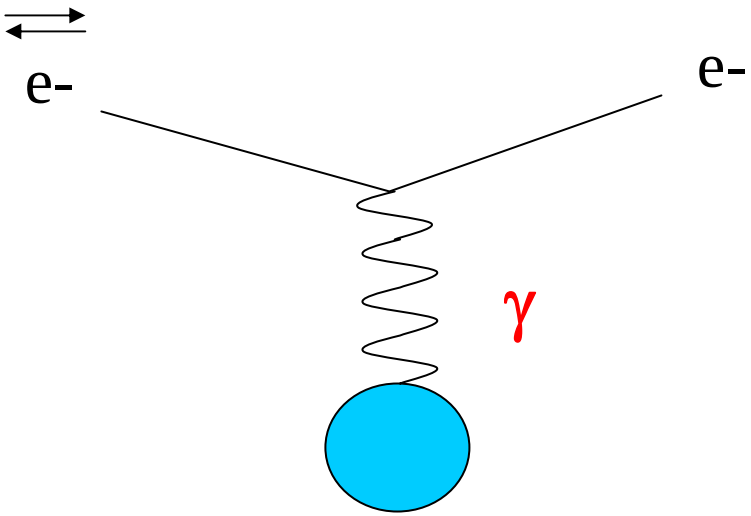
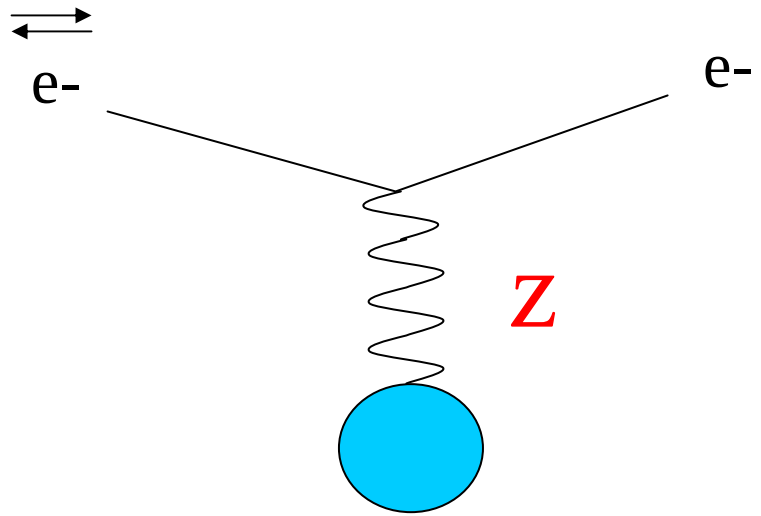
Parity Violation in Electron Scattering

* SLAC E122
* SLAC E158
* FUTURE

Emlyn Hughes
SLAC DOE Review
June 2, 2004

Polarized Electron Scattering





unpolarized quarks or electrons or protons

Parity conserving

Parity violating

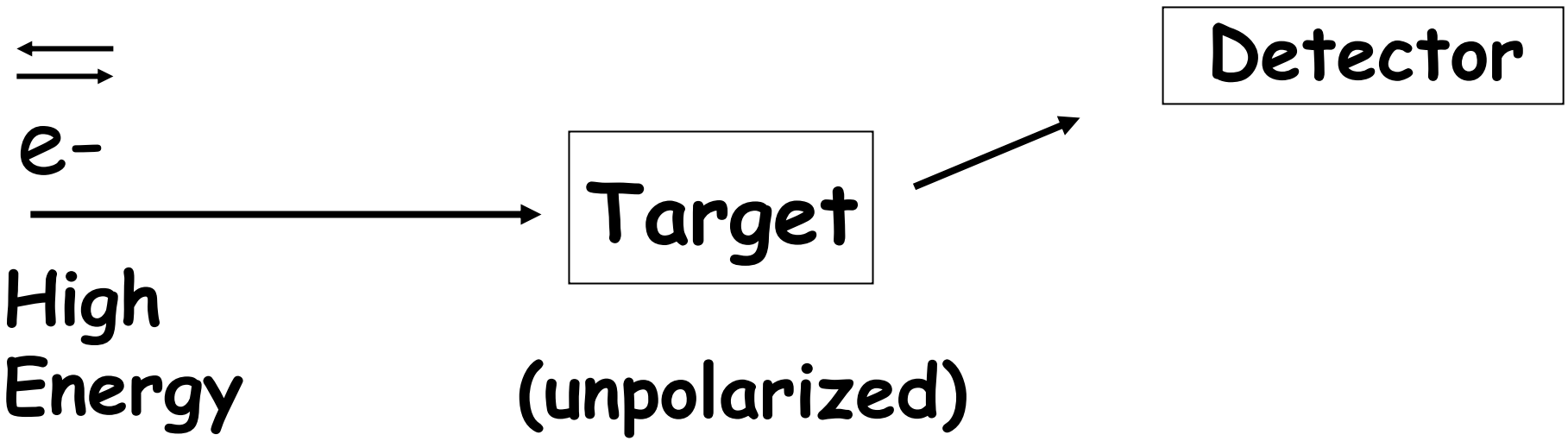
Electroweak Mixing Angle

$$e = g \sin\theta_w$$

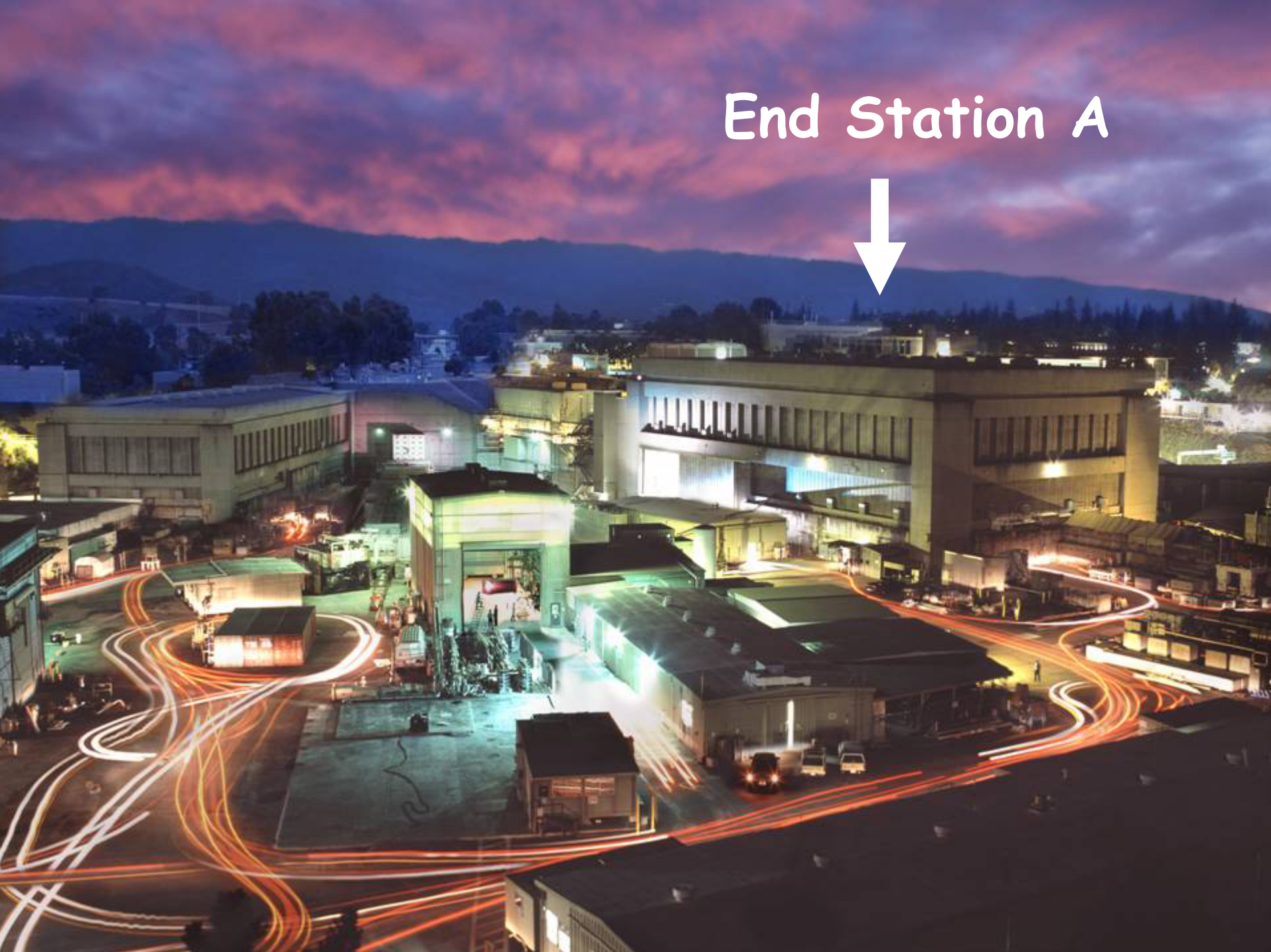
Characterizes the mixing between the weak and EM interaction in the electroweak theory

$$\sin^2\theta_w = 1 - M_w^2 / M_z^2$$

SLAC Parity Experiments



Parity-violating asymmetry $A^{PV} = \dfrac{\sigma^R - \sigma^L}{\sigma^R + \sigma^L}$


End Station A

SLAC E122

PARITY NON-CONSERVATION IN INELASTIC ELECTRON SCATTERING ☆

C.Y. PRESCOTT, W.B. ATWOOD, R.L.A. COTTRELL, H. DeSTAEBLER, Edward L. GARWIN, A. GONIDEC [1], R.H. MILLER, L.S. ROCHESTER, T. SATO [2], D.J. SHERDEN, C.K. SINCLAIR, S. STEIN and R.E. TAYLOR
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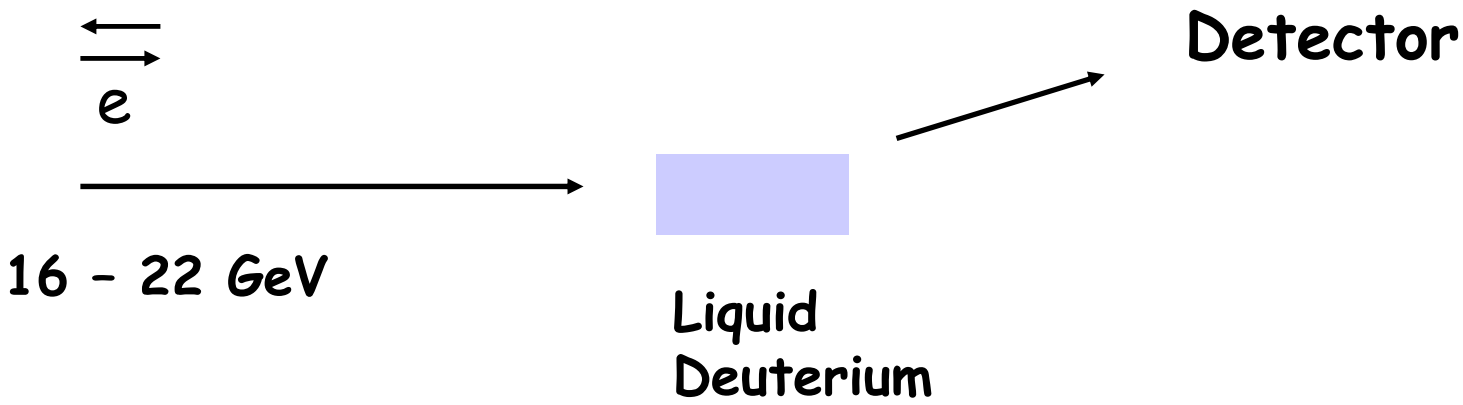
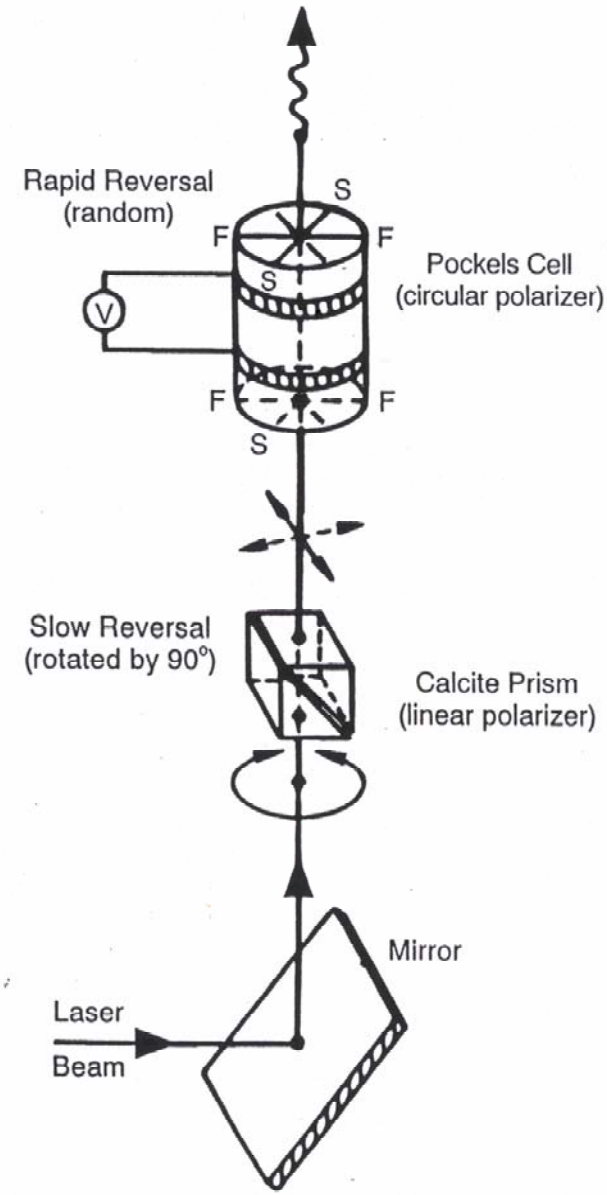
SLAC E122



- GaAs source
- High current
- 30 cm target
- Dedicated run

Polarized Laser Beam to the Ga As Cathode

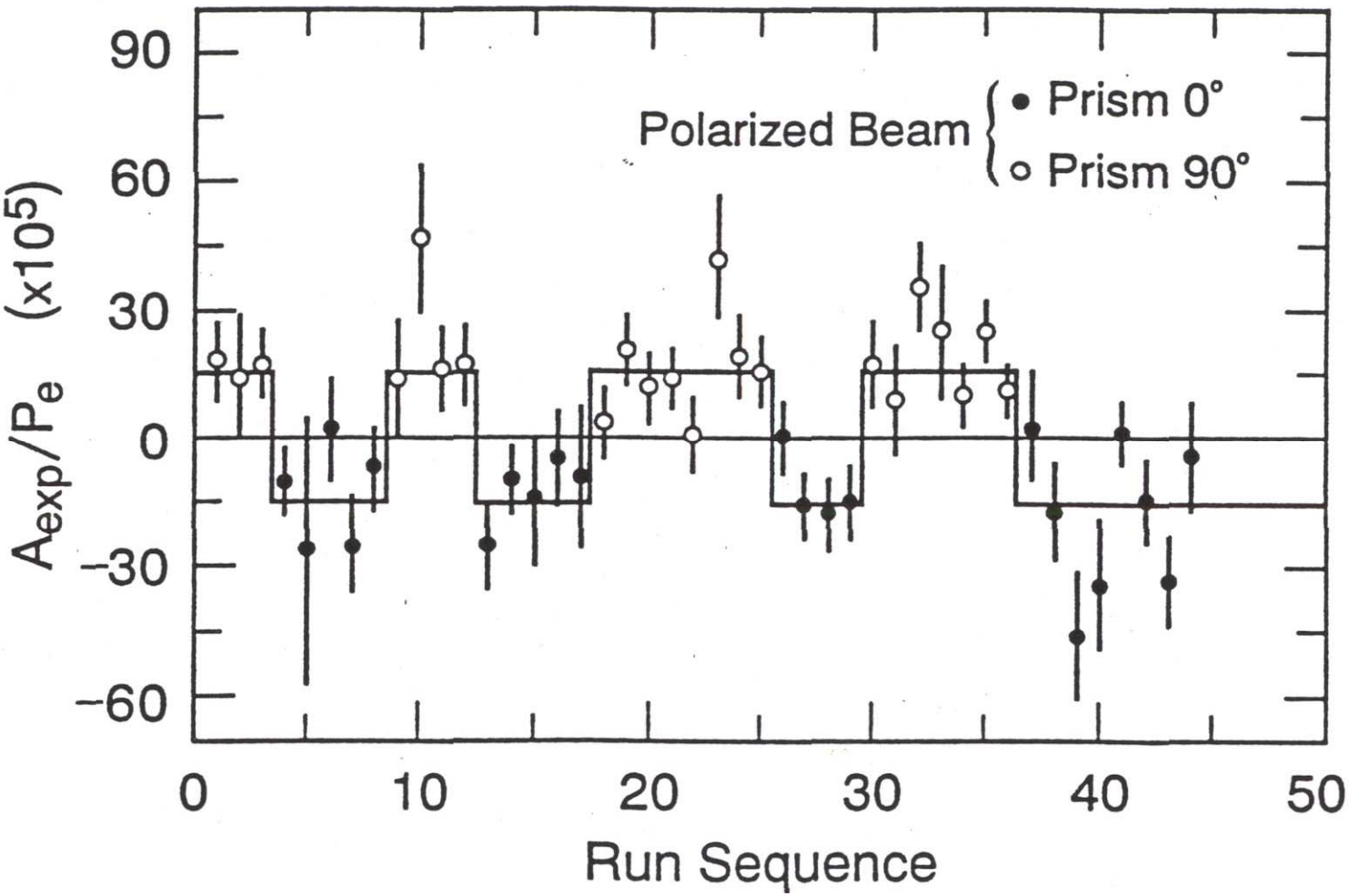
120 Hz →



Reversed every few runs →

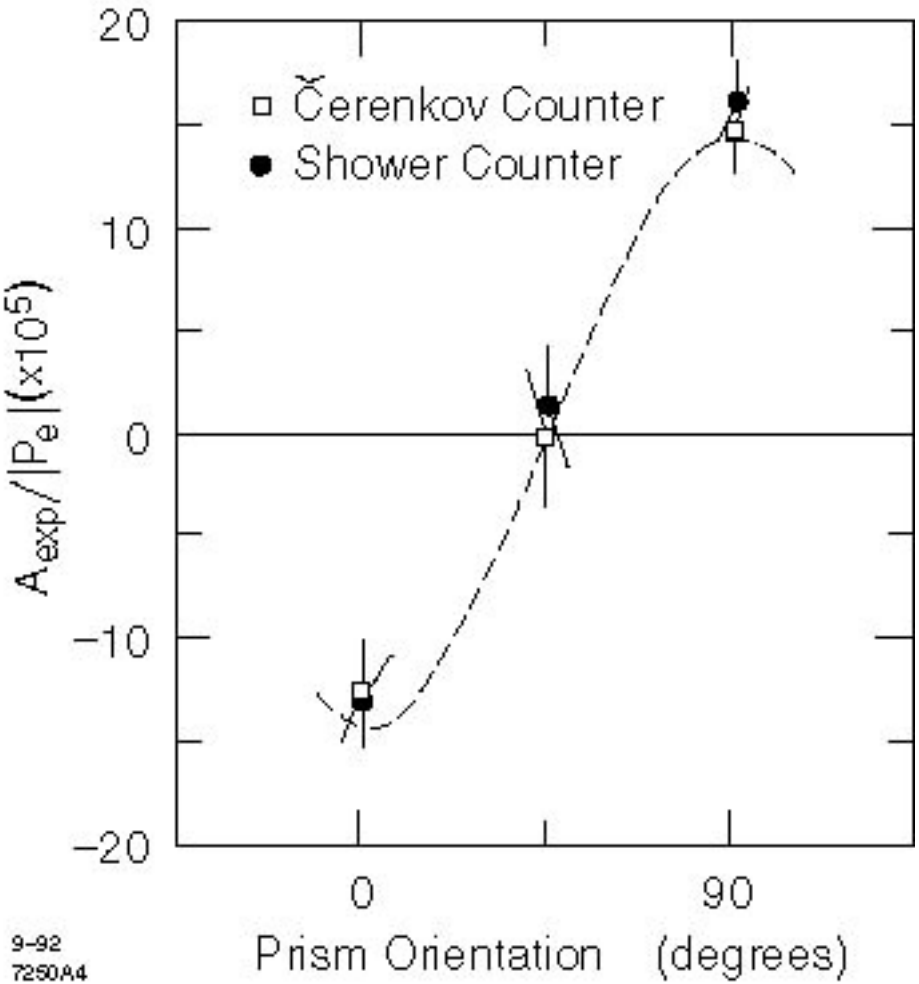
Optical Reversal Scheme

SLAC E122 waveplate reversal



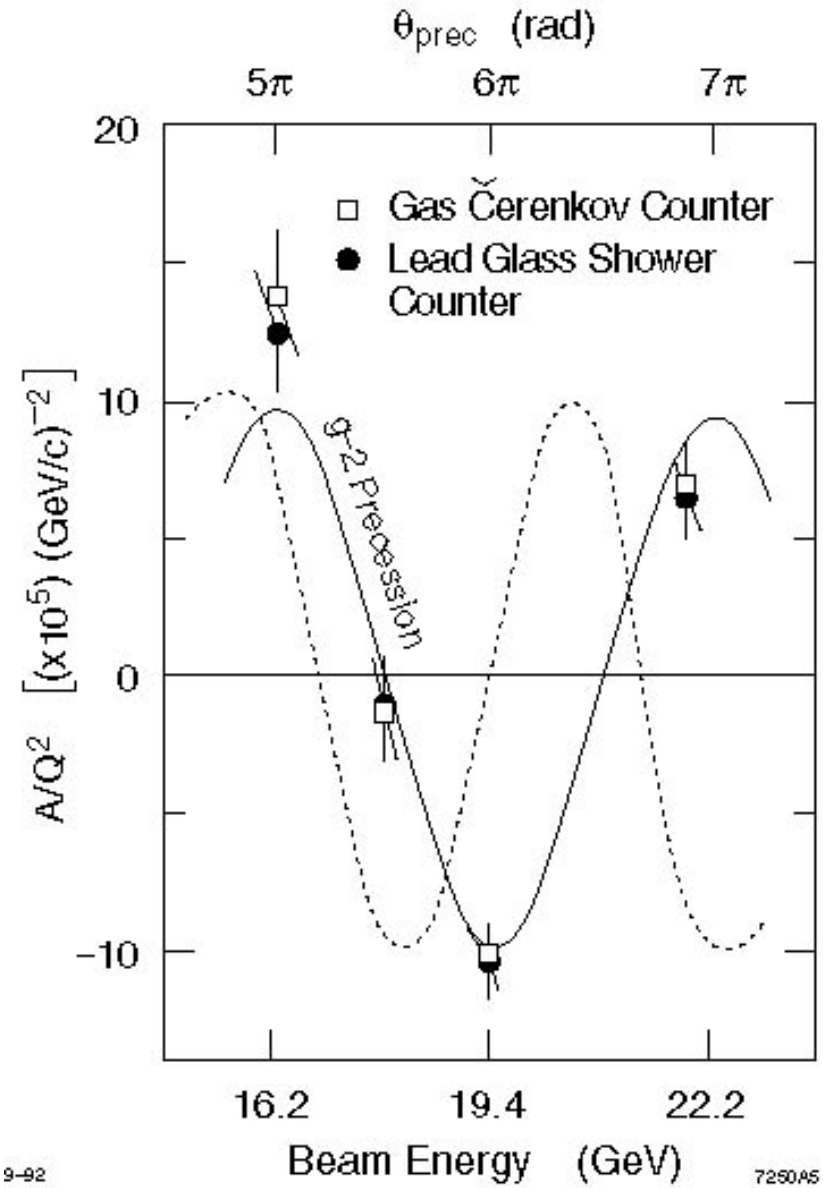
SLAC E122 waveplate reversal

Parity-violating asymmetry



SLAC E122 Energy Scan

Parity-violating asymmetry



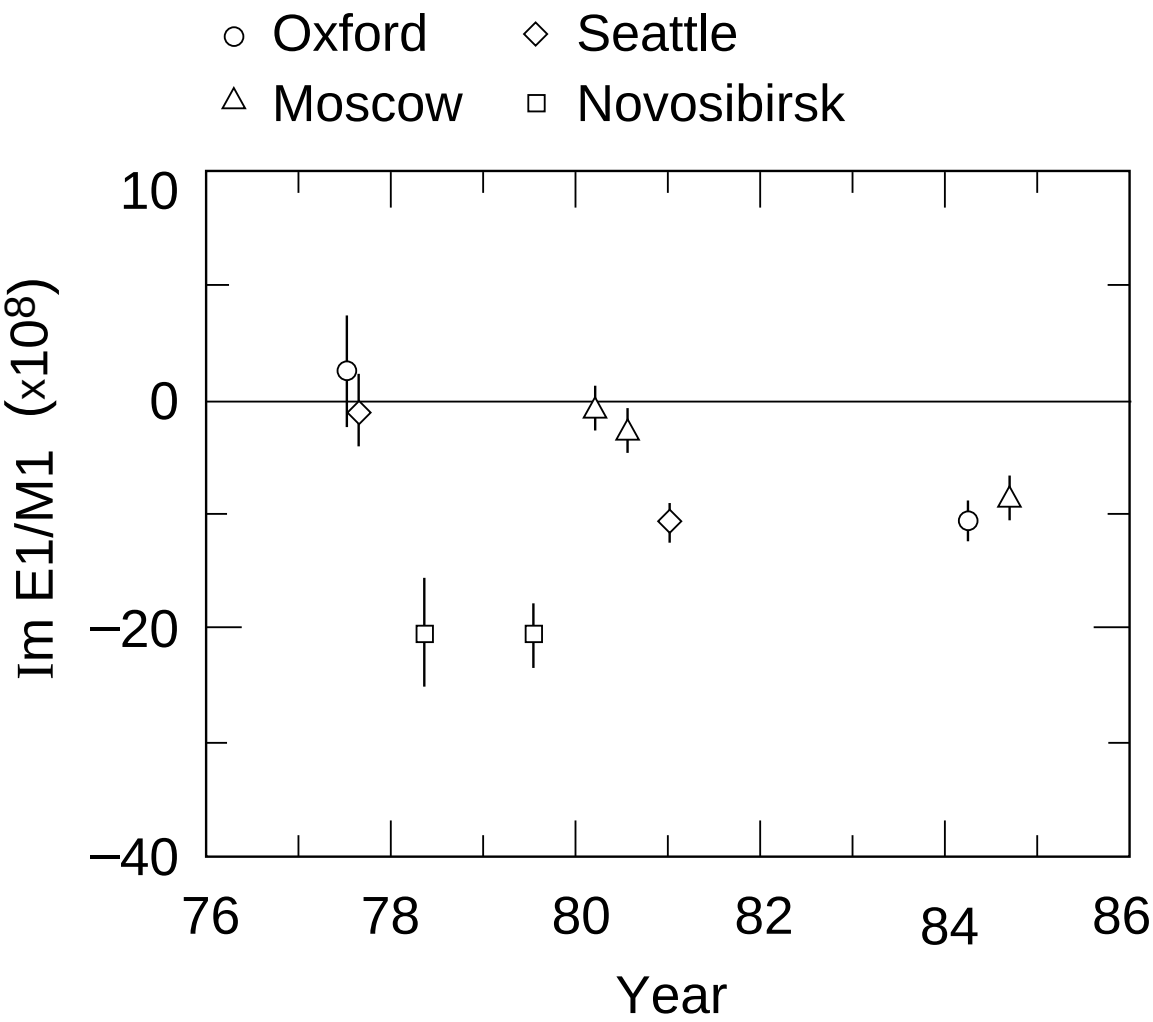
SLAC E122 Result

(1978)

$$\sin^2\theta_w = 0.224 \pm 0.020$$

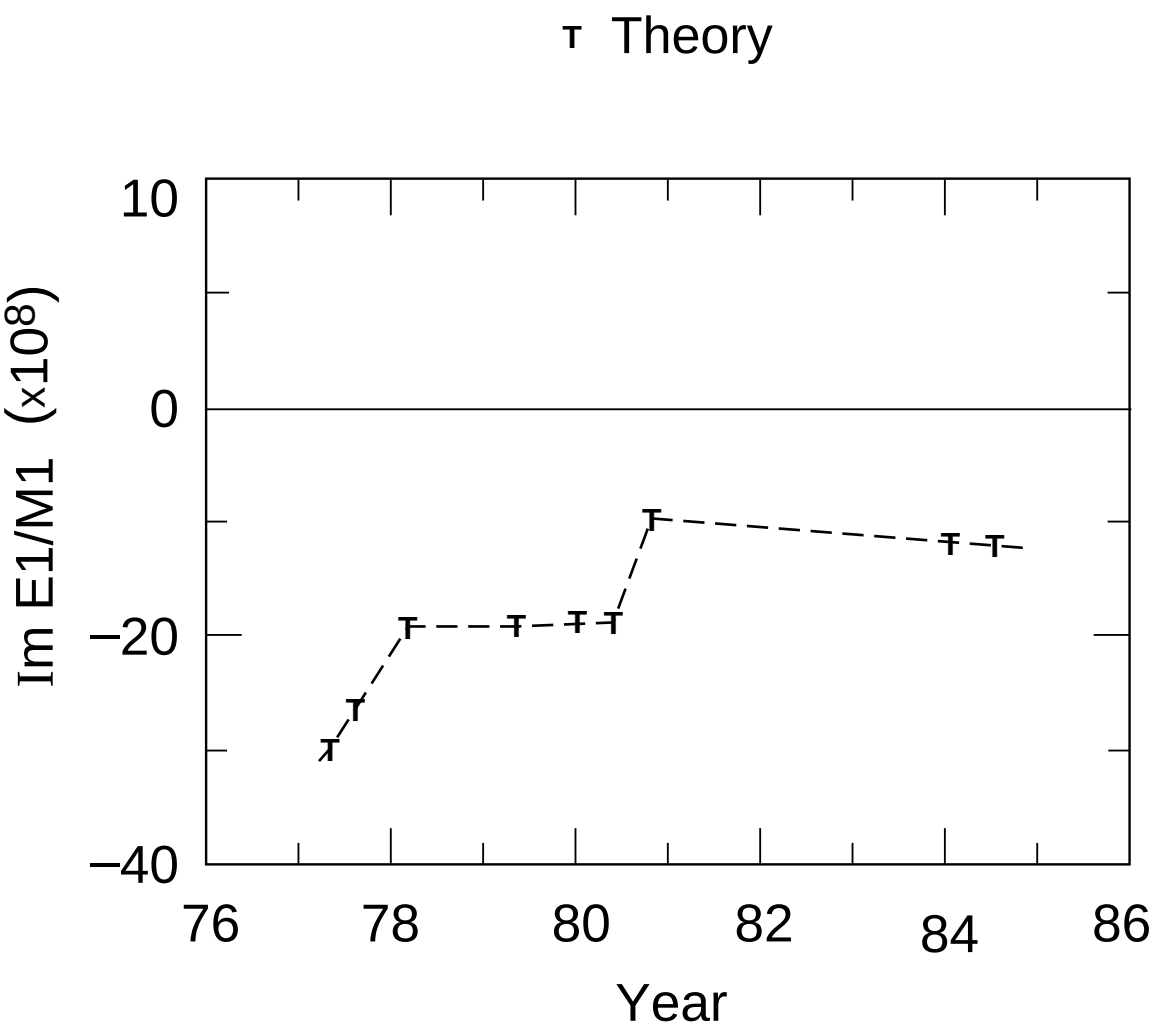
First definitive measurement of mixing between the weak and electromagnetic interaction

Atomic Parity Violation



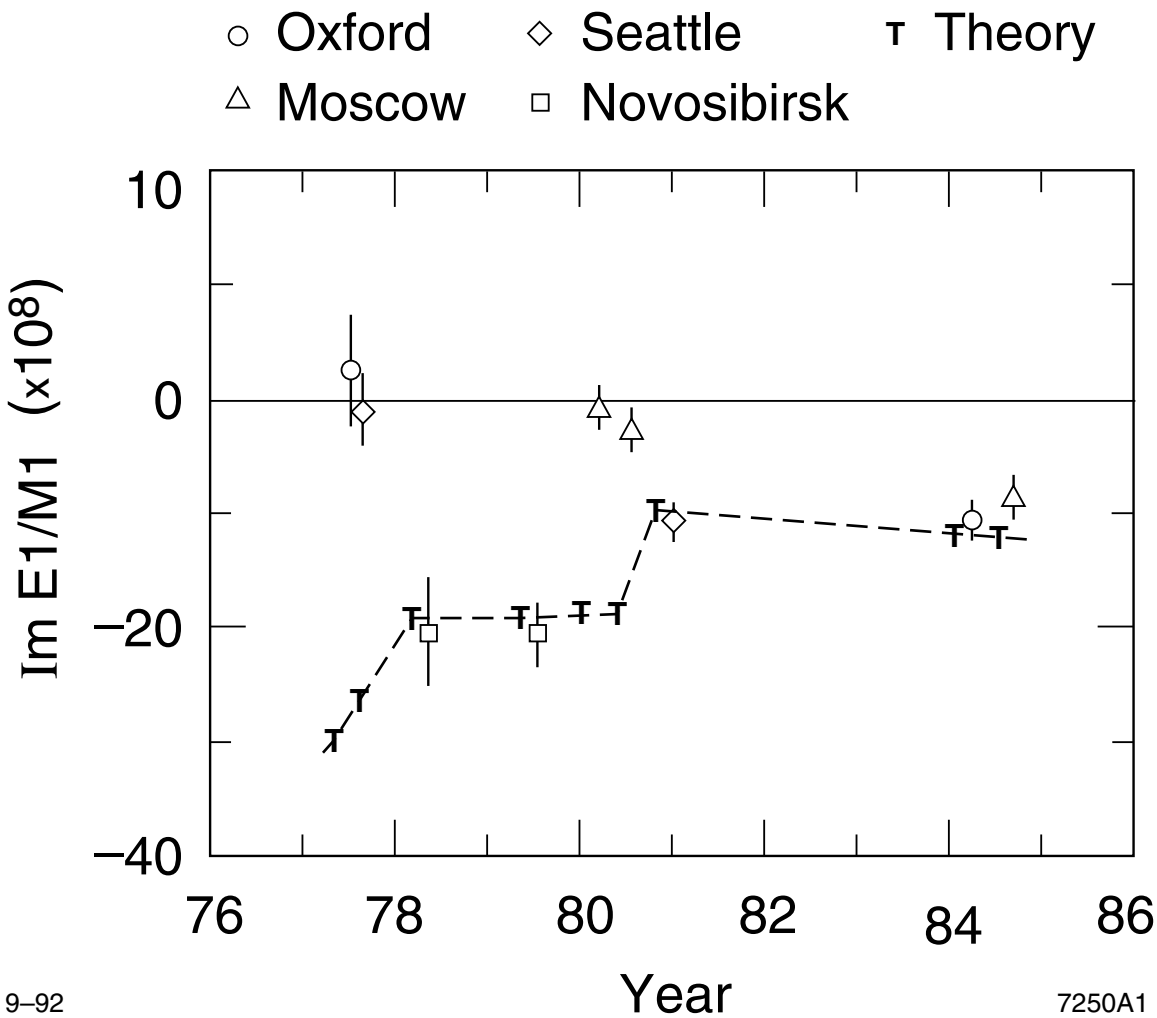
Bismuth

Atomic Parity Violation



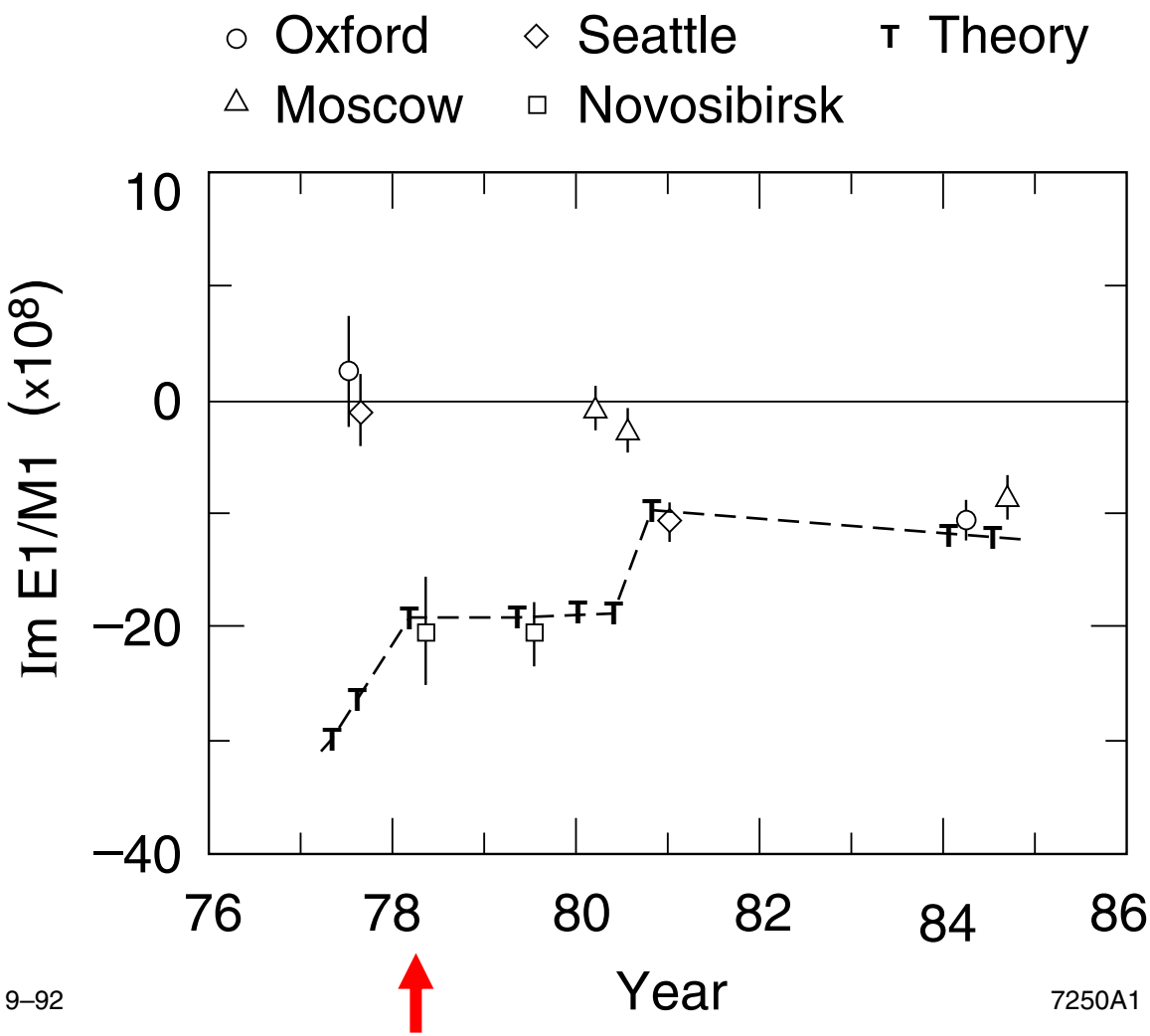
Bismuth

Atomic Parity Violation



Bismuth

Atomic Parity Violation

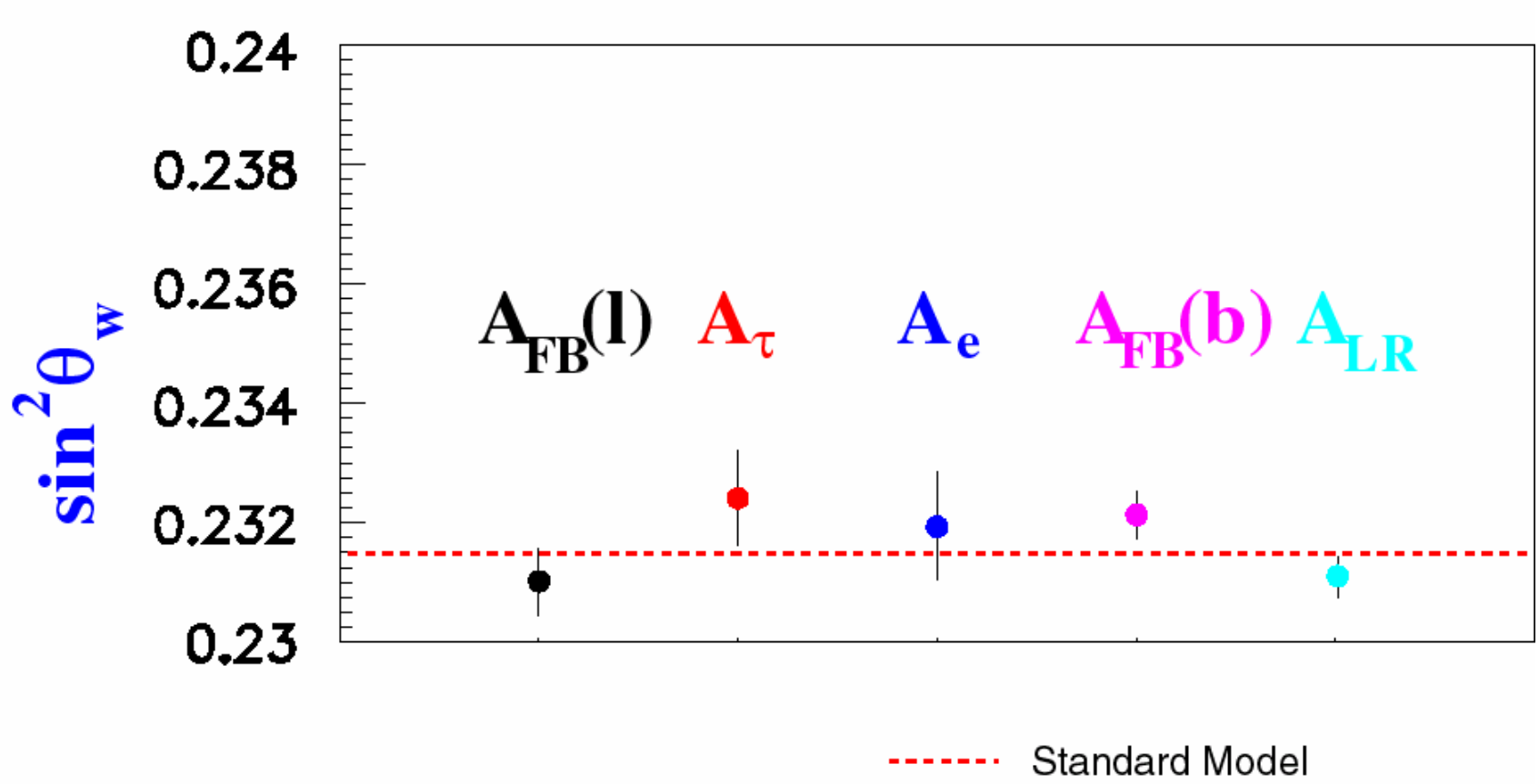


E122

Bismuth

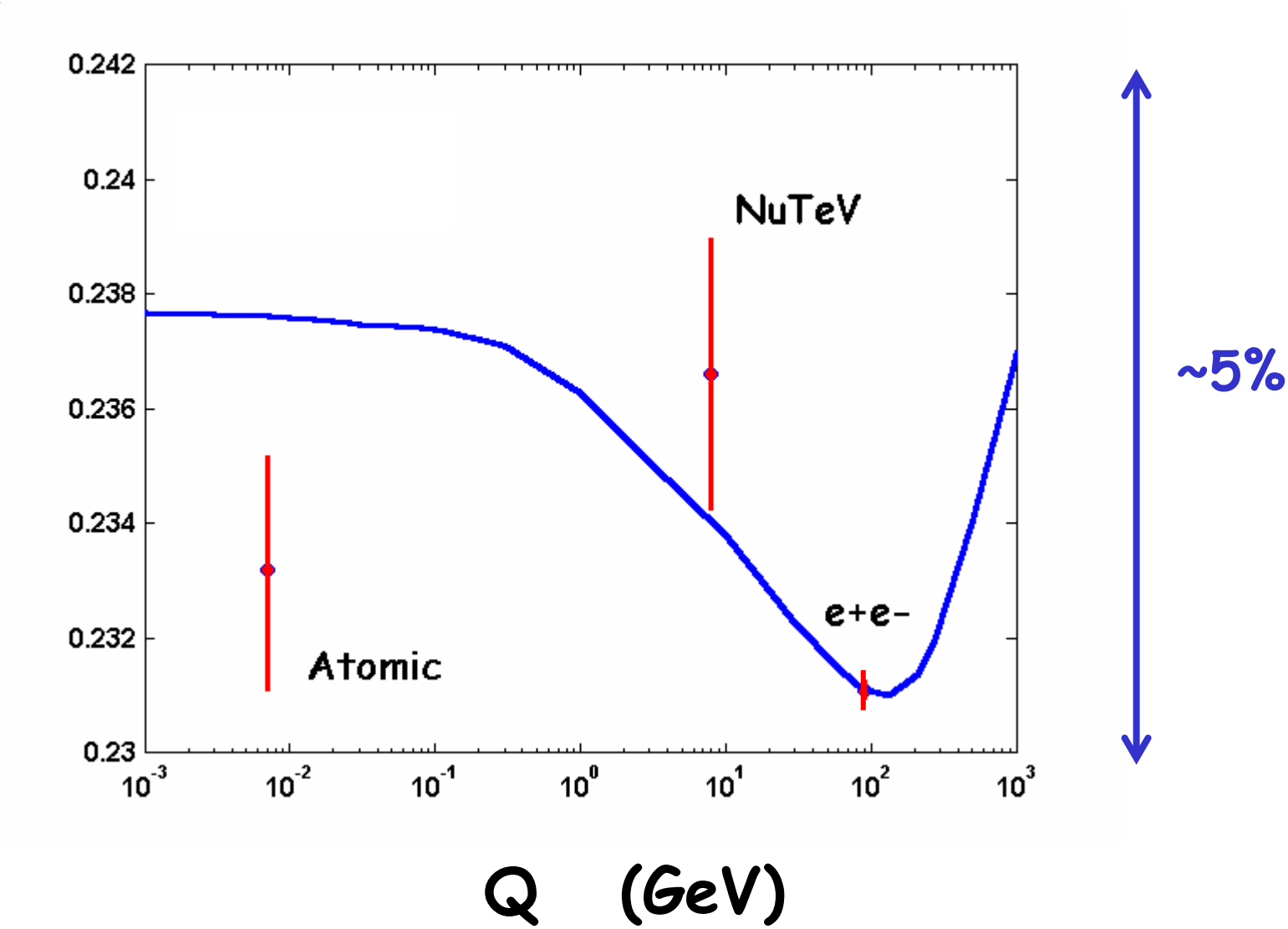
TODAY...

LEP and SLC e^+e^- collider

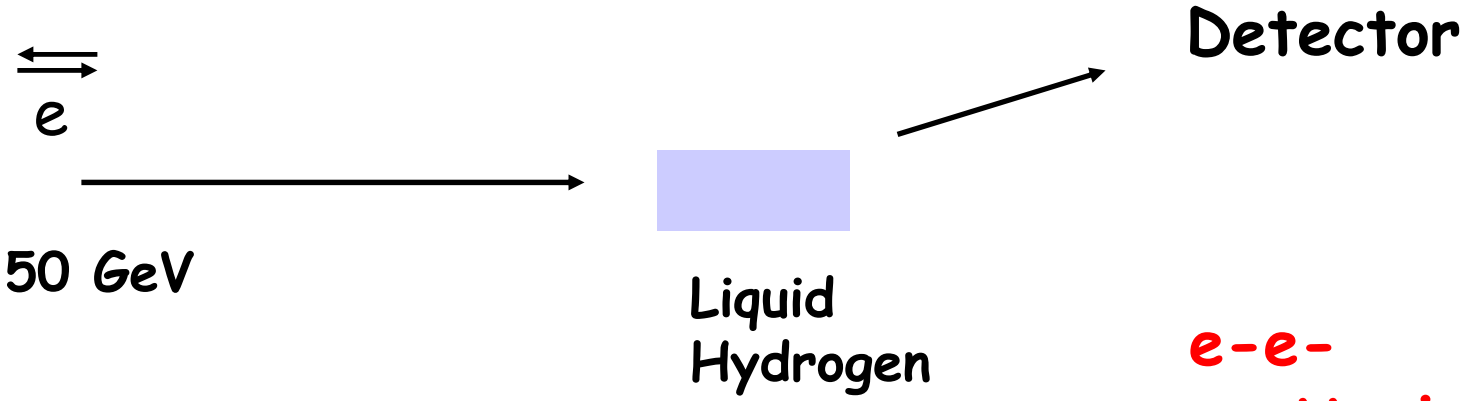


$\Delta\sin^2\theta_w = 0.00017$ (PDG2002) from Z pole measurements

Status in 1999



SLAC Experiment E158



e-e- scattering

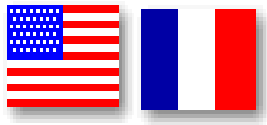
$$A^{PV} = \frac{\sigma^{\uparrow} - \sigma^{\downarrow}}{\sigma^{\uparrow} + \sigma^{\downarrow}}$$

Without electroweak radiative corrections,

$$A^{PV} = \frac{m\ E\ G_F}{\sqrt{2\pi}\,\alpha} \frac{16 \sin\ \theta^2}{(3 + \cos^2\theta)^2} \left(\frac{1}{4} - \sin^2\theta_w\right)$$

In practice: $A^{PV} \sim 1.5 \times 10^{-7}$

E158 Collaboration



- UC Berkeley
- Caltech
- Jefferson Lab
- Princeton
- Saclay
- SLAC
- Smith College
- Syracuse
- UMass
- Virginia

7 Ph.D. Students
60 physicists

Sept 97: *EPAC approval*
1998-99: *Design and Beam Tests*
2000: *Funding and construction*
2001: *Engineering run*
2002: *Physics Runs 1 (Spring), 2 (Fall)*
2003: *Physics Run 3 (Summer)*

Challenges

I. Statistics

II. Beam monitoring & resolution

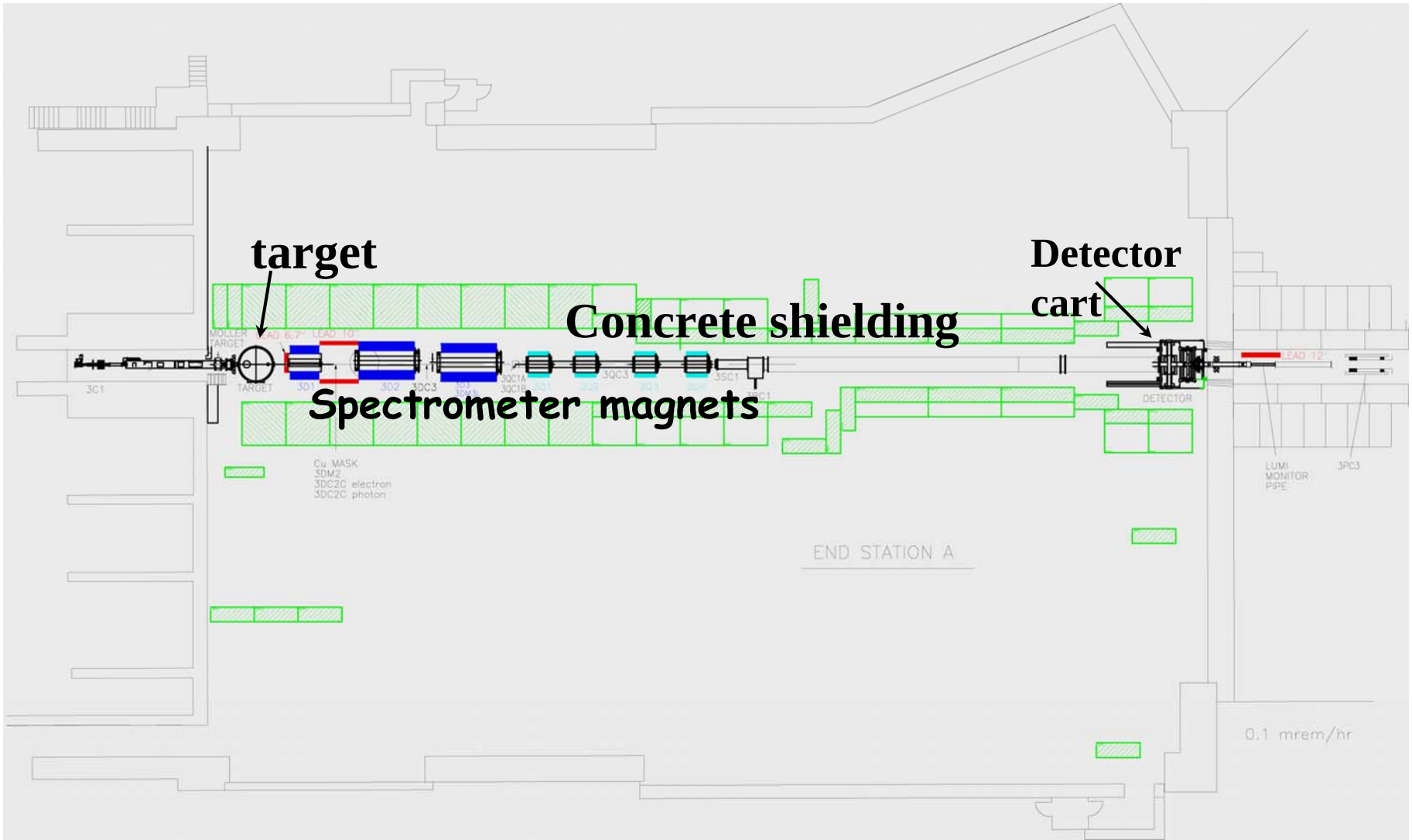
→ jitter vs. statistics

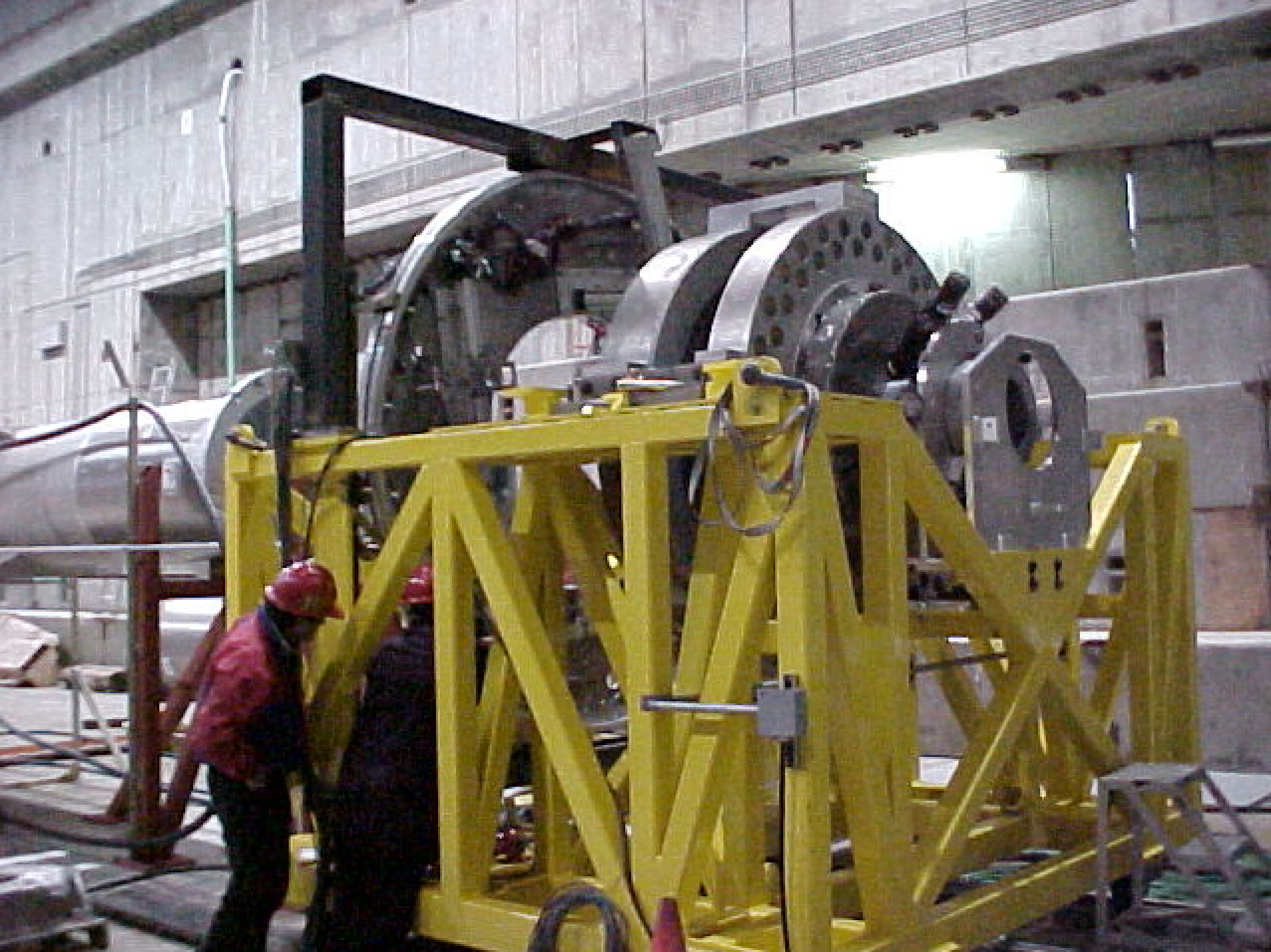
III. Beam systematics

→ false asymmetries

IV. Backgrounds

Setup in End Station A



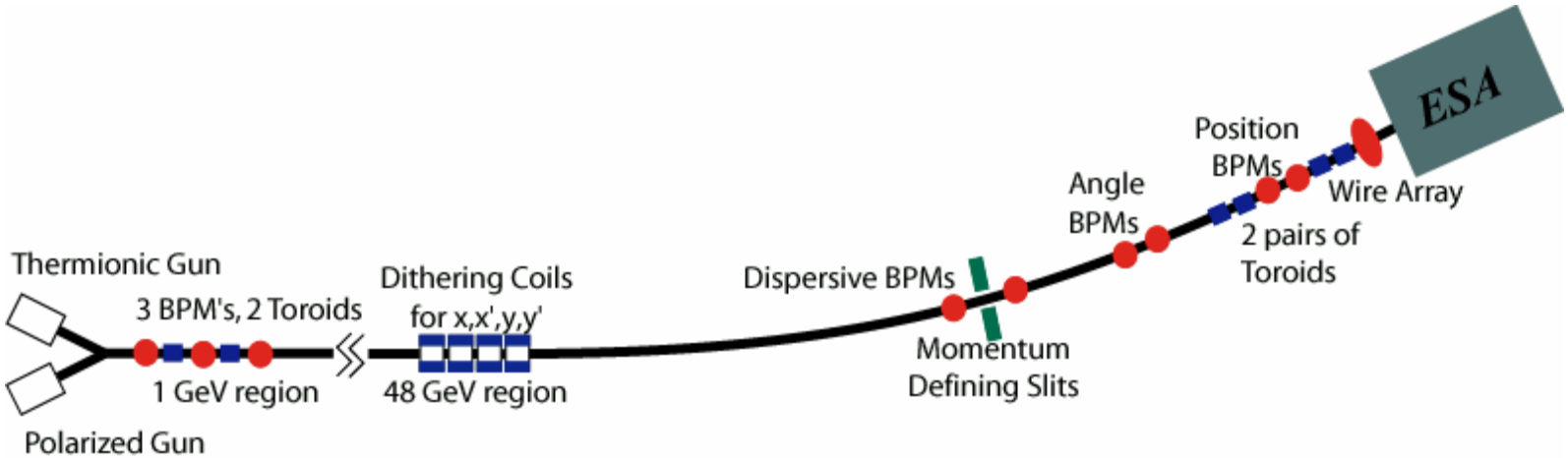


STATISTICS

# electrons per pulse	10^7
Rep rate (120 Hz)	10^9
Seconds/day	10^{14}
100 days	10^{16}

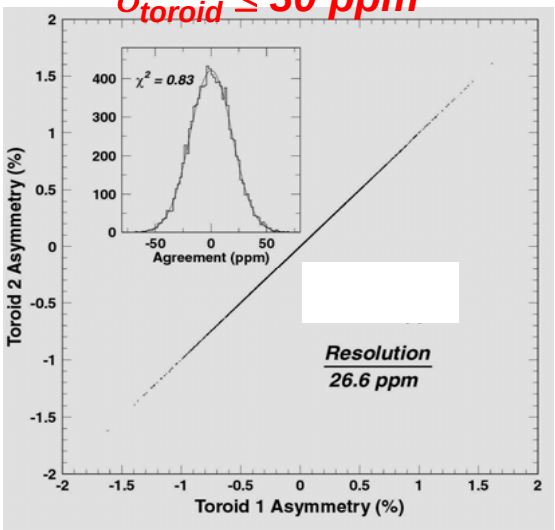
$$\Delta A \sim 10^{-8}$$

II. BEAM MONITORING

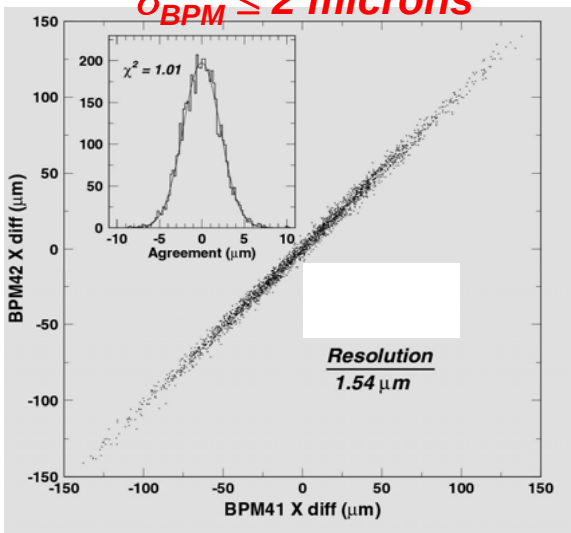


Beam Monitoring Correlations

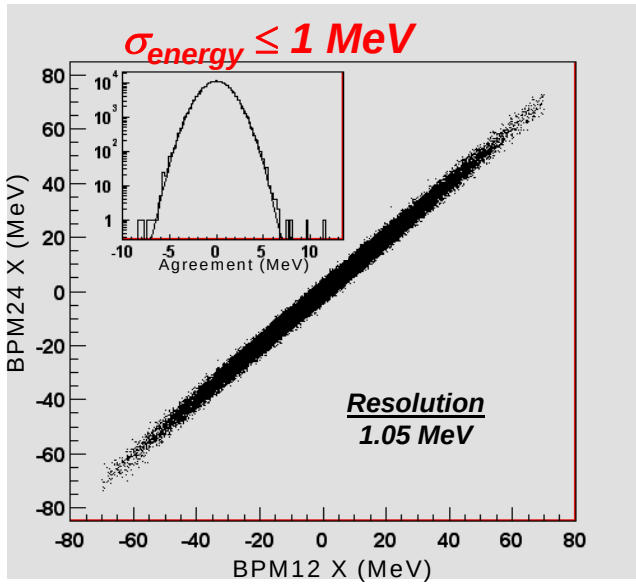
$\sigma_{toroid} \leq 30$ ppm



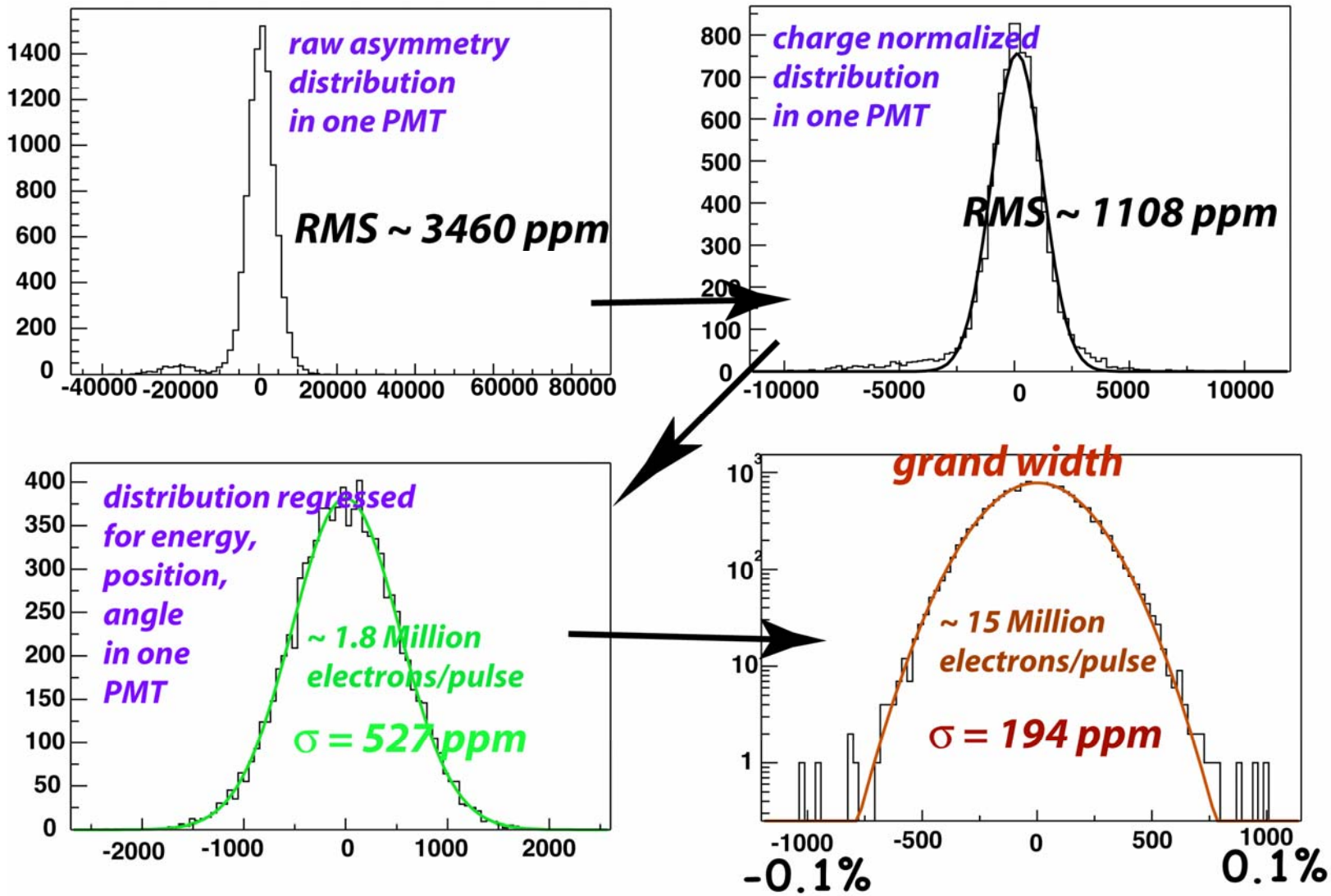
$\sigma_{BPM} \leq 2$ microns



$\sigma_{energy} \leq 1$ MeV

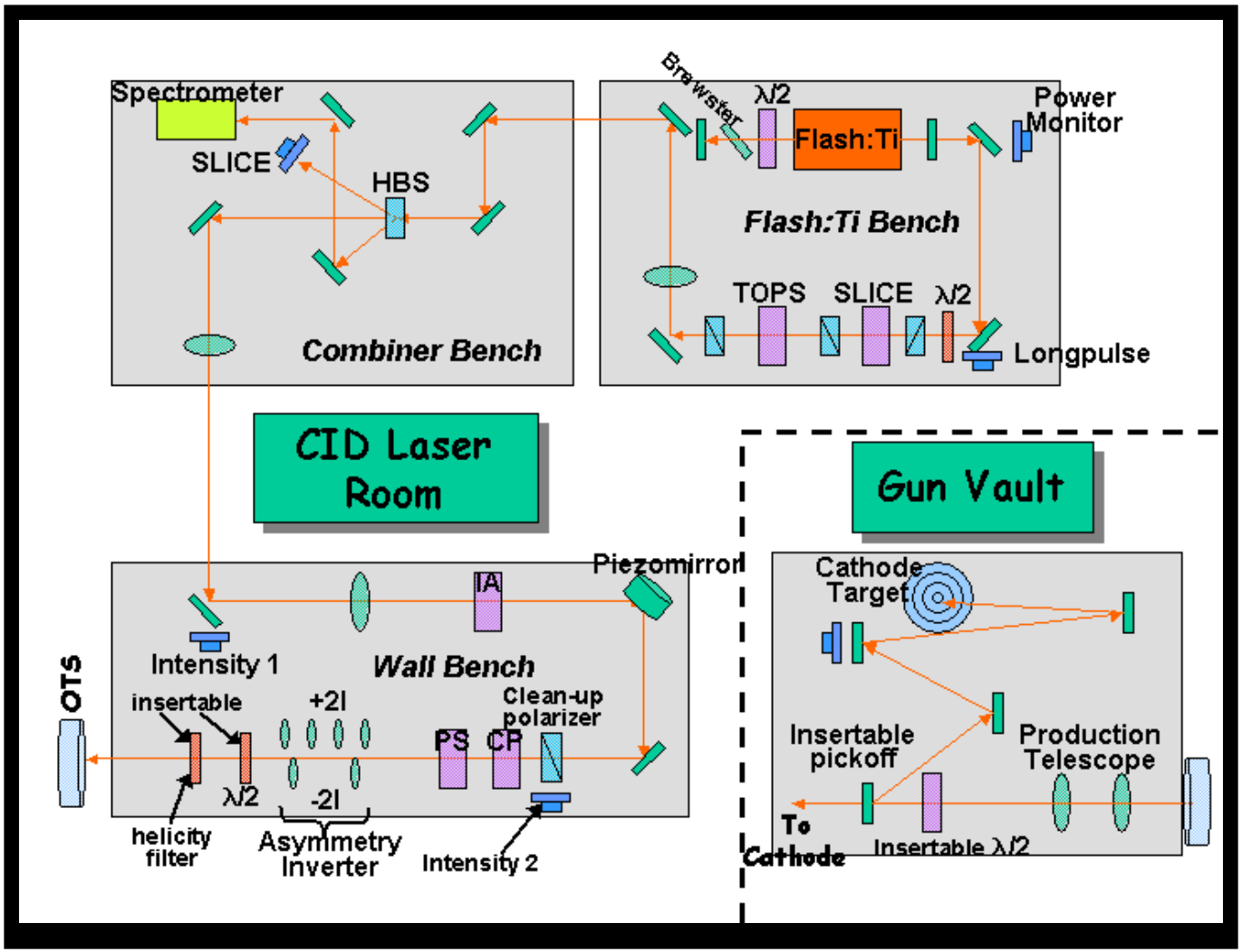


observed left-right asymmetry distribution



III. Beam Asymmetries

Polarized source



SLOW REVERSALS

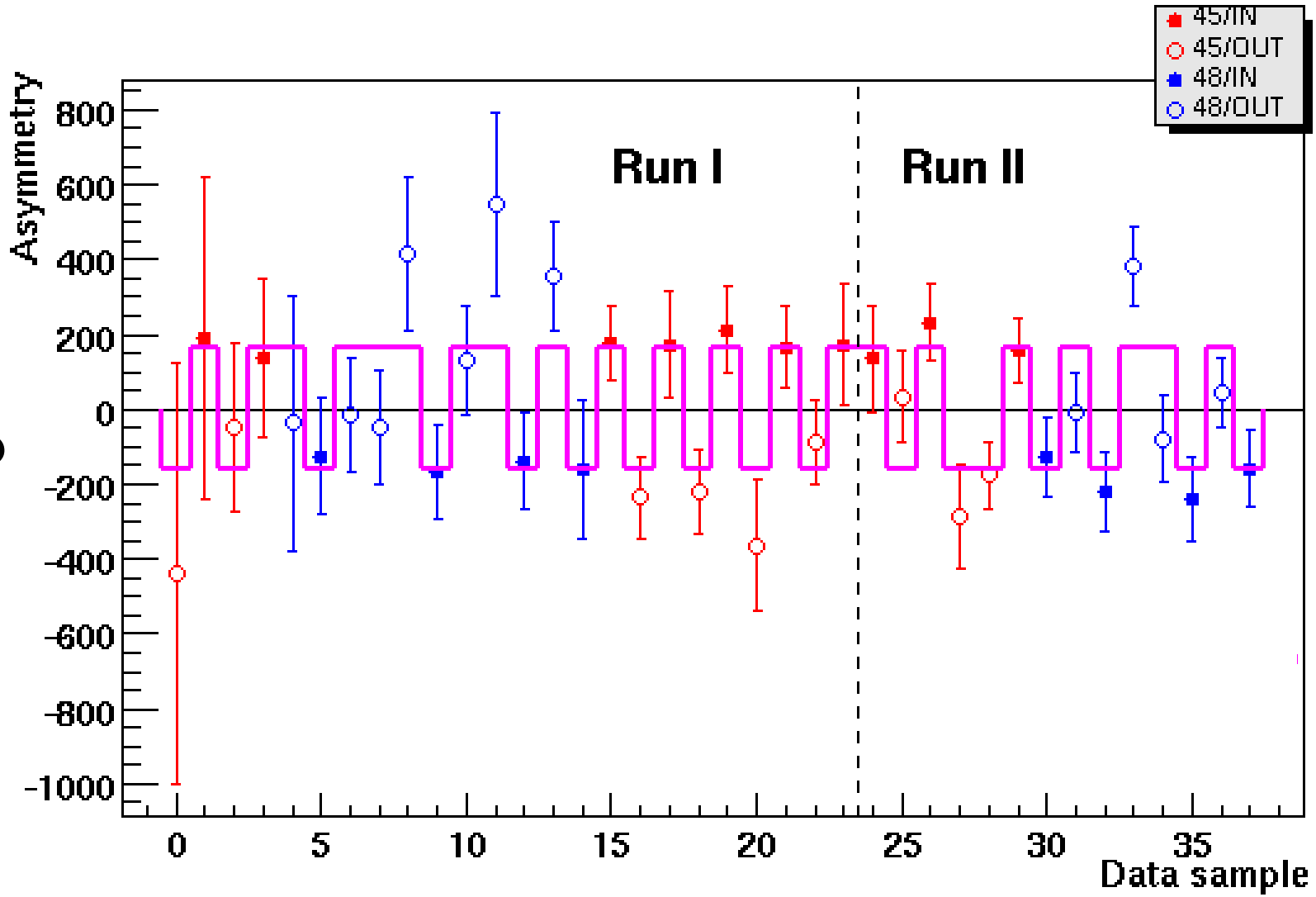
* Halfwaveplate @ source

~few hours

* 48 vs. 45 GeV energy

~ few days

A^{PV} vs. time


45/IN
45/OUT
48/IN
48/OUT
Run I
Run II
Asymmetry
ppb
800
600
400
200
0
-200
-400
-600
-800
-1000
0
5
10
15
20
25
30
35
Data sample

IV. BACKGROUNDS

* electron-proton elastic scattering

* pion production

* radiative inelastic electron-proton scattering

$$W^2 > 3\ GeV^2$$

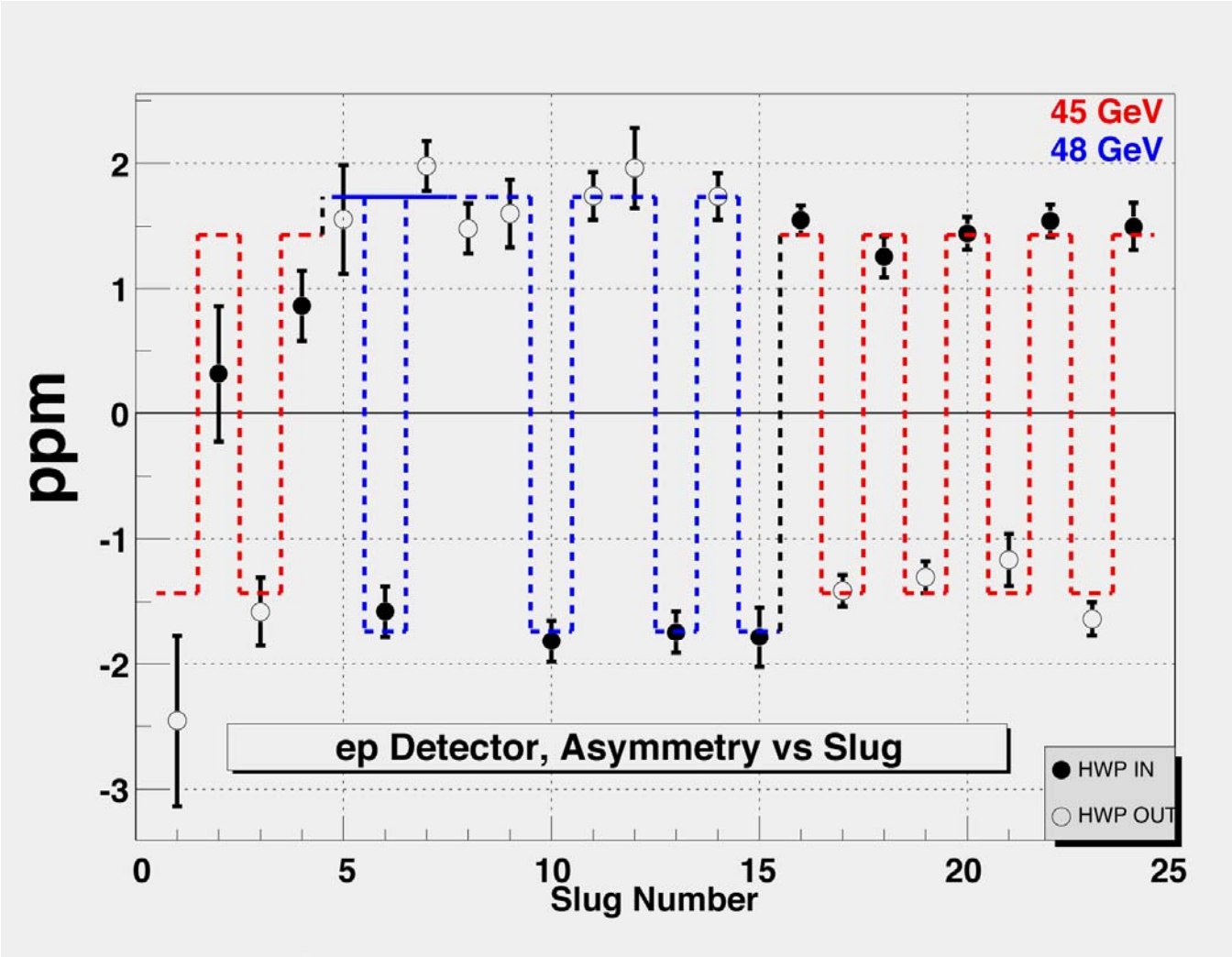
* 2 photon events with transverse polarization

*

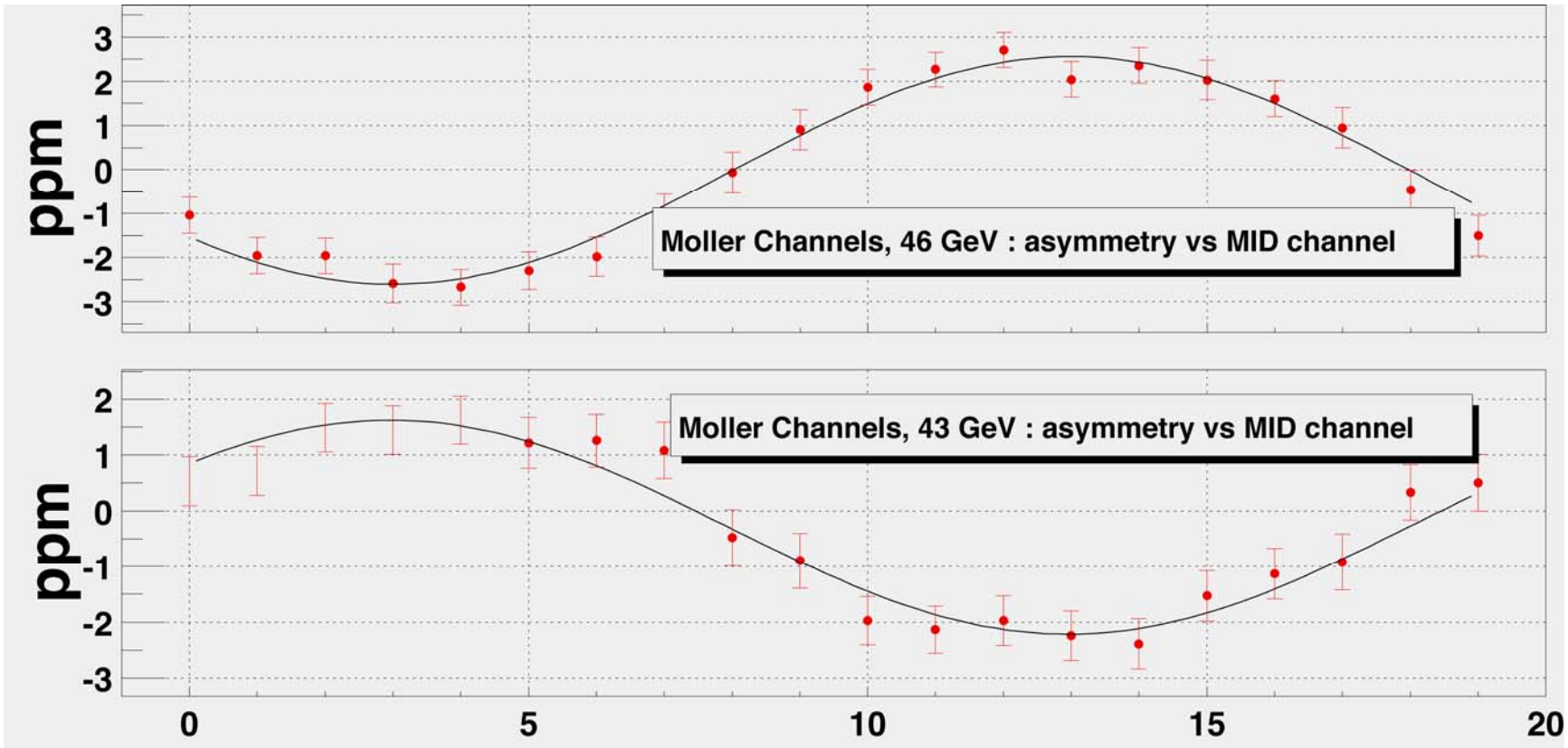
*

*

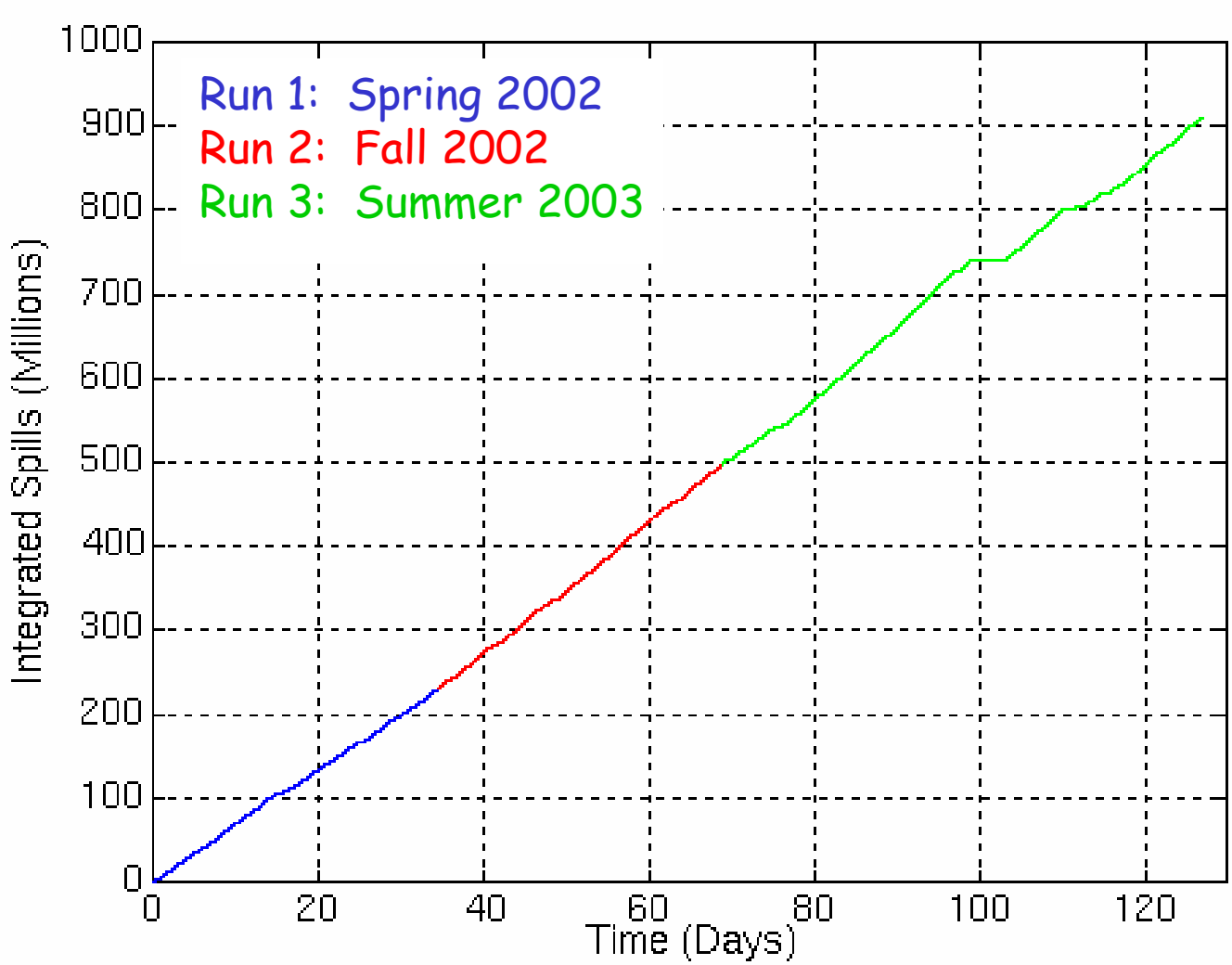
ep Detector Asymmetry



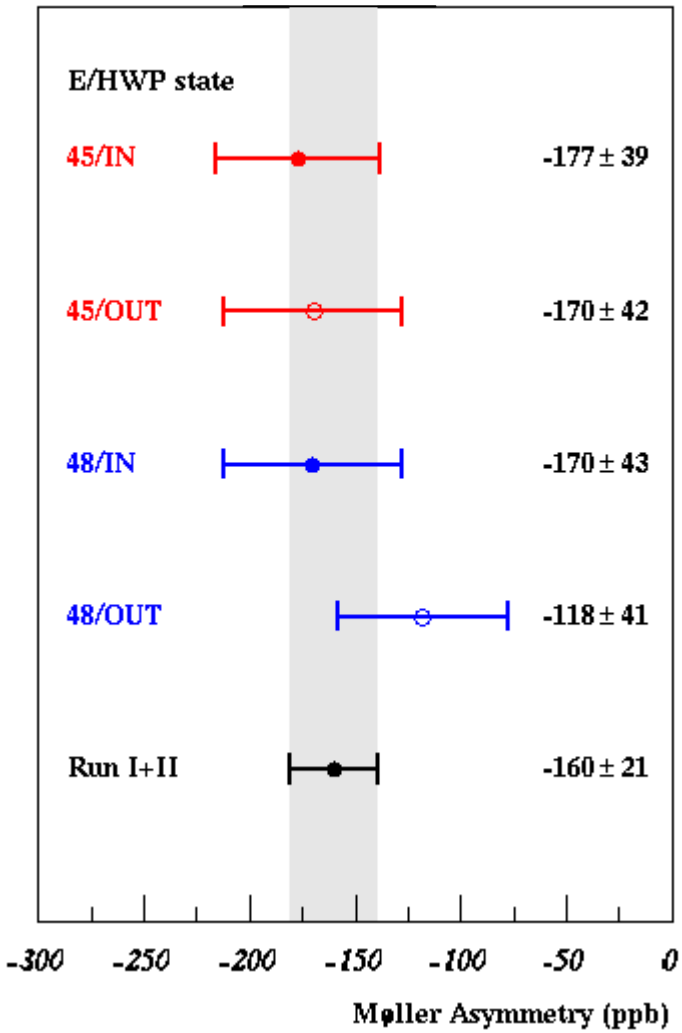
Transversely Polarized Beam



E158 Physics Runs



Run I & II


E/HWP state
45/IN
-177 ± 39
45/OUT
-170 ± 42
48/IN
-170 ± 43
48/OUT
-118 ± 41
Run I+II
-160 ± 21
-300
-250
-200
-150
-100
-50
0
Møller Asymmetry (ppb)

Run I

VOLUME 92, NUMBER 18 PHYSICAL REVIEW LETTERS week ending 7 MAY 2004

Observation of Parity Nonconservation in Møller Scattering

P. L. Anthony,[7] R. G. Arnold,[3] C. Arroyo,[3] K. Baird,[7] K. Bega,[2] J. Biesiada,[1,4] P. E. Bosted,[3] M. Breuer,[3] R. Carr,[2] G. D. Cates,[10] J-P. Chen,[9] E. Chudakov,[9] M. Cooke,[1] F. J. Decker,[7] P. Decowski,[6] A. Deur,[10] W. Emam,[8] R. Erickson,[7] T. Fieguth,[7] C. Field,[7] J. Gao,[2] K. Gustafsson,[2,*] R. S. Hicks,[3] R. Holmes,[8] E. W. Hughes,[2] T. B. Humensky,[4] G. M. Jones,[2] L. J. Kaufman,[3] Yu. G. Kolomensky,[1] K. S. Kumar,[3] D. Lhuillier,[5] R. Lombard-Nelsen,[5] P. Mastromarino,[2] B. Mayer,[5] R. D. McKeown,[2] R. Michaels,[9] M. Olson,[7] K. D. Paschke,[3] G. A. Peterson,[3] R. Pitthan,[7] K. Pope,[6,†] D. Relyea,[4,7] S. E. Rock,[3] O. Saxton,[7] G. Shapiro,[1,†] J. Singh,[10] P. A. Souder,[8] Z. M. Szalata,[7] W. A. Tobias,[10] B. T. Tonguc,[8] J. Turner,[7] B. Tweedie,[1] A. Vacheret,[5] D. Walz,[7] T. Weber,[7] J. Weisend,[7] D. Whittum,[7] M. Woods,[7] and I. Younus[8]

(SLAC E158 Collaboration)

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[4]*Princeton University, Princeton, New Jersey 08544, USA*
[5]*CEA Saclay, DAPNIA/SPhN, F-91191 Gif-sur-Yvette, France*
[6]*Smith College, Northampton, Massachusetts 01063, USA*
[7]*Stanford Linear Accelerator Center, Menlo Park, California 94025, USA*
[8]*Syracuse University, Syracuse, New York 13244, USA*
[9]*Thomas Jefferson Laboratory, Newport News, Virginia 23606, USA*
[10]*University of Virginia, Charlottesville, Virginia 22903, USA*
(Received 11 December 2003; published 7 May 2004)

RUN I

FINAL RESULT

At $Q^2 = 0.027\ (GeV/c)^2$….

$$A^{PV} = -175 \pm 30\ (stat) \pm 20\ (syst)\ \ ppb$$

$$\sin^2 \theta_w^{\overline{MS}} = 0.2293 \pm 0.0024\ (stat) \pm 0.0016\ (syst)$$

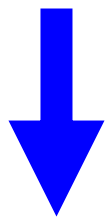
Theory: $\sin^2 \theta_w^{\overline{MS}} = 0.2311 \pm 0.00016$

RUN I & II

PRELIMINARY

At $Q^2 = 0.027\ (GeV/c)^2$….

$$A^{PV} = -160 \pm 21\ (stat) \pm 17\ (syst)\ \ ppb$$

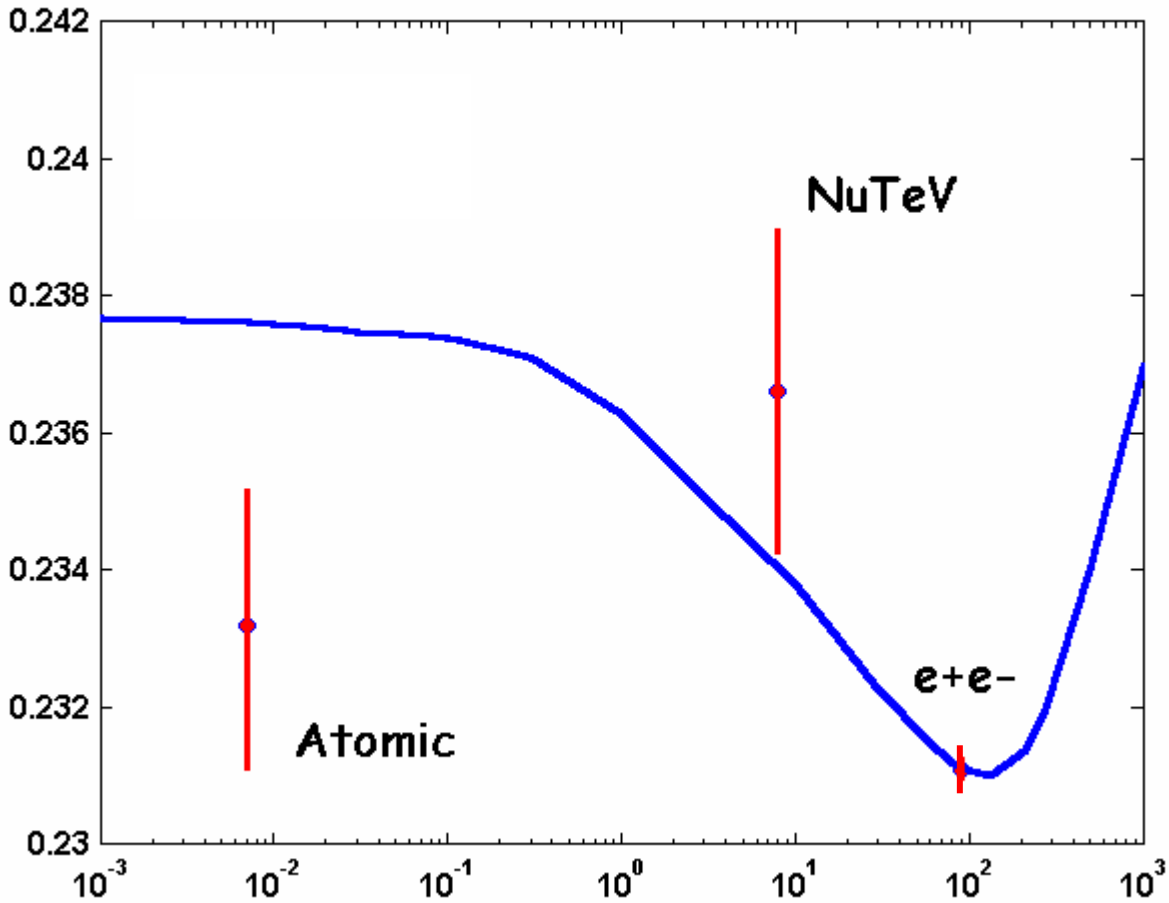


$$\sin^2\theta_w^{\overline{MS}} = 0.2308 \pm 0.0015\ (stat) \pm 0.0014\ (syst)$$

Theory: $\sin^2\theta_w^{\overline{MS}} = 0.2311 \pm 0.00016$

Status in 1999

$\sin^2\theta_w$



Q (GeV)

Precise Determination of Electroweak Parameters in Neutrino-Nucleon Scattering

G. P. Zeller,[5] K. S. McFarland,[8,3] T. Adams,[4] A. Alton,[4] S. Avvakumov,[8] L. de Barbaro,[5] P. de Barbaro,[8] R. H. Bernstein,[3] A. Bodek,[8] T. Bolton,[4] J. Brau,[6] D. Buchholz,[5] H. Budd,[8] L. Bugel,[3] J. Conrad,[2] R. B. Drucker,[6] B. T. Fleming,[2] R. Frey,[6] J. A. Formaggio,[2] J. Goldman,[4] M. Goncharov,[4] D. A. Harris,[8] R. A. Johnson,[1] J. H. Kim,[2] S. Koutsoliotas,[2] M. J. Lamm,[3] W. Marsh,[3] D. Mason,[6] J. McDonald,[7] C. McNulty,[2] D. Naples,[7] P. Nienaber,[3] A. Romosan,[2] W. K. Sakumoto,[8] H. Schellman,[5] M. H. Shaevitz,[2] P. Spentzouris,[2] E. G. Stern,[2] N. Suwonjandee,[1] M. Tzanov,[7] M. Vakili,[1] A. Vaitaitis,[2] U. K. Yang,[8] J. Yu,[3] and E. D. Zimmerman[2]

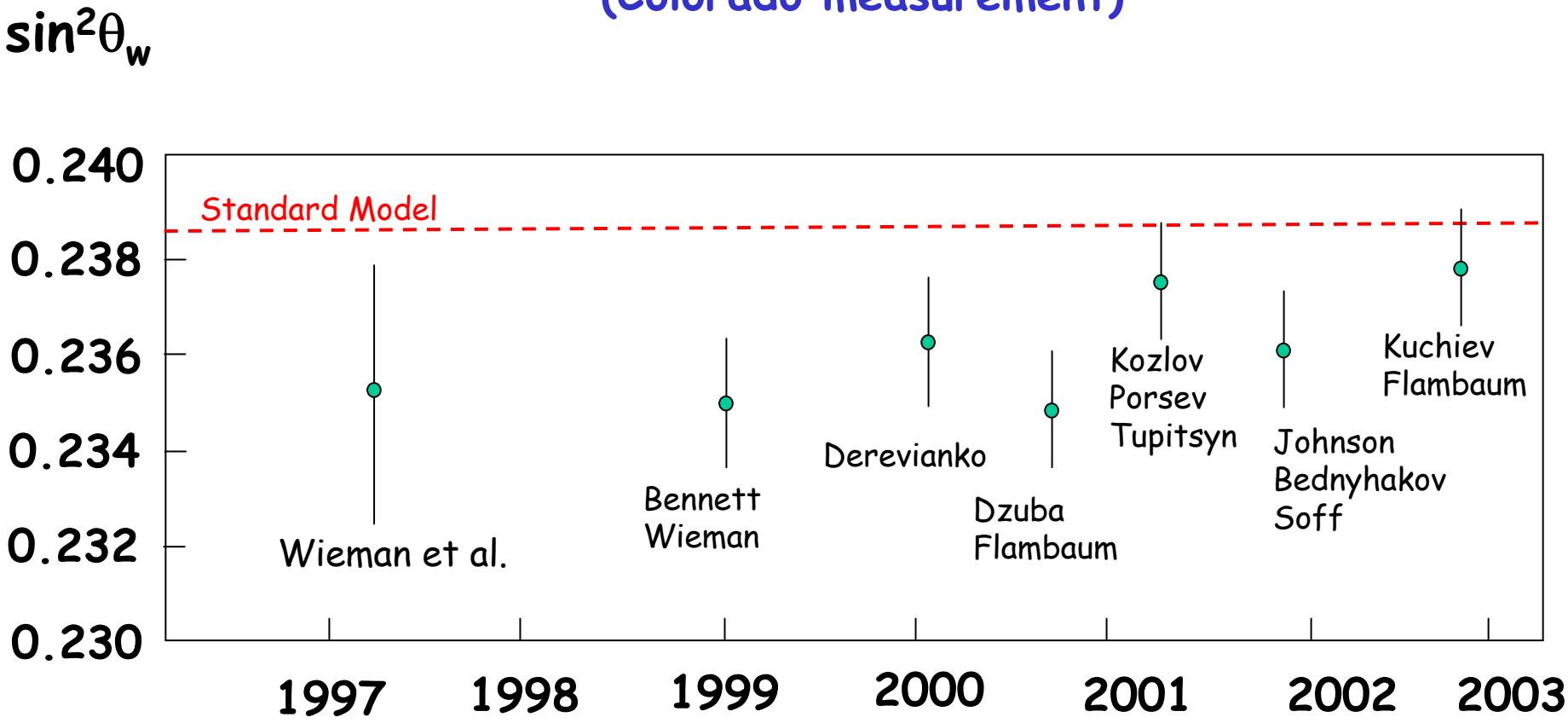
[1]*University of Cincinnati, Cincinnati, Ohio 45221*
[2]*Columbia University, New York, New York 10027*
[3]*Fermi National Accelerator Laboratory, Batavia, Illinois 60510*
[4]*Kansas State University, Manhattan, Kansas 66506*
[5]*Northwestern University, Evanston, Illinois 60208*
[6]*University of Oregon, Eugene, Oregon 97403*
[7]*University of Pittsburgh, Pittsburgh, Pennsylvania 15260*
[8]*University of Rochester, Rochester, New York 14627*

(Received 25 October 2001; published 12 February 2002)

The NuTeV Collaboration has extracted the electroweak parameter $\sin^2\theta_W$ from the measurement of the ratios of neutral current to charged current ν and $\overline{\nu}$ cross sections. Our value, $\sin^2\theta_W{}^{(\text{on-shell})} = 0.2277 \pm 0.0013(\text{stat}) \pm 0.0009(\text{syst})$, is 3 standard deviations above the standard model prediction. We also present a model independent analysis of the same data in terms of neutral-current quark couplings.

DOI: 10.1103/PhysRevLett.88.091802 PACS numbers: 12.15.Ji, 12.15.Mm, 13.15.+g

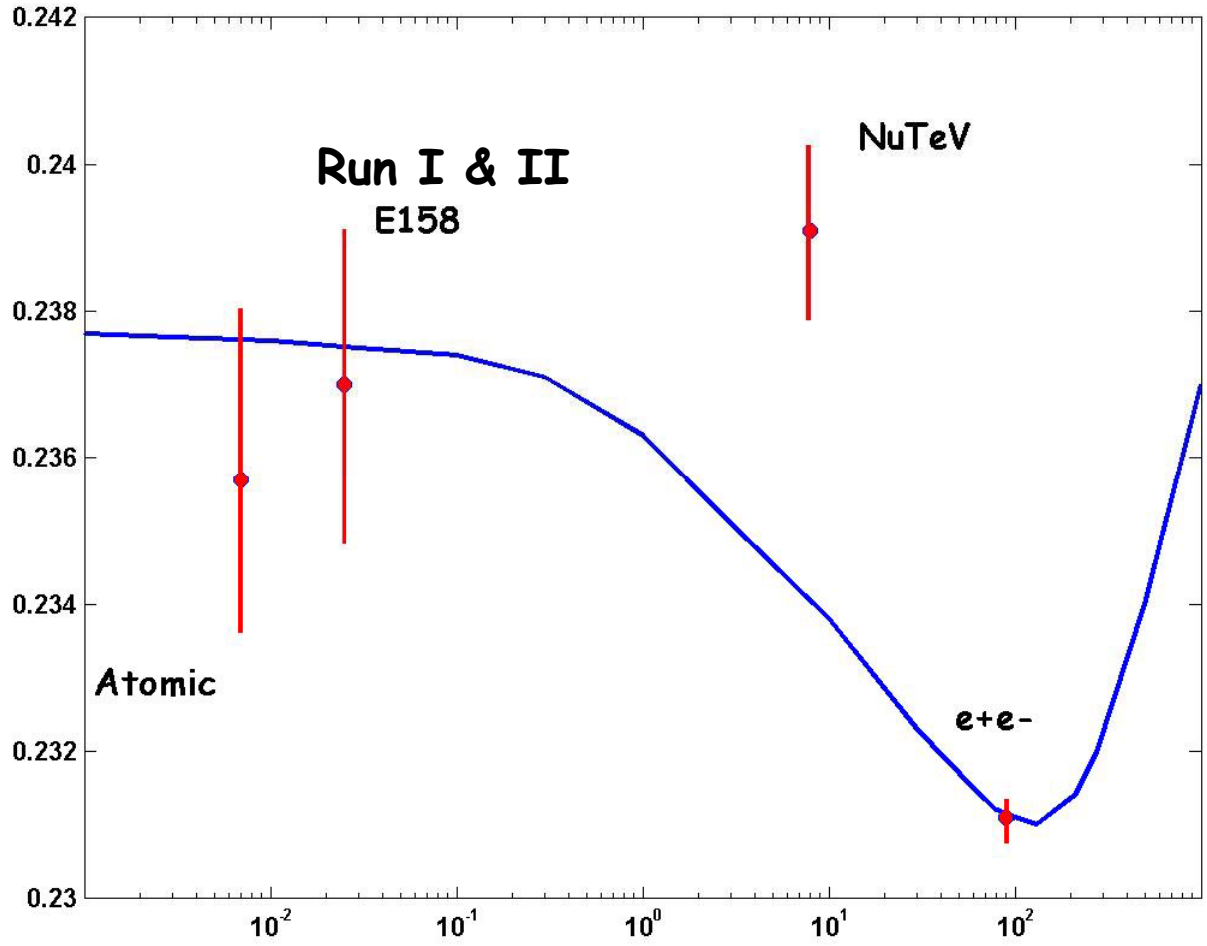
Cesium Atomic Parity Violation Result vs. Time
(Colorado measurement)



Modifications in the theoretical corrections to the atomic structure

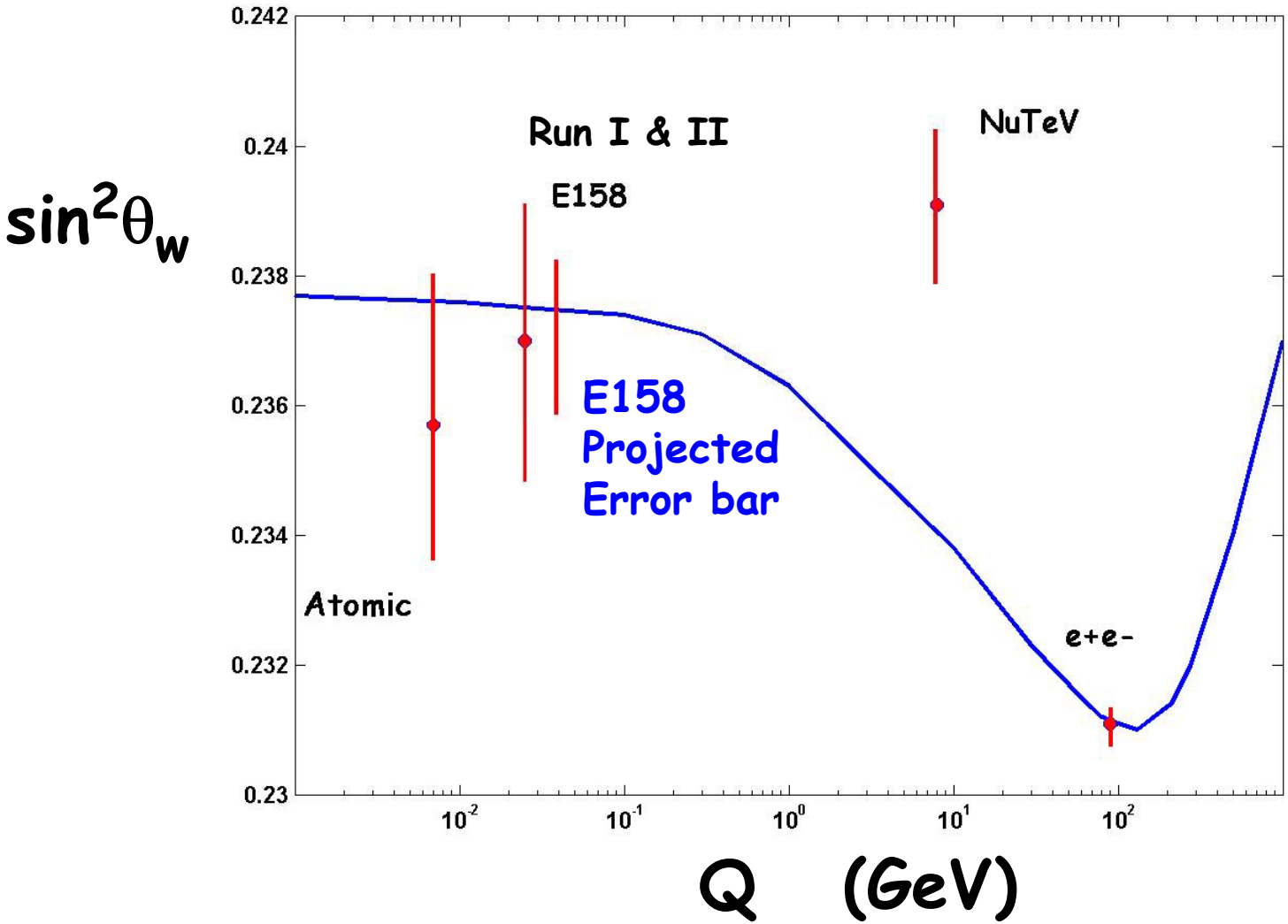
Status today

$\sin^2\theta_w$



Q (GeV)

Including E158 projections...

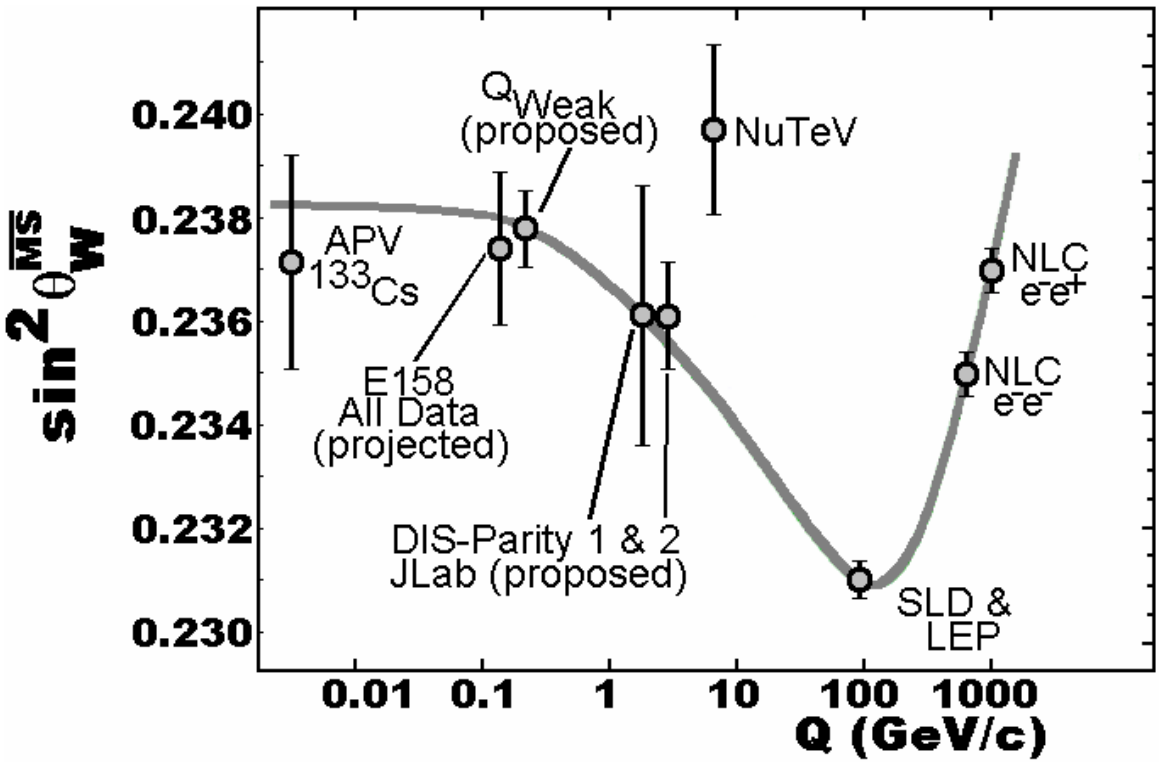


Beyond Standard Model Implications...

* Limit on Λ_{LL} ~ 7 TeV
* Limit on Z_χ ~ 400 GeV
* Limit on lepton flavor violating coupling ~ $0.02G_F$

→ Limits will improve with new data

Future Measurements



LHC

Not a parity experiment …

→ Has major impact on precision low energy tests for discovery potential

Z', supersymmetry, compositeness, leptoquarks, etc…

in the TeV range

SUMMARY

* Performed a first measurement of parity violation in e^-e^- scattering

Final results in ~ 1/2 year

* Future parity experiments active

* Complementary to collider experiments

Run I Systematics

Correction	f_{bkg}	$\sigma(f_{bkg})$	A_{corr} (ppb)	$\sigma(A_{corr})$ (ppb)
Beam first order	-	-	-	3
Beam higher orders	-	-	-	10
Beam spotsize	-	-	0	1
Transverse asymmetry	-	-	-8	3
High energy photons	0.004	0.002	3	3
Synchrotron photons	0.0015	0.0005	0	5
Neutrons	0.003	0.001	-5	3
ep elastic	0.064	0.007	-8	2
ep inelastic	0.011	0.003	-26	6
Pions	0.006	0.002	1	1
TOTAL	0.090	0.009	-43	14

Run I Dilutions

Normalization Factor	f	σ(f)
Dilutions	0.91	0.01
Polarization	0.85	0.05
Analyzing power	1.0	0.02
Linearity	0.99	0.01

Run II Systematics

Correction	f_{bkg}	$\sigma(f_{bkg})$	A_{corr} (ppb)	$\sigma(A_{corr})$ (ppb)
Beam first order	-	-	-	3
Beam higher orders	-	-	-	15
Beam spotsize	-	-	0	1
Transverse asymmetry	-	-	-5	3
High energy photons	0.004	0.002	3	3
Synchrotron photons	0.0015	0.0005	0	2
Neutrons	0.003	0.001	-5	3
ep elastic	0.053	0.005	-7	1
ep inelastic	0.009	0.002	-21	6
Pions	0.006	0.002	1	1
TOTAL	0.074	0.008	-30	17

Run II Dilutions

Normalization Factor	f	σ(f)
Dilutions	0.91	0.01
Polarization	0.85	0.05
Analyzing power	1.0	0.02
Linearity	0.99	0.01

Asymmetry Results

A_{PV}(Run I) = -176 ± 30 (stat) ± 20 (syst) ppb
(5σ significance)

A_{PV}(Run II) = -145 ± 28 (stat) ± 23 (syst) ppb
(4σ significance)

A_{PV}(Run I+II) = -161 ± 21 (stat) ± 17 (syst) ppb
(6σ significance)

Electroweak Mixing Parameter

$\sin^2\theta_{eff}$(Run I) = 0.2353 ± 0.0025 (stat) ±0.0017 (syst)
(-1.0σ from Standard Model)

$\sin^2\theta_{eff}$(Run II) = 0.2381 ± 0.0023 (stat) ±0.0019 (syst)
(-0.1σ from Standard Model)

$\sin^2\theta_{eff}$(Run I) = 0.2366 ± 0.0018 (stat) ±0.0014 (syst)
(-0.8σ from Standard Model)

☞ Standard Model prediction: 0.2385 ± 0.0006
(Czarnecki, Marciano, 2000)