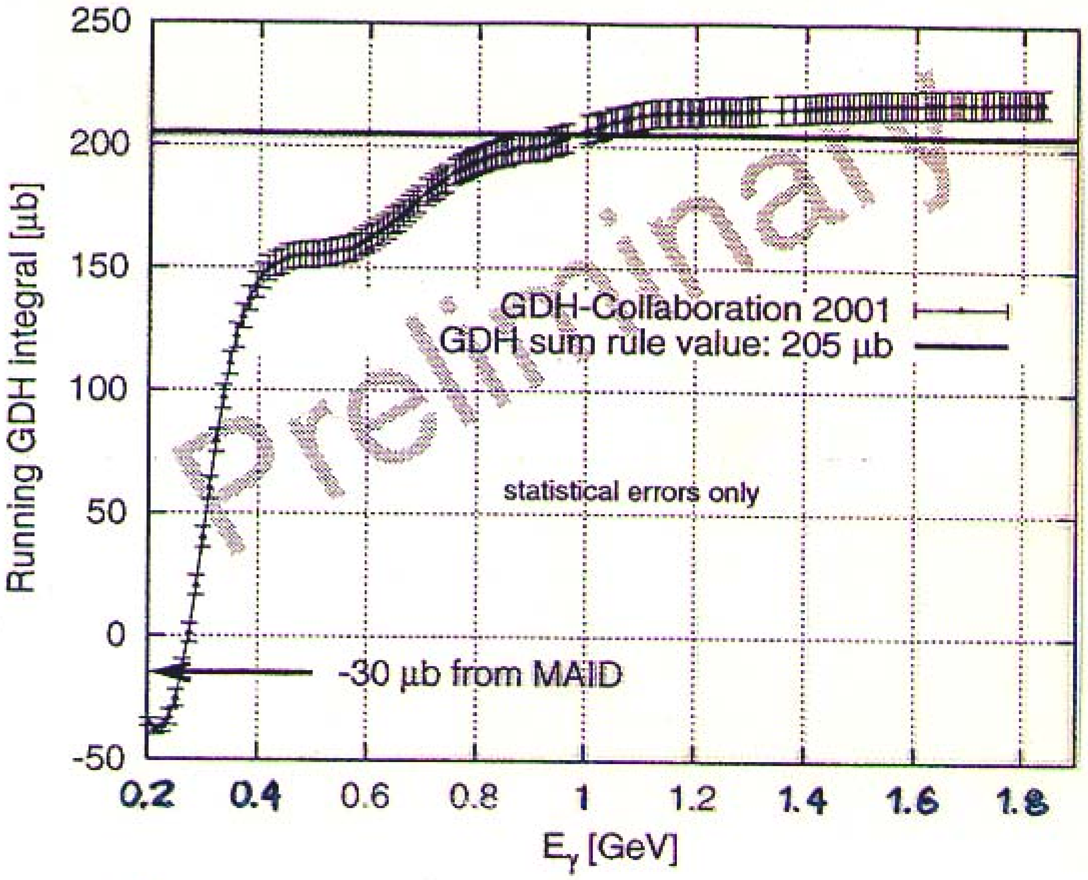
- VARIETY of MODELS (Review: T. Sato)



- STATUS:
  - ➡ Physics of Δ RESONANCE: o.k.
  - ➡ 2nd RESONANCE region: important to get ππN CHANNELS under control!
  - ➡ 3rd and "higher" RESONANCE region: MUCH to do: detailed resonance vs. background analysis etc.

- Hints & comments:
  - ➡ Reminder of FANO THEORY (W. Ligterink) (see: Atomic physics & quantum optics)
  - ➡ Quest for PARITY DOUBLETS (Cohen & Glozman)

GERASIMOV – DRELL – HEARN SUM RULE



MAINZ & BONN

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

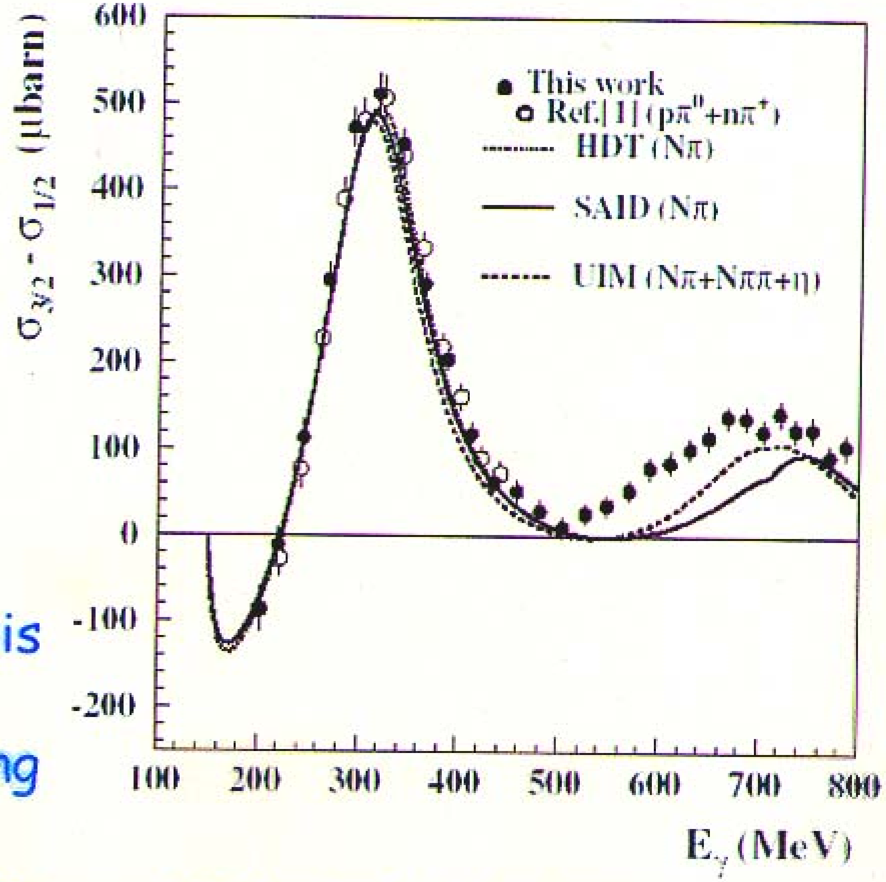
➡ high energy part of GDH integral needs to be tested!

(SLAC E-159)

Double polarization measurements

Polarized beams and targets:
first results

- MAINZ
- LEGS
- BONN

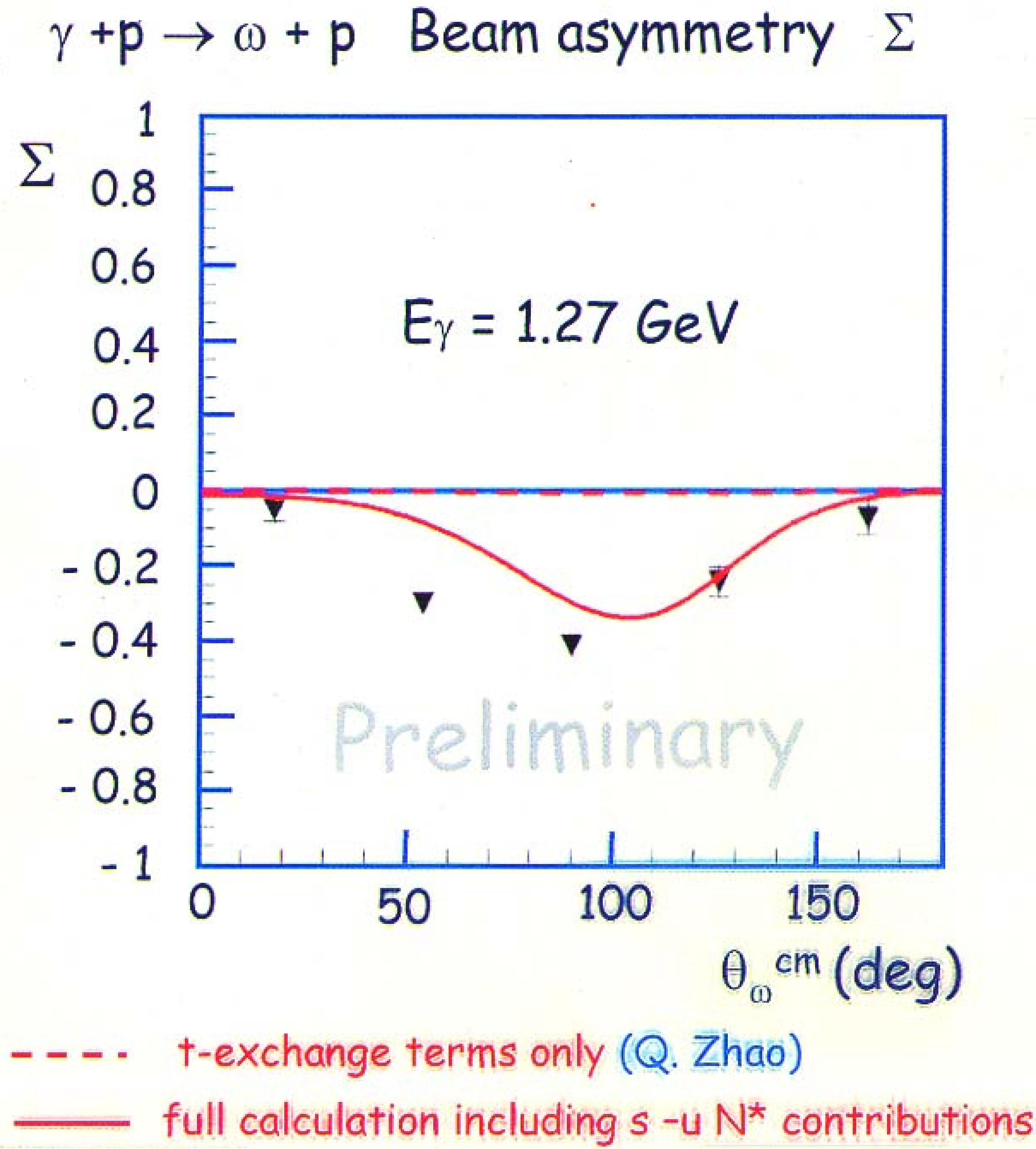


- Predictions based on multipole analysis do not include $N\pi\pi$ and η channels
- Unitary Isobar Model is missing strength in the second resonance region
- Contributions to GDH sum-rule and γ_0 spin polarizability are measured for the first time.

PRL 87(2001)022003

→ Braghieri, Michel

$\vec{\gamma} + p \rightarrow \omega + p$



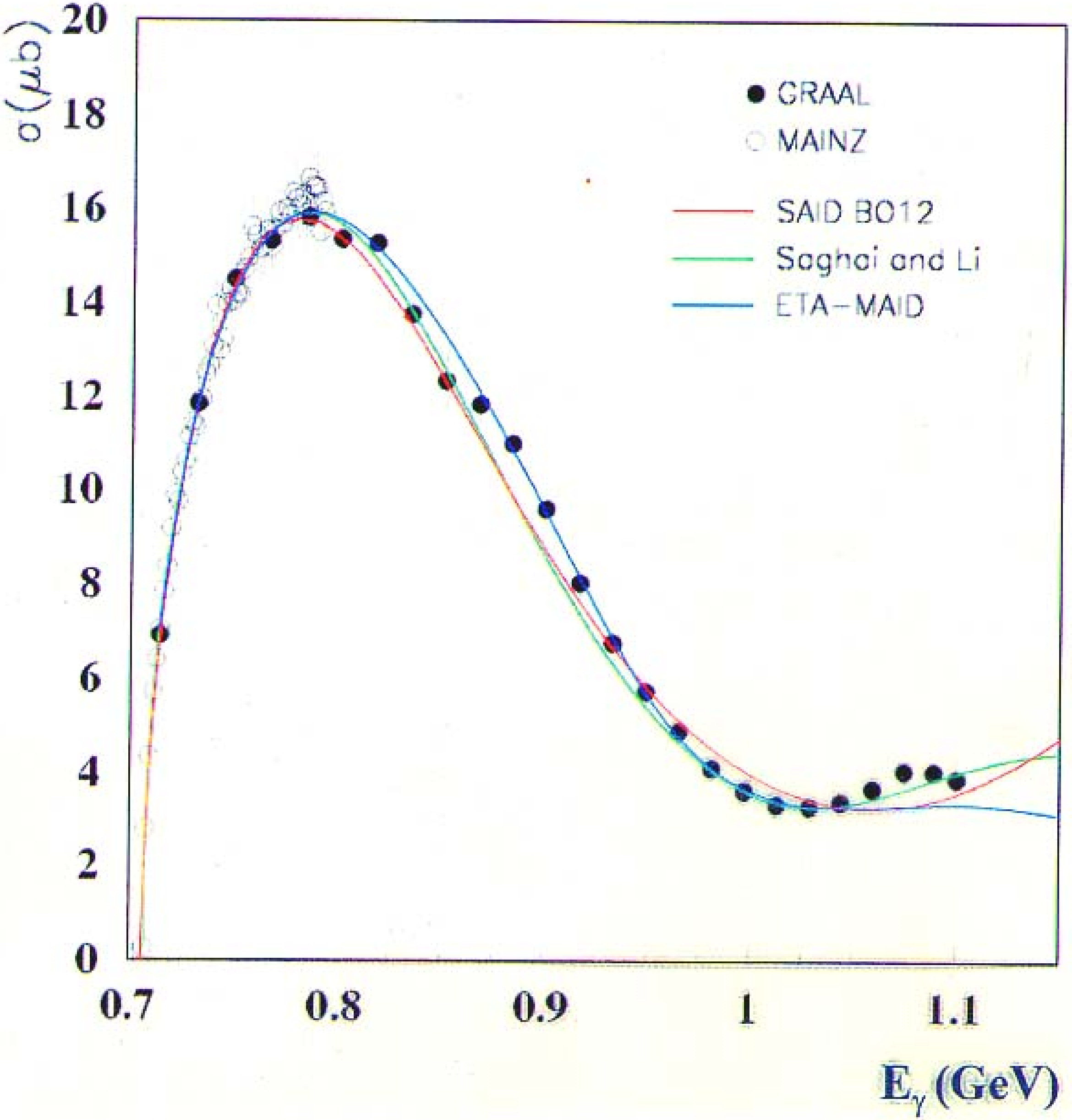
The beam asymmetry Σ is very sensitive to the inclusion of the N* resonances.

The inclusion of the diffractive t-exchange terms alone produces no asymmetry.

First preliminary results from GRAAL.
Sizable contribution from N* resonances.

Model from Zhao includes $P_{11}(1440)$, $S_{11}(1535)$, $D_{13}(1520)$, $P_{13}(1720)$, $F_{15}(1680)$, $P_{13}(1900)$, $F_{15}(2000)$

$\vec{\gamma} + p \rightarrow \eta + p$



Graal and Mainz data

Graal data cover the full resonance.

They show a "structure" at 1050 MeV, confirmed by new CLAS data

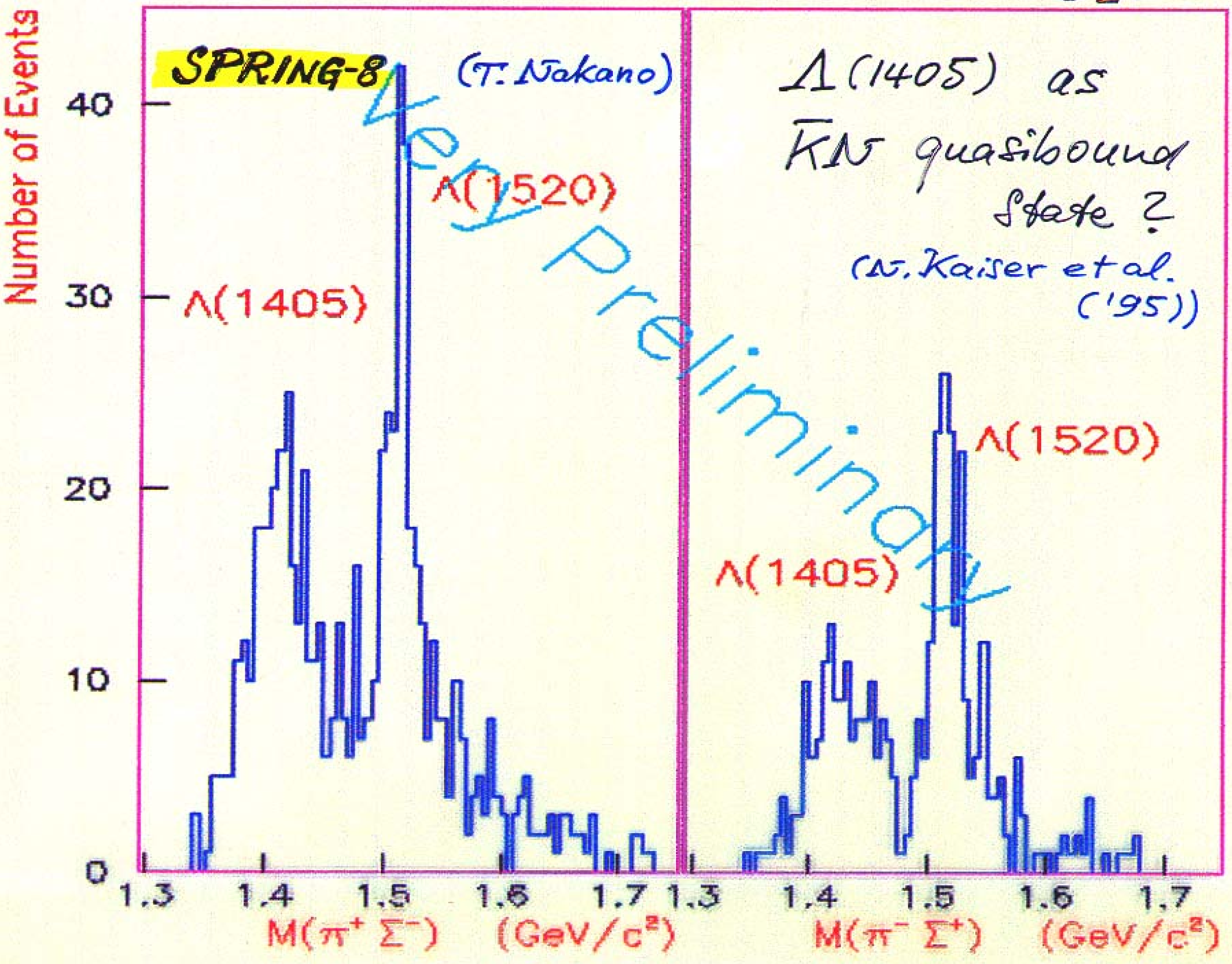
→ Pasyuk

Red curve: SAID BO12

Blue curve : eta MAID

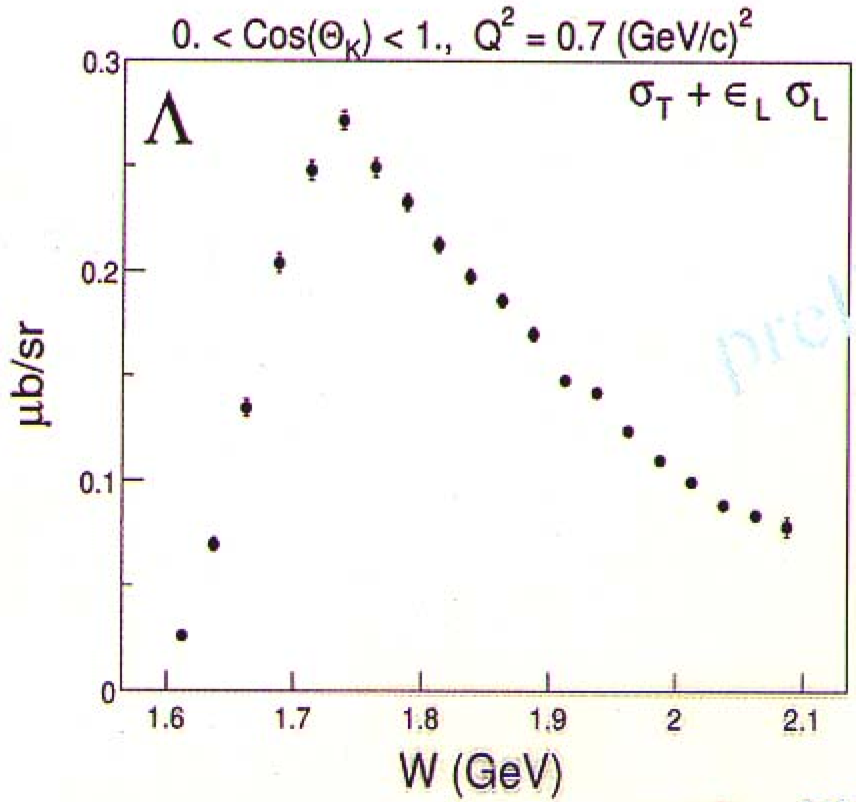
Green curve: B. Saghai and Z. Li

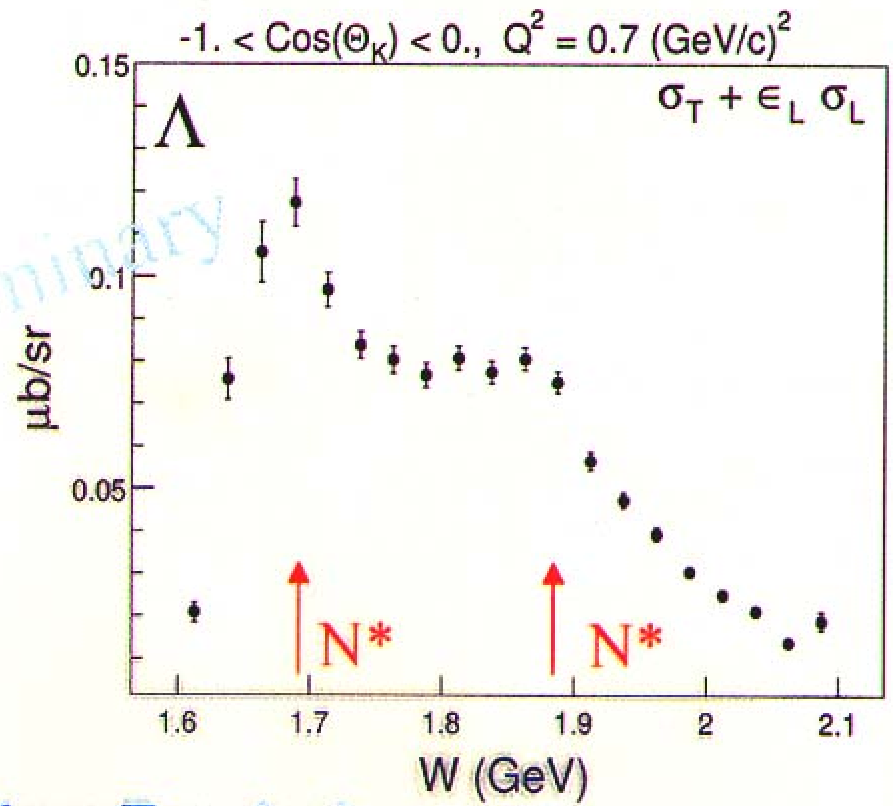
K+ PHOTOPRODUCTION



Search for resonances in hyperon production

CLAS $ep \longrightarrow eK^{+}Y$





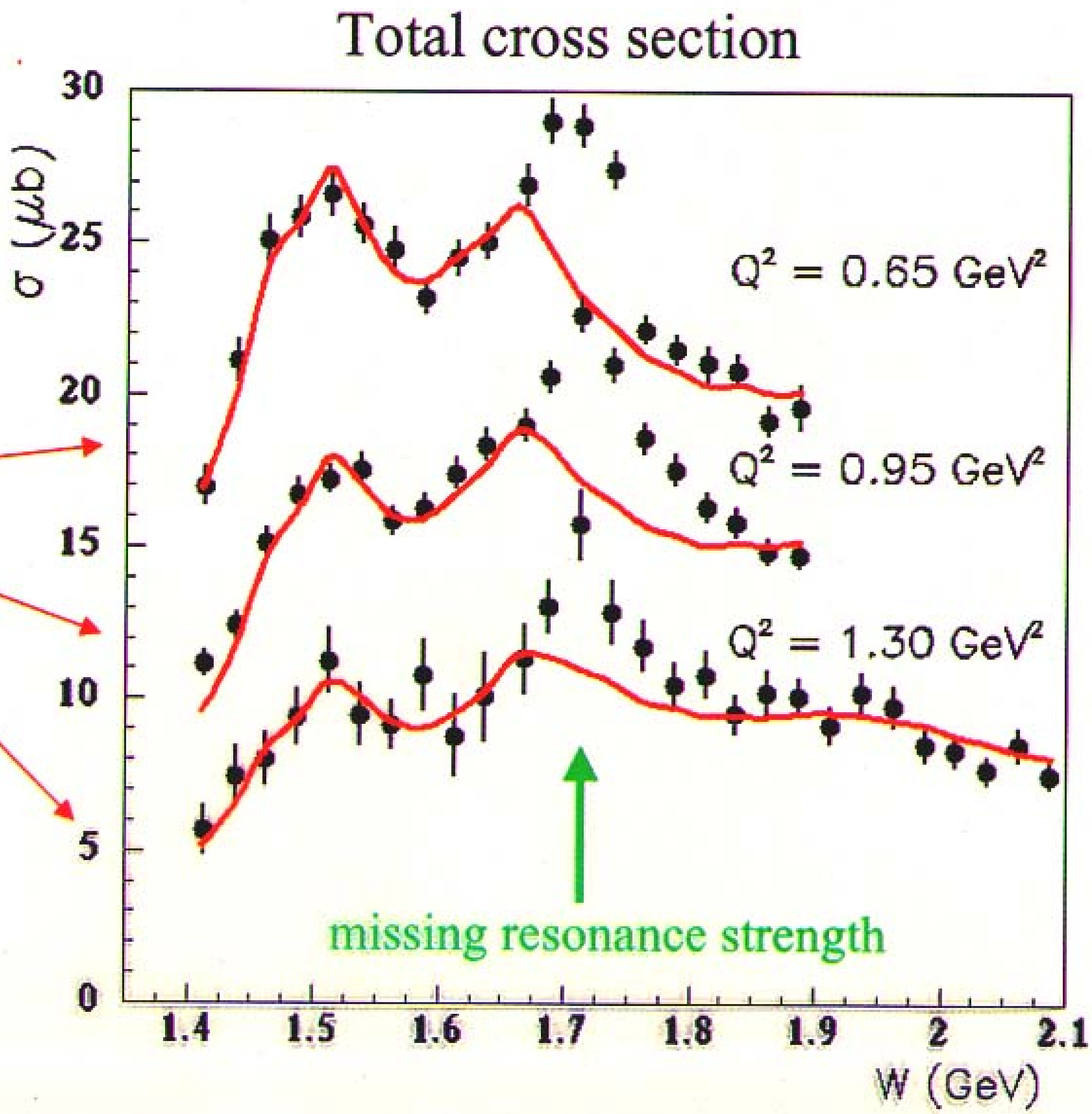
→ ***Niculescu/Feuerbach***

Resonances in $\gamma^* p \rightarrow p\pi^+\pi^-$

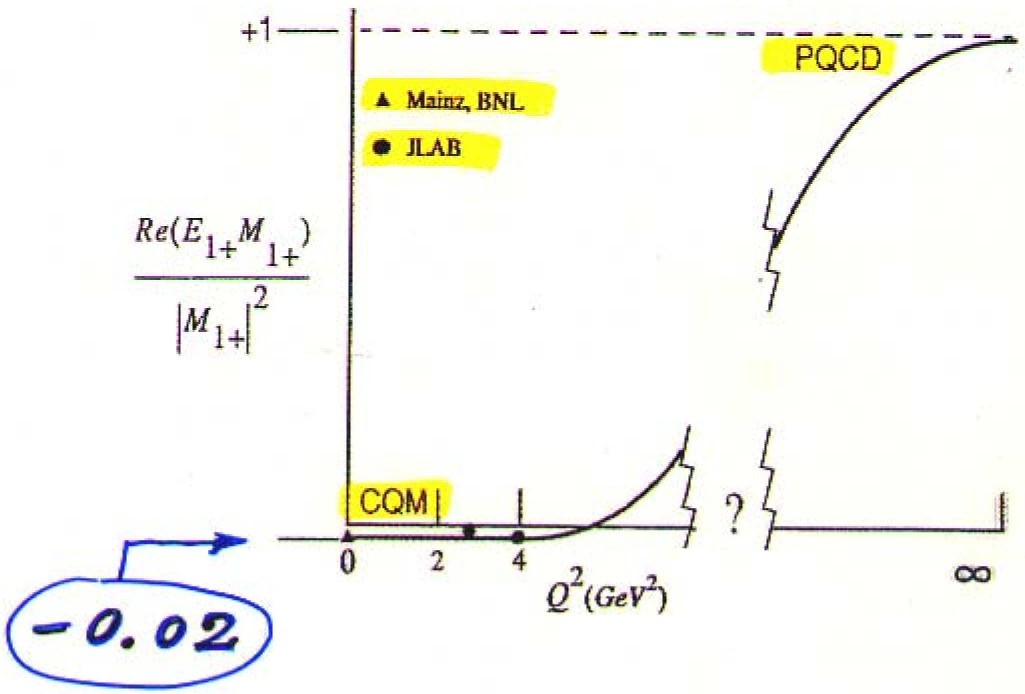
CLAS

Genova-Moscow
Isobar model fit

$\Gamma_{N\pi\pi}$ PDG
$\Gamma_{N\gamma}$ AO/SQTM



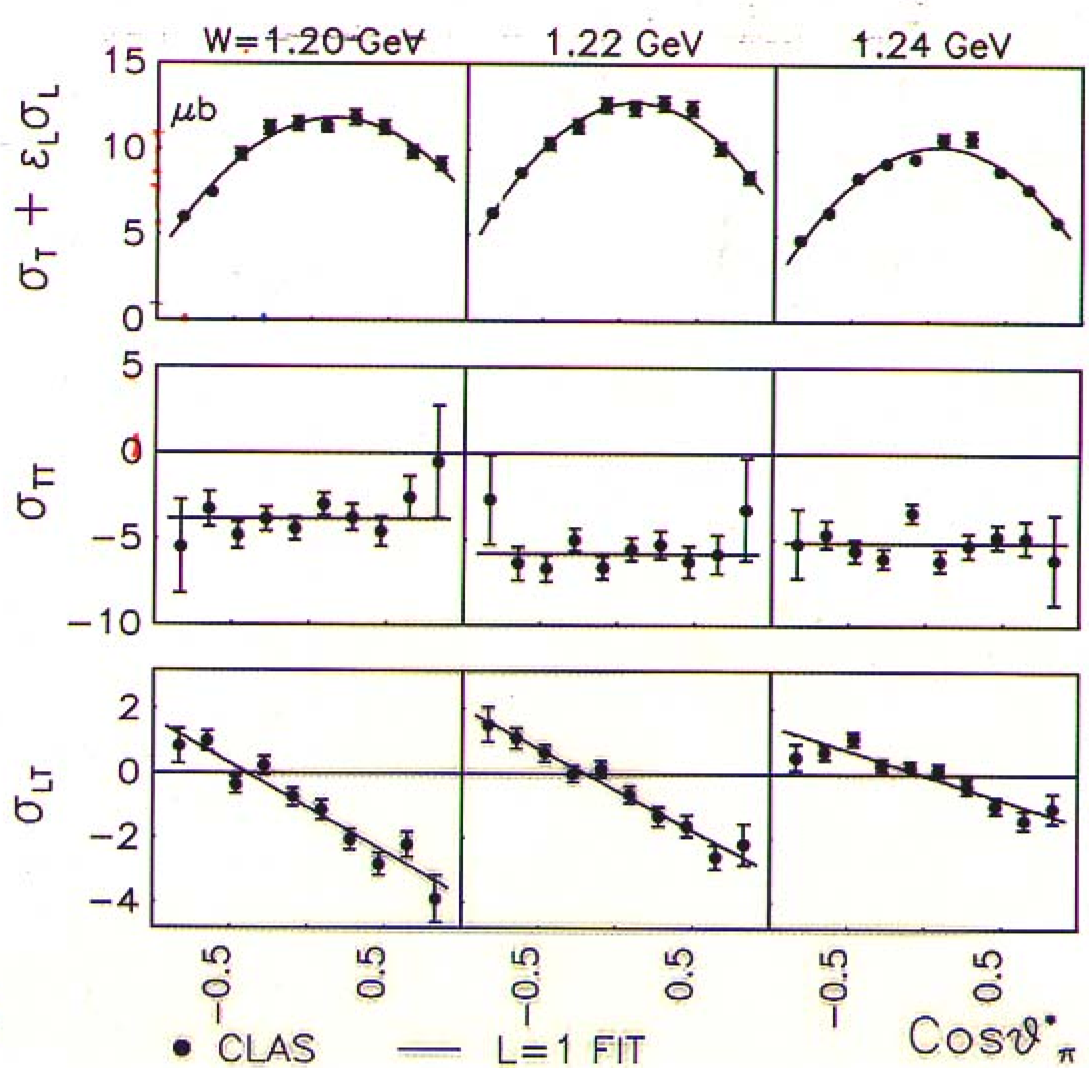
E2/M1 RATIO
N → Δ



... Looking forward!

Multipole Analysis for $\gamma^* p \longrightarrow p\pi^o$

CLAS



$Q^2 = 0.9$ GeV^2

$|M_{1+}|^2$

$Re(E_{1+}M_{1+}^*)$
$|M_{1+}|^2$

$Re(S_{1+}M_{1+}^*)$

→ *L.C. Smith*

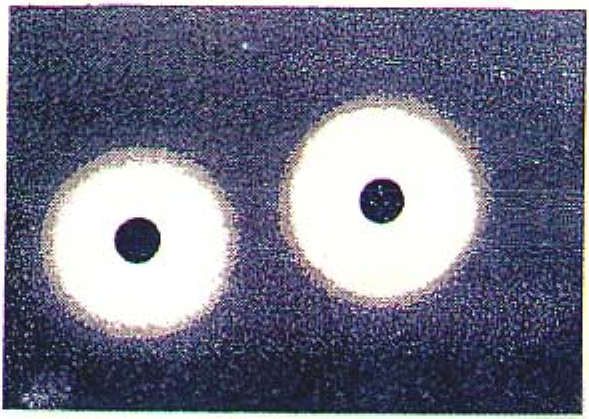
3. BARYON RESONANCES

significant progress:

- CLAS
- MAINZ
- BONN
- GRAAL
- LEGS

REMINDER of QUASIPARTICLES in MANY-BODY SYSTEMS

example: QUASI-ELECTRONS in electron gas



COULOMB int. SCREENED by cloud of ELECTRON-HOLE excitations

QUASIPARTICLES interact WEAKLY

but:

CONSTITUENT QUARKS

experience

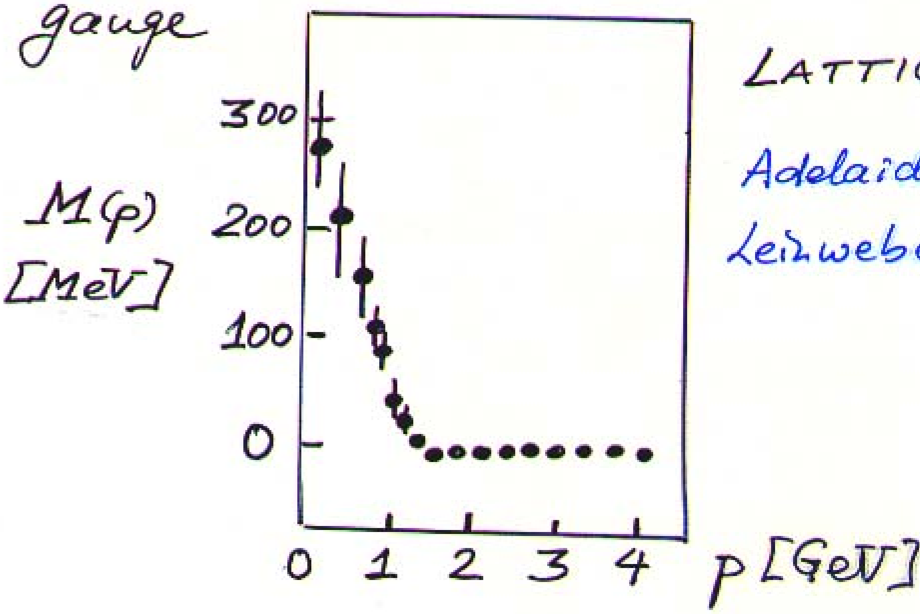
- CONFINEMENT
- relatively strong RESIDUAL INTERACTIONS

both gluon (color) exchange
and spin-flavour dependent interactions
(e.g. Goldstone pion exchange)
} HF splittings

QUARK PROPAGATOR

* (EUCLIDEAN) $S_E(p) = \dfrac{Z(p^2)}{i\gamma\cdot p + M(p^2)}$

LANDAU gauge

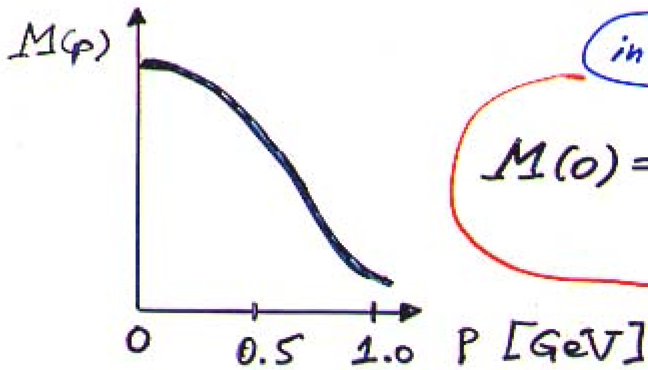


LATTICE

Adelaide group
Leinweber et al.

* compare: CONSTITUENT QUARK MASS from **INSTANTONS**

(D. Diakonov)



instanton size $\simeq$ 1/3 fm

$$M(0) = \frac{\pi\,\bar{\rho}}{N_c\,\bar{R}^2} \simeq 350\ \text{MeV}$$

average instanton separation $\simeq$ 1 fm

... but:
No confinement!

2. CONSTITUENT QUARKS

- How many **QUARKS** in a **BARYON**?

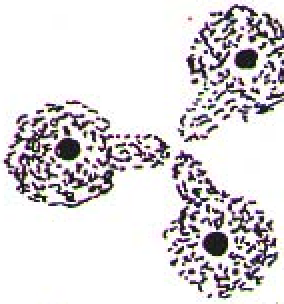
  a) SPECTROSCOPY : $N = 3$
  (S. Capstick)

  b) DEEP-INELASTIC SCATTERING:
  (HERA; R. Yoshida) $N \to \infty$

  $$\left(\int_0^1 \frac{dx}{x} F_2(x) = \int d\ln x \, F_2 \to \infty \right)$$

★ Interpolate between "**3**" and "**∞**":
"CONSTITUENT QUARKS"
(fuzzy concept!)

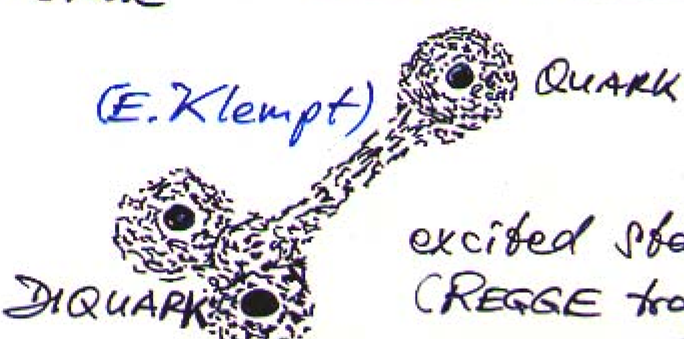
(Y. Simonov)



ground state

VACUUM STRUCTURE!

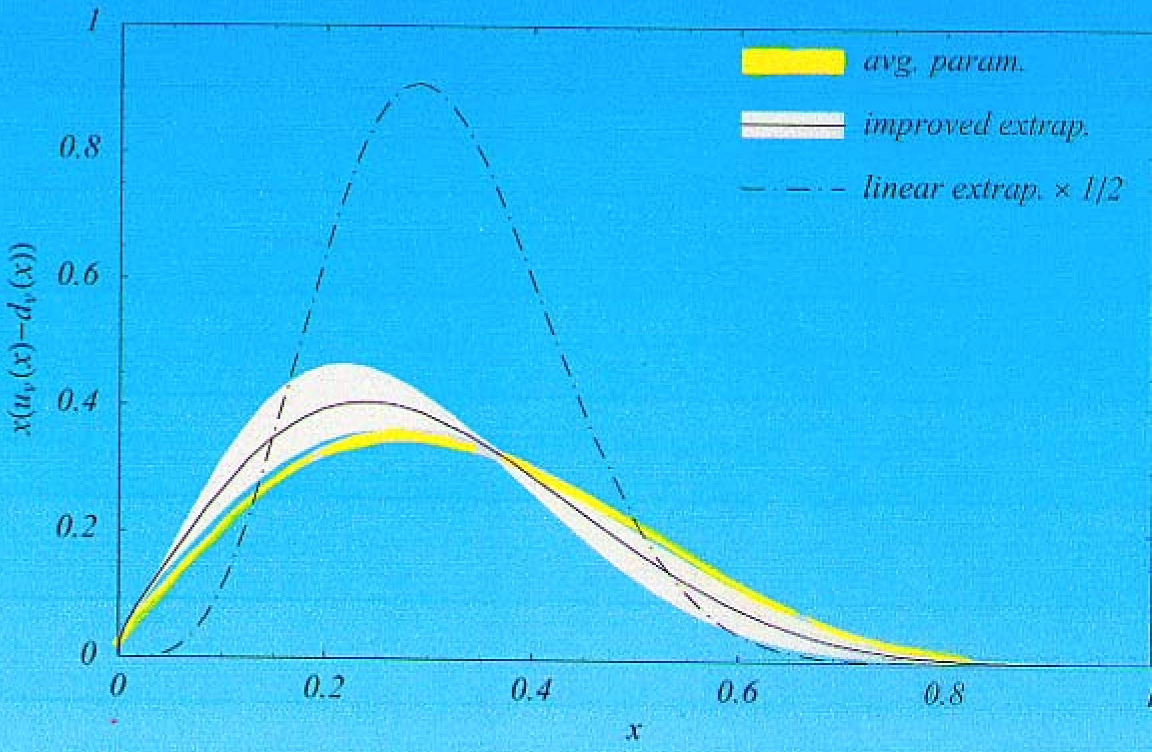
(E. Klempt)



excited states
(REGGE traj.)

Comparison with Data

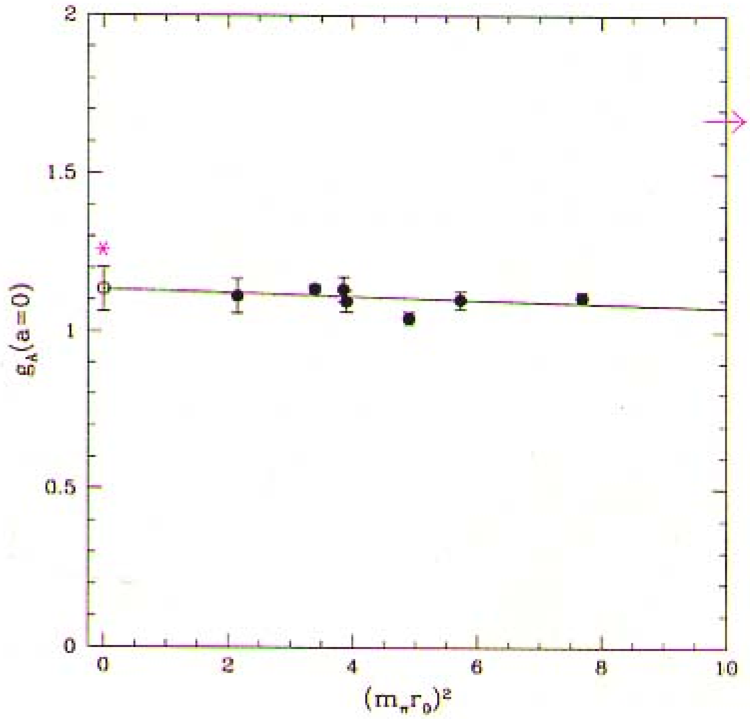
- Can use lowest 4 moments to reconstruct x-dependence of $u_v(x) - d_v(x)$

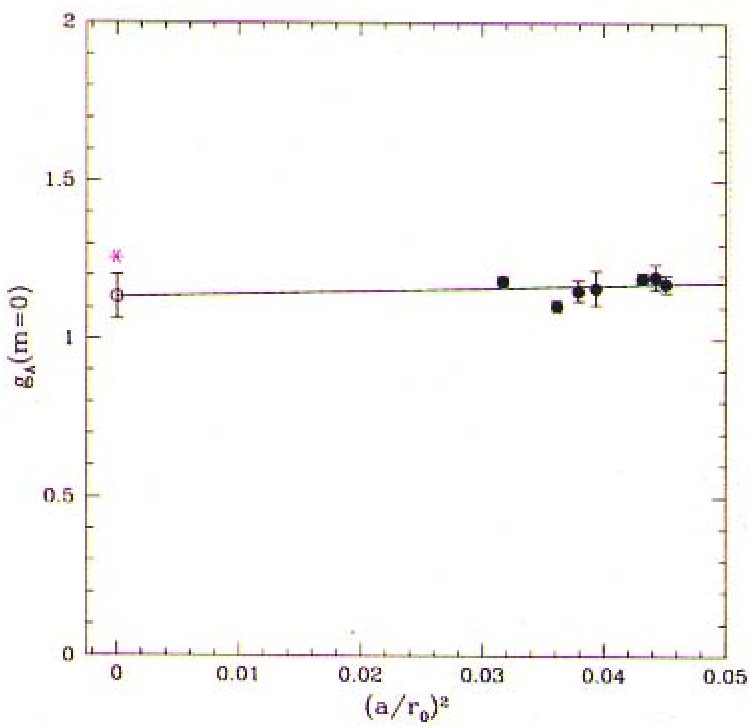


Detmold, Melnitchouk....

- Dark shading is world data
- Light shading chiral extrapolation

$g_A \quad N_f = 2$





Fit ansatz: $g_A = A + B(m_\pi r_0)^2 + C(a/r_0)^2$

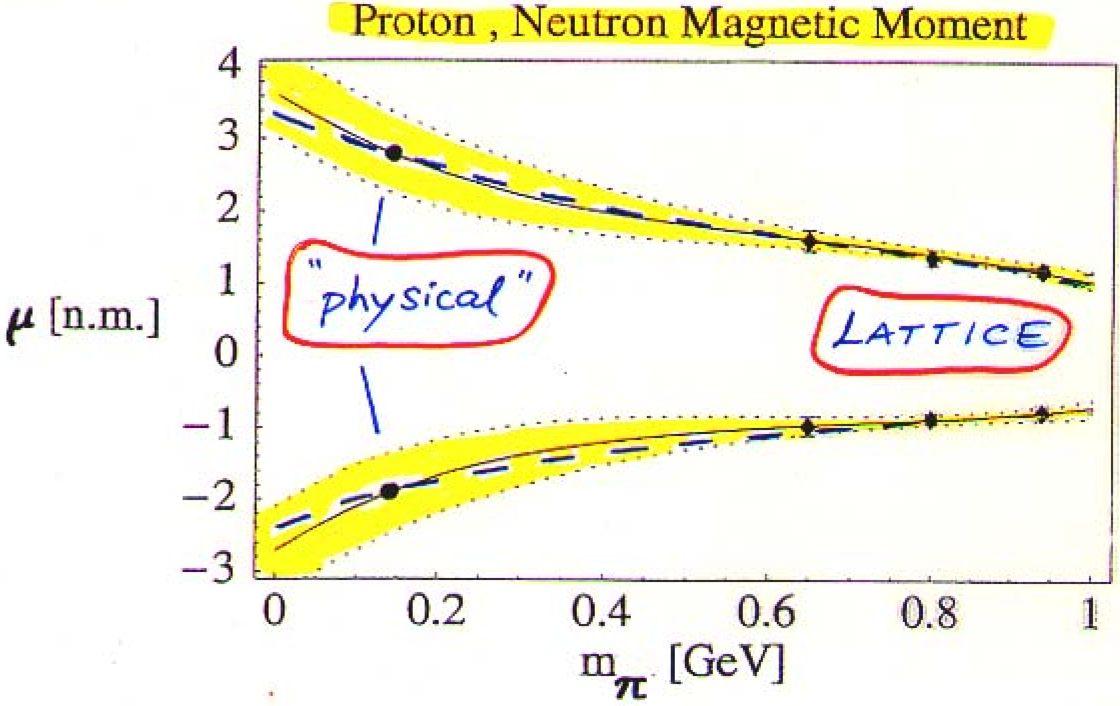
g_A on the LATTICE: "FULL" QCD

G. Schierholz

$g_A = 1.26$

CHIRAL EXTRAPOLATION of LATTICE QCD RESULTS

(part II)



T. Hemmert, W.W.

- - - - PADÉ fit $\mu_i = \frac{\mathring{\mu}_i}{1 + \alpha_i m_\pi + \beta_i m_\pi^2}$

(A.W. Thomas)

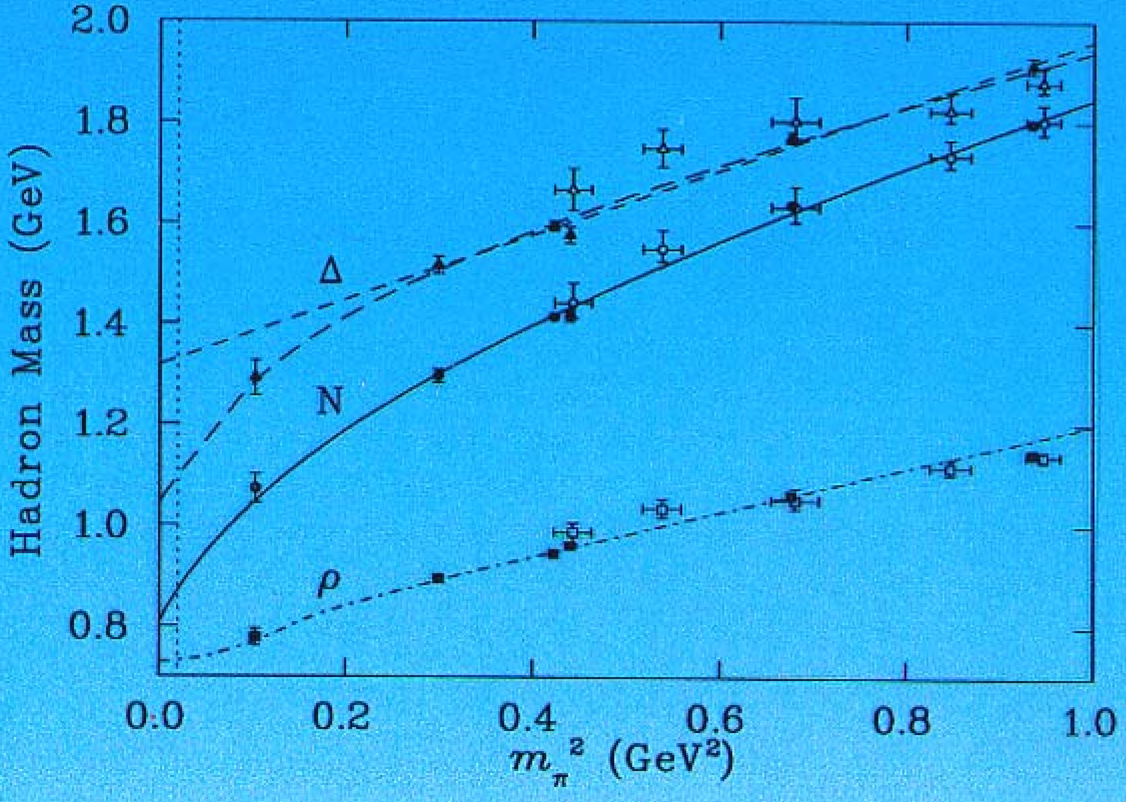
——— CALCULATED using CHIRAL EFFECTIVE FIELD THEORY (incl. Δ(1232) in NLO)

(T. Hemmert, W.W.)

➡ LATTICE, near future : $m_\pi \sim 0.3$ GeV

Overview of Hadron Masses

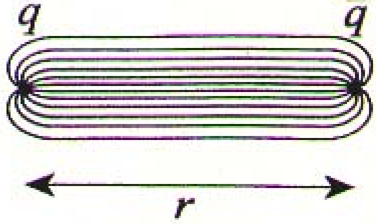
- **Behave like constituent quark model for m_π above 400–500 MeV:**



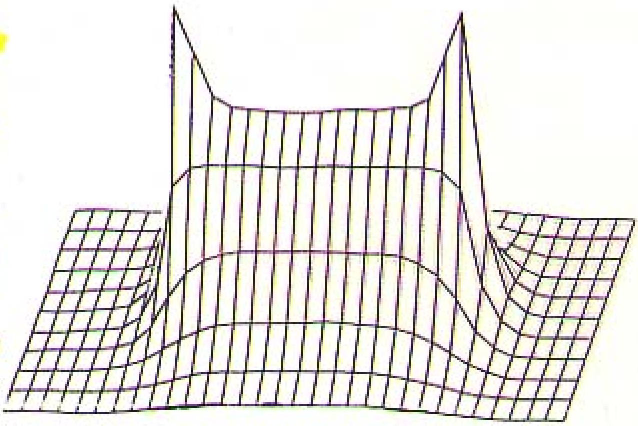
Leinweber, Wright.......

1. LATTICE QCD

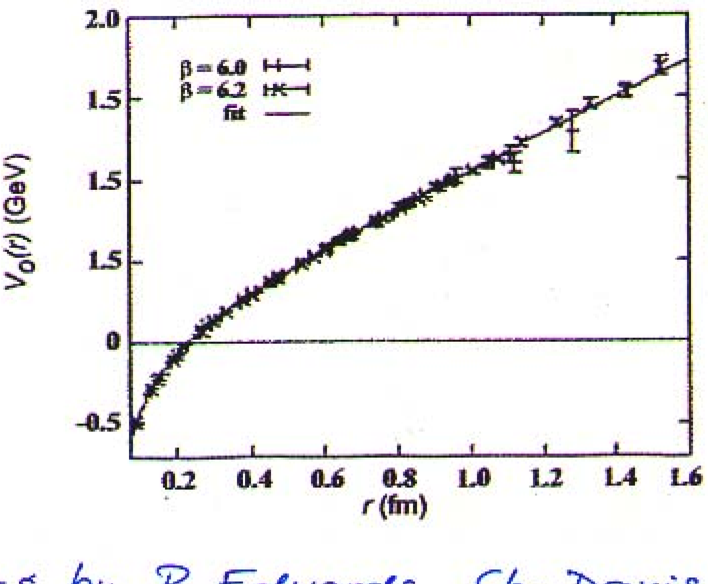
FLUX TUBE



Gluonic Action Density around STATIC SOURCES [$SU(2)_c$]



Bali, Schlichter, Schilling (1998)



STATIC $Q\bar{Q}$ POTENTIAL

(Reviews by R. Edwards, Ch. Davis)

OUTLOOK SUMMARY

* BARYON : fascinating QCD – MANY - BODY PROBLEM

* the FIELD is HEALTHY :

DATA driven ⟷ BRAIN driven ⟷ COMPUTER driven

DATA driven	BRAIN driven	COMPUTER driven
high PRECISION	"intelligent" theoretical approaches	LATTICE QCD
future: JLab upgrade, MAMI C, HERMES II/III, COMPASS, SPRING-8, ⋮	constrained by symmetries of QCD	steadily increasing power ... towards observables