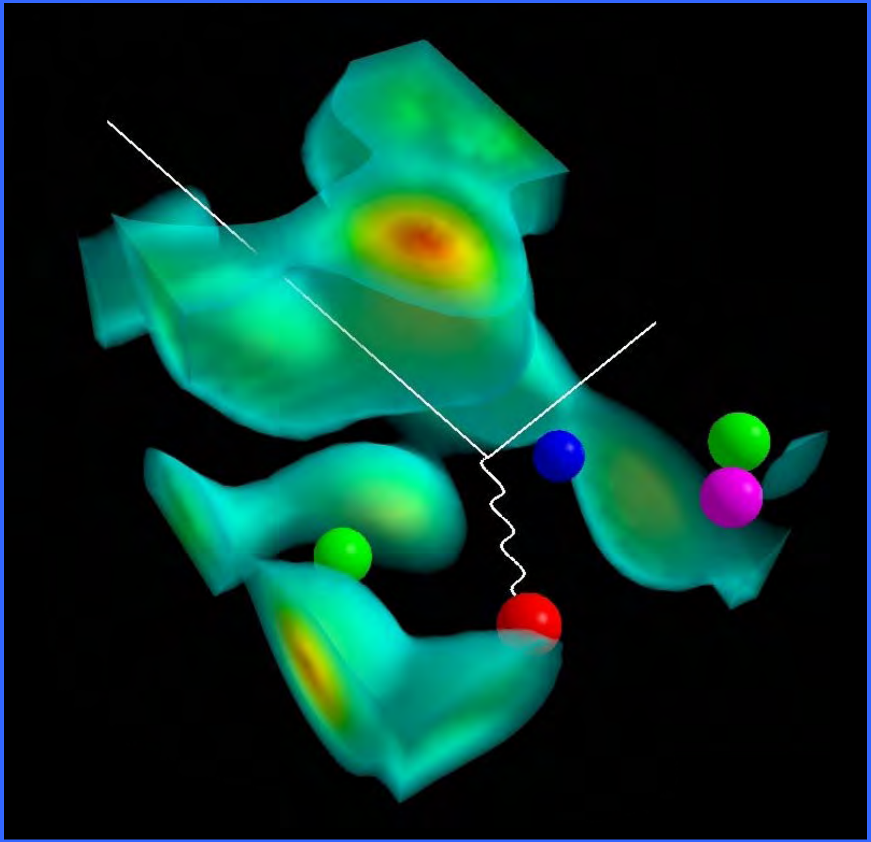
Overview of Ξ Physics at JLab



Anthony W. Thomas

Workshop on Cascade Physics

Jlab : December 1st, 2005

Outline

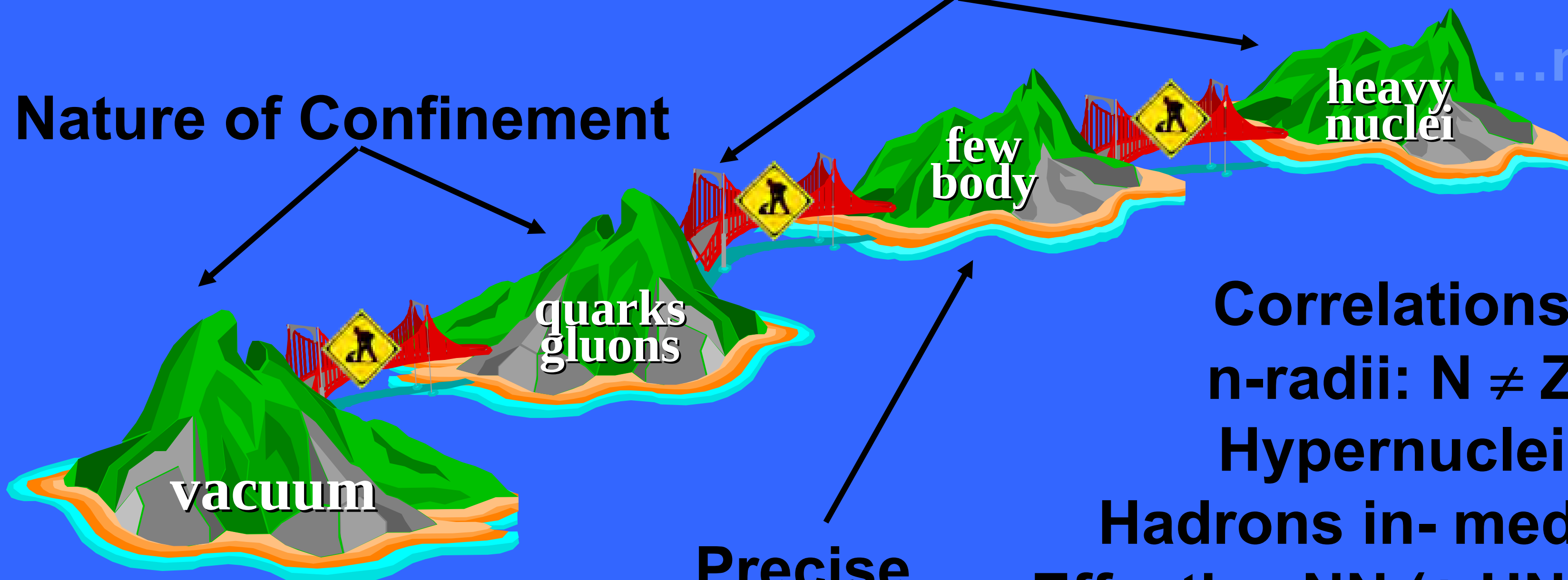
- Remarks on Baryon Mass Calculations in Lattice QCD
- Chiral extrapolation is MUCH simpler
- Hence meaningful Ξ spectral studies SOON
- Strangeness and dense nuclear matter
- Doubly Strange Hypernuclei ??

JLab Central to *all* of Nuclear Science

Quark-Gluon Structure
Of Nucleons and Nuclei

Nature of Confinement

…n-stars

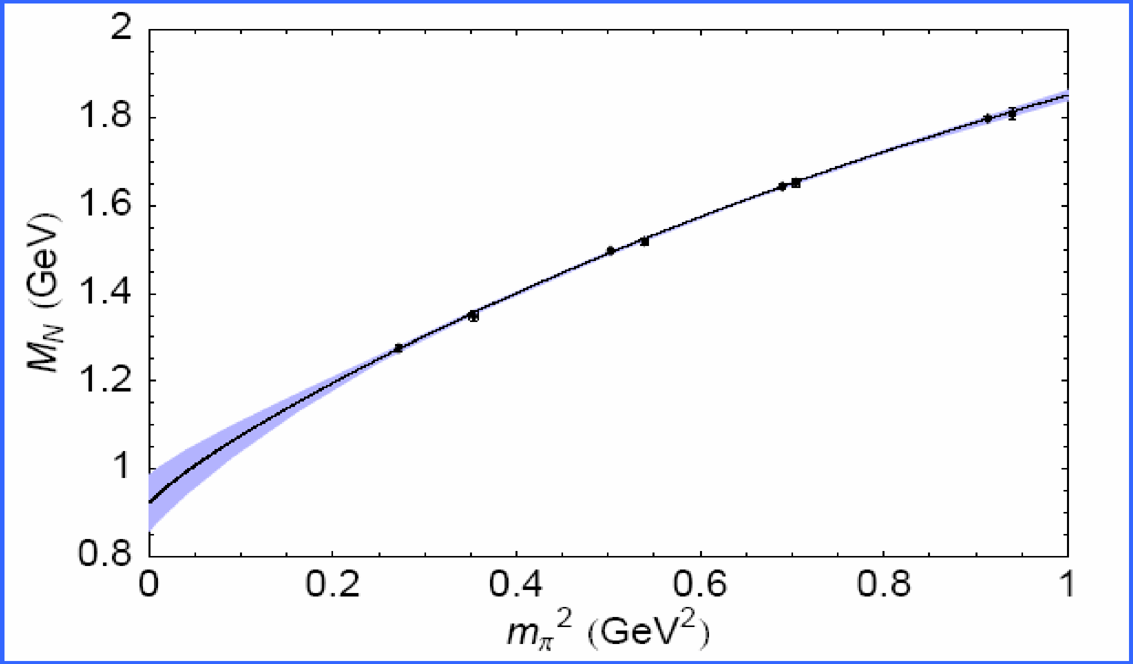


Correlations
n-radii: N ≠ Z
Hypernuclei
Hadrons in- medium
Effective NN (+ HN) force

Precise
few-nucleon
calculations

Exotic mesons
and baryons

χ'al Extrapolation Under Control when Coefficients Known – e.g. for the nucleon



FRR give same answer to <<1% systematic error!

	Bare Coefficients			Renormalized Coefficients				
Regulator	a_0^Λ	a_2^Λ	a_4^Λ	Λ	c_0	c_2	c_4	m_N
Monopole	1.74	1.64	−0.49	0.5	0.923(65)	2.45(33)	20.5(15)	0.960(58)
Dipole	1.30	1.54	−0.49	0.8	0.922(65)	2.49(33)	18.9(15)	0.959(58)
Gaussian	1.17	1.48	−0.50	0.6	0.923(65)	2.48(33)	18.3(15)	0.960(58)
Sharp cutoff	1.06	1.47	−0.55	0.4	0.923(65)	2.61(33)	15.3(8)	0.961(58)
Dim. Reg. (BP)	0.79	4.15	+8.92	–	0.875(56)	3.14(25)	7.2(8)	0.923(51)

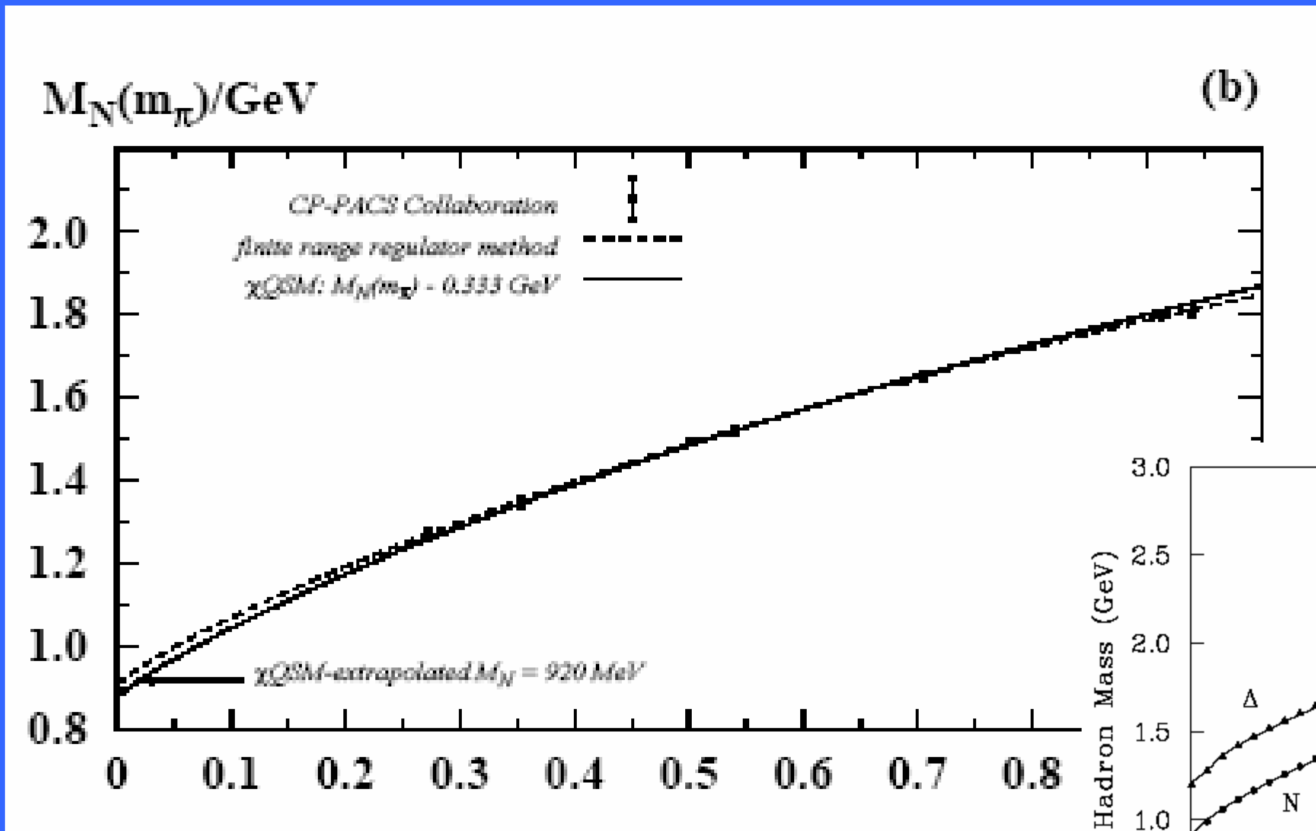
Leinweber et al., PRL 92 (2004) 242002

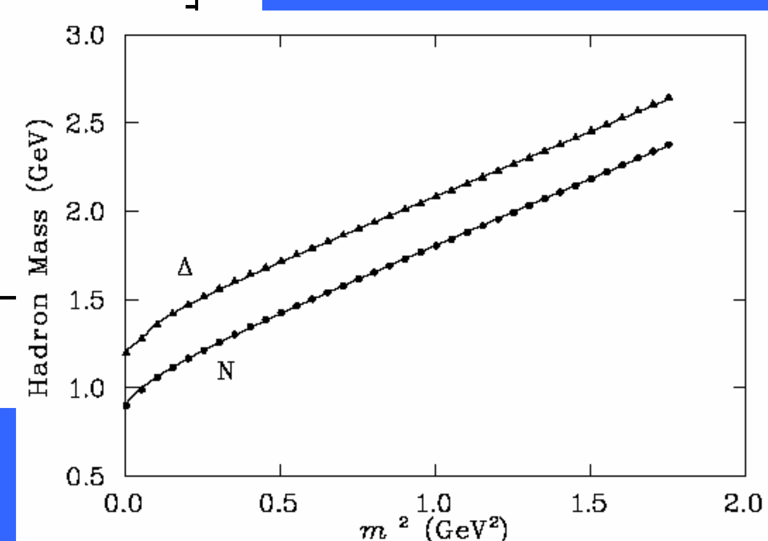
Convergence from LNA to NLNA is Rapid – Using Finite Range Regularization

Regulator	LNA	NLNA
Sharp	968	961
Monopole	964	960
Dipole	963	959
Gaussian	960	960
Dim Reg	784	884

M_N in MeV

Comparison with χ QSM





Goeke *et al.*, hep-lat/0505010

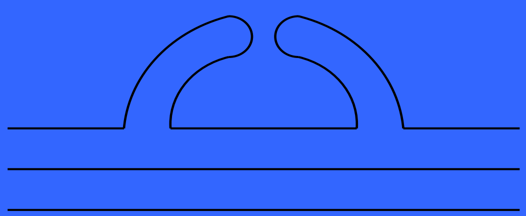
CBM: Leinweber et al.,
Phys.Rev.D61:074502,2000

Baryon Masses in Quenched QCD

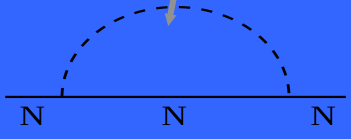
Chiral behaviour in QQCD quite different from full QCD

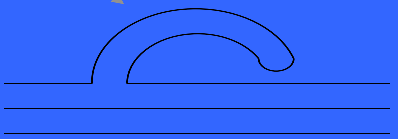
η' is an additional Goldstone Boson , so that:

$$m_N = m_0 + c_1 m_\pi + c_2 m_\pi^2 + c_3 m_\pi^3 + c_4 m_\pi^4 + m_\pi^4 \ln m_\pi + \ldots$$



Contribution from η' and π





LNA term now ~ $m_q^{1/2}$

origin is η' double pole

Extrapolation Procedure for Nucleon in QQCD

Coefficients of non-analytic terms again model independent

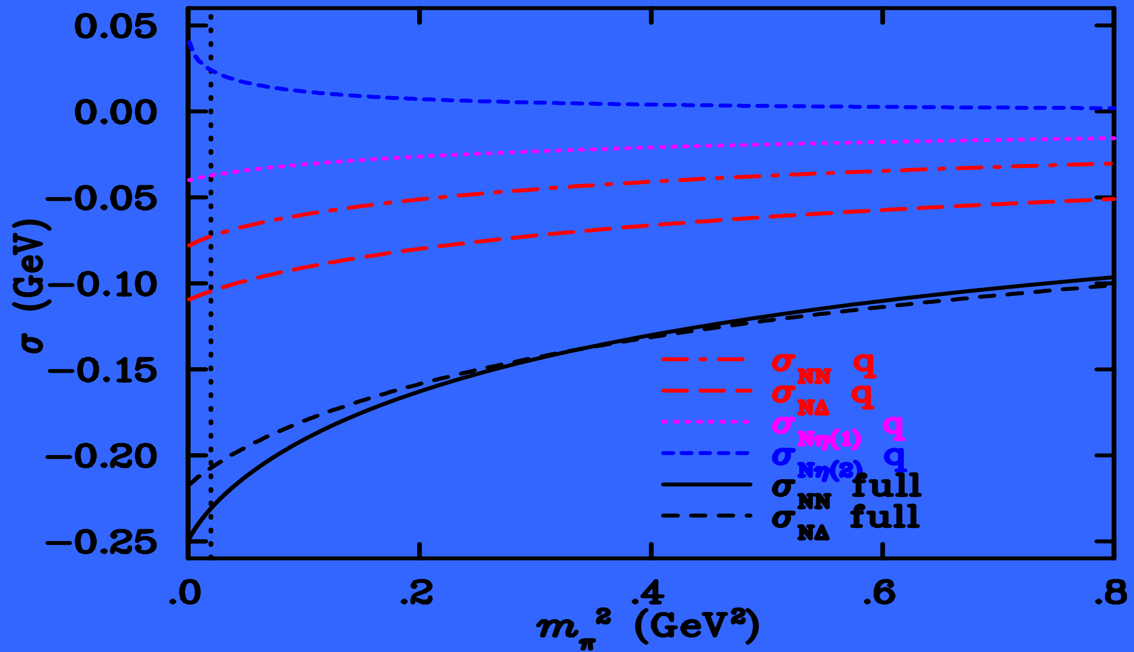
(Given by: Labrenz & Sharpe, Phys. Rev., D64 (1996) 4595)

Let:

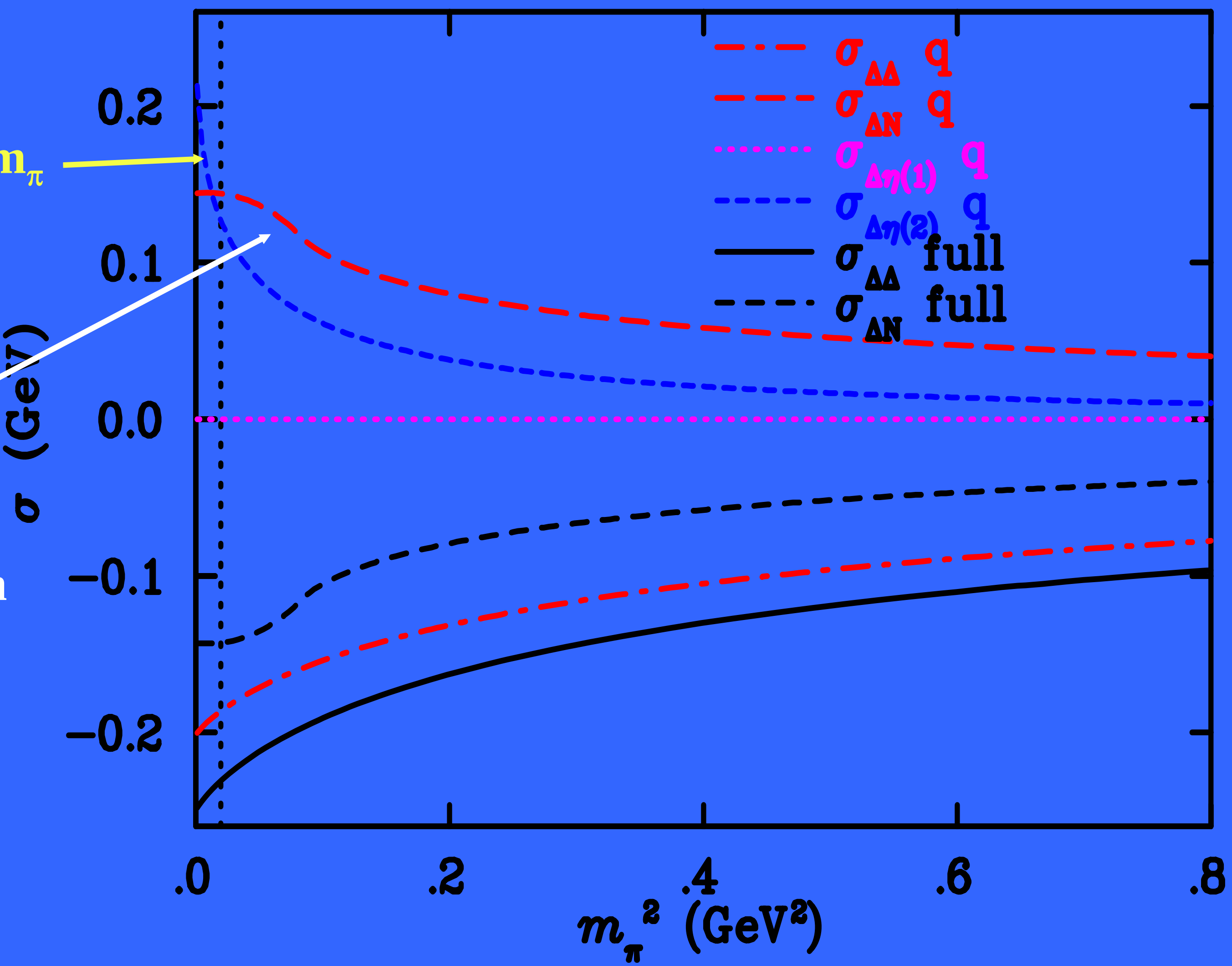
$m_N = \alpha' + \beta' m_\pi^2 + \sigma_{QQCD}$

with same Λ as

full QCD



Δ in QQCD



LNA term linear in m_π

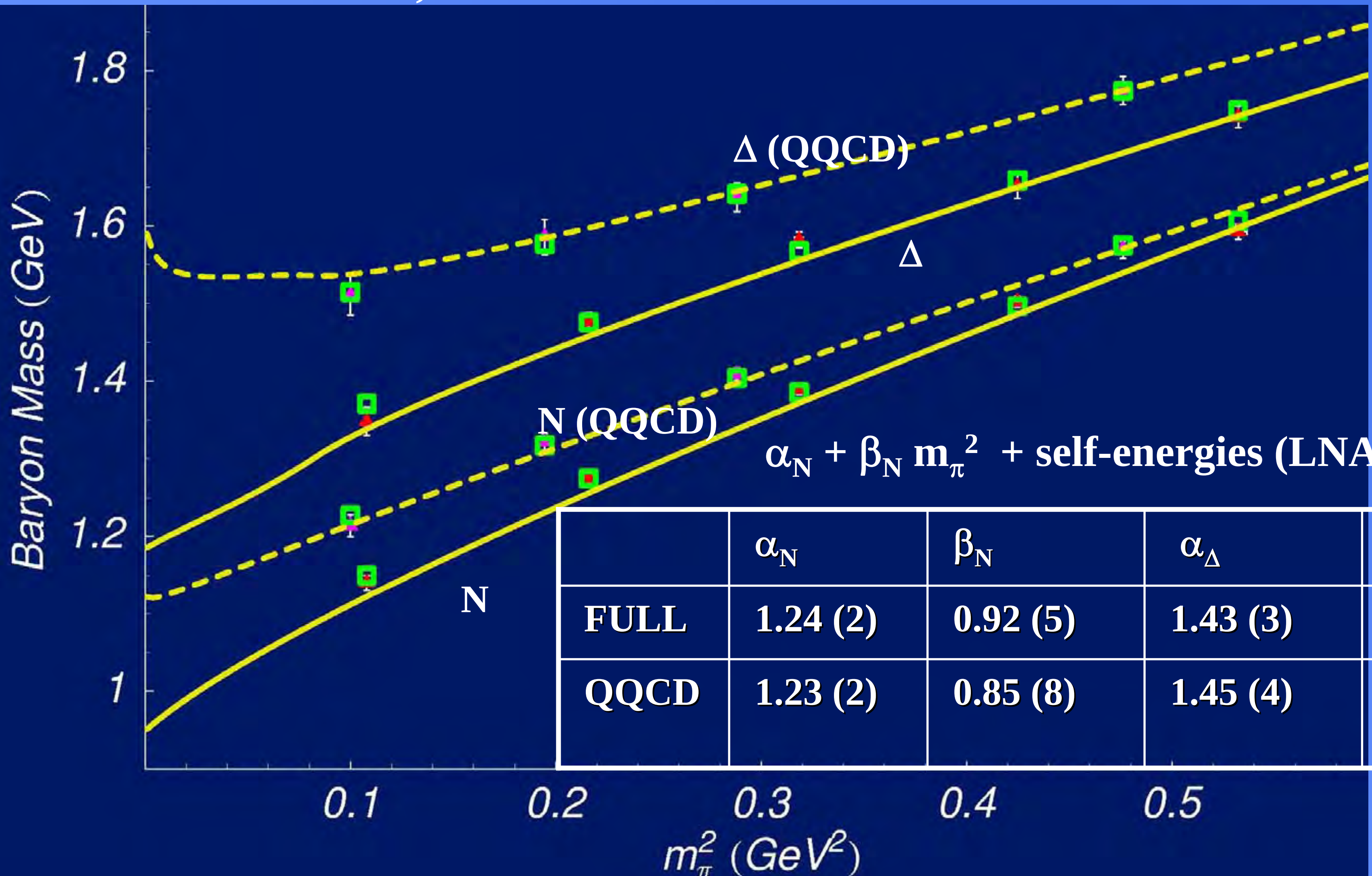
$\Delta \to N\pi$ contribution has opposite sign in QQCD (repulsive)

Overall σ_{QQCD} is repulsive !

•Lattice data (from MILC Collaboration) : red triangles

•Green boxes: fit evaluating σ's on <u>same finite grid as lattice</u>

•Lines are exact, continuum results

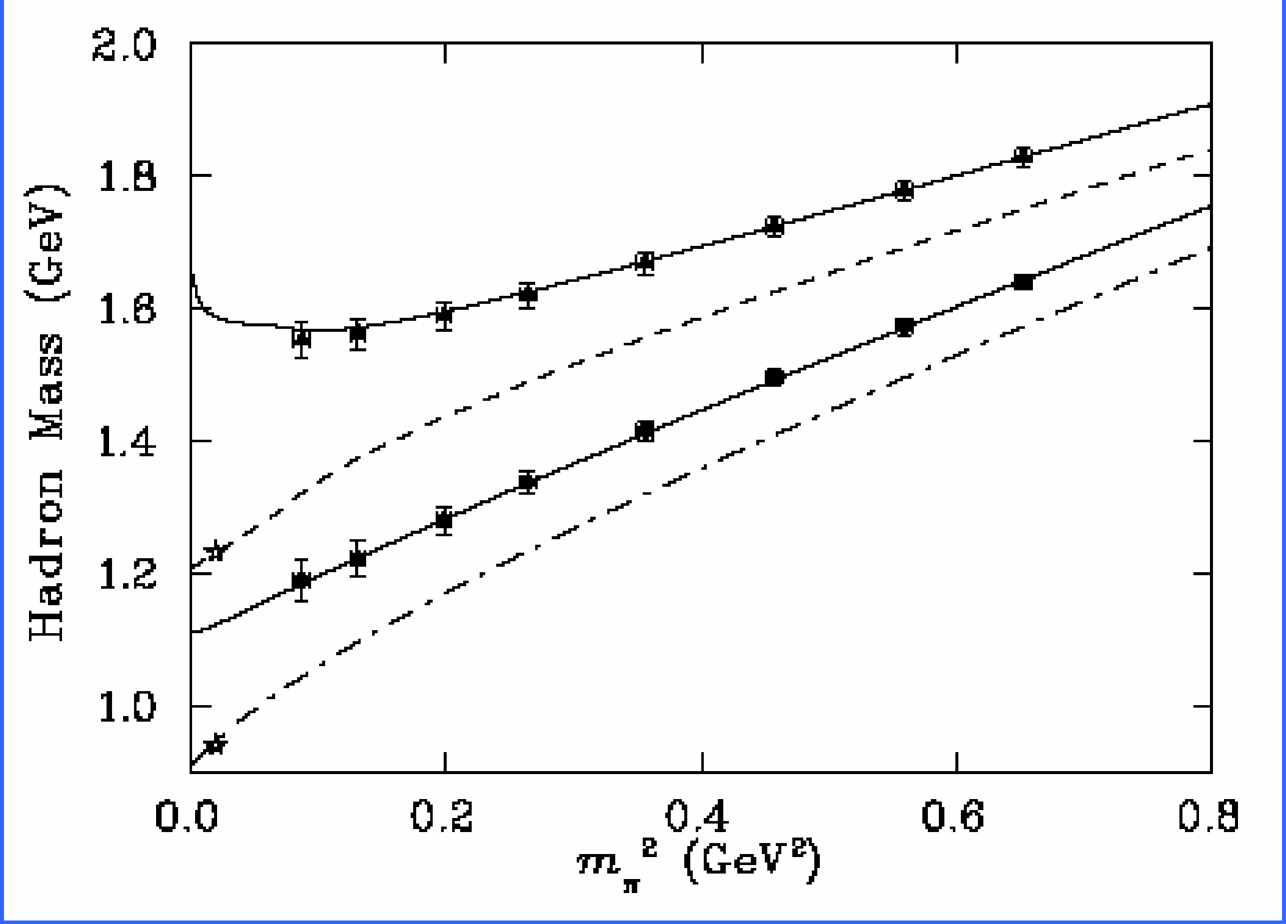


$\alpha_N + \beta_N m_\pi^2$ + self-energies (LNA+NLNA)

	α_N	β_N	α_Δ	β_Δ
FULL	1.24 (2)	0.92 (5)	1.43 (3)	0.75 (8)
QQCD	1.23 (2)	0.85 (8)	1.45 (4)	0.71 (11)

Young *et al.*, hep-lat/0111041; Phys. Rev. D66 (2002) 094507

Confirmation of Predicted Behavior of Δ



Zanotti et al., hep-lat/0407039

Decuplet-Octet Mass Splitting (QQCD)

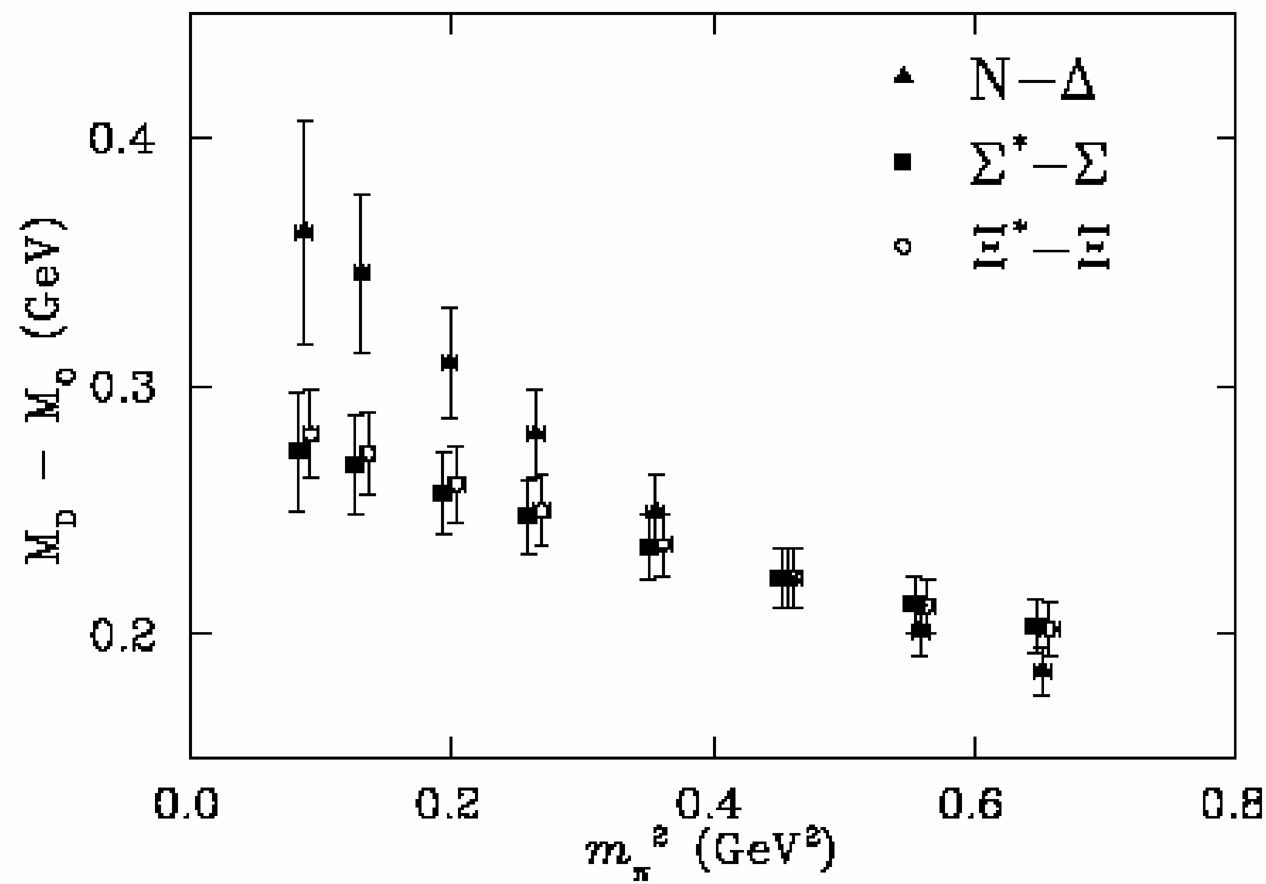


Fig. 13. Decuplet (M_D) - octet (M_O) baryon mass splittings for the FLIC-fermion action on a $20^3 \times 40$ lattice with $a = 0.132$ fm.

Zanotti et al., hep-lat/0407039

These results suggest following conjecture

IF lattice scale is set using static quark potential (e.g. Sommer scale)

(insensitive to chiral physics)

Suppression of Goldstone loops for $m_\pi > \Lambda$ implies:

Analytic terms (e.g. $\alpha + \beta\, m_\pi^2 + \gamma\, m_\pi^4$)

representing "hadronic core" are the same in QQCD & QCD

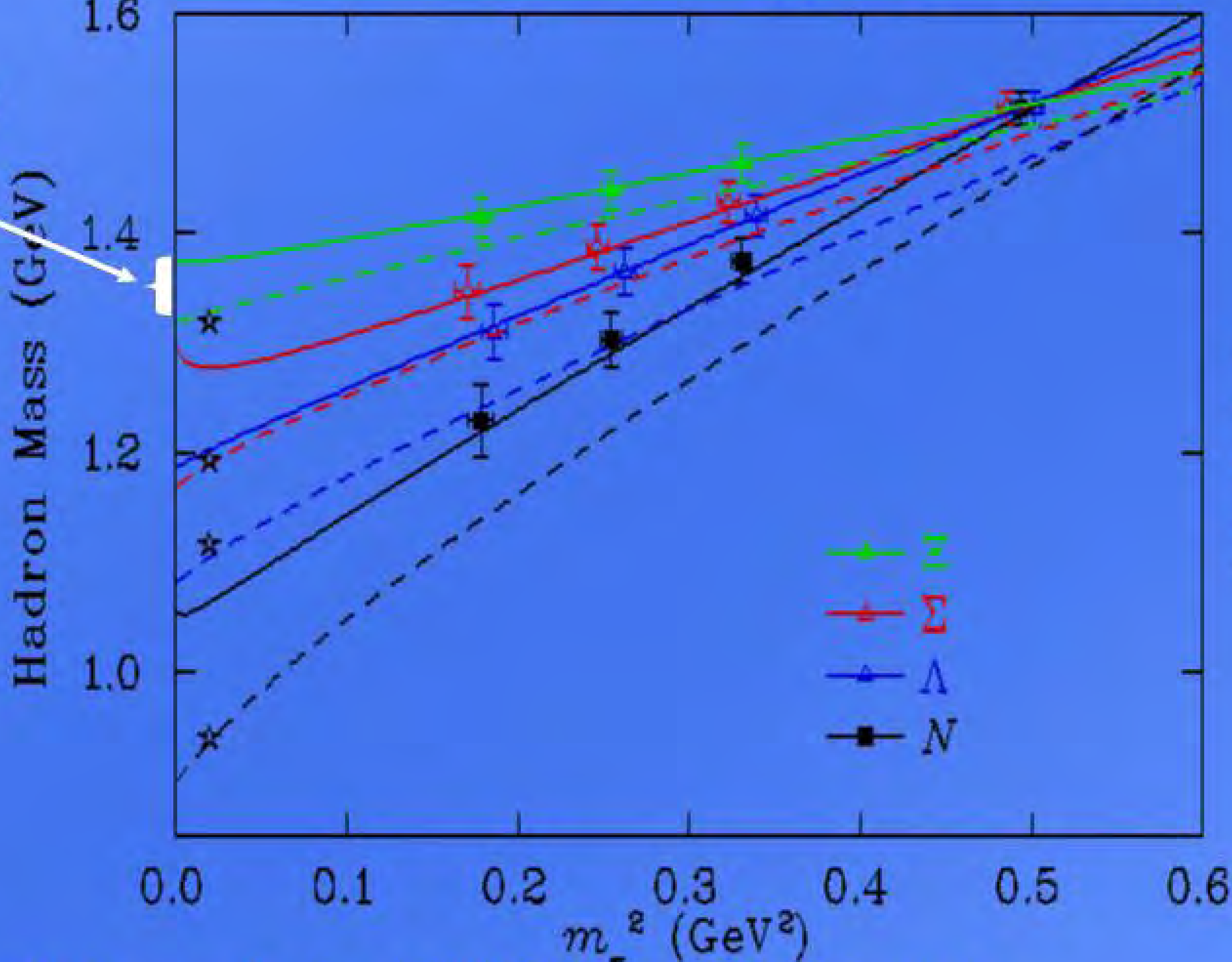
Can then correct QQCD results by replacing LNA & NLNA behaviour in QQCD by corresponding terms in full QCD

Quenched QCD is then no longer an "uncontrolled approximation" !

Octet Masses

Fit quenched data with : $\alpha + \beta\, m_\pi^2 + \sigma_{QQCD}$; then $\sigma_{QQCD} \rightarrow \sigma_{QCD}$

Effect of unquenching a mere 50- 60 MeV

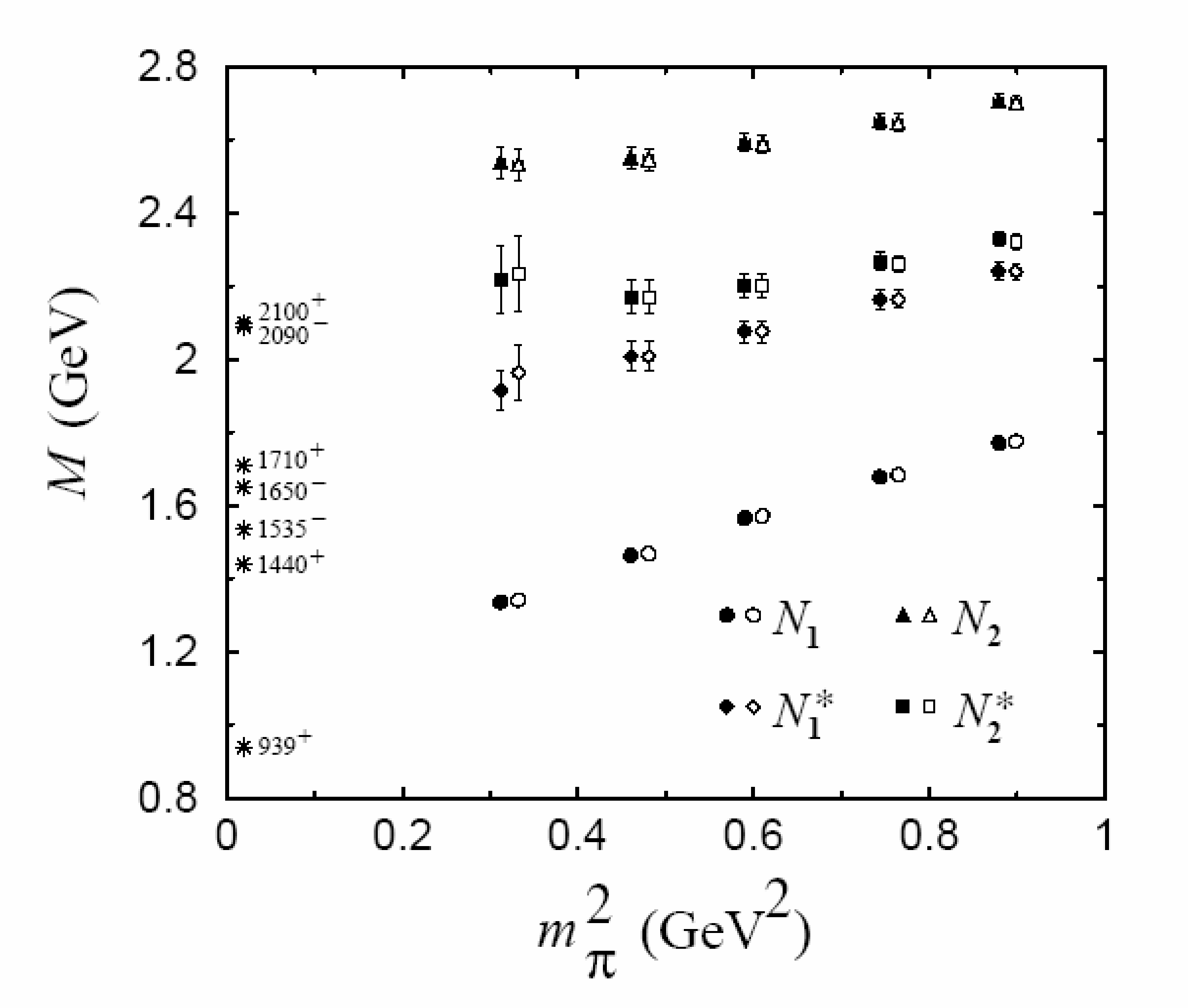


Errors for:
- **Stats**
- **a→ 0**
- **finite L**

NOT SHOWN

(Early results from CSSM: Young, Zanotti et al.)

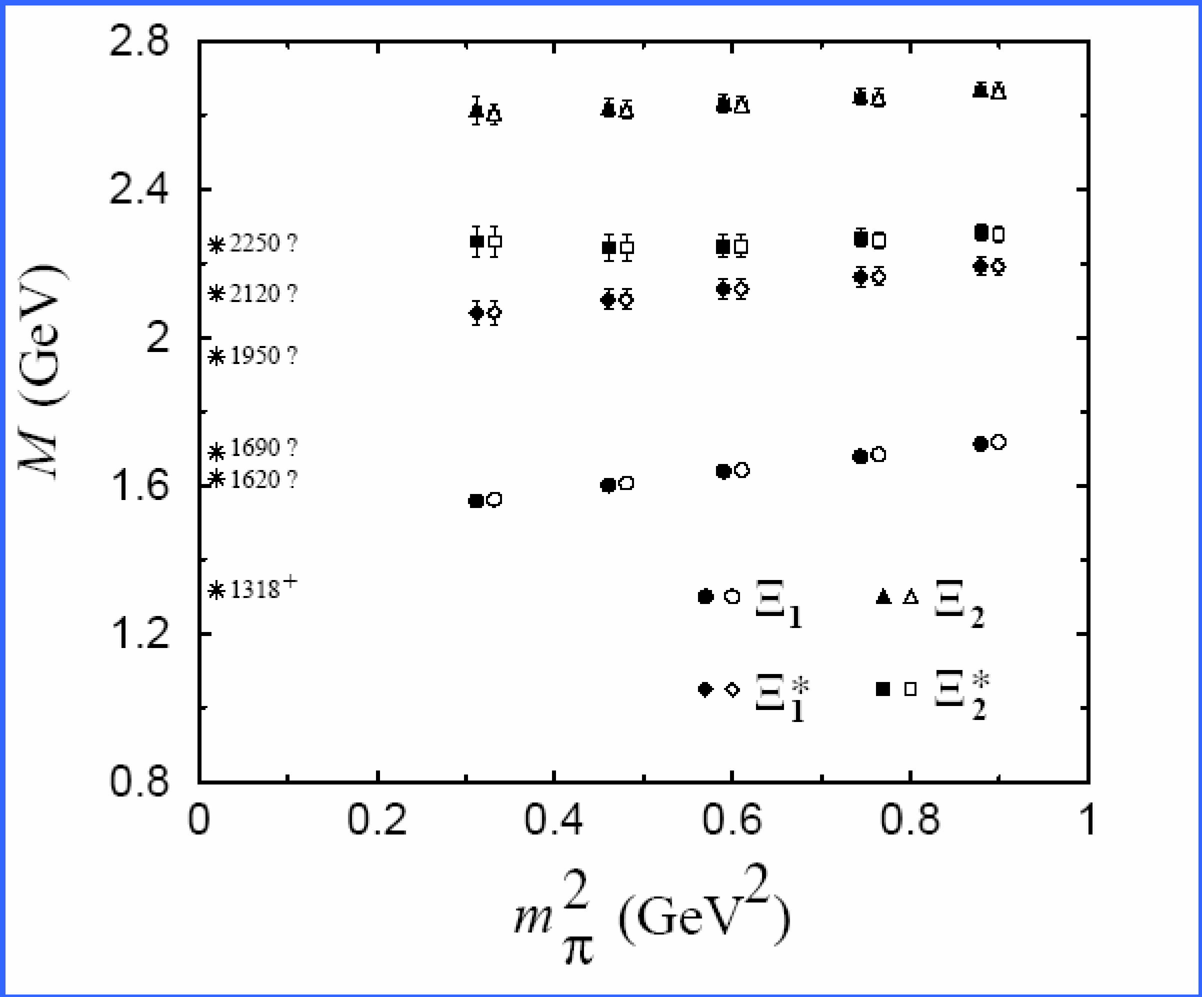
Oscillator-type Spectrum



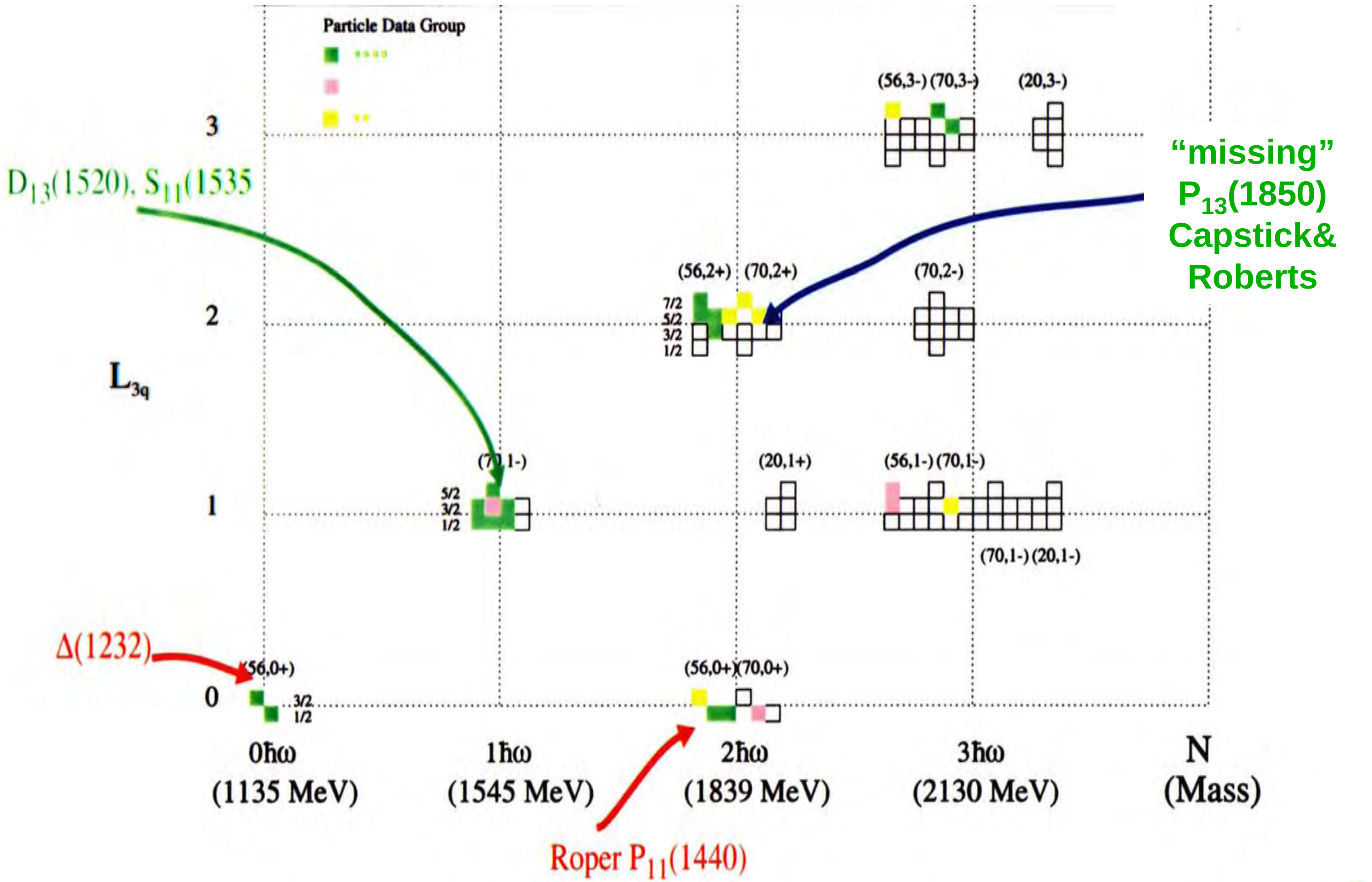
Melnitchouk et al., hep-lat/0202022

Ξ Baryons

Exploratory work from CSSM group… QQCD



Baryon Spectroscopy: e.g. "Missing States"



Excited-Baryon Analysis Center

A proposal for the establishment of an excited-baryon analysis center at JLab

HP 2009

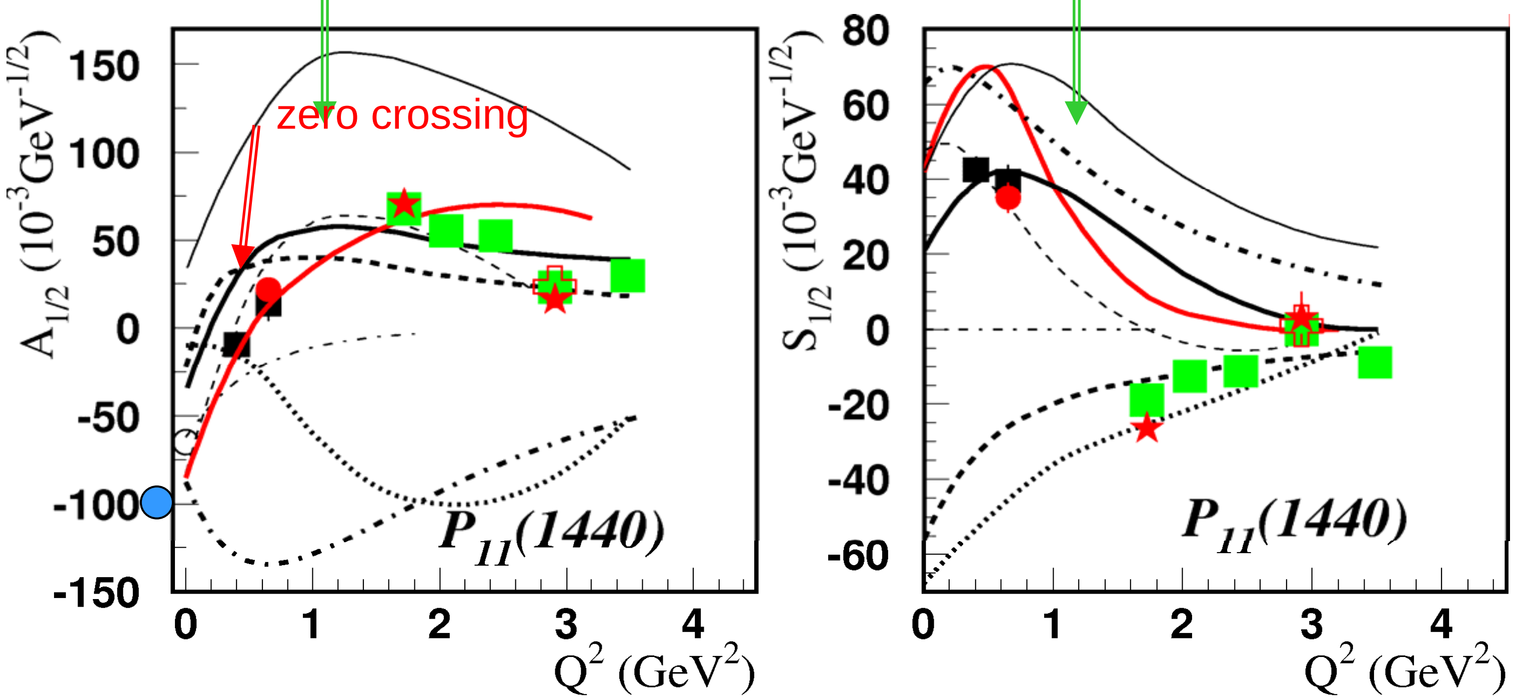
- Role: **To develop theoretical tools (e.g. coupled channel; EFT) to analyze existing & future CLAS (and other) data**

- Scientific relevance:
  - **i) identify new baryon resonances**
  - **ii) measure couplings & transition form factors**
  - **iii) comparison with LQCD**
  - **iv) deepen understanding of how QCD is realized**

- Critical theoretical issues:
  - **i) background-resonance separation**
  - **ii) incorporation of multi-particle final states**
  - **iii) importance of unitarity, analyticity…**

Transition form factor γp $P_{11}(1440)$

- Transition from meson-cloud behavior to quark core behavior ?



- ■ ■ ● UIM analysis of CLAS $p\pi^0$, $n\pi^+$, data
- Low Q^2 behavior consistent with meson-cloud model
- High Q^2 behavior consistent with small quark core
- Roper amplitudes not consistent with gluonic excitation??

Summary

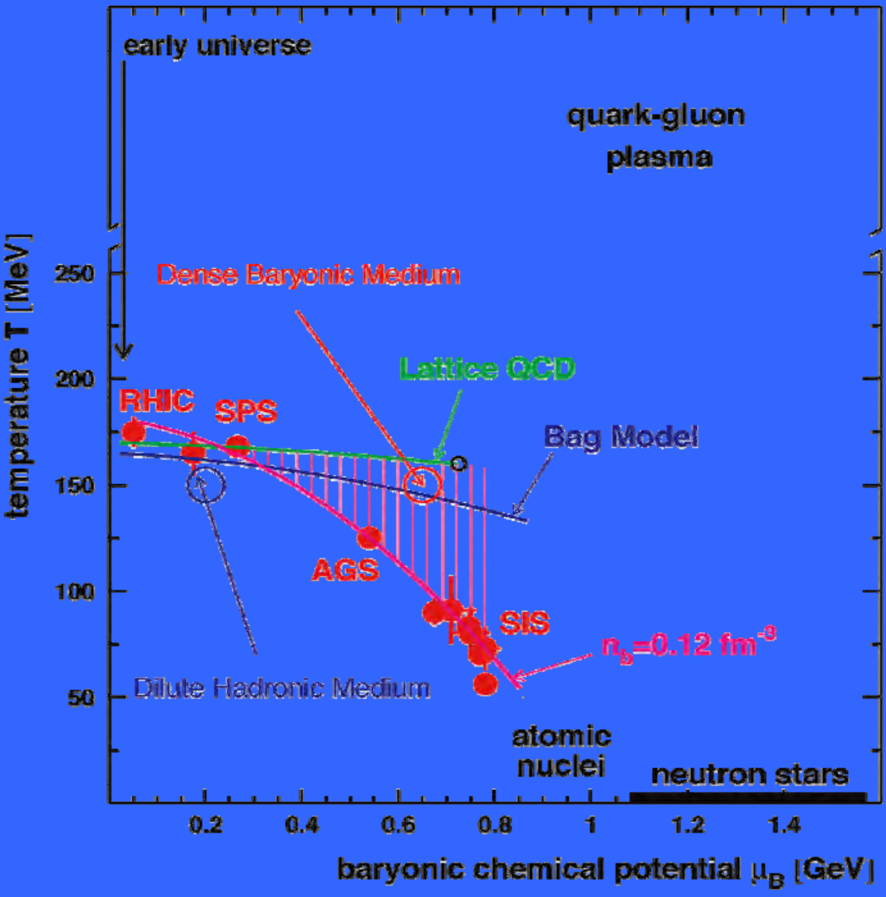
- Can now make lattice calculations with correct m_s and light quark mass 3 - 4 times true value

- more about this from David Richards and Costas Orginos …..

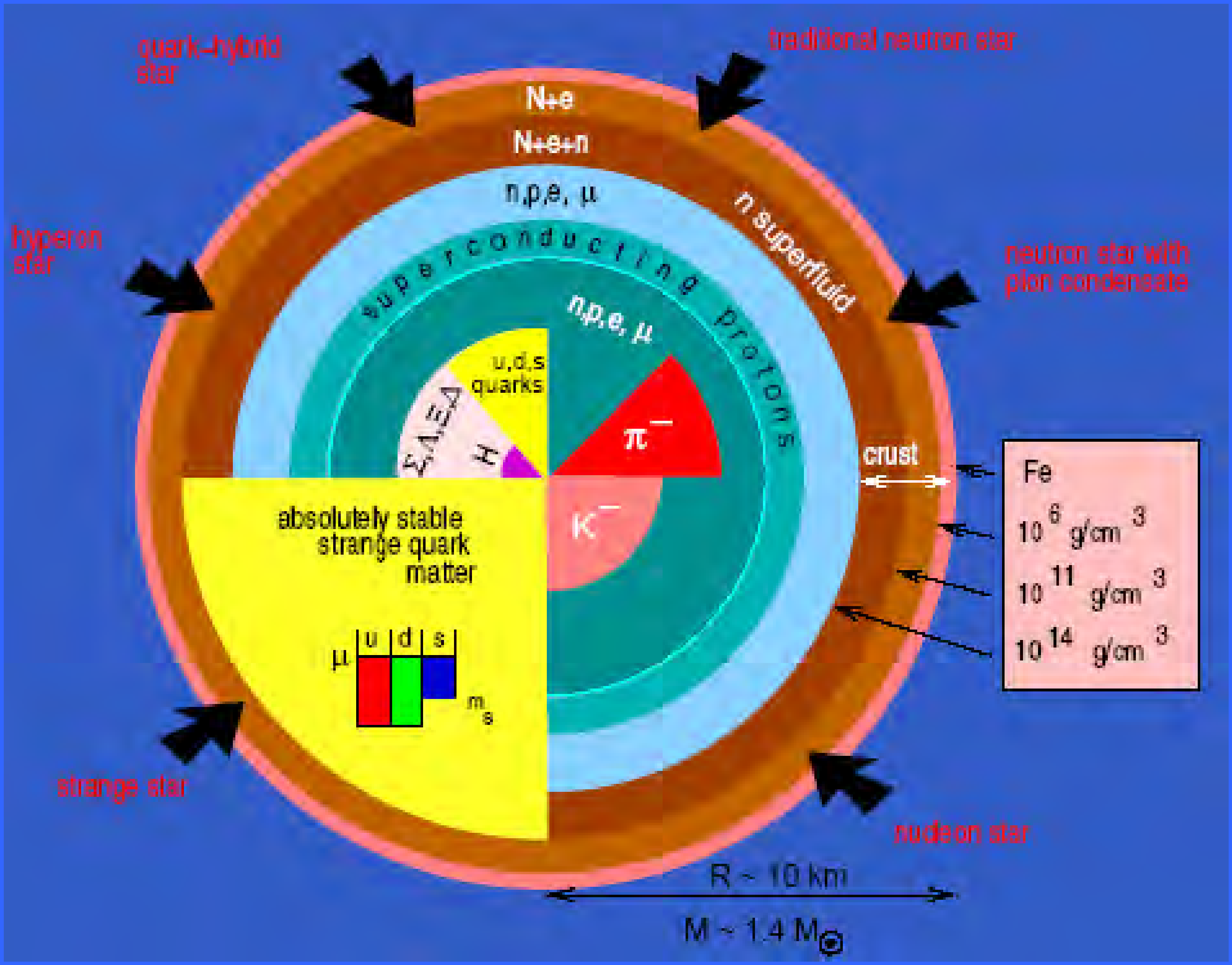
- Chiral corrections scale like square of number of non-strange quarks $\Rightarrow$ for Ξ^* only 10% of N^*

- Finally, much narrower than non-strange baryons of similar mass (same reason as chiral corrections) and hence less difficult to extract from background

Major Challenges for Nuclear Physics



- Origin of Nuclear Saturation
- EOS … as ρ ↑ ; as T ↑
  as S ↑ ; as N-Z ↑
- Phase Transition to:
  - quark matter (QM), superconducting QM, strange condensate
  - related to nuclear astrophysics; n-stars….


quark–hybrid star
traditional neutron star
N+e
N+e+n
n,p,e, μ
n superfluid
hyperon star
neutron star with pion condensate
superconducting protons
n,p,e, μ
u,d,s quarks
Σ,Λ,Ξ,Δ
H
π⁻
crust
Fe
10 6 g/cm 3
10 11 g/cm 3
10 14 g/cm 3
K⁻
absolutely stable strange quark matter
μ
u d s
m s
strange star
nucleon star
R ~ 10 km
M ~ 1.4 M☉

Linking QMC to Familiar Nuclear Theory

- Since early 70's tremendous amount of work in nuclear theory is based upon effective force
- Used for everything from nuclear astrophysics to collective excitations of nuclei
- Skyrme Force: Vautherin and Brink
- Systematic phenomenology analogous to phase shifts connecting data and deeper derivation of NN force

P. Guichon and A.W. Thomas, Phys. Rev. Lett. 93, 132502 (2004)

Microscopic Origin of Skyrme Force

	QMC	Skyrme III	QMC(N=3)
$m_\sigma (MeV)$	600		600
$t_0 (MeV\ fm^3)$	-1082	-1129	-1047
x_0	0.59	0.45	0.61
$t_3 (MeV\ fm^6)$	14926	14000	12996
M_{eff}/M	0.814	0.763	0.821
$5t_2 - 9t_1 (MeV\ fm^5)$	-4330	-4030	-4036
$W_0 (MeV\ fm^5)$	97	120	91

$$\frac{M_{eff}}{M} = \left(1 + \frac{(3t_1 + 5t_2) M \rho_0}{8}\right)^{-1}$$

Guichon & Thomas, PRL 93 (2004) 132502

Great Start: What's Next

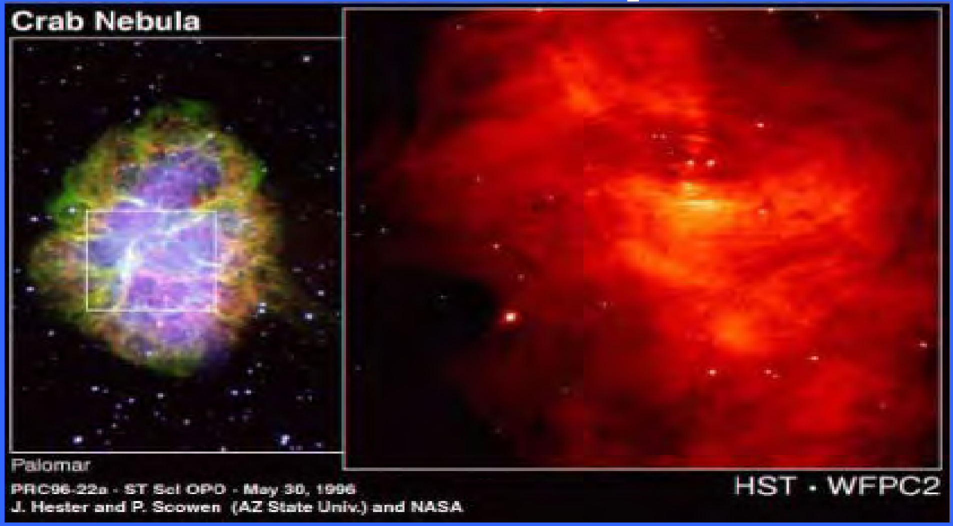
- Remove zero-range approximation
- Derive density-dependent forms
- Add the pion
- Derive Λ N, Σ N, Λ Λ … effective forces in-medium
  with no additional free parameters!
- Hence attack dense hadronic matter, n-stars,
  transition from NM to QM or SQM with
  more confidence

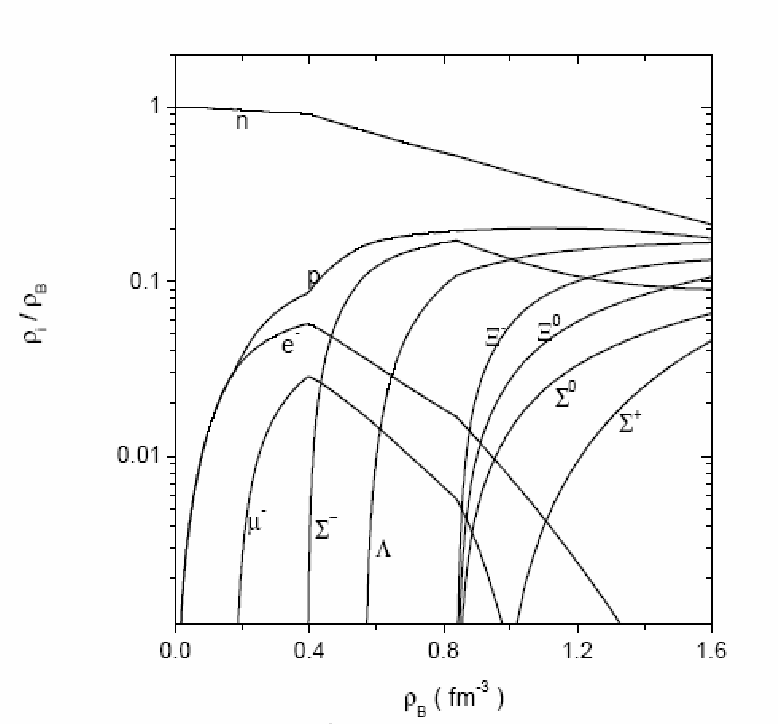
Neutron Star Composition

Hyperons enter at just 2-3 ρ_0

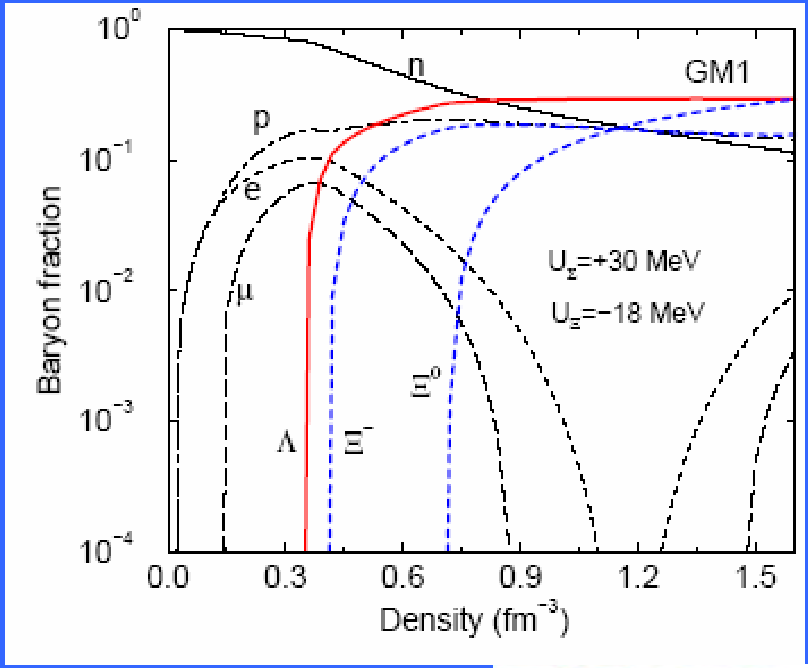
Hence need effective Σ-N and Λ-N forces in this density region!

Hypernuclear data is important input





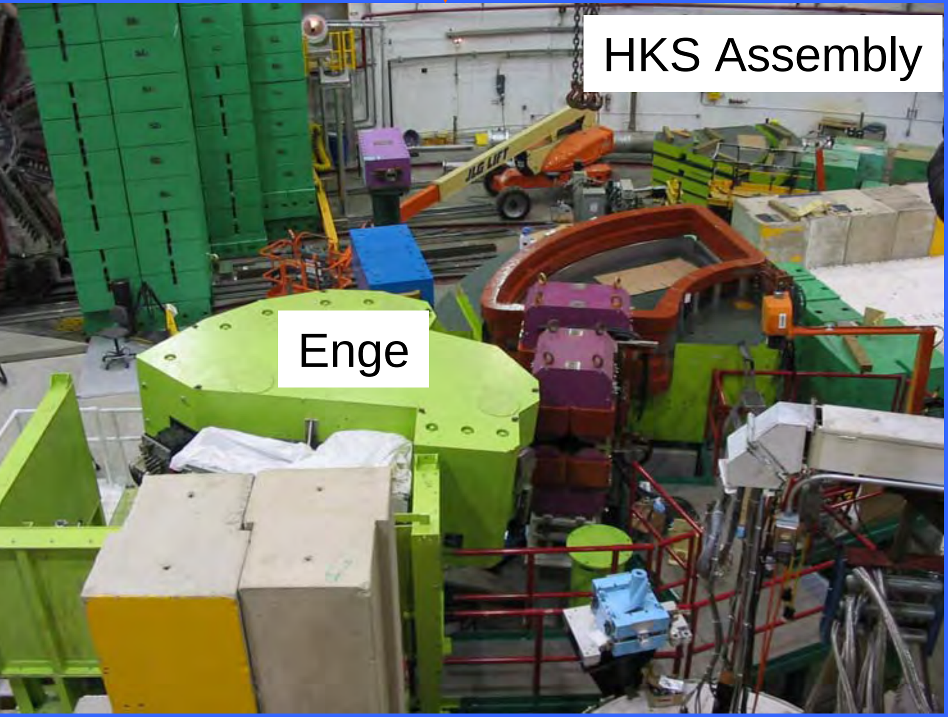
?



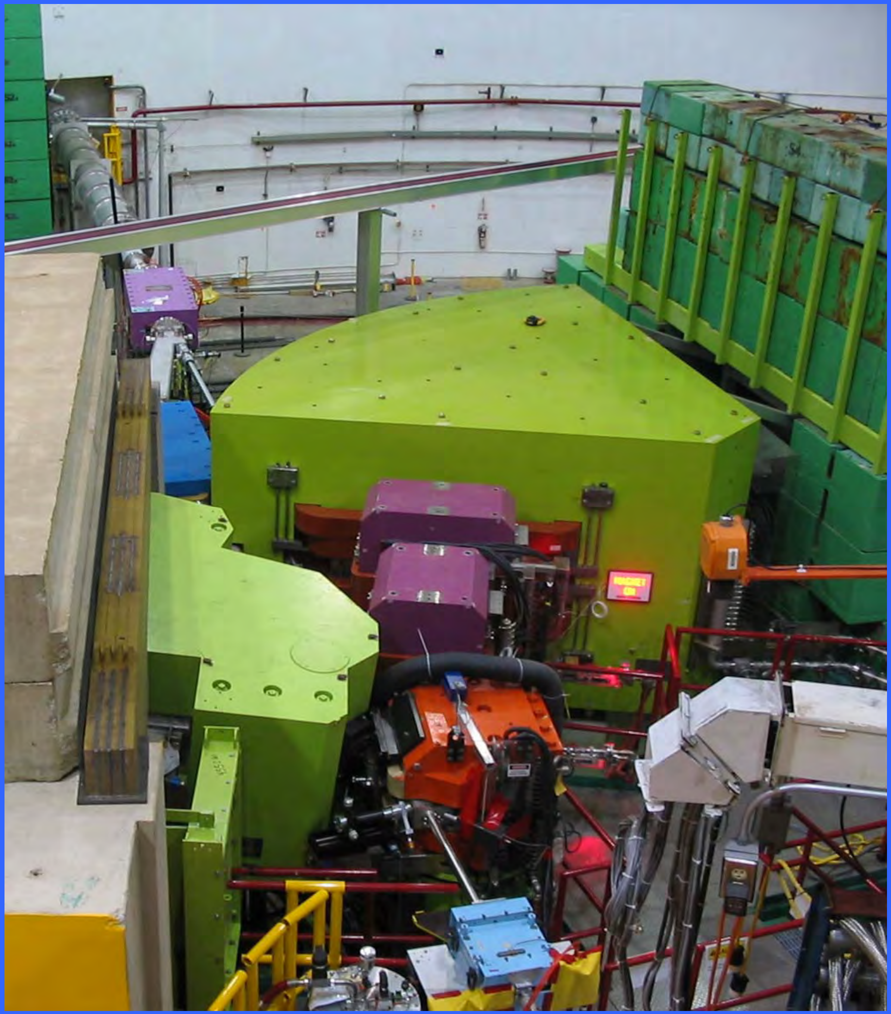
Present Installation: HKS

Present Hypernuclear Spectroscopy equipment combination is beam splitter, Enge (e^-), HKS (K^+)

Installation ongoing in Hall C (April 13)



Installation completed



Desperate need for data…

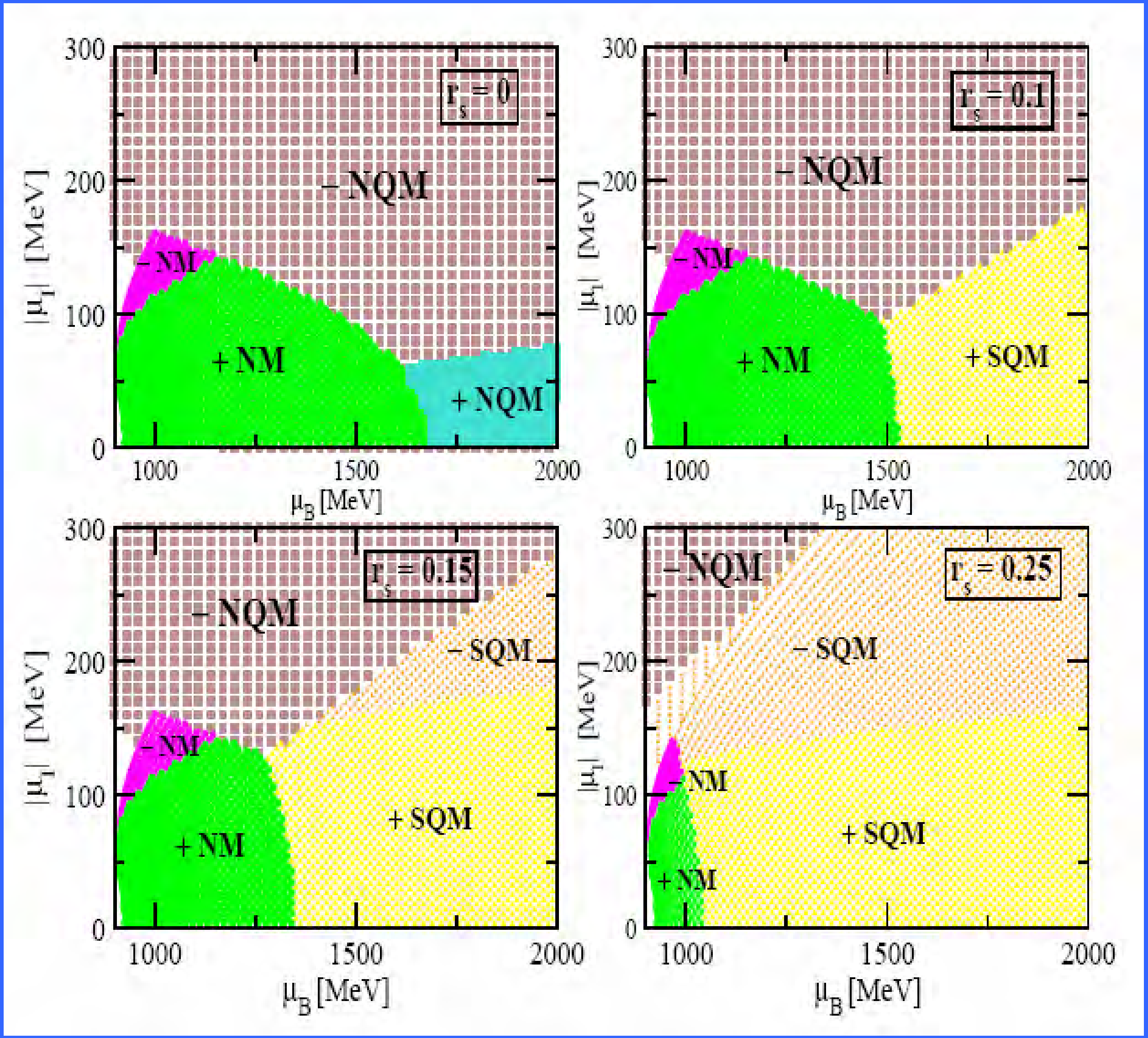
- Only one Σ hypernucleus known to be bound

- BUT for doubly strange hypernuclei world has only 6 <u>events</u> (most controversial)

- Would be tremendous help in attempting to understand EOS for dense matter to have real data for Σ and Ξ hypernuclei!

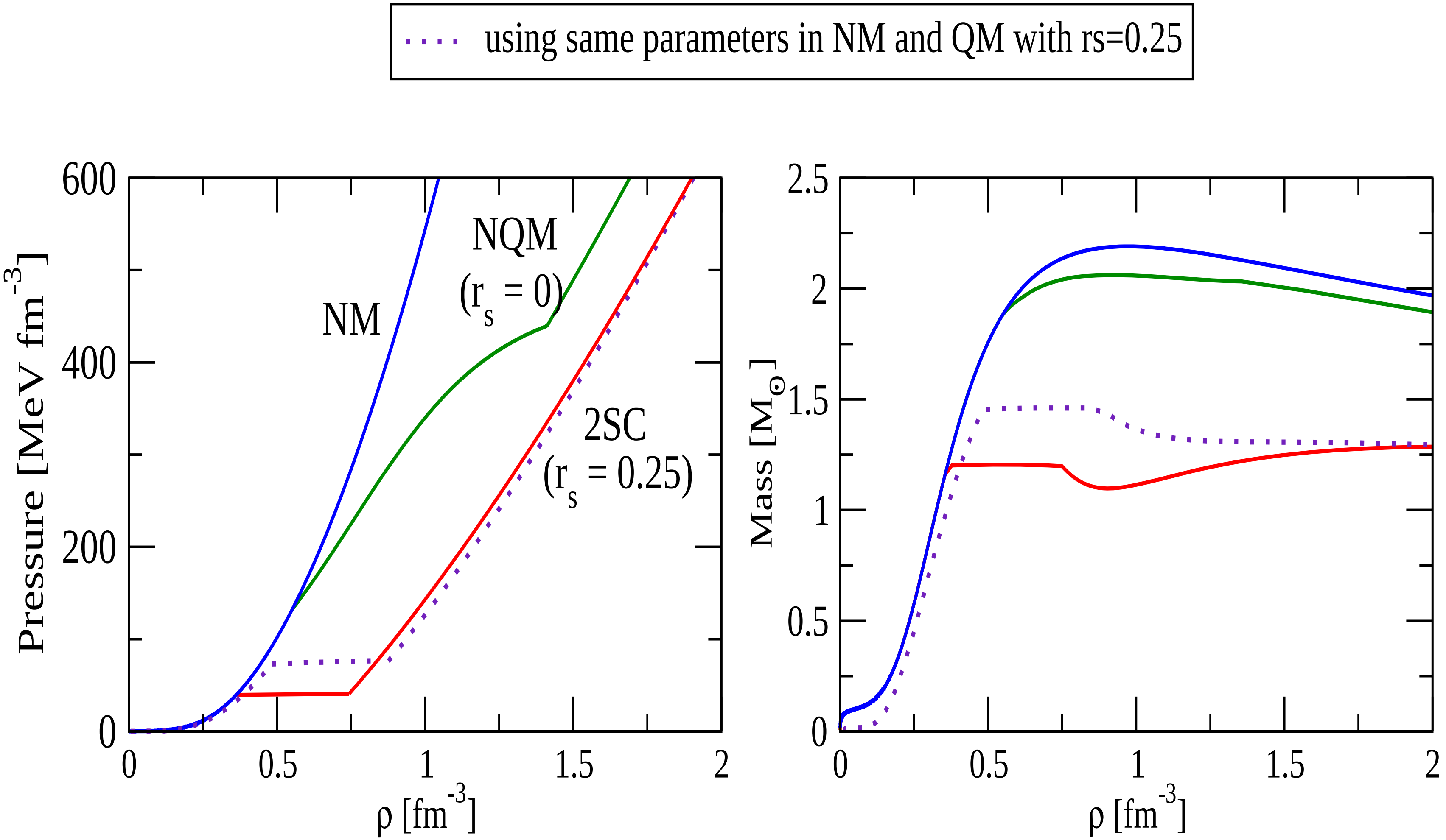
- <u>If</u> JLab can contribute it would be a major step forward

Covariant, NJL model with confinement and QMC mechanism for saturation of nuclear matter



Lawley, Bentz, AWT, nucl-th/0504020

Neutron Star Properties with Pairing Constraint



Conclusion

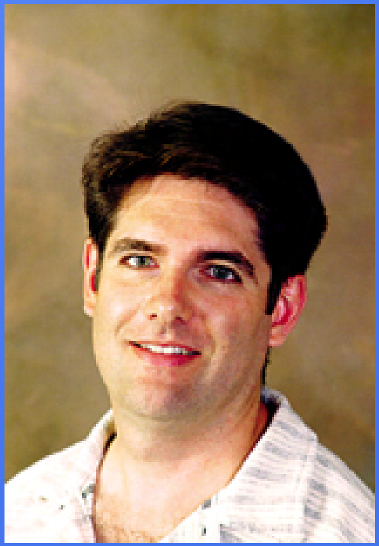
- It appears that we may have wonderful opportunities to contribute in a genuinely new way to baryon spectroscopy - with theory and experiment better able to work together

- There may also be an opportunity to extend our understanding of nuclear matter along a new axis - non-zero strangeness

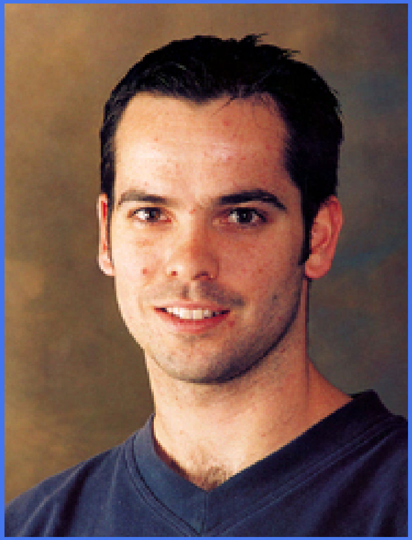
- I look forward to learning over the next two days just what the experts meeting here have to say about these issues

"QUARKS. NEUTRINOS. MESONS. ALL THOSE DAMN PARTICLES YOU CAN'T SEE. THAT'S WHAT DROVE ME TO DRINK. BUT NOW I CAN SEE THEM."

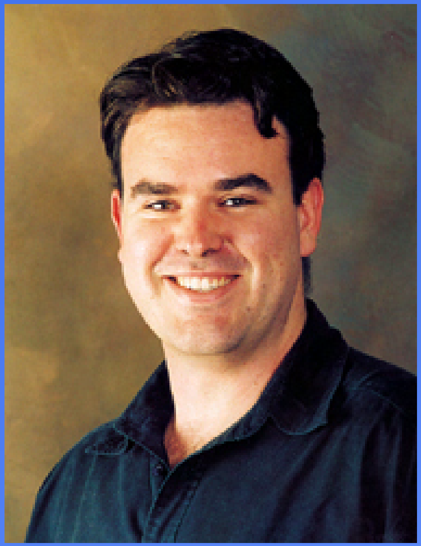
Special Mentions……
Mentions……



Derek Leinweber



Ross Young



Stewart Wright

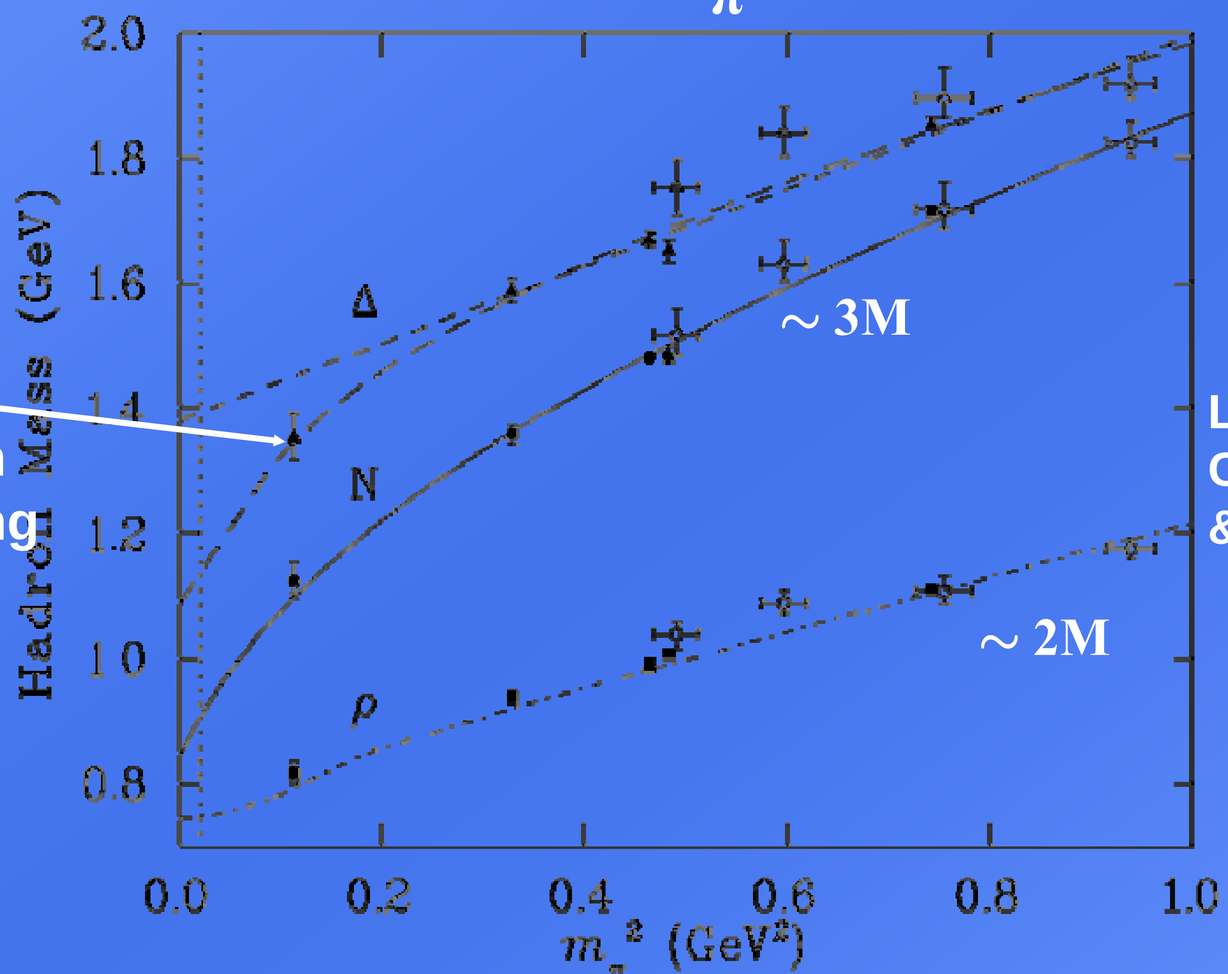
Behaviour of Hadron Masses with m_π

Hadron Masses with m_π

m_π

From: Leinweber *et al.*, Phys. Rev., D61 (2000) 074502

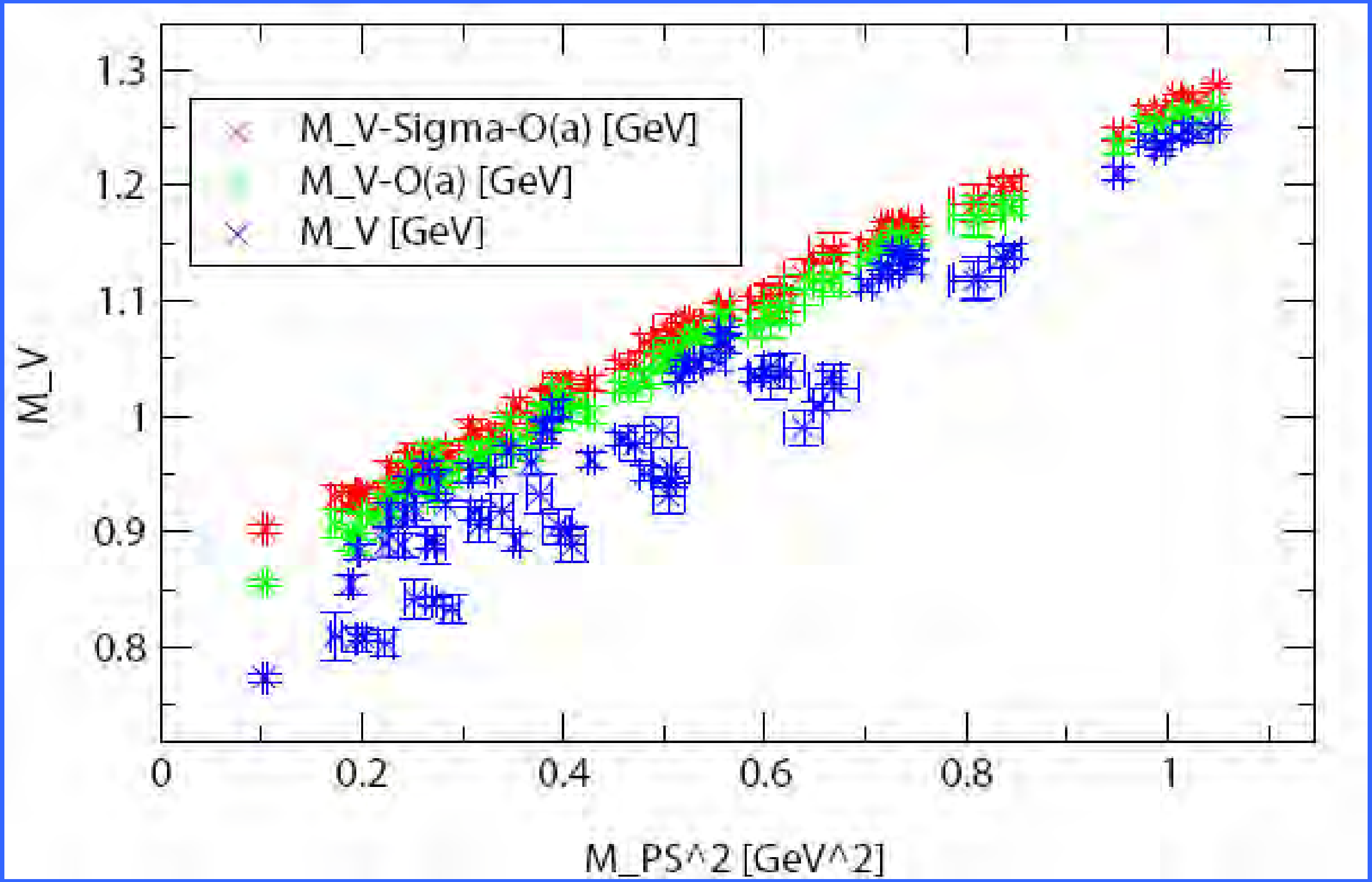
Point of inflection at opening of N π channel



Lattice data from CP-PACS & UKQCD

BUT how <u>model dependent</u> is the extrapolation to the physical point?

Analysis of pQQCD ρ data from CP PACS

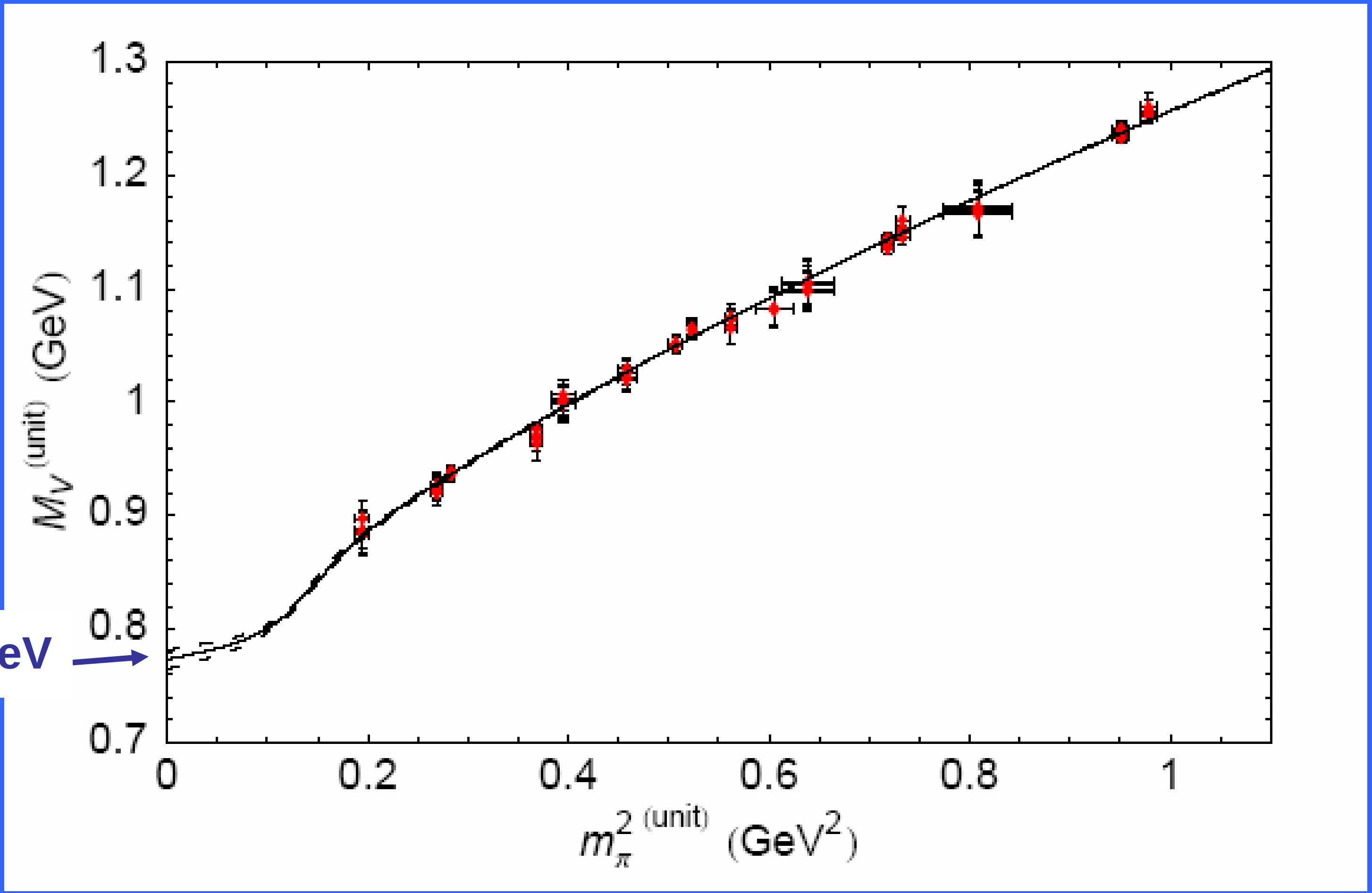


$$\sqrt{(M_V^{deg})^2 - \Sigma_{TOT}} = (a_0^{cont} + X_1 a + X_2 a^2) + a_2 (M_{PS}^{deg})^2 + a_4 (M_{PS}^{deg})^4 + a_6 (M_{PS}^{deg})^6$$

Infinite Volume Unitary Results

All 80 data points drop onto single, well defined curve

777 ± 7 MeV



Allton, Young *et al.*, hep-lat/0504022

Lattice QCD Simulation of Vacuum Structure