Parity Violating Electron Scattering and Strangeness in the Nucleon

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Miramare-Trieste
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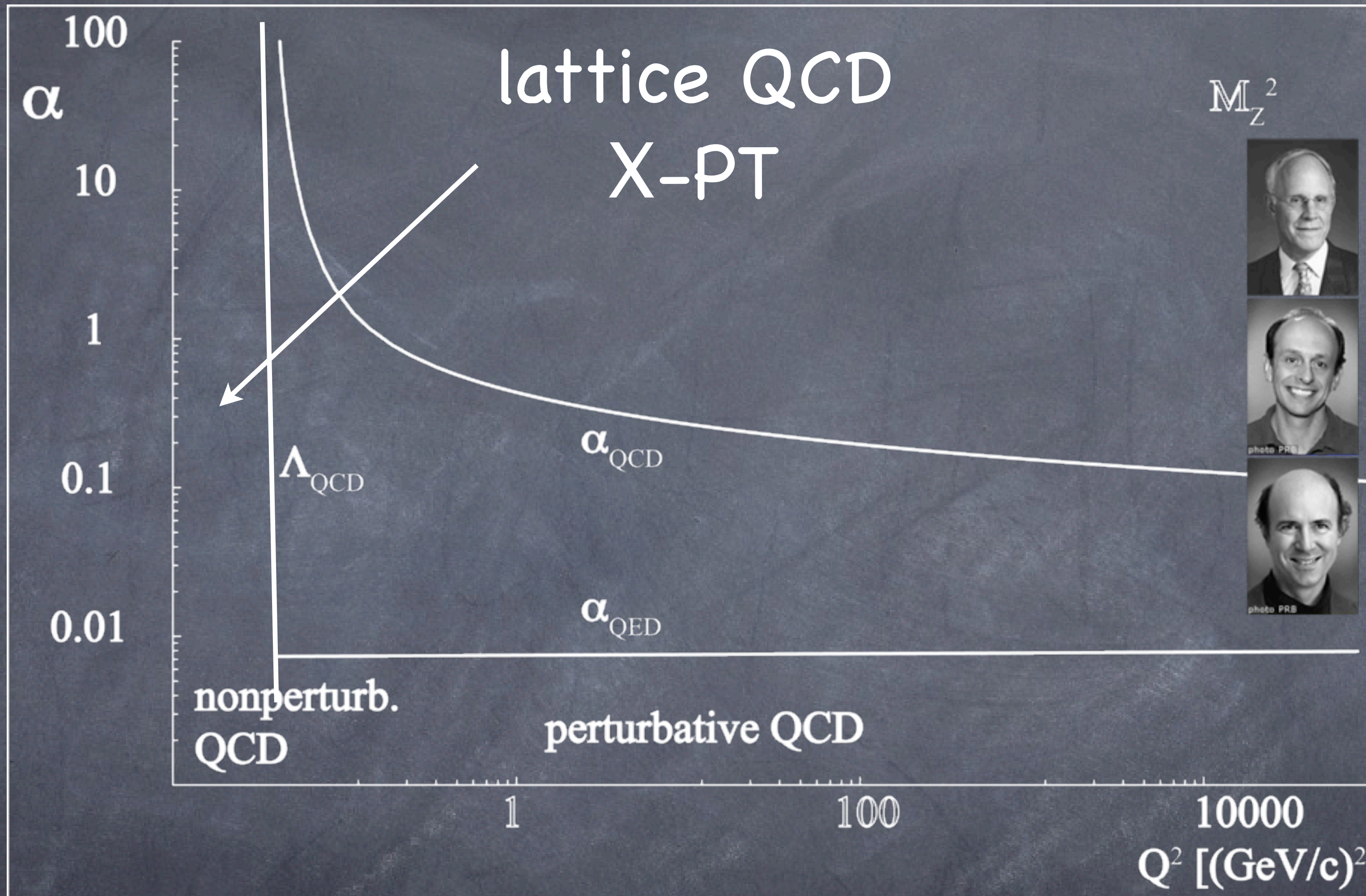
Outline

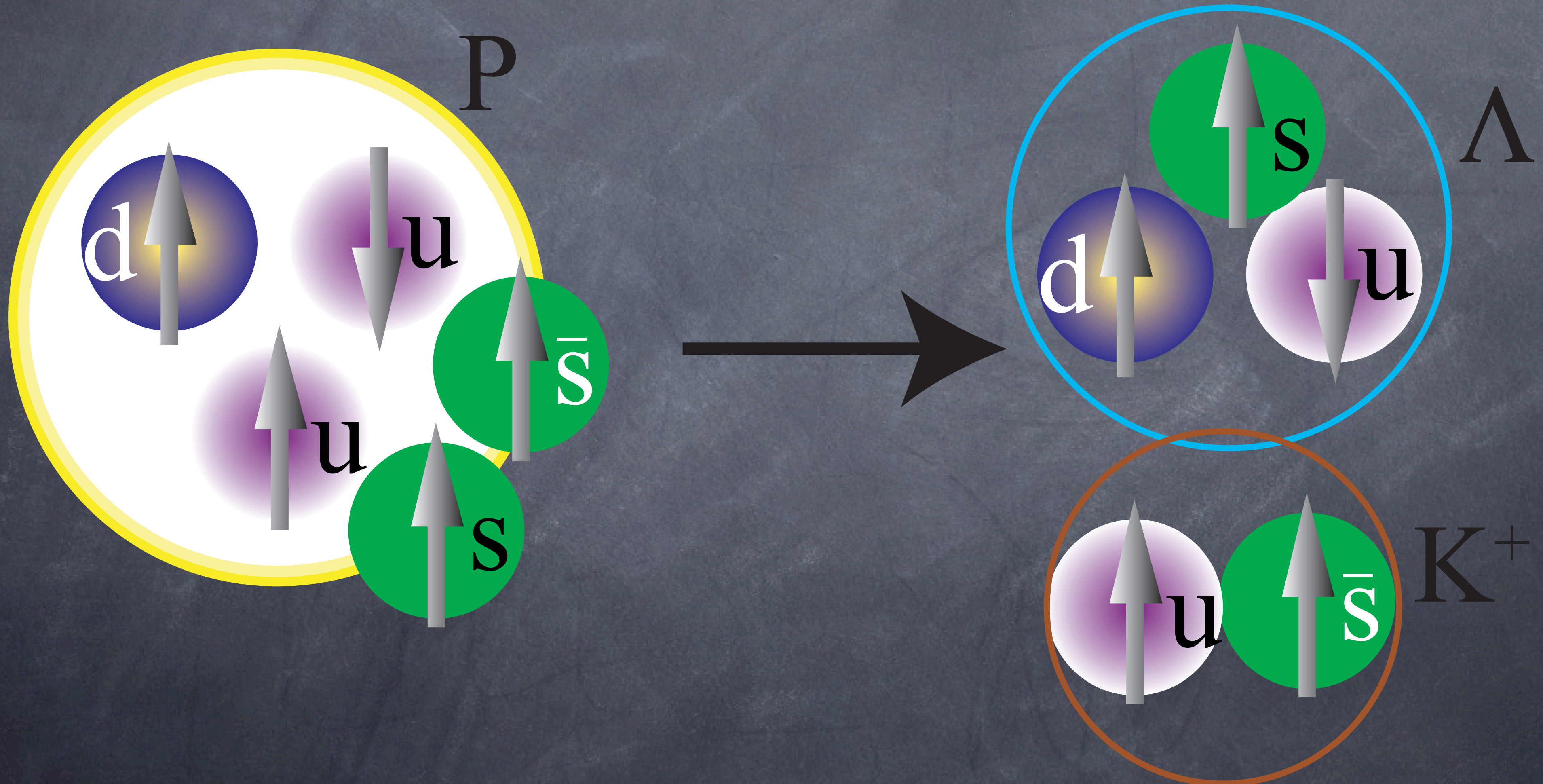
- Nonperturbative QCD: Strangeness
- weak form factors -> asymmetries in ep-scattering
- strangeness parity experiments: A4 in Mainz

QCD-Renormalisation à la QED

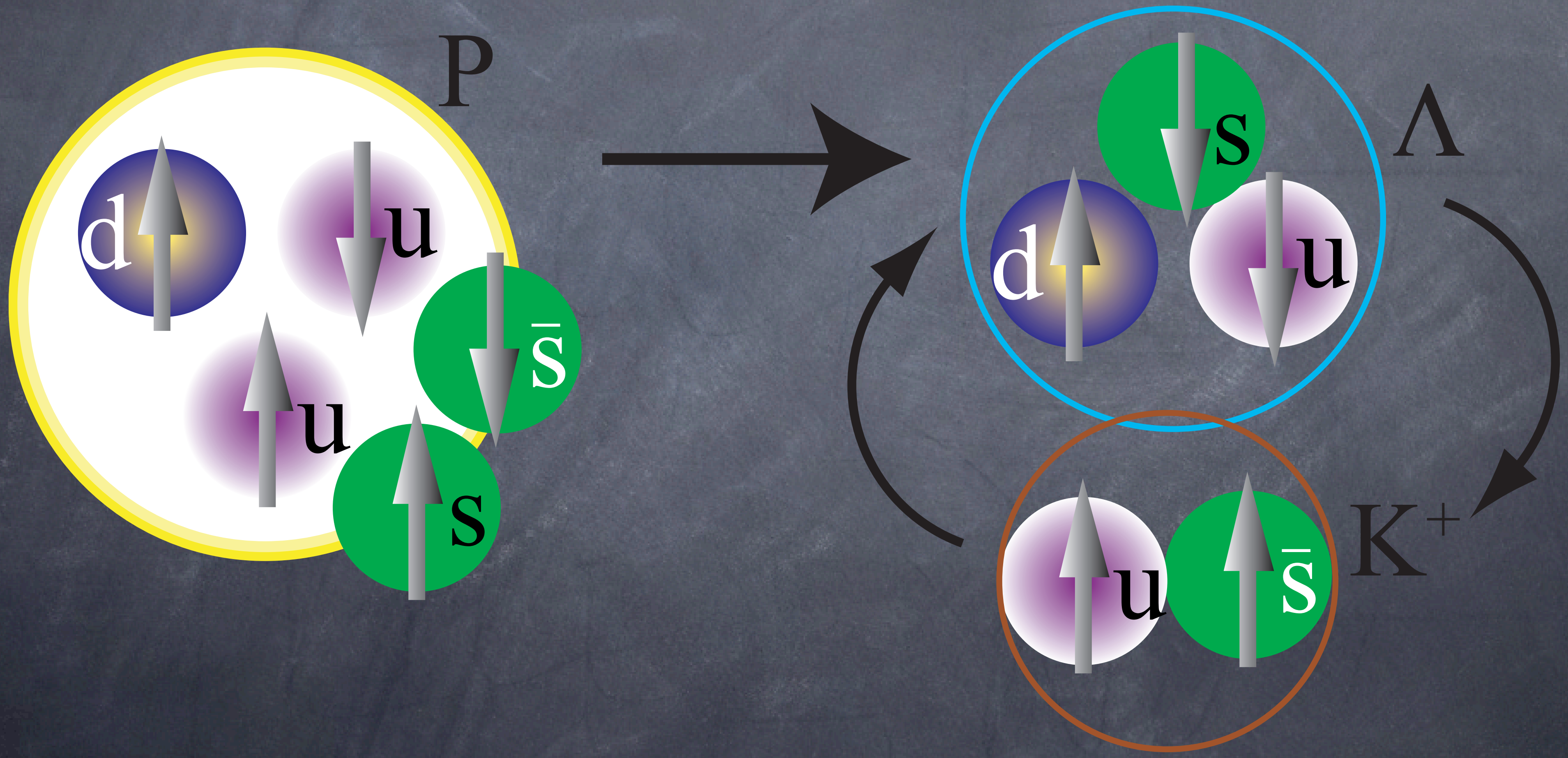


$m_u, m_d \ll m_s \approx \Lambda_{QCD} \ll m_c, m_b, m_t$

Contribution to CHARGE distribution (G_E^s)



Contribution to MAGNETISATION distribution (G_M^s)



Strangeness in the Nucleon

Vacuum	$\langle 0 \vert \bar{s}s \vert 0 \rangle$	(0.8 ± 0.1) $\langle 0 \vert \bar{q}q \vert 0 \rangle$	QCD sum rules
Momentum	$\int x(\bar{s}+s)dx$	2-4%	DIS ν, μ, e
Mass	$m_s \langle N \vert \bar{s}s \vert N \rangle$	220 MeV	πN-scatt. $\Sigma_{\pi N}$-Term
Spin	$\langle N \vert \bar{s}\gamma_\mu \gamma^5 s \vert N \rangle$	- 10 %	pol. DIS
EM FF G_E^s, G_M^s	$\langle N \vert \bar{s}\gamma_\mu s \vert N \rangle$	???	PVelectron scattering

Theoretical Estimates of Strangeness

- Dispersion Theory: Vector Meson Dominance
  Jaffe, Drechsel, Musolf, Hammer
- Quark Models
  Jido and Weise $\mu_s = +0.16\mu_N$
  Zou and Riska: $\mu_s > 0$, s in ground state, uuds: $L = 1$

$p \to K^+ + \Lambda$, $p \to \pi^+ + n$ ($G_E^s, G_M^s < 0$)

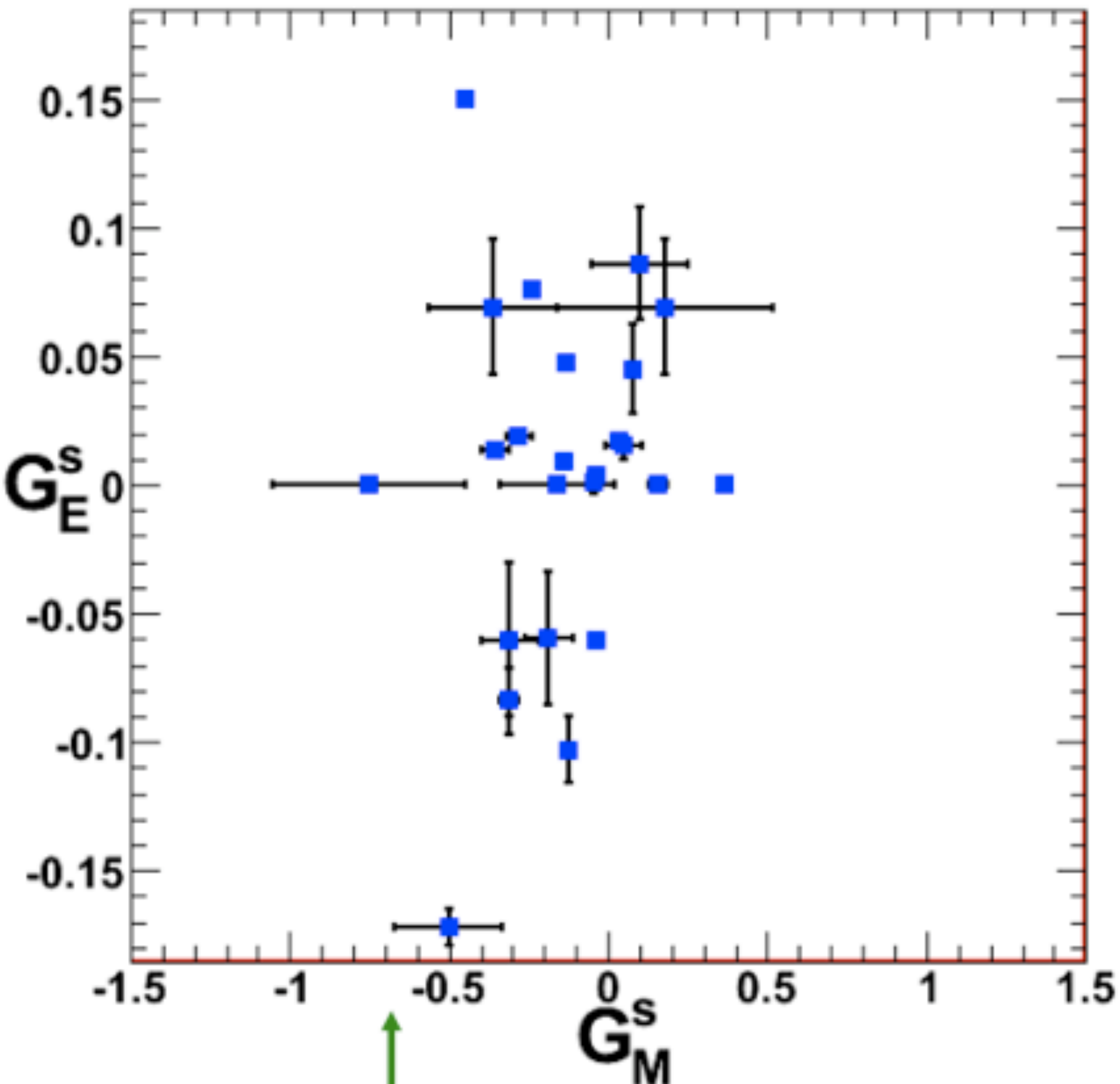
Skyrme-Models (Baryon as Soliton of Mesons)

Chiral Perturbation Theory

Lattice Gauge Theory:

$G_M^s(0) = \mu_s = -0.051 \pm 0.021\ \mu_N$

Strangeness Models



10% of $\mu_N^{T=1}$

Define leading moments of form factors:

$$\mu_s = G_M^s\,(Q^2 = 0)$$

(strange magnetic moment)

$$\rho_s = \left.\frac{\partial G_E^s}{\partial \tau}\right|_{\tau=0}$$

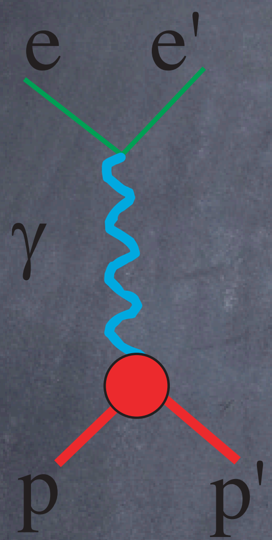
(strange radius)

$$\tau = \frac{Q^2}{4M^2}$$

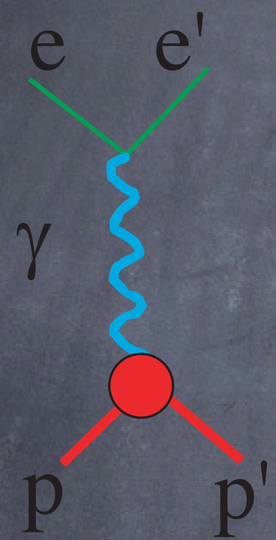
note: caveats...

from D.Armstrong

Born Approximation
Elastic Scattering



Born Approximation
Elastic Scattering

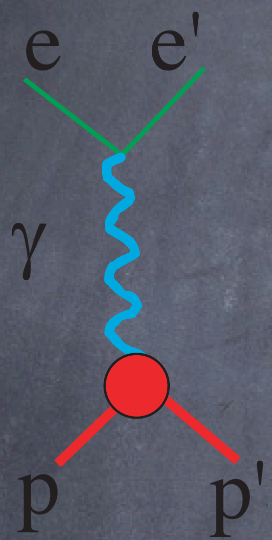


$$\sigma \sim \mathcal{M}\,\mathcal{M}^*$$

$$\sim \left(j_\mu \frac{1}{Q^2} J^\mu\right)\left(j_\mu \frac{1}{Q^2} J^\mu\right)^*$$

$$j_\mu \sim \bar{e}\,\gamma_\mu\, e$$ Vector Current

Born Approximation
Elastic Scattering



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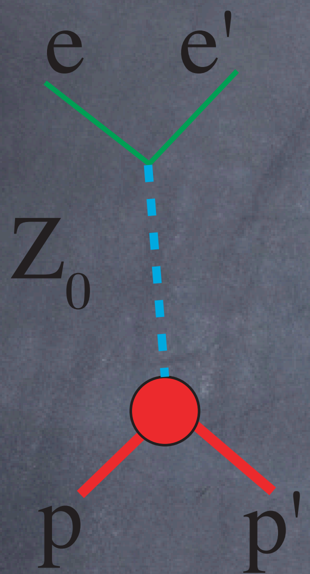
$$j_\mu \sim \bar{e}\,\gamma_\mu\, e \quad \text{Vector Current}$$

$$J^\mu_\gamma \sim \left\langle N \middle| q^u \bar{u}\,\gamma_\mu\, u + q^d \bar{d}\,\gamma_\mu d + q^s \bar{s}\,\gamma_\mu s \middle| N' \right\rangle$$

$$= \bar{\mathcal{P}}\left[\gamma^\mu F_1 - i\sigma^{\mu\nu} q_\nu \frac{\kappa_p}{2M_N} F_2\right]\mathcal{P}$$

Born Approximation
Elastic Scattering



Born Approximation
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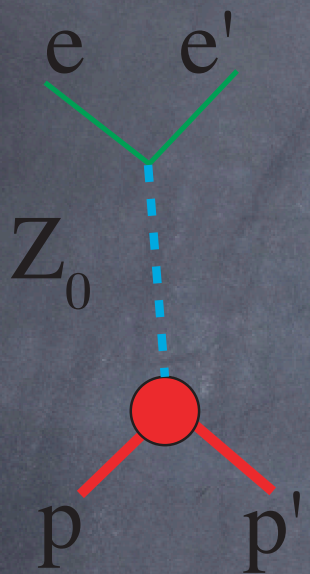
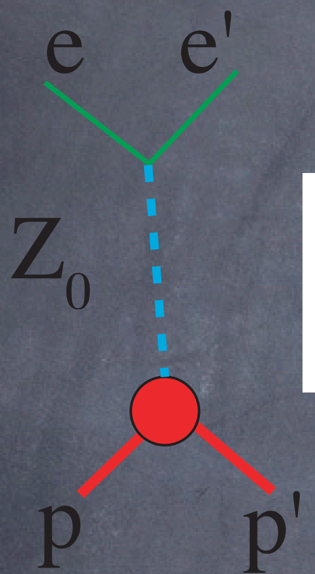


$$\tilde{J}^{\mu}_{Z} \sim \left\langle N \middle| \tilde{q}^{u}\,\overline{u}\,\gamma_{\mu}\,u + \tilde{q}^{d}\,\overline{d}\,\gamma_{\mu} d + \tilde{q}^{s}\,\overline{s}\,\gamma_{\mu} s \middle| N' \right\rangle$$

$$= \overline{\mathcal{P}}\left[\gamma^{\mu}\tilde{F}_{1} - i\sigma^{\mu\nu} q_{\nu}\frac{\kappa_{p}}{2M_{N}}\tilde{F}_{2}\right]\mathcal{P}$$

Born Approximation
Elastic Scattering



$$\tilde{q}^{d}{}_{V} \quad = \quad \tau_3 - 2q^{d} sin^2(\theta_W)$$

weak vector charge

$$\tilde{J}^{\mu}_{Z} \;\sim\; \left\langle N|\tilde{q}^{u}\overline{u}\,\gamma_{\mu}\,u + \tilde{q}^{d}\overline{d}\,\gamma_{\mu}d + \tilde{q}^{s}\overline{s}\,\gamma_{\mu}s|N'\right\rangle$$

$$= \;\; \overline{\mathcal{P}}[\gamma^{\mu}\tilde{F}_1 - i\sigma^{\mu\nu}q_{\nu}\frac{\kappa_p}{2M_N}\tilde{F}_2]\mathcal{P}$$

Strangeness Contribution to electromagnetic Form Factors

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Isospin

$$F_1^p = \frac{2}{3}{F^u}_1 - \frac{1}{3}{F^d}_1 - \frac{1}{3}{F^s}_1$$

$$F_1^n = \frac{2}{3}{F^d}_1 - \frac{1}{3}{F^u}_1 - \frac{1}{3}{F^s}_1$$

Strangeness Contribution to electromagnetic Form Factors

Isospin

Universality

EW mixing

$$F_1^p = \frac{2}{3}F^u{}_1 - \frac{1}{3}F^d{}_1 - \frac{1}{3}F^s{}_1$$

$$F_1^n = \frac{2}{3}F^d{}_1 - \frac{1}{3}F^u{}_1 - \frac{1}{3}F^s{}_1$$

$$\tilde{F}_1^p = (\frac{1}{4} - \frac{2}{3}sin^2\theta_W)F^u{}_1 - (\frac{1}{4} - \frac{1}{3}sin^2\theta_W)F^d{}_1 - (\frac{1}{4} - \frac{1}{3}sin^2\theta_W)F^s{}_1$$

$$\tilde{F}_1^p = \frac{1}{4}(F^u{}_1 - F^d{}_1) - \frac{1}{4}F^s{}_1 - sin^2\theta_W(\frac{2}{3}F^u{}_1 - \frac{1}{3}F^d{}_1 - \frac{1}{3}F^s{}_1)$$

$$\tilde{F}_1^p = \frac{1}{4}(F_1^p - F_1^n) - sin^2\theta_W F_1^p - \frac{1}{4}F^s{}_1$$

Strangeness Contribution to electromagnetic Form Factors

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$$F_1^n = \frac{2}{3}F^d{}_1 - \frac{1}{3}F^u{}_1 - \frac{1}{3}F^s{}_1$$

$$\tilde{F}_1^p = (\frac{1}{4} - \frac{2}{3}sin^2\theta_W)F^u{}_1 - (\frac{1}{4} - \frac{1}{3}sin^2\theta_W)F^d{}_1 - (\frac{1}{4} - \frac{1}{3}sin^2\theta_W)F^s{}_1$$

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$$\tilde{F}_1^p = \frac{1}{4}(F_1^p - F_1^n) - sin^2\theta_W F_1^p - \frac{1}{4}F^s{}_1$$

electric (G_E) and magnetic (G_M) form factor

$$G_E = F_1 - \tau F_2$$

$$G_M = F_1 + F_2$$

Isospin breaking in the vector current of the nucleon

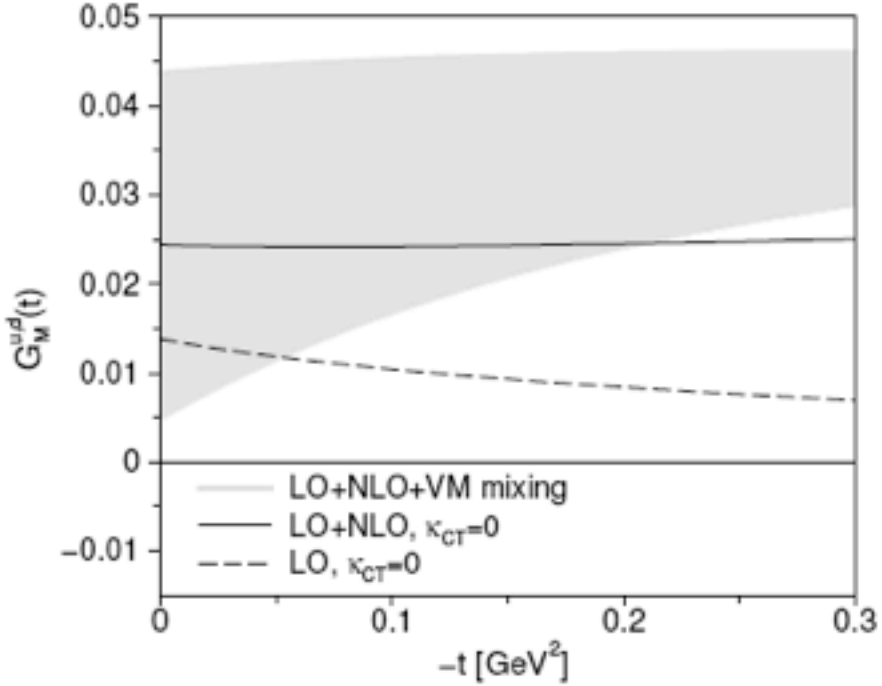
0. motivation

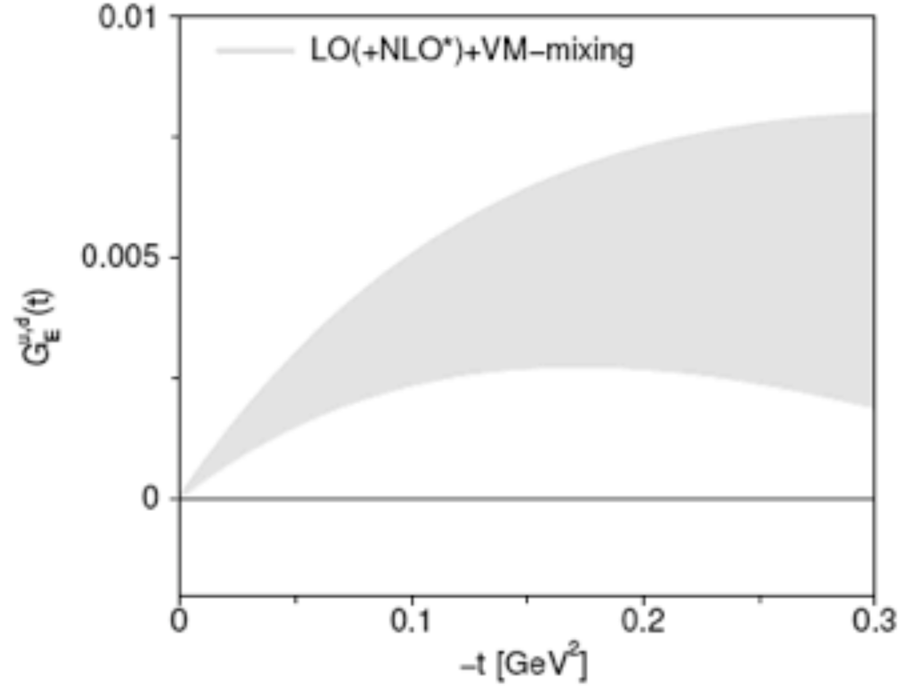
1. constituent quark model
   - ▷ *Dmitrašinović and Pollock, Phys. Rev. C52, 1061 (1995).*
   - ▷ *Miller, Phys. Rev. C57, 1492 (1998).*

2. light-cone meson-baryon model
   - ▷ *Ma, Phys. Lett. B408, 387 (1997).*

3. chiral perturbation theory
   - ▷ *Lewis and Mobed, Phys. Rev. D59, 073002 (1999).*

4. chiral perturbation theory with resonance saturation
   - ▷ *Kubis and Lewis, nucl-th/0605006 (2006).*





SAMPLE: $G_M^s\left(-0.1\,\mathrm{GeV}^2\right) = 0.37 \pm 0.20 \pm 0.26 \pm 0.07$

$G_M^{u,d}\left(-0.1\,\mathrm{GeV}^2\right) = 0.02 \ldots 0.05$

A4: $\left[G_E^s + 0.106\,G_M^s\right]\left(-0.108\,\mathrm{GeV}^2\right) = 0.071 \pm 0.036$

$\left[G_E^{u,d} + 0.106\,G_M^{u,d}\right]\left(-0.108\,\mathrm{GeV}^2\right) = 0.004 \ldots 0.010$

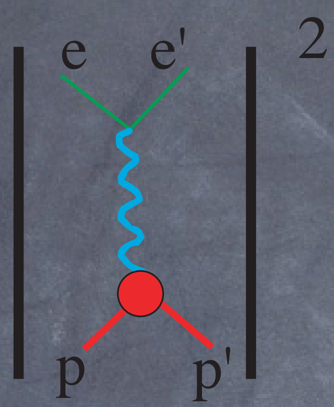
HAPPEX: $\left[G_E^s + 0.080\,G_M^s\right]\left(-0.099\,\mathrm{GeV}^2\right) = 0.030 \pm 0.025 \pm 0.006 \pm 0.012$

$\left[G_E^{u,d} + 0.080\,G_M^{u,d}\right]\left(-0.099\,\mathrm{GeV}^2\right) = 0.004 \ldots 0.009$

[KL] = Kubis and Lewis, nucl-th/0605006 (2006)

Parity Violation in Electroweak Interaction

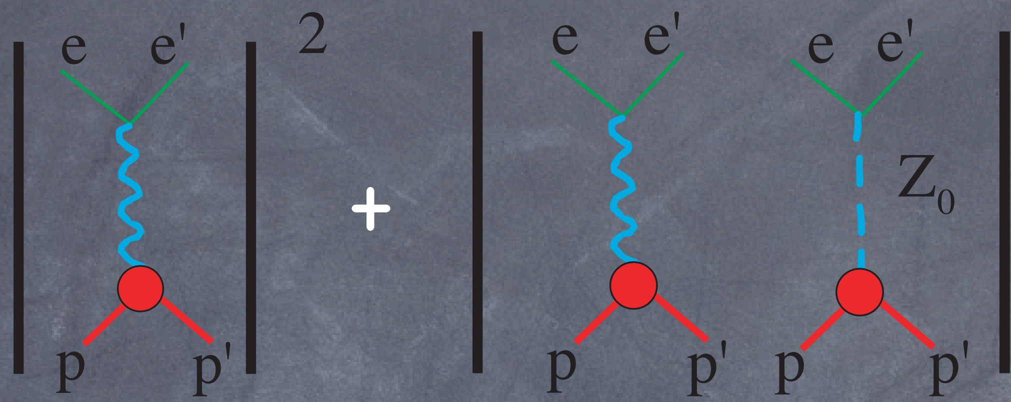
$\sigma \approx$



1

Parity Violation in Electroweak Interaction

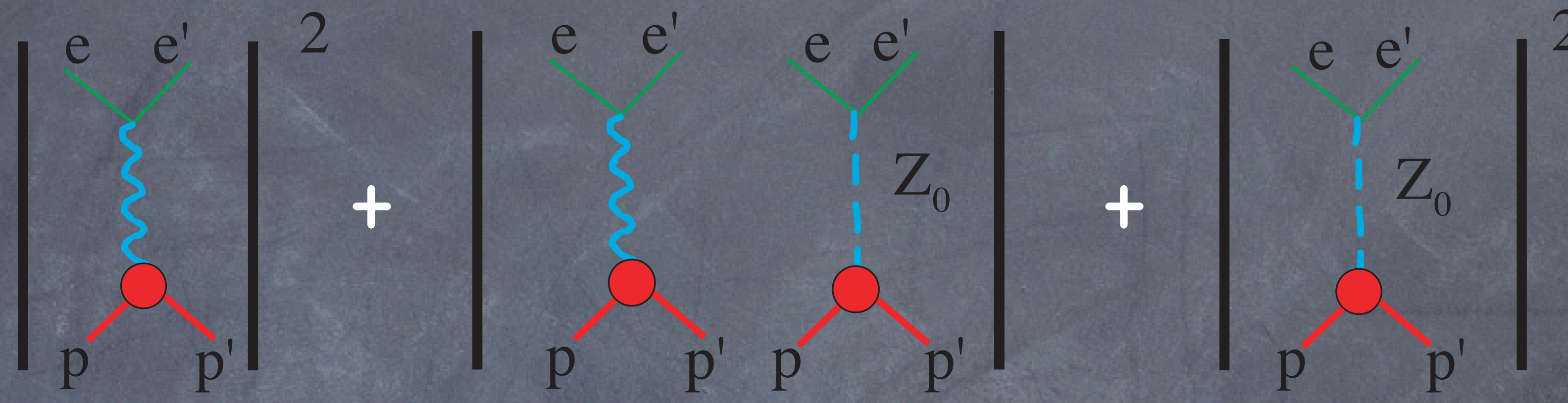
σ ≈



$1 \quad + \quad 10^{-5}$

Parity Violation in Electroweak Interaction

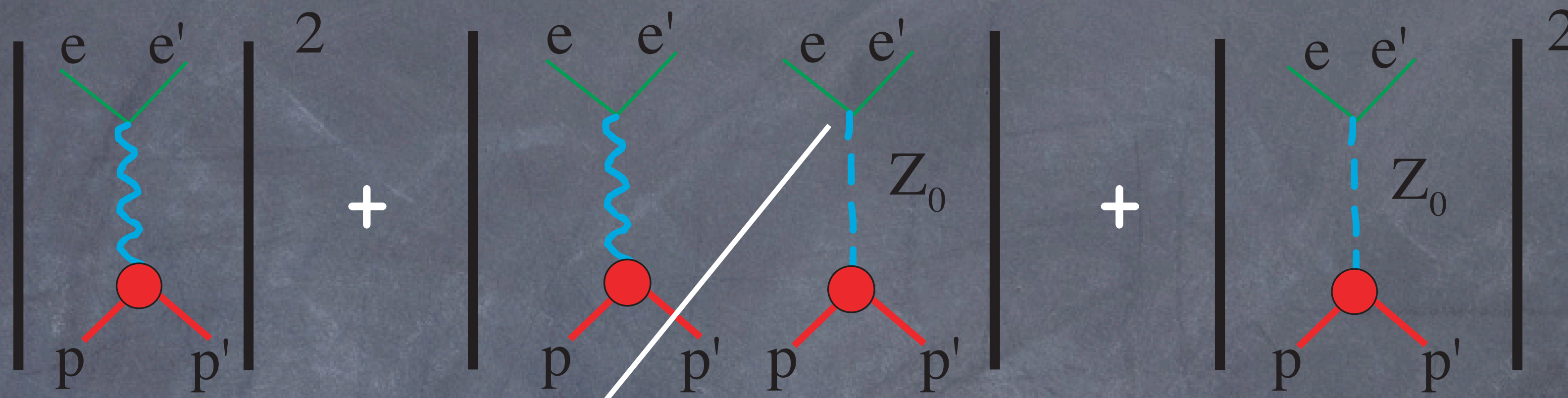
$\sigma \approx$



$1 \quad + \quad 10^{-5} \quad + \quad 10^{-10}$

Parity Violation in Electroweak Interaction

$\sigma \approx$

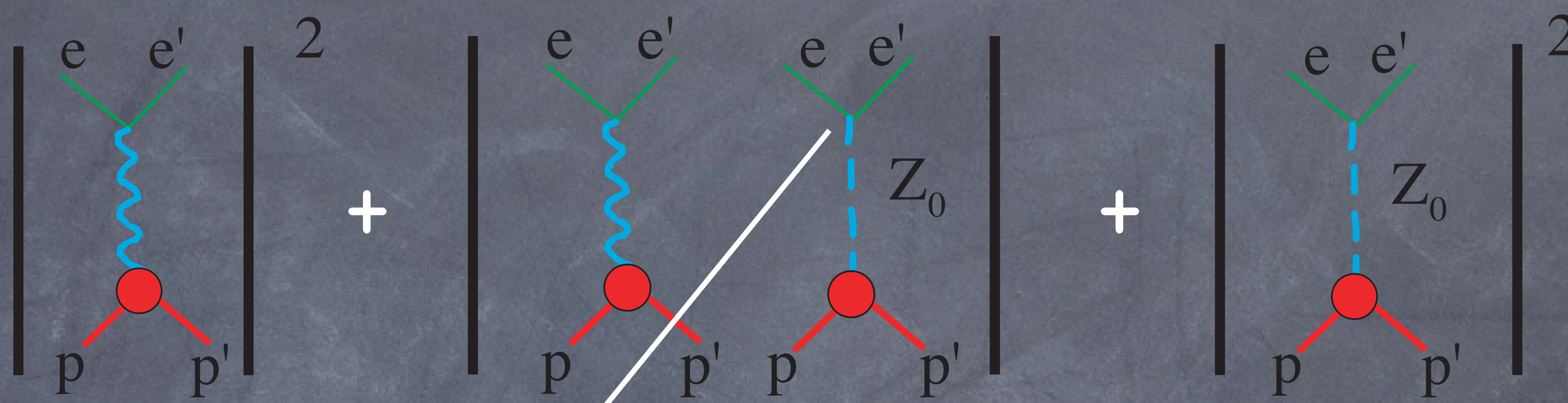


$1 + 10^{-5} + 10^{-10}$

V-A Coupling

Parity Violation in Electroweak Interaction

$\sigma \approx$



$1 \quad + \quad 10^{-5} \quad + \quad 10^{-10}$

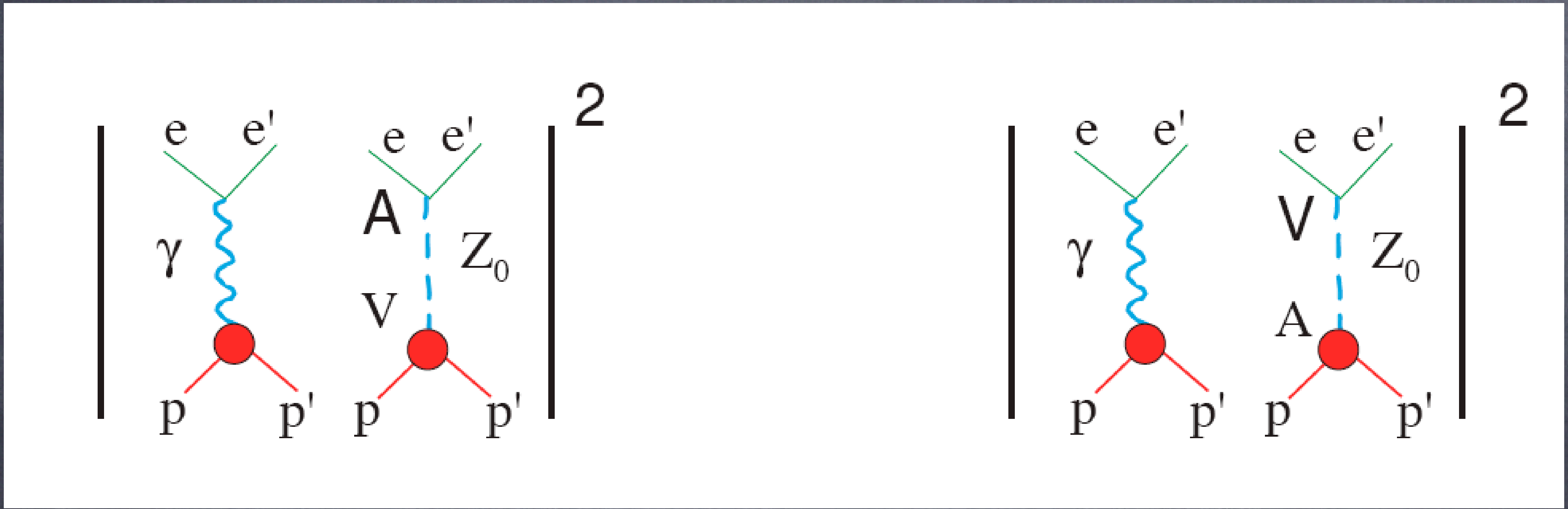
V-A Coupling

$$A = \frac{\sigma_R - \sigma_L}{\sigma_R + \sigma_L}$$

long. polarised electrons

unpolarised protons

Parity Violation in Electroweak Interaction



Vector-Form Factor Axial-Form Factor

$G^s{}_E$, $G^s{}_M$: “Rosenbluth Separation”, G_A: different Targets: p, d

Separation of Strangeness

$$A^{PV} = \frac{\sigma_R - \sigma_L}{\sigma_R + \sigma_L} = -\frac{G_F Q^2}{\pi\alpha\sqrt{2}} \times \frac{\varepsilon G_E^p \tilde{G}_E^p + \tau G_M^p \tilde{G}_M^p + \delta G_M^p \tilde{G}_A^p}{\varepsilon (G_E^p)^2 + \tau (G_M^p)^2}$$

$$\tilde{G}_E^p = \frac{1}{4}(G_E^p - G_E^n) - sin^2\theta_W G_E^p - \frac{1}{4} G^s{}_E$$

$$\tilde{G}_M^p = \frac{1}{4}(G_M^p - G_M^n) - sin^2\theta_W G_M^p - \frac{1}{4} G^s{}_M$$

$$A^{PV} = -\frac{G_F Q^2}{4\pi\alpha\sqrt{2}} \times [(1 - 4sin^2\theta_W) - \frac{\varepsilon G_E^p G_E^n + \tau G_M^p G_M^n}{\varepsilon (G_E^p)^2 + \tau (G_M^p)^2}$$

$$-\frac{\varepsilon G_E^p G^s{}_E + \tau G_M^p G^s{}_M}{\varepsilon (G_E^p)^2 + \tau (G_M^p)^2}$$

$$-\{\frac{(1 - 4sin^2\theta_W)\sqrt{1-\varepsilon^2}\sqrt{\tau(1+\tau)} G_M^p \tilde{G}_A^p}{\varepsilon (G_E^p)^2 + \tau (G_M^p)^2}\}]$$

$$A^{PV} = (A_{ns} + A_s)_V + A_A = A_0 + A_s$$

Error in Asymmetry from Input Parameters

at E_e = 315MeV, θ_e = 145°:

Q2=(0.223 GeV^2/c2)

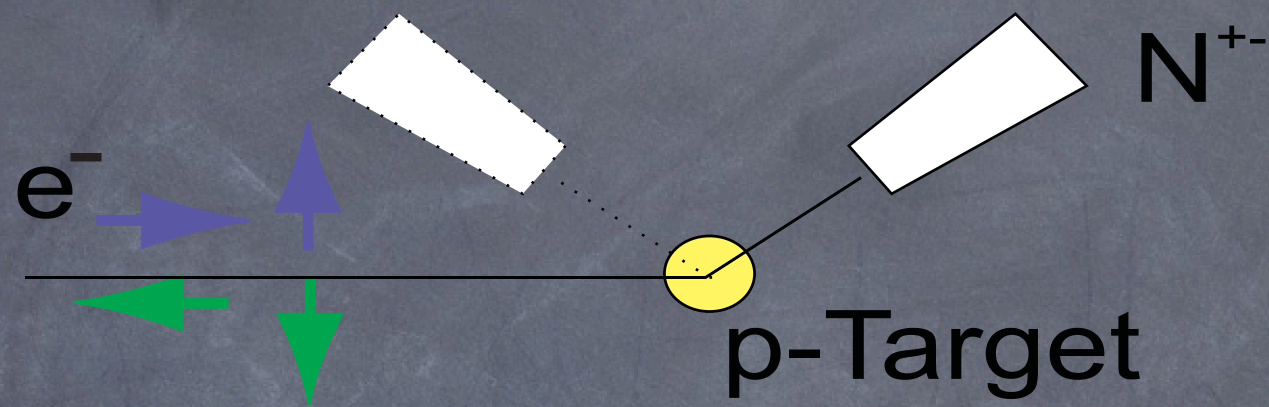
A0 = (-16.17+-1.02) ppm

* Error contribution to A0 at 145 degree:
* GAp err: 0.96 ppm
* GMn err: 0.27 ppm
* GMp err: 0.23 ppm
* GEp err: 0.04 ppm
* Weinberg err: 0.03 ppm
* GEn err: 0.02 ppm
* Gmue err: 0.00 ppm

==============================

* quadr. sum 1.02 ppm

Parity Violating Electron Scattering



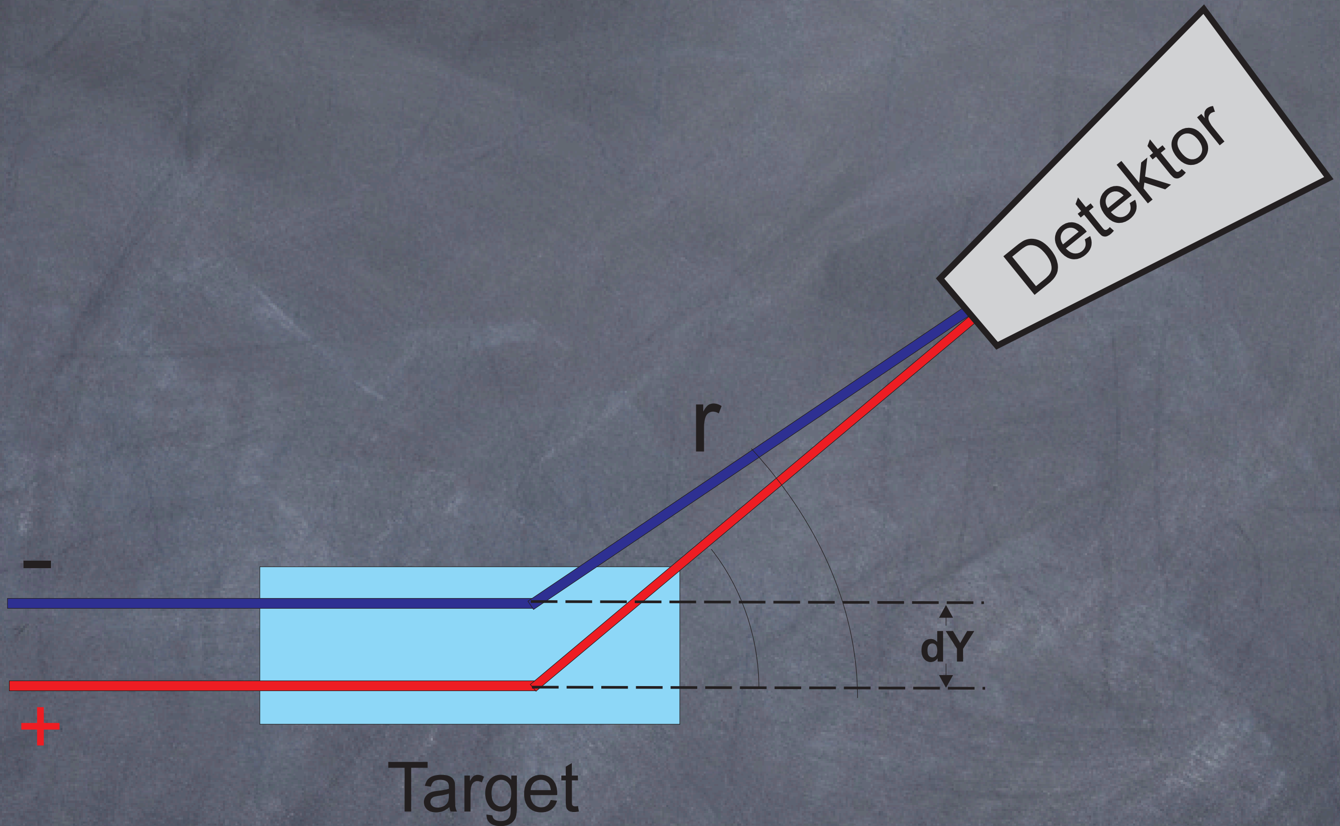
$$A = \frac{N^+ - N^-}{N^+ + N^-}$$

$$A_{exp} - A_0 \rightarrow A_s$$

$$G_E^s + a\, G_M^s$$

Rosenbluth Separation, different Targets (p, d, He)

False Asymmetries



$$A_{exp} = A_{PV} + A_f^{\theta}$$

Experiments

Asymmetries: 10^{-6} -> 10^{14} events

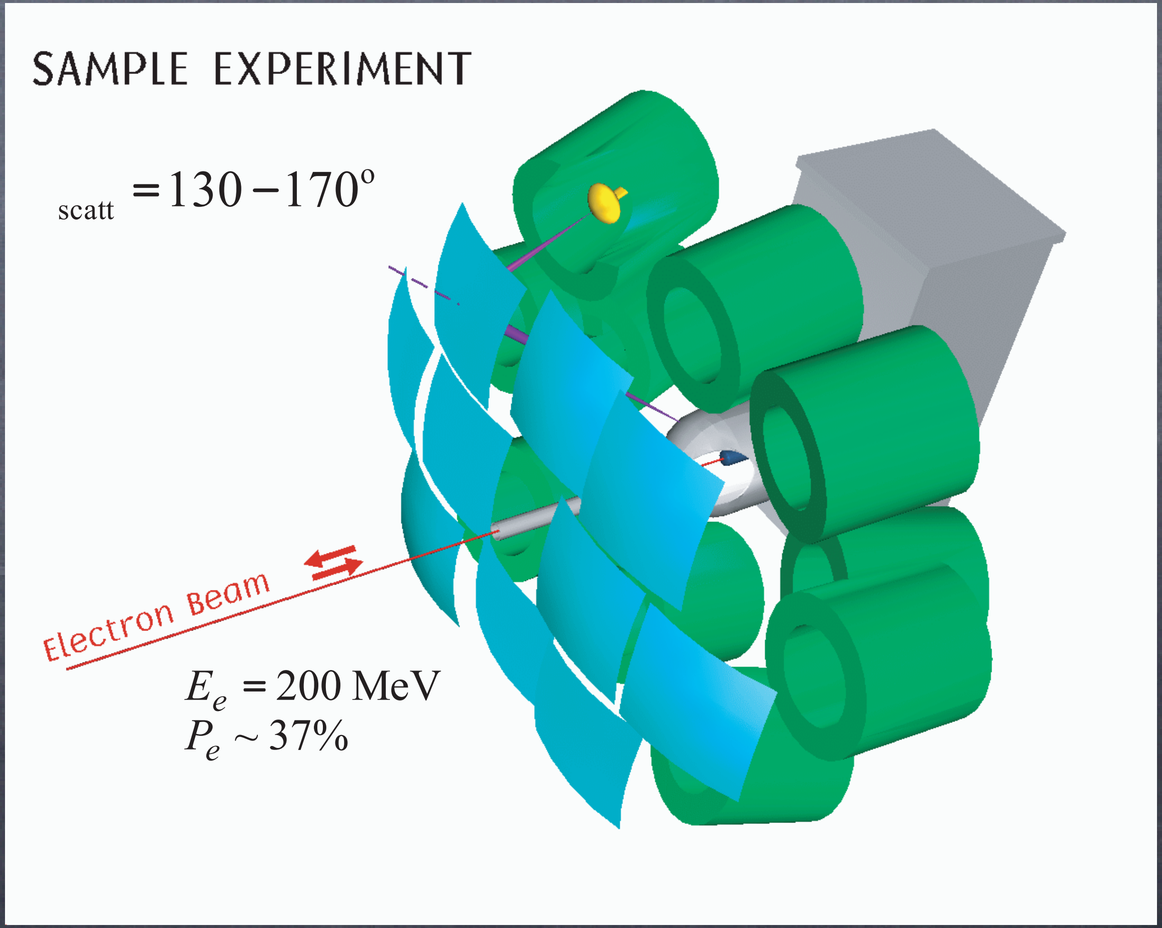
high luminosity, high count rates

inelastic scattering

Experiments

Asymmetries: 10^{-6} -> 10^{14} events
high luminosity, high count rates
inelastic scattering

SAMPLE
MIT/Bates
Air Cherenkov
Integrating
No Magnet
Backward



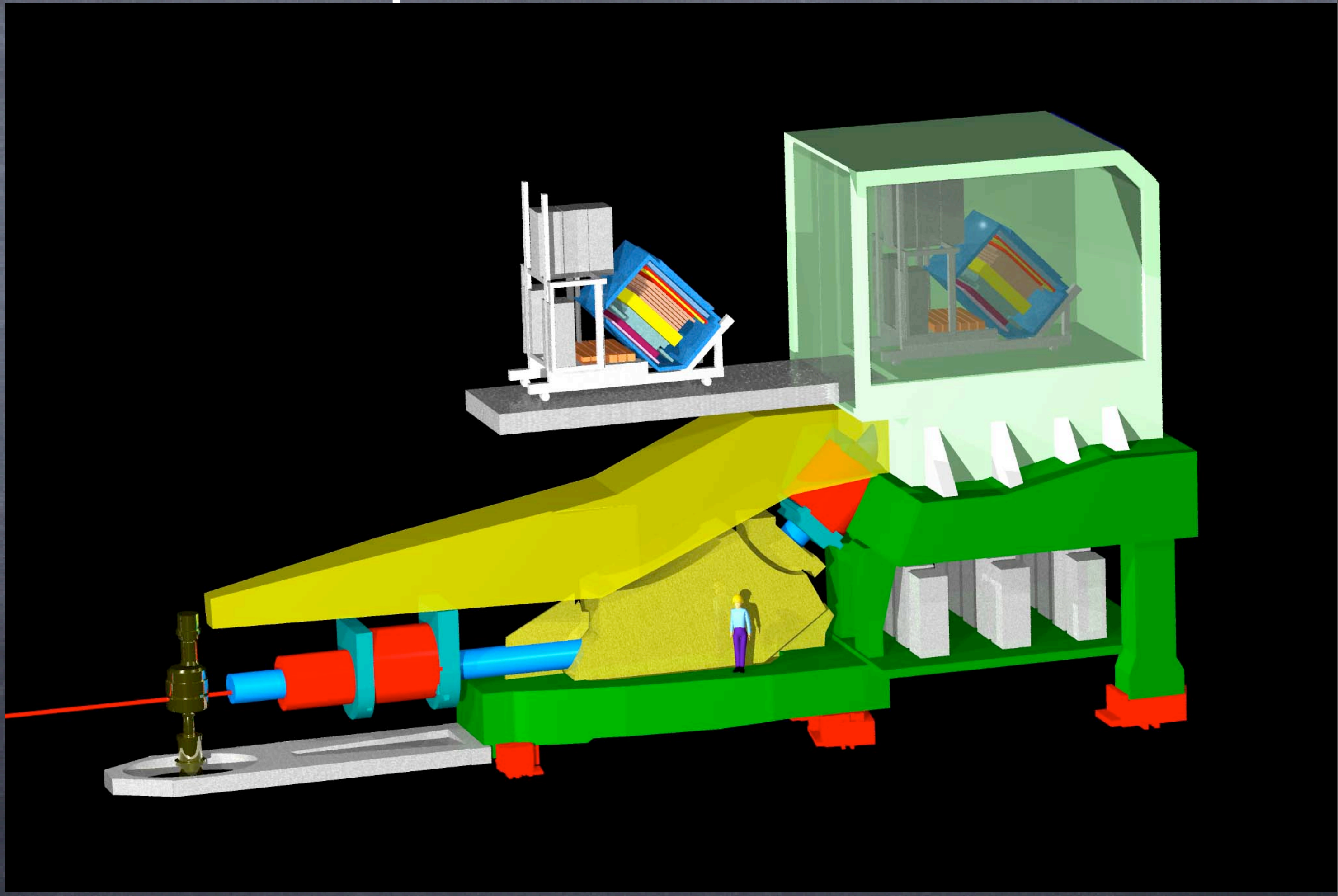
Experiments

Asymmetries: 10^{-6} -> 10^{14} events

high luminosity, high count rates

inelastic scattering

HAPPEX
Hall A,
Jefferson Lab
Magnetic
Spectrometer
Integrating
Forward

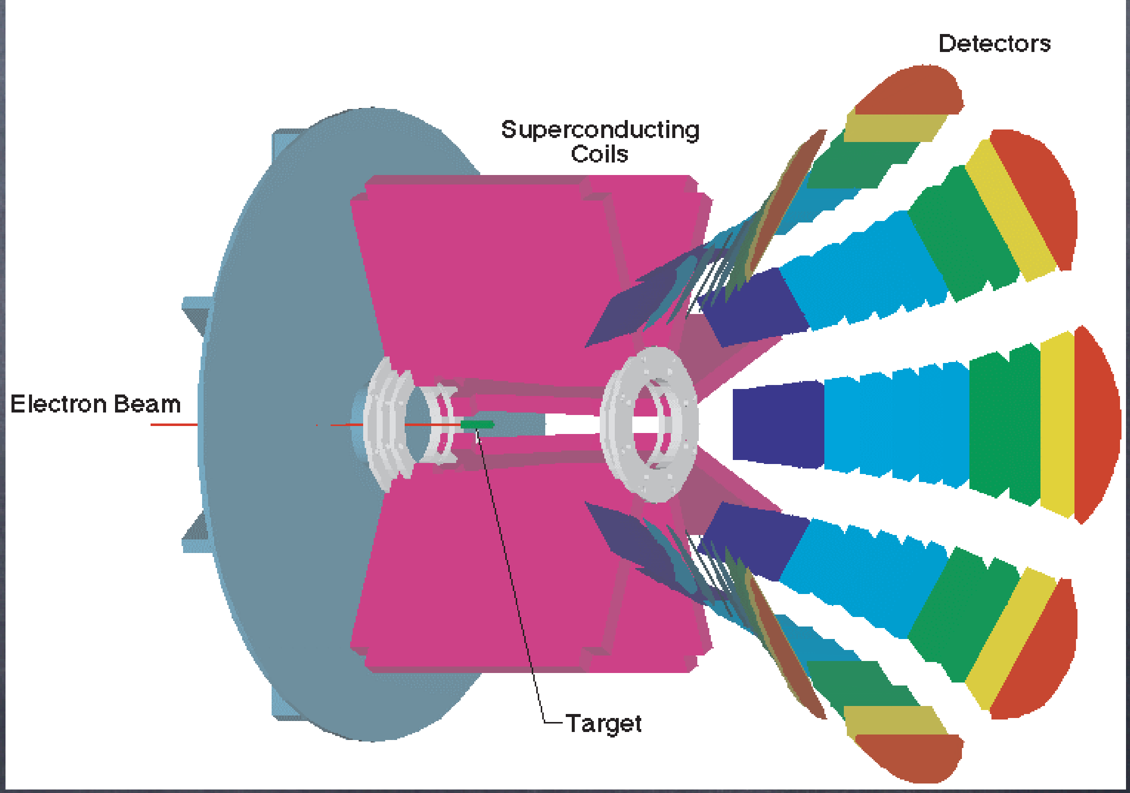


Experiments

Asymmetries: 10^{-6} -> 10^{14} events
high luminosity, high count rates
inelastic scattering

G0
HALL C
Jefferson Lab
Toroidal magnetic
Spectrometer
Forward
Backward
Counting
ToF

G_E^s , G_M^s and G_A^e separated
over range $Q^2 \sim 0.1 \quad 1.0\,(\mathrm{GeV/c})^2$

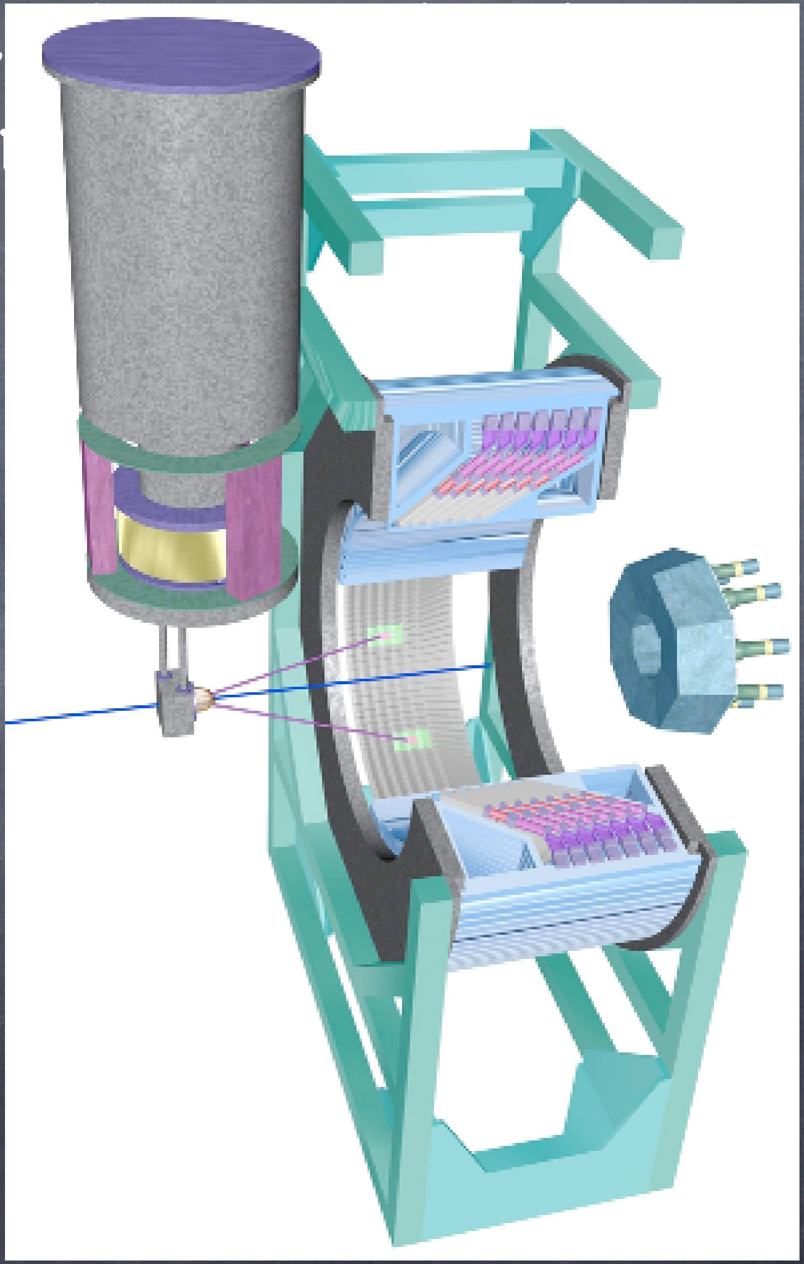


Experiments

Asymmetries: 10^{-6} -> 10^{14} events

high luminosity,

inelastic scatte



A4

MAMI (Mainz)

Electromagnetic

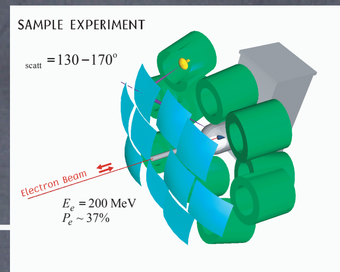
Calorimeter

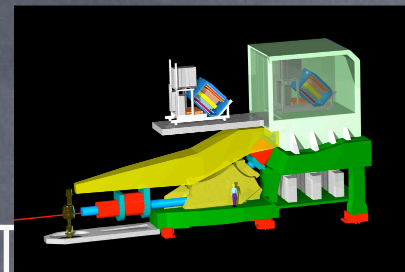
Counting

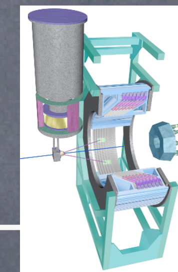
Forward

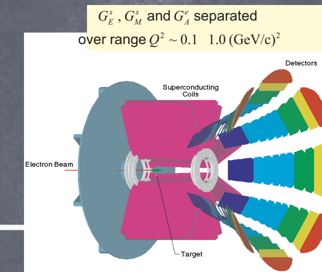
Backward

PV Experiments



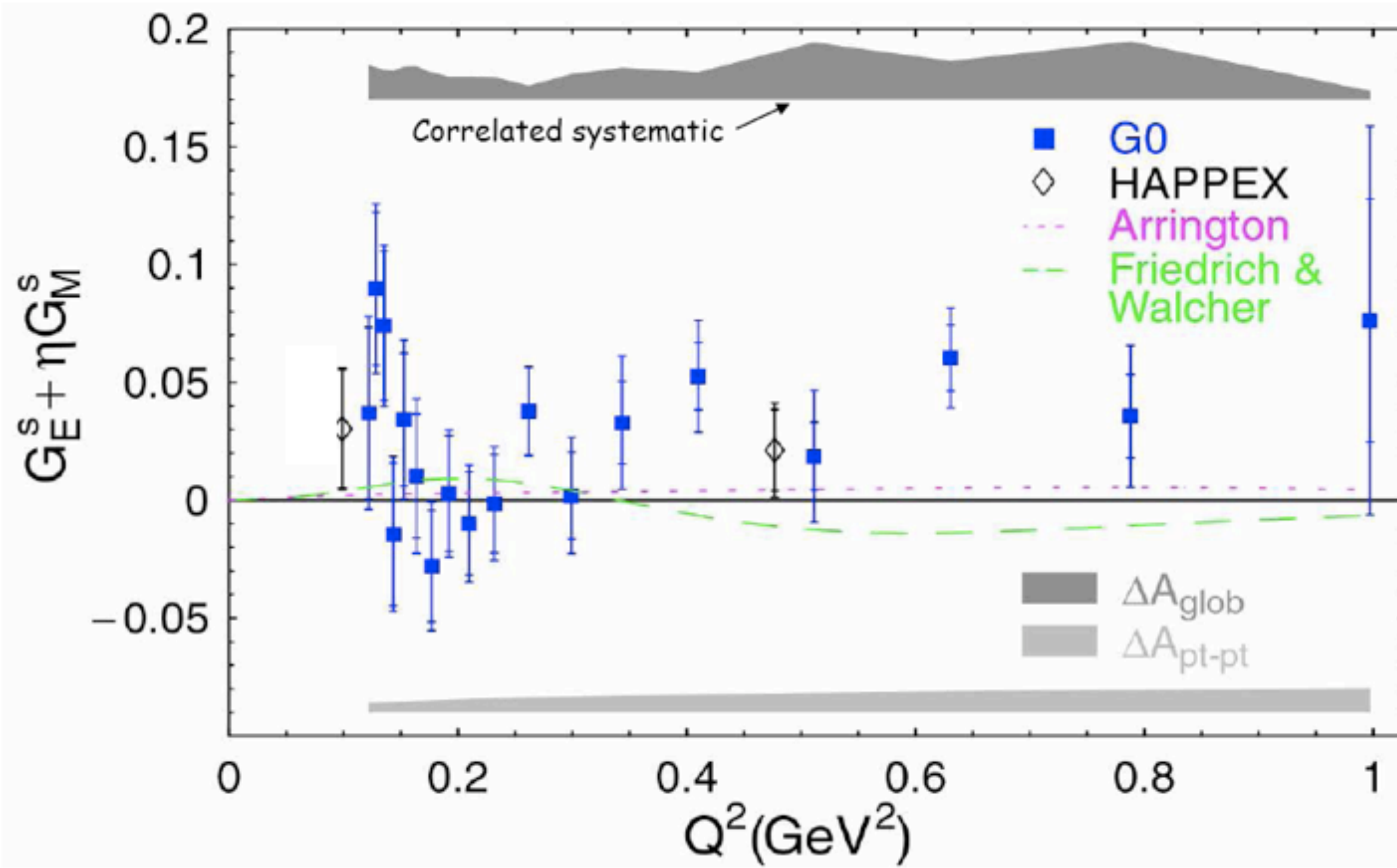






	SAMPLE (MIT Bates)	HAPPEX (CEBAF, JLab)	A4 (MAMI)	G^0 (CEBAF, JLab)
Q^2 [GeV^2/c^2]	0.04, 0.1	0.1, 0.48, (0.63)	0.1, 0.23, (0.48) (0.23 fw)	0.1, ... 1,0 0.23, 0.63
Angle	B	F	F, B	F, B
Target	H, D	H, He	H, D	H, D
Separation	G_M^s, G_A	G_E^s, G_M^s	G_E^s, G_M^s, G_A	G_E^s, G_M^s, G_A

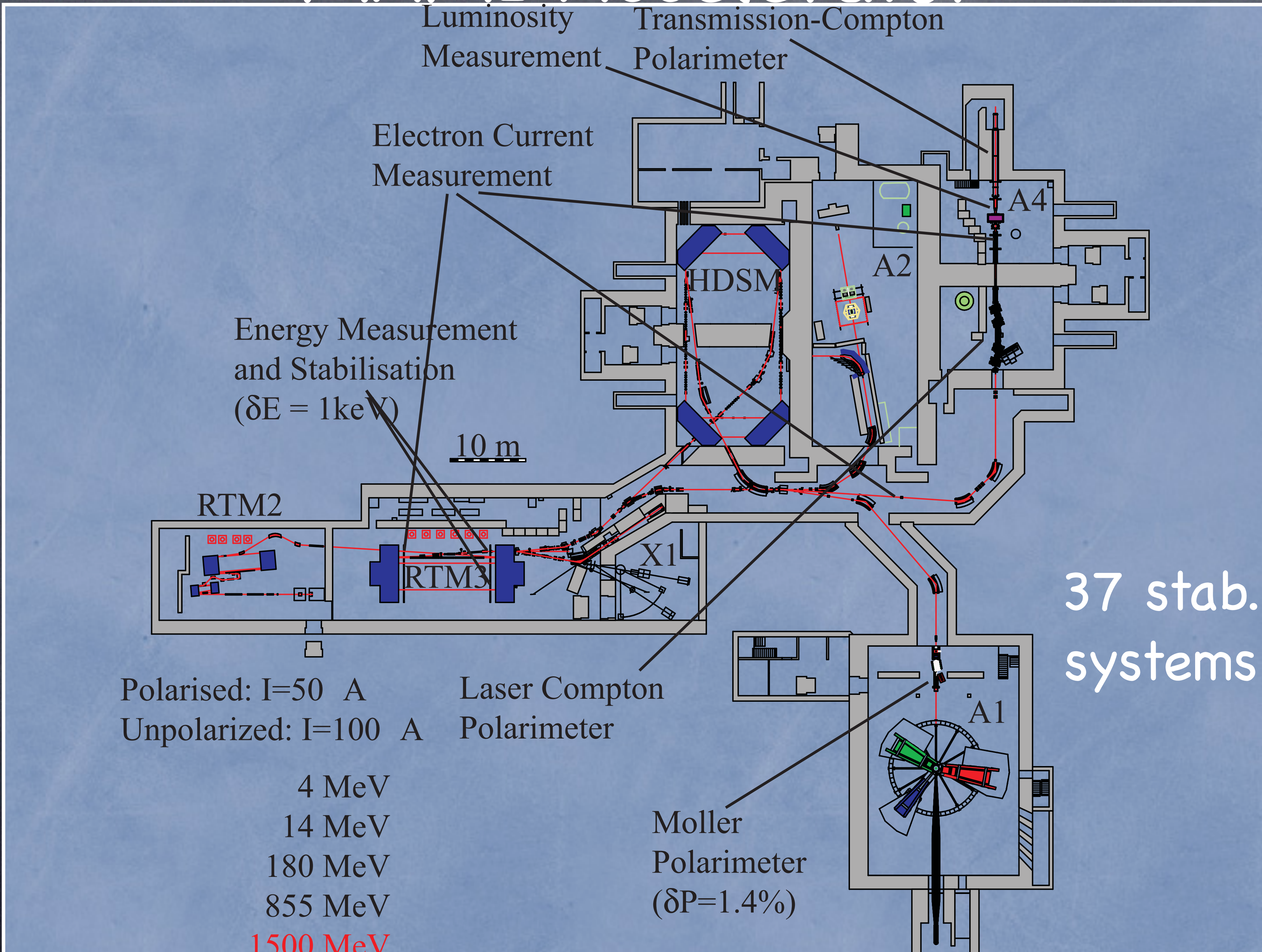
G0: Forward-angle results



$G_E^s = G_M^s = 0$ Hypothesis excluded at 89% C.L.

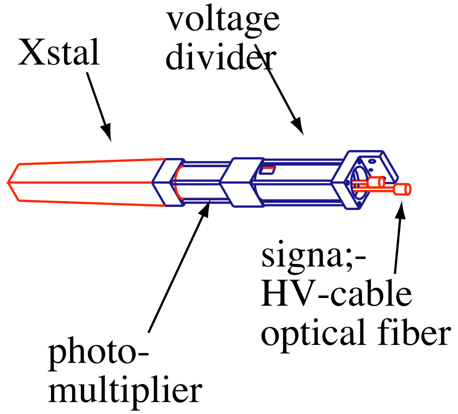
D.S. Armstrong *et al.*, PRL 95, 092001 (2005)

MAMI Accelerator

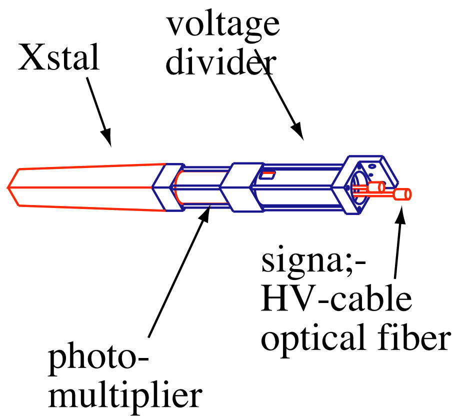


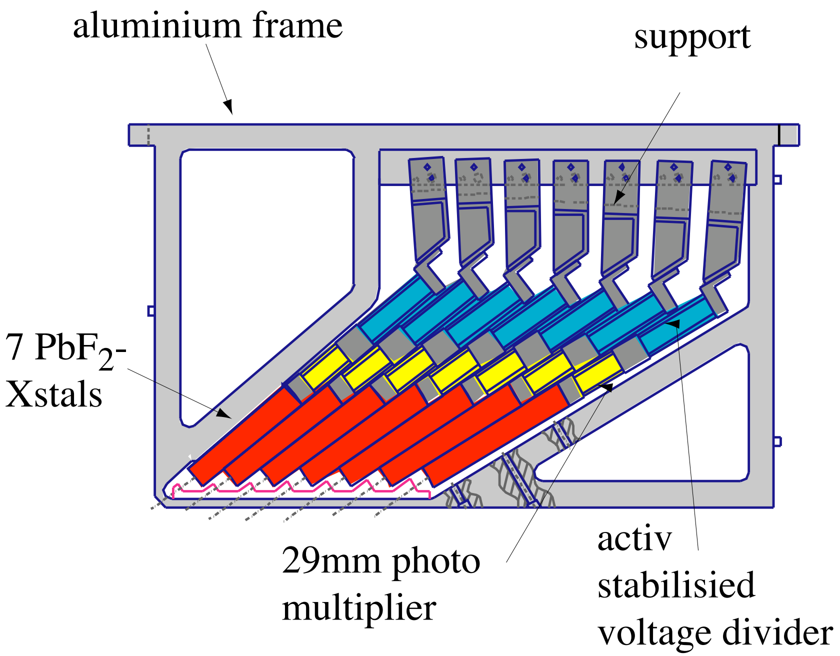
37 stab.
systems

Fast PbF_2 Calorimeter



Fast PbF_2 Calorimeter





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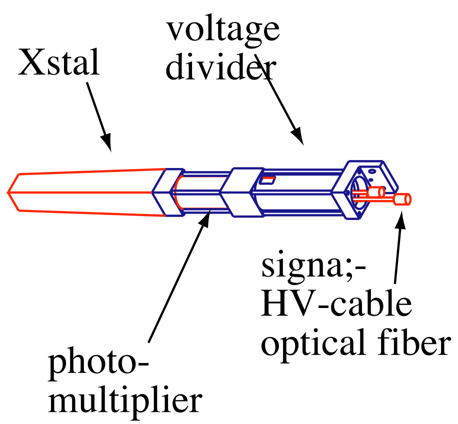
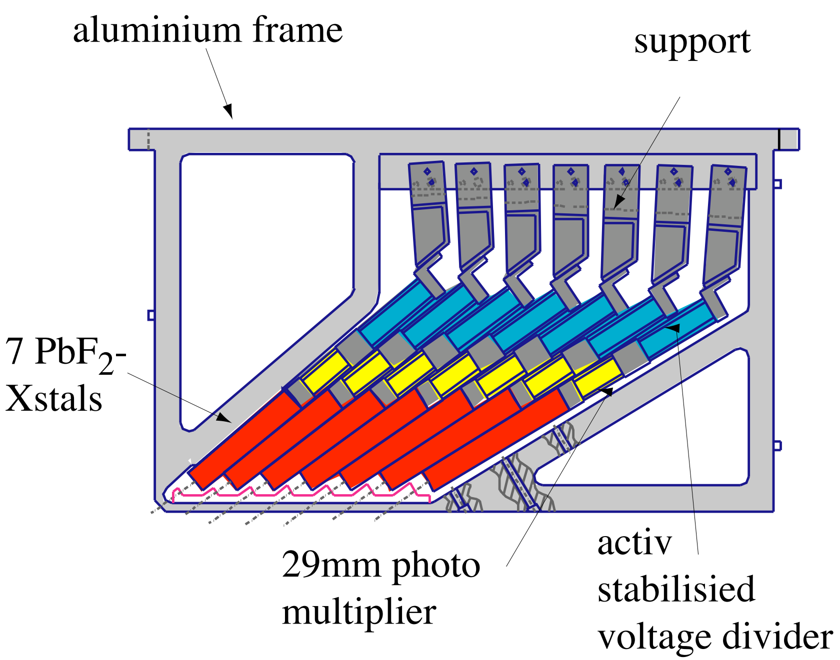
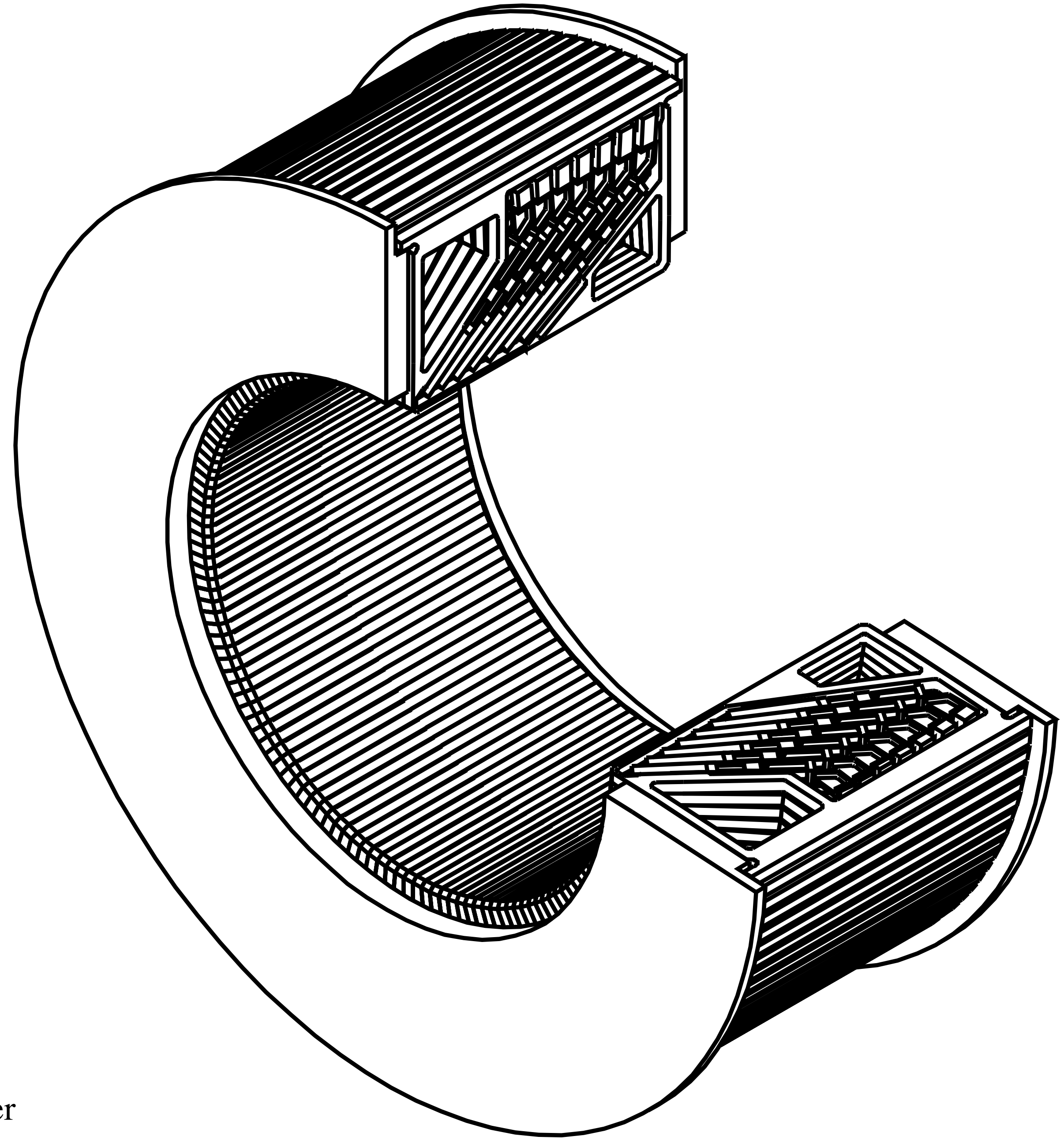
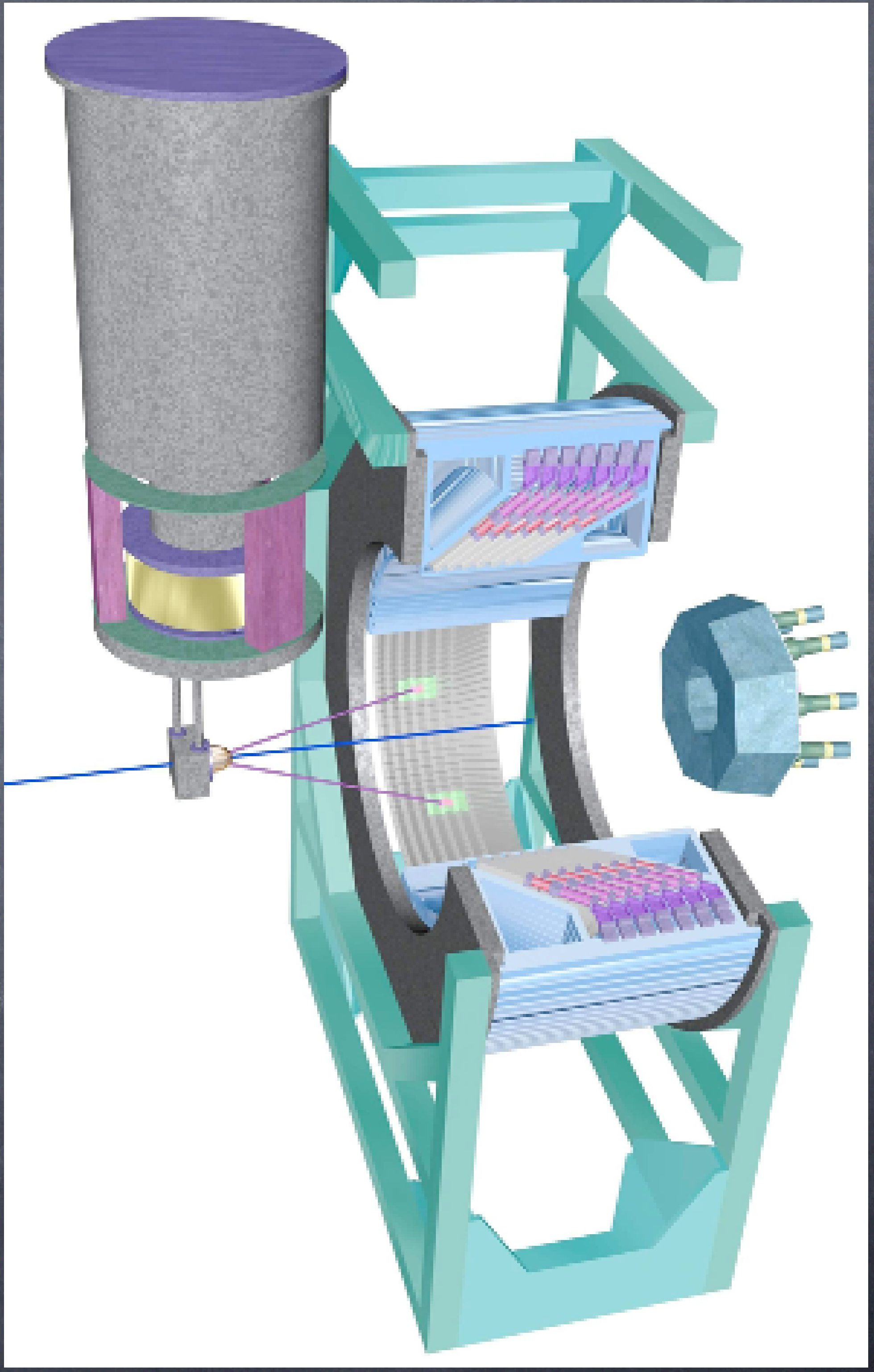
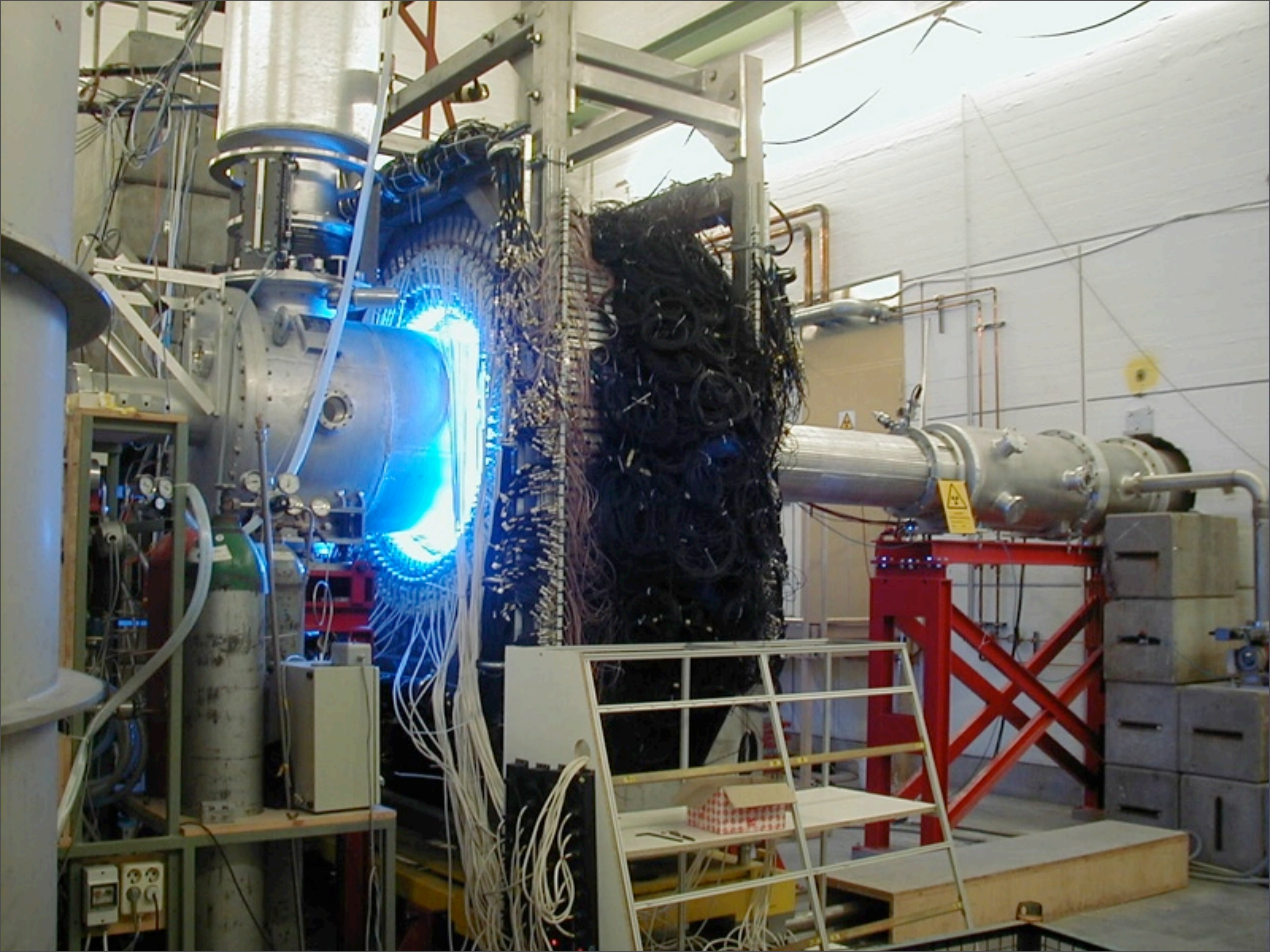




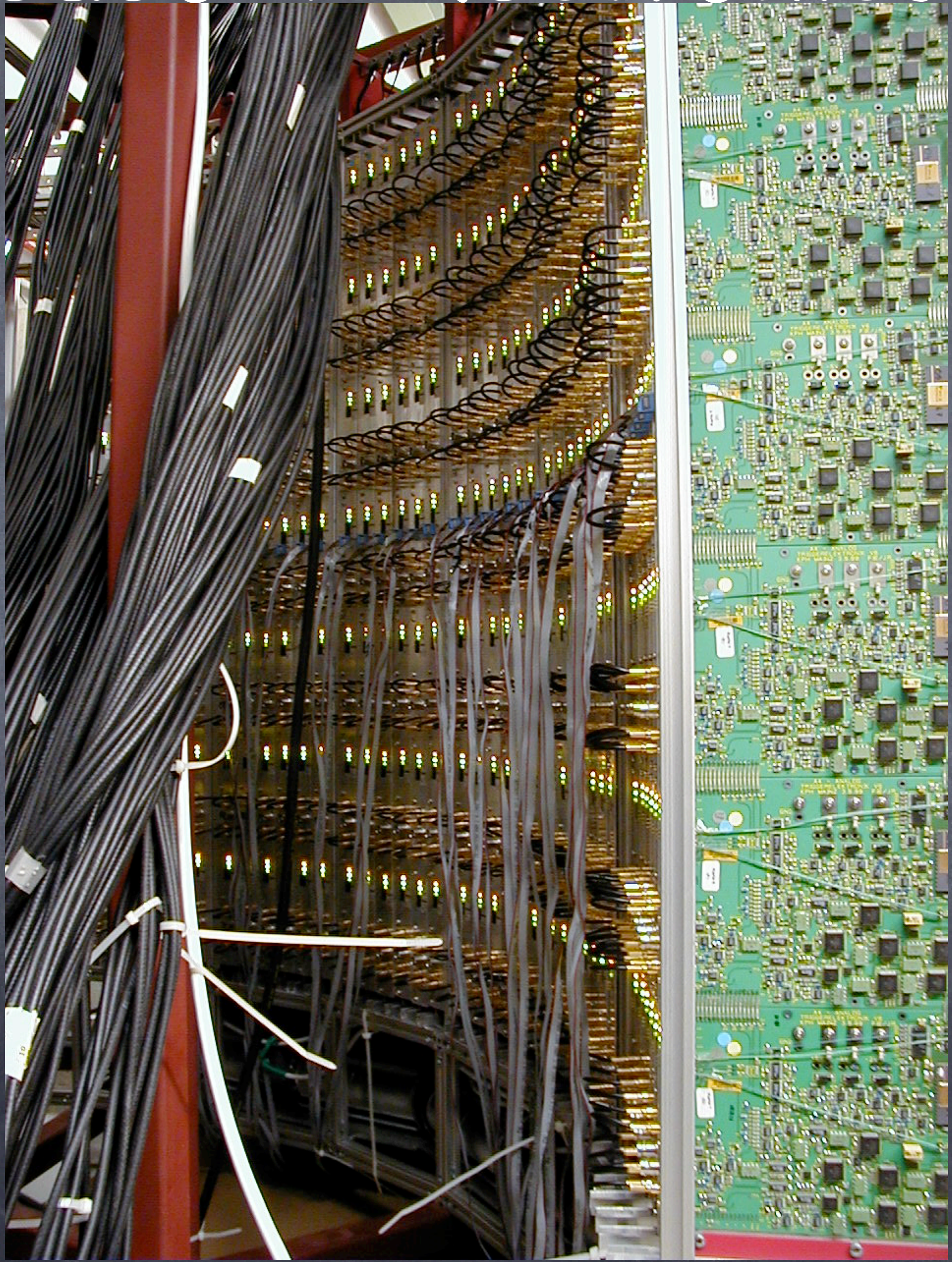


A4: Fast PbF_2 Calorimeter





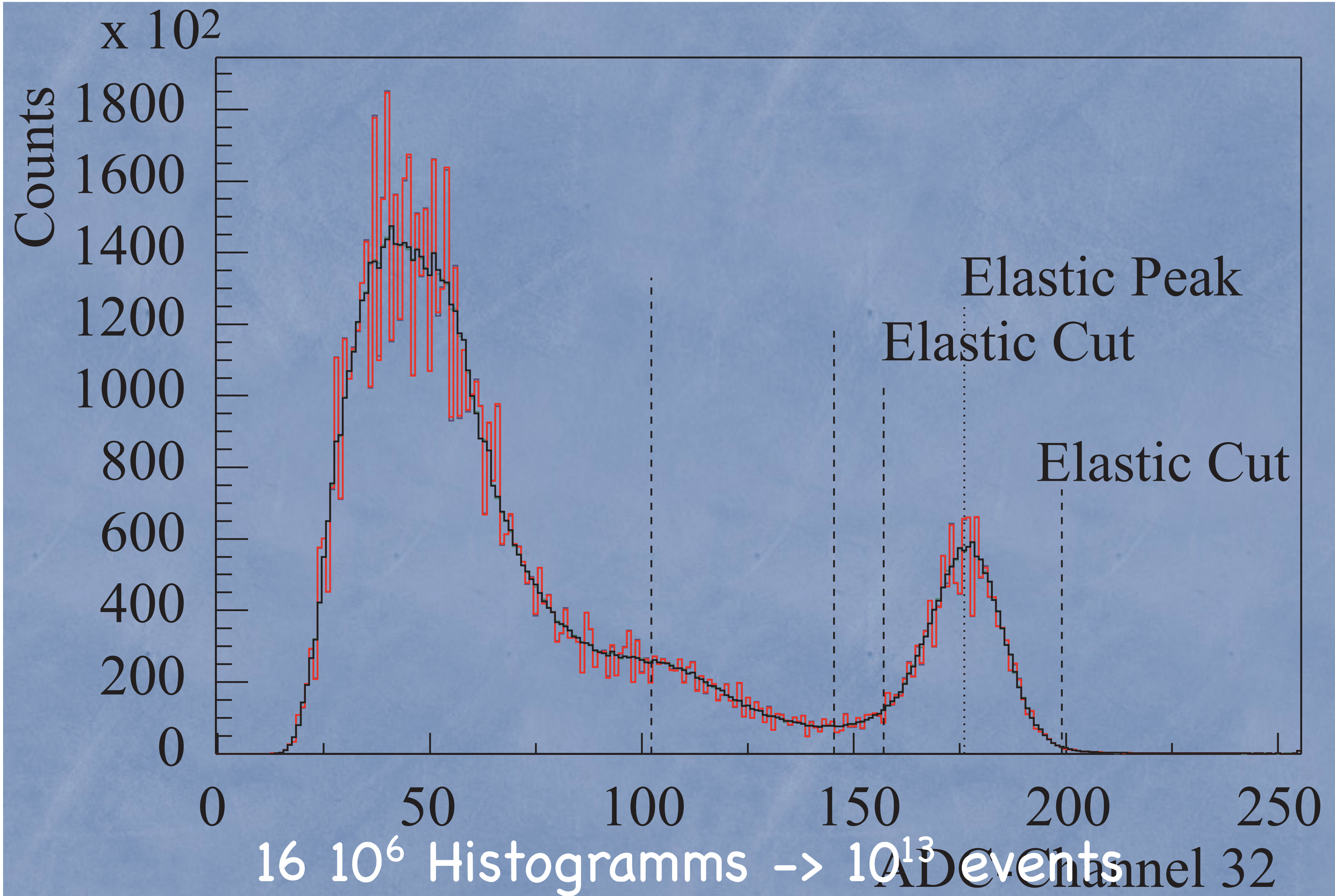
Readout Electronics



Readout Electronics

Readout Electronics

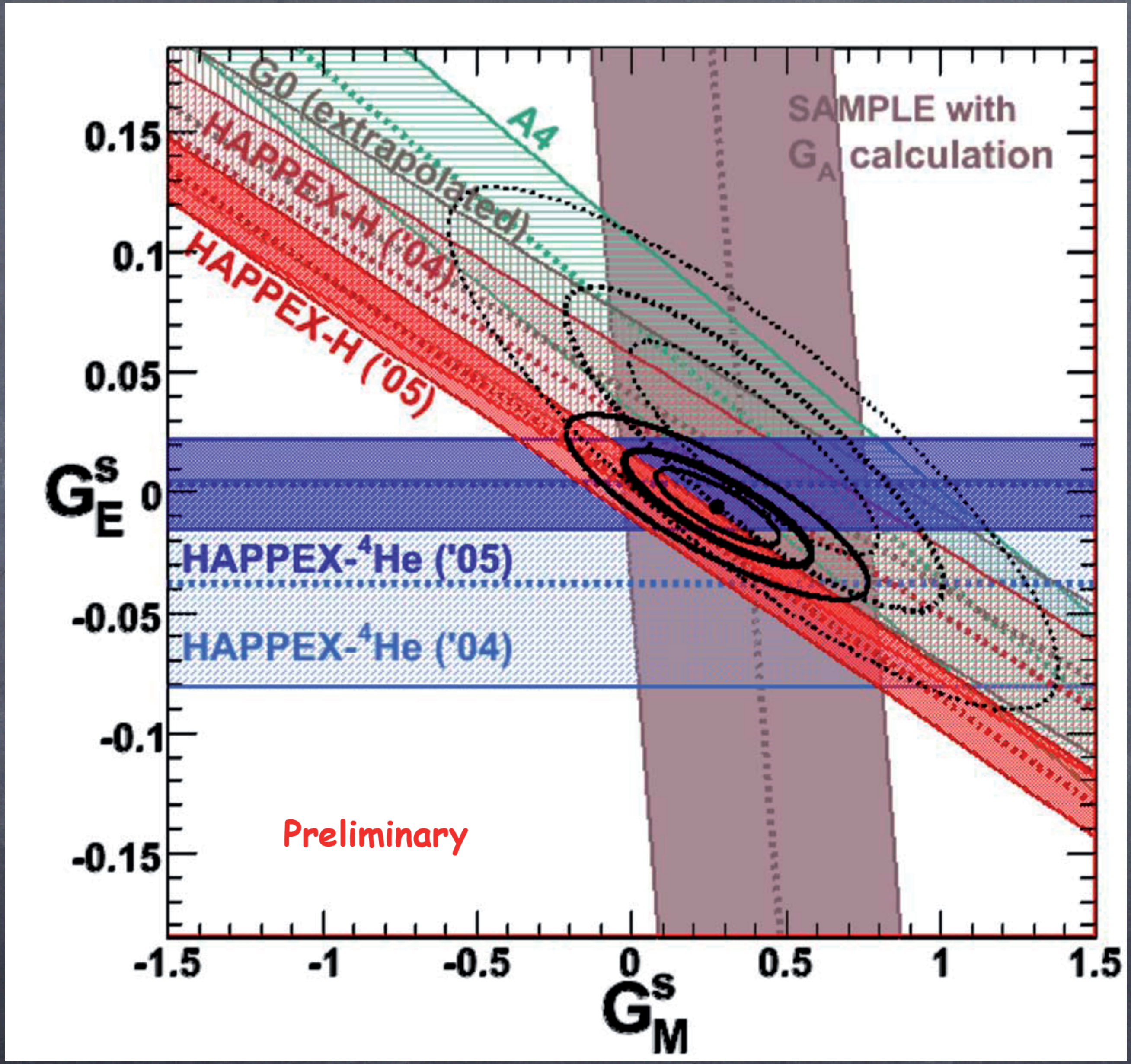
Detector Data



16 10^6 Histogramms -> 10^{13} events

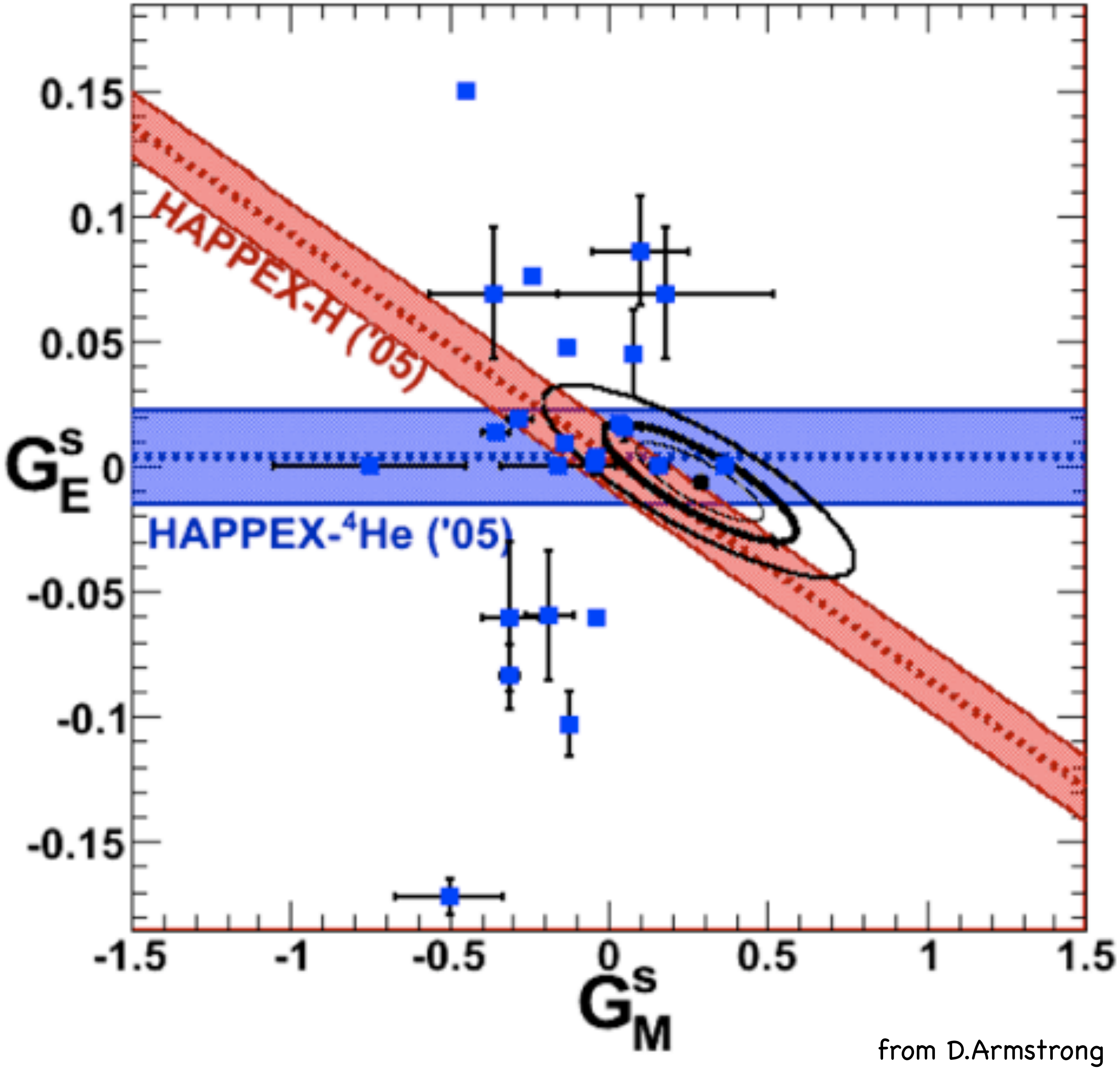
Filtering

World Data at 0.1 (GeV/c)^2



$G_M^s = 0.28 \pm 0.20$ $\quad$ $G_E^s = -0.006 \pm 0.016$

World Data near Q^2 ~0.1 GeV^2



from D.Armstrong

$$G_M^s = 0.28 \pm 0.20$$

21% of $\mu_N^{T=0}$

$$\langle r^2 \rangle_E^p = 0.766 \pm 0.012\, fm^2$$

$$\langle r^2 \rangle_E^s = 0.002 \pm 0.015\, fm^2$$

Lattice: Leinweber et al.

$$G_M^s = -0.046 \pm 0.022$$

$$G_E^s = +0.001 \pm 0.006$$

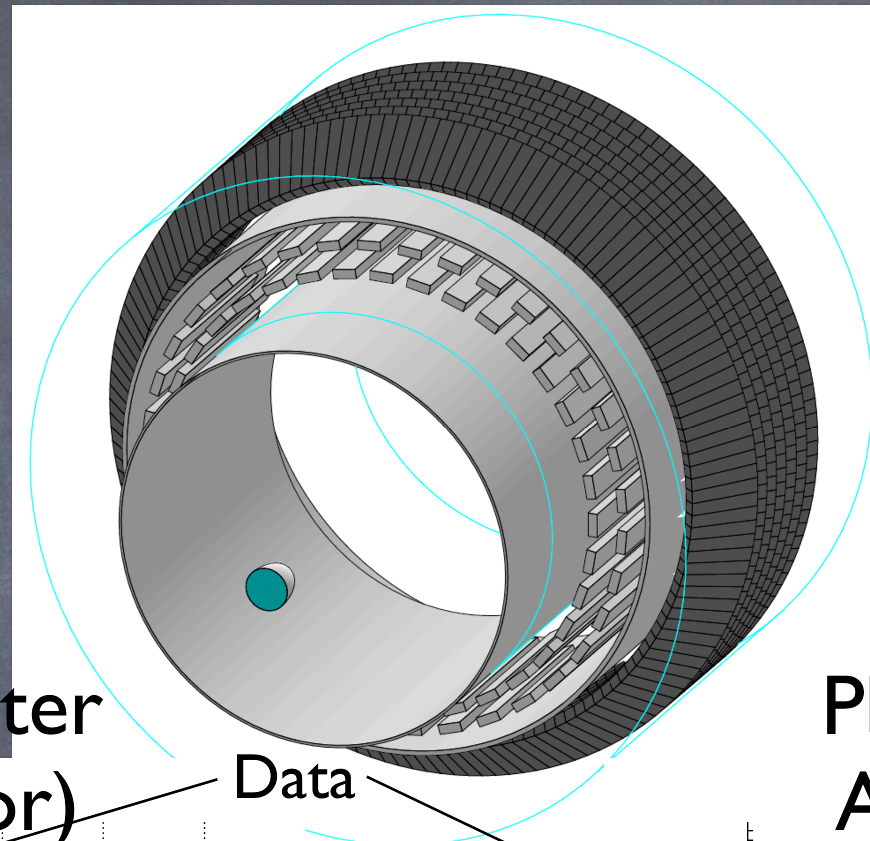
A4-Backward Angle

A4-Backward Angle

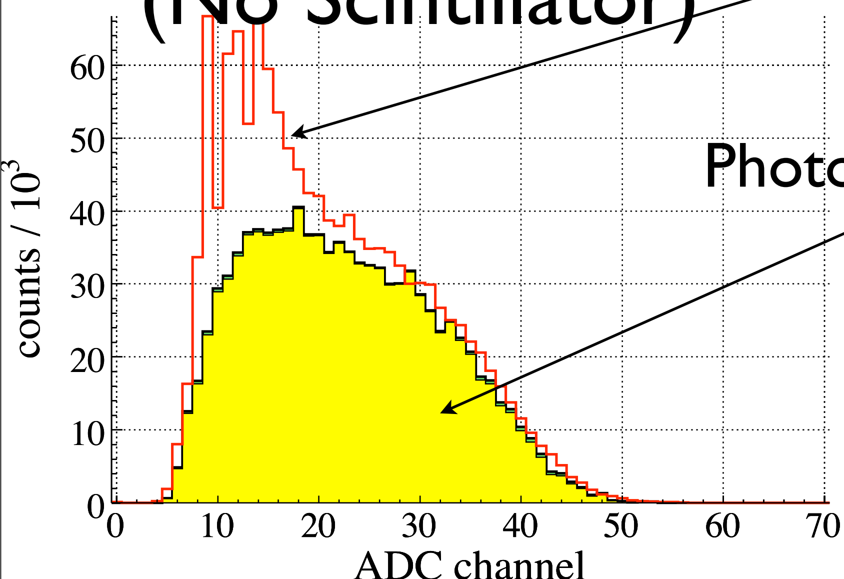
Zur Anzeige wird der QuickTime™
Dekompressor „“
benötigt.

Q^2=0.23 (GeV/c)^2
backward

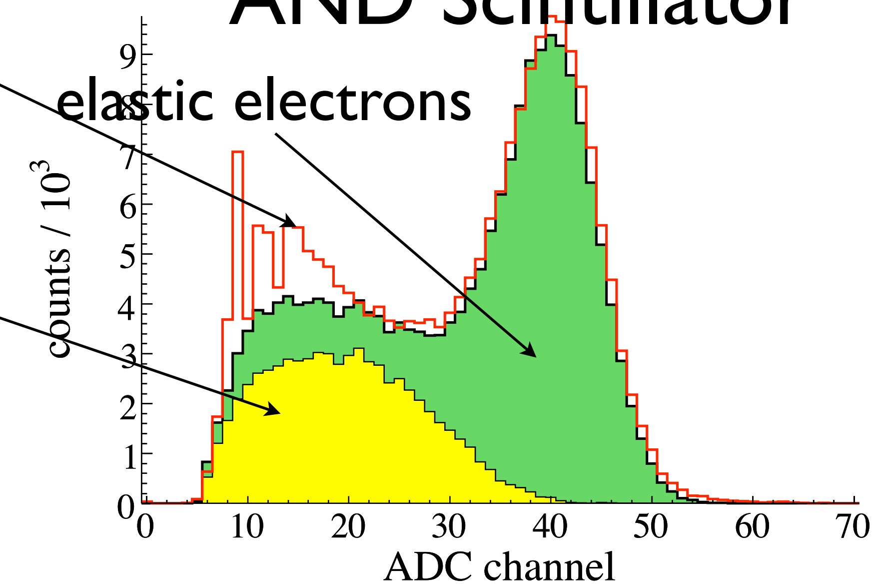
Data and Simulations



PbF$_2$-Calorimeter
(No Scintillator)



PbF$_2$-Calorimeter
AND Scintillator



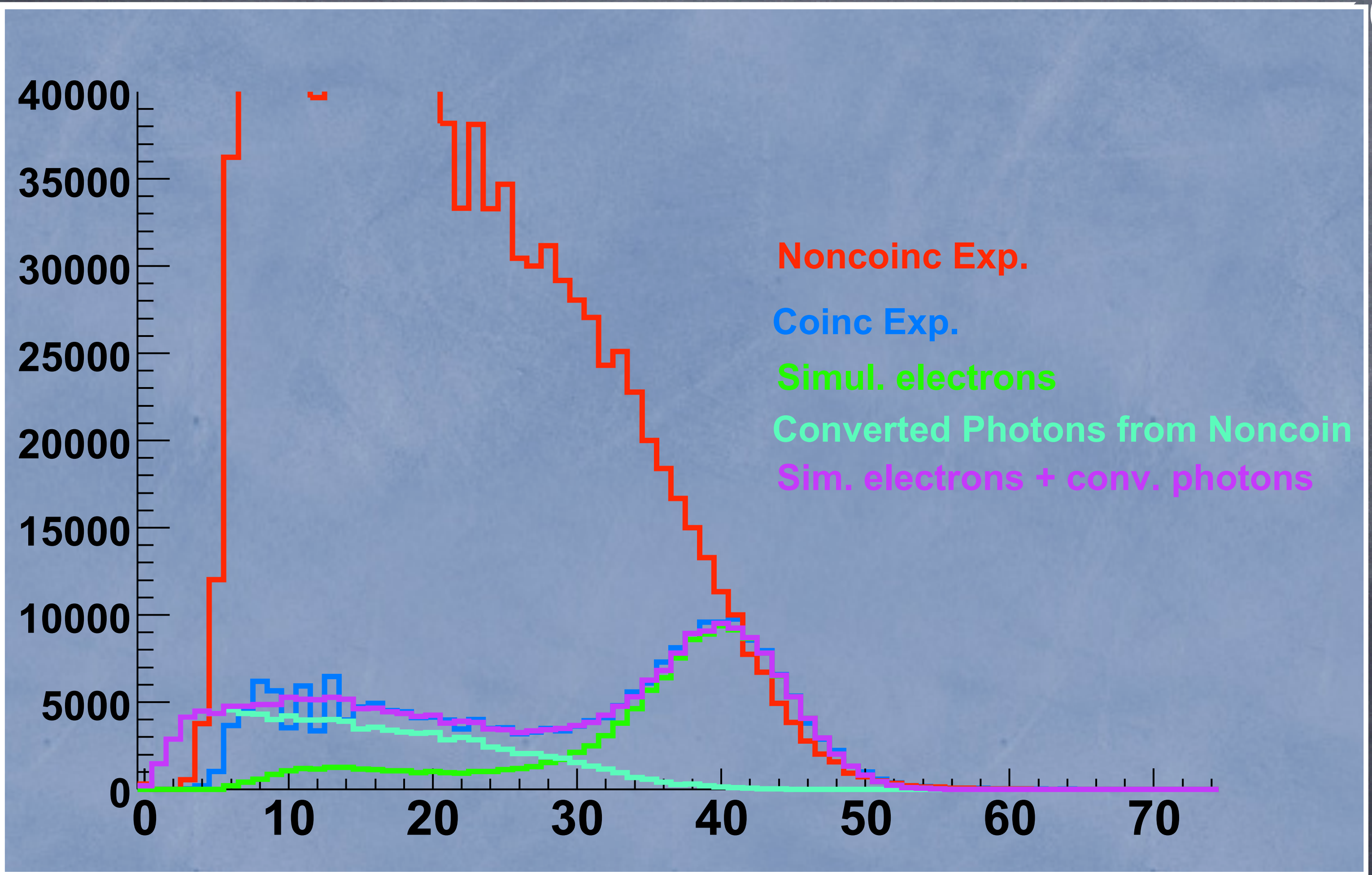
Q^2=0.23 $(GeV/c)^2$ backward

About 1050h of data

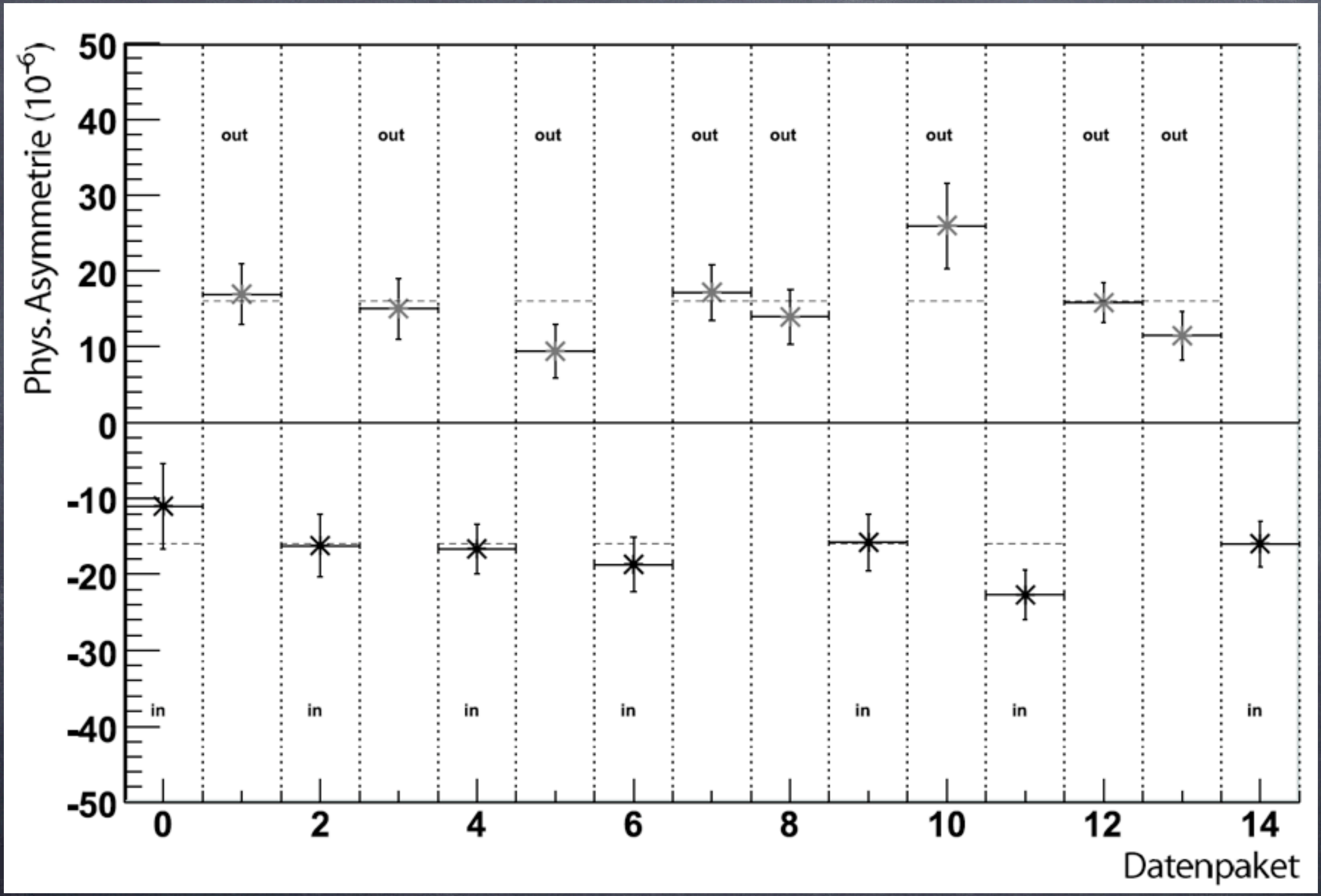
$N_{elastic}$=2.1×10^{12}

A_{coinc}= (-16.22 ± 1.15)ppm

(± 0.93stat ± 0.67sys)

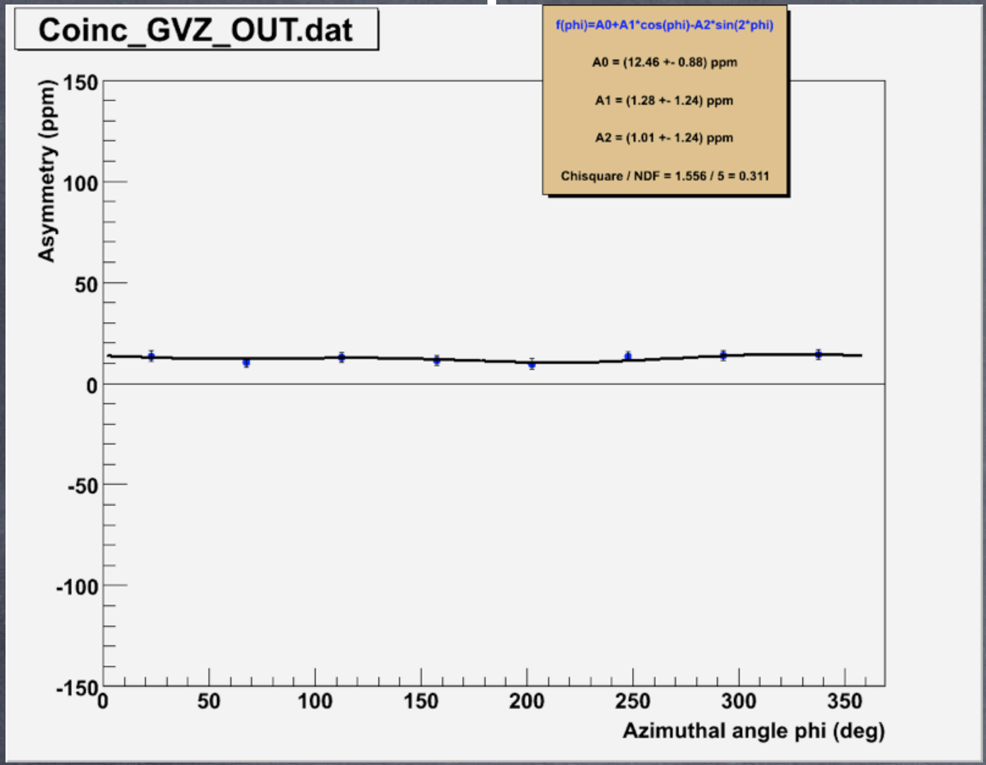


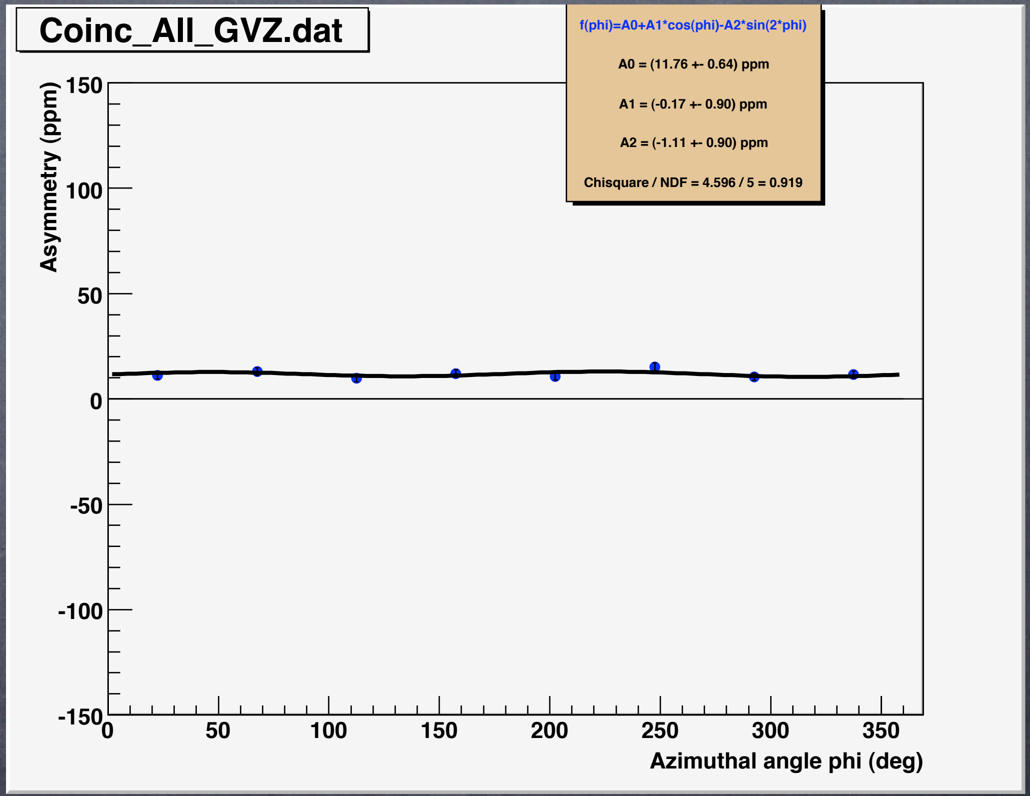
Q^2=0.23 $(GeV/c)^2$ backward



About 1100h of stored data (2000h real time)

A4-Data, proton, backward angle, signal



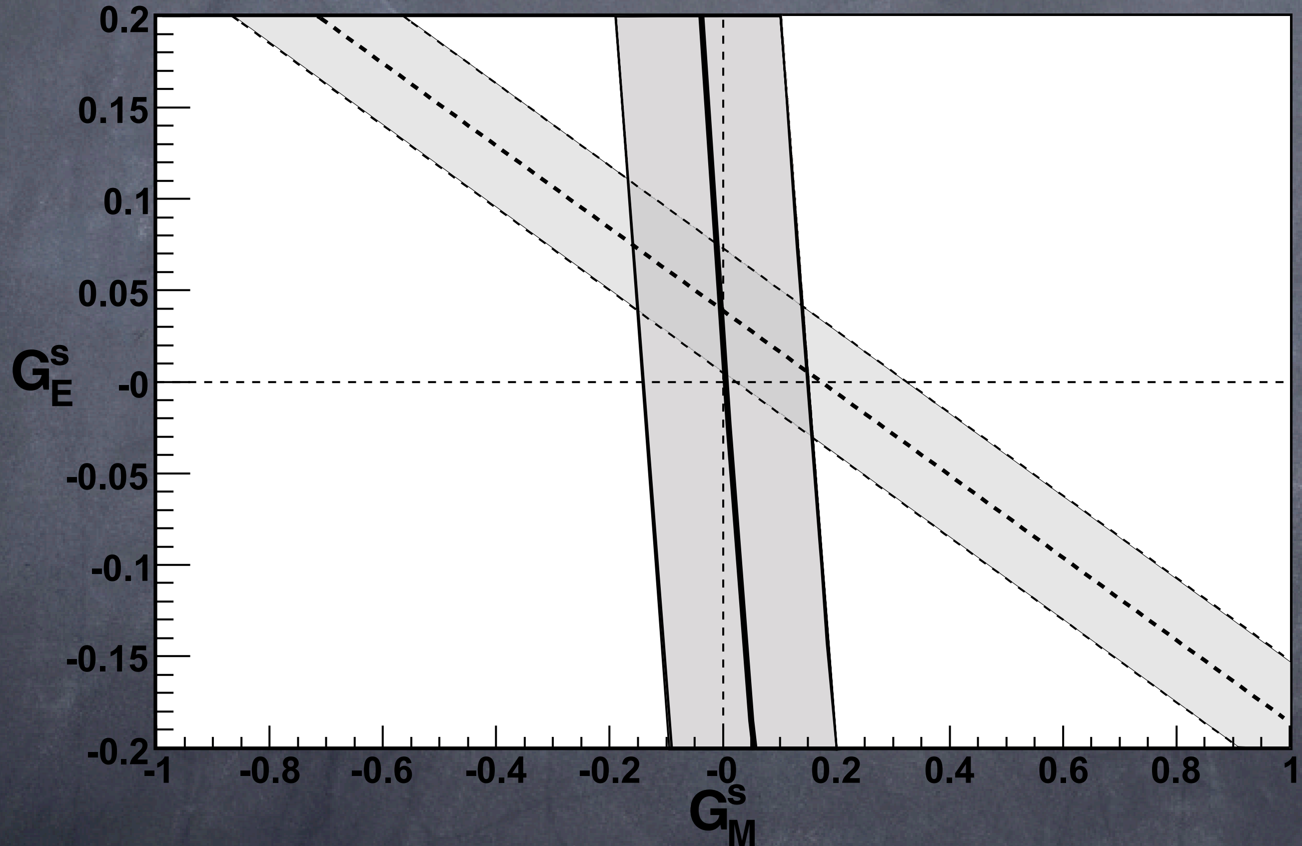


signal, preliminary

Q^2=0.23 $(GeV/c)^2$ backward

APV=($-16.23 \pm 0.96_{stat} \pm 0.75_{syst}$) 10^{-6}

GsM + 0.25 GsE = 0.004 +- 0.146

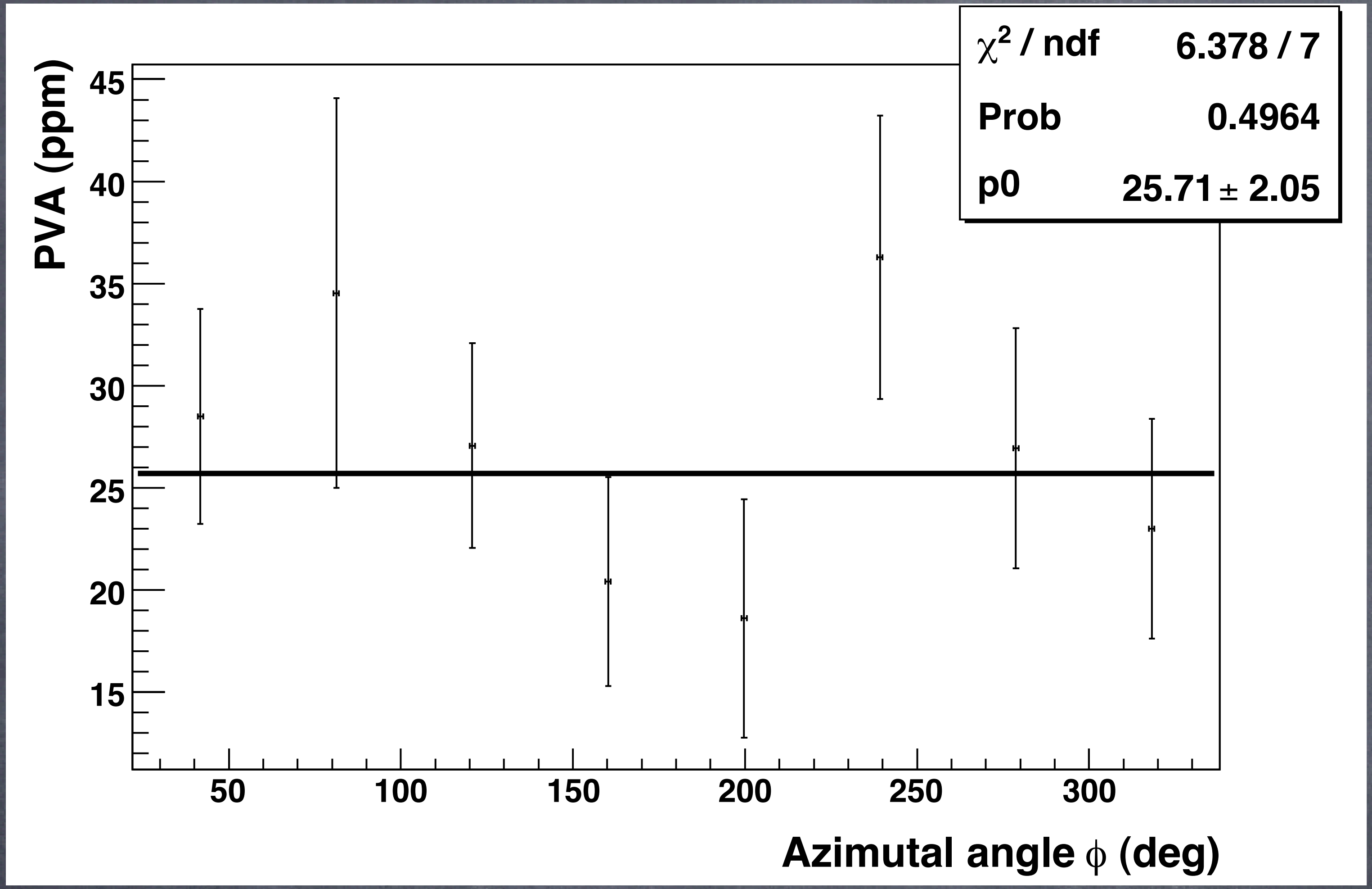


preliminary

GsM = −0.01 +- 0.15

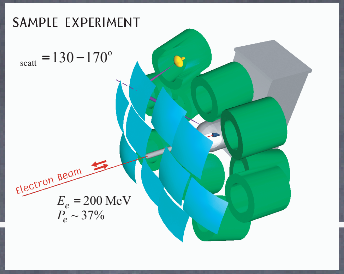
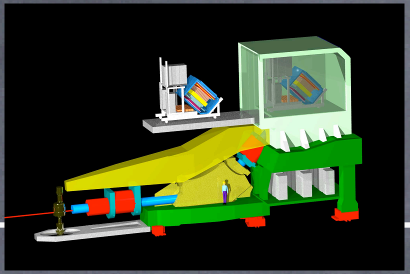
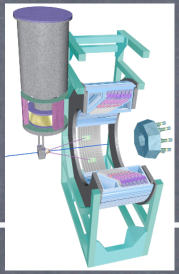
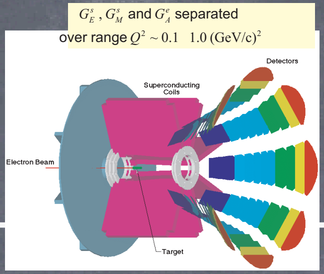
GsE = 0.034 +- 0.050

A4-Data, deuterium, backward angle



signal preliminary

PV Experiments

	 SAMPLE (MIT Bates)	 HAPPEX (CEBAF, JLab)	 A4 (MAMI)	 G^0 (CEBAF, JLab)
Q^2 [GeV^2/c^2]	0.04, 0.1	0.1, 0.48, (0.63)	0.1, 0.23 (0.23 fw)	0.1, ... 1,0 0.23, 0.63
Angle	B	F	F, B	F, B
Target	H, D	H, He	H, D	H, D
Separation	G_M^s, G_A	G_E^s, G_M^s	G_E^s, G_M^s, G_A	G_E^s, G_M^s, G_A

Summary

- Perturbative QCD
- PV e(p, p′)e′: Strangeness Vector Form Factors

    A4: Fast (100 Mhz) EM Calorimeter

    Situation on Strangeness,

    world data:

    $Q^2 = 0.10\ (GeV/c)^2$: $G_M^s = 0.28 \pm 0.20$ $G_E^s = -0.006 \pm 0.016$

    A4:

    $Q^2 = 0.23\ (GeV/c)^2$: $G_M^s = -0.01 \pm 0.15$ $G_E^s = 0.034 \pm 0.050$

    preliminary!!

    Effect of Sea in nonpert. QCD

    Effect is small: Constituent s-quark suppressed

    Analysis of Backward Angles (0.23 GeV^2, deuterium)