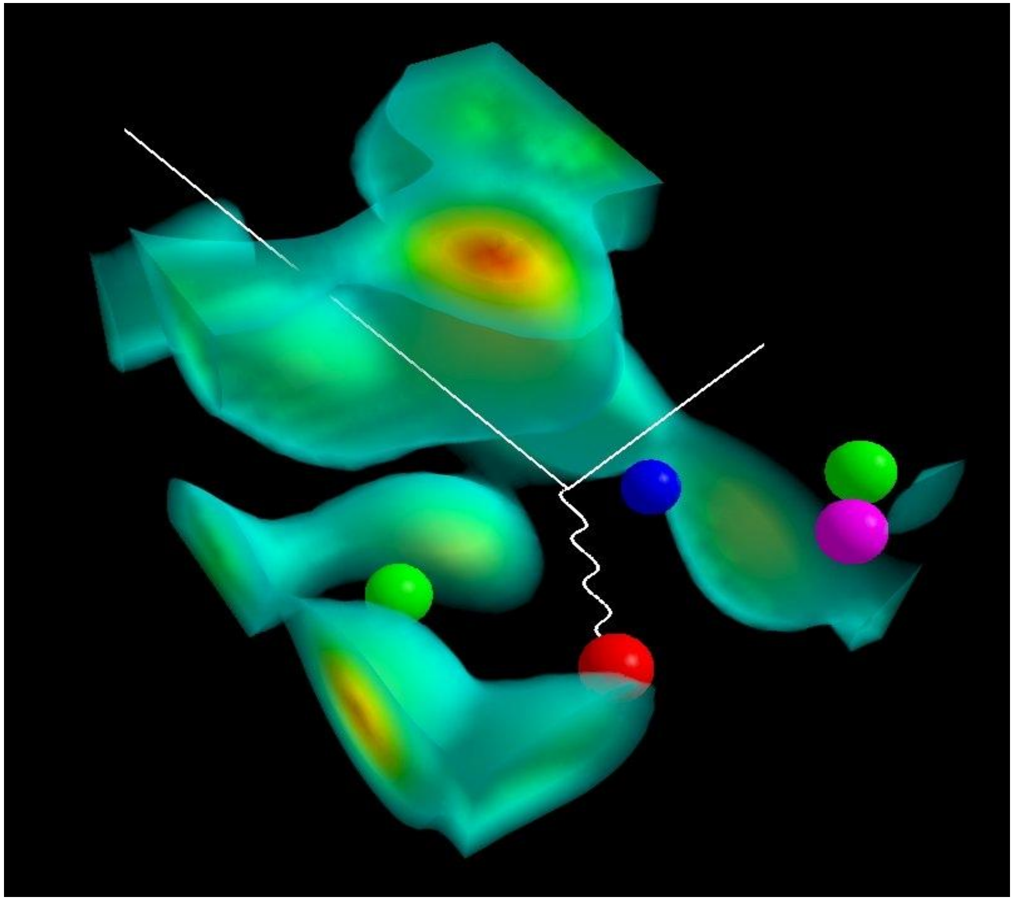
Meson-Nucleon Physics : An Overview



Australian Government

Australian Research Council

Anthony W. Thomas

12th International Conference on Meson-Nucleon Physics and the Structure of the Nucleon

College of William and Mary : May 31st 2010

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SPECIAL RESEARCH CENTRE FOR THE SUBATOMIC STRUCTURE OF MATTER

Outline

- **Nucleon Structure**
  - strangeness, quark & gluon spin & angular mom
- **Meson and Baryon Excited States**
  - discovery and structure
- **Nucleon & Hadron Structure in-Medium**
  - EMC effect, hypernuclei, meson binding
- **Symmetry Breaking and Standard Model Tests –** NuTeV, Qweak…
- **“New Facilities”**
  - FAIR, JLab 12 GeV, JPARC, EIC

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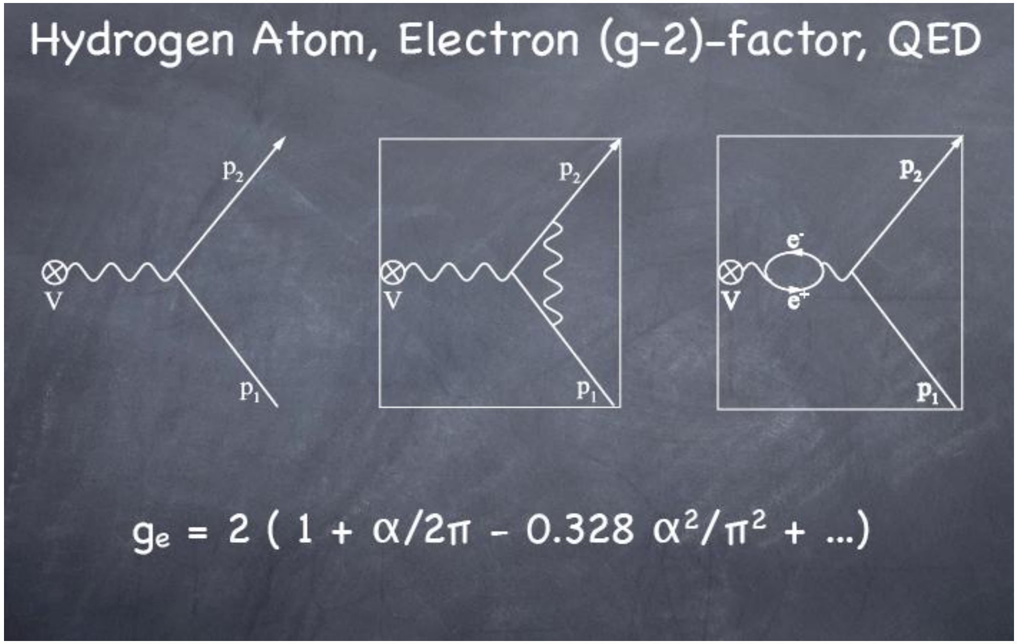
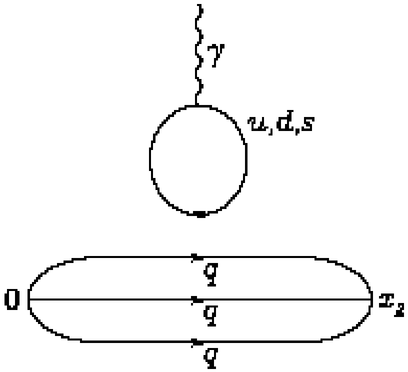
Nucleon Structure

– **Bacchetta, Brash, Burkardt, Burtin, Hägler, Jiang, Kroll, Moutarde, Pitt, Riedl, Tandy, Young**

Testing Non-Perturbative QCD

- Strangeness contribution is a vacuum polarization effect, analogous to Lamb shift in QED





- It is a fundamental test of non-perturbative QCD

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Strange Quarks in the Proton

There have been a number of major steps forward recently, both theory and experiment :

- Calculation of $G_{E,M}^s(Q^2)$:
  - Direct: Kentucky (χQCD : K.-F. Liu)
  - Indirect: JLab-Adelaide
- Experimental determination of $G_{E,M}^s(Q^2)$
  - G0 and Happex
  - Mainz PVA4 and Bates
- Agreement between theory and experiment excellent
  - consistent global analysis valuable

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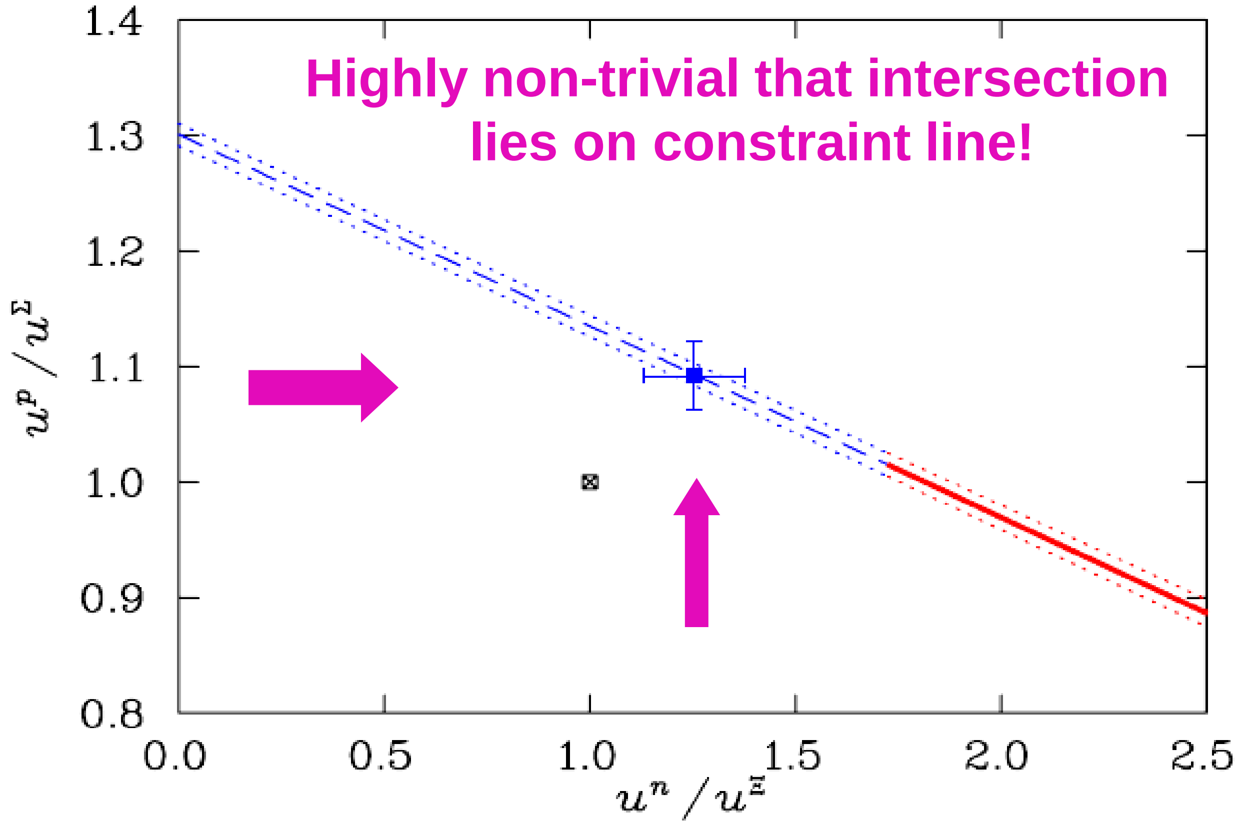
First Accurate Determination of G_M^s from QCD

1.10±0.03



1.25±0.12

Yields : G_M^s = - 0.046 ± 0.019 μ_N

Leinweber et al., PRL 94 (2005) 212001

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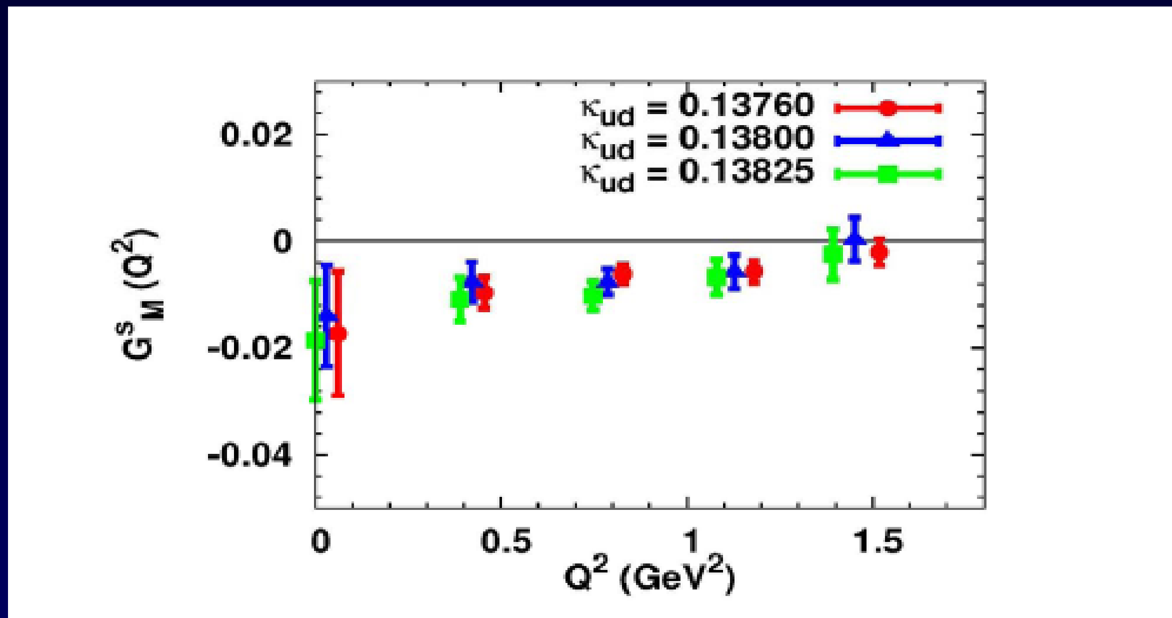
Direct Calculation of $G_M^s(Q^2)$ – K.-F. Liu et al.

Strangeness Magnetic Form Factors with 3 Quark Masses
(m_π = 0.6, 0.7, 0.8 GeV); T. Doi et al. (χQCD) arXiV:0903.3232



$$G_M^S(Q^2=0) = -\,0.017(25)(07)\ \mu_N$$

c.f. -0.046 ± 0.019 (Leinweber et al.)

N.B. Result of Doi et al. would increase by factor ~1.8 when light quark mass takes physical value with m_s fixed
(Wang et al., hep-ph/0701082 :Phys Rev D75, (2008))

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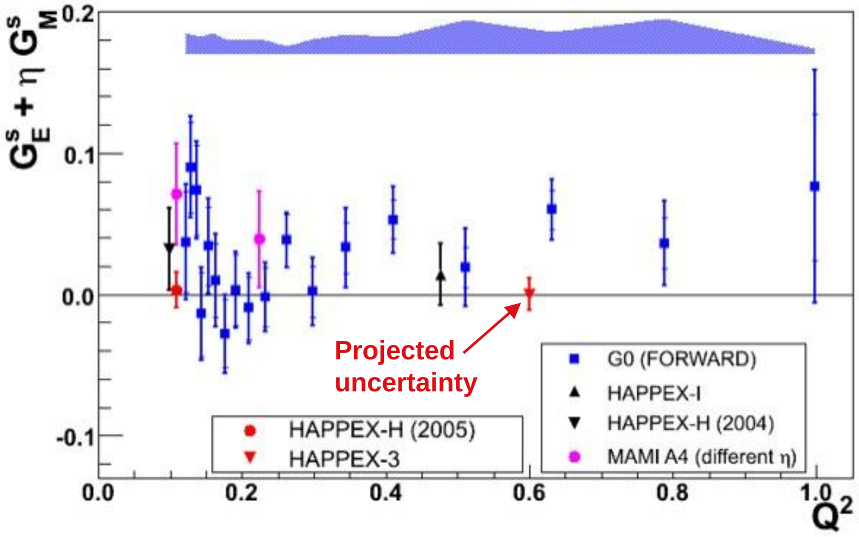
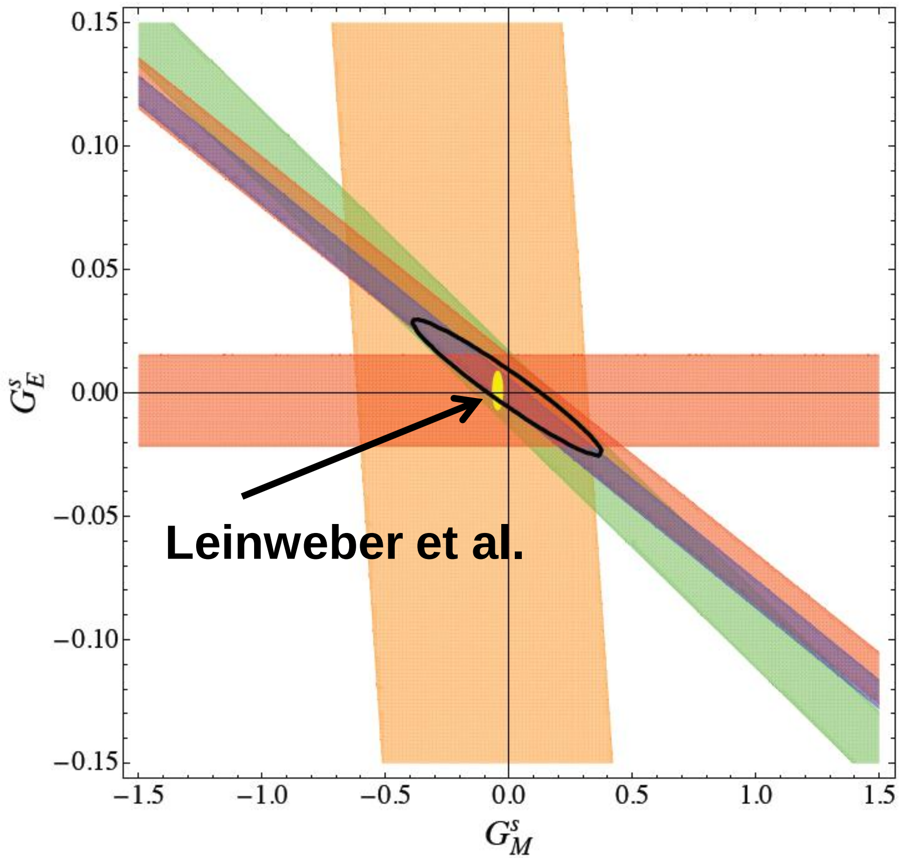
Global Analysis of PVES Data

$Q^2 = 0.1\ GeV^2$



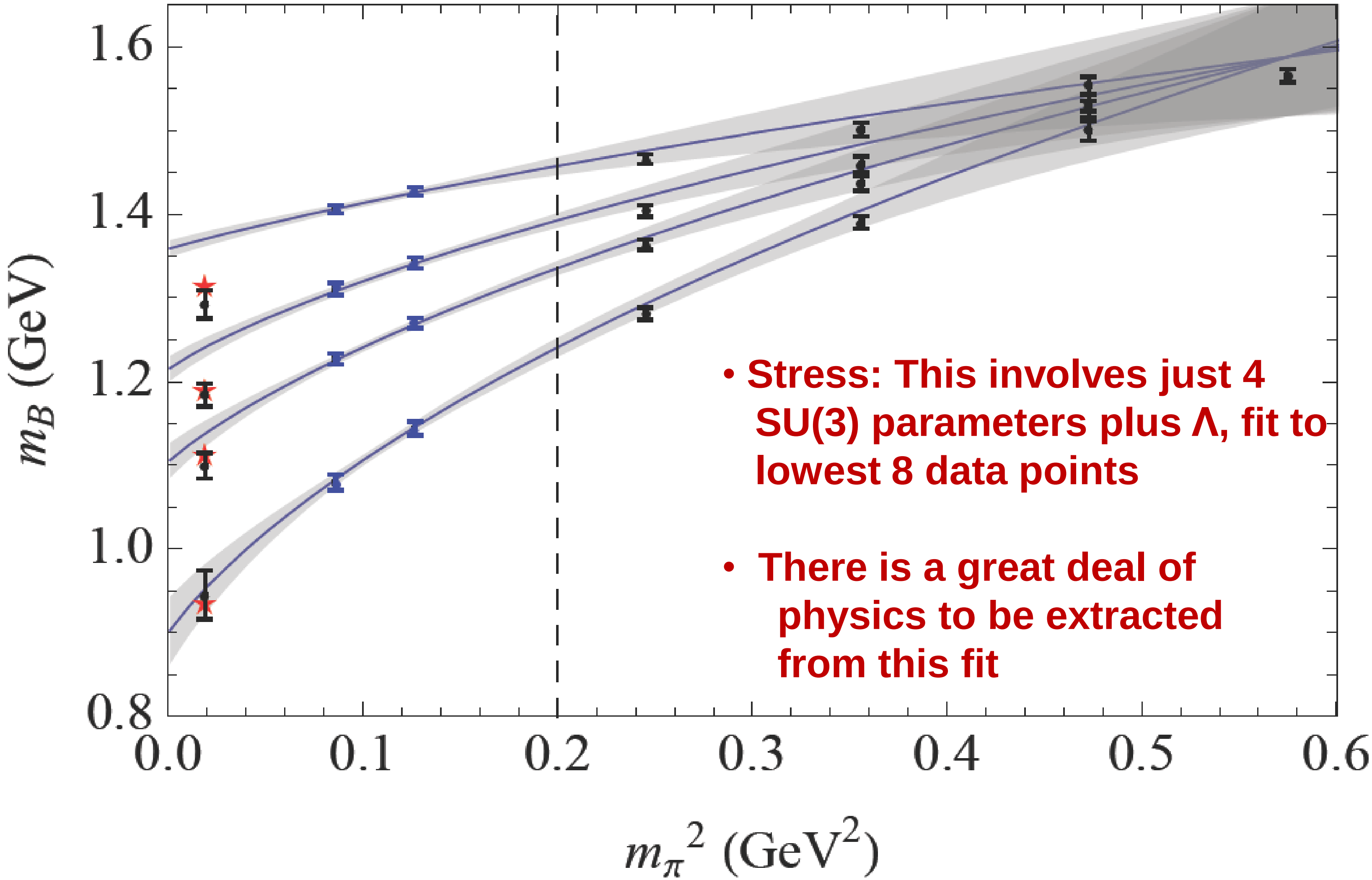


- **Proton not all that strange**
- **New data not yet included at 0.23 and 0.6 GeV^2 (PVA4 , G0, HAPPEx III – data taken this year)**

Global analysis: Young et al., PRL 99 (2007)122003 and Young arXiv 1004.5163 [nucl-th]

Octet Baryon Masses - LHPC Data

(Walker-Loud et al., arXiv:0806.4549)



- **Stress: This involves just 4 SU(3) parameters plus Λ, fit to lowest 8 data points**
- **There is a great deal of physics to be extracted from this fit**

Young & Thomas, arXiv:0901.3559 [nucl-th]
Phys Rev D (2010)

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Summary of Results of Combined Fits
(of 2008 LHPC & PACS-CS data)

B	Mass (GeV)	Expt.	$\bar{\sigma}_{Bl}$	$\bar{\sigma}_{Bs}$
N	0.945(24)(4)(3)	0.939	0.050(9)(1)(3)	0.033(16)(4)(2)
Λ	1.103(13)(9)(3)	1.116	0.028(4)(1)(2)	0.144(15)(10)(2)
Σ	1.182(11)(2)(6)	1.193	0.0212(27)(1)(17)	0.187(15)(3)(4)
Ξ	1.301(12)(9)(1)	1.318	0.0100(10)(0)(4)	0.244(15)(12)(2)

$$\bar{\sigma}_{Bq} = (m_q/M_B)\partial M_B/\partial m_q$$

Of particular interest:

σ commutator well determined : $\sigma_{\pi N}$= 47 (9) (1) (3) MeV

and strangeness sigma commutator small

$m_s\, \partial M_N / \partial m_s$ = 31 (15) (4) (2) MeV

NOT several 100 MeV !

Profound Consequences for Dark Matter Searches

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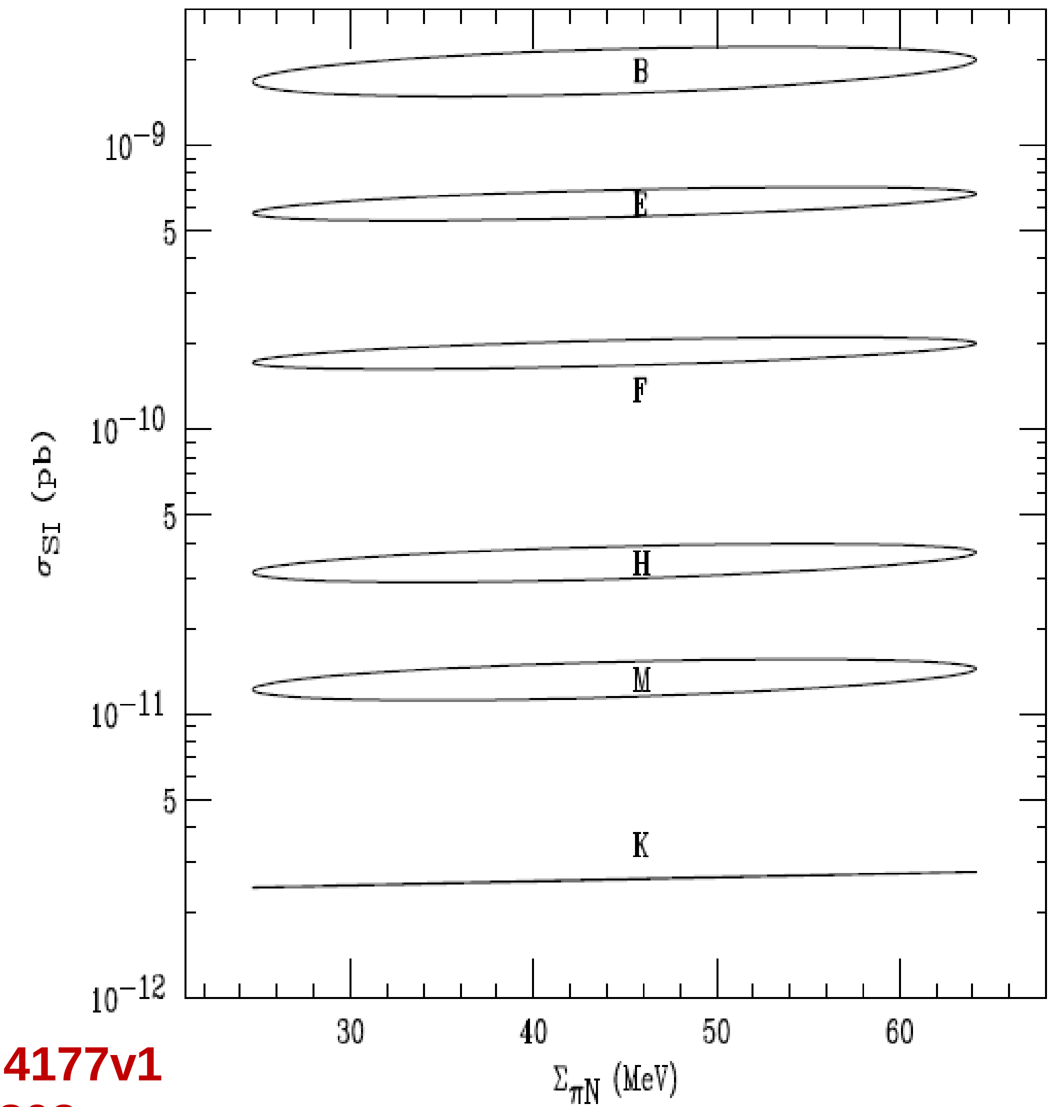
CMSSM Predictions for Dark Matter σ

95% CL predictions for all Constrained Minimal Super-Symmetric Standard Model extensions consistent with astrophysical data

Cross sections 1-2 orders of magnitude smaller than before BUT very well determined and separated!



Giedt et al., arXiv: 0907.4177v1
PRL 103 (2009) 201802

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SUBATOMIC STRUCTURE OF MATTER

Where is the Spin of the proton?

- Modern data (Hermes, COMPASS) yields:
  $\Sigma = 0.33 \pm 0.03 \pm 0.05$

  (c.f. $0.14 \pm 0.03 \pm 0.10$ originally)

- In addition, there is little or no polarized glue
  - COMPASS: $g^D_1 = 0$ to $x = 10^{-4}$
  - A_{LL} (π^0 and jets) at PHENIX & STAR: $\Delta G \sim 0$ - Hermes, COMPASS and JLab: ΔG small

- Hence: axial anomaly plays at most a small role in explaining the spin crisis

- Return to alternate explanation lost in 1988 in rush to explore the anomaly

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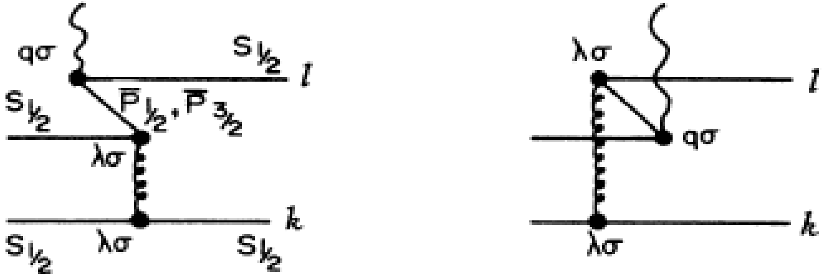
One-Gluon-Exchange Correction

- **Further reduces the fraction of spin carried by the quarks in the bag model (naively 0.65)**

- **$\Sigma \rightarrow \Sigma - 3G$; with G ~ 0.05**
  $\Sigma \rightarrow 0.65 - 0.15 = 0.5$

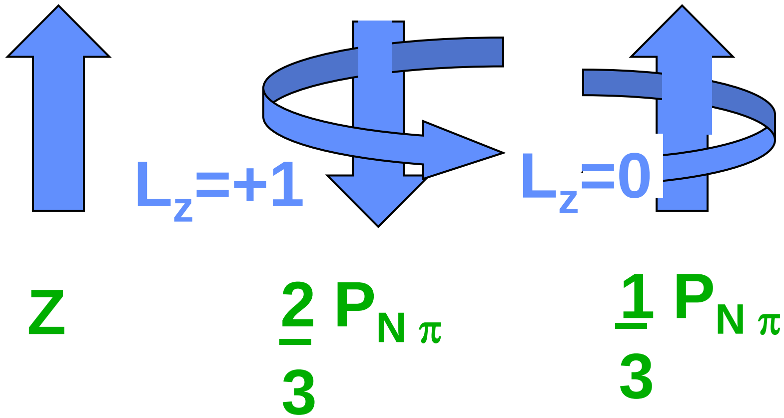


(c) (d)

- **Effect is to transfer quark spin to quark (relativity) and anti-quark (OGE) orbital angular momentum**

Effect of the Pion Cloud

- Probability to find a bare N is Z ~ 70%
- Biggest Fock Component is N π ~ 20-25% and 2/3 of the time N spin points down



- Next biggest is $\Delta\, \pi$ ~ 5-10%
- To this order (i.e. including terms which yield LNA and NLNA contributions):
- Spin gets renormalized by a factor :

$$Z - 1/3\, P_{N\pi} + 15/9\, P_{\Delta\pi} \sim 0.75 - 0.8$$

Hence: $\Sigma = 0.65 \rightarrow 0.49 - 0.52$

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Schreiber-Thomas, Phys Lett B215 (1988)

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The Balance Sheet – fraction of total spin

	$2\ L_{u+ubar}$	$2\ L_{d+dbar}$	Σ
Non-relativistic			1.0
Relativity (e.g. Bag)	0.46	-0.11	0.65
Plus OGE	0.52	-0.02	0.50
Plus pion	0.50	0.12	0.38

At model scale: $L_u + S_u = 0.25 + 0.42 = 0.67 = J_u$

$: L_d + S_d = 0.06 - 0.22 = - 0.16 = J_d$

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Phys Rev Lett, 101 (2008) 102003

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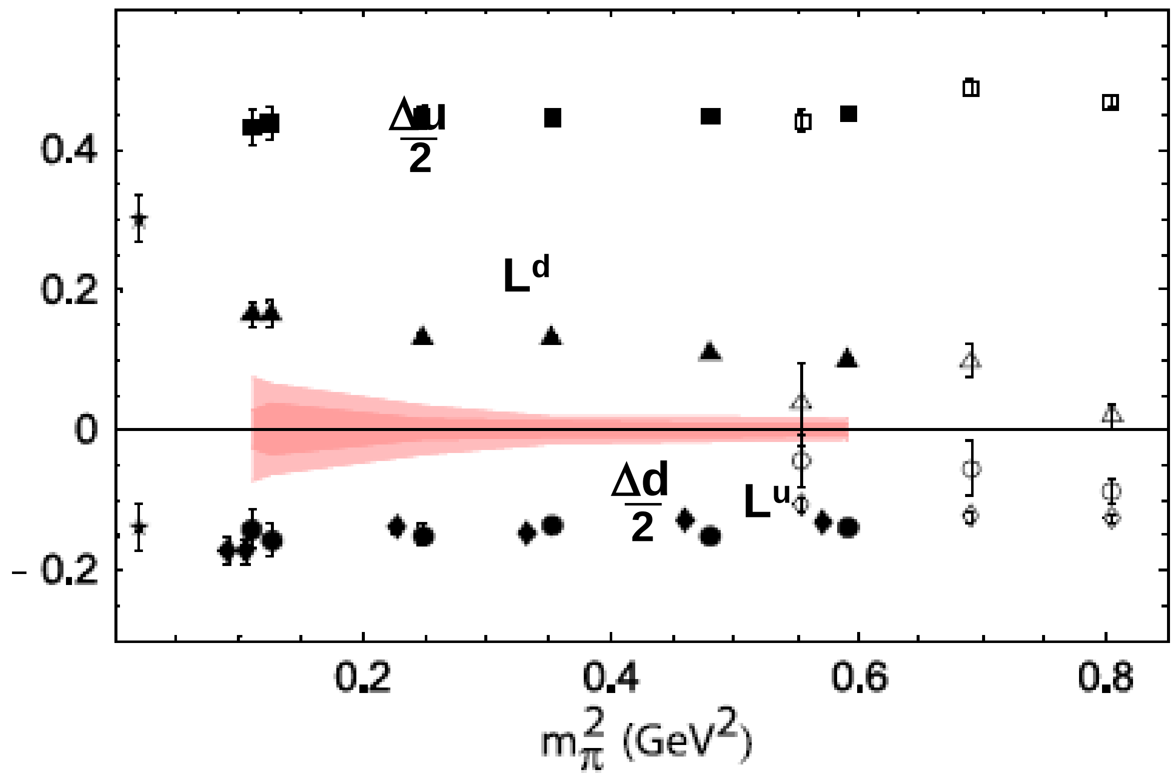
LHPC Lattice Results

- At first glance shocking : $L^u \sim -0.14$ and $L^d \sim +0.18$
  (c.f. + 0.25 and +0.06 in this model)

- N.B. Disconnected terms missing : NO idea of the of the error in L^{u+d}
  Also: unknown volume dependence in L^{u-d}



LHPC: Hägler et al. - hep-lat/0610007

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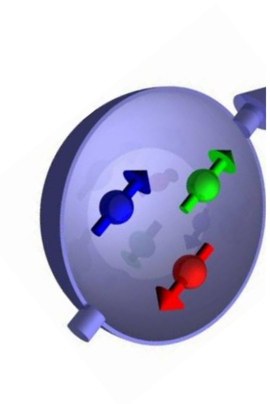
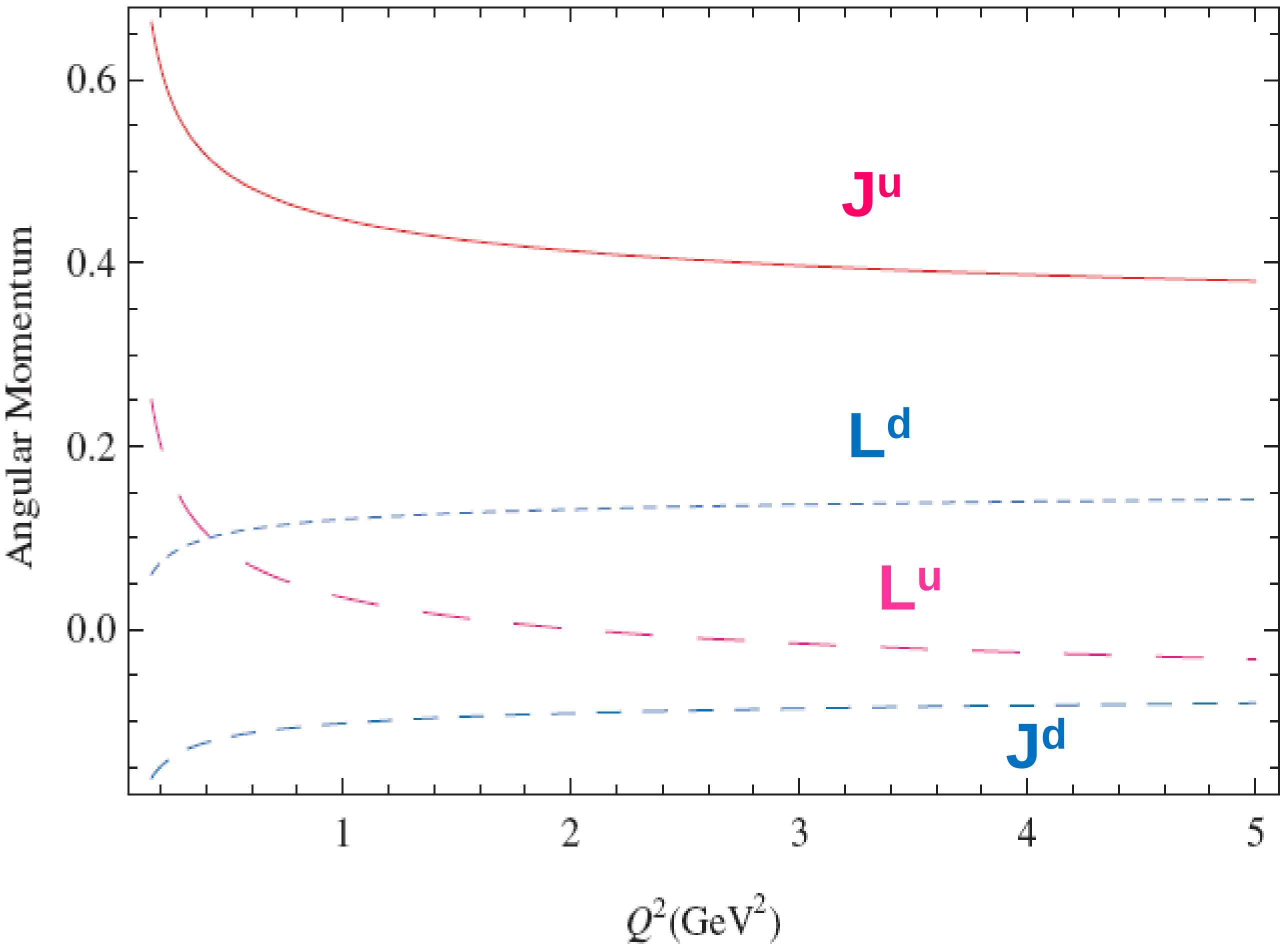
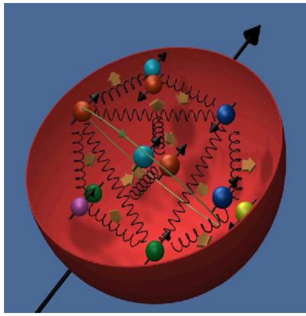
Solution of the LO Evolution Equations

L^u and L^d both small and cross-over rapidly: AWT, PRL 101 (2008) 102003







NLO Evolution – using Bass-Thomas update

Remarkable agreement between model and LQCD

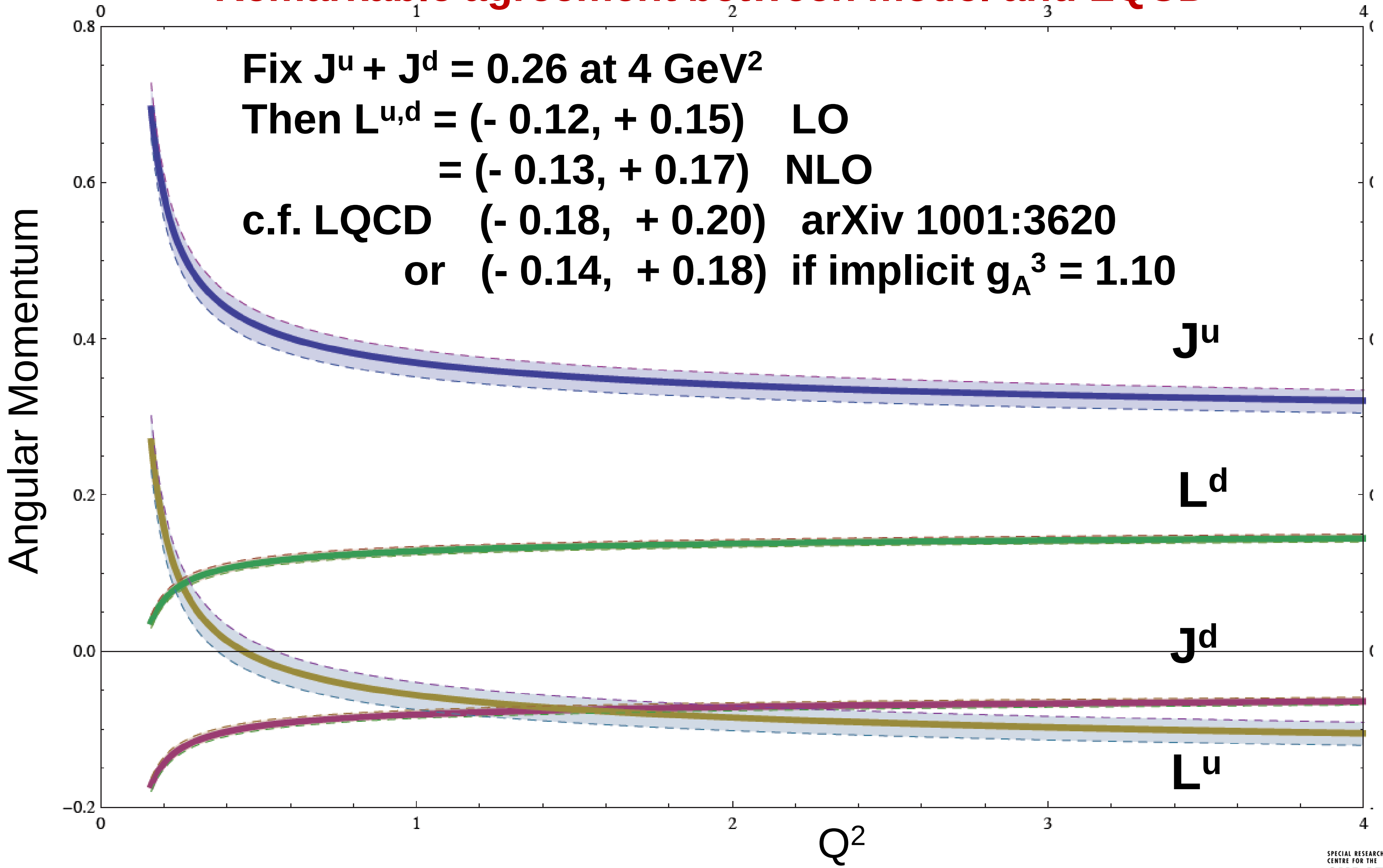
Fix $J^u + J^d = 0.26$ at 4 GeV^2

Then $L^{u,d}$ = (- 0.12, + 0.15) LO

= (- 0.13, + 0.17) NLO

c.f. LQCD (- 0.18, + 0.20) arXiv 1001:3620

or (- 0.14, + 0.18) if implicit $g_A^3 = 1.10$

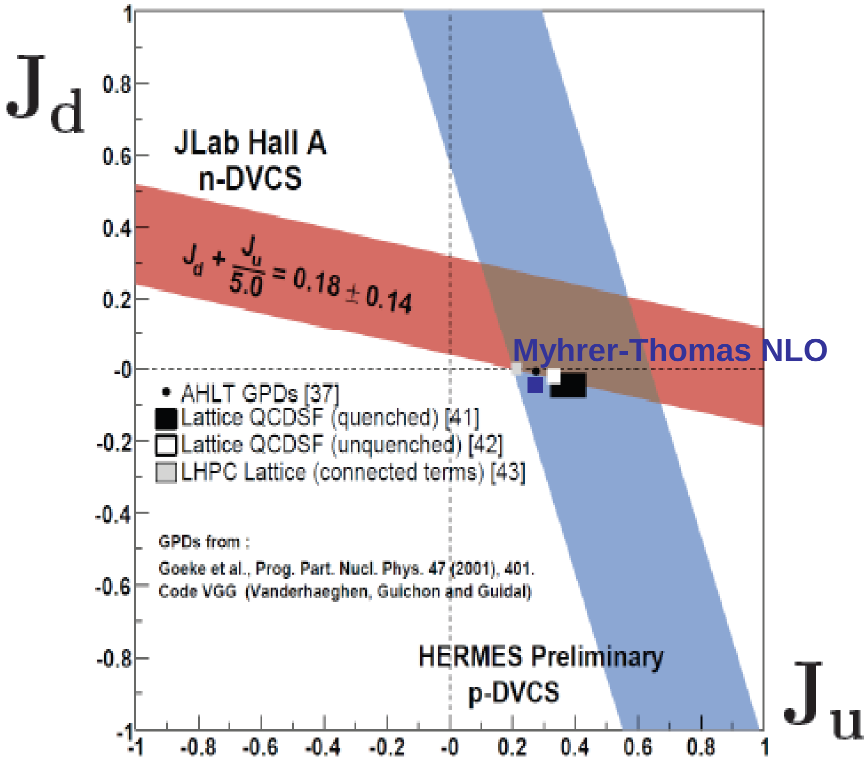


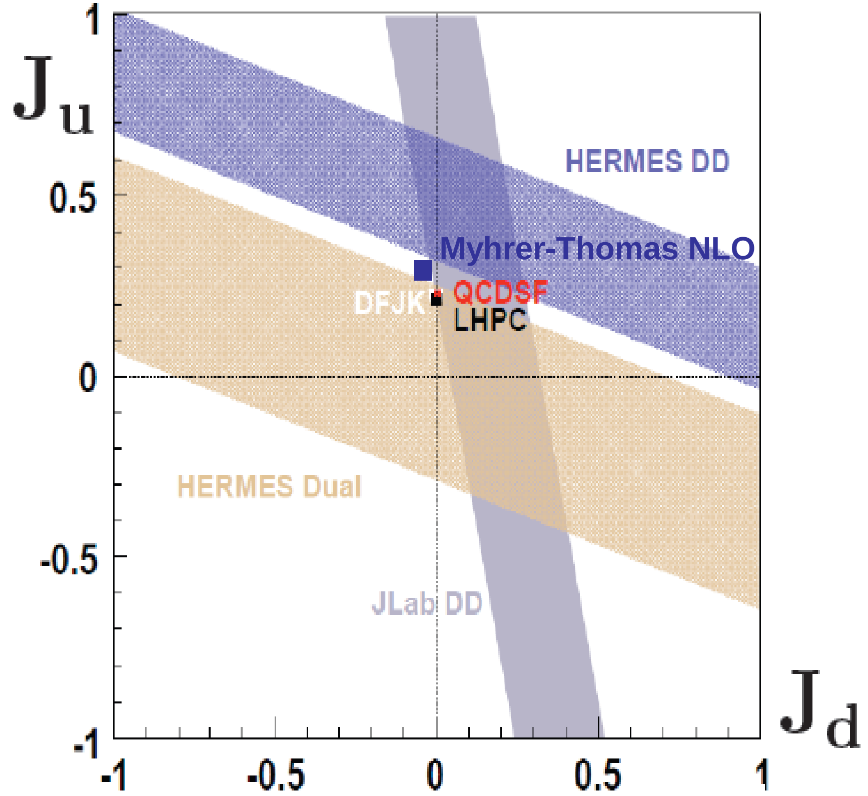
* Phys Lett 684 (2010) 216 & AWT, Casey & Matevosyan, in preparation

Experimental effort just beginning!

For the moment analysis highly model dependent – but promising!

- ... from DVCS: (**JLAB** PRL 99 (2007) 242501 and **HERMES** JHEP 0806:066 (2008)





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Meson and Baryon Excited States

- Arends, Beck, Berger, Braaten, D'Angelo, De Vita, Edwards, Giovannella, Julia Diaz, Lange, Mitchell, Schumacher

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SUB CRUCE LUMEN

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Situation on the analysis of meson production reaction

$\pi N \rightarrow$ $\gamma N \rightarrow$	πN	ηN	$\pi\pi N$	$K\Lambda, \Sigma$
Dubna-Mainz-NTU	○ (red)	○ (red)		
MAID	○ (blue)	○ (blue)		
Bonn-Gatchina	○ (red) ○ (blue)	○ (red) ○ (blue)	○ (red) ○ (blue)	○ (red) ○ (blue)
IHEP(Beijin)-Saclay		○ (red) ○ (blue)		
Zagreb	○ (red)	○ (red)		
CLAS	○ (blue)	○ (blue)	○ (blue)	
Juelich-Georgia	○ (red) ○ (blue)	○ (red)		○ (red)
EBAC	○ (red) ○ (blue)	○ (red) ○ (blue)	○ (red) ○ (blue)	○ (red) ○ (blue)

Important to study all available inelastic reactions with coupled channel analysis for both strong and em probes.

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from T. Sato

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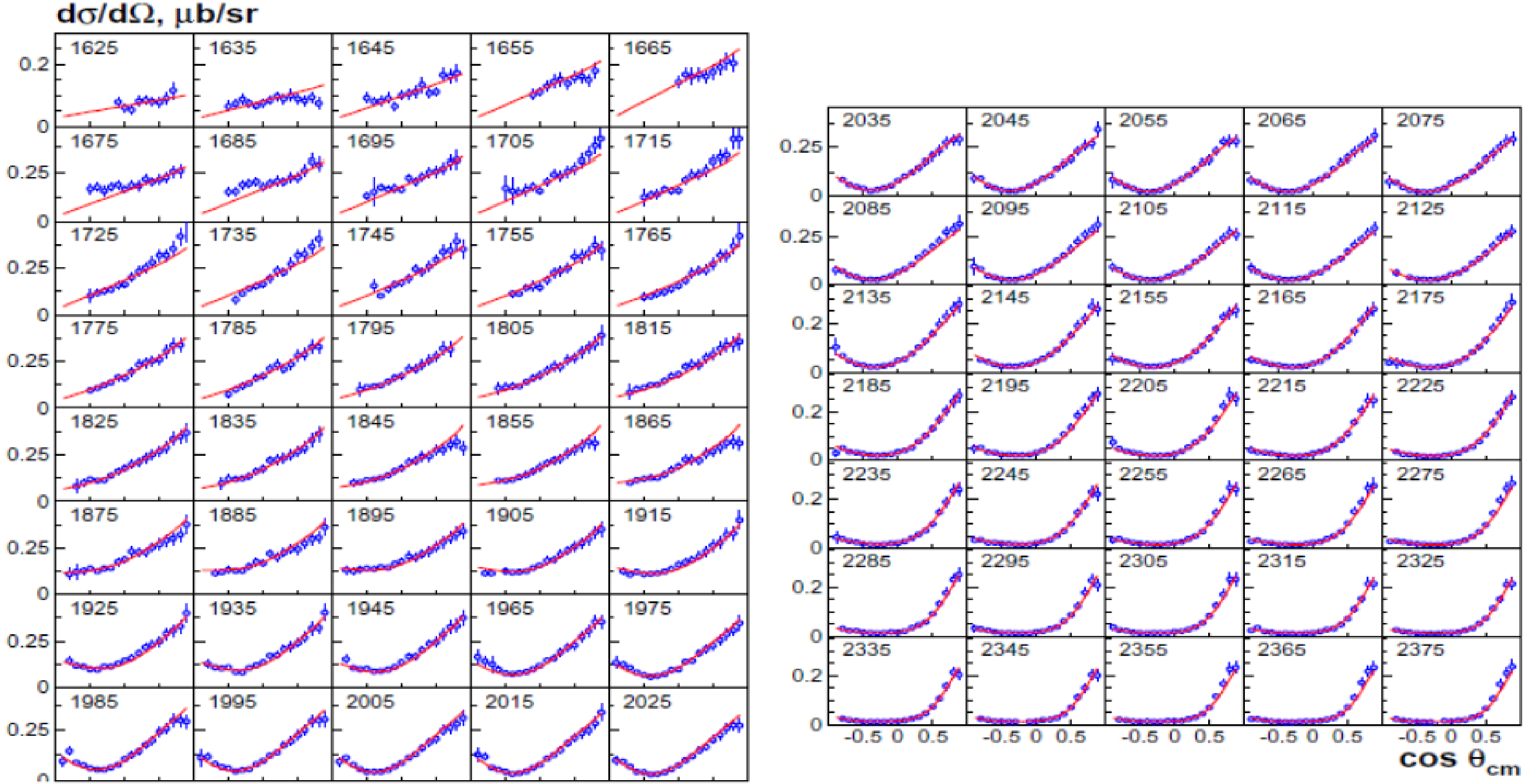
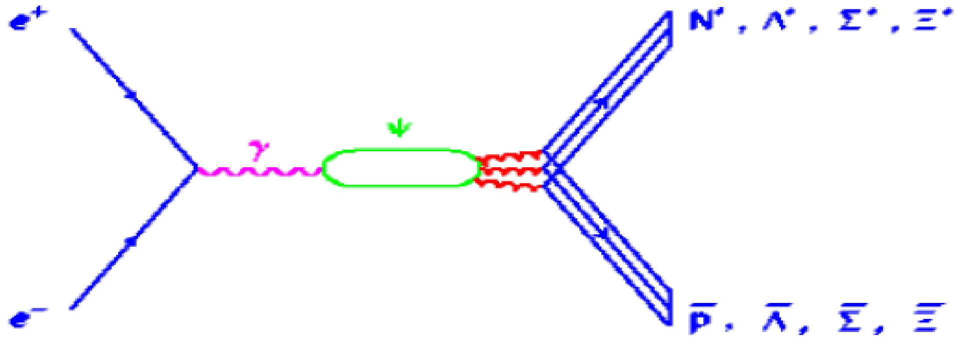
The fit of the $\gamma p \to K\Lambda$ differential cross section

(CLAS 2009)

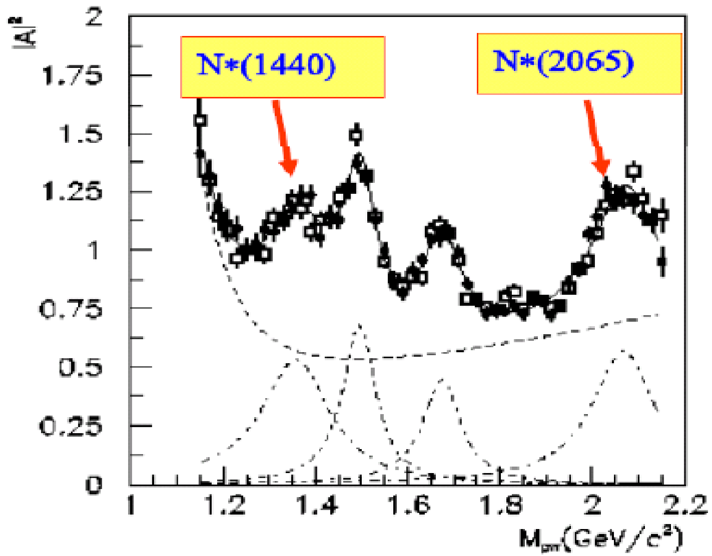


IHEP(Beijing)-BES



$$\psi, J/\psi \to \bar{B}MB$$

$J/\psi \rightarrow \bar{p}n\pi^+$ & $\bar{n}\pi^-p$



New tool for N*,Y* study : completely differrent S/N from $\pi N, \gamma^* N$

The first experiment "seeing" N*(1440) in πN mass spectrum

BESII	M = 1358 ± 17 ,	Γ = 179 ± 56	MeV
PDG08	M = 1365 ± 15 ,	Γ = 190 ± 30	MeV

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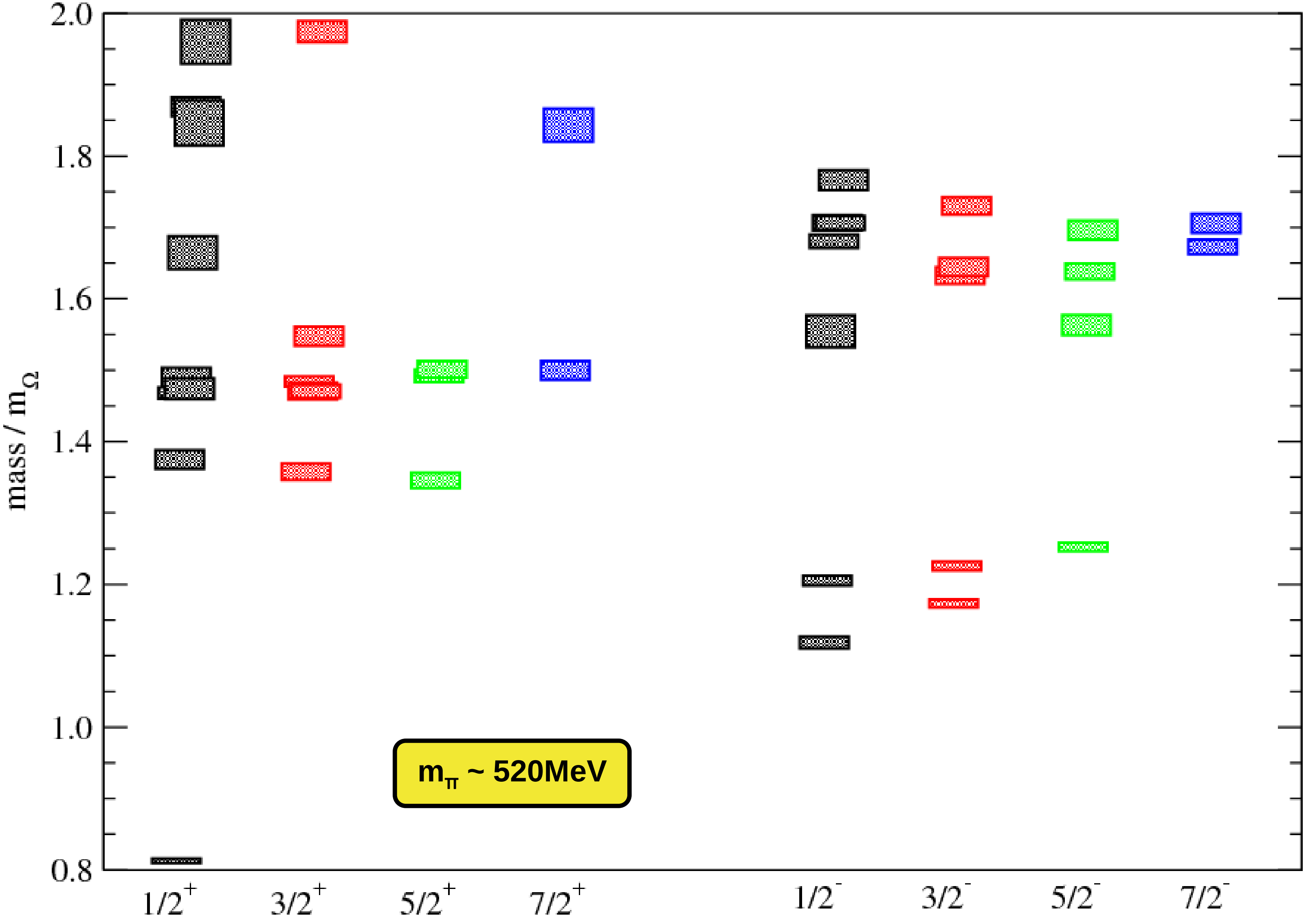
Lattice QCD: Spin Identified Nucleon Spectrum



from R. Edwards

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SUBATOMIC STRUCTURE OF MATTER

Phenomenology: Nucleon Spectrum

Looks like quark model?

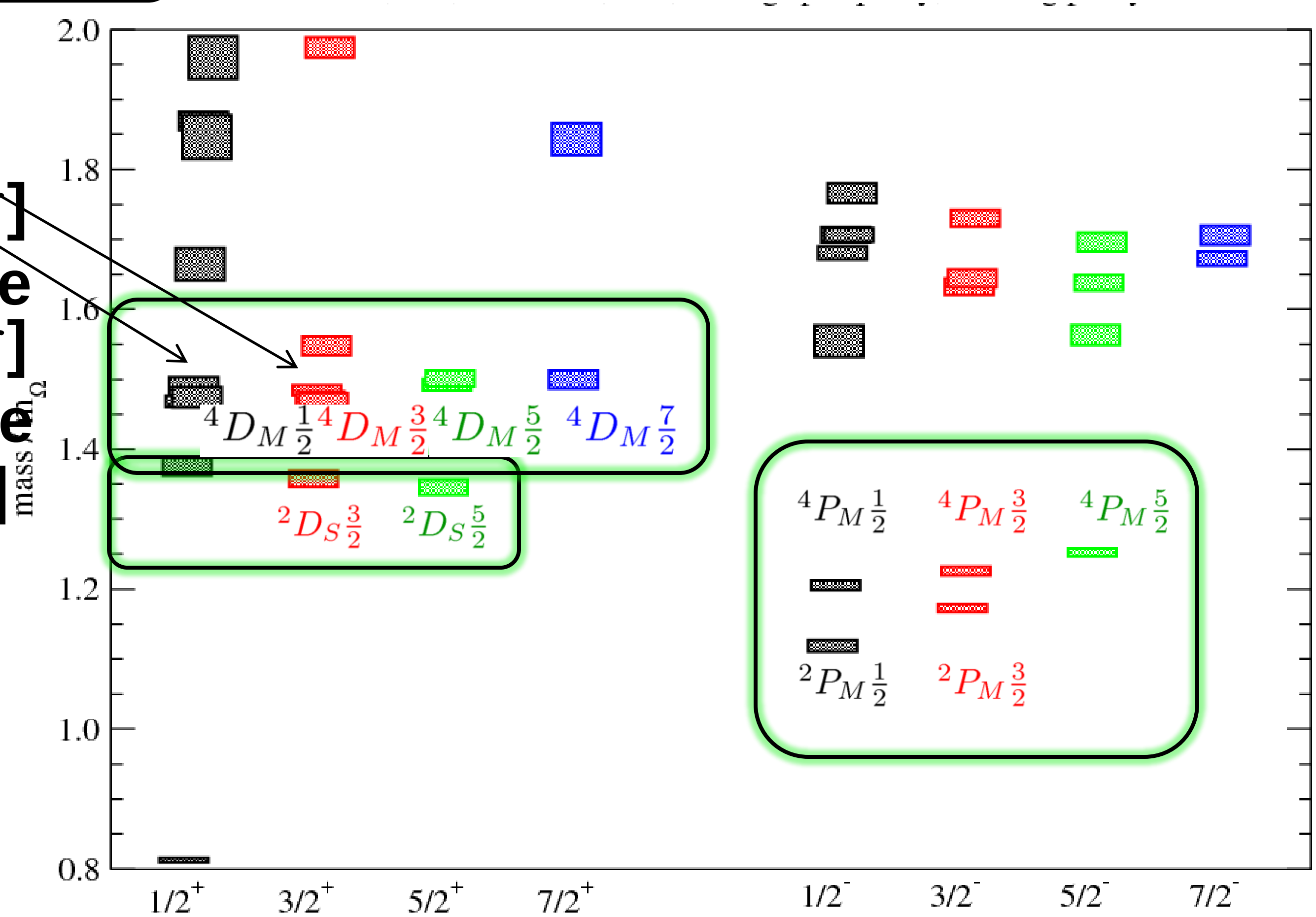
Compare overlaps & QM mixings

$m_\pi \sim 520$MeV

[20,1⁺] P-wave

[70,2⁺] D-wave

[56,2⁺] D-wave



[70,1⁻] P-wave

from R. Edwards

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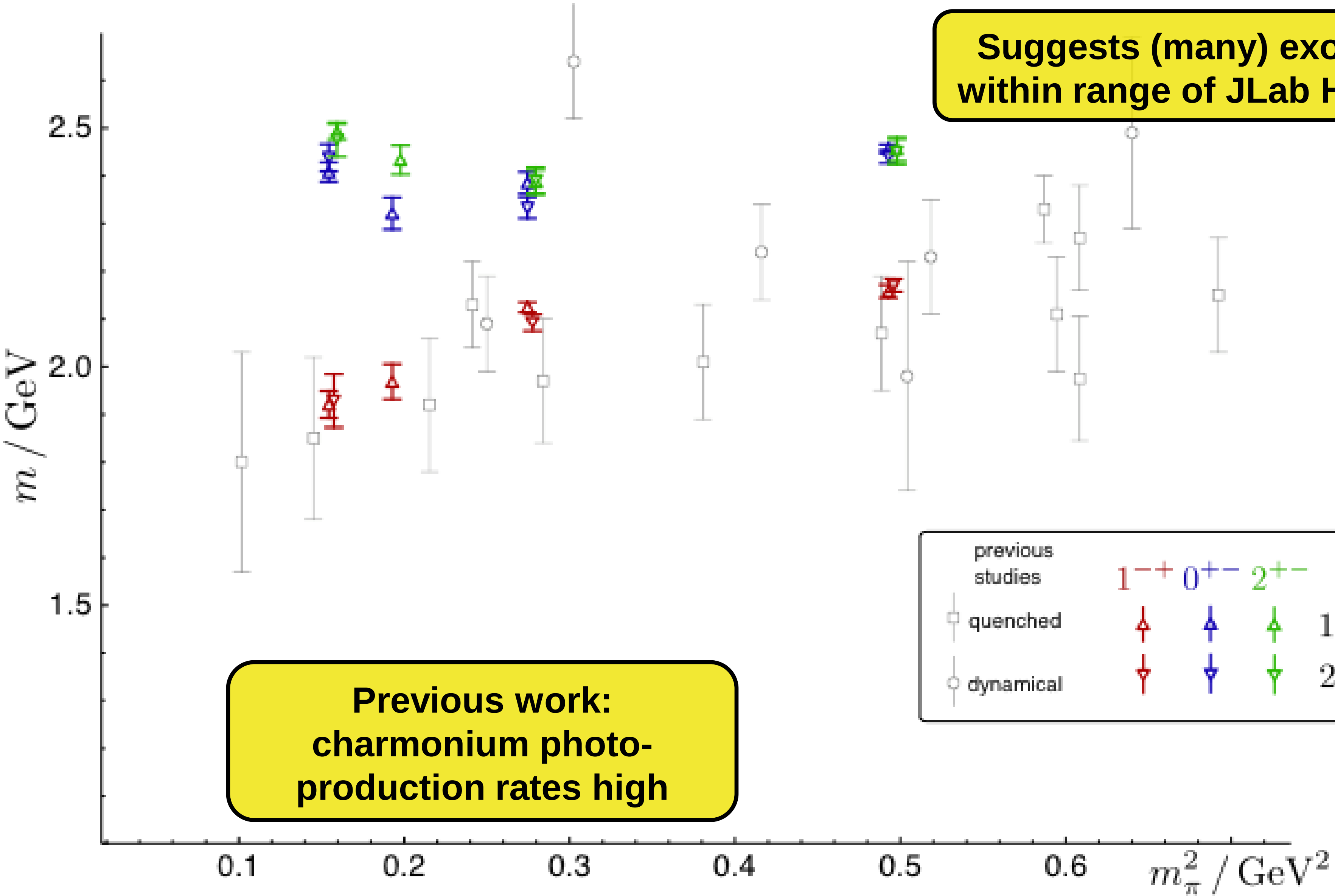
Exotic Matter



Suggests (many) exotics within range of JLab Hall D

Previous work: charmonium photo-production rates high

from R. Edwards

Nucleon and Hadron Structure in-Medium

— Cloët, Djalali, Higinbotham, Hinterberger

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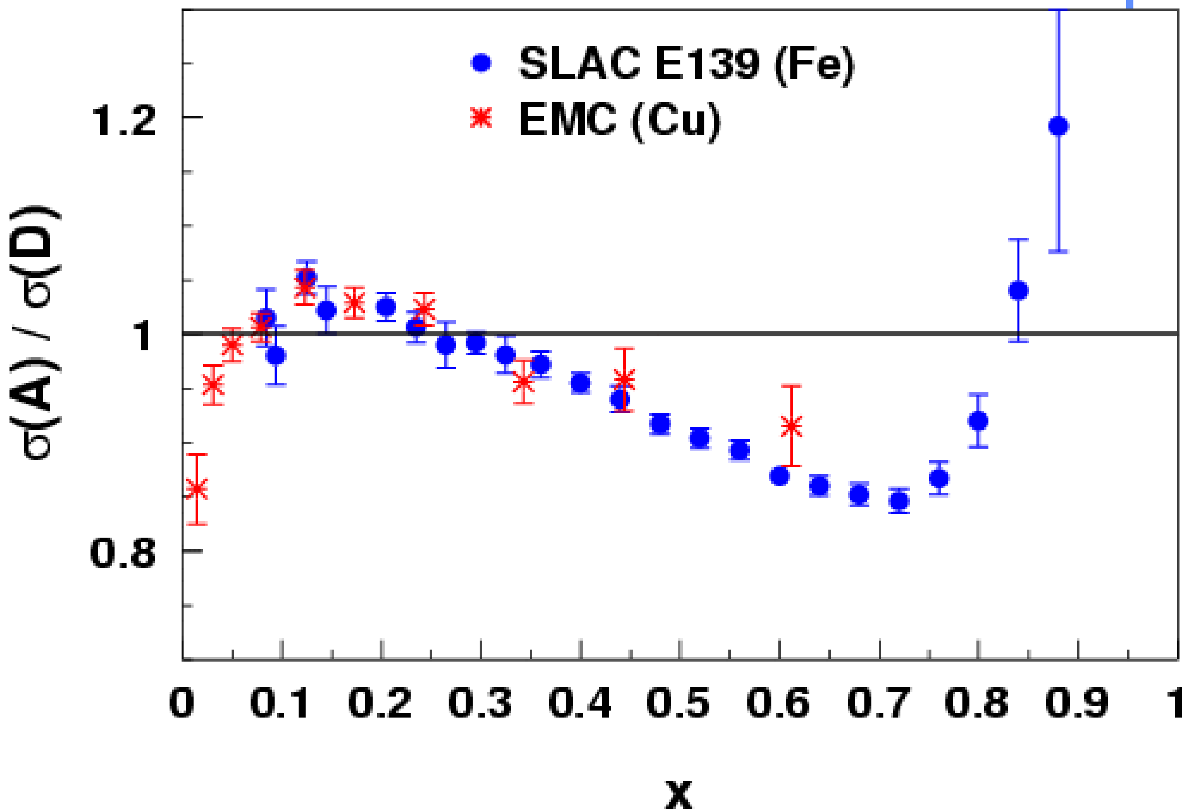
The EMC Effect: Nuclear PDFs

- Observation **stunned and electrified** the
  HEP and Nuclear communities 20 years ago

- Nearly 1,000 papers have been generated…..

- Medium modifies the momentum distribution of the quarks!



J. Ashman *et al.*, Z. Phys. C57, 211 (1993)

J. Gomez *et al.*, Phys. Rev. D49, 4348 (1994)

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Recent Calculations for Finite Nuclei

Spin dependent EMC effect TWICE as large as unpolarized

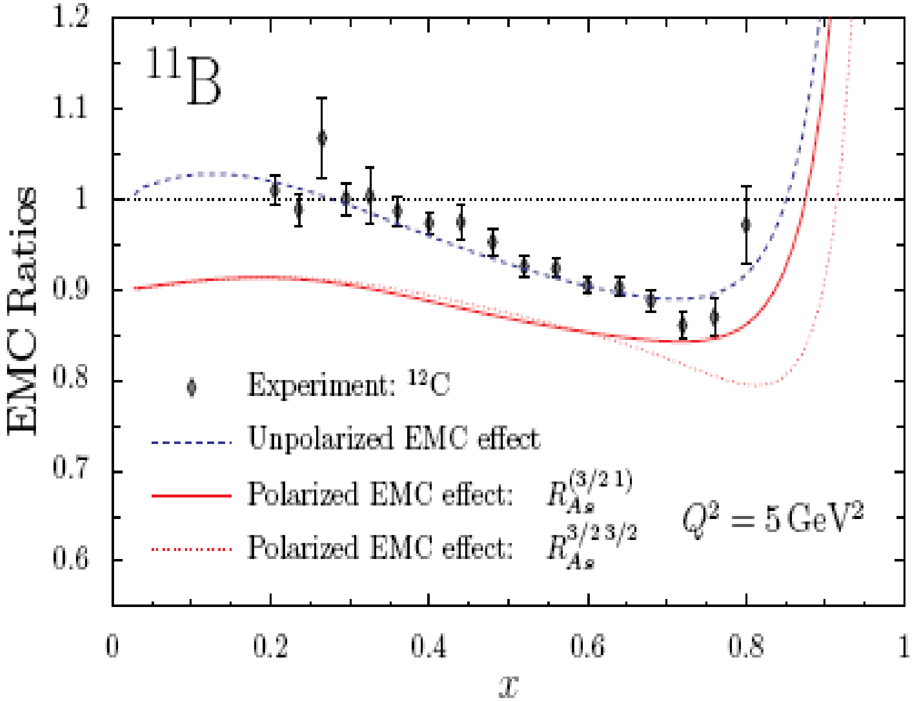

FIG. 7: The EMC and polarized EMC effect in ^{11}B. The empirical data is from Ref. [31].

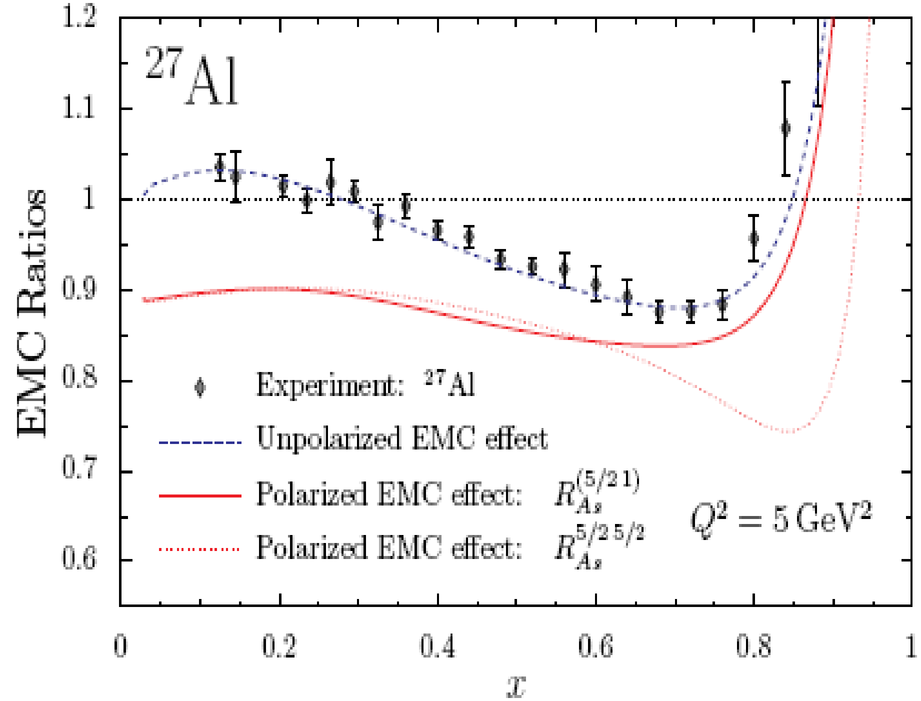

FIG. 9: The EMC and polarized EMC effect in ^{27}Al. The empirical data is from Ref. [31].

Cloët et al., Phys. Lett. B642 (2006) 210 (nucl-th/0605061)

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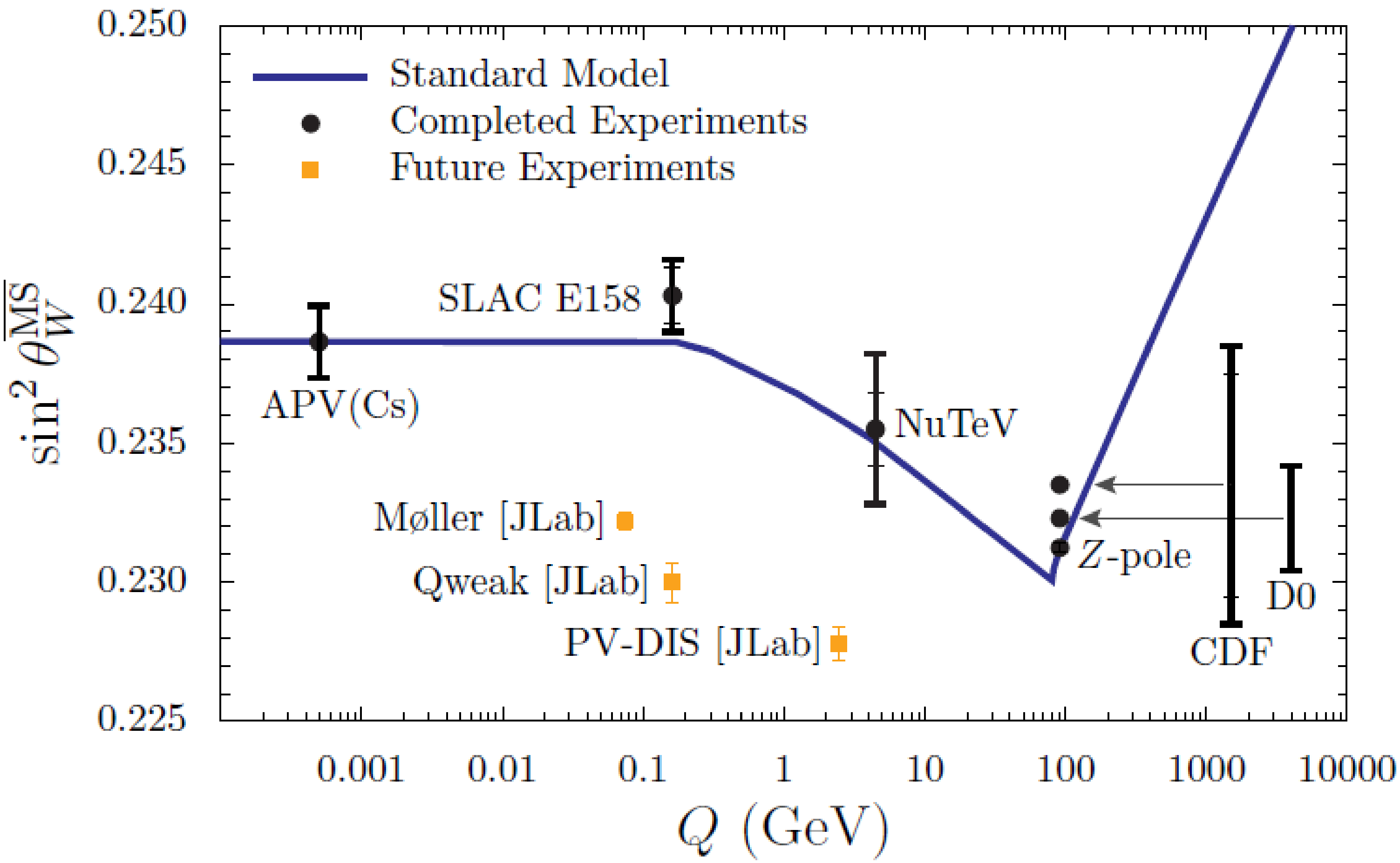
The Standard Model Works Again

Apply CSV and isovector EMC corrections
plus estimate systematic error arising from $s^-(x) \neq 0$:



Bentz et al., arXiv: 0908.3198

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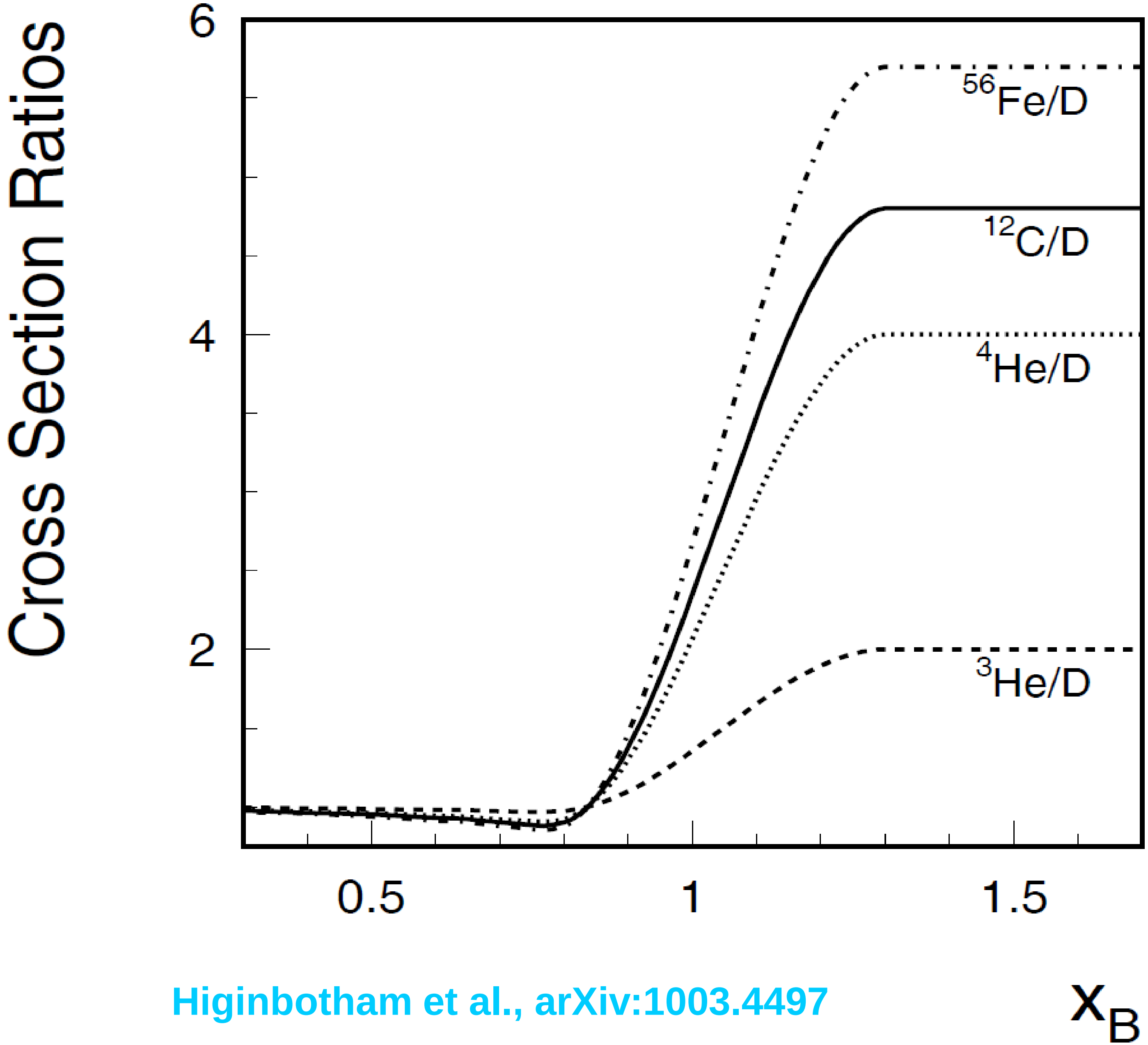
Large-x Behaviour of Nuclear Structure Functions



Higinbotham et al., arXiv:1003.4497

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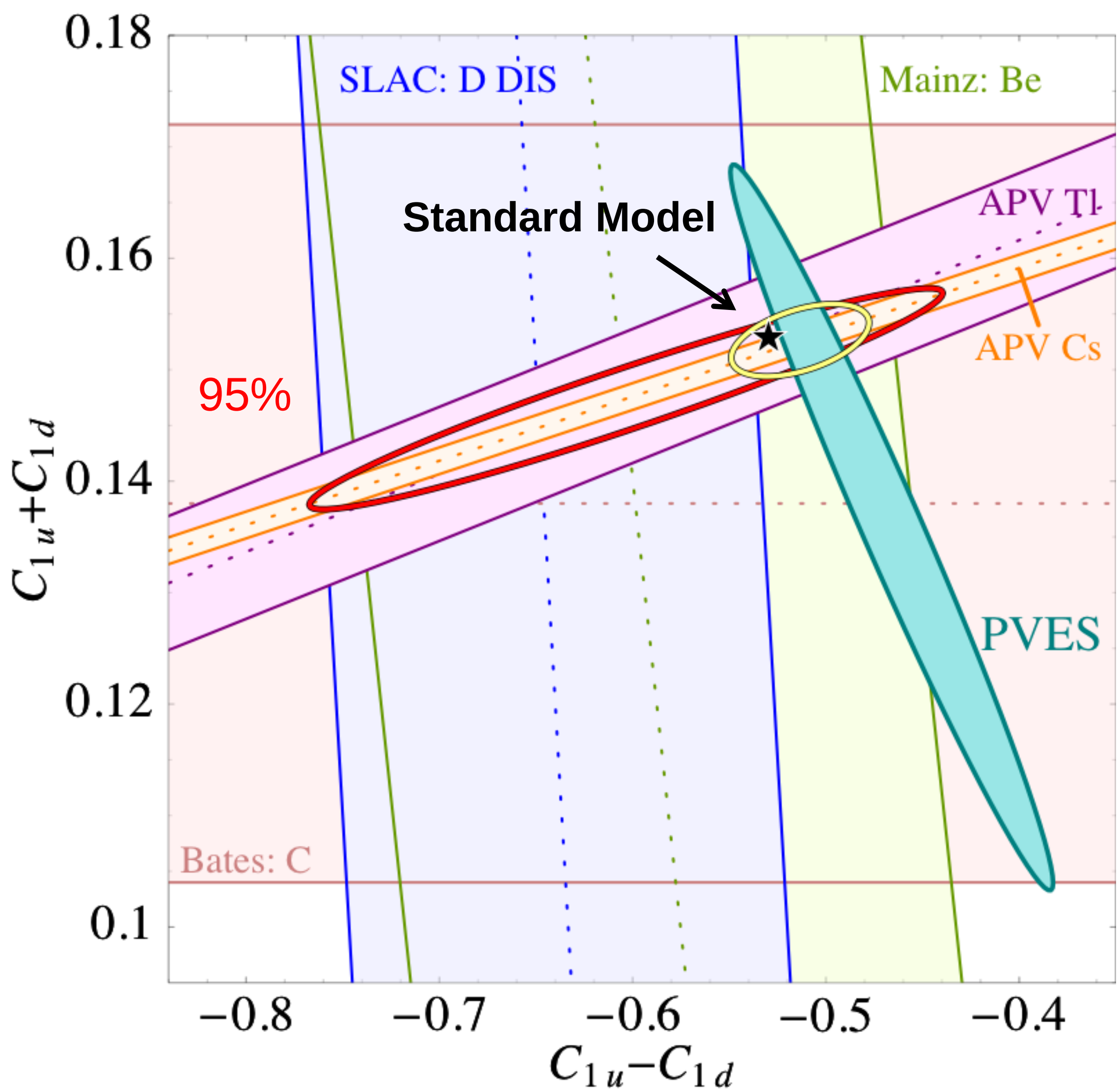
Symmetry Breaking and Standard Model Tests

– Cloët, Kupsc

Test of Physics beyond the Standard Model : PVES



$Q_{weak} = 2C_{1u} + C_{1d}$

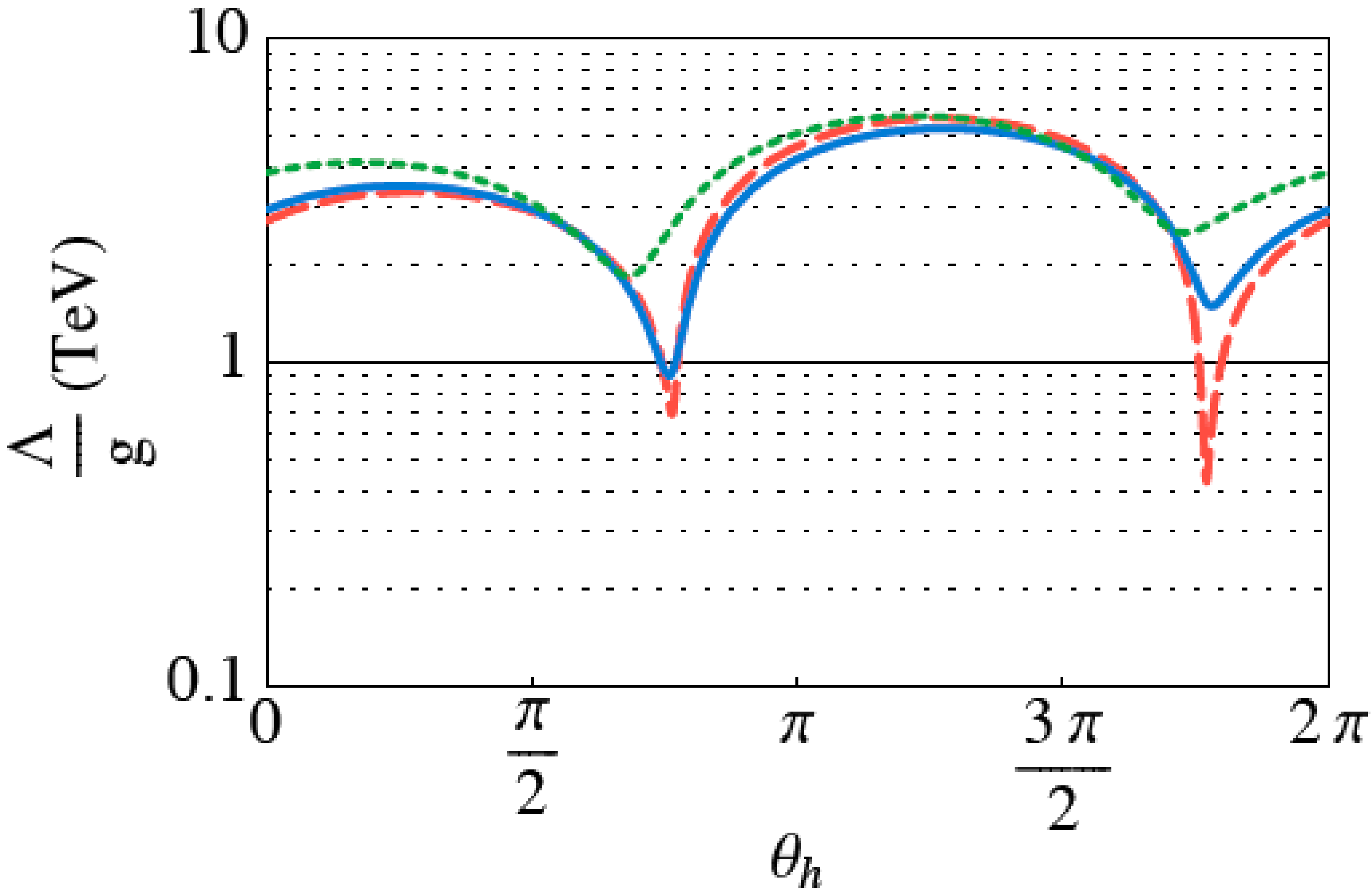
$L_{eff} \sim C_{1q}\, \bar{e}\gamma^{\mu}\gamma_5 e\, \bar{q}\gamma_{\mu}q$

Dramatic improvement in knowledge of weak couplings!

Factor of 5 increase in precision of Standard Model test

Young et al., Phys Rev Lett 99 (2007) 122003

Lower Limit on Mass Scale for New Physics



Q_{weak} limit *if* data agrees with Standard Model

with PVES

Atomic only

95% CL

Qweak constrains new physics to beyond 2 TeV

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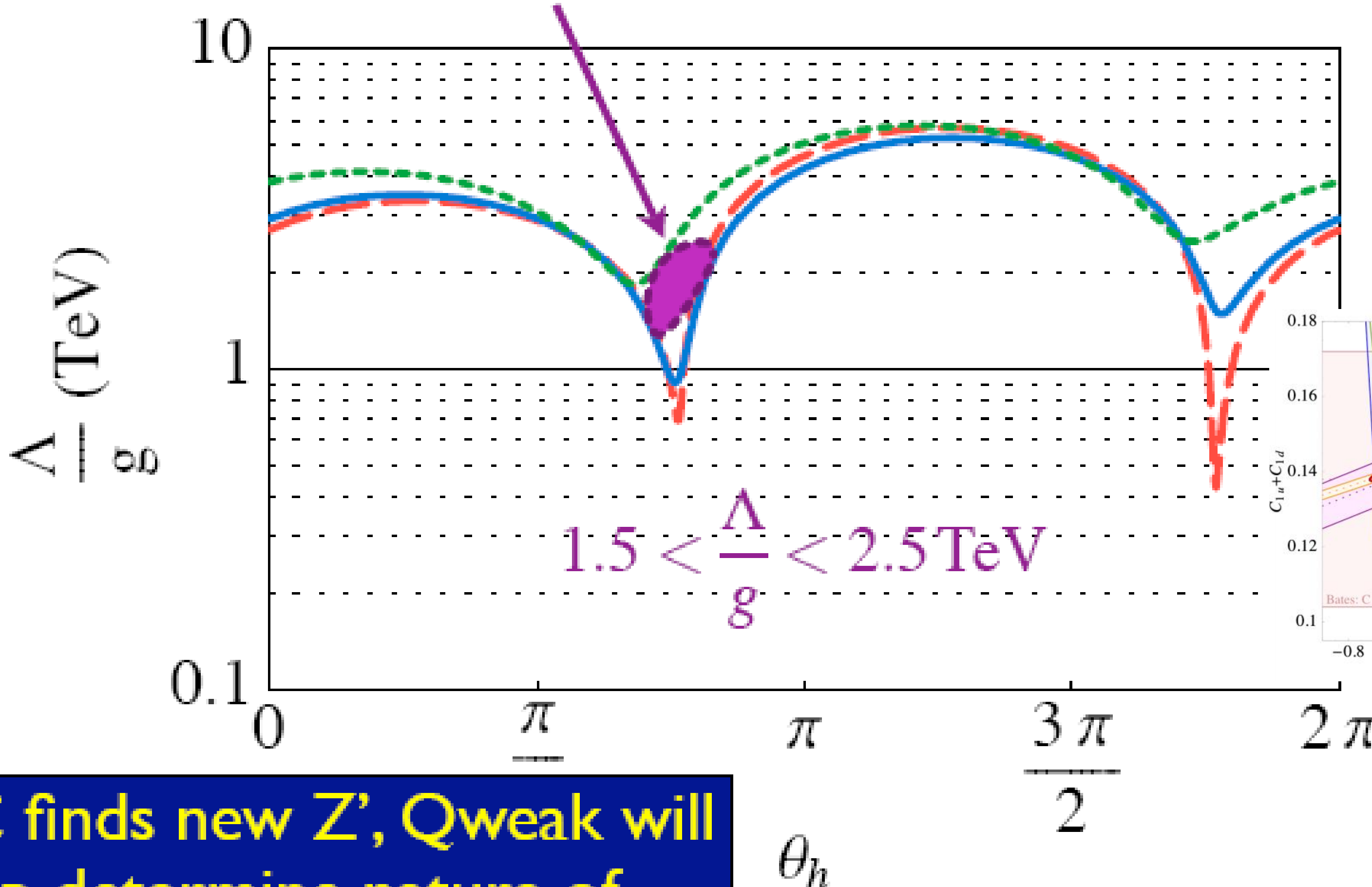
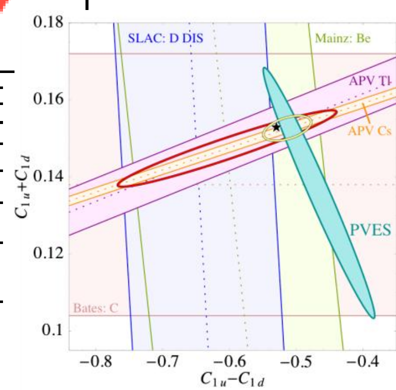
Or… Discovery

Assume Qweak takes central value of current measurements



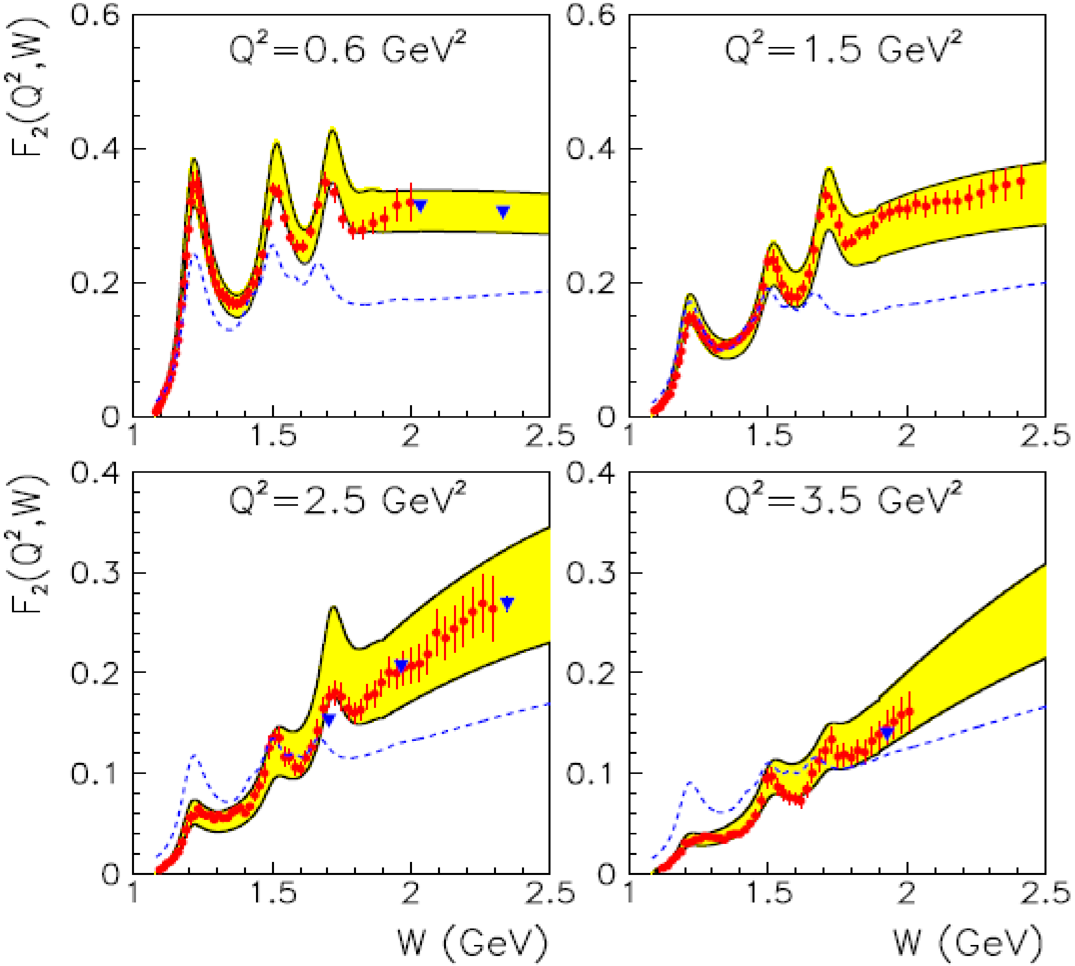


If LHC finds new Z', Qweak will help determine nature of interaction

γ-Z Box Diagram

- **Re-examined by Sibirtsev et al., following Gorchtein & Horowitz (arXiv:1002.0740 [hep-ph])**

- **Took advantage of CLAS data on photo-production (and HERA data)**



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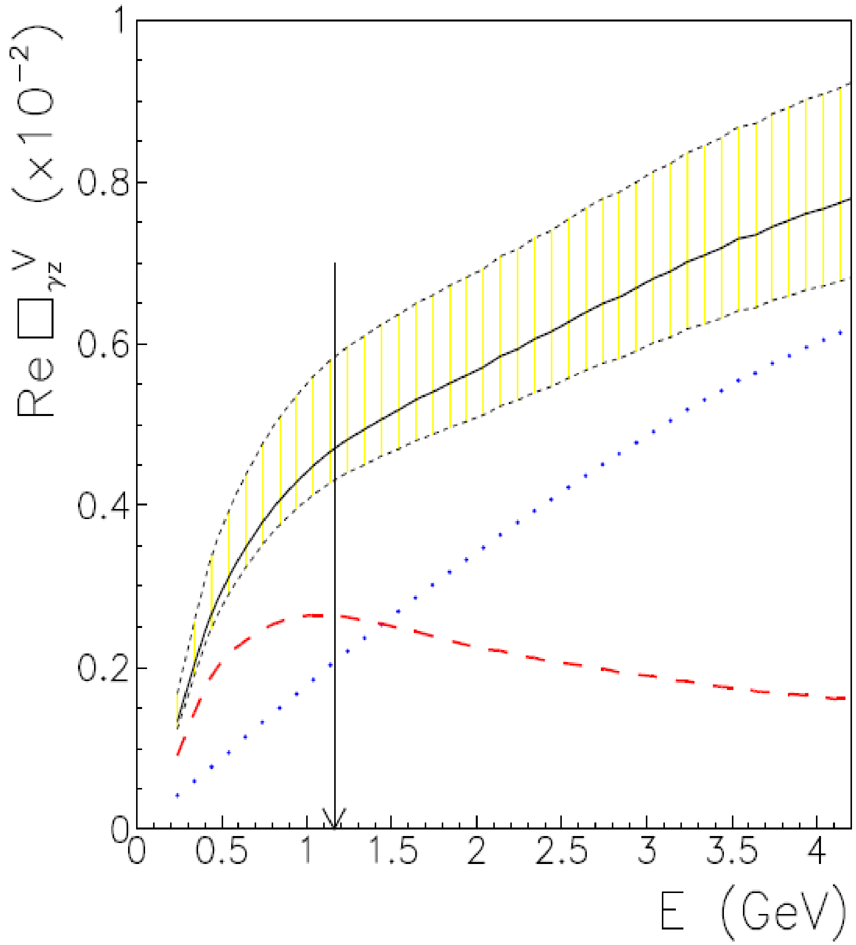
Result for γ – Z box

- **From measurement of A_{PV} at 1.165 GeV (Q_{weak}) the value of Q_W^p extracted needs to be reduced by** $0.0047^{+0.0011}_{-0.0004}$ **before comparison with the value deduced from atomic PV**

- **SUMMARY: This new correction is large but under control, thanks largely to CLAS data on photo-production and with it Q_{weak} can achieve its goal**



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“New” Facilities

– McKeown, Sawada, Wiedner

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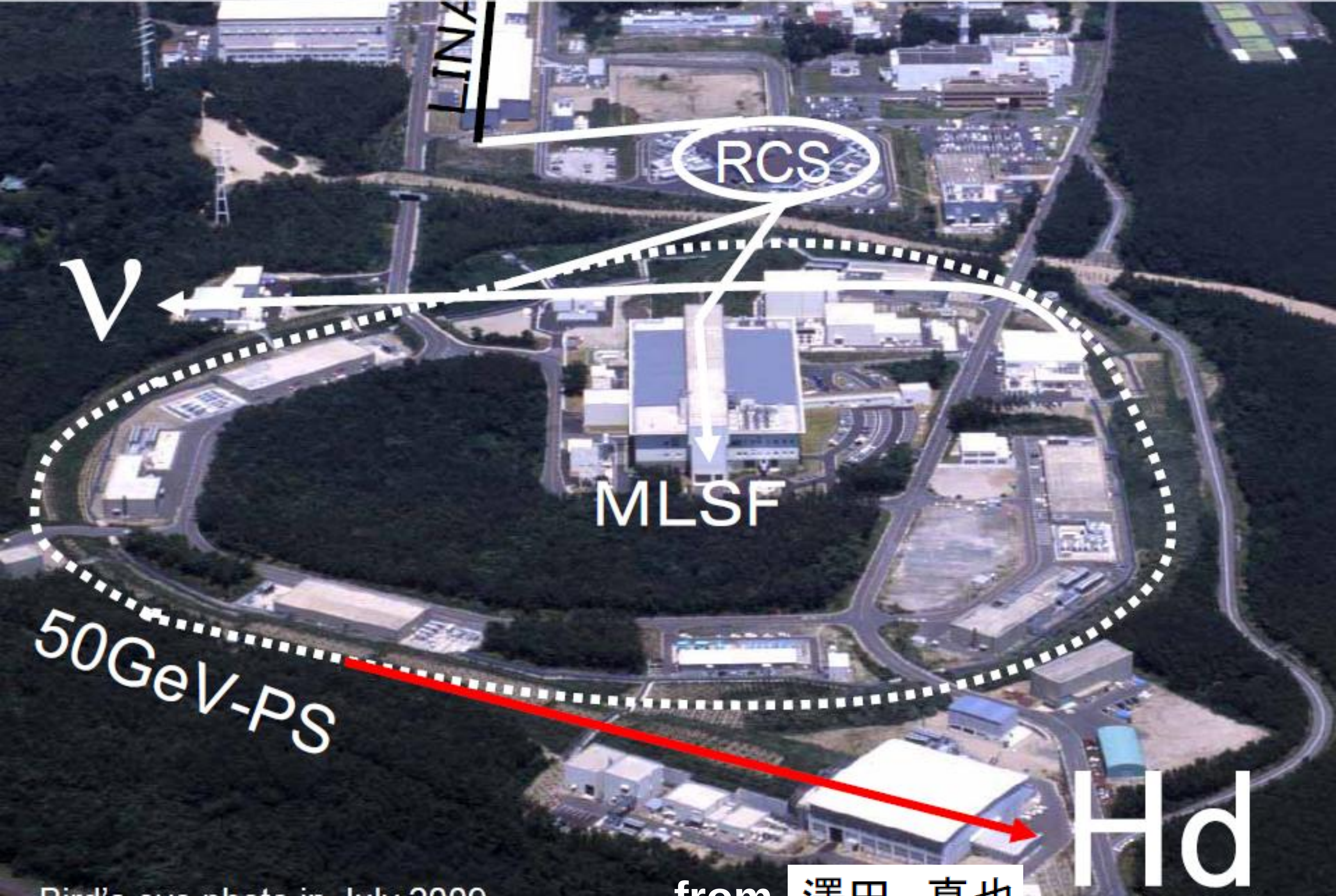
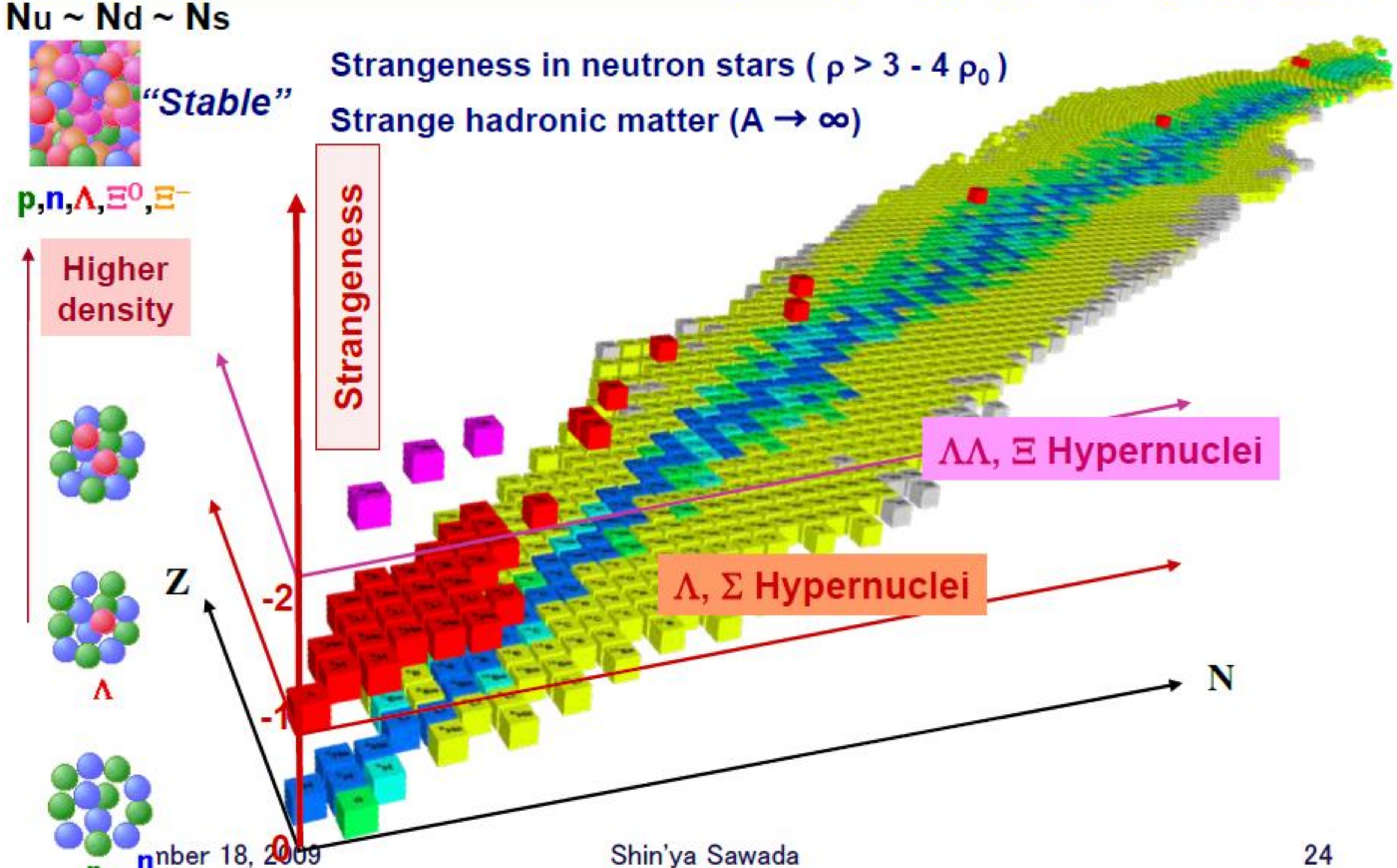
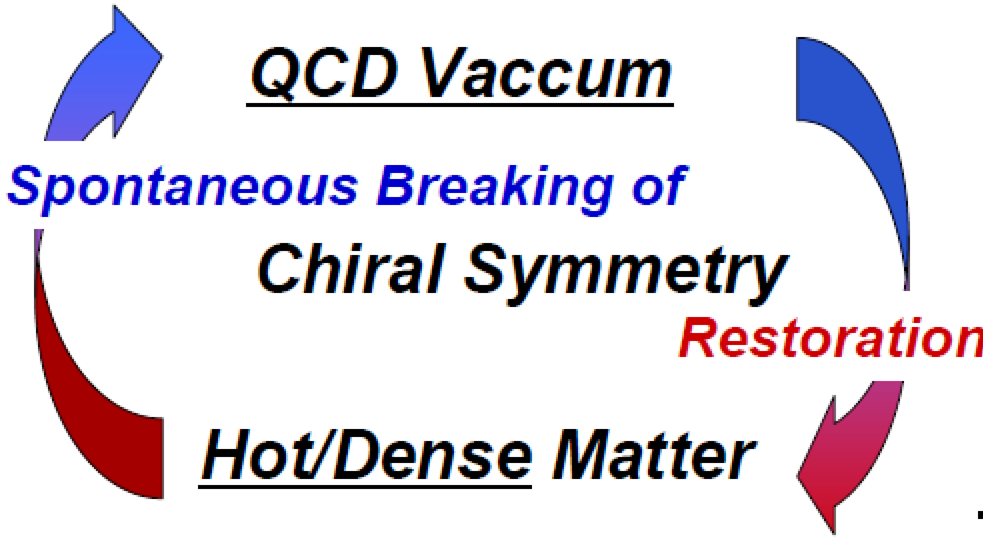
Hadron Facility of J-PARC

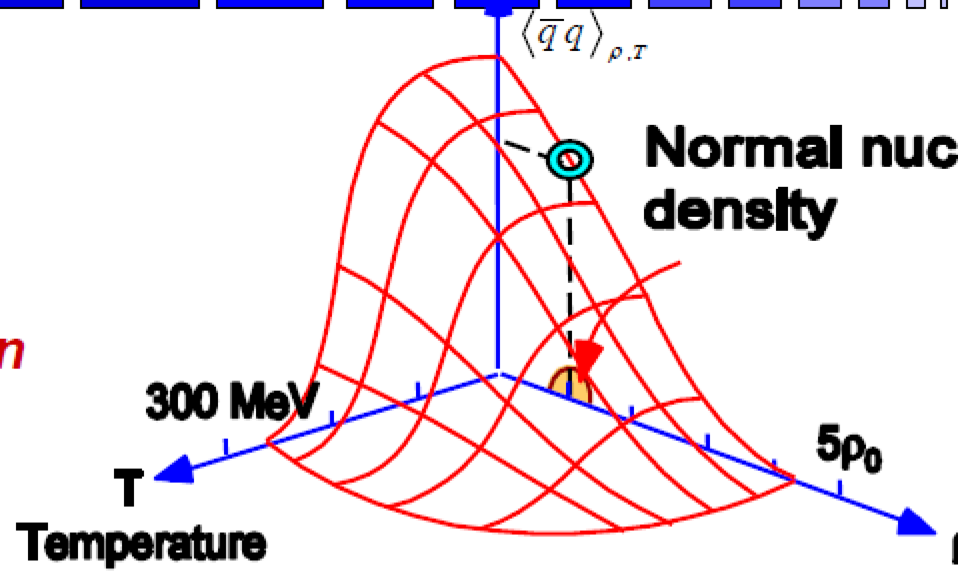


Three Dimensional Nuclear Chart



Mass modification of vector meson





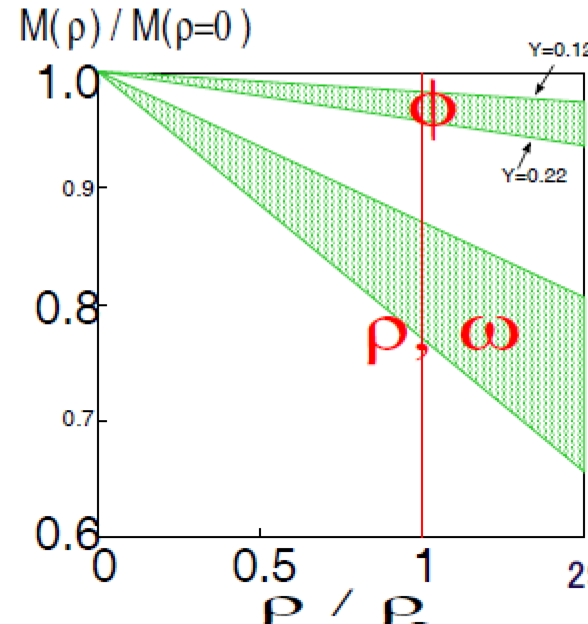
Vector meson mass at normal nuclear density

$m^*/m = 1 - k\rho/\rho_0$

(Hatsuda&Lee PRC46(92)R34)

ρ/ω : Δm = 130 MeV at ρ_0

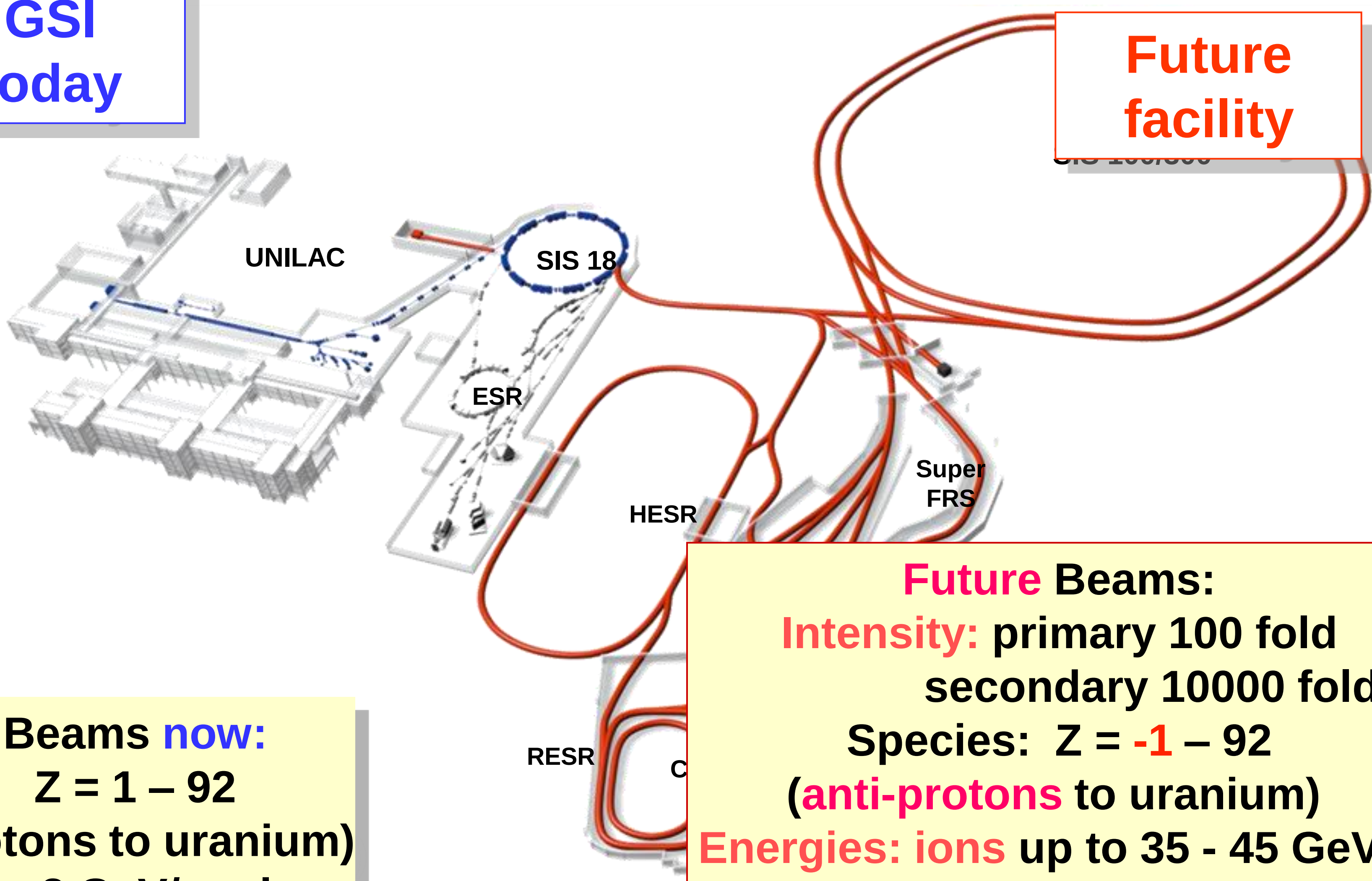
ϕ : Δm = 20~40 MeV at ρ_0



FAIR - Facility for Antiproton and Ion Research

GSI today

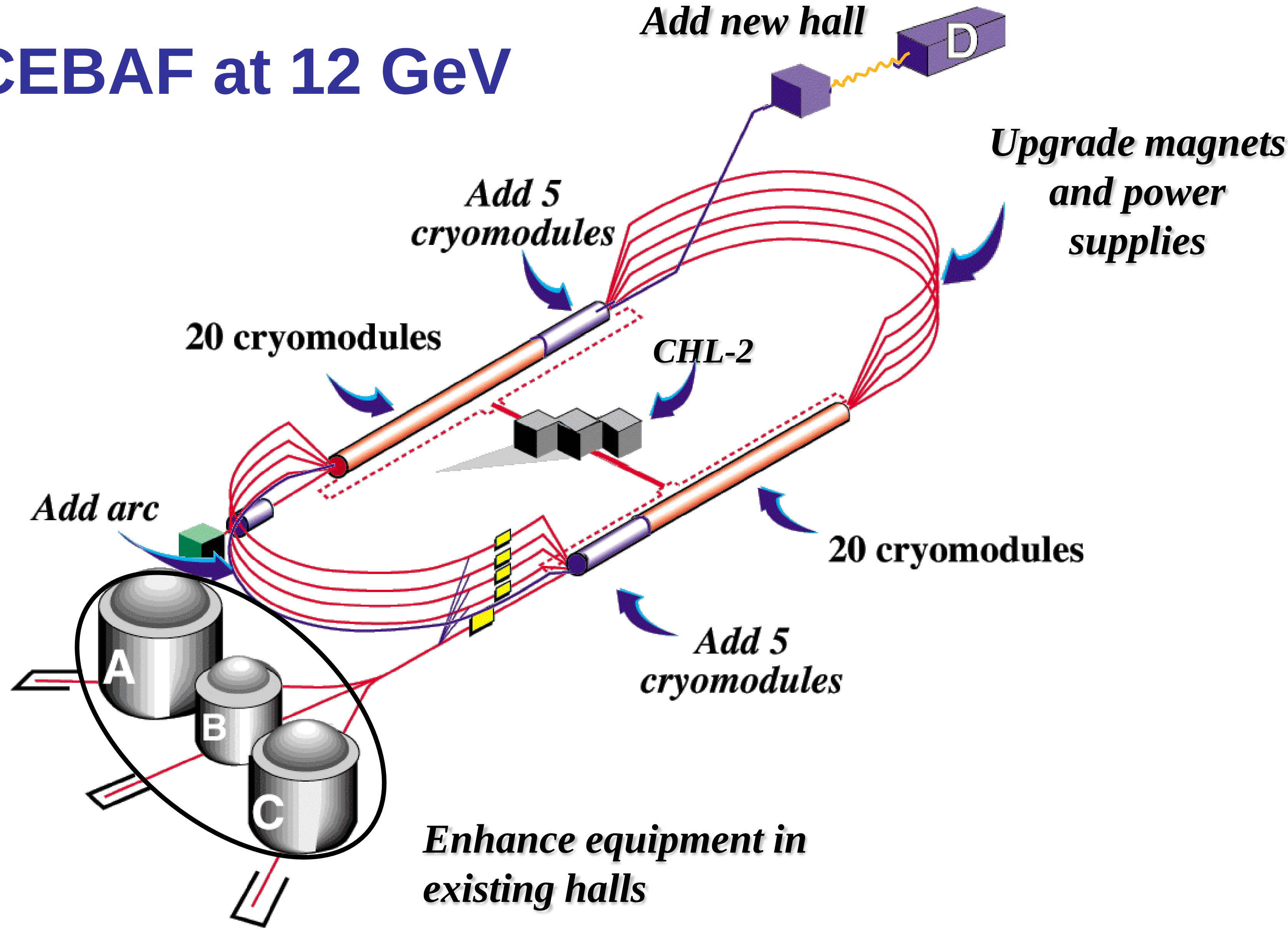
Future facility



Beams now:
Z = 1 – 92
(protons to uranium)
up to 2 GeV/nucleon
Some beam cooling

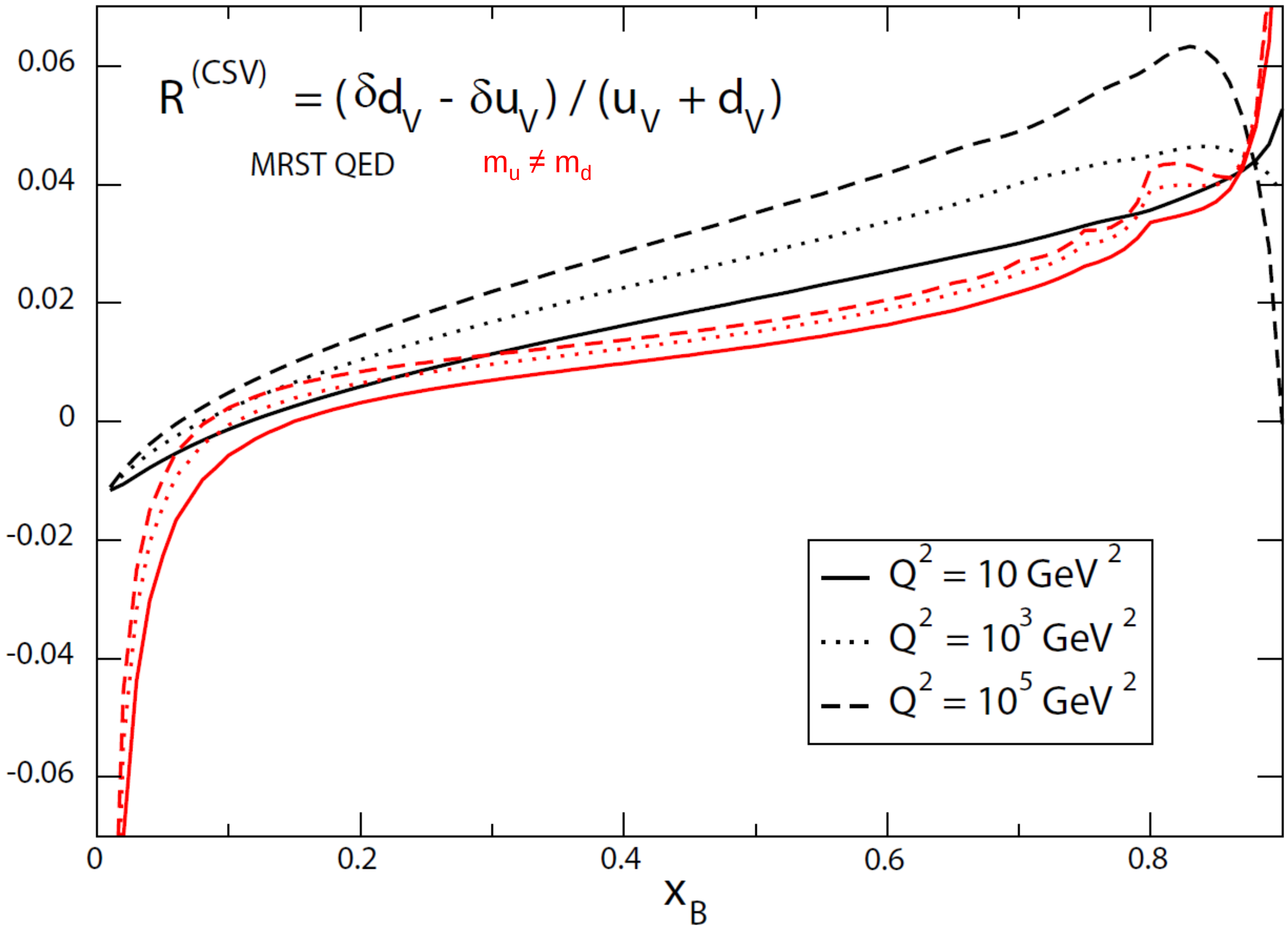
Future Beams:
Intensity: primary 100 fold
secondary 10000 fold
Species: Z = -1 – 92
(anti-protons to uranium)
Energies: ions up to 35 - 45 GeV/u
antiprotons 0 -15 GeV/c
Precision: full beam cooling

CEBAF at 12 GeV



EIC an Ideal Place to test QED Splitting

- **Effect increases with Q^2. Use (e^-, ν) and (e^+, $\bar{\nu}$) on p and d**
- **This gives CSV <u>and</u> d/u unambiguously**



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Hobbs, Londergan and Thomas, in preparation

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Summary

Enjoy the meeting!

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