Hyperon Physics and QCD Studies at BESIII

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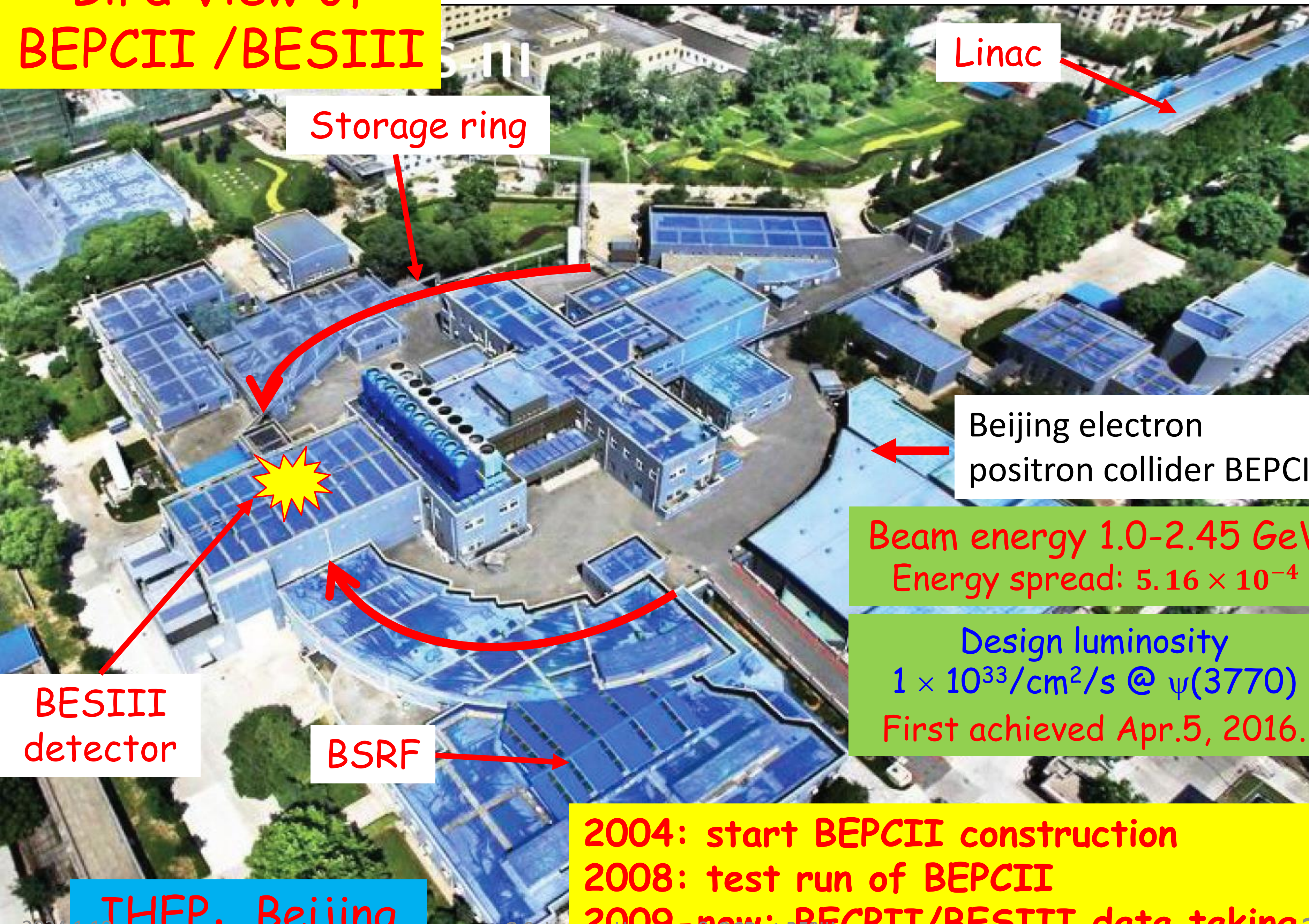
Outline

- Introduction
- Hyperon CPV at BESIII
- QCD studies at BESIII
  - Hadronic cross sections
  - Baryon form factors
- Summary

Bird View of BEPCII /BESIII



Beam energy 1.0-2.45 GeV
Energy spread: 5.16×10^{-4}

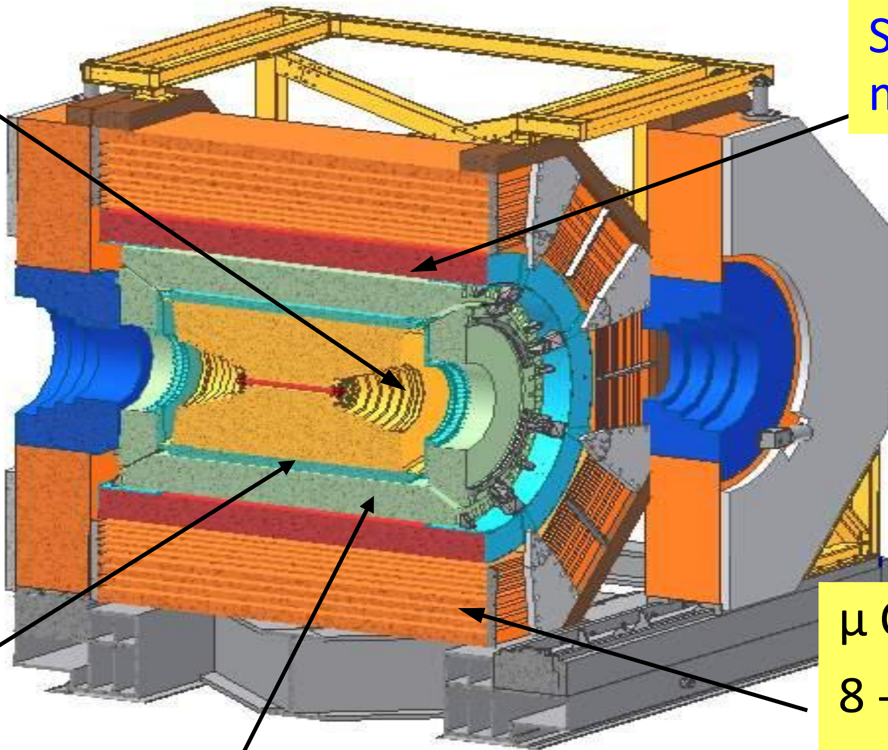
Design luminosity
$1 \times 10^{33}/cm^2/s$ @ $\psi(3770)$
First achieved Apr.5, 2016.

2004: start BEPCII construction
2008: test run of BEPCII
2009-now: BECPII/BESIII data taking

The BESIII Detector

Drift Chamber (MDC)
$\sigma p/p$ ($^0/_0$) = 0.5%(1GeV)
$\sigma_{dE/dx}$ ($^0/_0$) = 6%

Super-conducting magnet (1.0 Tesla)



Time of Flight (TOF)
σ_T: 90 ps for Barrel;
110 ps $\rightarrow$ 65 ps for Endcaps

μ Counter
8 - 9 layers RPC
δR=1.4 cm~1.7 cm

EMC: $\sigma E/\sqrt{E}$($^0/_0$) = 2.5 % (1 GeV)
(CsI) $\sigma_{z,\phi}$(cm) = 0.5 - 0.7 cm/$\sqrt{E}$

BESIII Collaboration

Europe (17/115)

Germany (6): Bochum University, GSI Darmstadt, Helmholtz Institute Mainz, Johannes Gutenberg University of Mainz, Universitaet Giessen, University of Münster

Italy (3): Ferrara University, INFN, University of Torino

Netherlands (1): KVI/University of Groningen

Russia (2): Budker Institute of Nuclear Physics, Dubna JINR

Sweden (1): Uppsala University

Turkey (1): Turkish Accelerator Center Particle Factory Group

UK (2): University of Manchester, University of Oxford

Poland (1) National Centre for Nuclear Research

Asia (6/10)

Pakistan (2): COMSATS Institute of Information Technology, University of the Punjab, University of Lahore

Mongolia (1): Institute of Physics and Technology

Korea (1): Chung-Ang University

India (1): Indian Institute of Technology madras

Thailand (1): Suranaree University of Technology

USA (4/8)

Carnegie Mellon University
Indiana University
University of Hawaii
University of Minnesota

China (58/367)

Institute of High Energy Physics (146), other units(221): Beijing Institute of Petro-chemical Technology, Beihang University, China Center of Advanced Science and Technology, Fudan University, Guangxi Normal University, Guangxi University, Hangzhou Normal University, Henan Normal University, Henan University of Science and Technology, Huazhong Normal University, Huangshan College, Hunan University, Hunan Normal University, Henan University of Technology, Institute of modern physics, Jilin University, Lanzhou University, Liaoning Normal University, Liaoning University, Nanjing Normal University, Nanjing University, Nankai University, North China Electric Power University, Peking University, Qufu normal university, Shanxi University, Shanxi Normal University, Sichuan University, Shandong Normal University, Shandong University, Shanghai Jiaotong Univeristy, Soochow University, South China Normal University, Southeast University, Sun Yat-sen University, Tsinghua University, University of Chinese Academy of Sciences, University of Jinan, University of Science and Technology of China, University of Science and Technology Liaoning, University of South China, Wuhan University, Xinyang Normal University, Zhejiang University, Zhengzhou University, YunNan University, China University of Geosciences

South America (1/1)

Chile: University of Tarapaca

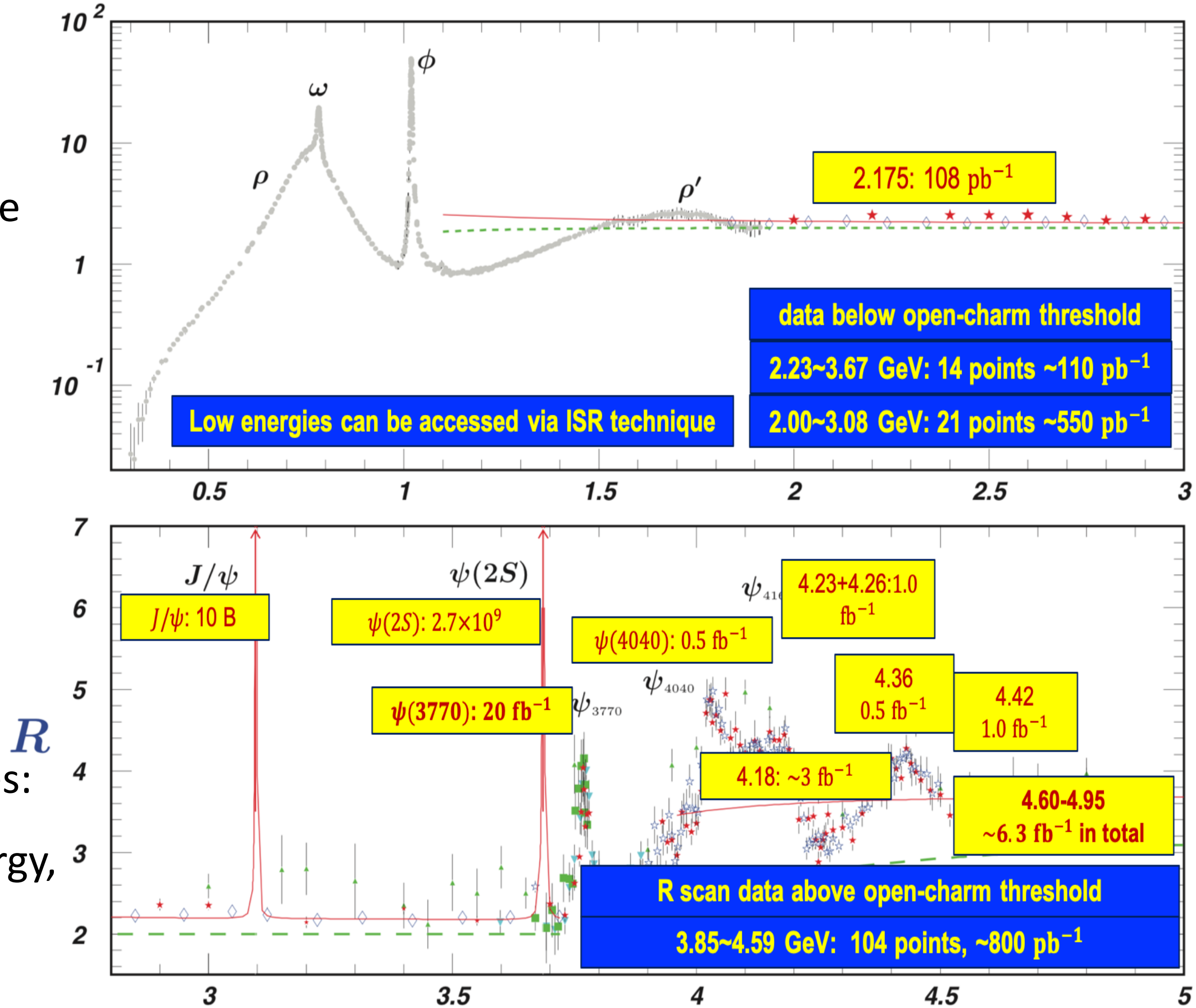
~600 members
From 86 institutions in 17 countries

BESIII Data Samples

Totally about 50 fb^{-1} integrated luminosity

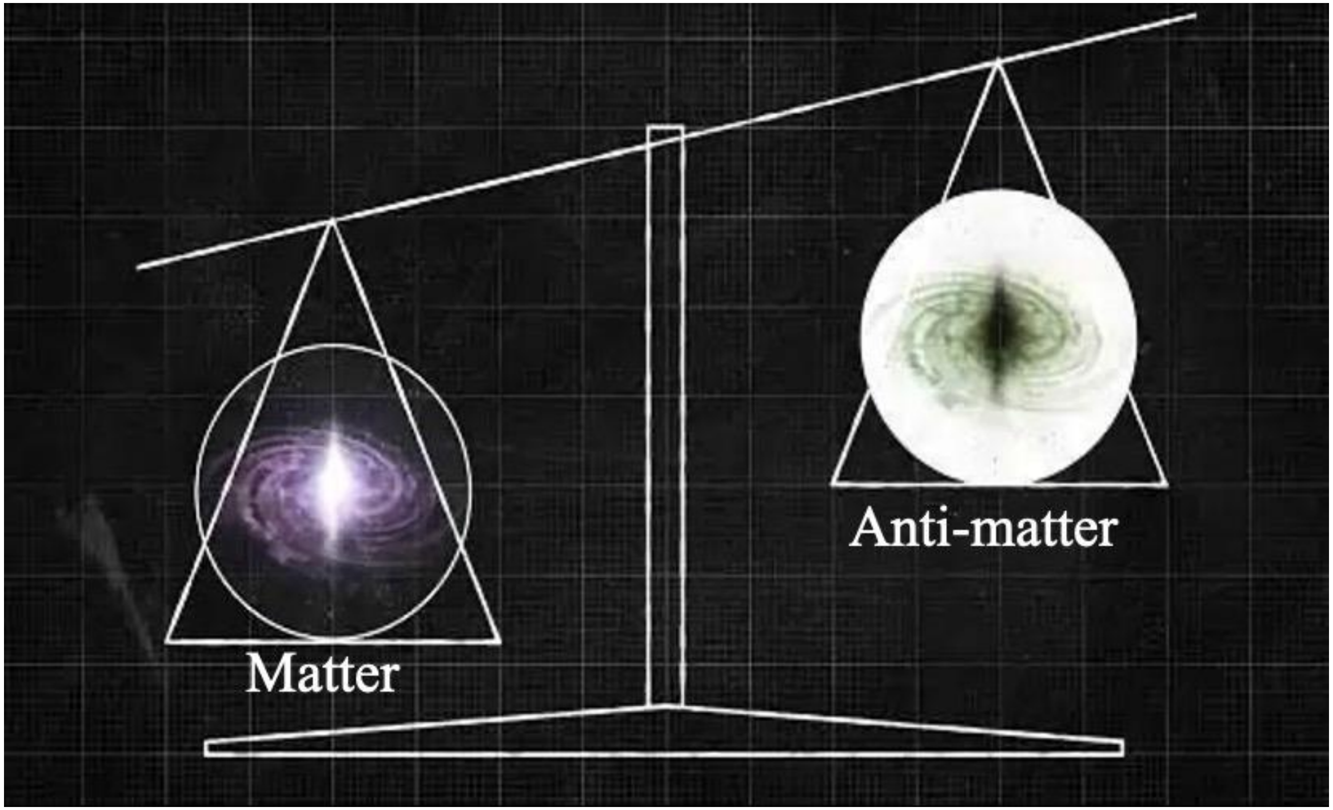
Data sets collected so far include

- 10×10^9 J/ψ events
- 2.7×10^9 ψ(2S) events
- 18 fb^{-1} ψ(3770)
- Scan data between 2.0 and 3.08 GeV, and above 3.74 GeV
- Large datasets for XYZ studies: scan with >500 pb^{-1} per energy, space 10 – 20 MeV apart



Data taking on ψ(3770), reaching 20 fb^{-1} in early 2024.

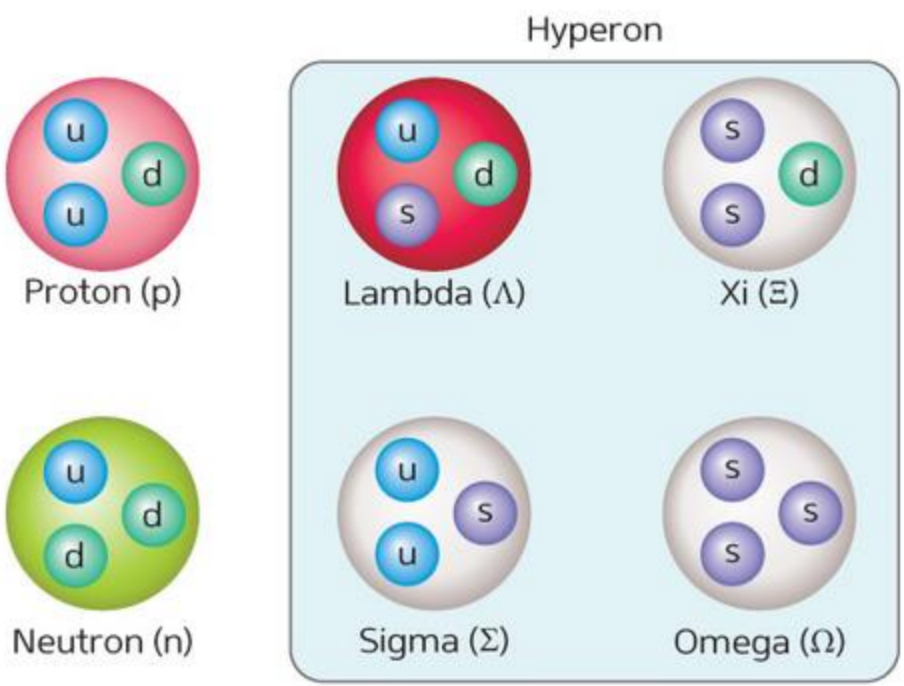
Mystery of the Universe

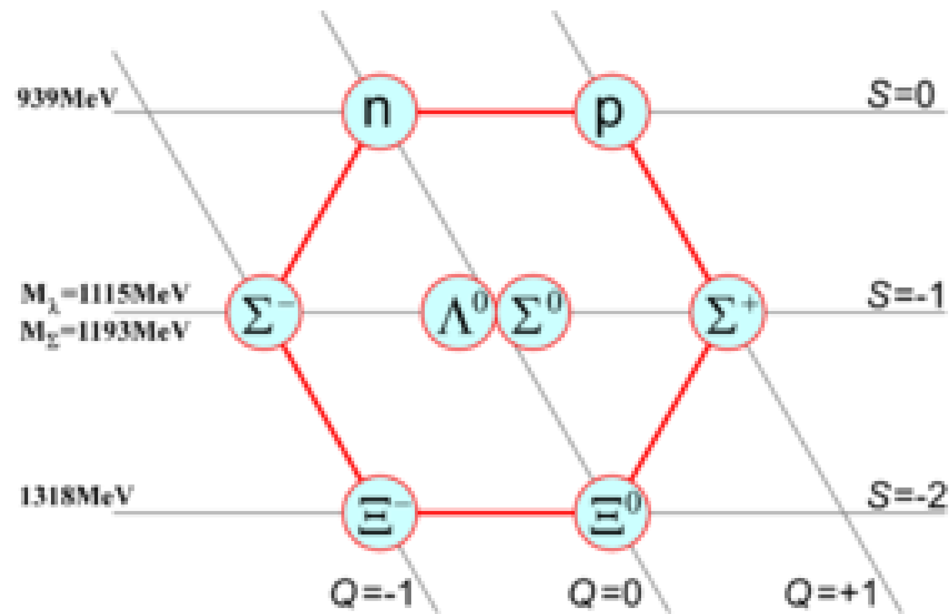


- Source: Charge-Parity Violation (CPV)?
- CPV found in mesons: K (1964), B (2001), D (2019);
- Baryon system? No evidence yet!

Baryon: Nucleon and Hyperon

- Nucleon: 3 normal quarks (u, d);
- Hyperon: ≥ 1 heavier quarks;
- Help to understand internal structure and dynamics;
- Hyperon pair production, apt to search for CPV.



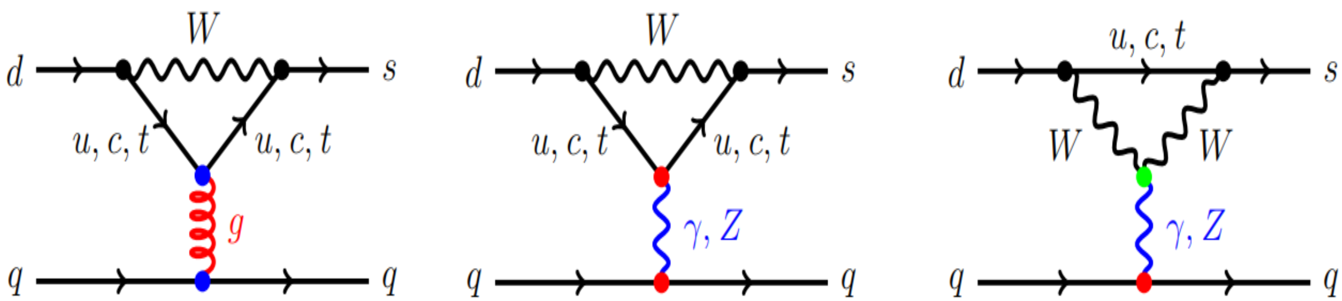


Spin $\frac{1}{2}^{+}$ SU(3) octet

Direct CPV effect in strange-quark sector

See talk by German Valencia on Jan.15: Pursuit of CP violation in hyperon decay

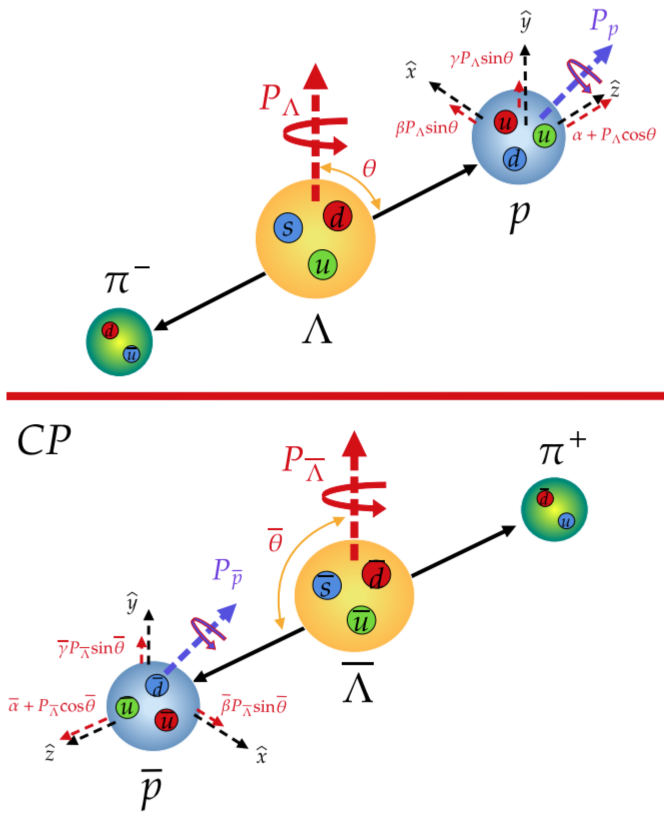
- Direct CP-violation effects in kaon and hyperon decays in the SM are given by QCD and EW penguin operators.



- To generate a CP asymmetry, one needs two different amplitudes that contribute coherently.
- Direct CPV in $K_L \to \pi^+\pi^-$ arise from $\Delta I = 1/2$ and $\Delta I = 3/2$ amplitudes interference in S-wave decay.
- Direct CPV in $Y' \to Y\pi$ arise from S wave and P wave amplitudes interference.

Study of CPV in hyperon decay is a complementary approach in two-body non-leptonic $\Delta S = 1$ transitions

CP observables in hyperon decays



- For spin ½ $B_i \rightarrow B_f + \pi$,

$$A \sim S\sigma_0 + P\sigma \cdot \hat{n}$$

where complex amplitudes:

ϕ weak phase, δ strong phase

$$S = \Sigma^i S_i e^{i(\phi_i^S + \delta_i^S)},$$
$$P = \Sigma^i P_i e^{i(\phi_i^P + \delta_i^P)},$$

- Under CP transformation:

$$\bar{S} = -\Sigma^i S_i e^{i(-\phi_i^S + \delta_i^S)},$$
$$\bar{P} = \Sigma^i P_i e^{i(-\phi_i^P + \delta_i^P)}$$

- The decay parameters:

$$\alpha_Y = \frac{2\,\mathrm{Re}\,(S^* P)}{|S|^2 + |P|^2}, \quad \beta_Y = \frac{2\,\mathrm{Im}\,(S^* P)}{|S|^2 + |P|^2}, \quad \gamma_Y = \frac{|S|^2 - |P|^2}{|S|^2 + |P|^2}$$

- **So if CP conserved:**

$$S \xRightarrow{CP} -S, \quad P \xRightarrow{CP} P$$

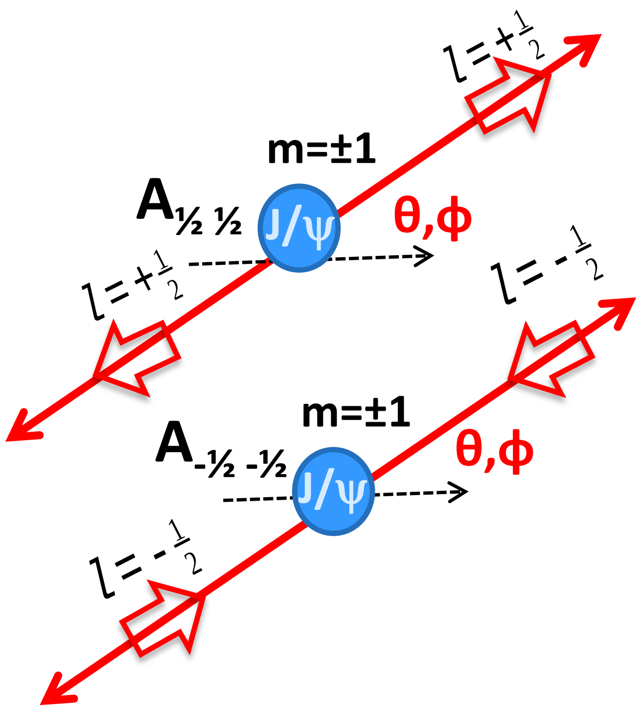
and thus,

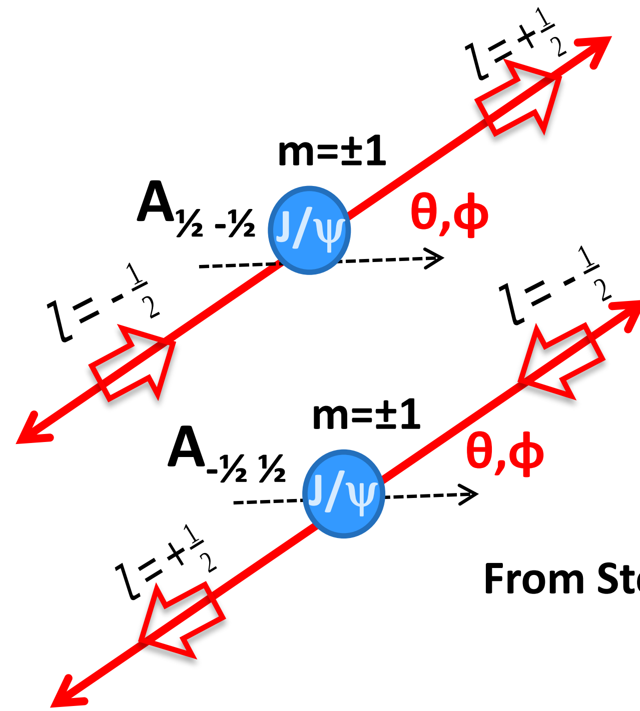
$$\alpha \xRightarrow{CP} \bar{\alpha} = -\alpha, \quad \beta \xRightarrow{CP} \bar{\beta} = -\beta$$

CPV observables

$$\Delta_{CP} = \frac{\Gamma - \bar{\Gamma}}{\Gamma + \bar{\Gamma}}$$
$$A_{CP} = \frac{\Gamma\alpha + \bar{\Gamma}\bar{\alpha}}{\Gamma\alpha - \bar{\Gamma}\bar{\alpha}} \approx \frac{\alpha + \bar{\alpha}}{\alpha - \bar{\alpha}} + \Delta$$
$$B_{CP} = \frac{\Gamma\beta + \bar{\Gamma}\bar{\beta}}{\Gamma\beta - \bar{\Gamma}\bar{\beta}} \approx \frac{\beta + \bar{\beta}}{\beta - \bar{\beta}} + \Delta$$

Entangled and Polarized hyperon pairs from e^+e^-





From Steve Olsen

Parity conservation : $A_{½\,½} = A_{-½\,-½}$

parity conservation : $A_{½\,-½} = A_{-½\,½}$

$\Delta\Phi$ = complex phase between $A_{½\,½}$ and $A_{½\,-½}$

$$\frac{d|\mathcal{M}|^2}{d\cos\theta} \propto (1+\alpha_{J/\psi}\cos^2\theta), \quad \text{with} \quad \alpha_{J/\psi} = \frac{|A_{1/2,-1/2}|^2 - 2|A_{1/2,1/2}|^2}{|A_{1/2,-1/2}|^2 + 2|A_{1/2,1/2}|^2}$$

If $\Delta\Phi \neq 0$, $\Lambda/\bar{\Lambda}$ transversely polarized

Correlated 5-dim. angular distribution in $e^+e^- \to J/\psi \to \Lambda\bar{\Lambda}$:

$$\mathcal{W}(\xi;\alpha_\psi,\Delta\Phi,\alpha_-,\alpha_+) = 1+\alpha_\psi\cos^2\theta_\Lambda$$

Unpolarized part

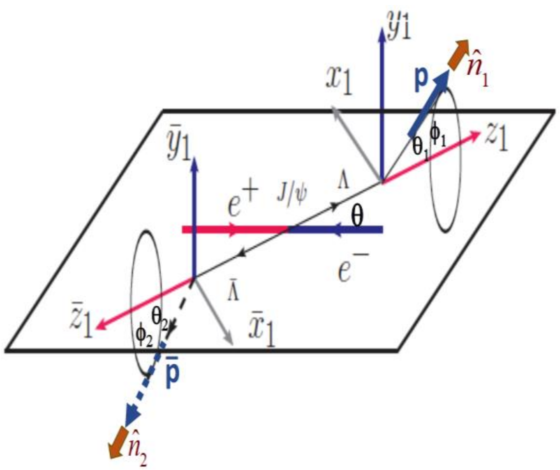
Entangled part

$$+\alpha_-\alpha_+\left[\sin^2\theta_\Lambda\left(n_{1,x}n_{2,x}-\alpha_\psi n_{1,y}n_{2,y}\right)+\left(\cos^2\theta_\Lambda+\alpha_\psi\right)n_{1,z}n_{2,z}\right]$$

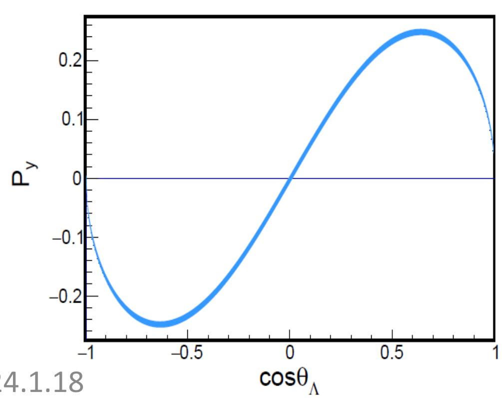
$$+\alpha_-\alpha_+\sqrt{1-\alpha_\psi^2}\cos(\Delta\Phi)\sin\theta_\Lambda\cos\theta_\Lambda\left(n_{1,x}n_{2,z}+n_{1,z}n_{2,x}\right)$$

$$+\sqrt{1-\alpha_\psi^2}\sin(\Delta\Phi)\,\sin\theta_\Lambda\cos\theta_\Lambda\left(\alpha_- n_{1,y}+\alpha_+ n_{2,y}\right),$$

Polarized part



Polarization-term can be used to determine α_- and α_+ simultaneously

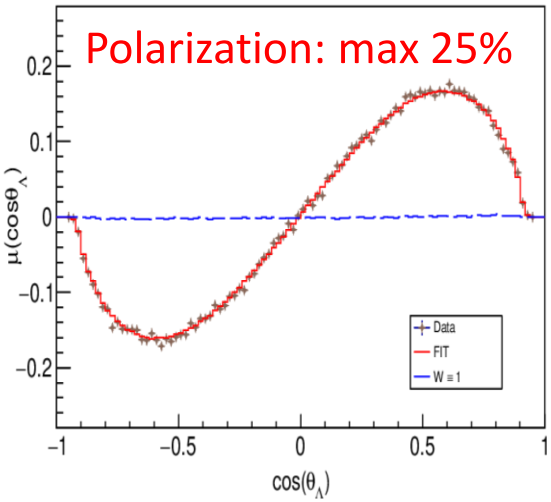


$$P_y(\cos\theta_\Lambda)=\frac{\sqrt{1-\alpha_\psi^2}\,\sin(\Delta\Phi)\cos\theta_\Lambda\sin\theta_\Lambda}{1+\alpha_\psi\cos^2\theta_\Lambda}$$

The most precise CP test in Λ and $\bar{\Lambda}$ decay

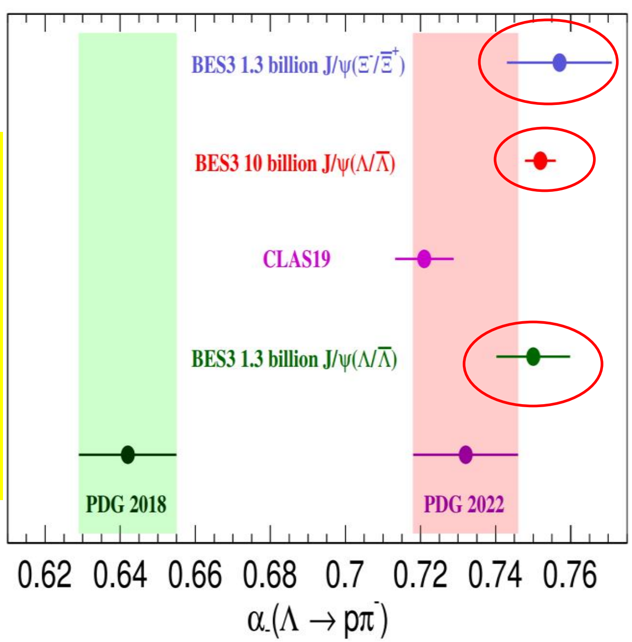
10 billion J/ψ, Phys. Rev. Lett. 129, 131801 (2022)

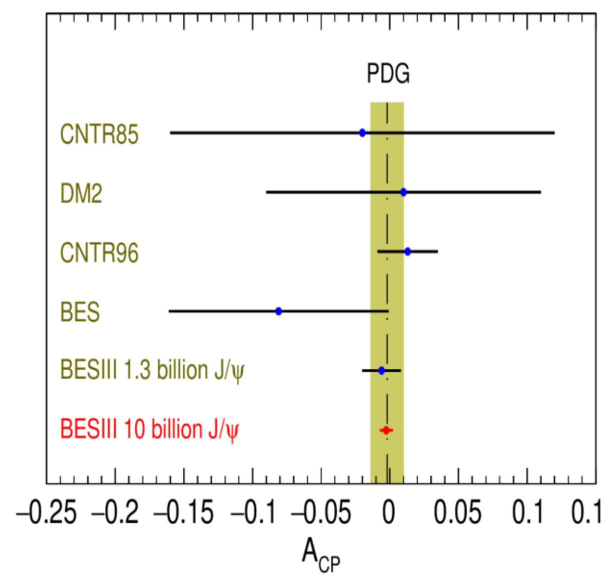
Nat. Phys. 15, 631 (2019)



Paras.	This Work (10 billion J/ψ)	Previous Results (1.3 billion J/ψ)
$\alpha_{J/\psi}$	$0.4748 \pm 0.0022 \pm 0.0024$	$0.461 \pm 0.006 \pm 0.007$
$\Delta\Phi$	$0.7521 \pm 0.0042 \pm 0.0080$	$0.740 \pm 0.010 \pm 0.009$
α_-	$0.7519 \pm 0.0036 \pm 0.0019$	$0.750 \pm 0.009 \pm 0.004$
α_+	$-0.7559 \pm 0.0036 \pm 0.0029$	$-0.758 \pm 0.010 \pm 0.007$
A_{CP}	$-0.0025 \pm 0.0046 \pm 0.0011$	$-0.006 \pm 0.012 \pm 0.007$
α_{avg}	$0.7542 \pm 0.0010 \pm 0.0020$	----

More than 10 standard deviation shift from all previous results.





A_{CP} sensitivity: below 0.5%, unprecedented precision

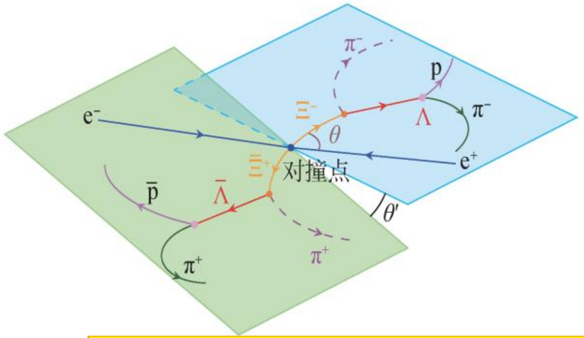
Standard Model prediction : A_{CP}~ 10^{-4} , PRD 34, 833 (1986)

CPV: $e^+e^- \to J/\psi \to \Xi^-\bar{\Xi}^+, \Xi^- \to \Lambda(\to p\pi^-)\pi^- + c.c.$

1.3B J/ψ events (13% of total)
9-dimensional fit:

~73200 signal events
Negligible bkgd

Nature 606, 64-69 (2022)



Parameter	This work	Previous result
α_ψ	$0.586\pm0.012\pm0.010$	$0.58\pm0.04\pm0.08$
$\Delta\Phi$	$1.213\pm0.046\pm0.016$ rad	–
α_Ξ	$-0.376\pm0.007\pm0.003$	-0.401 ± 0.010
ϕ_Ξ	$0.011\pm0.019\pm0.009$ rad	-0.037 ± 0.014 rad
$\bar{\alpha}_\Xi$	$0.371\pm0.007\pm0.002$	–
$\bar{\phi}_\Xi$	$-0.021\pm0.019\pm0.007$ rad	–
α_Λ	$0.757\pm0.011\pm0.008$	$0.750\pm0.009\pm0.004$
$\bar{\alpha}_\Lambda$	$-0.763\pm0.011\pm0.007$	$-0.758\pm0.010\pm0.007$
$\xi_P-\xi_S$	$(1.2\pm3.4\pm0.8)\times10^{-2}$ rad	–
$\delta_P-\delta_S$	$(-4.0\pm3.3\pm1.7)\times10^{-2}$ rad	$(10.2\pm3.9)\times10^{-2}$ rad
A^Ξ_{CP}	$(6\pm13\pm6)\times10^{-3}$	–
$\Delta\phi^\Xi_{CP}$	$(-5\pm14\pm3)\times10^{-3}$ rad	–
A^Λ_{CP}	$(-4\pm12\pm9)\times10^{-3}$	$(-6\pm12\pm7)\times10^{-3}$
$\langle\phi_\Xi\rangle$	$0.016\pm0.014\pm0.007$ rad	

First measurement of Ξ^- polarization in J/ψ decay

First direct and simultaneously measurement of the charged Ξ decay parameters

First measurement of weak phase difference :
weak phase < 3.6 degree
strong phase <6.0 degree

First measurement of weak phase difference in Ξ decay

Three independent *CP* tests

HyperCP: PRL 93, 011802 (2004)

HyperCP: $\phi_{\Xi,HyperCP} = -0.042 \pm 0.011 \pm 0.011$
BESIII: $\langle\phi_\Xi\rangle = 0.016\pm0.014\pm0.007$

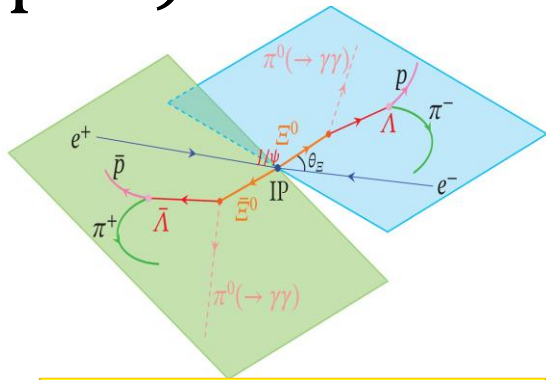
We obtain the same precision for ϕ as HyperCP with ***three orders of magnitude*** smaller data sample!

CPV: $e^+e^- \to J/\psi \to \Xi^0\bar{\Xi}^0, \Xi^0 \to \Lambda(\to p\pi^-)\pi^0 + c.c.$

10B J/ψ events
9-dimensional fit:

~320k signal events
Purity: > 98%

arXiv:2305.09218
PRD 108, L031106 (2023),
as Editor's Suggestion



Parameter	This work	Previous result
$\alpha_{J/\psi}$	$0.514 \pm 0.006 \pm 0.015$	0.66 ± 0.06
$\Delta\Phi$(rad)	$1.168 \pm 0.019 \pm 0.018$	-
α_Ξ	$-0.3750 \pm 0.0034 \pm 0.0016$	-0.358 ± 0.044
$\bar{\alpha}_\Xi$	$0.3790 \pm 0.0034 \pm 0.0021$	0.363 ± 0.043
ϕ_Ξ(rad)	$0.0051 \pm 0.0096 \pm 0.0018$	0.03 ± 0.12
$\bar{\phi}_\Xi$(rad)	$-0.0053 \pm 0.0097 \pm 0.0019$	-0.19 ± 0.13
α_Λ	$0.7551 \pm 0.0052 \pm 0.0023$	0.7519 ± 0.0043
$\bar{\alpha}_\Lambda$	$-0.7448 \pm 0.0052 \pm 0.0017$	-0.7559 ± 0.0047
$\xi_P - \xi_S$(rad)	$(0.0 \pm 1.7 \pm 0.2) \times 10^{-2}$	-
$\delta_P - \delta_S$(rad)	$(-1.3 \pm 1.7 \pm 0.4) \times 10^{-2}$	-
A_{CP}^{Ξ}	$(-5.4 \pm 6.5 \pm 3.1) \times 10^{-3}$	$(-0.7 \pm 8.5) \times 10^{-2}$
$\Delta\phi_{CP}^{\Xi}$(rad)	$(-0.1 \pm 6.9 \pm 0.9) \times 10^{-3}$	$(-7.9 \pm 8.3) \times 10^{-2}$
A_{CP}^{Λ}	$(6.9 \pm 5.8 \pm 1.8) \times 10^{-3}$	$(-2.5 \pm 4.8) \times 10^{-3}$
$\langle\alpha_\Xi\rangle$	$-0.3770 \pm 0.0024 \pm 0.0014$	-
$\langle\phi_\Xi\rangle$(rad)	$0.0052 \pm 0.0069 \pm 0.0016$	-
$\langle\alpha_\Lambda\rangle$	$0.7499 \pm 0.0029 \pm 0.0013$	0.7542 ± 0.0026

First measurement of Ξ^0 polarization in J/ψ decay

Most precise measurements of the neutral Ξ decay parameters

First measurement of weak phase difference in neutral Ξ decay, most precise result for any weakly-decaying baryon

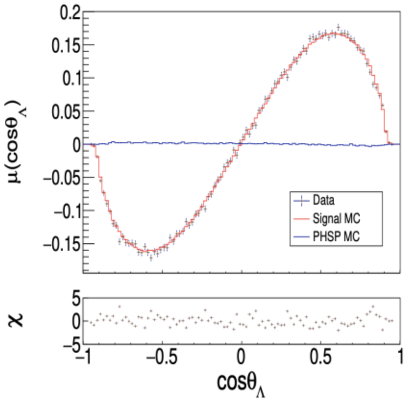
Three *CP* tests

Comparable with obtained from ~3.2 M $\Lambda\bar{\Lambda}$ events.
Phys.Rev.Lett.129, 131801(2022)

Polarization behavior for hyperon pair productions

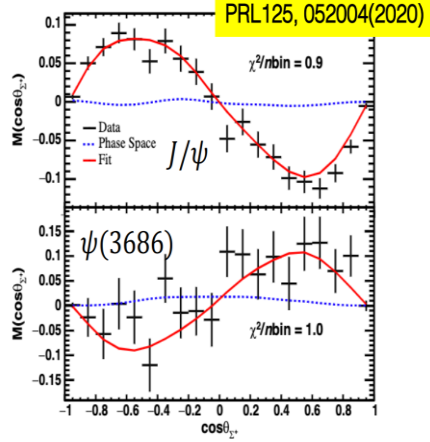
$J/\psi \to \Lambda\bar{\Lambda}$

PRL129, 131801(2022)



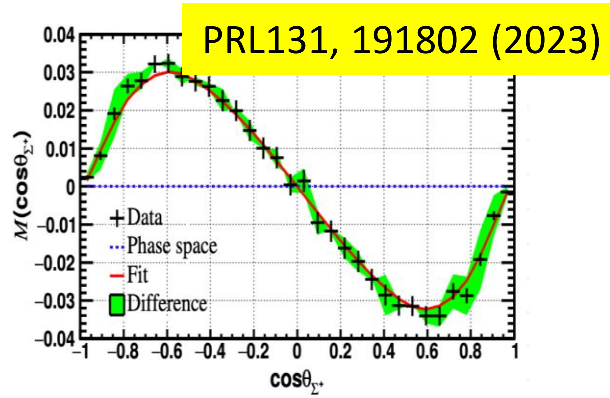
$\Delta\Phi = (0.7521 \pm 0.0042 \pm 0.0066)\, rad$
$A_{CP} = -0.0025 \pm 0.0046 \pm 0.0012$

$\psi \to \Sigma^+\bar{\Sigma}^- \to p\pi^0\bar{p}\pi^0$



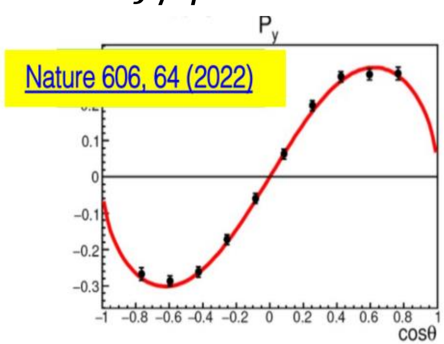
$\Delta\Phi(J/\psi) = (-15.5 \pm 0.7 \pm 0.5)^\circ$
$\Delta\Phi(\psi(2S)) = (21.7 \pm 4.0 \pm 0.8)^\circ$
$A_{CP} = -0.004 \pm 0.037 \pm 0.010$

$J/\psi \to \Sigma^+\bar{\Sigma}^- \to n\pi^+\bar{p}\pi^0$



$\Delta\Phi = (-0.277 \pm 0.004 \pm 0.004)\, rad$
$A_{CP} = -0.080 \pm 0.052 \pm 0.028$

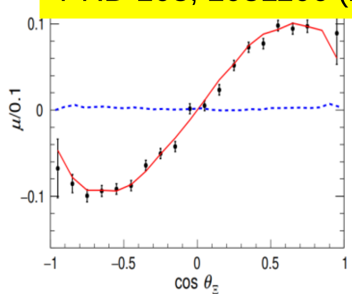
$J/\psi \to \Xi^-\bar{\Xi}^+$



$\Delta\Phi = (1.213 \pm 0.046 \pm 0.016)\, rad$
$A_{CP} = -0.006 \pm 0.013 \pm 0.006$

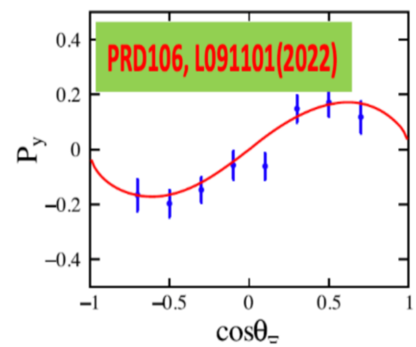
$J/\psi \to \Xi^0\bar{\Xi}^0$

PRD 108, L031106 (2023)



$\Delta\Phi = (1.168 \pm 0.019 \pm 0.018)\, rad$
$A_{CP} = -0.0054 \pm 0.0065 \pm 0.0031$

$\psi(2S) \to \Xi^-\bar{\Xi}^+$

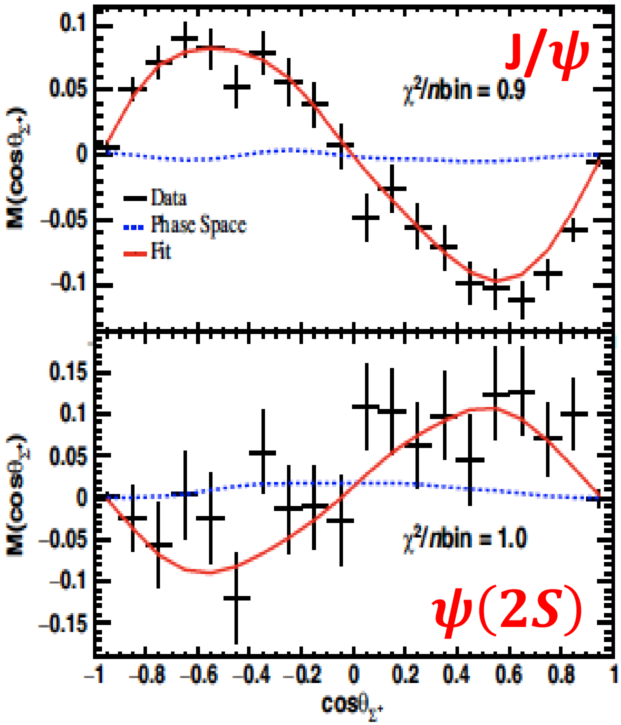


$\Delta\Phi = (0.667 \pm 0.111 \pm 0.058)\, rad$
$A_{CP} = -0.015 \pm 0.051 \pm 0.010$

Polarization and CP test in $J/\psi \to \Sigma^+\bar{\Sigma}^-$ & $\psi(2S) \to \Sigma^+\bar{\Sigma}^-$

Both J/ψ *and* $\psi(2S)$ *are polarized*

from 1.3B J/ψ events



PRL125, 052004 (2020)

Parameter	Measured value
$\alpha_{J/\psi}$	$-0.508 \pm 0.006 \pm 0.004$
$\Delta\Phi_{J/\psi}$	$-0.270 \pm 0.012 \pm 0.009$
$\alpha_{\psi'}$	$0.682 \pm 0.03 \pm 0.011$
$\Delta\Phi_{\psi'}$	$0.379 \pm 0.07 \pm 0.014$
α_0	$-0.998 \pm 0.037 \pm 0.009$
$\bar{\alpha}_0$	$0.990 \pm 0.037 \pm 0.011$

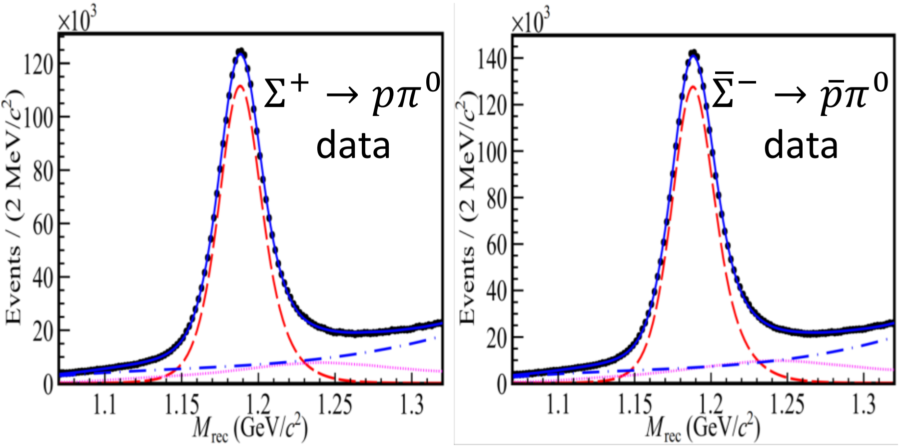
The world best result for the average decay parameter:

$$\frac{\alpha_0 - \bar{\alpha}_0}{2} = -0.994 \pm 0.004 \pm 0.002$$

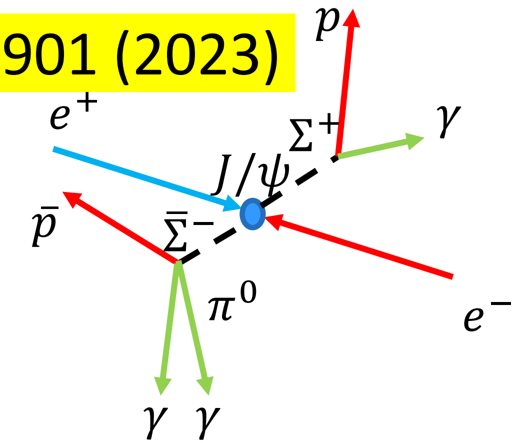
The first CP violation test for Σ decay:

$$A_{CP,\Sigma} = (\alpha_0 + \bar{\alpha}_0)/(\alpha_0 - \bar{\alpha}_0) = -0.004 \pm 0.037 \pm 0.010$$

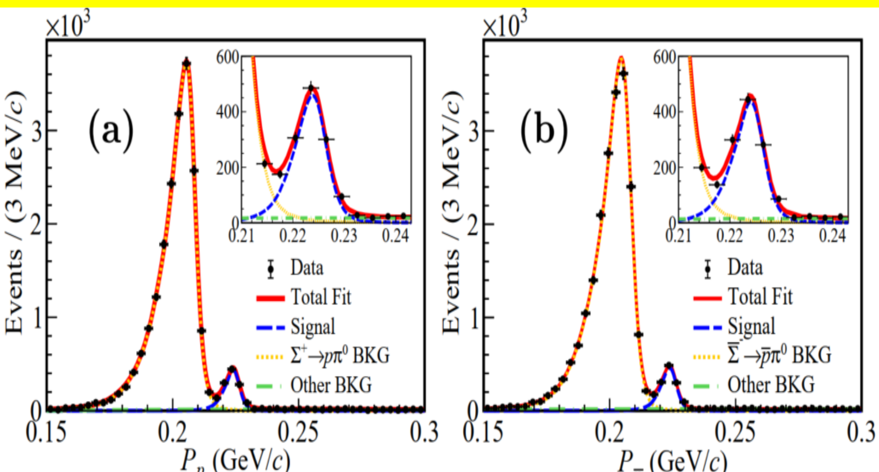
Radiative decay: $\Sigma^+ \to p\gamma$ in $J/\psi \to \Sigma^+\bar{\Sigma}^-$



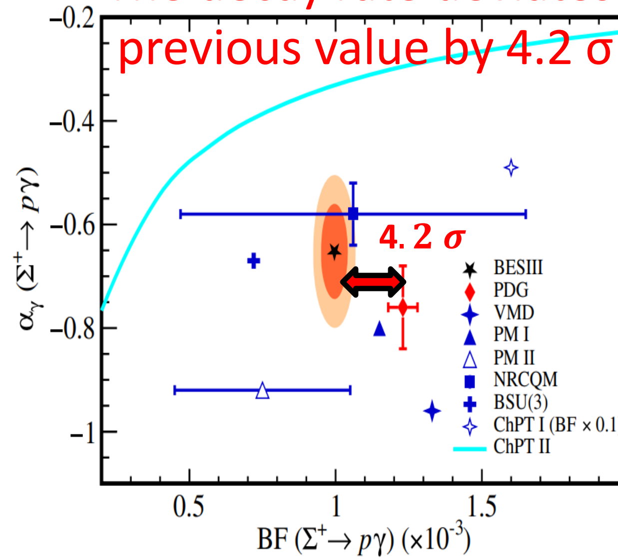
PRL130, 211901 (2023)



Signal side: proton momentum in rest frame of Σ :



The decay rate deviates from previous value by 4.2 σ



The CP asymmetry is calculated to be:

$$A_{CP} = (\alpha_- + \alpha_+)/(\alpha_- - \alpha_+) = 0.095 \pm 0.087 \pm 0.022$$

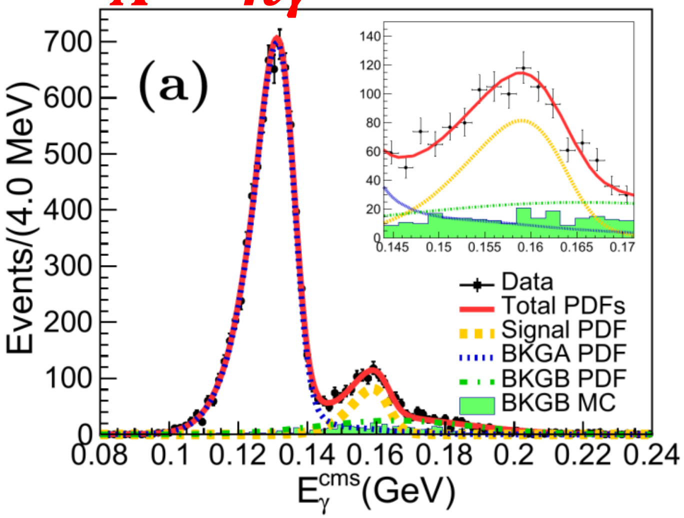
$$\Delta_{CP} = (\mathcal{B}_+ - \mathcal{B}_-)/(\mathcal{B}_+ + \mathcal{B}_-) = 0.006 \pm 0.011 \pm 0.006$$

decay rate $(0.996 \pm 0.022_{stat} \pm 0.017_{syst}) \times 10^{-3}$

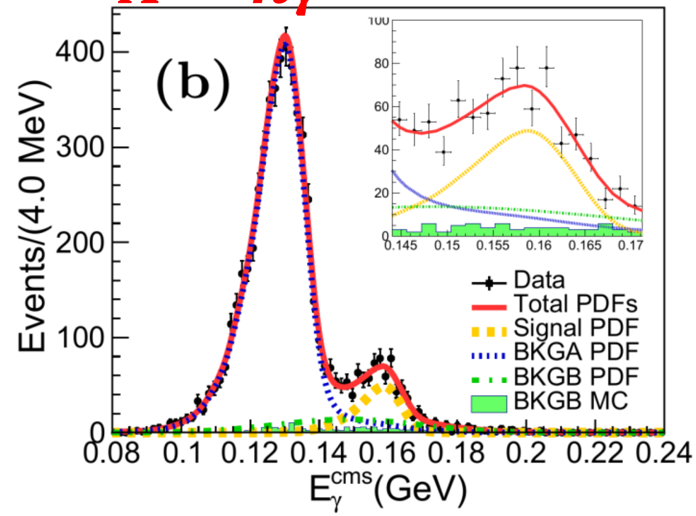
decay parameter: $-0.651 \pm 0.056_{stat} \pm 0.020_{syst}$

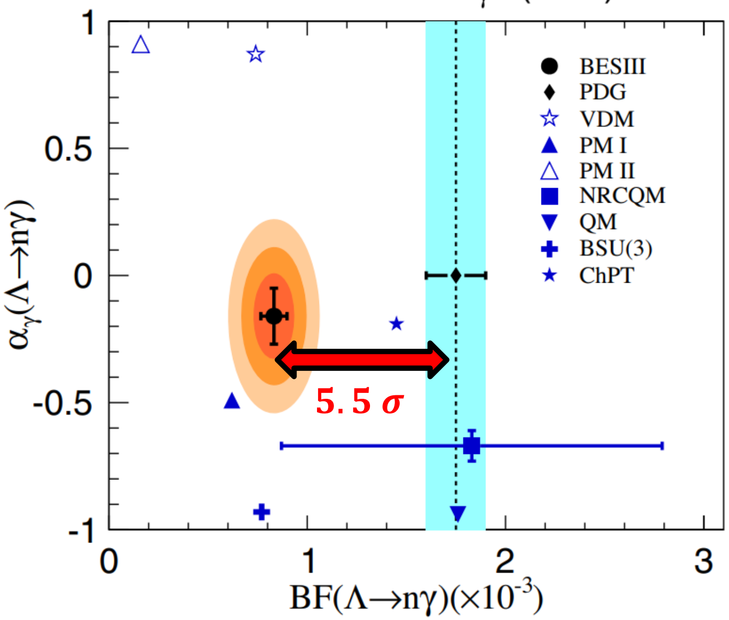
Radiative decay: $\Lambda \to n\gamma$ in $J/\psi \to \Lambda\bar{\Lambda}$

$\Lambda \to n\gamma$



$\bar{\Lambda} \to \bar{n}\gamma$



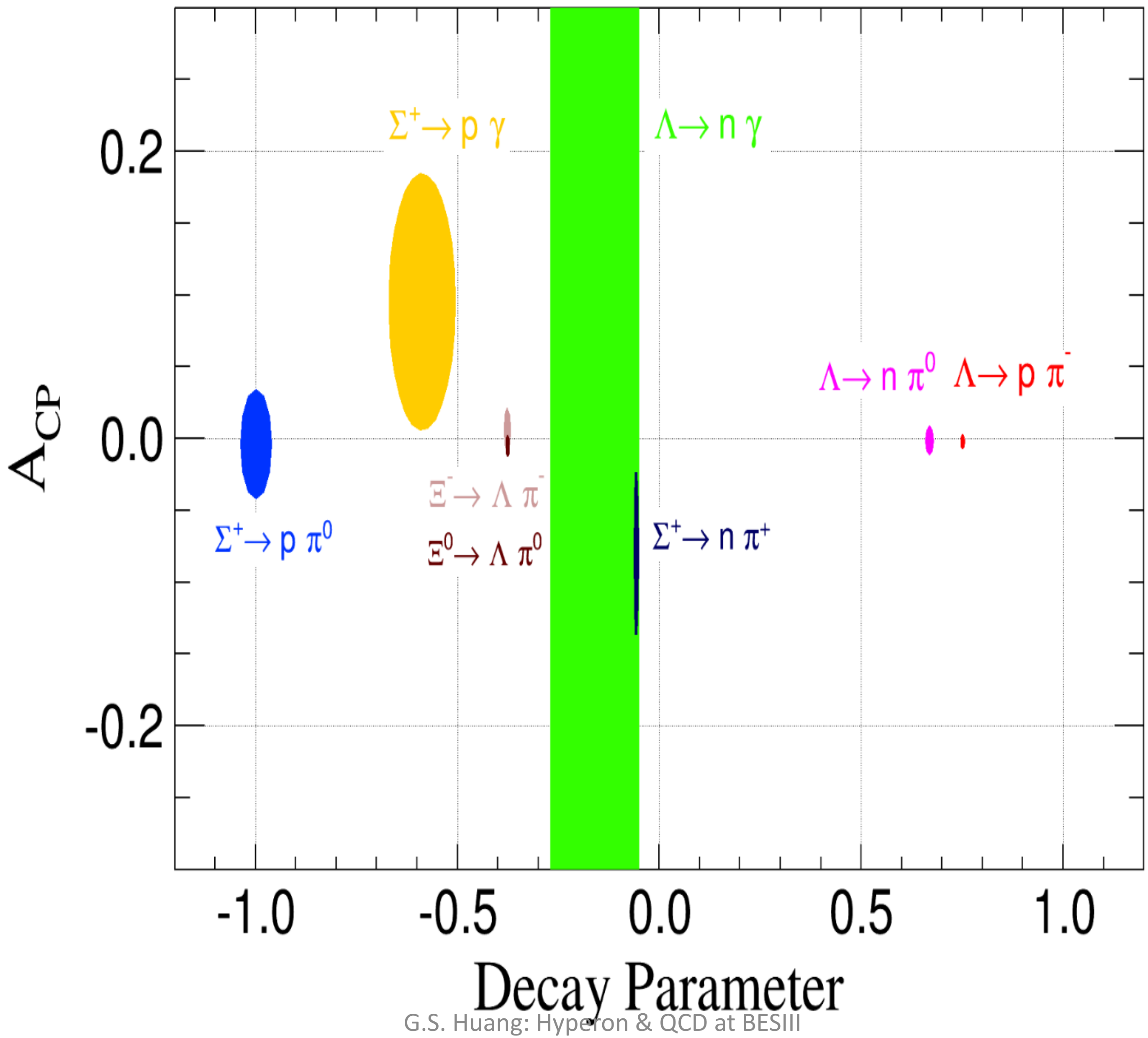


Variables	$\Lambda \to \gamma n$	$\bar{\Lambda} \to \gamma \bar{n}$
BF ($\times 10^3$)	$0.834 \pm 0.046 \pm 0.064$	$0.876 \pm 0.071 \pm 0.082$
α_{γ}	$-0.13 \pm 0.13 \pm 0.02$	$0.21 \pm 0.15 \pm 0.06$
Δ_{CP}	$-0.025 \pm 0.049 \pm 0.060$	
A_{CP}	$-0.25 \pm 0.61 \pm 0.15$	

BF of $\Lambda \to n\gamma$, with improved precision, smaller than PDG value by 5.5σ

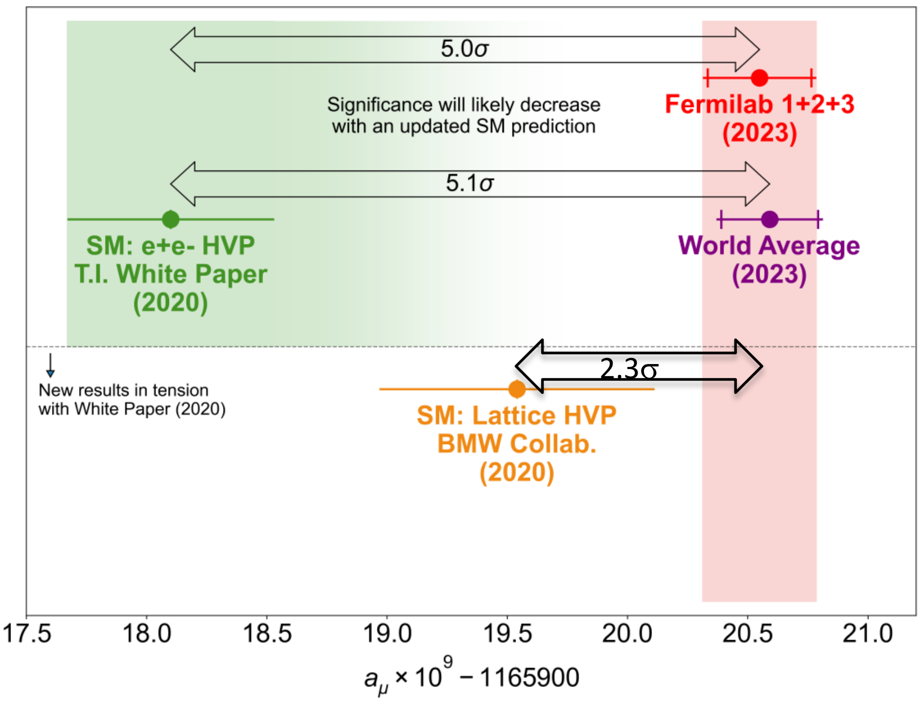
PRL129, 212002 (2022)

BESIII achievements on hyperon decays

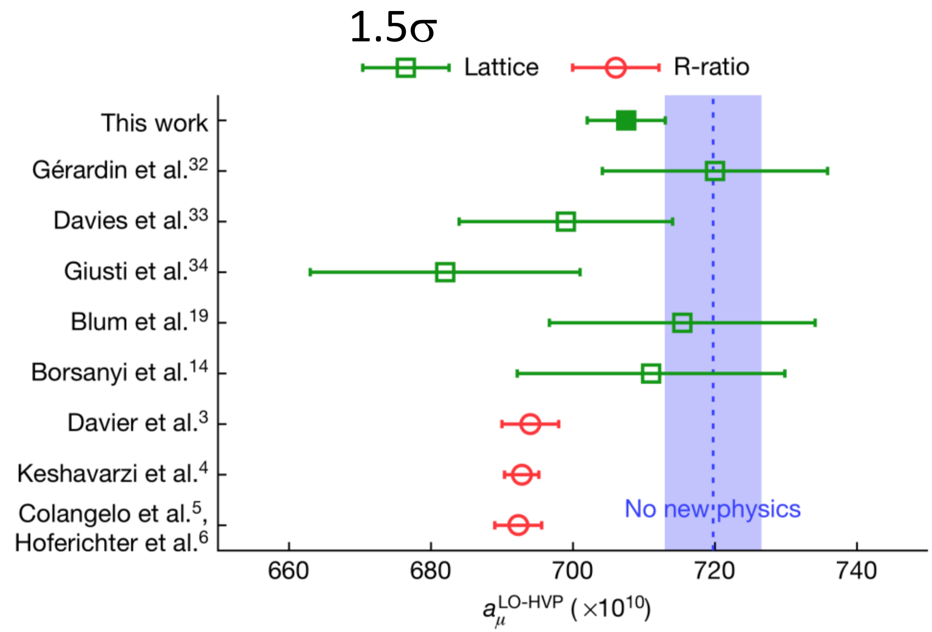


QCD studies at BESIII

- Precision measurement for SM test;
- e.g. ~5σ discrepancy in $a_\mu \equiv (g_\mu - 2)/2$?



Phys. Rev. Lett. 126, 141801 (2021)
Phys. Rev. Lett. 131, 161802 (2023)

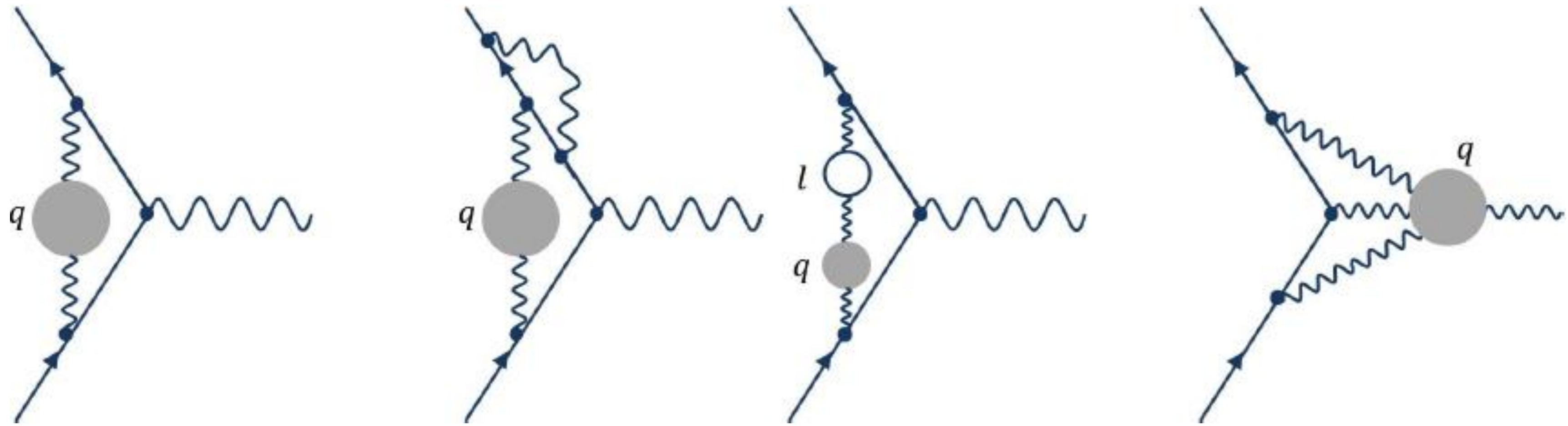


Nature 593, 51 (2021)

$a_\mu^{\text{LO-HVP}}$ (R-ratio) 6931 ± 40
$a_\mu^{\text{LO-HVP}}$ (lattice) 7075 ± 55

$a_\mu \equiv (g_\mu - 2)/2$

$$a_\ell^{\text{SM}} = a_\ell^{\text{QED}}\surd + a_\ell^{\text{Weak}}\surd + a_\ell^{\text{had}}\ \text{X}$$

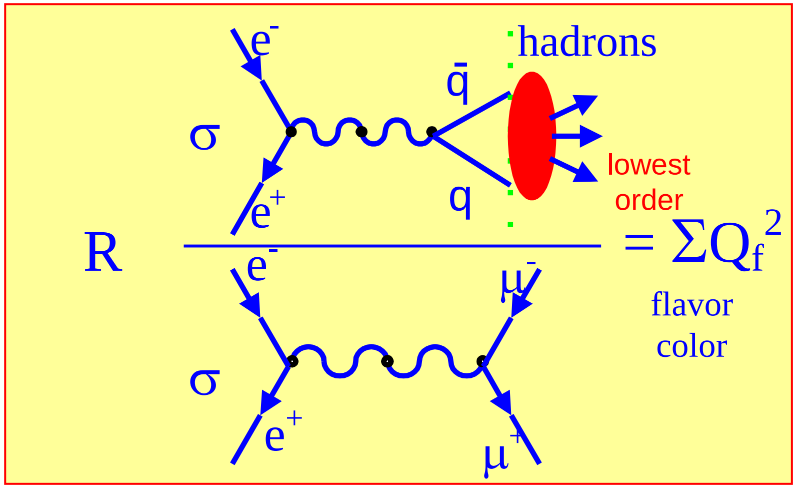


$$a_\ell^{\text{had}} = a_\ell^{\text{LO-HVP}} + a_\ell^{\text{NLO-HVP}} + a_\ell^{\text{HLbL}}$$

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

- R in low energy matters more!

Definition of R:



- At lowest order

$$R \equiv \frac{\sigma(e^+e^- \to \text{hadrons})}{\sigma(e^+e^- \to \mu^+\mu^-)} = \frac{\sum_q \sigma(e^+e^- \to q\bar{q})}{\sigma(e^+e^- \to \mu^+\mu^-)} = 3\sum_q Q_q^2$$

Number of quark colors

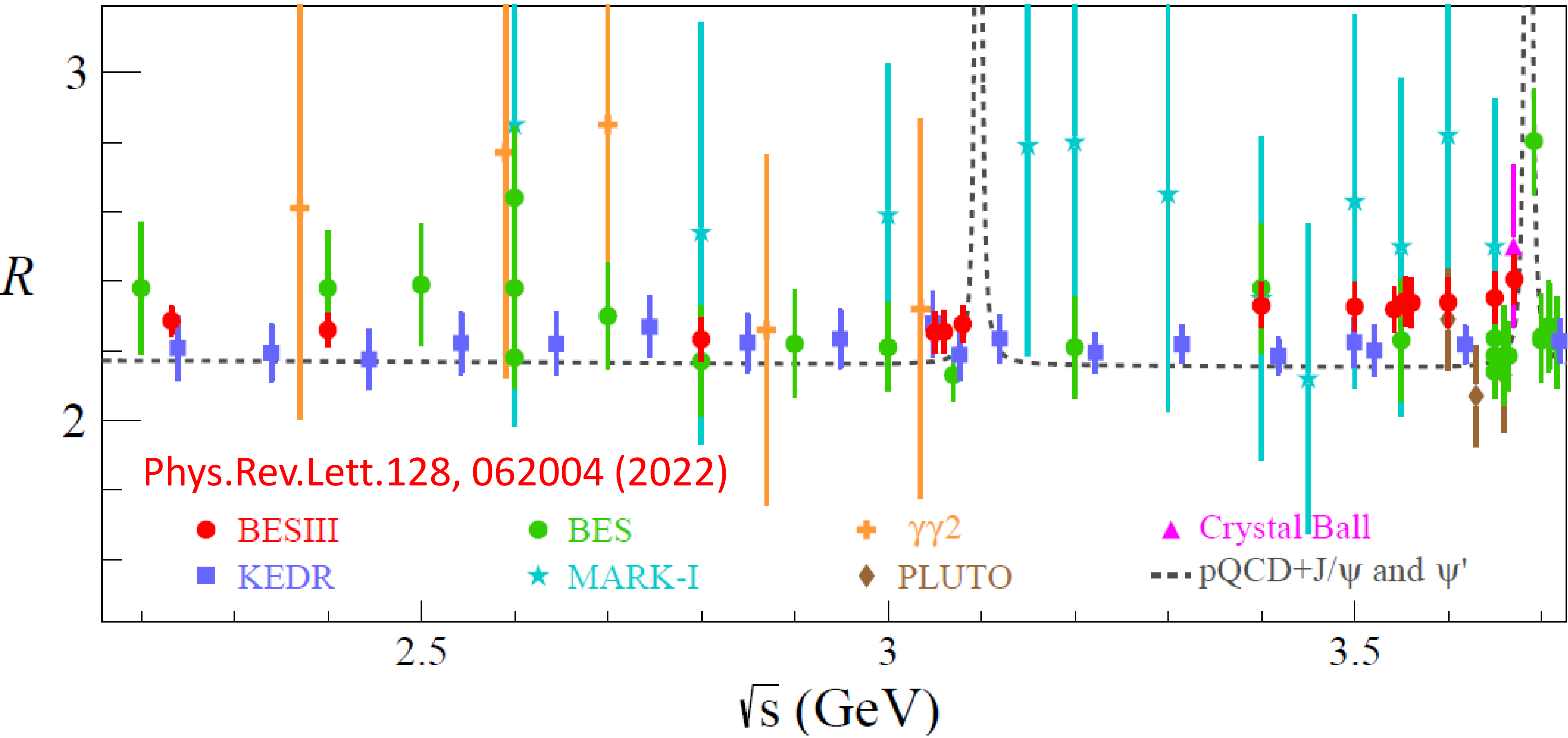
- At higher order

$$R = 3\,K_{QCD}\sum_q Q_q^2\,,$$

$$K_{QCD} = 1 + \frac{\alpha_S(\mu^2)}{\pi} + \sum_{n\geq 2} C_n\left(\frac{s}{\mu^2}\right)\left(\frac{\alpha_S(\mu^2)}{\pi}\right)^n$$

- R is one of the most fundamental quantities in particle physics that directly reflect the flavor and color of quarks.
- Directly test quark model & QCD, and discover new particles.

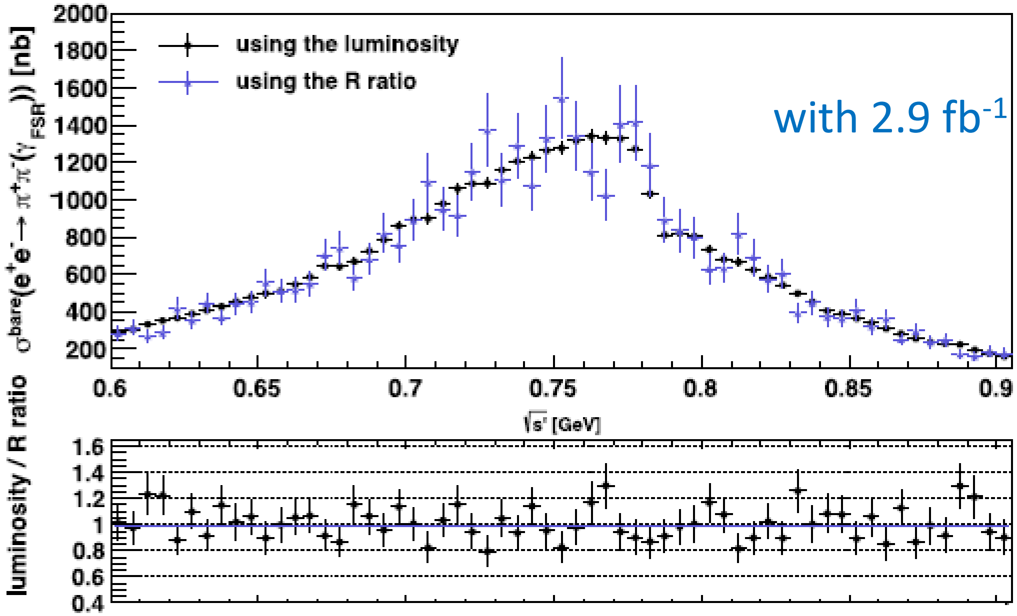
R value in [2.2324, 3.6710] GeV



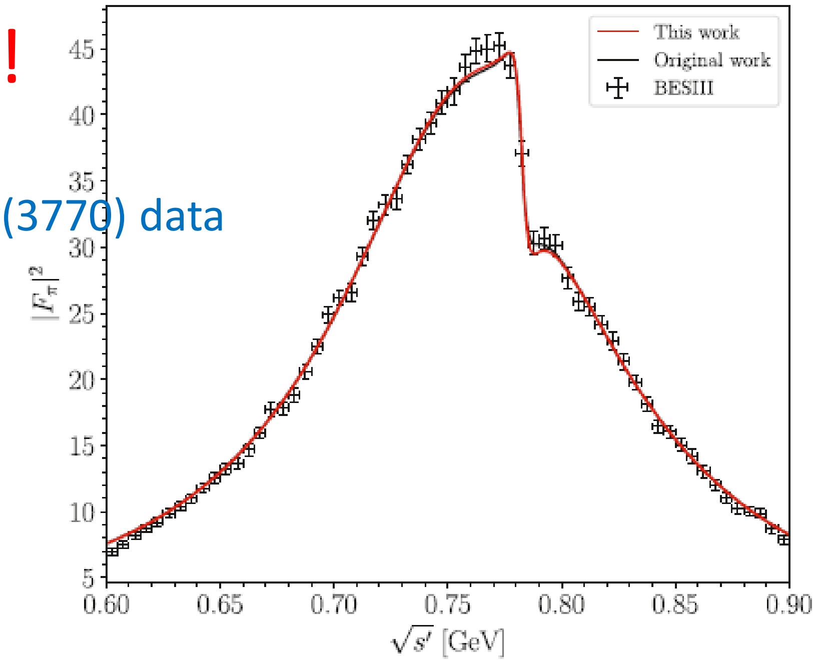
- Precision better than 3%;
- Larger than pQCD by 2.7σ in [3.4, 3.7] GeV;
- R in full range [2.0, 4.95] GeV ongoing.

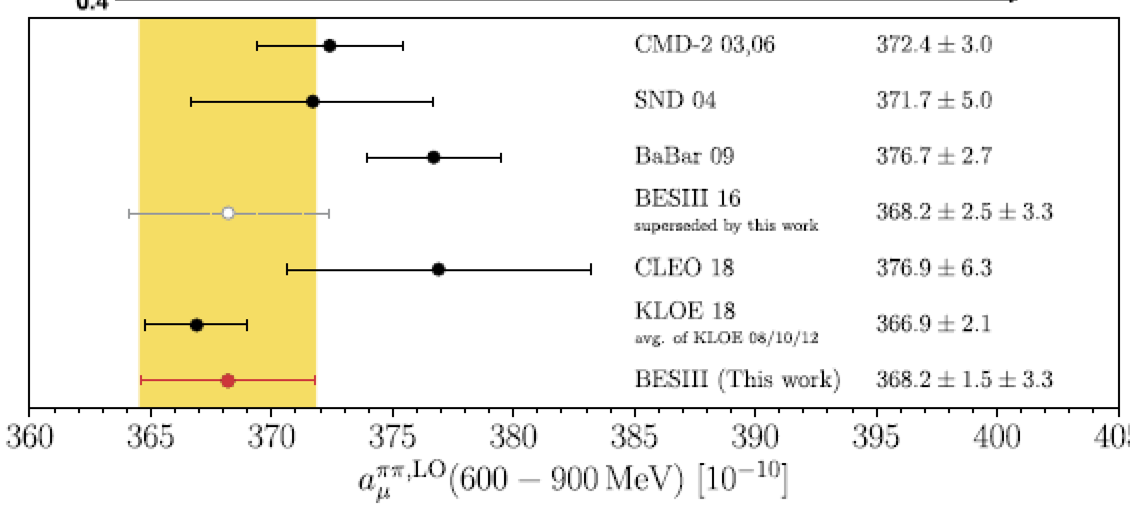
ISR $e^+e^- \to \pi^+\pi^-$

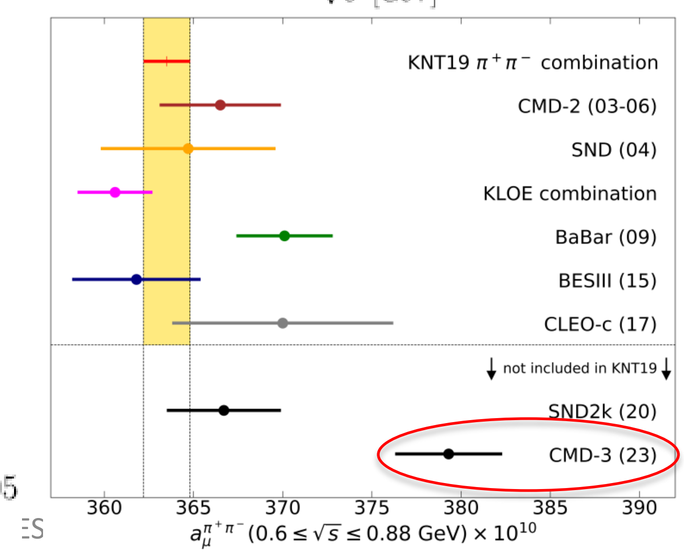
- PLB 753, 629 (2016); Erratum: 812, 135982 (2021).
- 20 fb^{-1} $\psi(3770)$ on the way!



with 2.9 fb^{-1} $\psi(3770)$ data

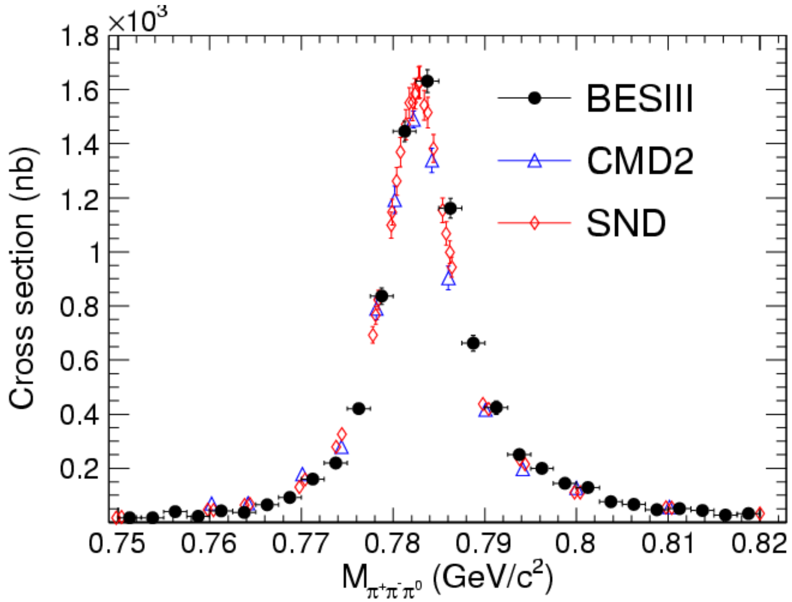


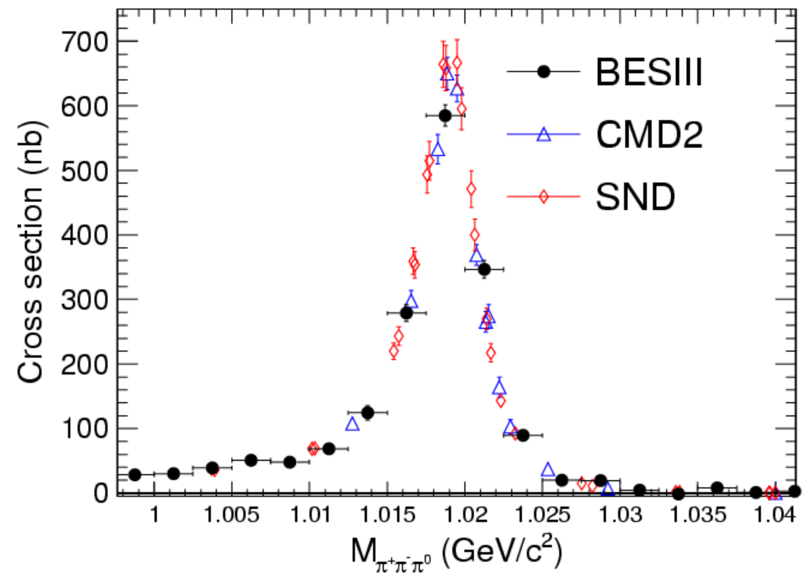


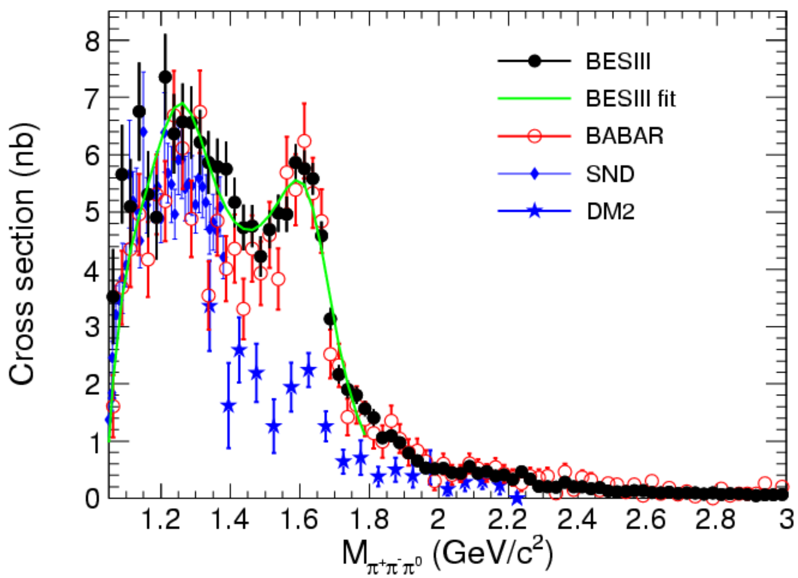


?

ISR $e^+e^-\to\pi^+\pi^-\pi^0$







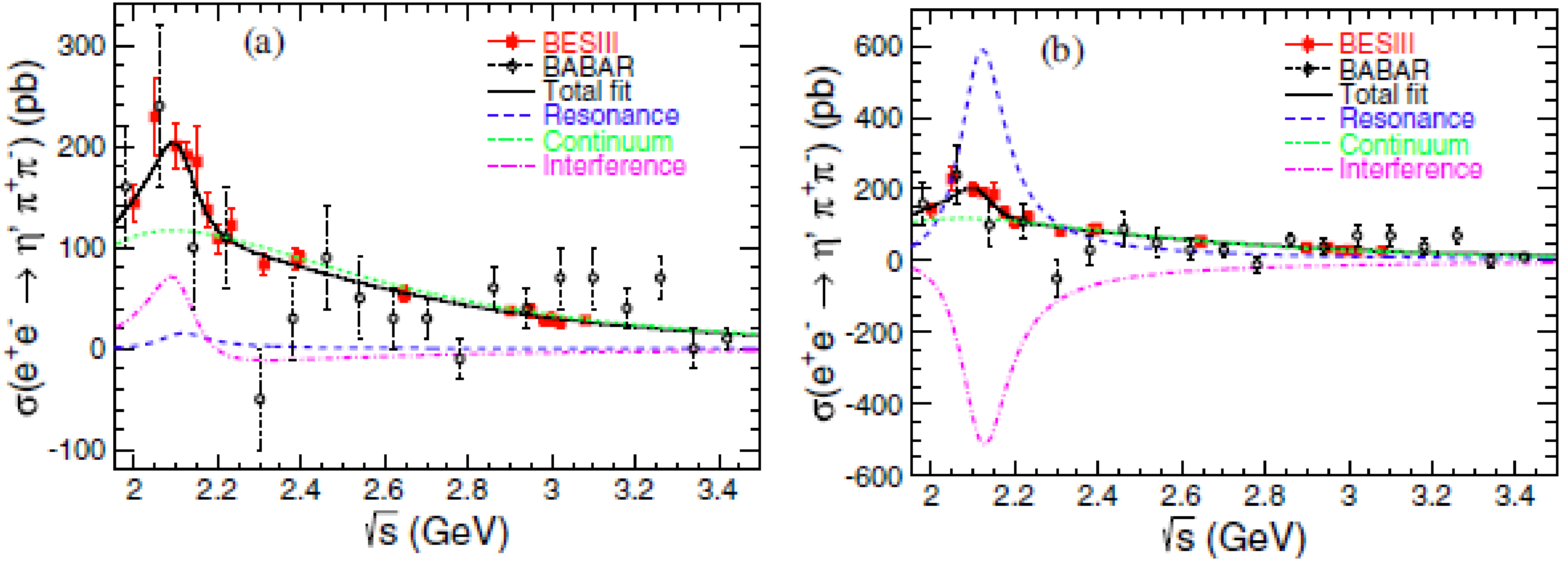
- Tagged & untagged analyses;
- 0.7 ~ 3.0 GeV, 1st result from a single experiment;
- arXiv:1912.11208.

Cross sections & form factors

- Energy scan data in [2.0 - 3.08] GeV;
- With high-statistics data at higher energies, Initial State Radiation (ISR) technique allows access below 2.0 GeV;
- Meson channels studied: $e^+e^- \to \pi^+\pi^-$, $\pi^+\pi^-\pi^0$, $\omega\pi^0/\eta$, $\eta'\pi^+\pi^-$, $\omega\pi^+\pi^-$, $\omega\pi^0\pi^0$, $\gamma\eta$, $\omega\eta'$, K^+K^-, K_SK_L, $2(K^+K^-)$, $\phi\pi^+\pi^-$, $\phi\pi^0$, $\phi\eta/\eta'$, ωK^+K^-, ...
- Baryon ½$^+$ octet, $\Omega^-\bar{\Omega}^+$, $\Lambda_c^+\bar{\Lambda}_c^-$ ...

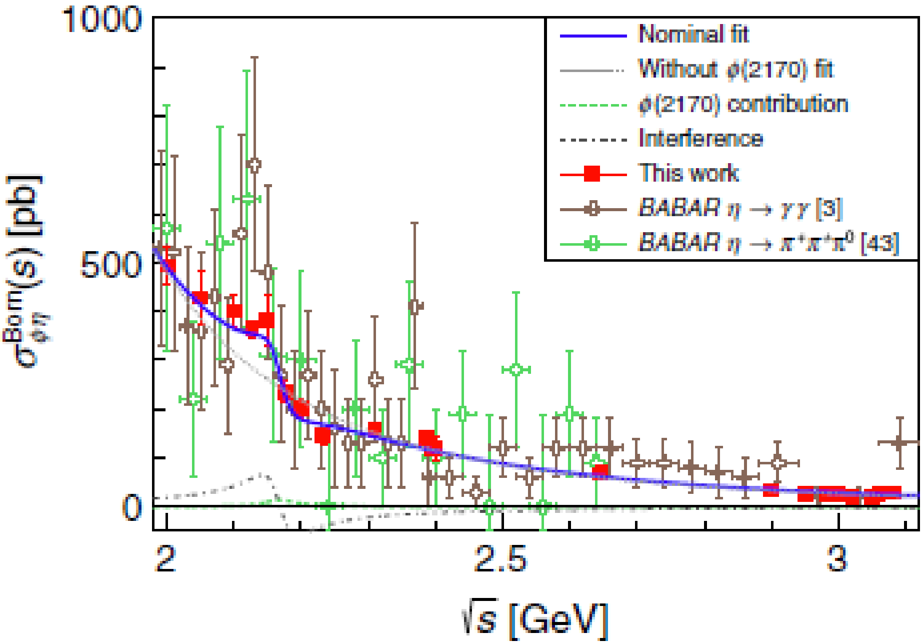
$e^+e^- \to \eta'\pi^+\pi^-$

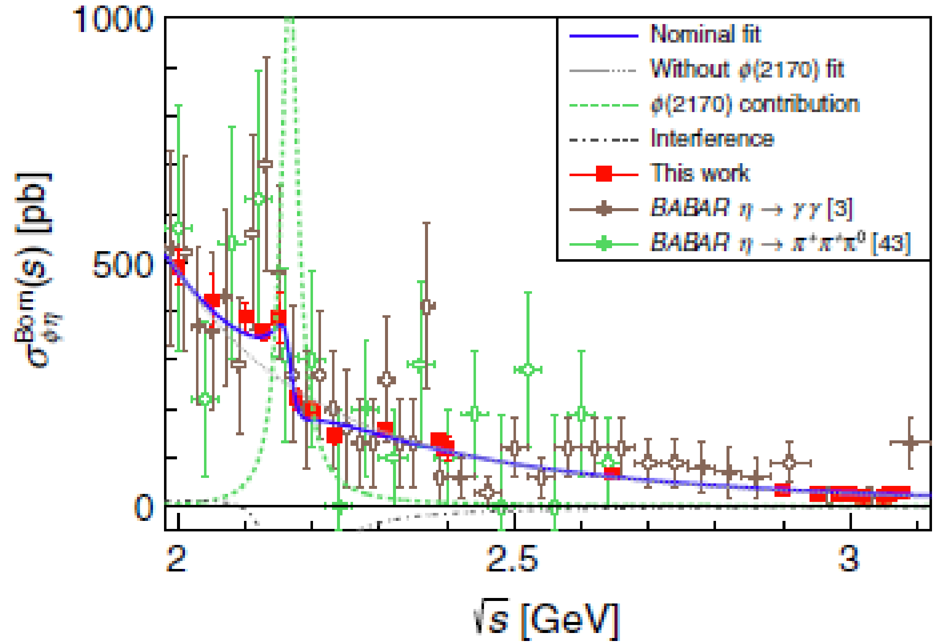
- M=2111±43±25 MeV/c^2, Γ=135±34±30 MeV;
- PRD103, 072007 (2021).



$e^+e^- \to \phi\eta$

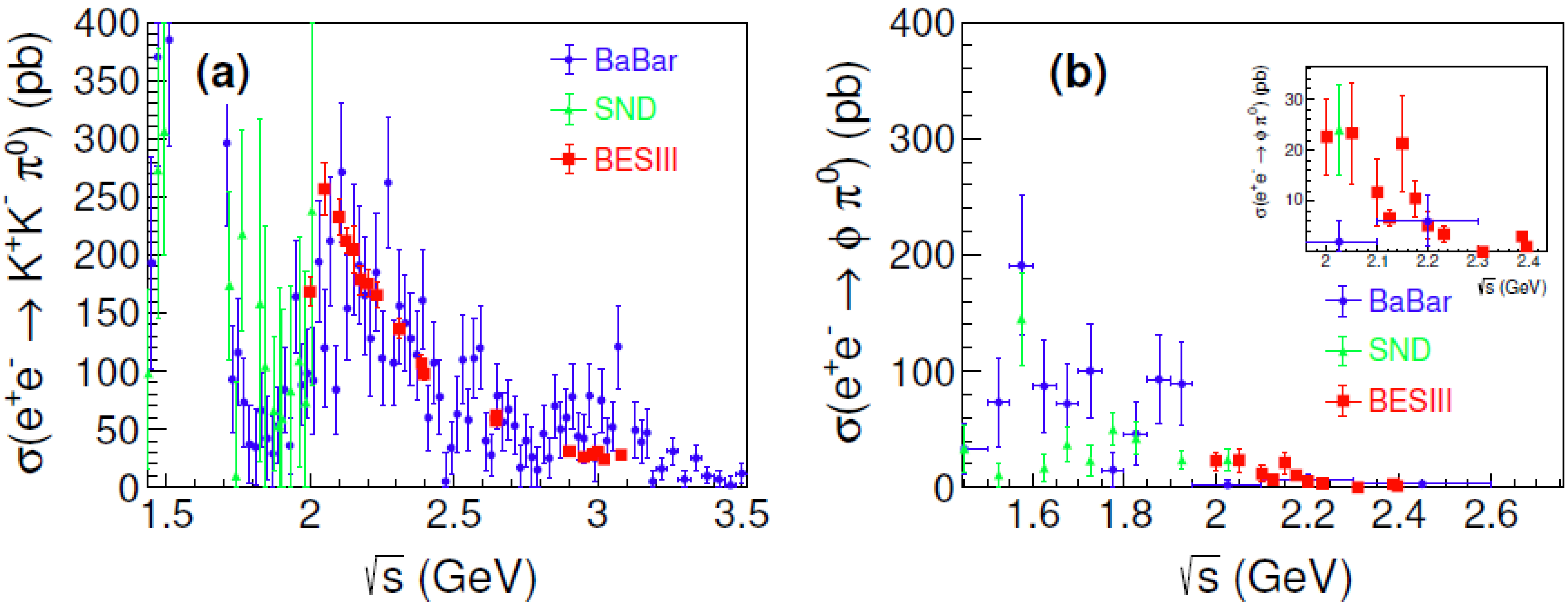
- $M = 2163.5 \pm 6.2 \pm 3.0$ MeV/c^2;
- $\Gamma = 31.1^{+21.1}_{-11.6} \pm 1.1$ MeV;
- PRD104, 032007 (2021).





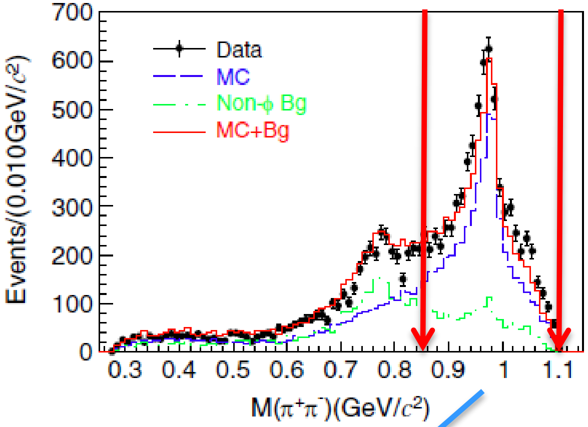
$e^+e^- \rightarrow K^+K^-\pi^0$

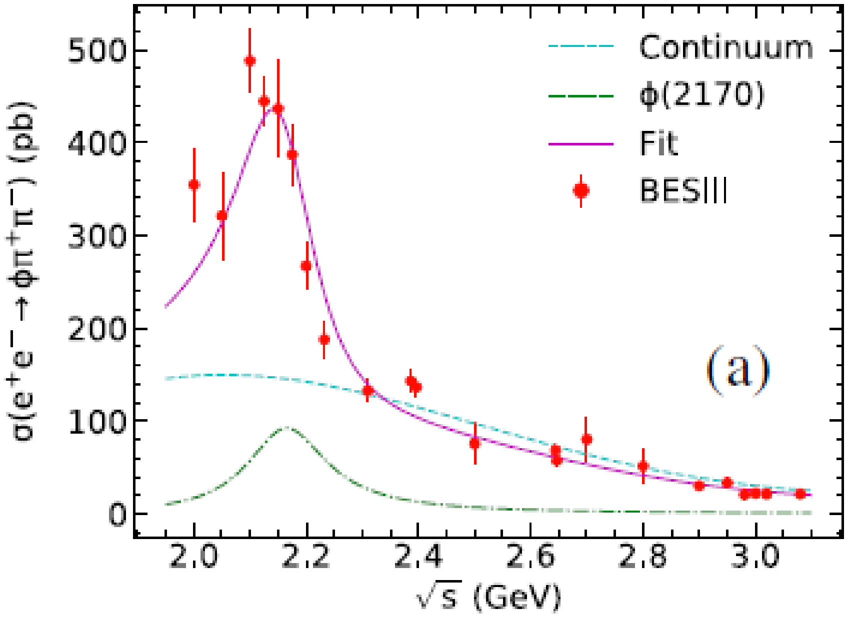
- M=2190±19±37 MeV/c^2, Γ=191±28±60 MeV from PWA of K*(892)K and K_2*(1430)K;
- JHEP07, 045 (2022).

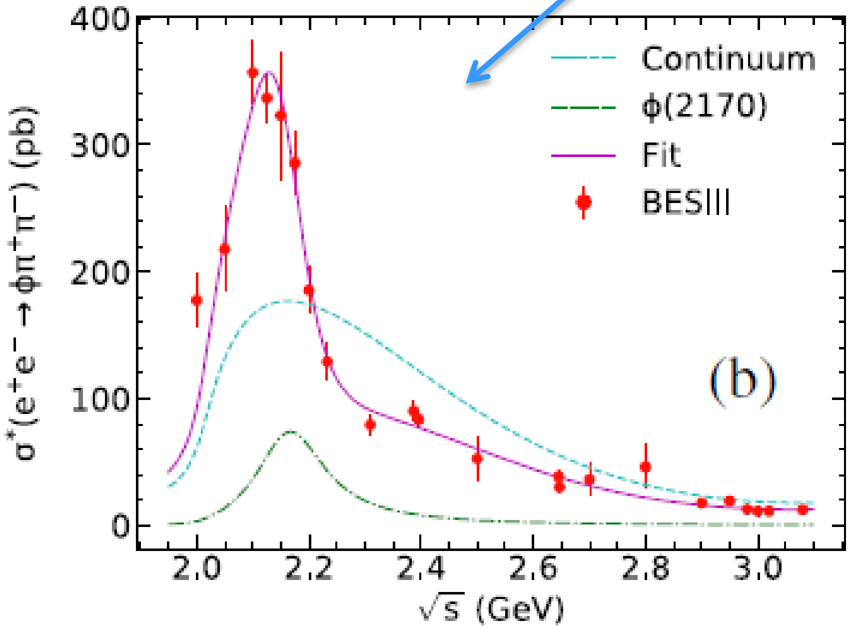


$e^+e^- \to \phi\pi^+\pi^-$

- M=2178±20±5 MeV/c^2, Γ=140±36±16 MeV;
- PRD108, 032011 (2023)

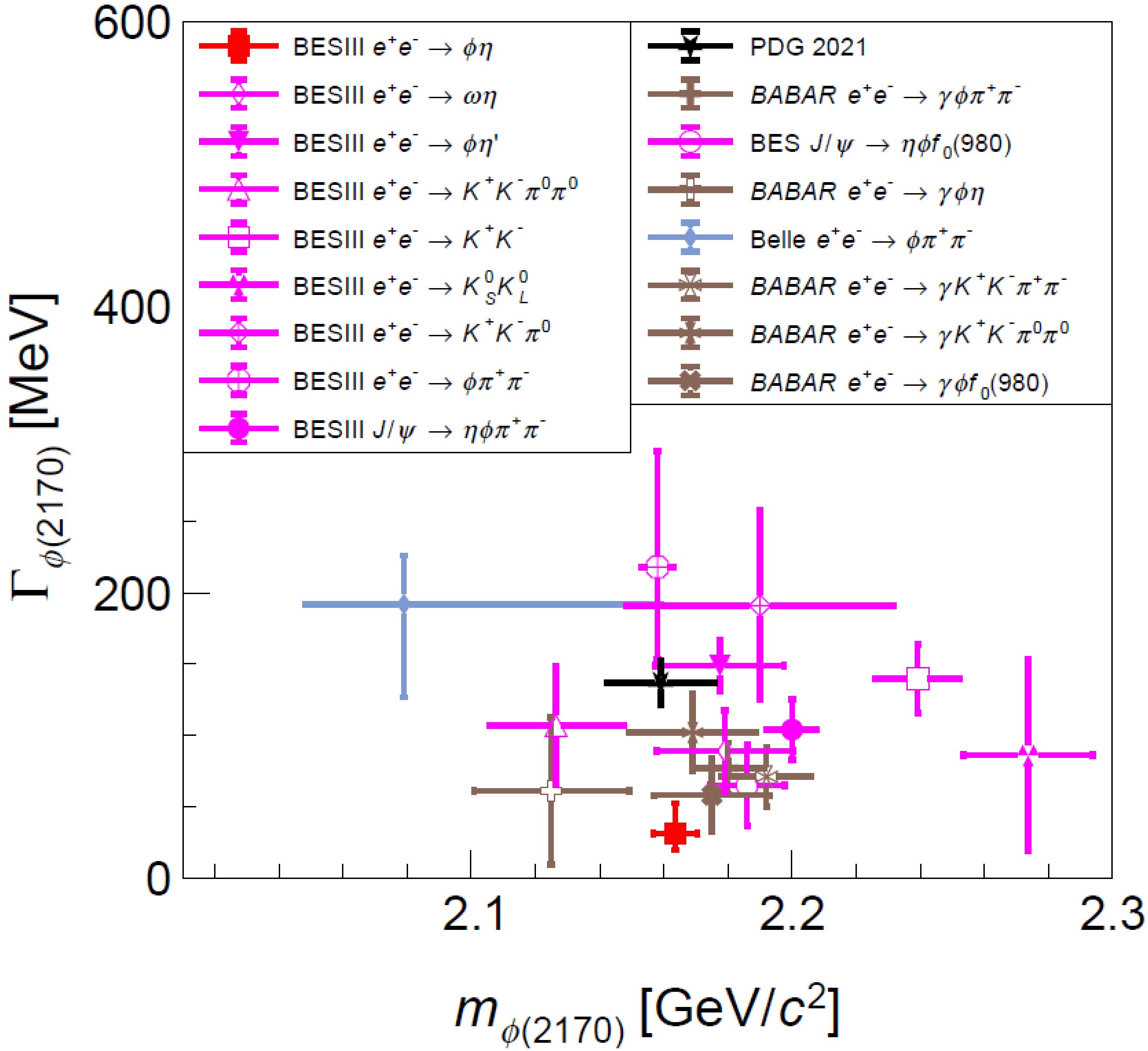






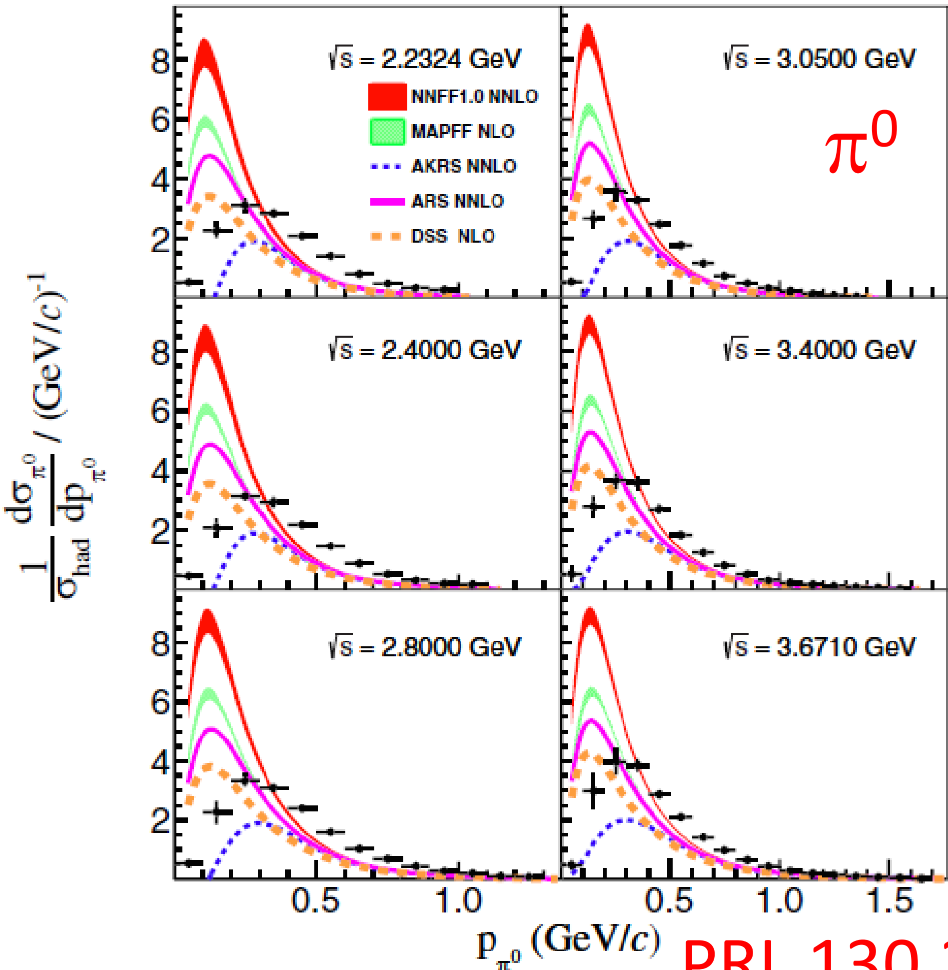
The property of ϕ(2170)

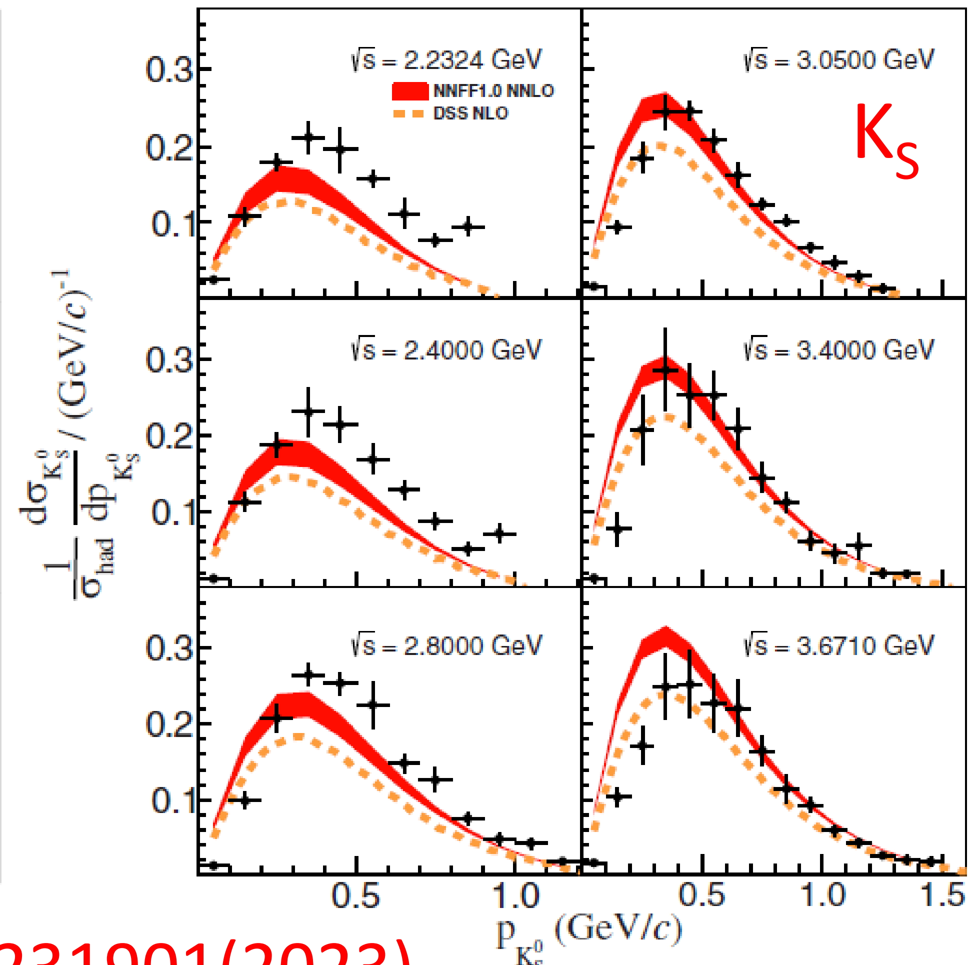
- Essential experimental data to address…



Unpolarized Fragmentation Functions

- $D_q^h(z)$, describing quark fragments into hadrons;
- Significantly deviate from theoretical calculations.



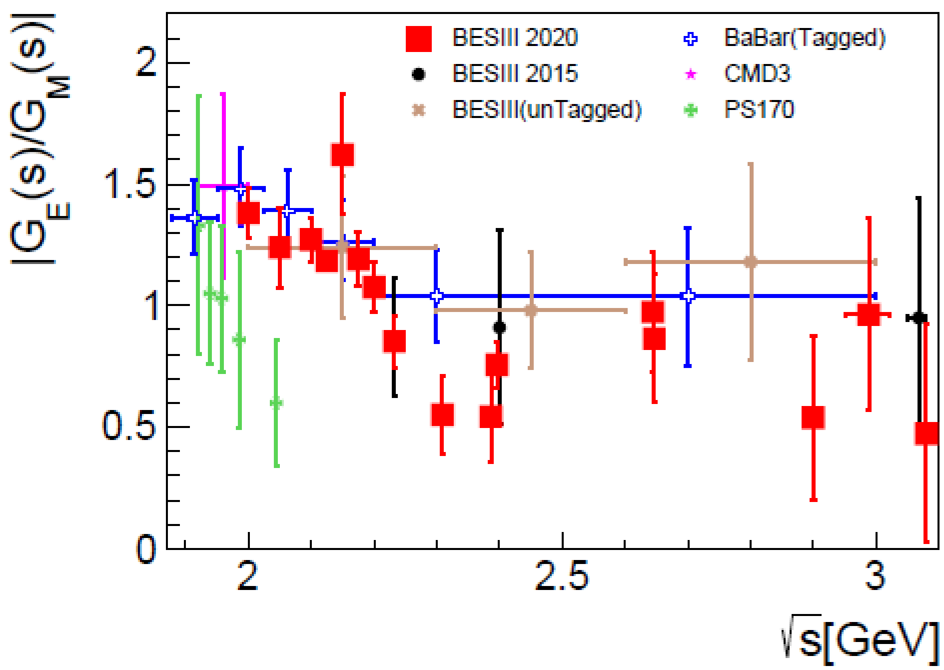


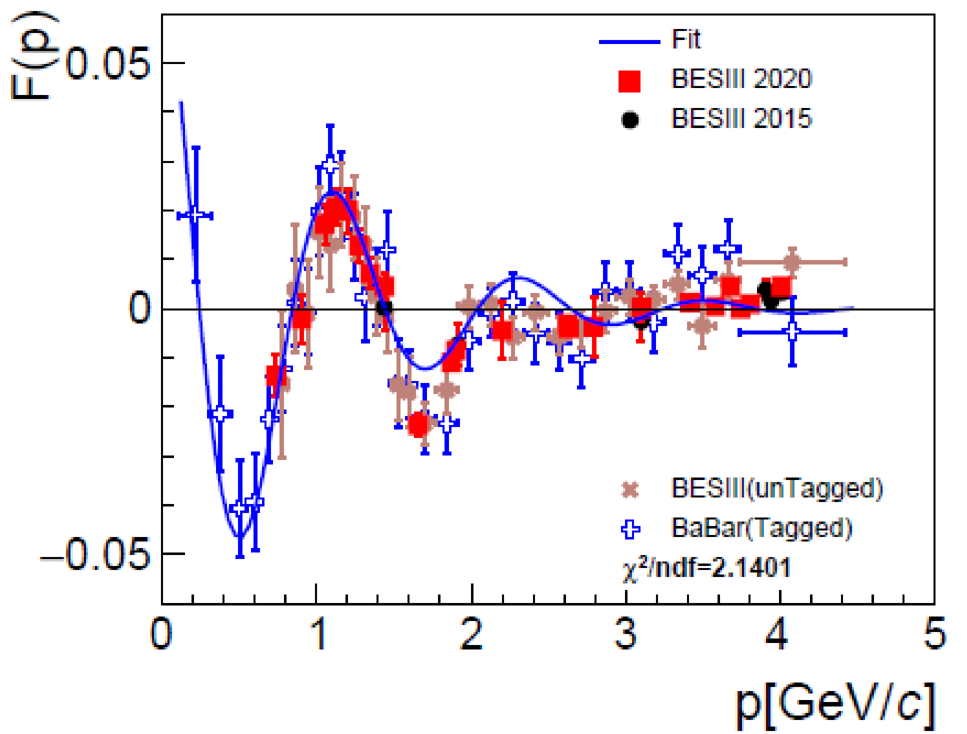
PRL 130,231901(2023)

Proton form factors

- Oscillation seen in the effective form factor $F^{osc}(p)=|G_{eff}|-F^0$ (F^0: regular shape)

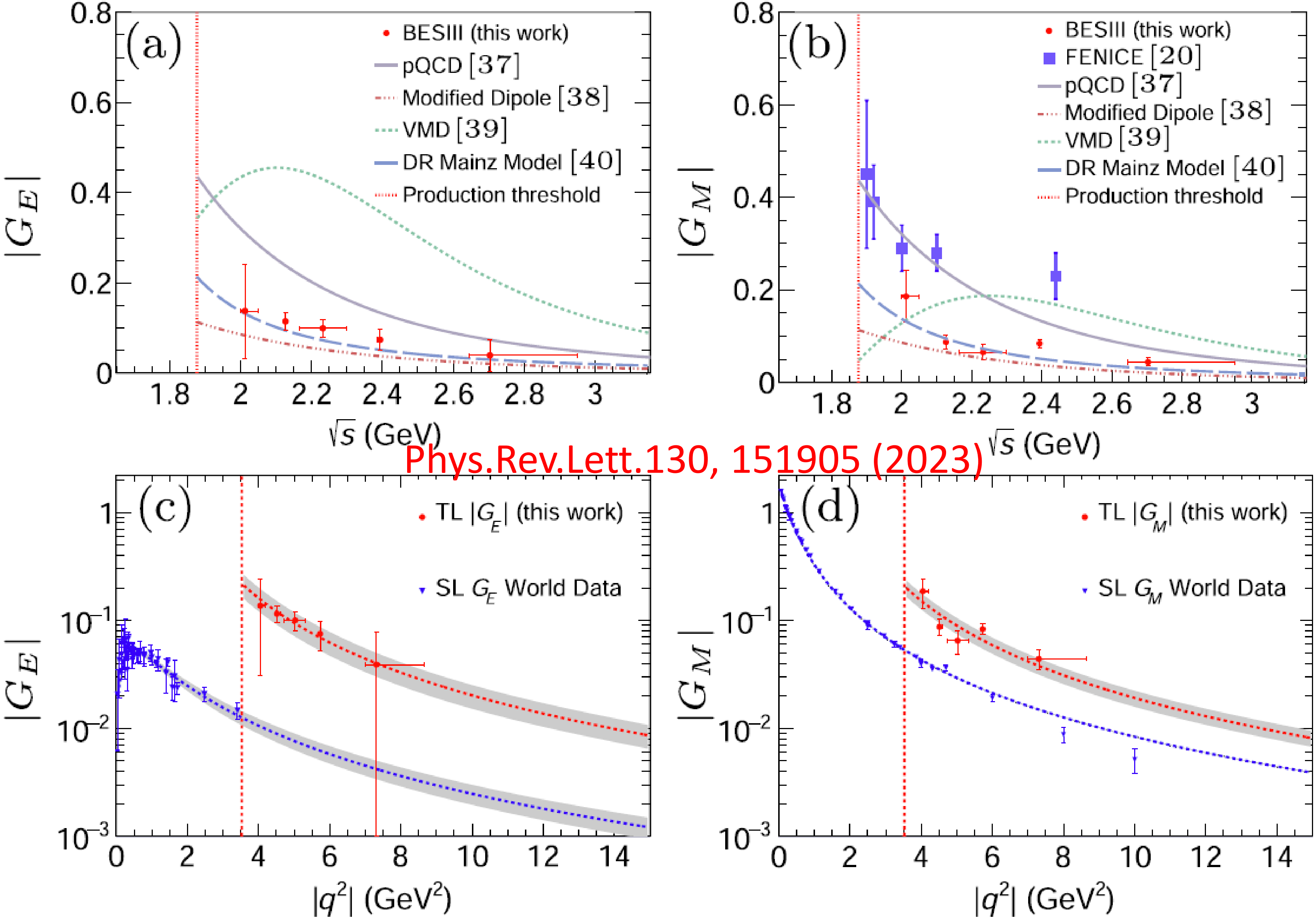
Phys. Rev. Lett. 124, 042001 (2020)





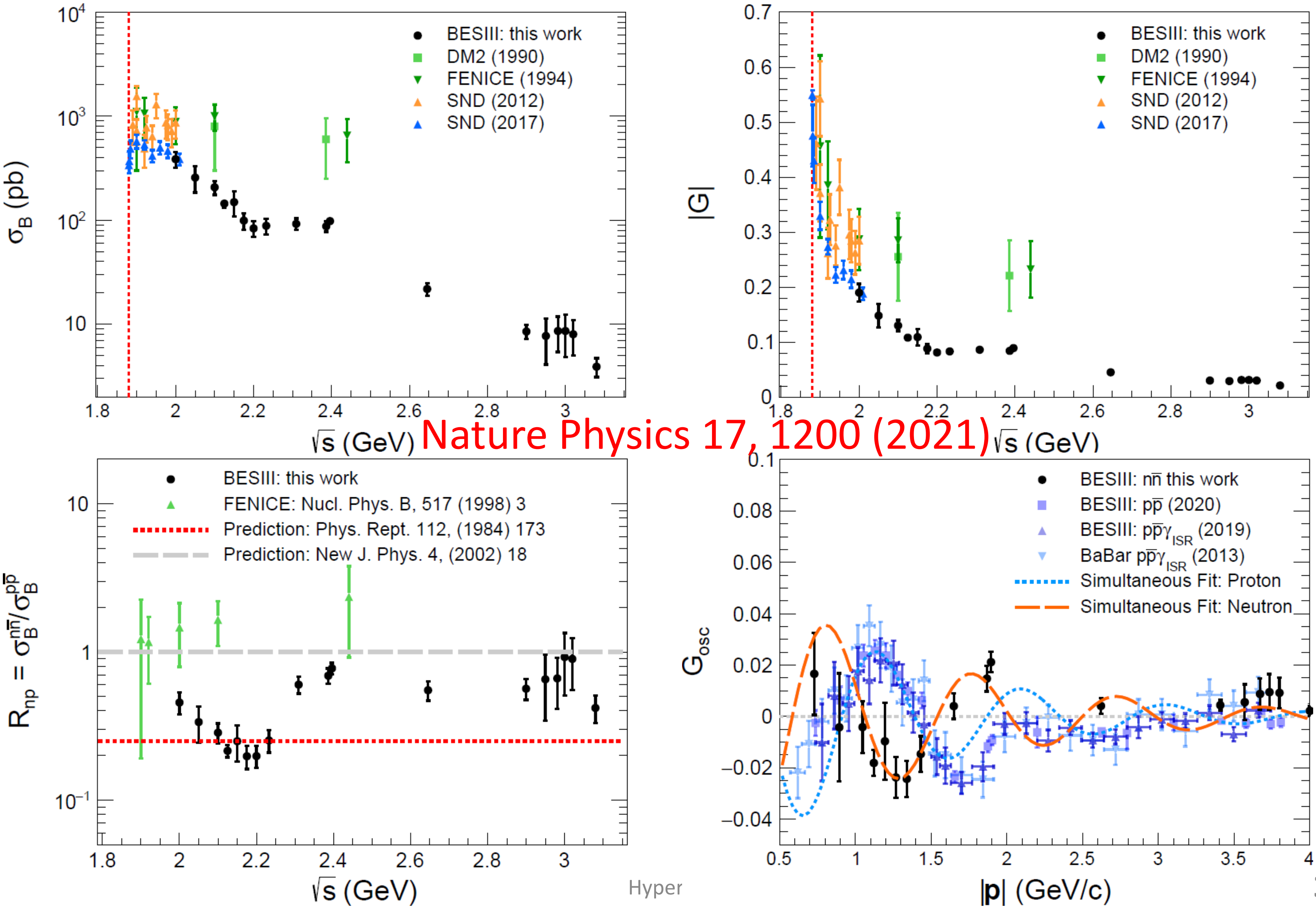
p is the 3-momentum of proton in the frame of anti-proton. Re-scattering effect?

Neutron E&M form factors



Phys.Rev.Lett.130, 151905 (2023)

Neutron effective form factors



Nature Physics 17, 1200 (2021)

First complete measurement of Λ E&M form-factors

First measurement of the relative phase

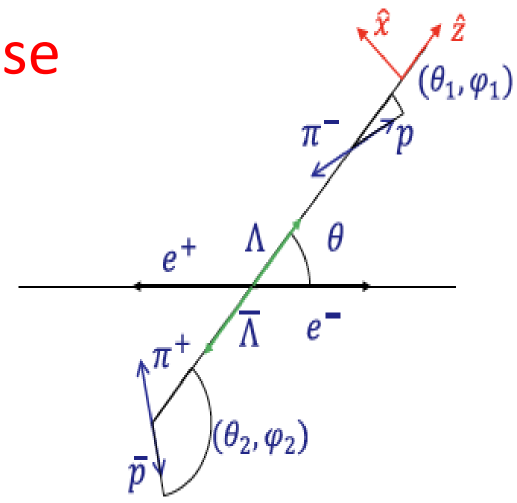
(E_{cm}=2.396 GeV , L=66.9 pb^{-1})

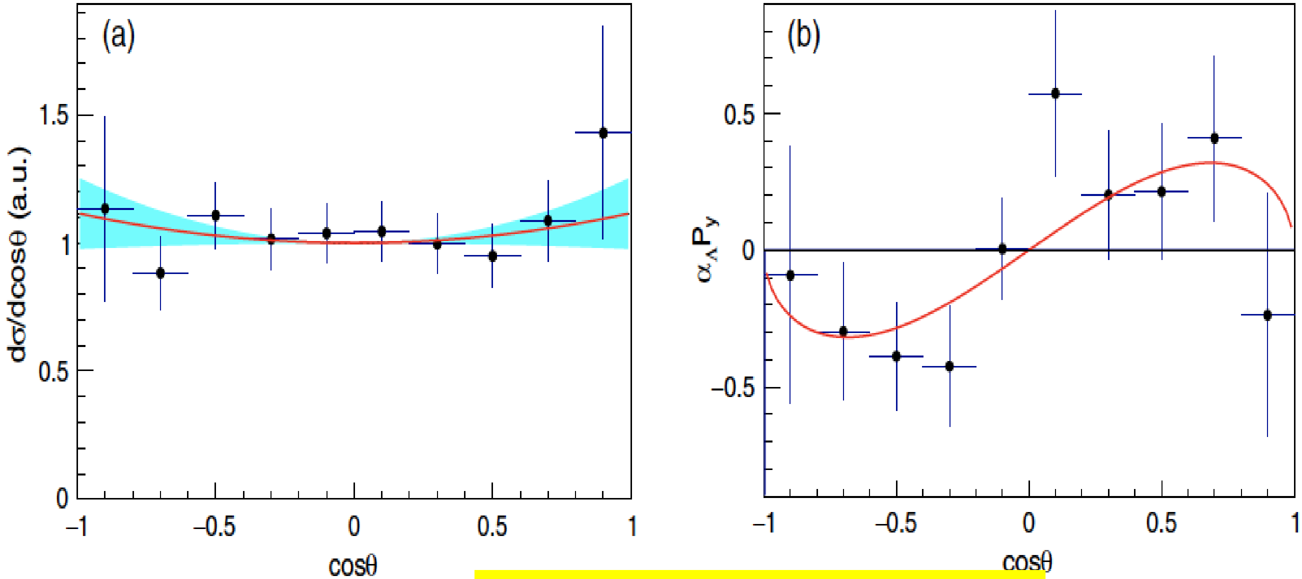
$$R = |\frac{G_E}{G_M}| = 0.96 \pm 0.14 \pm 0.02$$

$$\Delta\phi = 37^0 \pm 12^0 \pm 6^0$$

$$\sigma(e^+e^- \to \Lambda\bar{\Lambda}) = 118.7 \pm 5.3 \pm 5.1 pb$$

(Phase between E&M form-factors)



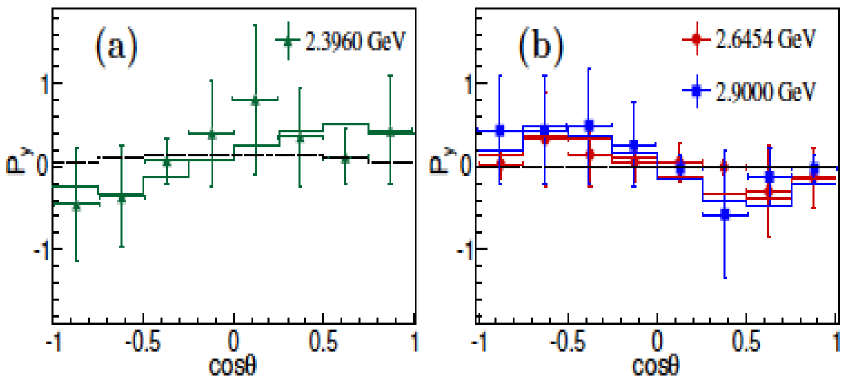


PRL 123, 122003 (2019)

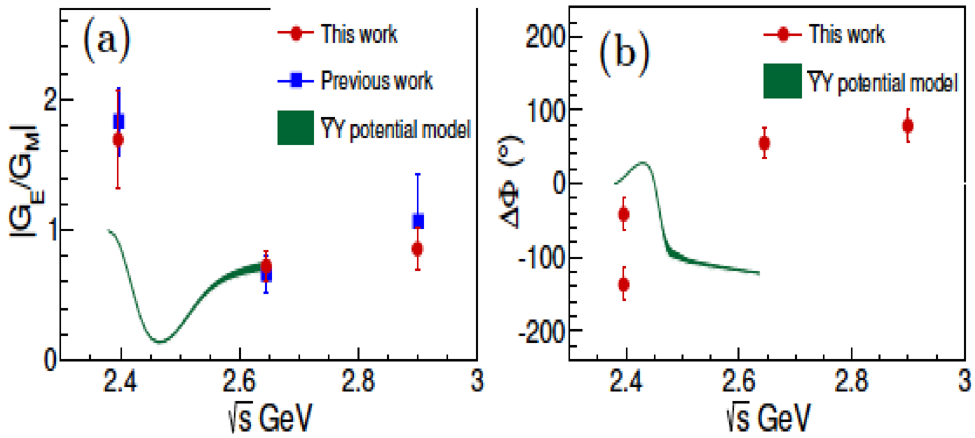
First complete measurement of Σ^+ EM form-factors

arXiv:2307.15894 (submitted to PRL)

Polarization measurements at different center of mass energies:



First measurement of the relative phase $\Delta\Phi$ between G_E and G_M form factors:

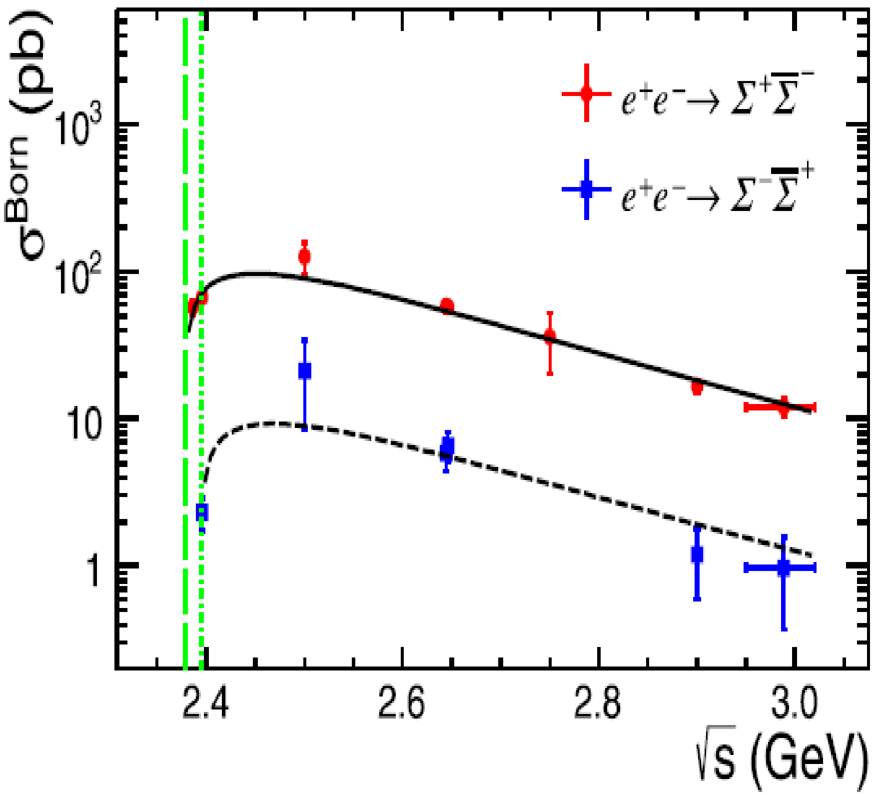


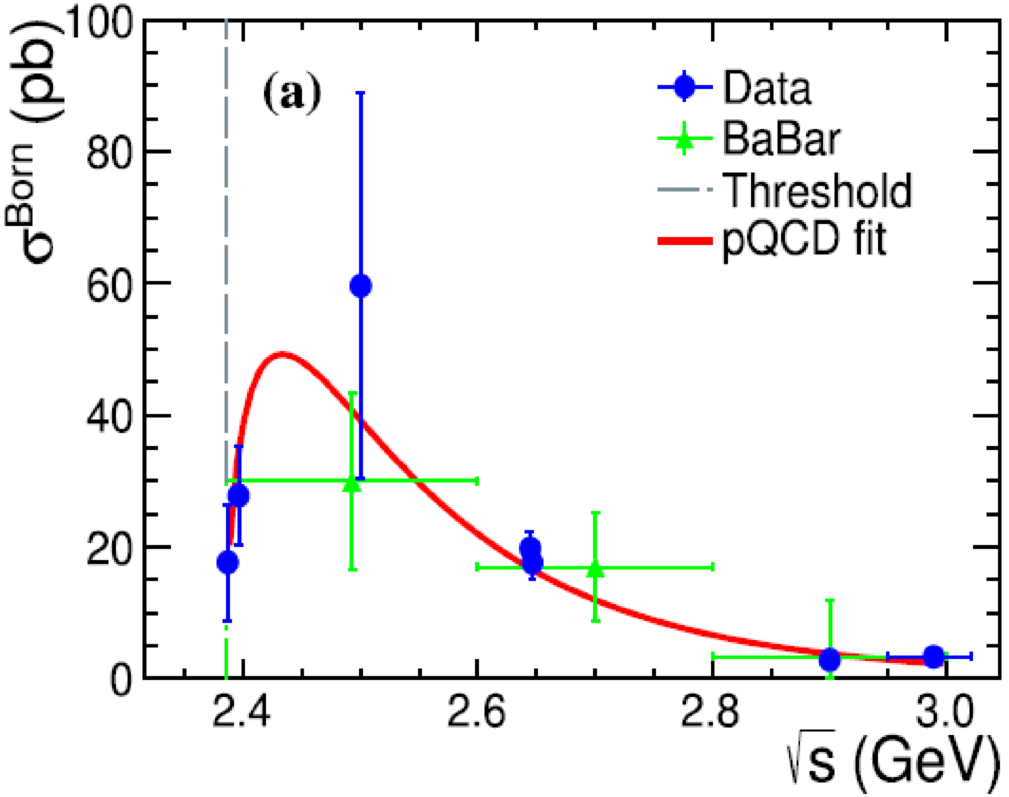
$\sqrt{s}$ (GeV)	2.3960	2.6454	2.9000
α	-0.47 ± 0.18 ± 0.09	0.41 ± 0.12 ± 0.06	0.35 ± 0.17 ± 0.15
$\Delta\Phi$ (°)	-42 ± 22 ± 14 (-138 ± 22 ± 14)	55 ± 19 ± 14	78 ± 22 ± 9
$\sin\Delta\Phi$	-0.67 ± 0.29 ± 0.18		
$\|G_E/G_M\|$	1.69 ± 0.38 ± 0.20	0.72 ± 0.11 ± 0.06	0.85 ± 0.16 ± 0.15

Such an evolution will be an important input for understanding its asymptotic behavior and the dynamics of baryons. Moreover, the fact that the relative phase is still increasing at 2.9 GeV indicates that the asymptotic threshold has not yet been reached.
-- A. Mangoni, S. Pacetti, and E. Tomasi-Gustafsson, Phys. Rev. D 104, 116016 (2021).

$e^+e^- \to \Sigma^+\bar{\Sigma}^-/\Sigma^-\bar{\Sigma}^+$、$\Sigma^0\bar{\Sigma}^0$

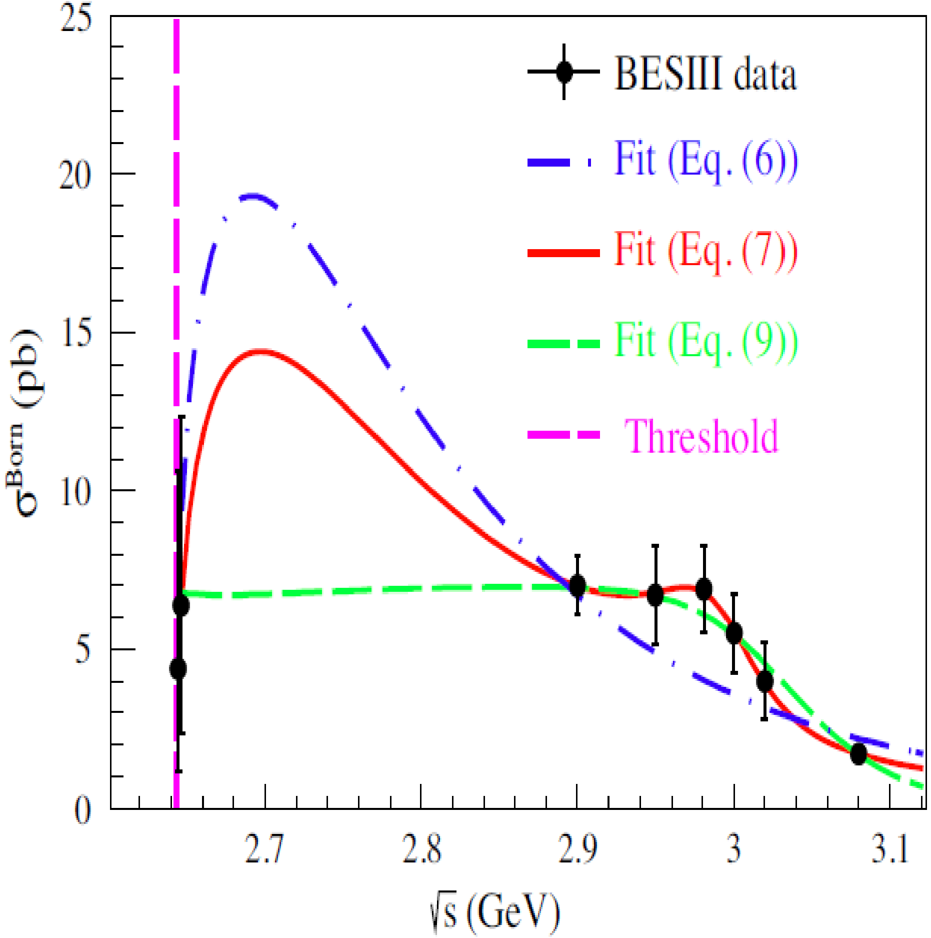
PLB814, 136110 (2021),   PLB831, 137187 (2022)

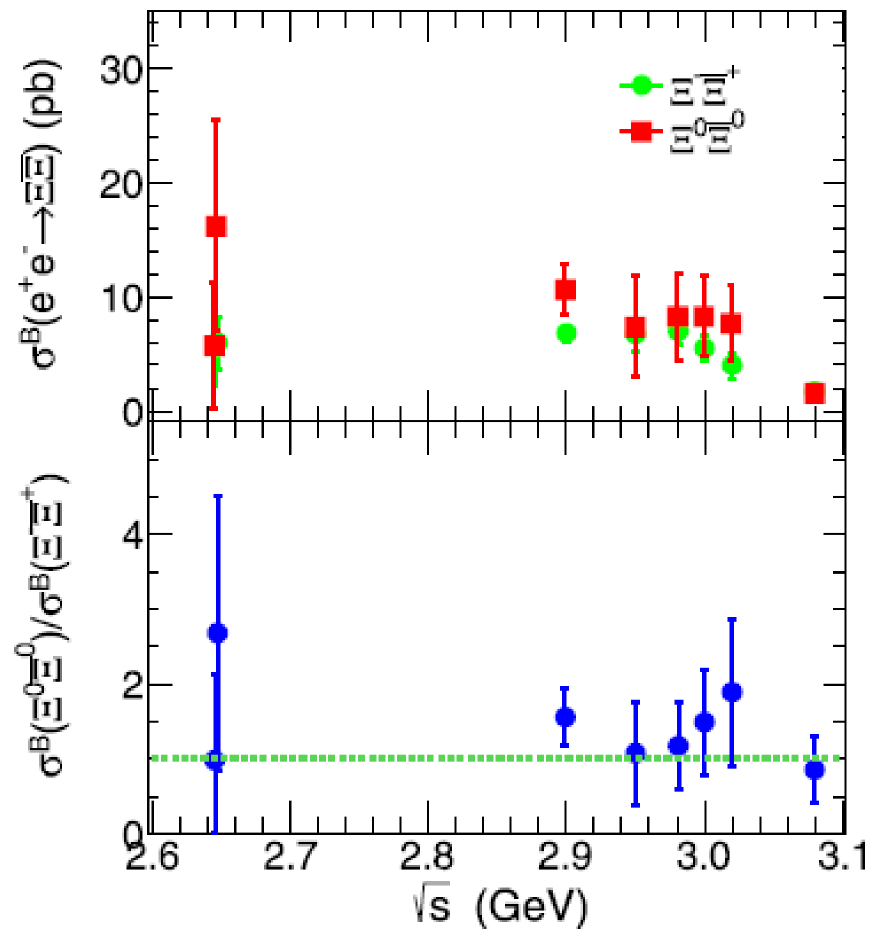




$e^+e^- \to \Xi^-\bar{\Xi}^+$、$\Xi^0\bar{\Xi}^0$

PRD103, 012005 (2021), PLB820, 136557 (2021)

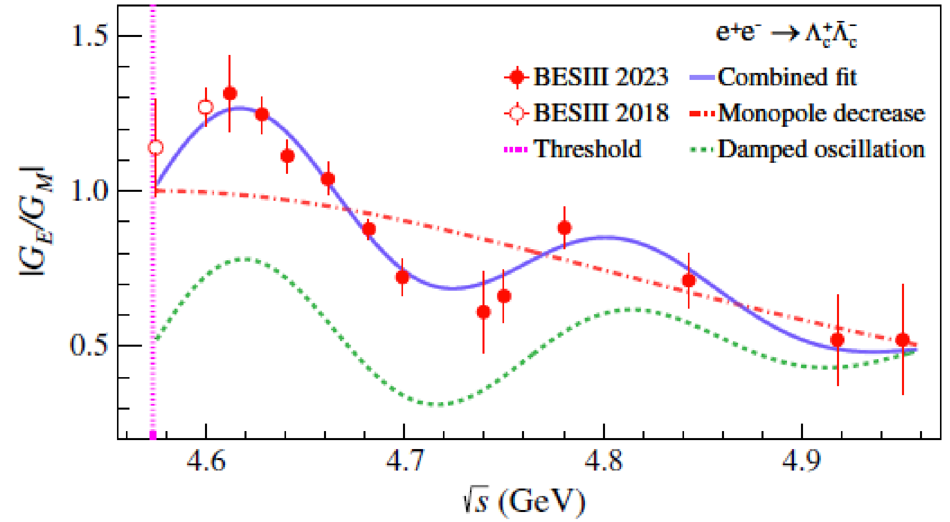


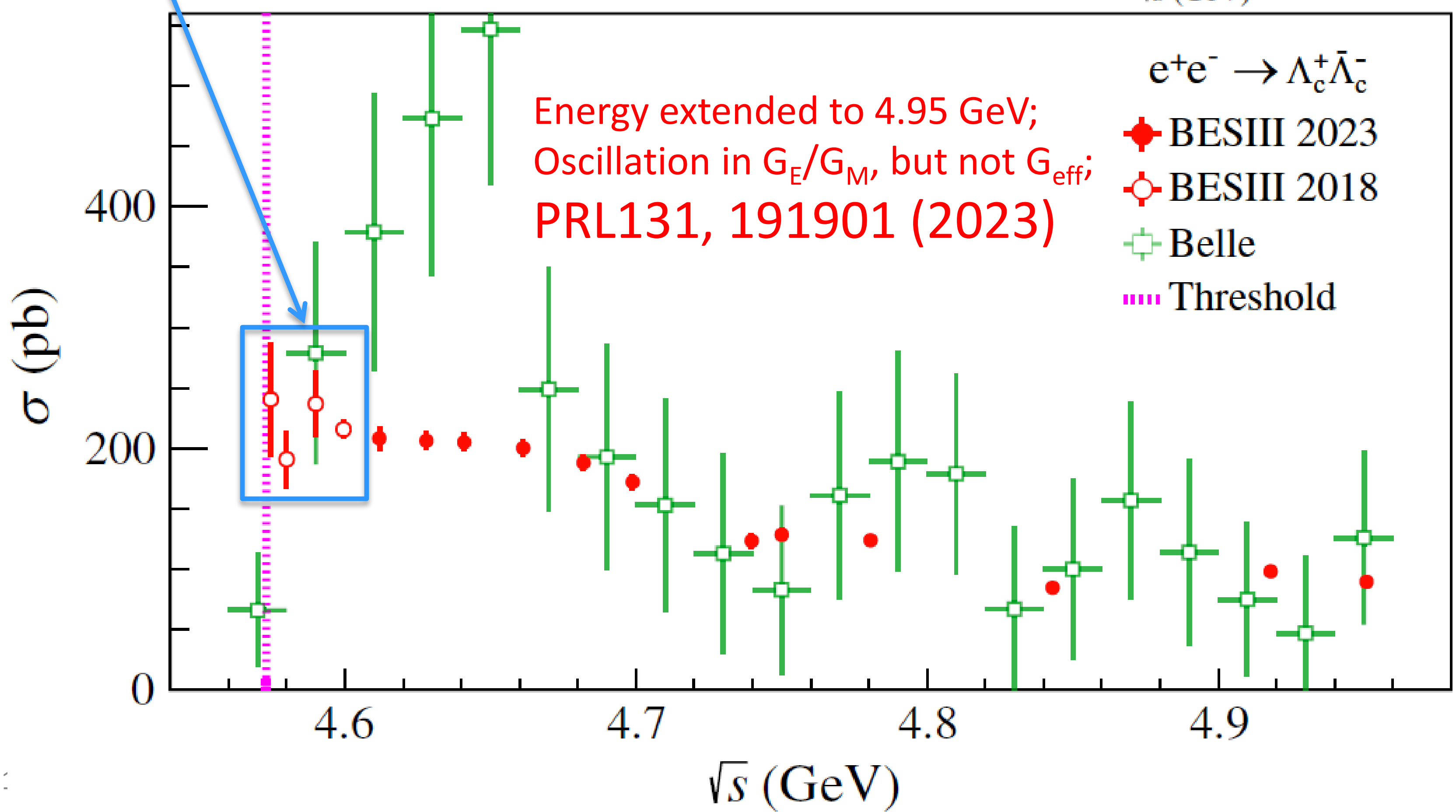


$e^+e^- \to \Lambda_c\overline{\Lambda}_c$

First observation of non-zero cross section near threshold; first Λ_c form factor measurement.

PRL 120,132001 (2018)

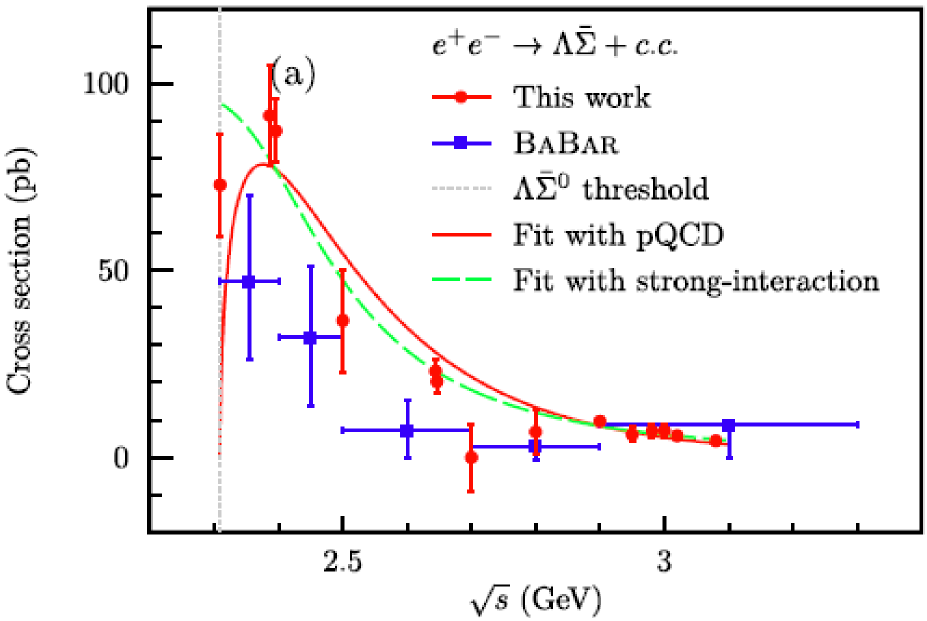


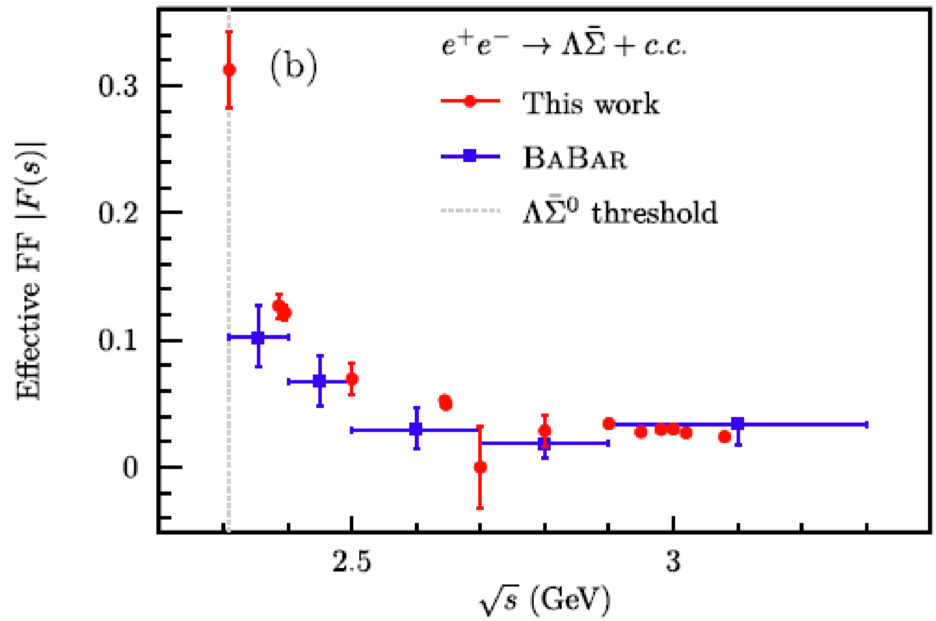


Cross section and effective form factor for $e^+e^- \to \Lambda\bar{\Sigma}^0 + c.c.$

arXiv:2308.03361, Phys.Rev.D109, 012002 (2024)

Born cross-sections measured at 14 energy points from 2.31 to 3.08 GeV





Fits with pQCD assumption and the plateau near threshold are performed on the line shape of the Born cross-sections, and the latter provides a better description of the data.

The measured effective form-factors (FFs) are consistent with BaBar's results for the c.m. energy above 2.31 GeV.

Baryon-pair production near threshold

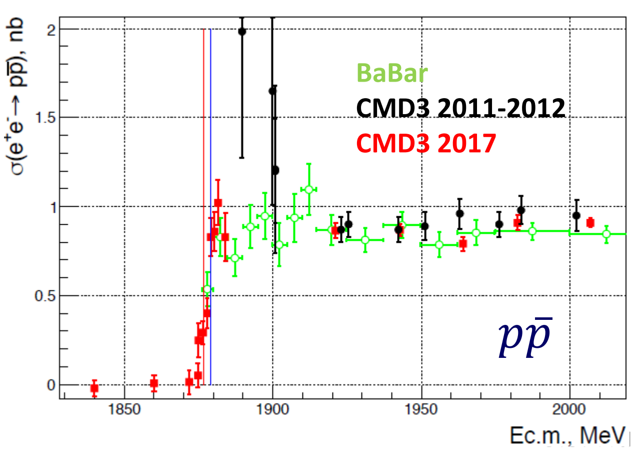
$$\bar{p}p,\quad \bar{\Lambda}\Lambda,\quad \bar{\Sigma}^-\Sigma^+,\quad \bar{\Sigma}^0\Sigma^0,\quad \bar{\Sigma}^-\Sigma^+,\quad \bar{\Xi}^0\Xi^0,\quad \bar{\Xi}^+\Xi^-,\quad \bar{\Omega}^+\Omega^-,\quad \bar{\Lambda}_c^-\Lambda_c^+$$

$\bar{\Lambda}\Lambda$	$\bar{\Sigma}^-\Sigma^+$	$\bar{\Sigma}^0\Sigma^0$	$\bar{\Sigma}^-\Sigma^+$	$\bar{\Xi}^0\Xi^0$	$\bar{\Xi}^+\Xi^-$	$\bar{\Omega}^+\Omega^-$	$\bar{\Lambda}_c^-\Lambda_c^+$
$\downarrow$	$\downarrow$	$\downarrow$	$\downarrow$	$\downarrow$	$\downarrow$	$\downarrow$	$\downarrow$
$p\pi^-$	$p\pi^0$	$\Lambda\gamma$	$n\pi$	$\Lambda\pi^0$	$\Lambda\pi$	ΛK	$\Lambda\pi$
64%	52%	$\approx$ 100%	$\approx$ 100%	$\approx$ 100%	$\approx$ 100%	68%	$\approx$ 1%

$e^+e^- \to \gamma^* \to B\bar{B}$ production cross section:

$$\sigma_{B\bar{B}}(m) = \frac{4\pi\alpha^2 C\boldsymbol{\beta}}{3m^2}\left[|G_M(m)|^2 + \frac{1}{2\tau}|G_E(m)|^2\right]$$

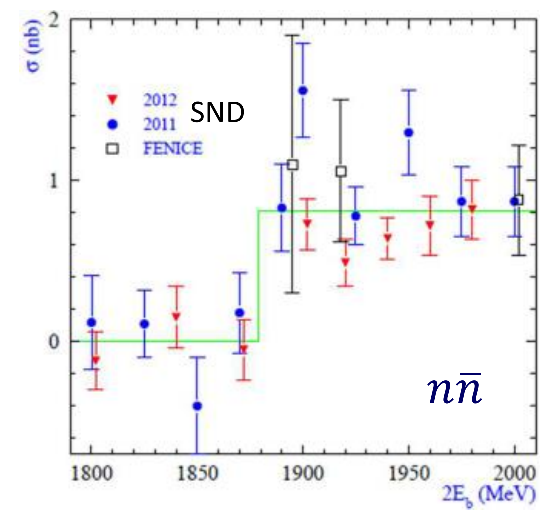
$$\text{Coulomb factor } C = \begin{cases} \dfrac{\pi\alpha}{\boldsymbol{\beta}}\dfrac{1}{1-\exp(-\frac{\pi\alpha}{\beta})}, & \text{for charged } B\bar{B} \\ 1, & \text{for neutral } B\bar{B} \end{cases}$$



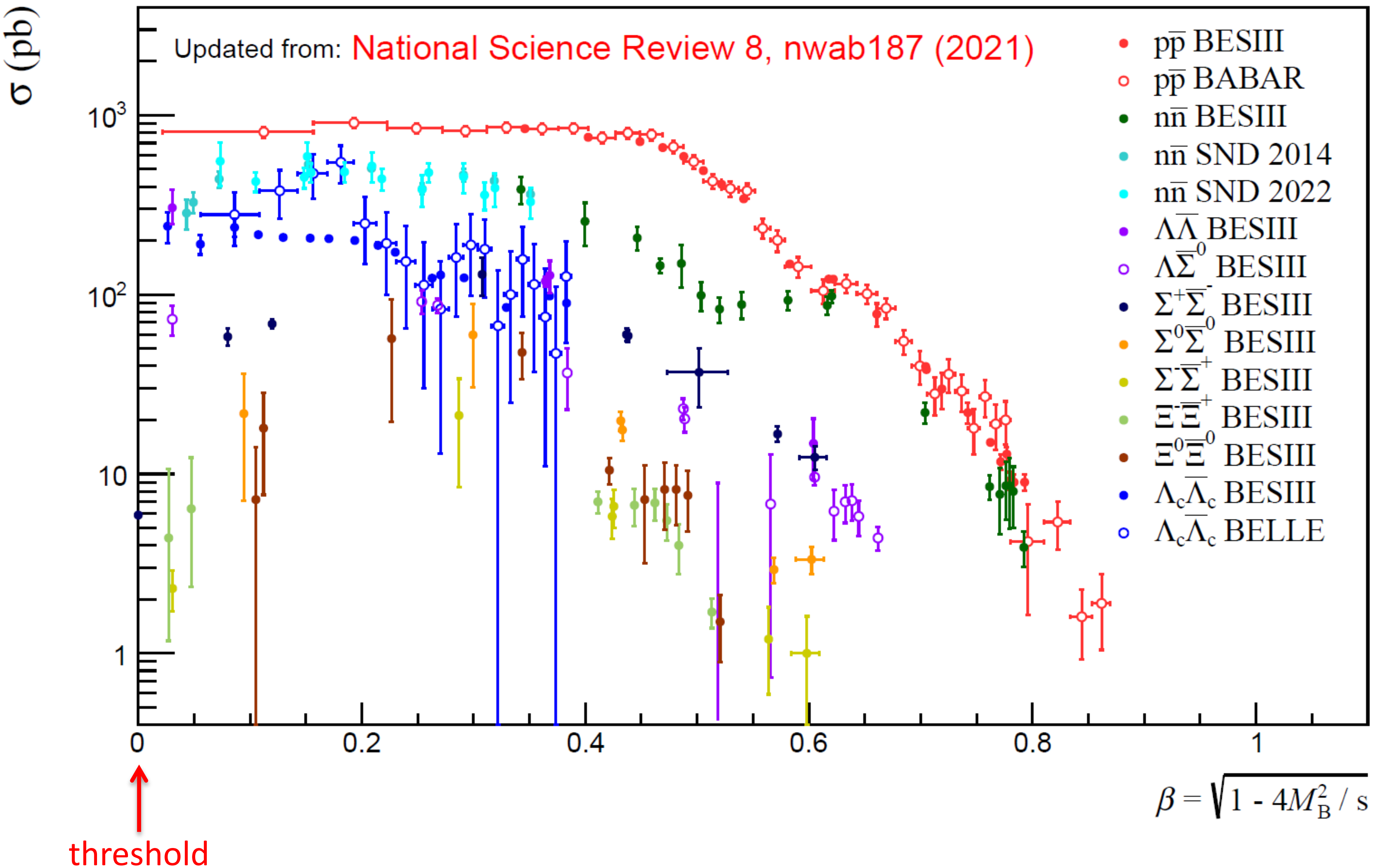
$p\bar{p}$、$n\bar{n}$ should be different, but poor precision for latter.

How about other baryon-pairs?

0 expected at threshold!



Baryon-pair productions in a glance



Summary

- High-quality, high-statistics data accumulated at BESIII;
- Huge amount hyperon pairs from 10B J/ψ, 2.7B $\psi(3686)$;
- Precision CP symmetry tests made for hyperon;
- No CPV evidence found in hyperon sector;
- Unique data in 2.0–4.95 GeV for R-QCD studies;
- First R values with uncertainties <3% in [2.2324, 3.6710] GeV;
- Cross section measurements for light hadron studies;
- Form factors measured and threshold production behavior studied for various baryons.
- More results coming…