物理分会报告总结

报告召集人：吕晓睿（中国科学院大学）
秦溱（华中科技大学）
耿聪（中山大学）

兰州大学，2024年7月10日








物理分会概况

◆ 6个session，22个报告

STCF工作组物理预研3个，理论邀请报告19个

CP破坏、奇特态和强子谱、格点QCD进展、g-2、强子衰变、超越标准模型新物理……

STCF预研进展报告

报告题目	报告人
陶轻子和粲强子的CP破坏研究	张宇
Charm mixing and indirect CPV studies at STCF	王英豪
eta/eta’ 物理研究进展	康晓琳

STCF物理预研进展：CP破坏研究专题

CP violation studies at Super tau-charm facility

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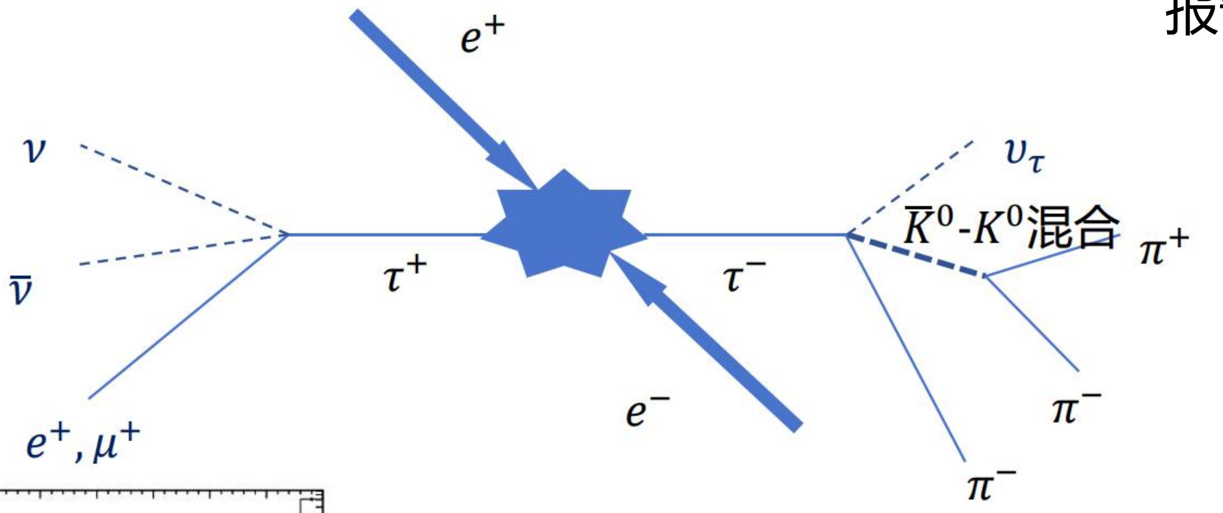
Abstract

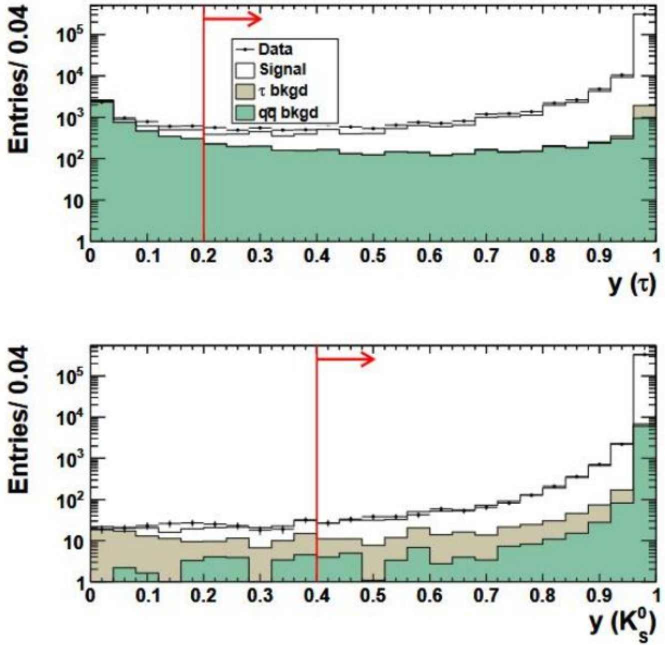
Charge-parity (CP) violation in tau-charm energy region is one of the promising areas to search for. The future tau-charm facility of next generation is designed to operate in a center-of-mass energy from 2.0 to 7.0 GeV with a peak luminosity of 0.5×10^{35} cm^{-2}s^{-1}. Huge amount of hadrons or τ leptons will be collected with well kinematic constraint and low-background environment. In this report, possibilities of CP violation studies in tau-charm energy region and at the future tau-charm facility are discussed from various aspects, i.e. in the production and decay of hyperons and τ lepton; in the decay of charmed hadrons. We also study the combined symmetry of CP and time reversal T, CPT invariance test in $K^0 - \bar{K}^0$ mixing.

Submitted to PHYSICS REPORTS

τ轻子的CP破坏：$\tau \to K_S^0 \pi \nu$

报告人：张宇





τ似然函数：
可见能量
标记侧中性簇射数目
Thrust
横动量

K_S^0似然函数：
横向飞行距离
不变质量
动量
极角

BABAR, PRD 85 (2012) 031102

STCF精度预研

报告人：张宇

STCF快模拟软件
1 ab^{-1}@4.26GeV
$e^+e^- \to \tau^+\tau^-$产生子: KKMC+TAUOLA

$\tau \to K_S^0\pi\upsilon_\tau$:
$$\frac{d\Gamma}{d\sqrt{s}} \propto \frac{1}{s}\left(1-\frac{s}{m_\tau^2}\right)^2\left(1+\frac{2s}{m_\tau^2}\right)P(s)\times\left\{P^2(s)|F_V|^2+\frac{3(m_{K_S}^2-m_\pi^2)^2|F_S|^2}{4s(1+\frac{2s}{m_\tau^2})}\right\}$$

$$P(s)=\frac{\sqrt{(s-(m_{K_S}+m_\pi)^2)(s-(m_{K_S}-m_\pi)^2)}}{2\sqrt{s}}$$

考虑了标量/矢量形状因子

$$F_S = a_{K_0^*(800)}\cdot BW_{K_0^*(800)},$$

$$F_V = \frac{BW_{K^*(892)}+a_{K^*(1410)}\cdot BW_{K^*(1410)}}{1+a_{K^*(1410)}},$$

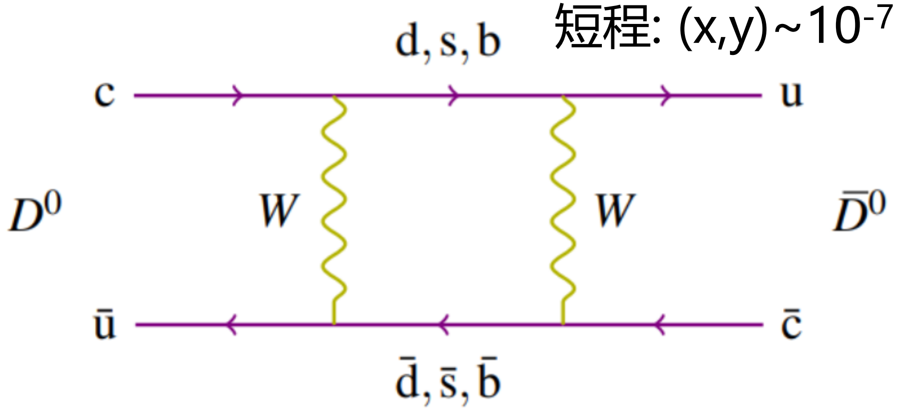
基于无CP不对称假设

~3.7 million τ^+/τ^- 信号事例
$\delta(A_{CP,\mathrm{EXP}}^{\tau})$~$9.7\times10^{-4}$
10 ab^{-1} 数据：$\delta(A_{CP,\mathrm{EXP}}^{\tau})$~$3\times10^{-4}$
$\delta(A_{CP,\mathrm{SM}}^{\tau})$~$1\times10^{-4}$

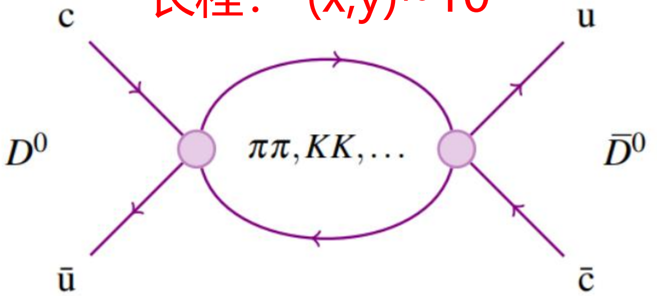
粲强子的CP破坏

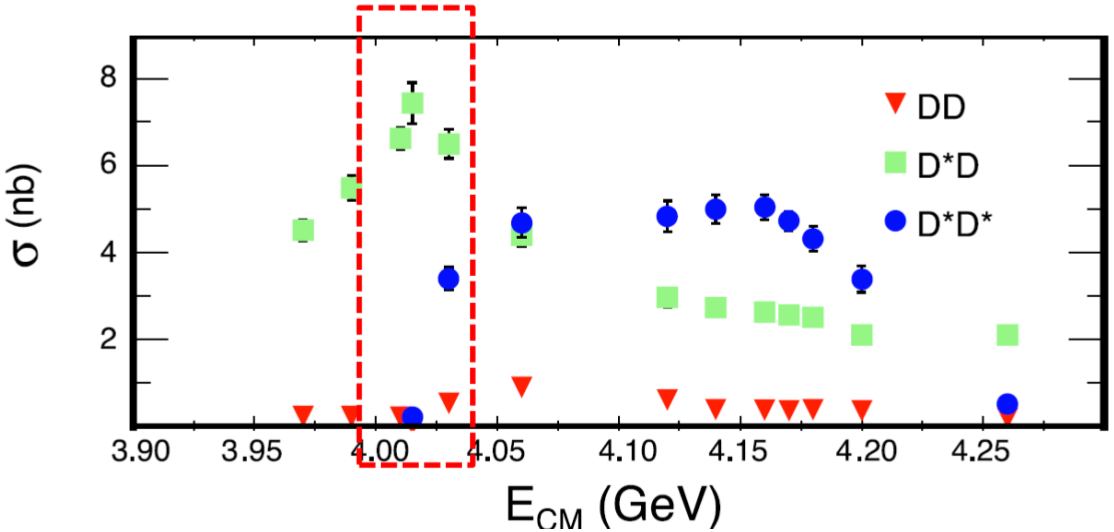
报告人：张宇、王英豪

短程: (x,y)~10^{-7}



长程： (x,y)~10^{-3}





	Component	Final State	$\mathcal{C}(D^0\bar{D}^0)$
Coherent	$D^0\bar{D}^0$	$D^0\bar{D}^0$	Odd
	$D^{*0}\bar{D}^0$	$\gamma D^0\bar{D}^0$	Even
		$\pi^0 D^0\bar{D}^0$	Odd
	$D^{*0}\bar{D}^{*0}$	$\gamma\pi^0 D^0\bar{D}^0$	Even
		$\gamma\gamma(\pi^0\pi^0)D^0\bar{D}^0$	Odd
Incoherent	$D^{*+}D^{*-}$	$\pi^+\pi^- D^0\bar{D}^0$	-
	$D^{*+}D^-$	$\pi^+ D^0 D^-$	-

粲强子的CP破坏预研精度

$1\ ab^{-1}$@4009MeV
信号重建效率：STCF快模拟软件

报告人：张宇、王英豪

	$\delta(x)/0.01$	$\delta(y)/0.01$	$\delta(\|\frac{q}{p}\|)$	$\delta(arg(\frac{q}{p}))/°$
$K\pi\pi^0$(STCF)	0.044	0.017	0.034	2.51
$K\pi\pi$(STCF)	0.047	0.025	0.042	3.10
$K_S^0\pi\pi$(STCF)	0.069	0.050	0.077	4.57
LHCb current best	0.056	0.026	0.052	2.9
HFLAV average	0.044	0.024	0.016	1.1

- 未考虑系统误差，由强相位贡献的系统误差将可忽略
- STCF可以在10^{-4}量级测量粲介子（间接）CP破坏
- 直接CP破坏精度有待进一步研究

理论邀请报告

P与CP破坏

报告题目	报告人
Large CP violation in charmed baryon decays	刘佳伟
Observable CPV in charmed baryons decays with SU(3)	邢志鹏
P and CP violation of octect baryon production in J/psi	杜勇
重子对的产生、衰变和CP破坏	曹须

粲重子中的CP破坏效应

报告人：刘佳伟

粲重子的单Cabibbo压低衰变

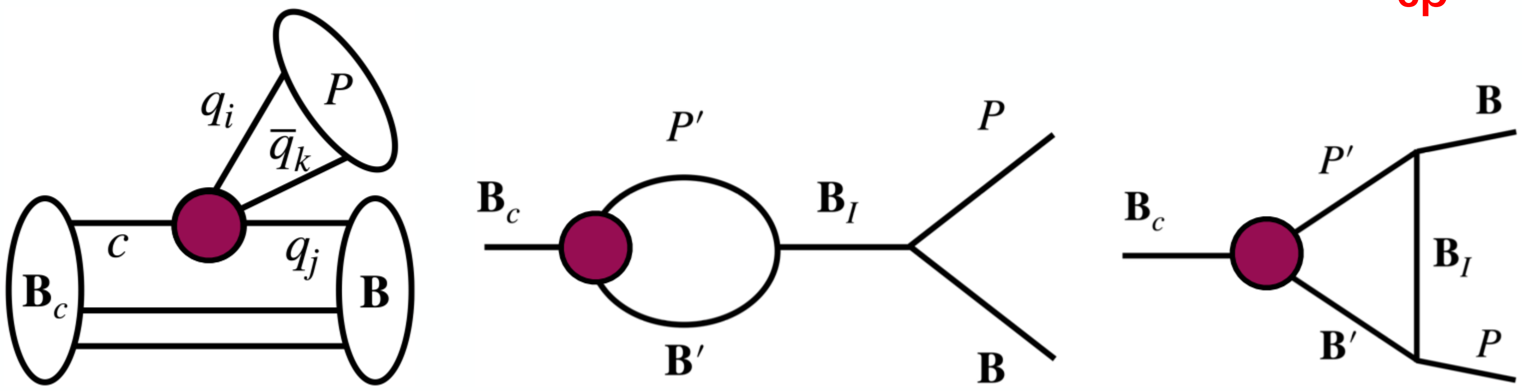
Final State Rescattering

$V_{cs}^* V_{us}$ Tree + $V_{cb}^* V_{ub}$ Tree × (Penguin / Tree)

Determined by the rescattering

$$\mathscr{L}_{\mathbf{B}_c\mathbf{B}P} = \mathscr{L}^{\mathrm{Tree}}_{\mathbf{B}_c\mathbf{B}P} + \mathscr{L}^{\mathrm{FSR-s}}_{\mathbf{B}_c\mathbf{B}P} + \mathscr{L}^{\mathrm{FSR-t}}_{\mathbf{B}_c\mathbf{B}P}$$

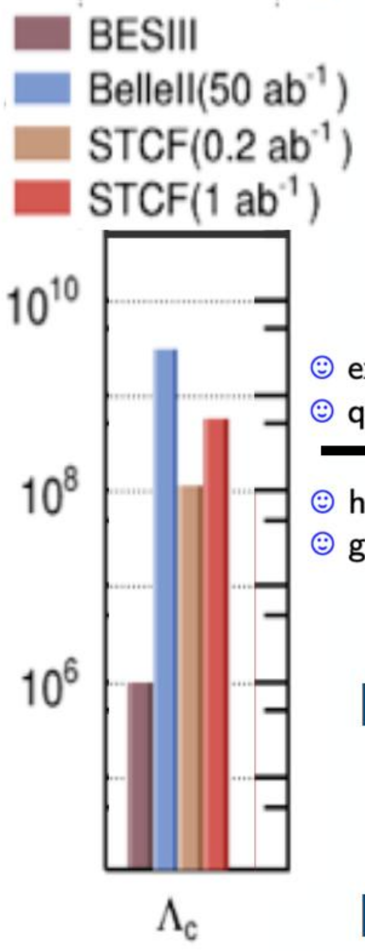
ΔA_{cp}可以到10^{-3}



粲重子中的CP破坏效应

报告人：刘佳伟

*Rough estimate from statistics only



A_{CP} at $\mathcal{O}(10^{-3})$

STCF

- ☺ extremely clean environment
- ☺ quantum coherence

BELLE

- ☺ high-efficiency detection of neutrals
- ☺ good trigger efficiency

Belle : A_{CP} at $\mathcal{O}(10^{-2})$

↓ Upgrade

Belle II : A_{CP} at $\mathcal{O}(10^{-3})$

LHCb

A_{CP} at $\mathcal{O}(10^{-3})$

↓ Upgrade

A_{CP} at $\mathcal{O}(10^{-4})$

- ☺ very large production cross-section
- ☺ large boost, excellent time resolution

BESIII

- ☺ extremely clean environment
- ☺ quantum coherence

Measurements on β and γ extract important information of strong phases !

粲重子两体衰变中的CP破坏

报告人：邢志鹏

The CPV in CBTD

考虑强相位

$$\mathcal{H}_{eff} = \frac{G_F}{\sqrt{2}}\left(\sum_{i=1,2} C_i \lambda O_i - \sum_{j=3}^{6} C_j \lambda_b O_j\right) + h.c.,$$

Our work $f_b \sim O(10^{-3})$ → $A_{CP} \sim O(10^{-3})$

Prediction

$$A_{CP}^{\Lambda_c^+ \to p\eta} = -0.047(45),\ A_{CP}^{\Lambda_c^+ \to n\pi^+} = -0.33(28),\ A_{CP}^{\Xi_c^+ \to \Xi^0 K^+} = -0.39(32)$$

~ 0.001 ~ 0.01

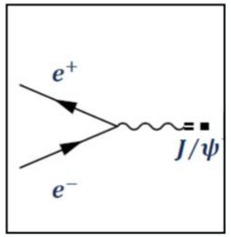
We need more data to reduce the error

重子八重态中的P和CP破坏效应

报告人：杜勇

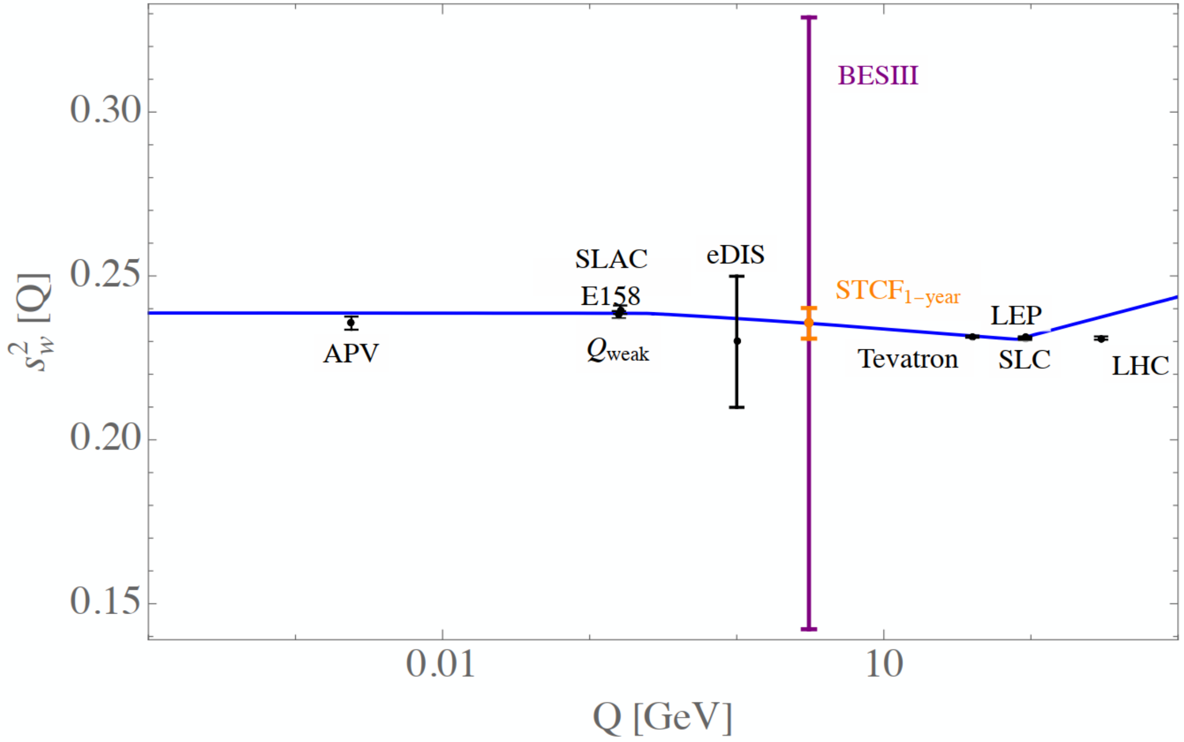
First determination of $\sin\theta_W$ at the J/ψ threshold

Recall it is related to the production of J/ψ only, and is thus the simplest one to compute from Z exchange to violate parity



$$d_J = \frac{\sqrt{2}sG_F}{32\pi\alpha_{\rm EM}} \cdot (3 - 8s_w^2)$$

Another weak mixing angle determinati
with a precision $A_{\rm PV}^{(1)}$



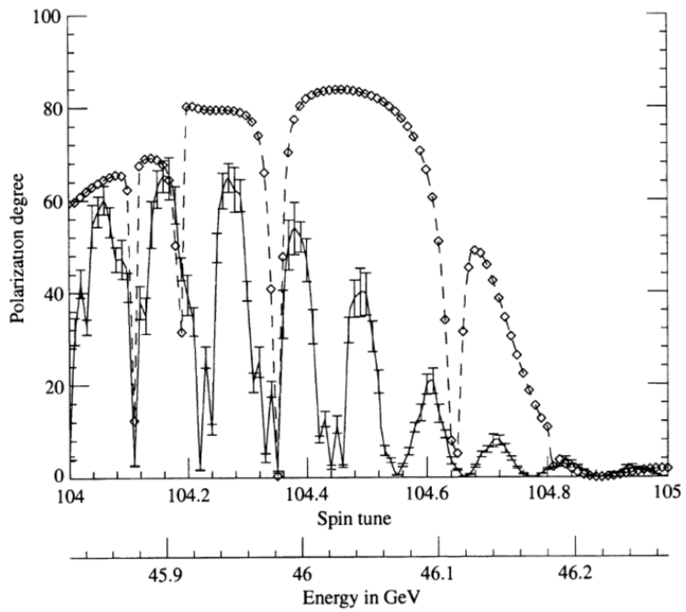
Polarized beams?

Bondar, Grabovsky, Reznichenko, Rudenko, Vorbyev, 1912.09760 (JHEP)
Jinlin Fu, Hai-Bo Li, Jian-Peng Wang, Fu-Sheng Yu, Jianyu Zhang, 2307.04346 (PRD)
Xu Cao, Yu-Tie Liang, Rong-Gang Ping, 2404.00298

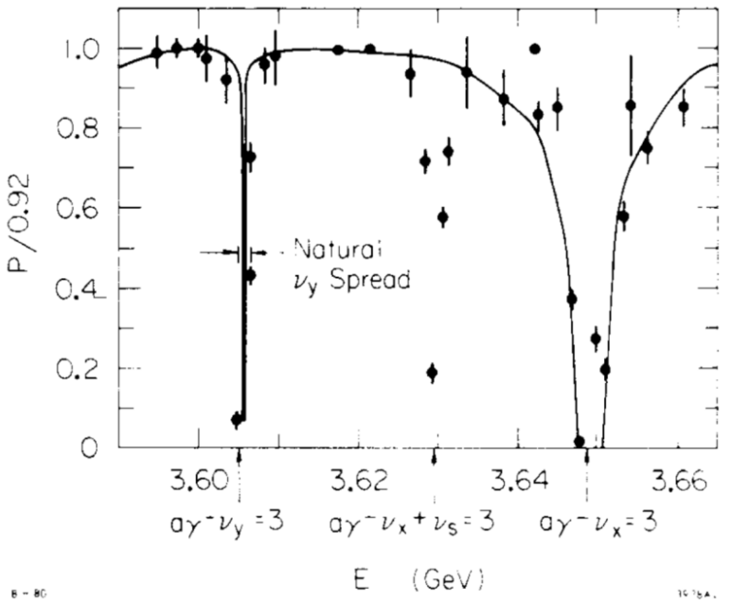
束流横向计划与超子CP破坏

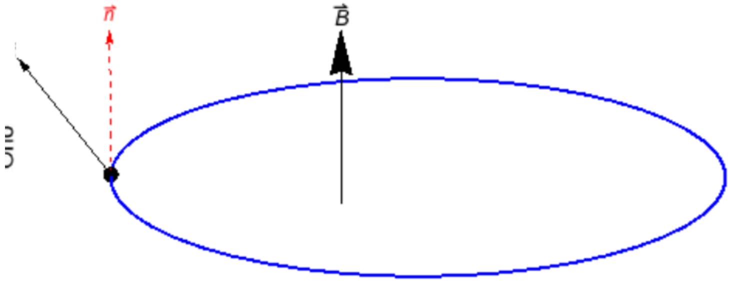
报告人：曹须

- Elliot Leader: Spin in particle physics
- LEP:
  The Large Electron-Positron Collider at CERN

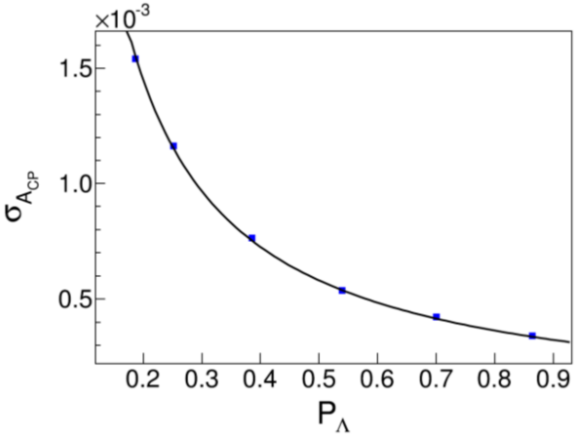


- 赵午：SLAC-PUB-2781(1981)
- SPEAR:
  Stanford Positron Electron Asymmetric Ring





$$\frac{4\pi}{\sigma}\frac{d\sigma}{d\Omega_B} = \frac{3}{3+\alpha_\psi}(1+\alpha_\psi\cos^2\theta + \alpha_\psi P_T^2\sin^2\theta\cos 2\phi)$$



理论邀请报告

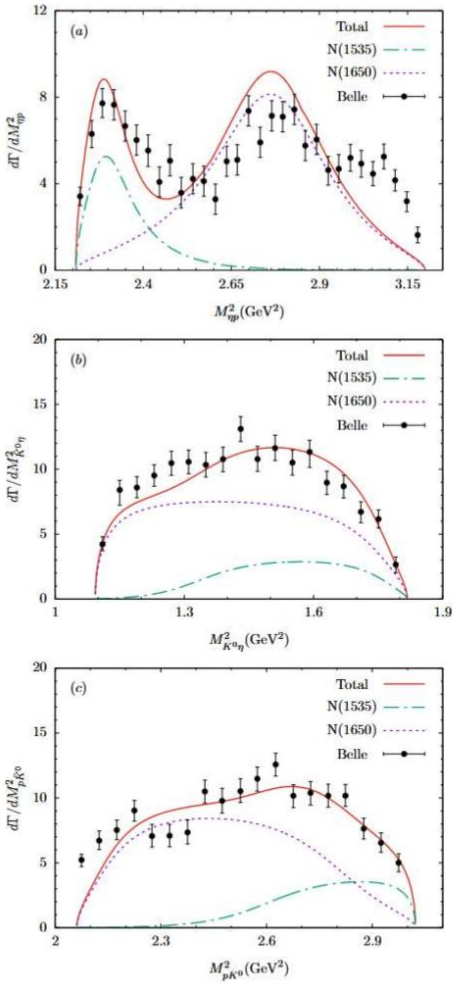
奇特态与强子谱

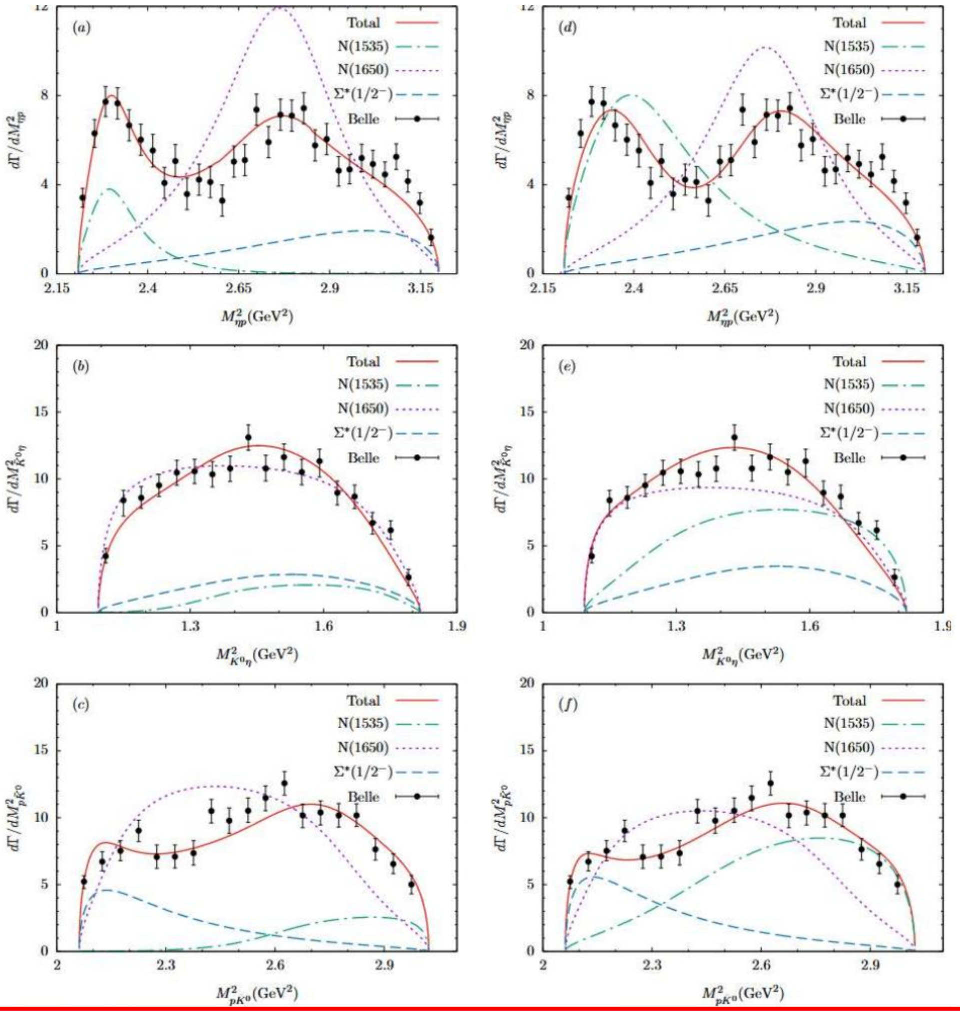
报告题目	报告人
Exotic states in charmed baryon decays	王恩
Establishing the missing $\Sigma^*(1/2^-)$ by probing the triangle singularity effect in $J/\psi \to \Lambda\bar{\Lambda}\pi^0$ process	黄琦
Entanglement suppression and low energy-scattering of heavy meson	郭奉坤
Three couple channel with OBE potential analysis on Zc(3900)	余康
QCDSR study on hadron spectrum	陈华星
Spectroscopy and decays of singly charmed baryon	罗肆强

粲重子衰变中的$\Sigma^*(1/2^-)$

报告人：王恩

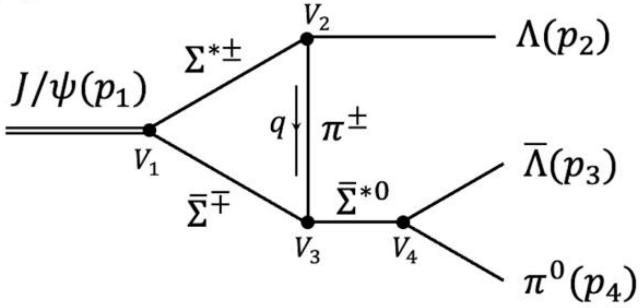
在$\Lambda_c^+ \to p\bar{K}^0\eta$中考虑$\Sigma^*(1/2^-)$





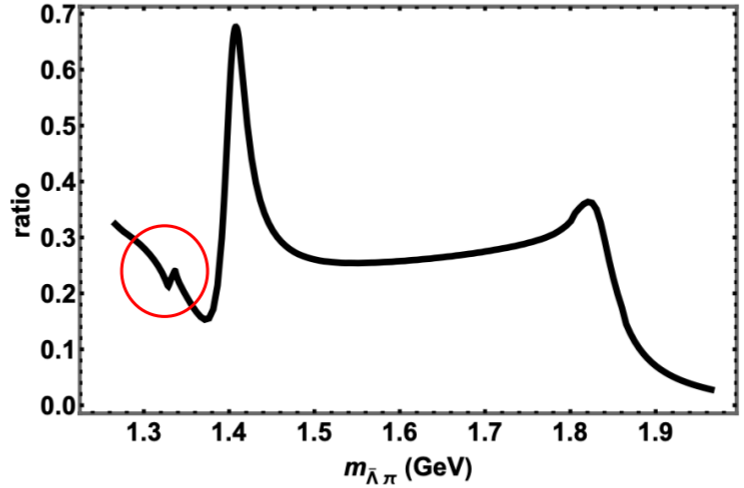
在$J/\psi \to \Lambda\bar{\Lambda}\pi^0$中寻找$\Sigma^*(1/2^-)$

报告人：黄琦

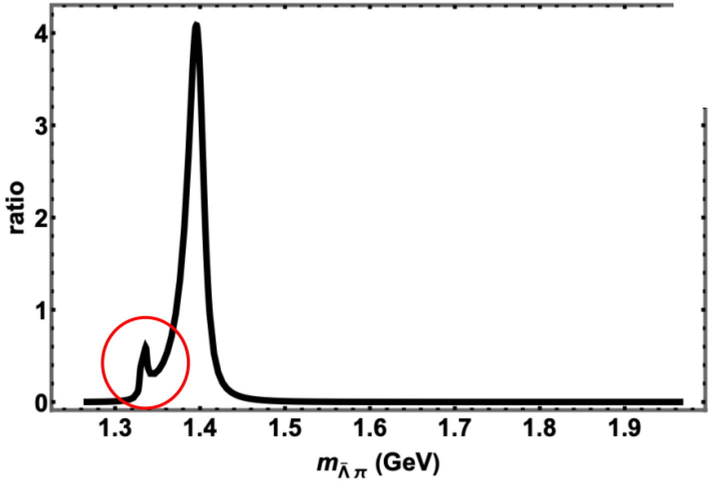


$10^{12} J/\psi, 10^{-8}$ sensitivity ?

$\Sigma(1670)\bar{\Sigma}\pi$ loop with $\Sigma(1381)$



$\Sigma(1620)\bar{\Sigma}\pi$ loop with $\Sigma(1381)$



Detection:

1. Polarization
2. CUSP ? 🤔

$$\text{Events:} \begin{cases} \Sigma(1670)\bar{\Sigma}\pi \text{ loop with } \Sigma(1381), \text{Br(TS/CUSP)}: 3.783\times10^{-6}/1.009\times10^{-7} \\ \Sigma(1620)\bar{\Sigma}\pi \text{ loop with } \Sigma(1381), \text{Br(TS/CUSP)}: 2.978\times10^{-6}/4.025\times10^{-9} \Rightarrow > 10^5/4000 \text{ events?} \\ \Sigma(1670)\bar{\Sigma}\pi \text{ loop with } \Sigma(1385), \text{Br(TS/CUSP)}: 1.345\times10^{-7}/1.855\times10^{-7} \end{cases}$$

低能重介子散射

报告人：郭奉坤

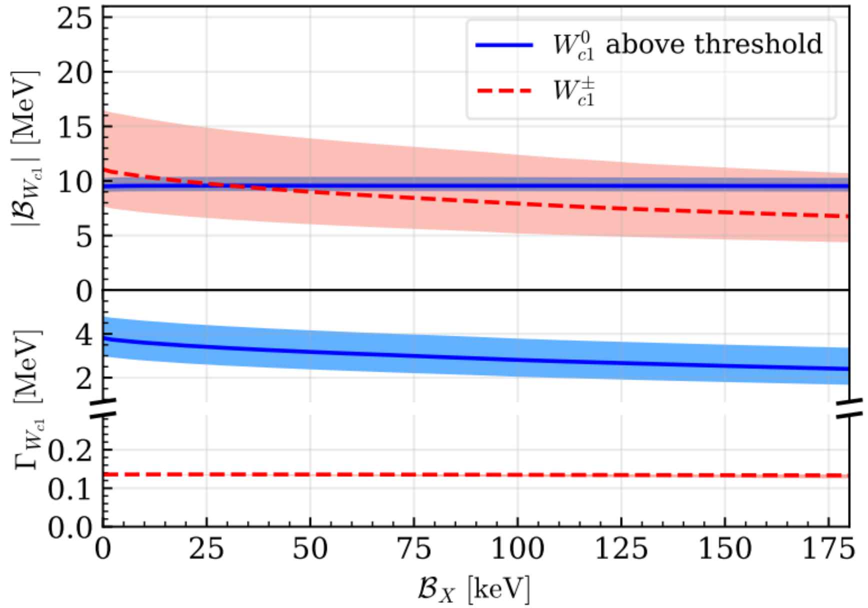
- There must be near-threshold isovector W_{c1} states
  - Virtual state pole in the stable D^* limit
    - W_{c1}^{+} in $D^+\bar{D}^{*0}$ single-channel scattering amplitude: pole on the 2nd Riemann sheet (RS), 8^{+8}_{-5} MeV below D^0D^{*-} threshold

      $W_{c1}^{\pm}$: $3866.9^{+4.6}_{-7.7} - i(0.07 \pm 0.01)$ MeV

    - W_{c1}^{0} in $(D\bar{D}^*)_0 - (D\bar{D}^*)_{\pm}$ scattering amplitudes: pole on the 4th RS (RS_{+-}), $1.3^{+0.8}_{-0.0}$ MeV above D^+D^{*-} threshold

      W_{c1}^{0}: $3881.2^{+0.8}_{-0.0} + i1.6^{+0.7}_{-0.9}$ MeV

  - Must appear as threshold cusps!!!
  - Compact tetraquarks (Maiani et al. (2005)) cannot be virtual states as they do not feel the thresholds



Cutoff independence checked: pole positions relative to thresholds changed within 5% for $\Lambda \in [0.5, 1.0]$ GeV

低能重介子散射

报告人：郭奉坤

- The entanglement suppression conjecture + $X(3872)$ and T_{cc} as molecules leads to an emergent symmetry for low-energy heavy-meson scattering: light quark spin symmetry

- Robust prediction of an isovector partner of $X(3872)$ in the hadronic molecular picture: $W_{c1}^{\pm,0}$
  - ☐ Virtual state poles (poles on RSs not directly connected to physical region), thus threshold cusps
  - ☐ Search for threshold cusps in high-statistic data
    - ➢ at D^0D^{*-} threshold in $J/\psi\pi^\pm\pi^0$, such as $e^+e^- \to \rho^\mp + J/\psi\pi^\pm\pi^0$: distinguishing hadronic molecular and compact tetraquark models for $X(3872)$
    - ➢ at D^+D^{*-} threshold in $J/\psi\pi^+\pi^-$, such as $e^+e^- \to \gamma/V + J/\psi\pi^+\pi^-$: could be more difficult due to interference between peak and dip

单玻色子模型研究Zc(3900)

报告人：余康

3 couple channels !

NOT a genuine particle,
But a threshold cusp ?

Observation of Zc(3900)/Zc(3885) in :

- $e^+e^- \to Y \to \pi^+\pi^- J/\psi$ @$\sqrt{s} = 4.23, 4.26\ GeV$
- $e^+e^- \to Y \to \pi^\pm (D\bar{D}^*)^\mp$ @$\sqrt{s} = 4.23, 4.26\ GeV$
- $e^+e^- \to Y \to \pi^\pm (\rho\eta_c)^\mp$ @$\sqrt{s} = 4.23\ GeV$

STCF可以提供更大的统计量！

For $e^+e^- \to \pi D\bar{D}^*$, Z_c structure:

- mainly from $Y \to D_1(2420)\bar{D} \to \pi D\bar{D}^*$ cascade decay
- enhanced by interference with triangle diagram

For $e^+e^- \to \pi\pi J/\psi$ $(\pi\rho\eta_c)$, Z_c structure:

- two cusps both exactly at $D\bar{D}^*$ threshold
- mainly from unitary cut of T-matrix, enhanced by cut of pure triangle loop

QCD求和规则研究混杂态

报告人：陈华星

Experiments

$I^G J^{PC} = 1^- 1^{-+}$: $\pi_1(1400)$ $\pi_1(1600)$ $\pi_1(2015)$?

$\pi_1(1600)$

COMPASS: $M = 1564 \pm 24 \pm 86$ MeV
$\Gamma = 492 \pm 54 \pm 102$ MeV

$I^G J^{PC} = 0^+ 1^{-+}$: $\eta_1(1855)$

BESIII: $M = 1855 \pm 9^{+6}_{-1}$ MeV
$\Gamma = 188 \pm 18^{+3}_{-8}$ MeV

Indistinguishable!

Theory ($q = up/down$, $s = strange$)

$|\bar{q}qg; 1^- 1^{-+}\rangle$: $M = 1670^{+150}_{-170}$ MeV
$\Gamma = 530^{+540}_{-330}$ MeV

$|\bar{q}qg; 0^+ 1^{-+}\rangle$: $M = 1670^{+150}_{-170}$ MeV
$\Gamma = 120^{+160}_{-110}$ MeV

$|\bar{s}sg; 0^+ 1^{-+}\rangle$: $M = 1840^{+140}_{-150}$ MeV
$\Gamma = 100^{+110}_{-80}$ MeV

Hybrid picture:

- One isovector: $\bar{q}qg$
- Two isosinglets: $\bar{q}qg$, $\bar{s}sg$

单粲重子谱学

报告人：罗肆强

Present

✓ Complete $1S$ states

✓ Many $1P$-$2S$ candinates

✓ Several $1D$、$2P$ candinates

？There are no $1F$ candidates

$\bar{3}_f$:

Decay channels	M_f (MeV)	$\Lambda_c(1F,5/2^-)$	$\Lambda_c(1F,7/2^-)$
$\Sigma_c(1S,3/2^+)\pi$	2520	0.5	0.8
$\Sigma_{c2}(1P,3/2^-)\pi$	2779	9.5	0.2
$\Sigma_{c2}(1P,5/2^-)\pi$	2796	0.8	9.5
ND		9.9	11.8
ND^*		21.6	40.2
$\cdots$		1.0	0.8
Total		43.3	63.3

$\mathrm{Br}\,[\Lambda_c(1F,5/2^-)\to ND^*]\approx 49.9\%,$
$\mathrm{Br}\,[\Lambda_c(1F,7/2^-)\to ND^*]\approx 63.5\%.$

Decay channels	M_f (MeV)	$\Xi_c(1F,5/2^-)$	$\Xi_c(1F,7/2^-)$
$\Xi'_{c2}(1P,3/2^-)\pi$	2926	1.5	0.1
$\Xi'_{c2}(1P,5/2^-)\pi$	2945	0.2	1.6
$\Sigma_c(1S,1/2^+)\bar{K}$	2455	0.7	0.7
$\Sigma_c(1S,3/2^+)\bar{K}$	2520	1.2	1.7
$\Sigma_{c2}(1P,3/2^-)\bar{K}$	2779	4.4	0.0
$\Sigma_{c2}(1P,5/2^-)\bar{K}$	2796	0.0	0.6
ΛD		0.5	2.1
ΣD		10.0	22.9
ΛD^*		4.0	5.2
ΣD^*		28.3	54.3
$\cdots$		0.9	0.9
Total		51.7	90.1

$\mathrm{Br}\,[\Xi_c(1F,5/2^-)\to \Sigma D^*]\approx 54.7\%,$
$\mathrm{Br}\,[\Xi_c(1F,7/2^-)\to \Sigma D^*]\approx 60.2\%.$

理论邀请报告

格点QCD研究进展

报告题目	报告人
粲介子含轻衰变的格点QCD的研究	刘超峰
格点QCD中多夸克态的研究	刘柳明
Hyperon-Nucleon Interaction from Lattice QCD	刘航

粲介子衰变常数和形状因子

报告人：刘朝峰

HPQCD给出D_s^*总宽度：0.070(28) keV

以及 $\mathrm{Br}(D_s^* \to l\nu) = 3.4(1.4) \times 10^{-5}$

(PRL112, 212002 (2014))

D_s^*总宽度及纯轻衰变分支比

$\Gamma(D_s^* \to \gamma D_s) = 0.0549(54)$ keV

$D_s^* \to D_s\gamma$分支比的实验值93.5(7)% PDG

} D_s^*总宽度：0.0587(54) keV

Y. Meng, ..., ZL et al., arXiv:2401.13475 (PRD109.074511)

$D_s^* \to l\nu\ (l = e, \mu)$分支比实验测量，结合总宽度，可给出$f_{D_s^*}|V_{cs}|$

实验测量　　抽取CKM矩阵元　　衰变常数可由LQCD给出

$$\Gamma(P \to \ell\nu) = \frac{G_F^2 |V_{q_1 q_2}|^2}{8\pi} f_P^2 m_\ell^2 M_P \left(1 - \frac{m_\ell^2}{M_P^2}\right)^2$$

BESIII对$D_s^{*+} \to e^+\nu_e$分支比的首个测量结果：$(2.1^{+1.2}_{-0.9\,\mathrm{stat}} \pm 0.2_{\mathrm{syst}}) \times 10^{-5}$

[2304.12159, PRL131.141802(2023)]

- BESIII + HPQCD

$$f_{D_s^*}|V_{cs}| = (207.9^{+59.4}_{-44.6\,\mathrm{stat.}} \pm 9.9_{\mathrm{syst.\,exp}} \pm 41.5_{\mathrm{syst.\,latt}})\ \mathrm{MeV}$$

- BESIII + arXiv:2401.13475

$$f_{D_s^*}|V_{cs}| = (190.5^{+55.1}_{-41.7\,\mathrm{stat.}} \pm 9.1_{\mathrm{syst.\,exp}} \pm 8.7_{\mathrm{syst.\,latt}})\ \mathrm{MeV}$$

STCF提高实验精度

(李东浩 et al., arXiv:2407.03697) + (arXiv:2401.13475)

$f_{D_s^*} = 277(11)$ MeV ➡ $\Gamma_{D_s^* \to l\nu} = 2.5(2) \times 10^{-6}$ keV ➡ $\mathrm{Br} = 4.26(52) \times 10^{-5}$

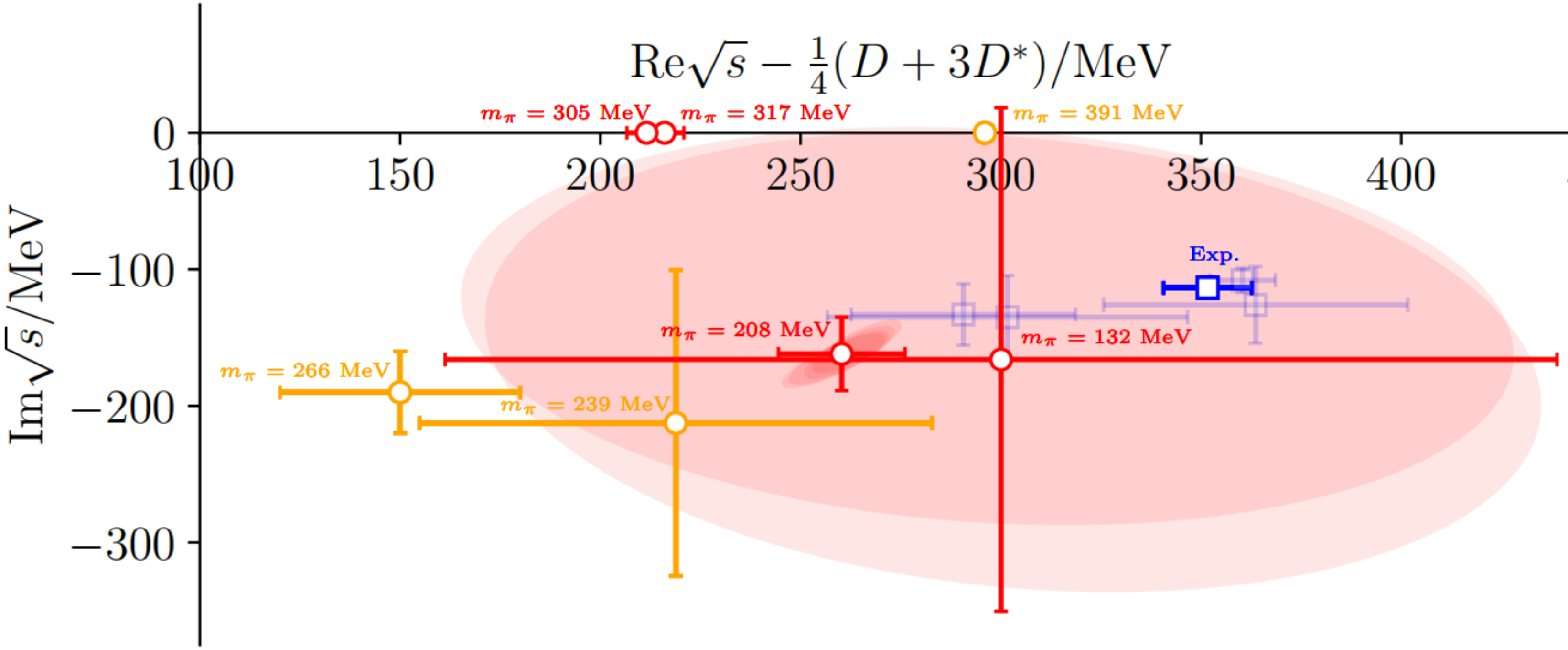
格点QCD中多夸克态的研究

报告人：刘柳明

$D\pi$ scattering and $D_0^*(2300)$

Pole position

中国组自己的组态



- At $m_\pi \sim 300$MeV, there is a virtual state pole. When pion mass decreases, it becomes a resonance and the pole position gets closer to the experimental value.

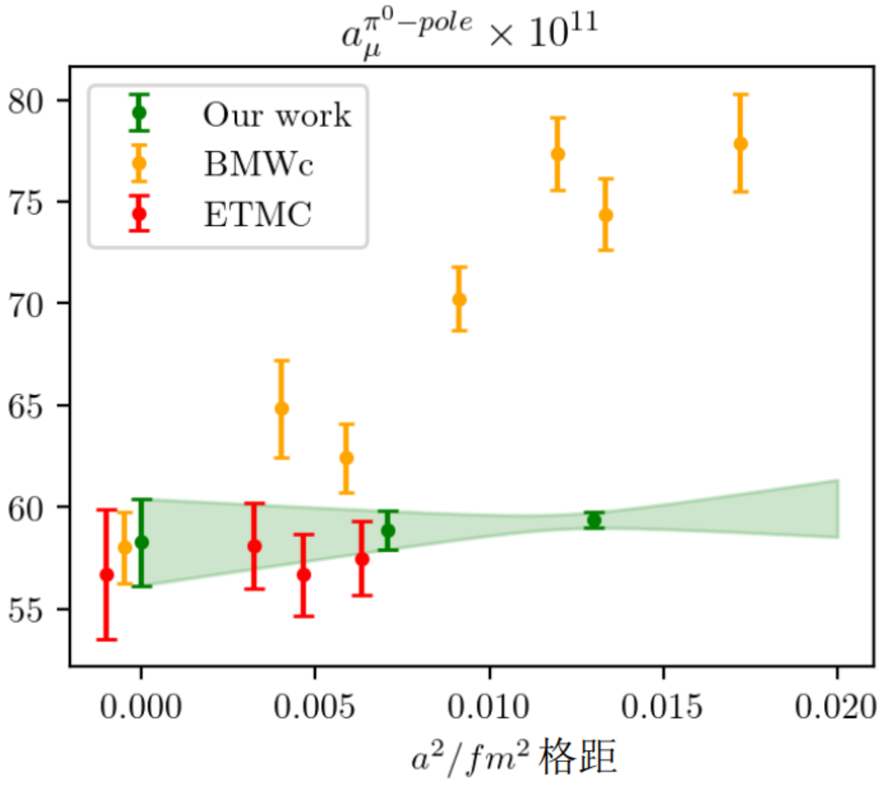
理论邀请报告

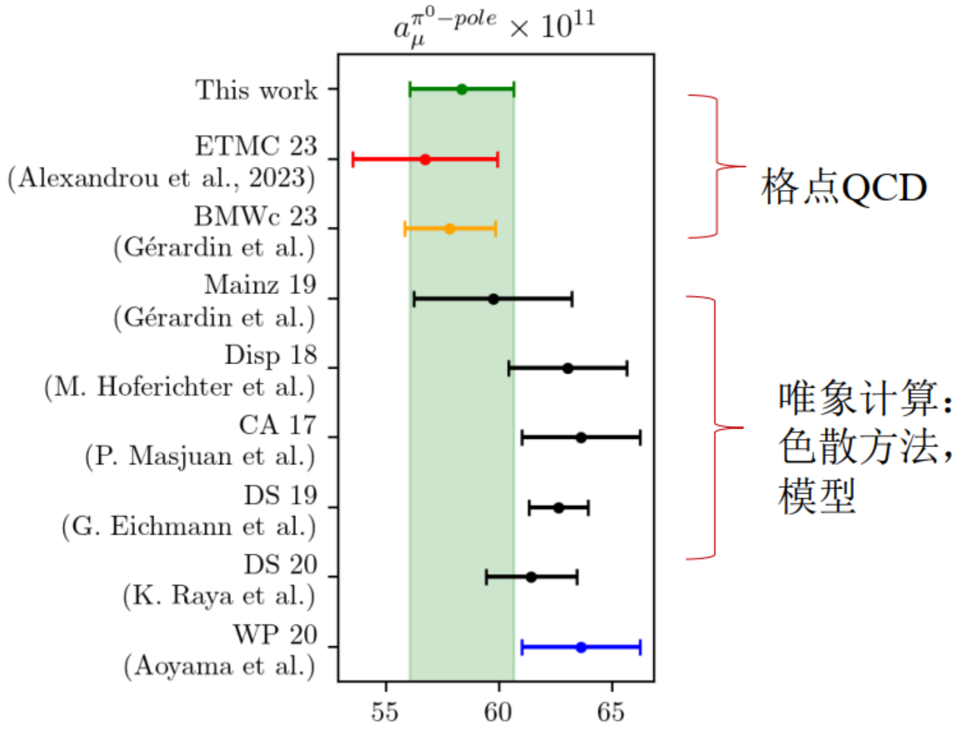
g-2的研究进展

报告题目	报告人
π^0-pole’ s contribution to HLbL in muon g-2	林天
光光对撞中陶轻子的g-2和EDM	张成

g-2: π^0极点在强光子光子散射的贡献

报告人：林天

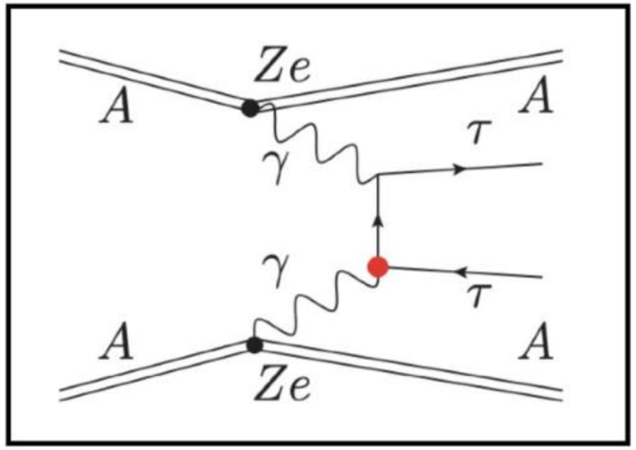


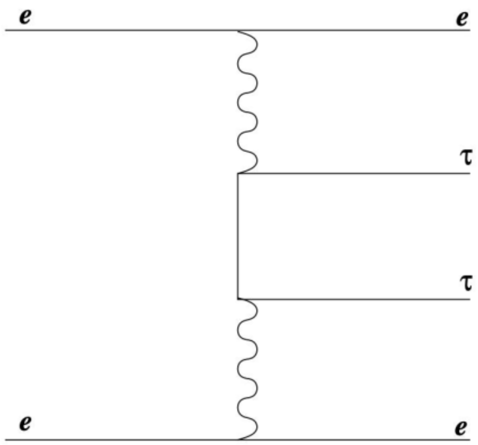


- 提出一种计算π^0-极点对HLbL贡献的全新方案
- 格点QCD在缪子反常磁矩中发挥越来越重要的作用

光光对撞中陶轻子的g-2和EDM

报告人：张成





$$\Gamma^{\mu}(q^2) = -ie\left\{\gamma^{\mu}F_1(q^2) + \frac{\sigma^{\mu\nu}q_{\nu}}{2m_{\tau}}\left[iF_2(q^2) + F_3(q^2)\gamma^5\right]\right\}$$

$$F_1(0) = 1,\ F_2(0) = a_{\tau}$$

$$F_3(0) = 2m_{\tau}d_{\tau}/e$$

*

DELPHI, 2004

$$\sqrt{s_{ee}} = 183\ GeV\sim208GeV,\ 650\ pb^{-1}$$

$$a_{\tau} = -0.018 \pm 0.017,$$

$$d_{\tau} = (0.0 \pm 2.0)\cdot 10^{-16}\, e\cdot\mathrm{cm}$$

CMS利用pp过程有了新的结果

理论邀请报告：粲强子衰变、新物理等

报告题目	报告人
D介子衰变为矢量介子对中的极化问题	赵强
Axion search in eta decay	郭志辉
形状因子和轻介子结构	程山
Final-state rescattering mechanism of charmed bayon decays	贾彩萍

报告细节请参看：
https://indico.pnp.ustc.edu.cn/event/1527/timetable/?view=standard

感谢各位专家！

感谢各位报告人！

第六届年未来陶粲国际研讨会（广州、11月17-21日）

https://indico.pnp.ustc.edu.cn/event/1948

期待各位专家
在广州深入讨论陶粲能区
的物理问题！