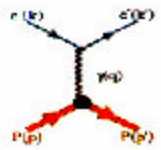
G0 - a parity violation experiment

Overview & Present status



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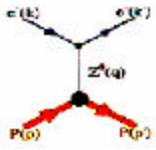
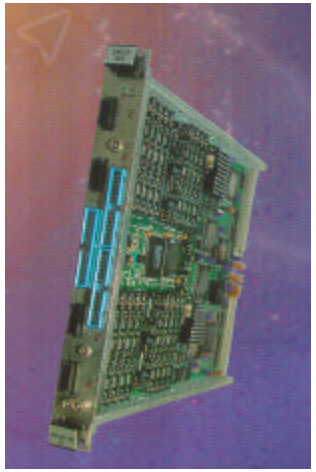
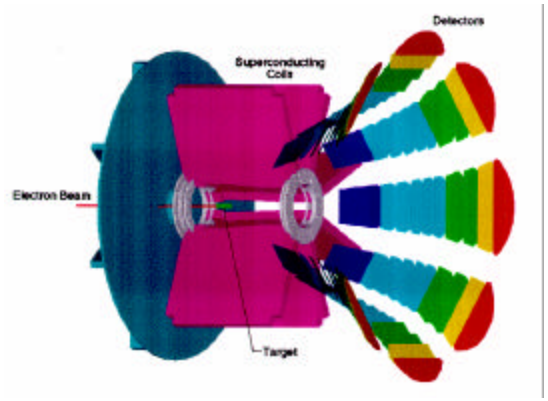
for the *G0 collaboration* **:** *http://www.npl.uiuc.edu/G0*







Plan for presentation

- Generalities
- Physics
- Requirements
- Set-up
  - ✓ Electronics
- Commissioning
- Present status & future

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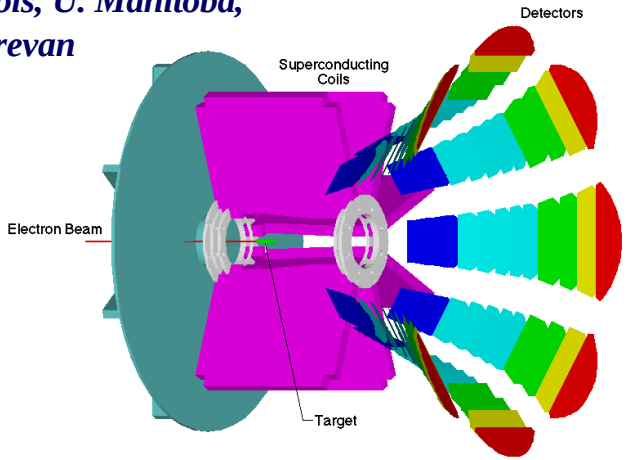
Generalities

Experiment Highlights:

- Map the vector strange form factors of the nucleon over Q2 range 0.1-1 (GeV/c2)
- First single experiment to separate strange electric, strange magnetic and axial form factors
- Parity violation experiment, measures PV asymmetries of the order 10^{-6} or ppm
- Level of precision 5% of the measured asymmetries

The G^0 Experiment in Jefferson Lab Hall C

Caltech, Carnegie-Mellon, Hampton, IPN-Orsay, JLab, LPSC-Grenoble, Kentucky, LaTech., NMSU, TRIUMF, U. Conn., U. Illinois, U. Manitoba, U. Maryland, U. Mass., UNBC, VPI, William&Mary, Yerevan

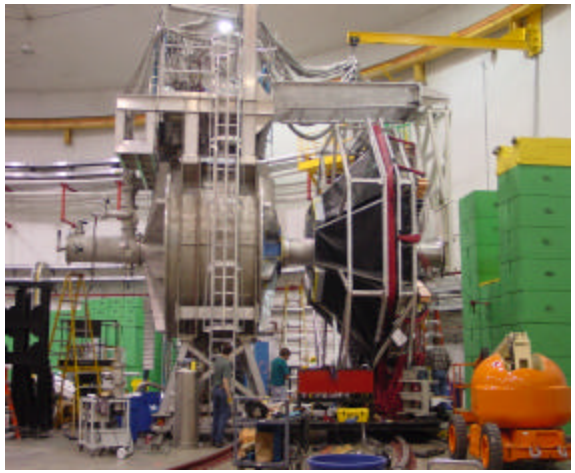


Main components:

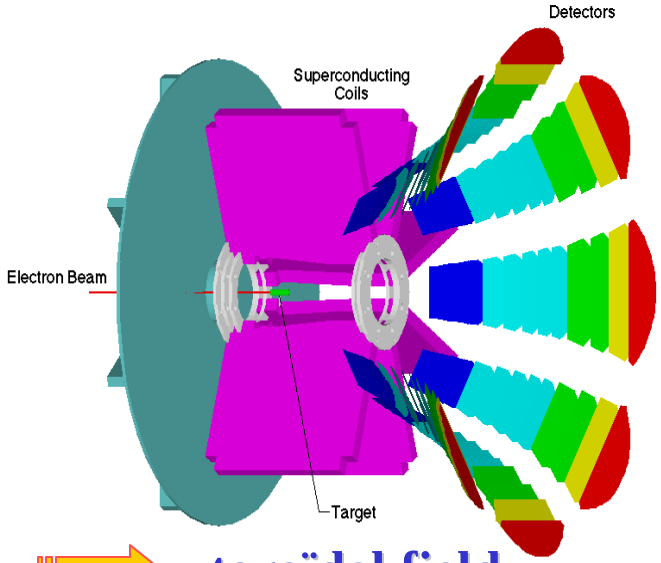
- Superconducting toroidal magnet
- Jefferson Lab polarized source
- High power LH_2 / LD_2 targets
- Large acceptance scintillation detector array
- Custom built high count rate electronics

History:

- Design and construction (1993 - 2001)
- Commissioning run (fall 2002 / winter 2003)
- Finish commissioning run (fall 2003 / winter 2004)
- Forward angle production run (winter 2004 / spring 2004)
- Back angle production runs (2005 - 2007)



G0 detection system



8 coils ➡ **toroïdal field**

16 pairs of scintillators per octant (256 total)

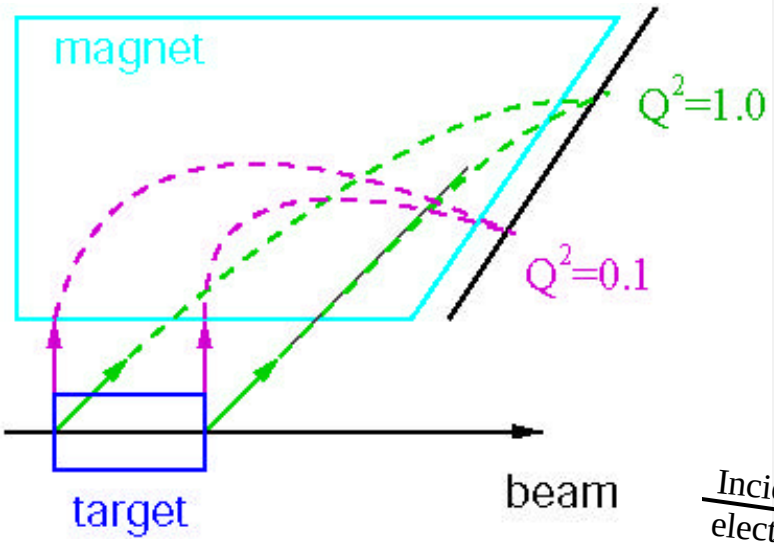
p or e detection : trajectory + TOF

➡ **4 octants built by American collaborators**

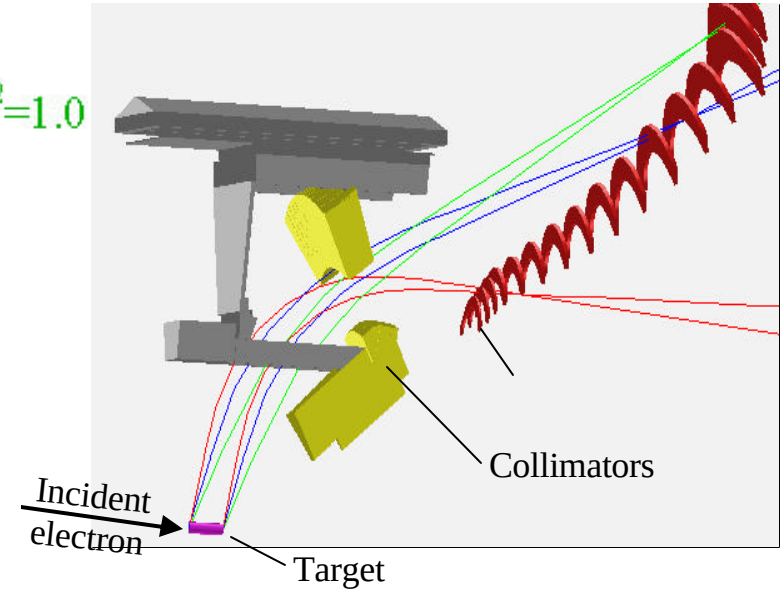
➡ **4 octants built by French collaborators**

G0 Forward Angle Mode

- Electron beam energy = 3 GeV on 20 cm LH_2 target
- Detect recoil protons (q ~ 62 - 78° corresponding to 15 - 5° electrons)
- Magnet sorts protons by Q^2 in focal plane detectors
- Full desired range of Q^2 (0.16 - 1.0 GeV^2) obtained in one setting
- Beam bunches 32 nsec apart (31.25 MHz = 499 MHz/16)
- Flight time separates p (about 20 ns) and p^+ (about 8 ns)



FP Detectors



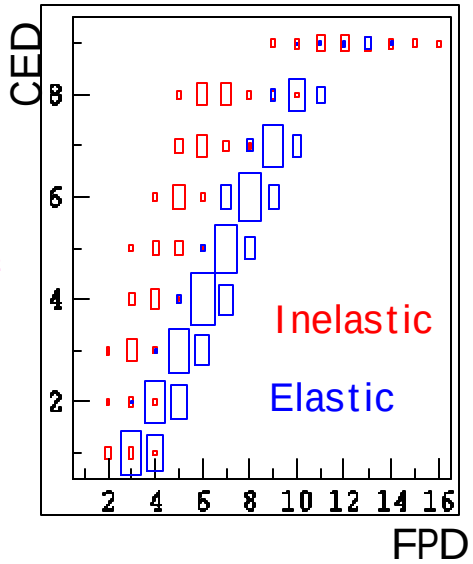
G0 Backward Angle Measurement

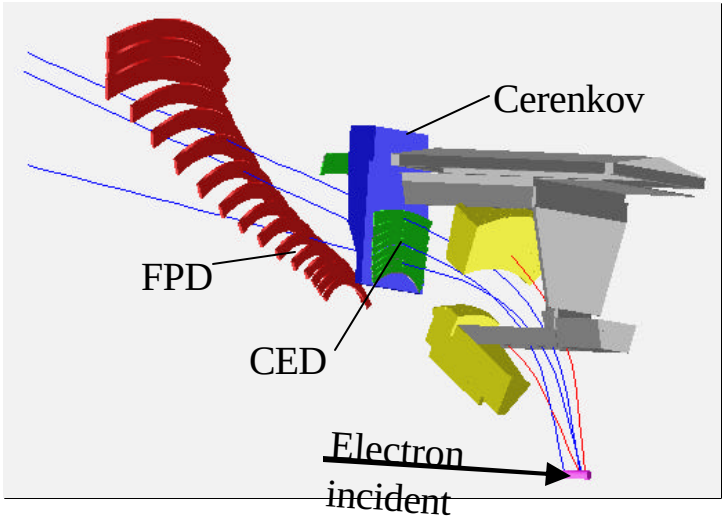
- At back angles Q^2 only has small variation in G^0 acceptance
- Detect scattered electrons at $q_e \sim 108^o$
  - ® Need separate runs at E = 424, 576, 799 MeV
    for Q^2 = 0.3, 0.5, 0.8 $(GeV/c)^2$
    for both LH_2 and LD_2 targets
    (total of 6 runs x 700 hours)

Requires additional detectors:

- Cryostat Exit Detectors (CED) to separate elastic and inelastic electrons
- Cerenkov detector for pion rejection (primarily for LD_2 target)

CED/FPD coincidences at Q^2 = 0.3 GeV^2





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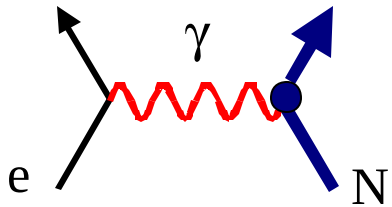
Nucleon form factors in elastic e-N scattering

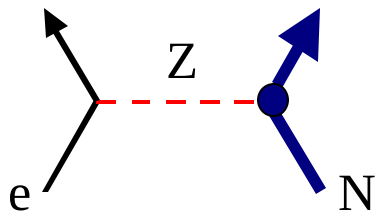
Nucleon form factors

- well defined experimental observables
- provide an important benchmark for testing non-perturbative QCD structure of the nucleon



$$< N \mid J_m^g \mid N > \quad \rightarrow \quad G_E^g, G_M^g$$

electromagnetic form factors



$$< N \mid J_m^Z \mid N > \quad \rightarrow \quad G_E^Z, G_M^Z$$

neutral weak form factors

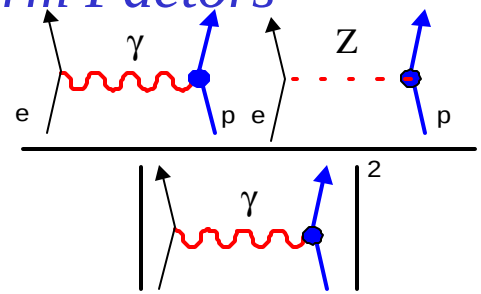
- Measured precision of EM form factors in 0.1 - 1 GeV^2 Q^2 range ~ 2 - 4%
- Projected precision of NW form factors in 0.1 - 1 GeV^2 Q^2 range ~ 10% from the current generation of experiments (for magnetic)

Parity Violating Electron Scattering -

Probe of Neutral Weak Form Factors

polarized electrons, unpolarized target

$$A = \frac{s_R - s_L}{s_R + s_L} = \left[\frac{-G_F Q^2}{4pa\sqrt{2}}\right]\frac{A_E + A_M + A_A}{2s_{unpol}}$$



$$A_E = e(q)\,G_E^Z(Q^2)G_E^g(Q^2)$$
$$A_M = t(Q^2)\,G_M^Z(Q^2)G_M^g(Q^2)$$
$$A_A = -(1-4\sin^2 q_W)e'\,G_A^e(Q^2)G_M^g(Q^2)$$

$\rightarrow G_E^s$
$\rightarrow G_M^s$
$\rightarrow G_A^e$

Strange electric and magnetic form factors,
+ axial form factor

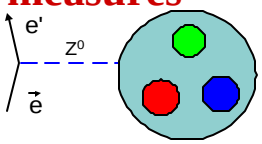
At a given Q^2 decomposition of G^s_E, G^s_M, G^e_A
Requires 3 measurements:

Forward angle $\bar{e} + p$ (elastic)
Backward angle $\bar{e} + p$ (elastic)
Backward angle $\bar{e} + d$ (quasi-elastic)

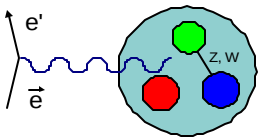
G^0 will perform all three measurements at three different Q^2 values - 0.3, 0.5, 0.8 GeV

Axial Coupling and the Anapole Moment

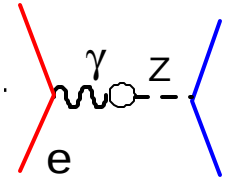
A_{PV} measures



but also



+



+ ...

$$\langle p' | J^{m}_{EM} | p \rangle = \bar{u}(p')\Big[F_1(q^2)g_m - \tfrac{i}{2M}F_2(q^2)s_{mn}q^n + \tfrac{1}{M^2}F_A(q^2)(q^2 g_m - \not{q} q_m)g_5 - \tfrac{i}{2M}F_E(q^2)s_{mn}q^n g_5\Big]u(p)$$

Anapole (TRI , PV)

Electric dipole (TRV, PV)

$$F_A(0) \approx M^2 G_F \approx 10^{-5}$$

Anapole: parity violating EM interaction

parity mixing in nucleon's wave function

I. Zel'dovich, JETP Lett 33 (1957) 1531

$$L_A \rightarrow -e^2 \frac{F_A}{M^2} \vec{s} \cdot \vec{j}$$

Recent updates:

- **Zhu, Puglia, Holstein, Musolf, PRD62 (2000) 033008**
- **Maekawa, Veiga, van Kolck, PLB 488 (2000) 167**
- **D. Riska, NPA 678 (2000) 79**

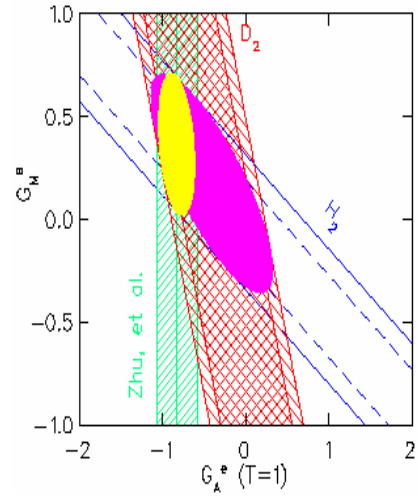
Strange form factors - published results

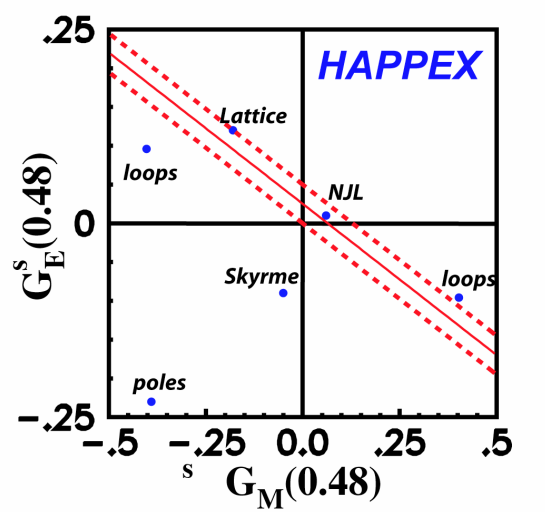
SAMPLE at MIT-Bates:

$\vec{e} + p$ elastic : $A_p = -4.92 \pm 0.61 \pm 0.73$ ppm

$\vec{e} + d$ quasielastic : $A_d = -7.55 \pm 0.70 \pm 0.60$ ppm

$$G_M^s(Q^2 = 0.1\,\mathrm{GeV}^2) = 0.14 \pm 0.35 \pm 0.40$$





HAPPEX at Jefferson Lab:

$\vec{e} + p$ elastic : $A_p = -15.05 \pm 0.98 \pm 0.56$ ppm

$$G_E^s + 0.39 G_M^s = 0.025 \pm 0.020 \pm 0.014$$

at $Q^2 = 0.48\ \mathrm{GeV}^2$

G0 elastic scattering program

A_F : one measurement for all Q^2 ® detect recoil protons
A_B : three measurements for three Q^2 values: ® detect electrons at 108°
A_d : Quasielastic scattering (x3) from deuterium ® detect electrons at 108°

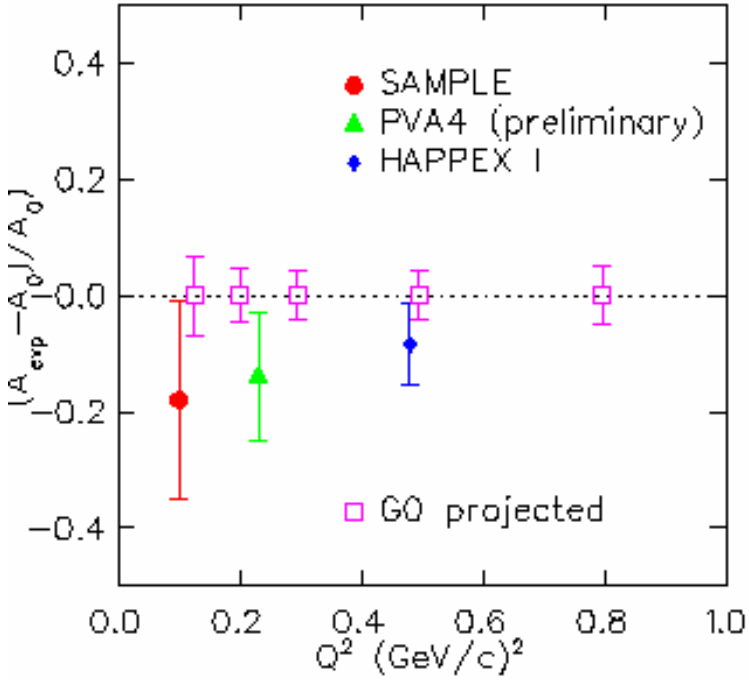
report G0-00-045 by R. Tieulent, et al.

$$\begin{pmatrix} A_F \\ A_B \\ A_d \end{pmatrix} = \begin{pmatrix} x_F & c_F & y_F \\ x_B & c_B & y_B \\ x_d & c_d & y_d \end{pmatrix} \begin{pmatrix} G_E^s \\ G_M^s \\ G_A^e \end{pmatrix} + \begin{pmatrix} h_F \\ h_B \\ h_d \end{pmatrix}$$

at $Q^2 = 0.44\ (GeV/c)^2$

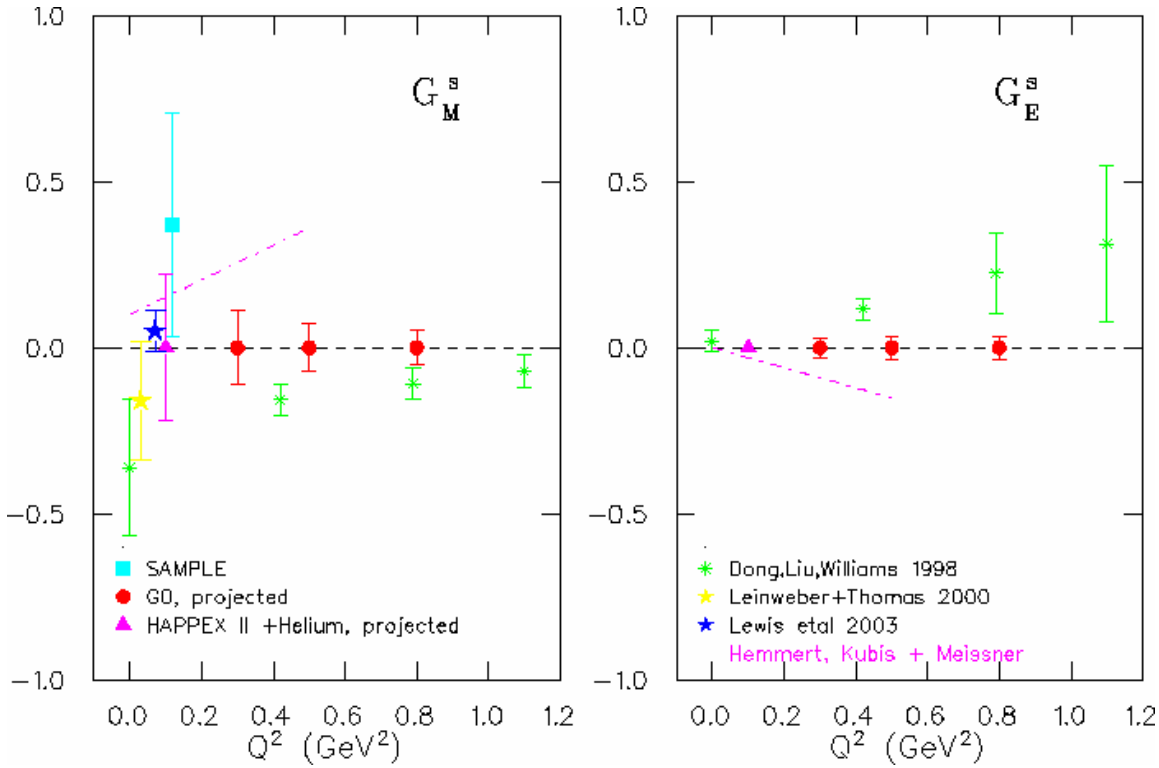
	η (ppm)	ξ (ppm)	χ (ppm)	ψ (ppm)
A_F	-13.77	51.80	18.63	1.01
A_B	-25.01	16.10	31.41	6.96
A_d	-34.00	13.13	7.07	8.41

G0 expectations



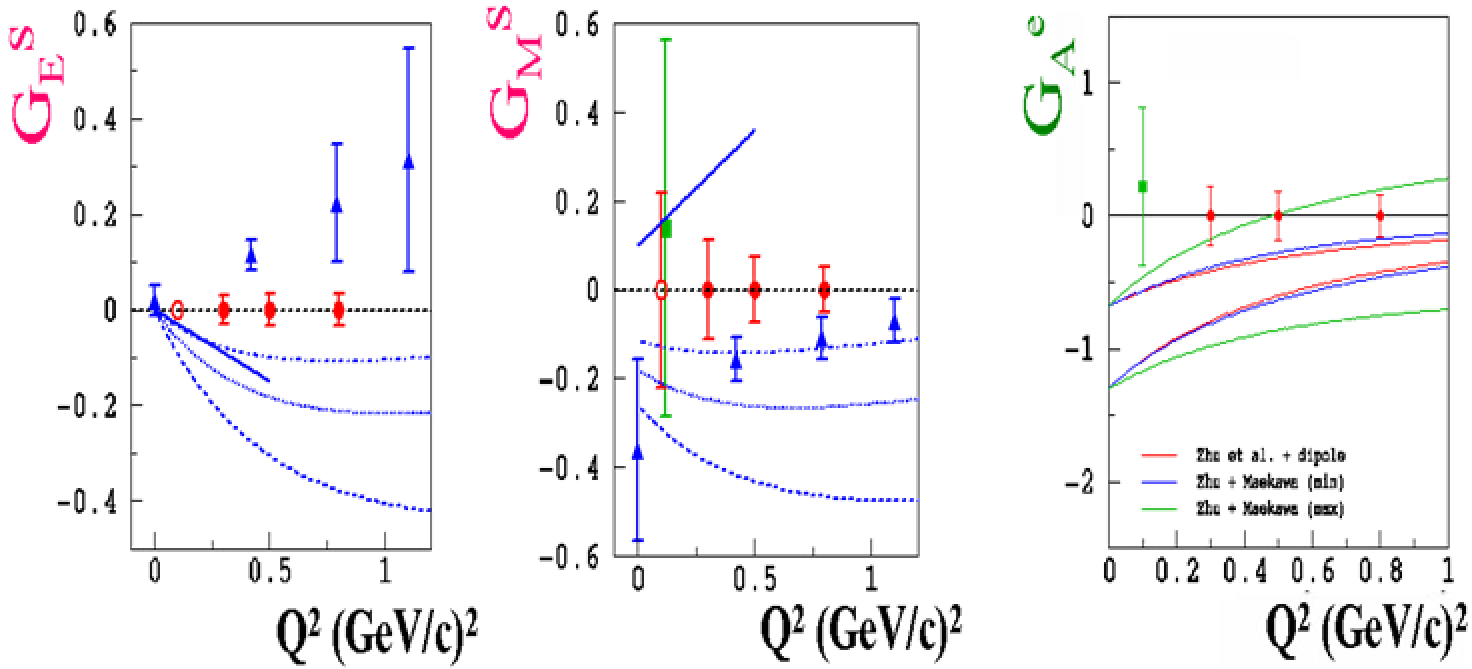
Asymmetries

G0 expectations



Strange form factors

G0 expectations



For G_E^S and G_M^S

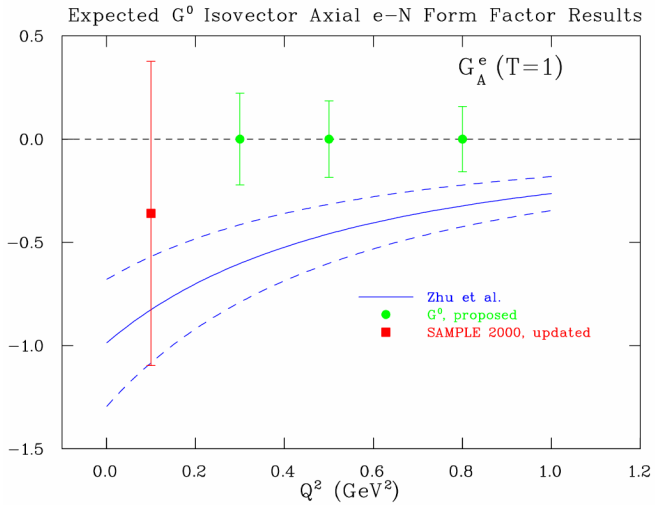
Comparison with theory

Δ - **Lattice QCD calculations** (Dong *et al.*)

___ - **Heavy baryon chiral perturbation theory** (Hemmert *et al.)*

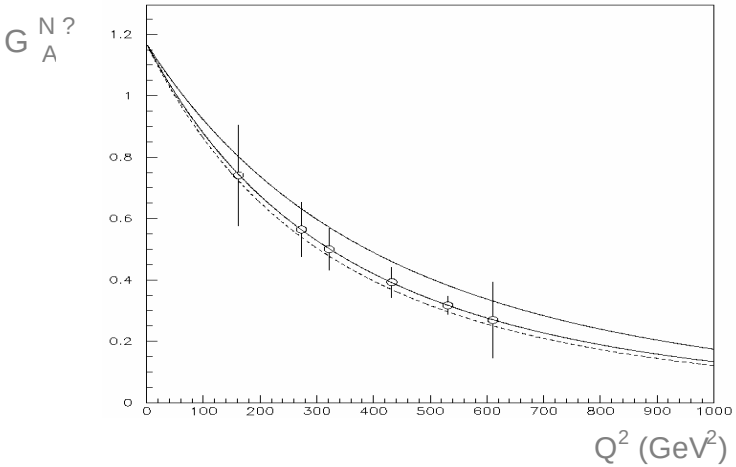
…… - **Dispersive approach** (Forkel)

Other Aspects of G^0 Physics Program



$G_A^e(Q^2)$ - e-N axial form factor

$\vec{e}$ + d quasielastic measurements at back angles will map out e - N axial form factor G_A^e as a function of Q^2



N→Δ Axial Transition Form Factor

data taken concurrently with back angle $\vec{e}$ + p elastic data-taking

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

- *Generalities*
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GO experimental requirements

- **longitudinally polarized electrons**
  intensity of 40 µA
  pulses every 32 nsec
- **helicity change every 33 msec**
- **helicity sequence by quartets like (+ - - +) or (- + + -)** ***pseudo randomly.***
- **helicity correlated beam fluctuations** ***(within a quartet)***
  DI/I < 2000 ppm : Dx and Dy < 20 µm .
- **LH_2 target:**
  20 cm long
  250 W heat load (40 µA beam)
- **superconducting toroidal magnet**
  5000 A
  Q^2 separation.
- **background minimized**
- **dead time determinations and corrections**

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Subsystems

* G0 special beam: Laser @ 31 MHz, 40 mA / 3 GeV e-
  Luminosity ~ 10^{38} $cm^{-2}s^{-1}$
  High polarization ~ 75 %

* High power LH2 target (*Caltech*)
  Designed for high speed flow 7-10 m/s

* Superconducting toroidal Magnet System (*UIUC*)
  Designed for operation at 5000 A

* Segmented large area focal plane detectors
  8 octants = 4 *French* + 4 *NA*
  16 segments/Octant ---> Q^2 bins
  (use scintillators)

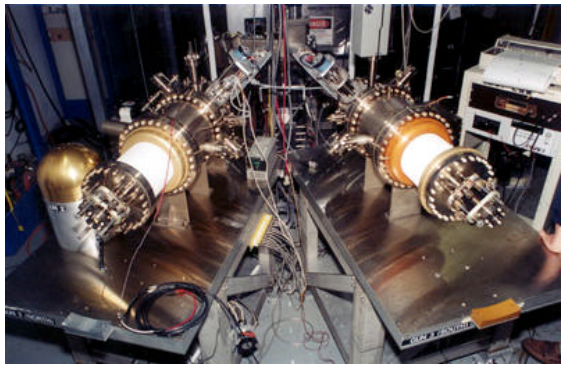
* Custom(*France*)/commercial(*North America*) electronics
  high rate counting (~ 1 MHz/segment)
  particle ID -> TOF

G^0 Beam

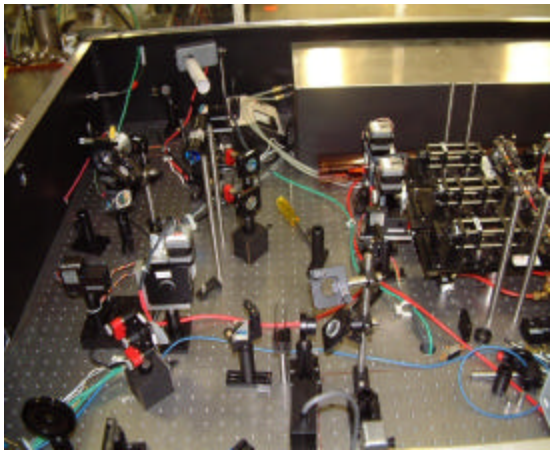
- G^0 beam requires unusual time structure: 31 MHz (32 nsec between pulses) (1/16 of usual CEBAF time structure of 499 MHz (2 nsec between pulses)
- Required new Ti:Sapphire laser in polarized electron gun
- Higher charge per bunch ® space charge effects complicated beam transport in injector (challenging beam optics problem)

- Beam with most desired properties delivered for Jan. 2003
  - Beam current 40 mA
  - Beam fluctuations at (30 Hz/4) ~ DX, DY < 20 mm DI/I < 2000 ppm

CEBAF polarized injector



CEBAF polarized injector laser table



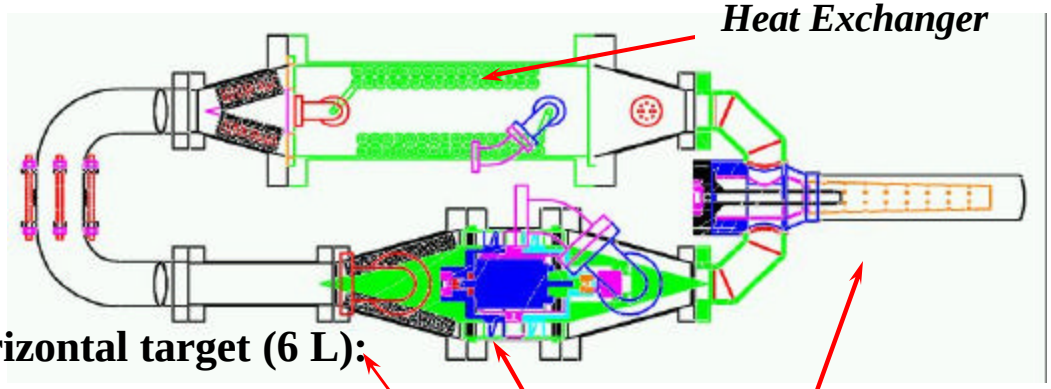
The G0 target system

Nominal running point

1.7 atm / 19 K LH_2

High power target

500 W



Cryogenic single loop horizontal target (6 L):

- *20 cm Al target cell*
- *cryogenic vane-axial pump –> 5.94 L/s at 30 Hz*
- *high power heater -> max 1000 W*
- *counter-flow heat exchanger*

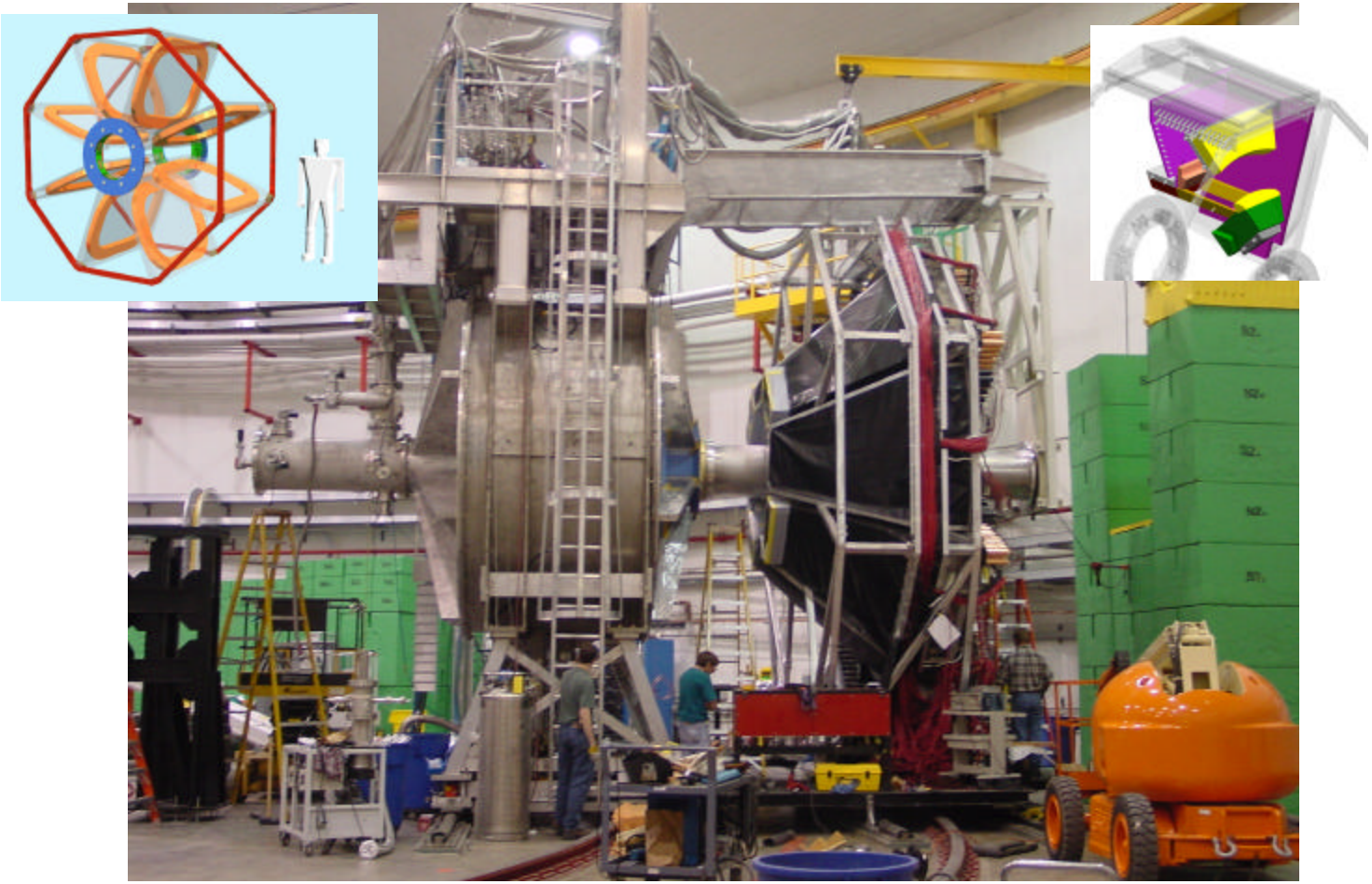
Gas handling system

- *gas panel, ballast tank and service lines*

Target controls

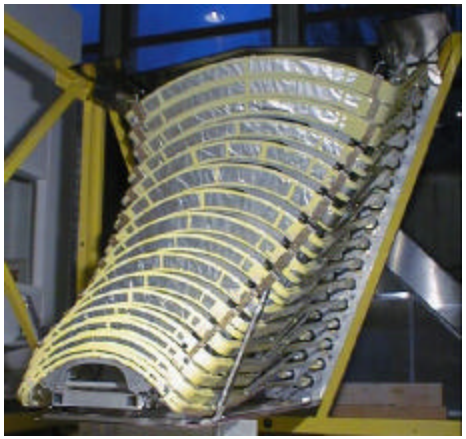
- *electronics readout*
- *monitoring through MEDM and StripTool GUI's*

G0 Superconducting magnet system (SMS)

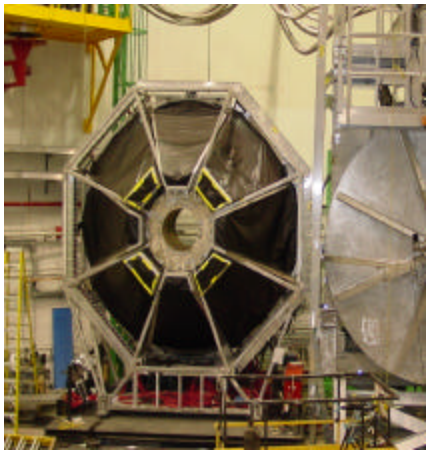


G0 Focal Plane Detectors (FPD)

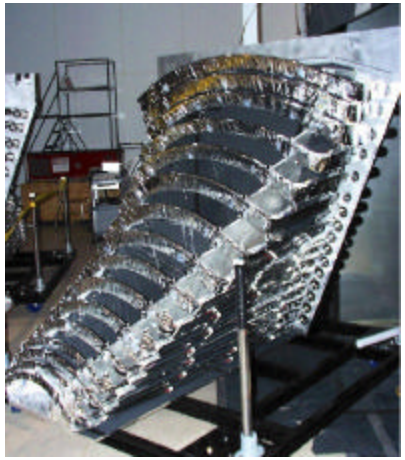
- 16 pairs of arc-shaped scintillators (iso-Q2)
  - Back and front coincidences to eliminate neutrals
  - 4 PMTs (one at each end of scintillators)
- Long light guides (PMT in low B field)



French octant



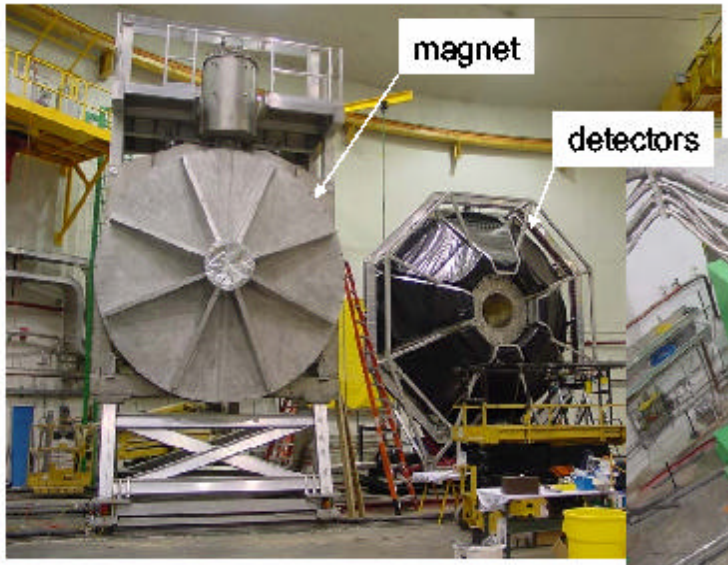
Detector "ferris wheel"



North American octant

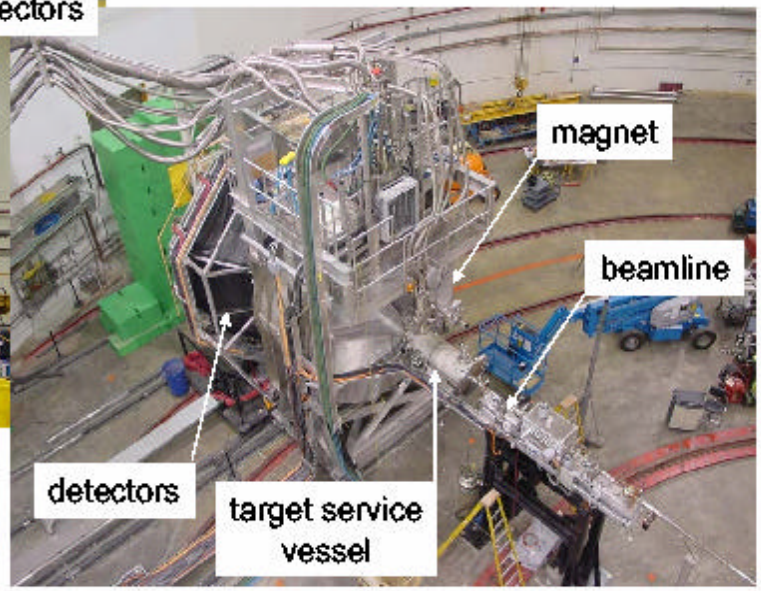
G0 installation in Hall C

- installation completed in late summer 2002



Hall C, April 02

Hall C, August 02



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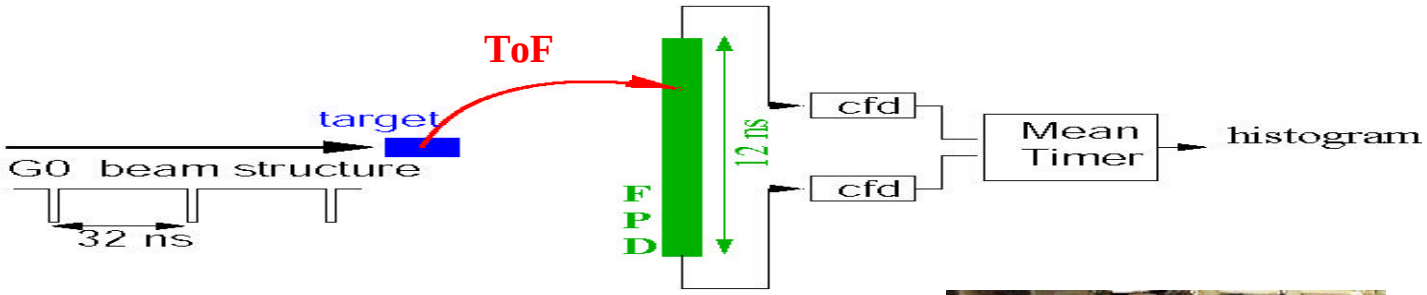
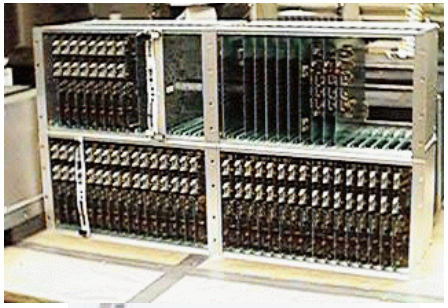
G0 Electronics and DAQ



Beam structure: 32 ns between pulses

NA octants:
MT ® latching time
digitizer ® scalers (1 ns)

LTD crate 1/2 (CMU)

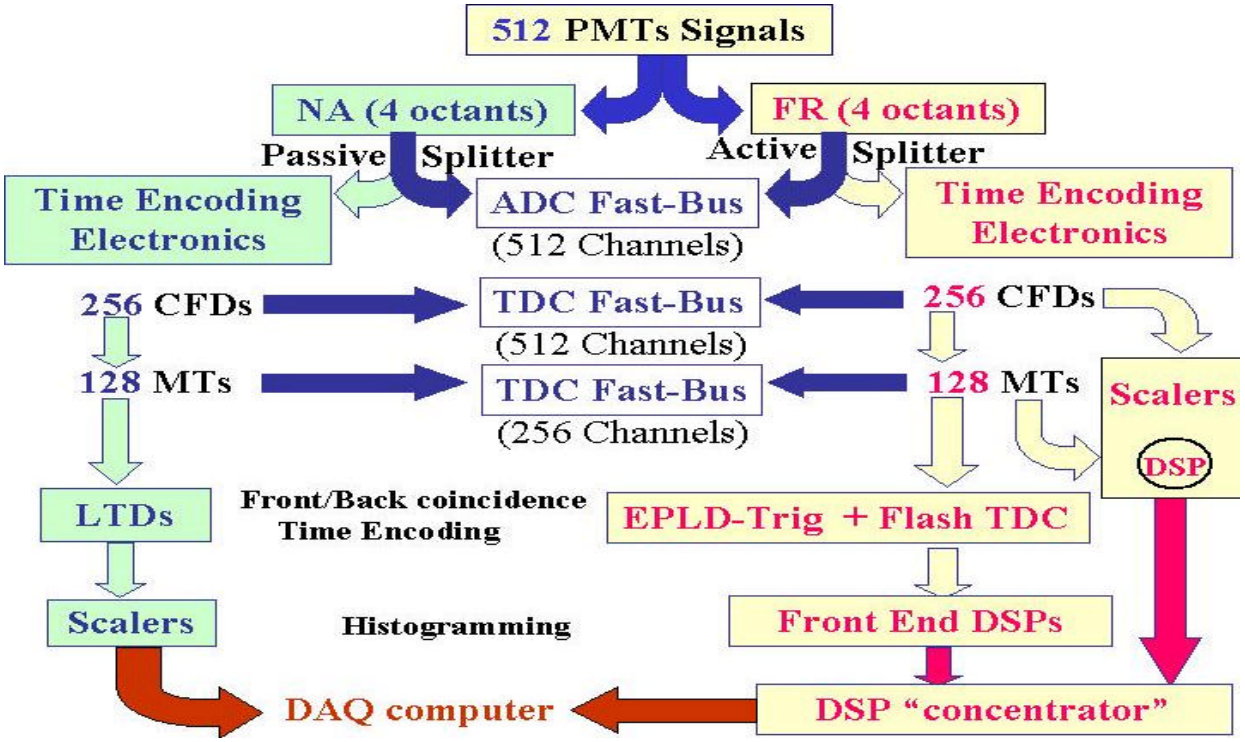


FR octants: MT ® flash TDCs (0.25 ns)

DMCH16 Module 1/8 (Orsay)

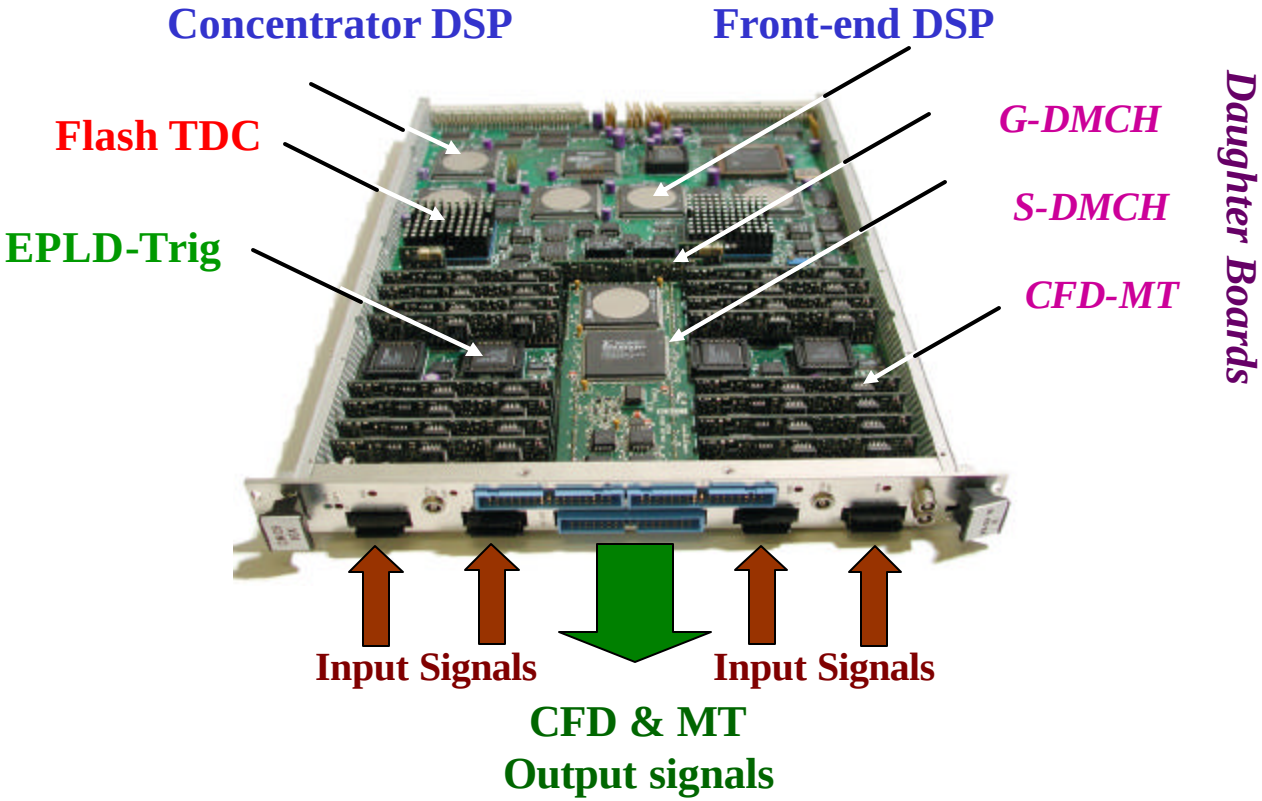
"Buddy" system for real time deadtime monitoring

G0 Electronics and DAQ



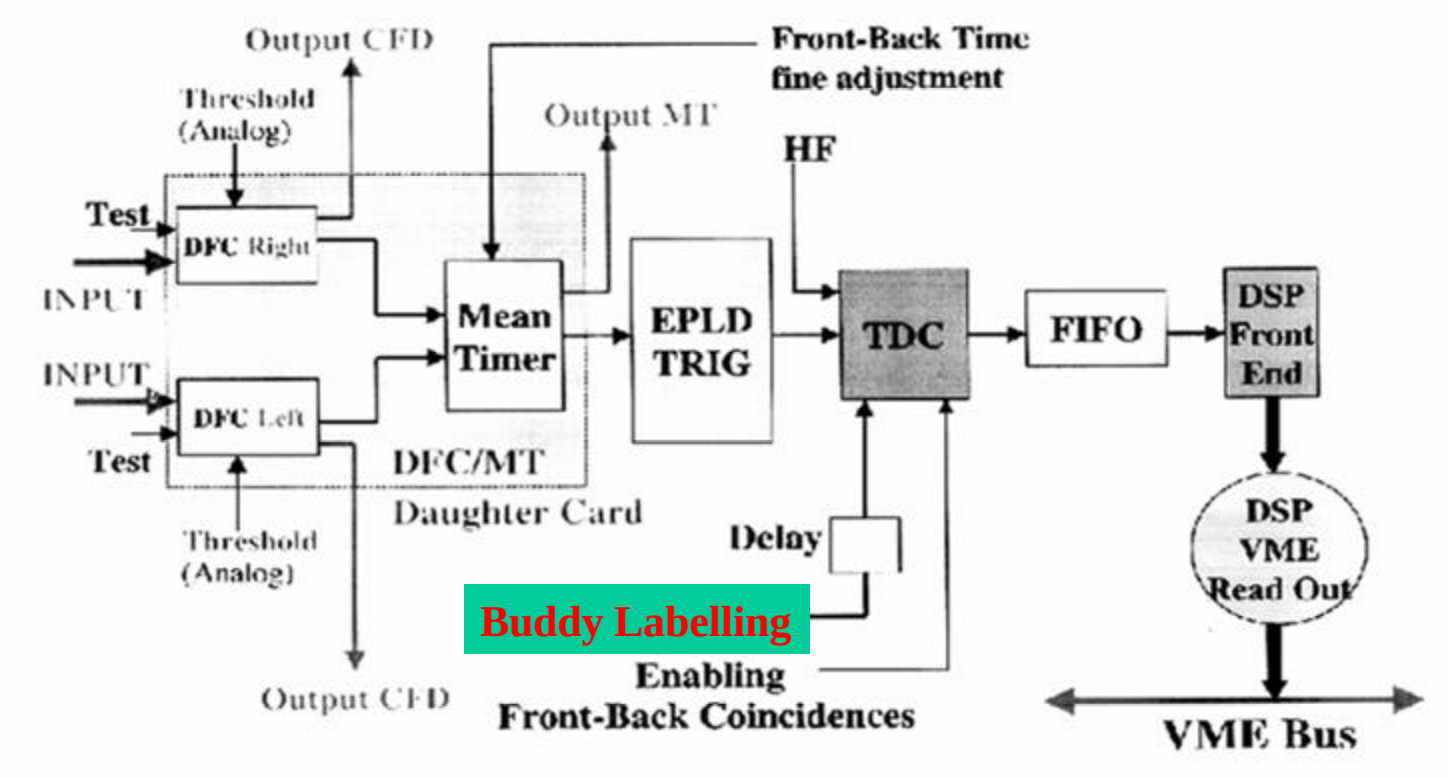
G0 signal flow diagram

G0 Electronics and DAQ



French DMCH-16X module

G0 Electronics and DAQ



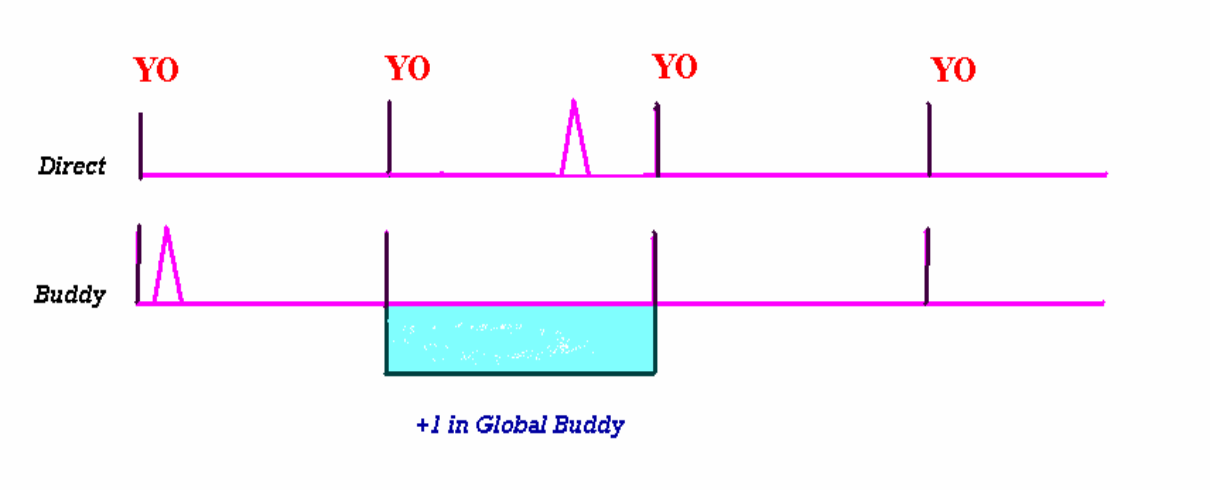
DMCH Architecture

G0 Electronics and DAQ

Buddy principle :

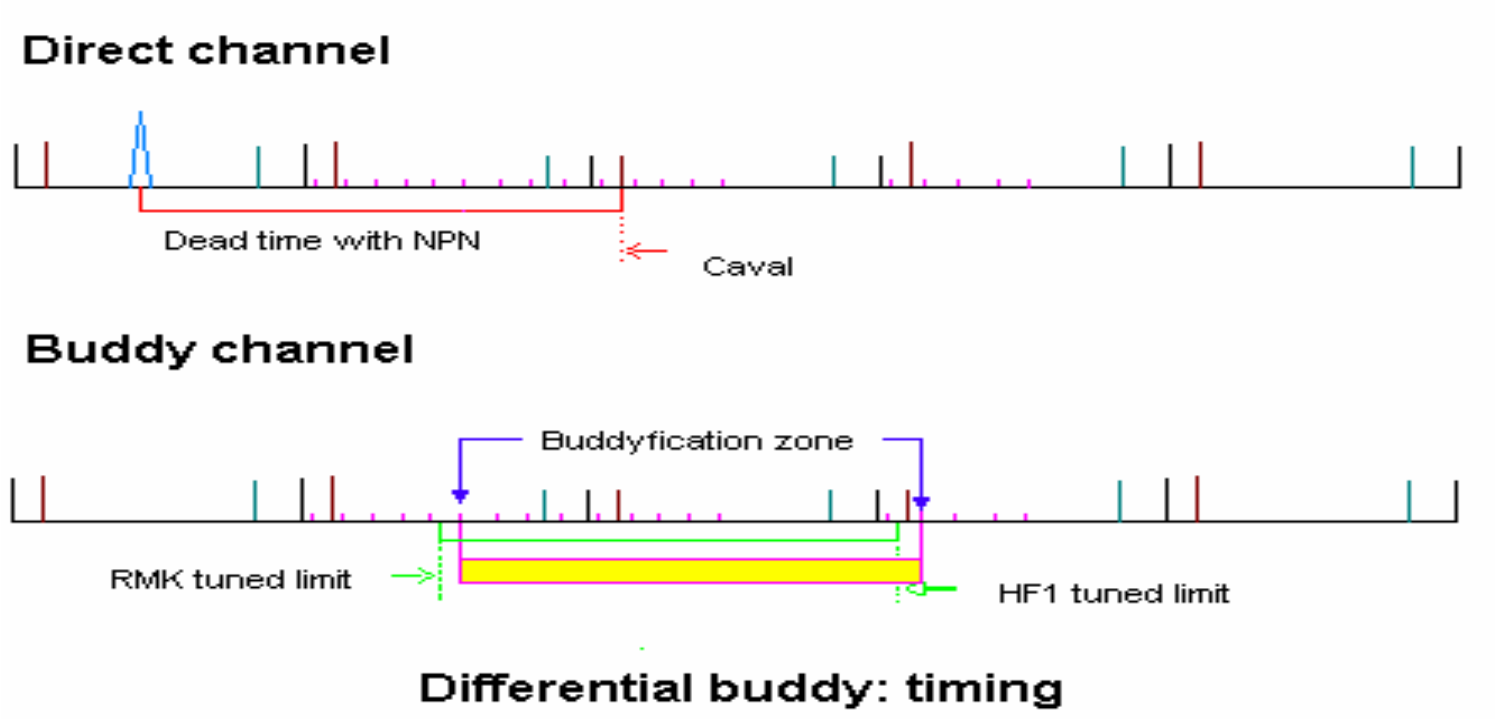
Loss due to dead time is the same for 2 symmetrical detectors
(rotation by 180° in space)

Loss due to dead time is the same for 2 following beam pulses
(translation by 32 nsec in time)



Global buddy : **only counting with SDMCH**
Next Pulse Neutralization (NPN) not done

G0 Electronics and DAQ



Differential buddy: **Histogramming of losses for each channel**

NPN taken into account

- *Generalities*
- *Physics*
- *Requirements*
- *Set-up*
  - ✓ *Electronics*
- Commissioning
- Present status & future

G0 Fall 02 Engineering Run

G0 Apparatus Checkout

- Magnet commissioned at designed operation current, 5000 A, stable
- LH2 target
  - commissioned with nominal 40 mA G0 beam, 500 W power target
  - operation very smooth
  - can put LH_2, GH_2, He, ^{12}C and "halo" targets in beam
  - density fluctuations negligible at nominal running point (30 Hz cryopump rotation)
- G0 Detector
  - detailed studies of detector gains, symmetry and centering
  - beam manipulation to measure detector sensitivity
  - photon background rates initially high, now shielded (dropped by 2, need more)
- Electronics + DAQ,
  - generally working well
  - deadtime studies underway.

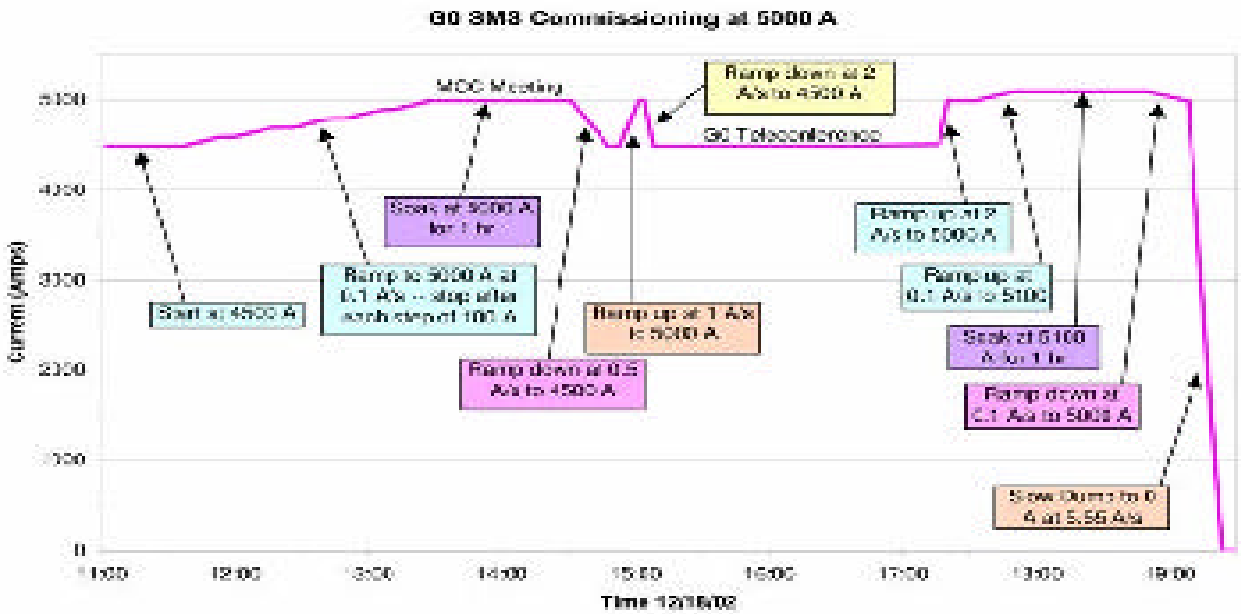
Beam checkout

- 40 mA G0 beam structure achieved but not stable
- beam polarization measured to be 75.03 +/- 1.2 %
- parity quality beam parameters: some achieved, some not

Physics asymmetry data *acquired in Jan. 2003 at 5000 A :* **51hours ~ 8% of Total**

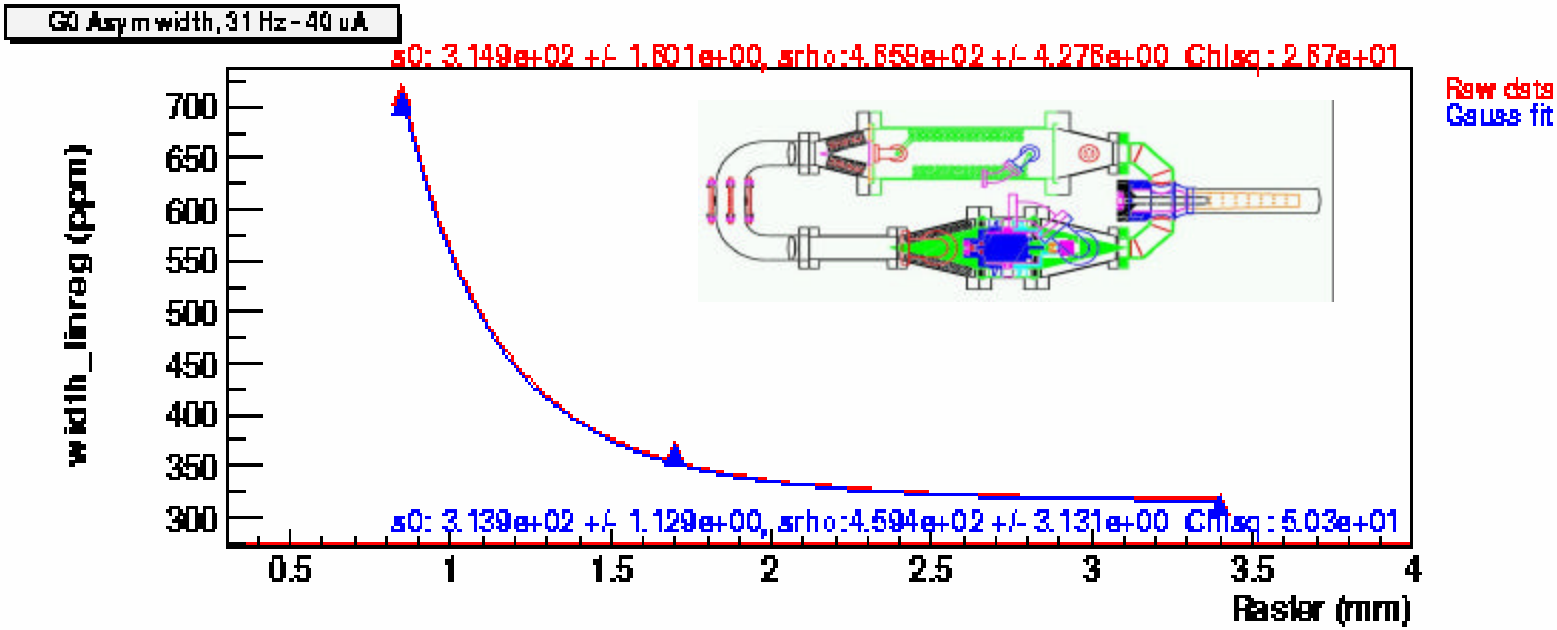
S. M. S. Commissioning

Magnet operational at design current *5000 A* : Dec 18 / 2002



First ramping to 5000 A, followed by 5100 A as a safety check

Liquid Hydrogen Target commissioning



Important role of the raster

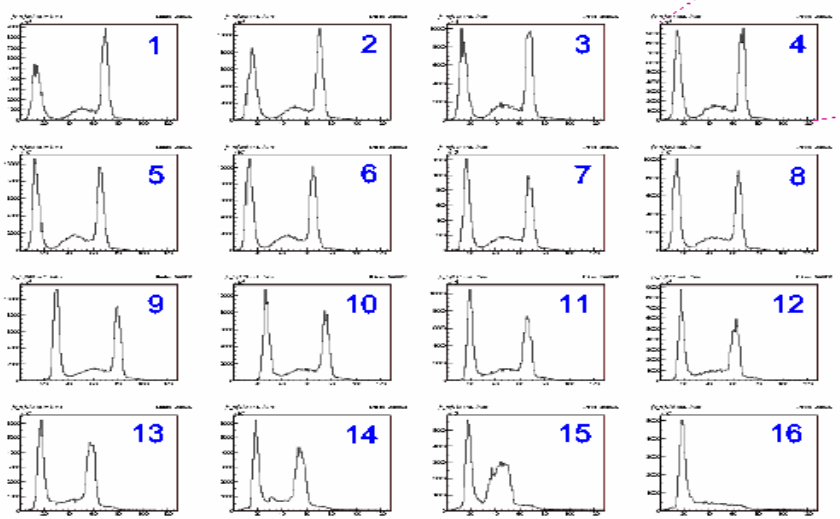
- Boiling tests at different beam intensity shows no effect if rastering applied

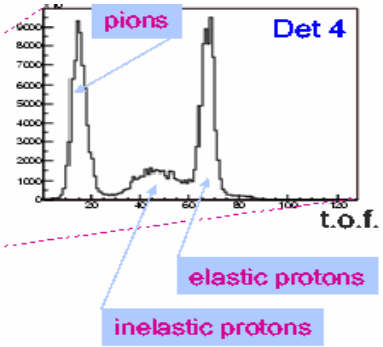
G0 Detector response

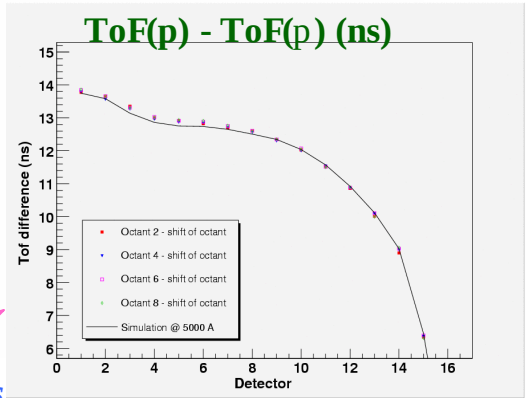
Commissioning: HV and threshold settings (uniform gain)
Reduced anode current with improved shielding around the beam pipe

✓ Detectors, electronics, DAQ and software all fully operational

✓ good t.o.f. spectra for all octants, all detectors







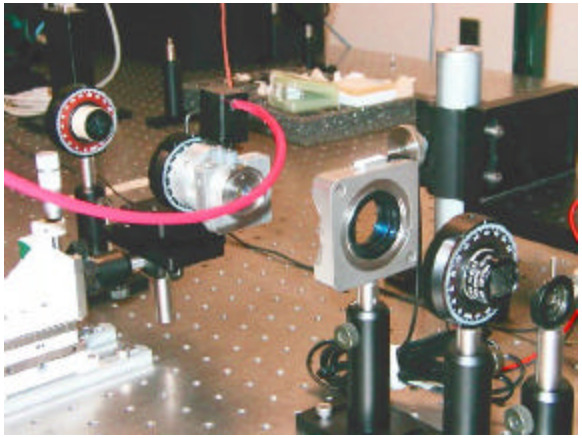
Q^2 determination

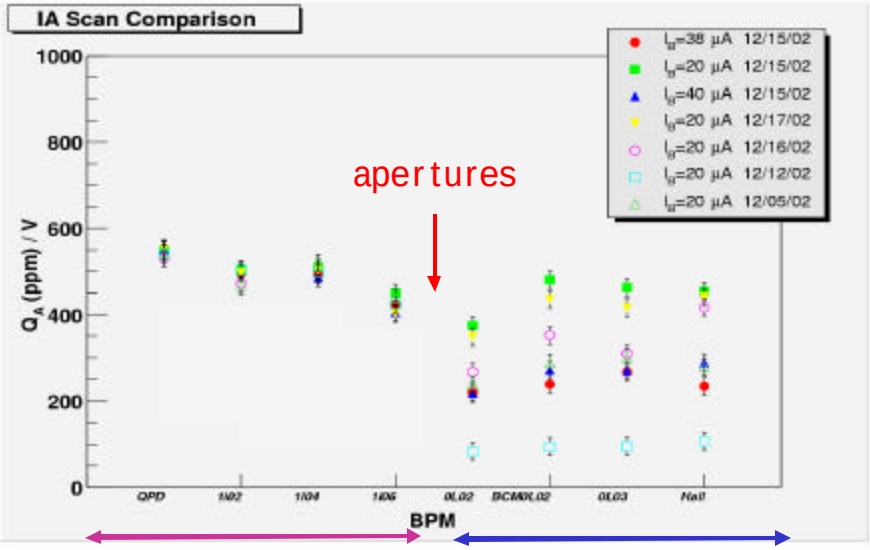
Goal : $DQ^2/Q^2 = 1\%$ Þ $Dtpp = 100ps$

Helicity - Correlated Beam Properties - Feedback

Minimization of helicity-correlated beam properties:
Done with optical devices on polarized injector laser table in feedback mode
Intensity: rotating half-waveplate, IA feedback Position: PZT mirror

Example: intensity feedback, IA cell → electro-optic intensity modulator
→ difficulties due to induced position differences and aperture scraping

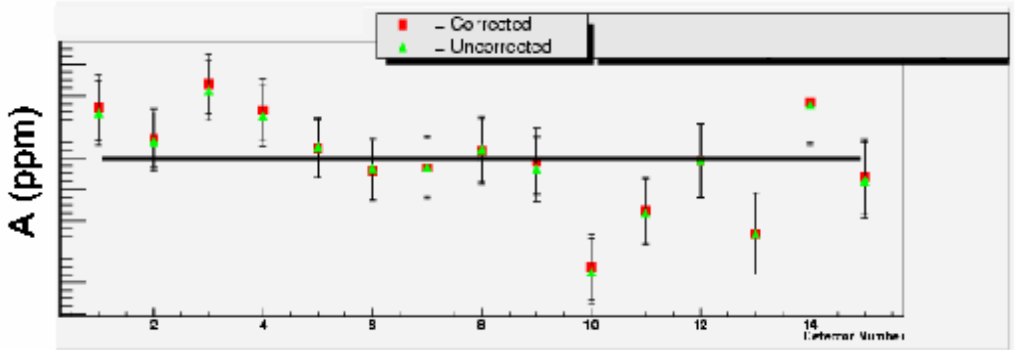




Goals: averaged over 700 hour run: intensity < 1 ppm
beam position differences < 20 nm

Helicity correlated beam properties studies

- for good beam setups, false asymmetries due to helicity-correlated beam properties are small ~ 10^{-7}



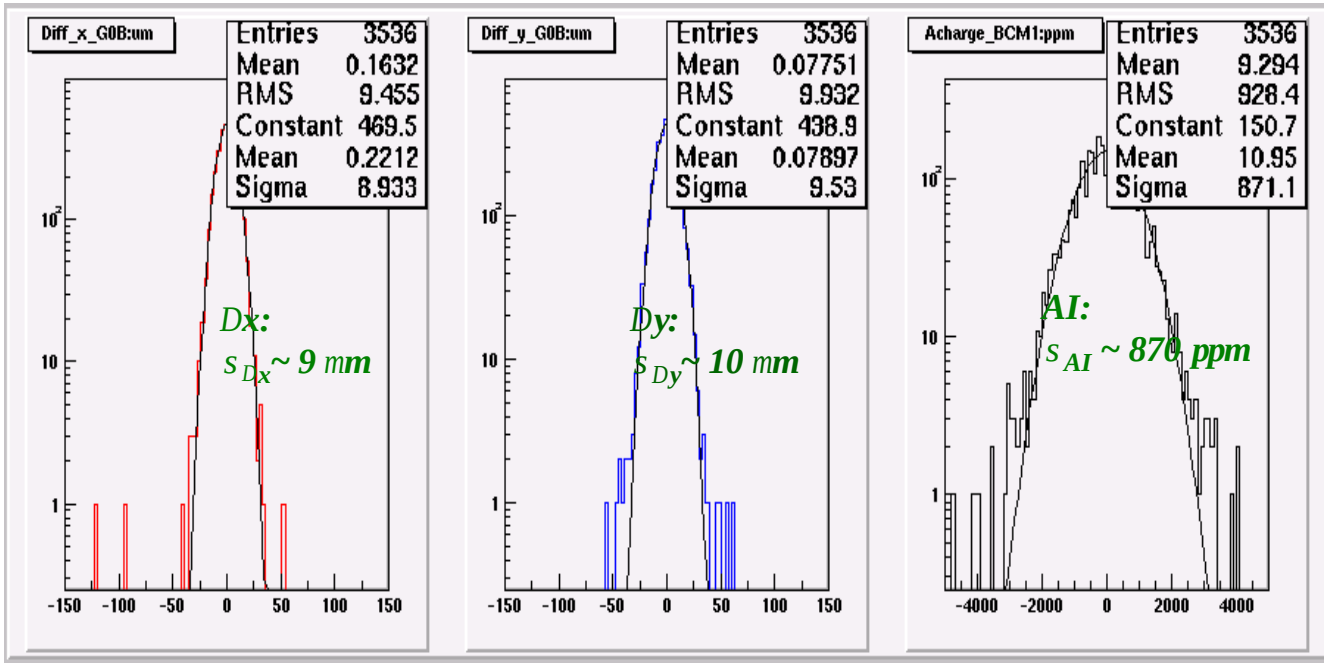
- Helicity-correlated beam charge feedback operational
- Helicity-correlated beam position feedback not operational
  - G0 collaborators diagnosing problems with polarized source laser position asymmetries and control
  - Accelerator Division launches major effort
    - establish rigorous setup procedure for injector
    - understand transverse optics from crystal to target

Data-taking and polarization flip sequence

Data readout interval = (1 / 30 Hz) = 33 msec

® **detector TOF histograms recorded**

integrated values of beam monitors (charge and position) recorded



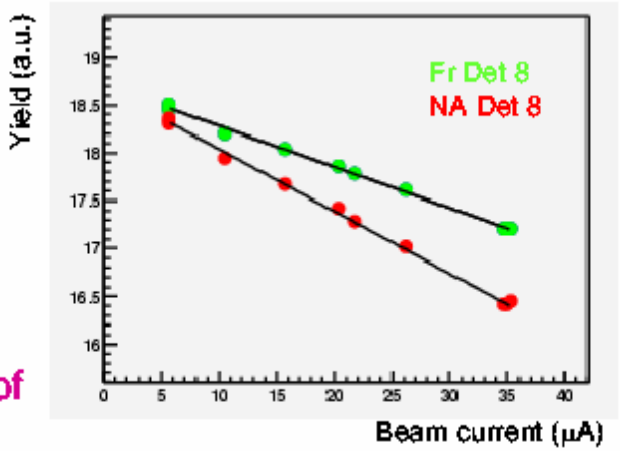
Typical difference and asymmetry histograms

GO post commissioning

- Deadtime
- False asymmetry

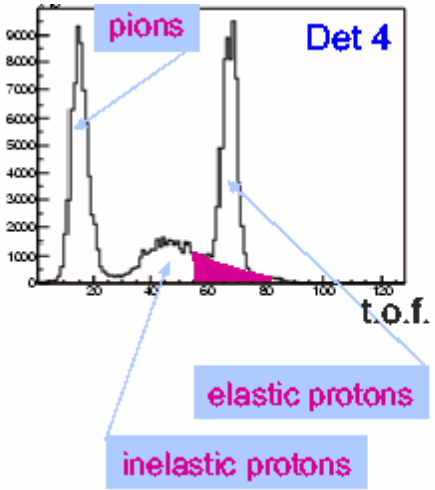
$$A_{f,deadtime} = f_{dead} A_{charge}$$

- must correct for typical deadtime of 10% and beam charge asymmetry of ~ 1 ppm
- automatically part of regression analysis of all helicity-correlated beam parameters
- NA deadtimes ~ x2 larger than French
  - traced to problem with LeCroy CFDs in NA electronics
  - requires adjustment of delay



GO post commissioning

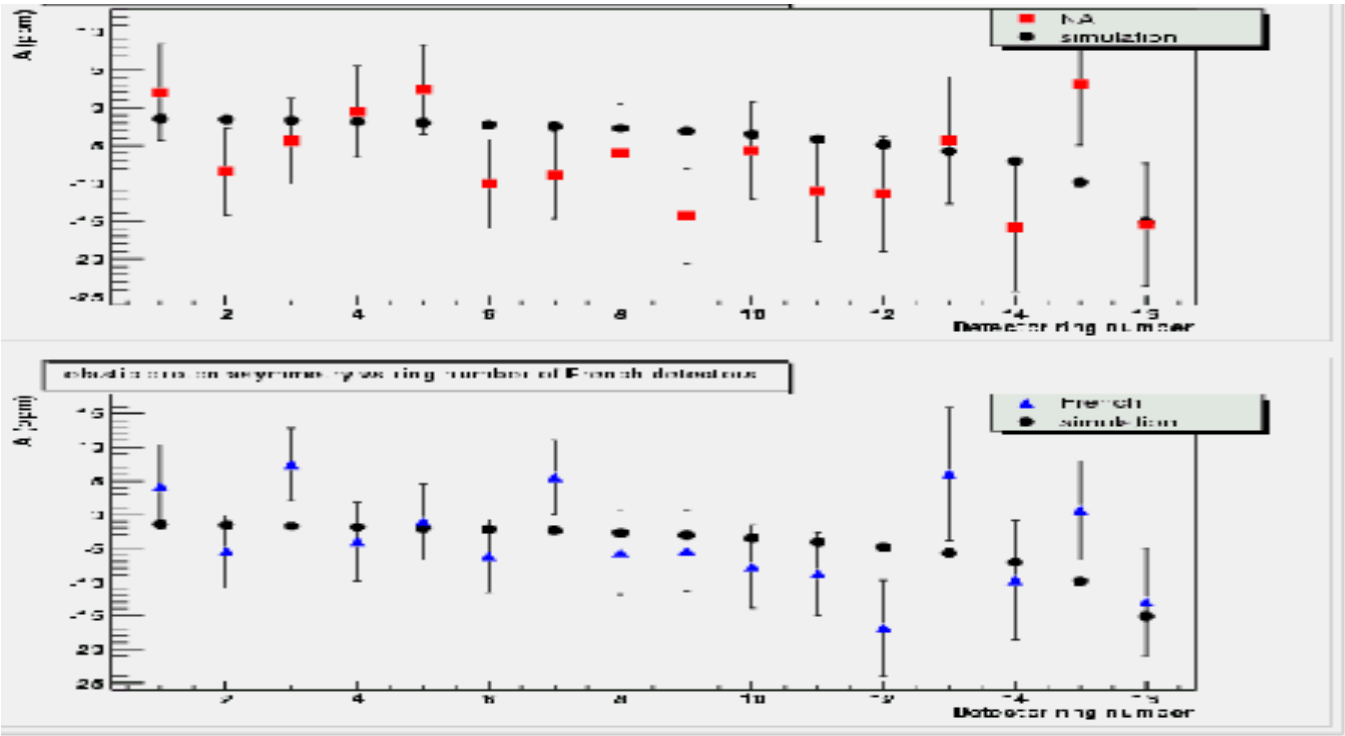
- Background determination
- Require both yield and asymmetry to correct elastic asymmetry
  - yield: ~10 – 25% depending on detector
  - simulation → important contribution from downstream target window
    - ✓ reduce window thickness in region near beam by x2
    - ✓ add insertable dummy window (thicker) for diagnostic runs
  - asymmetry of background
    - preliminary indication $|A_{back}| \sim |A_{el}|$ near elastic peak



- *Generalities*
- *Physics*
- *Requirements*
- *Set-up*
  - ✓ *Electronics*
- *Commissioning*
- Present status & future

G0 Preliminary Results

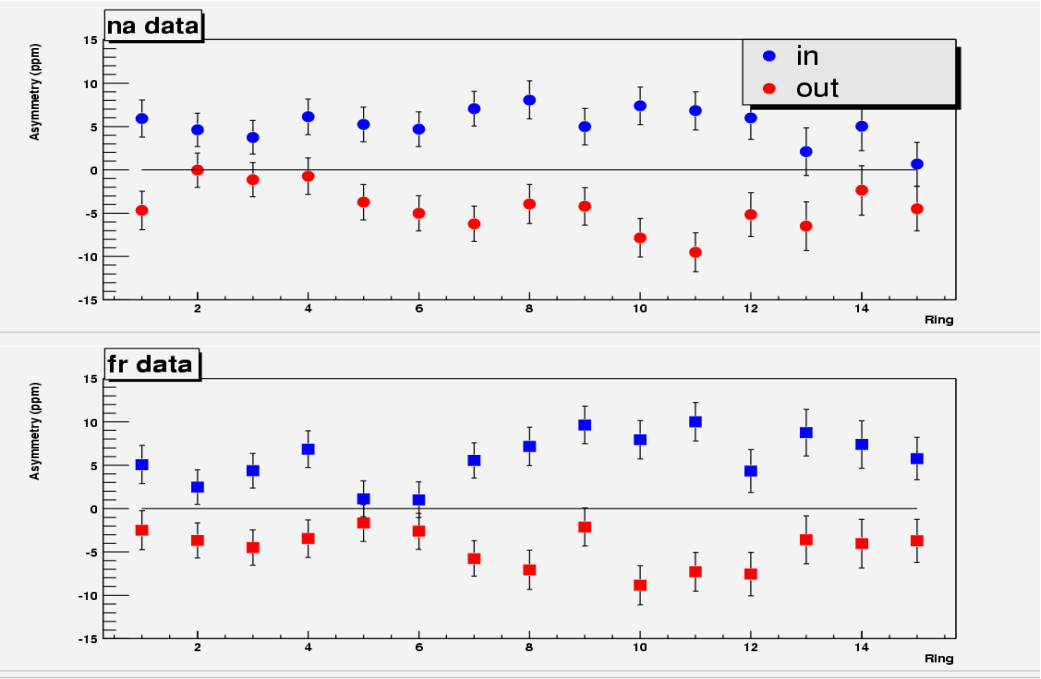
No unexpected false asymmetries seen



10 hours asymmetry data at 14µA beam current

G0 Preliminary Results

Based on 51 hours of data at 40 µA



Behavior of raw asymmetry under helicity reversal

(half wave plate in / out , Jan. 2003)

Systematics: From raw asymmetry to physics results

Form raw measured asymmetry from the detector yields:

$$A_{meas} = \frac{Y_{1+} + Y_{2+} - Y_{1-} - Y_{2-}}{Y_{1+} + Y_{2+} + Y_{1-} + Y_{2-}}$$

Correct for false asymmetries from helicity-correlated beam properties:

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

$$\text{where } \Delta P_i = P_+ - P_-$$

- helicity-correlated beam properties
- deadtime corrections

Correct for background and its asymmetry:

$$A_{sig} = \frac{A_{corr} - A_{back}\ f_{back}}{f_{sig}}$$

- background dilution factor correction

Correct for beam polarization and radiative corrections:

$$A_{phys} = \frac{A_{corr}}{P_{beam}\ R_{rad}}$$

- electron beam polarization
- electromagnetic radiative corrections

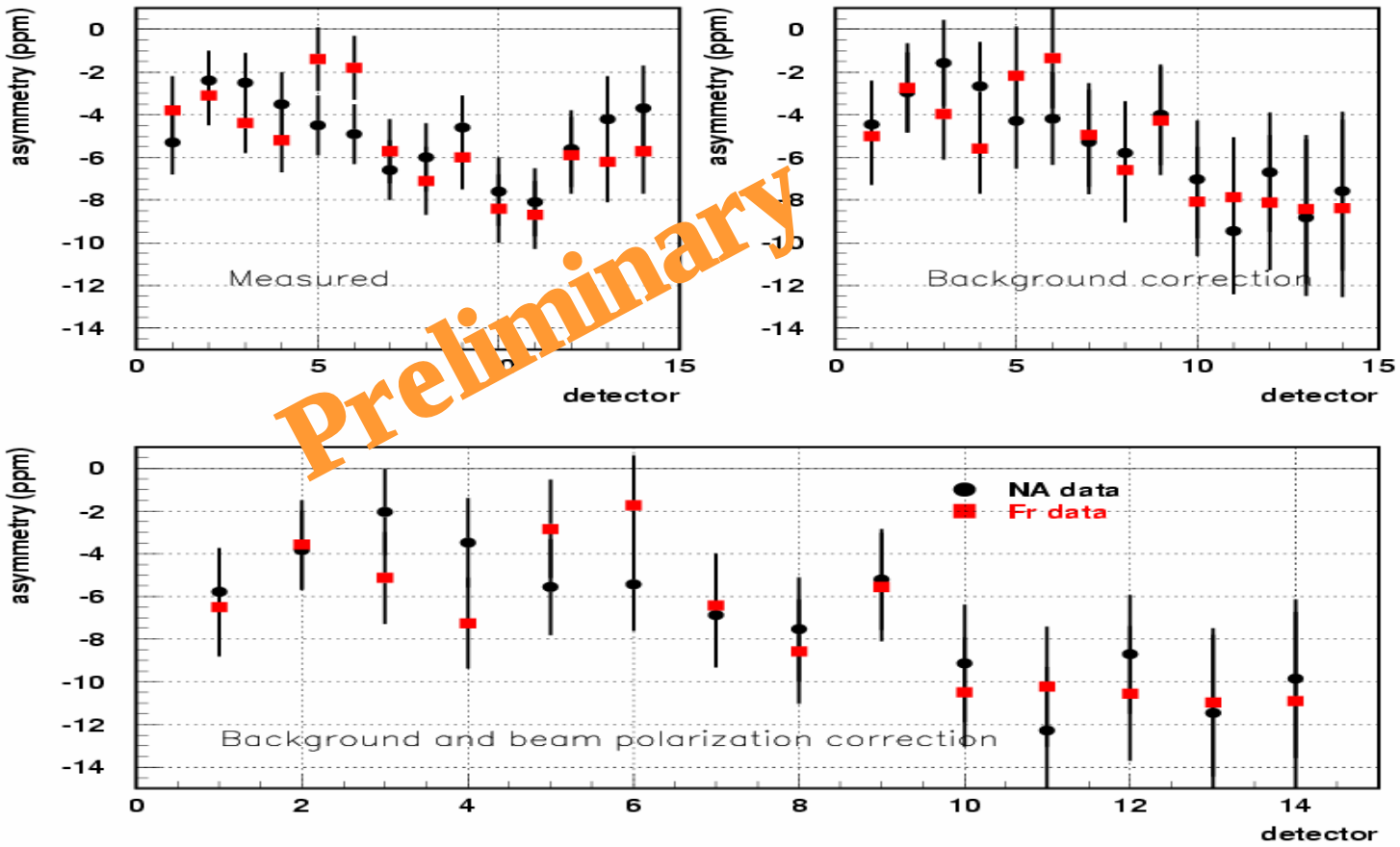
Correct for measured Q^2 and EM form factors:

$$A_{phys} \propto Q^2\ f(G_E^g, G_M^g, G_E^s, G_M^s)$$

- $\langle Q^2 \rangle$ determination
- electromagnetic form factors

G0 Results from first commissioning

Asymmetries for detectors 1 to 14



Summary

Feasability established

all subsystems are operational

no unexpected false asymmetry

no abnormal deviations from simulations

normal error bars for limited time of measurement

More to do

investigate dilution from inelastic scattering

improve beam properties and feedback systems

carefully determine Q^2 values

Next steps

2nd commissioning at forward angle

data taking at forward angle

turn around and backward angle measurements

End *of the talk : now !*

of GO : 2007 ?