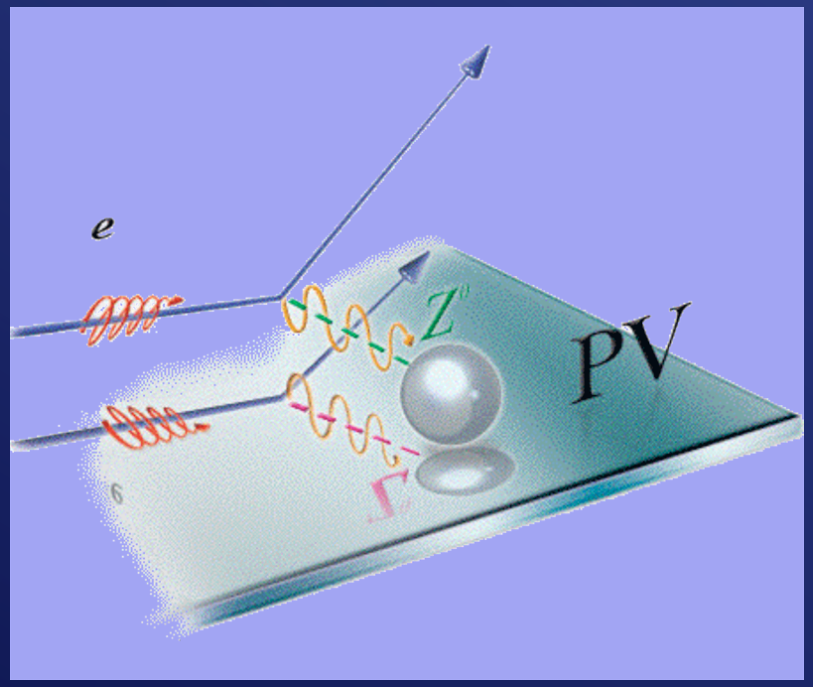
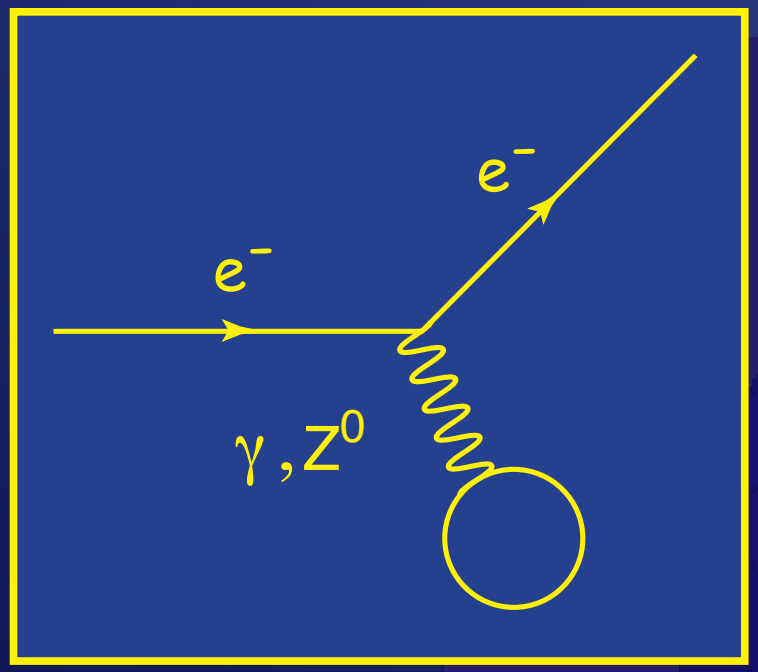
The 12 GeV Moller Experiment



Gordon D. Cates and Krishna Kumar
UVa and UMass

Hall A Collaboration Meeting - June 13, 2008

Electroweak interference and parity violation and in electron scattering



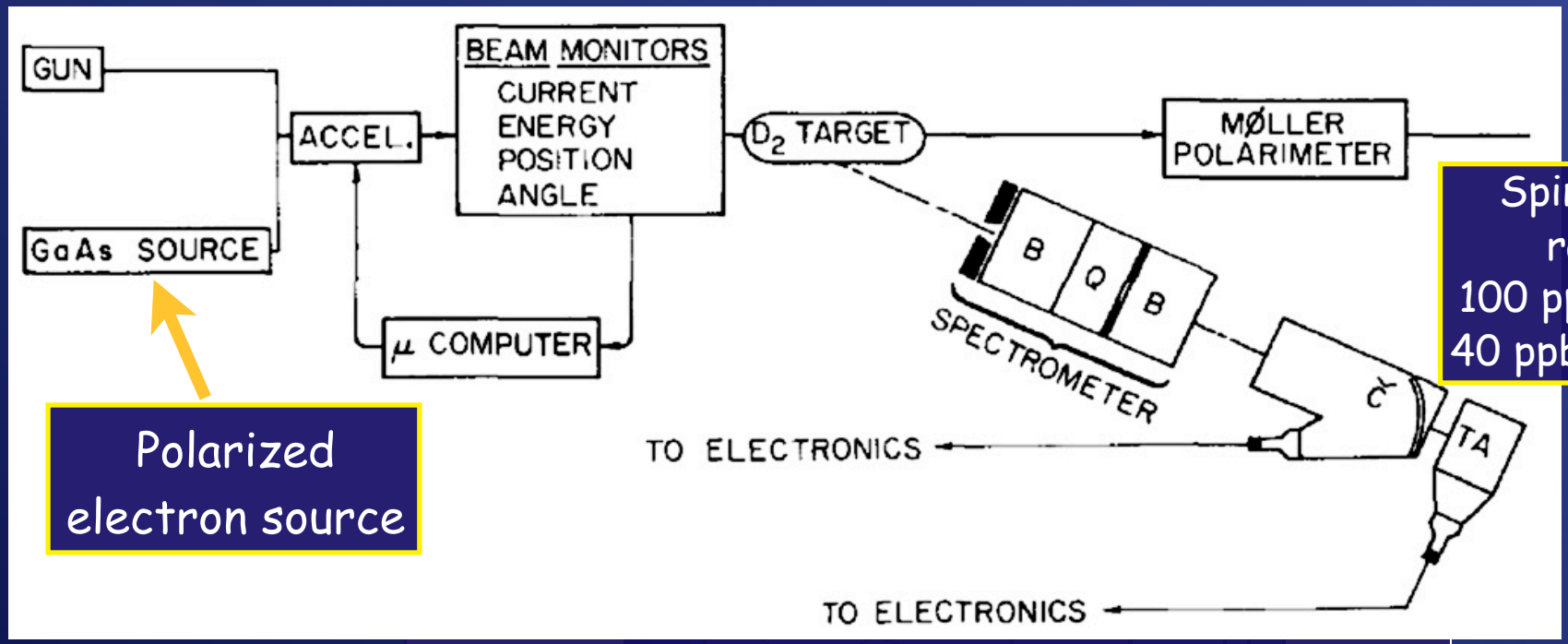
$$\sigma \sim |A_\gamma + A_{weak}|^2$$

- Pivotal in establishing the standard model at SLAC during the Prescott Experiment (SLAC E122)
- Currently provides the most precise measurement of $\sin^2\theta_W$ at low Q^2 (SLAC E158 - Moller)
- Will soon provide an even more precise measurement of $\sin^2\theta_W$ at low Q^2 (Qweak)

$$-A_{LR} = A_{PV} = \frac{\sigma_\uparrow - \sigma_\downarrow}{\sigma_\uparrow + \sigma_\downarrow} \sim \frac{A_{weak}}{A_\gamma} \sim \frac{G_F\, Q^2}{4\,\pi\,\alpha}$$

The experimental challenge

Many of the issues are the same as those faced by Prescott during E122



Polarized electron source

Spin asymmetries ranging from 100 ppm (Prescott) to 40 ppb (11 GeV Moller)

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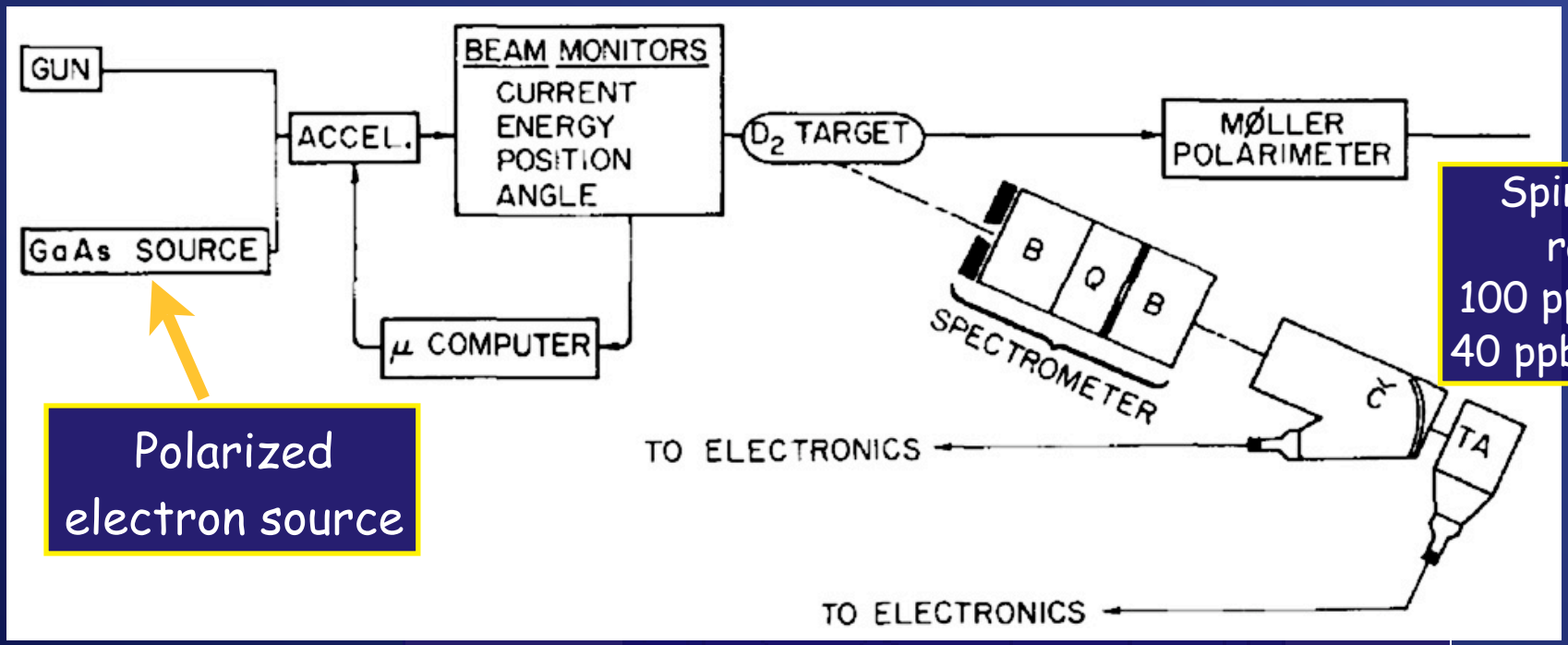

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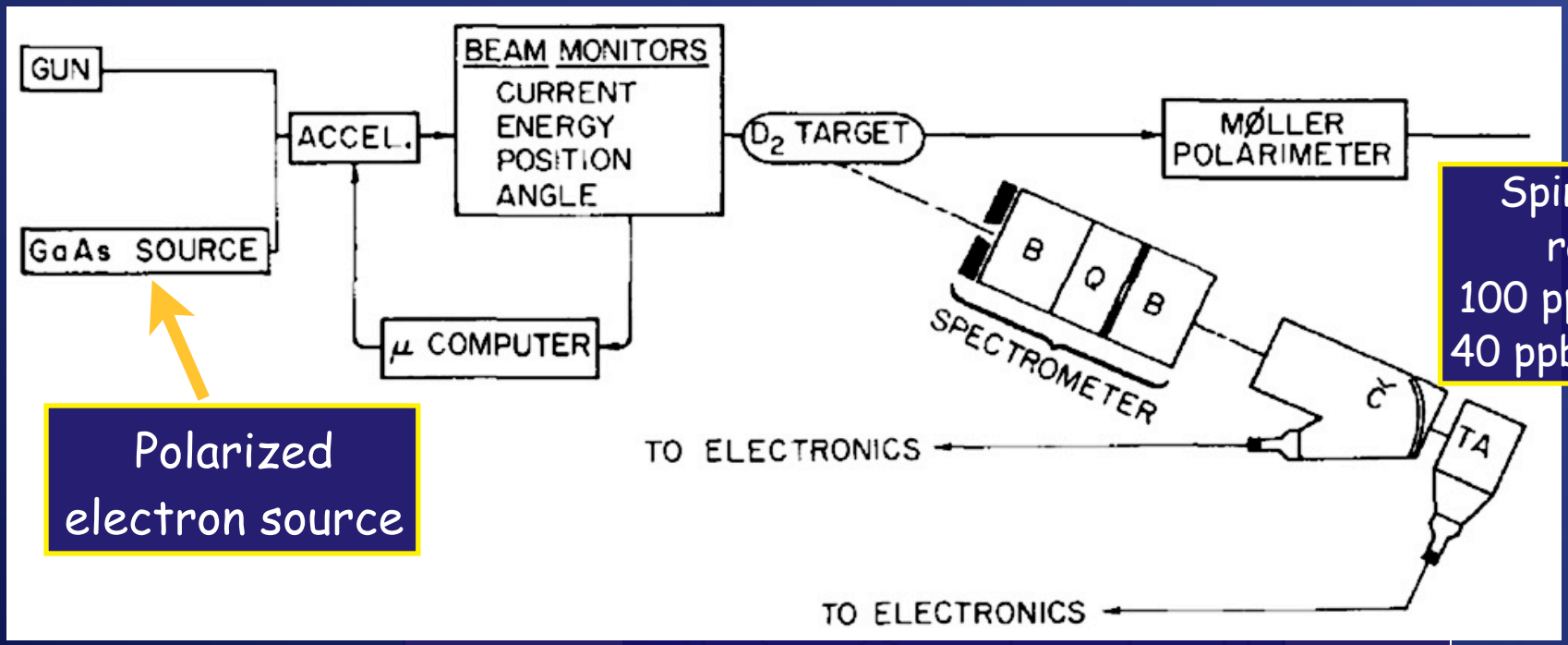

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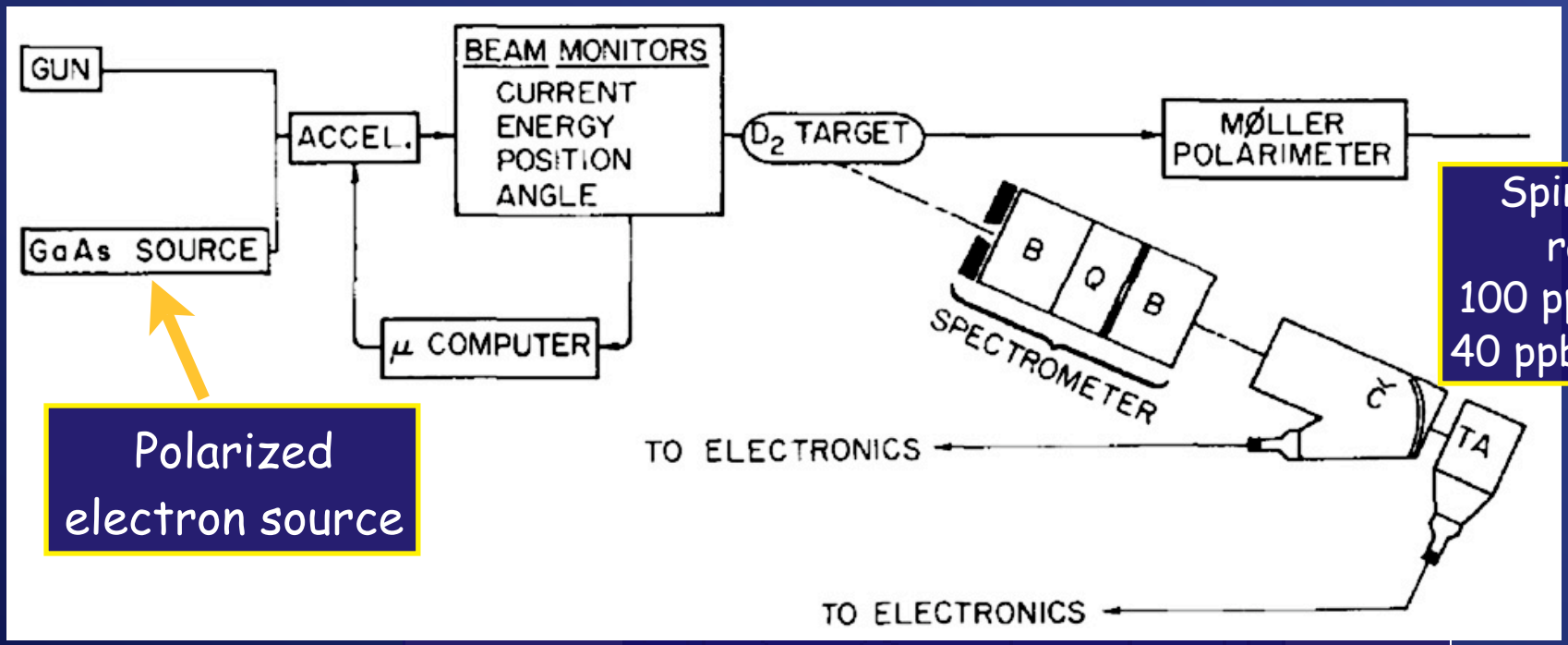

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Spectrometer and detectors must be capable of performing integrating detection with intrinsically low background.

Steady progress has made it possible to consider increasingly challenging parity experiments

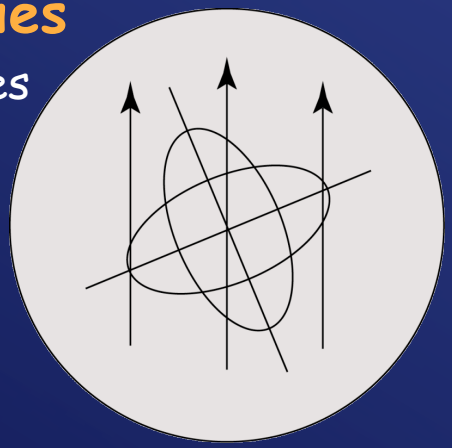
Selected parity experiments and their measured or projected demands on suppression of helicity-correltated beam-parameter differences					
Experiment (*) actual (†) projected	physics asymmetry	stat. error	sys. error due to beam	limits on position differences	limits on angle differences
*HAPPEX I	-15,050 ppb	980 ppb	± 20 ppb	< 12 nm	
*SLAC E158	-131 ppb	14 ppb	± 3 ppb	< 12 nm	0.4 nrad
*HAPPEX II-p	-1,580 ppb	120 ppb	± 17 ppb	< 1.7 nm	0.2 nrad
†PREX	510 ppb	15 ppb	± 1.0 ppb	< 1.0 nm	
†HAPPEX III	-22,100 ppb	550	± 66 ppb	< 40 nm	
†Qweak	-288 ppb	5 ppb	14 ± 1.4 ppb	< 40 nm	100 nrad
† 12 GeV Møller	40 ppb	0.6 ppb	± 0.2 ppb	~ 1 nm	0.03 nrad

What are some of the ingredients that permit experiments to reach such precision?

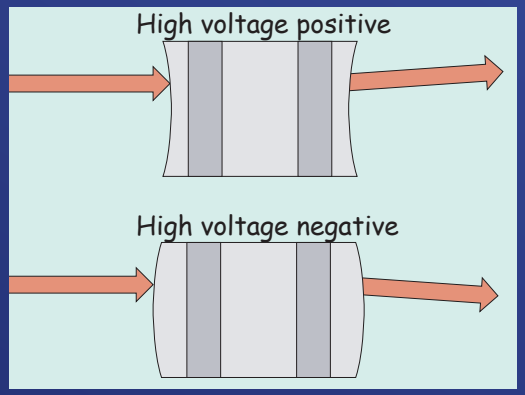
- Targets that can handle big beam currents without boiling or boiling-like effects.
- "Adiabatic damping" in which helicity correlated effects are suppressed in the accelerator with increasing energy.
- Sophisticated control over the polarized-electron-source optics.

Atomic-scale control over helicity-correlated beam parameter differences using the source optics

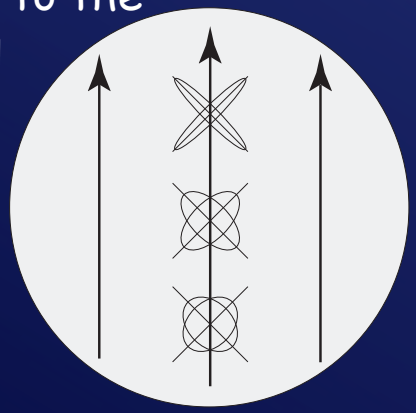
Charge asymmetries or "PITA" effect: Bates carbon experiment.

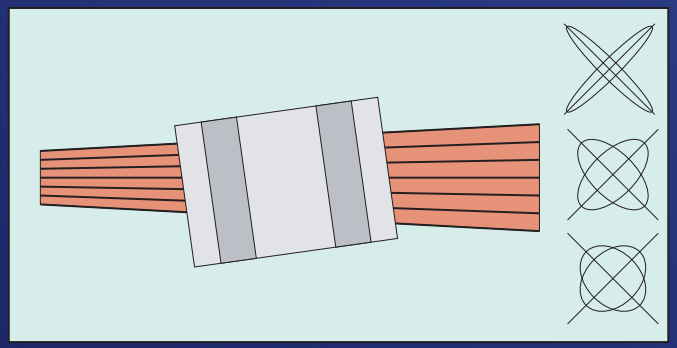


Position differences from lensing: steering from lensing-type phenomena: Bates carbon experiment.



Position differences from intrinsic phase gradients: due to phase gradients intrinsic to the Pockels cell or other optical components, SLAC E158.





Position differences from induced phase, the Paschke effect: due to coupling of divergence to the Pockels cell tilt: Happex II.

Parity violation in Moller scattering at the tree level

$$A_{PV} = -\frac{m_e\, E\, G_F}{\sqrt{2}\,\pi\,\alpha} \cdot \frac{16\,\sin^2\theta_{CM}}{(4-\sin^2\theta_{CM})^2} \cdot \left(\frac{1}{4} - \sin^2\theta_W\right)$$

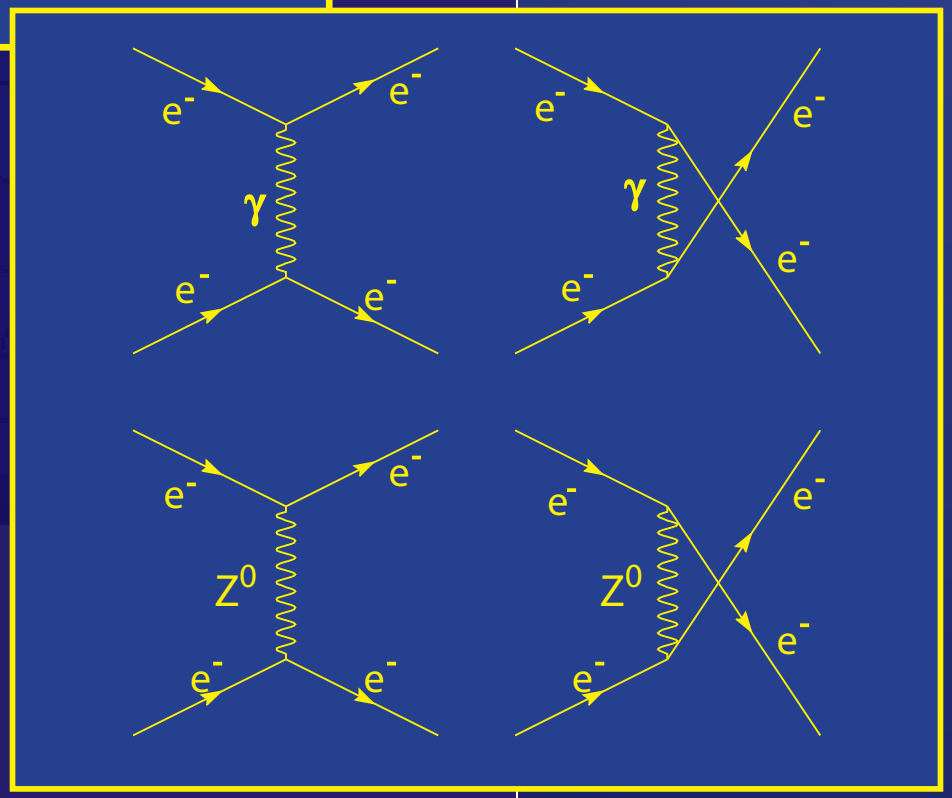
$$\frac{d\sigma}{d\Omega} = \frac{\alpha^2}{2\,m\,E}\,\frac{(3+\cos^2\theta_{CM})^2}{\sin^4\theta_{CM}}$$

For 50 GeV at $\Theta_{CMS} = 90°$:

$A_{PV} \approx -300$ ppb

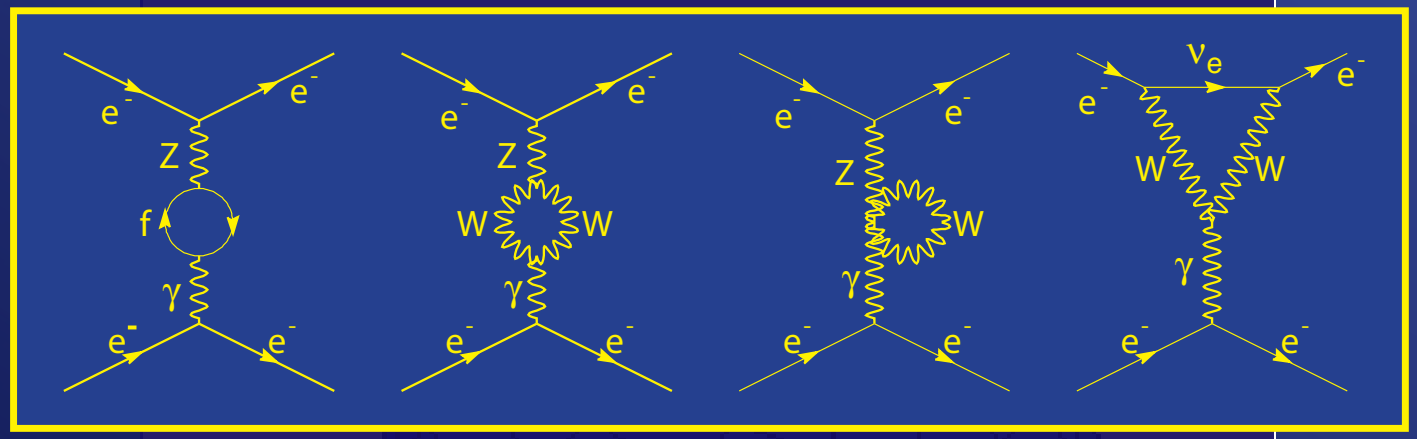
For 11 GeV at $\Theta_{CMS} = 90°$:

$A_{PV} \approx -70$ ppb



The Moller asymmetry is significantly smaller because of the running of $\sin^2\theta_W$

(Thus showing nice sensitivity to quantum loop effects)



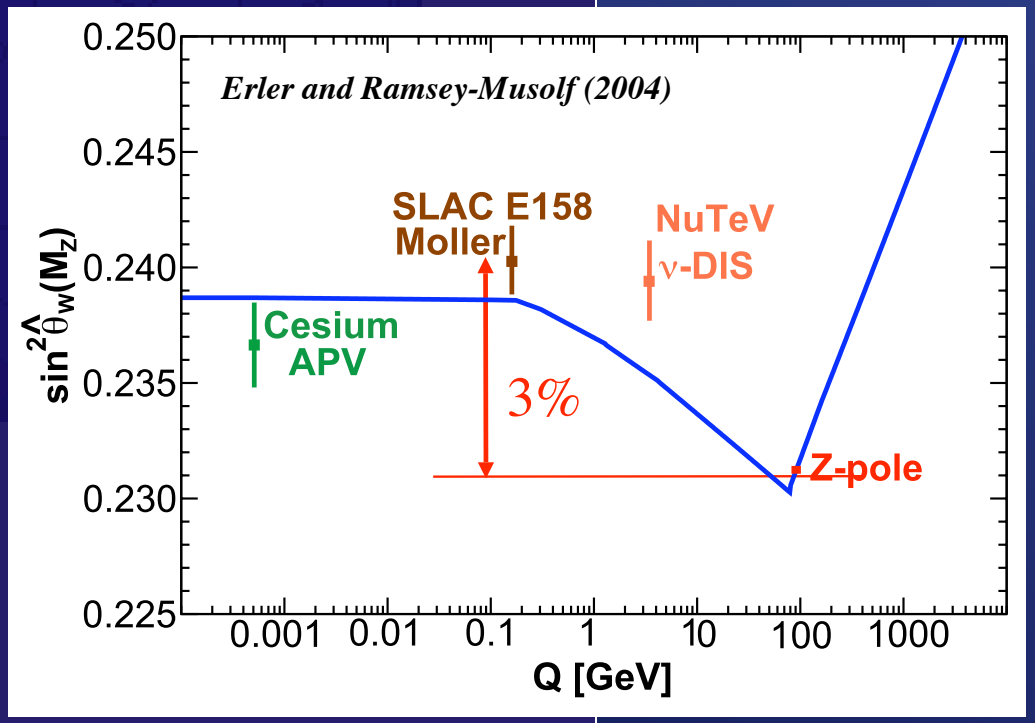
With radiative effects included:

For 50 GeV at $\Theta_{CMS} = 90°$:

$A_{PV} \approx -150$ ppb

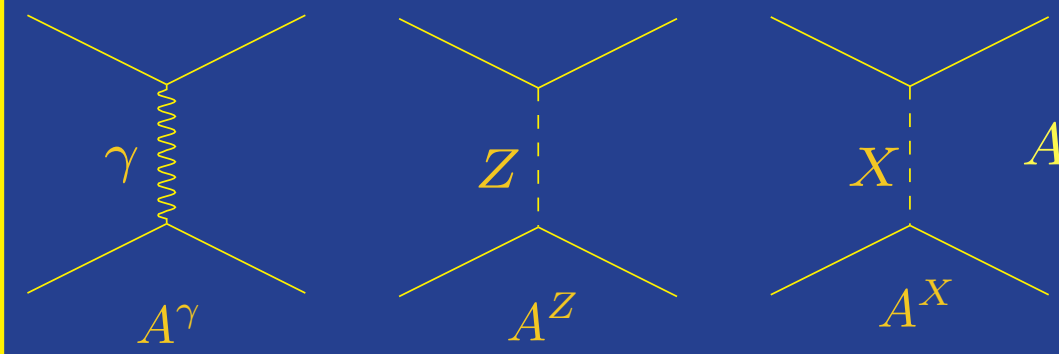
For 11 GeV at $\Theta_{CMS} = 90°$:

$A_{PV} \approx -40$ ppb



Moller parity measurements compliment collider experiments

Consider an amplitude A^X due to new physics at a mass scale $M_X^2 \gg Q^2$.



$$A^X \propto \frac{1}{Q^2 - M_X^2} \sim \frac{1}{M_X^2}$$

On the Z pole, A^Z will be purely imaginary while A^X will likely be real. Accordingly:

$$\sigma \sim |A^Z|^2 + |A^X|^2 \quad \text{and} \quad A_{RL} \sim \frac{\sigma_R - \sigma_L}{\sigma_R + \sigma_L} \sim A_{RL}^Z \left(1 + \frac{|A^X|^2}{|A^Z|^2}\right)$$

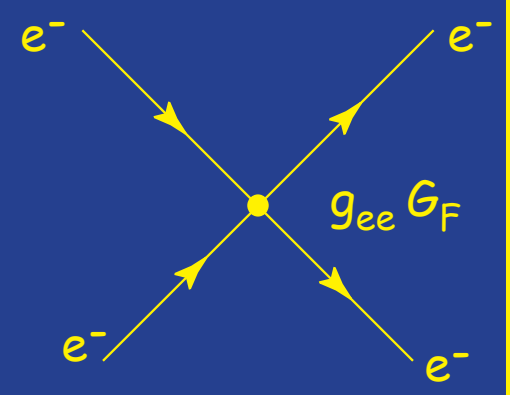
At higher and lower energies both amplitudes will be real and interference can occur.

$$\sigma \sim |A^\gamma + A^Z + A^X|^2 \quad \text{and} \quad A_{RL} \sim \frac{\sigma_R - \sigma_L}{\sigma_R + \sigma_L} \sim \frac{A^Z + A^X}{A^\gamma}$$

Moller has excellent sensitivity to new contact interactions

For a general contact interaction:

$$A_{ee} = \frac{m\,E_B G_F}{\sqrt{2}\,\pi\,\alpha}\,\frac{8\,\sin^2\theta_{CM}}{(3+\cos^2\theta_{CM})^2}\,g_{ee}$$



If there is new physics, we can write

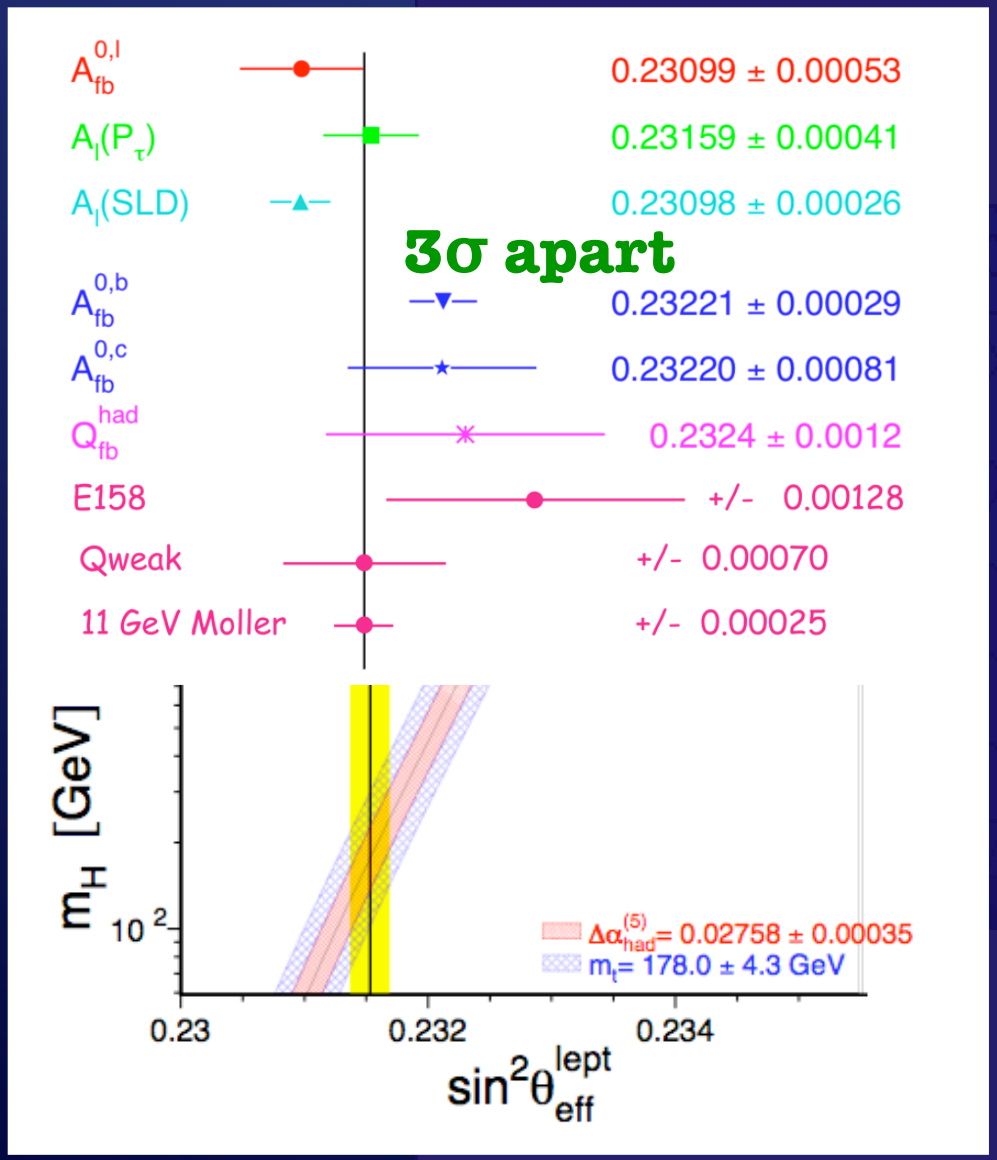
$$g_{ee}^{meas.} - g_{ee}^{S.M.} = \pm\frac{\pi\sqrt{2}}{G_F}\frac{(\eta_{RR}-\eta_{LL})}{\Lambda_{ee}^2} \quad \text{where} \quad g_{ee}^{S.M.} = \frac{1}{2} - 2\,\sin^2\theta_W$$

and Λ_{ee} characterizes the scale of the new physics.

- ✧ Moller PV experiments are complimentary to collider experiments which are sensitive to $(\eta_{RR} + \eta_{LL})$ instead of $(\eta_{RR} - \eta_{LL})$.
- ✧ Moller has sensitivity to $\Lambda_{ee} > 14$ TeV (E158) and $\Lambda_{ee} > 25$ TeV (JLab 12 GeV Moller).

The precise value of $\sin^2\theta_W$ has huge implications

Adapted from W. Marciano



Grand average value of
$\sin^2\theta_W$=0.23122(17)
$\Rightarrow m_H = 89^{+38}_{-28}$ GeV

S = -0.13 ± 0.10
Rules out Technicolor, favors SUSY

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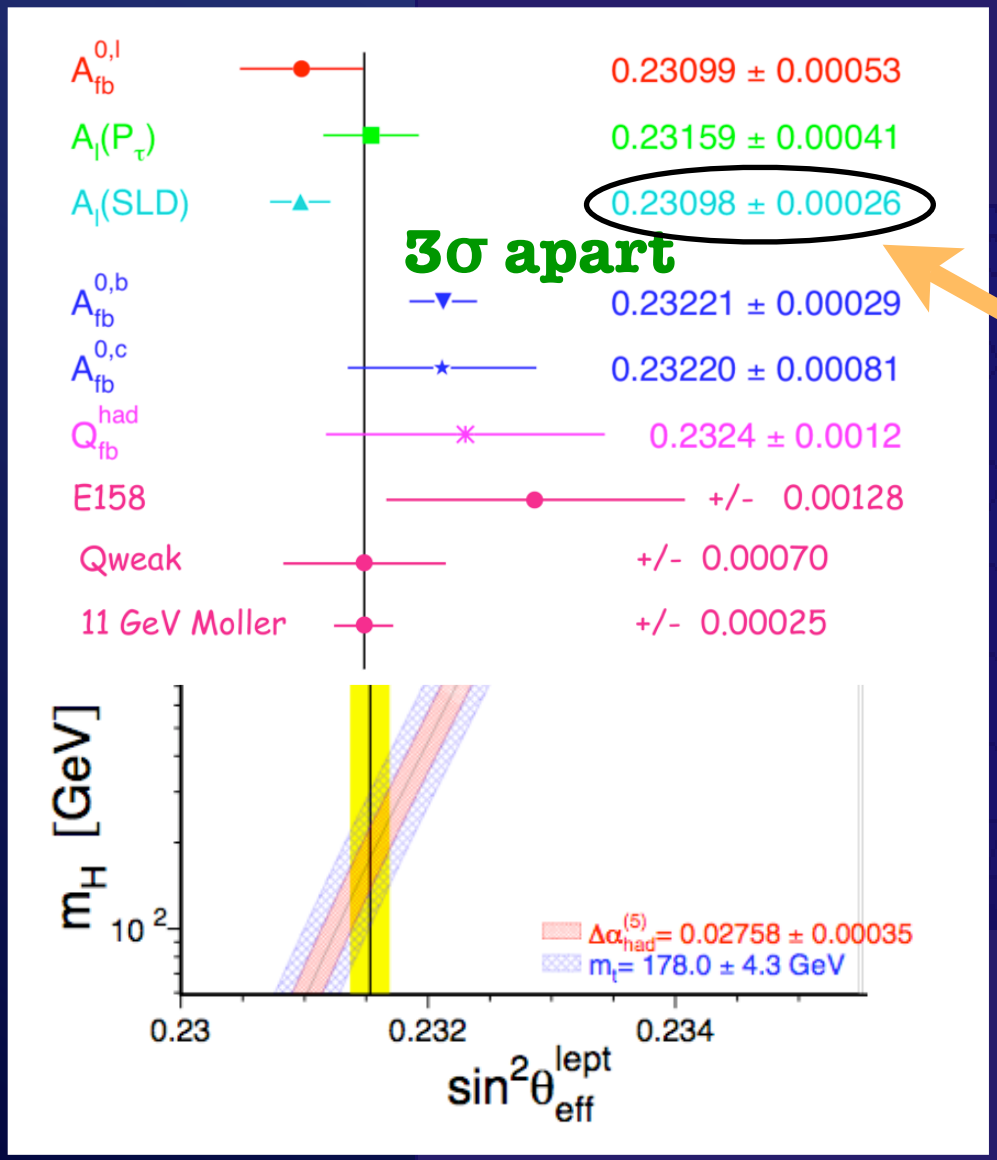

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Rules out SM!!

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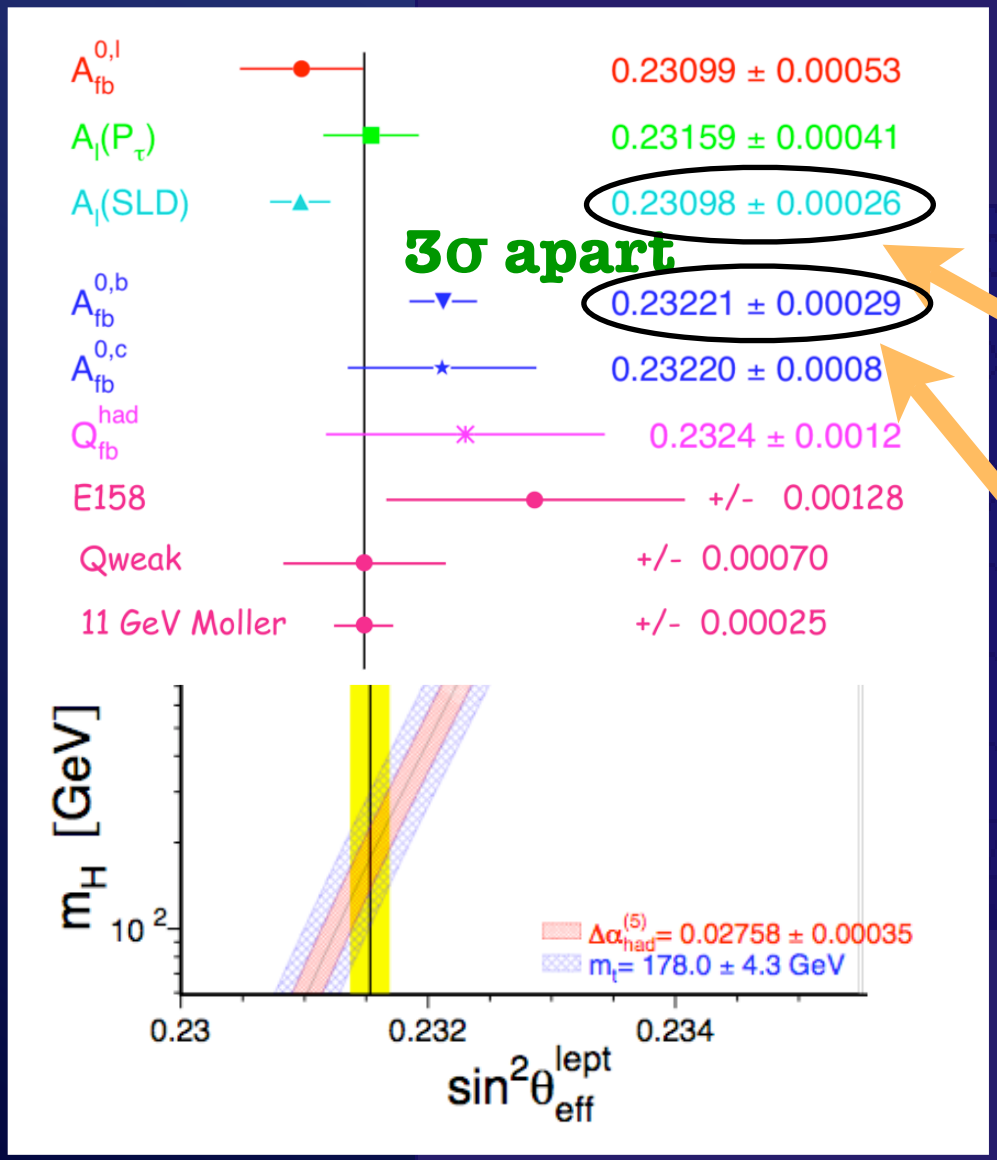

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CERN $A_{fb(b)}$ value of
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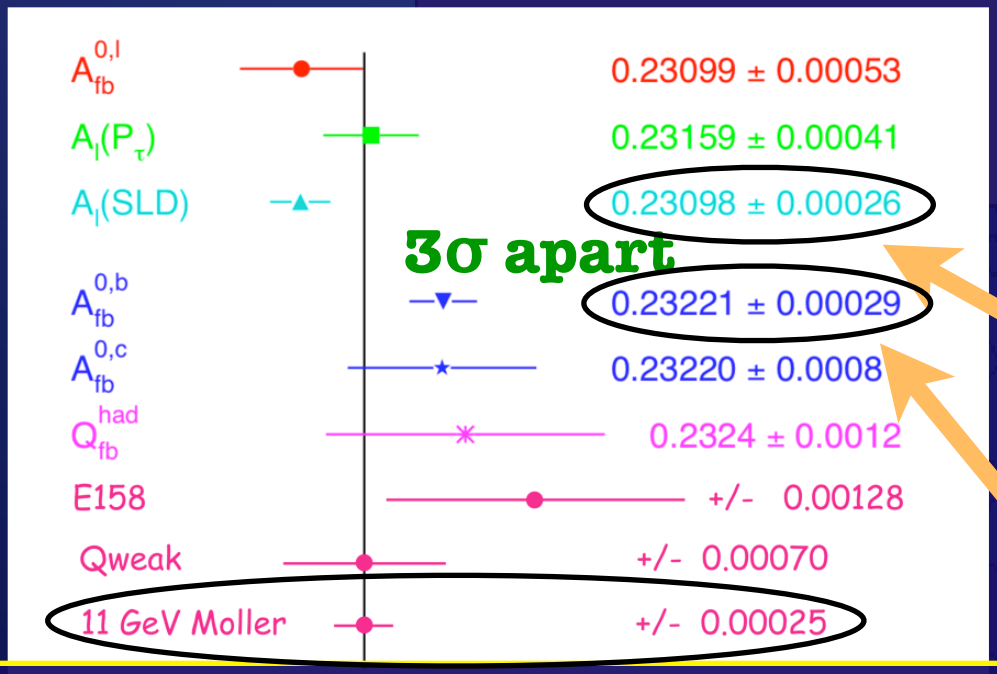

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11 GeV Moller could in principle achieve an error smaller than either SLD or CERN A_{fb} taken individually!

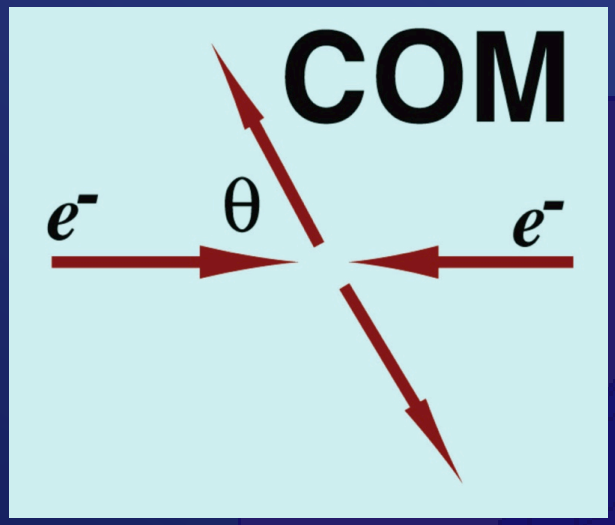
LRP: Primary recommendations

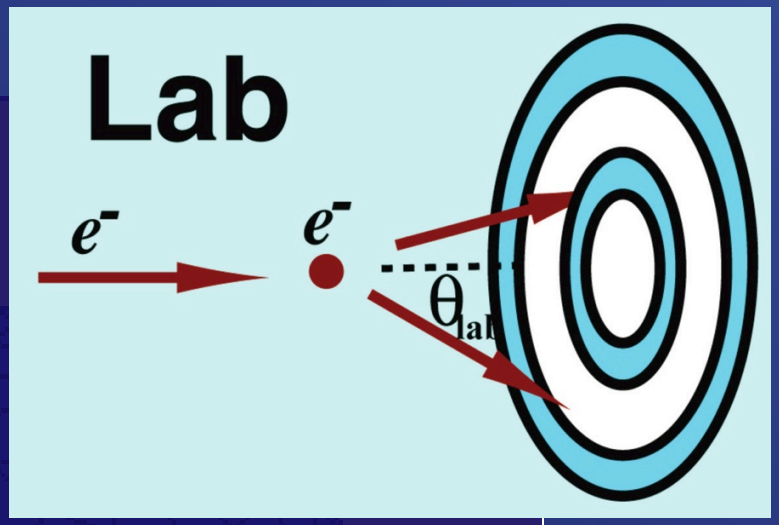
- We recommend completion of the 12 GeV upgrade at Jefferson Lab. The Upgrade will enable new insights into the structure of the nucleon, the transition between the hadronic and quark/gluon descriptions of nuclei, and the nature of confinement.
- We recommend construction of the Facility for Rare Isotope Beams, FRIB, a world-leading facility for the study of nuclear structure, reactions and astrophysics. Experiments with the new isotopes produced at FRIB will lead to a comprehensive description of nuclei, elucidate the origin of the elements in the cosmos, provide an understanding of matter in the crust of neutron stars, and establish the scientific foundation for innovative applications of nuclear science to society.
- We recommend a targeted program of experiments to investigate neutrino properties and fundamental symmetries. These experiments aim to discover the nature of the neutrino, yet unseen violations of time-reversal symmetry, and other key ingredients of the new standard model of fundamental interactions. Construction of a Deep Underground Science and Engineering Laboratory is vital to US leadership in core aspects of this initiative.
- The experiments at the Relativistic Heavy Ion Collider have discovered a new state of matter at extreme temperature and density – a quark-gluon plasma that exhibits unexpected, almost perfect liquid dynamical behavior. We recommend implementation of the RHIC II luminosity upgrade, together with detector improvements, to determine the properties of this new state of matter.

Efforts are underway to plan and design an 11 GeV Moller Experiment

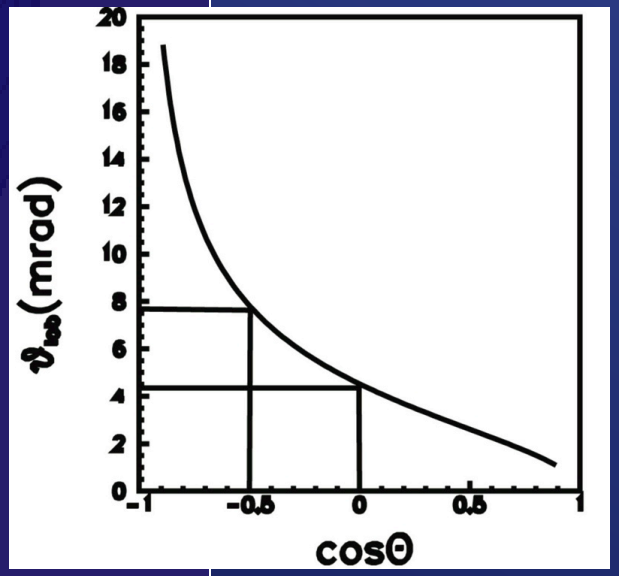
- Electroweak Workshop: The Scientific Impact and Feasibility of an Ultra-precise 12 GeV Moeller Experiment to Test the Standard Model --- Dec. 11-13, 2006
- Consensus statement submitted to Town Hall Meeting in preparation for LRP exercise.
- Moeller Steering Committee formed to explore design options and begin establishing framework for an LOI.
- First real collaboration meeting likely in mid-August.

Kinematics

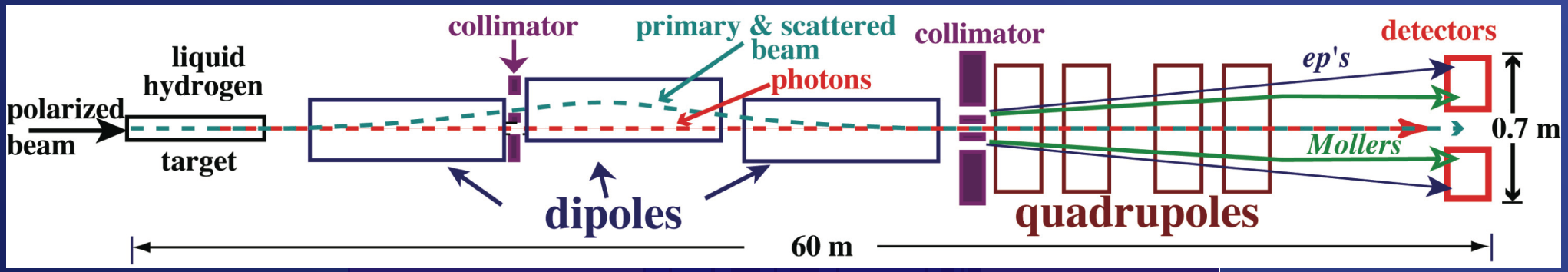




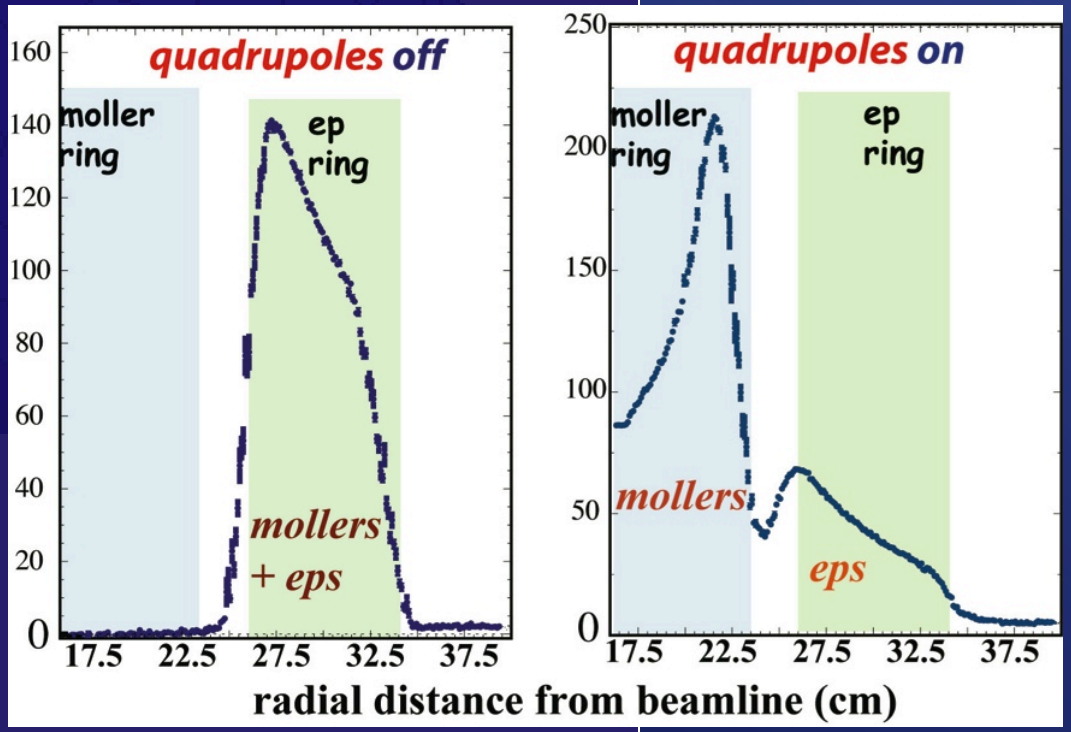
- For 90° C.O.M. scattering, the electrons have half the energy.
- The E158 Spectrometer accepted C.O.M. angles with $-0.5 < \cos\Theta_{com} < 0.0$
- The spectrometer needs to be designed to block the other electron of the Moller pair corresponding to $0.0 < \cos\Theta_{com} < 0.5$
- Large angles must also be blocked to cut out e-p (Mott) scattering.



Spectrometer design from E158

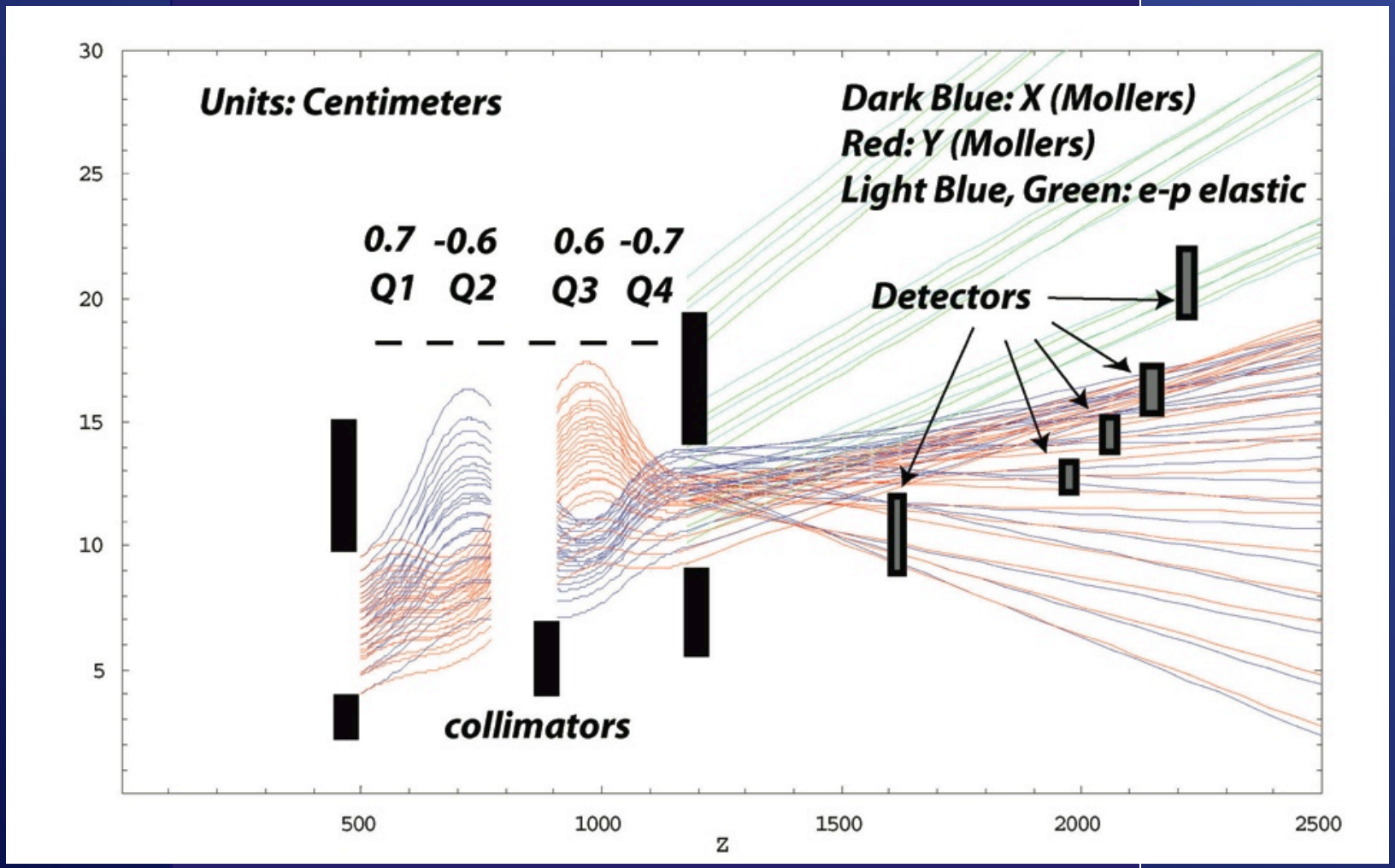


- Dipoles block line-of-sight for photons.
- Quads focus Mollers and defocus e-p's.
- One or more rings detect Mollers.
- Outer ring detects e-p's and provides measurement of the e-p asymmetry.



Possible quad-based spectrometer design for 11 GeV Moller

See the poster by Luis Mercado!



Can use the same quads as were used for E158 (the dipoles will need to be different).

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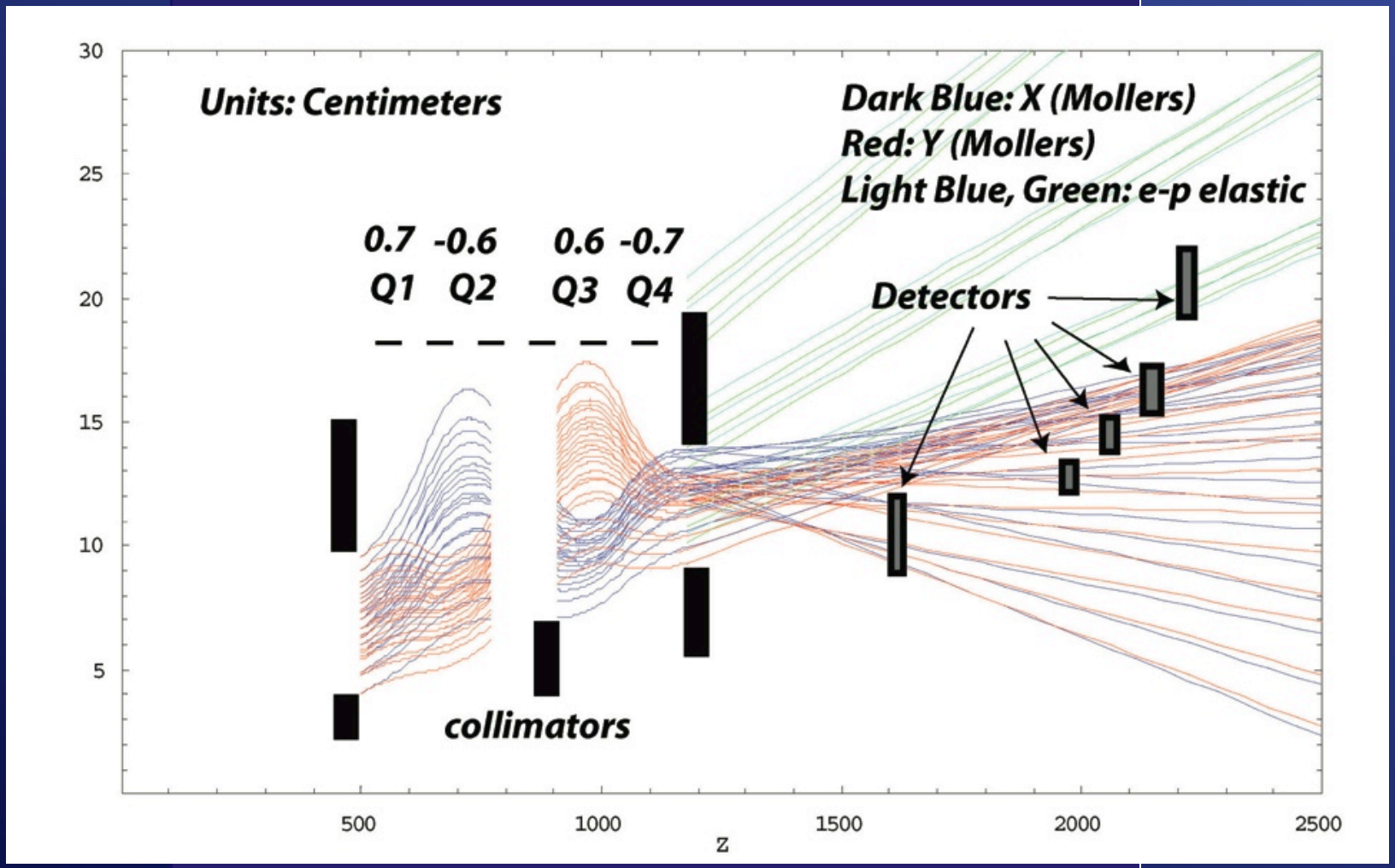

Fits in Hall A !!!

First guesstimate for rate and errors

- Quad-based spectrometer
- 90 μA beam
- 150 cm LH_2 target
- 4000 hours of beam

Rate = 186 GHz!

$\delta(A_{exp}) = 0.61$ ppb

- Instrumentation noise: 10% (25% FOR E158)
- Background dilution: 5% (8% for E158)
- Beam Polarization: 85%

$\delta(A_{PV}) = 0.83$ ppb

All this yields: $\delta(\sin^2\theta_W) = 0.00026$ and $\delta(Q_W^e) = 2.25\%$

Conclusions

- The Physics motivation is very strong, even in the LHC era.
- The experiment has received strong endorsement in the LRP
- While very challenging, the experiment appears feasible.
- With tweaking, $\delta(\sin^2\theta_W) = 0.00025$ appears achievable.
- Collaboration meeting coming in mid-August - come and join!
- Planning to submit LOI to January '09 PAC.