C. CIOFI degli ATTI

# NUCLEON-NUCLEON CORRELATIONS: from $^3He$ to Complex Nuclei

## Short-Range Correlations in Nuclei

A Workshop in memory of Kim Egiyan

October 21-22, 2006

Università degli Studi di Perugia

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## 1. Introduction and Motivations

**Transition matrix element for the process $\mathbf{A(e,e'p)B}$:**

$$T_{fi} = \langle \Psi^{f}_{A,\mathbf{p}}(1,2,...,A) | \hat{J} | \Psi^{0}_{A}(1,2,...,A) \rangle$$

**High Energies** $\Psi^{f}_{A,\mathbf{p}}(1,2,...,A) = \hat{\mathcal{A}} \left[ e^{i\mathbf{p}\cdot\mathbf{r}} \otimes \hat{\mathcal{S}}\, \Psi^{f}_{A-1} \right]$

$\hat{\mathcal{S}} \Rightarrow$ **FSI Operator**

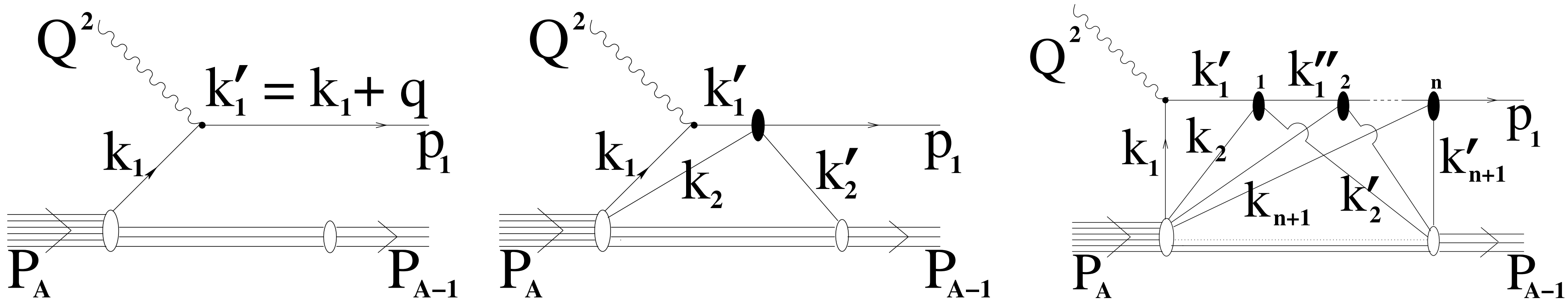
**This talk:**

**realistic few- and many-body wave functions and Generalized Eikonal Approximation (GEA) for the FSI operator**

**Collaborators:**

**M. Alvioli (PG), L. Kaptari (PG-Dubna), H. Morita (PG-Sapporo)**

# 2. ISC and FSI at medium and high energies in $\mathrm{A(e,e'p)B}$ processes




## The Factorized Cross Section

$$\frac{d^6\sigma}{dE'\,d\Omega'\,d\mathbf{p}_m} = \mathcal{K}(Q^2,x,\mathbf{p}_m)\,\sigma_{cc1}^{eN}(\bar{Q}^2,\mathbf{p}_m)\,{P_A}^D(\mathbf{p}_m,E_m)$$

$P_A^D(\mathbf{p}_m,E_m)$ **Distorted Spectral Function**

**(describes both ISC and FSI)**

$$P_A^D(\mathbf{p}_m, E_m) = \frac{1}{(2\pi)^3}\frac{1}{2J_A+1} \sum_f \sum_{\mathcal{M}_A, \mathcal{M}_{A-1}, s_1} \times$$

$$\times \left| \sum_{n=0}^{A-1} \mathcal{T}_A^{(n)}(\mathcal{M}_A, \mathcal{M}_{A-1}, s_1) \right|^2 \times \delta\Big(E_m - (E_{A-1}^f + E_{min})\Big)$$

$\mathcal{T}_A^{(n)}$ **- from Feynman diagrams;** $n$ **- order of rescattering**.

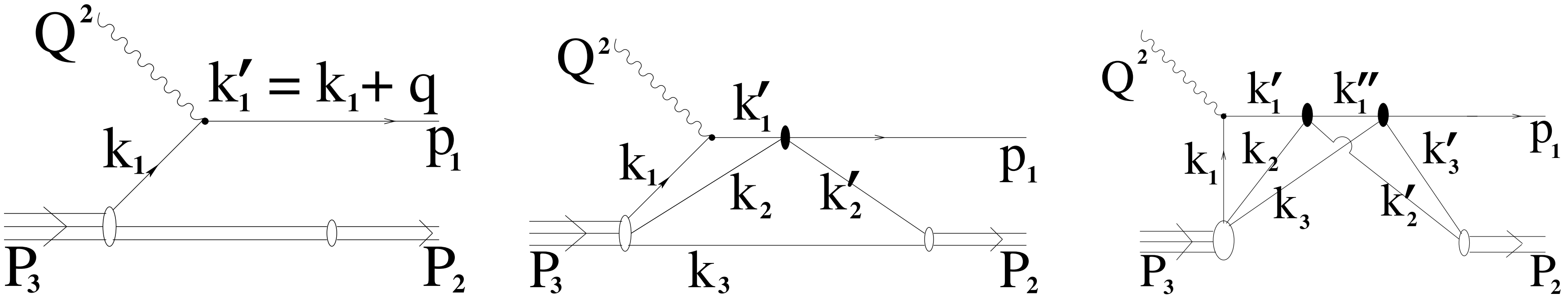
Missing momentum:

$$\mathbf{p}_m = \mathbf{q} - \mathbf{p}_1$$

Missing energy:

$$E_m = \sqrt{P_{A-1}^2} + M_N - M_A = M_N + M_{A-1} - M_A + E_{A-1}^f =$$
$$= E_{min} + E_{A-1}^f,$$

# $\boxed{A=3}$




$$\mathcal{S}_{\Delta}^{FSI}(\rho,\mathbf{r}) = \mathcal{S}_{(1)}^{FSI}(\rho,\mathbf{r}) + \mathcal{S}_{(2)}^{FSI}(\rho,\mathbf{r})$$

$$\mathcal{S}_{(1)}^{FSI}(\rho,\mathbf{r}) = 1 - \sum_{i=2}^{3}\theta(z_i - z_1)\mathrm{e}^{i\Delta\cdot\,(z_i - z_1)}\Gamma(\mathbf{b}_1 - \mathbf{b}_i)$$

$$\mathcal{S}_{(2)}^{FSI}(\rho,\mathbf{r}) = \Big[\theta(z_2 - z_1)\theta(z_3 - z_2)\mathrm{e}^{-i\Delta_3\cdot(z_2 - z_1)}\mathrm{e}^{-i(\Delta_3 - \Delta)\cdot(z_3 - z_1)} +$$

$$+\;\theta(z_3 - z_1)\theta(z_2 - z_3)\mathrm{e}^{-i\Delta_2\cdot\,(z_3 - z_1)}\mathrm{e}^{-i(\Delta_2 - \Delta)\cdot(z_2 - z_1)}\Big]\;\Gamma(\mathbf{b}_1 - \mathbf{b}_2)\Gamma(\mathbf{b}_1 - \mathbf{b}_3)$$

where $\Delta_i = (q_0/|\mathbf{q}|)(E_{\mathbf{k}_i} - E_{\mathbf{k}_i'})$ and $\Delta = q_0/|\boldsymbol{q}|\, E_m$.

$$\Delta = 0 \;\; \rightarrow \mathcal{S}_{\Delta}^{FSI} \rightarrow \mathcal{S}_G(\rho,\mathbf{r}) = \prod_{i=2}^{3}\;[1 - \theta(z_i - z_1)\,\Gamma(\mathbf{b}_1 - \mathbf{b}_i)]$$

## 3. ISC and FSI in $(e, e'p)$ processes off $^3He$ and $^4He$

**CdA, H. Morita, D. Treleani**, *Phys. Rev.* **C60 (2003)034603**

**CdA, L. P. Kaptari**, *Phys. Rev.* **C71 (2005)024005**

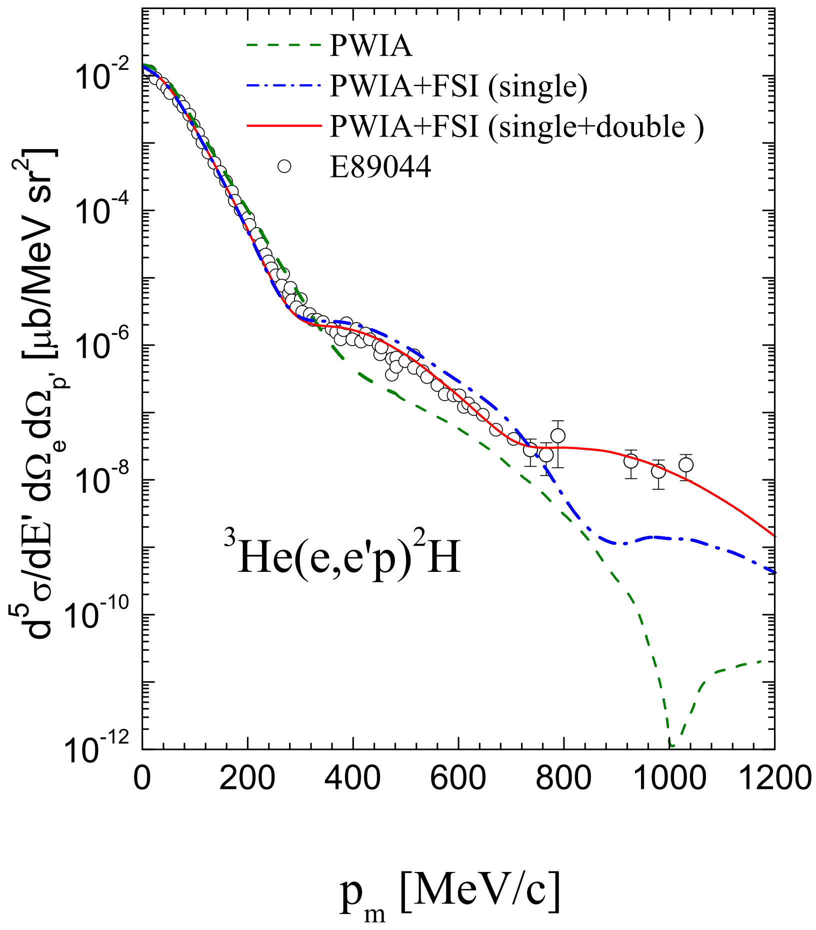
**CdA, L. P. Kaptari**, *Phys. Rev. Lett.* **95(2005)052502**

**CdA, L. P. Kaptari, H. Morita**, *Nucl. Phys.A, to appear*

1. **Realistic few-body wave functions (AV18 interactions)**
2. **Generalized Eikonal Approximation**
3. **Elastic NN scattering amplitude from experimental world data**

**No free parameters throughout the periodic table**

# Results: 2bbu channel $^3He(e,e'p)^2H$ at $Q^2 \simeq 1.55\ (GeV/c)^2$, $x = 1$

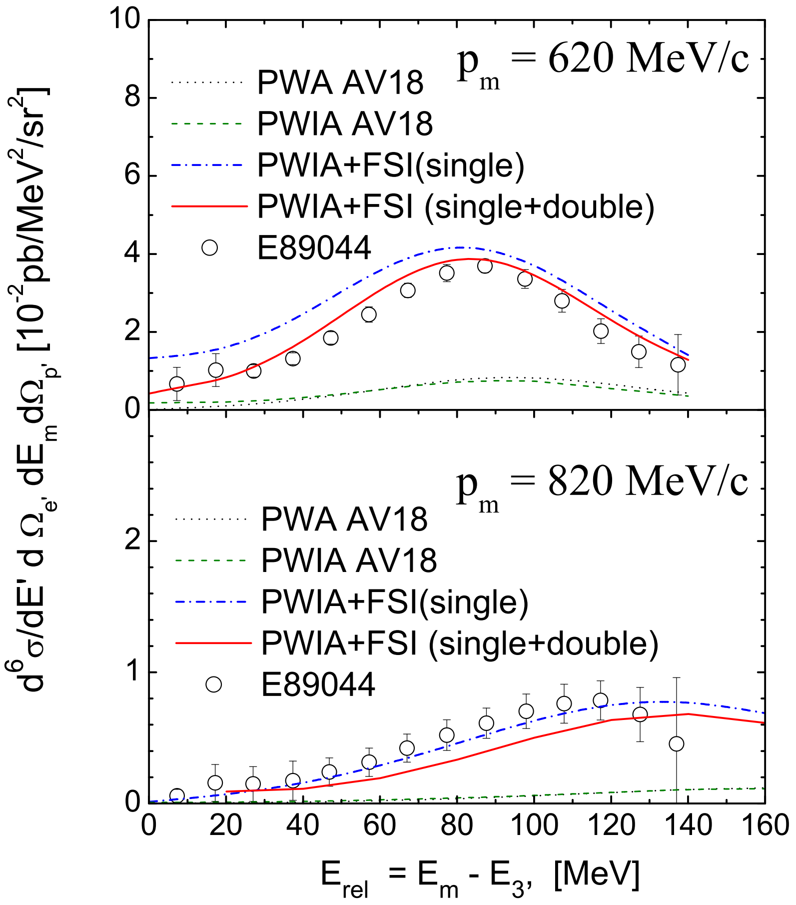



*Experiment* **:**

**M. M. Rvachev *et al.*, Phys. Rev. Lett. 94(2005)192302**

## Results: 3bbu channel $^3He(e,e'p)(pn)$

(F. Benmokhtar *et al.*, Phys. Rev. Lett. 94(2005)082325 )




$$\mathbf{Q^2 = 1.55\ (Gev/c)^2}$$

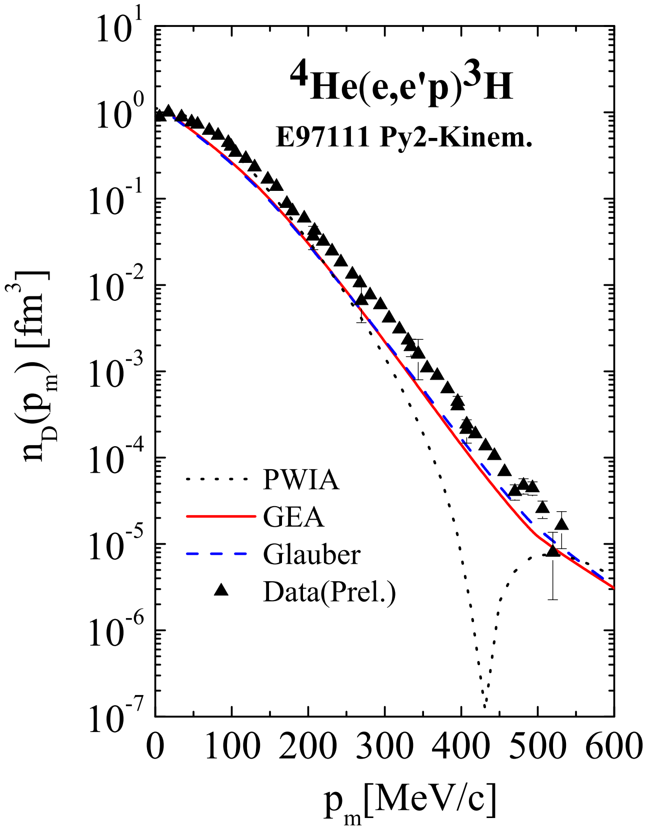
$$\mathbf{x = 1}$$

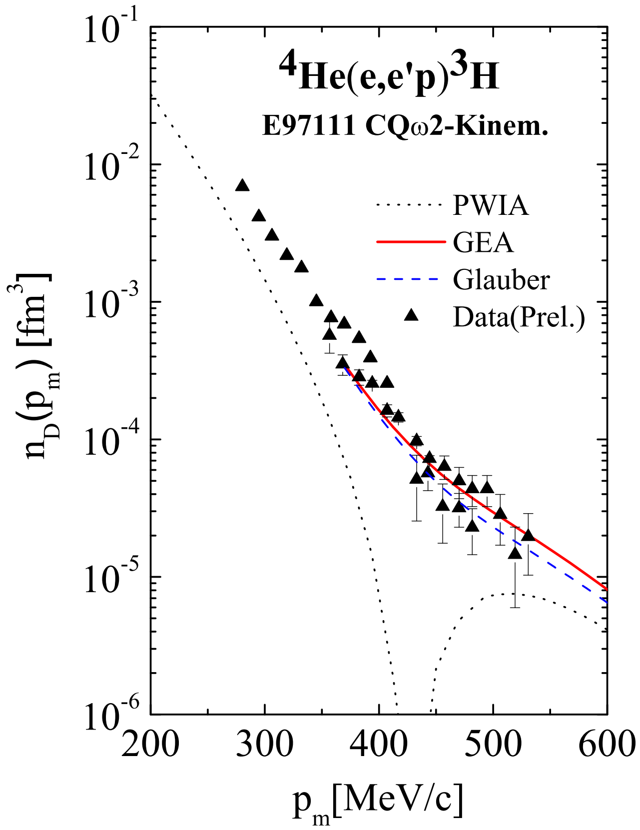
$$\mathbf{E_{rel} = E_2^f = E_m - E_3}$$

**FSI in (n-p) pair- irrelevant;**
**FSI in n-(n-p) system- very large**

## Results: $^4He(e,e'p)^3H$ Jlab E97-11,EPJA S19(2004)165

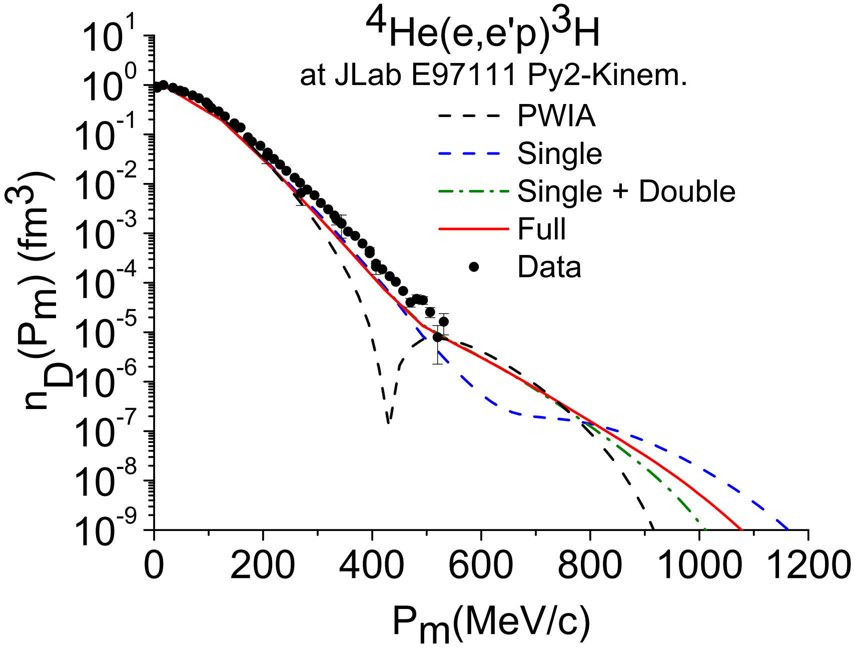
## Py2 Parallel Kinematics CQw2 Perpendicular Kinematics

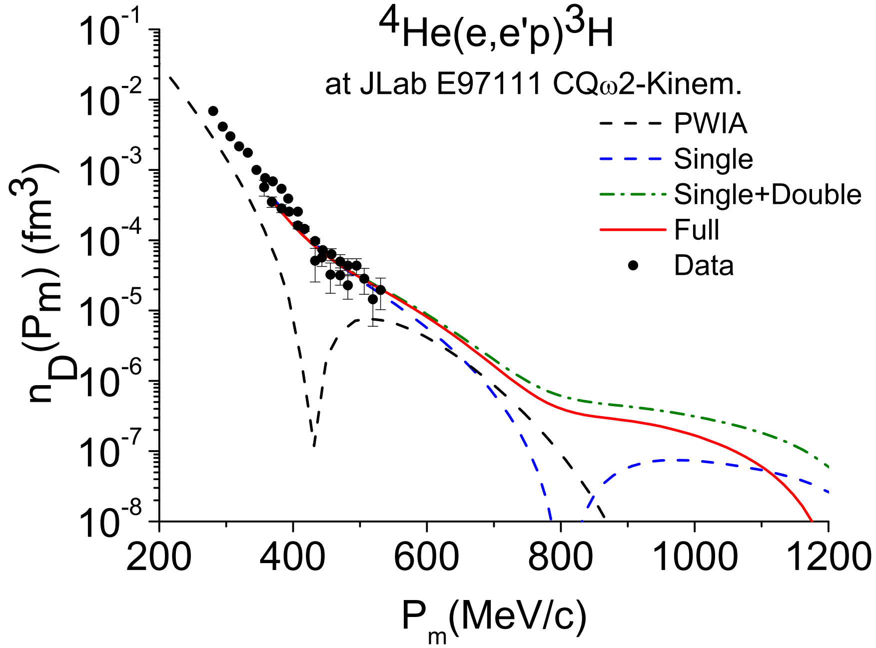



$$n_D(|\mathbf{p}_m|) = \frac{d^5\sigma^{exp}}{d\Omega' dE' d\Omega_{\mathbf{p}_m}} \left[f_{rec}\,\mathcal{K}\,\sigma^{eN}_{cc1}\right]^{-1}$$

# Effects of final state rescattering



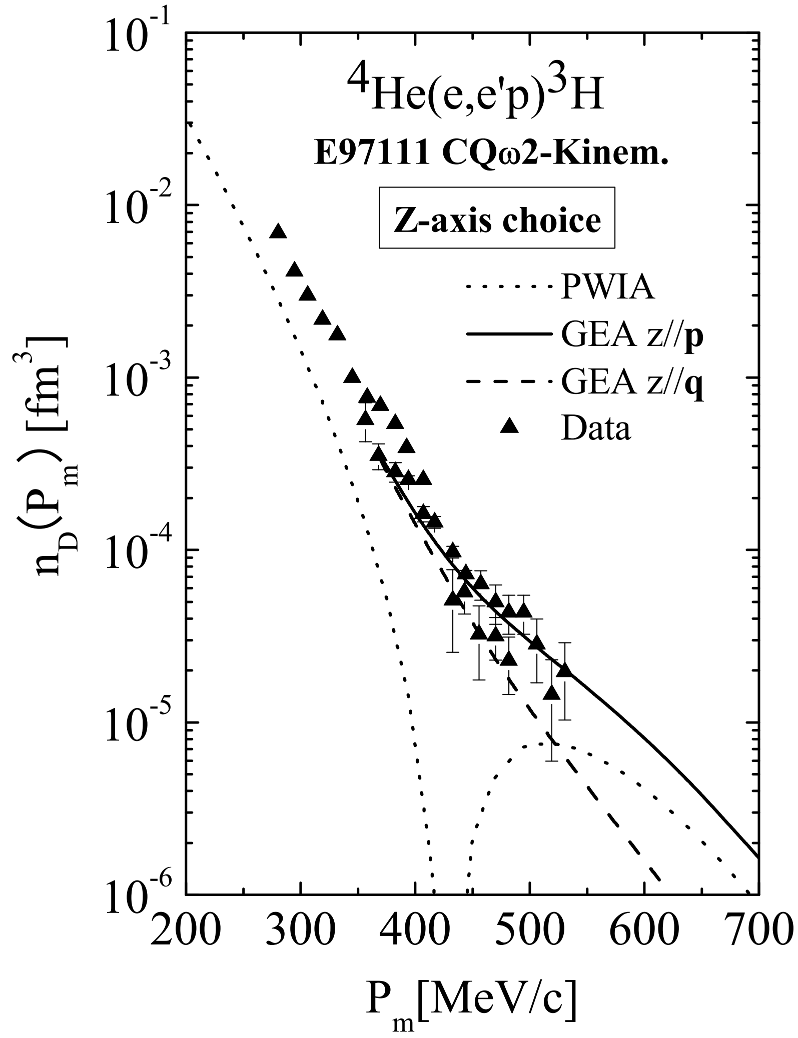




$p_m \leq 500 MeV/c$ **(experimental data): single rescattering**

$500 \leq p_m \leq 800 MeV/c$: **single + double rescattering**

$p_m \geq 800 MeV/c$: **single + double + triple rescattering**

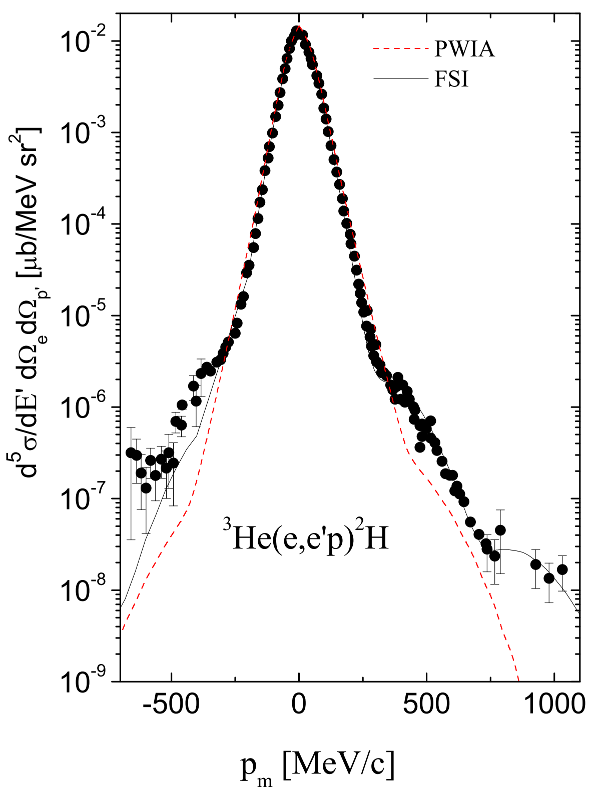
# Choice of the z-axis

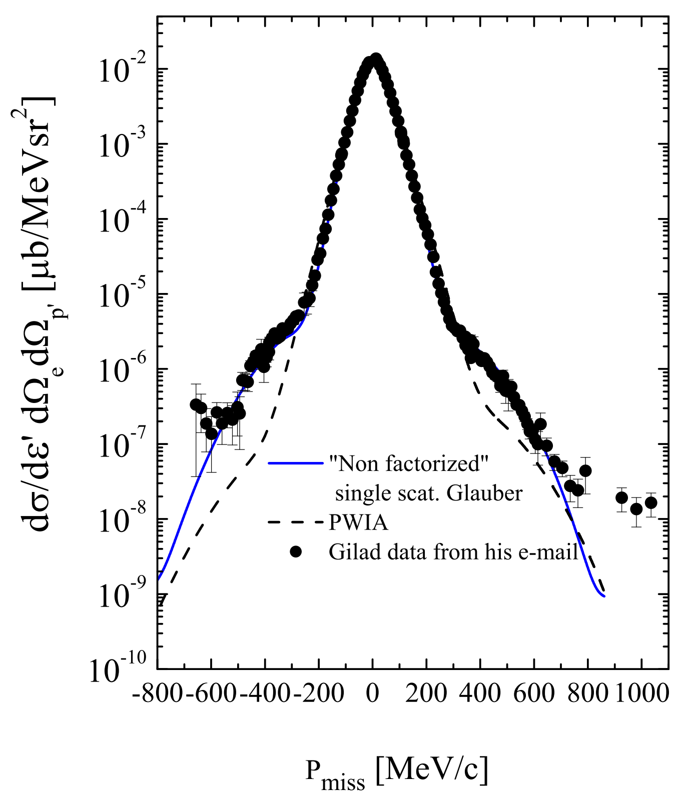


## 3.3 Results $^3He(e,e'p)D$: non factorized cross section

$$\frac{d^6\sigma}{d\Omega' dE'\ d^3\mathbf{p}_m} = \sigma_{Mott} \sum_i V_i\ W_i^A(\nu, Q^2, \mathbf{p}_m, E_m)$$

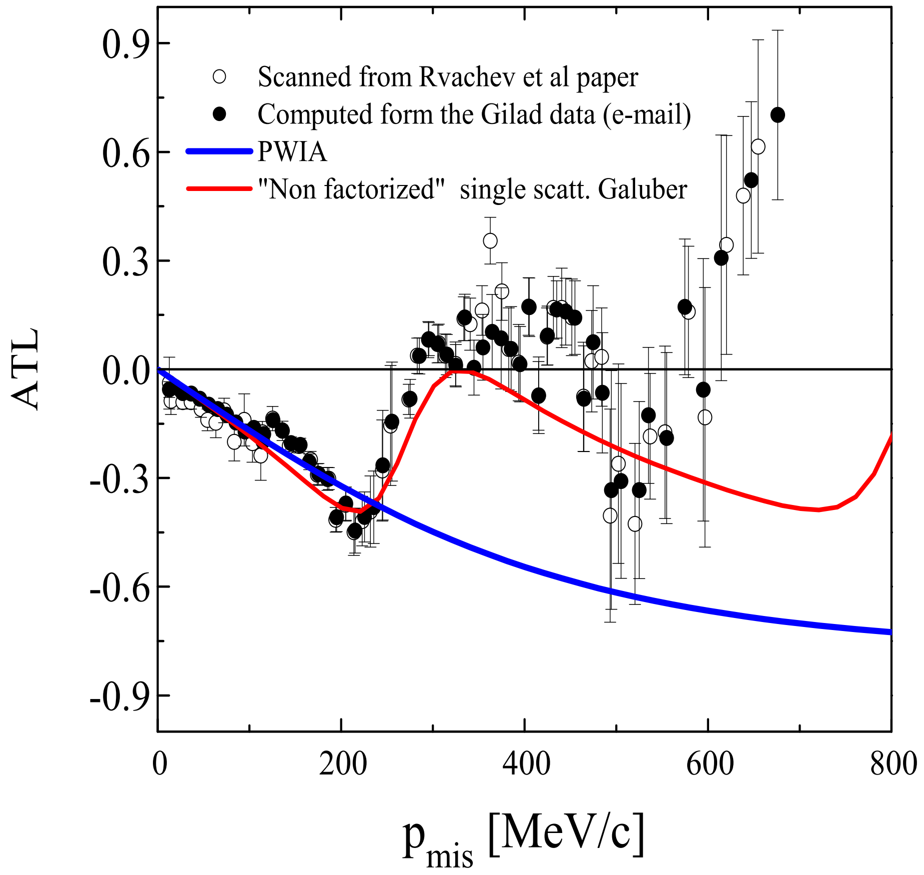
**Current operator: *cc1*** $\longrightarrow$ **no p/q expansion** $\longrightarrow$ **k− space** $\psi$


PWIA
FSI
$^3He(e,e'p)^2H$
$d^5\sigma/dE'\,d\Omega_e d\Omega_{p'}$ [μb/MeV sr$^2$]
$p_m$ [MeV/c]


"Non factorized"
single scat. Glauber
PWIA
Gilad data from his e-mail
$d\sigma/d\varepsilon'\,d\Omega_e d\Omega_{p'}$ [μb/MeVsr$^2$]
$P_{miss}$ [MeV/c]

# $^3He(e,e'p)D$: the $A_{TL}$ Asymmetry

$$A_{TL} = \frac{\sigma_{right} - \sigma_{left}}{\sigma_{right} + \sigma_{left}}$$



## 3.4 Conclusions

- **A realistic and transparent treatment of ISC and FSI in $A(e,e'p)B$ processes off few-nucleon systems at high energies has been developed.**
- **Theoretical calculations show that FSI have a relevant effect but also show that in the region $|\mathbf{p}_{mis}| \le 600MeV/c$, $E_{mis} \le 150MeV$ , proper kinematical conditions can be chosen where the effects from FSI of the struck nucleon with $A-1$ , MEC, etc could be minimized and ISC can be investigated.**
- **The agreement between existing experimental data and theoretical calculations performed within GEA and realistic few-nucleon wave functions containing a rich correlation structure appears to be a satisfactory one. .**

# 4. Complex Nuclei

## 4.1 Introduction (two points)

**1** What is the wave function of Complex Nuclei? Realistic calculations (e.g. VMC-Urbana) show that it contains a rich *central* and *non central* correlation structure. If so, the usual approximation of Glauber type calculations i.e

$$|\Psi(1,2,3,....,A)|^2 \simeq \prod_i \rho(i)$$

has to be carefully checked.

**2** Wave functions resulting from full many-body calculations (e.g. VMC) are difficult to be used in scattering processes; a recent realistic and practicable (*cluster expansion*) approach will be described

(*M. Alvioli, CdA, H.Morita, Phys. Rev.* C72 *(2005) 054210*)

## 4.2 The Theoretical Approach (*number conserving $\eta-$expansion*)

$$\hat{\mathbf{H}}\,\Psi_n = E_n\,\Psi_n\,, \quad with: \quad \hat{\mathbf{H}} = -\frac{\hbar^2}{2\,m}\sum_i \hat{\nabla}_i^2 + \frac{1}{2}\sum_{i<j}\hat{v}_{ij}$$

**where**

$$\hat{v}_{ij} = \sum_n v^{(n)}(r_{ij})\,\hat{\mathcal{O}}_{ij}^{(n)}$$

$$\hat{\mathcal{O}}_{ij}^{(n)} = \left[1\,,\,\boldsymbol{\sigma}_i\cdot\boldsymbol{\sigma}_j\,,\,\hat{S}_{ij}\,,\,(\boldsymbol{L}\cdot\boldsymbol{S})_{ij}\,,\,...\right]\otimes\left[1\,,\,\boldsymbol{\tau}_i\cdot\boldsymbol{\tau}_j\right]$$

**The same operatorial dependence is cast onto $\Psi_o$:**

$$\Psi_o = \hat{\mathbf{F}}\,\phi_o$$

**where $\phi_o$ is the mean-field wave function and**

$$\hat{\mathbf{F}} = \hat{S}\prod_{i<j}\hat{f}_{ij} = \hat{S}\prod_{i<j}\sum_n f^{(n)}(r_{ij})\,\hat{\mathcal{O}}_{ij}^{(n)}$$

- **The ground state energy $E_0$ is given by:**

$$E_o = -\frac{\hbar^2}{2\,m} \int d\boldsymbol{r} \left[\hat{\nabla}^2 \rho^{(1)}(\boldsymbol{r}, \boldsymbol{r}')\right]_{\boldsymbol{r}=\boldsymbol{r}'} + \sum_n \int d\boldsymbol{r}_1 d\boldsymbol{r}_2\, \hat{v}^{(n)} \rho^{(2)}_{(n)}(\boldsymbol{r}_1, \boldsymbol{r}_2)$$

$$\longrightarrow \rho^{(1)}(\boldsymbol{r}, \boldsymbol{r}') = A \int \prod_{j=2}^{A} d\boldsymbol{r}_j\, \Psi_o^\dagger(\boldsymbol{r}, \boldsymbol{r}_2 \ldots, \boldsymbol{r}_A)\, \Psi_o(\boldsymbol{r}', \boldsymbol{r}_2 \ldots, \boldsymbol{r}_A)$$

$$\longrightarrow \rho^{(2)}_{(n)}(\boldsymbol{r}_1, \boldsymbol{r}_2) = \frac{A(A-1)}{2} \int \prod_{j=3}^{A} d\boldsymbol{r}_j\, \Psi_o^\dagger(\boldsymbol{r}_1 \ldots, \boldsymbol{r}_A)\, \hat{O}^{(n)}_{12}\, \Psi_o(\boldsymbol{r}_1 \ldots, \boldsymbol{r}_A)$$

- $\rho^{(1)}(\boldsymbol{r}, \boldsymbol{r}')$ **and** $\rho^{(2)}_{(n)}(\boldsymbol{r}_1, \boldsymbol{r}_2)$ **are cluster expanded;**
- **cluster expansion truncated at 2nd order in $\eta_{ij}$;**
- **the wave function and correlation functions which minimize the ground-state energy are used to calculate the expectation value of any operator at the same order.**

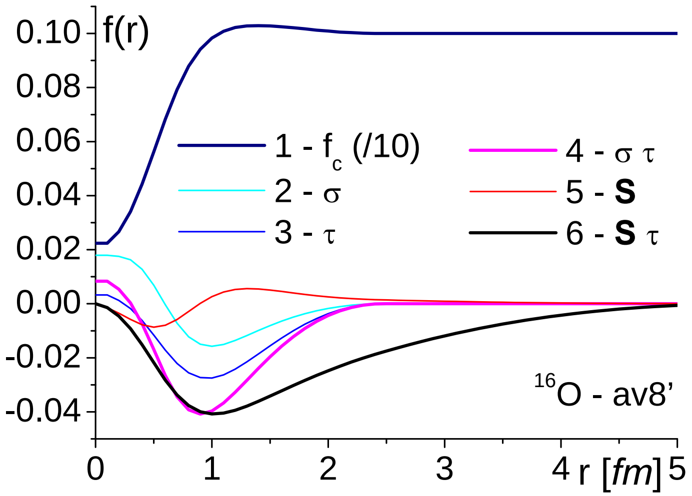
**NO FREE PARAMETERS**

## 4.3 The ground state energy, density and radii

**Benchmark calculation with $V8'$ interaction - $^{16}O$**

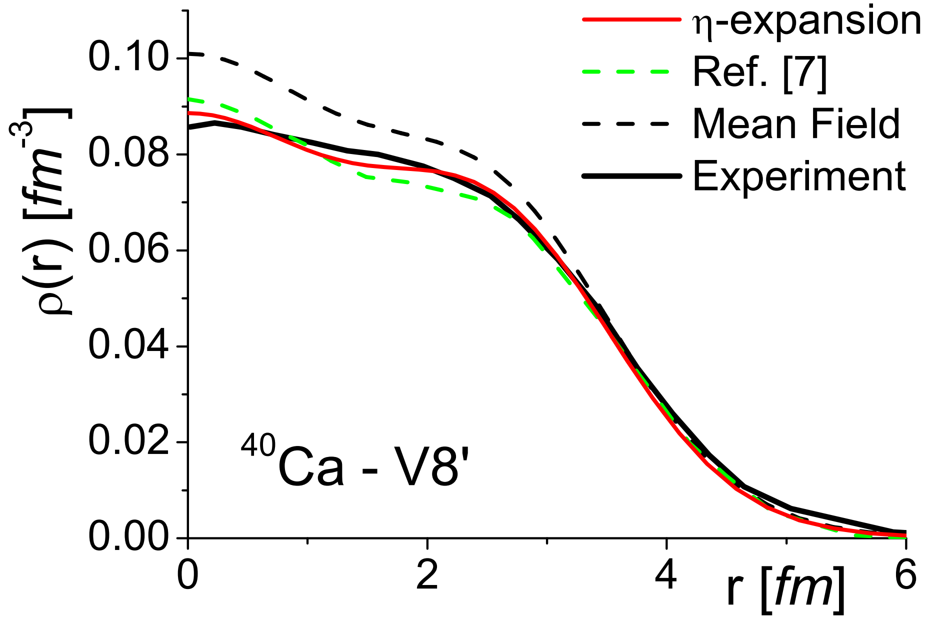
| | $< V_c >$ | $< V_\sigma >$ | $< V_\tau >$ | $< V_{\sigma\tau} >$ | $< V_S >$ | $< V_{S\tau} >$ | $< \mathbf{V} >$ | $< \mathbf{T} >$ | **E** | **E/A** |
|---|---|---|---|---|---|---|---|---|---|---|
| $\eta - exp$ | 0.20 | -36.00 | -9.50 | -171.30 | -0.003 | -172.90 | -389.40 | 323.50 | -65.90 | -4.12 |
| FHNC | 0.69 | -40.13 | -10.61 | -180.00 | -0.07 | -160.32 | -390.30 | 325.18 | -65.12 | -4.07 |

(All quantities in MeV)



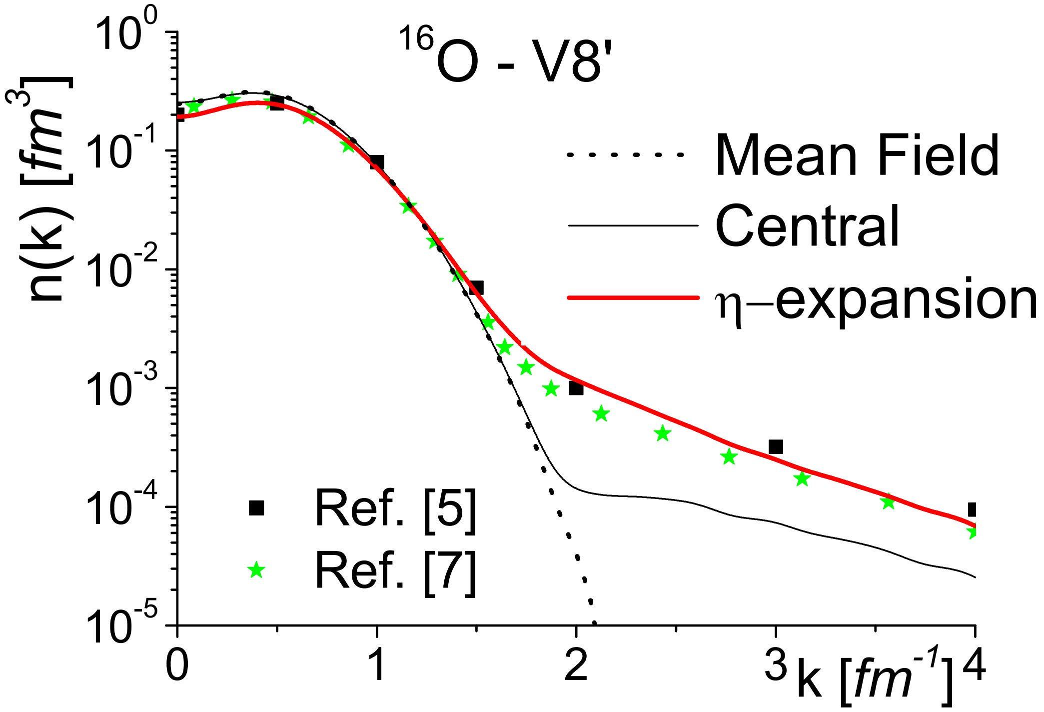

**A. Fabrocini, G. Co'** ***Phys. Rev.*** **C61 (2000) 044302**

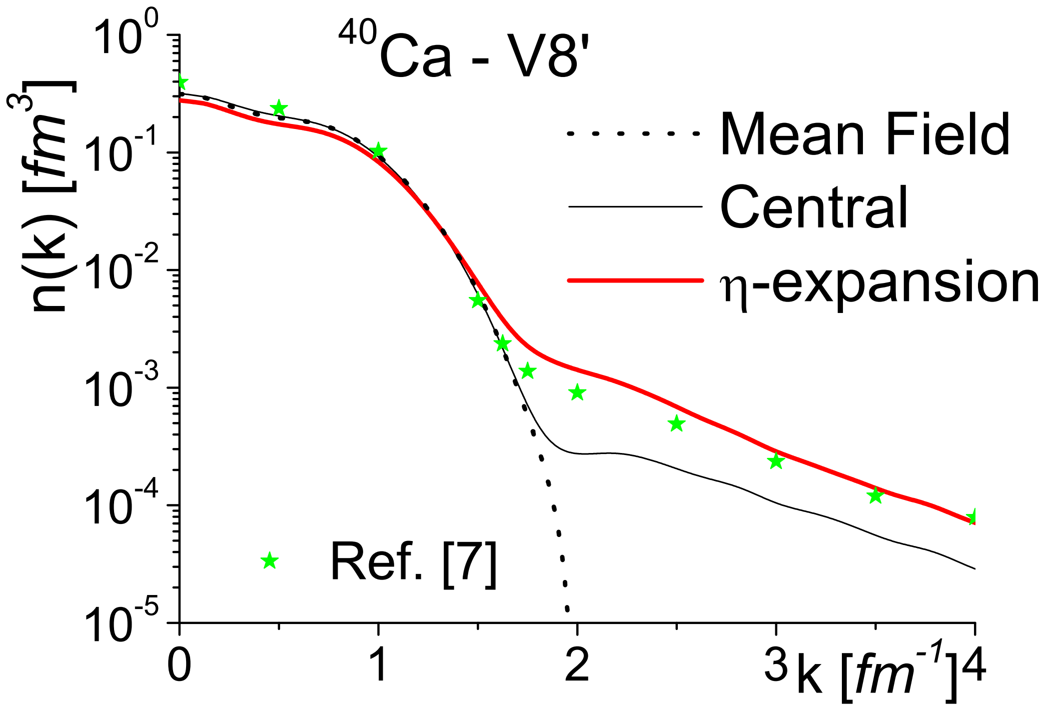
# *The charge density*




**Ref. [7]** <u>*FHNC*</u>**:** ***Fabrocini, de Saavedra, Co',***
***Phys. Rev. C72, (2005) 054310***

## *The momentum distributions*

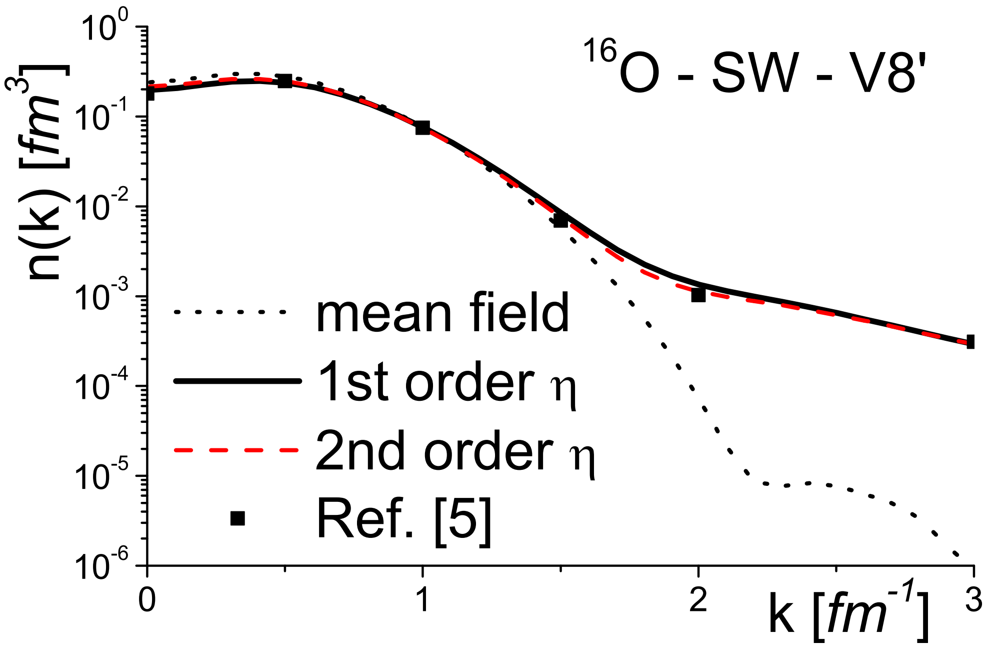



Ref.[5]<u>*VMC*</u>: *Pieper, Wiringa, Pandharipande,* ***Phys. Rev. C46,(1992) 1741***

Ref.[7]<u>*FHNC*</u>: *Fabrocini, de Saavedra, Co',* ***Phys. Rev. C61,(2000) 044302***

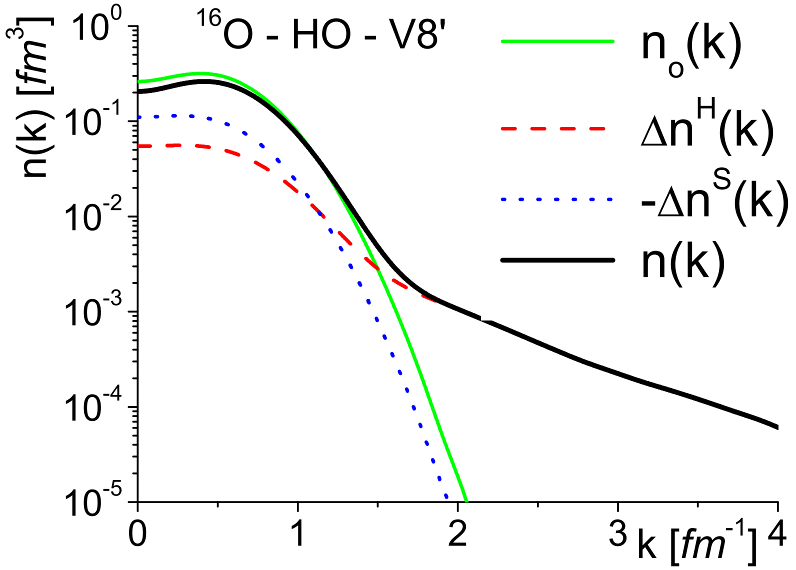
# Convergence of the expansion

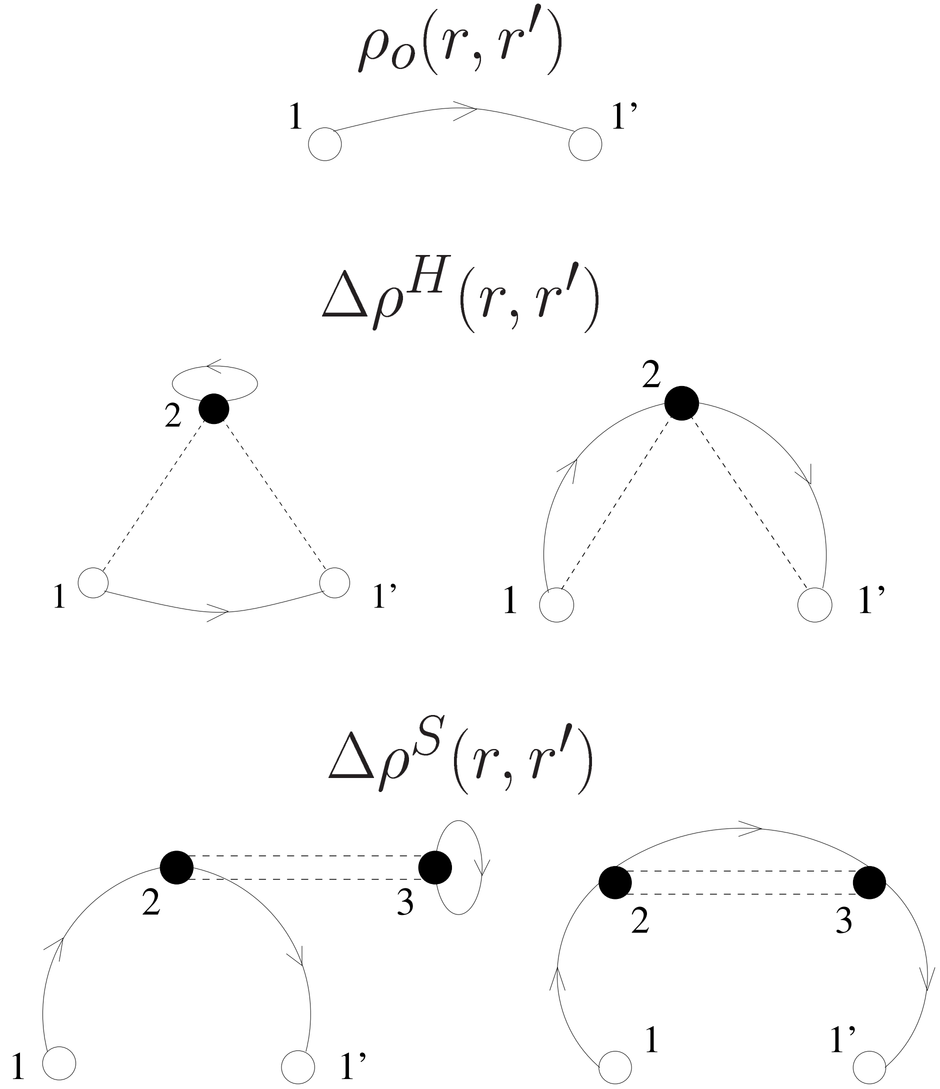



## Comments

- **good values for $E_o$, $\rho(r)$ and $n(k)$, qualitatively and quantitatively comparable with FHNC/SOC and VMC calculations, have been obtained**
- **a realistic and practicable $\psi_o$, which can be used in calculations of various scattering processes is at disposal.**

## Effects of correlations




**$\Delta n^S$ reduces the SM occupation; $\Delta n^S$ mostly originates correlations (populates states above the Fermi sea)**

## 4.4 The distorted momentum distributions

$$n_A^D(\boldsymbol{p}_m) = \frac{1}{(2\pi)^3} \int d\boldsymbol{r}_1 d\boldsymbol{r}'_1 \, e^{i\boldsymbol{p}_m \cdot (\boldsymbol{r}_1 - \boldsymbol{r}'_1)} \, \rho_D(\boldsymbol{r}, \boldsymbol{r}')$$

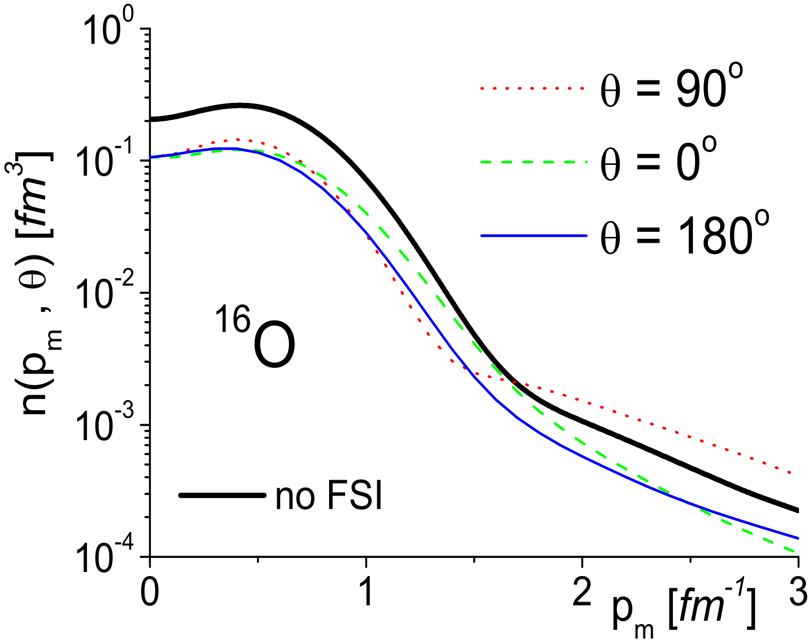
$$\rho_D(\boldsymbol{r}, \boldsymbol{r}') = \frac{\langle \Psi | \, \hat{S}_G^\dagger \;\; \hat{\rho}^{(1)}(\boldsymbol{r}, \boldsymbol{r}') \;\; \hat{S}_G \, | \Psi_o \rangle}{\langle \Psi_o | \, \Psi_o \rangle}$$

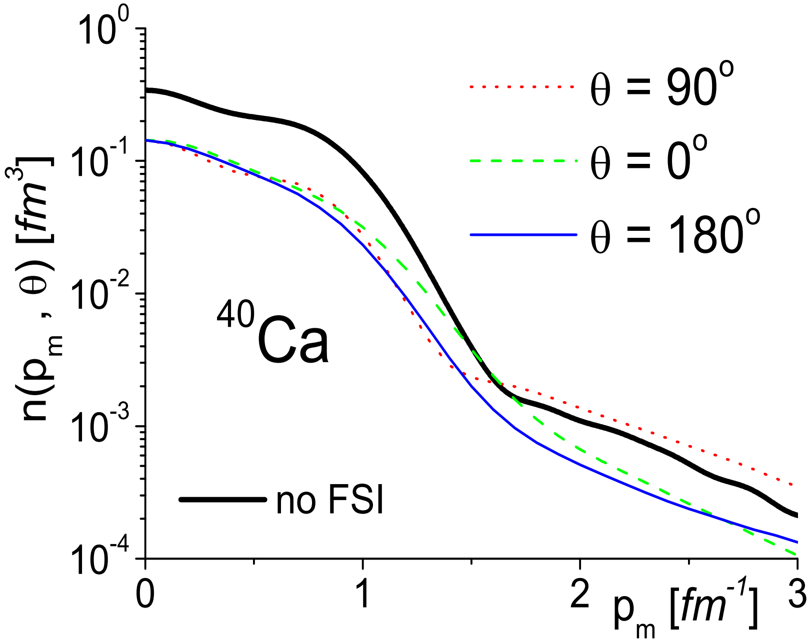
$$\mathcal{S}_G(\boldsymbol{r}_1, ..., \boldsymbol{r}_A) = \prod_{i=2}^{A} \left[1 - \theta(z_i - z_1)\, \Gamma(\mathbf{b}_1 - \mathbf{b}_i)\right]$$

$$\Psi_o = \left[\sum_n f^{(n)}(r_{ij}) \, \hat{\mathcal{O}}_{ij}^{(n)}\right] \phi_o$$

**Cluster expansion of $\rho_D(\boldsymbol{r}, \boldsymbol{r}')$ at first order in $\eta_{ij} \equiv 1 - f_{ij}^* f_{ij}$ including rescattering to all orders**

**(CdA, D. Treleani, Phys. Rev. C60 (1999) 024602)**




$$|\boldsymbol{p}_m| = |\boldsymbol{q} - \boldsymbol{p}_1| \textbf{ and } \theta = \widehat{\boldsymbol{p}_1 \boldsymbol{q}}$$

$$n_A(\boldsymbol{p}_m) \equiv n_A(p_m, \theta)$$

## 4.5 The exclusive $(e, e'p)$ process and the Spectral Function

$$P_A(|\mathbf{k}|, E) = P_0(|\mathbf{k}|, E) + P_1(|\mathbf{k}|, E)$$

$$P_0(|\mathbf{k}|, E) = \sum_{\alpha<\alpha_F} \tilde{n}_\alpha(|\mathbf{k}|)\delta(E - |\epsilon_\alpha|) \qquad \int \tilde{n}_\alpha d\boldsymbol{k} \ < \ 1$$

$$P_1(|\mathbf{k}|, E) = \sum_{f\neq\alpha} \left| \int d\mathbf{r} \ e^{i\mathbf{k}\cdot\mathbf{r}} \ G_{f0}(\vec{r}) \right|^2 \ \delta[E - (E^f_{A-1} - E_A)]$$

$P_0$ - **renormalized shell model** $\qquad$ $P_1$ - **correlations**

| |
|---|
| **A=3 and $\infty$ Theory OK $\qquad$ Complex Nuclei-Models** |

**Local Density Approximation (*Benhar et al.*),**
**The FNC model (*F & S, CdA & Simula*)**

$$P_1^A(|\mathbf{k}|, E) = \int d^3P_{cm} \ n^A_{rel}\left(|\mathbf{k} - \mathbf{P_{cm}}/2|\right) n^A_{cm}(|\mathbf{P_{cm}}|)$$
$$\delta\left[E - E^{(2)}_{thr} - \frac{(A-2)}{2M(A-1)} \cdot \left(\mathbf{k} - \frac{(A-1)\mathbf{P_{cm}}}{(A-2)}\right)^2\right]$$

## 4.6 The Spectral Function for $A = \infty$: Many-Body *vs* FNC

440 M. Baldo et al. / Nuclear Physics A 604 (1996) 429–440

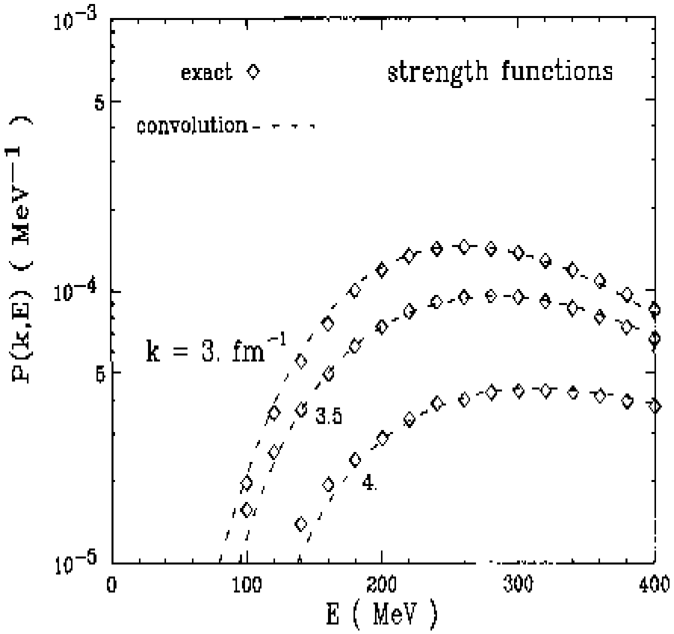



Fig. 4. Comparison between the SF obtained from the convolution model (dashed lines) and the one obtained from BBG theory (diamonds) for different values of the nucleon momentum $k$.

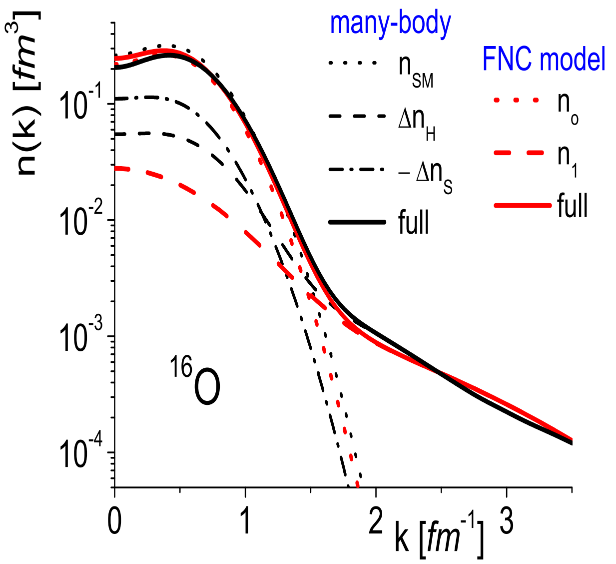
**FNC MODEL WELL GROUNDED FOR A=3 AND $\infty$. WHAT ABOUT FINITE NUCLEI ?**

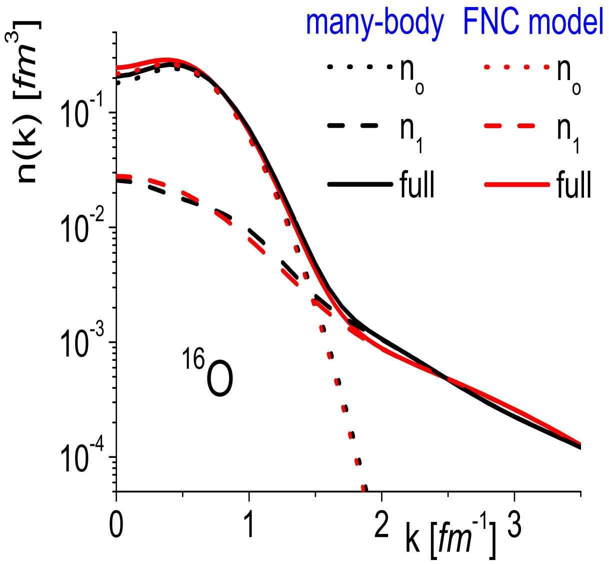
$$n^A_{rel}(|\mathbf{p}|) = C^A \cdot n^D_{rel}(|\mathbf{p}|) \qquad n^A_{CM}(|\mathbf{P}_{CM}|) = N^A \cdot \exp(-\alpha P^2_{CM})$$

$C^A$, $N^A$, $\alpha$ **ARE NOT ADJUSTABLE PARAMETERS, THEY RESULT FROM MB THEORIES**

***see: CdA, S. Simula, Phys. Rev. C53 (1996) 1689***

## 4.6 Momentum distributions of finite nuclei: MB *vs* FNC




$$n_o(\boldsymbol{k}) = n_{SM}(\boldsymbol{k}) + \Delta n_S(\boldsymbol{k}) + C_H\, n_{SM}^H(\boldsymbol{k})$$

$$n_1(\boldsymbol{k}) = \Delta n_H(\boldsymbol{k}) - C_H\, n_{SM}^H(\boldsymbol{k})$$

$$S_o = \int d\boldsymbol{r}\, n_o(\boldsymbol{r})$$

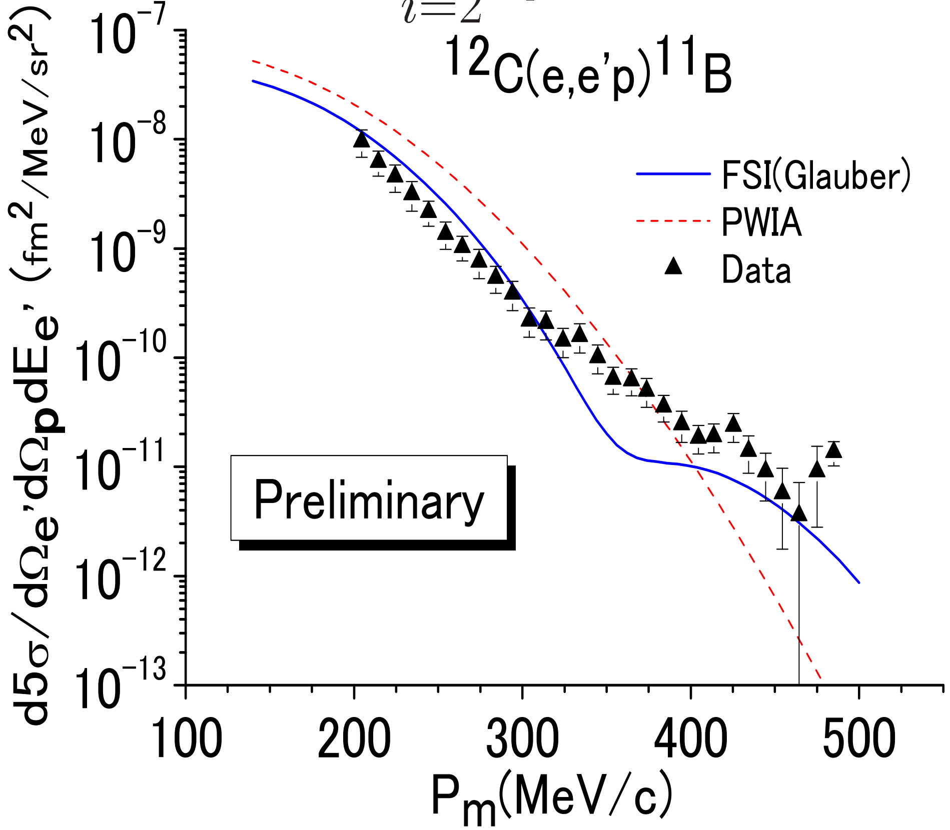
$$S_1 = \int d\boldsymbol{r}\, n_1(\boldsymbol{r})$$

| A | $S_o$ | $S_1$ |
|---|---|---|
| 3 | 0.65 | 0.35 |
| 16 | 0.8 | 0.2 |

## 4.6 The FNC distorted Spectral Function

$$\Psi^f_{A,\mathbf{p}}(1,2,3,...,A) = \hat{\mathcal{A}}\left[e^{i\mathbf{p}\cdot\mathbf{r}} \otimes \hat{\mathcal{S}}^{FSI}(1,2,3,...A)\Psi^f_{A-1}(2,3,...,A)\right]$$

$$\mathcal{S}^{FSI} \to \mathcal{S}_G(1,2,3,...A) = \prod_{i=2}^{A}\left[1-\theta(z_i - z_1)\,\Gamma(\mathbf{b}_1 - \mathbf{b}_j)\right]$$




*S. Gilad, P.Monaghan, E. Piasetsky, private communication*

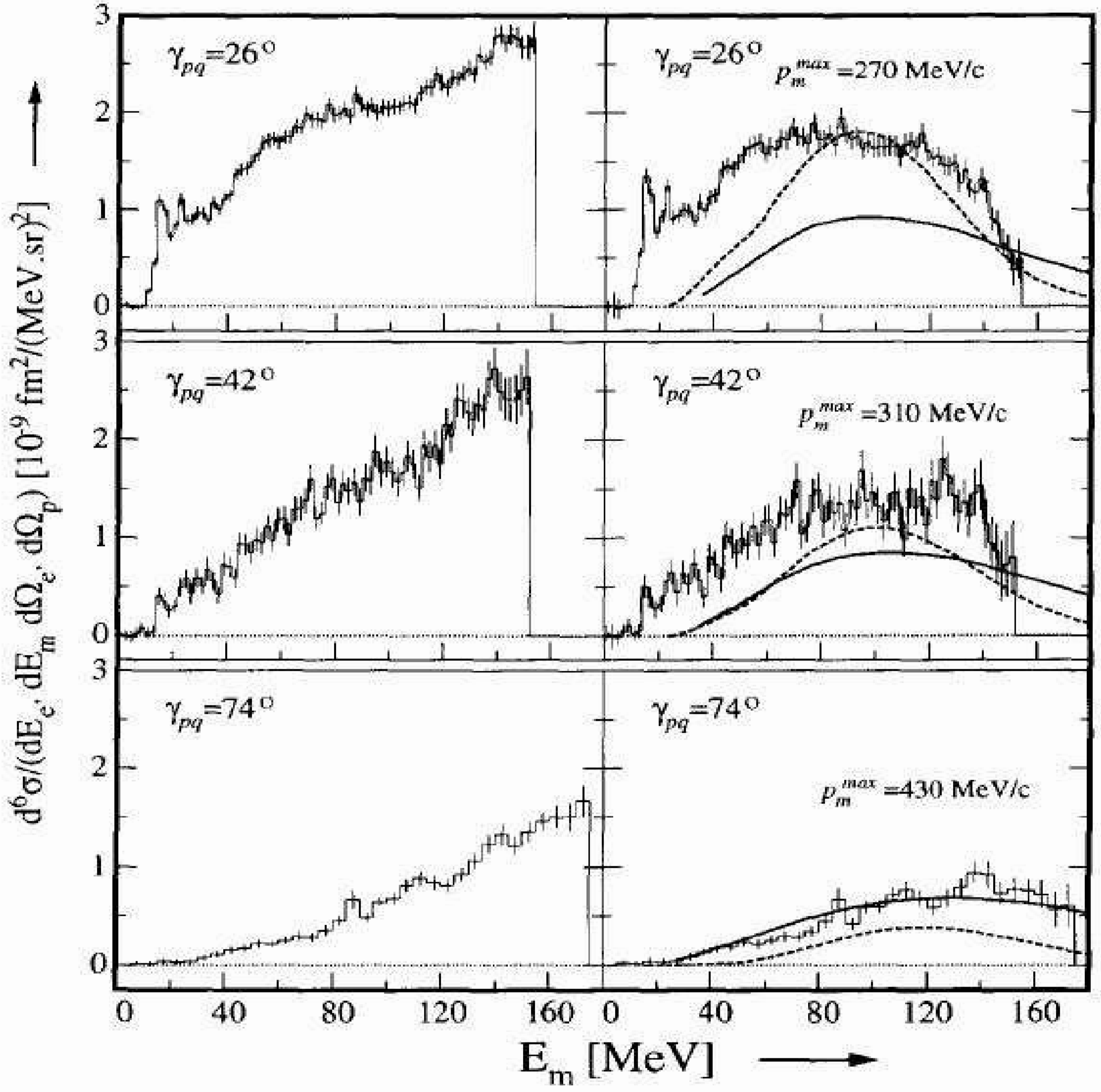
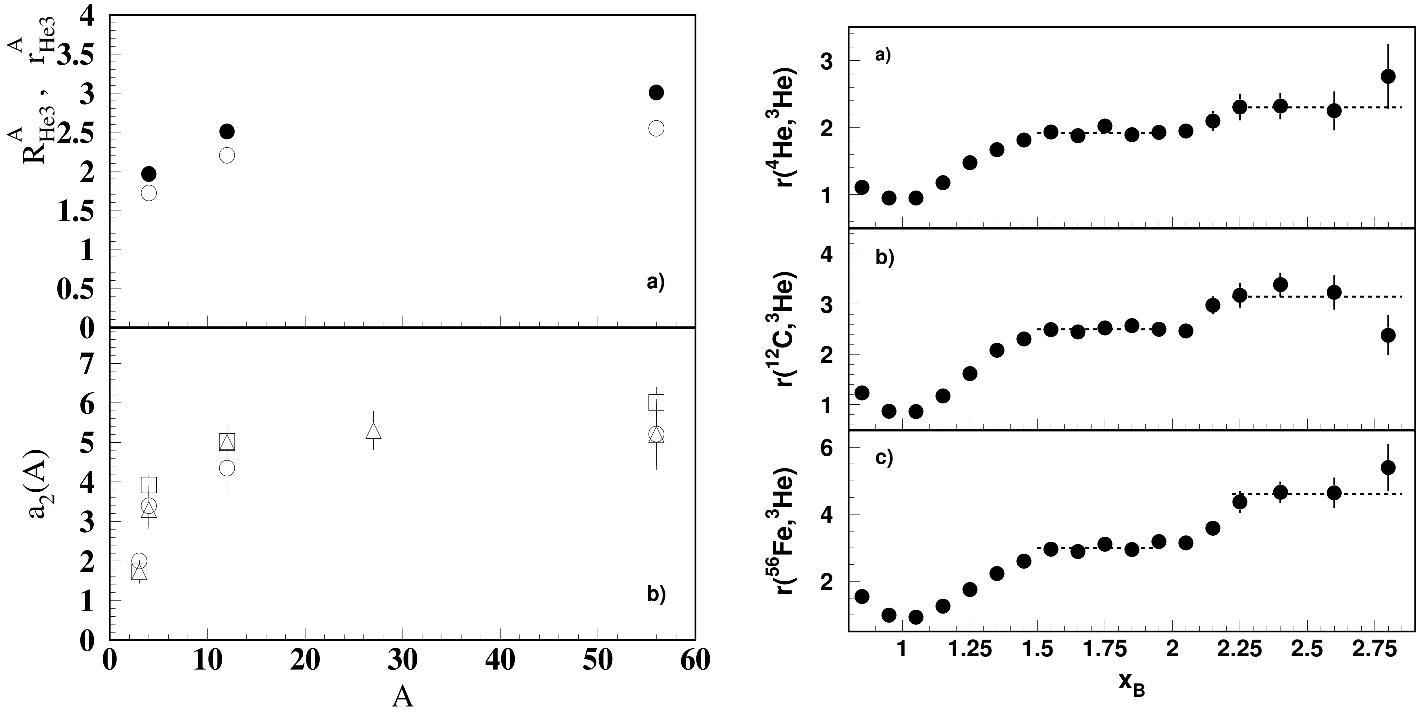



Fig. 1. Cross sections of the $(e,e'p)$ reaction at positive values of the angle $\gamma_{pq}$. The spectra shown in the right panels are corrected for radiative effects. Also presented are results of calculations performed with the two-nucleon correlation model (dashed lines) and calculations whereby two-nucleon knock-out is due to MEC and intermediate Δ-excitation (solid lines). The missing momentum values, at which the cross section according to two-nucleon correlation model reaches its maximum value, are given by $p_m^{max}$.

# 5 Experimental evidence of *Few Nucleon Correlations*

**Kim Egiyan et al, Phys. Rev. C68 (2003) 014313, Phys. Rev. Lett. 96 (2006) 082501**

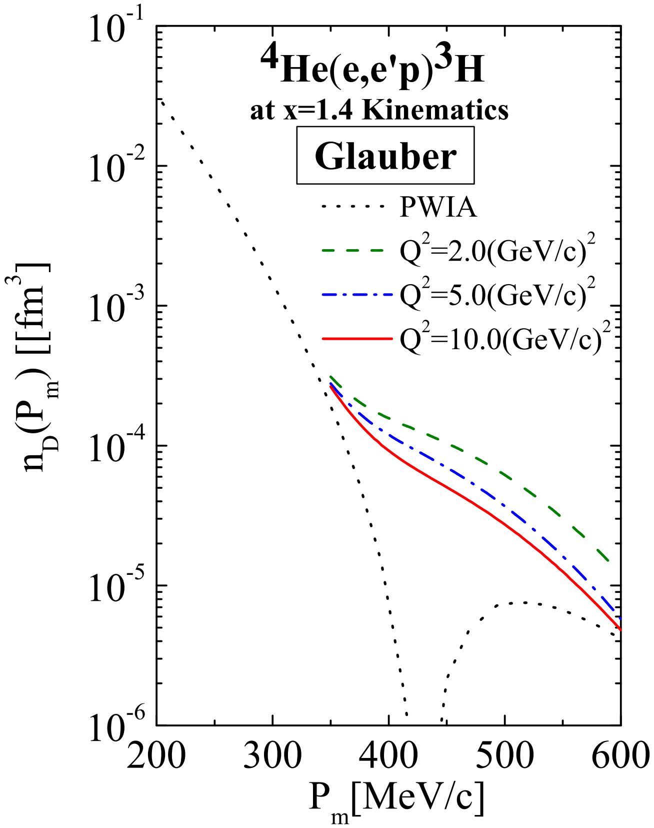


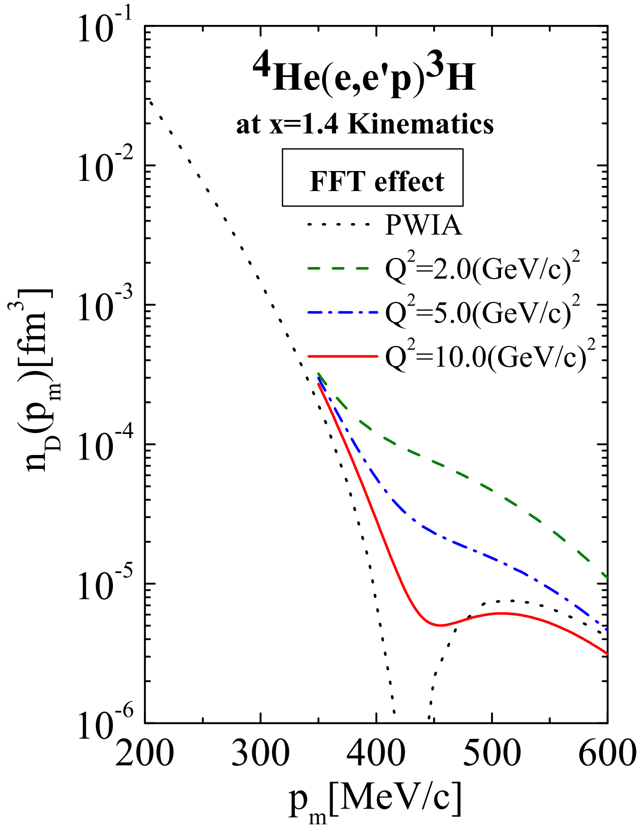

**Probability of 2NC in agreement with FNC model. Recent analysis of $^{12}C(p,pp)$ and $^{12}C(p,ppn)$ (Piaetzky, Sargsian Frankfurt, Strikman, Watson, Phys. Rev. Lett., *to appear*) yields $n_{CM}$ in agreement with FNC model (CdA, Simula , Phys. Rev. C53 (1995)1689)**

## 6. Conclusions

1. **A realistic treatment of ISC and FSI in $A(e,e'p)X$ processes off few-body nuclei at medium and high energies is nowadays possible.**
2. **Proper kinematical conditions which minimize FSI and other "disturbing" effects can be figured out and ISC can be investigated.**
3. **A practicable and realistic treatment of ISC in finite nuclei can be achieved by a cluster expansion approach; this, coupled with GEA, allows one to calculate various kinds of scattering processes at medium and high energies.**
4. **Convincing experimental evidence of few nucleon correlations is increasing, thanks, in particular, to the invaluable efforts by Kim Egiyan and his friends and collaborators.**

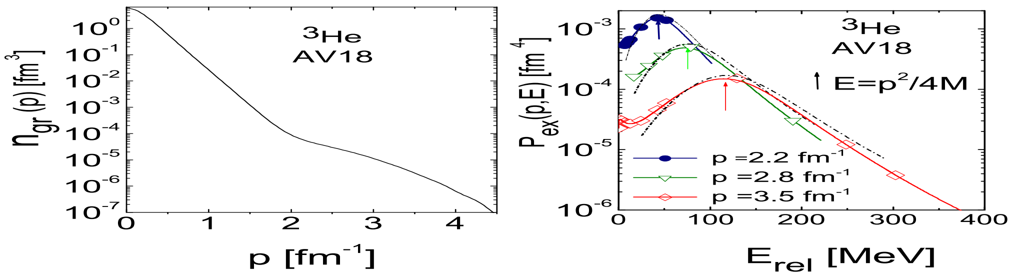
# EXTRA SLIDES


$^4He(e,e'p)^3H$
at x=1.4 Kinematics
Glauber
PWIA
$Q^2$=2.0(GeV/c)$^2$
$Q^2$=5.0(GeV/c)$^2$
$Q^2$=10.0(GeV/c)$^2$
$n_D(P_m)$ [[fm$^3$]
$P_m$[MeV/c]

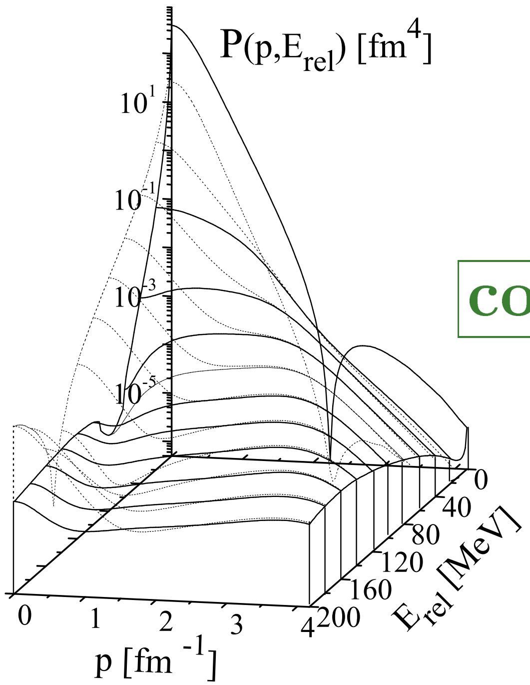

$^4He(e,e'p)^3H$
at x=1.4 Kinematics
FFT effect
PWIA
$Q^2$=2.0(GeV/c)$^2$
$Q^2$=5.0(GeV/c)$^2$
$Q^2$=10.0(GeV/c)$^2$
$n_D(p_m)$[fm$^3$]
$p_m$[MeV/c]

# Proton Spectral Function

$$p \equiv |\boldsymbol{k}_1|$$
$$E_{rel} = E_m - E_{min}$$
$$= t^2/M_N$$




# Neutron Spectral Function



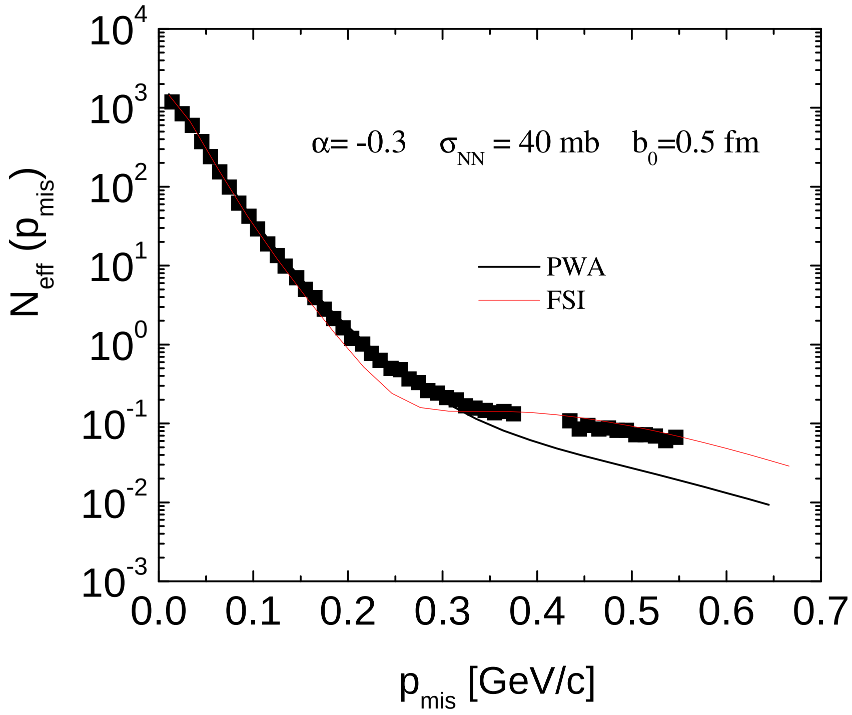

*dotted curves:* PWA

*solid curves:* PWIA

**correlation bumps located at**

$$E_{rel} = p^2/4M$$

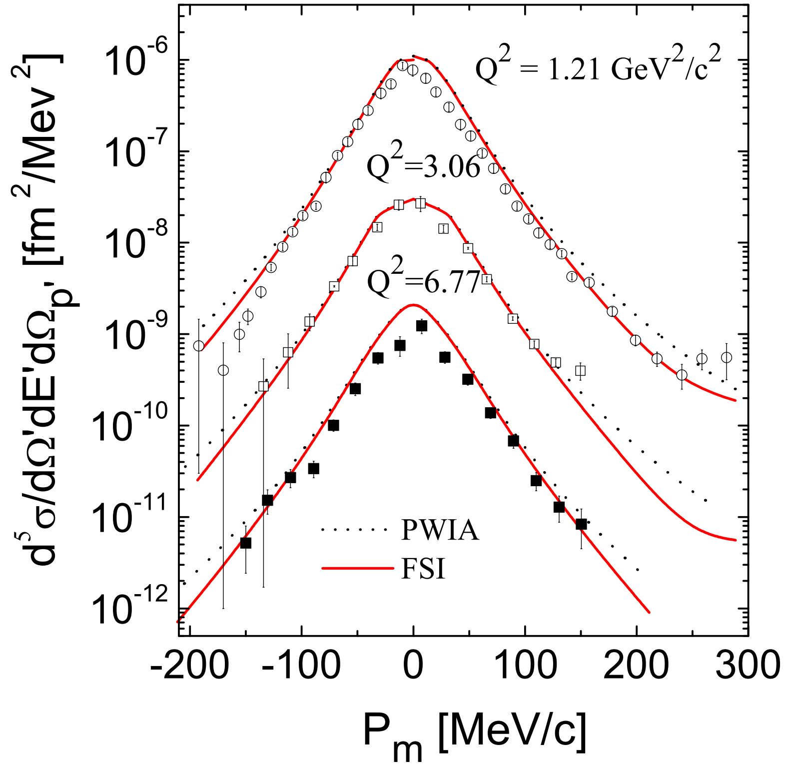
## 3.1 The Process $^2H(e,e'p)n$




***Jlab*** **data (Ulmer *et al.* Phys. Rev. Lett. 89 (2002)) at *perpendicular* kinematics, with:**

$$Q^2 \simeq 0.665 \ (GeV/c)^2 , \quad |\boldsymbol{q}| \simeq 0.7 \ GeV/c \, , \quad x \simeq 0.96$$

$$N_{eff} = \frac{d^4\sigma^{exp}}{d\Omega' \, dE' \, d\Omega_{\boldsymbol{p}_m}} \left[ f_{rec} \, \mathcal{K} \, \sigma^{eN}_{cc1} \right]^{-1}$$




***SLAC*** **data (Bulten *et al.* , Phys. Rev. Lett, 74 (1995)), at:**

$$\mathbf{x \simeq 1}$$

## 4.5 *Example 3*: The total neutron-Nucleus cross section at high energies

$$\boxed{\sigma_{tot} = \frac{4\pi}{k} Im\left[F_{00}(0)\right] \qquad\qquad F_{00}(\boldsymbol{q}) = \frac{ik}{2\pi}\int d^2 b_n e^{i\mathbf{q}\cdot\mathbf{b_n}}\left[1 - e^{i\,\chi_{opt}(\mathbf{b_n})}\right]}$$

$$e^{i\,\chi_{opt}(\boldsymbol{b}_n)} = \int \Pi_{j=1}^{A}\left[1-\Gamma(\boldsymbol{b}_n - \boldsymbol{s}_j)\right] \left|\Psi_0(\boldsymbol{r}_1,\ldots,\boldsymbol{r}_A)\right|^2 \delta\left(\frac{1}{A}\Sigma\,\mathbf{r}_j\right)\,\Pi_{j=1}^{A}\,d\boldsymbol{r}_j.$$

$$|\Psi(\boldsymbol{r}_1,\ldots,\boldsymbol{r}_A)| = \Pi_{j=1}^{A}\,\rho(\boldsymbol{r}_j) + \Sigma_{i<j=1}^{A}\,\boldsymbol{\Delta}(\boldsymbol{r}_\mathbf{i},\boldsymbol{r}_\mathbf{j})\,\Pi_{k\neq(il)}^{A}\,\rho(\boldsymbol{r}_k) + \ldots$$

**where the *two-body contraction* $\Delta$ is**

$$\boldsymbol{\Delta}(\boldsymbol{r}_\mathbf{1},\boldsymbol{r}_\mathbf{2}) = \left[\rho^{(2)}(\boldsymbol{r}_1,\boldsymbol{r}_2) - \rho^{(1)}(\boldsymbol{r}_1)\,\rho^{(1)}(\boldsymbol{r}_2)\right],$$

**Then**

$$e^{i\,\chi_{opt}(\boldsymbol{b}_n)} \simeq$$
$$exp\left[-A\int d\boldsymbol{r}_1\,\rho(\boldsymbol{r}_1)\,\Gamma(\boldsymbol{b}_n-\boldsymbol{s}_1) + A^2\,\frac{\int d\boldsymbol{r}_1 d\boldsymbol{r}_2\,\boldsymbol{\Delta}(\boldsymbol{r}_\mathbf{1},\boldsymbol{r}_\mathbf{2})\,\Gamma(\boldsymbol{b}_n-\boldsymbol{s}_1)\,\Gamma(\boldsymbol{b}_n-\boldsymbol{s}_2)}{1-\int d\boldsymbol{r}_1\,\rho(\boldsymbol{r}_1)\,\Gamma(\boldsymbol{b}_n-\boldsymbol{s}_1)}\right]$$

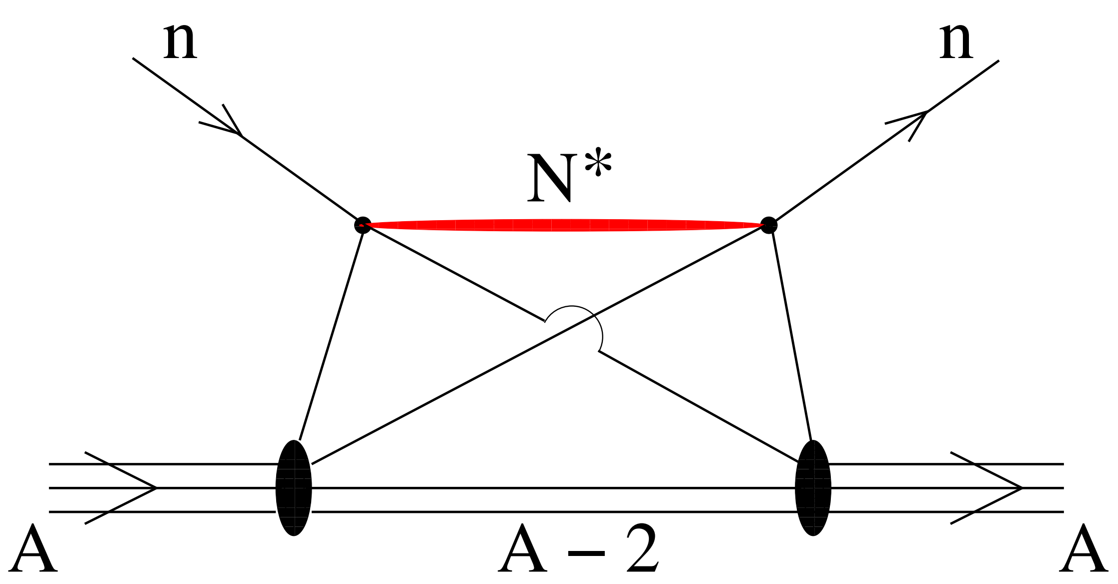
# Inelastic shadowing

**(Diffractive excitation of the projectile)**

**V. N. Gribov, Sov JETP 29(1969)483;**

**V. A. Karmanov, L. A. Kondratyuk, Sov JETP Lett. 18(1973)451;**

**B. K. Jennings, G. A. Miller, Phys. Rev. C49 (1999)2637**

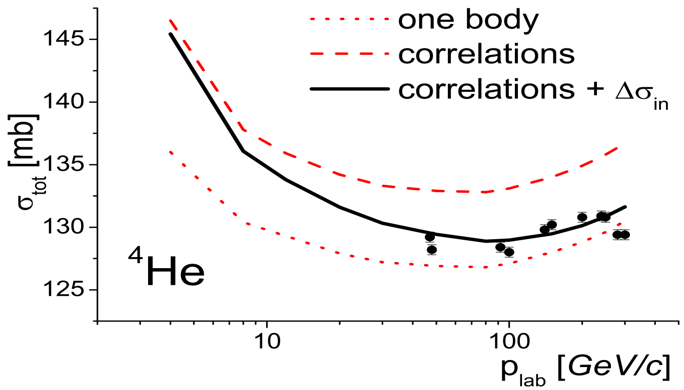


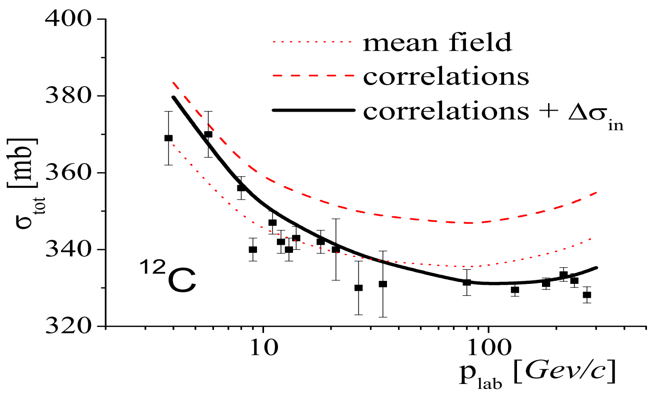

$$\sigma_{tot} = \frac{4\pi}{k} Im\left[F_{00}(0)\right] + \Delta\sigma_{in}$$

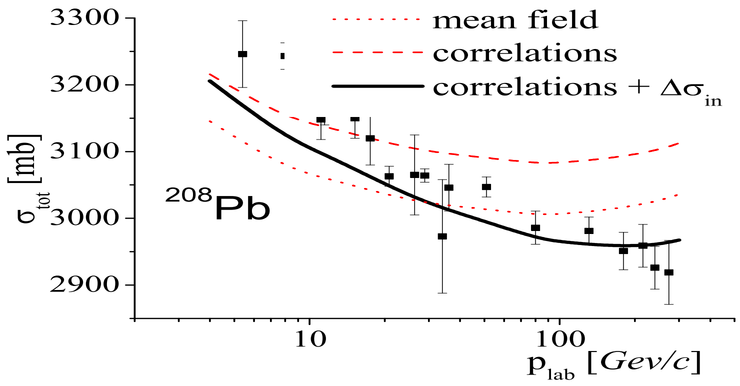
# RESULTS

Isabella Marchino, Undergraduate Thesis (2004)

M. Alvioli, C.d.A, I. Marchino, H. Morita, to appear




No adjustable parameters