Overview of New Physics Searches at BESIII

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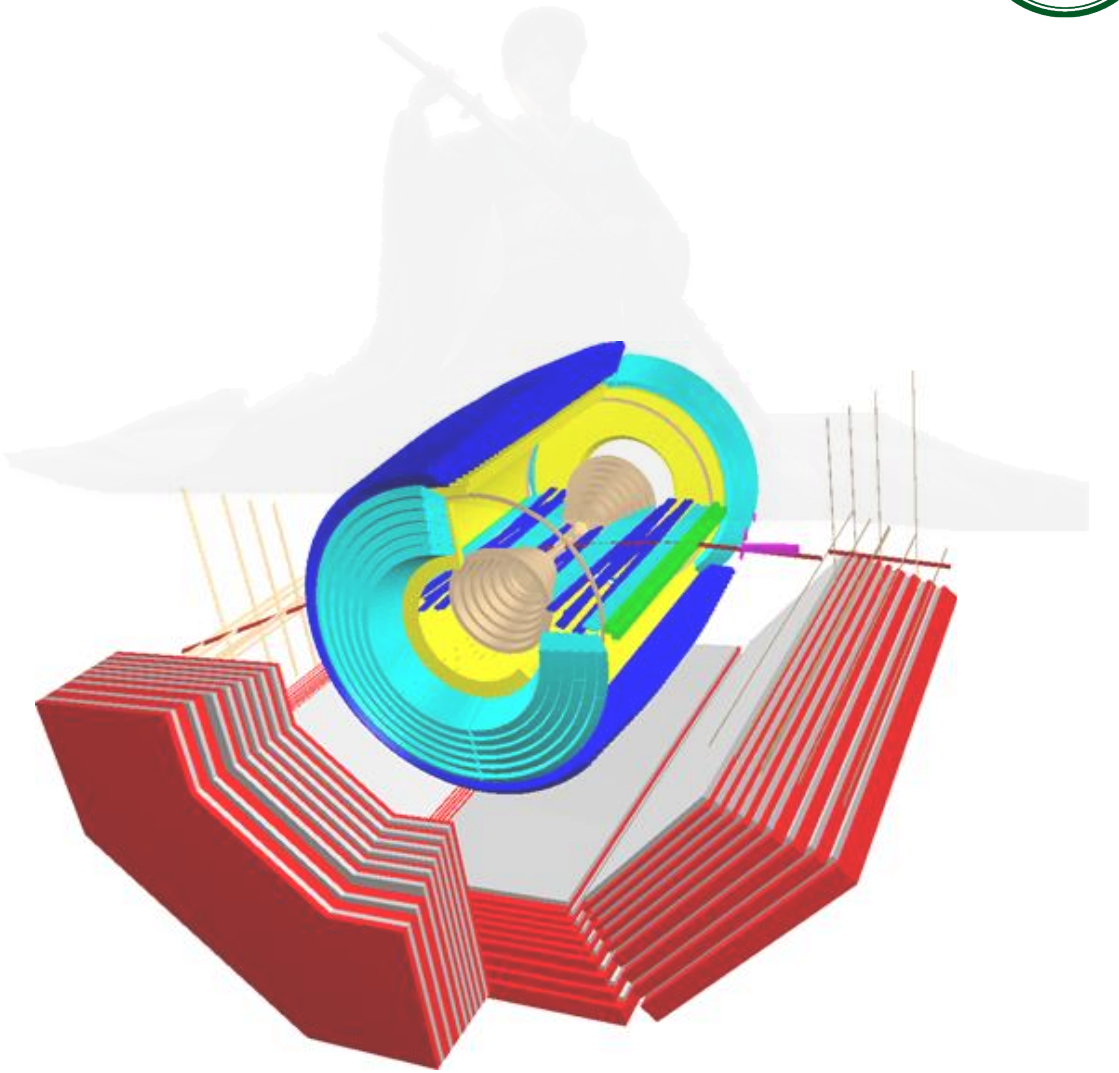
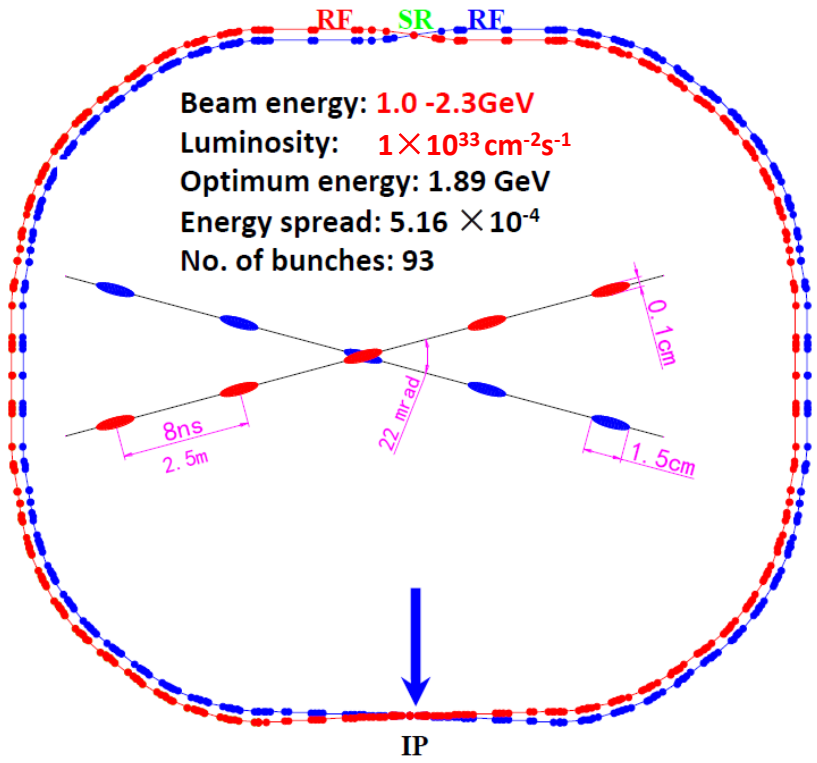
Outline

- BEPCII & BESIII
- Overview of BESIII physics & data
- New physics searches at BESIII
  - Symmetry violation
  - Rare decays
  - Exotics
- Publications
- Summary



BEPCII and BESIII

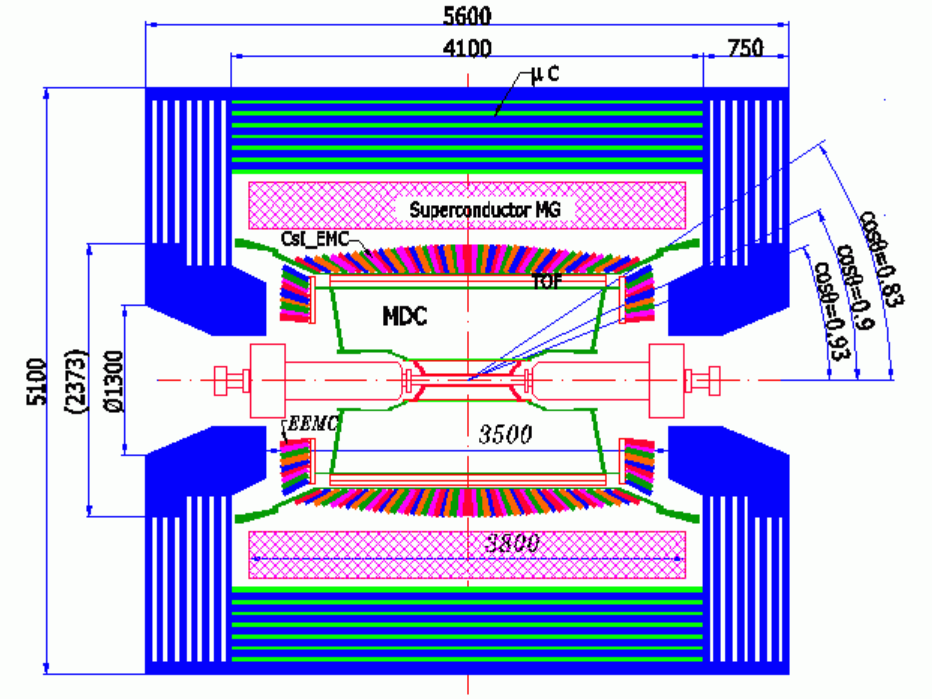
Beijing Electron Positron Collider II



BESIII Detector

Multi-layer Drift Chamber (MDC):
Δp/p =0.5% @ 1GeV/c dE/dx: ~ 6%

Time of Flight (TOF):
σT=68 (60) ps barrel (endcap)

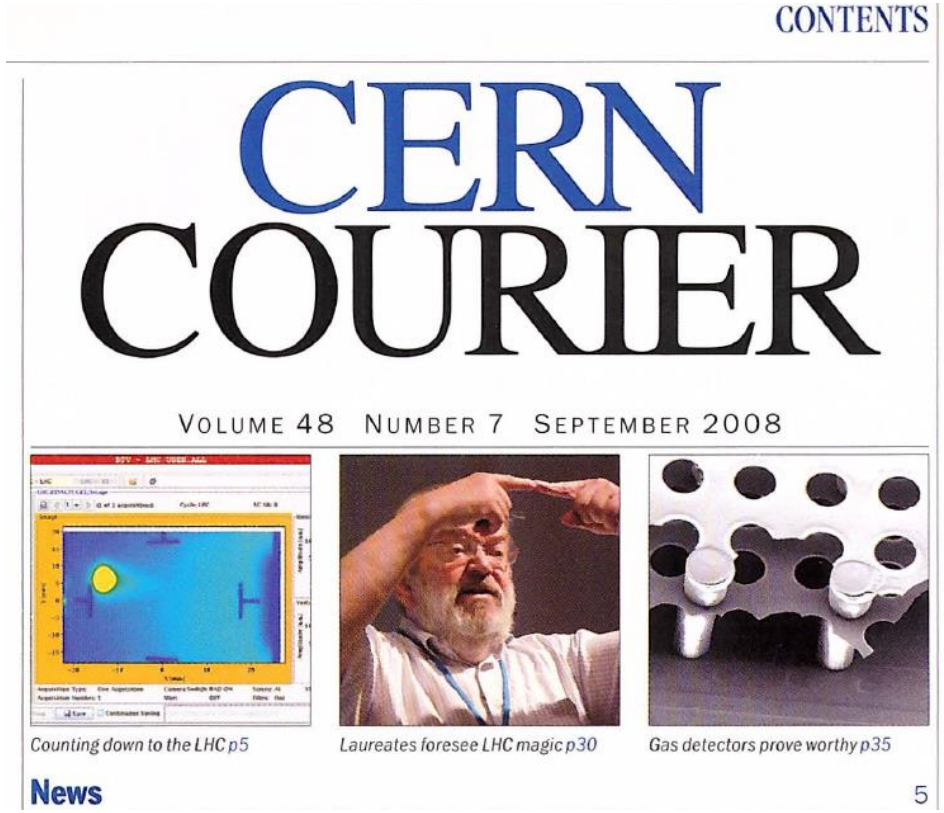


ElectroMagnetic Calorimeter (EMC):
CsI (Tl) 2.5% (5.0%) barrel (endcap) @ 1GeV

Muon Chamber (MUC):
RPC 9 (8) layers barrel (endcap)

BESIII Data Taking

- Successful running for 15 years since 2008
- Thanks to BEPC II, BESIII shifters, hardware, software & computing colleagues



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Gas detectors prove worthy p35

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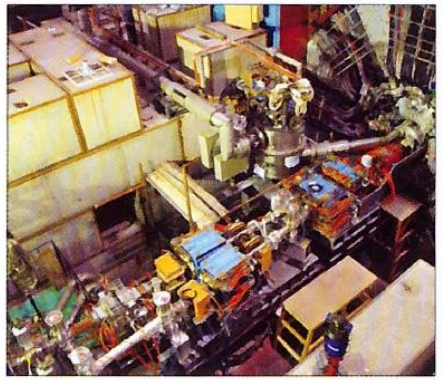
COLLIDERS

BEPC II celebrates the first collision events

Champagne-bottle corks popped early on the morning of 20 July, as researchers at the Institute of High Energy Physics (IHEP) in Beijing celebrated the observation of the first particle collisions in the upgraded Beijing Electron Positron Collider (BEPC II) and the new Beijing Spectrometer, BES III. Although BEPC II and BE III had already been carefully tested separately, this was the first time that they had operated together.

The first collisions, occurring late the previous afternoon, represent a new milestone for the project, which was nearly four years in planning and took another four and half years to construct. When fully operational, the BEPC II/BES III complex will be the world's premier facility for studying properties of charmed mesons and τ leptons.

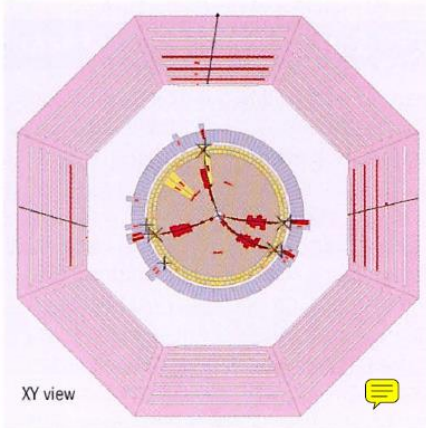
BEPC II is a major upgrade of IHEP's previous e^+e^- collider, BEPC. The major change has been the addition of a second ring of magnets that allows the electron and



The BES III detector in the interaction region of BEPC II. (Courtesy BES III/IHEP.)

final focusing of the stored beams as they enter the interaction region.

The linac upgrade was finished in late 2004 and quickly reached its design goals. With the exception of the conventional focusing magnets in the interaction region,



The first candidate charmed-meson pair event seen in BES III. The red slashes straddling some portions of the tracks indicate wire hits in small-angle-stereo layers. The yellow boxes are time-of-flight counters and the blue trapezoids indicate caesium iodide crystals in the barrel. The outer layers show muon chambers in the magnet yoke.

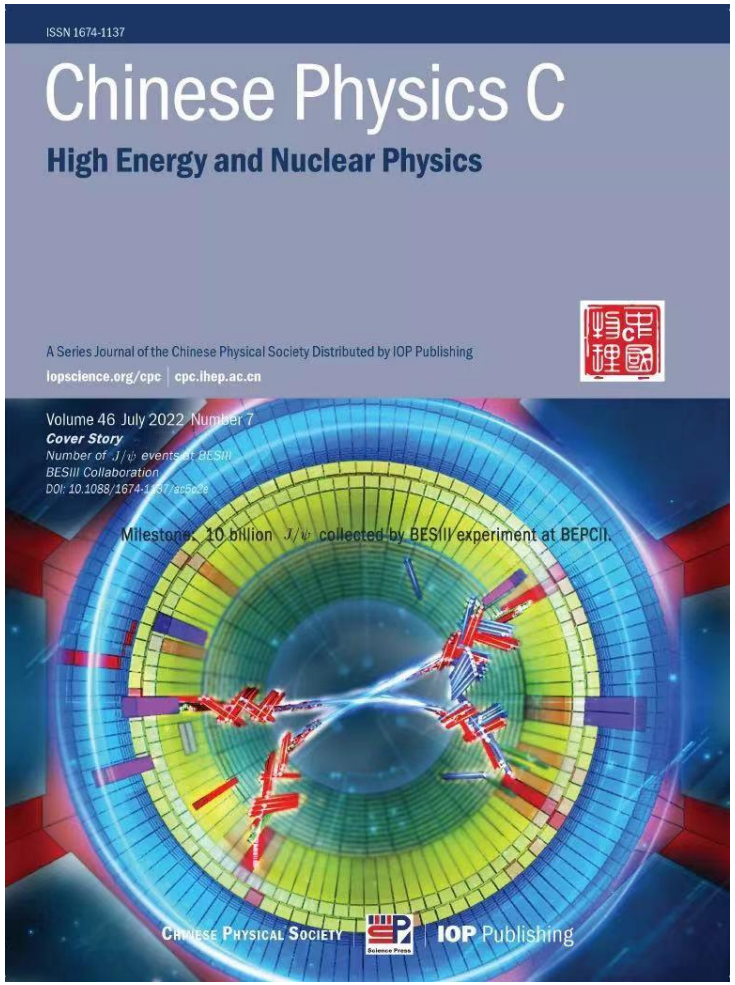
BESIII Physics Data

Physics of BESIII

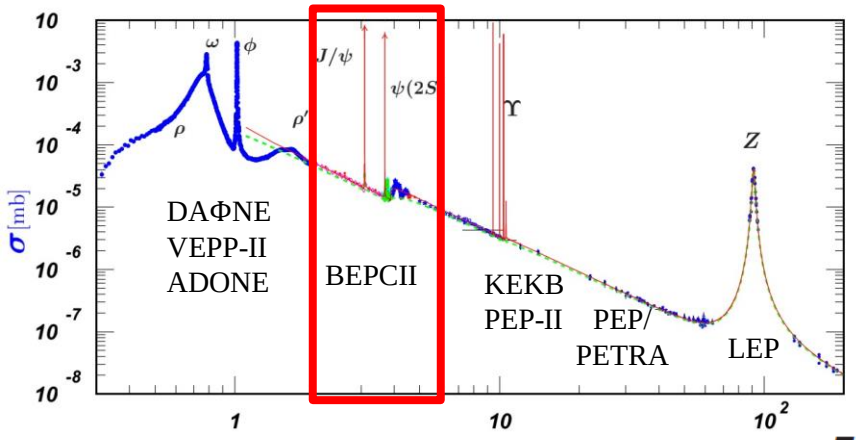
NSR 8 (11) 2021

10 Billion J/ψ collected by BESIII

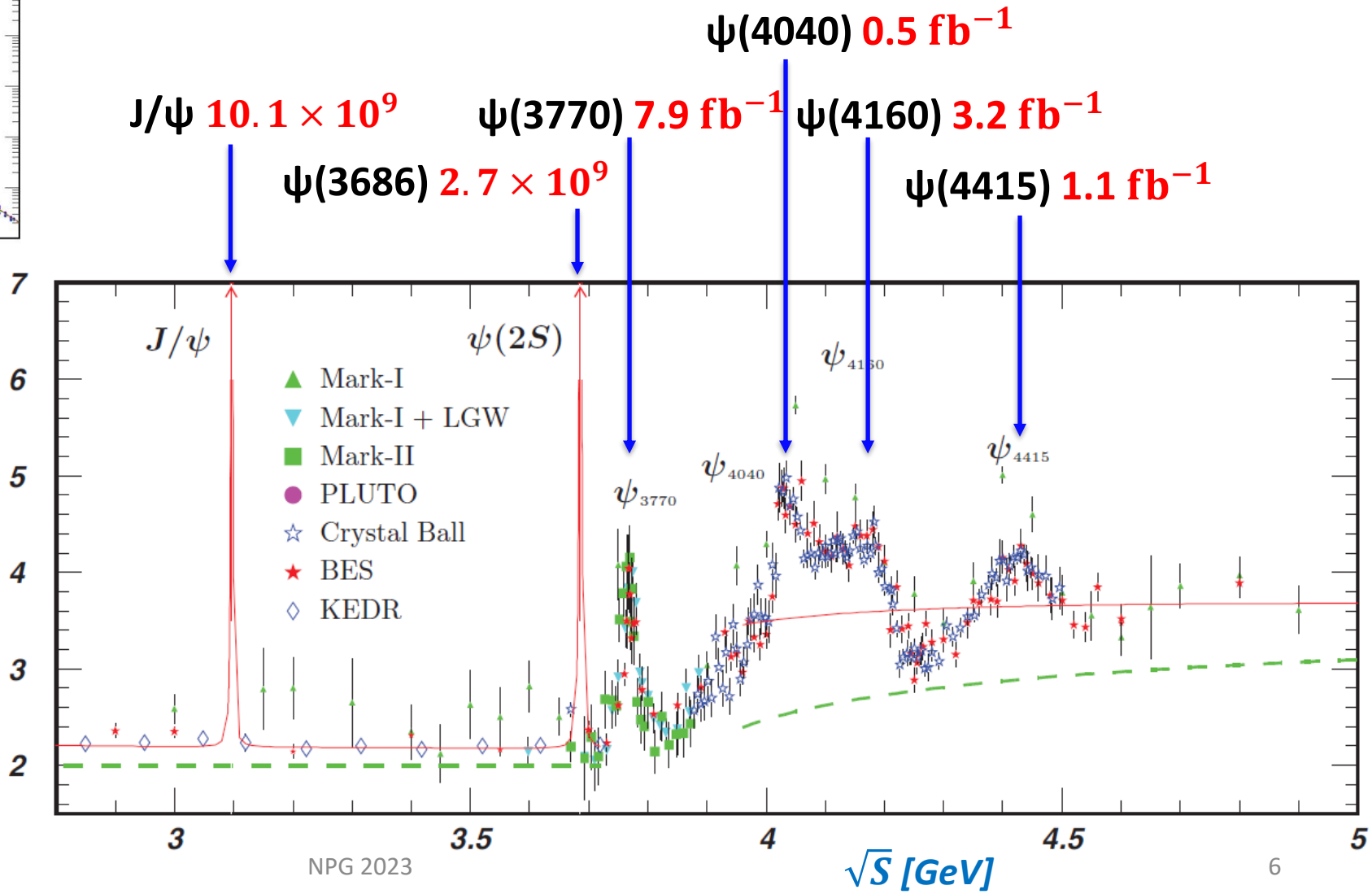
CPC 46 074001 (2022)



Charmonium Data at BESIII



- BESIII has collected the largest J/ψ, $\psi(3686)$ data samples on threshold
- > 20 fb^{-1} above 4.0 GeV in total
- 20 fb^{-1} $\psi(3770)$ expected until 2024



BESIII Physics

Light hadrons
$\eta, \eta', f, a,$
hyperon,
glueball,
hybrid

Charmonium
$J/\psi, \psi', \eta_c, \chi_c$
Transitions,
XYZ particles,
Tetraquark

Charm
D, D_s, Λ_c
CKM matrix,
Decay constants,
Charm rare decays

τ & QCD
τ mass, LFU
R value,
Transitions,
Baryon form factor

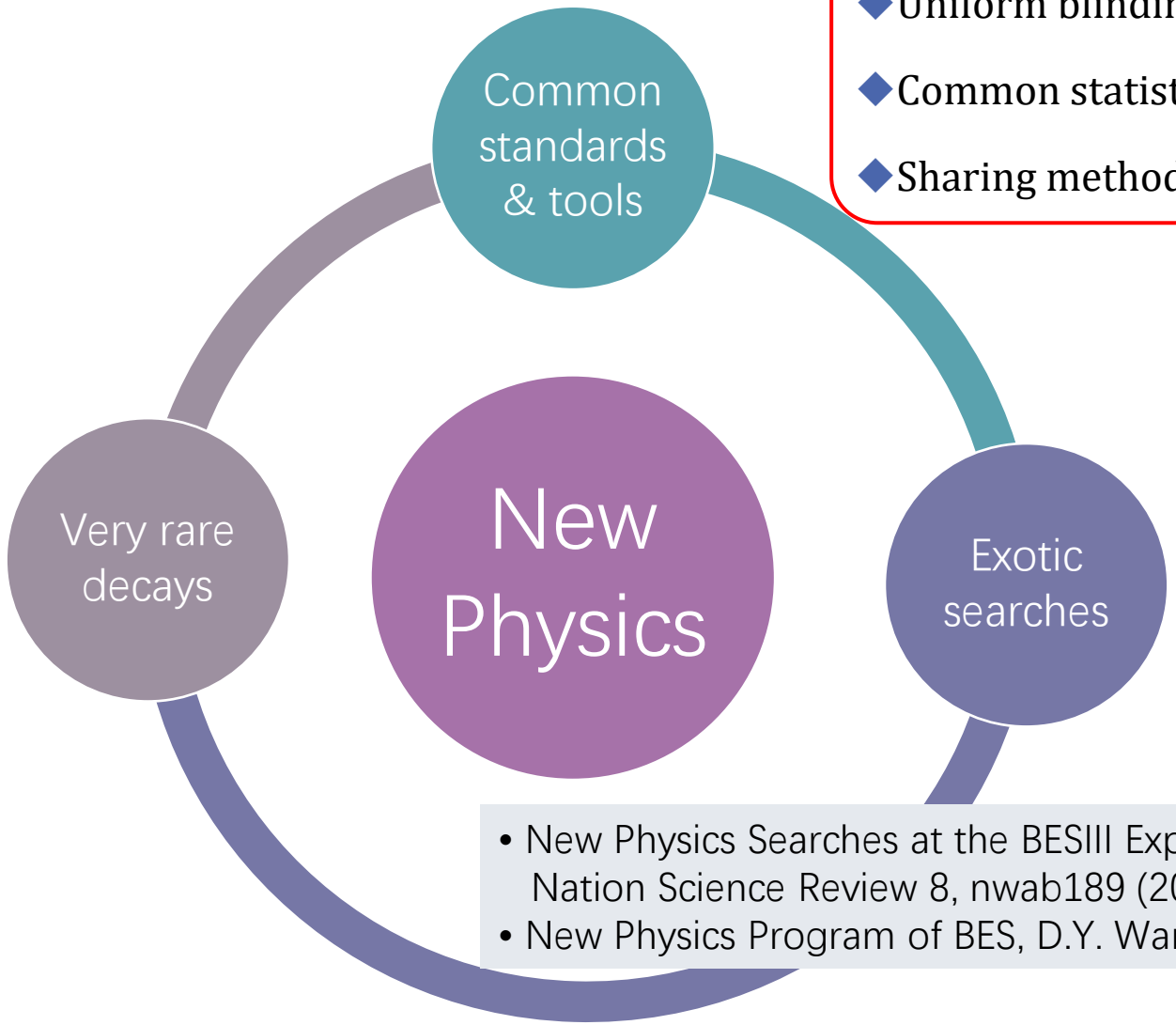
New Physics
Symmetry violation,
Rare decays,
Invisible decays,
Exotics

Timeline of BESIII New Physics Workshop

- 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 （线上,69）
- 2023.11 武汉大学 WHU 65人

- **Joint discussion between theorists and BESIII collaborators**
- **Discussion with other experiment collaborators**

New Physics Searches at BESIII



- Uniform blinding strategy and datasets
- Common statistic and standards
- Sharing methods, tools and codes

Symmetry

- BNV & LNV processes
- LFV processes
- Other symmetry violation

- FCNC processes
- Charmonium weak decays
- Other rare decays

Very rare

Exotic

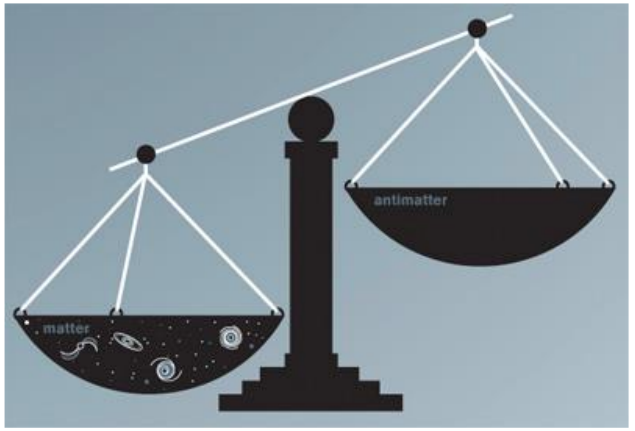
- Dark photon
- Invisible signatures
- Light Higgs, Z'
- Exotic resonances

- 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"

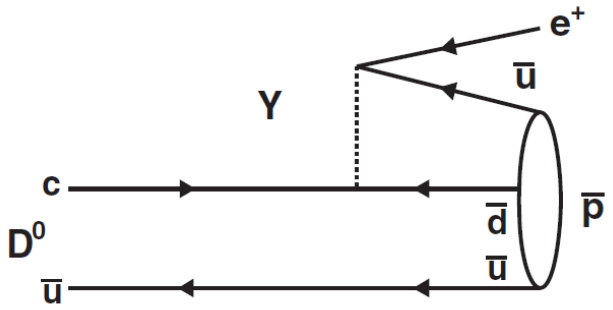
Symmetry Violation

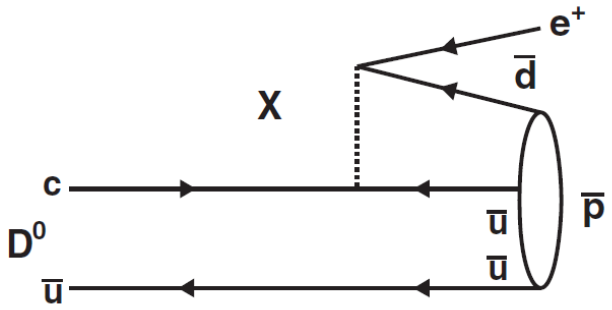
Baryon Number Violation

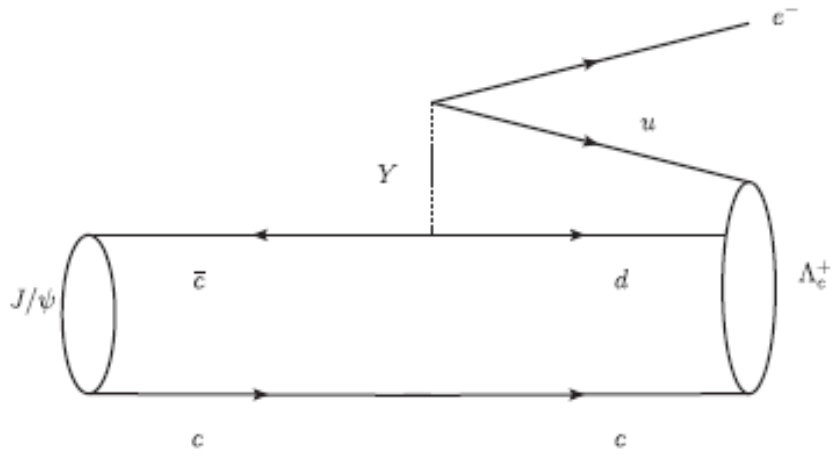
- In the Standard Model, baryon number is conserved
- However, baryon anti-baryon number is highly asymmetric in the universe
- BNV is allowed in GUT and SM extensions $\boldsymbol{\Delta(B-L)=0}$
- Furthermore, another BNV under dimension seven operators allow $\boldsymbol{\Delta(B-L)=2}$



- BNV processes
  - $D^0 \to \bar{p}e^+, D^+ \to \bar{n}e^+, D^+ \to \bar{\Lambda}l^+, J/\psi \to \Lambda_c e^-$



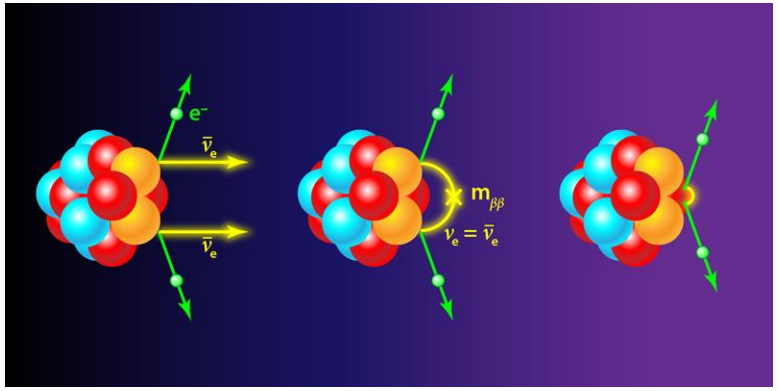




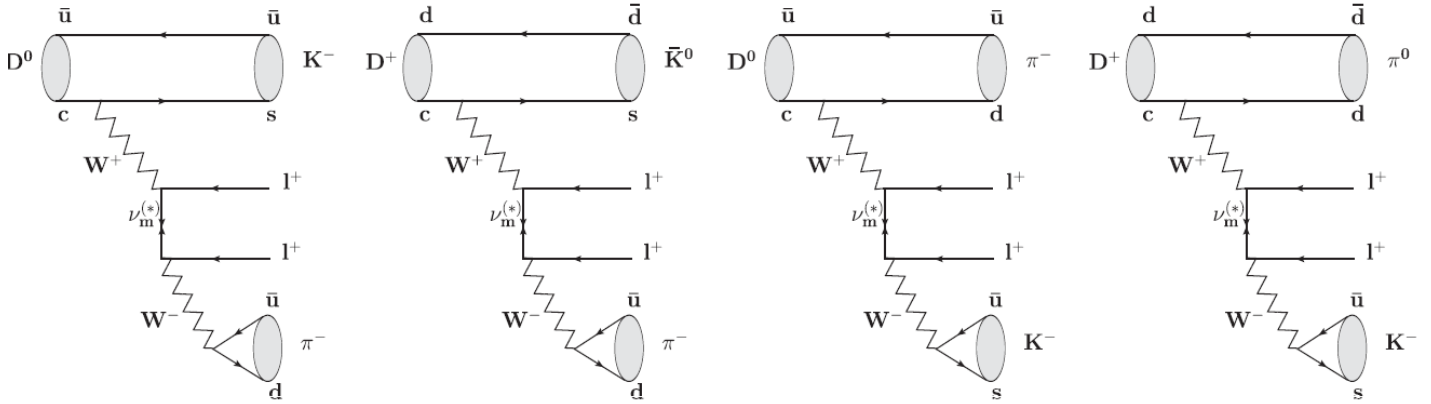
see GuoRong Che's BNV talk

Lepton Number Violation

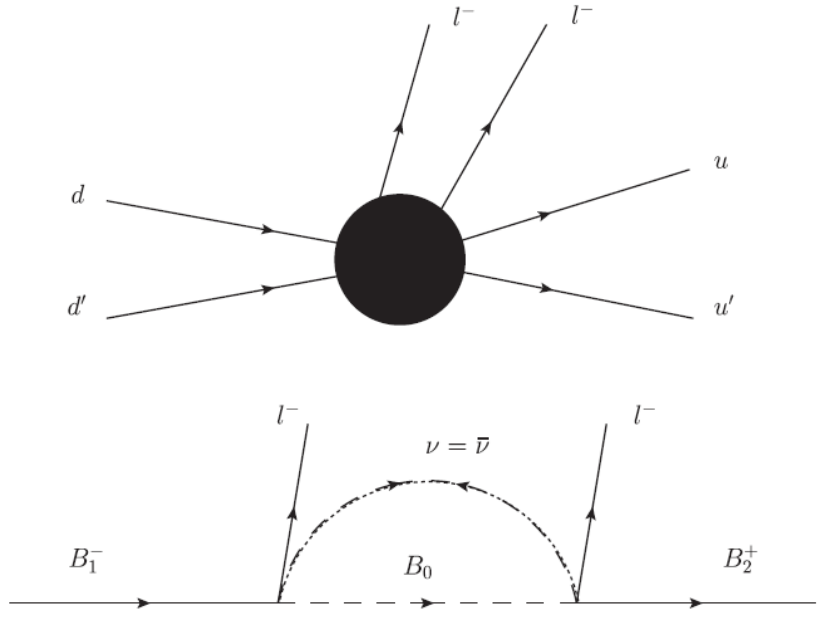
- Lepton Number Violation processes can be used to test the nature of neutrino, Dirac or Majorana?
- Neutrinoless double beta decay is the most promising
- LNV can also be probed with hadron/lepton decays



- LNV processes
  - $D \to h(h')e^+e^+, D_s \to h(h')e^+e^+$



(a) $D^0 \to K^-\pi^-l^+l^+$ (CF) (b) $D^+ \to \bar{K}^0\pi^-l^+l^+$ (CF) (c) $D^0 \to K^-\pi^-l^+l^+$ (DCS) (d) $D^+ \to K^-\pi^0l^+l^+$ (DCS)

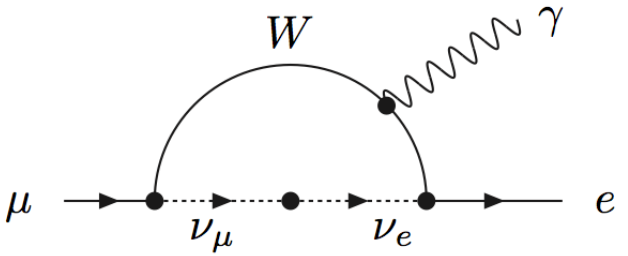


see Xueyin Liu's LNV talk

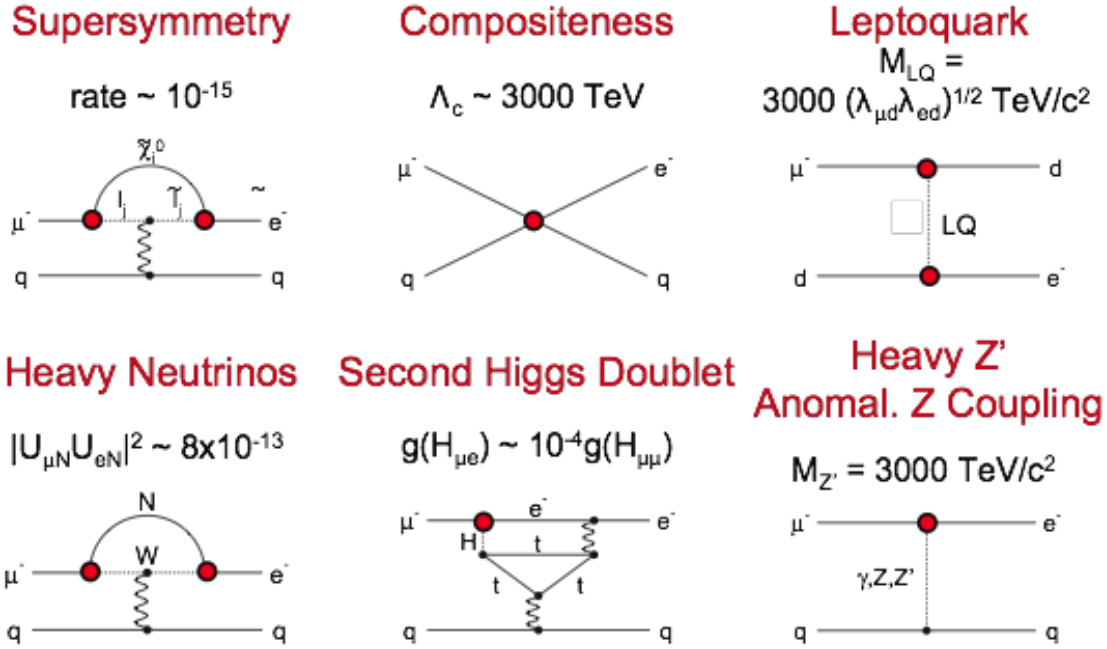
Lepton Flavor Violation

- With neutrino mixing, LFV is allowed in extended SM, but too small to be detectable

$$BR(\mu \to e\gamma) = \frac{3\alpha}{32\pi}\left|\sum_{i=2,3} U^*_{\mu i}U_{ei}\frac{\Delta m^2_{1i}}{M_W^2}\right|^2 < 10^{-54}$$



- New Physics models predict
  - $\mathcal{B}(J/\psi \to e\mu) \sim 10^{-16}\sim10^{-9}$
  - $\mathcal{B}(J/\psi \to e\tau(\mu\tau)) \sim 10^{-10}\sim10^{-8}$
  - Model-independent prediction [1, 2]
  - Rotating mass matrix [3]
  - Unparticle physics [4]
  - Effective Lagrangian [5]
  - MSSM with gauged baryon and lepton number [6]



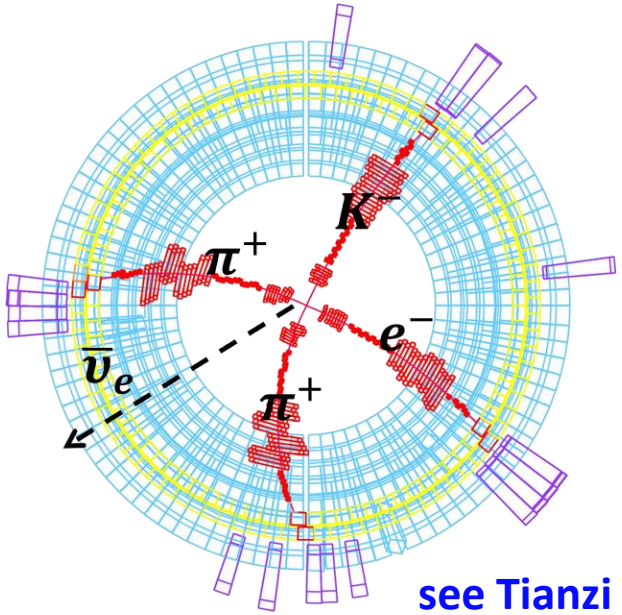
see Jingshu Li's LFV talk

[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).

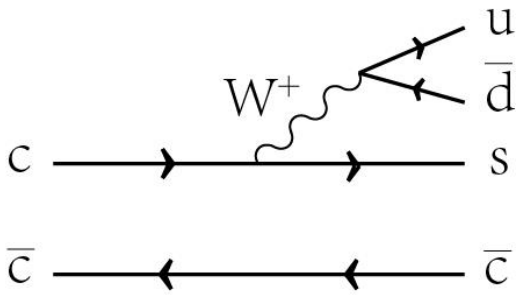
SM Rare Decays

Charmonium Weak Decays

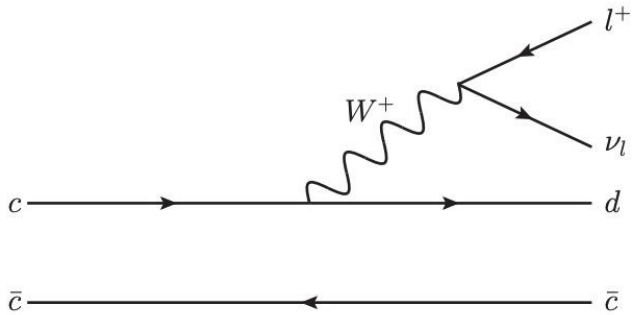
- Charmonium weak decays are **allowed in SM**, but highly suppressed by strong and EM decays
- The inclusive J/ψ weak decay branching fraction (BF) is predicted to be at the order of **10^{-8}** or lower
- Hadronic weak decays
  - $J/\psi \to D_s^{(*)-}\rho^+/\pi^+, J/\psi \to D^-\rho^+,\ \psi(3686) \to \Lambda_c^+\bar{\Sigma}^-$
- Semi-leptonic weak decays
  - $J/\psi \to D_s^{(*)-}e^+\upsilon_e, J/\psi \to D^-e^+\upsilon_e, J/\psi \to D^-\mu^+\upsilon_\mu$



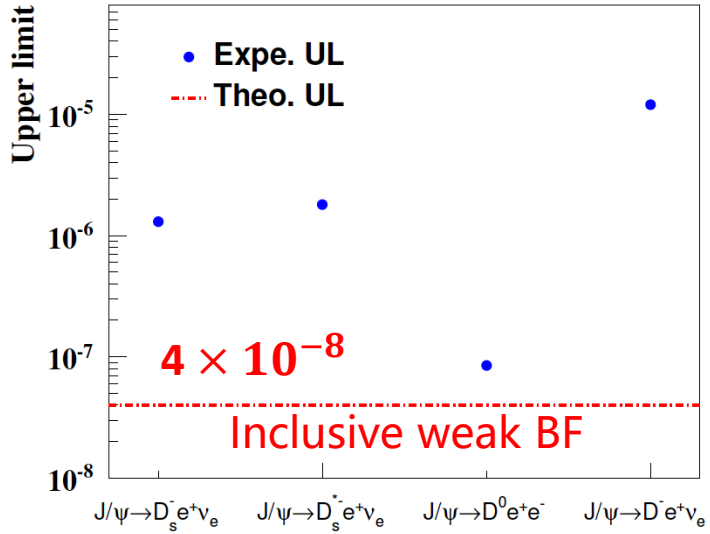
see Tianzi Song's talk



$J/\psi \to D_s^-\pi^+$

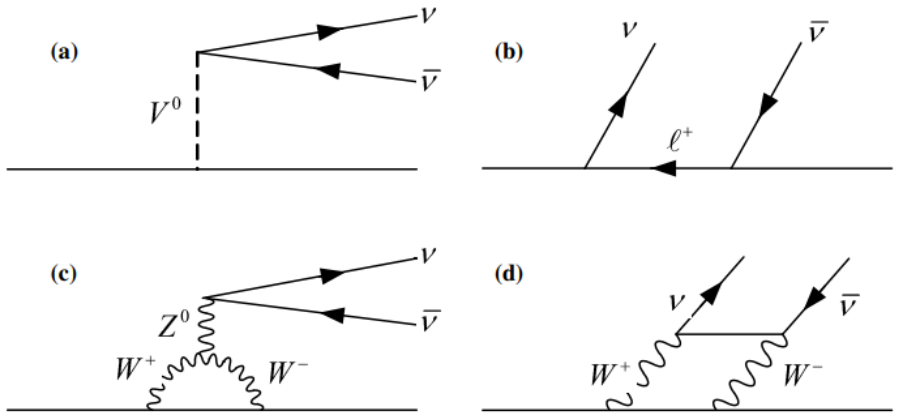


$J/\psi \to D^-e^+\upsilon_e$

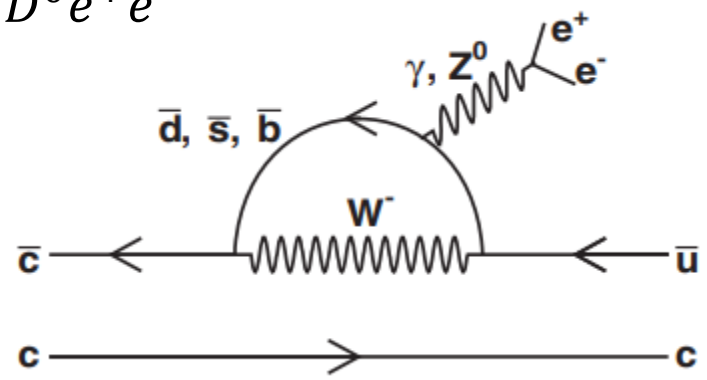


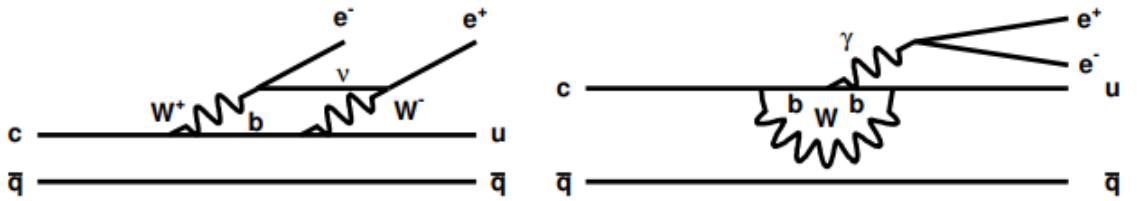
FCNC Processes

- 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

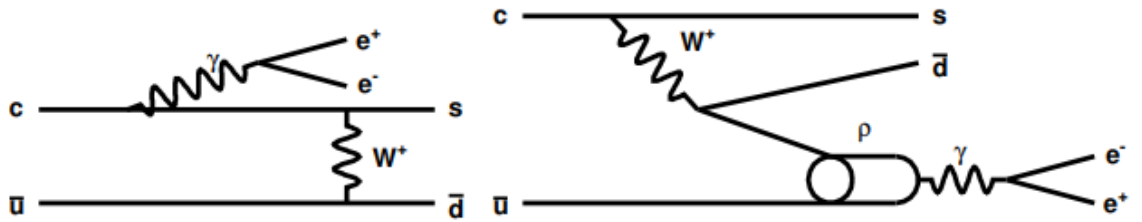


- Meson FCNC decays
  - $D^0 \to \pi^0 \nu\bar{\nu}, D_{(s)} \to h(h')e^+e^-$
- Charmonium FCNC decays
  - $J/\psi \to D^0 e^+ e^-$





Short Distance (SD)



Long Distance (LD)

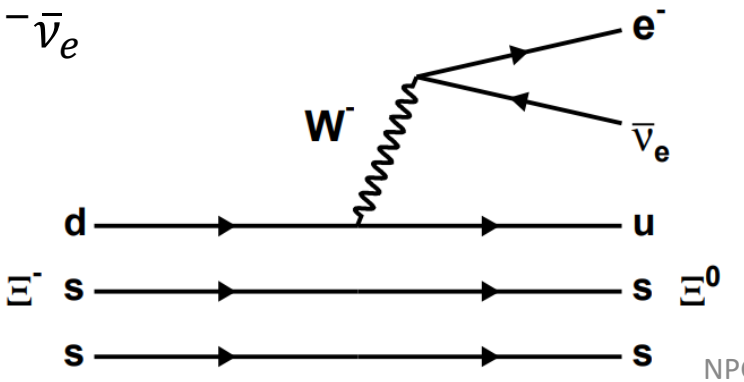
see Tianzi Song's talk

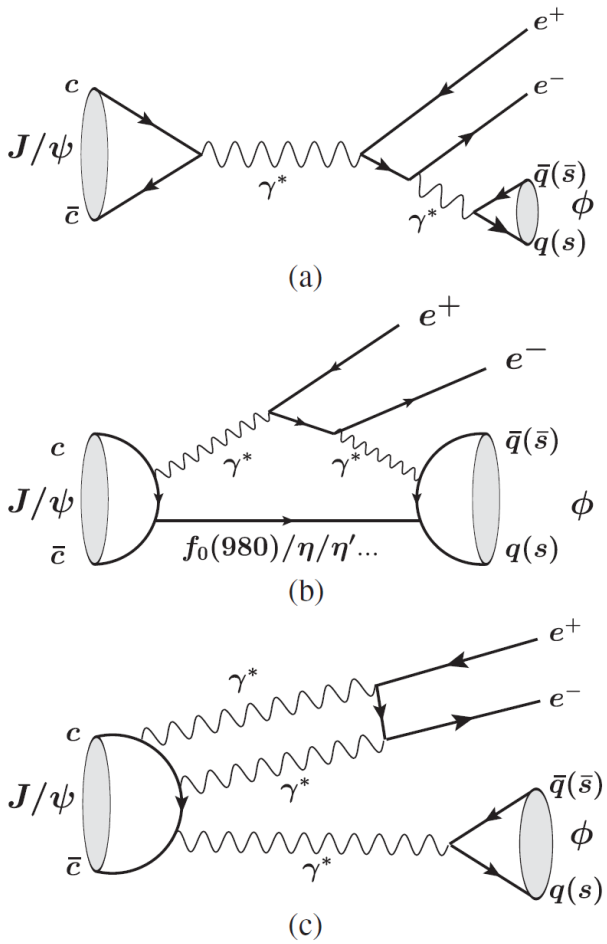
Other Rare Decays

- In SM, $J/\Psi \to \phi e^+ e^-$ is predicted to be at the order of **10^{-8} ~ 10^{-11}**
- New particles (dark γ / glueball) could enhance the contribution (b) to an observable level

- Measurement of EM Dalitz decay
  - $\Psi(3686) \to \eta_c e^+ e^-$

- Hyperon semi-leptonic decay
  - $\Xi^- \to \Xi^0 e^- \bar{\nu}_e$





(a) the leading-order EM process

(b) the EM and strong mixed loop process

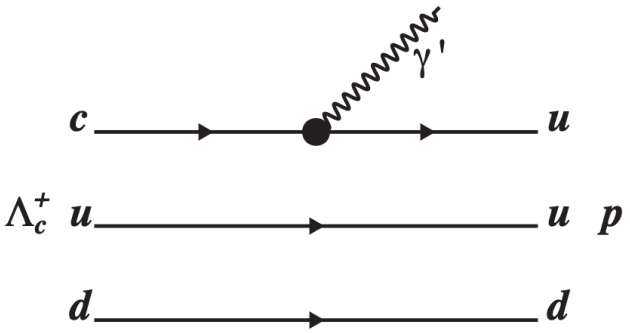
(c) the EM process proceeding through three virtual photons

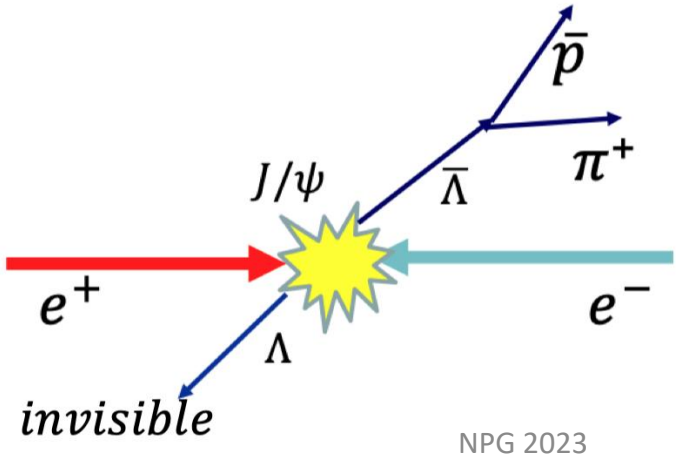
see Dong Xiao, Xiaoxuan Ding, Jinlin Fu's talks

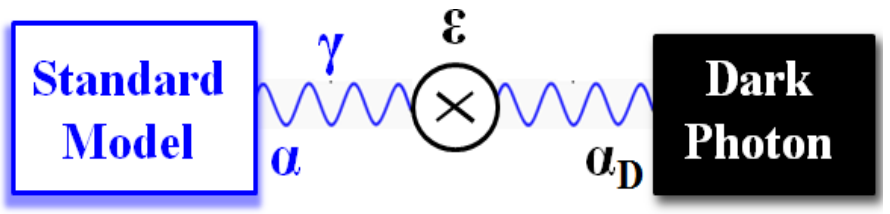
Exotics

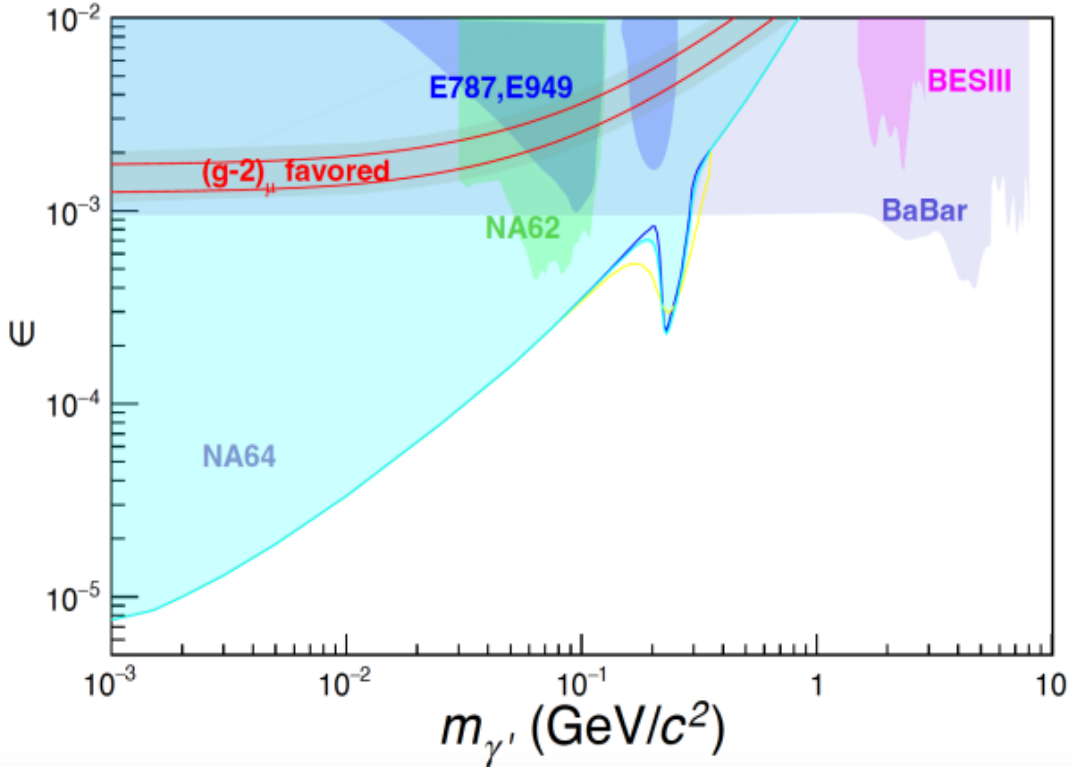
Search for the Invisibles

- Light dark matter particles γ'
- Candidates:
  - Dark photon U, Axion Like Particles (ALP) a, Light Higgs boson A^0
- Search for the particles fully invisible to the detector, energy and momentum conservation
- Fully invisible particles
  - $J/\psi \to U\eta^{(\prime)},\ \Lambda_c^+ \to p\gamma', \Lambda \to invisible$





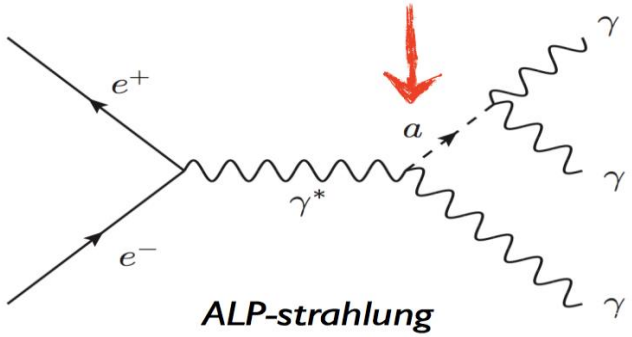


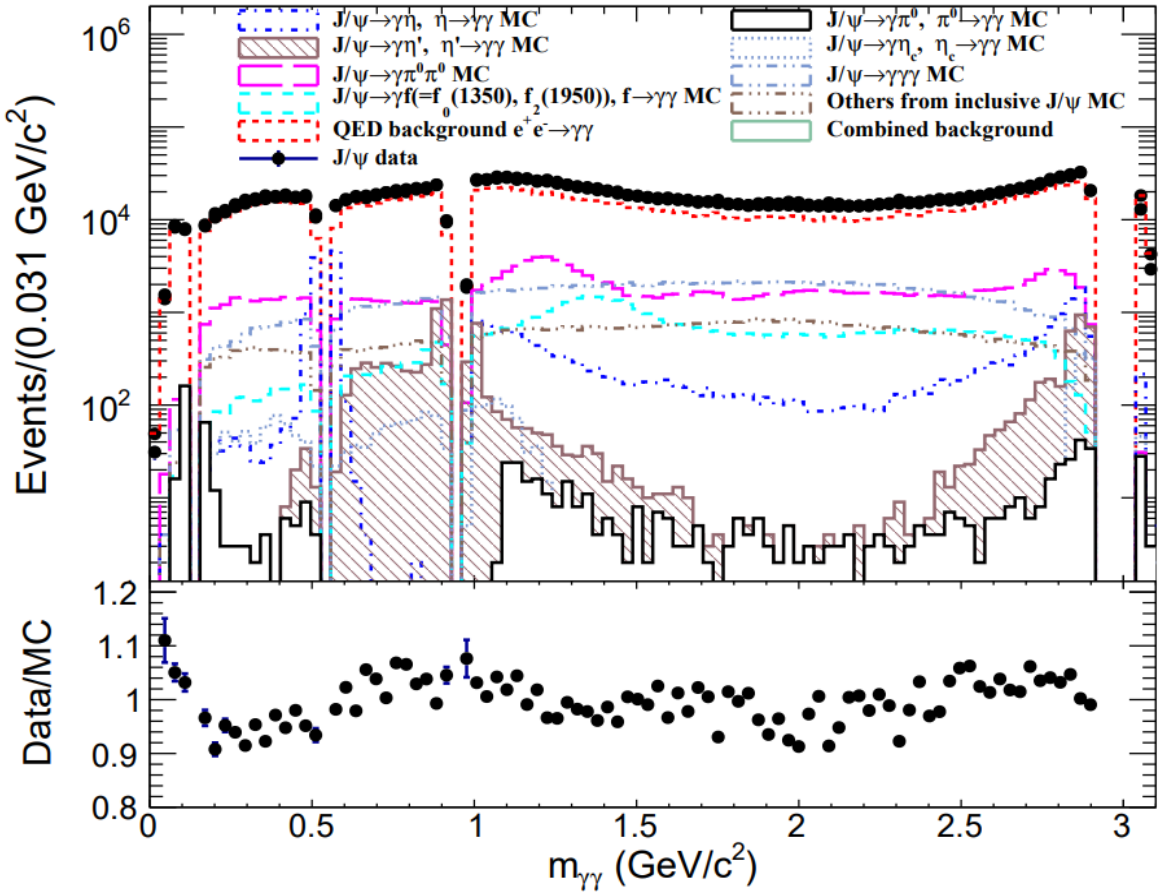


see Peicheng Jiang's talk

Search for Exotic Visible Decays

- Exotic particle γ' decays to visible particles
- Candidates:
  - Dark photon $\gamma' \to e^+e^-$
  - Axion Like Particles (ALP) $a \to \gamma\gamma$
  - Light Higgs boson $A^0 \to \mu^+\mu^-$
- Search for the Invariant mass peak reconstructed with final particles
- Exotic visible decays
  - $J/\psi \to \gamma a,\ J/\psi \to \gamma A^0,\ J/\psi \to Z'\mu^+\mu^-$





see Houbing Jiang's talk

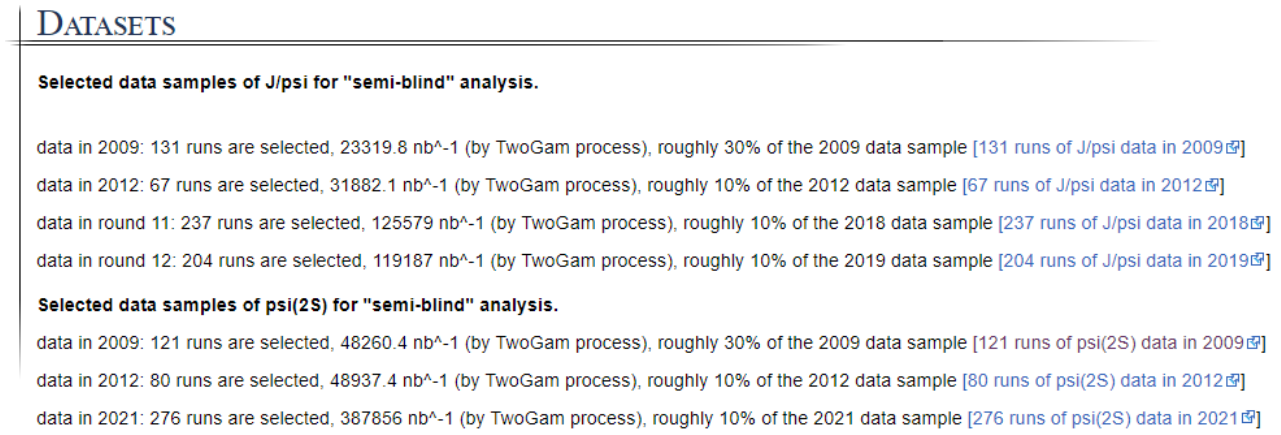
Common Standards & Tools

Data Analysis Strategy

- In the New Physics Group (NPG), we propose a **semi-blind analysis** strategy
  1. Use signal and inclusive **MC data samples** to tune your analysis algorithms
  2. Make a presentation at the NPG group meeting to apply for using semi-blind dataset, which is about **~10% of real data**, needs clear approval from the NPG convenors
  3. Write analysis memo, after approval from the convenors, apply for a talk at the Physics & Software Meeting (PSM) to get a BAM
  4. At the internal review stage, with the approval of all referees, the **full real data** can be used

- Semi-blind datasets
  - J/ψ, 10 $Billion$ $\times 10\%$, ready
  - $\psi(3686)$, 2.7 $Billion$ $\times 10\%$, ready
  - $D\overline{D}$, 7.9 fb^{-1} $\times 10\%$, ready

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



DATASETS

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]

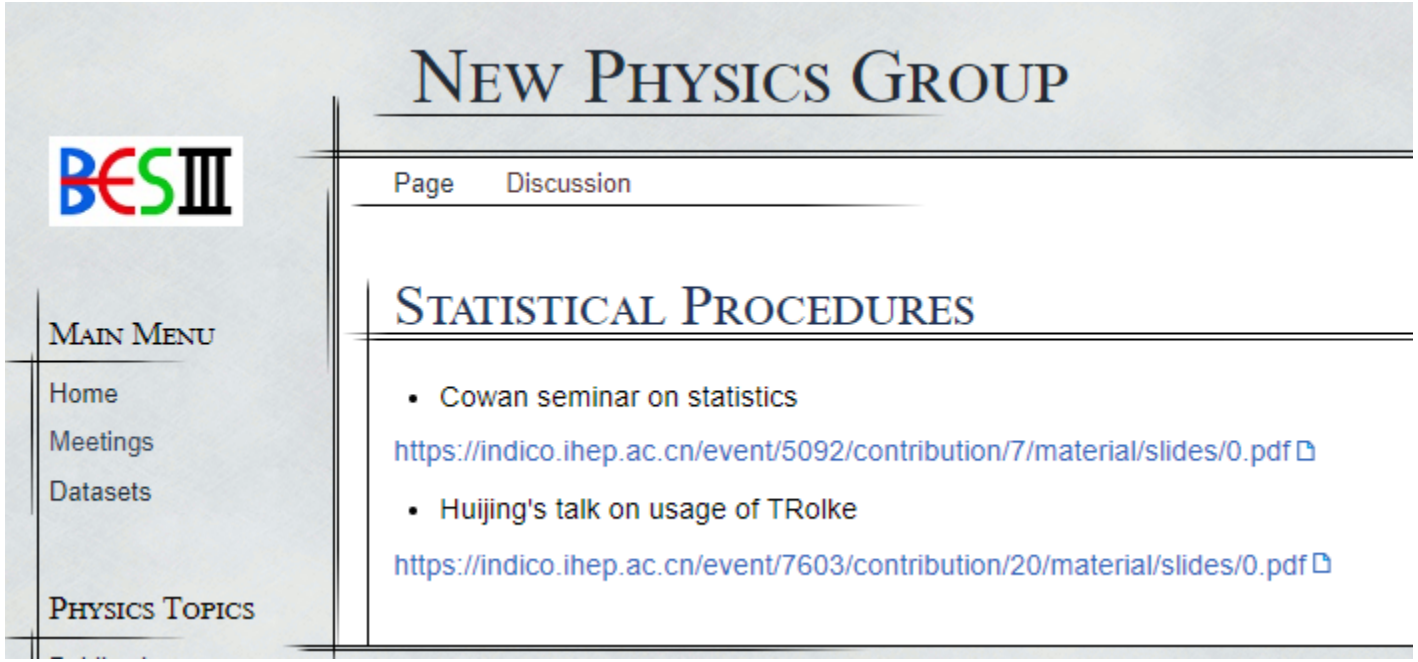
data in 2012: 80 runs are selected, 48937.4 nb^-1 (by TwoGam process), roughly 10% of the 2012 data sample [80 runs of psi(2S) data in 2012]

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]

Statistical Procedures

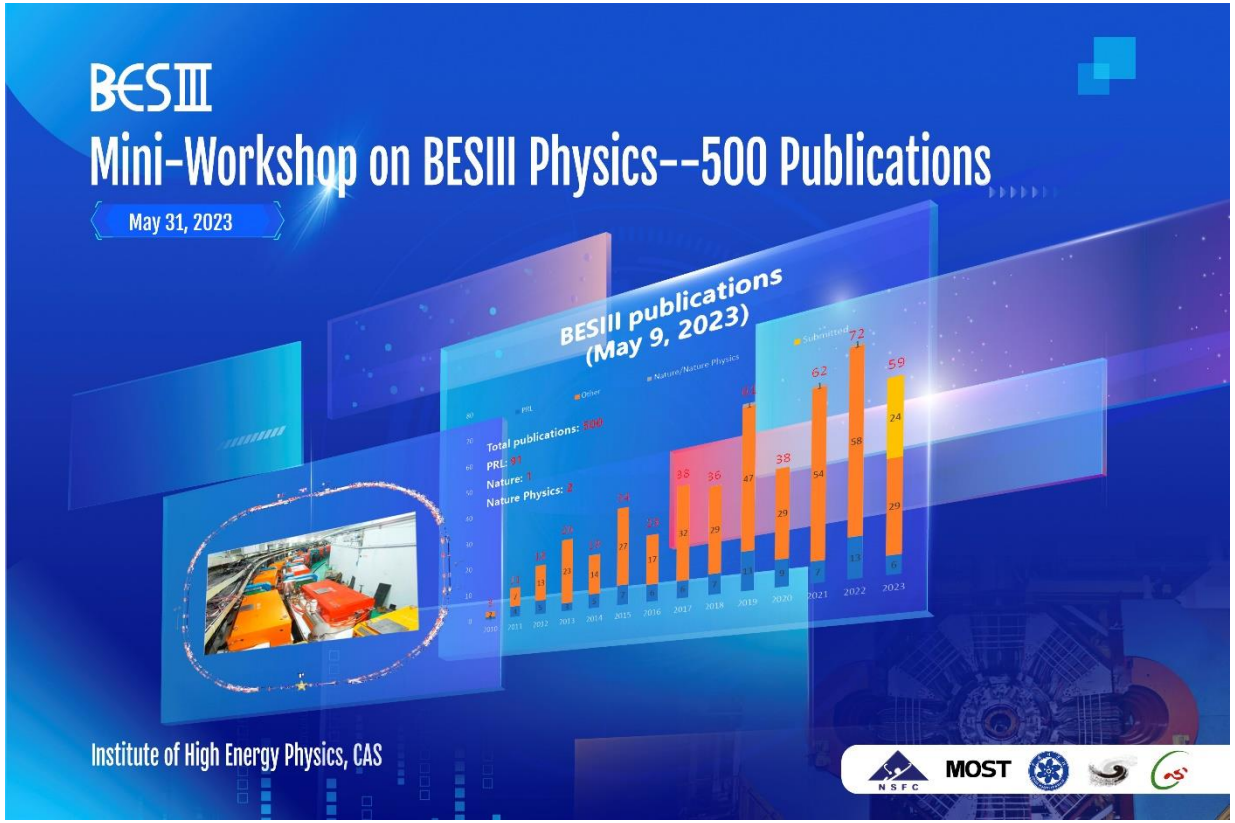
- Common statistical procedures, follow them to facilitate your analysis
- Cut parameter optimization
- Likelihood function
- Upper limits calculation

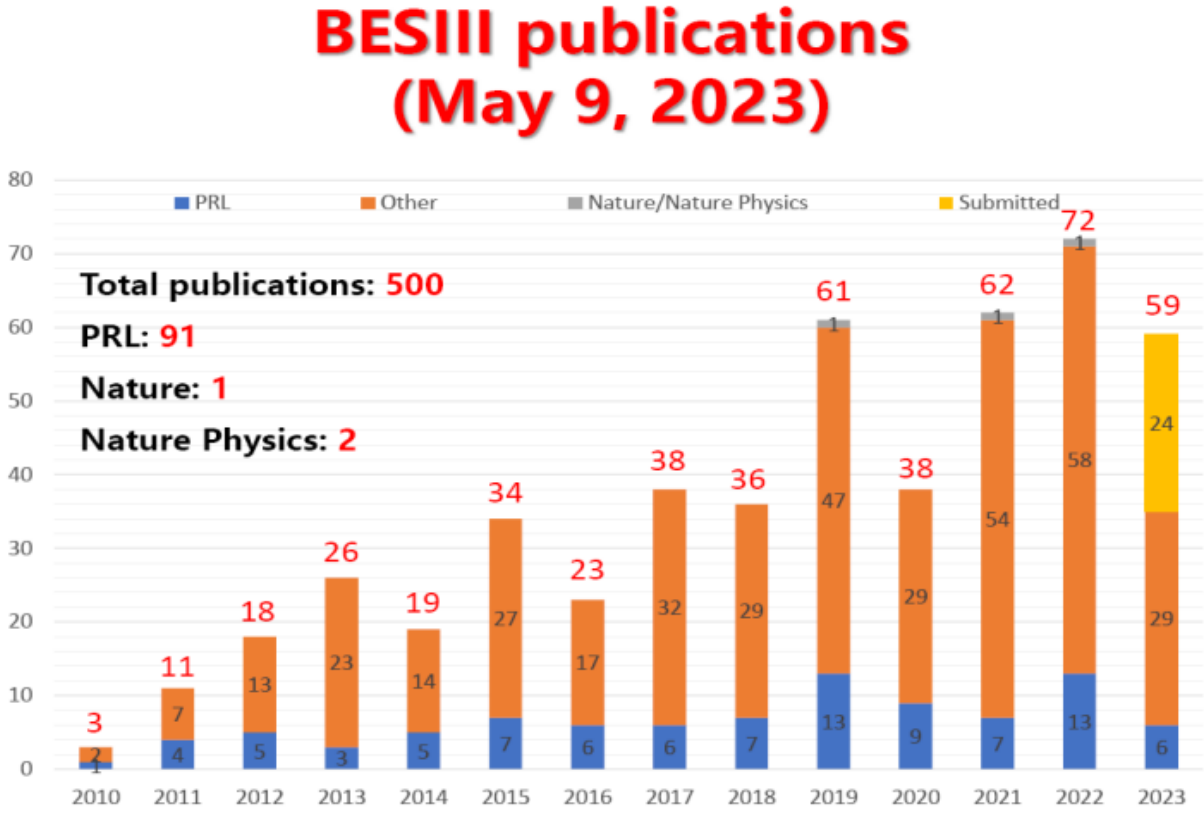
https://docbes3.ihep.ac.cn/~newphysgroup/index.php/Statistical_Procedures



BESIII Publications

More than 500 publications





New Physics Group Publications

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Search for $\bar{\Lambda}$–Λ Baryon-Number-Violating Oscillations in the Decay $J/\psi \to pK^-\bar{\Lambda} + \text{c. c.}$

M. Ablikim *et al.* (BESIII Collaboration)
Phys. Rev. Lett. **131**, 121801 – Published 19 September 2023

Article References No Citing Articles PDF HTML Export Citation

ABSTRACT

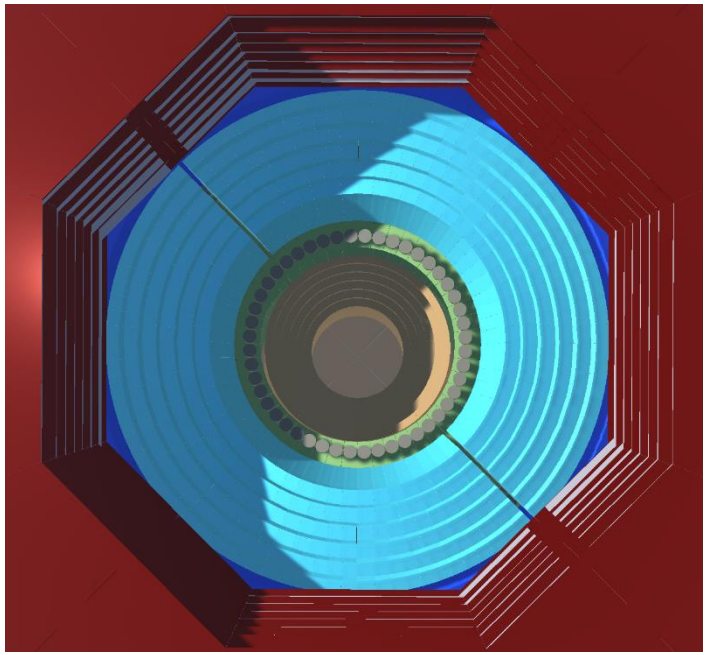
We report on the first search for $\bar{\Lambda}$–Λ oscillations in the decay $J/\psi \to pK^-\bar{\Lambda} + \text{c. c.}$ by analyzing 1.31×10^9 J/ψ events accumulated with the BESIII detector at the BEPCII collider. The J/ψ events are produced using e^+e^- collisions at a center of mass energy $\sqrt{s} = 3.097$ GeV. No evidence for hyperon oscillations is observed. The upper limit for the oscillation rate of $\bar{\Lambda}$ to Λ hyperons is determined to be $\mathcal{P}(\Lambda) = [\mathcal{B}(J/\psi \to pK^-\Lambda + \text{c. c.})/\mathcal{B}(J/\psi \to pK^-\bar{\Lambda} + \text{c. c.})] < 4.4 \times 10^{-6}$ corresponding to an oscillation parameter $\delta m_{\Lambda\bar{\Lambda}}$ of less than 3.8×10^{-18} GeV at the 90% confidence level.

- More than **40 papers** from NPG
- The **501*st*** BESIII publication (PRL) is from NPG **see Xiqing Hao's talk**
- Discussion with theorists is important
- More physics results from NPG are expected
  - Publication List (40)
  - Ongoing analyses (>50)

501	354	PRL	2022-10-04	2022-11-24, Johan, Ryan	2023-02-08, Wolfgang	2023-05-08	arXiv:2305.04568	2023-08-29/19Sep2023	Phys. Rev. Lett. 131, 121801 (2023)	0(0)	Xiqing Hao	Search for $\bar{\Lambda}$-Λ Baryon-Number-Violating Oscillations in the Decay $J/\psi \to pK^-\bar{\Lambda} + \text{c. c.}$

Summary

- **Probe New Physics beyond the Standard Model with BESIII**
- **Great potential with unique datasets and advanced analysis techniques**
- **Thanks to all NPG collaborators and theorists**
- **More & better results are coming!**



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Thank you!