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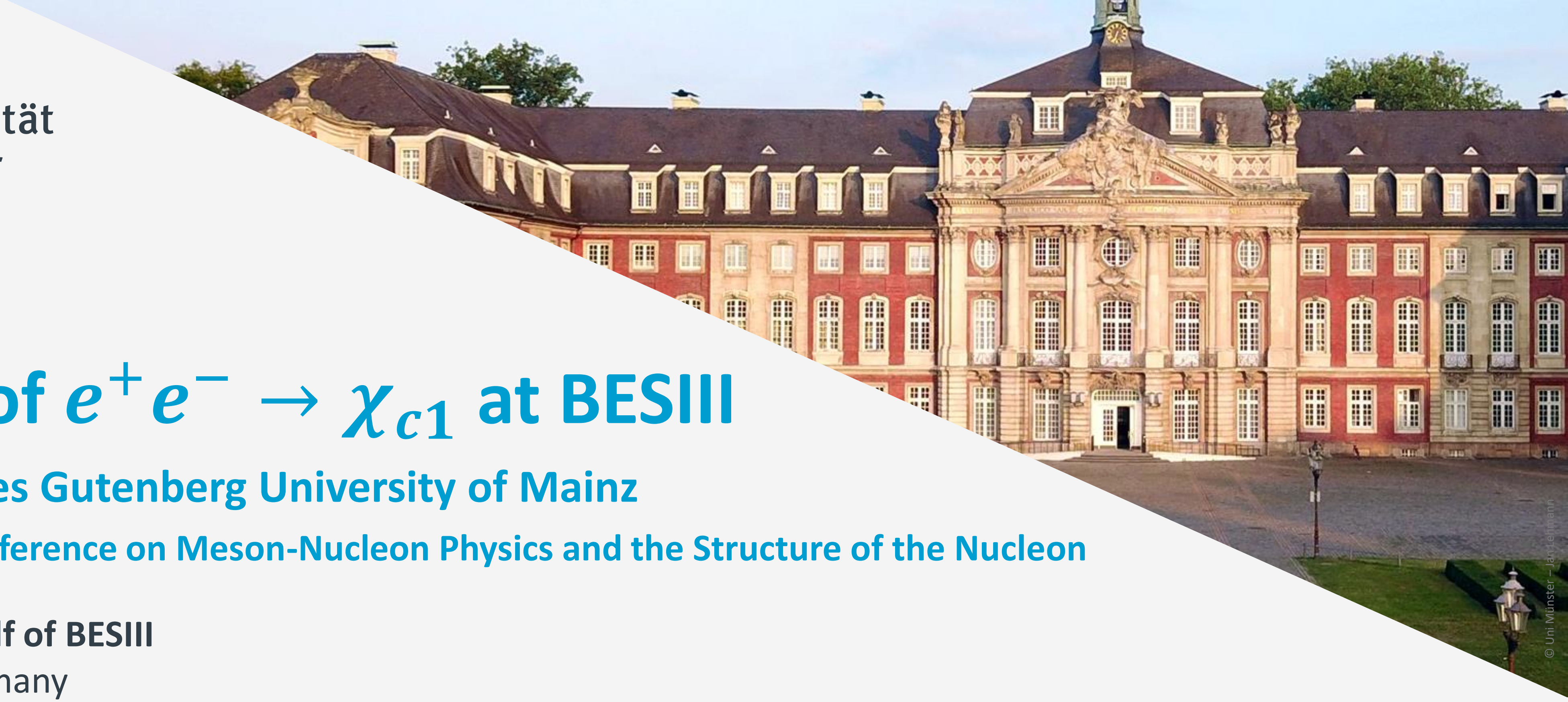

Observation of $e^+e^- \rightarrow \chi_{c1}$ at BESIII

MENU 2023 – Johannes Gutenberg University of Mainz

The 16th International Conference on Meson-Nucleon Physics and the Structure of the Nucleon

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MENU 2023

Graduiertenkolleg 2149
Research Training Group

DFG

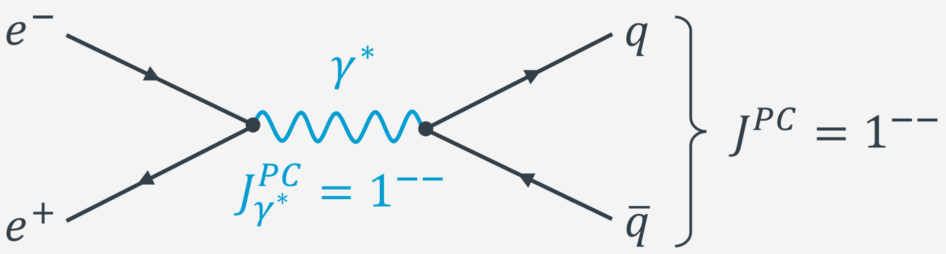
BESIII Beijing Spectrometer(BESIII) Experiment

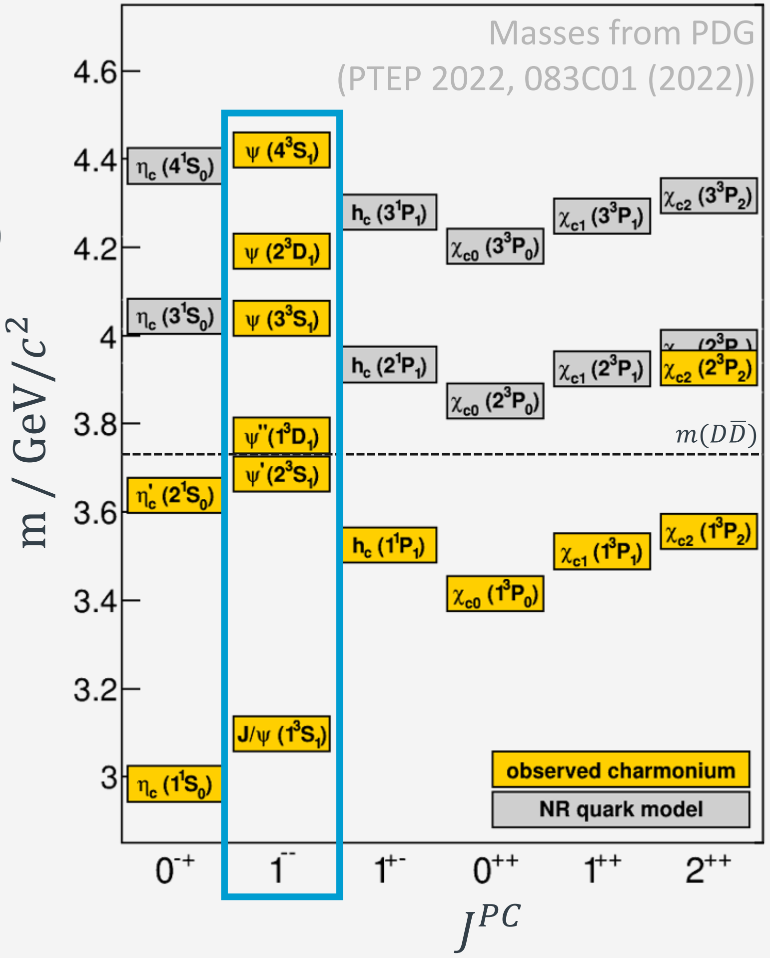
Direct Production of Hadronic Resonances in e^+e^- Annihilations

dominant process: production of vector resonances ($J^{PC} = 1^{--}$)

- e^+e^- annihilates dominantly into **one virtual photon γ^*** with $J^{PC}_{\gamma^*} = 1^{--}$
- virtual photon decays, e. g., into quark-antiquark pair ($q\bar{q}$-quarkonium resonance)
- in electromagnetic processes: conservation of P and C parity

$\rightarrow J^{PC}$ of resonance restricted to quantum numbers of virtual photon

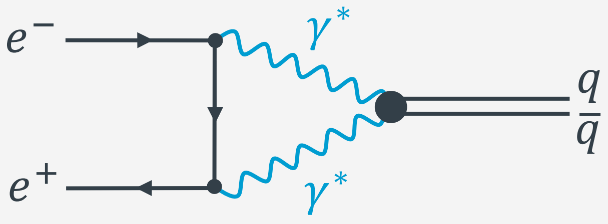




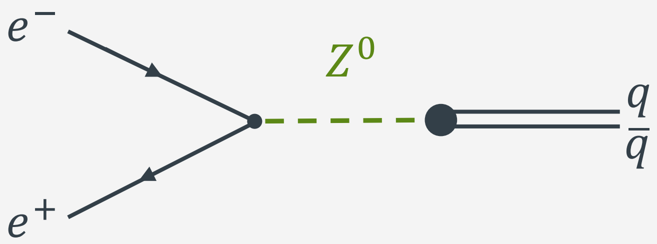
Direct Production of Hadronic Resonances in e^+e^- Annihilations

supressed: production of C-even resonances ($0^{-+}, 0^{++}, 1^{++}, 2^{++}, \ldots$)

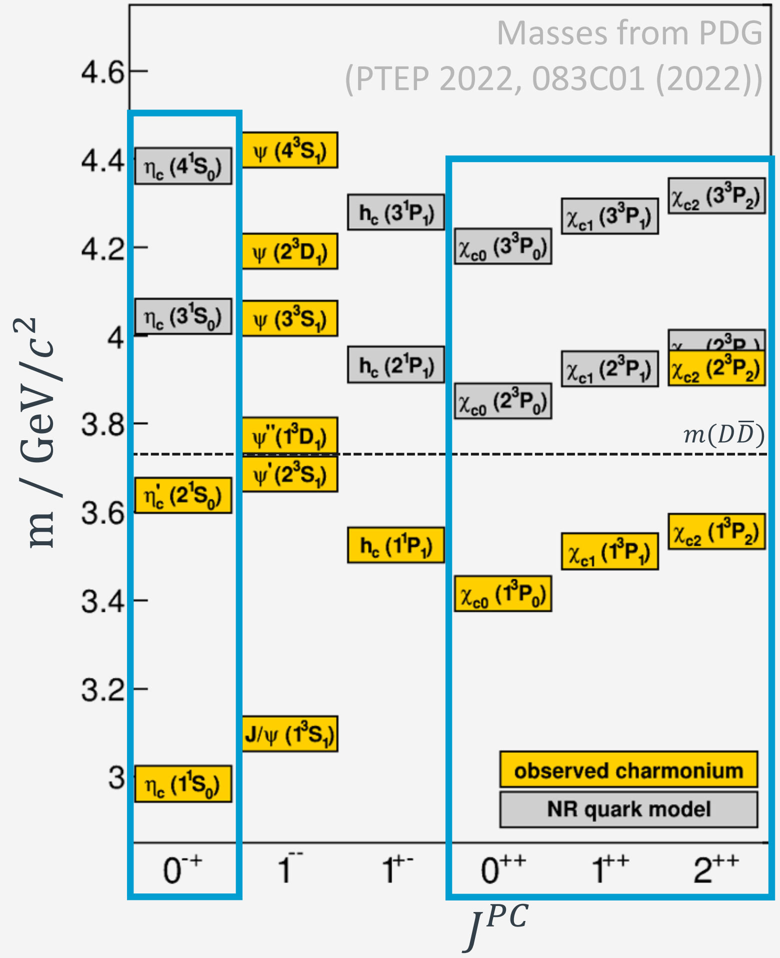
- forbidden via one virtual photon
- allowed via e^+e^- annihilation into **two virtual photons γ^*** or **neutral current Z^0**



via two virtual photons γ^*



via neutral current Z^0



Direct Production of Hadronic Resonances in e^+e^- Annihilations

supressed: production of C-even resonances ($0^{-+}, 0^{++}, 1^{++}, 2^{++}$, …)

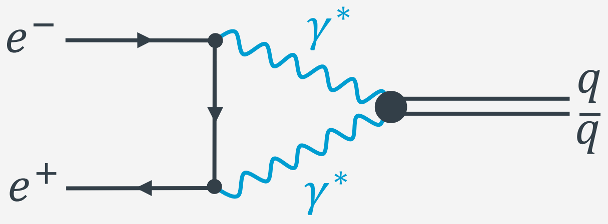
- first theoretical prediction in 1978 Kaplan, Kühn, PLB78, 252 (1978)
- experimental searches (so far unsuccessful):

most significant signal (2.5σ) by SND
M. N. Achasov et al., PLB800, 135074 (2020)

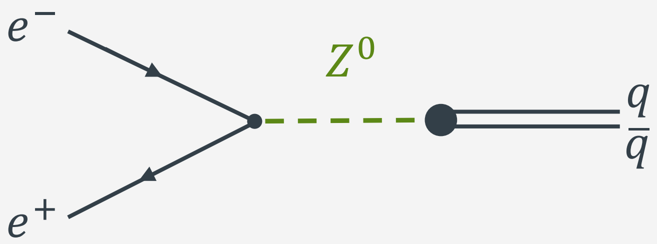
$$\underbrace{\eta, \eta'}_{0^{-+}}, \underbrace{f_0(980), f_0(1300), a_0(980)}_{0^{++}}, \underbrace{f_1(1285), \chi_{c1}(3872)}_{1^{++}}, \underbrace{f_2(1270), a_2(1320)}_{2^{++}}$$

by the ND, SND, CMD-3, and BESIII collaborations (see backup slides)

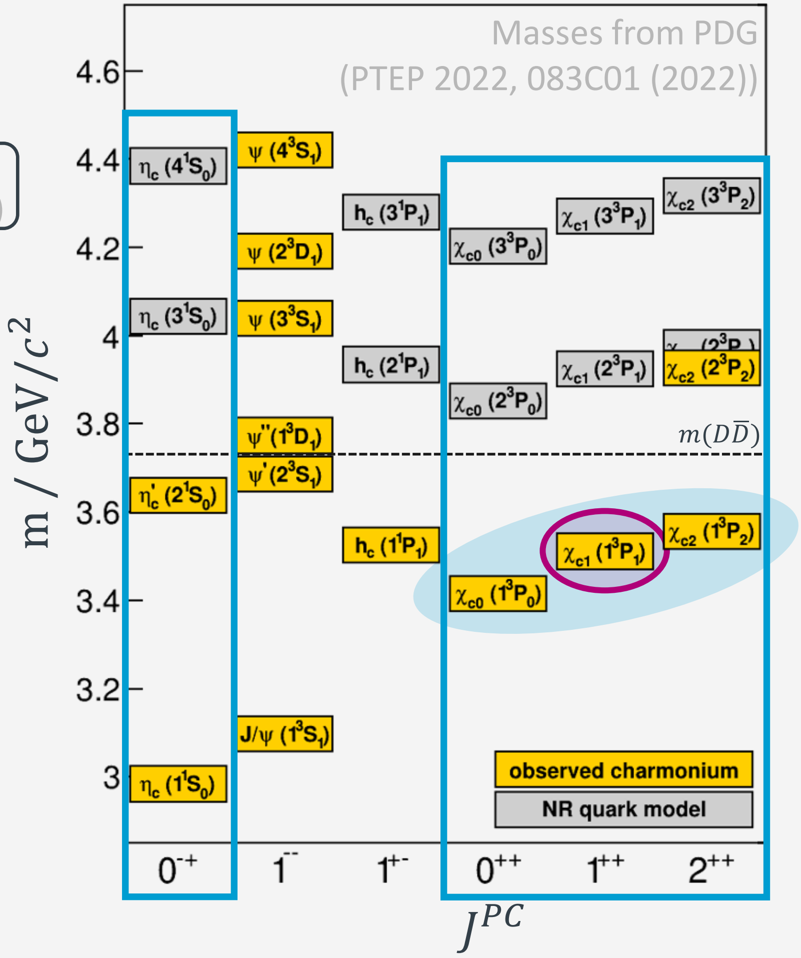
- direct production provides new approach for studying resonances properties
- promising candidate to search for at BESIII: $\boldsymbol{\chi_{c1}(1P)}$



via two virtual photons γ^*

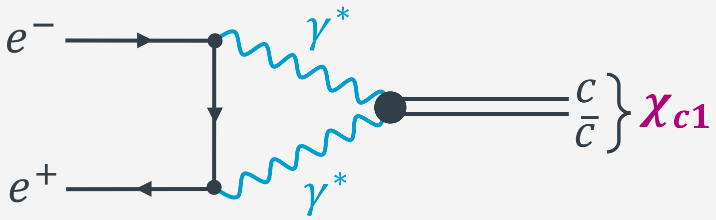


via neutral current Z^0

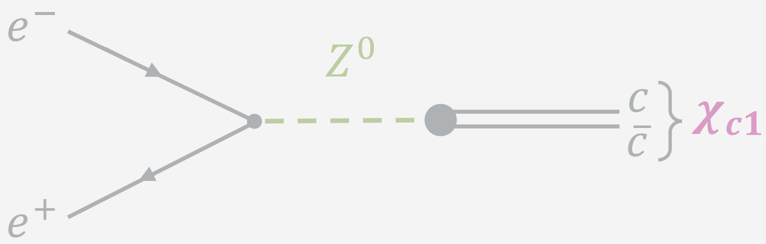


Theory Predictions for Direct χ_{c1} Production in e^+e^- Annihilations

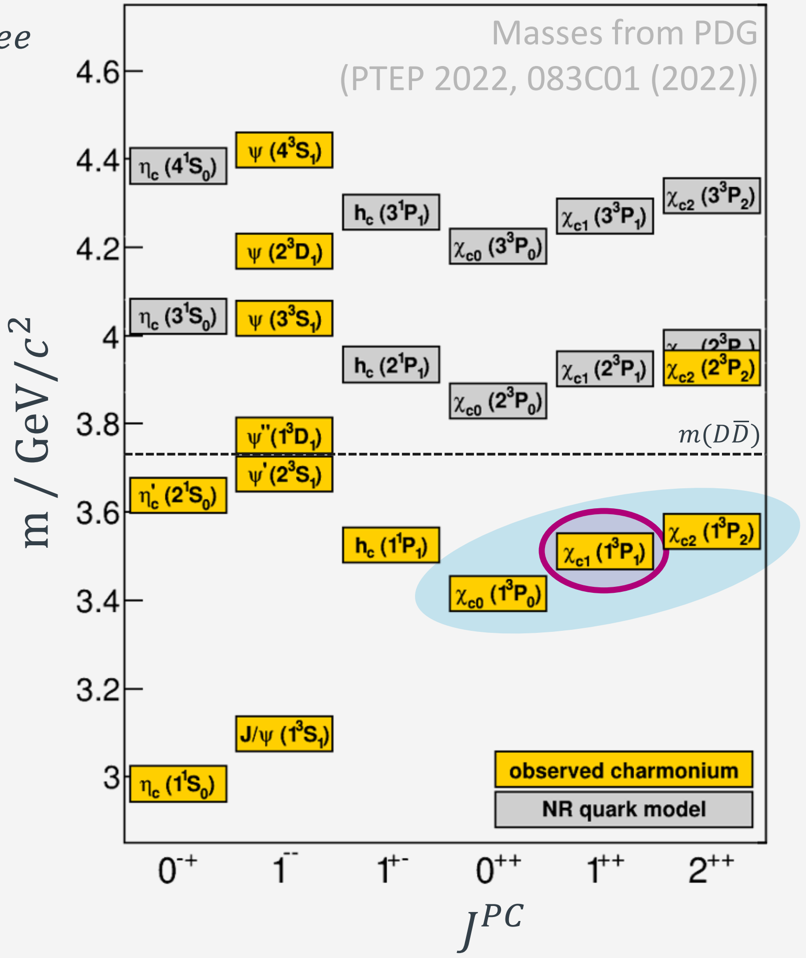
- cross section of $e^+e^- \to \chi_{c1}$ unknown, but proportional to χ_{c1} electronic width Γ_{ee}
- **theoretical predictions for Γ_{ee}:**
  - lower limit based on unitarity: $\Gamma_{ee} > 0.044$ eV
    Kaplan, Kühn, PLB78, 252 (1978)
  - using vector meson dominance model (VDM): $\Gamma_{ee} = 0.46$ eV
    Kaplan, Kühn, Safiani, NPB157, 125 (1979)
  - more recent calculations using VDM or non-relativistic QCD: $\Gamma_{ee} \approx 0.1$ eV
    Denig, Guo, Hanhart, Nefediev, PLB736, 221 (2014); Kivel, Vanderhaeghen, JHEP02, 032 (2016)
  - latest prediction: $\Gamma_{ee} = 0.41$ eV (+ study provides entire analysis strategy and predictions for experimental search for χ_{c1})
    Czyz, Kühn, Tracz, PRD94, 034033 (2016)



via two virtual photons γ^*



via neutral current Z^0

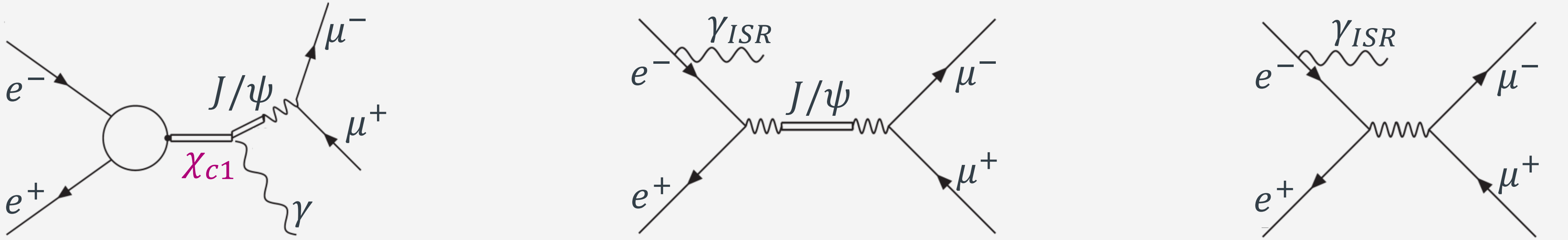


Czyz, Kühn, Tracz, PRD94, 034033 (2016)

Experimental Search for χ_{c1} as Proposed by H. Czyz, J. H. Kühn, S. Tracz (2016)

- prediction accounts for interference between **signal** and **irreducible ISR background processes** having same final state

$e^+e^- \to \chi_{c1} \to \gamma(J/\psi \to \mu^+\mu^-)$ $\quad$ $e^+e^- \to \gamma_{ISR}(J/\psi \to \mu^+\mu^-)$ and $e^+e^- \to \gamma_{ISR}\mu^+\mu^-$

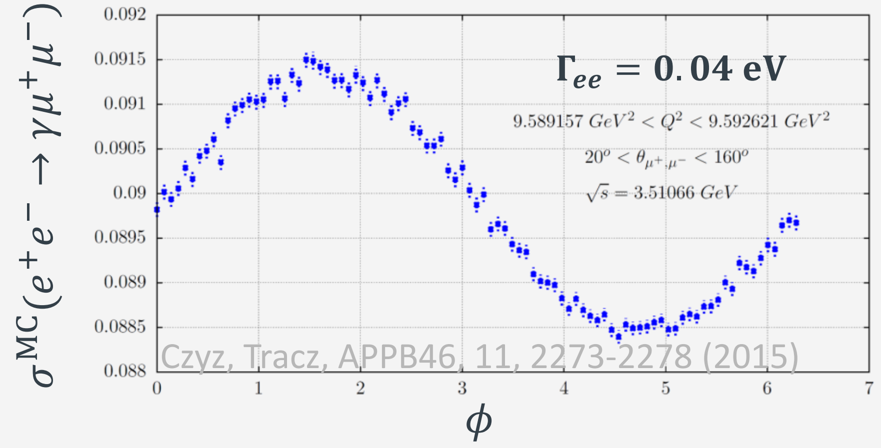


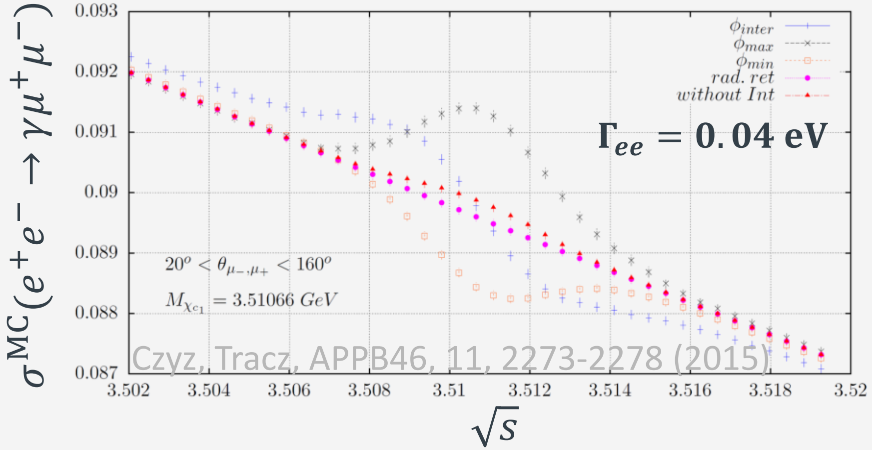
ISR: initial state radiation

$$\boxed{\mathcal{B}(\chi_{c1} \to \gamma J/\psi) = (34.3 \pm 1.0)\%, \quad \mathcal{B}(J/\psi \to \mu^+\mu^-) = (5.961 \pm 0.033)\%}$$

- amplitudes and their interference implemented into **PHOKHARA**[1)] Monte Carlo (MC) event generator

1) Czyz, Grzelinska, Kühn, PRD81, 094014 (2010)





depending on the relative phase ϕ between signal and background the cross section line shape σ^{MC} changes significantly

Czyz, Kühn, Tracz, PRD94, 034033 (2016)

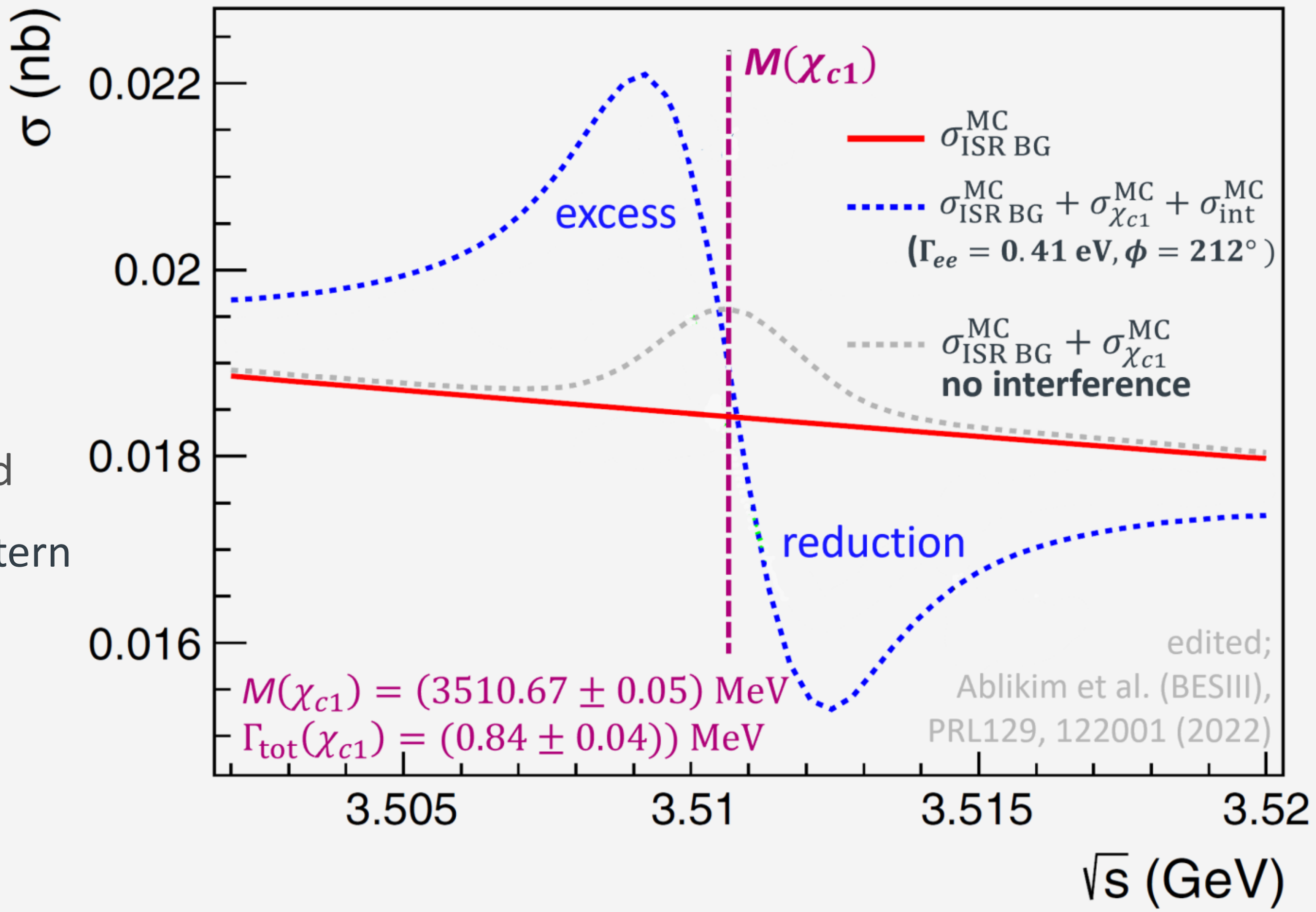
Experimental Search for χ_{c1} as Proposed by H. Czyz, J. H. Kühn, S. Tracz (2016)

prediction taking **interference** (int) between **signal** (χ_{c1}) and **irreducible ISR background** (ISR BG) into account:

- **below χ_{c1} mass** $M(\chi_{c1})$:
  constructive interference (excess of events)
- **at χ_{c1} mass**: minimal effect,
  almost no signal beyond irreducible background
- **above χ_{c1} mass**:
  deconstructive interference (reduction of events)
- **if no interference**: largest excess at χ_{c1} mass expected

$\rightarrow$ χ_{c1} production mainly observable as interference pattern

$\rightarrow$ signal of up to 75% of the irreducible ISR background



via energy scan in the χ_{c1} vicinity BESIII should be able to observe the interference pattern

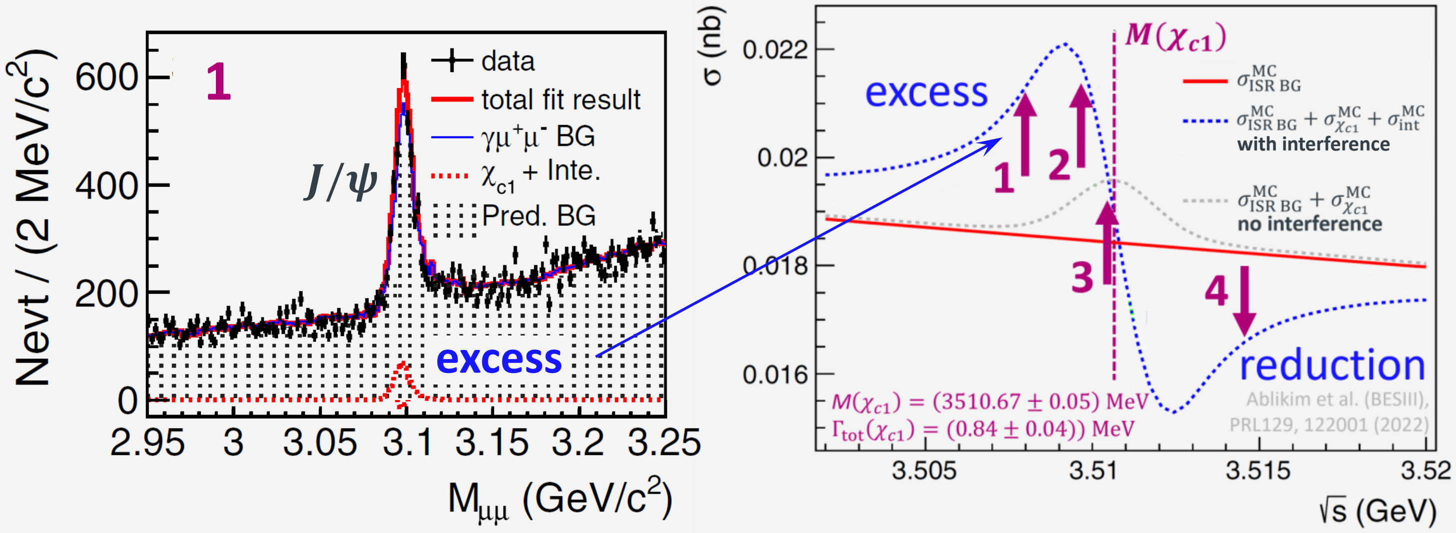
Analysis Strategy at BESIII (Ablikim et al. (BESIII), PRL129, 122001 (2022))

Energy scan in χ_{c1} vicinity:

- four data points in χ_{c1} mass region collected at BESIII in 2017
- total integrated luminosity: $\mathcal{L}_{\text{int}}^{\text{tot}} = 446\ \text{pb}^{-1}$
  (measured by large angle Bhabha events)
- uncertainty of center-of-mass energy: $\Delta E_{\text{cms}} = \pm 50\ \text{keV}$
- energy spread of $(736 \pm 27)\ \text{keV}$
  (both measured by beam energy measurement system)

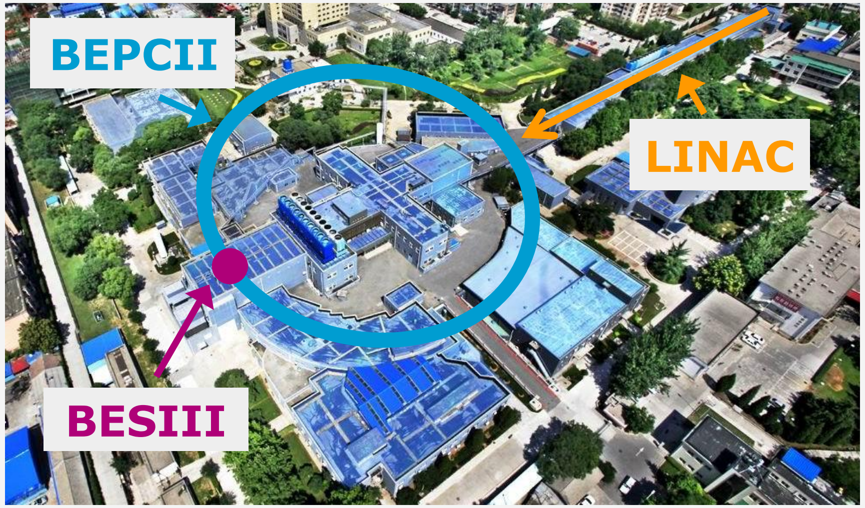
data point	E_{cms} (GeV)	$\mathcal{L}_{\text{int}}$ (pb^{-1})
1	3.5080	$181.79 \pm 0.04_{\text{stat}} \pm 1.04_{\text{sys}}$
2	3.5097	$39.29 \pm 0.02_{\text{stat}} \pm 0.22_{\text{sys}}$
3	3.5104	$183.64 \pm 0.04_{\text{stat}} \pm 1.05_{\text{sys}}$
4	3.5146	$40.92 \pm 0.02_{\text{stat}} \pm 0.23_{\text{sys}}$

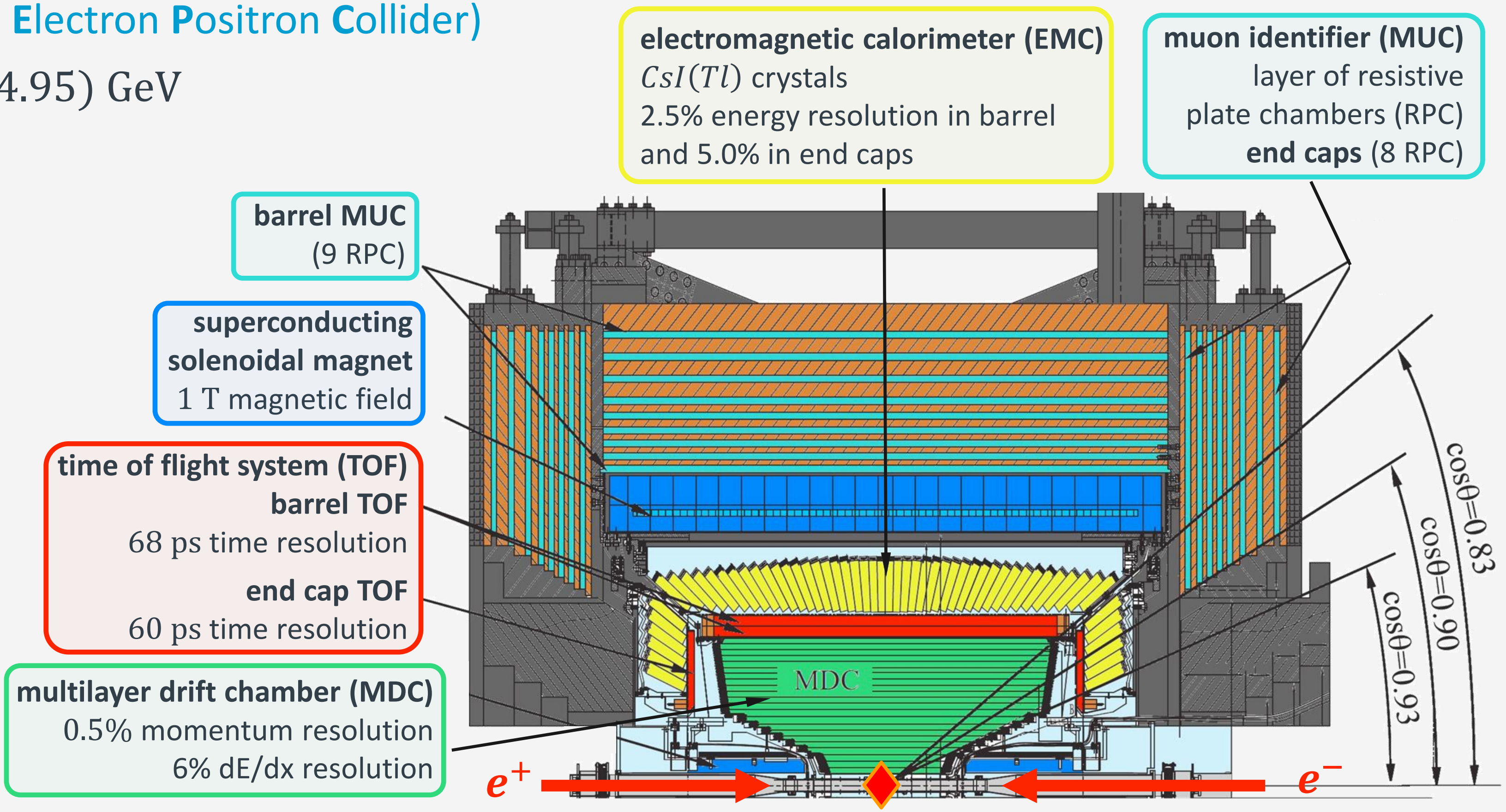
1. search for $e^+e^- \to \chi_{c1} \to \gamma(J/\psi \to \mu^+\mu^-)$
2. analyse/ reduce background processes
3. look for excess or reduction of signal beyond background via invariant mass $M_{\mu\mu}$ distribution of J/ψ candidates in all four data sets
4. compare with predicted interference pattern



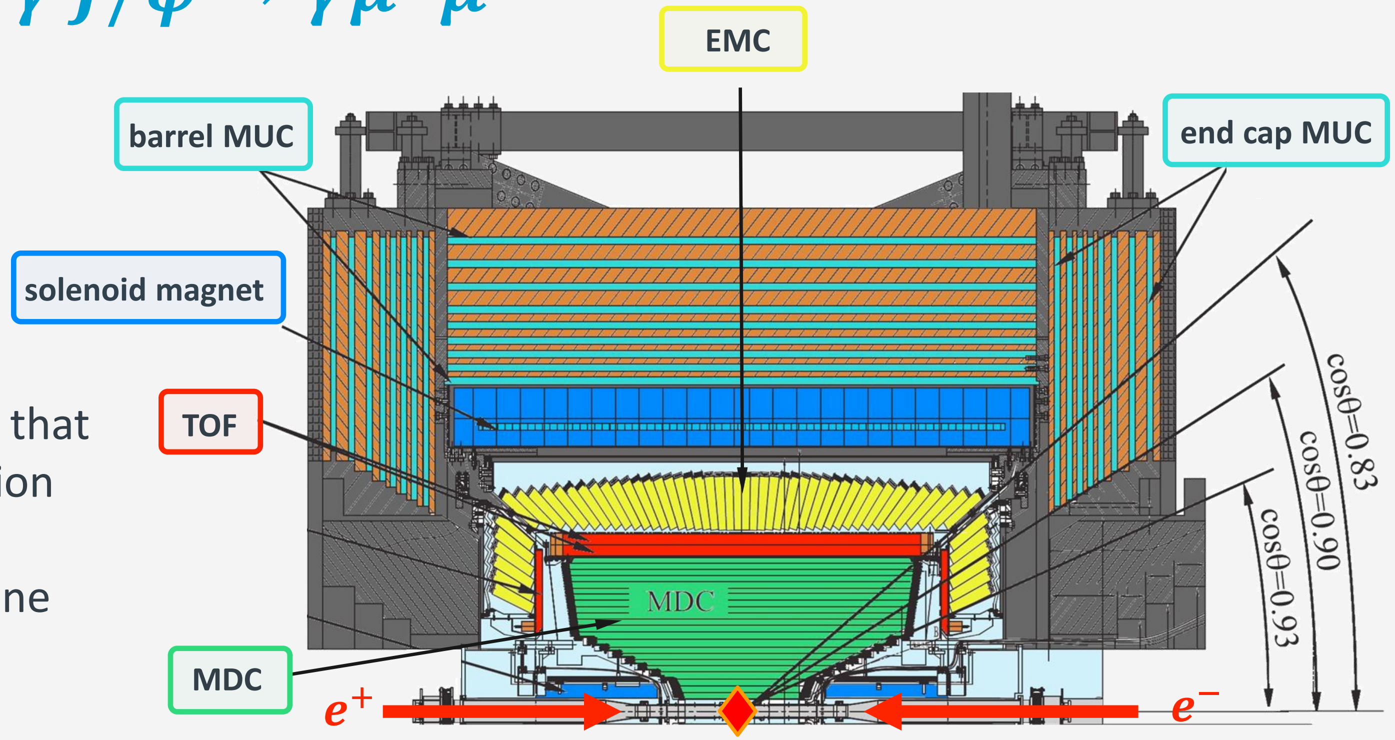
BESIII Experiment (Beijing, China)

- **BESIII (Beijing Spectrometer)** = detector around the interaction point ♦ of the symmetric double ring e^+e^- collider **BEPCII (Beijing Electron Positron Collider)**
- center-of-mass energy range of $(2.00 - 4.95)$ GeV
- peak luminosity of $1 \cdot 10^{33}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$
- solid angle coverage of 93% of 4π





Event Selection for $e^+e^- \rightarrow \chi_{c1} \rightarrow \gamma J/\psi \rightarrow \gamma\mu^+\mu^-$



final state reconstruction:
- two good, oppositely charged tracks
- at least one good photon

general, standard BESIII event selection criteria

four constraint kinematic fit:
- constrain total four momentum of $\gamma\mu^+\mu^-$ system to that of initial state for energy and momentum conservation (= four constraints)
- select out of reconstructed photon candidates the one with lowest χ^2 of kinematic fit

muon identification:
- require EMC energy deposition of $E_{\mathrm{EMC}} < 0.4\ \mathrm{GeV}$
- exclude polar angles $0.8 < |cos\theta_\mu| < 0.86$ (where EMC is blind) to suppress Bhabha contamination

exclude good photon candidates in EMC end caps:
- exclude polar angles $|cos\theta_\gamma| > 0.80$ to suppress ISR background reactions

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Background Studies

data points	E_{cms} (GeV)	$\mathcal{L}_{int}$ (pb^{-1})
two points of ψ' scan	3.581	$85.28 \pm 0.03_{stat} \pm 0.58_{sys}$
	3.670	$83.61 \pm 0.03_{stat} \pm 0.57_{sys}$
ψ''	3.773	$2932.39 \pm 0.17_{stat} \pm 12.61_{sys}$
high luminosity	4.178	$3192.49 \pm 0.20_{stat} \pm 15.99_{sys}$

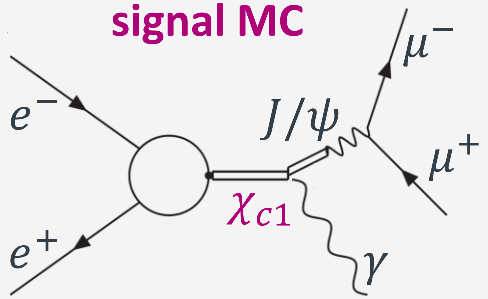
control data samples for background studies:

- four data points above χ_{c1} mass collected at BESIII
- no signal component
- total integrated luminosity: $\mathcal{L}_{int}^{tot} = 6294\ \mathrm{pb}^{-1}$

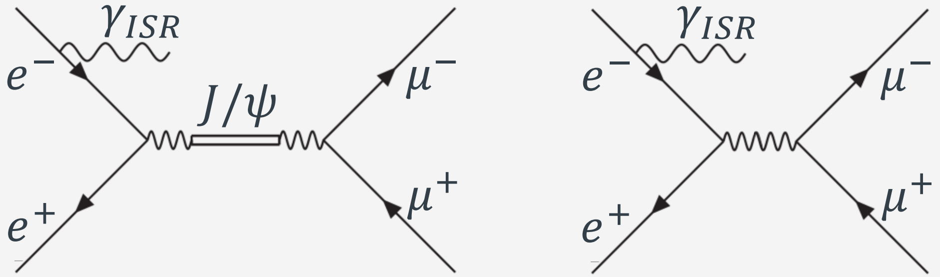
Monte Carlo (MC) simulations at each energy point:

- exclusive MC samples of 200 Mio events each using PHOKHARA generator
  - signal simulation: $e^+e^- \to \chi_{c1} \to \gamma(J/\psi \to \mu^+\mu^-)$
  - irreducible background simulation:
    $e^+e^- \to \gamma_{ISR}(J/\psi \to \mu^+\mu^-)$ and $e^+e^- \to \gamma_{ISR}\mu^+\mu^-$
    + interference (using electronic width $\Gamma_{ee}^{J/\psi}$ of J/ψ and fixed relative size)
  - + interference sample between signal and background
    (using Γ_{ee} and ϕ as input parameters)
- inclusive MC samples at 3.773 GeV and 4.178 GeV

signal MC



irreducible ISR background MC



Background Studies

non-$\gamma_{(ISR)}\mu^+\mu^-$ background

- studied using inclusive MC and control data samples at 3.773 GeV and 4.178 GeV
- found to be **negligible ($< 0.2\%$)**

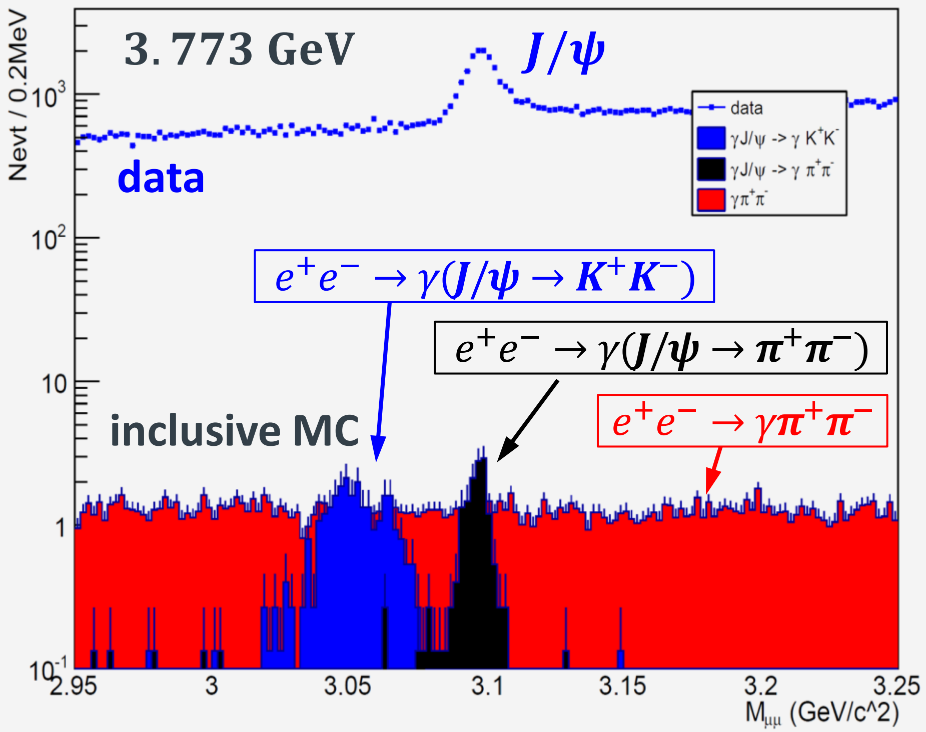
→ **high purity data achieved** of $\gamma\mu^+\mu^-$ final state

BUT: remaining **irreducible background processes** as they feature the same final state

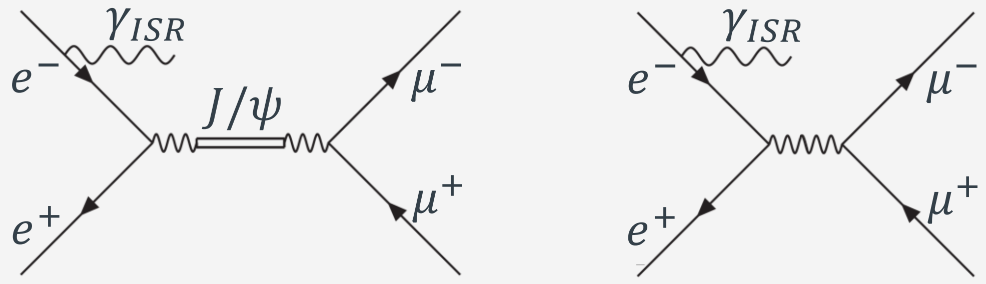
→ precise description of these background reactions needed

→ approach: use MC simulation of background by PHOKHARA

verification needed



irreducible ISR background processes



Background Studies

prove of irreducible ISR background description of PHOKHARA event generator

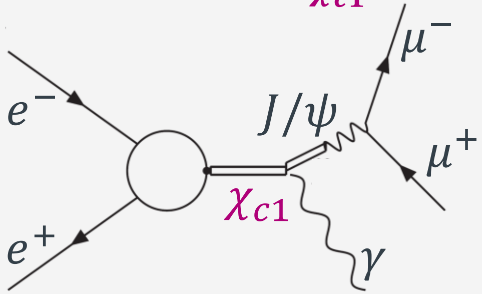
- performance of **unbinned two-dimensional fit to $M_{\mu\mu}$ and $|cos\theta_\mu|$ distributions of all four control data samples**

PDF: $\underbrace{N_{\chi_{c1}}\mathbf{MC}_{\chi_{c1}} + N_{\text{bg}}\mathbf{MC}_{\text{ISR bg}}}$

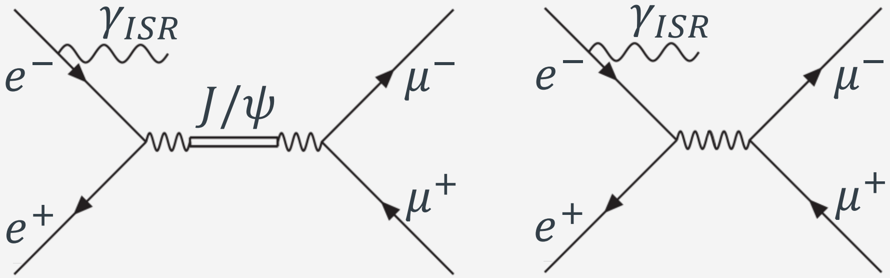
no interference included

line shapes extracted from MC simulations

signal MC ($\mathbf{MC}_{\chi_{c1}}$)



irreducible ISR background MC ($\mathbf{MC}_{\text{ISR bg}}$)

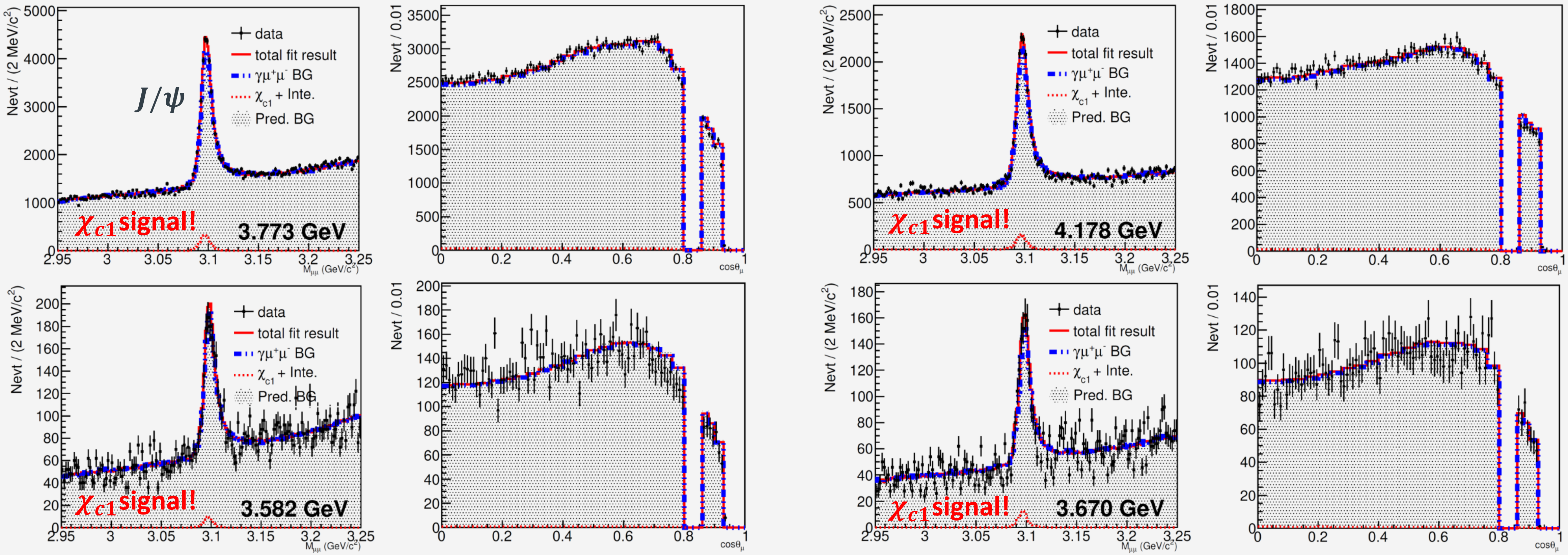


- **χ_{c1} signal line shape $\mathbf{MC}_{\chi_{c1}}$** from signal MC at 3.5080 GeV, smeared with Gaussian
- **background line shape $\mathbf{MC}_{\text{ISR bg}}$** from MC of irreducible background processes
- number of signal events $N_{\chi_{c1}}$ and irreducible background events N_{bg} are free fit parameters
- **$N_{\chi_{c1}} = 0$ expected for all control data samples as they do not contain any signal**

Background Studies

prove of irreducible ISR background description of PHOKHARA event generator

- unbinned 2-d fit to $M_{\mu\mu}$ and $|cos\theta_{\mu}|$ within $[2.95, 3.25]$ GeV/c^2 and $[0, 1]$ of all four control data samples



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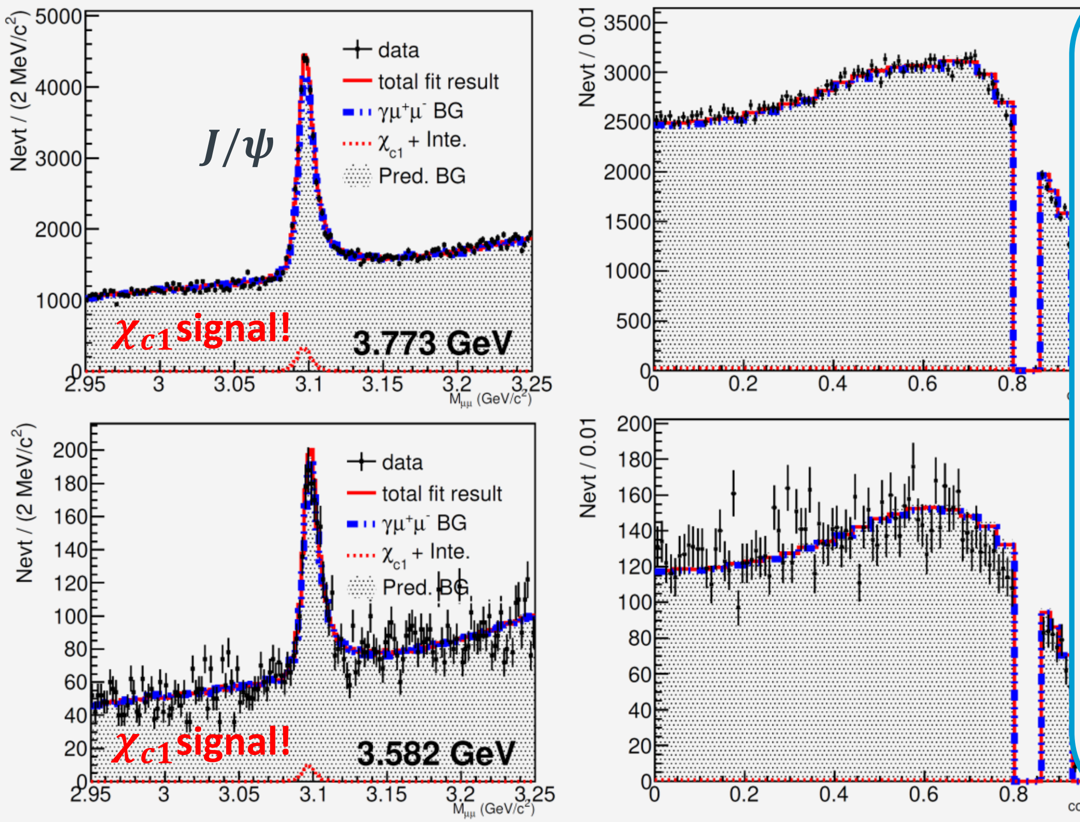
Background Studies

prove of irreducible ISR background description of PHOKHARA event generator

- **unbinned 2-d fit to $M_{\mu\mu}$ and $|cos\theta_{\mu}|$ within $[2.95, 3.25]$ GeV/c^2 and $[0, 1]$ of all four control data samples**



$\sqrt{s}$ (MeV)	$\mathcal{L}$ (pb^{-1})	$N_{\chi_{c1}}$ w/o corr.
3773.0	2932.4	1027 ± 140 (7.5σ; $1.9\sigma_{180}$)
4178.4	3192.5	522 ± 104 (5.1σ; $1.2\sigma_{180}$)
3581.5	85.3	31 ± 29 (1.1σ; $1.6\sigma_{180}$)
3670.2	83.6	38 ± 26 (1.5σ; $2.2\sigma_{180}$)

→ **$N_{\chi_{c1}} \neq 0$ observed,** but $N_{\chi_{c1}} = 0$ expected

→ **discrepancy between data and MC** of irreducible background (statistical significance $< 2.3\sigma$, when normalized to 180 pb^{-1})

- due to uncertainties of electronic width $\Gamma_{ee}^{J/\psi}$ of J/ψ
- due to limitations of PHOKHARA event generator

Background Studies

prove of irreducible ISR background description of PHOKHARA event generator

- **unbinned 2-d fit to $M_{\mu\mu}$ and $|cos\theta_\mu|$ within $[2.95, 3.25]$ GeV$/c^2$ and $[0, 1]$ of all four control data samples**

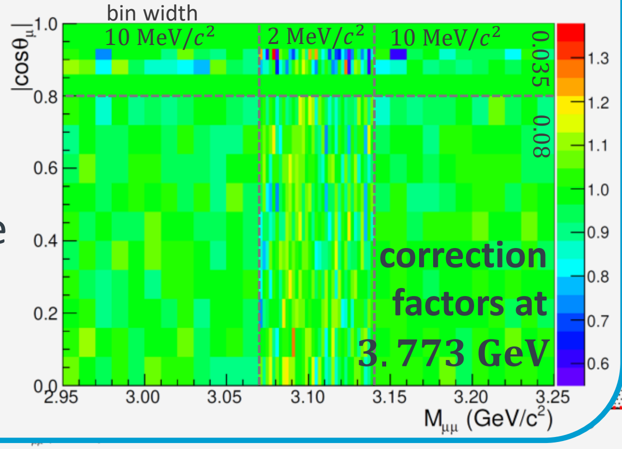
correction of data-MC discrepancy

by 2-d comparison of binned $M_{\mu\mu}$ and $|cos\theta_\mu|$ distributions between data and MC at 3.773 GeV

$\rightarrow$ obtained factors $f(M_{\mu\mu}, cos\theta_\mu)$ used to reweight event-by-event the MC simulations of irreducible background at all energy points

cross checks:

- using factors from 4.178 GeV sample
- via 1-d fit to $M_{\mu\mu}$



$\sqrt{s}$ (MeV)	$\mathcal{L}$ (pb^{-1})	$N_{\chi_{c1}}$ w/o corr.
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$\rightarrow$ **$N_{\chi_{c1}} \neq 0$ observed,** but $N_{\chi_{c1}} = 0$ expected

$\rightarrow$ **discrepancy between data and MC** of irreducible background (statistical significance $< 2.3\sigma$, when normalized to 180 pb^{-1})

- due to uncertainties of electronic width $\Gamma_{ee}^{J/\psi}$ of J/ψ
- due to limitations of PHOKHARA event generator

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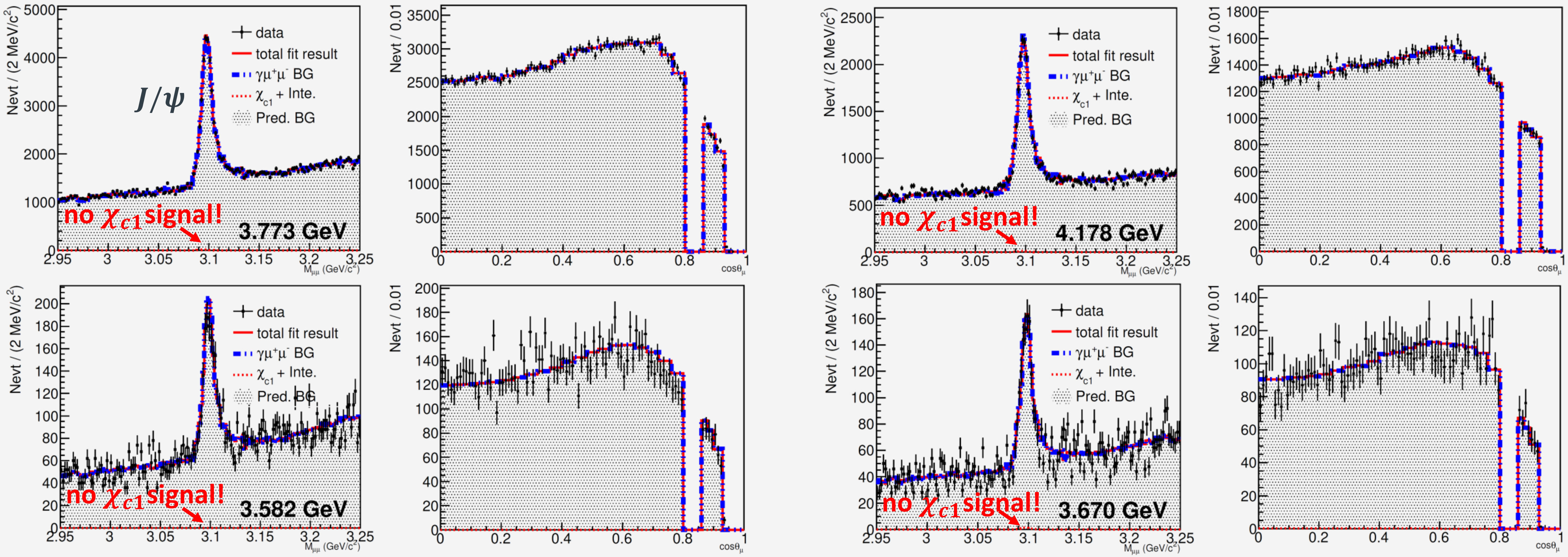
Background Studies

with MC correction

prove of irreducible ISR background description of PHOKHARA event generator

- unbinned 2-d fit to $M_{\mu\mu}$ and $|cos\theta_{\mu}|$ within $[2.95, 3.25]$ GeV/c^2 and $[0, 1]$ of all four control data samples

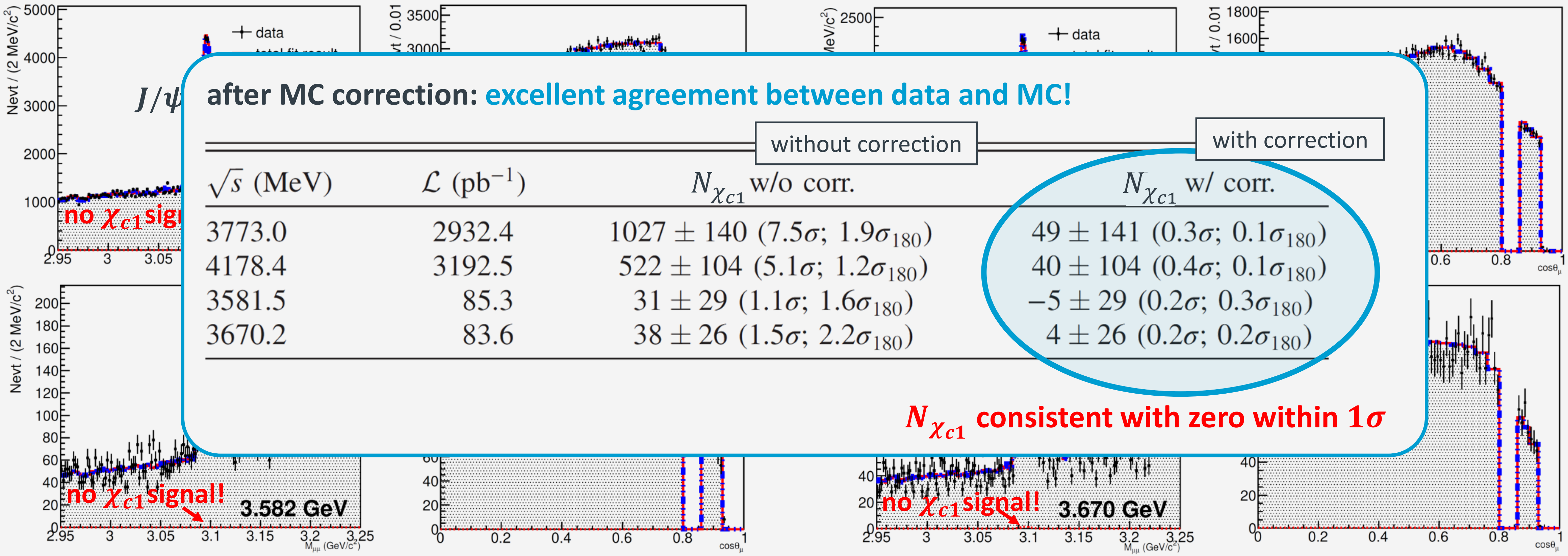


Background Studies

with MC correction

prove of irreducible ISR background description of PHOKHARA event generator

- unbinned 2-d fit to $M_{\mu\mu}$ and $|cos\theta_{\mu}|$ within $[2.95, 3.25]$ GeV/c^2 and $[0, 1]$ of all four control data samples



after MC correction: excellent agreement between data and MC!

$\sqrt{s}$ (MeV)	$\mathcal{L}$ (pb^{-1})	without correction: $N_{\chi_{c1}}$ w/o corr.	with correction: $N_{\chi_{c1}}$ w/ corr.
3773.0	2932.4	1027 ± 140 (7.5σ; $1.9\sigma_{180}$)	49 ± 141 (0.3σ; $0.1\sigma_{180}$)
4178.4	3192.5	522 ± 104 (5.1σ; $1.2\sigma_{180}$)	40 ± 104 (0.4σ; $0.1\sigma_{180}$)
3581.5	85.3	31 ± 29 (1.1σ; $1.6\sigma_{180}$)	-5 ± 29 (0.2σ; $0.3\sigma_{180}$)
3670.2	83.6	38 ± 26 (1.5σ; $2.2\sigma_{180}$)	4 ± 26 (0.2σ; $0.2\sigma_{180}$)

$N_{\chi_{c1}}$ consistent with zero within 1σ

Extraction of χ_{c1} Signal Events

- performance of **2-d unbinned maximum likelihood fit to $M_{\mu\mu}$ and $|cos\theta_\mu|$ of all four χ_{c1} data samples, individually**

PDF: $$\underbrace{N_{\chi_{c1}}\mathbf{MC}_{\chi_{c1}} + N_{bg}\mathbf{MC}_{\mathbf{ISR\ bg}} + \underbrace{N_{\text{int}}\mathbf{MC}_{\mathbf{int}}}_{\text{interference included}}}_{\text{line shapes extracted from binned MC histograms}}$$

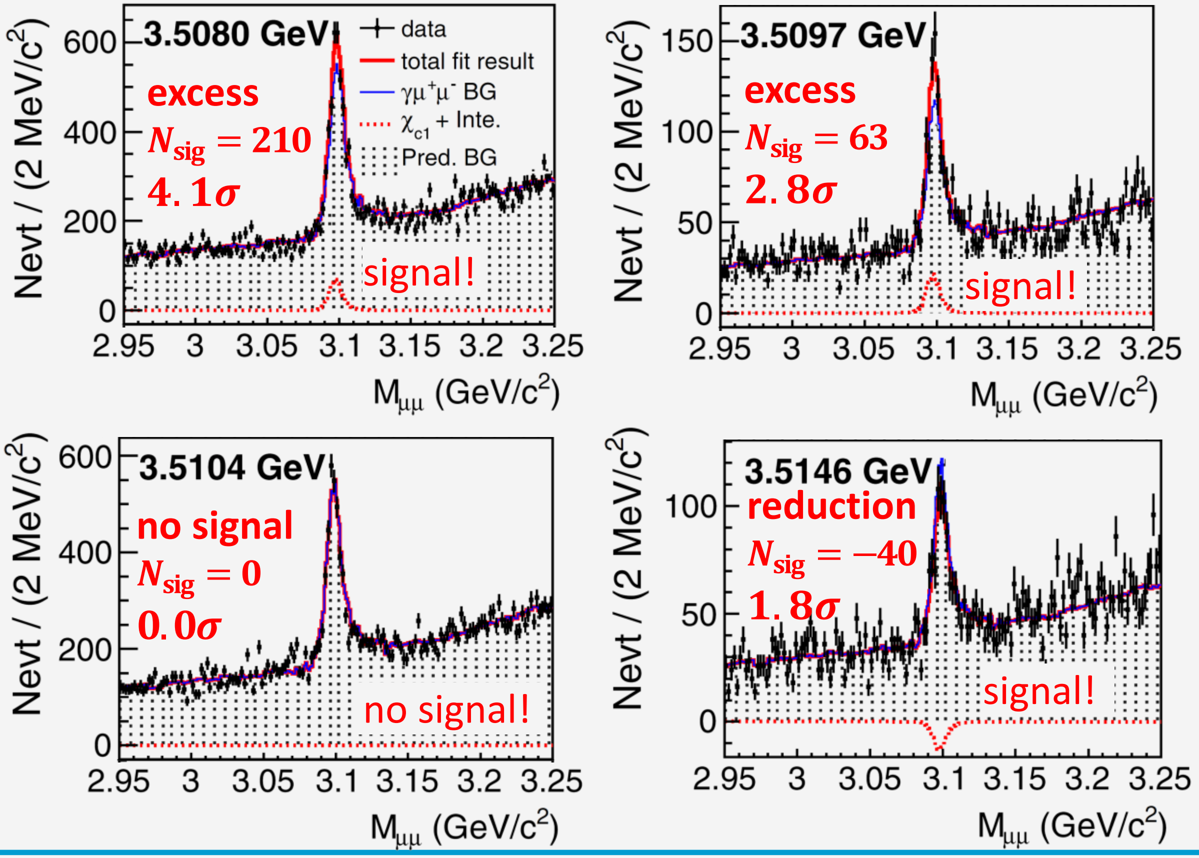
- **χ_{c1} signal line shape $\mathbf{MC}_{\chi_{c1}}$** from signal MC
- **background line shape $\mathbf{MC}_{\mathbf{ISR\ bg}}$** from **corrected MC** of irreducible background processes
- **interference line shape $\mathbf{MC}_{\mathbf{int}}$** from **corrected MC** of interference between signal and background
  (using square root of correction factors $\sqrt{f(M_{\mu\mu}, cos\theta_\mu)}$ for correction)
- interference constraint to[1] $N_{\text{int}} = a(\Gamma_{ee}, \phi) \cdot \sqrt{N_{\chi_{c1}} \cdot N_{\text{bg}}}$ with a describing dependency of the coherent sum of signal and background processes from χ_{c1} electronic width Γ_{ee} and relative phase ϕ between signal and background, a is determined from signal MC using Γ_{ee} and ϕ (determination of Γ_{ee} and ϕ see later)

1) Czyz, Kühn, Tracz, PRD94, 034033 (2016)

- number of χ_{c1} signal events $N_{\chi_{c1}}$ and irreducible background events N_{bg} are free fit parameters

Extraction of χ_{c1} Signal Events

- 2-d unbinned maximum likelihood fit to $M_{\mu\mu}$ and $|cos\theta_{\mu}|$ within $[2.95, 3.25]$ GeV/c^2 and $[0,1]$ of all four χ_{c1} data samples



first observation of $e^+e^- \to \chi_{c1}$

(as predicted in Czyz, Kühn, Tracz, PRD94, 034033 (2016))

signal yield $N_{\text{sig}} = N_{\chi_{c1}} + N_{\text{int}}$ and significances:

		without MC correction	with MC correction
$\sqrt{s}$ (MeV)	$\mathcal{L}$ (pb^{-1})	N_{sig} w/o corr.	N_{sig} w/ corr.
3508.0	181.8	320 ± 51 (6.5σ)	$210 \pm 52 \pm 18$ $(4.1\sigma;\ 4.0\sigma_{\text{low}})$
3509.7	39.3	85 ± 24 (3.9σ)	$63 \pm 24 \pm 6$ $(2.8\sigma;\ 2.7\sigma_{\text{low}})$
3510.4	183.6	100 ± 48 (1.7σ)	$0^{+16}_{-19} \pm 23$ $(0.0\sigma;\ 0.0\sigma_{\text{low}})$
3514.6	40.9	-16^{+16}_{-21} (0.7σ)	$-40 \pm 22 \pm 7$ $(1.8\sigma;\ 1.6\sigma_{\text{low}})$
Combined	445.6	$\cdots$	$\cdots$ $(5.3\sigma;\ 5.1\sigma_{\text{low}})$

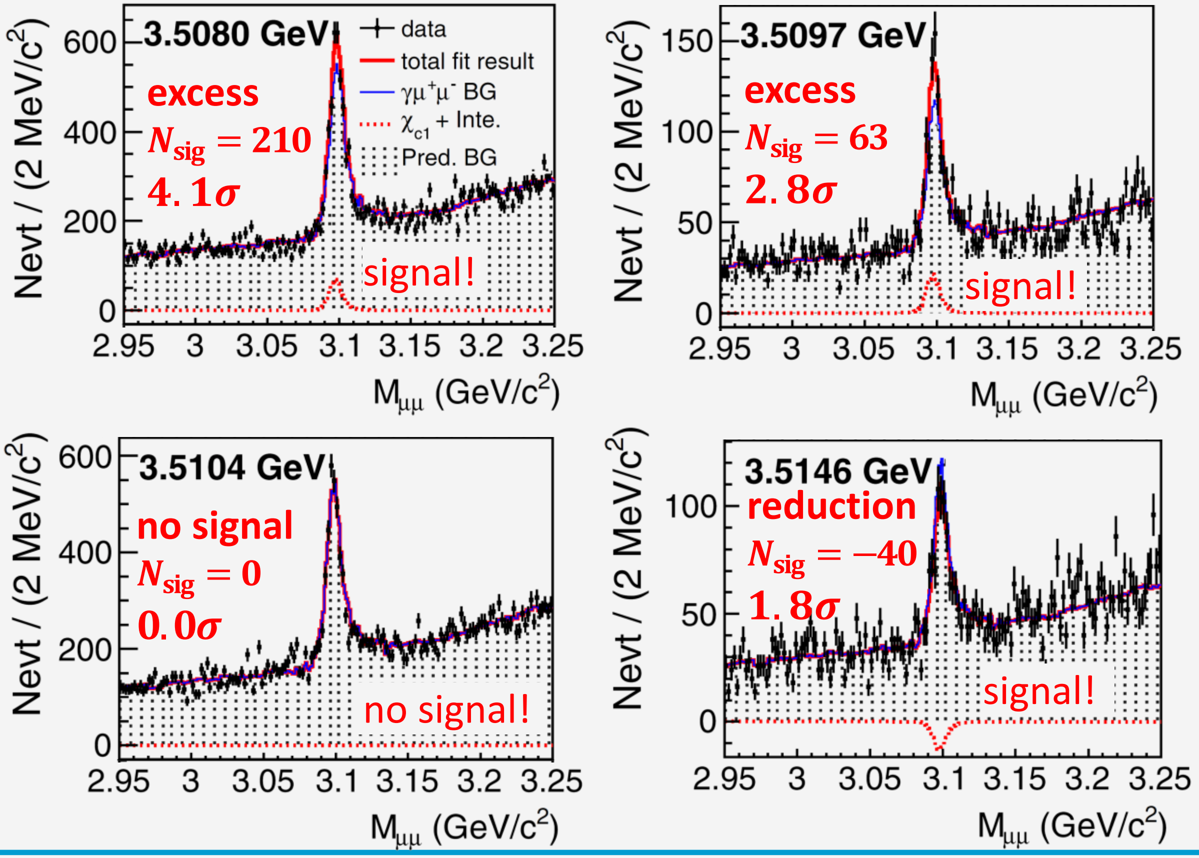
statistical significance

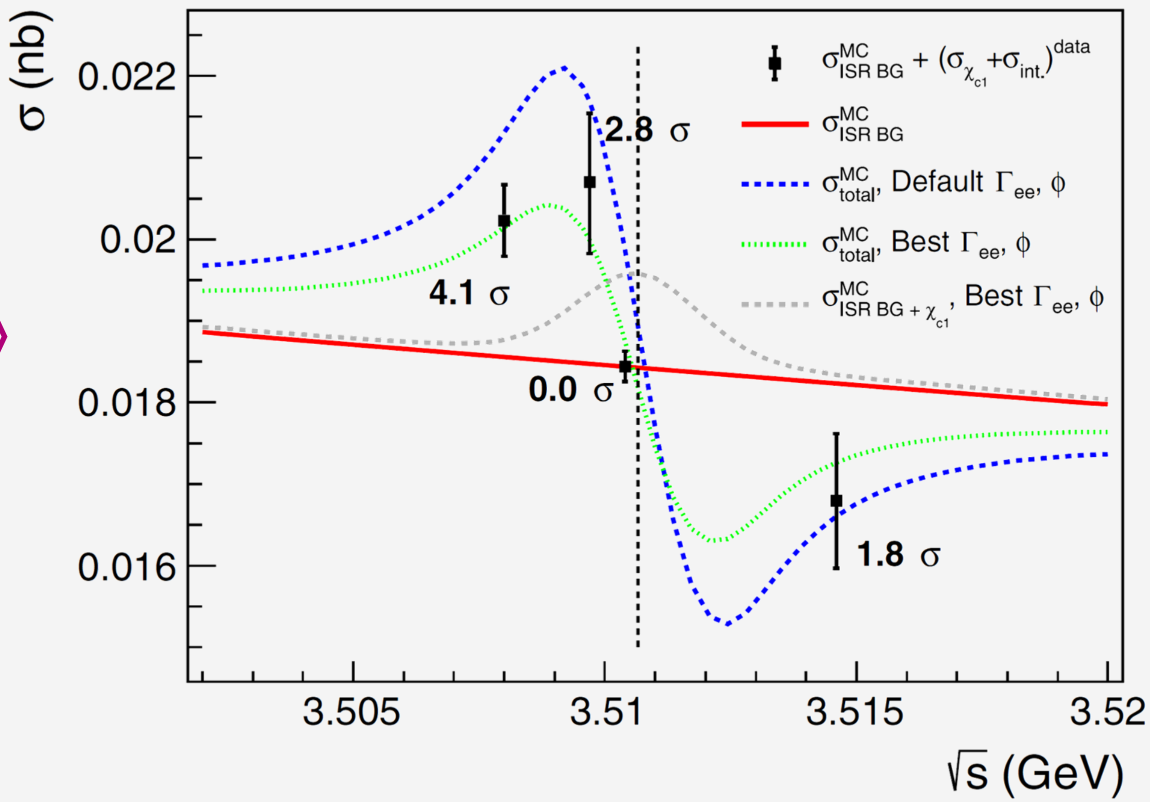
lowest significance with systematics

- combined statistical significance of all four χ_{c1} data samples: 5.3σ
- taking systematic effects into account: **lowest significance 5.1σ**

Extraction of χ_{c1} Signal Events

determination of total cross section $\sigma^{\mathrm{MC}}_{\mathrm{ISR\,bg}} + \left(\sigma_{\chi_{c1}} + \sigma_{\mathrm{int}}\right)^{\mathrm{data}} = \sigma^{\mathrm{MC}}_{\mathrm{ISR\,bg}} + N_{\mathrm{sig}}/(\mathcal{L}\cdot\epsilon)$, with efficiencies ϵ obtained from signal MC simulations, $\mathcal{L}$ being the integrated luminosity, $\sigma^{\mathrm{MC}}_{\mathrm{ISR\,bg}}$ calculated using PHOKHARA





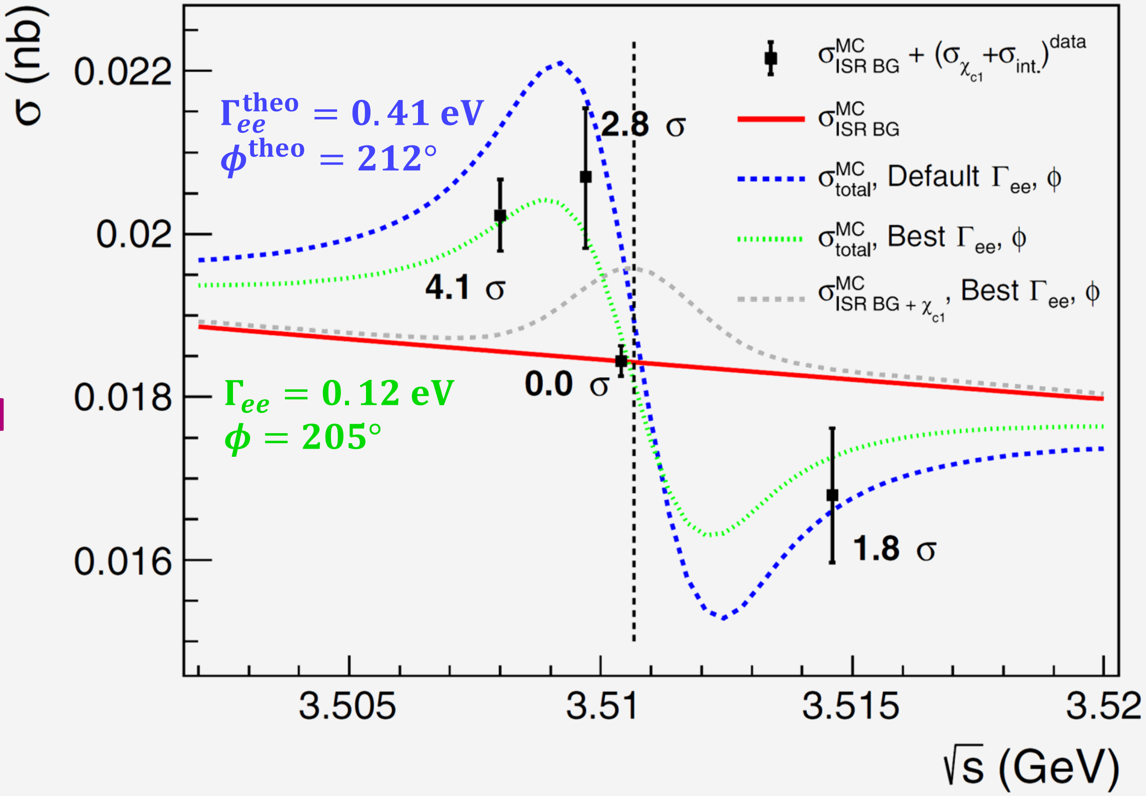
Extraction of χ_{c1} Signal Events

determination of total cross section $\sigma^{\mathrm{MC}}_{\mathrm{ISR\,bg}} + \left(\sigma_{\chi_{c1}} + \sigma_{\mathrm{int}}\right)^{\mathrm{data}} = \sigma^{\mathrm{MC}}_{\mathrm{ISR\,bg}} + N_{\mathrm{sig}}/(\mathcal{L}\cdot\epsilon)$, with efficiencies ϵ obtained from signal MC simulations, $\mathcal{L}$ being the integrated luminosity, $\sigma^{\mathrm{MC}}_{\mathrm{ISR\,bg}}$ calculated using PHOKHARA

- **statistical tests** to validate hypothesis including χ_{c1} signal
  - based on likelihood ratios and toy MC simulations
  - **tests of binning strategy**, as line shapes are extracted from binned MC histograms
  - **tests of fit method**, as fraction of $N_{\mathrm{sig}} \approx 2\%$
  - **cross check** via 1-d fit to $M_{\mu\mu}$

  no obvious bias found

- **BUT:** observation of discrepancy between **theory prediction** and **experimental result**, due to differences in Γ_{ee} and ϕ



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Extraction of Interference Parameters Γ_{ee} and ϕ

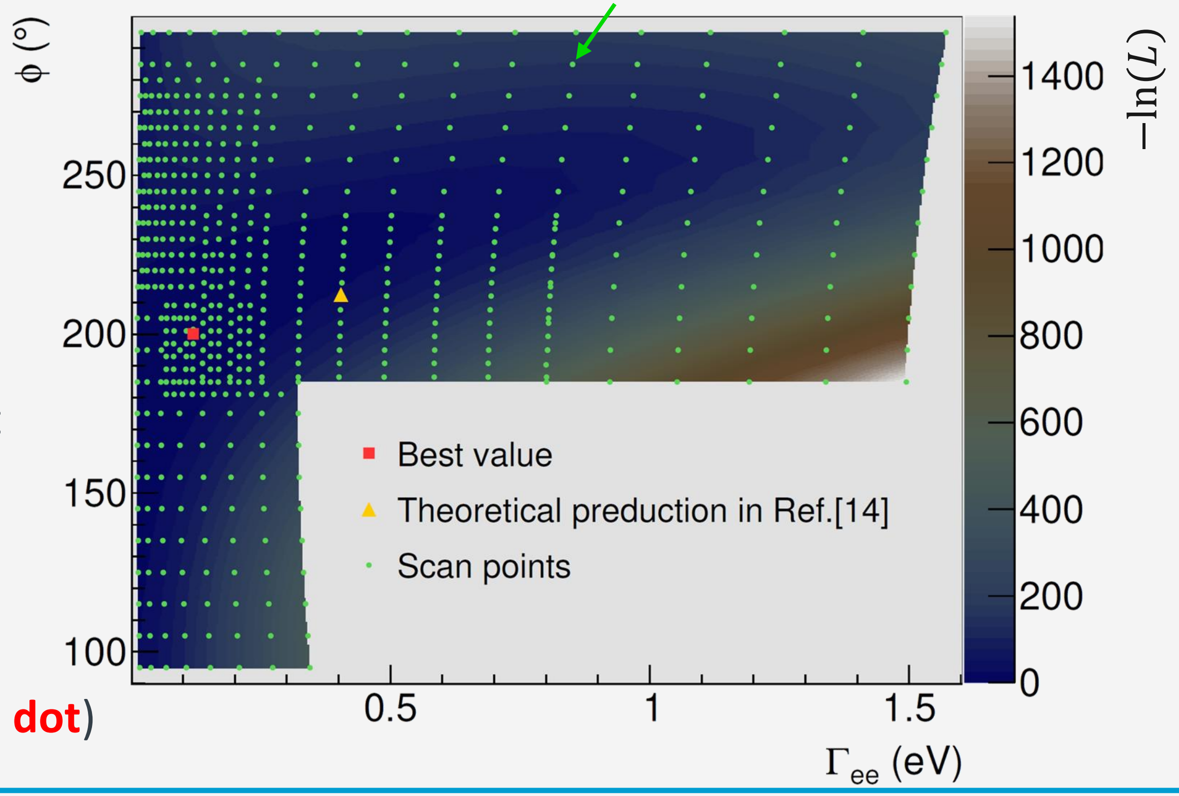
performance of simultaneous fits to all four χ_{c1} data samples scanning the (Γ_{ee}, ϕ) parameter phase space for best solution

- analytic description of σ_{tot} unknown, but depends on Γ_{ee} and ϕ → use scan method to determine Γ_{ee} and ϕ
- generation of MC samples with 200 Mio events for each χ_{c1} data point and each (Γ_{ee}, ϕ) set (green circles)
- **same fit approach** as for extraction of χ_{c1} signal events: 2-d unbinned maximum likelihood fit to $M_{\mu\mu}$ and $|cos\theta_{\mu}|$

PDF: $N_{\chi_{c1}}\mathbf{MC}_{\chi_{c1}} + N_{\text{bg}}\mathbf{MC}_{\text{ISR bg}} + N_{\text{int}}\mathbf{MC}_{\text{int}}$

- **but here:**
  - common fit to all four χ_{c1} data samples for each (Γ_{ee}, ϕ) set
  - number of events $N_{\chi_{c1}}$, N_{bg} fixed to number of events obtained from MC

  → for given (Γ_{ee}, ϕ) set: $N_{\text{int}} = a(\Gamma_{ee}, \phi) \cdot \sqrt{N_{\chi_{c1}} \cdot N_{\text{bg}}}$ fixed
- maximum likelihood value gives best solution for Γ_{ee} and ϕ (**red dot**)



Extraction of Interference Parameters Γ_{ee} and ϕ

performance of simultaneous fits to all four χ_{c1} data samples scanning the (Γ_{ee}, ϕ) parameter phase space for best solution

first experimental determination of Γ_{ee} of χ_{c1}

- best fitted values (**red dot**):

  $\Gamma_{ee} = \left(0.12^{+0.13}_{-0.08}\right)$ eV and $\phi = \left(205^{+15.4}_{-22.4}\right)^\circ$

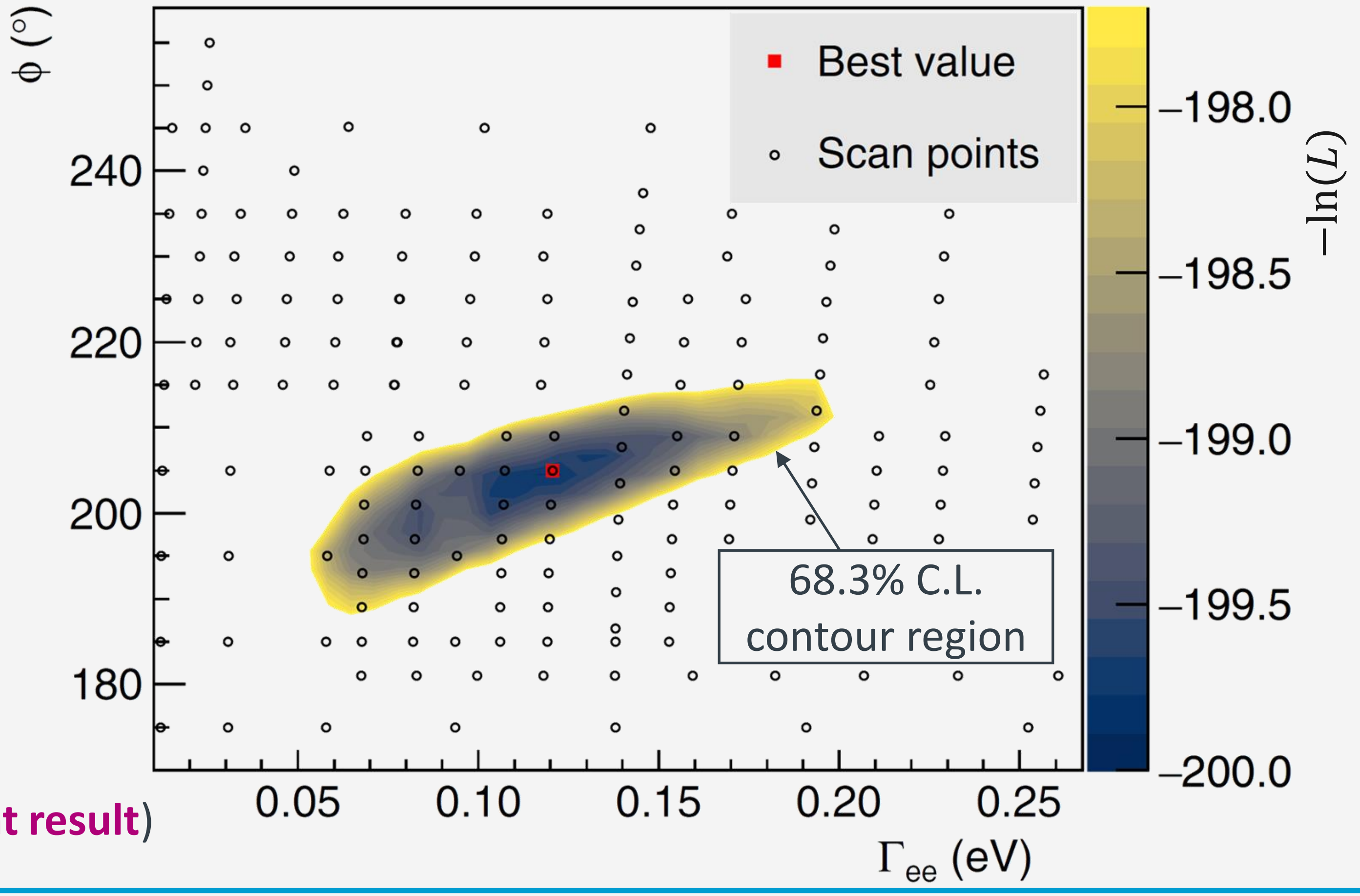
  including statistical and systematic uncertainties (are of same order)

- theoretical predictions:

  $\Gamma_{ee}^{\mathrm{theo}} = 0.41$ eV and $\phi^{\mathrm{theo}} = 212^\circ$

  Czyz, Kühn, Tracz, PRD94, 034033 (2016)

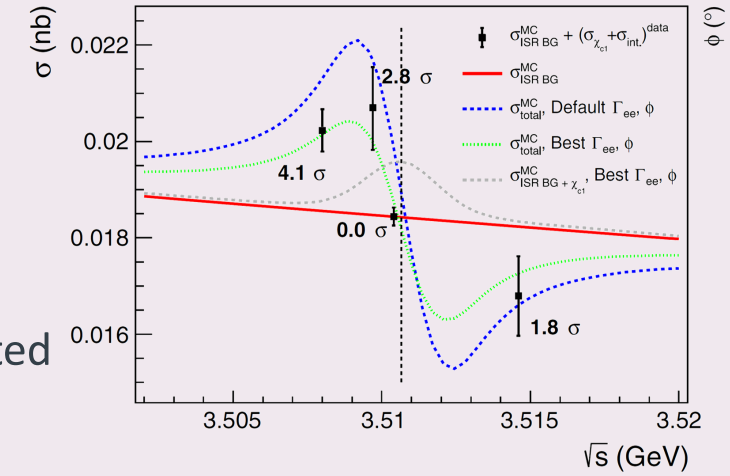
- **cross check:** based on best (Γ_{ee}, ϕ) set, calculation of number of signal events $N_{\mathrm{sig}} = N_{\chi_{c1}} + N_{\mathrm{int}}$ for each χ_{c1} data point individually
  → combined statistical significance 5.1σ (**consistent result**)

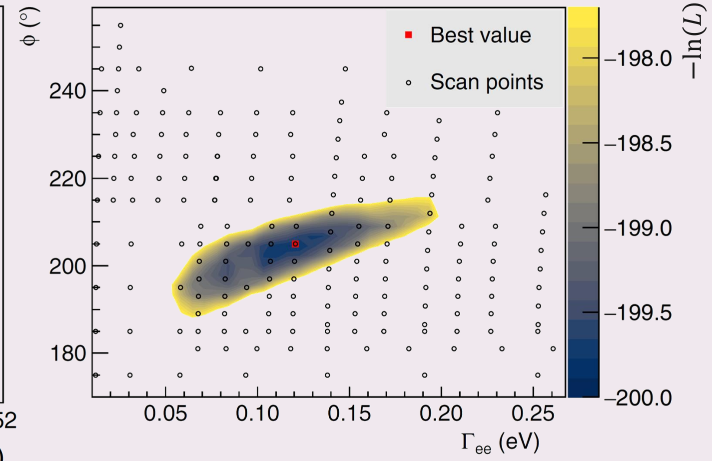


Summary

First observation of direct production of χ_{c1} resonance with $J^{PC} = 1^{++}$ in e^+e^- collisions

- statistical significance $> \mathbf{5\sigma}$
- first measurement of χ_{c1} electronic width
  $\boldsymbol{\Gamma_{ee} = \left(0.12^{+0.13}_{-0.08}\right)}$ **eV**
  (of same order as theory predictions)
- observation of interference pattern as predicted
- **published in PRL129, 122001 (2022)**





- **new approach applied** for search for $J^{PC} \neq 1^{--}$ resonances, directly produced in e^+e^- annihilations
  - using energy scan data in the resonance‘s vicinity
  - taking interference with irreducible background into account (Γ_{ee}, ϕ dependency)
  - search for signal beyond background based on fits to data using validated MC line shapes und (Γ_{ee}, ϕ) scan method
- **Outlook for BESIII:** applying and proving analysis strategy to search for directly produced χ_{c2} resonance with $J^{PC} = 2^{++}$

Thank you for your attention!

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Experimental Search for Directly Produced C-even States in e^+e^- Annihilations

ND collaboration

- $\eta', f_0(980), f_0(1300), a_0(980), f_2(1270), a_2(1320)$ at VEPP-2M collider (Vorobev et al. (ND), SJNP48, 273 (1988))

SND collaboration

- $f_2(1270), a_2(1320)$ at VEPP-2M collider (Achasov et al. (SND), PLB492, 8 (2000))
- η at VEPP-2M collider (Achasov et al. (SND), PRD98, 052007 (2018))
- η' at VEPP-2000 collider (Achasov et al. (SND), PRD91, 092010 (2015))
- $f_1(1285)$ at VEPP-2000 collider (Achasov et al. (SND), PLB800, 135074 (2020))

CMD-3 collaboration

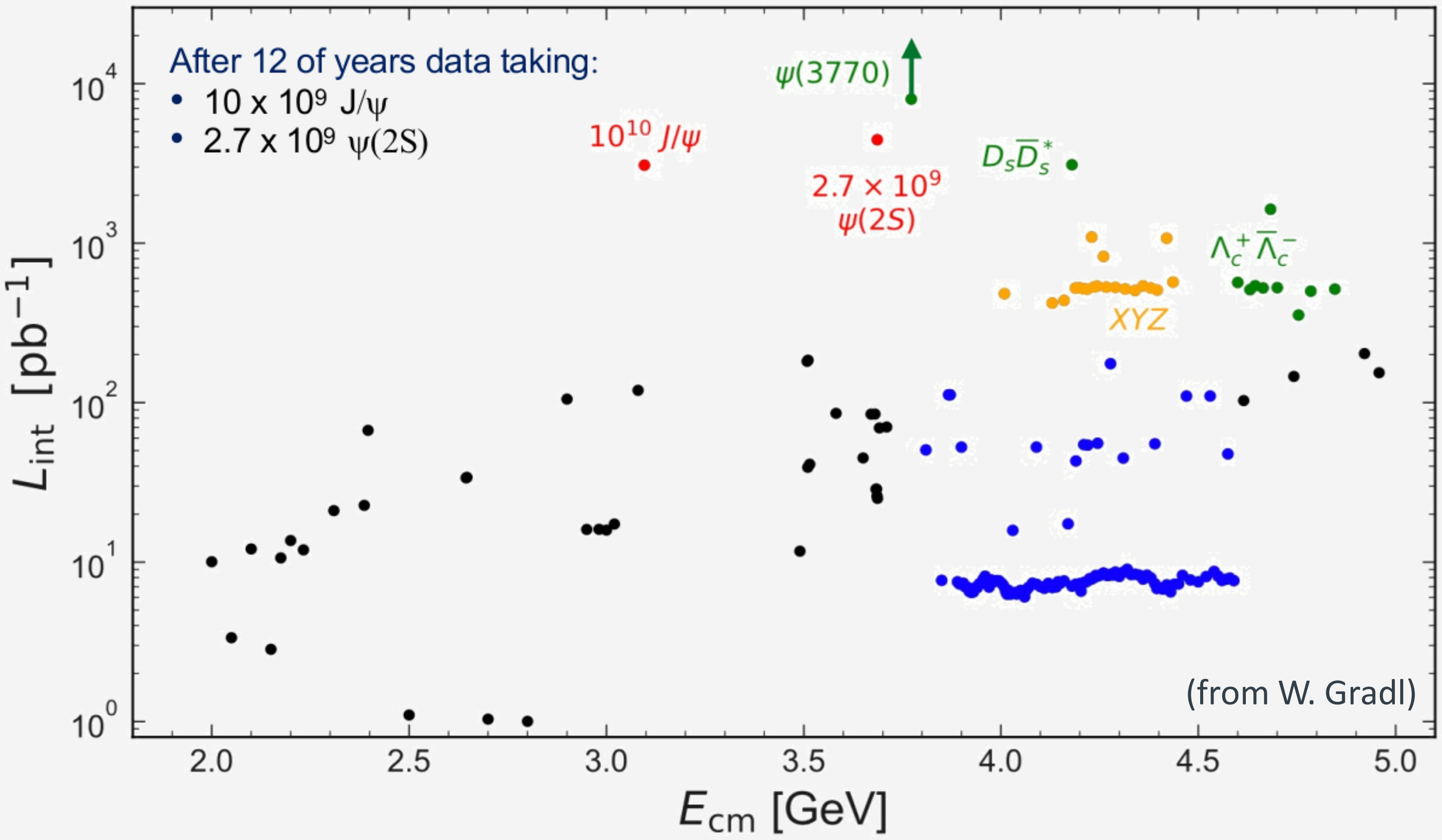
- η' at VEPP-2000 collider (Akhmetshin et al. (CMD-3), PLB740, 273 (2015))

BESIII collaboration

- $\chi_{c1}(3872)$ at BEPCII collider (Ablikim et al. (BESIII), PLB749, 414 (2015), Ablikim et al. (BESIII), PRD107, 032007 (2023))

BESIII Data Sets

- world's largest data sets at 1^{--} resonances: $J/\psi, \psi(2S), \psi(3770)$
- scans around resonances: $\chi_{c1}, \psi(2S), \psi(3770)$
- energy scan in the "XYZ" region: $4.0\text{ GeV} \leq \sqrt{s} \leq 5.0\text{ GeV}$
- additional data sets at lower energies: $2.0\text{ GeV} \leq \sqrt{s} \leq 3.0\text{ GeV}$



(from W. Gradl)

Extraction of χ_{c1} Signal Events

(2-d unbinned maximum likelihood fit to $M_{\mu\mu}$ and $|cos\theta_\mu|$ within $[2.95, 3.25]$ GeV$/c^2$ and $[0,1]$ of all four χ_{c1} data samples)

→ one-dimensional projections to the $M_{\mu\mu}$ and $|cos\theta_\mu|$ distributions: