Overview of New Physics Searches at BESIII

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On behalf of the BESIII New Physics Group

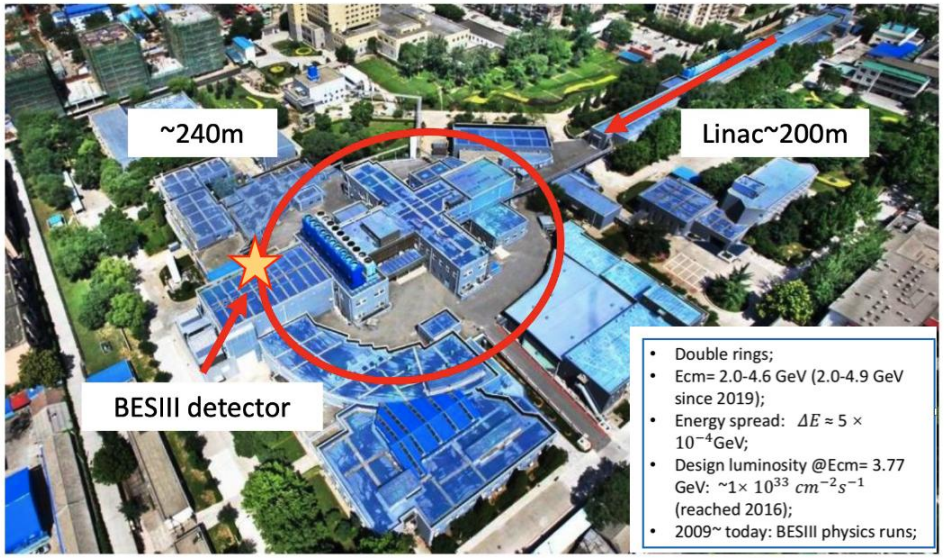
26-30/8/2024 BESIII New Physics Group Workshop

Outline

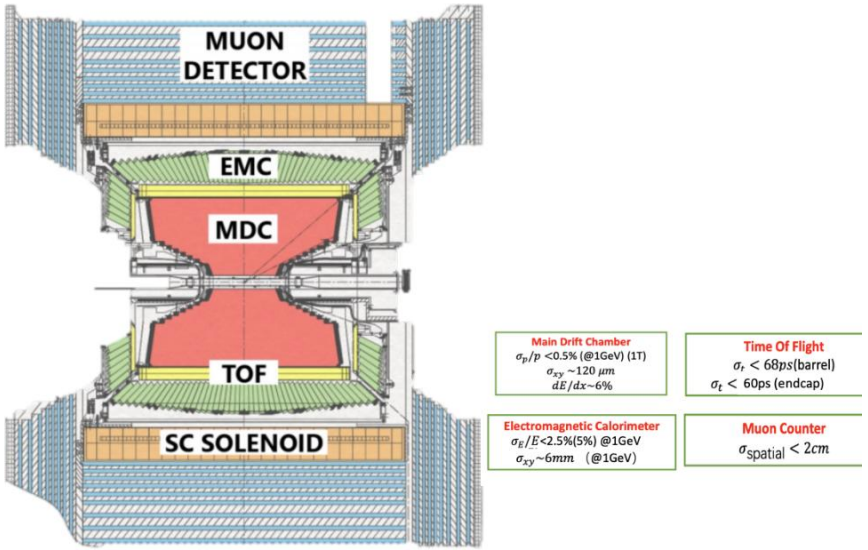
- BEPCII and BESIII
- BESIII data sets
- New physics studies at BESIII
  - Symmetry violation
  - Rare decays
  - Exotics
- Publications
- Analyses procedure
- Summary

BEPCII and BESIII

Beijing Electron–Positron Collider II



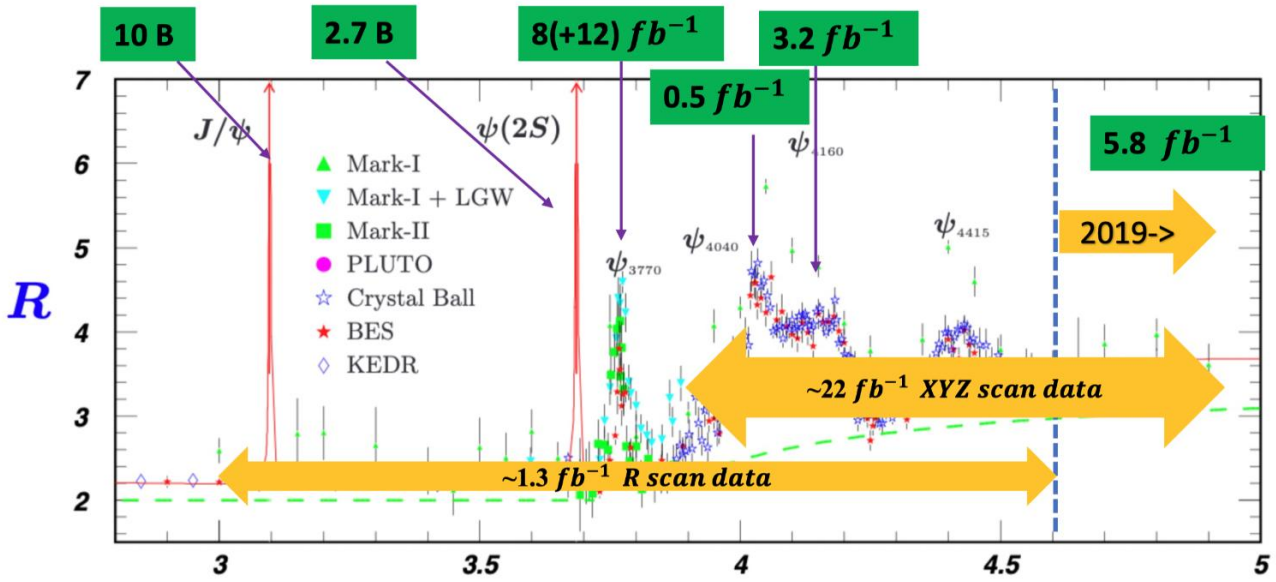
Beijing Spectrometer III



A symmetric e^+e^- collider running at tau-charm (2-5 GeV) region

BESIII data sets

- World's largest data samples in tau-charm region
- 10 billion J/ψ, 2.7 billion $\psi(3686)$, 20 fb^{-1} $\psi(3770)$ on threshold and >20 fb^{-1} beyond 4 GeV



- Charmonium
- XYZs
- Charm physics
- Light hadron
- Tau physics
- New physics

BESIII New Physics Workshops

• 2015.3	南京大学 (NJU)		19人
• 2015.12	中国科学技术大学 (USTC)		22人
• 2016.4	南京大学 (NJU)		24人
• 2016.12	北京大学 (PKU)		52人
• 2017.9	中国科学院大学 (UCAS)		33人
• 2018.10	南华大学 (USC)		35人
• 2019.5	中国科学技术大学 (USTC)		52人
• 2020.10	南开大学 (NKU)		34人
• 2021.11	山东大学 (SDU)	online	69人
• 2023.11	武汉大学 (WHU)		65人
• 2024.9	国科大杭高院 (HIAS, UCAS)		**80人**

Physics projects

Rare/forbidden decays

- BNV/LNV processes
- cLFV processes
- FCNC processes
- SM weak decays
- Other rare decays

- Data sets
- Experimental methods
- Statistical tools

Exotic phenomena

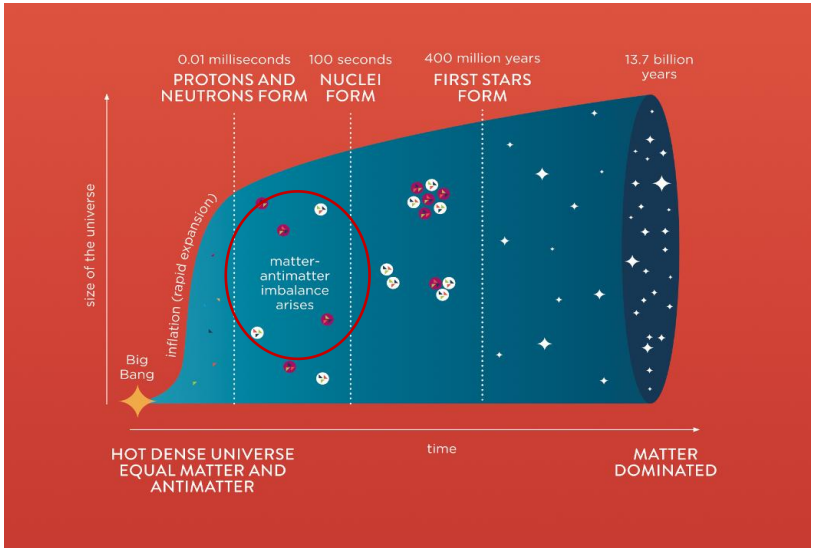
- Invisible/visible decays
- Dark photon
- Light Higgs, Z′
- Axion-like particle

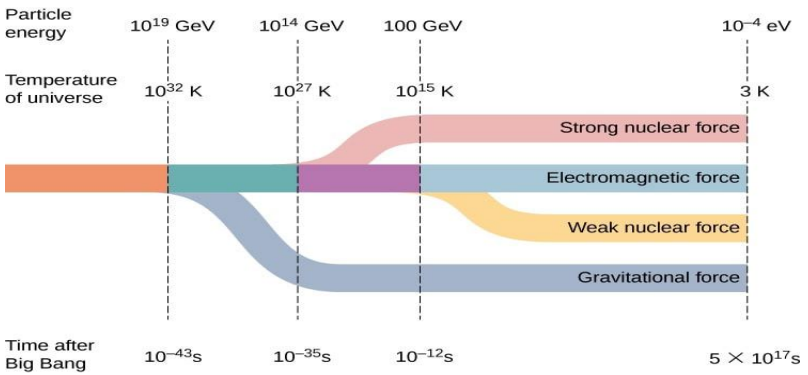
- New Physics Searches at the BESIII Experiment, S. J. Chen and S. Olsen, Nation Science Review 8, nwab189 (2021), arXiv: 2102.13290
- New Physics Program of BES, D. Y. Wang, in “30 Years of BES Physics”

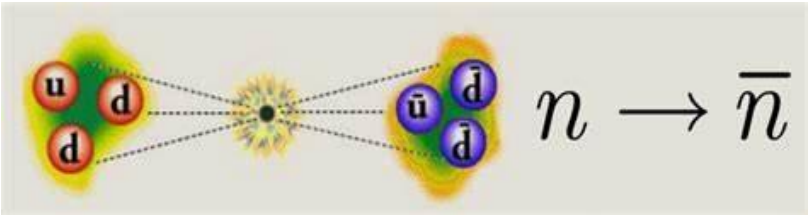
Symmetry violation

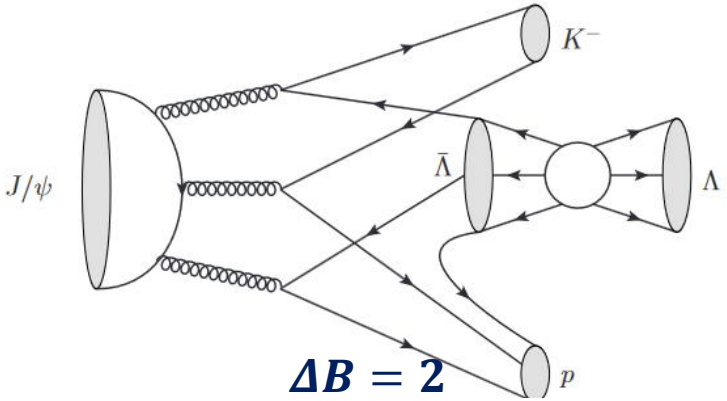
See Xiqing Hao's talk

Baryon number violation

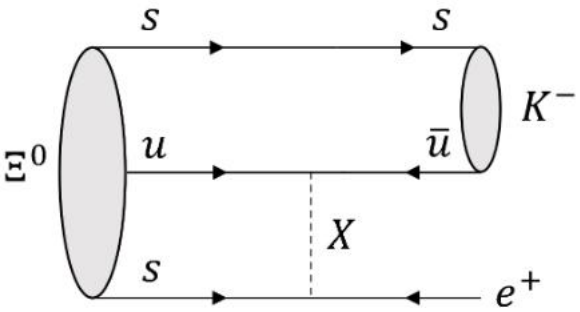




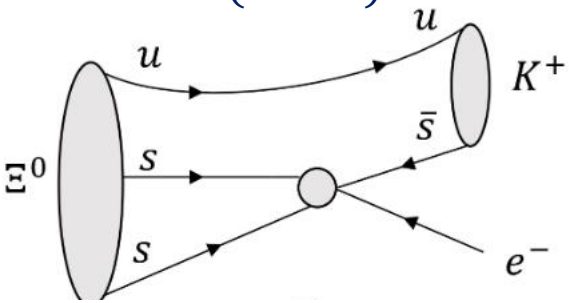




$\boldsymbol{\Delta B = 2}$



$\boldsymbol{\Delta(B - L) = 0}$



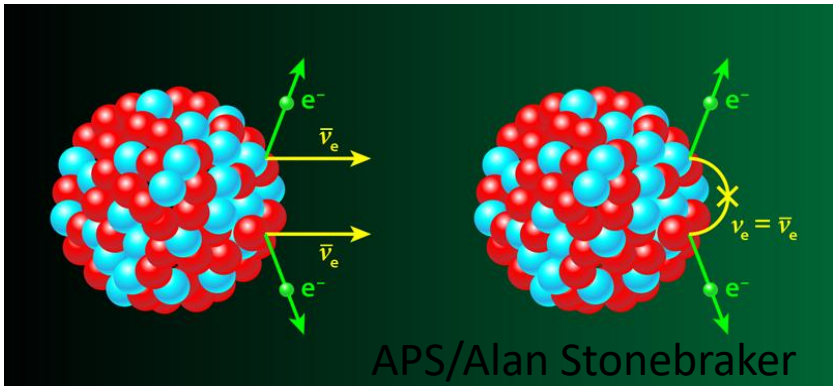
$\boldsymbol{\Delta(B - L) = 2}$

Baryon number violation

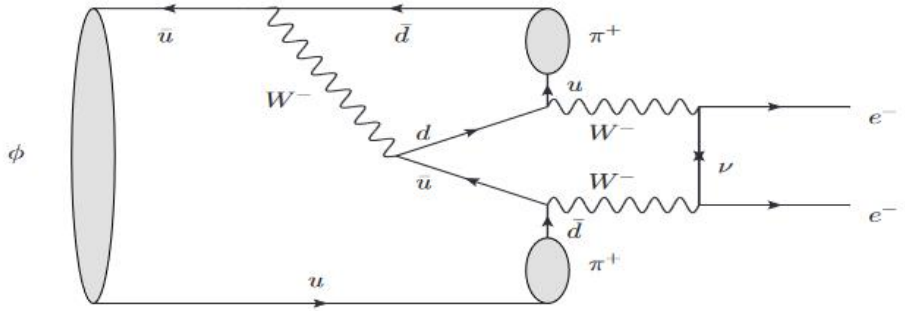
Search for J/ψ → Λc+e- + c.c.	Phys. Rev. D 99, 072006(2019)
Search for D+ → Λ/Σe+ and D+ → Λ/Σe+	Phys. Rev. D 101, 031102(2020)
Search for BNV and LNV decay D0 → pe	Phys. Rev. D 105, 032006 (2022)
Search for D+ → ne+ and D- → ne-	Phys. Rev. D 106, 112009 (2022)
Search for ΛΛ oscillation via J/ψ → pK-Λ	Phys. Rev. Lett. 131, 121801 (2023)
Search for BNV and LNV decays of Ξ0 → K+e-/K-e+	Phys. Rev. D 108, 012006 (2023)

See Tengjiao Wang's talk

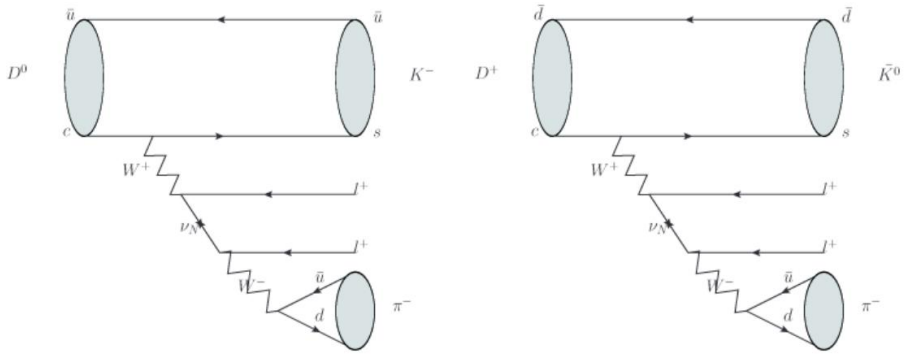
Lepton number violation



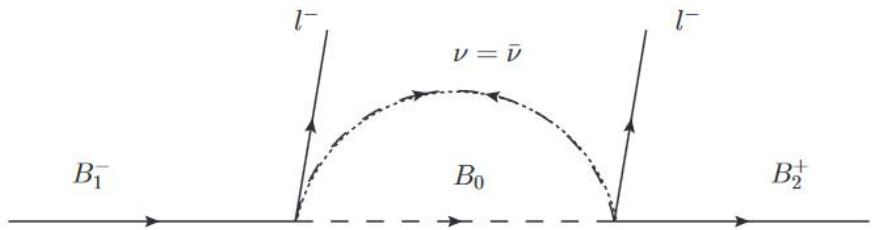
$0\upsilon2\beta$ Majorana neutrino?



Light meson



Charm meson



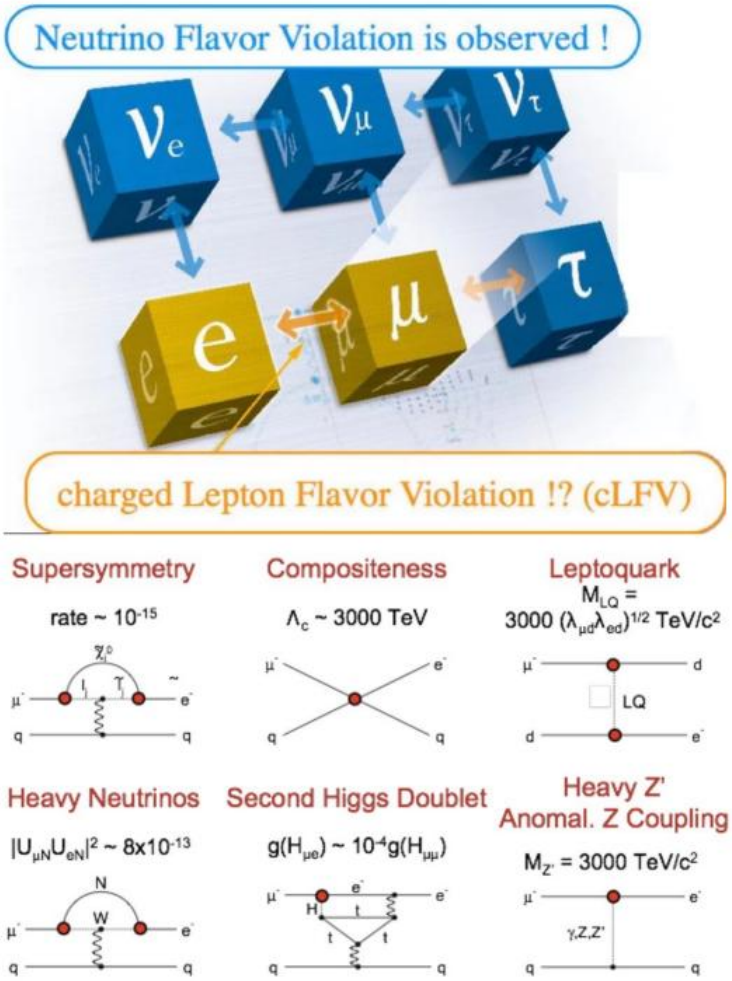
Baryon

Lepton number violation

Search for D0 → K-π-e+e+ and D+ → Kπe+e+	Phys. Rev. D 99, 112002(2019)
Search for Σ- → pe-e-	Phys. Rev. D 103, 052011(2021)
Search for LNV process phi→PiPie-e- via J/ψ→etaphi	arXiv:2308.05490

See Mingkuan Yuan's talk

Charged lepton flavour violation



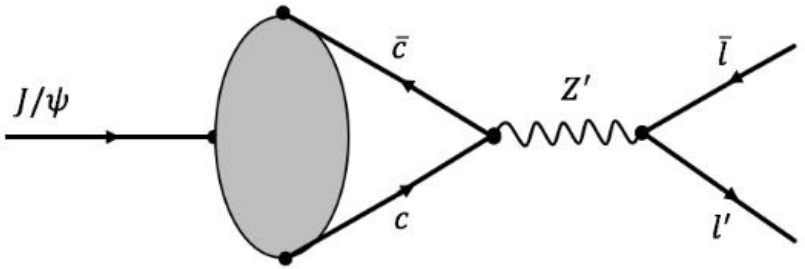
- BFs with NP are set to be

$10^{-16}\sim10^{-9}$ for J/$\psi \to e\mu$

$10^{-10}\sim10^{-8}$ for J/$\psi \to e\tau(\mu\tau)$

- model-independent indirect constraints [1, 2]
- rotating mass matrix [3]
- unparticle physics [4]
- effective Lagrangian [5]
- MSSM with gauged baryon and lepton number [6]

[1] X. M. Zhang et al, Phys. Rev. D 63, 016003 (2000)
[2] T. Gutche et al, Phys. Rev. D 83, 115015 (2011)
[3] J. Bordes and H. M. Chan, Phys. Rev. D 63, 016006 (2000)
[4] K. S. Sun et al, Mod. Phys. Lett. A 27, 1250172 (2012)
[5] D. E. Hazard and A. A. Petrov, Phys. Rev. D 94, 074023 (2016)
[6] X. X. Dong et al, Phys. Rev. D 97, 056027 (2018)



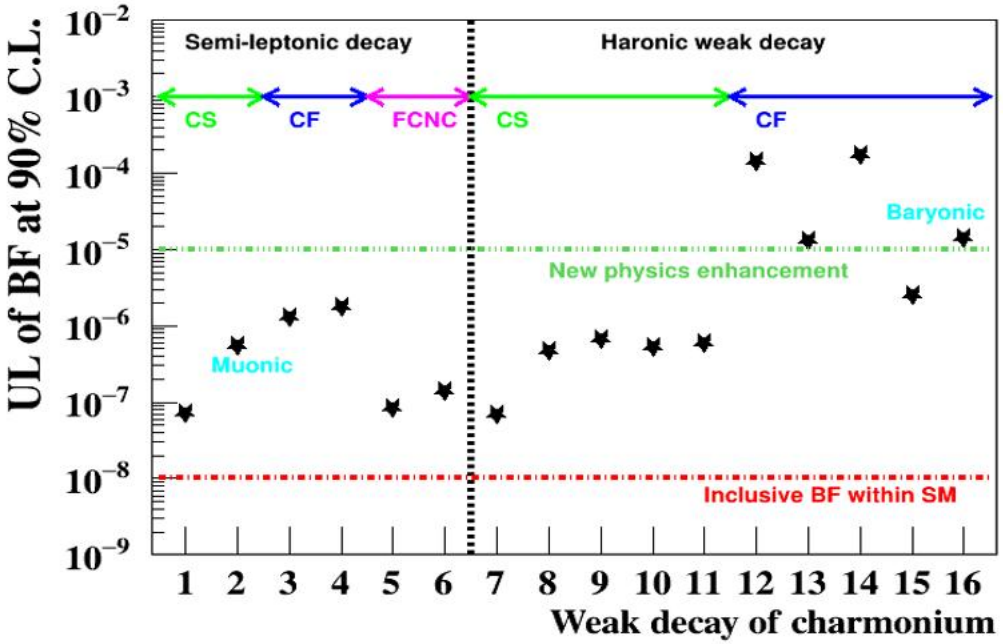
Charged lepton flavour violation

Search for the lepton flavor violation process $J/\psi \rightarrow e\mu$	Phys. Rev. D87, 112007(2013)
Search for the charged lepton flavor violating decay $J/\psi \rightarrow e\tau$	Phys. Rev. D 103, 112007 (2021)
Search for $J/\psi \rightarrow e\mu$	Sci. China-Phys. Mech. Astron. 66, 221011 (2023)

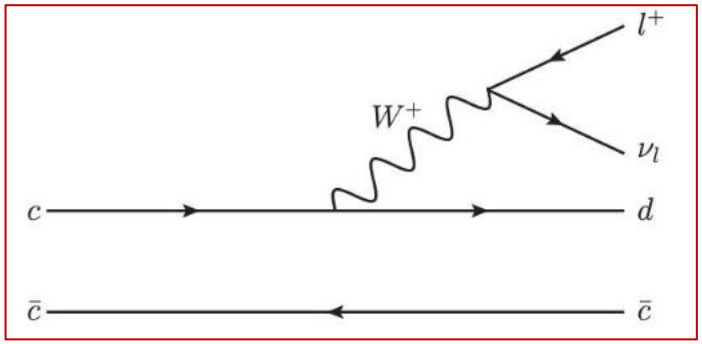
Rare decays

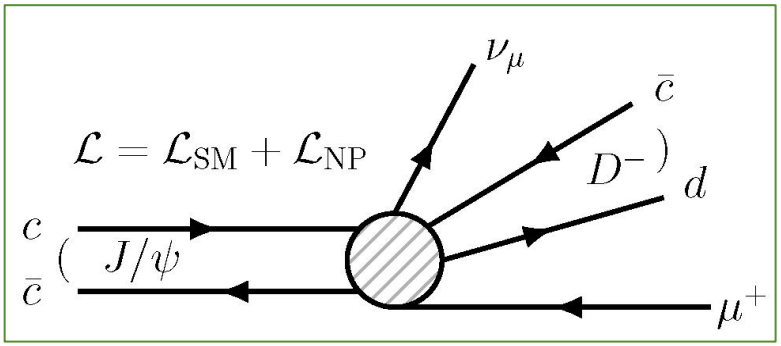
See Yonghua Zhan's talk

Charmonium weak decays



1: $J/\psi \to D^- e^+ \nu_e$+c.c.
2: $J/\psi \to D^- \mu^+ \nu_\mu$+c.c.
3: $J/\psi \to D_s^- e^+ \nu_e$+c.c.
4: $J/\psi \to D_s^{*-} e^+ \nu_e$+c.c.
5: $J/\psi \to D^0 e^+ e^-$+c.c.
6: $\psi(2S) \to D^0 e^+ e^-$+c.c.
7: $J/\psi \to D^- \pi^+$+c.c.
8: $J/\psi \to D^0 \pi^0$+c.c.
9: $J/\psi \to D^0 \eta$+c.c.
10: $J/\psi \to D^0 \rho^0$+c.c.
11: $J/\psi \to D^- \rho^+$+c.c.
12: $J/\psi \to D_s^- \pi^+$+c.c.
13: $J/\psi \to D_s^- \rho^+$+c.c.
14: $J/\psi \to D^0 K^0$+c.c.
15: $J/\psi \to D^0 K^{*0}$+c.c.
16: $\psi(2S) \to \Lambda_c^+ \bar{\Sigma}^-$+c.c.



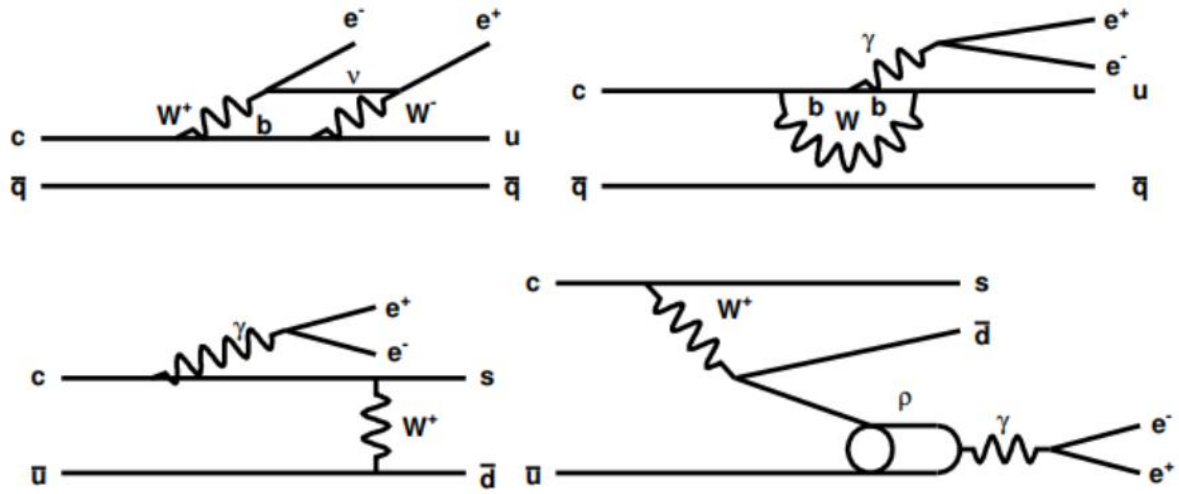


Charmonium weak decays

Search for the rare decays J/ψ → Ds-ρ+ and J/ψ → D0K*0	Phys. Rev. D 89, 071101(2014)
Search for the weak decays J/ψ → Ds(*)-e+νe+c.c	Phys. Rev. D 90, 112014(2014)
Search for the rare decay J/ψ→ D-e+νe	JHEP157(2021)
Search for the Rare Decay ψ(2s) → Λc+ anti-Σ-	Chinese Phys. C 47 013002 (2023)
Search for the semi-muonic charmonium decay J/ψ → D+μ-νμ	JHEP 01 126 (2024)
Search for J/psi weak decays containing D meson	Phys. Rev. D 110, 032020 (2024)

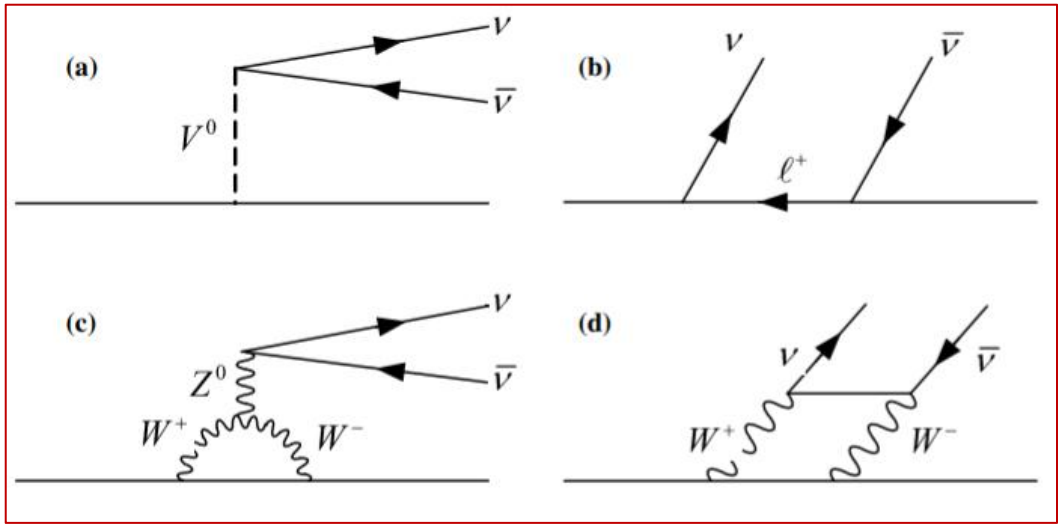
See Liang Sun's talk

FCNC processes



短程贡献~10^{-9}

长程贡献主导



长程贡献压低
与短程贡献相
当~10^{-13}

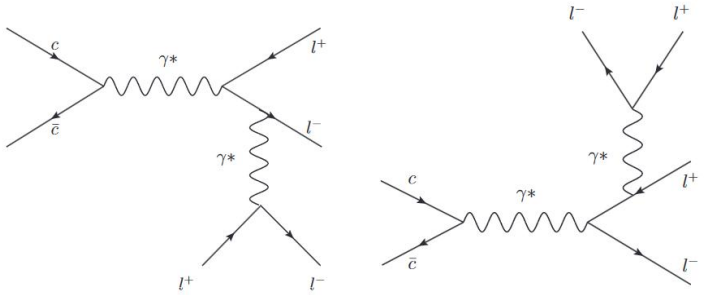
FCNC processes

Search for the rare decays J/ψ → D0e+e- + c.c. and ψ(3686) → D0e+e- + c.c.	Phys. Rev. D 96, 111101(2017)
Search for the rare decays D → h(h(′))e+e-	Phys. Rev. D 97, 072015(2018)
Search for the rare decays of ψ(3686) → Λc+pe+e-	Phys. Rev. D 97, 091102(2018)
Search for the FCNC process D0→ Pi0νν	Phys. Rev. D 105, L071102 (2022)
Searching for D_S+ → h(h′)e+e-	arxiv:2404.05973
Search for J/ψ → γD	arxiv:2408.08826

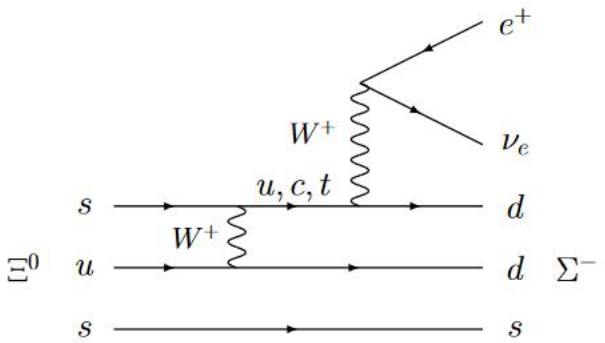
See Luyan Tao's talk

Other rare decays

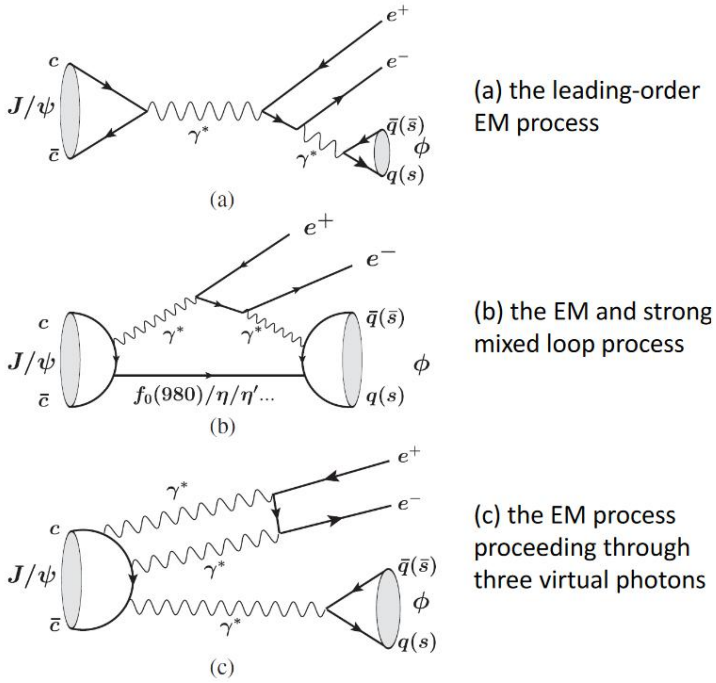
J/ψ 纯轻衰变 10^{-7}~10^{-5}



超子半轻衰变 $\Delta S = \Delta Q$压低



J/ψ 电磁衰变 10^{-8}~10^{-11}



(a) the leading-order EM process

(b) the EM and strong mixed loop process

(c) the EM process proceeding through three virtual photons

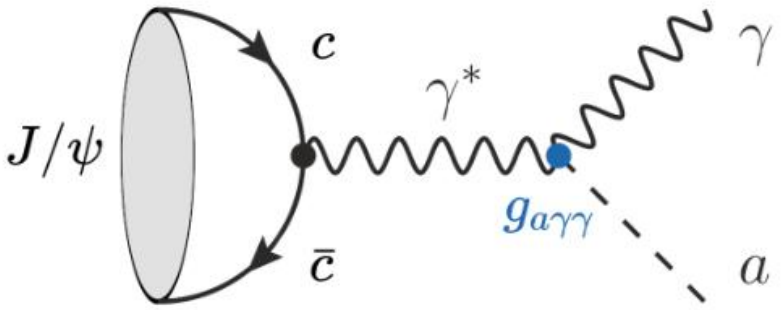
Other rare decays

Search for J/ψ → ϕe+e- via ψ'→ π+π+J/ψ	Phys. Rev. D 99, 052010(2019)
Study of EM Dalitz Decay ψ(3686) → e+e- ηc	Phys. Rev. D 106, 112002 (2022)
Search for hyperon ΔS=ΔQ violating decay Ξ0 → Σev	Phys. Rev. D 107, 012002 (2023)
Measurement of J/ψ → 4 leptons via ψ'→ π+π-J/ψ	Phys. Rev. D 109 (2024) 052006
Search for ΔS=2 nonleptonic hyperon decays Ω−→Σ0Pi-, nK-	JHEP 05 141 (2024)

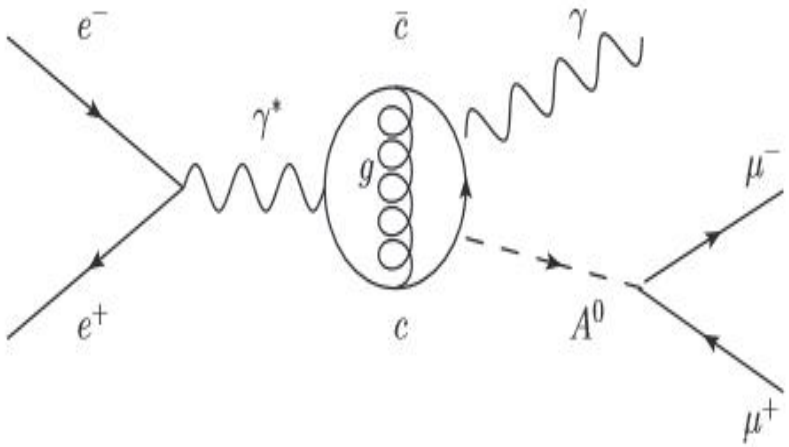
Exotic processes

See Zhijun Li&Xiaoxuan Ding's talk

Visible decays



- Axion-like particles
  - $J/\psi \to \gamma a(\to \gamma\gamma)$
- Light Higgs boson
  - $J/\psi \to \gamma A^0(\to l^+l^-)$
- Dark photon
  - $J/\psi \to P\gamma'(\to l^+l^-)$,
  - ISR process $l^+l^- \to \gamma\gamma'(\to l^+l^-)$



- Search for resonances with the photon/lepton pair spectrum

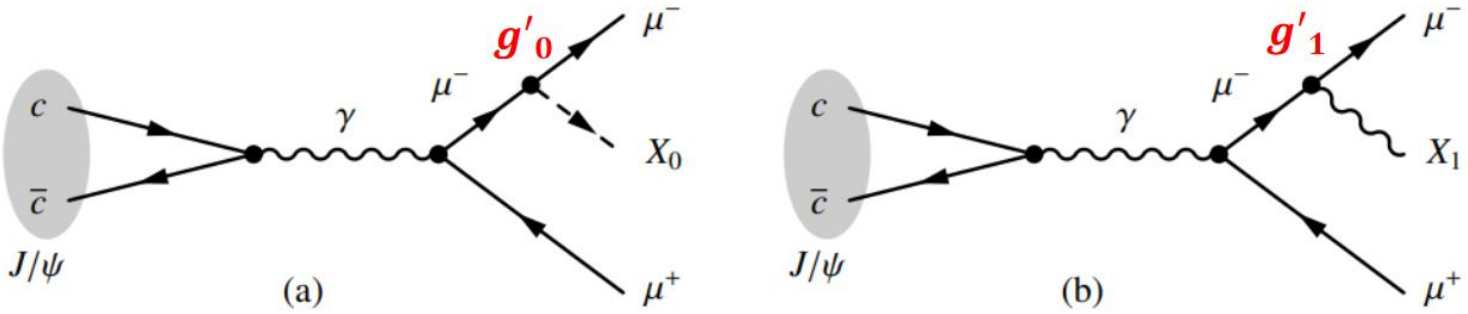
Visible decays

Search for a light CP-odd Higgs boson in radiative decays of J/ψ	Phys. Rev. D 93, 052005 (2016)
Dark photon search in the mass range between 1.5 and 3.4 GeV/c^2	Phys. Lett. B 774, 252 (2017)
Study of the Dalitz decay J/ψ → e+e-η and probing the dark photon	Phys. Rev. D 99, 012006 (2019)
Probe dark photon via J/ψ → η'e+e-	Phys. Rev. D 99, 012013 (2019)
Search for light Higgs A^0 in radiative decays of J/ψ	Phys. Rev. D 105, 012008 (2022)
Search for axion-like particles via J/ψ → aγ	Phys. Lett. B 838, 137698 (2023)
Search for an Axion-like particle with J/ψ data	Phys. Rev. D 110, L031101 (2024)

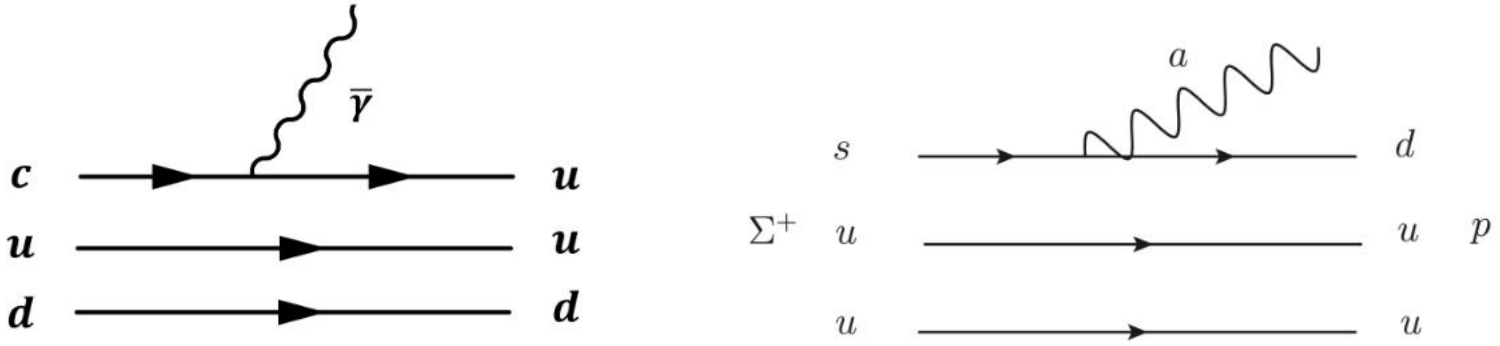
See Zhijun Li&Xiaoxuan Ding's talk

Invisible decays

Muonphilic scalar/vector



Dark photon, QCD axion, light Higgs boson



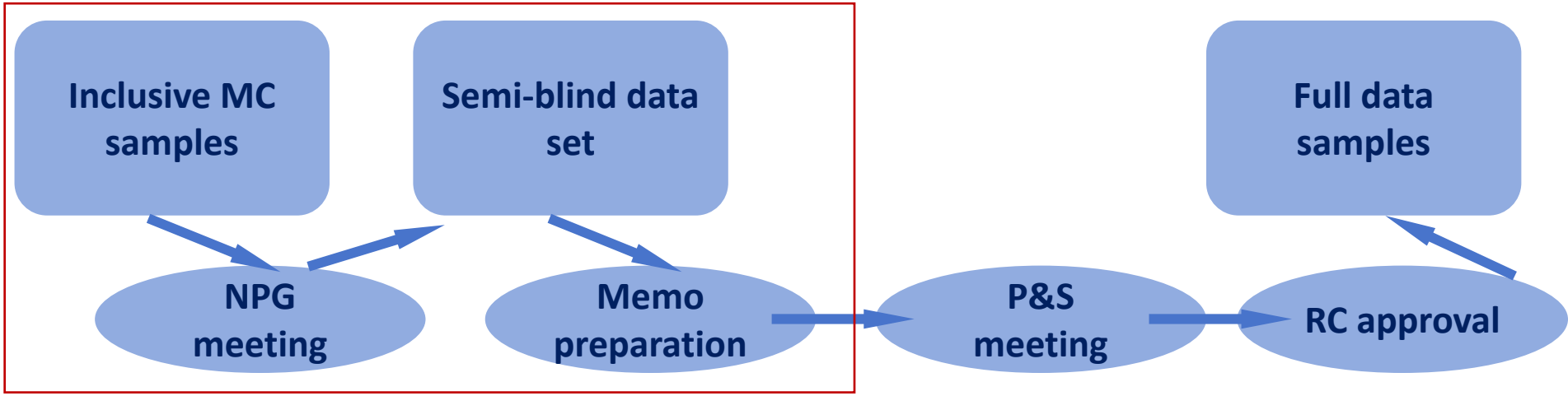
Invisible decays

Search for the invisible decays of V(=ω , ϕ) mesons in J/ψ → Vη decays	Phys. Rev. D 98, 032001 (2018)
Search for J/ψ → γ + invisible via ψ'→ π+π- J/ψ	Phys. Rev. D 101, 112005(2020)
Search for the invisible decay of Λ baryon	Phys. Rev. D 105, L071101 (2022)
Search for Λ_C → P+ invisible	Phys. Rev. D 106, 072008 (2022)
Search for invisible dark photon decays using initial state radiation	Phys. Lett. B 839, 137785 (2023)
Search for a muonphilic scalar X0 or vector X1 via J/ψ → mu+mu- + invisible decays	Phys. Rev. D 109, L031102 (2024)
Search for BSM particles via Sigma+ to p invisible	Phys. Lett. B 852 (2024) 138614

Analysis procedures and tools

Analaysis procedure

- Semi-blind analysis



The proponents of new physics analyses are required to follow the next steps to make the analysis and review run smoothly.

1. In the primary stage of all analyses, the **FULL** blind strategy is required. The authors should present the full blind results in the New Physics group meeting (usually take place bi-weekly). The analysis can proceed to analyse **SEMI**-blind data, as listed below on this page, with the approval of NP convenors during the meeting. Meanwhile the analysis strategy and event selections are determined.

2. The analysis and results based on semi-blind data should be presented in NP group meeting. With convenors' approval, the authors can prepare and circulate the Memo in NP group.

3. The Memo is usually reviewed by two of the convenors and then enter a 3-day MFR. Afterwards, the authors can proceed to apply for a P&S talk etc..

Analysis procedures *https://docbes3.ihep.ac.cn/~newphysgroup/index.php/Datasets*

- Semi-blind data sets
  - J/ψ, 10% of 10 Billion, ready
  - ψ(3686), 10% of 2.7 Billion, ready
  - ψ(3770),
    - 10% of 7.9 fb^{-1}, ready
    - 10% of 20 fb^{-1}, soon ready

Selected data samples of J/psi for "semi-blind" analysis.

data in 2009: 131 runs are selected, 23319.8 nb^-1 (by TwoGam process), roughly 30% of the 2009 data sample [131 runs of J/psi data in 2009]

data in 2012: 67 runs are selected, 31882.1 nb^-1 (by TwoGam process), roughly 10% of the 2012 data sample [67 runs of J/psi data in 2012]

data in round 11: 237 runs are selected, 125579 nb^-1 (by TwoGam process), roughly 10% of the 2018 data sample [237 runs of J/psi data in 2018]

data in round 12: 204 runs are selected, 119187 nb^-1 (by TwoGam process), roughly 10% of the 2019 data sample [204 runs of J/psi data in 2019]

Selected data samples of psi(2S) for "semi-blind" analysis.

data in 2009: 121 runs are selected, 48260.4 nb^-1 (by TwoGam process), roughly 30% of the 2009 data sample [121 runs of psi(2S) data in 2009]

data in 2012: 80 runs are selected, 48937.4 nb^-1 (by TwoGam process), roughly 10% of the 2012 data sample [80 runs of psi(2S) data in 2012]

data in 2021: 276 runs are selected, 387856 nb^-1 (by TwoGam process), roughly 10% of the 2021 data sample [276 runs of psi(2S) data in 2021]

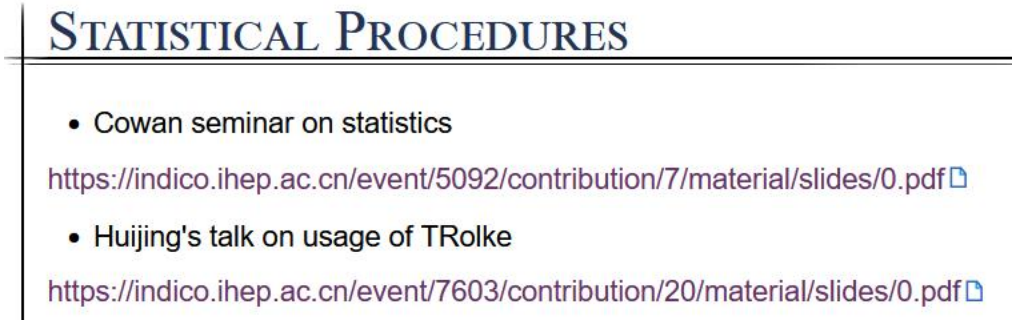
Psi(3770) data for semi-blind analysis

- Dst list for Round03-04 data File:Dstlist 3773semidata 10-11.txt, run info of the filtered Round03 data File:SelectedRound03-1.txt and File:SelectedRound03-2.txt, run info of the filtered Round04 data File:SelectedRound04.txt
- Dst list for Round15 data File:Dstlist 3773semidata 22.txt, run info of the filtered Round015 data File:SelectedRound15.txt

https://docbes3.ihep.ac.cn/~newphysgroup/index.php/Datasets

Statistical tools

https://docbes3.ihep.ac.cn/~newphysgroup/index.php/Statistical_Procedures



STATISTICAL PROCEDURES

- Cowan seminar on statistics

https://indico.ihep.ac.cn/event/5092/contribution/7/material/slides/0.pdf

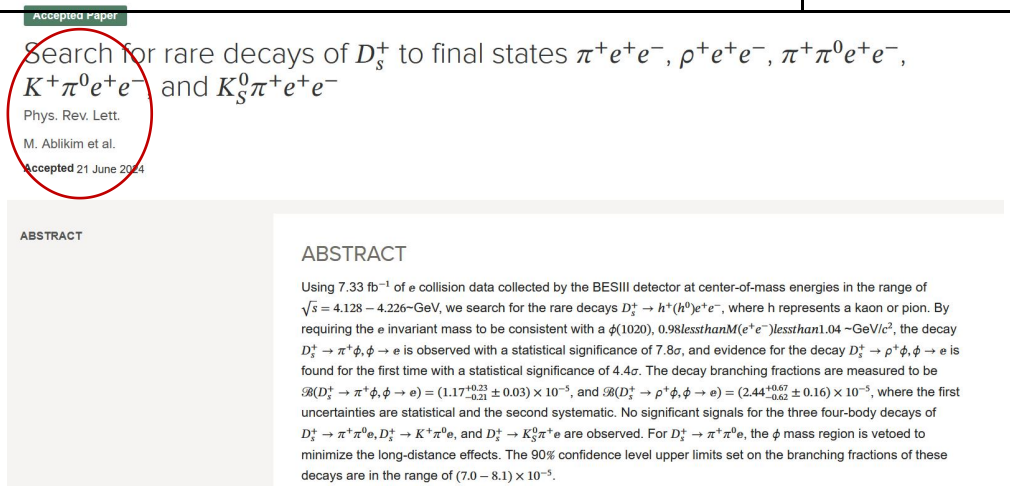
- Huijing's talk on usage of TRolke

https://indico.ihep.ac.cn/event/7603/contribution/20/material/slides/0.pdf

- FOM to optimize event selection requirements
- “Data driven” method
- Meachine learning
- Likelihood functions
- Upper limit and signal significance
- Systematic uncertainties

Publications

Search for the semi-muonic charmonium decay J/ψ→D+μ-νμ	JHEP 01 126 (2024)
Search for J/psi weak decays containing D meson	Phys. Rev. D 110, 032020 (2024)
Search for ΔS=2 nonleptonic hyperon decays Ω−→Σ0Pi-, nK-	JHEP 05 141 (2024)
Search for a muonphilic scalar X0 or vector X1 via J/ψ → mu+mu- + invisible decays	Phys. Rev. D 109, L031102 (2024)
Search for BSM particles via Sigma+ to p invisible	Phys. Lett. B 852 (2024) 138614
Search for an Axion-like particle with J/ψ data	Phys. Rev. D 110, L031101 (2024)
Measurement of J/ψ → 4lepton via ψ'→ π+π-J/ψ	Phys. Rev. D 109 (2024) 052006
Searching for DS+ → h(h')e+e-	arxiv:2404.05973
Search for J/ψ → γD	arxiv:2408.08826
Search for LNV process phi→PiPie-e- via J/ψ→etaphi	arXiv:2308.05490


Accepted Paper

Search for rare decays of D_s^+ to final states $\pi^+e^+e^-$, $\rho^+e^+e^-$, $\pi^+\pi^0e^+e^-$, $K^+\pi^0e^+e^-$, and $K_S^0\pi^+e^+e^-$

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ABSTRACT

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Using 7.33 fb^{-1} of e collision data collected by the BESIII detector at center-of-mass energies in the range of $\sqrt{s} = 4.128 - 4.226$−GeV, we search for the rare decays $D_s^+ \to h^+(h^0)e^+e^-$, where h represents a kaon or pion. By requiring the e invariant mass to be consistent with a $\phi(1020)$, $0.98 less than M(e^+e^-) less than 1.04$ ~GeV/c^2, the decay $D_s^+ \to \pi^+\phi, \phi \to e$ is observed with a statistical significance of 7.8σ, and evidence for the decay $D_s^+ \to \rho^+\phi, \phi \to e$ is found for the first time with a statistical significance of 4.4σ. The decay branching fractions are measured to be $\mathcal{B}(D_s^+ \to \pi^+\phi, \phi \to e) = (1.17^{+0.23}_{-0.21} \pm 0.03) \times 10^{-5}$, and $\mathcal{B}(D_s^+ \to \rho^+\phi, \phi \to e) = (2.44^{+0.67}_{-0.62} \pm 0.16) \times 10^{-5}$, where the first uncertainties are statistical and the second systematic. No significant signals for the three four-body decays of $D_s^+ \to \pi^+\pi^0e$, $D_s^+ \to K^+\pi^0e$, and $D_s^+ \to K_S^0\pi^+e$ are observed. For $D_s^+ \to \pi^+\pi^0e$, the ϕ mass region is vetoed to minimize the long-distance effects. The 90% confidence level upper limits set on the branching fractions of these decays are in the range of $(7.0 - 8.1) \times 10^{-5}$.

- 7(published)+1(accepted)+2(submitted) till August in 2024
- List of publications (48)
- Active analyses (~70)

Summary

- BESIII has a good potential to search for various NP effects
  - Unique data sets and analysis techniques
  - Competitive outputs
  - Complementary to other experiments
- NPGers have been productive over the year, more results will come soon
- Collaboration with theorists are highly desired
  - Two sessions tomorrow

BESIII NPG convenors

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