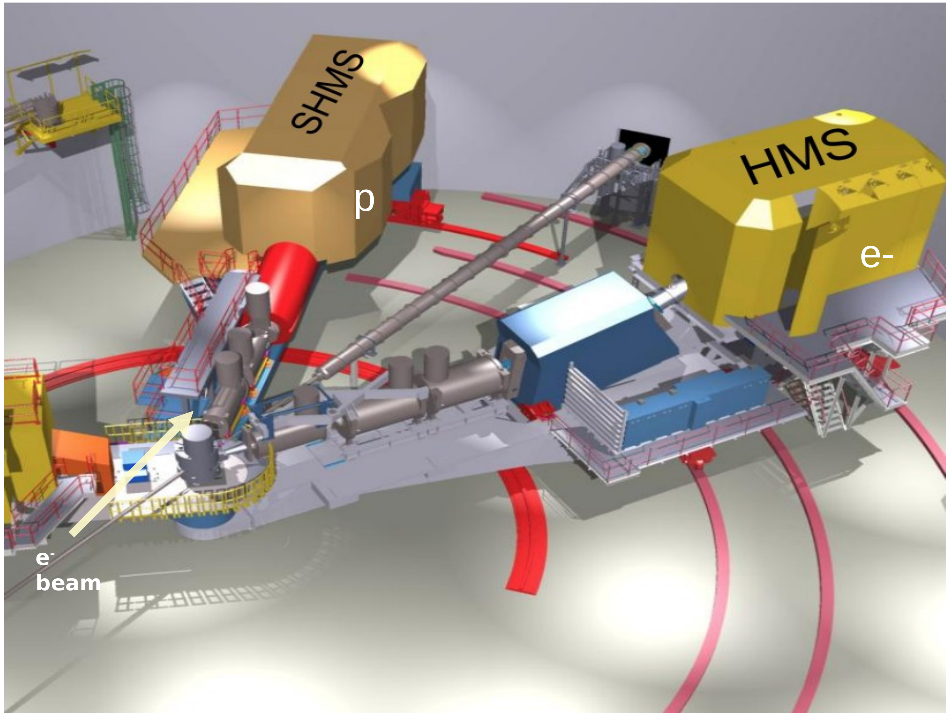
(1s/1p) SHELL DEPENDENCE ON TRANSPARENCY IN E12-06-107



Deepak Bhetuwal

Mississippi State University

Hall C Collaboration Meeting (Virtual)

Jan 29, 2021

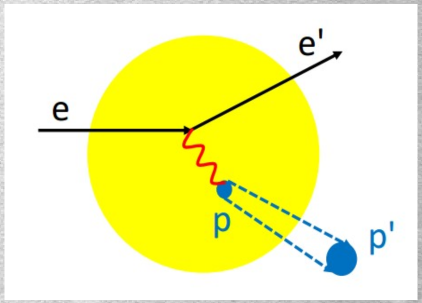
INTRODUCTION

Color transparency (CT) is a a unique prediction of Quantum Chromo Dynamics (QCD) where the final (and/or initial) state interactions of hadrons with the nuclear medium are suppressed for **exclusive processes** at high momentum transfers squared(Q^2).

A clear signal for the onset of CT for baryons would show the transition from the nucleon-meson picture to quark-gluon degrees of freedom → **Onset is signature for QCD degrees of freedom in nuclei.**

- Introduced by Mueller and Brodsky, 1982. It arises in picture of quark-gluon interactions only.
- Basically, CT takes place in the following 3 steps:

  - **Squeezing (QM)**.
  - **Freezing (Relativity)**.
  - **Reduced interaction due to Color Screening (Strong force / QCD)**.



A(e, e'p)

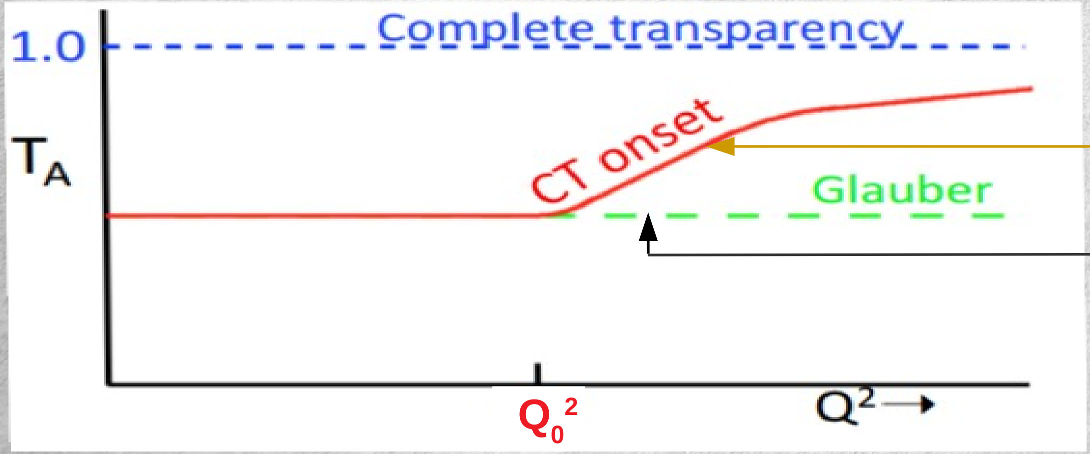
CT ONSET

Signature for the onset of CT involves a rise in nuclear transparency (T_A), as a function of the momentum transfer (Q^2).

$$T_A = \frac{\sigma_A}{A\ \sigma_N}$$ (nuclear cross section) / (free nucleon cross section)

$\sigma_A/A \rightarrow$ bound nucleon cross section

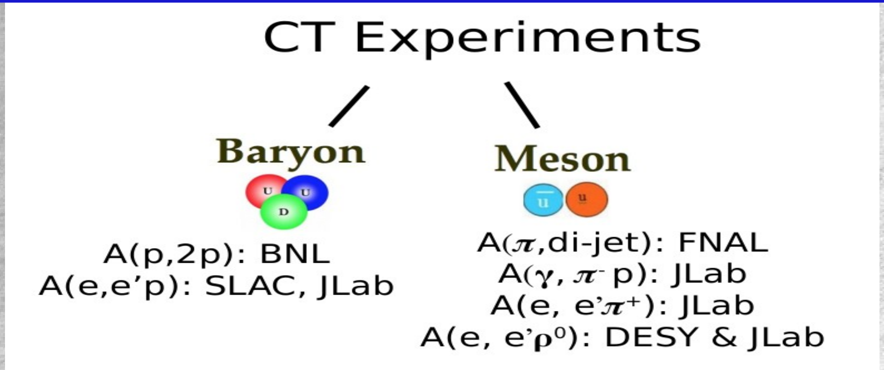
Clear onset of CT would be dramatic rise in T around some Q_0^2

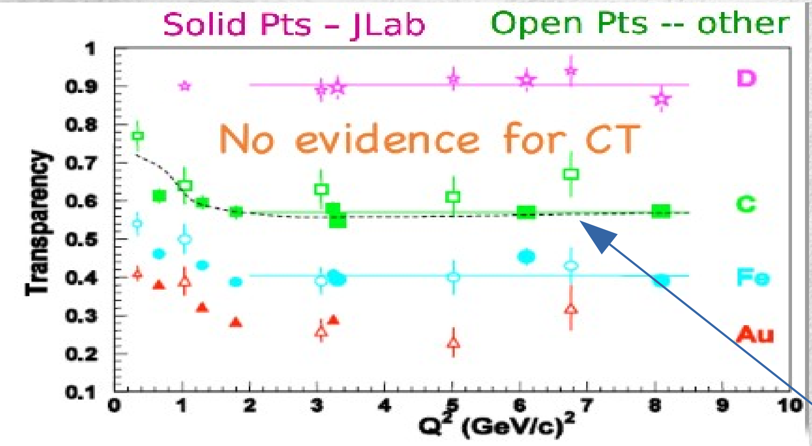


QCD prediction

Traditional nuclear physics prediction
OR
Glauber calculations

CT PAST EXPERIMENTS / RESULTS





PROTON

A(e,e'p) results consistent with standard nuclear physics

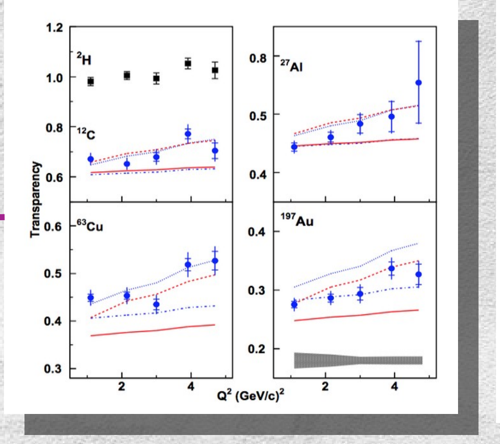
N. C. R. Makins et al. PRL 72, 1986 (1994)
G. Garino et al. PRC 45, 780 (1992)
D. Abbott et al. PRL 80, 5072 (1998)
K. Garrow et al. PRC 66, 044613 (2002)

Plateau consistent with conventional calculations …

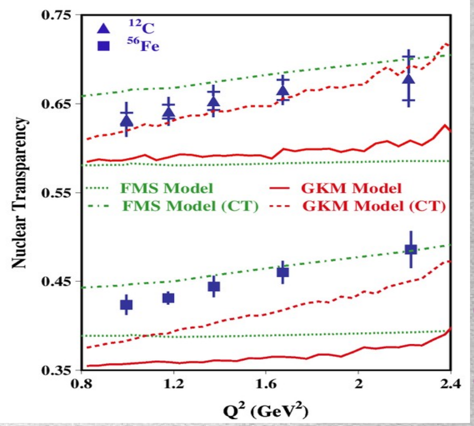
PION

RHO

Hall C E01-107 pion electroproduction



B.Clasie *et al.* PRL 99:242502 (2007) X. Qian *et al.* PRC81:055209 (2010)



L. El Fassi *et al.* PLB 712,326 (2012)

CLAS E02-110 rho electroproduction

CT is well established at high energies [essential for x – scaling in Deep Inelastic Scattering (DIS)].

Onset of CT has been measured in Mesons but not in Baryons.

CT EXPERIMENT: E12-06-107

The experiment E12-06-107

First experiment to run in Hall C in the 12 GeV era

Coincidence trigger: SHMS measures protons,
HMS measures electrons

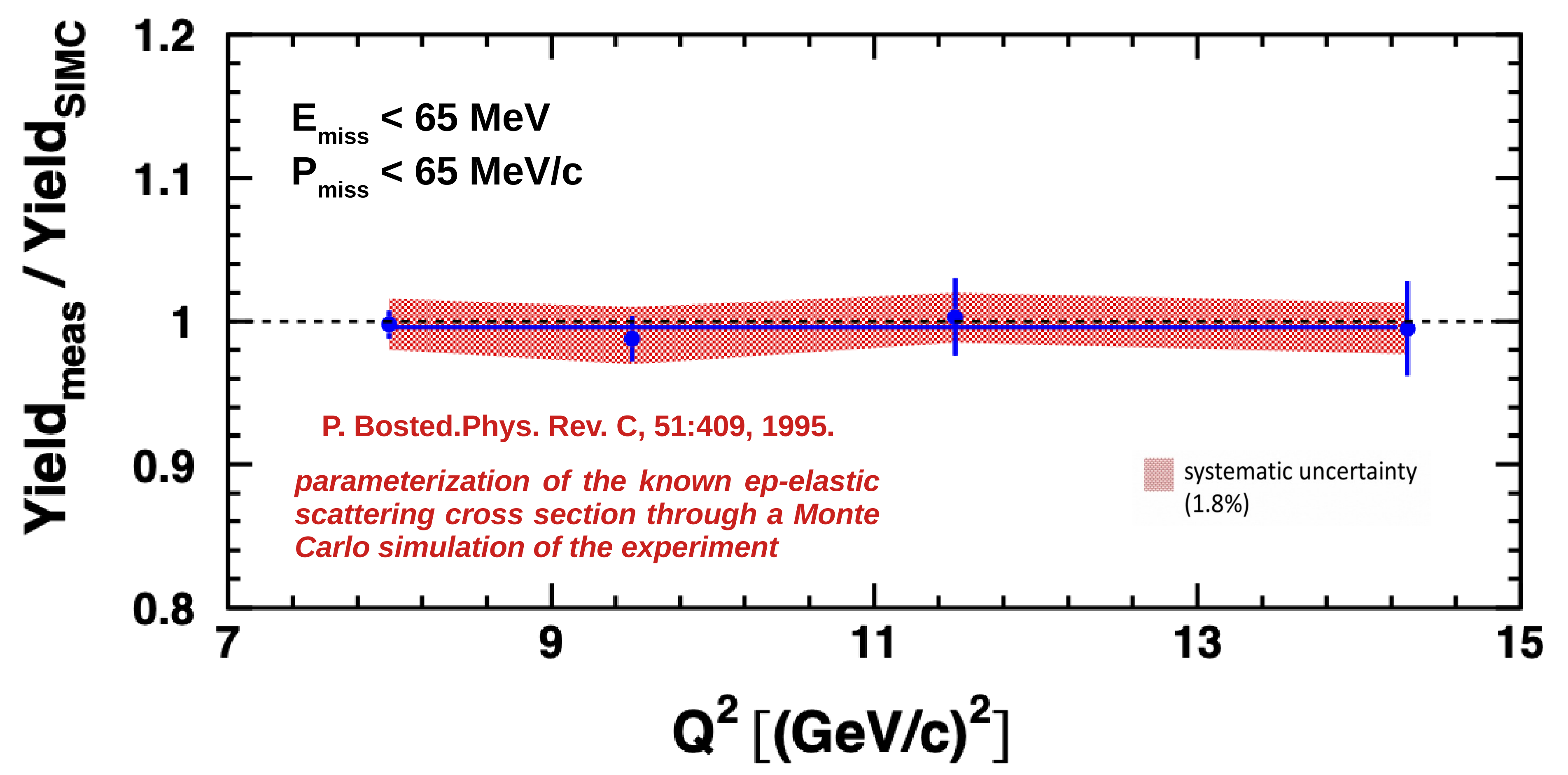
Targets: 10 cm LH_2 ,5% radiation length (r.l.)
^{12}C , 10 cm Al dummy

~20 days, E_{beam} of 6.4 GeV and 10.6 GeV, up to 65 uA of beam current

Data taken with 4 Q^2 points

Beam	Q^2 [GeV^2]	SHMS angle [deg]	SHMS central P [GeV/c]	HMS angle [deg]	HMS central P [GeV/c]
6.4 GeV beam	8.0	17.1	5.030	45.1	2.125
10.6 GeV beam	9.4	21.6	5.830	23.2	5.481
	11.4	17.8	6.882	28.5	4.451
	14.2	12.8	8.352	39.3	2.970

HYDROGEN NORMALIZATION

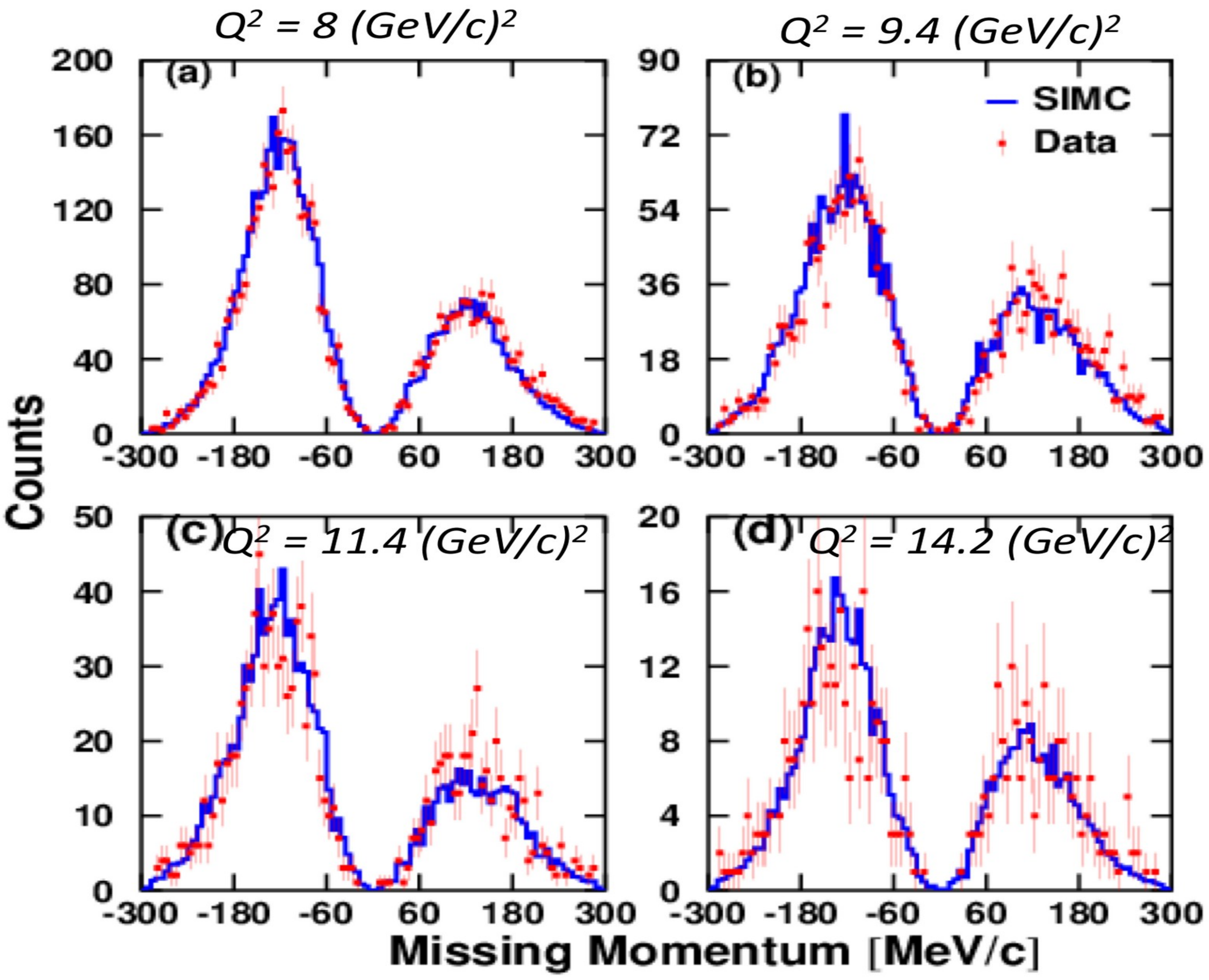


MISSING MOMENTUM (^{12}C)- P_{miss}

Standard Hall C Monte Carlo - SIMC

- **Optics (COSY) and spectrometer apertures**
- **Radiative corrections, multiple scattering, ionization energy loss, particle decay**
- **Prescriptions for FSI, coulomb corrections, off shell corrections**
- **Parametrization of**
  elastic ep scattering cross section
  +
  ^{12}C spectral function

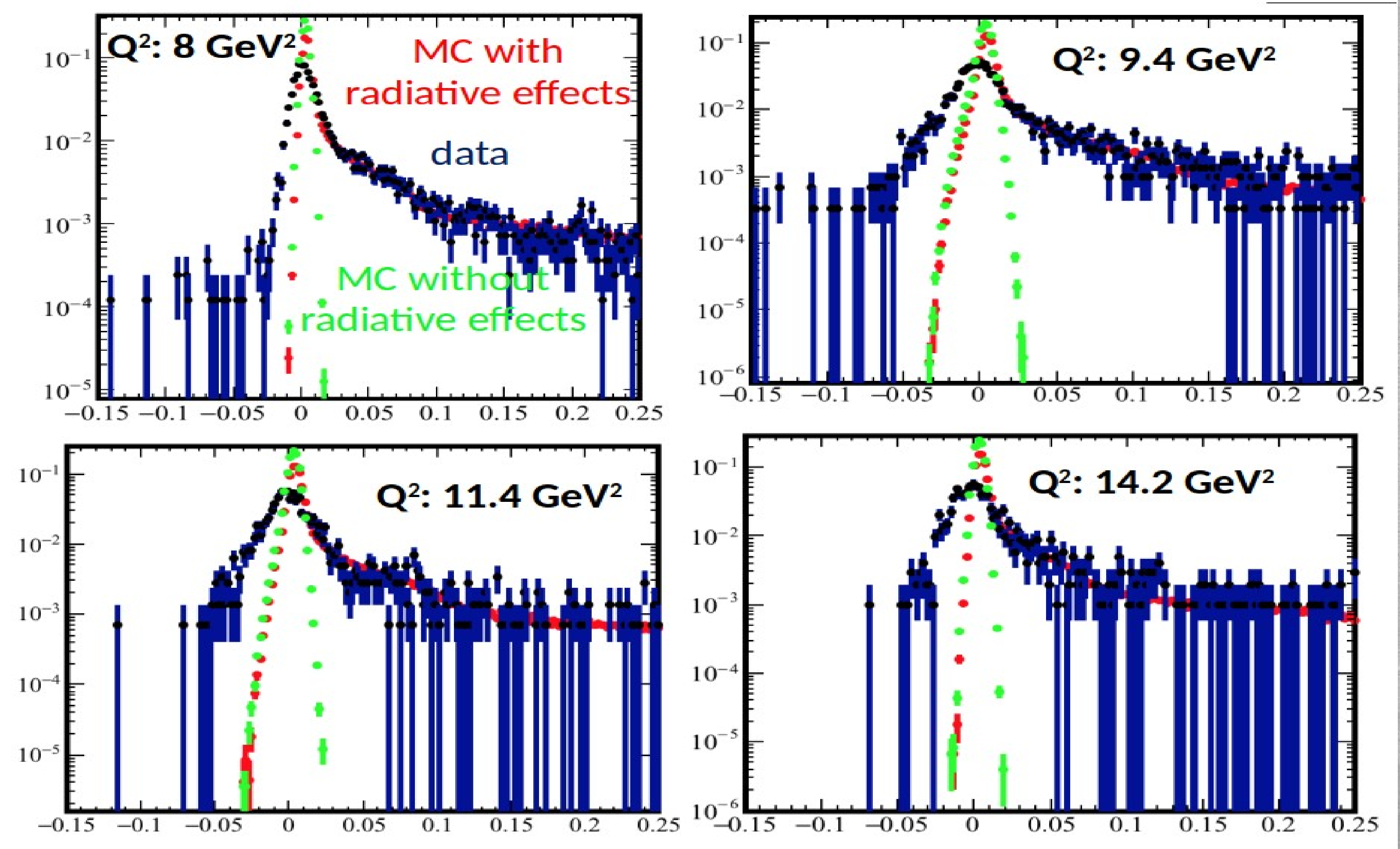
$$\frac{d^6\sigma}{dE_{e'}d\Omega_{e'}dE_{p'}d\Omega_{p'}} = E_{p'}|p_{p'}|\sigma_{ep}S(E_m,\vec{p}_m)$$



RADIATIVE CORRECTIONS

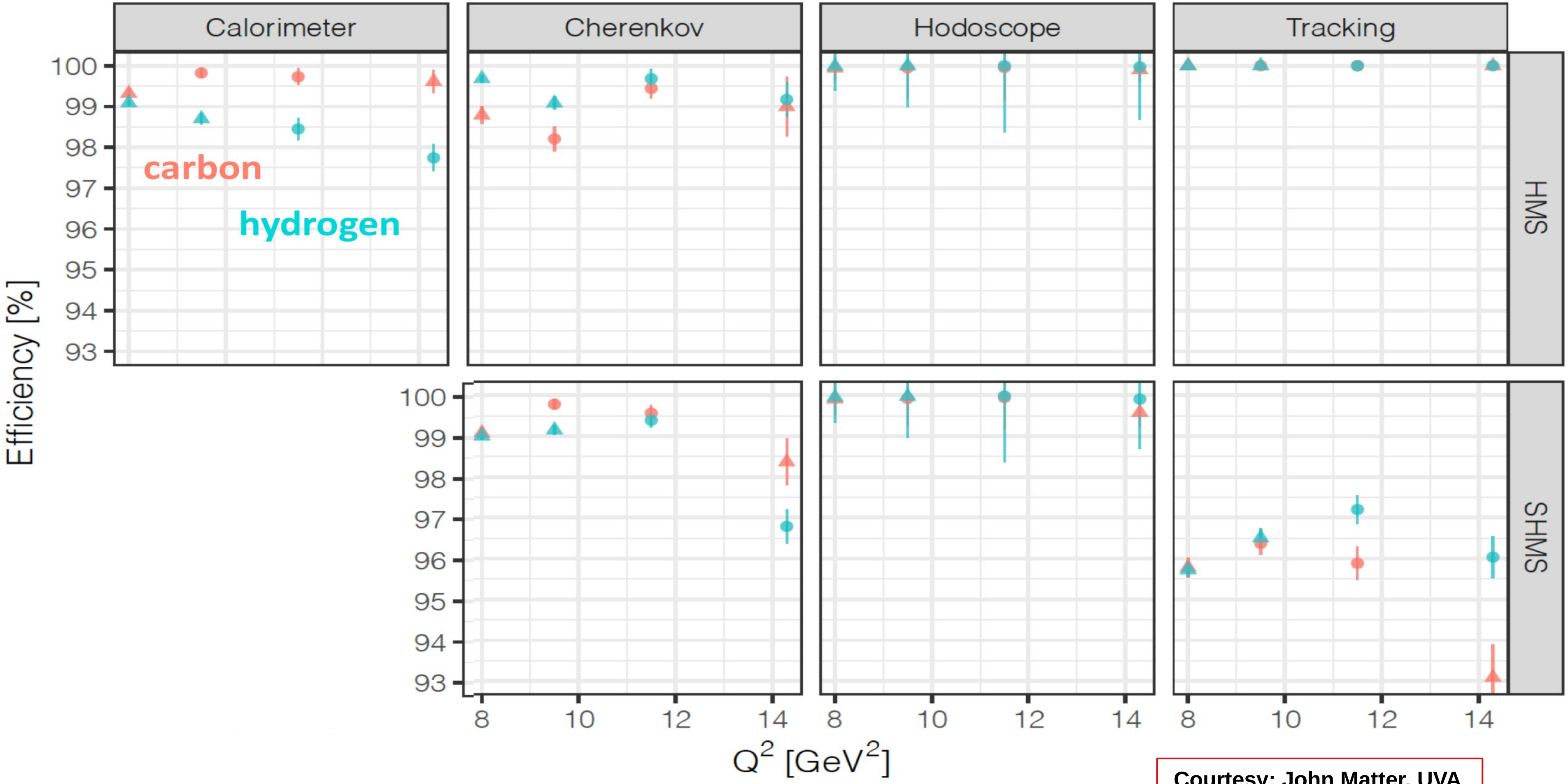
Hydrogen radiative tails: E_{miss} spectra

PWIA model in Monte Carlo (SIMC) is in agreement with Radiative effects in data



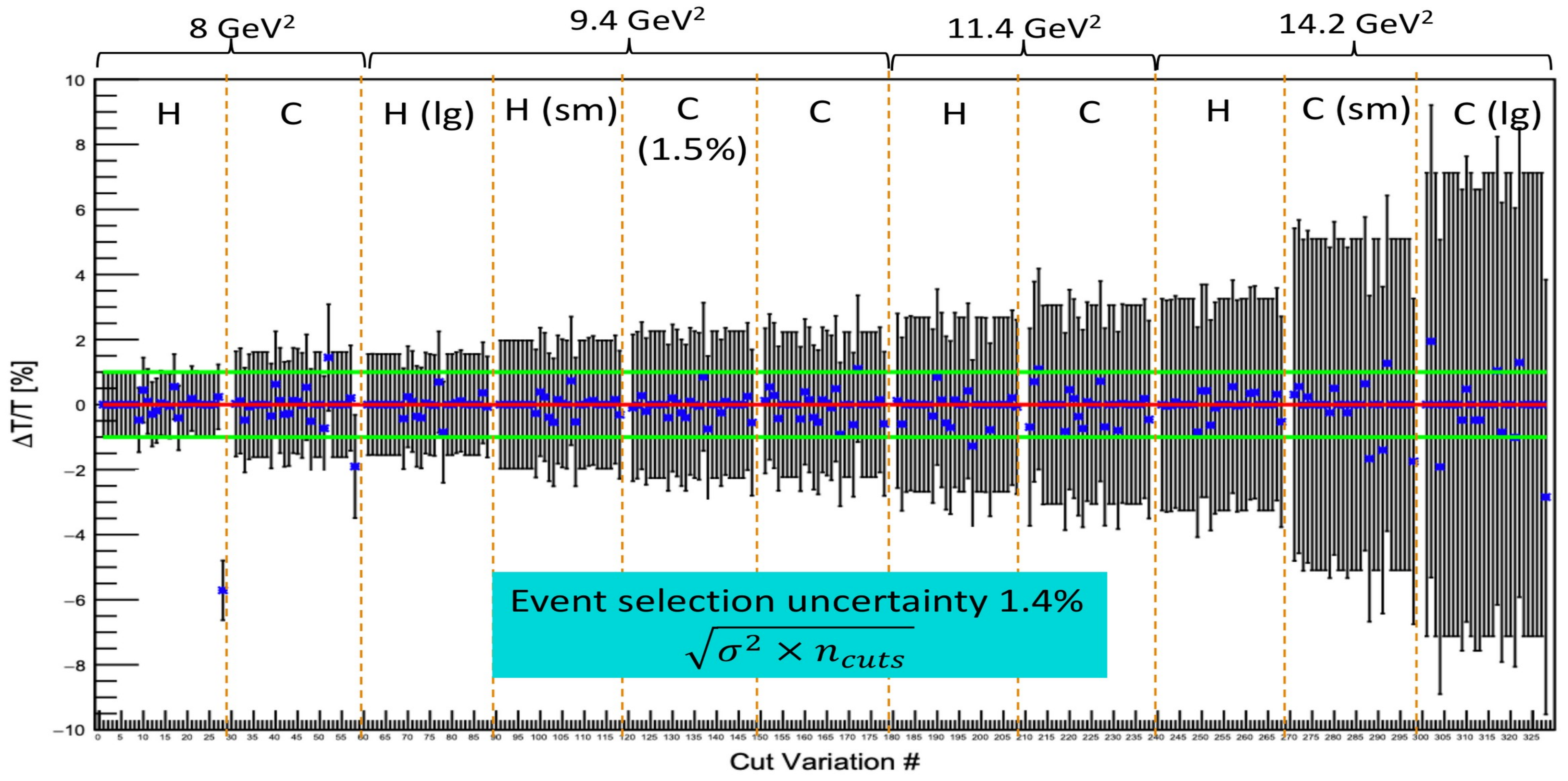
Courtesy: Holly Szumila-Vance, JLab

DETECTOR EFFICIENCY



Courtesy: John Matter, UVA

CUT DEPENDENCE STUDY (+/- 10%)

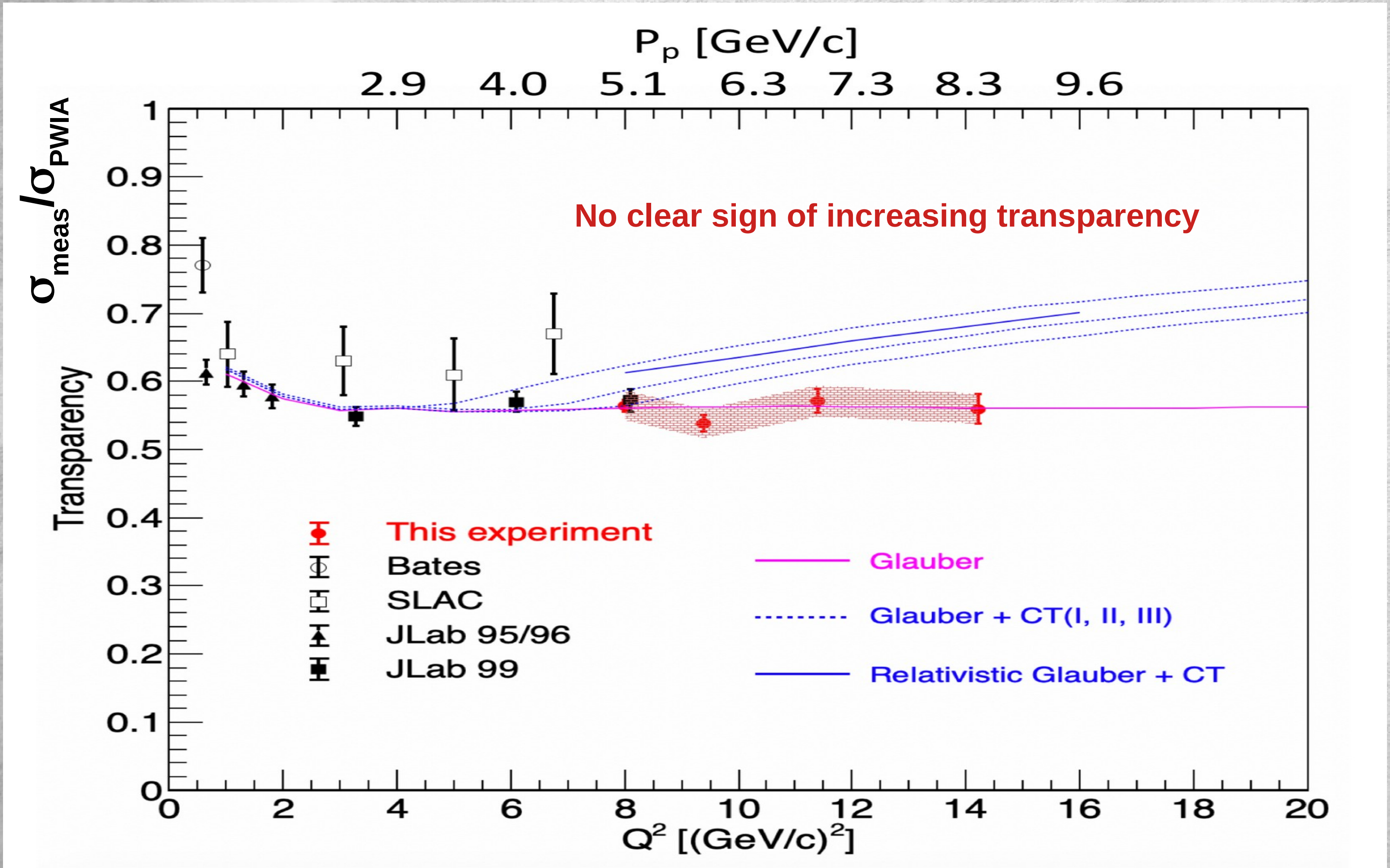


Varied cuts on β, δ, Cerenkov, calorimeter, E_{miss}, P_{miss}

SYSTEMATIC UNCERTAINTY

Source	Q^2 dependent uncertainty (%)
Spectrometer acceptance	2.6
Event selection	1.4
Tracking efficiency	0.5
Radiative corrections	1.0
Live time & Det. efficiency	0.5
Source	**Normalization uncertainty (%)**
Free cross section	1.8
Target thickness	0.5
Beam charge	1.0
Proton absorption	1.2
Total	4.0

TRANSPARENCY



This result is appearing in PRL

E_{miss} < 80 MeV
P_{miss} < 300 MeV/c

Systematic Uncertainty

4 %

SHELL TRANSPARENCY

COLOR TRANSPARENCY EFFECTS FOR HOLE EXCITATIONS IN A(e, e′p) REACTIONS

L.L. FRANKFURT, M.I. STRIKMAN and M.B. ZHALOV

Leningrad Nuclear Physics Institute, 188350, Gatchina, USSR

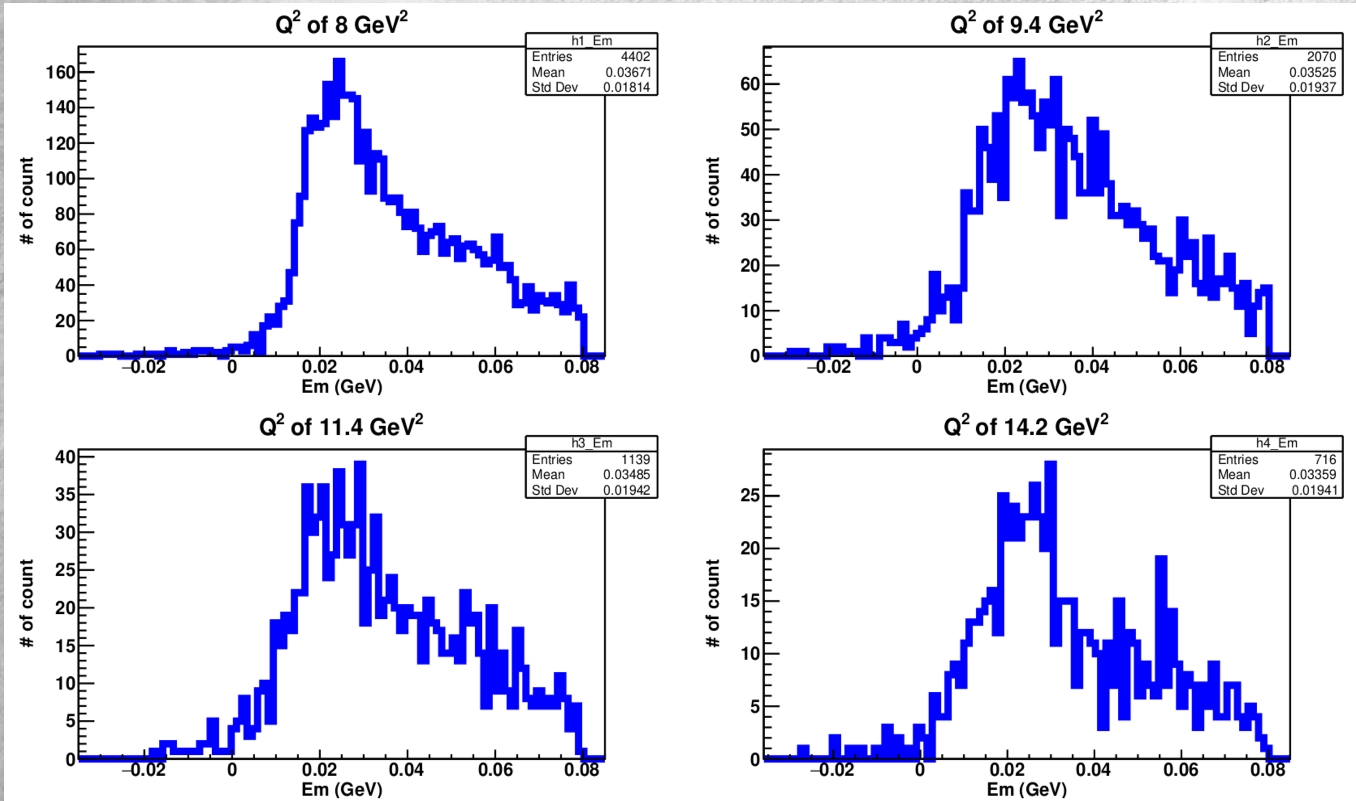
Received 20 February 1990

Abstract: The color transparency effect is estimated for the hole excitation of the levels in high-Q^2 A(e, e′p) reactions which can be studied in the high-resolution experiments at CEBAF. We find that the optimal strategy in a wide Q^2 range where the effect is expected to be rather small would be to study transitions to the s-levels because (i) the effect is significantly enhanced for these transitions, (ii) the cross section in the absence of the color transparency effect can be reliably calculated for small nucleon momenta, (iii) the off-shell effects in the discussed kinematics are small.

L. Frankfurt, M. Strikman, and M. Zhalov, Nuclear Physics A, vol. 515, no. 4, 1990, pp. 599–608.

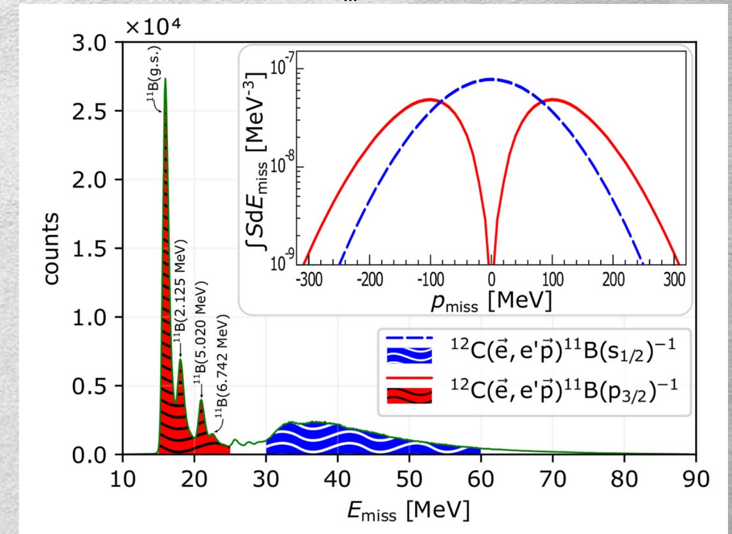
MISSING ENERGY

$Q^2\,[\mathrm{GeV^2/c^2}]$	0.40
$p_{\mathrm{miss}}\,[\mathrm{MeV/c}]$	-130 to 100
$p_e\,[\mathrm{MeV/c}]$	385
$\theta_e\,[\mathrm{deg}]$	82.4
$p_p\,[\mathrm{MeV/c}]$	668
$\theta_p\,[\mathrm{deg}]$	-34.7
# of events after cuts	1.7 M



~10 μA, 600 MeV CW polarized e⁻ beam

Q^2 = 0.4 (GeV/c)^2, proton E_m plot for ^{12}C(e,e'p) at the MAMI



D. Izraeli et al.,Physics Letters B, vol. 781,Jun 2018, p. 95–98

Spectrometer resolution of ~0.1% → 2-5.5 MeV resolution

MISSING ENERGY – CONTD.

$Q^2\,[\mathrm{GeV}^2/\mathrm{c}^2]$	0.40
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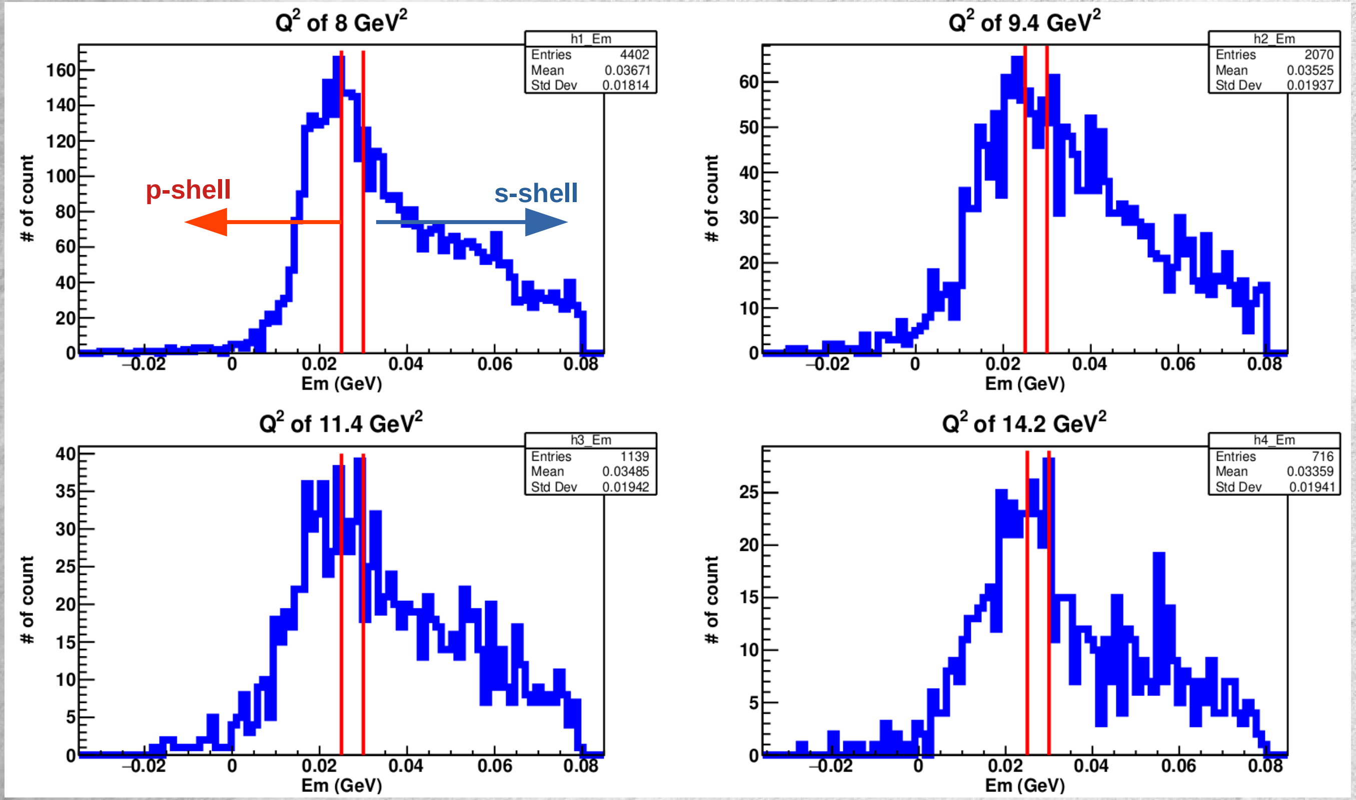
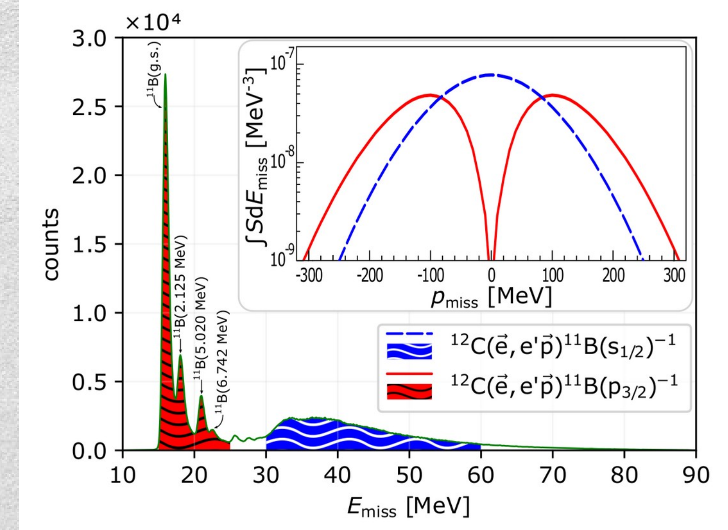


~10 μA, 600 MeV CW polarized e^- beam

$Q^2 = 0.4\ (\mathrm{GeV/c})^2$, proton E_m plot for $^{12}C(e,e'p)$ at the MAMI



D. Izraeli et al.,Physics Letters B, vol. 781,Jun 2018, p. 95–98

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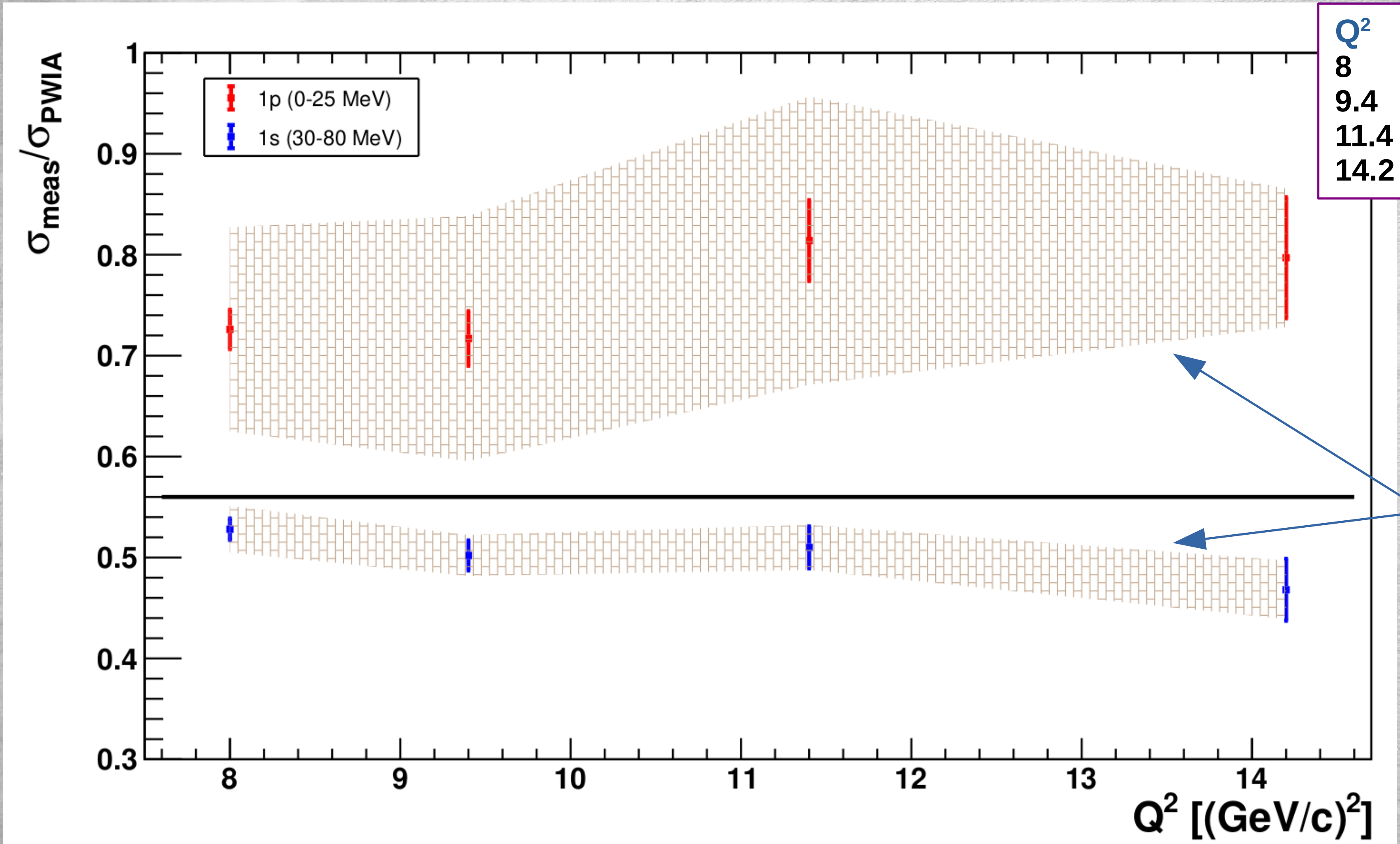
SHELL DEPENDENT TRANSPARENCY



Q^2	1p (%)	1s (%)
8	13.36	1.7
9.4	16.46	0.4
11.4	17.08	1.76
14.2	7.6	4.7

Uncertainty from Em variation in s/p shell

4% total uncertainty
+
uncertainty from Em variation in s/p shell

STATUS OF THE WORK

- Done with calibration of the detectors, improved HMS and SHMS efficiencies calculation, improved HMS and SHMS optics now.
- Analysis to understand systematic is completed.
- An article has been accepted to PRL for publication.

SUMMARY

- Measuring the onset of CT is a signature for the onset of QCD degrees of freedom in nuclei.
- First experiment to run in the 12 GeV era in Hall C and to take data using both the SHMS and HMS.
- Our results **DO NOT SHOW** the onset of Color transparency in protons up to 14.2 $(GeV/c)^2$, covering all kinematics of previous BNL results (proton momentum, Q^2).
- Future experiments will measure CT effects with different reaction mechanisms and precision.

U.S. DEPARTMENT OF ENERGY | Office of Science

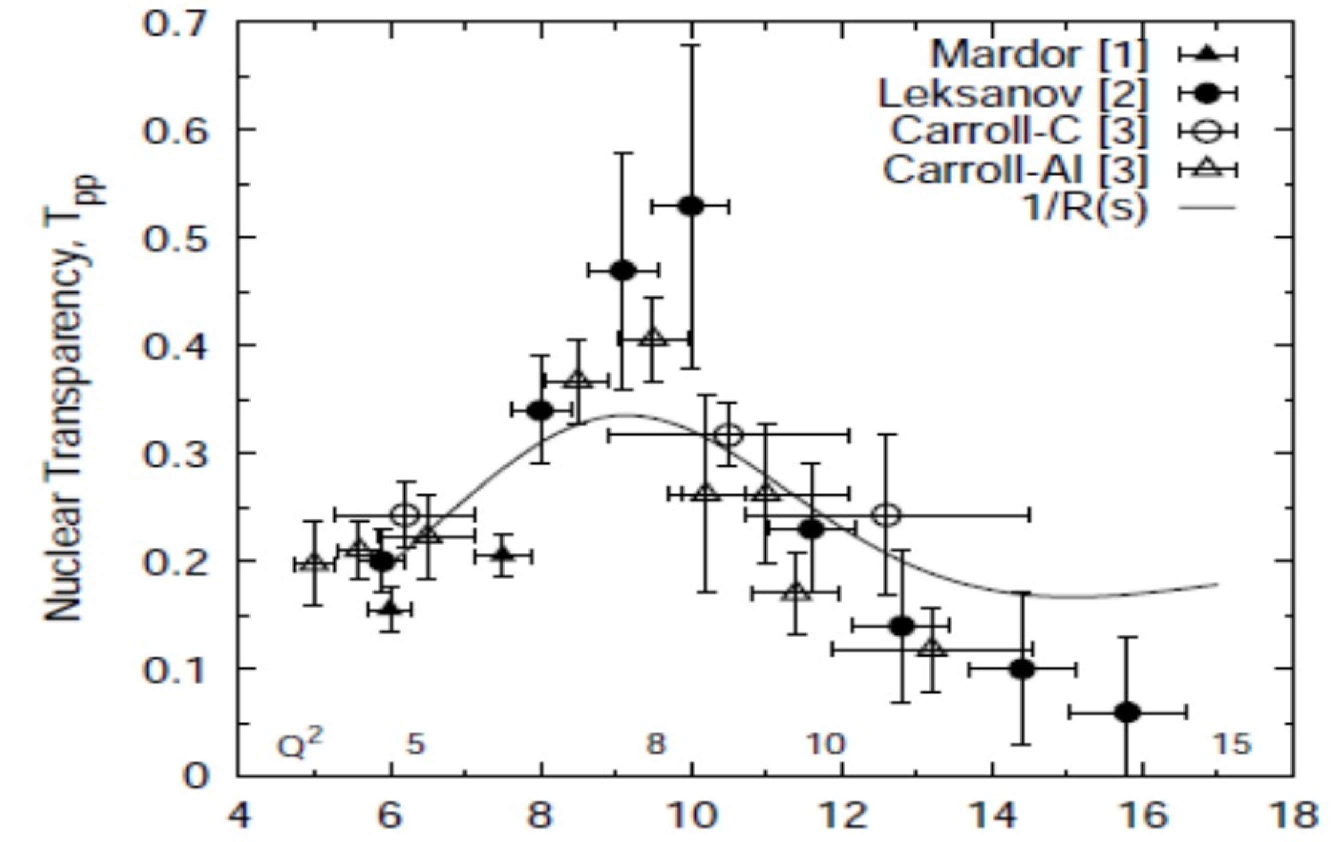
Work supported by DOE office of science
(US DOE Grant Number:
DE-FG02-07ER41528)

Thanks to the Hall C Collaborators!

THANK YOU !

BACK-UPS

CT PAST RESULTS [BNL A(P,2P)]



A. Leksanov et al. PRL 87 (2001)
J. L. S. Aclander et al., PRC 70 (2004)

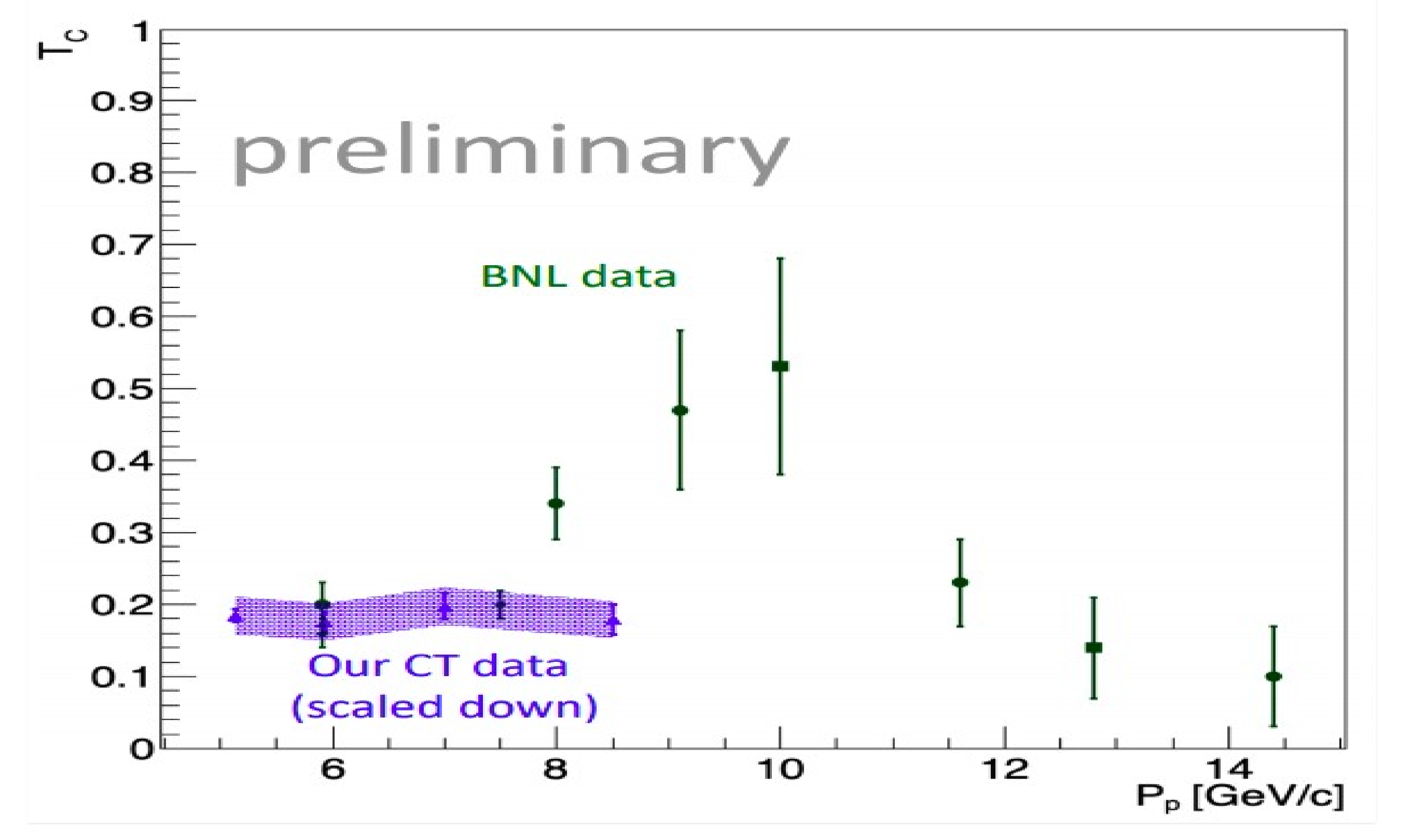
(p, 2p) experiment at BNL found an enhancement in the transparency.

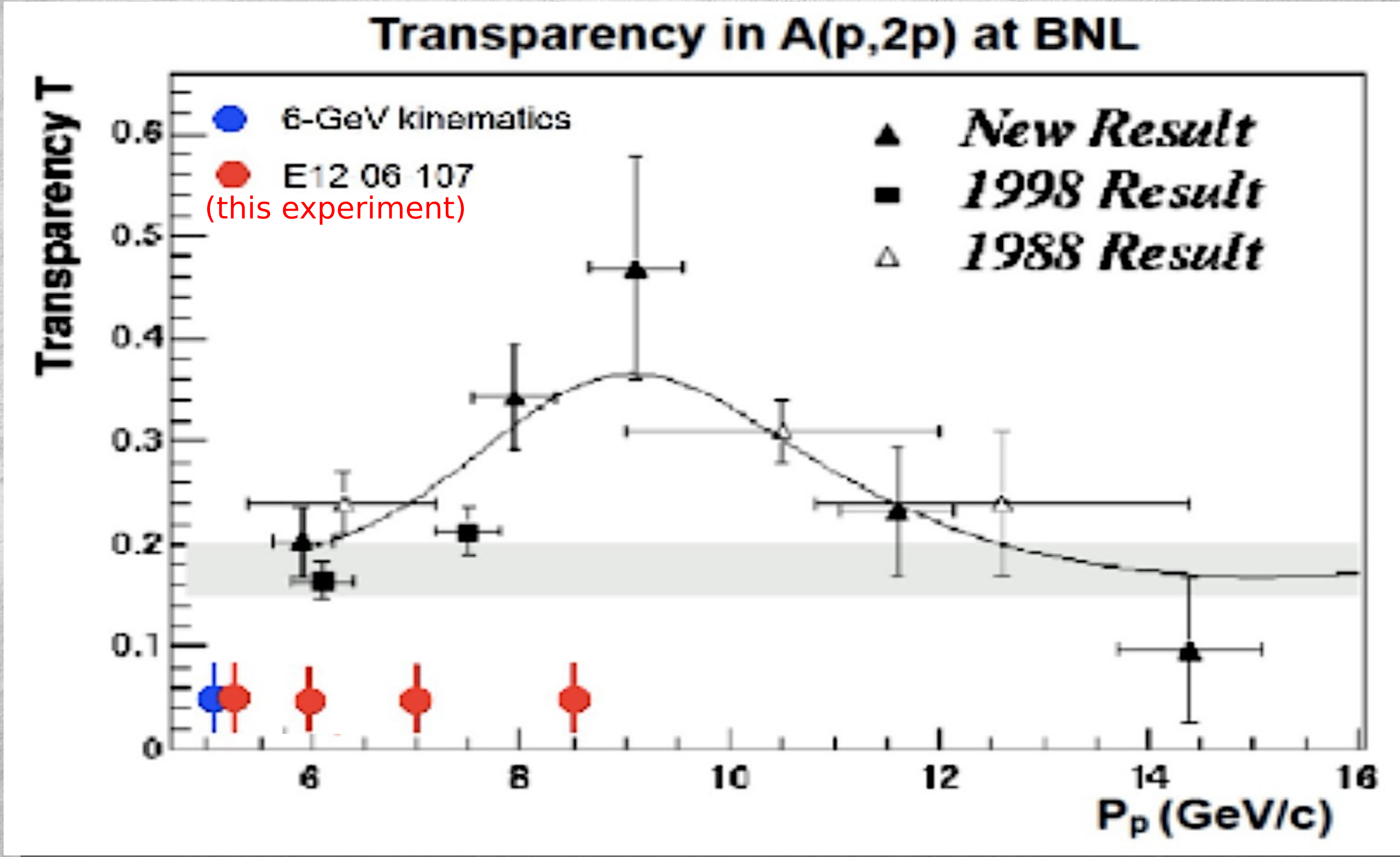
Decreases at higher momentum.

Result inconsistent with CT only.

Can be explained by including additional mechanisms such as nuclear filtering or charm resonance.

CT RESULT VS BNL RESULT [SCALED]




Transparency in A(p,2p) at BNL
Transparency T
6-GeV kinematics
E12 06 107
(this experiment)
New Result
1998 Result
1988 Result
0.6
0.5
0.4
0.3
0.2
0.1
0
6
8
10
12
14
16
Pp (GeV/c)

FRANKFURT ET AL. RESULT

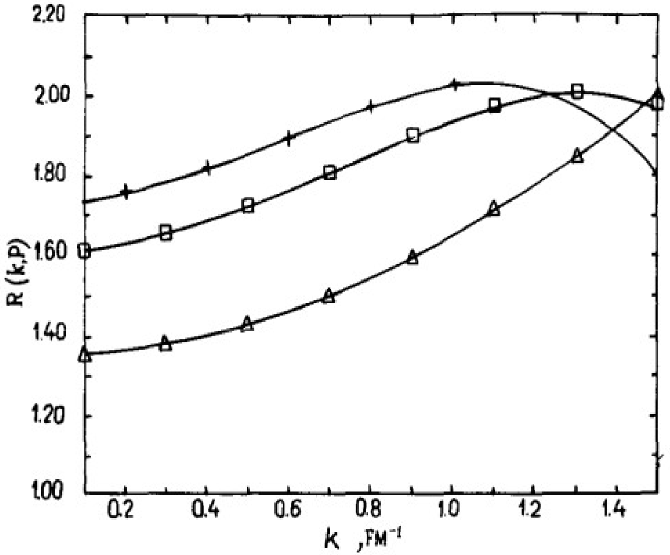


Fig. 5. [12]C(e, ep) reaction; $R(k,p) = F(k,p,v=1)/F(k,p=5\ \mathrm{GeV}/c,\ v=0)$ for $1s_{1/2}$ shell: $p = 5$ GeV/c - curve marked with squares, $p = 10$ GeV/c - curve marked with triangles, $p = 15$ GeV/c - curve marked with plusses.

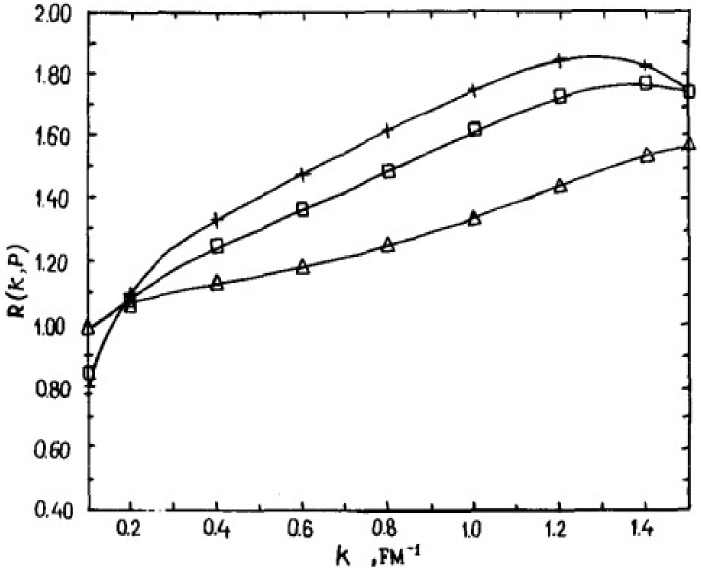


Fig. 6. [12]C(e, ep) reaction; $R(k,p) = F(k,p,v=1)/F(k,p=5\ \mathrm{GeV}/c,\ v=0)$ for $1p_{3/2}$ shell: $p = 5$ GeV/c - curve marked with squares, $p = 10$ GeV/c - curve marked with triangles, $p = 15$ GeV/c - curve marked with plusses.

FRANKFURT ET AL. RESULT – CONTD.

It can be seen from the figures that the color transparency effect is considerably enhanced for transitions to s-holes as compared to the integral nuclear transparency η and especially to the excitation of p-holes. In fact, soft rescatterings increase the cross section of the excitation of p-holes at small k (which would tend to zero for $k \to 0$ in the plane-wave impulse approximation). Consequently, a decrease of the probability of such rescatterings due to color transparency should lead to a decrease of the fraction of transitions to p-holes with increase of p_N. Thus, it may be advantageous to study the color transparency effect via study of the energy dependence of the ratio of the cross sections for knockout of protons from s- and p-holes for small $k < 50$ MeV/c – in such ratios many experimental errors and theoretical uncertainties are likely to cancel out.

FRANKFURT ET AL. RESULT – CONTD.

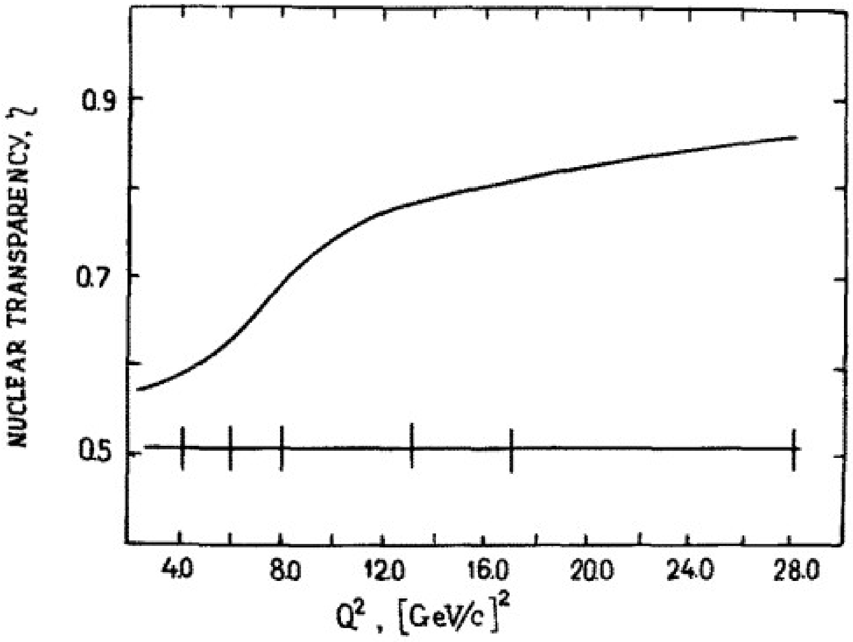


Fig. 9. Integral color transparency factor for $^{12}C(e, ep)$ reaction as compared to prediction of Glauber model as a function of Q^2. Error indicate the sensitivity of the result to the variation of the parameters of the Skyrme model, α, σ.