奇特强子态与强子结构

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内容提要

一. 原子、原子核、强子

二. 强子结构：夸克模型与QCD

三. 探索强子内部结构的基本途径

四. 质子中的多夸克成分

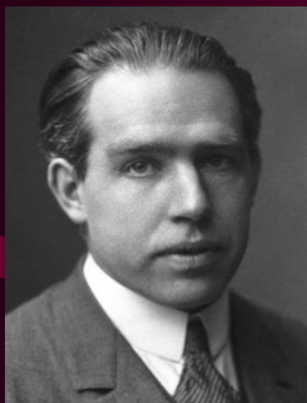
五. 奇特强子态

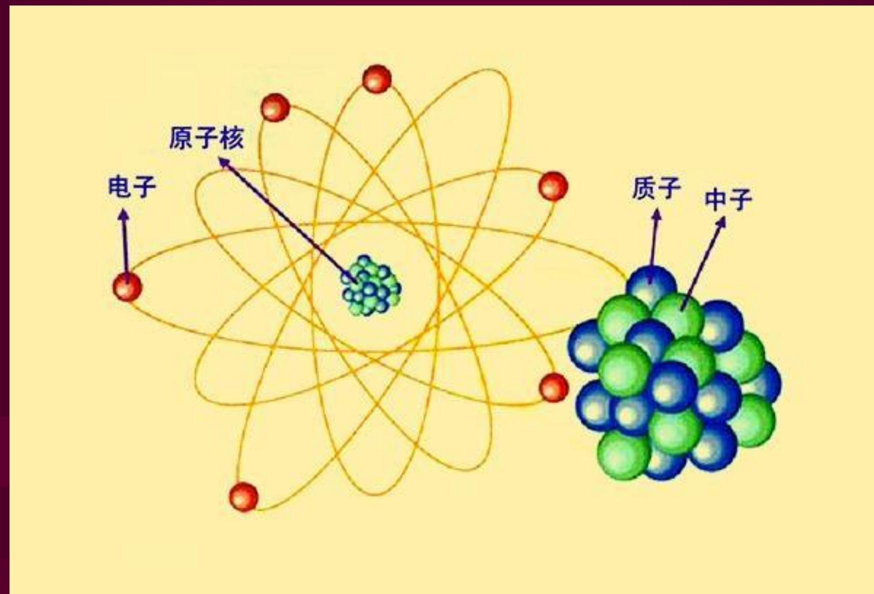
六. 总结与展望

一. 原子、原子核、强子

$$V(r) = -g^2 \frac{e^{-\mu r}}{r}$$

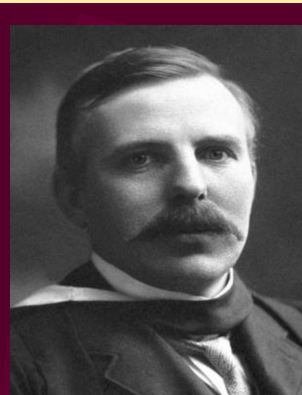
波尔原子模型



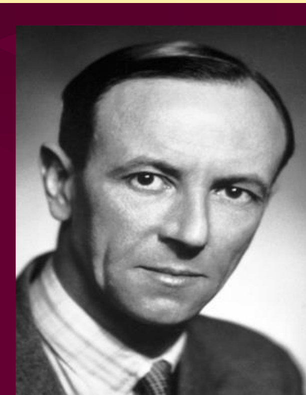


核力 – π 介子

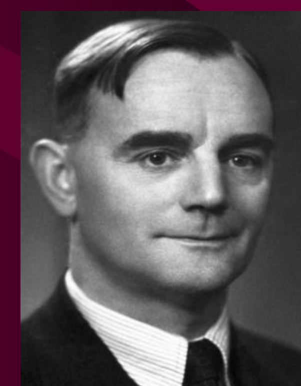
电子



原子核，质子



中子

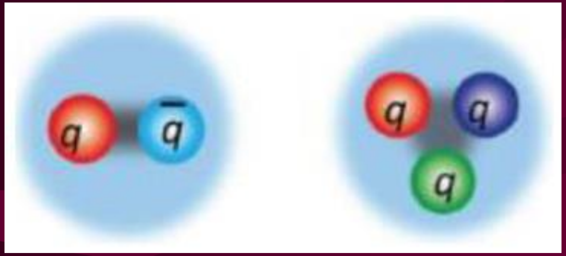


π 介子 ……

强子

二. 强子结构：夸克模型与QCD

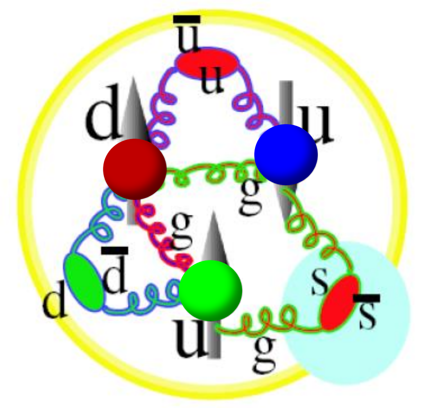
夸克模型



介子 **重子**

q = u, d, s, c, b, t

QCD



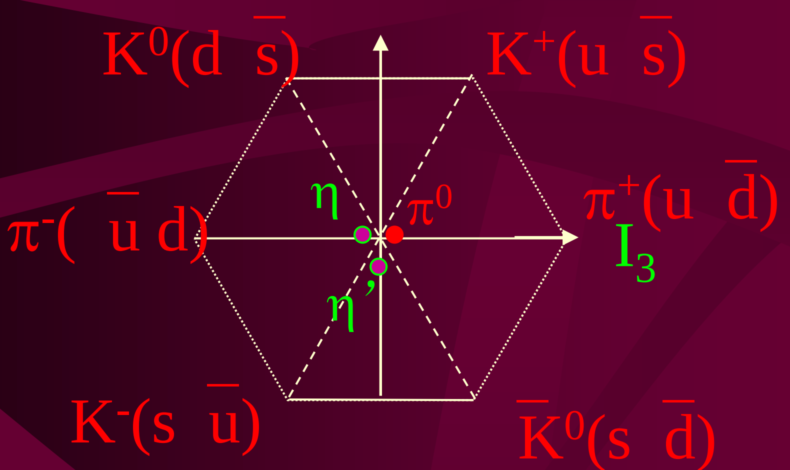
QCD 两大特性：　渐近自由 ＋ 夸克禁闭

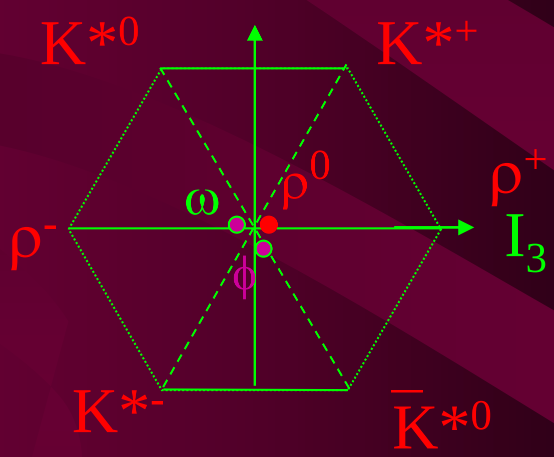
夸克唯象势模型：　$V(r) = kr - a/r$

介子的 SU(3) $\bar{q}q$-夸克模型

$\bar{q}q$ - 介子： $^{2S+1}L_J$ J^{PC} $P=(-1)^{L+1}$

$^1S_0$ 0^- $^3S_1$ 1^-

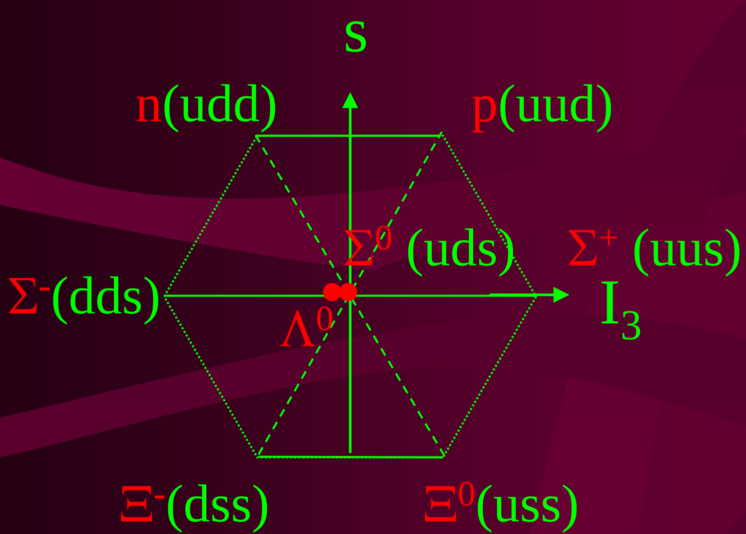


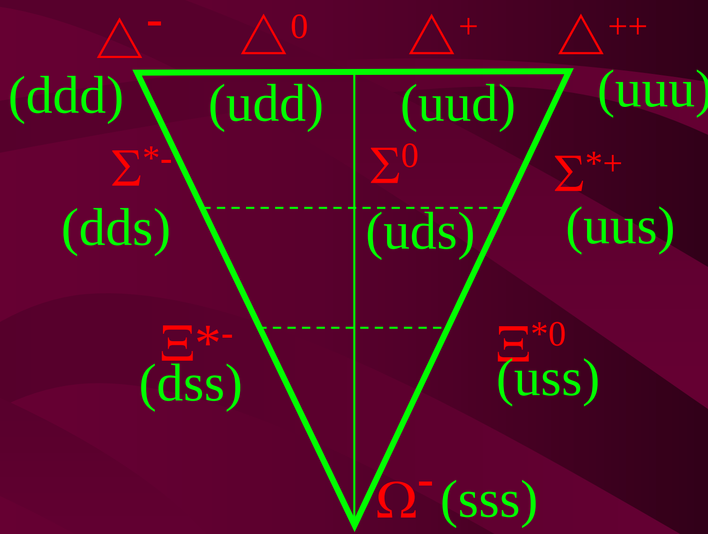


$$\pi^0 = \frac{u\bar{u} - d\bar{d}}{\sqrt{2}}$$

重子的 SU(3) 3q-夸克模型

1/2 +　　　自旋-宇称　　　3/2+

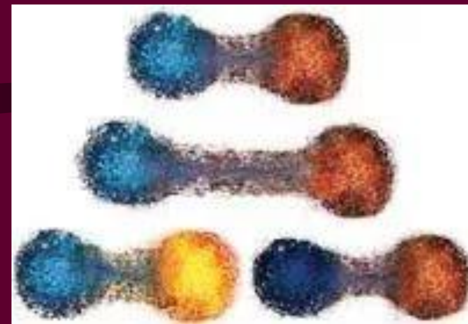




空间轨道基态
相当成功！

质量公式预言　$m_{\Omega^-} \cong 1670$ MeV

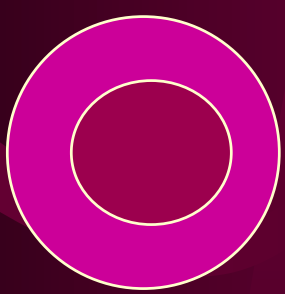
实验　$m_{\Omega^-} \cong 1672.45 \pm 0.29$ MeV

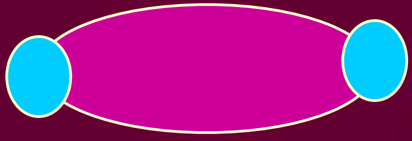


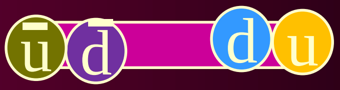
强子衰变对夸克禁闭的作用？

夸克模型：　　重子 = 3 夸克　　　介子 = 夸克-反夸克
QCD　：　　新的自由度 --- 具有自相互作用的胶子

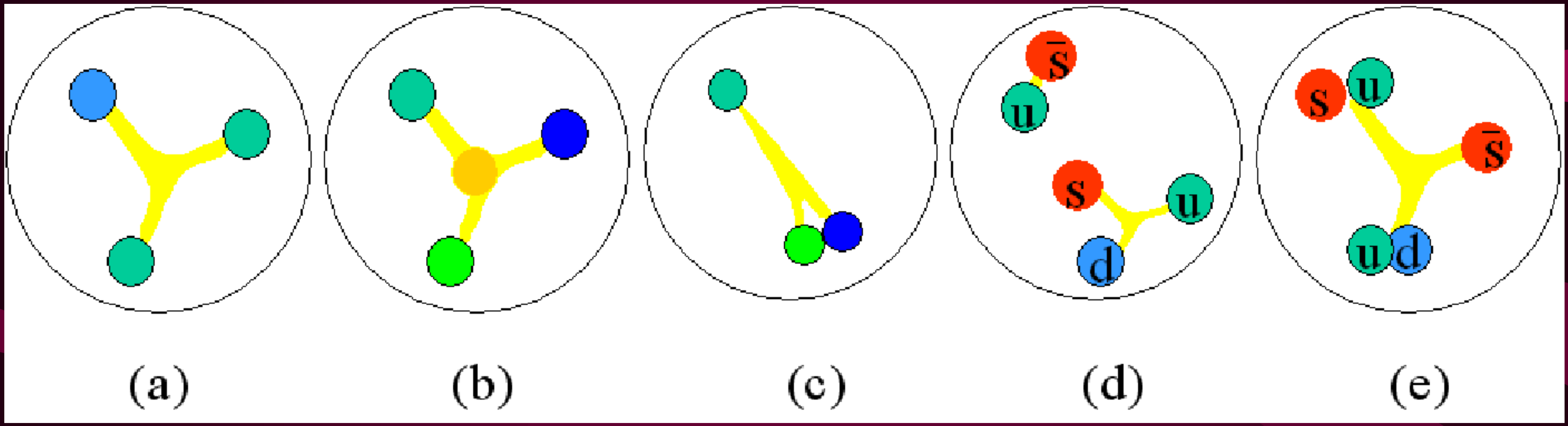
胶球、夸克-胶子混杂态、多夸克态？







重子是如何构成的?



A. 3夸克态 B. 夸克-胶子混杂态 C. 偶夸克-夸克态 D-E. 多夸克态

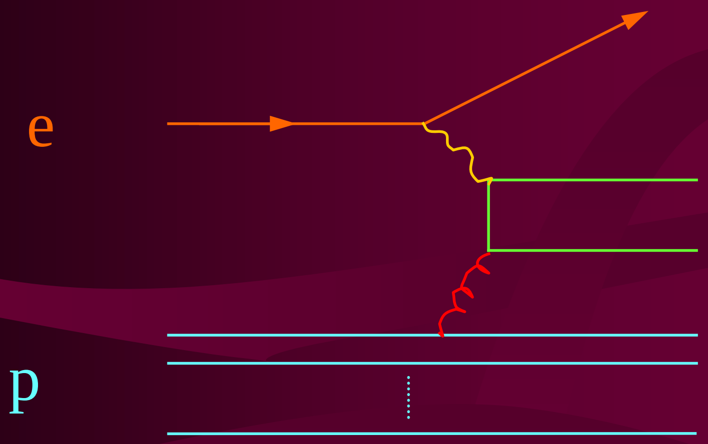
预言的核子激发态N*数目：D-E>B>A>C

实验已观测到的N*数目 <A，“失踪”？

人类对重子谱的了解还非常贫乏
缺乏行之有效的理论计算

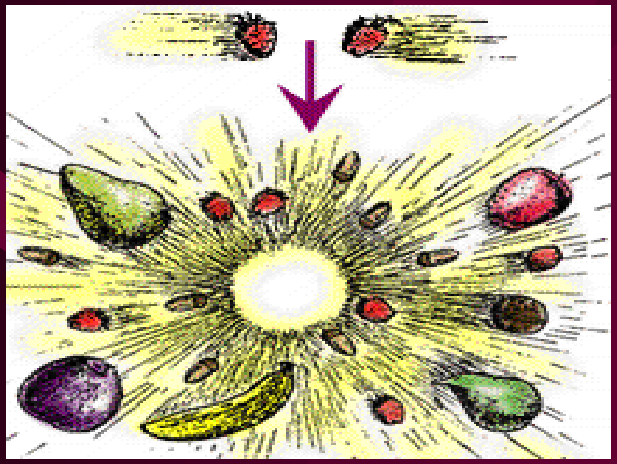
三. 探索强子内部结构的基本途径

1）高能轻子-质子散射 → 质子内部夸克-胶子分布函数



问题：光子、胶子与海夸克的相互转化，原有的、再生的？

2）强子、轻子、光子束流打靶 → 强子谱、强子衰变

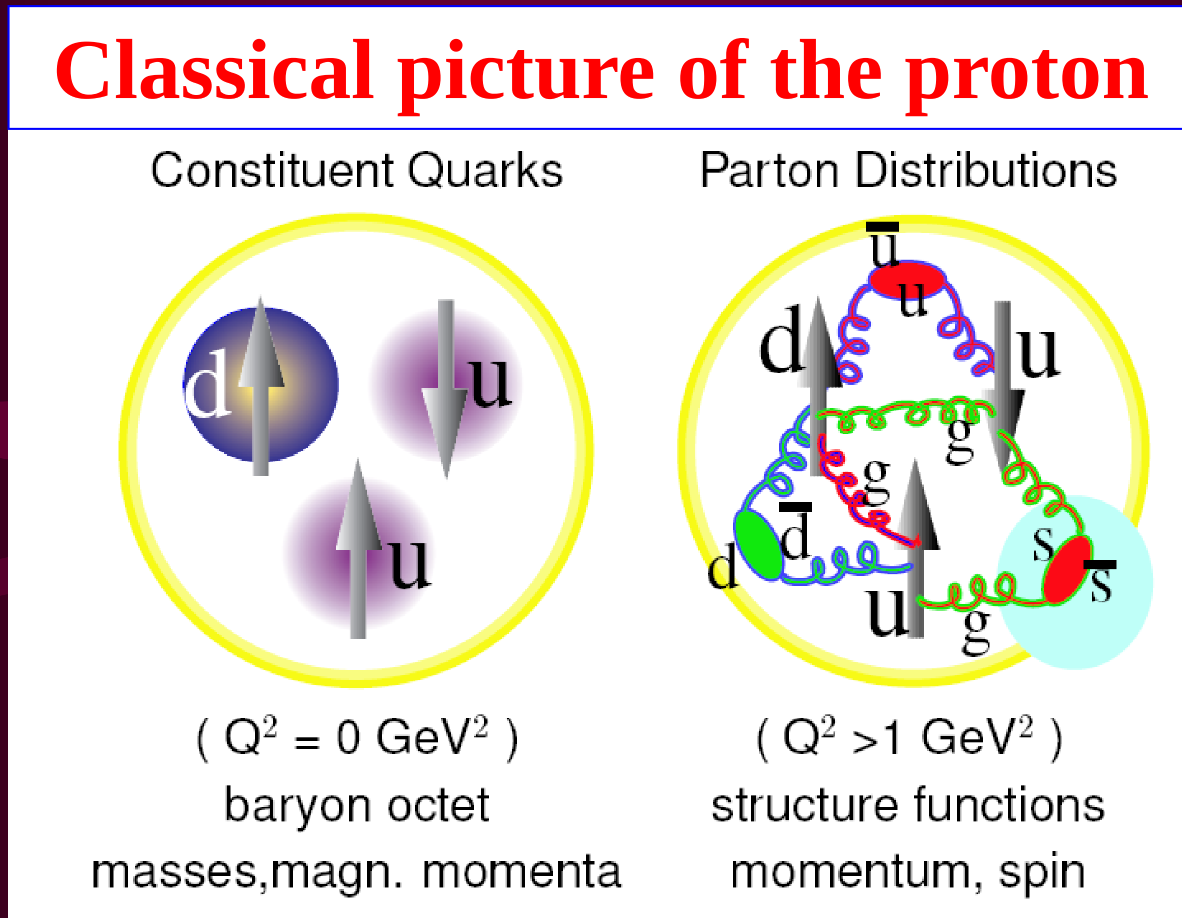


原子谱 ⇒ 玻尔原子的量子理论

核　谱 ⇒ 壳模型 &集体运动模型

强子谱 ⇒ ？

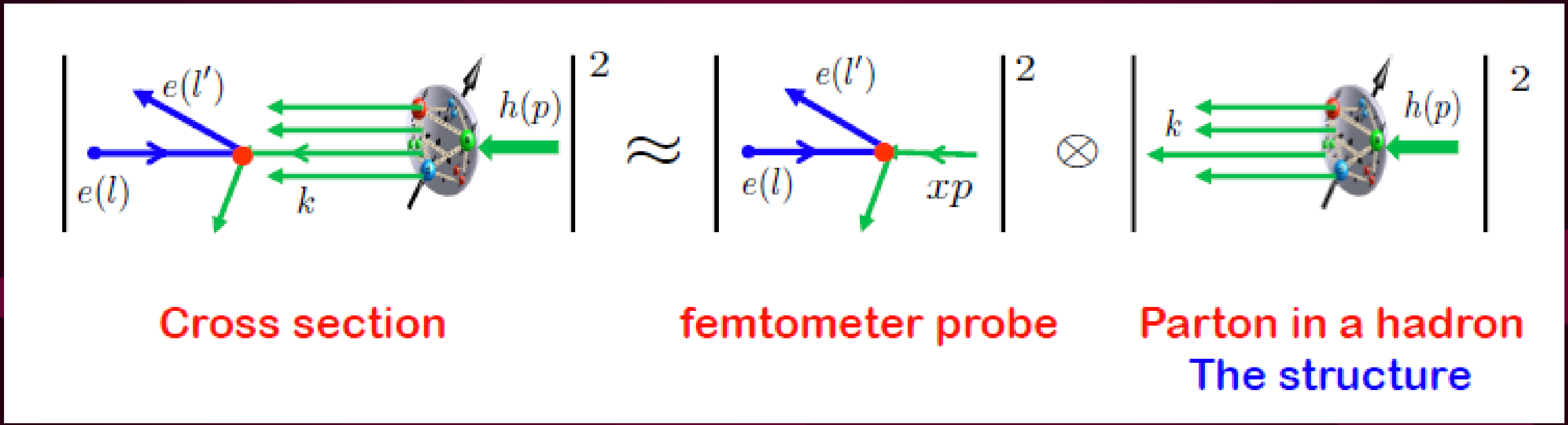
四. 质子中的多夸克成分



$\bar{u}(x) = \bar{d}(x)\ ,\quad \bar{s}(x) = s(x)$

1964-1974

1974–1992



QCD 因子化 → 核子的部分子 (味、自旋、3维动量) 分布函数

质子自旋 "危机" 、 $\bar{d} - \bar{u} \sim 0.12$ 、 $\bar{s}(x) \neq s(x)$ 、 …

质子自旋“危机”、 $\bar{d}-\bar{u}\sim 0.12$、 $\bar{s}(x)\neq s(x)$ 等问题

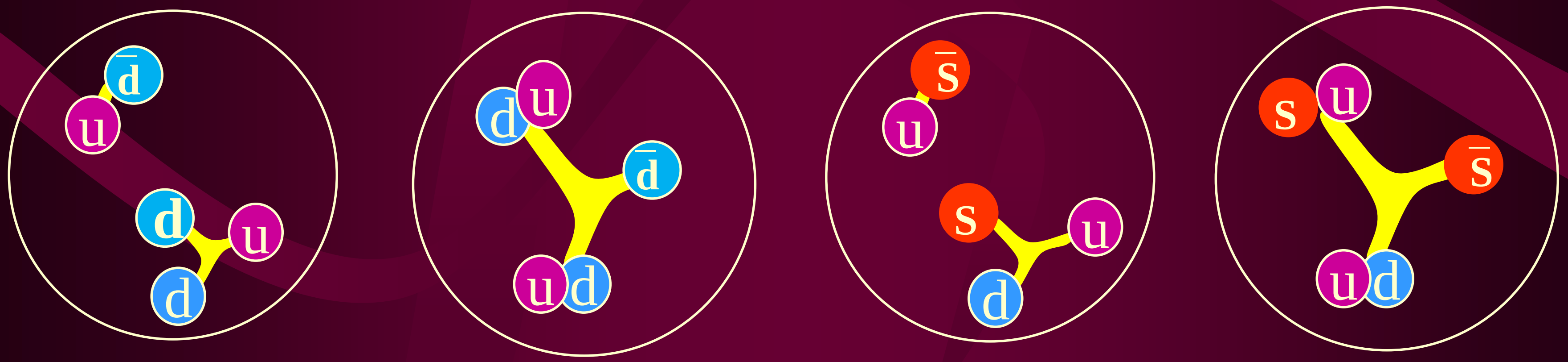
两种不同的唯象解释:

介子云图像: Thomas, Speth, Weise, Oset, Brodsky, Ma, …

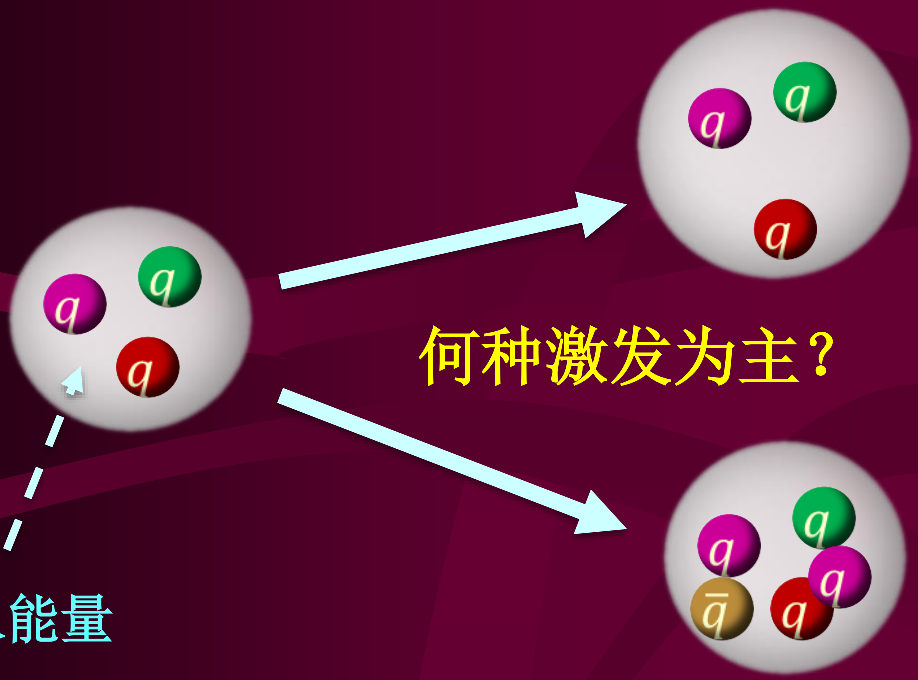
$$|\,p> \sim |\,uud> + \varepsilon_1\,|\,n\,(udd)\,\pi^+(\bar{d}u)> + \varepsilon_2\,|\,\Delta^{++}(uuu)\,\pi^-(\bar{u}d)> + \varepsilon'\,|\,\Lambda\,(uds)\,K^+(\bar{s}u)> \ldots$$

夸克对图像 : Riska, Zou, Zhu, …

$$|\,p> \sim |\,uud> + \varepsilon_1\,|\,[ud][ud]\,\bar{d}> + \varepsilon'\,|\,[ud][us]\,\bar{s}> + \ldots$$



质子含有~30%的五夸克成分，那么重子激发态呢？



何种激发为主？

注入能量

传统夸克模型：
重子激发态 = 3夸克激发态

我们新的观点：
最低的重子激发SU(3)八重态
都已经以5夸克激发为主

要真正了解重子谱，必须研究五夸克态

五. 奇特强子态

Fate of the first pentaquark predicted and observed: $1/2^-$

1959: $\bar{K}N$ molecule predicted by Dalitz-Tuan, PRL2, 425

1961: $\Lambda(1405) \rightarrow \Sigma\pi$ observed by Alston et al., PRL6, 698

1964: Quark model (uds) for $\Lambda(1405)$

1995: $\bar{K}N$ dynamically generated -- Kaiser et al., NPA954, 325

2001: 2 pole structure by $\bar{K}N$-$\Sigma\pi$ -- Oller et al., PLB500, 263

PDG2010: "The clean Λ_c spectrum has in fact been taken to settle the decades-long discussion about the nature of the $\Lambda(1405)$ —true 3-quark state or mere $\bar{K}N$ threshold effect?— unambiguously in favor of the first interpretation."

Fate of the last famous fading pentaquark $\theta^+(1540)$: $1/2^+$

1997: $Z^+(1530)$ predicted by Diakonov et al., ZPA359, 305

2003: $\theta^+(1540) \rightarrow K^+n$ claimed by LEPS, PRL91, 012002

2003: $\bar{s}$ (ud)(ud) for $\theta(1540)$ by Jaffe&Wilczek, PRL91, 232003

2003: $\bar{s}$ ud)(ud) for $\theta(1540)$ by Karliner&Lipkin, PLB575, 249

2004: supported by 10 expts $\rightarrow$ $\theta(1540)$ well-established by PDG

2004: not supported by BESII, PRD70, 012004

2005: not supported by many high stats experiments

2006: removed from PDG

Note: $\theta^+(1540)$ is not supported by hadronic molecule model & chiral quark model by Huang, Zhang, Yu, Zou, PLB586(2004)69

$1/2^-$ baryon nonet with strangeness

Zou, EPJA 35 (2008) 325

- Mass pattern : quenched or unquenched ?

  uds (L=1) $1/2^-$ ~ $\Lambda^*(1670)$ ~ $[us][ds]\,\bar{s}$

  uud (L=1) $1/2^-$ ~ $N^*(1535)$ ~ $[ud][us]\,\bar{s}$

  uds (L=1) $1/2^-$ ~ $\Lambda^*(1405)$ ~ $[ud][su]\,\bar{u}$

  uus (L=1) $1/2^-$ ~ $\Sigma^*(1390)$ ~ $[us][ud]\,\bar{d}$

  Zou et al, NPA835 (2010) 199 ; CLAS, PRC87(2013)035206

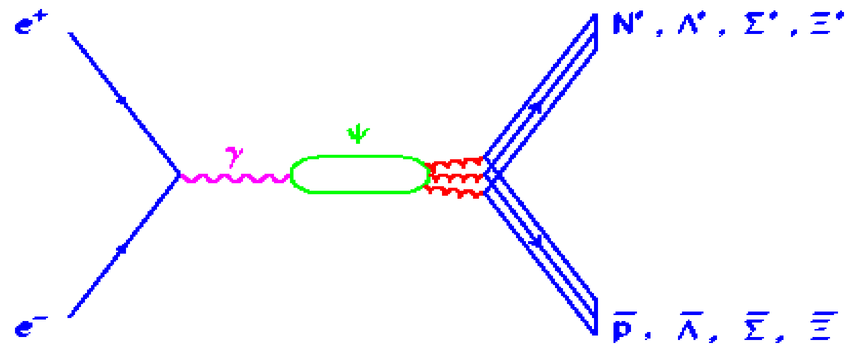
- Strange decays of $N^*(1535)$ and $\Lambda^*(1670)$:

  $N^*(1535)$ large couplings $g_{N^*N\eta}$, $g_{N^*K\Lambda}$, $g_{N^*N\eta'}$, $g_{N^*N\phi}$

  $\Lambda^*(1670)$ large coupling $g_{\Lambda^*\Lambda\eta}$

BEPC核子和超子激发态（N*, Λ*, Σ*, Ξ*, Ω*）新项目

$$\Psi \rightarrow \overline{B}BM \Rightarrow N^*,\ \Lambda^*, \Sigma^*, \Xi^*, \Omega^*$$



特点和优势： 理想的同位旋、低自旋分离器，独具特色

国际上其它实验 (ep, γp, πp, Kp) 不具备这些优点

美国橡树岭实验室 T. Barnes教授国际会议综述报告大篇幅评述

“相当令人惊讶，邹等人[21]在BEPC的BES上利用J/ψ强子衰变研究N*谱。…”

3.3 J/Ψ hadronic decays.

Rather surprisingly, BES at BEPC is being used to study N* spectroscopy using J/Ψ hadronic decays. Zou *et al.* [21] note that one might expect hybrid baryons to have larger production amplitudes from J/Ψ than conventional qqq baryons, because a ggg state produced in J/Ψ annihilation should have a larger overlap with a final hybrid baryon (see Fig.4). It is certainly interesting to establish which baryons are produced with large amplitudes in J/Ψ annihilation, as any unusual states thus produced are possible hybrid baryon candidates.

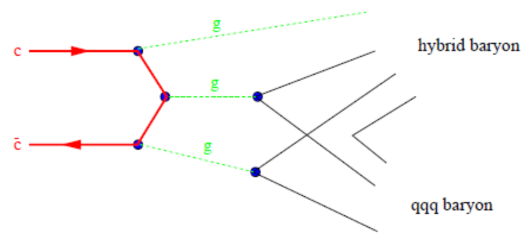


Figure 4: Production of $qqqg$ states from J/Ψ radiative decays occurs at $O(\alpha_s^5)$ (followed by nonperturbative pair production), which leads $J/\Psi \to ggg \to (qqq) + (\bar{q}\bar{q}\bar{q})$ by one power of α_s.

To date BES has 7.8M J/Ψ events, from which they select $p\bar{p}\pi^o$ and $p\bar{p}\eta$. This approach has the additional advantage that it is an I= 1/2 filter, so the many Δ (and hybrid Δ) states will not be present to complicate the analysis. The only clear peak in the present data is the $S_{11}(1535)$, in the $p\bar{p}\pi^o$ channel (see Fig.5). Since *ca.* 50M J/Ψ events are expected in the near future, hybrid baryon candidates may yet be identified in this process.

nucl-th/0009011

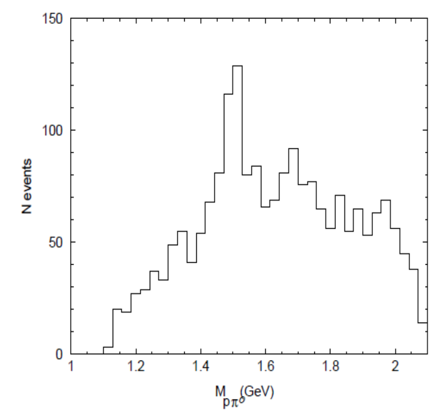


Figure 5: BES data for the $p\pi^o$ invariant mass distribution in $J/\Psi \to pp\pi^o$ [21], showing evidence for the $1/2^-$ $N_{11}(1535)$.

美国JLab实验部负责人V.D. Burkert国际会议总结报告评述

arXiv: 1309.5108， Int. J. Mod. Phys. Conf. Ser. 26 (2014) 1460050

2.3. *New nucleon candidates from charmonium decays*

A different approach in the search for N* states comes from BESIII with studies of the decay $\psi' \to p\bar{p}\pi^{\circ}$. The $p\pi^{\circ}$ mass is analyzed[18] and shows some of the well-known isospin $\frac{1}{2}$ states. Above 2 GeV a large, isolated enhancement was found to represent two new N* candidates at 2300 and 2570 MeV. An interesting aspect of this reaction is that it not only selects isospin $\frac{1}{2}$ states but suppresses high spin states due to the short range interaction involved in the $c\bar{c}$ annihilation that generates the $N^*\bar{p}$ system. The suppression of higher spin states greatly simplifies partial wave analysis.

“BESIII是寻找N*态的一个不同渠道… 该反应令人感兴趣的是：它不仅选择出同位旋1/2态，还由于通过短程$c\bar{c}$ 湮灭产生$\bar{p}$N* 系统而压制了高自旋态的产生，从而极大地简化了分波分析。”

国际著名理论物理学家牛津大学 F.Close 教授国际会议总结报告高度肯定

The End of the Constituent Quark Model?

F.E. Close

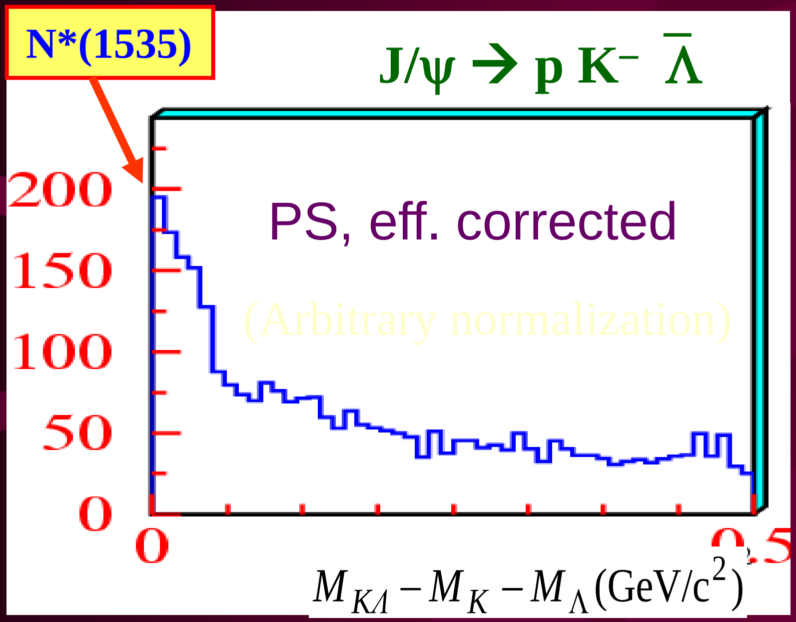
Department of Theoretical Physics, University of Oxford,

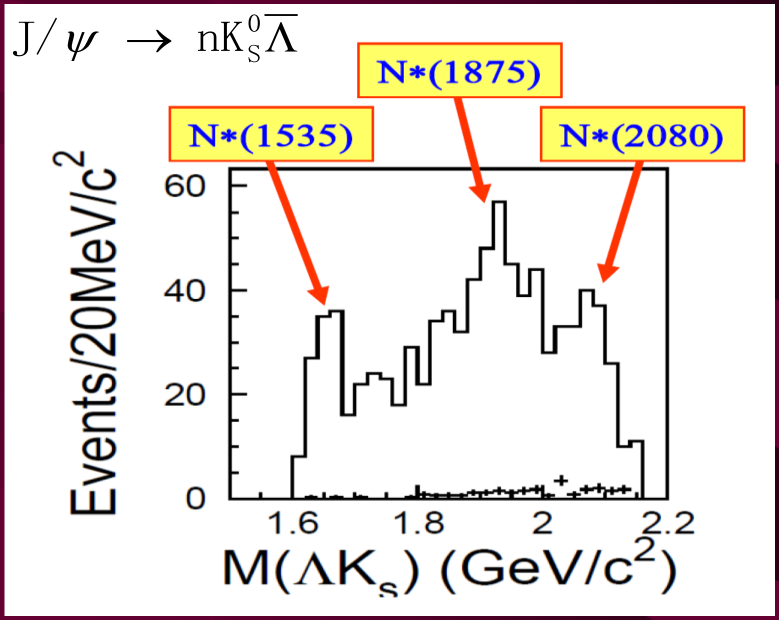
Summary talk at HADRON2003　AIP Conf. Proc. 717 (2004) 919; hep-ph/0311087

We have also heard[6] how ψ decays can give novel insights into baryon resonances in the timelike region through $\psi \to NN^*$ or $\Delta\Delta^*$. This selects isospin states apart from a background due to the intermediate $\psi \to \gamma^*$ channel, and gives complementary information to that from the maturing data from Jefferson Laboratory[9]. Finally we have

"ψ衰变提供了类时区域研究重子激发态的新颖的视角"

N* observed in J/ψ → $\bar{\Lambda}$ K N





BESII, IJMPA20 (2005) 1985

BESII, PLB659 (2008) 789

我们结合BES等实验数据论证了N*(1535)以 $\bar{s}$suud-五夸克成分为主

E. Klempt, J. Richard, Rev. Mod. Phys. 82 (2010) 1095:

Examples of baryons which may deserve an interpretation beyond the quark model are $N_{1/2^+}(1440)$, which is found at an unexpectedly low mass, $N_{1/2^-}(1535)$, a resonance which is observed at the expected mass but with an unusual large decay branching ratio to $N\eta$, and the $\Lambda_{1/2^-}(1405)$ and $\Lambda_{3/2^-}(1520)$ resonances with their low mass and unusual splitting. A consistent (Liu and Zou, 2006; Zou, 2008)—even though controversial (Liu and Zou, 2007; Sibirtsev, Haidenbauer, and Meißner, 2007)—picture for these possibly crypto-exotic baryons ascribes the mass pattern to a large $qqqq\bar{q}$ fraction in the baryonic wave functions.

Liu, B. C., and B. S. Zou, 2006, Phys. Rev. Lett. 96, 042002.
Liu, B. C., and B. S. Zou, 2007, Phys. Rev. Lett. 98, 039102.
Zou, B. S., 2008, Eur. Phys. J. A 35, 325.

"(刘&邹)关于这些可能隐性的奇特重子的一个自洽图像将其质量模式归因于重子波函数中的一个大的五夸克成分，…"

$\bar{s}suud \rightarrow \bar{c}cuud$ 预言了P_c五夸克态 - 被LHCb实验证实

- 我们首次预言了3个可衰变到J/ψ-p的五夸克态 (P_c), 建议通过J/ψ-p衰变道寻找：

  Wu, Molina, Oset, Zou, PRL 105 (2010) 232001

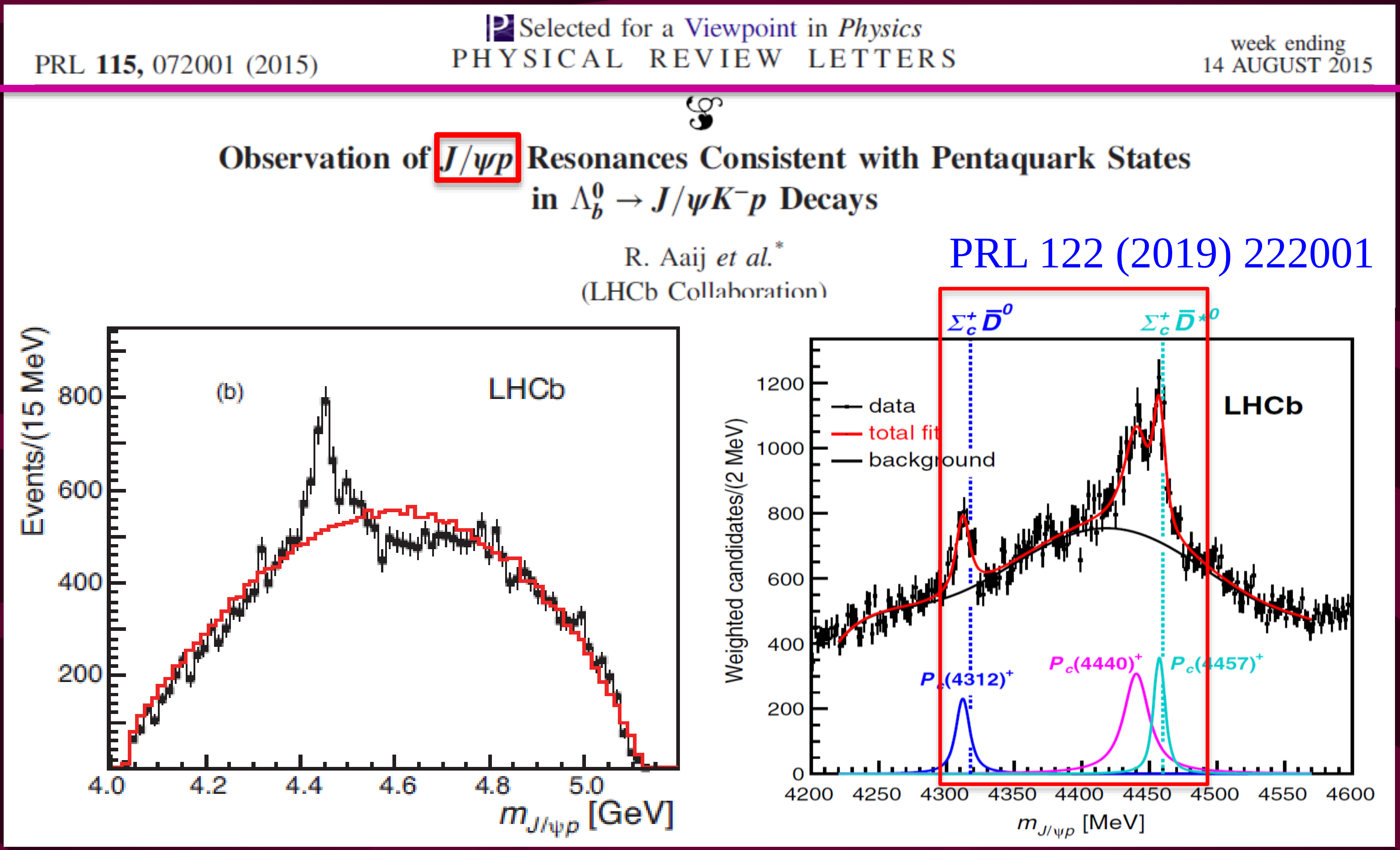
  Wang, Huang, Zhang, Zou, PRC 84 (2011) 015203

  Wu, Lee, Zou, PRC 85 (2012) 044002

  → 3个 $\bar{c}cuud$- P_c五夸克态：1个$\bar{D}\Sigma_c$ + 2个$\bar{D}^*\Sigma_c$分子态

- 国际系列会议特邀大会报告： HYP2012 (西班牙), NSTAR2015 (日本), MENU2016 (日本), CHARM2018 (俄国)
- 列入美国JLab-12GeV和德国PANDA实验寻找计划
- LHCb实验2015-2019年观测到3个与我们预言相符的P_c态

LHCb观测到与我们预言相符的3个P_c五夸克态

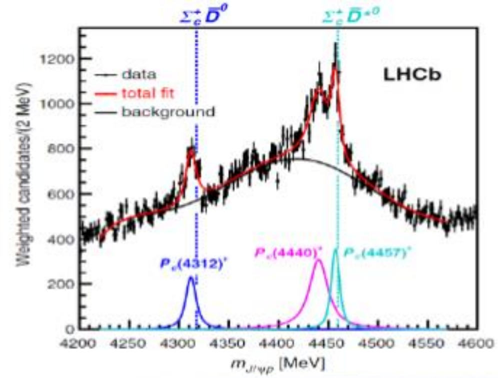


入选美国物理杂志2015年度八大突破之一

各类五夸克态半个多世纪的寻找，终获确证！

P_c states: observation vs predictions

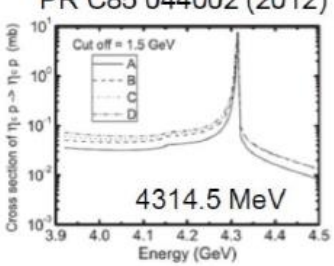
LHCb, PRL122 (2019) 222001



Comparison to numerical predictions

- Many theoretical predictions for $\Sigma_c^+\overline{D}^{(*)0}$ published before 2015, **some in quantitative agreement with the LHCb data**
  - Wu,Molina,Oset,Zou, PRL105, 232001 (2010),
  - **Wang,Huang,Zhang,Zou, PR C84, 015203 (2011),**
  - **Yang,Sun,He,Liu,Zhu, Chin. Phys. C36, 6 (2012),**
  - **Wu,Lee,Zou, PR C85 044002 (2012),**
  - Karliner,Rosner, PRL 115, 122001 (2015)

PR C85 044002 (2012)



ΔE – binding energy

Example:

Nucleon resonances with hidden charm in coupled-channels models

Jia-Jun Wu, T.-S. H. Lee, and B. S. Zou
Phys. Rev. C **85**, 044002 – Published 17 April 2012

arXiv:1202.1036

TABLE III: The pole position ($M - i\Gamma/2$) and "binding energy" ($\Delta E = E_{thr} - M$) for different cut-off parameter Λ and spin-parity J^P. The threshold E_{thr} is 4320.79 MeV of $\bar{D}\Sigma_c$ in PB system and 4462.18 MeV of $\bar{D}^*\Sigma_c$ in VB system. The unit for the listed numbers is MeV.

		PB System		VB System	
$J^P = \frac{1}{2}^-$	Λ	$M - i\Gamma/2$	ΔE	$M - i\Gamma/2$	ΔE
	650	-	-		
	800		-	$4462.178 - 0.002i$	0.002
	1200	$4318.964 - 0.362i$	1.826	$4459.513 - 0.417i$	2.667
	1500	$4314.531 - 1.448i$	6.259	$4454.088 - 1.662i$	8.092
	2000	$4301.115 - 5.835i$	19.68	$4438.277 - 7.115i$	23.90
$J^P = \frac{3}{2}^-$					
	650	-	-	-	-
	800	-	-	$4462.178 - 0.002i$	0.002
	1200	-	-	$4459.507 - 0.420i$	2.673
	1500	-	-	$4454.057 - 1.681i$	8.123
	2000	-	-	$4438.039 - 7.268i$	23.14

$\Delta E(4312) = 5.8^{+1.0}_{-6.8}$ MeV

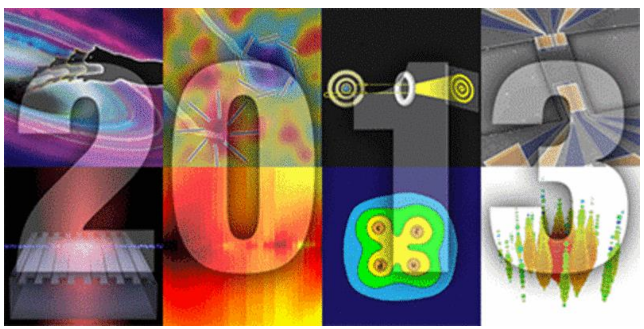
$\Delta E(4457) = 2.5^{+4.3}_{-4.1}$ MeV

$\Delta E(4440) = 19.5^{+4.9}_{-4.3}$ MeV

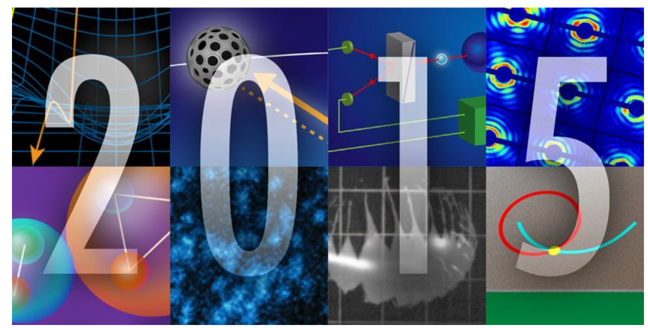
Λ - cut off on exchanged meson mass.

Top highlights in strong QCD in last ten years (APS)

#1. Discovery of Zc(3900)
by BESIII & Belle



#2. Discovery of Pc states
by LHCb



中德CRC110 PLs played leading role for predictions and explanations

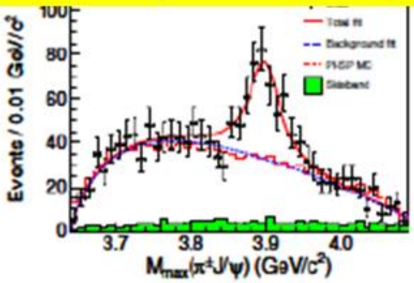
W.Chen, H.X.Chen, X.Liu, S.L.Zhu, Phys. Rept. 639 (2016) 1 — 856 cites

F.K.Guo, C.Hanhart, U.Meißner, Q.Wang, Q.Zhao, B.S.Zou,
Rev. Mod. Phys. 90 (2018) 015004 — 803 cites

BESIII上发现的Zc家族

Zc(3900)$^+$

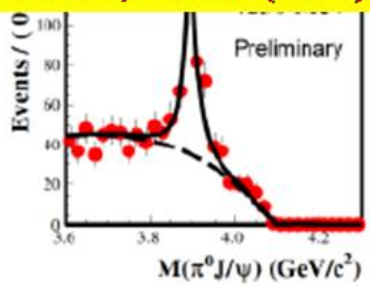
PRL 110, 252001 (2013)



$e^+e^- \to \pi^-\pi^+ J/\psi$

Zc(3900)^0

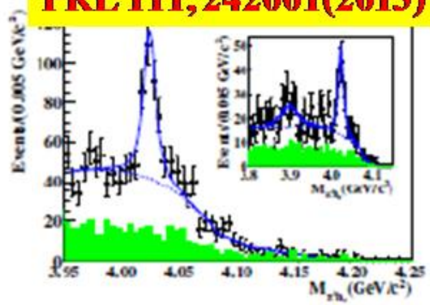
PRL 115, 112003 (2015)



$e^+e^- \to \pi^0\pi^0 J/\psi$

Zc(4020)$^+$

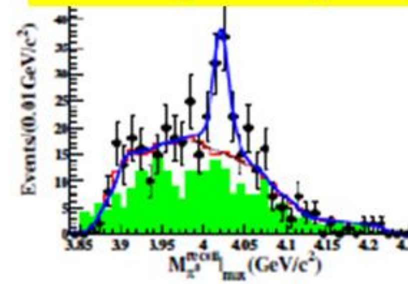
PRL 111, 242001(2013)



$e^+e^- \to \pi^-\pi^+ h_c$

Zc(4020)^0

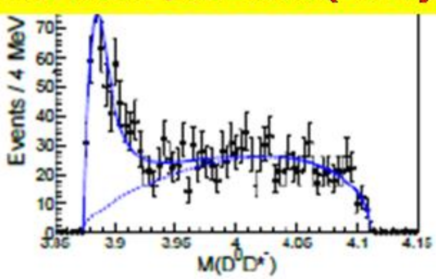
PRL113,212002 (2014)



$e^+e^- \to \pi^0\pi^0 h_c$

Zc(3885)$^+$

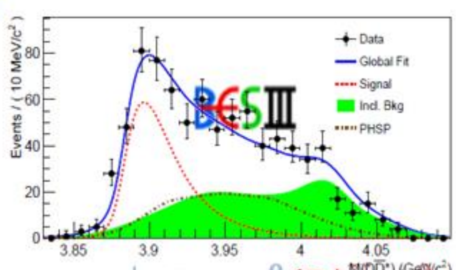
ST: PRL 112, 022001(2014)
DT: PRD92, 092006 (2015)



$e^+e^- \to \pi^-(D\bar{D}^*)^+$

Zc(3885)^0

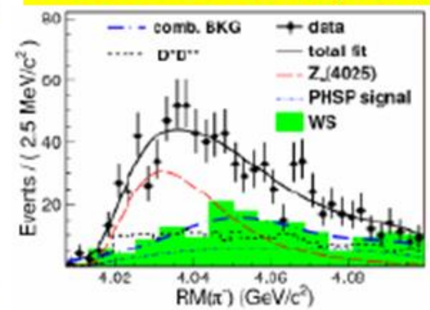
PRL 115, 222002 (2015)



$e^+e^- \to \pi^0(D^*\bar{D})^0$

Zc(4025)$^+$

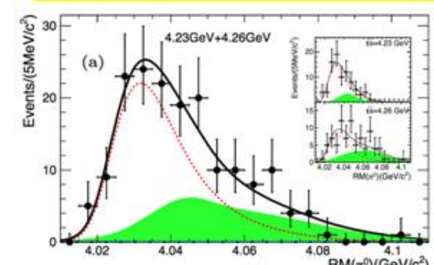
PRL 112, 132001 (2014)



$e^+e^- \to \pi^-(D^*\bar{D}^*)^+$

Zc(4025)^0

PRL115, 182002 (2015)

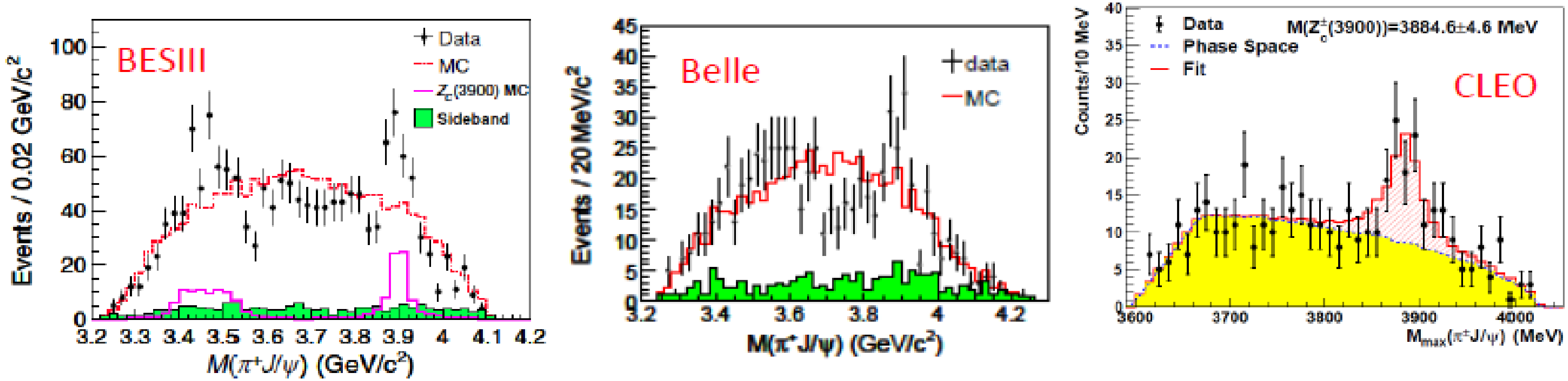


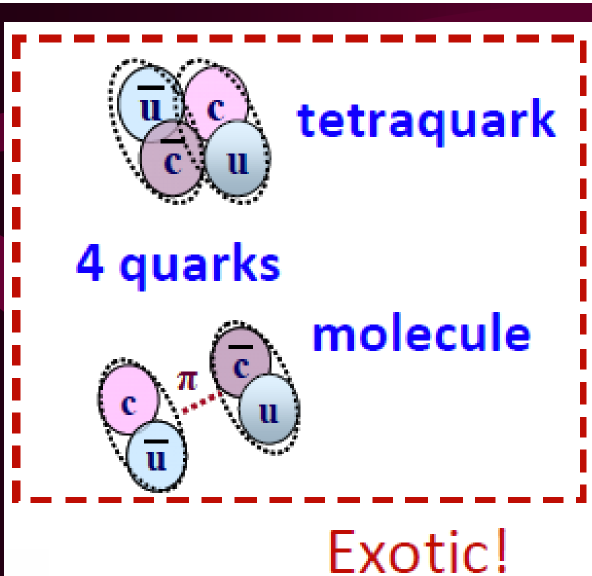
$e^+e^- \to \pi^0(D^*\bar{D}^*)^0$

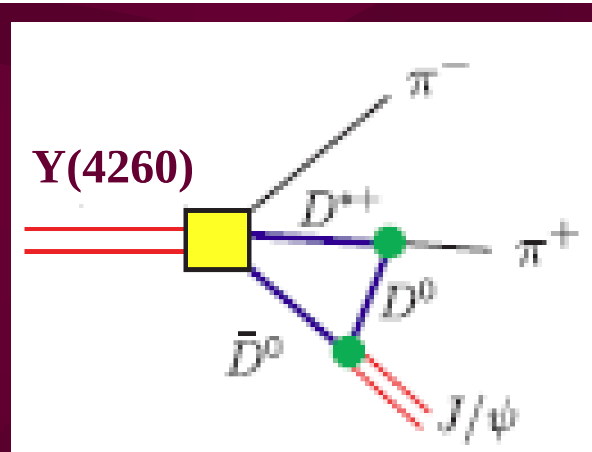
“Y(4260)的结构以及带电Zc(3900)的产生”

PRL **110**, 252001 (2013) PHYSICAL REVIEW LETTERS week ending 21 JUNE 2013

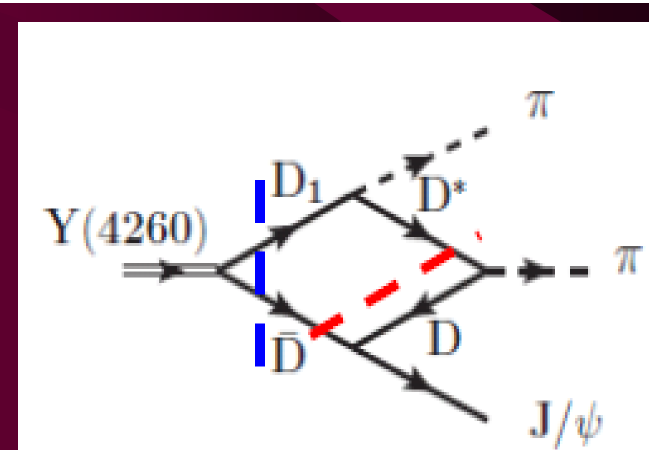
Observation of a Charged Charmoniumlike Structure in $e^+e^- \to \pi^+\pi^- J/\psi$ at $\sqrt{s} = 4.26$ GeV







D.Y.Chen, X.Liu, PRD84(2011)034032



Q.Wang,C.Hanhart,Q.Zhao PRL111(2013)132003

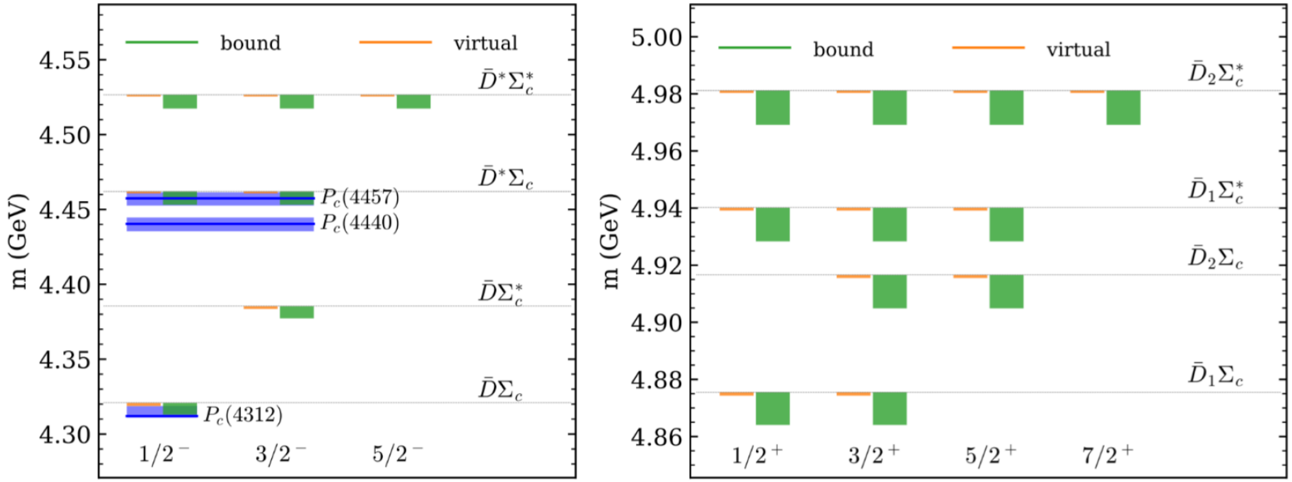
New Particles		relevant thresholds	
Zc(3900)	**$\bar{d}u\ \bar{c}c$**	$\bar{D}$*D	3880 MeV
Zc(4020)		$\bar{D}$*D*	4020 MeV
Zb(10610)	**$\bar{d}u\ \bar{b}b$**	$\bar{B}$*B	10605 MeV
Zb(10650)		$\bar{B}$*B*	10650 MeV
Pc(4312)	**uud $\bar{c}c$**	$\bar{D}\Sigma$c	4318 MeV
Pc(4440) & Pc(4457)		$\bar{D}$*Σc	4459 MeV

Hadron-hadron resonances ?

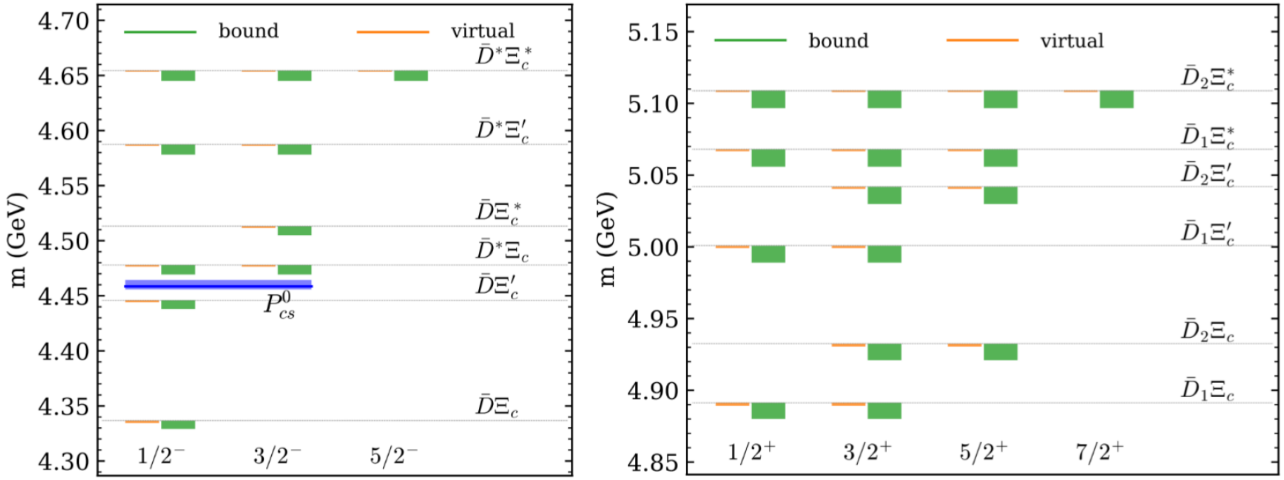
F.K.Guo, Hanhart, Meissner,Q.Wang,Q.Zhao,Zou, **Rev.Mod.Phys.90 (2018)015004**

A survey of hadronic molecules with hidden charm

X.K.Dong, F.K.Guo, B.S.Zou Progr. Phys. 41 (2021) 65

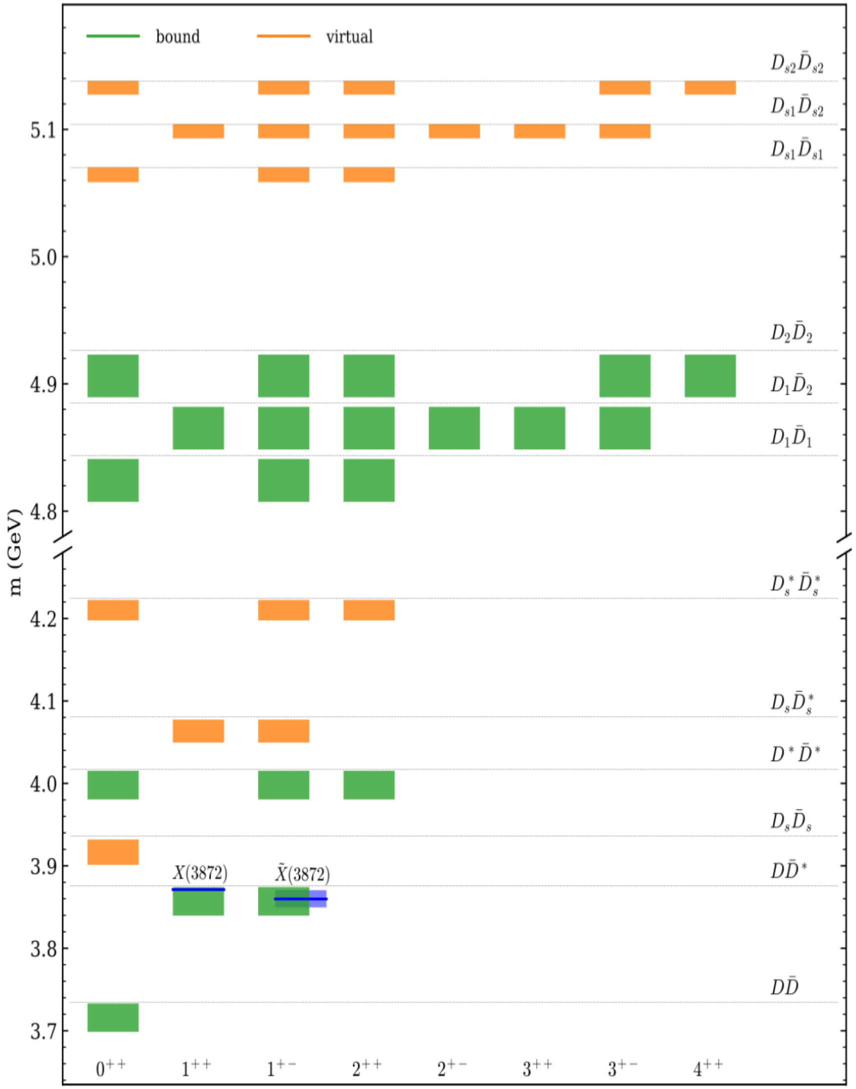


P_c

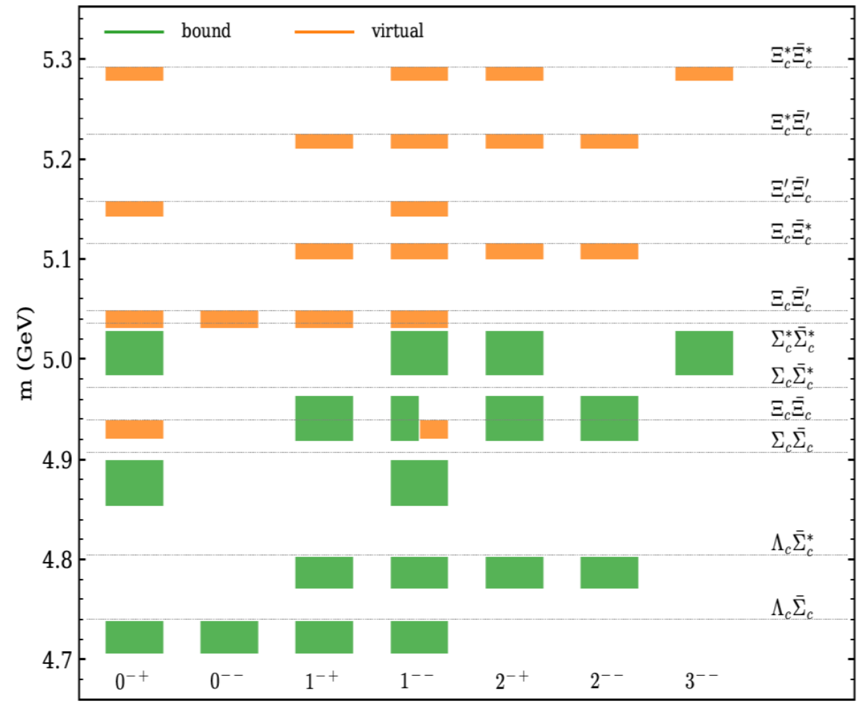


P_{cs}

Meson-meson molecules (I=0)



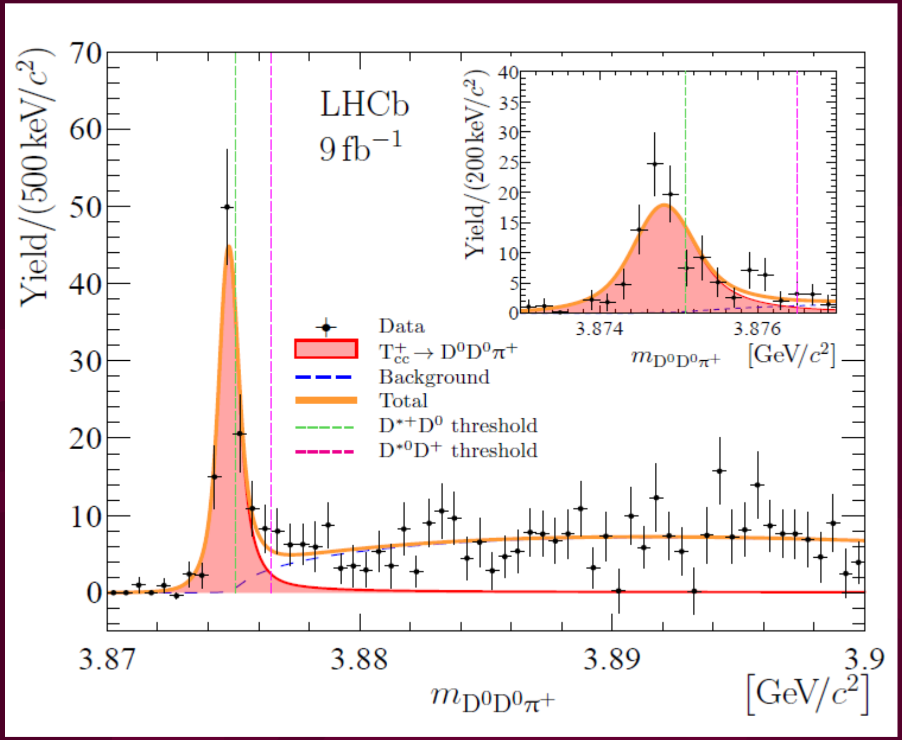
Baryon molecules (I=1) with $\bar{c}c$



- ✓ Isovector interaction between $D^{(*)}\bar{D}^{(*)}$ from light vector exchange vanishes
- ✓ Charmonia exchange could be important here: J/ψ, ψ' exchange
- ✓ $Z_c(3900{,}4020)$ as $\bar{D}^{(*)}D^*$ virtual states
- ✓ $Z_{cs}(3985)$ as $D_s\bar{D}^*, D\bar{D}_s^*$ virtual state
- ✓ $Z_c(4430)$ as $\bar{D}^*\bar{D}_1^*$virtual states

Observation of T_{cc}^+ by LHCb

Nature Phys. 18 (2022) 7, 751



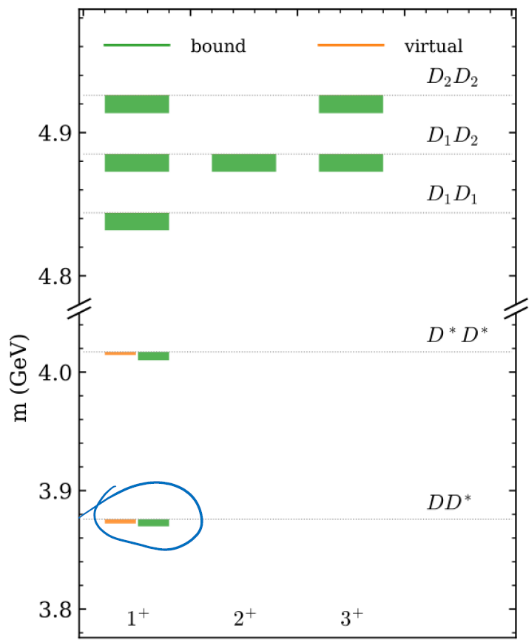
与D*D 分子态预期一致

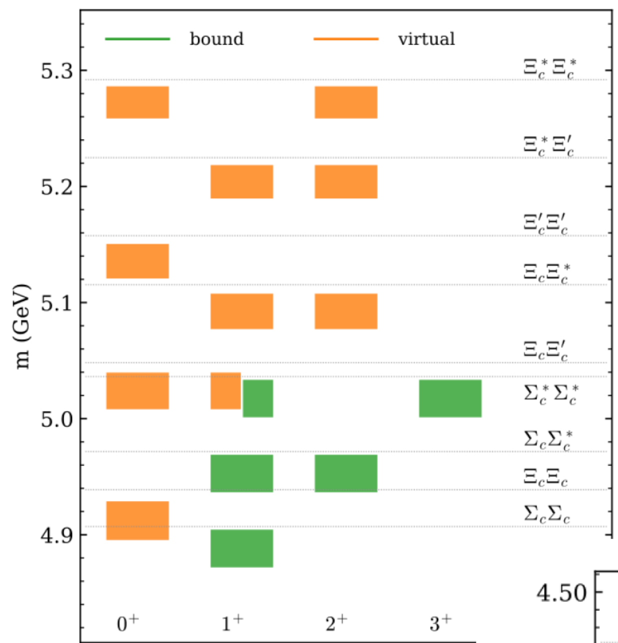
N.Li, Z.F.Sun, X.Liu, S.L.Zhu, PRD88(2013)114008

X.K.Dong, F.K.Guo, B.S.Zou, Commun.Theor.Phys.73(2021)125201

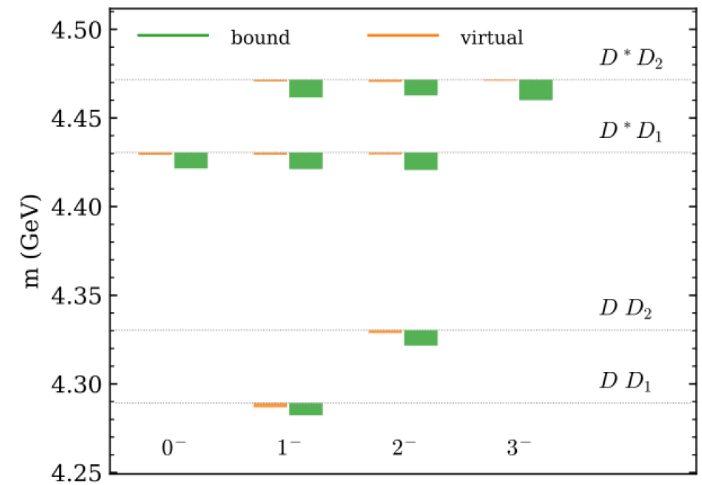
A survey of heavy-heavy hadronic molecules

X.K.Dong, F.K.Guo, B.S.Zou, Commun.Theor.Phys.73(2021)125201





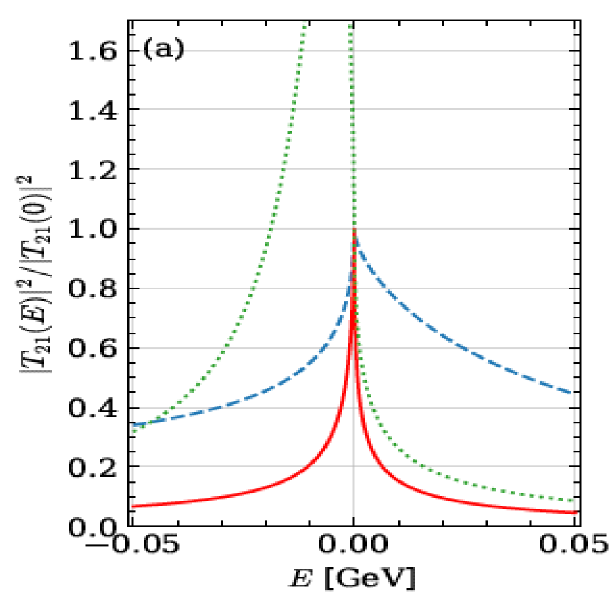
✓ Isoscalar $\Sigma_c^{(*)}\Sigma_c^{(*)}$ dibaryons very likely bound



- ✓ T_{cc} as an isoscalar DD^* bound or virtual state, D^*D^* predicted to be similar, with $P = +$
- ✓ Similar in $P = -$ sector

Explaining the many threshold structures in hadron spectrum with heavy quarks

X.K.Dong, F.K.Guo, B.S.Zou, PRL126 (2021) 152001



Prediction of a narrow exotic D^*D_1 molecule with $J^{PC}=0^{--}$

T.Ji, X.K.Dong, F.K.Guo, B.S.Zou, PRL129 (2022) 102002

$e^+e^- \rightarrow \eta\psi_0(4360) \rightarrow \eta\eta\psi$

Hybrid, Glueball or hadronic molecules ?

Observation of $\eta_1(1855)$ with exotic $J^{PC}=1^{-+}$ in $J/\psi \to \gamma\eta\eta'$

BESIII Collaboration, ArXiv: 2202.00621 [hep-ex]

Interpretation of the $\eta_1(1855)$ as a $\bar{K}K_1$ (1400)+ c.c. molecule

X.K.Dong, Y.H.Lin, B.S.Zou, SCIENCE CHINA PMA 65 (2022) 261011

Two dynamical generated a_0 resonances by VV interactions

Z.L.Wang, B.S.Zou, EPJC 82 (2022) 509

$\rho\rho$ / $\rho\omega$ molecules → f_0 (1500) / a_0 (1450)

$\bar{K}^*K^*$(I=0,1) molecules → f_0 (1710) / a_0 (1710)

Observation of a_0 (1710) → $K_S^0K^+$ in D_s^+ → $K_S^0K^+\pi^0$ decay

BESIII Collaboration, ArXiv: 2204.09614 [hep-ex]

六. 总结与展望

- all kinds of observed exotic states fit in hadronic molecule picture well, many more to be observed
- to understand hadron spectrum, quark model needs to be unquenched, with large hadronic molecule components when close to some thresholds

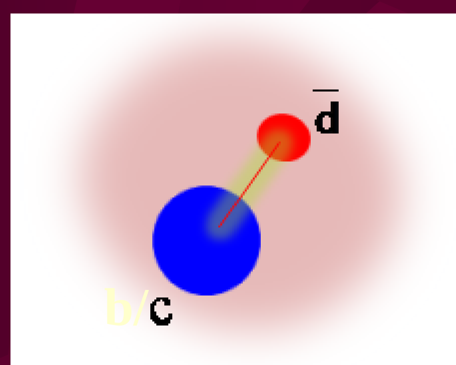
How to proceed ?

- **my favorite strategy for hadron spectroscopy:**

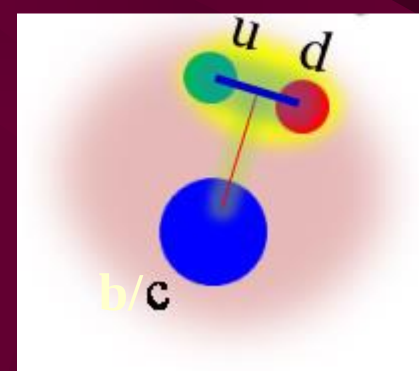
$\bar{c}$cuud & $\bar{c}$cuds → sss - $\bar{q}$qsss → csq - $\bar{q}$qcsq
→ cqq - $\bar{q}$qcqq → hyperons → light baryons

$\bar{c}$c $\bar{u}$d & $\bar{c}$s $\bar{u}$d → $\bar{c}$c - $\bar{q}$q $\bar{c}$c → $\bar{c}$s - $\bar{c}$s $\bar{q}$q
→ $\bar{c}$q - $\bar{c}$q $\bar{q}$q → K mesons → light mesons

s → c → b



charm & beauty meson



charm & beauty baryon

结束语

我们对强子谱和强子结构的了解还很贫乏。

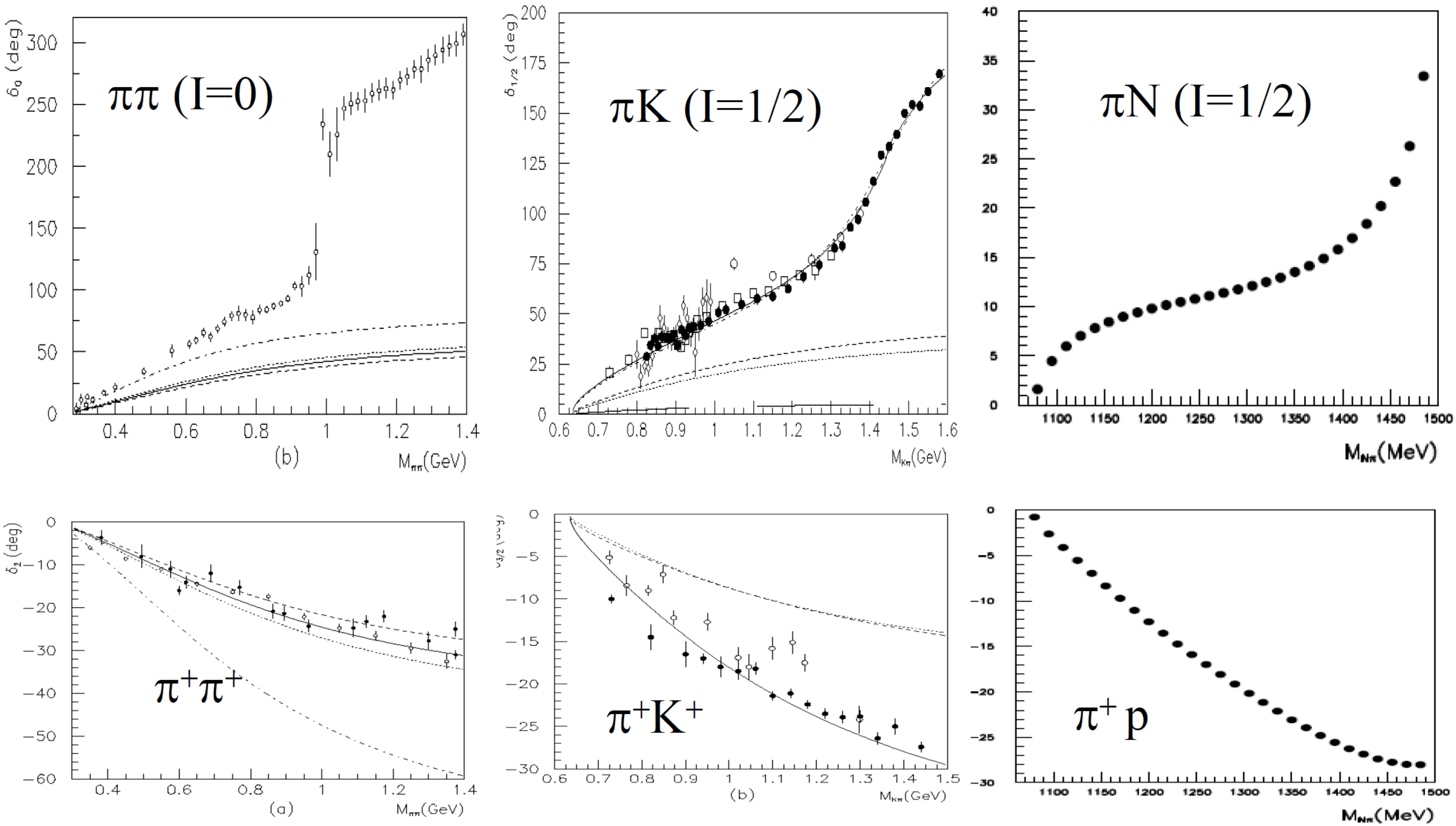
国际上多个大型实验装置在开展这方面的研究。

我国BEPCII及可能的 EicC@HIAF & super-τc &CEPC有独到之处，为我国强子物理发展提供了良好的机遇。

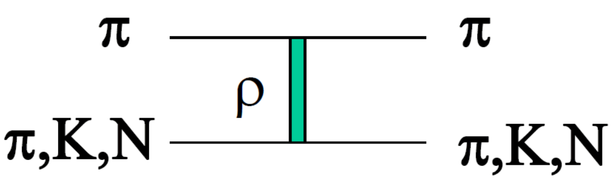
我们期待着从量变积累到质变的时刻。

谢谢大家！

Similarity for ππ, πK and πN s-wave scattering → VMD



Important role by t-channel ρ exchange for all these processes



$\pi\pi$ $\qquad$ πK & πN

$K_\rho^{I=0} = -2\, K_\rho^{I=2}$, $\qquad$ $K_\rho^{I=1/2} = -2\, K_\rho^{I=3/2}$

D. Lohse, J.W. Durso, K. Holinde, J. Speth, Nucl.Phys.A516, 513 (1990)
B.S.Zou, D.V.Bugg, Phys. Rev. D50, 591 (1994)

U. -G. Meissner, "Low-energy hadron physics from effective chiral Lagrangians with vector mesons", Phys. Rept. 161 (1988) 213

	$\bar{K}N(I=0)$	$\bar{K}N(I=1)$	$KN(I=0)$	$KN(I=1)$
Phase shifts:	strong +	weaker +	weaker –	strong –
VMD :	$-V_\omega - 3V_\rho$	$-V_\omega + V_\rho$	$V_\omega - V_\rho$	$V_\omega + 3V_\rho$

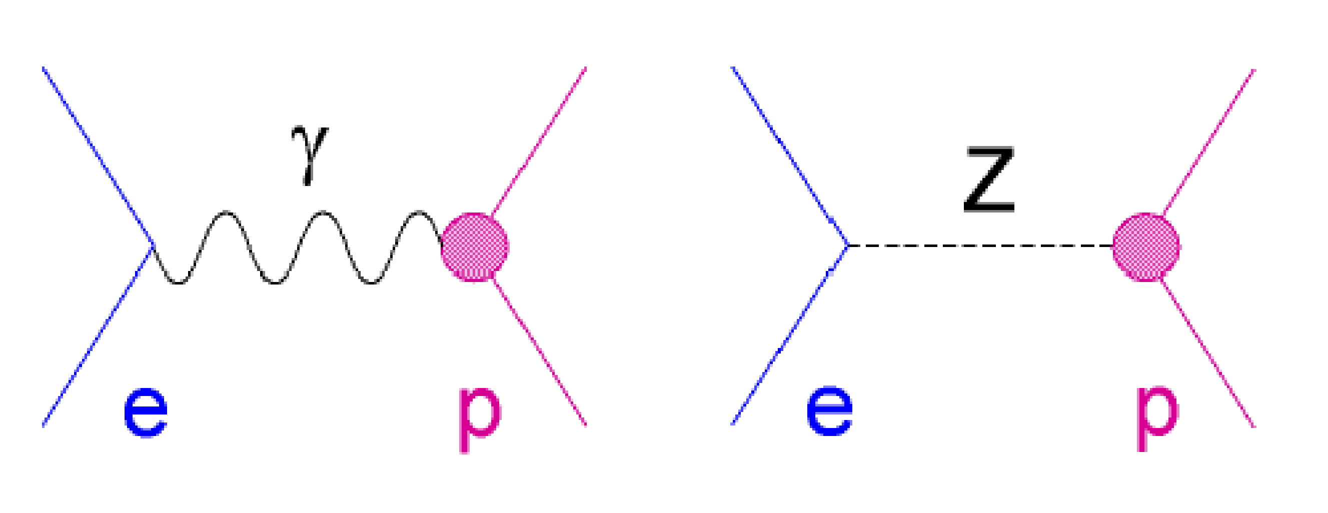
Similarity between $\pi\Sigma$ - $\bar{K}N(I=0)$ and $\pi\pi$ - $\bar{K}K(I=0)$

dipole structure for $\Lambda(1405)$ ← σ - $f_0(980)$

VMD – ChPT unitarized → N*(1535) as $K\Sigma$ bound state

Kaiser et al., PLB362(1995)23

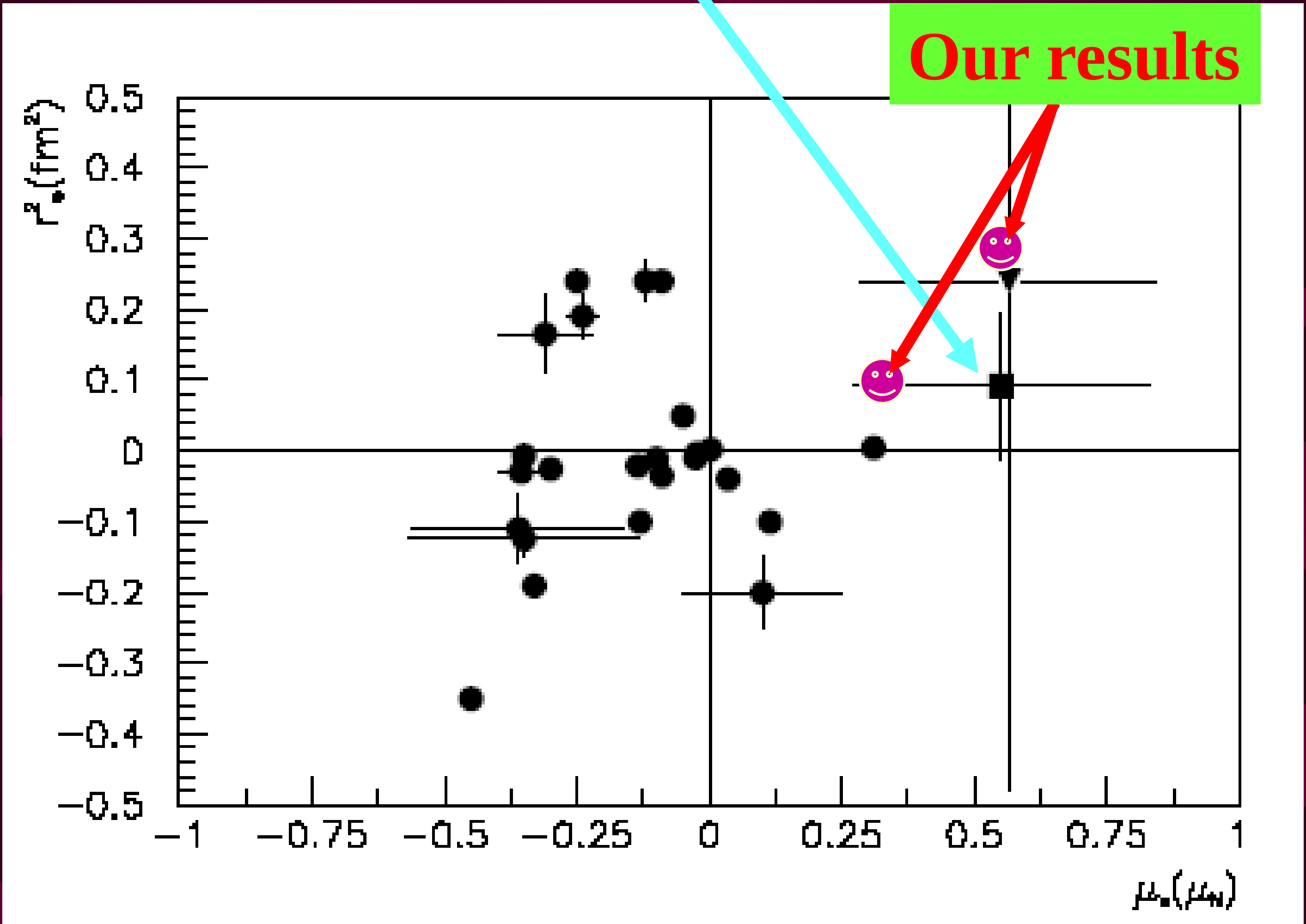
The strange magnetic moment μ_s and radii r_s from parity violating electron scattering



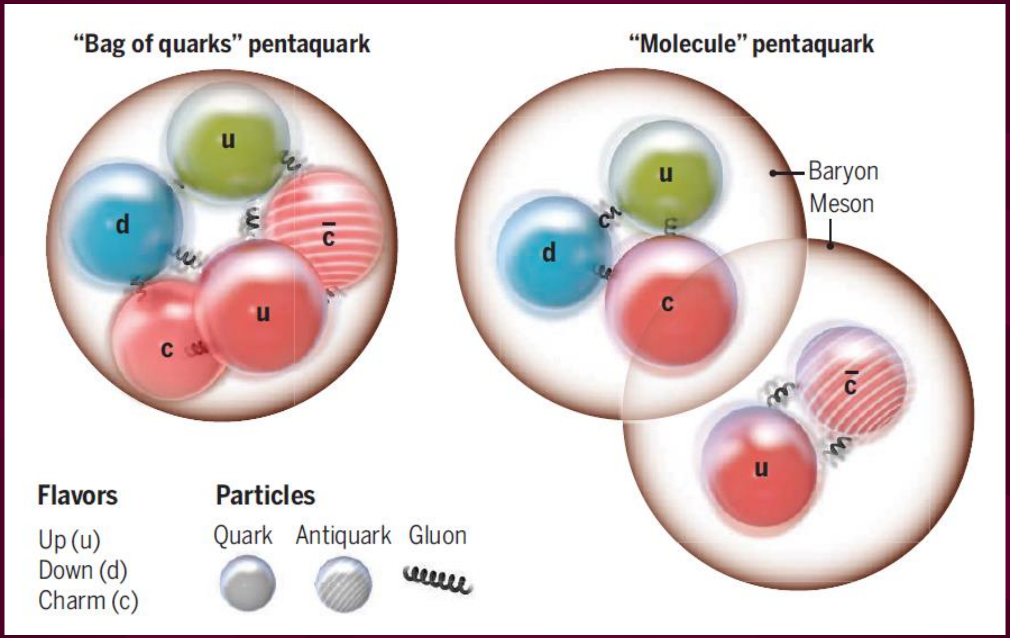
G0,HAPPEX/CEBAF, SAMPLE/MIT-Bates, A4/MAMI

HAPPEX/CEBAF, Phys.Rev.Lett. 96 (2006) 022003
G0/CEBAF, Phys.Rev.Lett. 95 (2005) 092001
A4/MAMI, Phys.Rev.Lett. 94 (2005) 152001
SAMPLE/MIT-Bates: Phys.Lett.B583 (2004) 79

Theory vs experiment for μ_s and r_s



B.S.Zou, D.O.Riska, Phys. Rev. Lett. 95 (2005) 072001
C.S.An,D.O.Riska,B.S.Zou, Phys. Rev. C73 (2006) 035207



“Bag of quarks” pentaquark
“Molecule” pentaquark
u
d
c̄
u
c
u
d
c
c̄
u
Baryon
Meson
Flavors
Up (u)
Down (d)
Charm (c)
Particles
Quark
Antiquark
Gluon