# Studying Strong and Electroweak Interactions Using Electron Scattering at JLab

Xiaochao Zheng
Univ. of Virginia
February 6, 2009

- Introduction — electron scattering and nucleon structure
- Parity Violating DIS
  - E08-011 using a 6 GeV beam – Physics and preparation status;
  - Program at the 12 GeV Upgrade
- Nucleon resonances study from pion electroproduction
- Summary of research program and outlook

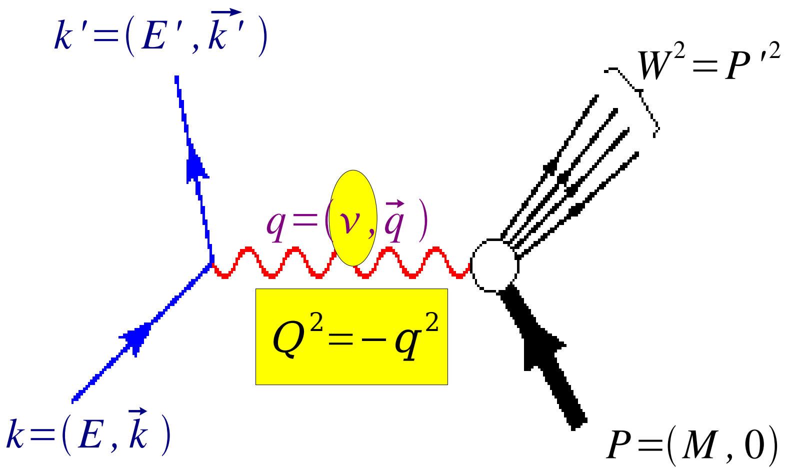
# Four Interactions of Our Nature

| | | | |
|---|---|---|---|
| Gravitational | $10^{-38}$ | General relativity | Well understood at large distances |
| Electro-Magnetic | 1/137 | SU(2) X U(1) gauge theory | EM, weak: fully understood, but there is room for New Physics |
| Weak | $10^{-5}$ | | |
| Strong | $10^{-1} \sim 10^{0}$ | SU(3), QCD | less understood, and no analytical calcul |

## Electron scattering has been widely used to study

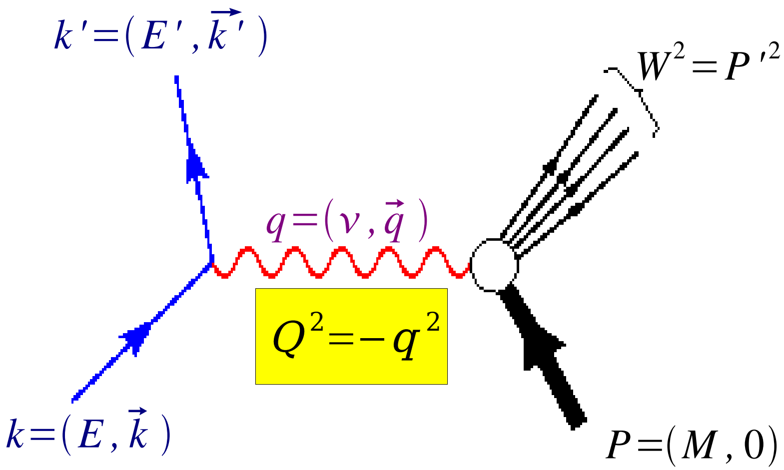
- Structure of the nucleon — strong interactions, pQCD;
- (Recently) parity violation electron scattering:
  - strange-quark content of the nucleon (elastic)
  - Electroweak interactions (DIS)

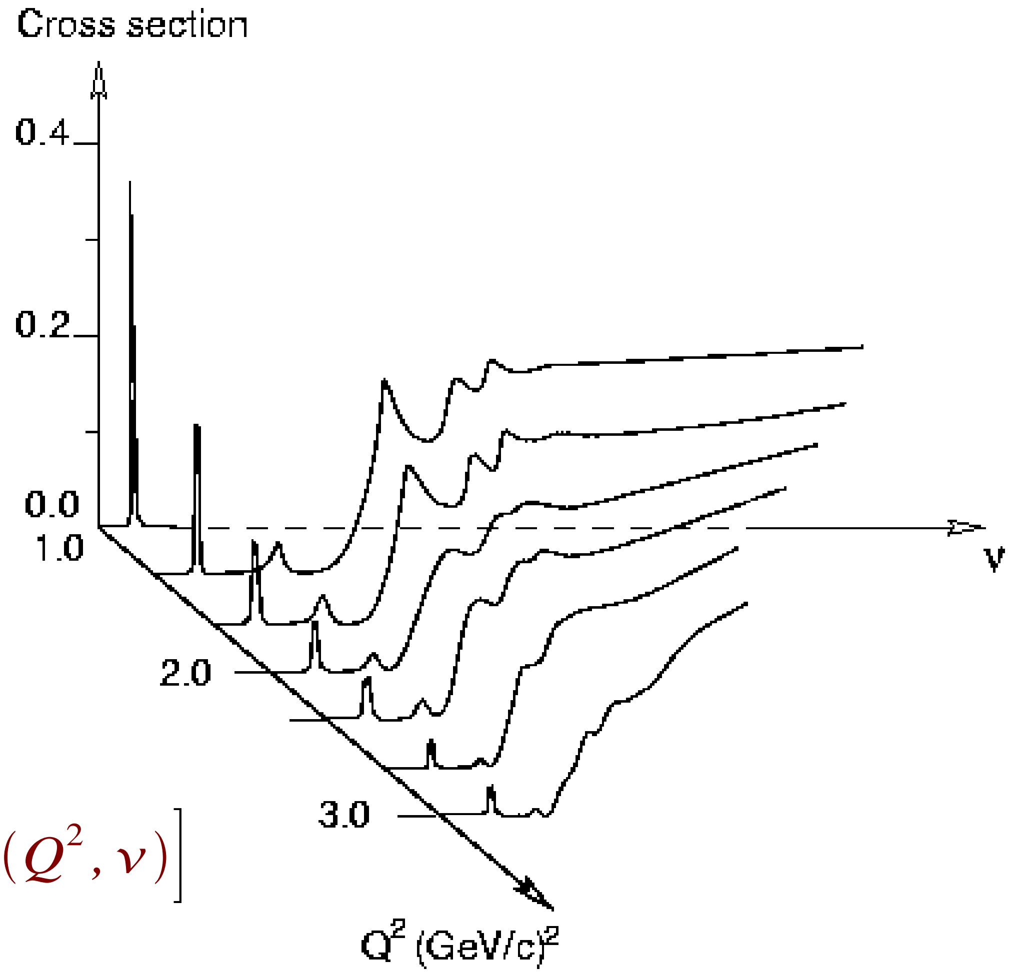
# Exploring Nucleon Structure Using Electron Scattering




- *Electrons ($\mu$'s)* interact with the target by exchanging a "virtual" photon;
- Two variables to describe how the target behaves: $1/Q^2$ and $\nu$;

# Exploring Nucleon Structure Using Electron Scattering




- The cross section:

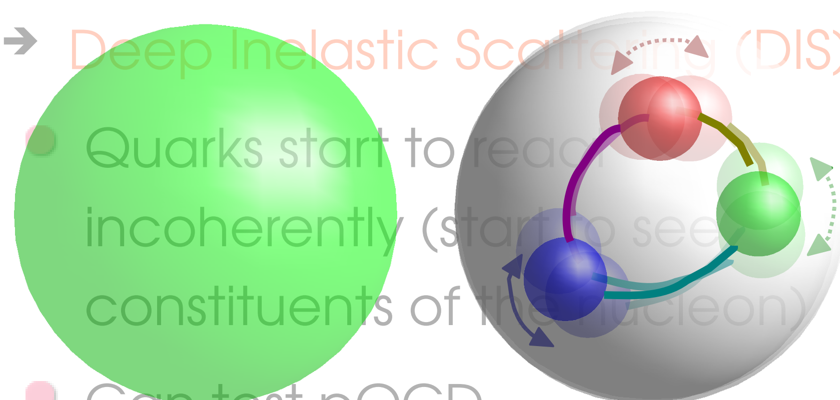
$$\frac{d^2\sigma}{d\Omega\, dE'} = \sigma_{Mott}\left[\alpha F_1(Q^2,\nu)+\beta F_2(Q^2,\nu)\right]$$

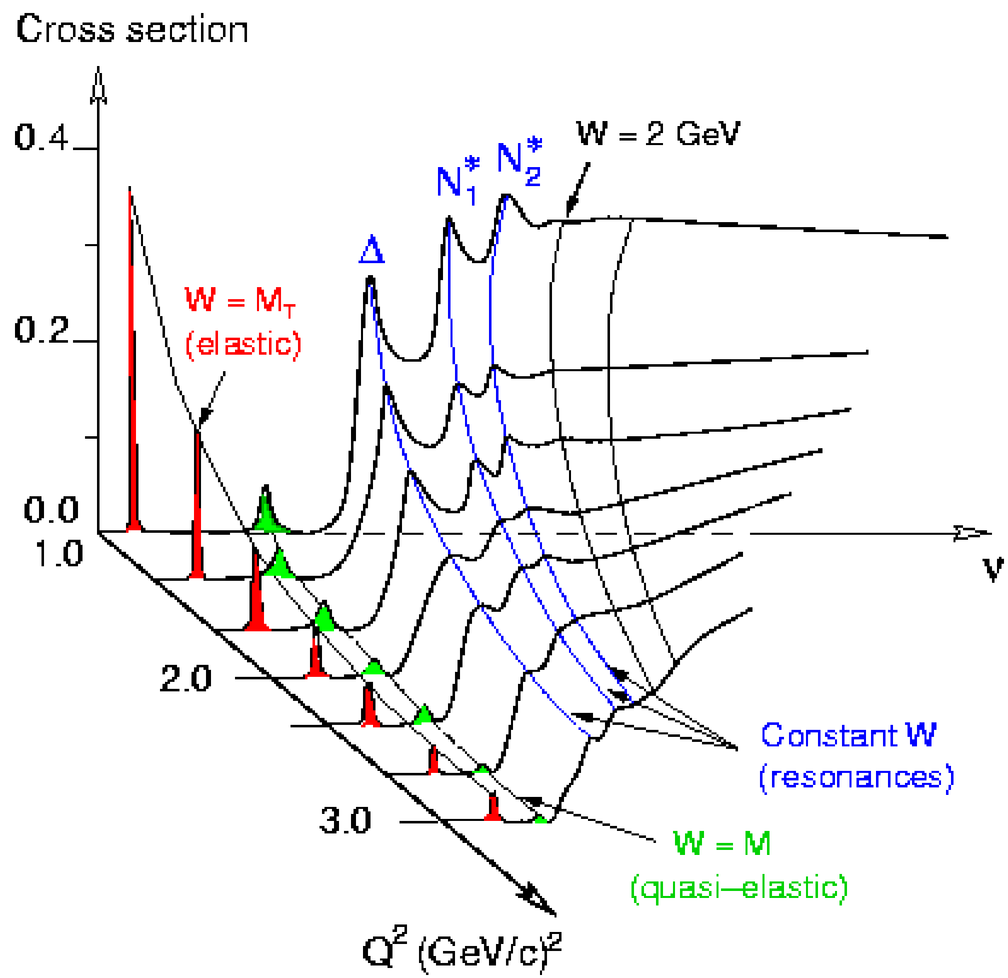
For point-like target

# Exploring Nucleon Structure Using Electron Scattering

Elastic, quasi-elastic, resonances, deep inelastic

- (Quasi-) elastic – the nucleus (nucleon) appears as a rigid body
  $$Q^2 = 2M_{T(N)}\nu$$
- Resonance region – quarks inside the nucleon react coherently
- Deep Inelastic Scattering (DIS):
  - Quarks start to react incoherently (start to see constituents of the nucleon)
  - Can test pQCD






(highly non-pertubative, phenomenology models)

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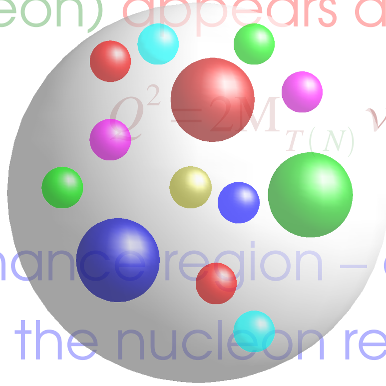

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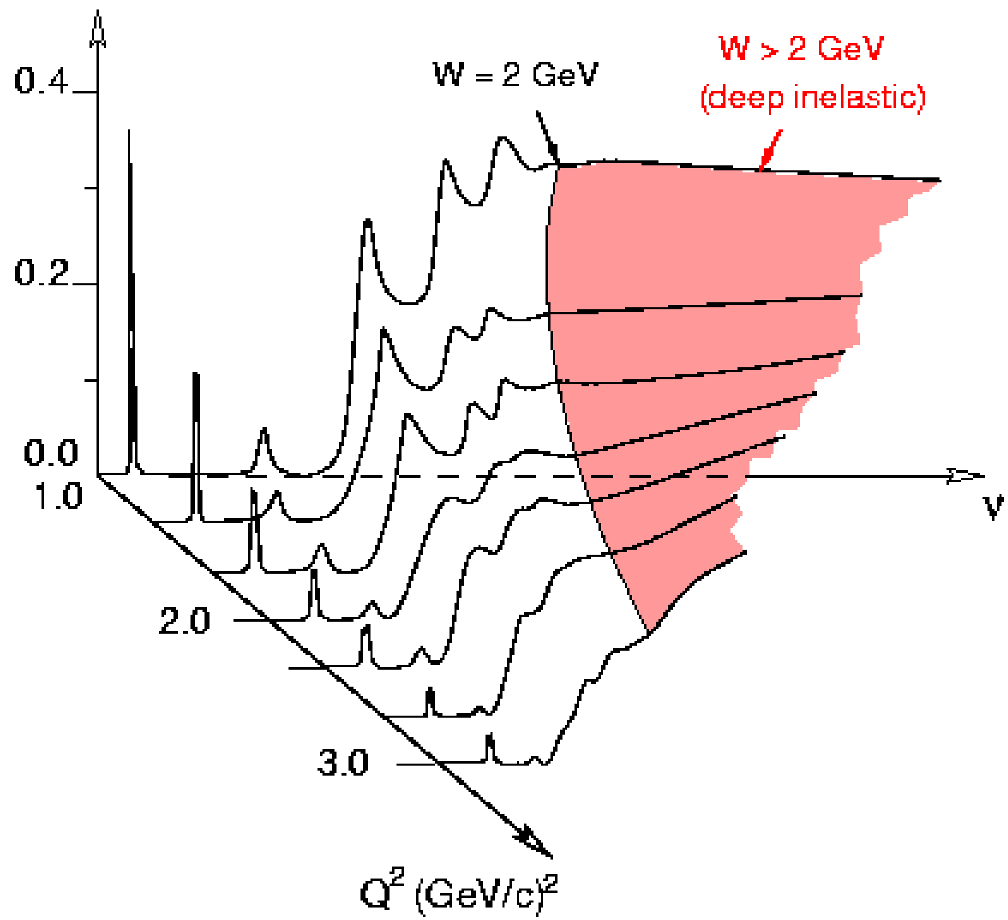
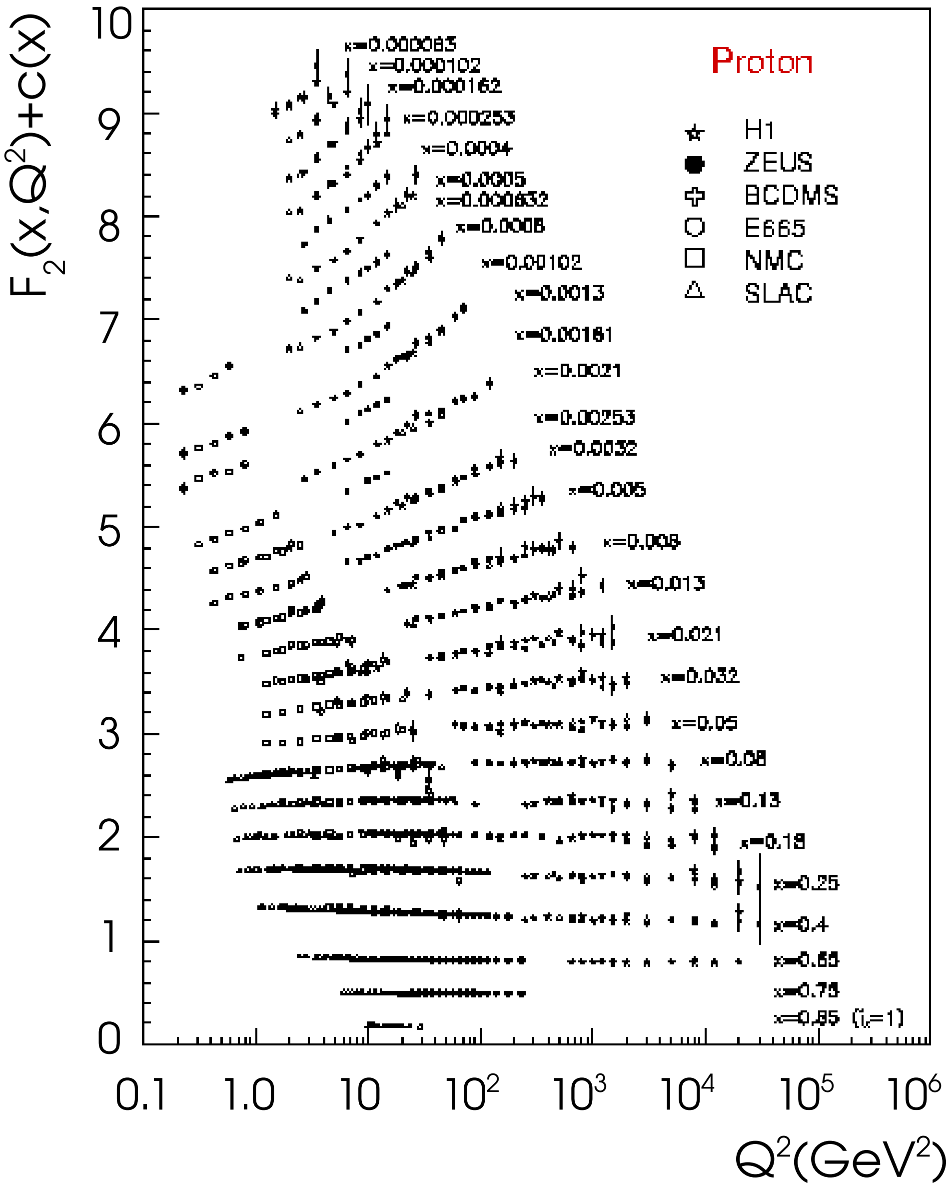
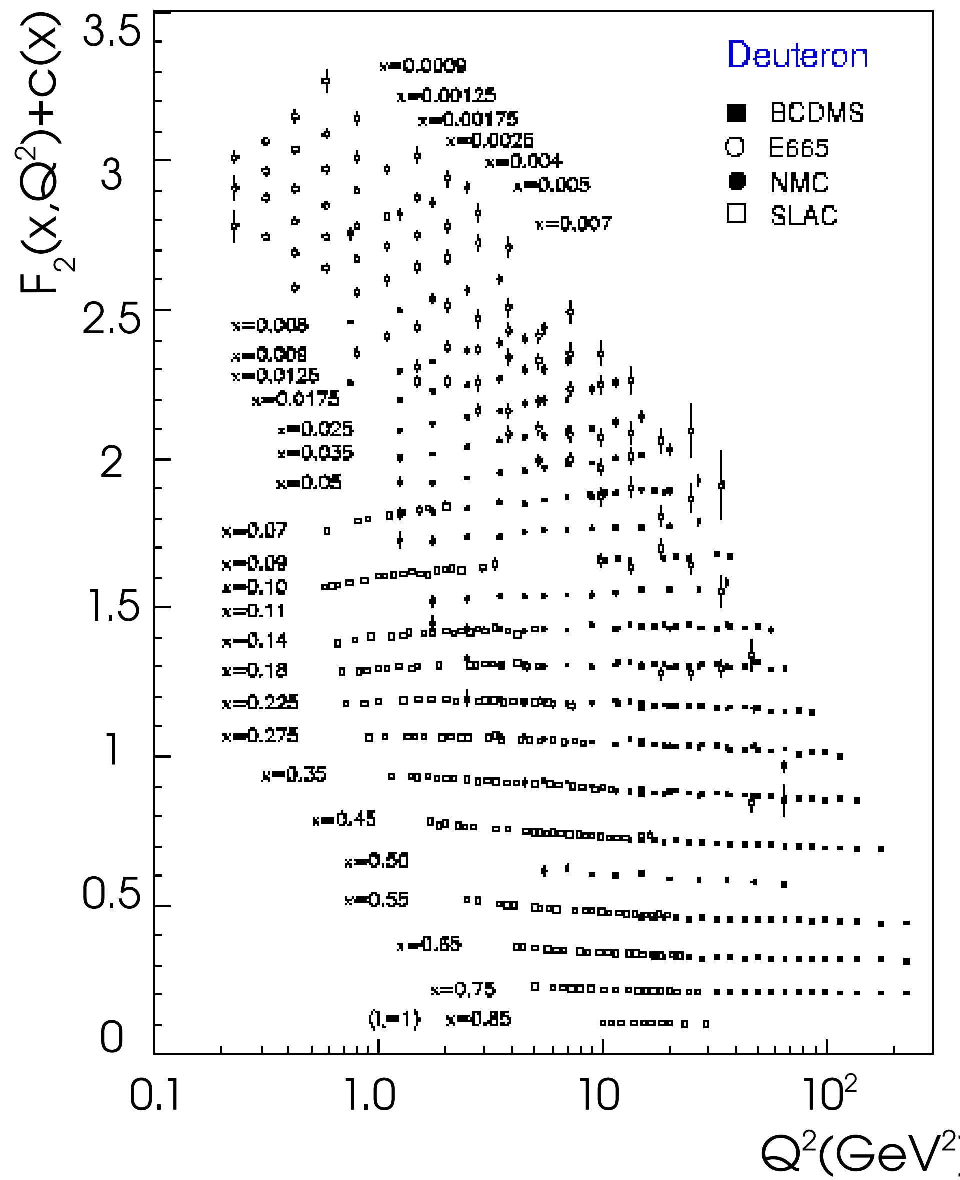


# Current Knowledge of Nucleon Unpolarized Structure

$$\frac{d^2\sigma}{d\Omega\, dE'} = \sigma_{Mott}\left[\alpha F_1(Q^2,x) + \beta F_2(Q^2,x)\right] \qquad F_1 = \frac{F_2(1+\gamma^2)}{2x\left(1+R(Q^2,x)\right)} \qquad x_{Bj} \equiv \frac{Q^2}{2M\nu}$$

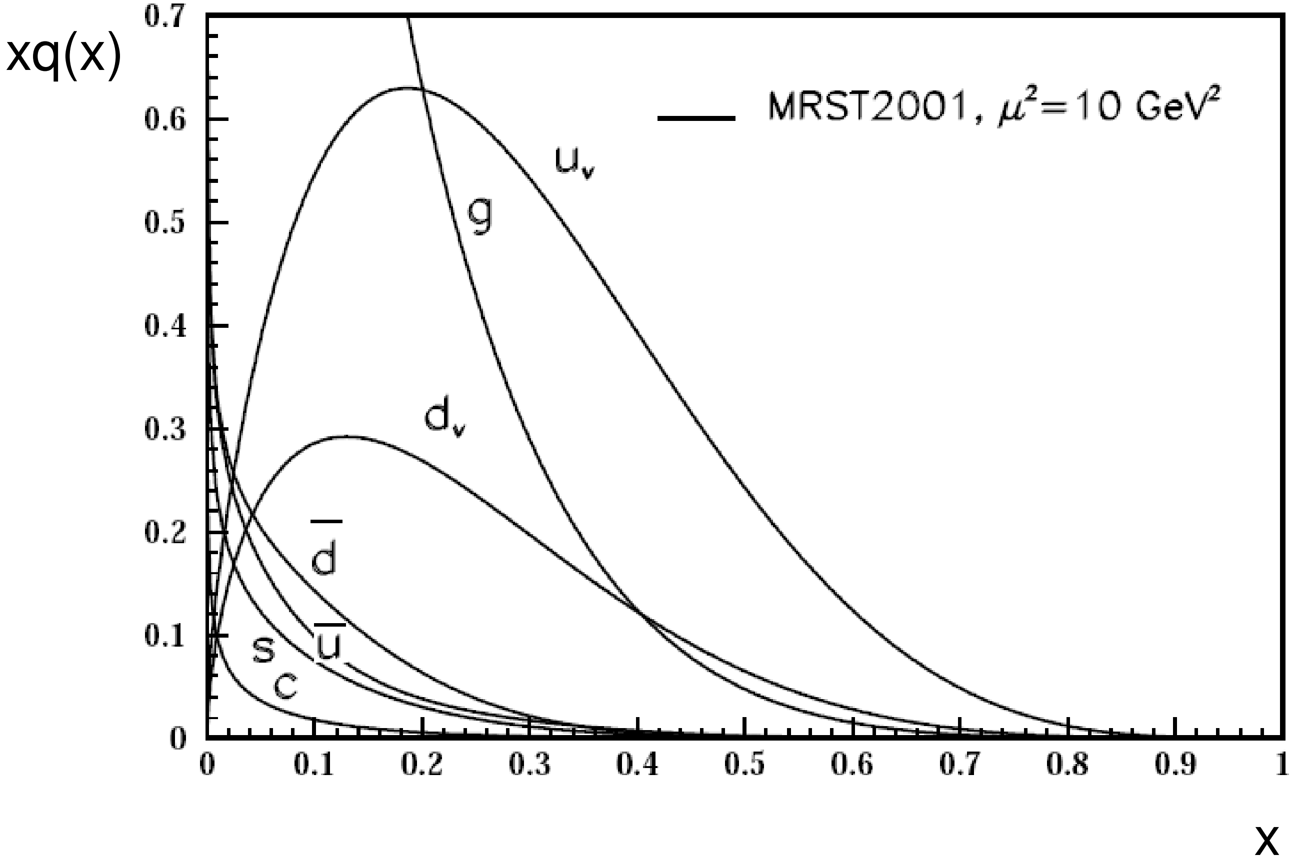


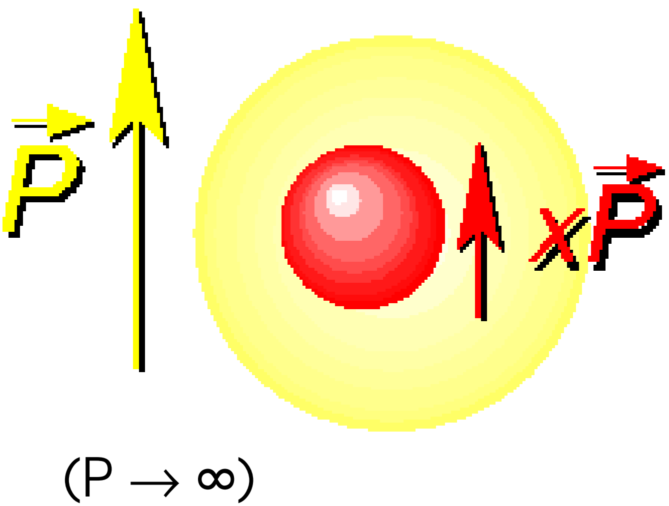




Phys. Rev. D 66, 010001 (2002)

# Current Knowledge of Nucleon Unpolarized Structure

$$F_1(x) = \frac{1}{2}\Sigma e_i^2 [q_i(x)]$$ — in the Quark-Parton Model and the infinite momentum frame (IMF)



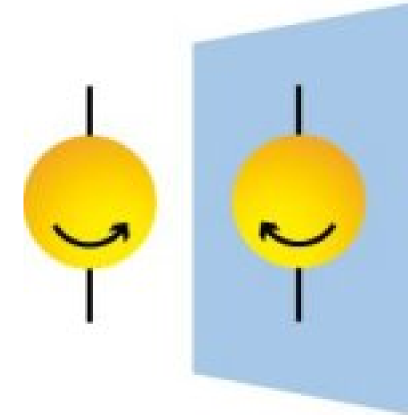




- After four decades of DIS experiments, the unpolarized structure of the nucleon is reasonably well understood (for moderate $x_{Bj}$ region);
- *Similar status for spin structure of the nucleon from polarized DIS.*

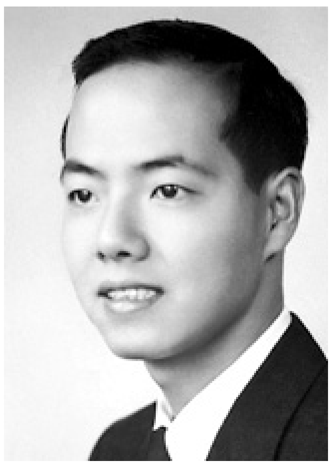
# Weak Interaction in DIS
# (Parity Violating DIS)

# What is Parity Violation

- The parity symmetry: the physical laws behind all phenomena must be the same as those behind their mirror images;
- However this symmetry is broken in weak interactions.



Chen-Ning Yang



Tsung-Dao Lee

Chien-Shiung Wu

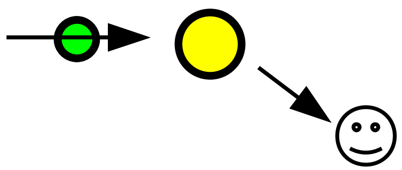
1957 Nobel Prize in Physics:

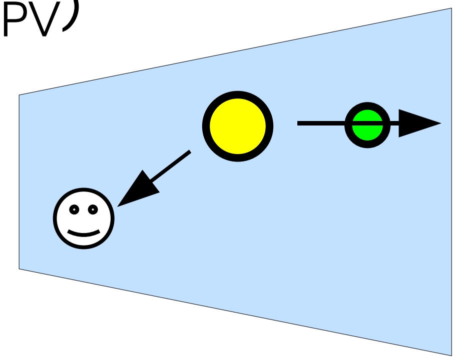
"for their penetrating investigation of the so-called parity laws which has led to important discoveries regarding the elementary particles"

# Parity Violating Electron Scattering

- Electromagnetic observables — $\sigma$, $A$...
- Weak observables — parity violating asymmetries ($A_{\mathrm{PV}}$)

  (polarized beam + unpolarized target)





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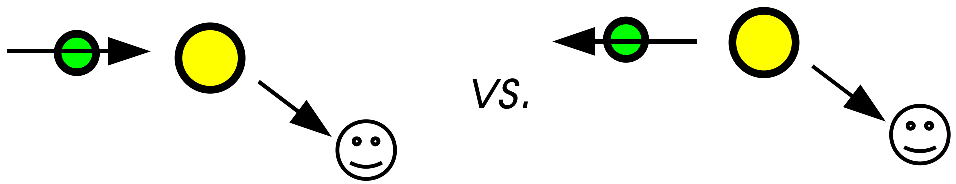

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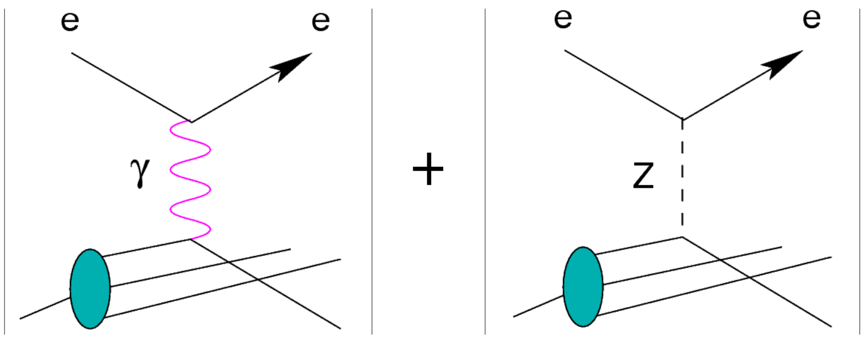
$A_{PV} =$




$$A_{LR} \equiv \frac{\sigma^r - \sigma^l}{\sigma^r + \sigma^l} \approx \frac{Q^2}{M_Z^2} \approx 120\ ppm$$

$$at\quad Q^2 = 1\,(GeV/c)^2$$

(ppm="parts per million"=$10^{-6}$)

# Parity Violating Electron Scattering

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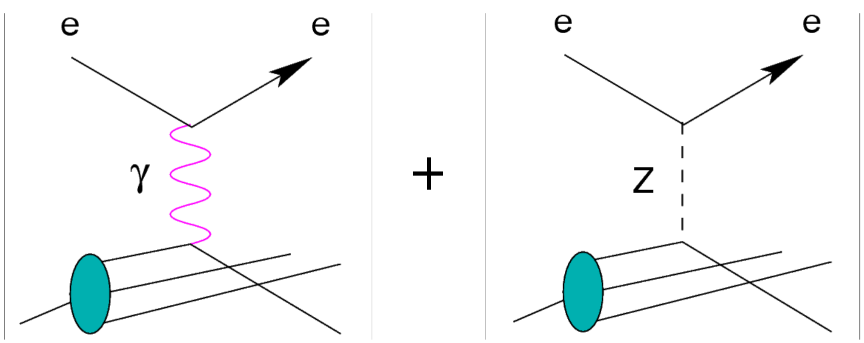
$A_{PV} =$ 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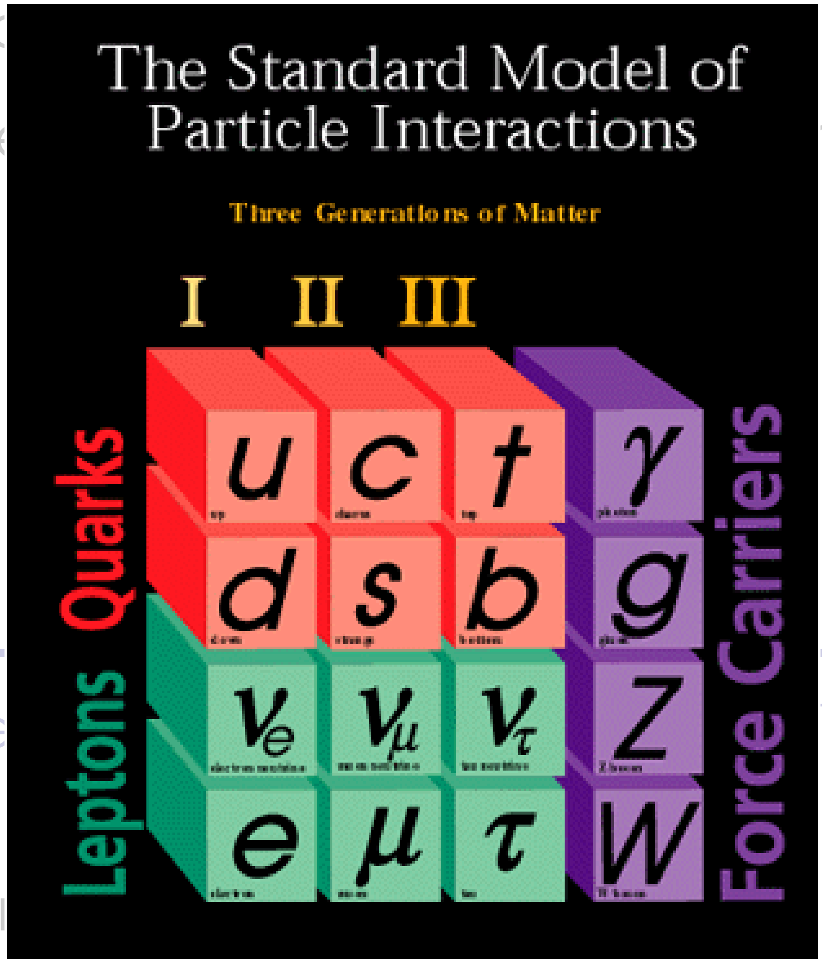
- study hadron structure
  - elastic scattering: strange form factors — A4(MAINZ), G0, HAPPEX (JLab), SAMPLE (MIT/Bates)
  - DIS: higher twist effects, charge symmetry violation... ← PVDIS
- test the electroweak standard model — E158(SLAC), Qweak(JLab)

# ElectroWeak Standard Model

- SM works well at present energy range;
- Conceptual rec

  What happe t"?




(250 Ge $^{14}$ GeV ~ 2.4 x $10^{18}$ GeV)?

- Data exist: can $m_\nu$, NuTeV anomaly...);

# ElectroWeak Standard Model

- SM works well at present energy range;
- Conceptual reasons for new physics:

  What happens in the "high-energy desert"?

(250 GeV ~ $5 \times 10^{14}$ GeV ~ $2.4 \times 10^{18}$ GeV)?

- Data exist: cannot be explained by the SM ( $m_\nu$, NuTeV anomaly...);

# ElectroWeak Standard Model

- SM works well at present energy range;
- Conceptual reasons for new physics:

  What happens in the "high-energy desert"?

indirect searches:

E158, NuTeV, Qweak, PVDIS

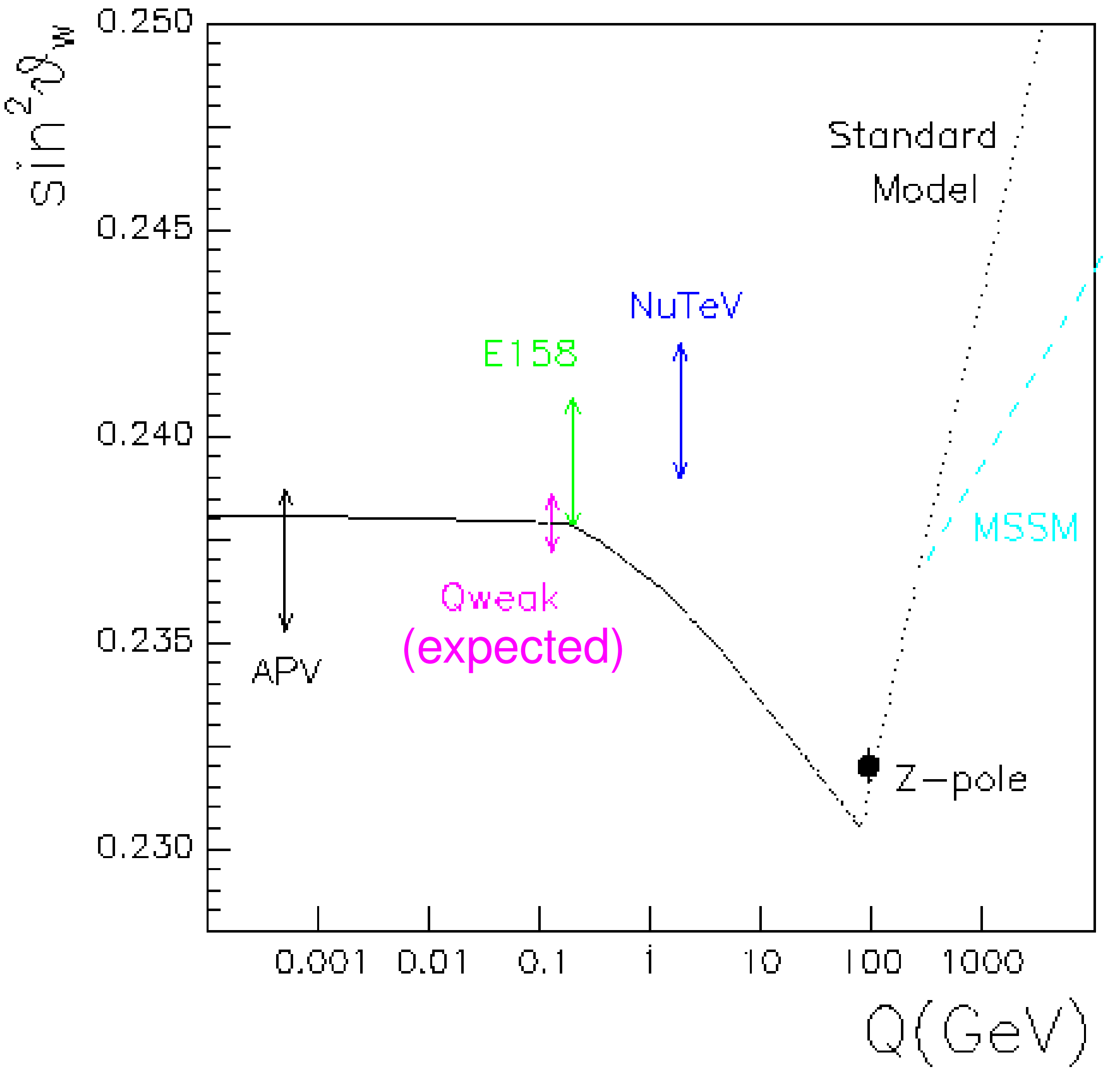
High energy direct searches:

LEP, LHC

(250 GeV ~ 5 x $10^{14}$ GeV ~ 2.4 x $10^{18}$ GeV)?

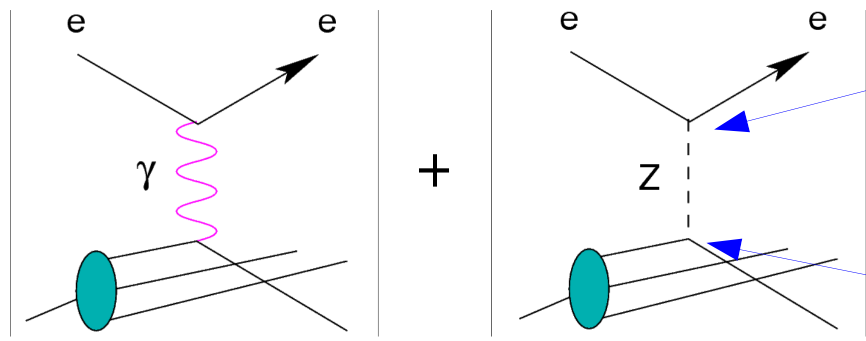
- Search for Physics beyond the Standard Model

# Testing the EW Standard Model – Running of $\sin^2\theta_W$ and the NuTeV Anomaly



# Neutral Weak Couplings in Electron DIS

$A_{PV} =$




$\frac{1}{2}\left(\bar{e}\gamma_\mu(g_V^e - g_A^e\gamma^5)e\right)$

$\frac{1}{2}\left(\bar{q}\gamma_\mu(g_V^q - g_A^q\gamma^5)q\right)$

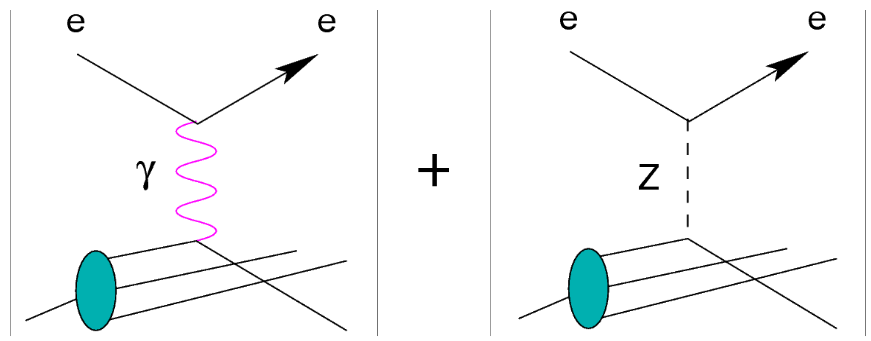
- axial electron * vector quark : $L_{SM}^{PV} = \frac{-G_F}{\sqrt{2}} \bar{e}\gamma_\mu\gamma^5 e \sum_q C_{1q}\bar{q}\gamma^\mu q$
- vector electron * axial quark : $L_{SM}^{PV} = \frac{-G_F}{\sqrt{2}} \bar{e}\gamma_\mu e \sum_q C_{2q}\bar{q}\gamma^\mu\gamma^5 q$

$$C_{1u} = g_A^e g_V^u = -\frac{1}{2} + \frac{4}{3}\sin^2(\theta_W) \qquad C_{2u} = g_V^e g_A^u = -\frac{1}{2} + 2\sin^2(\theta_W)$$

$$C_{1d} = g_A^e g_V^d = \frac{1}{2} - \frac{2}{3}\sin^2(\theta_W) \qquad C_{2d} = g_V^e g_A^d = \frac{1}{2} - 2\sin^2(\theta_W)$$

# PVDIS Asymmetries

$A_{PV} =$




- Deuterium:

$$A_d = (540\ ppm)\,Q^2\,\frac{2C_{1u}[1+R_C(x)] - C_{1d}[1+R_S(x)] + Y(2C_{2u} - C_{2d})R_V(x)}{5 + R_S(x) + 4R_C(x)}$$

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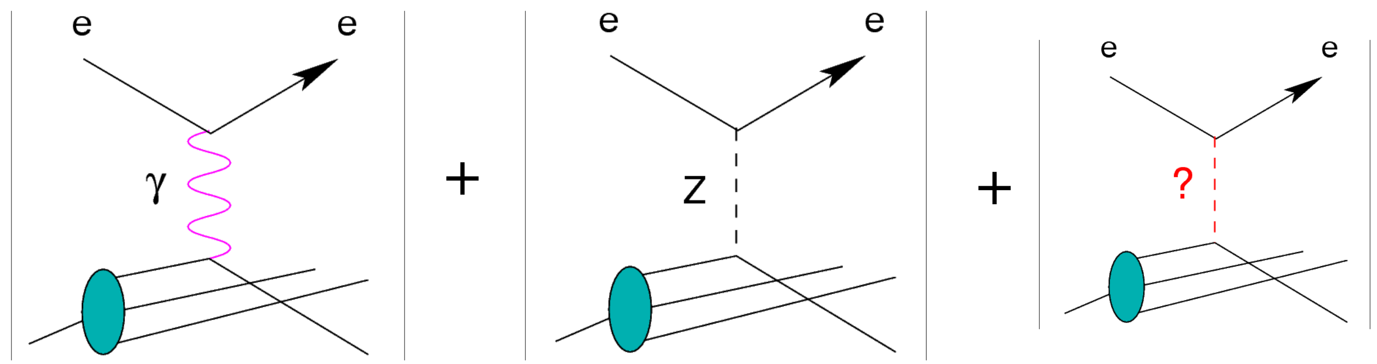
$A_{PV} =$ 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- New physics sensitivity: $L = L^{PV}_{SM} + L^{PV}_{NEW}$

$$L^{PV}_{SM} = \frac{-G_F}{\sqrt{2}} \bar{e}\gamma_\mu e \sum_q C_{2q} \bar{q}\gamma^\mu\gamma^5 q \qquad L^{PV}_{NEW} = \frac{g^2}{4\Lambda^2} \bar{e}\gamma_\mu e \sum_f h^q_A \bar{q}\gamma^\mu\gamma^5 q$$

$g$: coupling constant, $\Lambda$: mass limit, $h_A^q$: effective coefficient

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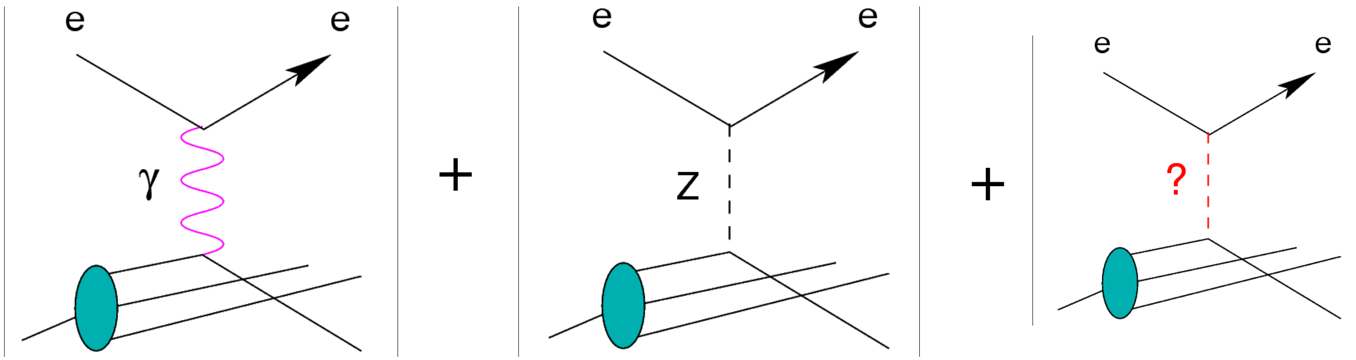


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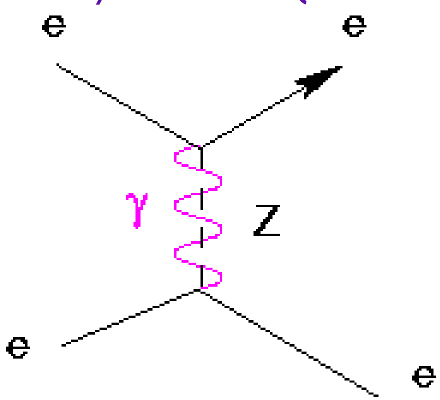
$g$: coupling constant, $\Lambda$: mass limit, $h_A^q$: effective coefficient

- Sensitive to: Z' searches, compositeness, leptoquarks
- Mass limit:

$$\Lambda/g \approx \left[\sqrt{8}G_F\left|\Delta(2C_{2u} - C_{2d})\right|\right]^{-1/2}$$

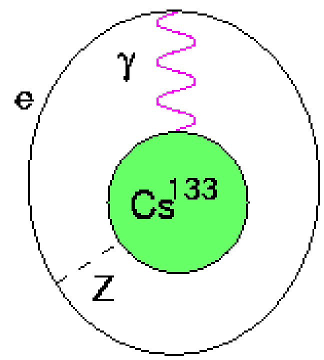
# PV DIS and Other SM Test Experiments

- *E158/Moller (SLAC)*



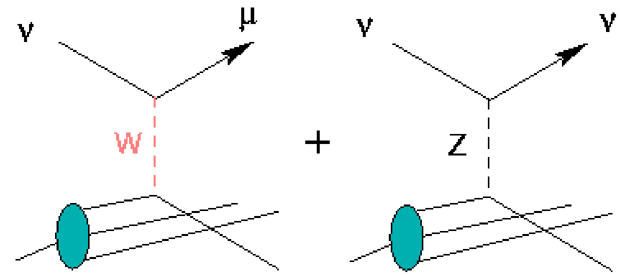

  - Purely leptonic

- *Atomic PV*



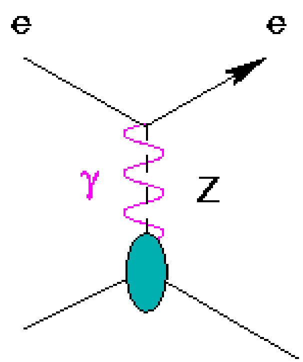

  - Coherent Quarks in the Nucleus
  - $-376C_{1u}-422C_{1d}$
  - Nuclear structure?

- *NuTeV (FNAL)*




  - Weak CC and NC difference
  - Nuclear structure?
  - Other hadronic effects?

- *Qweak (JLab)*

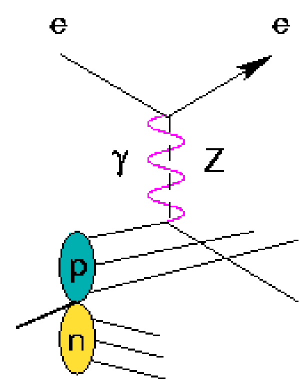



  - $2(2C_{1u}+C_{1d})$
  - Coherent quarks in the proton

*Different Experiments*
*Probe Different*
*Parts of Lagrangian,*
*<u>PVDIS is the only one accessing $C_{2q}$</u>*

*Cartoons borrowed from R. Arnold (UMass)*

- *PVDIS (JLab)*




  - $(2C_{1u}-C_{1d})+Y(2C_{2u}-C_{2d})$
  - Isoscalar quark scattering

# PVDIS Asymmetries

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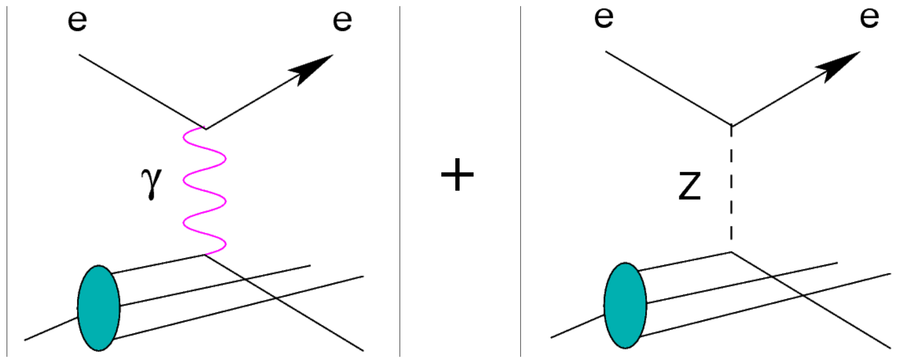


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$$R_S(x) = \frac{2[s(x)+\bar{s}(x)]}{u(x)+\bar{u}(x)+d(x)+\bar{d}(x)} \quad R_C(x) = \frac{2[c(x)+\bar{c}(x)]}{u(x)+\bar{u}(x)+d(x)+\bar{d}(x)} \quad R_V(x) = \frac{u_V(x)+d_V(x)}{u(x)+\bar{u}(x)+d(x)+\bar{d}(x)}$$

- Also sensitive to:
  - quark-gluon correlations (higher-twist effects)
  - Charge symmetry violation

$$u^p(x) \neq d^n(x) \qquad d^p(x) \neq u^n(x)$$

# PVDIS Experiment – Past, Present and Future

- 1970's, result from SLAC E122 consistent with $\sin^2\theta_W$=1/4, established the Electroweak Standard Model; C.Y. Prescott, *et al.*, Phys. Lett. B77, 347 (1978)
- PVDIS asymmetry has the potential to explore New Physics, study hadronic effects/CSV ...... However, hasn't been done since 1978.

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  - (Re)start PVDIS at JLab 6 & 12 GeV
  - Difficulty: separate New Physics and hadronic effects

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  - Do a first measurement at JLab 6 GeV:
    - If observe a significant deviation from the SM value, it will definitely indicate something exciting;
    - *Indicate either electroweak new physics, or current understanding of strong interation is worse than we thought*

– New electroweak Physics

– Non-perturbative QCD (higher-twist) effects ← Likely to be small, but need exp confirmation

– Charge symmetry violation ← Small from MRST fit (90% CL ~1%)

At the 6 GeV precision:

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    - *Indicate either electroweak new physics, or current understanding of strong interation is worse than we thought*
  - At 12 GeV, a larger, well-planned PVDIS program could separate all three: New Physics, HT, CSV, *important information for both EW and Strong interaction study*.

# JLab 6 GeV Experiment 08-011

Co-spokesperson & contact: X. Zheng

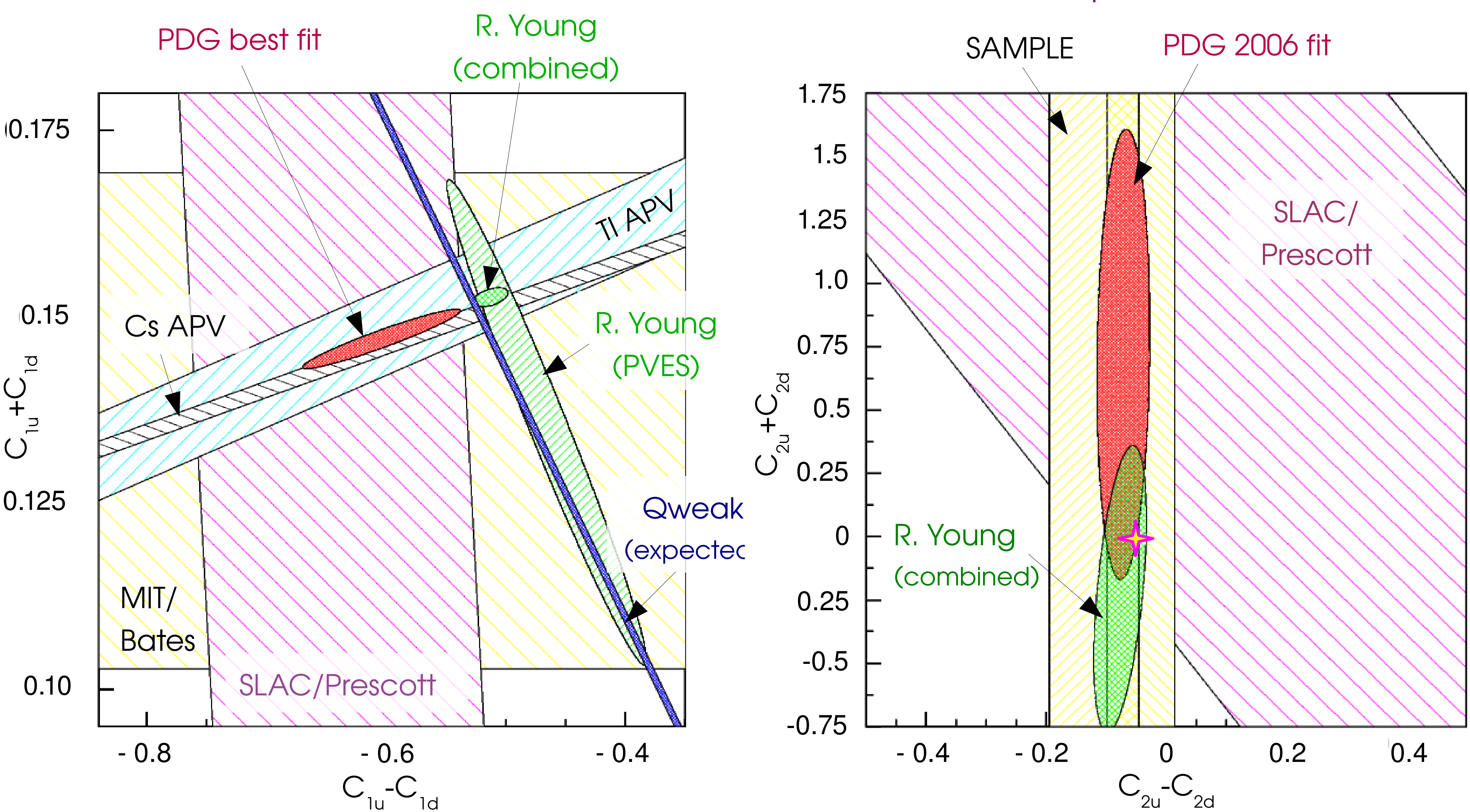
Co-spokesperson: P.E. Reimer, R. Michaels

(Hall-A Collaboration Experiment, approved by PAC27, re-approved by PAC33 for 32 days, rated A-)

- Use 85μA, 6 GeV, 80% polarized beam on a 25-cm LD2 target;
- Two Hall A High Resolution Spectrometers detect scattered electrons;
- Measure PV asymmetry $A_d$ at $Q^2$=1.10 and 1.90 GeV$^2$ to 2.7% (stat.);
  - $A_d$ at $Q^2$=1.10 will limit the higher twist effects;
  - If HT is small, can extract $2C_{2u}$-$C_{2d}$ from $A_d$ at $Q^2$=1.90 to ±0.04 (or with reduced precision if higher twists are un-expectedly large)

# Current Knowledge on $C_{1,2q}$

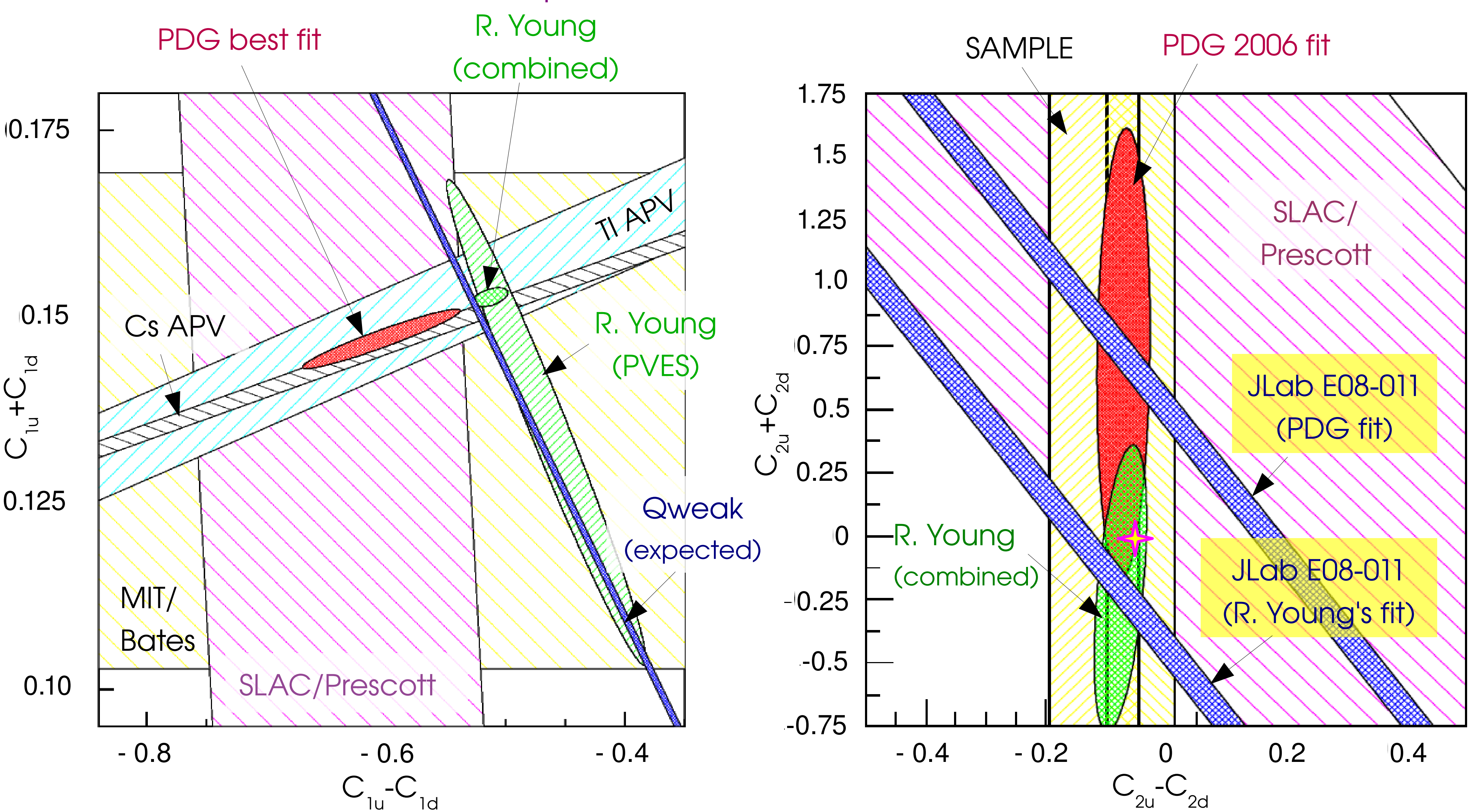
all are 1 σ limit




- Best: $\Delta(2C_{2u}-C_{2d}) = 0.24$

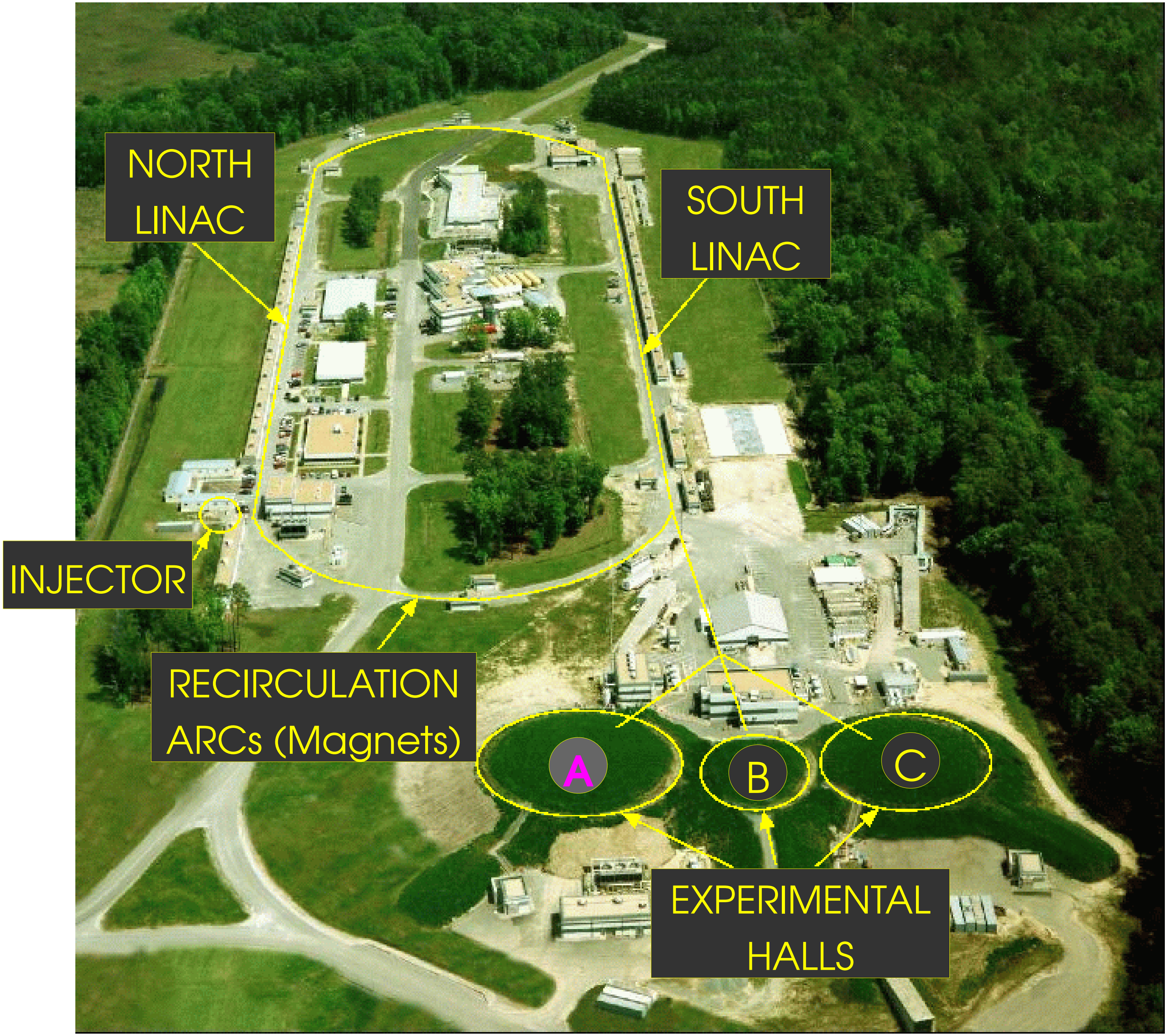
# $C_{2q}$ from JLab E08-011

all are 1 σ limit

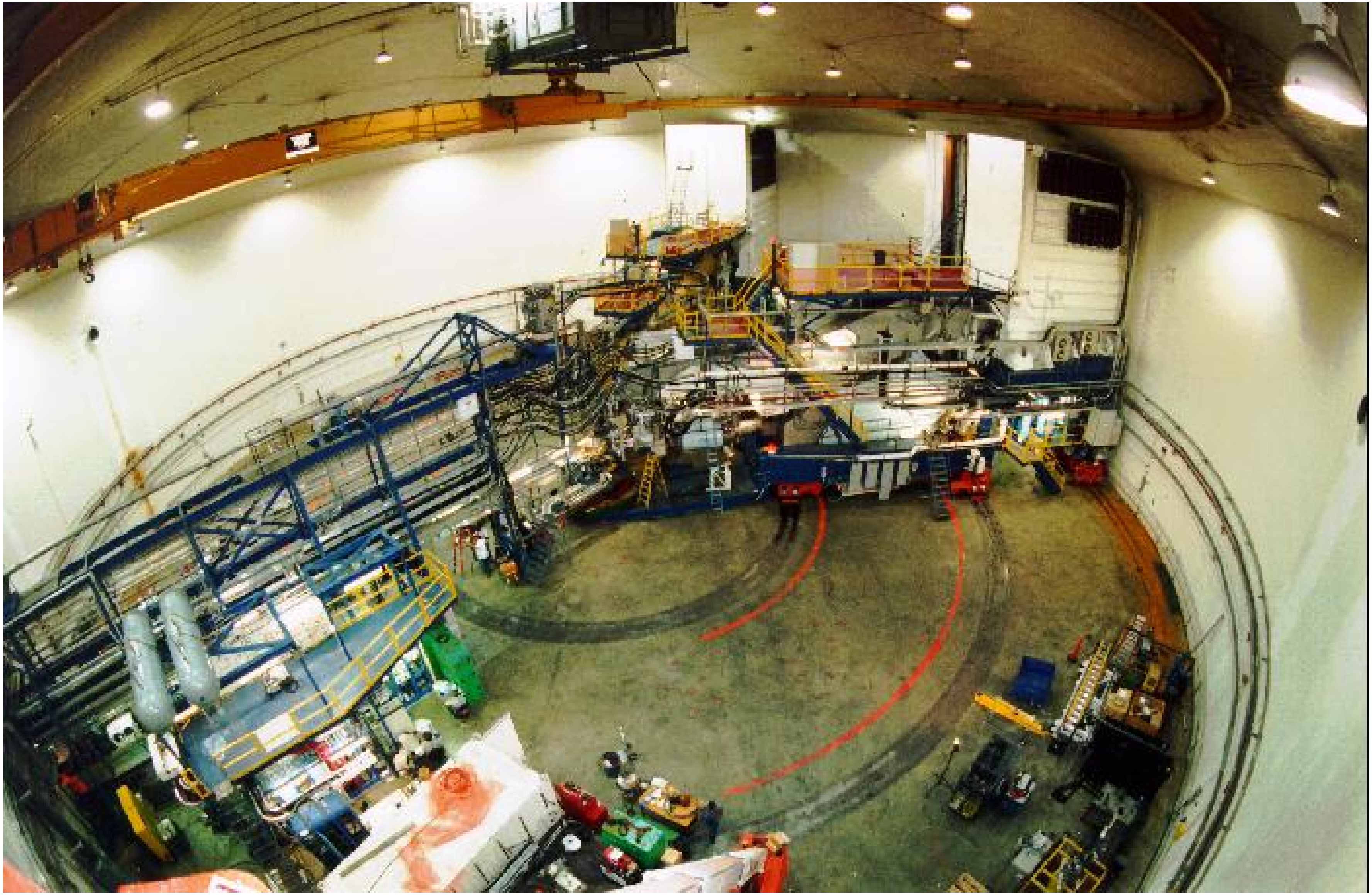



- Best: $\Delta(2C_{2u}-C_{2d}) = 0.24 \longrightarrow 0.04$ (factor of <u>six</u> improvement);
- New physics mass limit: $$\Lambda / g \approx \left[\sqrt{8}\,G_F \left|\Delta\left(2C_{2u}-C_{2d}\right)\right|\right]^{-1/2} \approx 0.9\,\mathrm{TeV}$$

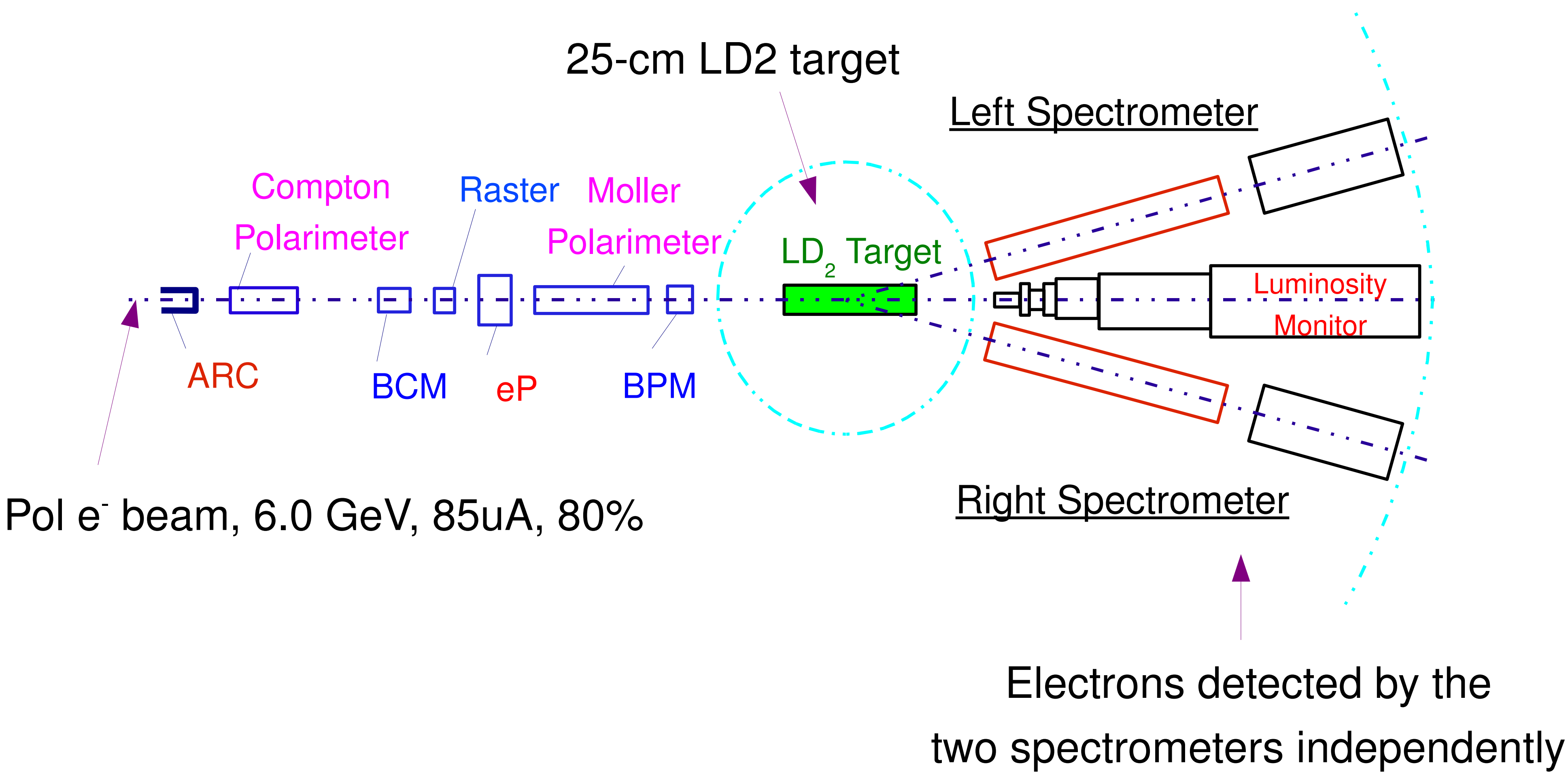
# The Accelerator (CEBAF)



# Experimental Hall A



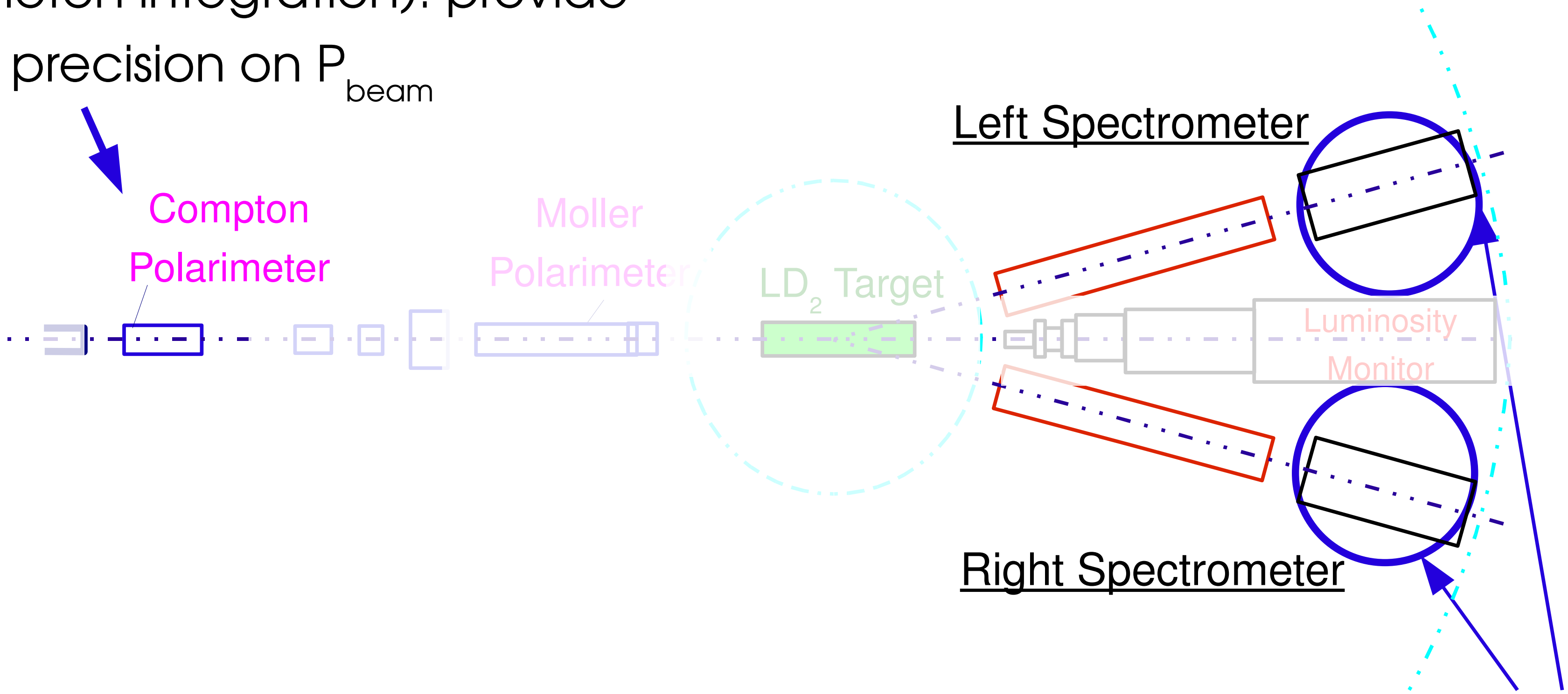
# Overview of the Experimental Setup in Hall A



# In Addition to the Standard Setup

- new method being developed (photon integration): provide 1% precision on $P_{beam}$

Also needed for two other approved PV experiments in Hall A




- Regular HRS DAQ up to 4KHz (expect: 500KHz)
- Integration method won't work for DIS
- Need a new fast-counting DAQ, design goal: 1MHz, on-line PID; Never been done before!

# The Collaboration

A. Afanasev, D.S. Armstrong, J. Arrington, T.D. Averett, E.J. Beise, W. Bertozzi, P.E. Bosted, H. Breuer, J.R. Calarco, A. Camsonne, G.D. Cates, J.-P. Chen, E. Chudakov, P. Decowski, **X.-Y. Deng, H.-B. Ding,** A. Deur, J. Erler, J.M. Finn, S. Gilad, K.A. Griffioen, K. Grimm, K. Hafidi, J.-O. Hansen, D.W. Higinbotham, R. Holmes, T. Holmstrom, R.J. Holt, J. Huang, P.M. King, W. Korsch, S. Kowalski, K. Kumar, N. Liyanage, A. Lukhanin, D.J. Mack, D.J. Margoziotis, P. Markowitz, D. McNulty, *R. Michaels*, B. Moffit, P. Monaghan, N. Muangma, V. Nelyubin, B.E. Norum, K. Paschke, C. Perdrisat, A.J. Puckett, Y. Qiang, *P.E. Reimer,* J. Roche, A. Saha, B. Sawatzky, N. Simicevic, J. Singh, S. Sirca, **A. Shahinyan**, R. Snyder, P. Solvignon, P.A. Souder, N. Sparveris, **R. Subedi**, V. Sulkosky, W.A. Tobias, **D.-C. Wang,** K. Wang, S.P. Wells, B. Wojtsekhowski, X.-H. Zhan, *X.-C. Zheng*

The Hall A Collaboration

*ANL, Calstate, FIU, JLab, Kentucky, Louisiana Tech, U. of Ljubljana (Slovenia), MIT, UMD, UMass, UNH, Universidad Nacional Autonoma de Mexico, Ohio U., Randolph-Mason C., Smith C., Syracuse, Temple U., TsingHua U. (China), UVa, W&M, Yerevan Phys. Inst.(Armenia)*

# Design and Structure for the Fast Counting DAQ

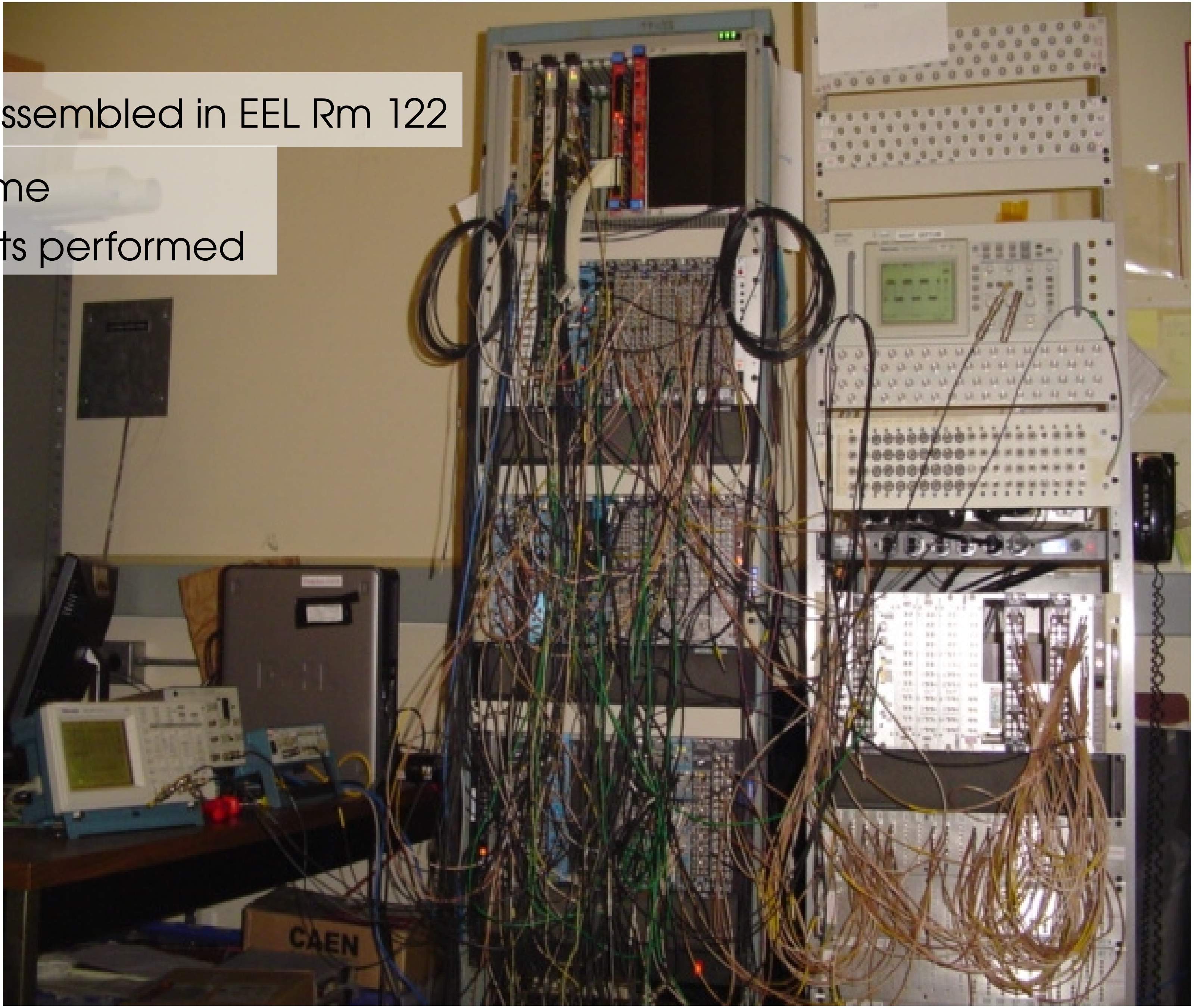
- Scaler-based:
  - A double-layered lead-glass counter (PID)
  - A gas cherenkov detector (PID)
  - Scintillators (suppress background)
  - Helicity-gated scalers count $e^-$ and $\pi$
- Deadtime measured by multiple methods (goal: 0.3%)
  - Two resolution times (20, 100ns)
  - "tagger", TDC system

$$A_{PV} = \frac{A_{measured}}{P_b \eta_{DT}}$$

- Cross-check with regular DAQ at low rate (PID performance)
- Some channels with flash-ADC, allowing full sampling of signals (PID performance and pileup effects)

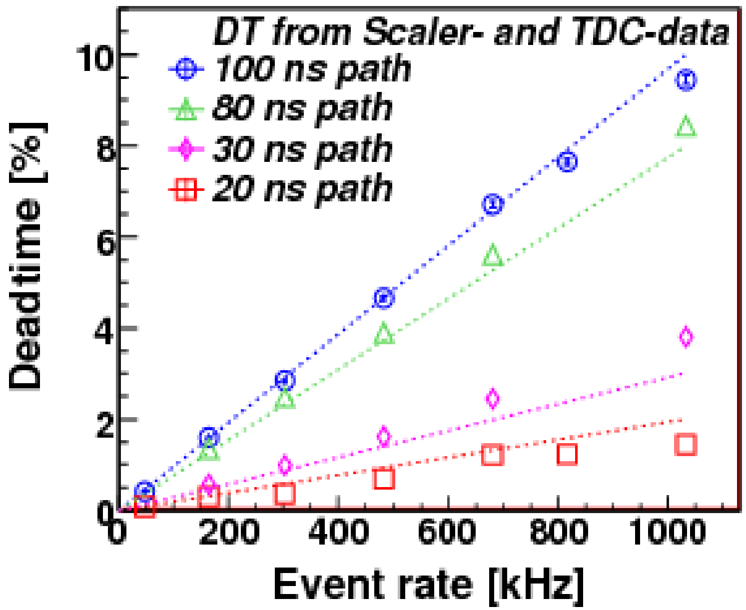
# E08-011 DAQ Status (Jan.-Aug. 2008)

- Half-system assembled in EEL Rm 122
- Three deadtime measurements performed



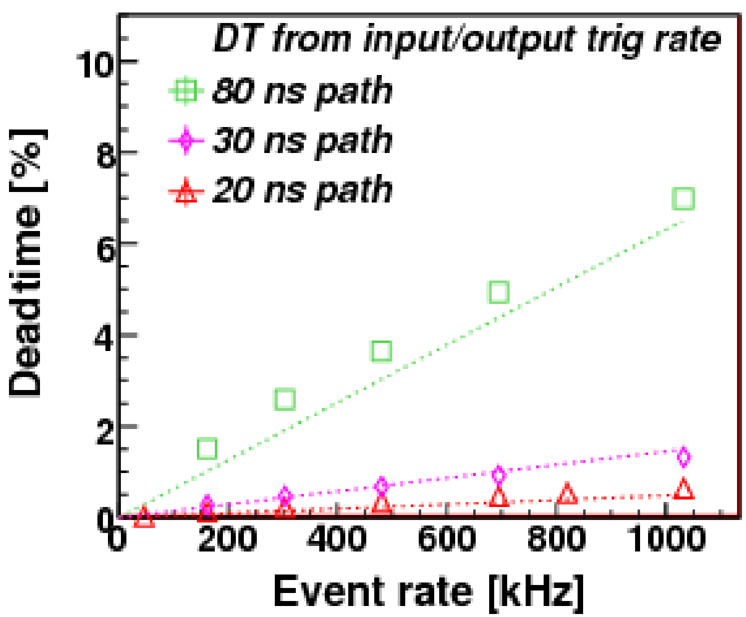
# E08-011 DAQ Status (Jan.-Aug. 2008)

Method I

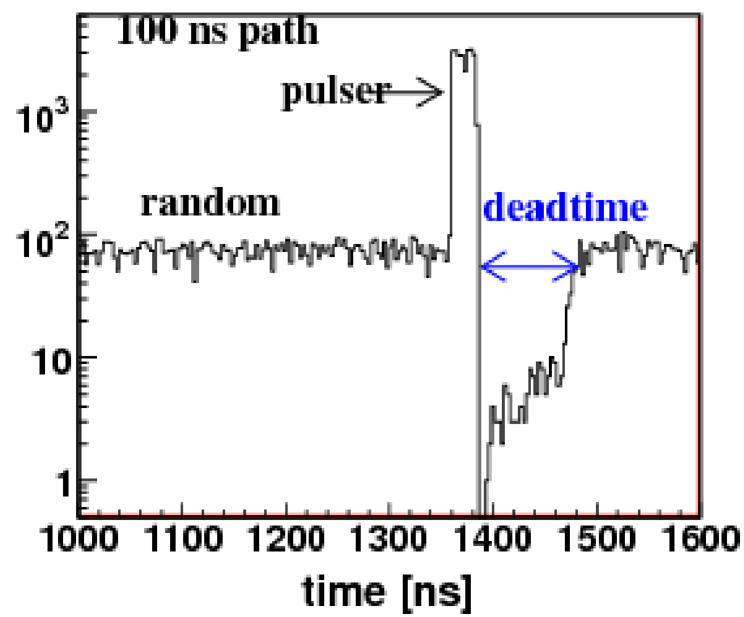



- Three deadtime measurements performed

Method II

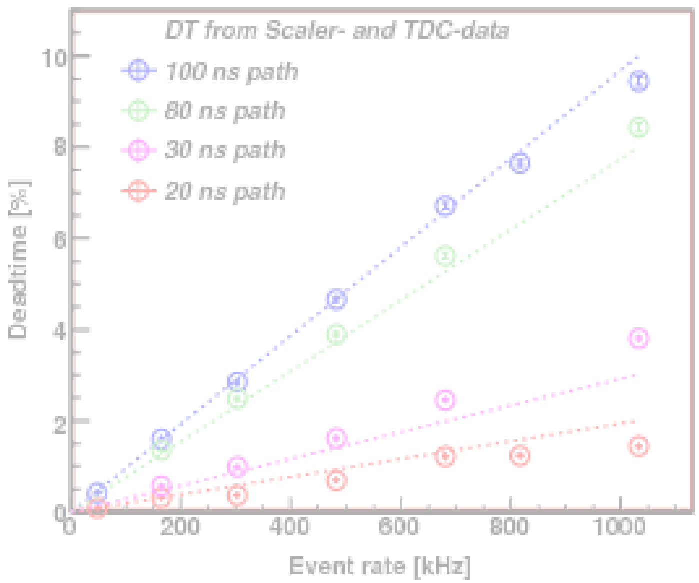



Method III

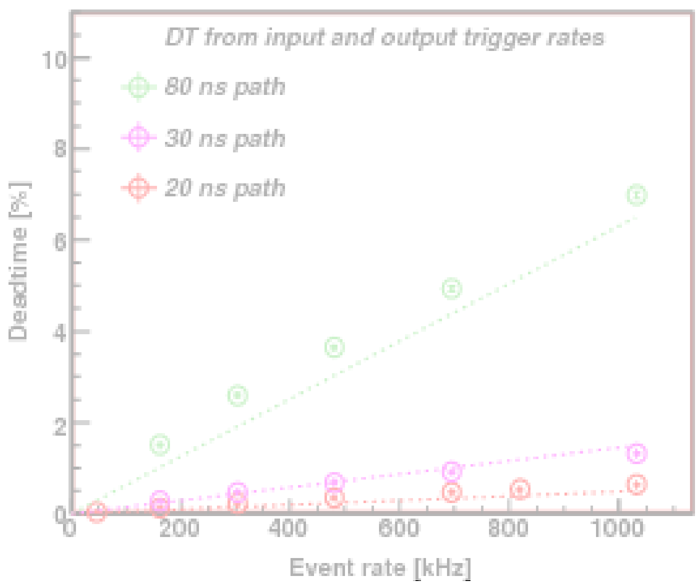


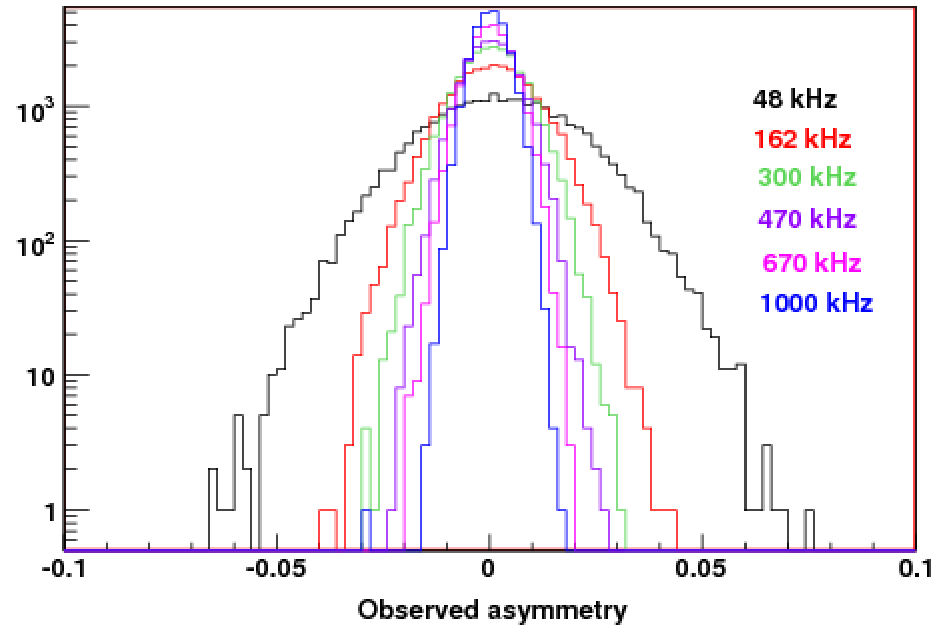
# E08-011 DAQ Status (Jan.-Aug. 2008)

Method I




Method II




- Measured induced asymmetry, width as expected $\sqrt{1/RT}$

# E08-011 DAQ Status (Aug. 2008-Feb. 2009)

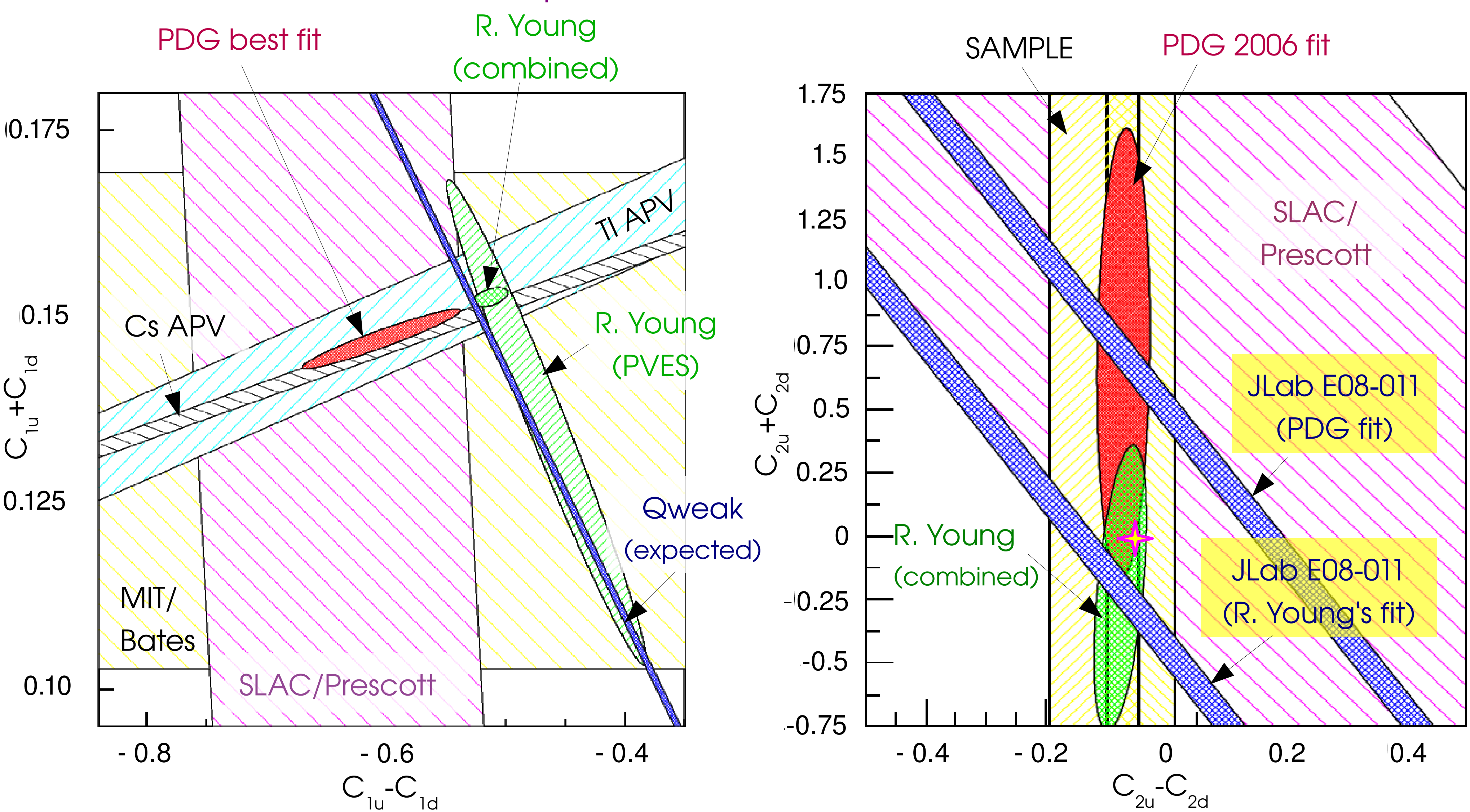
- ✔ Installed in Right HRS in Hall A — Aug. 2008
- ✔ Parasitic test using cosmics — until Nov. 2008
- ✔ Parasitic test using low rate electrons and pions — Dec. 2008 - Feb. 2009:
  - ✔ All detectors working;
  - ✔ Can measure large (induced) asymmetries from beam;
  - ✔ Communicating with two existing DAQs.

# E08-011 Plan (Mar. - Dec. 2009)

- DAQ Parasitic test using medium-rate electrons and pions — Mar-May 2009
  - Cross-checking with regular HRS DAQ for PID performance, determine system characteristics;
- Duplicate the system to install in the Left HRS — June-July 2009;
- Test performance with very high rate electrons (a few MHz) during HAPPEX-III — Aug.-Oct.2009.
- Run PVDIS — Nov.-Dec. 2009
- Data analysis, publishing results: 1 ~ 2 years

# $C_{2q}$ from JLab E08-011

all are 1 σ limit




- Best: $\Delta(2C_{2u}-C_{2d}) = 0.24 \longrightarrow 0.04$ (factor of <u>six</u> improvement);
- New physics mass limit: $\Lambda/g \approx \left[\sqrt{8}\,G_F \left|\Delta\left(2C_{2u}-C_{2d}\right)\right|\right]^{-1/2} \approx 0.9\,\mathrm{TeV}$

# PVDIS Program at JLab 12 GeV

- Higher precision, possibly sensitive to 1) New Physics beyond the SM; 2) Charge Symmetry Violation (CSV)
- Two approaches (conditionally approved):
  - Hall C "baseline" SHMS+HMS: PR12-07-102 (P.E. Reimer, X-C. Z, K. Paschke)
    - 1% on $A_d$, extraction of $C_{2q}$, $\sin^2\theta_W$ (if higher-twist and CSV are negligible);
  - Hall A large acceptance "solenoid" device: PR09-012
    - Measure $A_d$ to 1% for a wide range of $(x, Q^2, y)$, clean separation of New Physics (via $C_{2q}$ and $\sin^2\theta_W$), HT and CSV possible;
    - Extract d/u at large x from PVDIS on a proton target, free of nuclear effects;
    - Other hadronic physics study possible: $A_1^n$ at large x, Semi-inclusive DIS.

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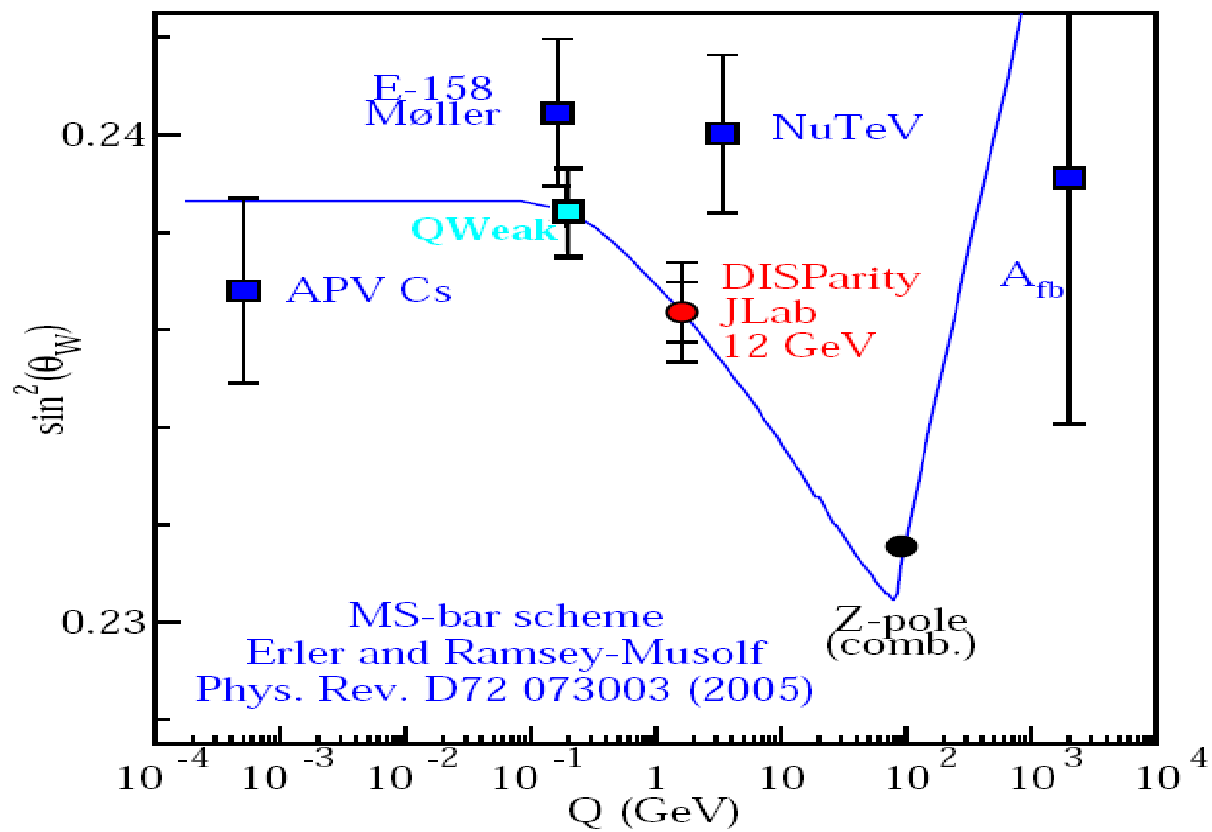

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# Nucleon Resonances Study from Doubly Polarized Electron Scattering

(CLAS Collaboration Approved Analysis)

# Extraction of Double and Single Spin Asymmetries for pion electroproduction from $NH_3$ and $ND_3$ targets using JLab EG4 data

Co-spokespeople: Xiao-chao Zheng (UVa), Angela Biselli (Fairfield U.), Peter Bosted (JLab) and Gail Dodge (ODU)

- Physics Motivation;
- EG4 Run Overview;
- Preliminary asymmetries from 3 GeV $NH_3$ data

*Acknowledgment*:

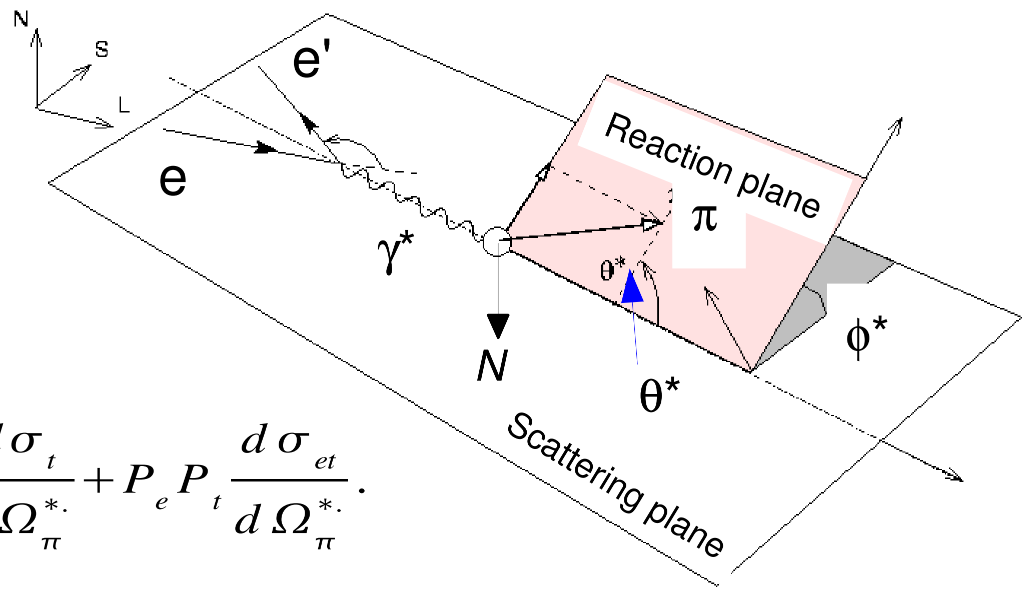
EG4 spokespeople: M. Battaglieri, R. De Vita, A. Deur, G. Dodge, M. Ripani, K. Slifer

CAA Review committee: D. Carman, P. Eugenio, C. Smith, M. Ungaro

# Physics Motivation

- Nucleon resonances form an important part of strong interaction study;
  - Mostly non-perturbative, cannot use pQCD;
  - Too light for lattice calculation;
- Must use effective theories or models:
  - Constituent Quark Model: resonance amplitudes, helicity structure... (not on interference terms)
  - Phenomenology models: MAID, SAID, DMT, JANR, Sato-Lee ($\Delta$) ... ...
  - *May compare to Chiral Perturbation Theory (very low $Q^2$ only).*
- Spin observables (asymmetries) provide constraints on: spin-dependent amplitudes, interference terms...

# Observables in Pion Electroproduction




- Cross section:

$$\frac{d\sigma}{d\Omega_\pi^{*}} \sim \frac{d\sigma_{unp}}{d\Omega_\pi^{*}} + P_e \frac{d\sigma_e}{d\Omega_\pi^{*}} + P_t \frac{d\sigma_t}{d\Omega_\pi^{*}} + P_e P_t \frac{d\sigma_{et}}{d\Omega_\pi^{*}}.$$

- Three independent asymmetries:
  - Single-beam $A_e = \frac{d\sigma_e}{d\sigma_{unp}} = \frac{\sigma(+h_e)-\sigma(-h_e)}{\sigma(+h_e)+\sigma(-h_e)}$ ← accessible from unpolarized target data
  - Single-target $A_t = \frac{d\sigma_t}{d\sigma_{unp}} = \frac{\sigma(+h_N)-\sigma(-h_N)}{\sigma(+h_N)+\sigma(-h_N)}$ ← only accessible from polarized target data
  - Double beam-target

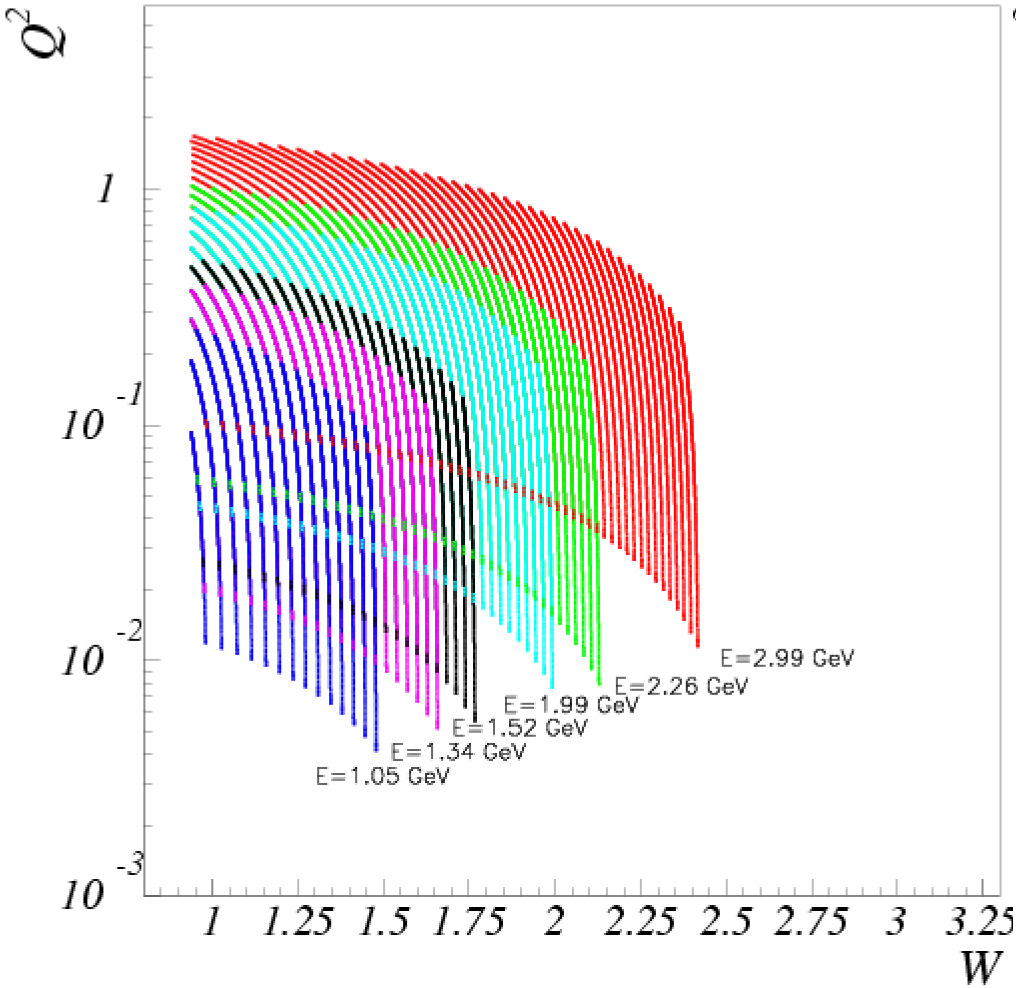
$$A_{et} = \frac{d\sigma_{et}}{d\sigma_{unp}} = \frac{\sigma(+h_e,+h_N)+\sigma(-h_e,-h_N)-\sigma(+h_e,-h_N)-\sigma(-h_e,+h_N)}{\sigma(+h_e,+h_N)+\sigma(-h_e,-h_N)+\sigma(+h_e,-h_N)+\sigma(-h_e,+h_N)}$$

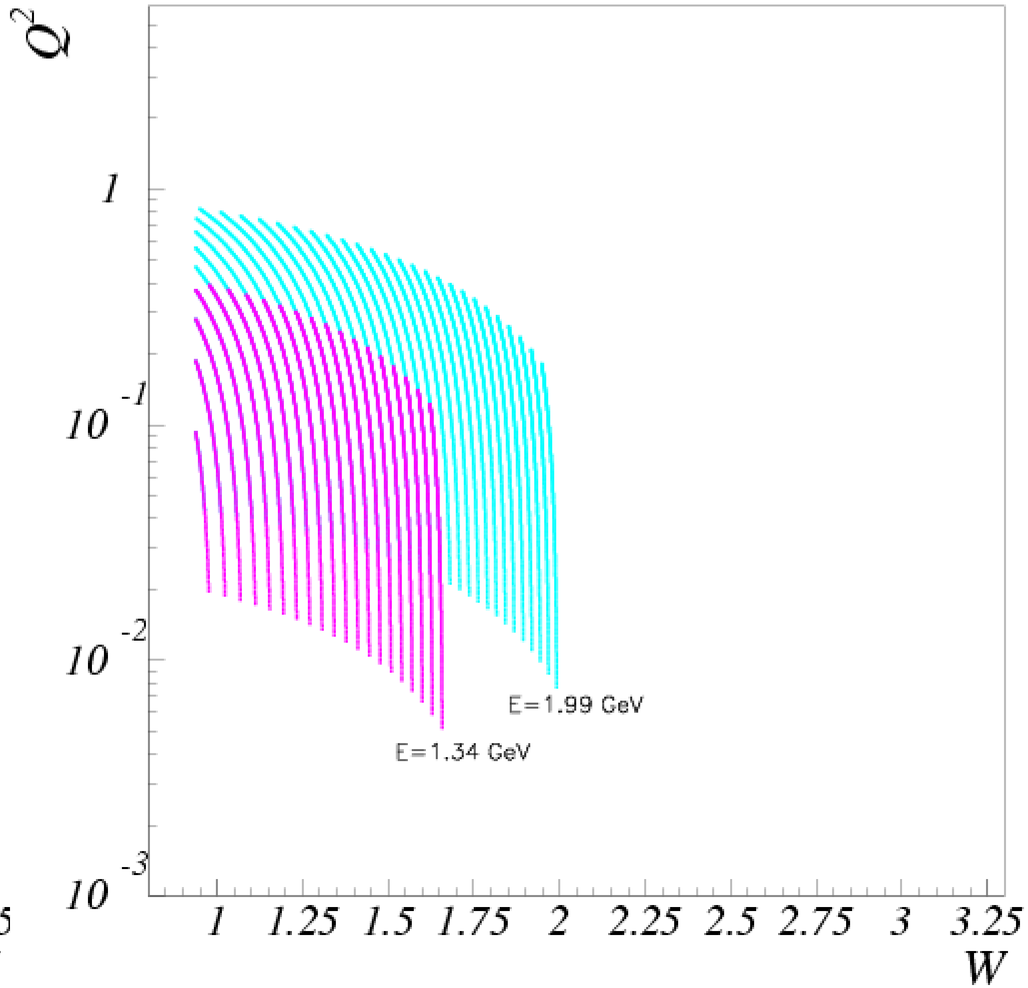
# EG4 Exclusive Channel Analysis

- Extract *At* and *Aet* from EG4 data for:
  - NH3 target: $\vec{e}\,\vec{p} \to e'\pi^{+}n$ and $\vec{e}\,\vec{p} \to e'\pi^{0}p$
  - ND3 target: $\vec{e}\,\vec{n} \to e'\pi^{-}p$ and $\vec{e}\,\vec{p} \to e'\pi^{+}n$
- Study dependence on $Q^2$, W, $\phi^*$ and $\cos\theta^*$— (binned in 4 simultaneously)
- Previous/other analyses: EG1a, EG1b;
- Our new results will help to constrain models at low $Q^2$;
  - Can compare to future real photon experiment, study transition from virtual to real photons;
  - Data on the neutron are rare.

# EG4 Kinematic Coverage

- $NH_3$ target
- $ND_3$ target



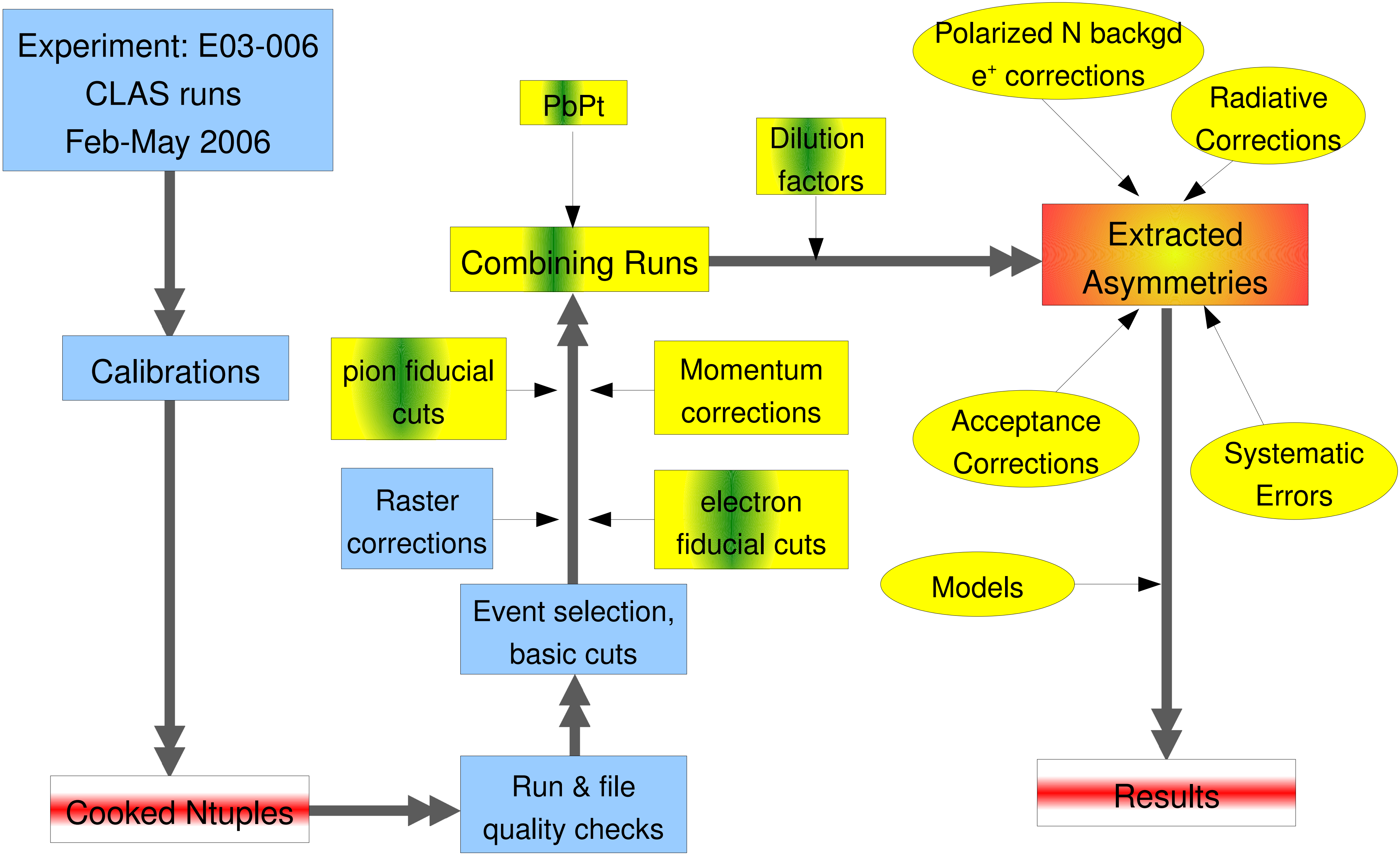




- Extensive running at 1.3 GeV.

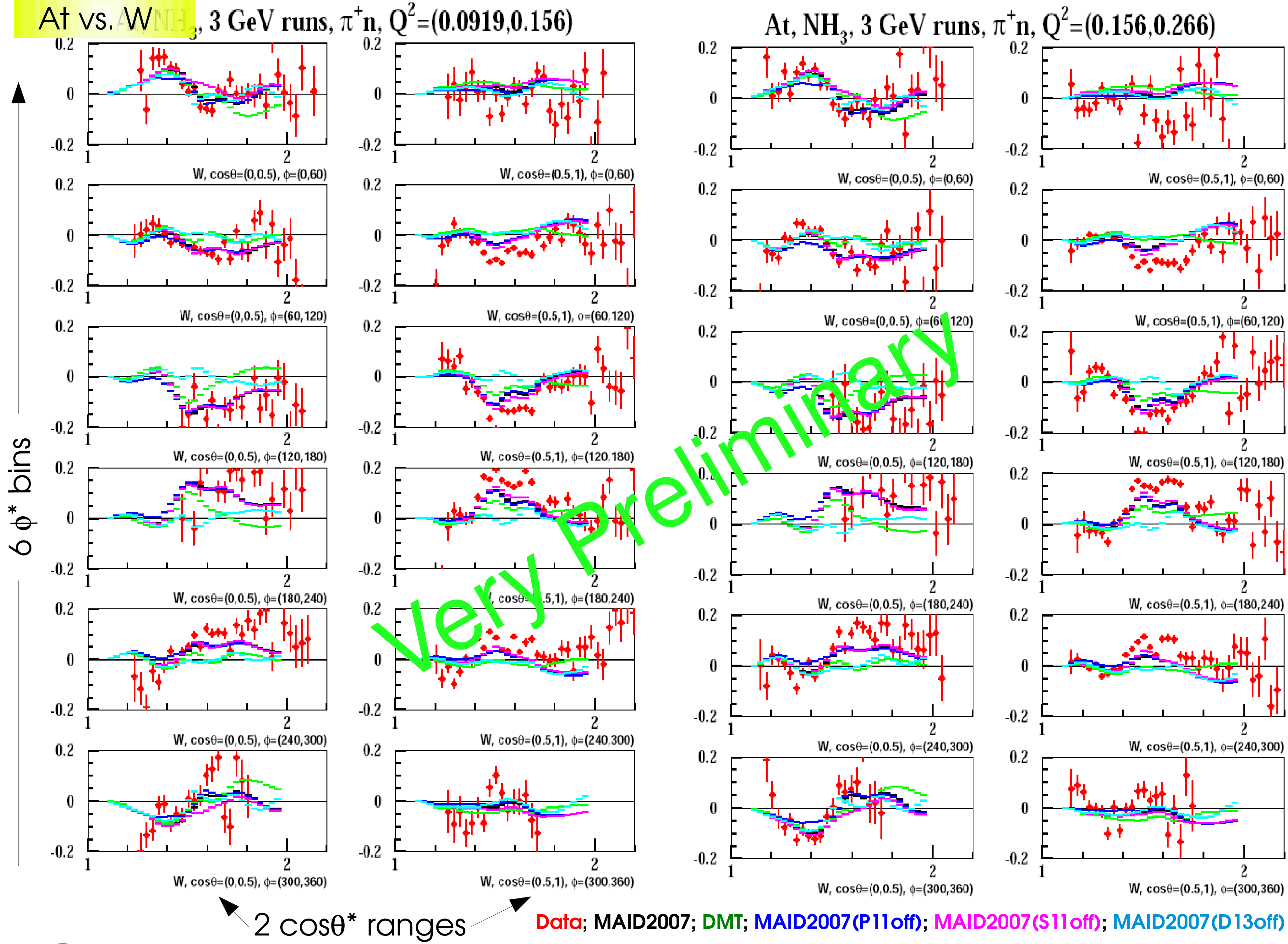
## Analysis and Very Preliminary Results for $\vec{e}\,\vec{p} \to e'\pi^{+}n$ using 3 GeV NH3 Data

# Charged Pion Exclusive Analysis Flow Charts (CLAS/EG4) 3 GeV NH3 Runs

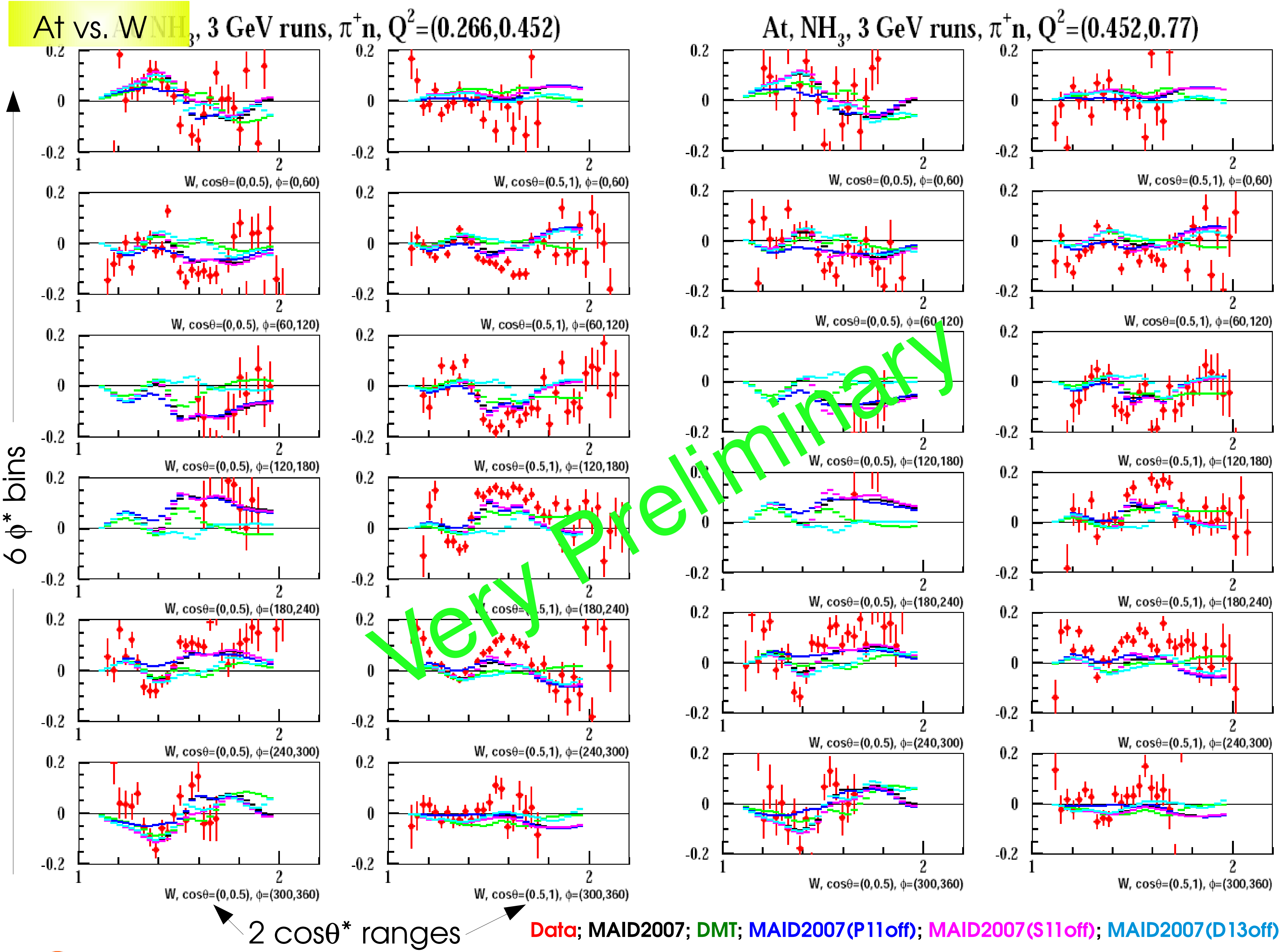
Legends:
Not yet started
In progress
Completed



# At vs. W




Data; MAID2007; DMT; MAID2007(P11off); MAID2007(S11off); MAID2007(D13off)

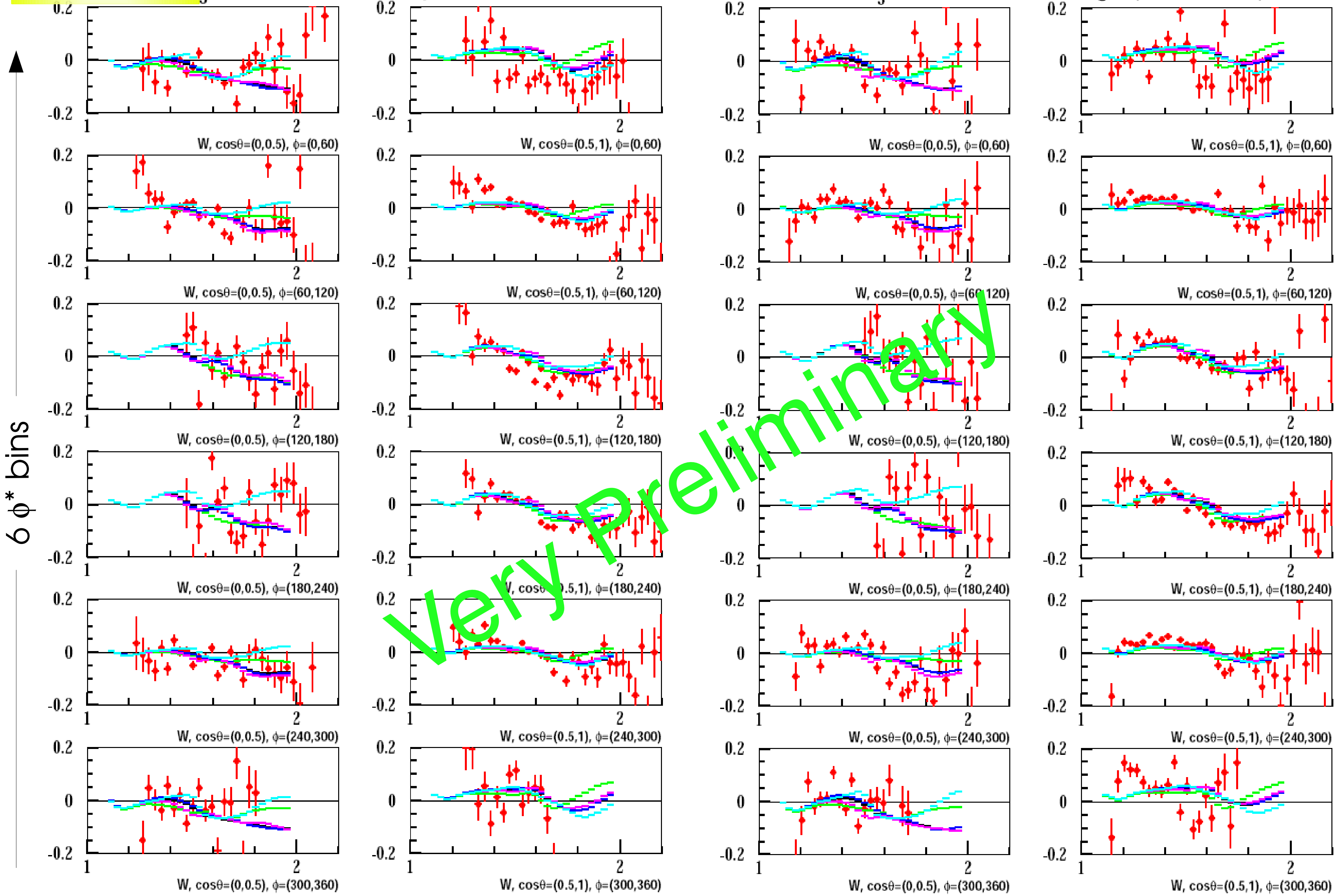



Data; MAID2007; DMT; MAID2007(P11off); MAID2007(S11off); MAID2007(D13off)

Aet vs. W

Aet, $NH_3$, 3 GeV runs, $\pi^+ n$, $Q^2$=(0.0919,0.156)

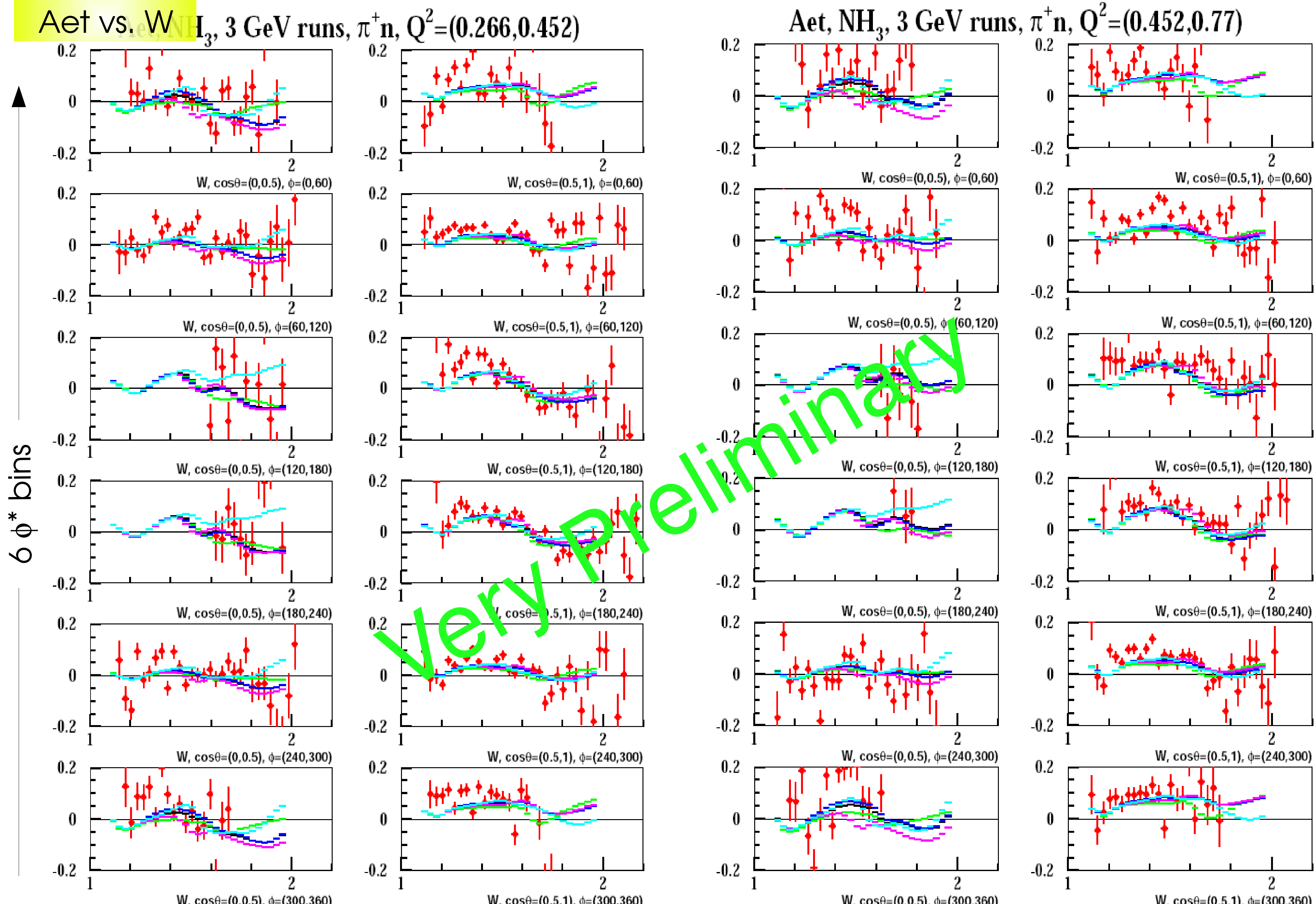
Aet, $NH_3$, 3 GeV runs, $\pi^+ n$, $Q^2$=(0.156,0.266)




2 cosθ* ranges

Data; MAID2007; DMT; MAID2007(P11off); MAID2007(S11off); MAID2007(D13off)

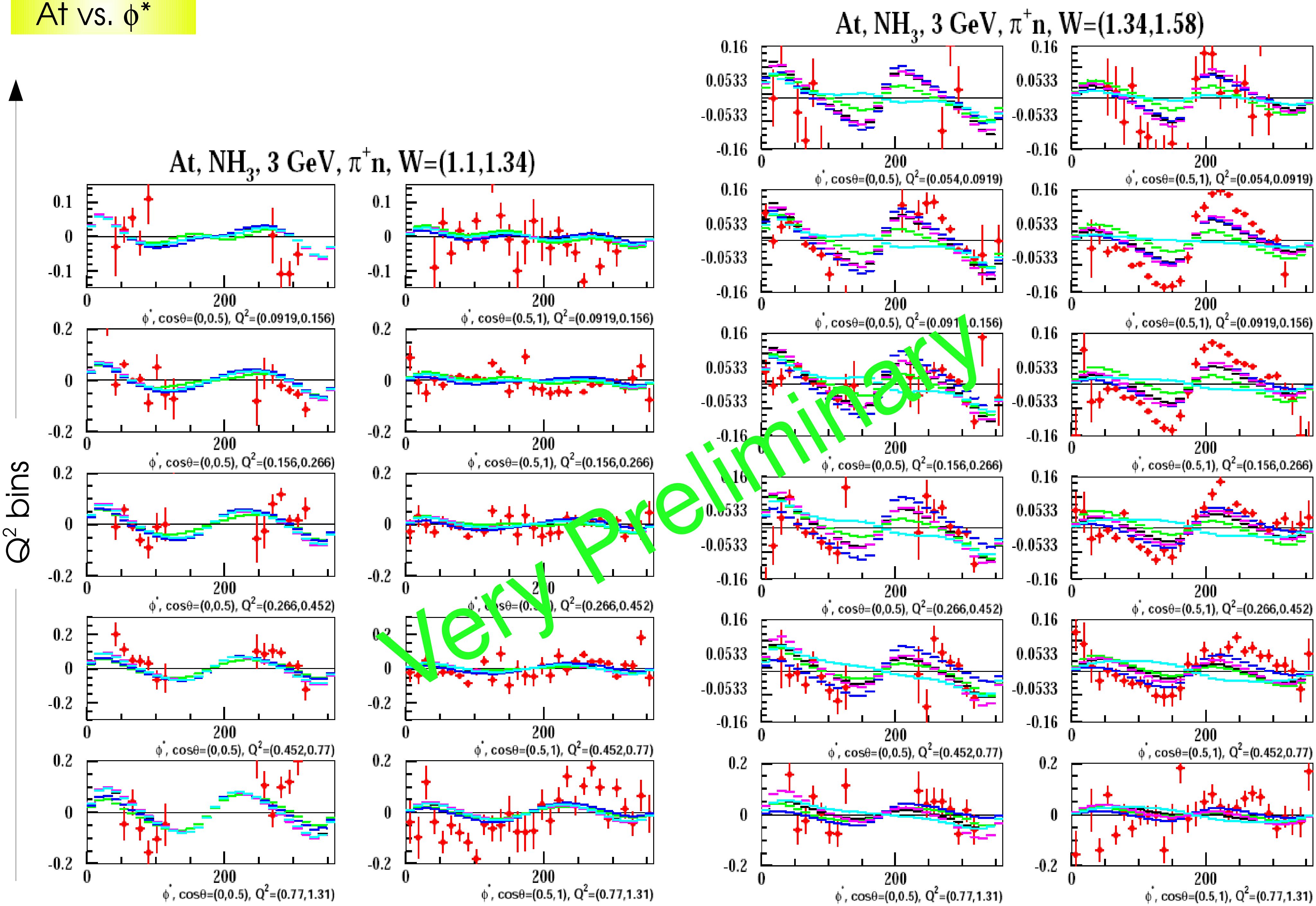
# Aet vs. W




2 cosθ* ranges

Data; MAID2007; DMT; MAID2007(P11off); MAID2007(S11off); MAID2007(D13off)

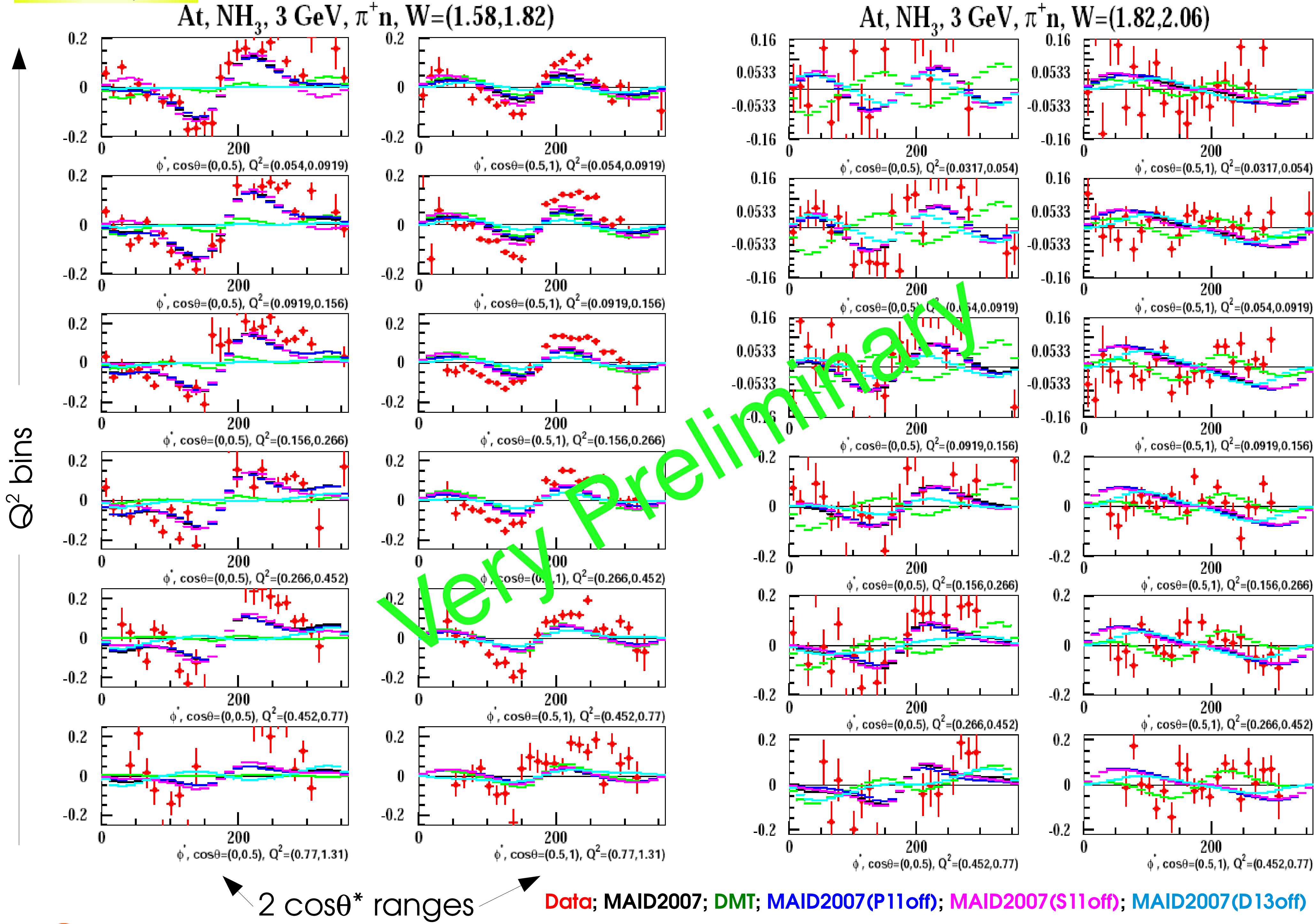
# At vs. $\phi^*$



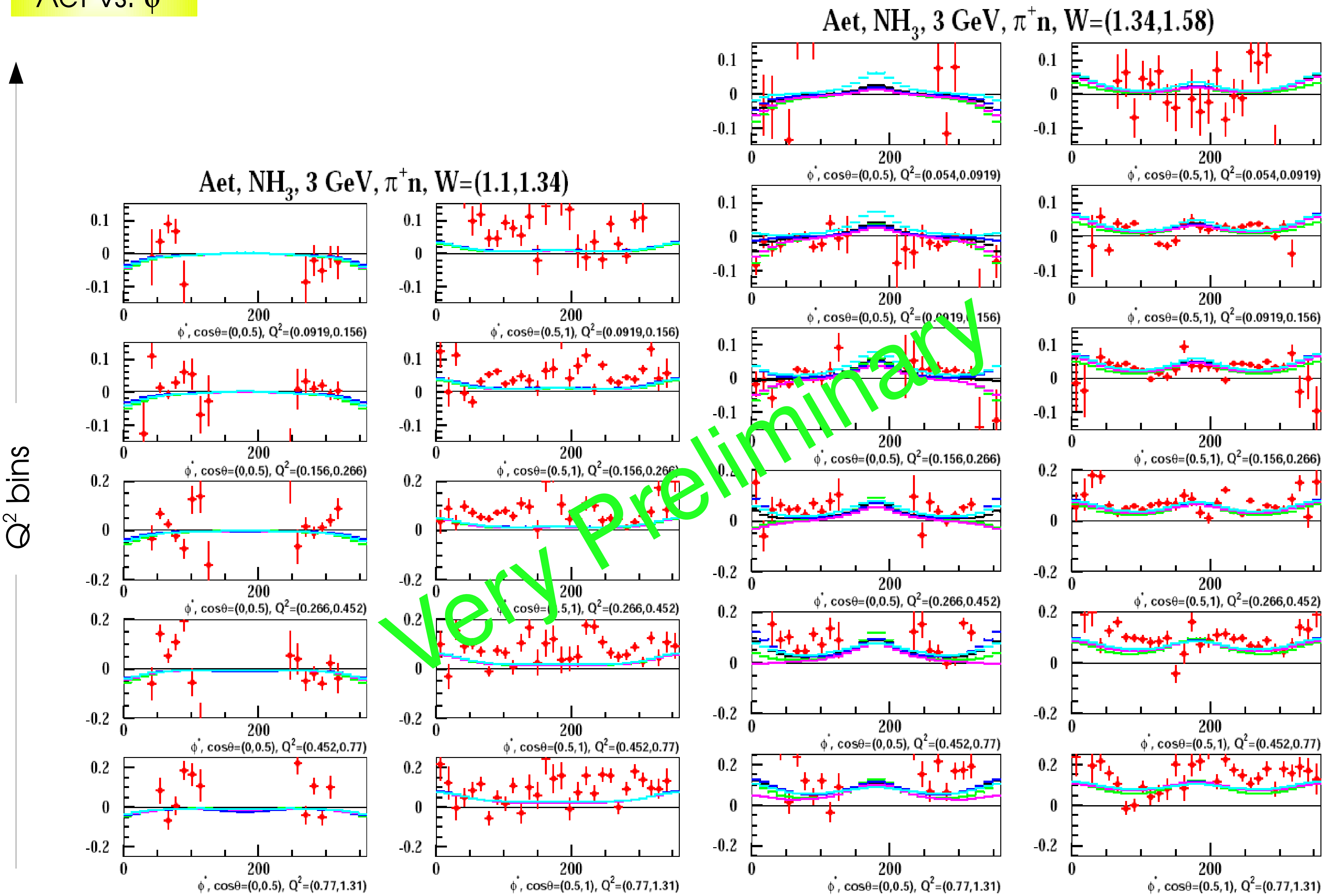

2 $\cos\theta^*$ ranges

Data; MAID2007; DMT; MAID2007(P11off); MAID2007(S11off); MAID2007(D13off)

At vs. ϕ*


At, NH3, 3 GeV, π+n, W=(1.58,1.82)
At, NH3, 3 GeV, π+n, W=(1.82,2.06)
Q2 bins
Very Preliminary
2 cosθ* ranges
Data; MAID2007; DMT; MAID2007(P11off); MAID2007(S11off); MAID2007(D13off)

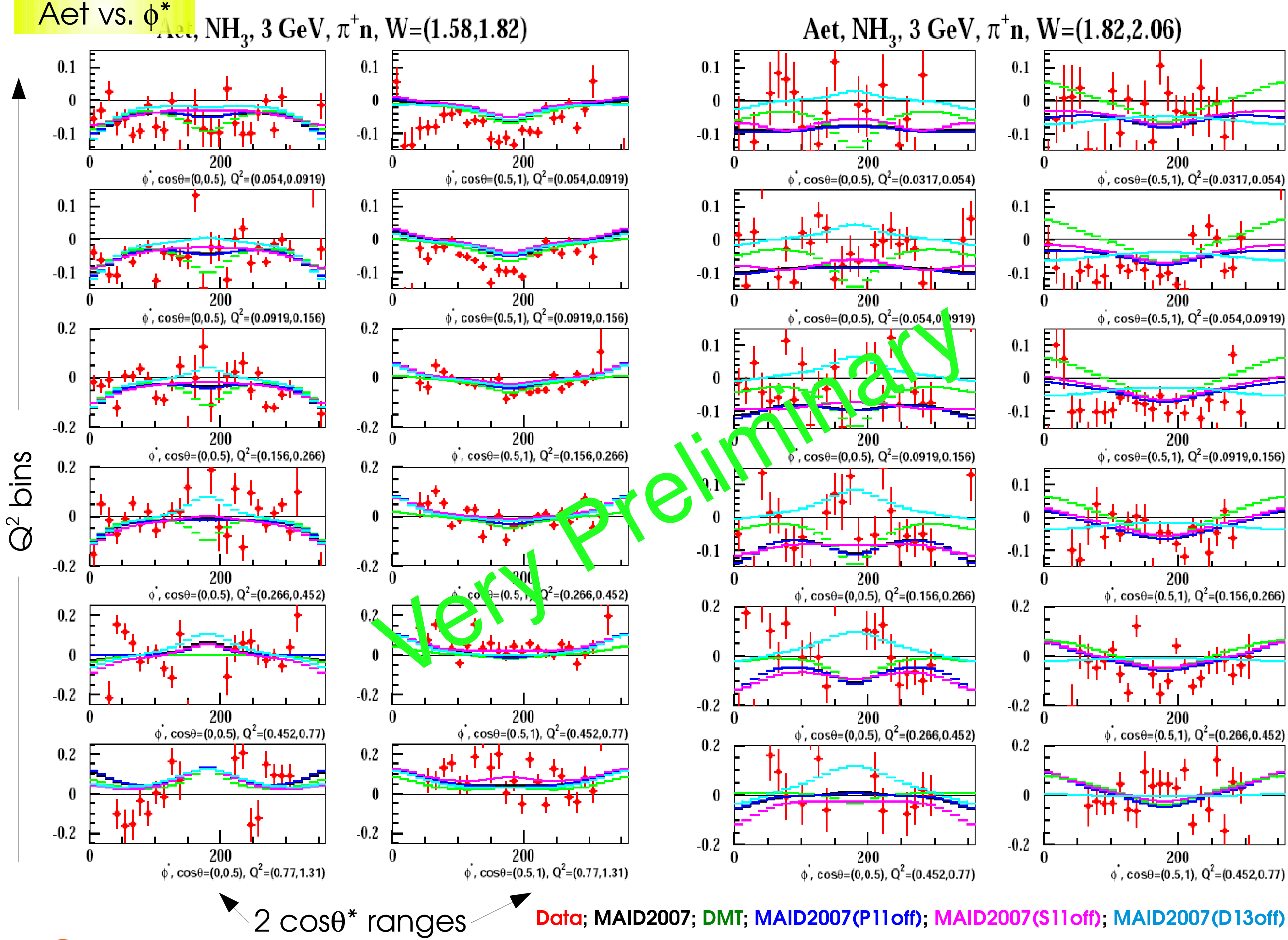
# Aet vs. $\phi^*$




2 cosθ* ranges

Data; MAID2007; DMT; MAID2007(P11off); MAID2007(S11off); MAID2007(D13off)

Aet vs. ϕ*


Aet, NH3, 3 GeV, π+n, W=(1.58,1.82)
Aet, NH3, 3 GeV, π+n, W=(1.82,2.06)
Q2 bins
Very Preliminary
ϕ*, cosθ=(0,0.5), Q2=(0.054,0.0919)
ϕ*, cosθ=(0.5,1), Q2=(0.054,0.0919)
ϕ*, cosθ=(0,0.5), Q2=(0.0919,0.156)
ϕ*, cosθ=(0.5,1), Q2=(0.0919,0.156)
ϕ*, cosθ=(0,0.5), Q2=(0.156,0.266)
ϕ*, cosθ=(0.5,1), Q2=(0.156,0.266)
ϕ*, cosθ=(0,0.5), Q2=(0.266,0.452)
ϕ*, cosθ=(0.5,1), Q2=(0.266,0.452)
ϕ*, cosθ=(0,0.5), Q2=(0.452,0.77)
ϕ*, cosθ=(0.5,1), Q2=(0.452,0.77)
ϕ*, cosθ=(0,0.5), Q2=(0.77,1.31)
ϕ*, cosθ=(0.5,1), Q2=(0.77,1.31)
ϕ*, cosθ=(0,0.5), Q2=(0.0317,0.054)
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2 cosθ* ranges
Data; MAID2007; DMT; MAID2007(P11off); MAID2007(S11off); MAID2007(D13off)

# Summary (2009-2013)

- Parity Violating DIS has the potential to study the Electro-weak Standard Model, and nucleon structure/QCD:
  - First step — JLab 6 GeV (E08-011): measure $A_d$ at two $Q^2$ to ~2.7% (stat.), could extract $\Delta(2C_{2u}-C_{2d}) = 0.04$ (impact on EW SM test);
    - DAQ construction and tests underway;
    - Will run in Nov.-Dec. 2009, data analysis/publishing before 2012.

- Extraction of *Aet* and *At* for single-pion electro-production $\vec{e}\,\vec{p} \to e'\pi^{+} n$ from NH3 and $\vec{e}\,\vec{n} \to e'\pi^{-} p$ from ND3 using CLAS EG4 data;
  - Analysis tools developed; preliminary asymmetries at the highest beam energy look very promising;
  - Will complete the analysis for 4 lower energies before 2012/13; Contribute to low $Q^2$ resonance structure study; May compare to chiral perturbation theory.

# Summary (2013 - )

- Measurement of neutron asymmetry $A_1^n$ in the valence quark region at JLab 12 GeV
  - Flagship experiment
  - Will be one of the first experiments to run (~2014?)
- PVDIS at 12 GeV
  - Ultimate goal: clean separation of New Physics and CSV (2015 or later?)

# Current Knowledge on Weak Coupling Coeffecients

$C_{1q} = g_A^e g_V^q$ $C_{2q} = g_V^e g_A^q$ $C_{3q} = g_A^e g_A^q$

| Facility | Process | $Q^2$ | $C_{iq}$ Combination | Result | SM Value |
|---|---|---|---|---|---|
| SLAC | $e^-$-D DIS | 1.39 | $2C_{1u}-C_{1d}$ | -0.90± 0.17 | -0.7185 |
| SLAC | $e^-$-D DIS | 1.39 | $2C_{2u}-C_{2d}$ | 0.62± 0.81 | -0.0983 |
| CERN | $\mu^\pm$-D DIS | 34 | $0.66(2C_{2u}-C_{2d})+2C_{3u}-C_{3d}$ | 1.80± 0.83 | 1.4351 |
| CERN | $\mu^\pm$-D DIS | 66 | $0.81(2C_{2u}-C_{2d})+2C_{3u}-C_{3d}$ | 1.53± 0.45 | 1.4204 |
| MAINZ | $e^-$-Be QE | 0.20 | $2.68C_{1u}-0.64C_{1d}+2.16C_{2u}-2C_{2d}$ | -0.94± 0.21 | -0.8544 |
| Bates | $e^-$-C elastic | 0.0225 | $C_{1u}+C_{1d}$ | 0.138±0.034 | 0.1528 |
| Bates | $e^-$-D QE | 0.1 | $C_{2u}-C_{2d}$ | -0.042± 0.057 | -0.0624 |
| Bates | $e^-$-D QE | 0.04 | $C_{2u}-C_{2d}$ | -0.12± 0.074 | -0.0624 |
| JLab | $e^-$-p elastic | 0.03 | $2C_{1u}+C_{1d}$ | approved | -0.0357 |
| | $^{133}$Cs APV | 0 | $-376C_{1u}-422C_{1d}$ | -72.69±0.48 | -73.16 |
| | $^{205}$Tl APV | 0 | $-572C_{1u}-658C_{1d}$ | -116.6±3.7 | -116.8 |
| Fit | $e^-$-A | low | $C_{1u}+C_{1d}$ | 0.1358±0.0326 | 0.1528 |
| All | | | $C_{1u}-C_{1d}$ | -0.4659±0.0835 | -0.5297 |
| PVES | | | $C_{2u}+C_{2d}$ | -0.2063±0.5659 | -0.0095 |
| Data | | | $C_{2u}-C_{2d}$ | -0.0762±0.0437 | -0.0621 |

new

PDG2002 (best):
$(2C_{2u}-C_{2d})=\pm0.24$

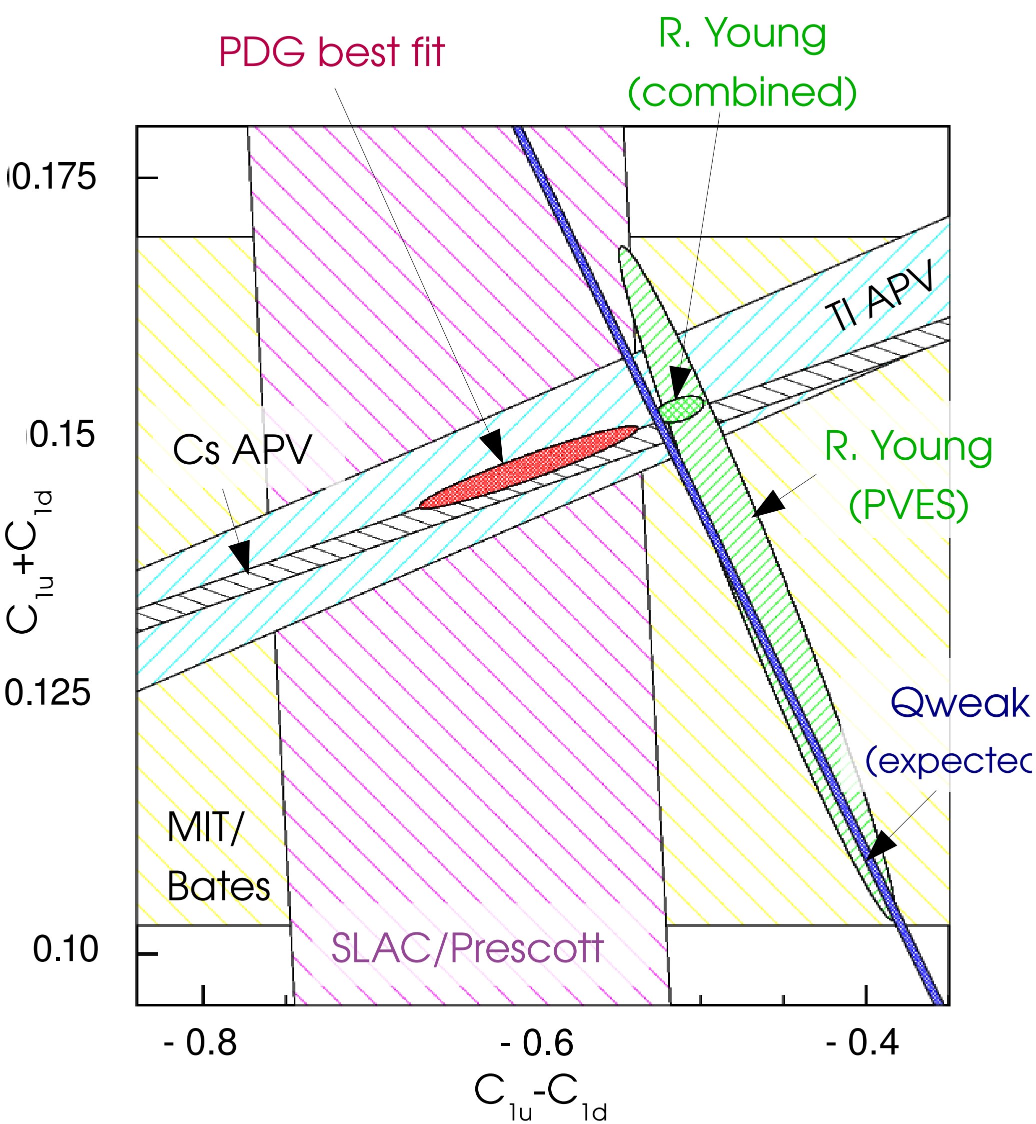
J. Erler, M.J. Ramsey-Musolf, Prog. Part. Nucl. Phys. **54**, 351 (2005)

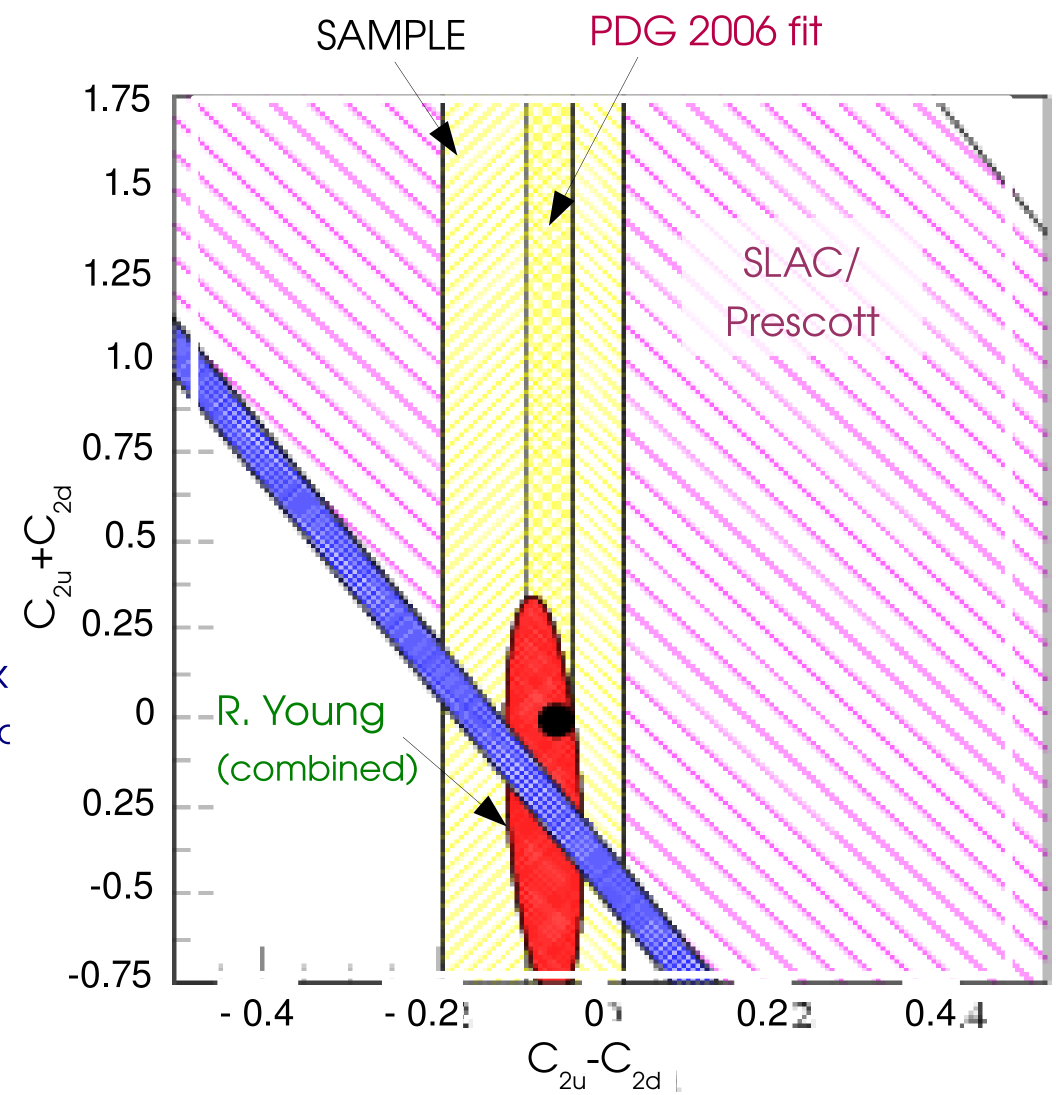
R. Young, R. Carlini, A.W. Thomas, J. Roche, PRL 99, 122003 (2007) & priv. comm.

Some New Physics can affect $C_{2q}$, but not $C_{1q}$

# Current Knowledge on $C_{1,2q}$

all are 1 σ limit

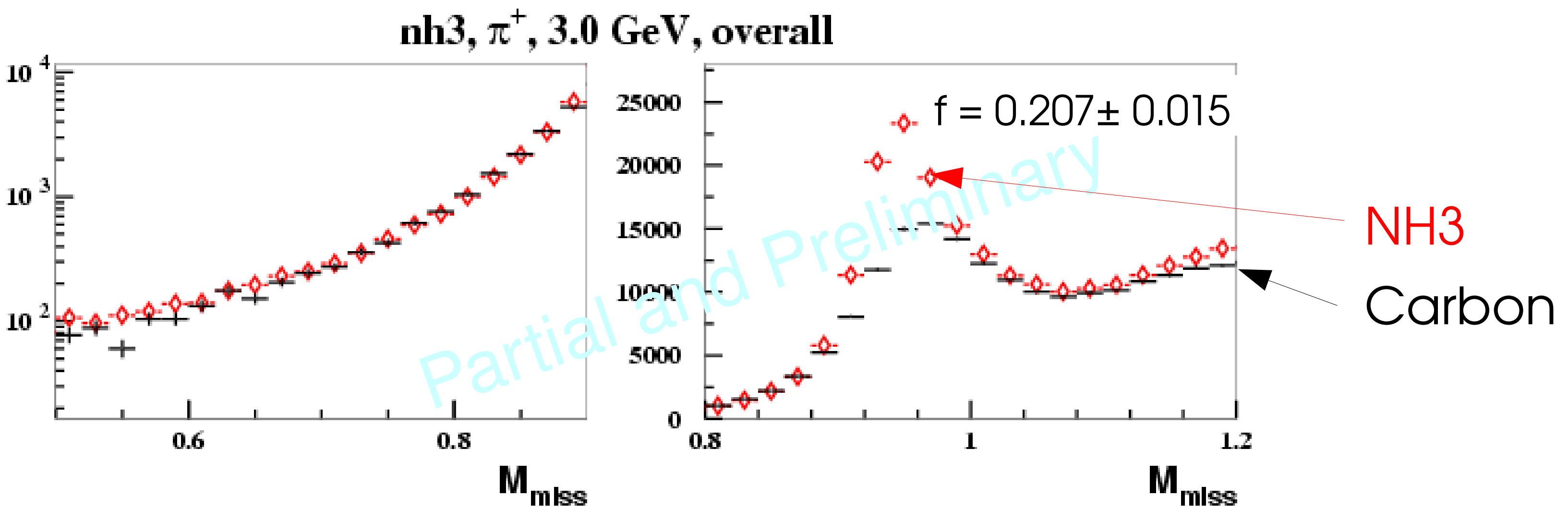



- Best: PDG2002 $\Delta(2C_{2u}-C_{2d}) = 0.24$

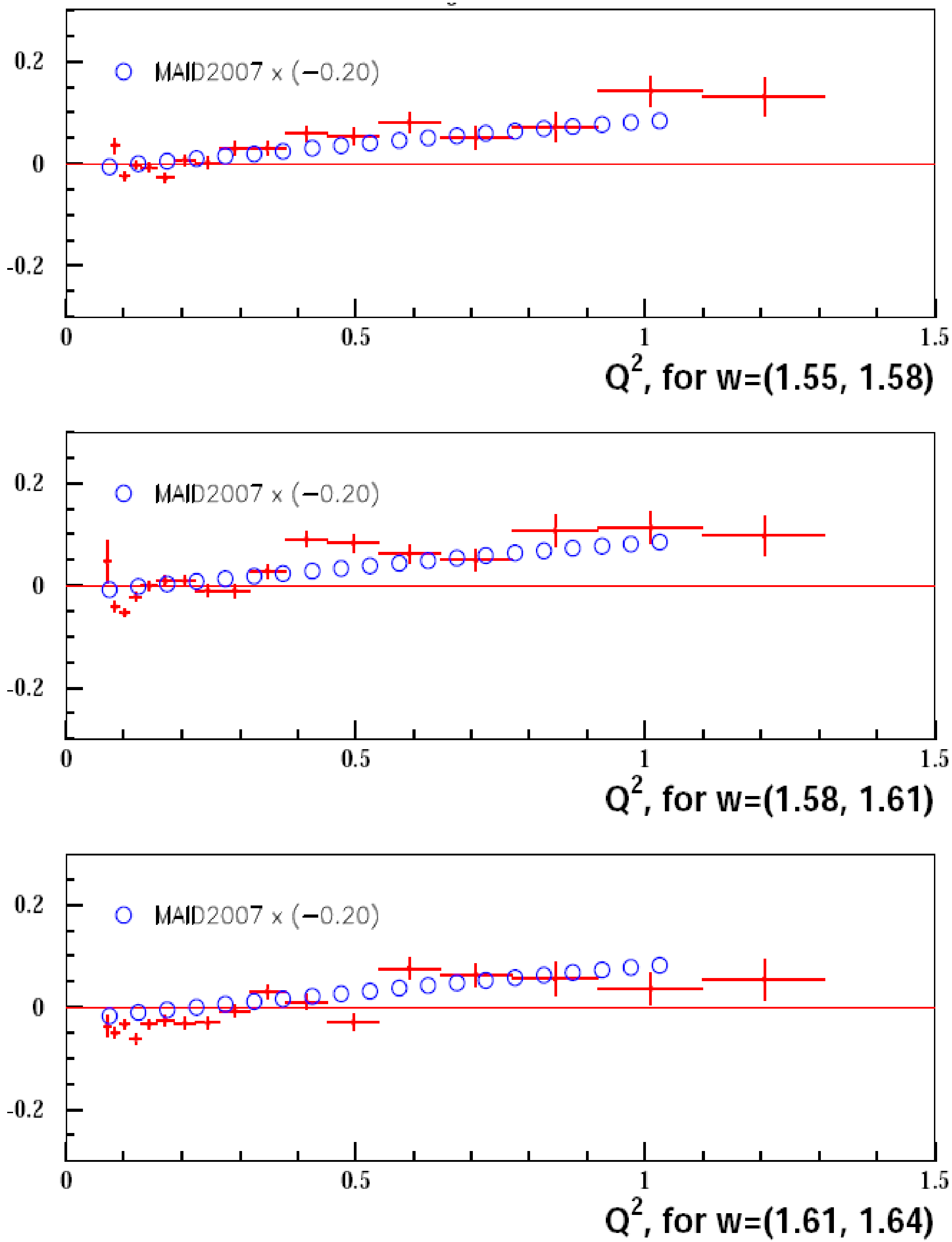
# Dilutions

- Dilution factor measures fraction of events from polarized nucleons (p in NH3 and D in ND3)




- With momentum corrections, expect to have sharper peak and higher *f*;
- Studying kinematic dependence of *f* with higher statistics.

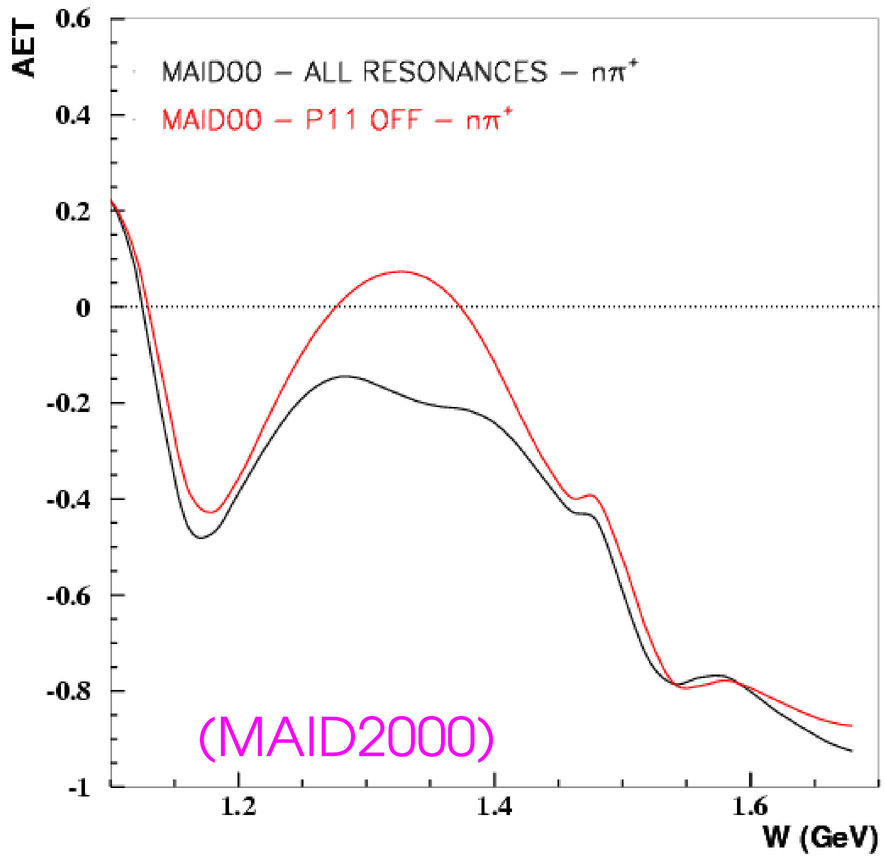
# Aet vs. $Q^2$

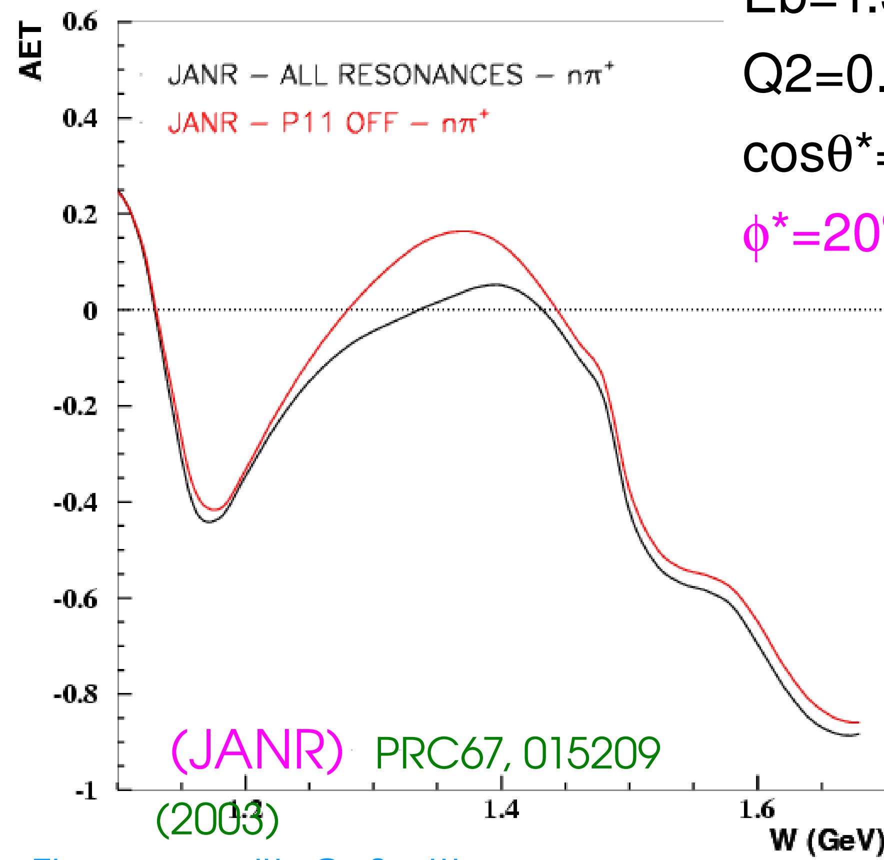



- (integrated over $\phi^*$ and $\cos\theta^*$)
- 0.20: overall "dilution factor"

# Physics Motivation (cont.)

- Example: Roper $P_{11}(1440)$ -- Least understood and most controversial
  - Radial excitation of 3q: $(1s)^2(2s)^1$ predicted by CQM;
  - Hybrid: 3qG with relativistic effect; ◄—— Favored by the recent CLAS ana. PRC71, 015201 (2005) PRC72, 058202(2005)
- Sensitivity of Aet ($n\pi^+$) to $P_{11}(1440)$:



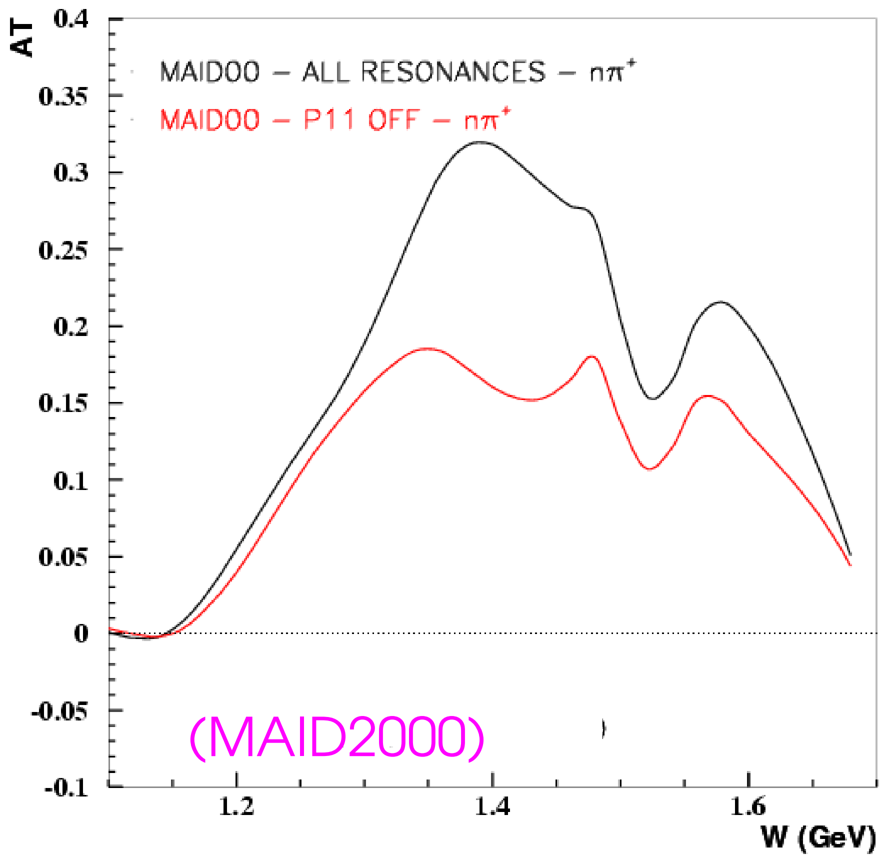




Eb=1.34
Q2=0.1
$\cos\theta^*=0.4$
$\phi^*=20^o$

Figure credit: C. Smith

# Physics Motivation (cont.)

- Sensitivity of At ($n\pi^+$) to $P_{11}$(1440):



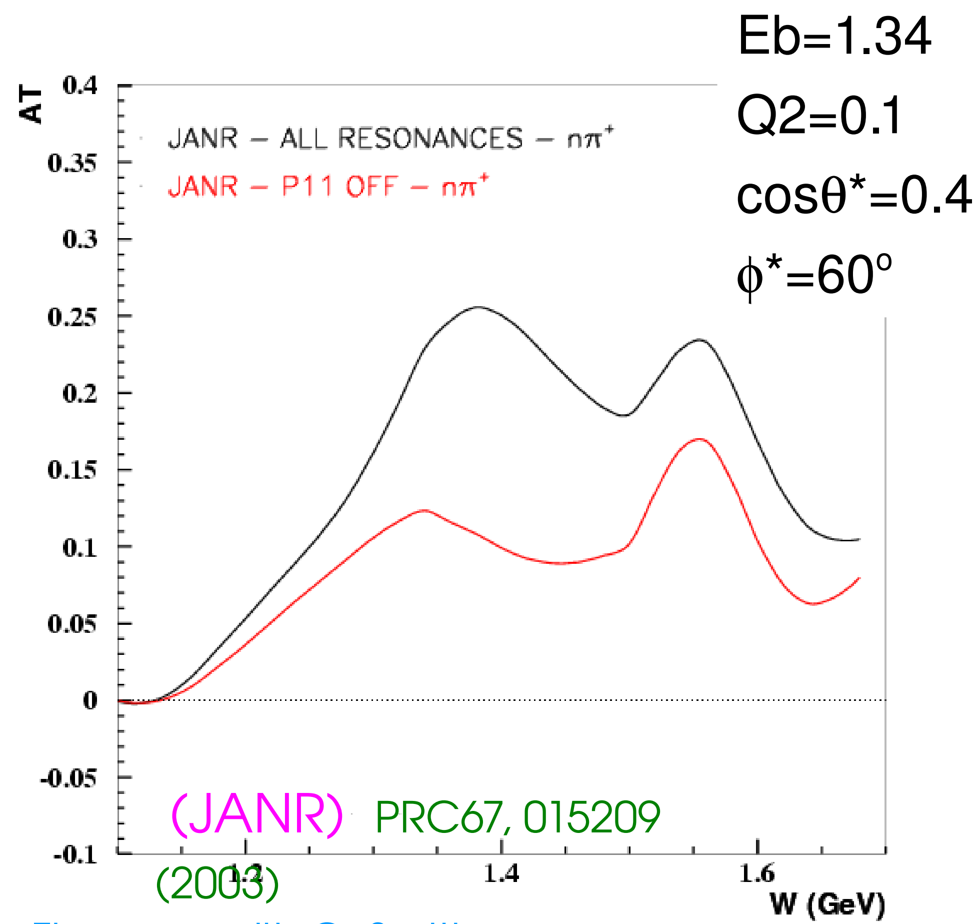
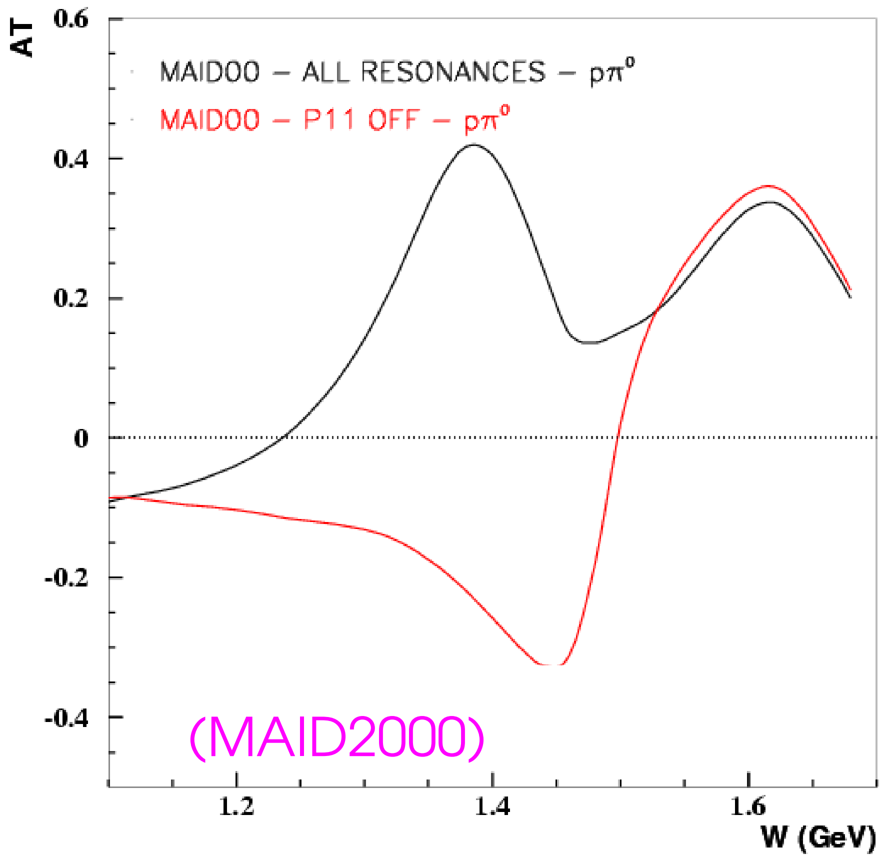



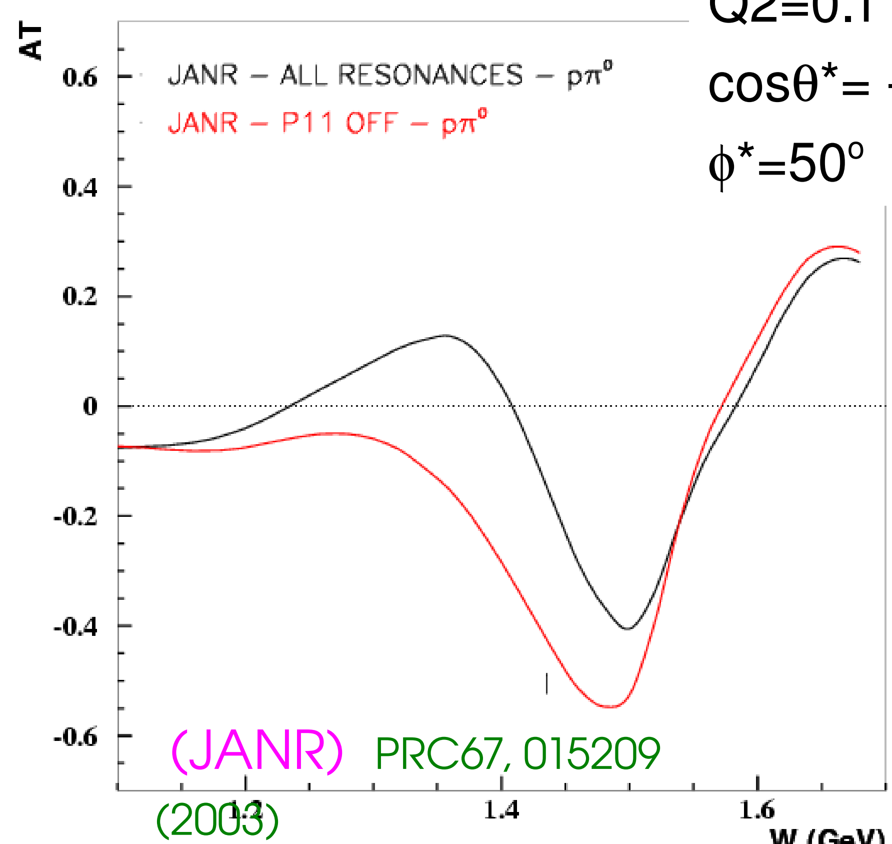

Figure credit: C. Smith

# Physics Motivation (cont.)

- Sensitivity of At ($p\pi^0$) to $P_{11}$(1440):

Spin observables may help to remove some model dependence in extraction of amplitudes -> better determination of the nature of $P_{11}$(1440).




Eb=1.34

Q2=0.1

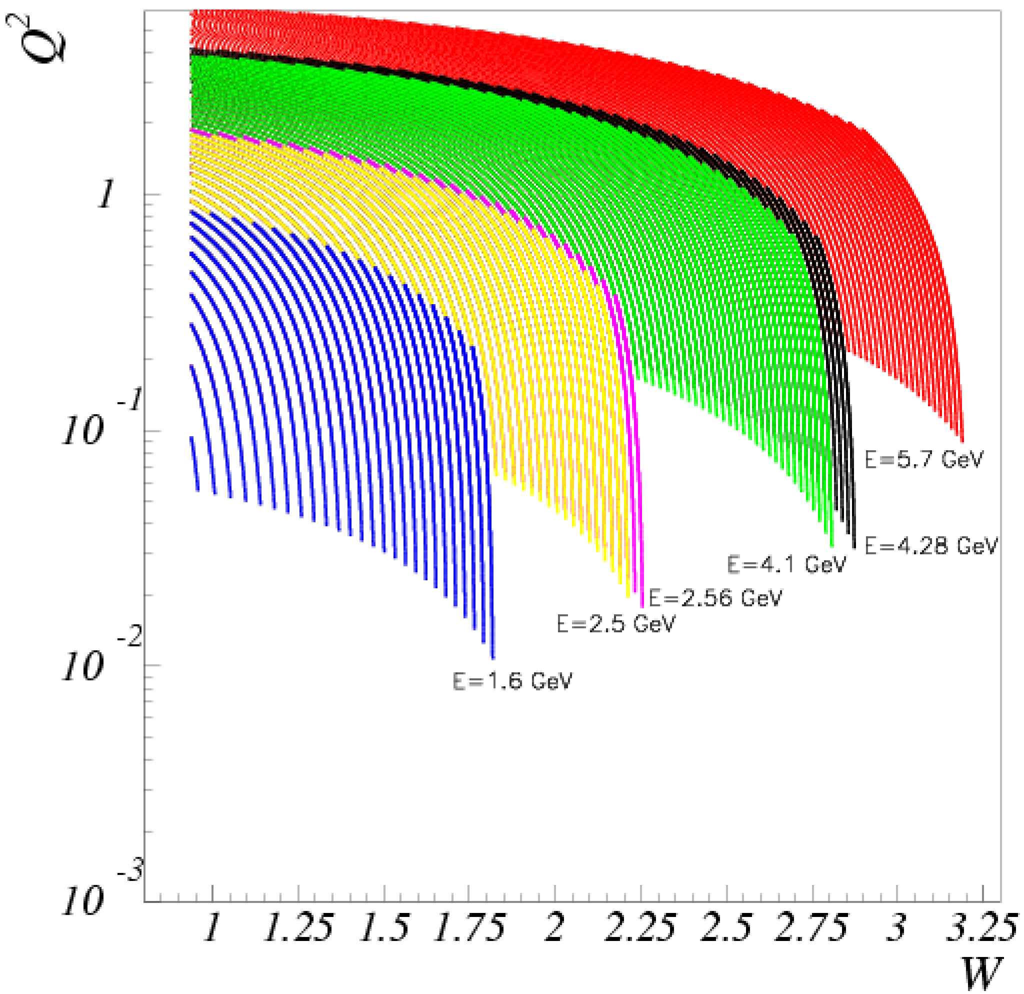
cosθ*= - 0.8

φ*=50°

Figure credit: C. Smith

# EG4 Kinematic Coverage

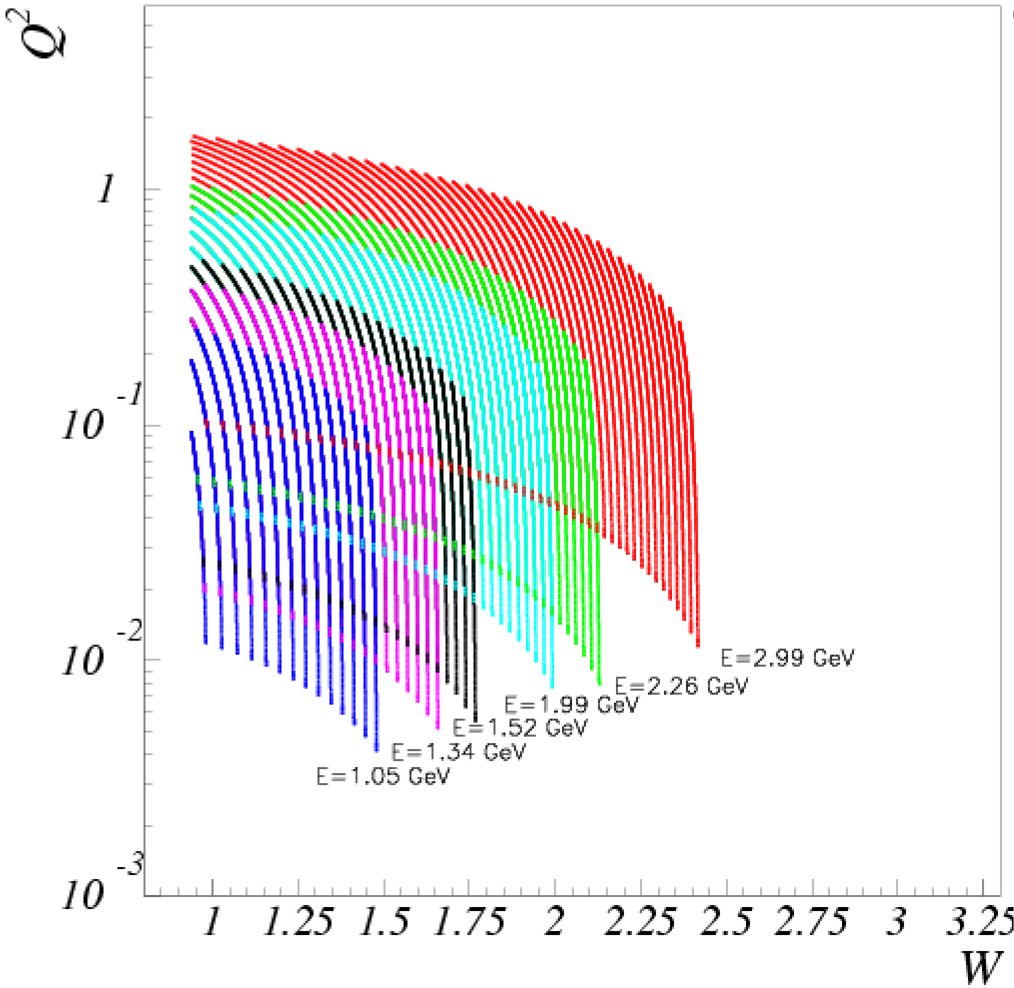
- eg1b coverage: (for comparison)



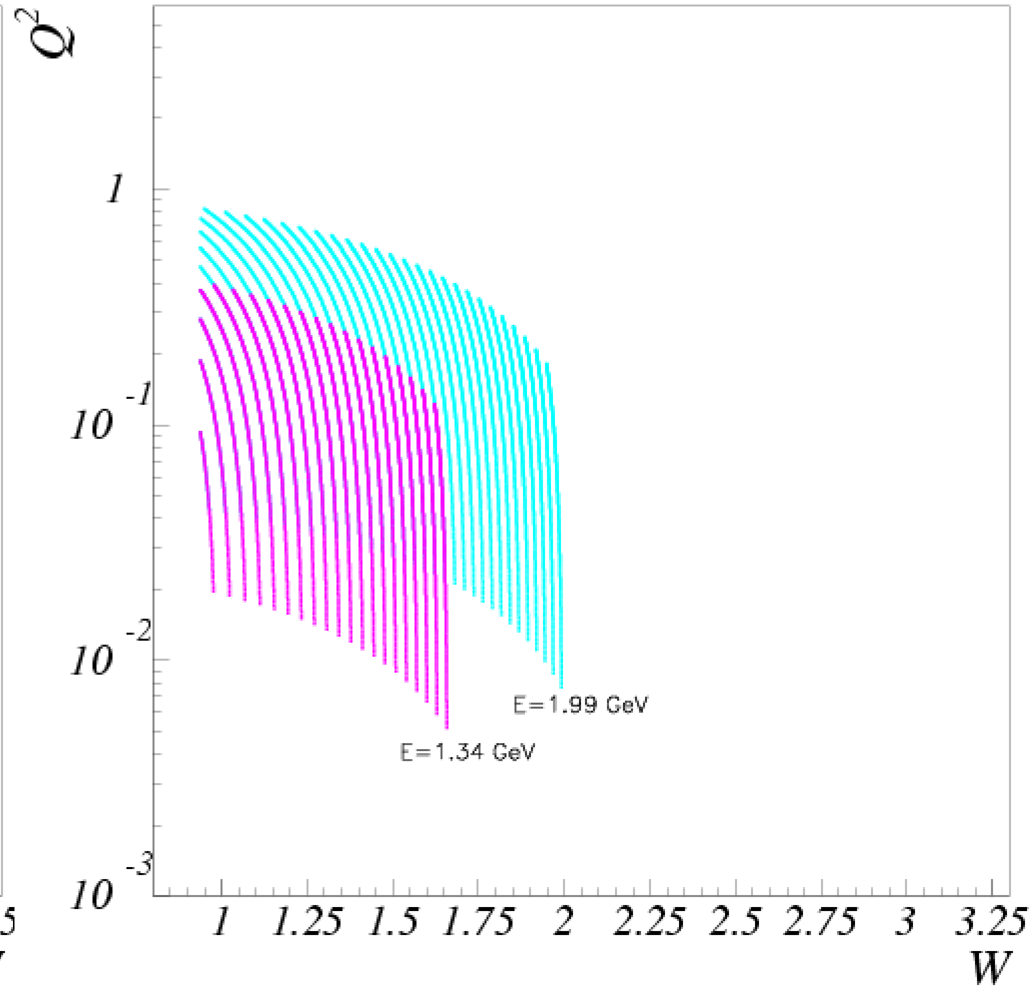

- Lowest Eb: 1.6 GeV

# EG4 Kinematic Coverage

- $NH_3$ target




- $ND_3$ target

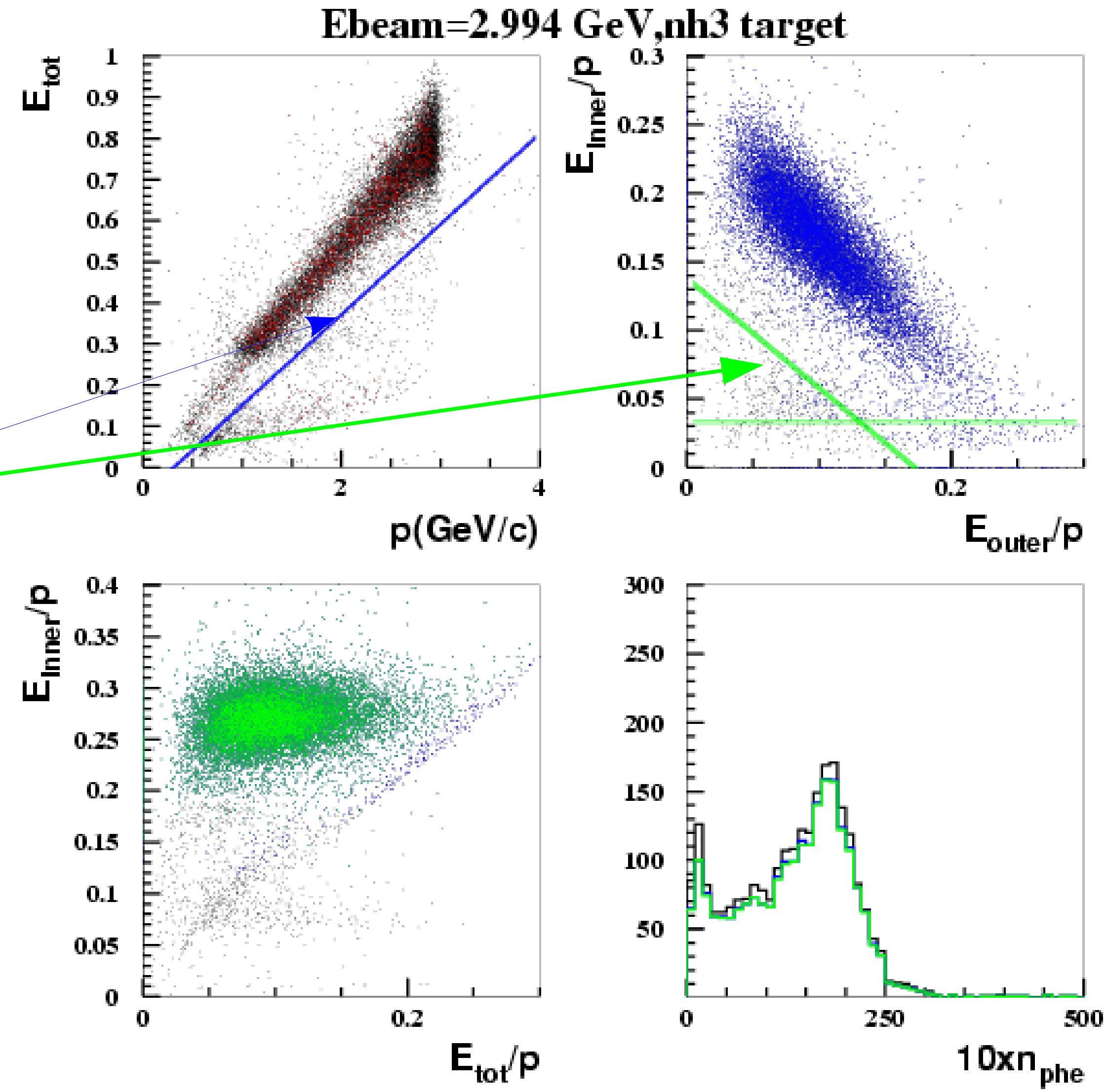



- Extensive running at 1.3 GeV;
- Better ND3 polarization

# Electron Selection

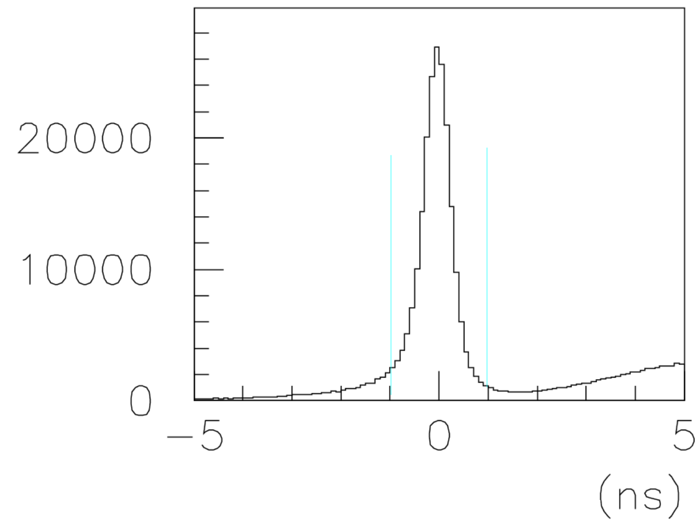
- EG4 had Cerenkov only in sector 6, use forward EC for e', will add Cerenkov cut in the final analysis

Electron cuts

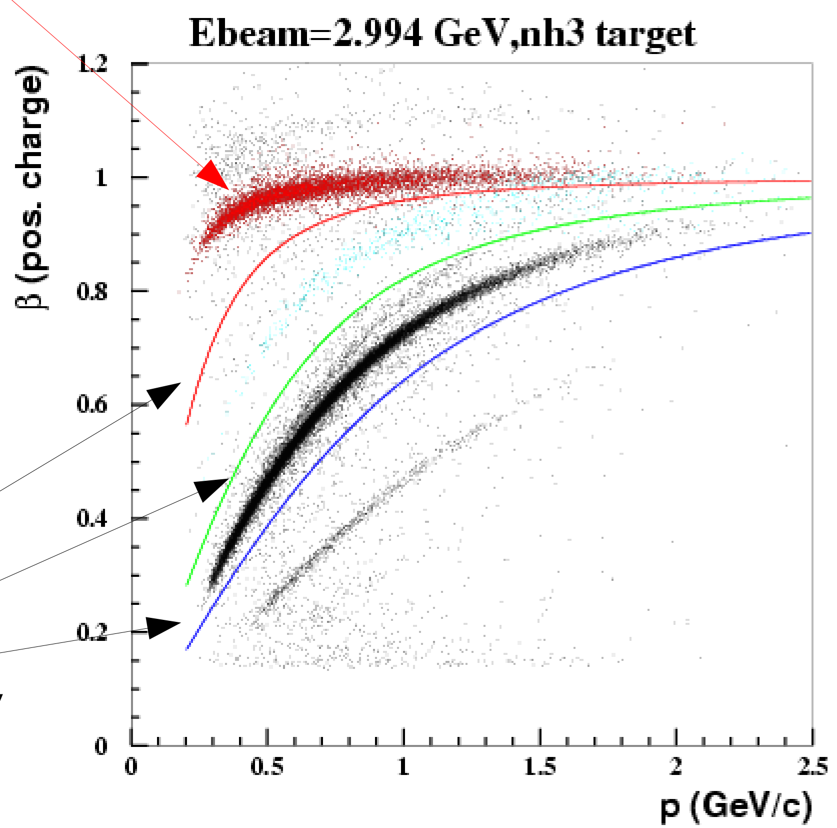


# Pion Selection

- Offline TOF calibration close to final (have not excluded non-working paddles yet)
- Used TOF cut |t-tπ|<1ns



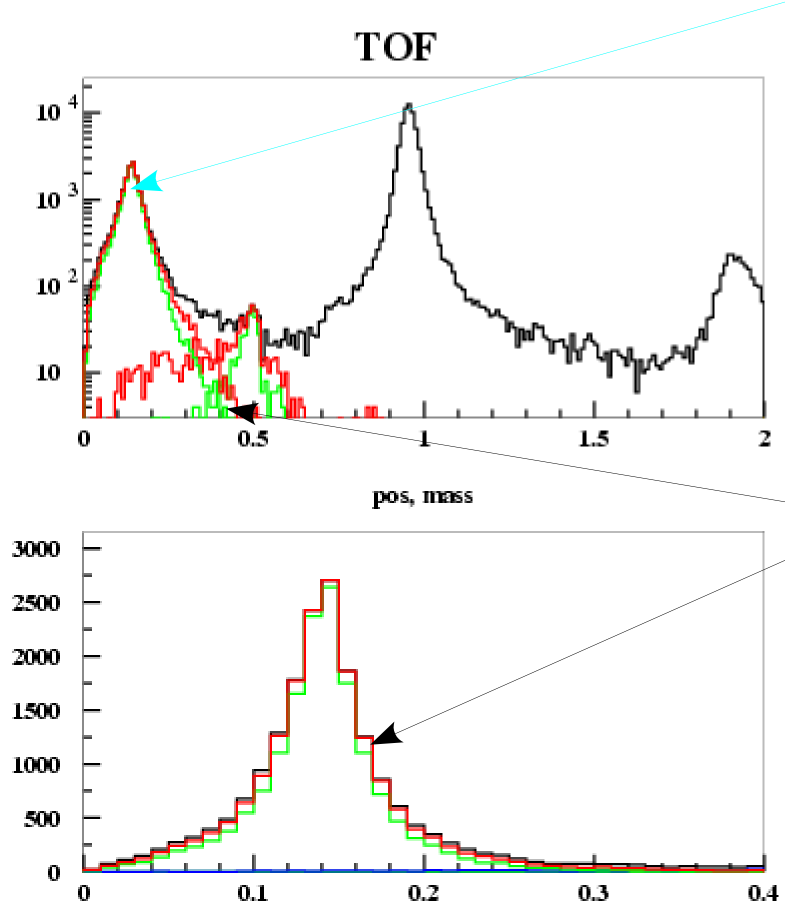

t-t_pion (ns)




M = 0.3, 0.7, 1.2 GeV

# Pion Selection

- Offline TOF calibration close to final (have not excluded non-working paddles yet)
- Used TOF cut |t-tπ|<1ns

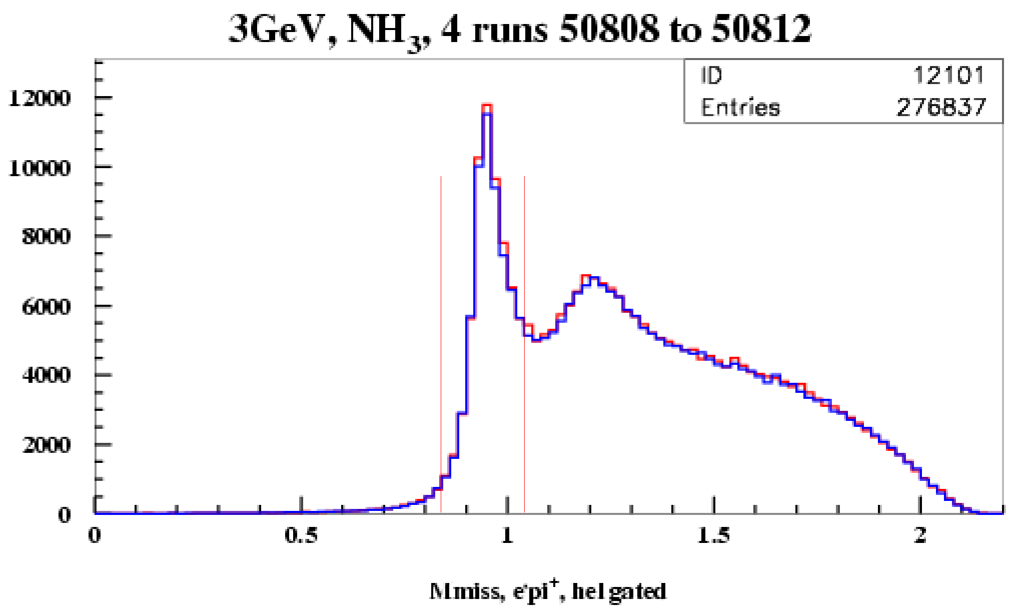



- Pion mass: 0.1497 ± 0.064 GeV/$c^2$

TOF cuts: 1.0, 0.5 ns

# Missing neutron (proton) selection

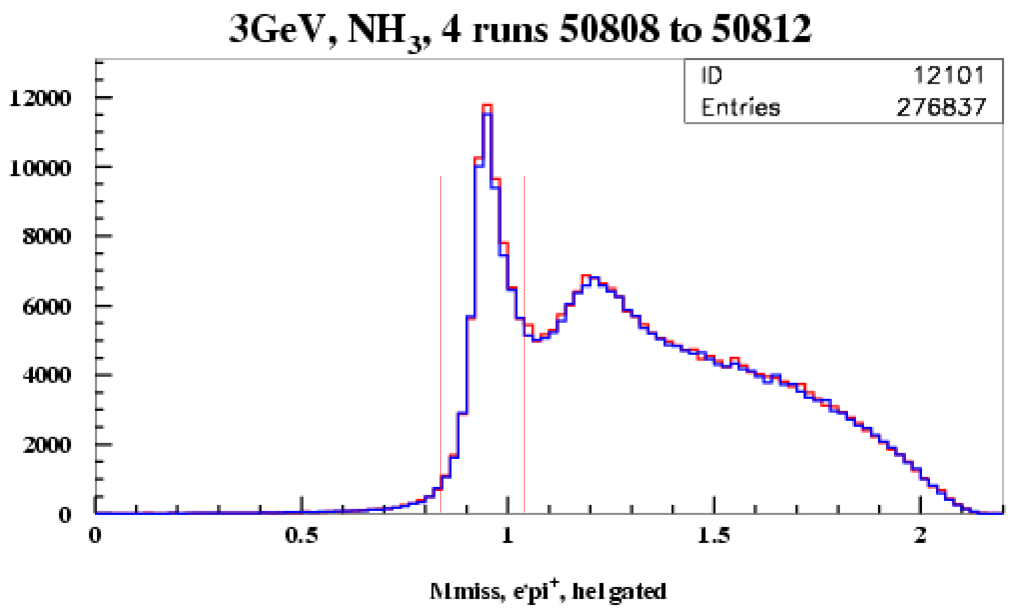
NH3 target, ep -> $e'\pi^+n$




- Cut used in analysis: 0.85<Mmiss<1.05 GeV

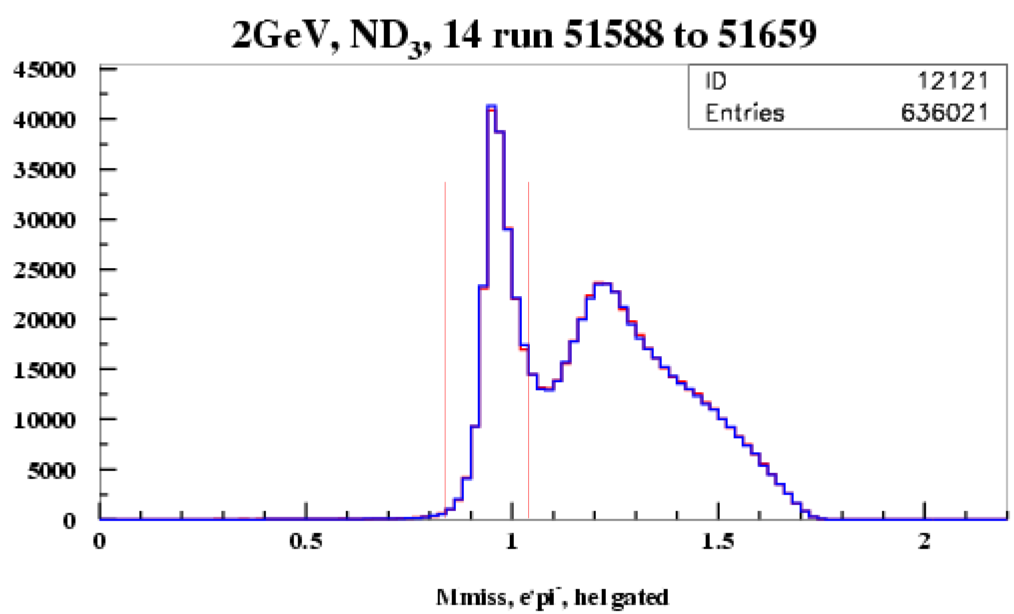
# Missing neutron (proton) selection

NH3 target, ep -> e'$\pi^+$n




- Cut used in analysis: 0.85<Mmiss<1.05 GeV
- Also checked: e'p($\pi$-), but not as good

ND3 target, en -> e'$\pi^-$p




- Have good channel selection 

# Dilutions

- Dilution factor measures fraction of events from polarized nucleons (p in NH3 and D in ND3)

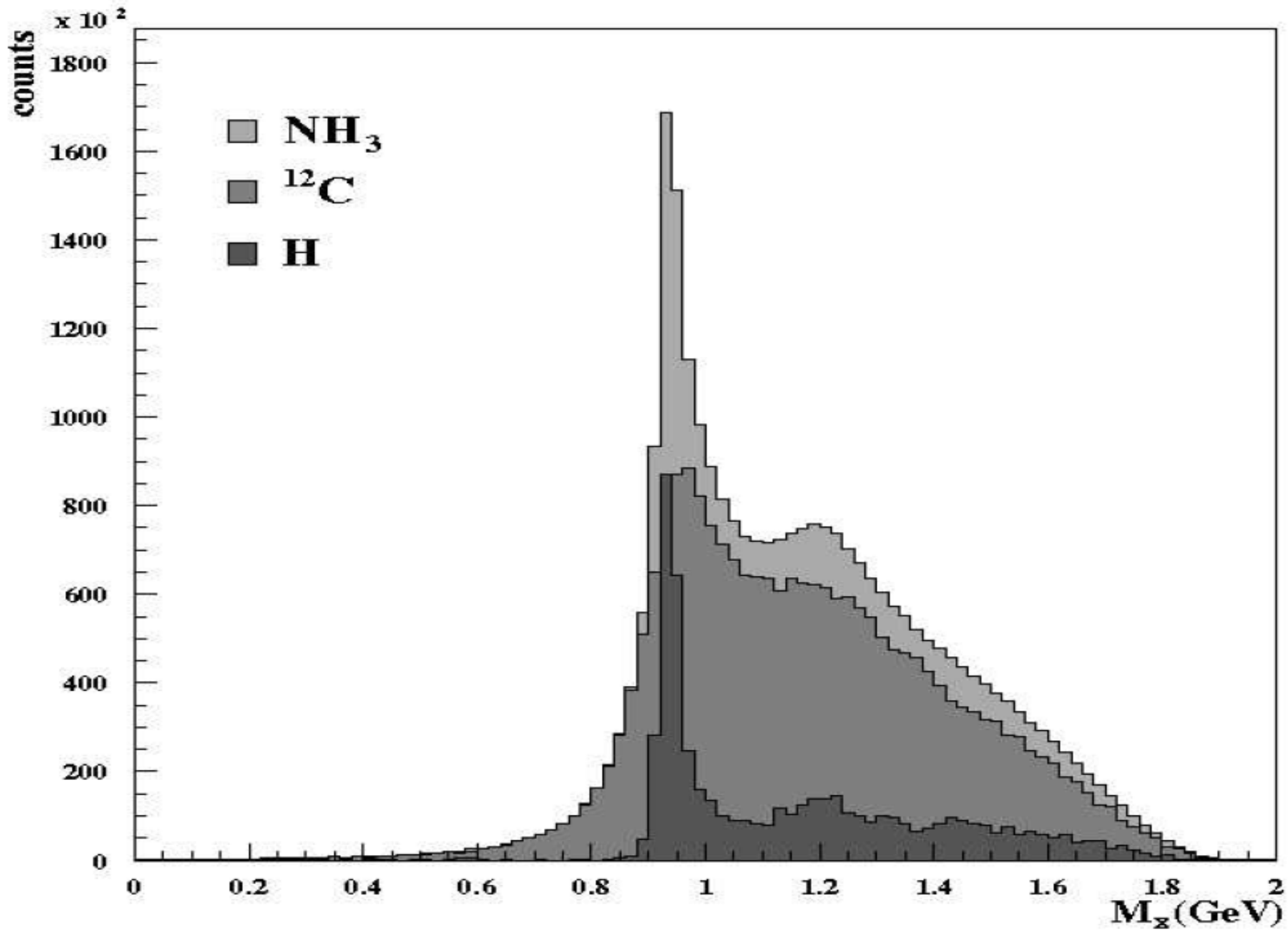



Figure from R. de Vita, Ph.D. thesis