G^0 experiment

E99-016, E01-115 and E01-116

G^0 Collaboration :

Caltech, Carnegie-Mellon, William&Mary, Hampton, IPN-Orsay, ISN-Grenoble, JLab, Kentucky, LaTech, NMSU, TRIUMF, U Con, UIUC, U Manitoba, U Maryland, U Mass, UNBC, VPI, Yerevan

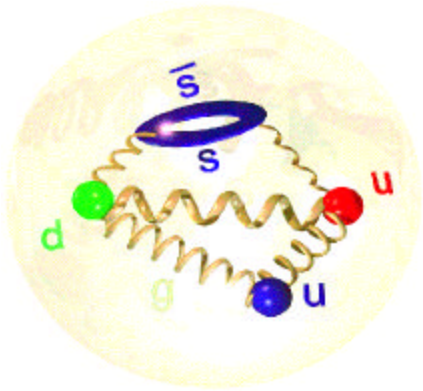
Physics case

Experimental set-up (Forward and Backward measurements)

Status of the experiment

C. Furget, Mainz, June 2002

Physics motivation



$$P = uud + \underbrace{u\bar{u} + d\bar{d} + s\bar{s} + ☹}_{\text{Sea quarks}} + g$$

Goal : Determine the contribution $\langle N | \bar{s} g^{m} s | N \rangle$ of the strange quarks to the electric and magnetic nucleon form factors

$Q^2 \sim 0$ (GeV/c)^2 : Static electric and magnetic properties

Q^2 dependence is required

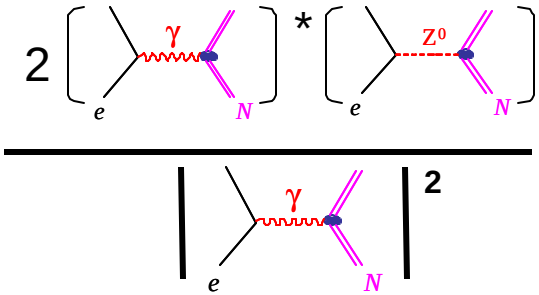
Mean : Measure PV asymmetries on several targets in electron-nucleon elastic scattering over wide Q^2 range to extract the electric and magnetic form factors (Q^2) and (Q^2)

Other goals : Axial form factor : New anapole effects

Q^2 dependence of the axial N-Δ transition form factor

Parity violation asymetry

$$A_{PV} = \frac{\sigma_R - \sigma_L}{\sigma_R + \sigma_L} =$$



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

with $\tau = Q^2 / (4M_p^2)$

$$\varepsilon = 1 / \left(1 + 2(1+\tau)\tan^2(\theta_e/2)\right)$$

$$\varepsilon' = \sqrt{\tau(1+\tau)(1-\varepsilon^2)}$$

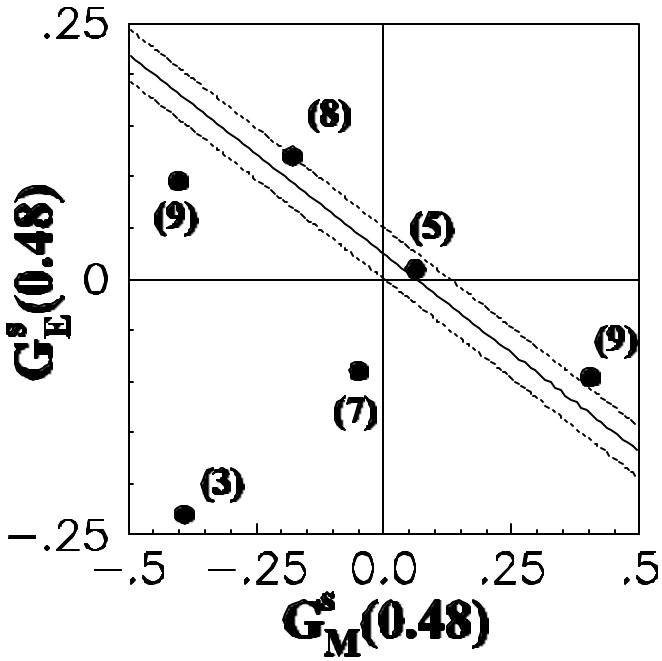
Contribution of strange quarks to weak and axial form factors :

$$G_{E,M}^{(Z,p)} = (1 - 4\sin^2\theta_W)(1 + R_V^p) G_{E,M}^{(\gamma,p)} - (1 + R_V^n) G_{E,M}^{(\gamma,n)} - ($$

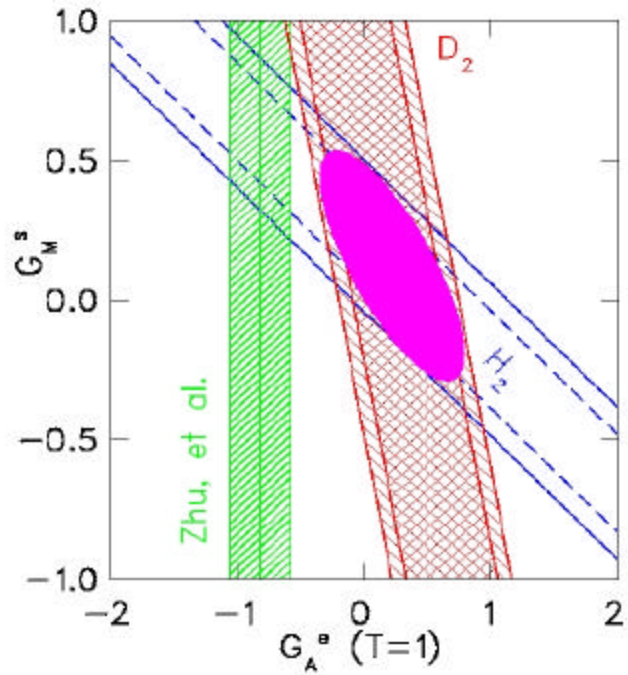
$$= -G_A + \Delta s + \eta F_A + R^e$$

PV experiments – Current status

HAPPEX : $Q^2 = 0.5\ (\mathrm{GeV}/c)^2$



SAMPLE: $Q^2 = 0.1\ (\mathrm{GeV}/c)^2$



PVA4 at Mainz : $Q^2 = 0.23\ (\mathrm{GeV}/c)^2$

SAMPLE 2002 : D_2 at $Q^2 = 0.04\ (\mathrm{GeV}/c)^2$

G^0 experimental strategy

Full separation of G_E^s, G_M^s et G_A^e (T=1) for Q^2 = 0.3, 0.5 and 0.8 $(GeV/c)^2$

$$A_{PV} = \eta + \xi \quad + \chi \quad + \psi \quad (T = 1)$$

A_F : one LH_2 measurement for $0.1 < Q^2 < 1$ $(GeV/c)^2$ → detect recoil protons at ~70° (electrons angles 7 – 15°)

A_B : three LH_2 measurements for three Q^2 values → detect electrons at ~110°

A_d : three LD_2 measurements (quasielastic scat.) → detect electrons at ~110°

Q^2 $(GeV/c)^2$	Target	η (ppm)	ξ (ppm)	χ (ppm)	ψ (ppm)
0.5	A_F	-16.7		25.0	1.4
	$A_B(LH_2)$	-29.0	18.0		8.5
	$A_B(LD_2)$	-39.8	14.7	9.0	

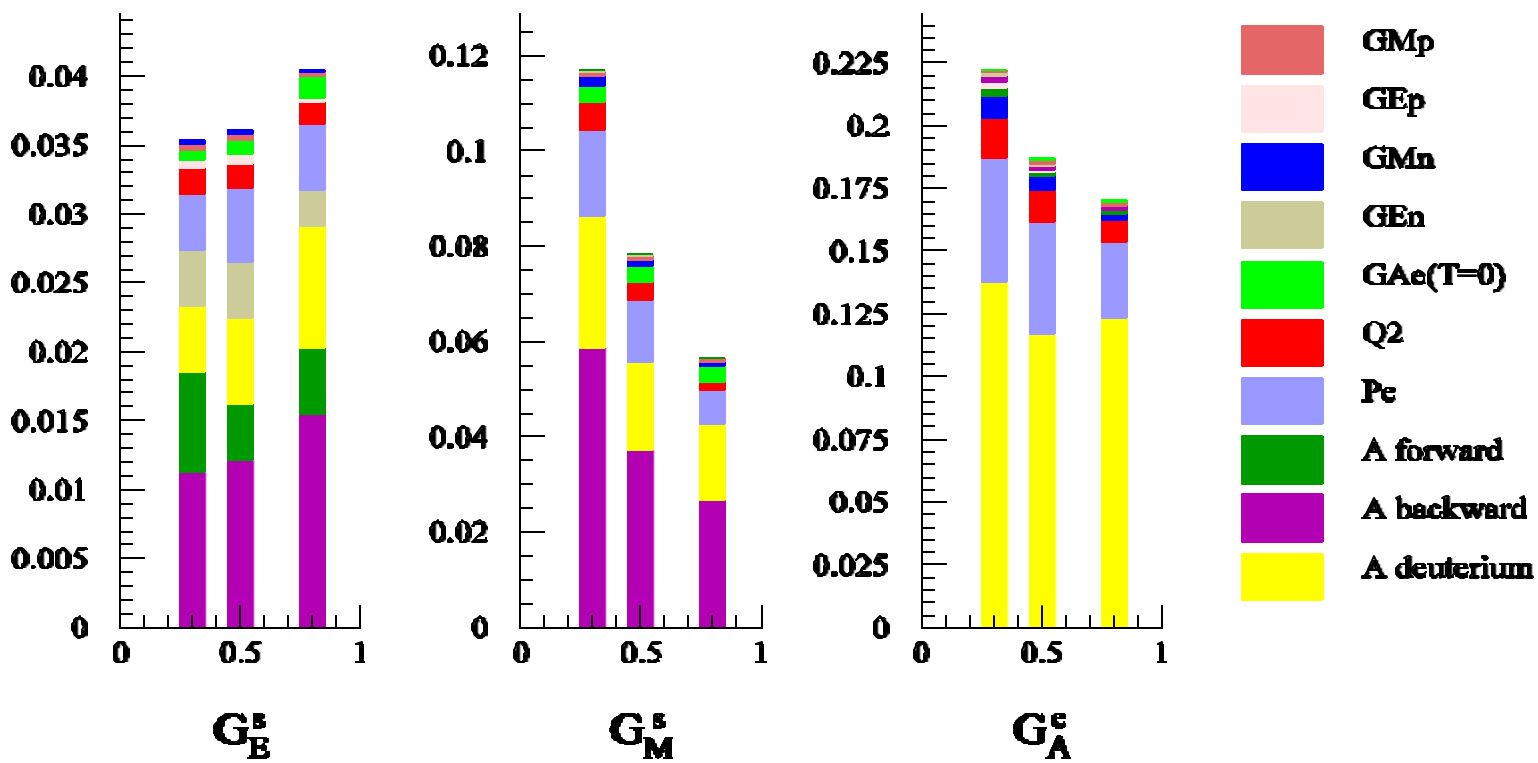
Expected errors on G_E^s and G_M^s

- Errors dominated by statistics

  Forward mode (700 h for all Q^2)

  Backward mode (700 h per target and per Q^2) → 4200 h

- Beam condition (I = 40 μA and P_e ~ 70 %)



Strange form factors

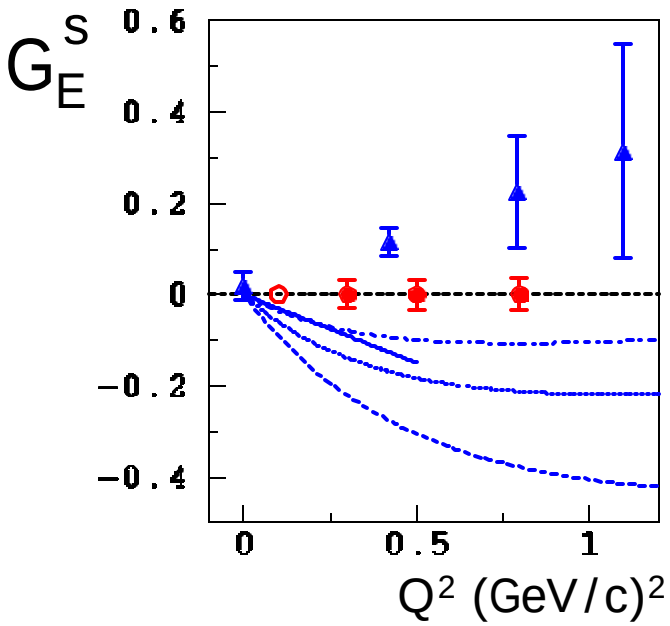
G^0 Expected results :

Separation of G_E^s, G_M^s and G_A^e at Q^2 = 0.3, 0.5 and 0.8 $(GeV/c)^2$

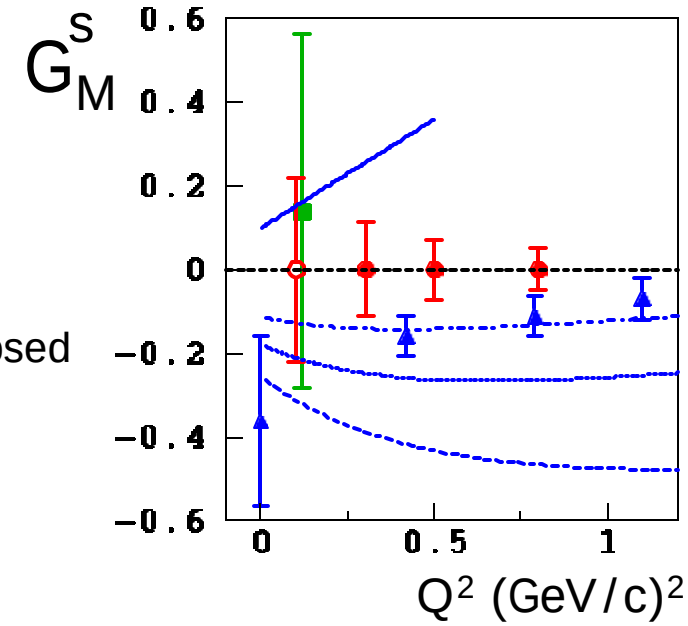
Other experiments :

HAPPEX2 (H, He) and PVA4

→ G_E^s, G_M^s at Q^2 = 0.1 $(GeV/c)^2$



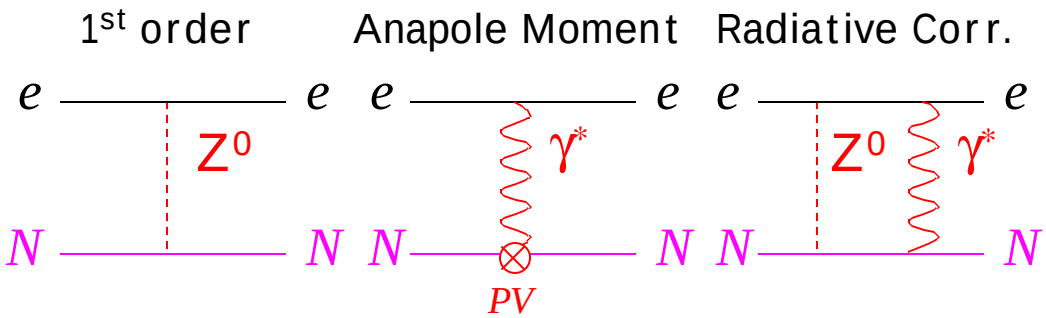
● G^0 proposed
○ HAPPEX2 proposed
■ SAMPLE 2000



- Chiral Pert. Theory (PRC60 (99) 045501)
- Vector Dominance Model (PRC56 (96) 510)
- Lattice QCD (PRD58 (98) 074504)

Axial form factor

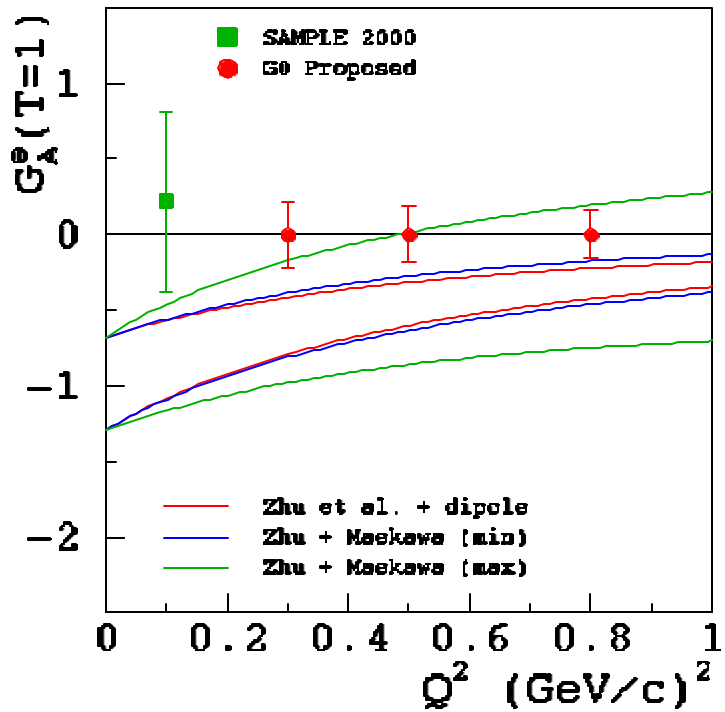
$$G_A^{e,N} = G_A^{(Z,N)} + ?\,F_A + R_e$$



Large uncertainties on anapole moment and radiative corrections

Other experiment :

SAMPLE 2001 at Q^2=0.04 $(GeV/c)^2$



Theory :

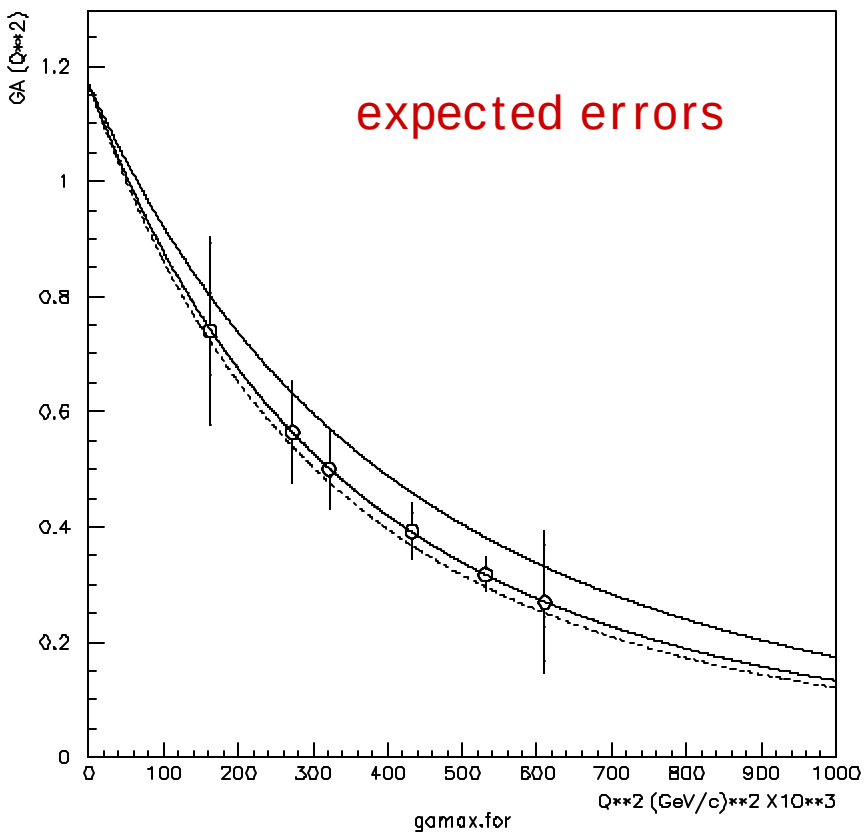
$G_A^e(T+1)$ at Q^2 =0 $(GeV/c)^2$: Zhu et al., PRD62 (2000) 033008

Q^2 dependence : Maekawa et al., PLB 488 (2000) 167

N-Δ transition form factor

S. Wells et al., LaTech

$$A_{inel} = -\frac{G_F Q^2}{4\pi\alpha\sqrt{2}}\left[\Delta^p_{(1)} + \Delta^p_{(2)} + \Delta^p_{(3)}\right]$$



$\Delta_{(1)} = 2(1-\sin^2\theta_W) = 1$

$\Delta_{(2)} =$ non-resonant contrib. (small)

$\Delta_{(3)} = 2(1-4\sin^2\theta_W)\, F(Q^2,s)$

at tree-level:

$$F(Q^2,s) \rightarrow G^A_{N\Delta}(Q^2)$$

- First measurement in neutral current process
- Sensitive to hadronic radiative corrections

data come for free w/ back-angle G0 elastic measurement

Experimental requirements

$$A_{PV} = \frac{1}{P_e}\frac{N_+ - N_-}{N_+ + N_-} \approx -3 \text{ to } -40 \text{ ppm} \quad \text{with} \quad \frac{\Delta A_{PV}}{A_{PV}} \approx 5\%$$

Figure of merit = P_e^2 I $N_{at/cm}$? O s

- Statistics : 10^{13}-10^{14} events

  Large luminosity (I = 40 μA, d_{target} = 20 cm, L = 2.1 ×10^{38} cm^{-2} s^{-1})

  Large acceptance detector ($\Delta\Omega$ = 0.5-0.9 sr)

  Background rejection (TOF, particle trajectory, PID)

  Histogramming capability for high rates (>1 MHz/detector)

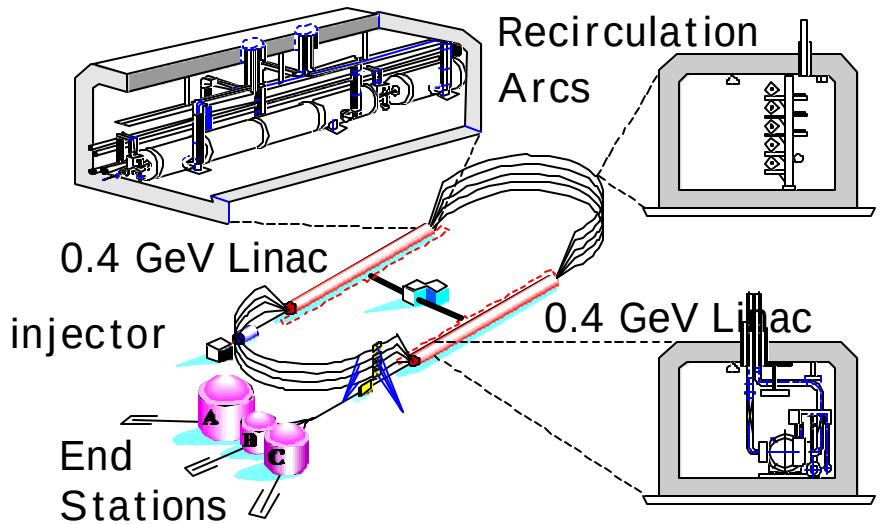
- Systematics :

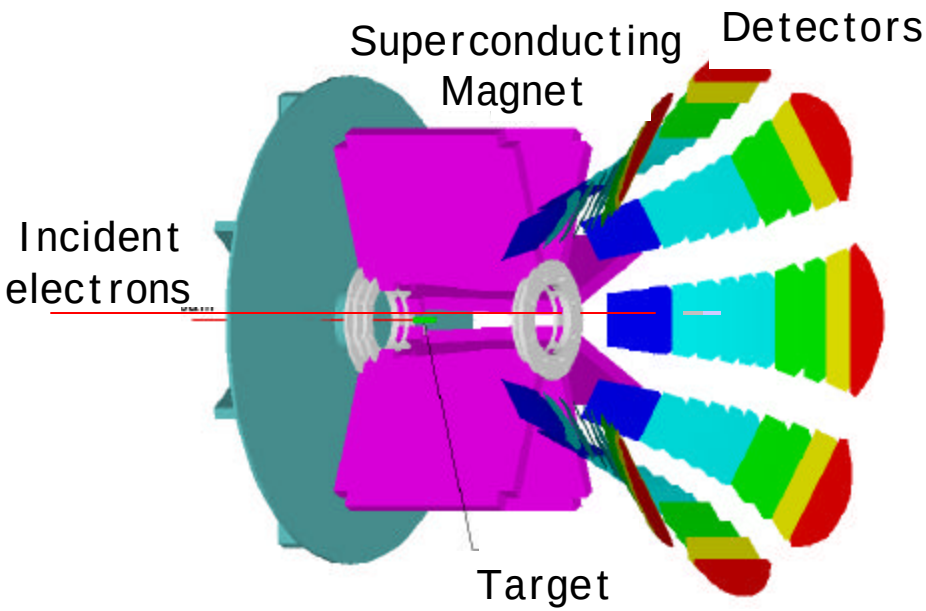
  High polarisation ($P_e \approx 70\%$)

  High quality beam (intensity, position, energy)

  Minimize helicity-correlated effects from detectors and electronics

G^0 experimental set-up



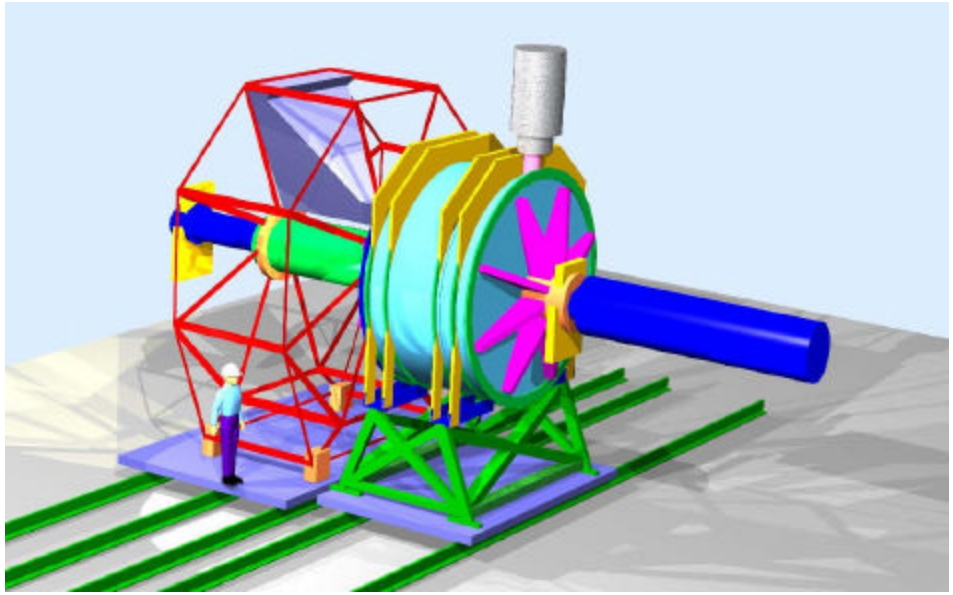


- Electron beam from CEBAF accel. with specific requirements

(31.25 MHz pulsed beam, Polar. Reversal at 30 Hz)

- Dedicated set-up with 2 different detector geometries

(Forward and Backward modes)



Beam requirements

Correction for helicity-correlated beam parameters P_i

Measure ΔP_i accurately so the error on the correction < 5% $\Delta A_{stat} \sim 5\times10^{-9}$

Keep ΔP_i small so individual run-averaged corrections < $\Delta A_{stat} \sim 10^{-7}$

Beam parameters	Nominal value	Beam fluctuation at 15 Hz	Helic. Corr. in 30 days
CW current	40 A	0.2 %	< 1 ppm
Energy	3 GeV	10^{-5}	$< 2.5 \times 10^{-8}$
Position	0 ± 0.2 mm	20 m	< 20 nm
Beam diam.	< 200 m	20 m	< 2 m
Angle	0 ± 0.05 mrd	2 rd	< 2 nrd

$$A_{meas} = A_{phys} + \sum_{i=1}^{N} \frac{1}{2Y}\left(\frac{\partial Y}{\partial P_i}\right)\Delta P_i$$

based on HAPPEX results *achieved in 1999 w/ strained GaAs*

G0 intensity + position feedback to be tested in Summer 2002

G0 Forward angle configuration

Proton detection

- Toroidal magnetic field used to select protons in the acceptance

  ($0.1 < Q^2 < 1$ (GeV/c)^2)

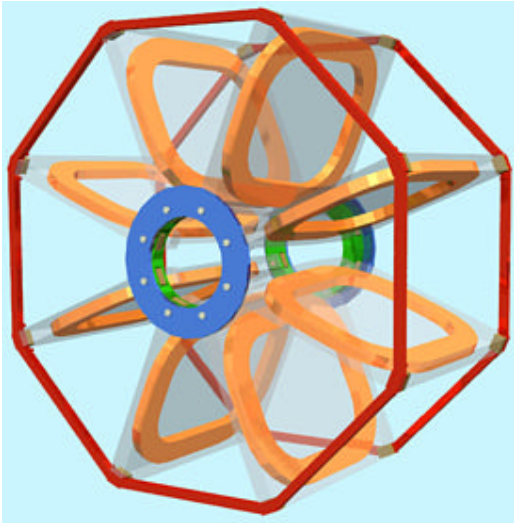
- Field and 16 Focal plane detectors (FPD) designed to sort protons by Q^2

  (No magnetic material used)

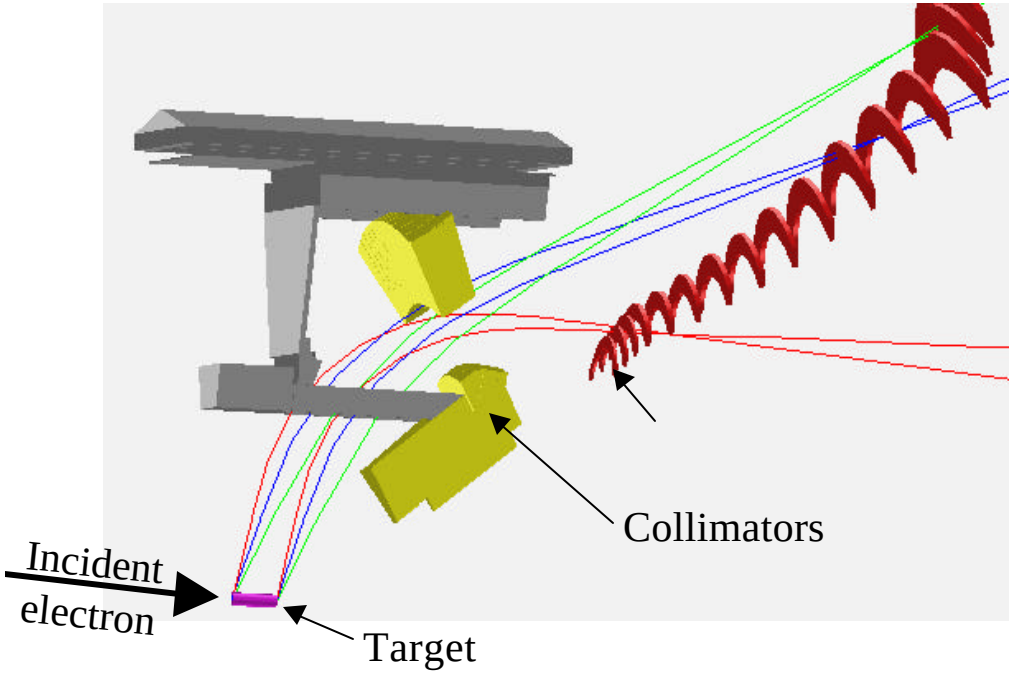
- Field (bend angle > 35°) and collimators used to stop (γ, **n**) background from target and define acceptance

  ($\Delta\phi = 20°$; $\Delta\theta \sim \pm 10°$)

- Time of flight used to discriminate between elastic protons and pions



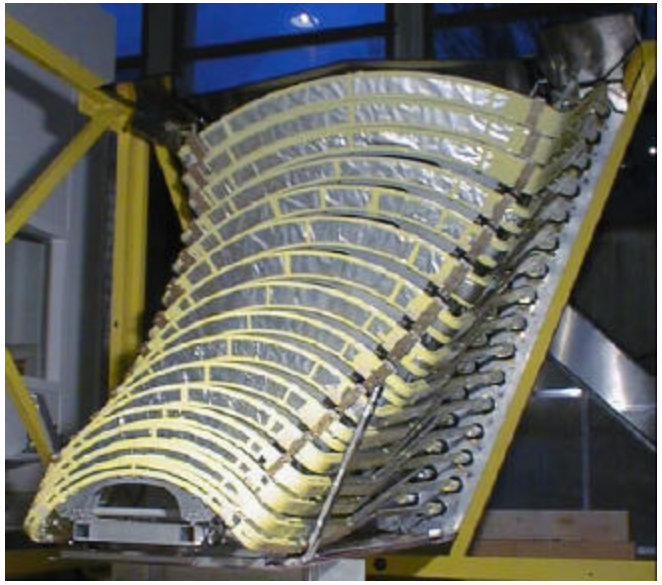
FP Detectors



Focal Plan Detectors (FPD)

- 16 pairs of arc-shaped scintillators (iso-Q^2)
- Back and Front coincidences
- 4 PMTs (one at each end of the scintillators)
- Long light guides (PMT at low B field)

French octant



NA octant

Detector tests using cosmics :

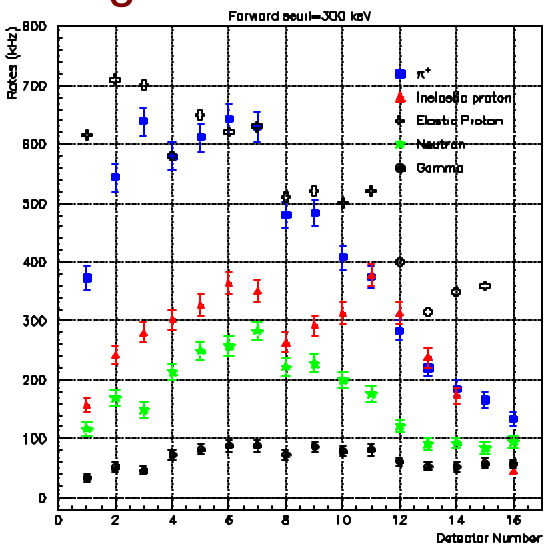
More than 100 p.e. signal expected with protons

About 300 ps time resolution measured

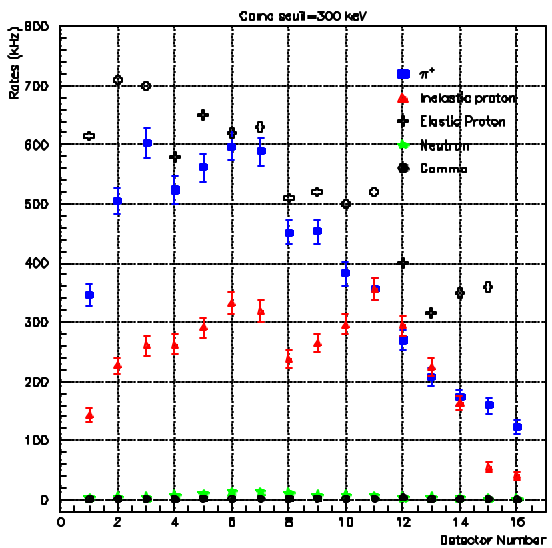
Simulated TOF spectra

Single counting

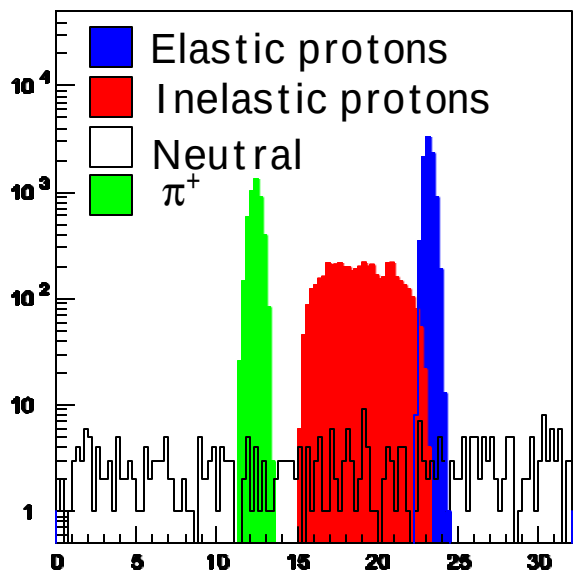
- Elastic p
- π^+
- Inelastic p
- n
- γ



Front-Back coincidences



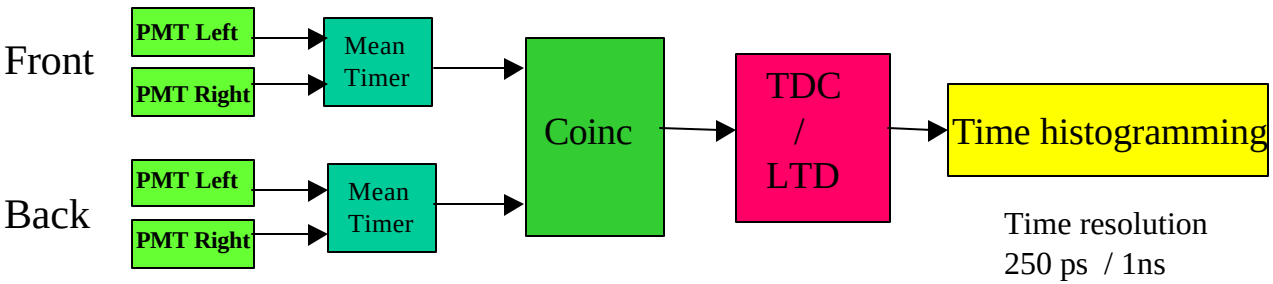
- SOS (hall C) data used for validation of event generators
- GEANT simulation used to estimate the counting rates and generate TOF information

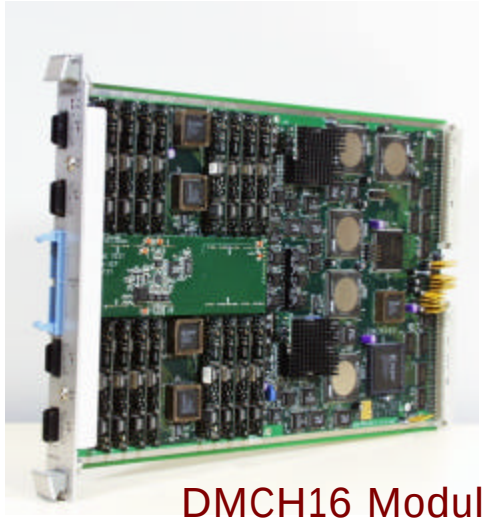


Time of Flight (ns)

Forward angle Electronics

Time of Flight measurement





DMCH16 Module
1/8 (Orsay)

Beam structure: 32 ns between pulses

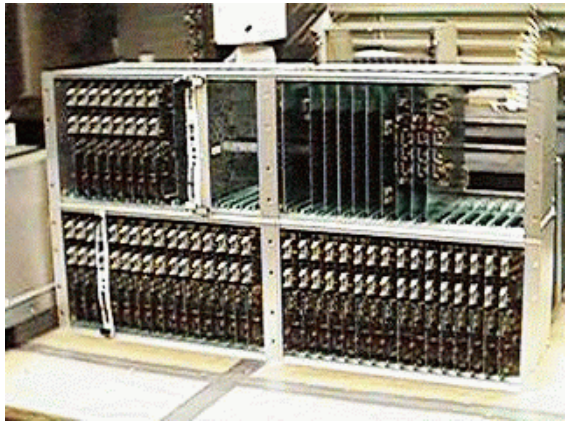
FR octants: flash TDCs (0.25 ns over 32 ns range)

NA octants: Latching Time Digitizer (500 MHz)
→ scalers (1 ns over 24 ns range)

Time histogramming read out at 30 Hz (polar. reversal)

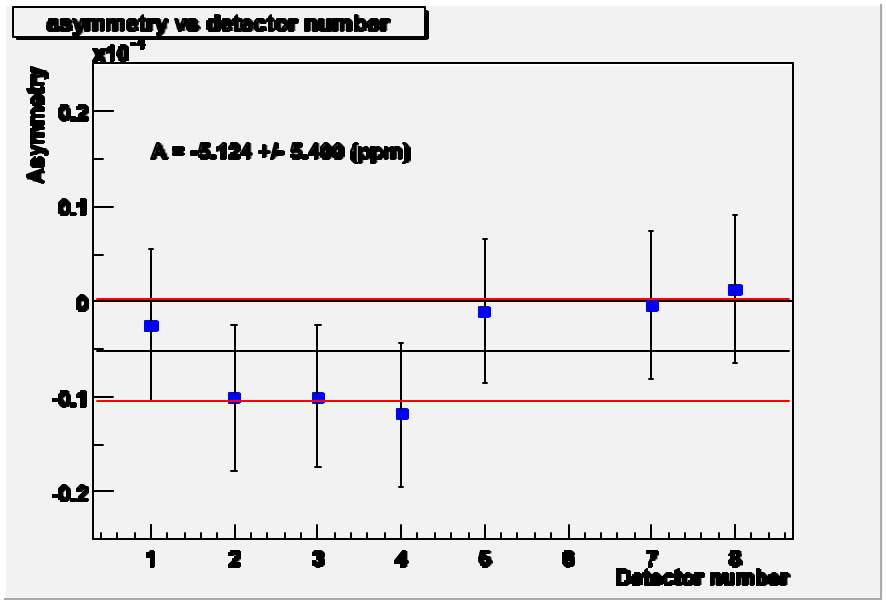
Deadtime less than 10% for 2 MHz/detector

"Buddy" system for online deadtime monitoring



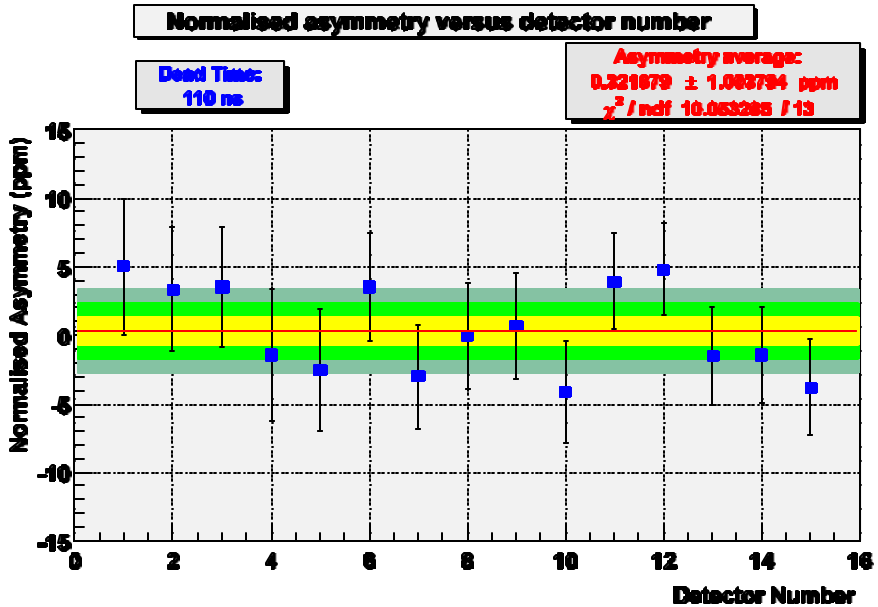
LTD crate 1/2 (CMU)

Asymmetry tests



Asymmetry tests have been performed with detectors and electronics using parasitic beam in the hall C.

Even with bad beam conditions, asymmetries compatible with zero have been obtained



G0 Backward angle configuration

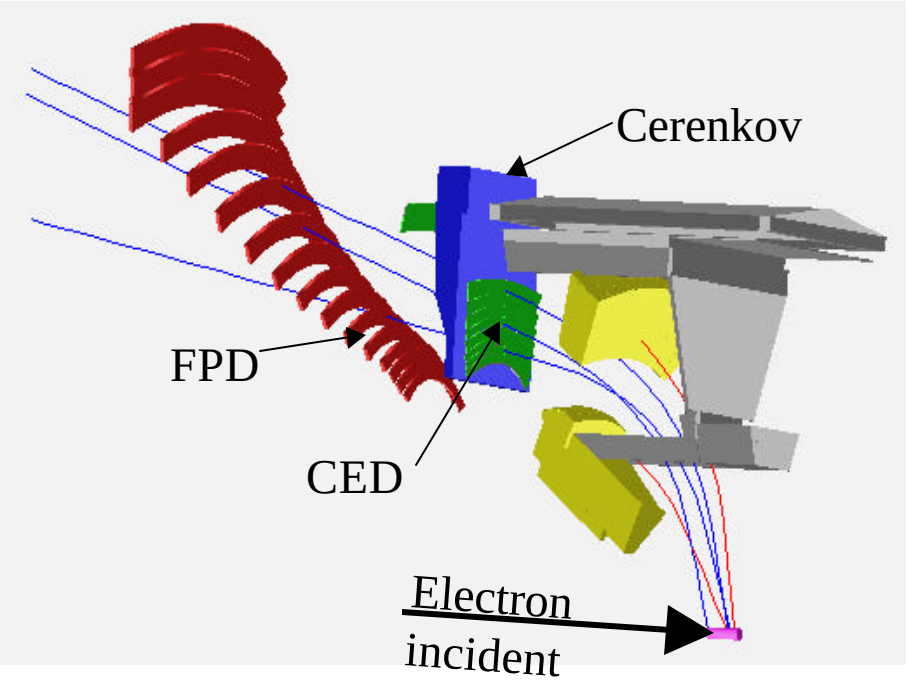
Detection of the scattered electrons ($\theta_e \sim 110°$)

Small Q^2 variation within the G^0 acceptance

Different beam energies required (424, 576 et 799 MeV)

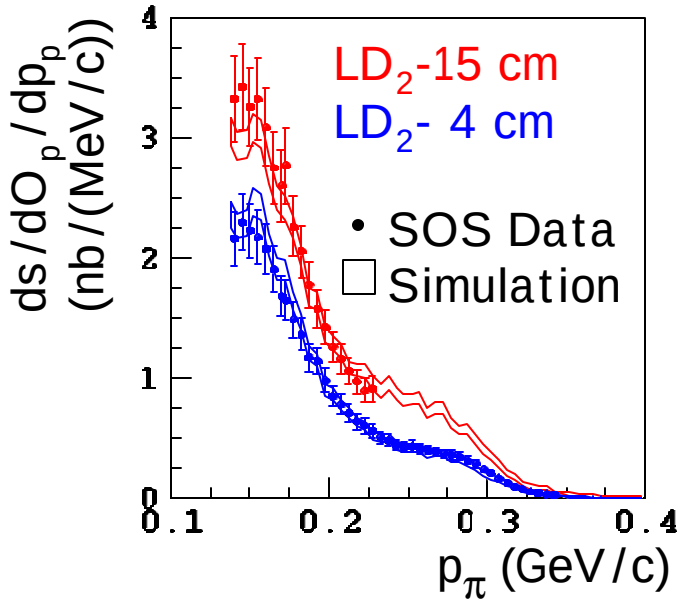
ð Q^2 = 0.3, 0.5 et 0.8 $(GeV/c)^2$

- Add Cryostat Exit Detectors (CED) to separate elastic and inelastic electrons
- Cerenkov detector for pion rejection (required for LD2 target)



Backward angle simulation

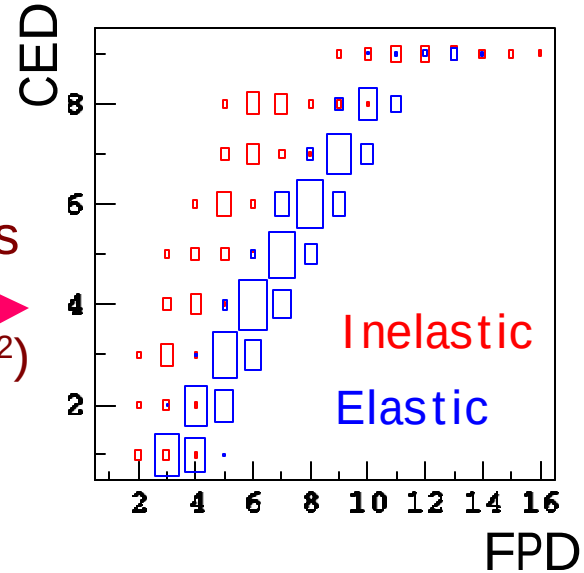
- Pion production generators tested by comparison with SOS (hall C) data



- GEANT simulation study :

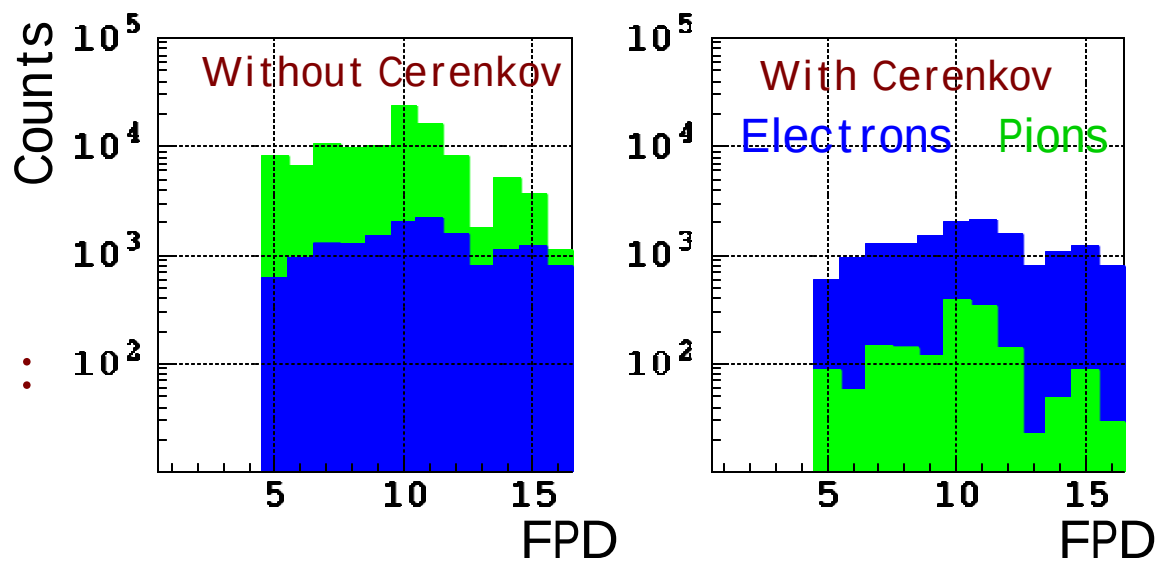
CED/FPD coincidences

(LH_2, Q^2 = 0.3 $(GeV/c)^2$)

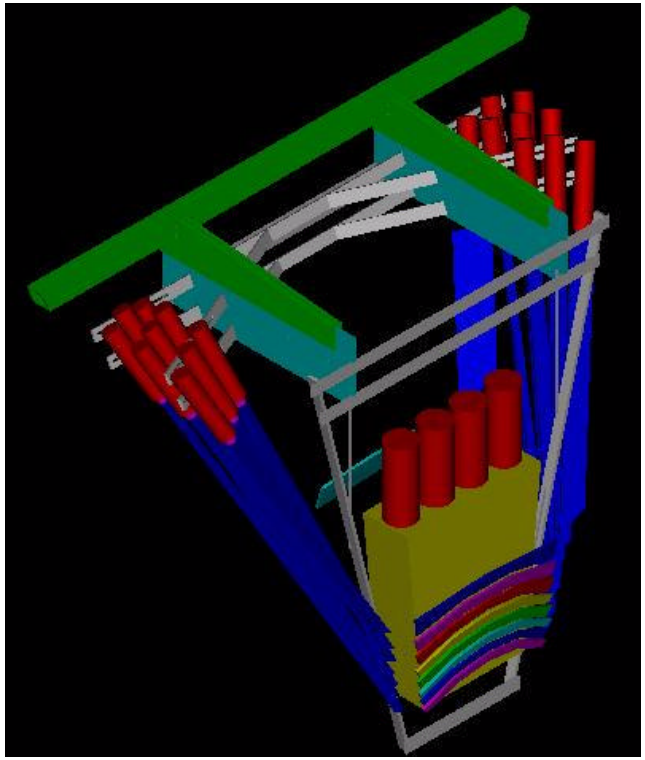


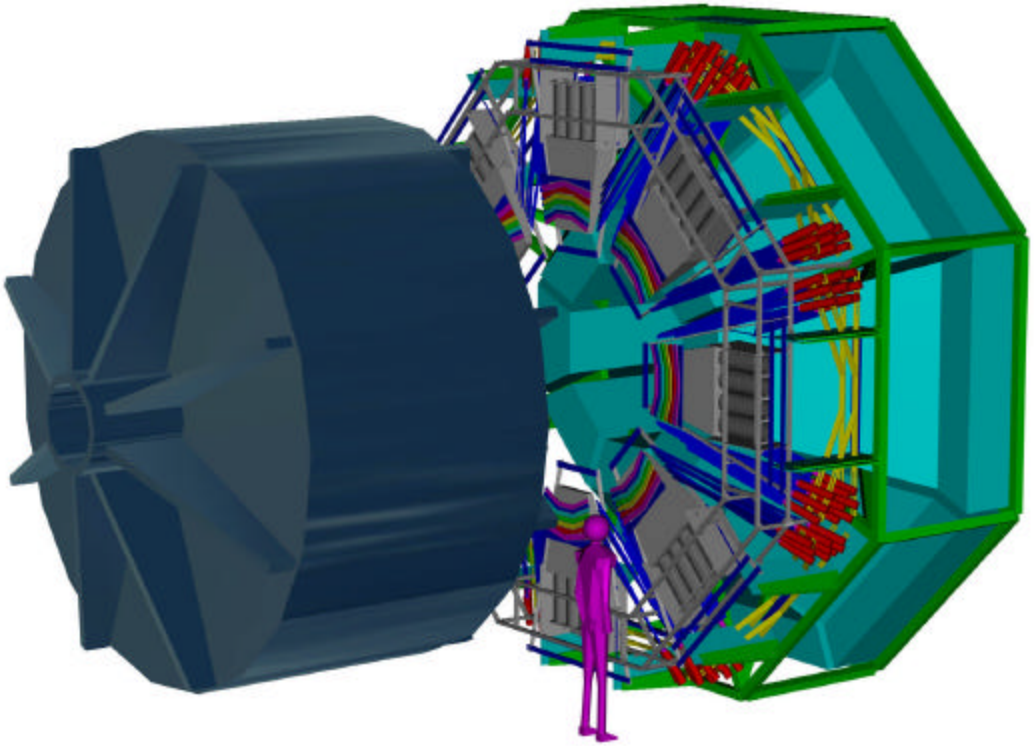
Pion rejection ~ 60

(LD_2, Q^2 = 0.8 $(GeV/c)^2$) :



Cryostat Exit Detectors (CED)





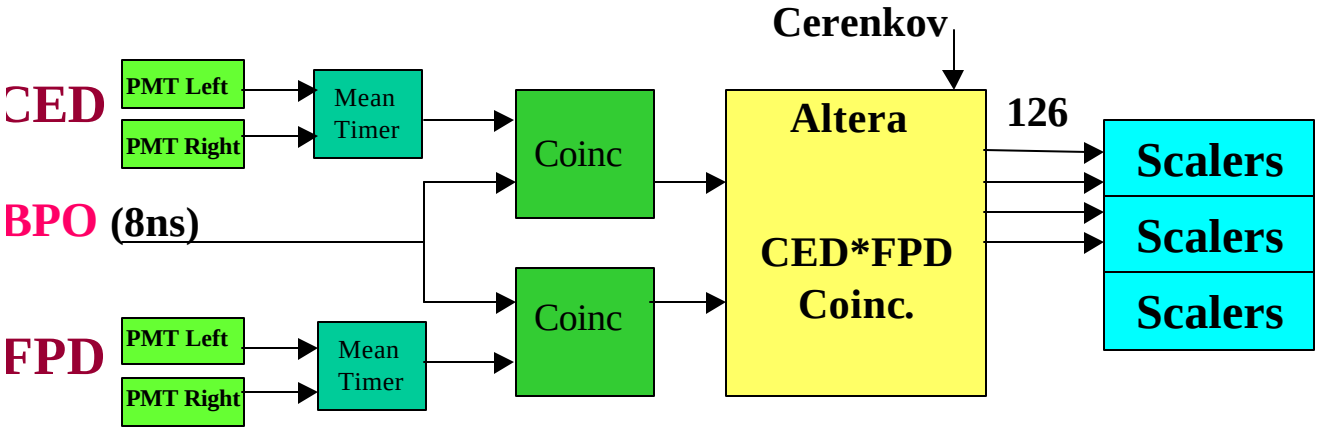
Cosmics tests have been performed on CED prototype (LaTech)

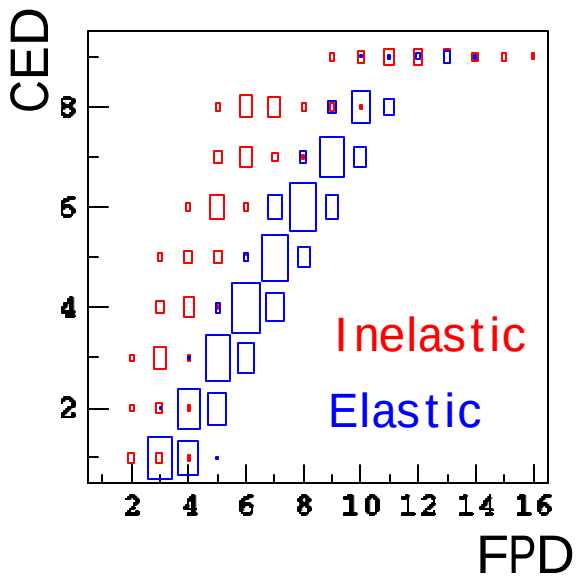
- More than 100 p.e. available
- ~ 300 ps of time resolution

Construction performed at TRIUMF

Backward angle Electronics

Coincidences matrix CED*FPD :





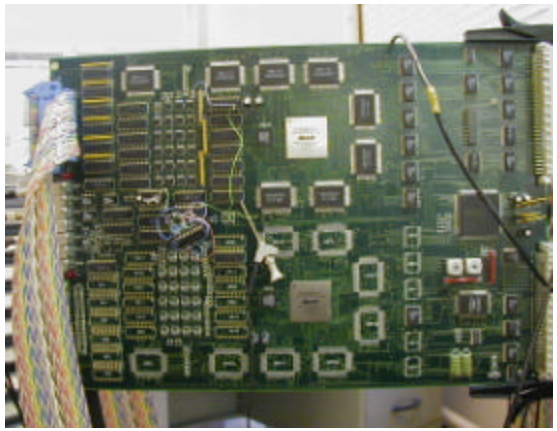
FR octants : Coincidence module added to the Forward electronics (TOF information available)

NA octants: Matrix module instead of LTD modules

For both electronics, coincidence counting readout by scalers (integrated over 1/30 s)

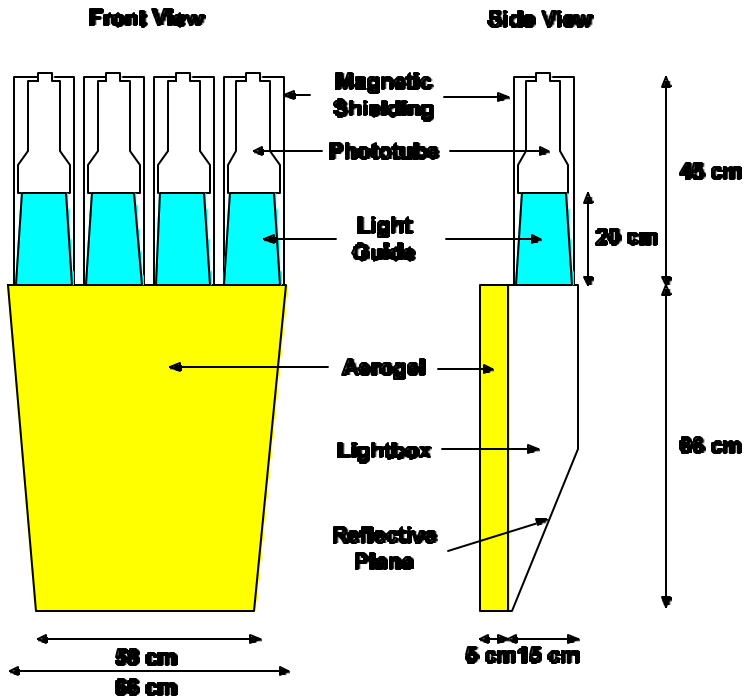
Cerenkov trigger included

Deadtime study with indiv. scalers and multi-hits counting



Coinc. Module (Grenoble)

Cerenkov detector



- 5 cm Aerogel (n=1.03)
- Light box geometry optimized
- Diffuse reflective covering (Millipore)
- 5 inch PMTs (X4572B Photonis)

  ~ 6-8 p.e. expected for electrons

- Cosmic tests performed on a small prototype (~1/3 scaled)

  Good agreement with simulation (LITRANI)

- Beam tests at TRIUMF on a full-scaled prototype

  Electron efficiency ~ 88 ± 2 %

  Pion rejection = electron efficiency/pions efficiency ~ 140 ± 7

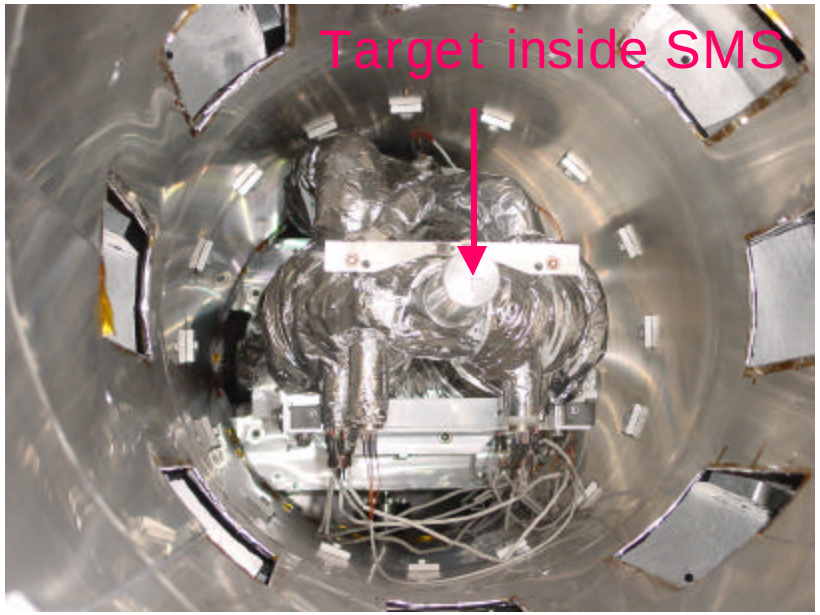
Status of G^0 experiment

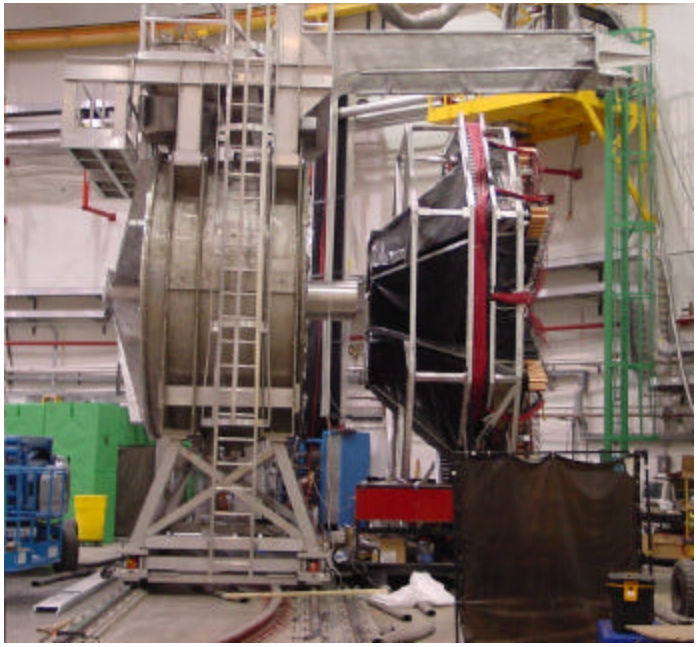
Magnet, target and detectors in hall C

Target&Magnet tests in June-July 2002

G^0 Beam tests in August 2002

Commissioning in Oct.-Dec. 2002





Forward Angle run in 2003

Backward angle exp. approved by PAC in Jul. 2001

Turnaround and First Q^2 at Backward angle in 2004

2nd, 3rd Q^2 Backward angle in 2005-06