QWEAK: searching for new Physics beyond the Standard Model.

J. Roche

Ohio University

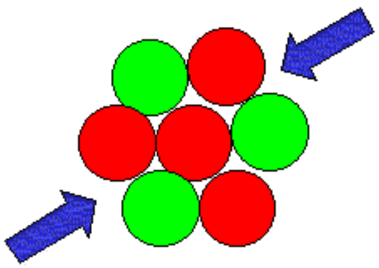
September 30, 2011

Grant # 0969788

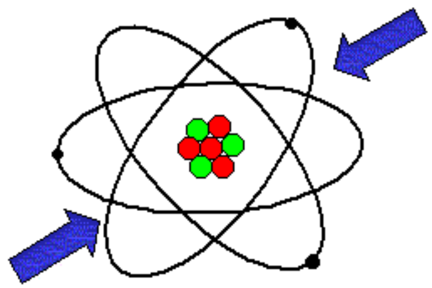
In a nutshell

- The Standard Model of Particle Physics is one of the biggest achievements of the twentieth century… still it is known to be incomplete
- Low energy precision tests of the Standard Model (like Parity Violation Electron Scattering) are proven avenues to discover Physics beyond the Standard Model
- QWEAK is one such experiment, currently taking data, in which my OU group is involved.

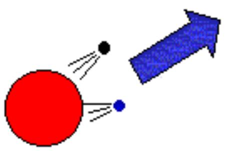
	Small →	
Fast ↓	Classical mechanics	Quantum mechanics
	Relativistic mechanics	Quantum Field Theory



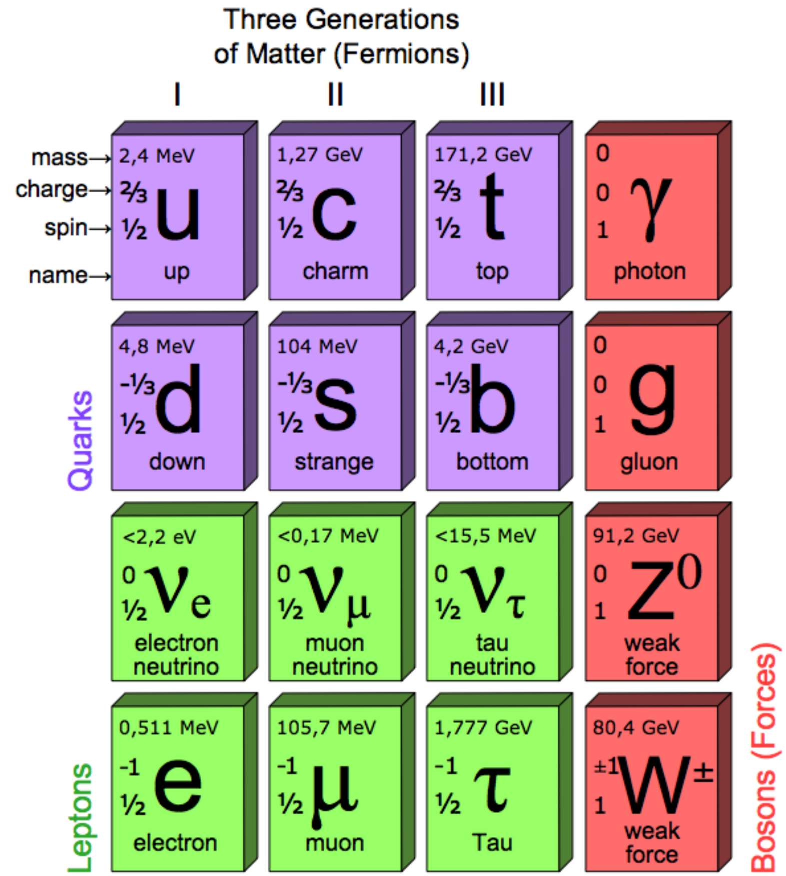
Strong force binds the nucleus



Electromagnetic force binds atoms



Weak force in radioactive decay



The Standard Model gives us a recipe to calculate rates at which particle interactions take place.

It includes

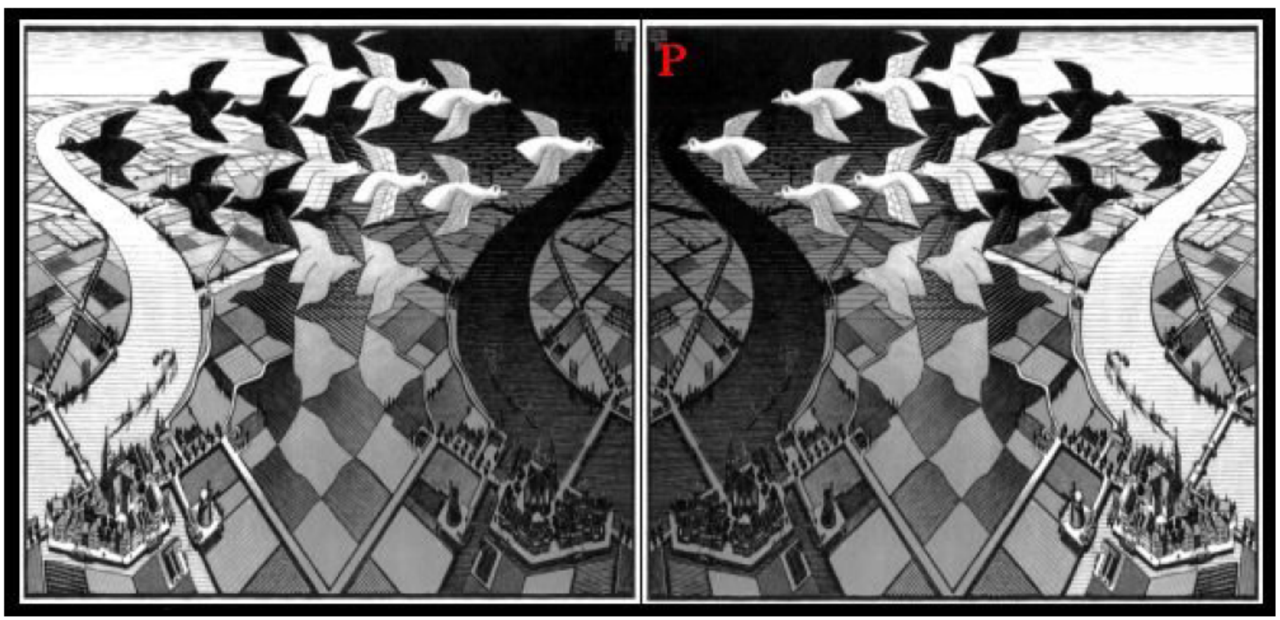
- a mechanics : Quantum field theory
- matter particles: quarks and leptons
- interactions and force carriers : bosons

The core of the model:

Electroweak unification

- Parity is conserved for the EM interaction (γ exchange)
- Parity is partially or fully violated for the weak interaction (resp. Z or Ws exchange)

Parity is a discrete symmetry of the wave function that results from inverting it around the origin.



2 D:
Mirror image

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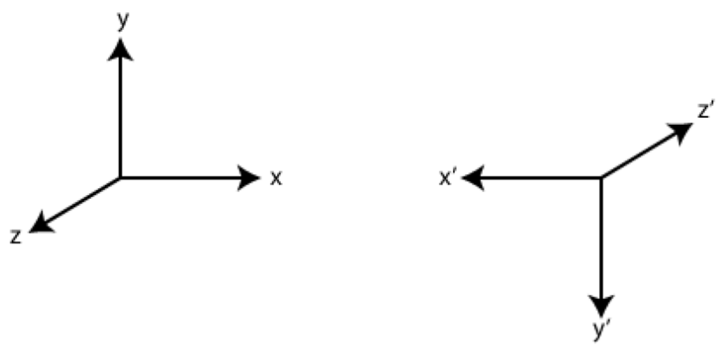

$$P(\vec{r}) = -\vec{r}$$

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

Angular momentum is left unchanged by the parity operation.

If an interaction rate depends on the spin (intrinsic angular momentum) of a particle, parity is violated.

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Parity violation ➔

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Glashow-Weinberg-Salam's ideas :

- Start with the Lagrangian energy density as

$$L = \alpha_W \left(J_\mu^- W_\mu^+ + J_\mu^+ W_\mu^- \right) + \alpha_Z J_\mu^Z Z_\mu + e\, J_\mu^{em} A_\mu$$

similar to E&M formulation $L = \vec{j} \cdot \vec{A} = q\ \vec{v} \cdot \vec{A}$

- Introduce hidden quantum numbers that mix the weak and the EM interaction to rewrite the Lagrangian as

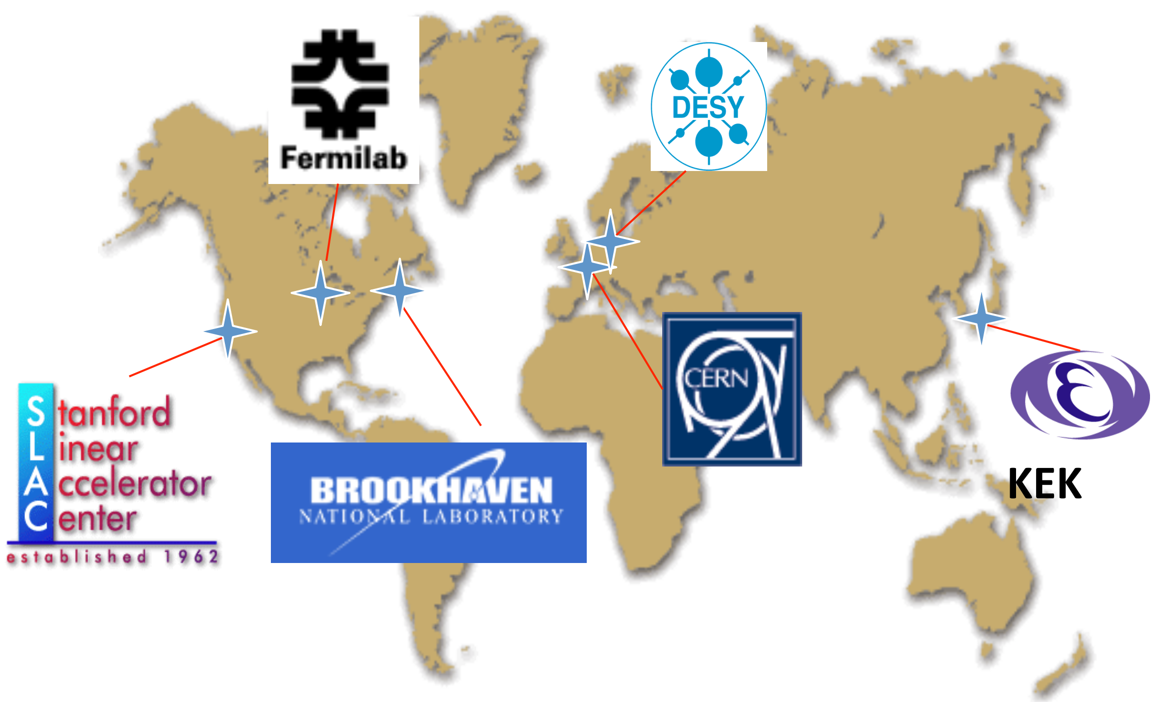
$$L = \frac{g}{\sqrt{2}} \left(J_\mu^- W_\mu^+ + J_\mu^+ W_\mu^- \right) + \frac{g}{\cos\theta_W} \left(J_\mu^3 - \sin^2\theta_W J_\mu^{em} \right) Z_\mu + g\ \sin\theta_W\ J_\mu^{em} A_\mu$$

$$\sin\theta_W = \frac{e}{g} \quad \textit{Weinberg angle}$$

The success of the Standard Model

HUGE !!!

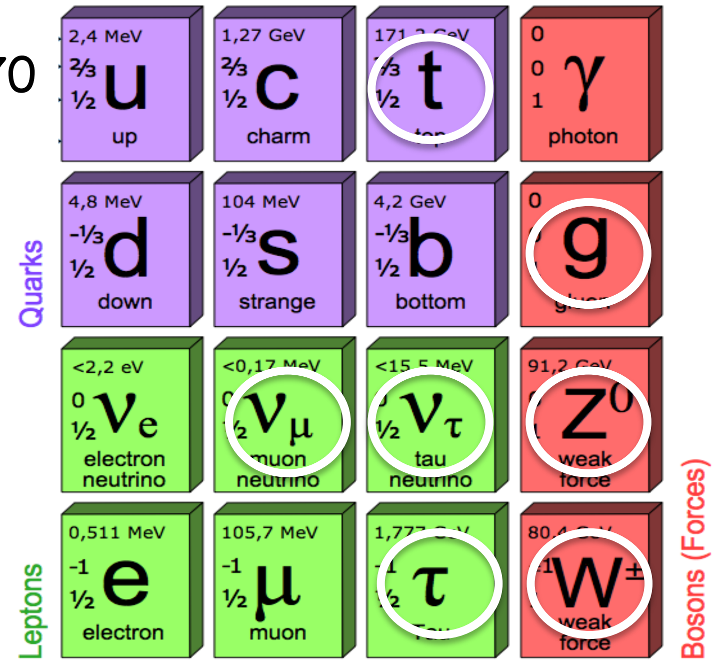
- Textbook physics : too many to cite..
- 7 Nobel prizes since 1970:
  - '79: Glashow, Weinberg and Salam for the electroweak unification.
  - '84: Rubbia and van der Meer for the discovery of the Z and the Ws.
  - '99: 'tHooft and Veltman for the renormalization of the theory.



The success of the Standard Model (ct'd)

- Most of the particles, the SM predicted in the '70 have since been observed

  eg: last one was "t" in 1995 at the Tevatron



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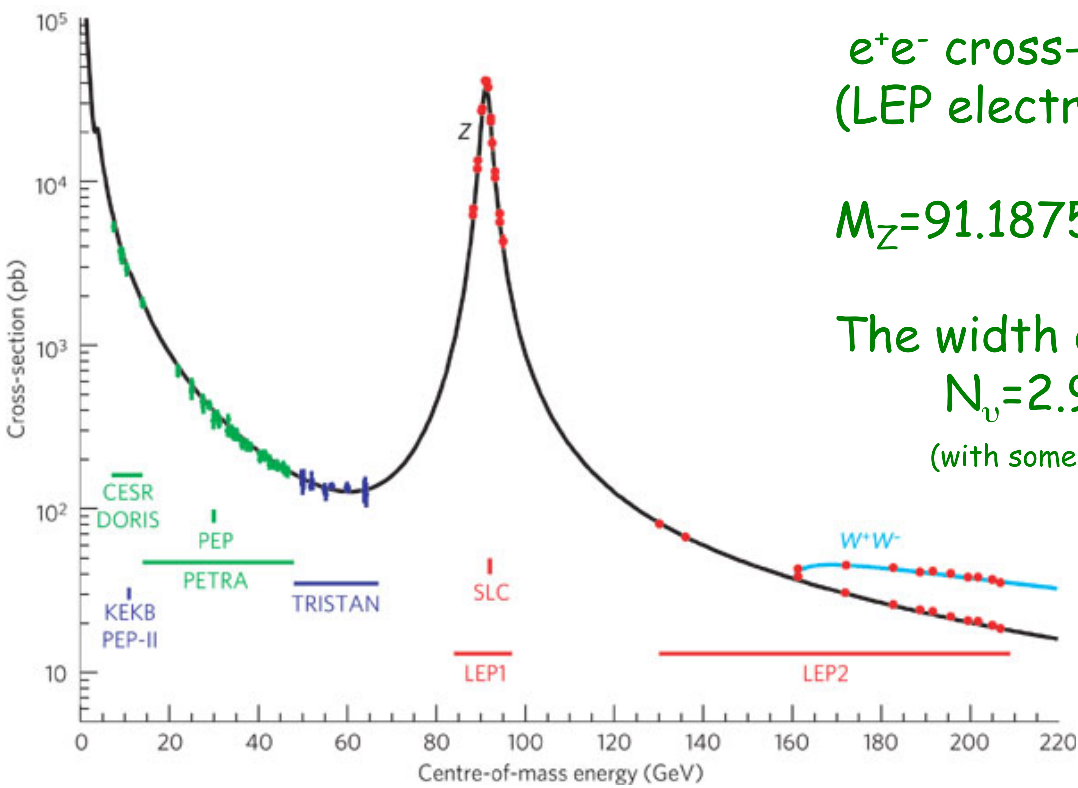
- Most parameters have been measured with extreme precision.



e^+e^- cross-section
(LEP electroweak working group,2007)

M_Z=91.1875+/-0.0021 GeV ($\Delta M_Z/M_Z$=2. 10^{-5})

The width of this mass distribution implies
N_υ=2.9840+/-0.0082
(with some caveats)

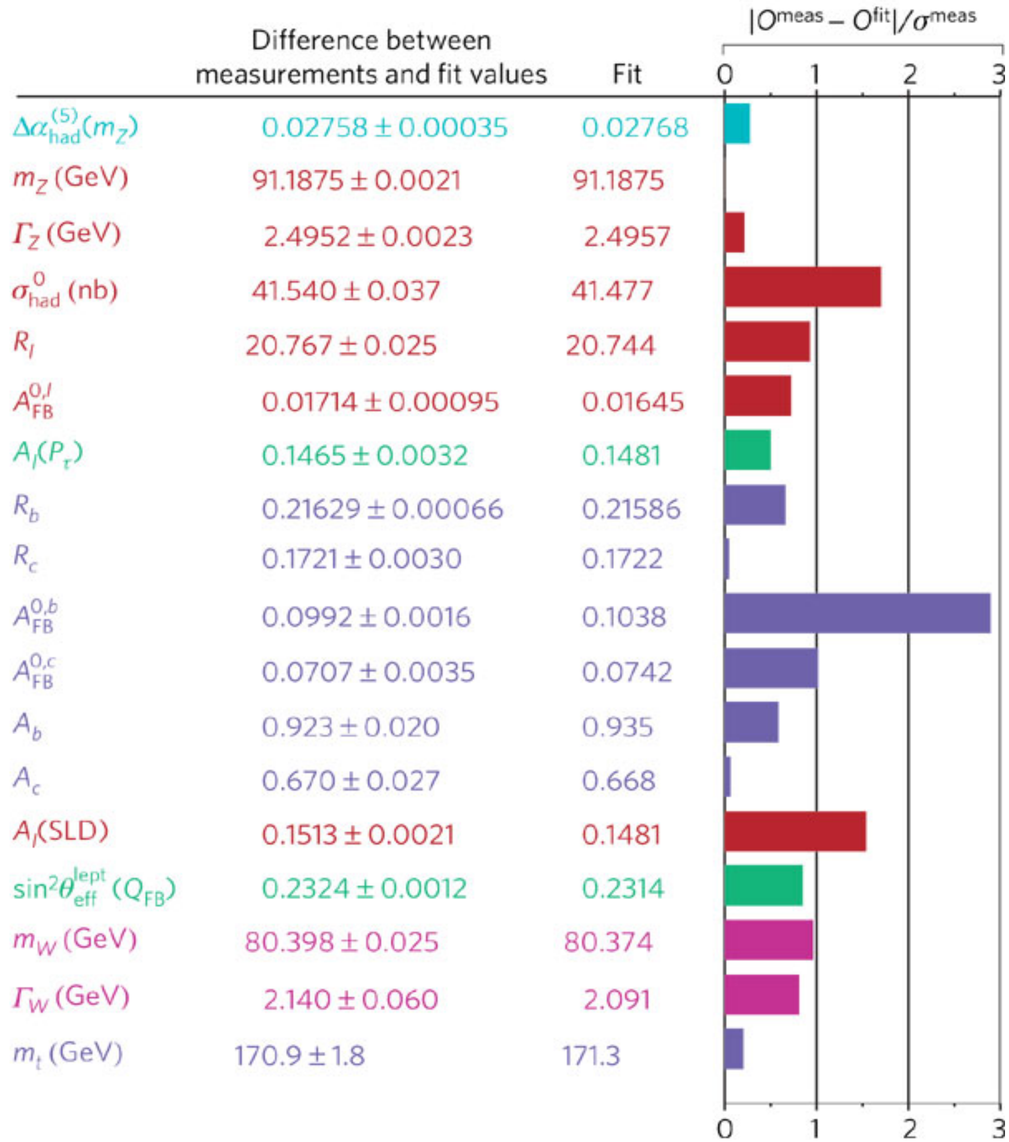
The success of the Standard Model (ct'd)

- Most of the particles, the SM predicted in the '70 have since been observed

- Most parameters have been measured with extreme precision.

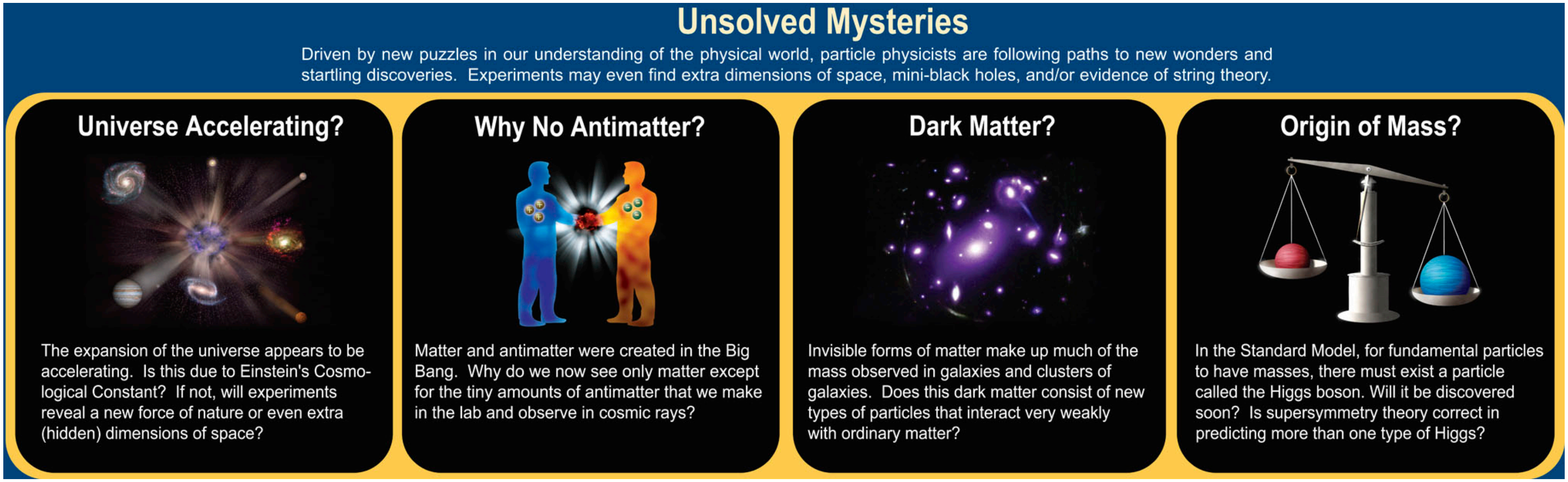
- The model is highly self-consistent

here use 3 parameters for the electroweak unification:
(M_Z, e and g) ⇔ (M_z, α and G_F)



LEP Electroweak working group (2007)

But the SM is incomplete…



CPEPweb.org

Contemporary view of the Standard model:

The Standard Model is an effective low-energy theory of the more fundamental underlying physics.

Can we discover this new physics beyond the Standard Model ??

Avenues to discover Physics beyond the Standard Model

- Energy Frontier: direct searches for new particles
- Precision and intensity frontiers: searches for indirect effects, exploit Heisenberg uncertainties ($\Delta E.\ \Delta t \sim h/2\pi$).

Energy Frontier

- Reach higher and higher energies
- Look for few signatures-events (HIGGS, WIMPs, …)
- eg: LHC, ILC…

Precision and intensity frontiers

- Modest to low energies
- High statistical precision
- Test of fundamental symmetries violation
- eg: g-2, EDM, $\beta\beta$, rare decays, PVES (QWEAK, Moeller), …

In a nutshell

- The Standard Model of Particle Physics is one of the biggest achievements of the twentieth century… still it is known to be incomplete

- Low energy precision tests of the Standard Model (like Parity Violation Electron Scattering) are proven avenues to discover Physics beyond the Standard Model

- QWEAK is one such experiment, currently taking data, in which my OU group is involved.

One precision test of the Standard Model : parity violation in electron scattering

The rate of scattering of an electron off a electrically charged target is electron spin dependent because it involves the EM and the weak interaction. (assume for now, will develop later)

The goal is to measure $\sin^2\Theta_W$ at low energy to very high precision.

Challenge: very small asymmetry !

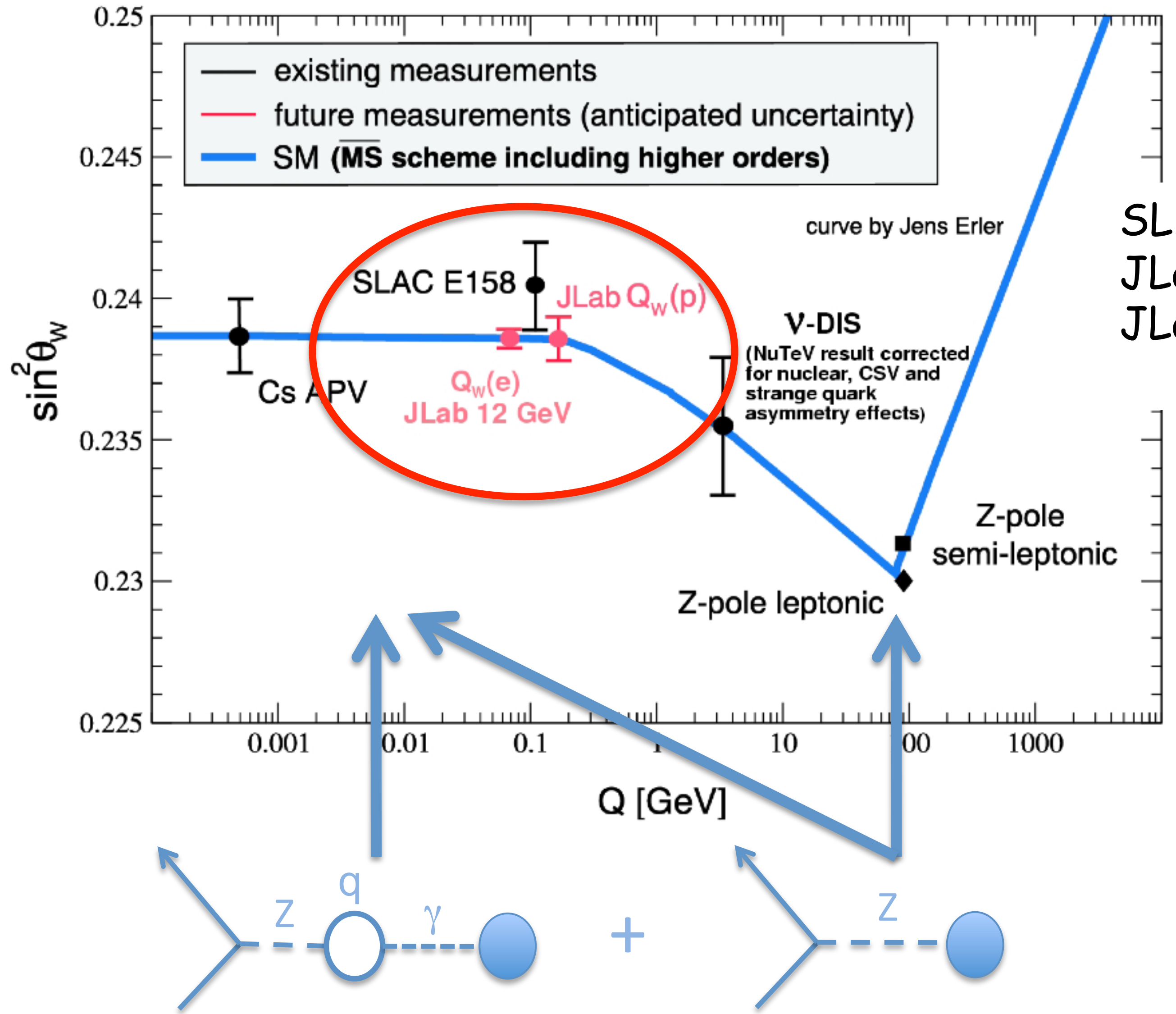
Helicity (spin) asymmetry: 200 ppb

(imagine measuring the height of Clippinger to a few μm)

Need: a very good experiment…

- To observe a lot of events to achieve statistical precision (in a reasonable amount of time)
- Low noise apparatus to manage systematic errors

To measure $\sin^2\Theta_W$ at low energy



SLAC 158: e+e

JLab $Q_w(p)$ (QWEAK): e+p

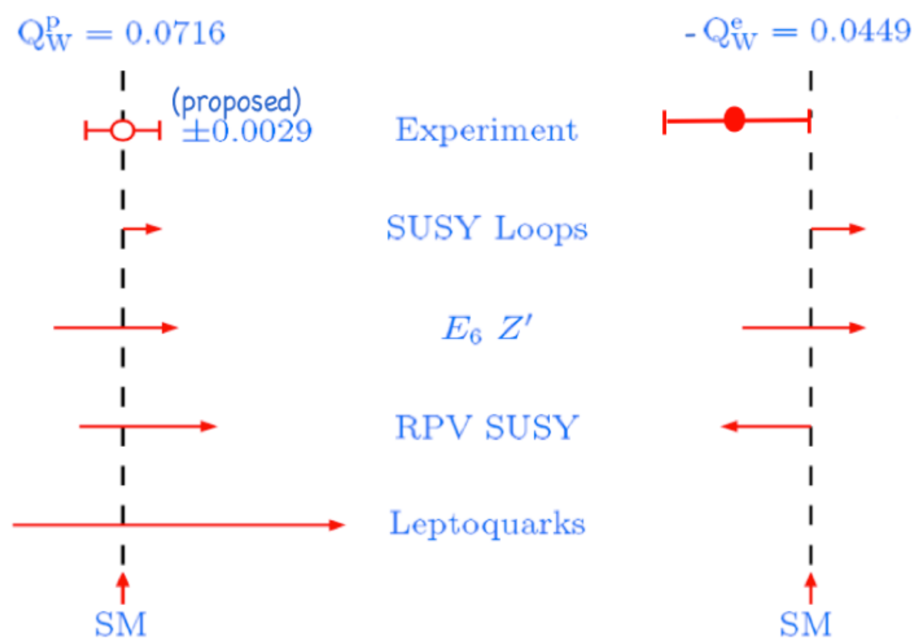
JLab $Q_w(e)$ (Moeller): e+e

Different targets particles have different sensitivities
to Physics beyond the Standard Model.

e+p -> e+p
(semi-leptonic process)

e+e -> e+e
(pure leptonic process)

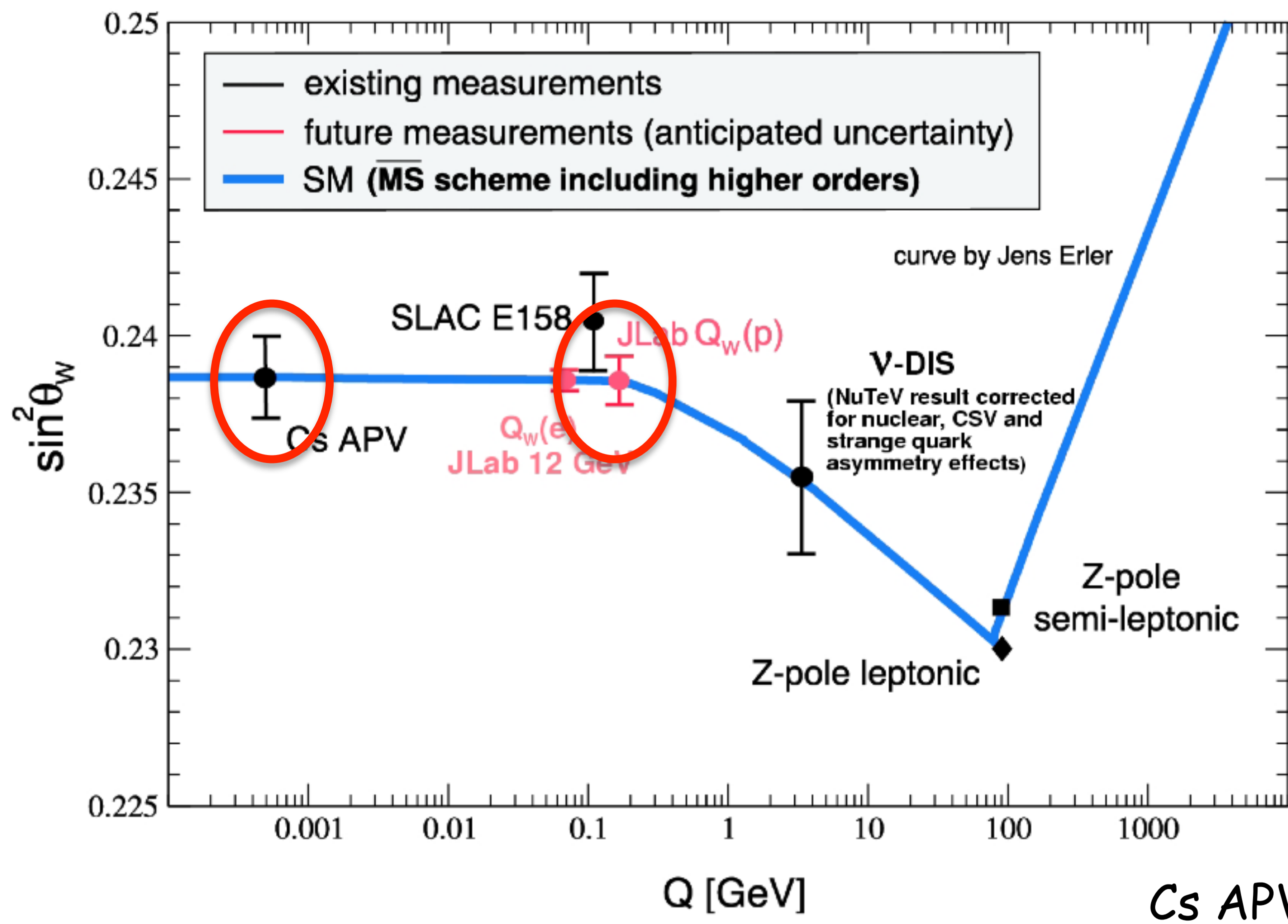
JLab Qweak **SLAC E158**



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

QWEAK proposal, 2004

To measure $\sin^2\Theta_W$ at low energy.



Cs APV:: neutron and proton

JLab $Q_w(p)$ (QWEAK): proton

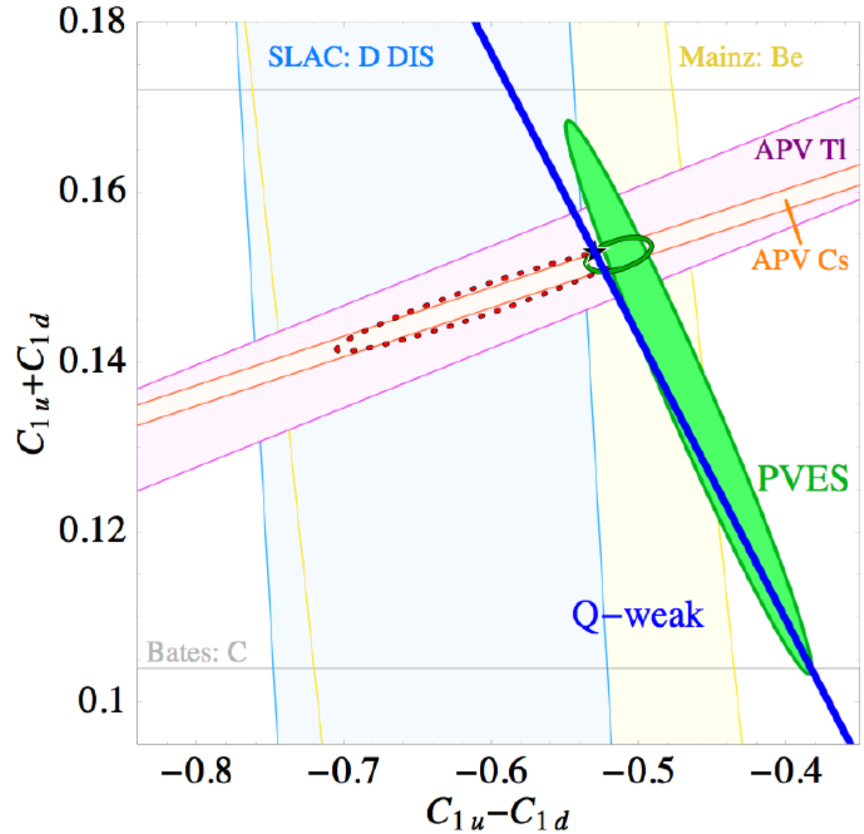
Particle	Electric charge	Weak vector charge ($\sin^2\theta_W \approx \frac{1}{4}$)
e	-1	$Q_W^e = 1 - 4\sin^2\theta_W \approx 0$
u	$+\frac{2}{3}$	$-2C_{1u} = +1 - \frac{8}{3}\sin^2\theta_W \approx +\frac{1}{3}$
d	$-\frac{1}{3}$	$-2C_{1d} = -1 + \frac{4}{3}\sin^2\theta_W \approx -\frac{2}{3}$
p(uud)	$+1$	$Q_W^p = 1 - 4\sin^2\theta_W \approx 0$
n(udd)	0	$Q_W^n = -1$

Nuclear target (p+n)

Standard model prediction

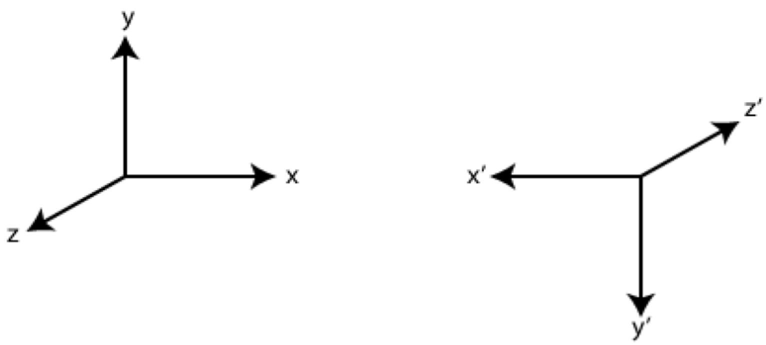
Hydrogen target (PVES)
Data already published (since 2000)

QWEAK (expected)
Assuming agreement with the Standard Model, the mass of bosons carriers of a new force would have a mass larger than 2 TeV.



R. Young, R. Carlini, A. Thomas, J. Roche
PRL 99 (2007) 122003 (On the cover of PRL)

Parity violation in electron scattering: how to measure it



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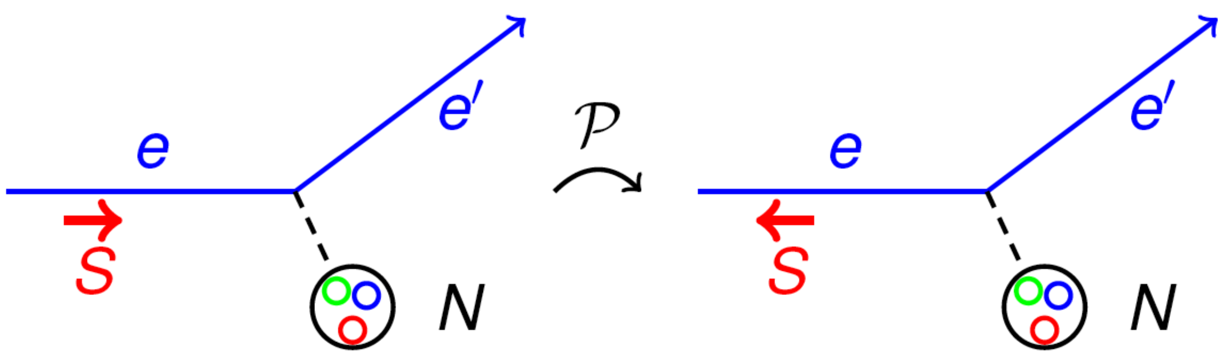
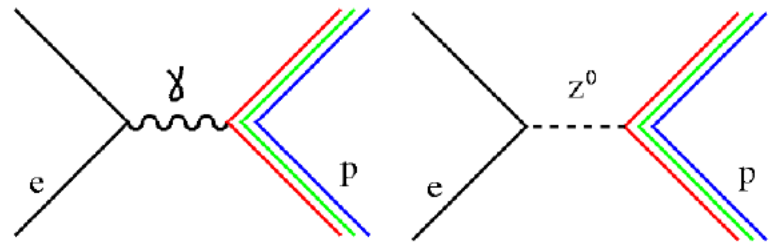
$$P(\vec{L}) = P(\vec{r}) \times P(\vec{p}) = \vec{L}$$

Angular momentum is left unchanged by the parity operation.
If an interaction depends on the spin (intrinsic angular momentum) of a particle, parity is violated.

- Scatter a polarized electron off an unpolarized target
- Instead of inverting **r**, **p** and leaving **S** unchanged, flip **S** but leave **r** and **p** unchanged.



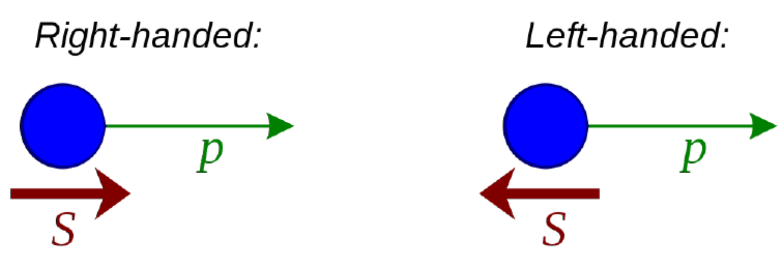
Parity violation in electron scattering??



$$\mathcal{M}^{EM} \propto \frac{1}{Q^2} \qquad \mathcal{M}_{PV}^{NC} \propto \frac{1}{M_Z^2 + Q^2}$$

$$\sigma = |\mathcal{M}^{EM}|^2 + 2\mathcal{M}^{EM}\mathcal{M}_{PV}^{NC} + |\mathcal{M}_{PV}^{NC}|^2$$

$$A_{PV}(p) = \frac{\sigma_R - \sigma_L}{\sigma_R + \sigma_L} \propto \frac{\mathcal{M}_{PV}^{NC}}{\mathcal{M}^{EM}} \propto \frac{Q^2}{M_Z^2} \quad \text{when } Q^2 \ll M_Z^2$$



PVES: it already "helped" the Standard Model

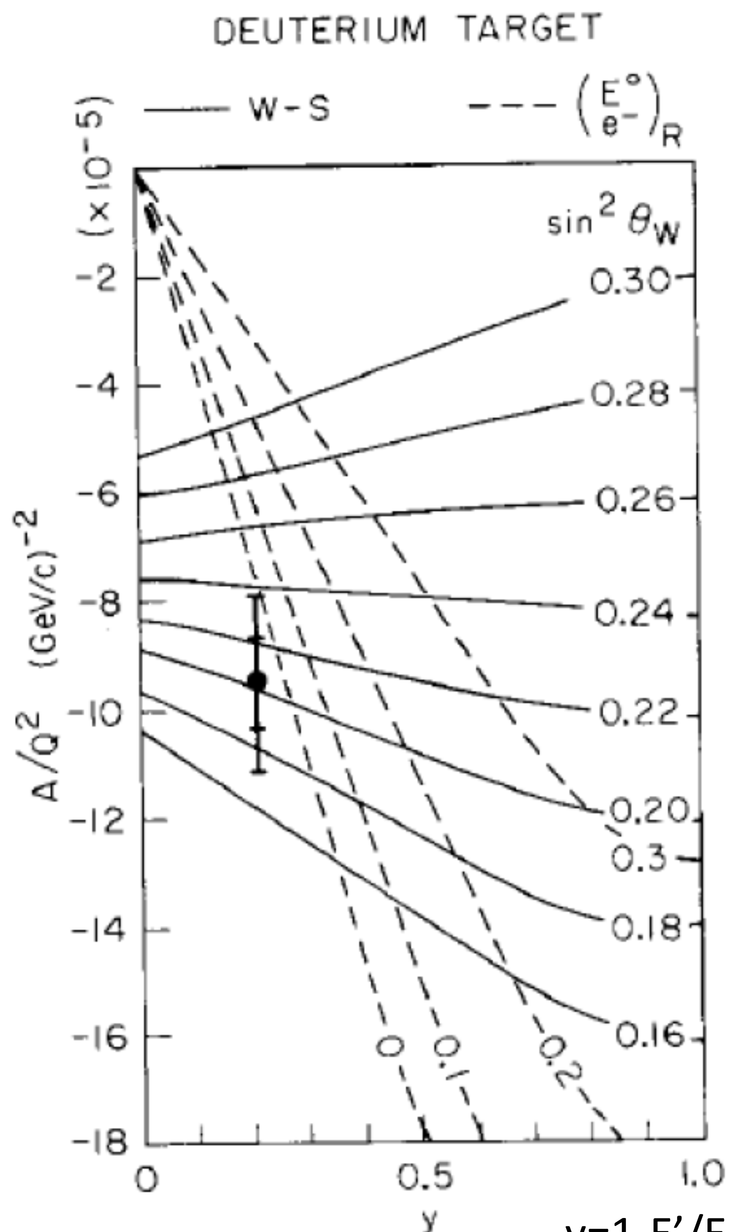
Prescott's experiment at SLAC (1978)

Deep inelastic scattering of polarized electrons off a deuterium target.

$A_{PV} \sim A/Q^2 \sim 10^{-4}\,(GeV/c)^2$
(M_Z=91.2 GeV, measured later circa 1985)

Confirmation of the Glashow-Weinberg-Salam's model

Important measurement of $\sin^2\Theta_W$
(albeit not very precise by today's standards)



$y=1-E'/E_0$

CE Prescott et al. Phys.Lett. B77 (1978) 347-352

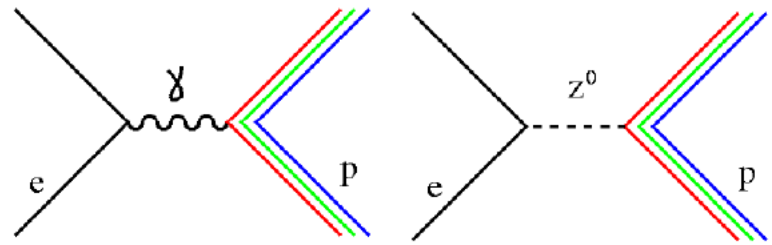
PVES: a mature experimental technique

J. Roche, W van Oers, R. Young, 2011, Chap 14 of the review book “Jefferson Lab : a long decade of Physics”

Experiment	Target	Physics	A_{RL}
	Completed Experiments		
SLAC E122	D	Weak mixing angle	10^{-4}
Mainz	^{9}Be	New physics	10^{-5}
MIT-Bates	^{12}C	New physics	10^{-6}
SAMPLE (MIT-Bates)	H, D	Strange form factor	10^{-5}
HAPPEX (JLab)	H, He	Strange form factor	10^{-6}
G^0 (JLab)	H, D	Strange form factor	10^{-5}
PVA4 (Mainz)	H	Strange form factor	10^{-5}
Møller (SLAC)	e	New physics	10^{-7}
	Upcoming Experiments		
HAPPEX (JLab)	H	Strange form factor	10^{-6}
PREX (JLab)	Pb	Neutron radius	10^{-7}
PVDIS (JLab)	D	Vector-axial coupling of quarks	10^{-4}
Q-weak (JLab)	H	New physics	10^{-7}
Møller (JLab)	e	New physics	10^{-8}

- A total of 5 PRL and 1 NIMA papers published with JR as collaborator since she joined OU
- Analysis and/or data taking in progress
- Data taking upcoming (~2017??)

Parity violation in electron scattering??



$$\mathcal{M}^{EM} \propto \frac{1}{Q^2} \qquad \mathcal{M}^{NC}_{PV} \propto \frac{1}{M_Z^2 + Q^2}$$

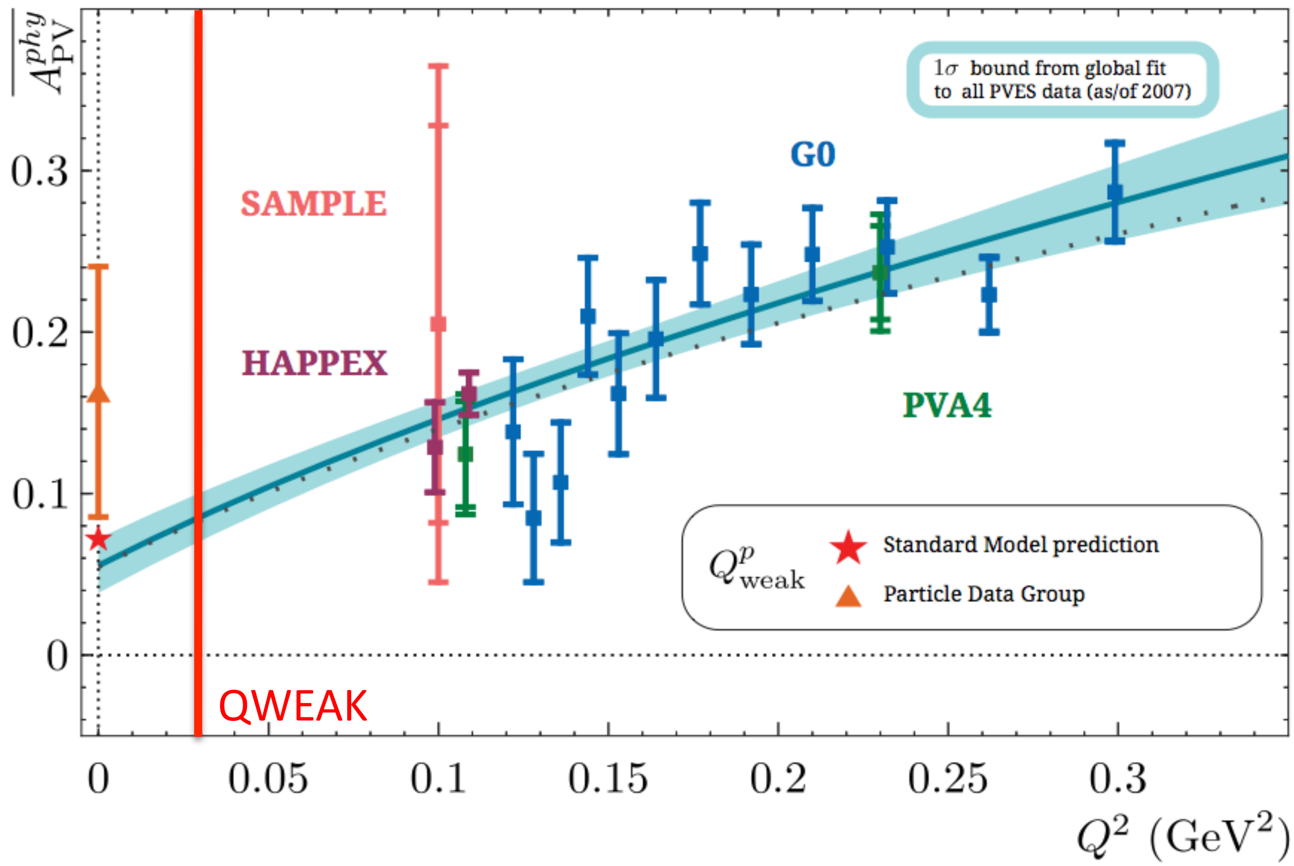
$$A_{PV}(p) = \frac{\sigma_R - \sigma_L}{\sigma_R + \sigma_L} \propto \frac{\mathcal{M}^{NC}_{PV}}{\mathcal{M}^{EM}} \propto \frac{Q^2}{M_Z^2} \quad \text{when } Q^2 \ll M_Z^2$$

For the specific case of e-p elastic scattering (ie QWEAK, G0, HAPPEX…)

$$A_{PV}(p) \xrightarrow{Q^2 \to 0} \frac{-G_F Q^2}{4\pi\alpha\sqrt{2}} \left[Q_W^p + Q^2 \cdot B(Q^2) \right]$$

$$A_{PV}(p) \xrightarrow{Q^2 \to 0} \frac{-G_F Q^2}{4\pi\alpha\sqrt{2}} \left[Q_W^p + Q^2 \cdot B(Q^2) \right] \Longleftrightarrow \overline{A_{PV}^{phy}} = \frac{A_{PV}^{phy}}{A_0 Q^2} = \left[Q_{weak}^p + B \cdot Q^2 \right]$$

R. Young, R. Carlini, A. Thomas, J. Roche PRL 99 (2007) 122003



Also use this type of analysis to extract

- The strange magnetic moment of the nucleon (μ_s=0.01 +/- 0.29) and
- The strange charge radius of the nucleon (ρ_s=0.02+/- 0.21 GeV^2).

R. Young, J. Roche , R. Carlini, A. Thomas PRL 97 (2006) 102002

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The QWEAK experiment

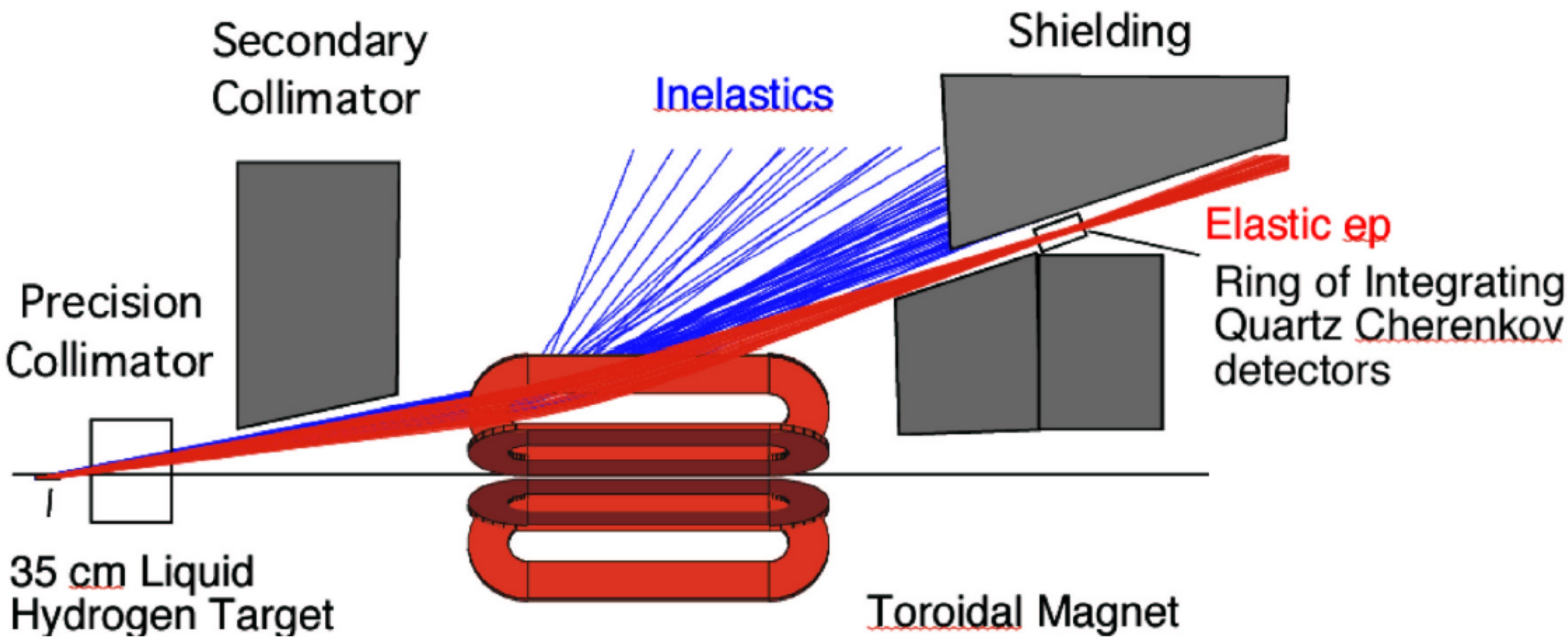
- Measures parity violation in electron-proton elastic scattering.
- Measures $\sin^2\Theta_W$ to 0.3% relative at low energy (Q^2=0.03 GeV^2).

- Pushing the luminosity envelope (number of events observed)
  - High beam current (180 μA)
  - Long powerful hydrogen cryo target (35 cm long, 2.5 kW removal power)
  - Large event rate 800 MHz
  - High beam polarization (~ 85%)
  - (Very) long data taking (>400 days of data taking over 2 years)

- Pushing the precision envelope (systematic-statistic)
  - Low noise apparatus
  - Helicity correlated beam characteristic at the level of the ppb.

QWEAK: conceptual overview

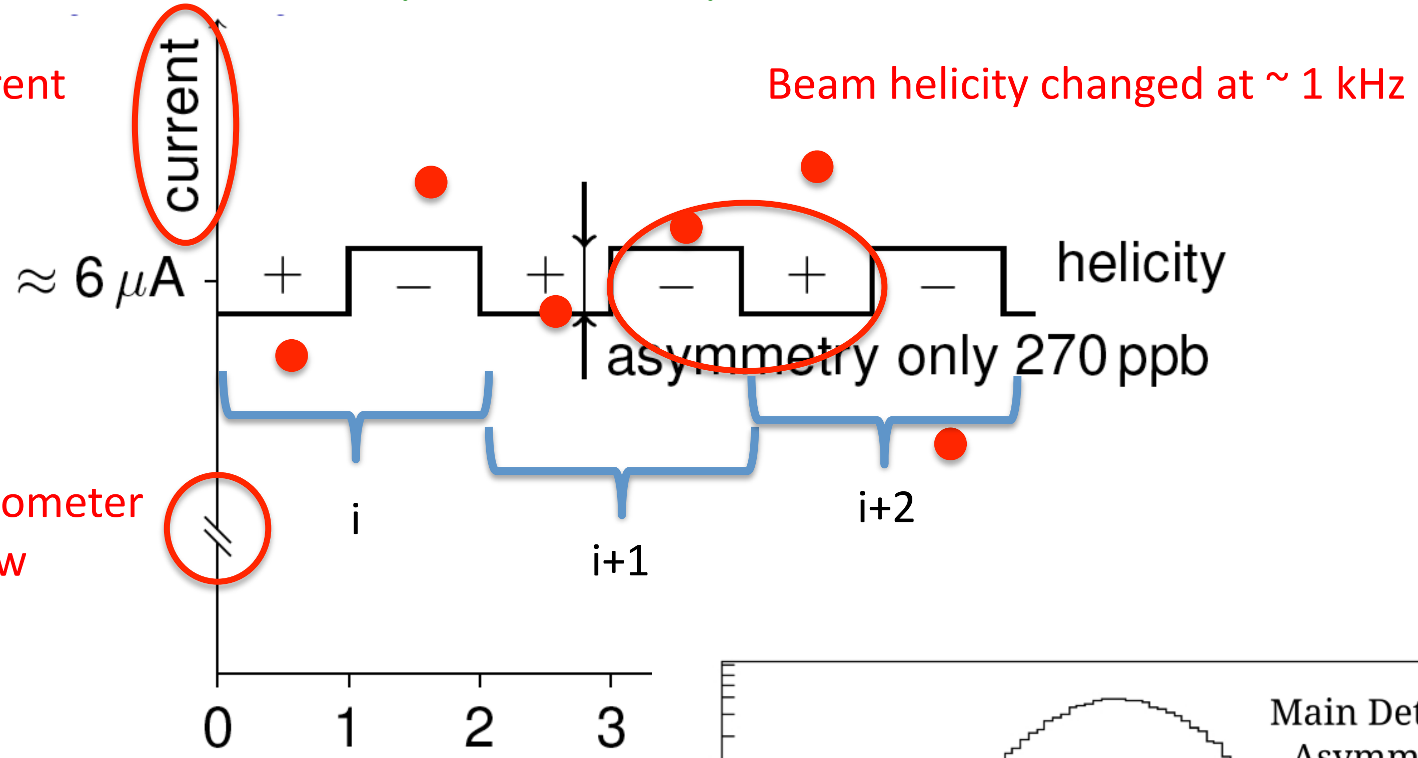
- Elastic e-p scattering on liquid hydrogen target
- Toroidal magnet to provide momentum dispersion
- Collimator system to select elastic events only
- Lower energy inelastic events bent outside of the detector acceptance



QWEAK: asymmetry measurement

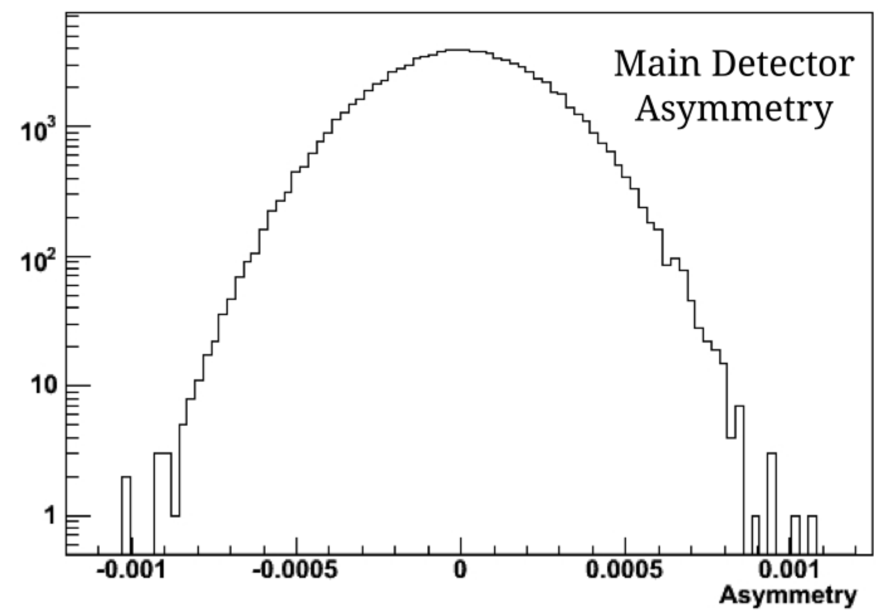
Detector current

Beam helicity changed at ~ 1 kHz



Zero few kilometer down below

Counting noise ~ 2000 larger than the asymmetry itself



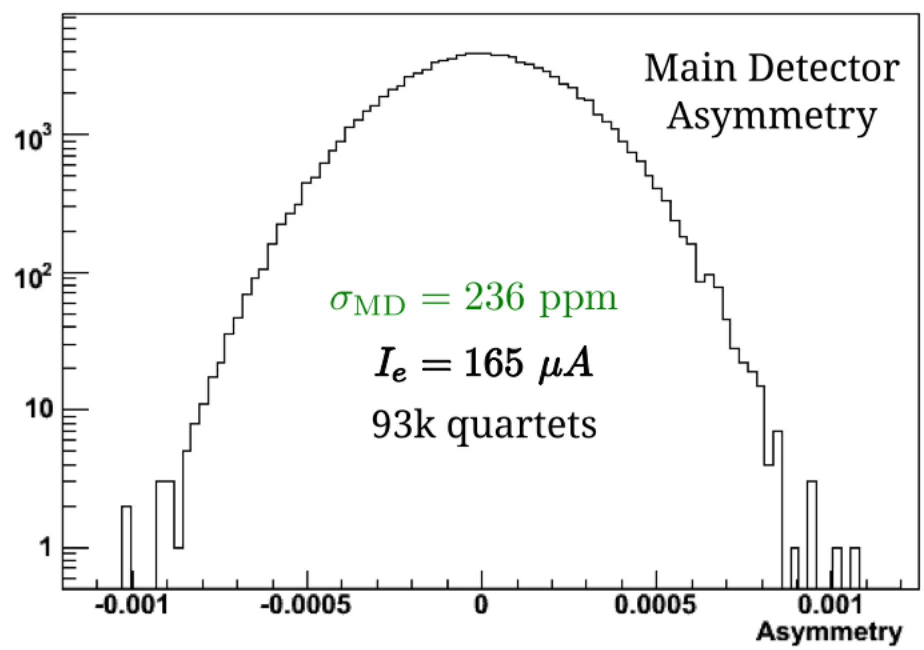
$$A_{exp} = \left\langle \sum_i \frac{I_+^i - I_-^i}{I_+^i + I_-^i} \right\rangle$$

QWEAK: asymmetry measurement width

- The random uncertainty on the measurement is $\Delta A = \sigma_{MD} / \sqrt{N}$

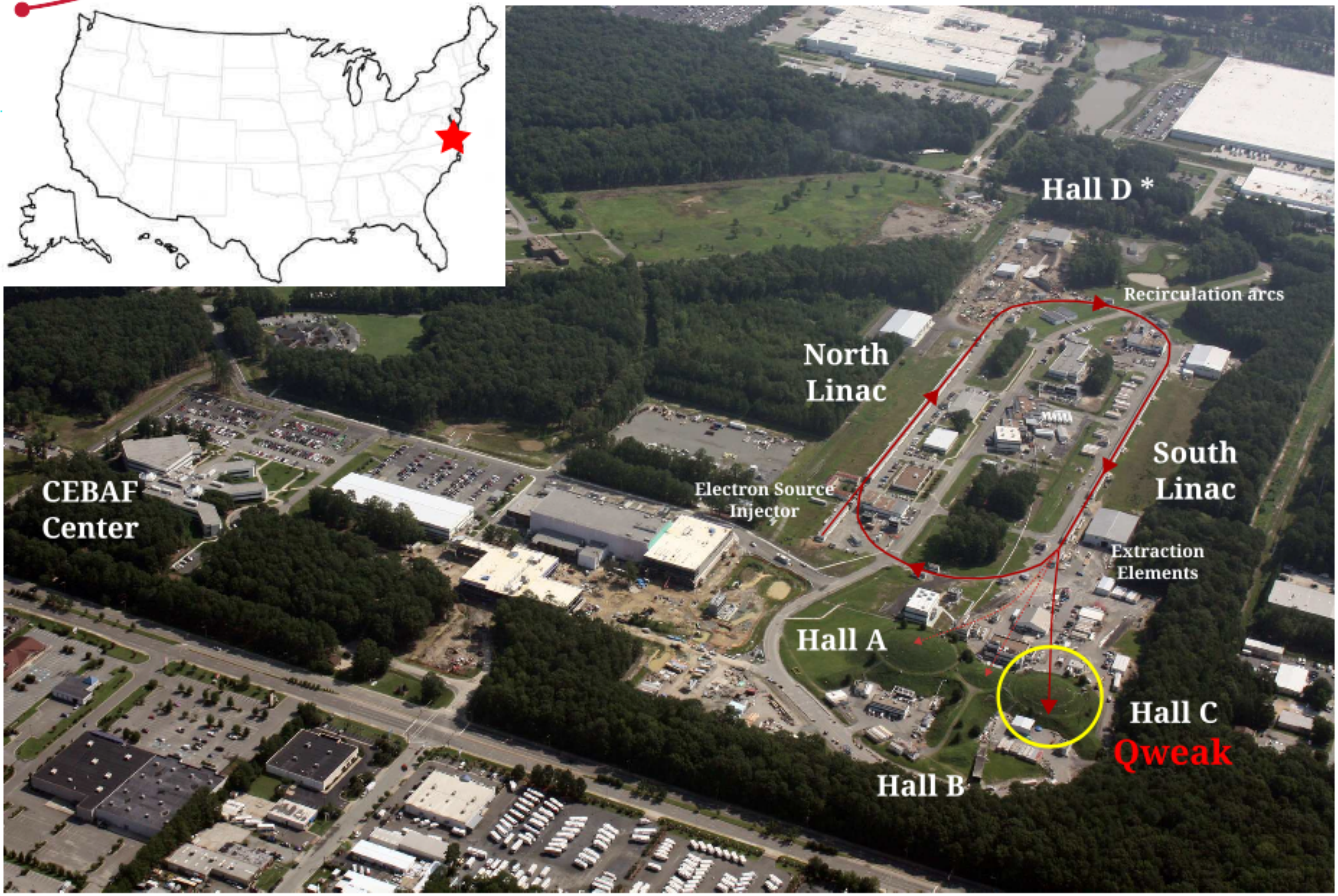
  with σ_{MD} is the intrinsic noise of the measurement
  and N is the number of integrated recording throughout the experiment

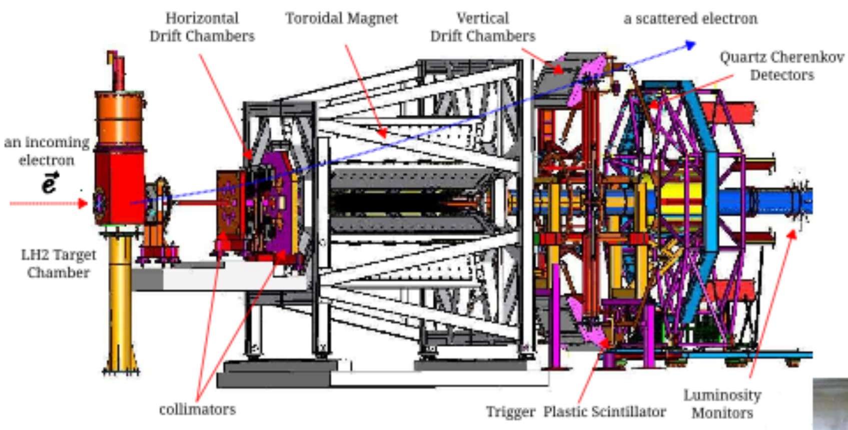
- Expected σ_{MD}~235 ppm
  $\sigma_{statistic}$ =215 ppm
  $\sigma_{detector\ energy\ resolution}$ = 87 ppm
  $\sigma_{current\ normalization}$ = 37 ppm

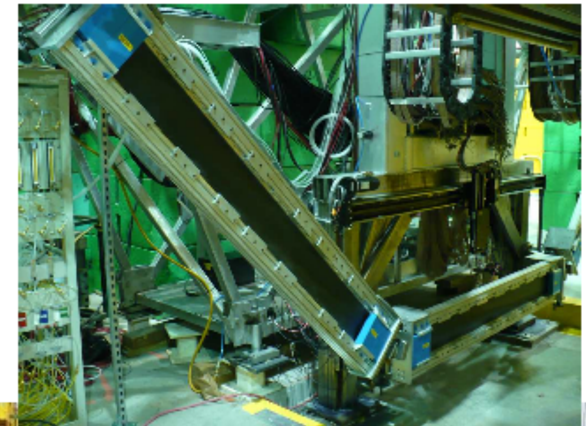


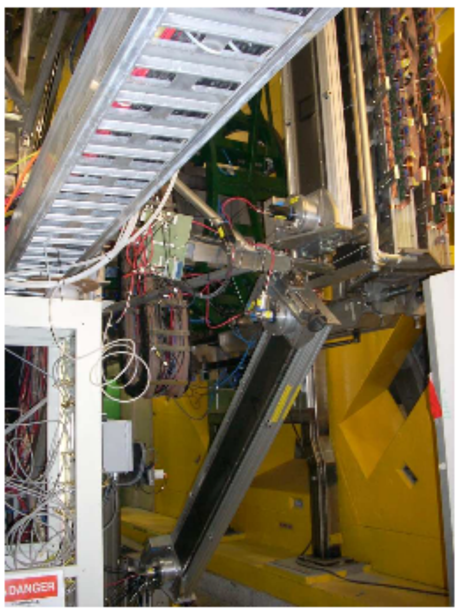
Jefferson Lab Newport News, Virginia, U.S.A.

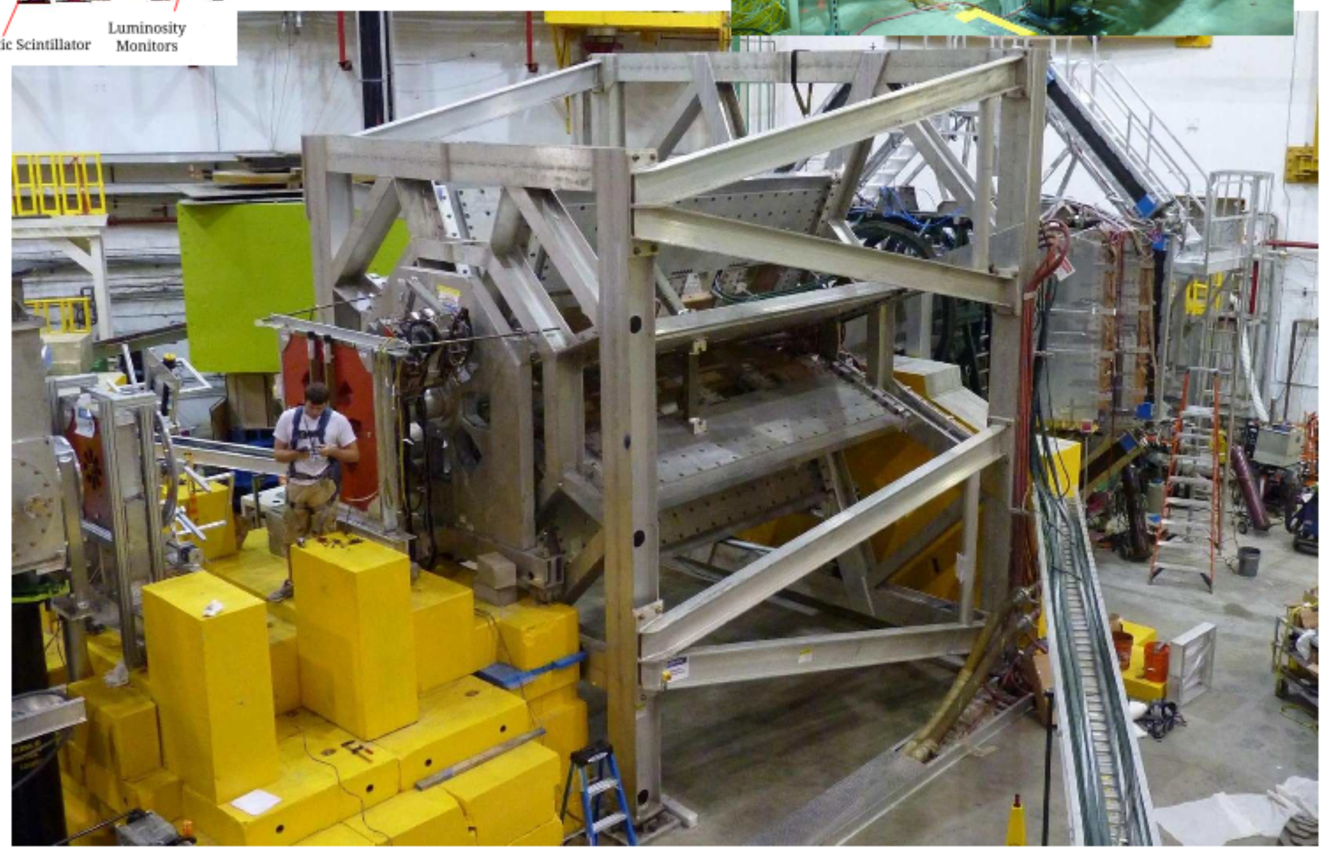
this aerial photo is courtesy of Jefferson Lab
at http://www.flickr.com/photos/jeffersonlab/




Horizontal
Drift Chambers
Toroidal Magnet
Vertical
Drift Chambers
a scattered electron
Quartz Cherenkov
Detectors
an incoming
electron
$\vec{e}$
LH2 Target
Chamber
collimators
Trigger Plastic Scintillator
Luminosity
Monitors




DANGER



A. Almasalha, D. Androic, D.S. Armstrong, A. Asaturyan, T. Averett, J. Balewski, R. Beminiwattha,J. Benesch, F. Benmokhtar, J. Birchall, R.D. Carlini (Principal Investigator), G. Cates, J.C. Cornejo, S. Covrig, M. Dalton, C. A. Davis, W. Deconinck, J. Diefenbach, K. Dow, J. Dowd, J. Dunne, D. Dutta, R. Ent, J. Erler, W. Falk, J.M. Finn*, T.A. Forest, M. Furic, D. Gaskell, M. Gericke, J. Grames, K. Grimm, D. Higinbotham, M. Holtrop, J.R. Hoskins, E. Ihloff, K. Johnston, D. Jones, M. Jones, R. Jones, K. Joo, J. Kelsey, C. Keppel, M. Kohl, P. King, E. Korkmaz, S. Kowalski, J. Leacock, J.P. Leckey, A. Lee, J.H. Lee, L. Lee, N. Luwani, S. MacEwan, D. Mack, J. Magee, R. Mahurin, J. Mammei, J. Martin, M. McHugh, D. Meekins, J. Mei, R. Michaels, A. Micherdzinska, A. Mkrtchyan, H. Mkrtchyan, N. Morgan, K.E. Myers, A. Narayan, Nuruzzaman, A.K. Opper, S.A. Page, J. Pan, K. Paschke, S.K. Phillips, M. Pitt, B.M. Poelker, J.F. Rajotte, W.D. Ramsay, M. Ramsey-Musolf, J. Roche, B. Sawatzky, T. Seva, R. Silwal, N. Simicevic, G. Smith, T. Smith, P. Solvignon, P. Souder, D. Spayde, A. Subedi, R. Subedi, R. Suleiman, E. Tsentalovich, V. Tvaskis, W.T.H. van Oers, B. Waidyawansa, P. Wang, S. Wells, S.A. Wood, S. Yang, R.D. Young, S. Zhamkochyan, D. Zou

Spokespersons, Project Manager, and * deceased

The members of the OU group :

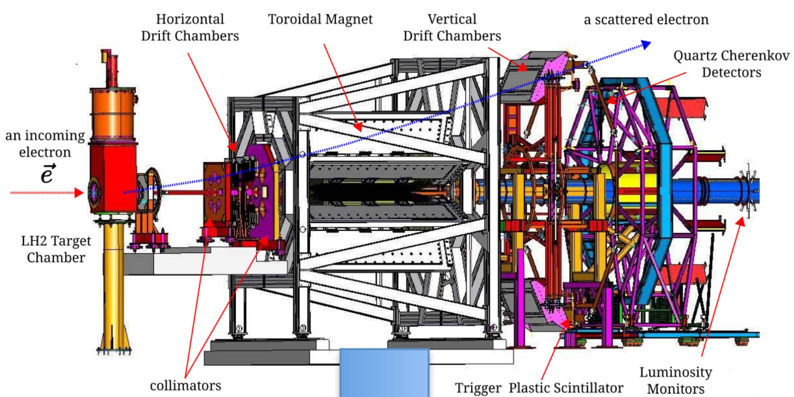
P. King, R. Beminiwattha*, B. Waidyawansa*, JH Lee**
and 6 OU undergraduate summer students (since 2006)

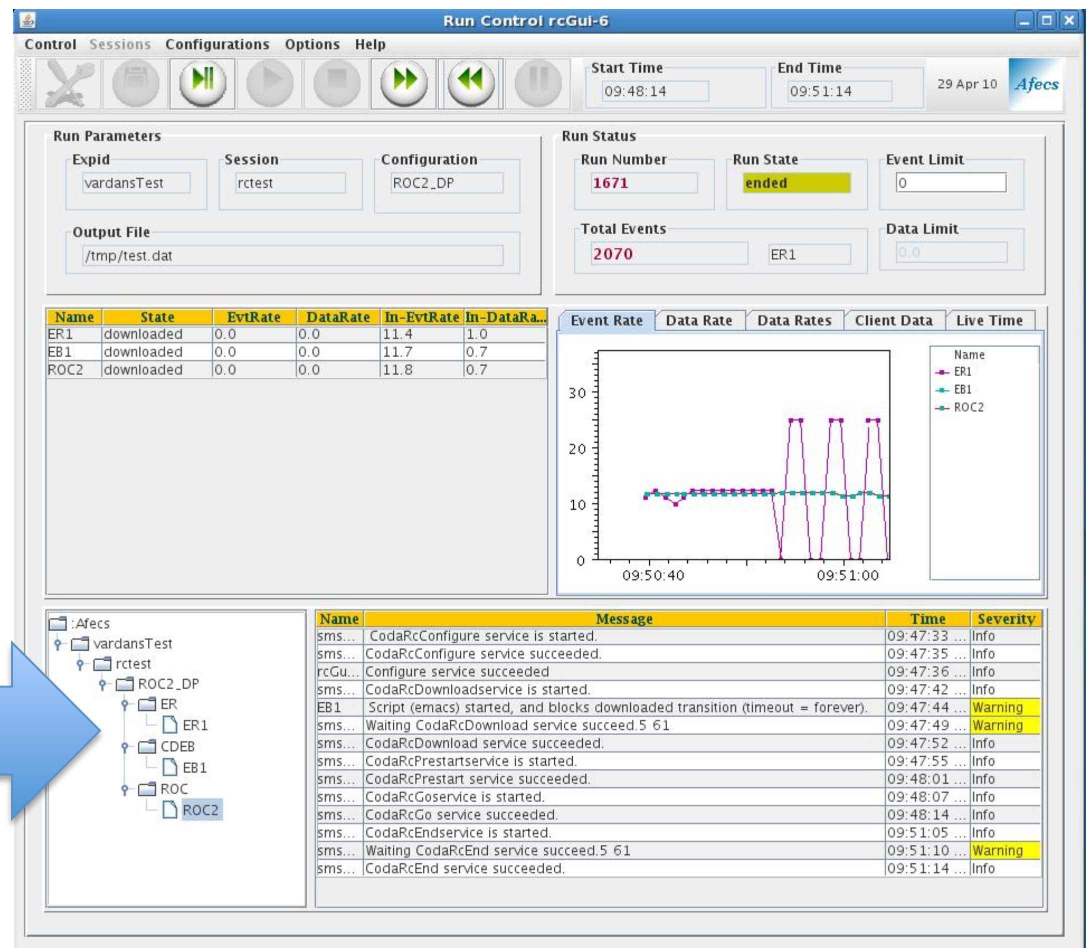
*OU graduate students   ** Postdoc

The role of the OU group

- Data Acquisition system:

  design, implement, test and maintain the read-out systems and the trigger systems



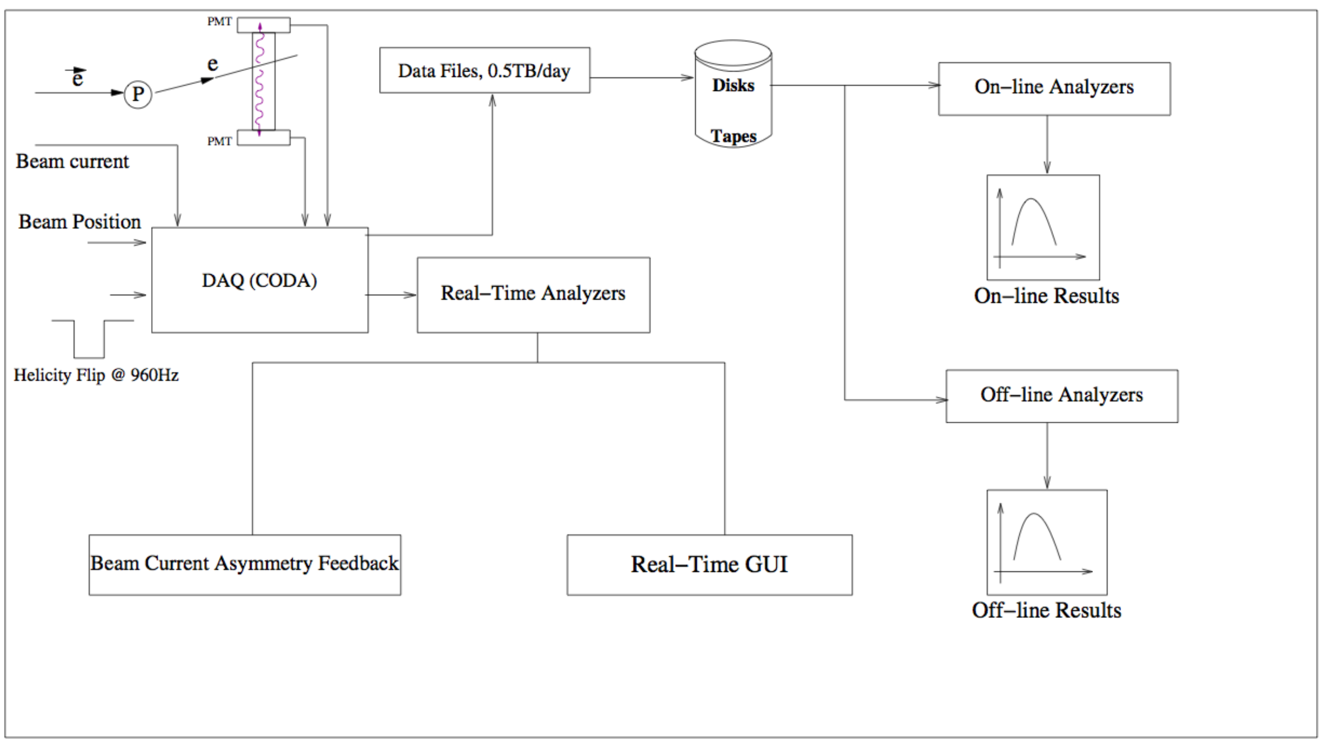


The role of the OU group

- Data Acquisition system:

  - design, implement, test and maintain the read-outs systems and the triggers systems
  - manage about 0.5 TB of data/day (expecting a total of 250 TB of data)

- Core analysis software:



The role of the OU group

- Data Acquisition system:

  - design, implement, test and maintain the read-outs systems and the triggers systems

  - manage about 0.5 TB of data/day (expecting a total of 250 TB of data)

- Core analysis software:

  - develop one software framework for online monitoring tools, feedback systems, and full fledged analysis code (over 100k lines of code)

  -test, operate, share and maintain the core C++ analysis software

  - support/mentor users in with their own additions to the code (to date 10 doctoral students, 7 senior persons, UGs and non-thesis students have contributed to the code – over time)

QWEAK status

- Schedule
  - First commissioning beam: July 2010
  - Commissioning run: Fall 2010
  - Run I: Jan-May 2011
  - Run II: Nov 2011-May 2012

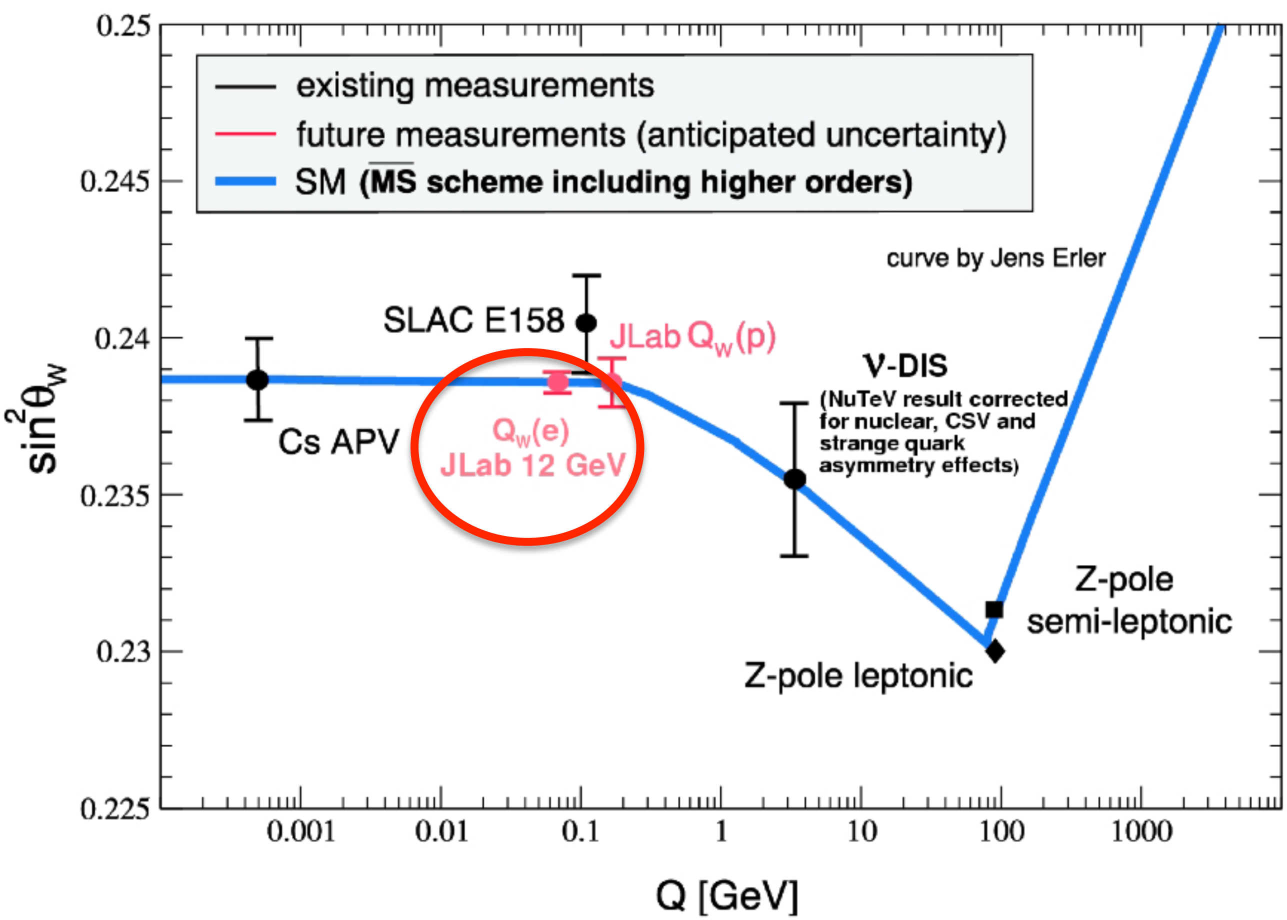
- Teething problems
  - Target pump, beam dump vacuum leakage, Qtor magnet power supply, etc..

- Achievement
  - Beam 150-180 uA with 86-88% polarization (better than our proposal)
  - Helicity-correlated beam properties are acceptable
  - At present, we have on tape 24% of proposed statistics
  - Many auxiliary measurements completed.

The future of PVES and the OU group: the Moeller experiment

- Moeller scattering on hydrogen **e**+e(in H)-> e+e
- Ultra precise measurement of $\sin^2\Theta_w$ in the leptonic sector

ΔA_{exp}=0.7 ppb (ΔA_{QWEAK}=6 ppb, ΔA_{G0}=500 ppb)



The future of PVES and the OU group: the Moeller experiment

- Moeller scattering on hydrogen **e**+e(in H)-> e+e
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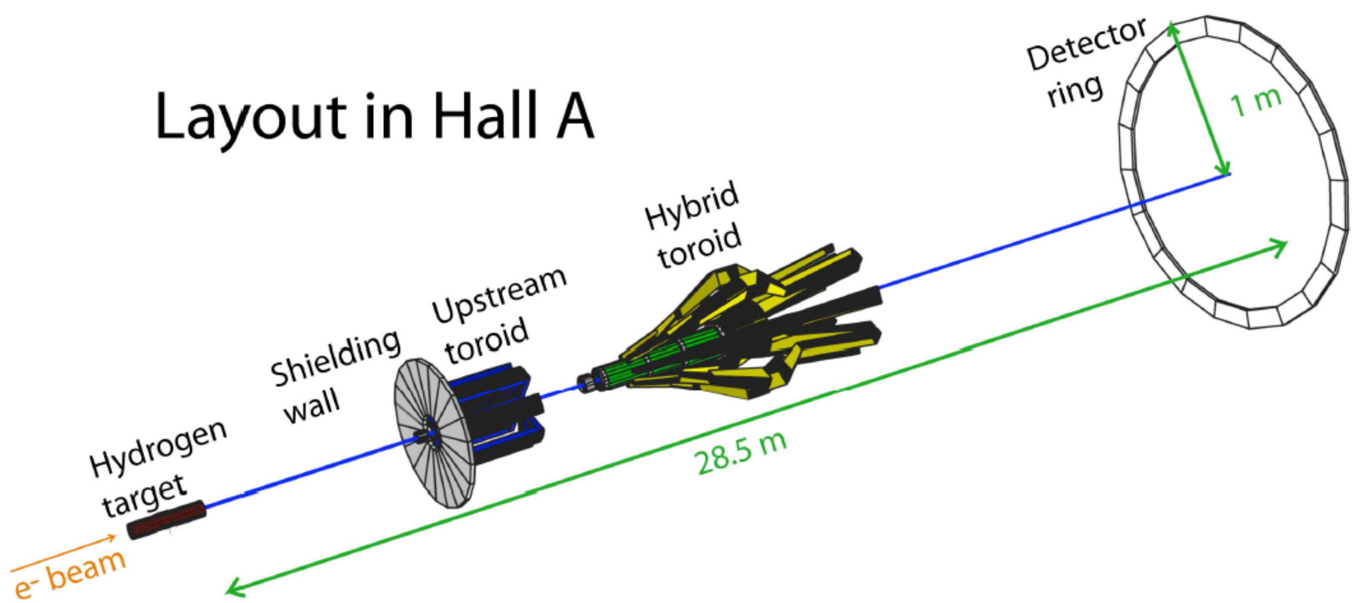
- Very forward experimental design

  Two toroidal magnets (one regular, one hybrid)



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- Moeller scattering on hydrogen **e**+e(in H)-> e+e
- Ultra precise measurement of $\sin^2\Theta_w$ in the leptonic sector

- Very forward experimental design

  Two toroidal magnets (one regular, one hybrid)

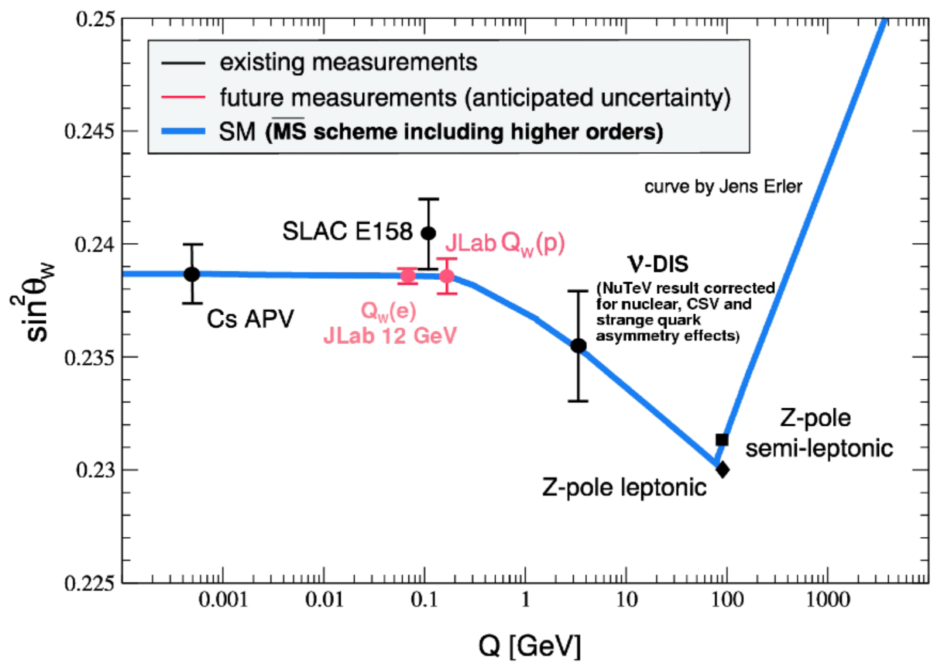
- Proposal accepted by the JLAB PAC with the highest scientific rating in January 2011
- DOE MIE proposal submitted in September 2011
- OU responsibility:
  - DAQ and software analysis
  - Luminosity detector
- Data taking to start (possibly) in 2017

In summary

- The Standard Model of Particle Physics is one of the biggest achievements of the twentieth century… still it is known to be incomplete

- Low energy precision tests of the Standard Model (like Parity Violation Electron Scattering) are proven avenues to discover Physics beyond the Standard Model

- QWEAK and Moeller are such experiments in which my OU group is involved.



The core of the model:

Electroweak unification

- Parity is conserved for the EM interaction (γ exchange)
- Parity is partially or fully violated for the weak interaction (resp. Z or Ws exchange)

Glashow-Weinberg-Salam's idea :

- Reformulate the Lagrangian energy density as

$$L = g\,\vec{J}_\mu \cdot \vec{W}_\mu + g'\,J^Y_\mu B_\mu$$ similar to E&M formulation $$L = \vec{j} \cdot \vec{A} = q\ \vec{v} \cdot \vec{A}$$

J_μ and J_μ^Y: weak isospin and weak hypercharge current carried by the fermions
W_μ and B_μ are the 4-potentials of the interactions
g and g': coupling constants and **$g'/g=\tan\Theta_W$ (Weinberg angle)**
$Y=Q-I_3$ hypercharge (Q: electric charge, I_3: 3rd component of weak isospin)

$$W^\pm_\mu = \frac{1}{\sqrt{2}}\left[W^1_\mu \pm iW^2_\mu\right] \qquad W^3_\mu = \frac{gZ_\mu + g'A_\mu}{\sqrt{g^2+g'^2}} \qquad B_\mu = \frac{-g'Z_\mu + gA_\mu}{\sqrt{g^2+g'^2}}$$

A_μ , Z_μ , W_μ^+ and W_μ^- are the fields for the boson particles γ, Z, W^+ and W^-

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$$L = g\,\vec{J}_\mu \cdot \vec{W}_\mu + g'\,J^Y_\mu\,B_\mu$$

- Introduce the Weinberg angle that describes the mixing of the weak and the EM interaction ($\tan\Theta_W = g'/g$)

$$L = \frac{g}{\sqrt{2}}\left(J^-_\mu W^+_\mu + J^+_\mu W^-_\mu\right) + \frac{g}{\cos\theta_W}\left(J^3_\mu - \sin^2\theta_W J^{em}_\mu\right)Z_\mu + g\,\sin\theta_W\,J^{em}_\mu A_\mu$$

$$\sin\theta_W = \frac{e}{g} \quad \textit{Weinberg angle}$$

Electroweak Interaction: Running of $\sin^2\theta_W$

Atomic parity-violation on ^{133}Cs

- New calculation in many-body atomic theory
- Porsev, Beloy, Derevianko; arXiv:0902.0335 [hep-ph]
- Experiment: $Q_W(^{133}\text{Cs}) = -73.25 \pm 0.29 \pm 0.20$
- Standard Model: $Q_W(^{133}\text{Cs}) = -73.16 \pm 0.03$

NuTeV anomaly explained

- Originally, $3\,\sigma$ deviation from Standard Model
- Erler, Langacker: strange quark PDFs
- Londergan, Thomas: charge symmetry violation, $m_u \neq m_d$
- Cloet, Bentz, Thomas: in-medium modifications to PDFs, isovector EMC-type effect
- Entire anomaly accounted for (everybody stops looking...)

Slide by W. Deconick, W&M

Sensitivity to New Physics

New physics

- Consider effective contact interaction
- Coupling constant g, mass scale Λ
- Effective charges $h_V^u = \cos\theta_h$ and $h_V^d = \sin\theta_h$

Effective Lagrangian

$$\begin{aligned}\mathcal{L}_{e-q}^{PV} &= \mathcal{L}_{SM}^{PV} + \mathcal{L}_{New}^{PV} \\ &= -\frac{G_F}{\sqrt{2}}\bar{e}\gamma_\mu\gamma_5 e \sum_q C_{1q}\bar{q}\gamma^\mu q + \frac{g^2}{4\Lambda^2}\bar{e}\gamma_\mu\gamma_5 e \sum_q h_q^V \bar{q}\gamma^\mu q\end{aligned}$$

Slide by W. Deconick, W&M

Sensitivity to New Physics

Lower bound on new physics (95% CL)

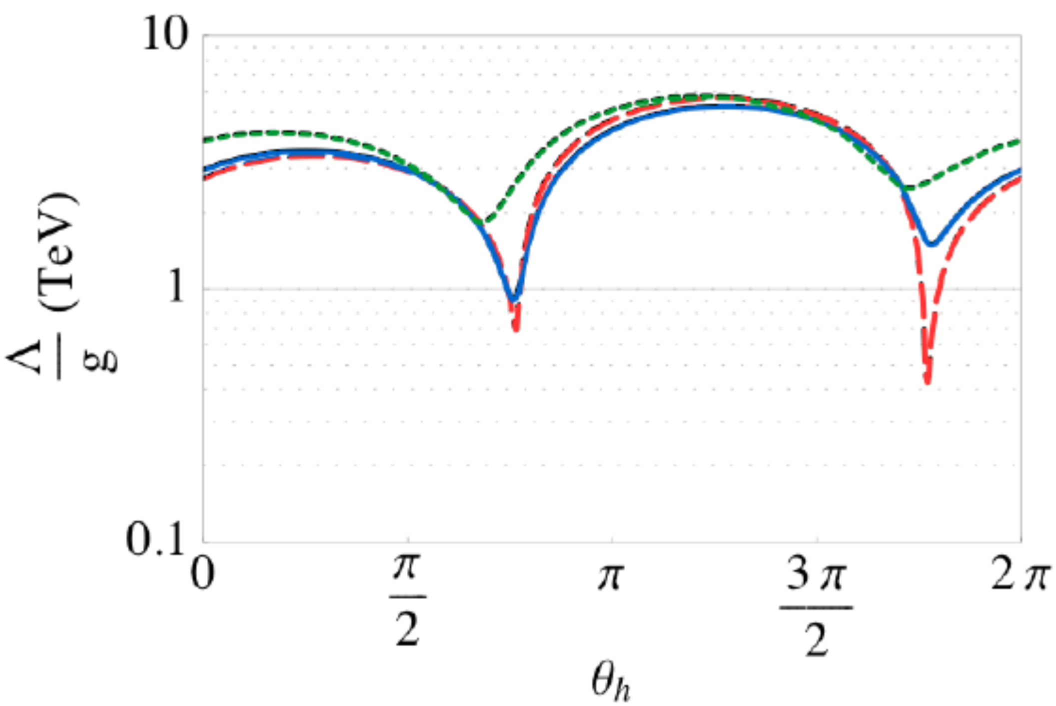


Figure: Young, Carlini, Thomas, Roche (2007)

Constraints from

- Atomic PV: $\frac{\Lambda}{g} > 0.4\ TeV$
- PV electron scattering: $\frac{\Lambda}{g} > 0.9\ TeV$

Projection Q_{weak}

- $\frac{\Lambda}{g} > 2\ TeV$
- 4% precision

Slide by W. Deconick, W&M

QWEAK: summary

Experiment Basic Parameters

Incident Beam Energy	1.165 GeV
Beam Polarization	85%
Beam Current	180 μA
Acceptance Averaged $A^p_{\rm LR}$	-0.234 ppm

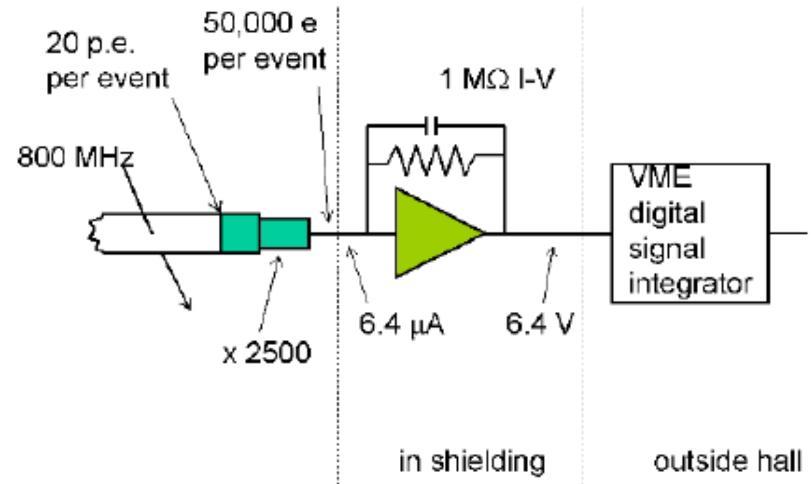
Error Estimate for the experiment

Source of error	$\Delta A^p_{\rm LR}/A^p_{\rm LR}$	$\Delta Q^p_{\rm W}/Q^p_{\rm W}$
Statistics	2.1%	3.2%
Hadronic structure	-	1.5%
Polarimetry	0.5%	1.0%
Absolute Q^2	0.5%	1.0%
Backgrounds	0.5%	0.7%
Helicity-correlated beam properties	0.5%	0.7%
Total	2.5%	4.1%

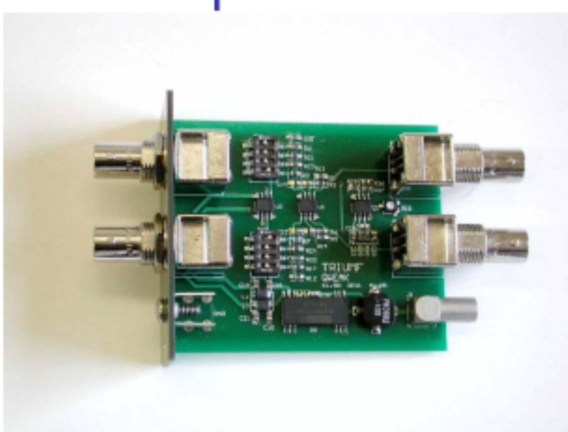
The Q_{weak} Experiment: Main Detector

Low noise electronics

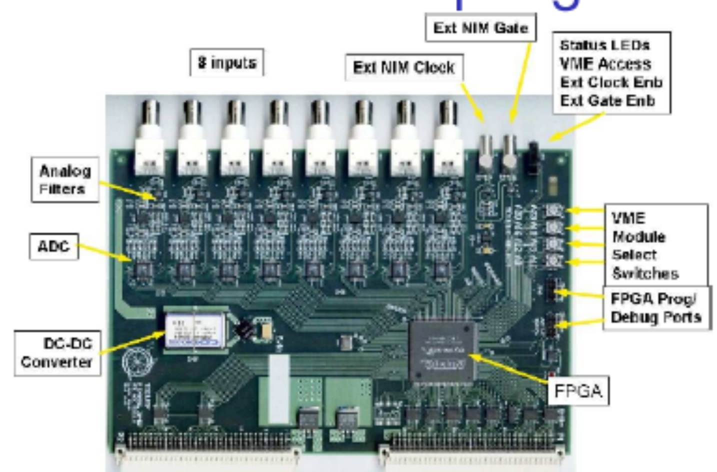
- Event rate: 800 MHz/PMT
- Asymmetry of only 0.2 ppm
- Low noise electronics (custom design, TRIUMF)



I-V Preamplifier



18-bit 500 kHz sampling ADC



Delivered, tested: noise is 3 times lower than counting statistics

Slide by W. Deconick, W&M

The Q_{weak} Experiment: Tracking Mode

Reasons for a tracking system?

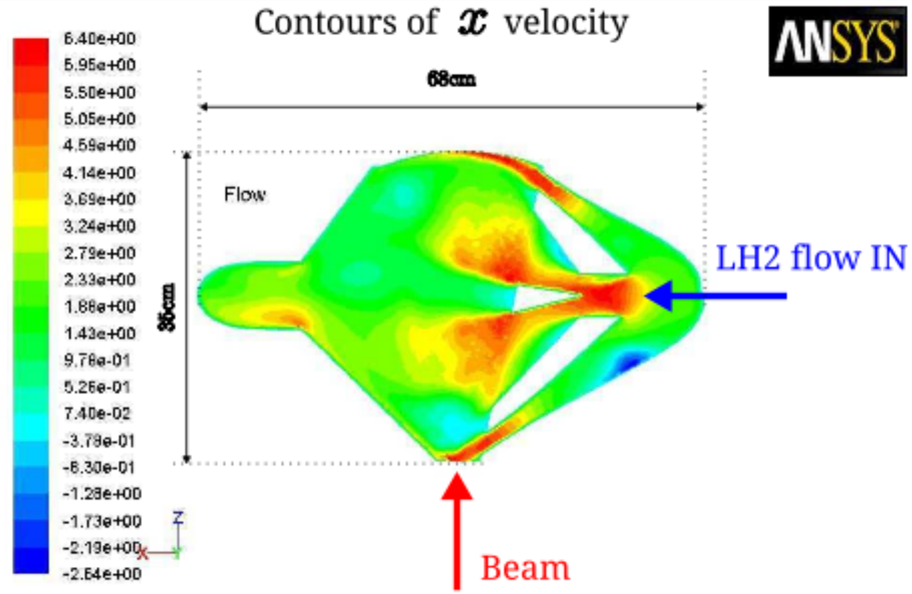
- Determine Q^2, note: $A_{meas} \propto Q^2 \cdot (Q_W^p + Q^2 \cdot B(Q^2))$
- Quartz detector light output versus position
- Contributions from inelastic background events

Instrumentation of two octants

- Gas-electron multiplier foils (GEM) close to target vertex
- Horizontal drift chambers (HDC) for front region
- Vertical drift chambers (VDC) for back region
- Rotation allows measurements in all 8 octants

Slide by W. Deconick, W&M

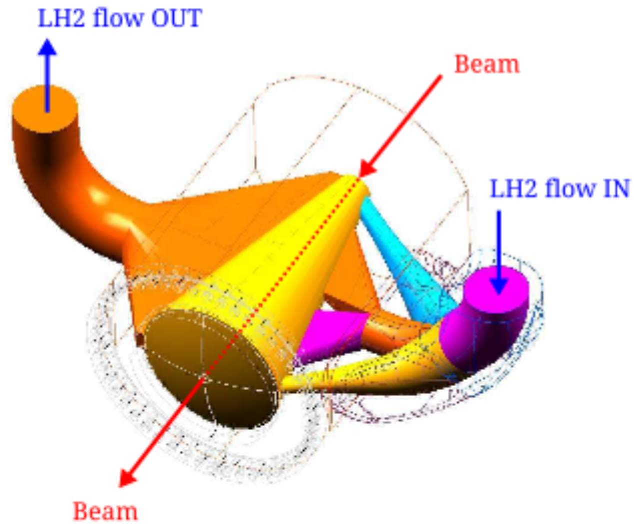
The Highest Power $\mathcal{L}H_2$ Target

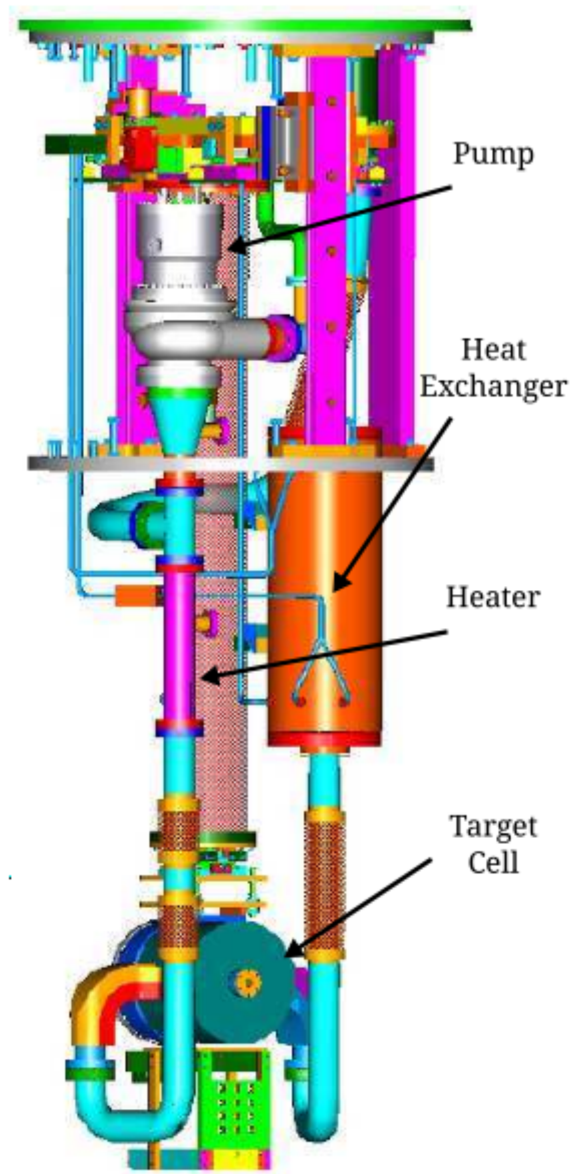


(m/s)

Designed by using
Computational Fluid Dynamics (CFD)

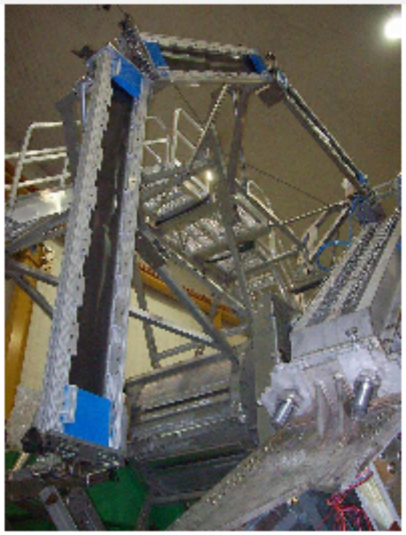
- 2500 W Power
- up to 180 μA
- transverse flow design by CFD (smaller ΔT in fluid and $\Delta \rho$ across target cell

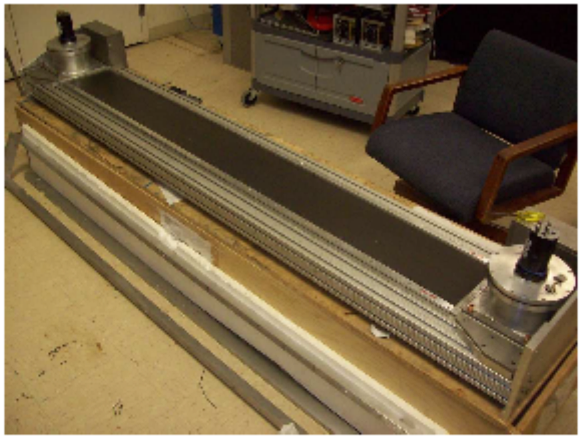


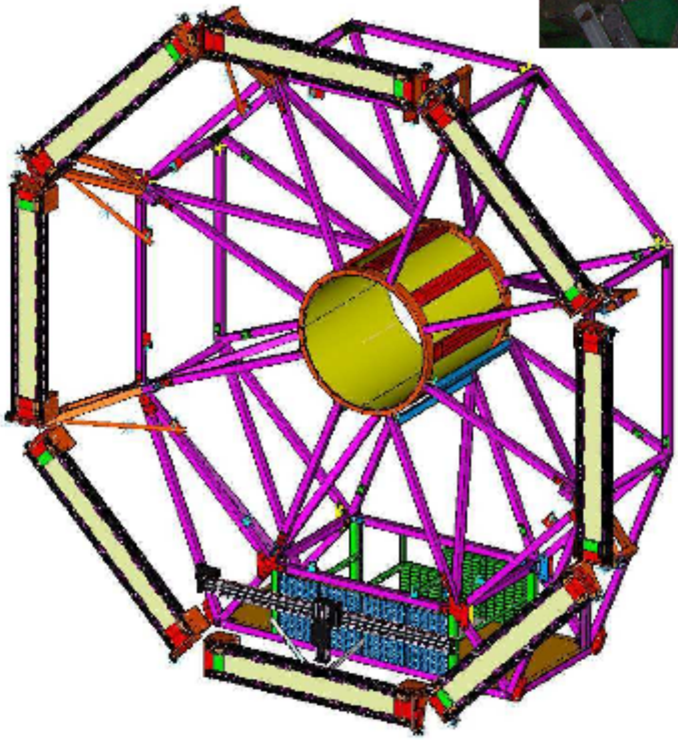


Main Detectors

- Cherenkov Radiator $200 \times 18 \times 1.25\ cm^3$ Spectrosil 2000 : radiation hardness, non-scintillating, and low-luminescence
- lightguide $18 \times 18 \times 1.25\ cm^3$ attached to each end (fused silica)
- Two 5 inch PMTs per bar
- Parity Mode up to 180 μA
- Tracking Mode 50 pA







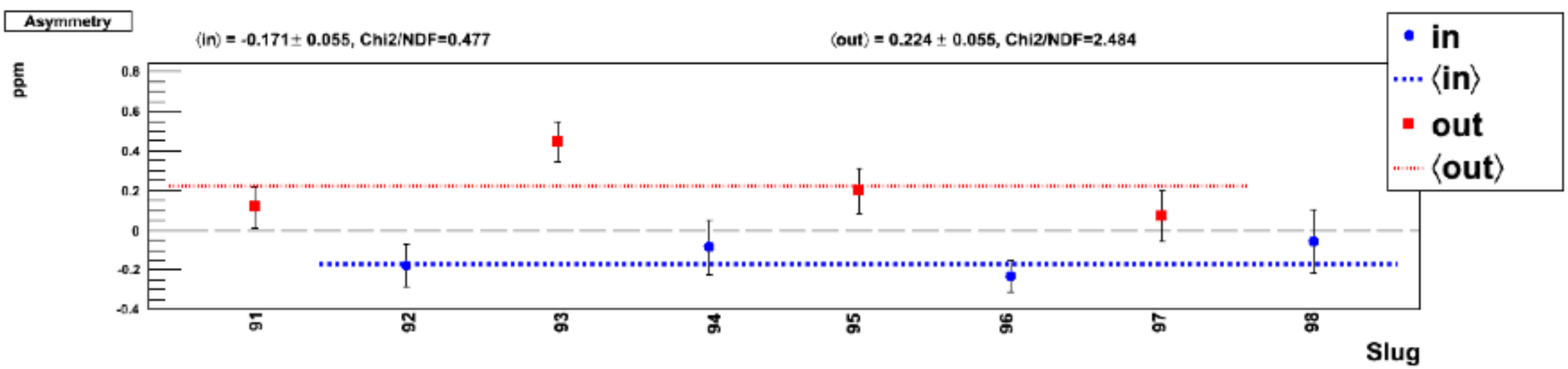
Parity Mode : PV Asymmetry Measurement

systematic check by optically reversing beam helicity

- change overall helicity pattern by insertable $\lambda/2$ plate

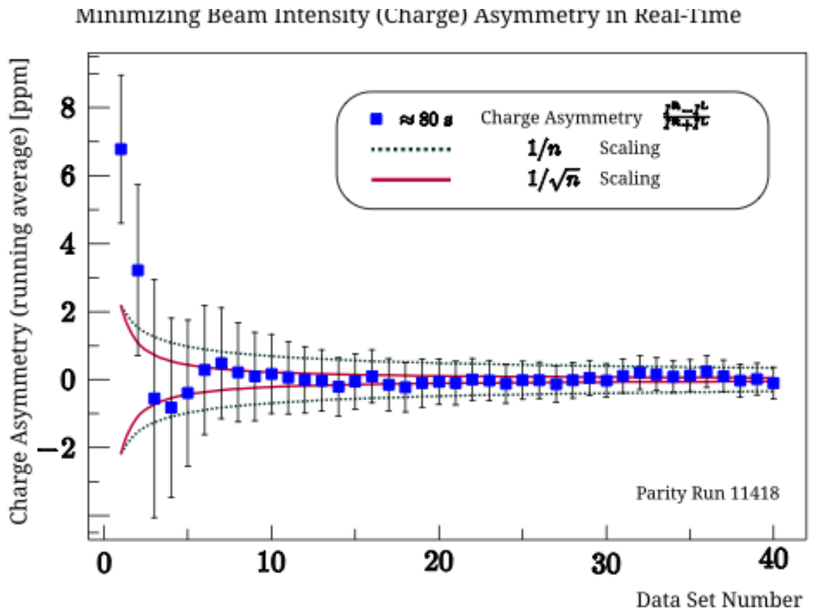
$$+ - - + \quad \Longleftrightarrow \quad - + + -$$

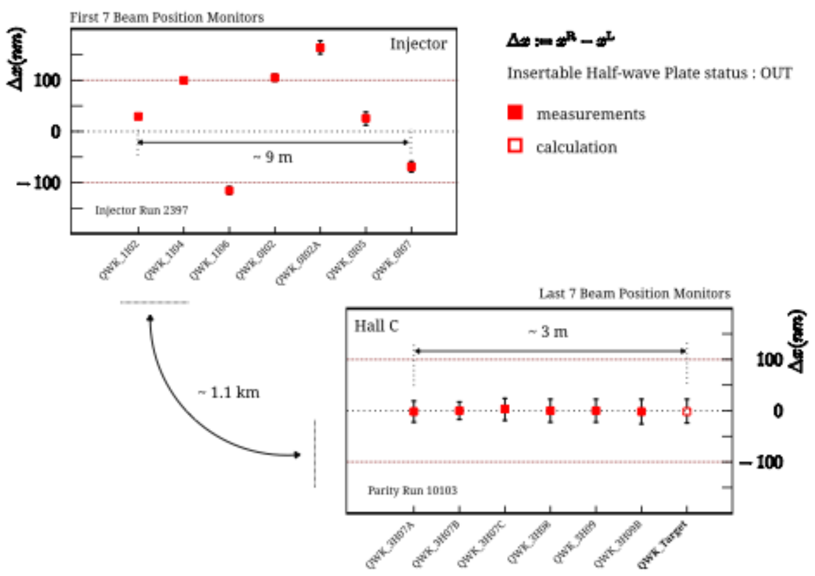
- expected the sign change of a measured PV asymmetry
- good systematic check of the main detector
- Slug is roughly 8 hours
- unregressed and uncorrected plot



Charge Asymmetry

- run a beam intensity feedback program during a data taking simultaneously
- keep the helicity-correlated beam intensity below 0.1 ppm
- the right result during one run period, which is usually 1 hour.



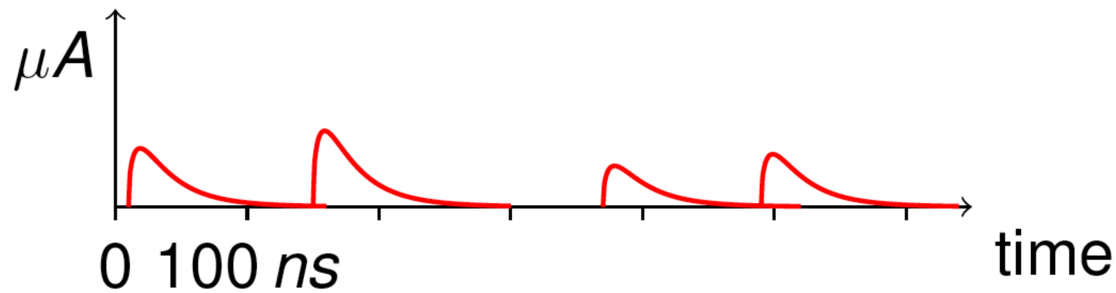


Position Differences

- monitor and record the beam position differences between two helicity states
- recorded data are used to extract the position sensitivities to the PV asymmetry
- have achieved the position sensitivities contribution to the asymmetry below 0.2 ppm

QWEAK: Integrating method

- Event mode (low intensity beam current 10 pA)
  - Each event individually registered
  - Selection or rejection possible



- Current (or integration) mode
  - High event rate possible
  - No suppression of background event possible