Study of a quasielastic $^{16}O(e,e'p)$ experiment combining a Monte Carlo with a RDWIA code

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E00-012 MEETING
JLAB, 26th SEPTEMBER 2006

0) INTRODUCTION:

- $^{16}O(e,e'p)$ and $^{208}Pb(e,e'p)$ experiments at JLAB

1) MOTIVATION for Mceep+RDWIA code

2) METHODS

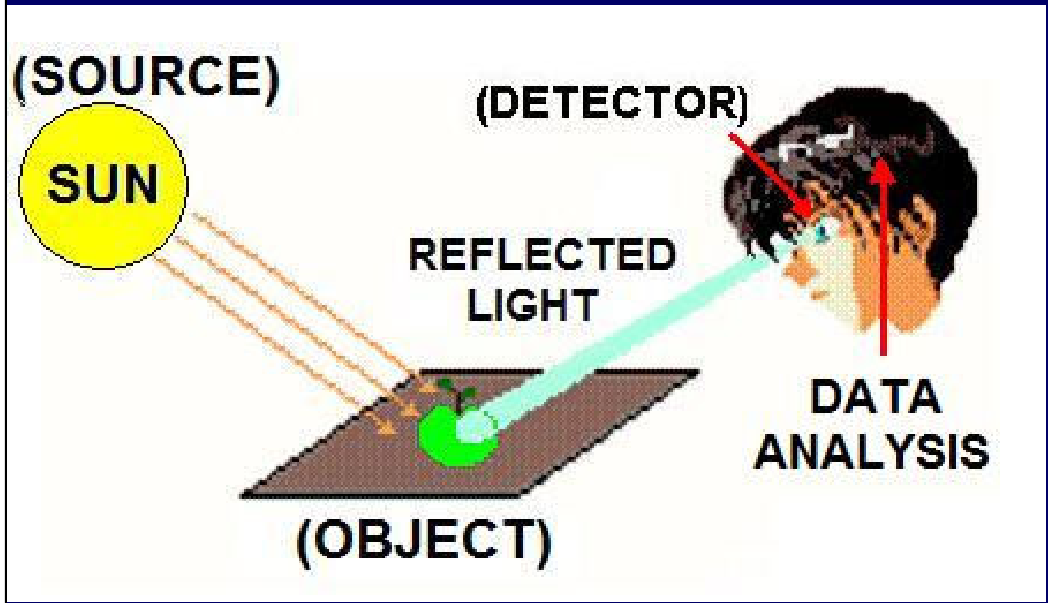
3) RESULTS

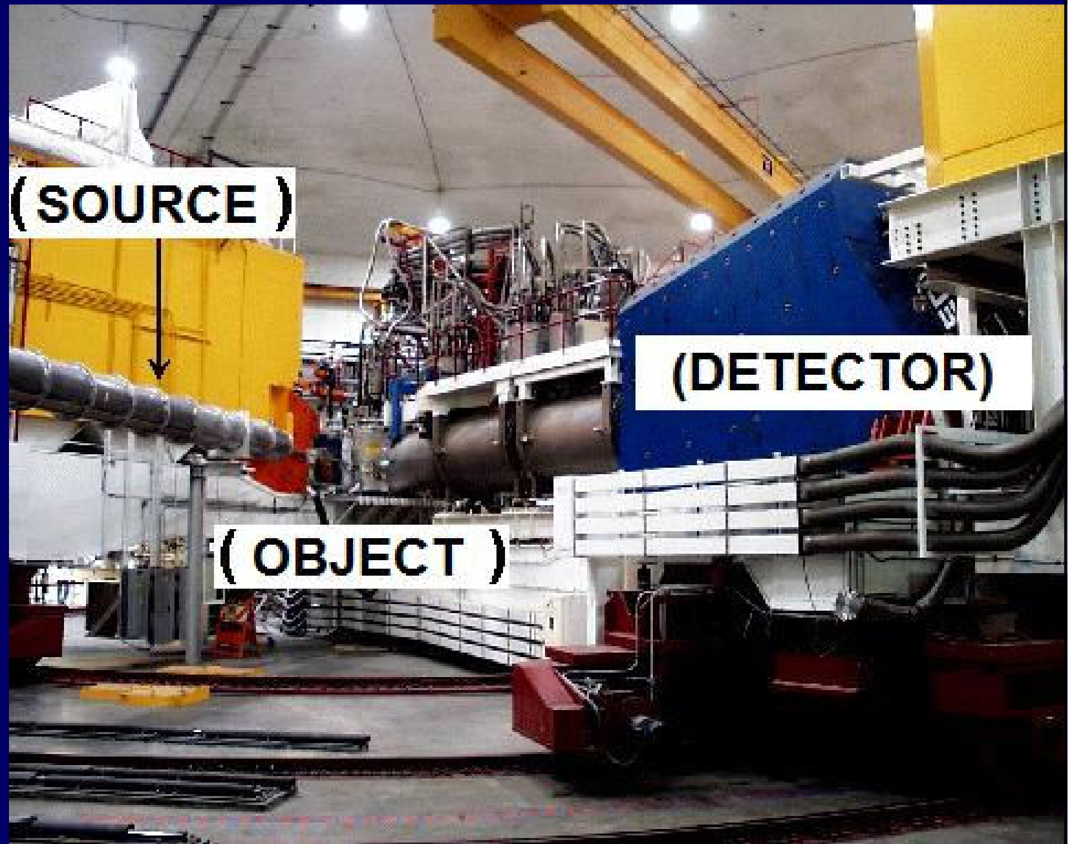
4) PRELIMINARY E00-102 RESULTS

5) FOLLOWING STEPS & CONCLUSIONS

Scattering experiments…

Why?





Data analysis…

done by a postgraduate/postdoc student.

EXPERIMENTS

- **E89-003** – A Study of the Quasielastic $^{16}O(e,e'p)$ Reaction at High Recoil Momenta (Summer 1997).
- **E00-102** - Testing the Limits of the Single Particle Model in ^{16}O (Autumn 2001).
- **E06-007** - Impulse Approximation Limitations to the (e,e'p) reaction on ^{208}Pb, Identifying Correlations and Relativistic Effects in the Nuclear Medium (Spring 2007).

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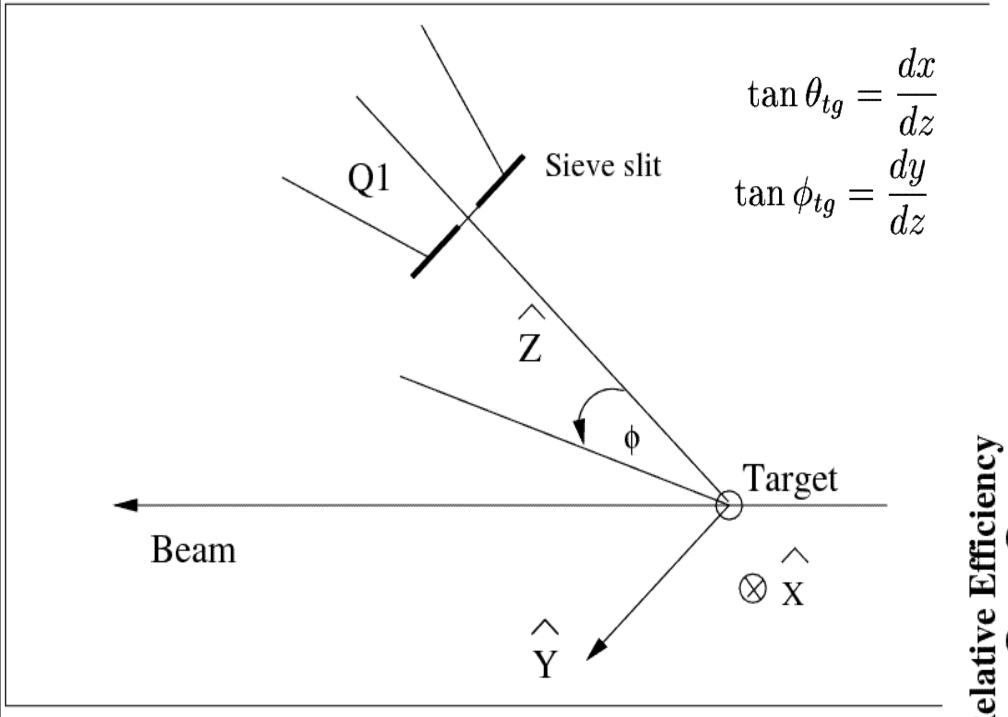
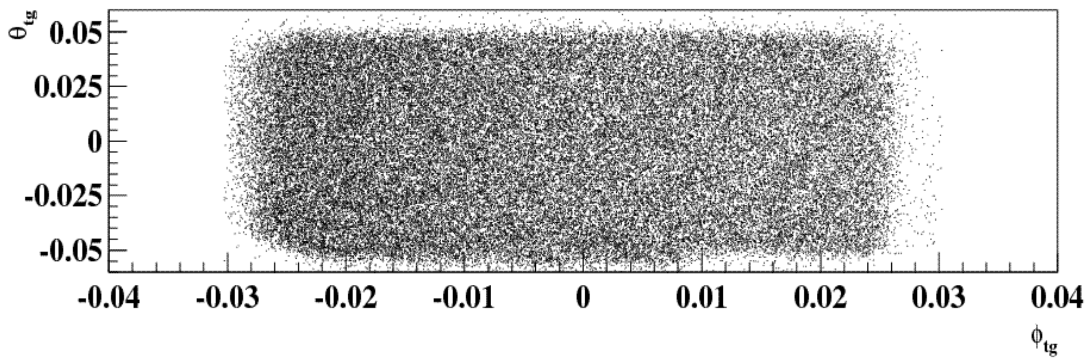
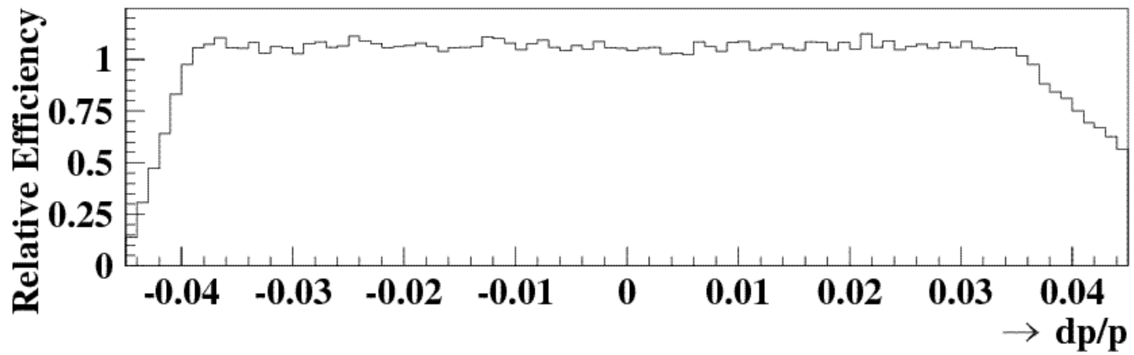
SPECTROMETER ACCEPTANCES



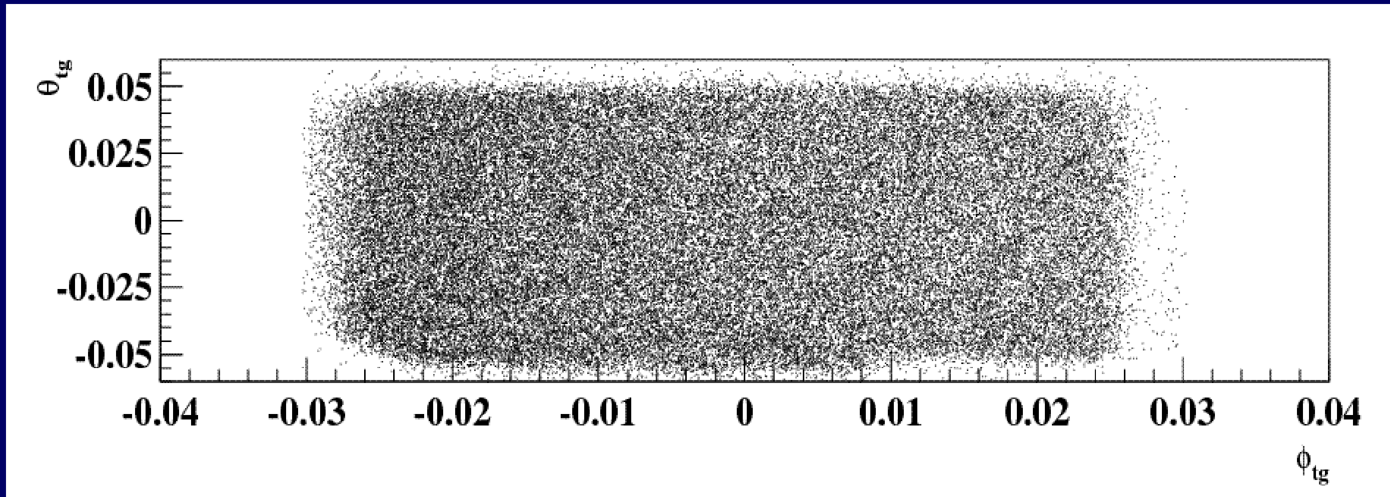
TARGET COORDINATE SYSTEM

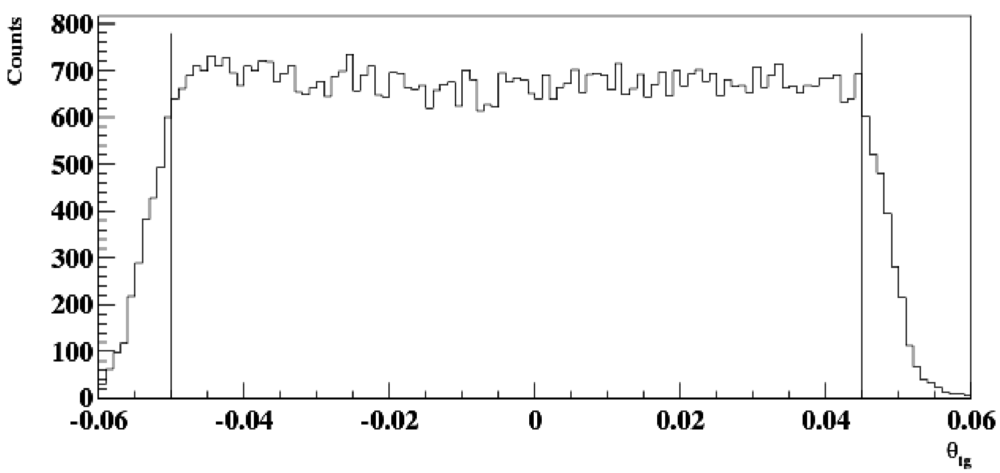


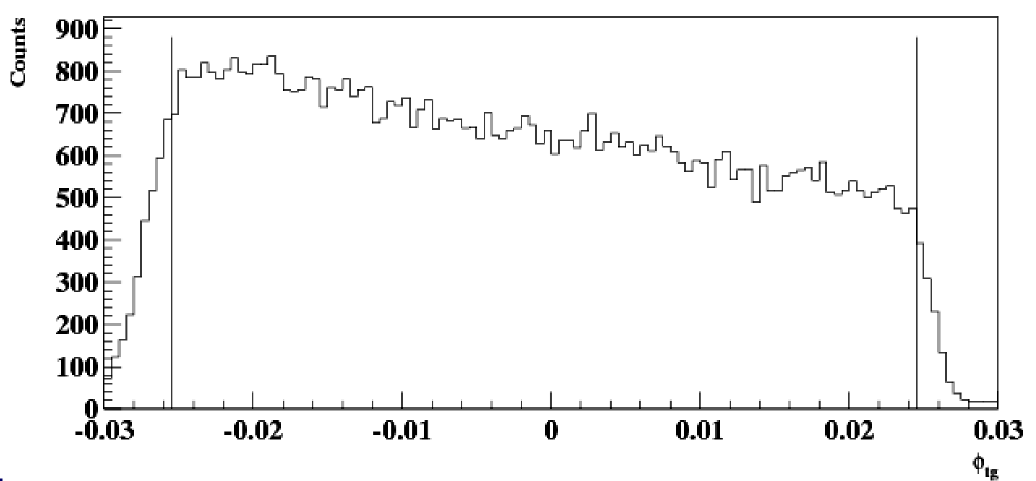


CUTS IN THE ACCEPTANCES

$-0.05 < \theta_{tg} < 0.045,$
$-0.026 < \phi_{tg} < 0.024$
HRSE
$-0.05 < \theta_{tg} < 0.05,$
$-0.022 < \phi_{tg} < 0.022$
HRSH



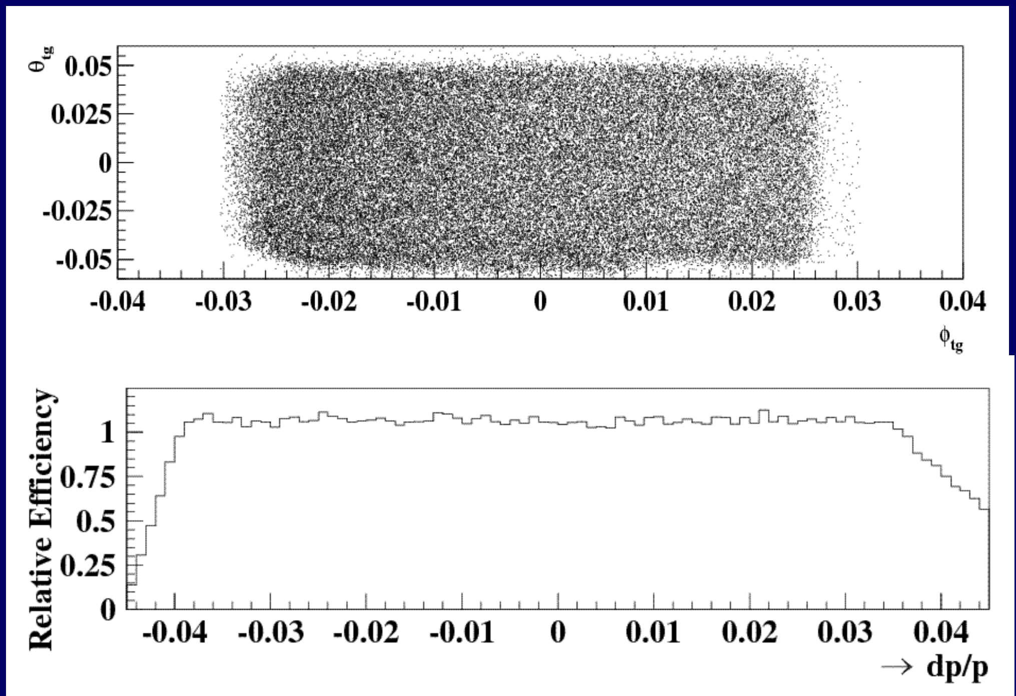


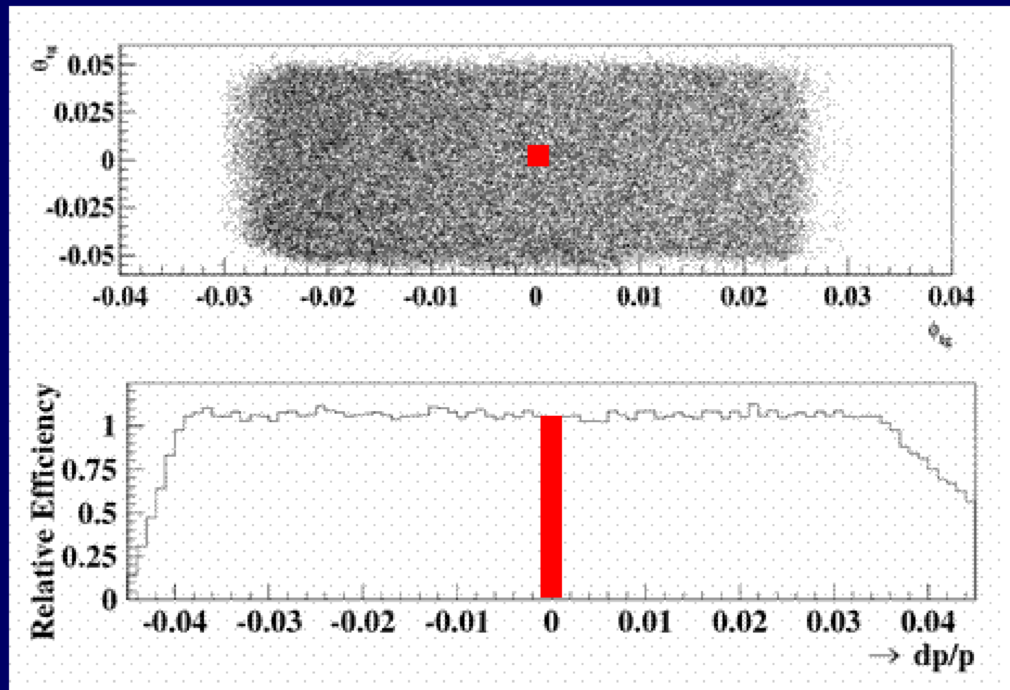


SPECTROMETER ACCEPTANCES

EXPERIMENTS:
Spectrometers with significant angular and momentum acceptances

THEORETICAL CALCULATIONS:
Assume central values for the spectrometer acceptances





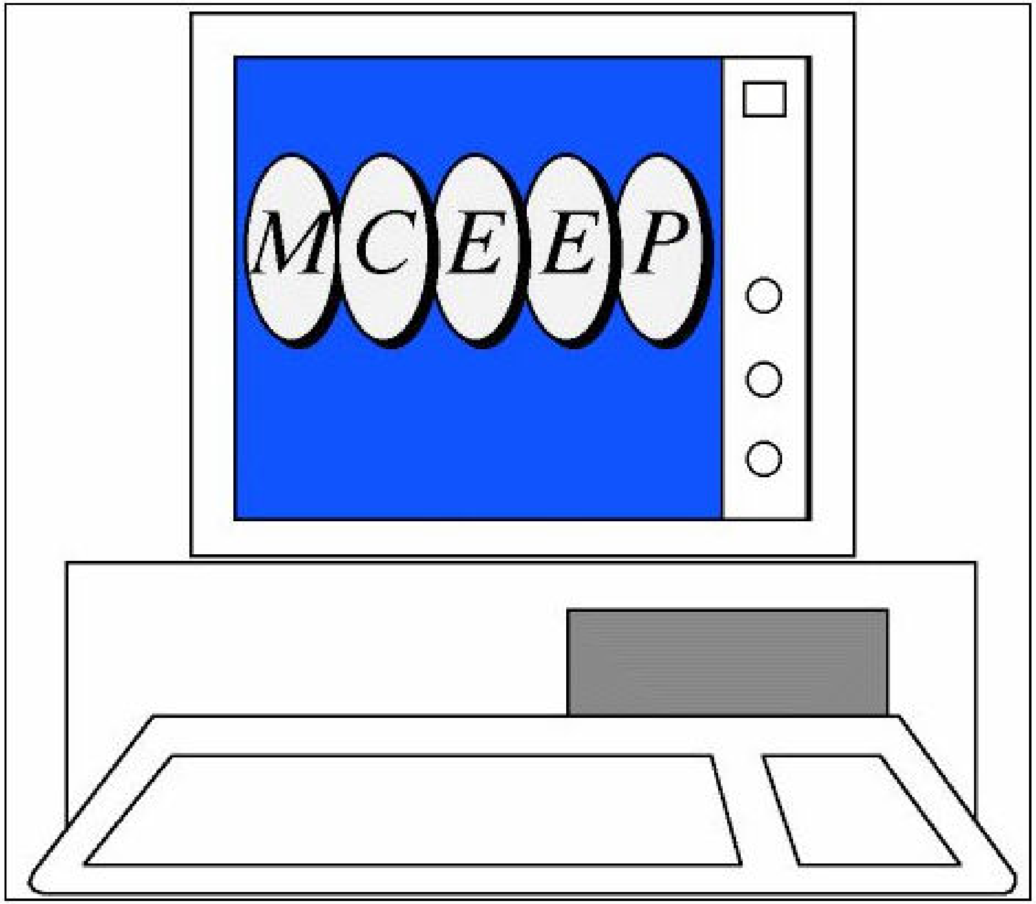
SPECTROMETER ACCEPTANCES

EXPERIMENTS:
Spectrometers with significant angular and momentum acceptances

THEORETICAL CALCULATIONS:
Assume central values for the spectrometer acceptances

In order to correctly compare data to theory, two obvious approaches exist:

- Acceptance effects may be removed from data via stringent cuts (statistics decreases).
- Calculations may be averaged over acceptance (requires very well-understood acceptances, time consuming).



MCEEP: Monte Carlo for (e,e'p) experiments

Version 3.9

June 2006

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http://hallaweb.jlab.org/software/mceep/mceep.html

MCEEP

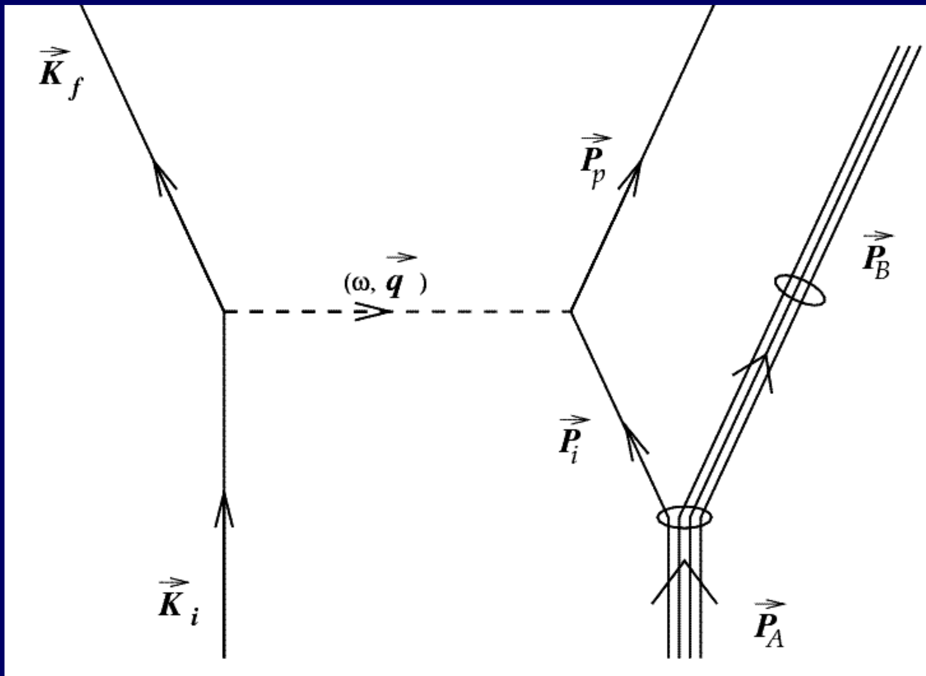
- MCEEP is a simulation open source code written in fortran. It was designed to simulate coincidence (e,e'X) experiments by averaging theoretical models over the experimental acceptances.

- Although it was initially designed with (e,e'p) processes in mind, it is applicable to any single hadron emission experiment.

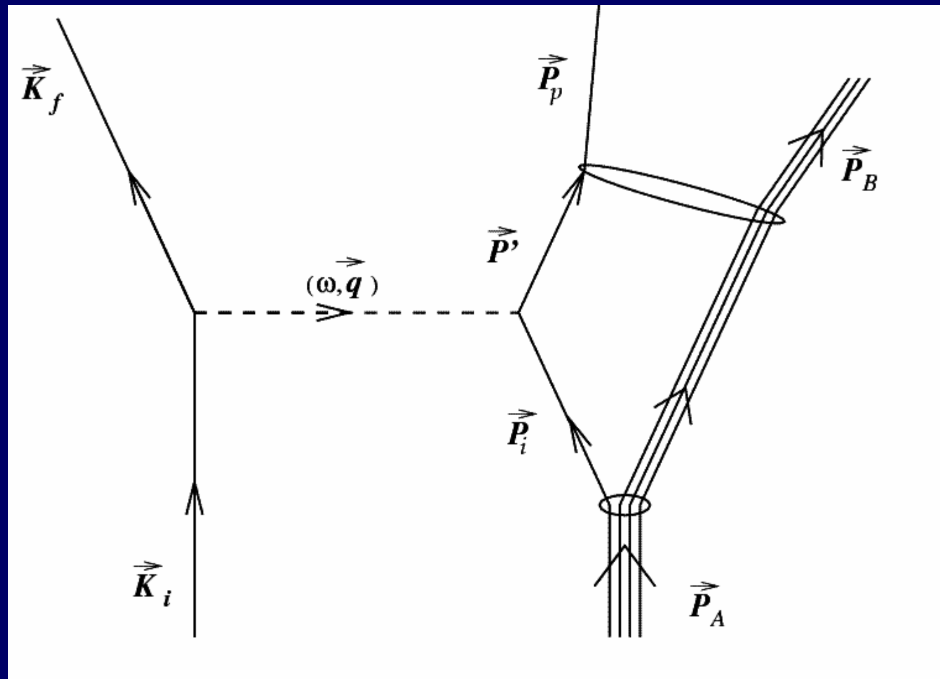
- MCEEP employs a uniform random sampling method to populate the experimental acceptance.

- It has an important limitation: it uses very simple models of the (e,e'p) reaction to avoid long computational time.

PWIA / DWIA / RDWIA CODES



Plane Wave Impulse Approximation in $(e, e'p)$

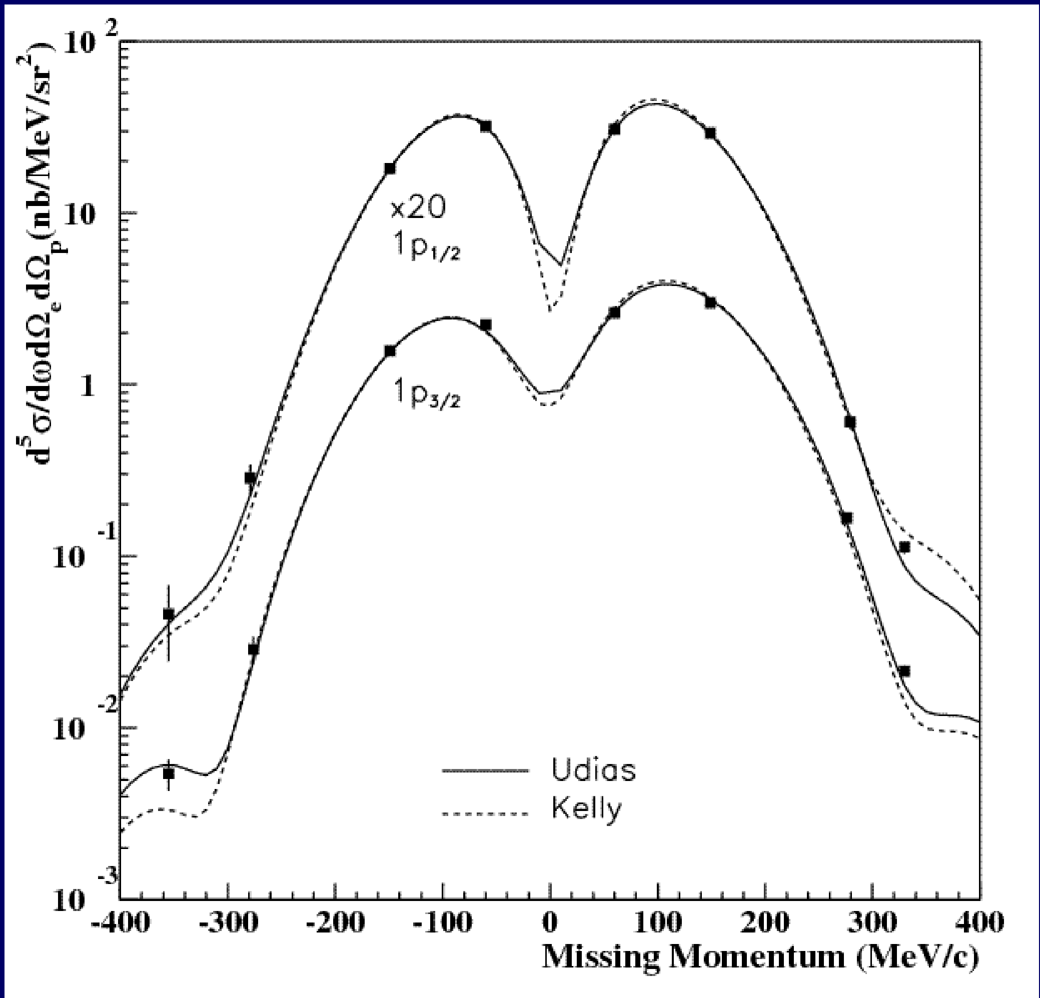


Distorted Wave Impulse Approximation in $(e, e'p)$

RDWBA codes have been shown to give the most accurate results for these kind of processes.

(RDWIA + Coulomb corrections) provides reasonable results.

RDWIA RESULTS



Experimental data from the E89-003 experiment and RDWIA theoretical calculation from Udias et al.

RDWIA code solves the Dirac equation directly in configuration space.

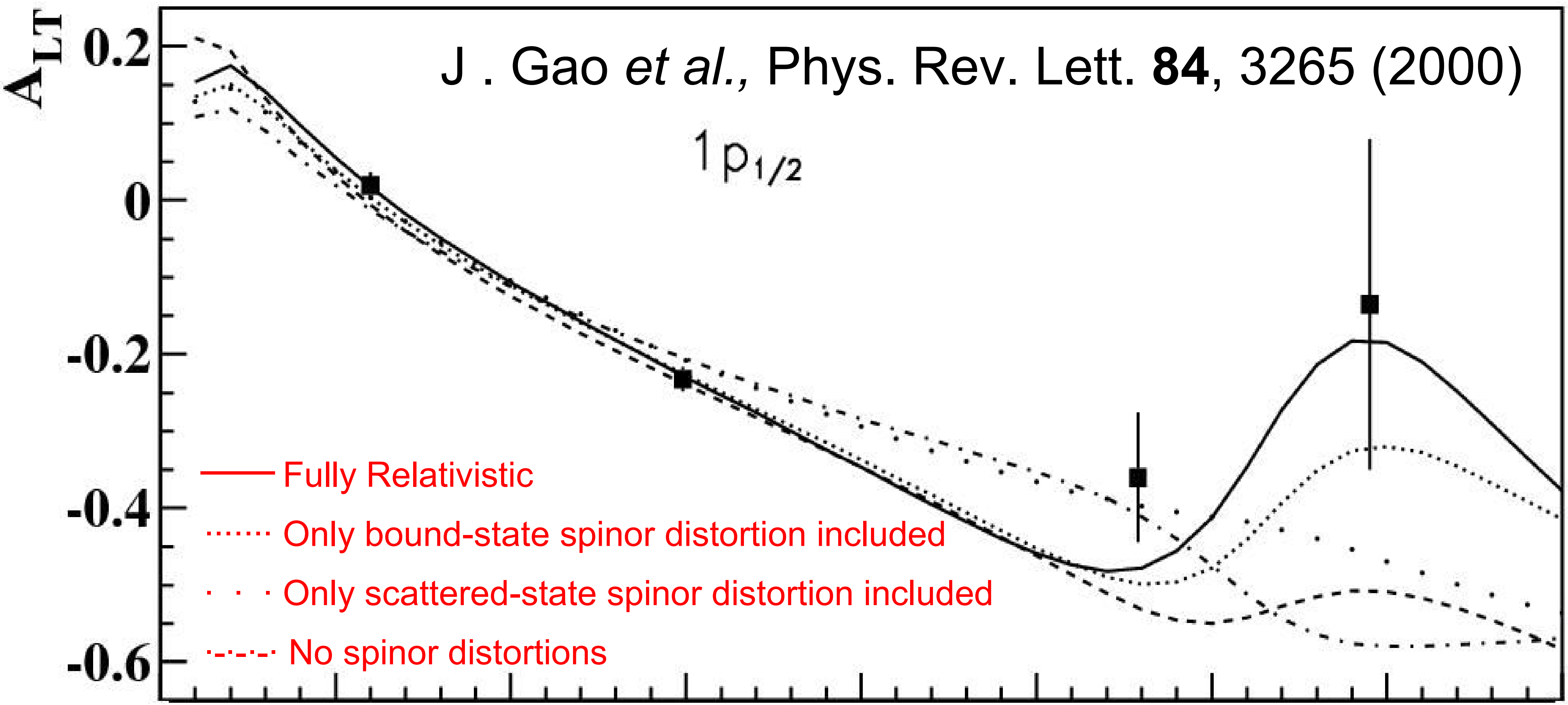
At high Q^2, quasielastic (e,e'p) is dominated by single-body interactions. Therefore RDWIA calculations should be more accurate than at low Q^2.

An excellent agreement between them can be observed. But no tools existed at the time to average the calculations over the extremes in acceptance.

Dynamical Relativistic Effects: ATL and RTL measurements

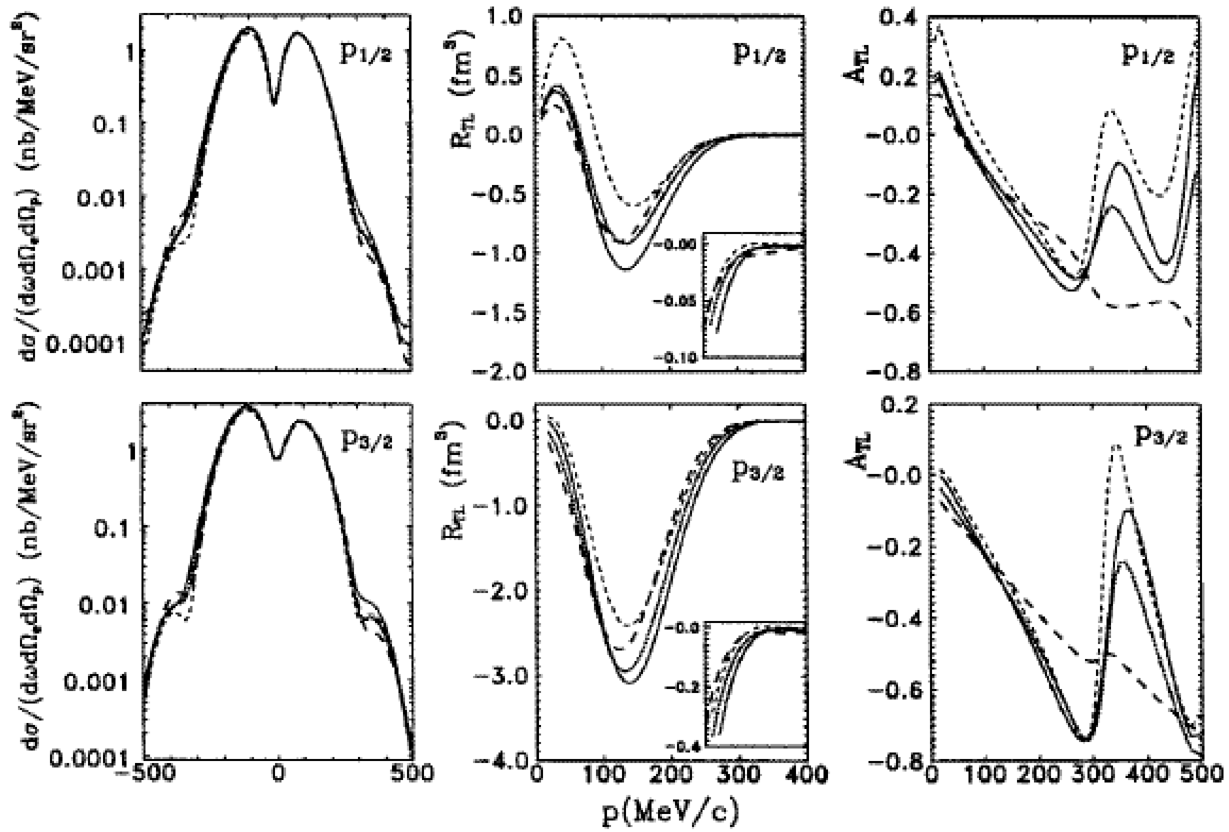
- In our RDWIA code, the nucleon current is computed with a fully relativistic operator. The wave functions are four-component spinor solutions of the Dirac equation with scalar and vector potentials.
- As a result, their lower components are dynamically enhanced with respect to a solution of Dirac equation without potentials (a free spinor).
- This dynamical effect of spinor distortions affects the ALT and RLT observables.

- To illustrate this point, we show calculations in which this enhancement of the lower components is removed from the relativistic wave functions.



Dynamical Relativistic Effects: ATL and RTL measurements

VOLUME 83, NUMBER 26 PHYSICAL REVIEW LETTERS 27 DECEMBER 1999



- J. M. Udias *et al.*, Phys. Rev. Lett. **83**, 5451 (1999).

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MCEEP + RDWIA

- In an extended-acceptance experiment, each event can correspond to somewhat different kinematics.
- Evaluating the cross section with the RDWIA code for each event simulated with Mceep requires too much time.
- Our approach has been to pre-calculate a structure-function grid (or "hypercube") which spans the experimental phase space, and then interpolate on this hypercube on an event-by-event basis, extracting the cross section.

HYPERCUBE

- The cross section of each simulated event can be expressed as a function of the variables (E_{miss},p_{miss},q,ω).
- If we consider only those cases where the ejected protons belongs to a given shell (like $1p_{1/2}$) → Only 3 variables: (p_{miss},q,ω).
- Using our RDWIA code we can obtain the Response Functions (R_L,R_T,R_{LT},R_{TT}), which contain information about the nuclear charge and current densities, as a function of (p_{miss},q,ω).

CROSS SECTION

$$\frac{d^5\sigma}{d\Omega_e d\Omega_p d\omega} = K\ \sigma_{\mathrm{Mott}}[v_L R_L + v_T R_T + v_{TL} R_{TL}\cos(\phi) + v_{TT} R_{TT}\cos(2\phi)],$$

$$K = R\,\frac{p_p E_p}{(2\pi)^3} \quad \text{(phase space factor)},$$

$$R = \left|1 + \frac{E_p}{E_{\mathrm{recoil}}}\frac{\boldsymbol{p_p}\cdot\boldsymbol{p}_{\mathrm{miss}}}{\boldsymbol{p_p}\cdot\boldsymbol{p_p}}\right|^{-1} \quad \text{(recoil factor)},$$

$$\sigma_{\mathrm{Mott}} = \left[\frac{\alpha\cos(\theta_e/2)}{2E_{\mathrm{beam}}\sin^2(\theta_e/2)}\right]^2,$$

$$v_L = \left[\frac{Q^2}{\boldsymbol{q}^2}\right]^2,$$

$$v_T = \frac{1}{2}\left[\frac{Q^2}{\boldsymbol{q}^2}\right] + \tan^2(\theta_e/2),$$

$$v_{TL} = \left[\frac{Q^2}{\boldsymbol{q}^2}\right]\sqrt{\frac{Q^2}{\boldsymbol{q}^2} + \tan^2(\theta_e/2)},$$

$$v_{TT} = \frac{1}{2}\left[\frac{Q^2}{\boldsymbol{q}^2}\right],$$

Cross section as a function of kinematical variables and the Response Functions RL,RT,RTL,RTT.

MCEEP
INPUT AND OUTPUT

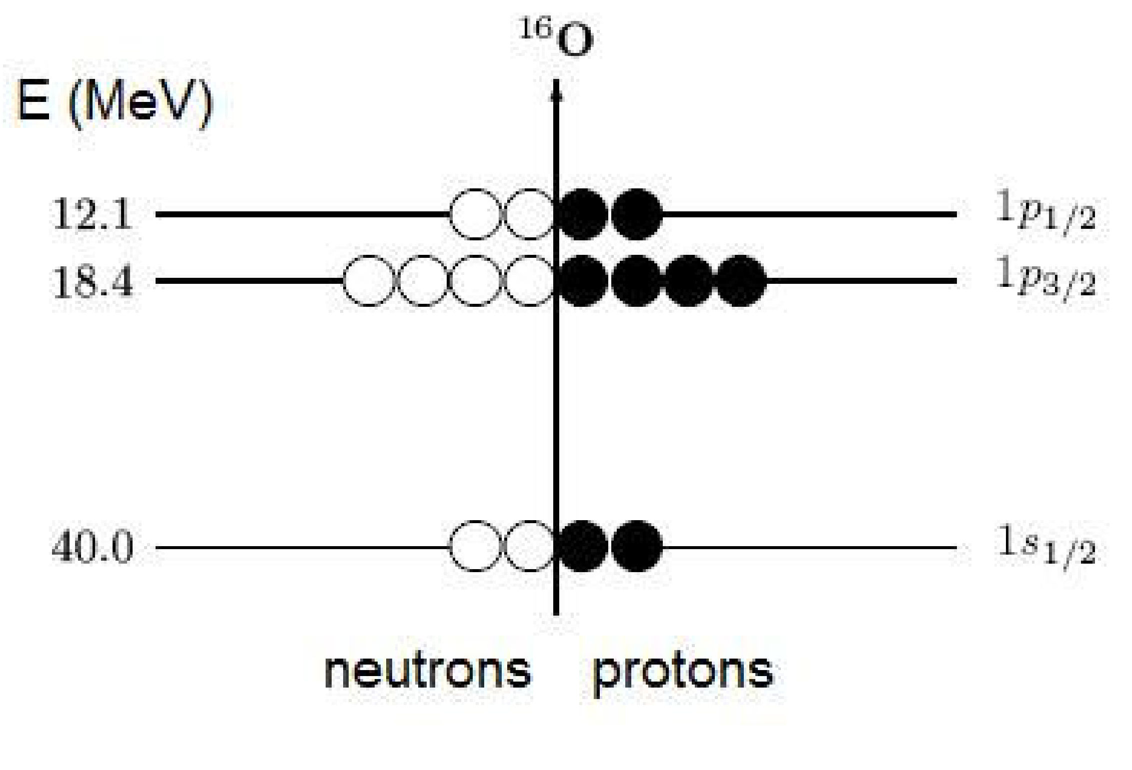
- INPUT FILES →
  - File with kinematics and options
  - File with the 3-Dimensional grid of response functions.
- OUTPUT FILE → hbook files

  They can be analyzed with PAW or ROOT

RUNPLAN

- 1) Creation of the Hypercube with RDWIA code:
  - Determination of the phase space range.
  - Determination of a proper step in each variable.
  - Computational calculation (a mere few hours in 1CPU)
- 2) Adding new Subroutines in Mceep:
  - Reading the response-function hypercube.
  - Interpolation and evaluation of the cross section.
- 3) Using an experiment already analyzed [E89-003] to check the accuracy of the method.

E89-003 experiment: ^{16}O NUCLEUS

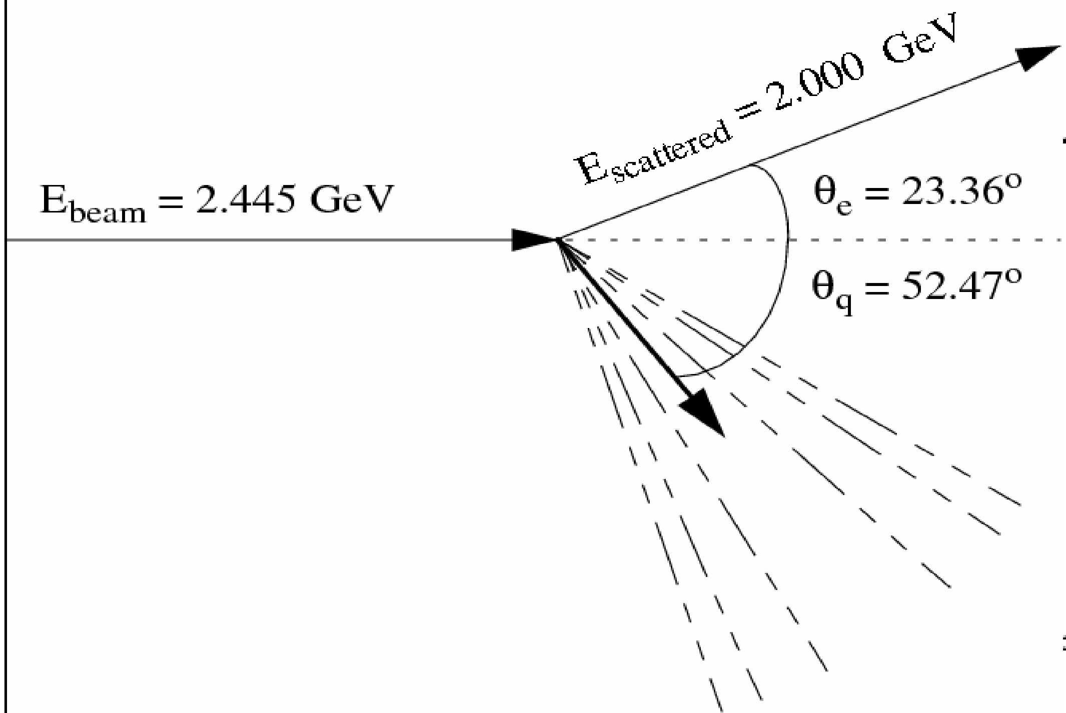


Idealized proton and neutron levels in ^{16}O

Objectives

- Cross section at high Pmiss
- Response Functions
- Asymmetry ATL
- Dynamical Relativistic effects

E89-003 KINEMATICS



E_{beam} (MeV)	θ_e (°)	θ_{pq} (°)	P_{miss} (MeV/c)
2445	23.38	-20	350
2445	23.38	-16	275
2445	23.38	-8	140
2445	23.38	0	0
2445	23.38	8	140
2445	23.38	16	275
2445	23.38	20	350

Kinematics settings for E89-003:
$\omega = 439$ MeV, $Q^2 = 0.8$ (GeV/c)^2, and $T_p = 427$ MeV.

Kinematics simulated for the E89-003 experiment to check the accuracy of our method (Mceep+RDWIA)

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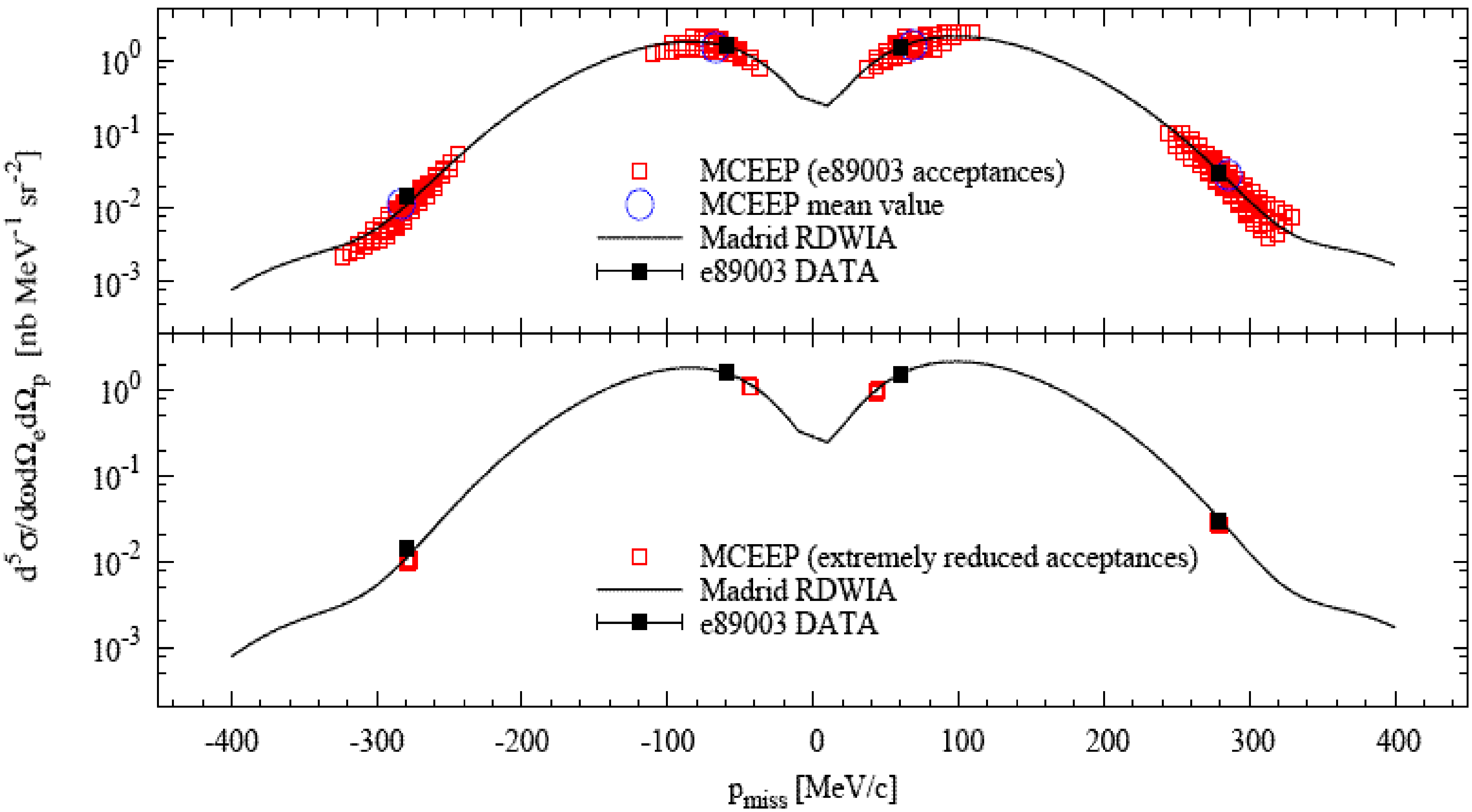
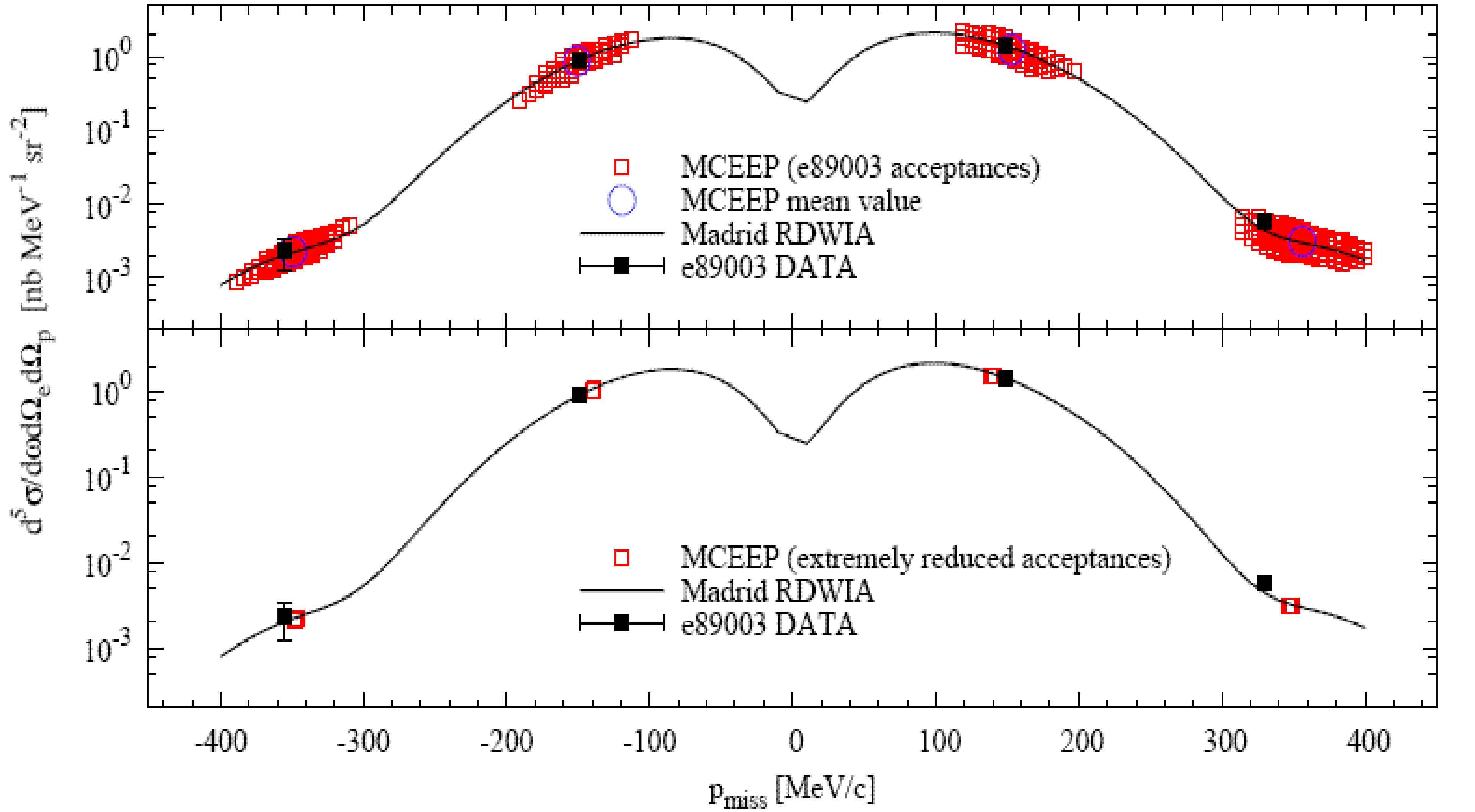
CROSS SECTION



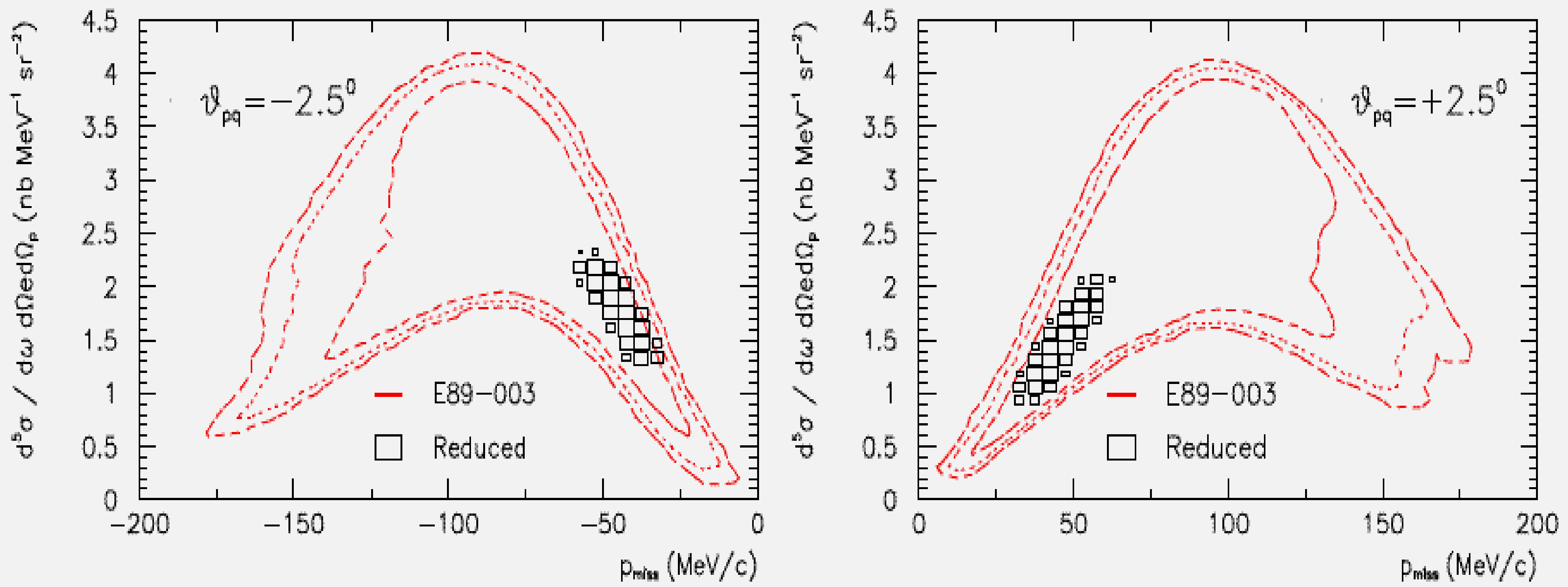
Cross section for spectrometer angles of θ_{pq}= ±2.5 and ±16.0 degrees.

CROSS SECTION



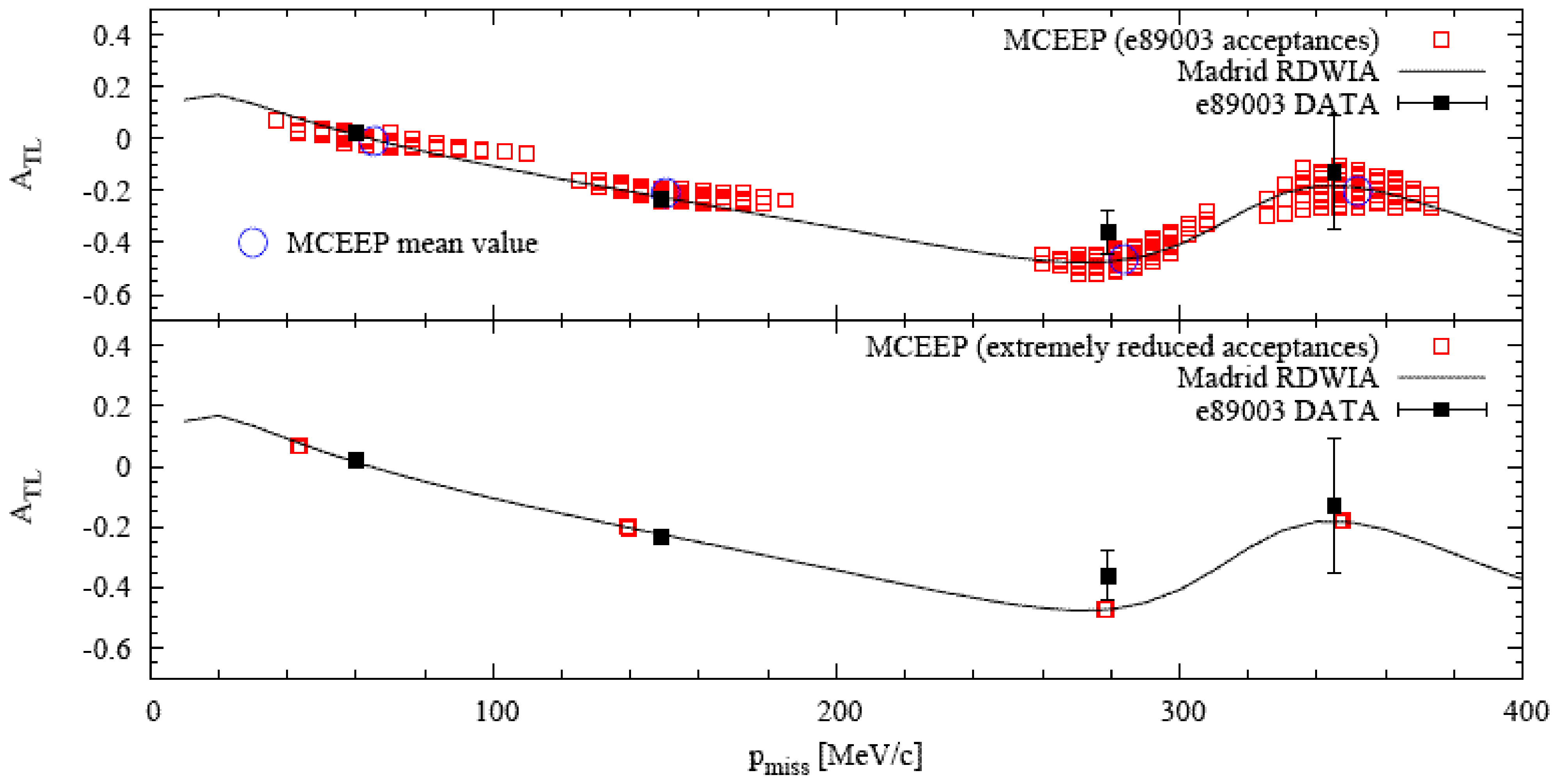
Cross section for spectrometer angles of θ_{pq}= ±8.0 and ±20.0 degrees.

ASYMMETRIC POPULATION OF EVENTS IN BOTH SIDES OF q



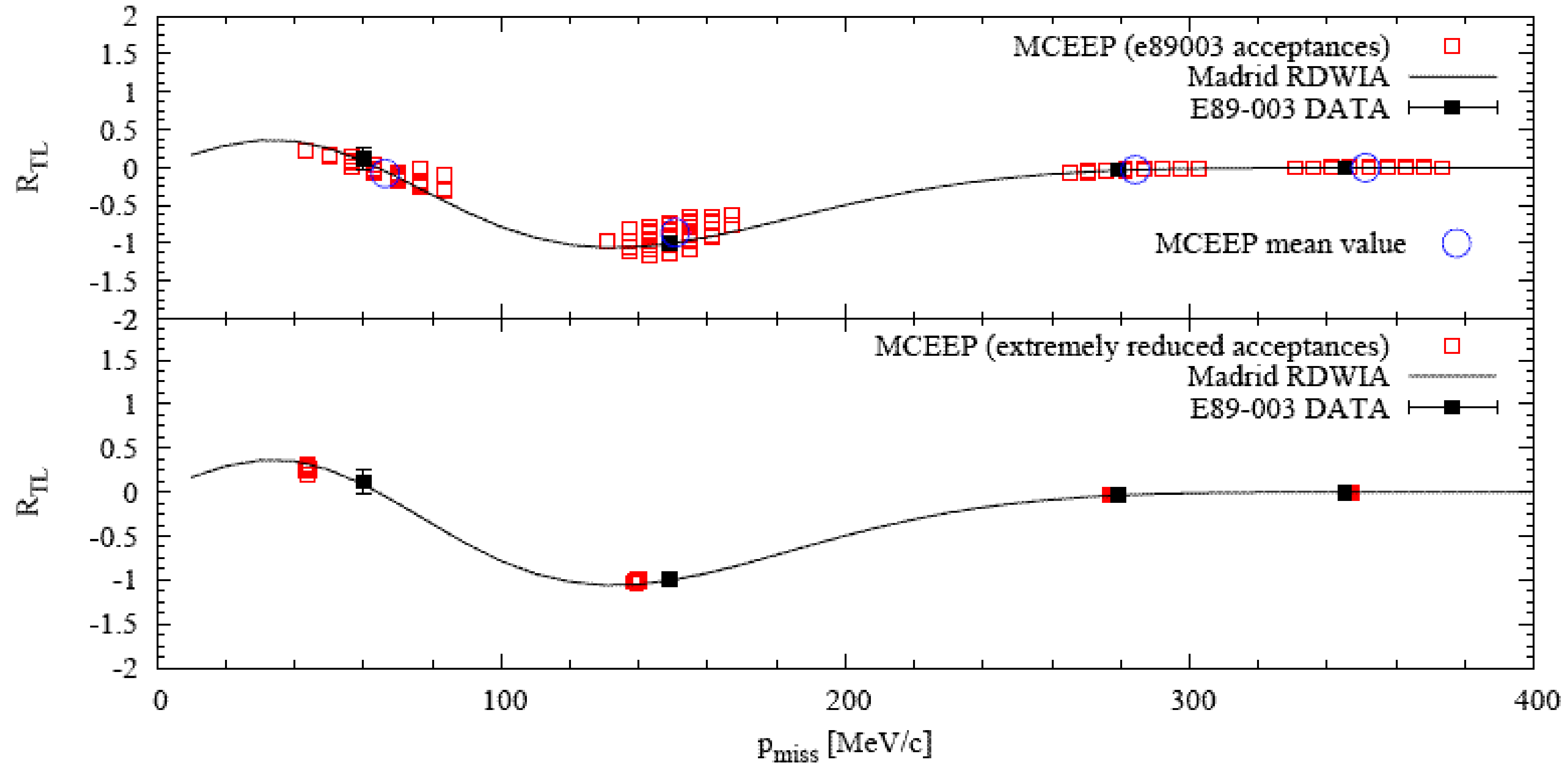
A_{TL}

$$A_{TL} = \frac{\sigma(\phi = 0^\circ) - \sigma(\phi = 180^\circ)}{\sigma(\phi = 0^\circ) + \sigma(\phi = 180^\circ)}.$$

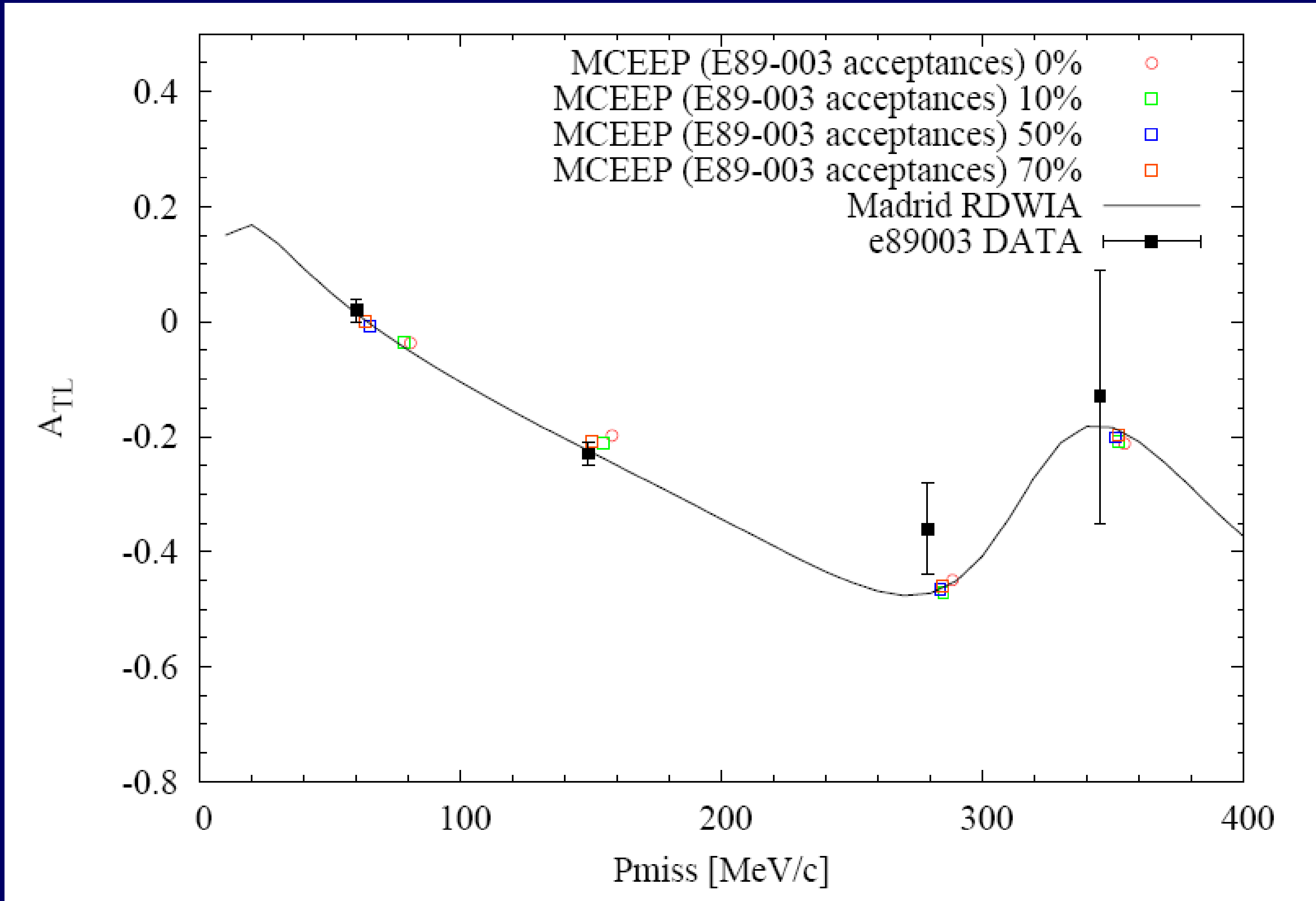


R_{TL}

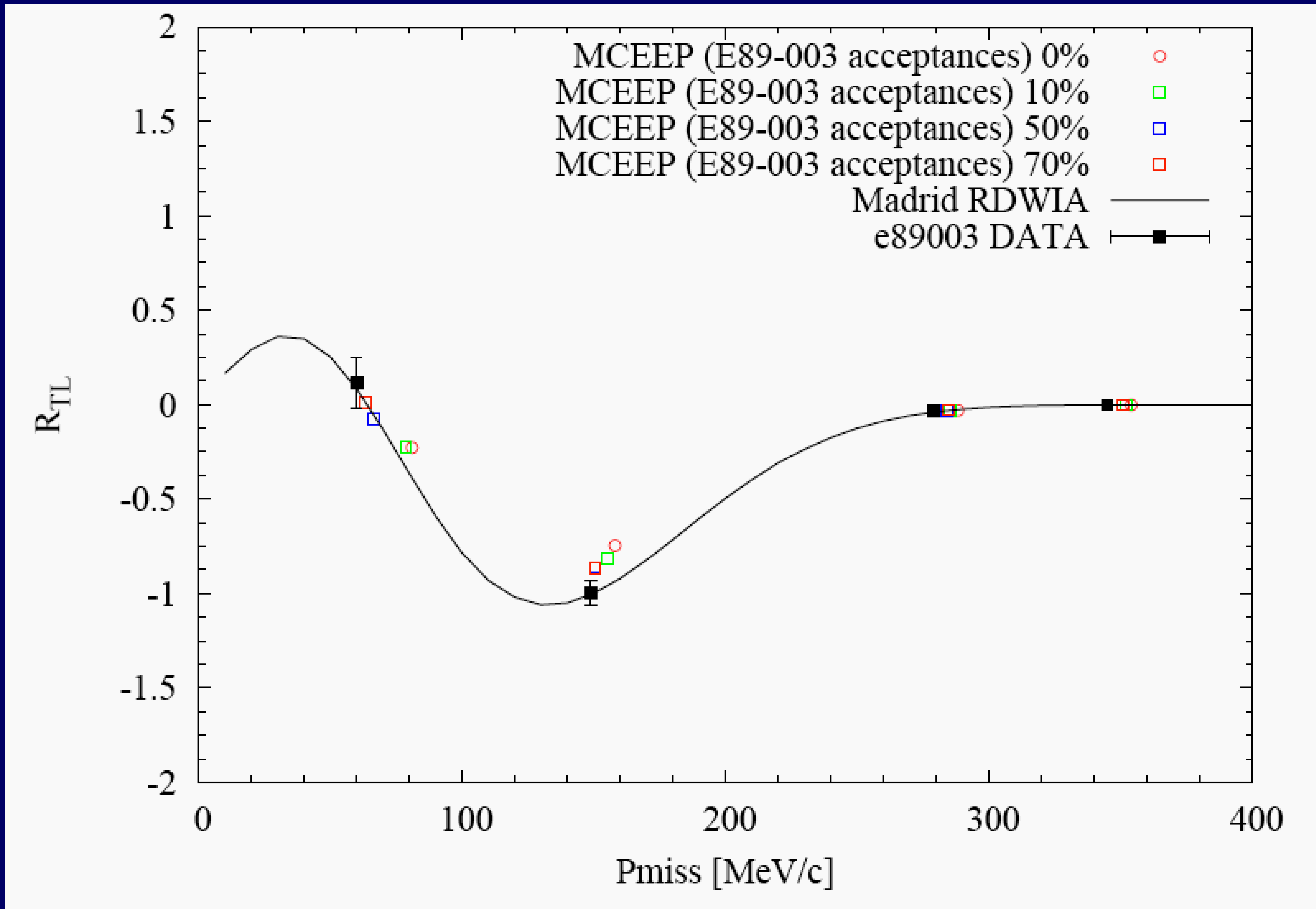
$$R_{TL} = \frac{1}{2 v_{LT} K \sigma_{\mathrm{Mott}}} \left[\sigma(\phi = 0^\circ) - \sigma(\phi = 180^\circ) \right]$$



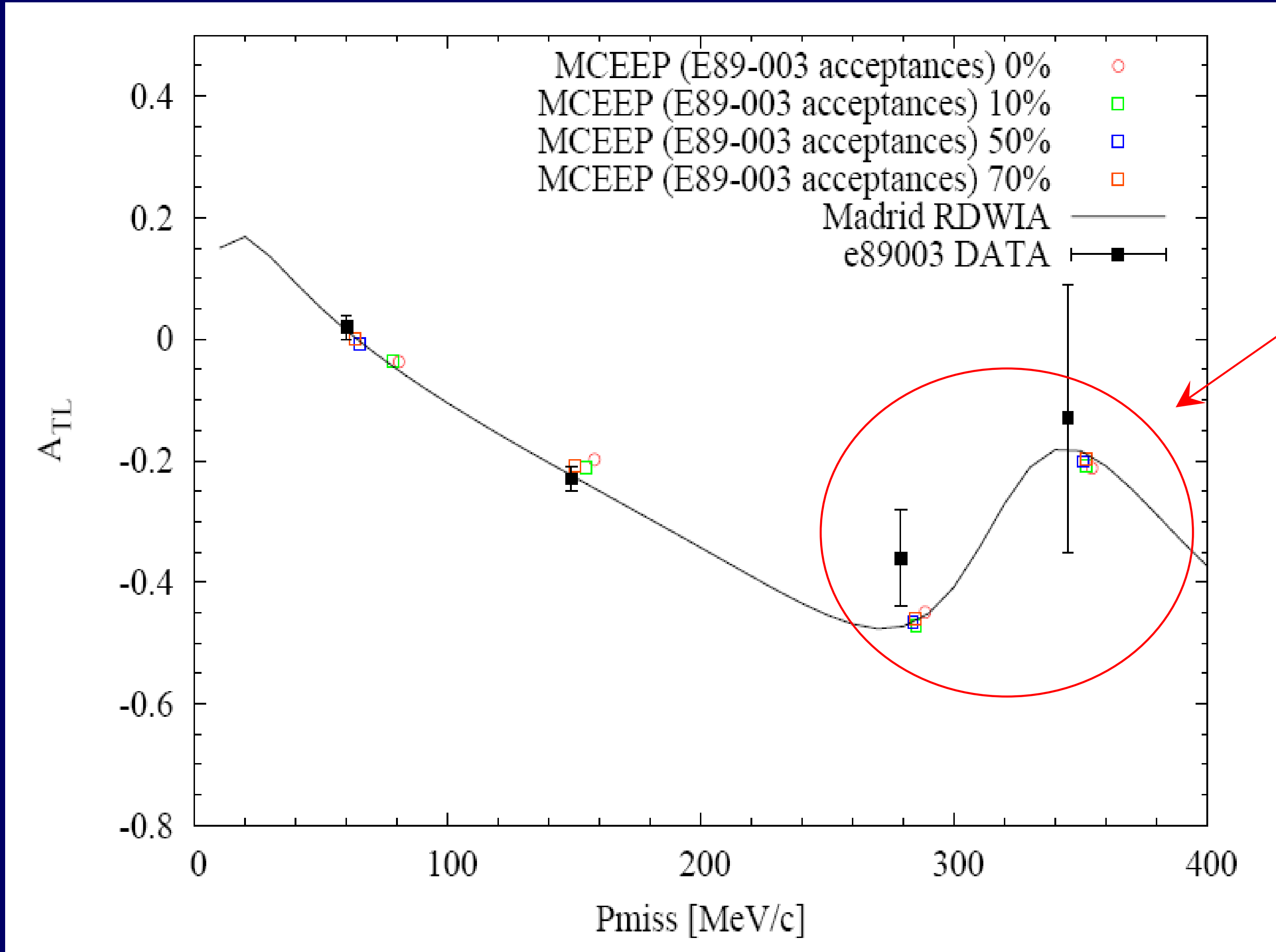
A_{TL} – Dependence on the criteria applied to the data during the analysis



R_{TL} – Dependence on the criteria applied to the data during the analysis



Dependence on the criteria applied to the data during the analysis



At high p_{miss} it can be seen that it is not necessary to be very restrictive with the cuts imposed on the data.

By relaxing this constraint, we anticipate that we can double our available statistics.

Dependence on the criteria applied to the data during the analysis

	θ_{pq}=±20.0°			
$\Delta V/V_{max}$	bins	events (rel)	$< p_{miss} >$ (MeV/c)	A_{TL}
0%	241	1.000	354.1	−0.218
10%	114	0.727	352.5	−0.208
20%	86	0.631	351.3	−0.206
30%	67	0.533	352.3	−0.202
40%	53	0.455	351.7	−0.202
50%	43	0.390	351.2	−0.201
60%	29	0.289	351.9	−0.197
70%	23	0.236	351.0	−0.192
80%	14	0.149	352.7	−0.197
90%	6	0.065	348.5	−0.200

- At high p_{miss} it can be seen that it is not necessary to be very restrictive with the cuts imposed on the data.
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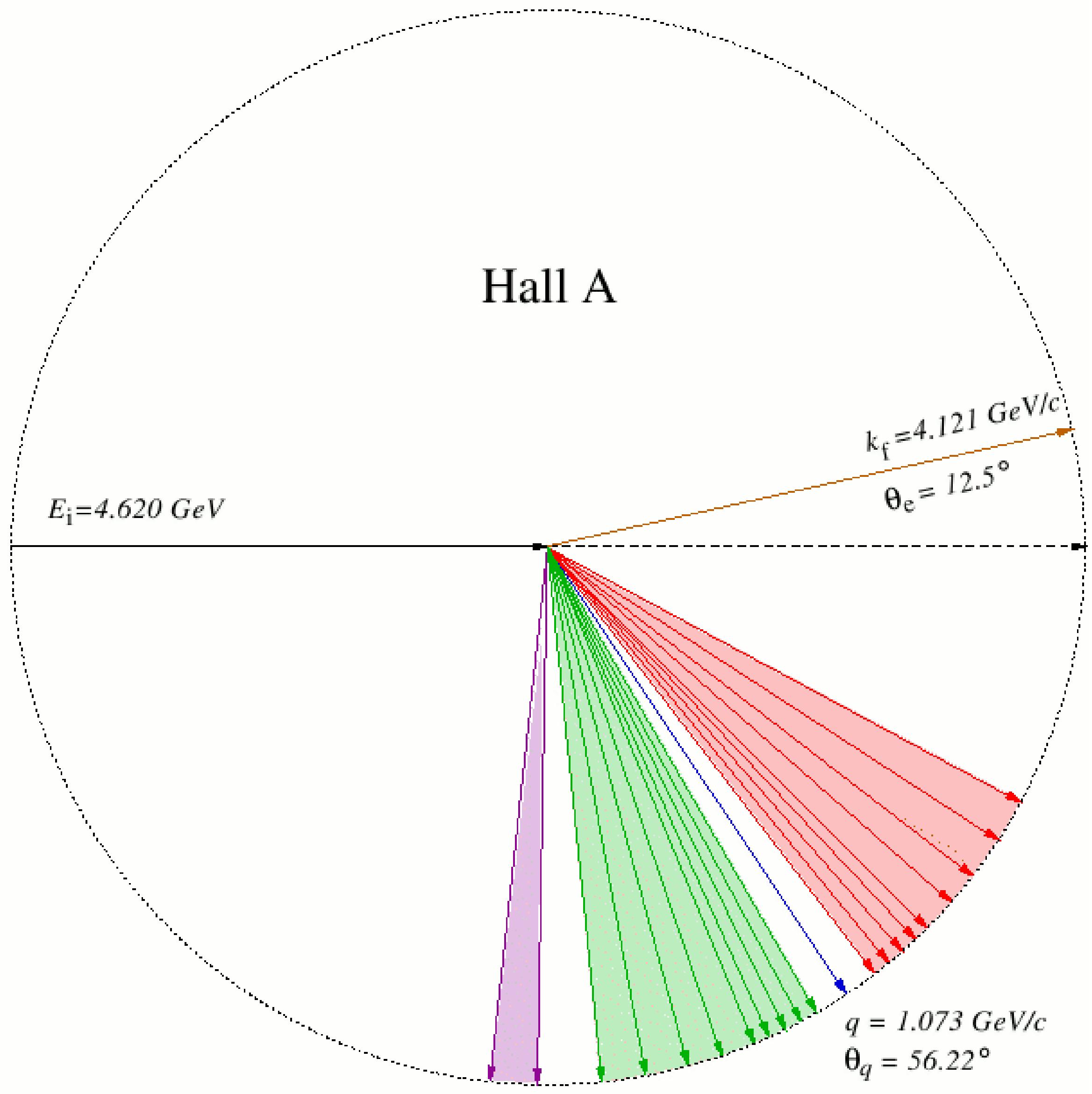
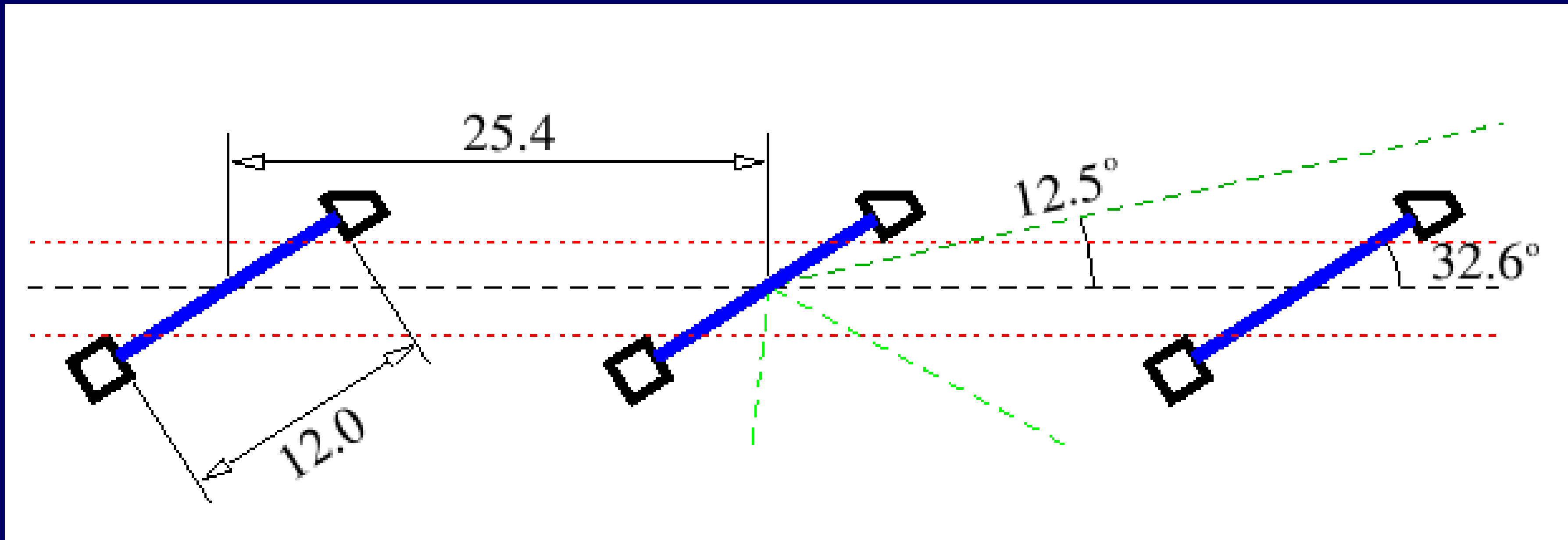
E00-102 KINEMATICS



Measurement	$p_{\rm miss}$ (MeV/c)	$\theta_{\rm pq}$ (deg)	$\theta_{\rm p}$ (deg)
I−	−515	−27.95	28.27
H−	−430	−23.27	32.95
G−	−345	−18.60	37.62
F−	−280	−14.90	41.32
E−	−210	−11.20	45.02
D−	−175	−9.40	46.82
C−	−140	−7.50	48.72
B−	−105	−5.60	50.62
A−	−70	−3.75	52.47
q	0	0	56.22
A+	+70	+3.75	59.97
B+	+105	+5.60	61.82
C+	+140	+7.50	63.72
D+	+175	+9.40	65.62
E+	+210	+11.20	67.42
F+	+280	+14.90	71.12
G+	+345	+18.60	74.82
H+	+430	+23.27	79.49
I+	+515	+27.95	84.17
J+	+635	+34.87	91.09
K+	+725	+39.88	96.19

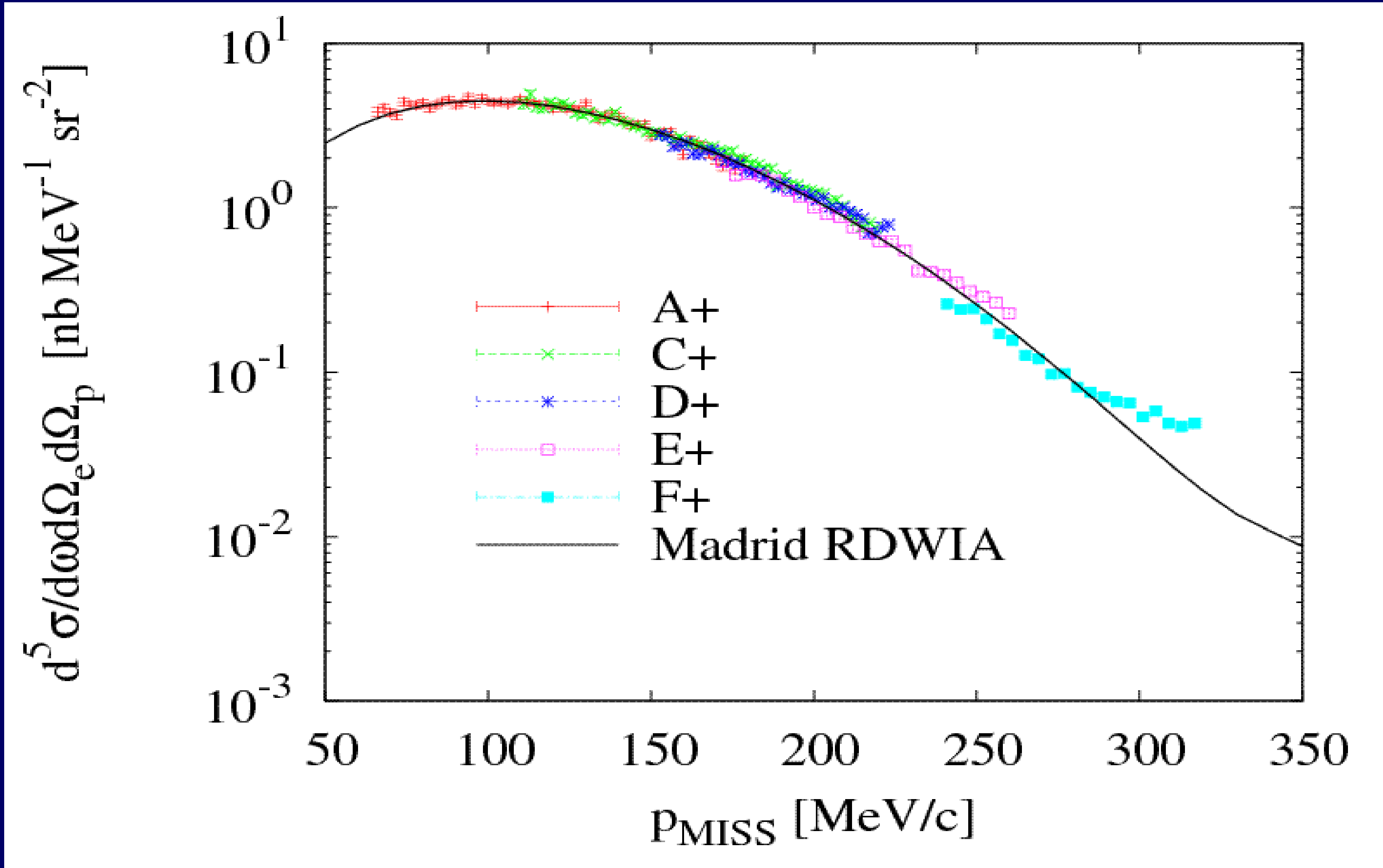
E00-102 TARGET



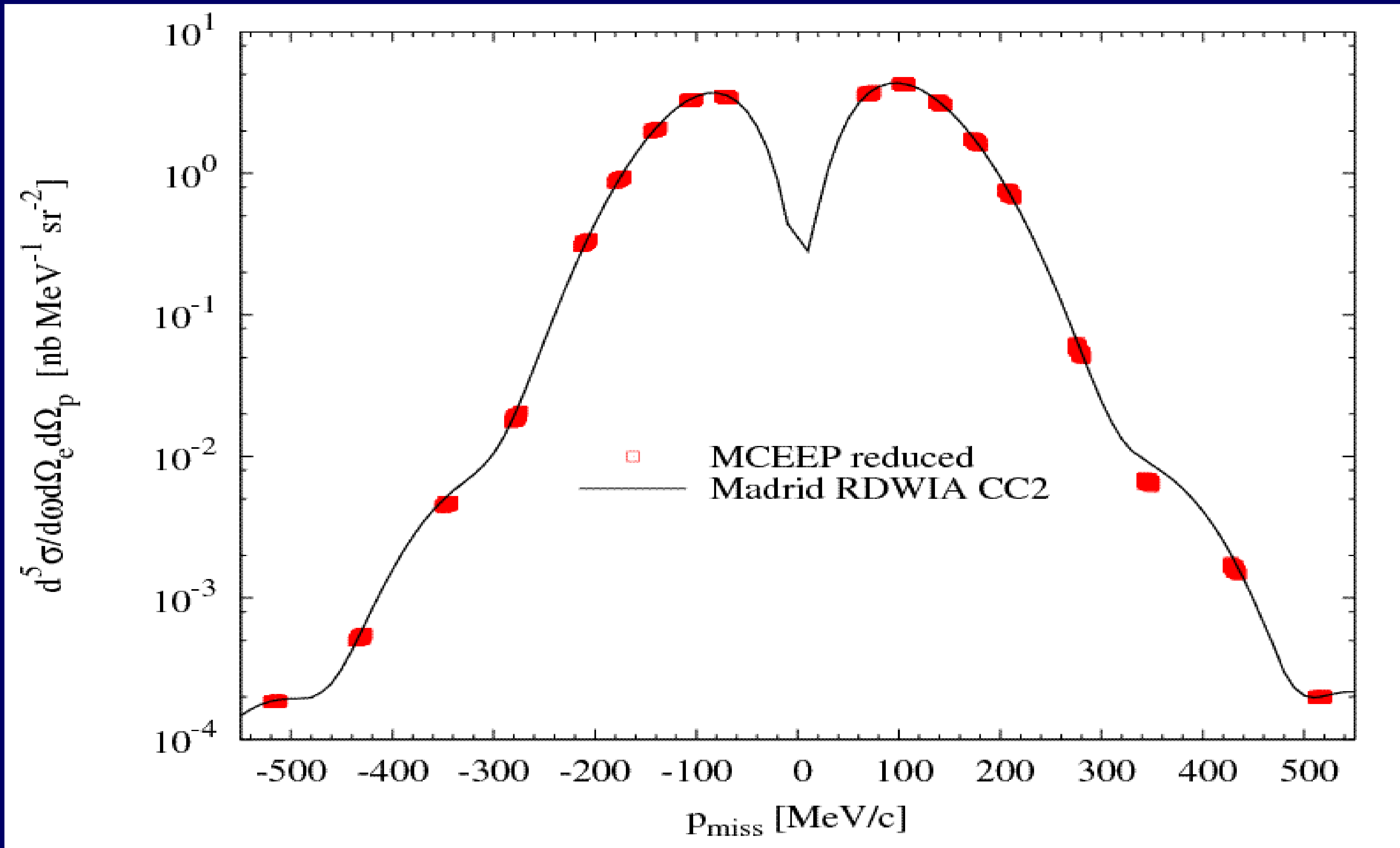
E00-102 TARGET:

3 WATER FOILS

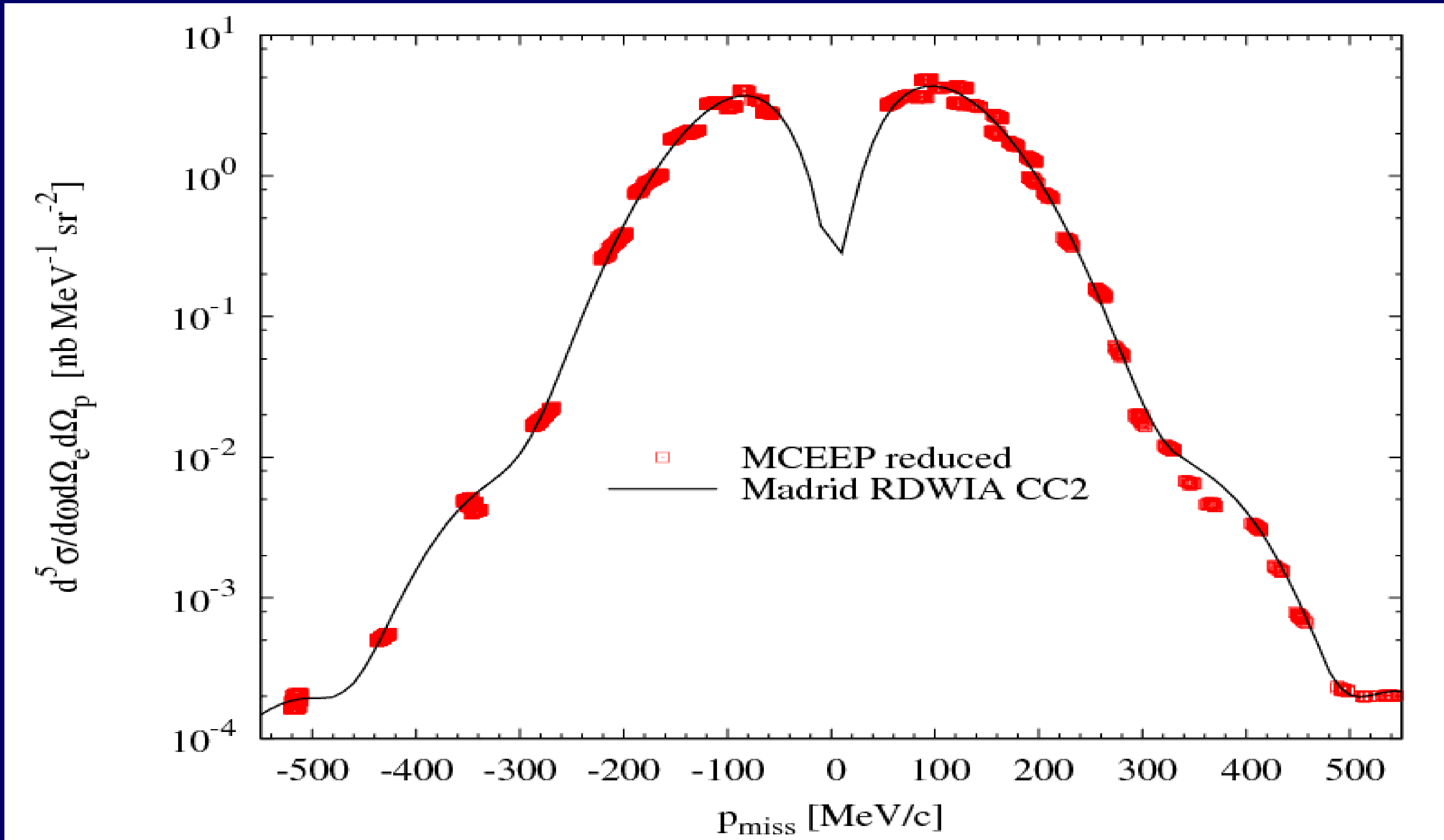
MATTIAS ANDERSSON MASTER THESIS RESULTS



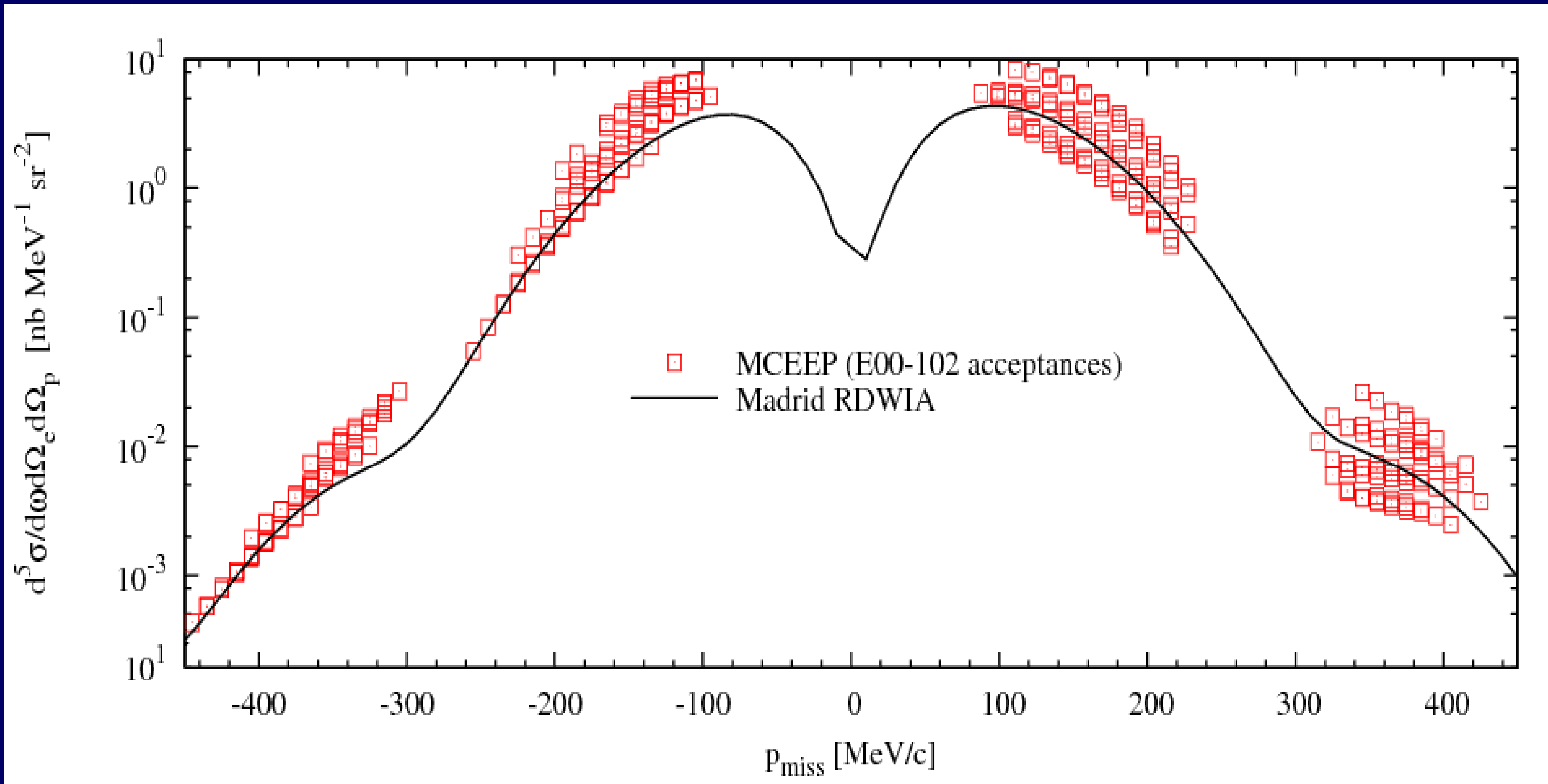
CROSS SECTION: 1 FOIL
(EXTREMELY REDUCED ACCEPTANCES)



CROSS SECTION: 3 FOILS
(EXTREMELY REDUCED ACCEPTANCES)



E00-102 ACCEPTANCES



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FOLLOWING STEPS: SIMULATIONS

- Include more effects in the simulations:
  - Radiative effects
  - Contamination of the ^{16}O data by ^{1}H

- Compare the results with other Monte Carlo codes (GEANT4) [Konrad Aniol]

FOLLOWING STEPS:
DATA ANALYSIS AND SIMULATIONS

- Study which are the optimal cuts
- Study the optimal binning of the data
- Study of criteria imposed on the data bins

CONCLUSIONS

- We have described a method for combining a Monte Carlo simulation software (Mceep) and our RDWIA code for the calculation of (e,e'p) reactions.
- With this procedure we can make use of a fully relativistic code with realistic kinematics and experimental acceptances, without extremely long computational time.
- The results of this approach have been validated against data from an already analyzed ^{16}O(e,e'p) experiment in quasielastic kinematics.
- The method is ready for the analysis of similar experiments [E00-102 and E06-007].

ACKNOWLEDGMENTS

- J.R. Vignote acknowledges S. Strauch his fruitful collaboration during his visit to Jlab and further years.
- Kevin Fissum acknowledges Paul Ulmer support with Mceep.
- J.L.Herraiz acknowledges the other authors his support in countless discussions and specially Kevin Fissum for his kind support in Lund, where most of this work was done.