The JLab/CLAS EG4 Experiment

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- The EG4 Experiment — overview
- EG4 inclusive channel analysis status
- EG4 exclusive channel analysis status
- Summary

Acknowledgment:

EG4 spokespeople: M. Battaglieri, R. De Vita, A. Deur, G. Dodge, M. Ripani, K. Slifer
EG4 Ph.D. students: K. Adhikari, H. Kang, K. Kovacs
Exclusive analysis CAA co-spokespeople: A. Biselli, P.E. Bosted, G. Dodge
Exclusive analysis CAA Review committee: D. Carman, P. Eugenio, C. Smith, M. Ungaro
Other members from the EG1a and EG2000 collaborations

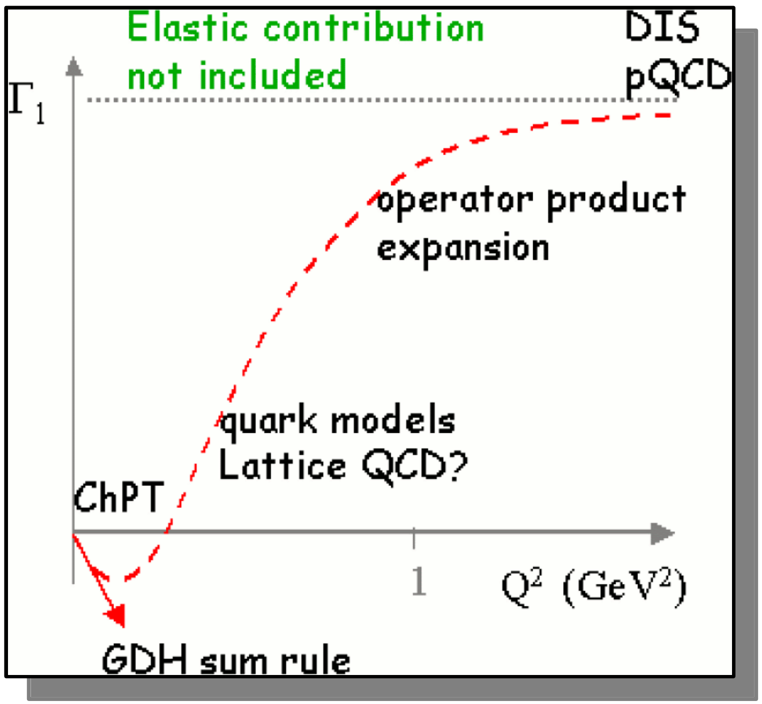
Introduction

- The CLAS/EG4 experiment focused on measurement of the generalized GDH sums for *p* and *n (D)* at very low Q^2 (0.01-0.5 GeV^2):

$$I_{GDH}=\frac{M^2}{8\alpha\pi^2}\int_{thr}^{\infty}\left(\sigma_{1/2}-\sigma_{3/2}\right)\frac{d\nu}{\nu}$$

$$I_{GDH}(Q^2=0)=-\frac{1}{4}\kappa^2$$

$$I_{GDH}(Q^2\neq 0)=\frac{16\pi^2\alpha}{Q^2}\int_0^{x_{th}}g_1(x,Q^2)\,dx=\frac{16\pi^2\alpha}{Q^2}\Gamma_1$$



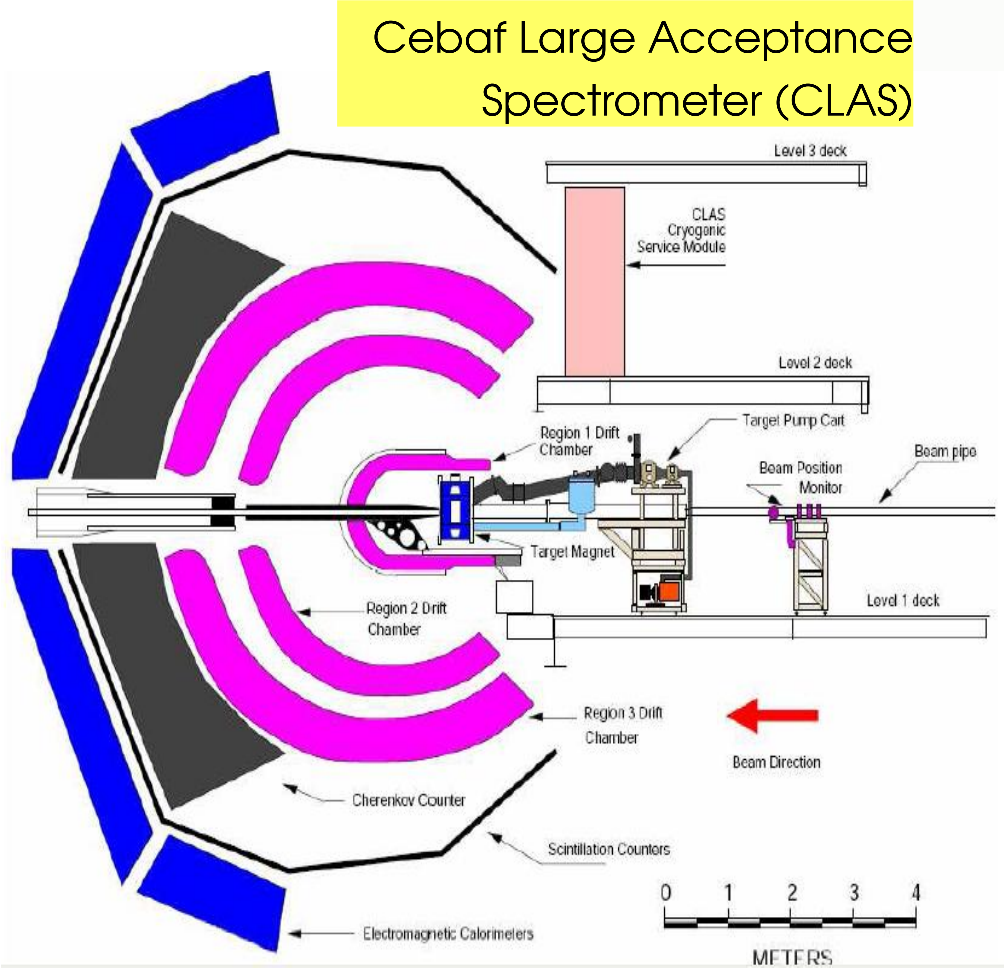
- Data at very low Q^2 will test the chiral perturbation theory.

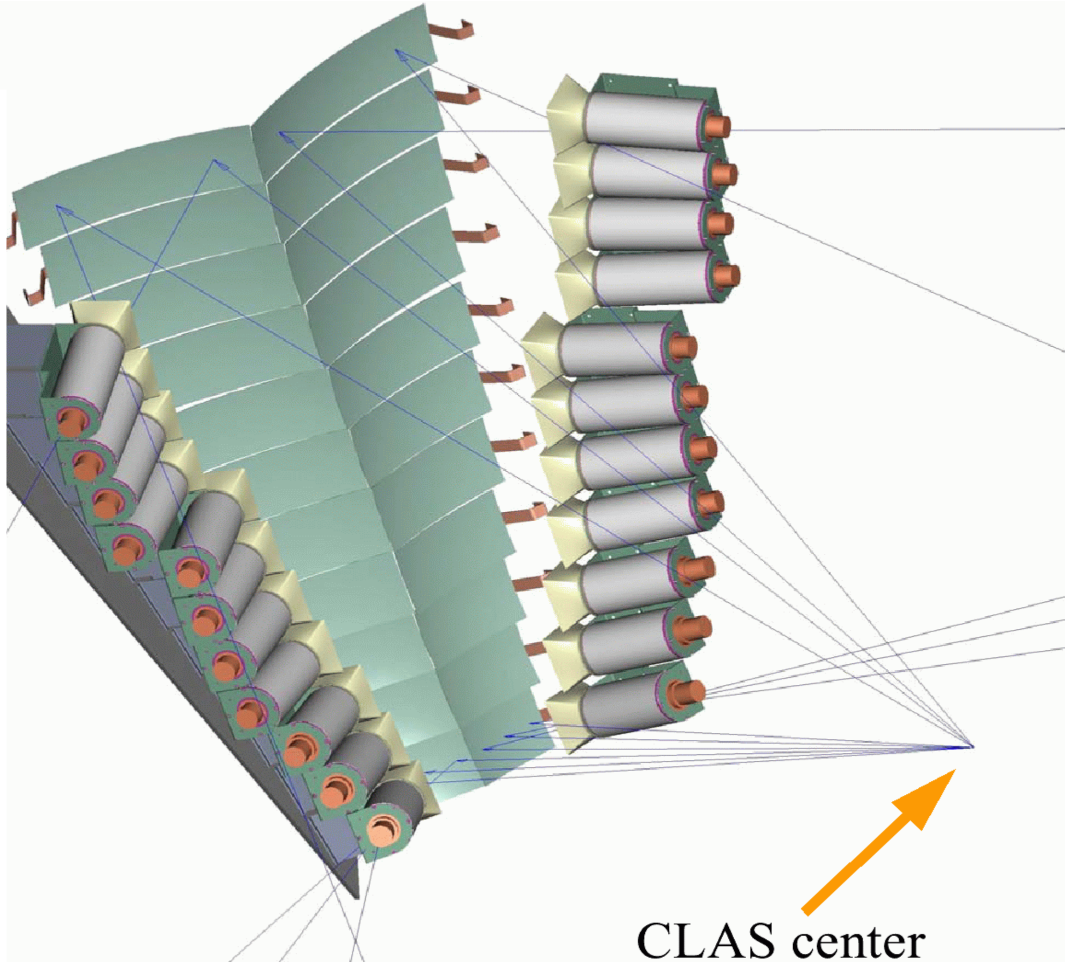
- Method: Extract helicity-dependent inclusive cross sections, then extract g_1:

$$\frac{d\sigma^{\rightarrow\leftarrow}}{d\Omega\,dE'}-\frac{d\sigma^{\rightarrow\rightarrow}}{d\Omega\,dE'}=\frac{4\alpha^2E'^2}{ME\nu Q^2}\left[(E-E'\cos\theta)\,g_1(x,Q^2)-2Mx\,g_2(x,Q^2)\right]$$

EG4 Run Features

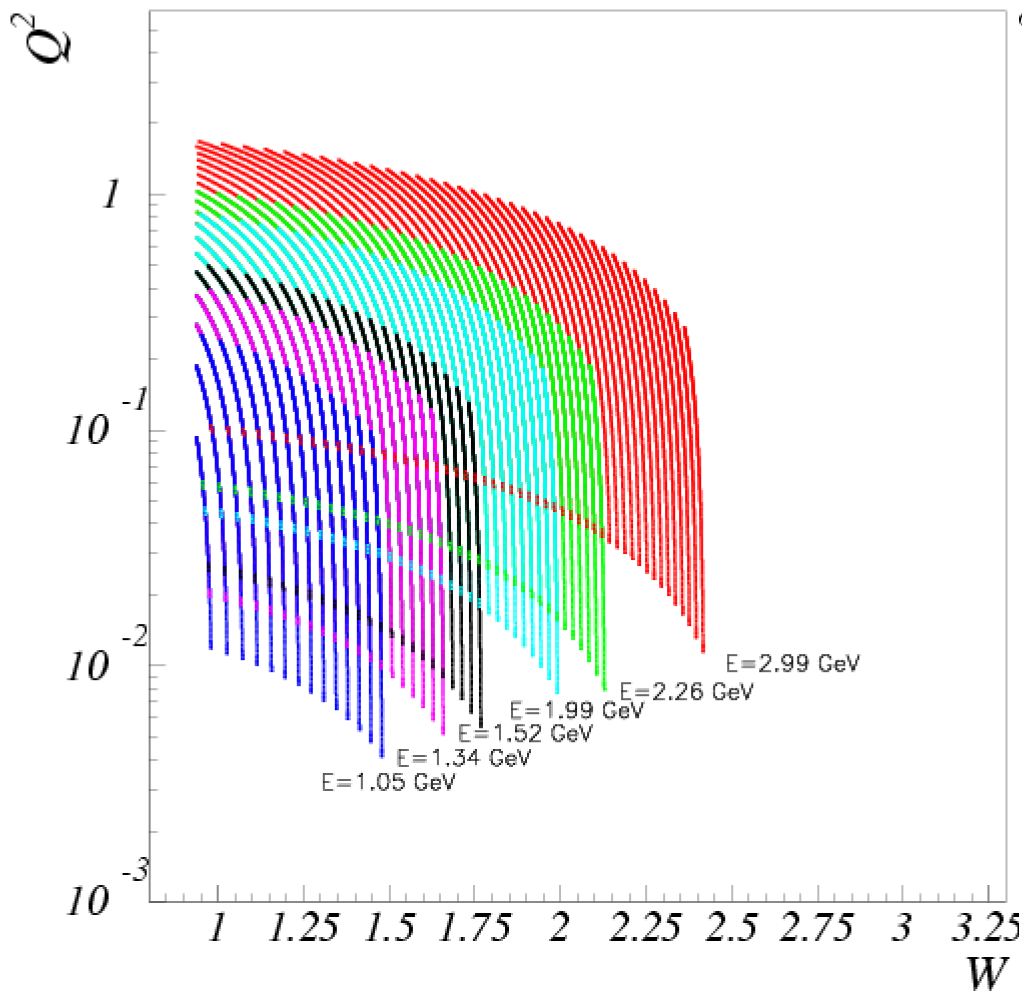
- Longitudinally polarized CLAS NH_3 and ND_3 targets at -1m w.r.t. CLAS center;
- New Cherenkov detector (INFN-Genova) in sector 6 for detecting small angle scatterings down to 6° with uniform and high efficiencies;
- Low (1-3 GeV) beam energy, outbending torus field.

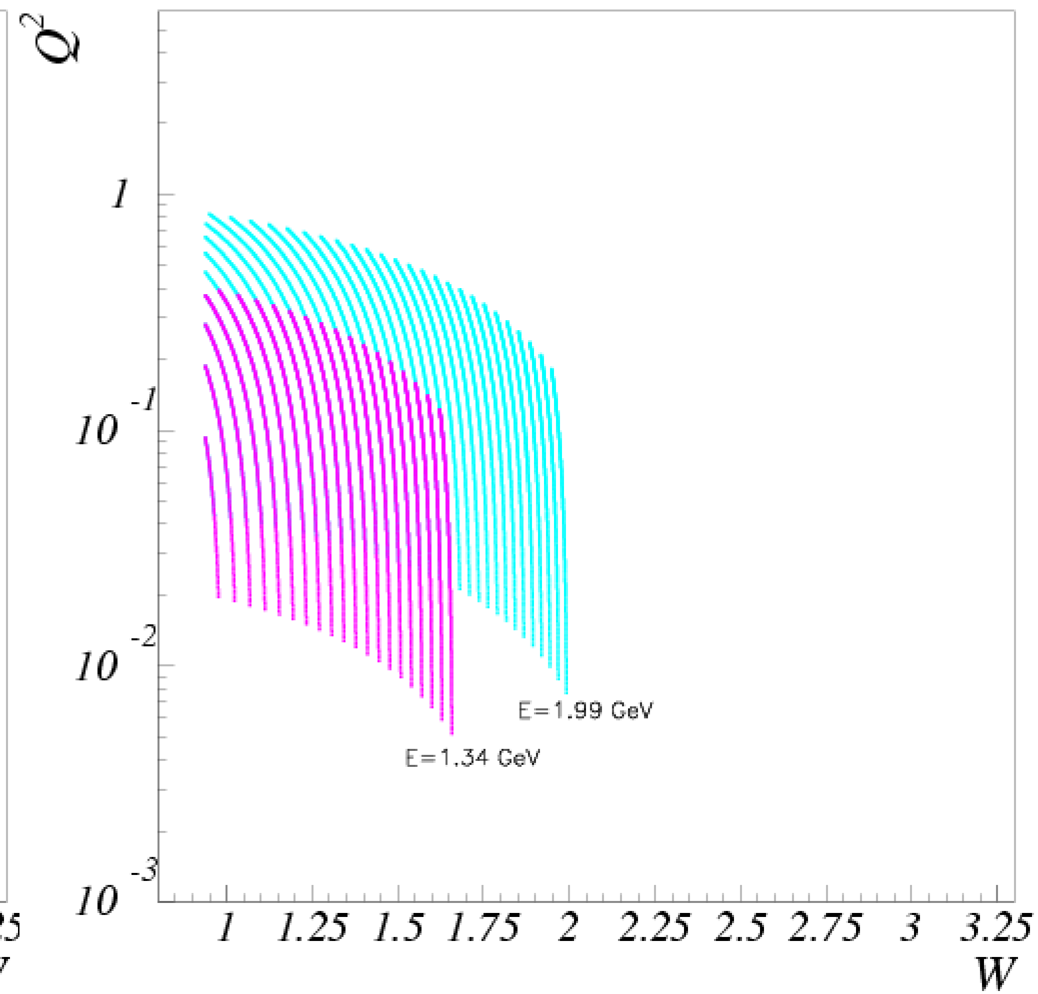




EG4 Kinematic Coverage

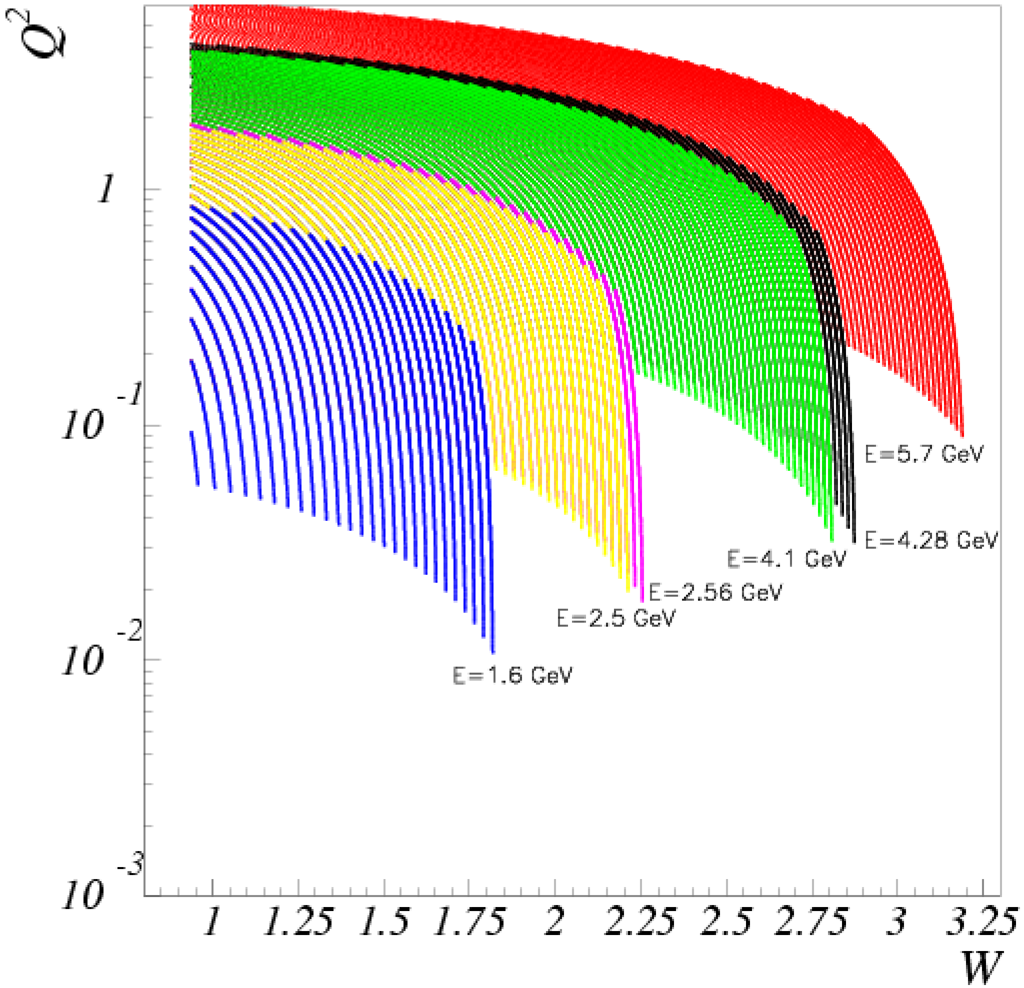
- NH_3 target (P_{targ} = 80-90%)
- ND_3 target (P_{targ} = 30-45%)





- Extensive running at 1.3 GeV.

EG1b Kinematic Coverage (for comparison)



- Lowest Eb: 1.6 GeV

EG4 Run Overview

- Ran in Jan.-April, 2006
- New Cerenkov in Sector 6 built in the main trigger (~90% of events)

Eb (GeV)	# runs	# trigger events for (target, beam) (x10^8)				Total trigger (x10^9)
		(1,out)	(1,out)	(-1,in)	(-1,in)	
1.1	161	30.6	21.3	8.4	15.6	7.4
1.3	175	25.0	20.8	9.9	9.8	6.4
1.5	25	5.7	0.0	0.0	0.0	.57
2.0	65	4.1	8.7	0.0	0.0	1.9
2.2	66	4.2	4.6	2.6	3.0	1.4
3.0	115	9.4	10.1	4.2	3.1	2.7
1.3	117	4.8	3.7	0.0	0.0	0.85
2	172	5.0	4.9	0.0	0.0	0.96

triggers normalized to PbPt=0.5 (→ Total trigger)

commissioning (→ .57)

- Beam, target spin reversed nearly half-way for most of energies.

Calibration and General Tasks Status

Calibration tasks	People in charge	Status
Drift Chamber	K. Slifer	Complete
Cherenkov Detector (CC)	M. Ripani, K. Michaelson, A. Vlassov, E. Golovach, J. Langheinrich, R. De Vita	Complete
Time-of-Flight (ToF)	M. Ripani, J. Santoro, R. De Vita	Complete
Faraday-cup	P. Konczykowski, A. Deur	Complete
Electromagnetic Calorimeter timing	R. De Vita, K. Adhikari	Complete

Analysis tasks	People in charge	Status
Cooking	R. De Vita	pass1 complete
CC Osipenko cuts and efficiencies	X. Zheng, H. Kang	Underway
Radiation Length	P. Konczykowski, A. Deur	Complete
Proton Polarimetry	H. Kang	Underway
Deuteron Polarimetry	K. Kovacs, K. Slifer	Underway
Beam parameters	K. Kovacs, M. Ripani	Underway
Beam charge asymmetry	H. Kang	Underway
DC performance	M. Ungaro, M. Ripani	Underway
Simulations	V. Drozdov, M. Ripani	Underway
Raster corrections	K. Adhikari, P. Bosted, S. Kuhn	Complete
Momentum corrections	K. Adhikari, P. Bosted, S. Kuhn	Underway

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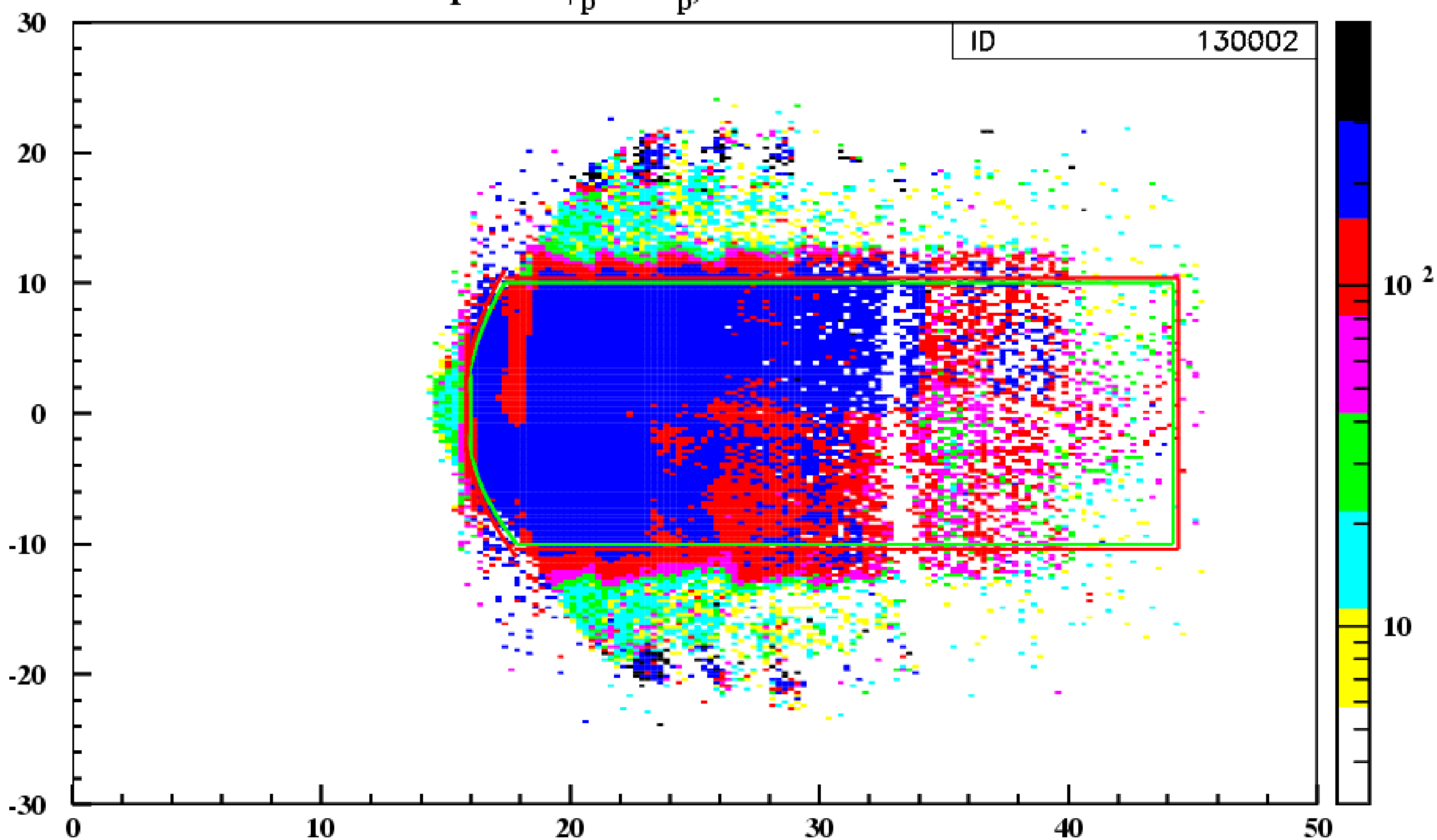
CC Performance

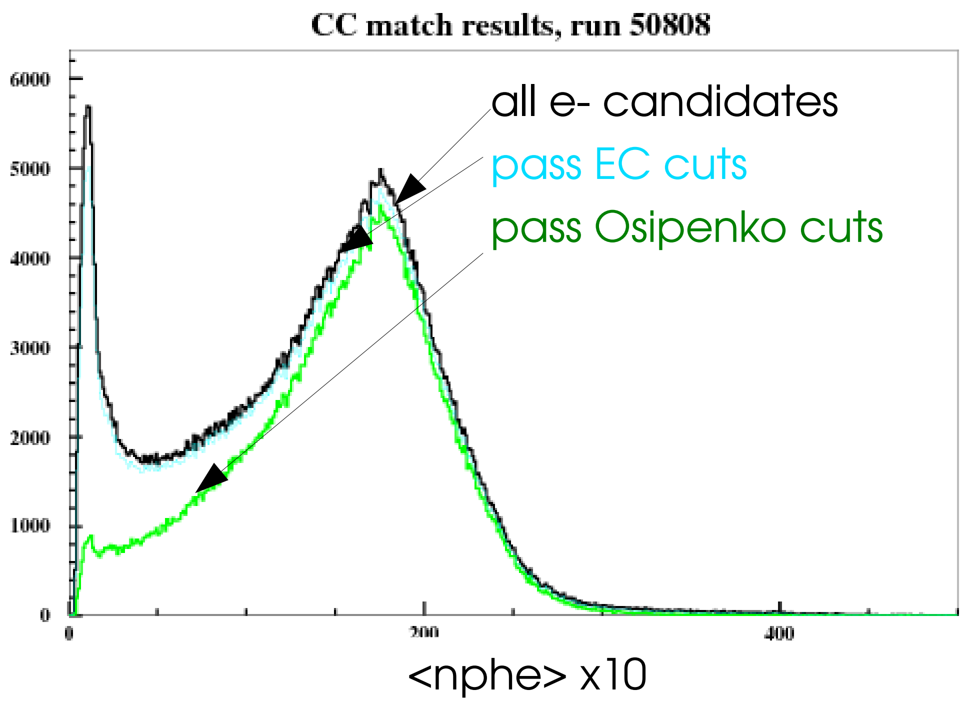
- New Cherenkov detector features nearly-uniform efficiency within limited ϕ range (±10°)
- Fiducial cuts on sector 6 CC θ and ϕ in the projected PMT plane, study still underway (H. Kang)

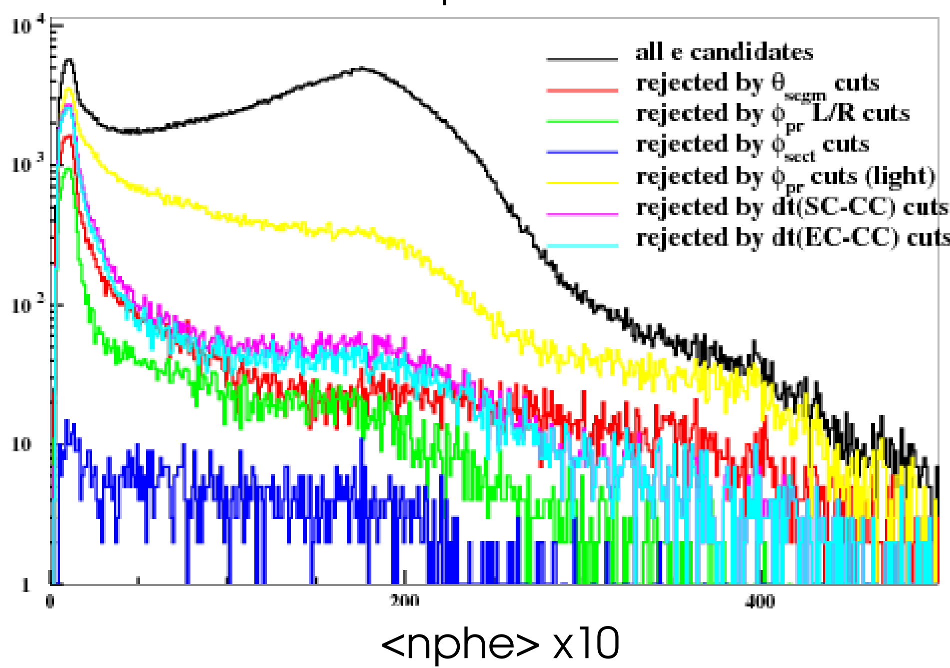


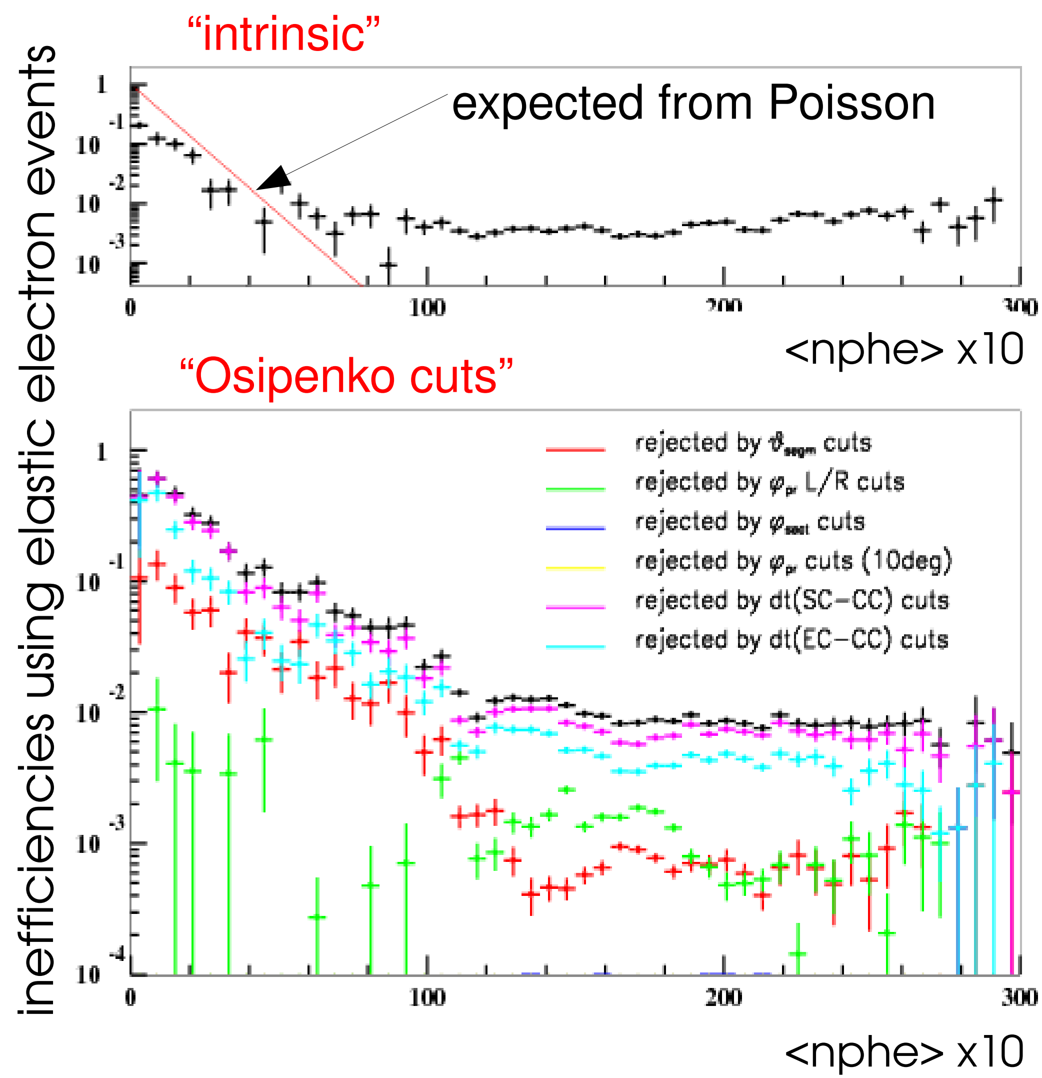
nphe in ϕ_p vs. θ_p, electrons with SC+EC cuts

Electron Selection

- Use timing ("Osipenko") cuts to define electrons; Efficiency study underway (H. Kang);

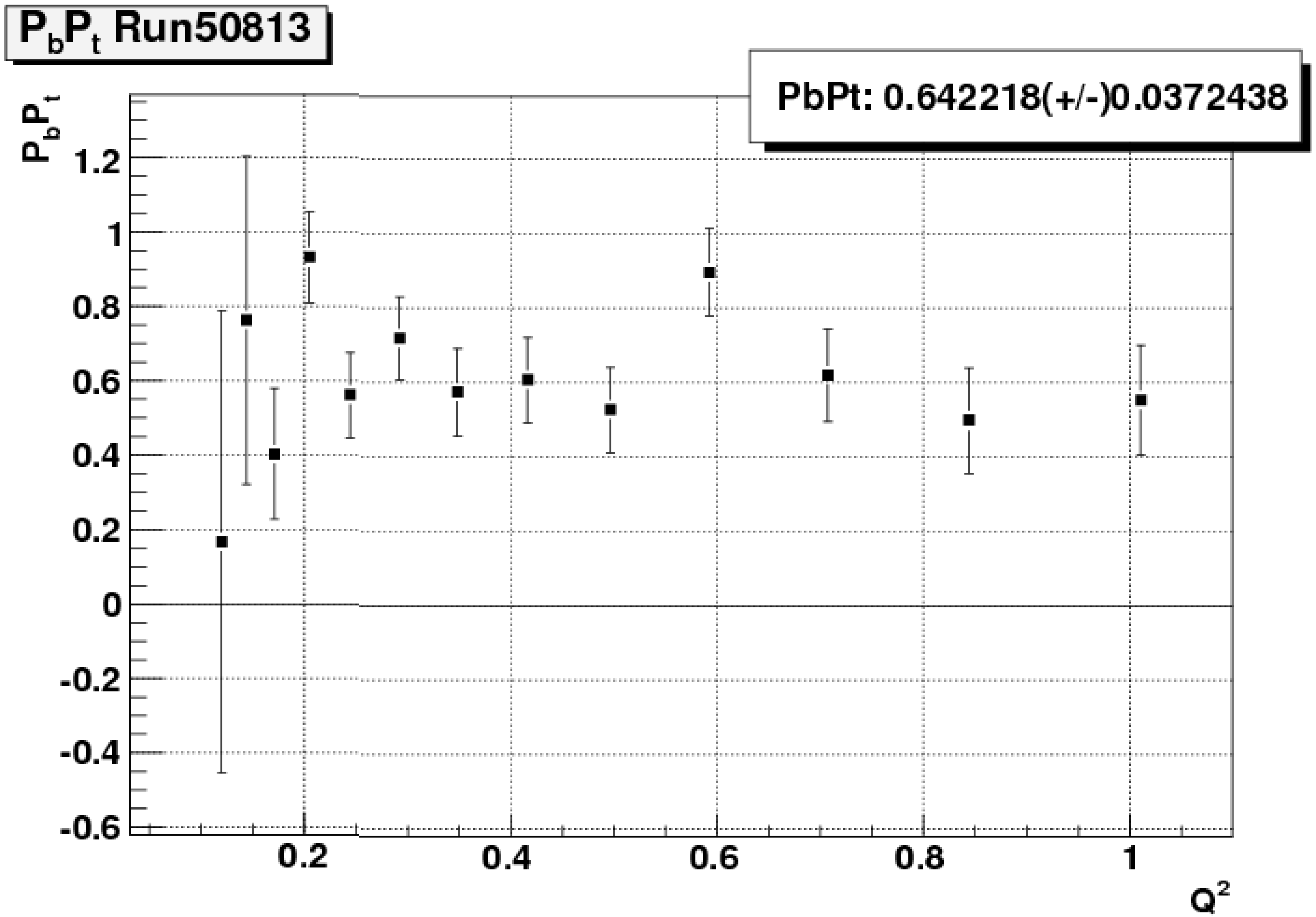






Proton Elastic PbPt (H. Kang's work – Seoul U.)

- E=3.0 GeV NH3 data, using elastic e-p events to extract PbPt;
- Preliminary results agree with Moller (Pb=80%) and target NMR (Pt=75-76%).



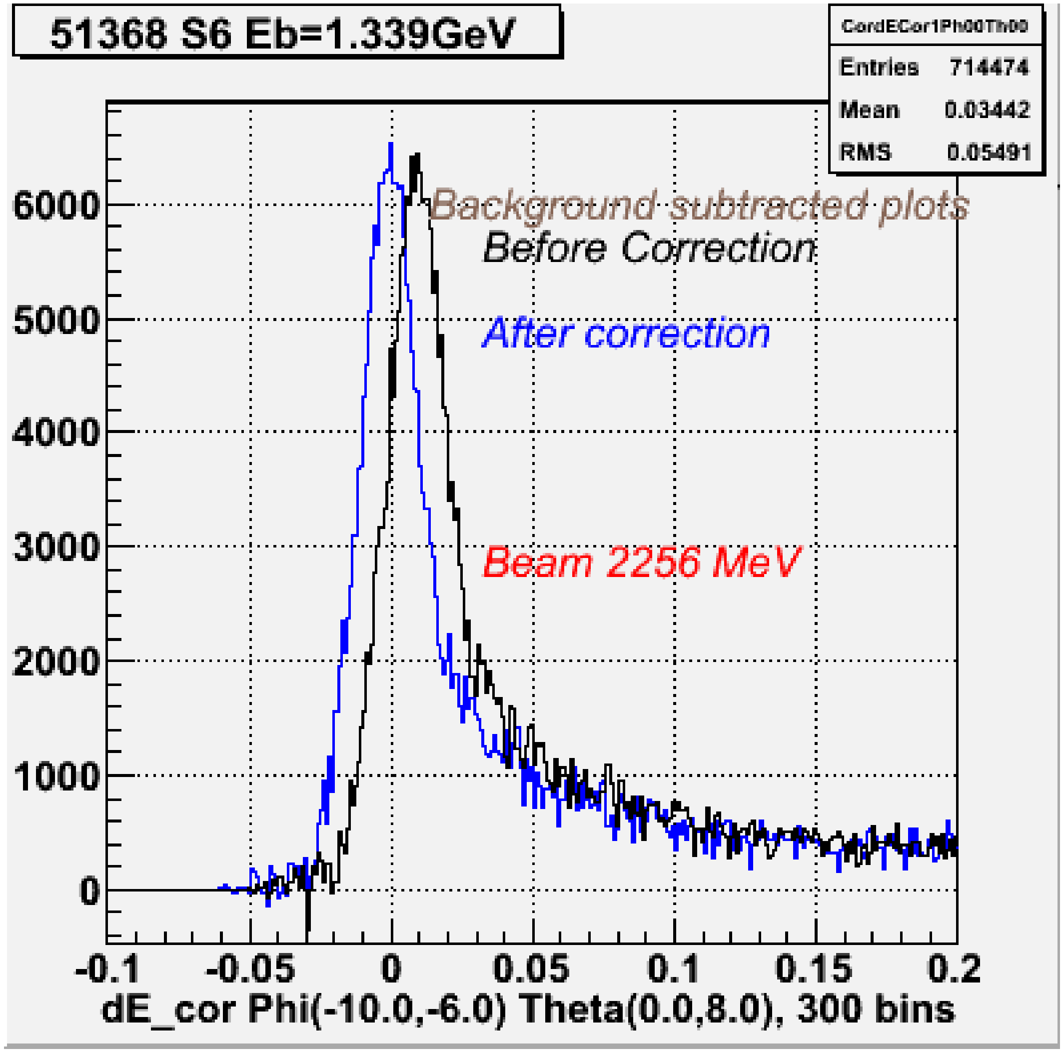
Momentum Corrections (K. Adhikari, S. Kuhn)

- Use elastic events assuming angles are correctly detected:

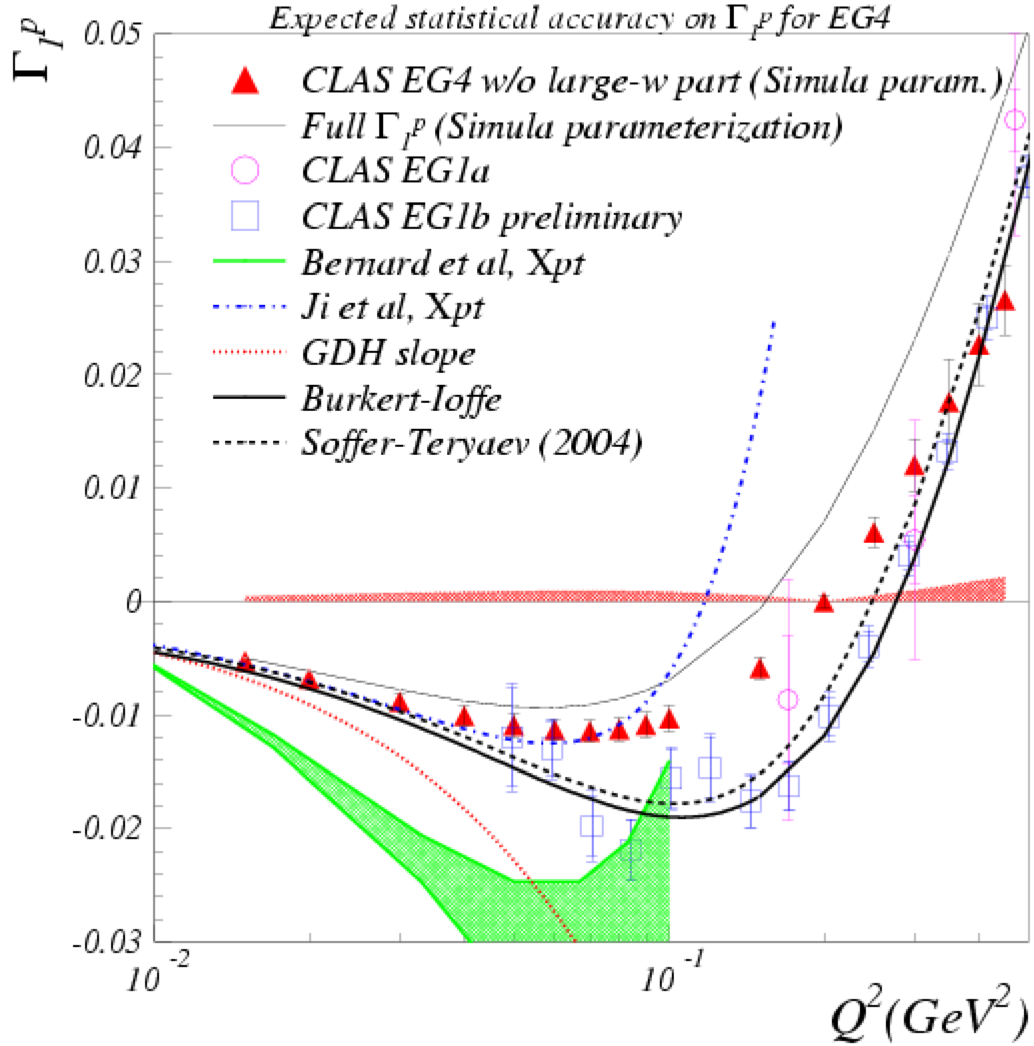
$$\frac{\delta p}{p} = \left[(E+F\phi)\frac{\cos\theta}{\cos\phi} + (G+H\phi)\sin\theta \right] \frac{p}{qB_{Torus}} + (J\cos\theta + K\sin\theta) + (M\cos\theta + N\sin\theta)\phi + 0.02\left[A + \left(B + C\frac{\phi}{30}\right)\frac{10^3}{\theta^3} \right]$$

$$B_{Torus} = 0.76\frac{I_{Torus}\sin^2 4\theta}{3375\theta}$$

- electron correction completed, pion correction underway (for exclusive analysis)



Expected Results from EG4 vs. EG1b

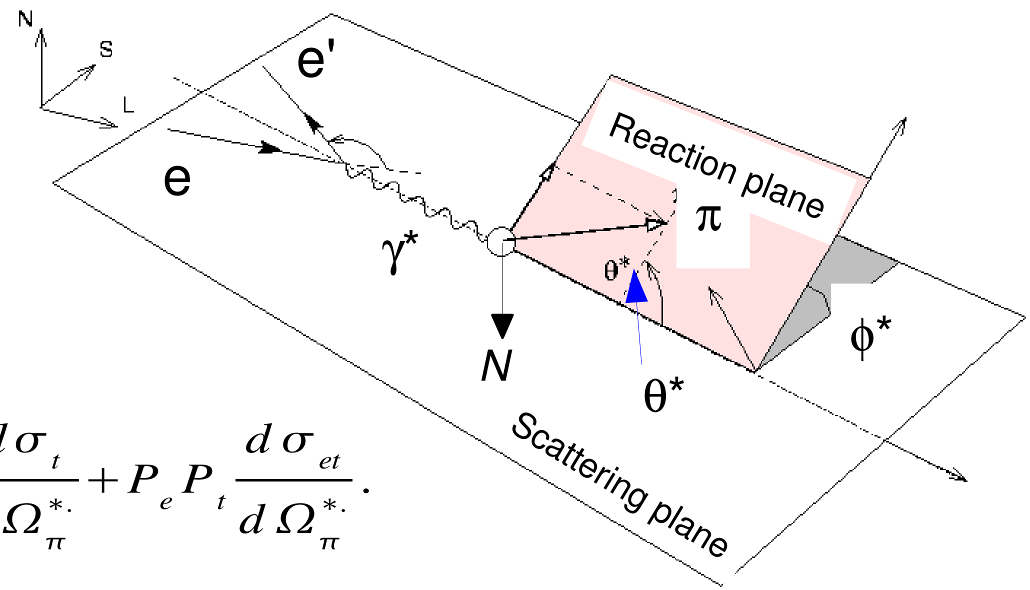


- Improvement (compared with EG1b) even better for ND3

Physics Topics

K. Adhikari	Ph.D. student (ODU)	Neutron inclusive analysis
H. Kang	Ph.D. student (Seoul U)	Proton inclusive analysis
K. Kovacs	Ph.D. student (UVa)	Deutron inclusive analysis
R. Subedi, X. Zheng	UVa	π^+, π^- exclusive analysis
A. Biselli	Fairfield U.	π^0 exclusive analysis

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

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

Exclusive Channel Analysis Physics Motivation

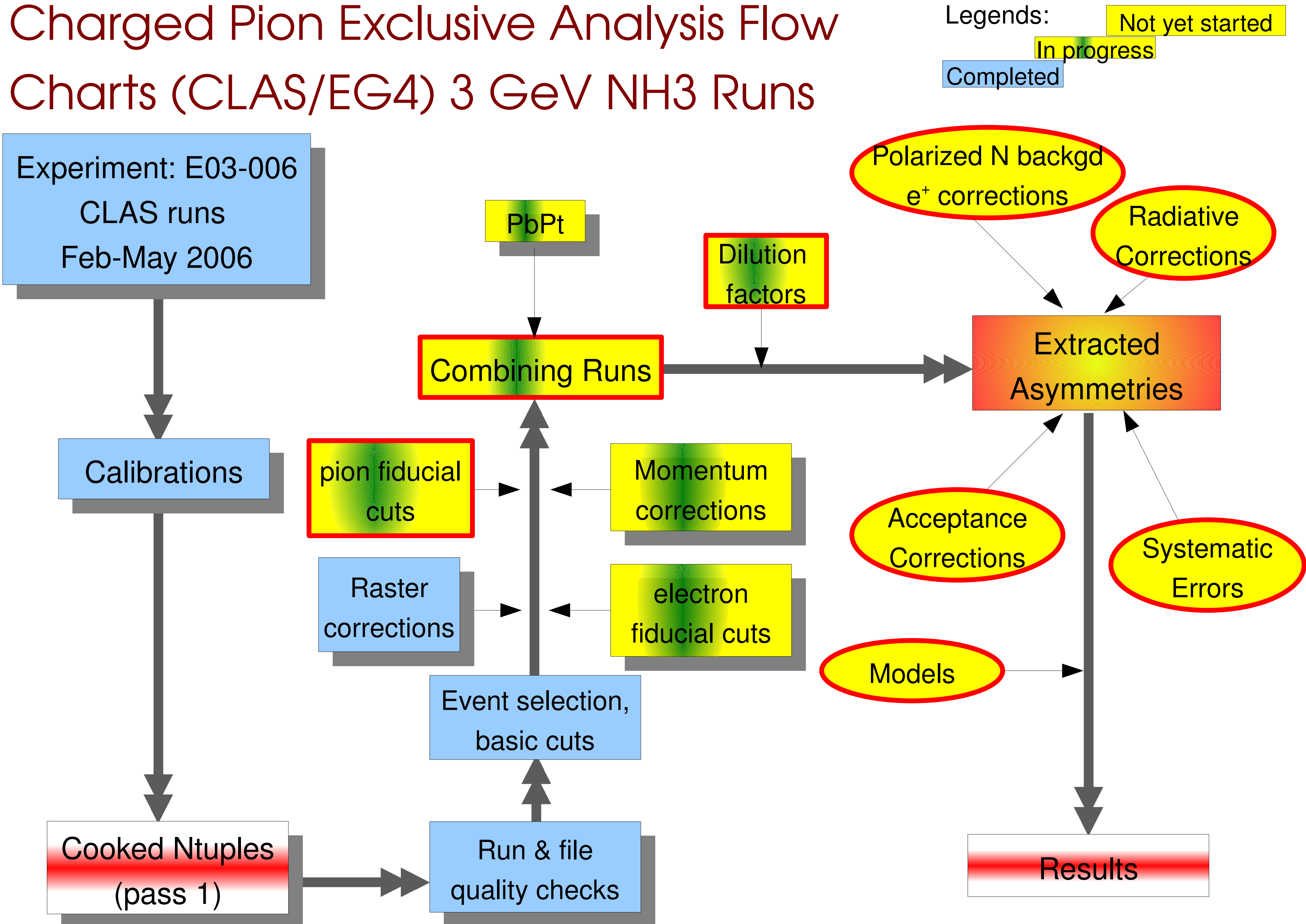
- Nucleon resonances study;
  - Mostly non-perturbative, cannot use pQCD;
  - Too light for lattice calculation;
- Must use effective theories or models:
  - Constituent Quark Model: resonance amplitudes, helicity structure... (not on interference terms)
  - Phenomenology models: MAID, SAID, DMT, JANR,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

EG4 Exclusive Channel Analysis

- Extract A_t and A_{et} 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, ϕ^* and $\cos\theta^*$— (binned in 4 simultaneously)
- $\int A_e \sin\phi \, d\phi$ were extracted to check the beam λ/2 status for each run;
- Previous/other analyses: EG1a, EG1b;
- Our new results will:
- help to constrain models and chiral perturbation theory at low Q^2;
- Can compare to real photon experiment (FROST or HDice), study transition from virtual to real photons;
  - Data on the neutron are rare.

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

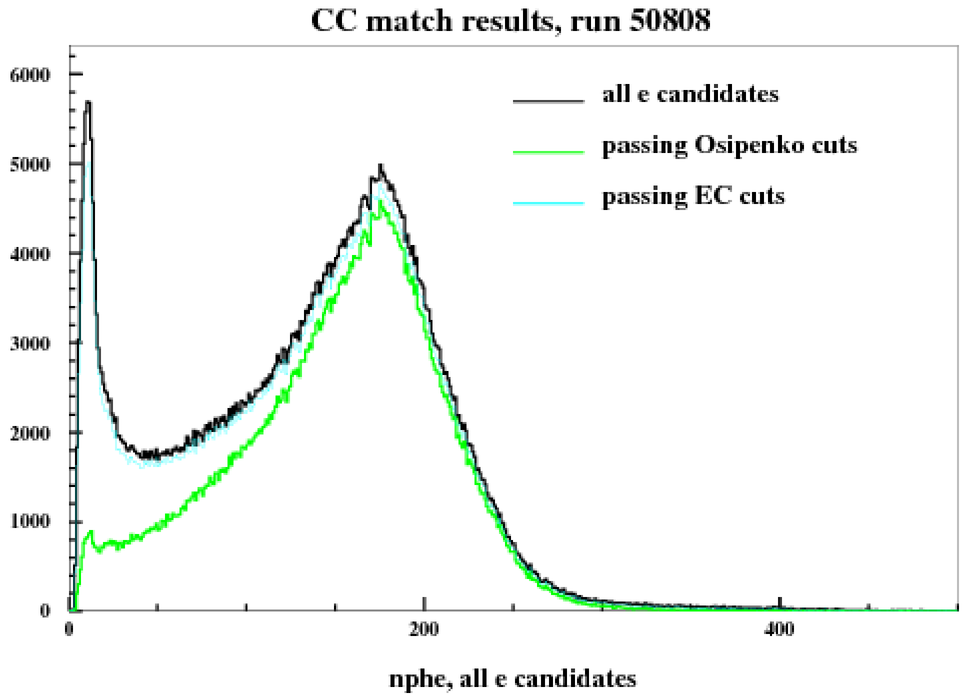
Charged Pion Exclusive Analysis Flow Charts (CLAS/EG4) 3 GeV NH3 Runs

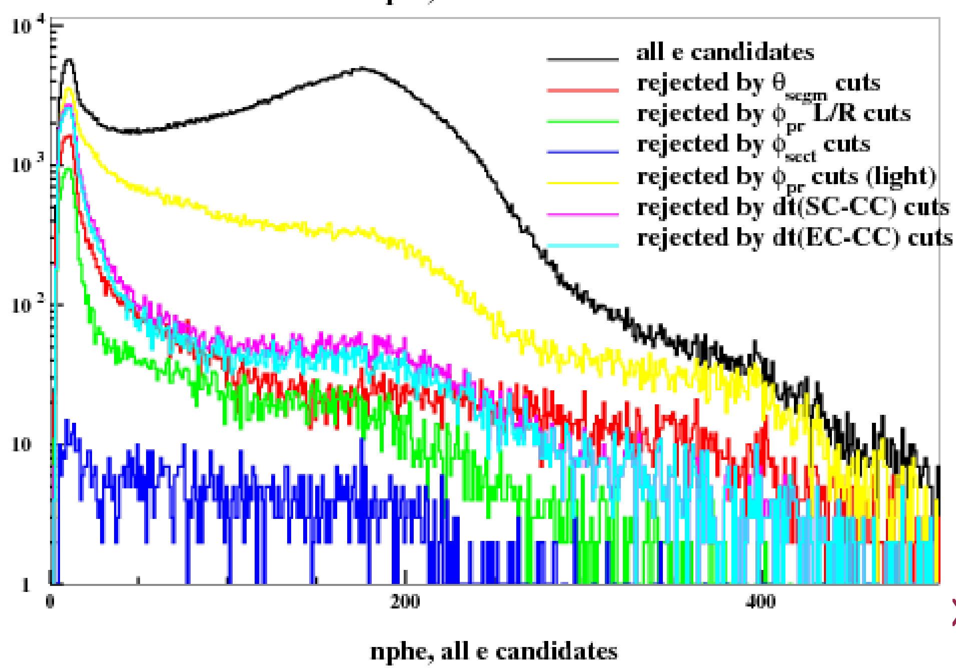


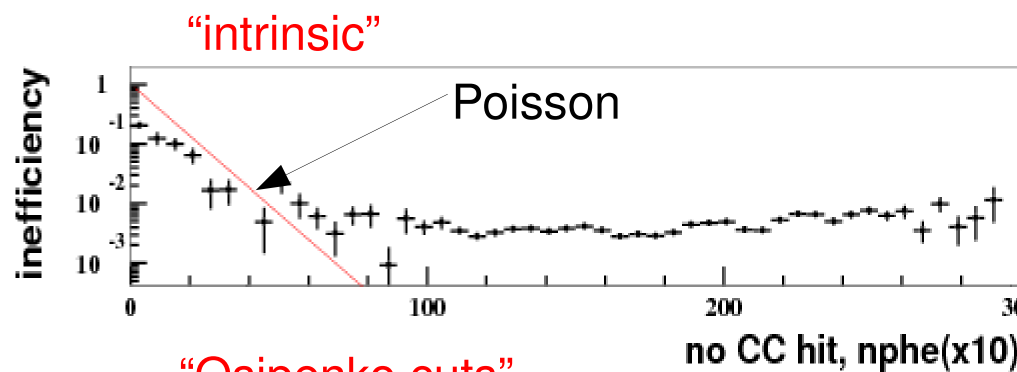
Electron Selection

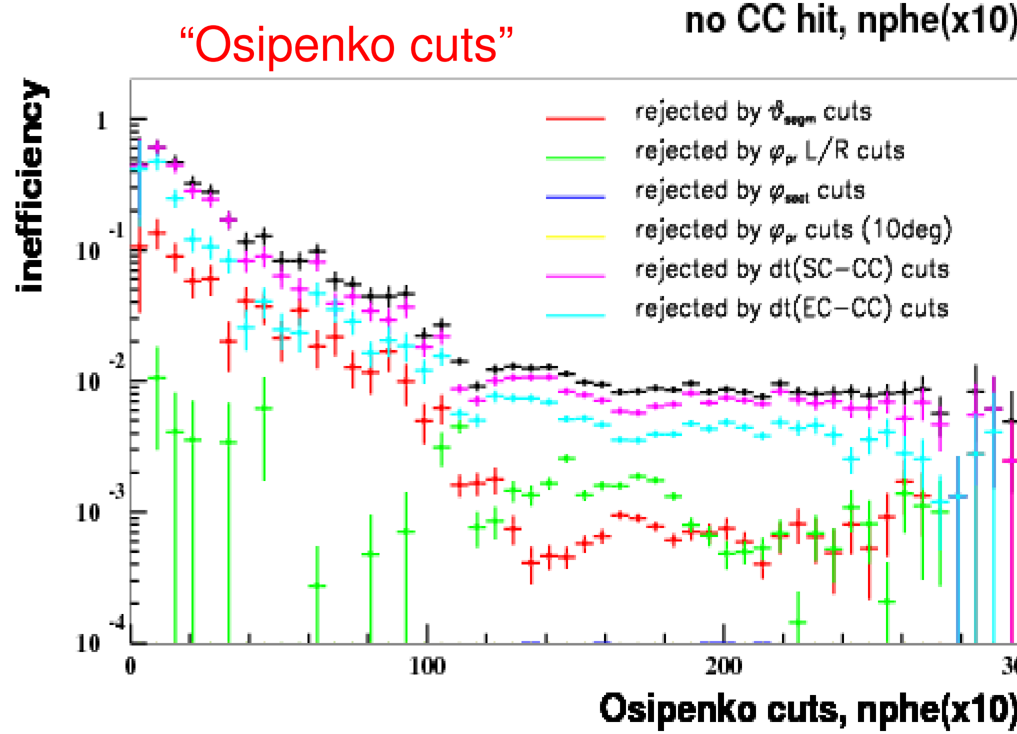
(e,e'π⁺)n

- Use Osipenko cuts to define electrons; shared with inclusive analysis, efficiency study still underway;





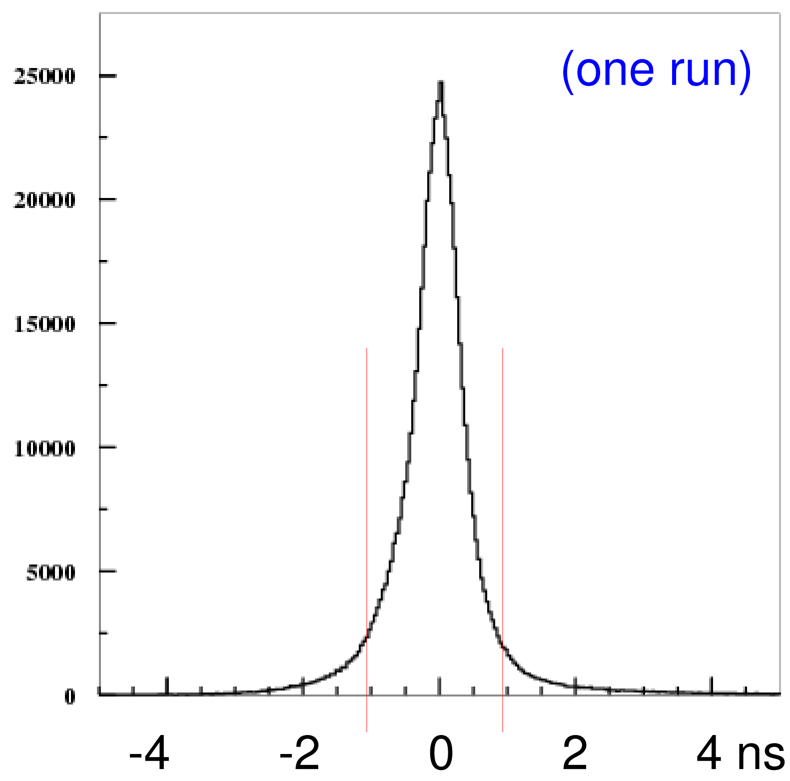




Pion Selection and Mx Cut

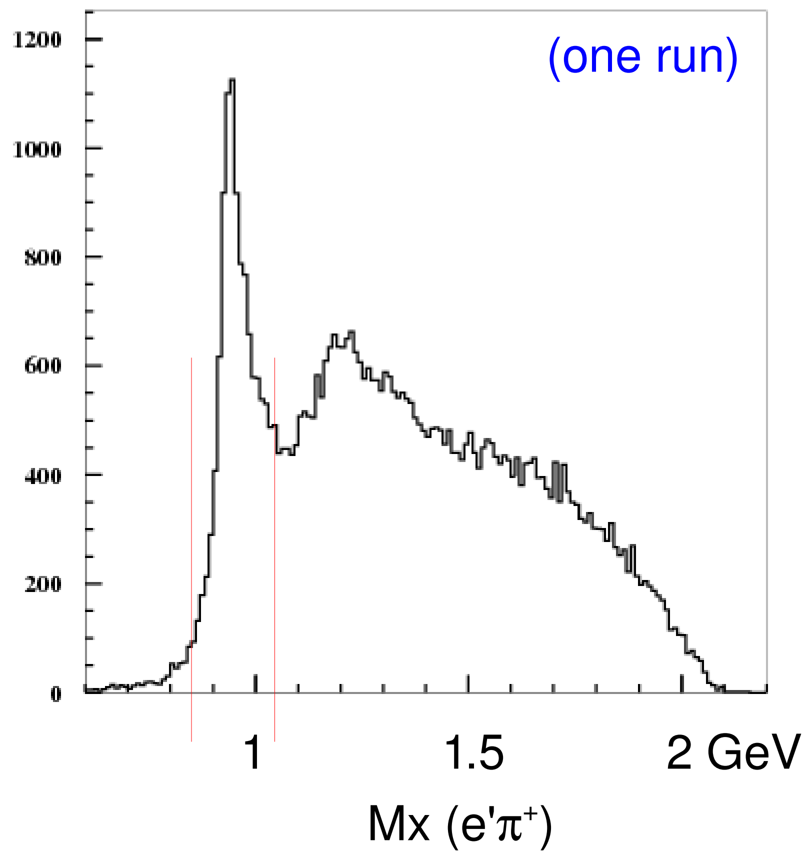
- Used TOF cut $|t - t_\pi| < 1$ns

$(e,e'\pi^+)n$



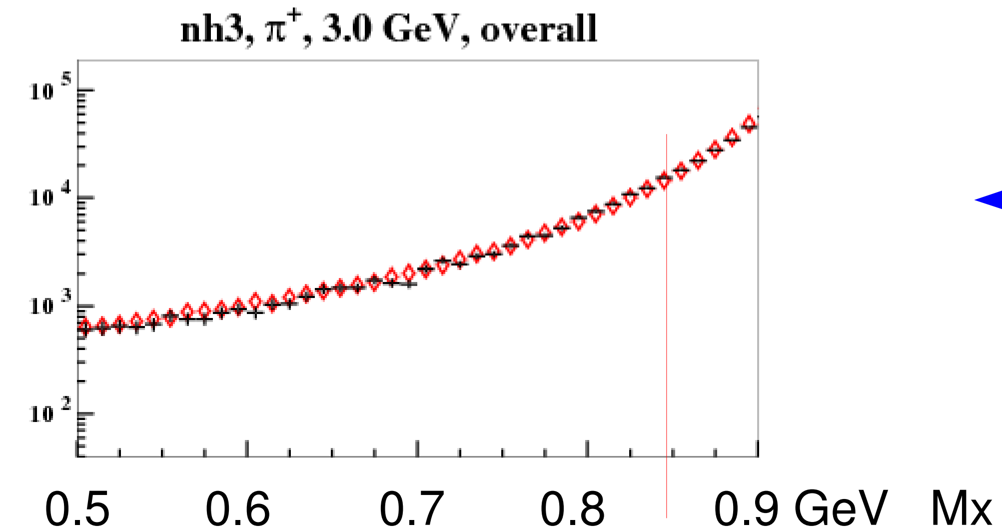
- Missing mass cut: (0.85,1.05) GeV

$(e,e'\pi^+)n$

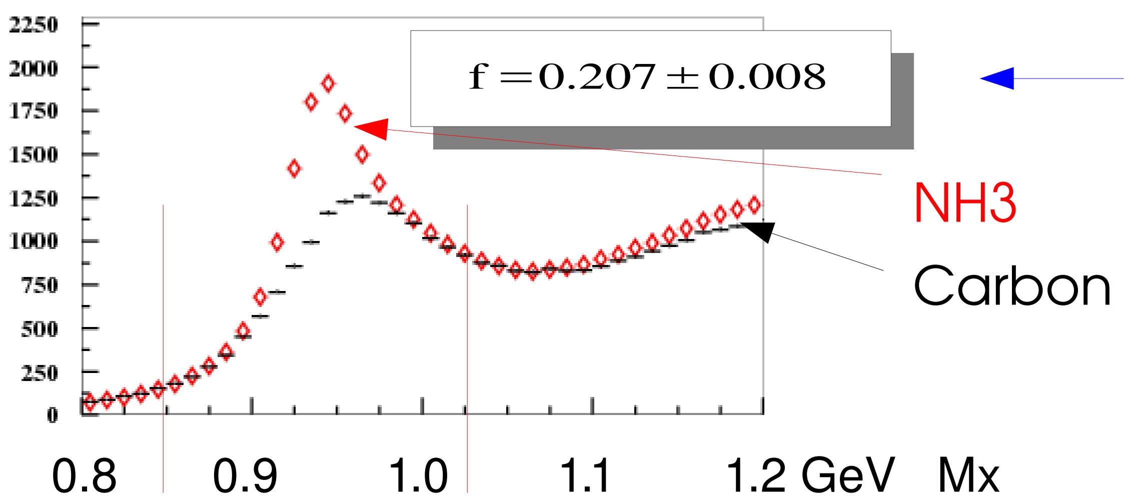


Dilutions

- Dilution factor measures fraction of events from polarized nucleons (p in NH_3 and D in ND_3)



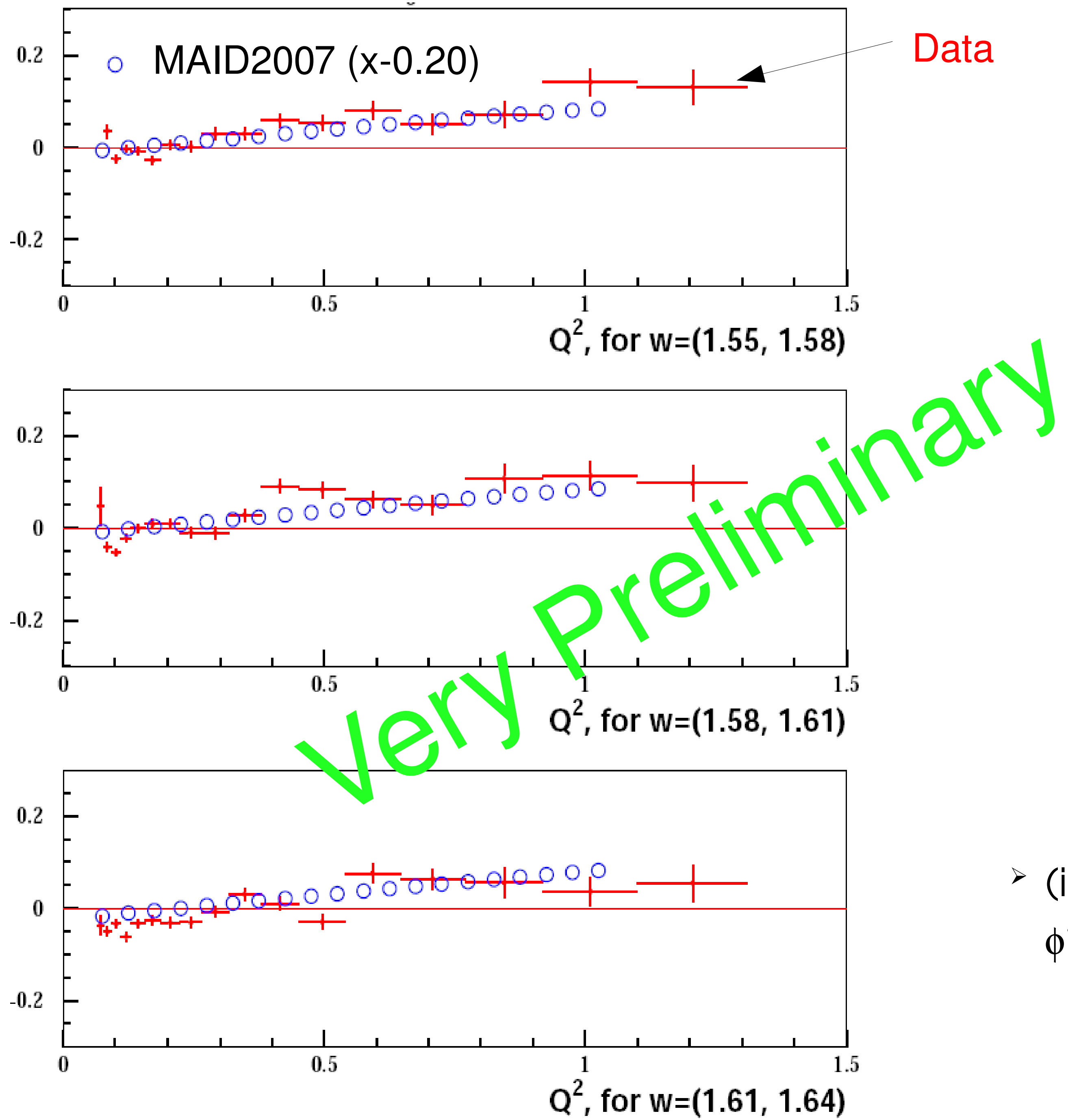
top: use low Mx region to line up carbon with NH3



bottom: use neutron peak to calculate dilution f

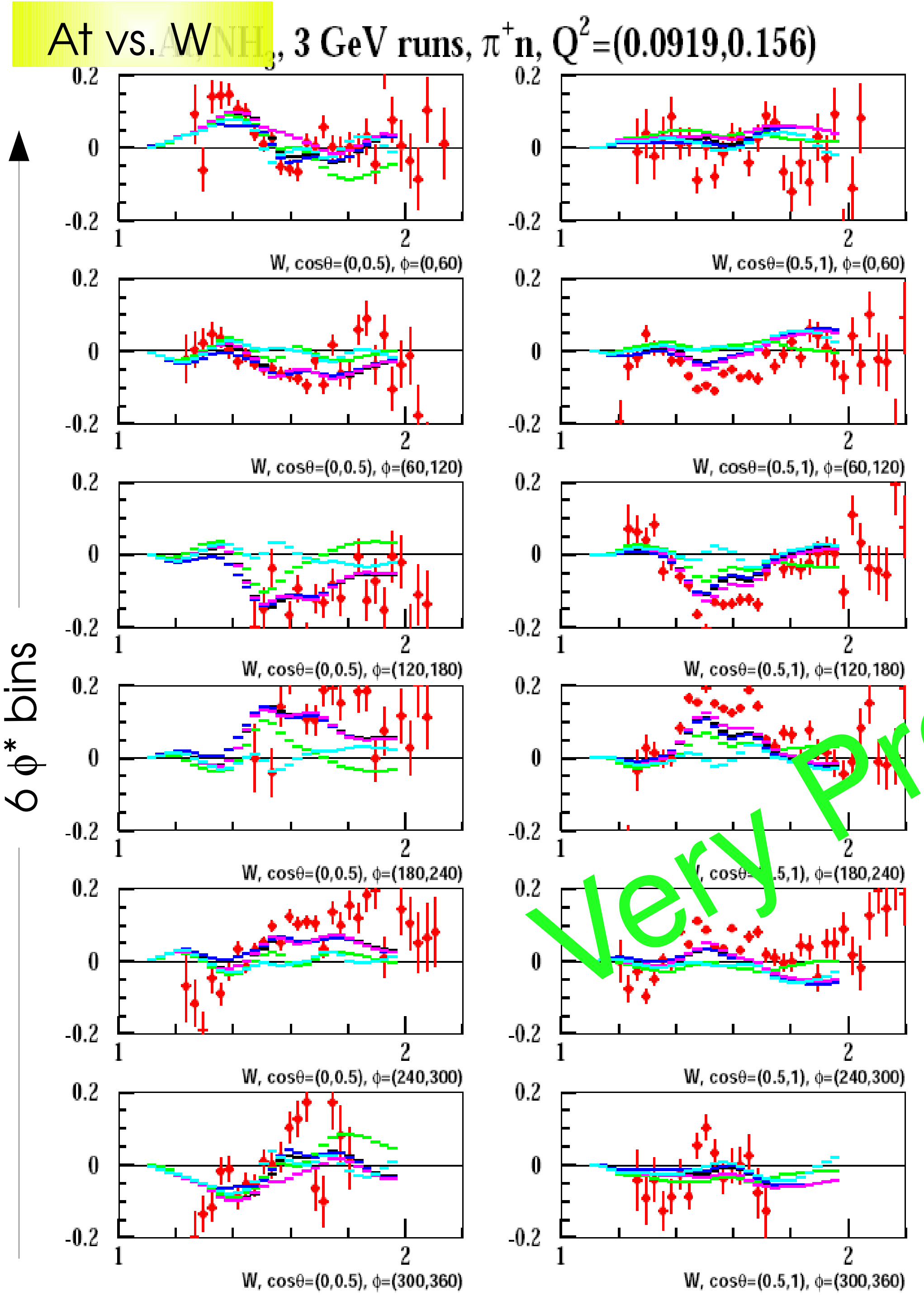
- In the following, will scale model by 0.2 to compare with data

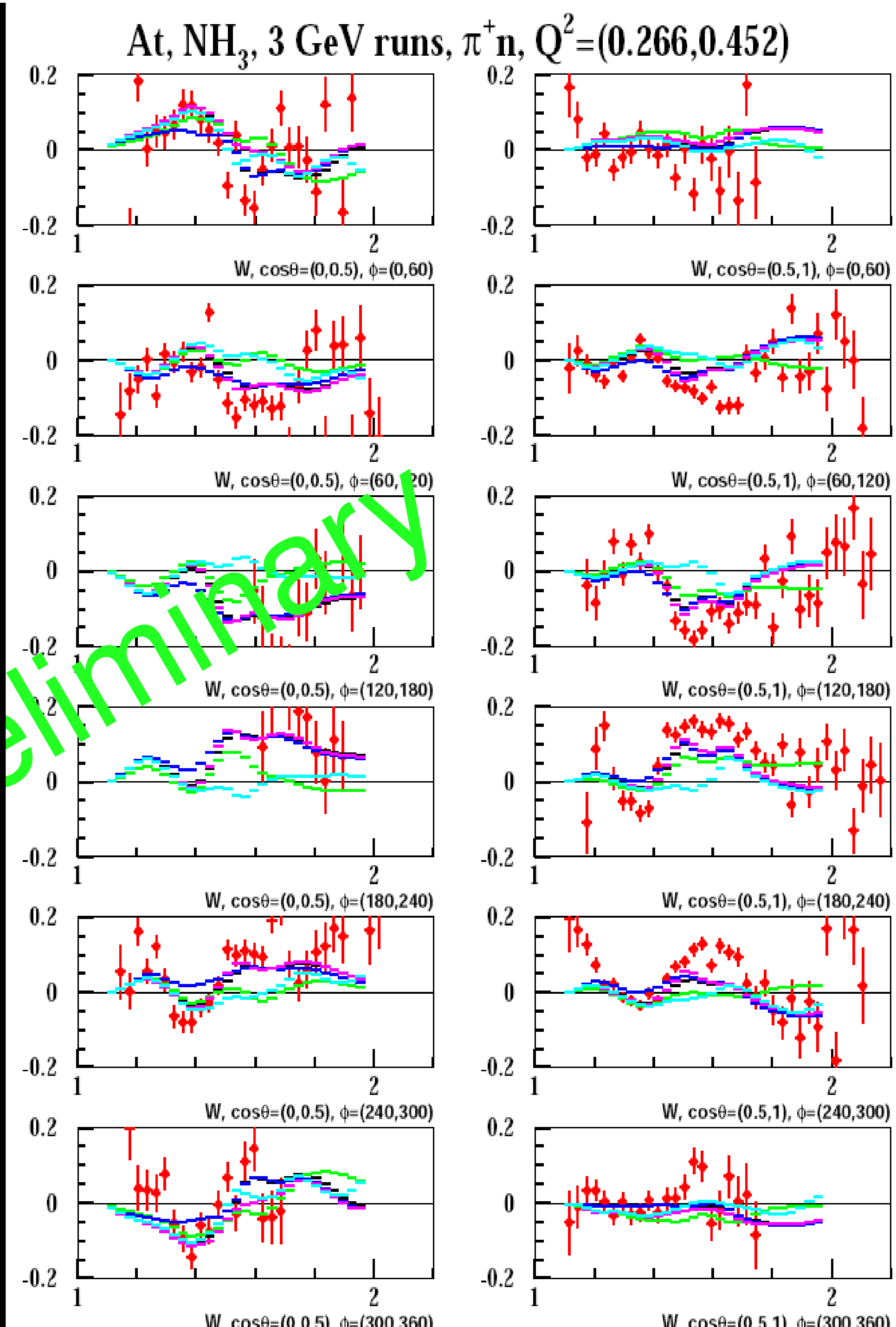
Aet vs. Q^2



- (integrated over ϕ^* and $\cos\theta^*$)

At vs. W



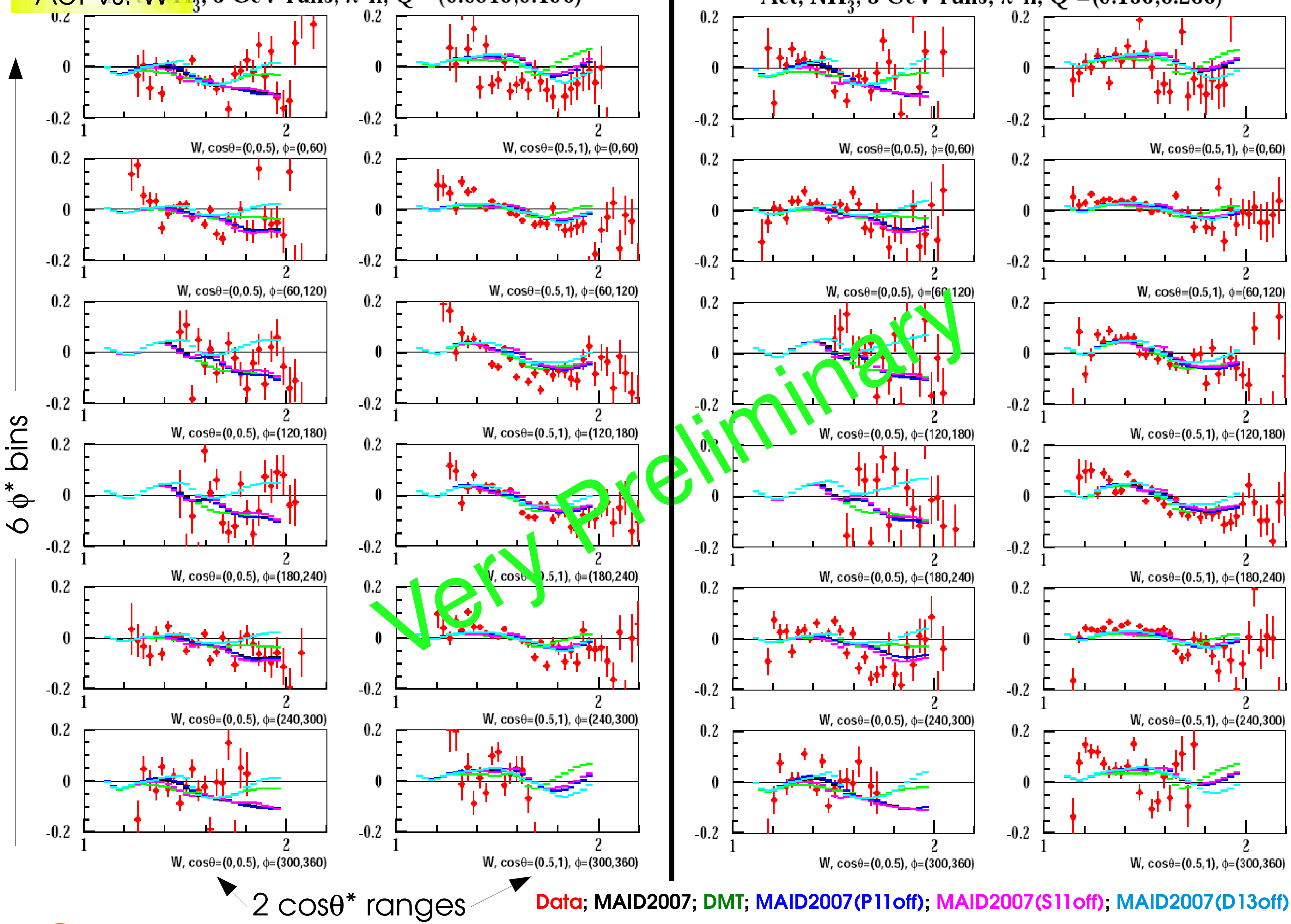


Very Preliminary

2 cosθ* ranges

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

Aet vs. W


H3, 3 GeV runs, π+n, Q2=(0.0919,0.156)
Aet, NH3, 3 GeV runs, π+n, Q2=(0.156,0.266)
6 φ* bins
W, cosθ=(0,0.5), φ=(0,60)
W, cosθ=(0.5,1), φ=(0,60)
W, cosθ=(0,0.5), φ=(60,120)
W, cosθ=(0.5,1), φ=(60,120)
W, cosθ=(0,0.5), φ=(120,180)
W, cosθ=(0.5,1), φ=(120,180)
W, cosθ=(0,0.5), φ=(180,240)
W, cosθ=(0.5,1), φ=(180,240)
W, cosθ=(0,0.5), φ=(240,300)
W, cosθ=(0.5,1), φ=(240,300)
W, cosθ=(0,0.5), φ=(300,360)
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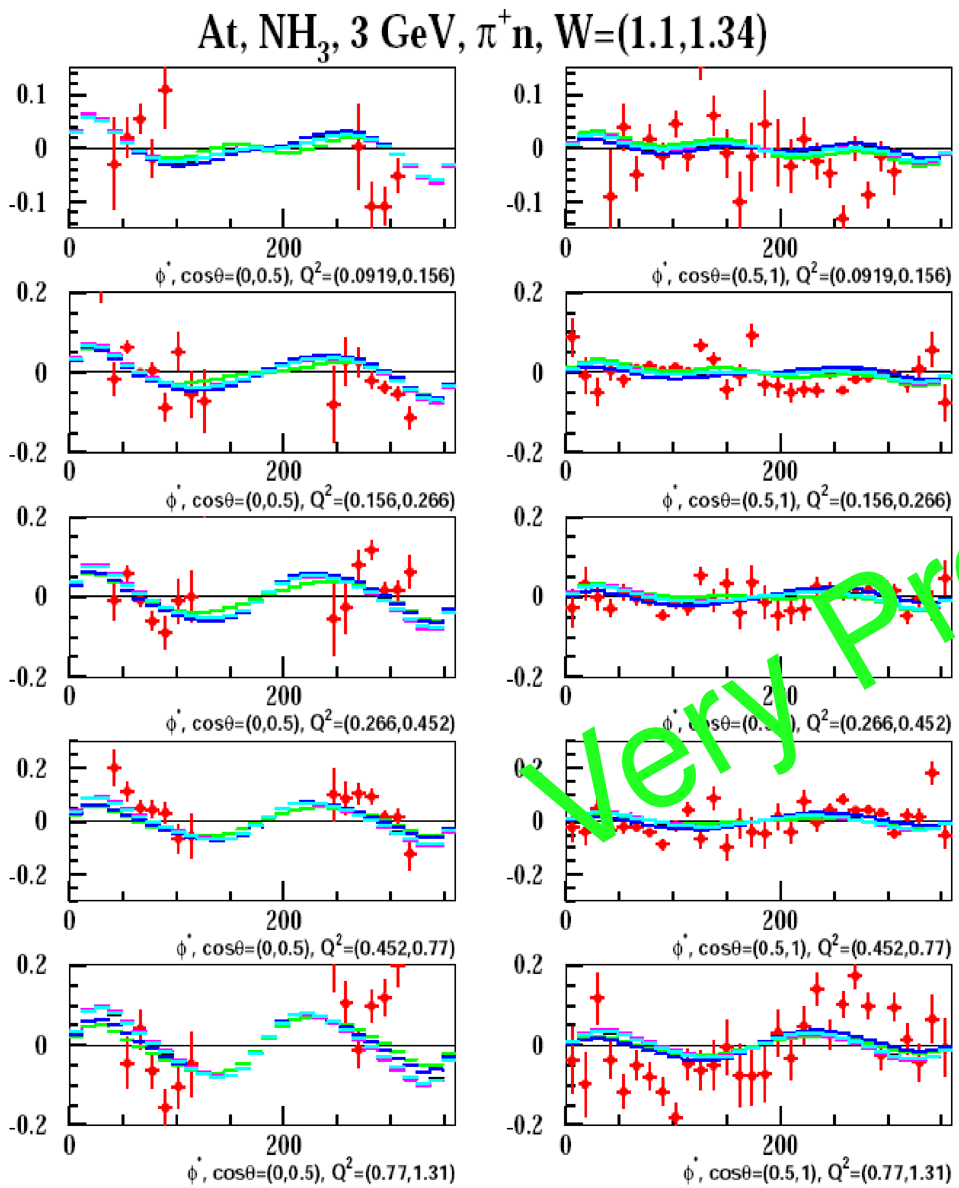
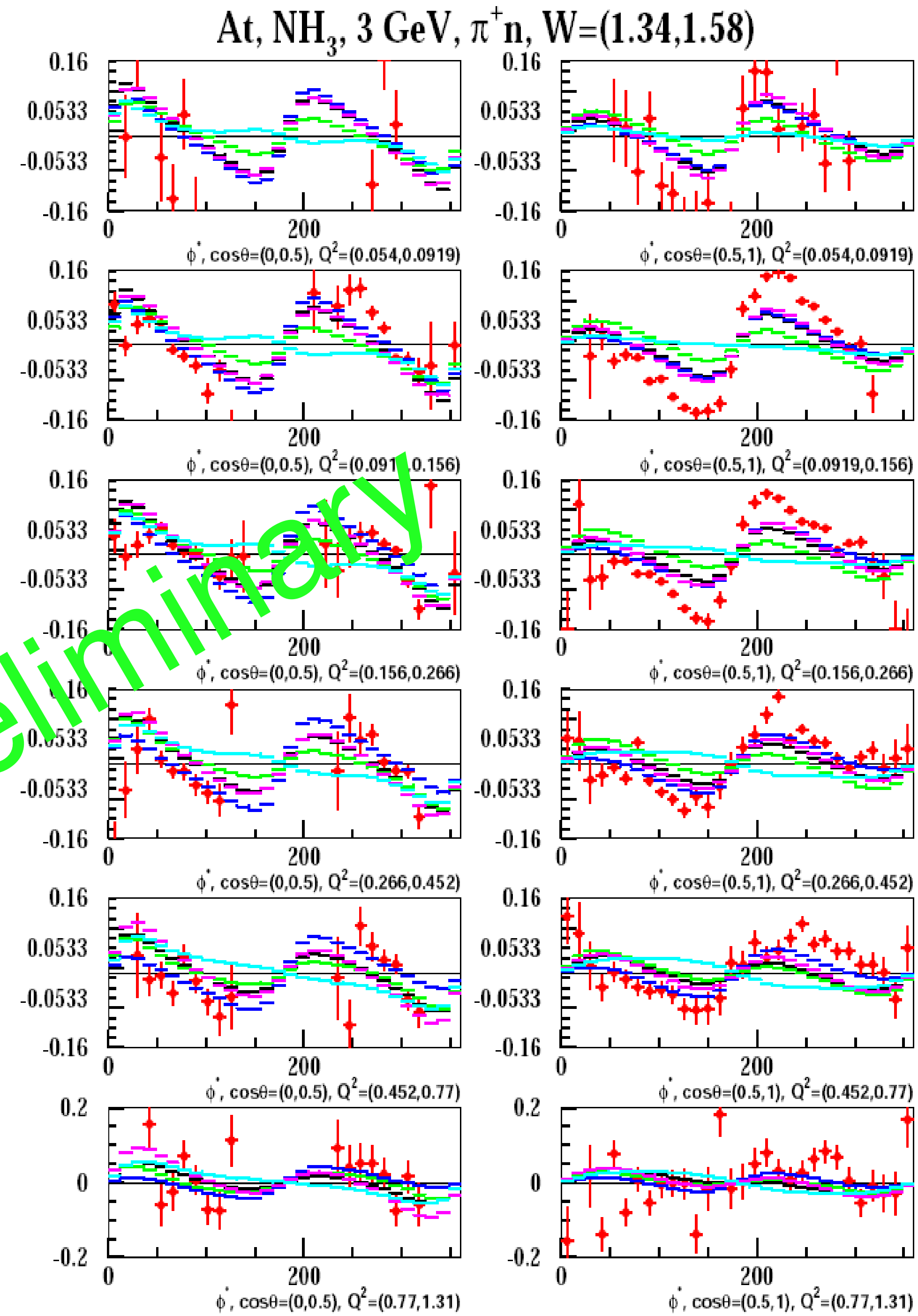
Very Preliminary
2 cosθ* ranges
Data; MAID2007; DMT; MAID2007(P11off); MAID2007(S11off); MAID2007(D13off)

At vs. ϕ^*

Q2 bins





Very Preliminary

2 cosθ* ranges

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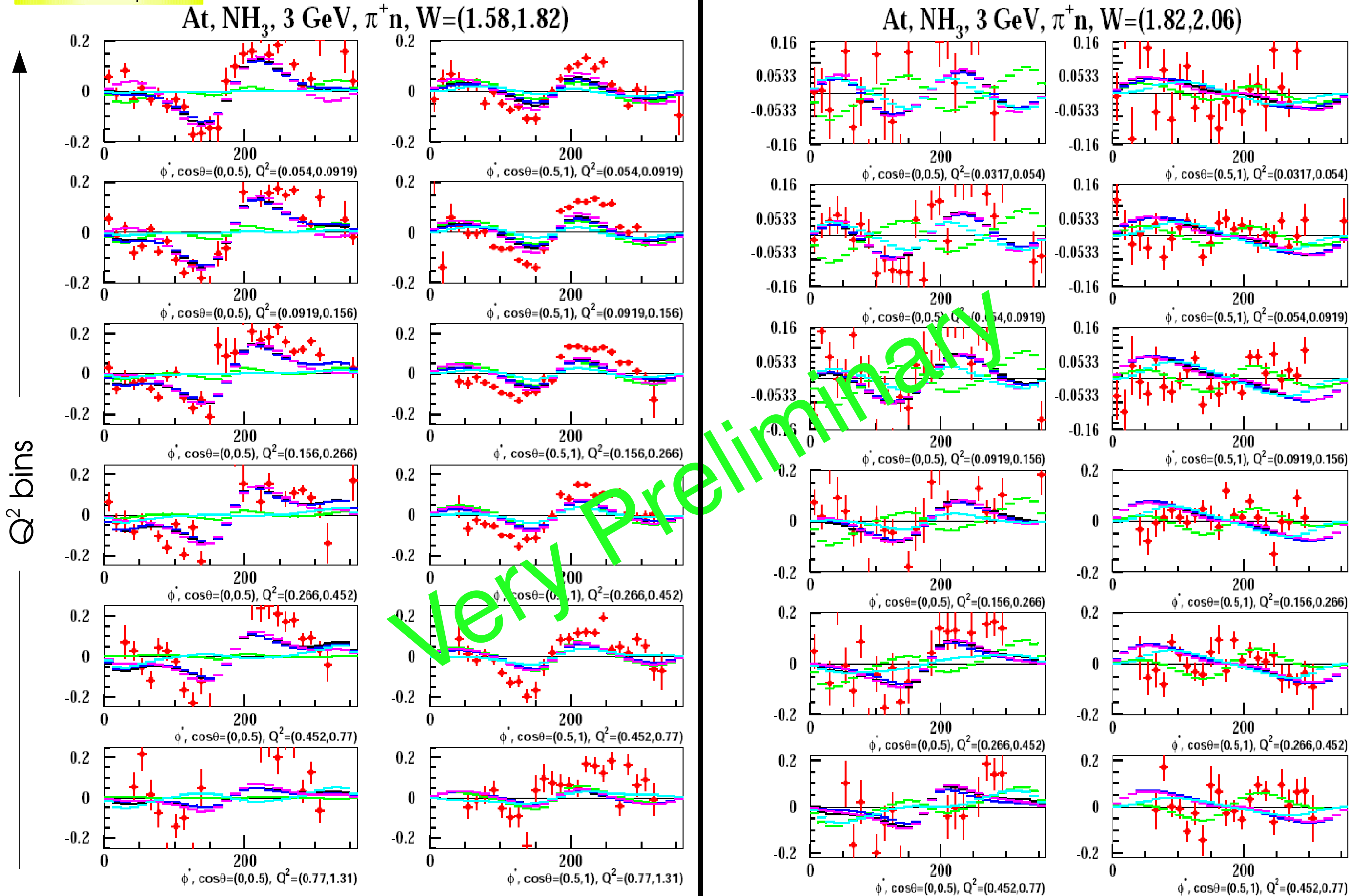
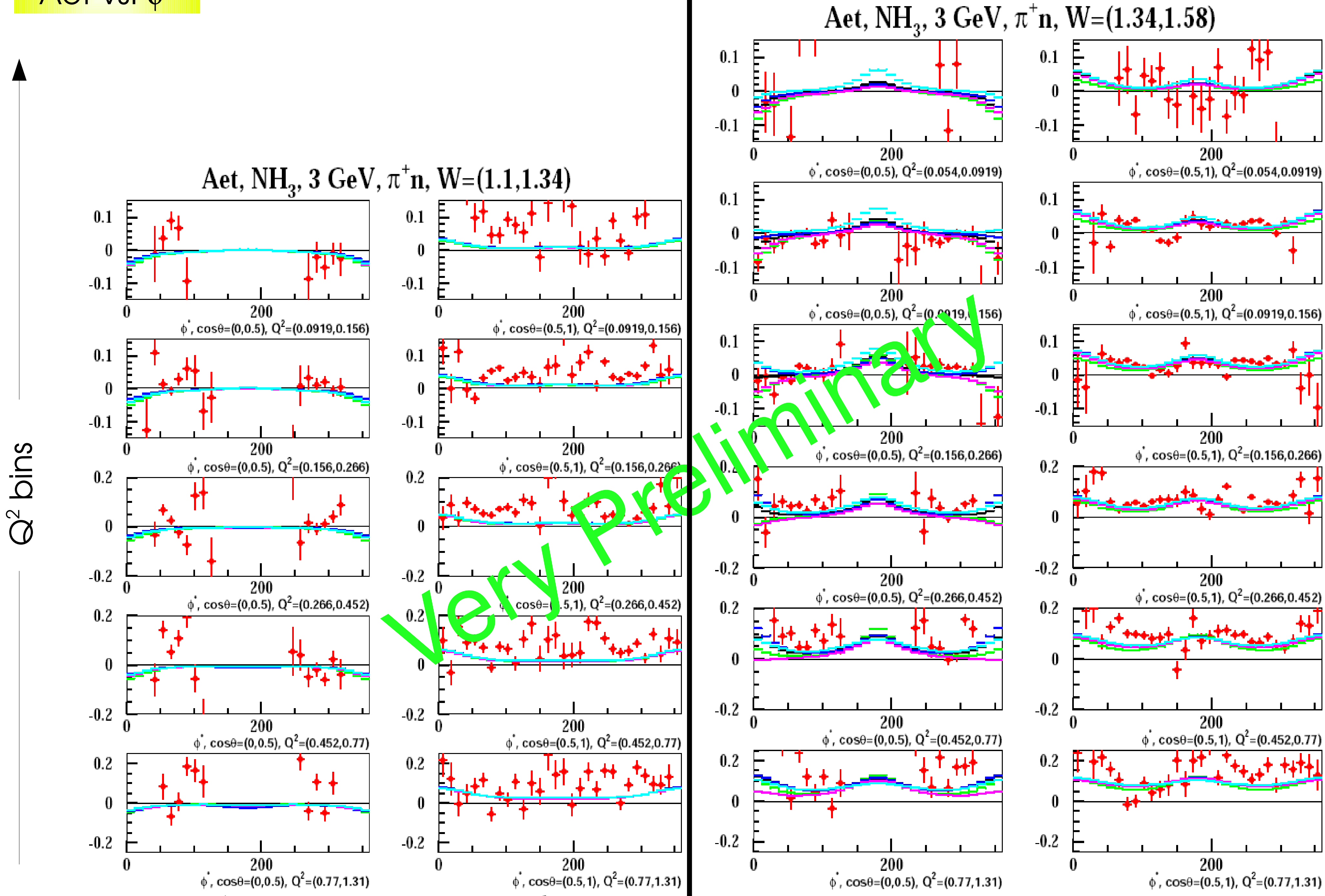
At vs. ϕ^*



2 cosθ* ranges

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

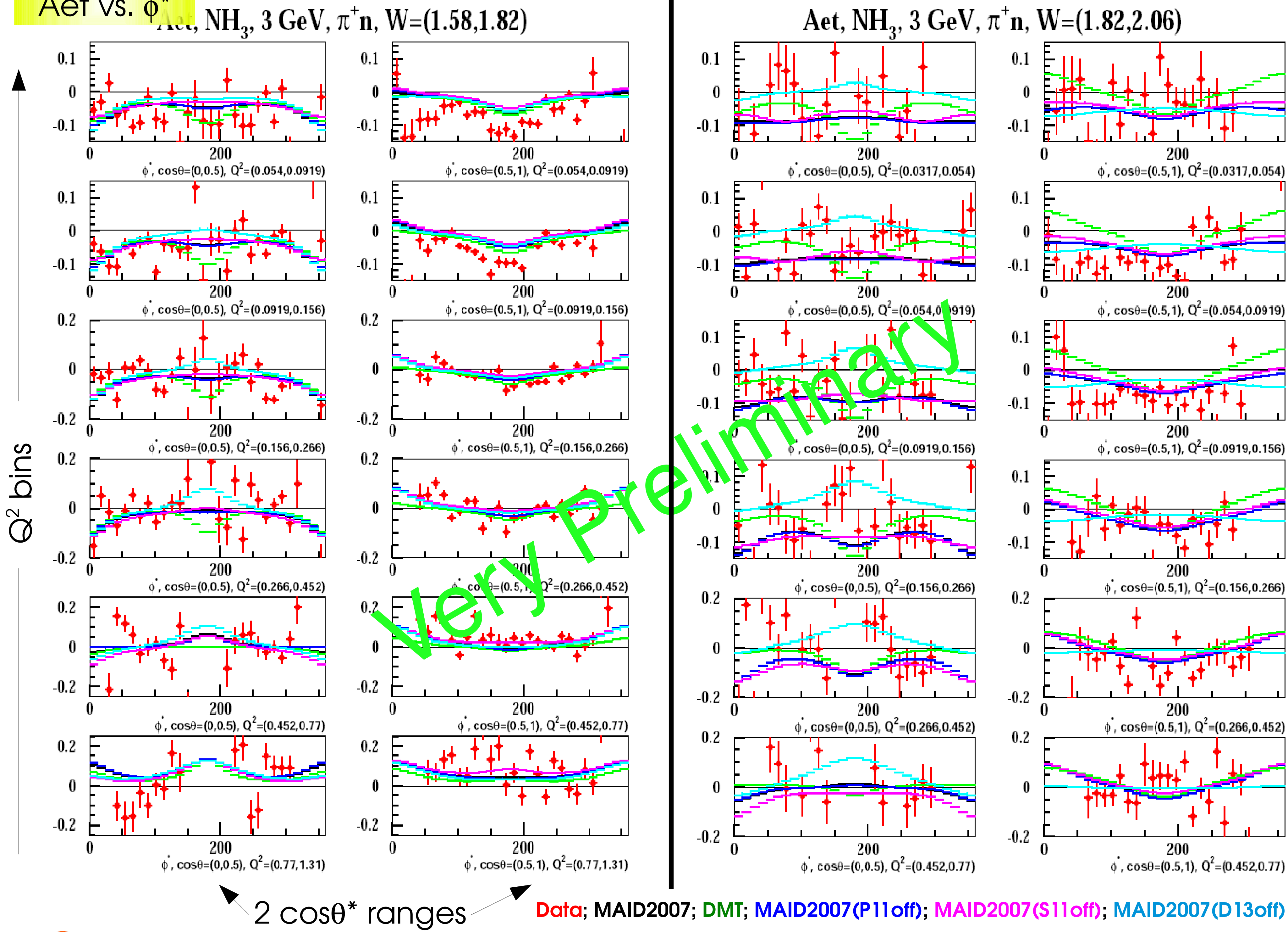
Aet vs. ϕ^*



2 cosθ* ranges

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

Aet vs. ϕ^*



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

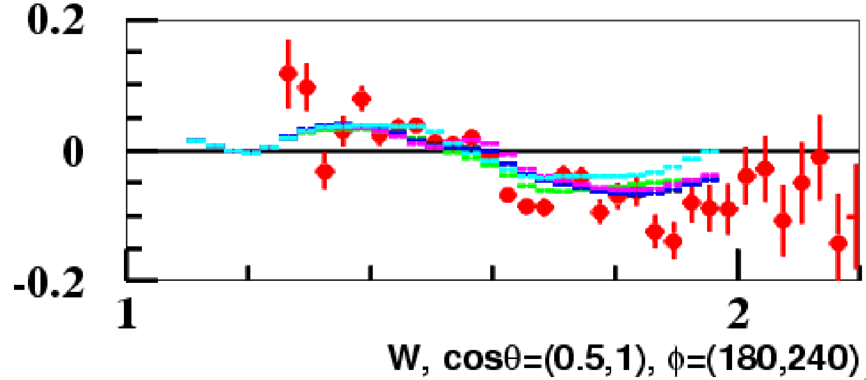
Overview of Data for all Beam Energies

Eb (GeV)	Target	# of runs with (beam,target) (-1,-1)	(-1,1)	(1,-1)	(1,1)	# of (e,e'π+)n evnts per run	DC sector status	Will analyze
1.05	long NH3	19	69	32	34	5k	sec 1,4,5 off	
1.34	long NH3	19	46	20	36	17k	3/4 runs had 1,4,5 off	At, Aet
	short NH3	0	26	0	28	14k	some had all sec on	
2.00	long NH3	20	12	3	30	20k	all sec on	At, Aet
2.25	long NH3	10	8	8	16	20k	1/3 runs had 1,4,5 off, all	At, Aet
	short NH3	5	11	5	9	38k	had 5 off	At, Aet
3.00	long NH3	21	33	16	31	22k	all had sec 5 off	At, Aet
1.34	long ND3	0	65	0	50		all sec on	Aet
2.00	long ND3	0	118	0	122		all sec on	Aet

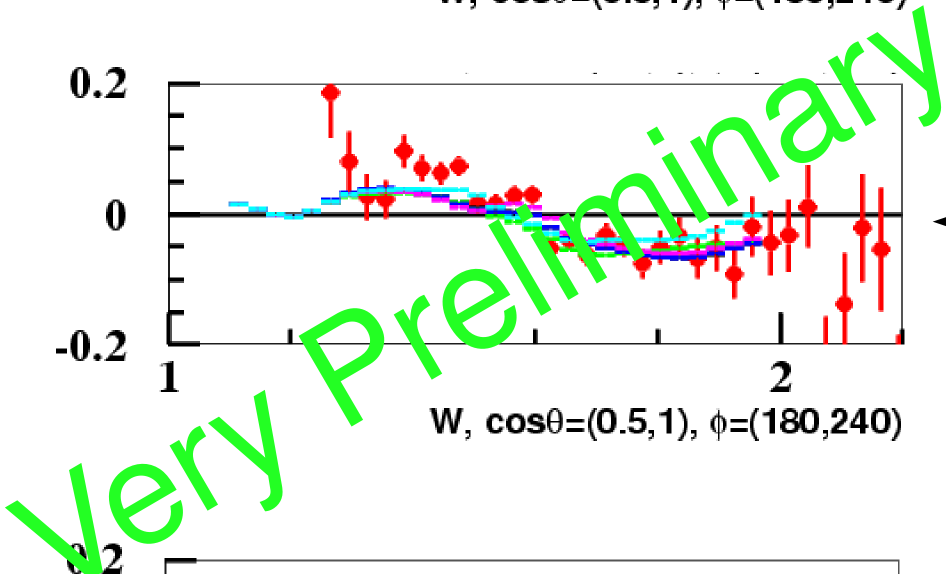
Cannot study ϕ^*-dependence
Rely on ϕ^* integrations of *Ae*, *At* being zero.

Aet vs. W, 3GeV NH3

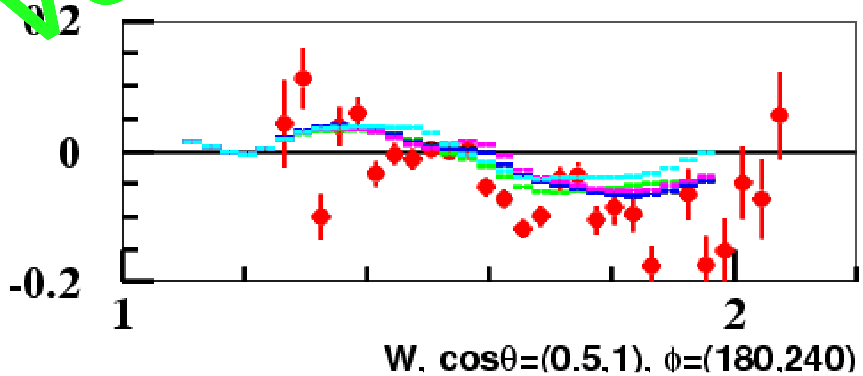
Q2=(0.0919,0.156)



Using all runs



Using runs with target spin > 0

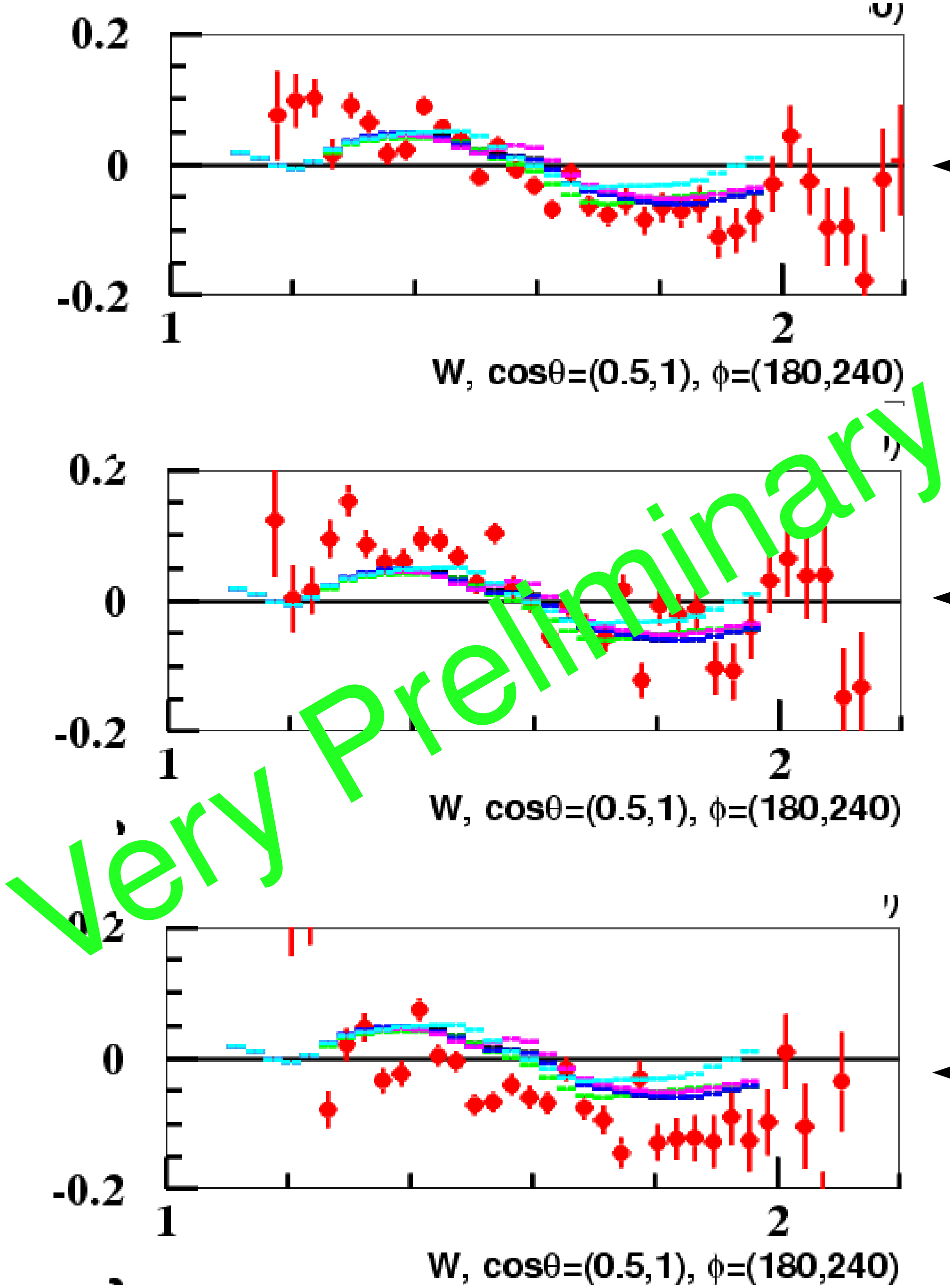


Using runs with target spin < 0

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

Aet vs. W, 3GeV NH3

Q2=(0.156, 0.266)



Using all runs

Using runs with target spin > 0

Using runs with target spin < 0

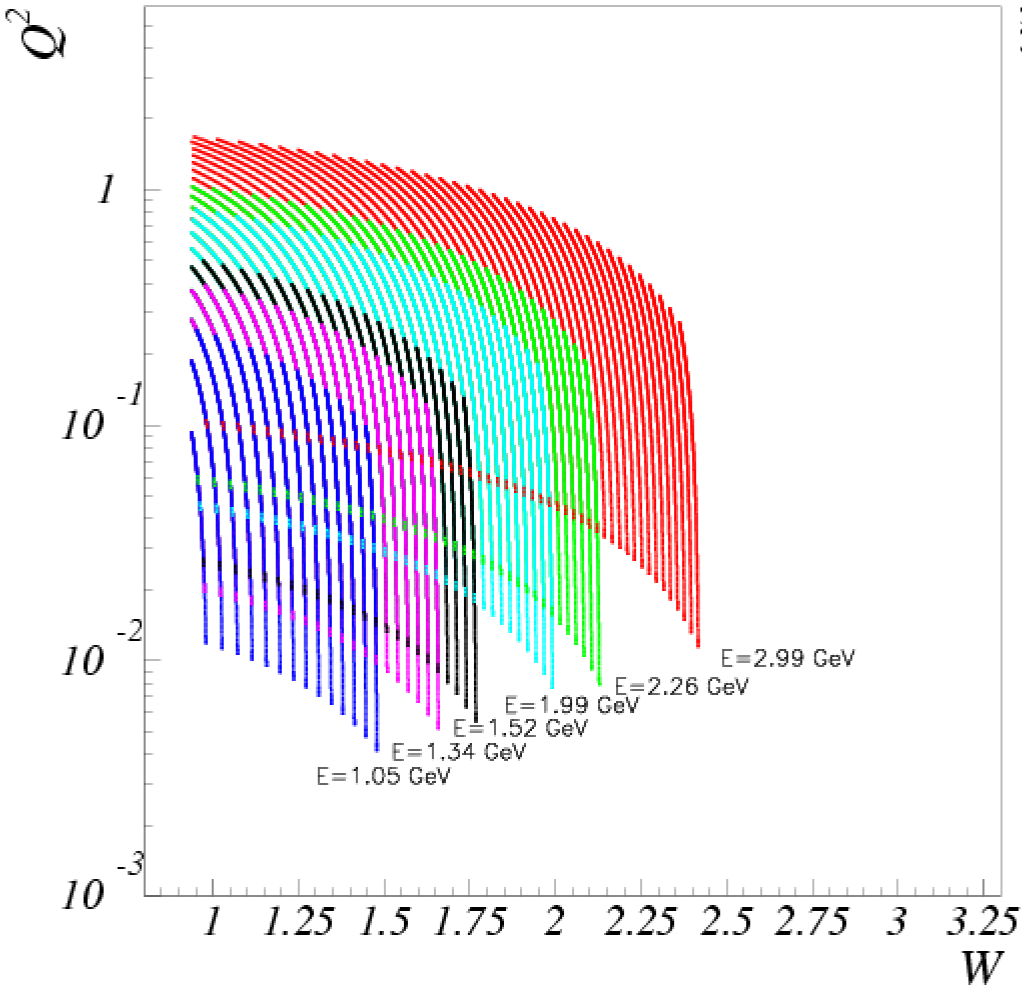
Data; MAID2007; DMT; MAID2007(P11off); MAID2007(S11off); MAID2007(D13off)

Summary (3^{rd} last slide)

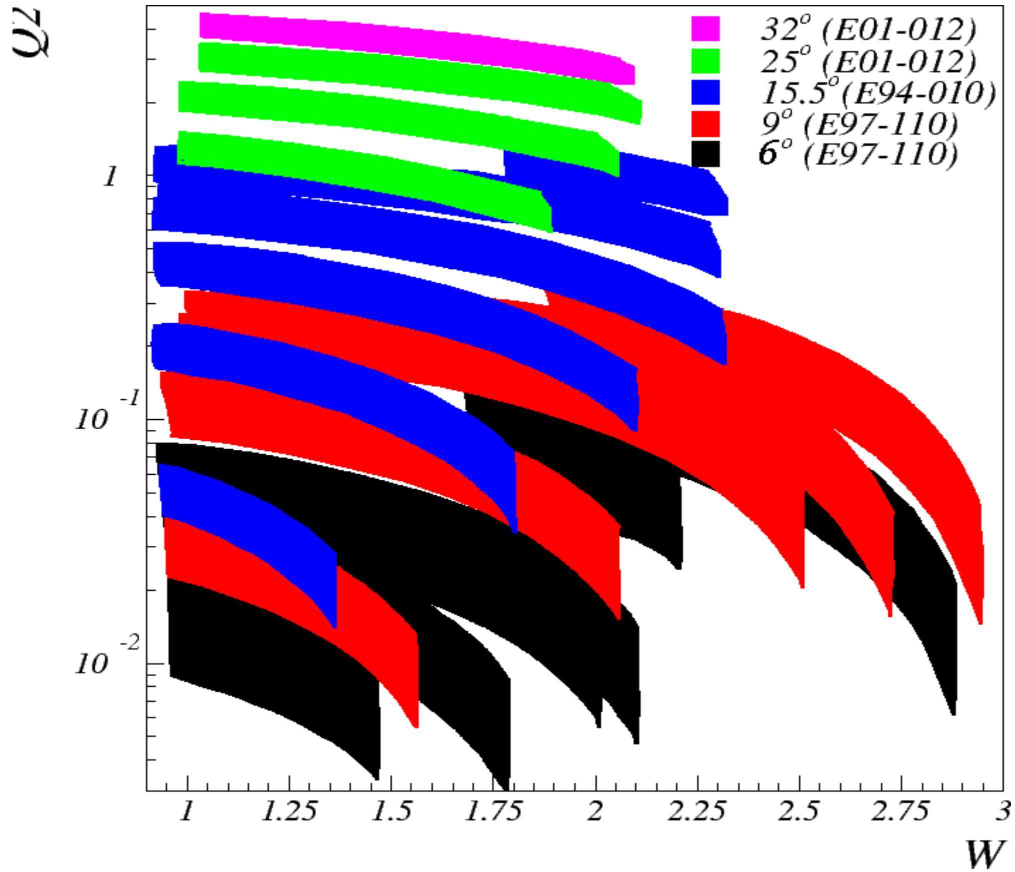
- EG4 will provide data to
  - Extract the proton and the neutron GDH sums at very low Q^2 ;
  - Extract pion electroproduction asymmetries At and Aet;
  - Both will compare to Chiral Perturbation Theory calculations.
- Analysis well underway and preliminary exclusive channel asymmetry results from the 3GeV NH3 data are very promising;
- Stay tuned for our new results!

CLAS/EG4 vs. Hall A/SAGDH Kinematic Coverage

- Hall B(CLAS) EG4 NH_3 (proton)

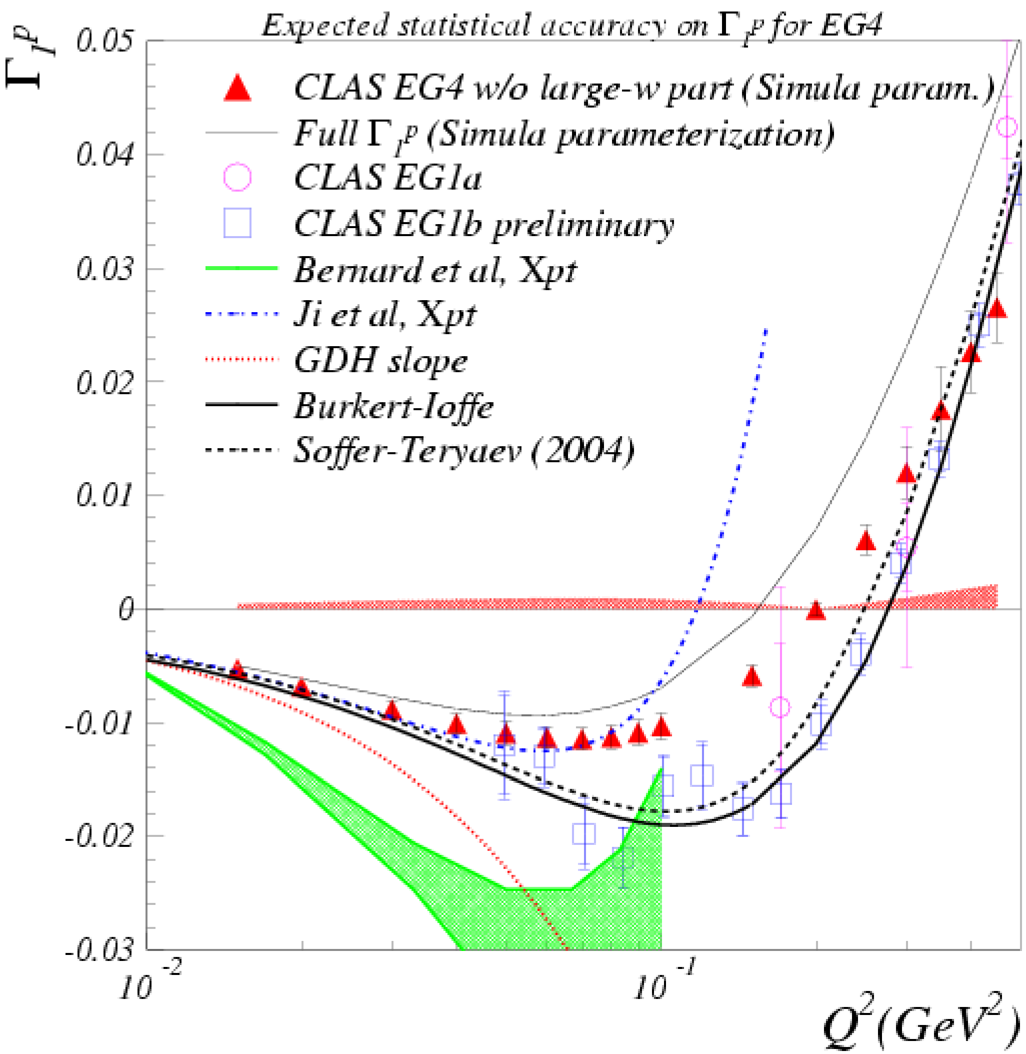


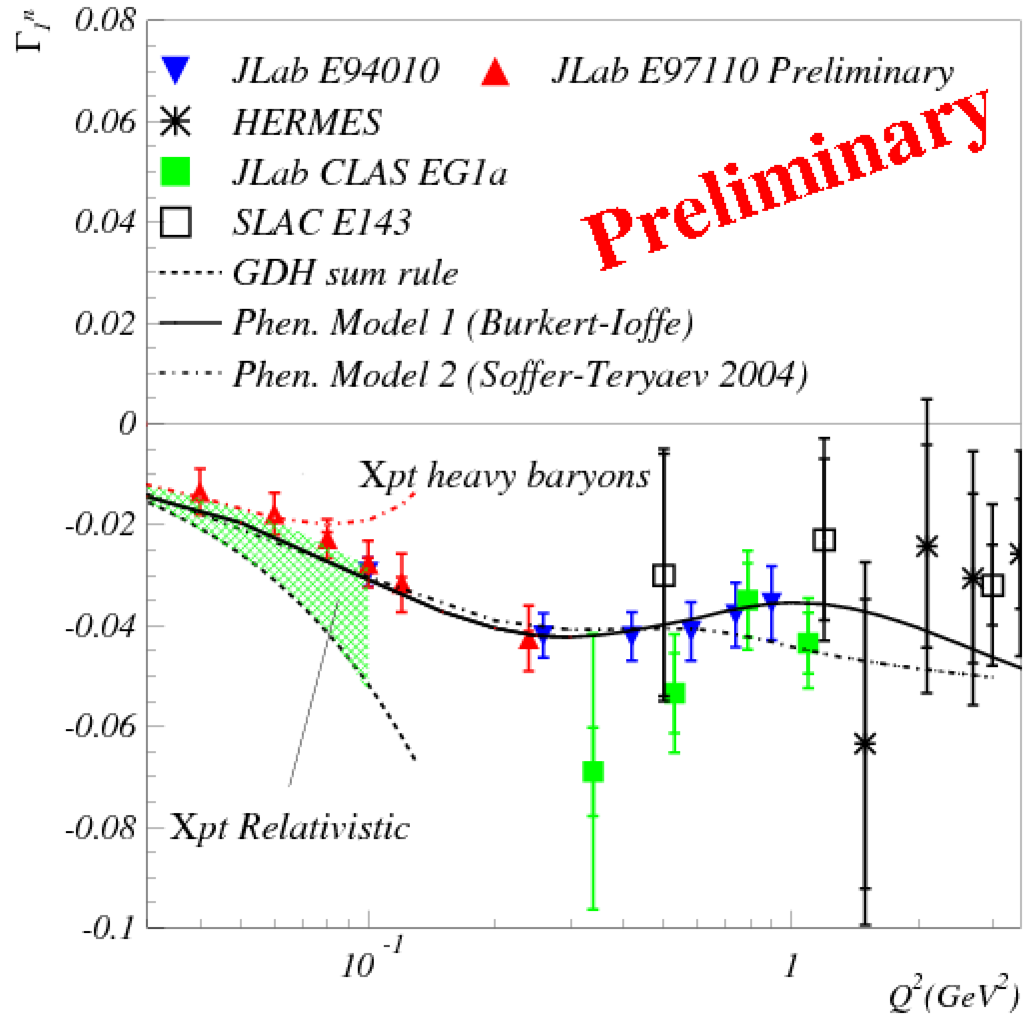
- Hall A E97-110 Polarized ^{3}He (neutron)



(talk by V. Sulkosky yesterday)

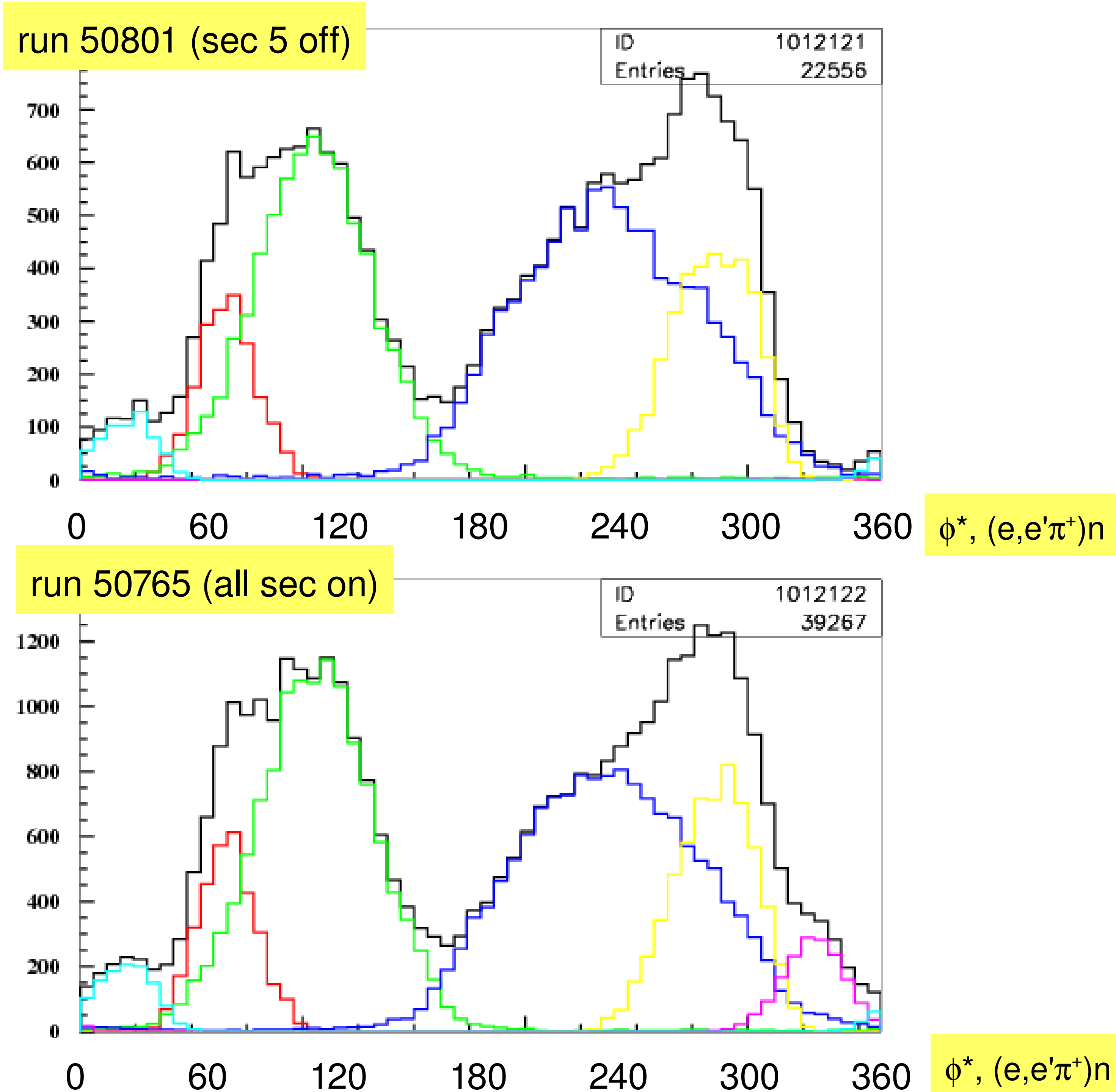
CLAS/EG4 vs. Hall A/SAGDH Expected Inclusive Channel Results





- Can combine Γ_1^p and Γ_1^n to form the Bjorken sum (see next talk).

Back-up Slides



electron in sec 6,
pion in:

sector 1
sector 2
sector 3
sector 4
sector 5
sector 6
sum of all sectors

Physics Motivation (cont.)

- Example: Roper $P_{11}(1440)$ -- Least understood and most controversial
- Sensitivity of Aet ($n\pi^+$) to $P_{11}(1440)$:

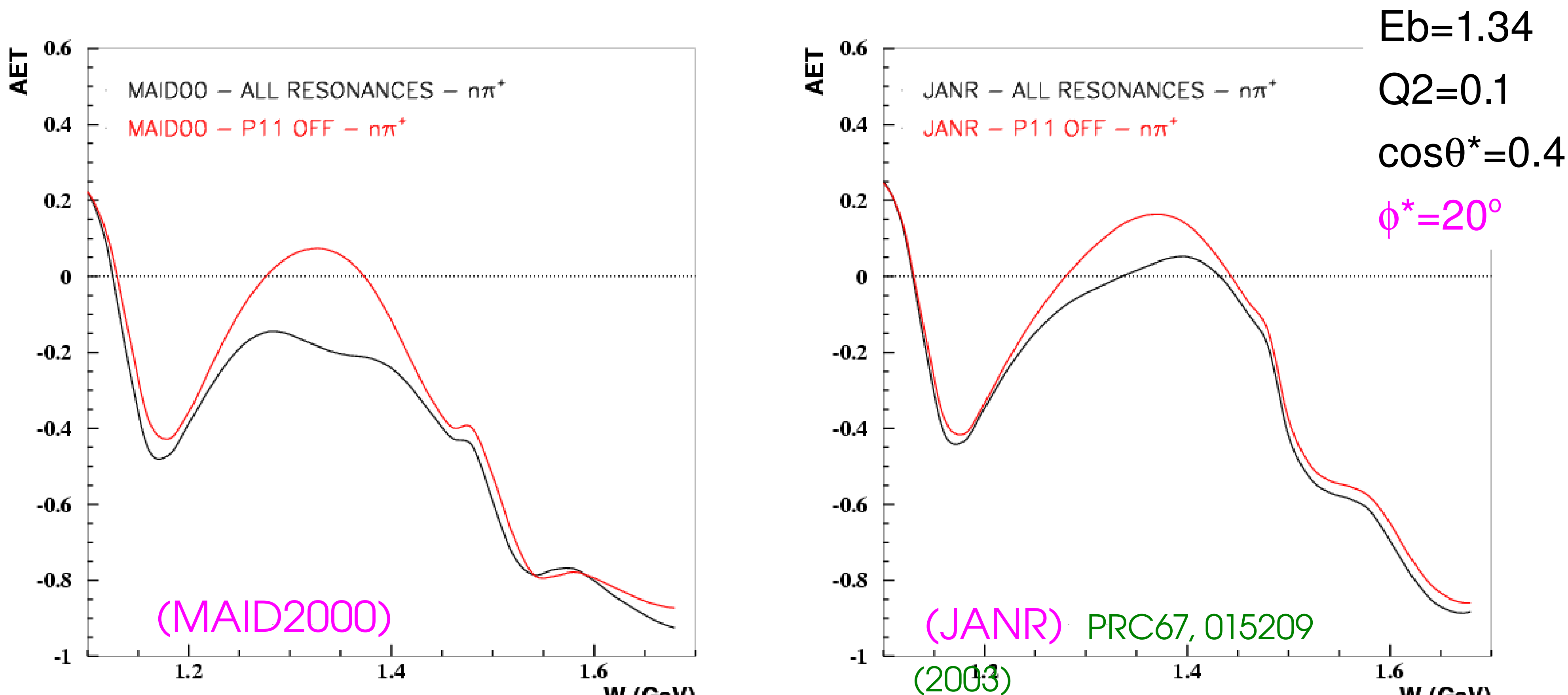
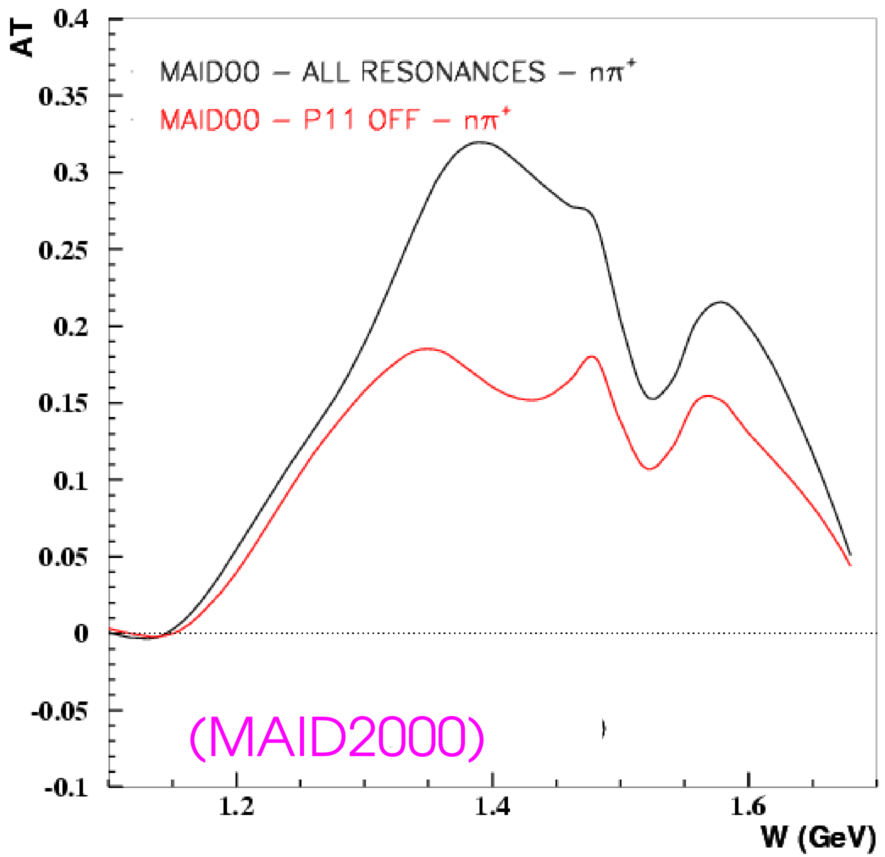
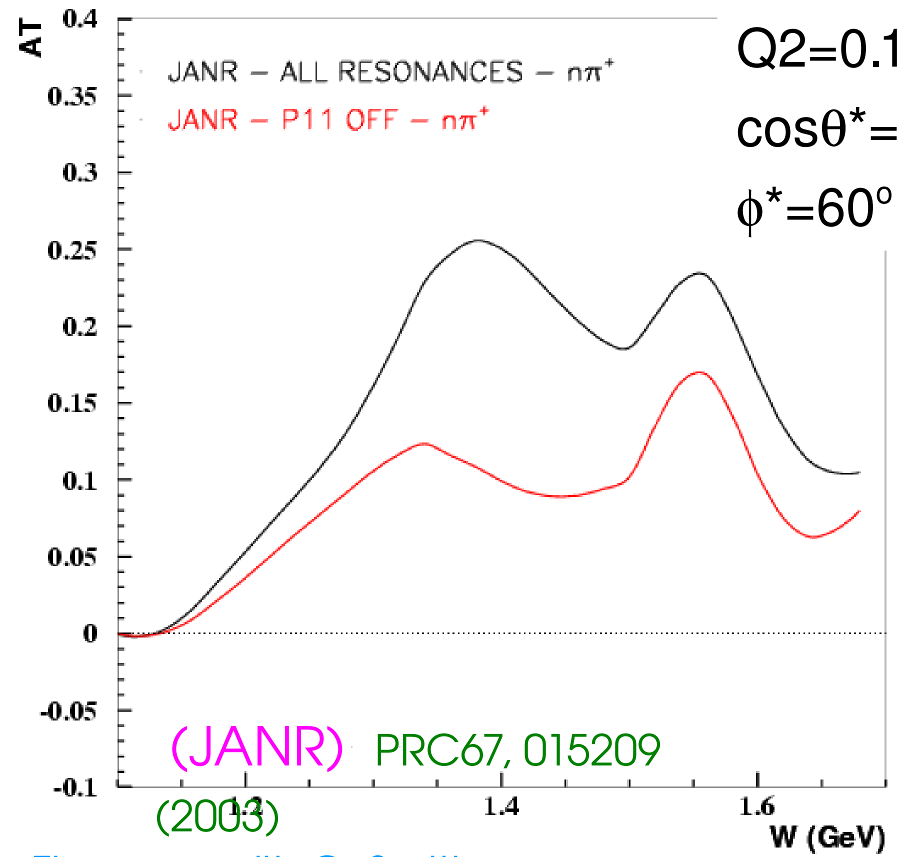


Figure credit: C. Smith

Physics Motivation (cont.)

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





Eb=1.34
Q2=0.1
cosθ*=0.4
φ*=60°

Figure credit: C. Smith

Physics Motivation (cont.)

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

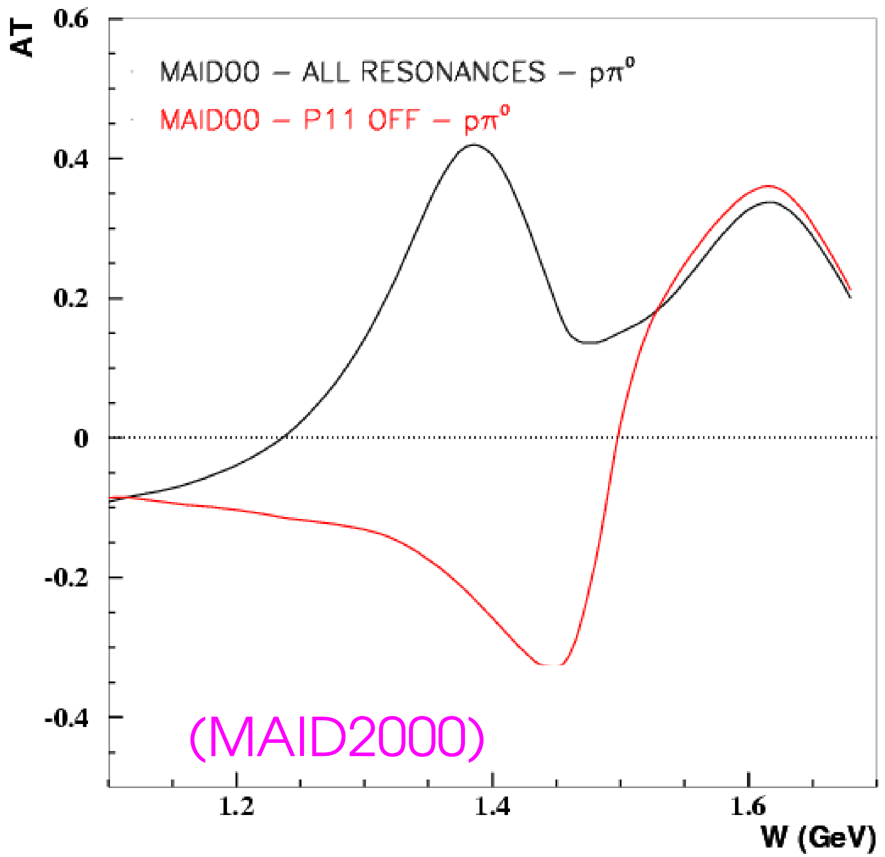
Spin observables may help to remove some model dependence in extraction of amplitudes -> better determination of the nature of P_{11}(1440).

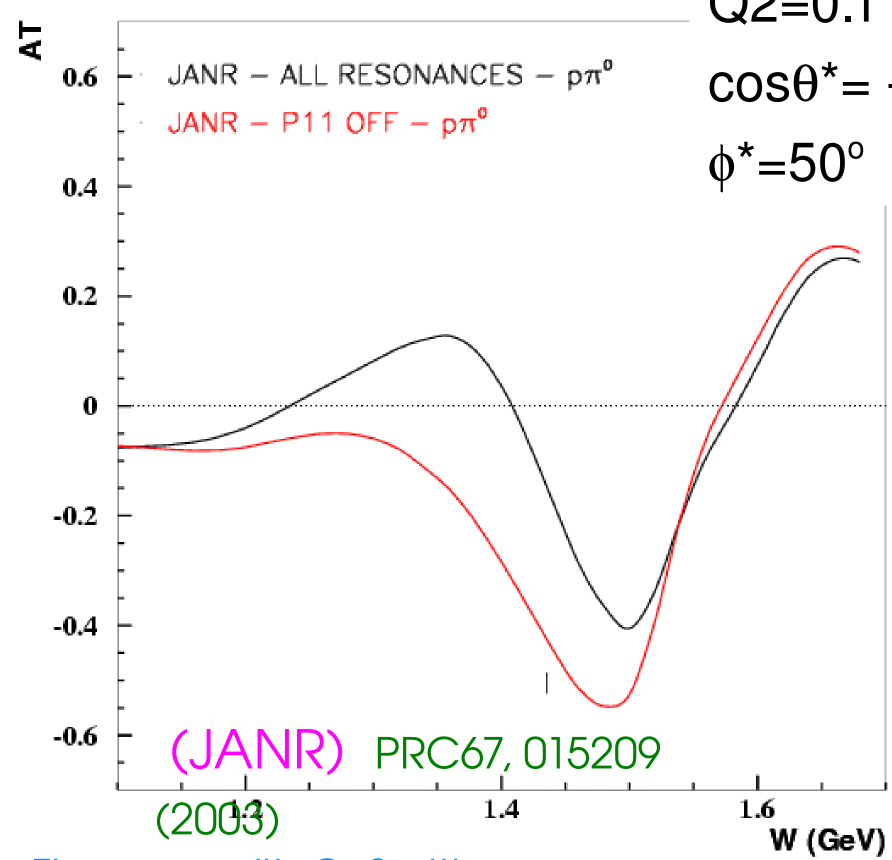
Eb=1.34

Q2=0.1

cosθ*= - 0.8

ϕ*=50°



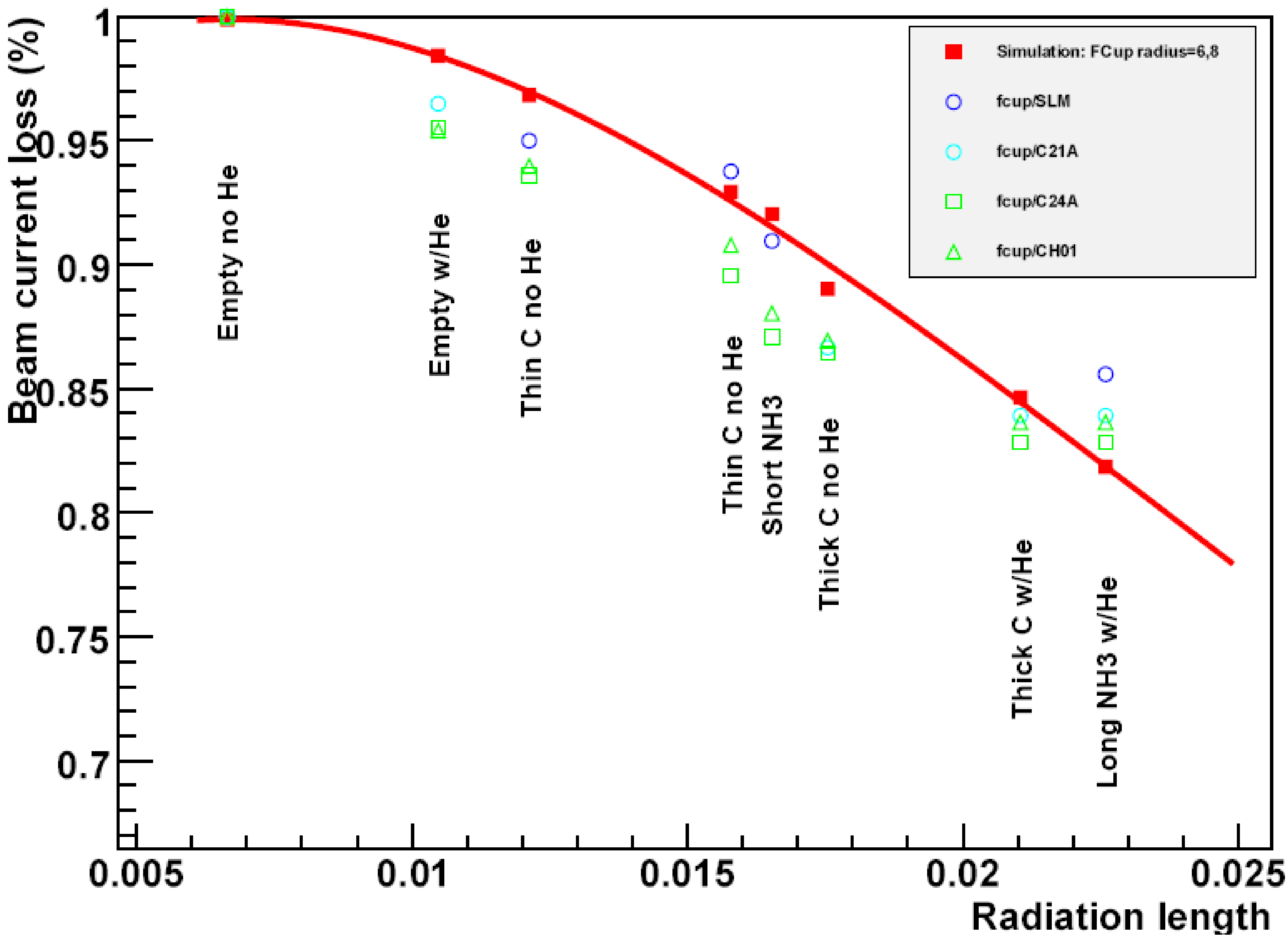


PRC67, 015209 (2003)

Figure credit: C. Smith

Radiation Length Study (by P. Konczykowski)

E = 1.34 GeV



Simulations (V. Drozdov and M. Ripani)

E = 1.339 GeV, NH_3 data (using 0.6 packing factor)

$Q^2 = 0.03 - 0.04\,GeV^2$ $Q^2 = 0.06 - 0.07\,GeV^2$ $Q^2 = 0.12 - 0.13\,GeV^2$