Qweak: Measuring the Proton's Weak Charge

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JLab Users' Group 2007

- Parity violation in e-p scattering at $Q^2 = 0.028\ (GeV/c)^2$
  → the weak charge of the proton to 4%
  → $\sin^2\theta_W$ to 0.3%
- Sets a limit on new physics at an energy scale of ~ 2 TeV
- Constrains properties of a possible Z′

The Qweak Collaboration

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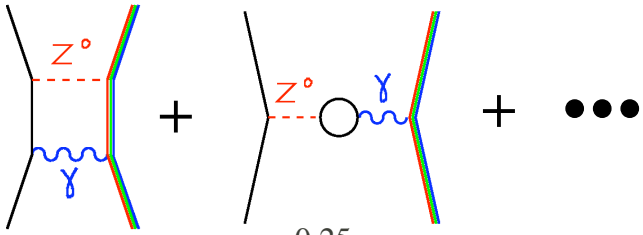
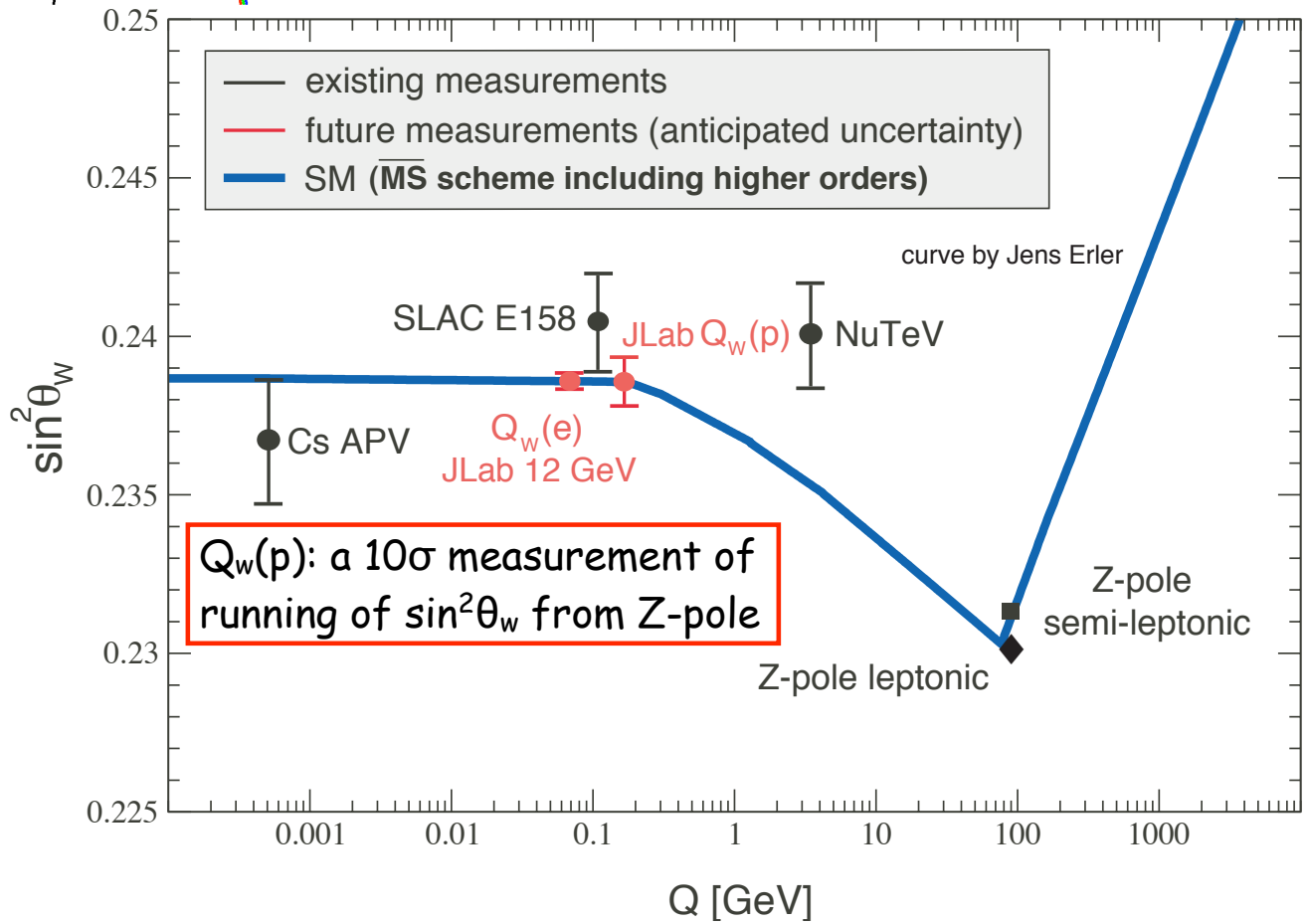
"Running of $\sin^2\theta_W$" in the Electroweak Standard Model

Radiative corrections cause $\sin^2\theta_W$ to change with Q :-



Any discrepancy of $\sin^2\theta_W$ with the standard model prediction indicates new physics.



Energy Scale of an Indirect Search for New Physics

quark weak charge

new physics

$$\mathcal{L}^{PV}_{e-q} = \mathcal{L}^{PV}_{SM} + \mathcal{L}^{PV}_{New}$$

$$= -\frac{G_F}{\sqrt{2}}\bar{e}\gamma_\mu\gamma_5 e \sum_q C_{1q}\bar{q}\gamma^\mu q + \frac{g^2}{4\Lambda^2}\bar{e}\gamma_\mu\gamma_5 e \sum_q h^q_V \bar{q}\gamma^\mu q$$

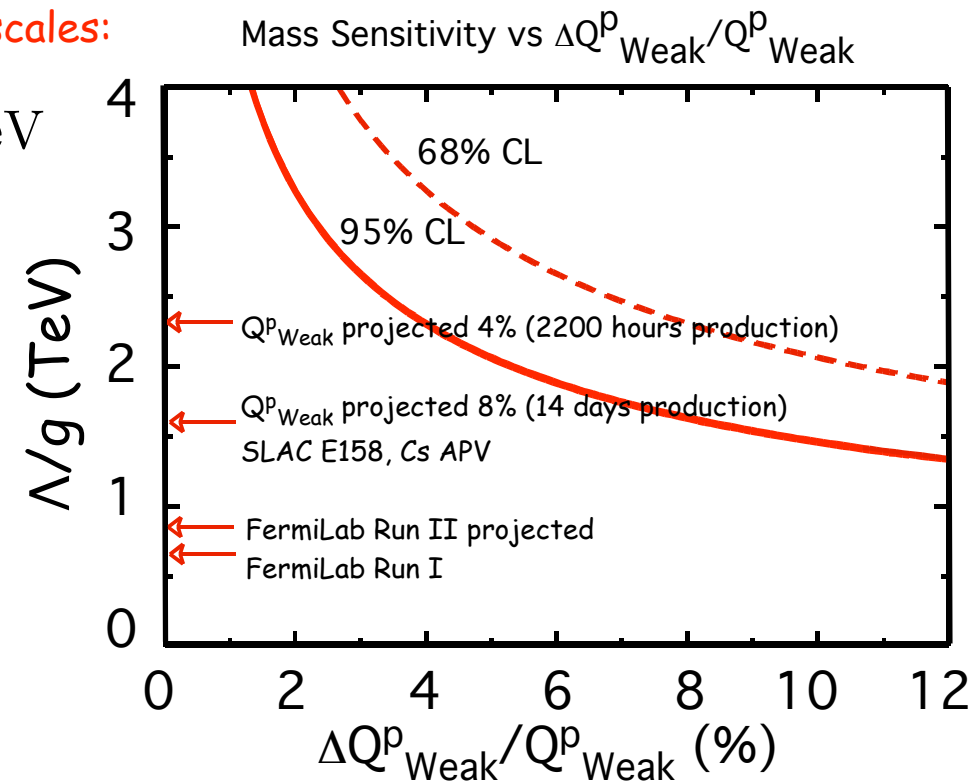
g = coupling constant, Λ = mass scale

A 4% measurement of Q^p_{weak} probes with 95% confidence for new physics at energy scales:

$$\frac{\Lambda}{g} \sim \frac{1}{2\sqrt{\sqrt{2}G_F|\Delta Q^p_W|}} \simeq 2.3 \text{ TeV}$$

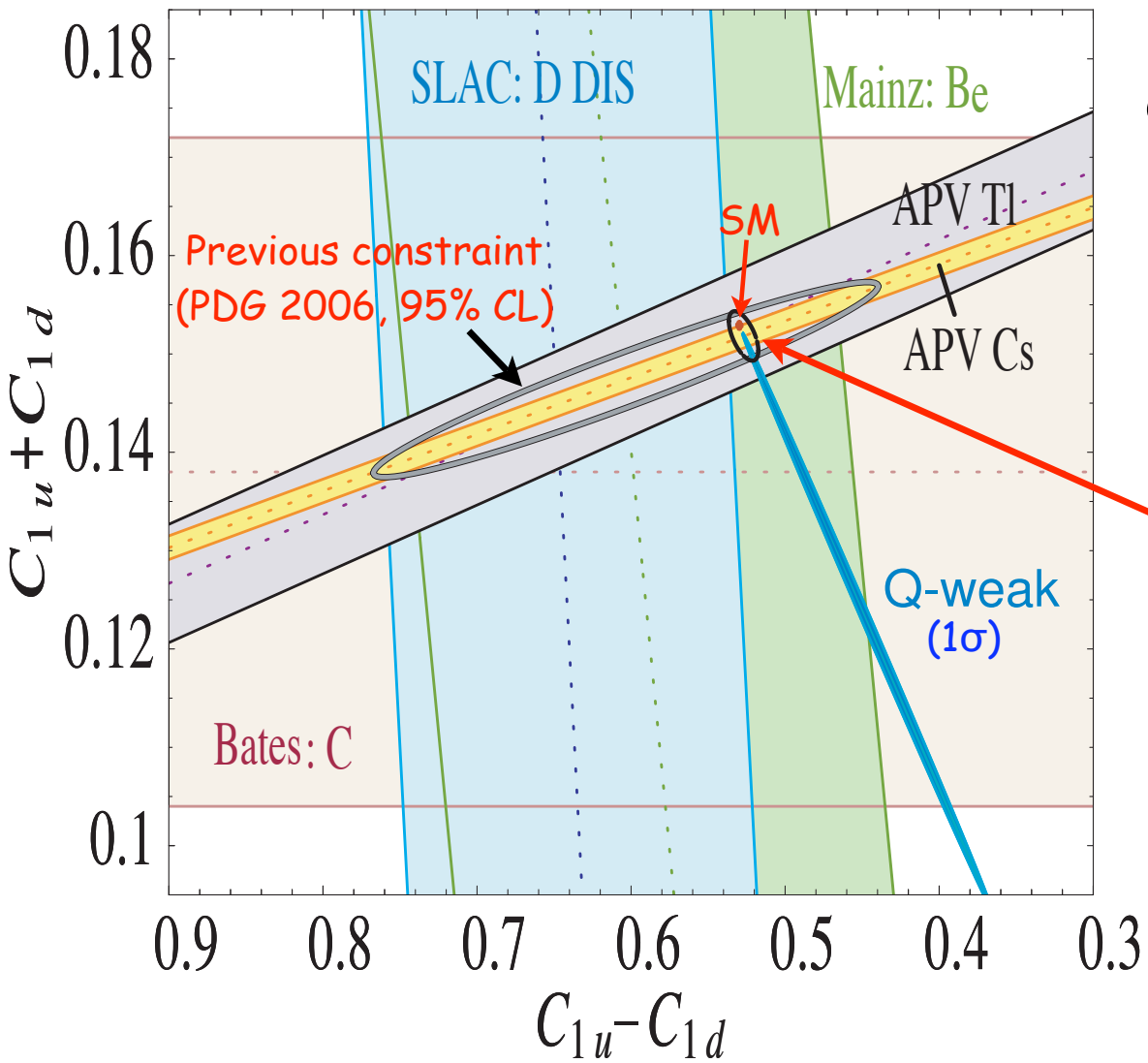
- **The TeV discovery potential of weak charge measurements will be unmatched until LHC turns on.**

- **If LHC uncovers new physics, then Qweak will constrain weak charges, coupling constants...**



Constraints on quark weak charges imposed by data

(Analysis by Ross Young, JLab)



$$Q_W^P = -2(2C_{1u} + C_{1d})$$

Full constraint at 95% confidence by combining all data plus future Qweak

New Physics Limits (assuming Standard Model)

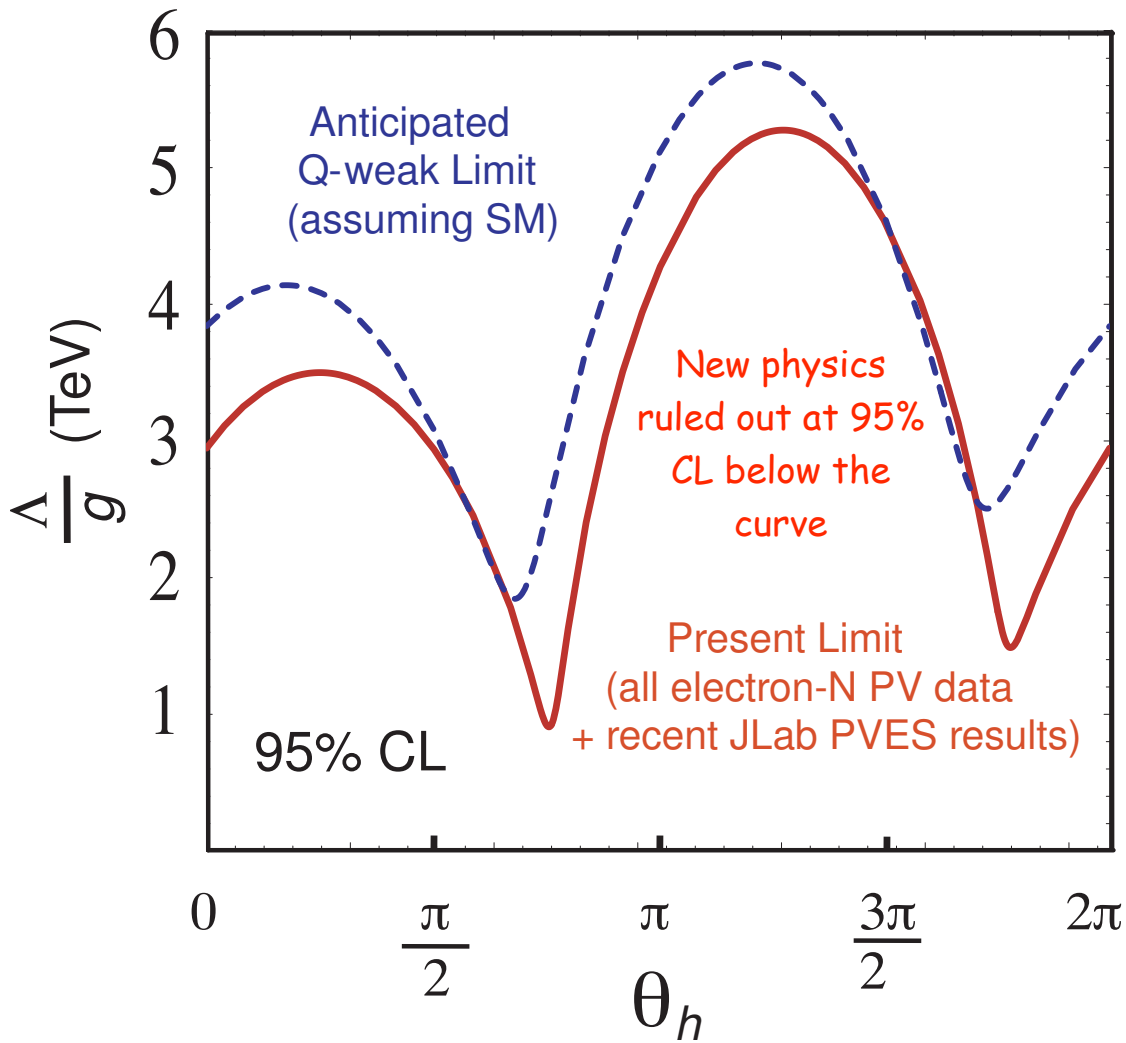
(Ross Young et al., arXiv:0704.2618v2)

$$\mathcal{L}_{New}^{PV} = \frac{g^2}{4\Lambda^2}\bar{e}\gamma_\mu\gamma_5 e \sum_q h_V^q \bar{q}\gamma^\mu q$$

$$h_V^u = \cos\theta_h$$

$$h_V^d = \sin\theta_h$$

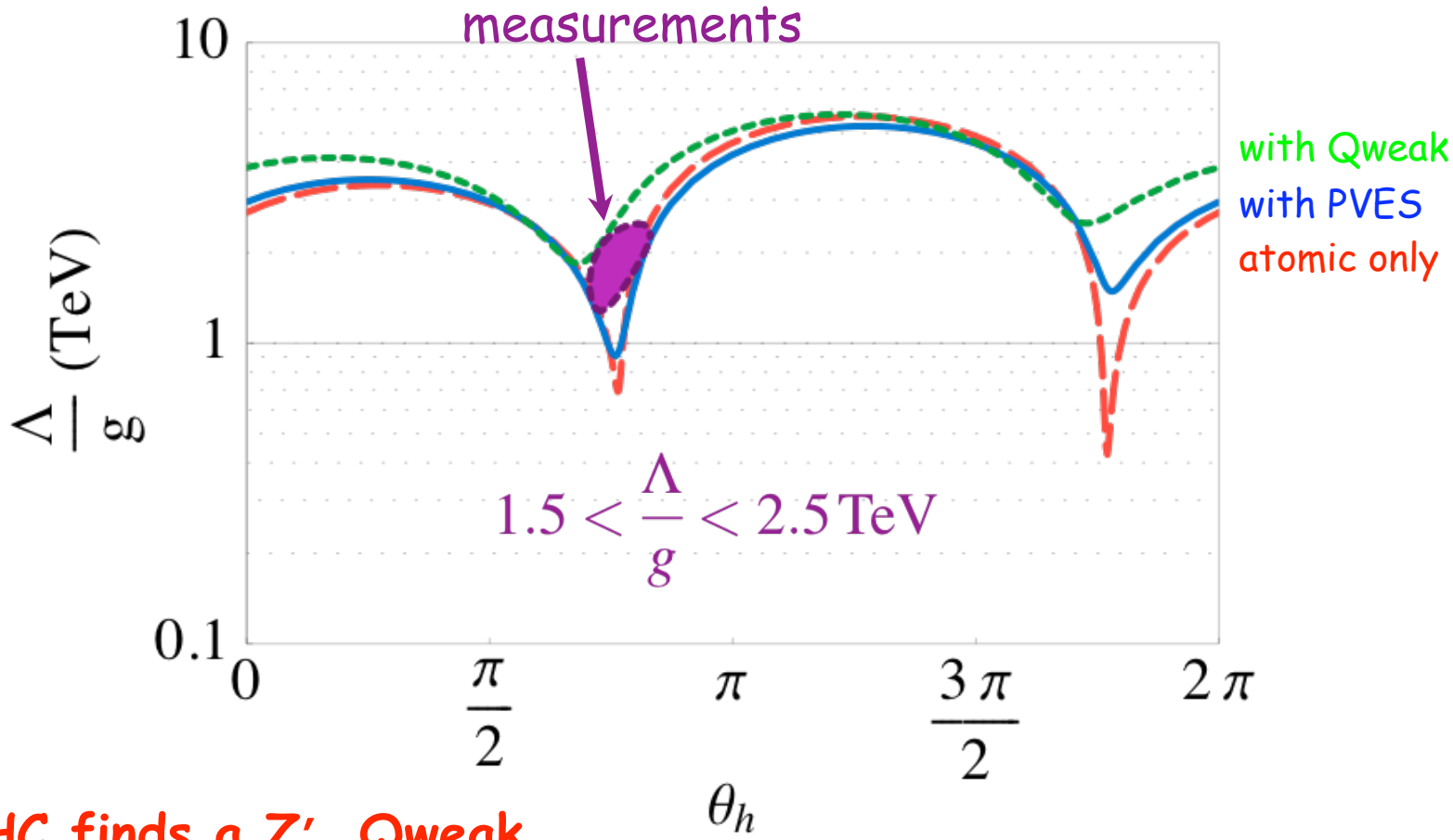
θ_h = flavor mixing angle



Qweak constrains new physics to beyond 2 TeV, raising the lower bound on the mass of a possible Z′ by ~ 1 TeV.

In the case of a significant deviation from SM…

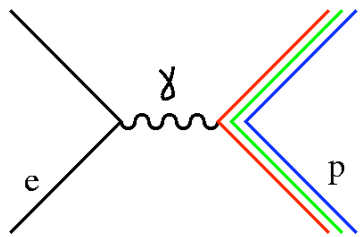
Constraint including Qweak at central value of current measurements



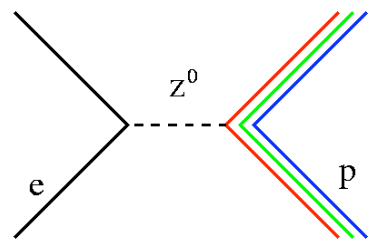
If LHC finds a Z′, Qweak will help determine its properties

Analysis by Ross Young, JLab

The link of Q^p_{weak} to the real world



As $Q^2 \to 0$



measures Q^p – proton's electric charge

measures Q^p_{weak} – proton's weak charge

The Q_{weak} experiment will measure the parity-violating analyzing power A_z:-

$$A_z = \frac{\sigma^+ - \sigma^-}{\sigma^+ + \sigma^-} \simeq -3 \times 10^{-7}$$

$$A_z \xrightarrow[\substack{Q^2 \to 0 \\ \theta \to 0}]{} \frac{-G_F}{4\pi\alpha\sqrt{2}}[Q^2 Q^p_{weak} + Q^4 B(Q^2)]$$

contains $G^\gamma_{E,M}$ and $G^Z_{E,M}$, constrained by other expts

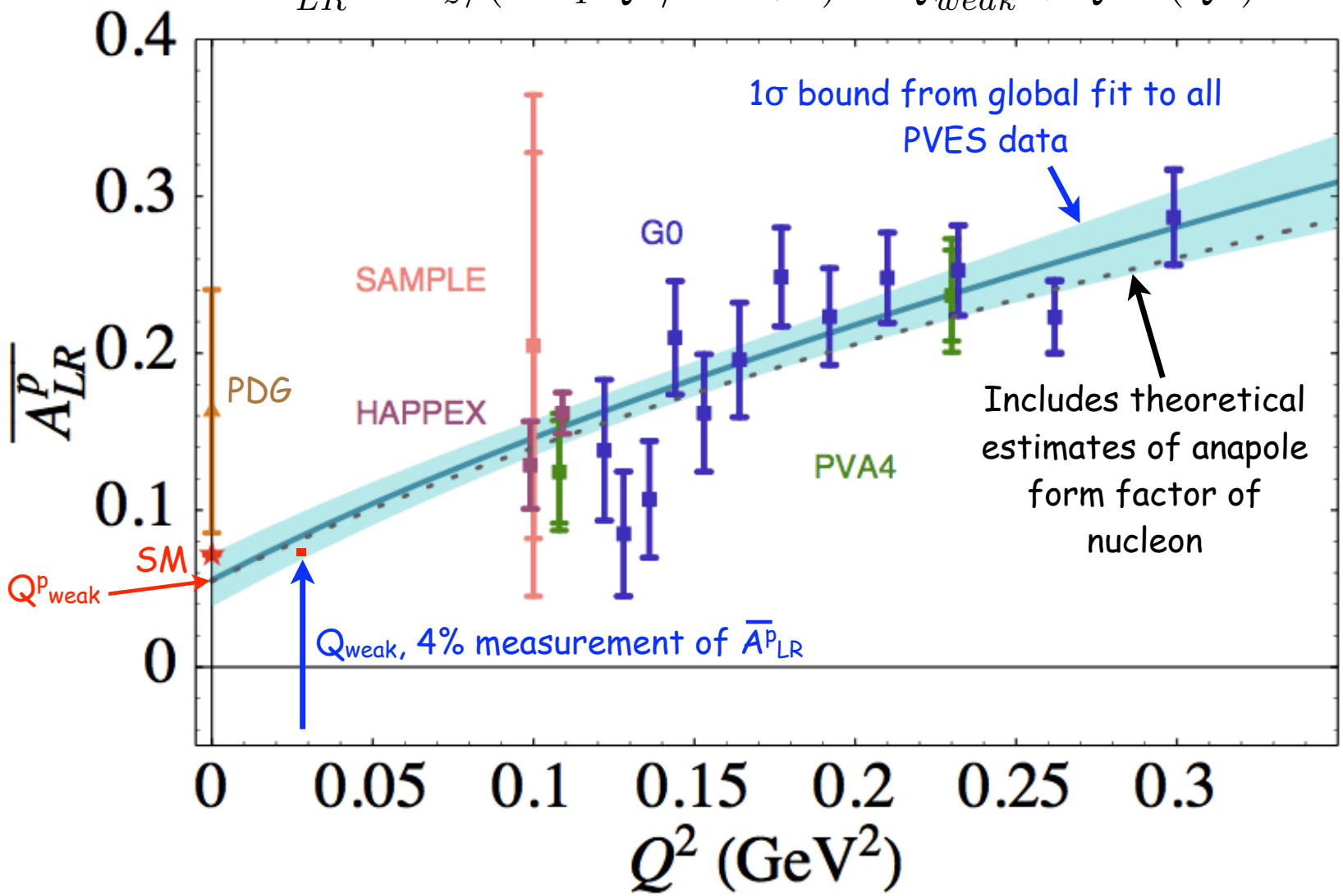
$$Q^p_{weak} = 1 - 4\sin^2\theta_W \sim 0.072 \text{ (at tree level)}$$

- Q^p_{weak} is a well-defined experimental observable
- Q^p_{weak} has a definite prediction in the electroweak Standard Model

Parity-Violating Asymmetry Extrapolated to $Q^2 = 0$

(Ross Young et al., arXiv:0704.2618v2)

$$\overline{A^p_{LR}} = A_z/(-G_F Q^2/4\pi\alpha\sqrt{2}) = Q^p_{weak} + Q^2 B(Q^2)$$

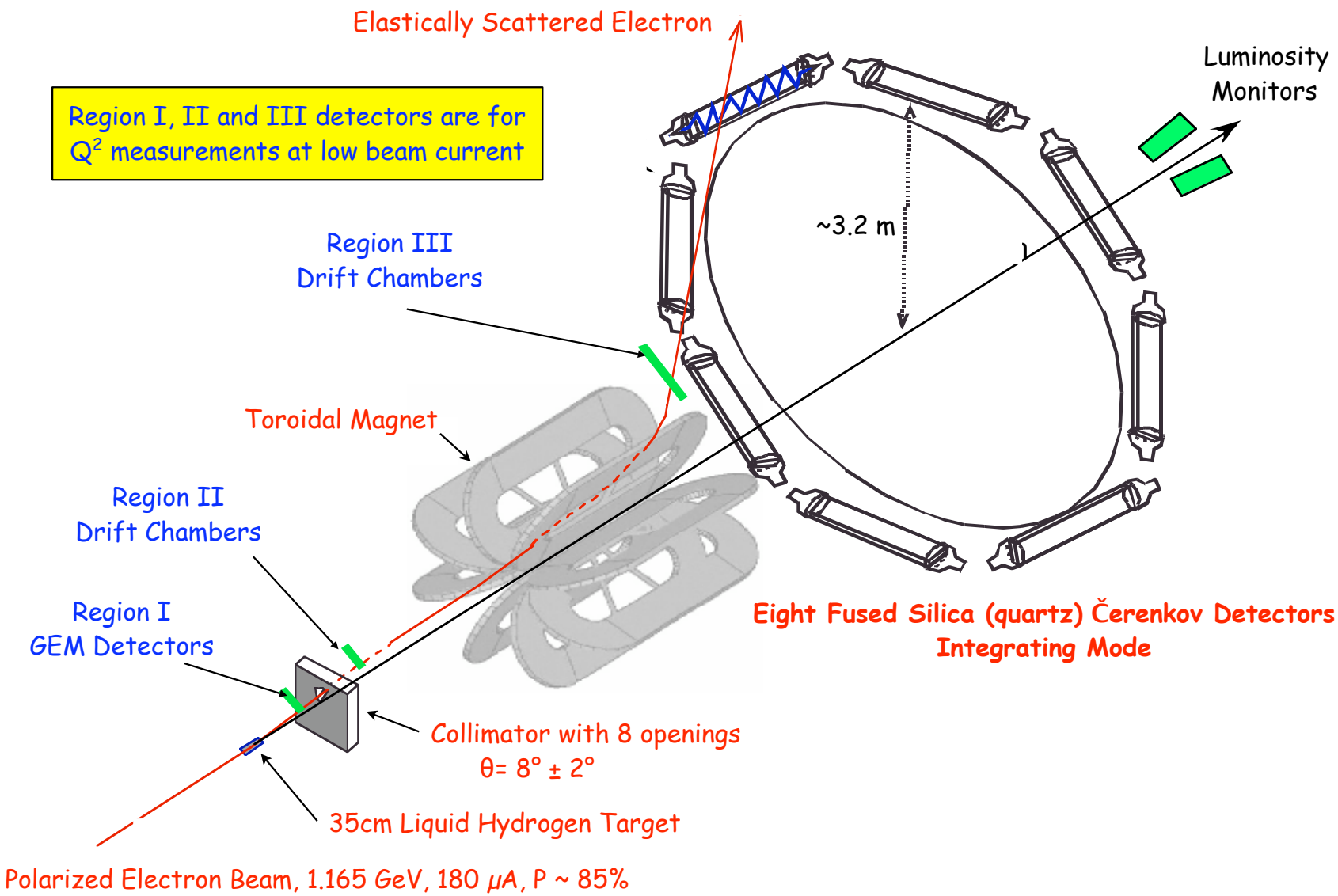


Anticipated Q^p_{Weak} Uncertainties

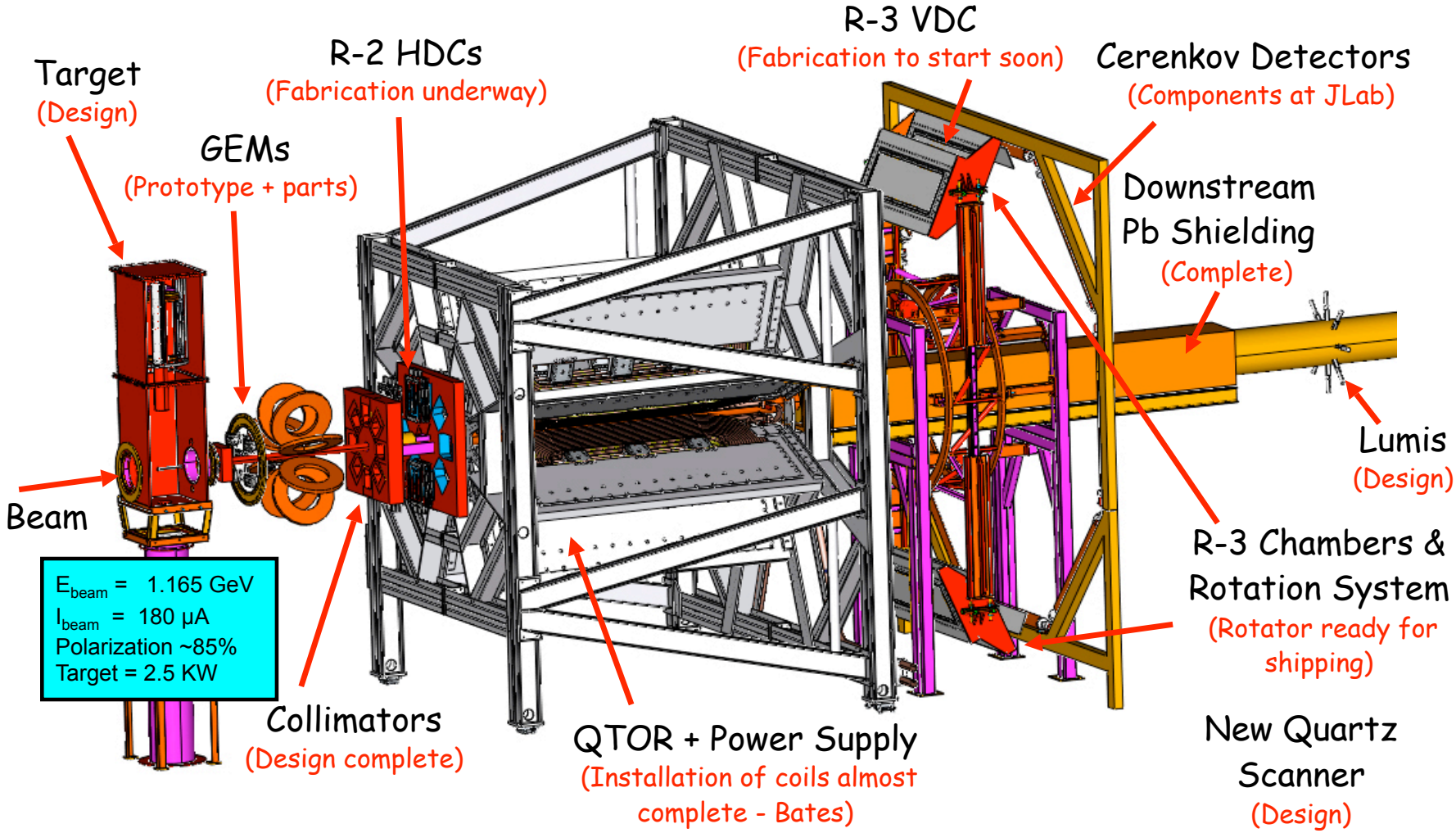
	$\Delta Q^p_{weak}/Q^p_{weak}$
Statistical (2200 hours)	**2.8%**
Systematic:	
Beam polarization	1.4%
Average Q^2 determination	1.0%
Helicity-correlated beam properties	0.6%
Uncertainty in inelastic contamination	0.2%
Target window background	<1.0%
Hadronic structure uncertainties (measured)	2.0%
Radiative correction uncertainties in Q^p_{Weak}	<1%
Total Systematic	**2.9%**
Total	**~4.0%**

$\rightarrow \Delta\sin^2\theta_W/\sin^2\theta_W = 0.3\%$

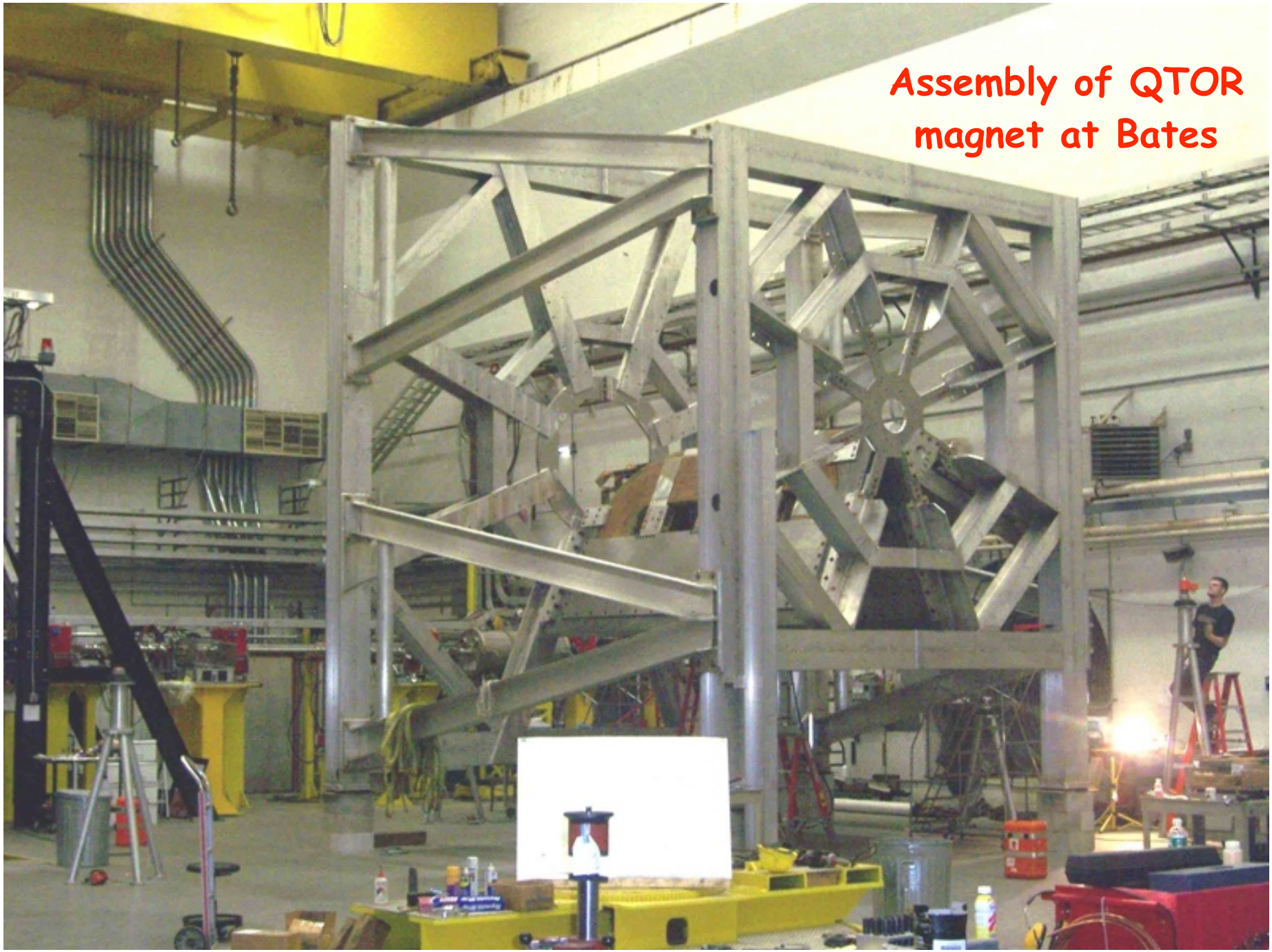
Overview of the Q^p_{Weak} Experiment



Major Components of the Qweak Experiment



Central scattering angle:	8° ± 2°	Acceptance averaged asymmetry:	–0.28 ppm
Phi Acceptance:	>50% of 2π	Integrated Rate (all sectors):	~6 GHz
Average Q^2:	0.028 GeV^2	Integrated Rate (per detector):	~750 MHz


Assembly of QTOR
magnet at Bates

A little on systematics...

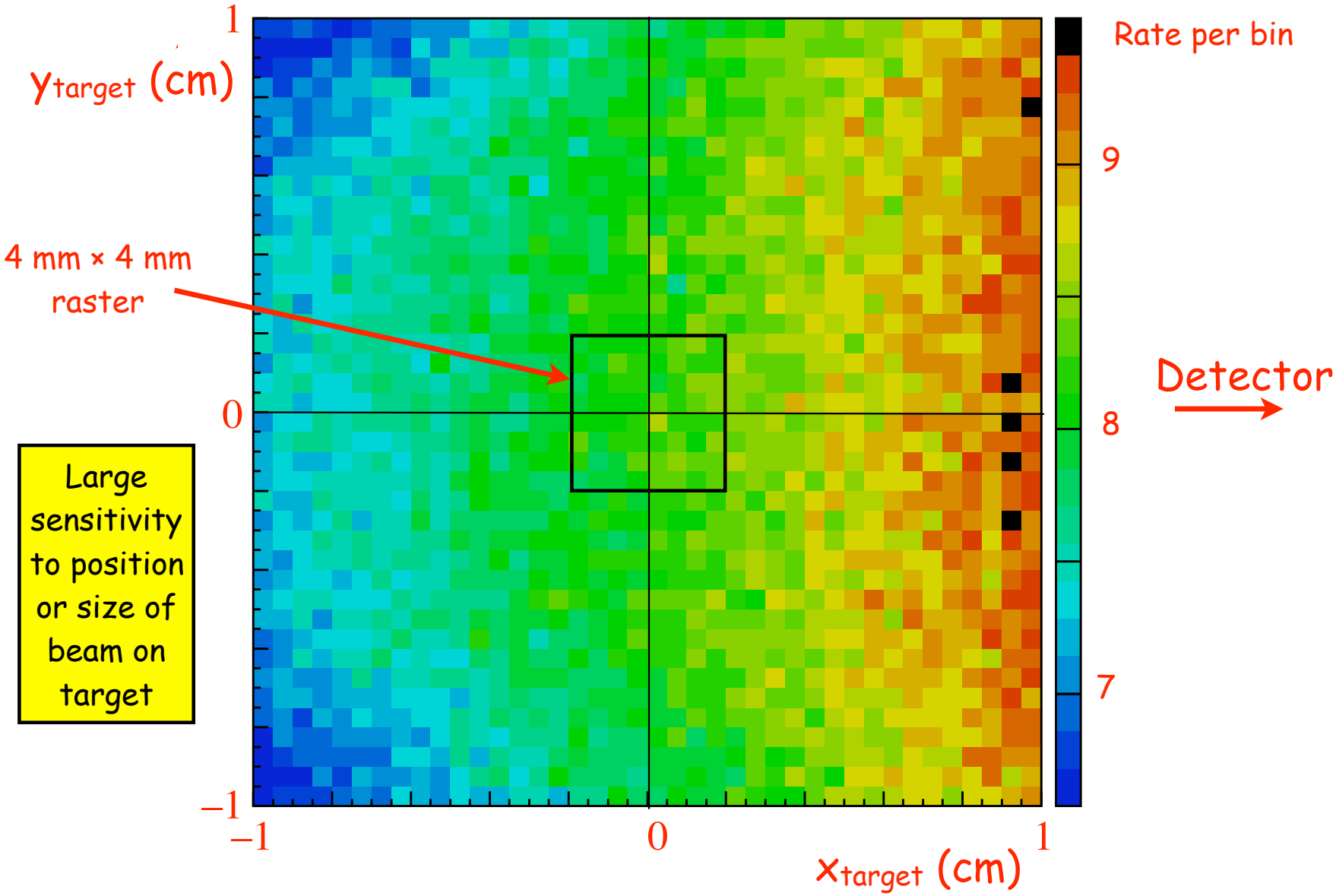
Expected PV asymmetry -3×10^{-7}.

Limit individual systematic errors to $\sim6\times10^{-9}$,
make corrections accurate to 10%.

Example, sensitivity to:

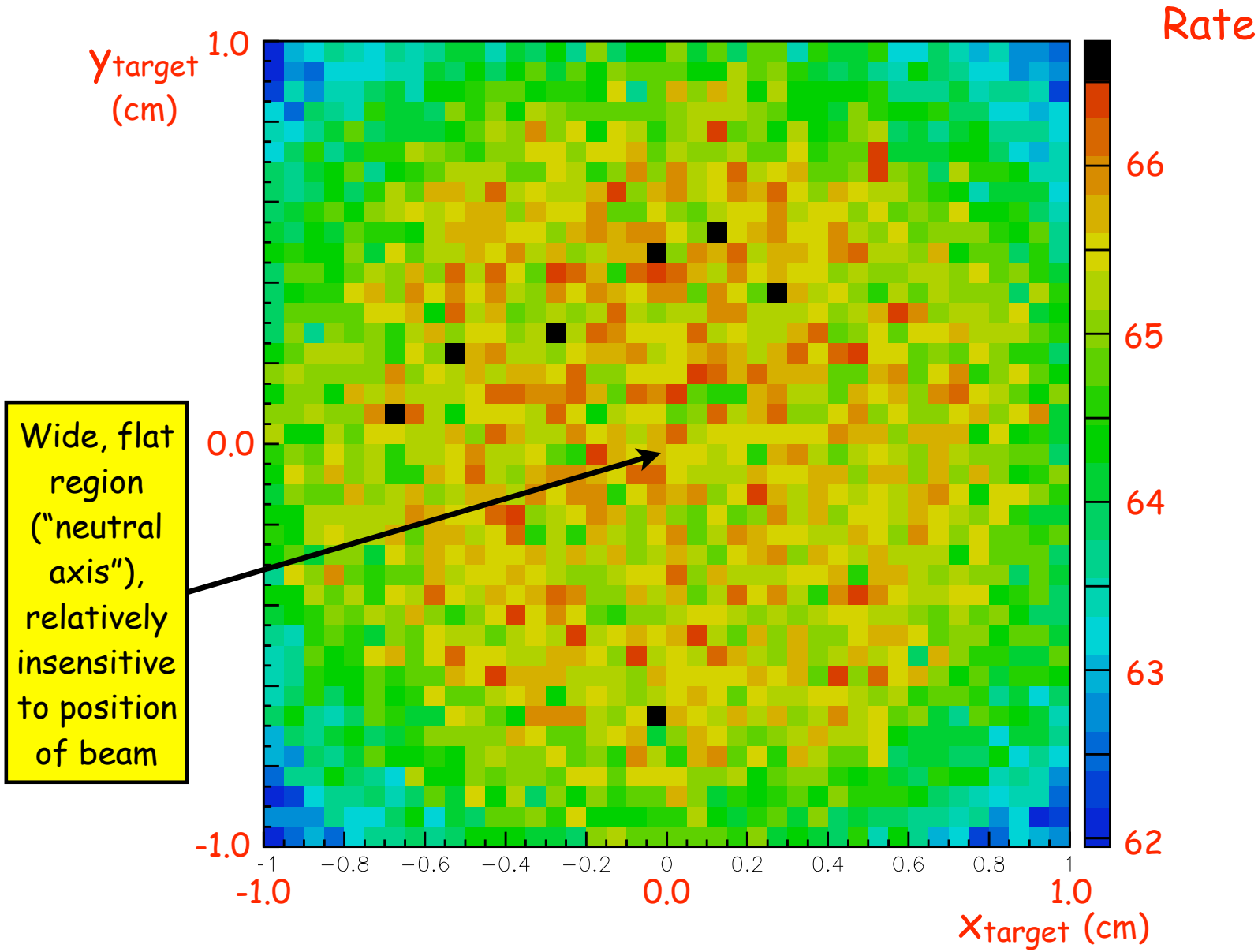
beam motion
beam breathing

Event rate in 1 detector as function of position of beam on target

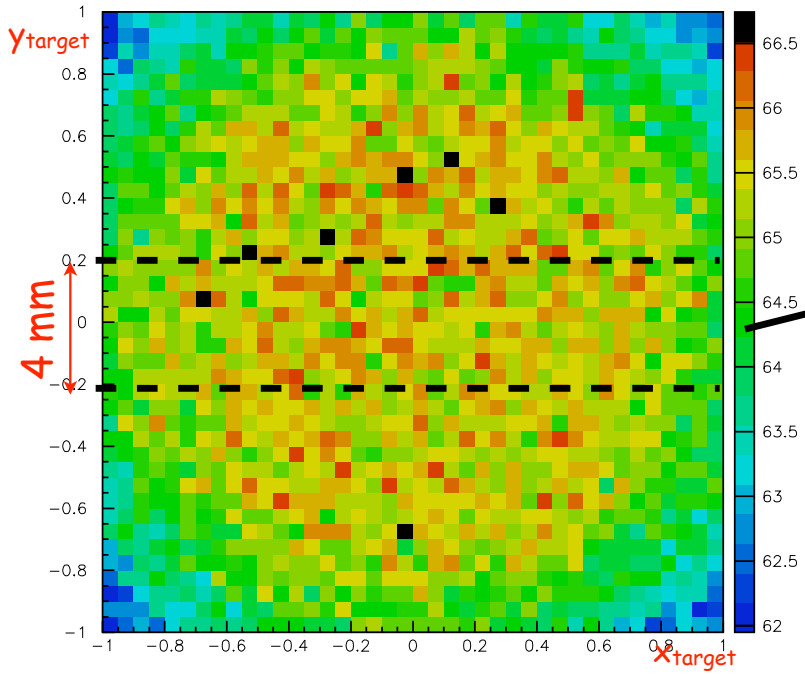


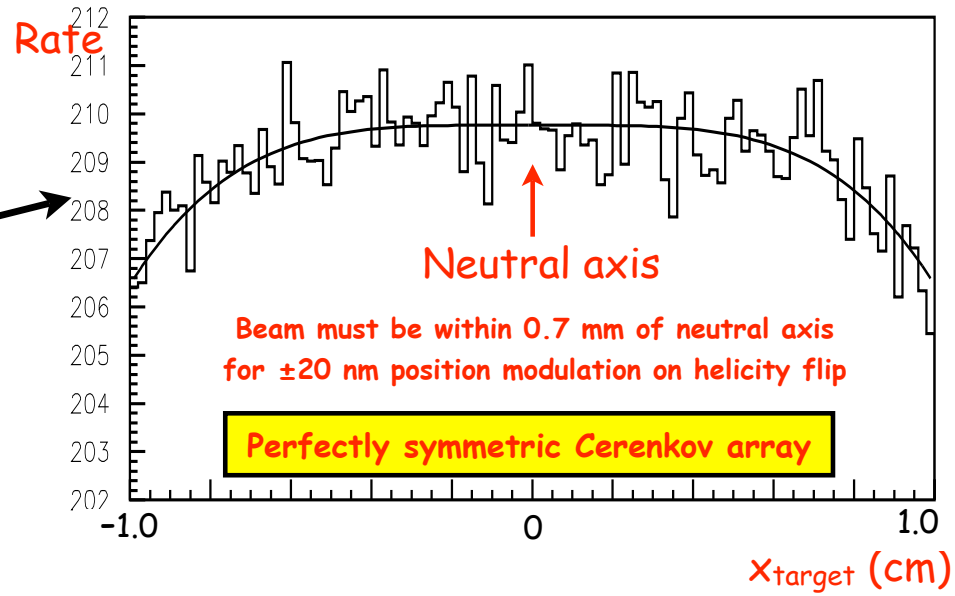
Large sensitivity to position or size of beam on target

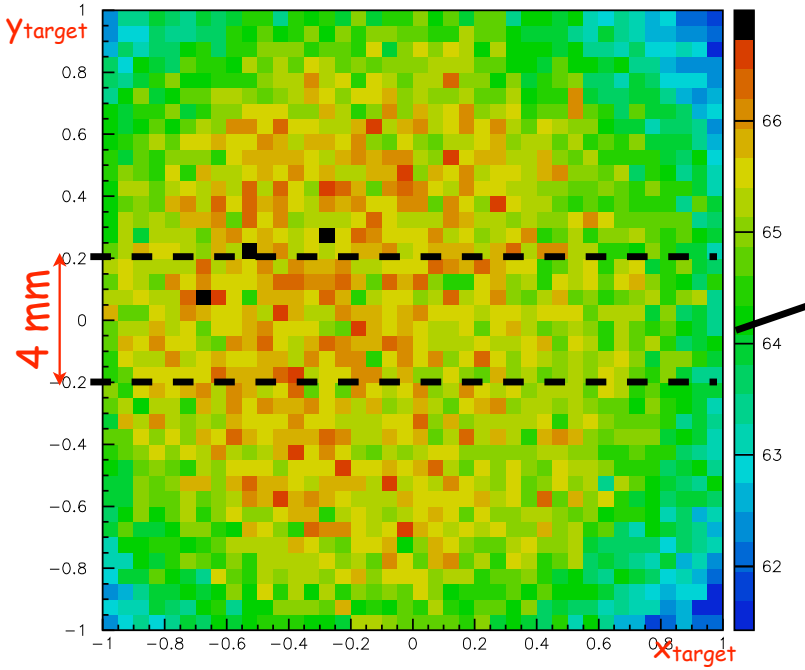
Events from all 8 Cerenkov bars, **perfect** detector array

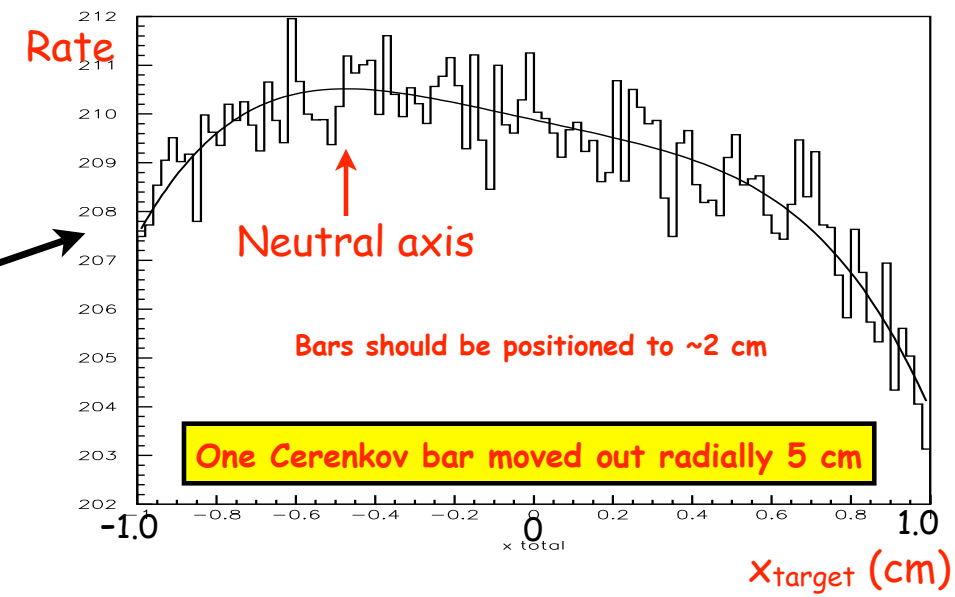


Effect of asymmetric Cerenkov array









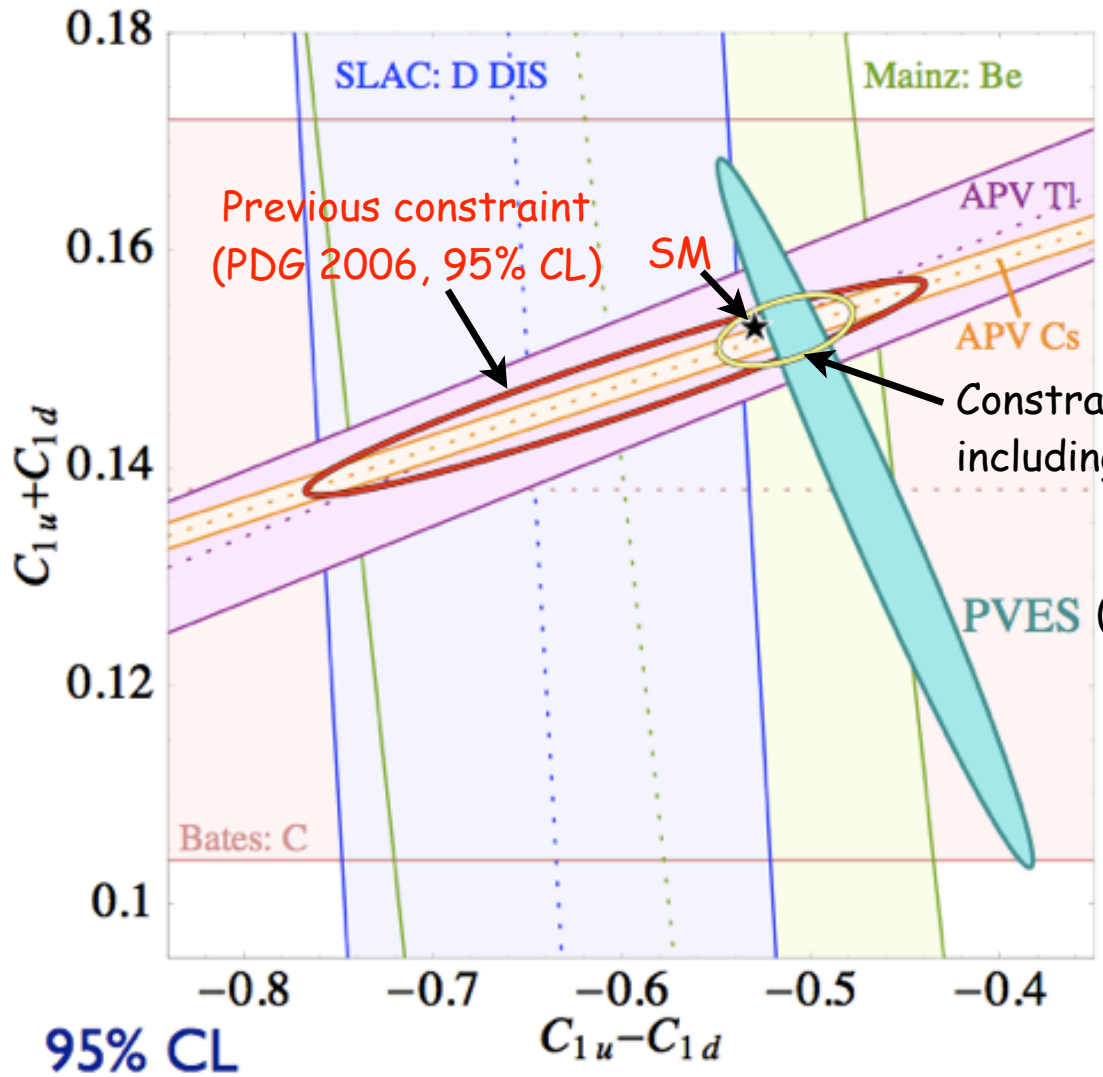
Summary

- Qweak Experiment
  - Precision measurement of the proton's weak charge in the simplest system.
  - Fundamental 10 σ measurement of the running of $\sin^2\theta_W$ at low energy.
  - Sensitive search for new physics with CL of 95% at the ~ 2.3 TeV scale.
  - Would raise the lower bound on a possible Z´ by ~ 1 TeV.
  - If LHC discovers a Z´ , Qweak will place a constraint on its properties.

- Possible 12 GeV Parity-Violating Møller Experiment at JLAB
  - Conceptual design indicates reduction of E158 error by ~5 may be possible at 12 GeV JLAB.

Extra Slides

C_{1q} Couplings with PVES



Previous constraint (PDG 2006, 95% CL)

SM

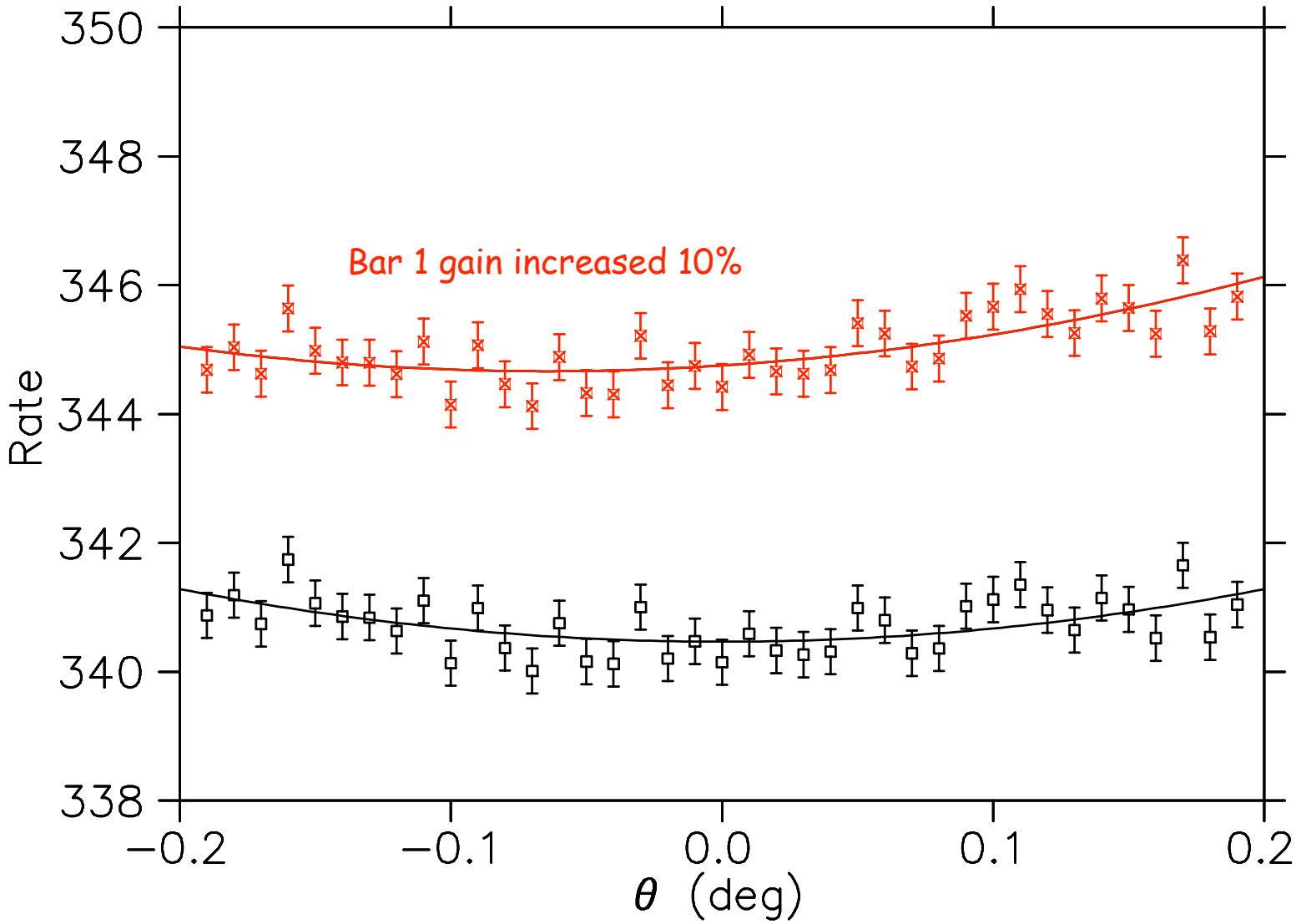
Constraint at 95% CL including PVES

PVES (not including Qweak)

Analysis by Ross Young

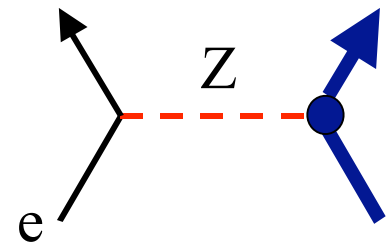
95% CL

Variation of rate with angle of beam on target



Low Energy Weak Neutral Current Standard Model Tests

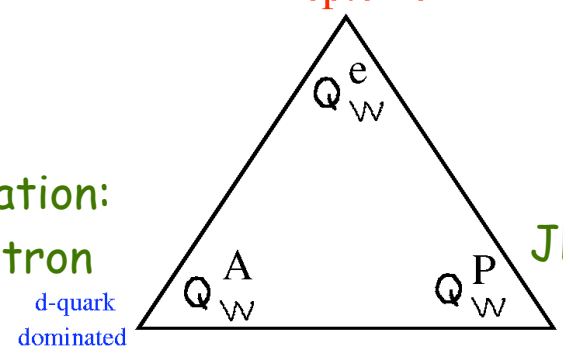
Low energy
weak charge "triad" (M. Ramsey-Musolf)
probed in weak neutral current experiments



SLAC E158: parity-violating
Moller scattering
$\vec{e} + e \rightarrow e + e$

$$Q_W^e \approx -(1 - 4\sin^2\theta_W)$$

Leptonic



d-quark dominated

u-quark dominated

Semi-Leptonic

Cesium Atomic Parity Violation:
primarily sensitive to neutron
weak charge

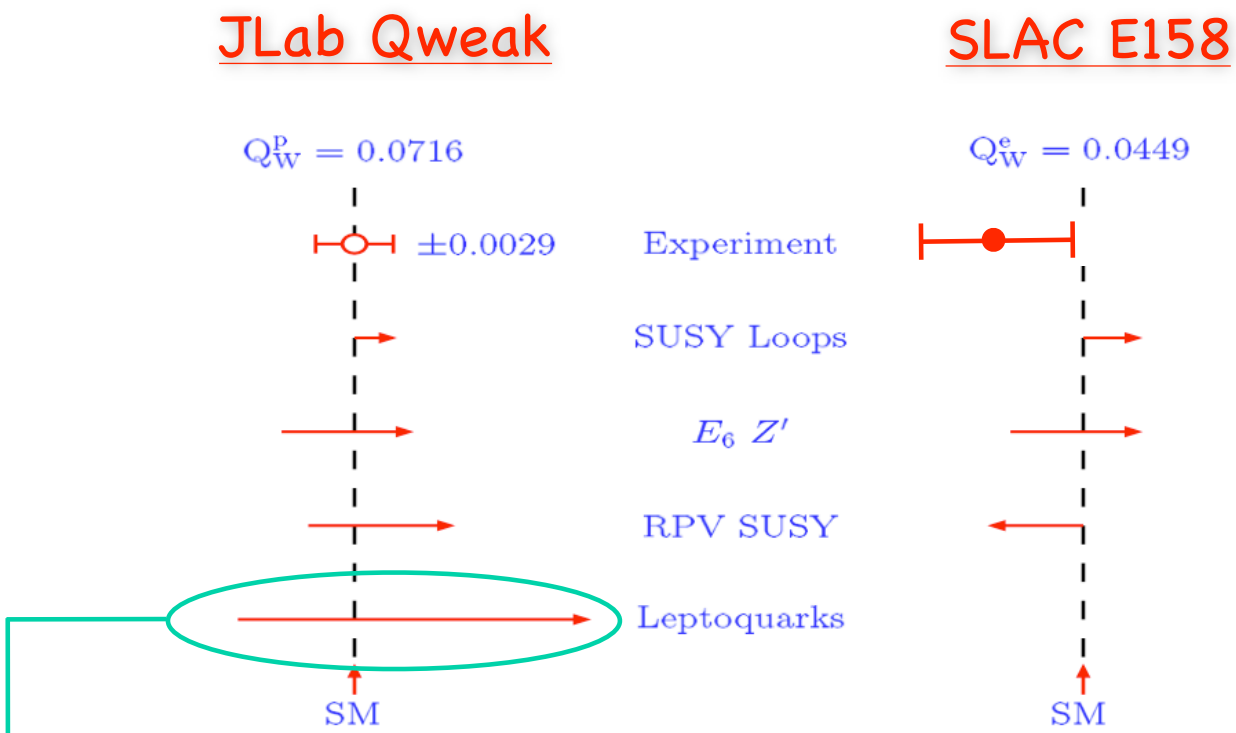
$$Q_W^A \approx -N + Z(1 - 4\sin^2\theta_W) \approx -N$$

JLAB Q^p_{weak}: parity-violating
p elastic scattering
$\vec{e} + p \rightarrow e + p$

$$Q_W^p \approx 1 - 4\sin^2\theta_W$$

These three types of experiments are a complementary set for exploring new physics possibilities well below the Z pole.

Influence of Possible New Physics on Q^p_w and Q^e_w



- Qweak measurement will provide a stringent standalone constraint on leptoquark based extensions to the SM.
- Q^p_{weak} (semi-leptonic) and E158 (pure leptonic) together make a powerful program to search for and identify new physics.