Hadron Spectroscopy with Strangenes
April 3rd - 5th, 2024 University of Glasgow, Glasgow, UK

Strangeonium at BESIII

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on behalf of the BESIII Collaboration

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The experimental scenario

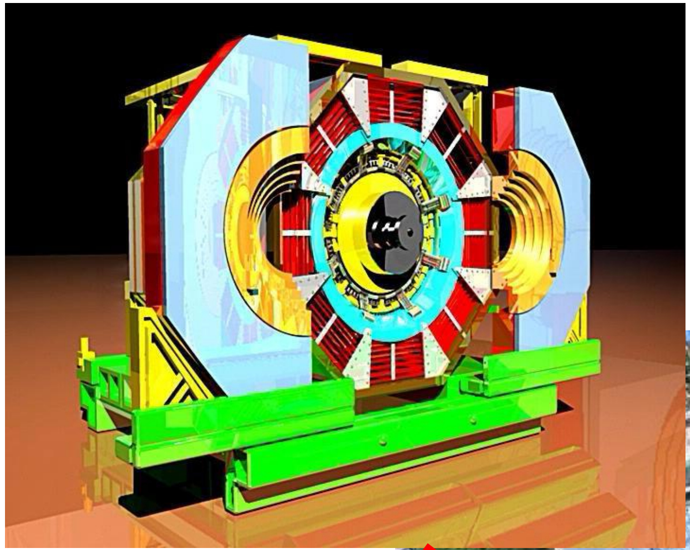
BESIII @ BEPC-II

- BEPCII: τ-charm factory
- Center of Mass Energy: 2 – 4.95 GeV
- Achieved design Luminosity $L_{design} = 1 \times 10^{33}\ cm^{-2}s^{-1}$

2016/04/05 22:29:47

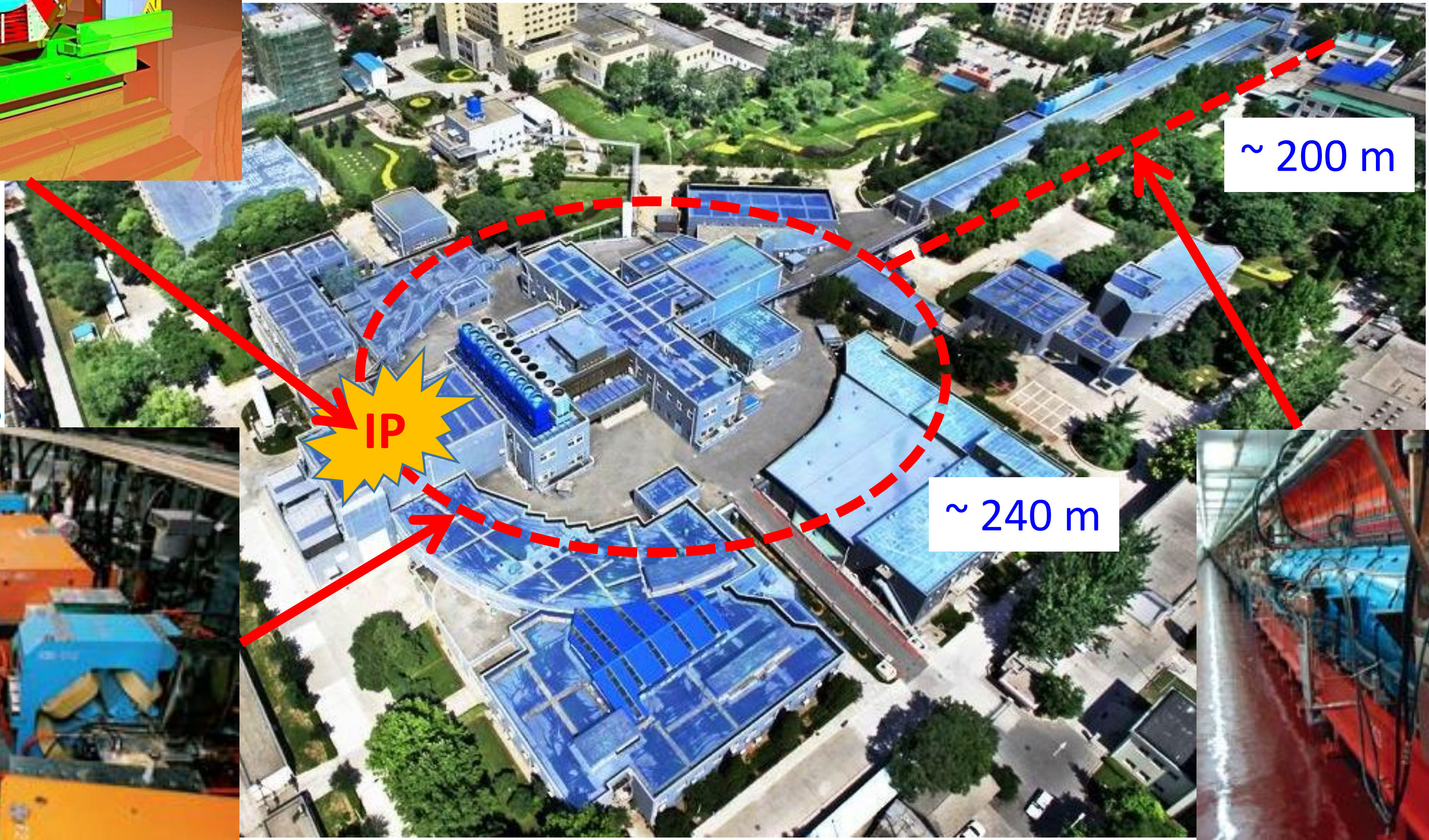
Luminosity 10.00 E32/cm^2/s

	e+	e–
Energy [GeV]	1.8831	1.8831
Current [mA]	849.18	852.31
Lifetime [hr]	1.53	2.30
Inj.Rate [mA/min]	0.00	0.00

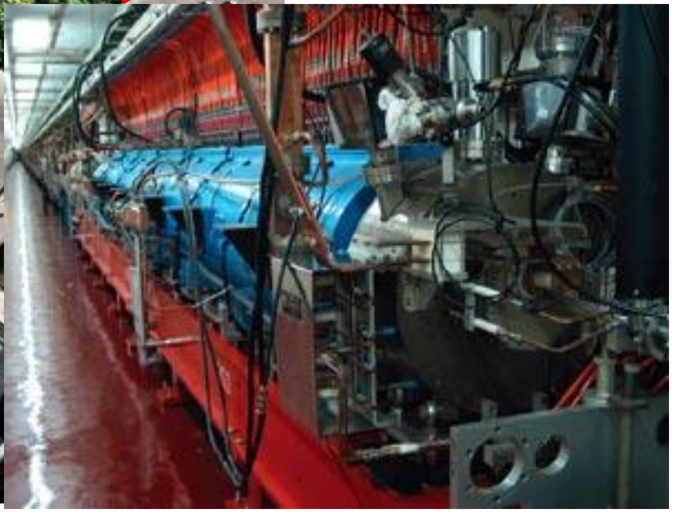


BESIII experiment

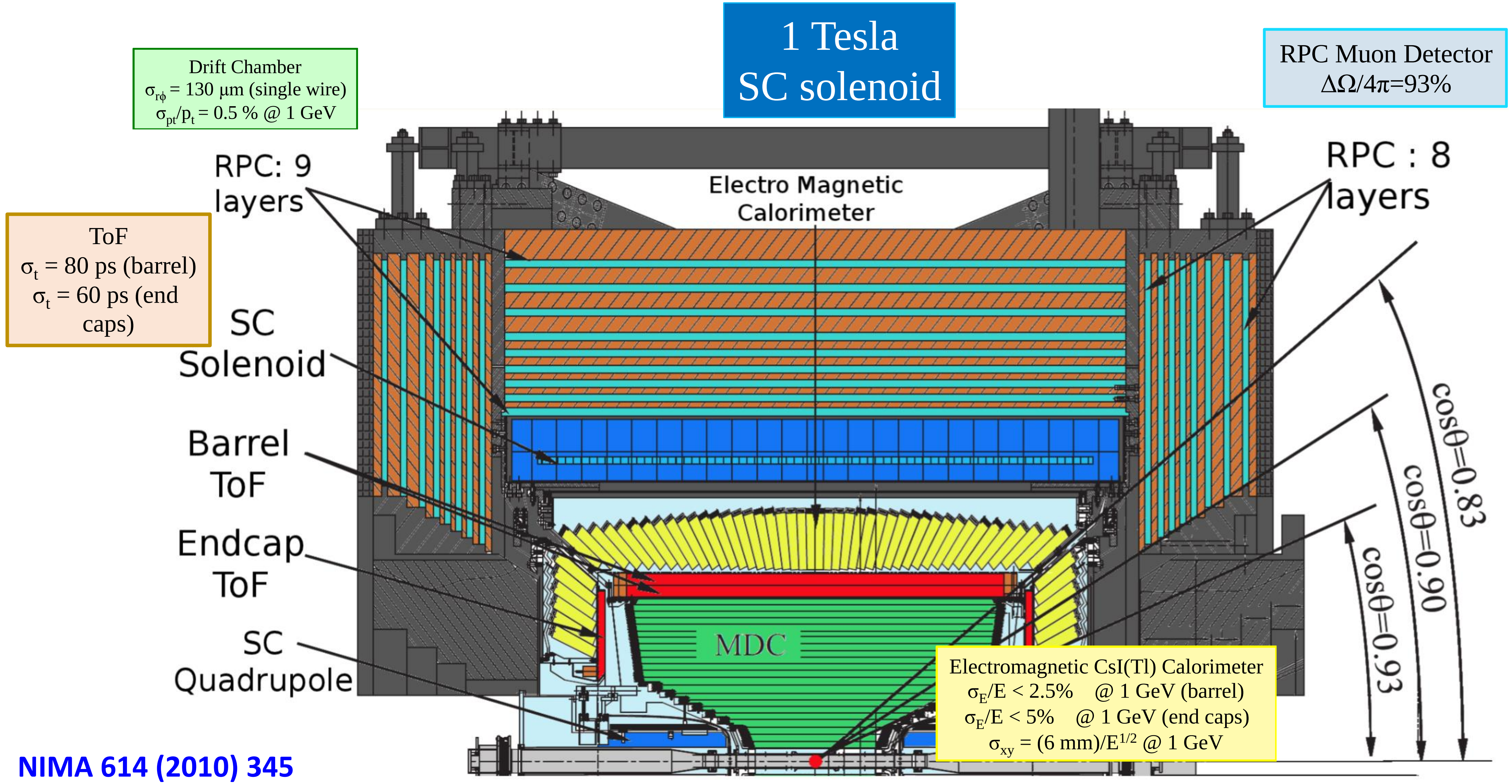
BEPC-II
e^+e^- storage ring



injection LINAC



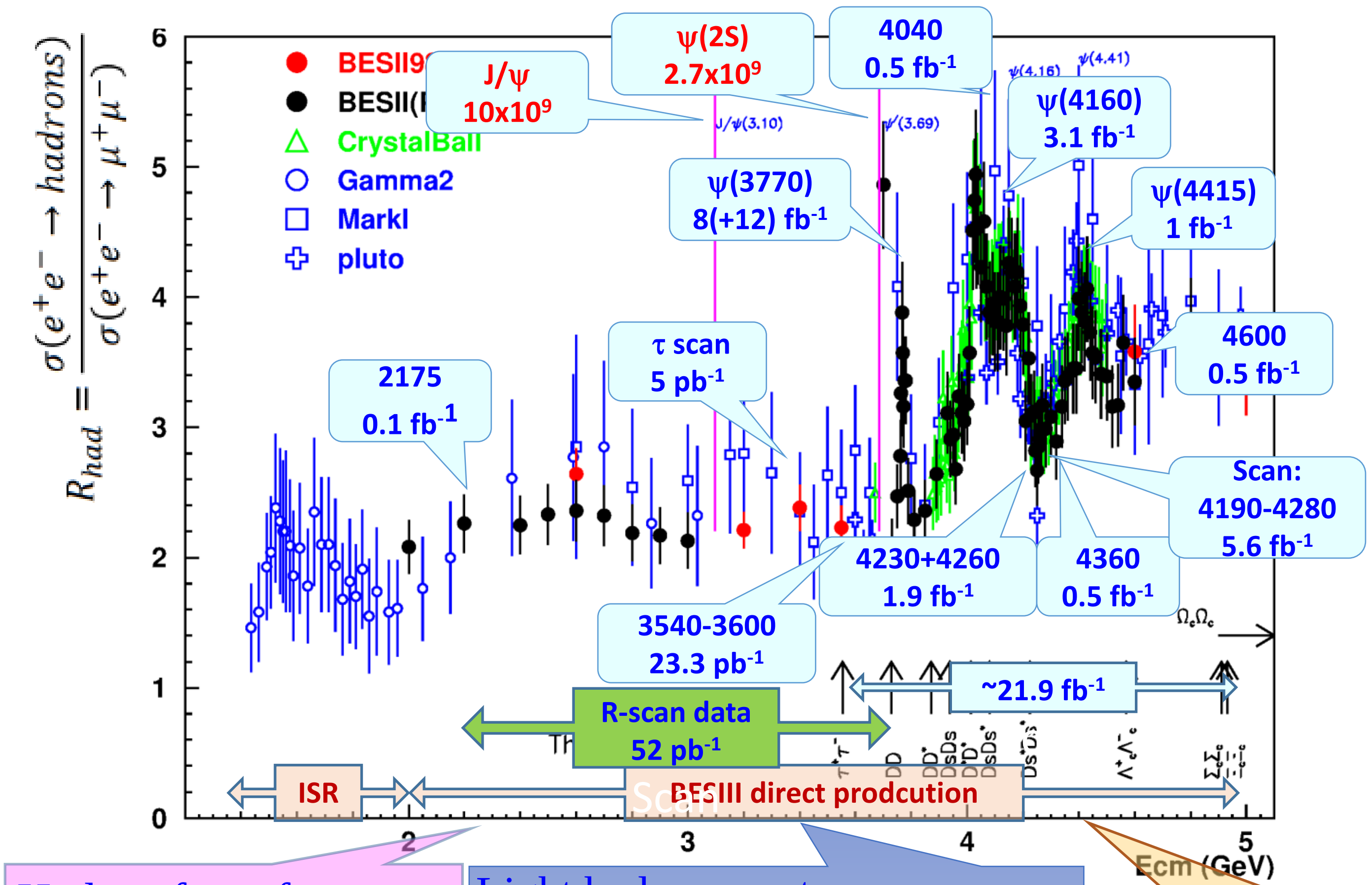
BESIII Spectrometer

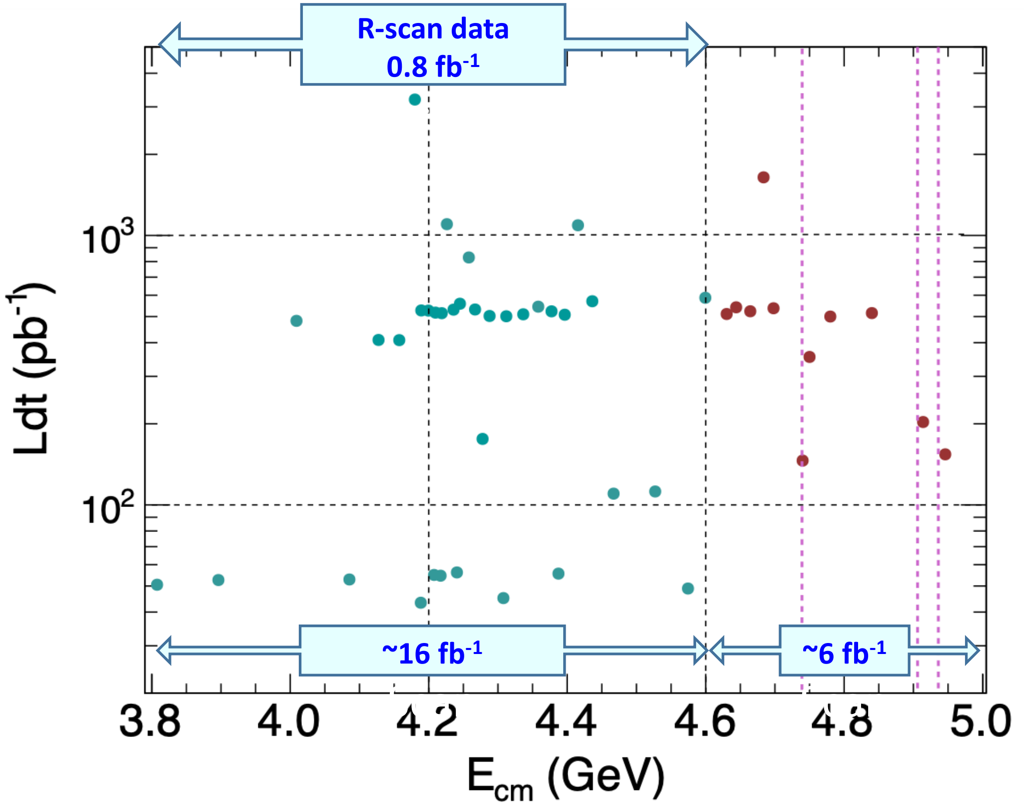


NIMA 614 (2010) 345

Excellent scenario for XYZ Physics

World's largest data samples directly produced from e^+e^- collision @ J/ψ and ψ(2S)





Hadron form factors
Y(2175)
Zs states?
QCD test

Light hadron spectroscopy
Glueballs, hybrids, multi-quark states
Rare decays
Tau Physics

XYZ
D and Ds Physics
(f_D and f_{Ds}, mixing, CP)
Charmed baryons

XYZ data:

- **46 energy points (21.9 fb⁻¹)**
- **29 energy points with L_i > 0.4 fb⁻¹**

Small scan sample:

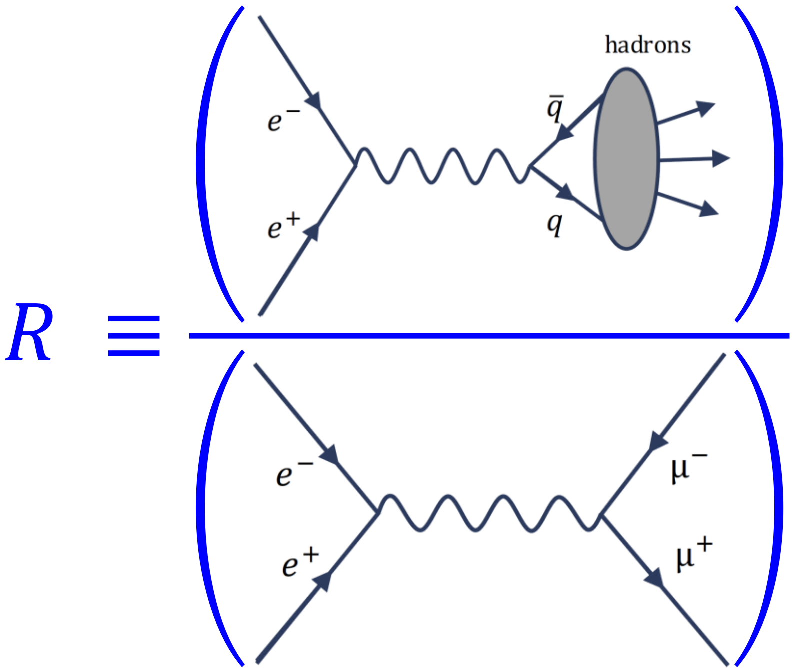
- **104 energy points (0.8 fb⁻¹)**

R $value$

Definition of R value

- *R value*
  - LO production cross section ratio of hadrons and muon pairs in e^+e^- annihilations

$$R \equiv \frac{\sigma^0(e^+e^- \to \text{hadrons})}{\sigma^0(e^+e^- \to \mu^+\mu^-)} \equiv \frac{\sigma^0_{\text{had}}}{\sigma^0_{\mu\mu}}$$



- σ^0_{had}
  - important input to current tests of Standard Model
  - critical to determine:
    - QED running coupling constant
    - anomalous magnetic moment of the muon

- $\sigma^0_{\mu\mu}$
  - QED $\quad \sigma^0_{\mu\mu}(s) = \frac{4\pi\alpha^2}{3s}\frac{\beta_\mu(3-\beta_\mu^2)}{2} \quad \beta_\mu = \sqrt{1-4m_\mu^2/s}$

QED running electromagnetic coupling constant $\Delta\alpha(s)$

- $\Delta\alpha(s)$

$$\Delta\alpha(s) = 1 - \frac{\alpha(0)}{\alpha(s)} = \Delta\alpha_{lepton}(s) + \Delta\alpha^{(5)}_{had} + \Delta\alpha_{top}(s)$$

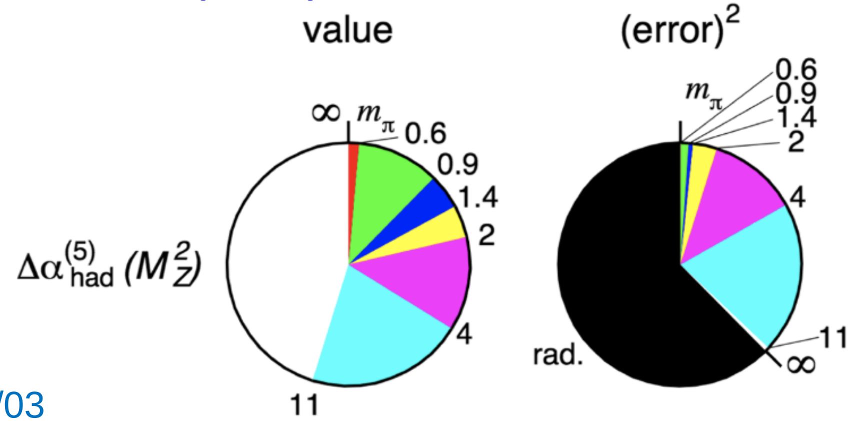
  - $\Delta\alpha_{lepton}(s)$ determined analytically by perturbation theory
  - $\Delta\alpha_{top}(s)$ negligible in BESIII energy range ($10^{-7} \sim 10^{-10}$) due to the large top quark mass
  - $\Delta\alpha^{(5)}_{had}(s)$ Hadronic Vacuum Polarization (HVP) contribution
    - inferred from **R value**
    - optical theorem → dispersion integral

$$\Delta\alpha^{(5)}_{\mathrm{had}}(s) = -\frac{\alpha s}{3\pi}\,\mathrm{Re}\int_{E_{\mathrm{th}}}^{\infty} \mathrm{d}s' \frac{R(s')}{s'(s'-s-i\varepsilon)}$$

    - $\Delta\alpha^{(5)}_{had}(s)$ limits precision Physics (EW fit) at m_Z: the 5 light quarks contribution is not computable by p-QCD at lower energies [$\alpha(m_Z^2)$ essential for EW precision Physics]

$\Delta\alpha^{(5)}_{had}(s)$ is sensitive with the R-value on a wide energy range

PRD 97, 114025 (2019)



Fundamental input

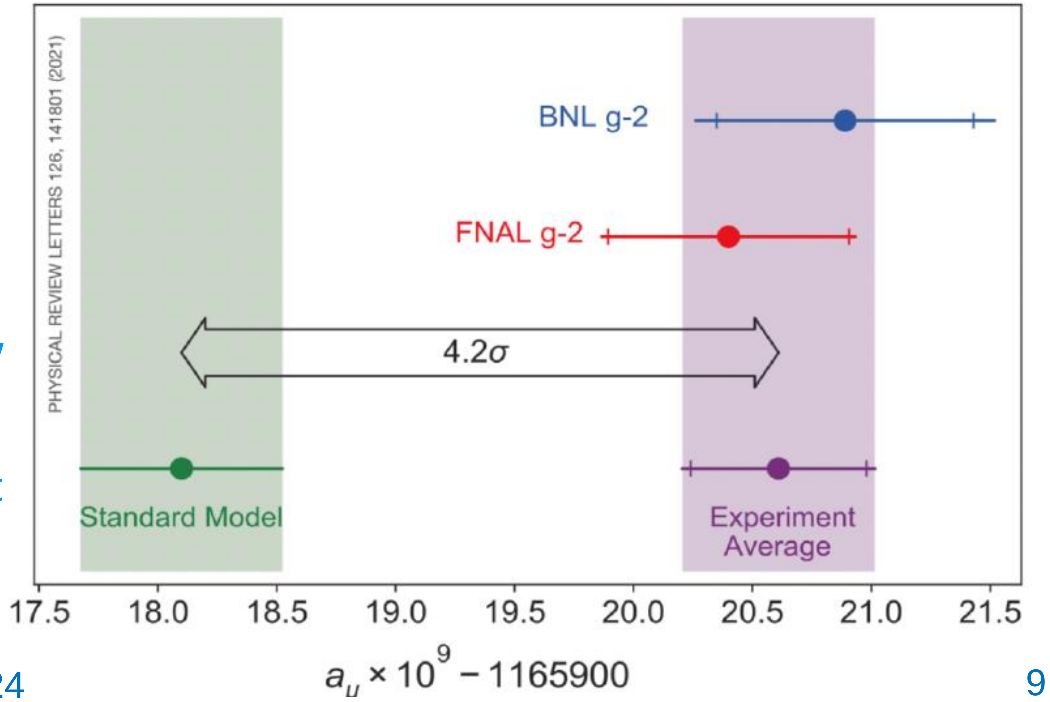
EPJ 80, 241 (2020)

Source	Contribution($\times 10^{-4}$)
$\Delta\alpha_{\mathrm{lepton}}(M_Z^2)$	314.979 ± 0.002
$\Delta\alpha^{(5)}_{\mathrm{had}}(M_Z^2)$	276.0 ± 1.0
$\Delta\alpha_{\mathrm{top}}(M_Z^2)$	-0.7180 ± 0.0054

Muon anomalous magnetic moment a_μ

- **magnetic moment of the muon:** $\vec{\mu} = g_\mu \frac{e}{2m_\mu}\vec{S}$
  - provides sharp test of EM theory and possible hints of BSM
  - Dirac: $g_\mu = 2$ $\rightarrow$ Quantum Field Theory: $a_\mu = \frac{|g_\mu - 2|}{2}$ (**Muon Anomaly**)
  - **Anomalous Magnetic Moment**: large discrepancy SM vs experimental data, **4.2 σ (BSM?)**
    - SM: $a_\mu^{SM} = a_\mu^{QED} + a_\mu^{QCD} + a_\mu^{weak}$
      PRD 97, 114025 (2019)
    - Experimental average (BNL and FNAL)
      PRL 126, 141801 (2021)
    - hadronic contributions dominate a_μ^{SM} uncertainties
      - **Hadronic Light-by-Light Scattering (HLbL):** irreducible, now
      - **Hadronic Vacuum Polarisation (HVP):** a_μ^{LO-HVP} from dispersion integral exploiting R-value as experimental input

$$a_\mu^{\text{LO-HVP}} = \left(\frac{\alpha m_\mu}{3\pi}\right)^2 \int_{4m_\pi^2}^{\infty} ds \frac{R(s)K(s)}{s^2}$$



Literature

- **existing R-values experimental data:**
  - ~20 experimental Collaborations measured R-value, ~10 in the lower energy region
  - best accuracy (~ 3.3%) for R measurements achieved in the 2 ÷ 5 GeV range by BESII and KEDR at a few energy points
  - systematic uncertainties dominate all R measurements

- **BESIII new R-values experimental data:** **PRL 128, 062004 (2022)**
  - inclusive R value measurement in 2.2 ÷ 3.7 GeV range (14 energy points, total of 52 pb^{-1})
  - Expected dominant backgrounds
    - beam associated
    - QED background events (e^+e^-, $\mu^+\mu^-$, $\tau^+\tau^-$, $\gamma\gamma$, …)

New BESIII R–value data: determination of R

Leading order QED Born cross section for $e^+e^- \to \mu^+\mu^-$; $\sigma^0_{\mu\mu}(s) = 86.85$ nb/s

Residual background events
- MC simulations
- Beam related contributions from data(SB)

$$R = \frac{N^{\rm obs}_{\rm had} - N_{\rm bkg}}{\sigma^0_{\mu\mu}\mathcal{L}_{\rm int.}\varepsilon_{\rm trig}\varepsilon_{\rm had}(1+\delta)}$$

Radiative corrections
- Feynman diagrams
- Structure functions
- Agreement better than 1.4%

Integrated luminosity (by LA-Bhabha) 0.8% uncertainty

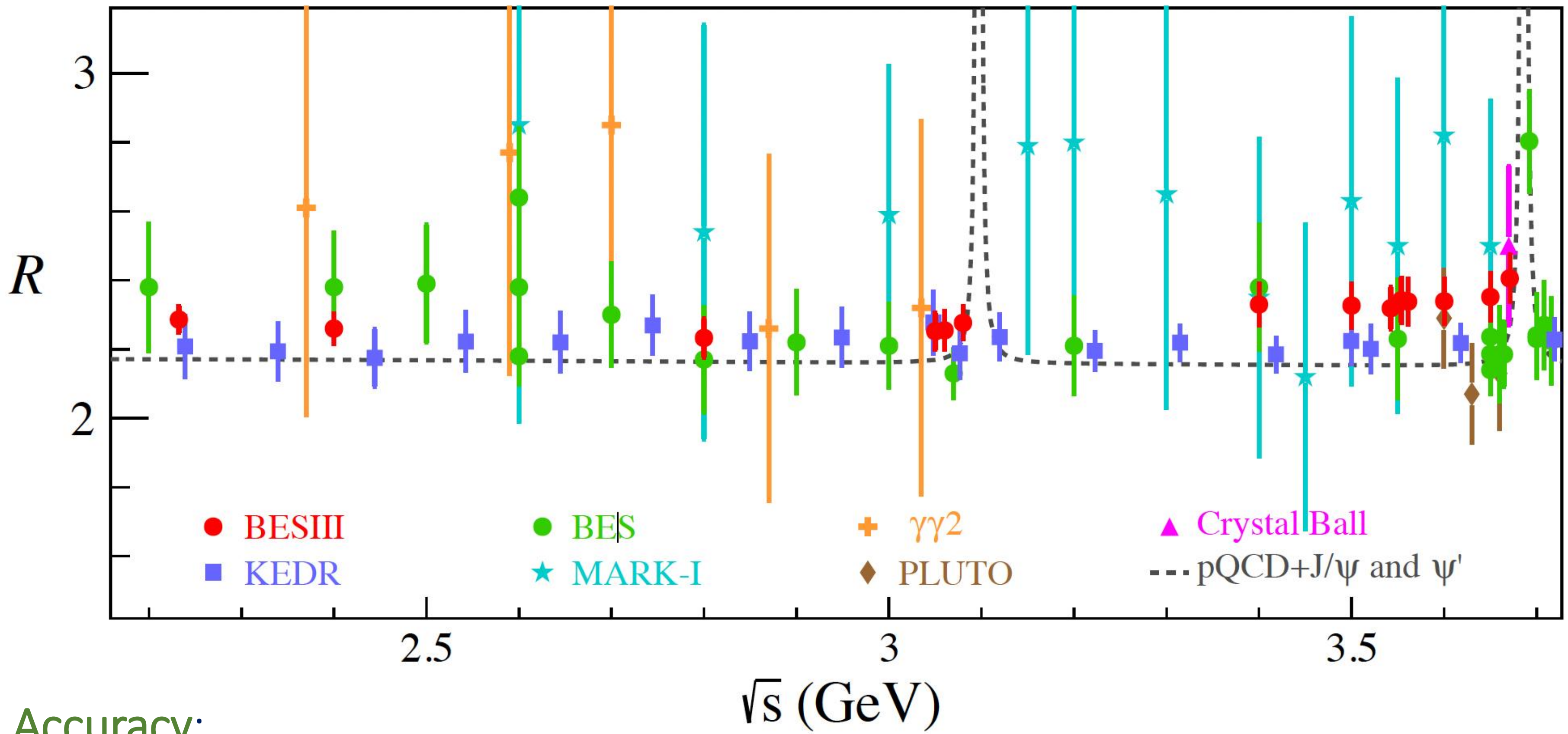
Trigger efficiency ~ 100%

Detection efficiency

MOST CHALLENGING!!

Exploiting two different signal simulations models!

BESIII experimental R data in the range 2.2 ÷ 3.7 GeV



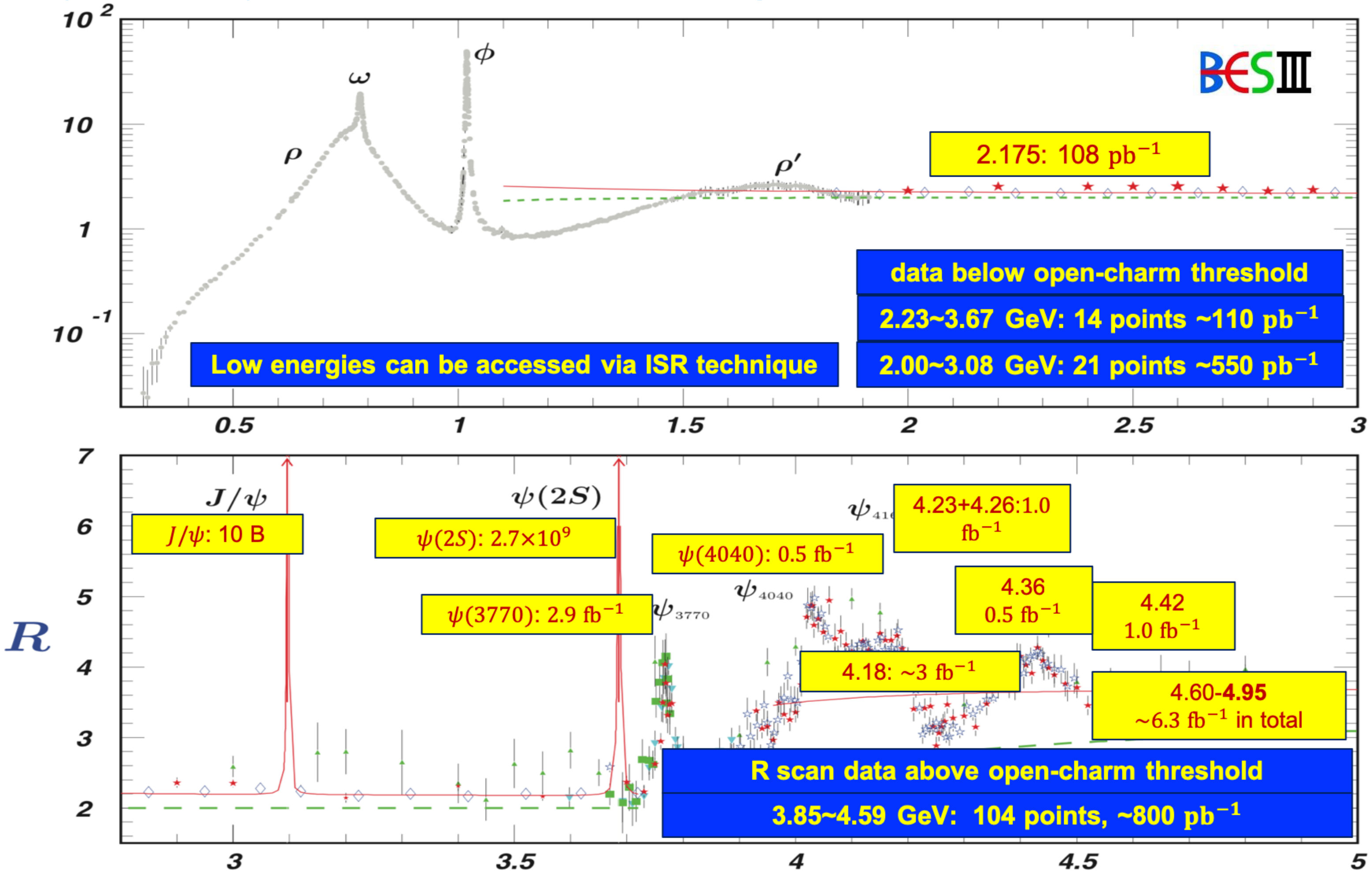
BESIII

14 energy points
total of 52 pb^{-1}

- Accuracy:
  - <2.6% below 3.1 GeV, 3.0% above
  - dominated by systematic uncertainties (statistic uncertaties: **~ 0.35%**)
- Average R value:
  - larger than the pQCD prediction by **2.7σ**
  - higher than KEDR by **1.7σ** between 3.4 and 3.6 GeV.

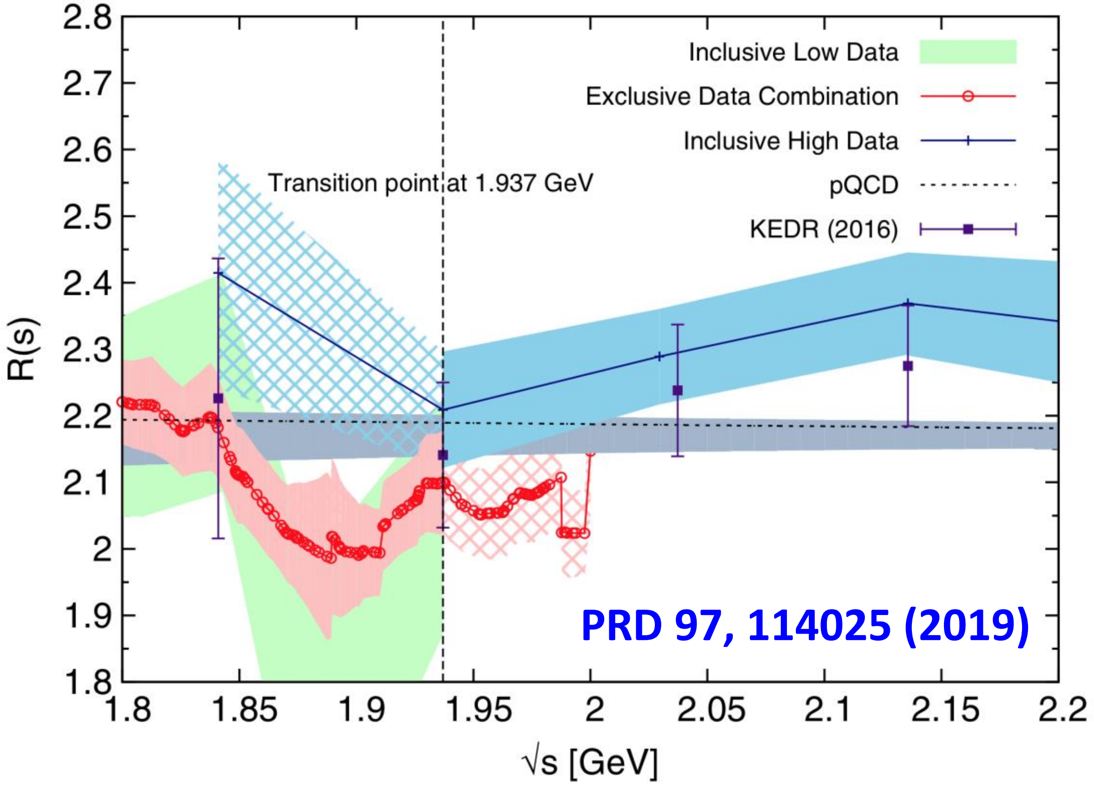
PRD 128, 062004 (2022)

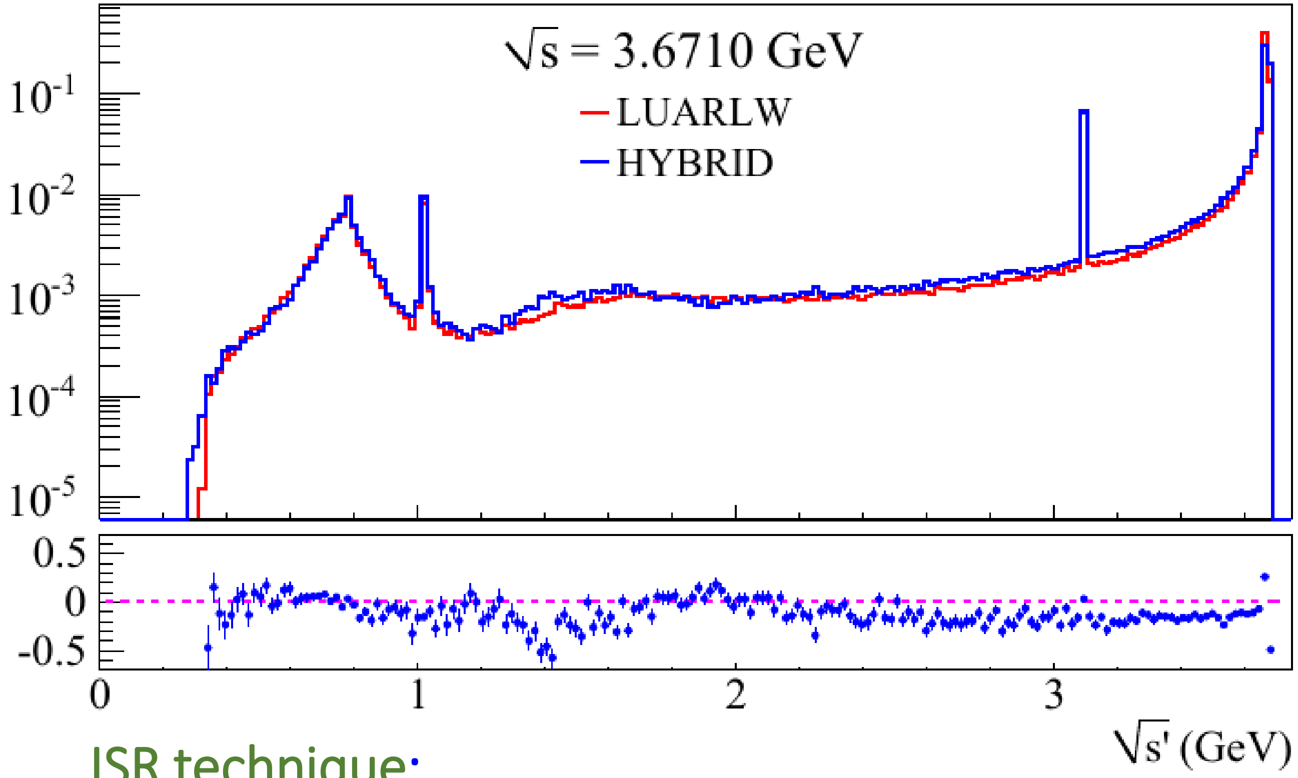
BESIII perspectives: large statistics available



- BESIII has collected data from 2.00 to 4.95 GeV suitable for R measurements:
  130 scan data points $>10^5$ hadrons
- R measurement both in the continuum and open-charm regions with high accuracy: significant impact

BESIII perspectives: exploring different methods





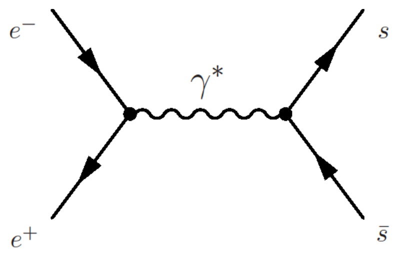
Exclusive vs inclusive measurements:

- Inclusive R measurements above 2.0 GeV
- Exclusive R measurement below 2.0 GeV
- Tension in the transition region!

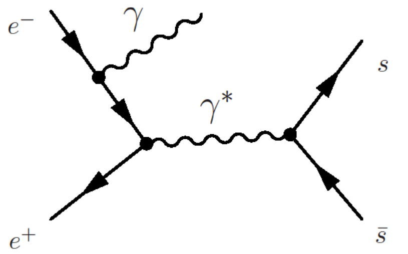
ISR technique:

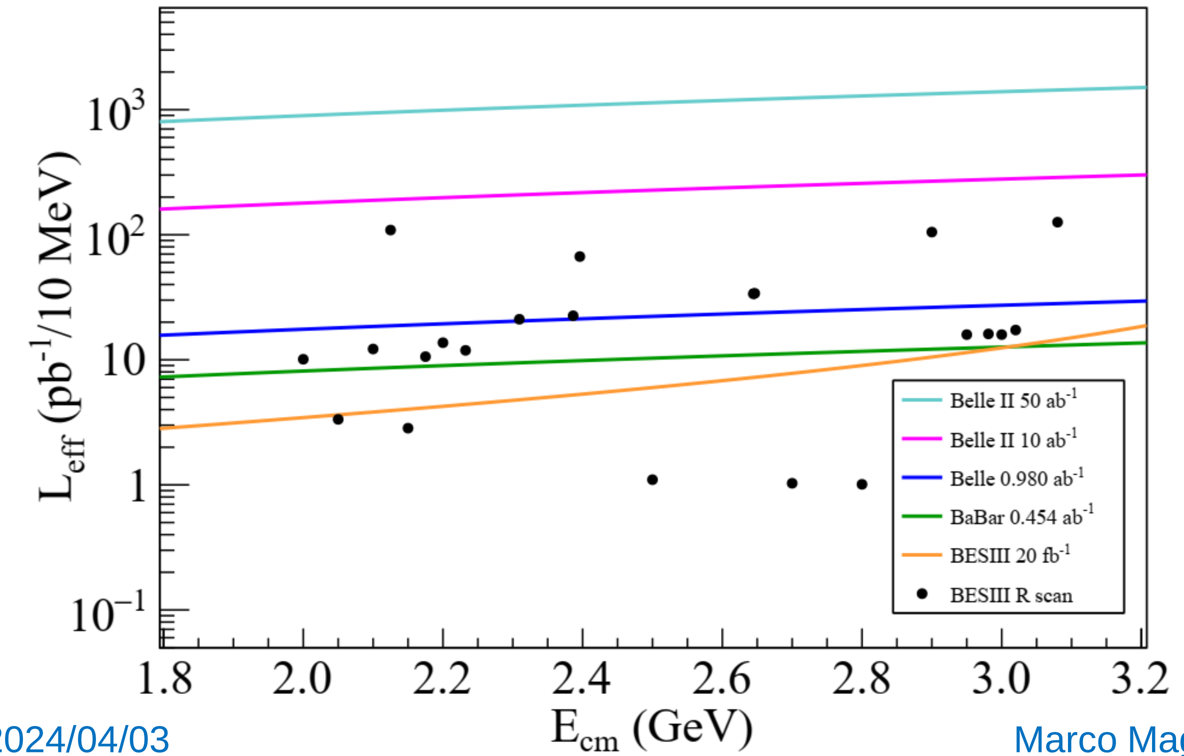
- exploits large charmonia data (e.g. $\psi(3770)$)
- allows measurement from threshold to continuum
- less dependent on MC event generator
- better detection efficiency respect to scan
- allows comparison btw inclusive and exclusive measurements

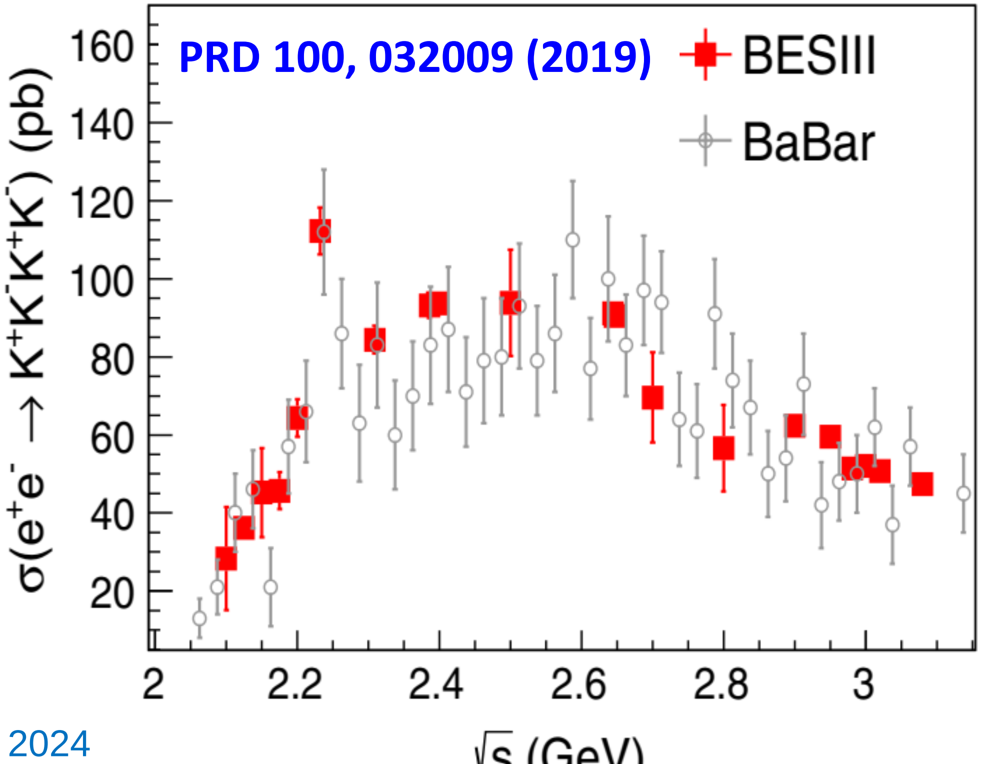
Energy scan vs ISR



	Energy Scan	Initial State Radiation
$\sqrt{s}$	discrete	fixed
$\mathcal{L}$	low at each beam energy	high at one beam energy
σ	$\frac{d\sigma_{p\bar{p}}}{d(\cos\theta)} = \frac{\pi\alpha^2\beta C}{2q^2}[\lvert G_M\rvert^2(1+\cos^2\theta) + \frac{4m_p^2}{q^2}\lvert G_E\rvert^2\sin^2\theta]$	$\frac{d^2\sigma_{p\bar{p}\gamma}}{dq^2 d(\cos\theta_\gamma)} = \frac{1}{s}W(s,x,\theta_\gamma)\sigma_{p\bar{p}}(q^2)$ $W(s,x,\theta_\gamma) = \frac{\alpha}{\pi x}(\frac{2-2x+x^2}{\sin^2\theta_\gamma} - \frac{x^2}{2})$
q^2	single at each beam energy	from threshold to s



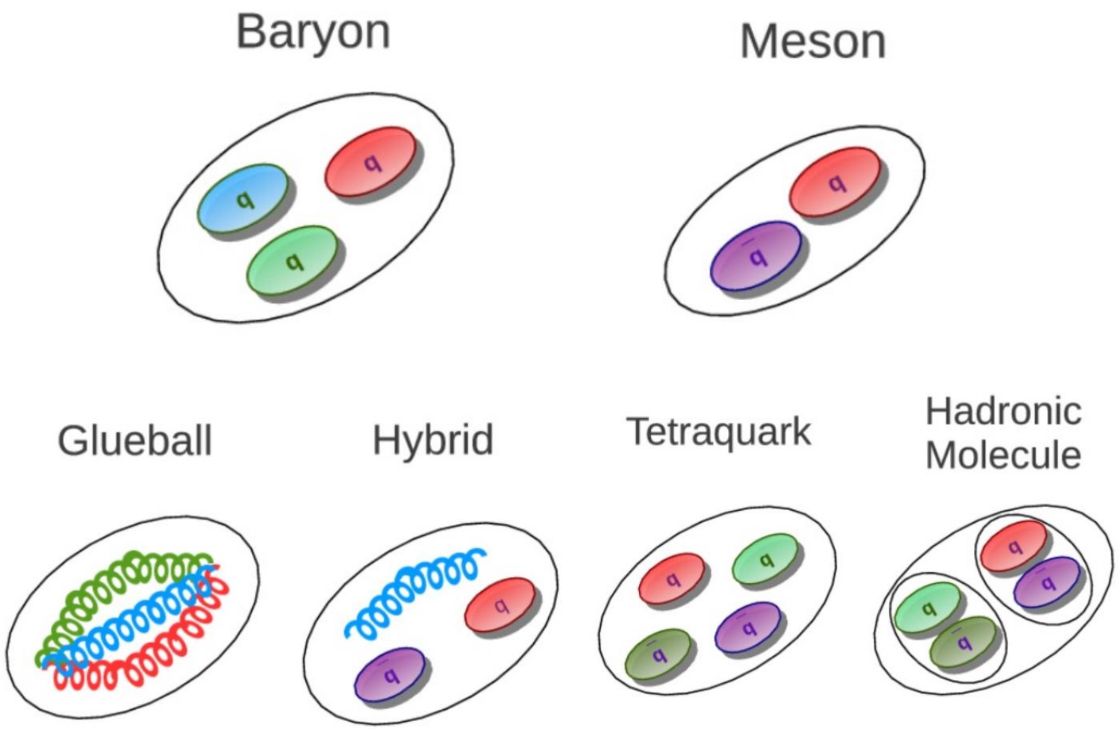




Hadron Spectroscopy

QCD Exotics

- Non-exotic hadrons: mesons ($q\bar{q}$), baryons (qqq)
- QCD allows for exotic hadrons:
  - multi-quark states
    strong evidence in heavy quark sector
    https://qwg.ph.nat.tum.de/exoticshub/
  - hybrids
  - Glueballs
- BESIII is an ideal scenario for light QCD Exotics
  - Charmonium decays ⟹ "gluon-rich processes"
  - clean high statistics data sample
  - kinematic constraints and I(J^{PC}) filter

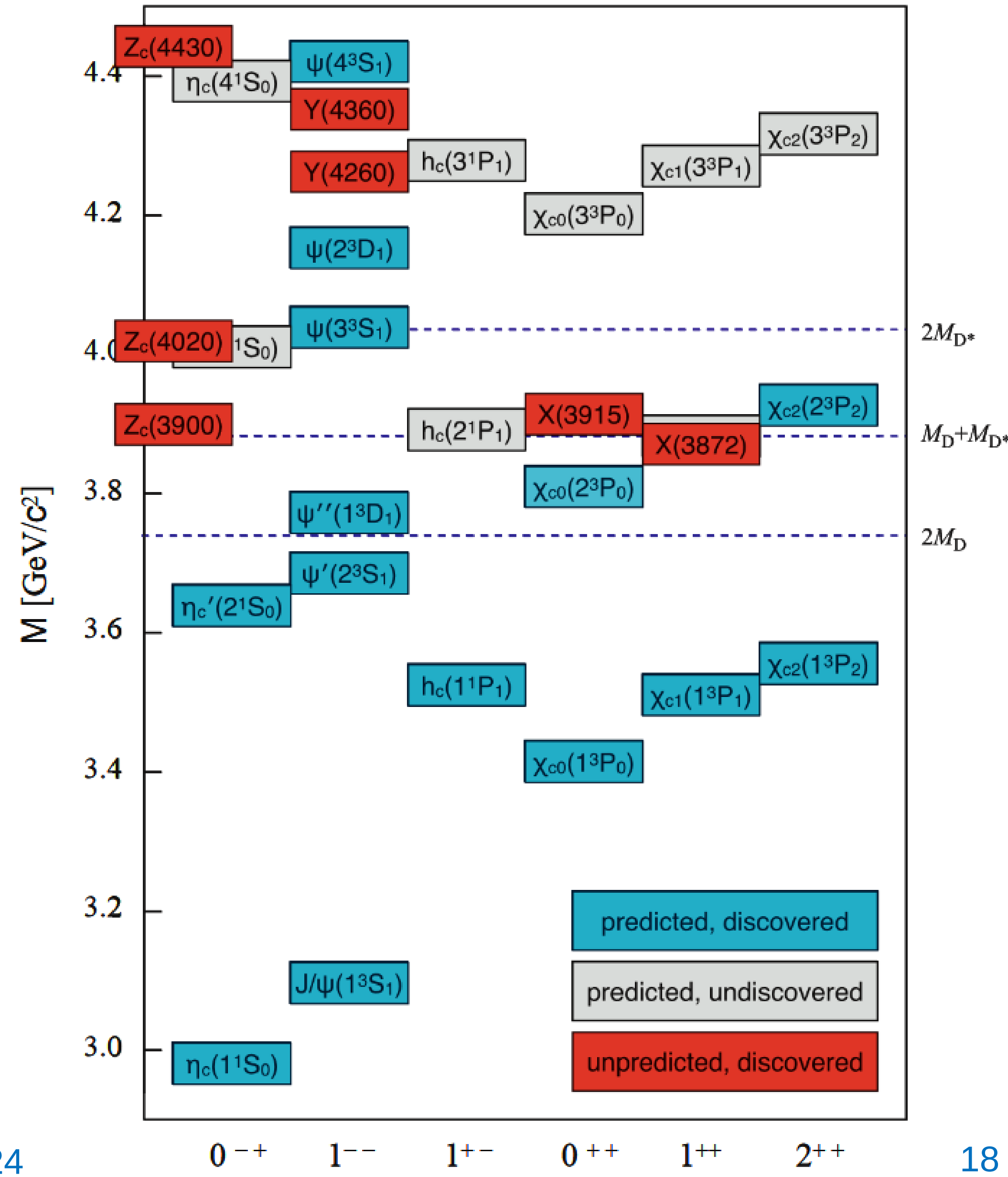


Charmonium Spectroscopy

- XYZ states: do not fit in the naïve quark model
  - X: neutral non-vector states
  - Y: neutral vector states
  - Z: charged, clearly multy-quark states

Ideal background for exotica!

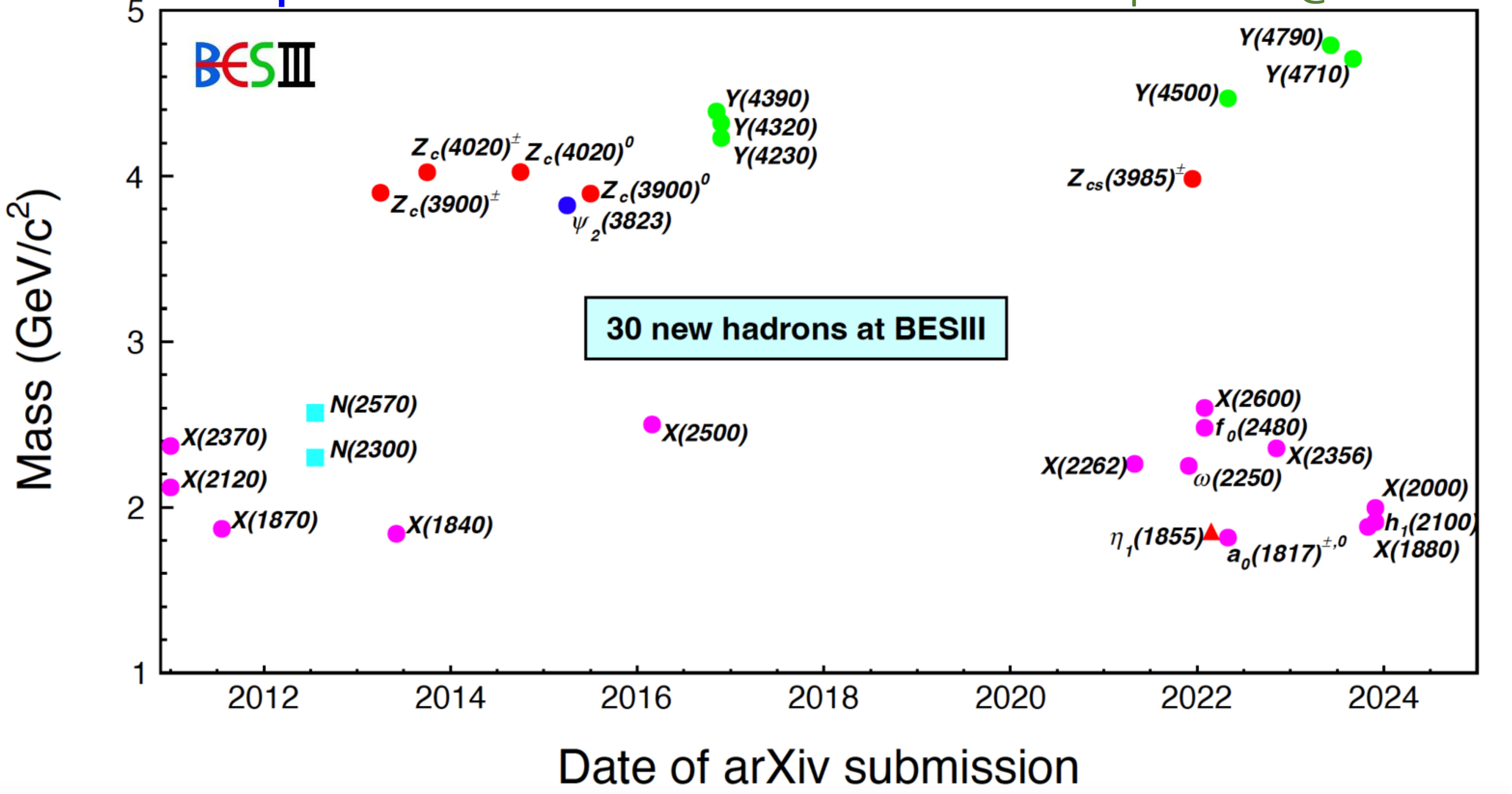
Picture cred: R. Mitchell and M. Kuessner



New discoveries

http://english.ihep.cas.cn/bes/re/pu/NewParticles/

New particles @ BESIII



manifestely exotic

- quark content more than $q\bar{q}$ or qqq
- $\bar{q}$ not accessible for ordinary mesons or barions

cryptically exotic

- overpulation of states
- M/Γ not fitting in spectra
- production and/or decay patterns incompatible with standard baryons/mesons

Charmonium Spectroscopy

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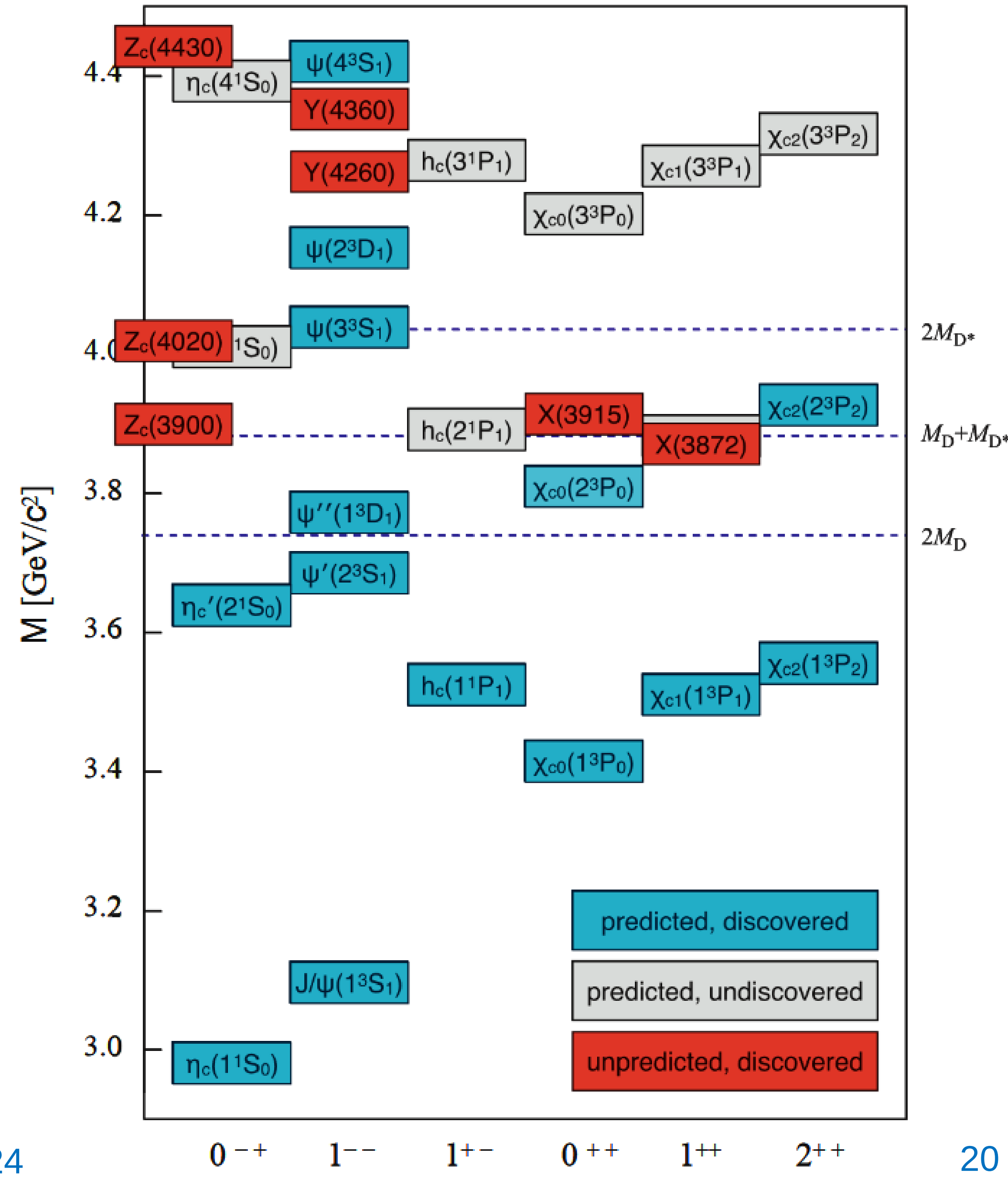
Ideal background for exotica!

Wide focus on
exotic states with charm and bottom quark but also…

Picture cred: R. Mitchell and M. Kuessner



Charmonium Spectroscopy

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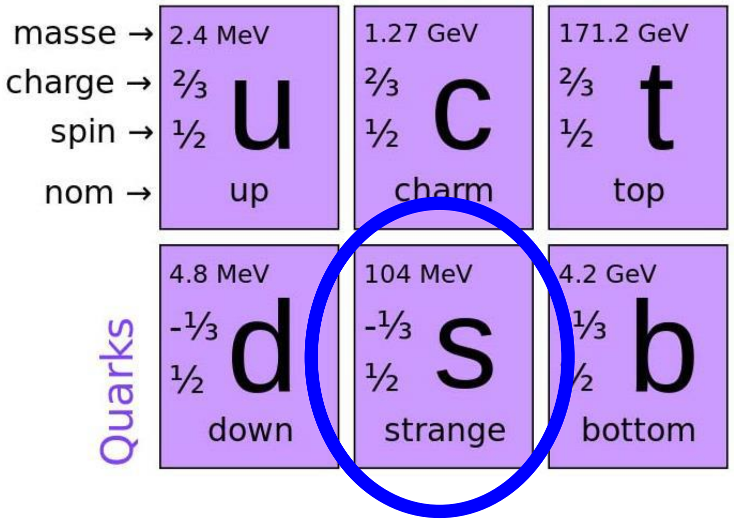

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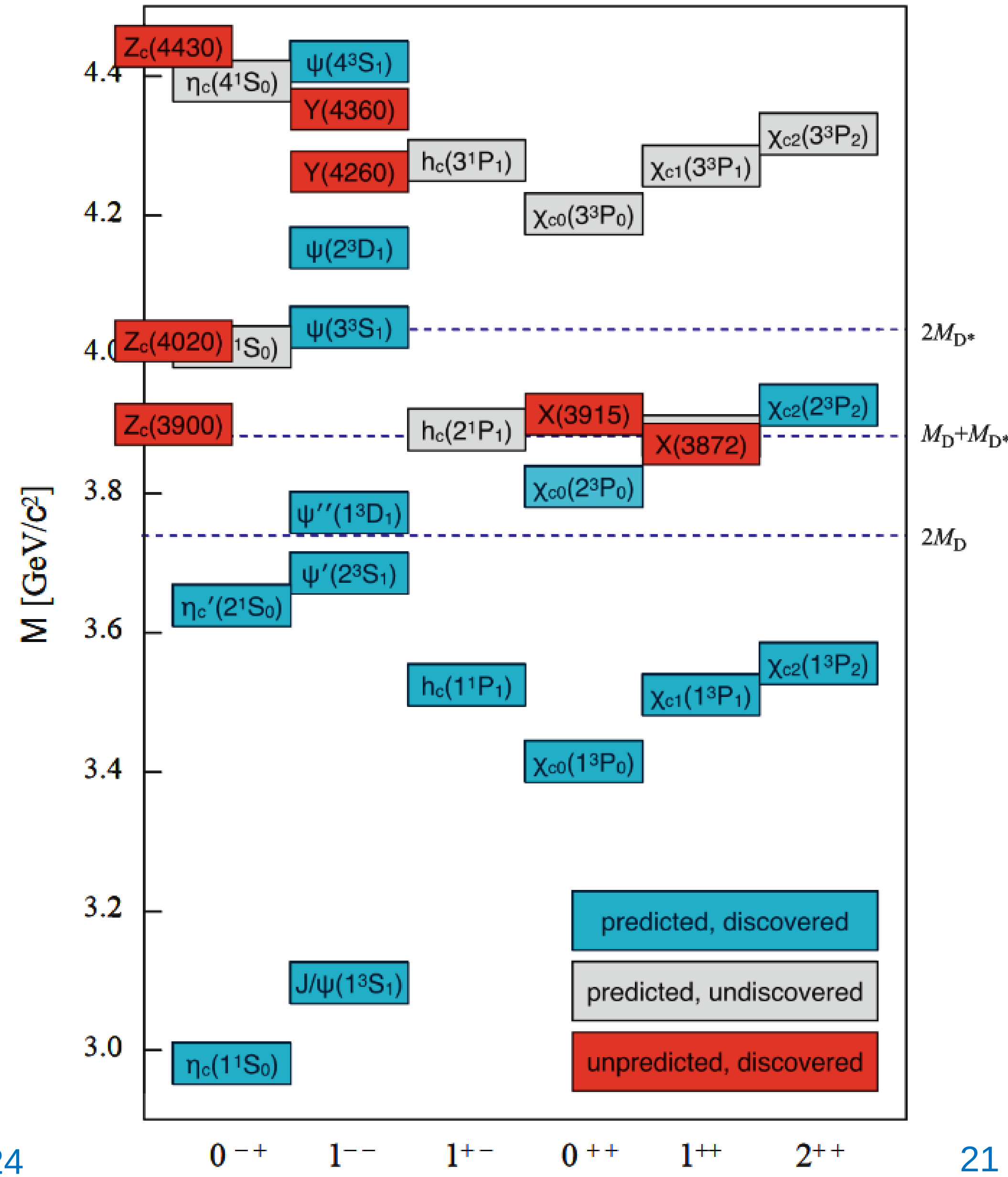
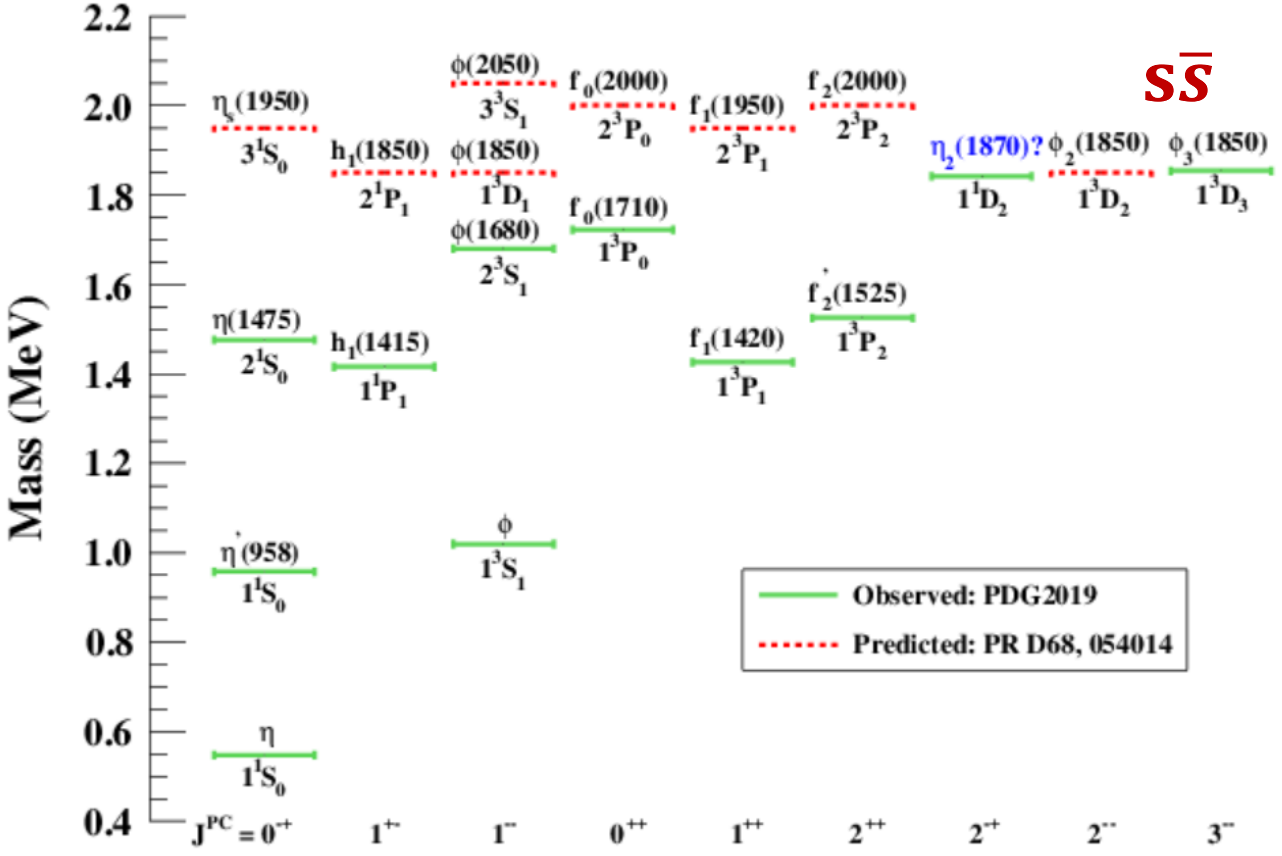
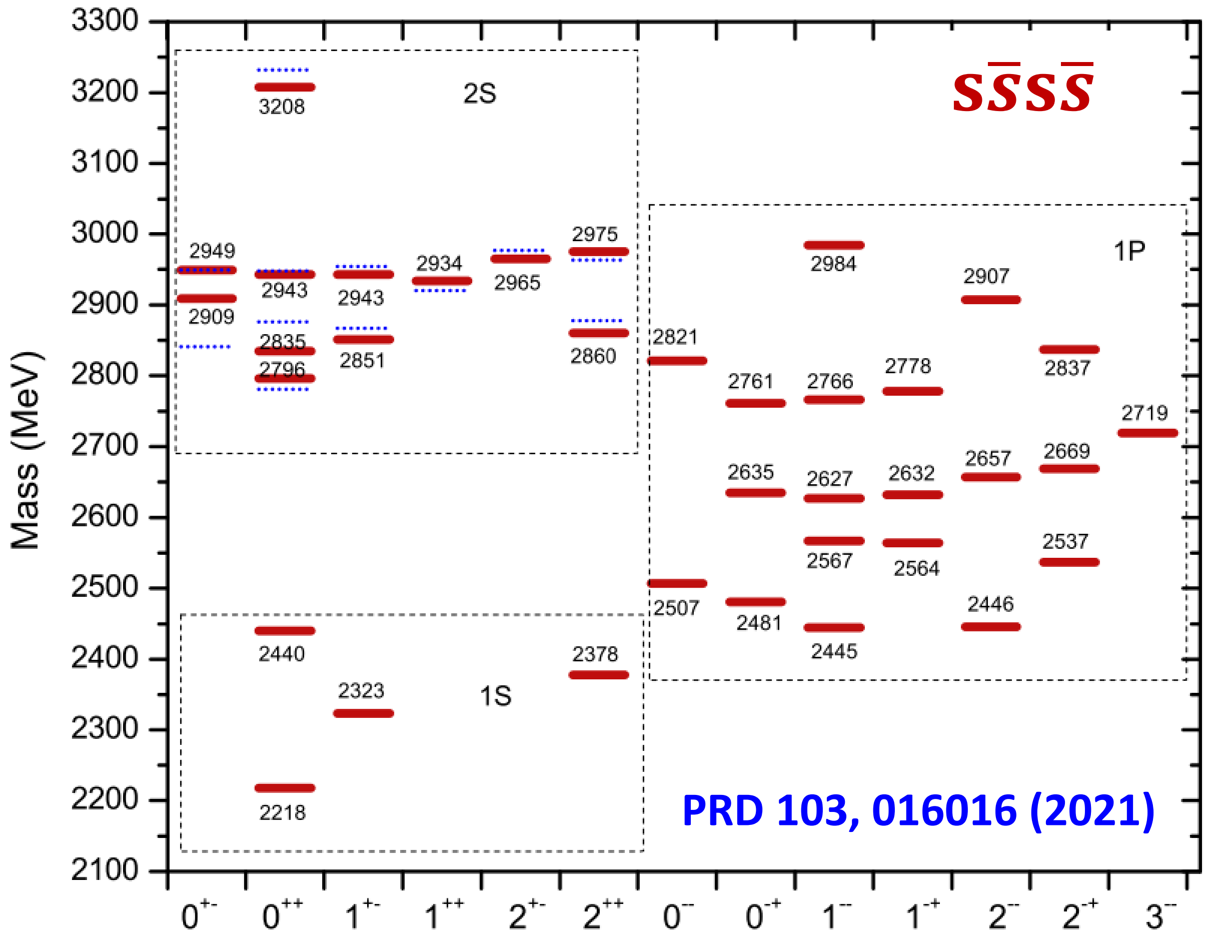


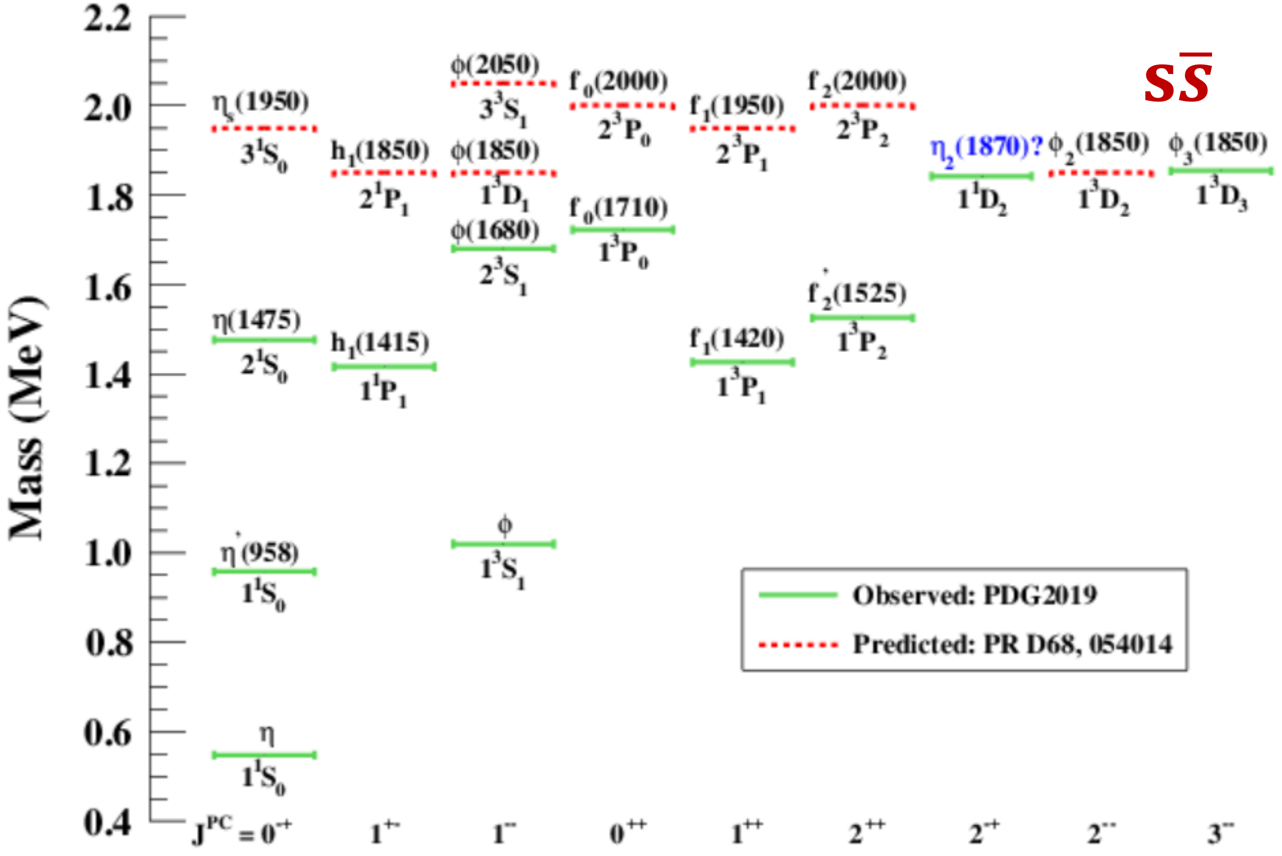
Strangeonium Spectroscopy

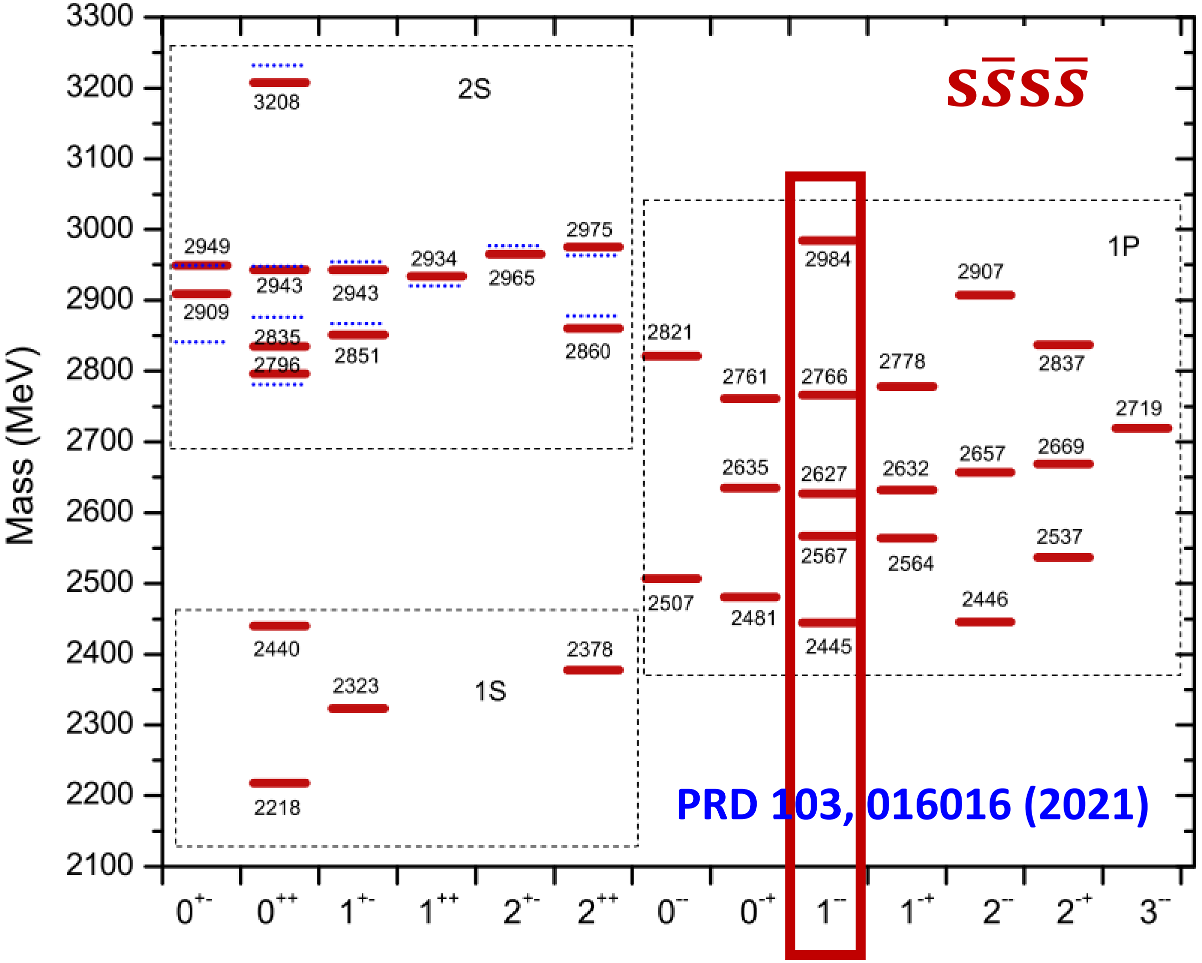




- exotic states with (just) light quarks
  - $s\bar{s}$ **spectrum far from being well known**
  - hybrid $s\bar{s}g$
  - **tetraquark** $s\bar{s}s\bar{s}/s\bar{s}u\bar{u}/s\bar{s}d\bar{d}$, …
  - **rich** $s\bar{s}s\bar{s}$ **spectrum spectrum**

Strangeonium Spectroscopy





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  - **rich** $s\bar{s}s\bar{s}$ **spectrum spectrum**

$J^{PC} = 1^{--}$ **above 2.4 GeV not yet in PDG 2022**

$\phi(2170)$ / Y(2175)

- $\boldsymbol{\phi(2170)\,/\,Y(2175)}$:
  - **first observed by BABAR in ϕf_0 [PRD 74, 091103 (2006)]**
  - **later confirmed:**

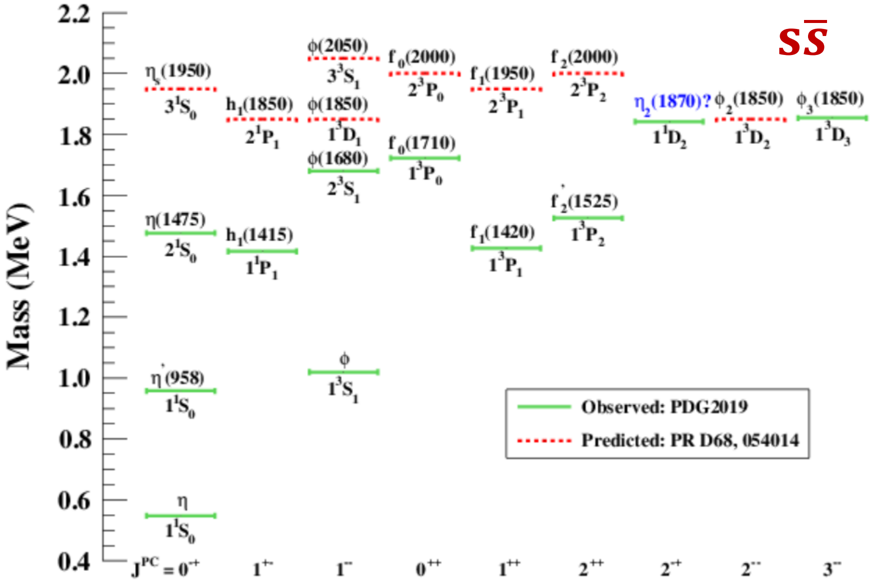
    BESIII [PRL 100, 102003 (2008)]

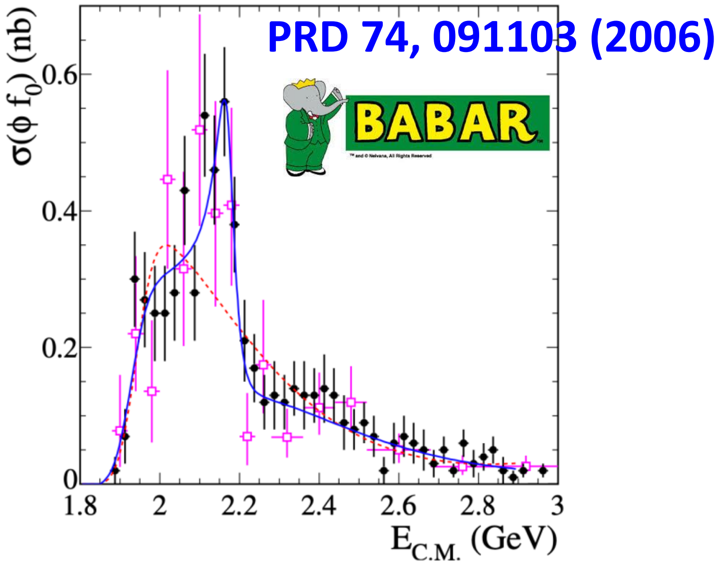
    Belle [PRD 80, 031101 (2009)]
  - $\boldsymbol{s\bar{s}}$ **is terra incognita**:
    - low BR
    - wide Γ
  - **a bridge among lighter and heavier quark states**

    [EPJ C72, 2008 (2012)]

$$e^+e^- \Rightarrow \begin{cases} Y(2175) \to \phi(1020)\pi^+\pi^- & \text{strange,} \\ Y(4260) \to J/\psi\pi^+\pi^- & \text{charm,} \\ \Upsilon(10860) \to \Upsilon(1S,2S)\pi^+\pi^- & \text{bottom,} \end{cases}$$

1. produced in e^+e^- **collisions** hence $\mathbf{1^{--}}$ **states**
2. observed **di-pion transitions in the three cases**
3. observed **anomalous phenomena** in e^+e^- collisions at the relevant energies

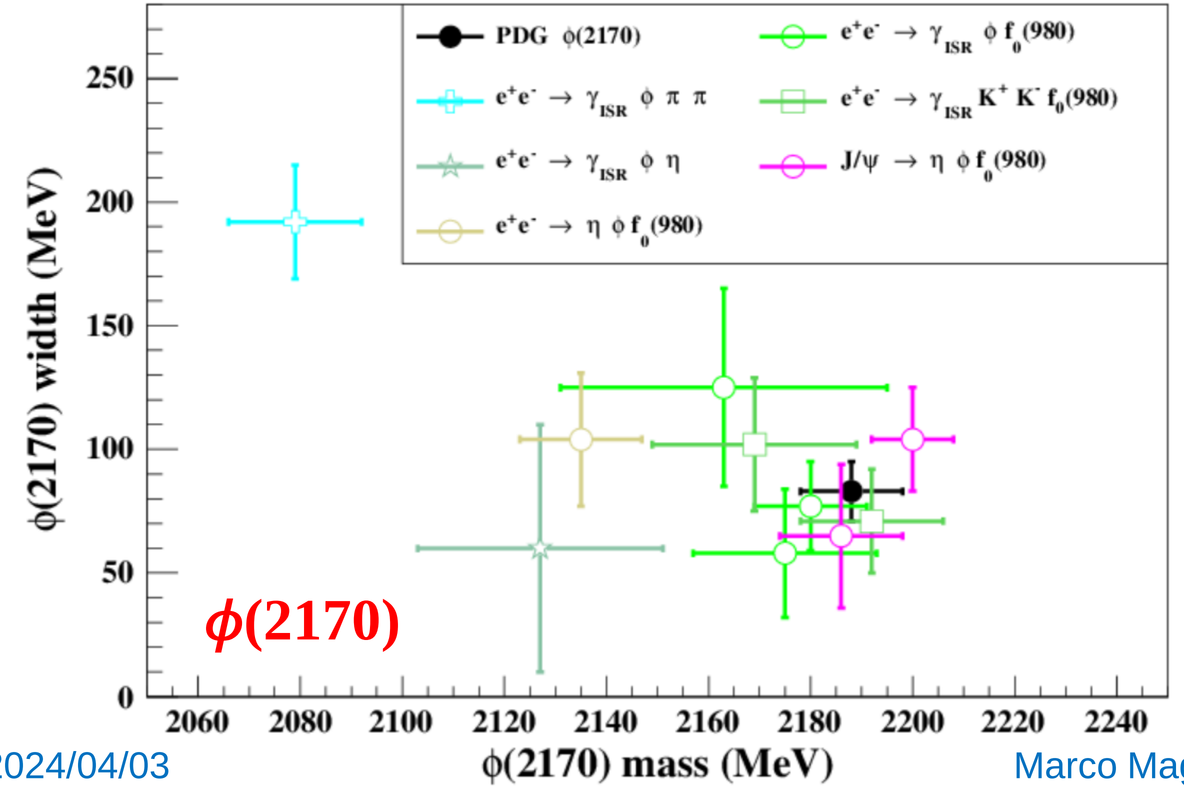




$\phi(2170)$ / Y(2175)

PDG2018 $\phi(2170)$ DECAY MODES

	Mode	Fraction (Γ_i/Γ)
Γ_1	e^+e^-	seen
Γ_2	$\phi\eta$	
Γ_3	$\phi\pi\pi$	
Γ_4	$\phi f_0(980)$	seen
Γ_5	$K^+K^-\pi^+\pi^-$	
Γ_6	$K^+K^-f_0(980) \to K^+K^-\pi^+\pi^-$	seen
Γ_7	$K^+K^-\pi^0\pi^0$	
Γ_8	$K^+K^-f_0(980) \to K^+K^-\pi^0\pi^0$	seen
Γ_9	$K^{*0}K^\pm\pi^\mp$	not seen
Γ_{10}	$K^*(892)^0\overline{K}^*(892)^0$	not seen



- **experimental scenario:**
  - **limited decay modes**
  - **mass and width inconsistencies**
- $\phi(2170)$ **interpretations:**
  - 2^3D_1 or 3^3S_1 $s\bar{s}$
  - $s\bar{s}g$ hybrid
  - **tetraquark**
  - **molecular $\Lambda\bar{\Lambda}$** state
  - **$\phi f_0(980)$** resonance with FSI
  - three body **ϕKK system**
- needing better knowledge of $\rho^*/\omega^*/\phi^*$ @ ~2.2 GeV

BESIII R scan: probing vector states

- **published/submitted paper:**
  1. $e^+e^- \to K^+ K^-$: PRD 99, 032001 (2019)
  2. $e^+e^- \to \phi K^+ K^-$: PRD 100, 032009 (2019)
  3. $e^+e^- \to K^+ K^- \pi^0 \pi^0$: PRL 124, 112001 (2020)
  4. $e^+e^- \to \phi \eta'$: PRD 102, 012008 (2020)
  5. $e^+e^- \to \omega \eta$, $e^+e^- \to \omega \pi^0$: PLB 813, 136059 (2021)
  6. $e^+e^- \to \phi \eta$: PRD 104, 032007 (2021)
  7. $e^+e^- \to K_S K_L$: PRD 104, 032007 (2021)
  8. $e^+e^- \to \eta' \pi^+ \pi^-$: PRD 104, 092014 (2021)
  9. $e^+e^- \to \omega \pi^0 \pi^0$: PRD 105, 032005 (2022)
  10. $e^+e^- \to K^+ K^- \pi^0$: JHEP 07, 045 (2022)
  11. $e^+e^- \to \omega \pi^+ \pi^-$: JHEP 01, 111 (2023)
  12. $e^+e^- \to \phi \pi^+ \pi^-$: PRD 108, 032011 (2023)
  13. $e^+e^- \to \pi^+ \pi^- \pi^0$: arXiv:2401.14711
  14. $e^+e^- \to \eta \pi^+ \pi^-$: PRD 108, L111101 (2023)
  15. $e^+e^- \to K_S K_L \pi^0$: JHEP 01, 180 (2024)

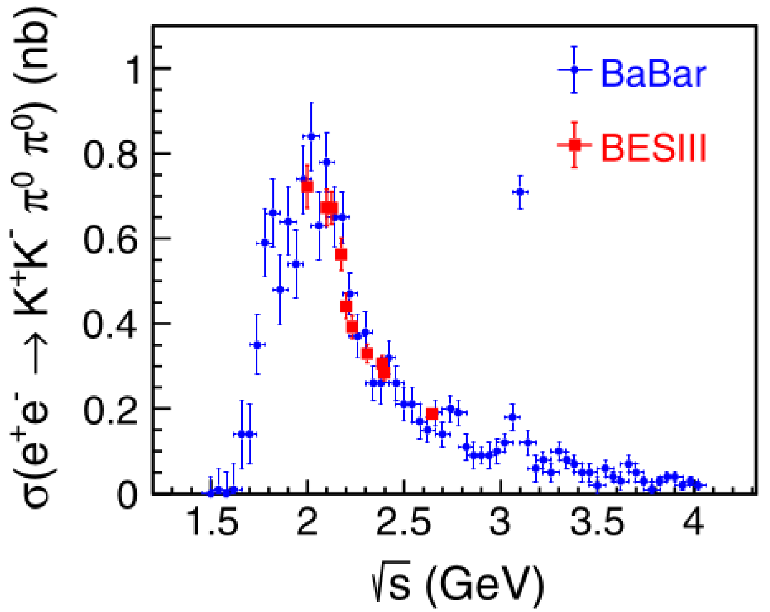
- **ongoing analyses:**
  1. $e^+e^- \to \omega \eta'$
  2. $e^+e^- \to \omega K^+ K^-$
  3. $e^+e^- \to \gamma \eta'$
  4. $e^+e^- \to K_S K^\pm \pi$
  5. $e^+e^- \to \omega \eta \pi$
  6. $e^+e^- \to K^+ K^- \pi^+ \pi^-$
  7. $e^+e^- \to f_1(1285) \pi^+ \pi^-$
  8. $e^+e^- \to \omega \pi^+ \pi^- \pi^0$
  9. $e^+e^- \to \pi^+ \pi^- 2\pi^0$

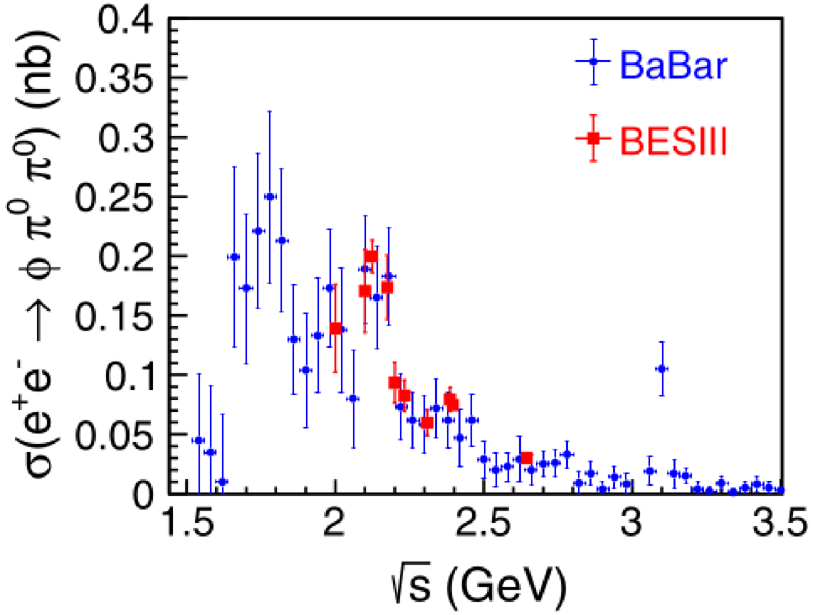
$\phi(2170)$ / Y(2175): $e^+e^- \to K^+K^-\pi^0\pi^0$

- $e^+ e^- \to K^+K^-\pi^0\pi^0$ **[PRD 124, 112001 (2020)]**
  - PWA on 300 pb^{-1} data between 2.00 and 2.644 GeV
  - cross sections consistent with BABAR data, more precise
  - $M = (2126.5 \pm 16.8 \pm 12.4) MeV/c^2$
  - $\Gamma = (106.9 \pm 32.1 \pm 28.1) MeV$
  - statistical significance: 6.3 σ ; **J^{PC}= 1^{--}**
  - simultaneous fit on 4 channels

Channel		$\mathcal{B}_r\Gamma_R^{e^+e^-}$ (eV)	ϕ (rad)	significance (σ)
$K^+(1460)K^-$		3.0 ± 3.8	5.6 ± 1.5	4.4
$K_1^+(1400)K^-$	Solution 1	4.7 ± 3.3	3.7 ± 0.4	4.8
	Solution 2	98.8 ± 7.8	4.5 ± 0.3	
$K_1^+(1270)K^-$	Solution 1	7.6 ± 3.7	4.0 ± 0.2	1.4
	Solution 2	152.6 ± 14.2	4.5 ± 0.1	
$K^{*+}(892)K^{*-}(892)$		0.04 ± 0.2	5.8 ± 1.9	1.2

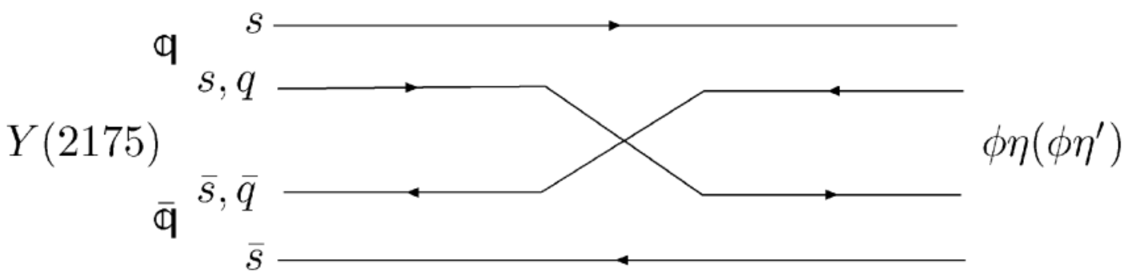
  - consistent with $\phi(2170)$
  - not consistent with 3^3S_1 or 2^3D_1 (K*K* decay favoured)
  - not consistent with $s\bar{s}g$ (comparing dominant decays)





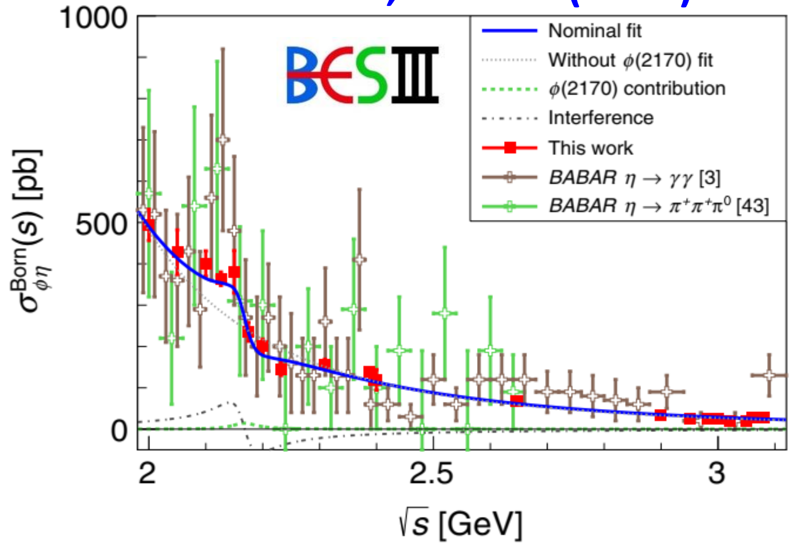
$\phi(2170)$ / Y(2175): $e^+e^- \to \phi\eta, \phi\eta'$

- $e^+ e^- \to \phi\eta$ **[PLB 669, 160 (2008): significant contribution]**

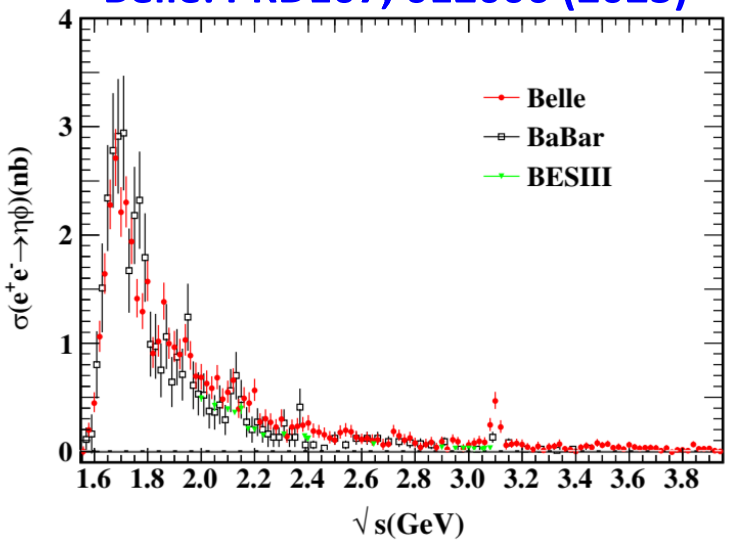


- 715 pb^{-1} data between 2.00 and 3.08 GeV
- $M = (2163.5 \pm 6.2 \pm 3.0) MeV/c^2$
- $\Gamma = \left(31.1^{+21.1}_{-11.6} \pm 1.1\right) MeV$
- statistical significance: $> 10.9\ \sigma$; **J^{PC}= 1⁻⁻**
- ω* OZI suppressed, ρ* suppressed by isoscalar mode

PRD 104, 032007 (2021)

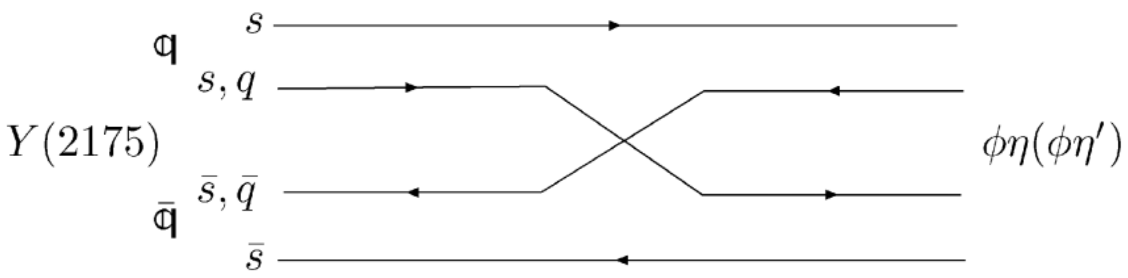


Belle: PRD107, 012006 (2023)

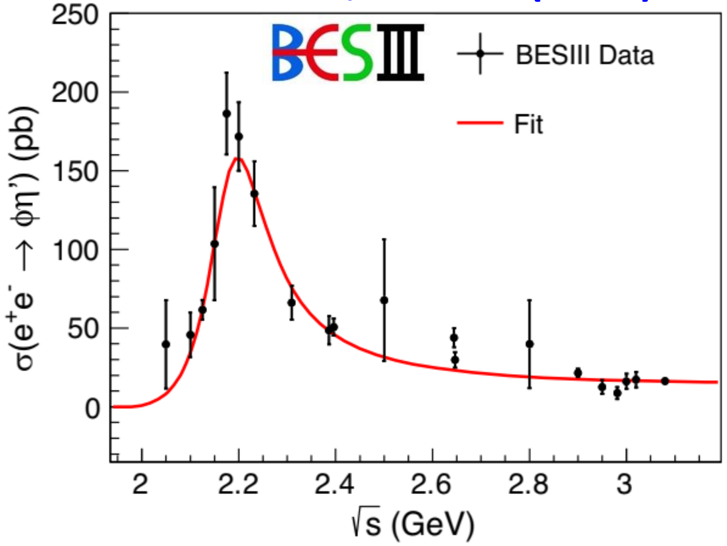


$\phi(2170)$ / Y(2175): $e^+e^- \to \phi\eta\,,\phi\eta'$

- $e^+\,e^- \to \phi\eta'$ **[PLB 669, 160 (2008): significant contribution]**



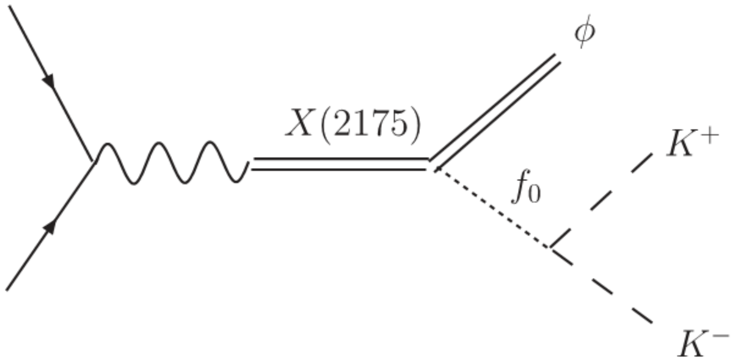
PRD 102, 012008 (2020)



  - $640\ \mathrm{pb}^{-1}$ data between 2.05 and 3.08 GeV
  - cross sections consistent with BABAR, more precise
  - $M = (2177.5 \pm 4.8 \pm 19.5) MeV/c^2$
  - $\Gamma = (149.0 \pm 15.6 \pm 8.9) MeV$
  - statistical significance: $> 10\ \sigma$; **J^{PC}= 1^{--}**
  - $\frac{\mathcal{B}(e^+\,e^- \to \phi\eta)}{\mathcal{B}(e^+\,e^- \to \phi\eta')} = 0.23 \pm 0.10 \pm 0.18 \ll \boldsymbol{s\bar{s}g}$ hybrid model predictions **[PRD59,034016; PLB650,390]**
  - 2^3D_1 $\boldsymbol{s\bar{s}}$ disfavoured by resonance parameters, 3^3S_1 $\boldsymbol{s\bar{s}}$ disfavoured by larger prediceted Γ

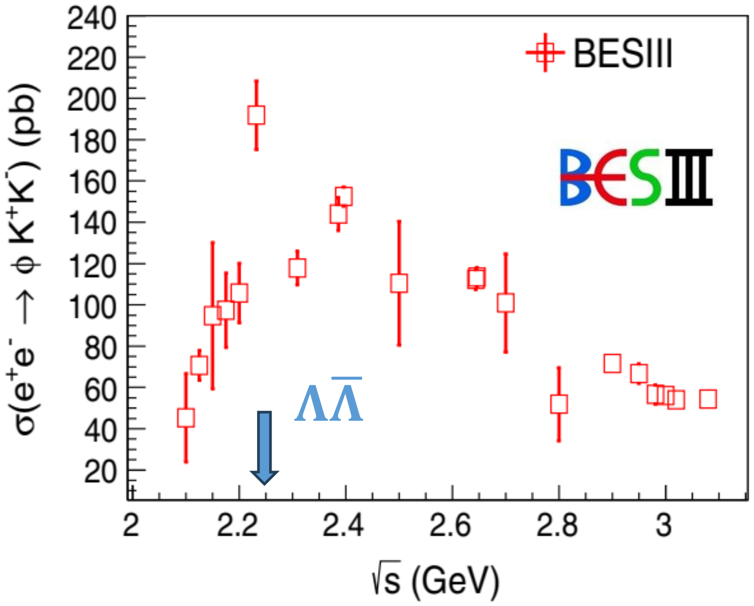
$\phi(2170)$ / Y(2175): $e^+e^- \to \phi K^+K^-, K^+K^- K^+K^-$

- $e^+ e^- \to \phi(2170) \to \phi K^+ K^-$

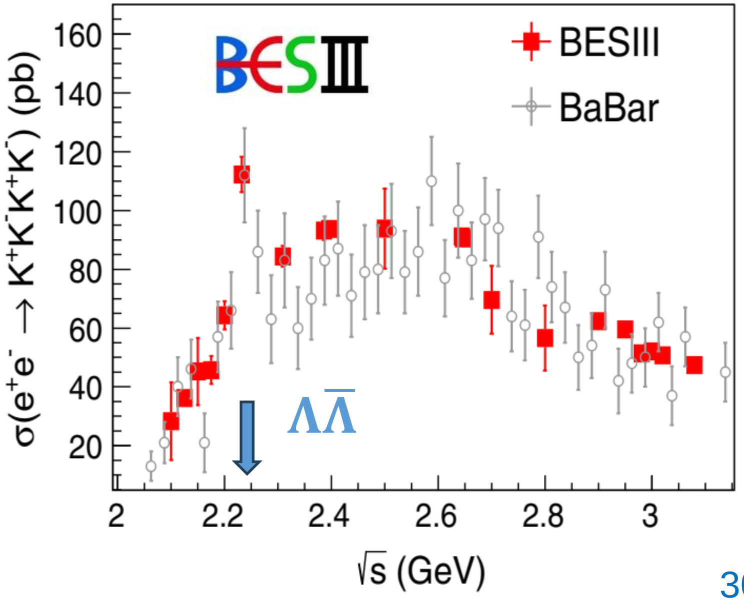


First measurement

PRD 100, 022009 (2019)



- $\phi(2170)$ is predicted to be a $\phi K^+ K^-$ resonance
  [PRD 79 034018 (2009)]
- $650\ \mathrm{pb}^{-1}$ data between 2.00 and 3.08 GeV
- cross sections consistent with BABAR, more precise
- similar enhancement @ 2.2324 GeV, near $\boldsymbol{\Lambda\bar{\Lambda}}$ threashold
- hint for a narrow reasonance ($\Gamma < 20\ MeV$) at $\boldsymbol{\Lambda\bar{\Lambda}}$ threashold



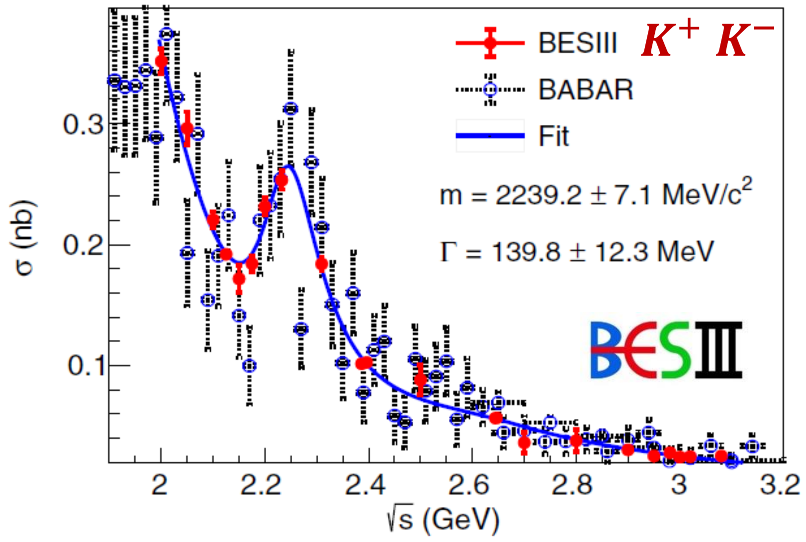
$\phi(2170)$ / Y(2175): $e^+e^- \to K^+K^-, K_SK_L$

- $e^+ e^- \to K^+ K^-, K_SK_L$
  - 582 pb^{-1} data between 2.00 and 3.08 GeV
  - one resonance at K^+K^- and K_SK_L

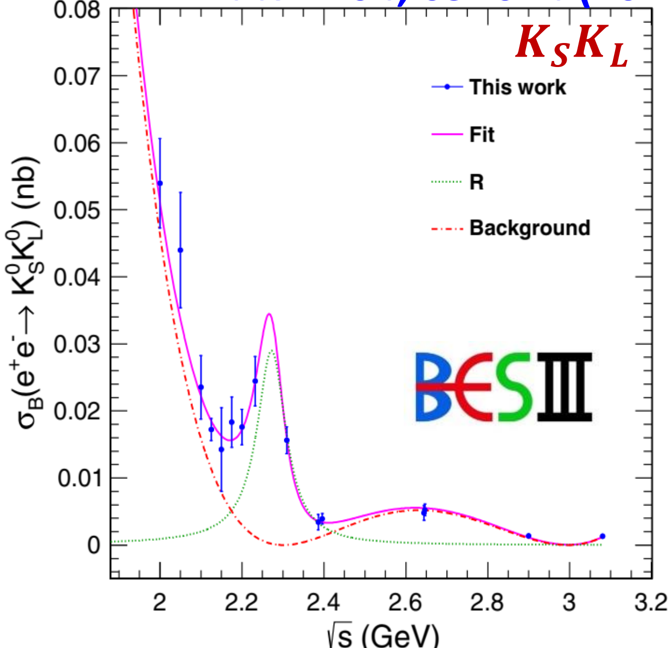
	K^+K^-	K_SK_L
Mass (MeV/c^2)	2239.2±7.1±11.3	2273.7±5.7±19.3
Width (MeV)	139.8±12.3±20.6	86±44±51
Γ_{ee}Br (eV)		0.9±0.6±0.7

- Dominant KK mode @ $\phi(2170)$?
  - Iso-scalar: ω*/ϕ*; iso-vector: ρ*
  - Extract isospin component

PRD 99, 032001 (2019)

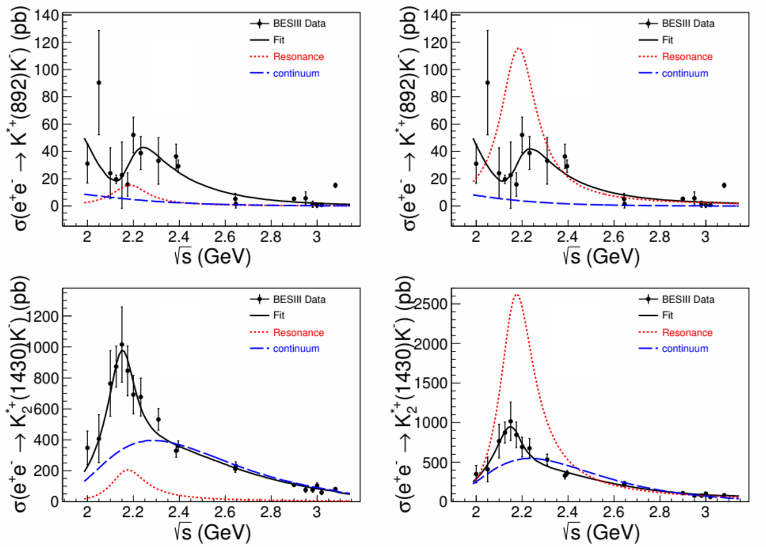


PRD 104, 092014 (2021)



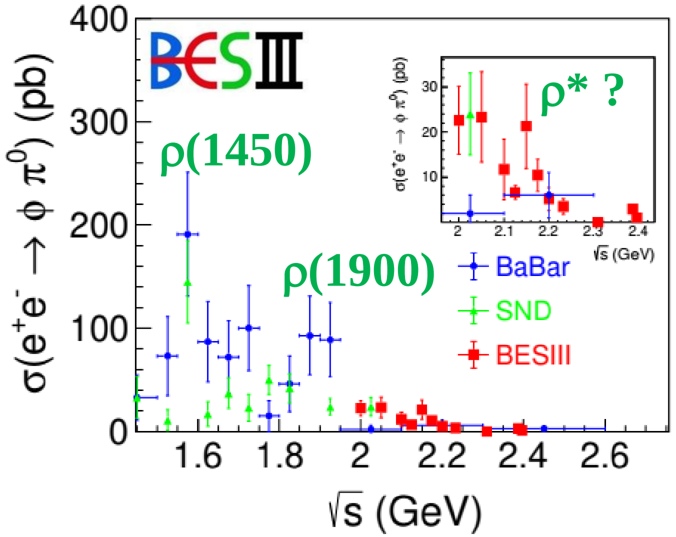
$\phi(2170)$ / Y(2175): $e^+e^- \to K^+K^-\pi^0$

JHEP 07, 045 (2022)



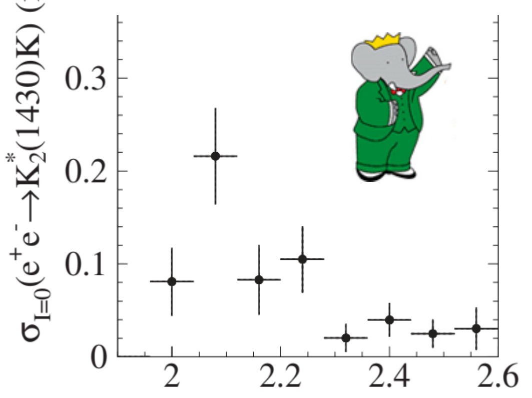
	$K_2^*(1430)K$	$K^*(892)K$
Mass (MeV/c²)	**2190±19±37**	
Width (MeV)	**191±28±60**	
Γ_{ee}Br (eV)	**12.6±2.4**	**1.0±0.3**
	161.1±20.6	**7.1±0.9**

$$\frac{\mathscr{B}(\phi(2170)\to K^{*+}(1430)K^-)}{\mathscr{B}(\phi(2170)\to K^{*+}(892)K^-)} = \begin{matrix} 12.6\pm4.5 \\ (22.7\pm4.1) \end{matrix}$$



- $e^+ e^- \to K^+ K^- \pi^0$
  - 648 pb^{-1} data between 2.00 and 3.08 GeV
  - cross sections consistent with BABAR, more precise
  - resonance in $K_2^*(1430)K$ / $K^*(892)$, statistical significance: $> 7.1\ \sigma$
  - compatible with $\phi(2170)$ in $K_2^*(1430)K$ (BABAR hint @ 2.1 GeV)
  - vector state in $\phi\pi^0$: ρ* OZI-suppressed, ω/ϕ* isospin violating
  - resonance in $\phi\pi^0$ @ 2.1 GeV?

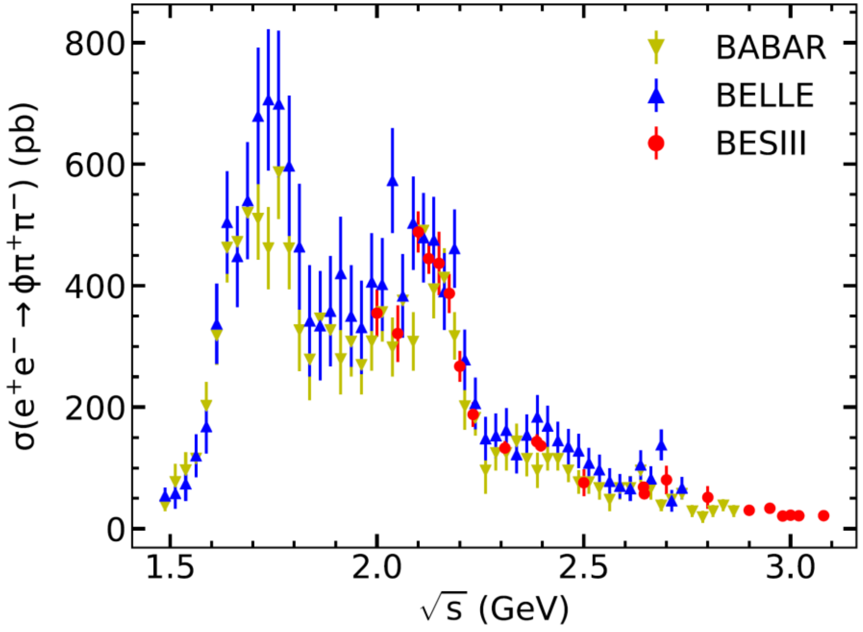
PRD 77, 092002 (2008)



$\phi(2170)$ / Y(2175): $e^+e^- \to \phi\pi^+\pi^-$

PRD 108, 032011 (2023)

- $e^+ e^- \to \phi\pi^+\pi^-$
  - 651 pb^{-1} data between 2.05 and 3.08 GeV
  - cross sections consistent with BABAR, more precise
  - $M = (2178 \pm 20 \pm 5) MeV/c^2$
  - $\Gamma = (140 \pm 36 \pm 16) MeV$
  - statistical significance: $> 10\,\sigma$; $J^{PC} = 1^{--}$
  - Belle data: structure @ 2.4GeV with 1.5σ
  - no resonance observed @ 2.4 GeV but…
  - …resonance observed @ 2.4 GeV in $K^+K^-f_0(980)$
  - PWA is needed

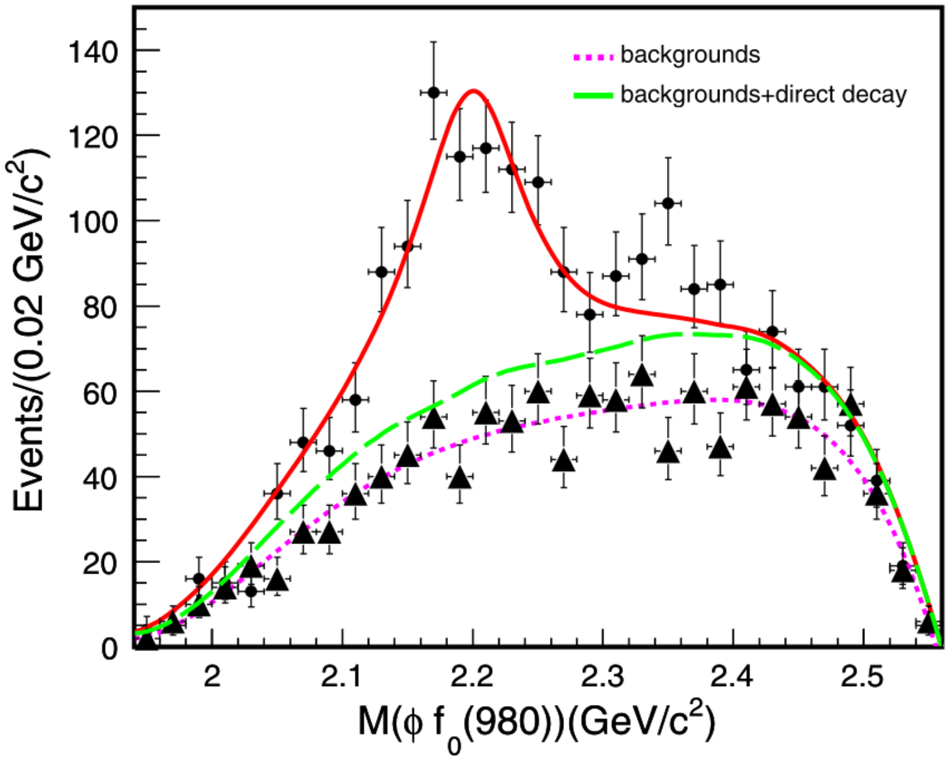


$\phi\ f_0(980)$	Mass (MeV)	Width (MeV)
BaBar (2006)	2175±10±15	58±16±20
BES (2008)	2186±10±6	65±23±17
Belle (2009)	2163±32	125±40
BaBar (2012)	2172±10±8	96±19±12
BESIII (2015)	2200±6±5	104±15±15
BESIII (2019)	2135±8±9	104±24±12
PDG2022	2160±7	100+31-23

$\phi(2170)$ / Y(2175): J/ψ → $\eta\phi\pi^+\pi^-$

- $e^+ e^- \rightarrow J/\psi \rightarrow \eta Y(2175)\,, Y(2175) \rightarrow \phi f_0(980)\ ,\ f_0(980) \rightarrow \pi^+\pi^-$
  - $2.25\ 10^8\ J/\psi \rightarrow \eta\phi\pi^+\pi^-$
  - invariant mass spectrum of $\phi f_0(980)$
  - $M = (2200 \pm 6 \pm 5) MeV/c^2$
  - $\Gamma = (104 \pm 15 \pm 15) MeV$
  - statistical significance: $> 10\ \sigma$
  - $\mathcal{B}(J/\psi \rightarrow \eta Y(2175)\,,$
    $Y(2175) \rightarrow \phi f_0(980)\,,$
    $f_0(980) \rightarrow \pi^+\pi^-) = (1.20 \pm 0.14 \pm 0.37) \times 10^{-4}$

PRD 91, 052017 (2015)



Summary

Conclusions

- High accuracy **R-value measurements**
- Impressive record of **new particles** discovered at BESIII
- Ideal experimental scenario for **Hadron Spectroscopy**
- Unique access to **nucleon**, **hyperon** and **hadronic structure**
- New exciting results expected:
  - high statistics datasets in wide energy range already collected
  - other approaches to be explored

Stay tuned!

Thank you!

Backup

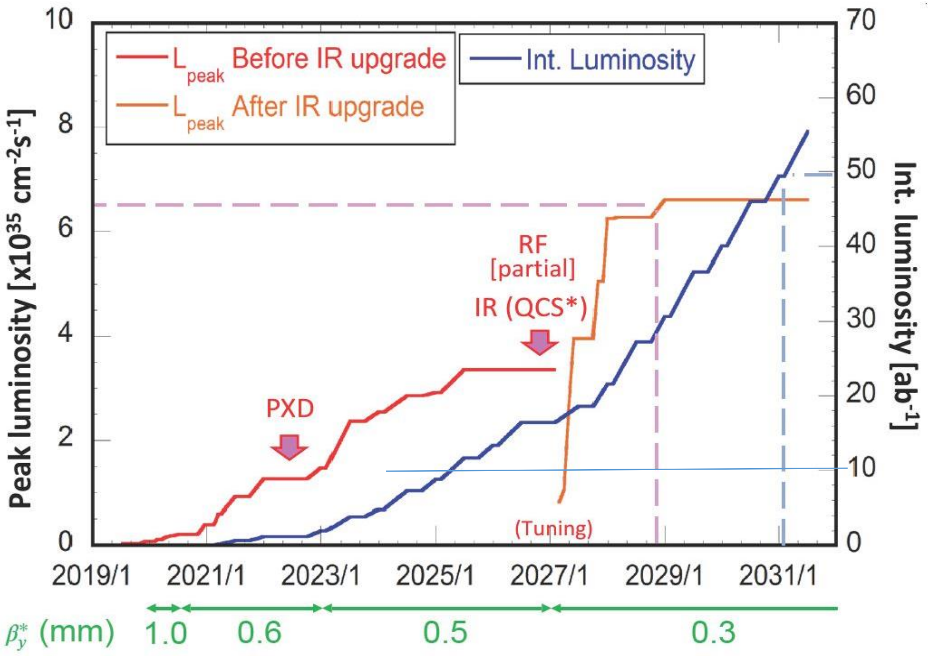
BESIII detector performance

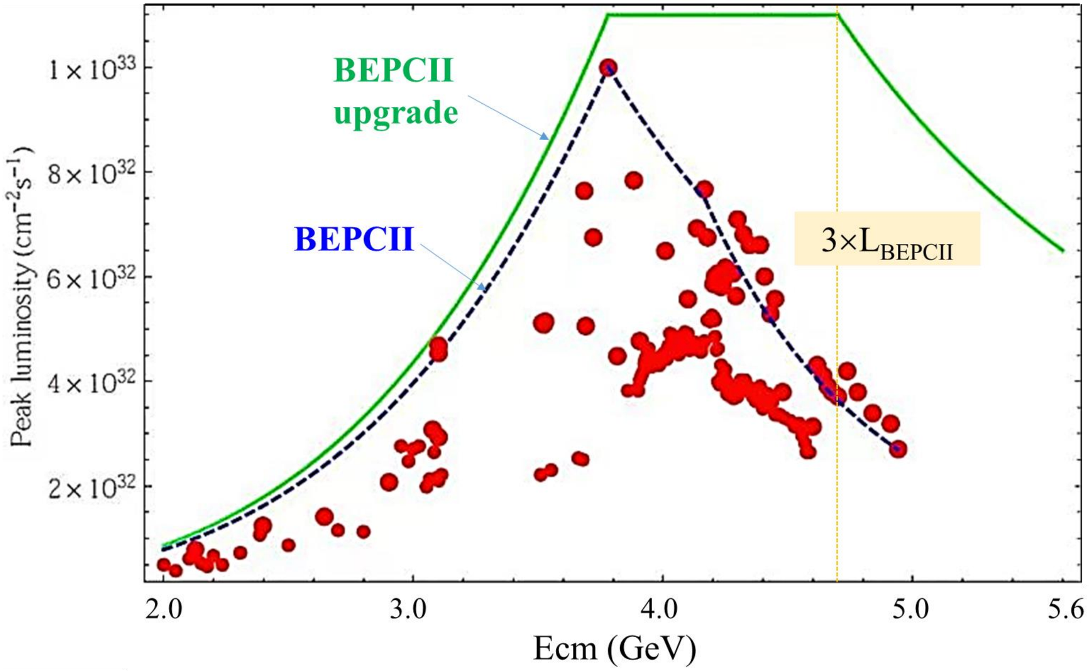
Experiments	**MDC** Spatial resolution	**MDC** dE/dx resolution	**EMC** Energy resolution
CLEOc	110 μm	5%	2.2-2.4 %
Babar	125 μm	7%	2.67 %
Belle	130 μm	5.6%	2.2 %
BESIII	115 μm	<5% (Bhabha)	2.4%

Experiments	**TOF** Time resolution
CDFII	100 ps
Belle	90 ps
BESIII	68 ps (BTOF) 60 ps (ETOF)

The near future

The near future

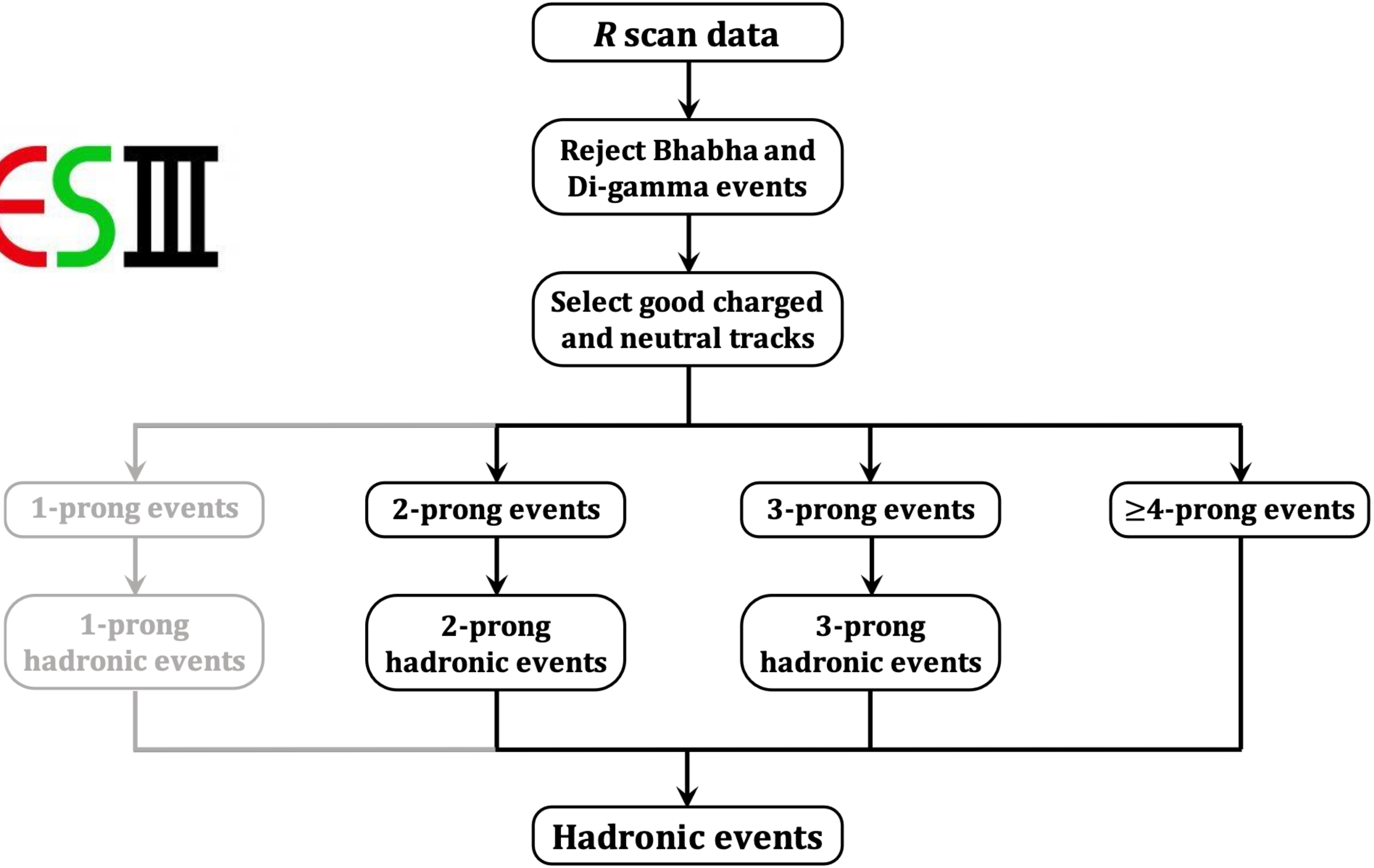




2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	203+
		Run III						Run IV					Run V	
LS2						LS3					LS4			
LHCb 40 MHz **UPGRADE I**		*L = 2 x 10^{33}*			**LHCb Consolidate: UPGRADE Ib**			*L = 2 x 10^{33}* *50 fb^{-1}*			**LHCb UPGRADE II**		*L=1-2x 10^{34}* *300 fb^{-1}*	
ATLAS Phase I Upgr		*L = 2 x 10^{34}* *300 fb^{-1}*			**ATLAS Phase II UPGRADE**			**HL-LHC** *L = 5 x 10^{34}*					**HL-LHC** *L = 5 x 10^{34}* *3000 fb^{-1}*	
CMS Phase I Upgr					**CMS Phase II UPGRADE**									

$R\ value\colon experimental\ data$

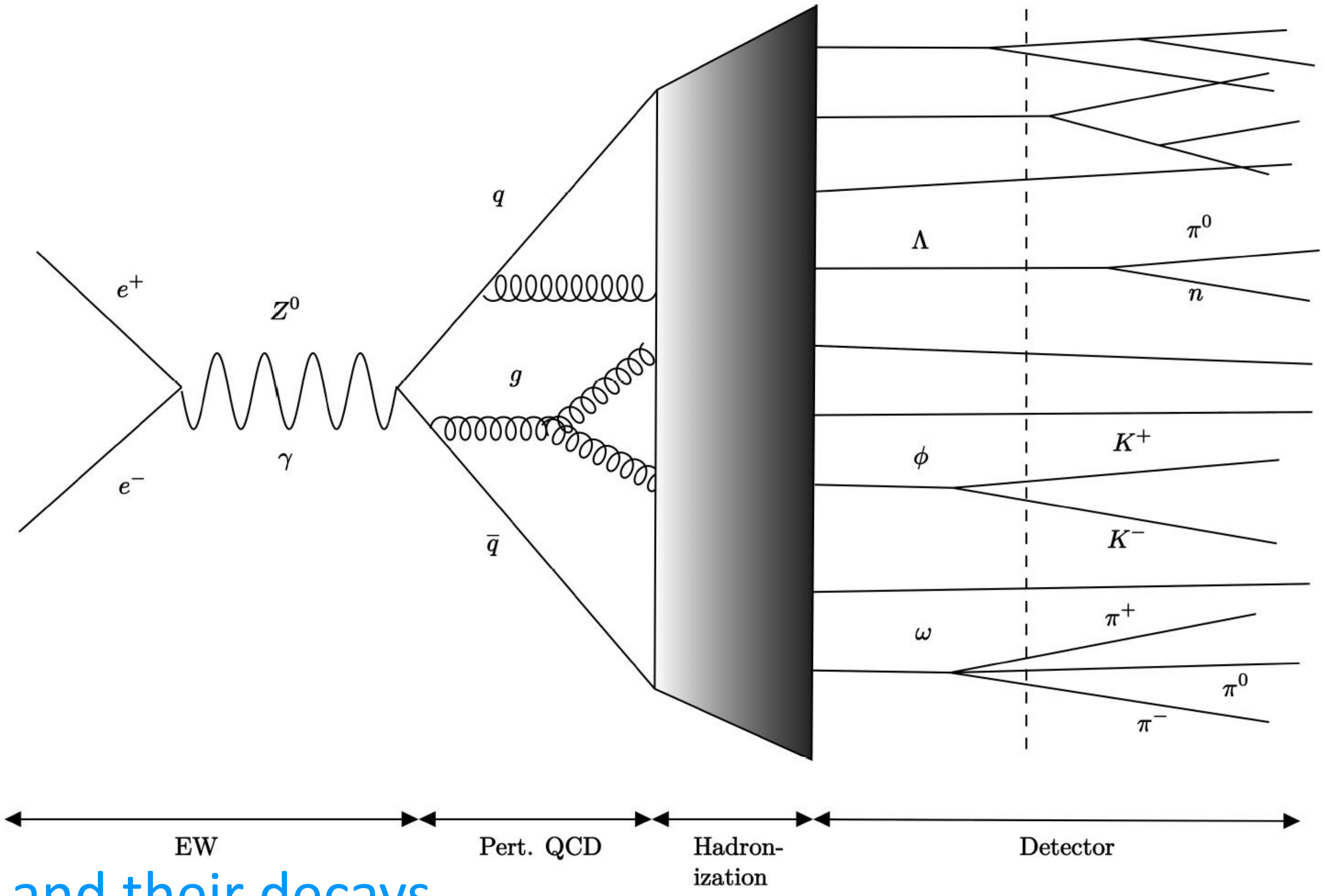
New BESIII R–value data: analysis strategy



PRD 128, 062004 (2022)

Nominal signal simulation model: LUARLW

LUARLW



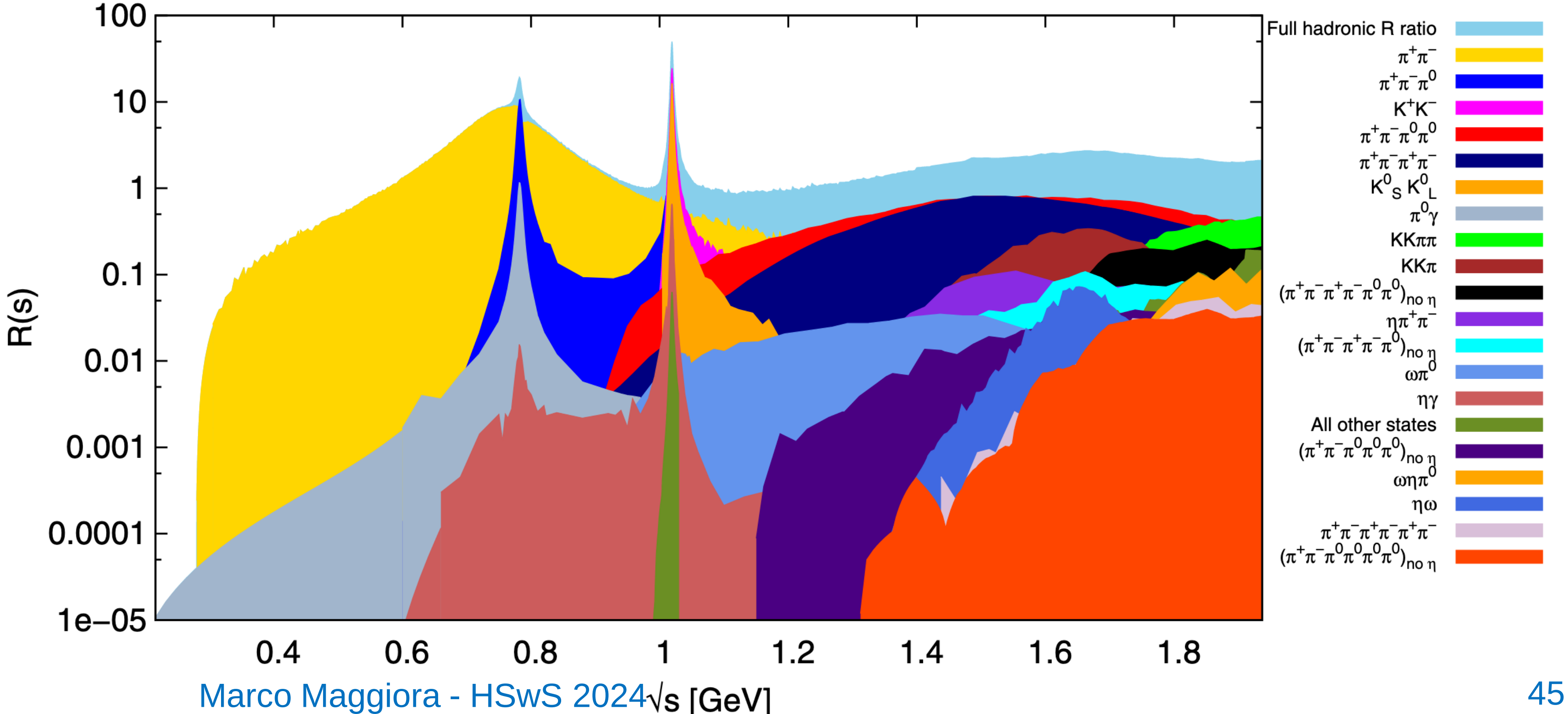
- self-consistent inclusive generator
- based on JETSET at low energies
- generation: continuum, resonant states and their decays
- Initial-State Radiation (ISR) processes implemented from $2m_\pi$ to $\sqrt{s}$
- kinematics of initial hadrons determined by Lund area law
- phenomenological parameters tuned to data
- adopted in most previous R-measurements (e.g. BESII and KEDR)

Alternative signal simulation model: HYBRID

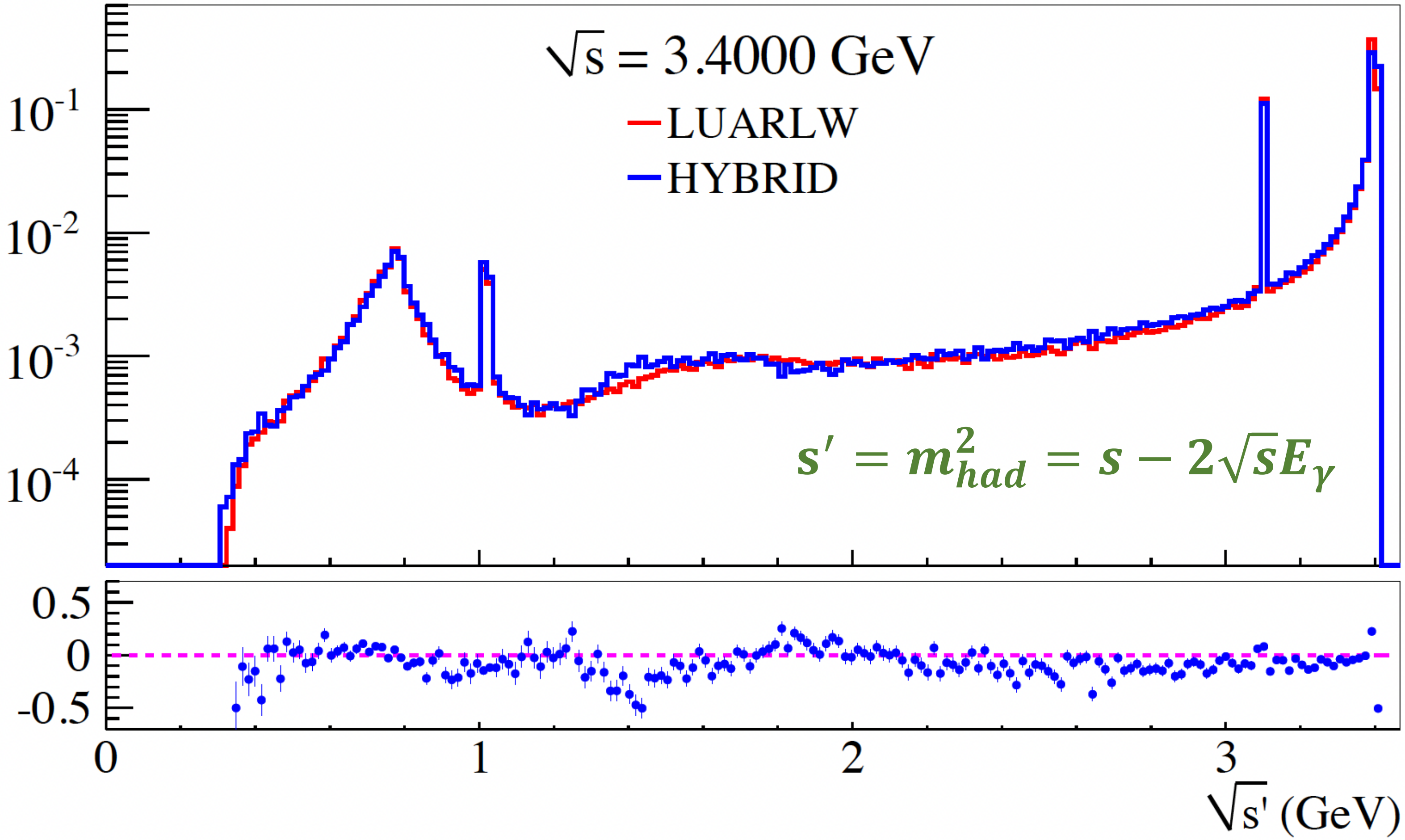
- **HYBRID**: as much experimental information as possible, combining 3 established models:
  - CONEXC (over 50 channels, experimental cross sections)
  - PHOKHARA (10 exclusive channels, hadronic models tuned to experimental data)
  - LUARLW (unknown processes)
- up-to-date experimental knowledge implemented
- alternative ISR and VP correction schemes from the nominal ones adopted

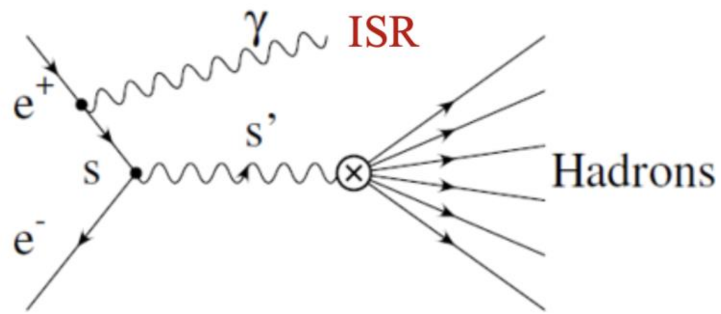
PRD 97, 114025 (2019)

HIBRID vs LUARLW: < 1.4%



Effective energy $\sqrt{s'}$ spectra: LUARLW vs HYBRID





maximum difference of the calculated ISR correction between HYBRID and LUARLW is 1.4%,

- $\sqrt{s'}$ spectrum directly reflects the fraction of the ISR-returned processes
- LUARLW and HYBRID adopts two different ISR simulation schemes, and yet …
- … effective energy spectrum results are consistent

PRD 128, 062004 (2022)

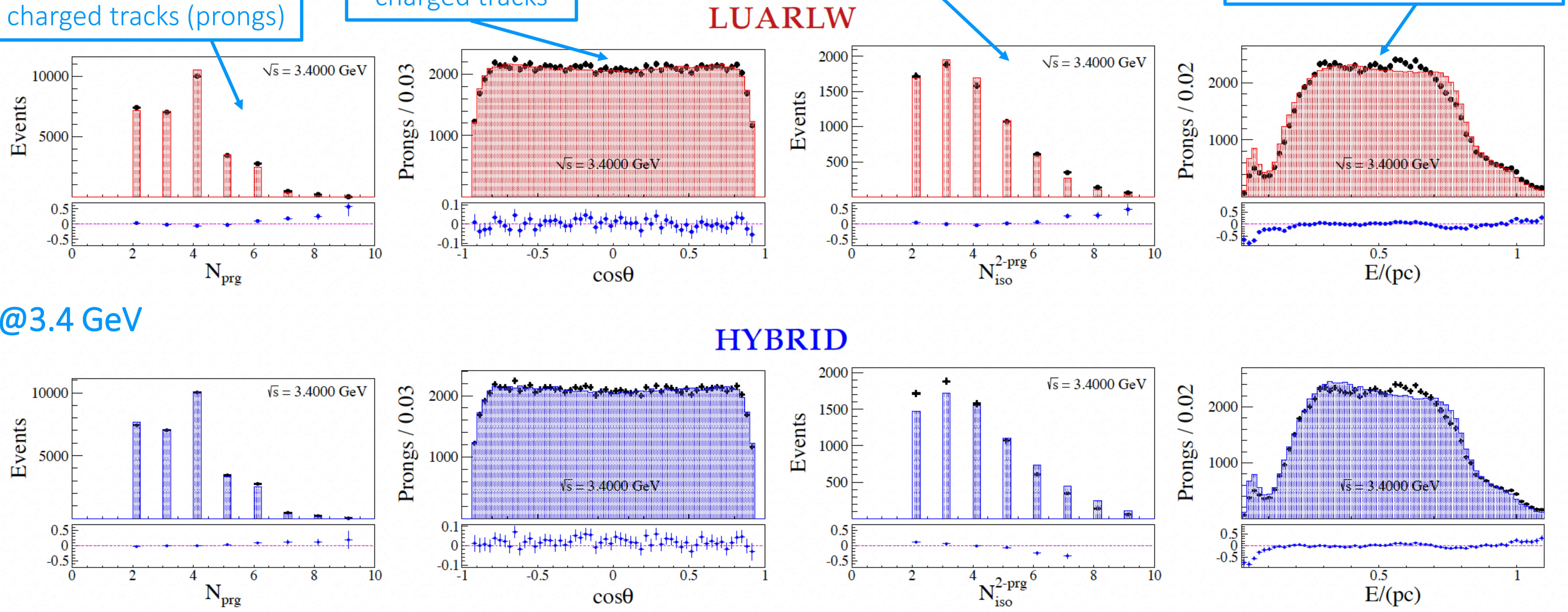
MC vs data consistency: LUARLW vs HYBRID

number of good charged tracks (prongs)

polar angle of charged tracks

number of isolated clusters in 2-prong events

ratio of EMC deposited energy and momentum



@3.4 GeV

Both models show good agreement with data!

PRD 128, 062004 (2022)

BESIII experimental R data in the range 2.2 ÷ 3.7 GeV

TABLE I. Summary of systematic uncertainties (in percent) at each c.m. energy, where the total uncertainty is the sum of the individual ones in quadrature. Uncertainties from the last four sources are correlated between the energy points.

$\sqrt{s}$ (GeV)	Event selection	QED background	Beam background	Luminosity	Trigger efficiency	Signal model	ISR correction	Total
2.2324	0.41	0.23	0.28	0.80	0.10	0.60	1.15	1.62
2.4000	0.55	0.27	0.15	0.80	0.10	1.11	1.10	1.87
2.8000	0.58	0.28	0.34	0.80	0.10	1.97	1.06	2.48
3.0500	0.61	0.33	0.41	0.80	0.10	1.76	1.01	2.33
3.0600	0.60	0.34	0.48	0.80	0.10	1.84	1.00	2.39
3.0800	0.61	0.35	0.35	0.80	0.10	1.31	1.05	2.02
3.4000	0.65	0.33	0.16	0.80	0.10	1.86	1.24	2.49
3.5000	0.60	0.35	0.62	0.80	0.10	2.05	1.16	2.66
3.5424	0.61	0.37	0.01	0.80	0.10	2.05	1.14	2.58
3.5538	0.66	0.31	0.39	0.80	0.10	2.22	1.13	2.74
3.5611	0.74	0.34	0.34	0.80	0.10	2.28	1.12	2.81
3.6002	0.66	0.33	0.38	0.80	0.10	2.27	1.09	2.77
3.6500	0.53	0.35	0.69	0.80	0.10	2.28	1.13	2.83
3.6710	0.61	0.42	0.63	0.80	0.10	2.23	1.04	2.77

14 energy points
total of 52 pb^{-1}

- accuracy dominated by systematic uncertainties
- statistic uncertaties: ~ 0.35%

PRD 128, 062004 (2022)