Neutron Duality from the BONuS Experiment

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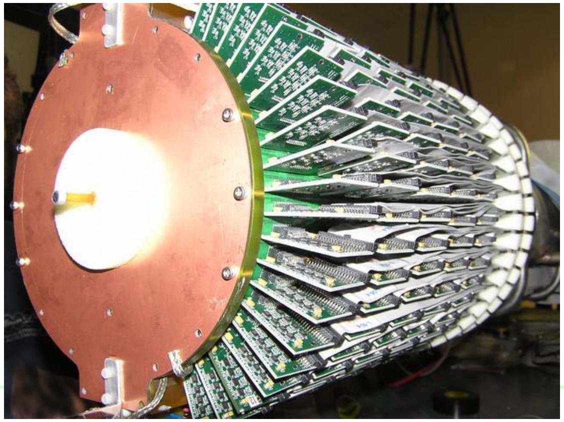
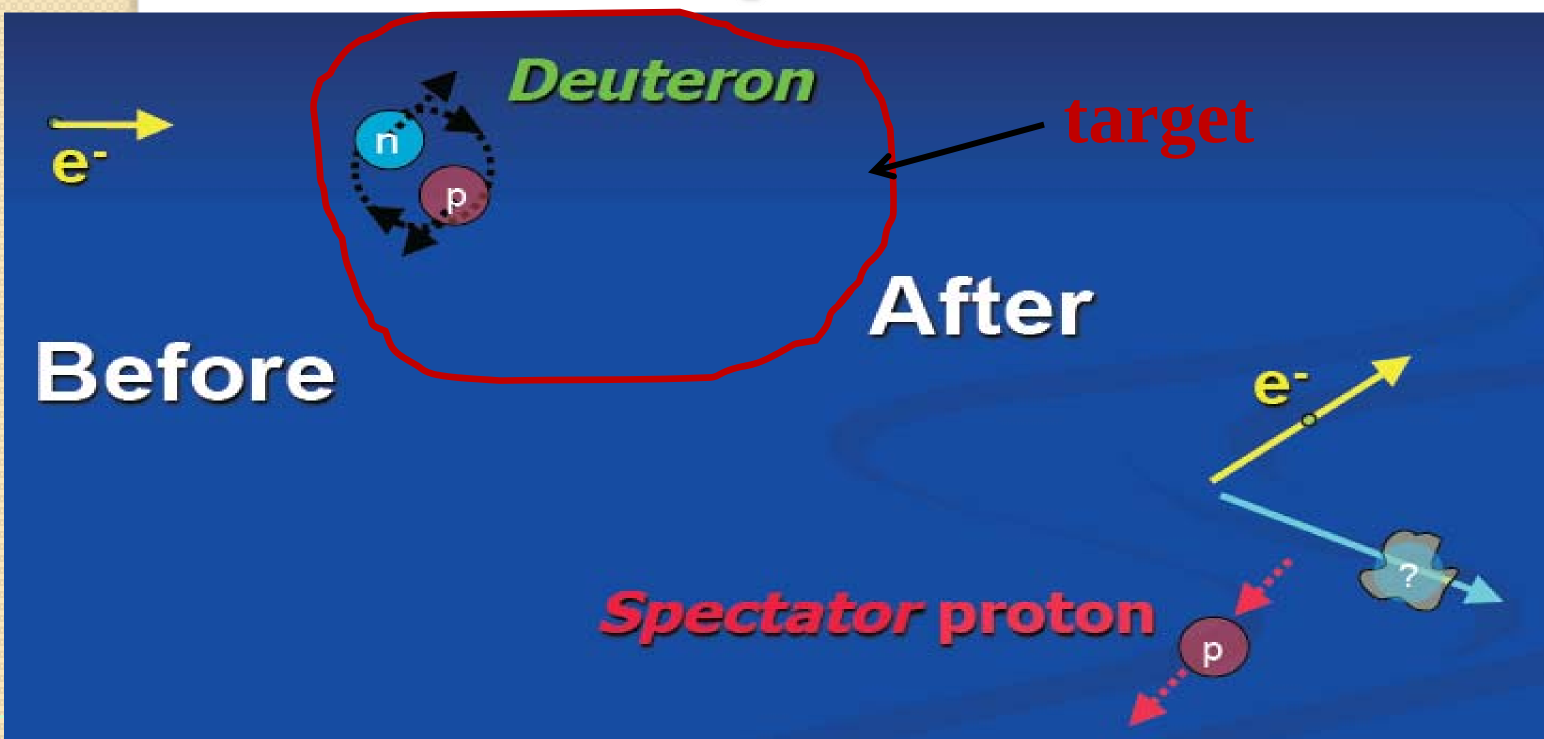
March 13, 2015

- **The BONuS experiment**
- **Local duality on the neutron**
- **Summary**

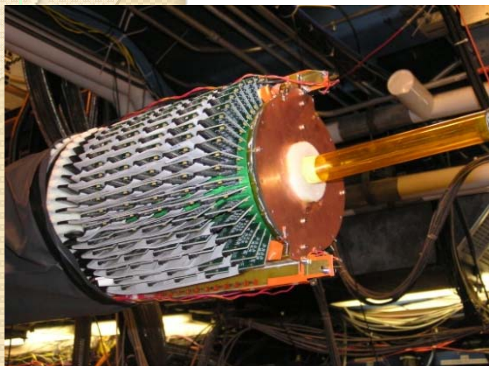


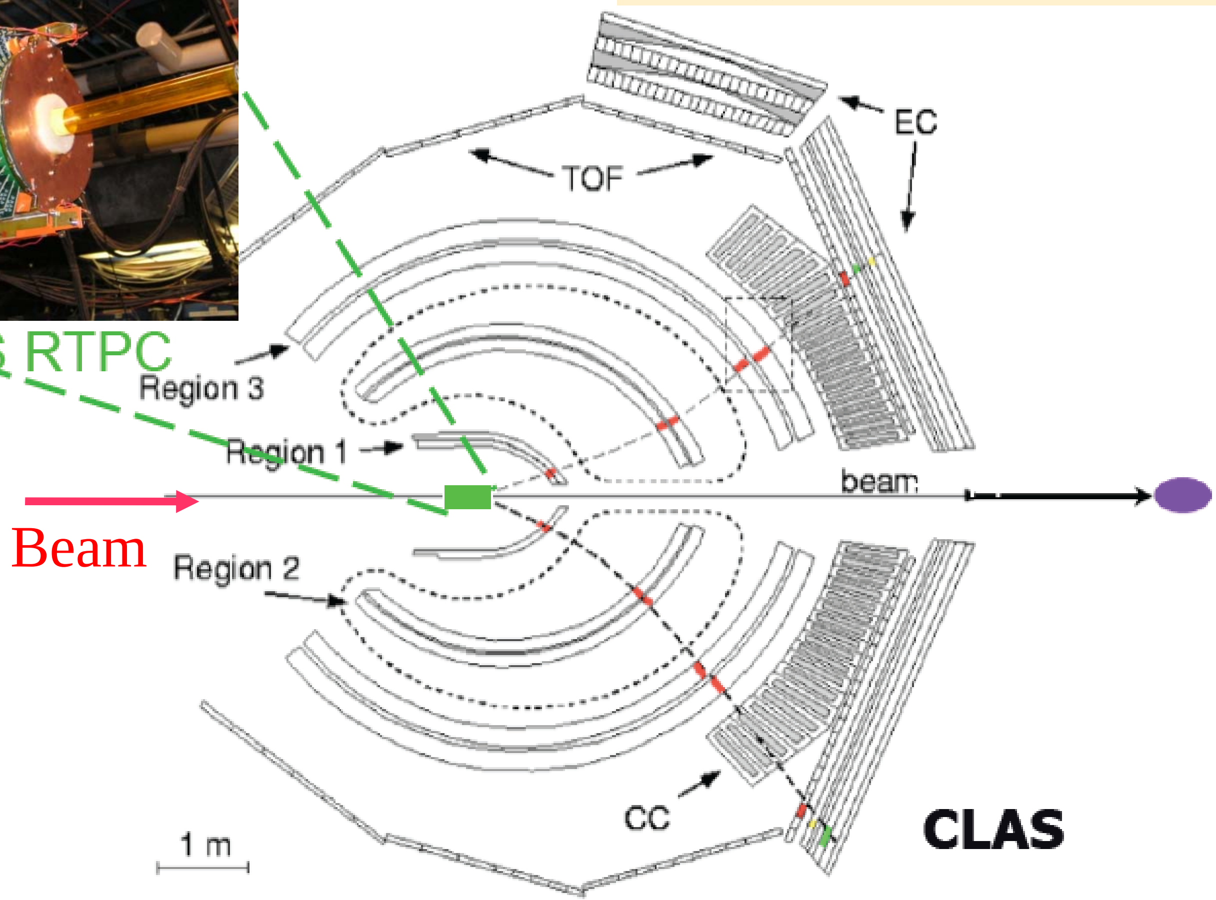
OQ-PHD

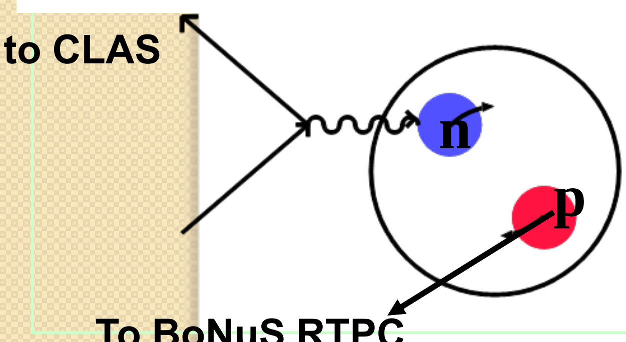
The BONUS Experiment



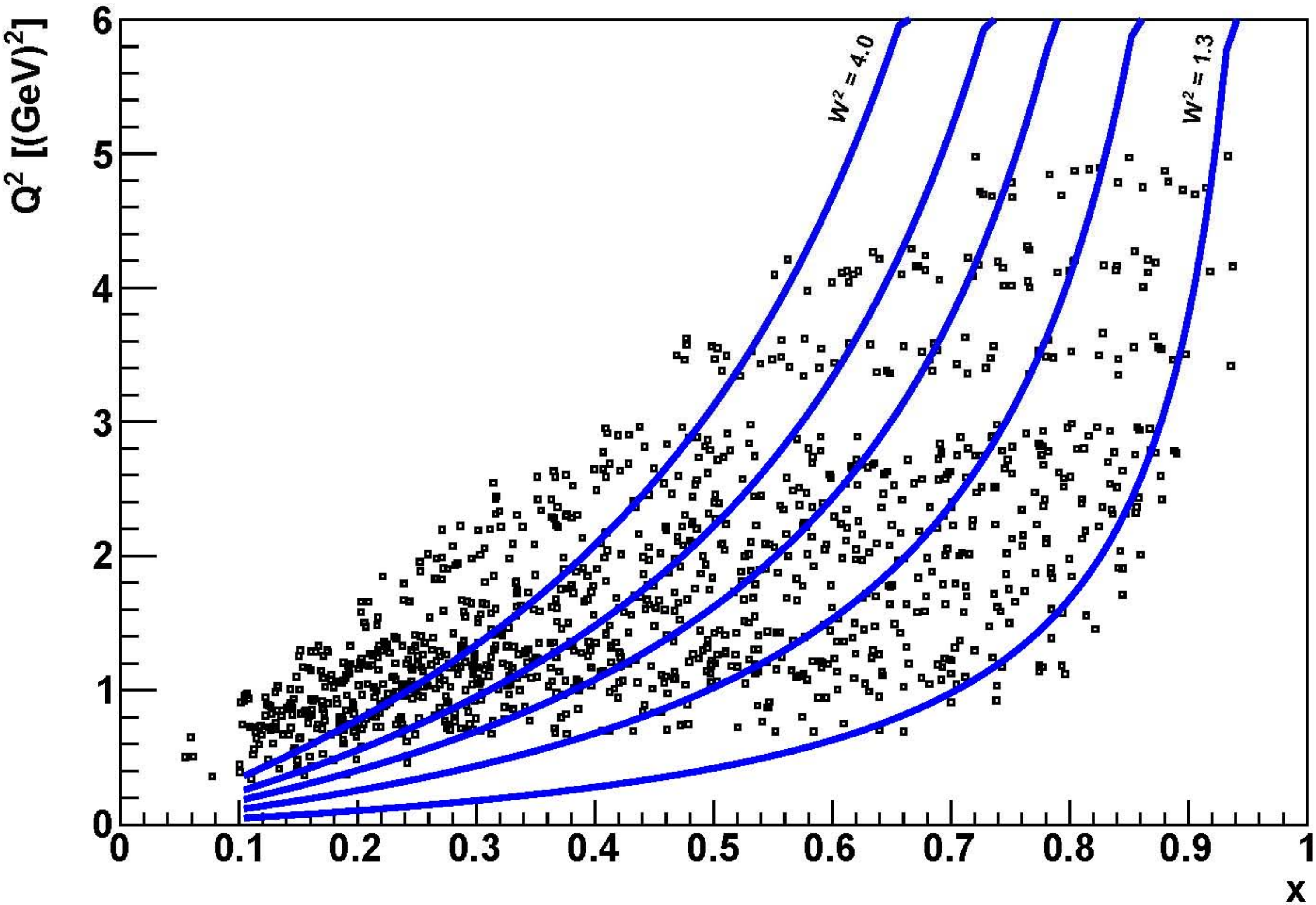
Experimental Setup:







BONUS Kinematic Coverage

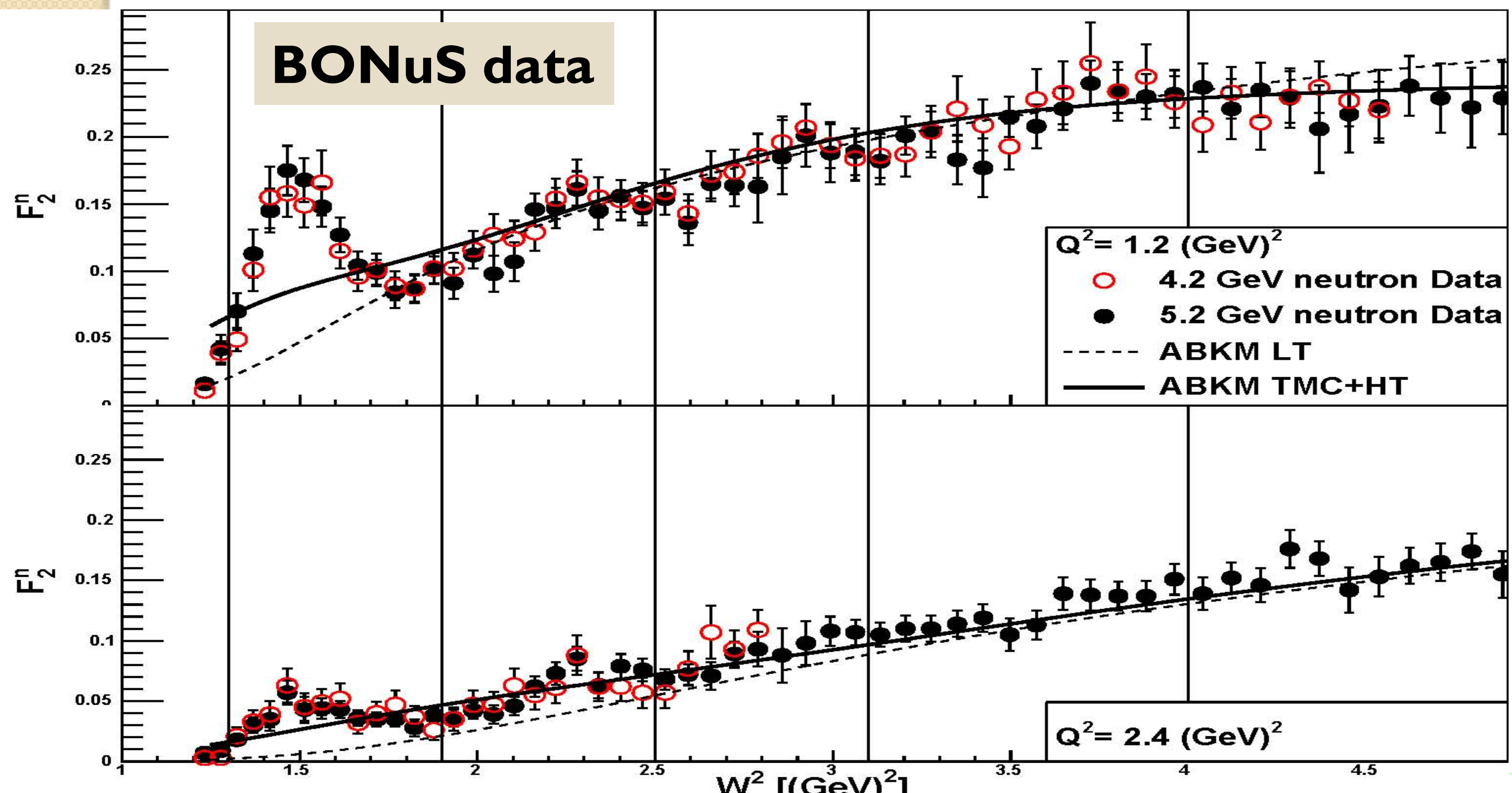


OQ-PHD

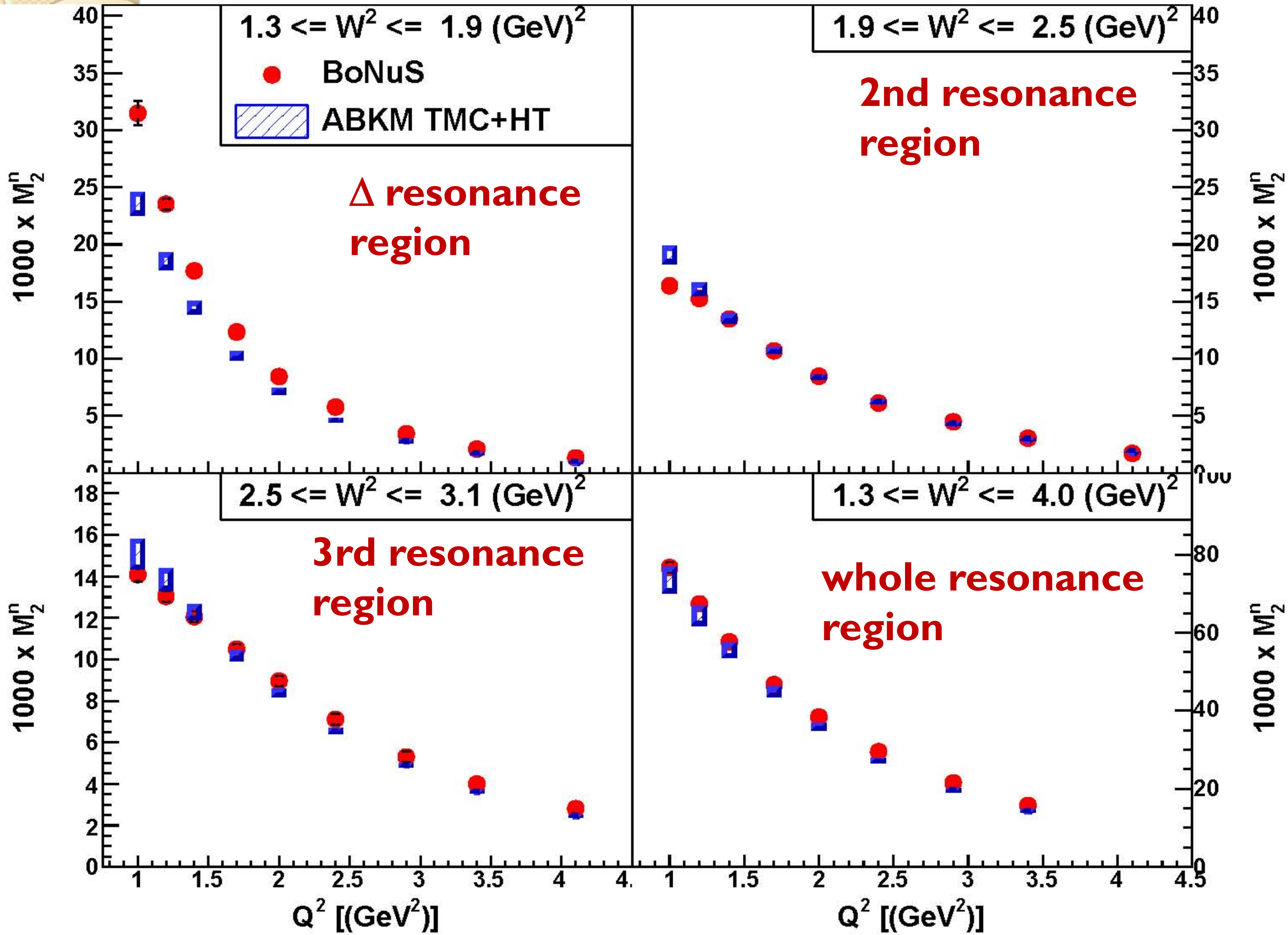
Truncated Moments and Local Duality

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

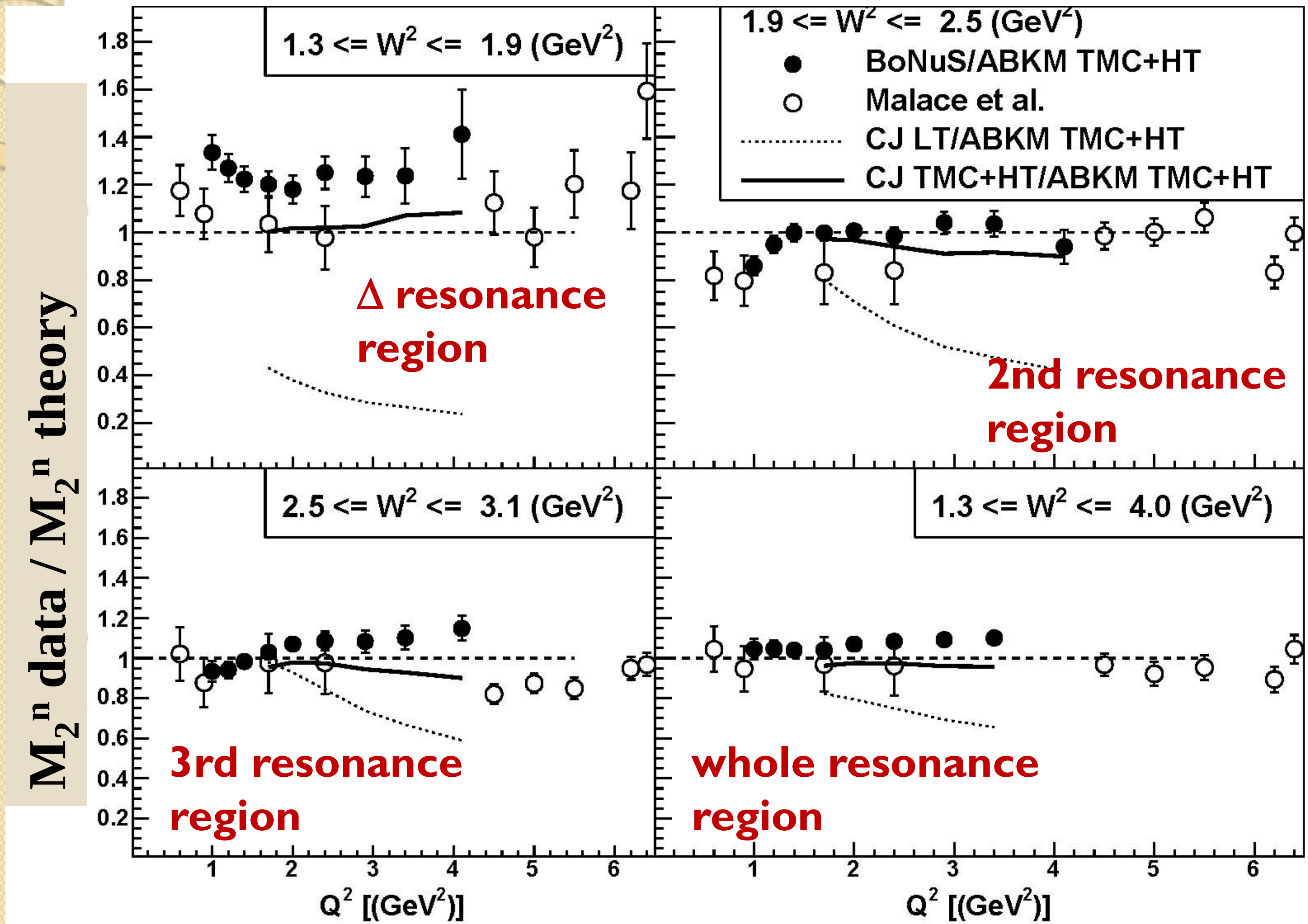
As defined in A. Psaker, W. Melnitchouk, E. Christy, C. Keppel, PRC 78 025206 (2008).



BONUS Truncated Moments

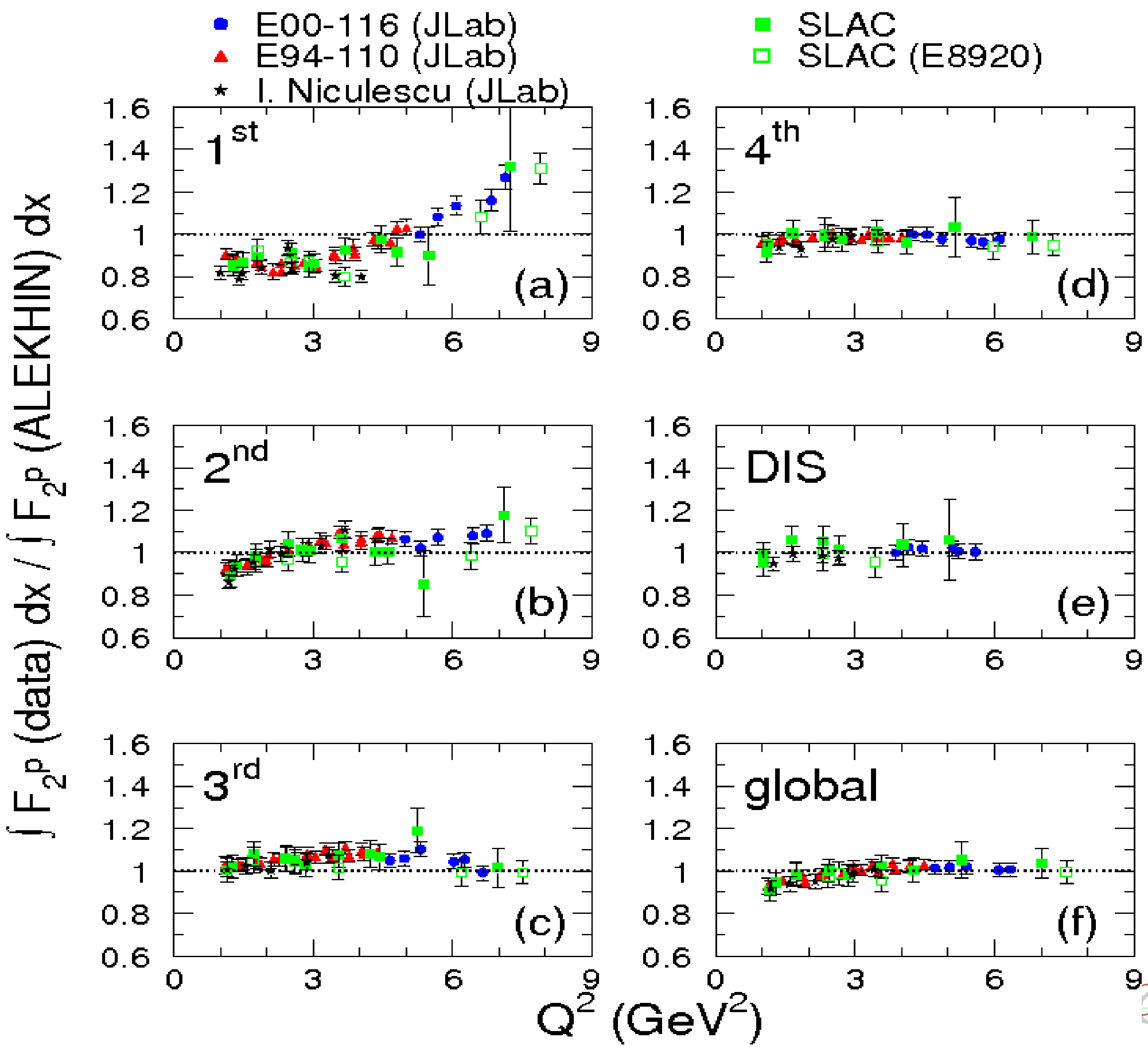


Local Quark Hadron Duality – Neutron



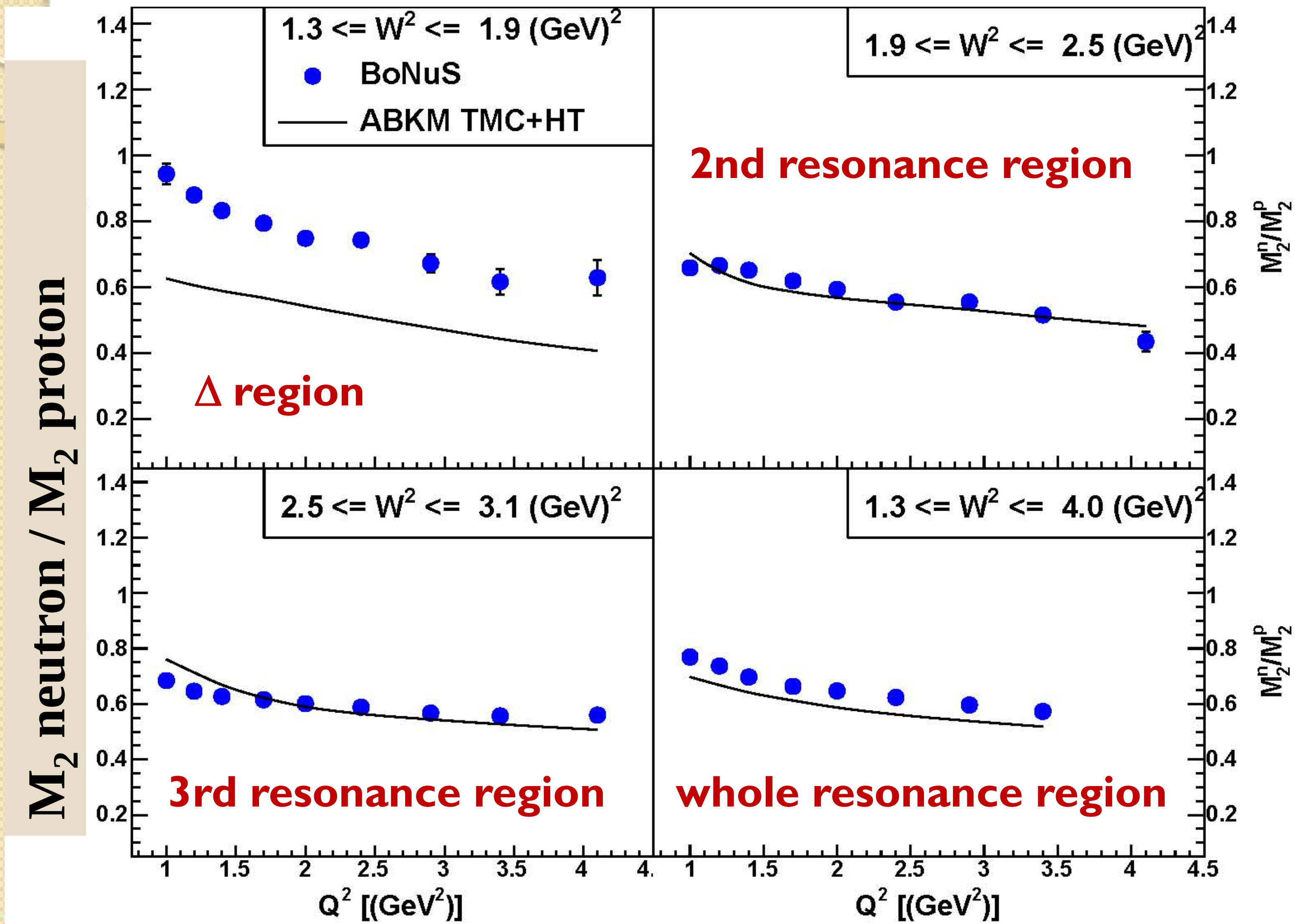
S. Malace *et al.*, PRL 104, 102001 (2010)

Local Quark Hadron 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. (S.P. Malace, Y. Kahn, W. Melnitchouk, C.E. Keppel, PRL104, 102001 (2010).)
- Truncated F_2 moments compared to DIS PDFs.
- Truncated F_2 moments compared to similar proton moments.
- Quark - hadron duality holds locally for second and third resonance region.
- Deviations in the Delta region (15% or more).

Gottfried Sum Rule

- Flavor symmetry of the proton sea

$$\bar{u} = \bar{d}$$

?

- Test by using Gottfried sum rule (GSR):

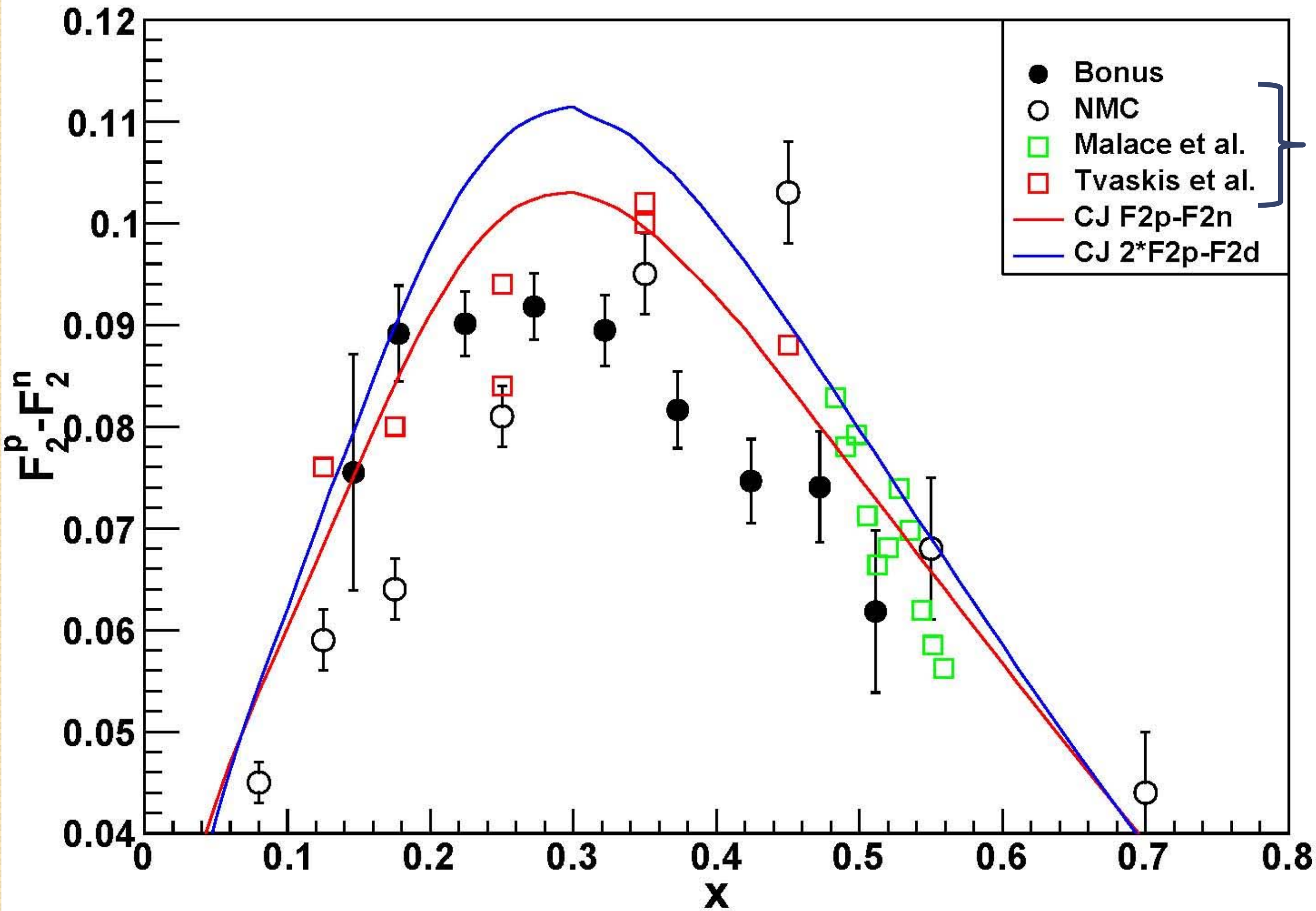
$$S_G = \int_0^1 \frac{F_2^p(x) - F_2^n(x)}{x} dx = \frac{1}{3} + \frac{2}{3} \int_0^1 (\bar{u}_p(x) - \bar{d}_p(x)) dx = \boxed{\frac{1}{3}}$$

=0 for symmetric sea

- NMC result (1994):

$$S_G(0,1) = 0.235 \pm 0.026$$

The Integrand



$$F_2^{\,p} - F_2^{\,n} = 2F_2^{\,p} - F_2^{\,d}$$

Results

R. Abbate, S. Forte **PRD 72 (2005) 11750**

TABLE I: The contribution to the Gottfried sum at $Q^2 = 4\ \text{GeV}^2$ from the region $x_{\min} \le x \le 0.8$ as obtained by NMC [2] and with neural networks. The error is only statistical for NMC, while it is the total combined statistical and systematic uncertainty for NNPDF. The total NMC systematics on $S_G(0.004 \le x \le 0.8)$ is equal to 0.019.

$x_{\min}$	$S_G(x_{\min} < x < 0.8)$	
	NMC	NNPDF
0.004	0.221 ± 0.008	0.2281 ± 0.0437
0.010	0.213 ± 0.005	0.2378 ± 0.0273
0.020	0.203 ± 0.004	0.2334 ± 0.0232
0.040	0.183 ± 0.004	0.2157 ± 0.0217
0.060	0.171 ± 0.003	0.1985 ± 0.0202
0.100	0.149 ± 0.003	0.1693 ± 0.0169
0.150	0.125 ± 0.003	0.1398 ± 0.0133
0.200	0.107 ± 0.003	0.1154 ± 0.0107
0.300	0.074 ± 0.003	0.0761 ± 0.0074
0.400	0.047 ± 0.002	0.0460 ± 0.0052
0.500	0.025 ± 0.002	0.0241 ± 0.0035
0.600	0.012 ± 0.002	0.0102 ± 0.0019

$$S_G(0.14,0.52) \approx 0.14$$

$$S_G(0.004,0.8) = 0.228 \pm 0.044$$

Original NMC (1994)

$$S_G(0.14,0.5) \approx 0.110$$

$$S_G(0.004,0.8) = 0.221 \pm 0.008$$

BONuS *x* coverage: (0.143-0.52)

Q^2 coverage: (1 – 4 GeV)

$$S_G(0.14,0.52) = 0.113$$

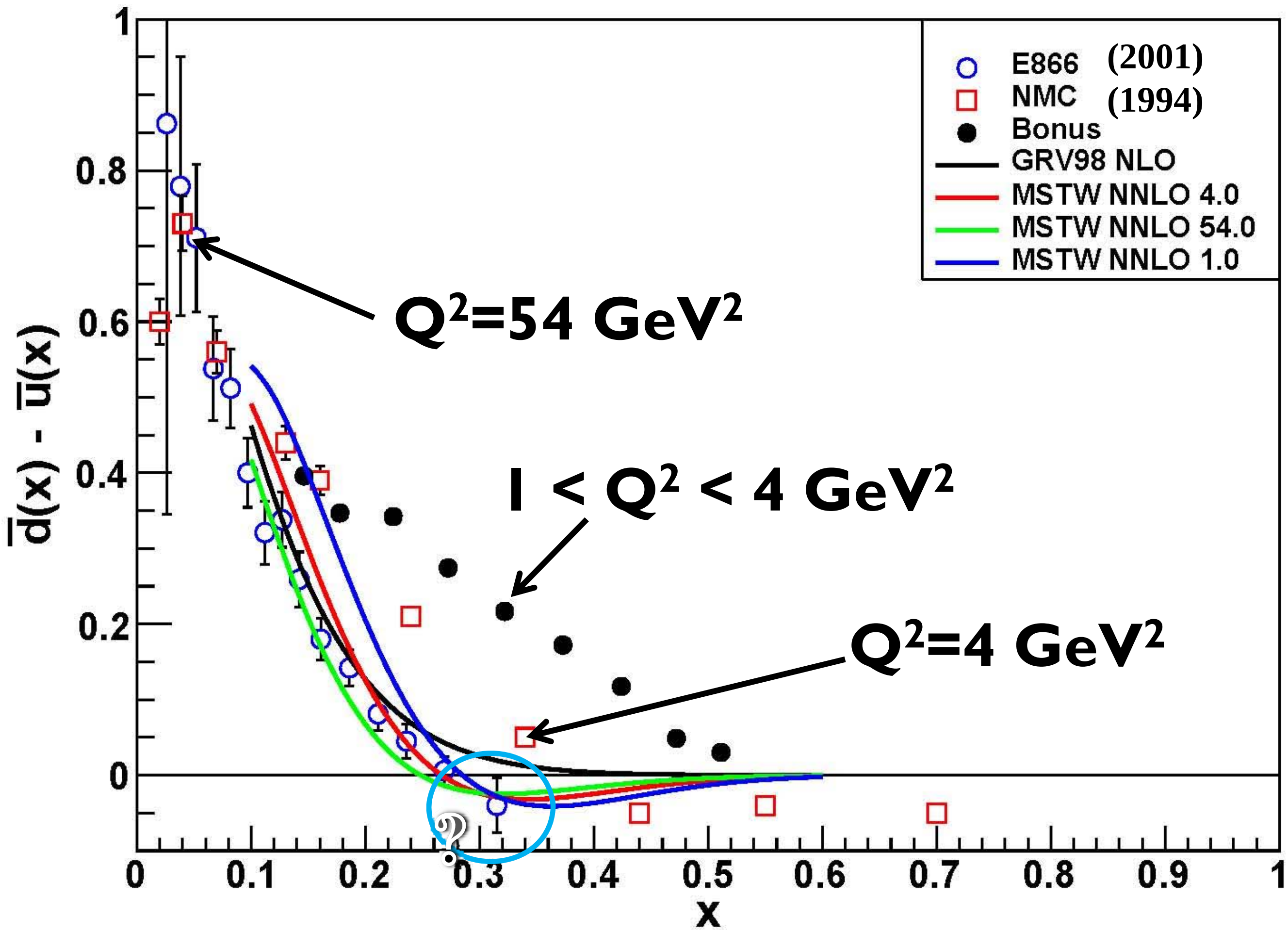
Extrapolate to *x*=0.004 and 0.8 using A&F method (Regge-like behavior)

$$S_G(0.004,0.8) = 0.220$$

Flavor Structure of Nucleon Sea

J.C. Peng *et al.*, PLB 736 (2014) 411

$$\bar{d}(x) - \bar{u}(x) = \frac{1}{2}[u_v(x) - d_v(x)] - \frac{3}{2x}[F_2^p(x) - F_2^n(x)]$$

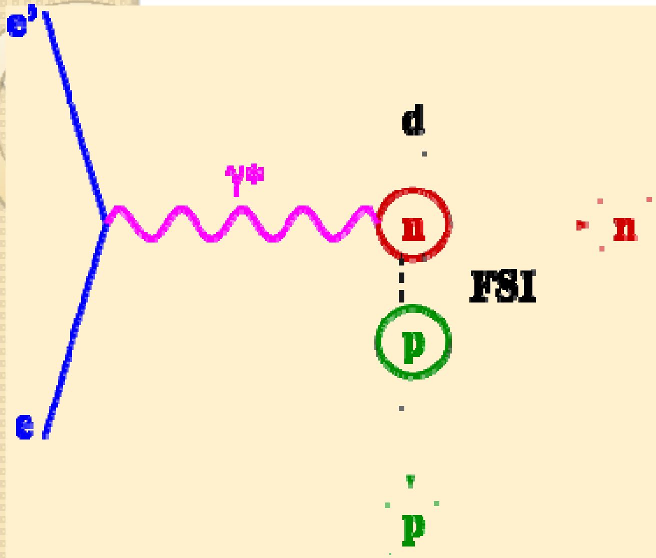


Summary

- **Investigated local quark - hadron duality in the neutron structure function.**
- **Influence of BONuS data on Gottfried Sum Rule**
- **Momentum dependence of nucleon sea flavor asymmetry**

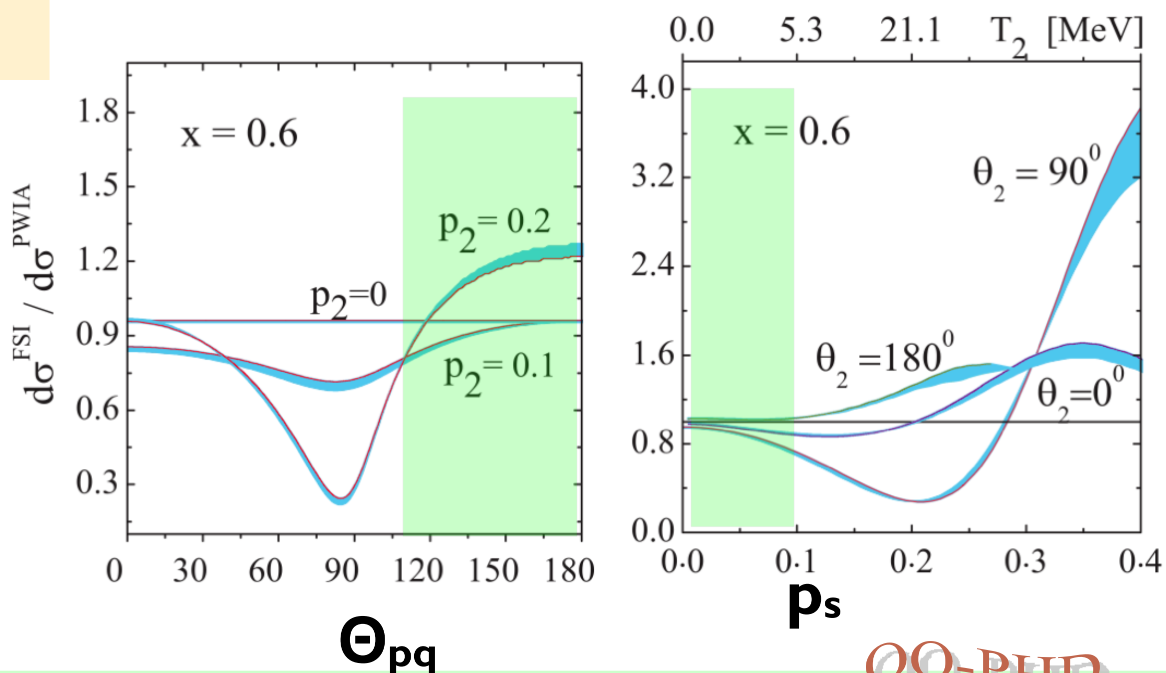
Extra Slides

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}

Palli et al, PRC80(09)054610



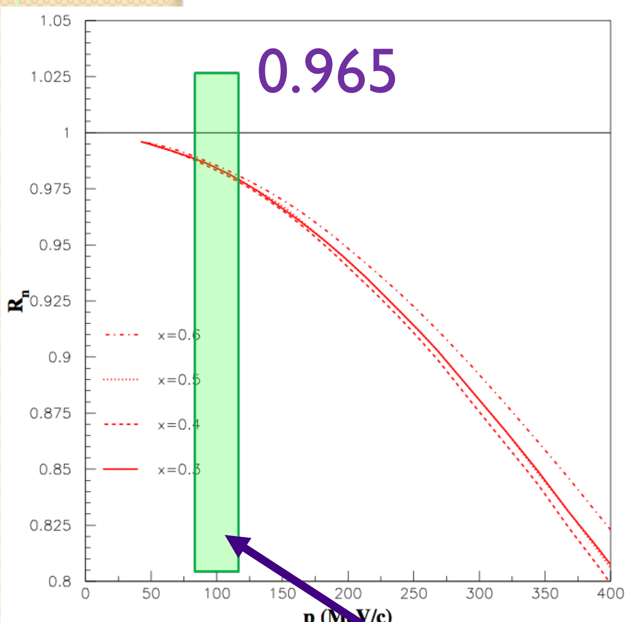
- Several groups have calculated FSIs
- Few percent for low momentum

OQ-PHD

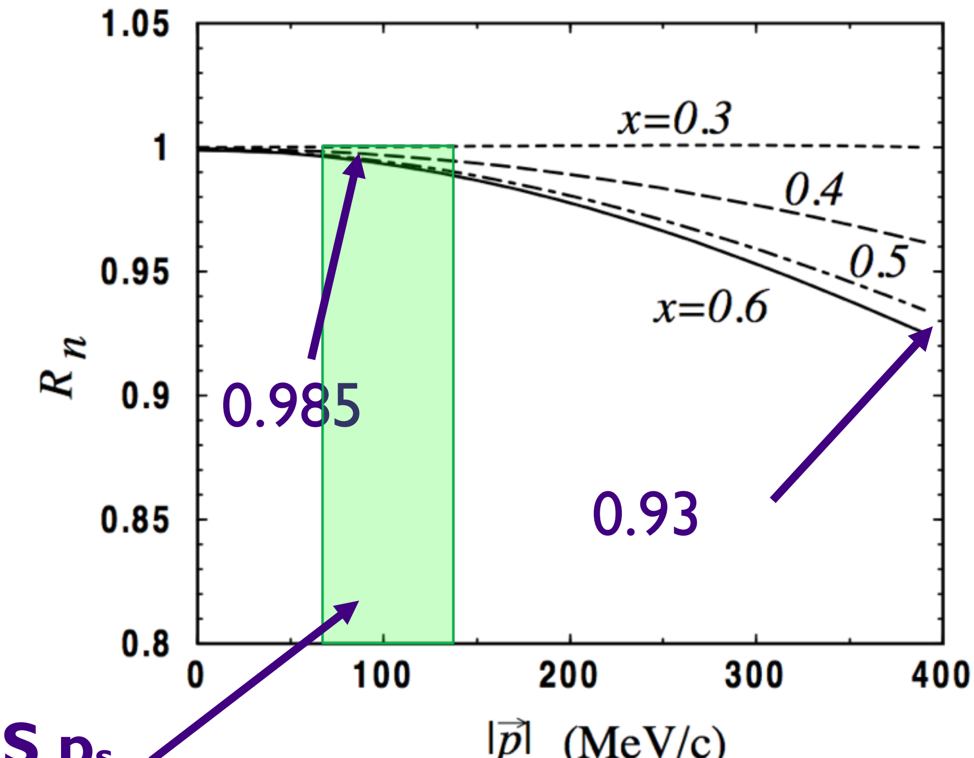
Off – shell Effects

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

Liuti & Gross PLB356(95)157



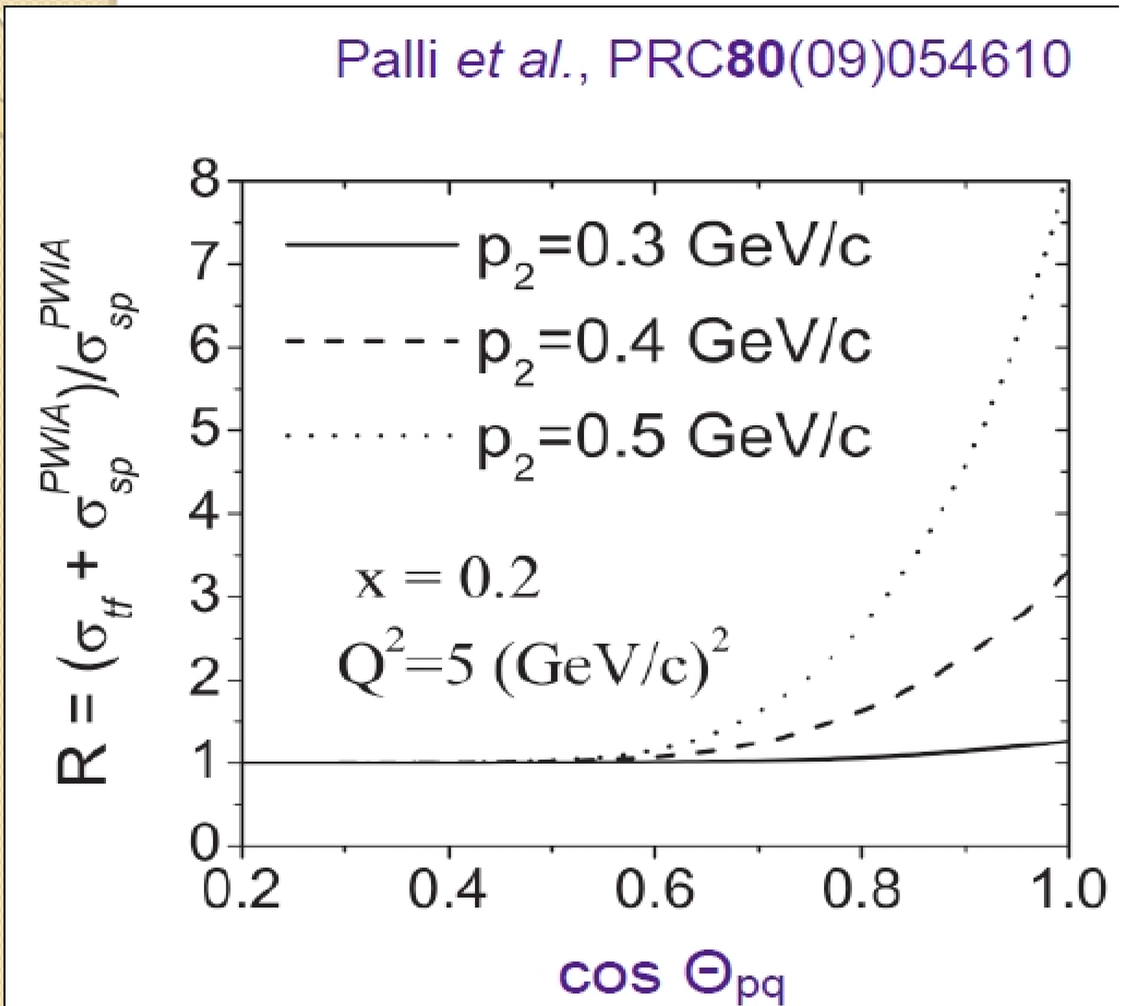
Melnitchouk *et al*, PLB335(94)11

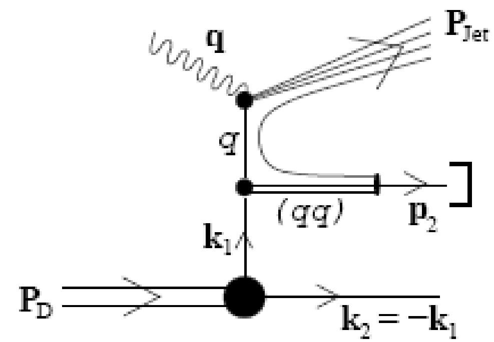


BoNuS p_s
detection range

OQ-PHD

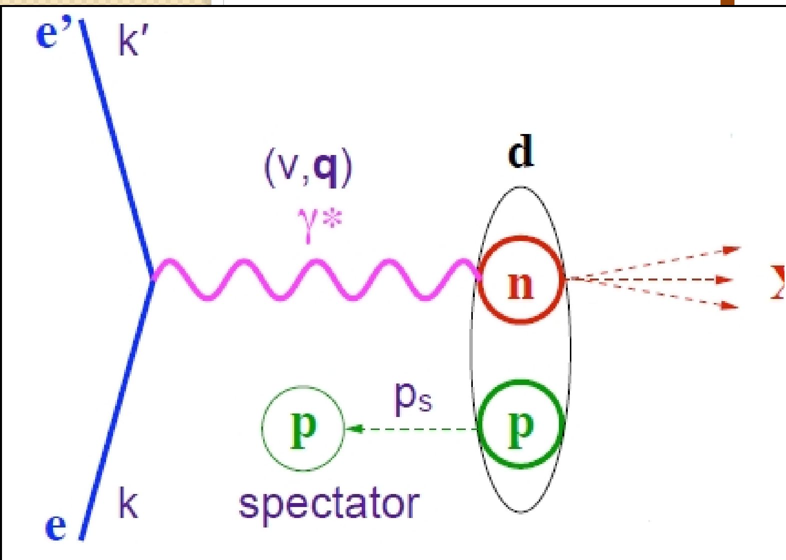
Target Fragmentation



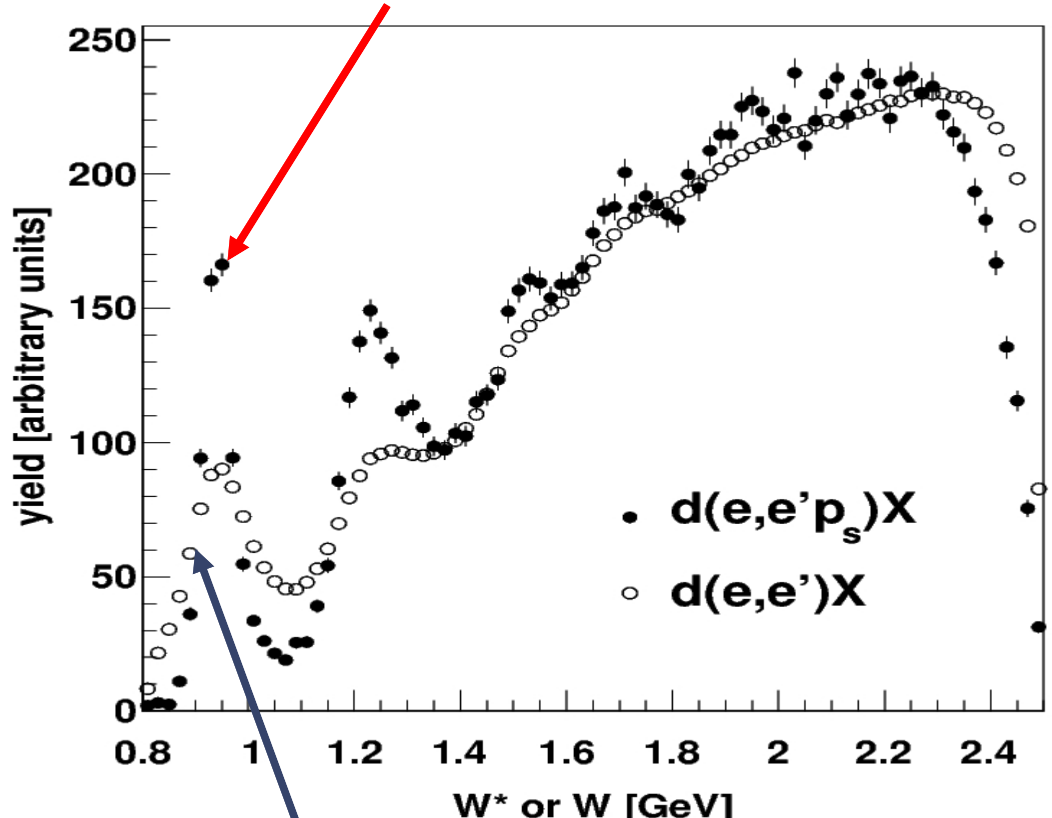


Enhancement in proton yield over PWIA negligible for backward protons

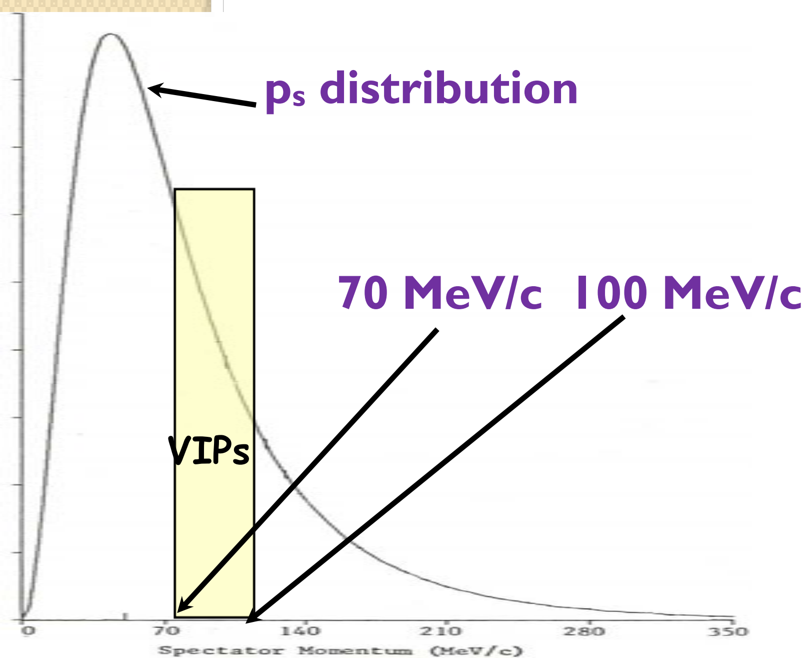
Kinematic reconstruction with tagged protons



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



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



Ratio Method

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

VIP (Very Important Protons)

P_s < 100 MeV/c, □$_{pq}$ ≥ 100 deg

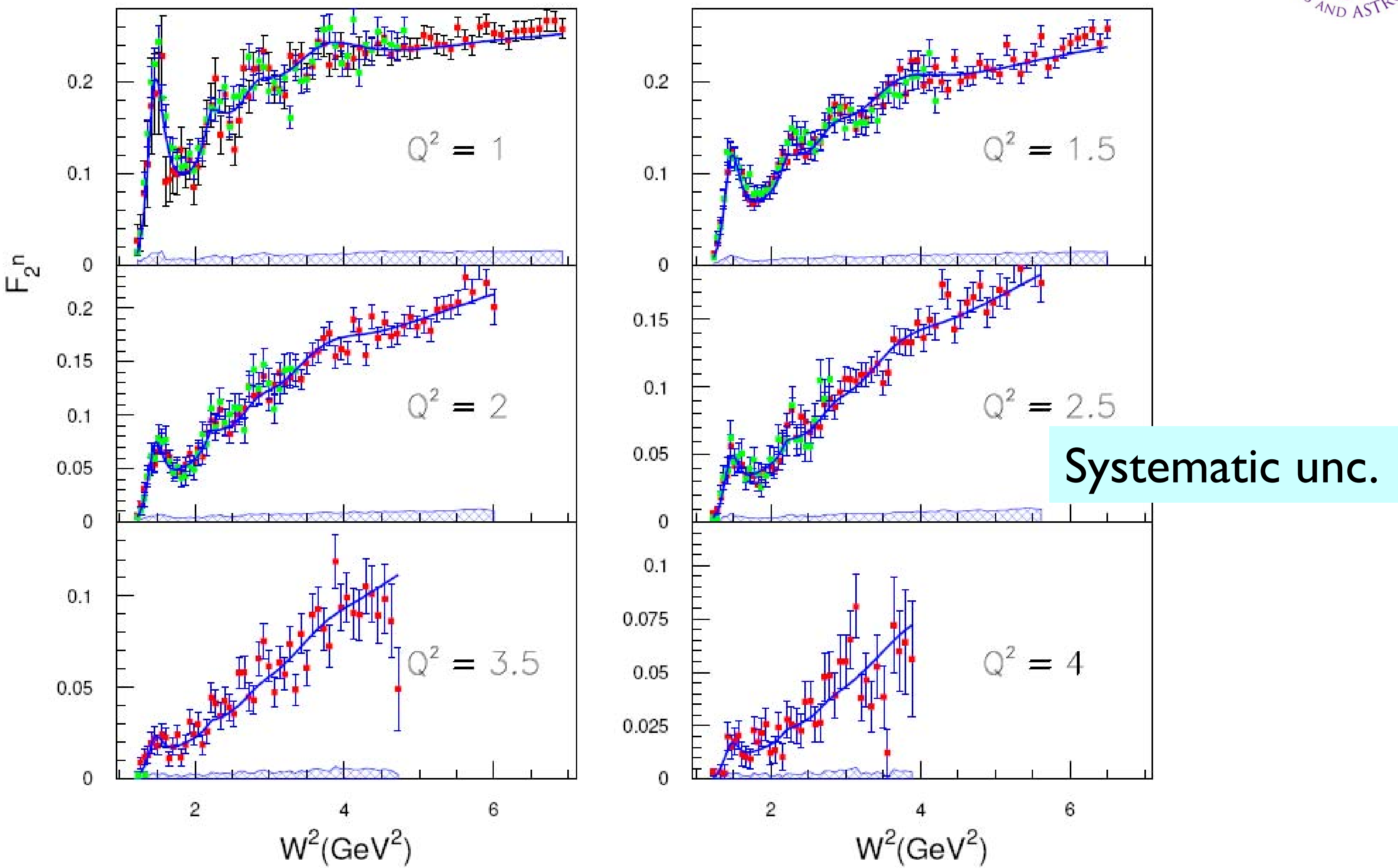
Experimental ratio

$$R_{exp} = \frac{N_{d(e,e'p_s)}(W^*,Q^2)}{N_{d(e,e')}(W,Q^2)} C(E_b,W^*,W,Q^2) = \frac{F_2^n(W^*,Q^2)}{F_2^d(W,Q^2)} \int_{VIP} d\alpha_s dp_s^\perp A_p(\alpha_s,p_s^\perp) S(\alpha_s,p_s^\perp).$$

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

Results

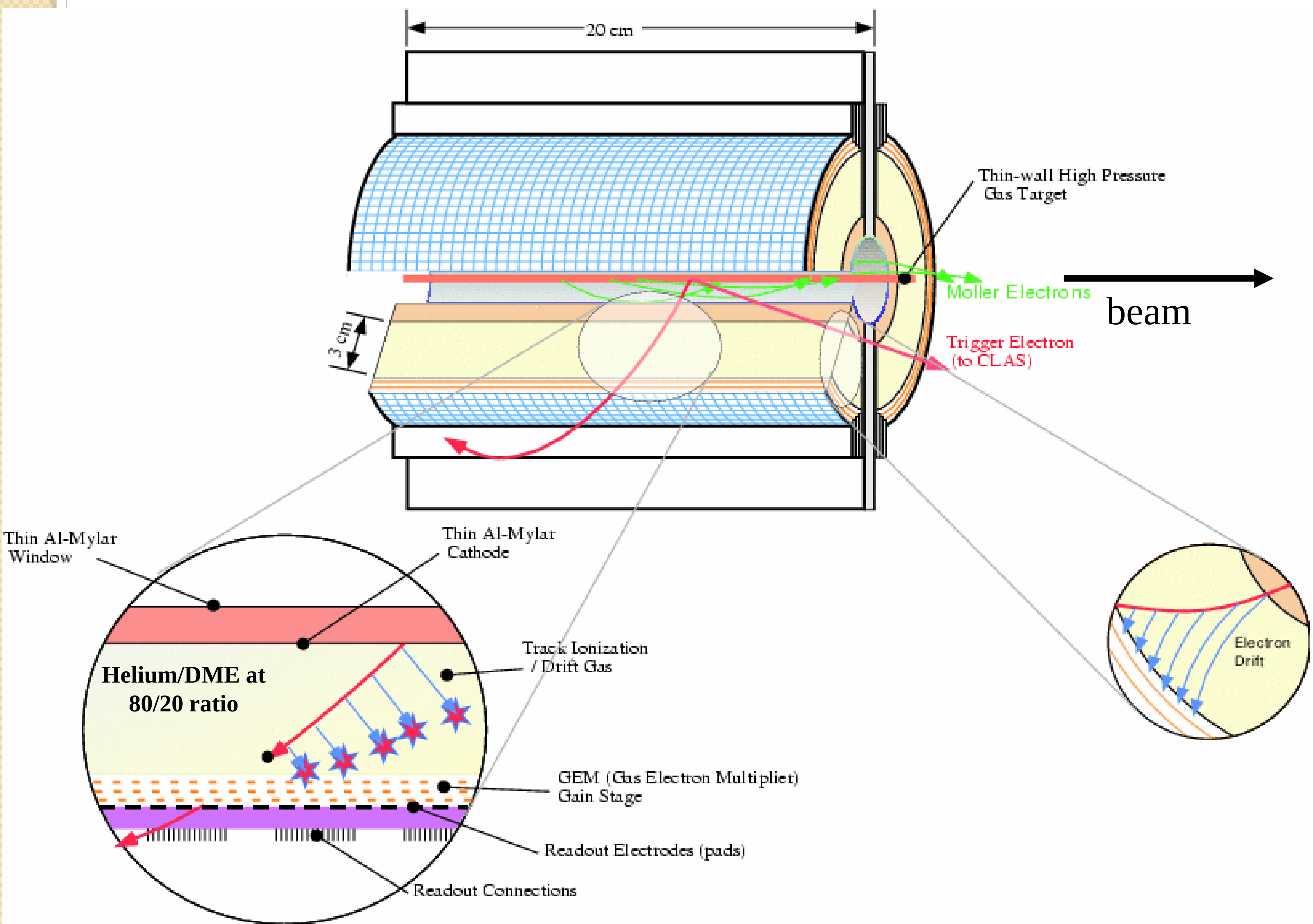
E=4.2 and 5.3 GeV



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

Experimental Setup: BoNuS RTPC

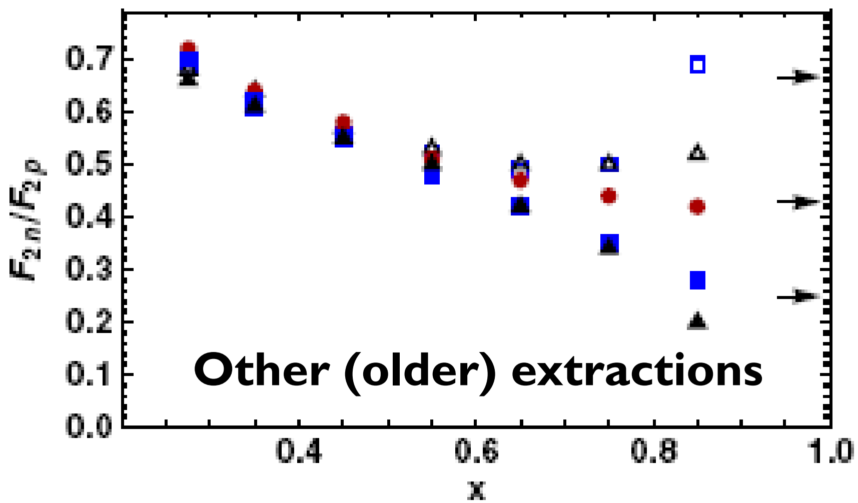
H. Fenker et al., Nucl. Instrum. Meth. A 592, 273 (2008)

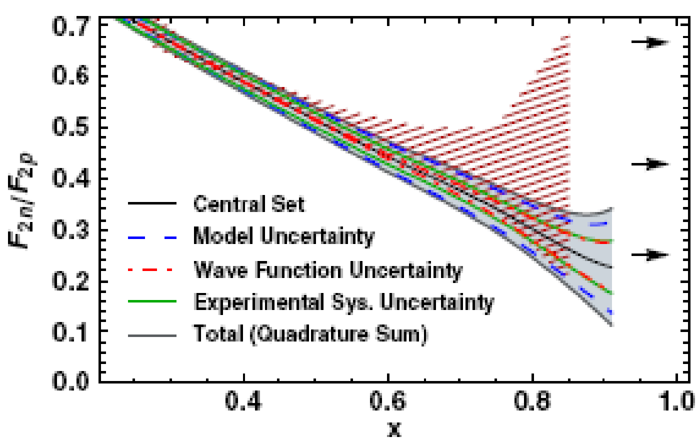


Extract neutron from deuteron data

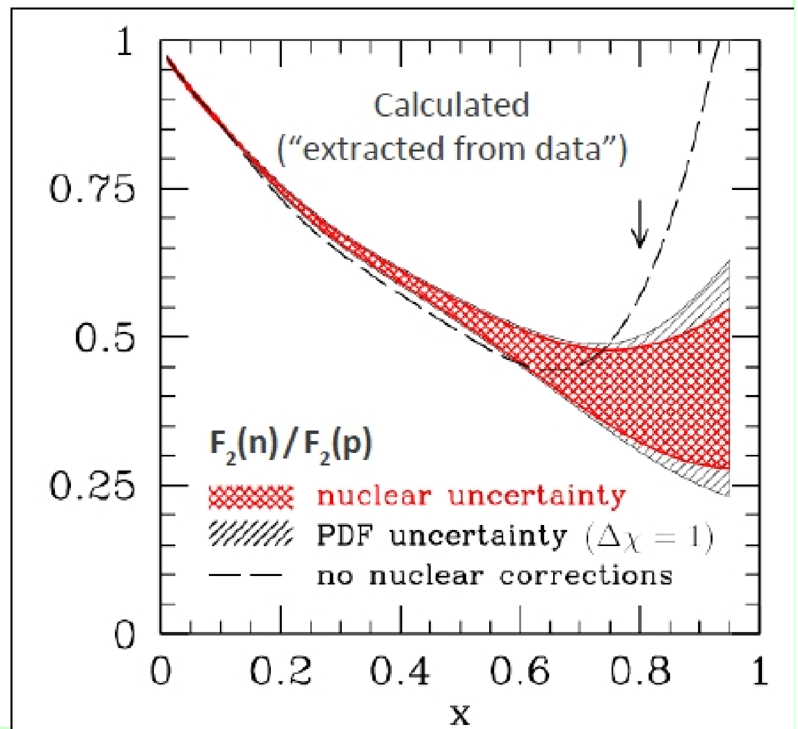
Large uncertainties due to nuclear effects

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

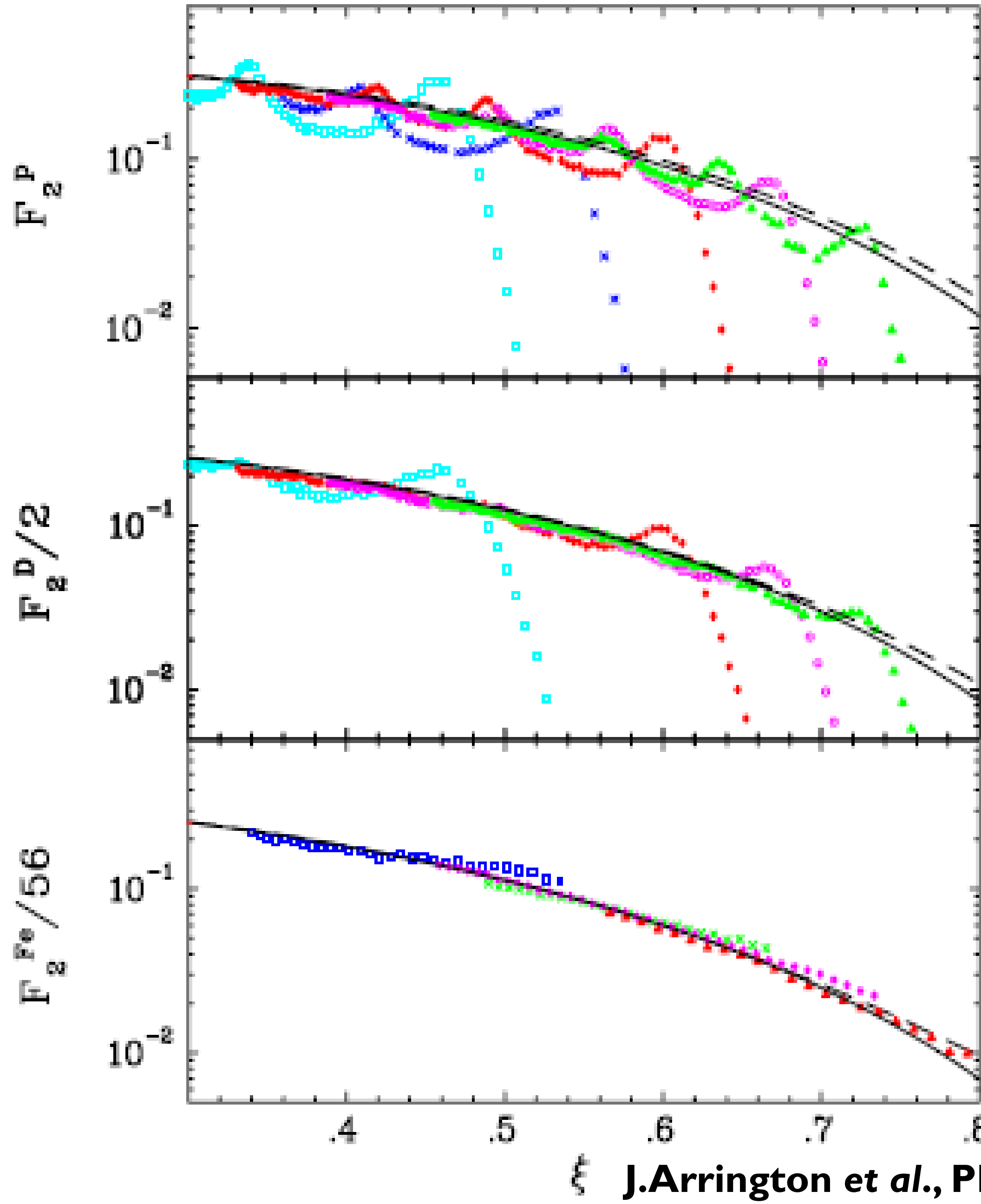




A. Accardi *et al.*, PRD 84 014008 (2011)



The Proton and the Deuteron



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

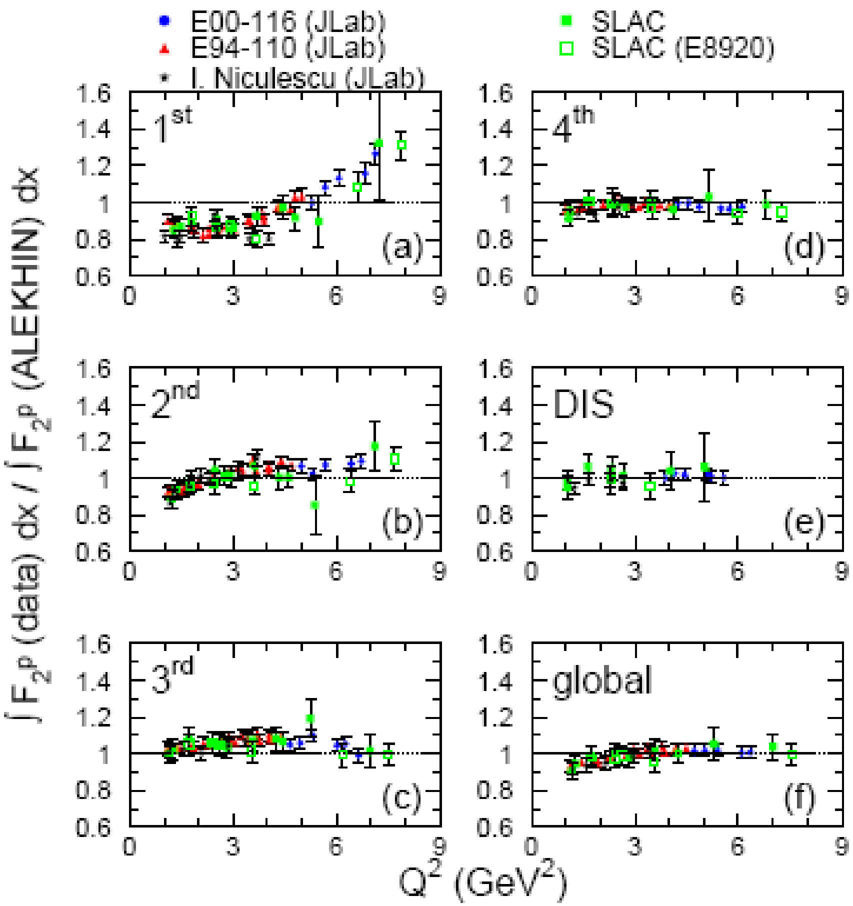
Scaling (duality) is observed in nuclei

Resonances less pronounced – washed out by Fermi motion

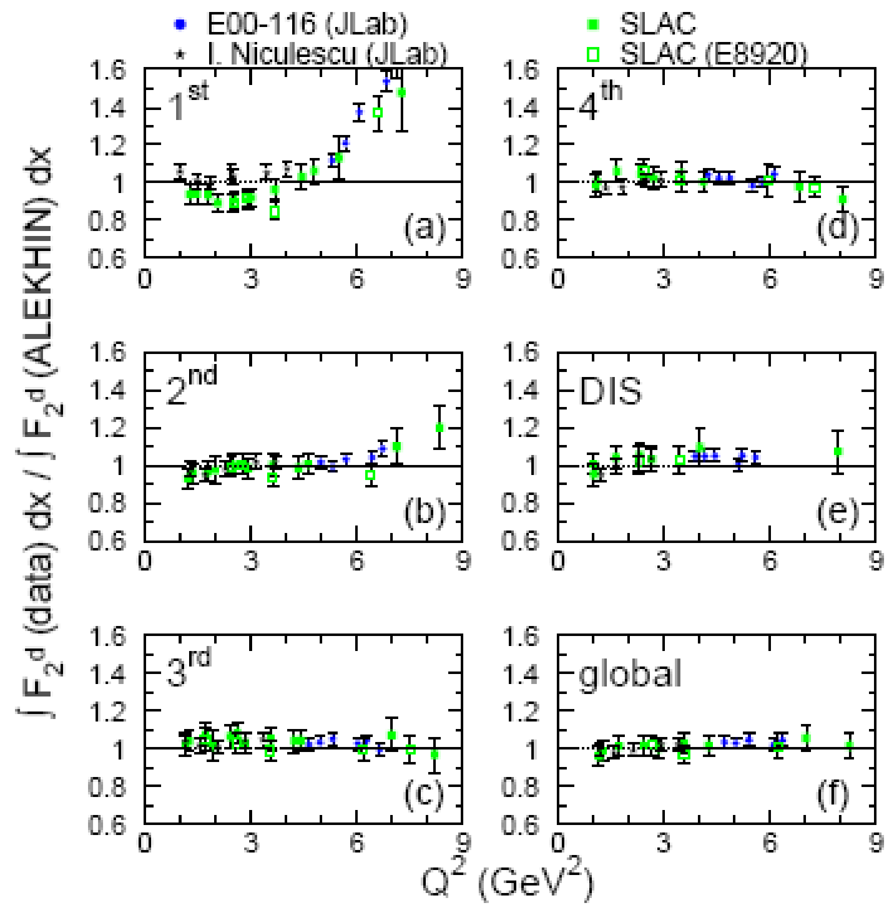
OQ-PHD

Local duality

The proton



The 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