Properties of Charmonium Resonances at BESIII

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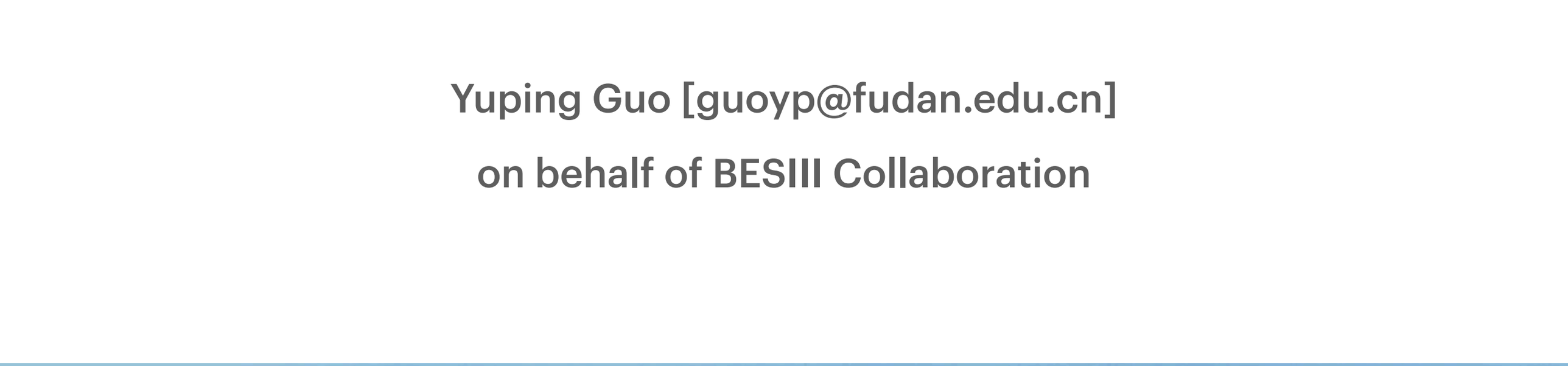
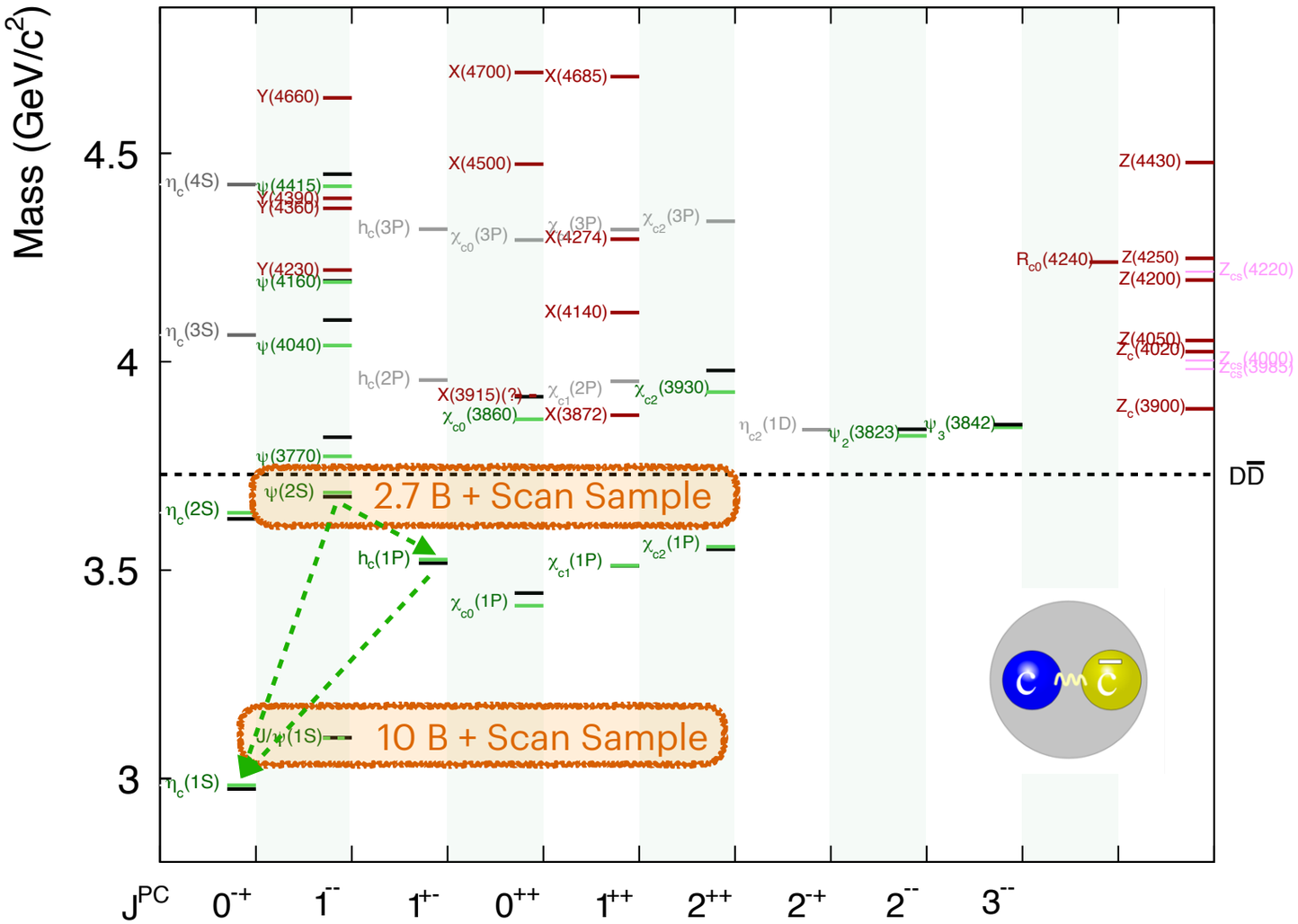
on behalf of BESIII Collaboration



Outline

- Introduction
- Total and leptonic width of J/ψ
- Properties of $h_c(1P)$ from $\psi(3686)\to\pi^0 h_c(1P)$
- Observation of the EM decay $\psi(3686)\to e^+e^-\eta_c(1S)$
- Summary

Charmonium System



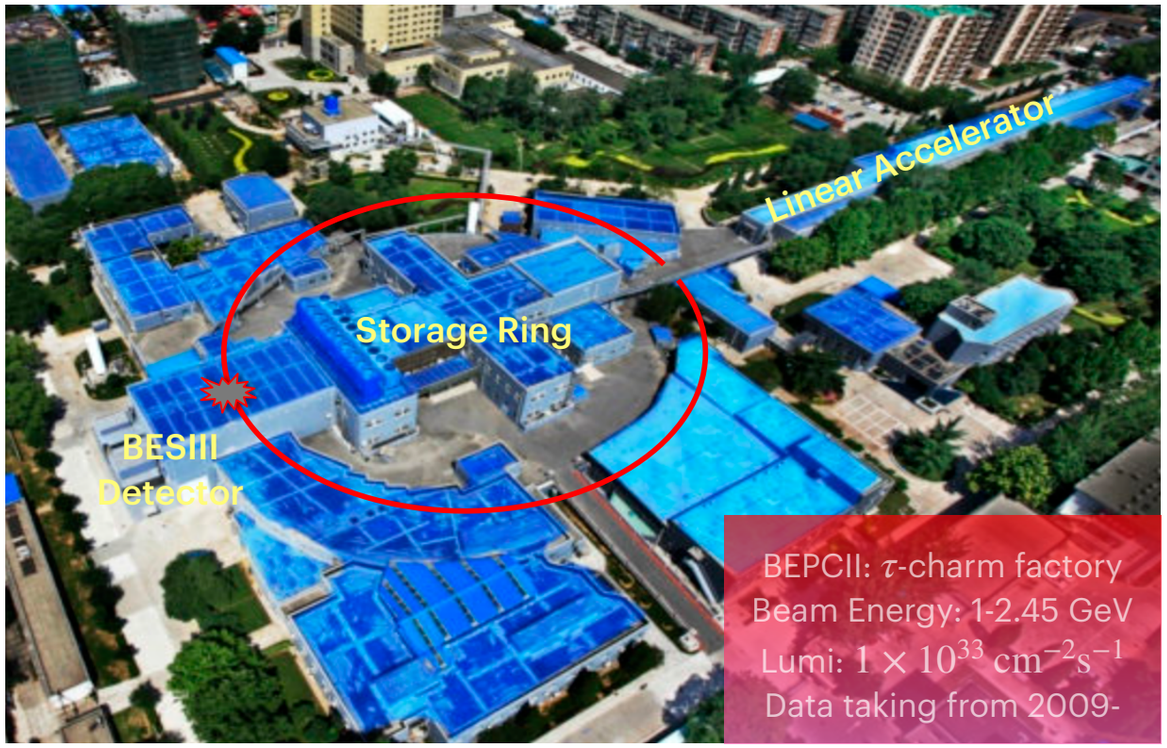
- Ideal laboratory to study QCD
- Charmonium states below open charm threshold well established
- Properties need to be further investigated
  - Mass, width, partial decay width, ...

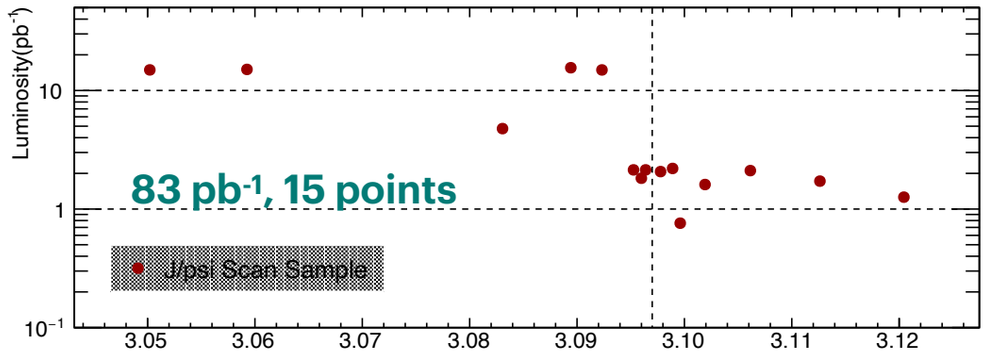
Phys. Rev. D72, 054026 (2005)

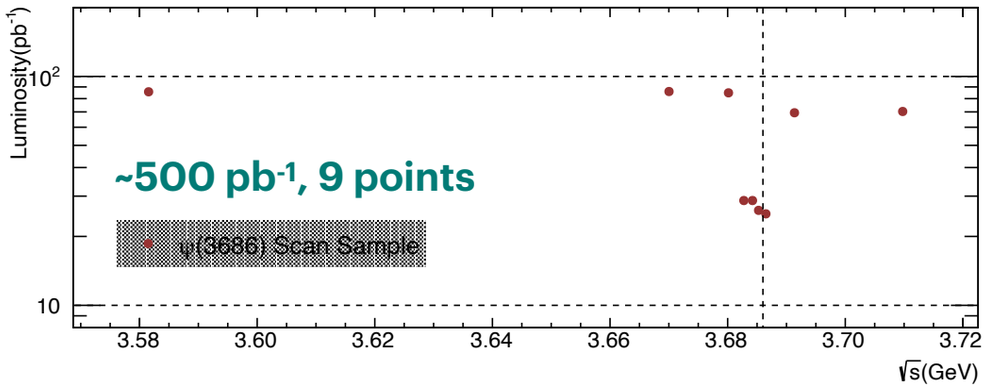
Notation: $^{2S+1}L_J$ J^{PC}

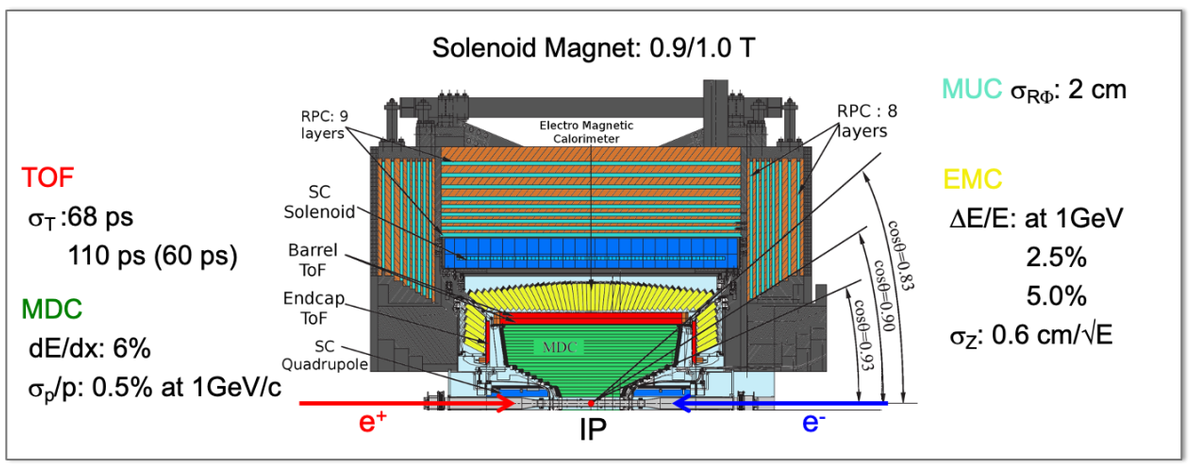
$P=(-1)^{L+1}$ $C=(-1)^{L+S}$

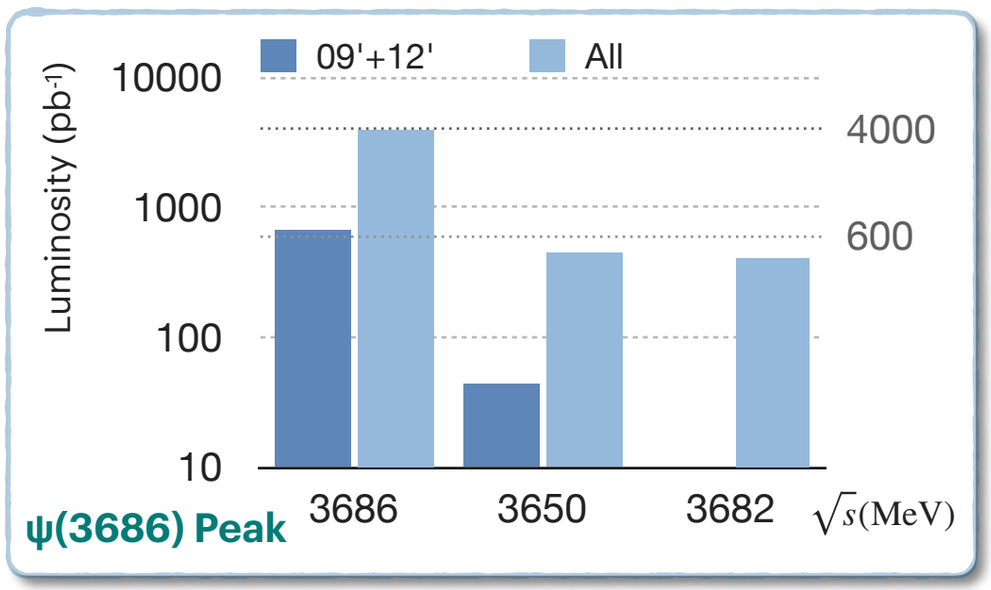
BESIII & Relavant Data Samples





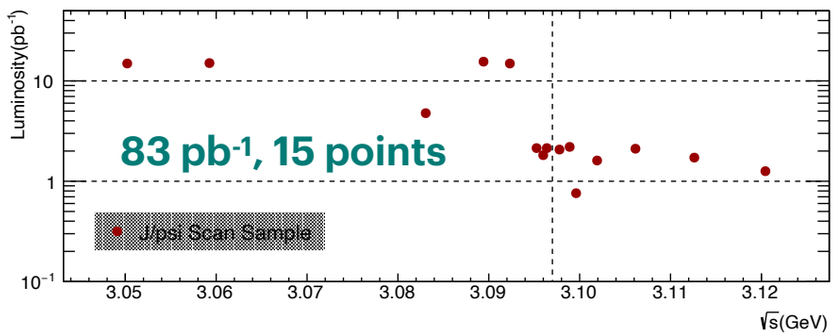






Total and Leptonic Width of J/ψ

- Motivation:
  - Measure Γ_{tot} and Γ_{ll} with high precision
  - Test lepton universality with $\Gamma_{ee}/\Gamma_{\mu\mu}$



- Measure the cross sections of $e^+e^- \to e^+e^-$ and $e^+e^- \to \mu^+\mu^-$ processes as functions of center-of-mass energy

arXiv:2206.13674

$$\sigma_0(s) = \sigma_0^C(s) + \sigma_0^R(s) + \sigma_0^I(s)$$

Measured by BESM, calibrated using J/ψ mass

- $\sigma_0^C(s)$: continuum term
- $\sigma_0^R(s)$: resonance term
- $\sigma_0^I(s)$: interference term

related to J/ψ decay widths

proportional to $\Gamma_{ee}\Gamma_{ee(\mu\mu)}/\Gamma_{tot}$

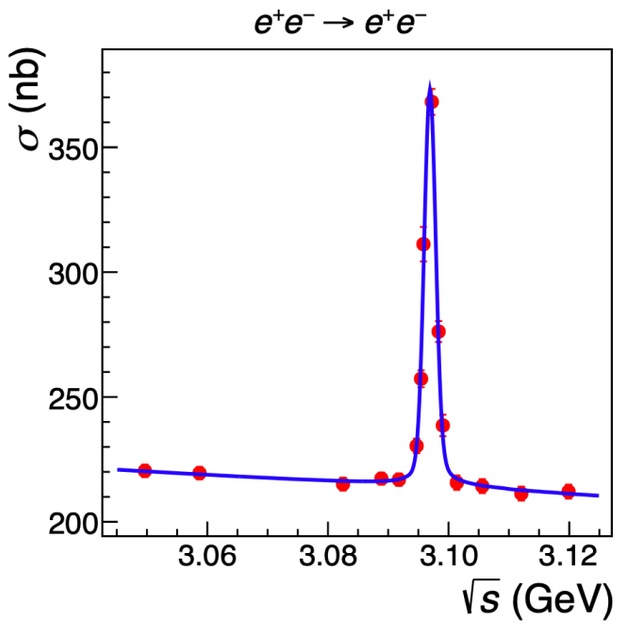
Additional effects:

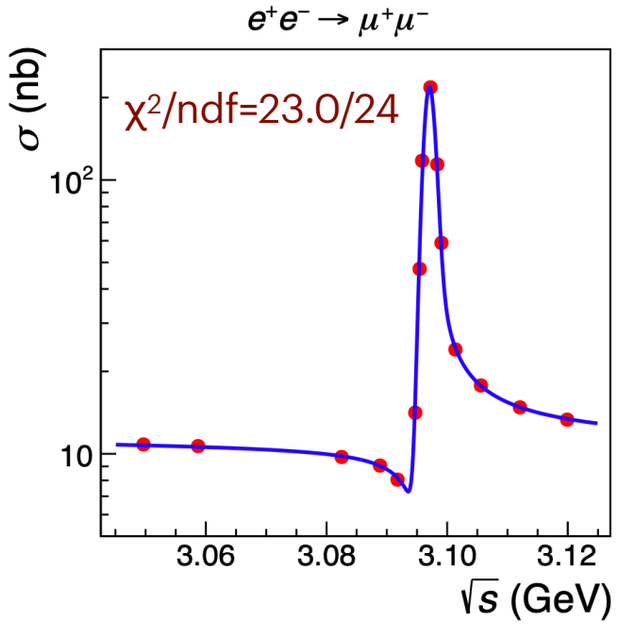
FSR

Energy spread

Total and Leptonic Width of J/ψ

- χ^2 fit to the cross section with correlations taken into account



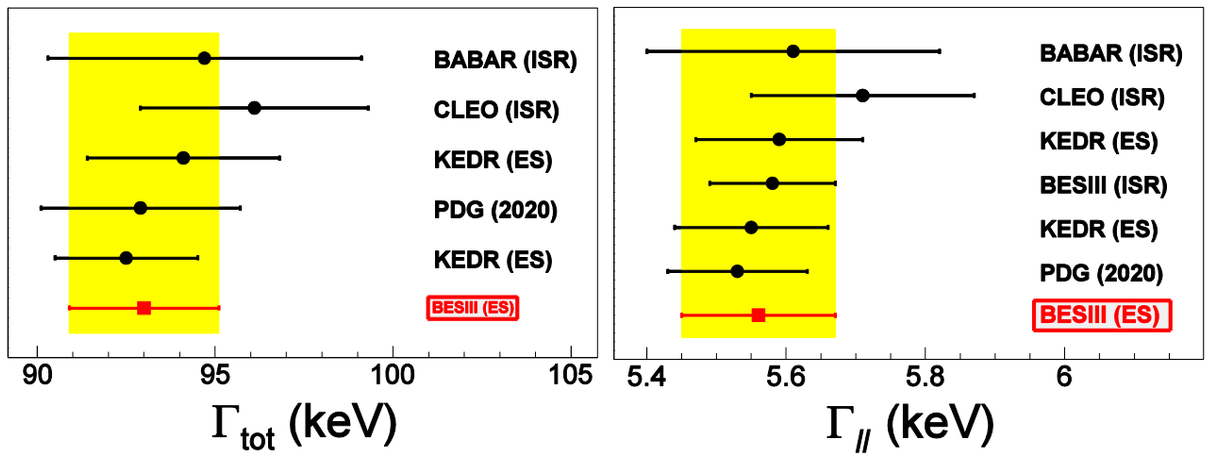


Systematic uncertainty of c.s. measurement ~1.4% (dominated by L)

arXiv:2206.13674

$$\Gamma_{ee}\Gamma_{ee}/\Gamma_{\rm tot} = (0.346 \pm 0.009)\ \text{keV}$$
$$\Gamma_{ee}\Gamma_{\mu\mu}/\Gamma_{\rm tot} = (0.335 \pm 0.006)\ \text{keV}$$
$$\Gamma_{\rm tot} = (93.0 \pm 2.1)\ \text{keV}$$
$$\Gamma_{ll} = (5.56 \pm 0.11)\ \text{keV}$$
$$\Gamma_{ee}/\Gamma_{\mu\mu} = 1.031 \pm 0.015$$

Stat. and Sys. error

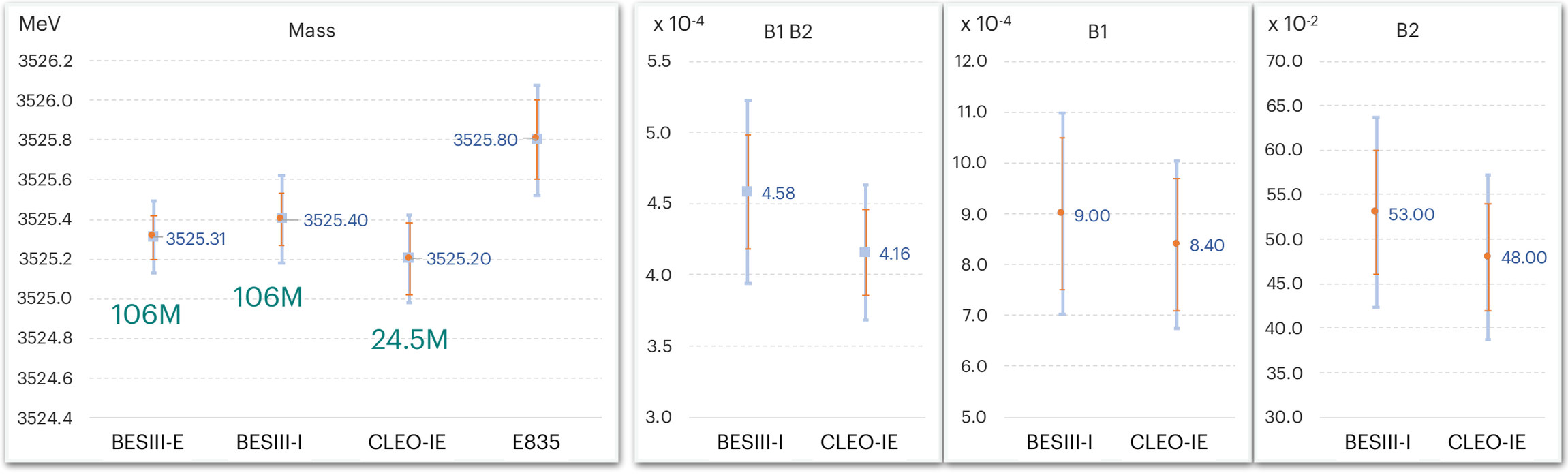


World leading precision level

Properties of $h_c(1P)$

- Motivation: improve precision
  - Mass and width of $h_c(1P)$

    [previously, only one measurement of width: 0.70±0.28±0.22 MeV]
  - Branching fractions of $\psi(3686)\to\pi^0 h_c(1P)$ and $h_c(1P)\to\gamma\eta_c(1S)$

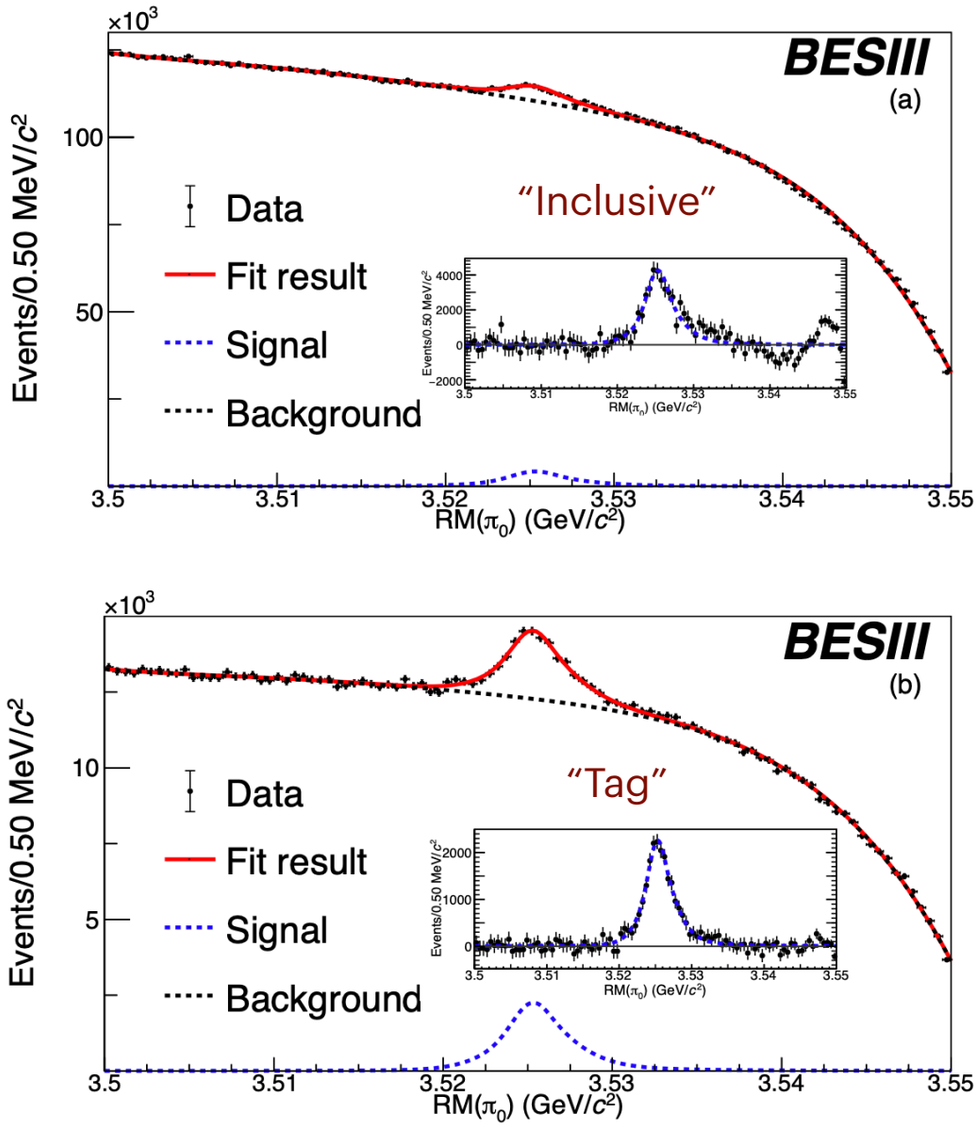


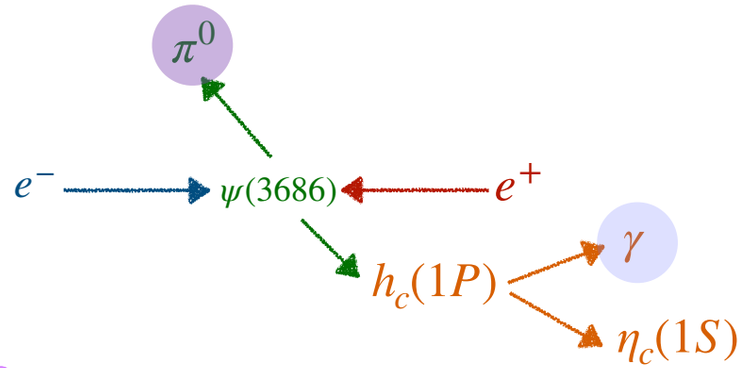
- 448 M $\psi(3686)$ events, $h_c(1P)$ from $\psi(3686)\to\pi^0 h_c(1P)$ *arXiv:2204.09413*

BESIII-E: PRD86, 092009 (2012), BESIII-I: PRL104, 132002 (2010)
CLEO-IE: PRL101, 182003 (2008), E835: PRD72, 032001 (2005)

Properties of $h_c(1P)$

- "Inclusive" and "Tag" selections





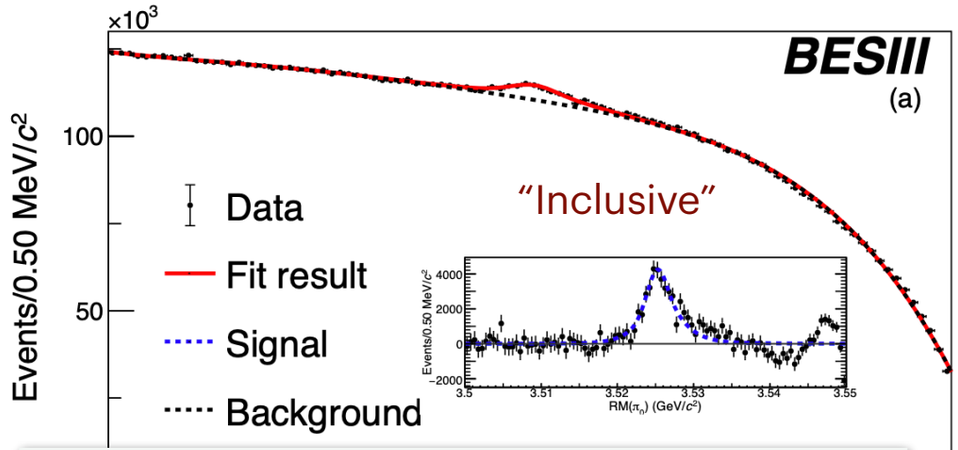
arXiv:2204.09413

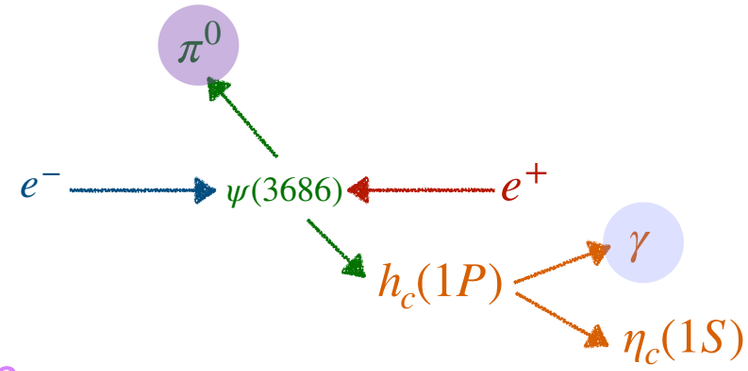
Variable	Value	PDG Value [5]
$M(h_c)$ (MeV/c^2)	$3525.32 \pm 0.06 \pm 0.15$	3525.38 ± 0.11
$\Gamma(h_c)$ (MeV)	$0.78\ ^{+0.27}_{-0.24} \pm 0.12$	0.7 ± 0.4
$N_{\rm Tag}(h_c)$	$23118\ ^{+1500}_{-1398}$	—
$\mathcal{B}_{\rm Inc} \times \mathcal{B}_{\rm Tag}$ (10^{-4})	$4.17\ ^{+0.27}_{-0.25} \pm 0.19$	4.58 ± 0.64 (BESIII [11]) 4.16 ± 0.48 (CLEO [23])
$N_{\rm Inc}(h_c)$	46187 ± 2123	—
$\mathcal{B}_{\rm Inc}$ (10^{-4})	$7.23 \pm 0.33 \pm 0.38$	8.60 ± 1.30
$\mathcal{B}_{\rm Tag}$ (%)	$57.66^{+3.62}_{-3.50} \pm 0.58$	50 ± 9

Dominant systematic uncertainties:
π π J/ψ veto, photon reconstruction and calibration

Properties of $h_c(1P)$

- "Inclusive" and "Tag" selections





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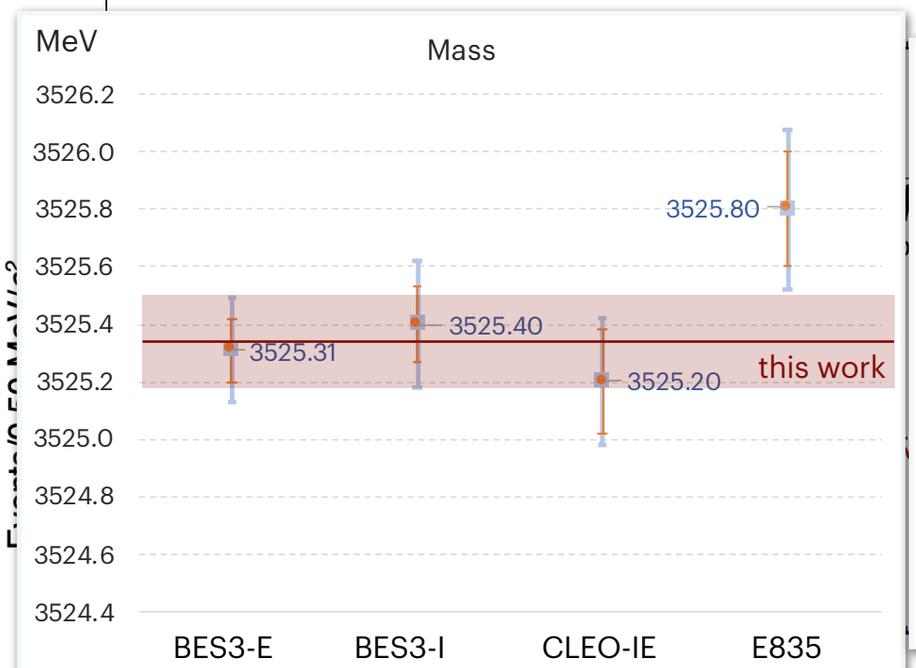
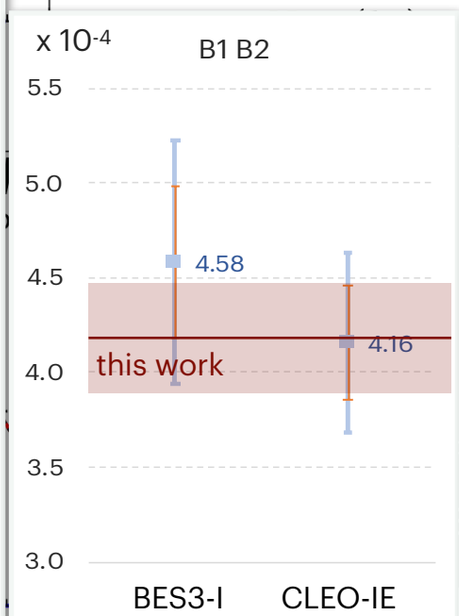
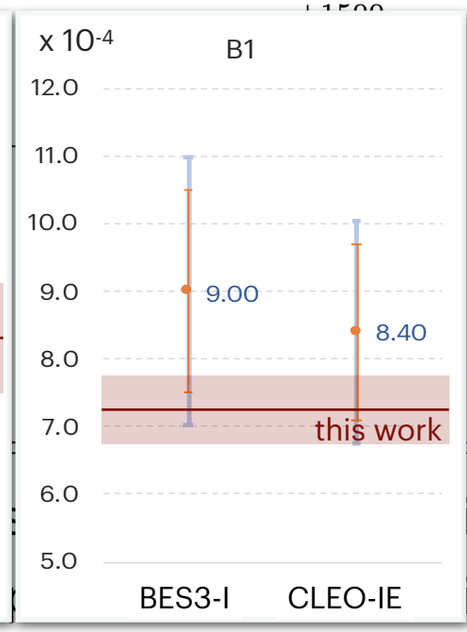
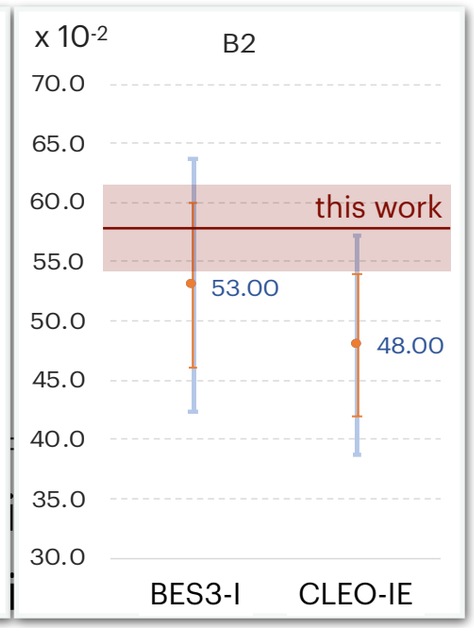




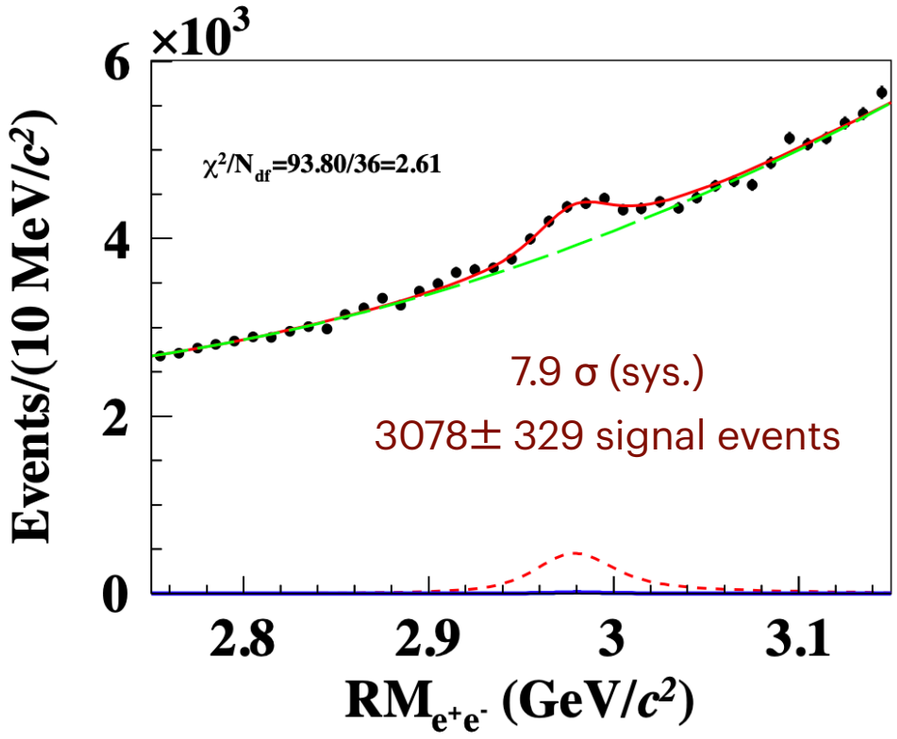


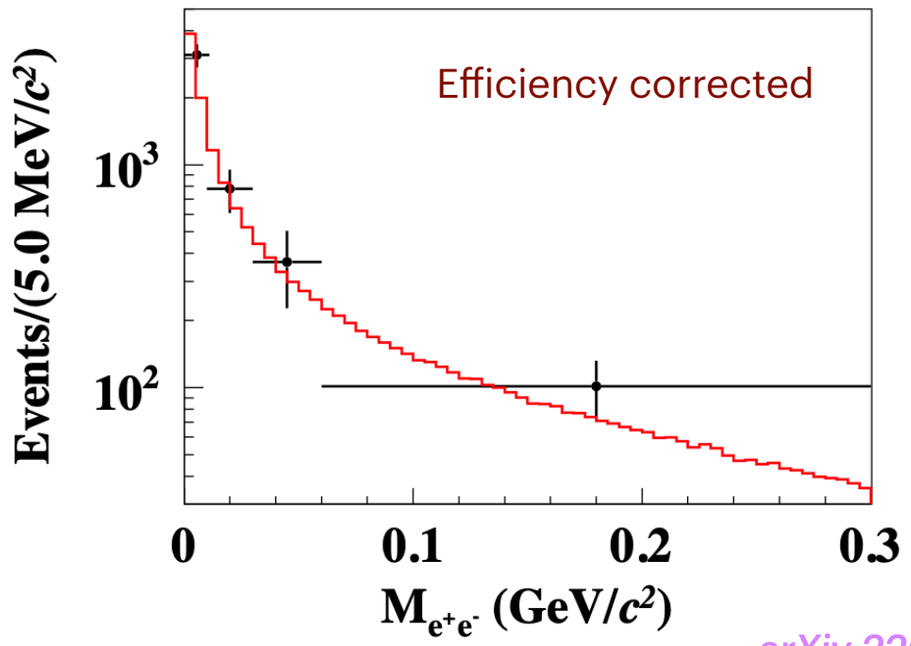


Observation of $\psi(3686) \to e^+e^-\eta_c(1S)$

- Electromagnetic Dalitz decay $V \to \gamma^* P \to l^+l^-P$
- Differential decay width $\frac{d\Gamma(V \to l^+l^-P)}{dq^2\Gamma(V \to \gamma P)} = |\frac{f_{\rm VP}(q^2)}{f_{\rm VP}(0)}|^2 \times {\rm QED}(q^2)$ (TFF)
- Vector Dominance Model (VDM) successfully described many EM TFF, but failed in describing the TFF of $\omega \to \mu^+\mu^-\pi^0$
- Enrich our understanding of the nature of $\psi(3686)$, pure *S*-wave or *S*- and *D*-wave mixture
- 448 M $\psi(3686)$ events, $\eta_c(1S)$ decay inclusively *arXiv:2208.12241*

Observation of $\psi(3686) \to e^+e^-\eta_c(1S)$





arXiv:2208.12241

- Signal events observed with 9.5σ (stat.)
- Branching fraction: $(3.77\pm0.40\pm0.18)\times10^{-5}$, consistent with theoretical prediction from the VMM model *Phys.Rev.D100,016018 (2019) Int.J.Mod.Phys.A34, 1950129 (2019)*
- TFF can not be well determined due to limited statistics

Summary and Outlook

- Large data samples collected at the ψ(3686) peak, J/ψ peak, as well as dedicated scan samples in the vicinity of the resonance allow precise study of the properties of charmonium resonance
  - Total width and leptonic width of J/ψ -- scan sample
  - Mass, width, branching fractions from ψ(3686) to h_c(1P) and h_c(1P) to η_c(1S) -- 448M ψ(3686) events
  - EM decay from ψ(3686) to η_c(1S) -- 448M ψ(3686) events
- New ψ(3686) samples collected in 2021-2022, including ~2.26B ψ(3686) events and two scan samples at 3.65 GeV and 3.682 GeV
  - In total will produce ~2M η_c(2S), ~20M h_c(1P), ~200M χ_{cJ}, and ~10M η_c(1S)
  - Improvements on both statistical uncertainty and systematic uncertainty are expected

Thank you for your attention!