课题4：新物理寻找

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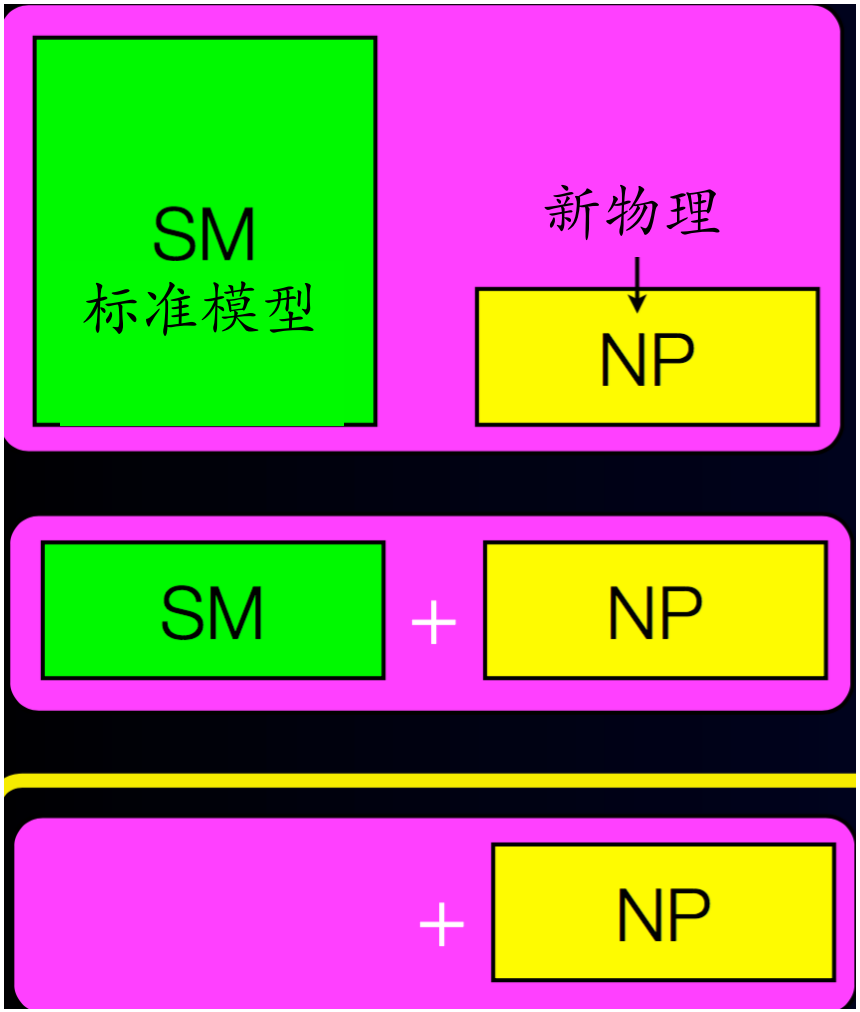
BESIII 实验上粲强子、QCD 及新物理研讨会

兰州，2022年8月22日

物理意义与目标

新物理效应微小，稀有/禁戒过程更敏感



目标： 利用 BESIII 采集的大统计量、高质量数据,特别是直接产生的粲偶素、独特的粲介子和粲重子近阈样本，在极高的实验精度下研究各种稀有或禁戒的过程，寻找超标准模型的 新粒子，检验标准模型及寻找新物理。

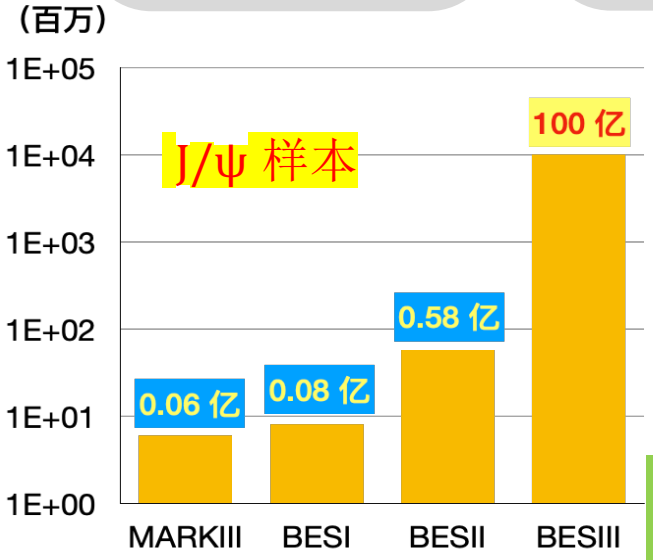
1. 标准模型贡献占主导

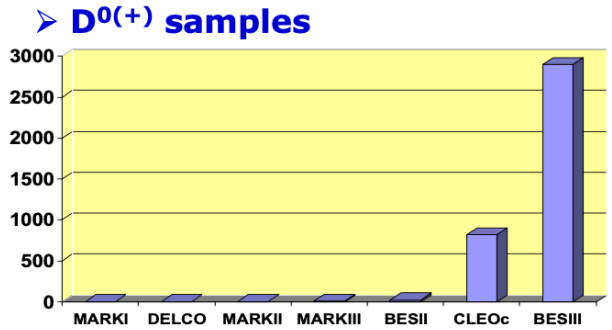
2. 标准模型贡献高度压低

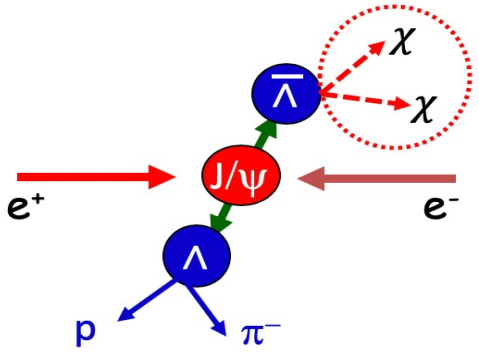
3. 标准模型过程禁戒

特色与优势

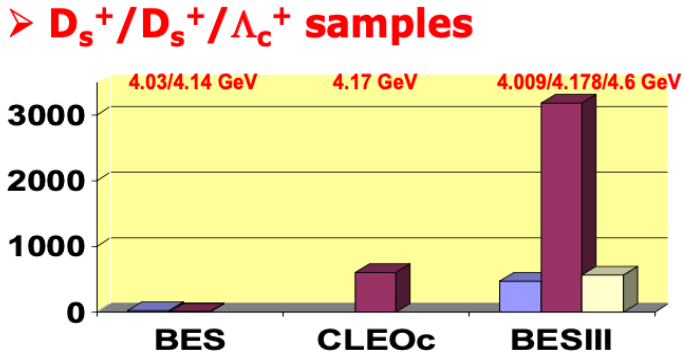
1. 理论和实验的紧密结合
2. 数据样本为本能区统计量最大、质量最好
3. 很多首次研究或高灵敏度
4. 关联标记方法在分析中的应用







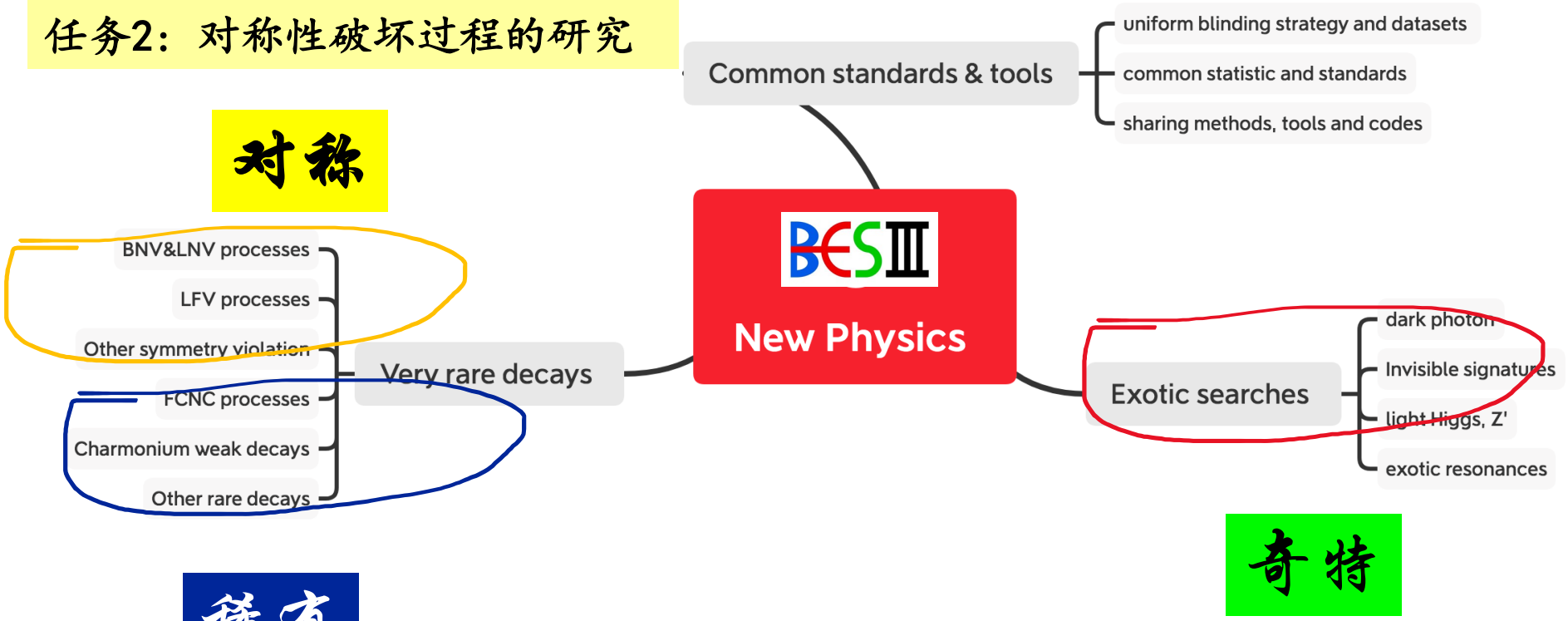
13年取数过程， 在2.0-4.95 GeV总共获取了近30fb-1数据



huge sub-samples, such as $\eta, \eta', \omega, \phi, K_S^0$,hyperons …

课题研究内容

任务2：对称性破坏过程的研究



任务3：寻找超出标准模型粒子与不可见衰变

任务1:粲偶素、超子、粲强子的稀有衰变任务

论文发表情况：29篇

年份	数量(exotic + rare)
<2015:	6 (2+4)
2015-2019：	11 (5+6)
2020-2022:	12 (3+9)

近期主要研究成果和进展

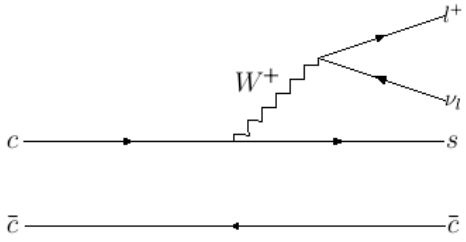
详见明天上午新物理session报告

Session VI (20″)	Chair: 尤郑昀 (SYSU)	
10:30-10:50	Charmonium hadronic weak decays at BESIII	陶璐燕 (USC)
10:50-11:10	Charmonium semi-leptonic weak decays at BESIII	李志军(SYSU)
11:10-11:30	Rare decay and NP search with Hyperons at BESIII	李彦谷 (PKU)
11:30-11:50	Search for CLFV decays at BESIII	李静舒(SYSU)
11:50-12:10	BSM particle searches at BESIII	蒋沛成 (PKU)

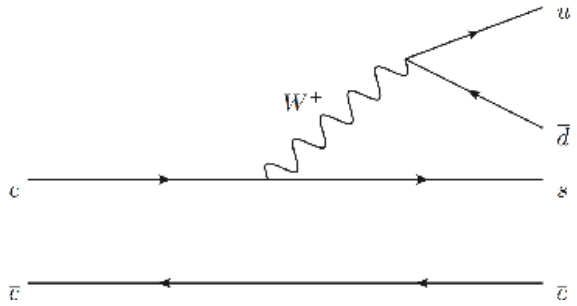
以下高亮一些最新结果，和以上报告未涵盖的研究内容/结果

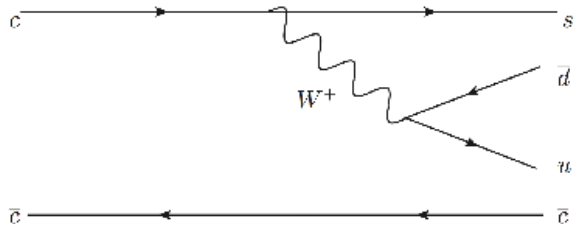
J/ψ weak decays

属于任务1



$J/\psi \to D_s^{(*)-} e^+ \nu_e$

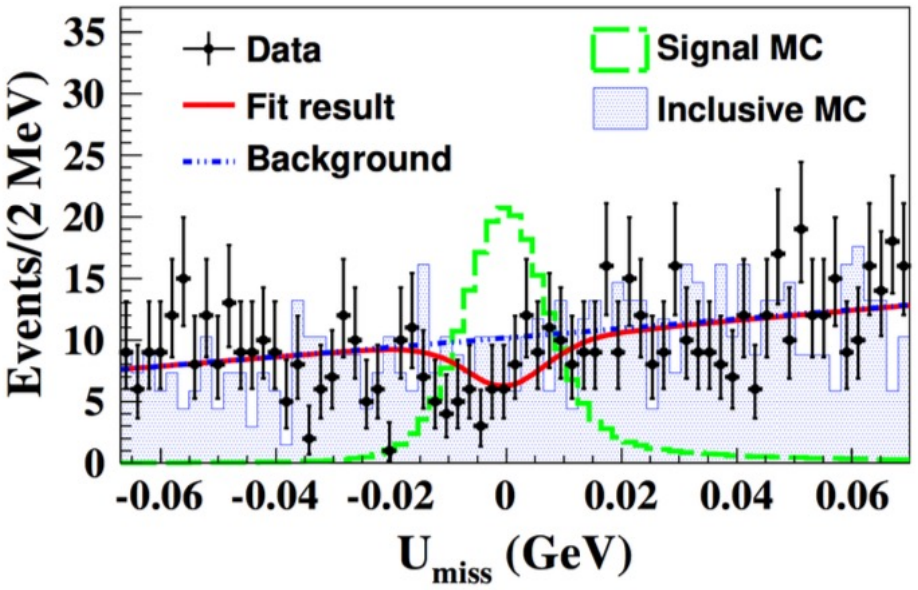




$J/\psi \to D_s^- \rho^+$ and $J/\psi \to \bar{D}^0 \bar{K}^{*0}$

- Hadronic, electromagnetic, and radiative decays of the J/ψ have been widely studied, weak decays seldom searched before, especially for purely hadronic processes.
- Kinematically, the J/ψ cannot decay to a pair of charmed D mesons, but can decay to a single D meson.
- The weak decay of charmonium are rare decays. Searches for weak decays of charmonium to single D or D_s mesons provide tests of standard model (SM) theory and serve as a probe of new physics.

Search for charmonium weak decays $J/\psi \to D^- e^+ \nu_e$ and $\psi(3686) \to \Lambda_c^+$ anti-Σ^-



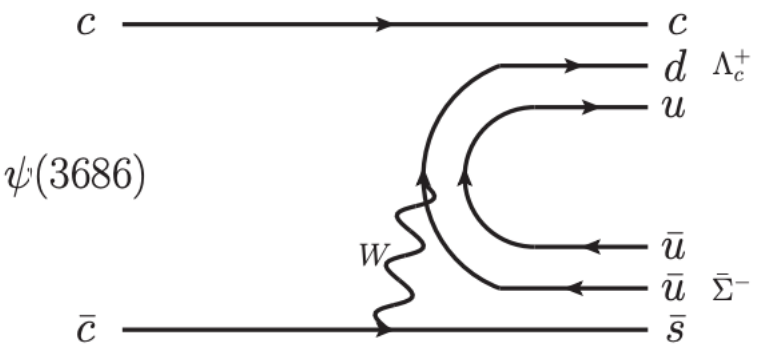
JHEP 06 (2021) 157

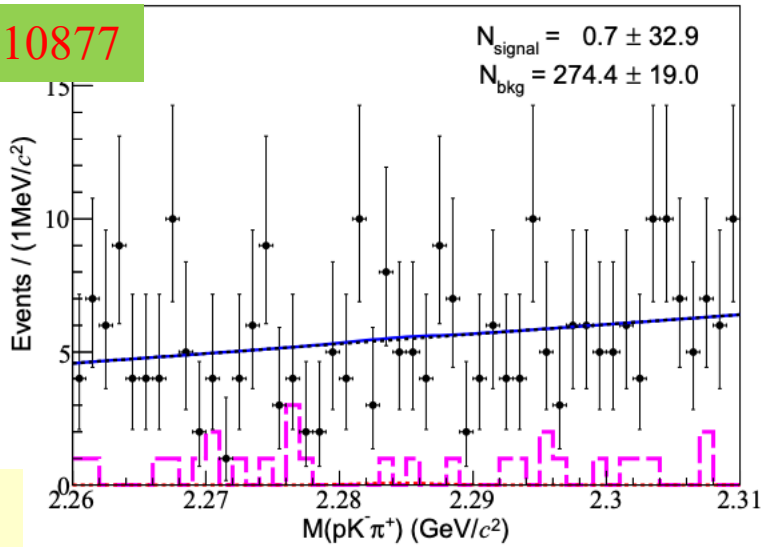
$$U_{miss} = E_{miss} - c|p_{miss}|$$

$J/\psi \to D^- e^+ \nu_e + c.c. < 7.1 \times 10^{-8}$ @ 90% CL

- ✓ **mproves the limit by a factor of 170.**
- ✓ **stringent constraint for NP models**
- ✓ muon channel analysis ongoing

Arxiv:2207.10877





See Zhijun and Luyan's talk

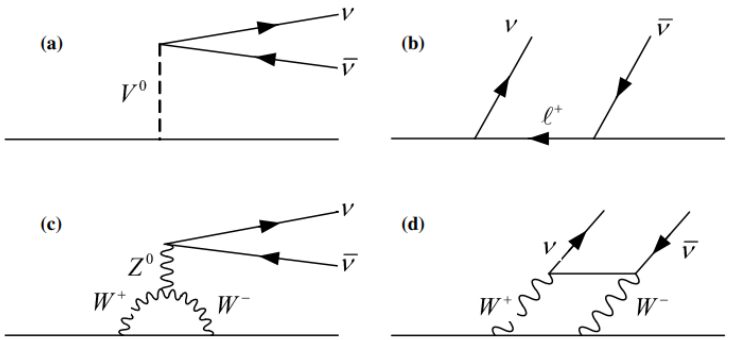
B($\psi(3686) \to \Lambda_c^+$ anti-Σ^-) < 1.4×10^{-5} .

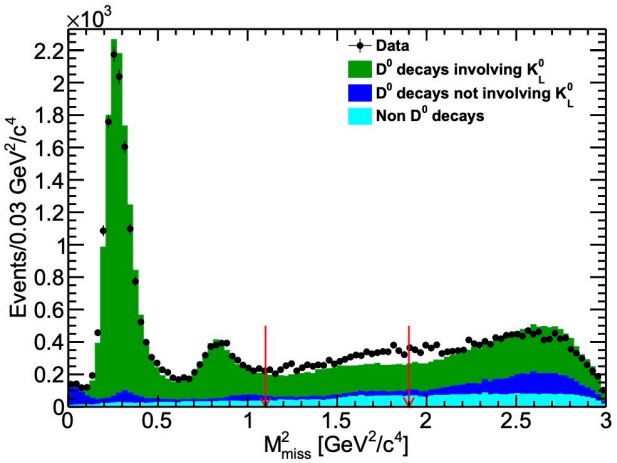
属于任务1

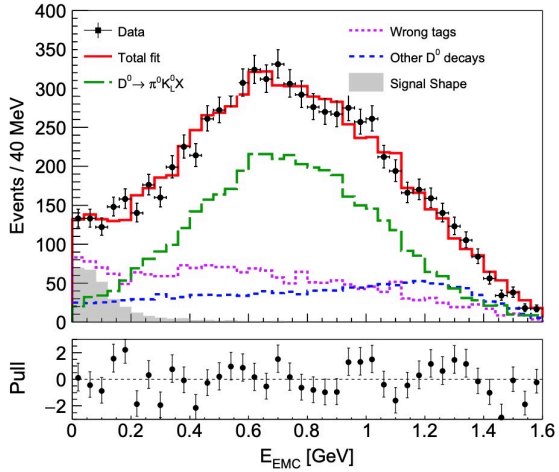
Search for FCNC process $D^0 \to \pi^0 \nu\bar{\nu}$

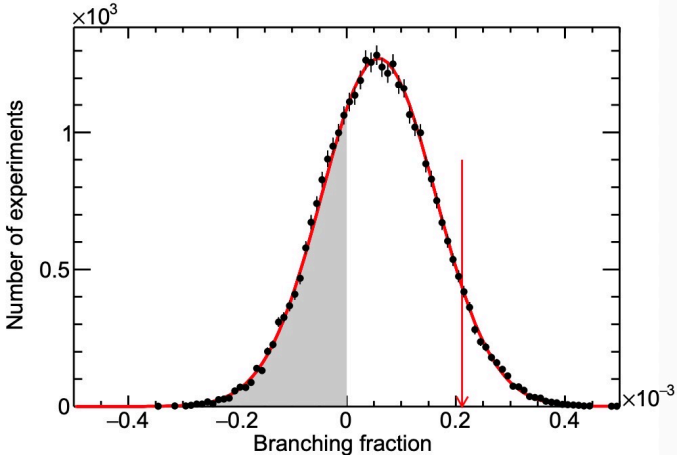
- In SM, FCNC is highly suppressed by GIM mechanism, only through loop diagram, a very small BF 10^{-9} ~10^{-15}
- The suppression in charm decay is much stronger than B & K system, stronger diagram cancellation
- Analyzing 10.6×10⁶ $D^0\bar{D}^0$ pairs
- $\mathcal{B}(D^0 \to \pi^0\nu\bar{\nu}) < 2.1\times10^{-4}$ @ 90% C. L.
- The first constraint on charmed hadron to di-neutrino

PRD 105 L071102 (2022)





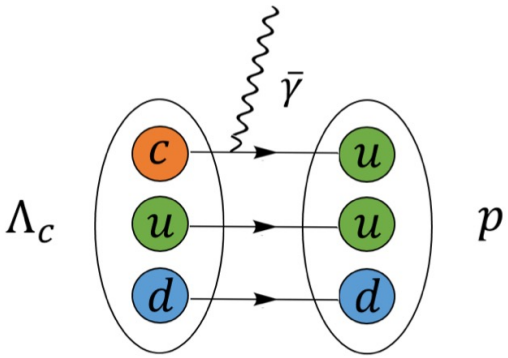




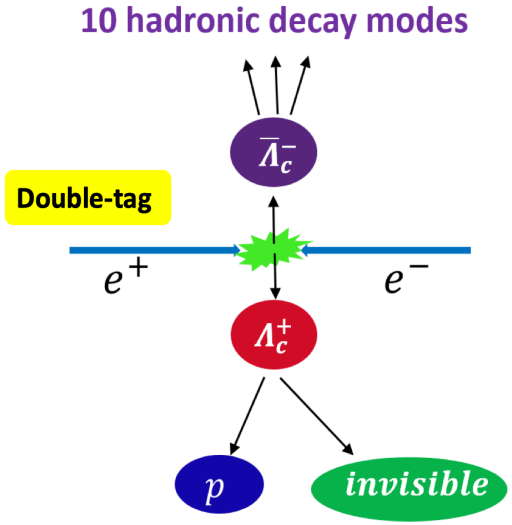
Search for $\Lambda_c \to p\gamma'$ (FCNC process)

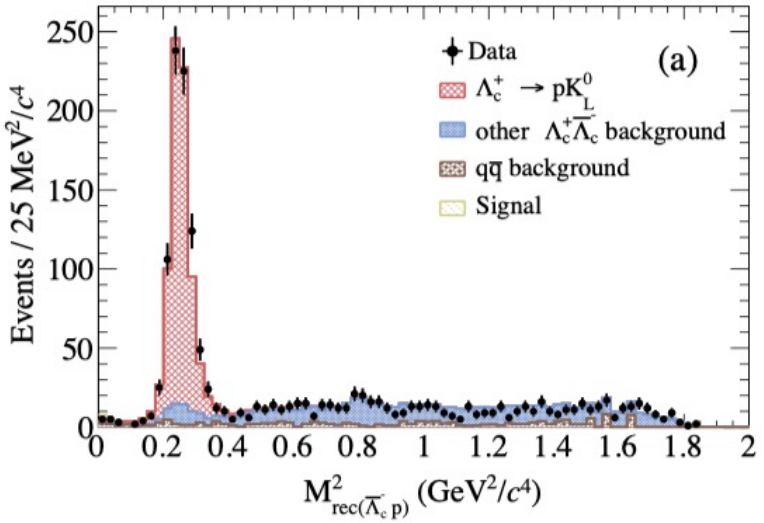
arXiv:2208.04496

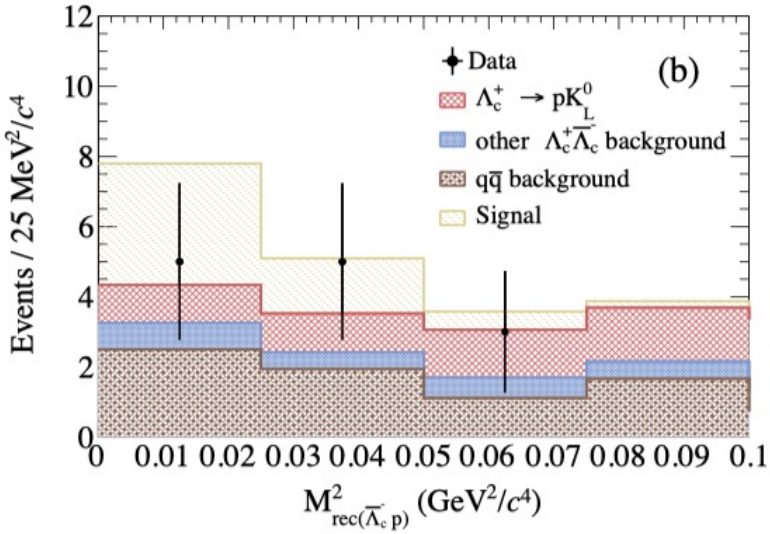
Massless dark photon is predicted with $U(1)_D$ staying unbroken, which can induce FCNC transitions



Using 4.5 fb^{-1} data in 4.6 - 4.7GeV







$\mathcal{B}(\Lambda_c \to p\gamma') < 8.0\times10^{-5}$ @ 90% C.L.

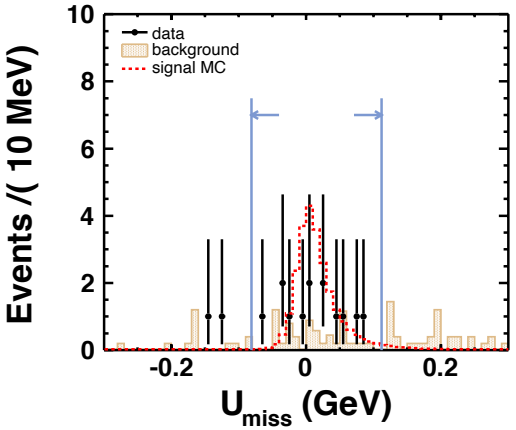
属于任务2

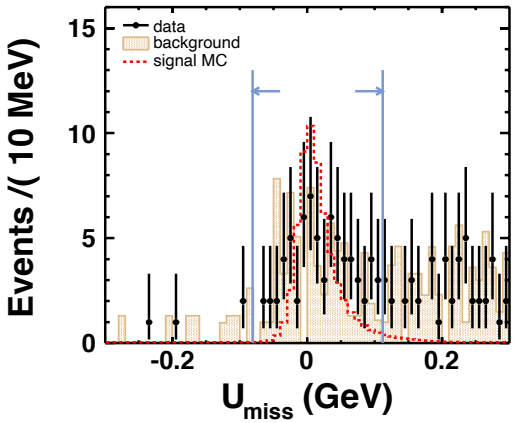
Search for cLFV: $J/\psi \to e^{\pm}\tau^{\mp}$

- Analyzing 10.087×10⁹ J/ψ events, with searching process $J/\psi \to e\tau, \tau \to \pi\pi^0\nu$

Phys. Rev. D 103, 112007 (2021)

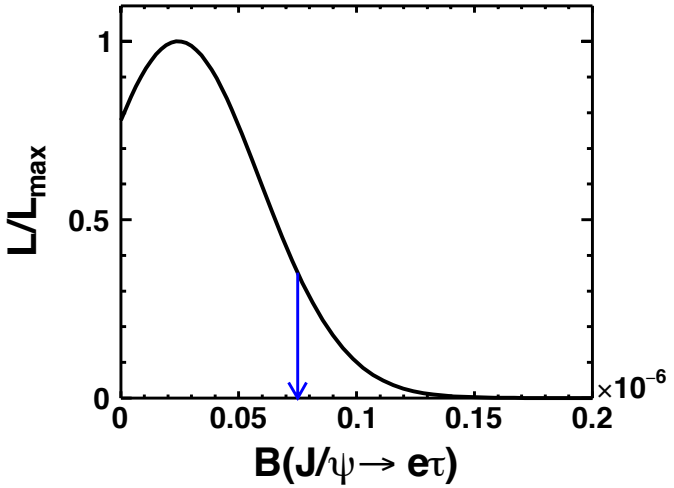
$$U_{miss} = E_{miss} - c|\vec{P}_{miss}|$$





See Jingshu's talk

- Determination of upper limit at 90% confidence level (C.L.) with Bayesian method. Combined result:
  - $BR(J/\psi \to e\tau) < 7.5\times10^{-8}$ @ 90% C.L.
- This result improves the previous published limits by two orders of magnitude and comparable with the theoretical predictions.
- 达到了项目计划书指标

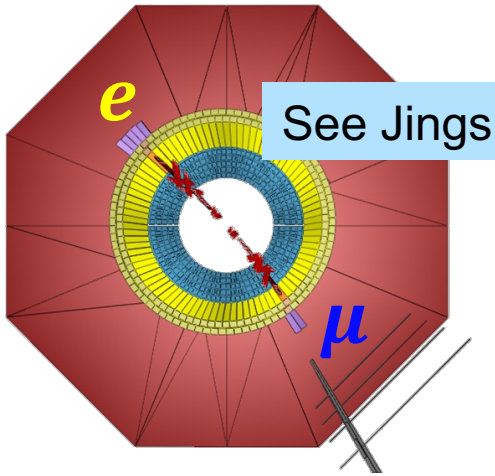


属于任务2

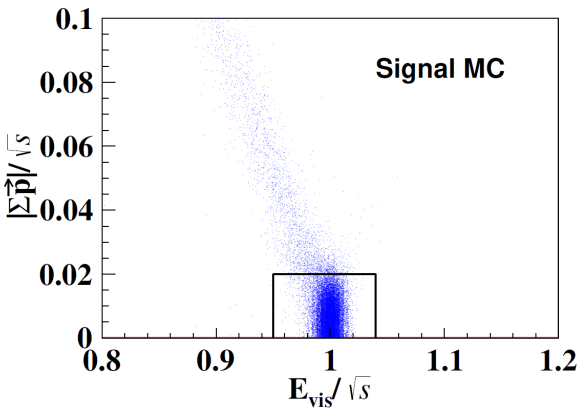
Search for LFV decay $J/\psi \to e^{\pm}\mu^{\mp}$

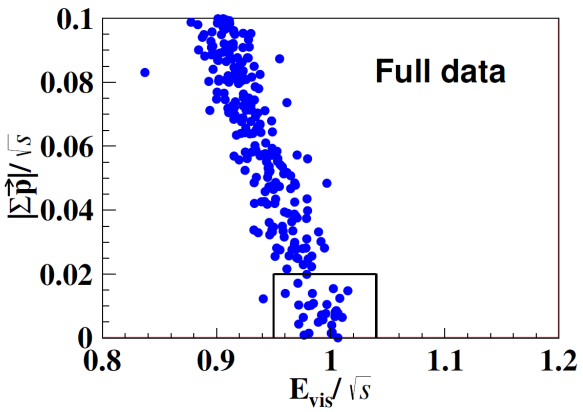
- Analyzing 8.998×10⁹ J/ψ events
- Searching for two back-to-back e μ
- $\mathcal{B}(J/\psi \to e\mu) < 4.5\times10^{-9}$ @ 90%C.L.
- Improve the previous best limit by a factor of > 30
- The most stringent BESIII upper limit measurement
- The most precise CLFV search in heavy quarkonium
- Excluding the parameter space of some models

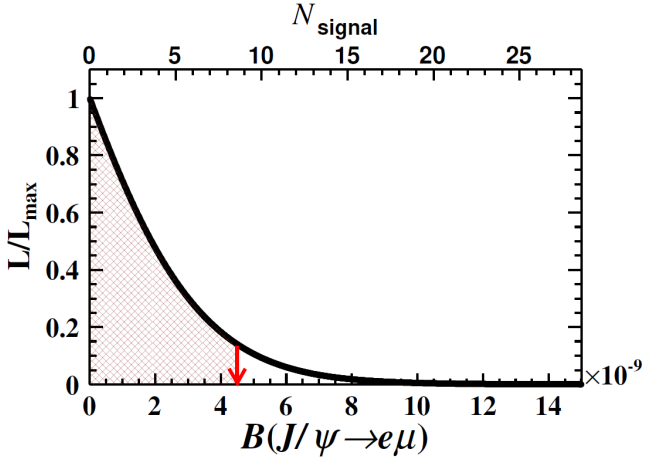
arXiv:2206.13956



See Jingshu's talk



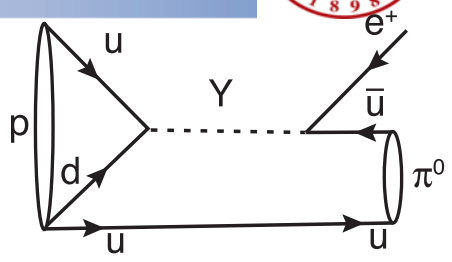




超过了项目计划书指标

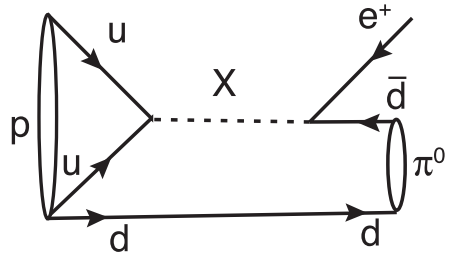
重子数/轻子数破坏过程(BNV/LNV)

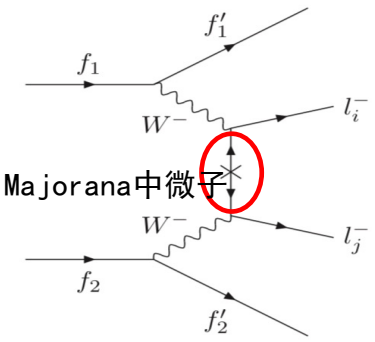
- 为解释宇宙正反物质不对称，要求“重子数守恒破坏”，对于理解宇宙演化具有重要意义。
- 很多理论模型可导致重子数破坏，例如大统一理论的Georgi－Glashow模型
- 多数理论模型：B-L守恒，可通过寻找LNV推测BNV过程，为正反物质不对称提供实验依据
- 如果中微子是Majorana型，则必然会存在轻子数破坏过程
- 对撞机实验的测量具有可重复性与过程多样性，必不可少，在强子衰变中寻找BNV/LNV过程是其他探寻方案的必要补充。
- 按反应前后的量子数变化可分为：(1) 重子数改变、但重子数与轻子数之差不变($\Delta B=1, \Delta(B-L)=0$)；(2)只有重子数改变($\Delta B=2$) (3)只有轻子数改变($\Delta L=2$)



(a)

Phys.Rev.Lett. 32 (1974) 438-





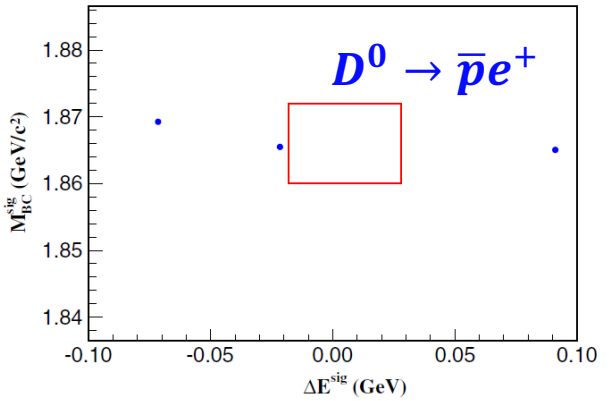
At BESIII, the BNV/LNV processes have been searched in the decays of $D, J/\psi$, and hyperons, with ULs on BFs are at the level of $10^{-8}\sim10^{-4}$

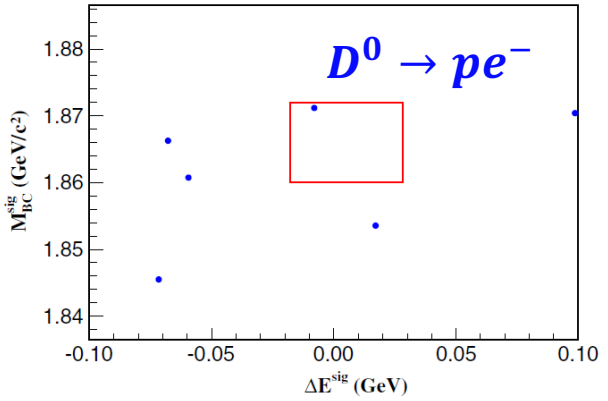
Search for LNV & BNV $D^0 \to pe^-$

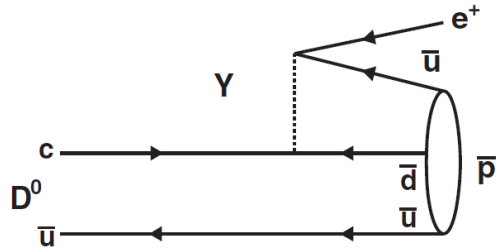
属于任务2

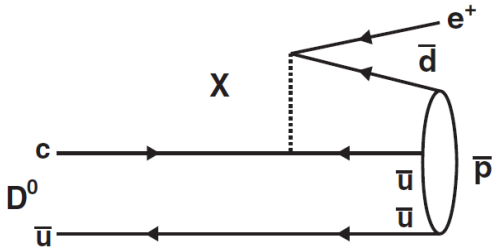
PRD 105 032006 (2022)

- BNV can happen with $\Delta(B-L)=0$ at dimension-six operators
- With $\Delta(B-L)=2$ allowed at dimension-seven operato
- Analyzing 2.93 fb^{-1} 3.773 GeV data
- $\mathcal{B}(D^0 \to \bar{p}e^+) < 1.2\times10^{-6}$ @ 90%C. L.
- $\mathcal{B}(D^0 \to pe^-) < 2.2\times10^{-6}$ @ 90%C. L.
- The most stringent ones to date for these processes
- Still far above higher generation model prediction



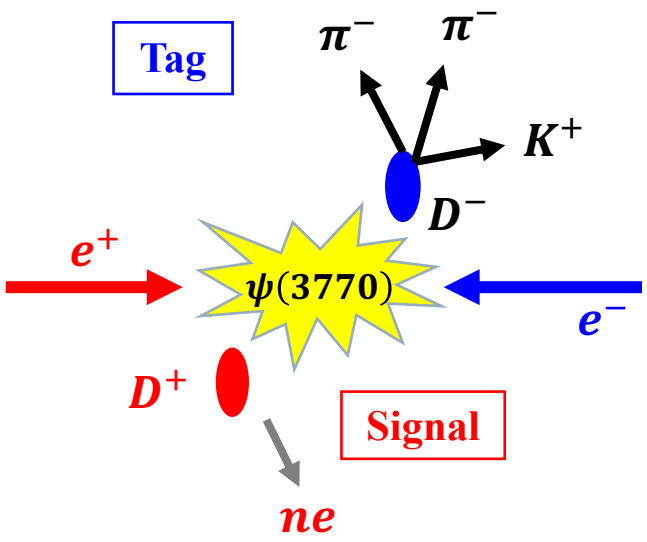






$D^{\pm} \to n(\bar{n})e^{\pm}$: search strategy

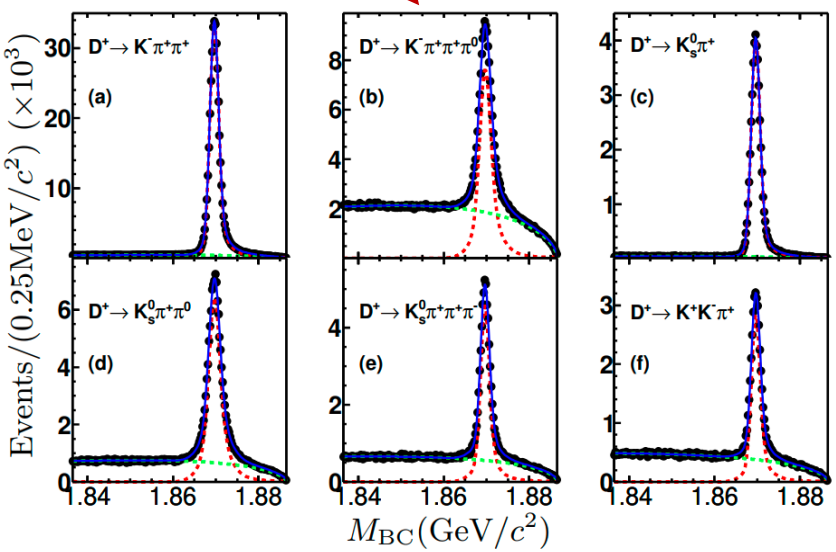
属于任务2



- Data: 2.93 fb^{-1} @ 3.770 GeV
- Double Tag analysis
- Absolute BFs

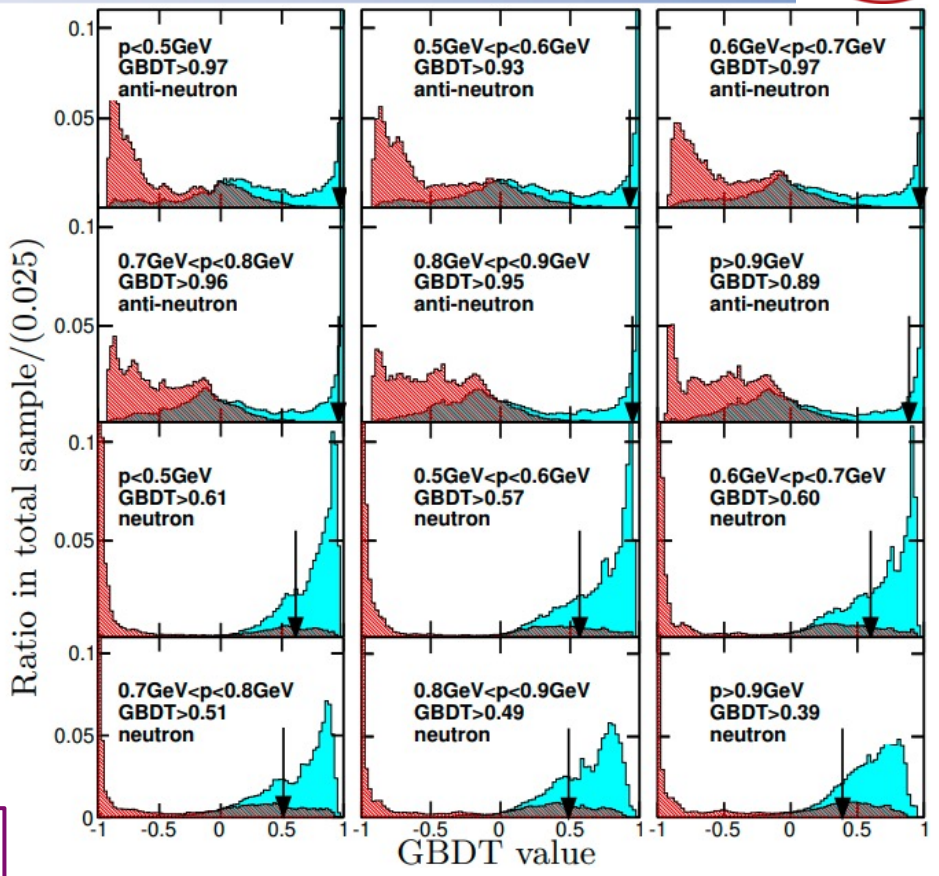
$$\mathcal{B} = N_{DT}/(N_{ST}^{tot} \times \varepsilon_{sig})$$

Charge conjugated processes are implied	
Tag Mode	Sig Mode
$D^- \to K^+\pi^-\pi^-$ $D^- \to K^+\pi^-\pi^-\pi^0$ $D^- \to K_S^0\pi^-$ $D^- \to K_S^0\pi^-\pi^0$ $D^- \to K_S^0\pi^-\pi^-\pi^+$ $D^- \to K^+K^-\pi^-$	$D^+ \to \bar{n}e^+$ $[\Delta(B-L)=0]$
	$D^+ \to ne^+$ $[\Delta(B-L)=2]$



Selection of $D^{+(-)} \to \bar{n}(n)e^{+(-)}$

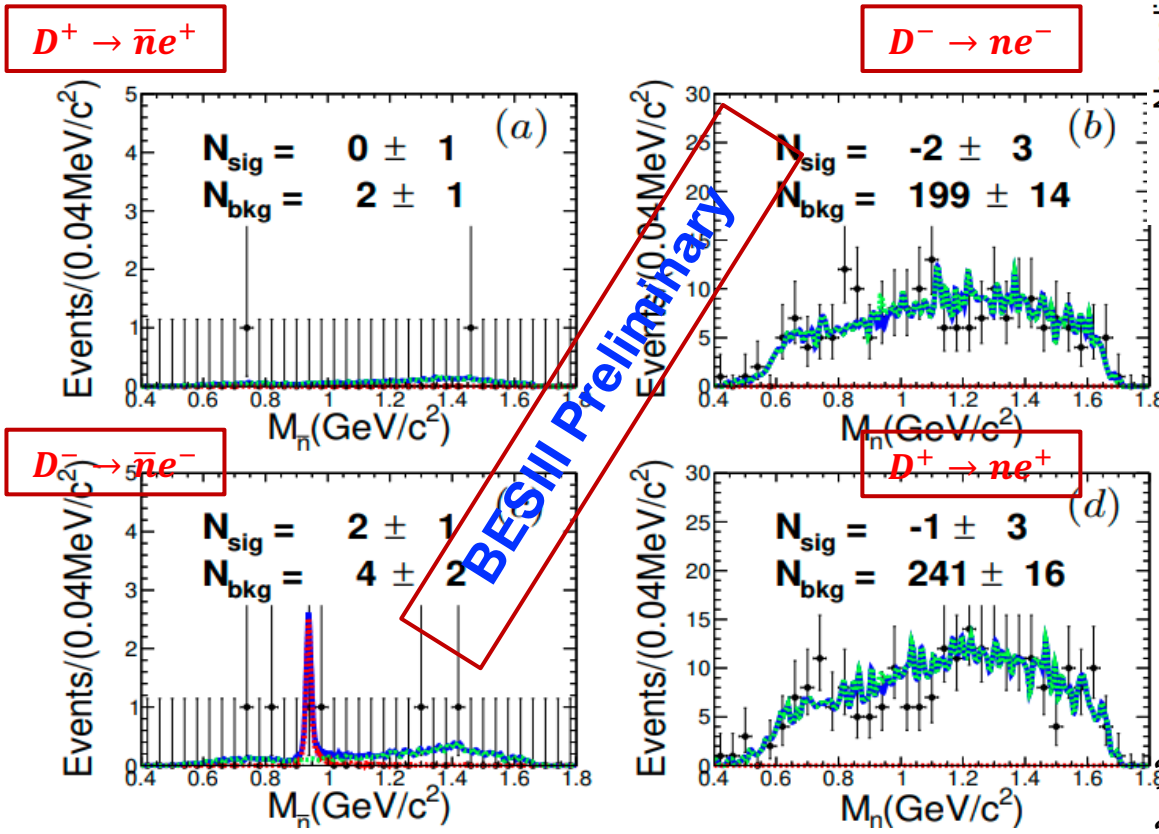
- A kinematic fit(2C): constrain the invariant mass of $D(\bar{D})$; loop 4-momentum of (anti-) neutron
- Opening angle of (anti-)neutron momentum to shower in the EMC: $10°(15°)$ for neutron(anti-neutron)
- Multivariate Data Analysis(MVA) based on a Gradient Boosted Decision Trees(GBDT) algorithm: EMC

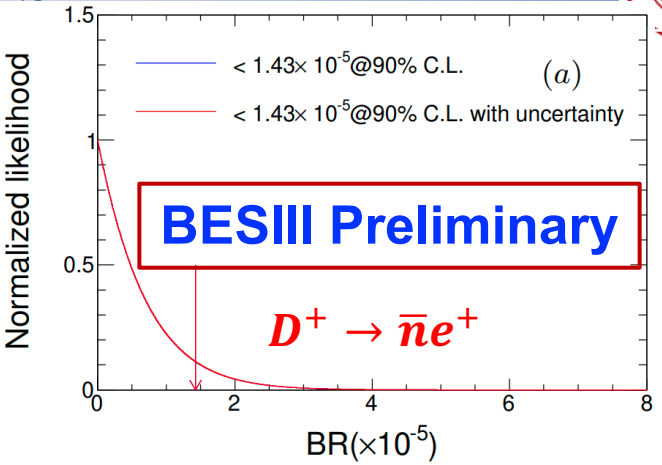


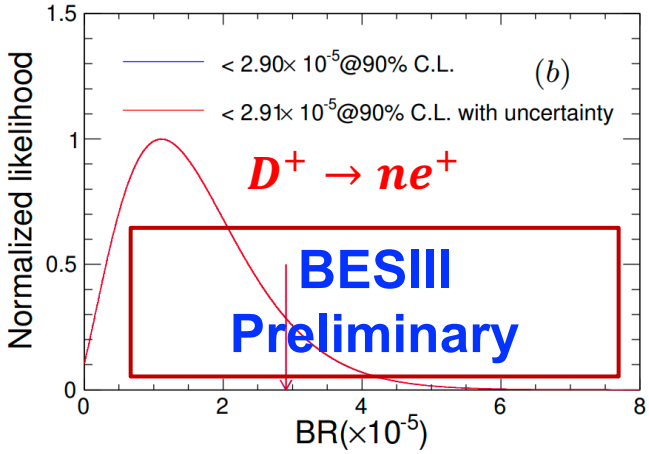
signal: $\bar{n}/n$
background: $K_L\&\gamma$

The shower-shape variables have a significant dependence on the momentum of the (anti-)neutron. MVA is performed in separate (anti-)neutron momentum bins of interval 100 MeV/c

Preliminary Results







$\mathcal{B}(D^+ \to \bar{n}e^+) < 1.4\times10^{-5}$

$\mathcal{B}(D^+ \to ne^+) < 2.9\times10^{-5}$,

at 90% C.L BESIII Preliminary

First searches!

属于任务2

BNV/LNV search at BESIII

Data	Source	Mode	$\|\Delta(B-L)\|$	UL on BF @ 90% CL
$\sqrt{s}=3.773$ GeV 2.93 fb^{-1} $N^{tot}_{D^+D^-}=(8,296\pm31\pm64)\times10^3$ $N^{tot}_{D^0\bar{D}^0}=(10,597\pm28\pm98)\times10^3$	D mesons	$D^+\to\bar{\Lambda}e^+$	0	6.5×10^{-7}
		$D^+\to\bar{\Sigma}^0e^+$	0	1.3×10^{-6}
		$D^+\to\Lambda e^+$	2	1.1×10^{-6}
		$D^+\to\Sigma^0e^+$	2	1.7×10^{-6}
		$D^0\to\bar{p}e^+$	2	$1.2(2.2)\times10^{-6}$
		$D^+\to\bar{n}e^+$	2	$1.4(2.5)\times10^{-5}$
		$D^0\to K^-\pi^+e^+e^+$	2	2.8×10^{-6}
		$D^+\to K^0_S\pi^-e^+e^+$	2	3.3×10^{-6}
		$D^+\to K^-\pi^0e^+e^+$	2	8.5×10^{-6}
$\sqrt{s}=3.097$ GeV $N^{tot}_{J/\psi}=(1,310.6\pm7.0)\times10^6$	J/ψ meson	$J/\psi\to\Lambda_c^+e^-$	0	6.9×10^{-8}
		$J/\psi\to pK^-\bar{\Lambda}\to pK^-\Lambda$	2 [BF ratio $P(\Lambda)<4.4\times10^{-6}$]	
	Σ^- hyperon	$\Sigma^-\to pe^-e^-$	2	6.7×10^{-5}
		$\Sigma^-\to\Sigma^+X$	2	1.4×10^{-4}
	Ξ^0 hyperon	$\Xi^0\to K^\pm e^\mp+cc.$	2	In progress

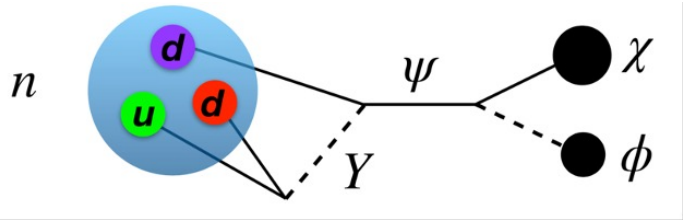
Search for Λ→ invisible

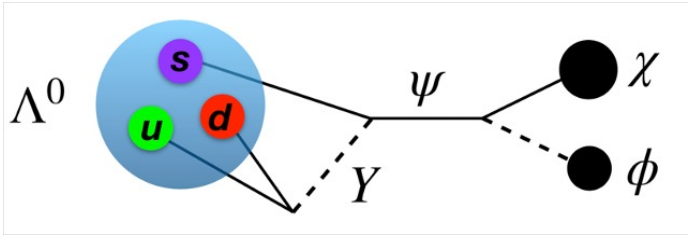
属于任务3

PRD105, L071102 (2022)

- Some models predict baryon invisible decays:

Phys. Rev.D 99(2019) 3, 035031



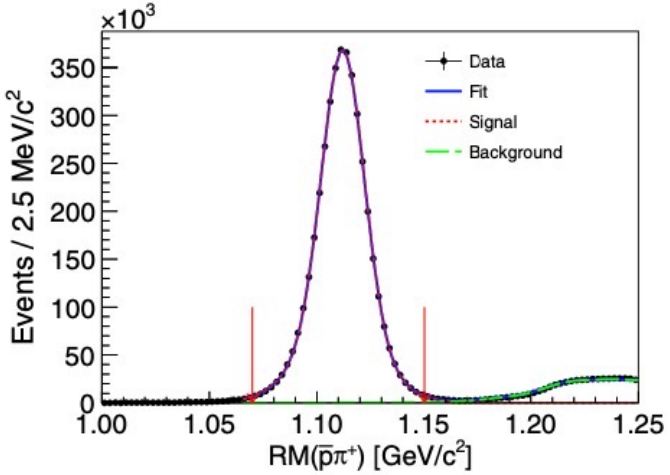


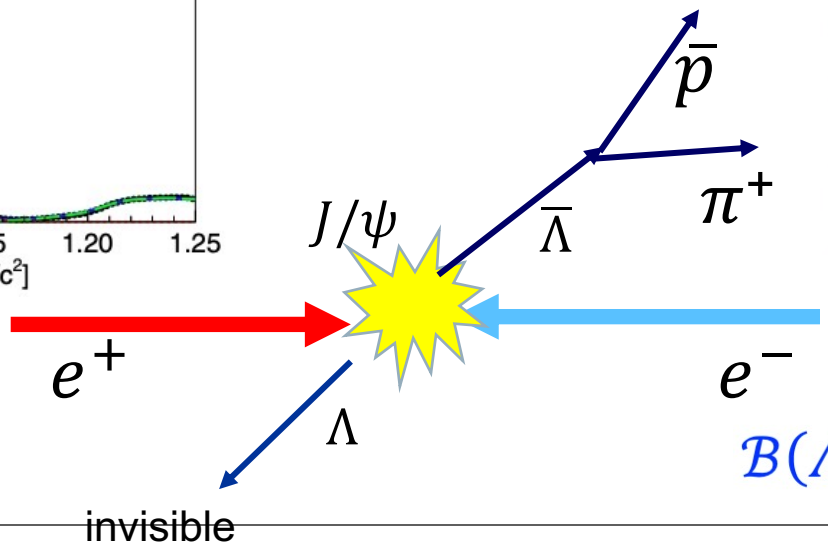
See Yangu's talk

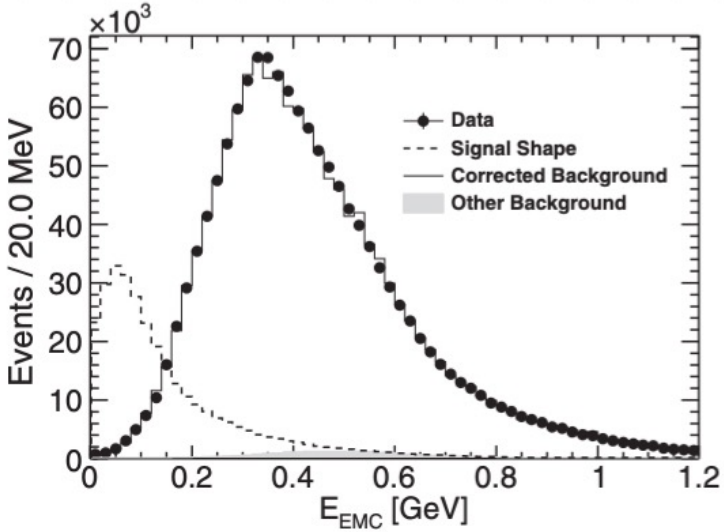
Phys. Lett. B 745 (2015), 79
Phys. Rev. Lett. 111, 222501 (2013)

- May also relate to neutron lifetime puzzle:

$$\tau_n^{beam} = \frac{\tau_n}{\mathcal{B}(n \to p + X)} > \tau_n^{bottle} \Rightarrow \mathcal{B}(n \to p + X) \approx 99\%$$



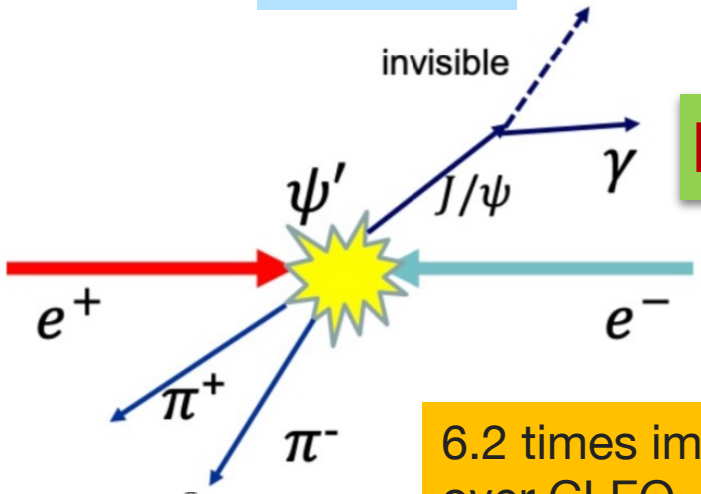




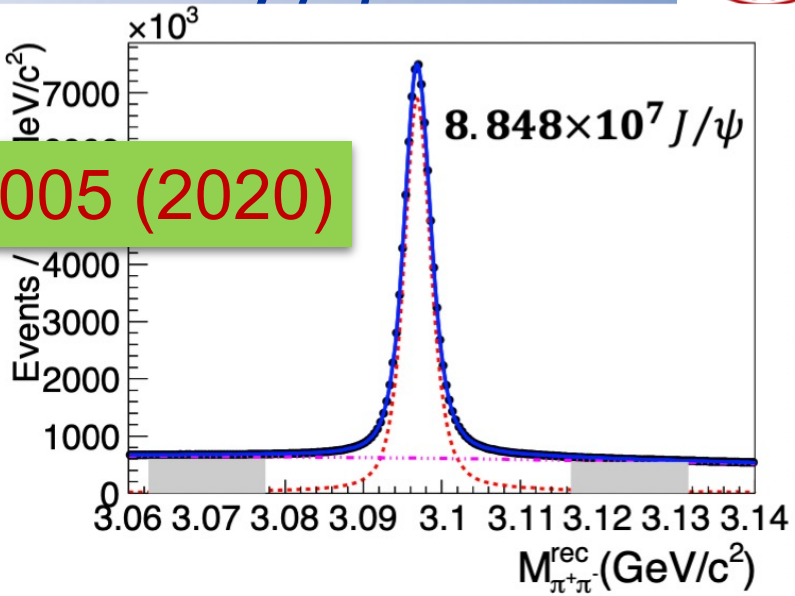
$$\mathcal{B}(\Lambda \to invisible) < 7.4 \times 10^{-5}$$

Search for $J/\psi \rightarrow$ gamma invisible via $\psi(3686) \rightarrow \pi^+\pi^- J/\psi$

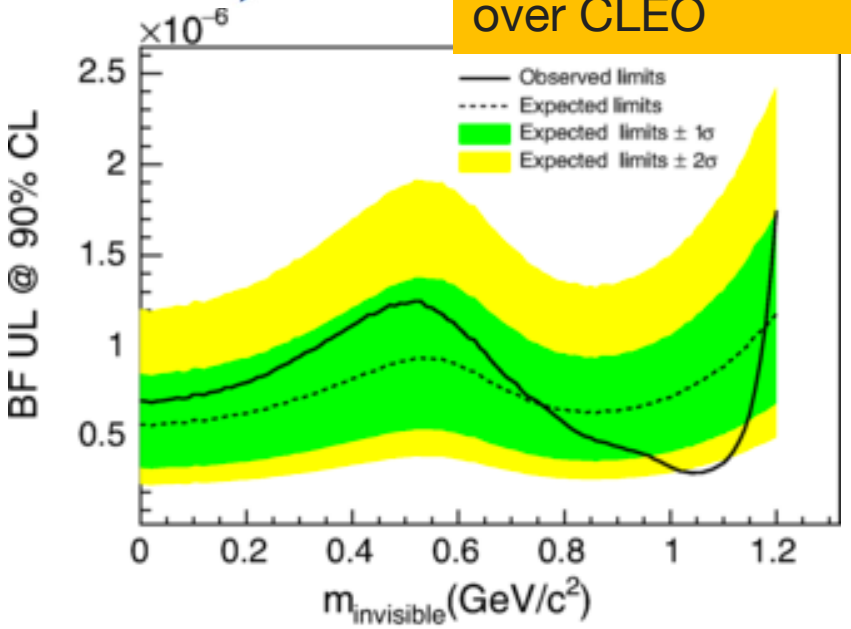
属于任务3

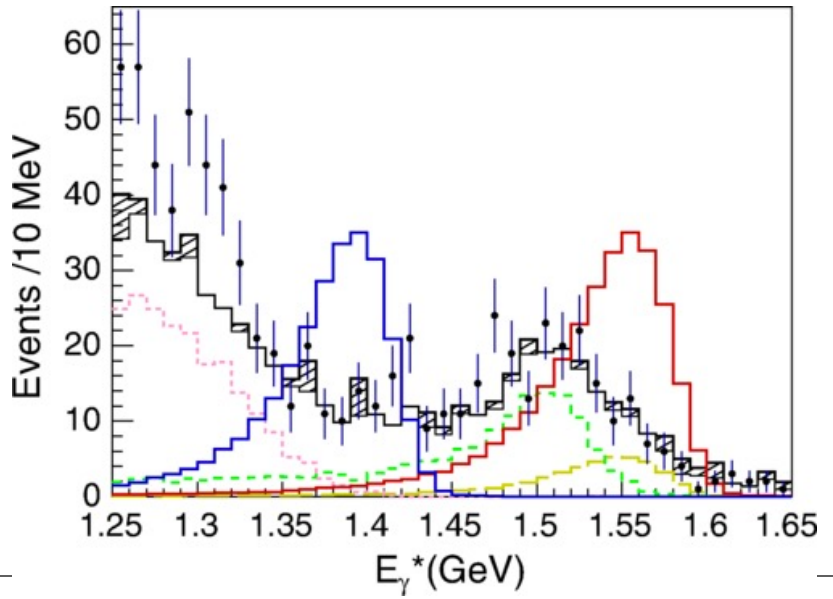


PRD101, 112005 (2020)



6.2 times imporvement over CLEO



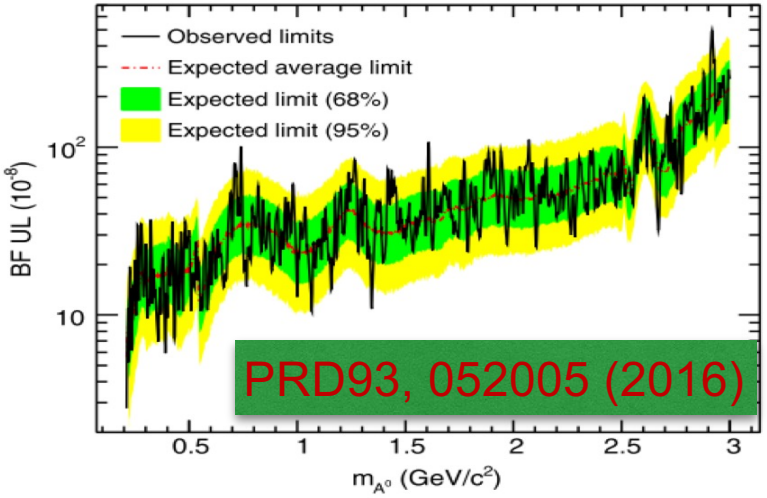


Light Higgs search

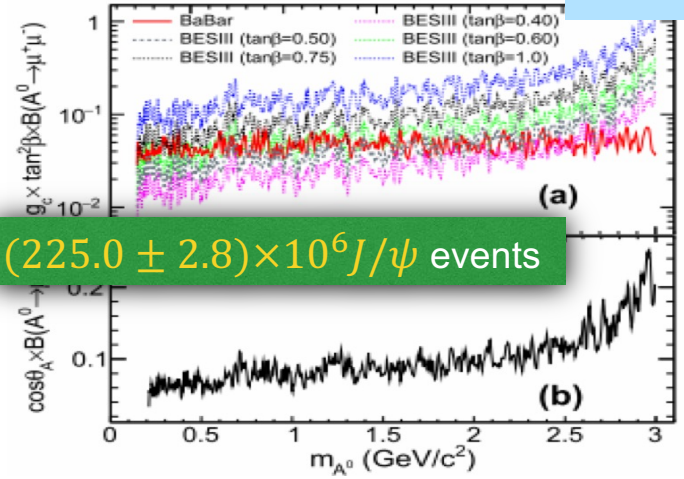
属于任务3

- Search for a CP-odd Higgs boson in $J/\psi \to \gamma A^0, A^0 \to \mu^+\mu^-$

See Peicheng's talk

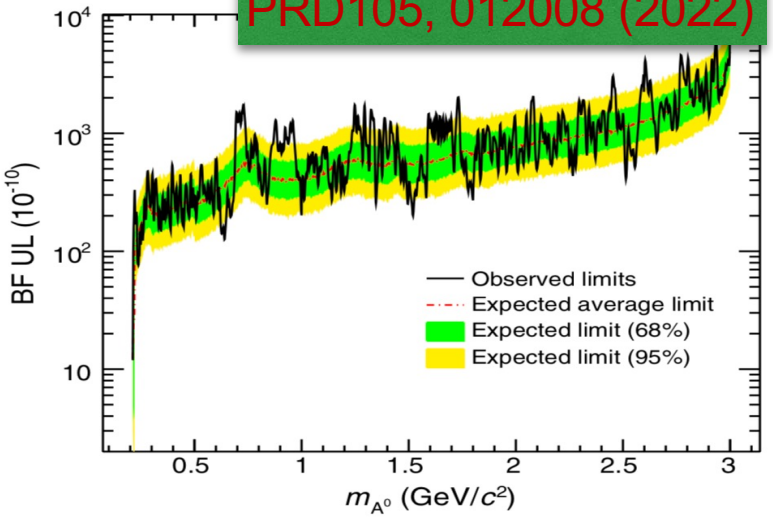


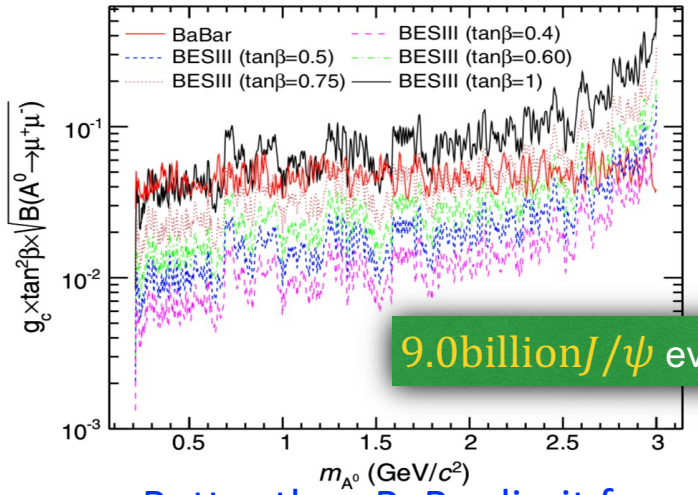
PRD93, 052005 (2016)



$(225.0 \pm 2.8)\times10^6 J/\psi$ events

PRD105, 012008 (2022)





9.0billionJ/ψ events

Better than BaBar limit for m(A0)<0.7 GeV

人才培养情况

- 培养毕业硕士研究生（1）
  - 北京大学：左羽生
- 培养毕业博士研究生（10）
  - 北京大学：刘霄，李正阳，金小博，王梦真，宋昀轩，夏世城
  - 高能物理研究所：高婧，张剑宇，张丰
  - 中山大学：林创新
- 培养出站博士后（2）
  - 北京大学：张鹏， 孟雨

课题组成员发表的其他论文(20)

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2. H. Deng, J. Gao, L.Y.Li, C.D.Lu, Y.L.Shen and C.X.Yu,``Study on pure annihilation type $B \to V \gamma$ decays,'' Phys. Rev. D 103，076004 (2021)
3. Ren-Hua Wu, Yu-Sheng Zuo, Ce Meng, Yan-Qing Ma, Kuang-Ta Chao, NLO effects for Ω QQQ baryons in QCD Sum Rules, Chin.Phys.C 45 (2021) 9, 093103
4. Peng Zhang, Ce Meng, Yan-Qing Ma, Kuang-Ta Chao,Gluon fragmentation into 3PJ[1,8] quark pair and test of NRQCD factorization at two-loop level, JHEP 08 (2021) 111
5. An-Ping Chen, Xiao-Bo Jin, Yan-Qing Ma, Ce Meng, Fragmentation function of g->QQ3s18 in soft gluon factorization and threshold resummation, JHEP 06 (2021) 046
6. X. Tuo, X. Feng, L. Jin, T. Wang，Lattice QCD calculation of K→l nu l+ l- decay width,, Phys. Rev. D 105 (2022) 5, 054518
7. Y. Li, S. Xia, C. Alexandrou, K. Cichy, M. Constantinou, X. Feng, et. al., Systematic study of transverse-momentum dependent soft function from lattice QCD, Phys. Rev. Lett. 128 (2022) 6, 062002
8. X. Feng, L. Jin, M. Riberdy, Lattice QCD calculation of the pion mass splitting, Phys. Rev. Lett. 128 (2022) 5, 052003
9. N. Christ, X. Feng, J. Karpie, T. Nguyen, π-π scattering, QED and finite-volume quantization, Phys. Rev. D 106 (2022) 1, 014508
10. Y. Fu, X. Feng, L. Jin, C. Lu, Lattice QCD calculation of the two-photon exchange contribution to the muonic hydrogen Lamb shift, Phys. Rev. Lett. 128 (2022) 17, 172002
11. Xiao Liu, Yan-Qing Ma, Multiloop corrections for collider processes using auxiliary mass flow, Phys.Rev.D 105 (2022) L051503
12. An-Ping Chen, Yan-Qing Ma, Hong Zhang, A Short Theoretical Review of Charmonium Production, Adv.High Energy Phys. 2022 (2022) 7475923
13. An-Ping Chen, Xiao-Bo Jin, Yan-Qing Ma, Ce Meng, Color-octet contributions for J/ψ inclusive production at B factories in soft gluon factorization, JHEP 03 (2022) 202
14. Zhi-Feng Liu, Yan-Qing Ma, Automatic computation of Feynman integrals containing linear propagators via auxiliary mass flow, *Phys.Rev.D* 105 (2022) 074003
15. Feng Zhang，Bin Gong，Jian-Xiong Wang， New approach for amplitudes with multiple fermion lines; ； Chin.Phys.C46(2022)8,083104
16. Feng Zhang，Jian-Xiong Wang ,Study of the rare decay J/\psi \to 2\gamma+hadronsJ/ψ→2γ+hadrons at the BESIII； Chin.Phys.C 46 (2022) 9, 093109
17. Z.R.Huang, E.Kou, C.D.Lu and R.Y.Tang, ``Un-binned Angular Analysis of $B\to D^*\ell \nu_\ell$ and the Right-handed Current,'' Phys. Rev. D105 (2022) no.1, 013010
18. S.H.Zhou, R.H.Li, Z.Y.Wei and C.D.Lu, ``Analysis of three-body charmed B-meson decays under the factorization-assisted topological-amplitude approach,'' Phys. Rev. D 104 (2021) no.11, 116012
19. Q.A.Zhang, J.Hua, F.Huang, R.Li, Y.Li, C.Lu, C.D.Lu, P.Sun, W.Sun and W.Wang, ``First lattice QCD calculation of semileptonic decays of charmed-strange baryons \Xi_c*,'' Chin. Phys. C 46 (2022) no.1, 011002
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总结与展望

- **BESIII上广泛开展了稀有衰变和新物理的研究**
  - 优势和特点：大统计量、高质量的粲偶素、超子数据，粲介子和粲重子近阈样本双标记、低本底
  - 研究各种稀有或禁戒的过程，寻找超标准模型的新粒子，检验标准模型及寻找新物理,不少结果都是世界最好或者首次研究
  - 随着更多数据采集和实验升级，研究前景光明

Future Physics Programme of BESIII
Chinese Phys. C **44**, 040001 (2020).

- **本课题进展顺利，基本上按计划执行**
  - 稳定的物理产出，部分任务完成，指标超过计划书
  - 人才培养稳定有序：研究生、博士后、本科生
  - 经费使用基本正常（受疫情影响， 执行率38%)
  - 理论与实验结合，需要更多交流，产生更好的新想法

Thanks!