Institute of High Energy Physics, CAS

China Center of Advanced Science and Technology

第十四届晨光杯青年优秀论文评选

BESIII 上超子电磁结构与激发态辐射跃迁研究

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01 报告内容

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为什么研究超子?
如何观测其极化?

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总结

两项工作共同
推进了什么?

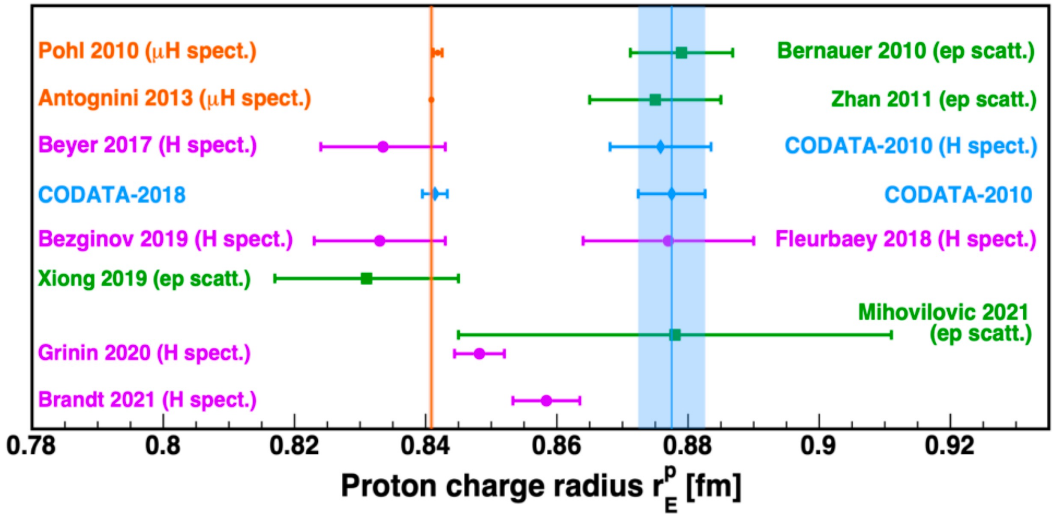
研究背景

01 质子与中子的结构研究取得显著进展

强子的内部结构，是理解强相互作用非微扰性质的重要途径。

质子　多种相互独立的实验测量手段

电子散射 ＋ 氢原子谱学

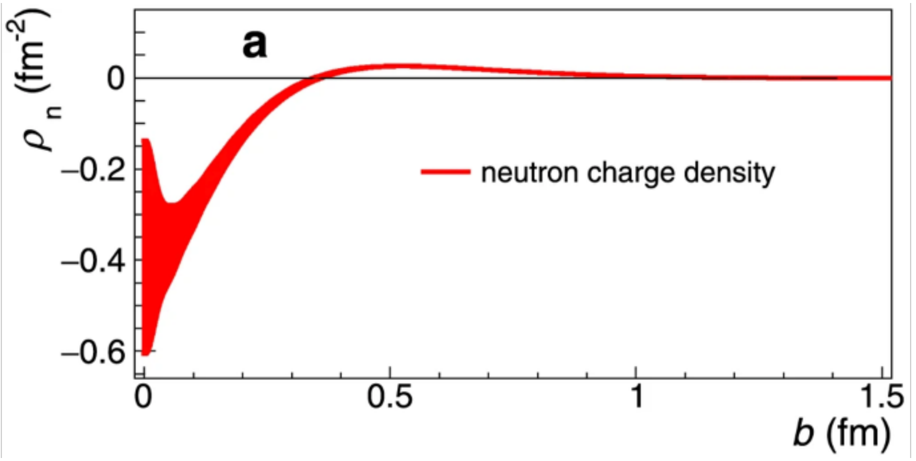


Picture credit: J. Zhou (Duke U.), NuPECC LRP draft

过去十几年取得了飞速进展

中子　实验数据与理论计算相结合

电子散射数据 ＋ 格点 QCD



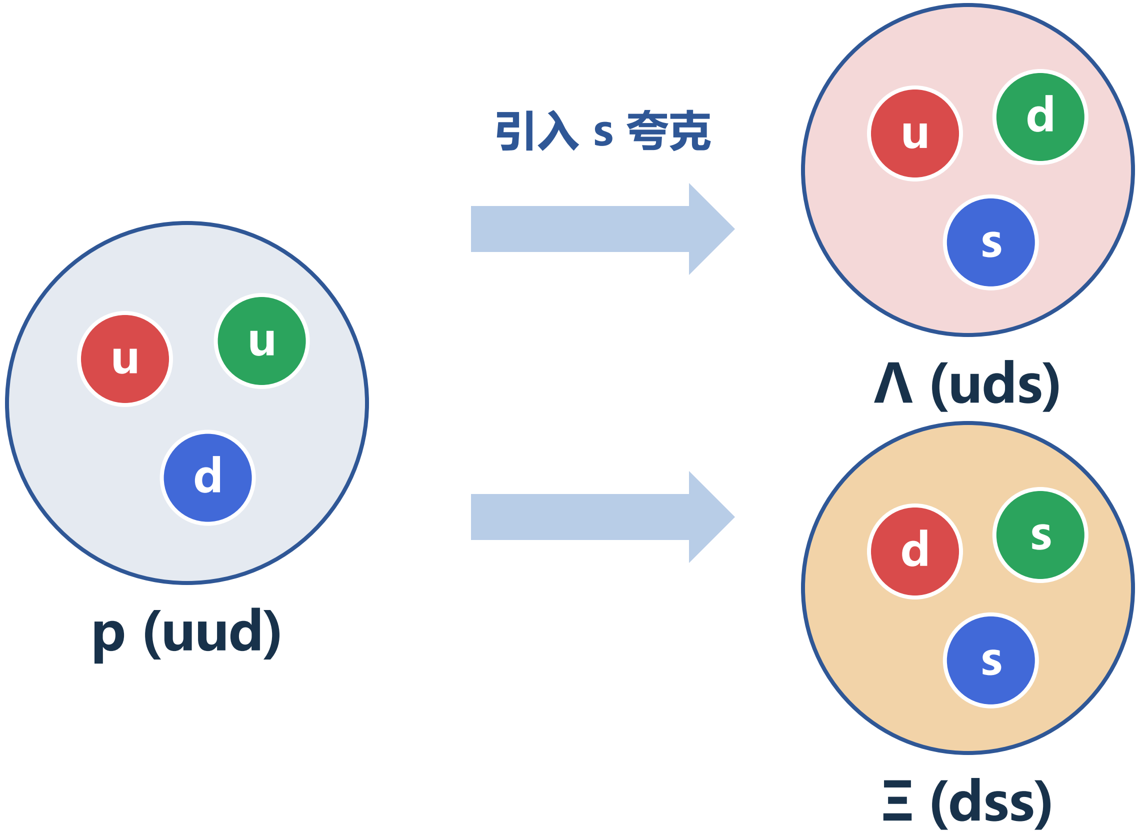
Nature Com. 12, 1759 (2021)

$\tau \approx 15$ min　形状因子也得到了很好的研究

将形状因子研究拓展到含奇异夸克的超子会怎么样?

01 超子是研究奇异夸克效应的下一站

科学问题　奇异夸克如何改变强相互作用动力学?



实验挑战：寿命逐级缩短

质子	> 10^{34} 年 （实验下限）
中子	≈ 15 min
超子	≈ 10^{-10} s

传统散射不再可行

$e^+e^- \to Y\bar{Y}$

类时电磁形状因子

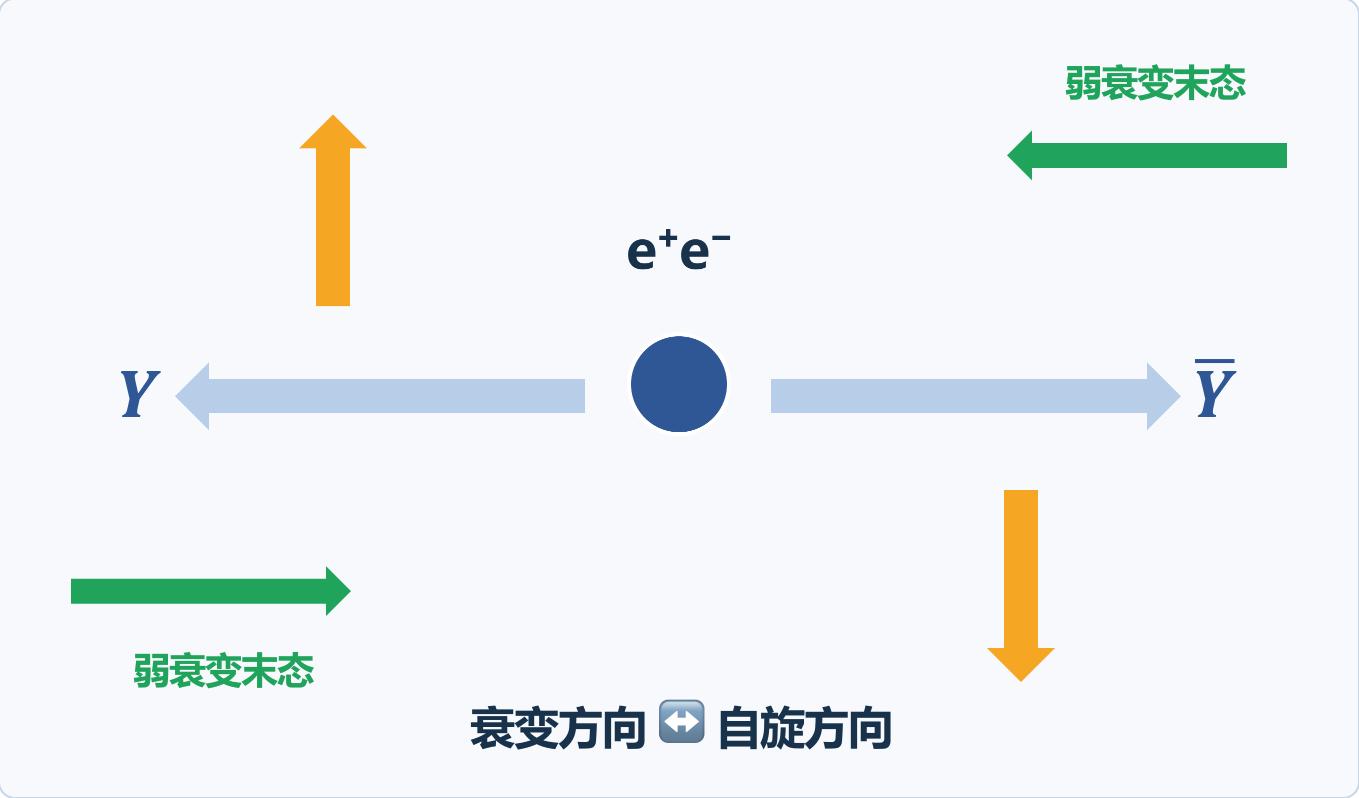
超子的价值在于“奇异夸克”，难点在于“极短寿命”

01 弱衰变多维角分布分析使超子极化和形状因子成为可观测量

短寿命超子不能作为散射靶

但其弱衰变方向直接记录自旋信息

Phys. Lett. B **772**, 16 (2017)



Phys. Rev. D **99**, 056008 (2019)

多维角分布

↓

极化与自旋关联

↓

$$R = |G_E/G_M|$$

$$\Delta\Phi = \arg(G_E / G_M)$$

$\Delta\Phi \neq 0 \Rightarrow$ 横向极化

弱衰变不是限制，而是超子极化的“自带分析仪”

01 BESIII 的百亿 J/ψ 样本把短寿命超子变成高统计对象

实验起点	预计产生的超子对数量	物理输出
10^{10} J/ψ 事例	$\Lambda\bar{\Lambda}$ 18.8 M	**多维角分布** 螺旋度振幅分析
高统计量	$\Sigma^0\bar{\Sigma}^0$ 11.7 M	**极化与相位** 提取 R、ΔΦ
低本底 完整重建	$\Xi^0\bar{\Xi}^0$ 11.7 M	**衰变与结构** 辐射跃迁、模型检验

百万量级超子样本

BESIII是研究超子形状因子及其衰变性质的理想场所

工作一：超子电磁结构

nature communications

Article

https://doi.org/10.1038/s41467-024-51802-y

Extracting the femtometer structure of strange baryons using the vacuum polarization effect

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Accepted: 19 August 2024

Published online: 11 October 2024

Check for updates

The BESIII Collaboration*

One of the fundamental goals of particle physics is to gain a microscopic understanding of the strong interaction. Electromagnetic form factors quantify the structure of hadrons in terms of charge and magnetization distribu-

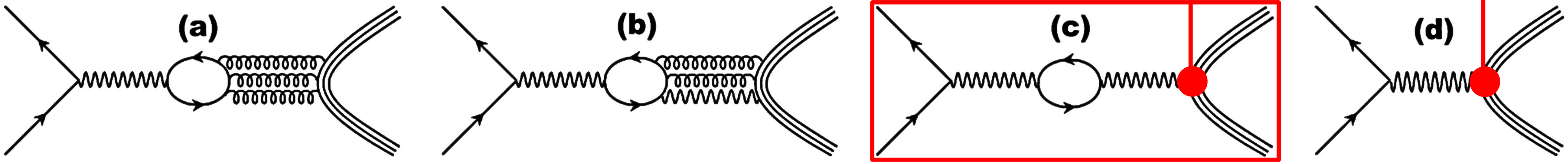
02 真空极化增强实现跃迁形状因子的高精度测量

Nature Communications 15, 8812 (2024)

异类超子对关联产生 $J/\psi \to \bar{\Lambda}\Sigma^0$：同位旋破缺 ＋ 纯电磁过程

Eur. Phys. J. C **80**, 903 (2020)

$\gamma^* Y\bar{Y}$



三胶子

强—电磁混合

J/ψ 真空极化 | 纯电磁

连续过程 | 纯电磁

连续过程（d）

$e^+e^- \to \gamma^* \to \bar{\Lambda}\Sigma^0$ | 低截面

相同电磁顶点

$\gamma^*\bar{\Lambda}\Sigma^0$ 顶点

共振过程（c）

$e^+e^- \to \gamma^* \to J/\psi(cc\ loop) \to \gamma^* \to \bar{\Lambda}\Sigma^0$

真空极化显著增强产生截面

多维角分布

螺旋度振幅分析

超子极化

提取 $\alpha_{J/\psi}$ 与 $\Delta\Phi$

物理量

R、相对相位与 CP 检验

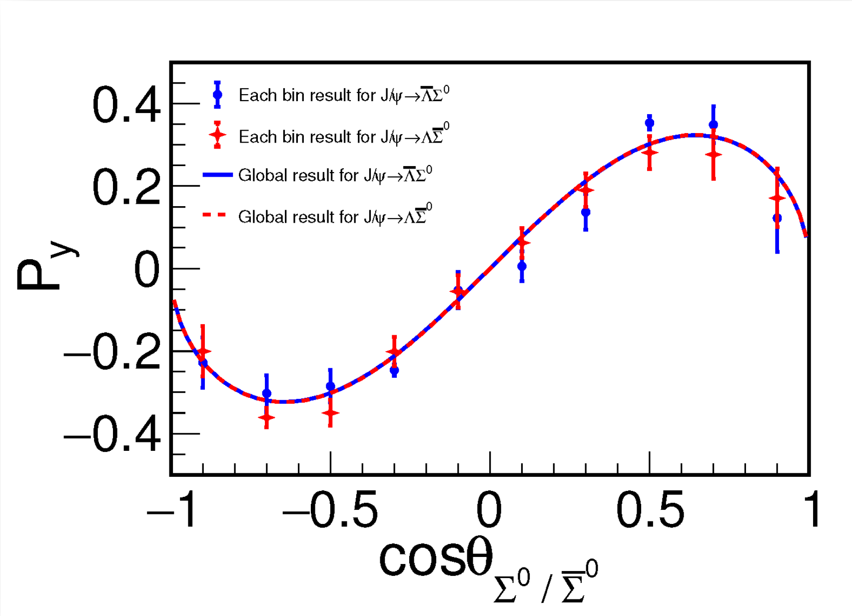
利用共振增强测量与连续过程相同的电磁顶点，实现跃迁形状因子的高精度提取

02 角分布与横向极化首次给出跃迁形状因子模比和相对相位

Nature Communications 15, 8812 (2024)

10 billion J/ψ → 26,260 ± 181 $\bar{\Lambda}\Sigma^0$ + c. c.

横向极化 $P_Y(\cos\theta)$



首次观测到 $\bar{\Lambda}\Sigma^0$ 横向超子极化

核心结果

$R = |G_E/G_M|$

$= 0.860 \pm 0.029 \pm 0.015$

相对相位

$\Delta\Phi(\bar{\Lambda}\Sigma^0) = 1.011 \pm 0.094 \pm 0.010$ rad

$\Delta\Phi(\Lambda\bar{\Sigma}^0) = 2.128 \pm 0.094 \pm 0.010$ rad

$\Delta\Phi_{CP} = 0.003 \pm 0.133 \pm 0.014$ rad

与 CP 对称性预期一致

三项首次： $\bar{\Lambda}\Sigma^0$ 横向极化观测 | 跃迁形状因子模比与相位提取 | 异类超子 CP 检验

02 推动超子极化方法走向更广泛的 CP 研究

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BESIII Beijing Spectrometer(BESIII) Experiment

Home Collaboration Operations Research User Information

Highlights

Highlights

Extracting the femtometer structure of strange baryons using the vacuum polarization effect

2024-10-12 Print Text Size A A

BESIII Highlights

Your article featured in a Nature Communications Editors' Highlights webpage

From : "Angelize Williams"<angelize.williams@nature.com>

To : "郑文静 Wenjing Zheng"<zhengwenjing@ihep.ac.cn>

Dear Dr. Wenjing

Nature Communications Editors' Highlights

Polarization analysis in $e^+e^- \to J/\psi \to$ baryon-antibaryon pairs

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(Received 9 August 2025; accepted 17 October 2025; published 10 November 2025)

We present a comprehensive polarization analysis for the process $e^+e^- \to J/\psi \to$ baryon-antibaryon pairs $B_1\bar{B}_2$. All possible helicity amplitudes for $e^+e^- \to J/\psi$ and $J/\psi \to B_1\bar{B}_2$ are provided, along with their transformation properties under parity and CP operations. Taking full account of beam polarization, we analyze the polarization of the J/ψ produced in e^+e^- annihilation and show that all eight independent polarization components can be nonzero. By introducing a polarization transfer matrix, we propose a novel method to compute the polarization transfer in the decay $J/\psi \to B_1\bar{B}_2$. Considering both hadronic and radiative baryon decay models, we derive the joint angular distribution of the final-state particles. Focusing on the process $J/\psi \to \Lambda\bar{\Sigma}^0$, we provide statistical uncertainty estimates for probing CP violation in associated production of different baryons. This work establishes a complete framework for studying the parity and CP violations present in baryon productions and decays within the helicity formalism.

DOI: 10.1103/mzkm-qw8w Phys. Rev. D 112, 096012 (2025)

后续工作建立完整极化分析框架

杂志审稿人评价	"first time … not each other's antiparticles" —— 原创性 "methodology is clear and the conclusions are solid" —— 方法可靠性 （Reviewer #3，第一轮）

1 → 2 → 3

1 学术认可
入选Nature Communications 编辑亮点及BESIII Highlights

2 方法推广
真空极化增强成为新的测量路径

3 研究拓展
关联产生中的极化传递与CP检验

工作二：激发态辐射跃迁

PHYSICAL REVIEW LETTERS **136,** 141801 (2026)

Observation of the Electromagnetic Radiative Decays of the $\Lambda(1520)$ and $\Lambda(1690)$ to $\gamma\Sigma^0$

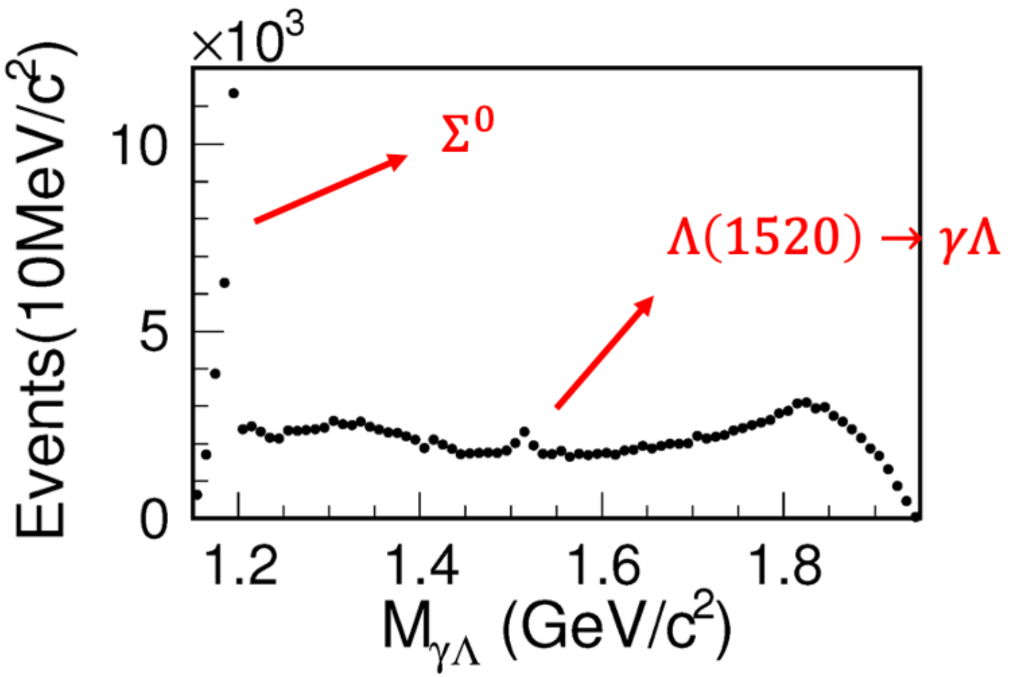
M. Ablikim *et al.*[*]
(BESIII Collaboration)

(Received 16 July 2025; revised 16 February 2026; accepted 3 March 2026; published 8 April 2026)

03 工作一的 Σ⁰ 重建中观测到 Λ(1520) 信号

Physical Review Letters 136, 141801 (2026)

工作一：重建 $\Sigma^0 \to \gamma\Lambda$



除 Σ^0 外，在 M(γΛ) 中看到 Λ(1520)

文献现状

PDG 中 Λ(1520)→γΛ 的最新直接测量仍来自 CLAS 2005

关键缺口

Λ(1520)→γΣ^0 尚无直接实验测量

理论分歧

Γ(γΛ)：32–215 keV ｜ Γ(γΣ^0)：17–293 keV

Phys. Rev. D **73**, 114001 (2006)

工作二

同时测量两种辐射跃迁，直接判别超子结构模型

工作一中的“意外收获”转化为新的科学问题：Λ(1520) 的辐射跃迁由什么结构主导?

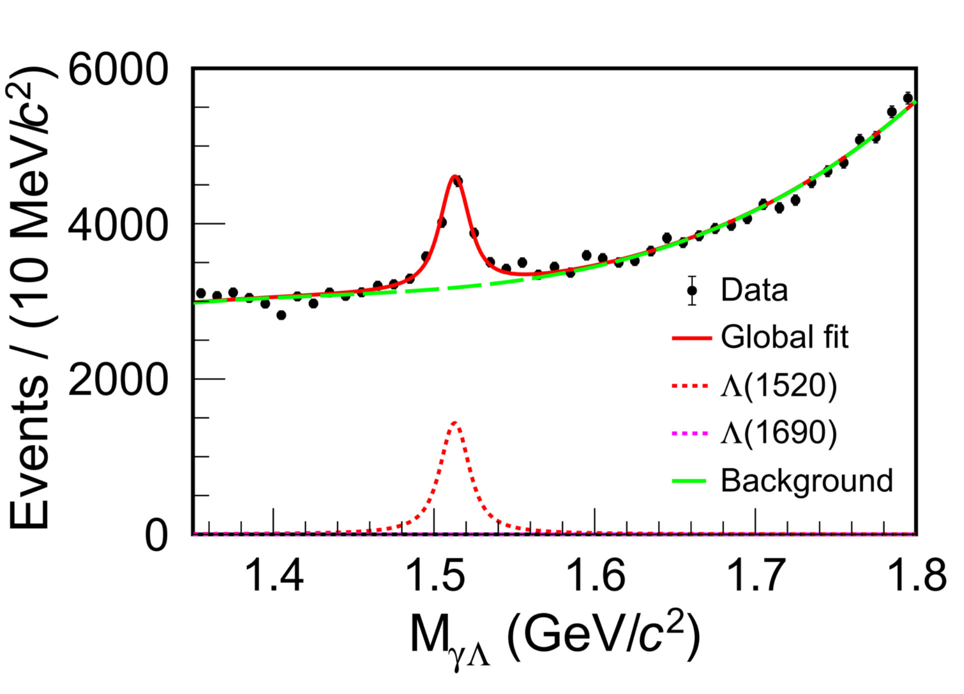
双过程质量谱揭示两种激发态的不同衰变图像

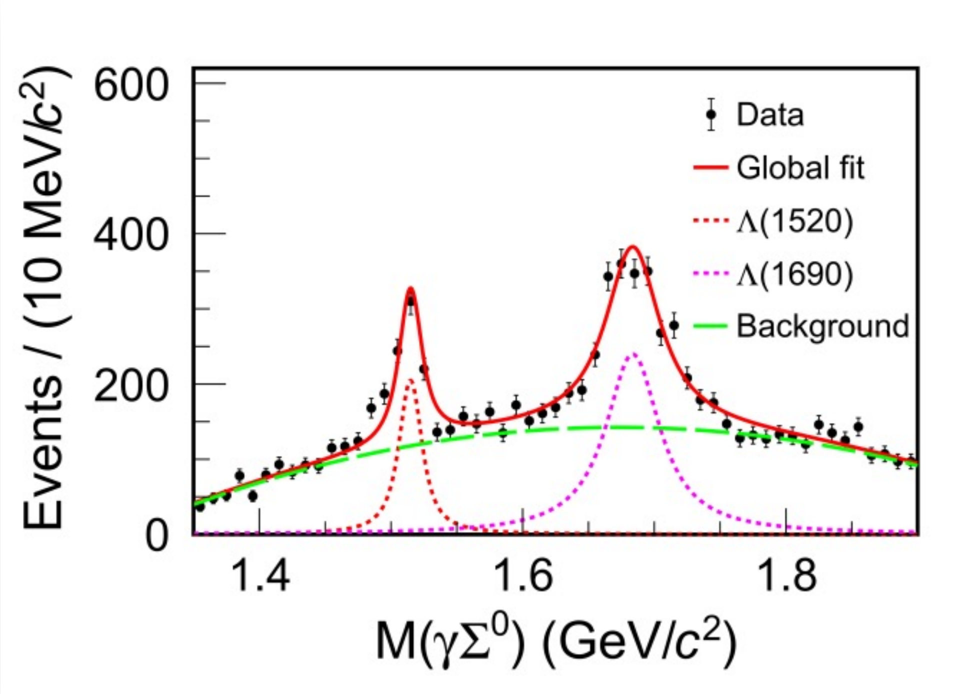
Physical Review Letters 136, 141801 (2026)

10.087×10^9 J/ψ → 两个互补衰变过程

$J/\psi \to \gamma\Lambda\bar{\Lambda}$ | 分析 M(γΛ)

$J/\psi \to \gamma\bar{\Lambda}\Sigma^0$ | 分析 M($\gamma\Sigma^0$)





Λ(1520)：4043 ± 247　Λ(1690)：< 341

Λ(1520)：621 ± 53　Λ(1690)：1754 ± 122

Λ(1520) 在两个过程均显著；Λ(1690) 仅在 $\gamma\Sigma^0$ 中显著出现

$\Lambda(1520)$ 的双过程测量检验理论模型

Physical Review Letters 136, 141801 (2026)

arXiv:2605.14946

首次观测 $\Lambda(1520) \to \gamma\Sigma^0$ 16.6σ

$R = B(\gamma\Lambda) / B(\gamma\Sigma^0)$

$= 3.19 \pm 0.34 \pm 0.19$

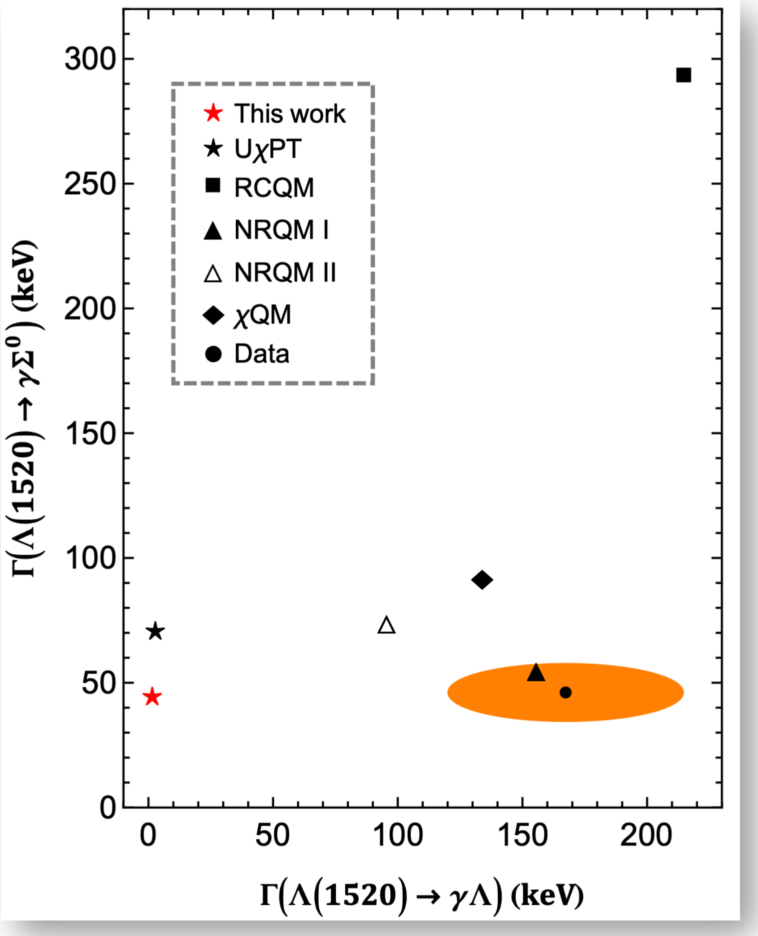
SU(3) 单态预期：$R \approx 0.3$ Phys.Atom.Nucl. 59, 2080 (1996)

实验结果高约 7σ

$\Gamma[\Lambda(1520) \to \gamma\Sigma^0]$

$= 46.8 \pm 6.6 \pm 9.3$ keV

实验结果与RCQM预言显著不相容



实验结果显著排除部分模型，为区分不同超子结构模型提供关键约束

03 Λ(1690) 两种辐射衰变模式呈现显著差异

Physical Review Letters 136, 141801 (2026)

首次观测 Λ(1690) → $\gamma\Sigma^0$ 23.2σ

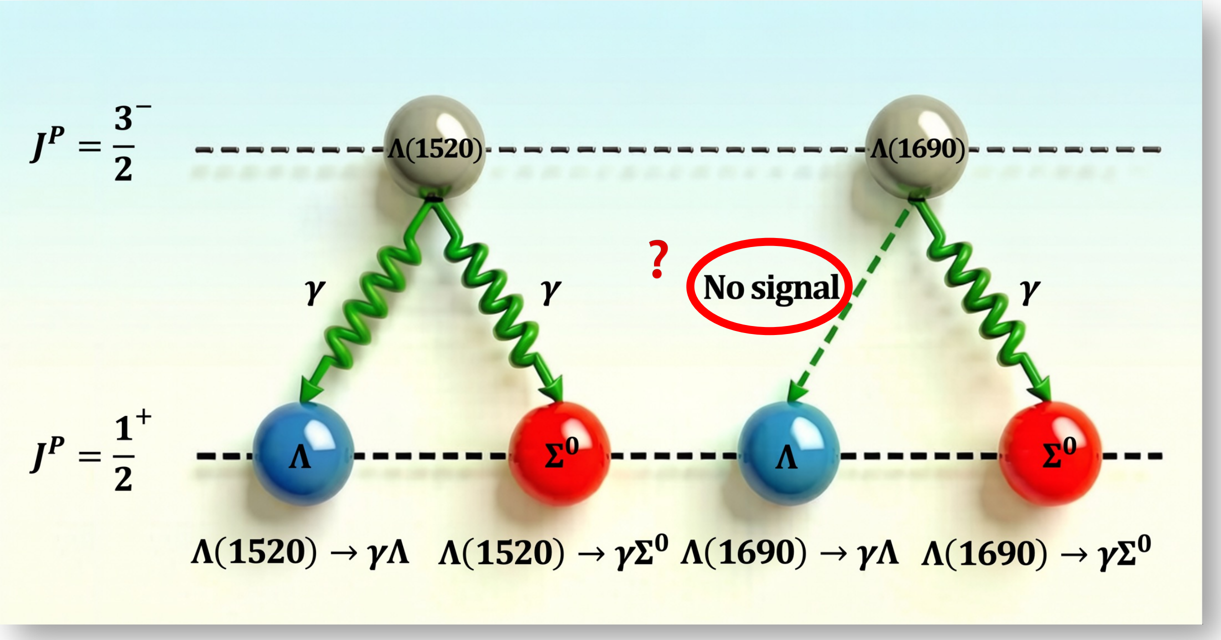
分支比乘积 = $(6.05 \pm 0.42 \pm 0.39) \times 10^{-6}$

未观测到 Λ(1690) → γΛ

分支比乘积 < 5.08×10^{-7} (90% C.L.)

R = B(γΛ) / B($\gamma\Sigma^0$) < 0.08

两种辐射衰变模式差异显著



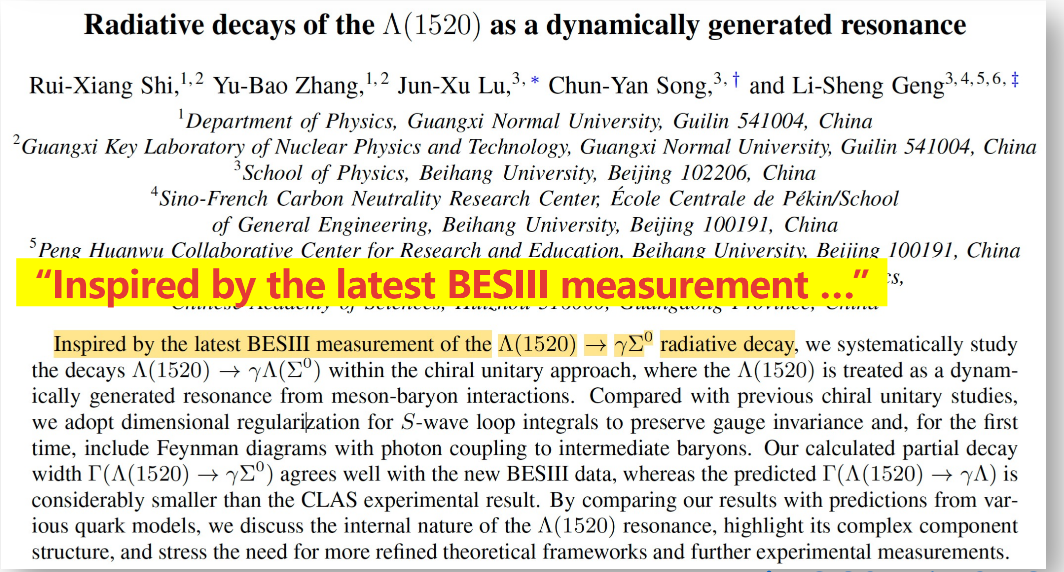
结构谜题 → 理论解释 → 其他过程交叉检验

可进一步开展 $J/\psi \to \bar{\Lambda}\Sigma^0\pi^0$ 分波分析

Λ(1690) 的显著模式差异为其内部结构提供新的实验约束

03 检验超子理论模型，并推动理论计算

BESIII Highlights



Radiative decays of the $\Lambda(1520)$ as a dynamically generated resonance

Rui-Xiang Shi,[1,2] Yu-Bao Zhang,[1,2] Jun-Xu Lu,[3,*] Chun-Yan Song,[3,†] and Li-Sheng Geng[3,4,5,6,‡]

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“Inspired by the latest BESIII measurement …”

Inspired by the latest BESIII measurement of the $\Lambda(1520) \to \gamma\Sigma^0$ radiative decay, we systematically study the decays $\Lambda(1520) \to \gamma\Lambda(\Sigma^0)$ within the chiral unitary approach, where the $\Lambda(1520)$ is treated as a dynamically generated resonance from meson-baryon interactions. Compared with previous chiral unitary studies, we adopt dimensional regularization for S-wave loop integrals to preserve gauge invariance and, for the first time, include Feynman diagrams with photon coupling to intermediate baryons. Our calculated partial decay width $\Gamma(\Lambda(1520) \to \gamma\Sigma^0)$ agrees well with the new BESIII data, whereas the predicted $\Gamma(\Lambda(1520) \to \gamma\Lambda)$ is considerably smaller than the CLAS experimental result. By comparing our results with predictions from various quark models, we discuss the internal nature of the $\Lambda(1520)$ resonance, highlight its complex component structure, and stress the need for more refined theoretical frameworks and further experimental measurements.

arXiv:2605.14946

杂志审稿人评价 | 原创性与重要性获明确肯定

“a statistical tour-de-force with 10B J/ψ decays”
— Referee A（第一轮）
“Publication in PRL is warranted due to first observation …”
— Referee B（第三轮）

Λ(1520)：首次观测检验多项理论模型

关键衰变宽度偏离多项既有预言

直接推动新的理论计算与解释

Λ(1690)：两种辐射衰变模式显著不同

$\gamma\Sigma^0$ 显著，$\gamma\Lambda$ 未观测

被评价为“有待解决的有趣问题”
期待理论解释与其他过程交叉检验

形成“实验发现—模型筛选—理论再计算—新过程验证”的完整研究链条

04 总结

以超子为探针，探索低能 QCD 中的强子结构

高统计量 J/ψ 数据 × 极化分析 × 辐射跃迁

工作一｜超子电磁结构

真空极化增强 × 超子极化观测

首次 提取 $\Lambda\Sigma^0$ 跃迁形状因子
模比 R 与相对相位 $\Delta\Phi$

CP 检验结果与 CP 对称性一致
拓展关联产生过程的 CP 研究

Nature Communications 15, 8812 (2024)

Editors' Highlight

工作二｜激发态超子辐射跃迁

首次观测 $\Lambda(1520)$、$\Lambda(1690) \to \gamma\Sigma^0$

$\Lambda(1520)$: $R = 3.19$

$\Lambda(1690)$: $R < 0.08$

模型检验 → 模式差异 → 理论再计算

Physical Review Letters 136, 141801 (2026)

BESIII Highlight

从极化观测到辐射跃迁：建立“结构参数提取—模型判别—理论反馈”的研究路径 | 谢谢各位老师！