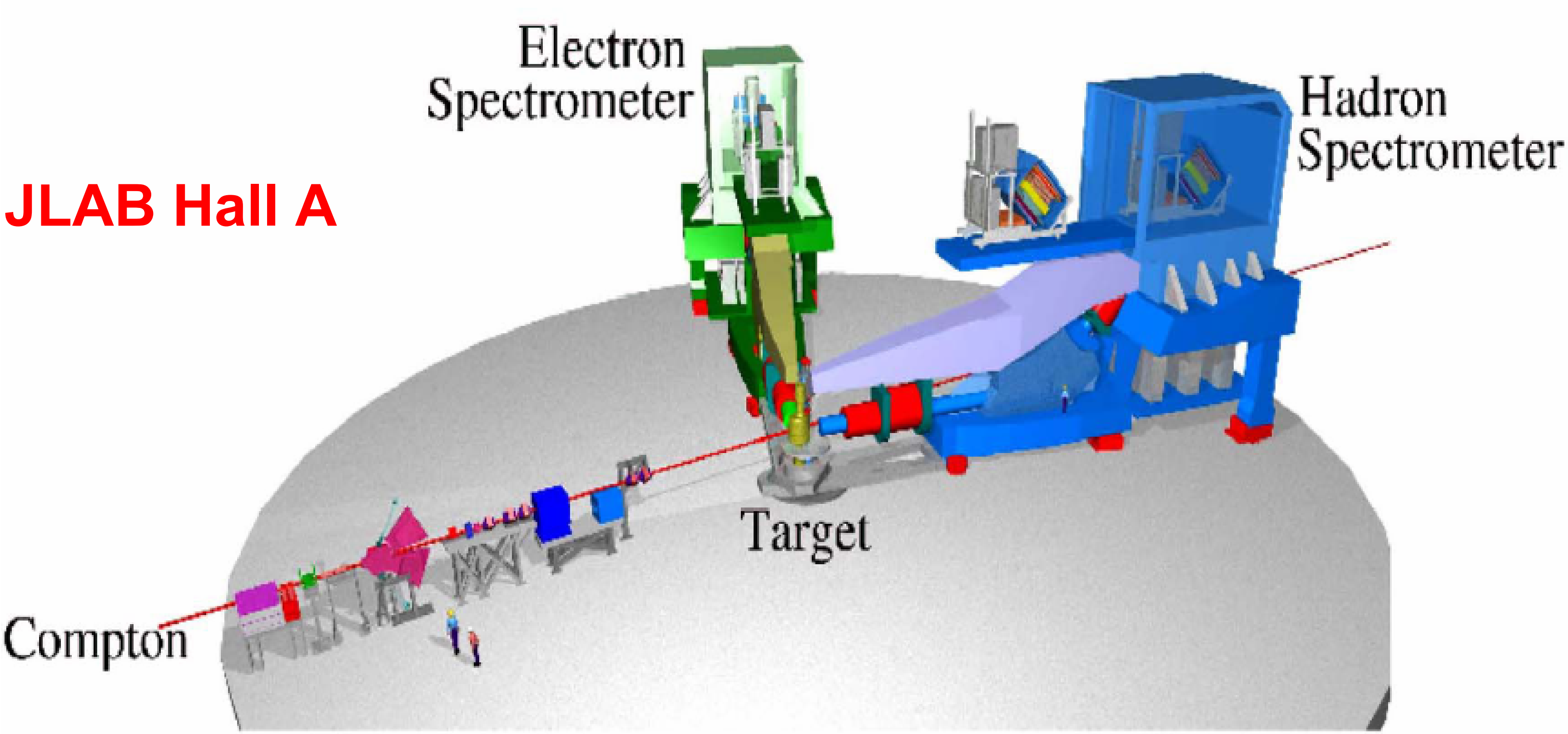
Nuclear Structure and Dynamics in the $^3He(e,e'p)d$ and $^3He(e,e'p)pn$ Reactions

JLAB Hall A



Two high resolution spectrometers ($\delta p/p \approx 10^{-4}$); $\delta\Omega$ = 6 msr
High current, high polarization (≈80%) cw beam
High pressure ^{3}He target - luminosity ≈ 10^{38} cm^2 sec^{-1}
Focal-plane hadron polarimeter

Shalev Gilad - MIT

A(e,e'p)

$$\frac{d^6\sigma}{d\vec{k}'d\vec{p}} = \Gamma_v \mathcal{J}\left[\sigma_T + \epsilon\left[\sigma_L + \sigma_{TT}\cos(2\phi)\right] - \sqrt{\frac{Q^2}{2\omega^2}}\sqrt{\epsilon(1+\epsilon)}\sigma_{LT}\cos(\phi)\right]$$

$\sigma_i = v_i R_i$

$$V_L = \frac{Q^4}{q^4}$$

$$V_T = \frac{1}{2}\frac{Q^2}{q^2} + \tan^2\left(\frac{\theta}{2}\right)$$

$$V_{TT} = \frac{1}{2}\frac{Q^2}{q^2}$$

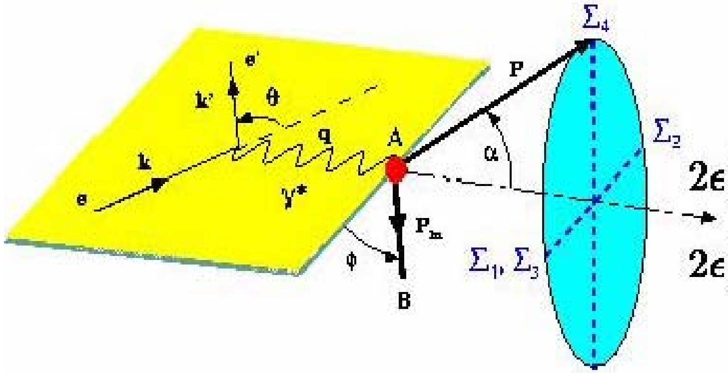
$$V_{LT} = \frac{Q^2}{q^2}\left[\frac{Q^2}{q^2} + \tan^2\left(\frac{\theta}{2}\right)\right]^{1/2}$$

$$R_L = \rho\rho^\dagger$$

$$R_T = J_x J_x^\dagger + J_y J_y^\dagger$$

$$R_{TT}\cos(2\phi) = J_x J_x^\dagger - J_y J_y^\dagger$$

$$R_{LT}\cos(\phi) = -(\rho J_x^\dagger + J_x \rho^\dagger)$$



$$2\epsilon_1' \sigma_{LT} = -\Sigma_1^r + \Sigma_2^r$$

$$2\epsilon_1'(\epsilon_2 - \epsilon_1)\sigma_T = [\epsilon_1'\epsilon_2 + \epsilon_1\epsilon_2']\,\Sigma_1^r + [\epsilon_1'\epsilon_2 - \epsilon_1\epsilon_2']\,\Sigma_2^r - 2\epsilon_1'\epsilon_1\Sigma_3^r$$

$$2\epsilon_1'(\epsilon_2 - \epsilon_1)\,[\sigma_L + \sigma_{TT}] = -\,[\epsilon_1' + \epsilon_2']\,\Sigma_1^r + [\epsilon_2' - \epsilon_1']\,\Sigma_2^r + 2\epsilon_1\Sigma_3^r$$

$$4\epsilon_1\sigma_{TT} = \Sigma_1^r + \Sigma_2^r - 2\Sigma_4^r$$

$$\Sigma_i^r = \Sigma_i/[\Gamma_v\mathcal{J}] \qquad \epsilon_i' = \sqrt{\frac{Q^2}{2\omega^2}}\sqrt{\epsilon_i(1+\epsilon_i)}$$

Shalev Gilad - MIT

Kinematics of Measurements

- **Fixed electron kinematics:**

  $q=1.5$ GeV/c
  $\omega=0.837$ GeV
  quasi-elastic: $x_B \sim 1$

- **"Perpendicular" proton kinematics**

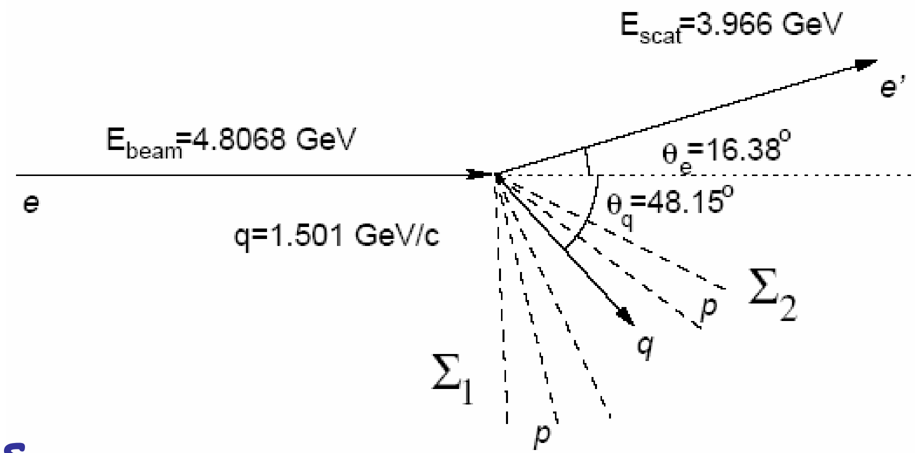
- **High energy of ejected proton:**

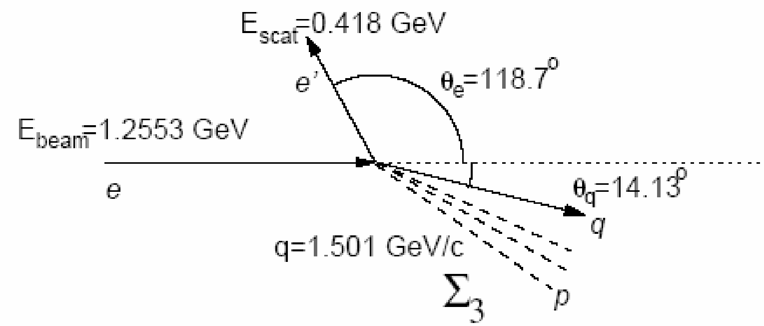
  $T_p > 0.8$ GeV

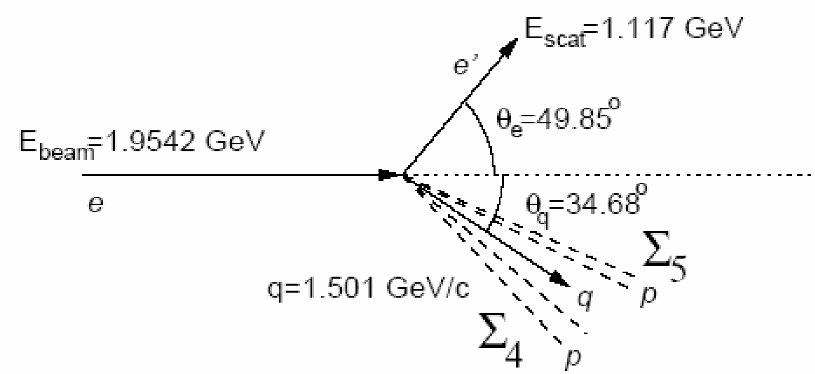
- **3 virtual photon polarizations:**

  $0.108 < \varepsilon < 0.943$

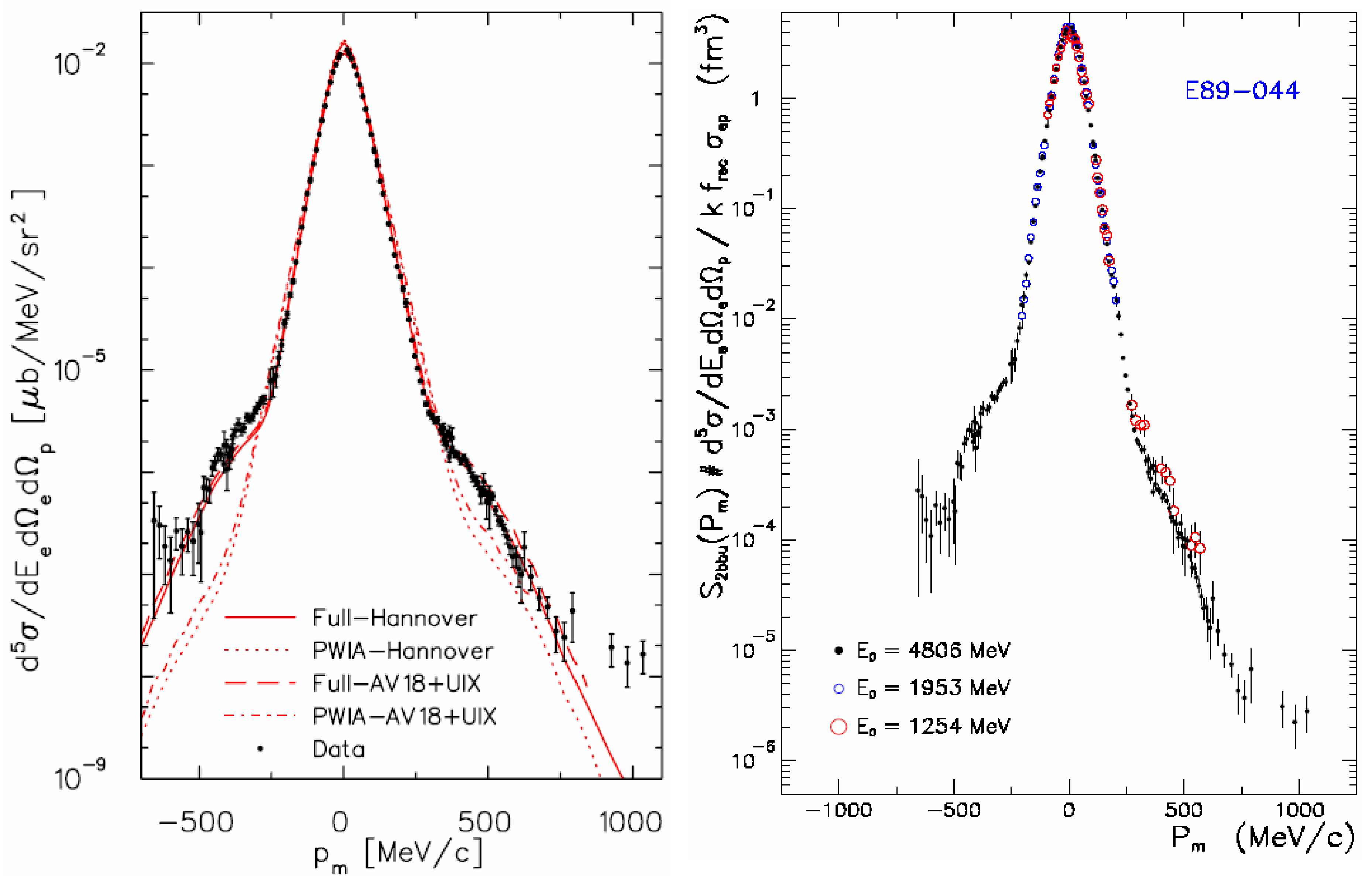
- **Parallel kinematics – poster, Eric Voutier**







2bbu x-sections; distorted $S(p_m)$

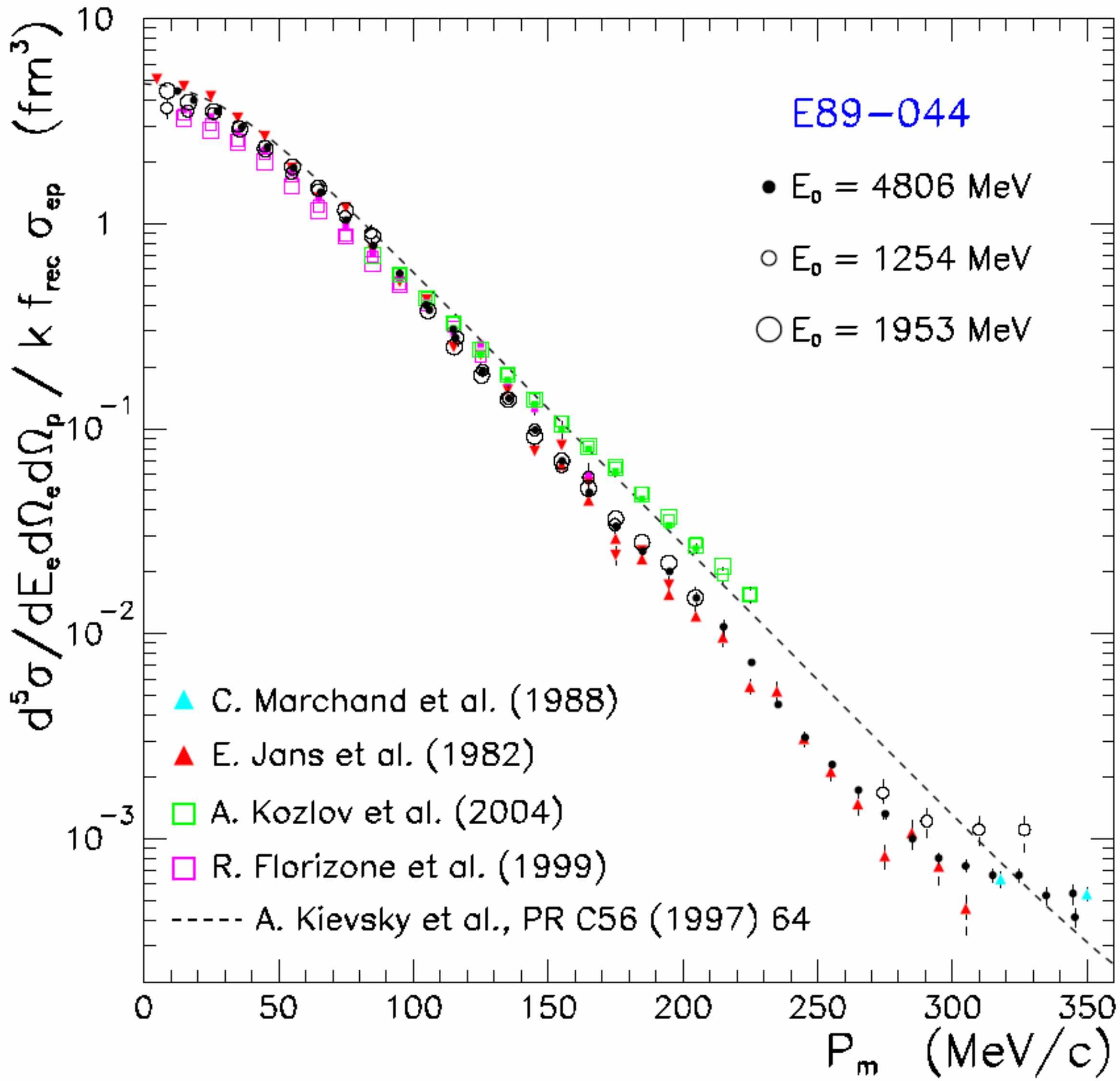


M. M. Rvachev *et al.*, PRL **94**, 192302 (2005)

Comparison to previous data

Florizone:
"Parallel" kinematics
$x_B \approx 1$

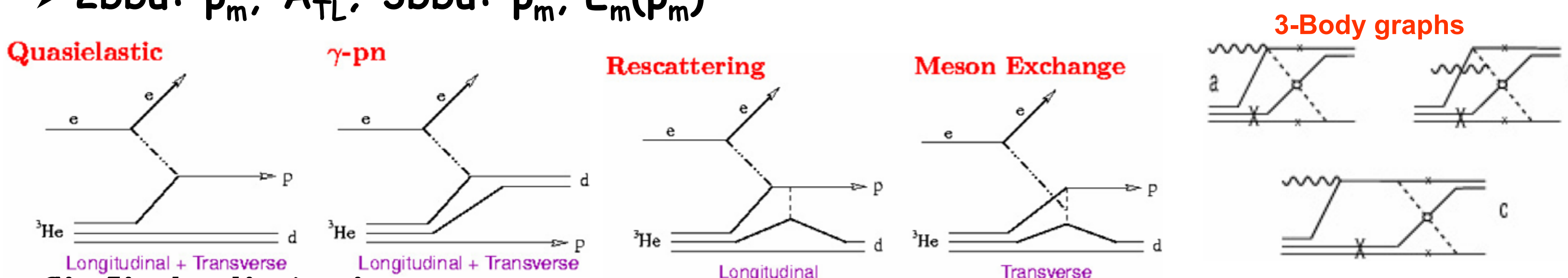
Kozlov:
"Parallel" kinematics
$x_B > 1$



Models

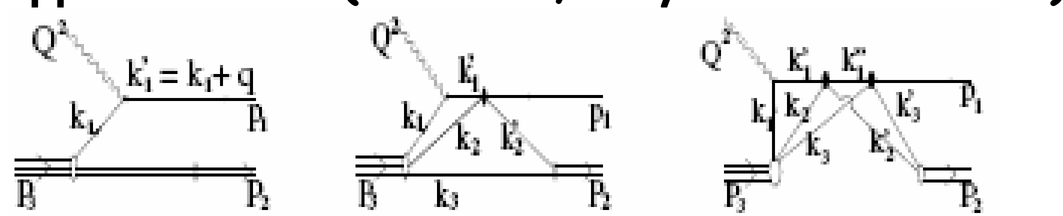
Laget:

- Gswf generated from solution to Faddeev eqn. with Paris NN potential
- (also variational calculations using AV18+UIX)
- Kinematics, nucleon & meson propagators are relativistic; un-factorized; Mott+FF
- One-, two- & 3-body interactions
- FSI globally parameterized from LANL, SATURN &COSY data
- No angular restriction (Glauber type) imposed on loop integrals
- 2bbu: p_m, A_{TL}; 3bbu: p_m, $E_m(p_m)$



Ciofi degli Atti:

- PWIA+FSI; factorized; CC1
- Gswf generated from AV18
- Kinematics is relativistic
- FSI using generalized Eikonal approximation ("frozen", only ⊥ mom. Trans.)
- Single-, double re-scattering
- 2bbu: p_m; 3bbu: $Em(p_m)$



Models (cont.)

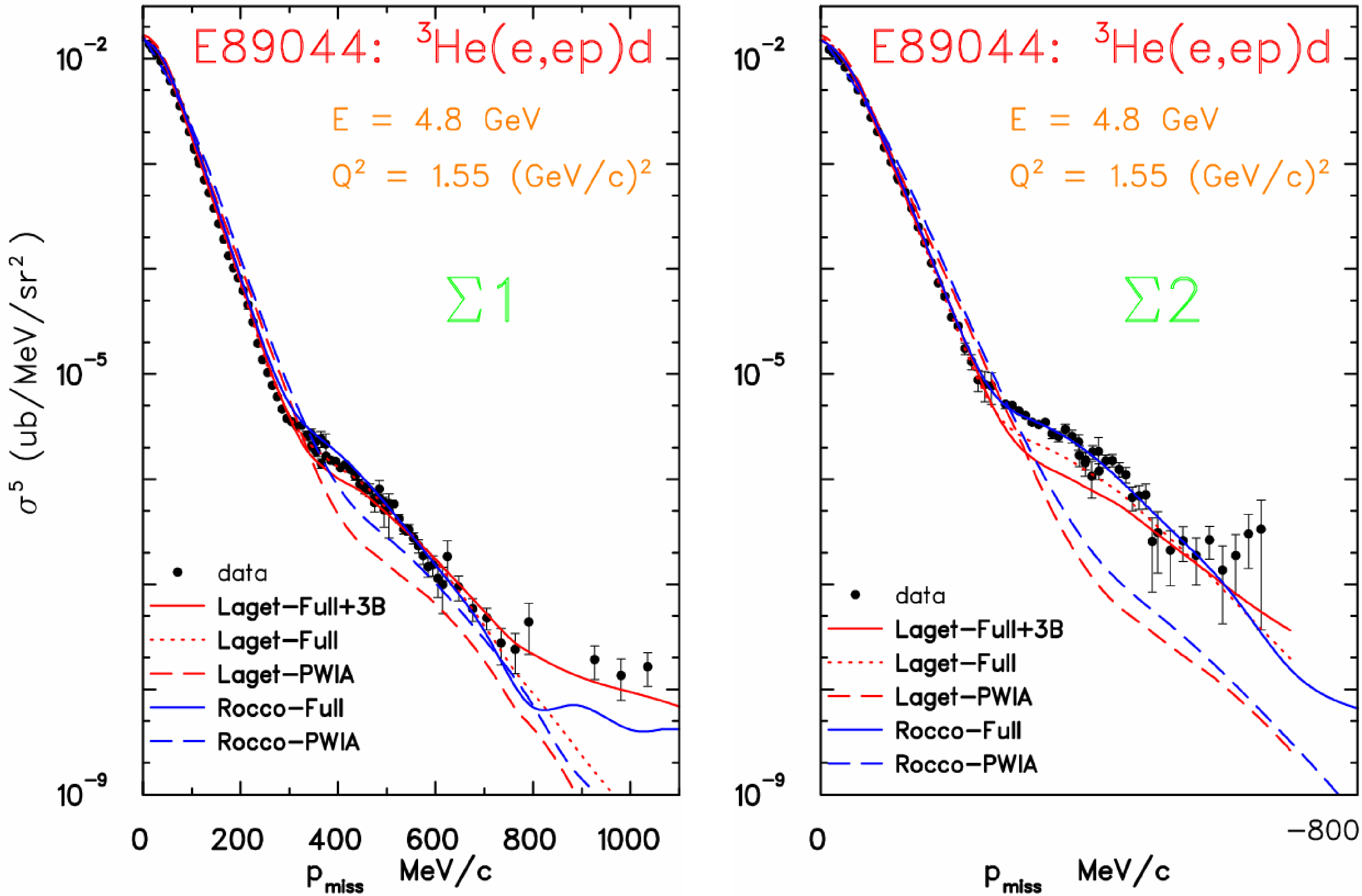
Schiavilla:

- Variational GSWF generated using AV18+UIX Hamiltonian using Correlated hyperspherical harmonics (CHH); un-factorized
- Relativistic one and two-body current operator (Jeschonnek & Donnely)
- FSI using Glauber approx. retaining spin & isospin dependencies
- Single-double re-scattering
- 2bbu: pm, A_{TL}; 3bbu: in near future

Udias:

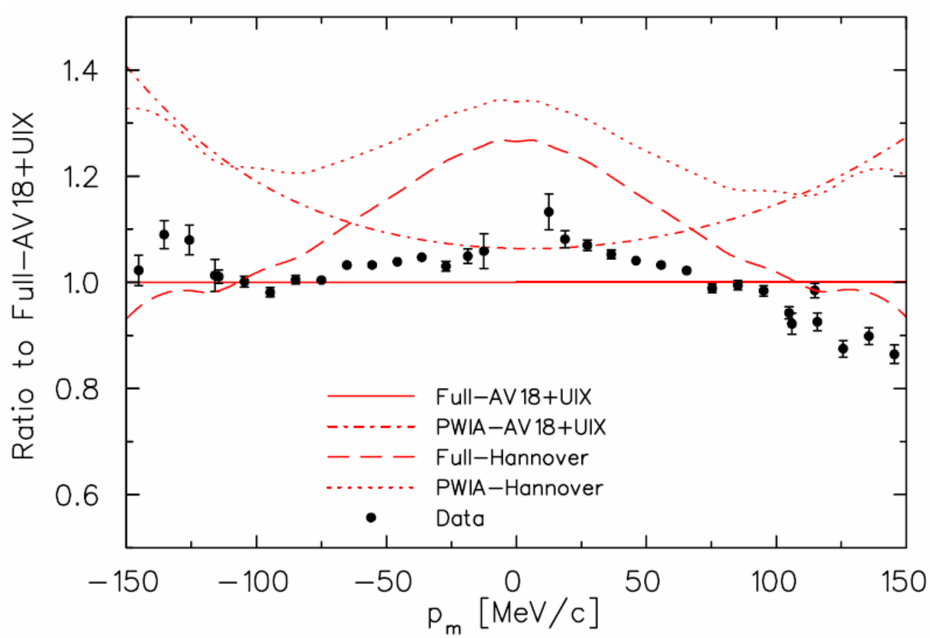
- GSWF generated by Faddeev technique using AV8+central NNN (Gaussian or exponential, adjusted for binding energy); un-factorized; CC2
- Fully relativistic kinematics and dynamics
- FSI using optical potential generated by relativistic folding model – fold effective £ with residual nuclei. Parameters of effective £ reproduce elastic p-d & p-He scattering data
- 2bbu: p_m, A_{TL}

3 regions in p_m

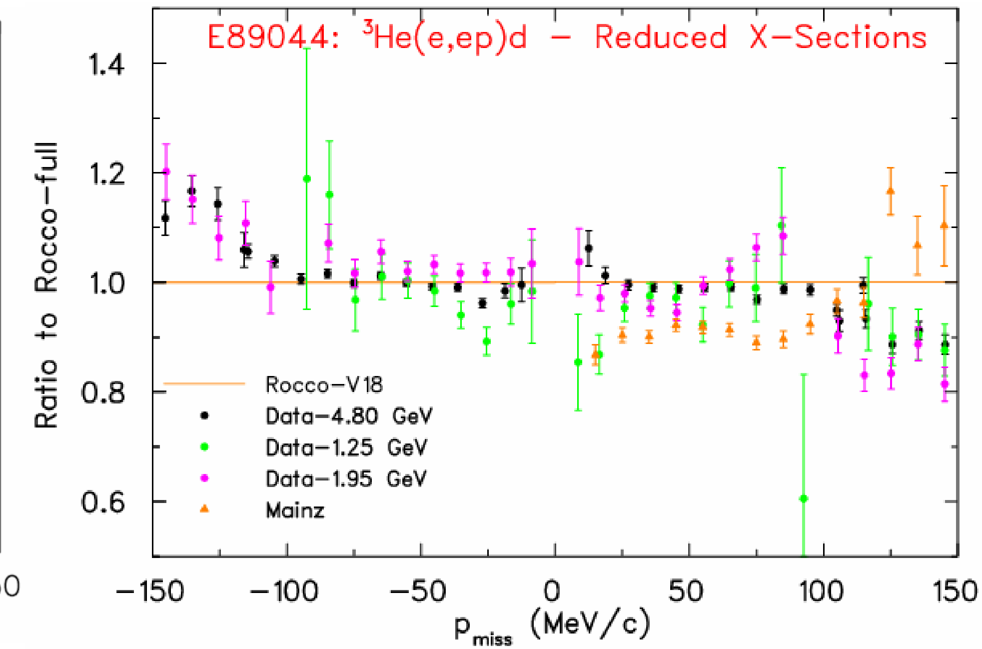


X-sections for -150 < p_m < 150 MeV/c

Laget

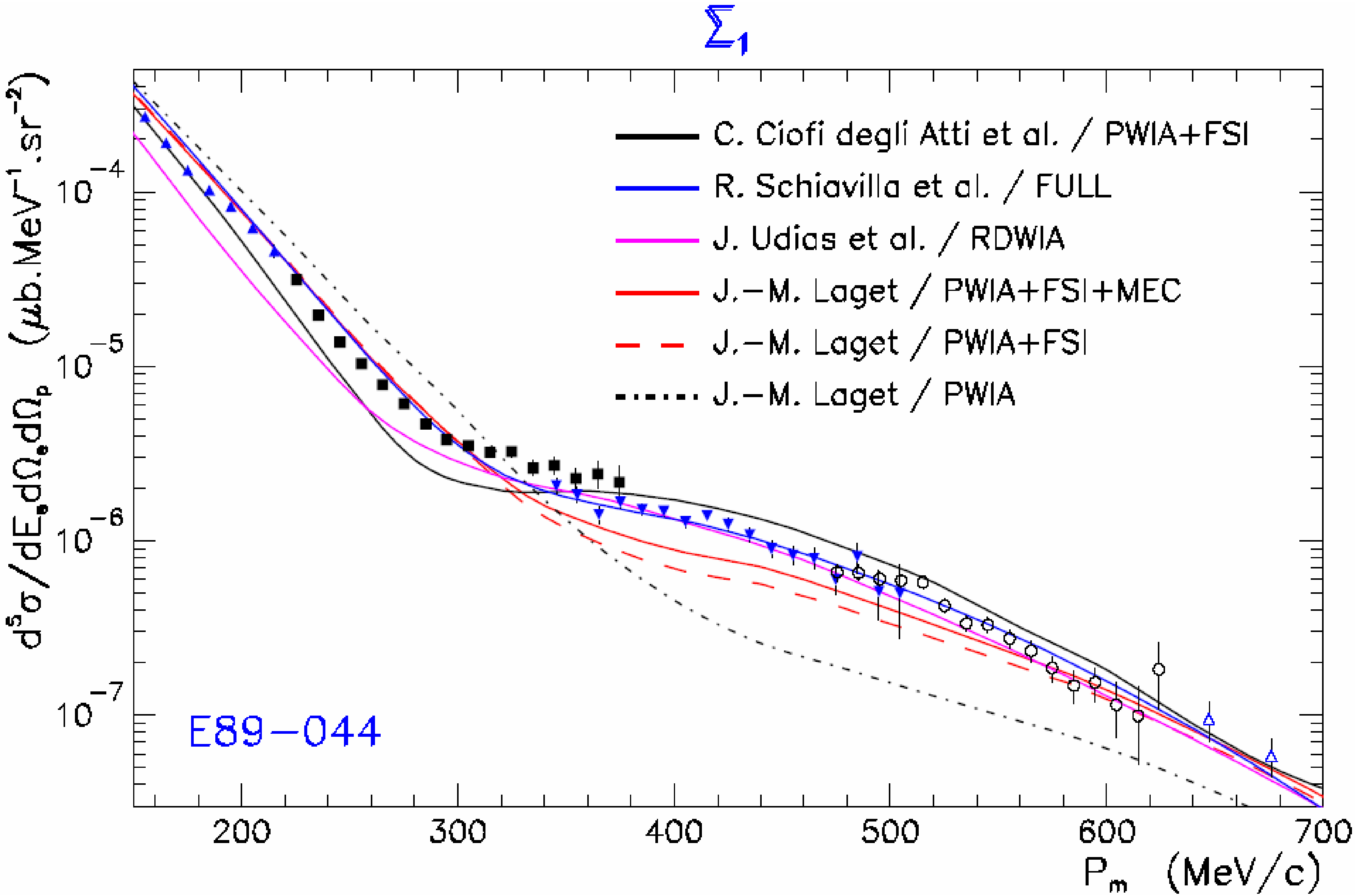


Schiavilla

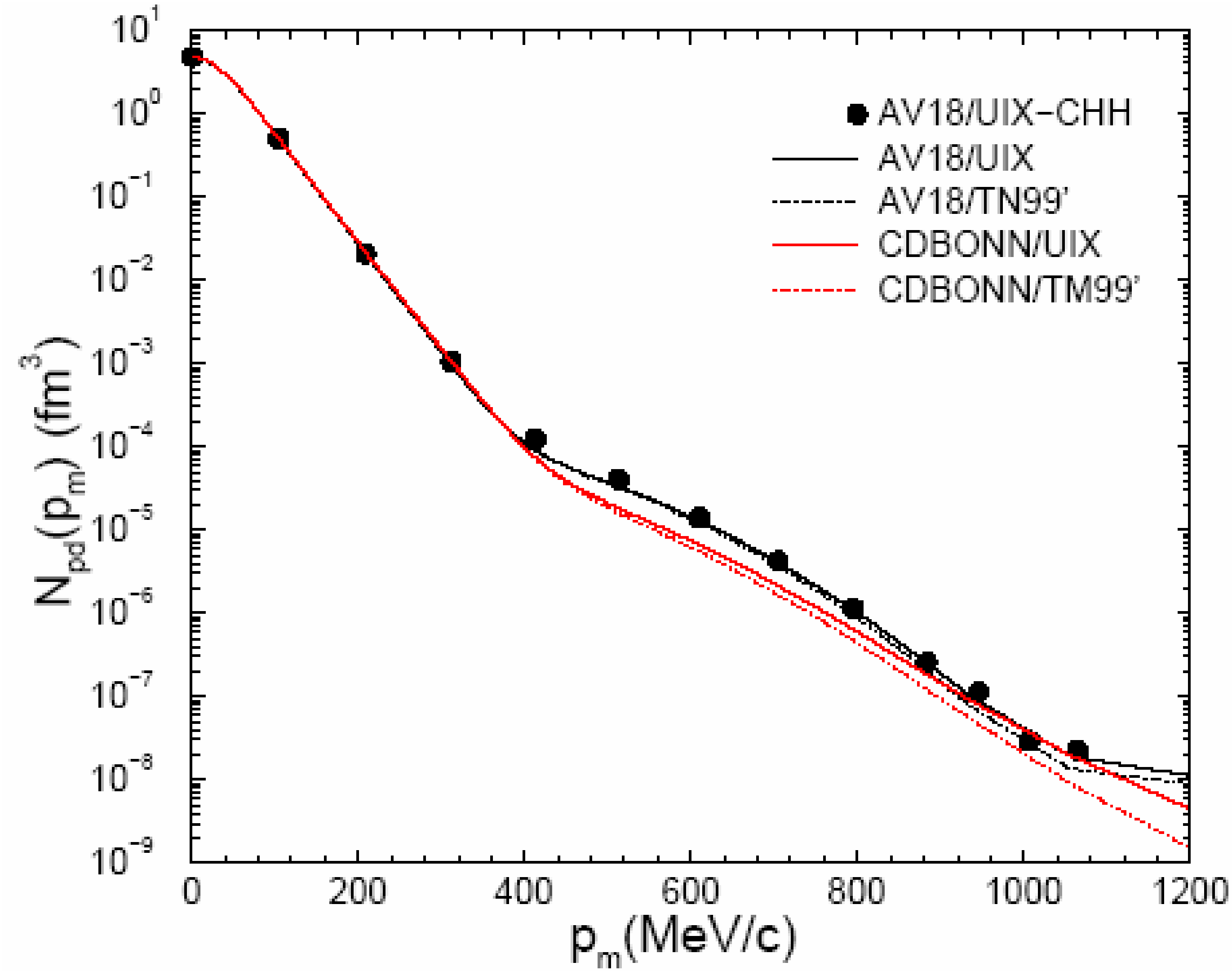


- NNN forces important at very low p_m (~25%)
- FSI starts to break factorization around $|p_m|$ > 150 MeV/c

150 < p_m < 700 MeV/c

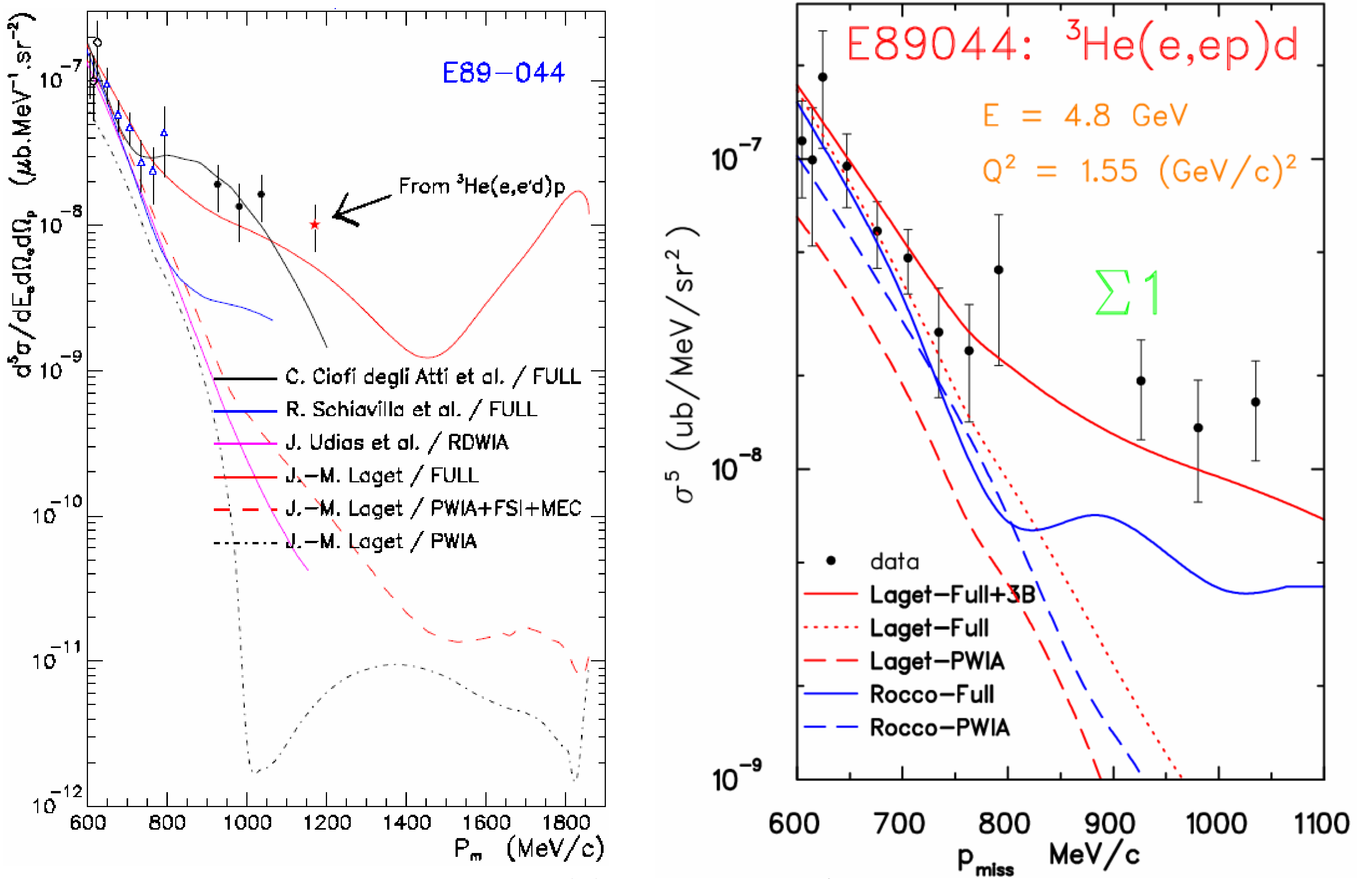


Affect of different NN potentials



R. Schiavilla *et al.*, nucl-th/0508048

P_m > 600 MeV/c



Laget: 3-body diagram(s) Ciofi: double scattering

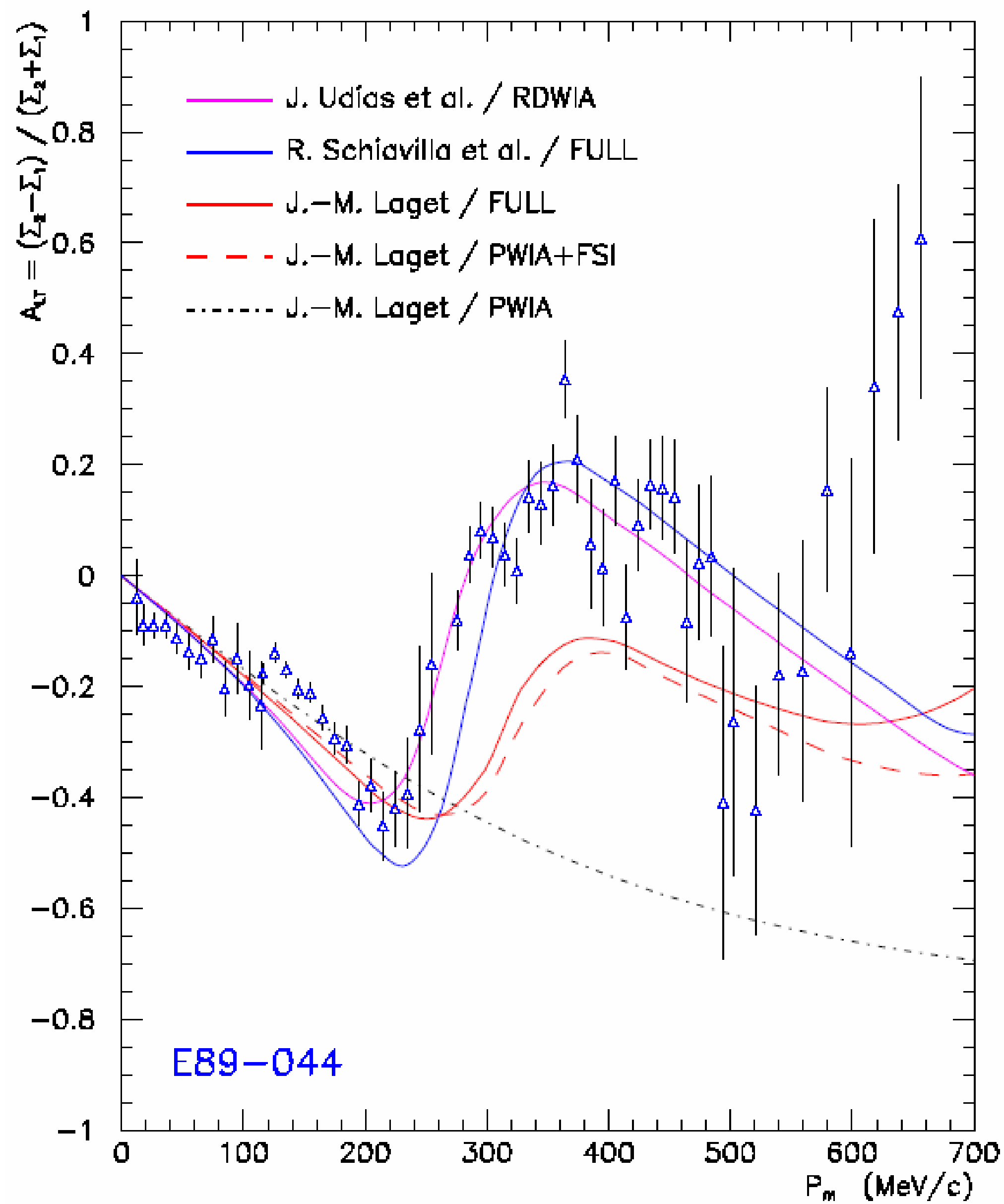
Schiavilla: double scattering Non-hadronic? "Exotic"?

A_{TL}

No structure in PWIA - factorized

Factorization broken by FSI

No A_{TL} from Ciofi – factorized calculations

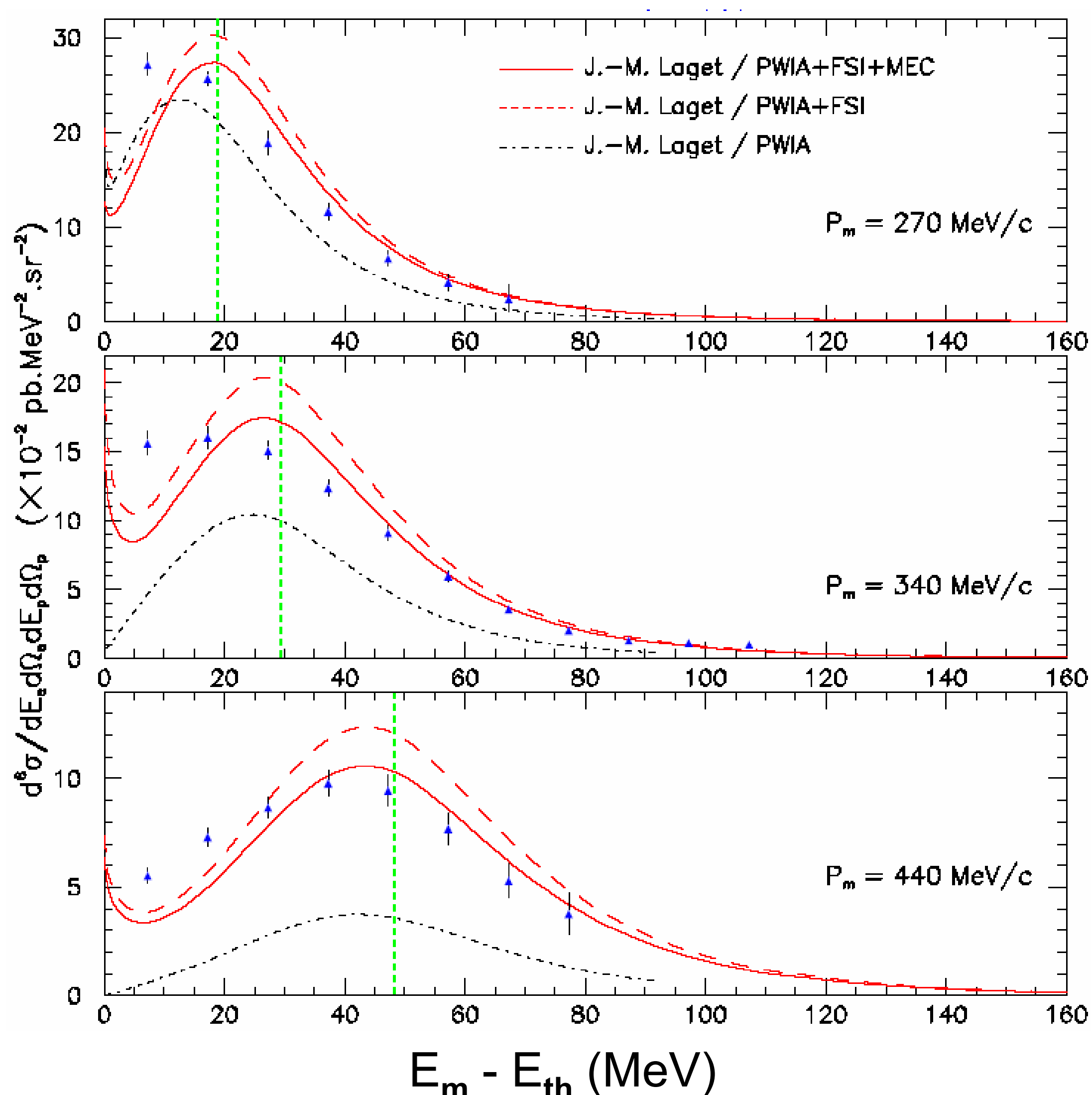


^{3}He(e,e'p)pn - 3bbu

For 2-body kinematics with a spectator A-2 – relationship between E_m and p_m

$$E_m = \sqrt{\left(M_{A-2} + \sqrt{M_N^2 + p_r^2}\right)^2 - p_r^2} + M_p - M_A$$

Low p_m: correlations?

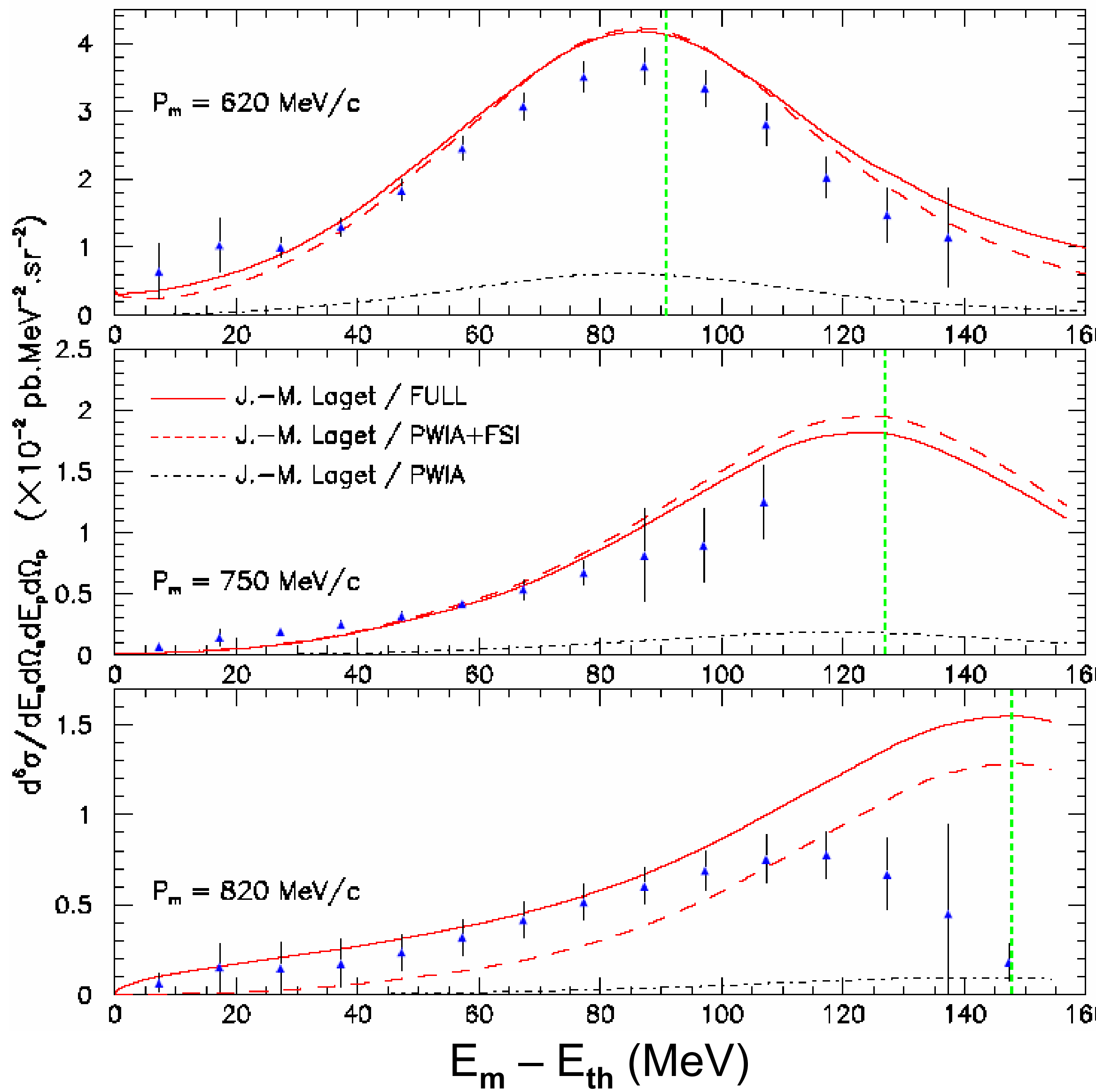


F. Benmokhtar *et al.*, PRL **94**, 082305 (2005)

3bbu - high p_m

High p_m: dominated by FSI

Note: similarly good calculations by Ciofi



2bbu, 3bbu "distorted" spectral functions

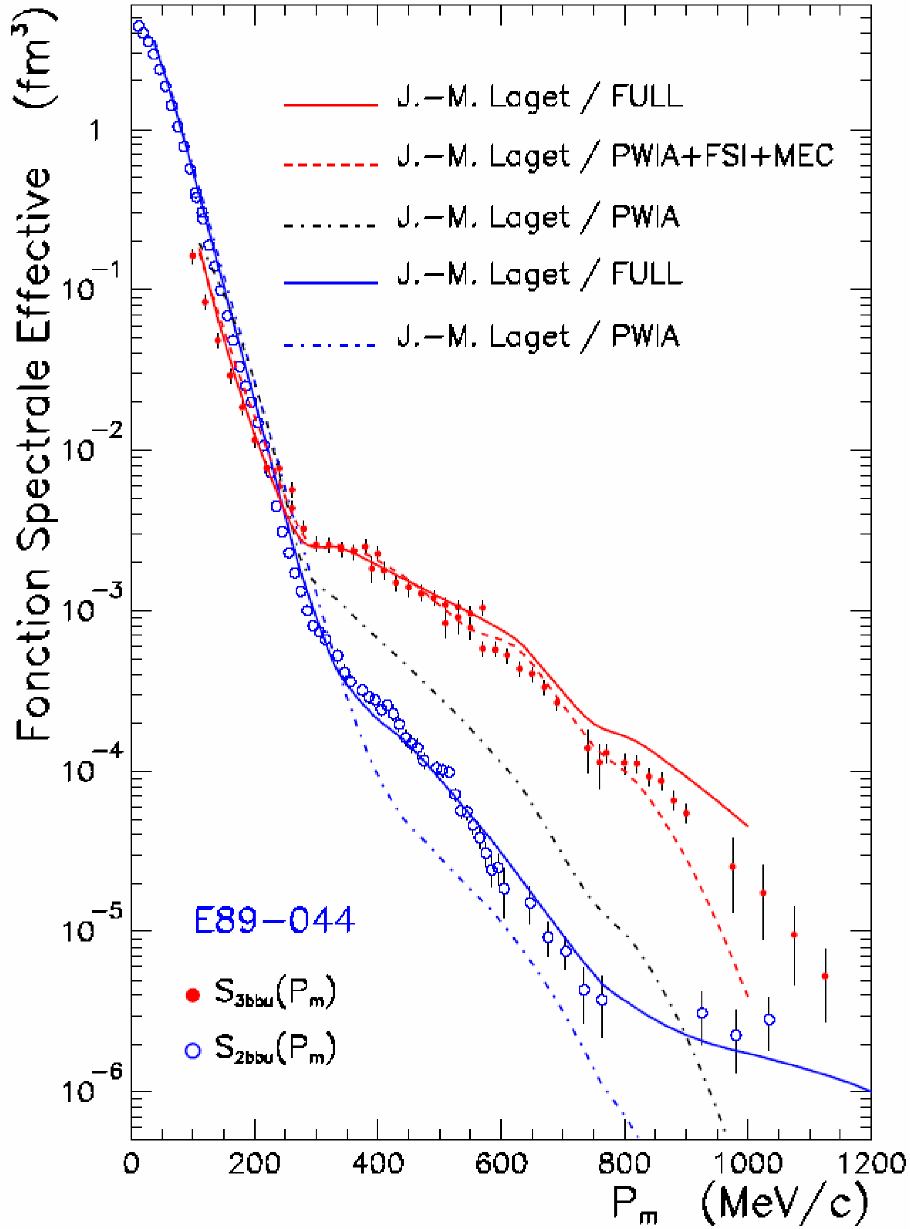
$$\eta(p_m) = \int \left(\frac{d^6\sigma}{dE_e dE_p d\Omega_e d\Omega_p} / K\sigma_{ep} \right) dE_m$$

High Q^2; $x_B \approx 1$
$\Rightarrow$ Reduced MEC, Δ contributions

At $p_m > p_F$ spectral function is much larger for 3bbu than for 2bbu due to correlations (SRC)

Calculations reproduce both 2bbu and 3bbu - confidence

Awaiting calculations by Schiavilla



Summary, conclusions, and outlook

- Extensive and precise data set for $^3He(e,e'p)d$ and $^3He(e,e'p)pn$
  - $-750 > p_m > 1000$ MeV/c
  - x-section over 6 decades
  - many kinematics
  - many observables (x-sections A_{TL}, R_L, R_T)
  - This is the only way to test ingredients of theory in details!!!!

- Data illuminates details of ^3He gswf (NN, NNN potentials, correlations) and reaction dynamics although x-sections dominated by FSI

- All models reproduce data reasonably well; some better than others
  - Ciofi - (factorized) has problems with A_{TL}
  - Laget - problems with GSWF, diagramatic approach not transparent
  - Schiavilla – most sound and sophisticated; does best job for $^3He(e,e'p)d$
  - Udias – does surprisingly well using RDWIA – o. p. for FSI in $^3He(e,e'p)d$

Summary, conclusions and outlook (cont.)

- Must Test models with other reactions, kinematics, and on deuteron (measured), ^{4}He (experiment approved for Hall A)
  - Ciofi – does ok with 2bbu, 3bbu, d, some predictions for ^{4}He
  - Laget – does reasonably well with 2bbu, 3bbu, ^{3}He(e,e′pN)N, d
  - Schiavilla – working on ^{3}He(e,e′p)pn, ^{4}He(e,e′p)^{3}H, ingredients tested on d
  - Udias – has predictions for ^{4}He(e,e′p)^{3}H

- Exciting times are ahead

M. M. Rvachev *et al*., PRL **94**, 192302 (2005)
F. Benmokhtar *et al*., PRL **94**, 082305 (2005)
J. M. Laget, Phys. Lett. **B609**, 49 (2005)
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J. M. Udias, private communications