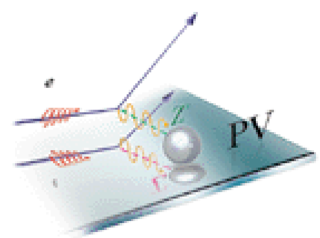
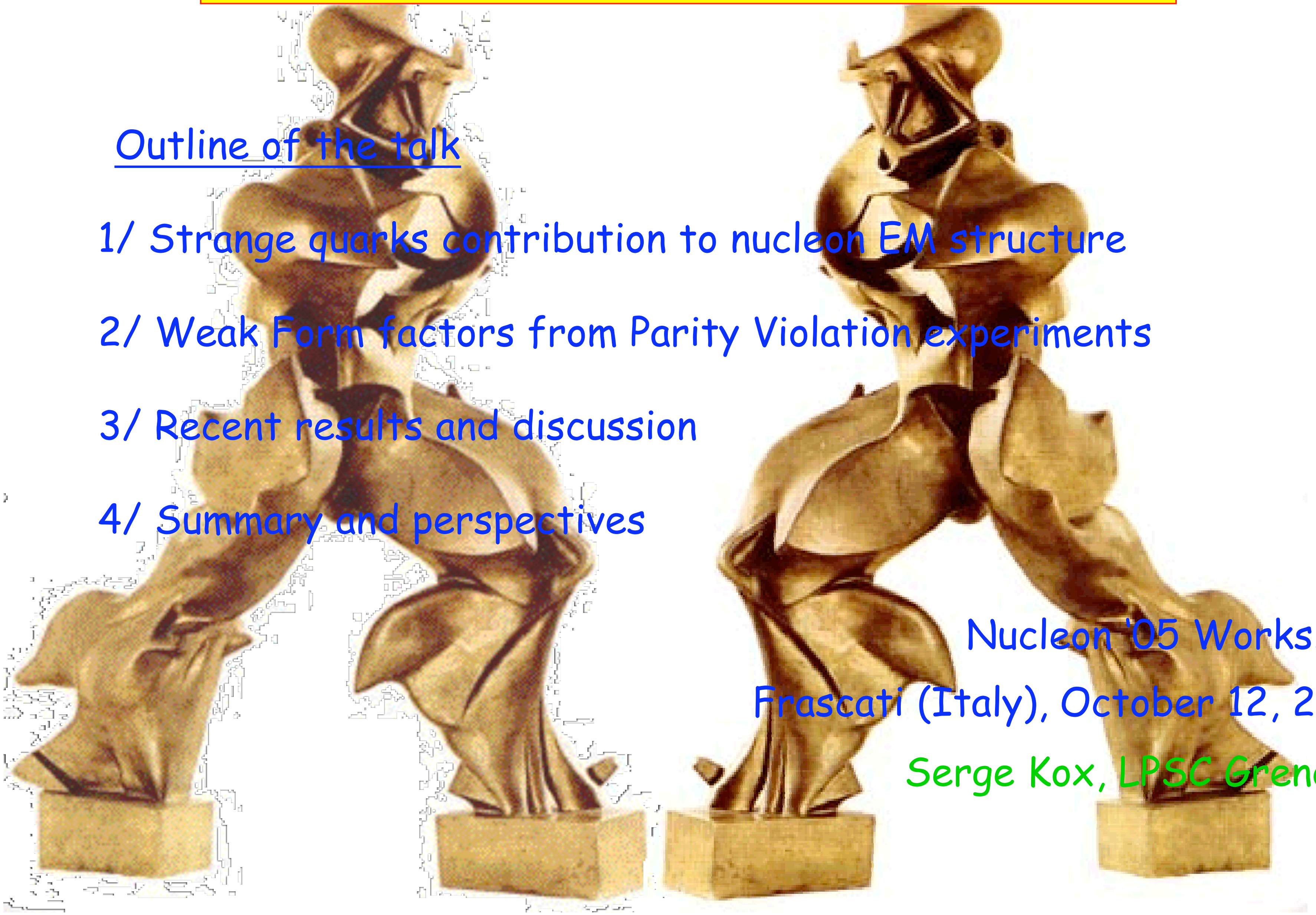

PV
Z

PV Experiments :
Electro-Weak probe and nucleon structure



Outline of the talk

1/ Strange quarks contribution to nucleon EM structure

2/ Weak Form factors from Parity Violation experiments

3/ Recent results and discussion

4/ Summary and perspectives

Nucleon '05 Workshop,

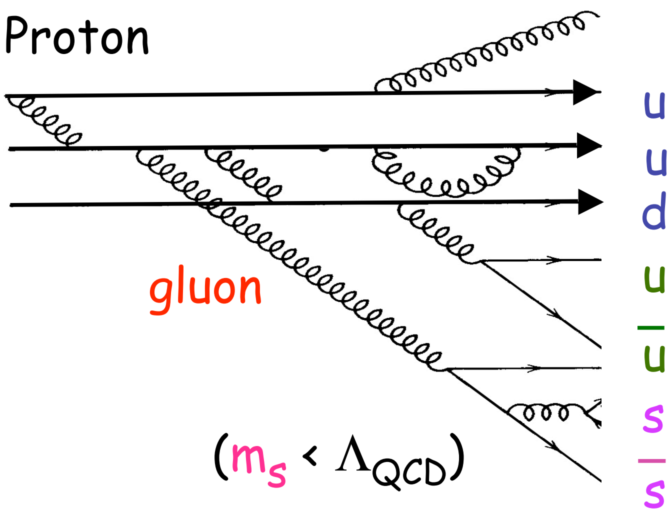
Frascati (Italy), October 12, 2005

Serge Kox, LPSC Grenoble

Physics case

Role of the strange quark in the nucleon structure

- Strange quarks are the lightest non valence quarks of the sea
  - ↳ Excellent candidate to study the dynamics and influence of the sea



- Evidence of the role of the strange quark ?
  - **Momentum** (Deep inelastic νN scattering)
    Contribution ≈ 4 %
  - **Mass** (σ–term in πN scattering)
    0 to 30 % (but SU(3) assumption)
  - **Spin** (polarized DIS)
    Δs = 0 to -10 % (but depends on ΔG)

New signal investigated in PV experiments

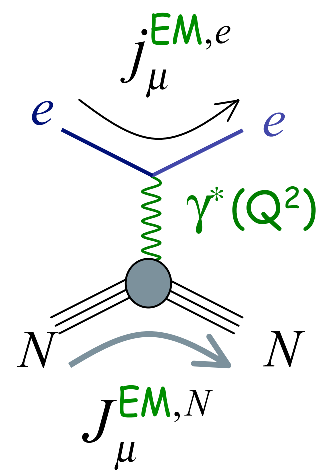
- Charge and magnetization (elastic electron–nucleon scattering)
- Cover large Q^2 domain to access different spatial resolution
  - Static properties (μ_s, ρ_s) near $Q^2 = 0$

Nucleon structure and EW probes

EM and Weak form factors

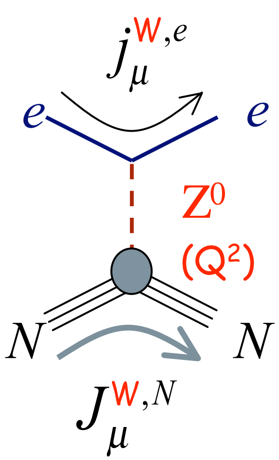
- Charge and magnetization (current/spin) extended distributions in nucleon (J=1/2)
  - Expressed with 2 form factors depending only on Q^2
- Elastic scattering of electron probes the nucleon via γ (EM) or Z^0 (Weak) exchange

$$< N \,|\, J_\mu^{EM} \,|\, N > \;\rightarrow\; G_E^{\gamma,N}, G_M^{\gamma,N}$$



Static EM properties at $Q^2 = 0$

$$\boxed{\begin{array}{l} G_E^{\,p}(0) = 1 \;,\; G_E^{\,n}(0) = 0 \\ G_M^{\,p}(0) = \mu_p \;,\; G_M^{\,n}(0) = \mu_n \end{array}}$$



$$< N \,|\, J_\mu^{W} \,|\, N > \;\rightarrow\; G_E^{(Z,N)}, \; G_M^{(Z,N)}$$

$$< N \,|\, J_{\mu 5}^{W} \,|\, N > \;\rightarrow\; G_A^{(Z,N)}$$

(see talks of U. Mueller and S. Pate on aspects of the axial part)

Decomposition on quark flavors

EM and Weak form factors

- Quark probed by a coupling to their electrical and weak charges

Flavor	Q_q	$C^q{}_V$
u, c, t	2/3	$1 - 8/3 \sin^2\theta_W$
d, s, b	-1/3	$-1 + 4/3 \sin^2\theta_W$

- Neglecting the heaviest quarks (c, b, t) in the flavor decomposition :

$$G^{(\gamma,N)}_{E,M} = \sum_{q=u,d,s} Q_q \, G^{(q,N)}_{E,M} \qquad G^{(Z,N)}_{E,M} = \sum_{q=u,d,s} c^q_V \, G^{(q,N)}_{E,M}$$

- Charge symmetry : neutron ↔ proton (valid at the 1% level)

$$G^{s}_{E,M} = (1 - 4\sin^2\theta_W)\, G^{\gamma,p}_{E,M} - G^{\gamma,n}_{E,M} - G^{Z,p}_{E,M}$$

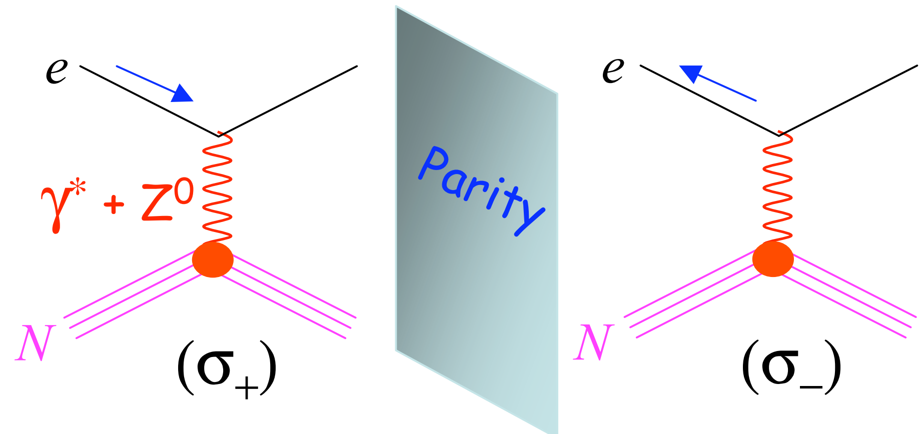
Strange quark form factors determination

- 4 EM Form Factors are measured (E,M on n,p) in the 0-1 GeV^2 domain
  - Need good precision on EM form factor ($G^n{}_E$) and 2 photon effects understanding
- Proton weak form factors (E, M) are measured in PV experiments

Parity Violation experiments

Weak form factors measurements

- EM and Weak contributions but $M_Z \ll M_\gamma$ in our energy domain
  - Must get rid of the dominant M_γ^2 term
  - ➯ Parity violation (PV) in polarized elastic electrons scattering on unpolarized proton target



$(\sigma_+) \neq \sigma_-(=P(\sigma_+))$

PV Asymmetry

$$A_{PV} \equiv \frac{\sigma_+ - \sigma_-}{\sigma_+ + \sigma_-} \approx \frac{\Re e\left(M^\gamma . M^Z\right)}{\left|M^\gamma\right|^2}$$

- Systematic errors (normalization) cancel in the ratio
- A_{PV} : 1 ppm to 50 ppm (part per million : 10^{-6}) for Q^2 = 0.1 - 1. $(GeV/c)^2$
- $A_{PV} = A_0\ (s=0) + A_S$

  ➯ Need to reach a precision of a few % (stat. + syst.) on A_{PV} !

Weak form factors determination

$$A_{PV} = -\frac{G_F Q^2}{4\sqrt{2}\pi\alpha} \frac{\varepsilon\, G_E^{(\gamma,p)}\, G_E^{(Z,p)} + \tau\, G_M^{(\gamma,p)}\, G_M^{(Z,p)} - \left(1 - 4\sin^2\theta_W\right) \varepsilon' G_M^{(\gamma,p)}\, G_A^e}{\varepsilon \left(G_E^{(\gamma,p)}\right)^2 + \tau \left(G_M^{(\gamma,p)}\right)^2}$$

Separation of weak form factors E, M, A (at each Q^2)

- Rosenbluth separation
  - H : Forward angle measurement ($\varepsilon' \to 0$) E + M
  - H : Backward angle measurement ($\varepsilon \to 0$) M + A
- Isospin/spin of targets
  - D (n + p) : Back angle measurement A + M
  - ^{4}He (J= 0, T= 0) : Forward angle E

Extraction of strange quarks contribution

- Strange quarks and vector form factors (E, M) after subtraction of A_0(s= 0)
  - EM form factors and correction of higher order EW terms
- Axial current in the nucleon also accessible (no flavor separation)

The experimental program

Worldwide effort since 10 years

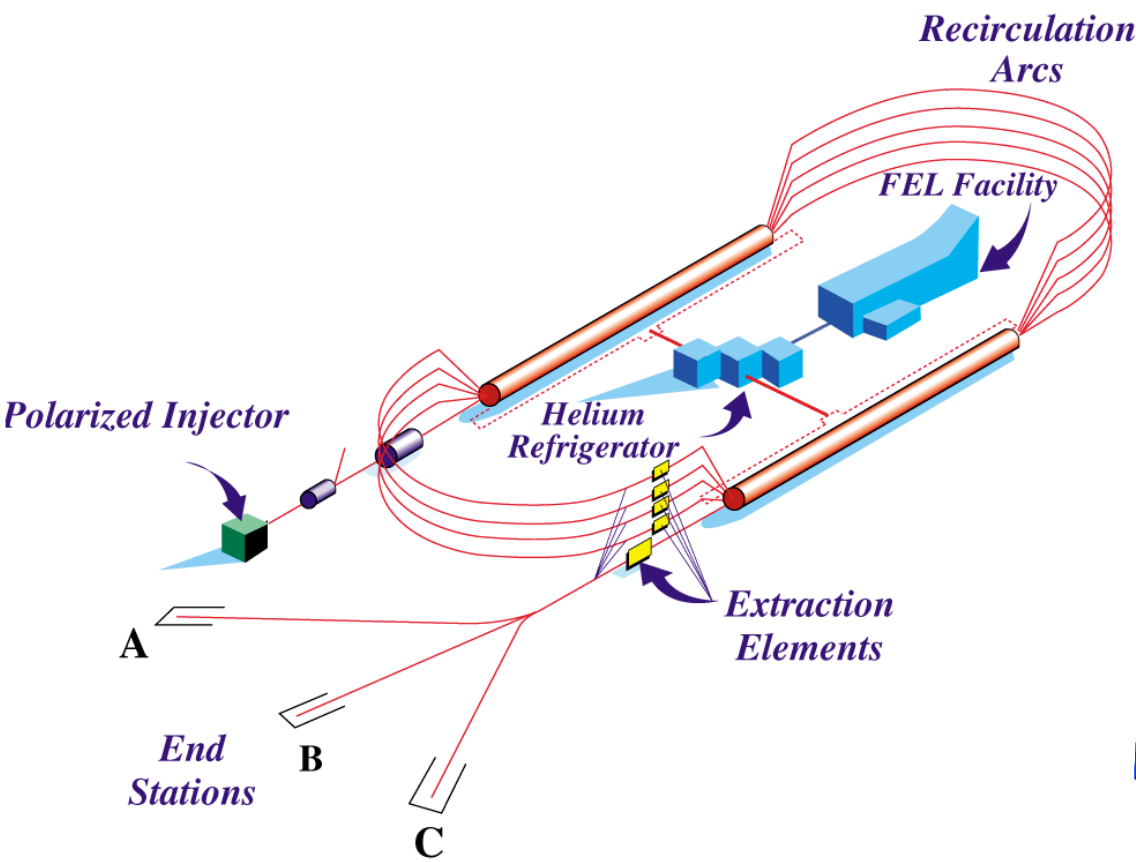
- 4 experiments : *SAMPLE, HAPPEX, PVA4 et G^0*
- 3 sites : *MIT-Bates* (Boston, USA), *JLab* (VA, USA), *MAMI* (Mainz, Germany)

	SAMPLE (Bates) *1998-2002*	HAPPEX (Jlab) *1998-2002*	HAPPEX II *2004-2005*	PVA4 (MAMI) *2002-04 + 06-08*	G^0 (JLab) *2003-04 + 06-08*
Q^2 $(GeV/c)^2$	0.04, 0.1	0.48	0.1	0.1, 0.23	0.12 - 1.0
Angle	B	F	F	F/B	F/B
Target	H,D	H	H, ^{4}He	H	H, D
Separation	G_M^s, $G_A^{(p+n)}$	$G_E^s + 0.4\, G_M^s$	G_E^s , G_M^s	G_E^s, G_M^s	G_e^s, G_M^s , $G_A^{(p+n)}$

Prospects and coordination

- Completion of HAPPEX II in 2005. New proposal of Happex III at 0.6-0.7 GeV^2
- 2 New measurement in G0 Backward (likely 0.23 and 0.6-0.7) in 2006
- A4 program running at Backward angle in 2006 (0.23 GeV^2)

PV experiments @ Jefferson Laboratory



CEBAF

- Recirculation arcs (N= 1-5 pass)
  - 2 LINAC of 0.6 GeV max
- RF superconducting Cavities
- Beam properties
  - CW beam, 200 μA (total)
  - Polarization 75 $\rightarrow$ 85 %
  - 6 GeV (with 8 MV/m)
  - Upgrade to 12 GeV (> 2010)
- 3 Halls A, B, C

PV experiments

- Happex in Hall A and G^0 in Hall C

Beam : The key element

Polarized electron source at JLab

- Photo emission from strained GaAs crystal
  - Laser light with circular polarization using optoelectronic device (Pockel cells)
  - High polarization : 75% for G0 (Happex II: 85% with supperlattice)
- Fast Helicity reversal (33 ms)
  - Reversal of polarization with sign of the voltage applied to the Pockel cells
- Feedback system
  - ↳ Minimize false asymmetries due to changes in beam properties

Beam Parameters	Achieved in G^0	False asymmetry
Charge asym.	-0.14 ± 0.32 ppm	10^{-8}
X-Y position dif.	3-4 ± 4 nm	10^{-9}
X-Y angle dif.	1-1.5 ± 1 nrad	10^{-9}
Energy dif.	29 ± 4 eV	10^{-9}

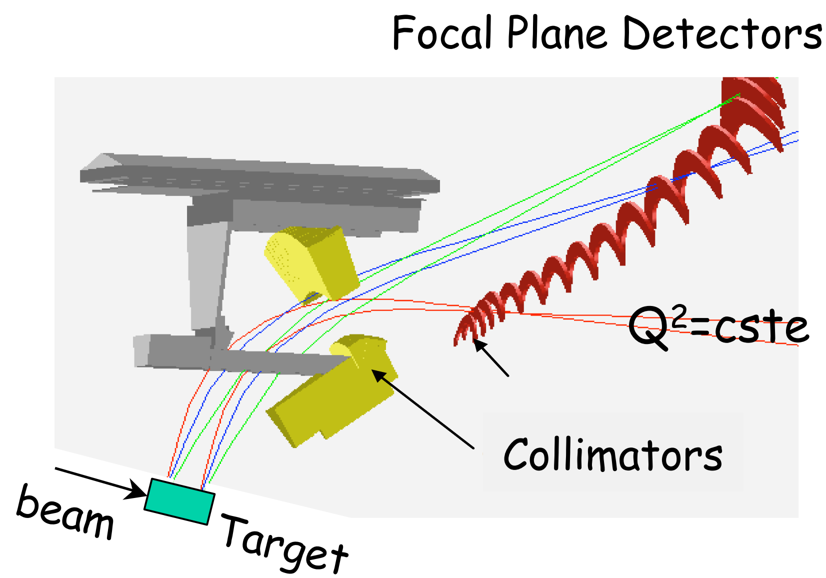
Additional challenge for G^0

- 40 μA beam current
  - 32 ns pulse spacing for ToF spectra
  - ↳ Higher bunch charge (x16)

G^0 : Forward angles

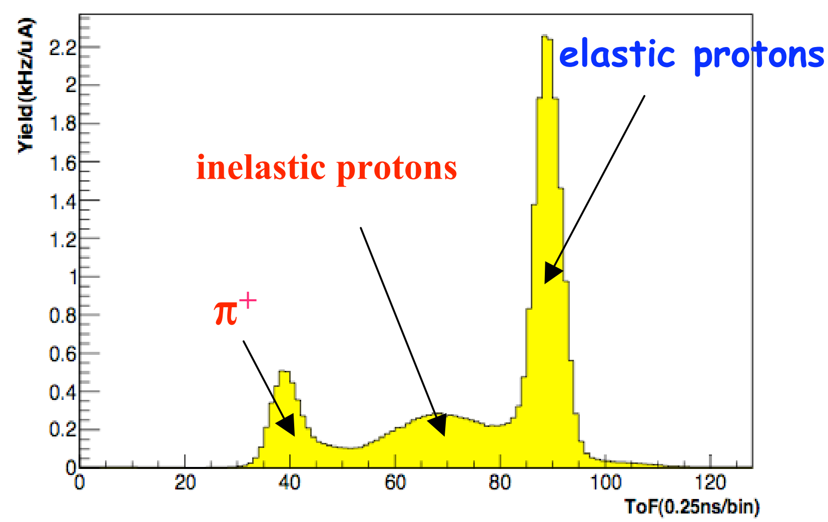
Specific features

- Detection of recoil proton : $\theta_p \approx 70° \leftrightarrow \theta_e = 7°$
  - Large Q^2 coverage = 0.1 - 1 $(GeV/c)^2$
  - Single measurement at E_{e-} = 3 GeV
- Counting experiment in Focal Plane Detectors
  - Scintillator pairs + PMTs
  - Segmentation : Rates/detector < 2 MHz
  - Q^2 uniquely selected with # of FPD fired

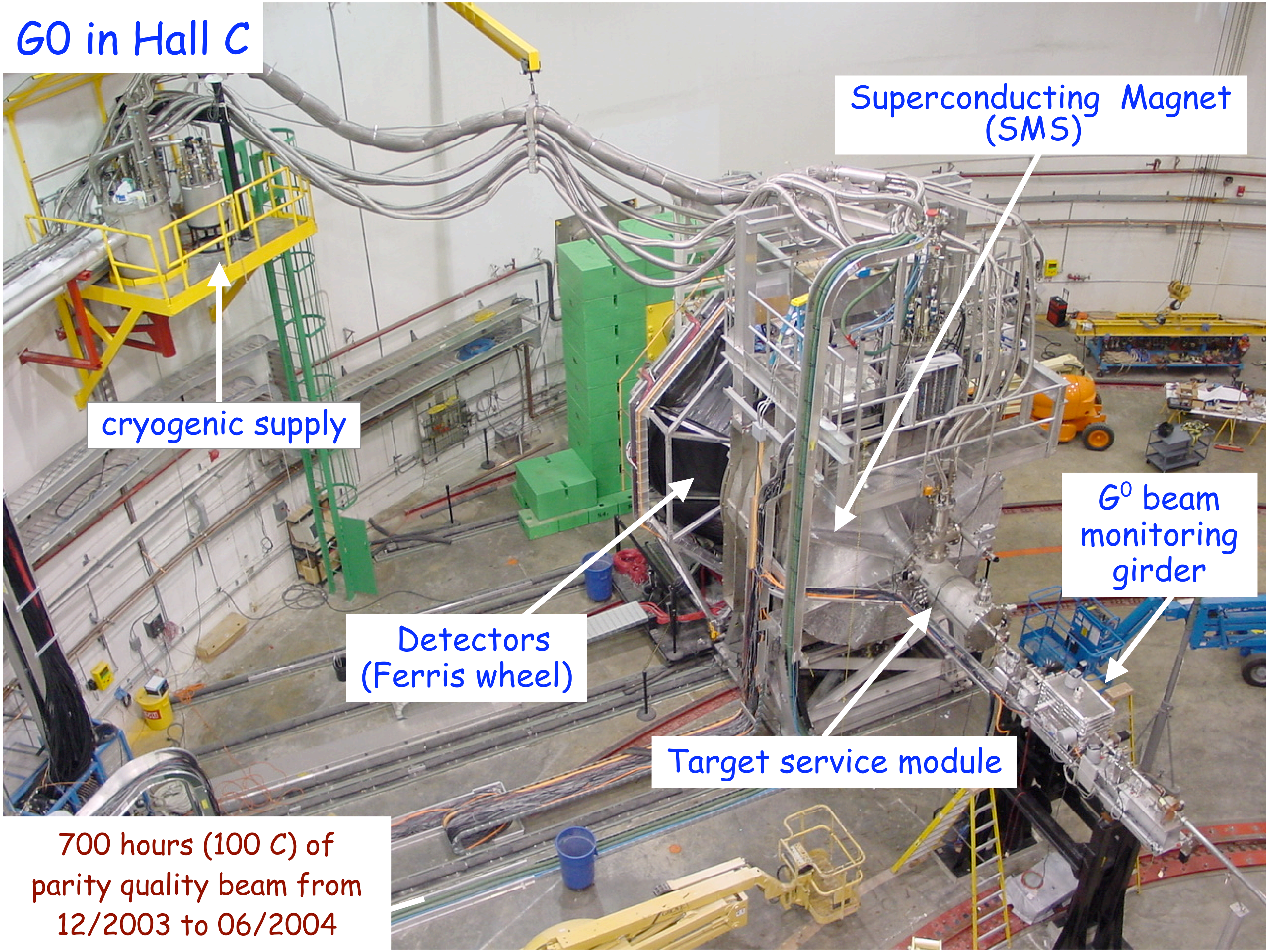


Identification of elastic protons

- ToF spectra
  - Special 32 ns beam time structure
  - Histograms built for each Macro-pulse (33 ms)
  - Corrections of dead time and non-linearity



G0 in Hall C



700 hours (100 C) of parity quality beam from 12/2003 to 06/2004

Data handling :

Raw Asymmetries

Source	Correction & Uncertainty
Helicity-correlated beam properties	$\Delta A \approx 0.02 \pm 0.01$ ppm
Beam polarization	$P_e = (73.7 \pm 1)$ %
Beam Leakage	$\Delta A = 0.71 \pm 0.14$ ppm
Deadtime	$\Delta A \approx 0.05 \pm 0.05$ ppm
Background	$\Delta A = -1$ to $42 \pm (0.2 - 9)$ ppm

Common to PV exp.

Specific to G0

Q^2 (1%)

EM Form Factors/ Subtraction of A_0

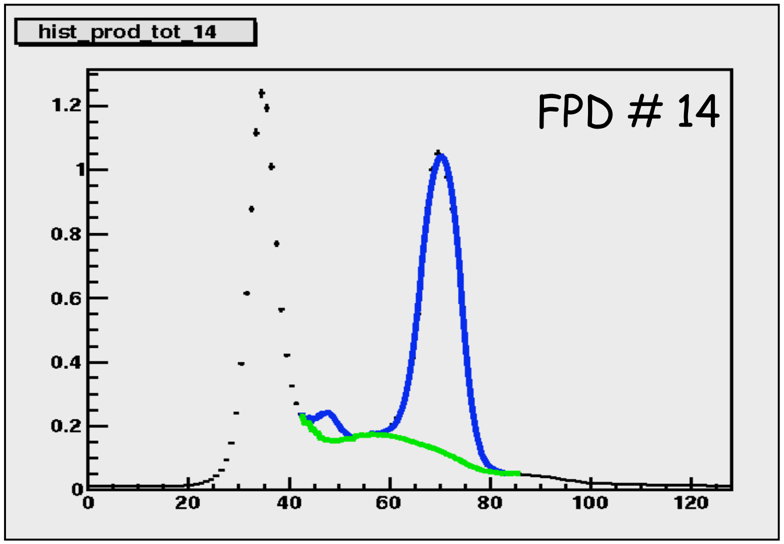
A_{phys}

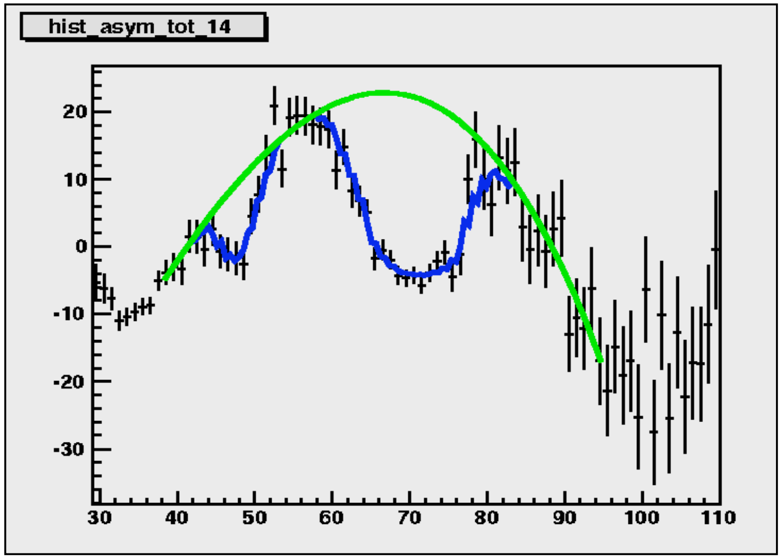
$G^s_E + \eta G^s_M$

G0 Background analysis

Subtraction of background

- Inelastic process in target cell, beam leakage …
- Fit of sum of elastic and inelastic contributions
  - Dilution factor (rates) and asymmetries
- Many tests performed
  - Dependences with cuts, fitting functions (polynomial, Fermi-Dirac …)
  - Correlations between fit parameters and χ^2/N
  - ↳ Estimate of systematic errors
- Variation of background shape
  - Conservatives ranges retained for errors
- Coherence of results from 4 PhD students
  - 8 Octants (4 NA and 4 French)

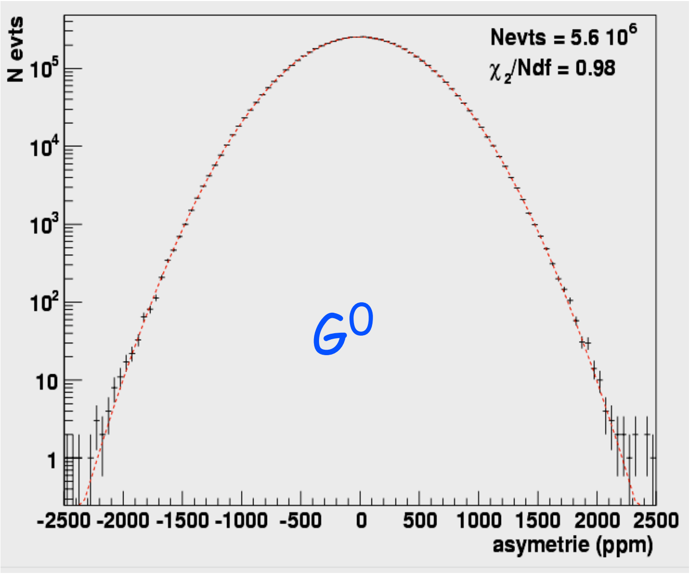




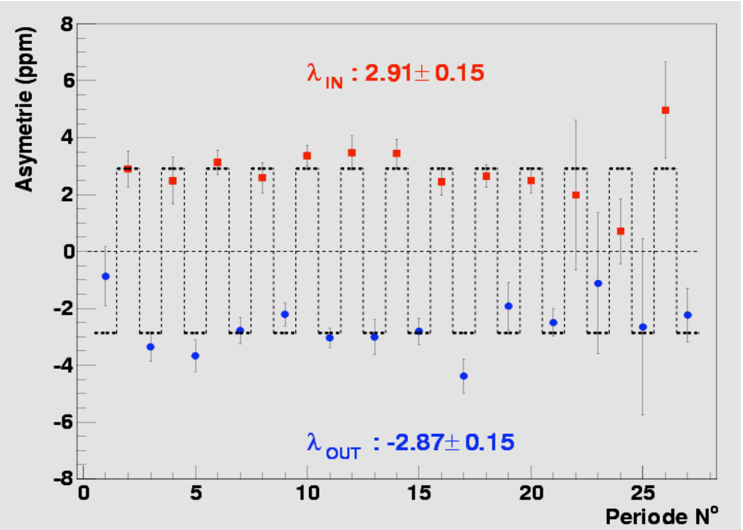
Quality checks

Search for experimental false asymmetries

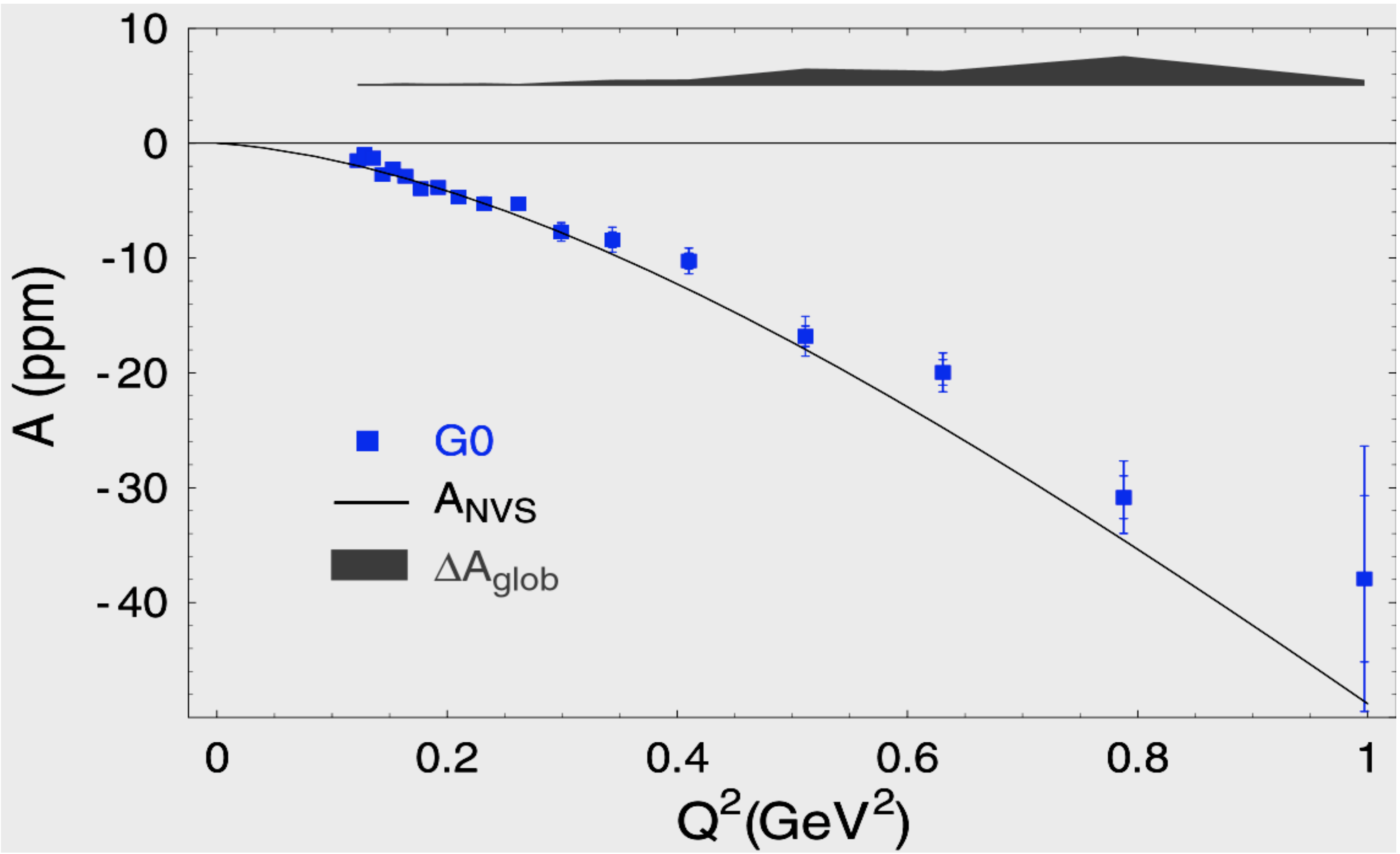
- Distribution of measured asymmetries
  - Quartet/quartet (sequence of 4 helicity states)
  - Signature of experimental asymmetries
    - ↳ Deviation to statistical (Gaussian) distribution
  - Width must be compatible with Luminosity



- Coherence test of data
  - $\lambda/2$ wave plate (mechanical insertion)
  - Polarization reversal $\rightarrow$ sign of asymmetries
    - ↳ A_{PV} (IN) = - A_{PV} (OUT)



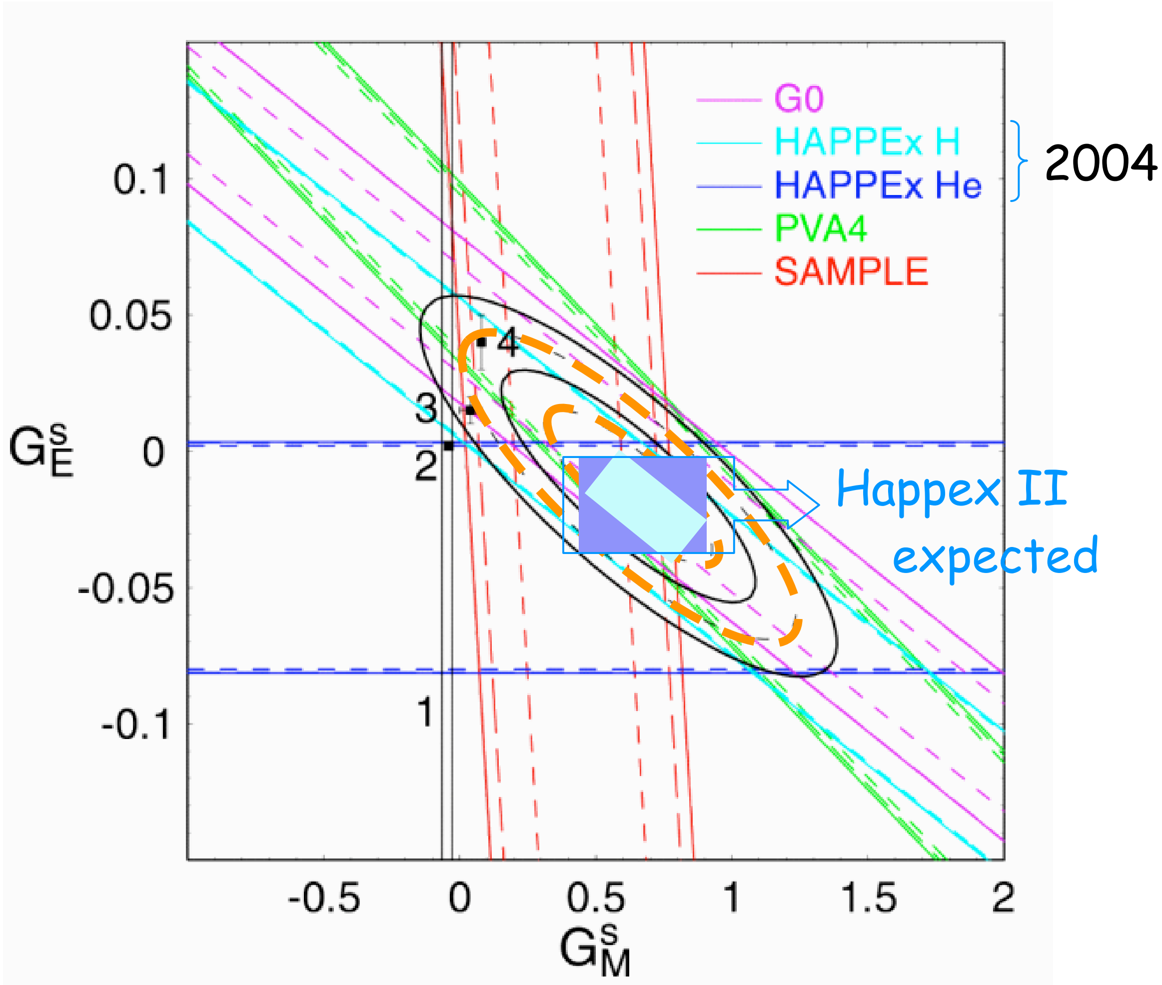
G^0 Experimental Asymmetries



Beam properties
- Polarization
- Leakage

- *Asymmetry without strangeness :* $A_{NVS} = A_0(G^s_{E,M} = 0)$
- EM Form Factors : Kelly PRC **70** (2004) 068202
- Errors : Statistical (inner) and point to point + Stat (outer)

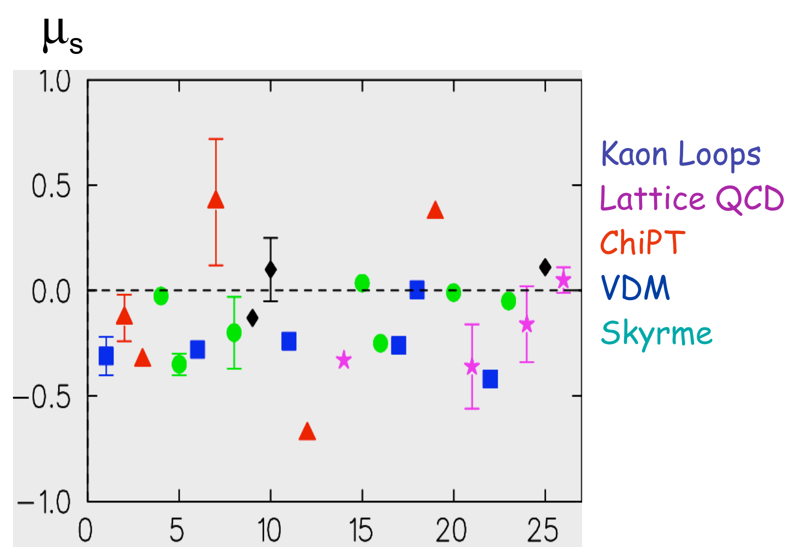
World Data at $Q^2 = 0.1$ GeV^2 (I)



K. Aniol et al.,
nucl-exp/0506011 + G^0 data

$$G_E^s = -0.013 \pm 0.028$$
$$G_M^s = +0.62 \pm 0.31$$
$$\pm 0.62\ (2\sigma)$$

contribution ≈ 10% in μ_p
(factor 1/3 for s quarks)



Large positive μ_s value
contradicts most predictions

<u>Contours</u>

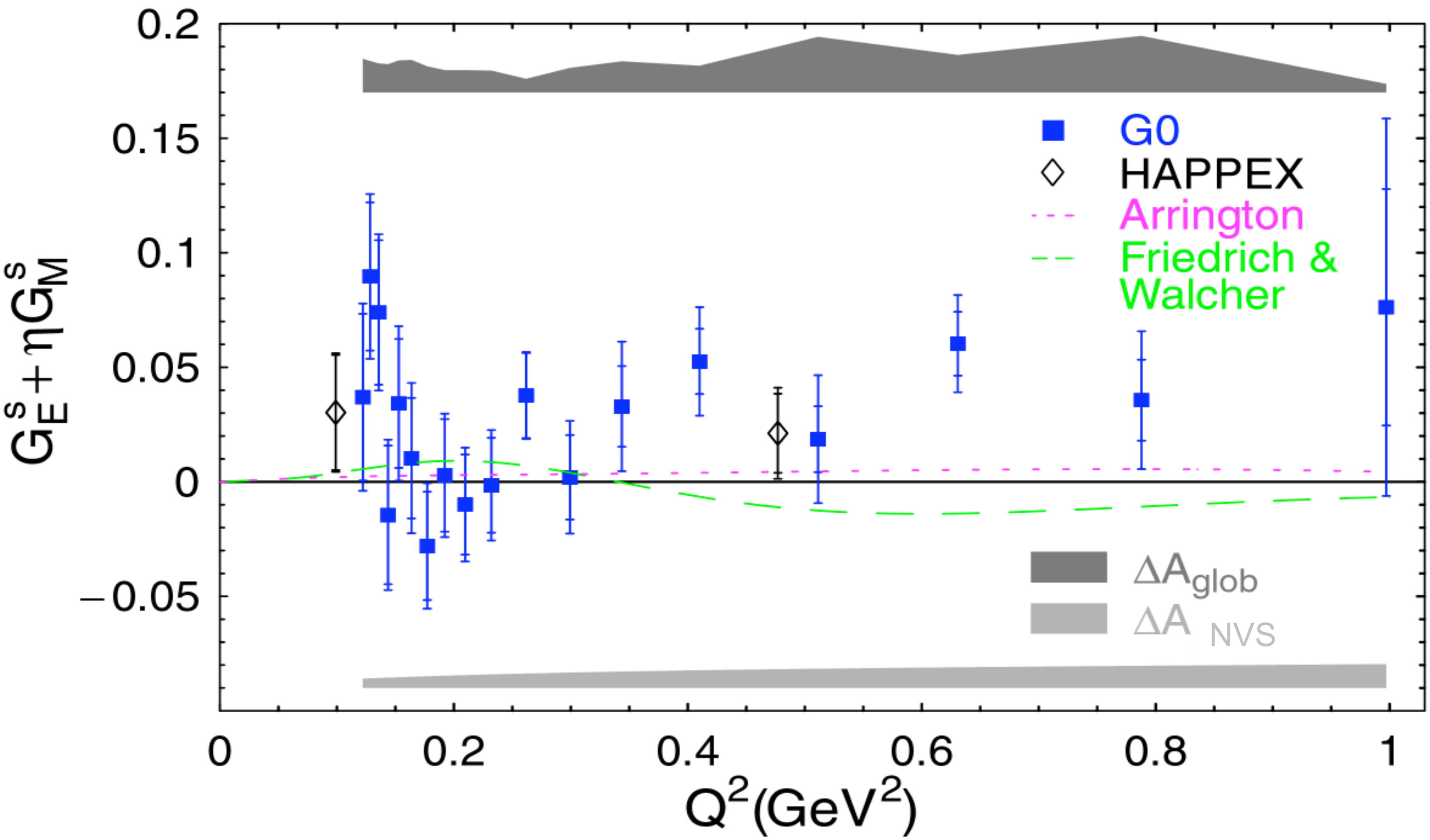
- - - - 1σ, 2σ
—— 68, 95% CL

<u>Theories</u>

1-Leinweber *et al.* PRL **94** (05) 212001
2-Lyubovitskij, *et al.* PRC **66** (02) 055204
3-Lewis, *et al.* PRD **67** (03) 013003
4-Silva, *et al.* PRD **65** (01) 014016

Strange Quark Contribution : Q^2 dependence

D. S Armstrong et al., PRL 95, 092001 (2005)



EM form factors
- parameterization

A_{NVS} subtraction
-SM, axial FF

Some conclusions

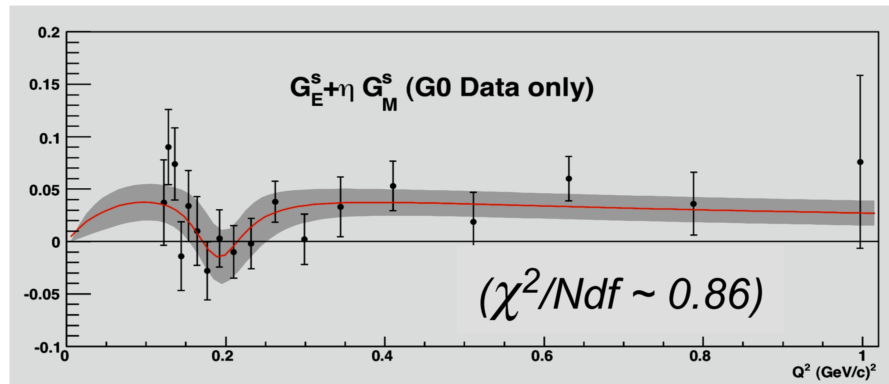
- Good agreement with HAPPEX data measured at similar kinematics

→ A null strange quark contribution ($G^s{}_E = G^s{}_M = 0$) is rejected at 90 % CL

Speculation …

Strange Form factors extraction

- Fit of the world data set (H, He) with sum of 2 strange Form Factors
  - Use parameterization for their Q^2 dependence (G^p_M and G^n_E types)
    - $G^s_M\left(Q^2\right) = \dfrac{G^s_M(0)}{\left(1+Q^2/\Lambda^{s\,2}_M\right)^2}$ *(proton)*
    - $G^s_E\left(Q^2\right) = \dfrac{a_1 Q^2}{1+b_1Q^2+b_2Q^4+b_3Q^6}$ *(neutron)*

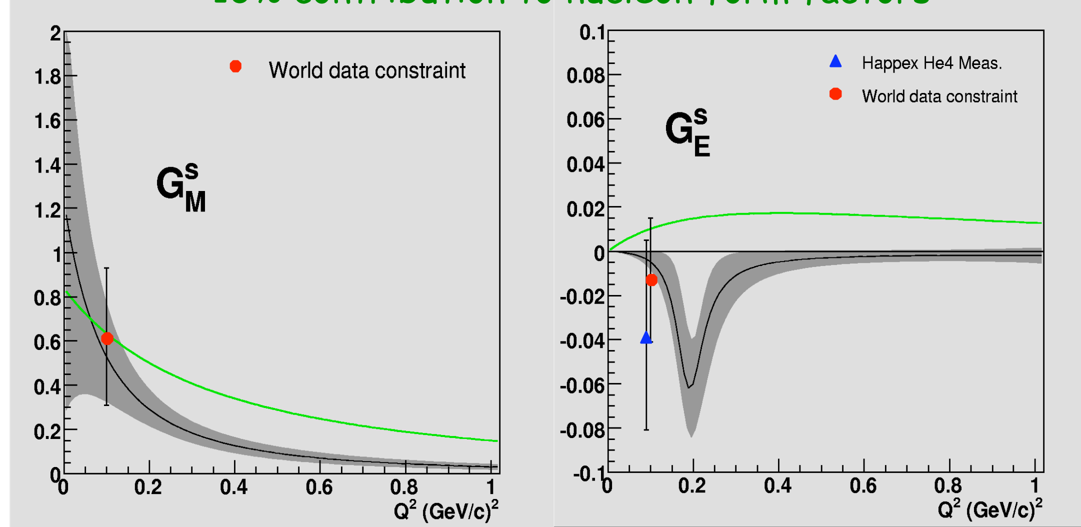


From the fit

- Large positive value for $G^s_M(0)$
- E and M contributions have opposite sign
- Sharp Q^2 dependence

→ Need additional data (separation) to come to any firm conclusion

— 10% contribution to nucleon form factors



G0 Backward angle configuration

G0 proposed backward measurement at Q^2 = 0.23, 0.47 and 0.8 $(GeV/c)^2$

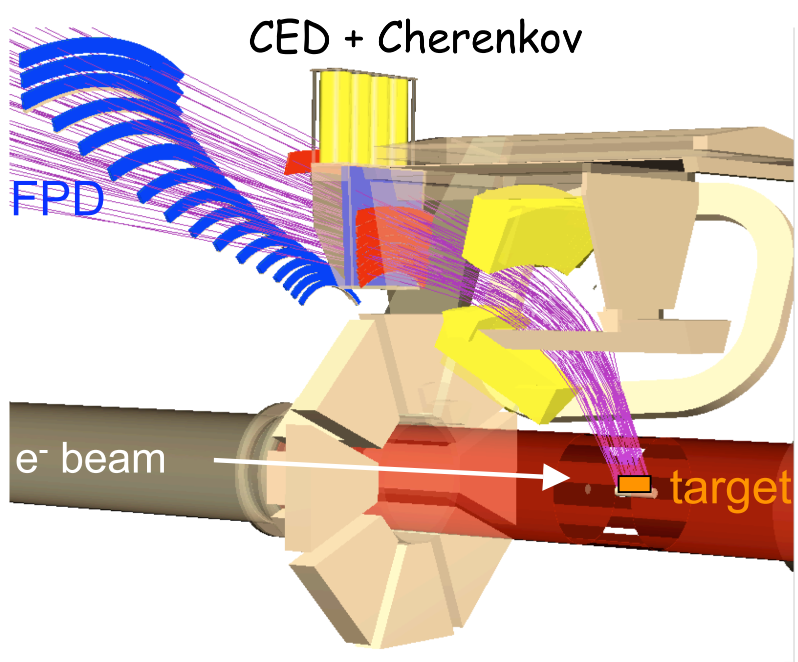
- Detection of the scattered electrons ($\theta_e \sim 110°$)
- Small Q^2 acceptance : different beam energies required
- Measurement on both LH_2 and LD_2 targets

E_e (MeV)	Q^2 (GeV^2)
360	0.23
585	0.47
799	0.8

PAC 28 : recommends a common strategy with HAPPEX III

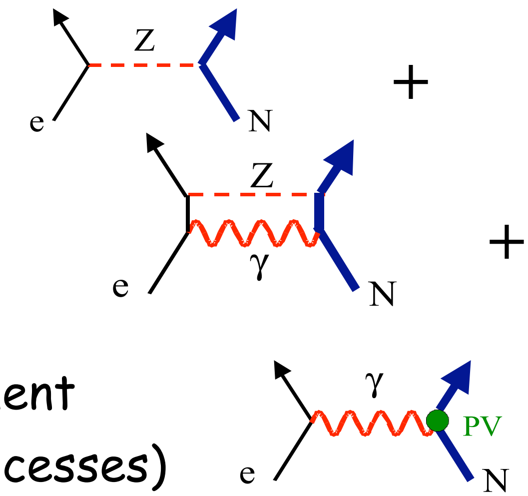
Set-up

- Standard 2 ns beam structure, 80 μA
- Turn-around of the magnet
- Add Cryostat Exit Detectors (CED) to separate elastic and inelastic electrons
- Cherenkov detector for pion rejection (required mostly for LD_2 target)



The axial part in e-N scattering : G^e_A

Unknown in the determination of $G^s_{E,M}$ (but also a physics case)

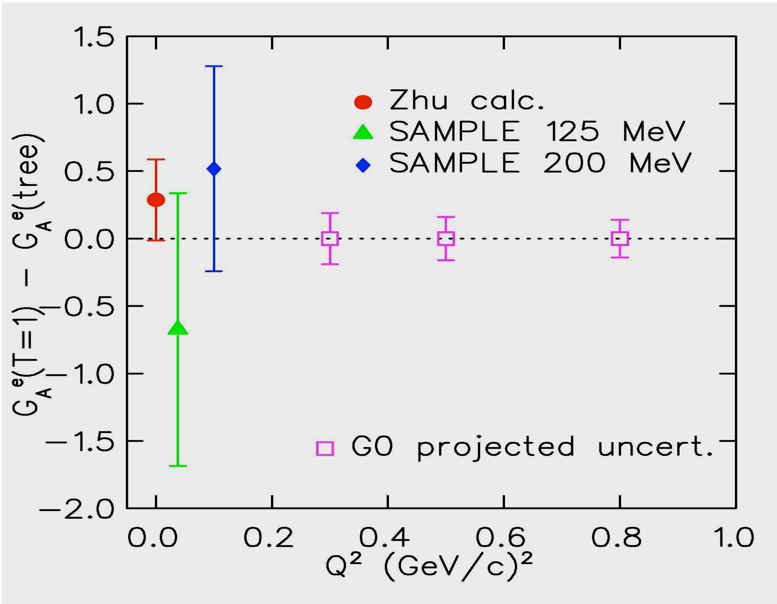


- Tree-level
  - Neutron β decay, ν-scattering
- EW radiative corrections
- Anapole form factor F_A
  - Parity-violating electromagnetic moment
  - Difficult to predict (multi-quarks processes)

↳ Large uncertainties and need to measure G^e_A

Program G^0 (backward angles)

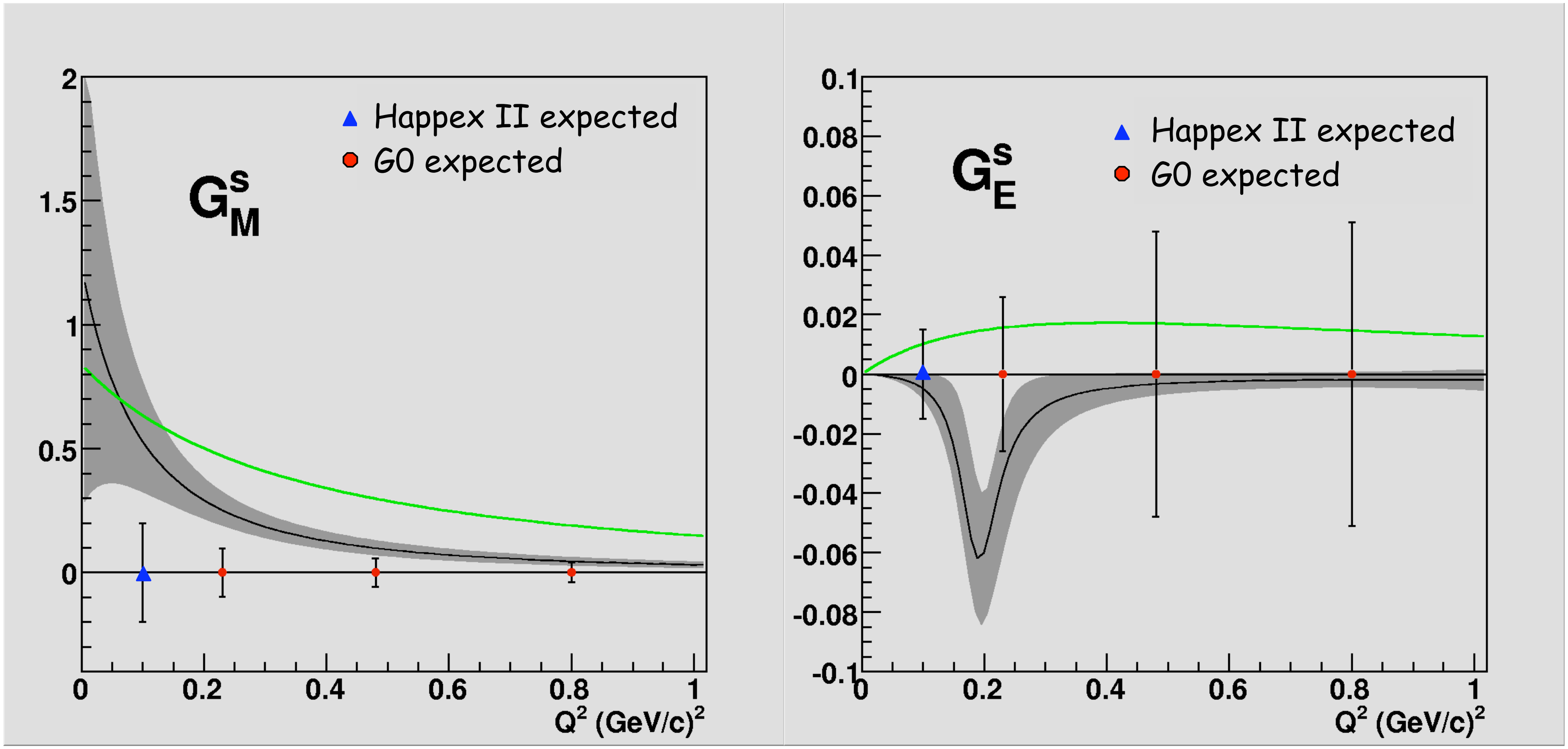
- New measurements combining H/D targets
  - Precise data for G^e_A (T=1) over a large Q^2 range
  - ↳ Q^2 dependence (unknown at present)
- Data recorded also for N-Δ transition
  - Dependence with Q^2 ($\rightarrow M_A$)



Perspectives for vector form factors

Important improvements from coming measurements

- Higher statistics of Happex II (factor 2-3 on errors) at 0.1 $(GeV/c)^2$
- Separation of the 2 terms (E,M) also at larger Q^2 (G0 but also A4, Happex III)
  - Allows for the determination of strange quark contribution over a large Q^2 domain
    - ↳ should strongly constrain the $G^s{}_M$ dependence, sign of $G^s{}_E$



Summary/Conclusions

Electroweak probes and PV experiments

- Powerful and mature technique (sub-ppm precision level) to study nucleon structure
  - Strange quarks distributions of charge/magnetization

New sets of results

- Contribution of strange quarks at small Q^2 (close to static properties)
  - 4 different experiments have provided data. Separation of E, M and Axial parts
  - Positive strange magnetic moment (contribution of 5-10% to the proton one)
- G0 Phase I : Large coverage in Q^2
  - Non null strange quark contributions is favored
  - Q^2 dependence : sum of 2 sizeable form factors (E, M) of opposite sign (speculative)

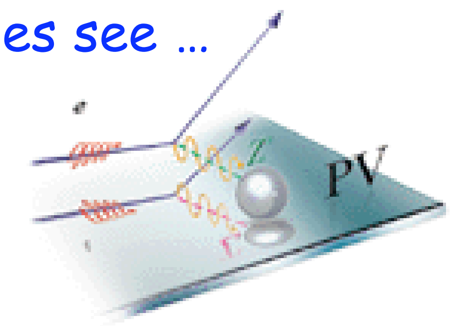
Perspectives

- New round of measurements to be completed within 2-3 years (HappexII, A4, G^0)
  - Will provide a complete separation of form factors (E, M) at several Q^2
  - ☞ Need axial form factor and its Q^2 dependence (from the G^0 program)
  - ☞ Precision/understanding on EM form factors could become a limitation (Happex III)

Along this topic ….

For a overview of PV experiments and related physics issues see …

Proceedings of the PAVI04 conference published in
European Physics Journal **A24** (2005)



And look forward/attend