Symmetries, Parity-Violation & the Structure of the Proton

*The **G^0** & **Q_{weak}** Experiments*

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Symmetries, Parity-Violation & the Structure of the Proton

Parity Violation as a Tool for Probing the Structure of the Proton

1) Parity Conservation and Parity Violation

Symmetries in Physics, Noether's Theorem
Parity Transformations & Observables

2) Probing Microscopic objects (e.g. proton, nucleus)

What/How?
Diffraction Patterns & Scattering objects
Form Factors

3) Electroweak Structure of the Proton: G^0 & Q_{weak}

G^0 and Q_{weak} experiments @ Jefferson Lab (JLab)
Our present picture/model of the proton (e.g. quark models,…)
(a) How do building blocks manifest themselves ?
Our present picture of the Standard Model
(b) Are there extensions beyond the Standard Model ?

(1)

Symmetries in Physics

Everyday use (implicit)
Mathematical/Quantitative counterpart (e.g. Rotational Symmetry)

Link between **Symmetries** & **Conservation Laws**: Noether's Theorem

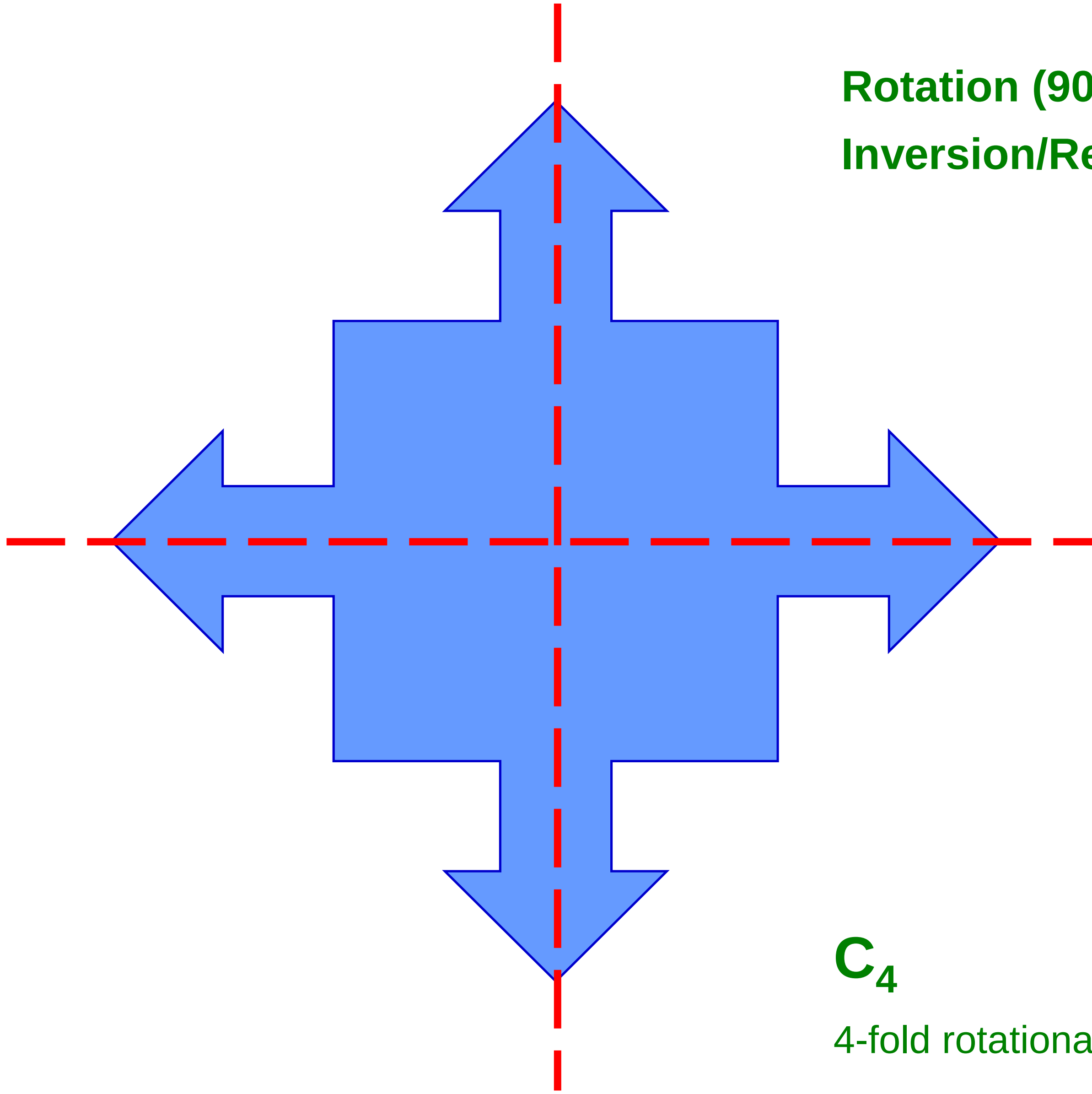
Wikipedia:
Noether's theorem *(1915, Emmy Noether)* is a central result in theoretical physics that expresses the one-to-one correspondence between the symmetries and the conservation laws.

Einstein (in reference to Noether): *"…penetrating mathematical thinking…"*

Some important examples of Noether's theorem are the following:

- The energy is conserved if and only if the physical laws are invariant under time translation (if their form does not depend on time – Time-translation symmetry)
- The momentum is conserved iff the physical laws are invariant under spatial translations (if the laws do not depend on the position – Space-translation symmetry)
- The angular momentum is conserved iff the physical laws are invariant under rotations (if the laws do not care about the orientation – Rotational Symmetry)

Symmetries (Spatial, Discrete)



Rotation (90º)

Inversion/Reflection

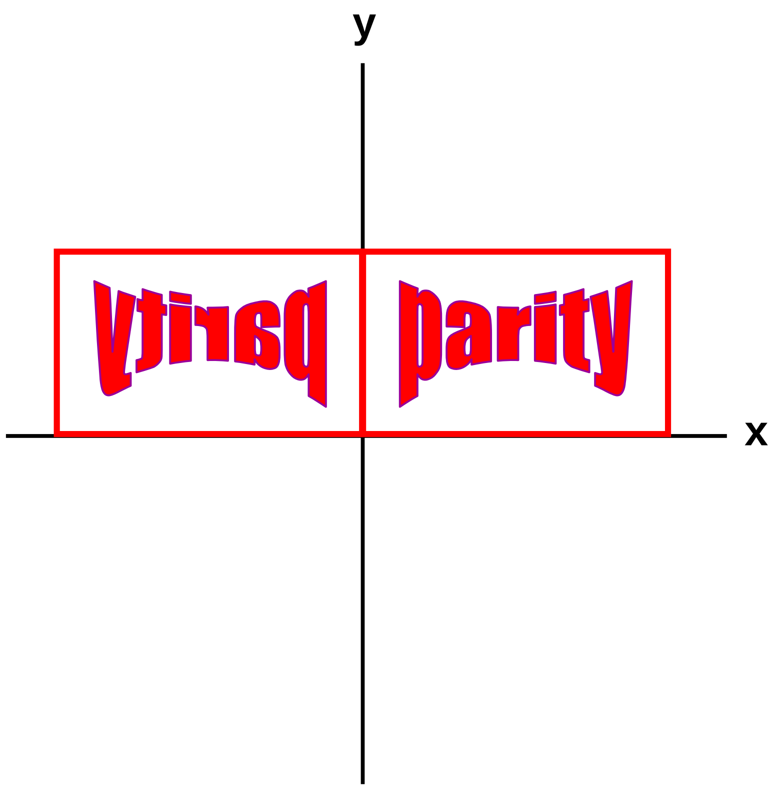
C_4

4-fold rotational symmetry

Parity Operation (in 2D)

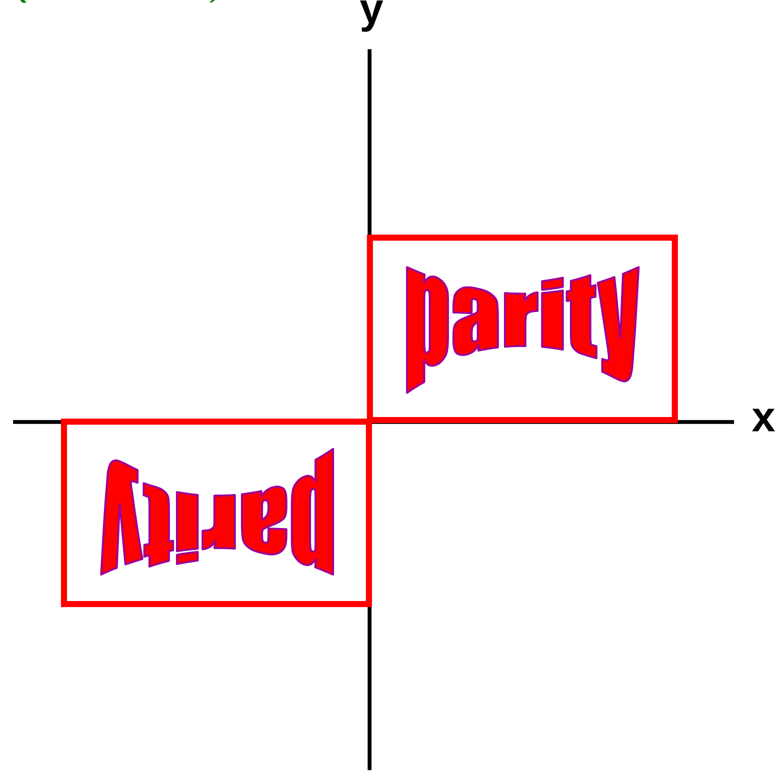
Space Reflection (Inversion) Symmetry

Mirror reflection:

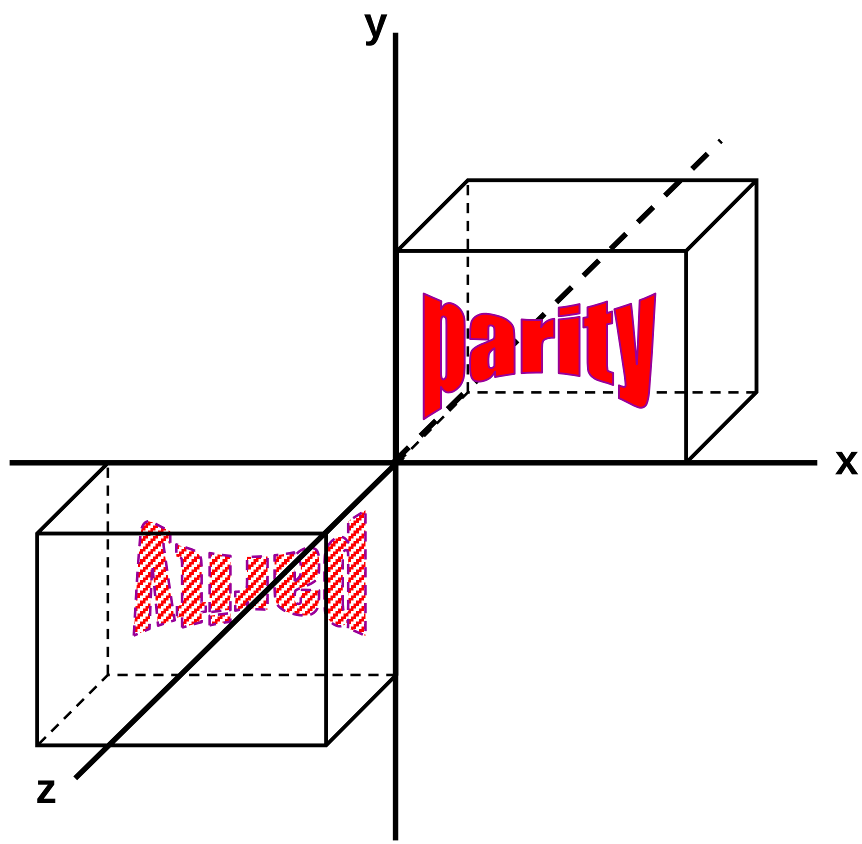


Parity transformation:

$(\mathbf{r} \rightarrow -\mathbf{r})$



Parity Operation (in 3D)

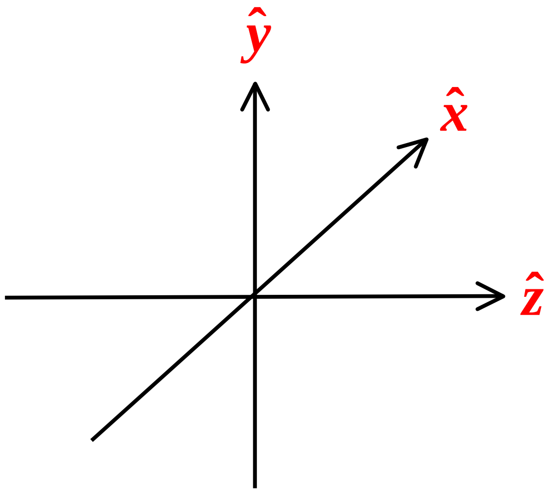


The Parity transformation: $(\mathbf{r} \rightarrow -\mathbf{r})$

- simultaneous reflection of all space coordinates through the origin
- equivalent to reflection plus 180º rotation
- if we assume rotational invariance, it is a mirror reflection

The Parity Transformation

Parity



$\hat{x} \times \hat{y} = \hat{z}$

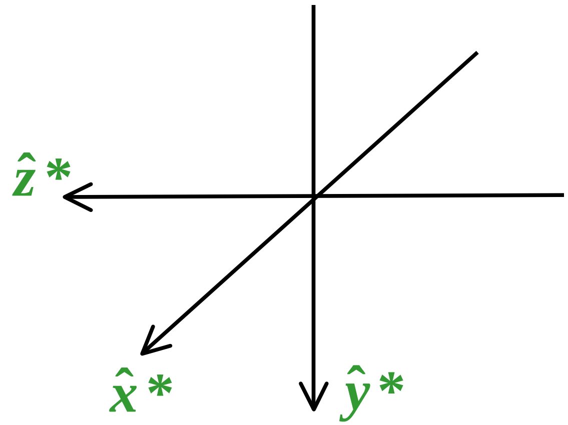
Right − handed

$\vec{r}$ (position)

$\vec{p}$ (momentum)

$\vec{L} = (\vec{r} \times \vec{p})$

$\vec{s}$ (intrinsic spin)



$\hat{x}* \times \hat{y}* = -\hat{z}*$

Left − handed

$-\vec{r}$

$-\vec{p}$

$\vec{L} = (-\vec{r} \times -\vec{p})$

$\vec{s}$

$\vec{L}, \vec{s}$ ***are pseudo or axial vectors***

Distinct: Cannot “rotate” RHS into LHS

The Parity Transformation as Depicted in Popular Culture

1968 ***Doppelganger***
Journey To The Far Side Of The Sun (US Title)

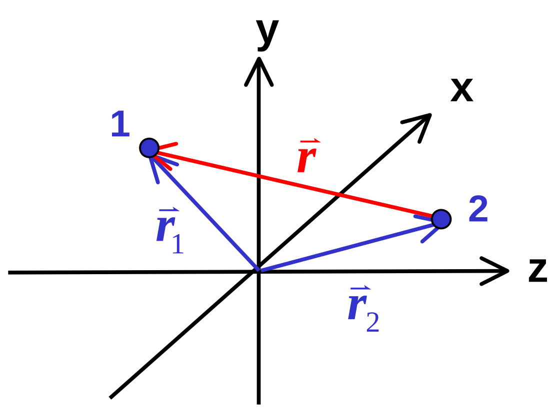
Parity analogue systems: “Right-handed” vs “Left-handed” systems

Parity Conservation (PC)

The absence of physics that would select a particular *handedness*

Strong Electromagnetic Gravitational	}	independent of *handedness* (PC)
Weak	→	*handedness-dependent* (PNC)

Example: Consider the Coulomb interaction of 2 protons



$$\vec{r} = \vec{r}_1 - \vec{r}_2 \quad ; \quad |\vec{r}| = \sqrt{\vec{r} \cdot \vec{r}}$$

$$V(\vec{r}) = \frac{e^2}{4\pi\varepsilon_0} \frac{1}{|\vec{r}|} = V(-\vec{r})$$

Conserves parity !

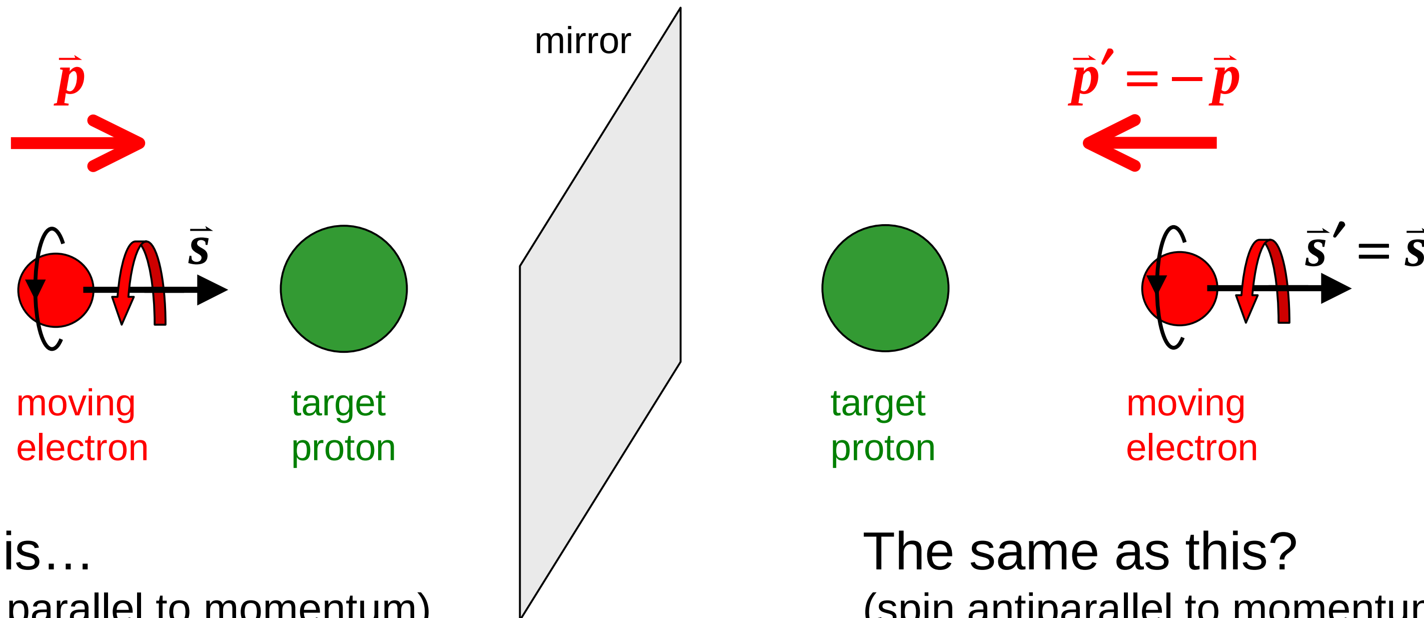
Counter example:

Weak Interaction violates parity **(PNC)**

→ has the form (**V**ector – **A**xial vector) → *handedness* built-in

$$\sim (\vec{v} - \vec{a}) \cdot (\vec{v} - \vec{a}) \approx \vec{v} \cdot \vec{v} + \vec{a} \cdot \vec{a} - 2(\vec{v} \cdot \vec{a})$$

Principle of a “beam-target” Parity-violation Measurement



Is this…
(spin parallel to momentum)

The same as this?
(spin antiparallel to momentum)

$\sigma^{(+)}$ **Scattering Rates** $\sigma^{(-)}$

Helicity: $h \sim \vec{s} \cdot \vec{p} \equiv (pseudovector) \cdot (vector)$

$\equiv pseudoscalar$

- To replace the experiment with its mirror image, you flip the beam helicity

Parity-sensitive Observables

In accelerator-based scattering experiments:

→ Prepare the beam *(e,p,n,…)* in (+) or (–) helicity states
(Parity analogue states)

→ Observable: Parity-Violating Longitudinal Asymmetry, ***A***
Difference/sum of Parity analogue reactions rates

$$A = \frac{\sigma^{(+)} - \sigma^{(-)}}{\sigma^{(+)} + \sigma^{(-)}}$$

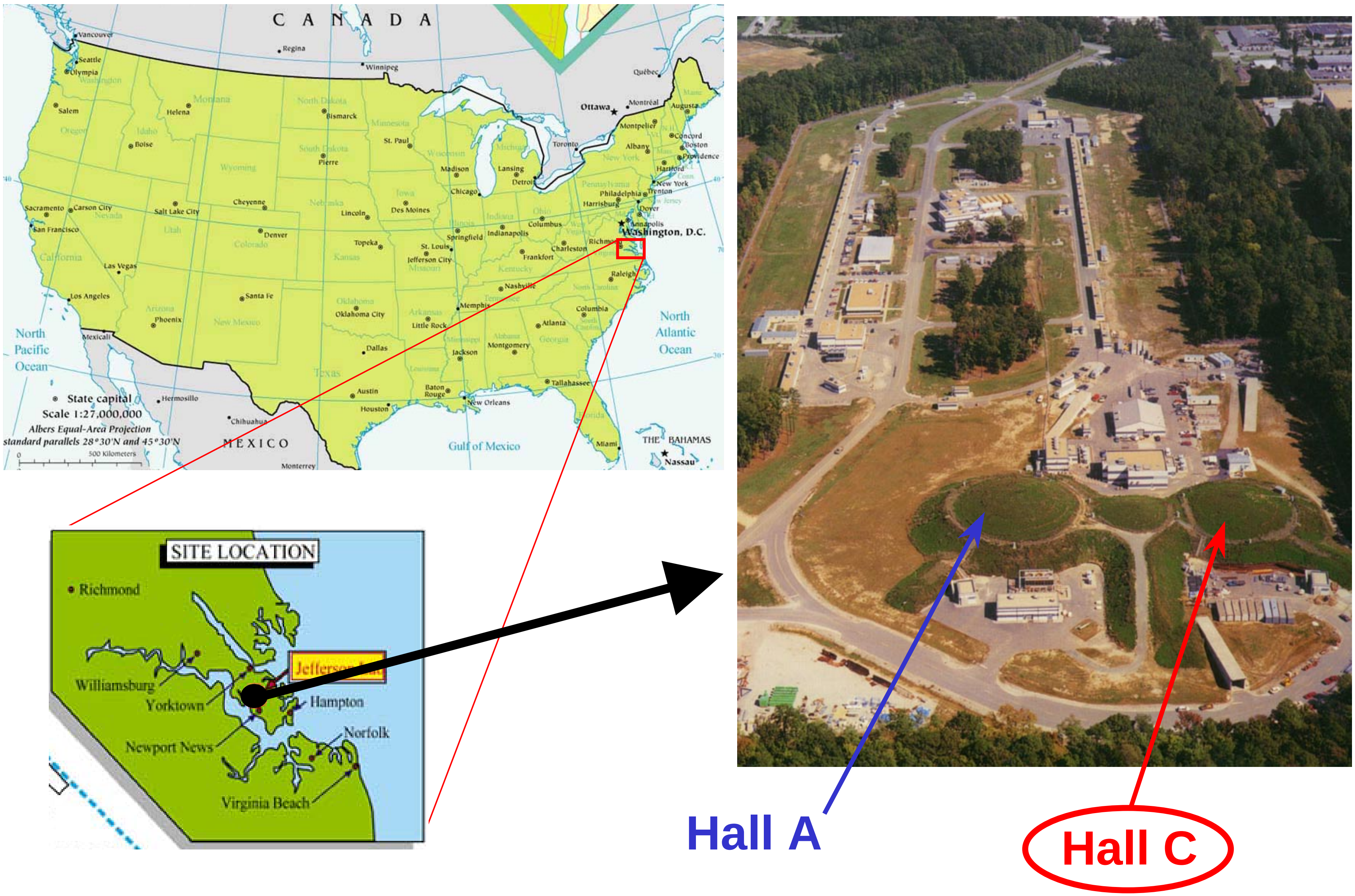
→ ***A*** is usually very very small ~ (1–10) x 10^{-7} *[0.1–1 ppm]*
(Signature of the Weak interaction)

Conceptually straightforward → but False Asymmetries!!

$$\boldsymbol{A_{measured} = A_{physics} + A_{false1} + A_{false2} + \ldots}$$

Many many sources of false asymmetries: keep ≤ (1–10) x 10^{-8}
→ **High Precision Experiments** *[0.01–0.1 ppm]*

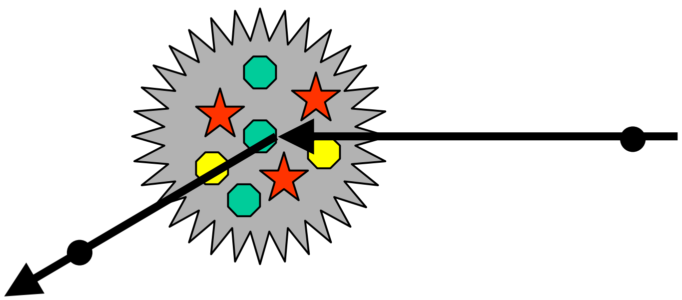
Parity-Violation Experiments w/ e^- beams @ Jefferson Lab



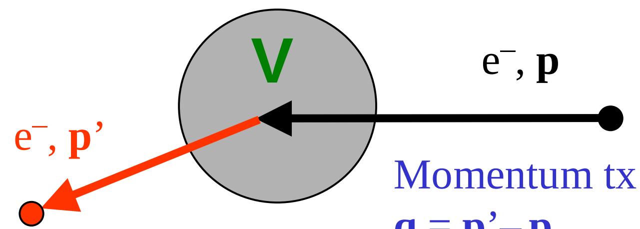
(2) Probing the Nucleus/Proton using subatomic beams

Beam on Target → Scattering Amplitudes → Target structure (form factor)

"The Accelerator as a Microscope".
Just bashing small things into other small things ?



Consider Coulomb (electric) Scattering
(eg, e^- from a Nucleus ← charge distr^n)



Momentum tx:
$\mathbf{q} = \mathbf{p'} - \mathbf{p}$
Wavelength:
$\lambda \sim 1/\mathbf{q}$

Q.M. Scattering Amplitude $\mathbf{M} \sim \langle \Psi^e_{out} | \mathbf{V}_{op} | \Psi^e_{in} \rangle$

bra vector *tx operator/potential* *ket vector*

Lowest Order
(plane wave)
Approx :

$$M \approx \int e^{i\vec{p}'\cdot\vec{r}}\, V(\vec{r})\, e^{-i\vec{p}\cdot\vec{r}}\, d^3r$$

$$M \approx \int V(\vec{r})\, e^{i(\vec{p}'-\vec{p})\cdot\vec{r}}\, d^3r = \int V(\vec{r})\, e^{i\vec{q}\cdot\vec{r}}\, d^3r$$

$$M \approx \tilde{V}(\vec{q}) \equiv$$ [Fourier Transform of $\mathbf{V(r)}$]

Tx. Potential

Aside/Reminder: Fourier Transform (FT)

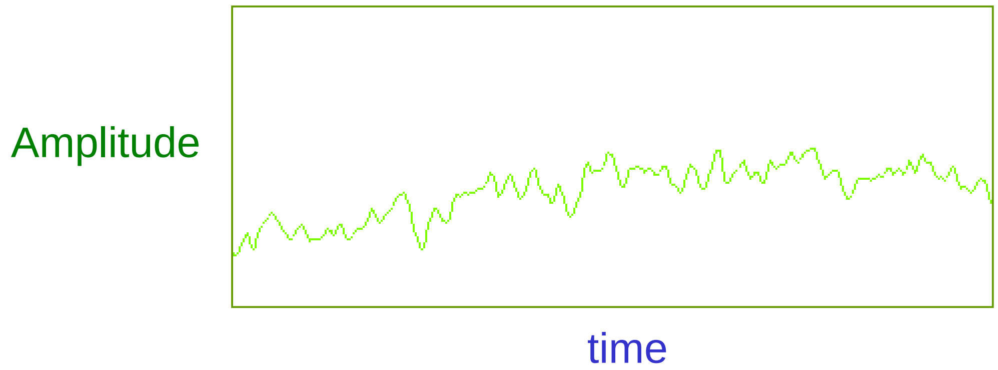
Function
f(x) $\rightarrow$ independent variable x

also described by

Fourier Transform
F(k) $\rightarrow$ conjugate variable k

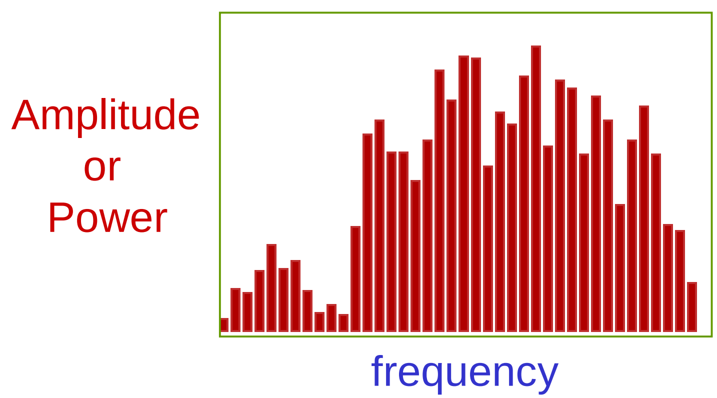
$$F(k) = \int f(x)\, e^{i\,k \cdot x}\, dx$$

eg) Electrical Signal / Sound wave (mp3, WMP)



F.T.

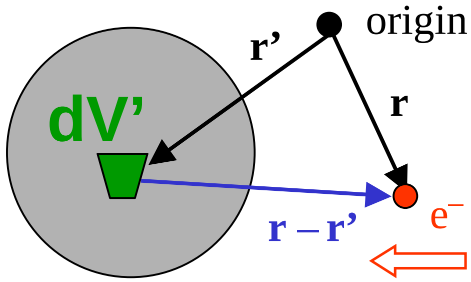
Freq. Spectrum (Spectral Components)



Transition Potential & Amplitude

$$M_{scat} \approx \tilde{V}(\vec{q}) = \int V(\vec{r})\, e^{i\vec{q}\cdot\vec{r}}\, d^3r \equiv F.T.\, of\ V(\vec{r})$$

Consider a nucleus: Nuclear Charge Distribution ρ(**r'**)



Interaction between e⁻ and dV' (at **r'**)

$$v(\vec{r}-\vec{r}\,') \approx \frac{k\, Q_e Q(\vec{r}\,')}{|\vec{r}-\vec{r}\,'|}$$

Total Interaction between e⁻ and Nucleus:

$$V(\vec{r}) = \int v(\vec{r}-\vec{r}\,')\, \rho(\vec{r}\,')\, d^3r'$$

Convolution of v∗ρ

Convolution Theorem:

The F.T. of a convolution of functions ≡ Product of the Individual transforms

$$\tilde{V}(\vec{q}) \qquad V(\vec{r}) = v * \rho \qquad \tilde{v}(\vec{q})\tilde{\rho}(\vec{q})$$

$$\therefore M_{scat} \approx \tilde{V}(\vec{q}) \approx \tilde{v}(\vec{q}) \cdot \tilde{\rho}(\vec{q})$$

Force/Int

$$\approx \int \frac{1}{|\vec{r}|} e^{i\vec{q}\cdot\vec{r}}\, d^3r \approx \frac{1}{q^2}$$

Form Factor

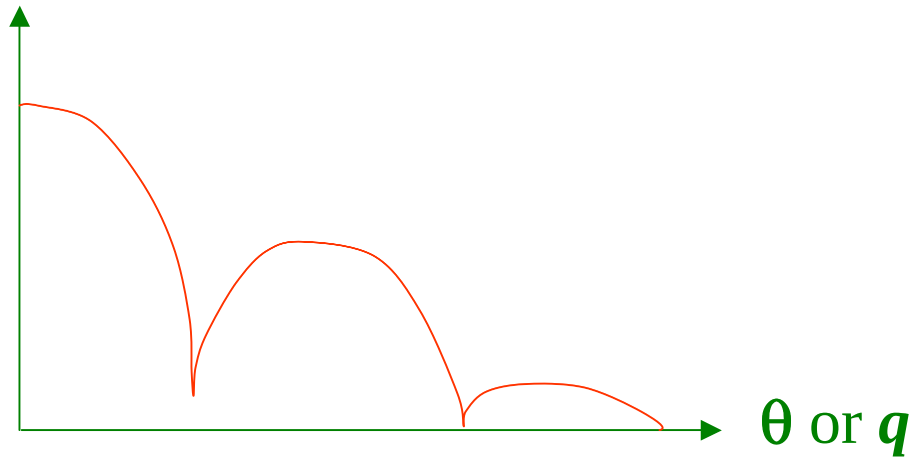
$$\approx \int \rho(\vec{r})\, e^{i\vec{q}\cdot\vec{r}}\, d^3r \equiv F(\vec{q})\ \ (or\ \ G(\vec{q}))$$

Cross Sections

Experiments measure *"Cross Sections"* *(Rate/Prob./Intensity)*

$$\sigma \propto \left|M_{scat}\right|^2 \approx \left|\tilde{v}(q)\,\tilde{\rho}(q)\right|^2 \approx \left|\frac{1}{q^2}G(q)\right|^2$$

$\sigma \equiv \sigma(\theta) \equiv \sigma(\boldsymbol{q}) \sim \boldsymbol{I}$



"Probe" $\rightarrow$ By looking at σ(q)

☞ Really looking @ *diffraction pattern*

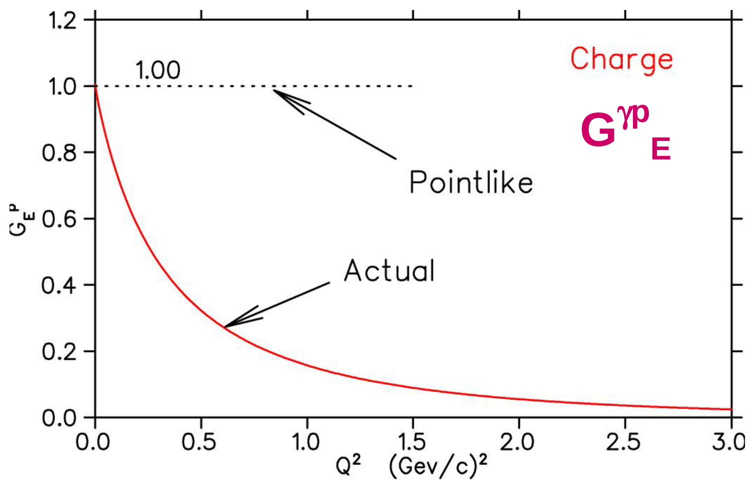
☞ Extracting the Form Factor [**G**(q) or ρ] *("separate out" the $1/q^2$ term)*

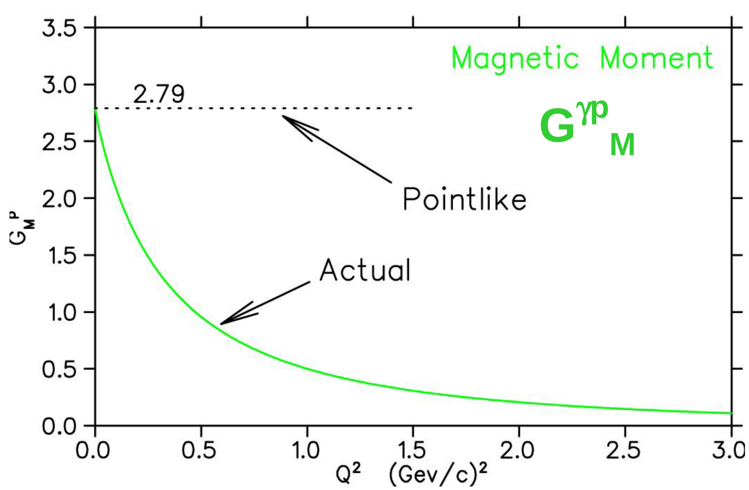
☞ ***Infer*** the shape/distribution of scattering object

"Listening to the shape of the drum"

Example: Proton EM Form Factors from Electron Scattering

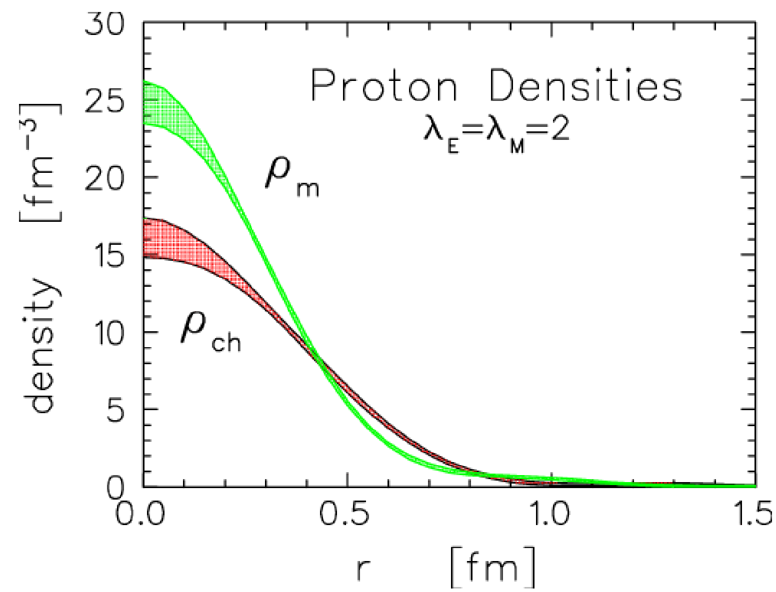
“Measure” Electric Charge & Magnetic Moment as functions of Q^2 **(momentum transfer)**





Low spatial frequency ← **High spatial frequency** →

- **Sachs Form Factors** (well established) *(many, extensive measurements)*
- Small proton ➜ slow fall-off
- Large proton ➜ rapid fall-off
- Form Factor is essentially the Fourier transform of the spatial distribution.



Parity-Violation in e-p Scattering:

JLab-Hall C "Parity" Experiments: G0 and Qweak

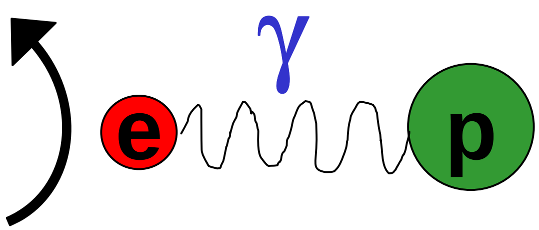
Using spin-polarized electrons and Parity-violation:
Probe the **"weak" structure** of the proton → learn something about:

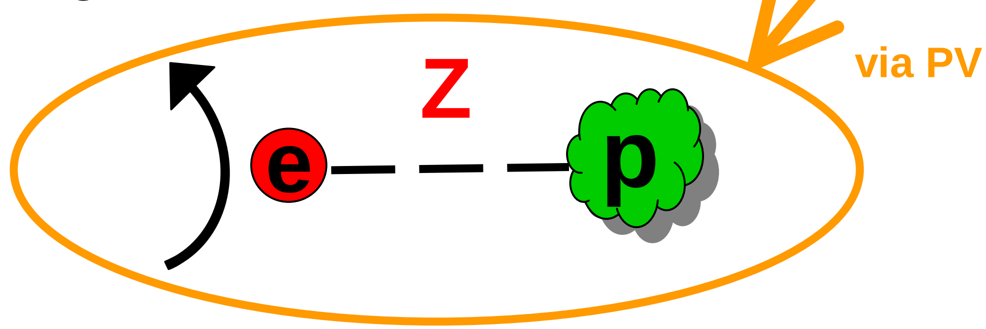
The strange quark currents in the proton (**G0**)
[Role of the sea quarks at low energy]

The weak charge of the proton (**Qweak**)
[Search for new physics beyond the Standard Model]

"NEW"

electron – proton scattering: Electroweak Interaction

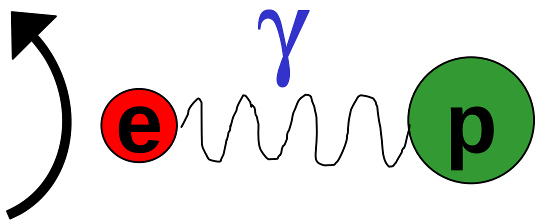




Electromagnetic
(Virtual photon exchange)
Probes proton's EM structure, $\mathbf{G}^{\gamma}$

Weak
(Virtual Z^o exchange)
Probes proton's "Weak" structure, $\mathbf{G}^{Z}$

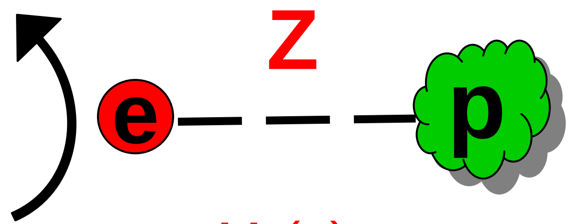
Electromagnetic vs Weak Processes and Parity-Violation



$M_\gamma(q)$

Electromagnetic Scatt

(Virtual photon exchange)



$M_Z(q)$

Weak Scatt

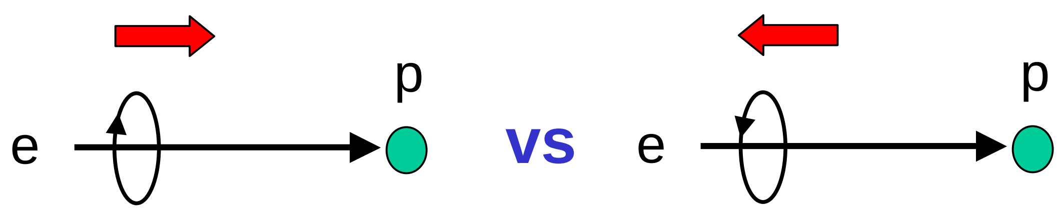
(Virtual Zº exchange)

Momentum tx.
q (or Q²); λ=1/q
and
$M \approx \tilde{v}(q) \cdot G(q)$

Scattering Amplitude $M = M_\gamma + M_Z$; with $M_\gamma >> M_Z$ (factor of ~ 10^5)

But: M_γ ⇨ parity conserving , while M_Z ⇨ parity non-conserving

Compare 2 parity-sensitive cross-sections
(whose parity-conserving parts are identical)



Scattering Asymmetry:
$A = (\sigma_+ - \sigma_-)/(\sigma_+ + \sigma_-) \sim M_\gamma M_Z/|M_\gamma|^2$

Recap (so far)

Scattering Processes *(Cross Sections/Diffraction Pattern)* $\longrightarrow$ ***Form Factors***

Coulomb Scattering

$$\sigma \propto \left|M_{scat}\right|^2 \approx \left|\tilde{v}(q)\,\tilde{\rho}(q)\right|^2 \approx \left|\frac{1}{q^2}G(q)\right|^2$$

Parity-Violation $\longrightarrow$ ***"Weak" Interaction components*** *(of F.F.)*

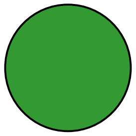
$$A = (\sigma_+ - \sigma_-)/(\sigma_+ + \sigma_-) \sim M_\gamma M_Z / |M_\gamma|^2$$

$$A = (\sigma_+ - \sigma_-)/(\sigma_+ + \sigma_-) \sim f(q)\times G_\gamma G_Z / |G_\gamma|^2$$

(3a)

Proton Structure: An open question

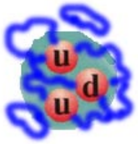
What does a proton look like ?



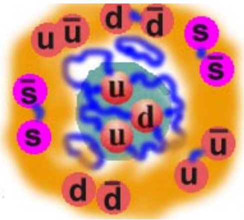
$$|\,p\rangle \approx \alpha\,|\,qqq\,\rangle + \beta\,|\,qqq\;g\,\rangle + \gamma\,|\,qqq\;q\bar{q}\rangle + \ldots$$

A Proton has 3 Quarks (Valence Quarks) (uud)

There may be contributions from gluons to the Proton's structure (?)



There may be contributions from a "sea" of Quark-AntiQuark pairs (?)
{strange-antistrange quark pairs (??)}



Strange quarks present only in the sea

(Proton has no "net" strangeness)

G0 : JLab E00-06

Measurement of the Strange Quark Currents in the Proton

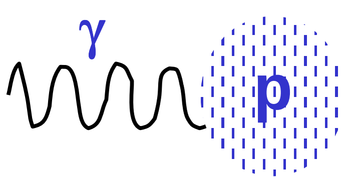
G0 Collaboration:
Canada (TRIUMF, U.Manitoba, UNBC, U.Winnipeg), France, USA

Measure $\mathbf{G^{Z,p}}$: Weak *vector-current* form factor
- a *“**new**”* & ***fundamental*** property of the proton
- Similar to normal electric & magnetic form factors, but for “weak” interaction (weak charge, weak magnetic)

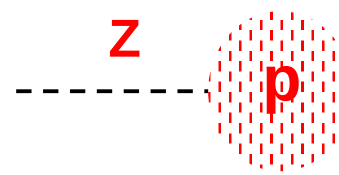
$\mathbf{G^{\gamma}_{E}, G^{\gamma}_{M}}$: EM charge & magnetic FF

$\rho \longrightarrow G_E$

$\mathbf{G^{Z}_{E}, G^{Z}_{M}}$: weak charge & magnetic FF



$j \longrightarrow G_M$



$\mathbf{G^{Zp}, G^{\gamma p}, G^{\gamma n} \Rightarrow G^{s,p}}$

Strangeness form factor of proton
Role of sea quarks at low *E*

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

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

Form Factors from Parity-Violating Asymmetry

Parity-Violating Asymmetry

$$A = \frac{\sigma^{(+)} - \sigma^{(-)}}{\sigma^{(+)} + \sigma^{(-)}} \sim \frac{f(q) \cdot G_\gamma G_Z}{|G_\gamma|^2}$$

Proton Weak Form Factors

$$A(Q^2) = -\frac{(G_F Q^2)}{\pi\alpha\sqrt{2}} \frac{\{ \varepsilon G^\gamma_E G^Z_E + \tau G^\gamma_M G^Z_M + \eta G^\gamma_M G^Z_A \}}{\varepsilon (G^\gamma_E)^2 + \tau (G^\gamma_M)^2} \; [1/P_Z]$$

(where ε , τ , η are kinematical parameters)

Want to determine **G^Z_E** and **G^Z_M**

Do **2** measurements of A at each momentum tx value (q or Q^2)

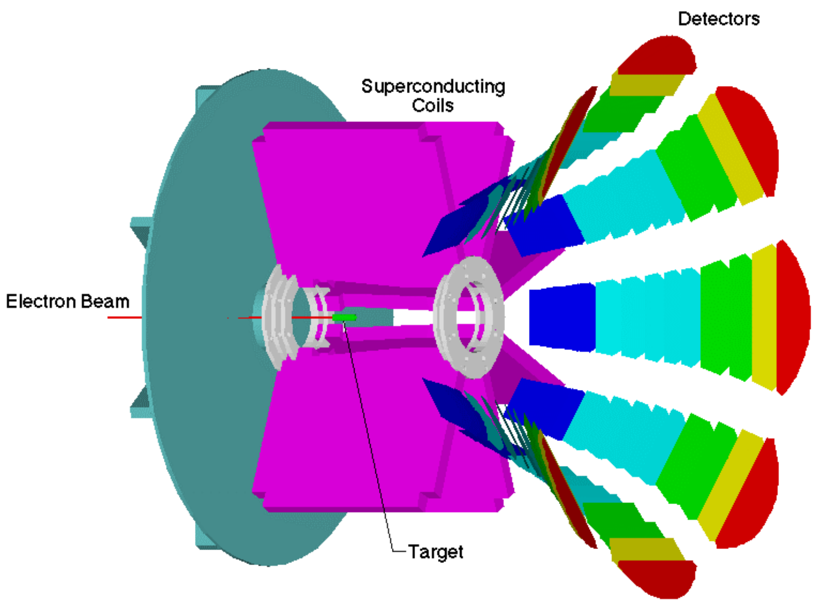
For a given Q^2, ε ranges from **1** (small angles) → **0** (large angles)

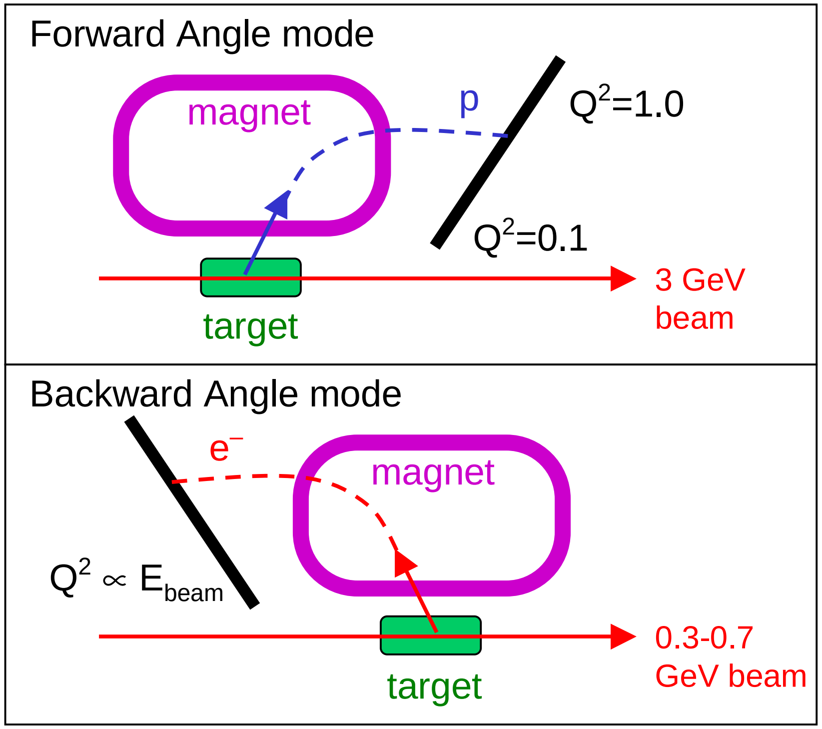
i) At small **(forward)** angles, measure a combination of G^Z_E and G^Z_M
ii) At large **(backward)** angles, measure G^Z_M
→ Combine both measurements to ***extract*** G^Z_E

G0 MEASUREMENTS :

A) Forward Angle Mode
B) Backward Angle Mode

G0 Schematic Layout and Experiment Parameters



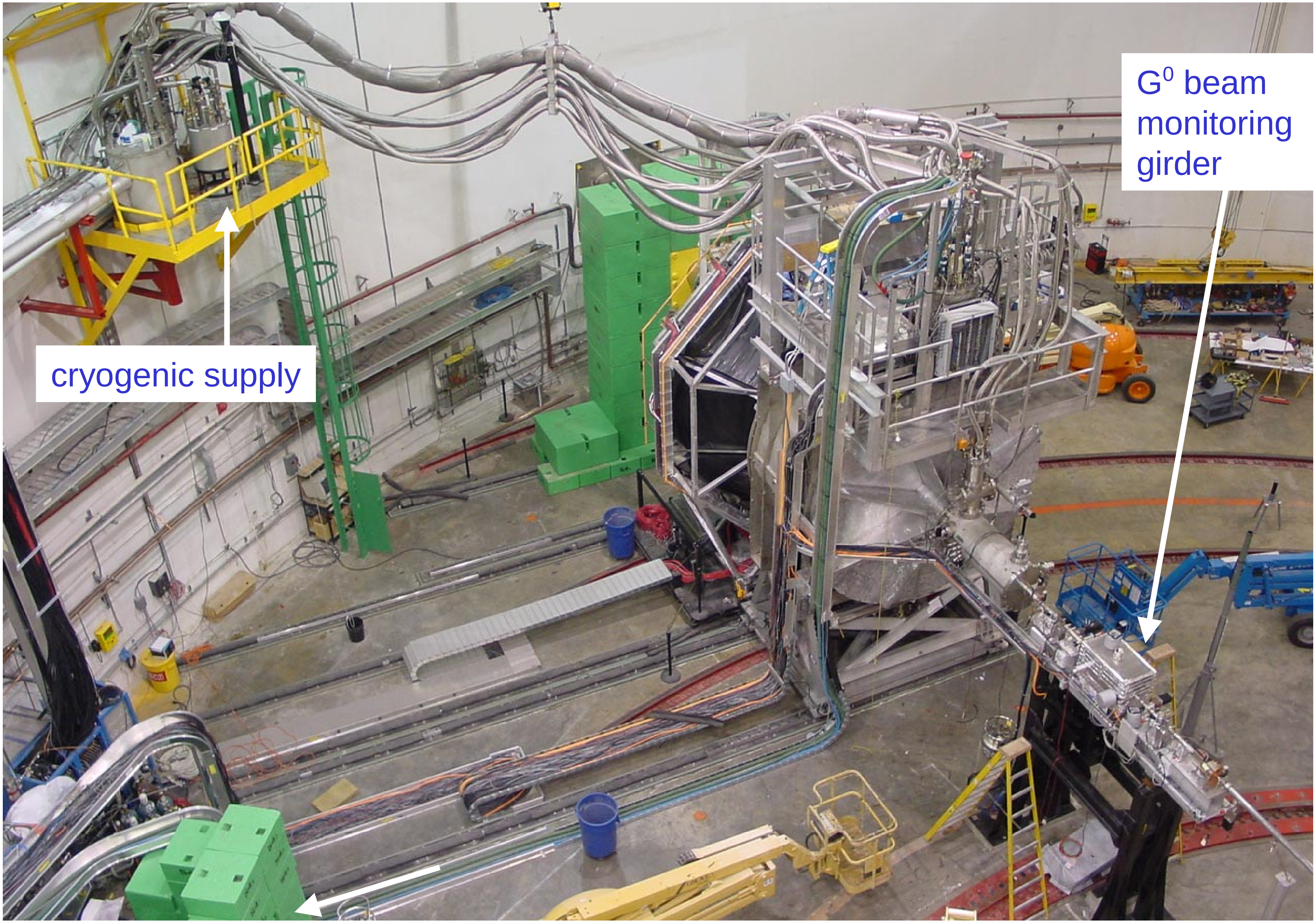


Goal: Measure $A_z \sim 5 \times 10^{-6}$ to $(\Delta A/A) \sim \pm 5$ % (10^{-7})

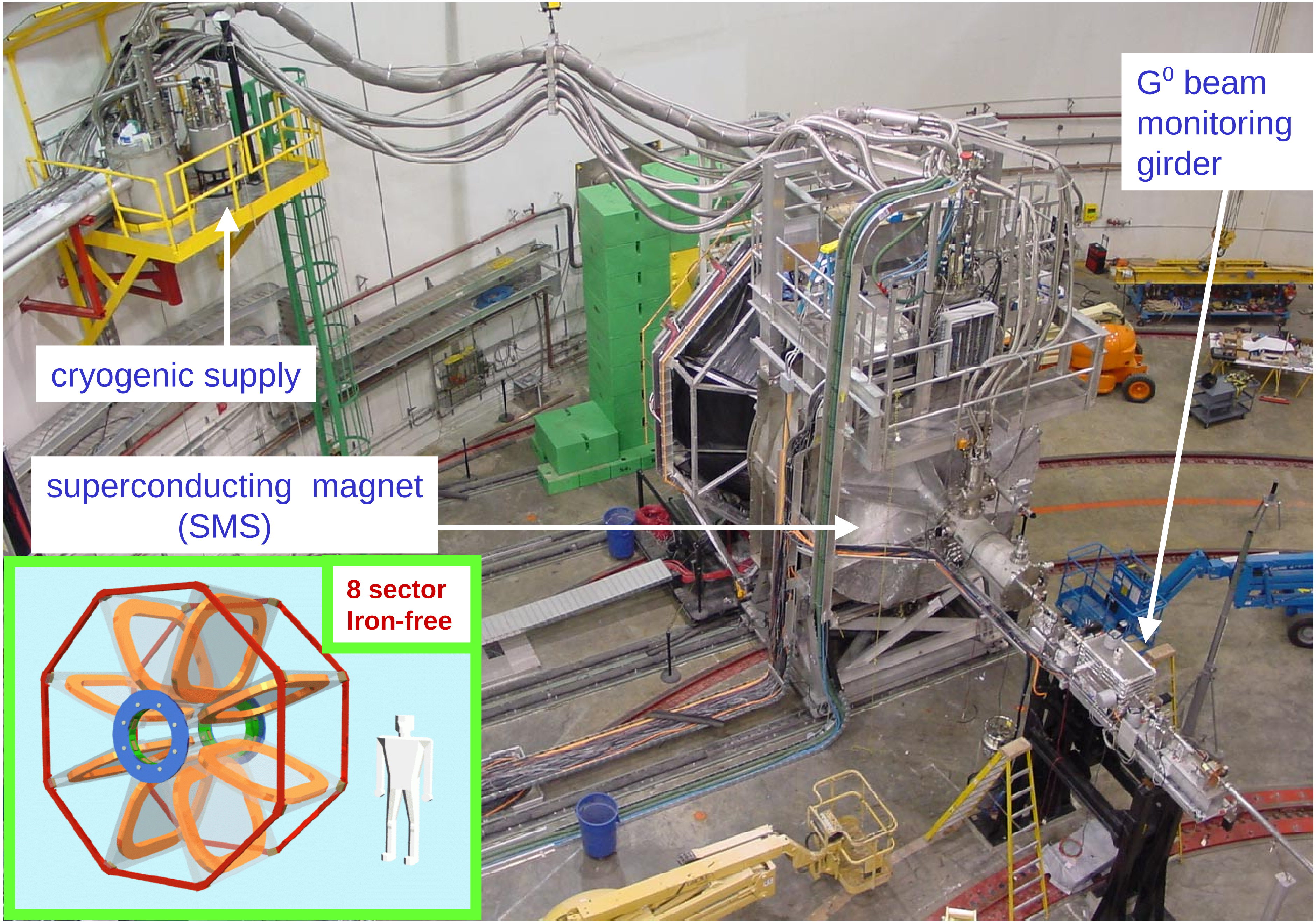
Systematics: (h.c. variables)

ΔE	$< 2.5 \times 10^{-8}$	over 30 days
$\Delta I_b/I_b$	< 1 ppm	
Δx	< 20 nm	
$\Delta\theta$	< 2 nrad	

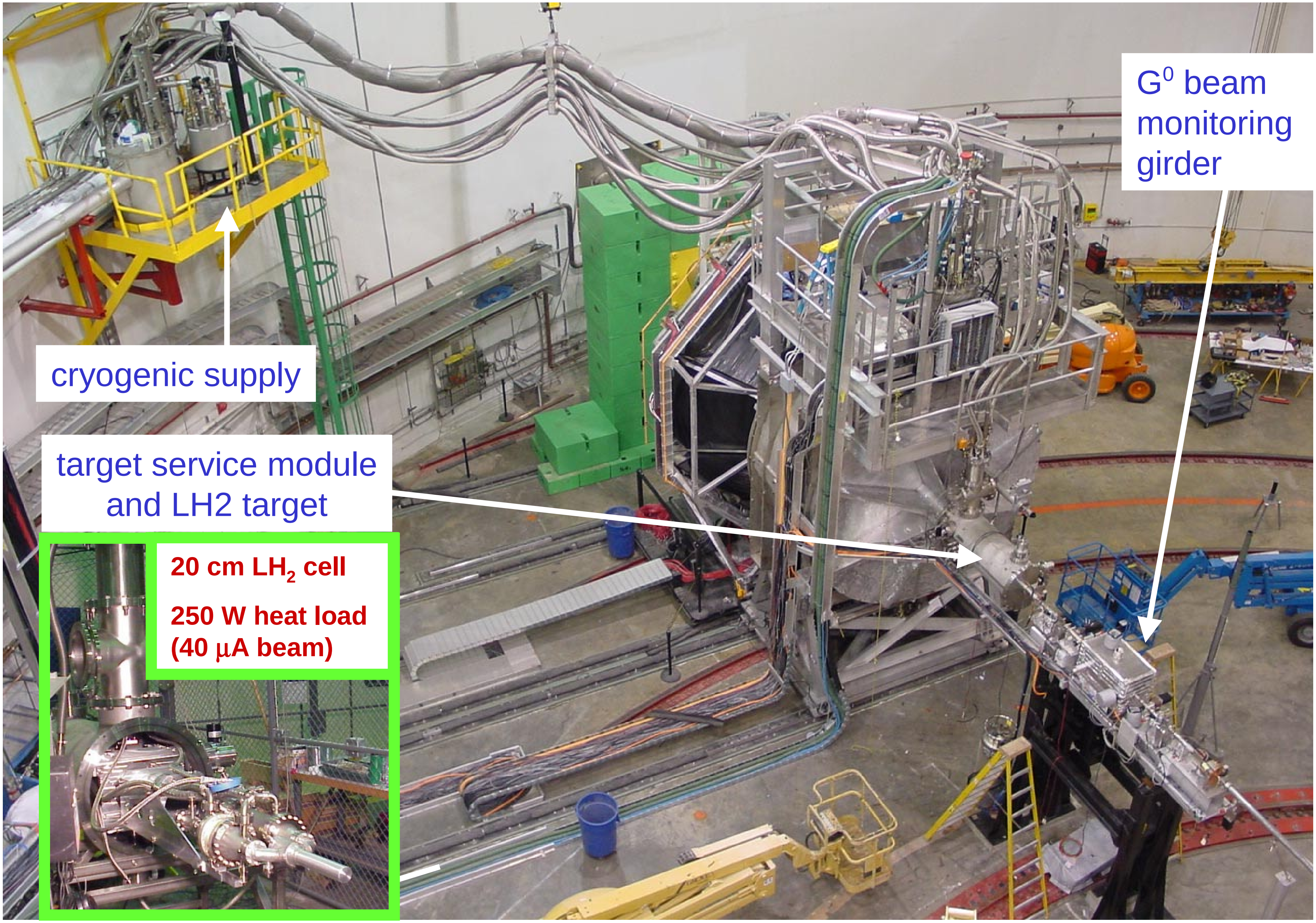
Forward Angle Configuration



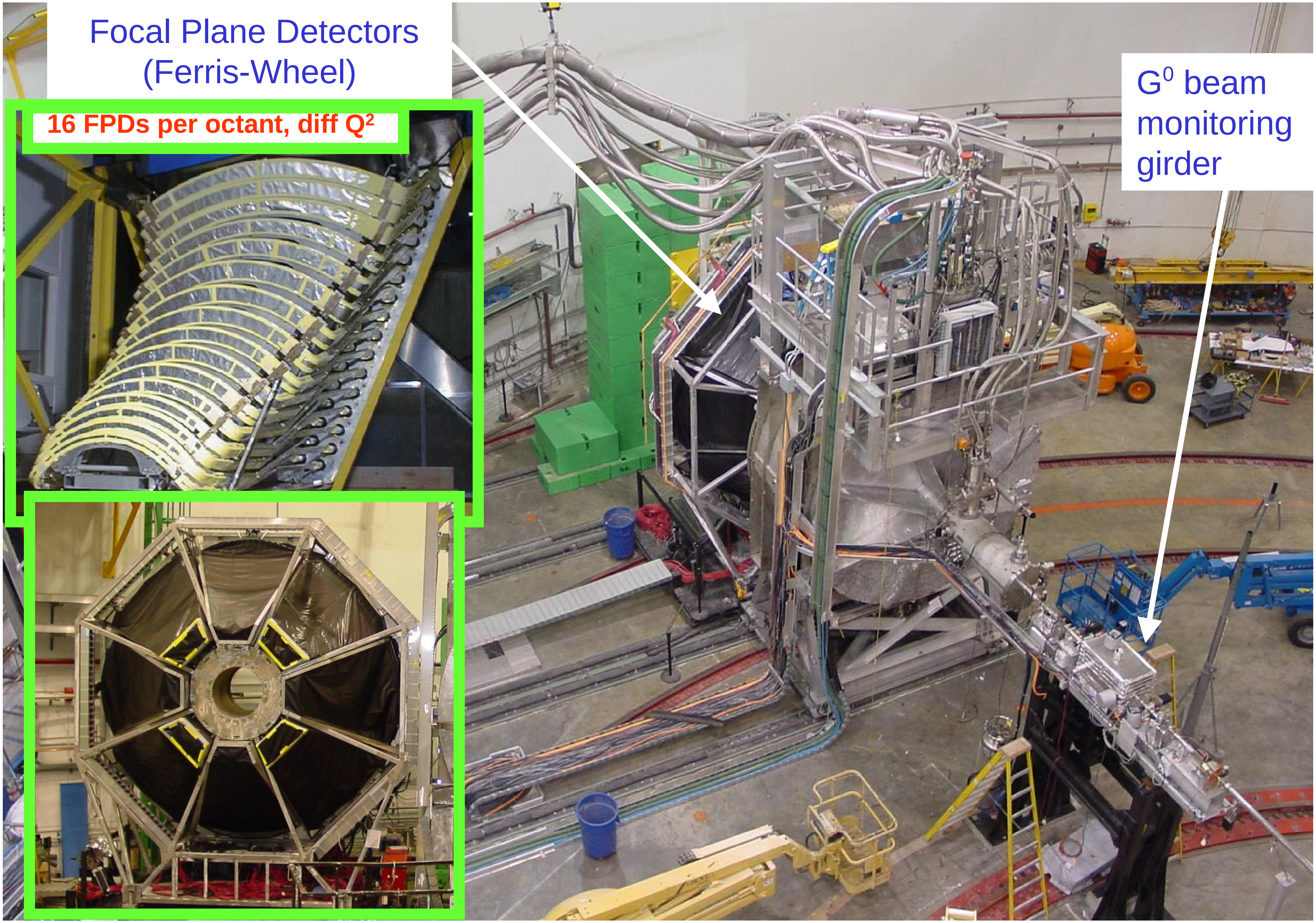
Forward Angle Configuration



Forward Angle Configuration

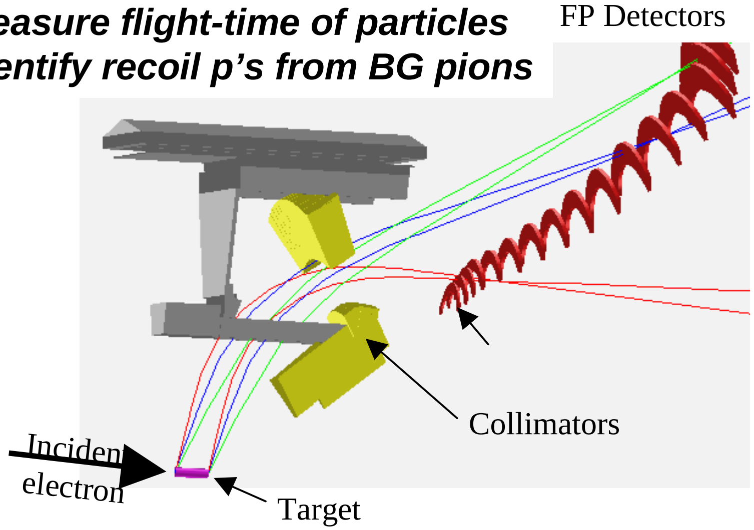


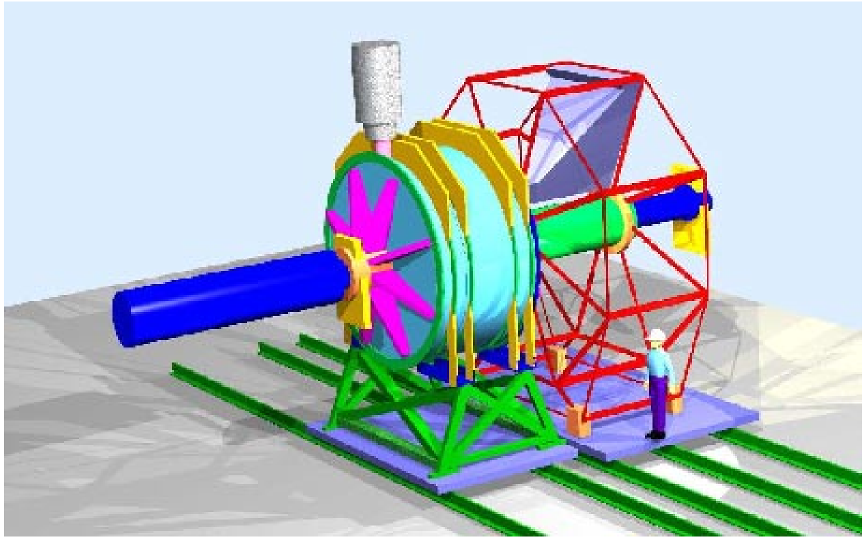
Forward Angle Configuration

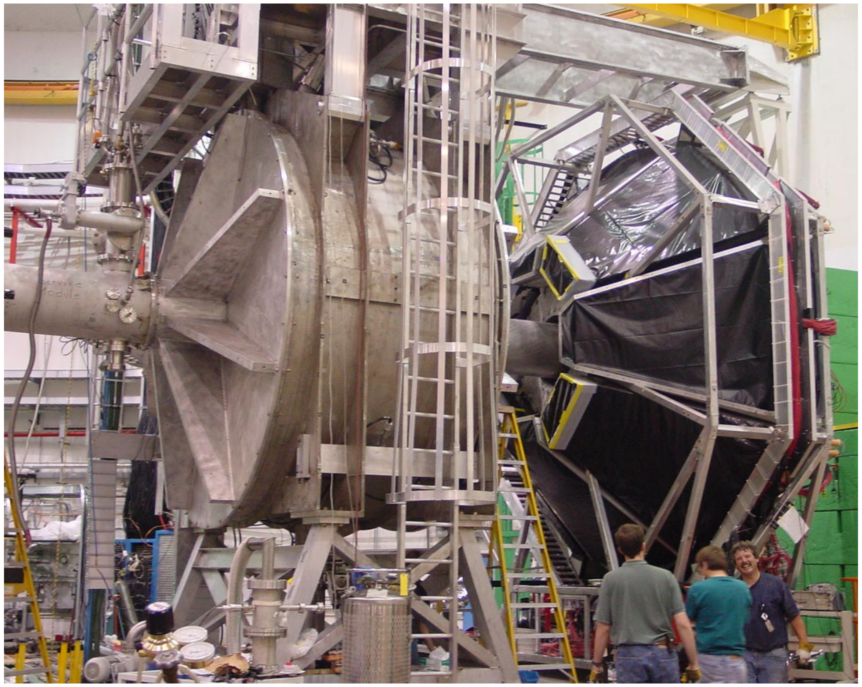


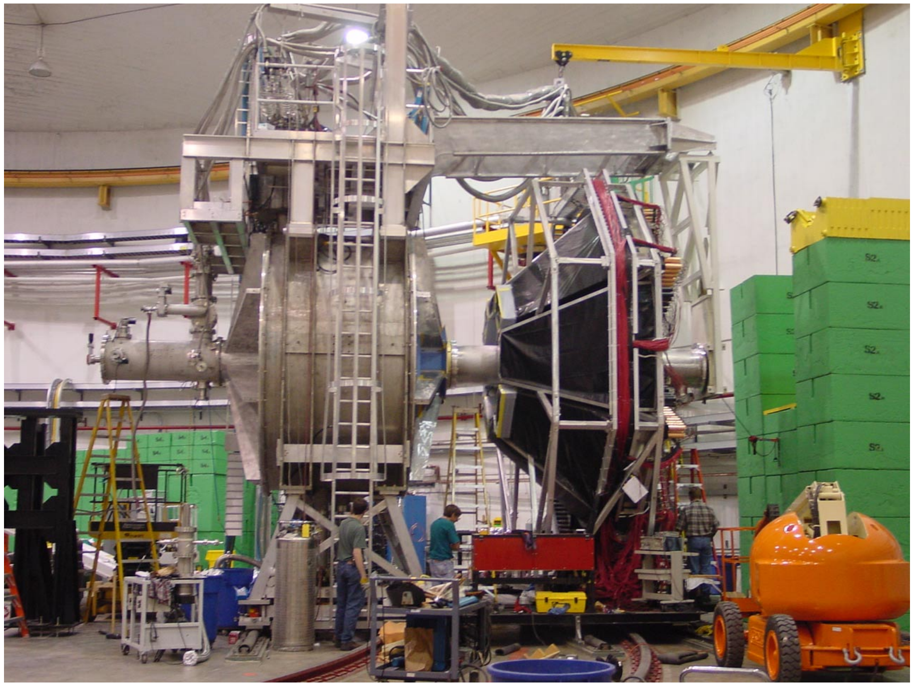
Forward Angle Configuration

Measure flight-time of particles
Identify recoil p's from BG pions







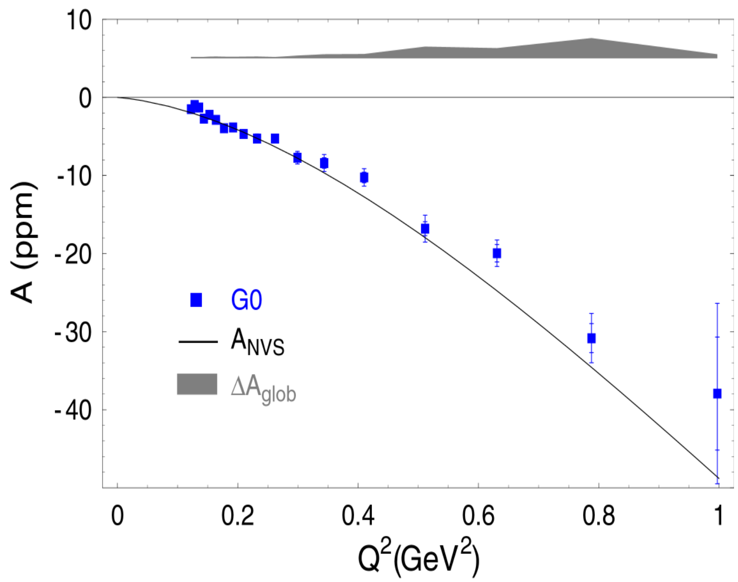


G0 Target-Magnet-FPD in Hall C

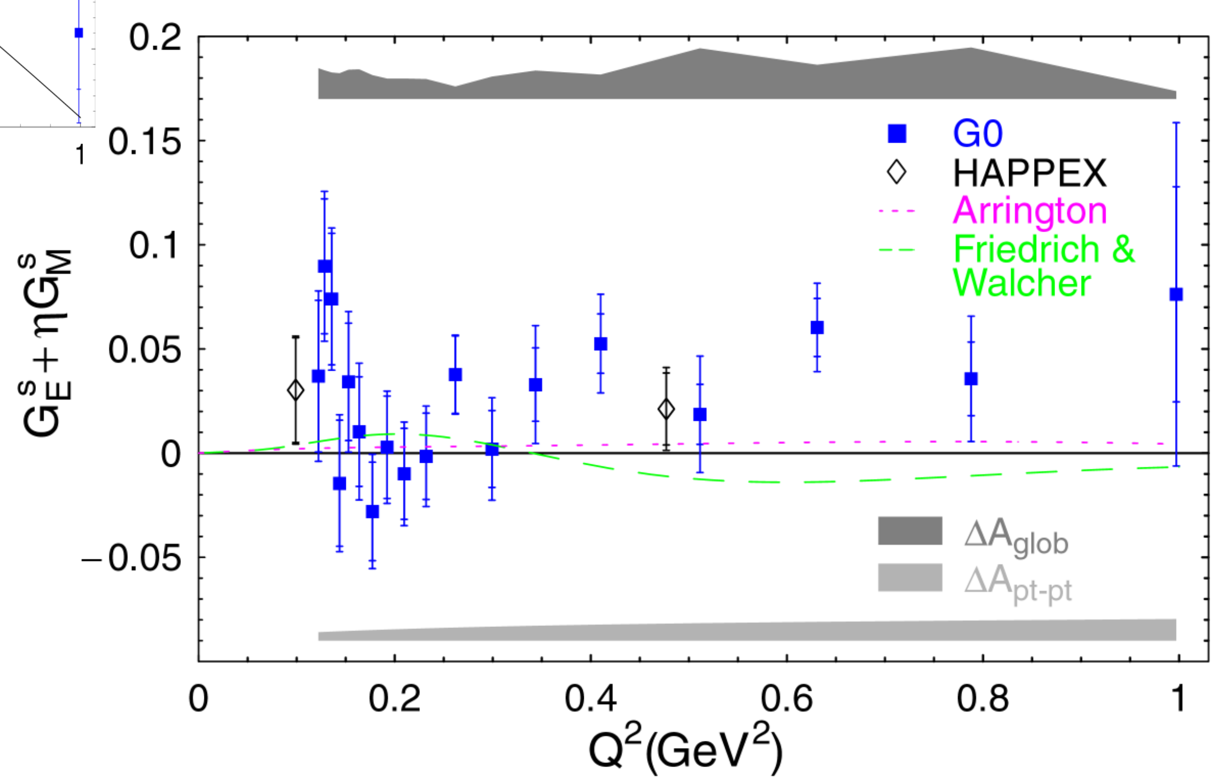
First Results from G0 Experiment

Phase I

(Forward Angle Measurement,** Fall/2002 – Summer/2004**)



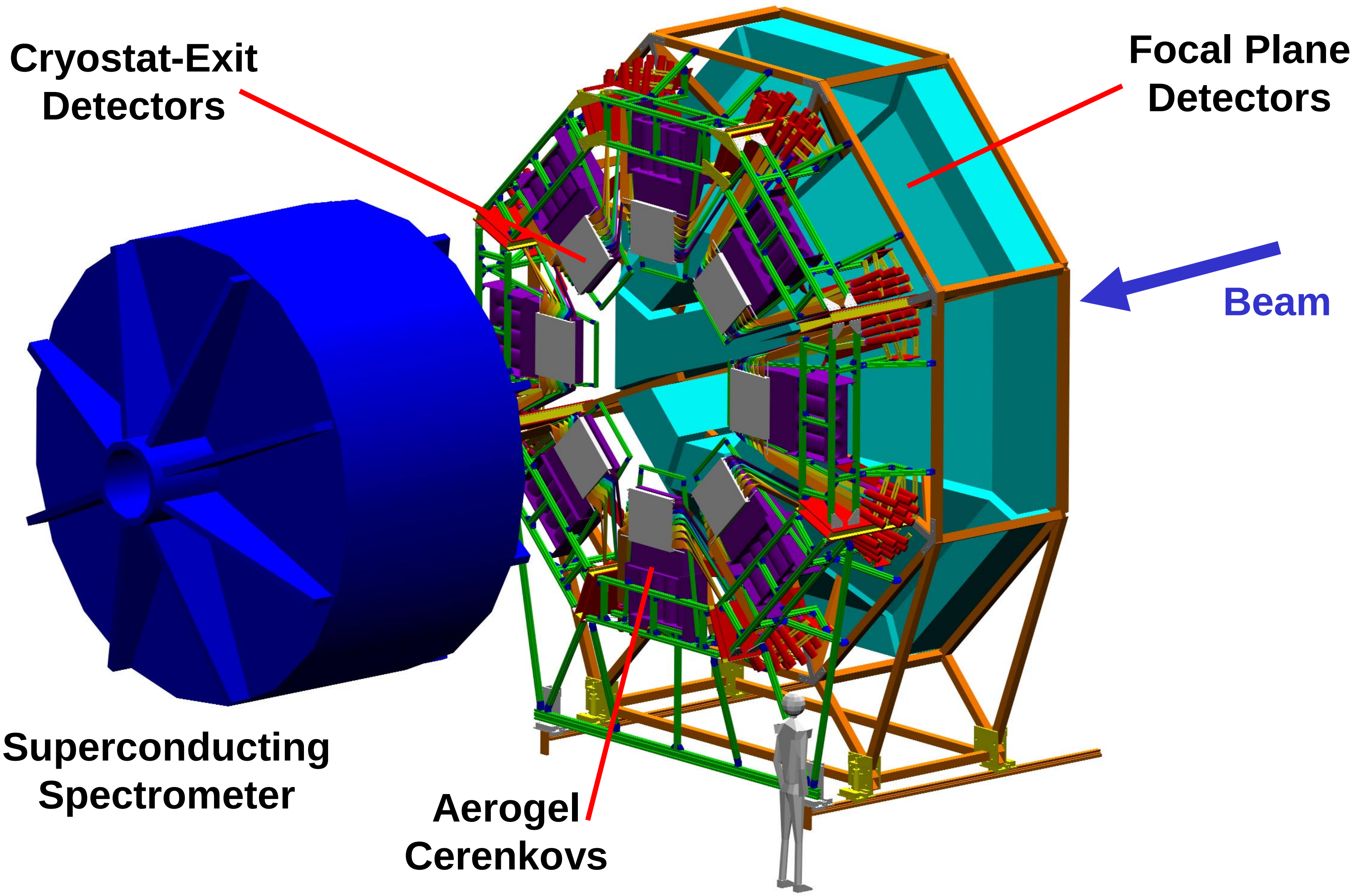
$$A(Q^2) = -\frac{(G_F Q^2)}{\pi\alpha\sqrt{2}} \; \frac{\{\, \varepsilon G^\gamma_E G^Z_E + \tau G^\gamma_M G^Z_M + \eta G^\gamma_M G^Z_A \,\}}{\varepsilon (G^\gamma_E)^2 + \tau (G^\gamma_M)^2} \; [\, 1/P_Z \,]$$



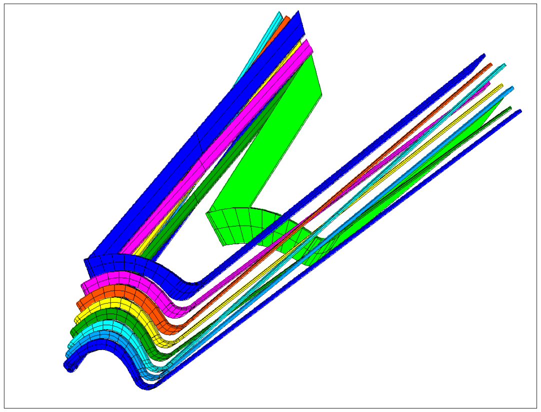
G0 Back-Angle Configuration

Magnet & Detector Package *turned around ;* Detect back-scattered electrons

Additional Detectors ; 2nd *(Mini)* Ferris-Wheel Support Structure



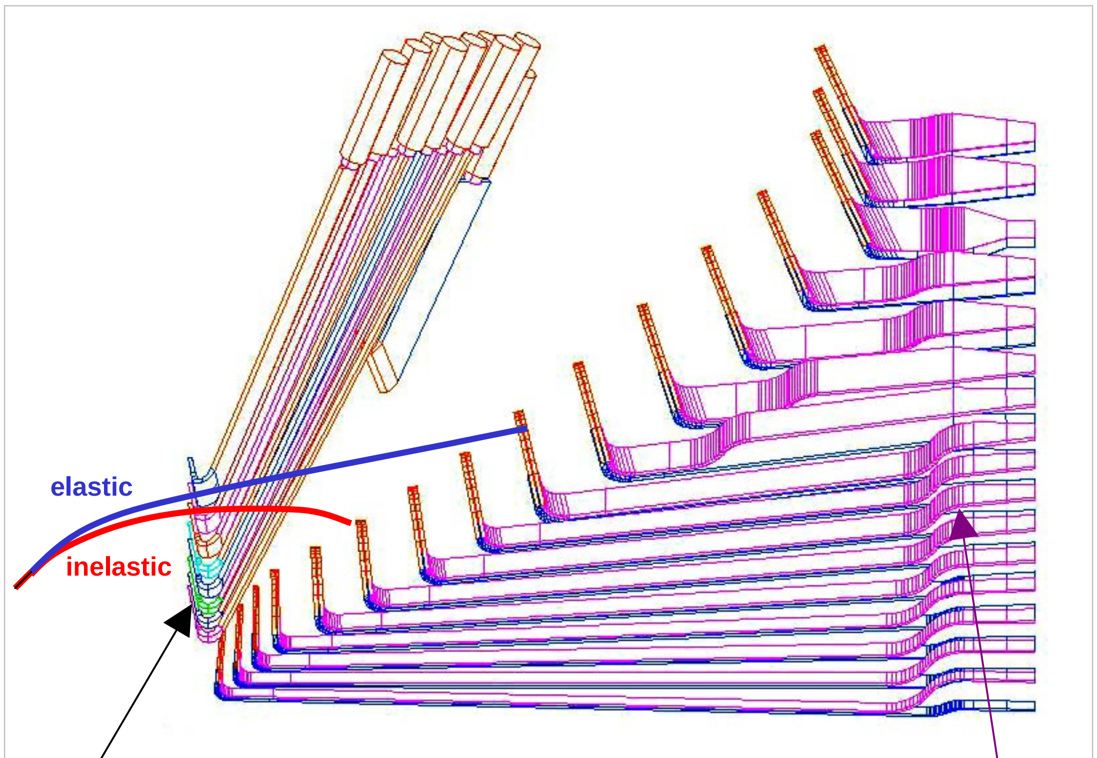
Back-Angle Configuration: Cryostat-Exit Detectors



Magnet & Detector Package *turned around*

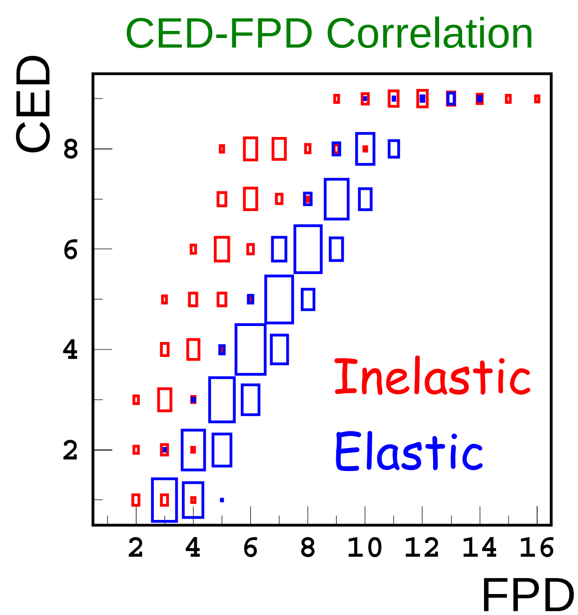
Measure back-scattered electrons *(instead of recoil p's)*

- Require additional det.^{s}: Cryostat-Exit Detectors (CED) (9 detectors per octant, fabricated at TRIUMF)
- CED-FPD coincidence to separate elastics/inelastics e^{-} (cannot use Time-of-Flight → electrons are relativistic)



CEDs (Cryostat Exit Detectors)

FPDs



Back-Angle Configuration: Aerogel Cerenkov Detectors

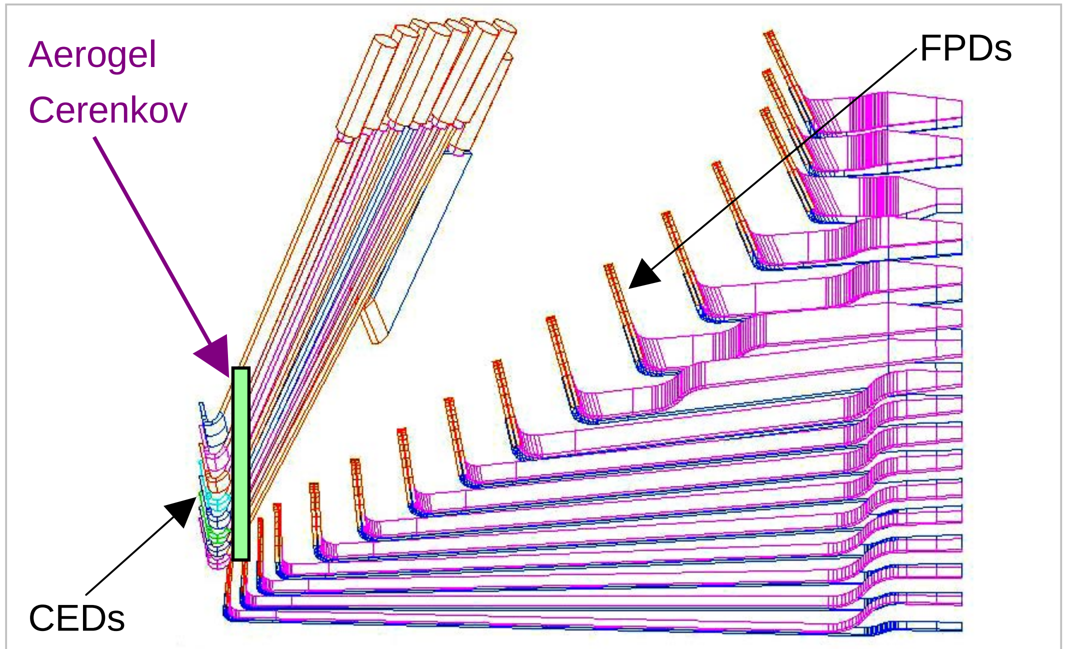
Back-scattered electron :
CED-FPD coinc. separates elastic & inelastic e⁻ 's

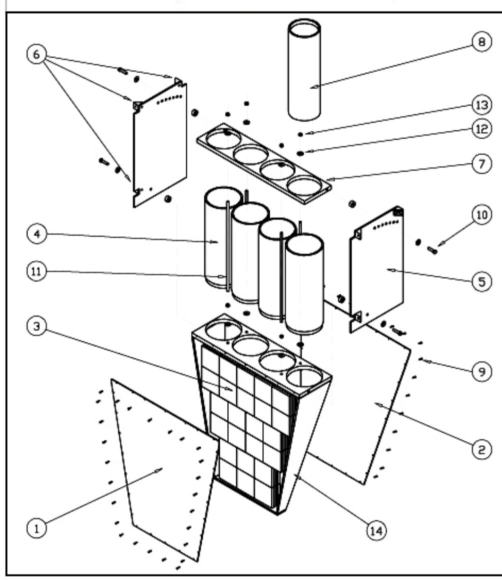
Background pions:
Need to separate π^- (backgnd) from e^- (signal)

Cerenkov Detectors: "Discriminate" electrons from pions by their velocity (e's create light in Cerenkov det., but pions do not).

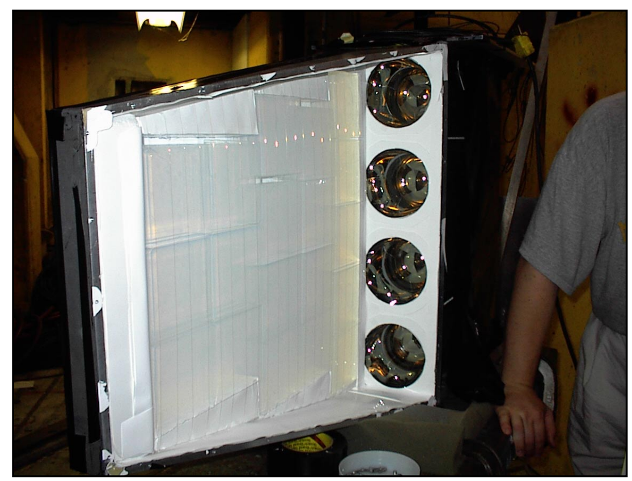
8 detectors: 4 Canadian
4 French

(FPD, CED) *plus* **Cerenkov Arrays**





Fabricated & tested @ TRIUMF



Aerogel Cerenkov
11x11x1 cm^3 tiles (5 deep)

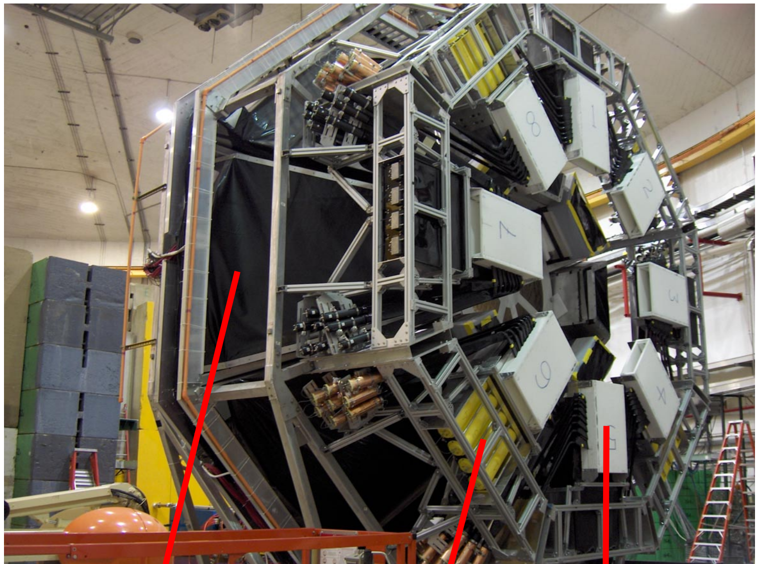
Aerogel, n ~ 1.03

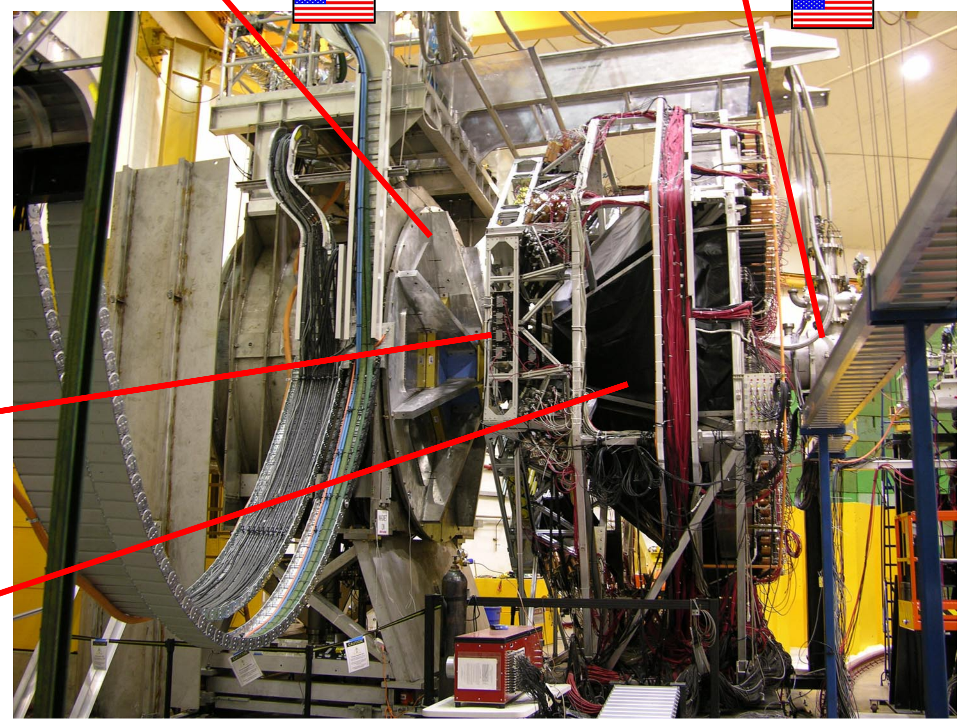
If v > 0.97c (speed of light in aerogel medium), Cerenkov radiation created

Backward Angle Measurement *(Recently started Mar/2006)*

Nov/2005: Backangle Detector octants *(Mini-Ferris Wheel)* installed in Hall C (JLab)

Mar/2006: Backangle Detector system cabled & taking cosmic data
LH_2/LD_2 Target installed





Superconducting Spectrometer

LH2/LD2 Target Service Module

Cryostat-Exit Detectors

Aerogel Cerenkovs

Focal Plane Detectors

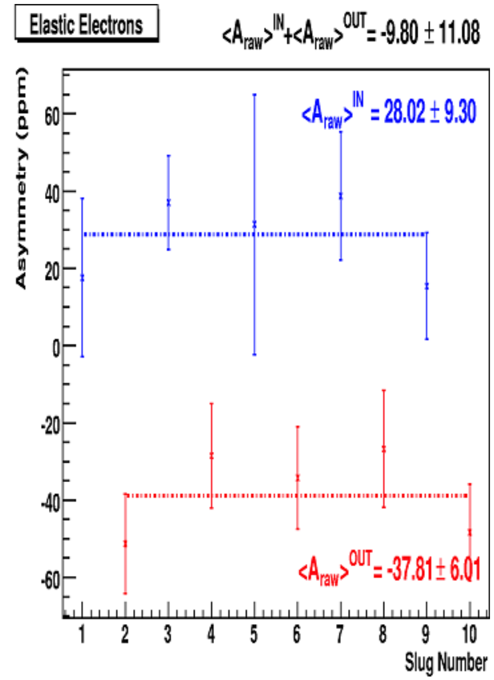
***Backward Angle Measurement** (Recently started Mar/2006)*

Spring 2006: Commissioning and 1st Data Run in Backward Angle Mode

System (Detectors/Target/Beam) checked out

1st set of (preliminary) production data obtained

1st set of Parity-violating asymmetries measured



Present Status of the G0 Experiment

Forward Angle Measurement Completed

Presently, in Backward Angle Configuration

G0 Backangle Measurements @ $Q^2 = 0.6, 0.23\ GeV^2$

- Run in Mar-Apr '06 at $Q^2 = 0.6\ GeV^2$ (Commissioning & H target)
- Run in July-Aug '06 at $Q^2 = 0.23\ GeV^2$ next (H and D targets)
- Run in Sep-Dec '06 at $Q^2 = 0.6\ GeV^2$ (H and D targets)
- Run in Jan-Feb '07 at $Q^2 = 0.23\ GeV^2$ (H and D targets)

(3b)

Physics Beyond the Standard Model ?

Standard Model: "Pillar of fundamental physics for ~ 30 years"
Electromagnetic, Weak, Strong interactions

Fermions ("matter particles"): leptons (e, ν_e, μ, ν_μ, τ, ν_τ)
quarks (u, d, s, c, b, t)
Gauge Bosons ("force carriers"): (γ, W^+, W^-, Z, g), H

Electroweak sector:
Unification of Electromagnetic (EM) and Weak Interactions
→ Electroweak Interaction (EW)

Proposed by Weinberg-Salam (γ, Z, $W^\pm$)
- predicted existence Z, $W^\pm$ → discovered later at CERN
Impressive agreement between Standard Model & EW observables

Issues: (Did not explain)
Large number of parameters (masses, couplings, mixing angles)
Origin of: quantization of EM charge and weak hypercharge,
P and CP violation, number of generations,…
Neutrino oscillations
Mass (scalar) hierarchy problem

Q: Extensions ("new" physics) beyond the Standard Model ?

Qweak : JLab E02-020

A Search for Physics at the TeV Scale Via a Measurement of of the Proton's Weak Charge

Q_{weak} Collaboration:
Canada (TRIUMF, U.Manitoba, UNBC, U.Winnipeg), USA

Measure Q^p_{weak} : Weak charge of the proton ; $Q^p_{weak} = 1 - 4 \bullet \sin^2\theta_W$

- ***first** precision measurement* of this property of the proton
- fundamental measurement of the running of $\sin^2\theta_W$ at low energies

At low energies and small scattering angles, the "weak charge" of the proton is proportional to the Parity-Violating asymmetry (in e-p scattering):

$$(As\ Q^2 \to 0, \theta \to 0): \quad \mathrm{A} \sim \left[Q^2 Q^{\mathrm{p}}_{\mathrm{weak}} + Q^4 \mathrm{B}(Q^2)\right] \sim \left[Q^2 Q^{\mathrm{p}}_{\mathrm{weak}}\right] \quad ; \quad \left\{ A = \frac{\sigma^{(+)} - \sigma^{(-)}}{\sigma^{(+)} - \sigma^{(-)}} \right\}$$

contains $G^{\gamma}_{E,M}$, $G^{Z}_{E,M}$ form factors

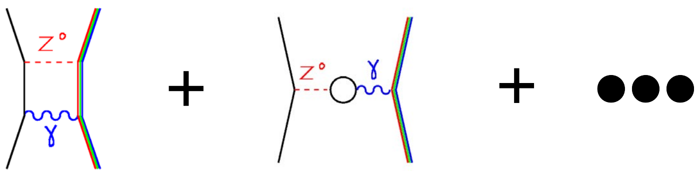
$Q^p_{weak} = 1 - 4\sin^2\theta_W \sim 0.072$ → a well-defined experimental observable
→ has a definite prediction in the Standard Model

→ Goal: Asymmetry Measurement: $\Delta A \sim 1 \times 10^{-8} \to \Delta Q^p_{weak} \sim \pm 4\% \to \Delta \sin^2\theta_W \sim \pm 0.3\%$

→ **Sensitive to *new* physics (particles) at ~4.6 TeV scale**

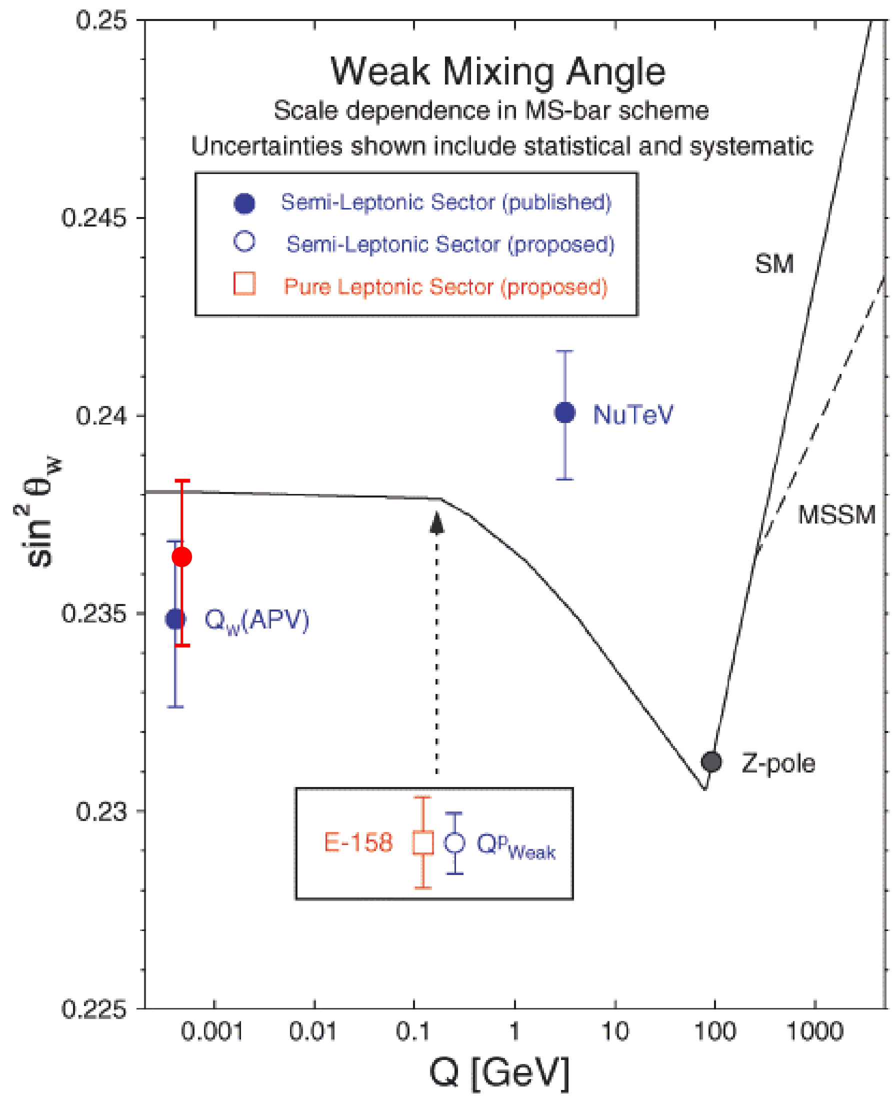
Running of the Weak Mixing Angle

Electroweak radiative corrections
⇨ $\sin^2\theta_W$ varies with Q



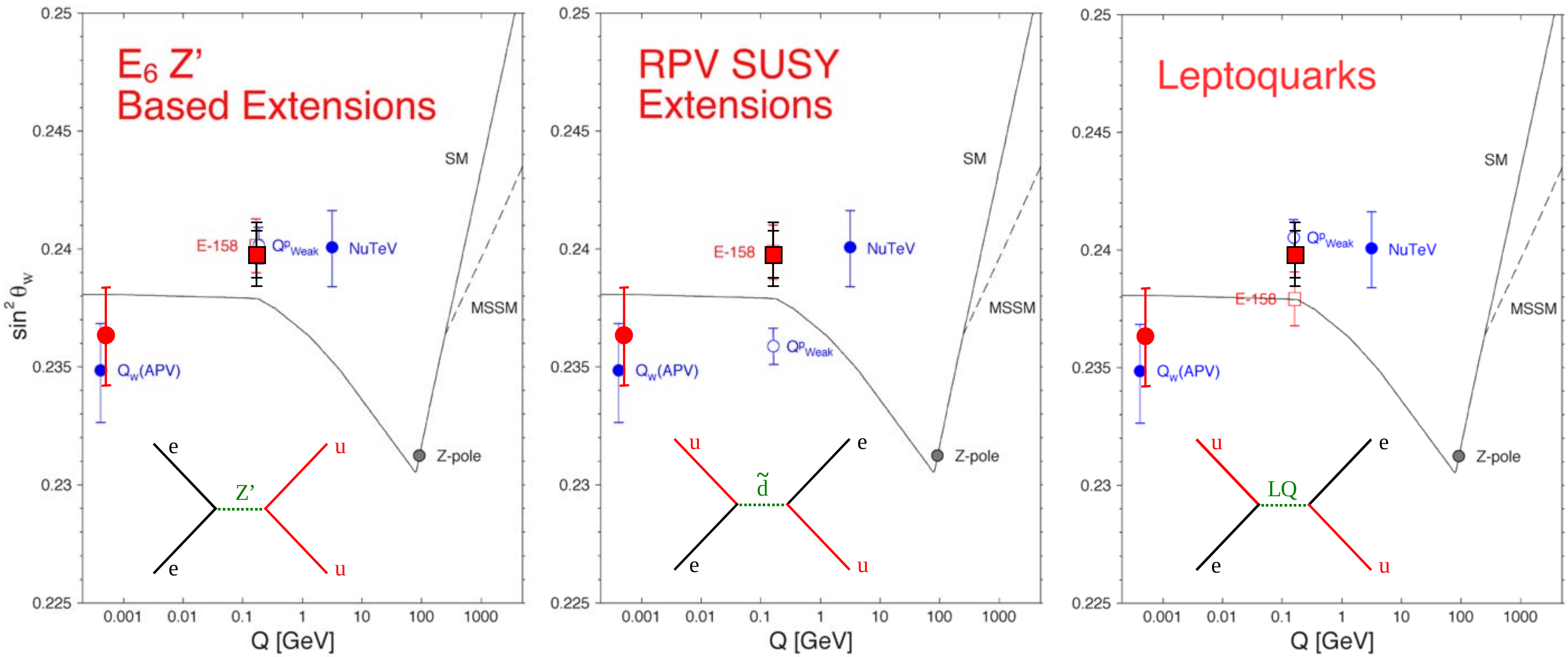
New Physics ??

Value of $\sin^2\theta_W$ at ~0.17 GeV/c:
SLAC E158: (e-e)
PV Moller Scattering ⇨ Q^e_{weak}
Complementary
JLab Q^p_{weak} (e-p)



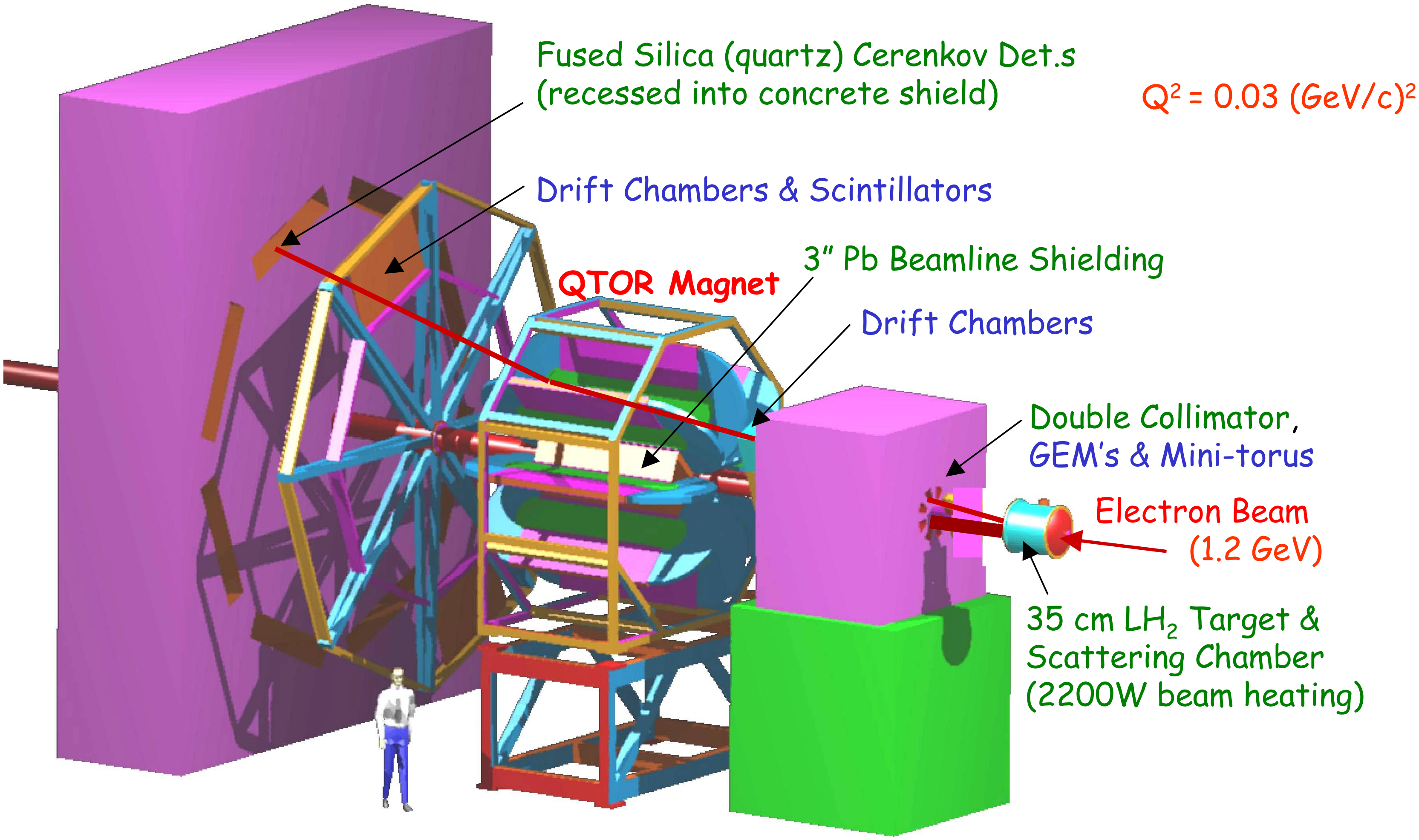
Useful Diagnostic for New Physics

Weak charge measurements: Q^p_{weak} , Q^e_{weak}



E158 recent results: $\sin^2\theta_W = 0.2397 \pm 0.0010$ (stat) ± 0.0008 (sys)

Layout of the Qweak Experiment



Qweak Toroidal (QTOR) Magnet

- 8 sector toroidal magnet
- water cooled copper coils
- 8600 A, 1.2 MW
- 4.3 m long, 1.5 m wide coils, simple racetrack shape
- ~3300 kg per coil
- Magnet coils → Canadian
- Field mapping with G0 Mapper (TRIUMF-designed & built)

$$\int \vec{B} \cdot d\vec{l} = 0.67 \text{ T.m}$$

Qweak experiment presently in design & prototyping phase

SUMMARY

G0

- G0 will measure a *new*, fundamental property of the proton.
  (**G^{Zp},** weak current distribution)
- Measurement of G^{Zp} allows decomposition of the proton ground state matrix elements into quark flavour contributions ($G^{u,p}$, $G^{d,p}$, & **$G^{s,p}$ – proton strange quark current distribution; direct measurement of the quark sea**).
  The physics is of great current interest.

Q_{weak}

- First precision measurement of the weak charge of the proton. (**Q_{weak}**)
- Fundamental measurement of the running of $\sin^2\theta_W$ at low energy.
- Sensitive search for new physics at the ~4.6 TeV scale.

Parity-violation is a useful tool indeed.

Proton "Weak" Form Factors & Strange Quarks

Flavour decomposition *("Proton is made up of quarks of different flavours")*

$G^{\gamma p}_{E,M} \rightarrow \Sigma$ (electric charge of quark q_j) $\times G^{q_j,p}_{E,M}$

$G^{Z p}_{E,M} \rightarrow \Sigma$ (weak charge of quark q_j) $\times G^{q_j,p}_{E,M}$

$G^{q_j,p}_{E,M}$ empirical, "unknown"
$q_j = \{ u, d, s, c, t, b \}$

Rewrite as a sum of contribution from each flavour (neglect heavy quarks c, t, b)

$$G^{\gamma p}_{E,M} = (2/3)\, G^{u,p}_{E,M} - (1/3)\, G^{d,p}_{E,M} - (1/3)\, G^{s,p}_{E,M}$$

$$G^{Z p}_{E,M} = (1/4 - 2/3 \sin^2\theta_W)\, G^{u,p}_{E,M} - (1/4 - 1/3 \sin^2\theta_W)\, G^{d,p}_{E,M} - (1/4 - 1/3 \sin^2\theta_W)\, G^{s,p}_{E,M}$$

$$G^{\gamma n}_{E,M} = (2/3)\, G^{d,p}_{E,M} - (1/3)\, G^{u,p}_{E,M} - (1/3)\, G^{s,p}_{E,M}$$

$\Downarrow$

Assuming **Charge Symmetry** between the proton and neutron

$$\begin{cases} G^{u,p}_{E,M} = G^{d,n}_{E,M} \\ G^{d,p}_{E,M} = G^{u,n}_{E,M} \\ G^{s,p}_{E,M} = G^{s,n}_{E,M} \end{cases}$$

$\Downarrow$

$$G^{u,p}_{E,M} = (3 - 4\sin^2\theta_W)\, G^{\gamma p}_{E,M} - \mathbf{G^{Z p}_{E,M}}$$

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

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