Pion Color Transparency Experiment (E01-107)

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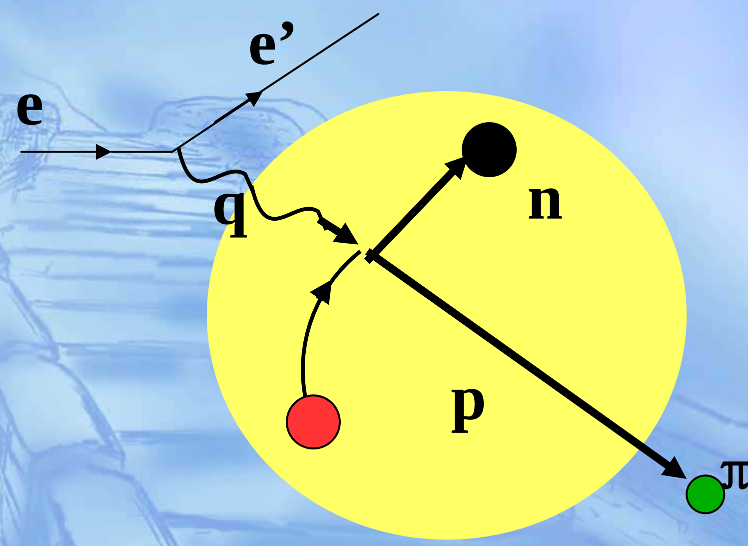
Spokespersons:

D. Dutta, R. Ent & K. Garrow

Thesis Student:

Ben Clasie (MIT)



Outline

- What is Color Transparency?
- What is the Importance of Searching for Onset of Color Transparency?
- πCT Overview
  - Experiment overview
  - Analysis overview
- Summary

Color Transparency

CT refers to the vanishing of the h-N interaction for h produced in exclusive processes inside nuclear medium at high Q

Original concept of CT introduced by Mueller and Brodsky in 1982

- At high Q ($\lambda \sim 1/Q$) , the hadron involved fluctuates to a small transverse size – called the PLC (quantum mechanics).

- The PLC remains small as it propagates out of the nucleus (relativity).

- The PLC experiences reduced attenuation in the nucleus – it is color screened. (color dipole)

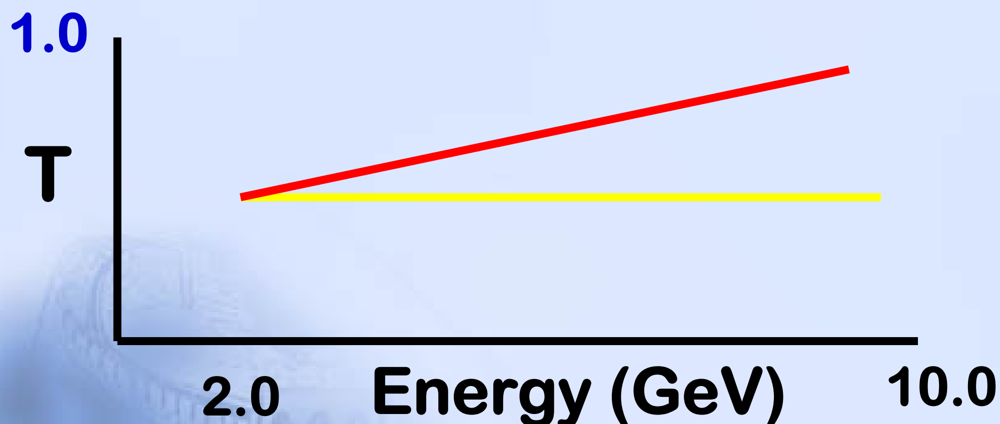
A.H.Mueller in Proc. of 17th recontre de Moriond, Moriond, p13 (1982)
S.J.Brodsky in Proc. of 13th intl. Symposium on Multiparticle Dynamics, p963 (1982)

Slide from D. Dutta

No CT in Traditional Nuclear Physics

- Glauber calculations predict the nuclear transparency T to be energy-independent.
  - when the fundamental h-N Xs is energy-independent

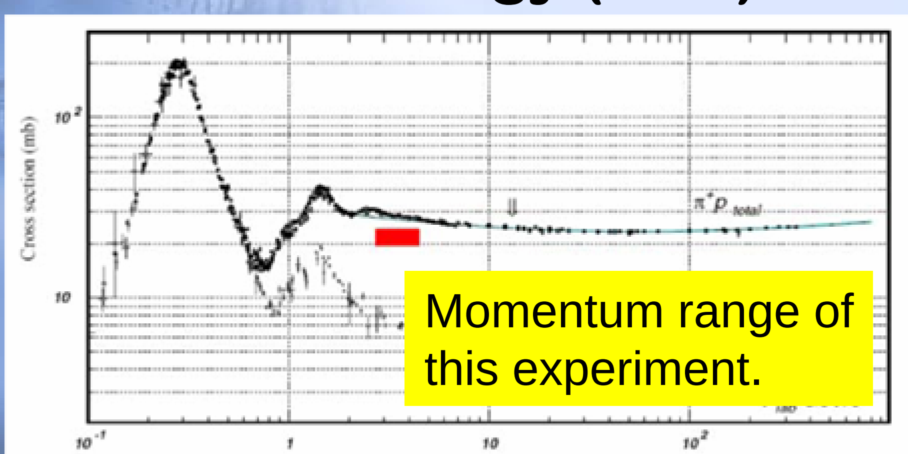
$$T = \frac{\sigma_N}{A\sigma_0}$$



$$T = f(\sigma_{\pi p}, \sigma_{\pi n})$$

Full calculations include

1. parameterization of pion-nucleon scattering Xs
2. glauber multiple scattering approximation
3. nucleon correlations,
4. FSI.



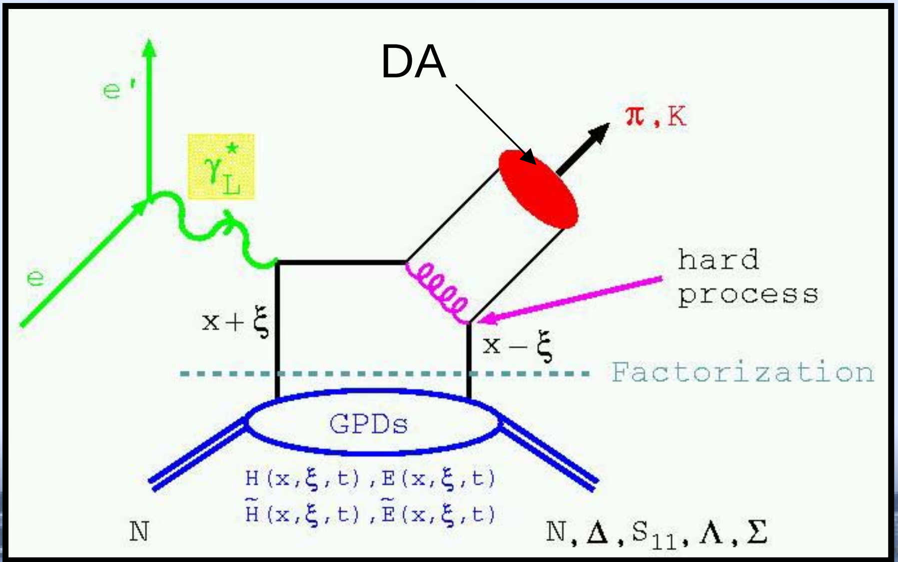
Importance of CT

- Reveal the transition from nucleon-meson effective degree of freedom to quark-gluon degree of freedom.
  - No explanations in traditional nuclear physics.
  - Natural in QCD picture in terms of parton.
- Connections between CT and General Parton Distribtution functions (GPDs).
  - Factorization theorem has been derived for the deep-exclusive scattering (DES) process which is essential to access GPDs through exclusive reactions.

Still not clear the energy range where the factorization works (see Tanja's talk).

Factorization is not rigorously possible without the onset of CT.

- Strikman, Frankfurt, Miller and Sargsian



Connection between CT and GPDs

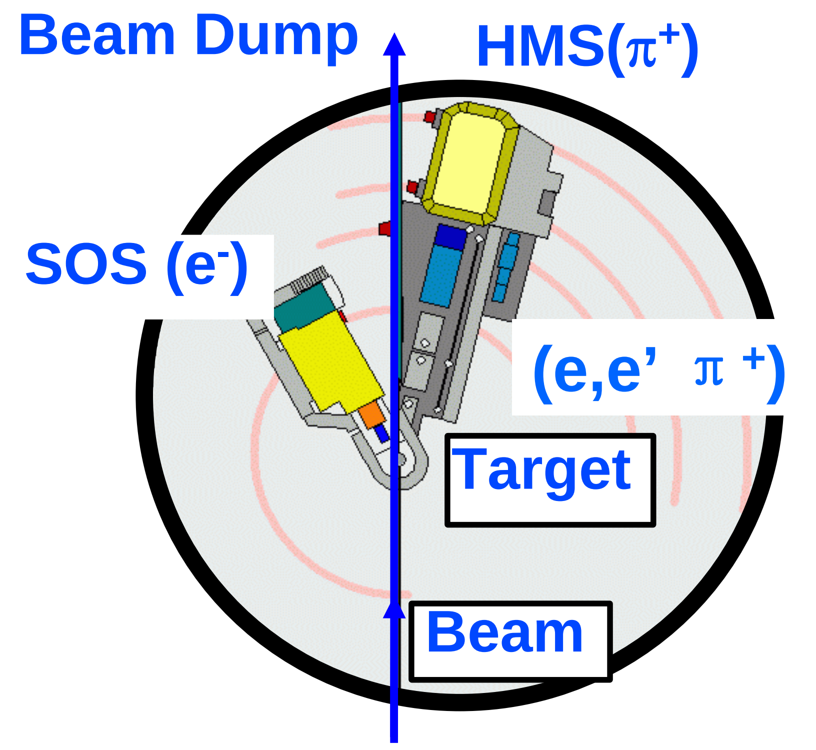
- **The existence of color transparency would place constraints on the analytic behavior and would provide testable predictions for GPD's.**
  - **M. Burkardt and G. Miller (hep-ph/0312190) have derived the effective size of a hadron in terms of GPD's.**
- **Nuclei can be used as filters to map the transverse components of hadron wave function: i.e.a new source of information on GPD's.**
  - **S. Liuti and S. K. Taneja (PRD 70,07419 (2004)) have explored structure of GPD in impact parameter space to determine characteristics of small transverse-separation components.**
- **Understanding DA is an important step to access GPDs with DES.**
  - **Together with Transverse Momentum Dependent Distribution Functions (TMDs) in DIS, provide a picture of nucleon structure in amplitude (wavefunction) level.**

Why searching for CT using pion?

- Negative results with proton with up to Q^2~8 GeV^2.
- Advantages of Pions
  - Formation length (length particle travel before it goes back to normal size) is estimated ~ 10 fm at moderate Q^2 in pion by models, larger than proton case due to smaller pion mass.
  - Small size is more probable in pion than in proton.
- Disadvantages of Pions
  - More model-dependence
    - Model of Pion electro-production on proton
    - Treatment of off-shell proton, proton distribution (fermi motion) inside nucleus, FSI, quasi-free assumption.
      - Quasi-free assumption can be checked by L/T separation on proton and nucleus.
  - Exclusive selection (exclude multi-pion production) results in smaller phase space (pion mass, ~140 MeV).

Overview of πCT

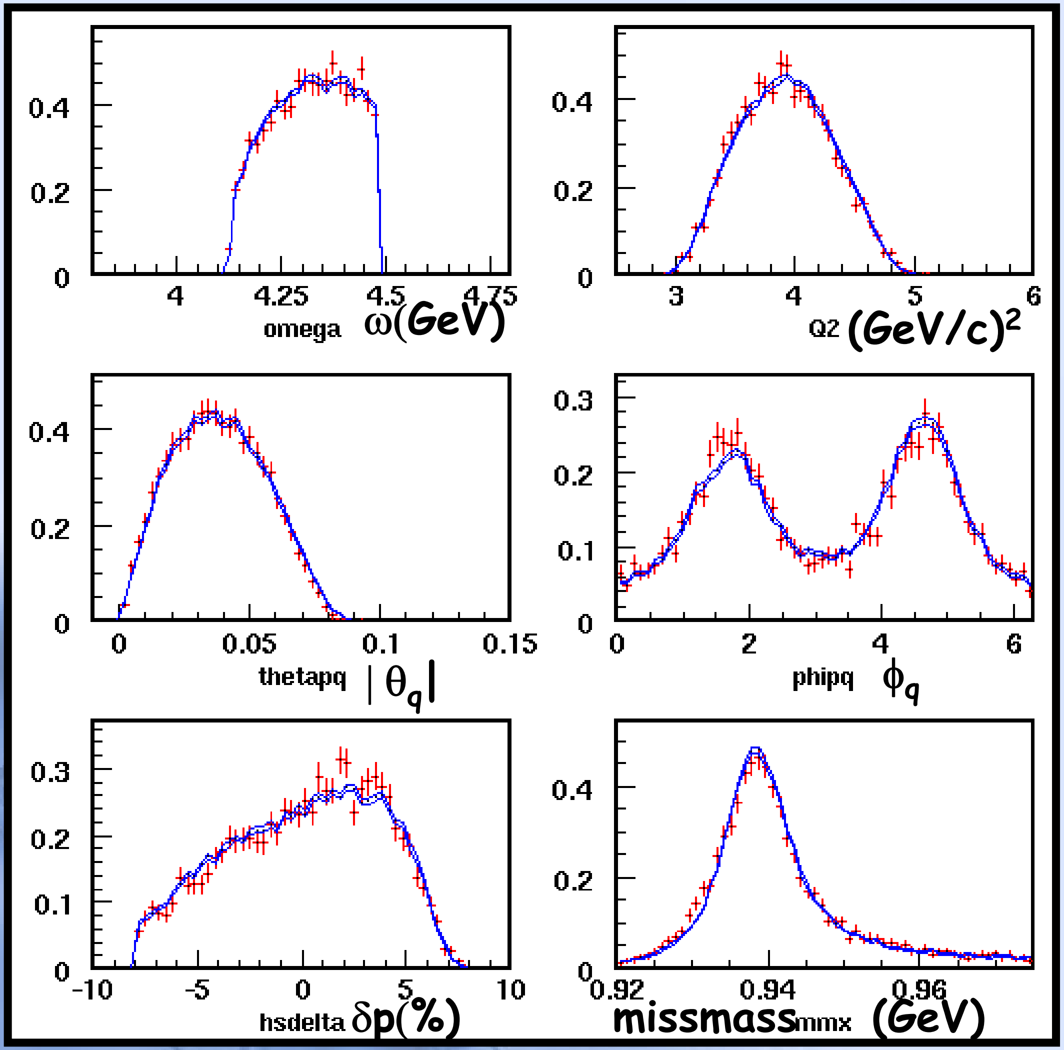
- Spokespersons: *D. Dutta*, *R. Ent* and *K. Garrow*
- Experiment ran at Jefferson Lab in Hall C in 2004
- Standard Hall C equipment was used



Q^2 (GeV^2)	W (GeV)	-t (GeV^2)	E_{beam} (GeV)	ε
1.1	2.3	0.05	4.0	0.50
2.15	2.2	0.16	5.0	0.56
2.15	2.2	0.16	4.0	0.27
3.0	2.1	0.29	5.0	0.45
4.0	2.2	0.40	5.8	0.39
4.0	2.1	0.44	5.0	0.25
4.8	2.2	0.52	5.8	0.26

- LH^2, LD^2, ^{12}C, ^{63}Cu and ^{197}Au targets at each kinematic setting

The $p(e,e'\pi^+)n$ Data



The model for $p(e,e'\pi^+)n$ is iterated until it agrees with the data.
Starting model is from Tanja Horn.

This new parametrization of the pion electroproduction cross-section from the nucleon is used as an input for the quasi-free model for the rest of the target nuclei.

analysis by
Ben Clasie (MIT)

Data in Red Blue is simulation Slide from D. Dutta

The Quasi-free Model

virtual photon flux

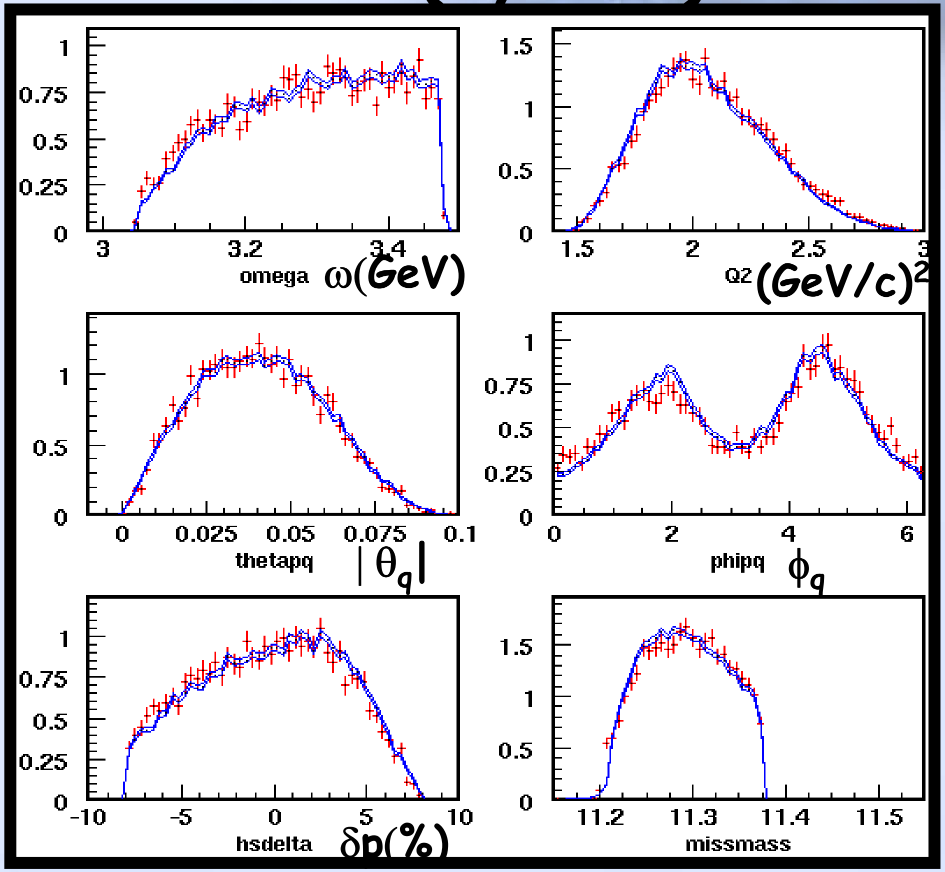
nucleon cross section from hydrogen data

$$\frac{d^6\sigma_A}{d\Omega_e\, dE\, d\Omega_\pi\, dP} = \frac{d}{dP}\int dE_m\, dp_m\, S(E_m, p_m)\, f_\Gamma\, \Gamma_v\, J\, \frac{d^2\sigma}{dt\, d\varphi}$$

spectral function

correction to flux for a moving proton

$^{12}C(e,e'\ \pi^+)$



Data in Red

Blue is quasi-free model with

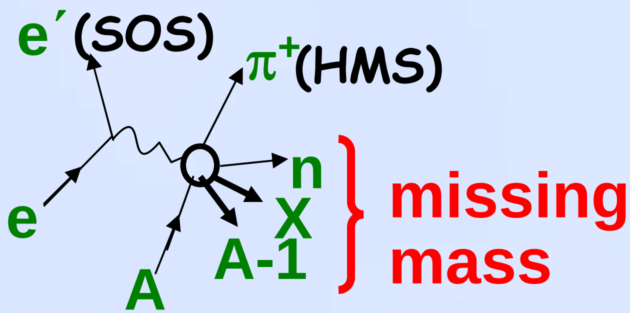
- ^{12}C spectral function
- Pauli Blocking[1]
- off-shell effects (both proton and spectator)

[1]Fermi distribution of Fantoni et al. (1984) including correlations

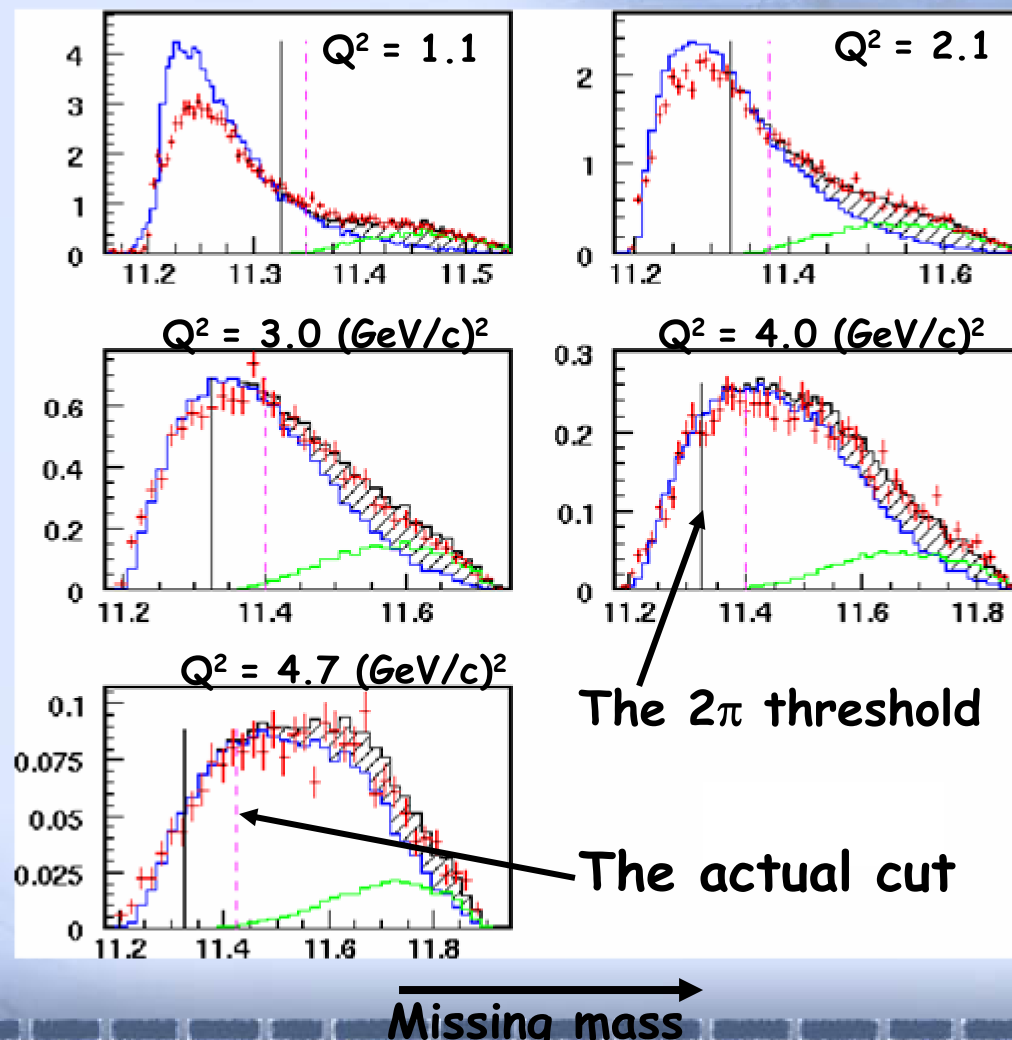
Model Can be further checked by L/T separation.

Slide from D. Dutta

The multi-pion Background



$^{12}C(e,e'\ \pi^+)$



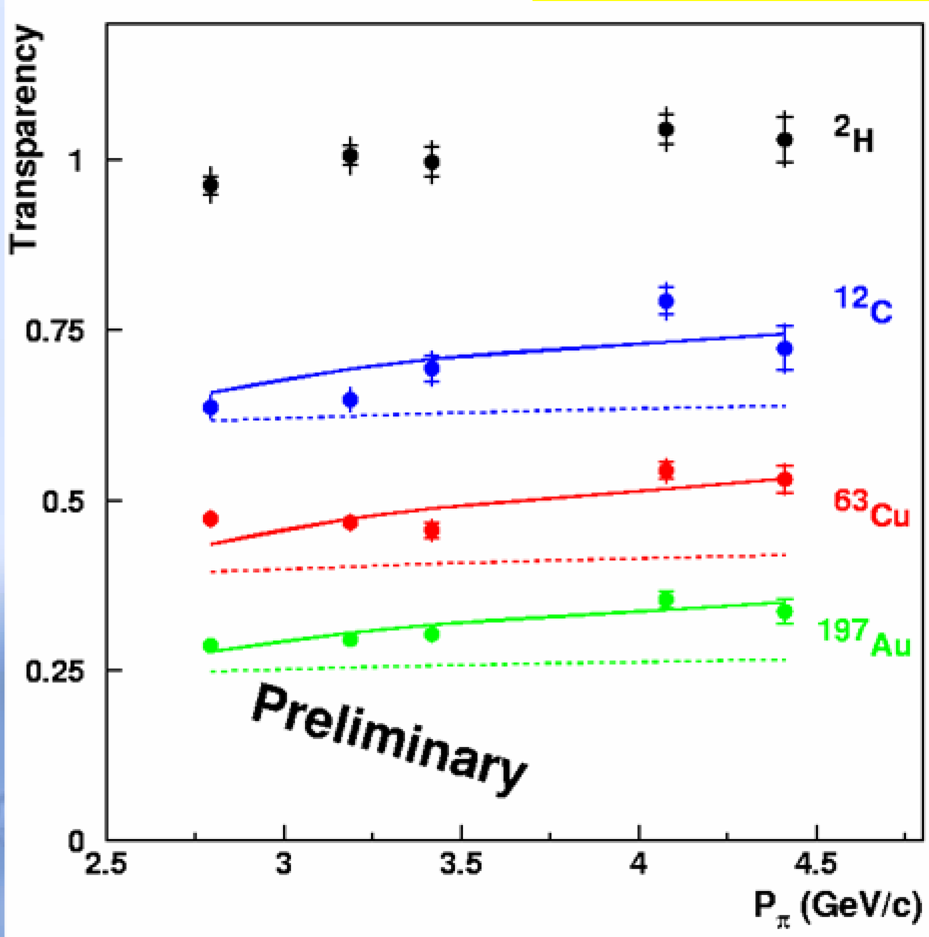
Data in Red

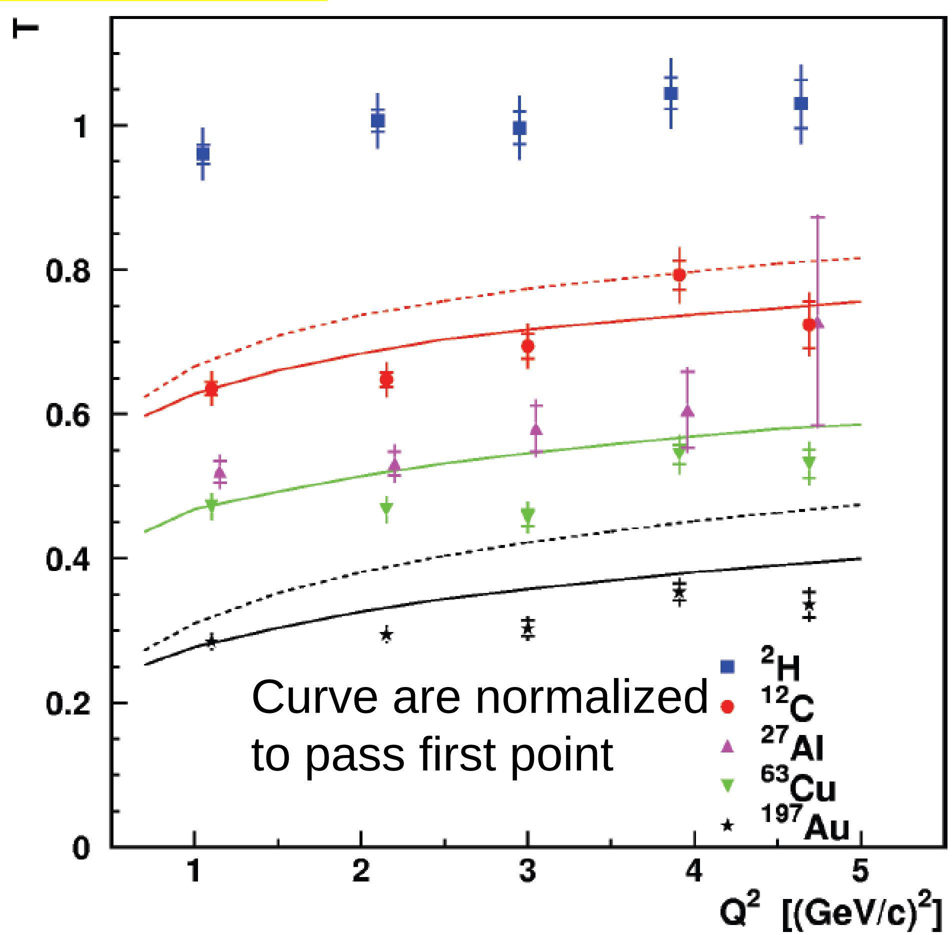
Blue is quasi-free model with

- ^{12}C spectral function
- Pauli Blocking
- off-shell effects

Slide from D. Dutta

$$T = \frac{(\text{Data/Simulation})_A}{(\text{Data/Simulation})_p}$$

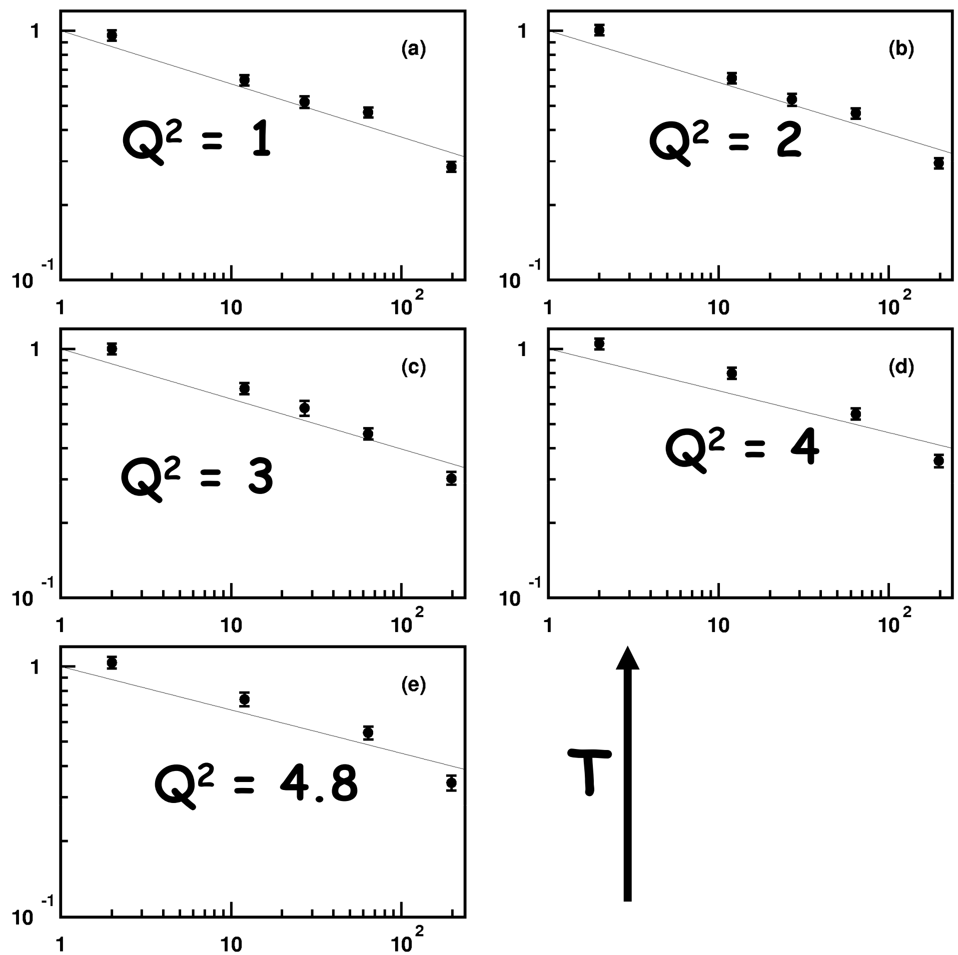


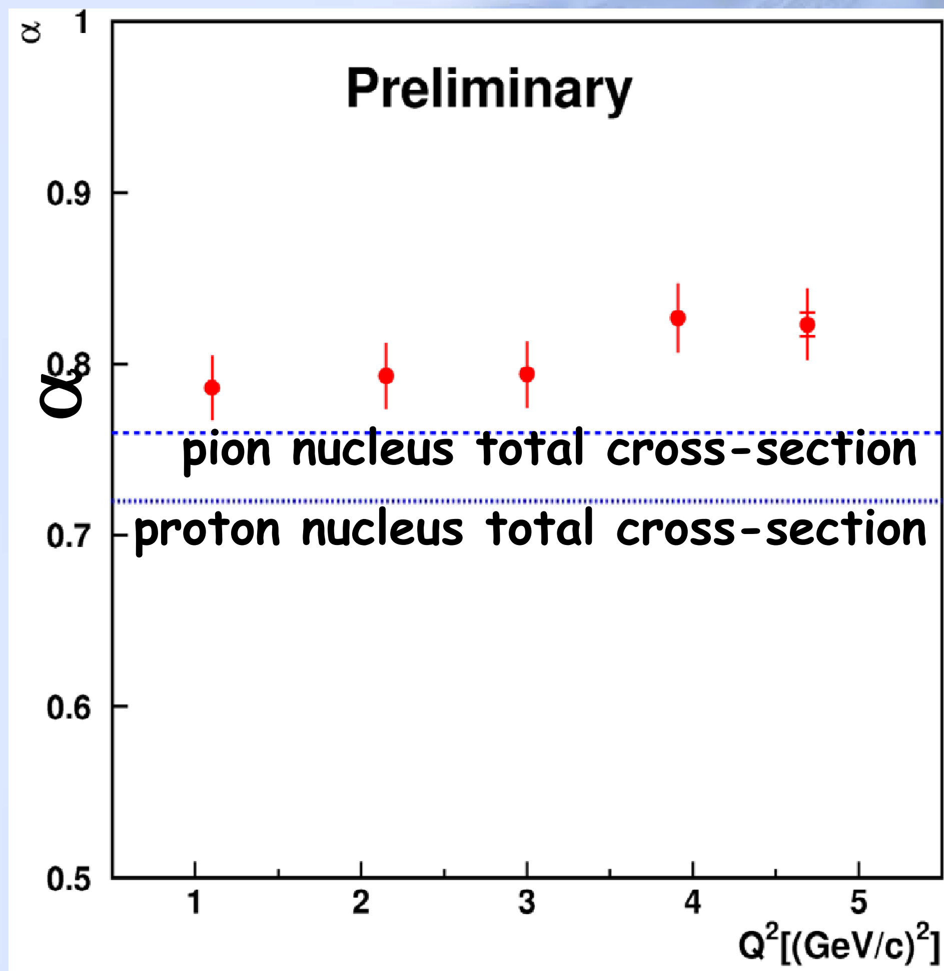


Solid/Dashed lines are predictions with and without CT
A. Larson, G. Miller and M. Strikman, nuc-th/0604022

Solid/Dashed lines are predictions with CT for different WFs
Kundu et al. PRD 62, 113009 (2000)
Normalized to pass the first Q^2 point.

'A' Dependence of Transparency





Fit of $T(A) = A^{\alpha-1}$ at fixed Q^2

Checking Quasi-free assumption

- Nuclear Transparency is defined by :

$$T = \frac{Y_{data}^{nucleus} / \boxed{Y_{SIMC}^{nucleus}}}{Y_{data}^{hydrogen} / Y_{SIMC}^{hydrogen}}$$

  - Expected Yield can be calculated using realistic nucleon momentum distributions **under quasi-free assumption**.
- Quasi-free assumption can be verified by carrying out Rosenbluth separation.

$$\frac{\sigma_L^{hydrogen}}{\sigma_T^{hydrogen}} \approx \frac{\sigma_L^{nucleus}}{\sigma_T^{nucleus}}$$

L/T: More from Tanja's talk.

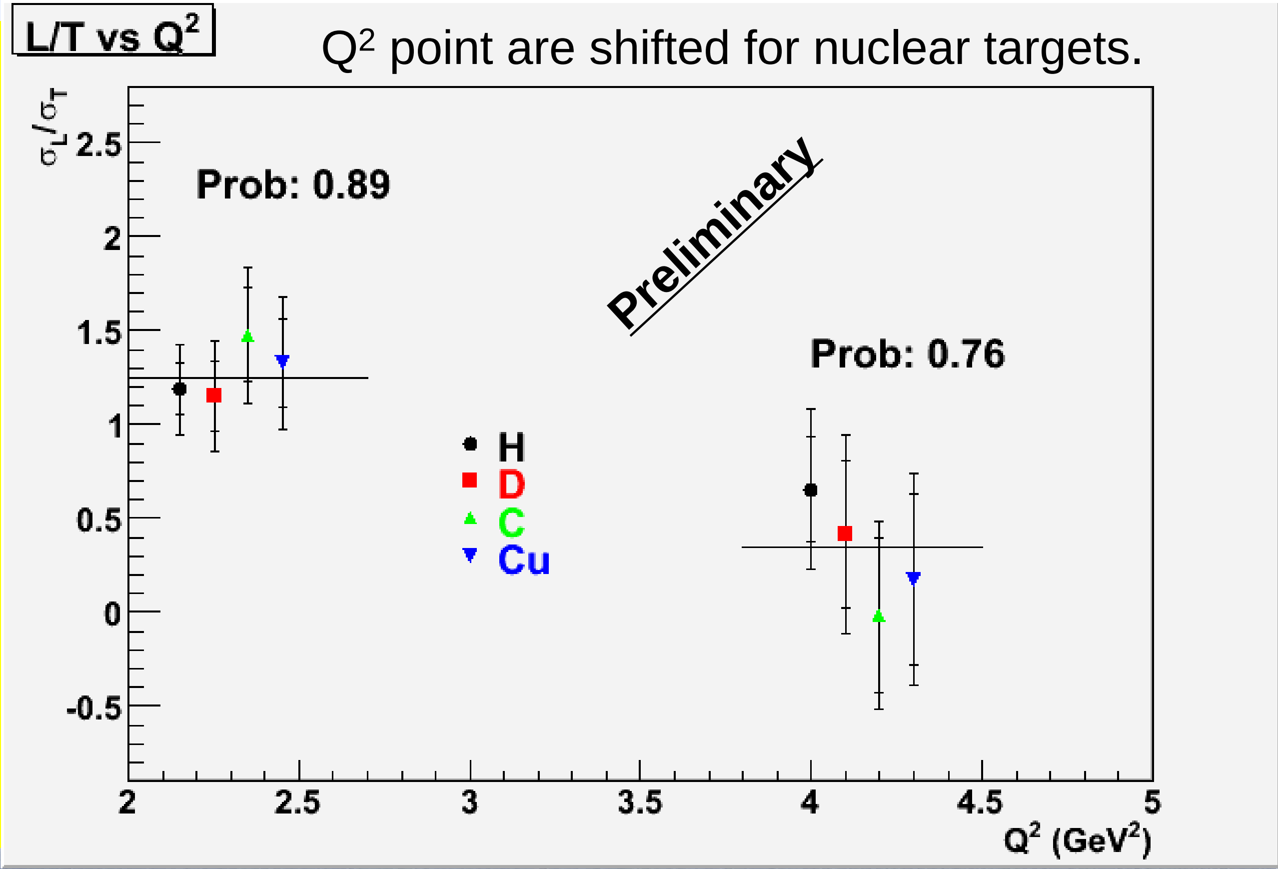
- What could violate the quasi-free assumption?
  - Final State Interaction
  - Meson exchange current, nuclear pions.
  - Two nucleon correlation, re-scattering effect at large t value …

L/T separation results

- Adapt Quasi-free assumption, extract ‘H’-like cross-section from nuclear targets.
- Extract average results over the acceptance.
- Results are consistent with quasi-free assumption at two Q^2 values.

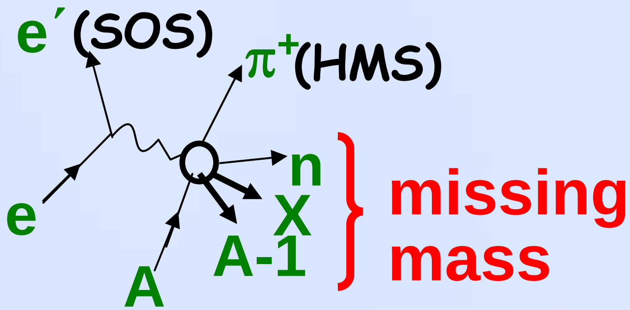
PID	0.2%
Charge	0.4-0.9%
HMS tracking	0.4-1.0%
SOS tracking	0.1%
Pion decay	0.1%
Coulomb corr.	0.-0.3%
Radiative corr.	0.5-1.0%
Collimator	0.5%
Acceptance	1.0%
Multi-pion	0.0-0.4%
Dead time	0.2%
Trigger	0.25%
Coin. blocking	0.2%
Sum:	1.4-2.0%

Q^2 point are shifted for nuclear targets.



Multi-pion Background Subtraction

$^{12}C(e,e'\ \pi^+)$

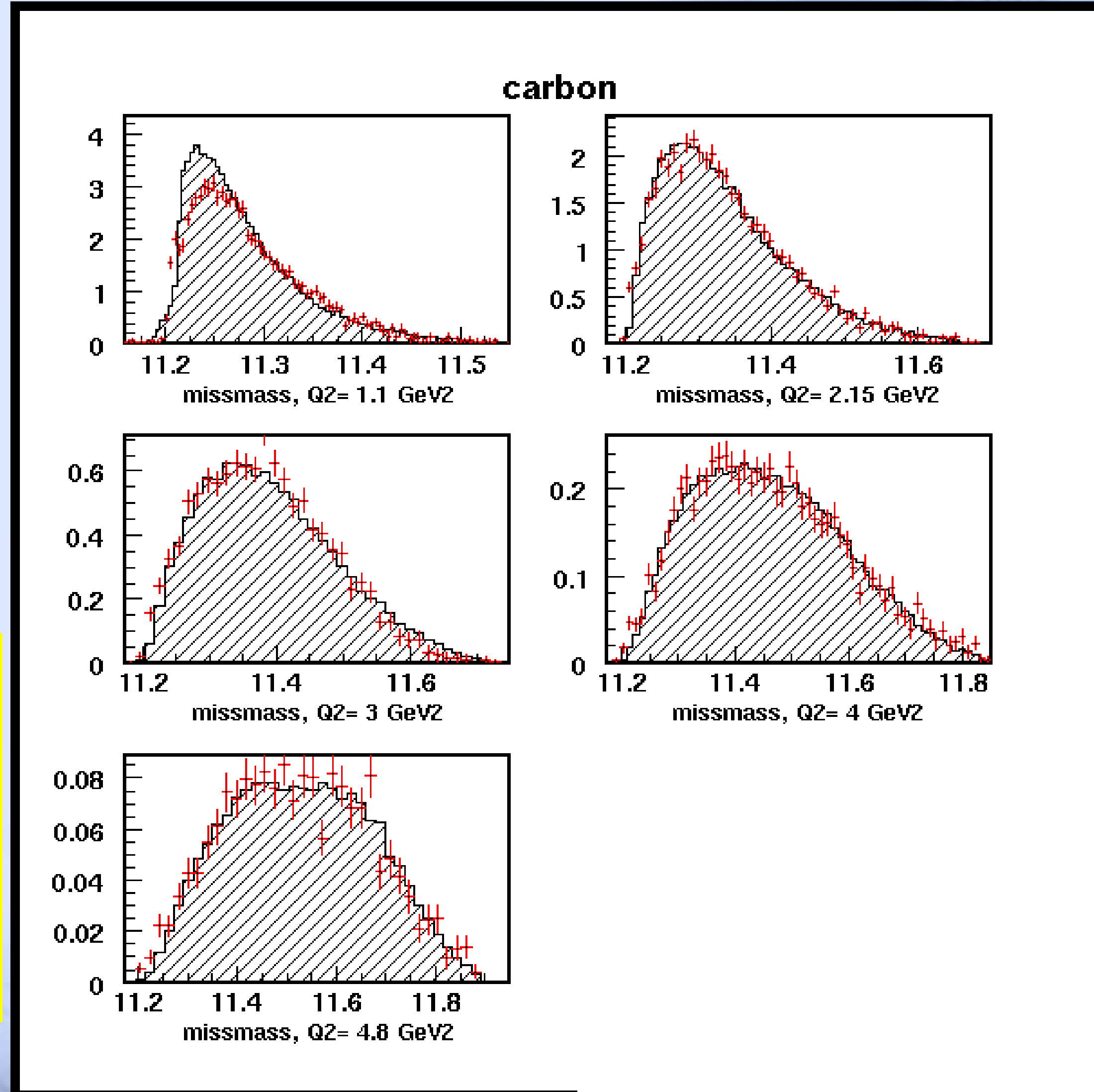


Data in Red with multi-pi background subtraction

Black is quasi-free model

For Q^2 = 3 GeV^2 and up, the Transparency obtained is within 2.5% of those obtained using the hard cut method.

Q^2 = 1, 2 GeV^2 differ by ~8-10%



Slide from D. Dutta

Summary

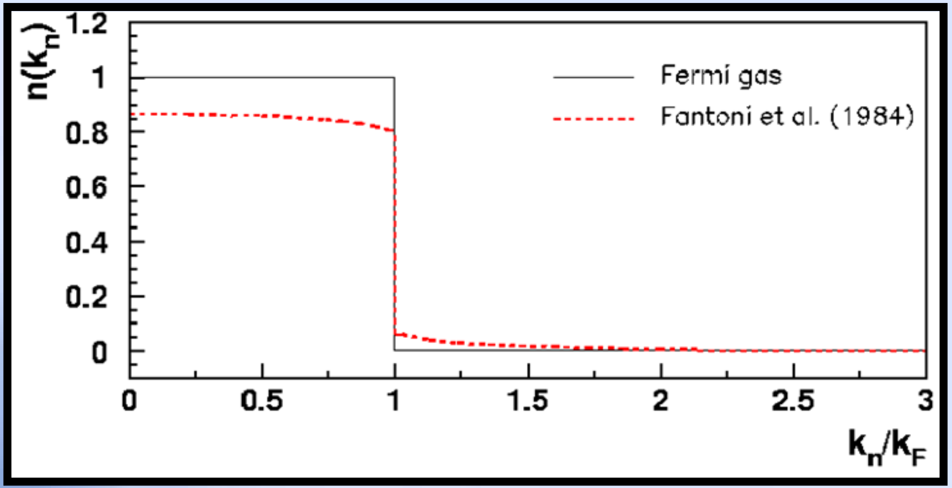
- CT is a signature of transition from nucleon-meson Dof to quark-gluon Dof and DES factorization theorem.
- New theoretical development identify the connection between CT and GPDs, which open a new window to constrain GPDs/GDAs.
- The nuclear transparency from A(e,e' π^+) was measured for the first time from H, D, C, Cu, Au targets (Results are final).
- Rosenbluth separation has been carried out for nuclear targets, results are consistent with quasi-free assumption (Results are final).
- The dependence of the nuclear transparency on Q^2, P_π show hints of CT-like behavior and a slow onset of CT.
- New Multi-pion subtraction method can be used in future 12 GeV experiments.

Backup slides

Pauli Blocking

The **recoiling neutron** in the $p(e,e'\pi^+)n$ process can be Pauli Blocked, when occurring inside a nucleus.

The momentum of the recoiling neutron can be reconstructed from the generated momentum of p, e, e' and π^+,



The neutron distribution function of Fantoni *et al.* is used to simulate the effect of Pauli Blocking & correlations.

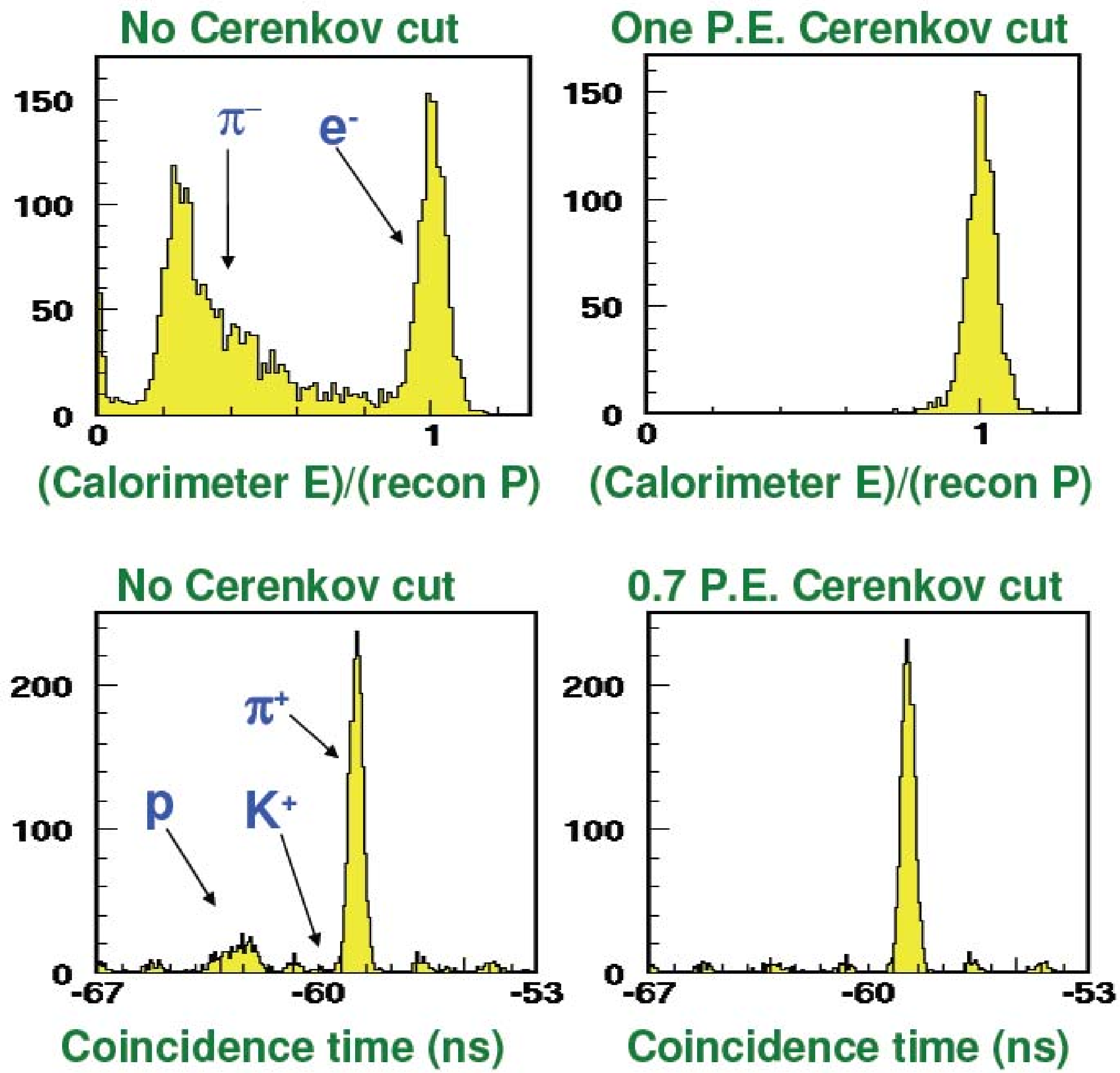
Data analysis - Particle identification

Electron arm (SOS) at 1.4 GeV

Cerenkov effic = 99.4%

Pion arm (HMS) at 3.2 GeV

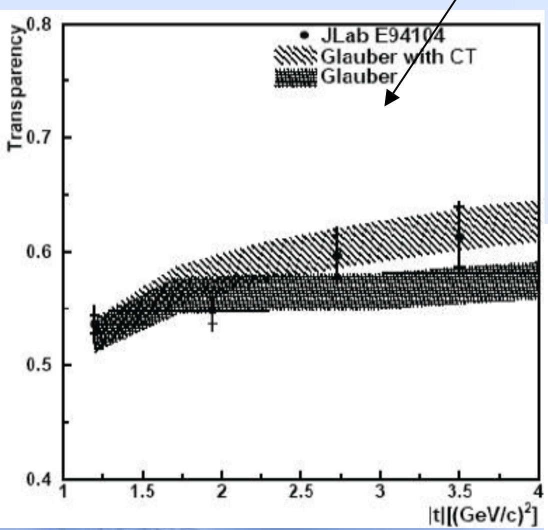
Cerenkov effic = 98.5%



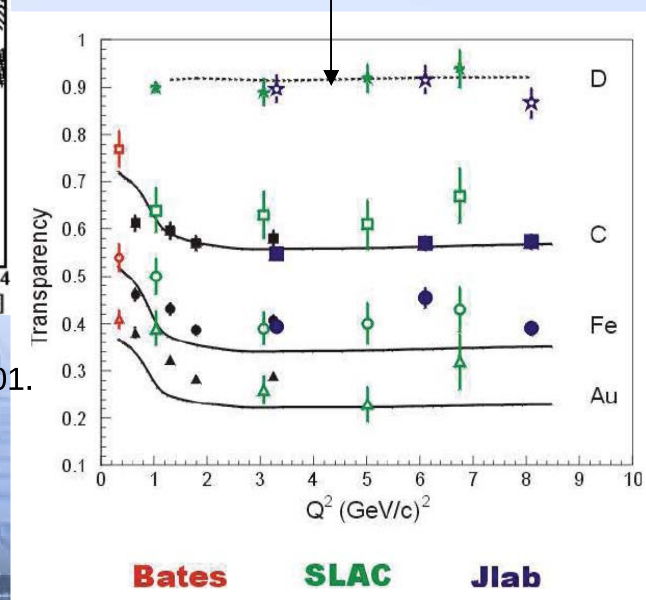
Slide From B. Clasie

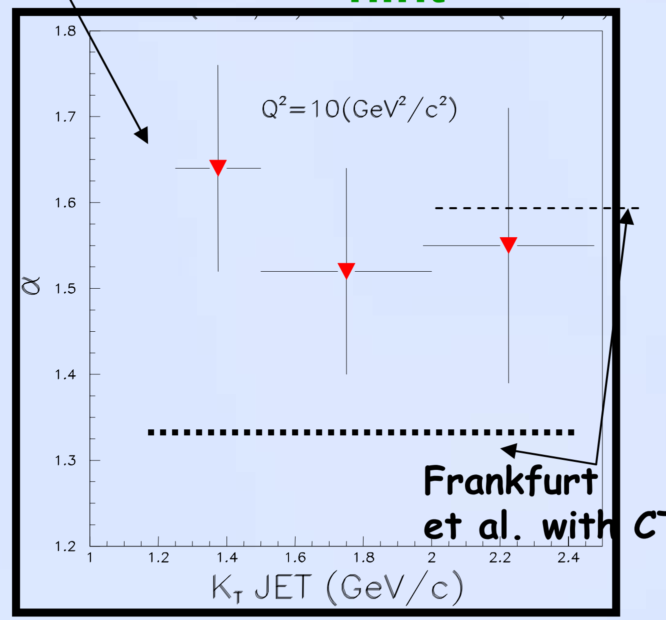
Status of Searching for onset of CT

- Color Transparency in **A(p,2p)** BNL — negative
- Color Transparency in **A(e,e' p)** SLAC, JLab — negative
- Color Transparency in **A(l,l' ρ)** FNAL,HERMES,JLab — hint
- Color Transparency in di-jet production FNAL — positive
- Color Transparency in **A(γ,pπ)** JLab — hint

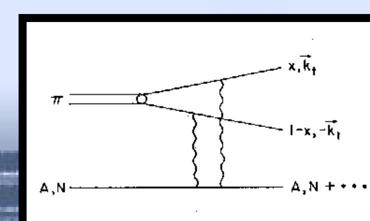


D. Dutta et al., PRC 68 (2003) 021001.
H. Gao et al. PRC 54 (1996) 2779.





Aitala *et al.,* PRL 86 4773 (2001)



Systematic Uncertainties

Item	point-to-point (%)	scale(%)	total(%)
Particle ID	0.3	0.4 - 0.7	
Charge	0.3	0.5	
Target thickness	0.5		
Coin blocking	0.1		
Trigger(HMS+SOS)	0.7		
Dead time correction	0.1		
Tracking(HMS+SOS)	0.5	0.5	
Pion Absorption	0.5	2.0	
Beam Energy	0.1	0.1	
Cut dependence	0.5	0.5	
Pion Decay	0.5	1.0	
Pauli Blocking	0.5		
Radiative Corrections	0.5	1.0	
collimator	1.0		
Acceptance	0.5	2.0	
Iteration	1.0	2.0	
Spectral Function	1.0	2.0	
TOTAL	2.4	4.4	5