Quark-hadron duality in the free neutron F2 structure function

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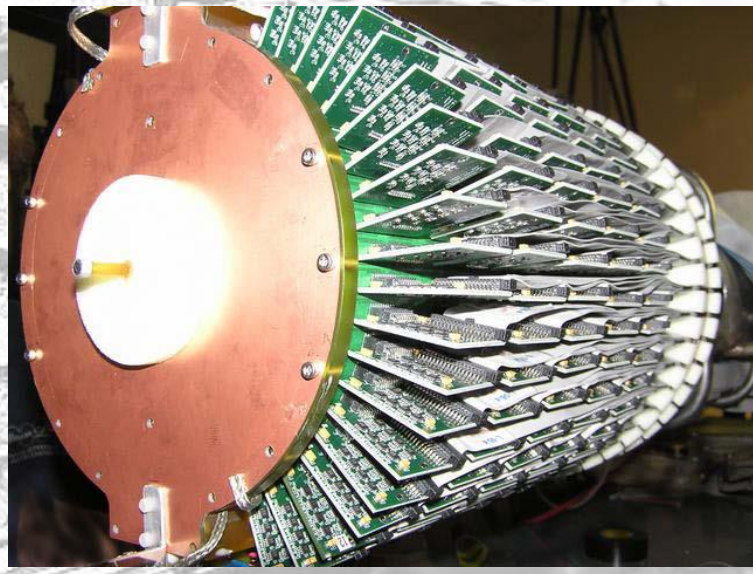
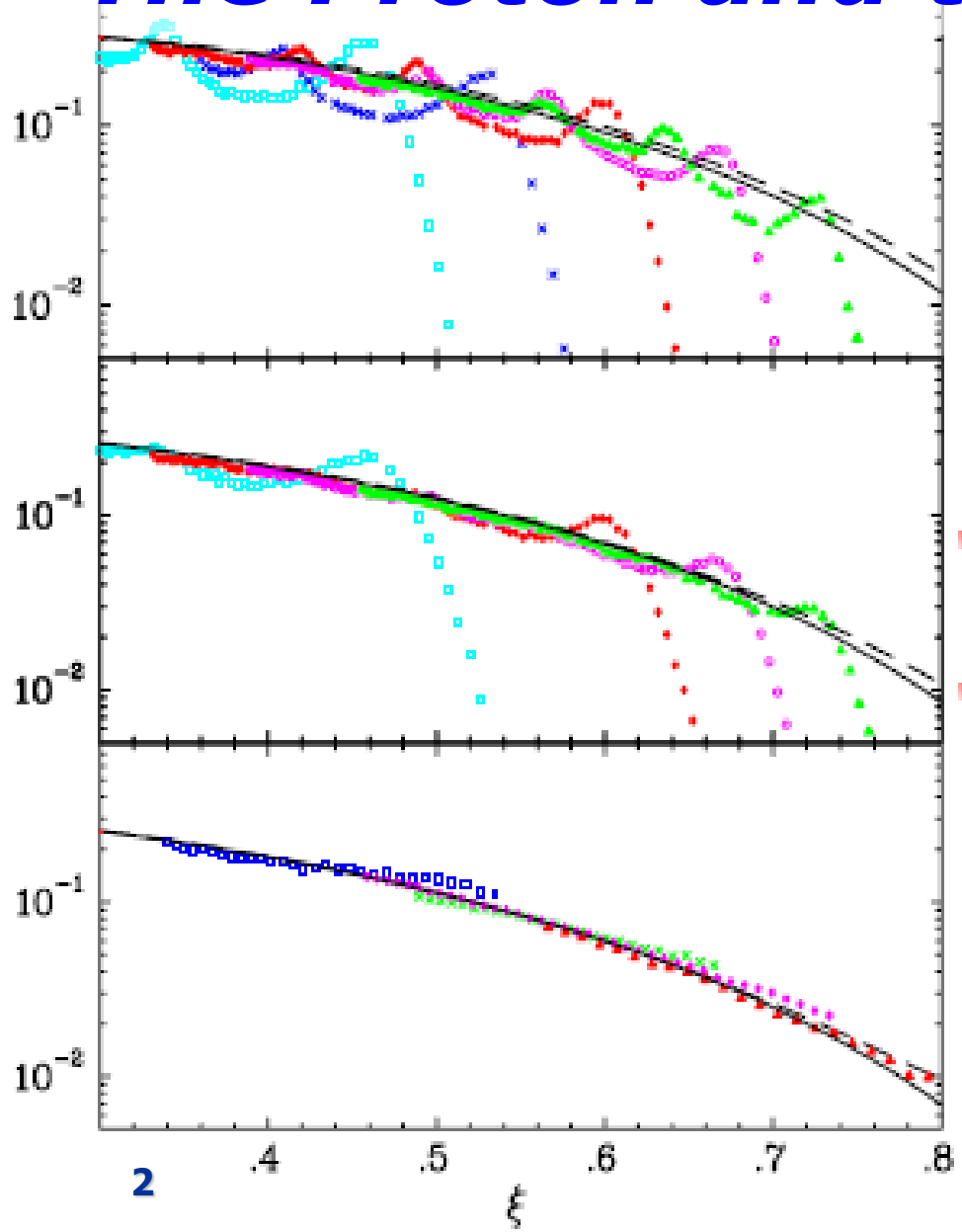


- *Why study duality on the neutron?*
- *The BONuS experiment*
- *Local duality on the neutron*
- *Summary*

The Proton and the Deuteron

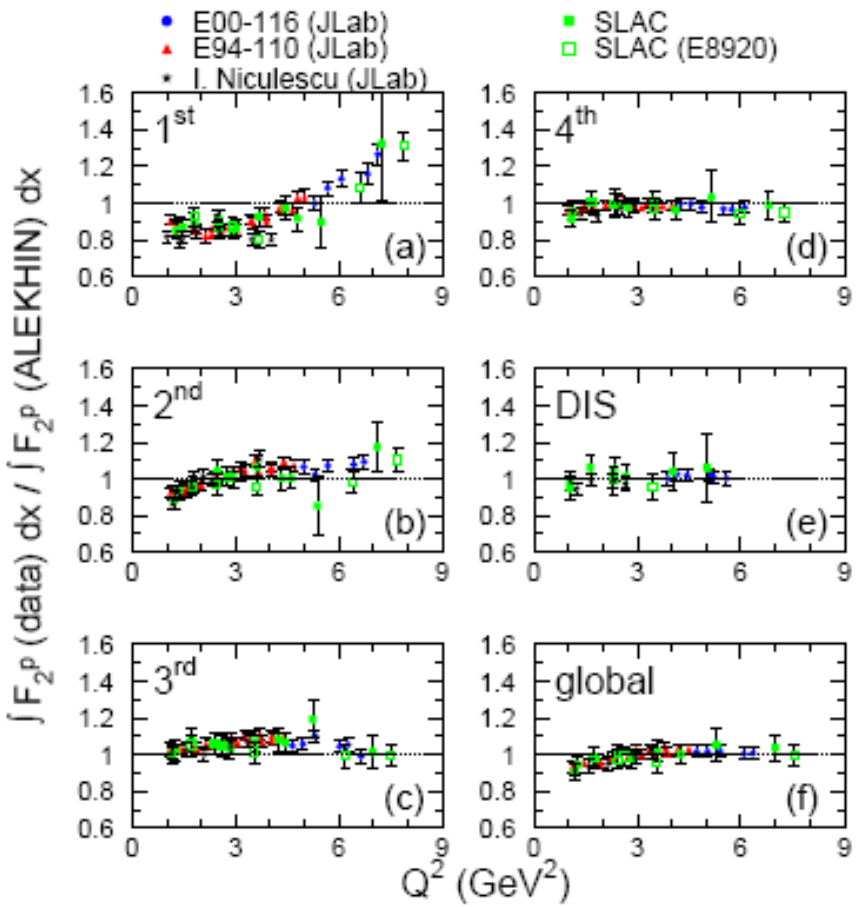
J. Arrington et al., PRC 73 (2006) 035205



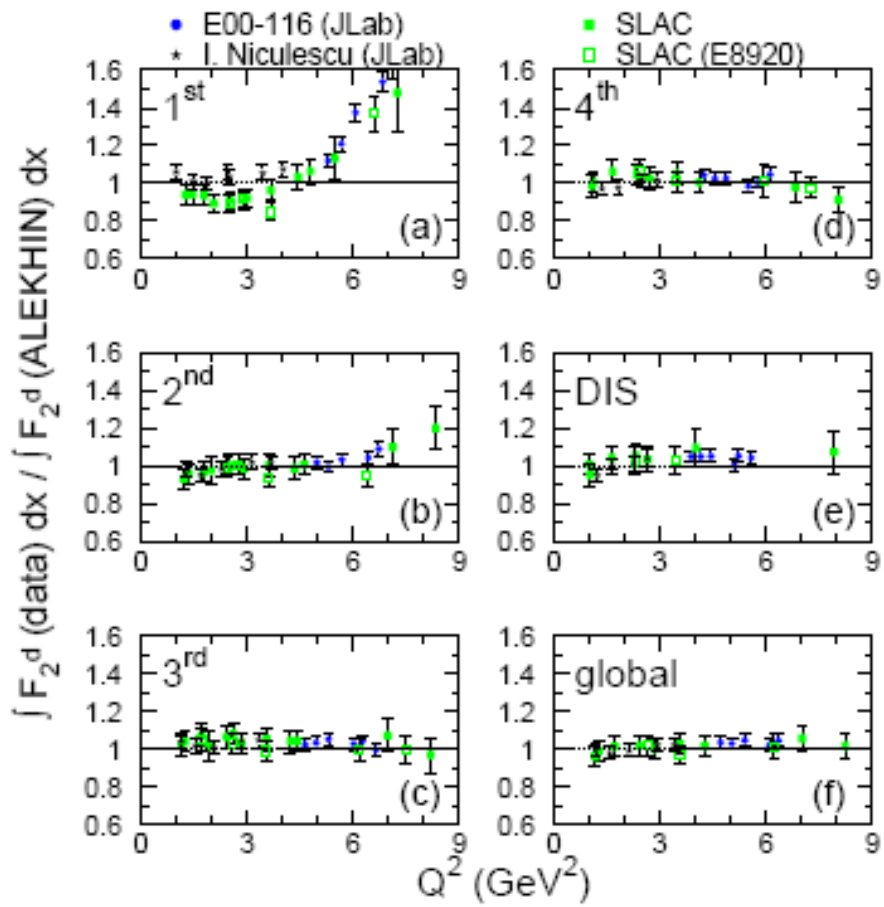
- Scaling (duality) is observed in nuclei
- Resonances less pronounced – washed out by Fermi motion

Local duality…

proton



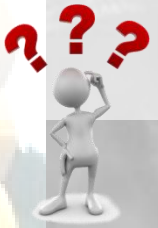
deuteron



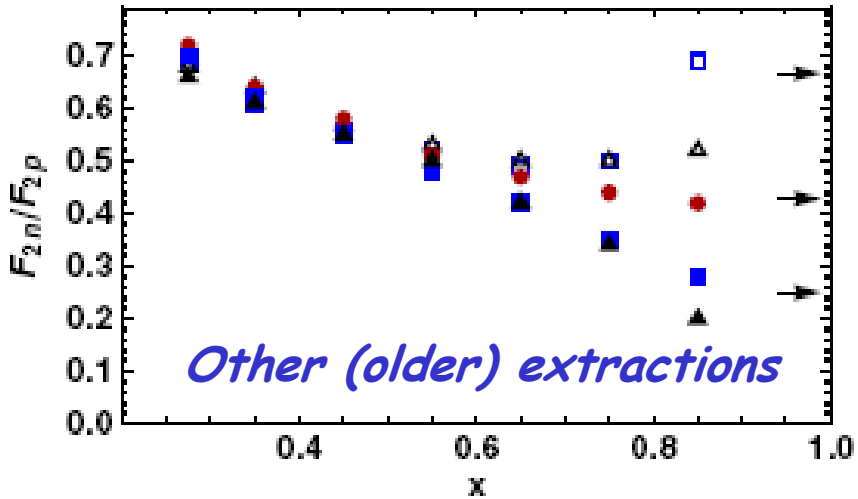
S. Malace et al., PRC 80, 035207 (2009)

Does it work for the Neutron?

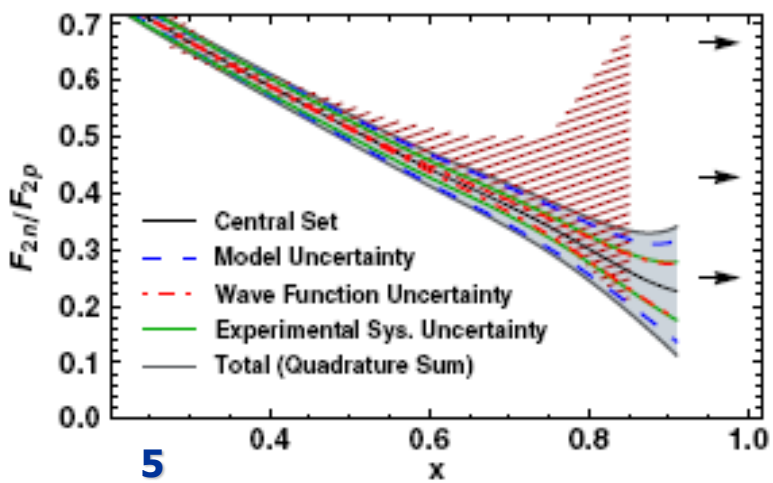
- Frank E. Close, Nathan Isgur PLB 509 (2001) 81
- "for the proton duality may be satisfied by W<1.6 GeV"
- "For neutron targets […] we anticipate systematic deviations from local duality"
- "the S11(1530) […] and the F15(1680) are enhanced relative to the deep inelastic scaling curve for proton targets"
- "for neutron targets, the S11(1530) region will fall below the scaling curve"

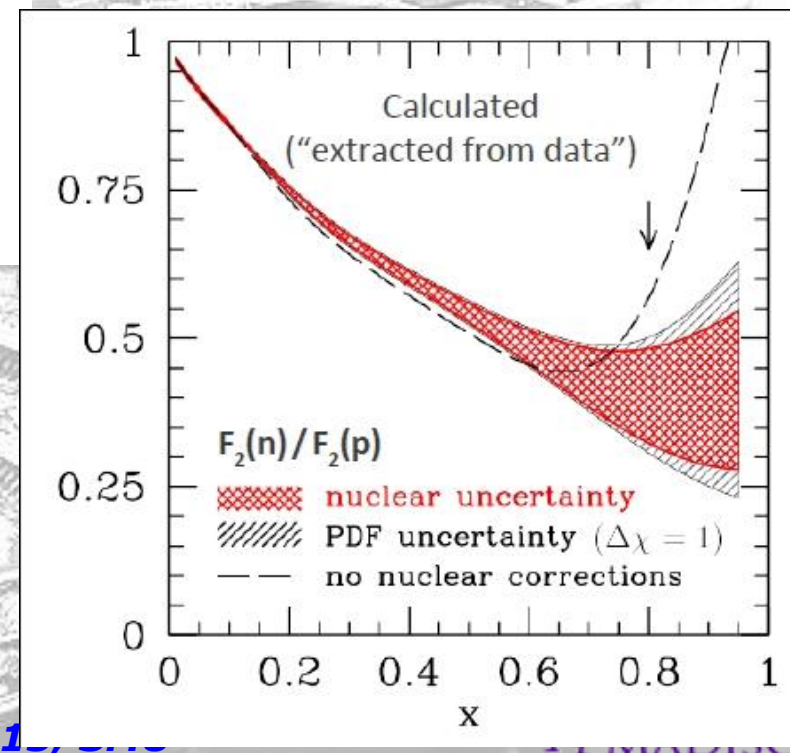


Extract neutron from deuteron data



- Large uncertainties due to nuclear effects
- Are there alternatives?

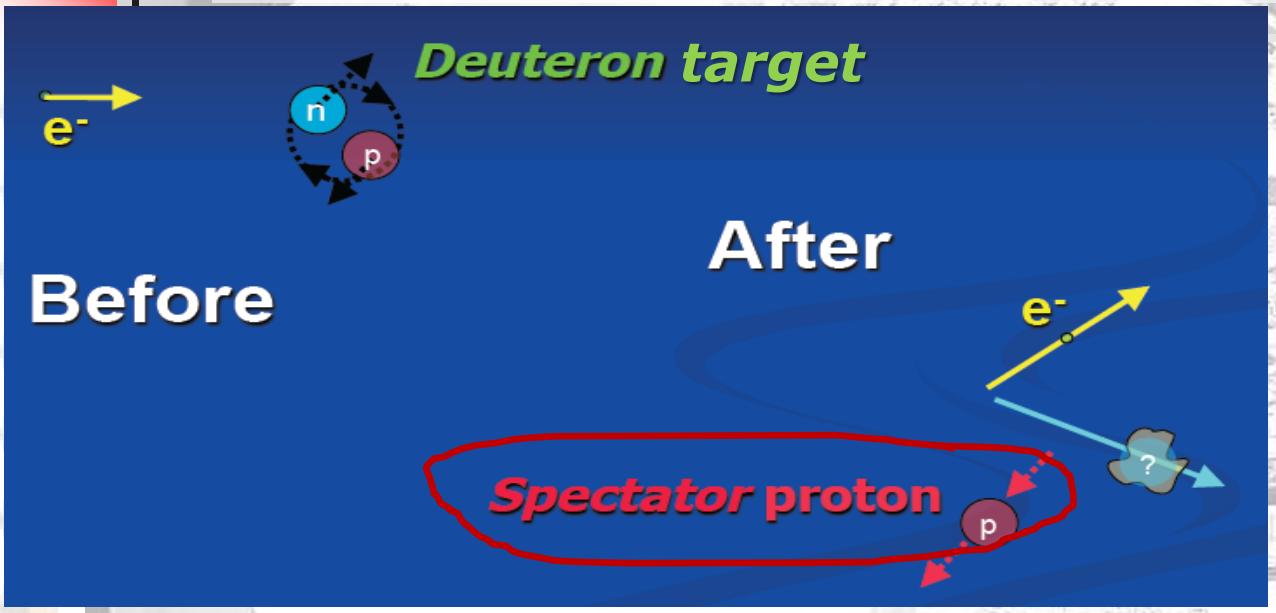


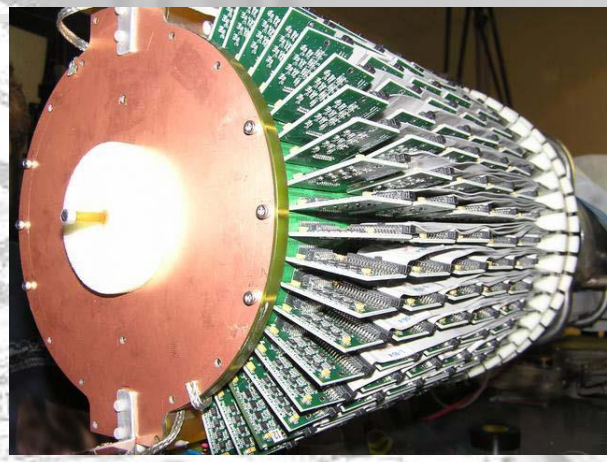


J. Arrington, J.G. Rubin, W. Melnitchouk PRL 108, 252001 (2012)

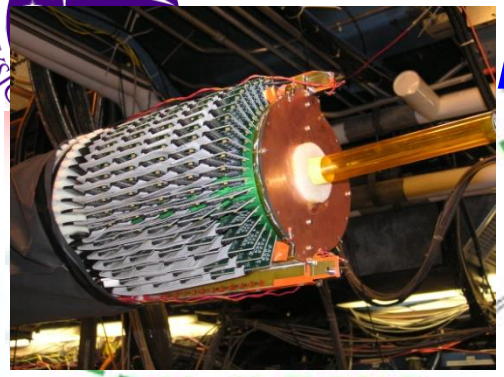
A. Accardi et al., PRD 84 014008 (2011)

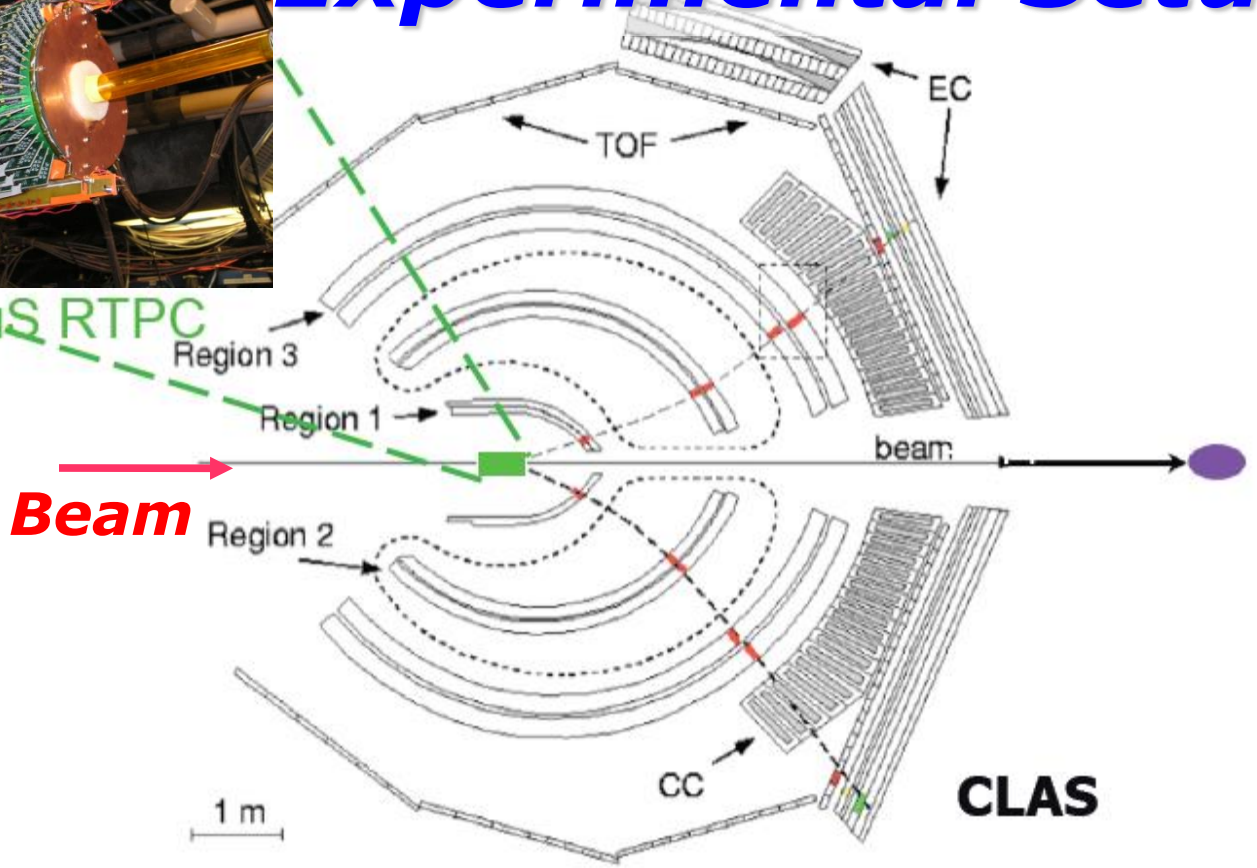
The BONUS Experiment

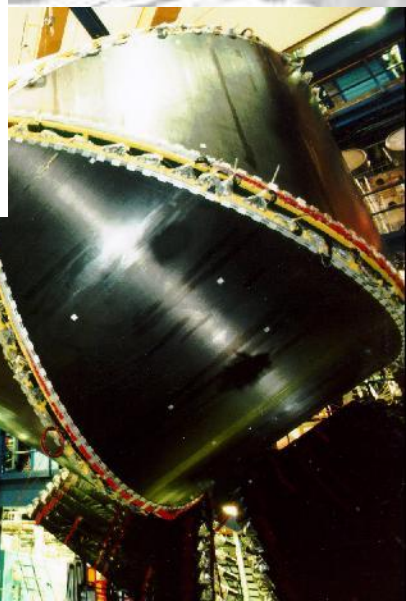


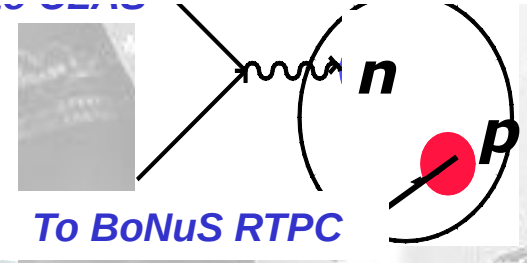


Experimental Setup



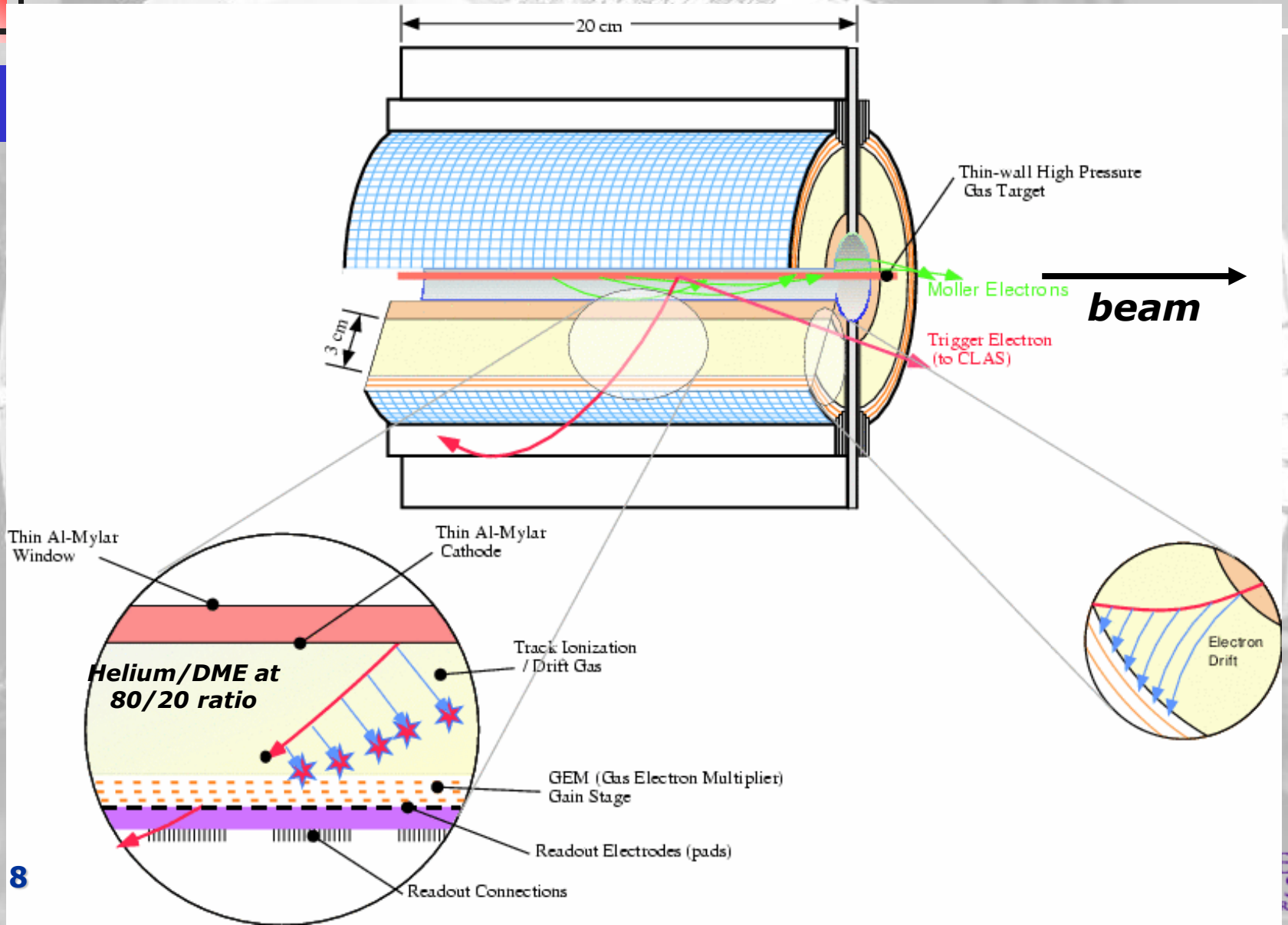




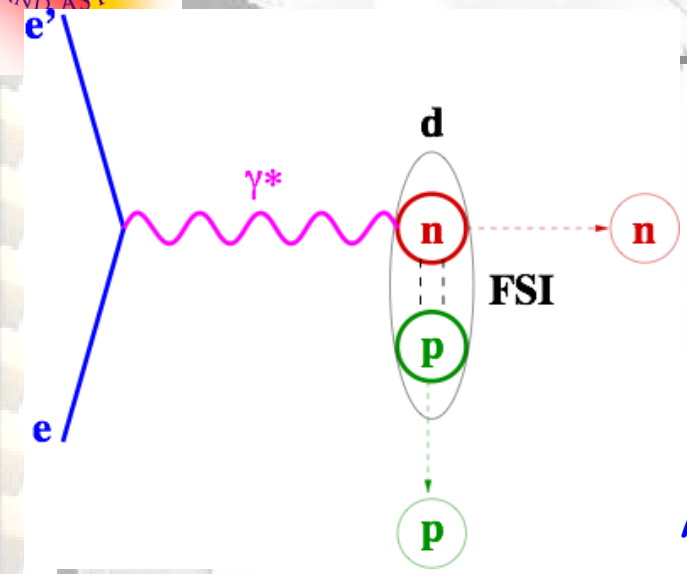


BoNuS RTPC

H. Fenker et al., Nucl. Instrum. Meth. A 592, 273 (2008)



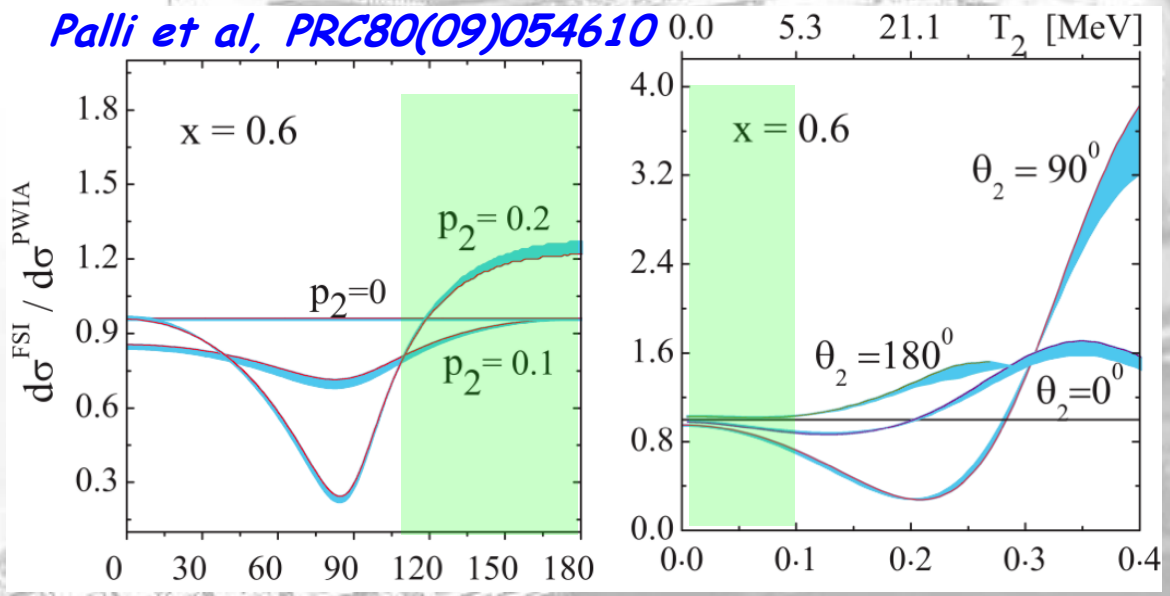
Final State Interaction



- struck neutron can interact with the spectator proton
- proton momentum is enhanced
- FSIs are small at low p_s and large Θ_{pq}

- Several groups have calculated FSIs
- Few percent for low momentum

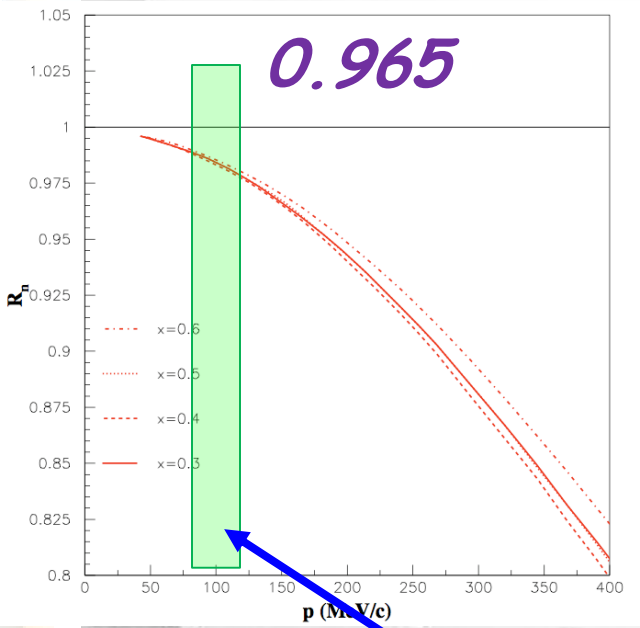
Palli et al, PRC80(09)054610



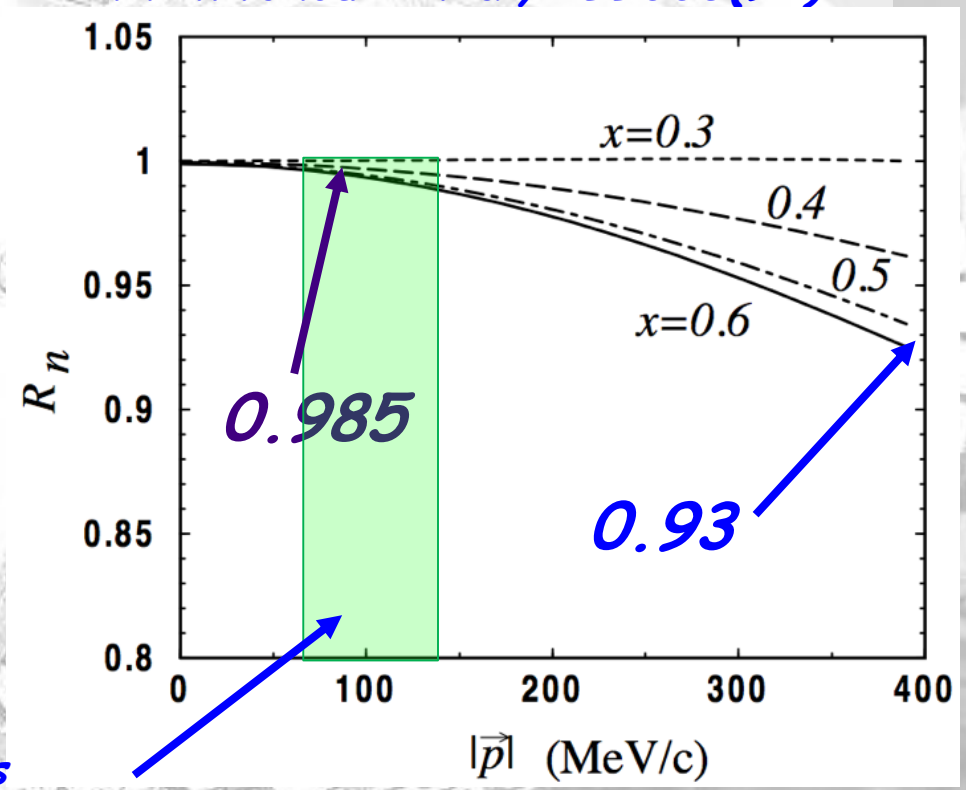
Off – shell Effects

$$R_n \equiv (F_2^n)^{\text{eff}} / (F_2^n)^{\text{free}}$$

Liuti & Gross PLB356(95)157



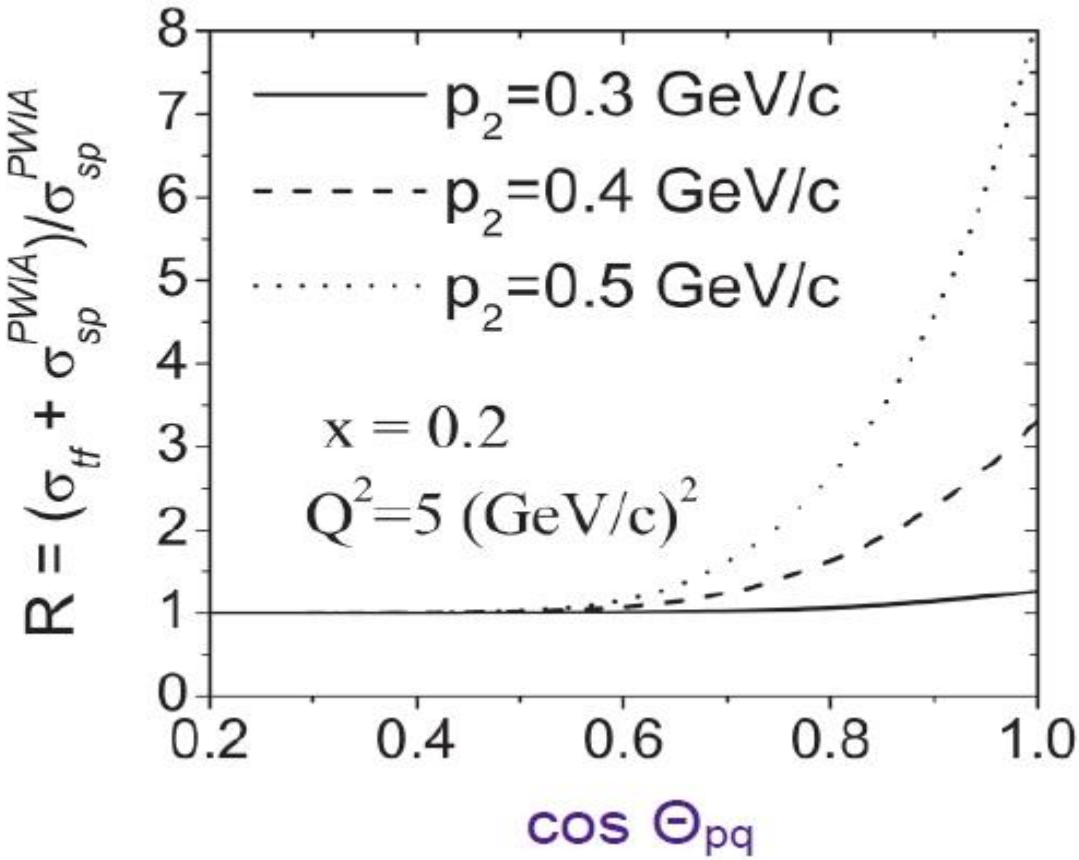
Melnitchouk et al, PLB335(94)11

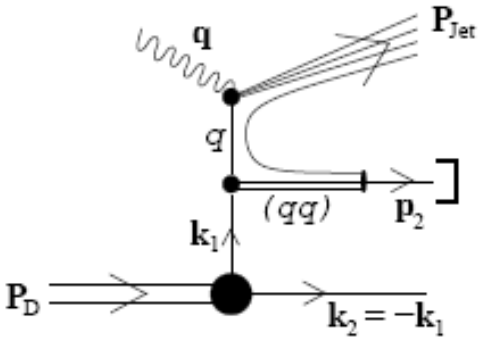


BoNuS p_s detection range

Target Fragmentation

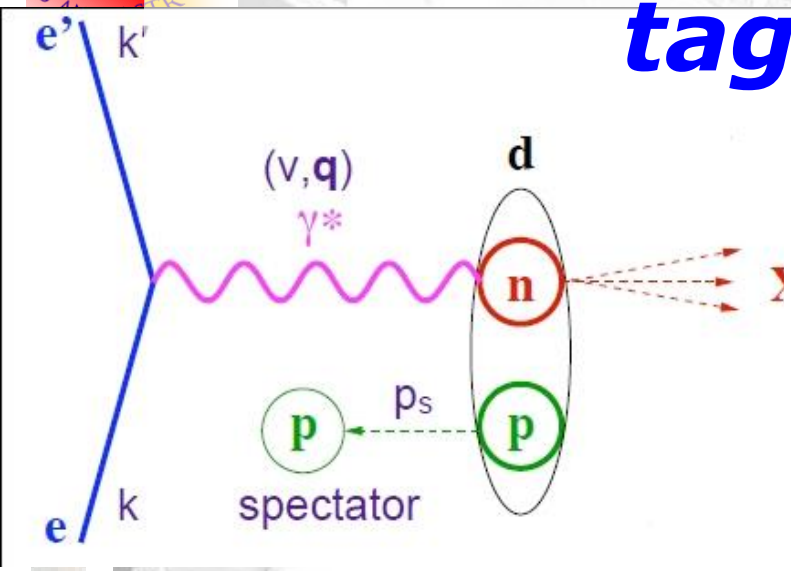
Palli *et al.*, PRC**80**(09)054610



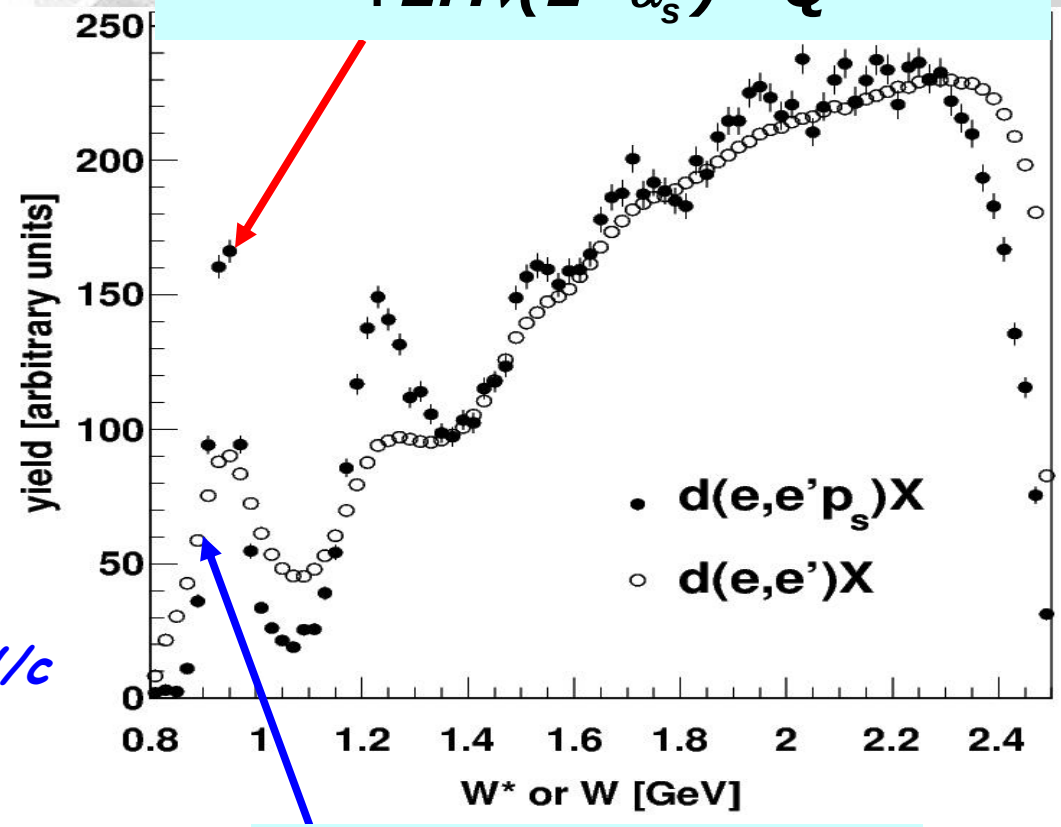


Enhancement in proton yield over PWIA negligible for backward protons

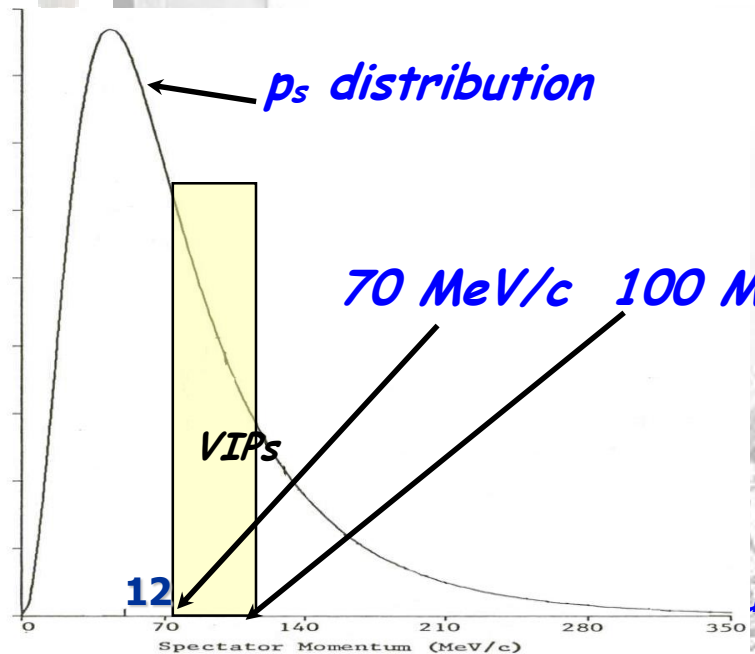
Kinematic reconstruction with tagged protons



$$W^{*2} = (p_n + q)^2 \approx M^{*2} + 2M\nu(2 - \alpha_s) - Q^2$$



$$W^2 = M^2 + 2M\nu - Q^2$$



Ratio Method

N. Baillie et al., PRL108, 199902 (2012)
S. Tkachenko et al., PRC 89,045206 (2014)

- Define: "VIP" (Very Important Protons)
  - P_s < 100 MeV/c && θ_{pq} ≥ 100 deg

1. Experimental ratio

$$R_{exp} = \frac{N_{d(e,e'p_s)}(W^*, Q^2)}{N_{d(e,e')}(W, Q^2)} C(E_b, W^*, W, Q^2) =$$

$$\frac{F_2^n(W^*, Q^2)}{F_2^d(W, Q^2)} \int_{VIP} d\alpha_s dp_s^{\perp} A_p(\alpha_s, p_s^{\perp}) S(\alpha_s, p_s^{\perp}).$$

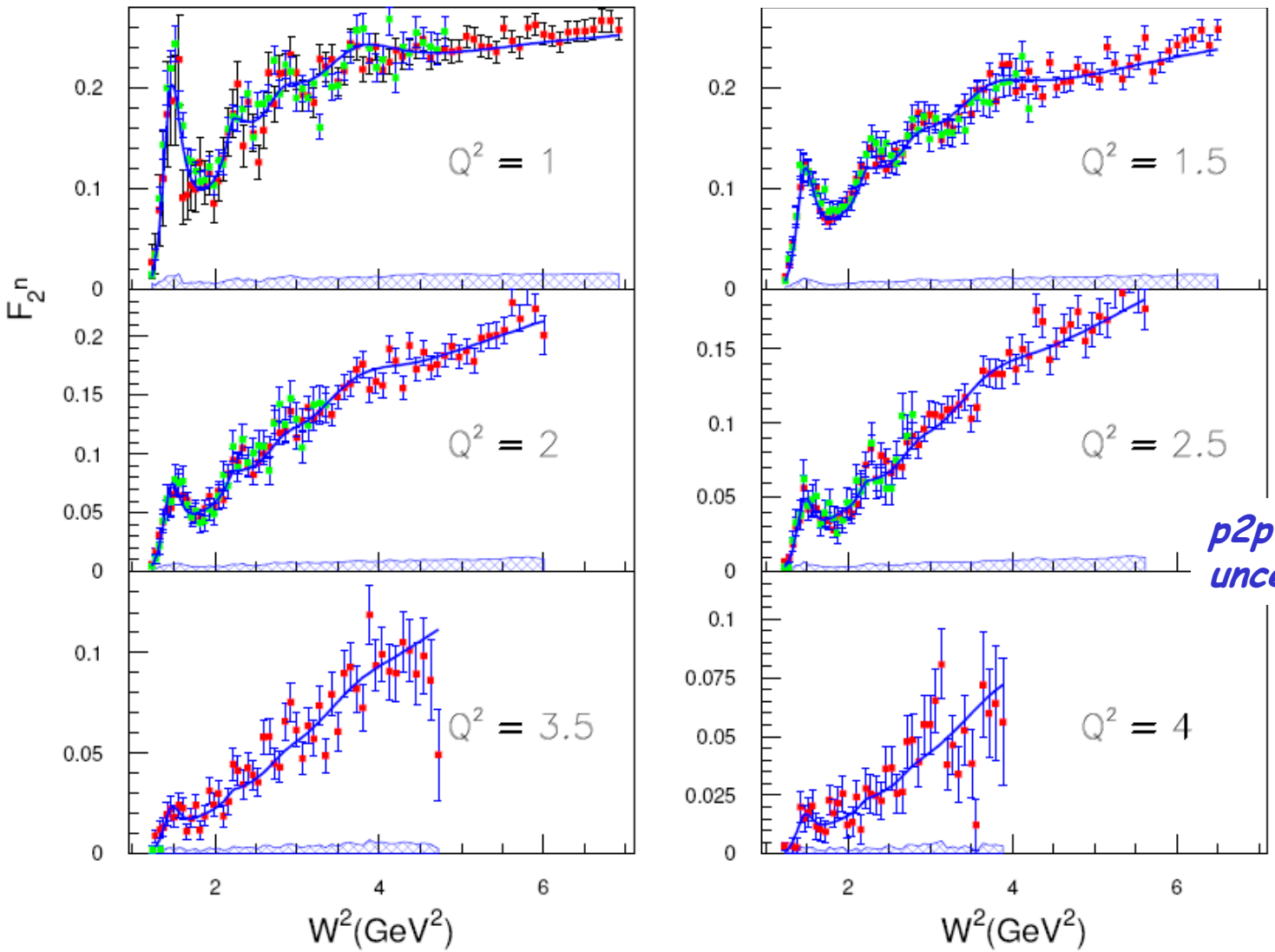
2. Extract F2n/F2d ratio

$$F_2^n = F_2^d \times R_{\exp}$$

3. Get F2n

Results

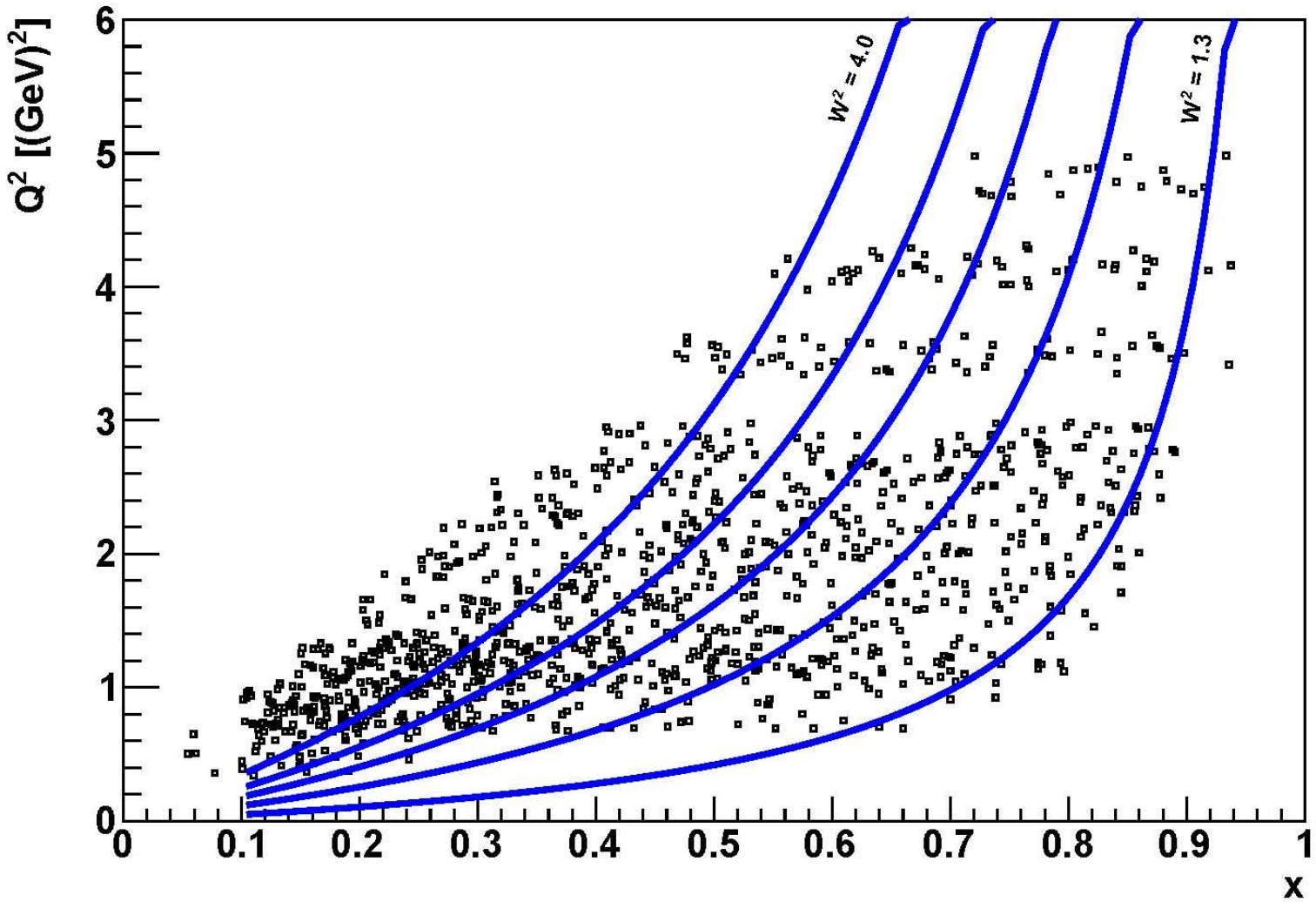
E=4.2 and 5.3 GeV



p2p Systematic uncertainty

S. Tkachenko et al., PRC 89, 045206 (2014)

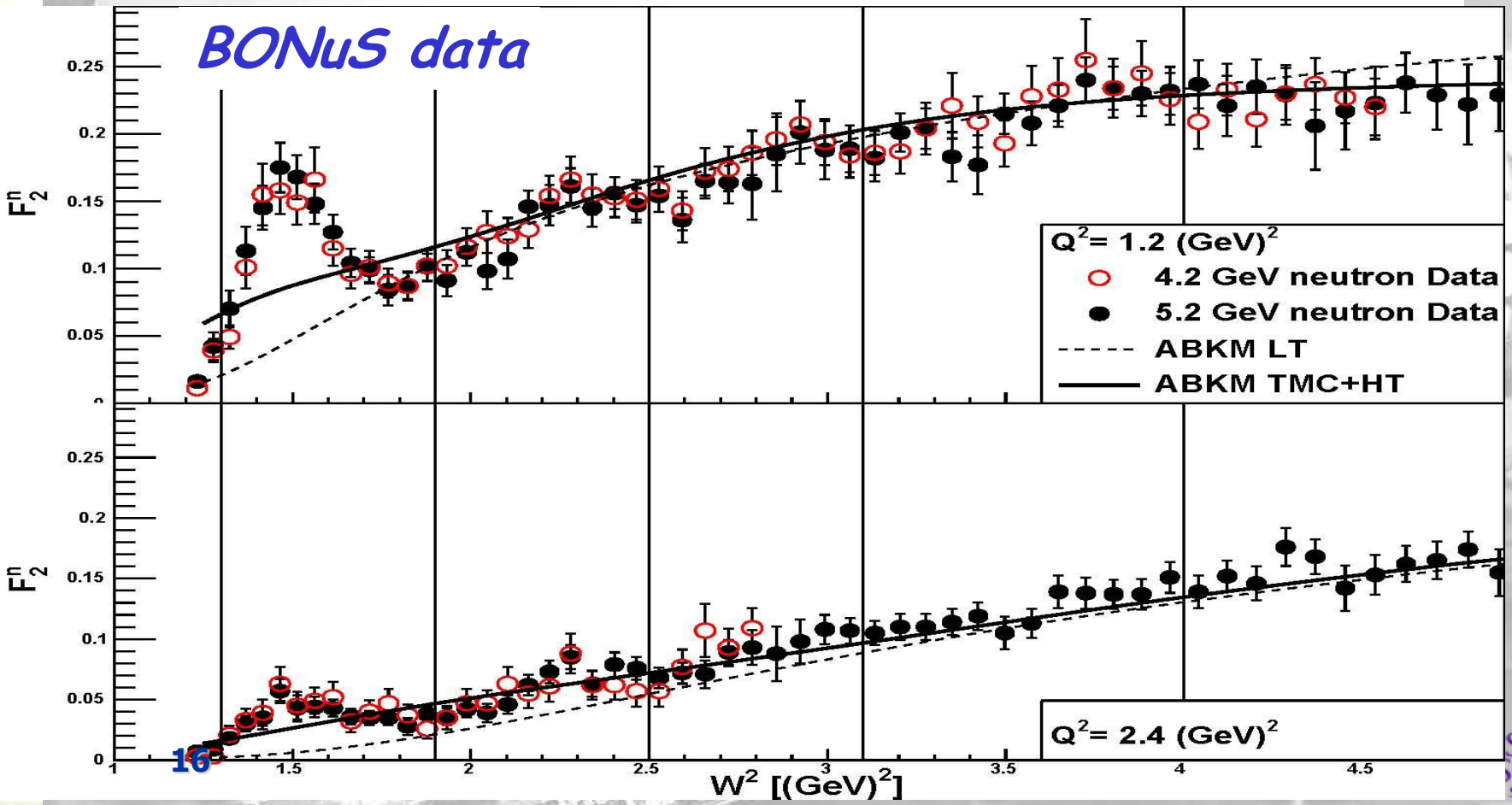
Kinematic Coverage



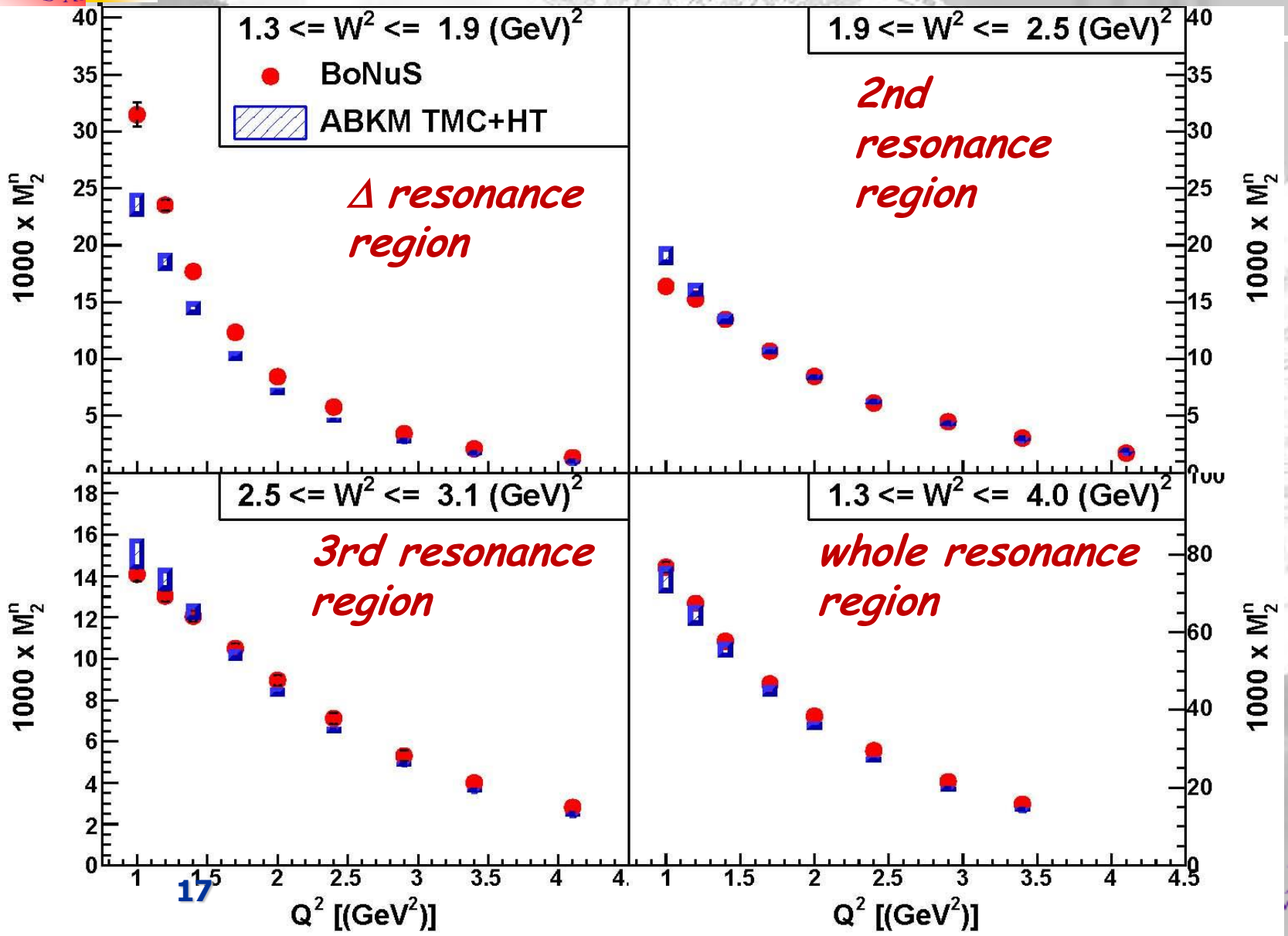
Truncated Moments and Local Duality

$$M_n(x\min, x\max, Q^2) = \int_{x\min}^{x\max} x^{n-2} F(x, Q^2)\,dx$$

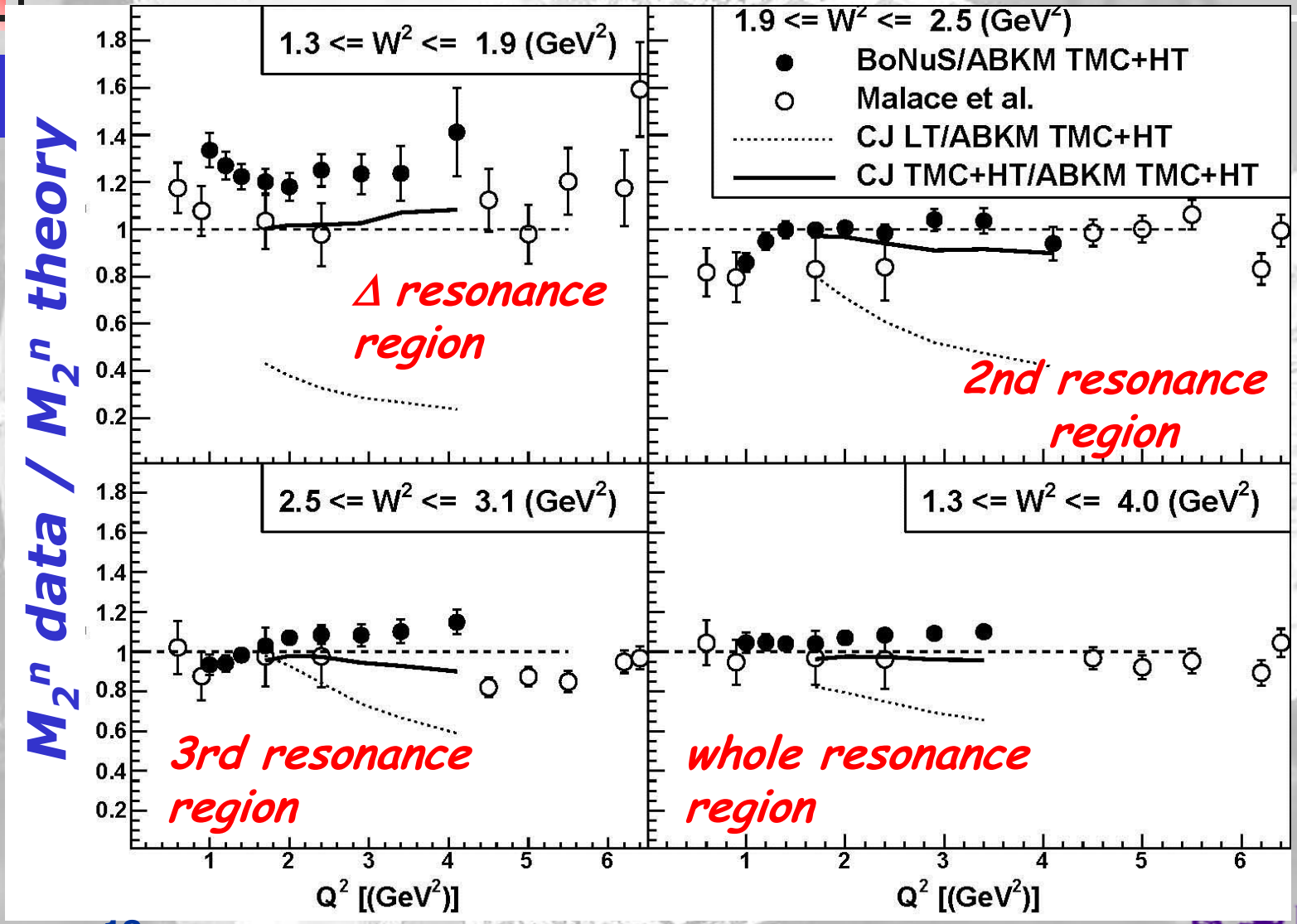
As defined in: A. Psaker, W. Melnitchouk, E. Christy, C. Keppel, PRC 78 025206 (2008).



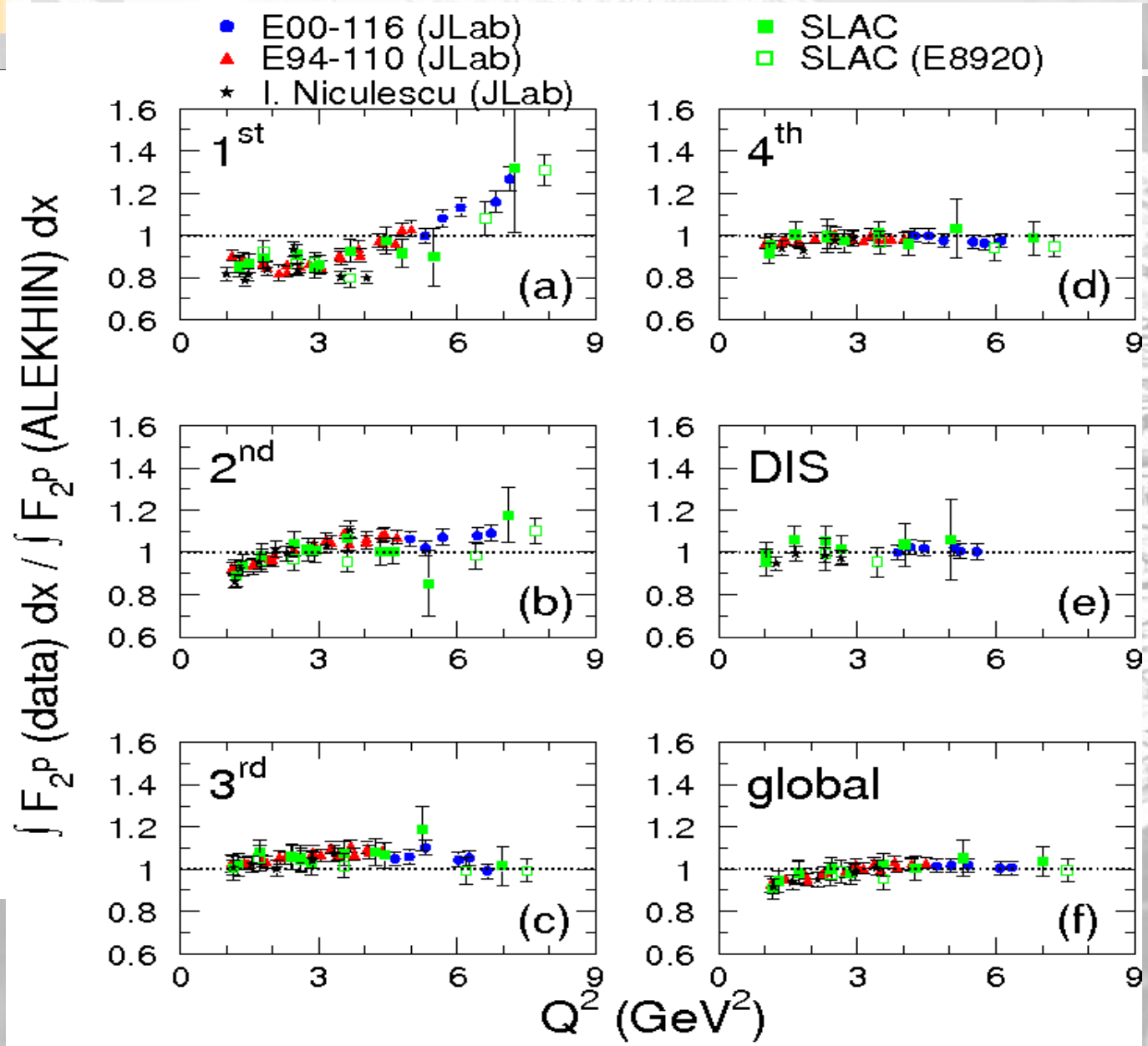
BONuS Truncated Moments



Local q-h Duality – Neutron

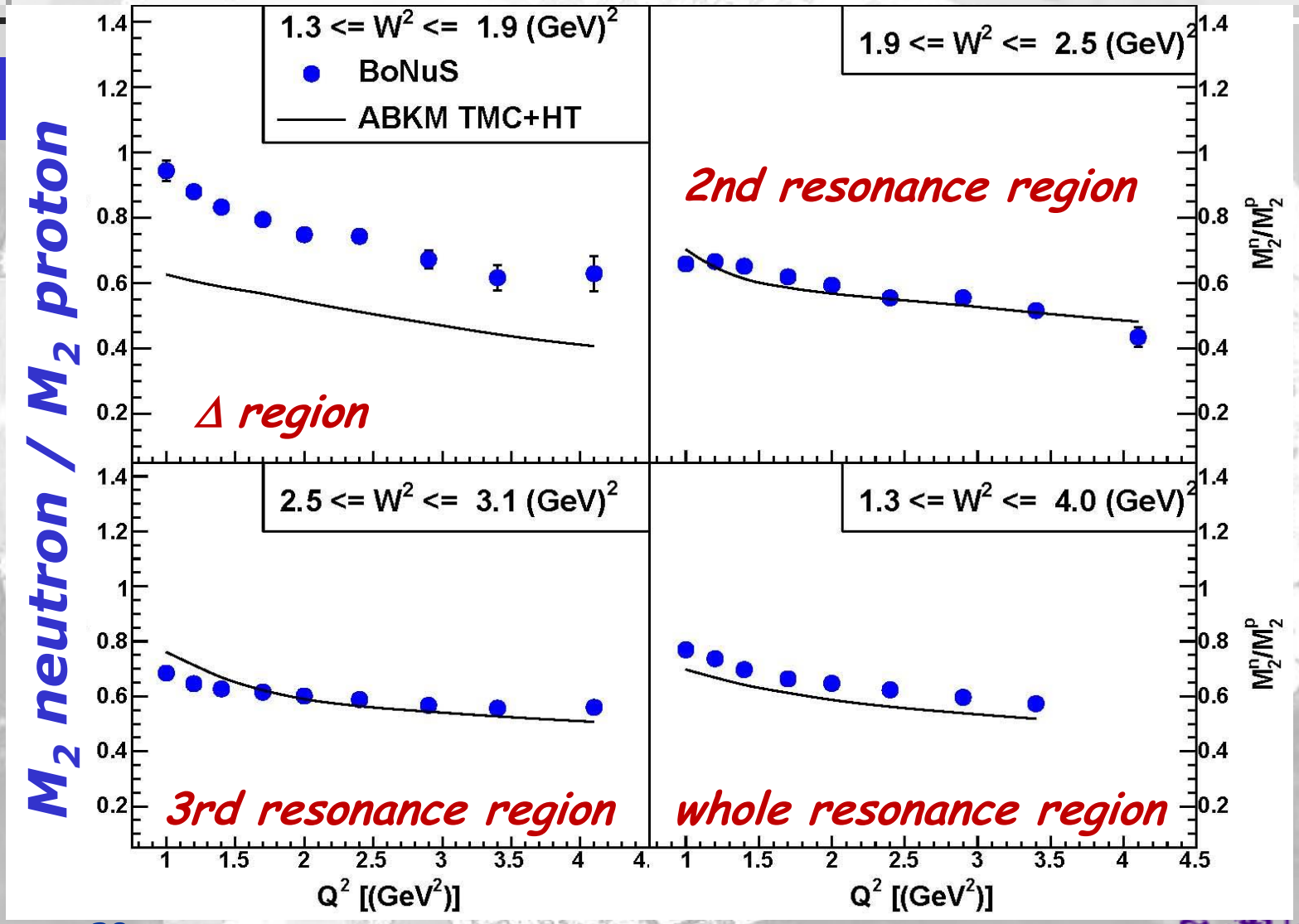


Local q-h Duality – Proton



S. Malace et al., PRC 80, 035207 (2009)

Proton/Neutron Comparison



Conclusion

- Investigated local quark - hadron duality in the neutron structure function.
- Smaller systematic uncertainties than earlier studies
- Truncated F_{2n} moments compared to DIS PDFs and with F_{2p} moments.
- Quark - hadron duality holds locally for second and third resonance region.
- Deviations in the Delta region (15%+).