



国家重点研发项目：

BESIII实验粲强子衰变和标准模型的精确检验

课题三：陶轻子物理和强子产生 机制的实验研究

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主要内容

- 课题组人员情况
- 研究动机
- 拟解决的关键问题
- 考核指标
- 主要研究内容进展
- 总结



课题组成员

序号	姓名	性别	出生日期	证件类型
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4	孙俊峰	男	1975-09-02	身份证
5	张丙新	男	1964-10-03	身份证
6	莫晓虎	男	1969-08-30	身份证
7	吕才典	男	1966-07-19	身份证
8	李衡讷	男	1980-11-17	身份证



1964.10-2025.6



研究动机

- 粒子物理标准模型取得了巨大成功!
- 但还有以下问题有待解决:
 - 标准模型参数精确测量;
 - 标准模型精确检验;
 - 超出标准模型的新物理探索;
 - 标准模型中QCD实验研究。
- 这些重要的基本问题都与本课题密切相关:
 - 陶轻子质量测量;
 - 电磁跑动耦合常数 $\alpha_{\text{QED}}(s)$: 电磁相互作用强度随相互作用能量改变规律;
 - μ 子反常磁矩($g-2$): 检验标准模型最灵敏、最精确的实验和理论预言;
 - Higgs粒子: 标准模型对Higgs质量(最可几值及上限)的全局拟合;
 - 直接检验量子色动力学预言: 强相互作用跑动耦合常数 $\alpha_s(s)$ 。



拟解决的关键问题

- 1) 通过开展正负电子湮灭为重子对和介子对过程截面的研究，深入理解强子的产生机制。
- 2) 深入理解强相互作用的非微扰本质。通过精确测量超子和核子的精细电磁结构和阈值增长效应，为非微扰 QCD 理论的计算提供实验依据。
- 3) 轻子普适性的精确检验。陶轻子质量是标准模型的基本参数，通过对陶轻子质量的精确测量，可以在更高精度下检验轻子普适性。



考核指标

- 陶轻子质量的高精度测量, 测量误差小于0.1 MeV。
- $\psi(3686) \rightarrow \tau^+\tau^-$ 分支比测量, 测量误差小于 5%。
- 质子精细电磁结构研究, 测量误差低于30%。
- 强作用和电磁作用相对相角测量, 首次完成 $\Psi(3686) \rightarrow KK$ 等过程的相角测量。

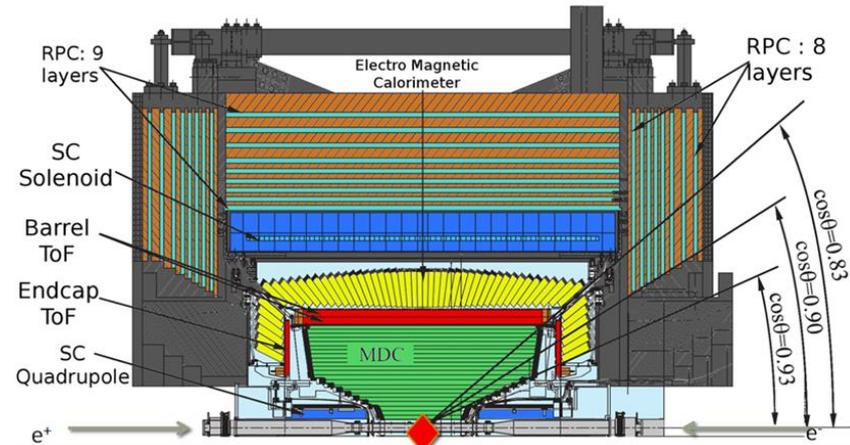
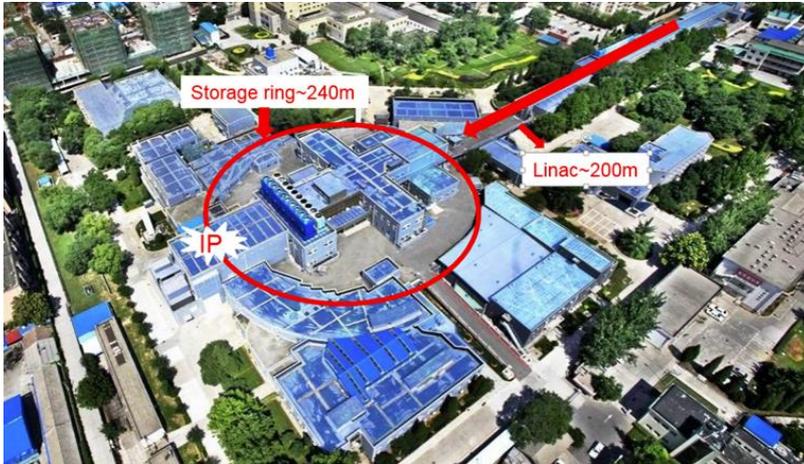


主要研究内容

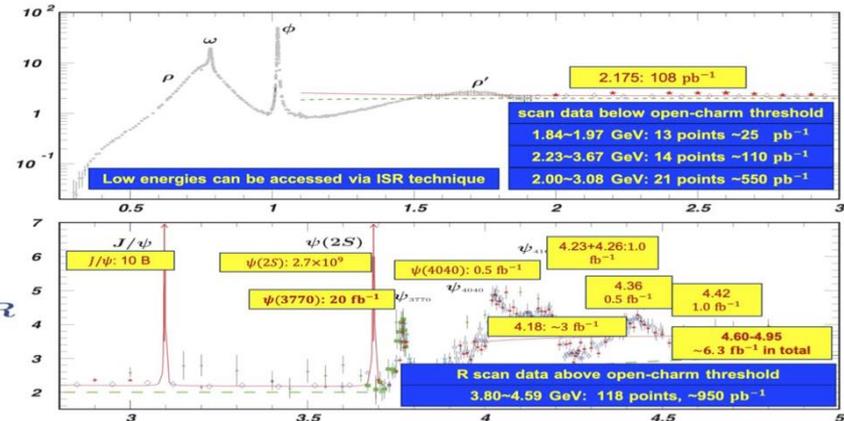
- 1) 利用阈值扫描的方法测量陶轻子的质量，陶轻子衰变。
- 2) 利用角分布分析方法，精确测量质子角分布的前后不对称性参数，并研究该参数随对撞质心能量的变化。
- 3) 利用 BESIII 获取的海量数据，研究粲偶素衰变到强子末态的三胶子强相互作用与电磁相互作用振幅之间的相对相角，并探索夸克偶素的衰变动力学机制。
- 4) 利用初态辐射方法，精确测量 $e+e^- \rightarrow \pi\pi$, KK , $\pi\pi\pi^0$ 等过程的产生截面。



BEPCII & BESIII



BEPCII: $\sqrt{s} = (1.84 - 4.95/5.6) \text{ GeV}$
 Peak luminosity: $1.1 \times 10^{33} \text{ cm}^{-2}\text{s}^{-1}$ @ 3.773
 BESIII: MDC: $\sigma_{P/P} = 0.5\%$ @ 1 GeV; $\sigma_{dE/dx} = 6\%$
 TOF: $\sigma_T = 68(60) \text{ ps}$ for barrel (endcap);
 EMC: $\sigma_{E/E} = 2.5\%(5\%)$ for barrel (endcap)
 CGEM





陶质量测量轻子普适性检验

- 陶质量是SM的基本参数，需要实验精确给出。
- SM电弱理论要求三代轻子的弱耦合常数相同，轻子普适性。

$$\left(\frac{g_\tau}{g_\mu}\right)^2 = \frac{\tau_\mu \left(\frac{m_\mu}{m_\tau}\right)^5 B(\tau \rightarrow e \nu_e \nu_\tau)}{\tau_\tau \left(\frac{m_\tau}{m_\mu}\right)^5 B(\mu \rightarrow e \nu_e \nu_\mu)} (1 + \Delta_c)$$

- 1992年之前，国际上实验测量给出的
 $G_\tau / G_\mu = 0.941 \pm 0.025$ 。
- 该结果与1的偏离意味着电弱理论的轻子普适性假设可能是存在问题的。

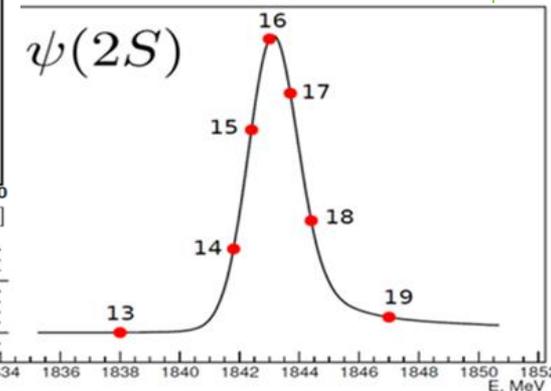
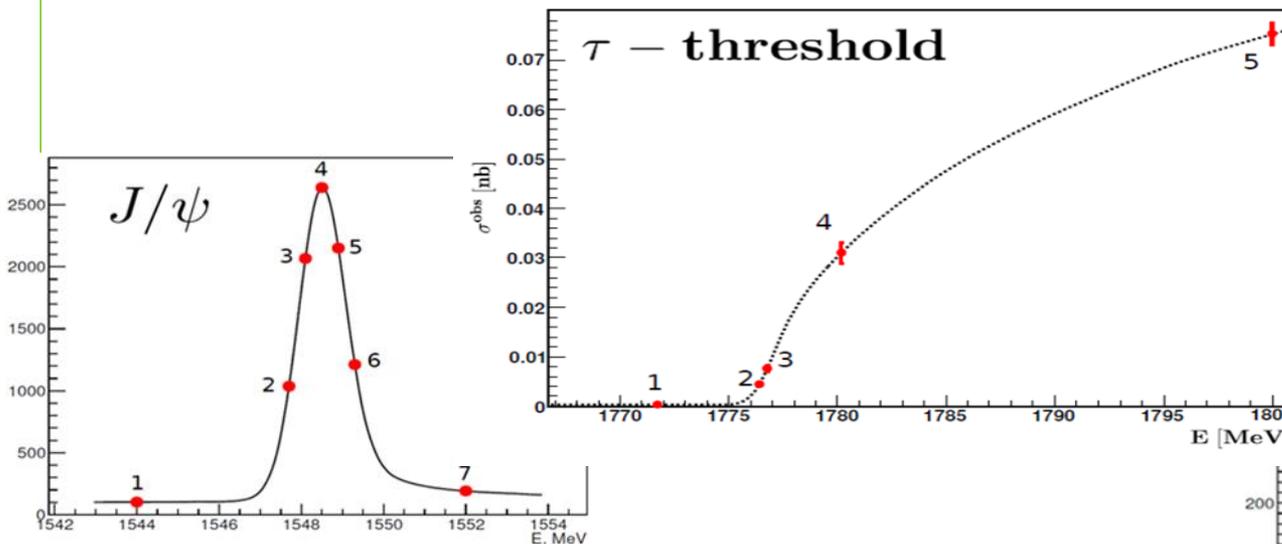


统计误差研究

Three stages:

- J/ψ scan, 7 points, determine $M_{J/\psi}$ and σ_E
- Tau mass threshold scan
- ψ' scan, 7 points, determine $M_{\psi'}$ and σ_E

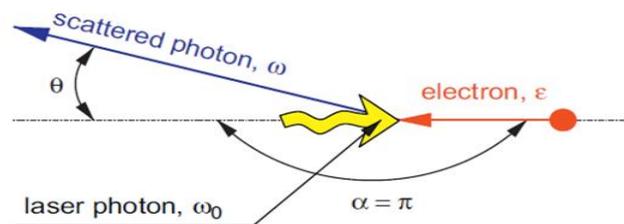
Total lum. $\sim 100\text{pb}^{-1}$,
uncertainty: 0.1MeV



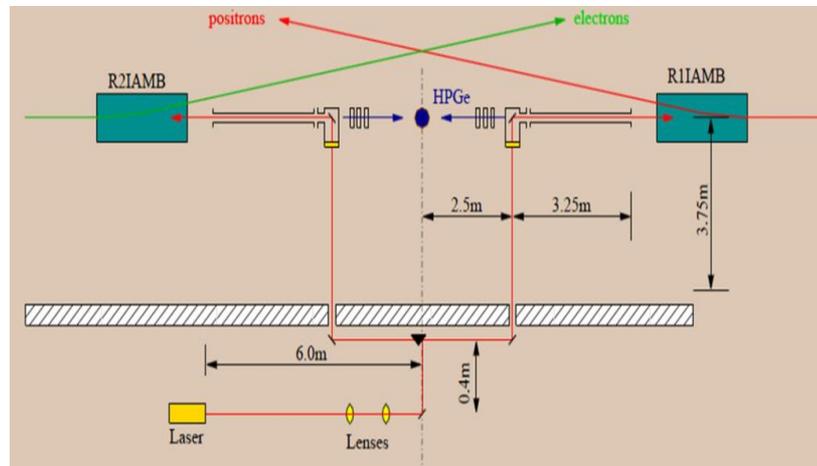
points	ΔE_1	ΔE_2	ΔE_3	ΔE_4	ΔE_5
$\Delta E_i/\text{MeV}$	-5	-0.325	+0.075	+3.5	+15
$L_i\%$	14	39	26	7	14

$$\Delta E_i = E_i - M_\tau$$

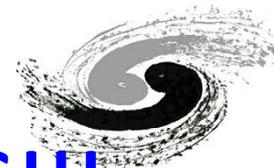
系统误差研究



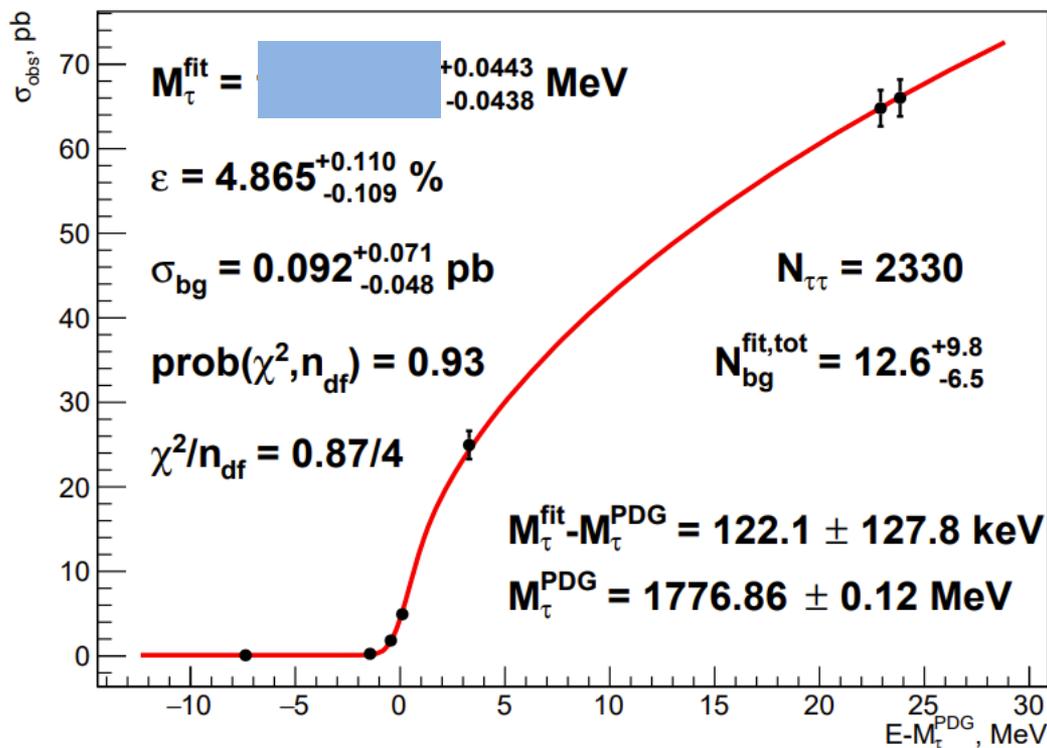
$$\omega_{max} = \frac{\epsilon^2}{\epsilon + m_e^2/4c} \quad \epsilon = \frac{\omega_{max}}{2} \left[1 + \sqrt{1 + \frac{m_e^2}{\omega_0 \omega_{max}}} \right].$$



能量不确定度：20keV



Tau mass measurement at BESIII



**Tau mass is measured using BESIII data,
total uncertainty is less than 0.1 MeV.**

$$\left(\frac{g_\tau}{g_\mu}\right)^2 - 1 = (18 \pm 28) \times 10^{-4}$$

source	comment	Δ_{M_τ} , keV
cross section calculation	ISR,FSR,VP, numer. integration	2.9
non gaussian energy spread		24.5
energy scale	multihadr selection	28.6
	two models of HpGe calibration	9.5
efficiency	$\epsilon^{\text{cor}} = 1$	6.3
luminosity	$e^+e^- \rightarrow e^+e^-$, $e^+e^- \rightarrow \gamma\gamma$	0.8
physics background	fix slope of the bg	6.5
beam background	$p_t = 50 \div 300$ MeV	7.5
cosmic background	$ z < 5 \div 12$ cm, $\rho = 0.5 \div 1.0$, $1 <$	12.8
	$\text{tof} < 6$ ns	
particle identification	$E/p = 0.75 \div 0.85$, χ_{dedx}^2 , tof	21.2
fit procedure	10k toy MC exper.	0.9
sum in quadrature		48



Br($\psi(3686) \rightarrow \tau^+\tau^-$)

- ◆ $\psi(3686)$ 可以同时衰变为 e^+e^- 、 $\mu^+\mu^-$ 和 $\tau^+\tau^-$ 轻子对, 通过测量 $B_{\tau\tau}$ 可以检验轻子普适性

$$B_{ee} \approx B_{\mu\mu} \approx B_{\tau\tau} / 0.3885$$

- ◆ 轻子味普适性标偏离准模型预言

$$R(D^{(*)}) = \frac{\Gamma(B \rightarrow D^{(*)}\tau^+\nu_\tau)}{\Gamma(B \rightarrow D^{(*)}l^+\nu_l)}, (l = e, \mu)$$

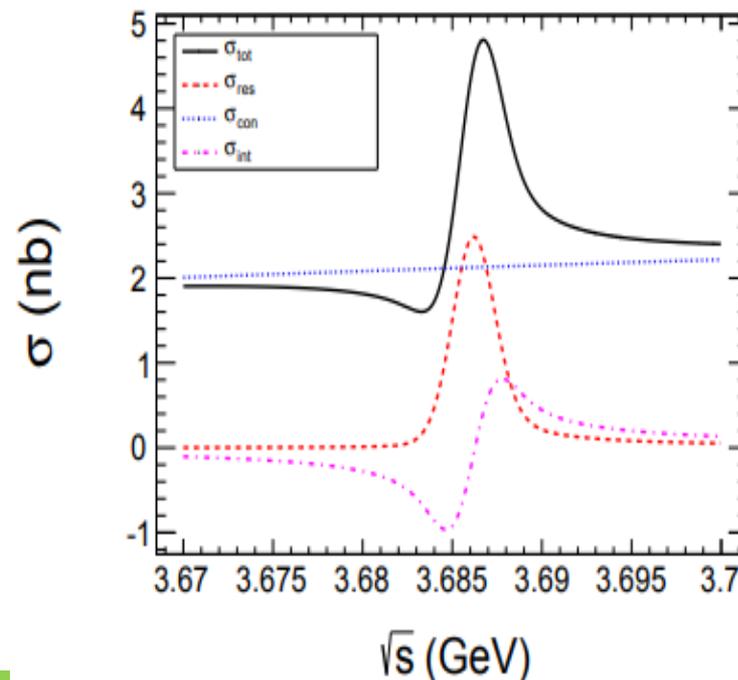
偏离3.1标准偏差

- ◆ 21年获取的 $\psi(3686)$ 数据

$$B_{\tau^+\tau^-} = \frac{\frac{N_{e\mu} - N_{bg}}{(B_{e\mu} \cdot \epsilon_{trig} \cdot \epsilon_d)} - \sigma_{Q+I} \mathcal{L}}{N_{\psi(2S)}}$$

$$\text{BESIII: } B_{\tau\tau} = (3.228 \pm 0.023 \pm 0.081) \times 10^{-3}$$

$$\text{PDG24: } B_{\tau\tau} = (3.1 \pm 0.4) \times 10^{-3}$$



精度由**13%**提高到**2.7%**



进行中的工作

- Measurement of the Strong Coupling Constant α_s from hadronic tau decay, 组内审核
- Study of $\tau^- \rightarrow a_1(\rho^0(\pi^+\pi^-)\pi^-)\nu_\tau$, Kexin Zhang's talk
- Study of $\tau^- \rightarrow \pi^-\pi^0\nu_\tau, K^-\pi^0\nu_\tau$, Shanshan Li's talk
- Measurement of $\text{Br}(\tau^- \rightarrow K^-K^+K^-\nu_\tau)$ at BESIII
- Search for the decay of $\tau^- \rightarrow K_S\pi^-\nu_\tau$

....



重子的精细电磁结构

- ◆ 核子有内部结构。PQCD无能为力，只能依靠实验测量。
- ◆ 电磁形状因子是核子的基本特性，它与电荷、磁分布有关，是核子内部结构模型的重要试验场所，可以通过角分布提取形状因子。
- ◆ 大统计量下，通过精确分析正负电子湮没到质子、反质子对极角分布以及其前后不对称性可以研究可能的双光子过程。

$$A_c(\cos\theta) = \frac{\sigma^+(\cos\theta) - \sigma^-(\cos\theta)}{\sigma^+(\cos\theta) + \sigma^-(\cos\theta)}$$

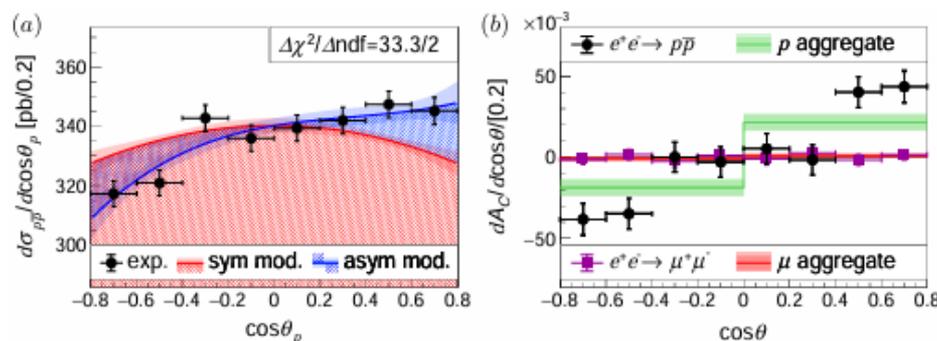


Fig. 1 The fit to the corrected proton distribution $d\sigma_{pp}/d\cos\theta$ using a symmetric model [illustrated by the red solid line and band, as equation (1)] and an asymmetric model [illustrated by the blue solid line and band, equations (1)+(2)] at $\sqrt{s} = 2.125$ GeV. The red shaded area represents the contribution from symmetry, while the blue shaded portion indicates the asymmetry contribution. (b) The charge asymmetry in the processes $e^+e^- \rightarrow p\bar{p}$ and $e^+e^- \rightarrow \mu^+\mu^-$ is depicted by the black dots with error bars and the purple squares with error bars, respectively. The latter is included for comparison. The overall charge asymmetry is represented by a green and red solid line with band, and a red solid line with band at $\sqrt{s} = 2.125$ GeV



碎裂函数的实验研究

◆ Confinement

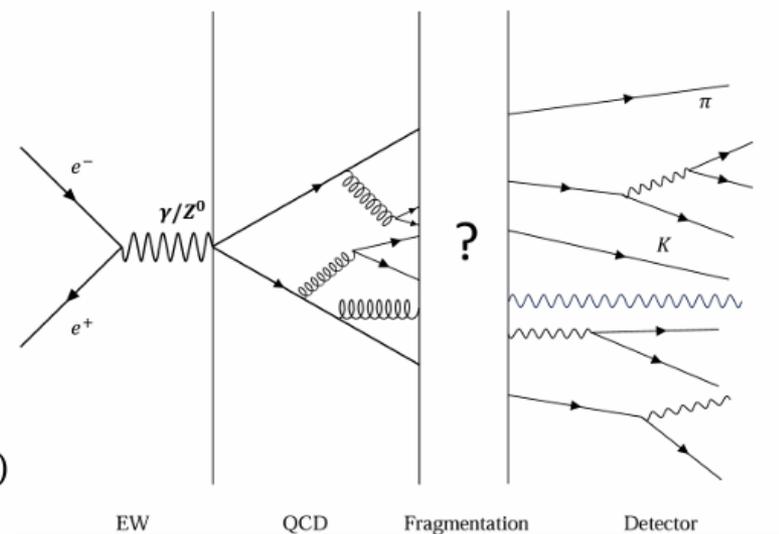
- ✓ No existing isolated quarks or gluons.

◆ Fragmentation functions (FFs)

- ✓ Describe how quarks or gluons transform into hadrons.

$$D_i^h(z, Q^2),$$

- i : quark, anti-quark or gluon
- h : hadrons like π^0, K_S^0, π^\pm etc..
- z : energy fraction of hadron. ($z = 2E_h/\sqrt{s}$ in e^+e^-)
- Q^2 : four momentum transfer in the reaction



- ✓ Probability of finding color-neutral h , need experimental data as input.
- ✓ Essential manifestations of QCD and confinement.



碎裂函数的实验研究

◆ Fragmentation function in e^+e^- annihilation

- ✓ Measure the normalized differential cross-section of the inclusive production of final state hadron “ h ”

$$\frac{1}{\sigma_{tot}(e^+e^- \rightarrow \text{hadrons})} \frac{d\sigma(e^+e^- \rightarrow h + X)}{dp_h}$$

- h is a particular type of hadron like $\pi^0, \pi^\pm, K^\pm \dots$
- p_h is momentum of hadron
- At leading order: $\sim \sum e_q^2 D_q^h(z, Q^2)$, Q^2 is the energy of virtual photon in e^+e^- annihilation

- ✓ In practice, the normalized differential cross-section for the inclusive production is measured by:

$$\frac{1}{\sigma_{had}} \frac{d\sigma}{dp} = f_{correct} \frac{N}{N_{had}} \frac{1}{\Delta p}$$

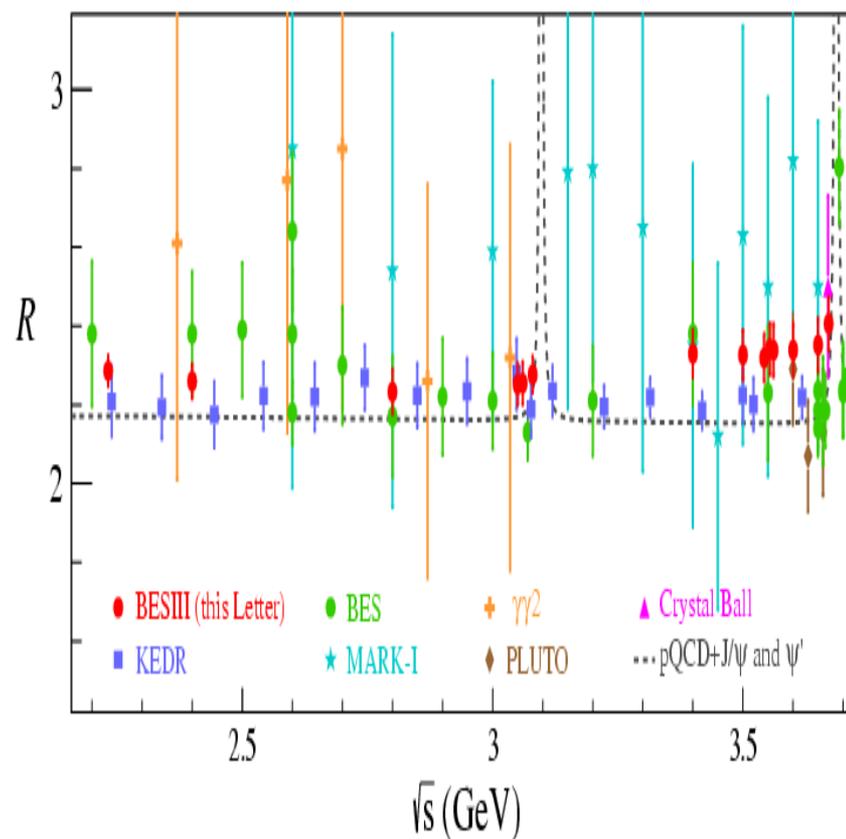
N_{had} : Number of total hadronic events
 $f_{correct}$ containing efficiency and ISR corrections

Yateng Zhang's talk



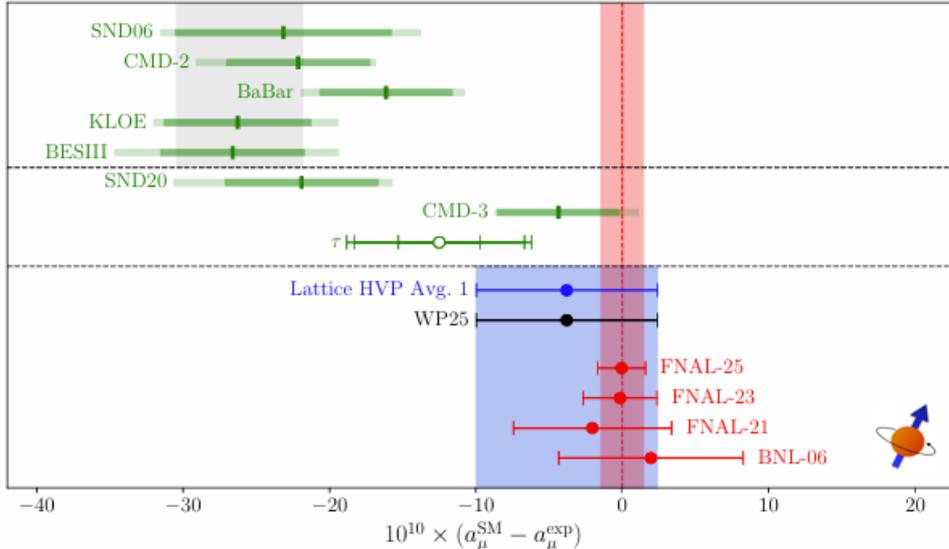
BESIII上的R值测量

- ◆ R值对夸克-部分子模型确立，夸克颜色及强作用SU(3)对称性提供直接证据。其测量精度对SM电磁 $\alpha(s)$, a_μ , M_{H0} 的全局拟合以及其它电弱参数的不确定性影响很大。
- ◆ 在 2.23 至 3.67 GeV 能量范围内测量R 值，3.1 GeV 以下精度优于 2.6%，3.1 GeV 以上精度优于 3.0%。
- ◆ 更宽范围内产生子调试。
- ◆ 2.0GeV至4.59GeV的R值测量基本完成。组内审核





强子产生截面和形状因子测量



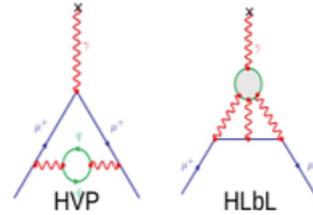
$$a_{\mu}^{\text{SM}} = 116\,592\,033(62) \times 10^{-11}$$

$$a_{\mu}^{\text{exp}} = 116\,592\,071.5(14.5) \times 10^{-11}$$

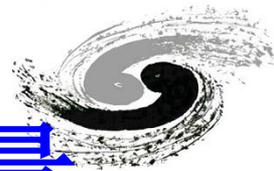
$$\Delta a_{\mu} \equiv a_{\mu}^{\text{exp}} - a_{\mu}^{\text{SM}} = 38(63) \times 10^{-11}$$

$$a_{\mu}^{\text{SM}} = a_{\mu}^{\text{QED}} + a_{\mu}^{\text{EW}} + a_{\mu}^{\text{had}}$$

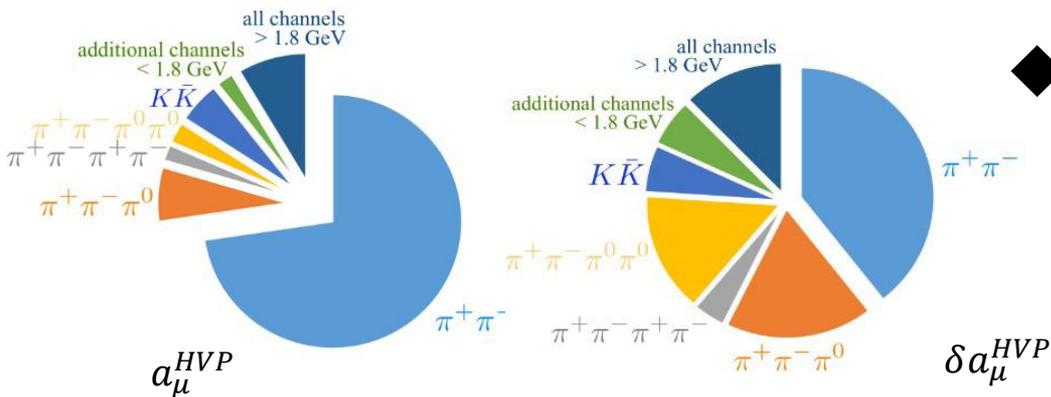
Input from experiments needed!



Contribution	WP25	WP20
HVP LO (lattice)	7132(61)	7116(184)
HVP LO (e^+e^- , τ)	Table 5	6931(40)*
HVP NLO (e^+e^-)	-99.6(1.3)	-98.3(7)
HVP NNLO (e^+e^-)	12.4(1)	12.4(1)
HLbL (phenomenology)	103.3(8.8)	92(19)
HLbL NLO (phenomenology)	2.6(6)	2(1)
HLbL (lattice)	122.5(9.0)	82(35)
HLbL (phenomenology + lattice)	112.6(9.6)	90(17)
QED	116584718.8(2)	116584718.931(104)
EW	154.4(4)	153.6(1.0)
HVP (LO + NLO + NNLO)	7045(61)	6845(40)
HLbL (phenomenology + lattice + NLO)	115.5(9.9)	92(18)
Total SM Value	116592033(62)	116591810(43)

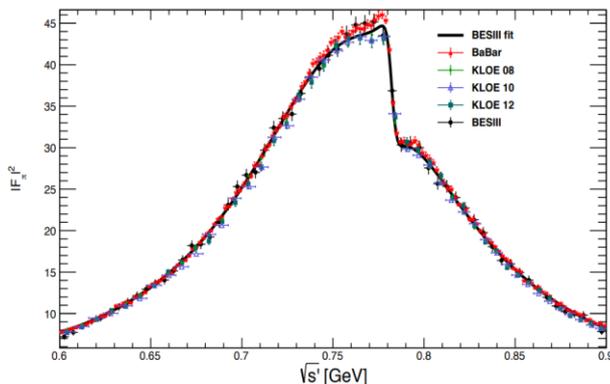


强子产生截面和形状因子测量



◆ 20 fb⁻¹ ψ(3770) 数据

- 测量 $e^+e^- \rightarrow \pi^+\pi^-$ 与 $e^+e^- \rightarrow \mu^+\mu^-$ 截面之比
- 部分系统误差, 如亮度、辐射函数, 真空极化修正将抵消
- 预计测量的系统误差: **0.5%**



- $e^+e^- \rightarrow \pi^+\pi^-$ at BESIII with ISR method:
 - Systematic uncertainty: **0.9%**.
 - Dominate uncertainty sources: luminosity (0.5%), radiator function (0.5%)

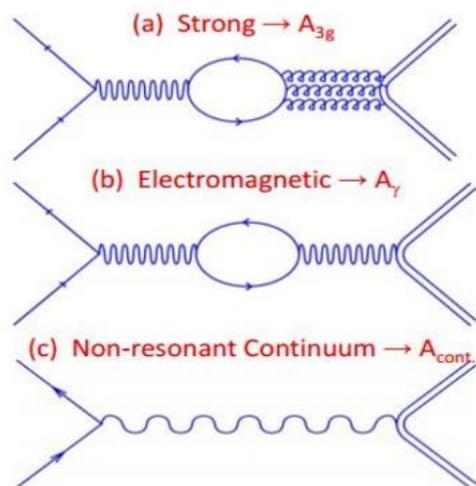
- $e^+e^- \rightarrow \gamma\gamma^* \rightarrow \pi^0\pi^0$
- $e^+e^- \rightarrow \gamma\gamma^* \rightarrow \pi^0\eta$
- $e^+e^- \rightarrow \gamma\gamma^* \rightarrow \eta$
- $e^+e^- \rightarrow \gamma\gamma^* \rightarrow \pi\pi\pi^0/\eta$
- $e^+e^- \rightarrow \gamma\gamma^* \rightarrow K^+K^-$
- $e^+e^- \rightarrow \gamma\gamma^* \rightarrow K_L K_S$

... ..



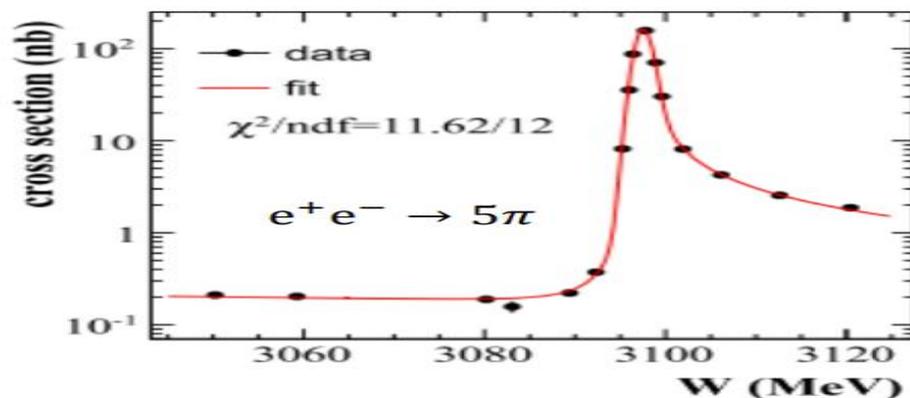
强作用与电磁作用振幅之间相角

- ◆ 研究粲偶素衰变到强子末态的三胶子强相互作用与电磁相互作用振幅之间的相对相角，为探索夸克偶素的衰变动力学提供了新的方向。



$$\sigma_{Born} = |A_{3g} + A_\gamma + A_{cont.}|^2$$

$$= \left| |A_{3g}|e^{i\Phi_{3g,EM}} + |A_\gamma|e^{i\Phi_{\gamma,cont.}} + |A_{cont.}| \right|^2$$



	$\Phi_{g,EM}$	$\mathcal{B}_{5\pi}$ (%)	χ^2/ndf
Solution I	$(84.9 \pm 3.6)^\circ$	4.73 ± 0.44	11.62/12
Solution II	$(-84.7 \pm 3.1)^\circ$	4.85 ± 0.45	11.62/12



Scan measurement -- upcoming

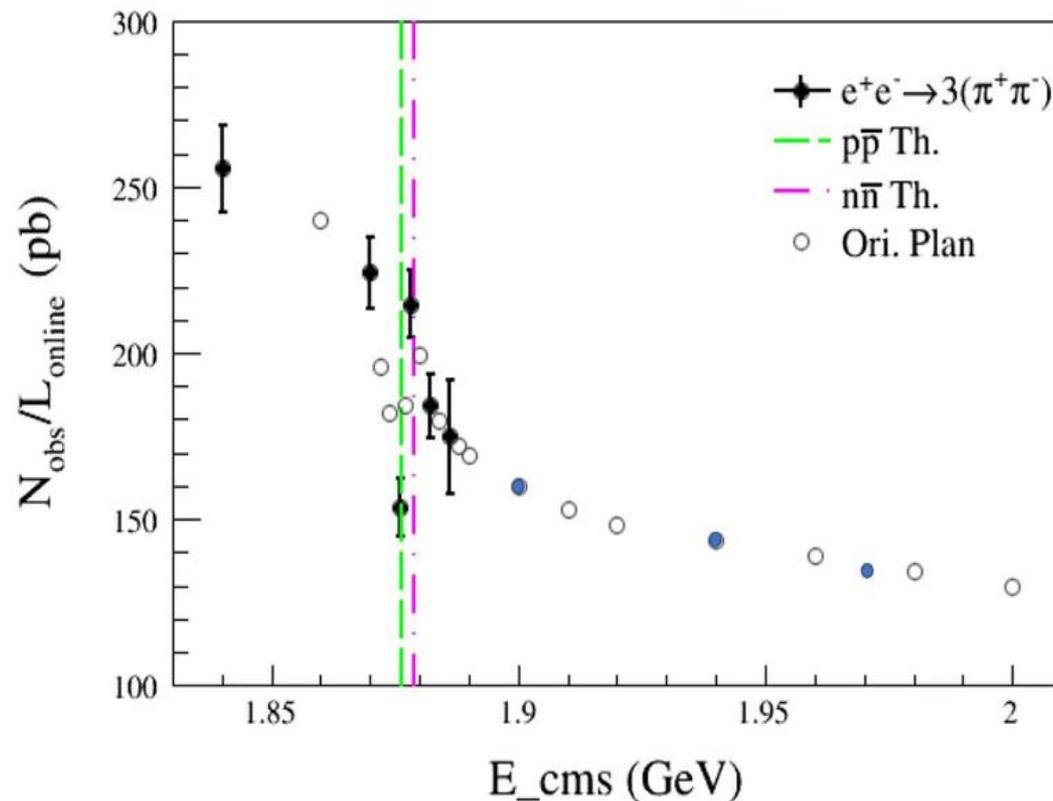
channel	J/ψ	$\psi(3686)$	$\psi(3770)$
K^+K^-	Francesca De Mori(Turino), report	Yadi Wang(NCEPU),draft	
$K_S K_L$		Jie Yuan(NCEPU),report	Bolun Zhang(IHEP), PRL132, 131901 (2024)
$\pi^+\pi^-$	Yipeng Zhao(NCEPU), under study	Yipeng Zhao(NCEPU), under study	Yipeng Zhao(NCEPU), under study
$\pi^+\pi^-\pi^0(\rho\pi)$	Tengjiao Wang (IHEP), report	Yijia Zeng(NKU)+Tengjiao Wang(IHEP)+Chen Xie(NJU), report	Yijia Zeng(NKU)+Tengjiao Wang(IHEP)+Chen Xie(NJU), report
$\pi^+\pi^-\eta(\rho\eta)$		Junhua Li+Caiying Pang(GXNU), BAM-889	Zhiqing Liu (SDU)
$\pi^+\pi^-\eta'(\rho\eta')$			
$K^+K^-\pi^0(K^{*\pm}K^\mp)$	Tianyou Li (NKU), BAM-968	Tianyou Li(NKU)+Chen Xie(NJU), report	Chen Xie(NJU)+Tianyou Li(NKU), report
$K_S K^\pm\pi^\mp(K^{*0}\bar{K}^0)$	Chen Xie (NJU), BAM-996	Chen Xie(NJU), report	Chen Xie(NJU), report
$\omega\eta$	Zhikun Xi (WHU), report	Yiqi Di (WHU), report	Jiaojiao Song(HNNU)+ Yateng Zhang(ZZU), report
$\omega\eta'$	Hailing Song (USTC)+Yanning Wang (WHU)	Zhifei Tian (WHU), report	Jiaojiao Song(HNNU)+ Yateng Zhang(ZZU), report
$\phi\pi$			
$\phi\eta$	Zequn Sun(IHEP)+Nefedov Yury(JINR), submitted to JHEP		Junhao Yin(NKU), report
$\phi\eta'$	Yanwen Luo+Jianxin Wang(WHU), report		

Xiang Zhou, Yadi Wang's talks



2024年数据 @1.84-1.97 GeV

- BEPC/BES的新纪录;
- 13个能量点, 积分亮度 $\sim 25 \text{ pb}^{-1}$;
- 研究核子的阈值行为;
- 单举、遍举R值;
- $e^+e^- \rightarrow PP, n\bar{n}, \Phi\pi^0, \omega\pi^0, \omega\eta \dots$



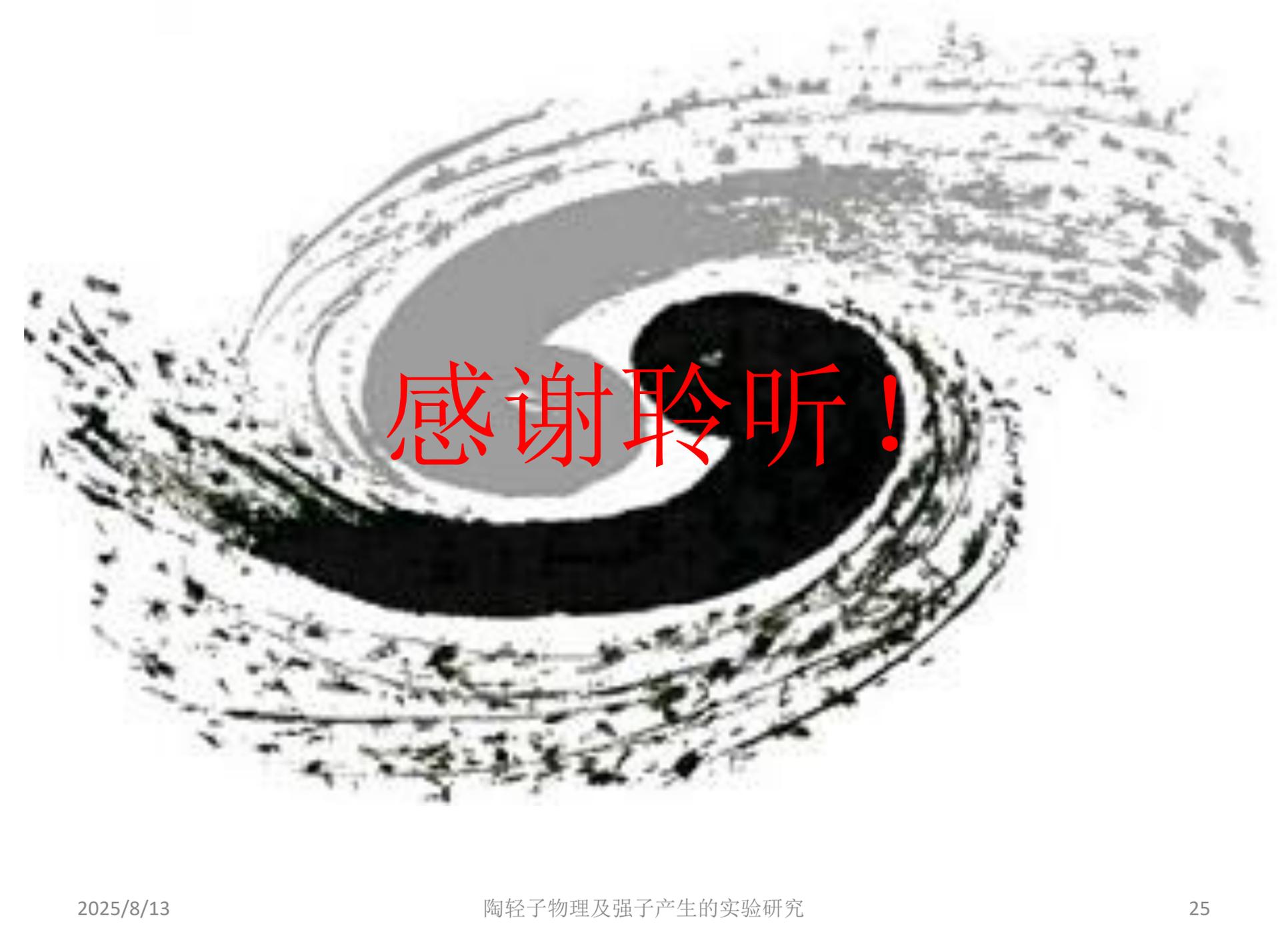
两强子产生截面阈效应理论, Haiming Hu's talk



总结

- ◆ 陶轻子质量的高精度测量, 测量误差小于0.1 MeV。文章在 BESIII 合作组内部审核阶段。
- ◆ $\psi(3686) \rightarrow \tau + \tau^-$ 分支比测量, 测量误差小于 5%。文章已经投递, 正在回答杂志审稿人问题。
- ◆ 质子精细电磁结构研究, 测量误差低于 30%。文章在 BESIII CWR 阶段。
- ◆ 强作用和电磁作用相对相角测量, 首次完成粲偶素 $\rightarrow PP, PV$ 等过程的相角测量。多篇文章处在 draft, MEMO 阶段。
- ◆ 2 - 4.59 GeV 的 R 值测量基本完成。
- ◆ $\pi\pi$ 、 3π 、 η 、 KK 等多个产生截面与形状因子正在研究中。
- ◆ 低于 2.0 GeV 的数据分析工作正在进行中。

... ..



感谢聆听!

Study of Jpsi Energy Correlator

- Stage: Memo ready for review. Posted on Jul 14.

$$\begin{aligned}\Sigma(\cos\chi) &= \frac{1}{\mathcal{L}} \int d(\mathcal{L}\sigma_{J/\psi X}) \sum_i \frac{E_i}{M_{J/\psi}} \delta(\cos\chi - \cos\theta_i), \\ &= \frac{1}{\mathcal{L}} \int \frac{dN_{J/\psi X}^{\text{sig}}}{\mathcal{B}_{J/\psi \rightarrow \mu^+ \mu^-}} \sum_i \frac{E_i}{M_{J/\psi}} \delta(\cos\chi - \cos\theta_i) \frac{1}{\varepsilon_i},\end{aligned}$$

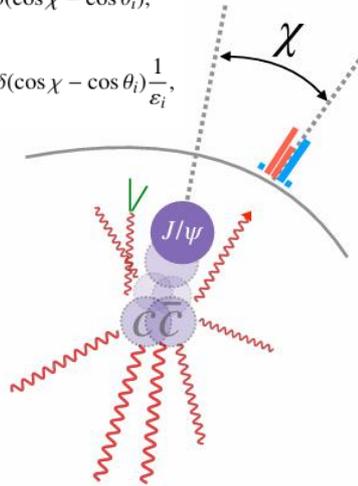


Figure 1: Measurement of the energy correlator around the J/ψ , where the energy deposit with the polar angle separation χ from the J/ψ is recorded. χ is measured in the J/ψ rest frame. [4]

BESIII

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BESIII Analysis Memo

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July 14, 2025

Study of J/ψ Energy Correlator

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Hypernews : <http://hnb3.ihep.ac.cn/HyperNews/get/paperxxx.html>

Study of the gamma gamma* -> pi0 pi0 Cross-Sections

- Stage: Memo ready for review. Posted on Jul 12.

80 2 The Two-Photon Particle Production Mechanism

The two-photon production of hadrons can be studied at electron positron colliders through the

$$e^+(p_1)e^-(p_2) \rightarrow e^+(p'_1)e^-(p'_2)X(p_x)$$

81 process, where both of the initial state leptons emit a virtual photon which fuse into the hadronic final
82 state.

83 The cross-section of the process is given by [6]

$$\begin{aligned} d\sigma = & \frac{\alpha^2}{8\pi^4 Q_1^2 Q_2^2} \frac{\sqrt{X}}{s(1-4m_c^2/s)^{1/2}} \frac{d^3\vec{p}'_1 d^3\vec{p}'_2}{E'_1 E'_2} \left\{ 4\rho_1^{++}\rho_2^{++} \frac{1}{2}(\sigma_0 + \sigma_2) + \rho_1^{00}\rho_2^{00} \sigma_{LL} \right. \\ & + 2\rho_1^{++}\rho_2^{00} \sigma_{TL} + 2\rho_1^{00}\rho_2^{++} \sigma_{LT} + 2(\rho_1^{++} - 1)(\rho_2^{++} - 1) \cos(2\bar{\phi}) \tau_{TT} \\ & + 8 [(\rho_1^{00} + 1)(\rho_2^{00} + 1)(\rho_1^{++} - 1)(\rho_2^{++} - 1)]^{1/2} \cos \bar{\phi} \frac{1}{2}(\tau_0 + \tau_1) \\ & + h_1 h_2 4 [(\rho_1^{00} + 1)(\rho_2^{00} + 1)]^{1/2} \frac{1}{2}(\sigma_0 - \sigma_2) \\ & \left. + h_1 h_2 8 [(\rho_1^{++} - 1)(\rho_2^{++} - 1)]^{1/2} \cos \bar{\phi} \frac{1}{2}(\tau_0 - \tau_1) \right\}, \end{aligned} \quad (1)$$



Memo version 1.0

BESIII Analysis Memo

BAM-xxx
July 11, 2025

1 Study of the $\gamma\gamma^* \rightarrow \pi^0\pi^0$ Cross-Sections and Measurement of 2 Light Meson Transition Form-Factors

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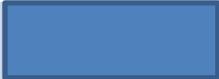
13 ^gUni. G

14 ^hUni. H

15 HN: <http://hnb3.ihep.ac.cn/HyperNews/get/paperxxx.html>

Thank you for your attention!

BESIII与BELLEII结果比较

	BESIII	BELLE II
优势	利用阈效应，精确布点	数据量超大
方法	阈值扫描法	赝质量端点法
数据量	138pb ⁻¹	190fb ⁻¹
能量值	新建束流能量测量系统，独立提供能量值	利用B介子对产生阈附近B介子能量
测量值 (MeV/c ²)	 ± 0.044 ± 0.048	1777.09 ± 0.08 ± 0.11

研究动机

- 粒子物理标准模型取得了巨大成功!
- 但还有以下问题有待解决:
 - 标准模型参数精确测量;
 - 标准模型精确检验;
 - 超出标准模型的新物理探索;
 - 标准模型中QCD实验研究。
- 这些重要的基本问题都与本课题密切相关:
 - 电磁跑动耦合常数 $\alpha_{\text{QED}}(s)$: 电磁相互作用强度随相互作用能量改变规律;
 - μ 子反常磁矩(g-2): 检验标准模型最灵敏、最精确的实验和理论预言;
 - Higgs粒子: 标准模型对Higgs质量(最可几值及上限)的全局拟合;
 - 直接检验量子色动力学预言: 强相互作用跑动耦合常数 $\alpha_s(s)$ 。

研究方法

1) 通过四动量守恒的方法寻找不可见粒子。由于 BESIII 实验初始正负电子的四动量精确已知，我们利用反应前后能量和三动量守恒，来标记探测器极难探测的末态粒子，如中微子、暗物质候选粒子等。

2) 机器学习技术的应用。探索应用深度学习技术处理海量实验数据，探索使用不同类型的机器学习模型，增加发现信号的机会，提高鉴别粒子的能力，以及降低探测器相关的系统误差。