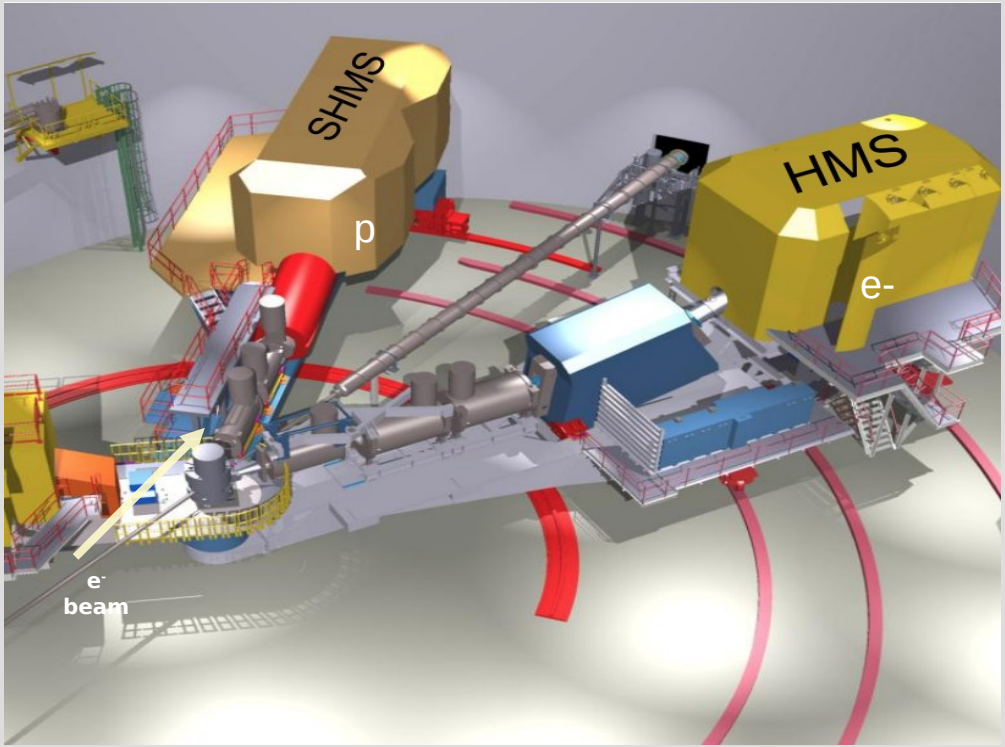
SHELL DEPENDENCE ON TRANSPARENCY IN E12-06-107



Deepak Bhetuwal

Mississippi State University

GHP Meeting (Virtual)

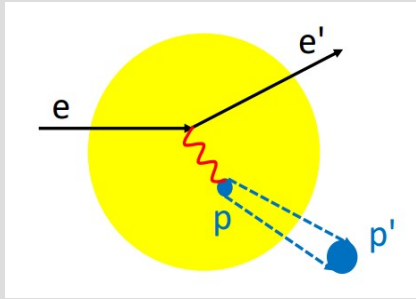
Apr 14, 2021

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:
  - **Selection of the PLC [Squeezing - QM]**.
  - **Lifetime of the PLC [Freezing - Relativity]**.
  - **Small sized objects have reduced interaction [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).

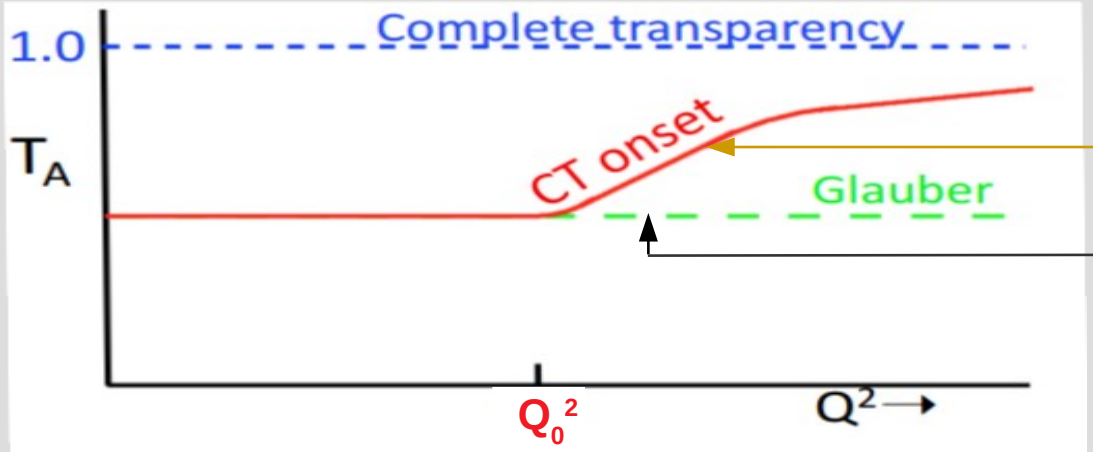
$$T_A = \frac{\sigma_A}{A\,\sigma_N}$$

(σ_A: nuclear cross section)

(σ_N: free nucleon cross section)

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

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



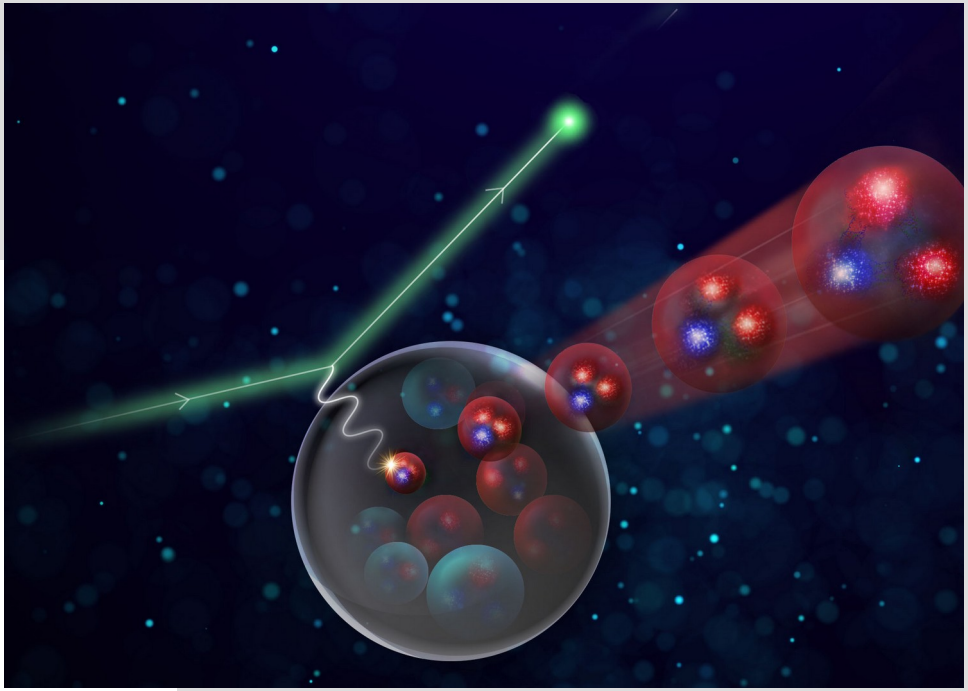
QCD prediction

Traditional nuclear physics prediction **OR** **Glauber calculations**

Ingredients

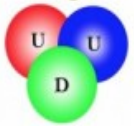
- σ_{hN} (h-N cross-section)
- Glauber multiple scattering approximation
- Correlations & FSI effects

CT PAST EXPERIMENTS



CT Experiments

Baryon



A(p,2p): BNL
A(e,e'p): SLAC, JLab

Meson

A(π,di-jet): FNAL
A(γ, π^- p): JLab
A(e, e'π^+): JLab
A(e, e'ρ^0): DESY & JLab

CT PAST RESULTS – FERMILAB

CT is well established at high energies.

500 GeV π^+ + Pt ⟶ 2 Jets

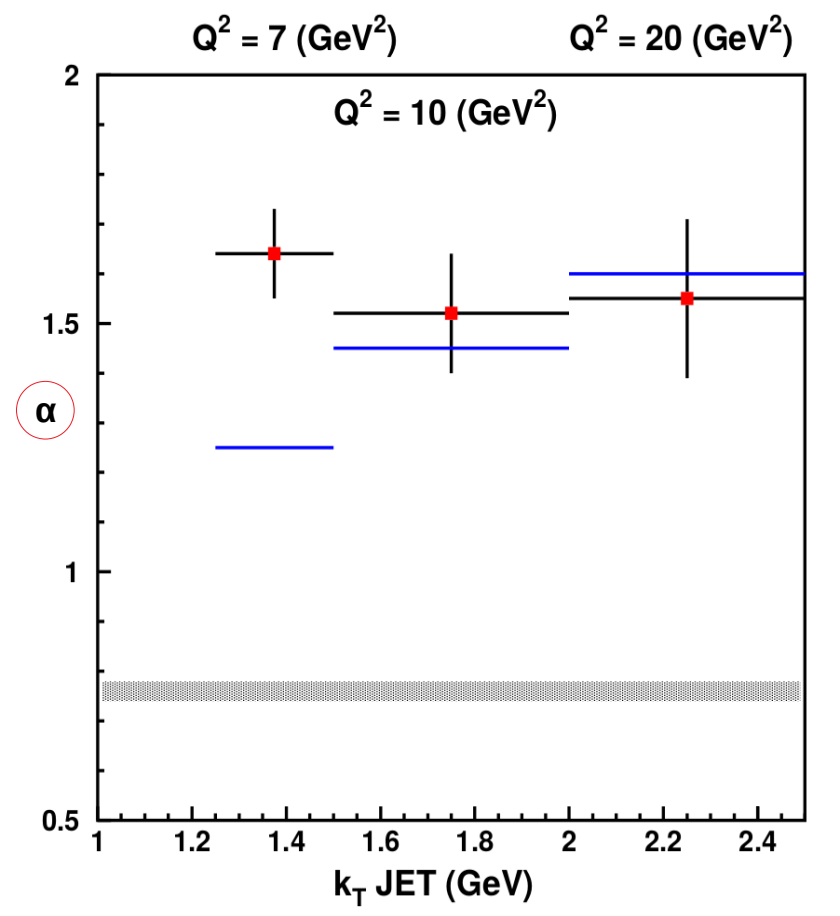
$$\sigma_A = \sigma_N A^{\alpha}$$

Experimentally α = 0.72 – 0.78 for π, κ, p

σ_A is Nuclear cross section

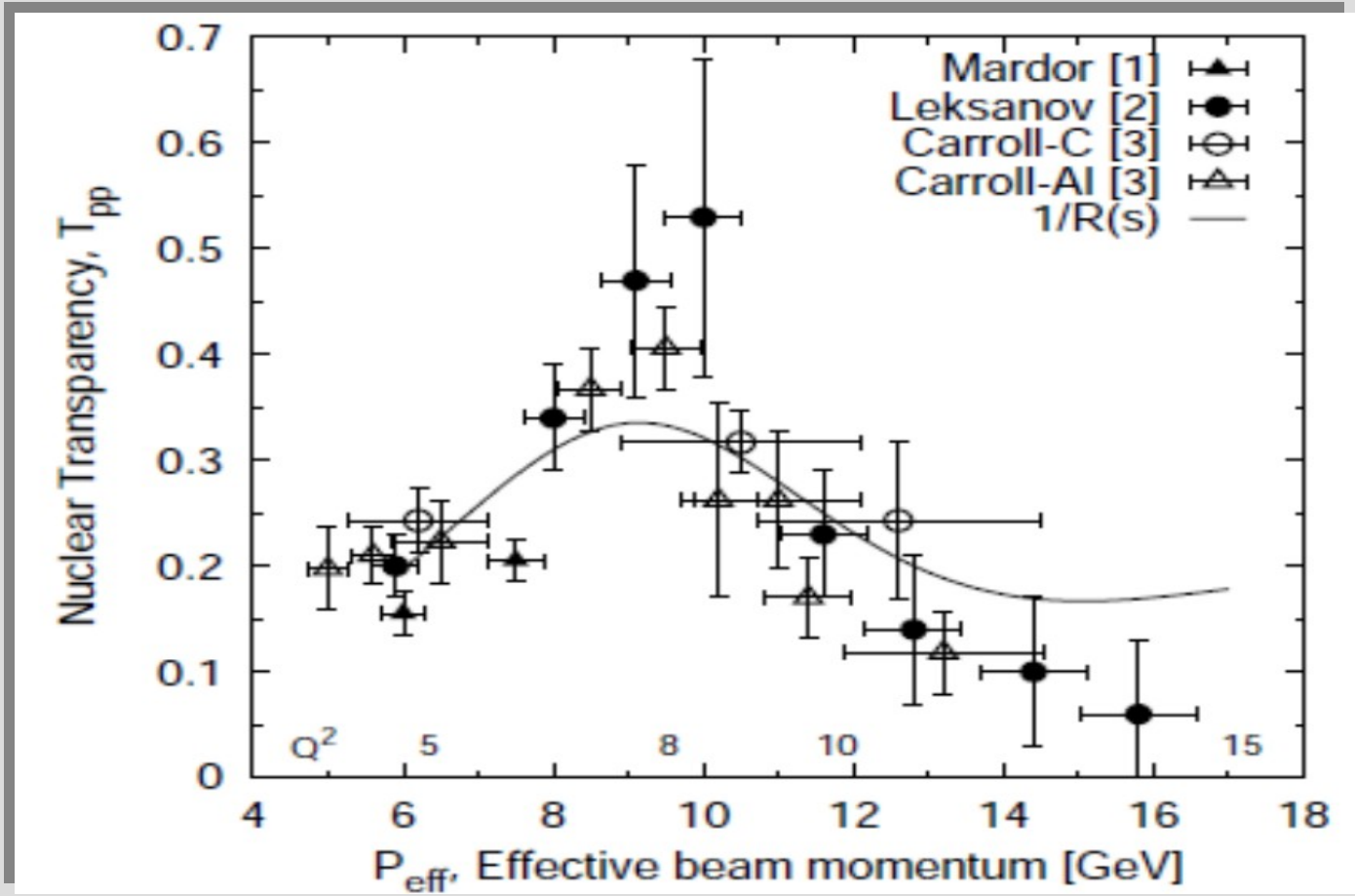
σ_N is free nucleon cross section

Coherent diffractive dissociation of pions at Fermilab (E791 Collaboration)



E. Aitala et al., Phys.Rev.Lett., vol. **86**, 2001, pp. 4773–4777.

CT PAST RESULTS - BNL A(p,2p)



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

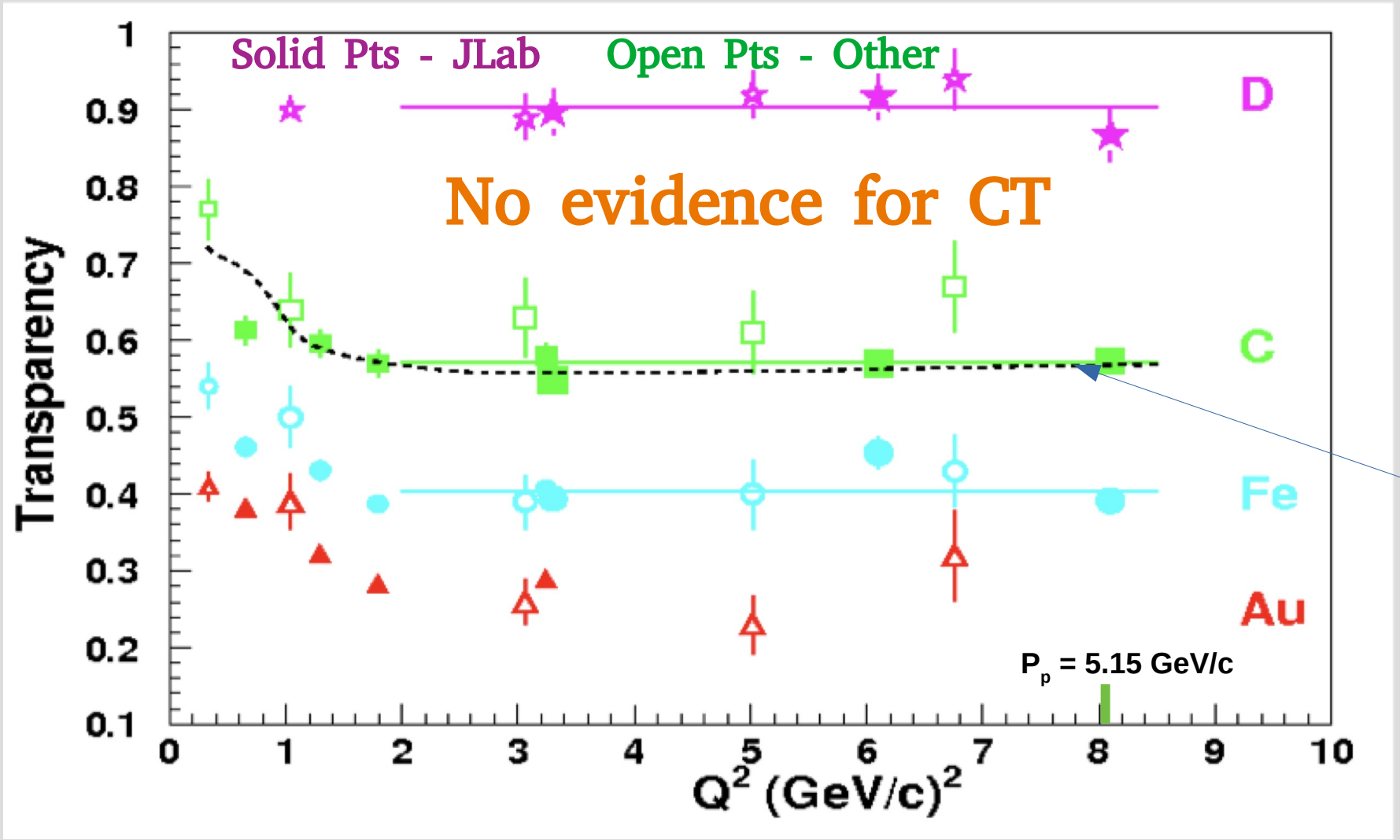
(p, 2p) experiment at BNL found an enhancement in the transparency.

Decreases at higher momentum.

Result inconsistent with CT only.

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

CT PAST RESULTS - A(e,e'p)



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)

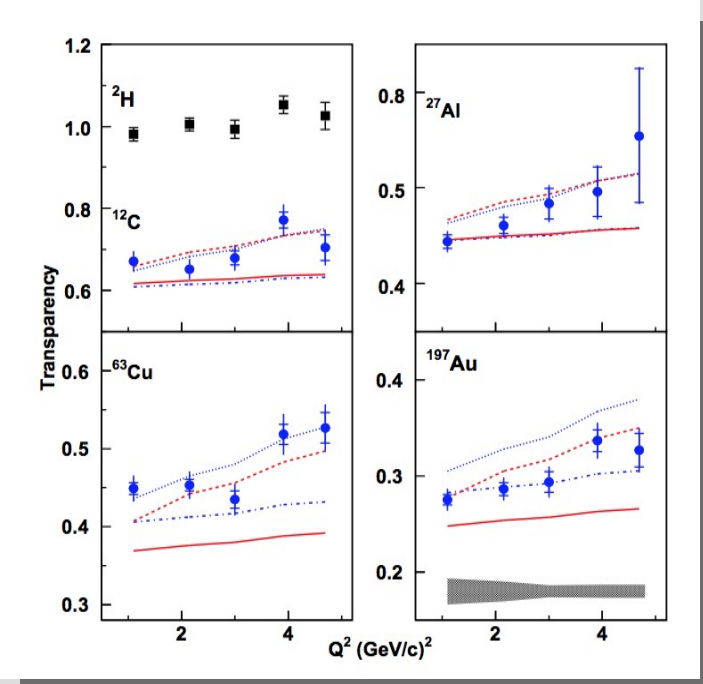
Plateau consistent with conventional calculations ...

CT PAST RESULTS - MESONS

CT is well established at high energies. Onset of CT has been measured in Mesons but not in Baryons.

Hall C E01-107 pion electroproduction

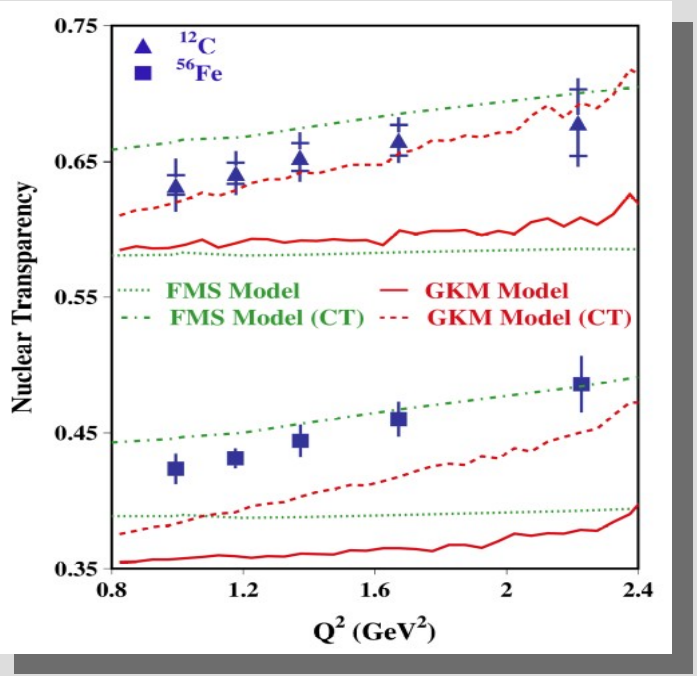
PION - A(e, e'π^+)



B.Clasie *et al.* PRL 99:242502 (2007)

X. Qian *et al.* PRC81:055209 (2010)

RHO - A(e, e'ρ^0)



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

CLAS E02-110 rho electroproduction

CT EXPERIMENT: E12-06-107

E12-06-107 was the first experiment to run in Hall C in the Jlab 12 GeV era

Ran in Hall C at JLab in Spring 2018

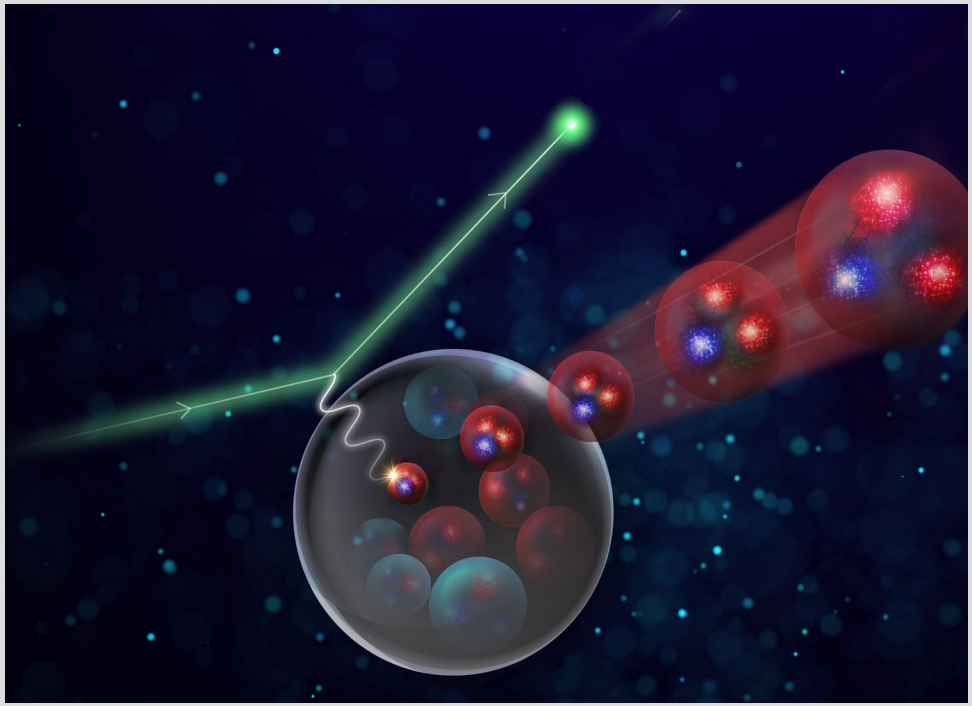
Coincidence trigger

Targets: 10 cm LH_2, 6% rl ^{12}C, ^{27}Al

~20 days of data taking

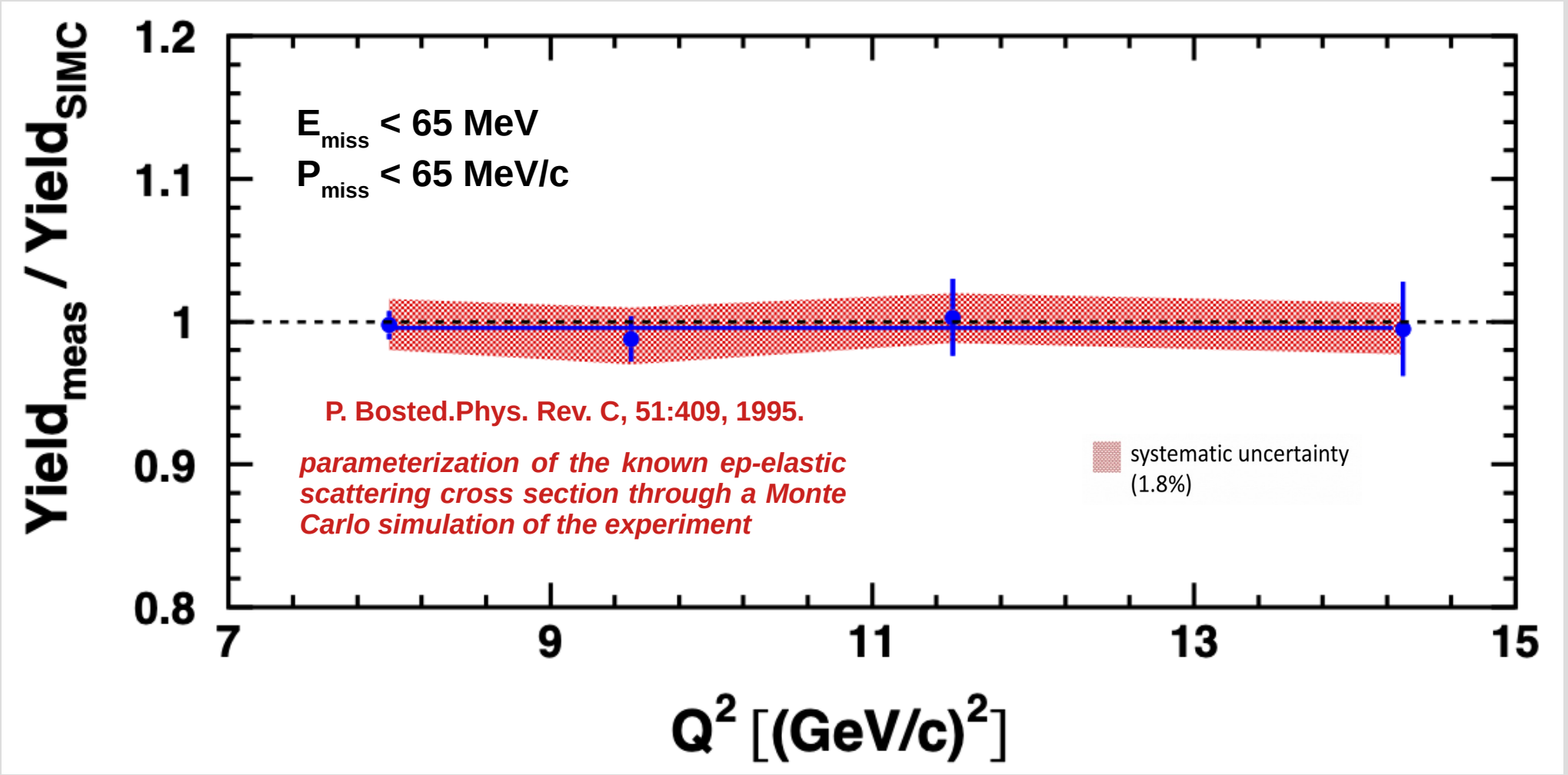
E_{beam} of 6.4 GeV and 10.6 GeV

Beam current up to 65 μA



	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	5.122	45.1	2.131
10.6 GeV beam	9.5	21.6	5.925	23.2	5.539
	11.5	17.8	7.001	28.5	4.478
	14.3	12.8	8.505	39.3	2.982

HYDROGEN NORMALIZATION

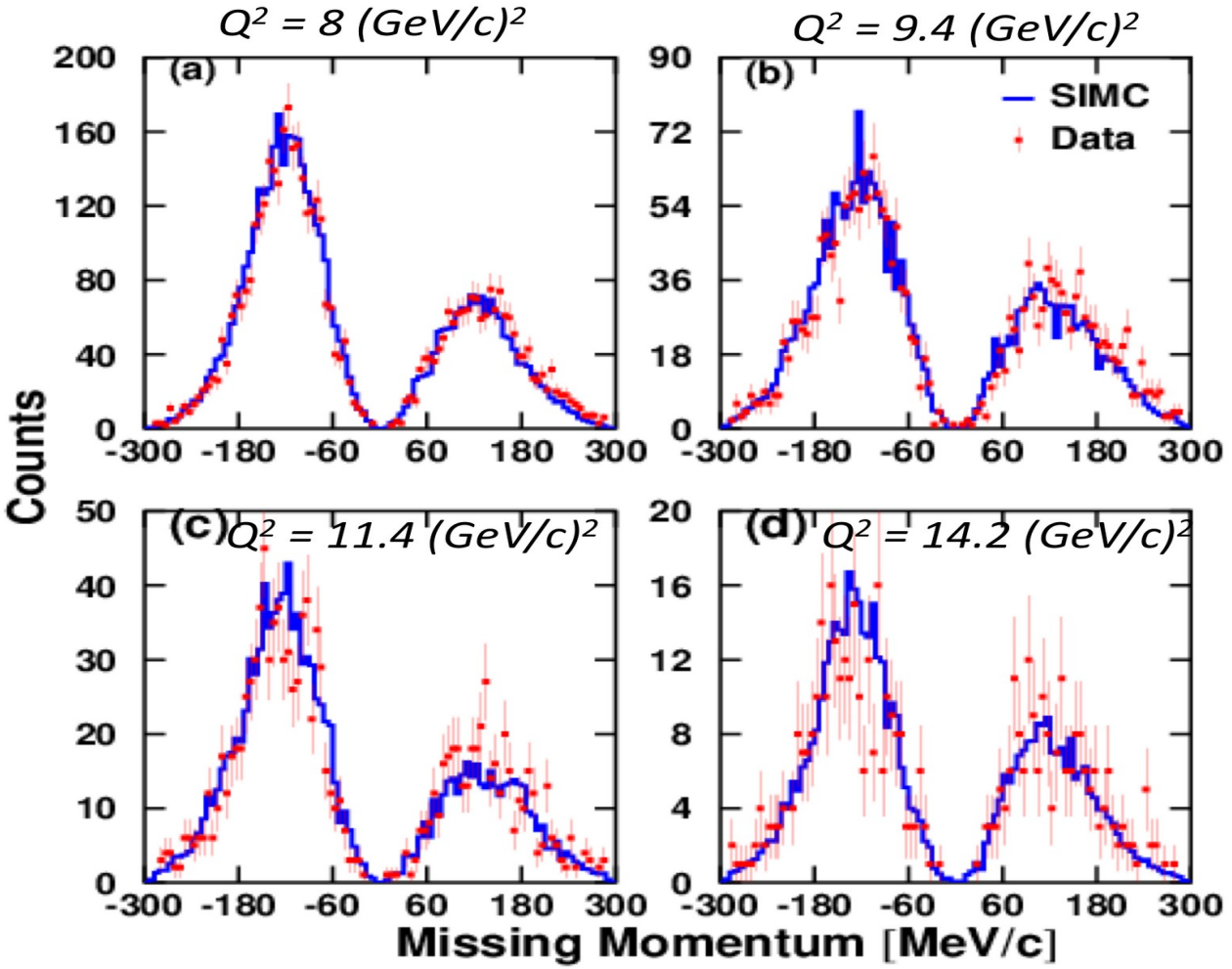


MISSING MOMENTUM (^{12}C) - P_{miss}

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

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



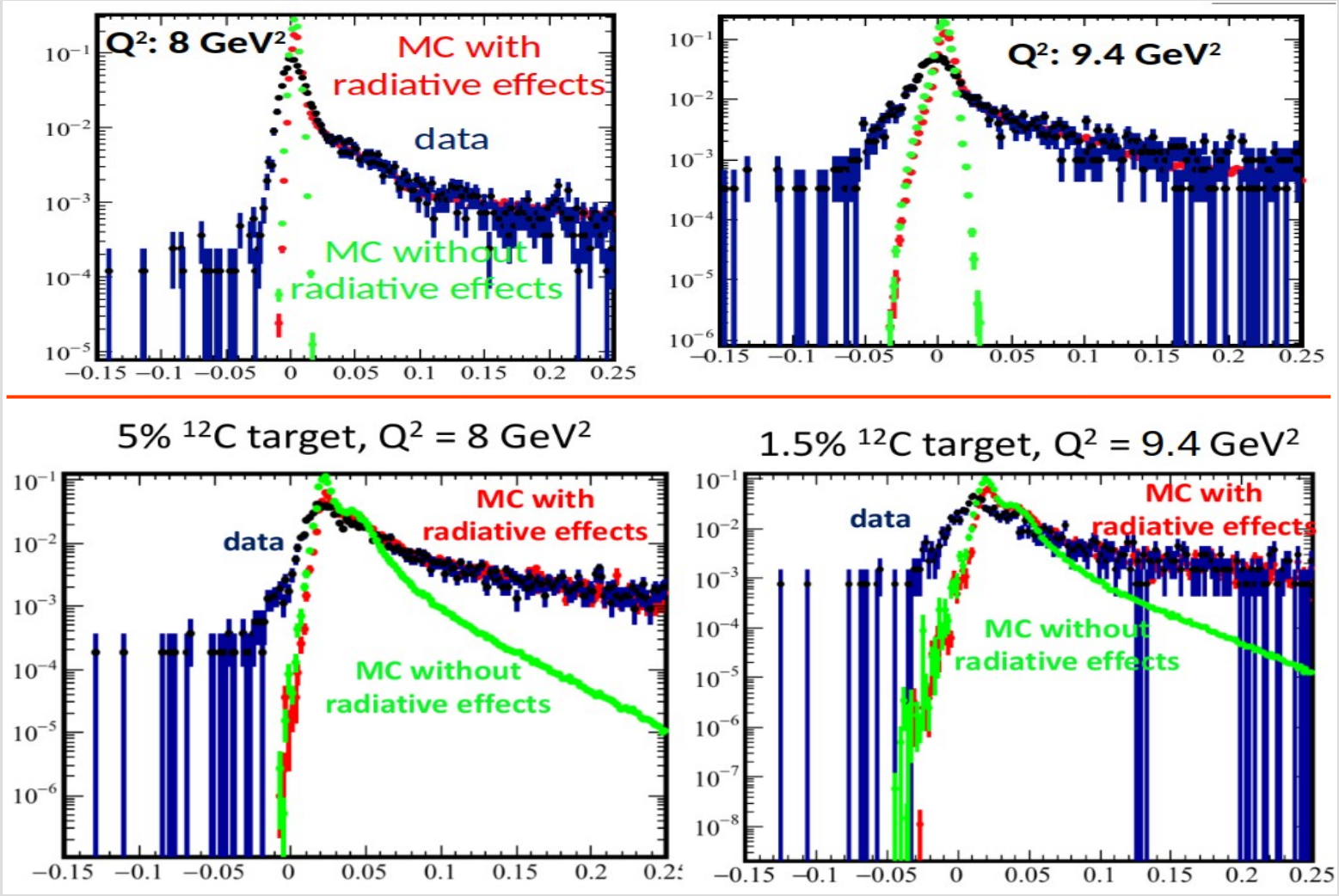
RADIATIVE CORRECTIONS

Courtesy: Holly Szumila-Vance, JLab

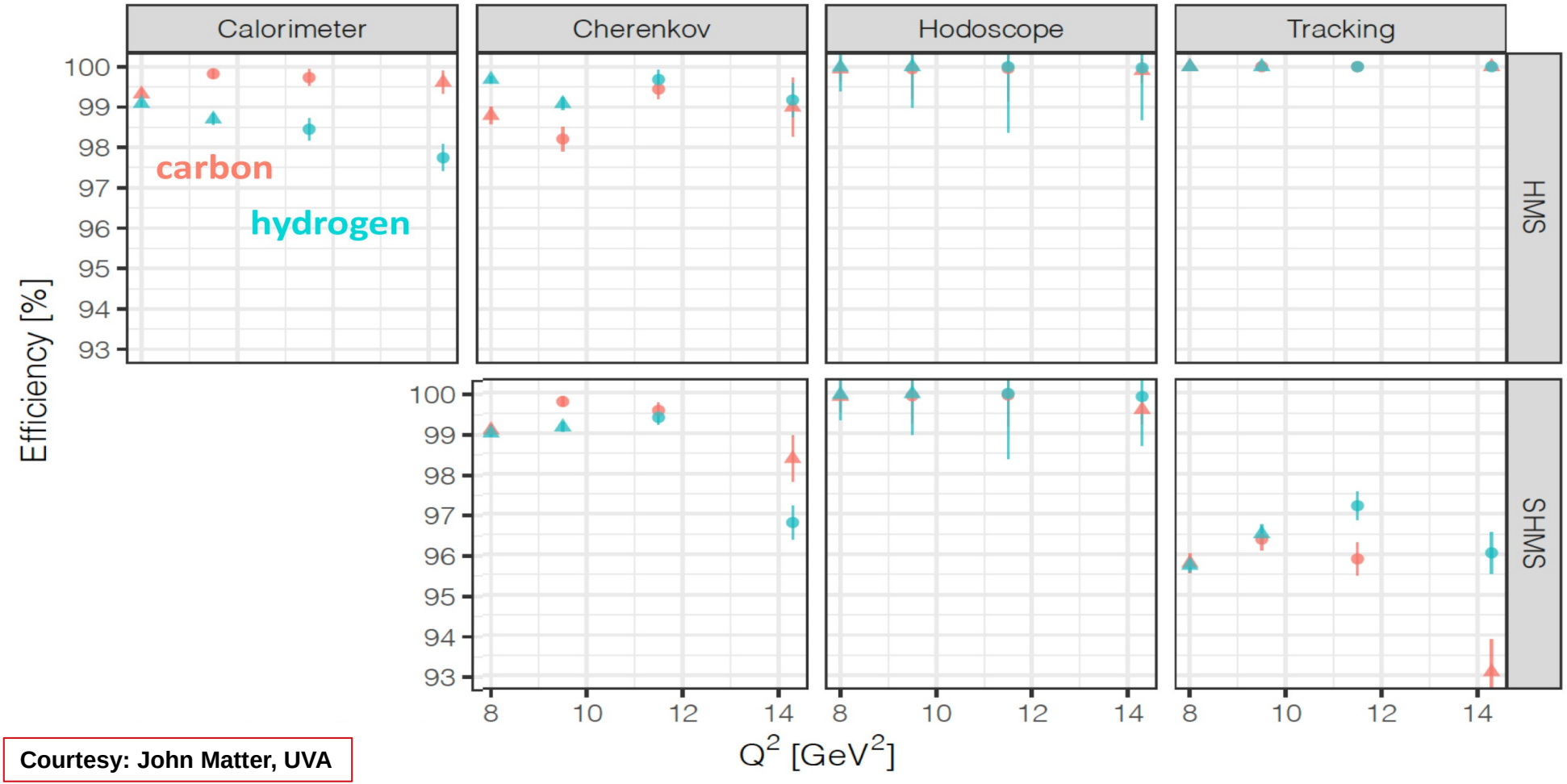
Hydrogen radiative tails: E_{miss} spectra

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

Carbon radiative tails: E_{miss} spectra

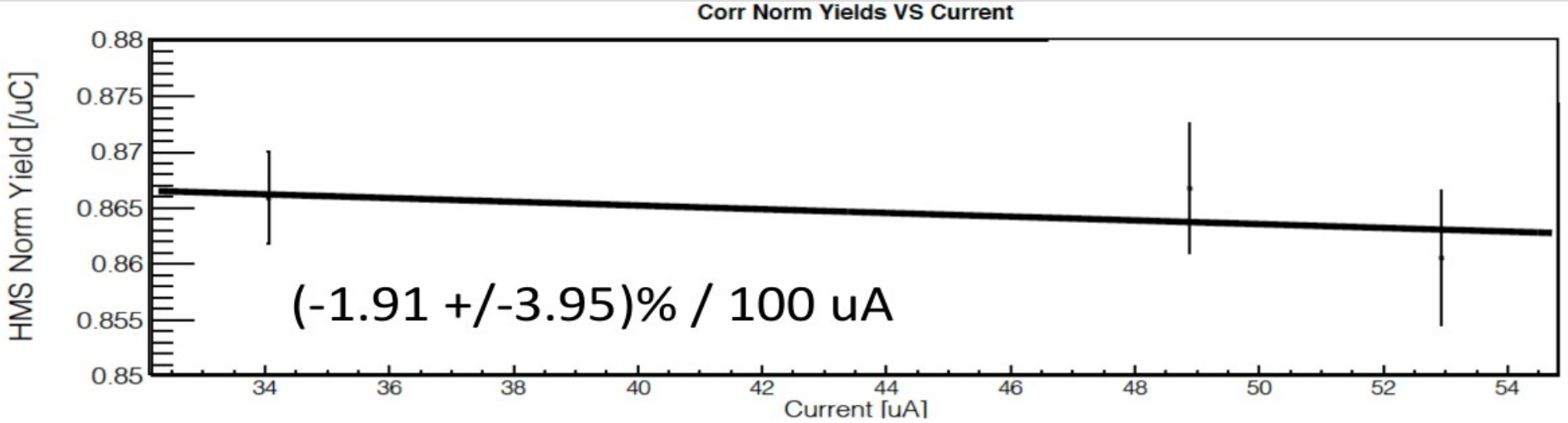


DETECTOR EFFICIENCY

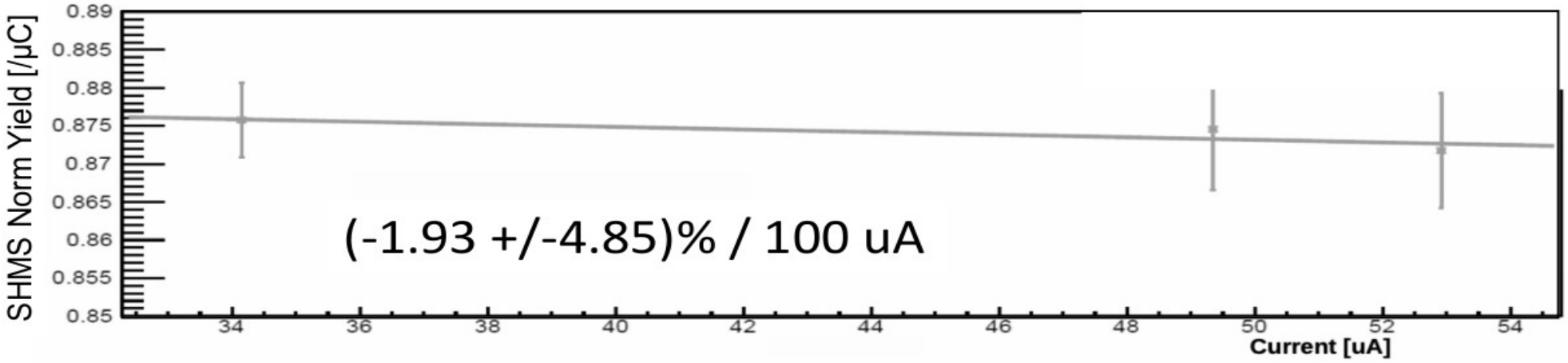


Courtesy: John Matter, UVA

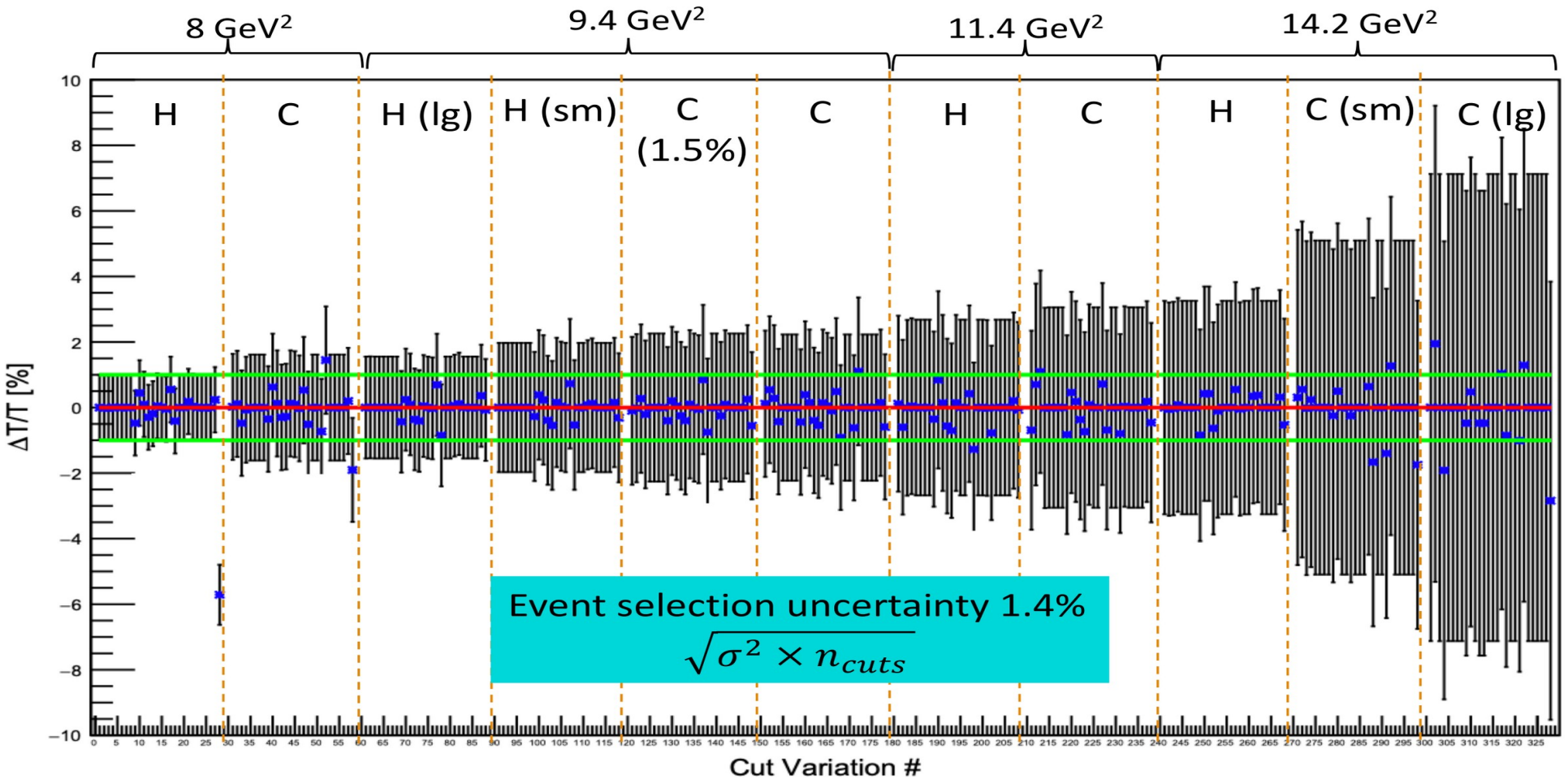
LUMINOSITY SCANS ON ^{12}C TARGET



Single arm runs varying with beam current

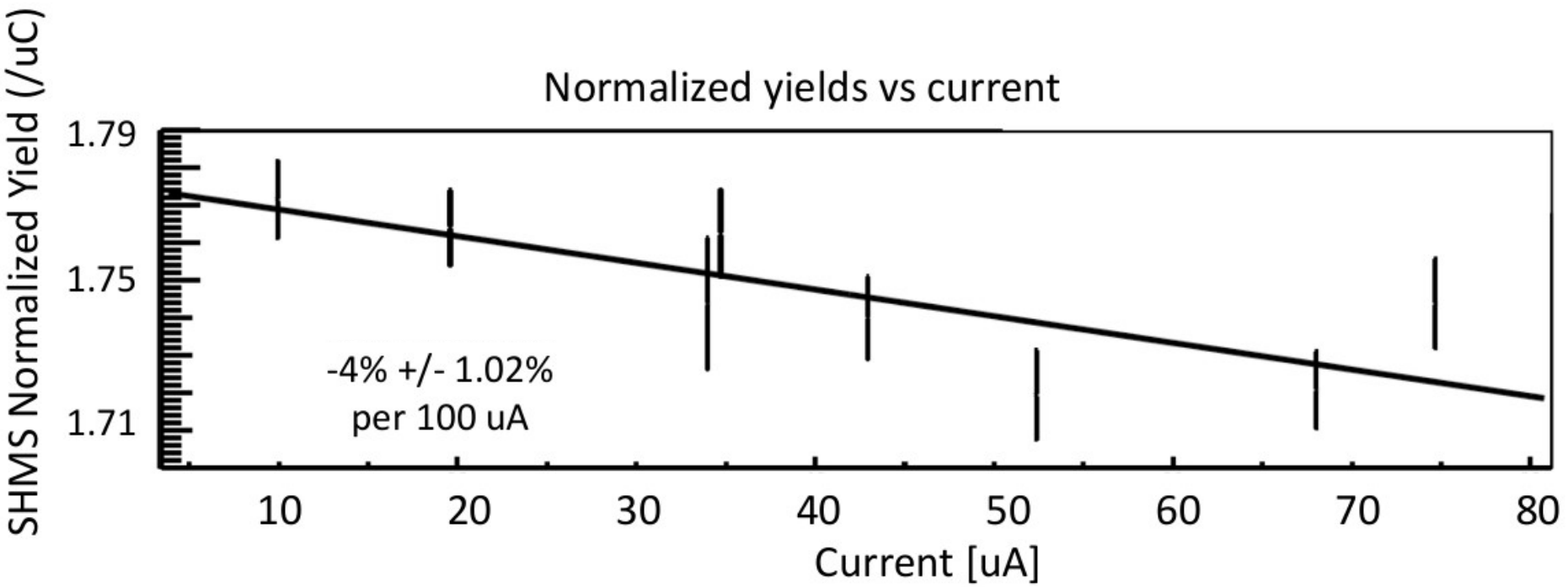


CUT DEPENDENCE STUDY (+/- 10%)



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

^{1}H TARGET BOILING CORRECTION

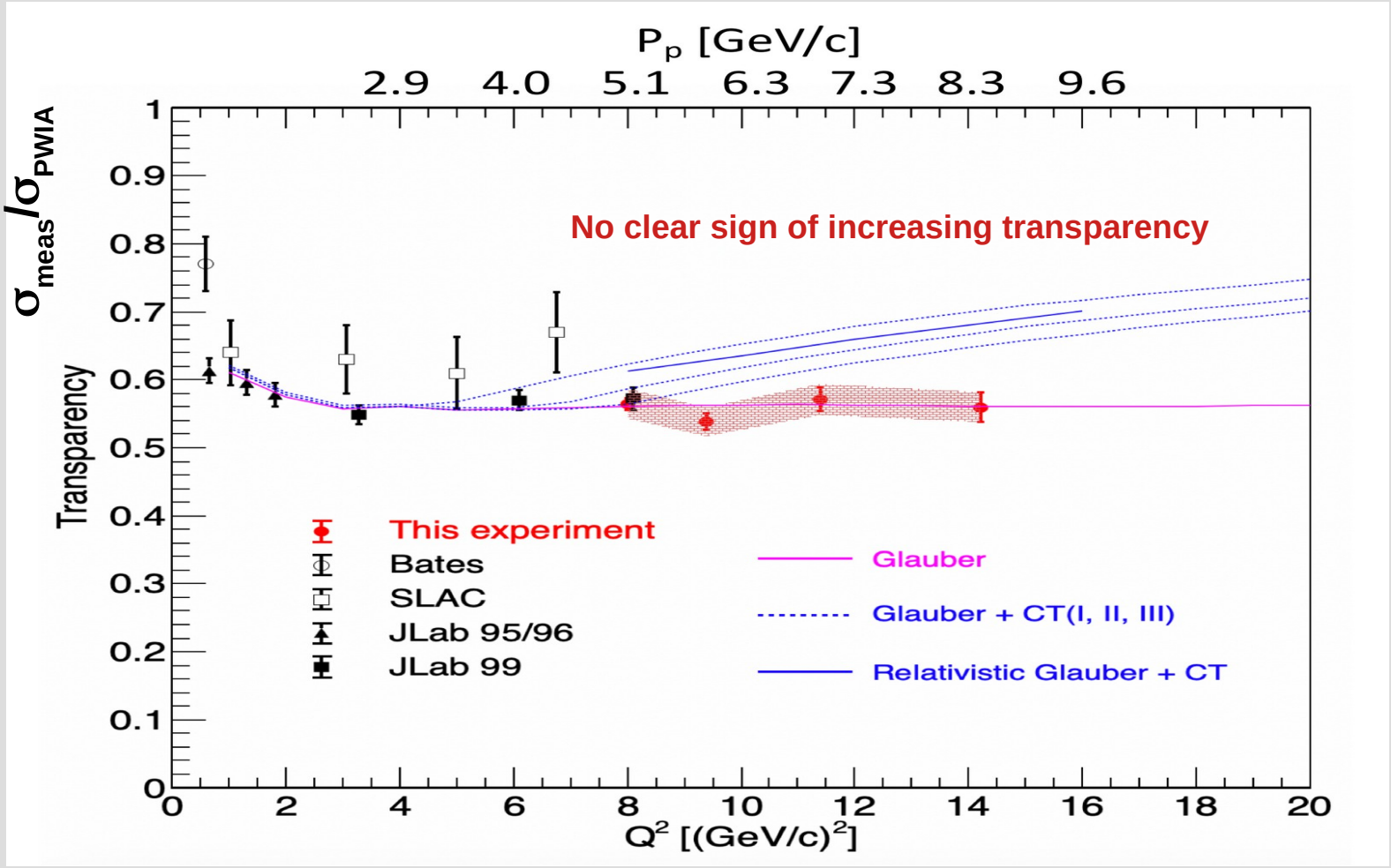


Correction of 2.6% at 65 uA, highest current in experiment

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



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

Systematic Uncertainty
4 %

D. Bhetuwal et al., Phys. Rev.Lett.,126(8), 082301 (2021).

SHELL DEPENDENT TRANSPARENCY

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

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

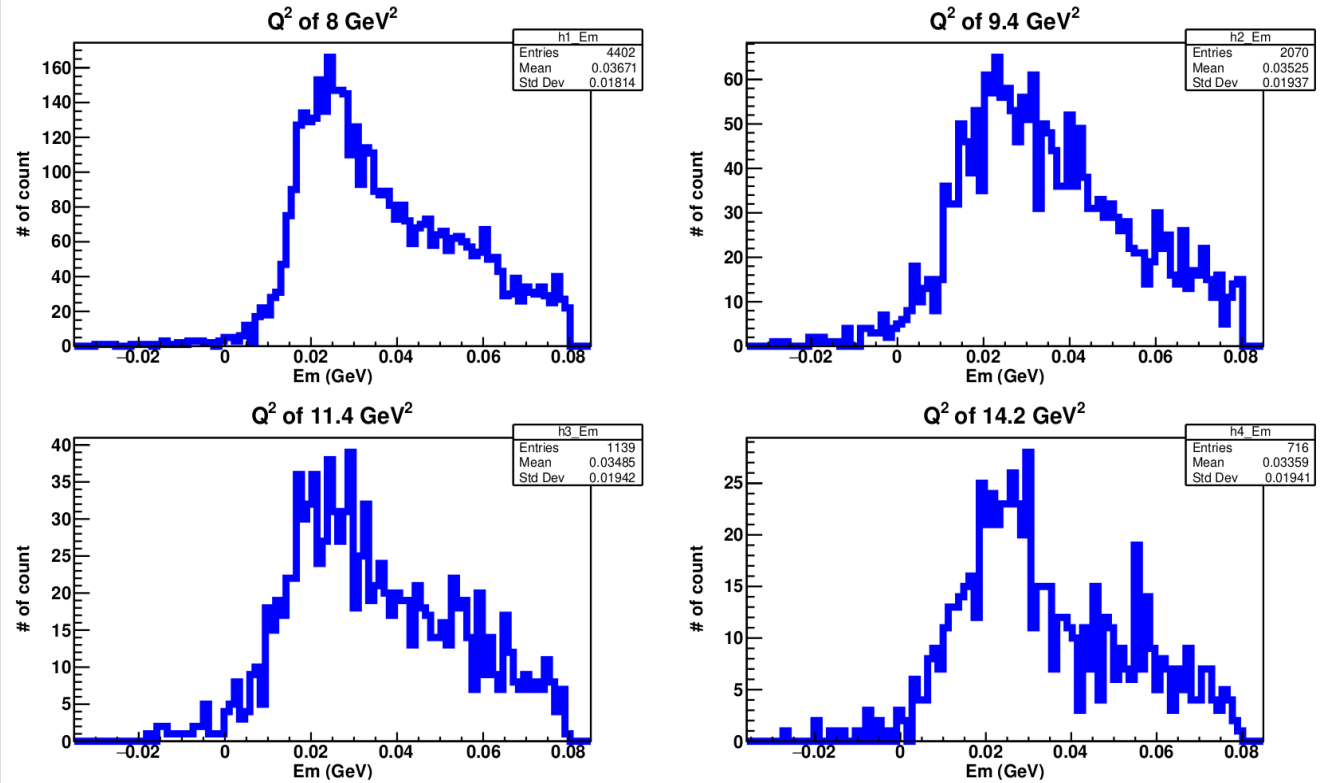
Leningrad Nuclear Physics Institute, 188350, Gatchina, USSR

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.

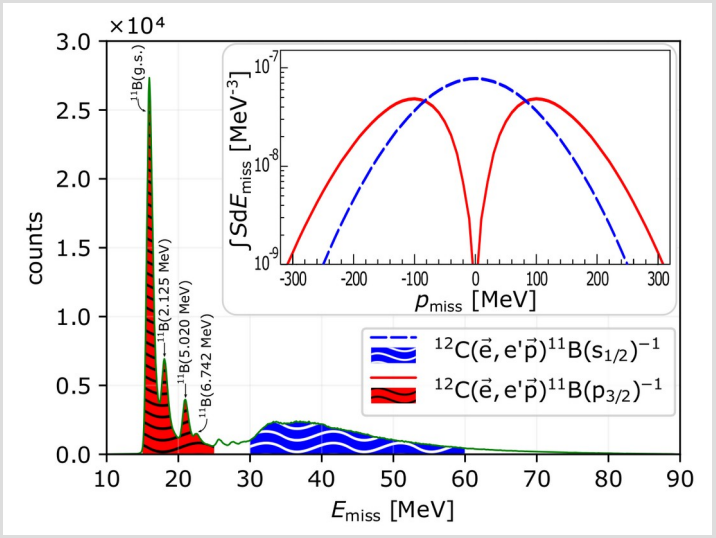
MISSING ENERGY



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

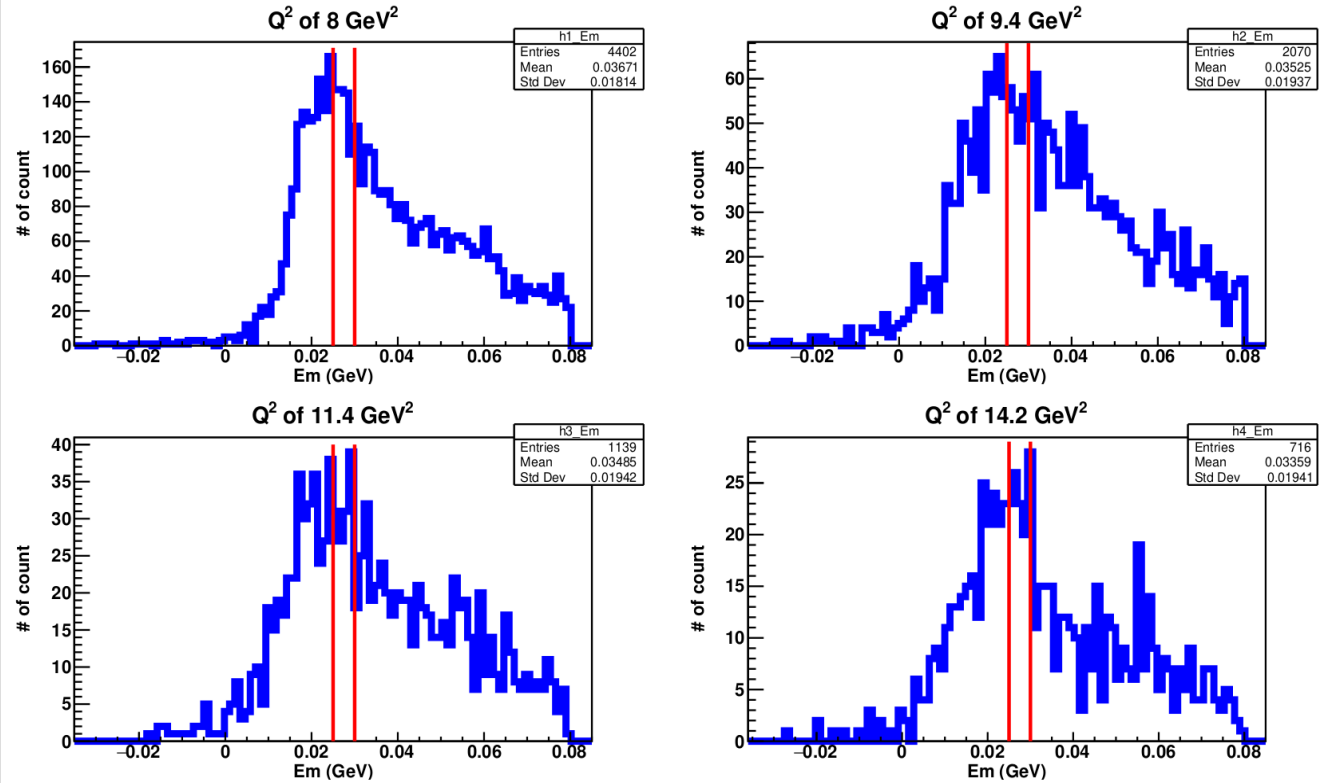
Q^2 = 0.4 (GeV/c)², proton E_m plot for $^{12}C(e,e'p)$ at the MAMI



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

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

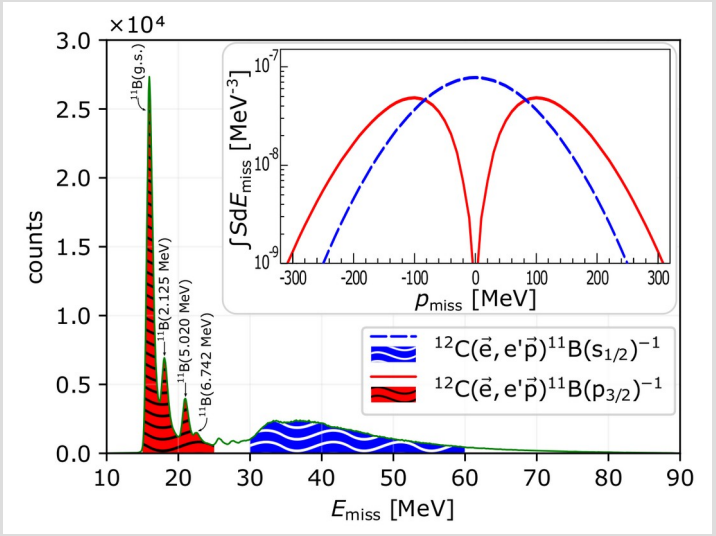
MISSING ENERGY – CONTD.



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

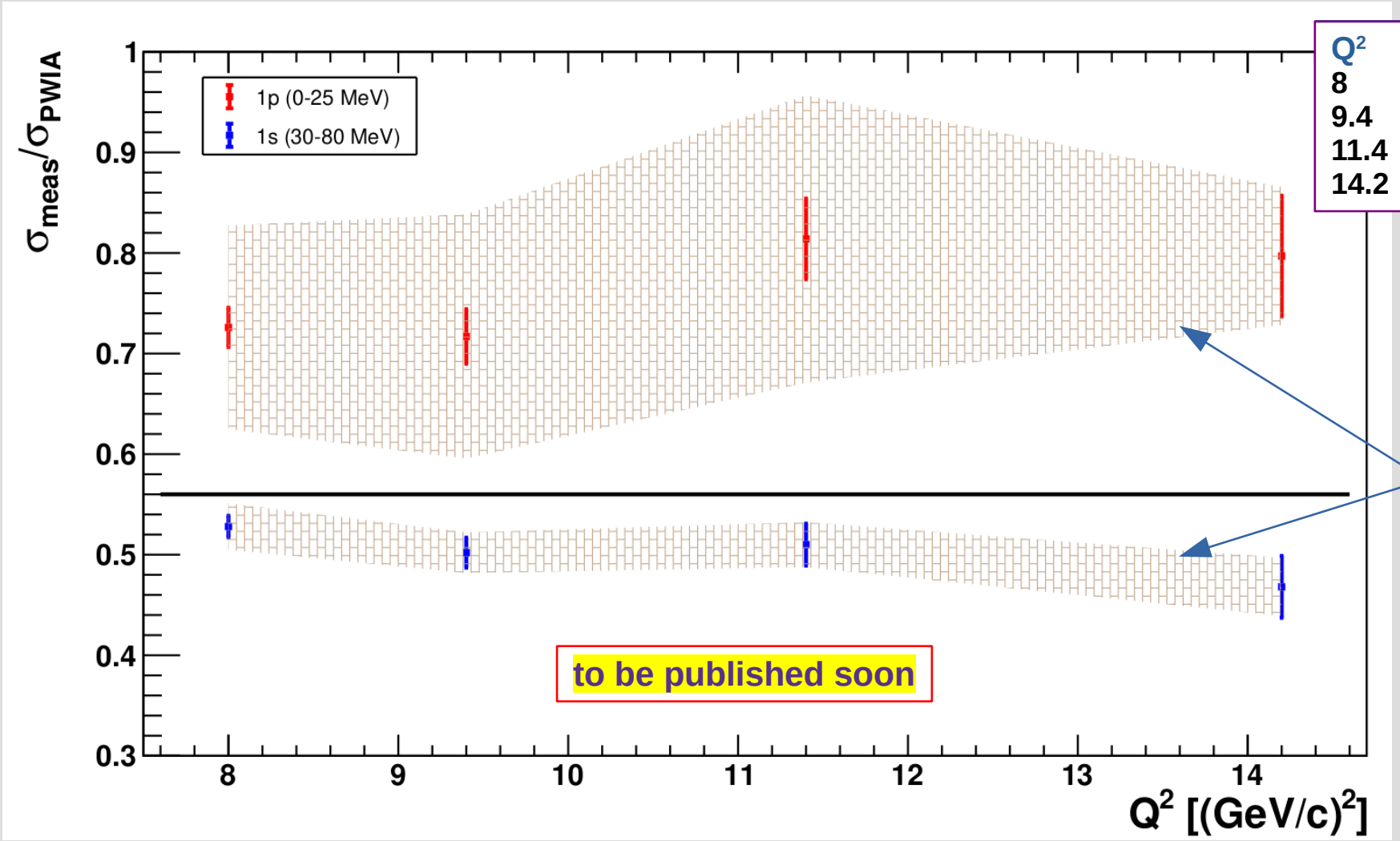
Q^2 = 0.4 (GeV/c)², proton E_m plot for $^{12}C(e,e'p)$ at the MAMI



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

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

SHELL DEPENDENT TRANSPARENCY RESULT



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.
- Results have been published in PRL last February 2021.

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 !