Electromagnetic structure of charmed hadrons in QCD

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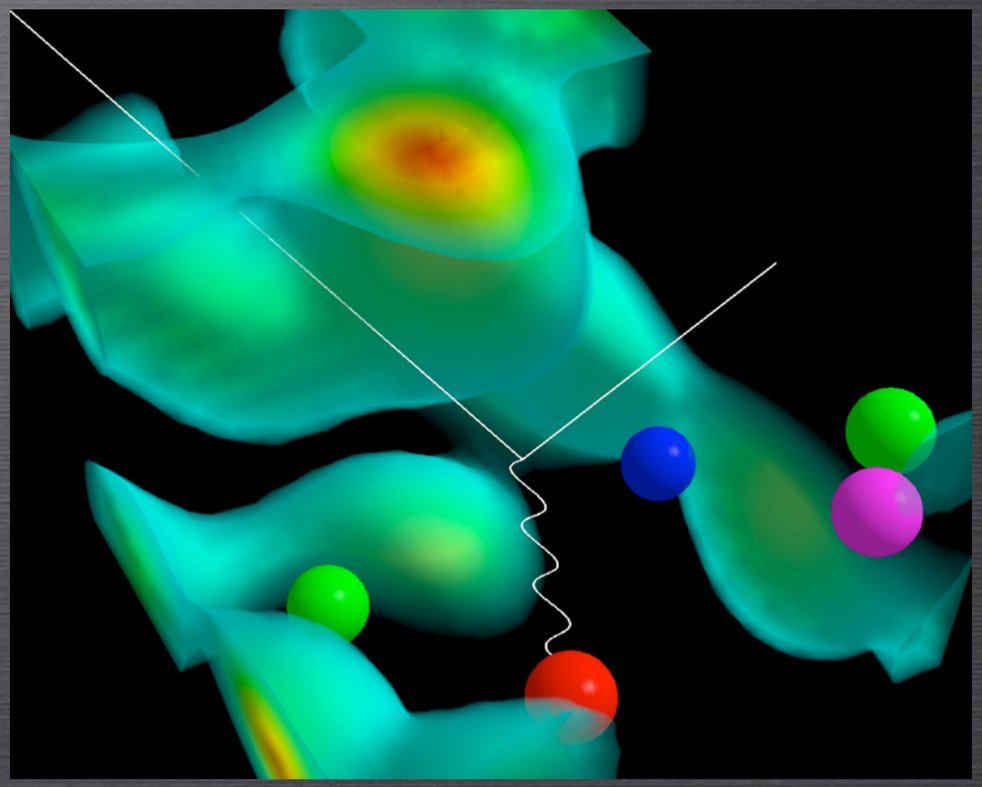
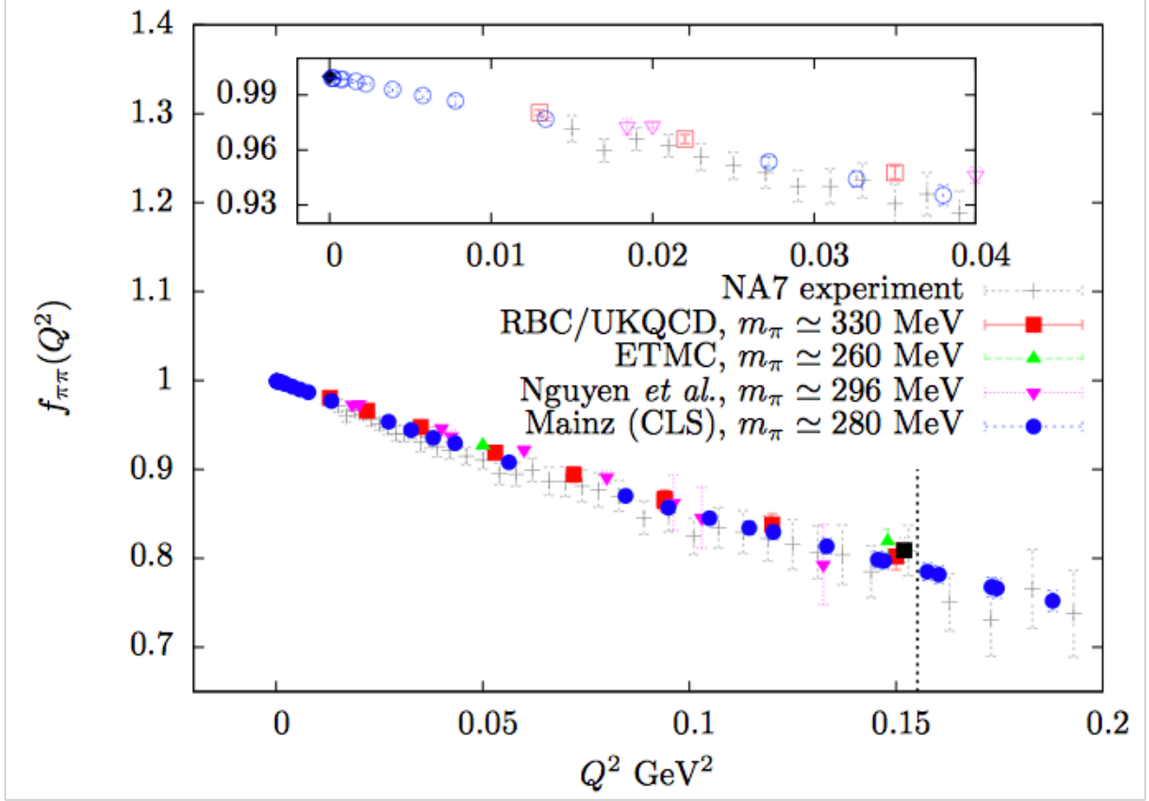
QUESTIONS

- What does QCD tell us about hadron structure and interactions?
- How do hadrons interact?
- To what extent are flavor symmetries such as SU(4) valid?
- What are the size and shape of hadrons?
- What is the role of the heavy quark?

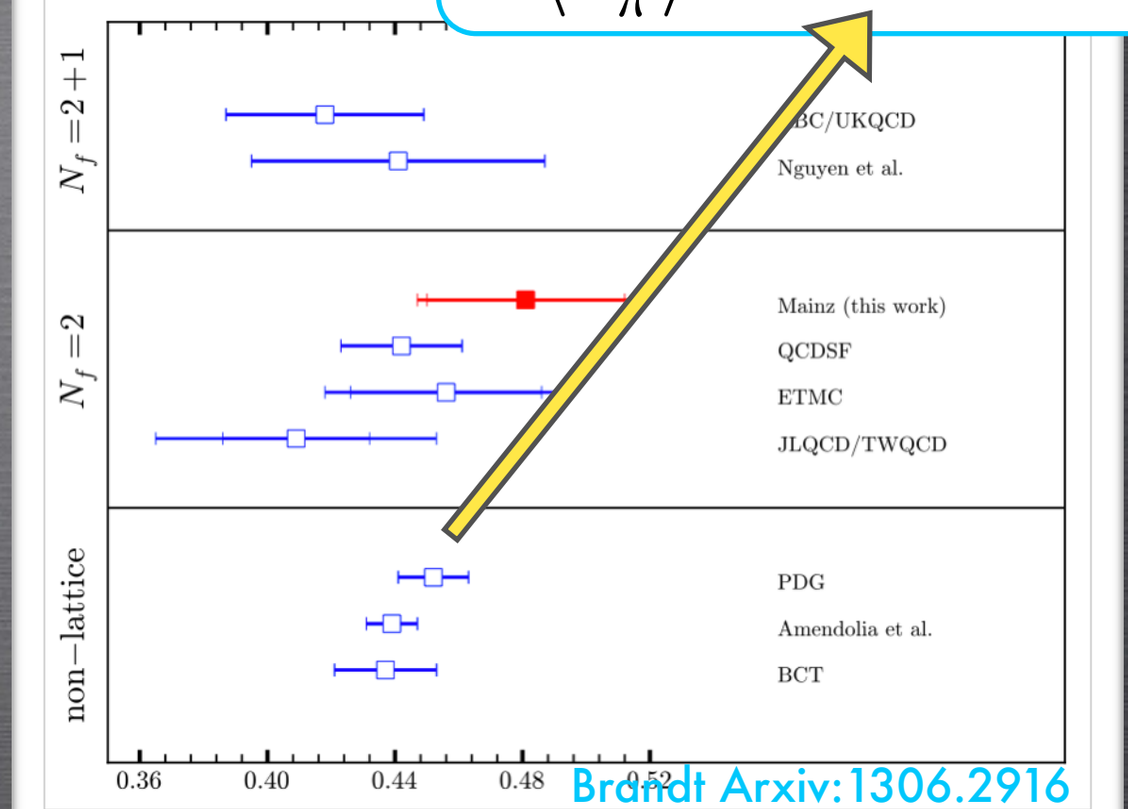


Visualizations of QCD, D. Leinweber

PION EM FORM FACTOR



$$\langle r_\pi^2 \rangle = 0.452 \text{ fm}^2$$

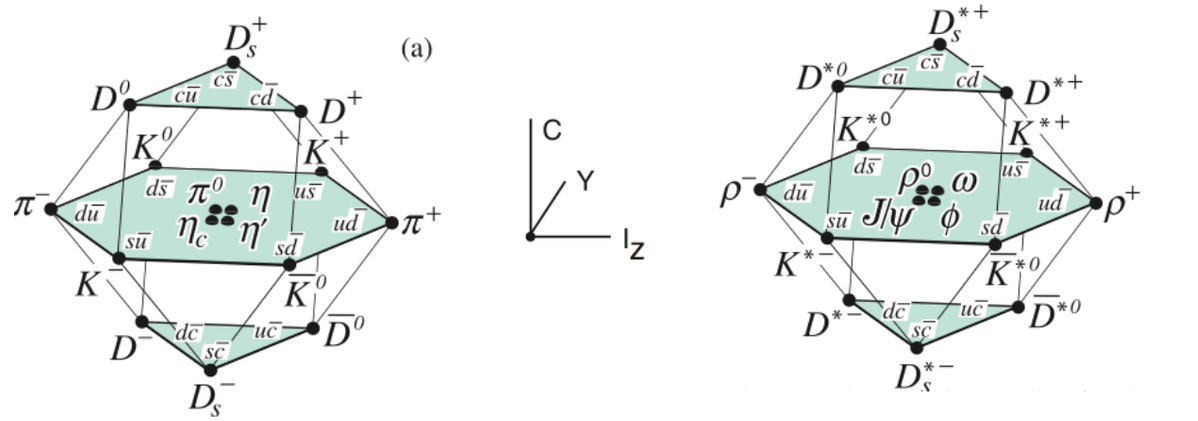


Brandt Arxiv:1306.2916

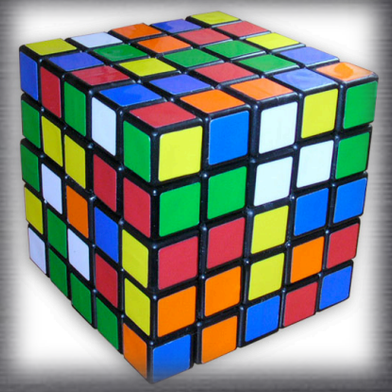
Brandt Arxiv:1310.6389

$$\langle M(p')|V_\mu(q)|M(p)\rangle = (p+p')F_E(Q^2)$$

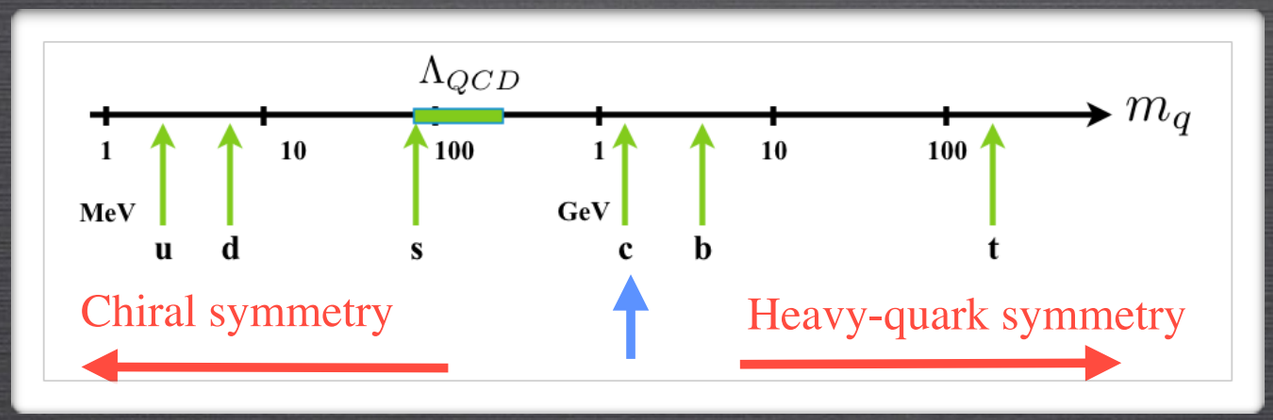
$$\langle r_E^2 \rangle = -\frac{6}{F_E(0)}\frac{d}{dQ^2}F_E(Q^2)\Big|_{Q^2=0}$$



LATTICE DETAILS

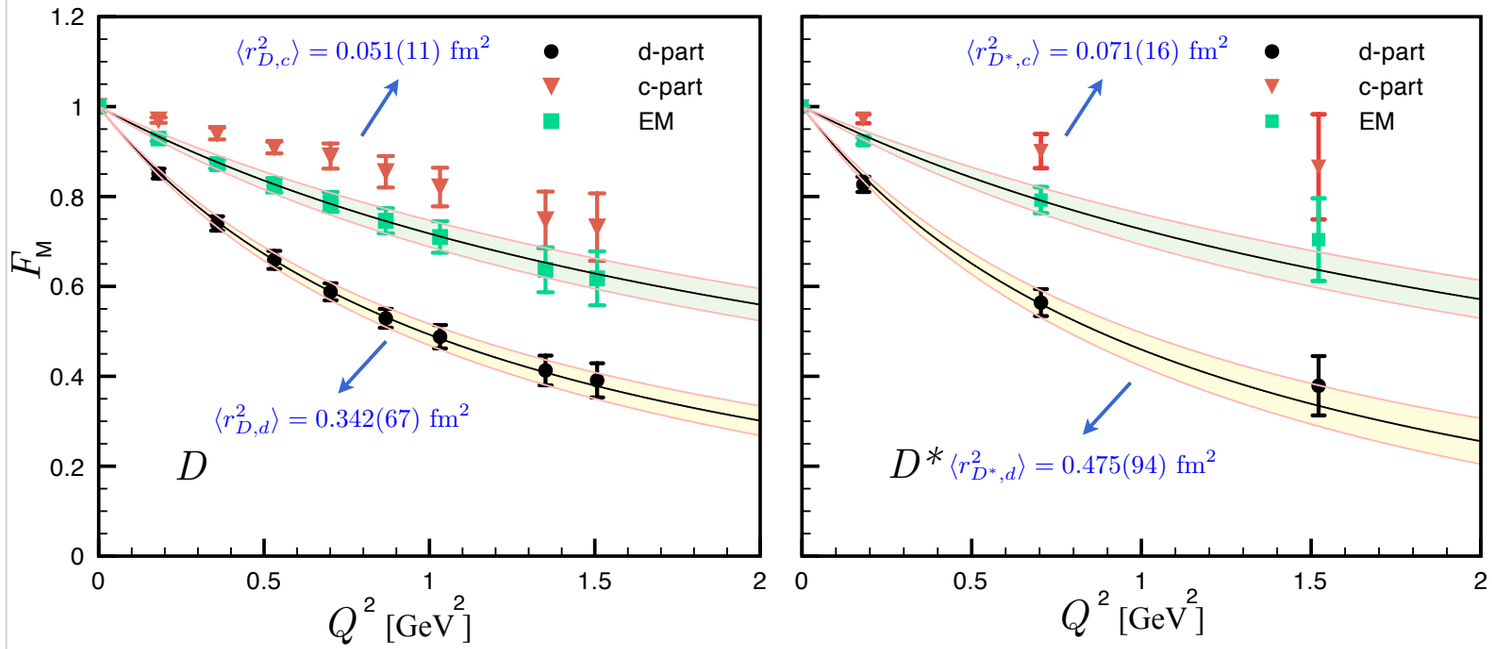


- $32^3 \times 64$ lattice with 2+1-flavors of dynamical quarks (generated by PACS-CS)
- Wilson Clover quark action (light quark) Fermilab-like action (charm quark)
- Lattice spacing 0.0907(13) fm and size = $(2.9\ \text{fm})^3 \times (5.8\ \text{fm})$.
- Pion masses from 702 MeV down to 156 MeV.



- See also the talks of Norman Christ and Andreas Jüttner

CHARMED MESONS



$\langle r^2_D \rangle = 0.138(13)$ fm^2

$\langle r^2_{D^*} \rangle = 0.185(24)$ fm^2

- The dominant contribution to charge radii of D and D* is due to light quark.
- Heavy charm quark acts so as to decrease the charge radii.
- Charmed mesons are compact as compared to pion.

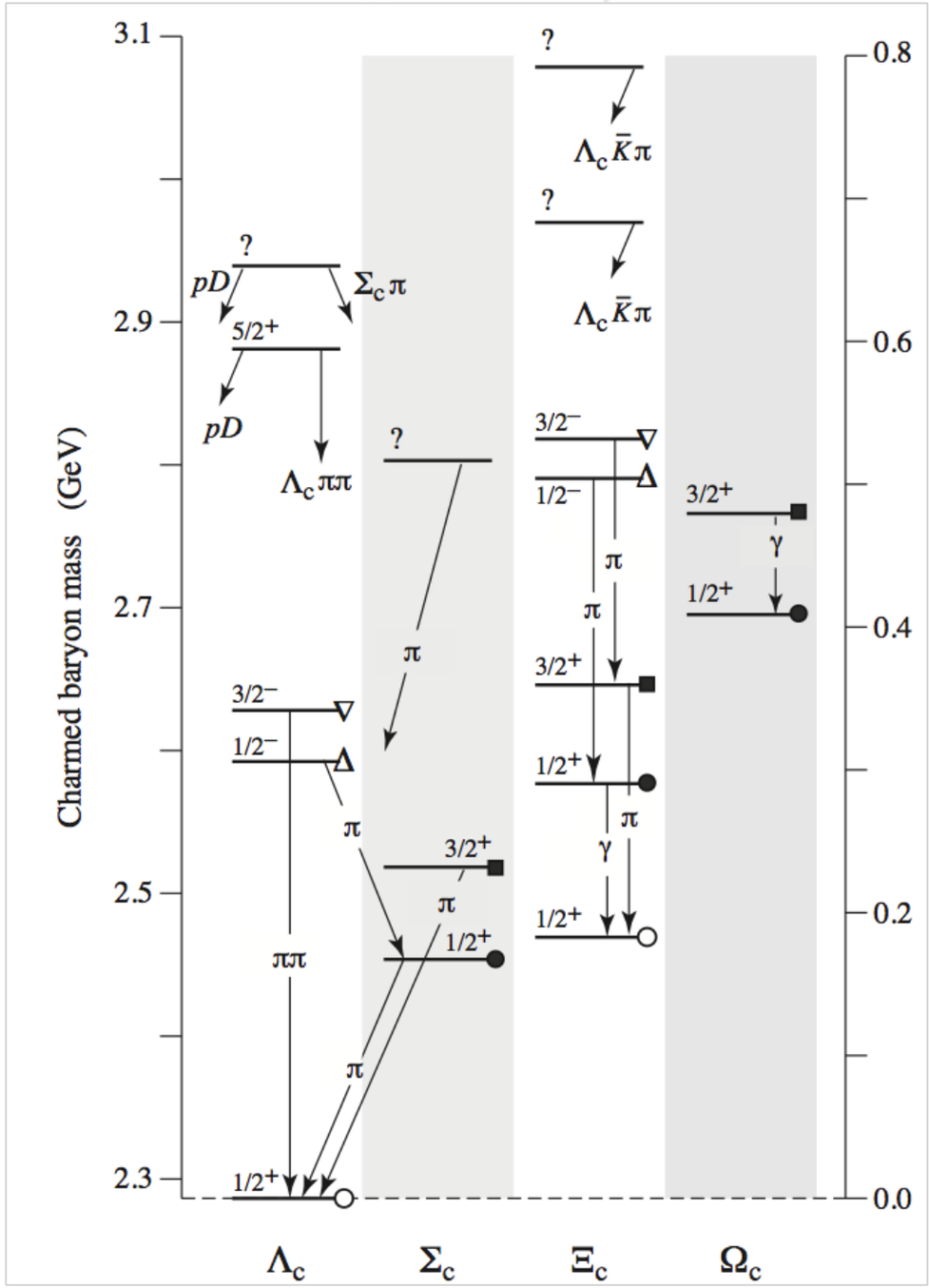
$g_{D^*D\pi} = 16.23\ (1.71), \qquad g_{DD\rho} = 4.84(34),$

$g_{D^*D^*\rho} = 5.94(56).$ Can et al, arXiv:1210.0869

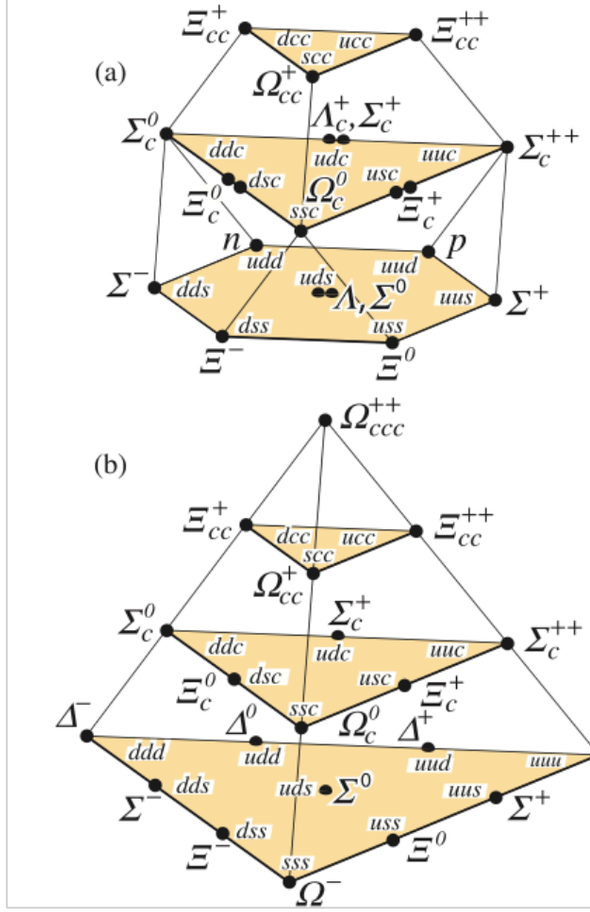
$(g_{D^*D\pi})_{\rm exp} = 16.92(19)$

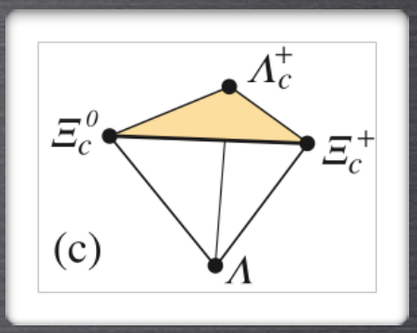
BaBar, arXiv:1304.5657

CHARMED BARYONS



PDG, 2013

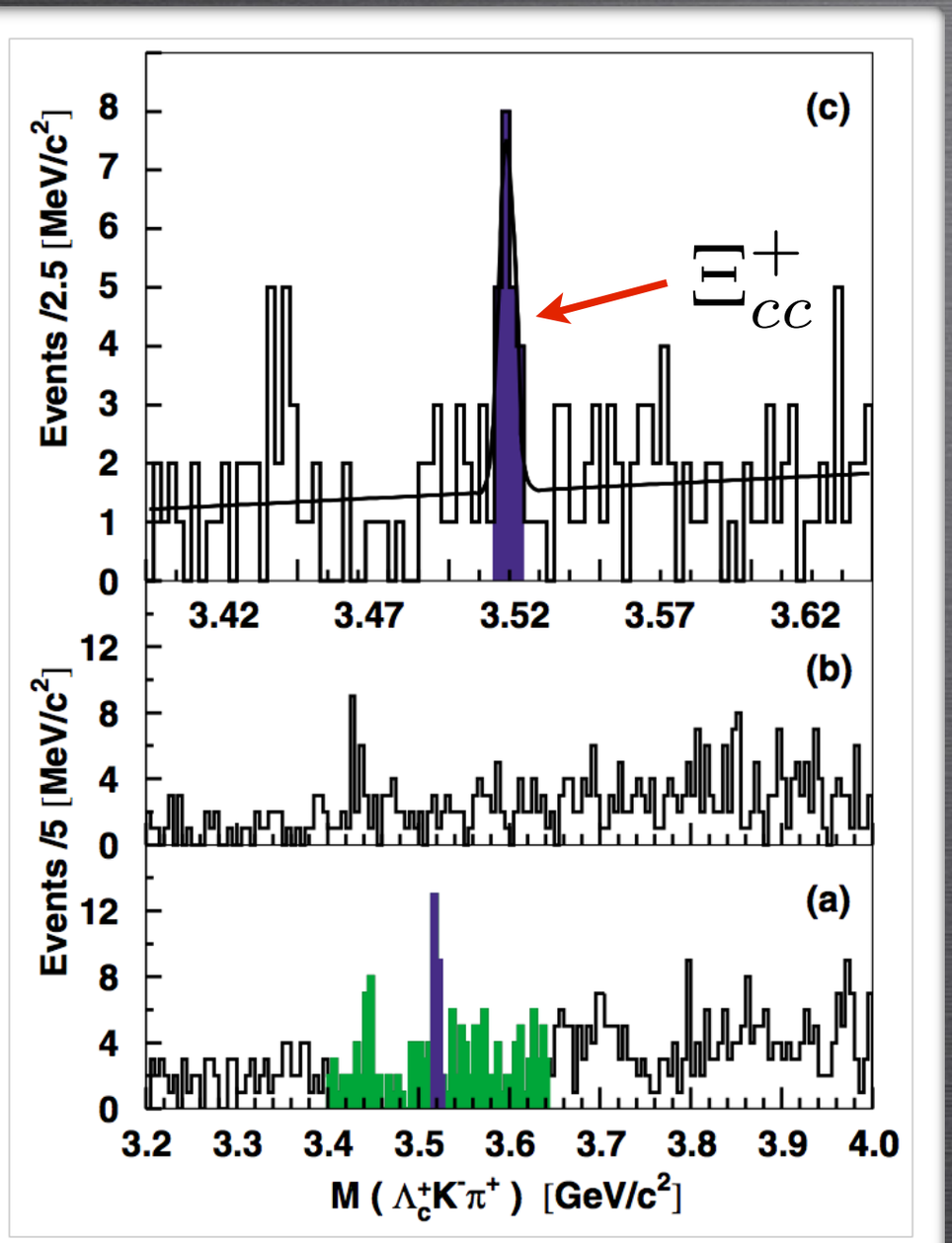




- 17 known charmed baryons
- 4 pending confirmation, others to be discovered

Ξ_{cc} PUZZLE

SELEX Collaboration (2002)



No signal from LHCb
(arXiv: 1310.2538)

$$\Xi_{cc}^+(3520) \to \Lambda_c^+ K^- \pi^+$$

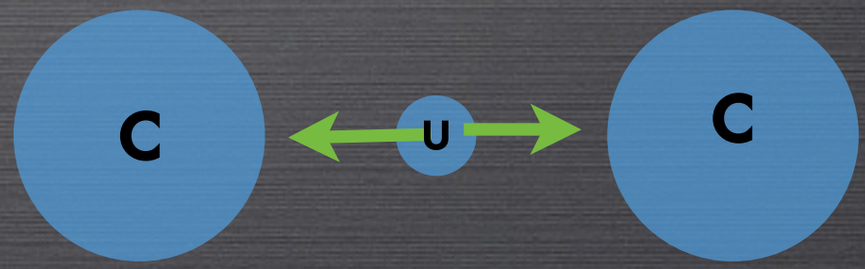
$$\Xi_{cc}^+(3520) \to p^+ D^+ K^-$$

$$\Xi_{cc}^{++}(3541) \to \Lambda_c^+ K^- \pi^+ \pi^+$$

$\Xi_{cc}^{++}(3520)$ 

$\Xi_{cc}^{++}(3541)$

Large isospin splitting of 21 MeV. It may be an indication of a compact structure.
(Brodsky et al., arXiv:1101.1983)



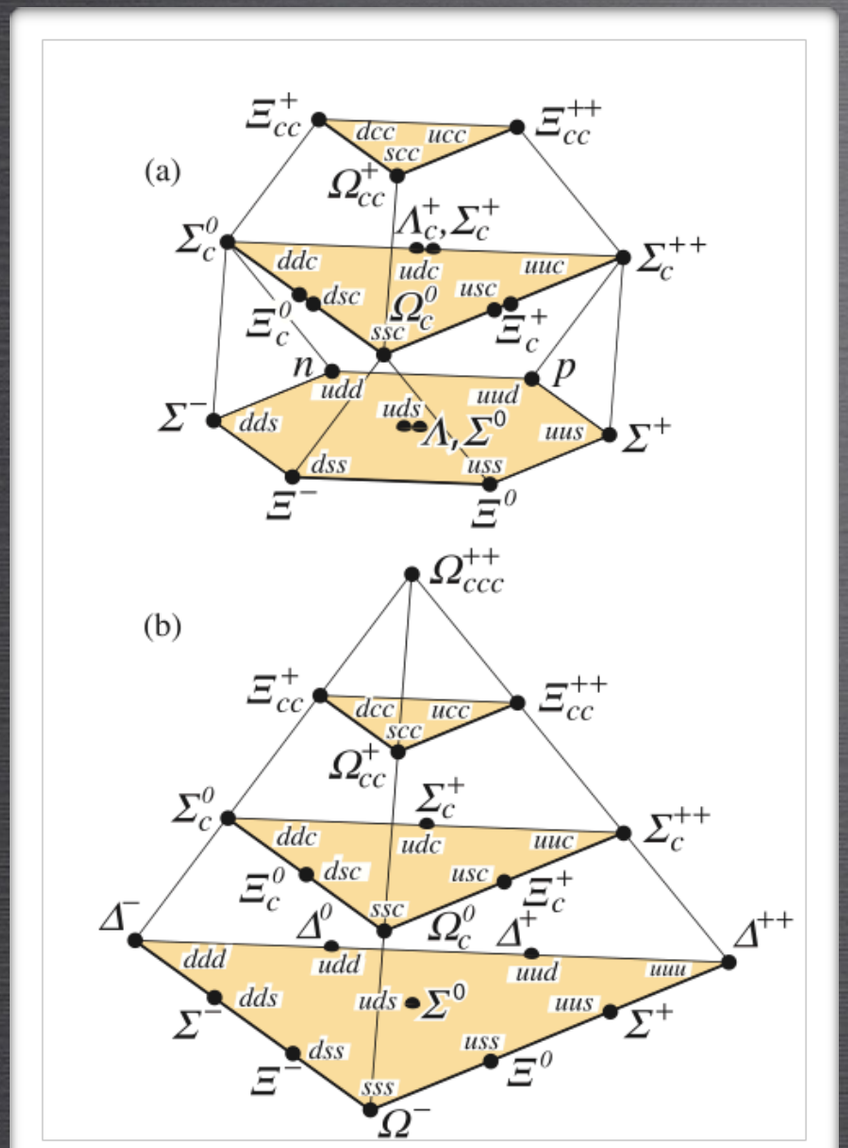
Citation: J. Beringer *et al.* (Particle Data Group), PR **D86**, 010001 (2012) (URL: http://pdg.lbl.go

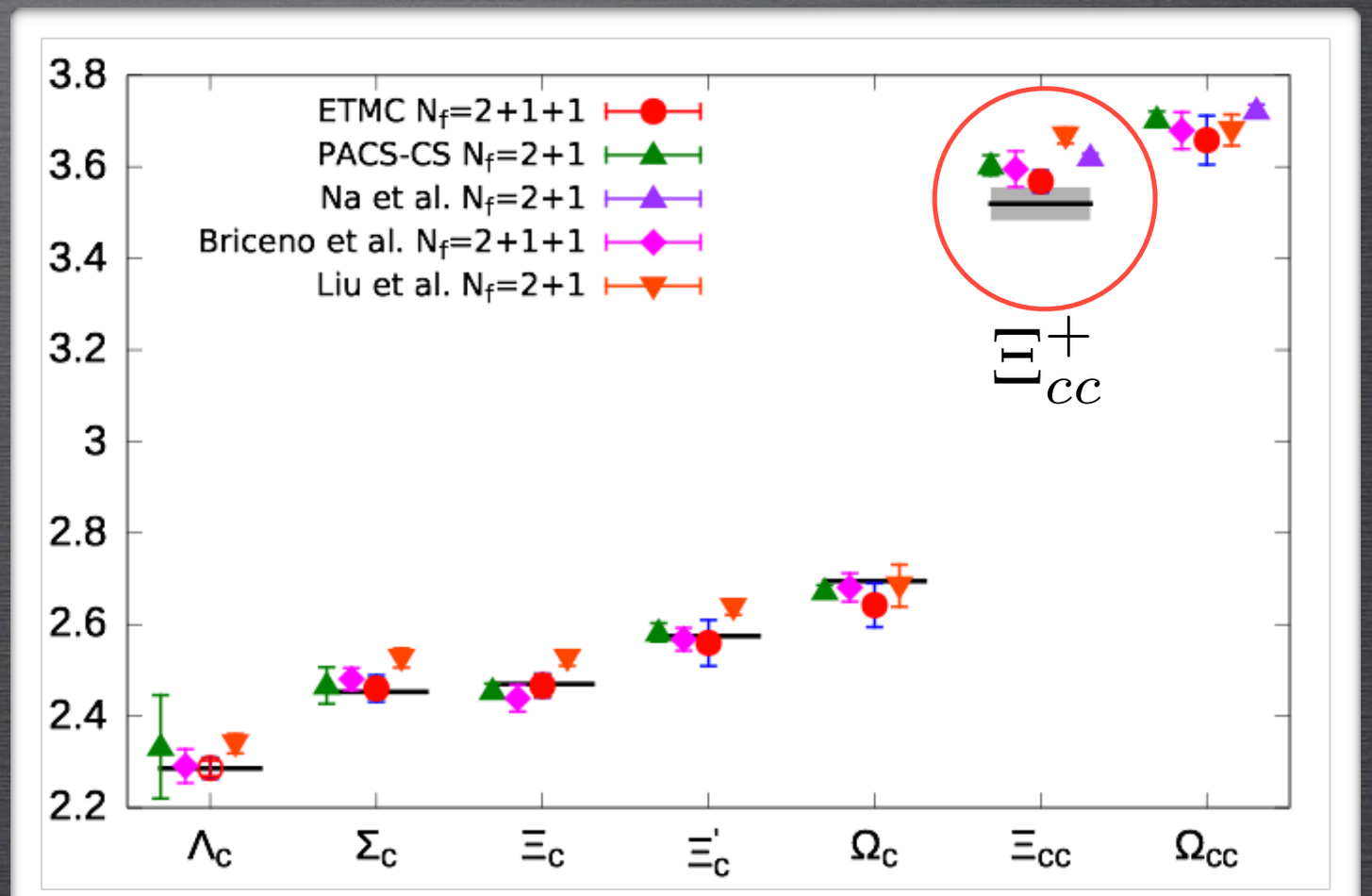
Ξ_{cc}^+ $I(J^P) = ?(?^?)$ Status: *

OMITTED FROM SUMMARY TABLE

CHARMED BARYONS

- Beijing Electron-Positron Collider (BEPCII) detector
- Beijing Spectrometer (BES-III)
- LHC
- future Gesellschaft fur Schwerionenforschung project
- Antiproton Annihilation at Darmstadt (PANDA)





Alexandrou et al. (arXiv:1406.4310)

Baryon EM form factors:

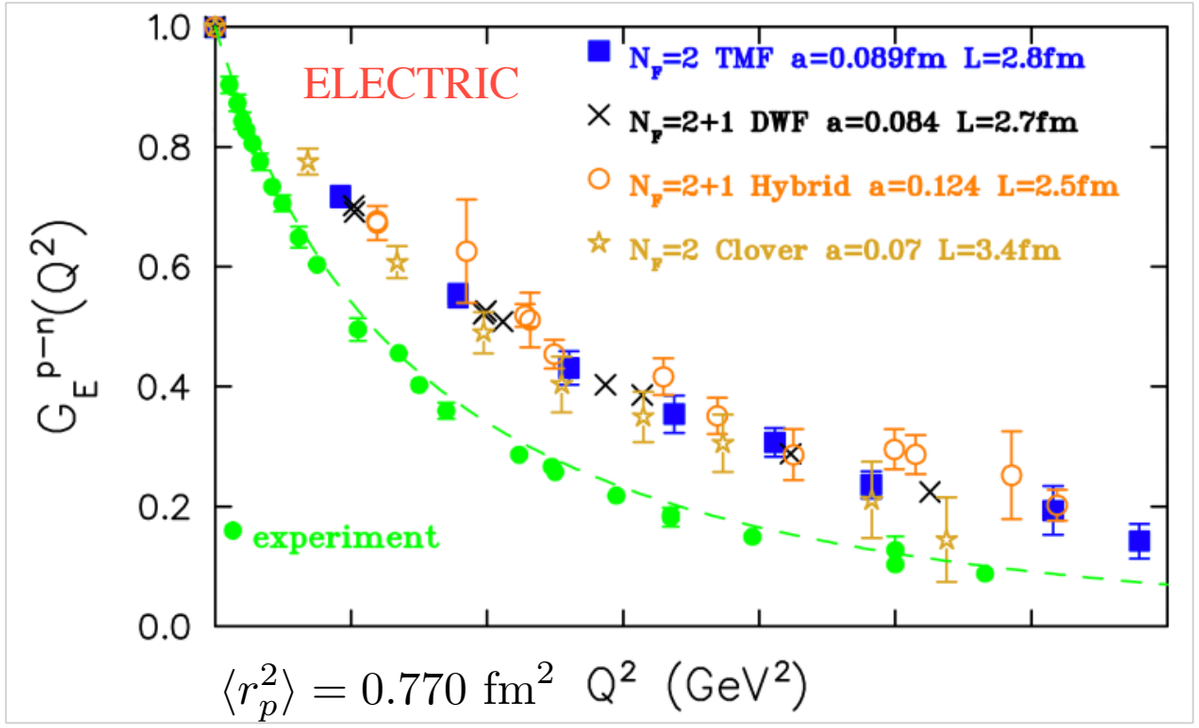
$$\langle \mathcal{B}(p)|V_\mu|\mathcal{B}(p')\rangle = \bar{u}(p)\left[\gamma_\mu F_{1,\mathcal{B}}(q^2) + i\frac{\sigma_{\mu\nu}q^\nu}{2m_\mathcal{B}}F_{2,\mathcal{B}}(q^2)\right]u(p)$$

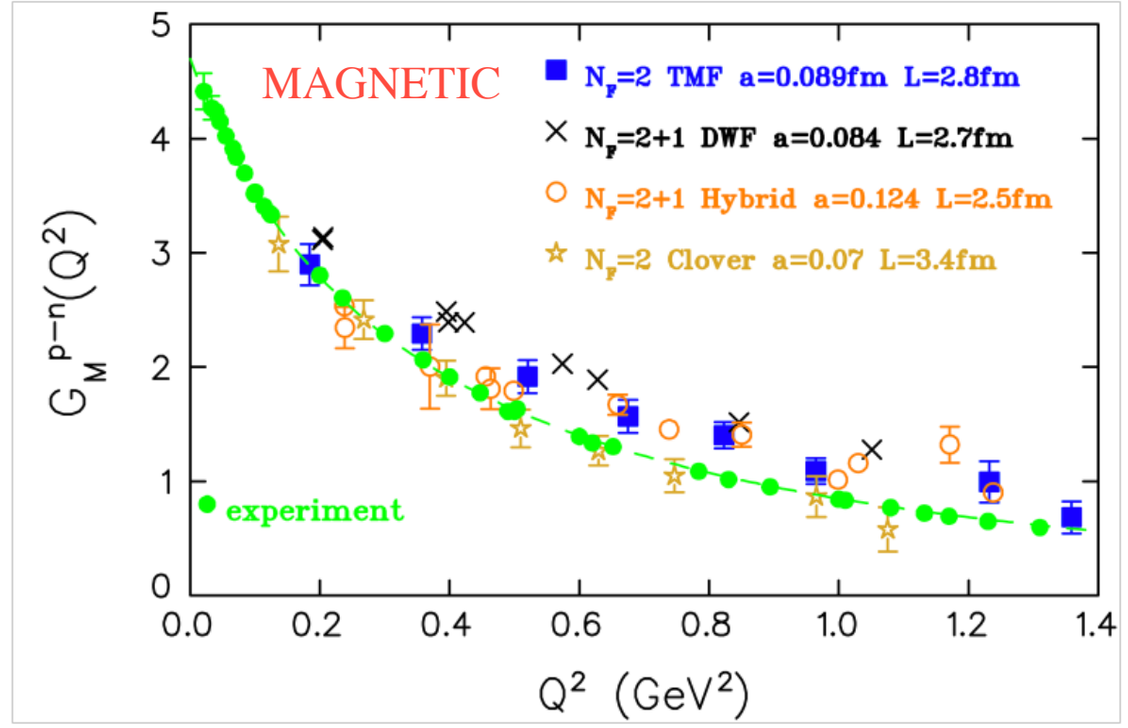
Baryon Sachs form factors:

$$G_{E,\mathcal{B}}(q^2) = F_{1,\mathcal{B}}(q^2) + \frac{q^2}{4m_\mathcal{B}^2}F_{2,\mathcal{B}}(q^2)$$

$$G_{M,\mathcal{B}}(q^2) = F_{1,\mathcal{B}}(q^2) + F_{2,\mathcal{B}}(q^2)$$

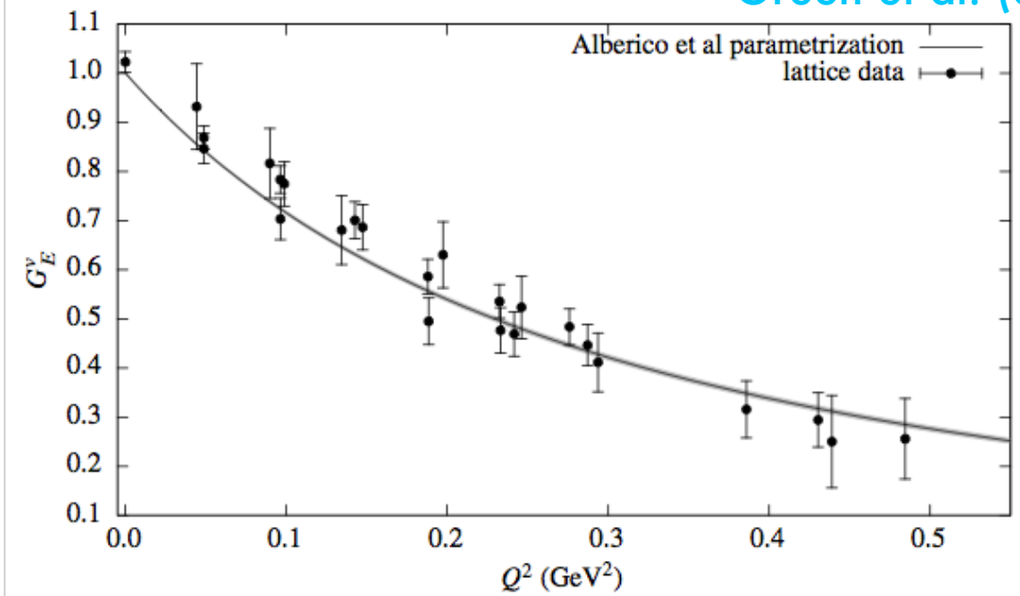
NUCLEON

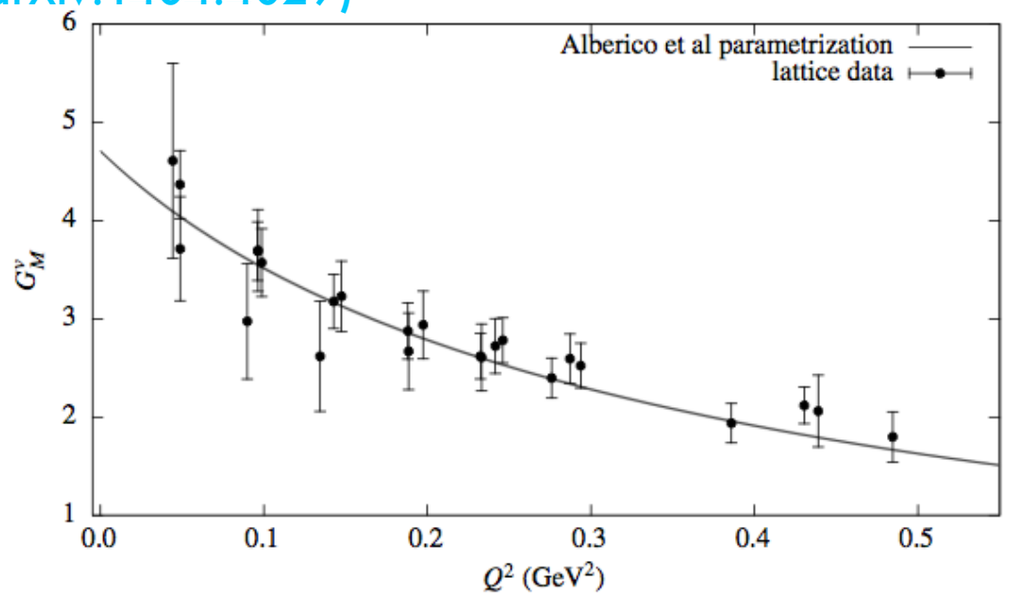




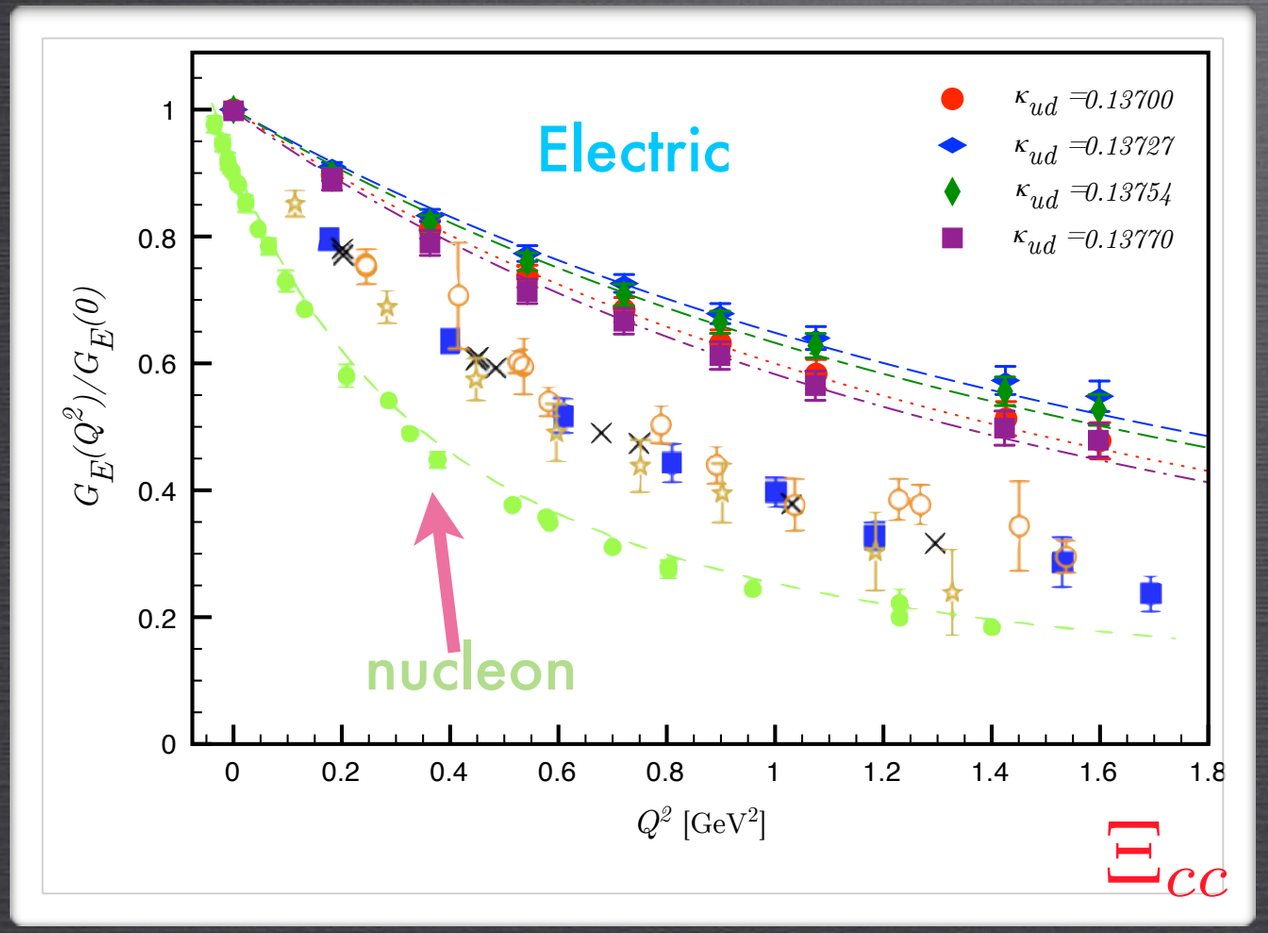
ETM COLLABORATION [PRD (2012)]

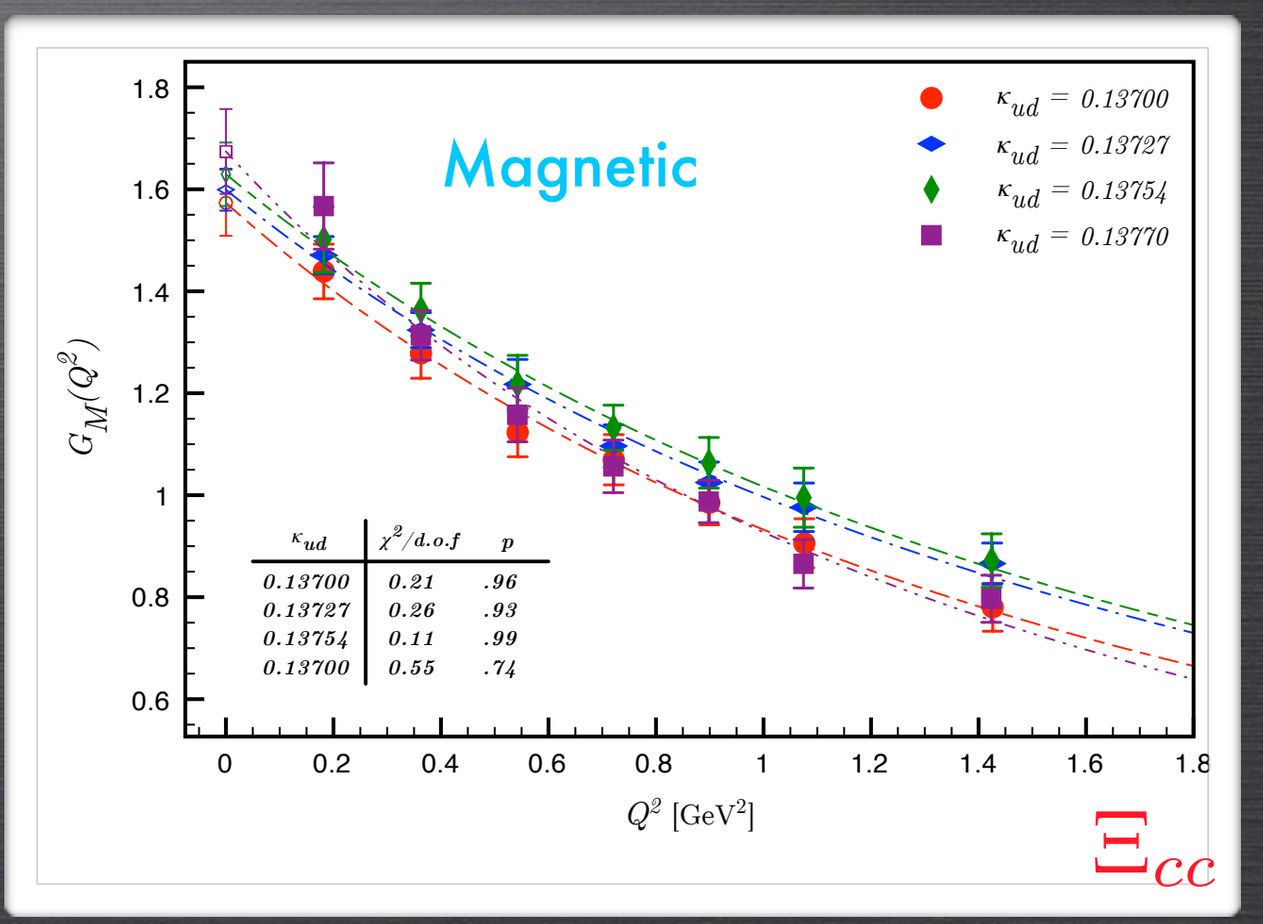
Green et al. (arXiv:1404.4029)



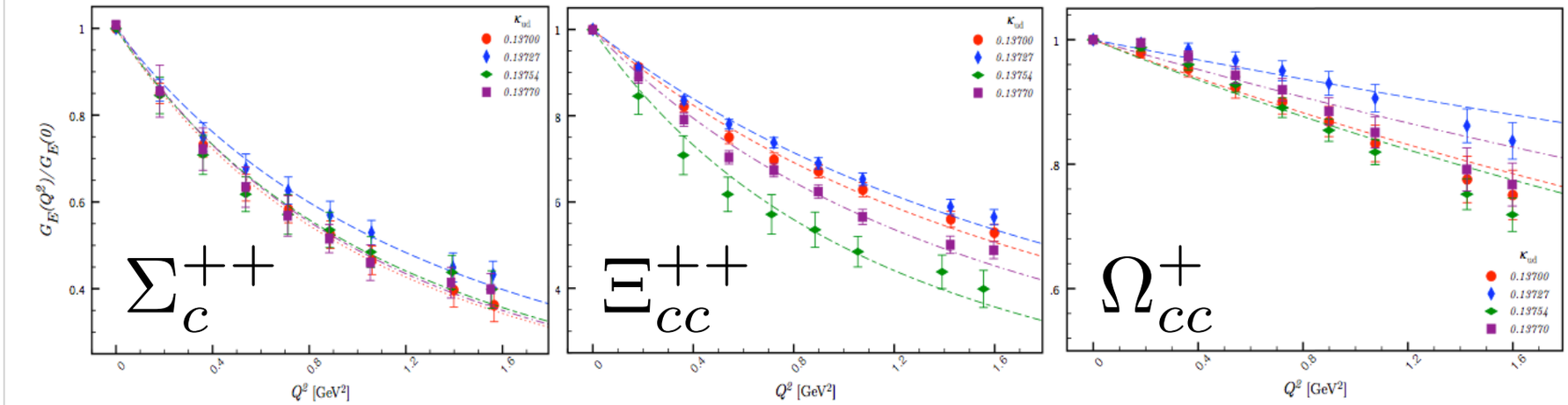


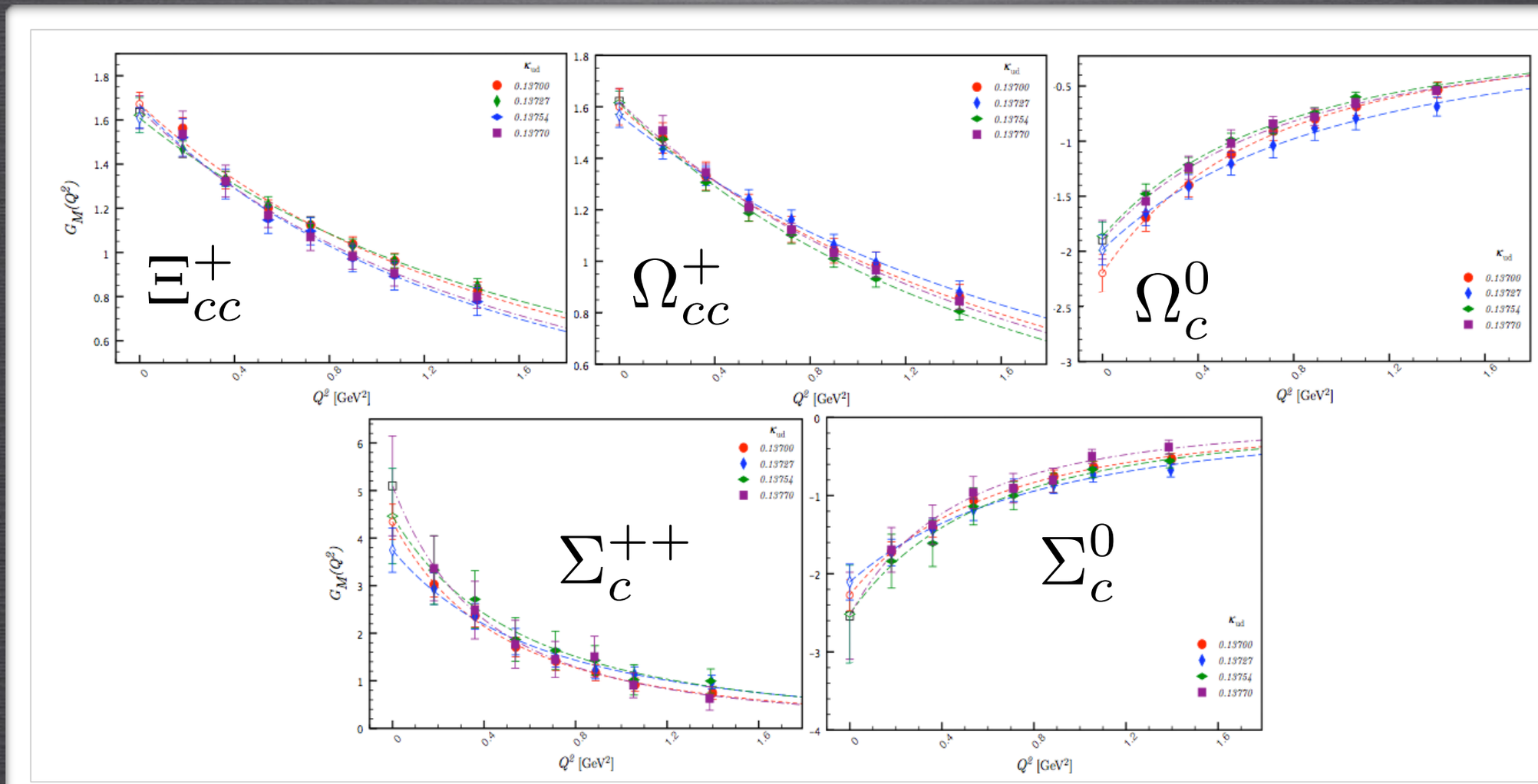
WHAT IS THE ROLE OF THE HEAVY QUARK?





κ_{ud}	χ^2/d.o.f	p
0.13700	0.21	.96
0.13727	0.26	.93
0.13754	0.11	.99
0.13700	0.55	.74





Can et al, arXiv:1306.0731; arXiv:1310.5915

$\kappa_{\rm val}^{u,d}$	$\langle r^2_{E,\Xi_{cc}^{++}}\rangle$
0.13700	0.118(8)
0.13727	0.107(6)
0.13754	0.127(8)
0.13770	0.142(9)
Lin. Fit	0.136(8)
Quad. Fit	0.165(12)

$\kappa_{\rm val}^{u,d}$	$\langle r^2_{E,\Sigma_c^{++}}\rangle$
	[fm^2]
0.13700	0.206(23)
0.13727	0.170(19)
0.13754	0.196(27)
0.13770	0.195(34)
Lin. Fit	0.192(22)
Quad. Fit	0.234(37)

$\kappa_{\rm val}^{u,d}$	$\langle r^2_{E,\Omega_{cc}}\rangle$
	[fm^2]
0.13700	0.038(8)
0.13727	0.019(6)
0.13754	0.040(6)
0.13770	0.029(6)
Lin. Fit	0.032(6)
Quad. Fit	0.043(11)

- Compare with proton charge radius: $\langle r^2\rangle_{\rm exp} = 0.770\ {\rm fm}^2$

Can et al, arXiv:1306.0731; arXiv:1310.5915

	Our result		[20]	[21]	[22]	[23]	[24]	[25]	[26]	[27]	[28]
	Lin. fit	Quad. fit									
$\mu_{\Sigma_c^0}$	-0.875(103)	-1.117(198)	-1.78	-1.04	-	-1.043	-1.60	-1.391	-1.17	-1.015	-1.6(2)
$\mu_{\Sigma_c^{++}}$	1.499(202)	2.027(390)	3.07	1.76	-	1.679	2.20	2.44	2.18	2.279	2.1(3)
$\mu_{\Xi_{cc}^+}$	0.411(15)	0.425(29)	0.94	0.72	$0.785^{+0.050}_{-0.030}$	0.722	0.84	0.774	0.77	-	-
$\mu_{\Omega_c^0}$	-0.608(45)	-0.639(88)	-0.90	-0.85	-	-0.774	-0.90	-0.85	-0.92	-0.960	-
$\mu_{\Omega_{cc}^+}$	0.405(13)	0.413(24)	0.74	0.67	$0.635^{+0.012}_{-0.015}$	0.668	0.697	0.639	0.70	0.785	-

CONCLUSION

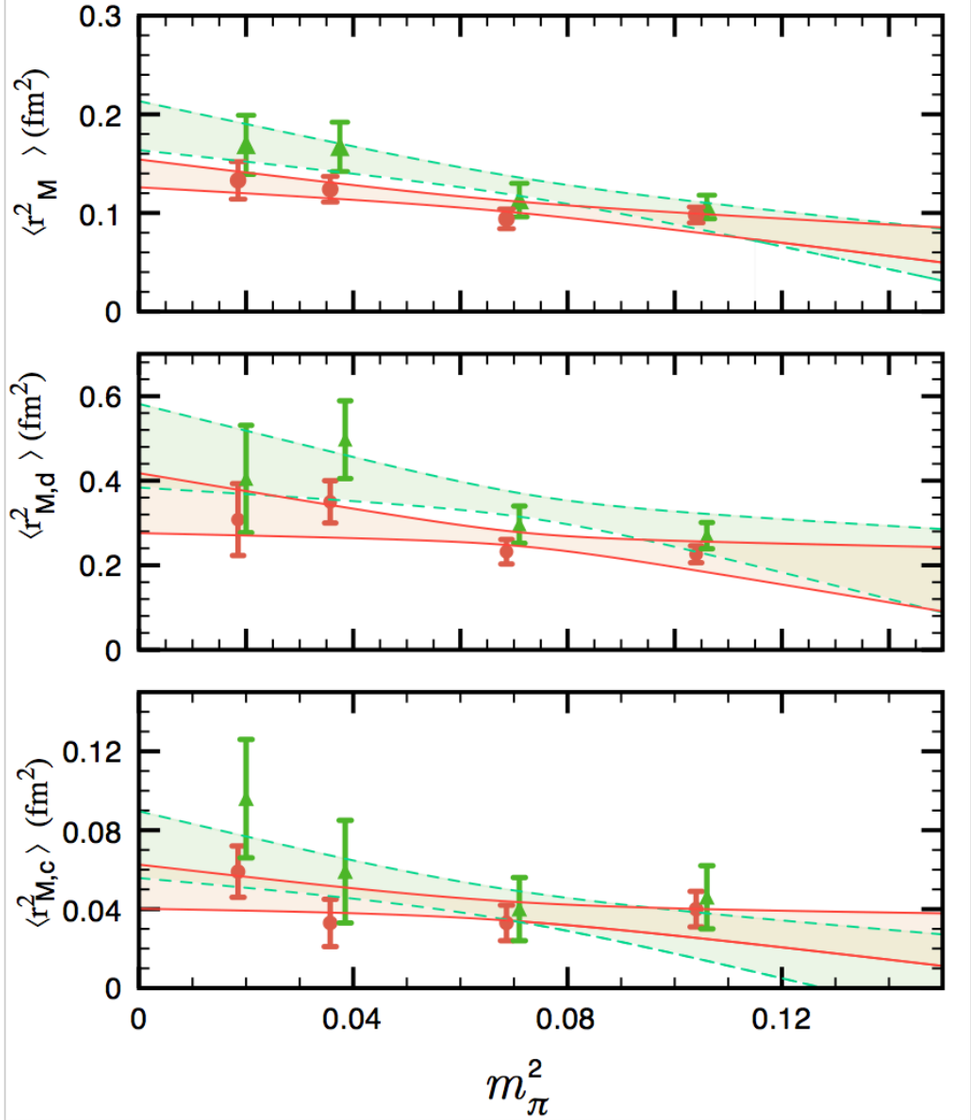
- Charmed hadrons have a compact structure.
- Light-quark distributions are **larger**
- The heavy quark acts to decrease the size of the baryon to smaller values.
- Doubly charmed baryons are more compact as compared to singly charmed ones.
- Magnetic moments of the singly charmed baryons are mainly determined by the light quark.
- The role of the heavy quark is significantly enhanced in the case of the doubly charmed baryons.

OUTLOOK

- Ongoing simulations on lattices with pion mass of 156 MeV.
- Controlled systematic and statistical errors.
- Include spin 3/2 charmed baryons and other couplings.

THANK YOU!

BACKUP



- Charge radius of D^* is larger than that of D, consistent with expectation from the quark model.
- They are coincident in the heavy-quark limit, where the hyperfine interaction is reduced:

$$\frac{\vec{\sigma}_Q \cdot \vec{\sigma}_q}{m_Q m_q}$$